MPI@LHC 2015

Rick's Story of the UE

Rick Field
University of Florida

Quantum Chromo-Dynamics

Outline of Talk

- Early days of Field-Feynman phenomenology.
- Early studies the underlying event at CDF and Tune A.
- Early days of UE@MB at CMS.
- LPCC MB&UE Working group and the "common plots".
- UE@CMS at 13TeV.
- CMS "Physics Comparisons & Generator Tunes group" and CMS UE Tunes.
- The last CDF UE Publication.
- Mapping out the energy dependence of the UE, Tevatron to the LHC.

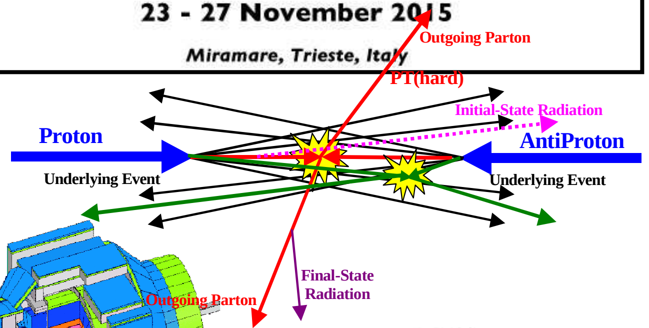
The Abdus Salam International Centre for Theoretical Physics
www.ictp.it

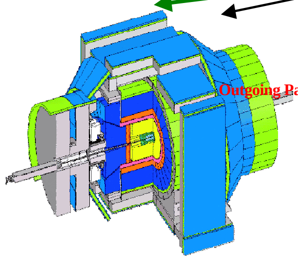
The Abdus Salam International Centre for Theoretical Physics (ICTP), in collaboration with the Italian Institute for Nuclear Physics (INFN), will hold the

7th International Workshop on Multiple Partonic Interactions at the LHC

23 - 27 November 2015

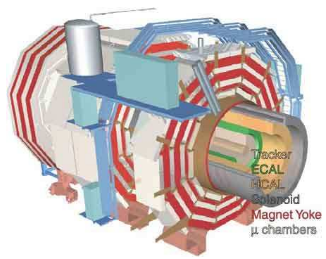
Miramare, Trieste, Italy





CDF "Tevatron Energy Scan"

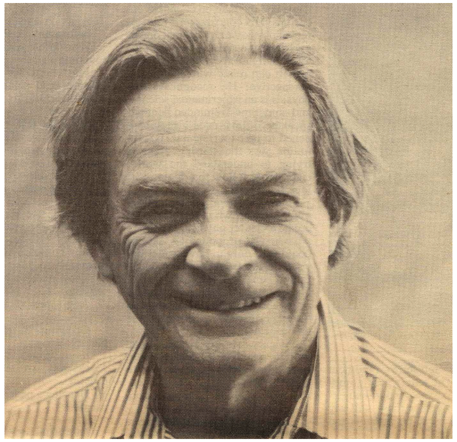
300 GeV, 900 GeV, 1.96 TeV



CMS at the LHC
900 GeV, 7 TeV, 13 TeV

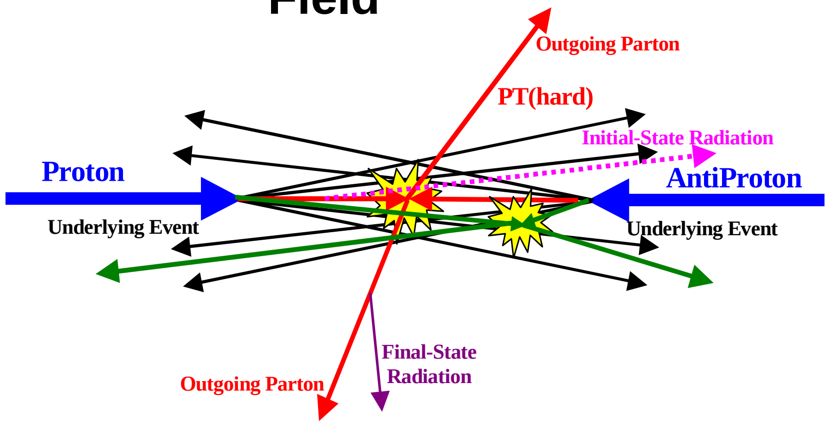
Toward and Understanding of Hadron-Hadron Collisions

Feynman-Field Phenomenology

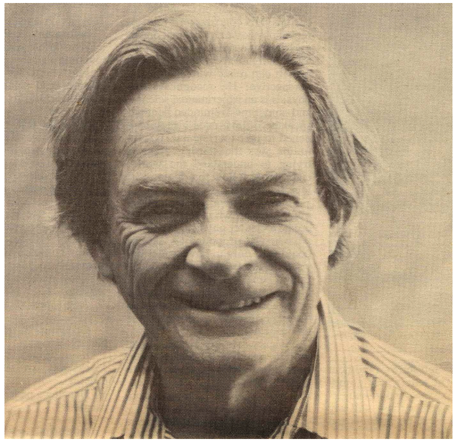


Feynman **and** **Field**

- **From 7 GeV/c π^0's to 1 TeV Jets. The early days of trying to understand and simulate hadron-hadron collisions.**

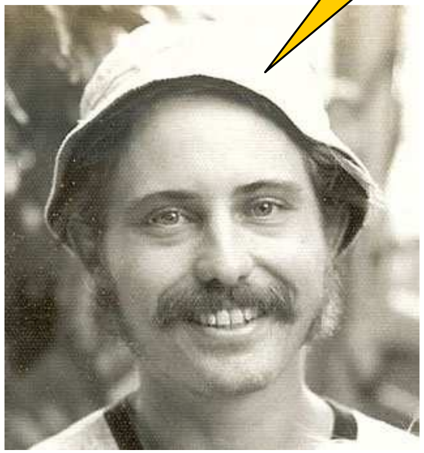


Feynman-Field Phenomenology



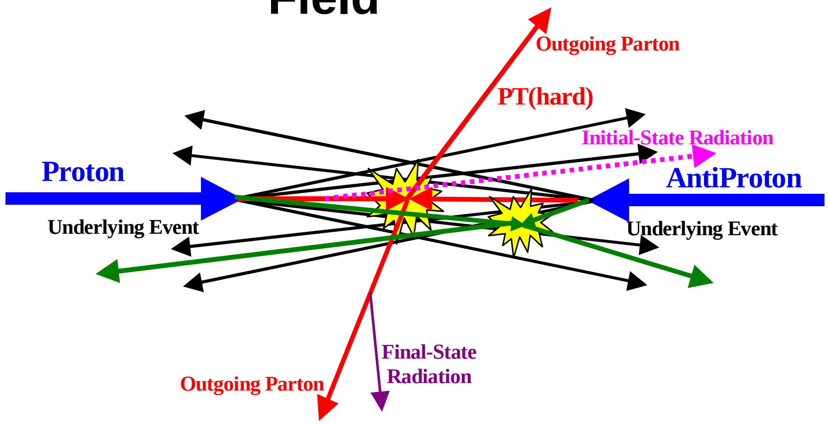
Feynman

and



Field

- From 7 GeV/c π^0's to 1 TeV Jets. The early days of trying to understand and simulate hadron-hadron collisions.



The Feynman-Field Days

1973-1983

"Feynman-Field Jet Model"

- **FF1: "Quark Elastic Scattering as a Source of High Transverse Momentum Mesons", R. D. Field and R. P. Feynman, Phys. Rev. D15, 2590-2616 (1977).**
- **FFF1: "Correlations Among Particles and Jets Produced with Large Transverse Momenta", R. P. Feynman, R. D. Field and G. C. Fox, Nucl. Phys. B128, 1-65 (1977).**
- **FF2: "A Parameterization of the properties of Quark Jets", R. D. Field and R. P. Feynman, Nucl. Phys. B136, 1-76 (1978).**
- **F1: "Can Existing High Transverse Momentum Hadron Experiments be Interpreted by Contemporary Quantum Chromodynamics Ideas?", R. D. Field, Phys. Rev. Letters 40, 997-1000 (1978).**
- **FFF2: "A Quantum Chromodynamic Approach for the Large Transverse Momentum Production of Particles and Jets", R. P. Feynman, R. D. Field and G. C. Fox, Phys. Rev. D18, 3320-3343 (1978).**

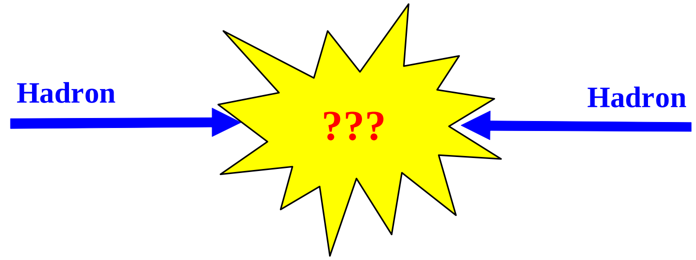
- **FW1: "A QCD Model for e^+e^- Annihilation", R. D. Field and S. Wolfram, Nucl. Phys. B213, 65-84 (1983).**

My 1st graduate student!

Hadron-Hadron Collisions

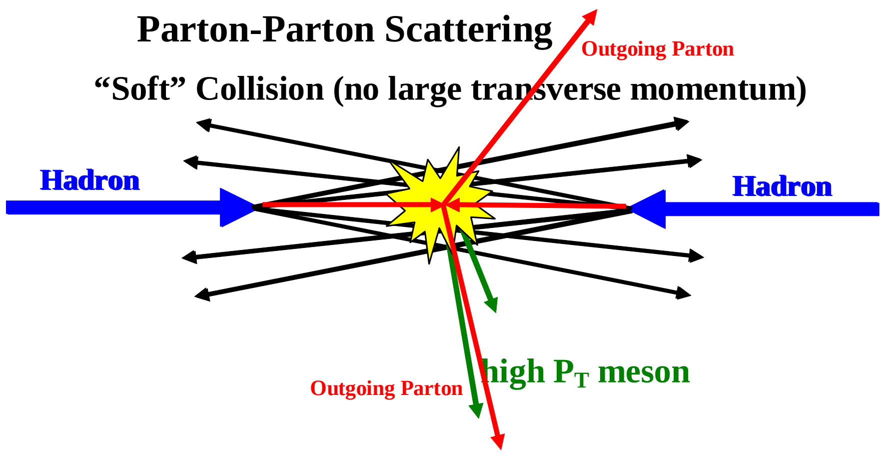
FF1 1977

- **What happens when two hadrons collide at high energy?**



- **Most of the time the hadrons ooze through each other and fall apart (*i.e.* no hard scattering). The outgoing particles continue in roughly the same direction as initial proton and antiproton.**

- **Occasionally there will be a large transverse momentum meson. Question: Where did it come from?**



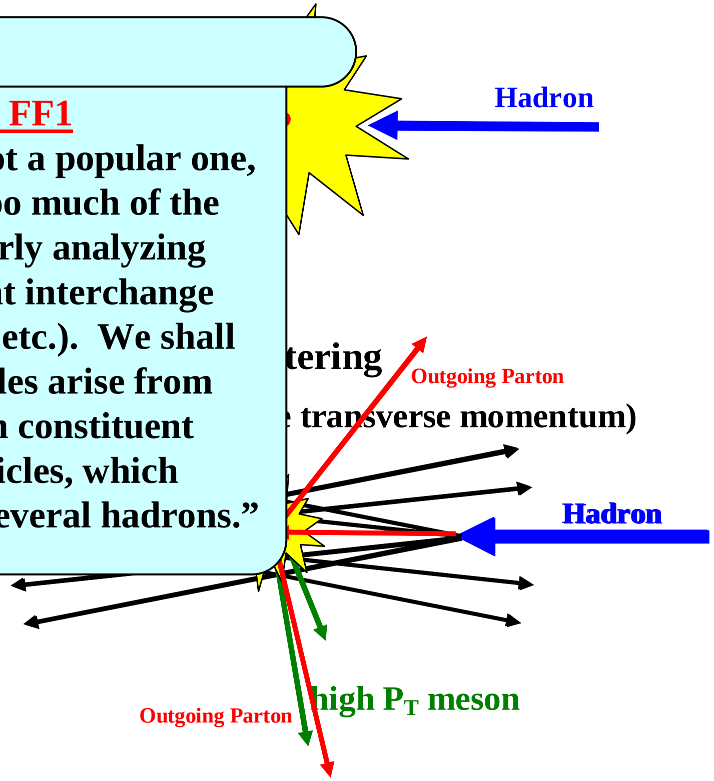
- **We assumed it came from quark-quark elastic scattering, but we did not know how to calculate it!**

"Black-Box Model"

Hadron-Hadron Collisions

FF1 1977

- **What happens when collide at high energ**
- **Most of the time th through each other no hard scattering) particles continue i direction as initial antiproton.**
- **Occasionally th transverse mom**
  Question: Where did it come from?
- **We assumed it came from quark-quark elastic scattering, but we did not know how to calculate it!**



Feynman quote from FF1

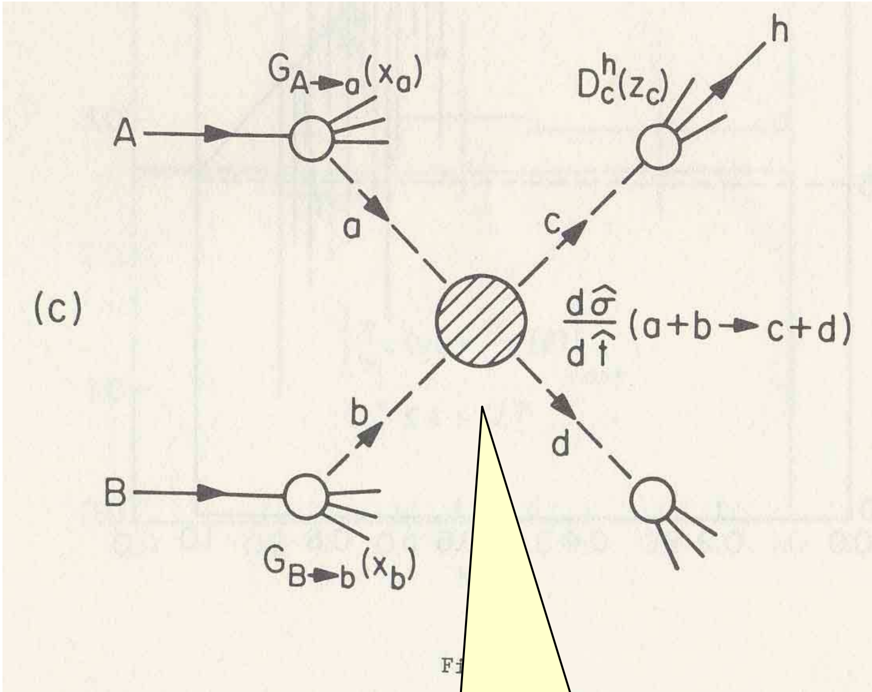
"The model we shall choose is not a popular one, so that we will not duplicate too much of the work of others who are similarly analyzing various models (e.g. constituent interchange model, multiperipheral models, etc.). We shall assume that the high P_T particles arise from direct hard collisions between constituent quarks in the incoming particles, which fragment or cascade down into several hadrons."

"Black-Box Model"

Quark-Quark Black-Box Model

FF1 1977

No gluons!



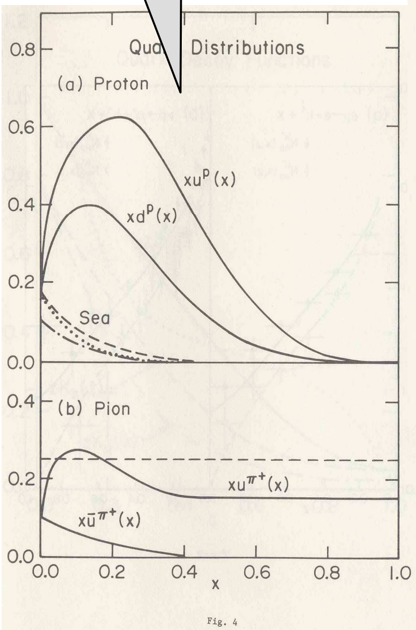
Quark-Quark Cross-Section
Unknown! Deteremined from hadron-hadron collisions.

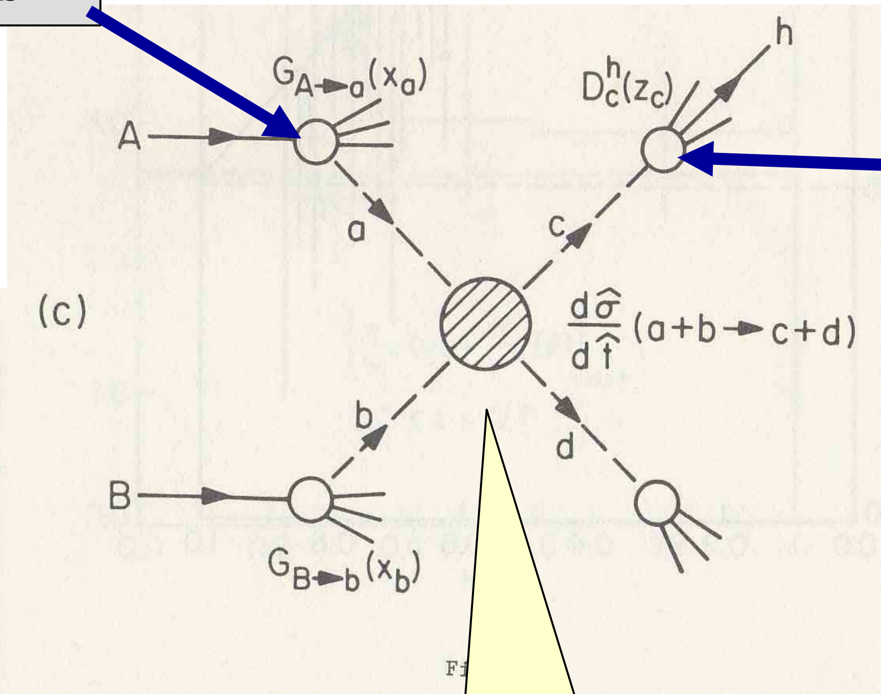
Quark-Quark Black-Box Model

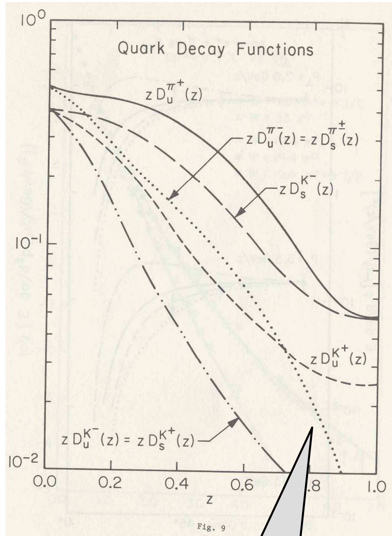
FF1 1977

No gluons!

Quark Distribution Functions
determined from deep-inelastic lepton-hadron collisions







Quark-Quark Cross-Section
Unknown! Deteremined from hadron-hadron collisions.

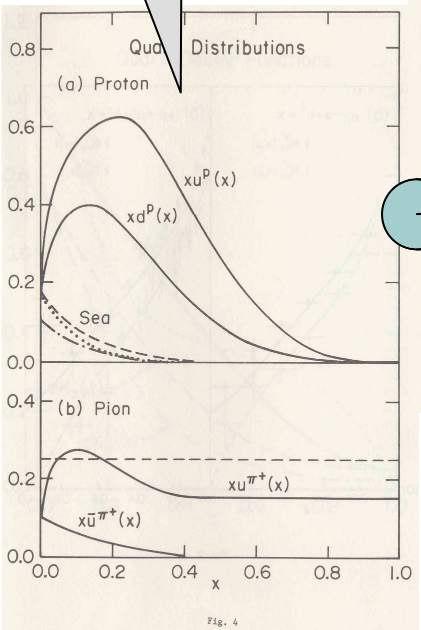
Quark Fragmentation Functions
determined from e^+e^- annihilations

Quark-Quark Black-Box Model

FF1 1977

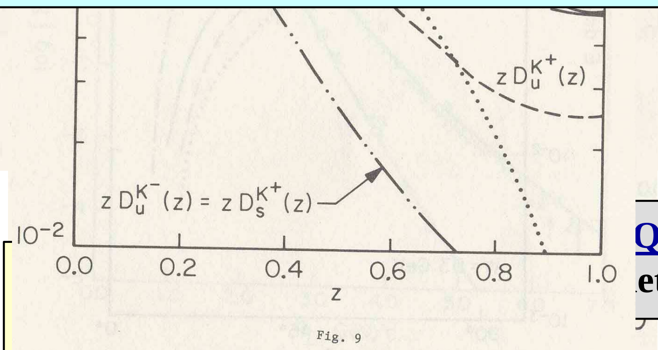
No gluons!

Quark Distribution Functions determined from deep-inelastic lepton-hadron collisions

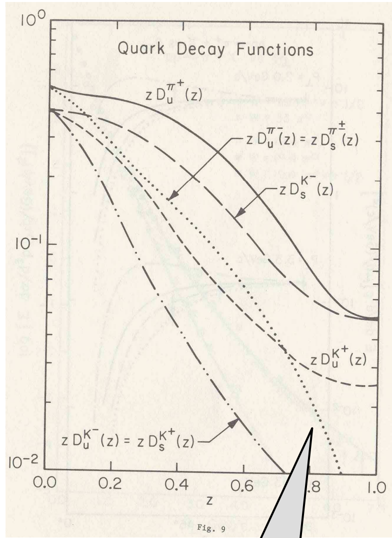


Feynman quote from FF1

"Because of the incomplete knowledge of our functions some things can be predicted with more certainty than others. Those experimental results that are not well predicted can be "used up" to determine these functions in greater detail to permit better predictions of further experiments. Our papers will be a bit long because we wish to discuss this interplay in detail."



hadron-hadron collisions.

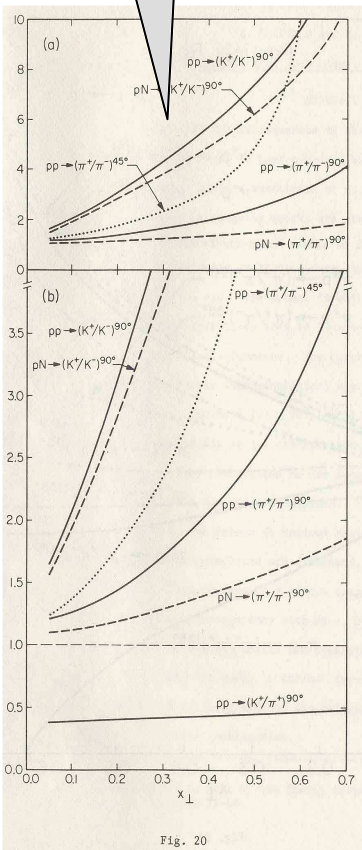


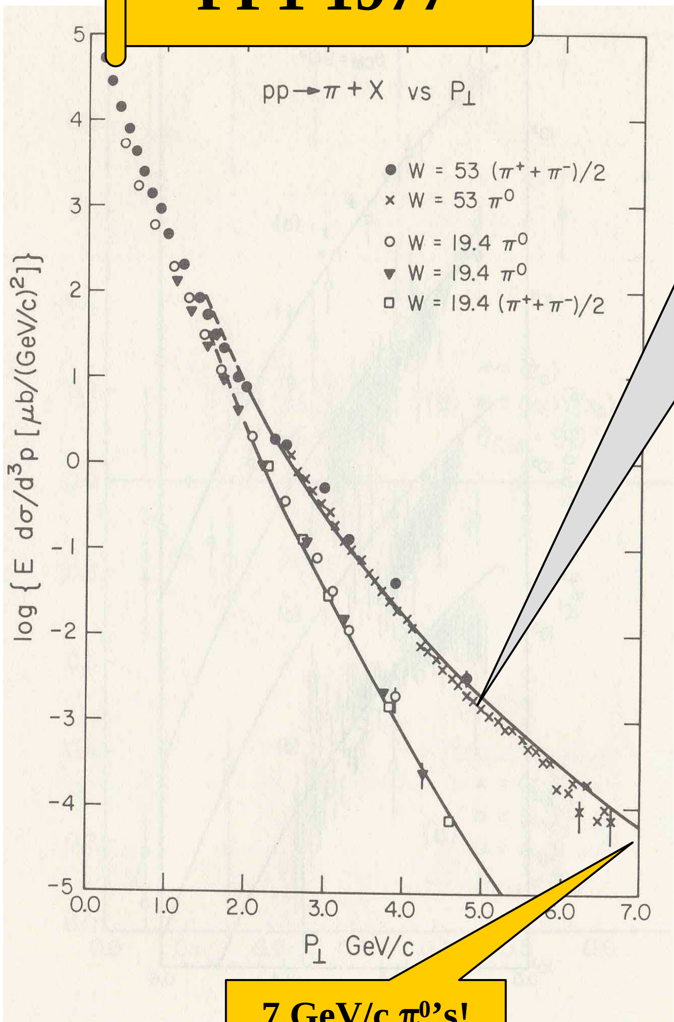
Quark Fragmentation Functions etermined from e^+e^- annihilations

Quark-Quark Black-Box Model

FF1 1977

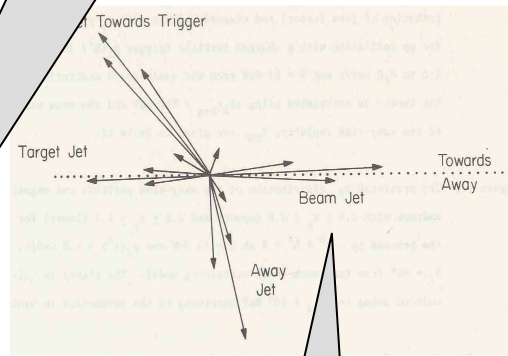
Predict
particle ratios





7 GeV/c π^0's!

Predict
increase with increasing CM energy W

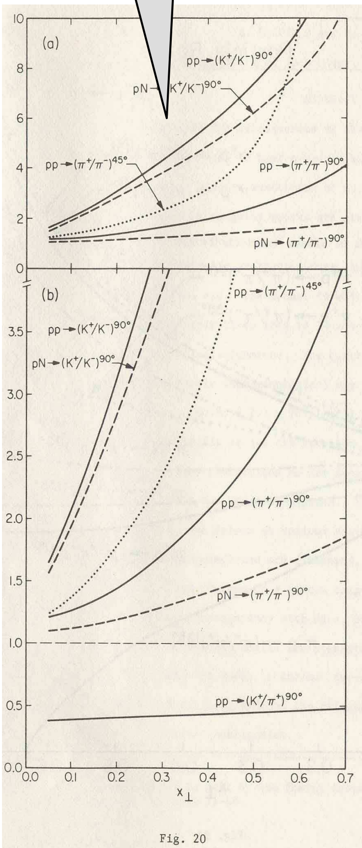


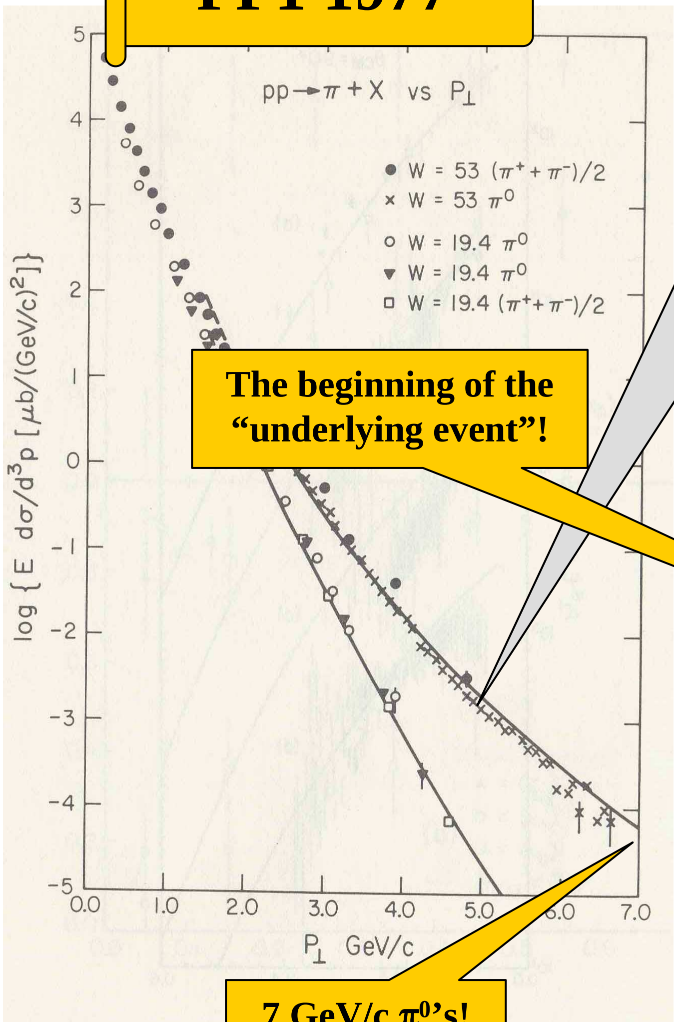
Predict
overall event topology (FFF1 paper 1977)

Quark-Quark Black-Box Model

FF1 1977

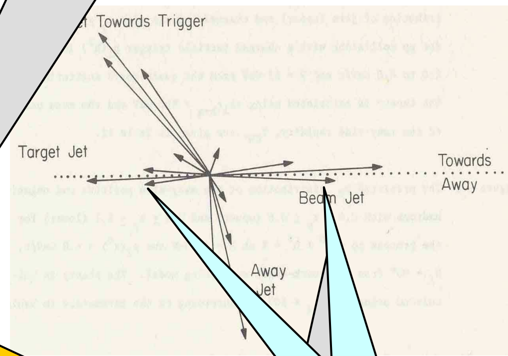
Predict particle ratios





Predict increase with increasing CM energy W

The beginning of the "underlying event"!



"Beam-Beam Remnants"

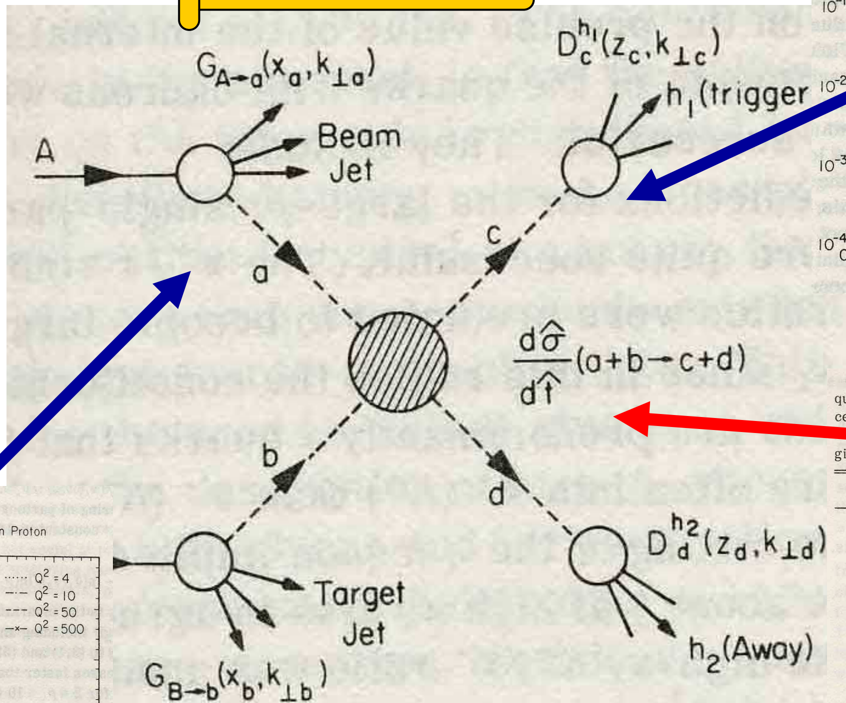
Predict overall event topology (FFF1 paper 1977)

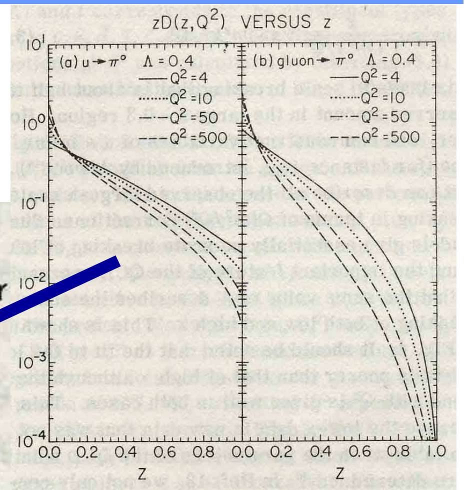
7 GeV/c π^0's!

QCD Approach: Quarks & Gluons

FFF2 1978

Parton Distribution Functions
Q^2 dependence predicted from QCD





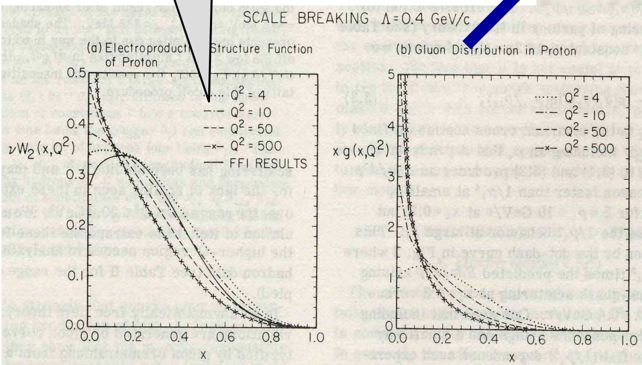


TABLE I. Cross sections for the various constituent quark-quark, quark-gluon, and gluon-gluon subprocesses.[a] The differential cross section is given by $d\hat{\sigma}/d\hat{t}$ $\alpha_s^2(Q^2)|A|^2/\hat{s}^2$, where $\alpha_s(Q^2)$ is the effective coupling given by Eq. (3.1).

	Subprocess	$\lvert A\rvert^2$
1.	$q_iq_j\to q_iq_j$ $q_i\bar{q}_j\to q_i\bar{q}_j$ $(i\neq j)$	$\frac{4}{9}\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}$
2.	$q_iq_i\to q_iq_i$	$\frac{4}{9}\left(\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}+\frac{\hat{s}^2+\hat{t}^2}{\hat{u}^2}\right)-\frac{8}{27}\frac{\hat{s}^2}{\hat{u}\hat{t}}$
3.	$q_i\bar{q}_i\to q_i\bar{q}_i$	$\frac{4}{9}\left(\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}+\frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2}\right)-\frac{8}{27}\frac{\hat{u}^2}{\hat{s}\hat{t}}$
4.	$q_i\bar{q}_i\to gg$	$\frac{32}{27}\left(\frac{\hat{u}^2+\hat{t}^2}{\hat{u}\hat{t}}\right)-\frac{8}{3}\left(\frac{\hat{u}^2+\hat{t}^2}{\hat{s}^2}\right)$
5.	$gg\to q_i\bar{q}_i$	$\frac{1}{6}\left(\frac{\hat{u}^2+\hat{t}^2}{\hat{u}\hat{t}}\right)-\frac{3}{8}\left(\frac{\hat{u}^2+\hat{t}^2}{\hat{s}^2}\right)$
6.	$q_ig\to q_ig$	$-\frac{4}{9}\left(\frac{\hat{u}^2+\hat{s}^2}{\hat{u}\hat{s}}\right)+\left(\frac{\hat{u}^2+\hat{s}^2}{\hat{t}^2}\right)$
7.	$gg\to gg$	$\frac{9}{2}\left(3-\frac{\hat{u}\hat{t}}{\hat{s}^2}-\frac{\hat{u}\hat{s}}{\hat{t}^2}-\frac{\hat{s}\hat{t}}{\hat{u}^2}\right)$

QCD Approach: Quarks & Gluons

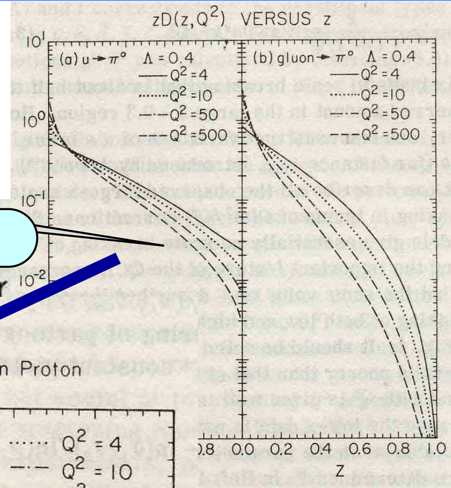
Quark & Gluon Fragmentation Functions
Q^2 dependence predicted from QCD

FFF2 1978

Parton Distribution Functions
Q^2 dependence predicted from QCD

Feynman quote from FFF2

"We investigate whether the present experimental behavior of mesons with large transverse momentum in hadron-hadron collisions is consistent with the theory of quantum-chromodynamics (QCD) with asymptotic freedom, at least as the theory is now partially understood."



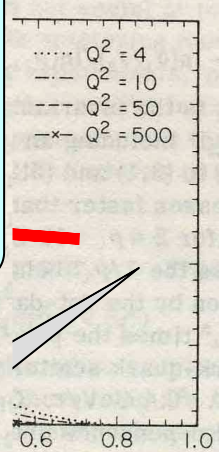
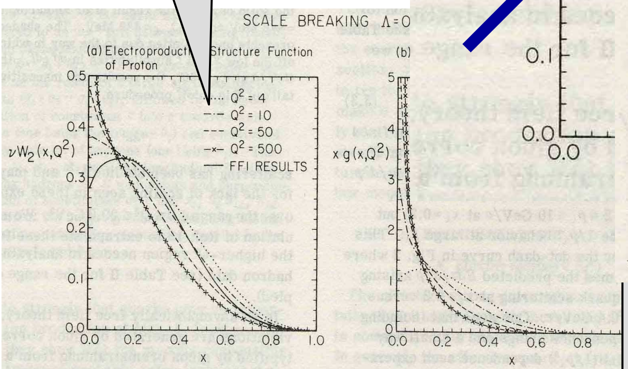


TABLE I. Cross sections for the various constituent ...

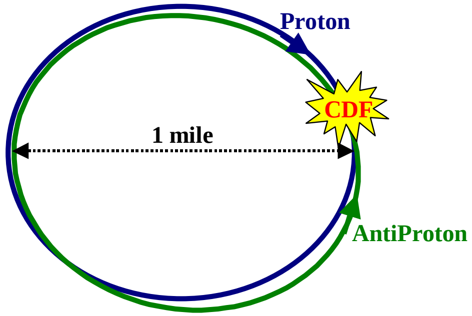
		$\lvert A\rvert^2$
4.	$q_i\bar q_i \to gg$	$\frac{32}{27}\left(\frac{\hat u^2+\hat t^2}{\hat u\hat t}\right)-\frac{8}{3}\left(\frac{\hat u^2+\hat t^2}{\hat s^2}\right)$
5.	$gg \to q_i\bar q_i$	$\frac{1}{6}\left(\frac{\hat u^2+\hat t^2}{\hat u\hat t}\right)-\frac{3}{8}\left(\frac{\hat u^2+\hat t^2}{\hat s^2}\right)$
6.	$q_i g \to q_i g$	$-\frac{4}{9}\left(\frac{\hat u^2+\hat s^2}{\hat u\hat s}\right)+\left(\frac{\hat u^2+\hat s^2}{\hat t^2}\right)$
7.	$gg \to gg$	$\frac{9}{2}\left(3-\frac{\hat u\hat t}{\hat s^2}-\frac{\hat u\hat s}{\hat t^2}-\frac{\hat s\hat t}{\hat u^2}\right)$



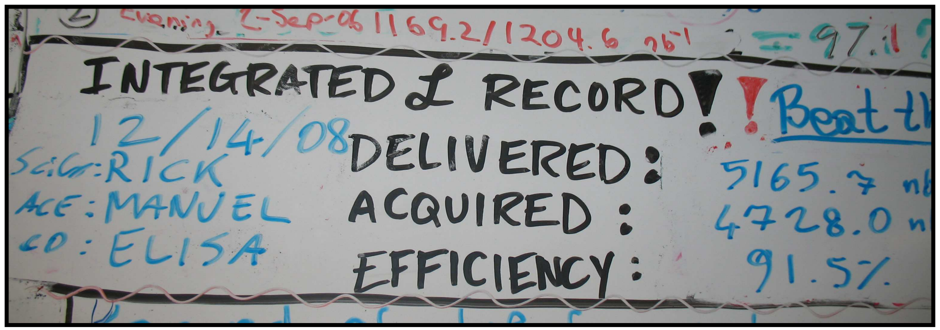
Quark & Gluon Cross-Sections
Calculated from QCD

The Fermilab Tevatron

CDF “SciCo” Shift December 12-19, 2008



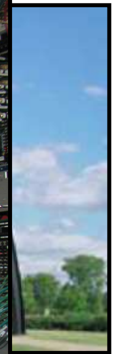
- I joined CDF in January 1998.



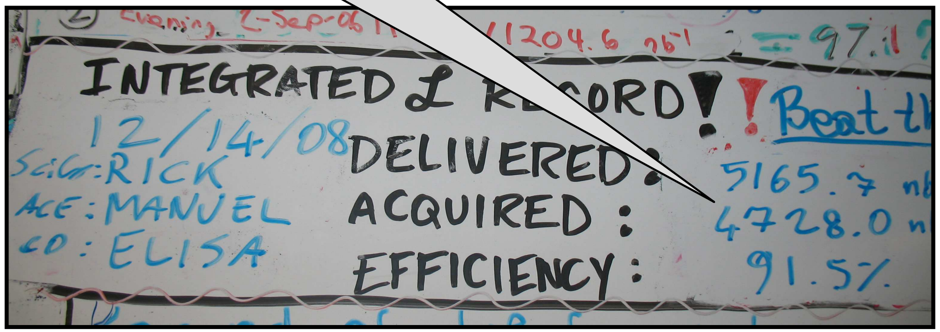
The Fermilab Tevatron

CDF "SciCo" Shift December 12-19, 2008

My wife Jimmie on shift with me!



Acquired 4728 nb^{-1} during 8 hour "owl" shift!



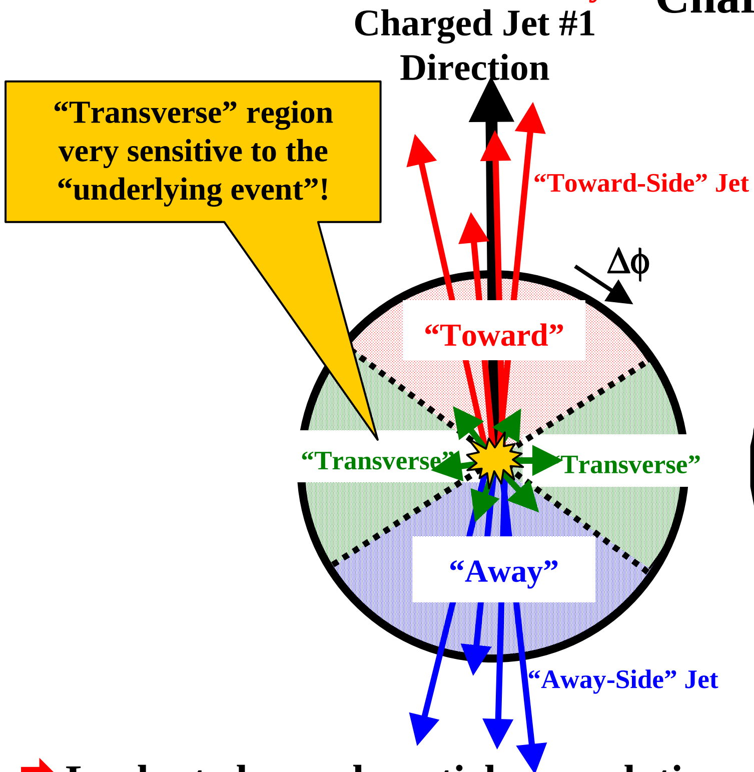
- **I joined CDF in January 1998.**

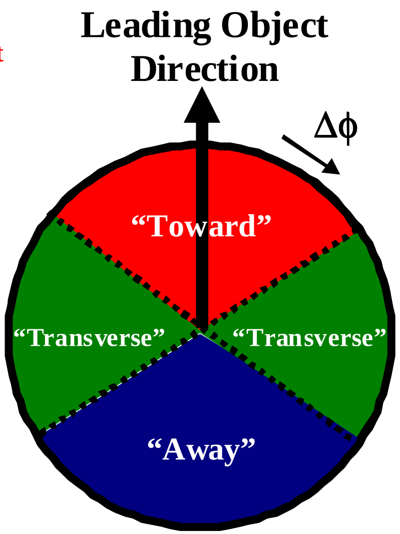
Traditional Approach

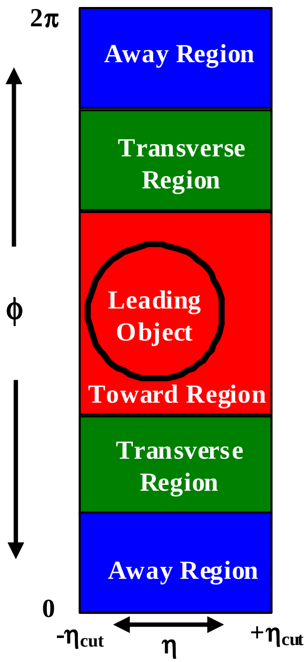
CDF Run 1 Analysis

Charged Particle $\Delta\phi$ Correlations

$P_T > PT_{min}\ |\eta| < \eta_{cut}$

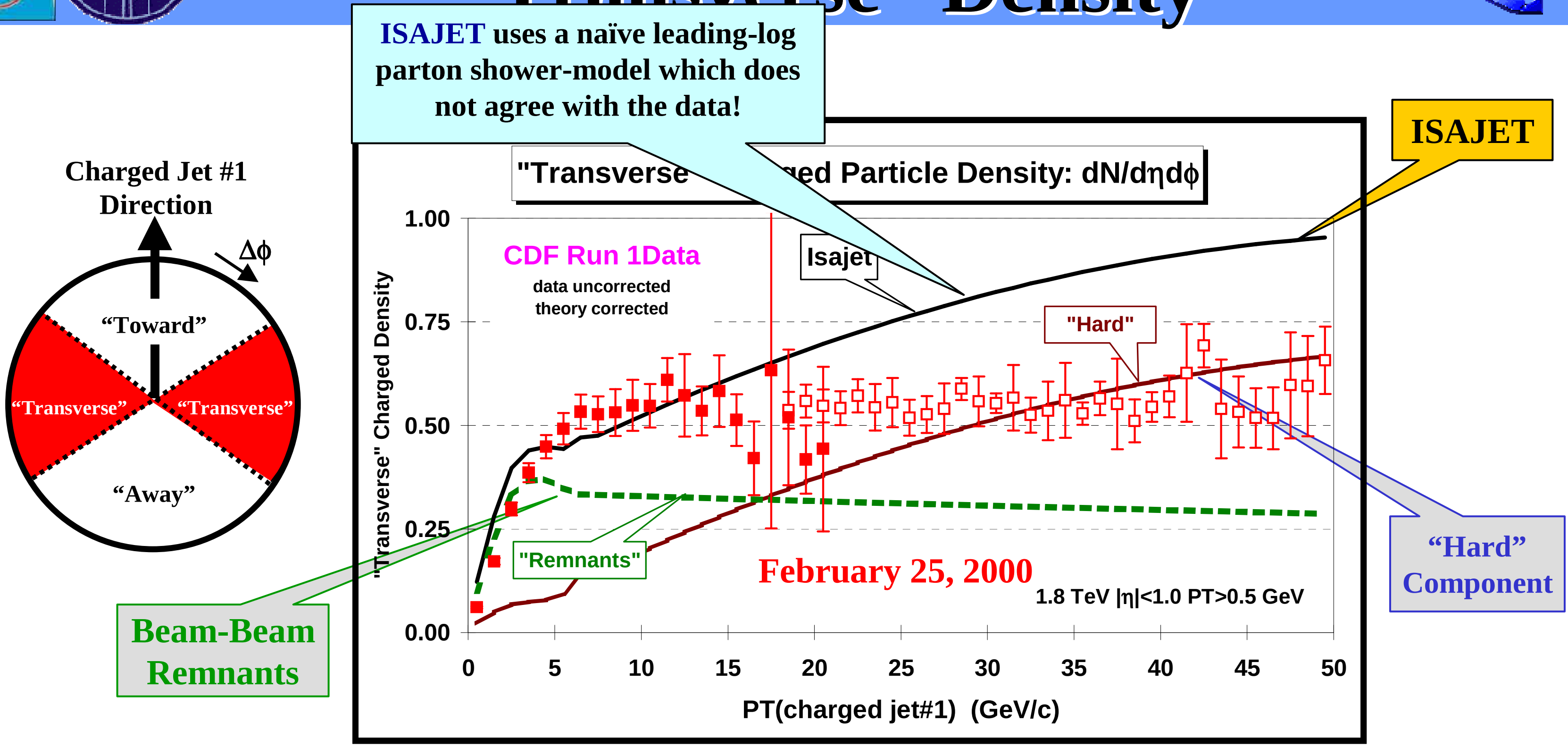






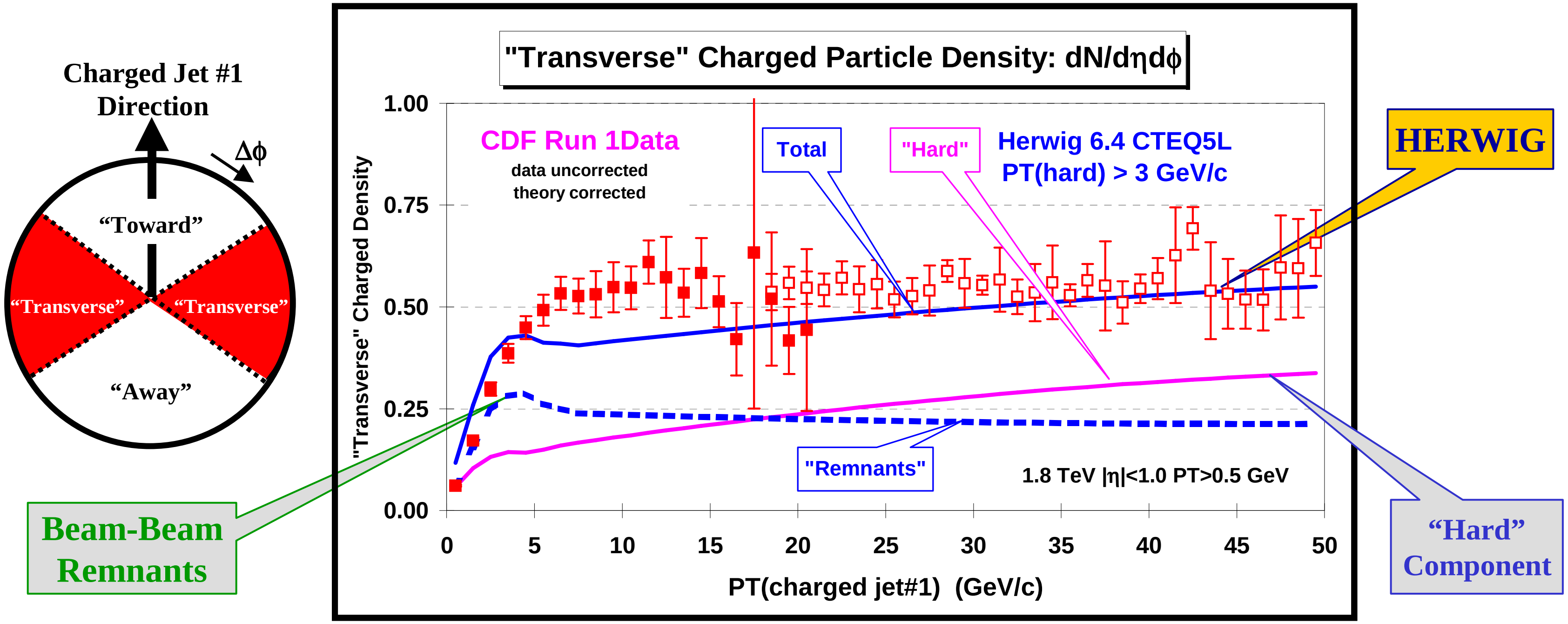
- **Look at charged particle correlations in the azimuthal angle $\Delta\phi$ relative to a leading object (*i.e.* CaloJet#1, ChgJet#1, PTmax, Z-boson). For CDF PTmin = 0.5 GeV/c η_{cut} = 1.0 or 0.8.**
- **Define $|\Delta\phi| < 60^o$ as "Toward", $60^o < |\Delta\phi| < 120^o$ as "Transverse", and $|\Delta\phi| > 120^o$ as "Away".**
- **All three regions have the same area in η-ϕ space, $\Delta\eta\times\Delta\phi = 2\eta_{cut}\times120^o = 2\eta_{cut}\times2\pi/3$. Construct densities by dividing by the area in η-ϕ space.**

ISAJET 7.32 (without MPI) "Transverse" Density



- Plot shows average "transverse" charge particle density ($|\eta|<1$, $p_T>0.5$ GeV) versus P_T(charged jet#1) compared to the QCD hard scattering predictions of ISAJET 7.32 (default parameters with P_T(hard)>3 GeV/c) .
- The predictions of ISAJET are divided into two categories: charged particles that arise from the break-up of the beam and target (beam-beam remnants); and charged particles that arise from the outgoing jet plus initial and final-state radiation (hard scattering component).

HERWIG 6.4 (without MPI) "Transverse" Density



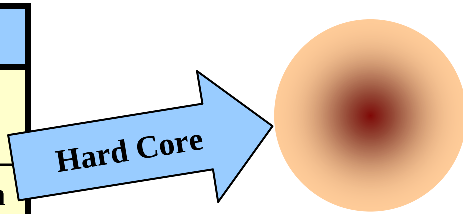
- Plot shows average "transverse" charge particle density ($|\eta|<1$, $p_T>0.5$ GeV) versus P_T(charged jet#1) compared to the QCD hard scattering predictions of **HERWIG 5.9** (default parameters with P_T(hard)>3 GeV/c without MPI).
- The predictions of HERWIG are divided into two categories: charged particles that arise from the break-up of the beam and target (**beam-beam remnants**); and charged particles that arise from the outgoing jet plus initial and final-state radiation (**hard scattering component**).

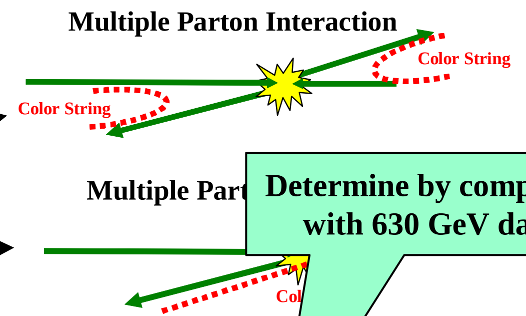
Tuning PYTHIA 6.2:
Multiple Parton Interaction Parameters

Parameter	Default	Description
PARP(83)	0.5	Double-Gaussian: Fraction of total hadronic matter within PARP(84)
PARP(84)	0.2	Double-Gaussian: Fraction of the overall hadron radius containing the fraction PARP(83) of the total hadronic matter.
PARP(85)	0.33	Pr… …uces two gluons w… …nearest neighbors.
PARP(86)	0.66	Prob… …luons eit… …s des… …closed …l loop. … …ists of …ark-antiqua… …s.
PARP(89)	1 Te…	Determin… …reference energy E_0.
PARP(82)	…9 GeV/c	The c… …ff P_{T0} that regulates the 2-to-2 sc… …ring divergence $1/PT^4 \rightarrow 1/(PT^2+P_{T0}^2)^2$
PARP(90)	0.16	Determines the energy dependence of the cut-off P_{T0} as follows $P_{T0}(E_{cm}) = P_{T0}(E_{cm}/E_0)^{\varepsilon}$ with ε = PARP(90)
PARP(67)	1.0	A scale factor that determines the maximum parton virtuality for space-like showers. The larger the value of PARP(67) the more initial-state radiation.

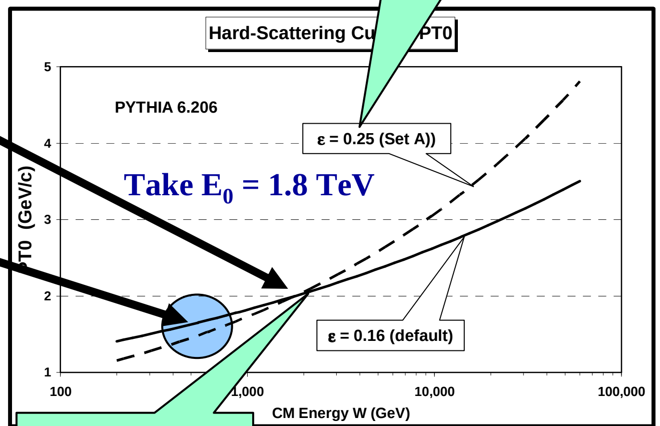
Determines the energy dependence of the MPI!

Affects the amount of initial-state radiation!





Determine by comparing with 630 GeV data!



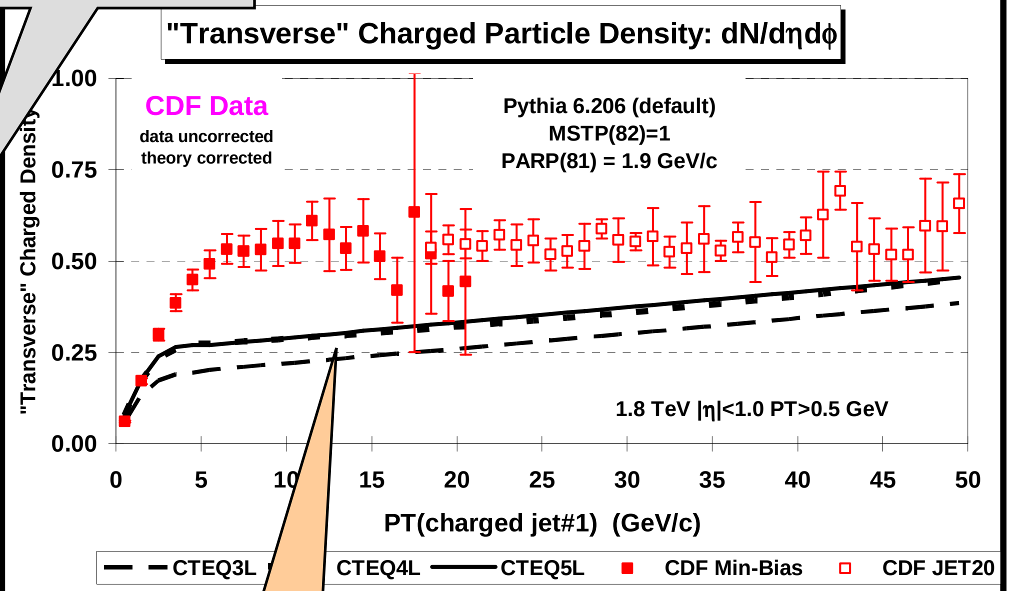
Reference point at 1.8 TeV

PYTHIA 6.206 Defaults

PYTHIA default parameters

Parameter	6.115	6.125	6.158	6.206
MSTP(81)	1	1	1	1
MSTP(82)	1	1	1	1
PARP(81)	1.4	1.9	1.9	1.9
PARP(82)	1.55	2.1	2.1	1.9
PARP(89)		1,000	1,000	1,000
PARP(90)		0.16	0.16	0.16
PARP(67)	4.0	4.0	1.0	1.0

MPI constant probability scattering



- Plot shows the "Transverse" charged particle density versus P_T(chgjet#1) compared to the QCD hard scattering predictions of PYTHIA 6.206 (P_T(hard) > 0) using the default parameters for multiple parton interactions and CTEQ3L, CTEQ4L, and CTEQ5L.

<u>Note Change</u>
PARP(67) = 4.0 (< 6.138)
PARP(67) = 1.0 (> 6.138)

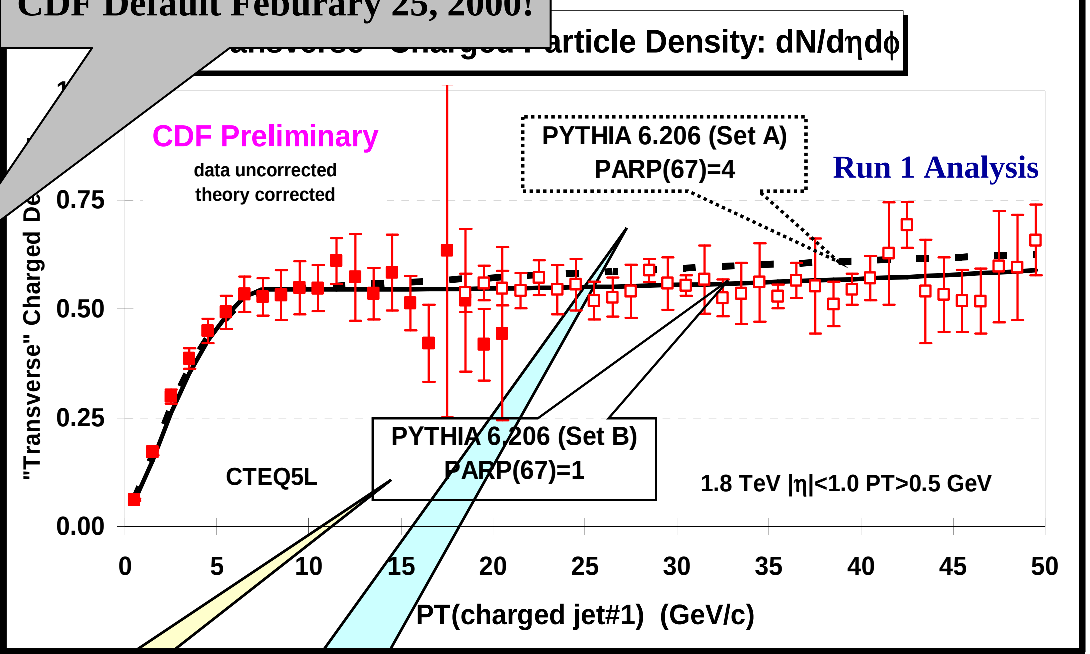
Default parameters give very poor description of the "underlying event"!

Run 1 PYTHIA Tune A

PYTHIA 6.206 CTEQ5L

Parameter	Tune B	Tune A
MSTP(81)	1	1
MSTP(82)	4	4
PARP(82)	1.9 GeV	2.0 GeV
PARP(83)	0.5	0.5
PARP(84)	0.4	0.4
PARP(85)	1.0	0.9
PARP(86)	1.0	0.95
PARP(89)	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25
PARP(67)	1.0	4.0

CDF Default Feburary 25, 2000!

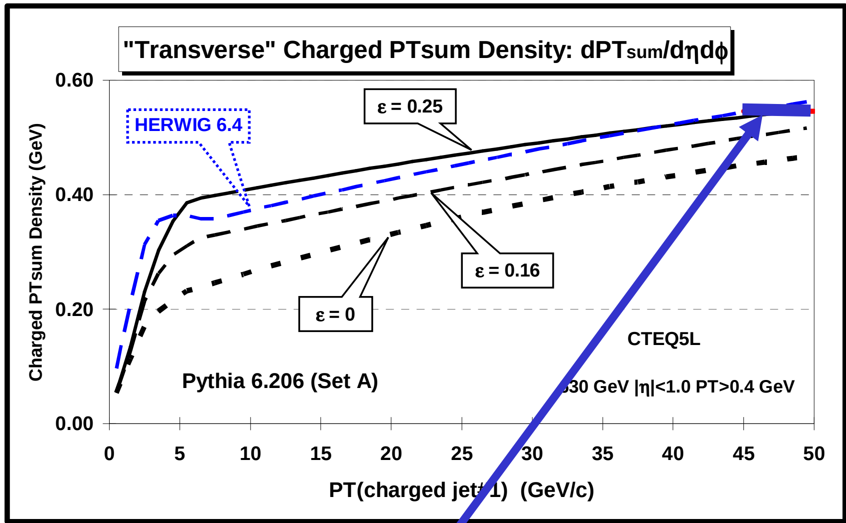


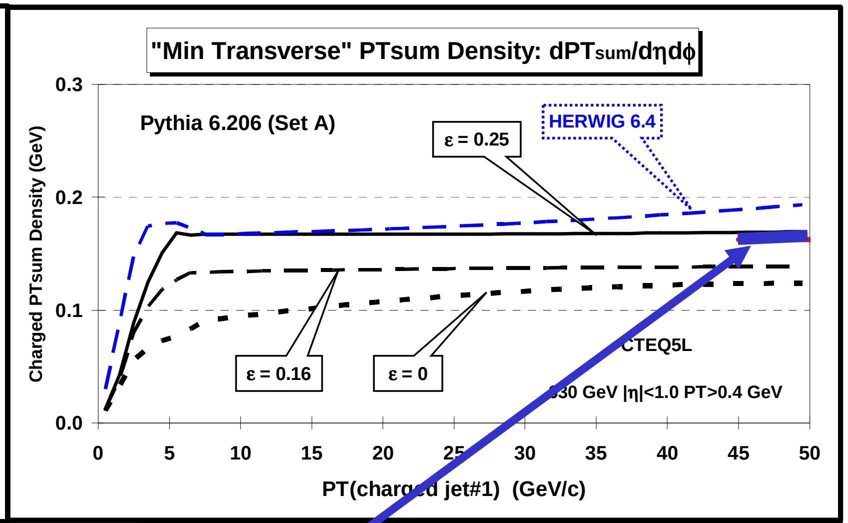
- Plot shows the "transverse" charged particle density versus P_T(chgjet#1) compared to the QCD hard scattering predictions of two tuned versions of PYTHIA 6.206 (CTEQ5L, Set B (PARP(67)=1) and Set A (PARP(67)=4)).

Old PYTHIA default (more initial-state radiation)

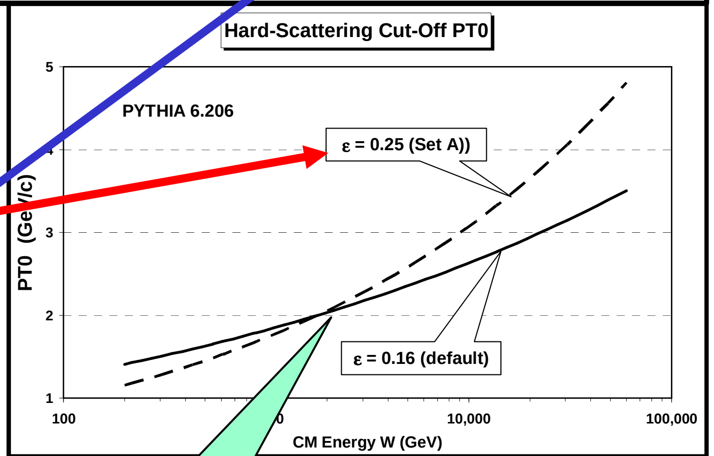
New PYTHIA default (less initial-state radiation)

"Transverse" Charged Densities Energy Dependence





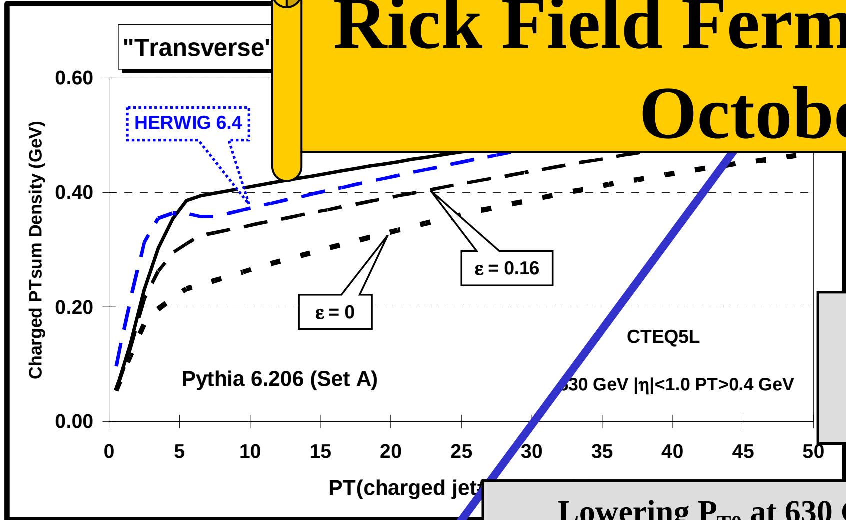
- Shows the "transverse" charged PT_{sum} density ($|\eta|<1$, $P_T>0.4$ GeV) versus P_T(charged jet#1) at 630 GeV predicted by **HERWIG 6.4** (P_T(hard) > 3 GeV/c, CTEQ5L) and a **tuned** version of **PYTHIA 6.206** (P_T(hard) > 0, CTEQ5L, Set A, **ε = 0, ε = 0.16 (default) and ε = 0.25 (preferred)**).
- Also shown are the PT_{sum} densities (**0.16 GeV/c** and **0.54 GeV/c**) determined from the **Tano, Kovacs, Huston, and Bhatti "transverse" cone analysis at 630 GeV**.

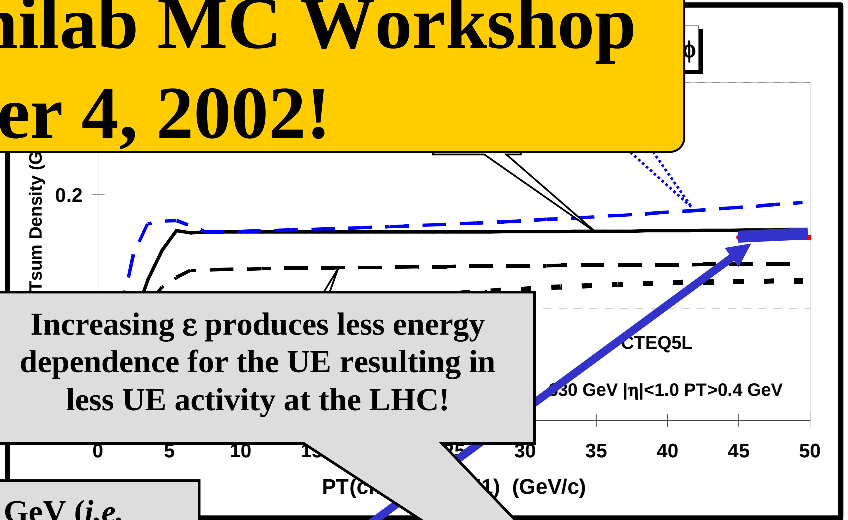


Reference point E_0 = 1.8 TeV

"Transverse" Charged Densities Energy Dependence

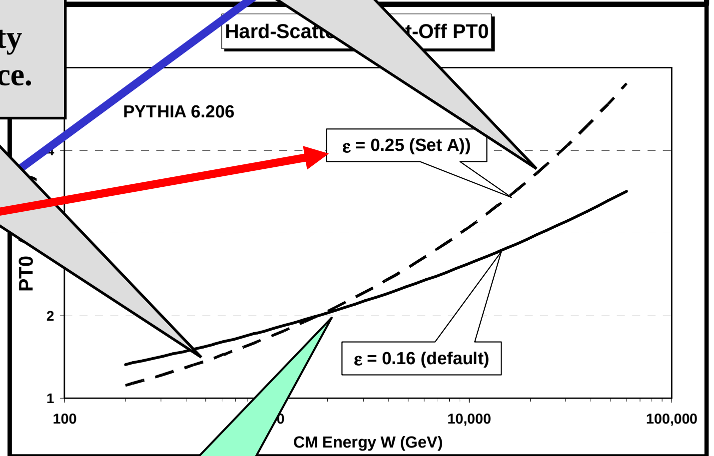
Rick Field Fermilab MC Workshop October 4, 2002!





Increasing ε produces less energy dependence for the UE resulting in less UE activity at the LHC!

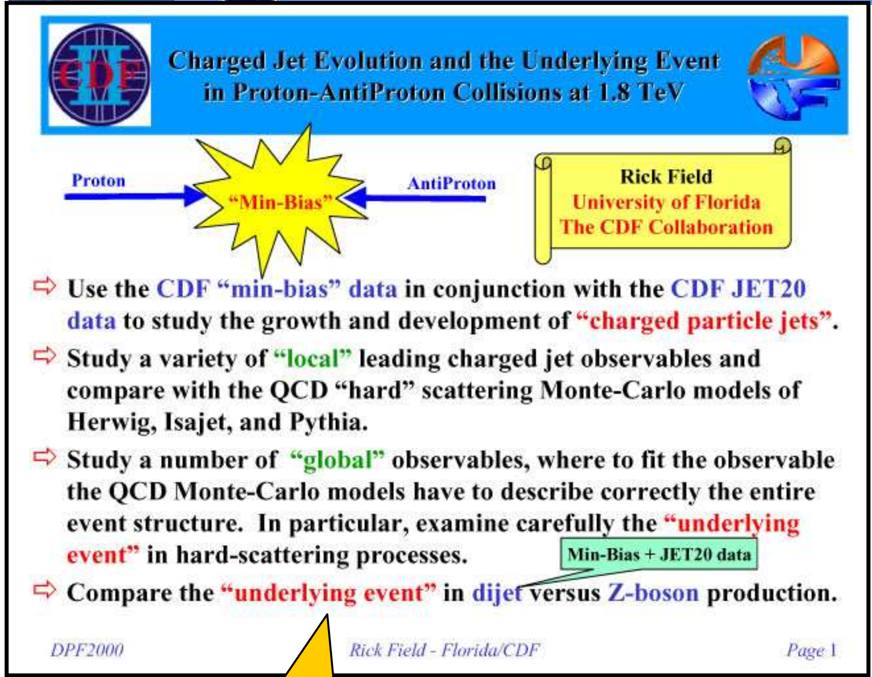
Lowering P_{T0} at 630 GeV (*i.e.* increasing ε) increases UE activity resulting in less energy dependence.

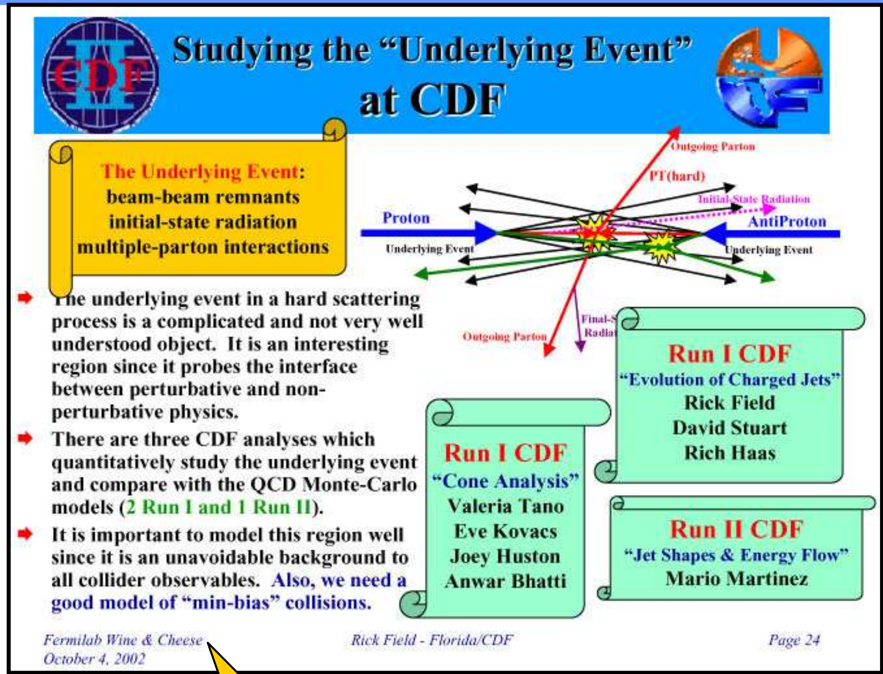


Reference point E_0 = 1.8 TeV

- Shows the "transverse" ch... ($|\eta|<1$, $P_T>0.4$ GeV) versus ... GeV predicted by **HERWIG 6.4** (P_T(hard) > 3 GeV/c, CTEQ5L) and a **tuned** version of **PYTHIA 6.206** (P_T(hard) > 0, CTEQ5L, Set A, ε = 0, ε = 0.16 (default) and ε = 0.25 (preferred)).
- Also shown are the PT_{sum} densities (0.16 GeV/c and 0.54 GeV/c) determined from the Tano, Kovacs, Huston, and Bhatti "transverse" cone analysis at 630 GeV.

Early Studies of the UE

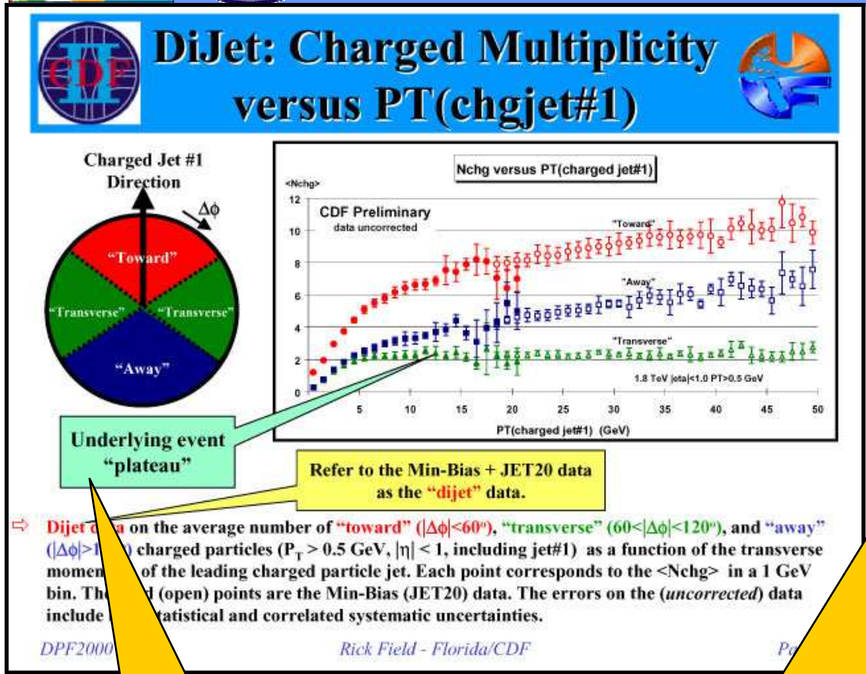


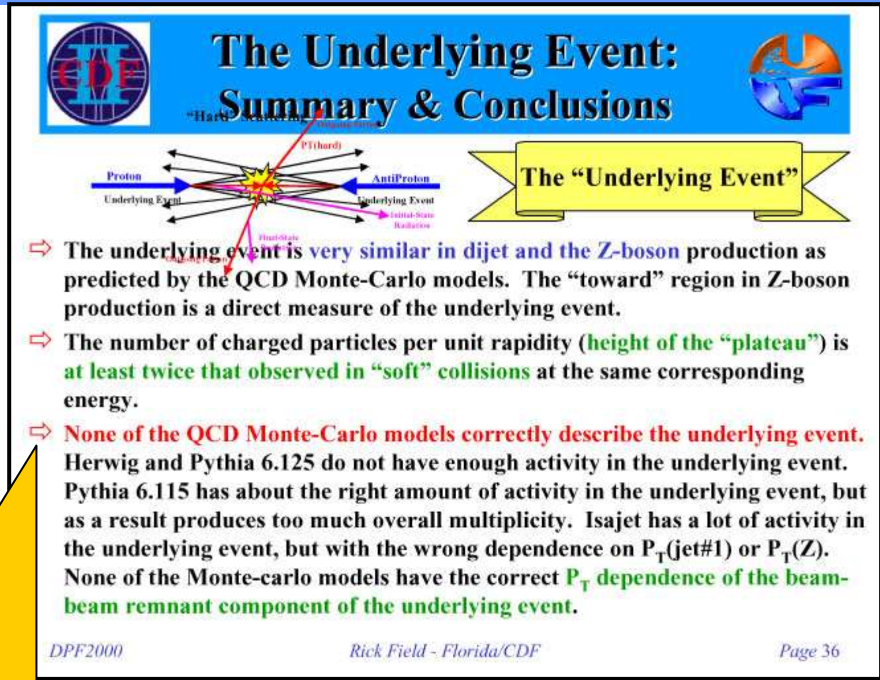


DPF 2000: My first presentation on the "underlying event"!

First CDF UE Studies
Rick Field Wine & Cheese Talk
October 4, 2002

My First Talk on the UE



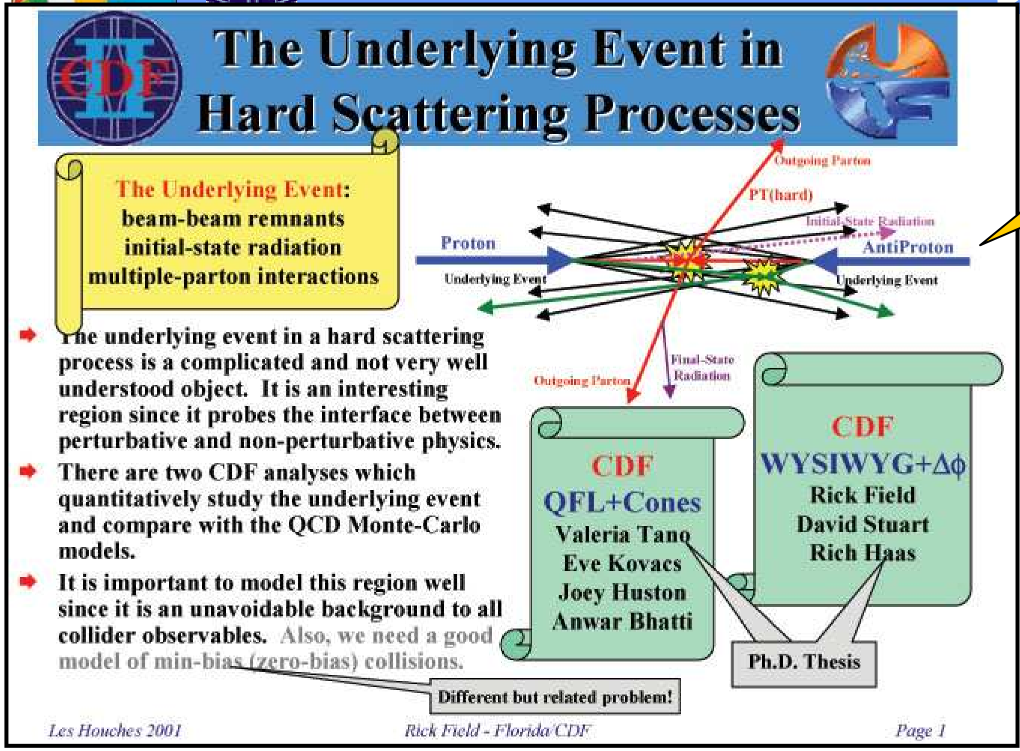


Need to "tune" the QCD MC models!

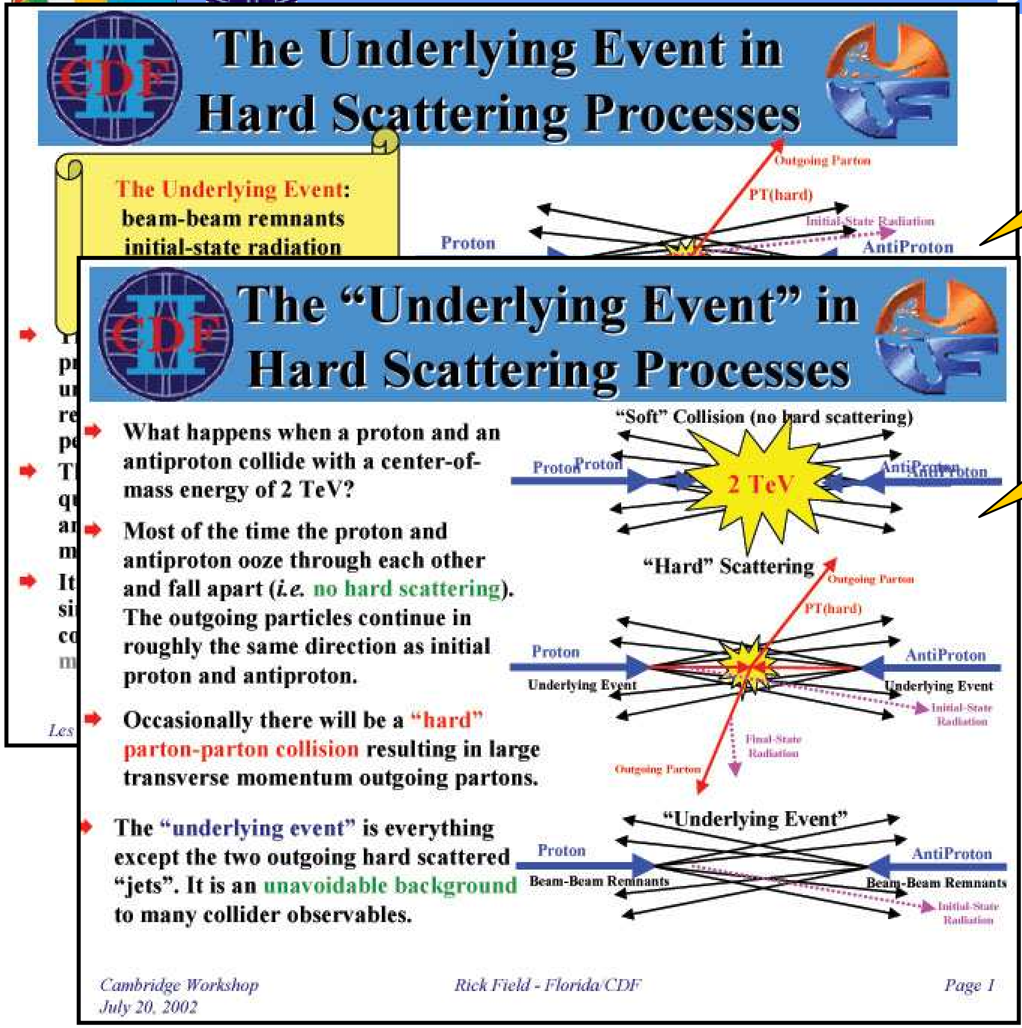
My first look at the "underlying event plateau"!

Other Early UE Talks

Workshop on Physics at TeV Colliders, Les Houches, *May 30, 2001*.



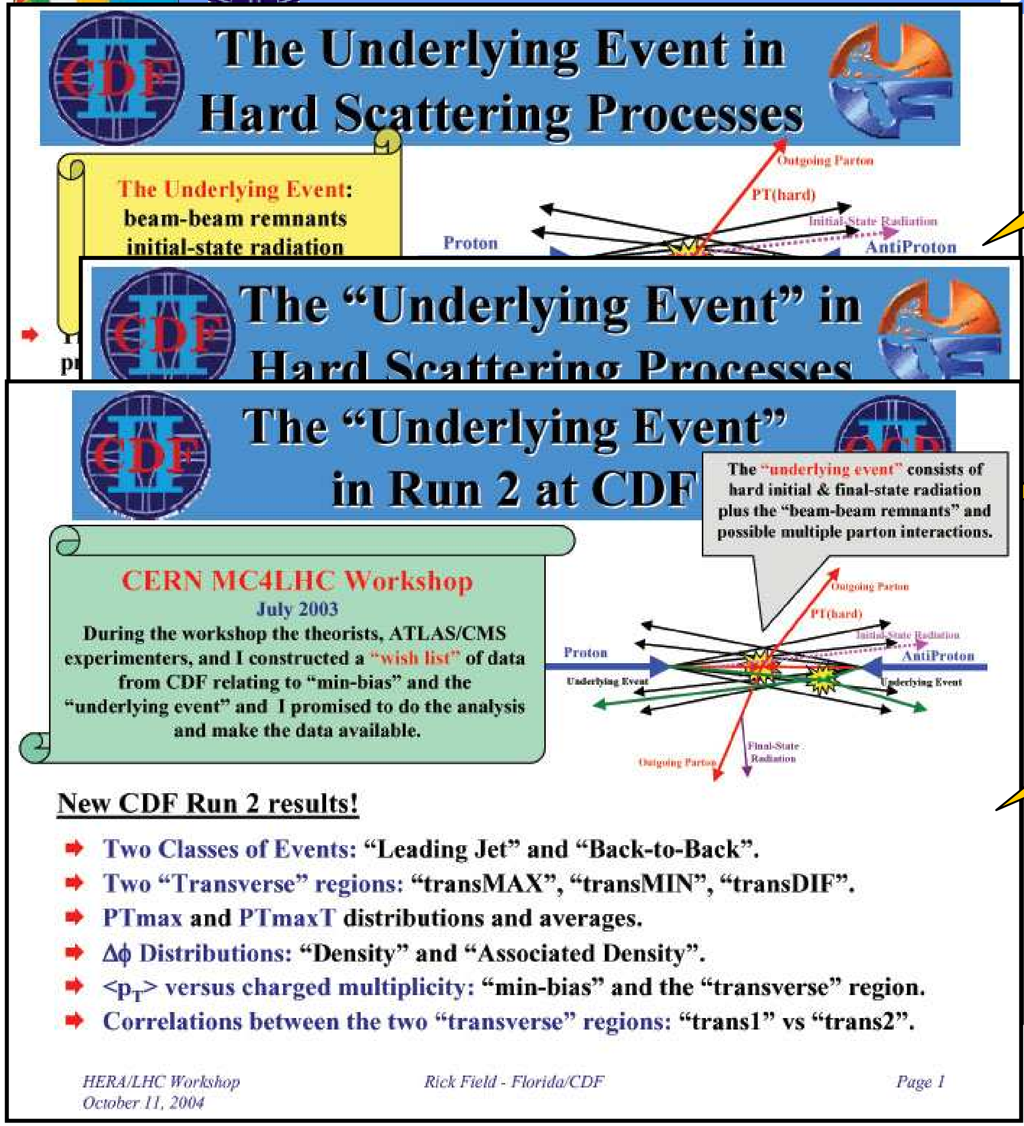
Other Early UE Talks



Workshop on Physics at TeV Colliders, Les Houches, *May 30, 2001*.

Cambridge Workshop on TeV-Scale Physics, *July 20, 2002*.

Other Early UE Talks



Workshop on Physics at TeV Colliders, Les Houches, *May 30, 2001*.

Cambridge Workshop on TeV-Scale Physics, *July 20, 2002*.

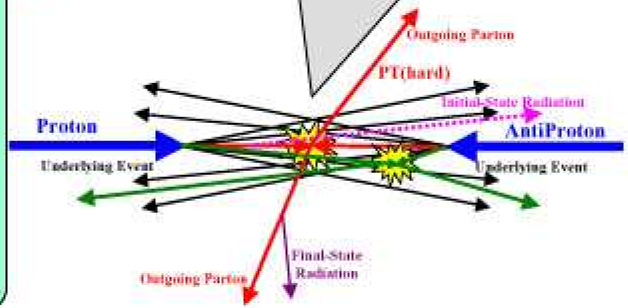
HERA and the LHC Workshop, CERN, *October 11, 2004*.

KITP Collider Workshop 2004

A Closer Look at the Underlying Event in Run 2 a...

The **"underlying event"** consists of hard initial & final-state radiation plus the "beam-beam remnants" and possible multiple parton interactions.

CERN MC4LHC Workshop
July 2003
During the workshop the theorists, ATLAS/CMS experimenters, and I constructed a **"wish list"** of data from CDF relating to "min-bias" and the "underlying event" and I promised to do the analysis and have the data available by the time of the Santa Barbara workshop in February 2004.



New CDF Run 2 results!

- Two Classes of Events: "Leading Jet" and "Back-to-Back".
- Two "Transverse" regions: "transMAX", "transMIN", "transDIF".
- PTmax and PTmaxT distributions and averages.
- $\Delta\phi$ Distributions: "Density" and "Associated Density".
- $<p_T>$ versus charged multiplicity: "min-bias" and the "transverse" region.
- Correlations between the two "transverse" regions: "trans1" vs "trans2".

KITP Collider Workshop
February 17, 2004 | *Rick Field - Florida/CDF* | *Page 1*

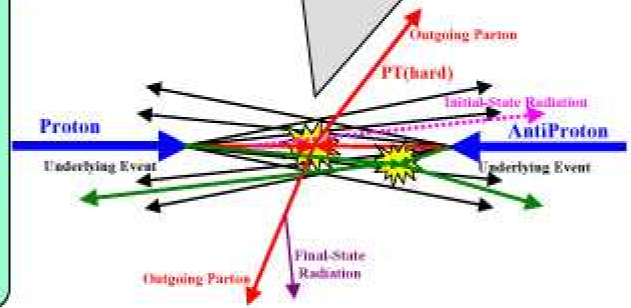
KITP Collider Workshop 2004

Together with Torbjörn Sjöstrand and his graduate student Peter Skands!

A Closer Look at the ...nderlying Event in Run 2 a...

CERN M... LHC Workshop
July ...3
During the workshop the theor...ts, ATLAS/CMS experimenters, and I constructed a "wish list" of data from CDF relating to "min-bias" and the "underlying event" and I promised to do the analysis and have the data available by the time of the Santa Barbara workshop in February 2004.

The "underlying event" consists of hard initial & final-state radiation plus the "beam-beam remnants" and possible multiple parton interactions.



New CDF Run 2 results!

- Two Classes of Events: "Leading Jet" and "Back-to-Back".
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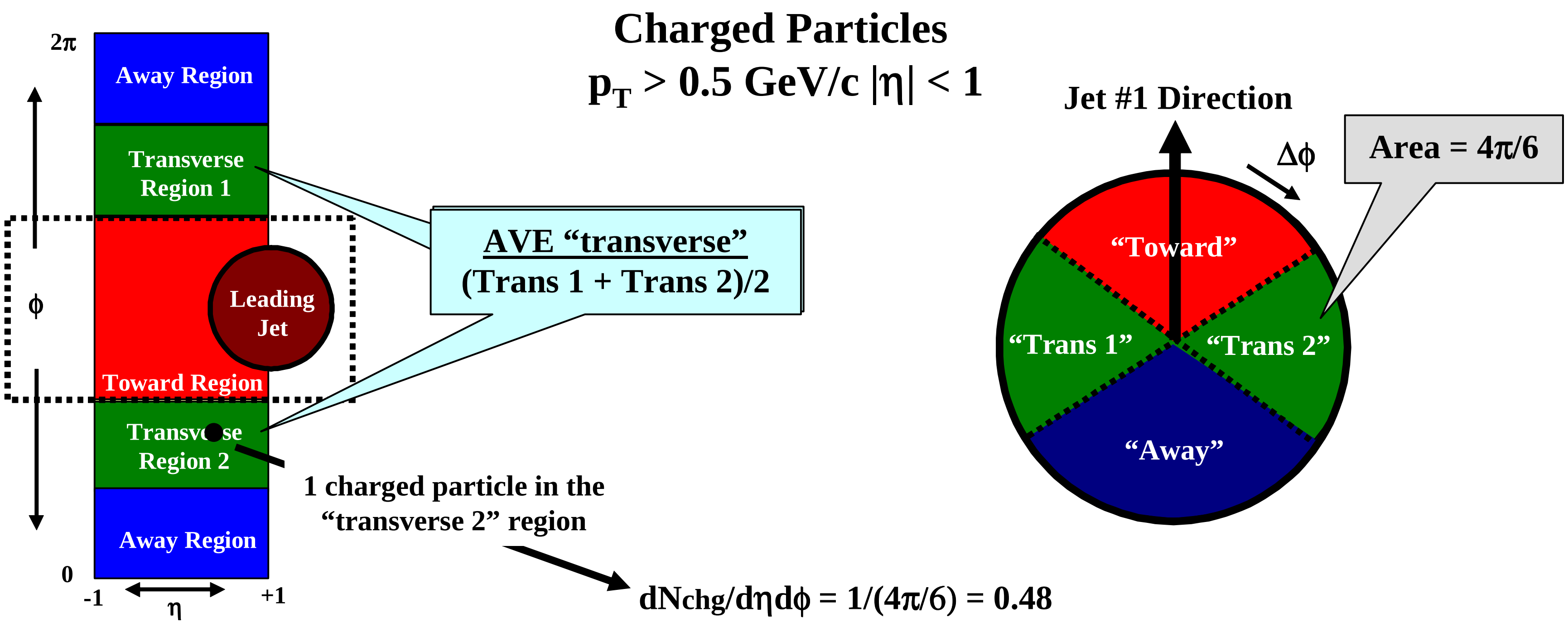
- Correlations between the two "transverse" regions: "trans1" vs "trans2".

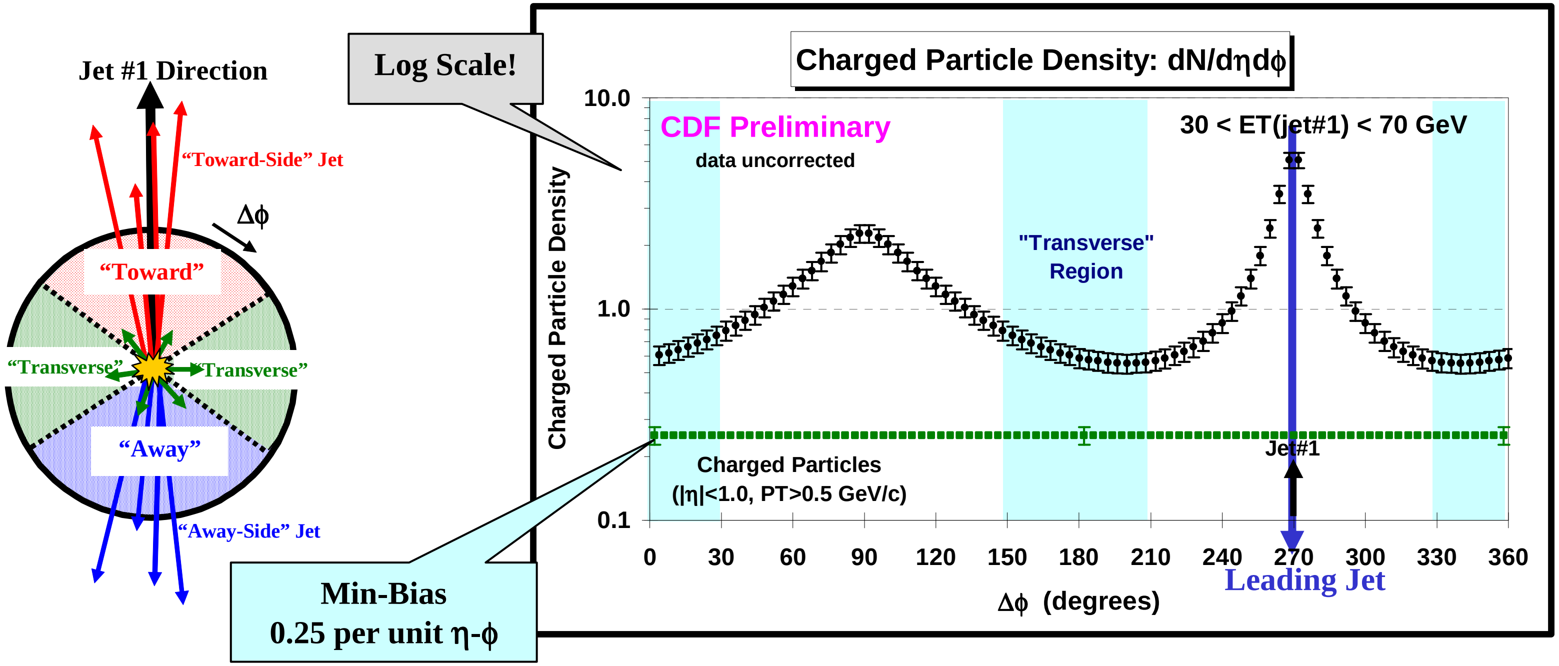
KITP Collider Workshop February 17, 2004 *Rick Field - Florida/CDF* *Page 1*

"Transverse" Particle Densities



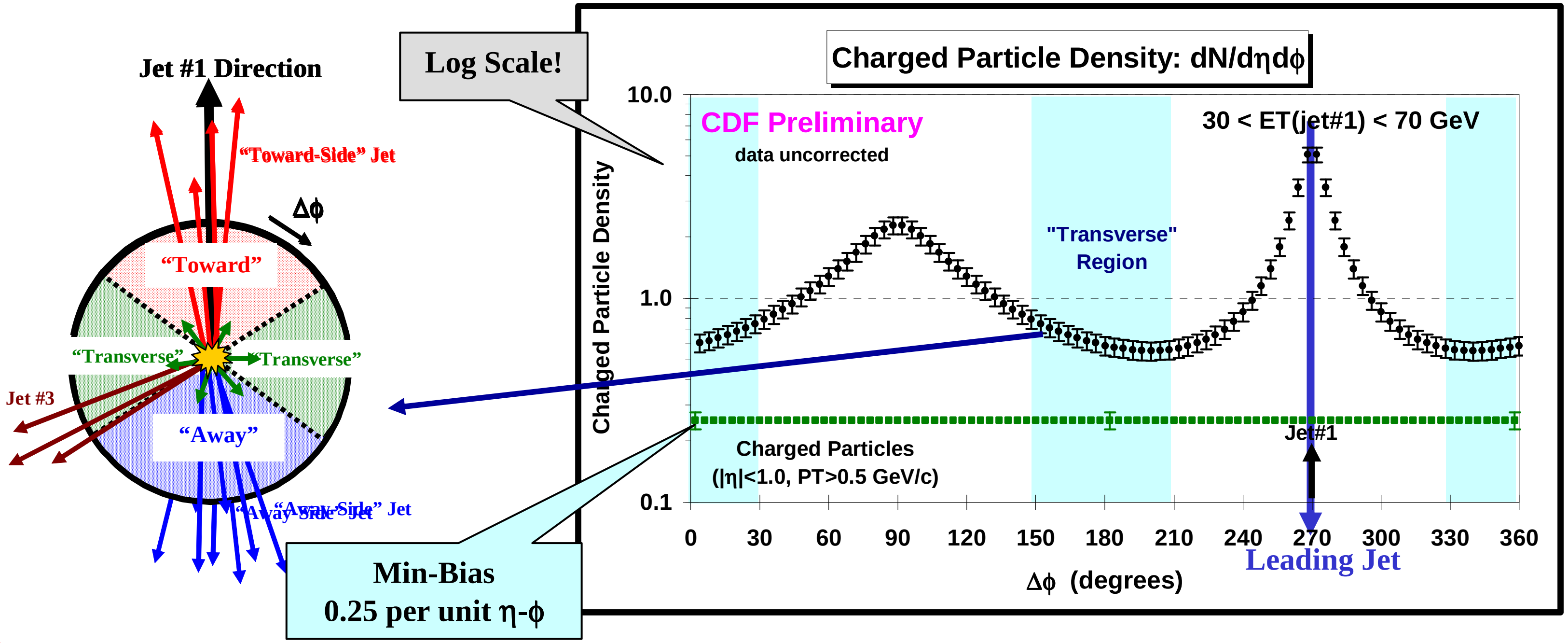
- Study the charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) in the "Transverse 1" and "Transverse 2" and form the charged particle density, dNchg/dηdφ, and the charged scalar p_T sum density, dPTsum/dηdφ.
- The average "transverse" density is the average of "transverse 1" and "transverse 2".

Charged Particle Density
Δϕ Dependence



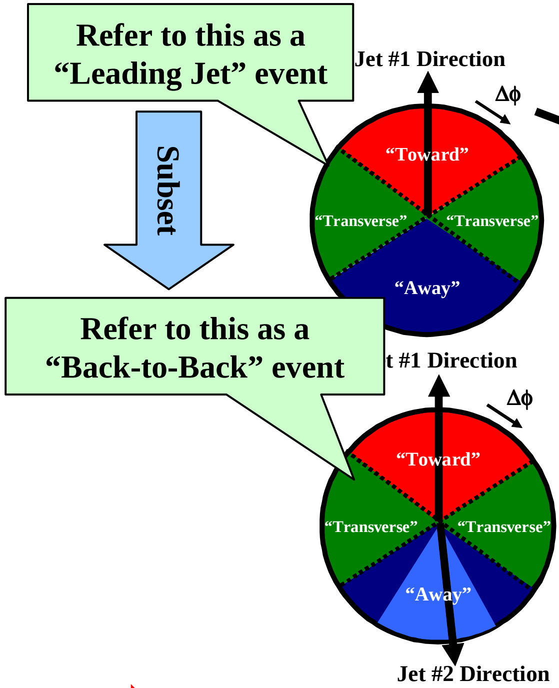
- **Shows the Δϕ dependence of the charged particle density, dNchg/dηdϕ, for charged particles in the range p_T > 0.5 GeV/c and |η| < 1 relative to jet#1 (rotated to 270°) for "leading jet" events 30 < E_T(jet#1) < 70 GeV.**
- **Also shows charged particle density, dNchg/dηdϕ, for charged particles in the range p_T > 0.5 GeV/c and |η| < 1 for "min-bias" collisions.**

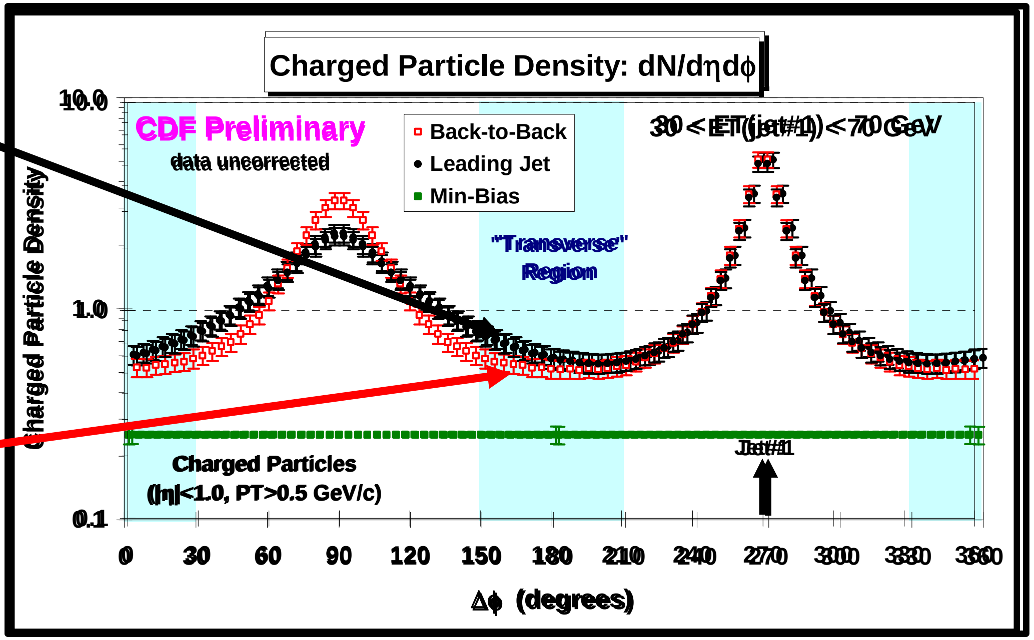
Charged Particle Density
Δϕ Dependence



- Shows the **Δϕ dependence of the charged particle density**, $dN_{chg}/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ relative to jet#1 (rotated to 270°) for **"leading jet"** events $30 < E_T(\text{jet\#1}) < 70$ GeV.
- Also shows charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ for **"min-bias"** collisions.

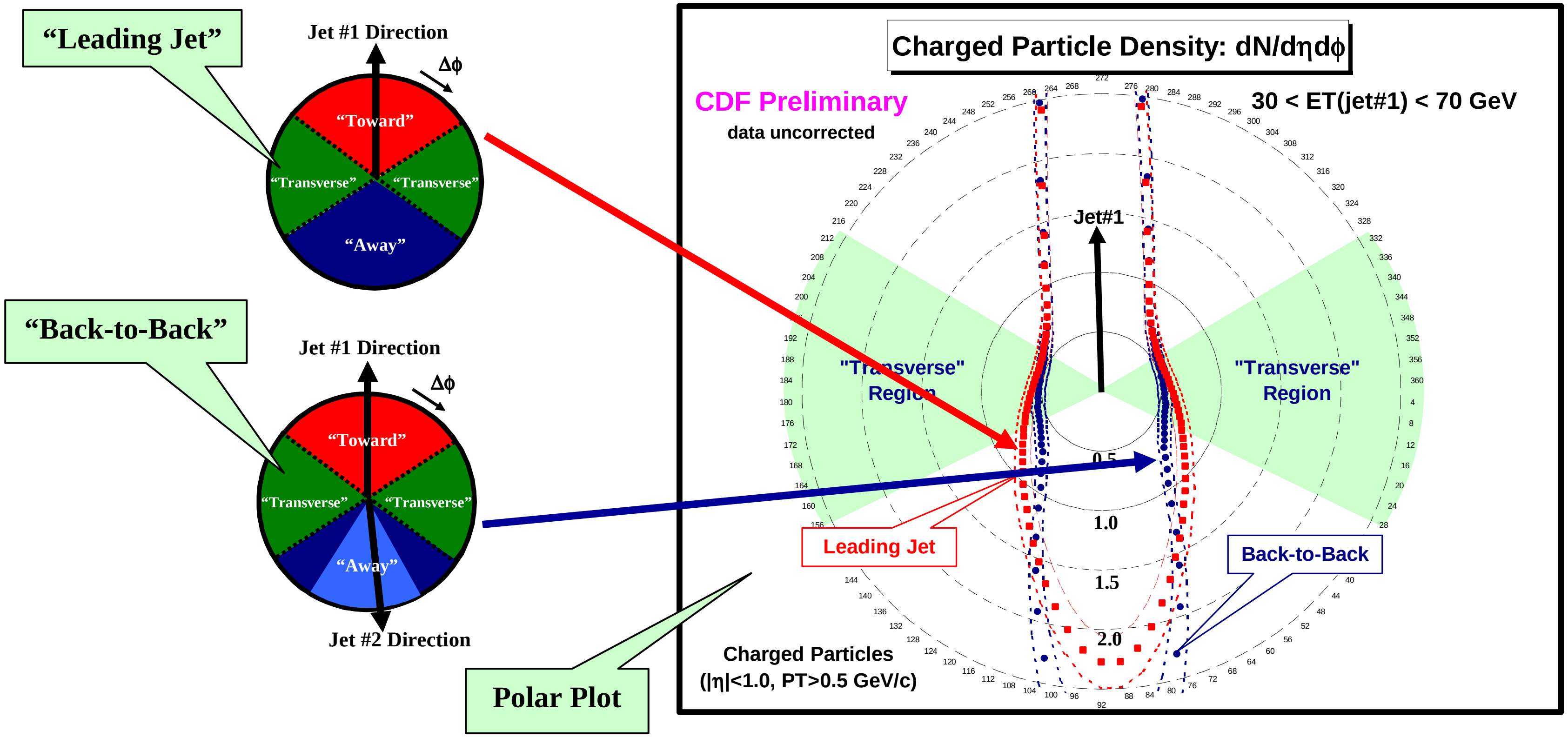
Charged Particle Density
Δφ Dependence





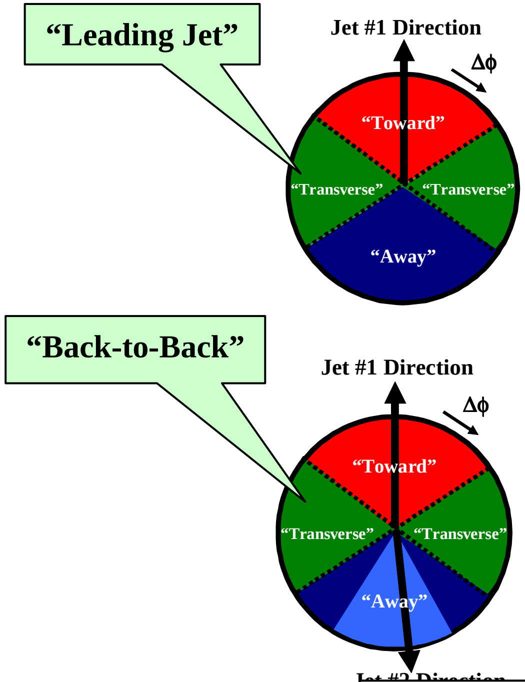
- Look at the "transverse" region as defined by the leading jet (JetClu R = 0.7, |η| < 2) or by the leading two jets (JetClu R = 0.7, |η| < 2). "Back-to-Back" events are selected to have at least two jets with Jet#1 and Jet#2 nearly "back-to-back" ($\Delta\phi_{12} > 150^o$) with almost equal transverse energies (E_T(jet#2)/E_T(jet#1) > 0.8).
- Shows the Δφ dependence of the charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and |η| < 1 relative to jet#1 (rotated to 270^o) for 30 < E_T(jet#1) < 70 GeV for "Leading Jet" and "Back-to-Back" events.

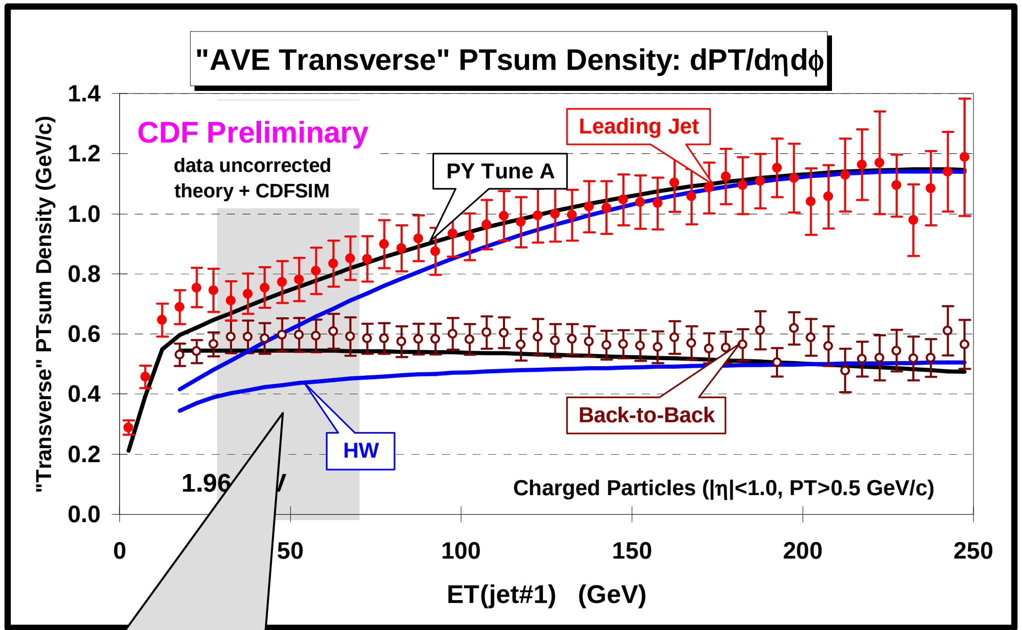
Charged Particle Density
$\Delta\phi$ Dependence



➡ **Shows the $\Delta\phi$ dependence of the charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ relative to jet#1 (rotated to 270°) for 30 < E_T(jet#1) < 70 GeV for "Leading Jet" and "Back-to-Back" events.**

“Transverse” PTsum Density PYTHIA Tune A vs HERWIG

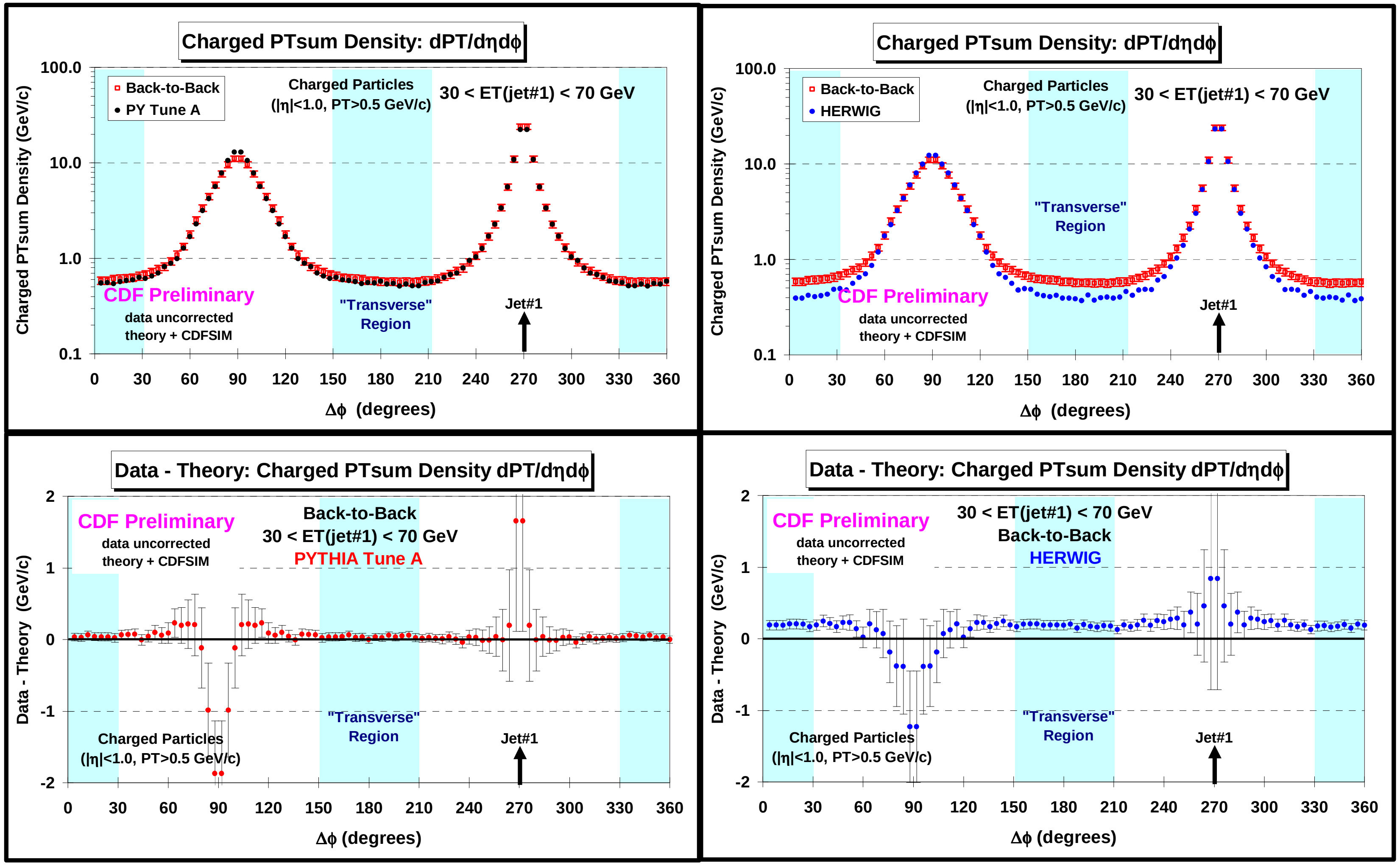




Now look in detail at “back-to-back” events in the region 30 < E_T(jet#1) < 70 GeV!

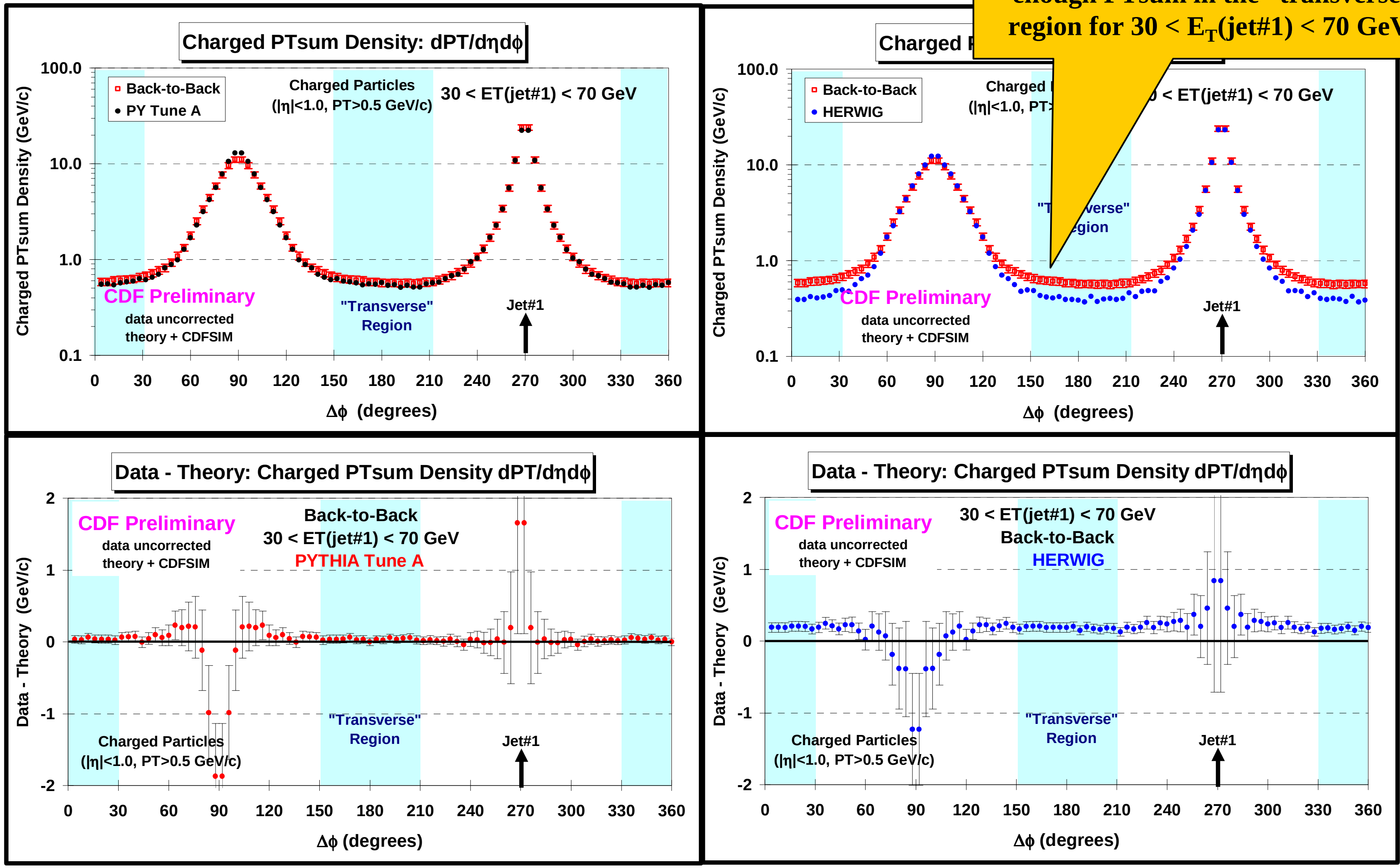
- Shows the **average charged PTsum density**, $dPT_{sum}/d\eta d\phi$, in the **“transverse” region** (p_T > 0.5 GeV/c, $|\eta|$ < 1) versus E_T(jet#1) for **“Leading Jet”** and **“Back-to-Back”** events.
- Compares the (*uncorrected*) data with **PYTHIA Tune A** and **HERWIG (no MPI)** after CDFSIM.

Charged PTsum Density
PYTHIA Tune A vs HERWIG

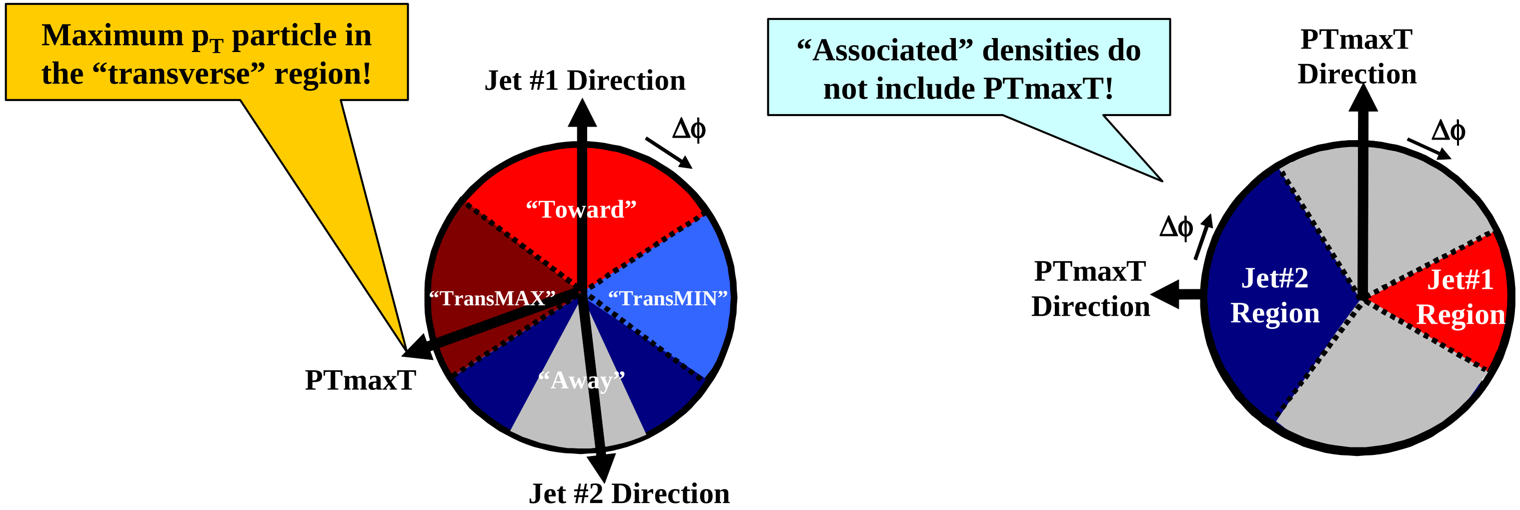


Charged PTsum Density PYTHIA Tune A vs HERWIG

HERWIG (*without multiple parton interactions*) does not produces enough PTsum in the "transverse" region for 30 < E_T(jet#1) < 70 GeV!

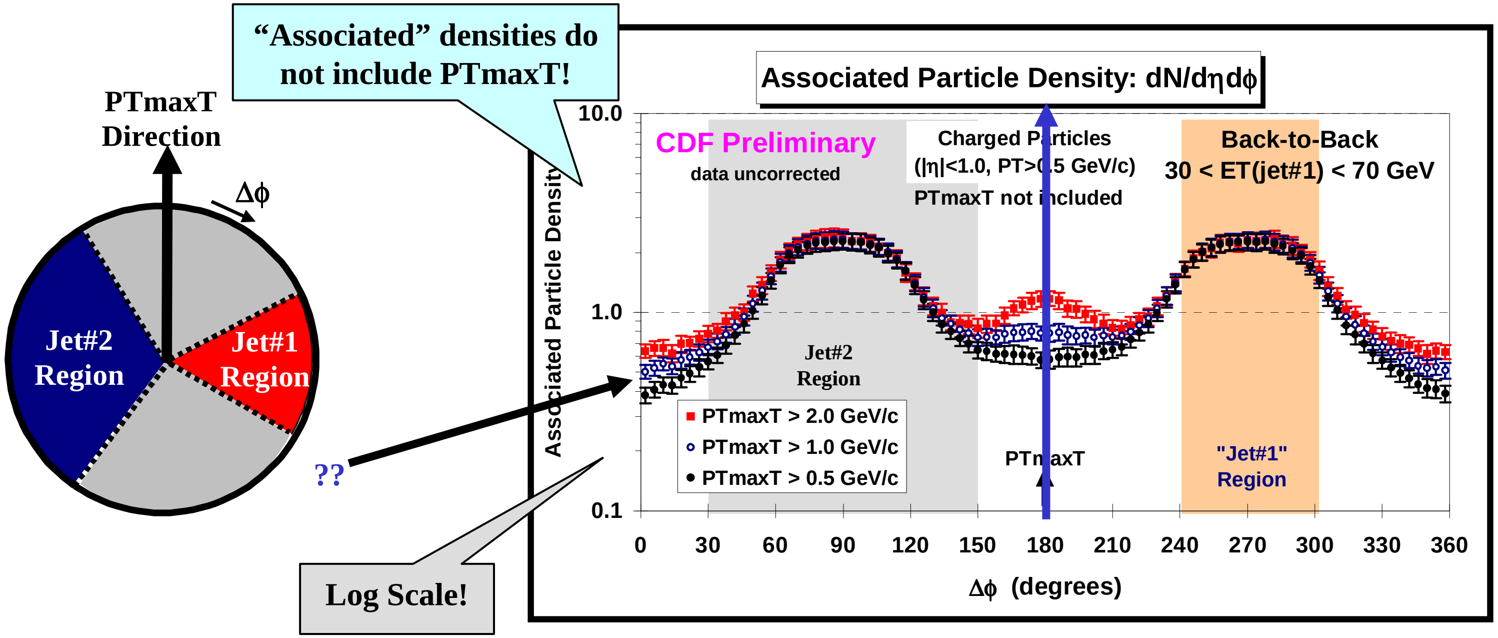


Back-to-Back "Associated" Charged Particle Densities



- Use the leading jet in "back-to-back" events to define the "transverse" region and look at the maximum p_T charged particle in the "transverse" region, PTmaxT.
- Look at the Δϕ dependence of the "associated" charged particle and PTsum densities, $dN_{chg}/d\eta d\phi$ and $dPT_{sum}/d\eta d\phi$ for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including PTmaxT*) relative to PTmaxT.
- Rotate so that PTmaxT is at the center of the plot (*i.e.* 180°).

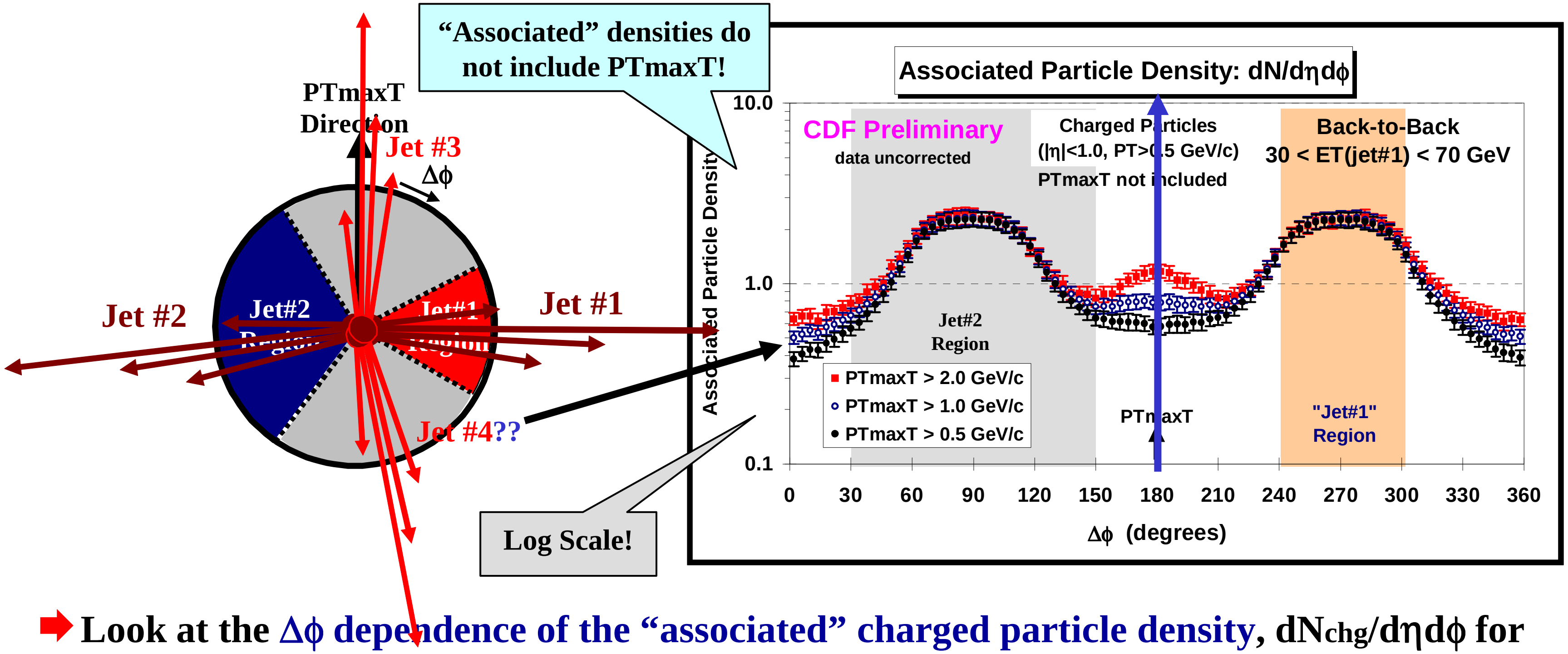
Back-to-Back "Associated" Charged Particle Density



- Look at the **Δφ dependence of the "associated" charged particle density**, $dN_{chg}/d\eta d\phi$ for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmaxT*) relative to PTmaxT (rotated to 180°) for PTmaxT > 0.5 GeV/c, PTmaxT > 1.0 GeV/c and PTmaxT > 2.0 GeV/c, for **"back-to-back" events with 30 < E_T(jet#1) < 70 GeV**.

- Shows **"jet structure" in the "transverse" region** (*i.e.* the "birth" of the 3rd & 4th jet).

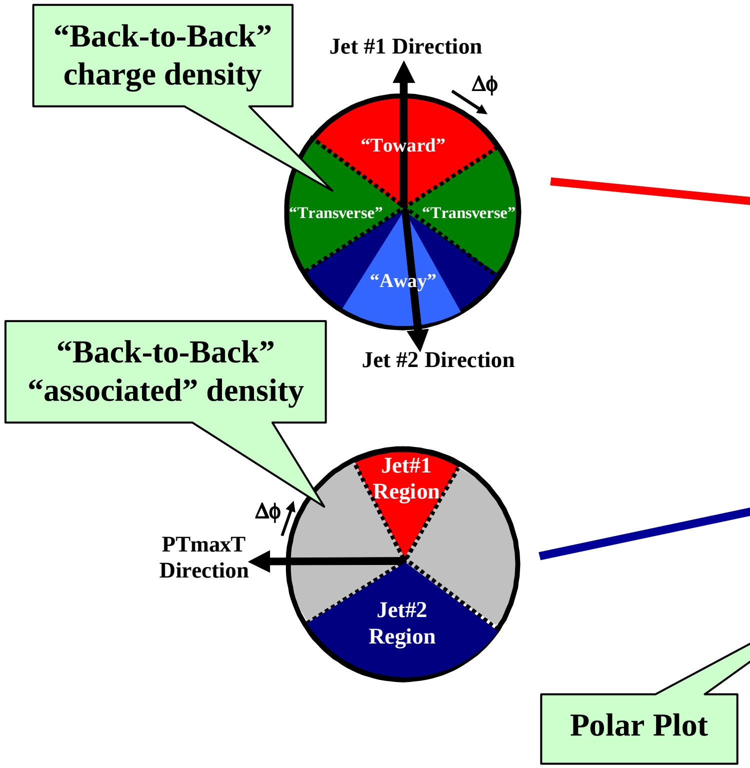
Back-to-Back "Associated" Charged Particle Density

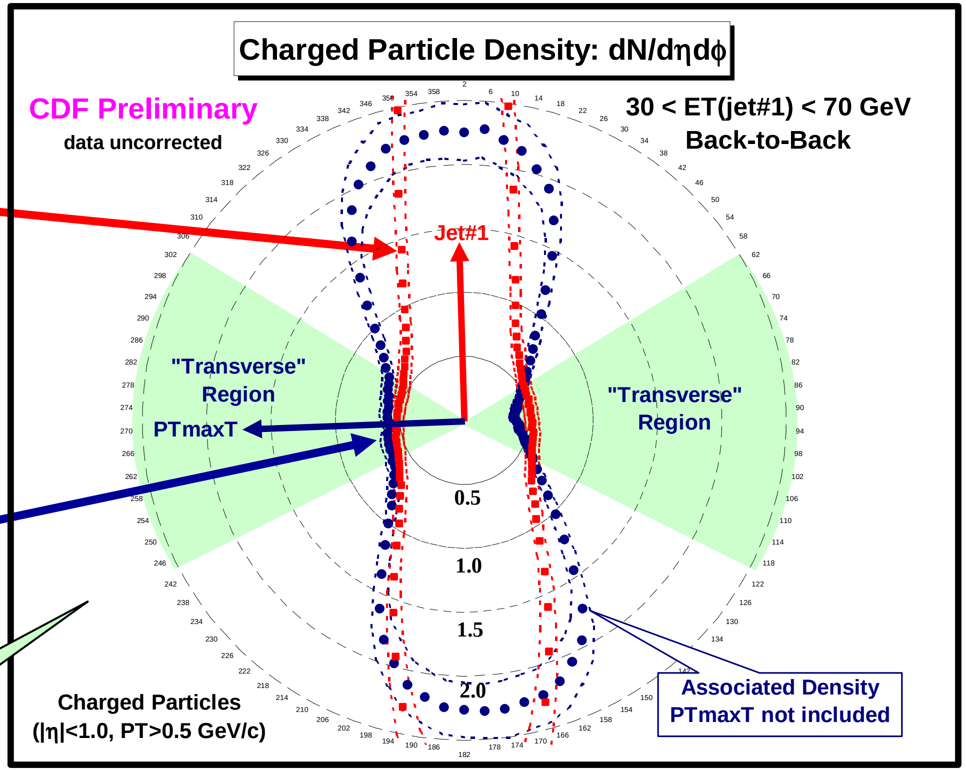


- Look at the Δϕ dependence of the "associated" charged particle density, $dN_{chg}/d\eta d\phi$ for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmaxT*) relative to PTmaxT (rotated to 180°) for PTmaxT > 0.5 GeV/c, PTmaxT > 1.0 GeV/c and PTmaxT > 2.0 GeV/c, for "back-to-back" events with 30 < E_T(jet#1) < 70 GeV.

- Shows "jet structure" in the "transverse" region (*i.e.* the "birth" of the 3rd & 4th jet).

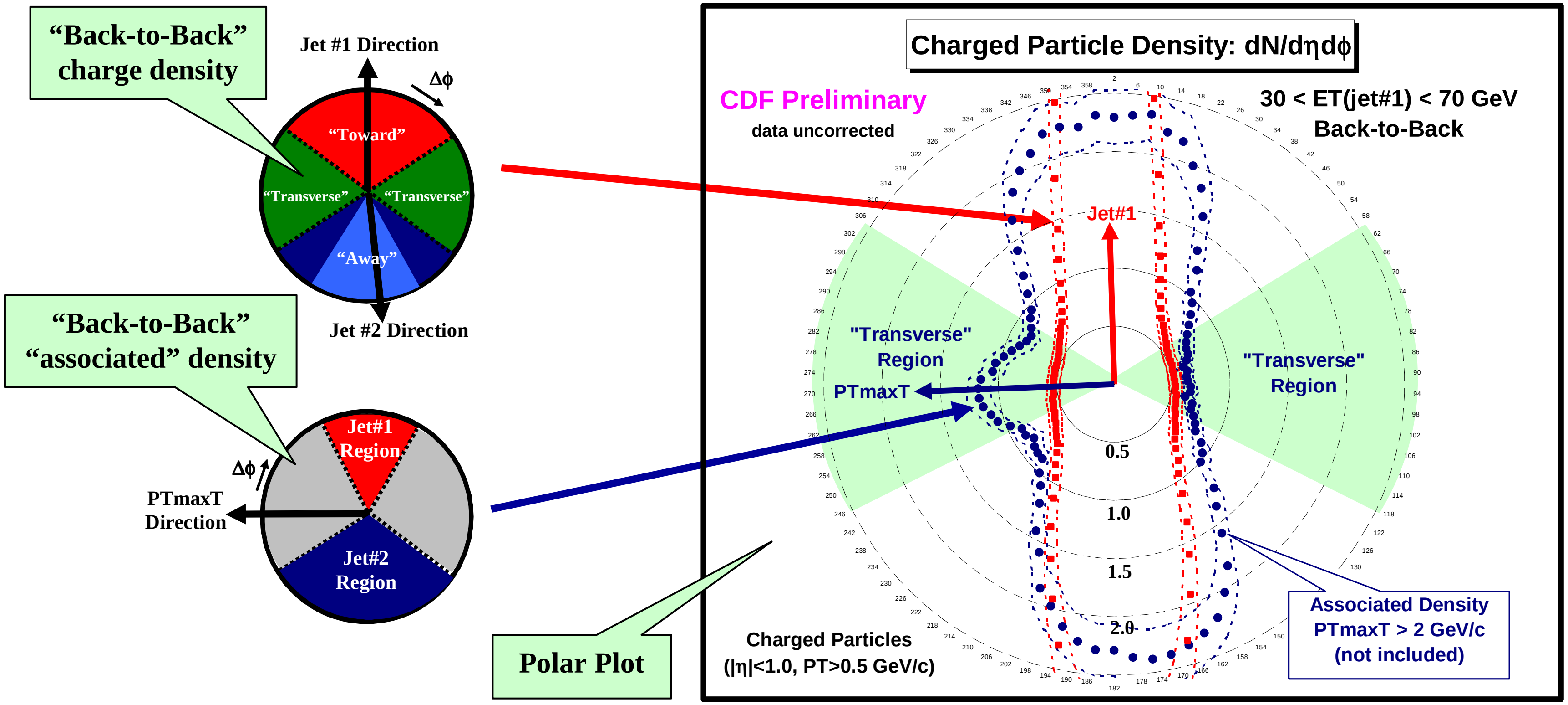
Back-to-Back "Associated" Charged Particle Densities





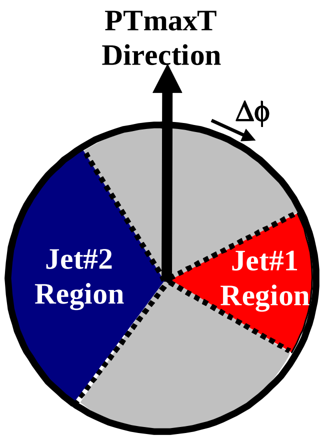
➡ **Shows the Δϕ dependence of the "associated" charged particle density, dNchg/dηdϕ, p_T > 0.5 GeV/c, |η| < 1 (*not including PTmaxT*) relative to PTmaxT (rotated to 180°) and the charged particle density, dNchg/dηdϕ, p_T > 0.5 GeV/c, |η| < 1 relative to jet#1 (rotated to 270°) for "back-to-back events" with 30 < E_T(jet#1) < 70 GeV.**

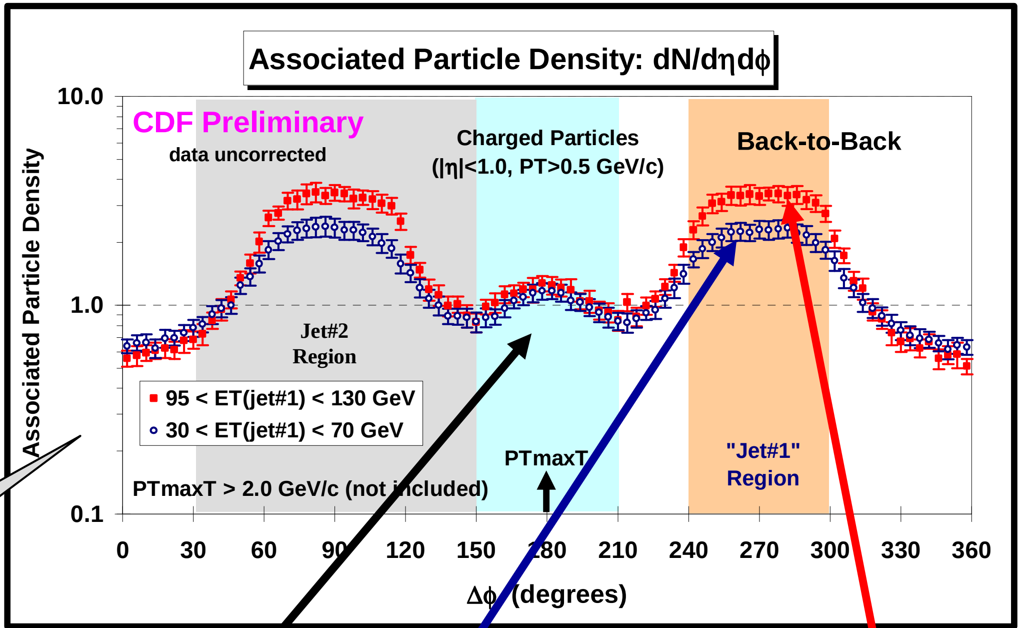
Back-to-Back "Associated" Charged Particle Densities



➡ **Shows the Δφ dependence of the "associated" charged particle density, $dN_{chg}/d\eta d\phi$, $p_T > 0.5$ GeV/c, $|\eta| < 1$, PTmaxT > 2.0 GeV/c (*not including PTmaxT*) relative to PTmaxT (rotated to 180º) and the charged particle density, $dN_{chg}/d\eta d\phi$, $p_T > 0.5$ GeV/c, $|\eta| < 1$, relative to jet#1 (rotated to 270º) for "back-to-back events" with $30 < E_T(\text{jet\#1}) < 70$ GeV.**

Back-to-Back "Associated" Charged Particle Density

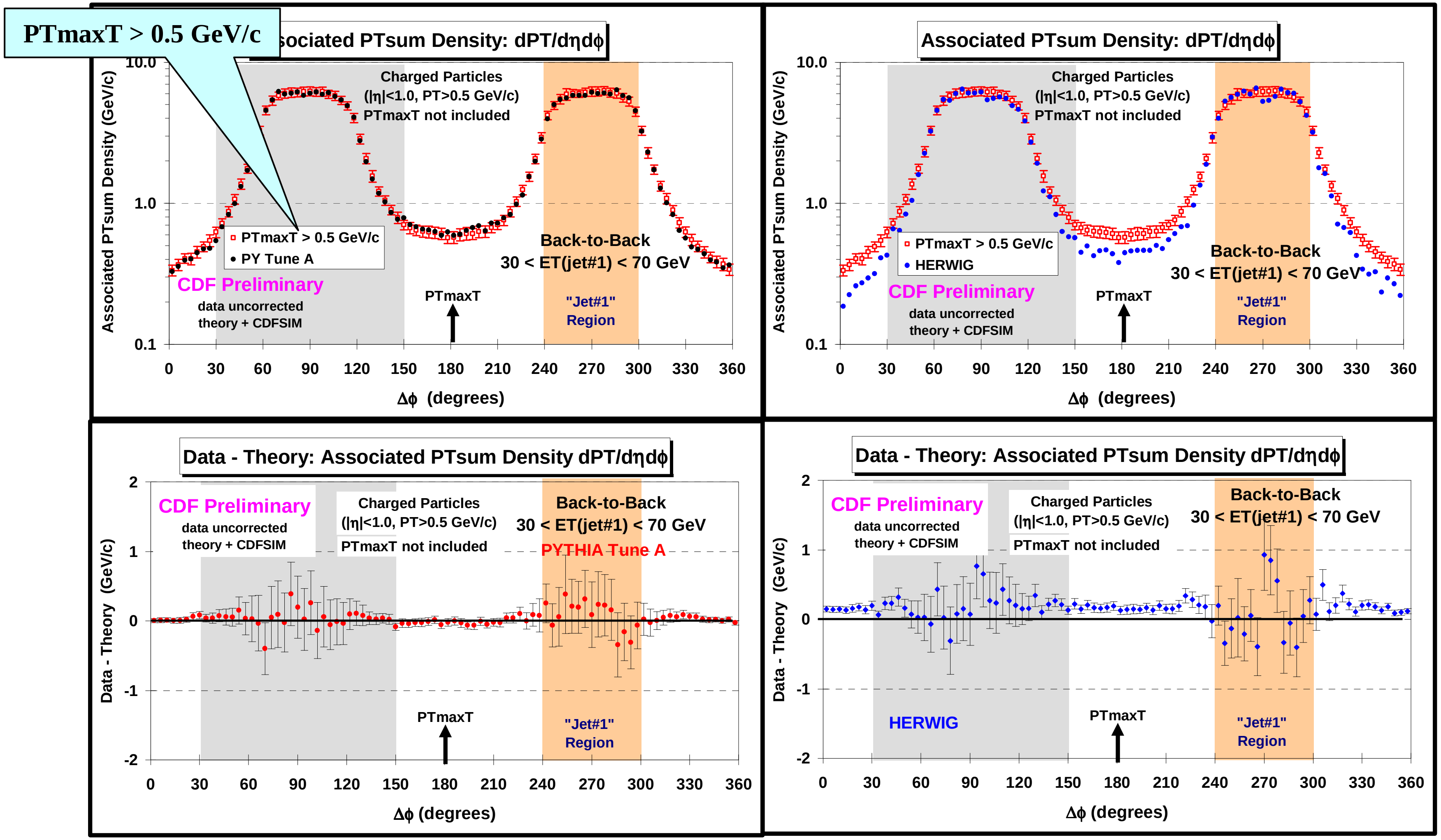




- Look at the **Δϕ dependence of the "associated" charged particle density**, $dN_{chg}/d\eta d\phi$, $p_T > 0.5$ GeV/c, $|\eta| < 1$ (*not including PTmaxT*) relative to PTmaxT (rotated to 180°) for PTmaxT > 2.0 GeV/c for **"back-to-back" events with 30 < E_T(jet#1) < 70 GeV** and **95 < E_T(jet#1) < 130 GeV**.

- Very little dependence on E_T(jet#1) in the "transverse" region for **"back-to-back" events**!

"Associated" PTsum Density PYTHIA Tune A vs HERWIG

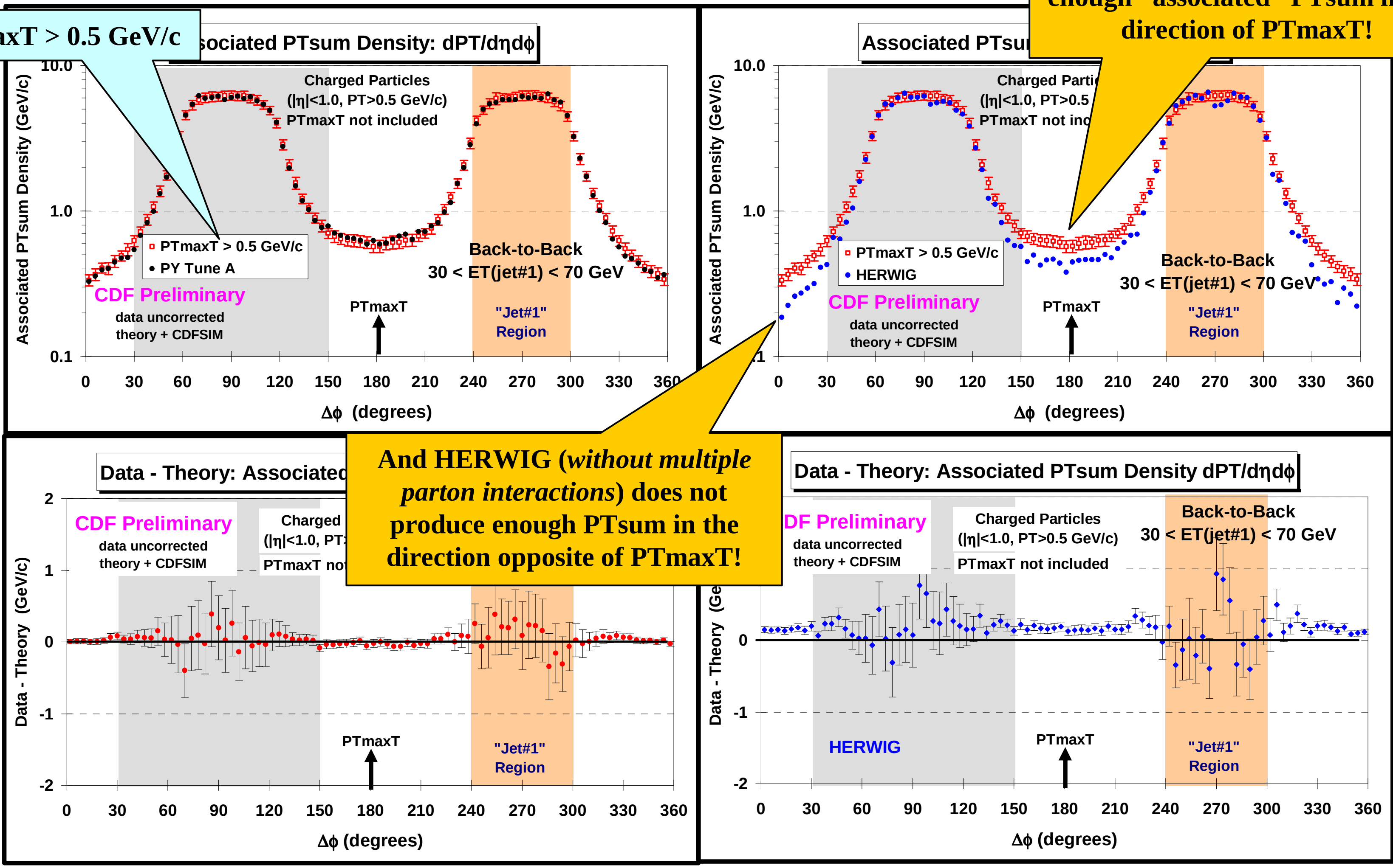


"Associated" PTsum Density PYTHIA Tune A vs HERWIG

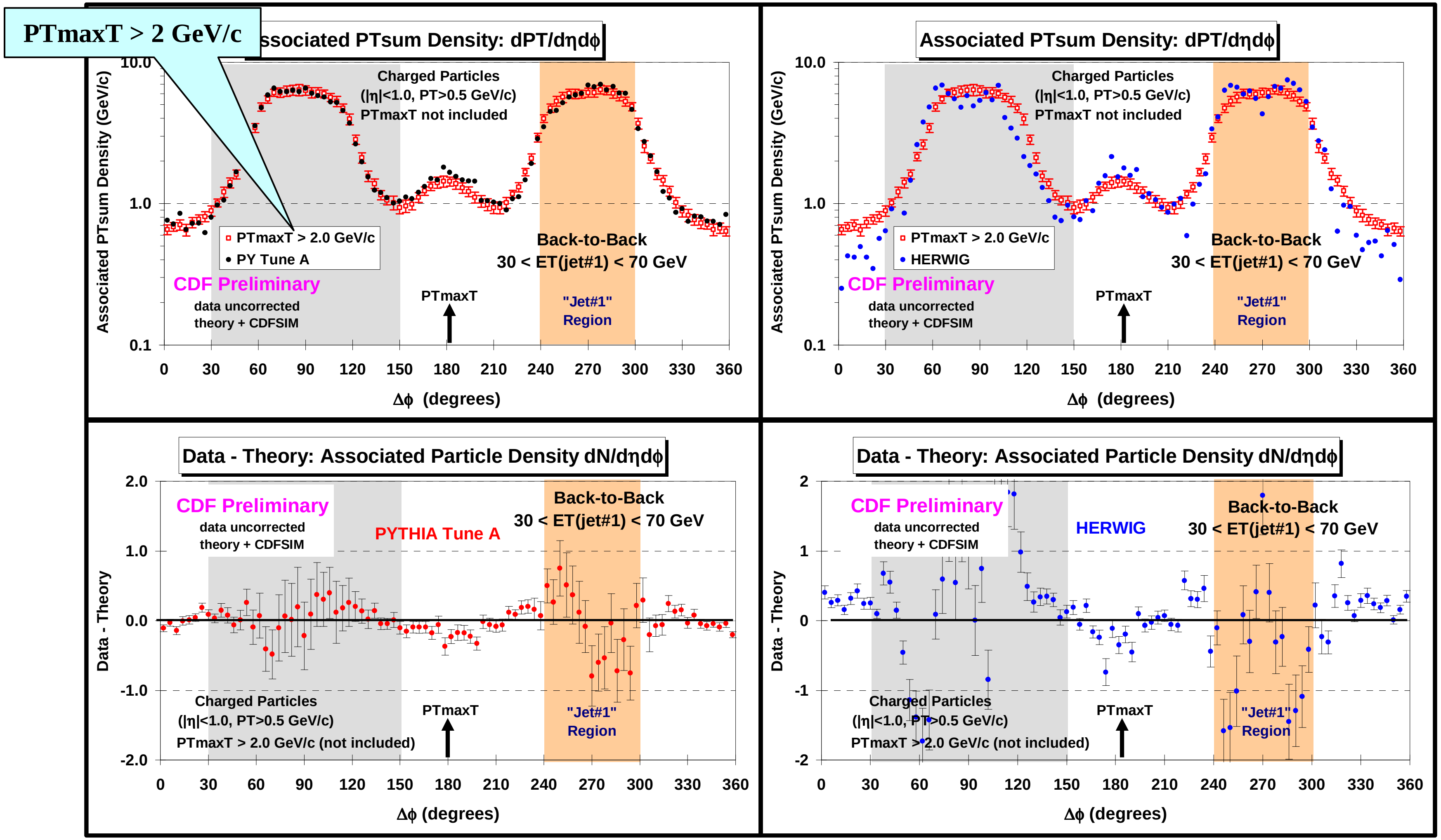
PTmaxT > 0.5 GeV/c

HERWIG (*without multiple parton interactions*) does not produce enough "associated" PTsum in the direction of PTmaxT!

And HERWIG (*without multiple parton interactions*) does not produce enough PTsum in the direction opposite of PTmaxT!



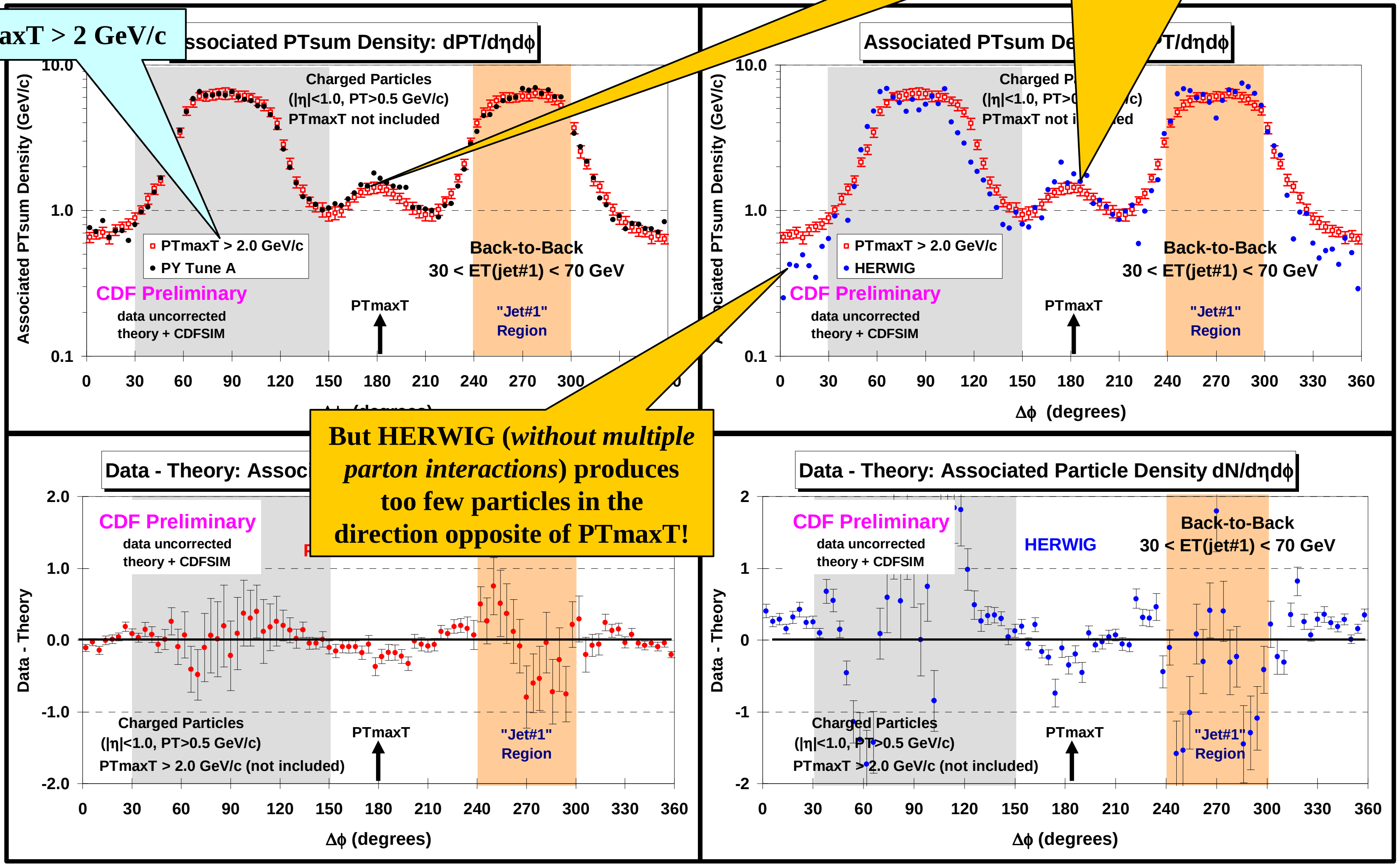
"Associated" PTsum Density PYTHIA Tune A vs HERWIG



“Associated” PTsum D
PYTHIA Tune A vs HE

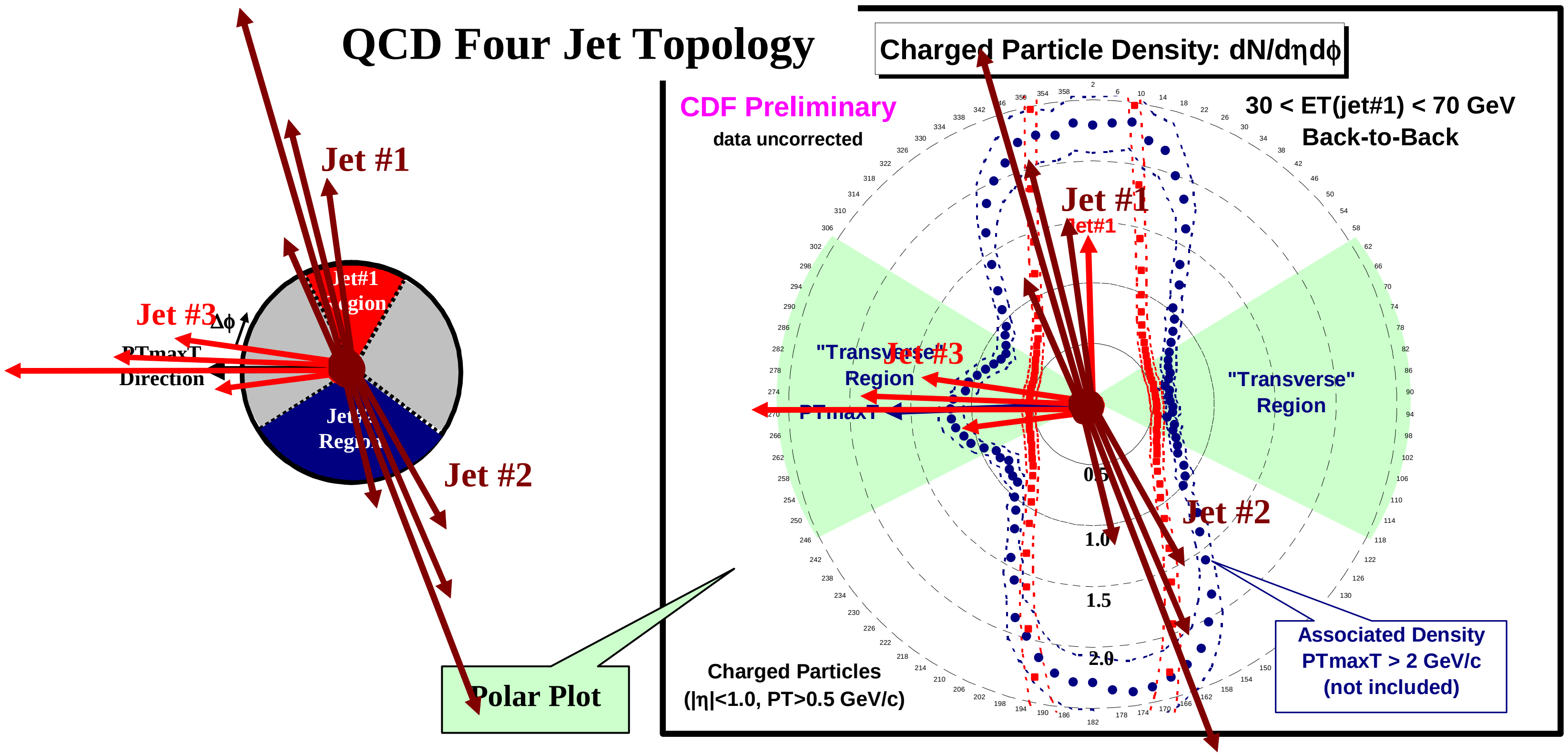
PTmaxT > 2 GeV/c

For PTmaxT > 2.0 GeV both PYTHIA and HERWIG produce slightly too much “associated” PTsum in the direction of PTmaxT!



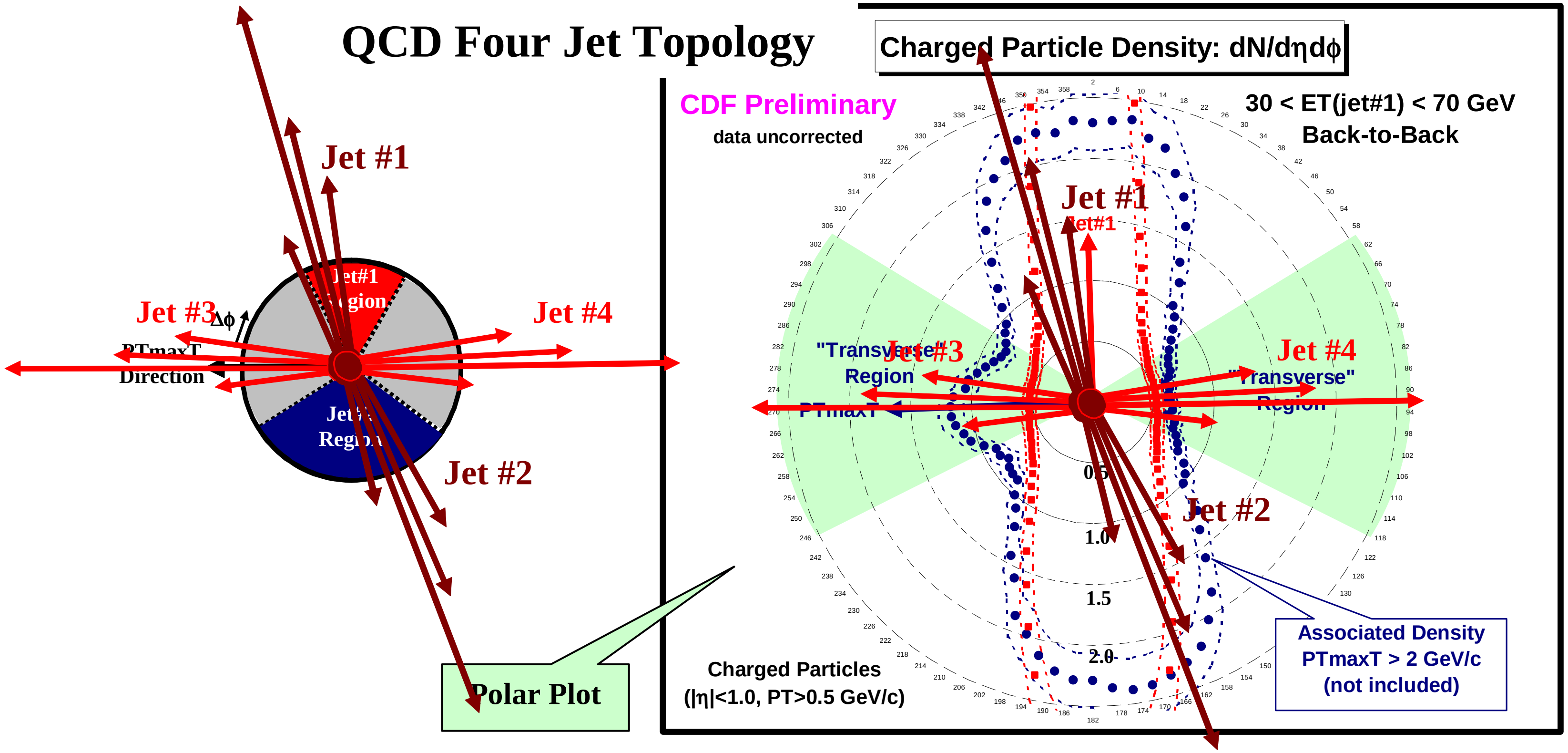
But HERWIG (*without multiple parton interactions*) produces too few particles in the direction opposite of PTmaxT!

Jet Topologies



➡ Shows the $\Delta\phi$ dependence of the "associated" charged particle density, $dN_{chg}/d\eta d\phi$, $p_T > 0.5$ GeV/c, $|\eta| < 1$, PTmaxT > 2.0 GeV/c (*not including PTmaxT*) relative to PTmaxT (rotated to 180°) and the charged particle density, $dN_{chg}/d\eta d\phi$, $p_T > 0.5$ GeV/c, $|\eta| < 1$, relative to jet#1 (rotated to 270°) for "back-to-back events" with $30 < E_T(\text{jet\#1}) < 70$ GeV.

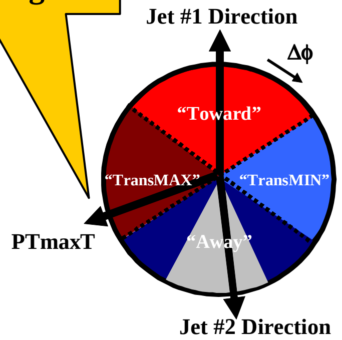
Jet Topologies

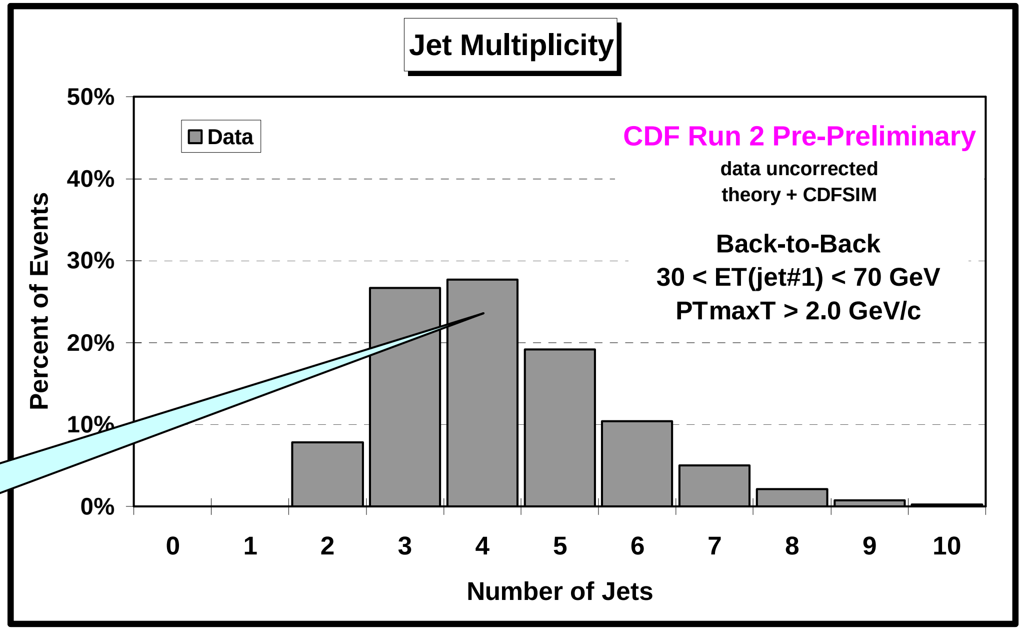


- Shows the **Δφ dependence of the "associated" charged particle density**, $dN_{chg}/d\eta d\phi$, $p_T > 0.5$ GeV/c, $|\eta| < 1$, PTmaxT > 2.0 GeV/c (*not including PTmaxT*) relative to PTmaxT (rotated to 180°) and the charged particle density, $dN_{chg}/d\eta d\phi$, $p_T > 0.5$ GeV/c, $|\eta| < 1$, relative to jet#1 (rotated to 270°) for **"back-to-back events" with $30 < E_T(\text{jet\#1}) < 70$ GeV**.

Jet Multiplicity

Max p_T in the "transverse" region!

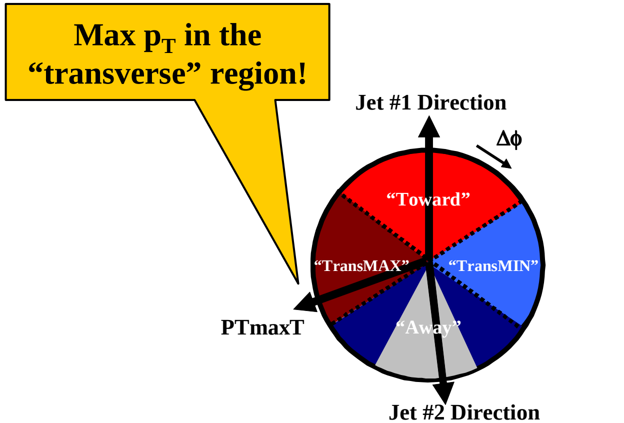


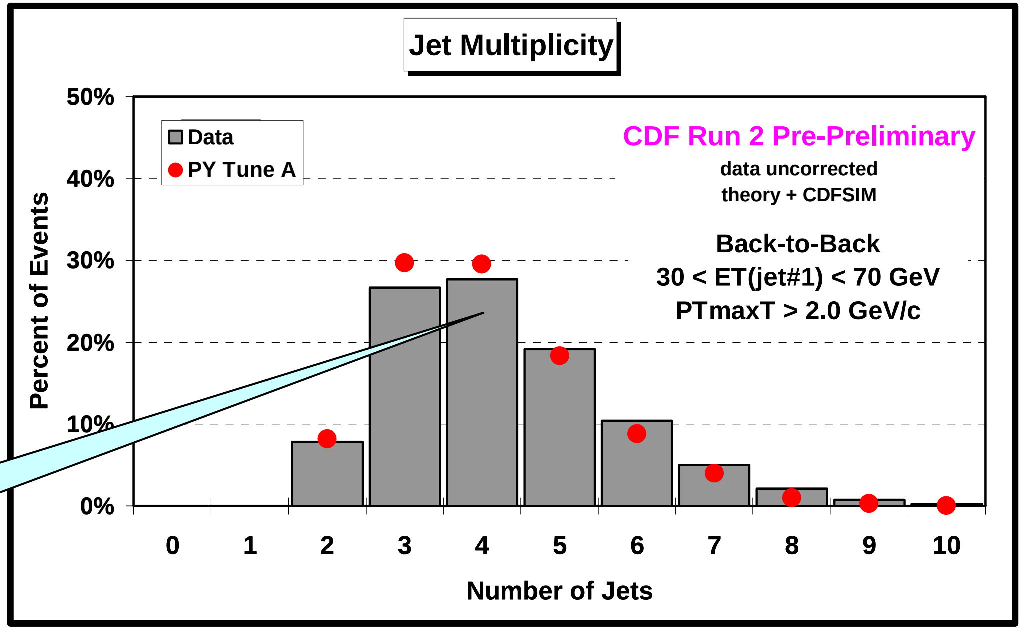


Data have about equal amounts of 3 and 4 jet topologies!

- Shows the data on the **number of jets** (JetClu, R = 0.7, $|\eta| < 2$, E_T(jet) > 3 GeV) for **"back-to-back" events** with 30 < E_T(jet#1) < 70 GeV and PTmaxT > 2.0 GeV/c.

Jet Multiplicity

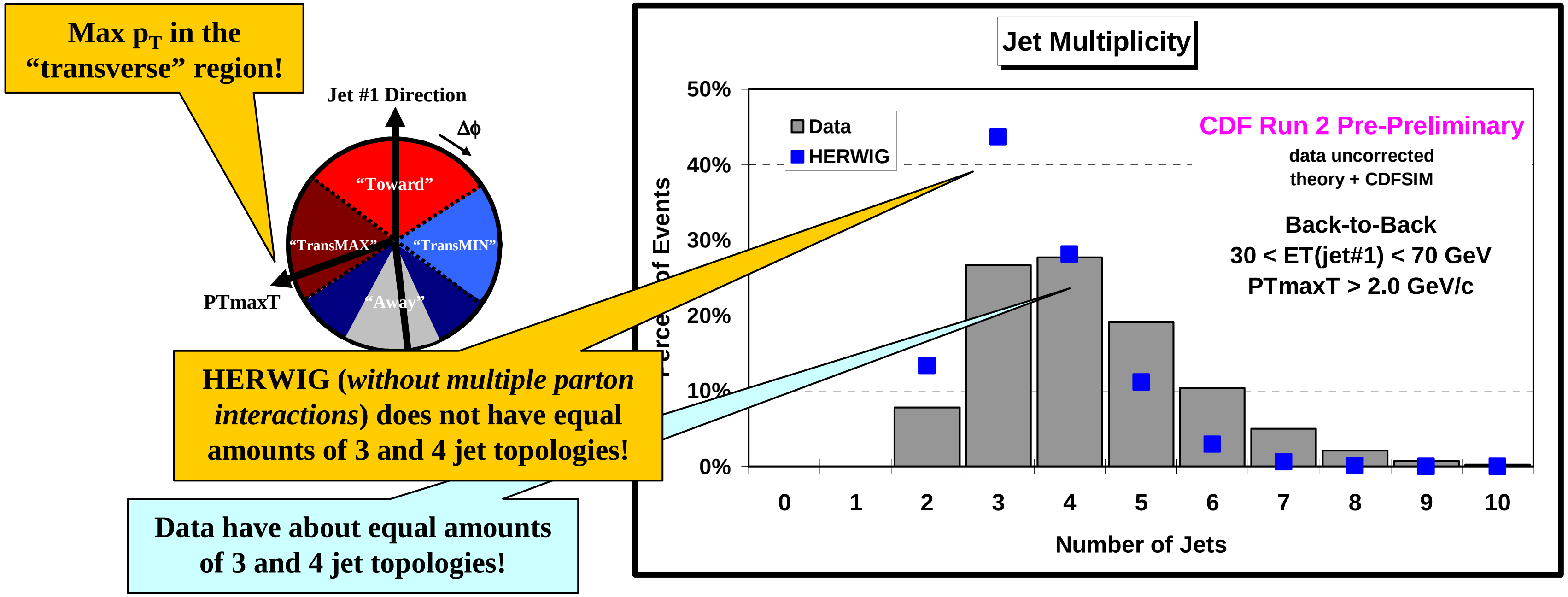




Data have about equal amounts of 3 and 4 jet topologies!

- Shows the data on the **number of jets** (JetClu, R = 0.7, $|\eta| < 2$, E_T(jet) > 3 GeV) for **"back-to-back" events** with 30 < E_T(jet#1) < 70 GeV and PTmaxT > 2.0 GeV/c.
- Compares the (*uncorrected*) data with **PYTHIA Tune A** after CDFSIM.

Jet Multiplicity

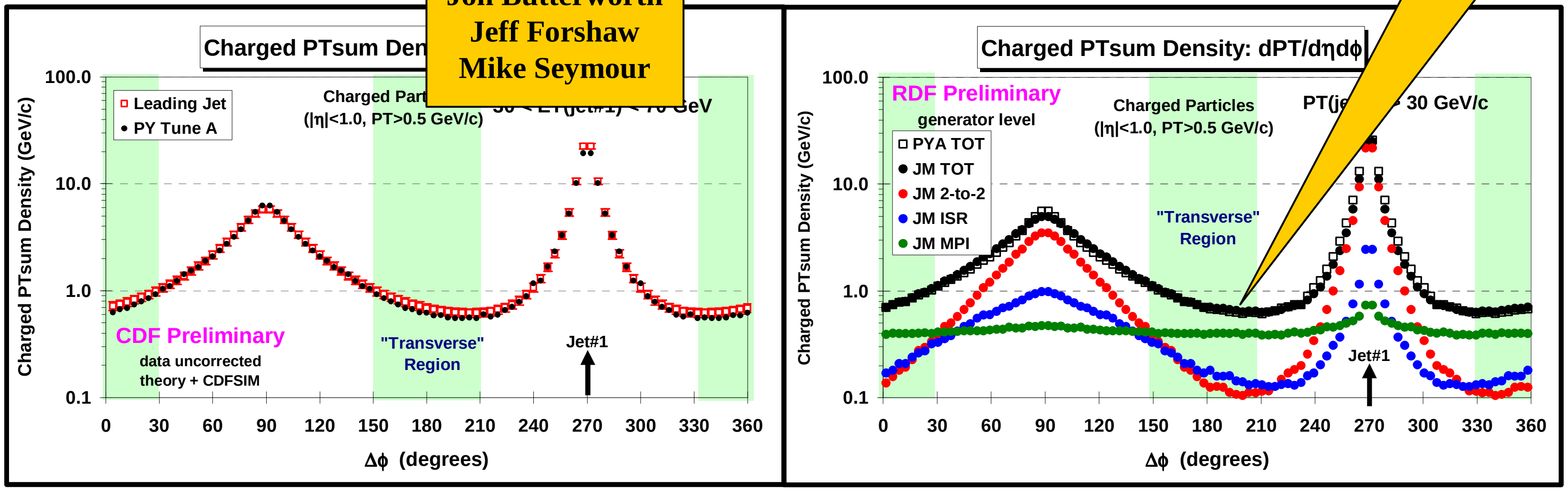


- Shows the data on the number of jets (JetClu, R = 0.7, |η| < 2, E_T(jet) > 3 GeV) for "back-to-back" events with 30 < E_T(jet#1) < 70 GeV and PTmaxT > 2.0 GeV/c.

- Compares the (*uncorrected*) data with HERWIG (no MPI) after CDFSIM.

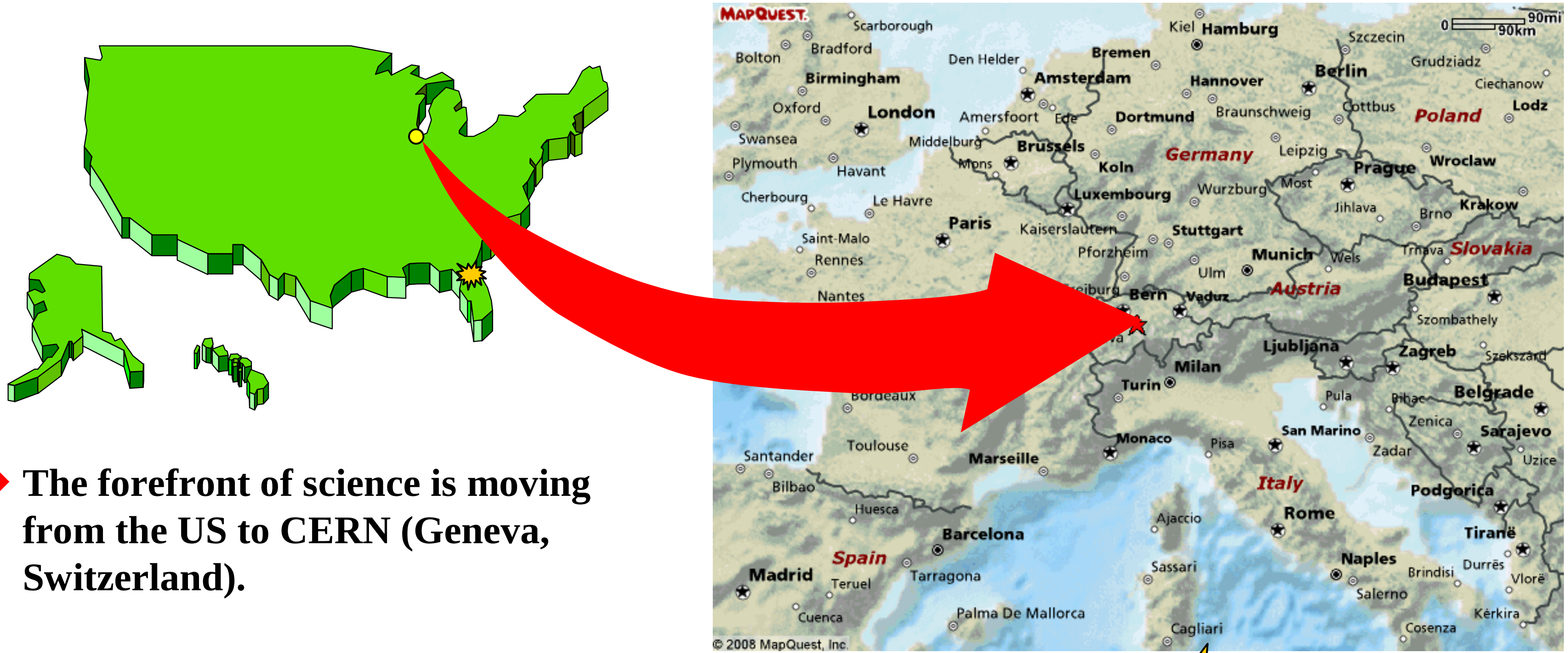
Tuned JIMMY versus PYTHIA Tune A

JIMMY tuned to agree with PYTHIA Tune A!



- (*left*) Shows the Run 2 data on the Δφ dependence of the charged *scalar* PTsum density ($|\eta|<1$, $p_T>0.5$ GeV/c) relative to the leading jet for 30 < E_T(jet#1) < 70 GeV/c compared with PYTHIA Tune A (*after CDFSIM*).
- (*right*) Shows the generator level predictions of PYTHIA Tune A and a tuned version of JIMMY (PT_{min}=1.8 GeV/c) for the Δφ dependence of the charged *scalar* PTsum density ($|\eta|<1$, $p_T>0.5$ GeV/c) relative to the leading jet for PT(jet#1) > 30 GeV/c. The tuned JIMMY and PYTHIA Tune A agree in the “transverse” region.
- (*right*) For JIMMY the contributions from the multiple parton interactions (MPI), initial-state radiation (ISR), and the 2-to-2 hard scattering plus finial-state radiation (2-to-2+FSR) are shown.

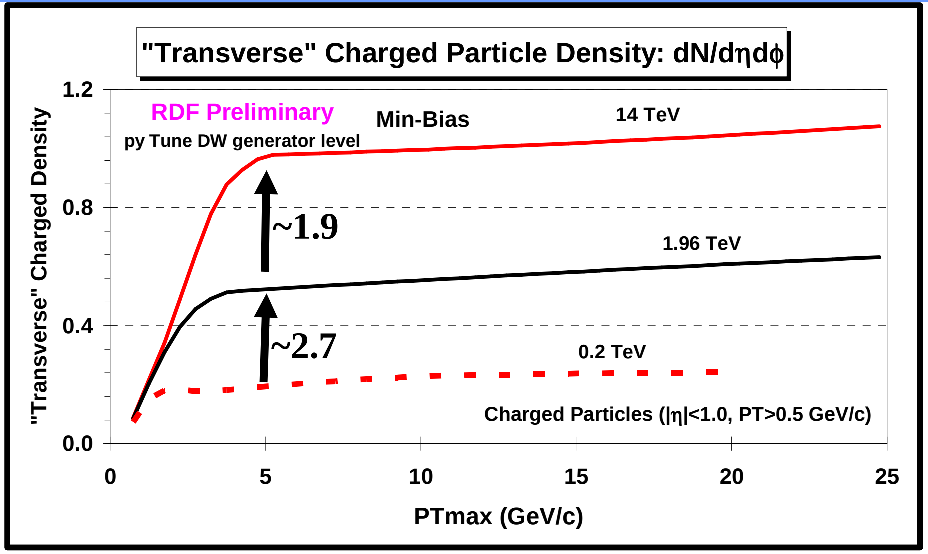
The New Forefront

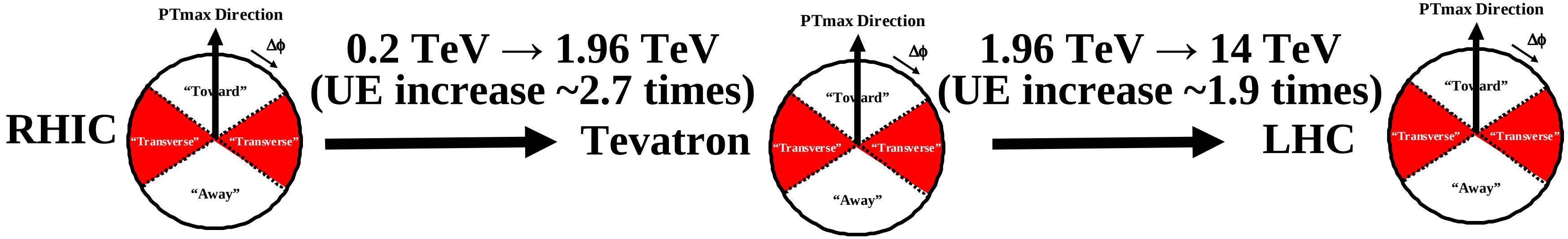


- The forefront of science is moving from the US to CERN (Geneva, Switzerland).

- The LHC is designed to collide protons with protons at a center-of-mass energy of 14 TeV (seven times greater energy than Fermilab)!

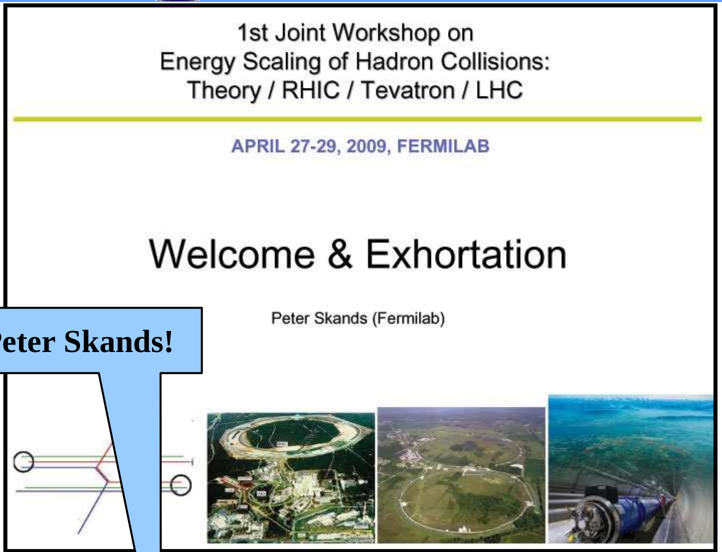
Min-Bias "Associated" Charged Particle Density





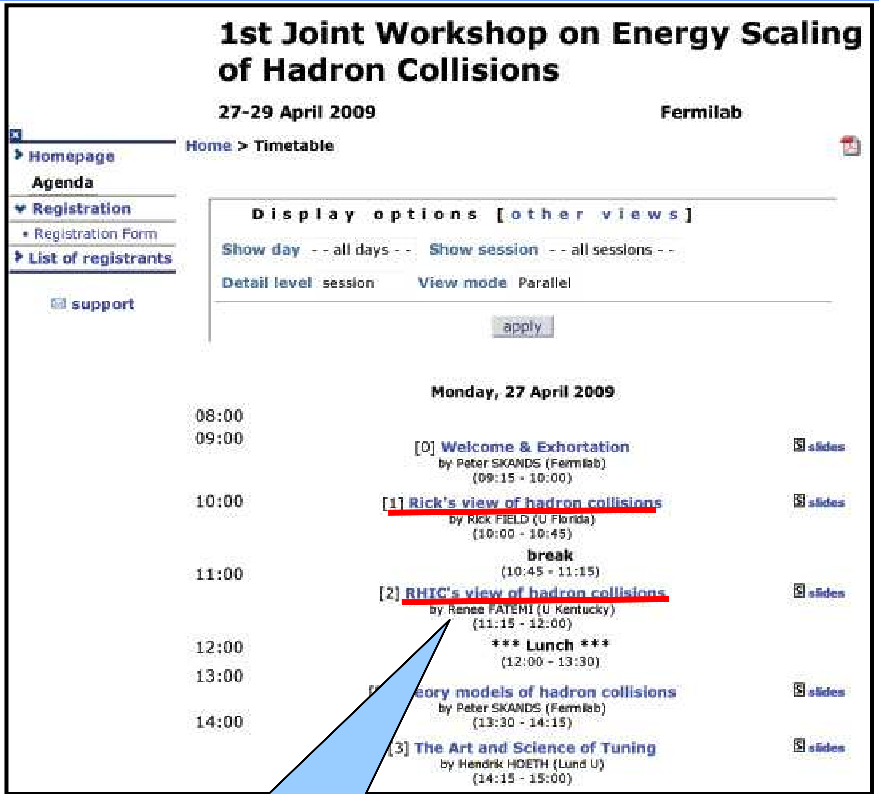
- Shows the "associated" charged particle density in the "transverse" region as a function of PTmax for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) for "min-bias" events at 0.2 TeV, 1.96 TeV and 14 TeV predicted by PYTHIA Tune DW at the particle level (*i.e.* generator level).

1st Workshop on Energy Scaling in Hadron-Hadron Collisions



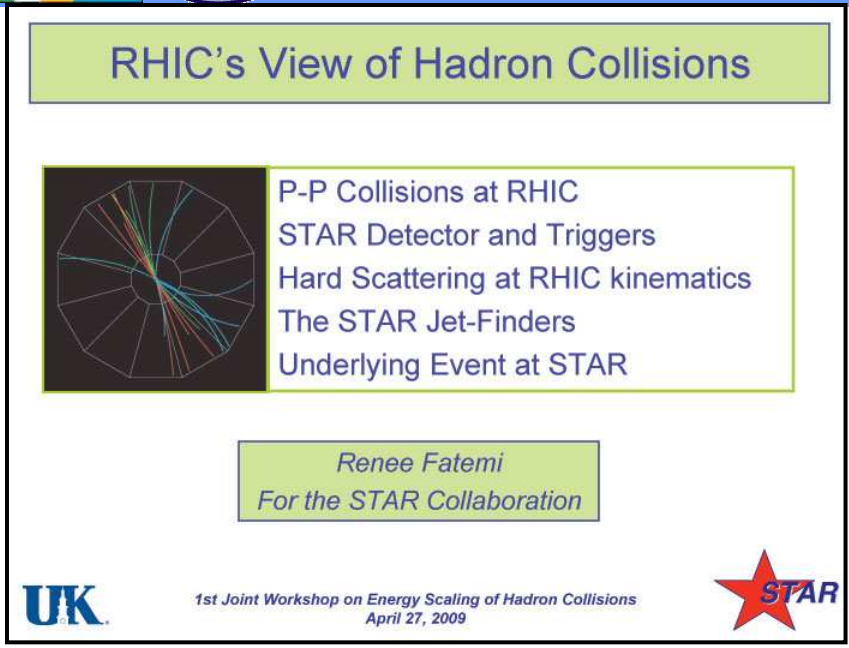
Peter Skands!

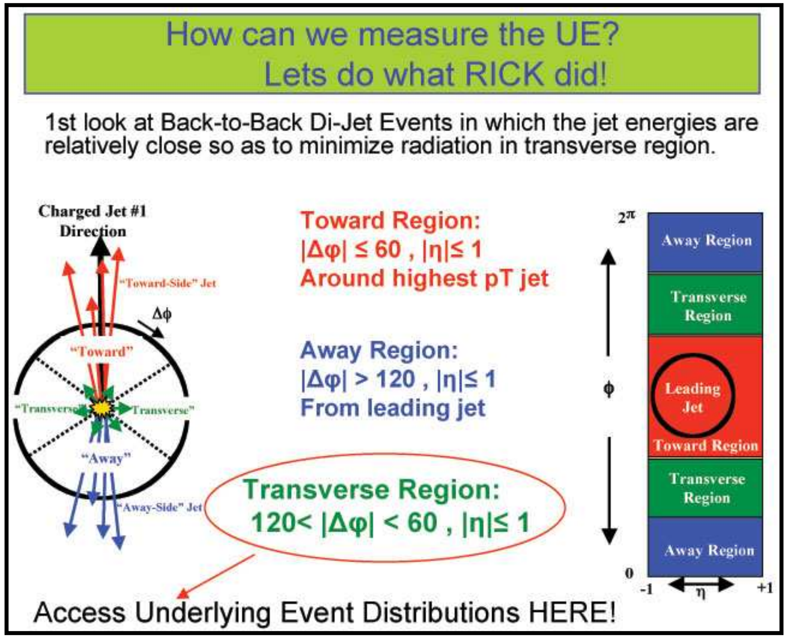
"On the Boarder" restaurant, Aurora, IL
April 27, 2009



Renee Fatemi gave a talk on the "underlying event at STAR!

The "Underlying Event" at STAR

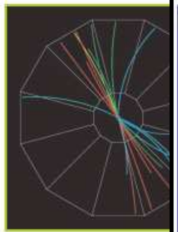




➡ **At** **STAR** **they have measured the "underlying event at W = 200 GeV (|η| < 1, p_T > 0.2 GeV) and compared their uncorrected data with PYTHIA Tune A + STAR-SIM.**

The "Underlying Event" at STAR

RHIC



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egion.

UK

Conclusions

I. Hadron Collisions at RHIC take place at an order of magnitude smaller $\sqrt{s}$ than the Tevatron. Nevertheless, jets are observed and reconstructed down to pT=5 GeV and are well described by pQCD

II. Comparisons between several jetfinders reveal consistent results

III. Interest in the Underlying Event at RHIC Kinematics is driven by the need for jet energy scale corrections as well as pure physics interests (see talks by M. Lisa and H. Caines)

IV. UE at RHIC appears to be independent of jet pT and decoupled from hard interaction

V. CDF Tune A provides an excellent description of the UE at $\sqrt{s}$ =200 GeV (thanks Rick!)

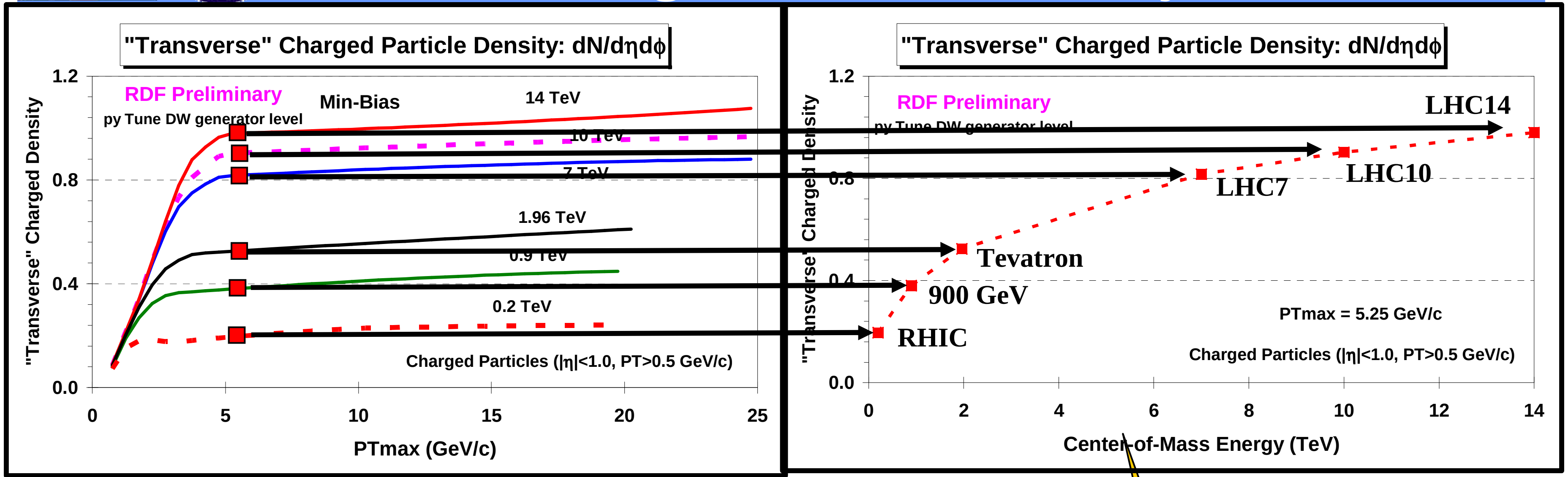
VI. Underlying Event distributions in general smaller than those at CDF. Tower & Track Multiplicities are the exception, but this may be due to the 0.2 (STAR) versus 0.5 GeV (CDF) pT/Et cut-off.

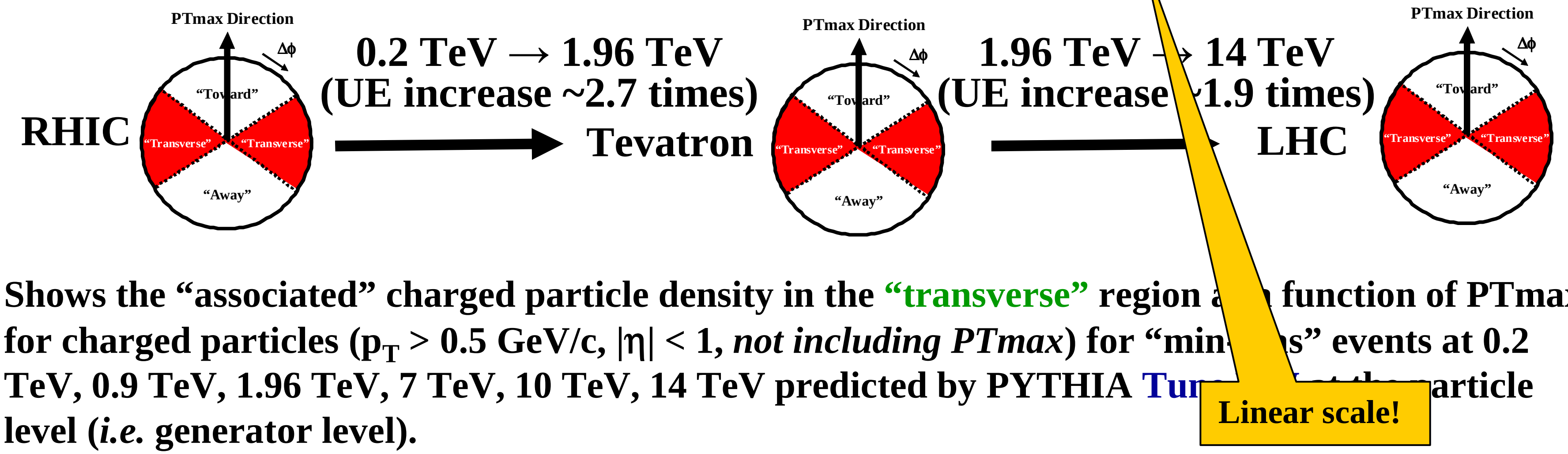
VII. For a cone jet with R=0.7 UE contributes 0.5-0.9 GeV.

VIII. Comparison of Leading Jet and Back-to-Back distributions indicate that large angle radiation contributions are small at RHIC energies.

➡ **At STAR** … **2 GeV)**
and comp …

Min-Bias “Associated” Charged Particle Density





- Shows the “associated” charged particle density in the **“transverse”** region as a function of PTmax for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) for “min-bias” events at 0.2 TeV, 0.9 TeV, 1.96 TeV, 7 TeV, 10 TeV, 14 TeV predicted by PYTHIA Tune DW at the particle level (*i.e.* generator level).

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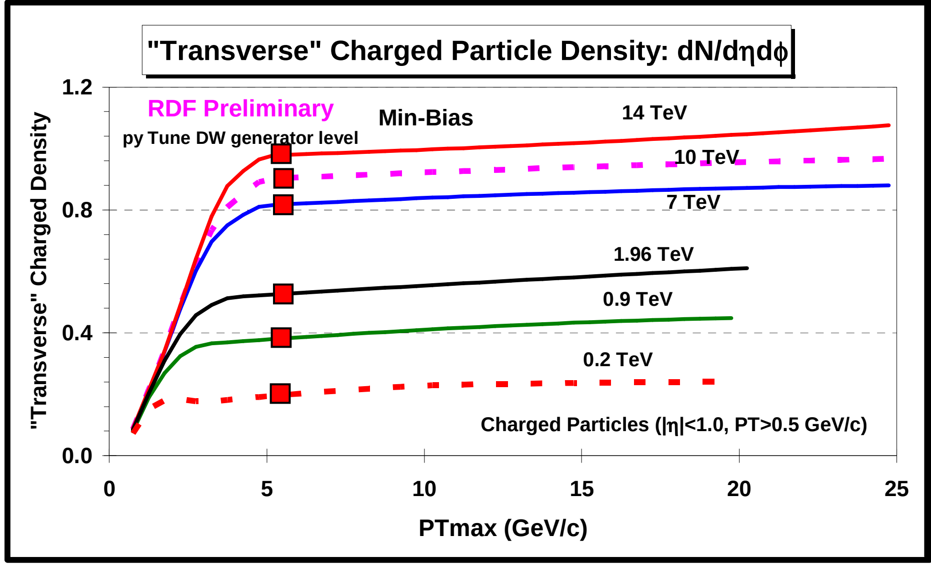
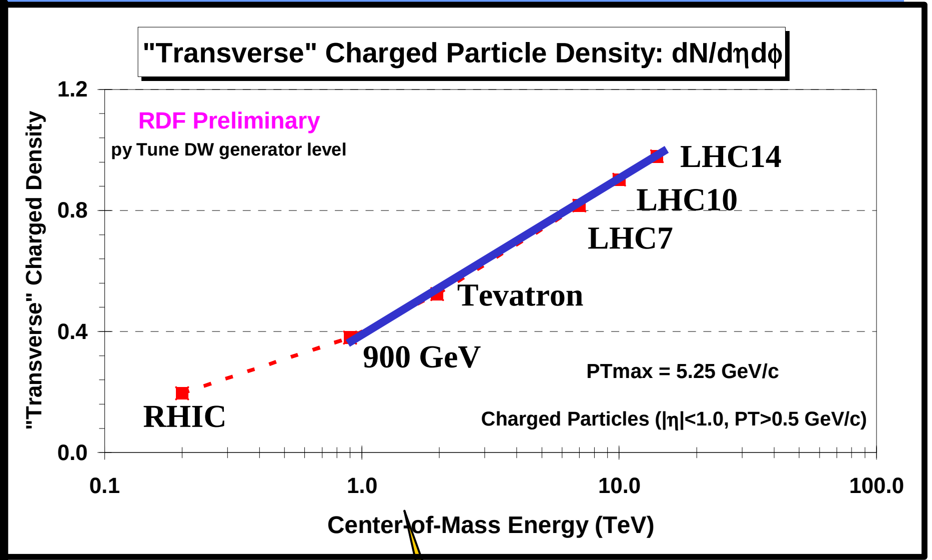
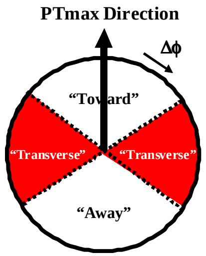


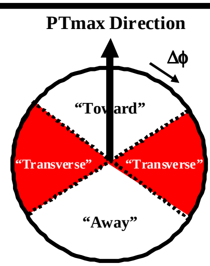


LHC7



7 TeV → 14 TeV
(UE increase ~20%)

LHC14



Linear on a log plot!

- **Shows the "associated" charged particle density in the "transverse" region as a function of PTmax for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) for "min-bias" events at 0.2 TeV, 0.9 TeV, 1.96 TeV, 7 TeV, 10 TeV, 14 TeV predicted by PYTHIA Tune DW at the particle level (*i.e.* generator level).**

Log scale!

UE&MB@CMS

Initial Group Members

Rick Field (Florida)
Darin Acosta (Florida)
Paolo Bartalini (Florida)
Albert De Roeck (CERN)
Livio Fano' (INFN/Perugia at CERN)
Filippo Ambroglini (INFN/Perugia at CERN)
Khristian Kotov (UF Student, Acosta)

Perugia, Italy, March 2006

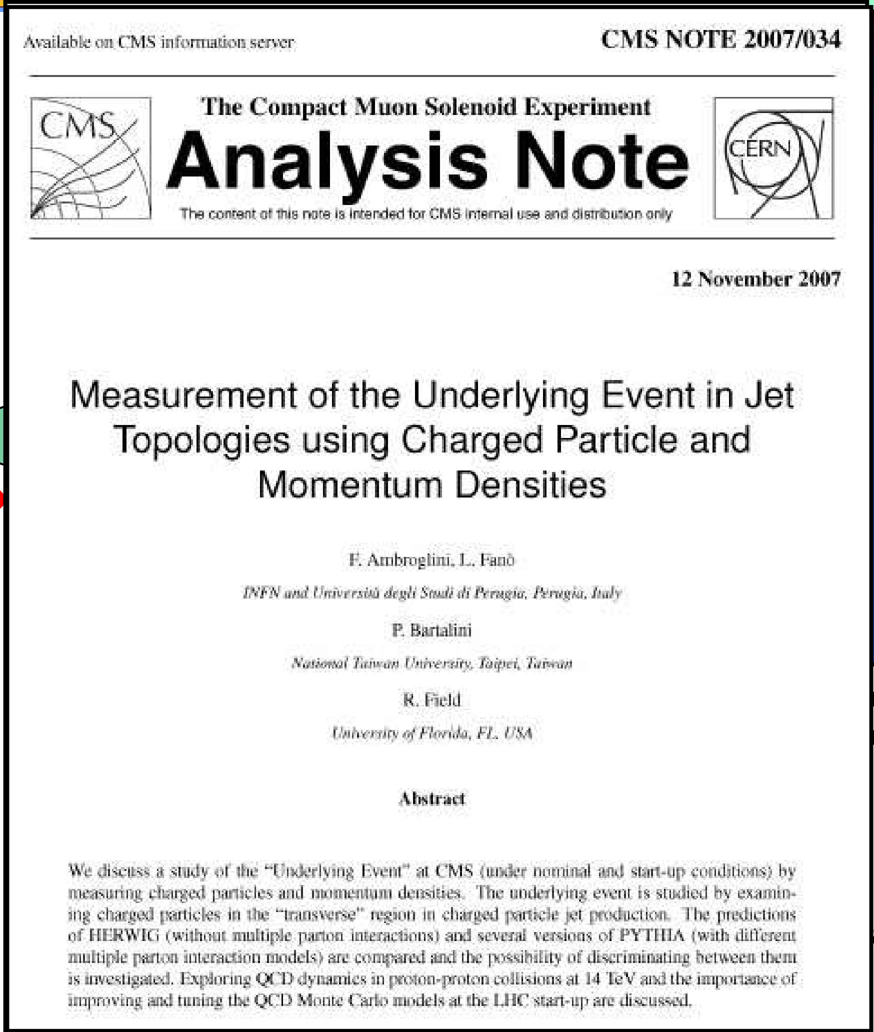
UE&MB@CMS

Florida-Perugia-CERN

University of Perugia

- **Measure Min-Bias and the "Underlying Event" at CMS**
  - **The plan involves two phases.**
  - **Phase 1 would be to measure min-bias and the "underlying event" as soon as possible (when the luminosity is low), perhaps during commissioning. We would then tune the QCD Monte-Carlo models for all the other CMS analyses. Phase 1 would be a service to the rest of the collaboration. As the measurements become more reliable we would re-tune the QCD Monte-Carlo models if necessary and begin Phase 2.**
  - **Phase 2 is "physics" and would include comparing the min-bias and "underlying event" measurements at the LHC with the measurements we have done (and are doing now) at CDF and then writing a physics publication.**

UE&MB@CMS


Available on CMS information server

CMS NOTE 2007/034

The Compact Muon Solenoid Experiment

Analysis Note

The content of this note is intended for CMS internal use and distribution only

12 November 2007

Measurement of the Underlying Event in Jet Topologies using Charged Particle and Momentum Densities

F. Ambroglini, L. Fanò

INFN and Università degli Studi di Perugia, Perugia, Italy

P. Bartalini

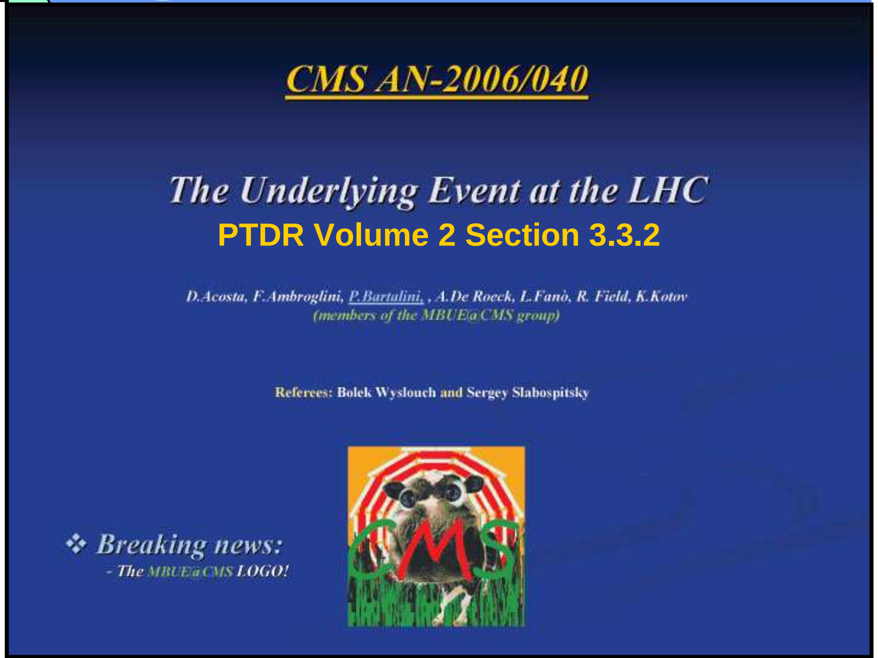
National Taiwan University, Taipei, Taiwan

R. Field

University of Florida, FL, USA

Abstract

We discuss a study of the "Underlying Event" at CMS (under nominal and start-up conditions) by measuring charged particles and momentum densities. The underlying event is studied by examining charged particles in the "transverse" region in charged particle jet production. The predictions of HERWIG (without multiple parton interactions) and several versions of PYTHIA (with different multiple parton interaction models) are compared and the possibility of discriminating between them is investigated. Exploring QCD dynamics in proton-proton collisions at 14 TeV and the importance of improving and tuning the QCD Monte Carlo models at the LHC start-up are discussed.



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INFN

QCD contribution to the Joint QCD/HI 2007 paper

Pre-approval talk

Authors:
F. Ambroglini, P. Bartalini
L. Fano', R. Field

Institutions:
INFN and Universita' di Perugia
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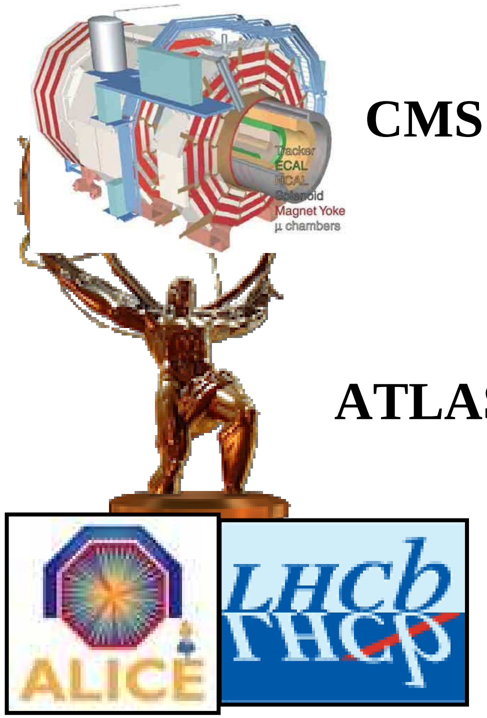
Referees:
W. Adam
C. Lourenco
P. Marage

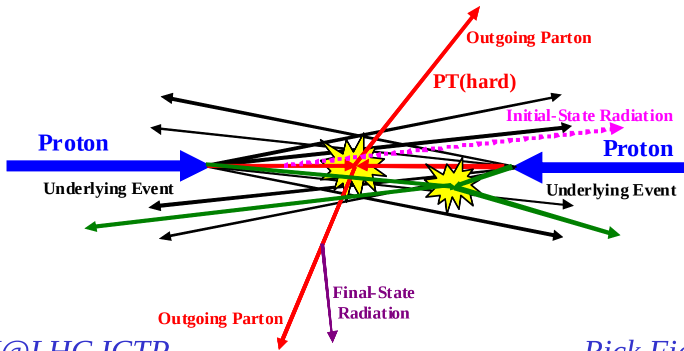
University of Perugia

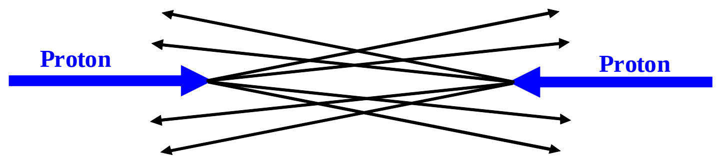
MB & UE Common Plots

Quantum **C**hromo- **D**ynamics

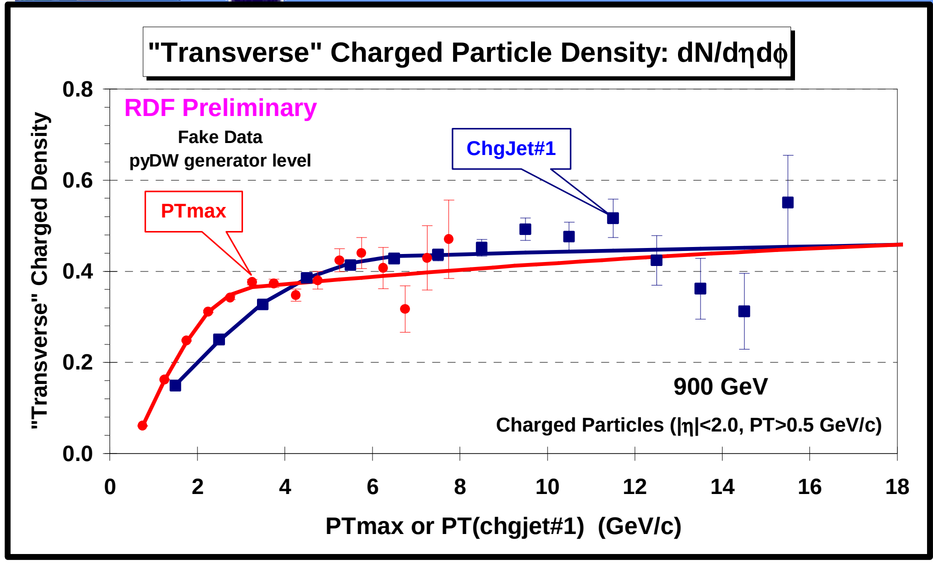


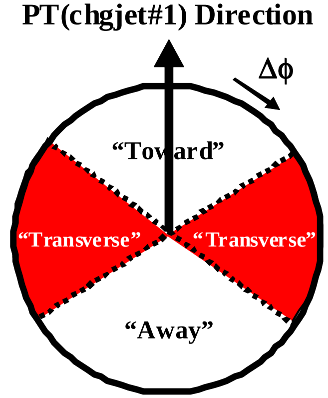
➡ **The LPCC MB&UE Working Group has suggested several MB&UE "Common Plots" the all the LHC groups can produce and compare with each other.**

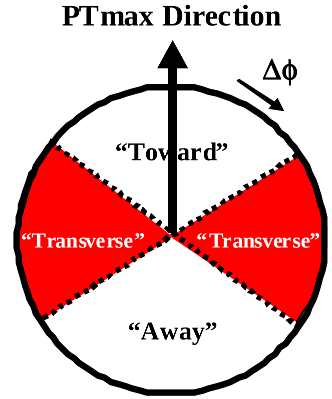




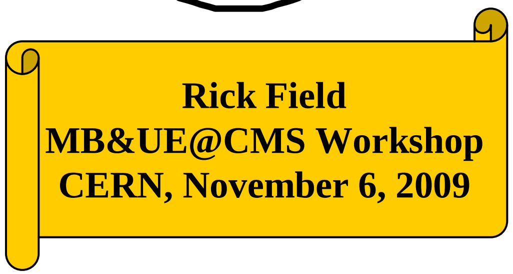
“Transverse” Charged Particle Density



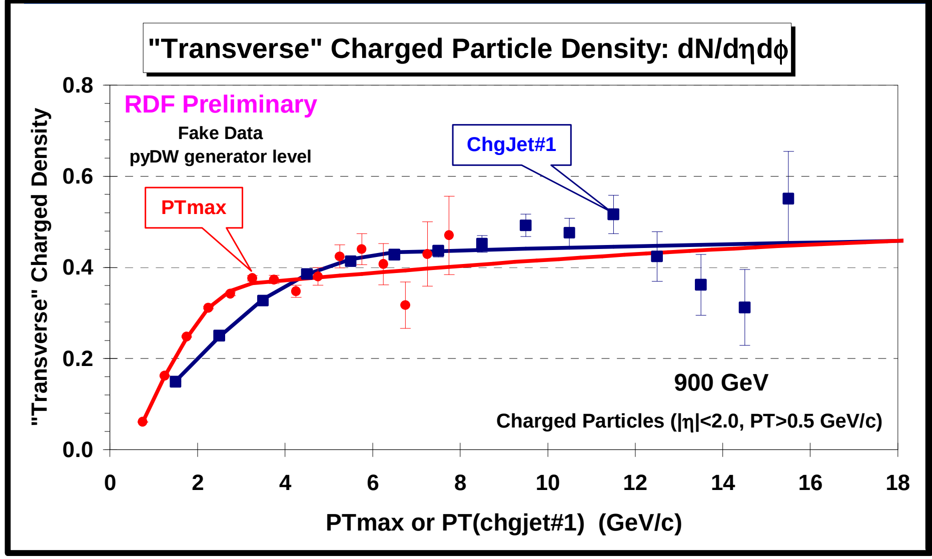


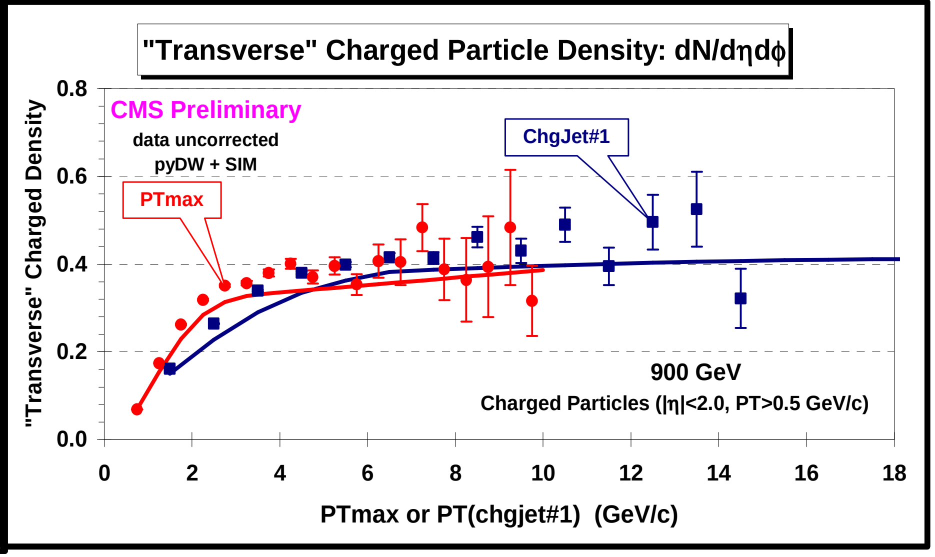


- **Fake data (from MC) at 900 GeV on the “transverse” charged particle density, dN/dηdϕ, as defined by the leading charged particle (PTmax) and the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 2. The fake data (from PYTHIA Tune DW) are generated at the particle level (*i.e.* generator level) assuming 0.5 M min-bias events at 900 GeV (361,595 events in the plot).**



"Transverse" Charged Particle Density





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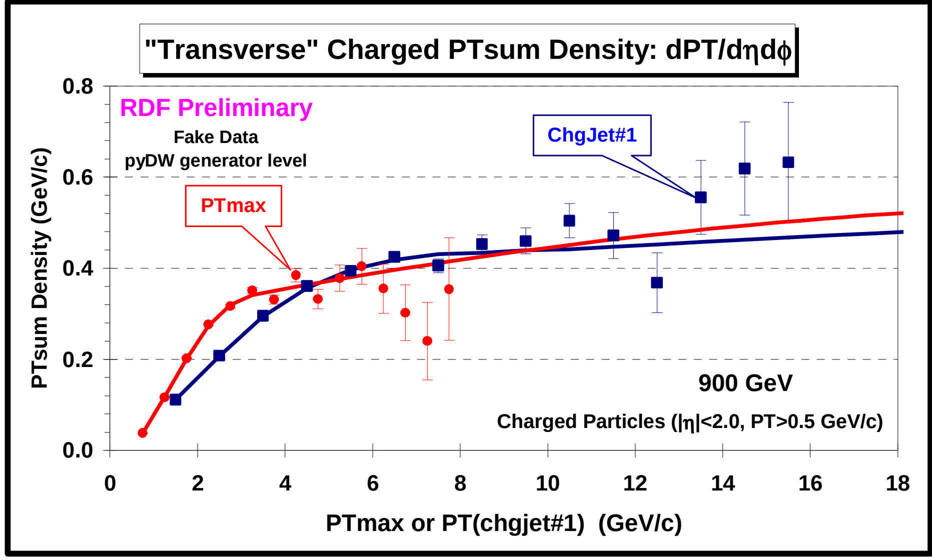
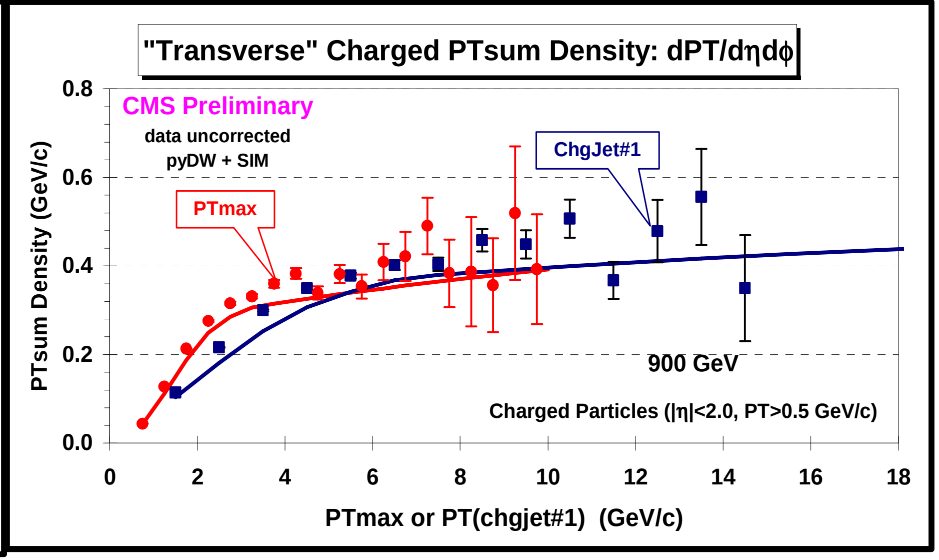
- **CMS preliminary data at 900 GeV on the "transverse" charged particle density, dN/dηdφ, as defined by the leading charged particle (PTmax) and the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 2. The data are uncorrected and compared with PYTHIA Tune DW after detector simulation (216,215 events in the plot).**

"Transverse" Charged PTsum Density





- **Fake data (from MC) at 900 GeV on the "transverse" charged PTsum density, dPT/dηdφ, as defined by the leading charged particle (PTmax) and the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 2. The fake data (from PYTHIA Tune DW) are generated at the particle level (*i.e.* generator level) assuming 0.5 M min-bias events at 900 GeV (361,595 events in the plot).**

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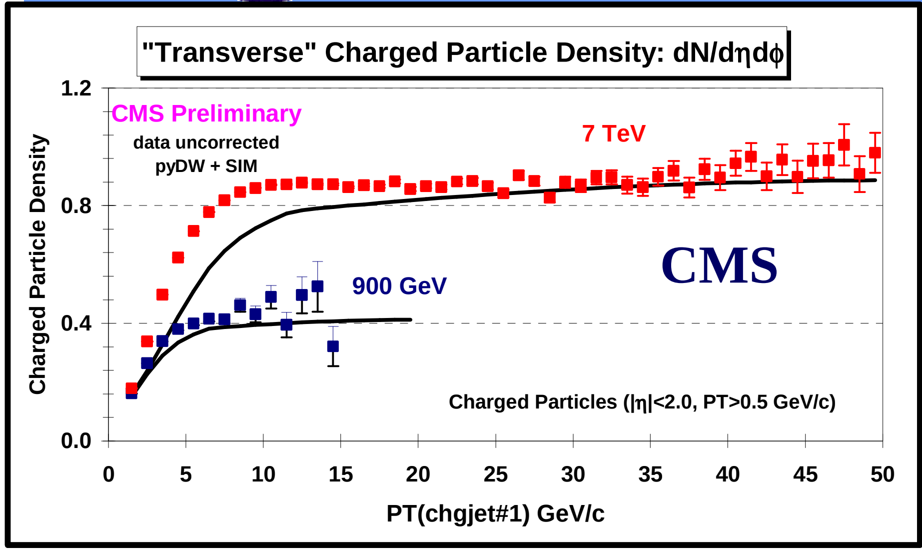
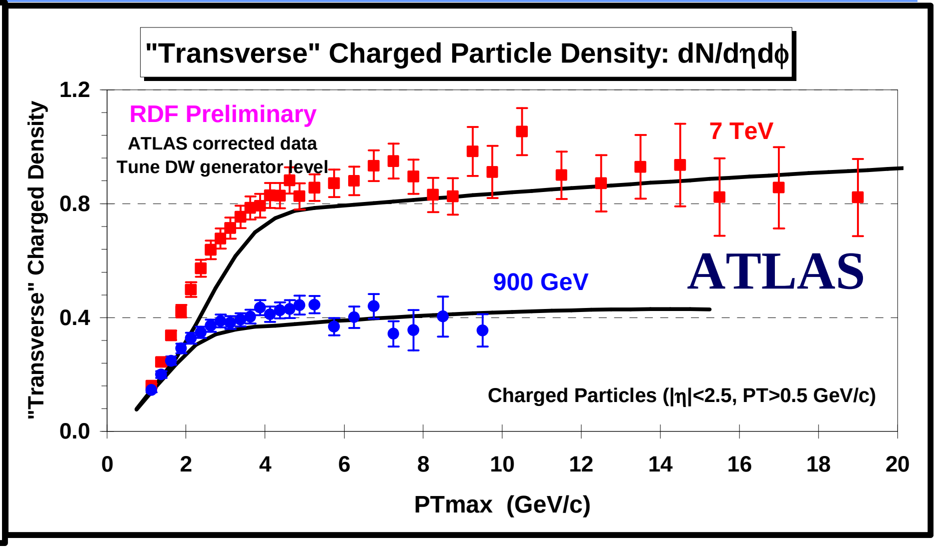
PYTHIA Tune DW

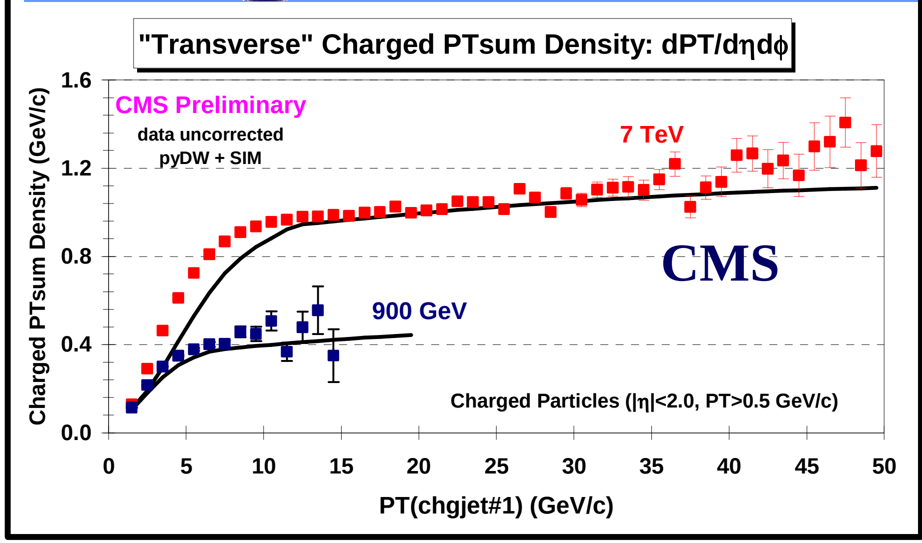


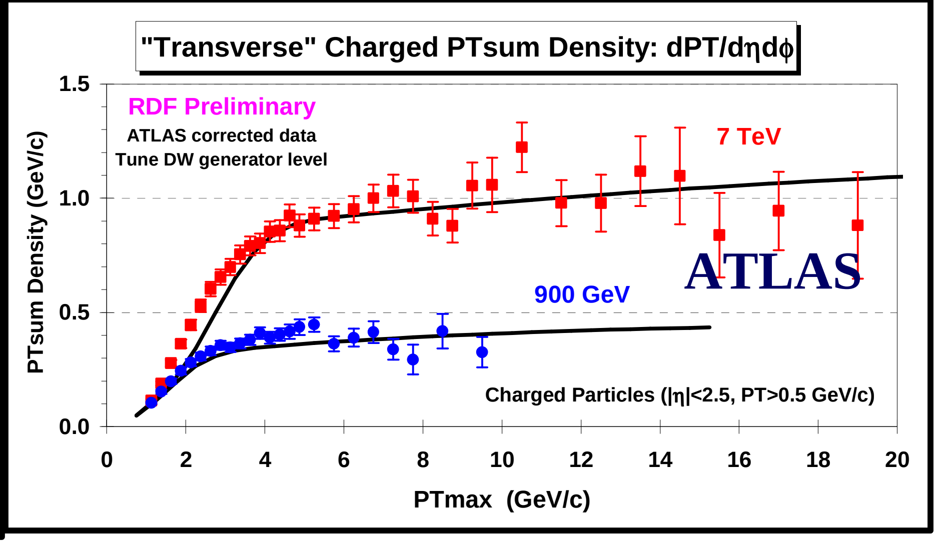


- **CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdφ, as defined by the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 2. The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.**

- **ATLAS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdφ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 2.5. The data are corrected and compared with PYTHIA Tune DW at the generator level.**

PYTHIA Tune DW

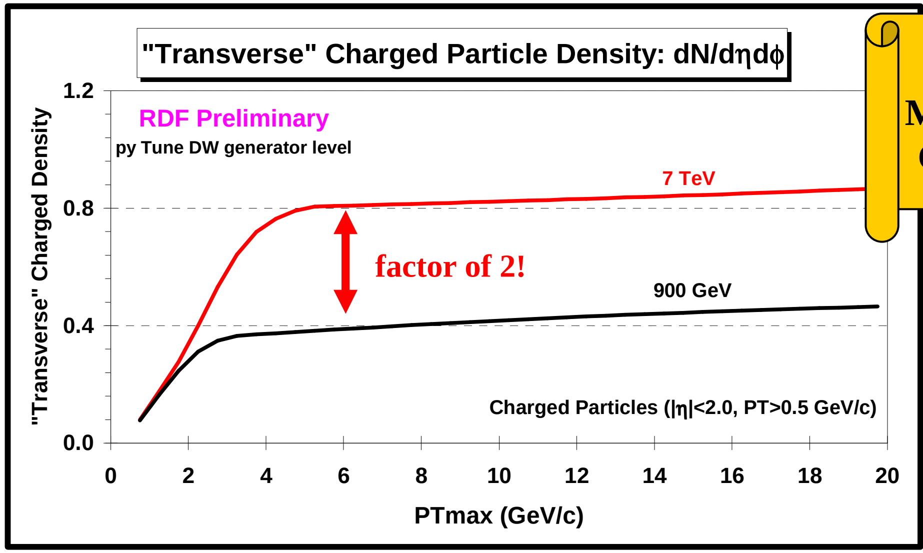




- **CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged PTsum density, dPT/dηdφ, as defined by the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 2. The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.**

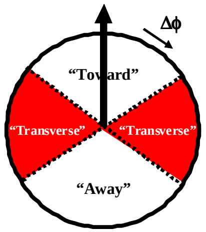
- **ATLAS preliminary data at 900 GeV and 7 TeV on the "transverse" charged PTsum density, dPT/dηdφ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 2.5. The data are corrected and compared with PYTHIA Tune DW at the generator level.**

"Transverse" Charge Density



Rick Field
MB&UE@CMS Workshop
CERN, November 6, 2009

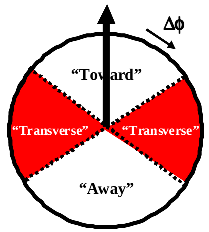
LHC 900 GeV



900 GeV → 7 TeV
(UE increase ~ factor of 2)

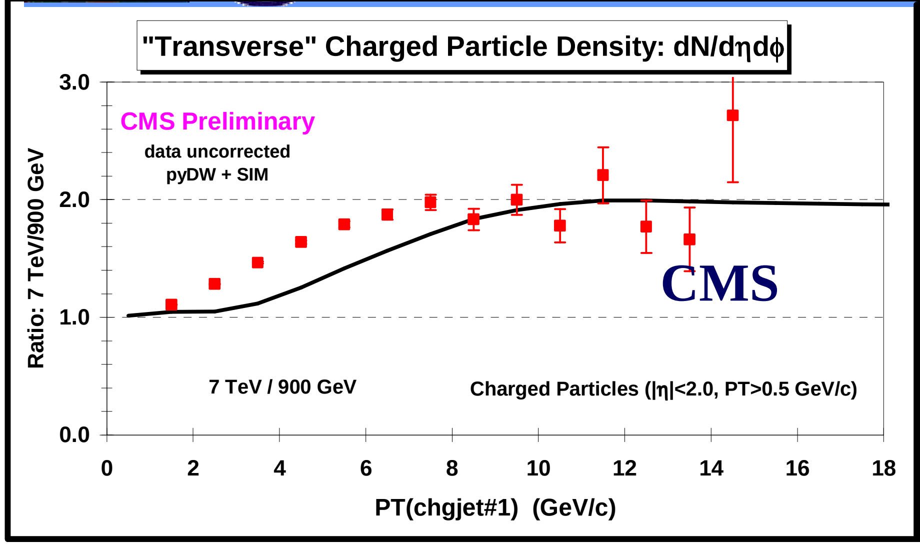
~0.4 → ~0.8

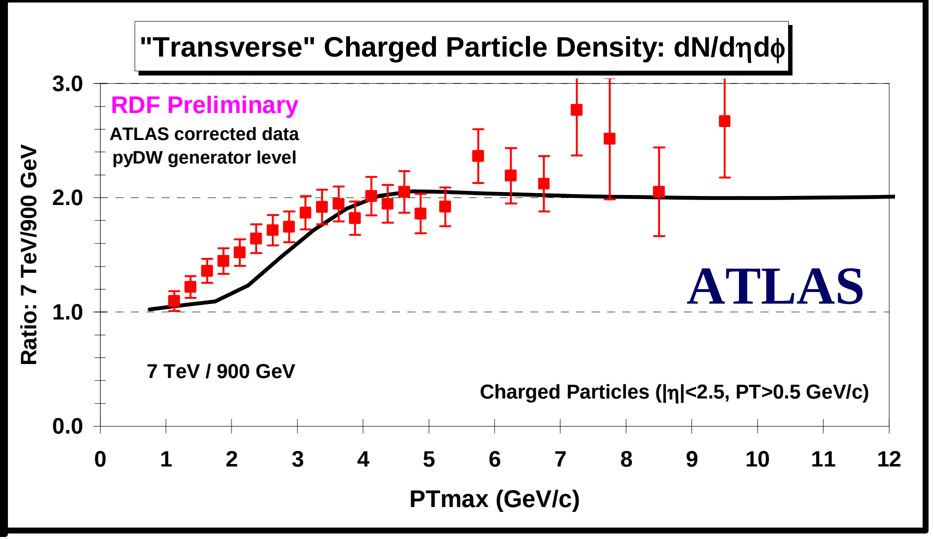
LHC 7 TeV



- **Shows the charged particle density in the "transverse" region for charged particles (p_T > 0.5 GeV/c, |η| < 2) at 900 GeV and 7 TeV as defined by PTmax from PYTHIA Tune DW and at the particle level (*i.e.* generator level).**

PYTHIA Tune DW

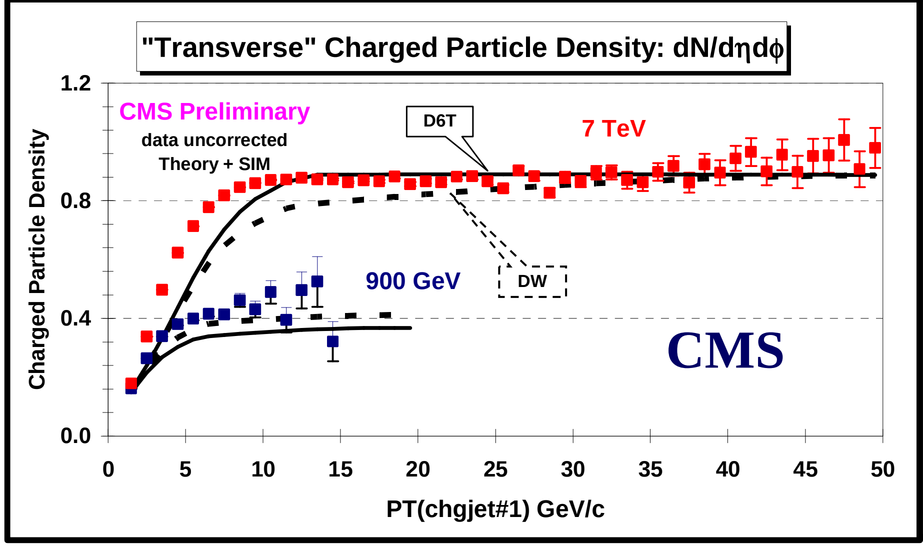


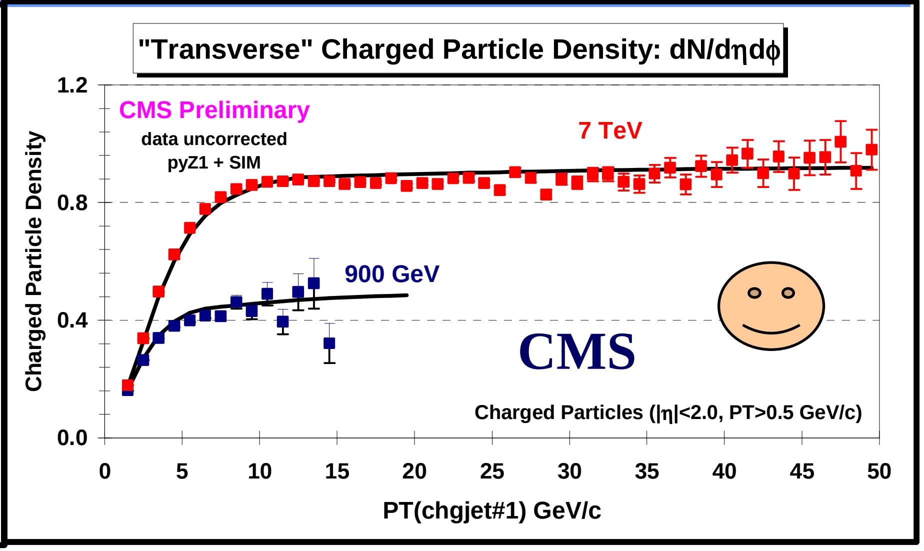


- **CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdφ, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2$. The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.**

- **ATLAS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdφ, as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.5$. The data are corrected and compared with PYTHIA Tune DW at the generator level.**

PYTHIA Tune Z1





- CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$. The data are uncorrected and compared with PYTHIA Tune DW and D6T after detector simulation (SIM).

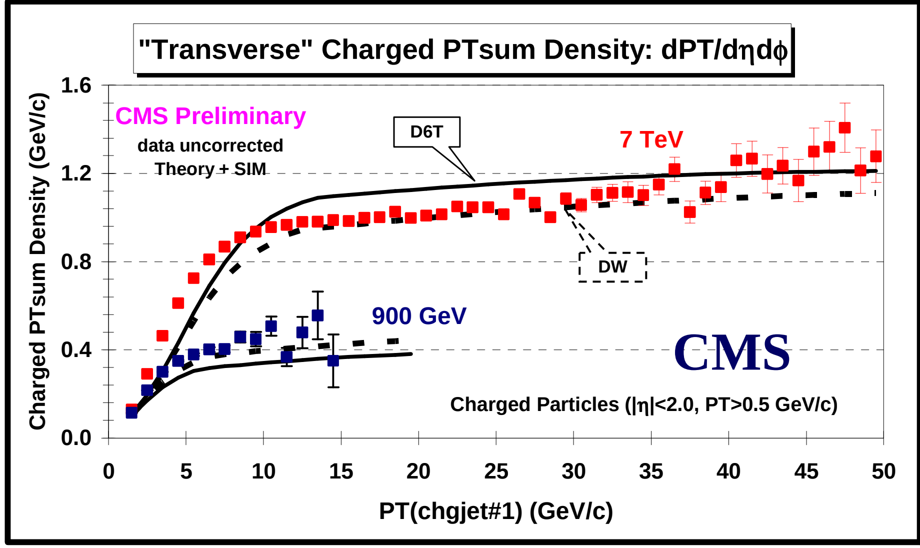
- CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$. The data are uncorrected and compared with PYTHIA Tune Z1 after detector simulation (SIM).

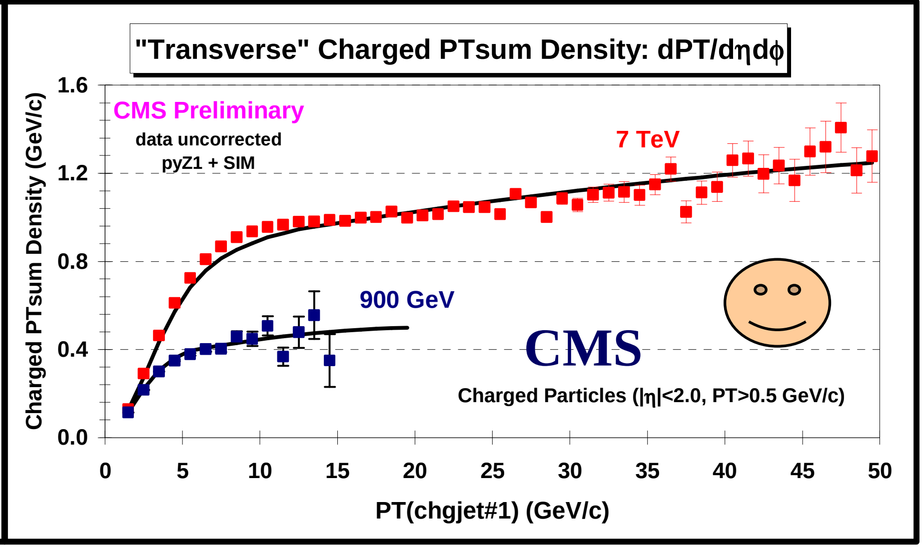
Color reconnection suppression.
Color reconnection strength.

Tune Z1 (CTEQ5L)
PARP(82) = 1.932
PARP(90) = 0.275
PARP(77) = 1.016
PARP(78) = 0.538

Tune Z1 is a PYTHIA 6.4 using p_T-ordered parton showers and the new MPI model!

PYTHIA Tune Z1





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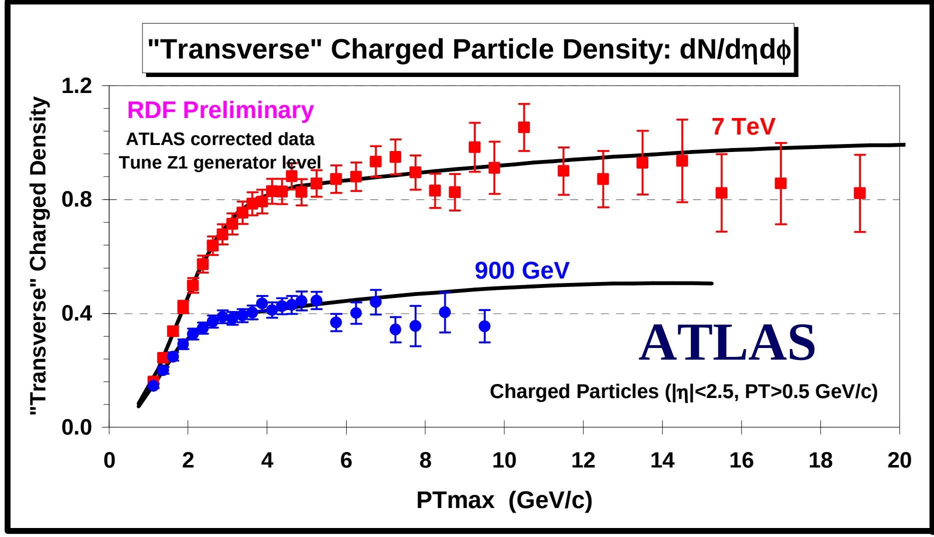

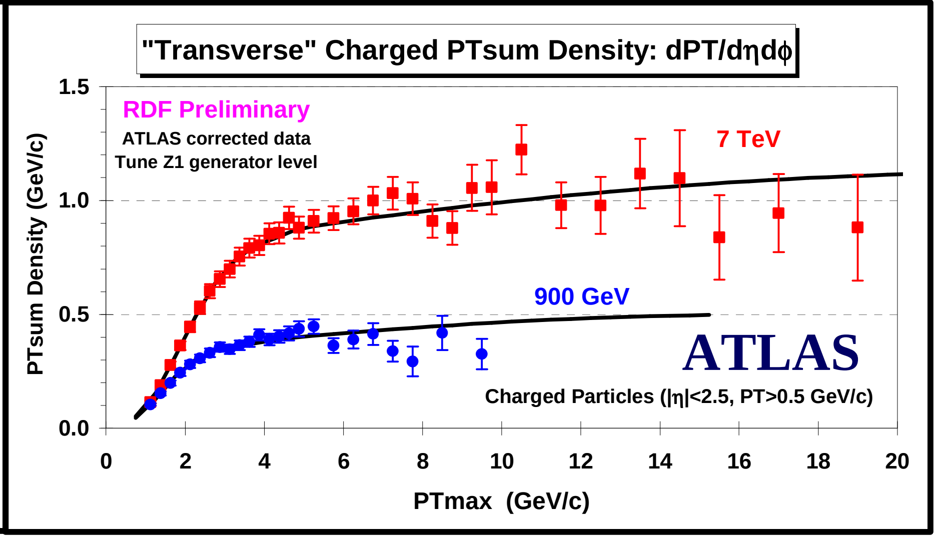

- **ATLAS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 2.5. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.**

- **ATLAS preliminary data at 900 GeV and 7 TeV on the "transverse" charged PTsum density, dPT/dηdϕ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 2.5. The data are corrected and compared with PYTHIA Tune Z1 at the generrator level.**

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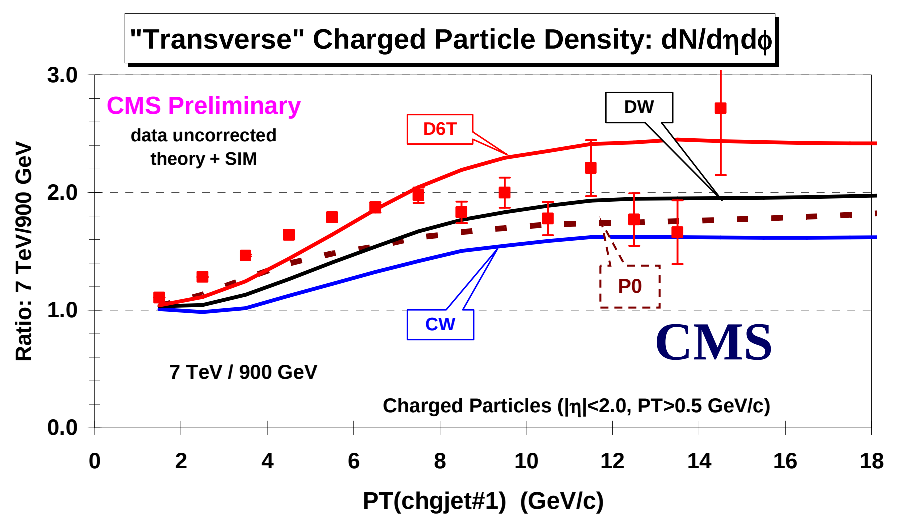
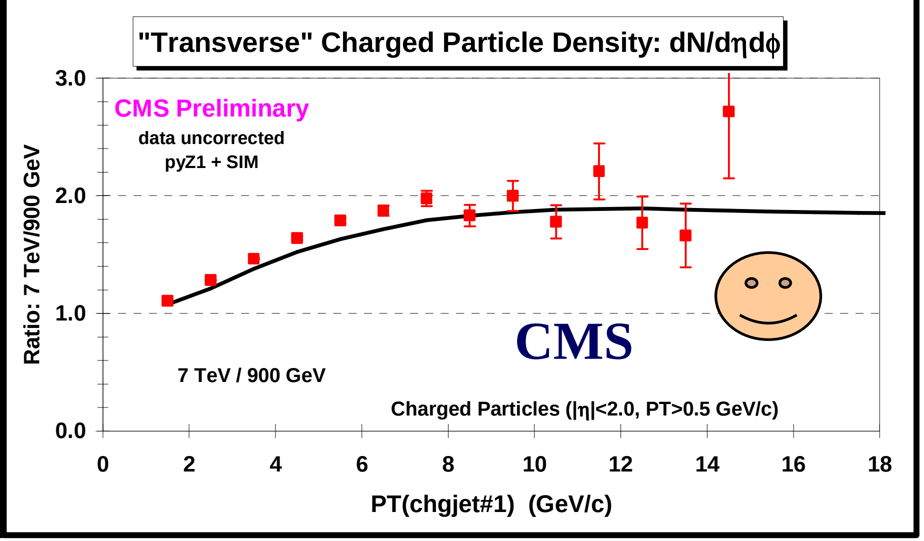
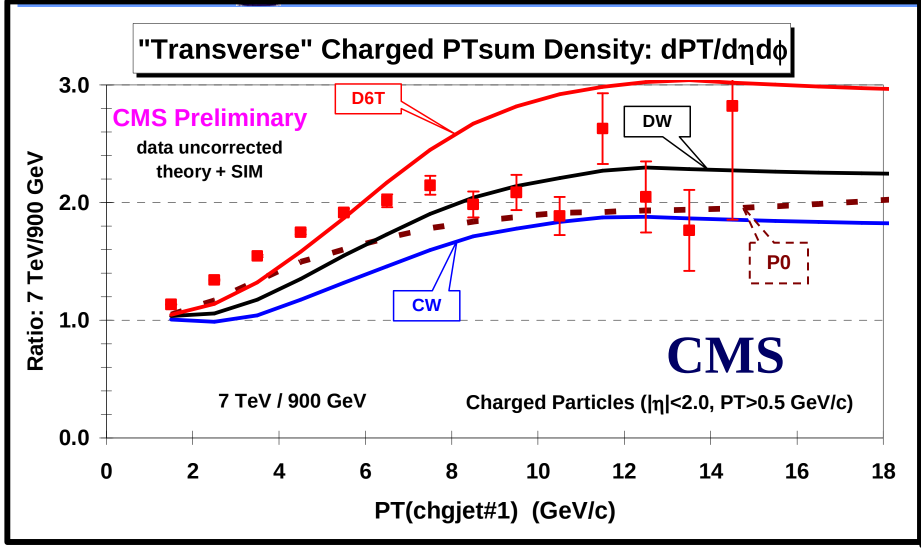


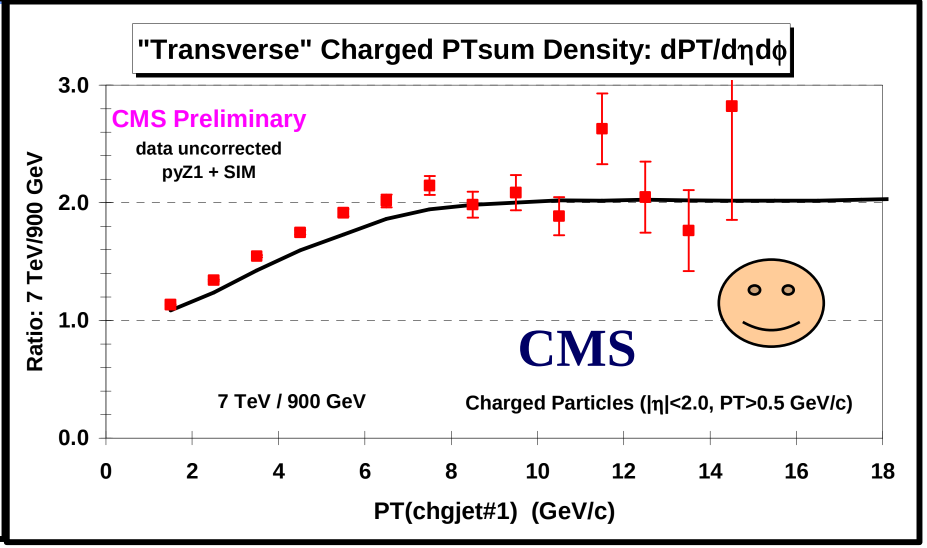


- **Ratio of CMS preliminary data at 900 GeV and 7 TeV (7 TeV divided by 900 GeV) on the "transverse" charged particle density as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$. The data are uncorrected and compared with PYTHIA Tune DW, D6T, CW, and P0 after detector simulation (SIM).**

- **Ratio of CMS preliminary data at 900 GeV and 7 TeV (7 TeV divided by 900 GeV) on the "transverse" charged particle density as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$. The data are uncorrected and compared with PYTHIA Tune Z1 after detector simulation (SIM).**

PYTHIA Tune Z1





- Ratio of CMS preliminary data at 900 GeV and 7 TeV (7 TeV divided by 900 GeV) on the "transverse" charged PTsum density as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$. The data are uncorrected and compared with PYTHIA Tune DW, D6T, CW, and P0 after detector simulation (SIM).

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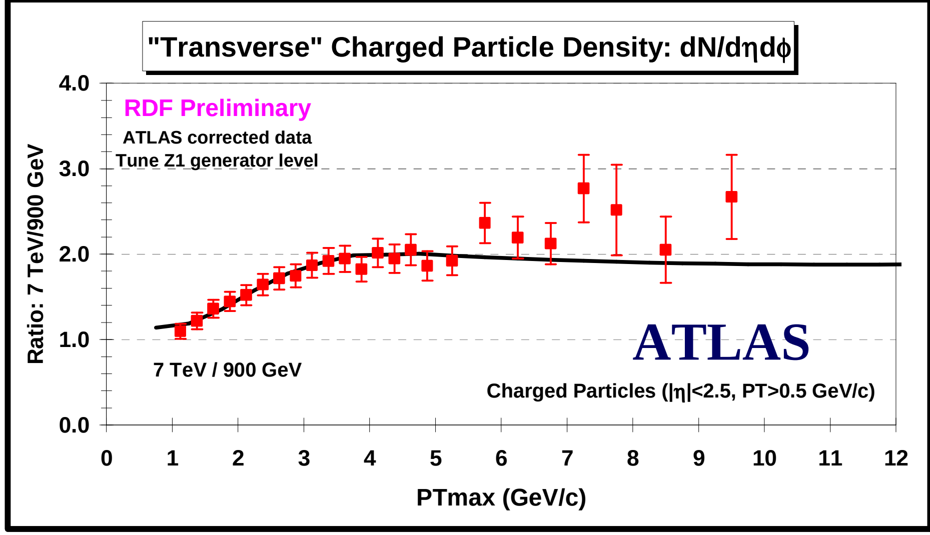
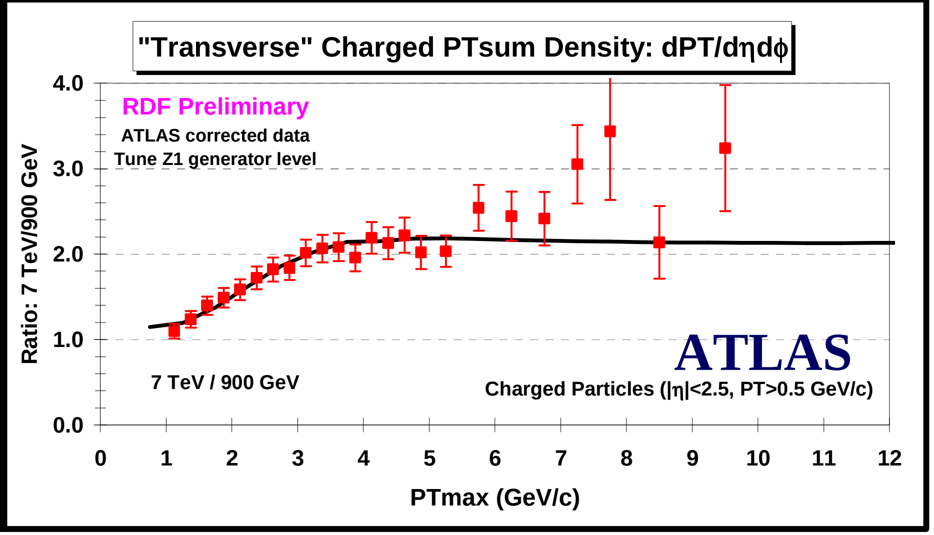
PYTHIA Tune Z1





- **Ratio of the ATLAS preliminary data on the charged particle density in the "transverse" region for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 2.5$) at 900 GeV and 7 TeV as defined by PTmax compared with PYTHIA Tune Z1 at the generator level.**
- **Ratio of the ATLAS preliminary data on the charged PTsum density in the "transverse" region for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 2.5$) at 900 GeV and 7 TeV as defined by PTmax compared with PYTHIA Tune Z1 at the generator level.**

CMS Common Plots

Observable	900 GeV	7 TeV
MB1: $dN_{chg}/d\eta$ $N_{chg} \geq 1$ $\|\eta\| < 0.8$ $p_T > 0.5$ Gev/c & 1.0 GeV/c	Done QCD-10-024	Done QCD-10-024
MB2: dN_{chg}/dp_T $N_{chg} \geq 1$ $\|\eta\| < 0.8$	Stalled	Stalled
MB3: Multiplicity Distribution $\|\eta\| < 0.8$ $p_T > 0.5$ GeV/c & 1.0 GeV/c	Stalled	Stalled
MB4: $\langle p_T \rangle$ versus Nchg $\|\eta\| < 0.8$ $p_T > 0.5$ GeV/c & 1.0 GeV/c	Stalled	Stalled
UE1: Transverse Nchg & PTsum as defined by the leading charged particle, PTmax $\|\eta\| < 0.8$ $p_T > 0.5$ GeV/c & 1.0 GeV/c	Done FSQ-12-020	Done FSQ-12-020

Direct charged particles (including leptons) corrected to the particle level with no corrections for SD or DD.

CMS Common Plots

Observable	900 GeV	7 TeV
MB1: d… /dη $N_{chg} \geq 1$ $\lvert\eta\rvert < 0.8$ p_T > … /c & 1.0 G…	Do… QC…	Done QC… 0-024
MB2: dN_{chg}/dp_T …		…talled
MB3 … $\lvert\eta\rvert < 0.8$ p_T …		
MB4: $<p_T>$ ver… $\lvert\eta\rvert < 0.8$ p_T > …		
UE1: … Nchg … defined by the leading … particle, PTmax $\lvert\eta\rvert < 0.8$ $p_T > 0.5$ GeV/c & 1.0 G…	FSQ…	…one F… 12-020

Note that all the "common plots" require at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$!

This was done so that the plots are less sensitive to SD and DD.

Direct charged partic… (including leptons) corrected to the particle level with… no corrections for SD or DD.

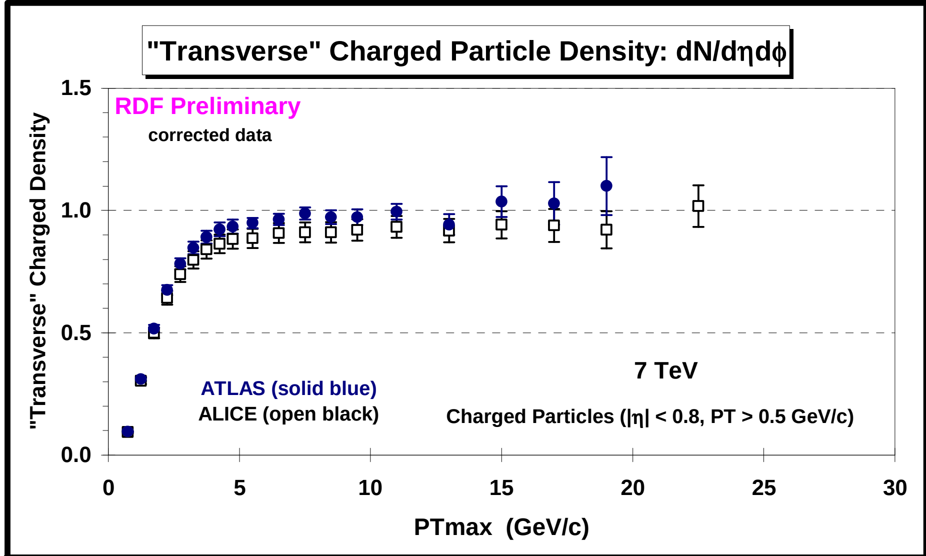
CDF Common Plots

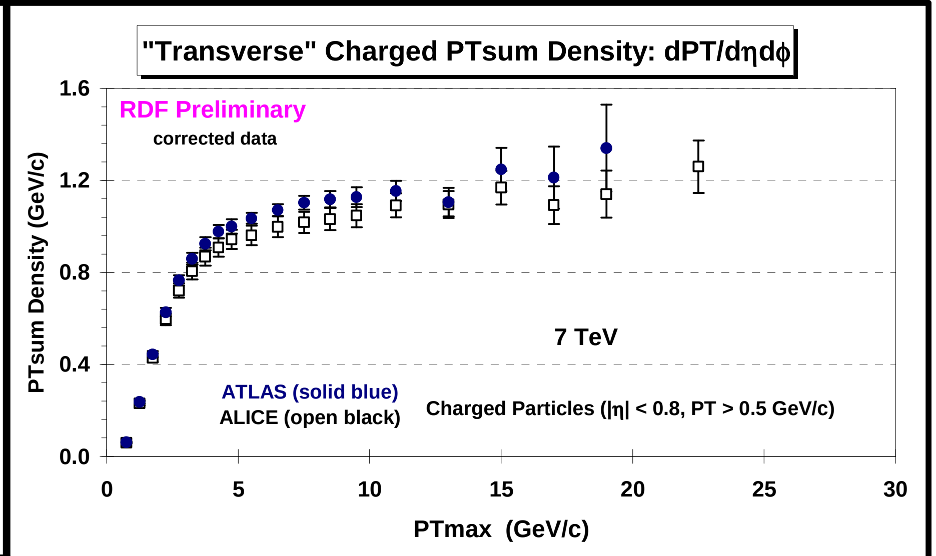
Observable	300 GeV	900 GeV	1.96 TeV
MB1: $dN_{chg}/d\eta$ $N_{chg} \geq 1$ $\|\eta\| < 0.8$ $p_T > 0.5$ Gev/c & 1.0 GeV/c	Done	Done	Done
MB2: dN_{chg}/dp_T $N_{chg} \geq 1$ $\|\eta\| < 0.8$	Stalled	Stalled	Stalled
MB3: Multiplicity Distribution $\|\eta\| < 0.8$ $p_T > 0.5$ GeV/c & 1.0 GeV/c	Stalled	Stalled	Stalled
MB4: $<p_T>$ versus Nchg $\|\eta\| < 0.8$ $p_T > 0.5$ GeV/c & 1.0 GeV/c	Stalled	Stalled	Stalled
UE1: Transverse Nchg & PTsum as defined by the leading charged particle, PTmax $\|\eta\| < 0.8$ $p_T > 0.5$ GeV/c & 1.0 GeV/c	$p_T > 0.5$ GeV/c Done	$p_T > 0.5$ GeV/c Done	$p_T > 0.5$ GeV/c Done

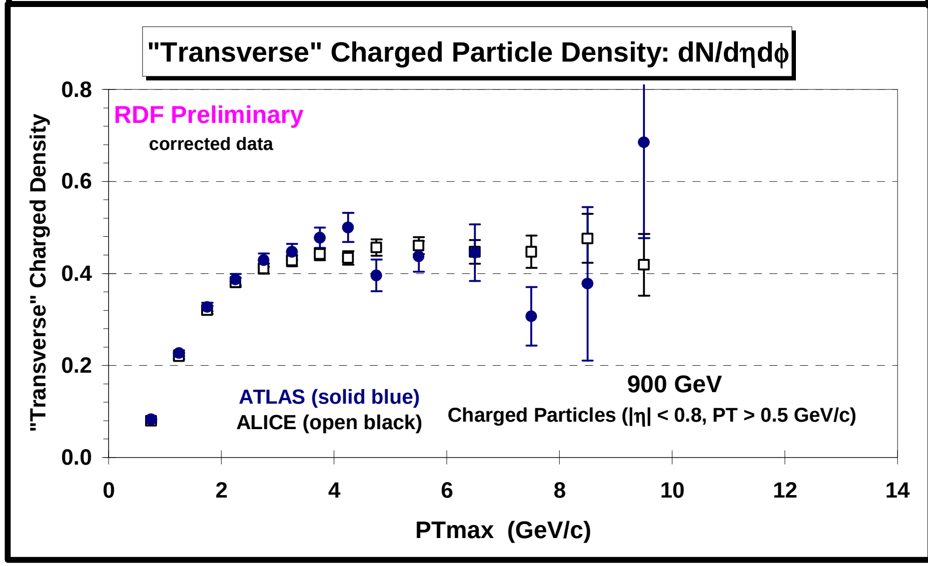
Direct charged particles (including leptons) corrected to the particle level with no corrections for SD or DD.

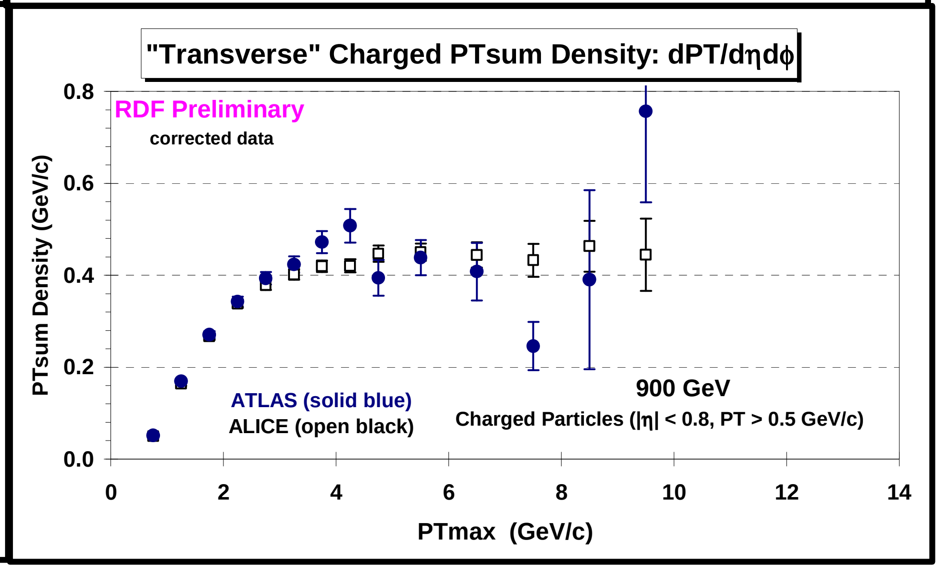
R. Field, C. Group, and D. Wilson.

UE Common Plots

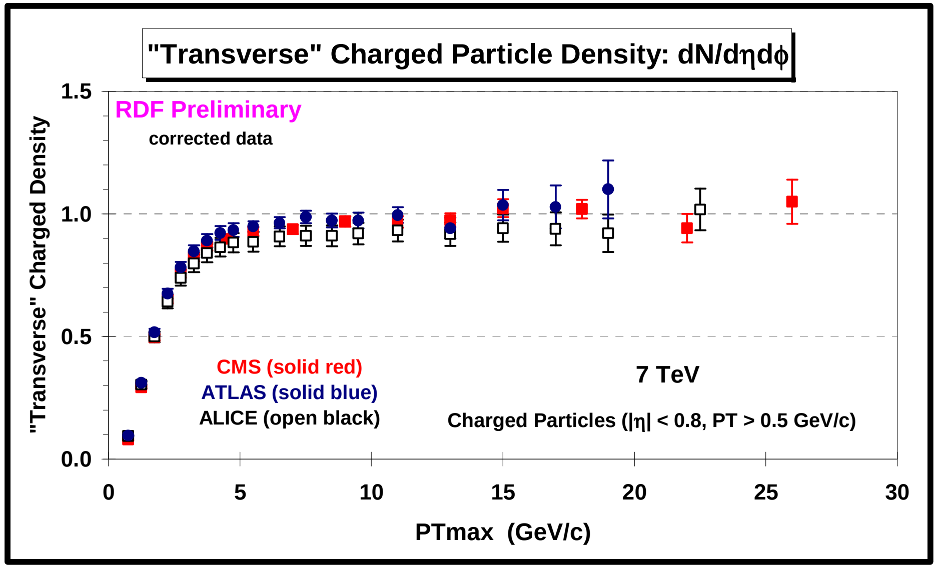


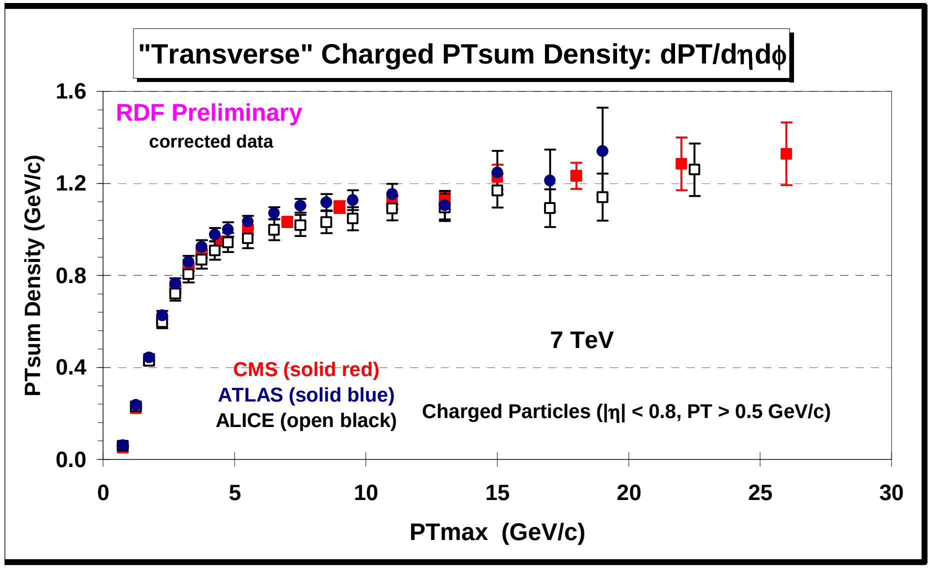


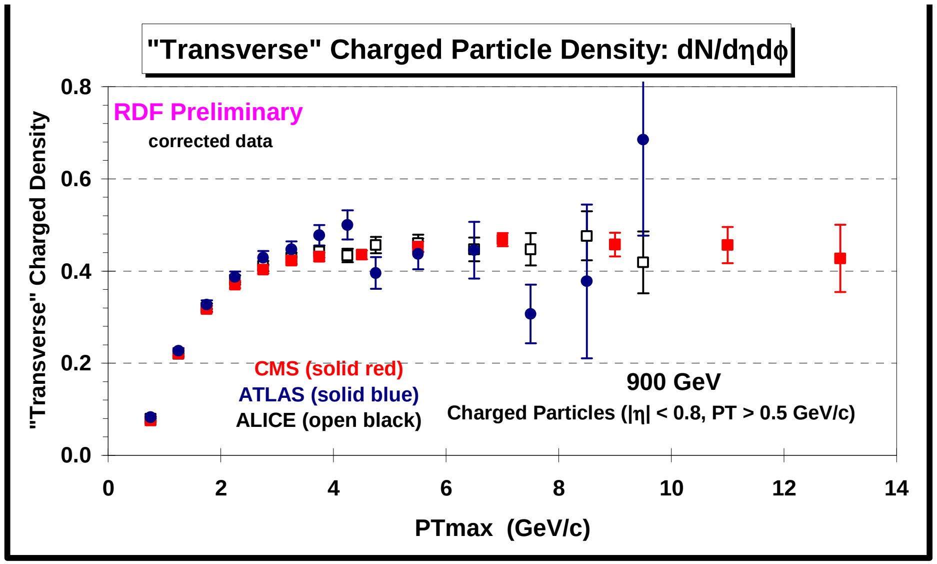


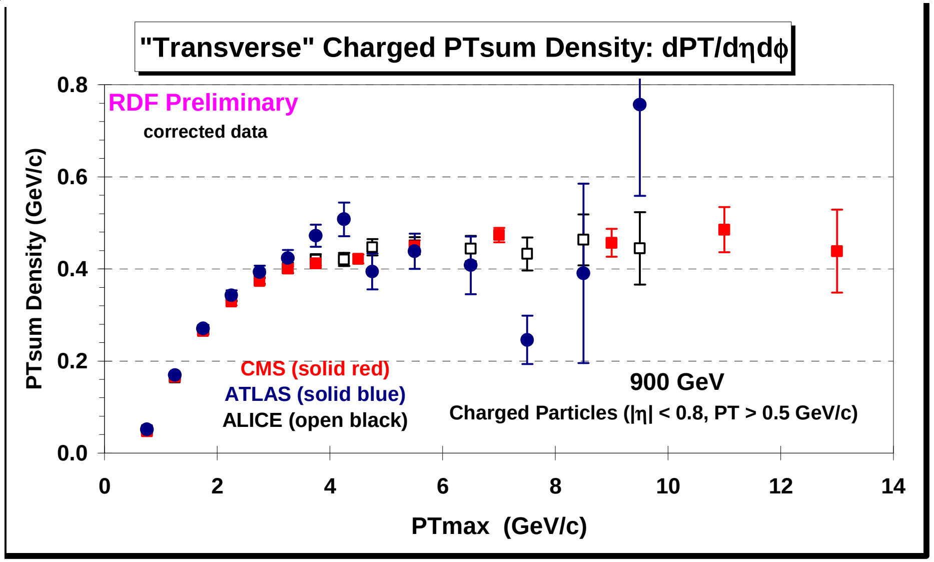


UE Common Plots

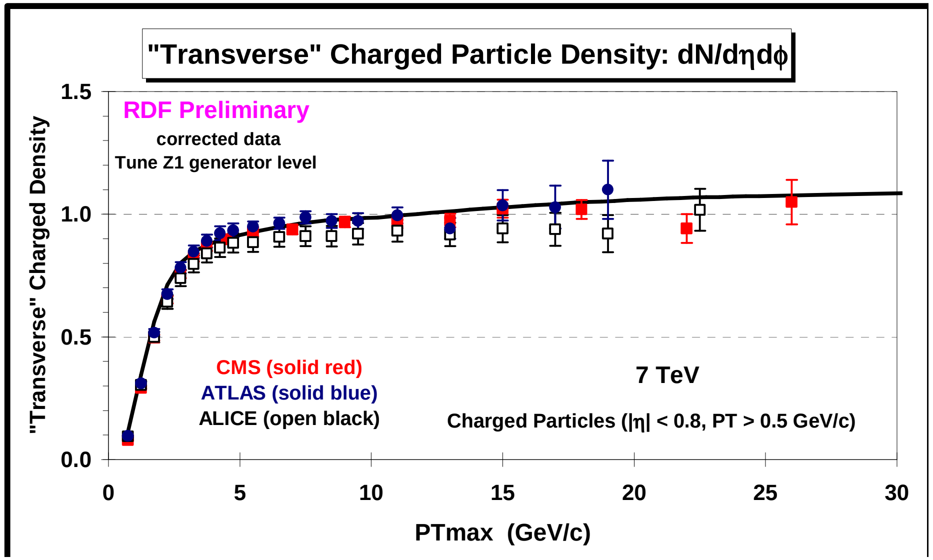


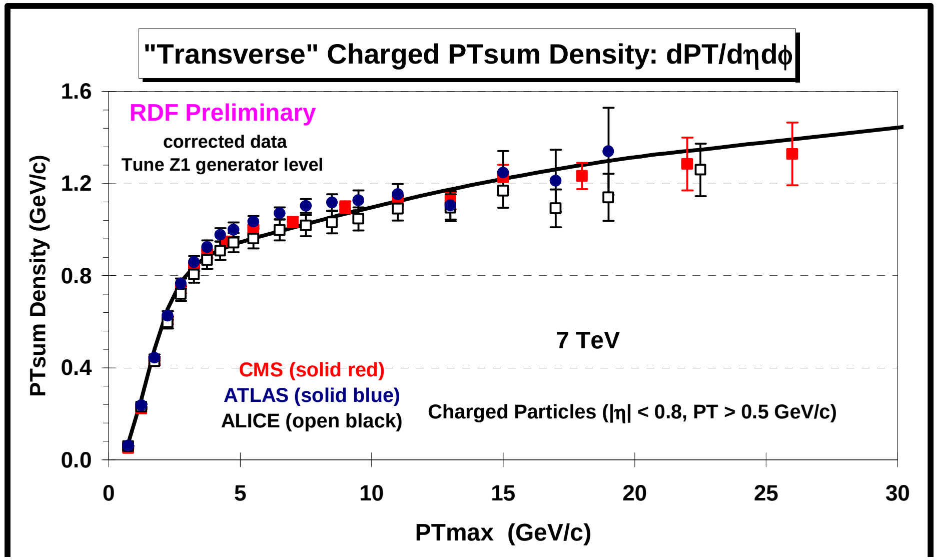


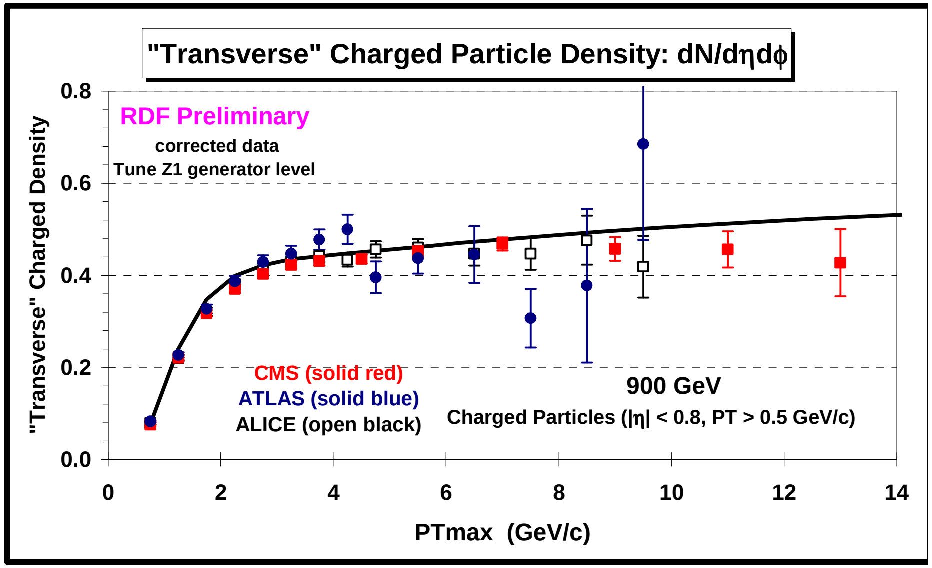


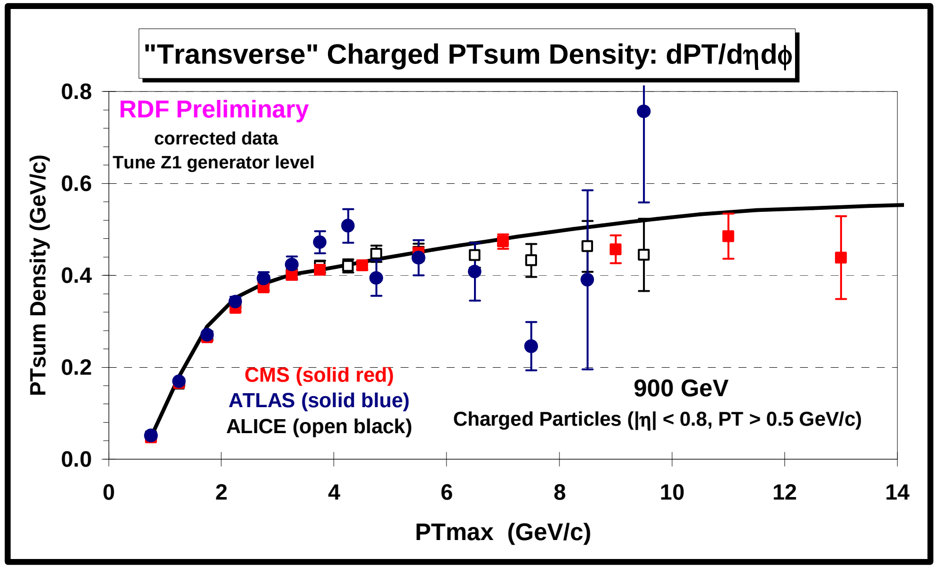


UE Common Plots

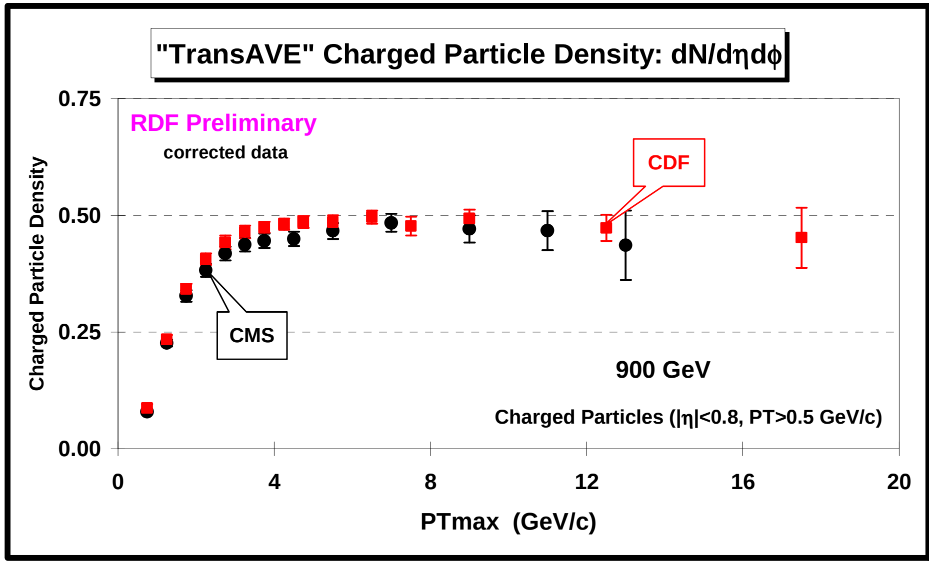


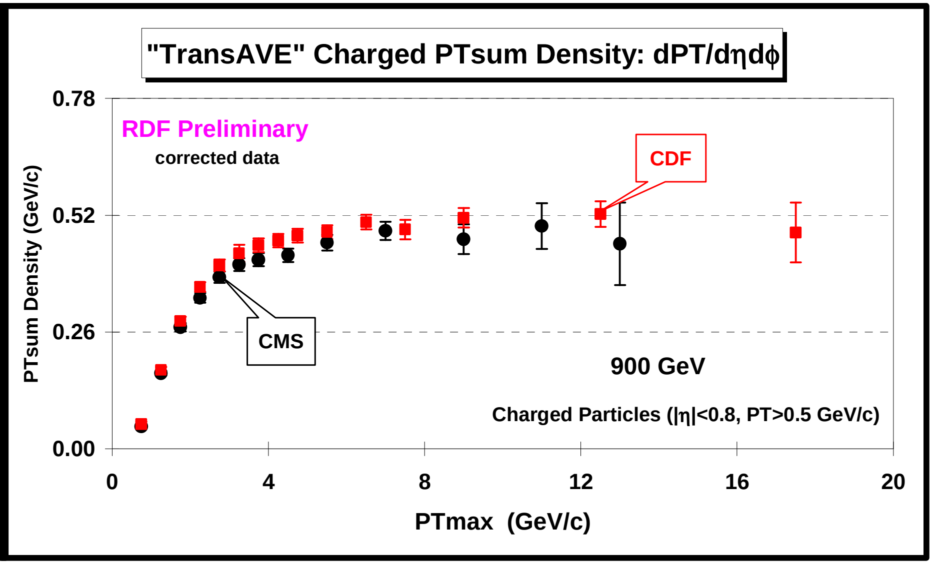






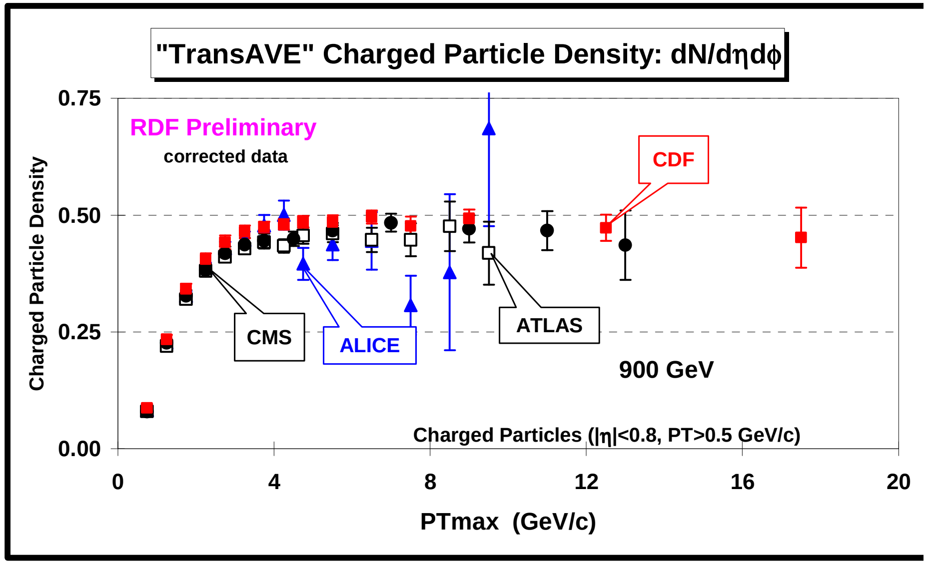
CDF versus LHC

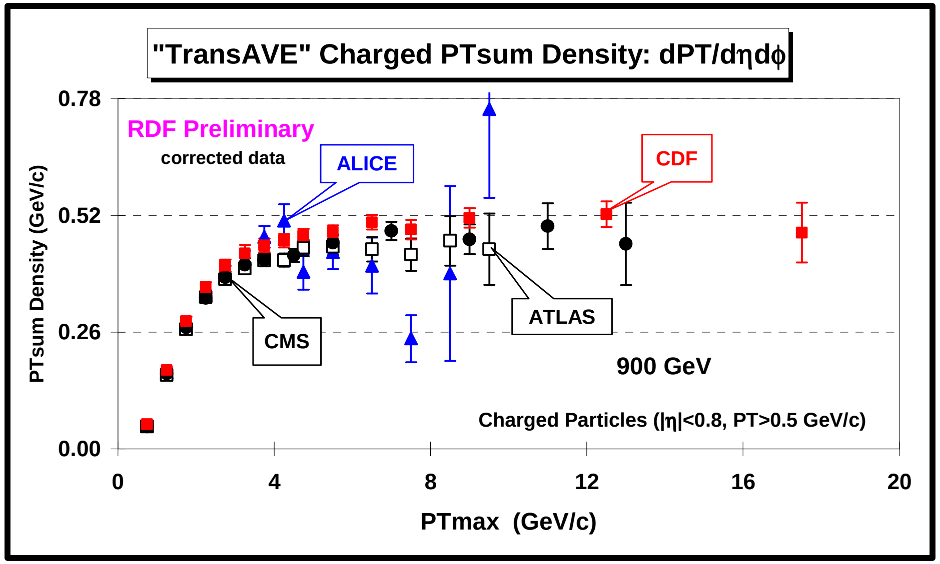




- **CDF and CMS data at 900 GeV/c on the charged particle density in the "transverse" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**
- **CDF and CMS data at 900 GeV/c on the charged PTsum density in the "transverse" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

CDF versus LHC





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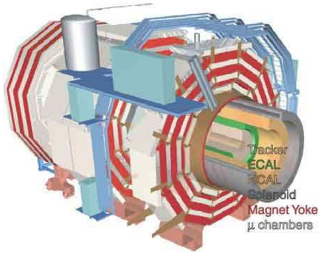
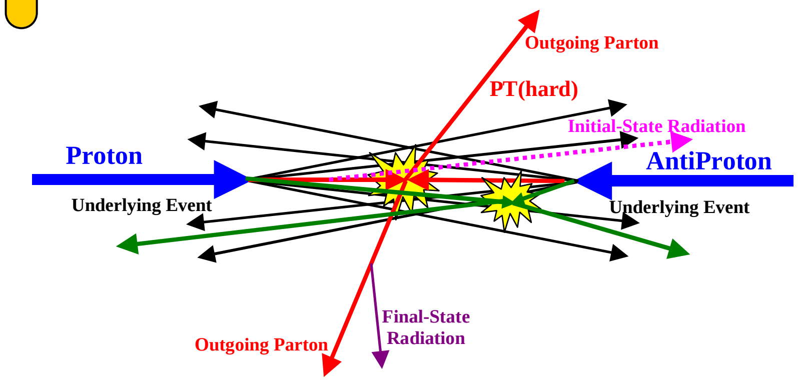
CMS Tuning Publication



CMS at the LHC

900 GeV, 2.96 TeV, 7 TeV, 8 TeV, 13 TeV

Physics Comparisons & Generstor Tunes



Hannes Jung, Paolo Gunnellini, Rick Field

To appear soon!

CMS PAPER GEN-14-001

DRAFT
CMS Paper

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2015/08/12
Head Id: 234706
Archive Id: 299863P
Archive Date: 2014/04/01
Archive Tag: trunk

CMS underlying event and double parton scattering tunes

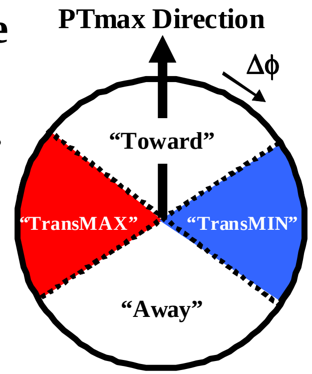
The CMS Collaboration

Abstract

Three new PYTHIA-8 underlying event (UE) tunes are constructed, one using the CTEQ6L1 parton distribution function (PDF), one using HERAPDF 1.5 leading order (LO), and one using the NNPDF2.3LO PDF; two new PYTHIA-6 UE tunes, one for the CTEQ6L PDF and one for the HERAPDF 1.5 LO, and one new HERWIG ++ UE tune for the CTEQ6L1 PDF are also available. Simultaneous fits to CDF UE data at 300 GeV, 900 GeV, and 1.96 TeV, together with CMS UE data at 7 TeV, check the UE models and constrain their parameters, providing thereby more precise predictions for proton-proton collisions at 13 TeV. In addition, several new double-parton scattering (DPS) tunes are investigated when the values of the UE parameters from fits to observables are consistent with the values determined from fitting DPS-sensitive observables. Also examined is how well the new UE tunes predict "minimum bias" (MB) events, jet and Drell–Yan ($q\bar{q} \to Z/\gamma^* \to$lepton-antilepton+jets) observables, as well as the MB and UE observables at 13 TeV.

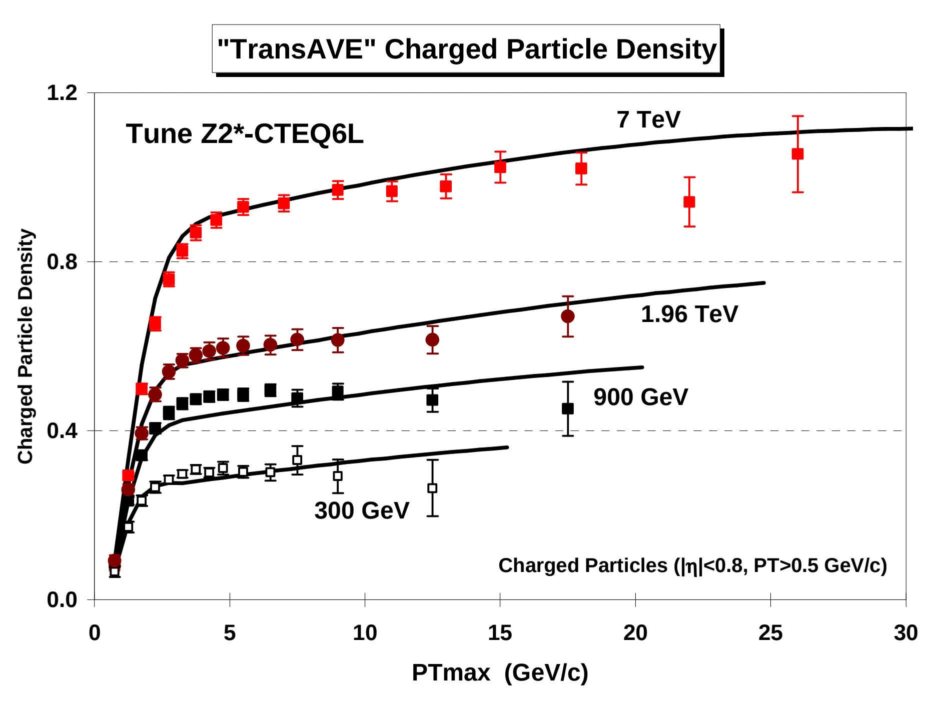
CMS UE Tunes

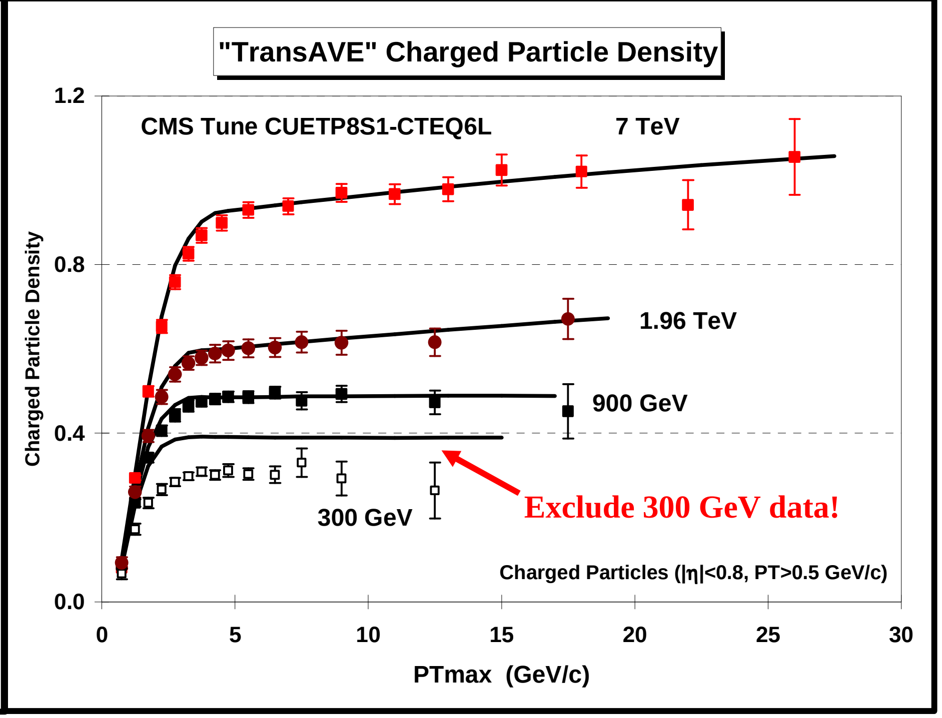
- **PYTHIA 6.4 Tune CUETP6S1-CTEQ6L:** Start with Tune Z2*-lep and tune to the CDF PTmax "transMAX" and "transMIN" UE data at 300 GeV, 900 GeV, and 1.96 TeV and the CMS PTmax "transMAX" and "transMIN" UE data at 7 TeV.
- **PYTHIA 6.4 Tune CUETP6S1-HERAPDF1.5LO:** Start with Tune Z2*-lep and tune to the CDF PTmax "transMAX" and "transMIN" UE data at 300 GeV, 900 GeV, and 1.96 TeV and the CMS PTmax "transMAX" and "transMIN" UE data at 7 TeV.



- **PYTHIA 8 Tune CUETP8S1-CTEQ6L:** Start with Corke & Sjöstrand Tune 4C and tune to the CDF PTmax "transMAX" and "transMIN" UE data at 900 GeV, and 1.96 TeV and the CMS PTmax "transMAX" and "transMIN" UE data at 7 TeV. Exclude 300 GeV data.
- **PYTHIA 8 Tune CUETP8S1-HERAPDF1.5LO:** Start with Corke & Sjöstrand Tune 4C and tune to the CDF PTmax "transMAX" and "transMIN" UE data at 900 GeV, and 1.96 TeV and the CMS PTmax "transMAX" and "transMIN" UE data at 7 TeV. Exclude 300 GeV data.
- **PYTHIA 8 Tune CUETP8M1-NNPDF2.3LO:** Start with the Skands Monash-NNPDF2.3LO tune and tune to the CDF PTmax "transMAX" and "transMIN" UE data at 900 GeV, and 1.96 TeV and the CMS PTmax "transMAX" and "transMIN" UE data at 7 TeV. Exclude 300 GeV data.
- **HERWIG++ Tune CUETHS1-CTEQ6L:** Start with the Seymour & Siódmok UE-EE-5C tune and tune to the CDF PTmax "transMAX" and "transMIN" UE data at 900 GeV, and 1.96 TeV and the CMS PTmax "transMAX" and "transMIN" UE data at 7 TeV.

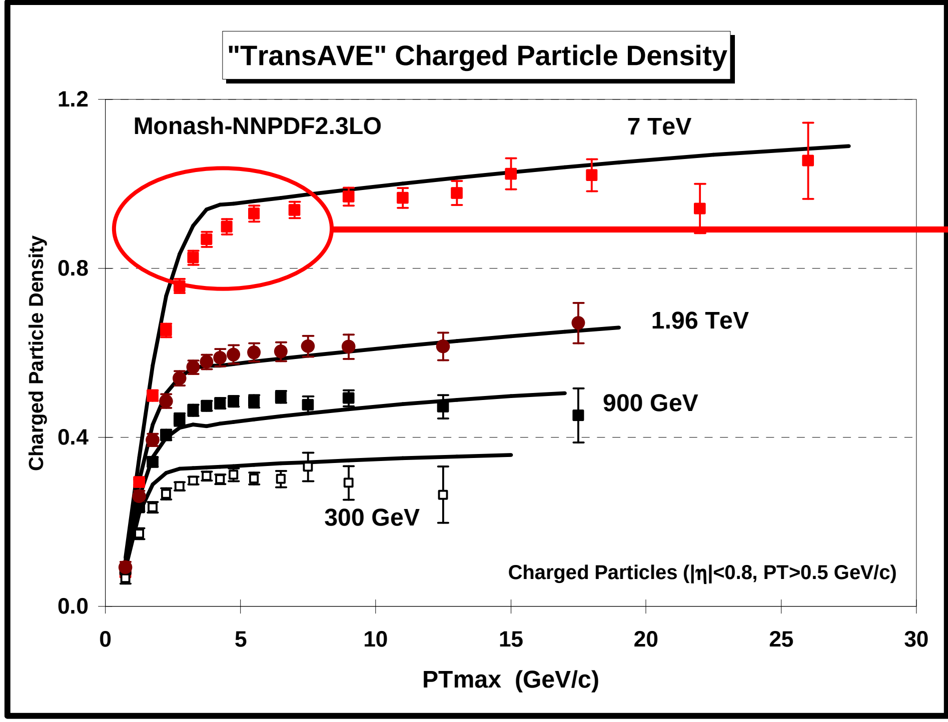
CUETP8S1-CTEQ6L

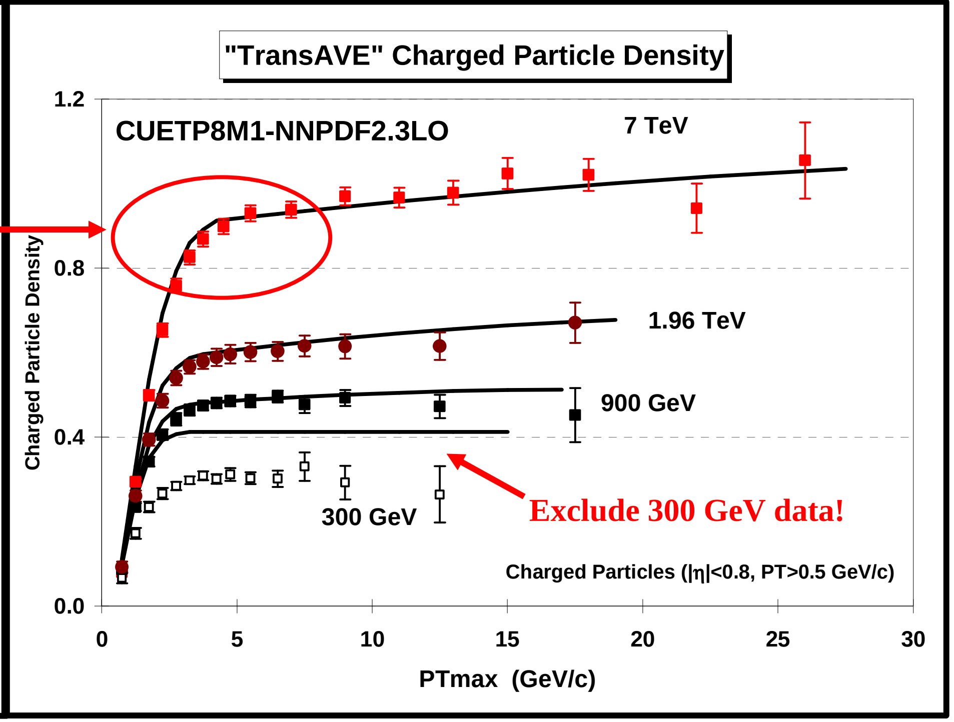




- **CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are compared with PYTHIA 6.4 Tune Z2*.**
- **CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are compared with PYTHIA 8 Tune CUETP8S1-CTEQ6L (excludes 300 GeV in fit).**

CUETP8M1-NNPDF2.3LO





- **CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are compared with the PYTHIA 8 Tune Monash-NNPDF2.3LO.**

- **CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are compared with the PYTHIA 8 Tune CUETP8M1-NNPDF2.3LO (excludes 300 GeV in fit).**

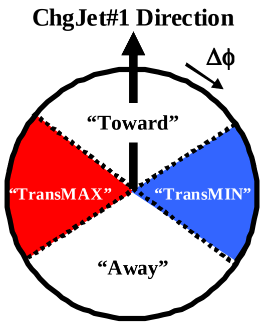
UE@CMS 13 TeV

UE@13TeV

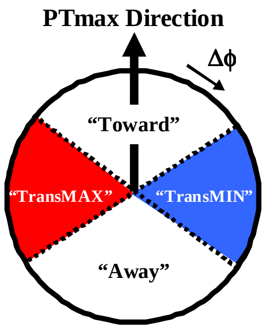
Livio Fano' (University of Perugia)
Diego Ciangottini (University of Perugia)
Rick Field (University of Florida)
Doug Rank (University of Florida)
Sunil Bansal (Panjab University Chandigarh)
Wei Yang Wang (National University of Singapore)

University of Perugia

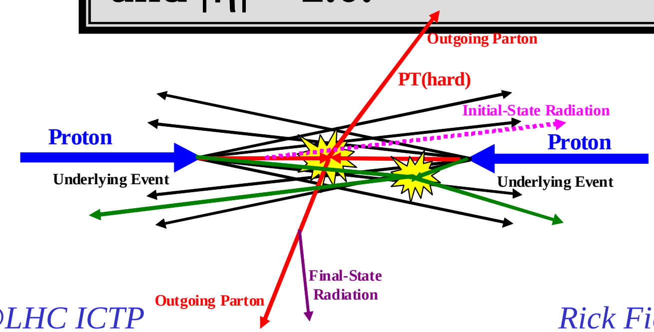
Measure the "Underlying Event" at 13 TeV at CMS



Measure the UE observables as defined by the leading charged particle jet, chgjet#1, for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$.



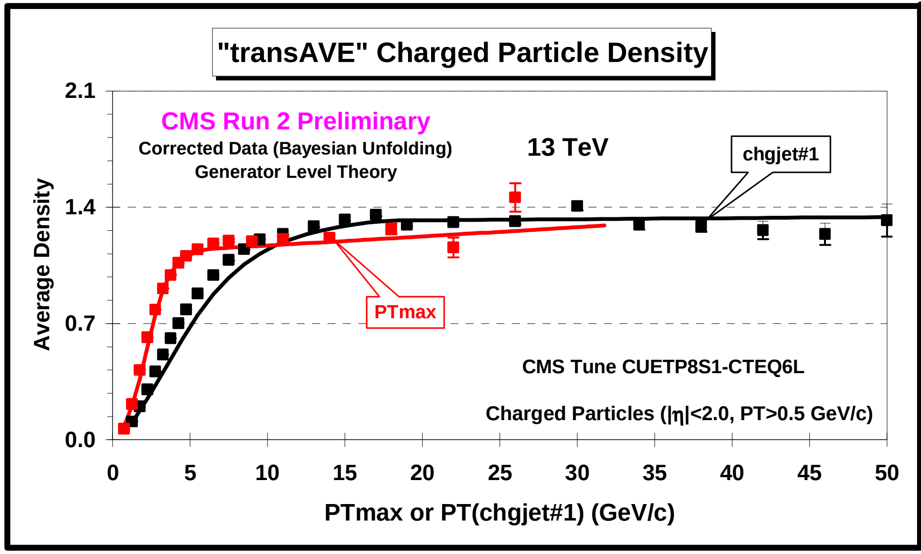
Measure the UE observables as defined by the leading charged particle, PTmax, for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$ and $|\eta| < 0.8$.

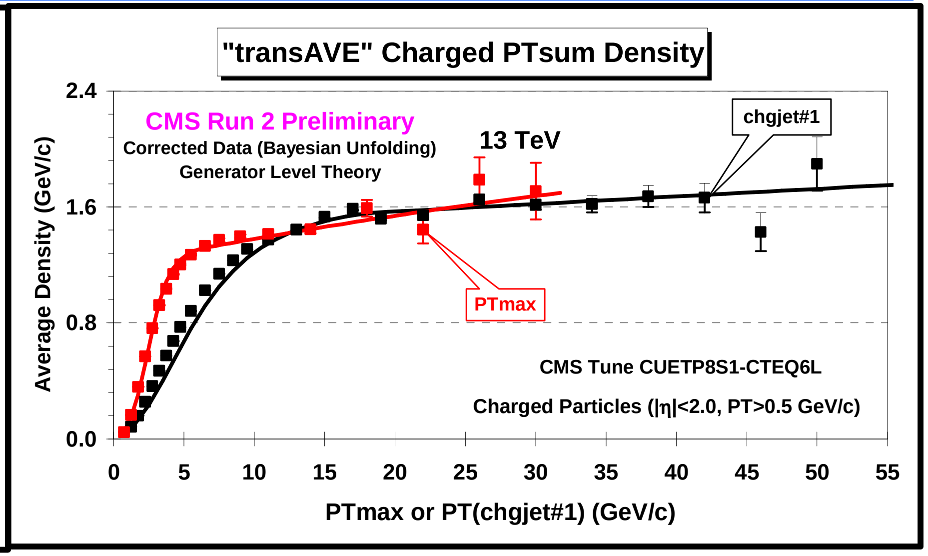


UE&MB@CMS

Livio & Rick were part of the CMS Run 1 UE&MB team!

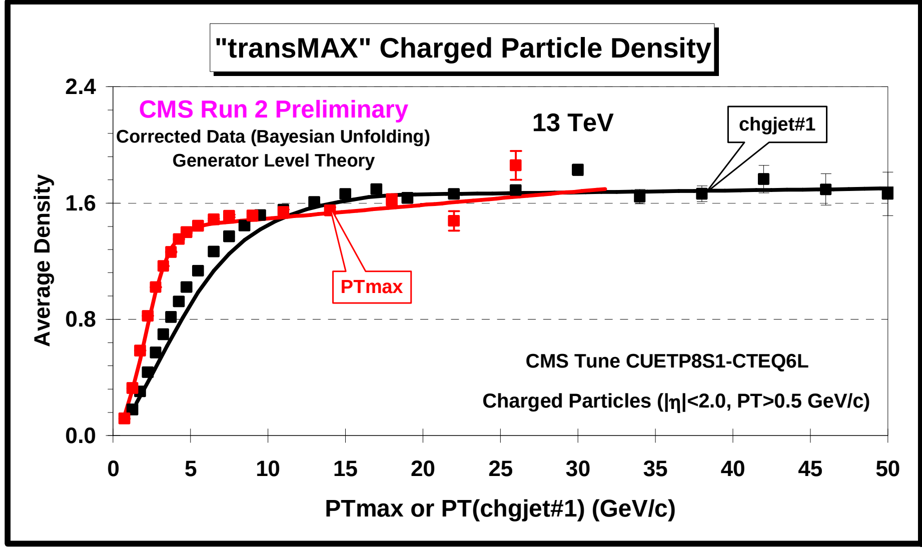
ChgJet#1 vs PTmax

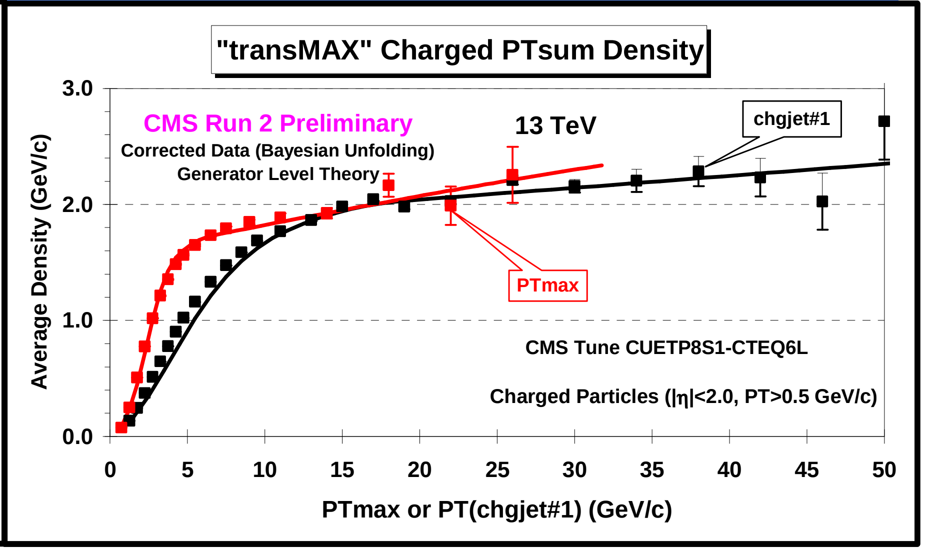




- **Corrected data (Bayesian unfolding) on the "transAVE" charged particle density with p_T > 0.5 GeV/c and |η| < 2.0 as defined by the leading charged particle, PTmax, and as defined by the leading charged particle jet, chgjet#1. The data are compared with PYTHIA 8 tune CUETP8S1-CTEQ6L at the generator level..**
- **Corrected data (Bayesian unfolding) on the "transAVE" charged PTsum density with p_T > 0.5 GeV/c and |η| < 2.0 as defined by the leading charged particle, PTmax, and as defined by the leading charged particle jet, chgjet#1. The data are compared with PYTHIA 8 tune CUETP8S1-CTEQ6L at the generator level..**

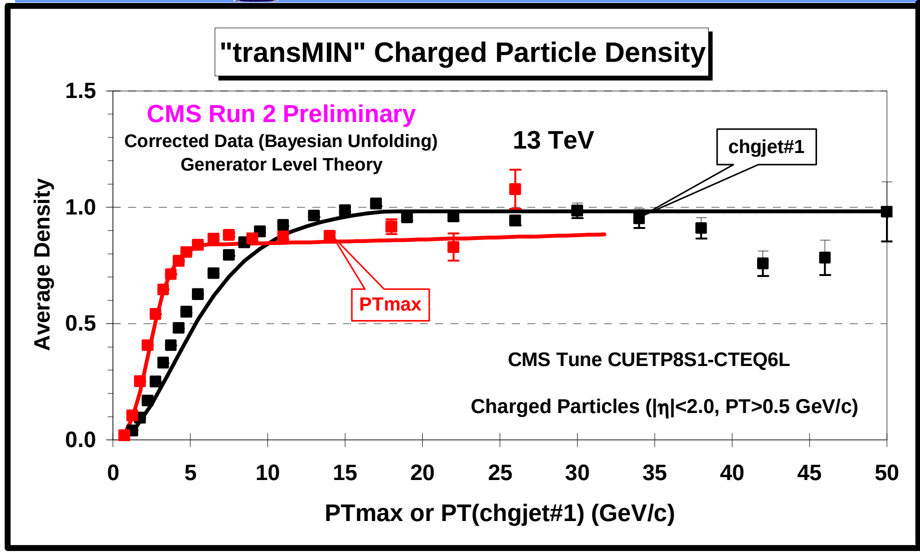
ChgJet#1 vs PTmax

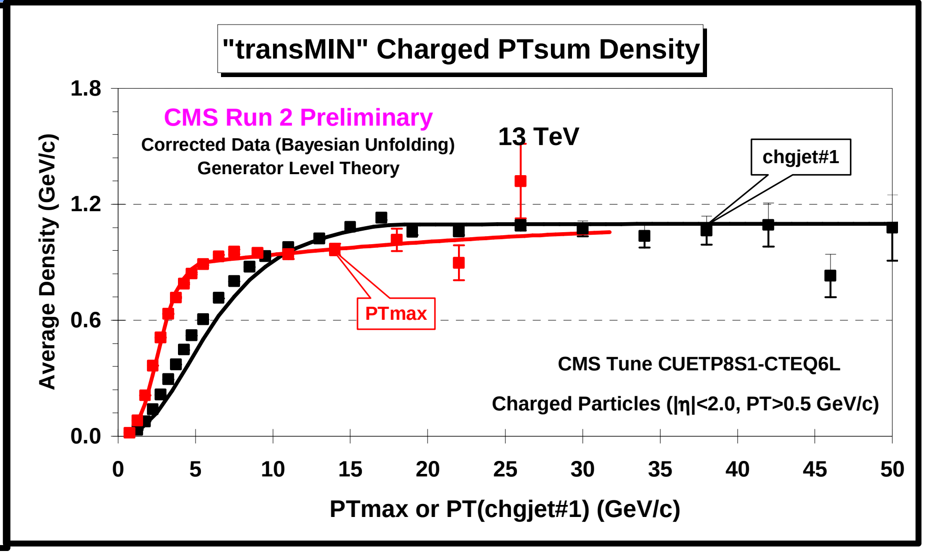




- **Corrected data (Bayesian unfolding) on the "transMAX" charged particle density with p_T > 0.5 GeV/c and |η| < 2.0 as defined by the leading charged particle, PTmax, and as defined by the leading charged particle jet, chgjet#1. The data are compared with PYTHIA 8 tune CUETP8S1-CTEQ6L at the generator level..**
- **Corrected data (Bayesian unfolding) on the "transMAX" charged PTsum density with p_T > 0.5 GeV/c and |η| < 2.0 as defined by the leading charged particle, PTmax, and as defined by the leading charged particle jet, chgjet#1. The data are compared with PYTHIA 8 tune CUETP8S1-CTEQ6L at the generator level..**

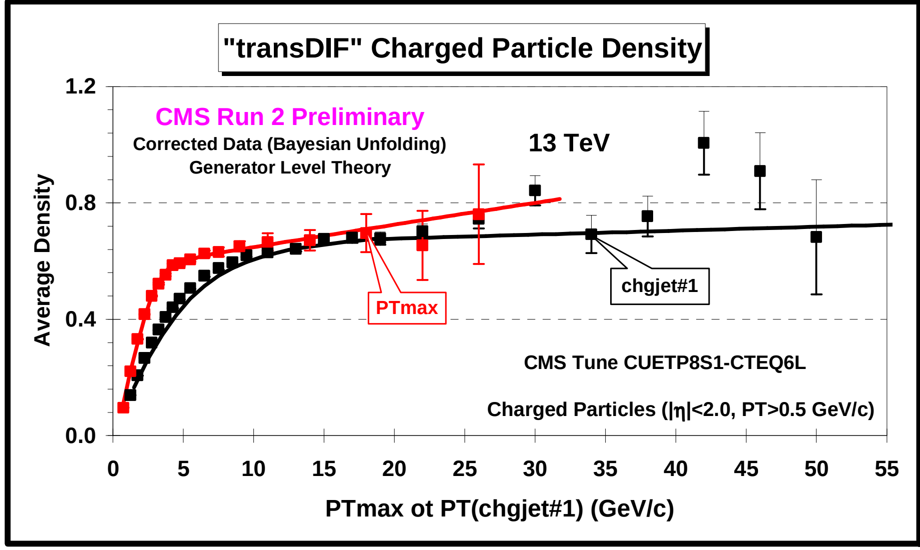
ChgJet#1 vs PTmax

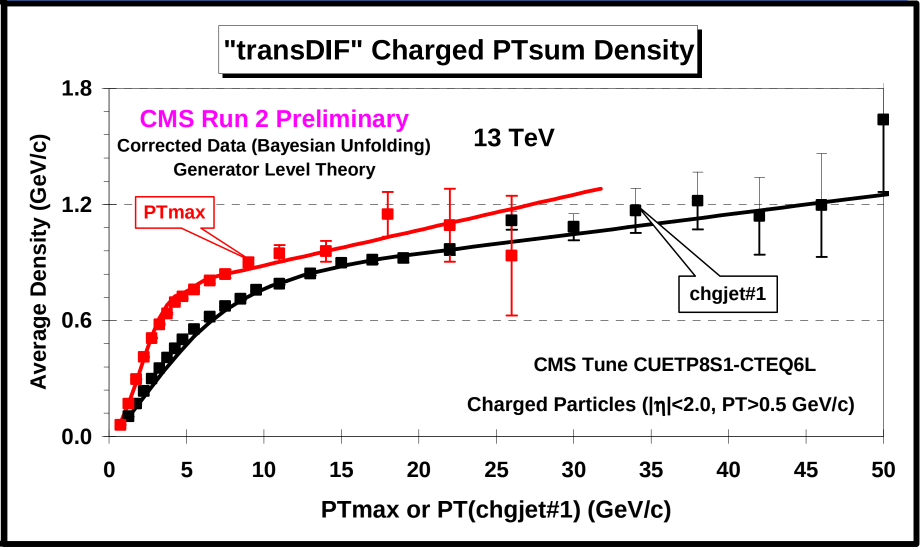




- **Corrected data (Bayesian unfolding) on the "transMIN" charged particle density with p_T > 0.5 GeV/c and |η| < 2.0 as defined by the leading charged particle, PTmax, and as defined by the leading charged particle jet, chgjet#1. The data are compared with PYTHIA 8 tune CUETP8S1-CTEQ6L at the generator level..**
- **Corrected data (Bayesian unfolding) on the "transMIN" charged PTsum density with p_T > 0.5 GeV/c and |η| < 2.0 as defined by the leading charged particle, PTmax, and as defined by the leading charged particle jet, chgjet#1. The data are compared with PYTHIA 8 tune CUETP8S1-CTEQ6L at the generator level..**

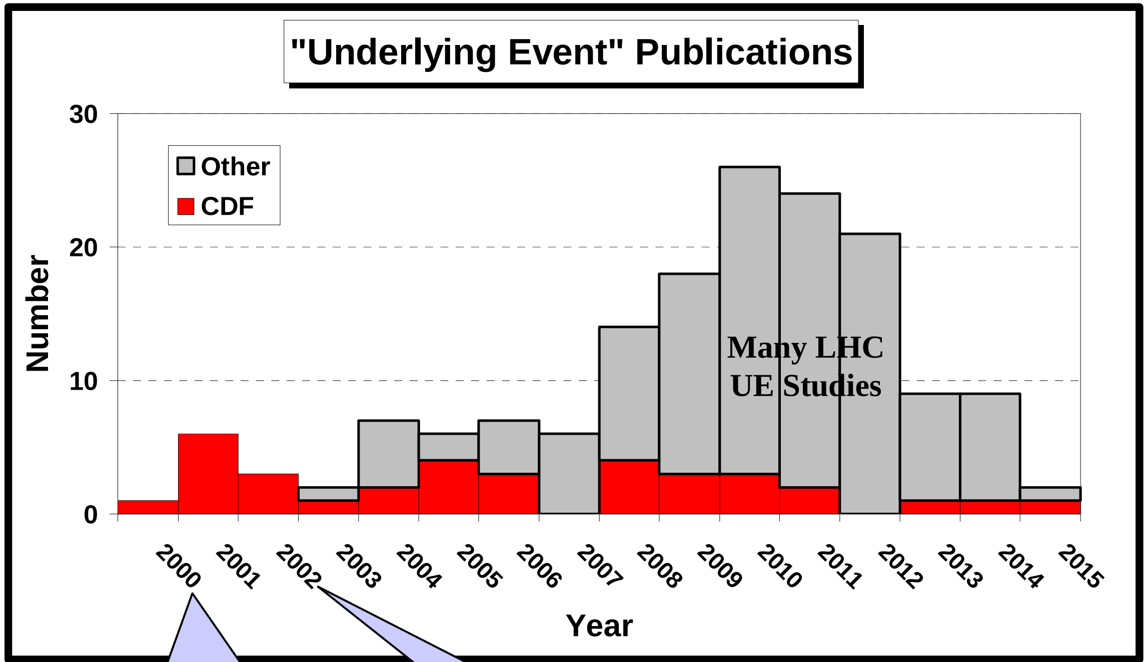
ChgJet#1 vs PTmax





- **Corrected data (Bayesian unfolding) on the "transDIF" charged particle density with p_T > 0.5 GeV/c and |η| < 2.0 as defined by the leading charged particle, PTmax, and as defined by the leading charged particle jet, chgjet#1. The data are compared with PYTHIA 8 tune CUETP8S1-CTEQ6L at the generator level..**
- **Corrected data (Bayesian unfolding) on the "transDIF" charged PTsum density with p_T > 0.5 GeV/c and |η| < 2.0 as defined by the leading charged particle, PTmax, and as defined by the leading charged particle jet, chgjet#1. The data are compared with PYTHIA 8 tune CUETP8S1-CTEQ6L at the generator level..**

UE Publications

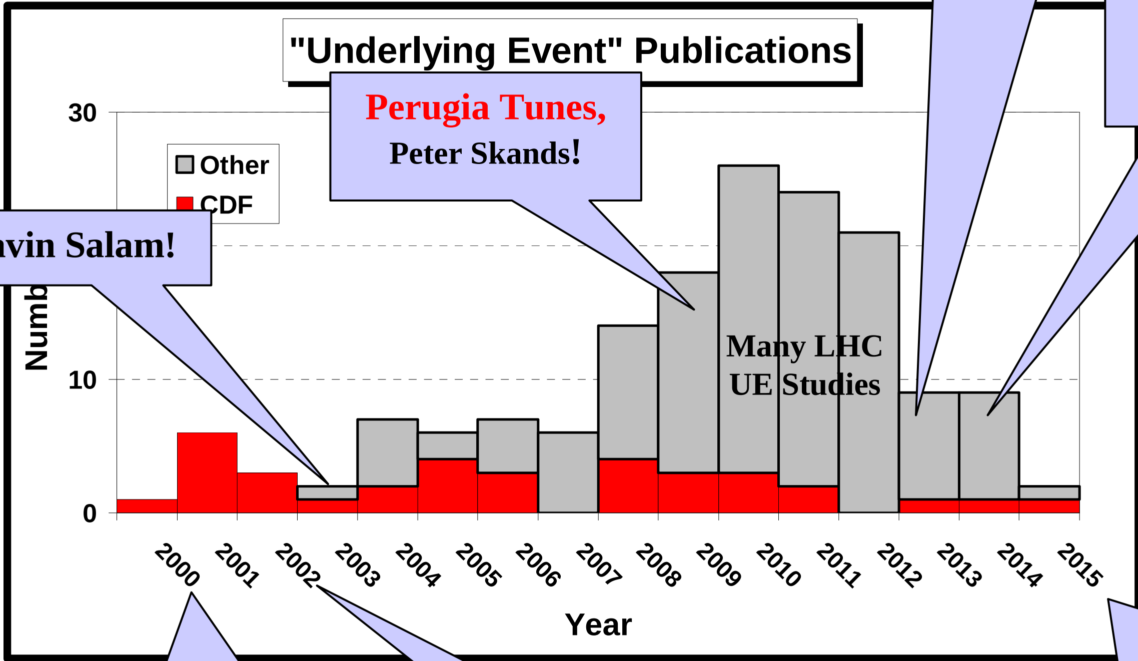


➡ **Publications on the "underlying event" (2000-2015).**

The Underlying Event in Large Transverse Momentum Charged Jet and Z−boson Production at CDF, R. Field, published in the proceedings of DPF 2000.

Charged Jet Evolution and the Underlying Event in Proton-Antiproton Collisions at 1.8 TeV, CDF Collaboration, Phys. Rev. D65 (2002) 092002.

UE Publications



HERWIG++ UE Tune, M. Seymour and A. Siódmok!

Monash Tune, Peter Skands!

Perugia Tunes, Peter Skands!

Gavin Salam!

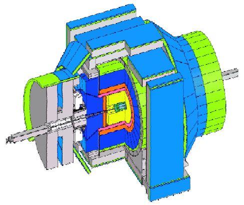
- **Publications on t**… **derlying ev**…

The Underlying Event in Large Transverse Momentum Charged Jet and Z−boson Production at CDF, R. Field, published in the proceedings of DPF 2000.

A Study of the Energy Dependence of the Underlying Event in Proton-Antiproton Collisions, CDF Collaboration, submitted to Phys. Rev. D. (August 24, 2015)!

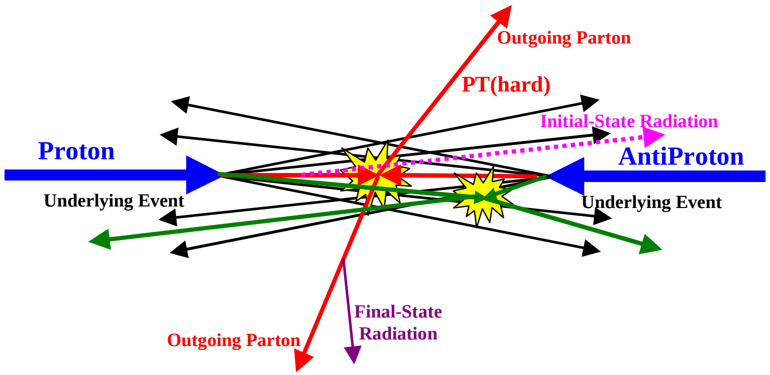
Charged Jet Evolution and the Underlying Event in Proton-Antiproton Collisions at 1.8 TeV, CDF Collaboration, Phys. Rev. D65 (2002) 092002.

Latest CDF UE Publication



CDF Run 2
Tevatron Energy Scan
300 GeV, 900 GeV, 1.96 TeV

Sorry to be so slow!!



Submitted to PRD

Draft PRD Version 6

A Study of the Energy Dependence of the Underlying Event in Proton-Antiproton Collisions

The CDF Collaboration

August 2, 2015

Abstract

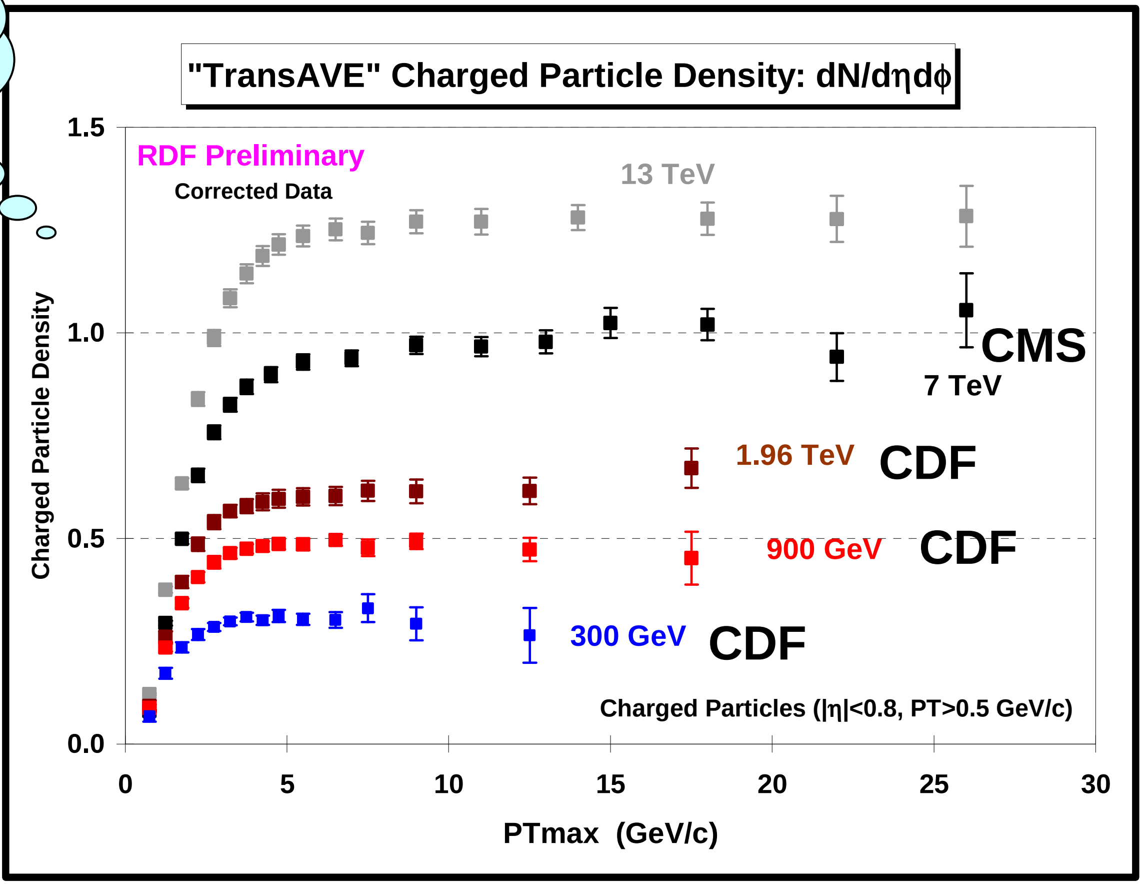
We study charged particle production ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in proton-antiproton collisions at 300 GeV, 900 GeV, and 1.96 TeV. We use the direction of the charged particle with the largest transverse momentum in each event to define three regions of η-ϕ space; "toward", "away", and "transverse". The average number and the average scalar p_T sum of charged particles in the transverse region are sensitive to the modeling of the "underlying event". The transverse region is divided into a MAX and MIN transverse region, which helps separate the "hard component" (initial and final-state radiation) from the "beam-beam remnant" and multiple parton interaction components of the scattering. The center-of-mass energy dependence of the various components of the event are studied in detail. The data presented here can be used to constrain and improve QCD Monte Carlo models, resulting in more precise predictions at the LHC energies of 13 and 14 TeV.

The goal is to produce data (corrected to the particle level) that can be used by the theorists to tune and improve the QCD Monte-Carlo models that are used to simulate hadron-hadron collisions.

http://arxiv.org/abs/1508.05340

"Tevatron" to the LHC

My dream!



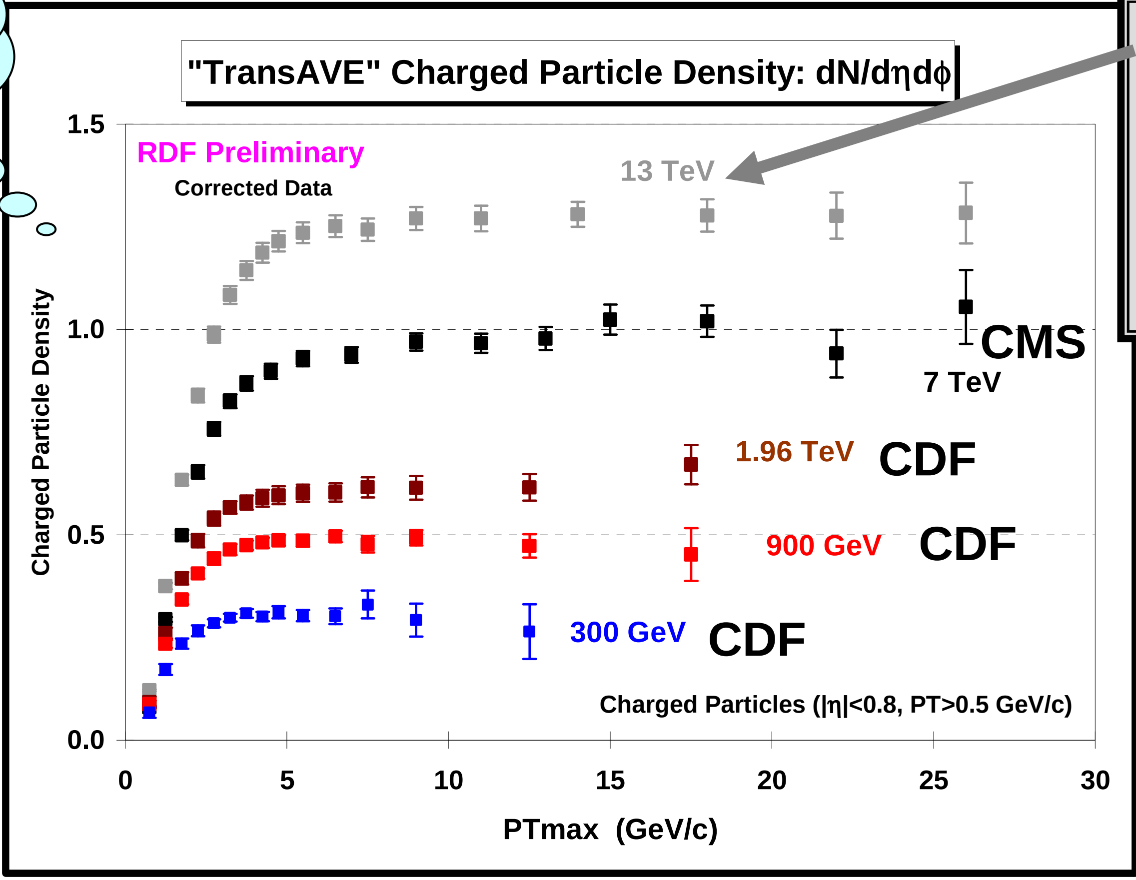
Mapping out the Energy Dependence of the UE

(300 GeV, 900 GeV, 1.96 TeV, 7 TeV, 13 TeV)

"Tevatron" to the LHC

My dream!

Fake data generated by Rick using the Monash tune with the statistics we currently have at CMS!



<u>Mapping out the Energy Dependence of the UE</u>

(300 GeV, 900 GeV, 1.96 TeV, 7 TeV, 13 TeV)

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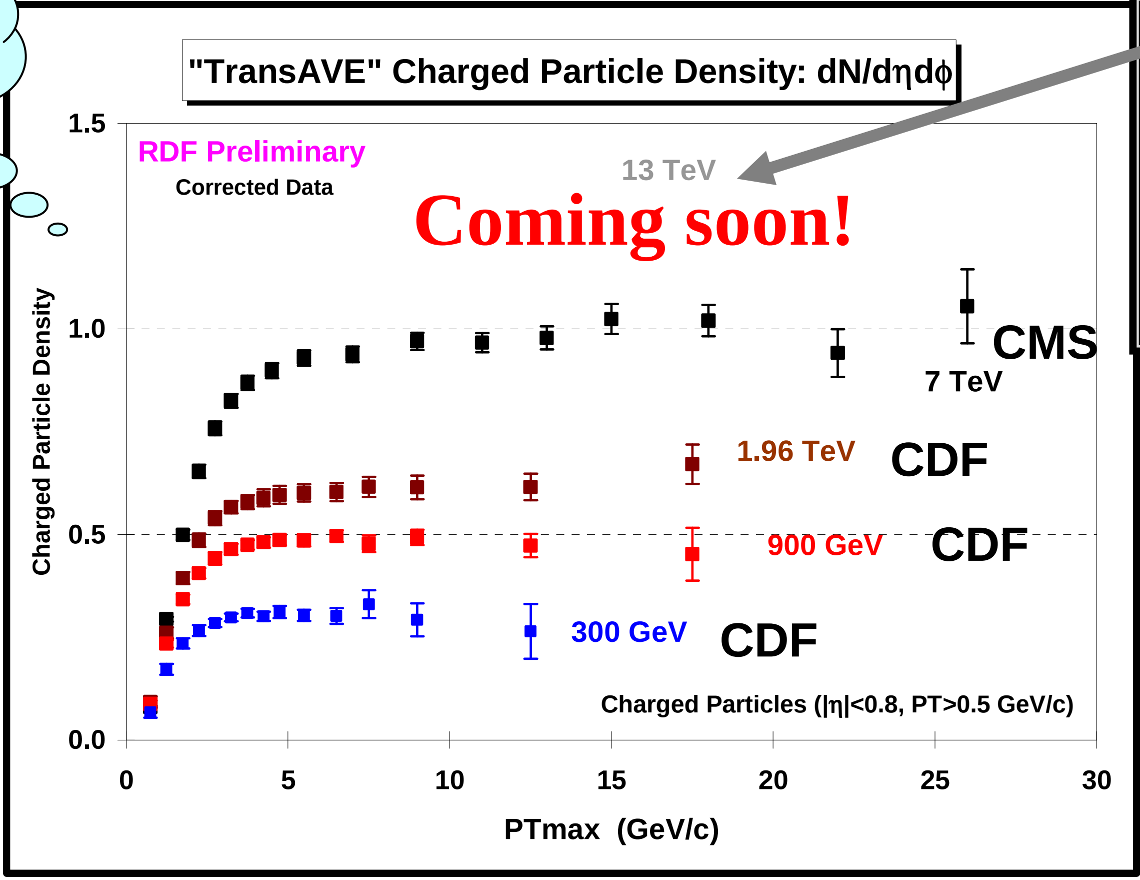
My dream!



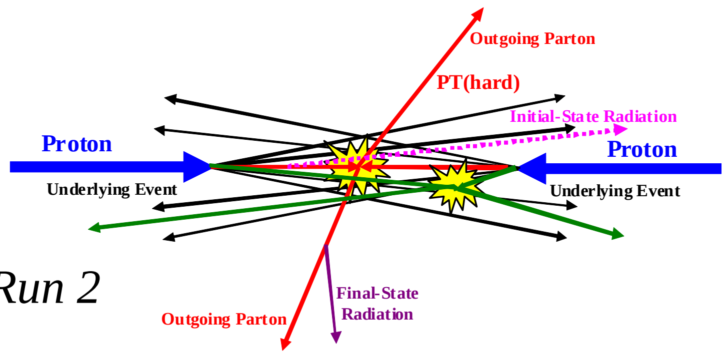
13 TeV UE data coming soon from both ATLAS and CMS!

Mapping out the Energy Dependence of the UE

(300 GeV, 900 GeV, 1.96 TeV, 7 TeV, 13 TeV)

Rick's UE Graduate Students

- **Richard Haas (CDF Ph.D. 2001):** *The Underlying Event in Hard Scattering Collisions of Proton and Antiproton at 1.8 TeV.*



- **Alberto Cruz (CDF Ph.D. 2005):** *Using MAX/MIN Transverse Regions to Study the Underlying Event in Run 2 at the Tevatron.*
- **Craig Group (CDF Ph.D. 2006):** *The Inclusive Jet Cross Section in Run 2 at CDF.*
- **Deepak Kar (CDF Ph.D. 2008):** *Studying the Underlying Event in Drell-Yan and High Transverse Momentum Jet Production at the Tevatron.*
- **Mohammed Zakaria (CMS Ph.D. 2013):** *Measurement of the Underlying Event Activity in Proton-Proton Collisions at the LHC using Leading Tracks at 7 TeV and Comparison with 0.9 TeV.*
- **Doug Rank (CMS Ph.D. Expected 2016):** *The Underlying Evant via Leading Track and Track Jet at 13 TeV.*

7 GeV π^0's → 1 TeV Jets

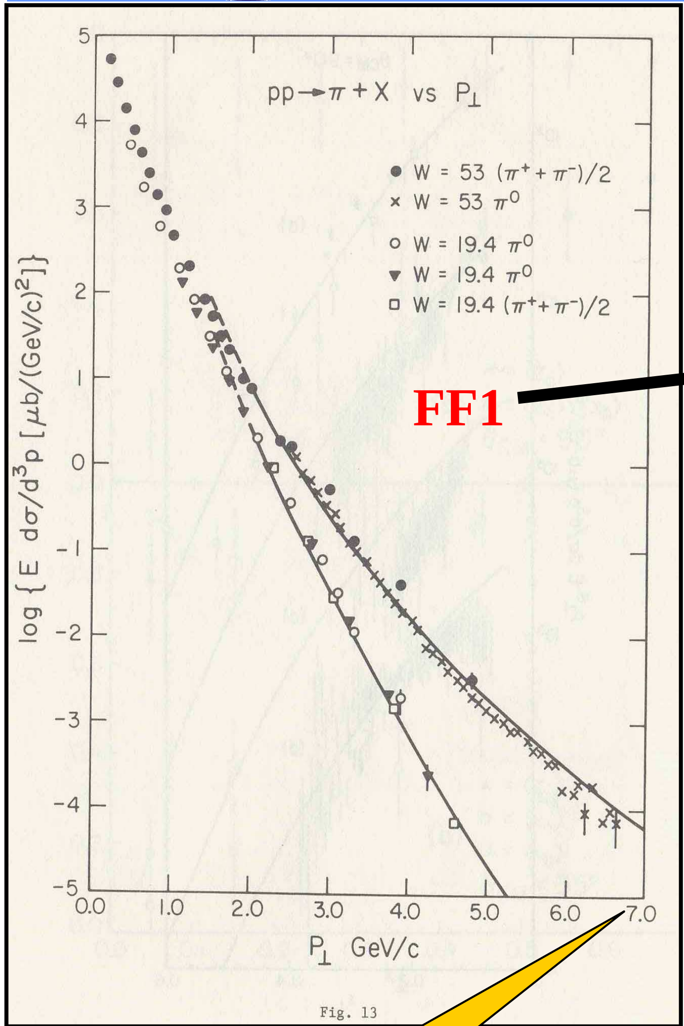
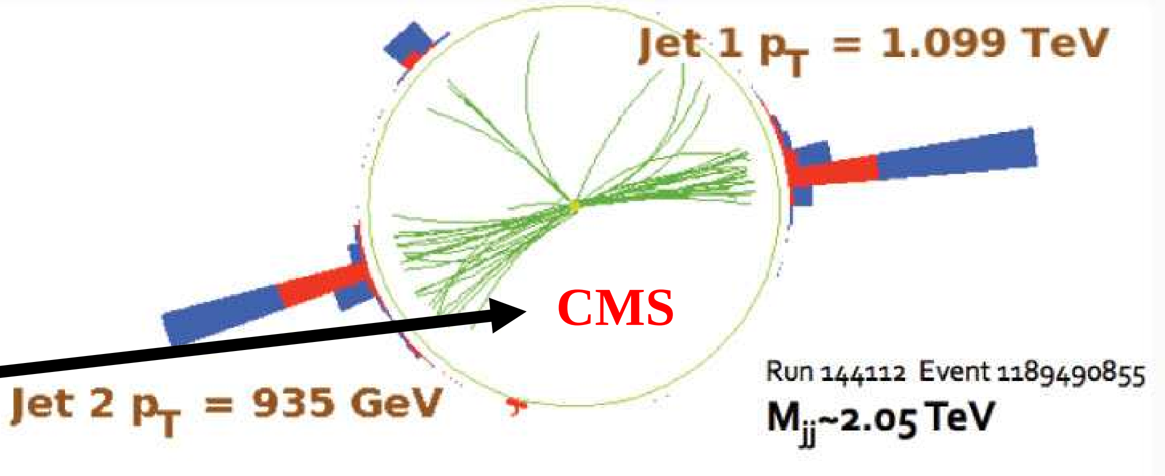


Fig. 13

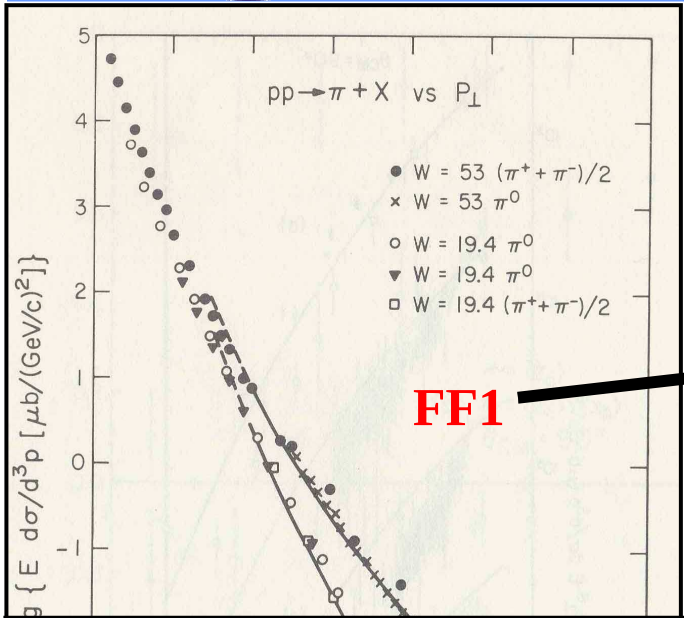
FF1

CMS

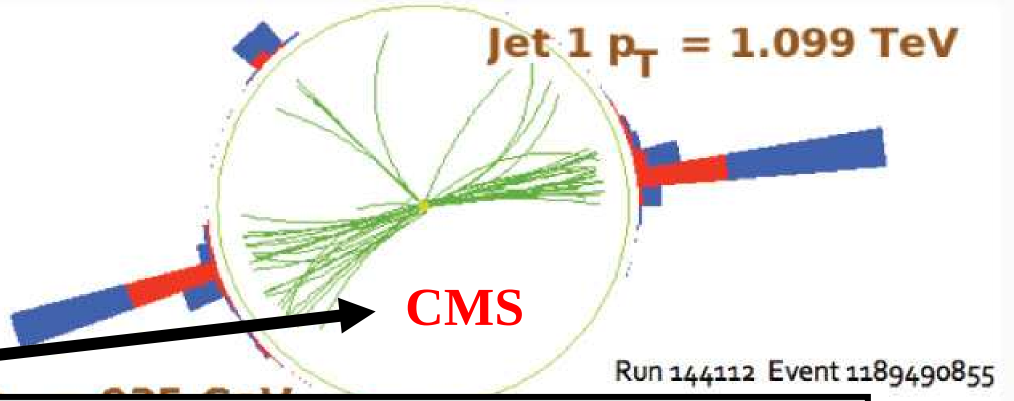


7 GeV/c π^0's!

7 GeV π^0's → 1 TeV Jets



FF1



CMS

Rick & Jimmie CALTECH 1973

Rick & Jimmie ISMD - Chicago 2013

Happy Anniversary 49 Years!

Jimmie and Rick Married
November 24, 1966