Jet Production with EPOS

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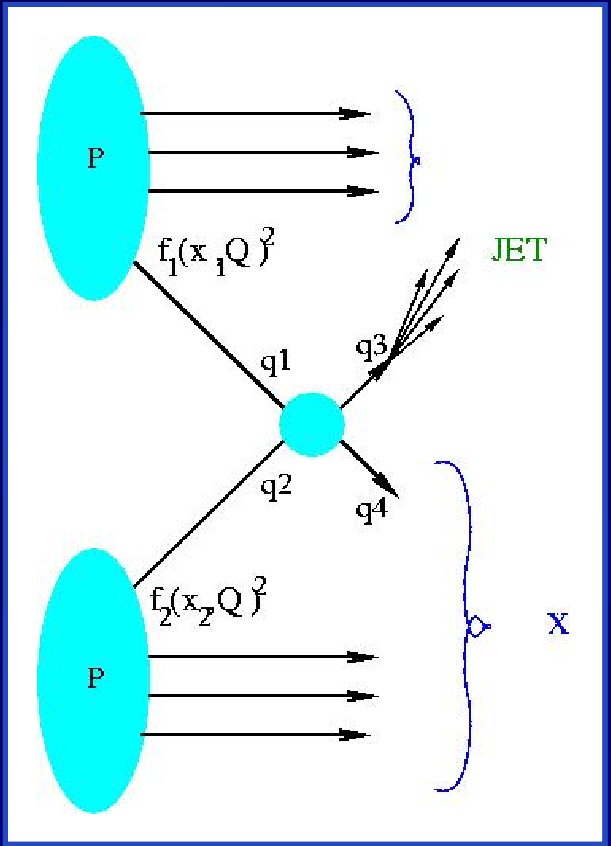
QCD from Colliders to Super-High Energy Cosmic Rays
TRIESTE, 25-29 Mai 2009

Summary

- Motivation for Multiple Interactions
- EPOS Event Generator
- Hard Processes in Complete Event
- Inclusif jet Spectrum : Comparison to Data

The Parton Model



Inclusive cross section : pp -> Jet +X

No way to compute X in details

Jet cross section :

$$\sigma_{pp \to q3q4} = \iiint dx_1\, dx_2\, d\hat{t} f_1\ (x_1, Q^2)\, f_2\ (x_2, Q^2) \frac{d\hat{\sigma}_{q1q2 \to q3q4}}{d\hat{t}}$$

No information about multiples interactions

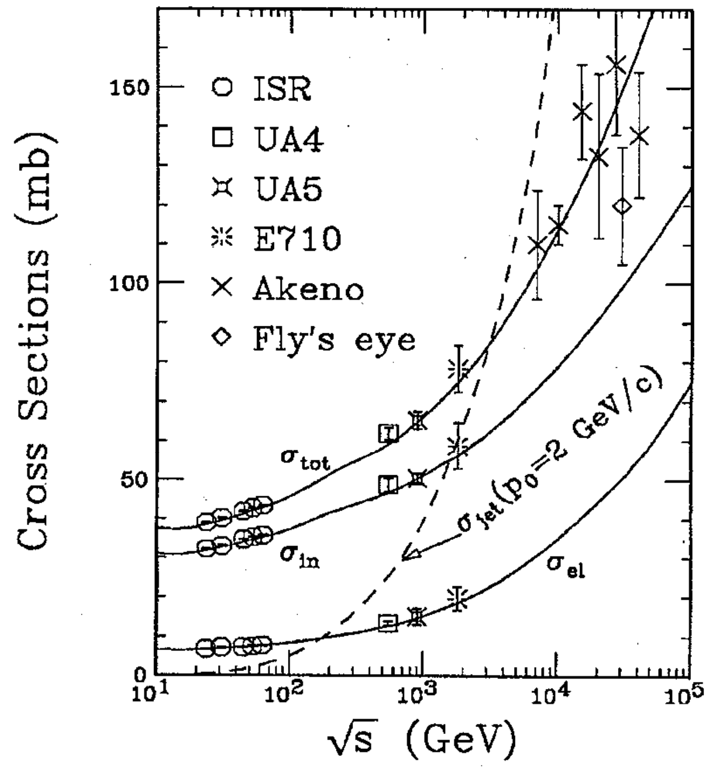
How to compute jets connected with the event ?

Multiples Interactions

High Energies : problem !!!

More than one interaction per collision

⇒Total cross section and partial one, inclusive and exclusive cross section



The total, inelastic, and elastic cross sections of pp and $p\bar{p}$ collisions as calculated by HIJING (solid lines). The data are from Refs. [27]-[32]. The dashed line is the total inclusive jet cross section with $p_T \geq p_0 = 2$ GeV/c.

X.N.Wang, M.Gyulassy, Phys. Rev. D45 (1992) 844-856

One need the complete event : with multiple interactions

Multiples Interactions

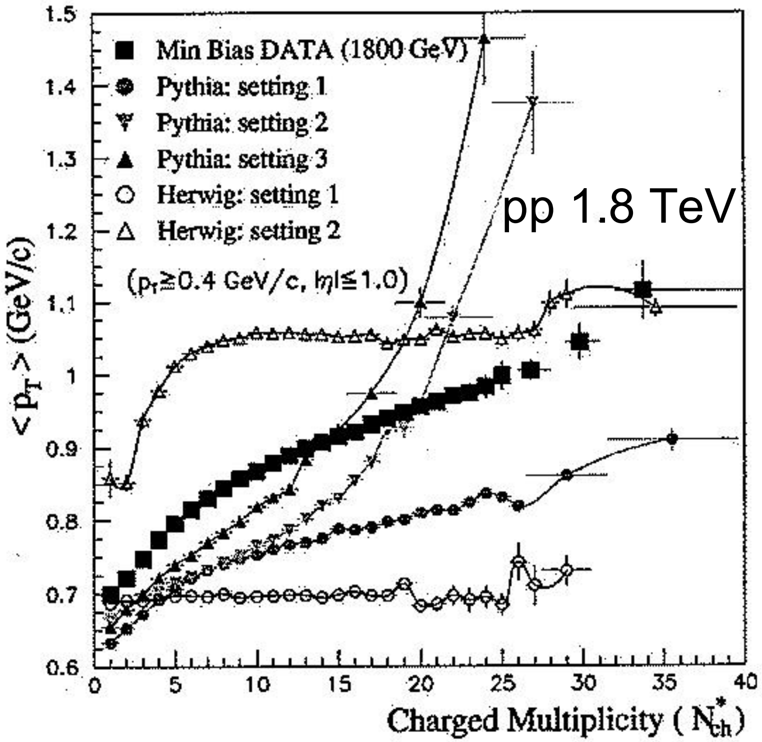


FIG. 10. Mean transverse momentum vs multiplicity from Monte Carlo. The different parameter settings for each MC generator are given in the Appendix.

Acosta, Darin E. and others for the CDF collaboration, Phys. Rev. D65 (2002) 072005

Multiples Interactions

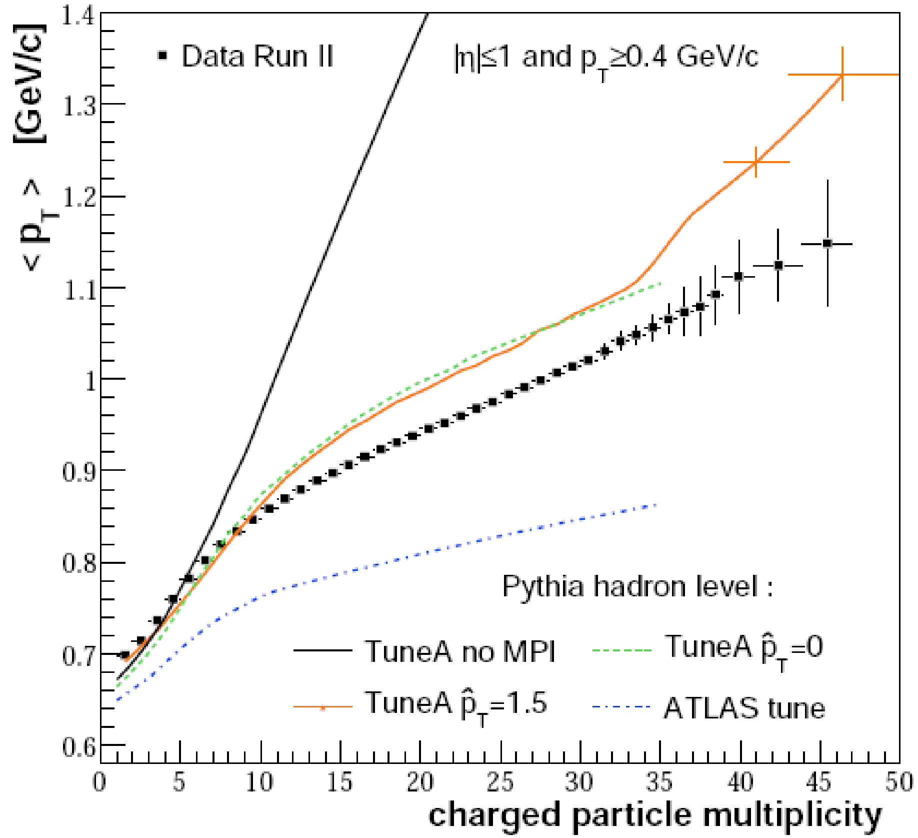
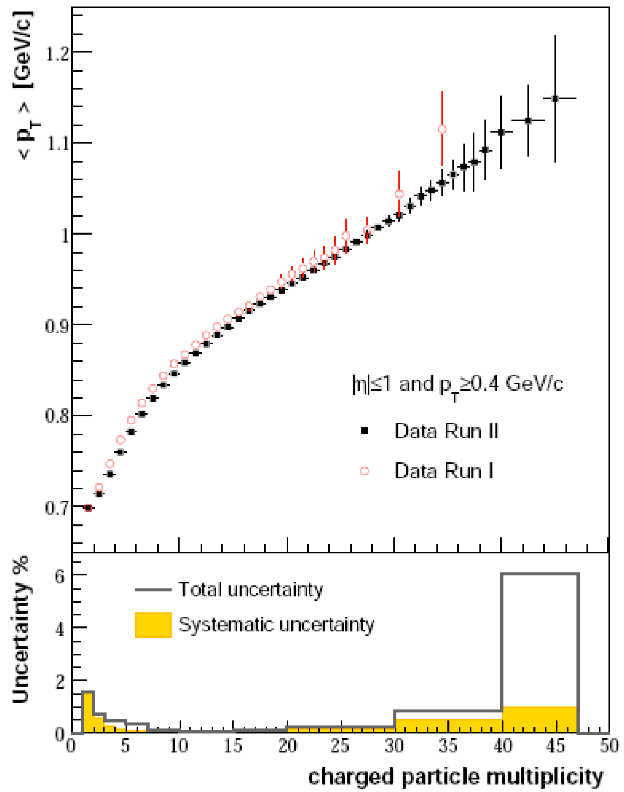


FIG. 8: For tracks with $|\eta| < 1$, the dependence of the average track p_T on the event multiplicity is shown. The error bars on data describe the uncertainty on the data points. This uncertainty includes the statistical uncertainty on the data and the statistical uncertainty on the total correction. A comparison with various PYTHIA tunes at hadron level is shown. Tune A with $\hat{p}_{T^0} = 1.5$ GeV$/c$ was used to compute the MC corrections in this analysis (the statistical uncertainty is shown only for the highest multiplicities where it is significant). Tune A with $\hat{p}_{T^0} = 0$ GeV$/c$ is very similar to $\hat{p}_{T^0} = 1.5$ GeV$/c$. The same tuning with no multiple parton interactions allowed ("no MPI") yields an average p_T much higher than data for multiplicities greater than about 5. The ATLAS tune yields too low an average p_T over the whole multiplicity range.

Aaltonen, T. and others, for the CDF collaboration, 2009, arXiv hep-ex 0904.1098

Multiples Interactions



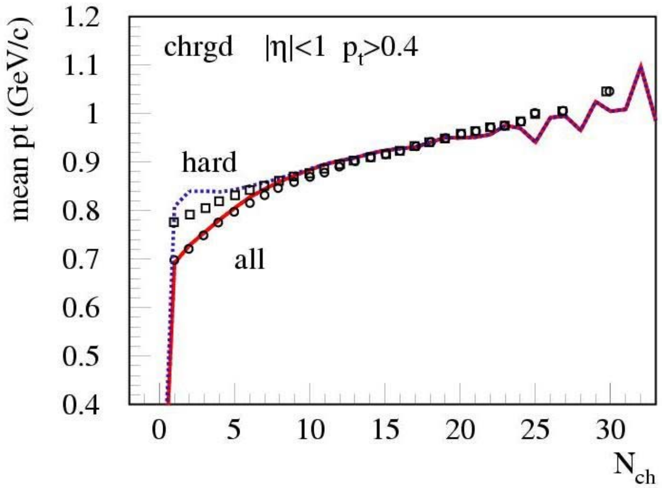


FIG. 7: The dependence of the average track p_T on the event multiplicity. A comparison with the Run I measurement is shown. The error bars in the upper plot describe the uncertainty on the data points. This uncertainty includes the statistical uncertainty on the data and the statistical uncertainty on the total correction. In the lower plot the systematic uncertainty (solid yellow band) and the total uncertainty are shown. The total uncertainty is the quadratic sum of the uncertainty reported on the data points and the systematic uncertainty.

WHY is it interesting …

… to compute a jet in a complete event ?

- To have a real event generator

  One event in experiment = One event from the generator

- To control the underlying event :

  Can substract the soft part of an event from the jet signal.
  Energy conservation, colour conservation.

- Event generator with hydrodynamics

  Parallel work, for the future : interaction jet-fluid

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- Hard Processes in Complete Event
- Inclusif jet Spectrum : Comparison to Data

EPOS

Energy conserving quantum mechanical multiple scattering approach

Based on

→ Partons, parton ladders, strings

→ Off-shell remnants

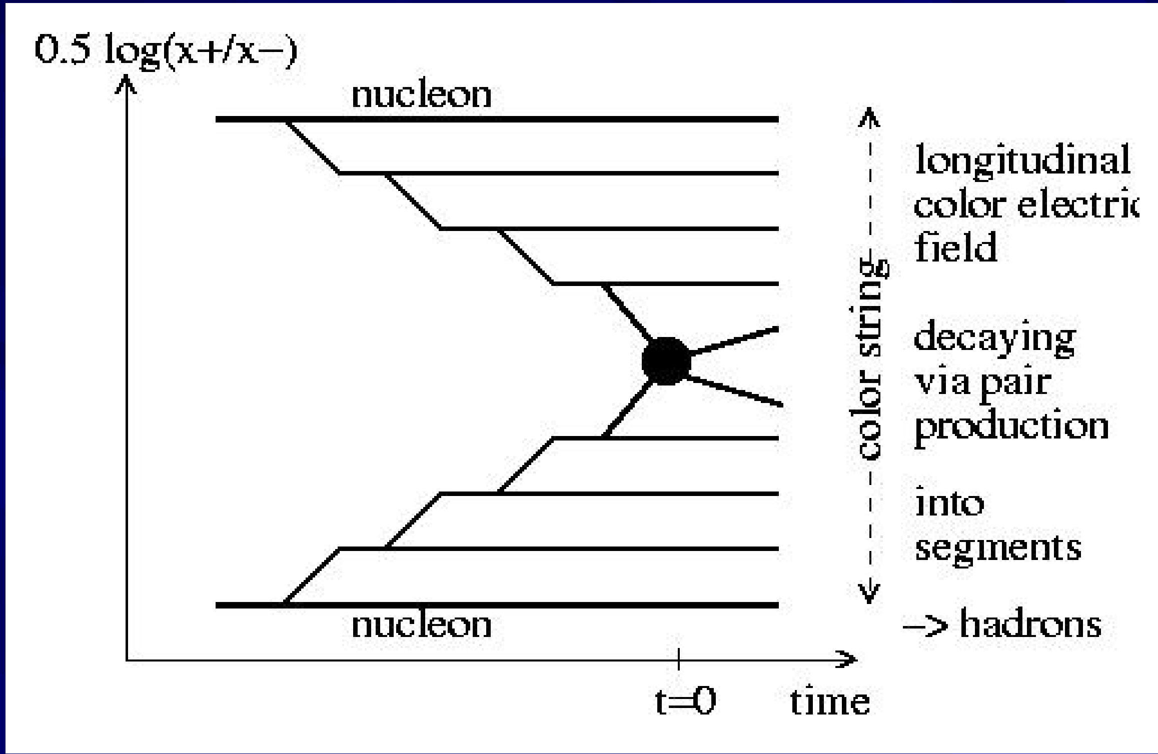
→ Splitting of parton ladder

EPOS MODEL

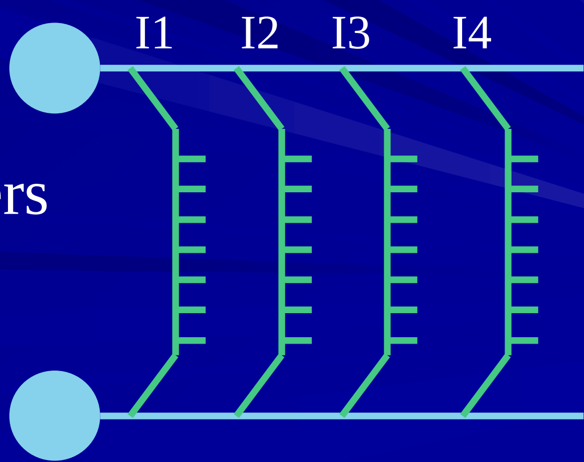
- Quantum mechanical multiple scattering approach based on partons and strings
- Cross sections and particle production calculation in the same framework with energy conservation
- Careful treatment of projectile and target remnants
- Contains nuclear effects : splitting of parton ladders (screening)
- High density effect : treatment of collective effects of a dense core

S.Ostapchenko, T.Pierog, K.Werner, H.J.Drescher, M.Haldik , Phys. Rep, 350, 2001.
K.Werner, Phys. Rev. Lett., 98:152301, 2007

EPOS MODEL



Parton ladders : soft or hard interaction



Multiple interaction : exchange of parton ladders in paralel with care of energy conservation

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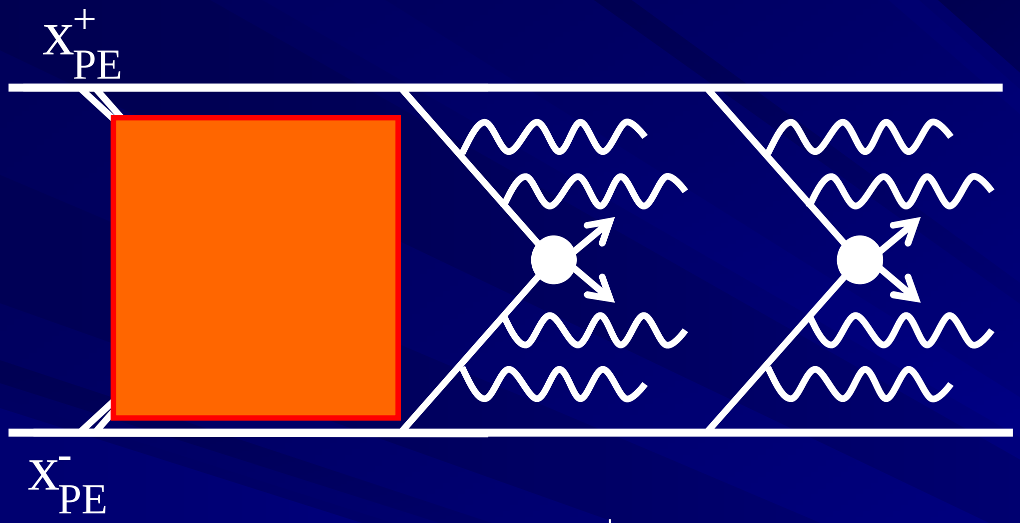
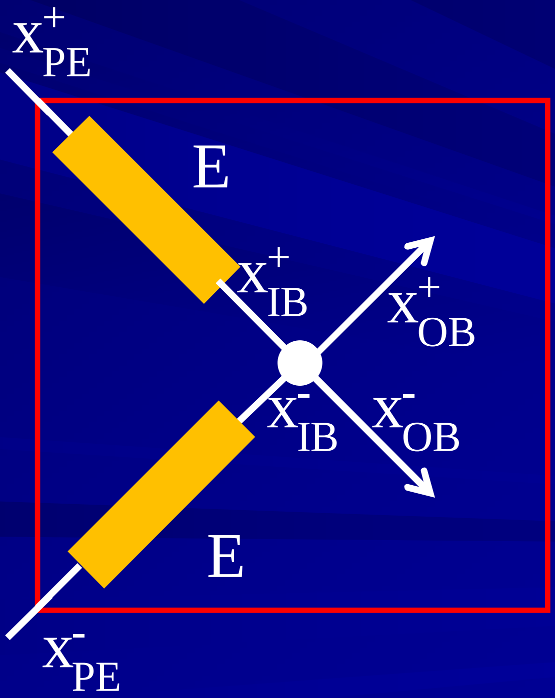
Structure of Semi-Hard Parton Ladder



Define different sub-structure as independent block.



$x^{+/-}_{PE}$: Light cone momentum of parton entering the ladder

$x^{+/-}_{IB}$: Light cone momentum of parton entering the Born Process

$x^{+/-}_{OB}$: Light cone momentum of parton out the Born Process

E : Evolution of the parton, branching, gluon emissison

Computing semi-hard ladders …

… A two step consistent procedure

1) Compute partial cross section over total one : proba of n collisions with Parton ladder End momentum fraction.

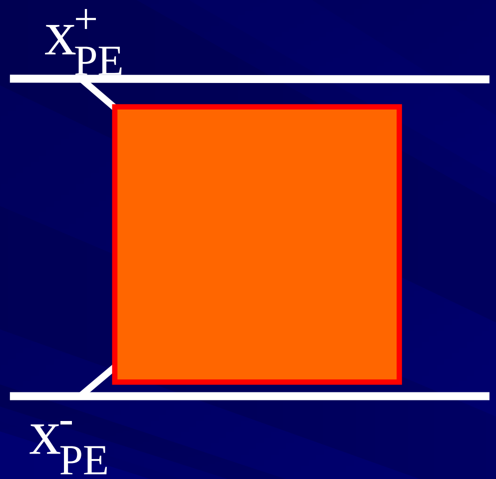
⟹ Number of ladders and the $x_{PE}^{+/-}$

2) Parton Generation : "Block Wise"

⟹ Determine all variables of the ladders

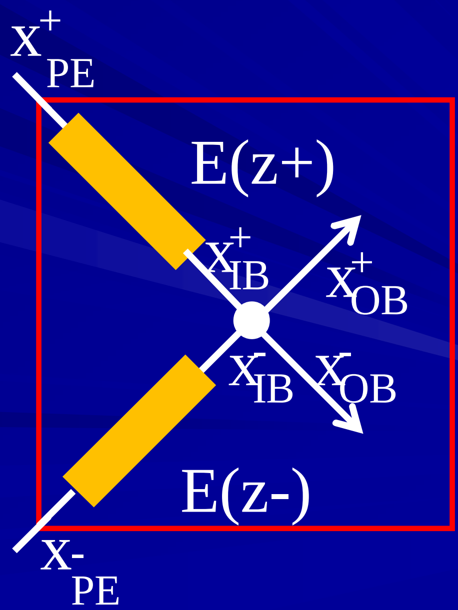
Several Options :
- Analytical
- Semi-Analytical
- Monte Carlo Based on Fast Generation
- Monte Carlo with trigger

Example of Inclusive Spectrum



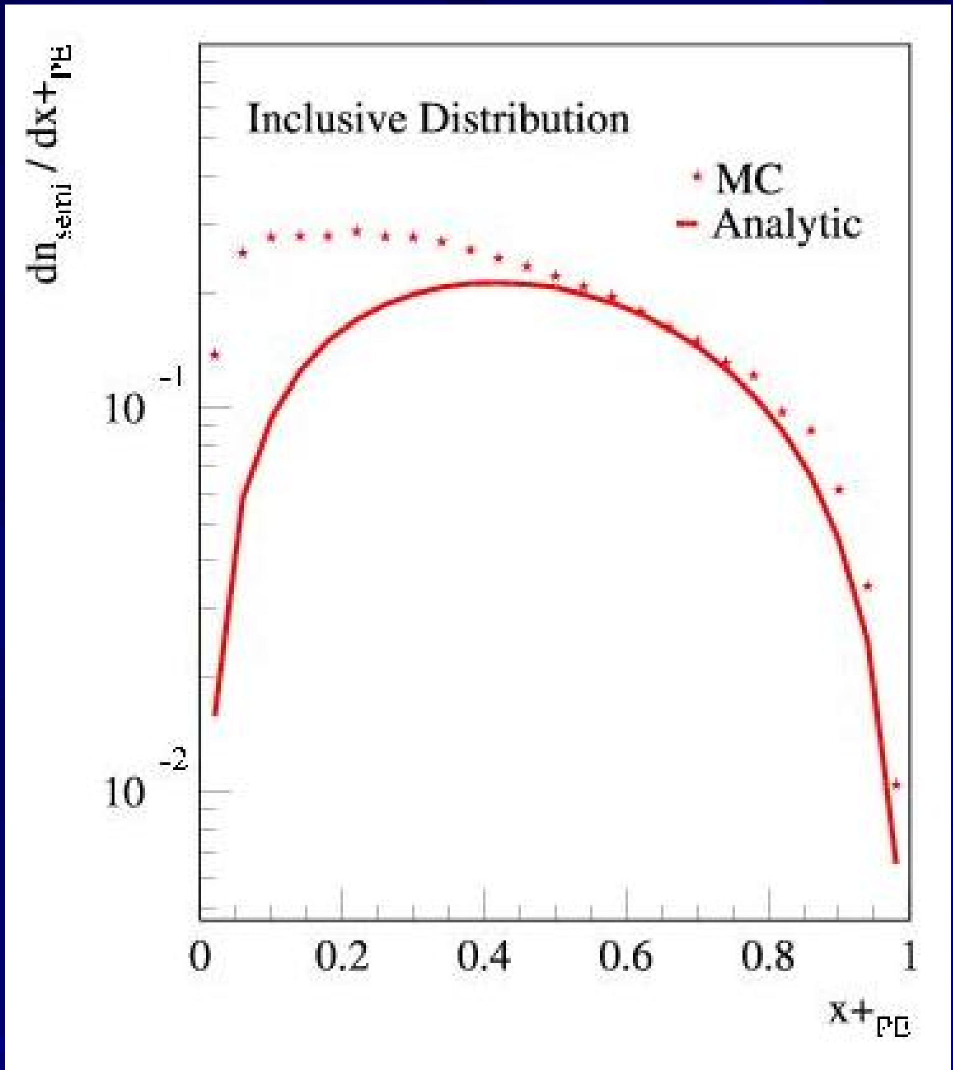
$$N(x^+_{PE}, x^-_{PE}) = \frac{dn_{semi}}{dx^+_{PE}\,dx^-_{PE}}$$

n_{semi} : represents the average number of Ladders with light cone momentum fractions of the Ladder ends in the intervals : $[x^+_{PE}, x^+_{PE}+dx^+_{PE}]$ and $[x^-_{PE}, x^-_{PE}+dx^-_{PE}]$

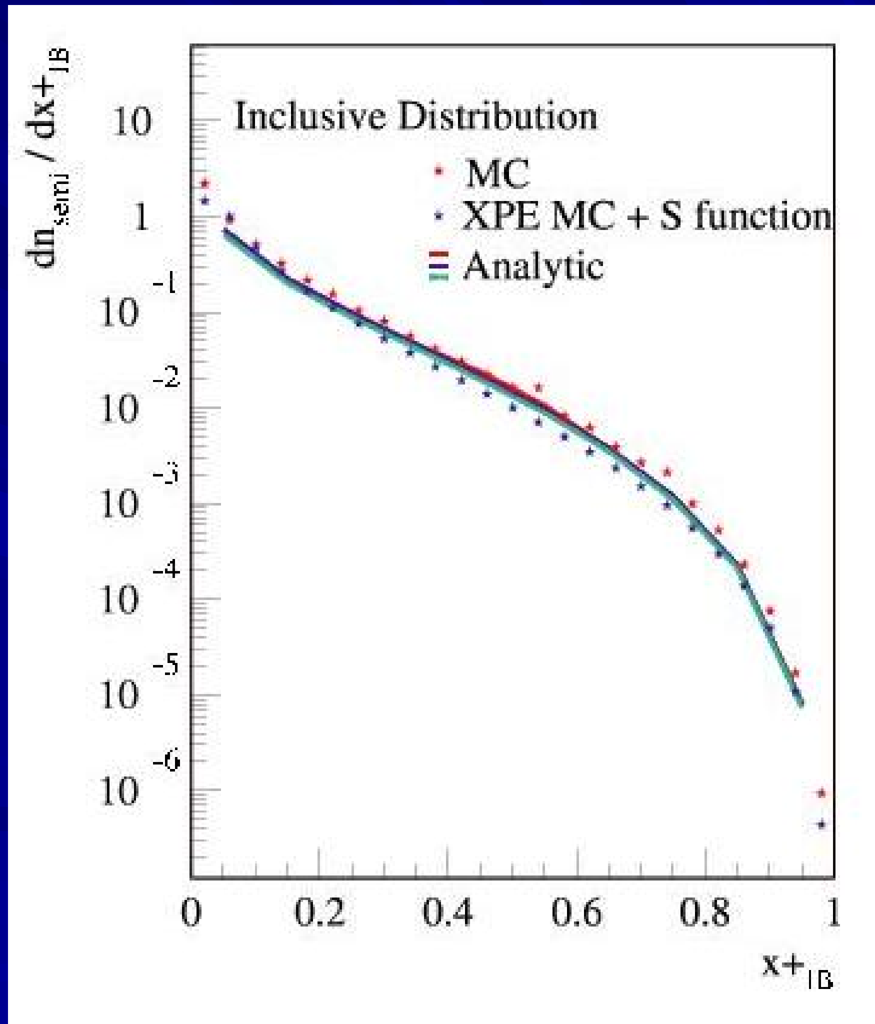


$$n_{semi} = \int dx^+_{PE}\,dx^-_{PE}\,dz^+\,dz^-\,N(x^+_{PE}, x^-_{PE}) \times S(x^+_{PE}, x^-_{PE}, z^+, z^-)$$

$$x_{IB} = z \times x_{PE}$$



$$\int N(x^{+}_{PE}, x^{-}_{PE})dx^{-}_{PE}$$



$$\int S(x^{+}_{IB}, x^{-}_{IB}, x^{+}_{PEMC} x^{-}_{PEMC})dx^{-}_{IB}$$

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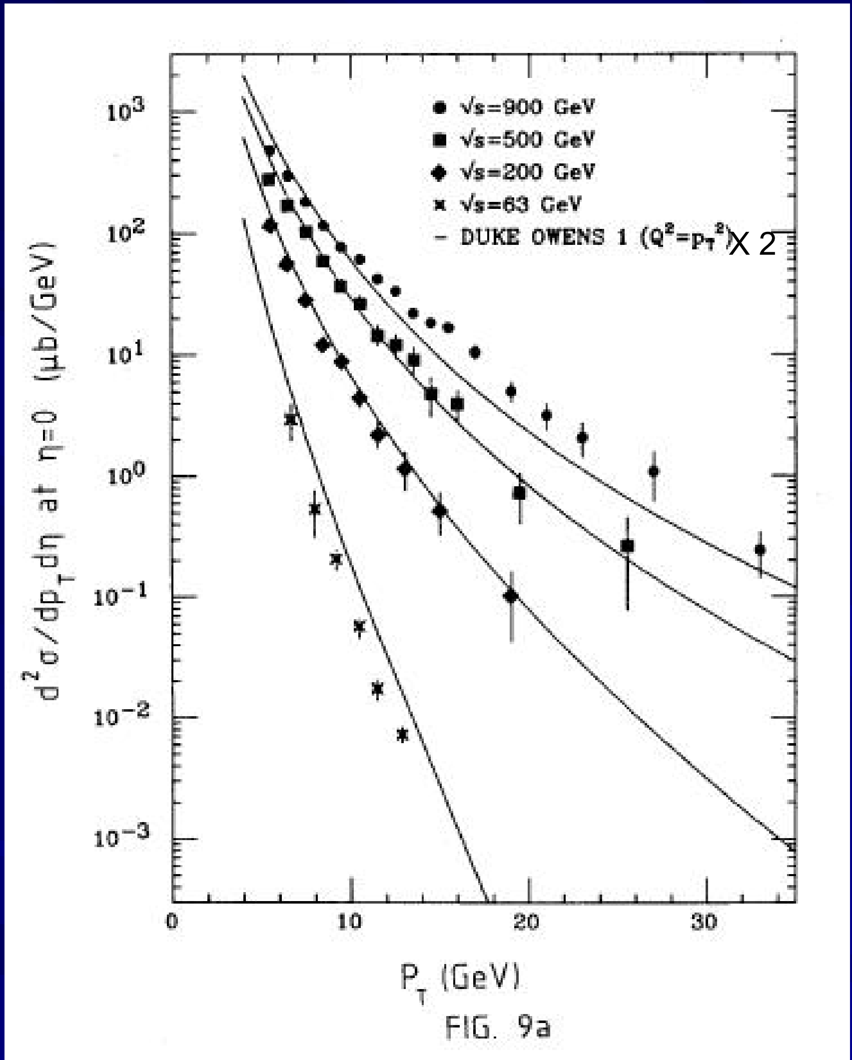
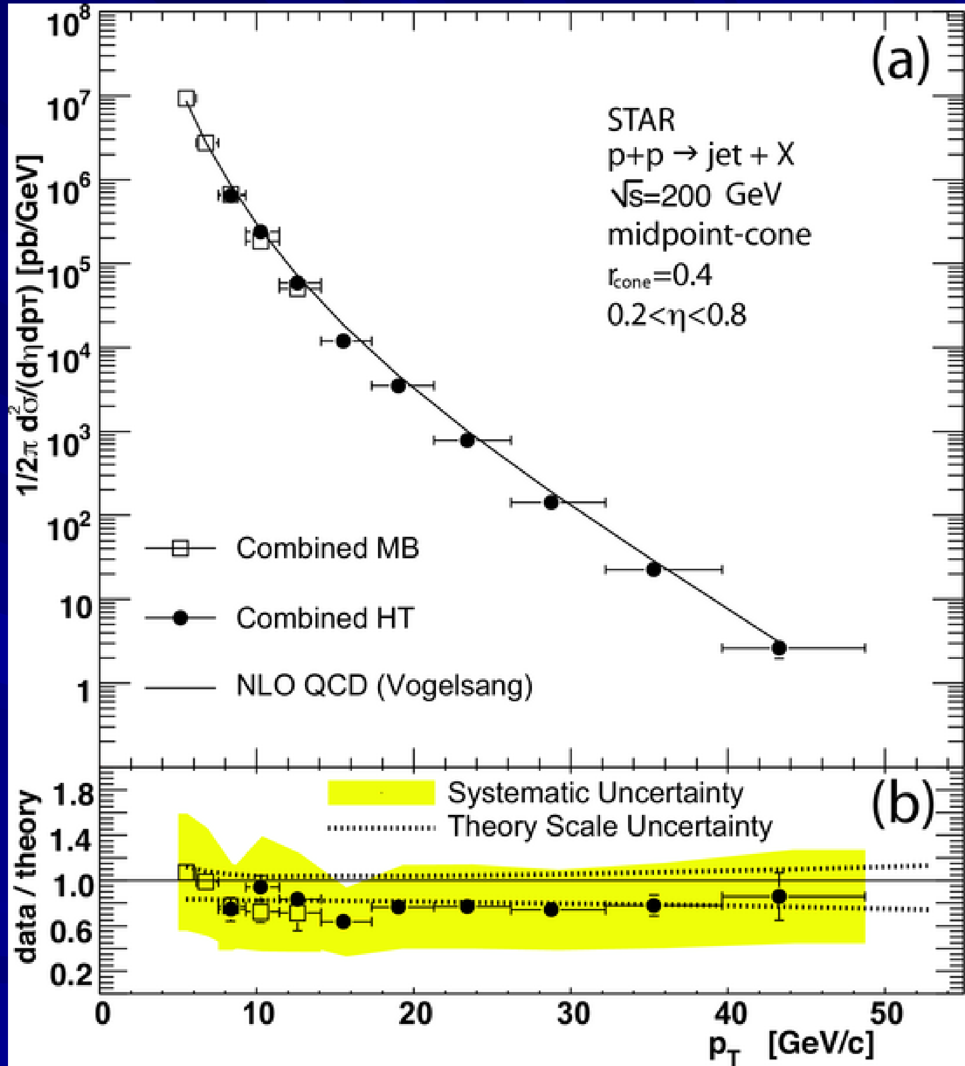
UA1 and STAR on the same Plot

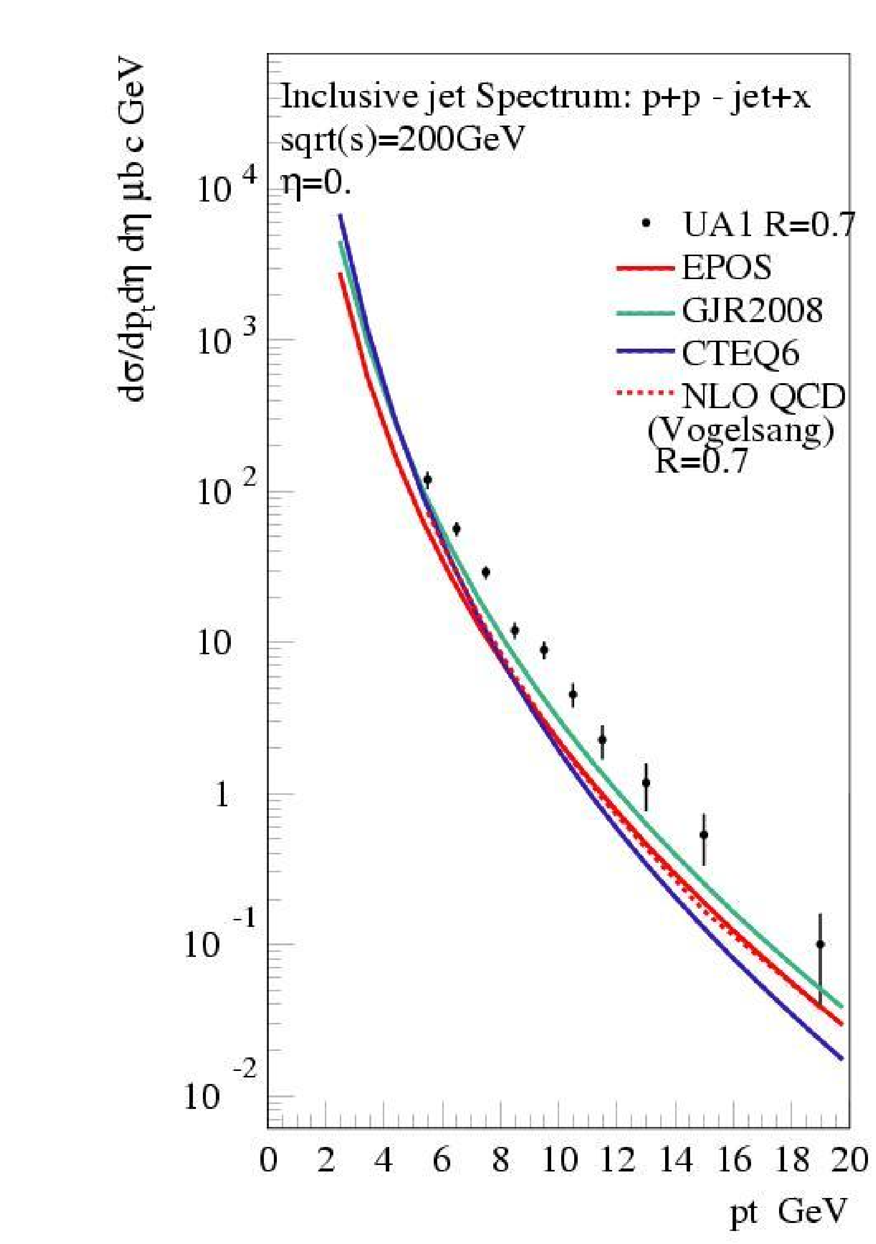


Nucl. Phys. B309 (1988) 405



Phys. Rev. Lett. 97 (2006) 252001

Comparison with UA1 DATA

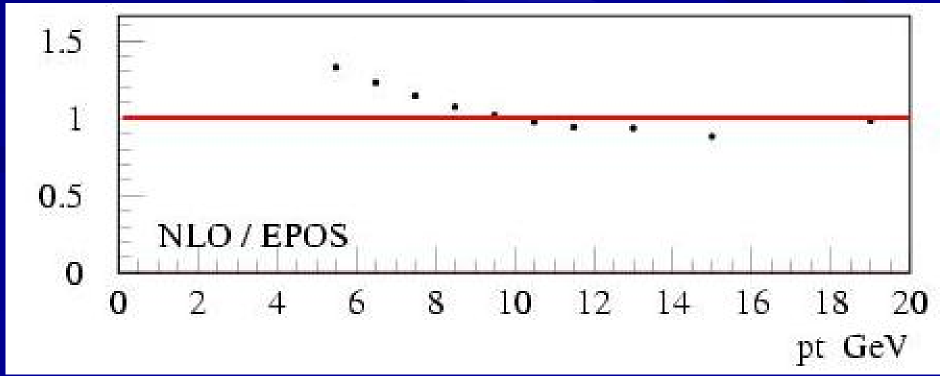


• Data : UA1, Nucl. Phys. B309 (1988) 405

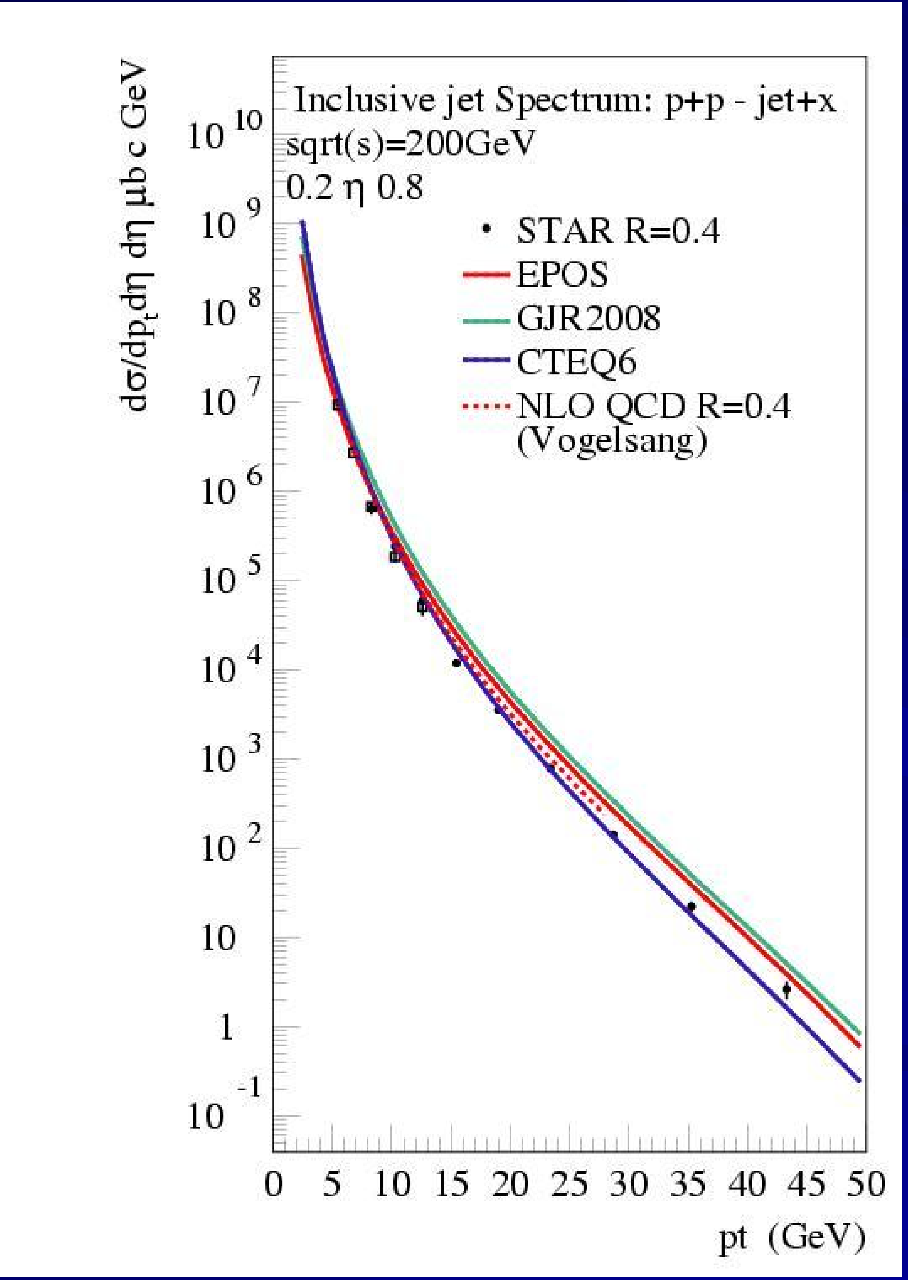
Jet Spectrum : use of a Jet Finder
R=0.7

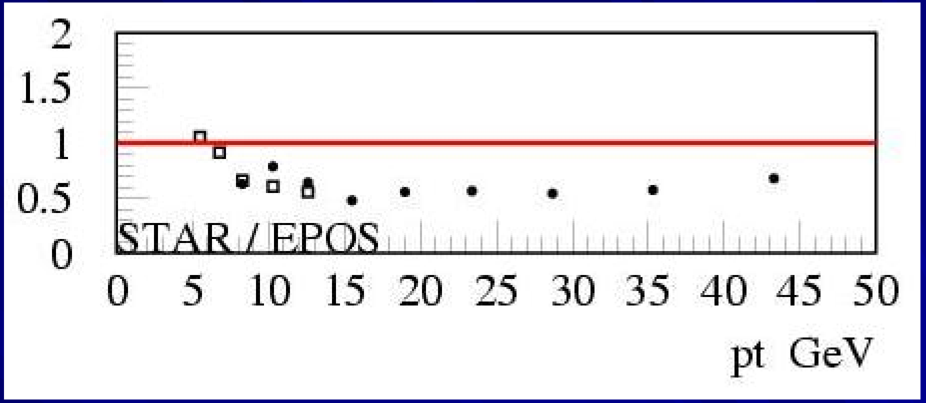
• EPOS : Out Born Parton, R =Rmax (everything is in the jet)

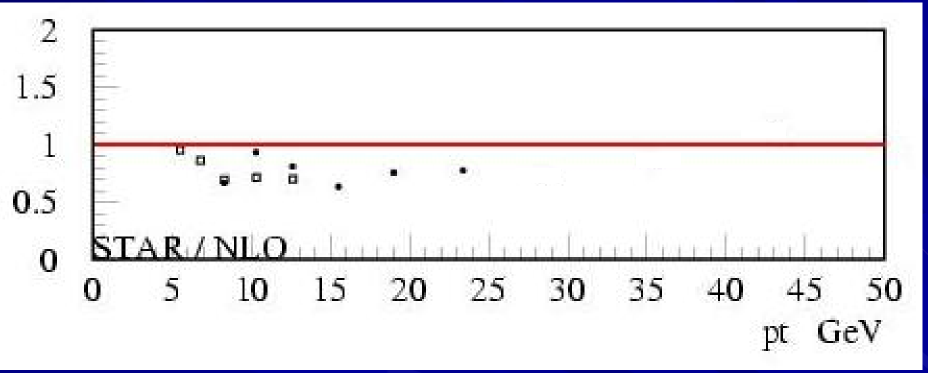
• NLO Vogeslgang : thanks to Joana Kiryluk for the plot, NLO computation with R=0.7

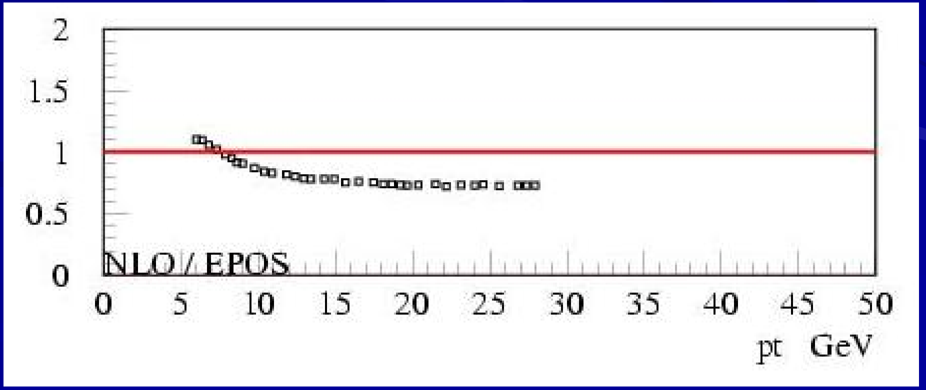


Comparison with STAR DATA









Comparison with STAR DATA

Data exctracted with a jet finder algorithm :

- Influence of the jet fnder : efficiency, cone, kt
- Influence of the jet resolution : systematic uncertainties

Could we really compare with analytic computation such as EPOS?

Comparison with NLO QCD Vogeslgang

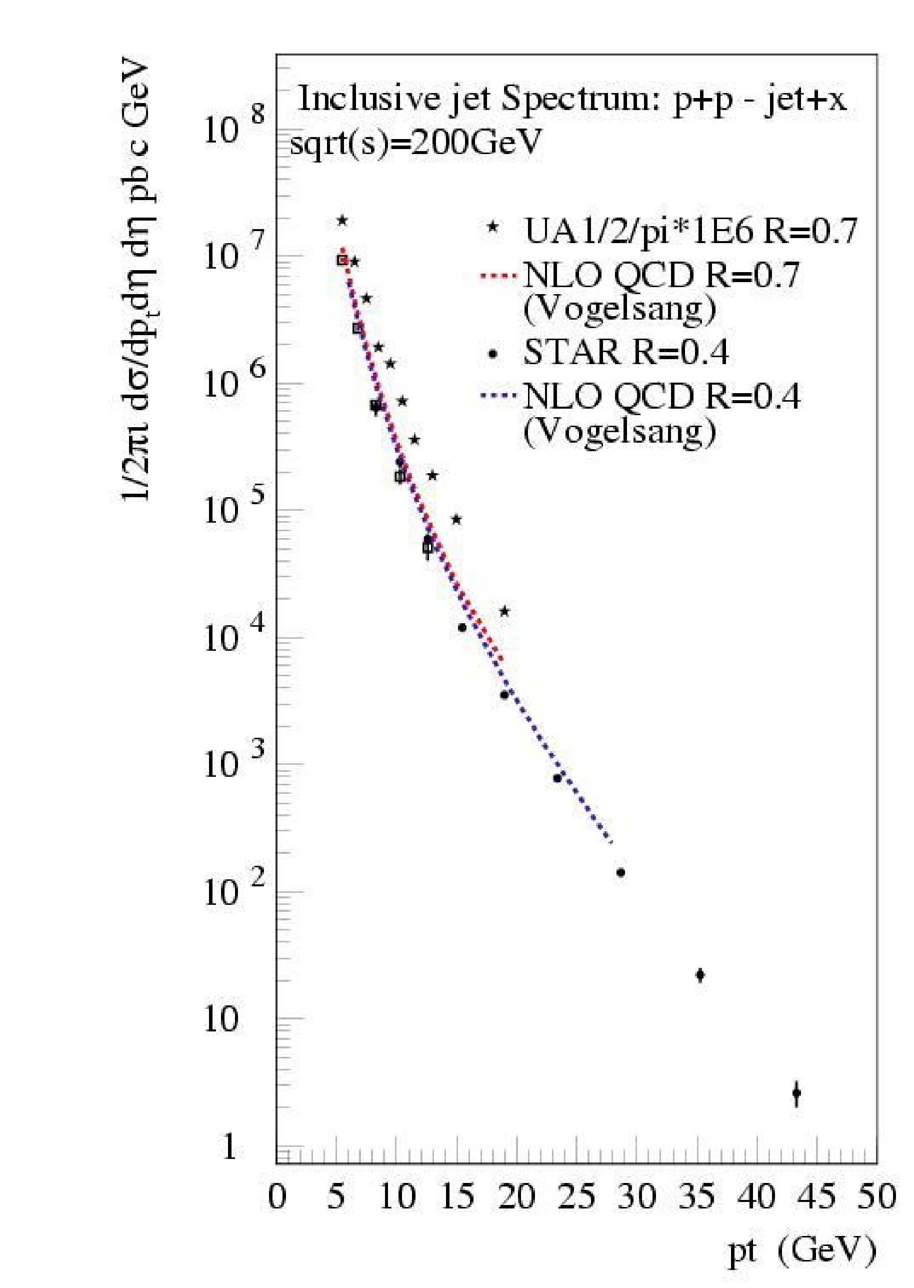
Take into account some effect of the small radius R=0.4

Comparison with UA1 DATA?

Same observable, same energy : same plot?

But : different analysis, different R, different binning

UA1 and STAR on the same Plot



Comparison with DATA

First good test for EPOS jet production :

- Good agreement between EPOS and NLO Vogelsgang (R=0.7)
- Less than a factor 2 between EPOS and Star Data over 9 orders of magnitude

Difficult task :

- EPOS : out Born parton = total jet (Rmax)
- DATA : Reconstructed Jets, Jet Finder, variable R
- NLO Vogeslgang : Computation with variable R

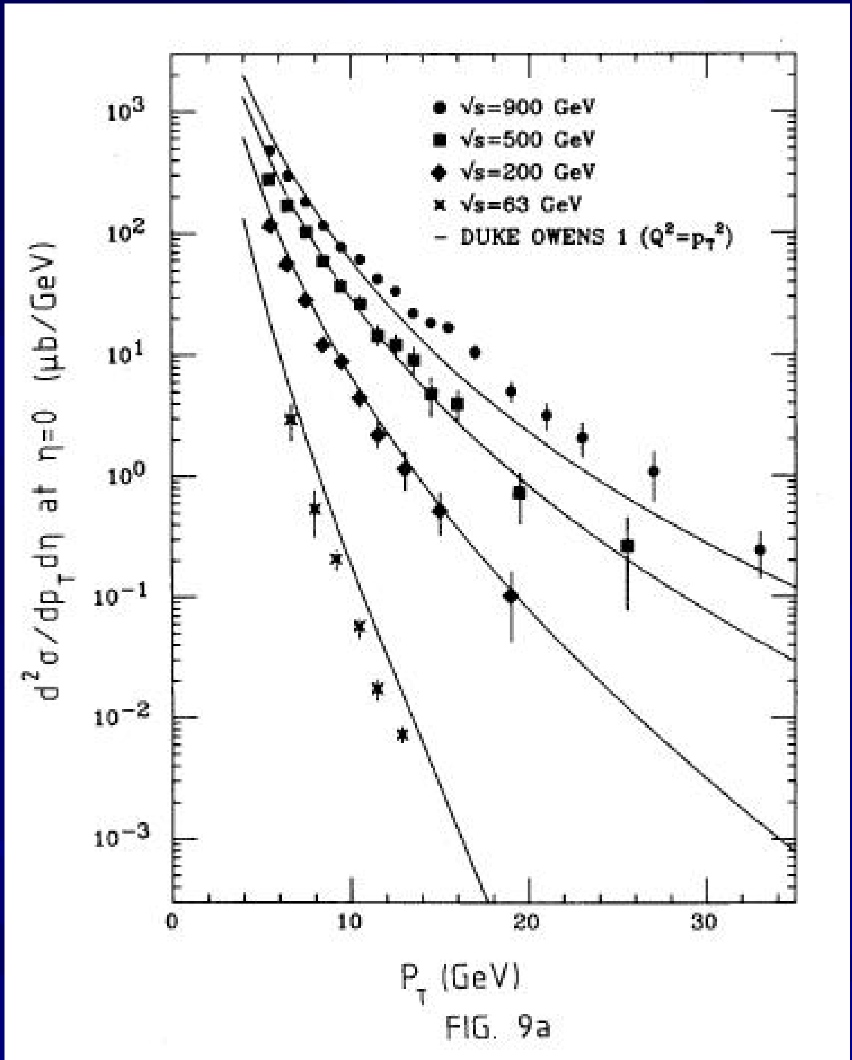
Need to do the Study by using jet finder on EPOS events

Conclusions and Outlook

- Epos : goal to be a generator of complete event
  - → One experimental event = one generator event
- Benefits of hard process in an event
- Hard process in this context : rare event, cuts
  - → Fast method : cuts but in the context of multiple scatering
- Test For the Inclusif jet spectra : good first test
  - → Need to do the study with jet finder on epos event
- Paralel work to have an event generator with hydrodynamics : interaction jet-fluid

Thanks

UA1 and STAR on the same Plot



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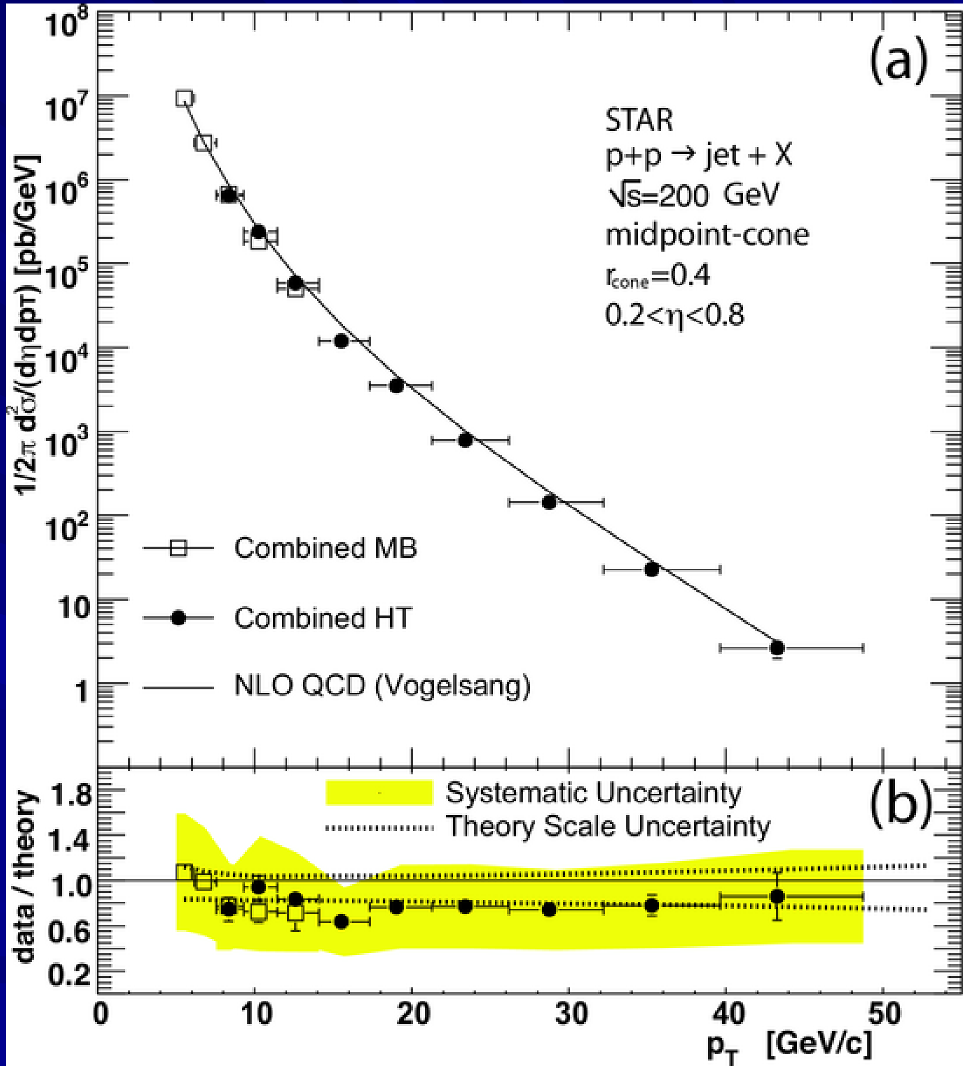


Phys. Rev. Lett. 97 (2006) 252001

Comparison with Tevatron DATA

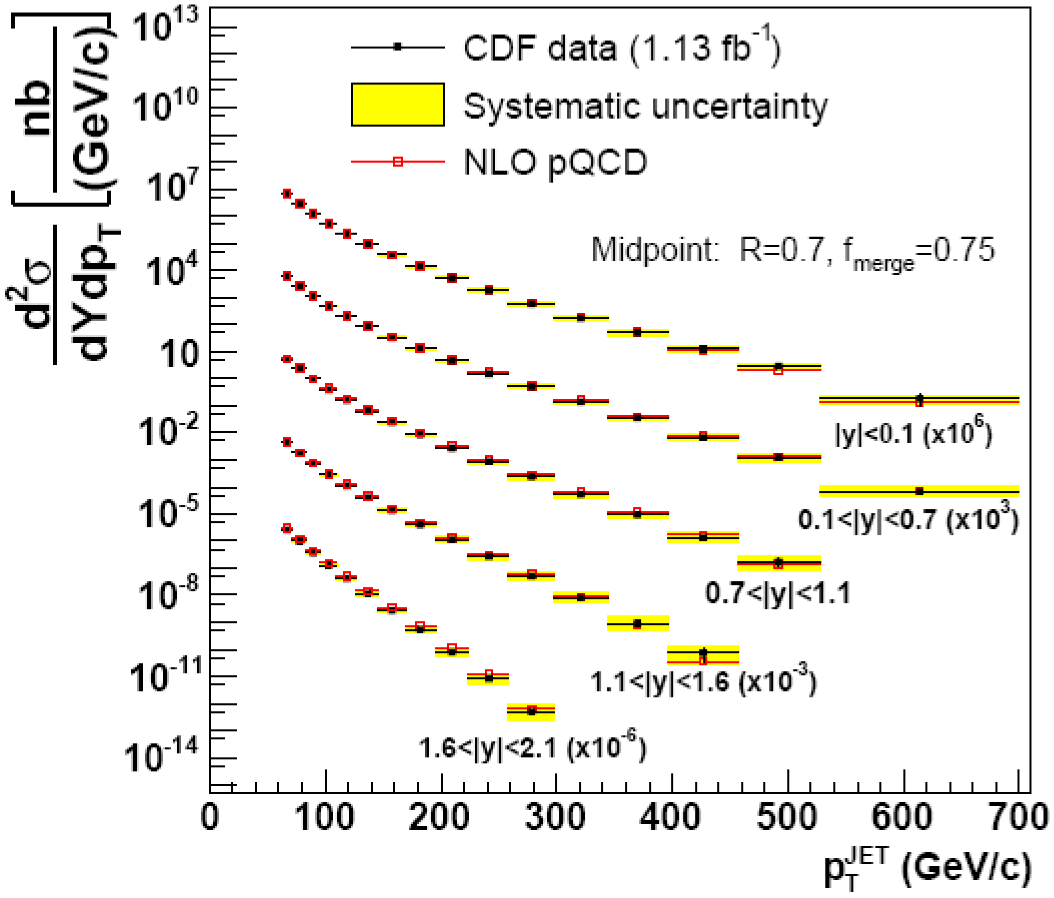


FIG. 15: Inclusive jet cross sections measured at the hadron level using the Midpoint algorithm in five rapidity regions compared to NLO pQCD predictions based on the CTEQ6.1M PDF. The cross sections for the five rapidity regions are scaled by a factor of 10^3 from each other for presentation purposes.

Phys. Rev. D78 (2008) 052006

Comparison with Tevatron DATA

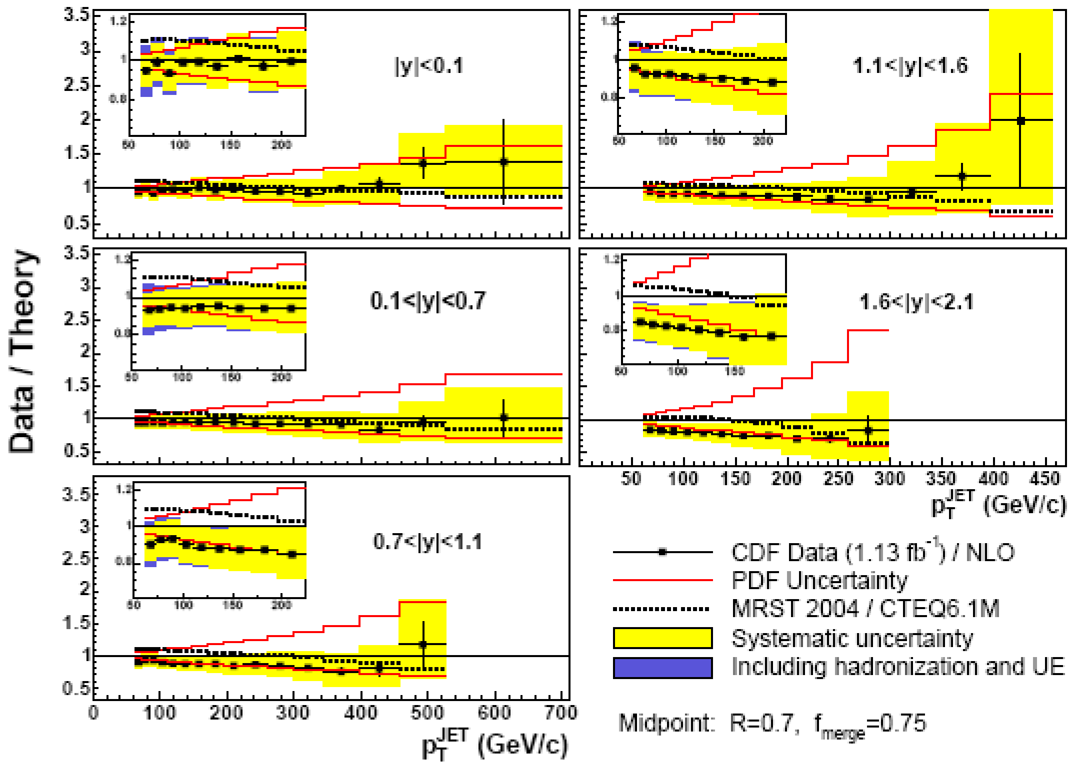
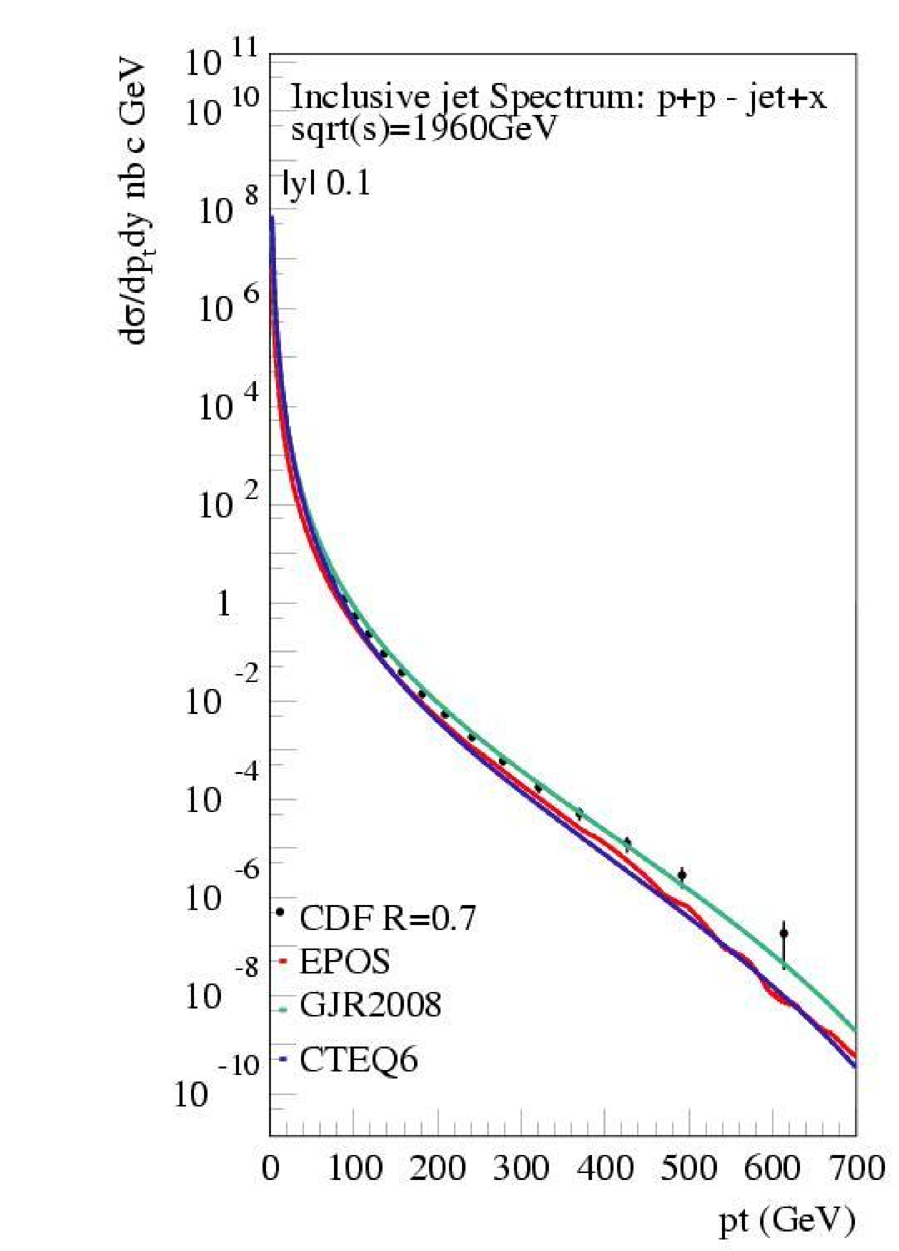
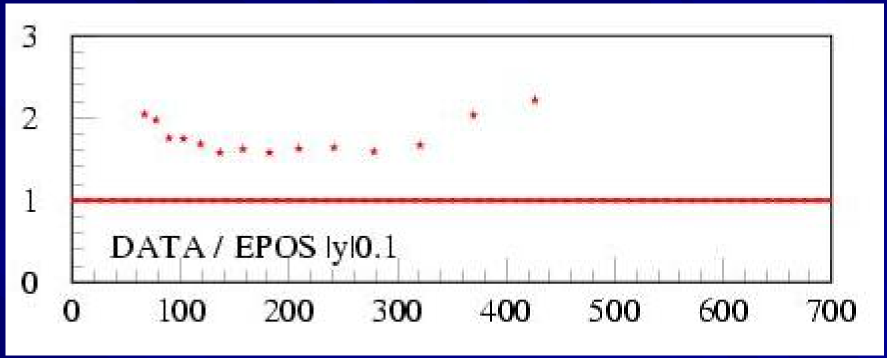


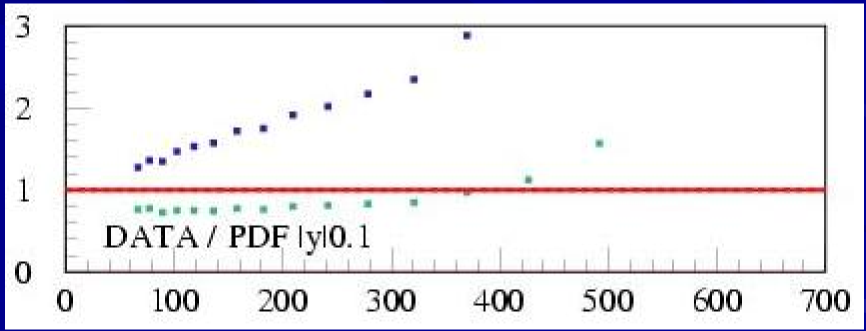
FIG. 16: The ratios of the measured inclusive jet cross sections at the hadron level with the Midpoint jet clustering algorithm to the NLO pQCD predictions (corrected to the hadron level) in five rapidity regions. Also shown are the experimental systematic uncertainties on the measured cross section, the uncertainties in the hadronization and underlying event corrections added in quadrature with the experimental systematic uncertainties, and the PDF uncertainties on the theoretical predictions. The ratios of the theoretical predictions based on the MRST2004 and CTEQ6.1M are shown by the dotted lines.

Phys. Rev. D78 (2008) 052006

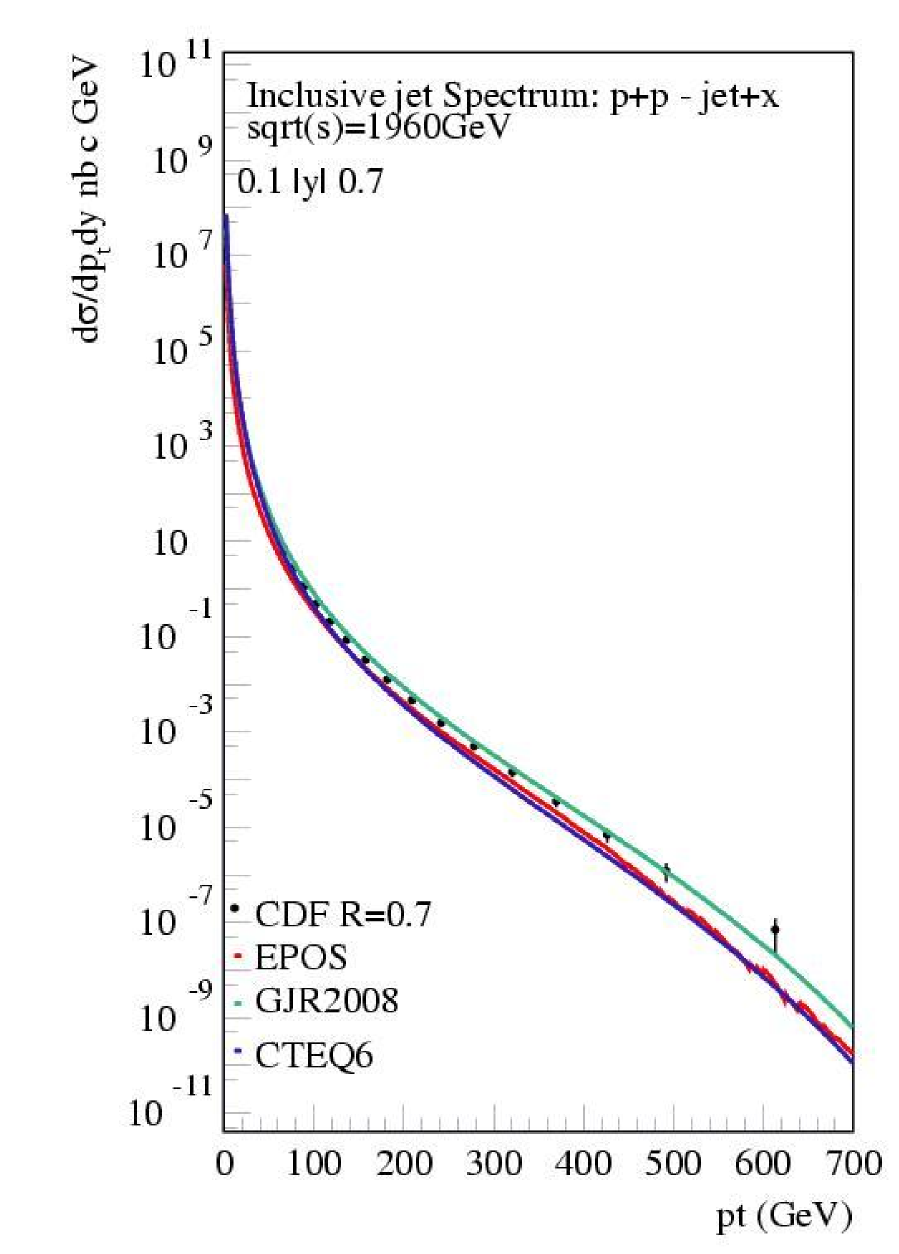
Comparison with Tevatron DATA

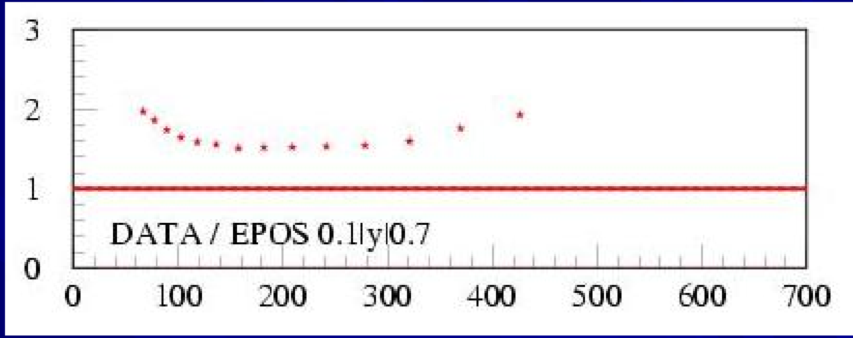


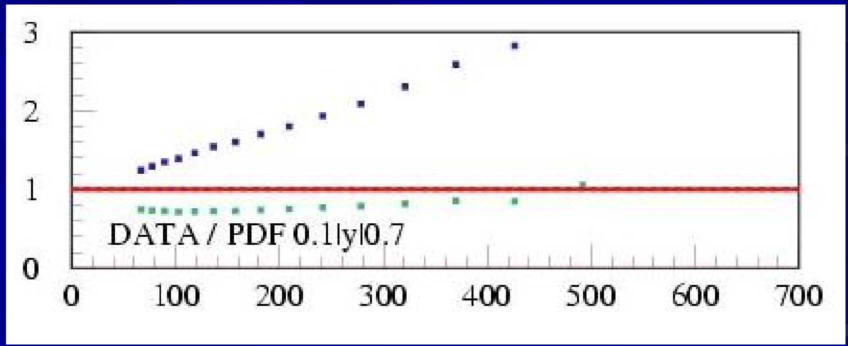




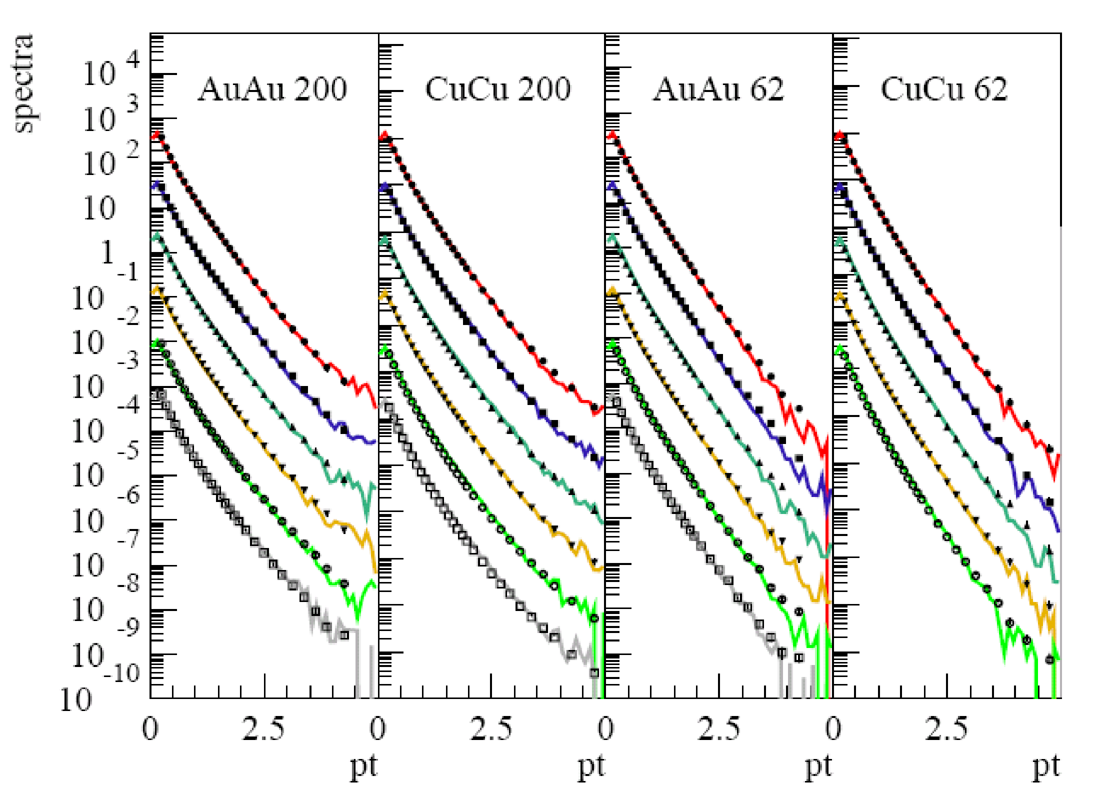
Comparison with Tevatron DATA

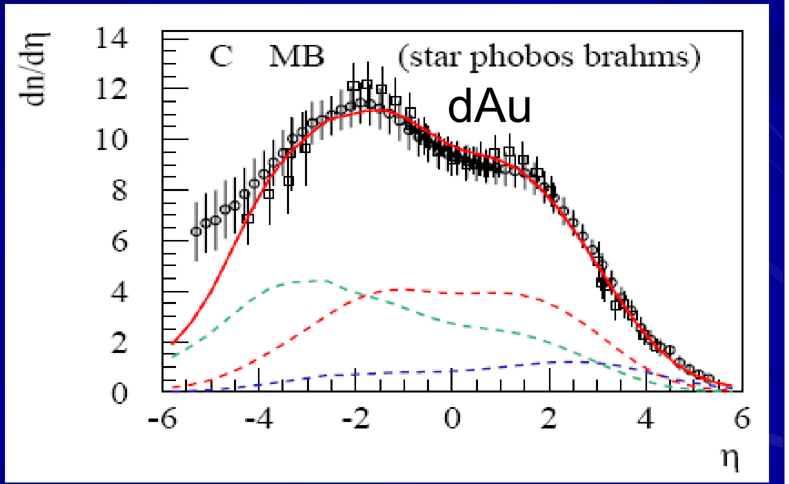






HIC @ RHIC

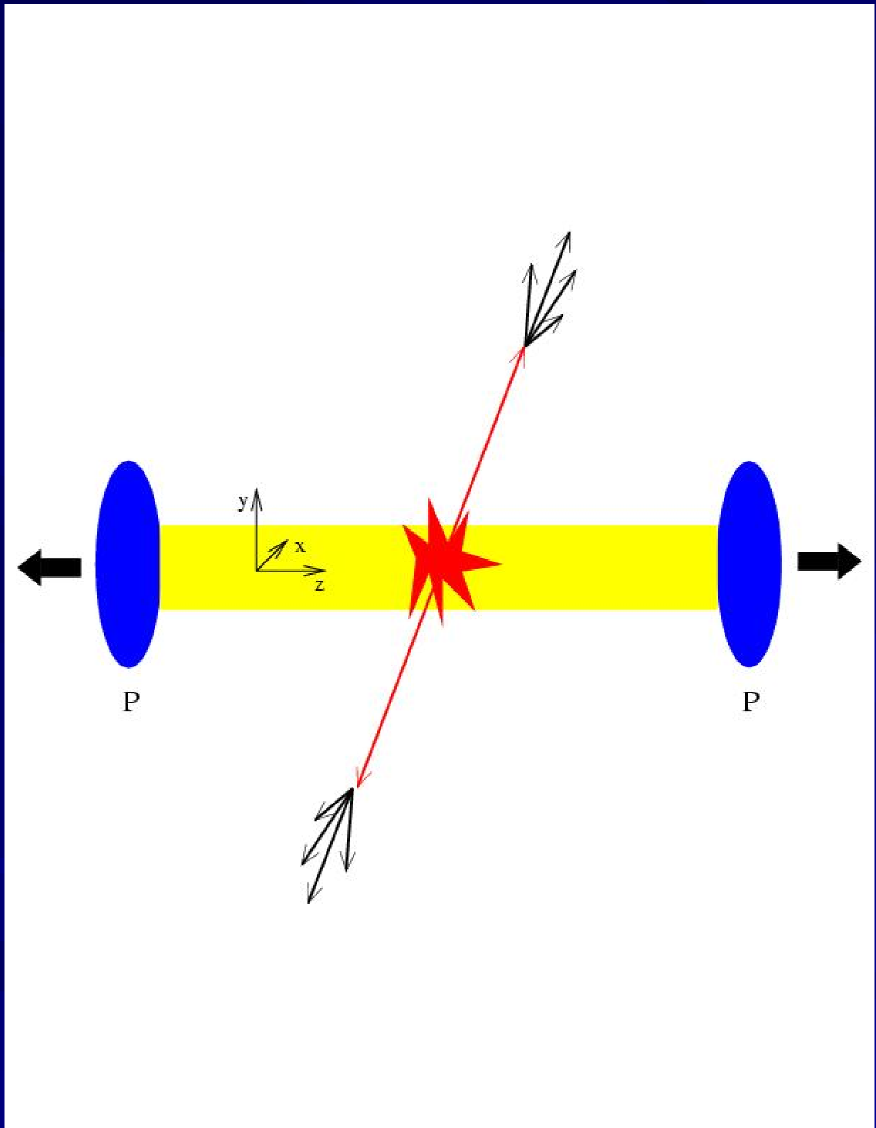


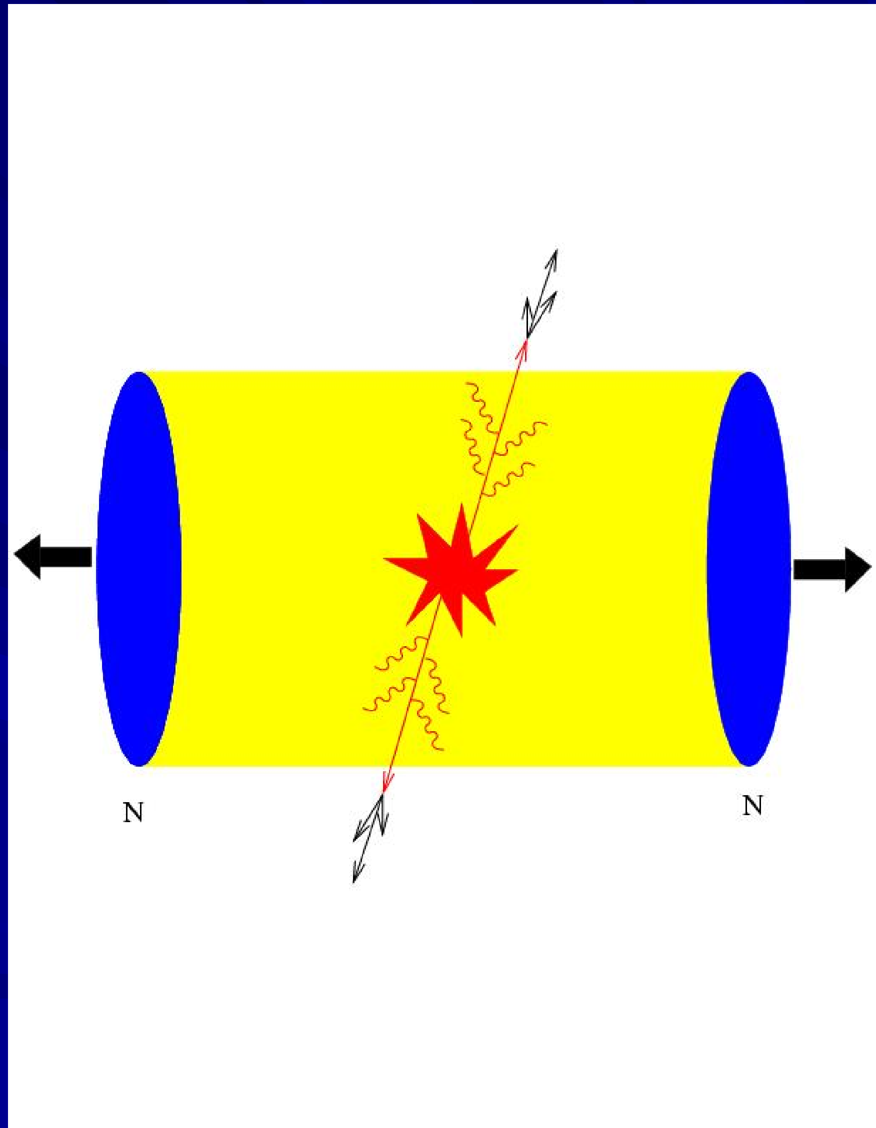


R.Bellwied. Acta Phys. Hung, A27:201-204,2006

B.I.Abelev et al. Phys. Rev., C76:054903, 2007

Jet / Jet Quenching

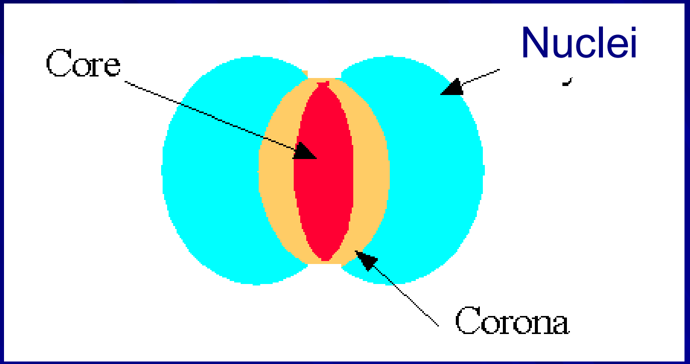


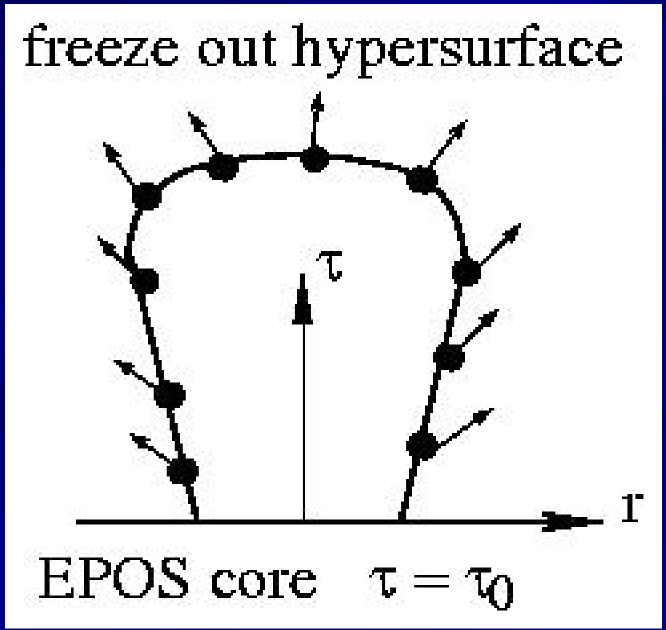


Collective Effect of a dense core

Modification of the string procedure :

- Corona = low density, classical EPOS particle production
- Core = high density, hydro expansion





One define a freeze-out surface : transition from strongly interacting matter to free hadrons.

Nowdays in EPOS : parametrisation of the freeze out hypersurface.

Already available in pp interactions.

Parton Ladder

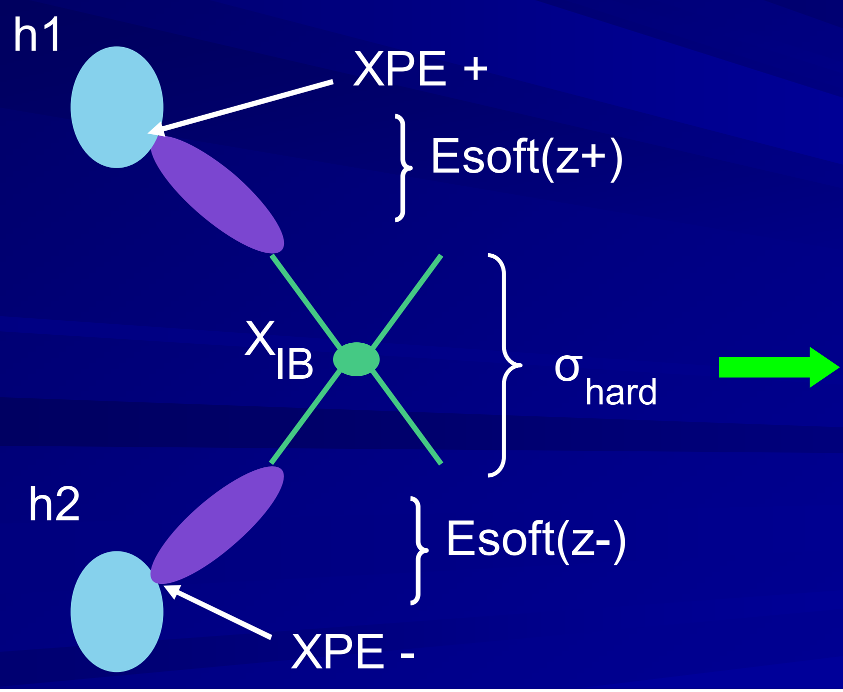
Proba of an interaction with b (impact parameter)

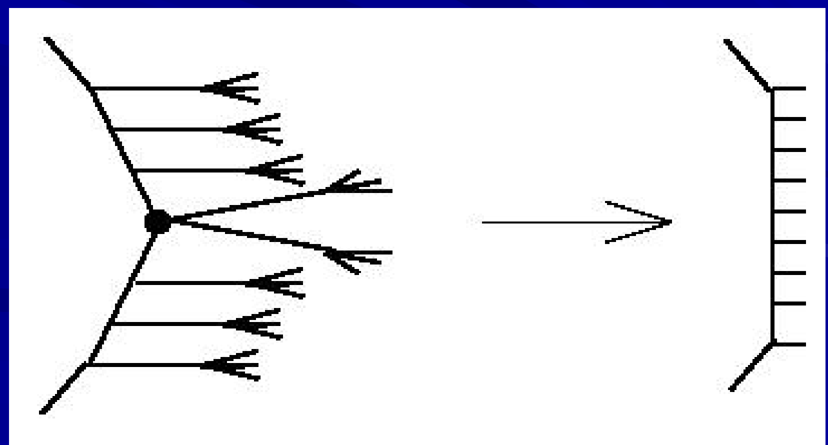
Moment distribution of parton (i,j) in soft part

pQCD, parton-parton cross-section (parton model)

Entering the ladder, proba of a parton with x+-

$$G^{h1h2}_{sea-sea}(x^+,x^-,s,b) \propto \int_0^1 dz^+ \int_0^1 dz^- \sum_{i,j} E^i_{soft}(z^+) E^j_{soft}(z^-) \sigma^{ij}_{hard}(z^+ z^- \hat{s}, Q_0^2) F^{h1}_{part}(x^+) F^{h2}_{part}(x^-)$$





- What we don't want :

  a spectrum generator

A generator of inclusive spectrum based on parton model

But, in such generators, one can deal with Pt cuts

- What we want :

  an event generator

A generator of complete event with both soft and hard part at the same time

But, as in experiment, if one wants a rare event, one needs a lot of simulation

How to compute hard partons, in a generator with multiple interactions, with cuts ?

How to get a fast simulation …

… without loosing advantages of hard partons in a complete event

- We need to compute rare events without doing a lot of events.
- We wants to work with cuts.
- We wants to keep the context of multiple scaterring with energy conservations.

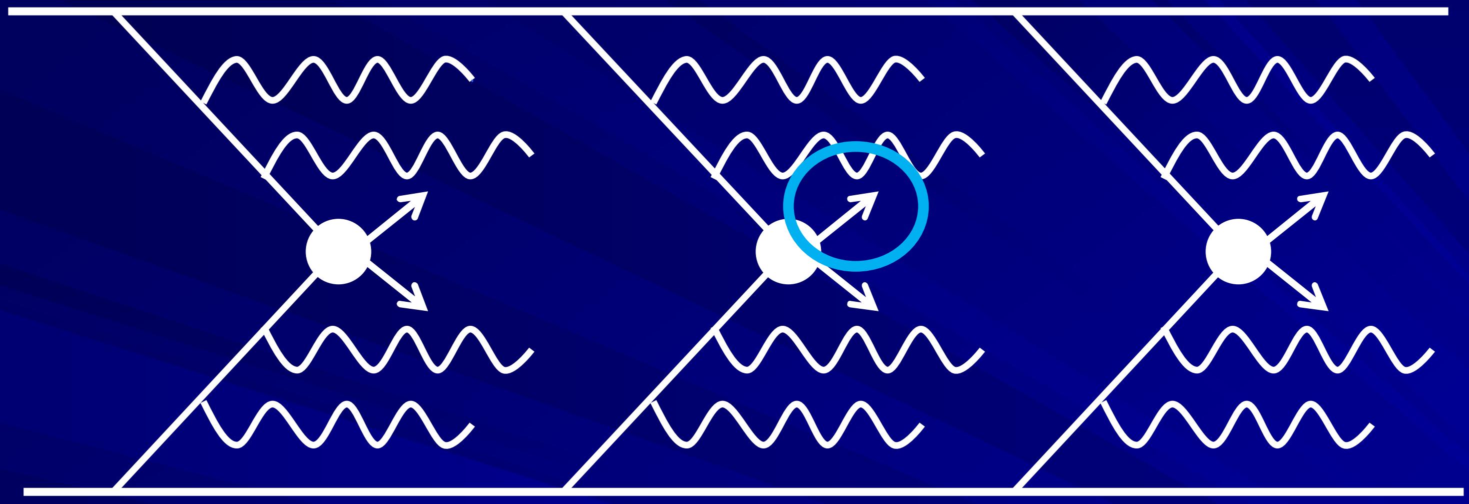
- First step : generate (XPE+,XPE-) by Monte Carlo
- Second step : Generate (XIB+,XIB-)

Replace the Monte Carlo procedure by a probability distribution S(xIB,xPE).

- Keep multiple scaterring and energy conservation by keeping XPE, change only the internal treatment of a ladder .

Compute events with cuts

Exemple of one events with multiple scatering



High Pt jets : rare events

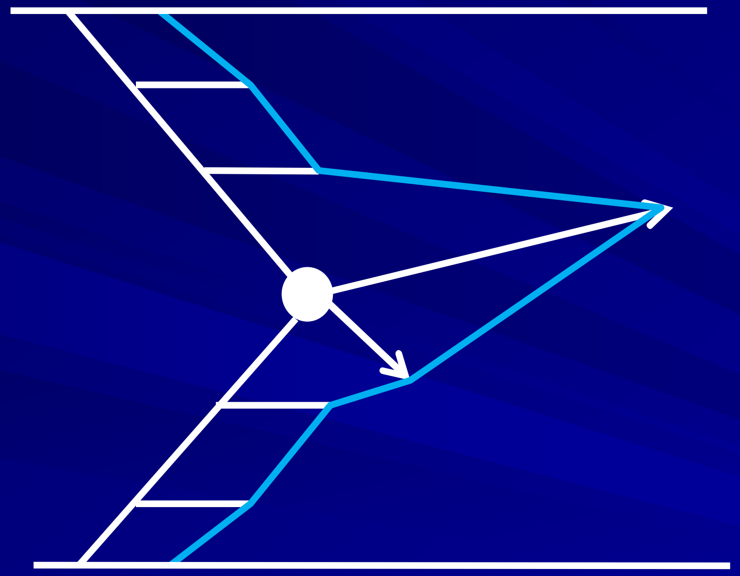
Wants to look at events with pt > cut

- Select a standard event
- Select a standard ladder
- Take xPE given by MC
- Change the procedure that give xIB
- Attribute a weight to the total event

Compute events with cuts

Particles production

Lund string model with kinky strings



The same particle production with a different weight for the total event

Exemple of Inclusive Spectrum

Once one have (XPE+,XPE) given by Monte Carlo simulation.

Generate (XIB+,XIB-) by a probability distribution.

$$N(x_{PE}^{+}, x_{PE}^{-}) = \frac{dn_{semi}}{dx_{PE}^{+} dx_{PE}^{-}}$$

n_{semi} : represents the average number of Pomeron with light cone momentum fractions of the Pomeron ends in the intervals $[x^{+}_{PE}, x^{+}_{PE} + dx^{+}_{PE}]$ and $[x^{-}_{PE}, x^{-}_{PE} + dx^{-}_{PE}]$

$$n_{semi} = \int dx_{PE}^{+} dx_{PE}^{-} dz^{+} dz^{-} N(x_{PE}^{+}, x_{PE}^{-}) S(x_{PE}^{+}, x_{PE}^{-}, z^{+}, z^{-})$$

$$x_{IB} = z \times x_{PE}$$

S, normalised

S is used as a probability distribution to generate z+,z- for a given (xPE+,xPE-)

Exemple of Inclusive Spectrum

$$S(x_{PE}^{+}, x_{PE}^{-}, z^{+}, z^{-}) = \frac{1}{\omega} \sum_{i,j} \int dt du E^{M,i}(z^{+}) E^{M,j}(z^{-}) \frac{1}{\sigma_{inel}} \frac{d\sigma_{i,j}}{dt du}(s,t,u)$$

With :

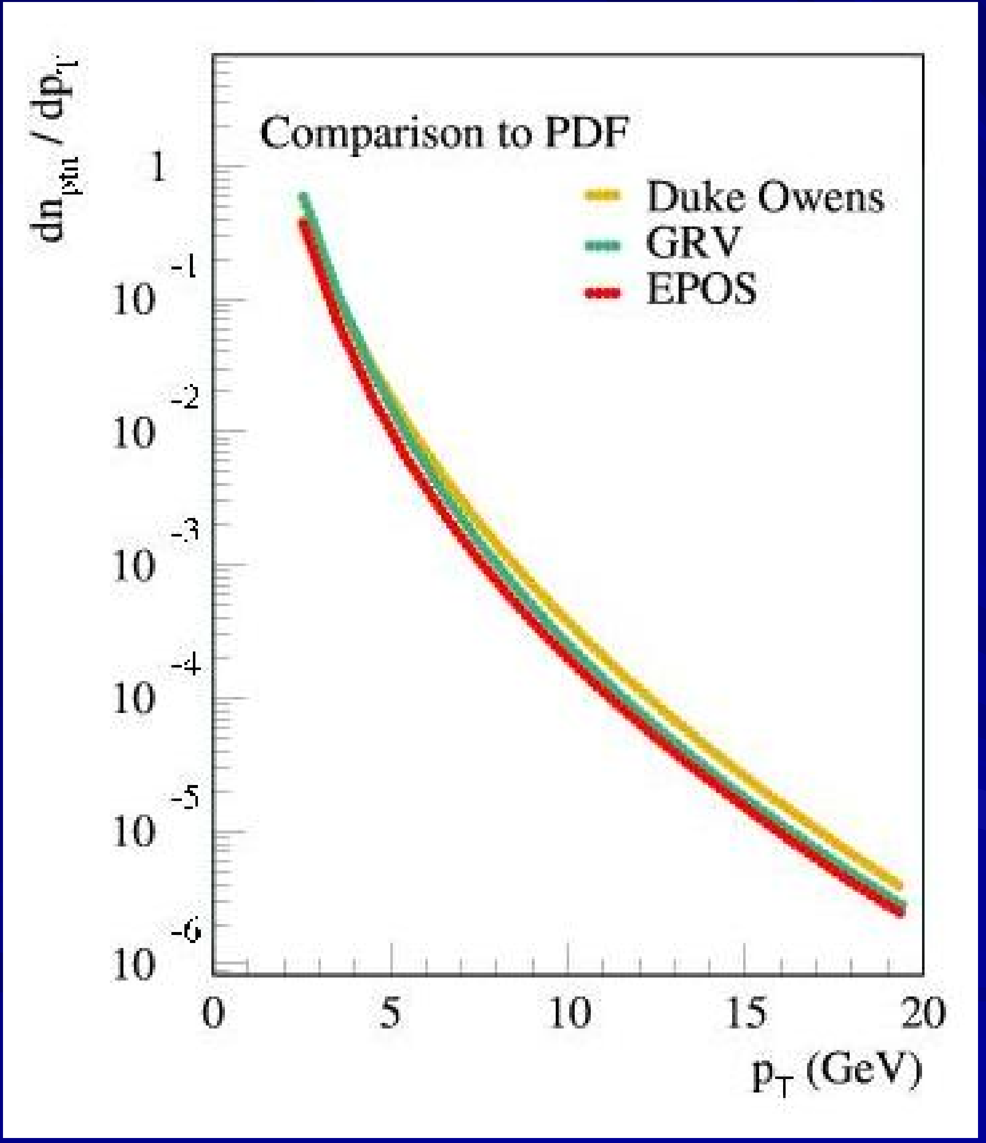
$$s = x_{PE}^{+} x_{PE}^{-} z^{+} z^{-} s_{hh}$$

and :

$$E^{M,i} = \sum_{k} E_{soft}^{k} \otimes E_{QCD}^{ki,M}$$

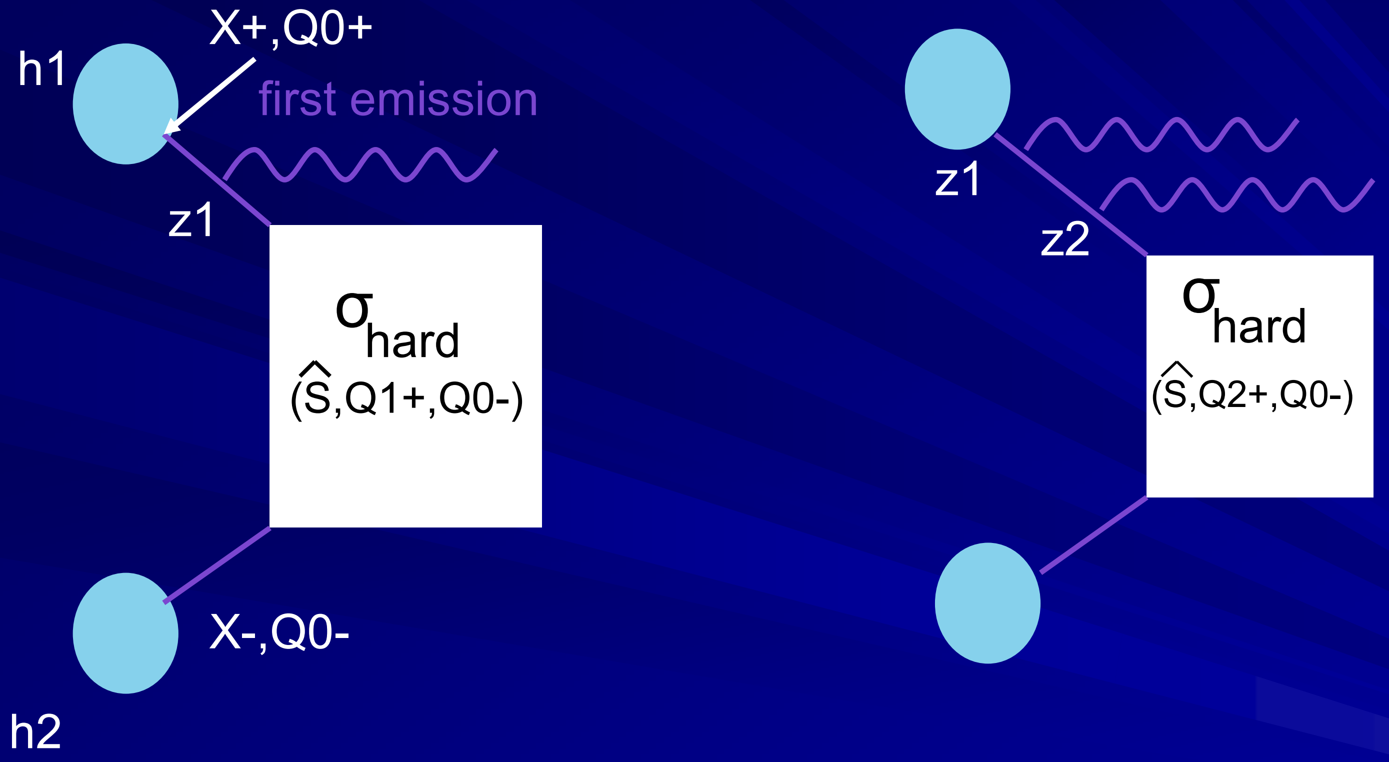
Omega assures normalisation.

Comparison with Parton Distribution Function



Parton ladder

Iterative procedure : determined each emission



$$P(\text{forward emission}) = \frac{\sigma_{hard} - \sigma_{ord}}{\sigma_{hard}}$$

S is used as a probability distribution to generate z+,z- for a given (xPE+,xPE-)

$$n_{semi} = \int dx_{PE}^{+} dx_{PE}^{-} dz^{+} dz^{-} \widetilde{N}(x_{PE}^{+}, x_{PE}^{-}) S(x_{PE}^{+}, x_{PE}^{-}, z^{+}, z^{-})$$

n_{semi} : represents the average number of Pomeron with light cone momentum fractions of the Pomeron ends in the intervals $[x^{+}_{PE}, x^{+}_{PE}+dx^{+}_{PE}]$ and $[x^{-}_{PE}, x^{-}_{PE}+dx^{-}_{PE}]$

Ntilde : distribution of (xPE+/-) given by Monte Carlo

Analytic Computation

$$\frac{dn_{semi}}{dx^+_{PE}dx^-_{PE}} = F_+(x^+_{PE})F_-(x^-_{PE})\int dx^+dx^-\sum_{kl}E^k_{soft}(x^+)E^l_{soft}(x^-)\frac{1}{\sigma_{inel}}\int dz^+dz^-dt\sum_{ij}E^{ki,M}_{QCD}(z^+)E^{lj,M}_{QCD}(z^-)\frac{d\sigma_{ij}}{dt}(s,t)$$

$$\frac{dn_{semi}}{dx^+_{IB}dx^-_{IB}} = \frac{1}{\sigma_{inel}}\int dt\sum_{ij} f^M_{+i}(x^+_{IB})f^M_{-j}(x^-_{IB})\frac{d\sigma_{ij}}{dt}(s,t)$$

avec $$f^{M,i}_{+-} = \sum_k F_{+-}\otimes E^k_{soft}\otimes E^{ki,M}_{QCD}$$

$$\frac{dn_{semi}}{dx^+_{IB}dx^-_{IB}} = \int dt F_{+-}(x_{PE})\otimes\omega(x_{IB})$$

avec $$\omega = \frac{1}{\sigma_{inel}}E^k_{soft}\otimes E^{ki,M}_{QCD}\frac{d\sigma_{ij}}{dt}$$