The Abdus Salam
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International Atomic Energy Agency

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Hadron Jets: new tools for new physics

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Hadron Jets : *new tools* for *new physics*

Yuri Dokshitzer
LPTHE, Paris & PNPI, St Petersburg

QCD-Cosmic Workshop
Trieste, May 2009

series of recent works by

Gavin Salam (GPS)
Matteo Cacciari
Gregory Soyez
...

- fast kt jet finding algorithm (FastJet)
- infrared safe cone algorithm (SISCone)
- the notion of "jet area" : UE and pileup
- exploiting jet substructure for new physics searches
- . . .

based on

Gavin P. Salam

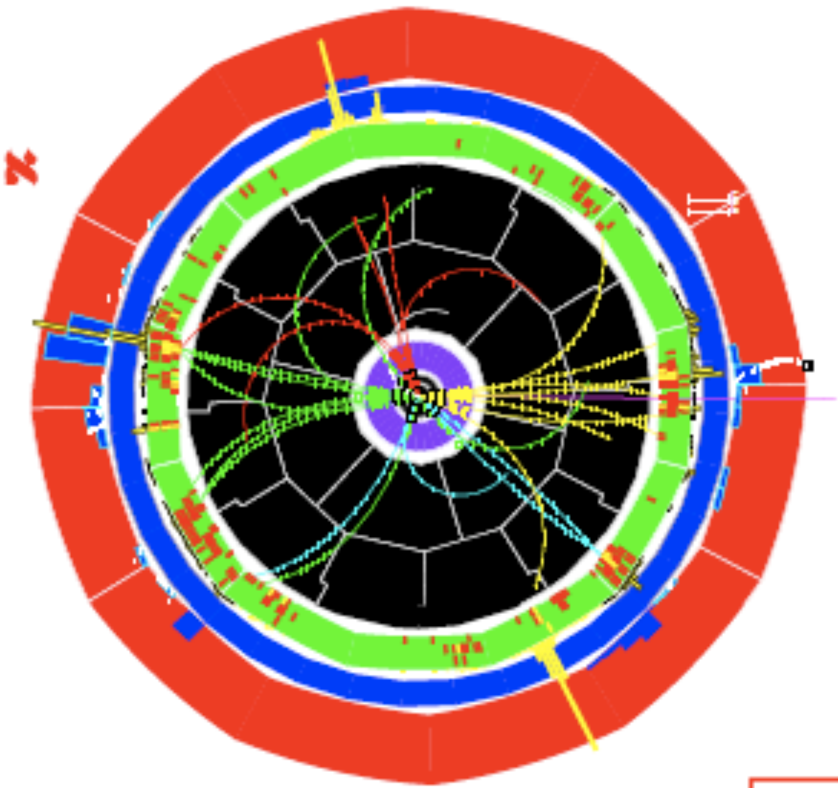
habilitation thesis presentation

" Towards Jetography "

given 5 May, 2009

at the LPTHE, Paris

quarks as jets of hadrons



Aleph Higgs event:

- Claim: it corresponds to $ZH \rightarrow q\bar{q}b\bar{b}$.
- But actually just bunches ('jets') of hadrons.
- Can they be related? And *How*?

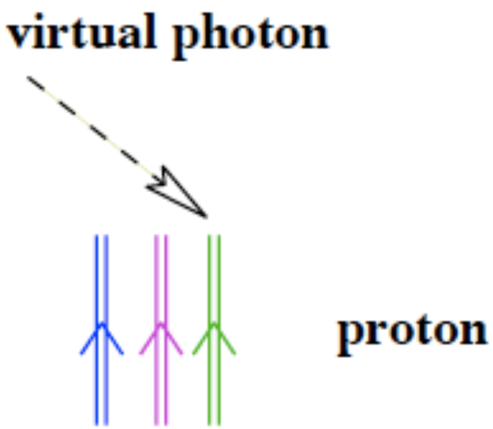
Need understanding of QCD

jet as a "string" of hadrons

Existence of Jets was envisaged from "parton models" in the late 1960's.

Kogut–Susskind vacuum breaking picture :

- In a DIS a *green* quark in the proton is hit by a virtual photon;



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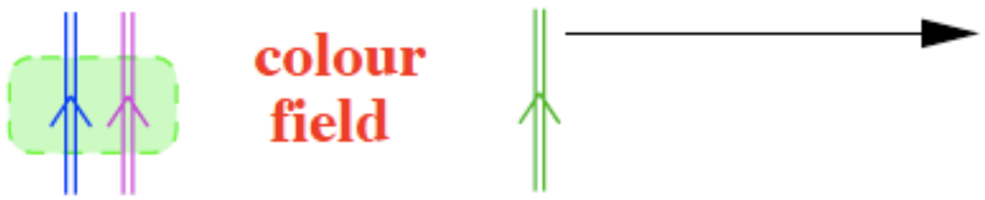

jet as a "string" of hadrons

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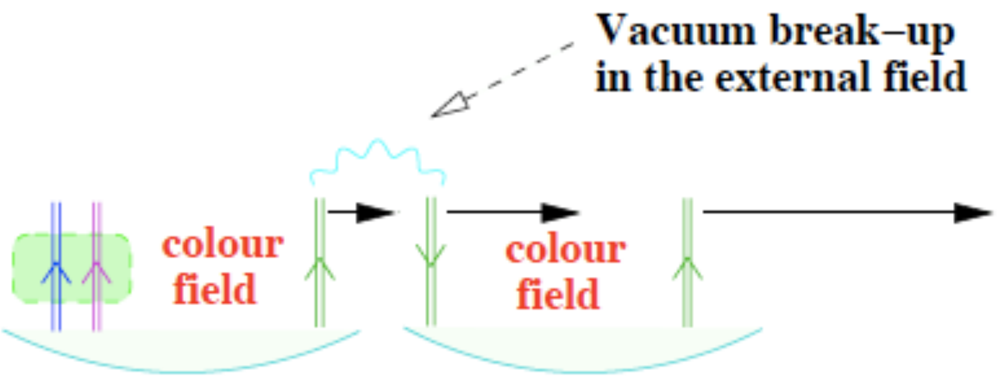
Kogut–Susskind vacuum breaking picture :

- In a DIS a *green* quark in the proton is hit by a virtual photon;
- The quark leaves the stage and the colour field starts to build up;
- A *green–anti-green* quark pair pops up from the vacuum, splitting the system into two globally blanched sub-systems.

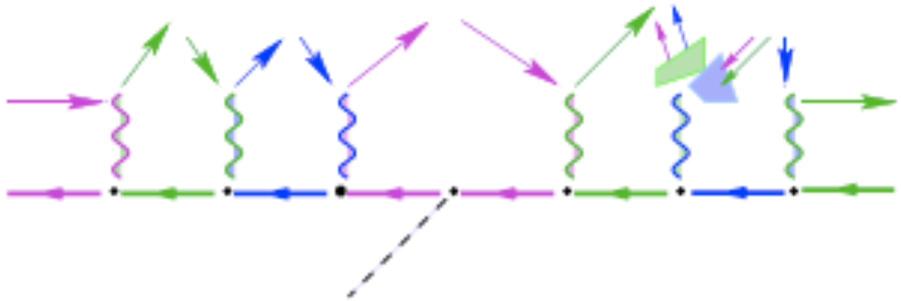


Repeating, one gets the "Feynman Plateau" :

"One" hadron per $\frac{\Delta\omega}{\omega}$; Hadron multiplicity $\propto \ln Q$.

Lund fragmentation

Phenomenological realization of the Kogut–Susskind scenario



$\Longrightarrow$ a "String" of hadrons

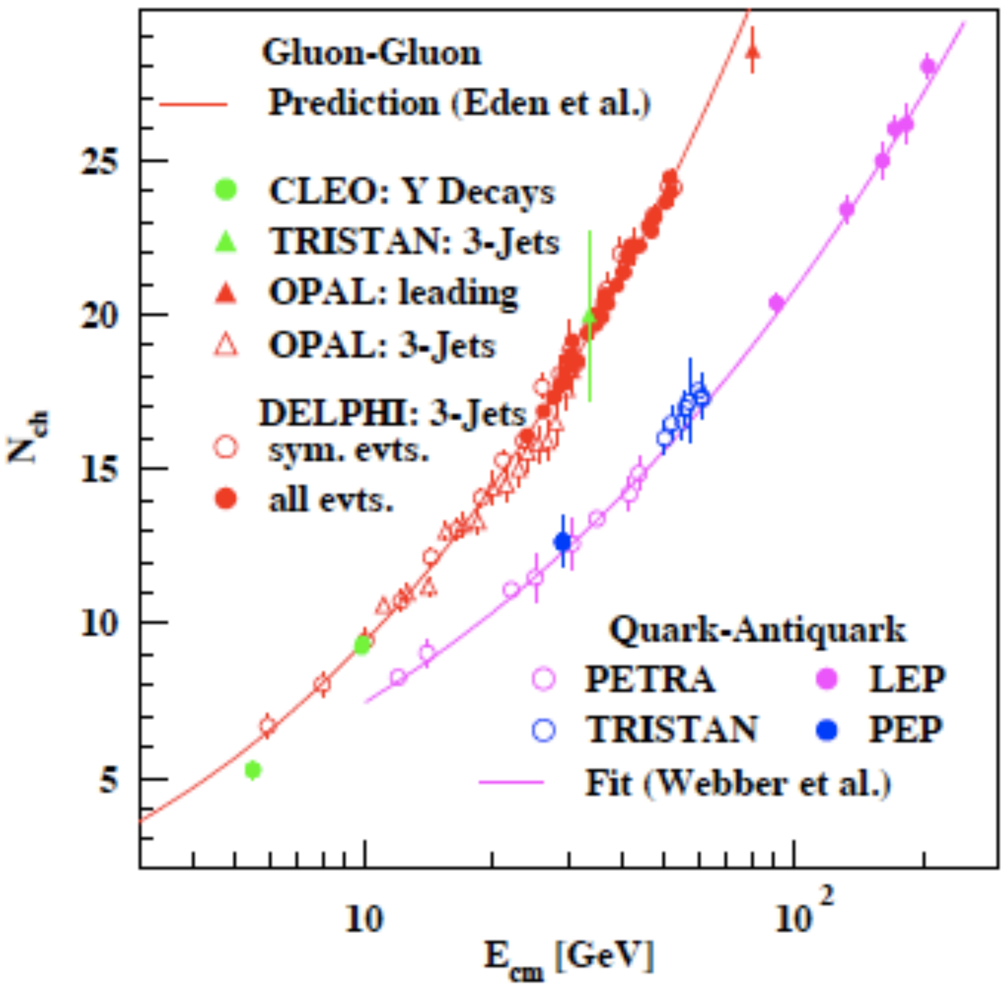
The base of the Lund Model

The key features of the Lund hadronization model:

- Uniformity in *rapidity*: $dN_h = \text{const} \times \dfrac{d\omega_h}{\omega_h}$
- Limited $k_\perp$ of hadrons
- Quark combinatorics at work:
  - u, d vs. s
  - *mesons* vs. *baryons*

comparing hadron multiplicities

from gluon & quark jets

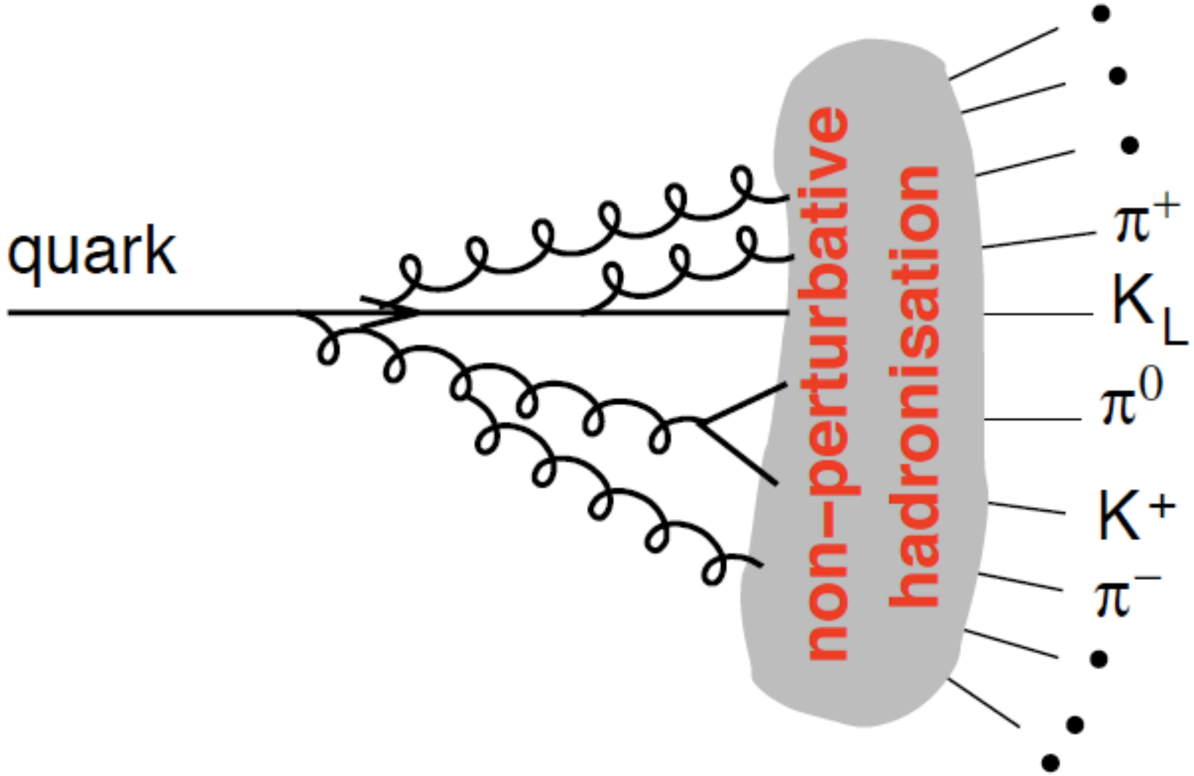


Look at experimental findings

Lessons :

- N increases *faster* than $\ln E$ ($\Longrightarrow$ Feynman was wrong)
- $N_g/N_q < 2$ however
- $\frac{dN_g}{dN_q} = \frac{N_c}{C_F} = \frac{2N_c^2}{N_c^2-1} = \frac{9}{4} \simeq 2$ ($\Longrightarrow$ bremsstrahlung gluons add to the hadron yield; QCD respecting parton cascades)

Parton fragmentation



Gluon emission:

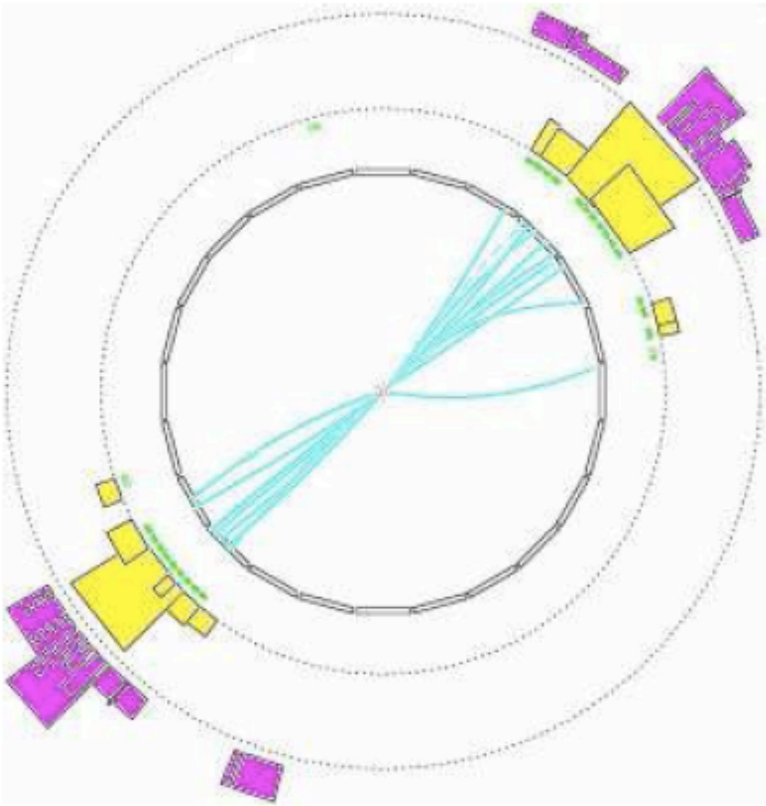
$$\int \alpha_s \frac{dE}{E} \frac{d\theta}{\theta} \gg 1$$

At low scales:

$$\alpha_s \to 1$$

This is a jet

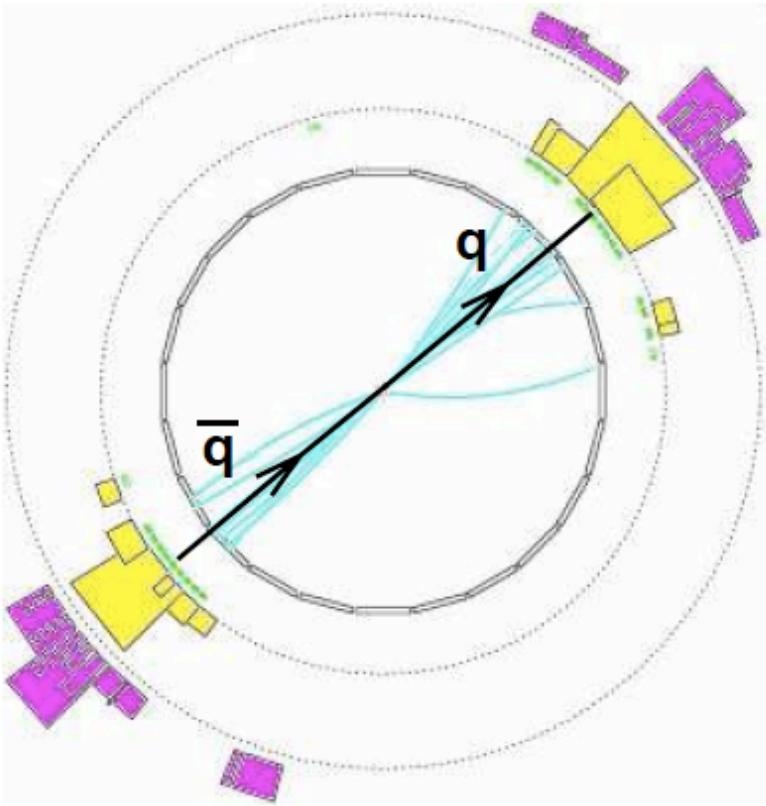
seeing vs. defining jets



Jets are what we see.
Clearly(?) 2 jets here

How many jets do you see?
Do you really want to ask yourself this question for 10^9 events?

seeing vs. defining jets



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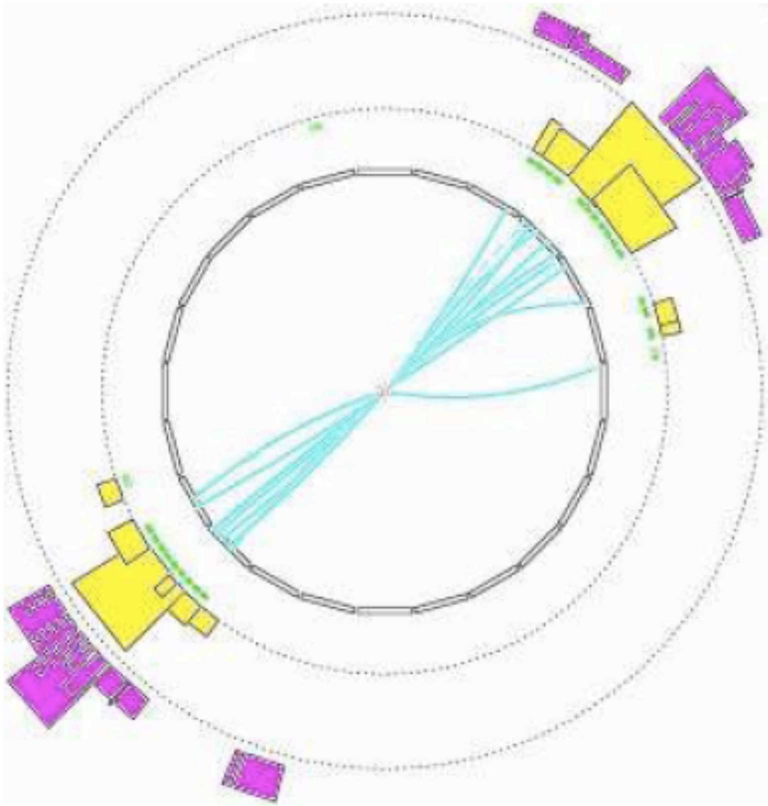

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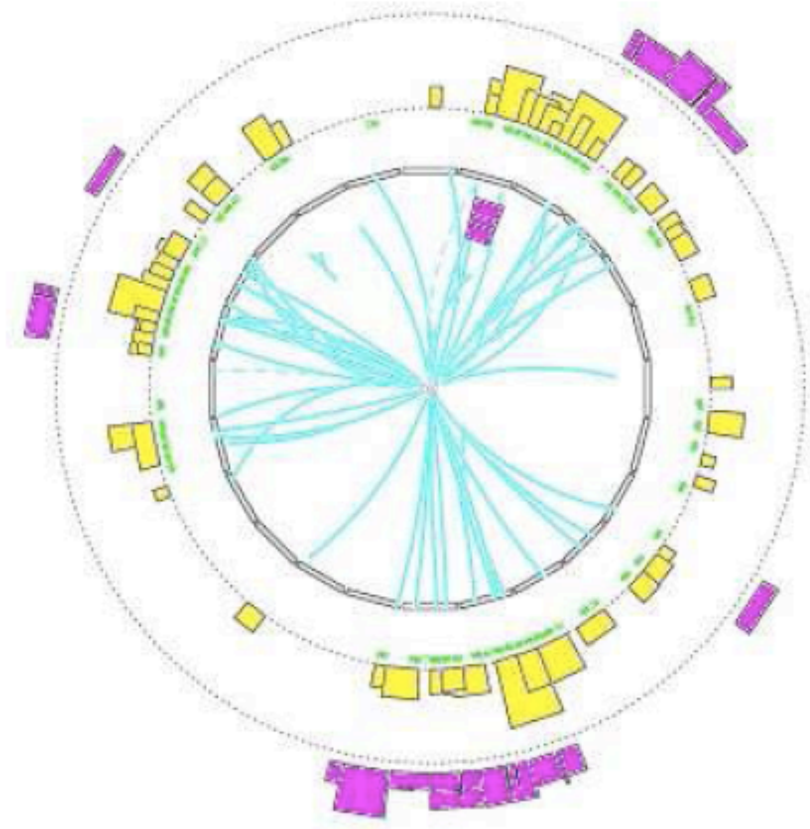

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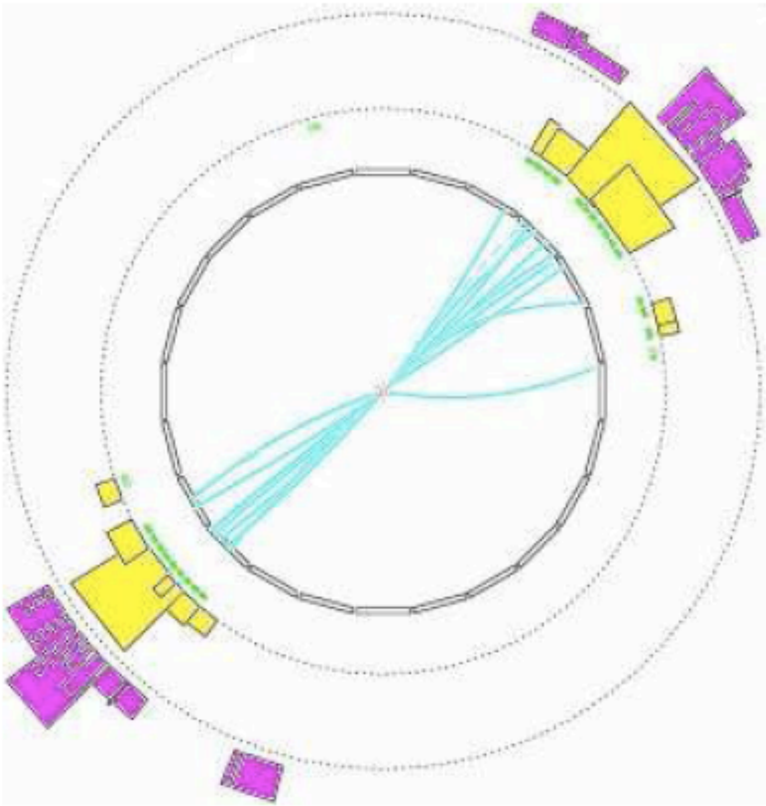

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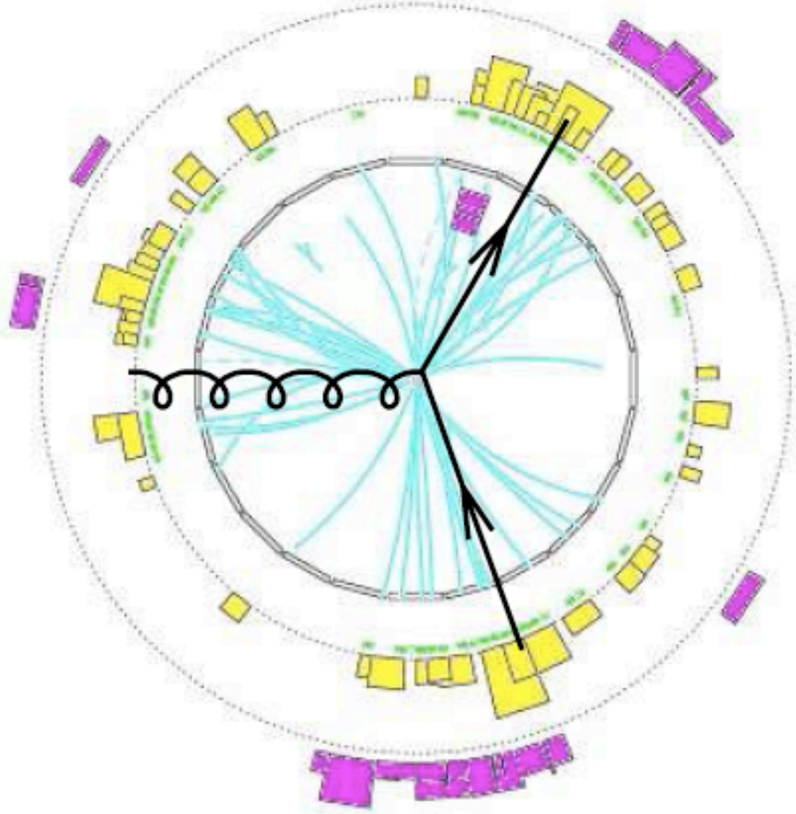

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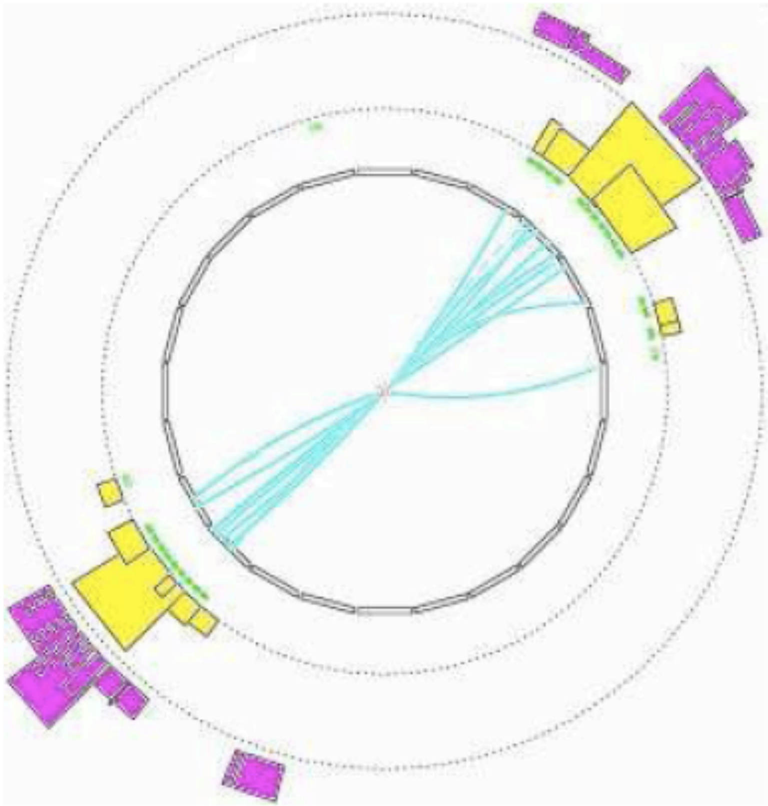

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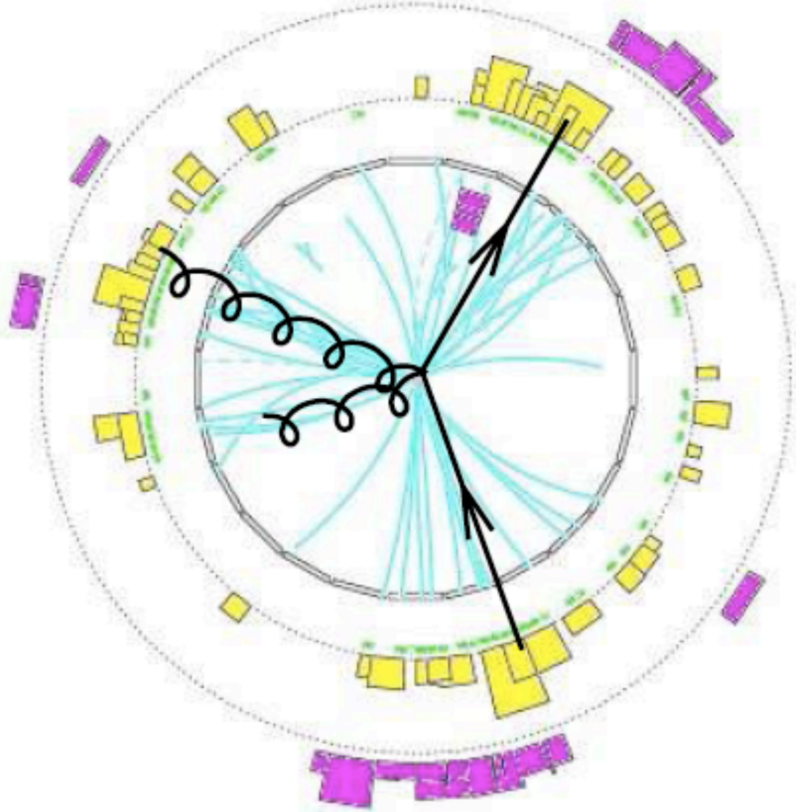

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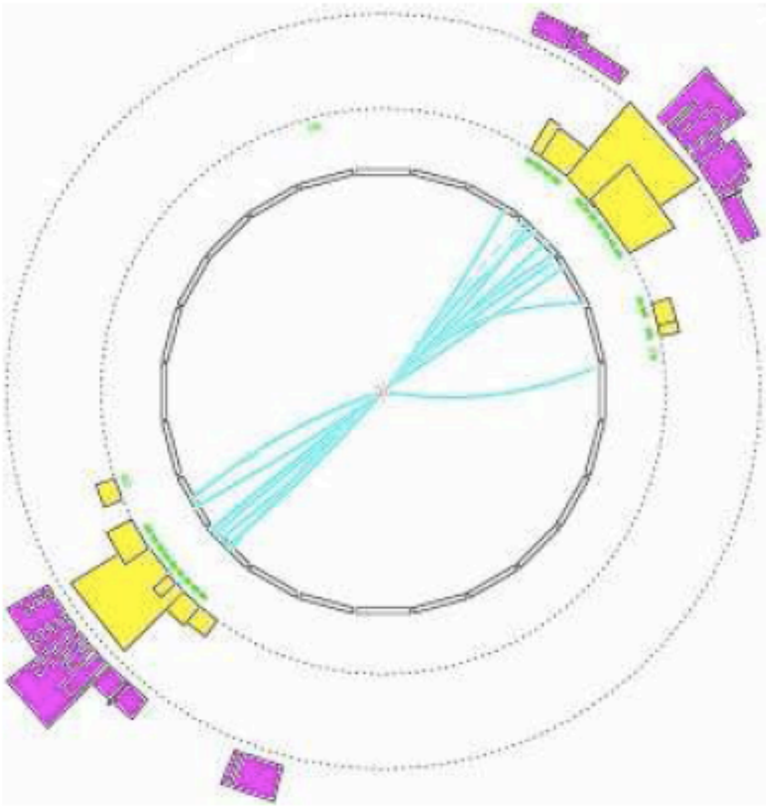

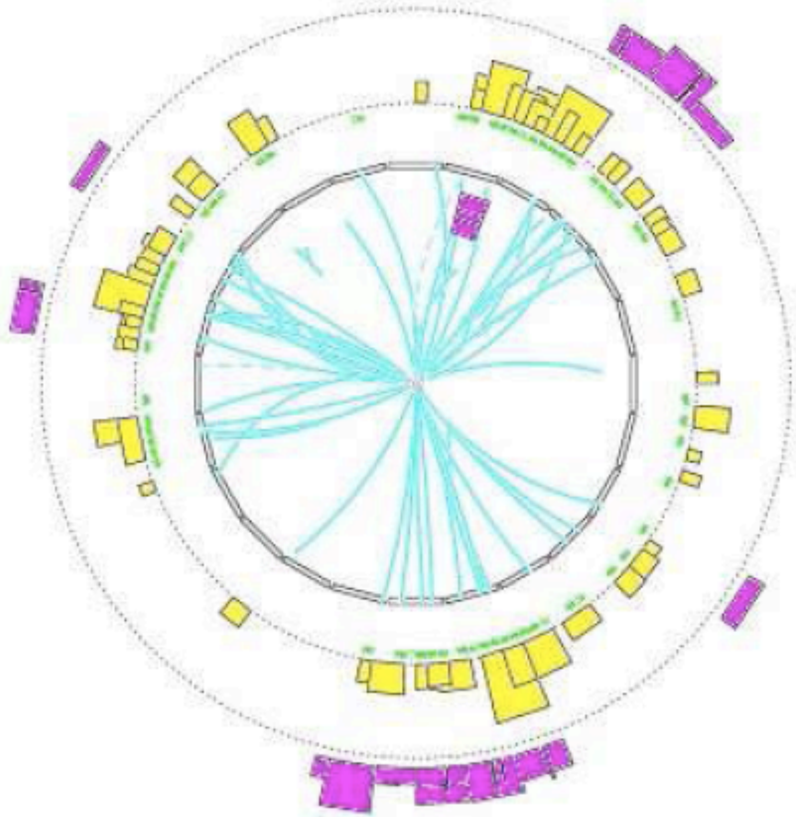

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Les Houches 2007 proceedings, arXiv:0803.0678

jet definition

jet algorithm

$\{p_i\} \longrightarrow \{j_k\}$

particles,
4-momenta,
calorimeter towers, ...

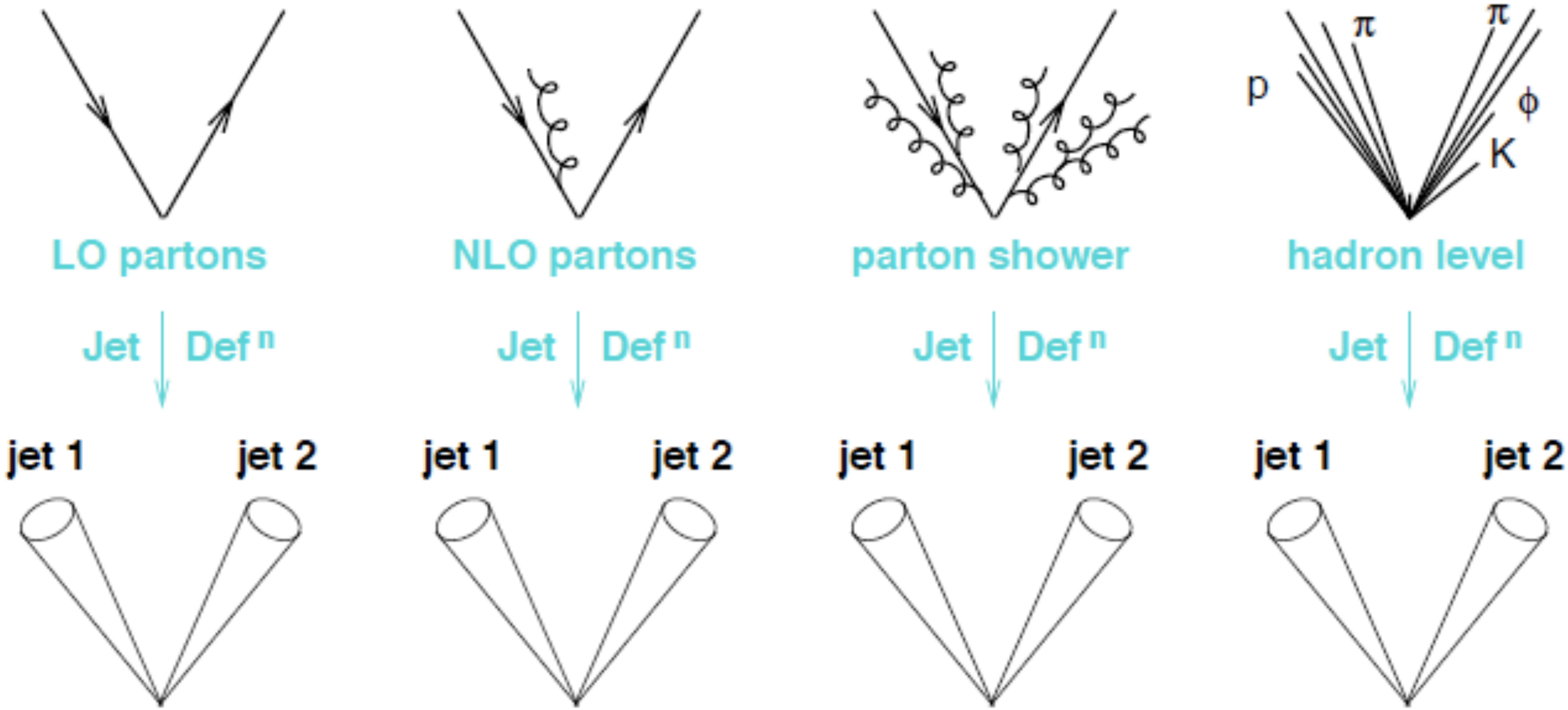
jets

+ parameters (usually at least the radius R)

+ recombination scheme

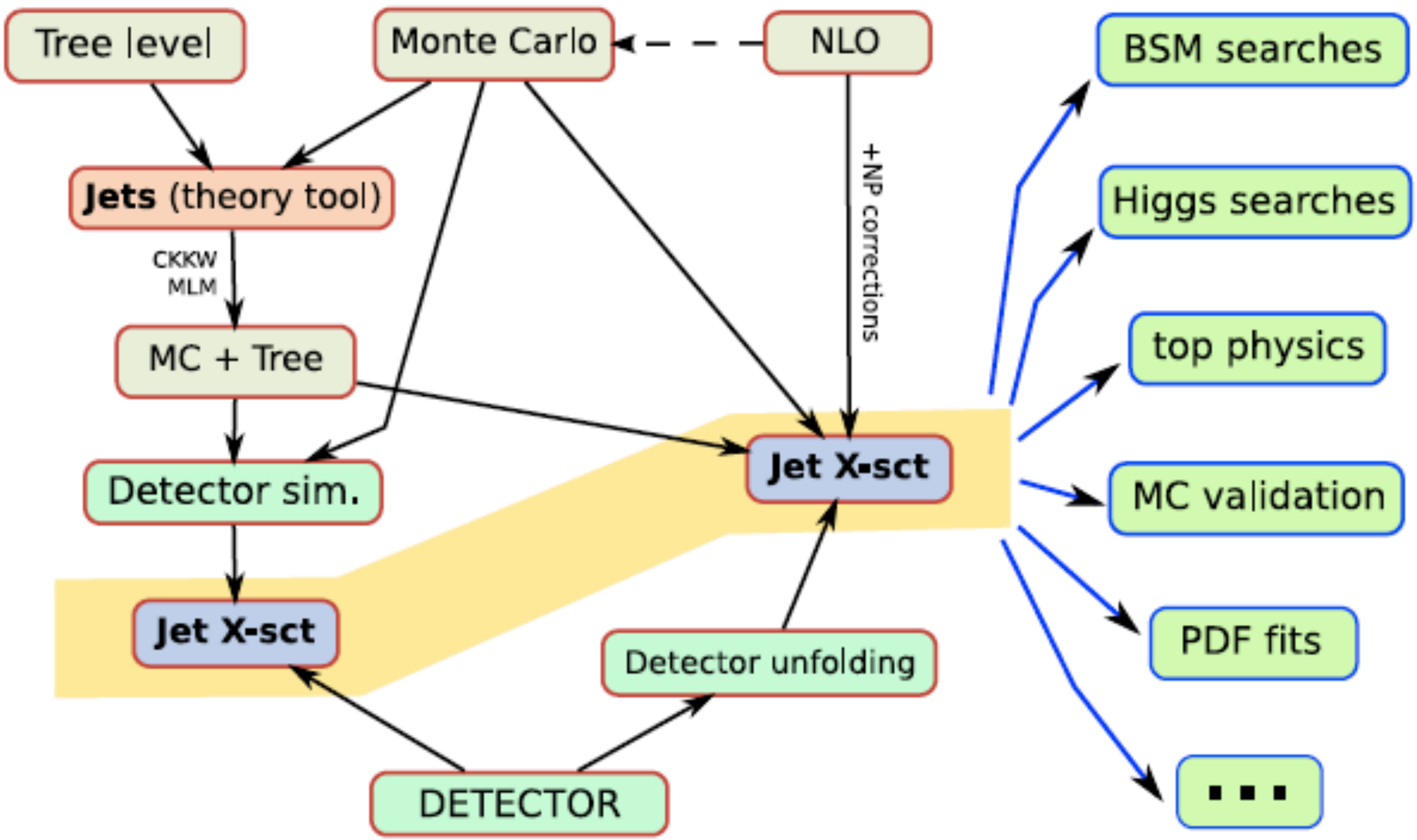
Reminder: running a jet definition gives a well defined physical observable, which we can measure and, hopefully, calculate

Jets as projections



Projection to jets should be resilient to QCD effects

QCD jets flowchart



Jet (definitions) provide central link between expt., “theory” and theory

And jets are an input to almost all analyses

What jet algorithms are out there?

2 broad classes:

1. sequential recombination

"bottom up", e.g. k_t, preferred by many theorists

2. cone type

"top down", preferred by many experimenters

sequential recombination algorithms

k_t or "***Durham***" alg.

Catani, D-r, Olsson, Seymour, Turnock, Webber `91
Ellis, Soper `93

Bottom-up jets:

Sequential recombination

sequential recombination algorithms

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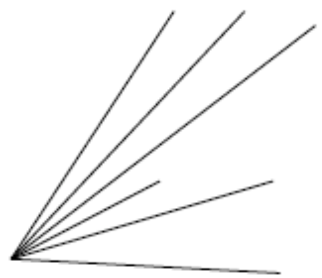
- Find smallest of all $d_{ij} = \min(k_{ti}^2, k_{tj}^2)\Delta R_{ij}^2/R^2$ and $d_{iB} = k_i^2$
- Recombine i, j (if iB: $i \to$ jet)
- Repeat



NB: hadron collider variables

- $\Delta R_{ij}^2 = (\phi_i - \phi_j)^2 + (y_i - y_j)^2$
- rapidity $y_i = \frac{1}{2} \ln \frac{E_i + p_{zi}}{E_i - p_{zi}}$
- ΔR_{ij} is boost invariant angle

R sets minimal interjet angle

sequential recombination algorithms

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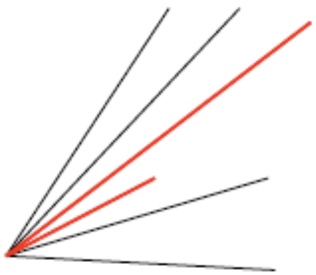

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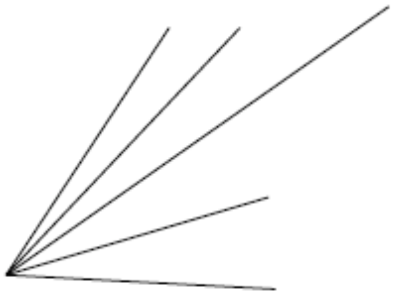

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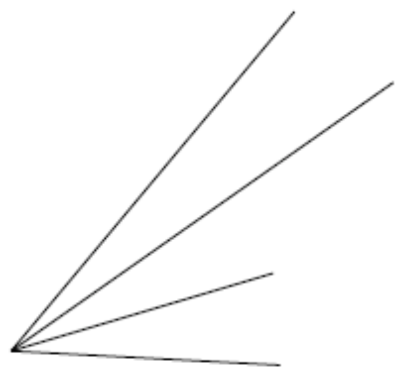

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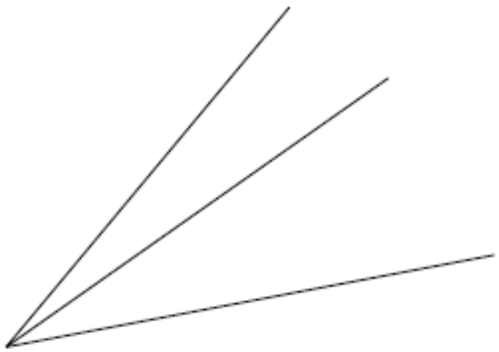

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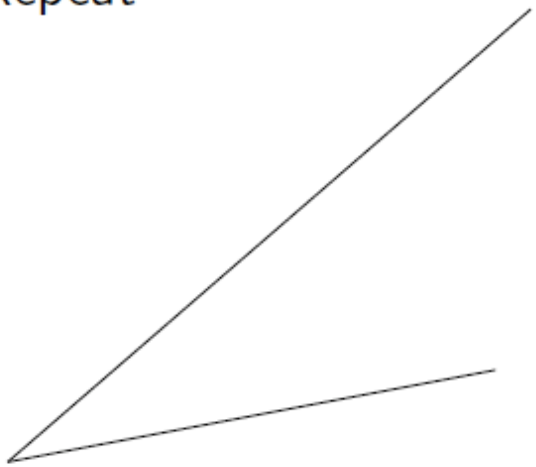

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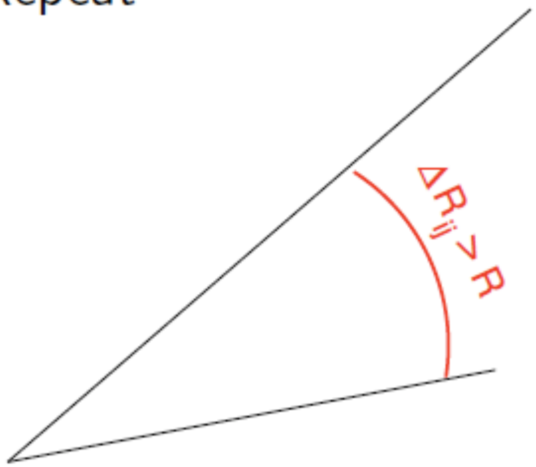

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why the relative k_t ?

k_t distance measures

$$d_{ij} = \min(k_{ti}^2, k_{tj}^2)\Delta R_{ij}^2, \qquad d_{iB} = k_{ti}^2$$

are closely related to structure of divergences for QCD emissions

$$[dk_j]|M^2_{g\to g_i g_j}(k_j)| \sim \frac{\alpha_s C_A}{2\pi}\frac{dk_{tj}}{\min(k_{ti}, k_{tj})}\frac{d\Delta R_{ij}}{\Delta R_{ij}}, \qquad (k_{tj} \ll k_{ti}\,,\ \Delta R_{ij} \ll 1)$$

and

$$[dk_i]|M^2_{Beam\to Beam+g_i}(k_i)| \sim \frac{\alpha_s C_A}{\pi}\frac{dk_{ti}}{k_{ti}}\, d\eta_i\,, \qquad (k_{ti}^2 \ll \{\hat{s}, \hat{t}, \hat{u}\})$$

k_t algorithm attempts approximate inversion of branching process

cones with Split Merge (SM)

Tevatron & ATLAS cone algs have two main steps:

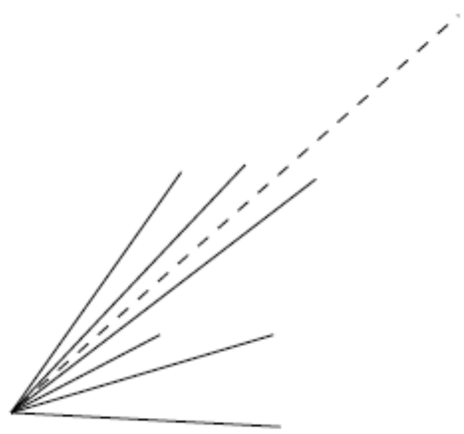
- Find some/all stable cones

  ≡ cone pointing in same direction as the momentum of its contents

  Found by iterating from some initial seed directions

- Resolve cases of overlapping stable cones

  By running a 'split–merge' procedure



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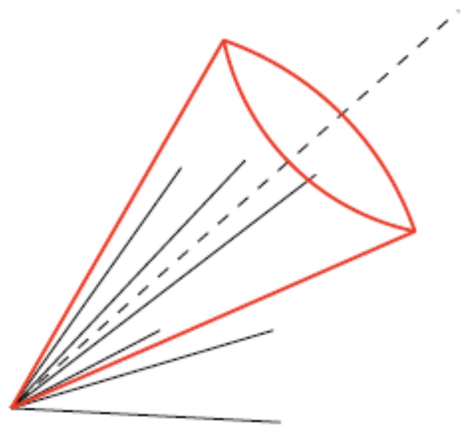

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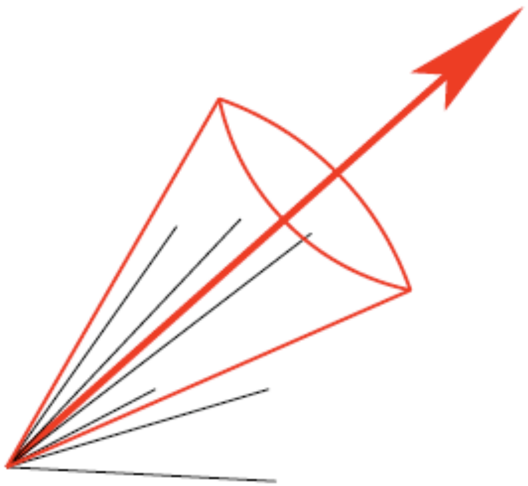

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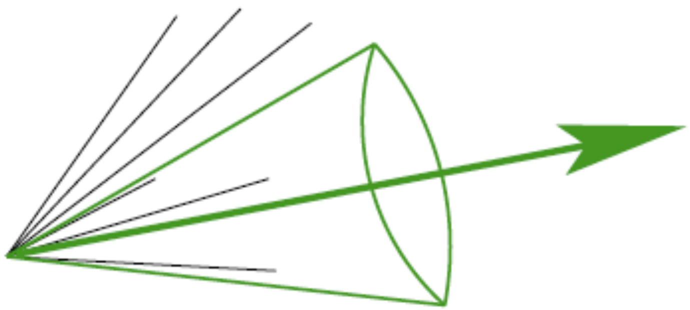

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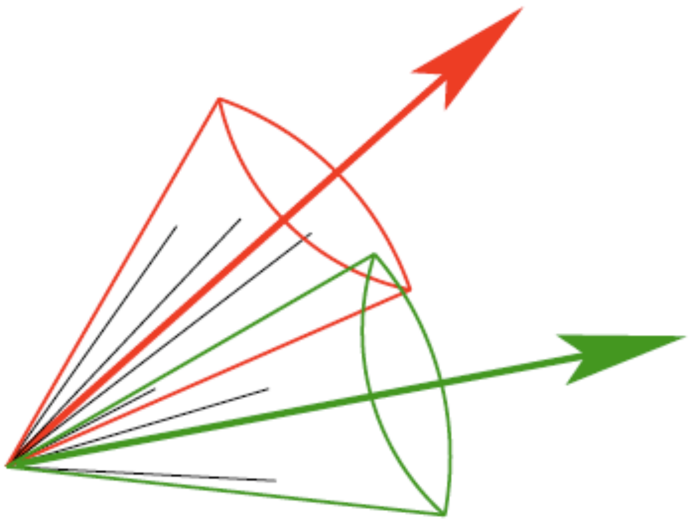

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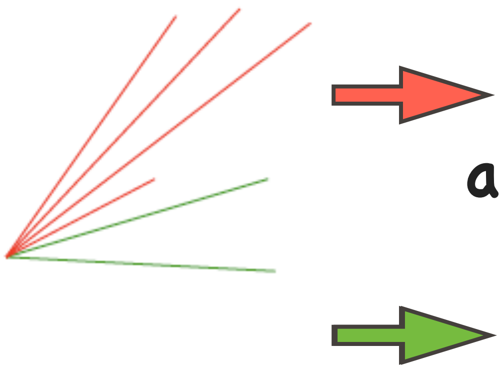
*what **seeds** do you see?*



originally [*JetClu, Atlas*] :

all particles above some threshold

Midpoint Cone [*Tevatron Run II*] :

+midpoints btw stable cones as seeds

Readying jet "technology" for the LHC era

[a.k.a. satisfying Snowmass]

Snowmass Accord

Snowmass Accord (1990):

FERMILAB-Conf-90/249-E
[E-741/CDF]

Toward a Standardization of Jet Definitions

Several important properties that should be met by a jet definition are [3]:

1. Simple to implement in an experimental analysis;
2. Simple to implement in the theoretical calculation;
3. Defined at any order of perturbation theory;
4. Yields finite cross section at any order of perturbation theory;
5. Yields a cross section that is relatively insensitive to hadronization.

Snowmass Accord

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Property 1 ⇔ speed. (+other aspects)

- LHC events may have up to $N = 4000$ particles (at high-lumi)
- Sequential recombination algs. (k_t) slow, $\sim N^3 \to 60s$ for $N = 4000$

k_t not practical for $\mathcal{O}(10^9)$ events

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Property 4 $\equiv$ Infrared and Collinear (IRC) Safety. It helps ensure:

- Soft (low-energy) emissions & collinear splittings don't change jets
- Each order of perturbation theory is smaller than previous (at high p_t)

Wasn't satisfied by the cone algorithms

Snowmass issue #1

The $\mathrm{k_t}$ algorithm and its speed

Computing and k_t

'Trivial' computational issue:

- for N particles: N^2 d_{ij} searched through N times $= N^3$
- 4000 particles (or calo cells): 1 minute

  NB: often study $10^7 - 10^9$ events (20-2000 CPU years)
- Heavy Ions: 30000 particles: 10 hours/event

As far as possible physics choices should not be limited by computing.

Even if we're clever about repeating the full search each time, we still have $\mathcal{O}\left(N^2\right)$ d_{ij}'s to establish

k_t and geometry

There are $N(N-1)/2$ distances d_{ij} — surely we have to calculate them all in order to find smallest?

k_t distance measure is partly *geometrical:*

$$\min_{i,j} d_{ij} \equiv \min_{i,j}(\min\{k_{ti}^2, k_{tj}^2\}\Delta R_{ij}^2)$$
$$= \min_{i,j}(k_{ti}^2 \Delta R_{ij}^2)$$
$$= \min_{i}(k_{ti}^2 \min_{j} \Delta R_{ij}^2)$$

2D dist. on rap., ϕ cylinder

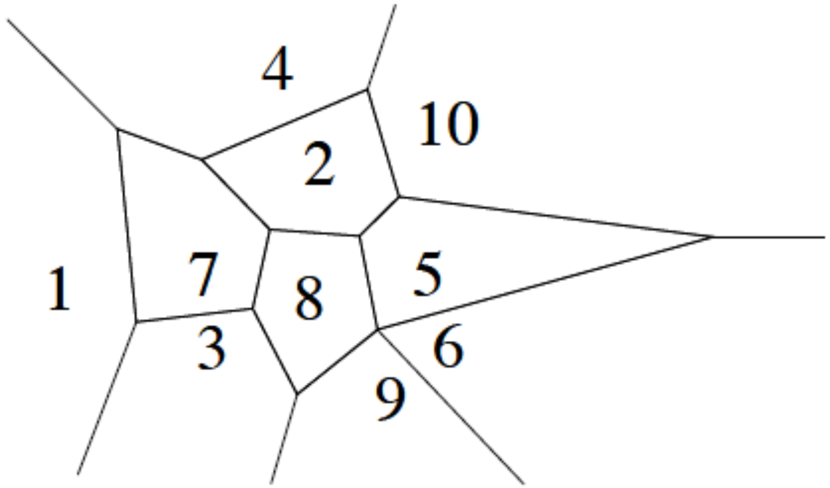
In words: for each i look only at the k_t distance to its 2D geometrical nearest neighbour (GNN).

k_t distance need only be calculated between GNNs

Each point has 1 GNN $\rightarrow$ need only calculate N d_{ij}'s
Cacciari & GPS, '05

How does use of GNN help?
Aren't there still $\frac{N^2}{2}$ ΔR_{ij}^2 to check. . . ?

Geometrical nearest neighbour finding is a classic problem in the field of Computational Geometry



Given a set of vertices on plane (1...10) a *Voronoi diagram* partitions plane into cells containing all points closest to each vertex

Dirichlet '1850, Voronoi '1908

A vertex's nearest other vertex is always in an adjacent cell.

E.g. GNN of point 7 must be among 1,4,2,8,3 (it is 3)

Construction of Voronoi diagram for N points: $N \ln N$ time — Fortune '88

Update of 1 point in Voronoi diagram: expected $\ln N$ time

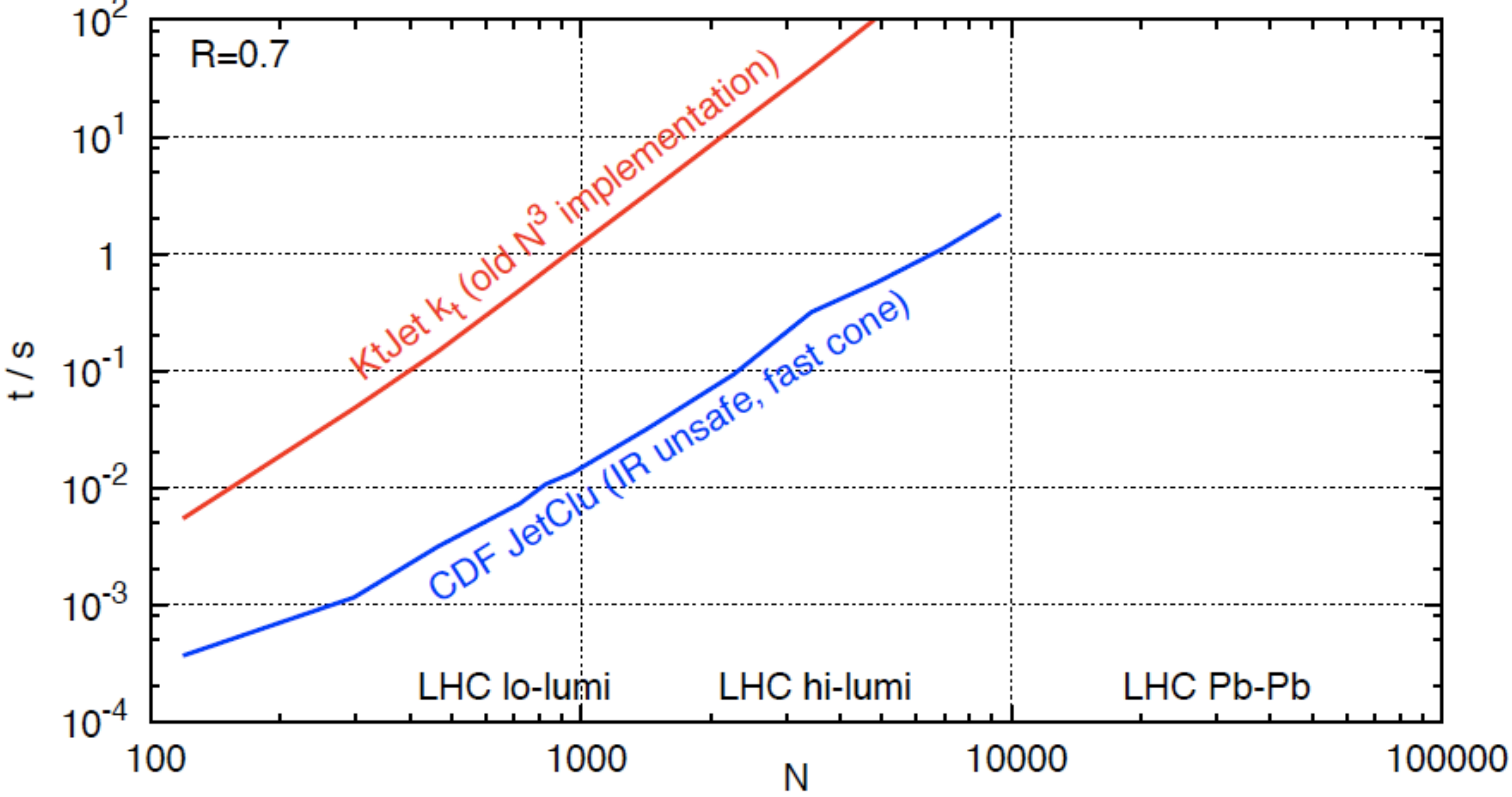
Devillers '99 [+ related work by other authors]

Convenient `C++` package available: CGAL, `http://www.cgal.org`

with help of CGAL, k_t clustering can be done in N ln N time

Coded in the FastJet package (v1), Cacciari & GPS '06

k_t algorithm speed: old & new



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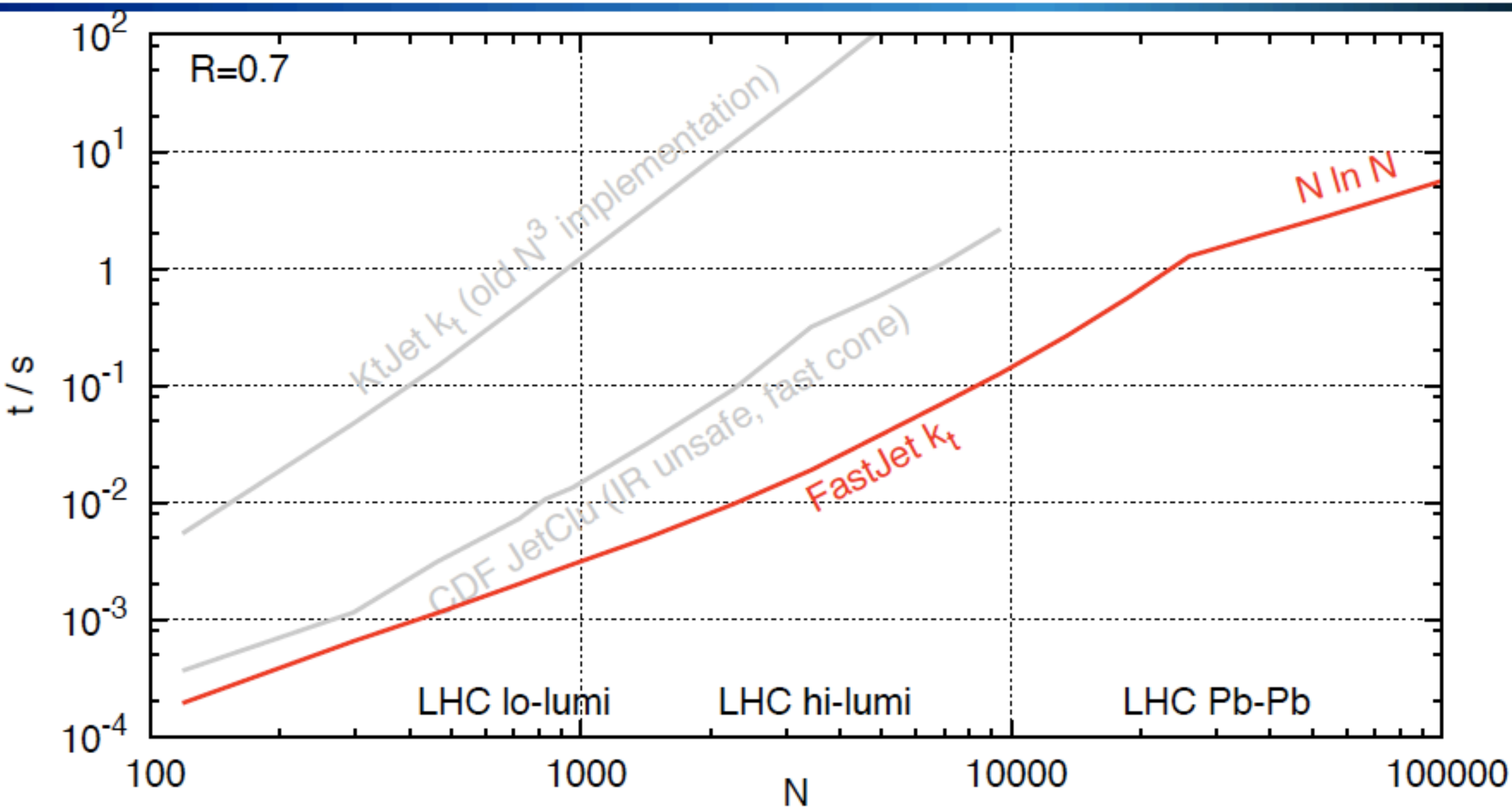
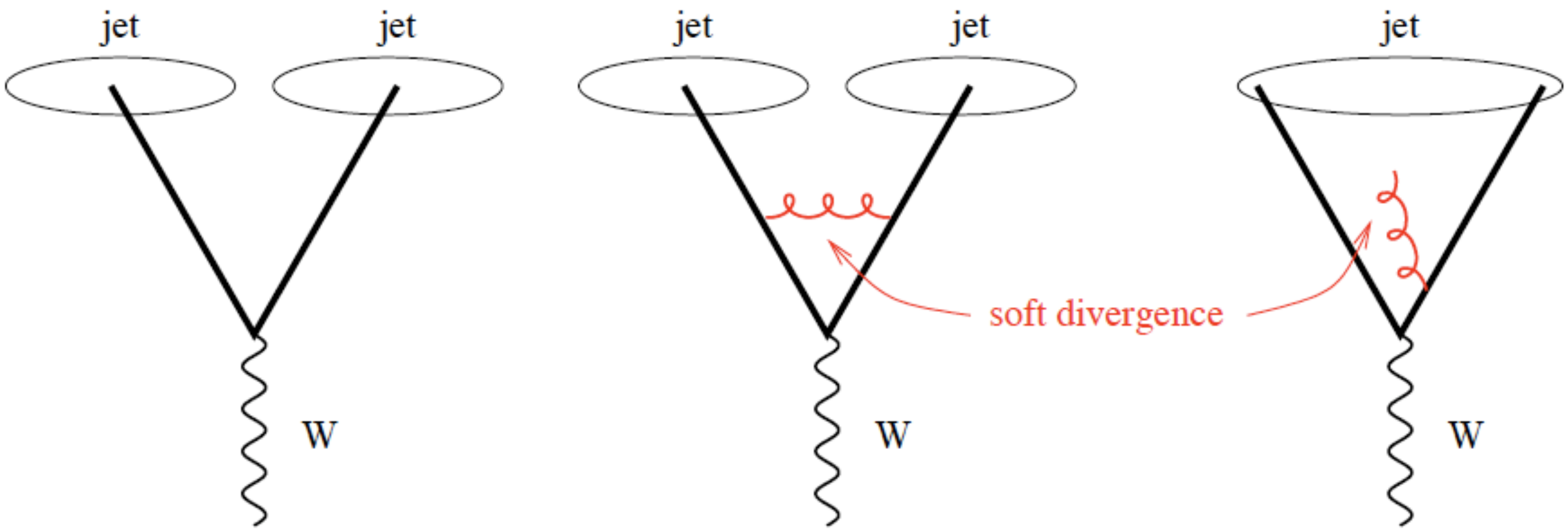


Factorisation of momentum & geometry

→ 2–3 orders of magnitude gain in speed!

Speed competitive with fast cone algorithms

JetClu (& Atlas Cone) in Wjj @ NLO



	$\alpha_s^2\alpha_{EW}$	$\alpha_s^3\alpha_{EW}$	$\alpha_s^3\alpha_{EW}$
1-jet			$+\infty$
2-jet	$\mathcal{O}(1)$	$-\infty$	**0**

With these (& most) cone algorithms, perturbative infinities fail to cancel at some order $\equiv$ **IR unsafety**

IRC safety & real-life

Real life does not have infinities, but pert. infinity leaves a real-life trace

$$\alpha_s^2 + \alpha_s^3 + \alpha_s^4 \times \infty \to \alpha_s^2 + \alpha_s^3 + \alpha_s^4 \times \ln p_t/\Lambda \to \alpha_s^2 + \underbrace{\alpha_s^3 + \alpha_s^3}_{\text{BOTH WASTED}}$$

Among consequences of IR unsafety:

	Last meaningful order			Known at
	JetClu, ATLAS cone [IC-SM]	MidPoint [IC$_{mp}$-SM]	CMS it. cone [IC-PR]	
Inclusive jets	LO	NLO	NLO	NLO ($\to$ NNLO)
W/Z + 1 jet	LO	NLO	NLO	NLO
3 jets	**none**	LO	LO	NLO [nlojet++]
W/Z + 2 jets	**none**	LO	LO	NLO [MCFM]
m_{jet} in $2j + X$	**none**	**none**	**none**	LO

NB: 50,000,000\$/£/CHF/€ investment in NLO

IRC safety & real-life

Real life does not have infinities, but pert. infinity leaves a real-life trace

$$\alpha_s^3 + \alpha_s^4 \times \infty \rightarrow \qquad \alpha_s^3 + \alpha_s^4 \times \ln p_t/\Lambda \rightarrow \qquad \underbrace{\alpha_s^3 + \alpha_s^3}_{\text{BOTH WASTED}}$$

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Inclusive jets	LO	NLO	NLO	NLO (→ NNLO)
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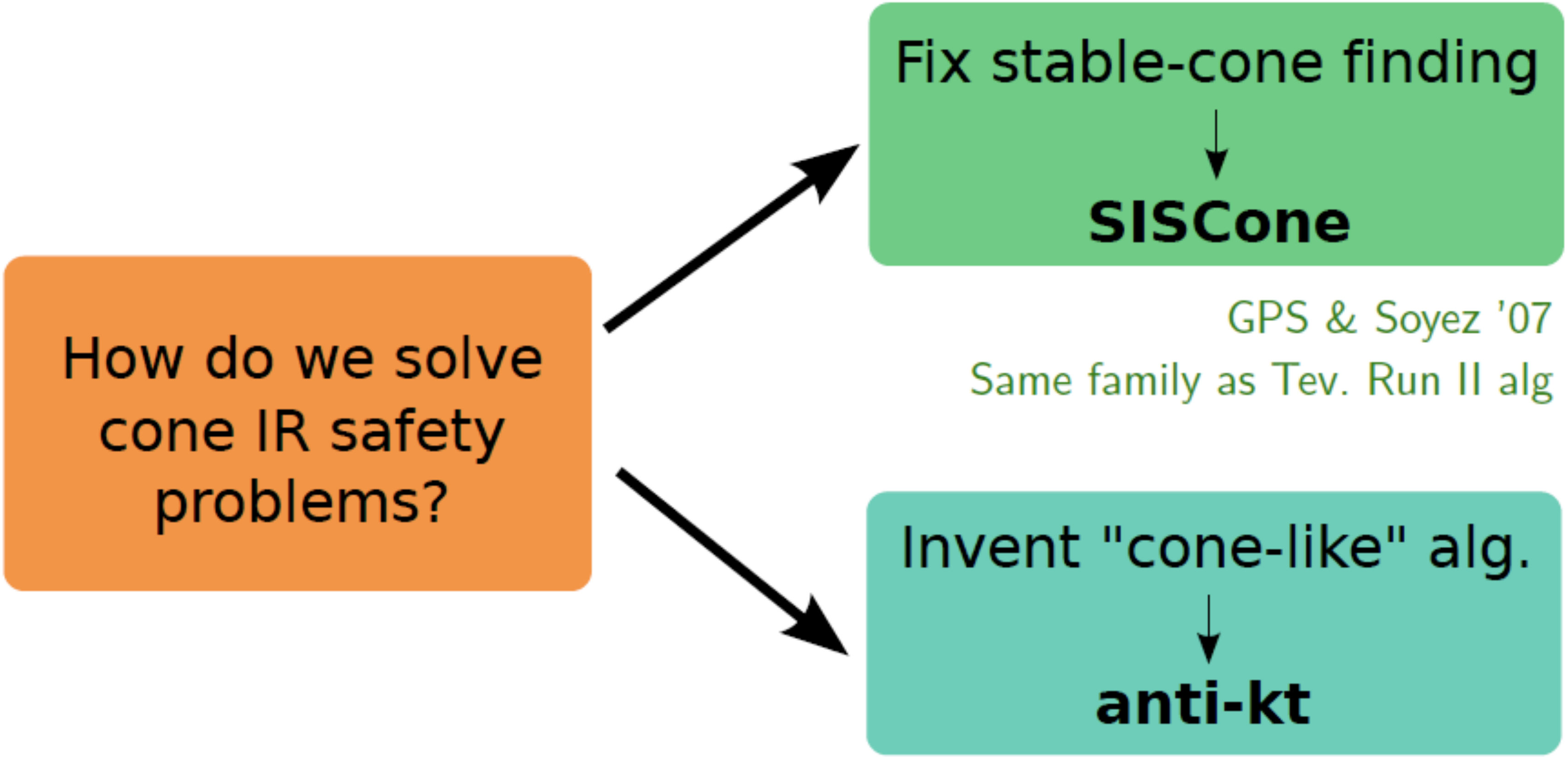
3 jets	**none**	LO	LO	NLO [nlojet++]
$W/Z + 2$ jets	**none**	LO	LO	NLO [MCFM]
m_{jet} in $2j + X$	**none**	**none**	**none**	LO

NB: 50,000,000\$/£/CHF/€ investment in NLO

Multi-jet contexts much more sensitive: **ubiquitous at LHC**

And LHC will rely on QCD for background double-checks
extraction of cross sections, extraction of parameters

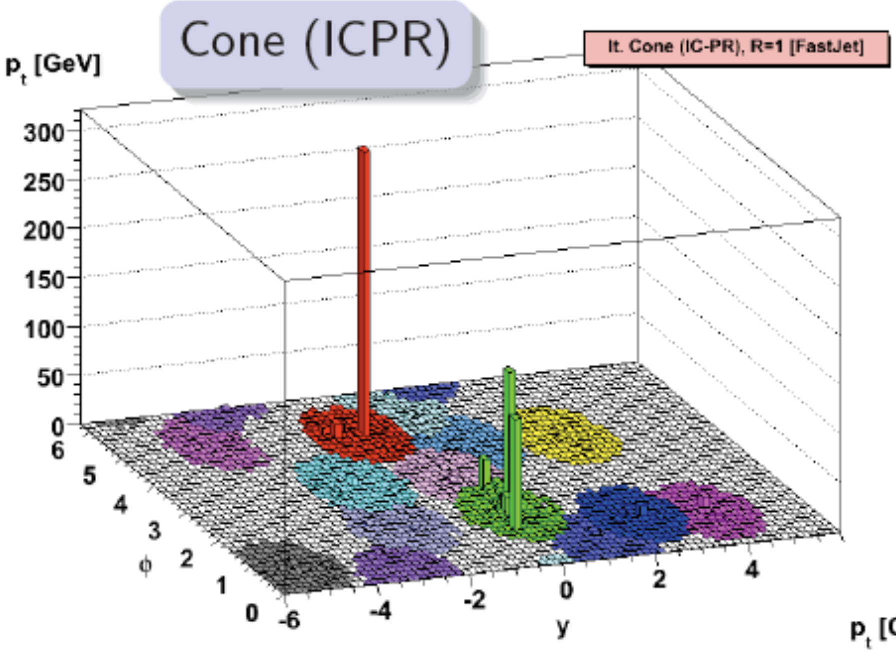
rescuing cones : two directions



GPS & Soyez '07
Same family as Tev. Run II alg

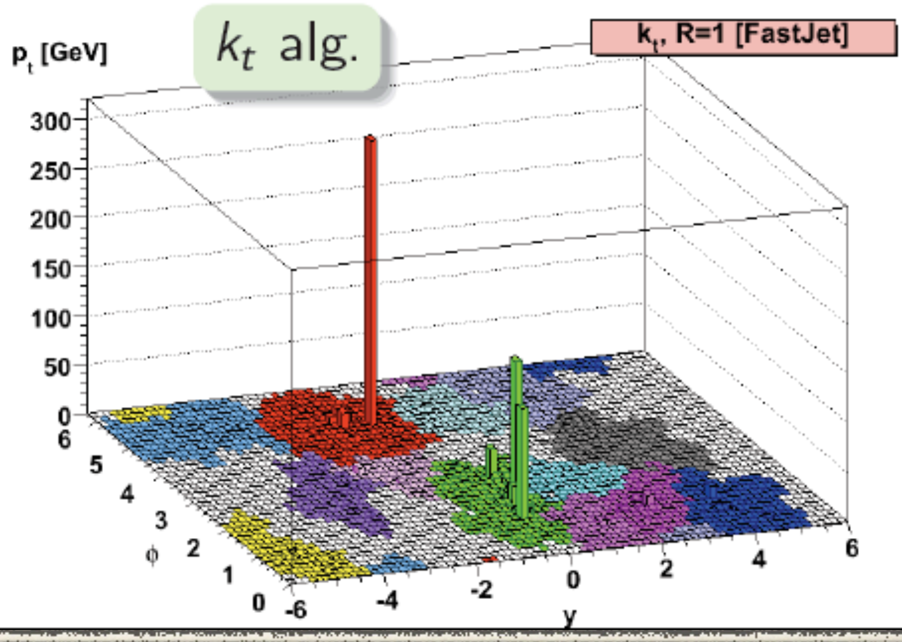
Cacciari, GPS & Soyez '08

essential characteristics of cones ?



(Some) cone algorithms give **circular** jets in $y - \phi$ plane

Much appreciated by experiments e.g. for acceptance corrections



k_t jets are **irregular**

Because soft junk clusters together first:

$$d_{ij} = \min(k_{ti}^2, k_{tj}^2)\Delta R_{ij}^2$$

Regularly held against k_t

essential characteristics of cones ?

Is there some other, non cone-based way of getting circular jets?

strange it may seem,

but **sequential recombination**

can be adjusted to give

"**circular jets**"

adapting sequential recombination to give circular jets

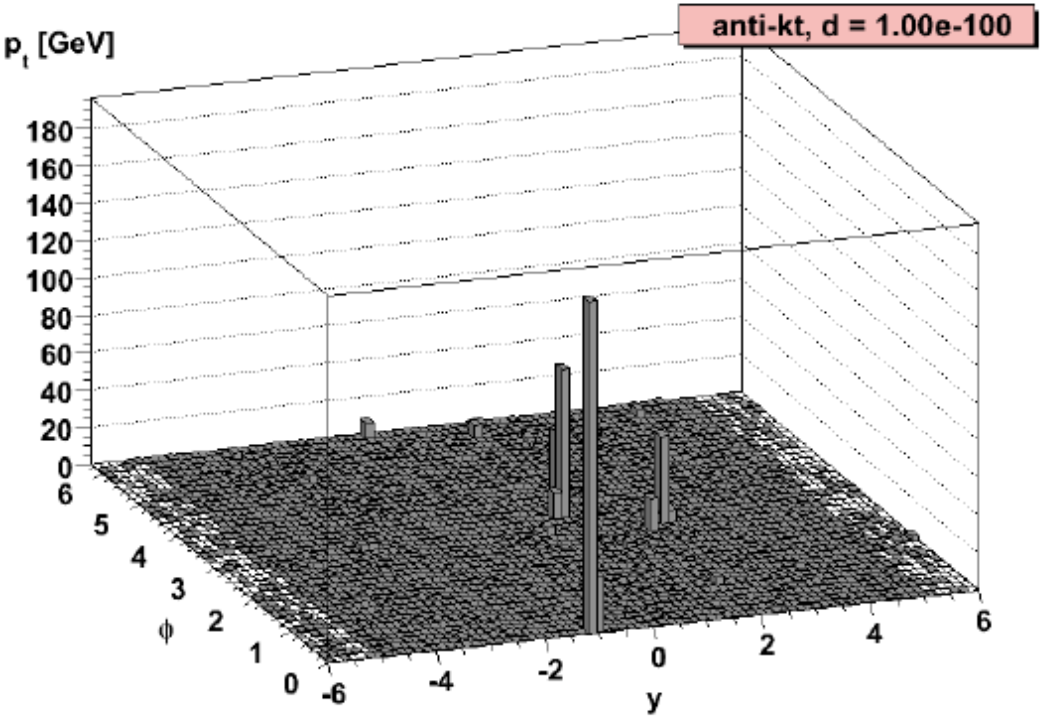
Soft stuff clusters with nearest neighbour

$$k_t:\ d_{ij} = \min(k_{ti}^2, k_{tj}^2)\Delta R_{ij}^2 \longrightarrow \textbf{anti-k}_\mathbf{t}:\ d_{ij} = \frac{\Delta R_{ij}^2}{\max(k_{ti}^2, k_{tj}^2)}$$

Hard stuff clusters with nearest neighbour

divergence over soft divergence

Cacciari, GPS & Soyez '08



adapting sequential recombination to give circular jets

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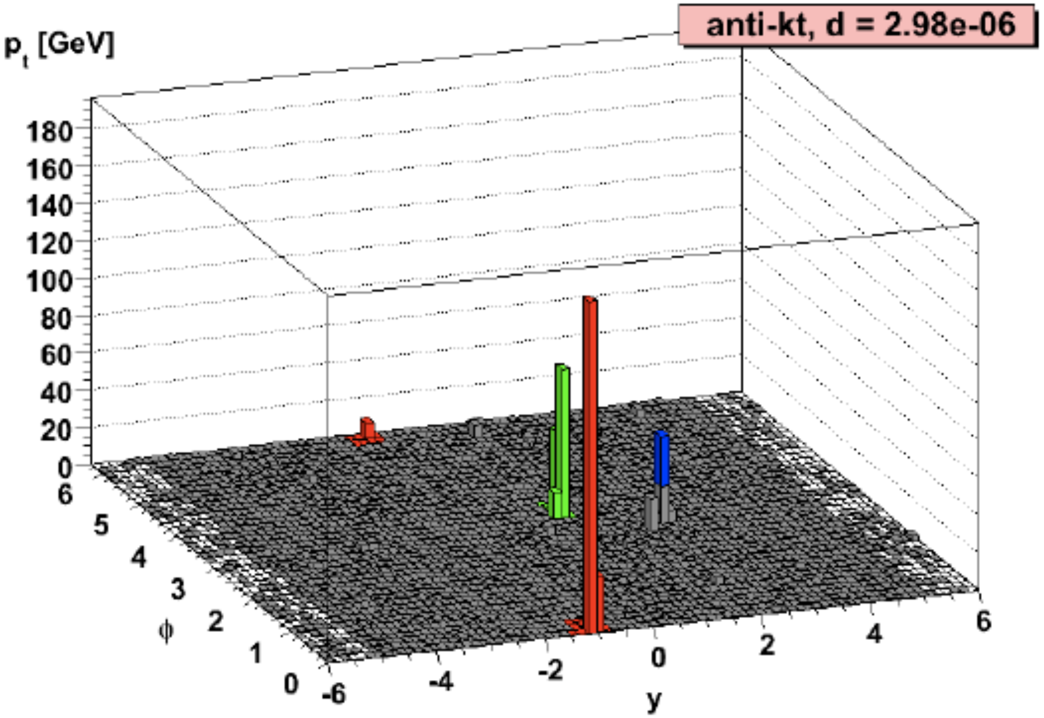

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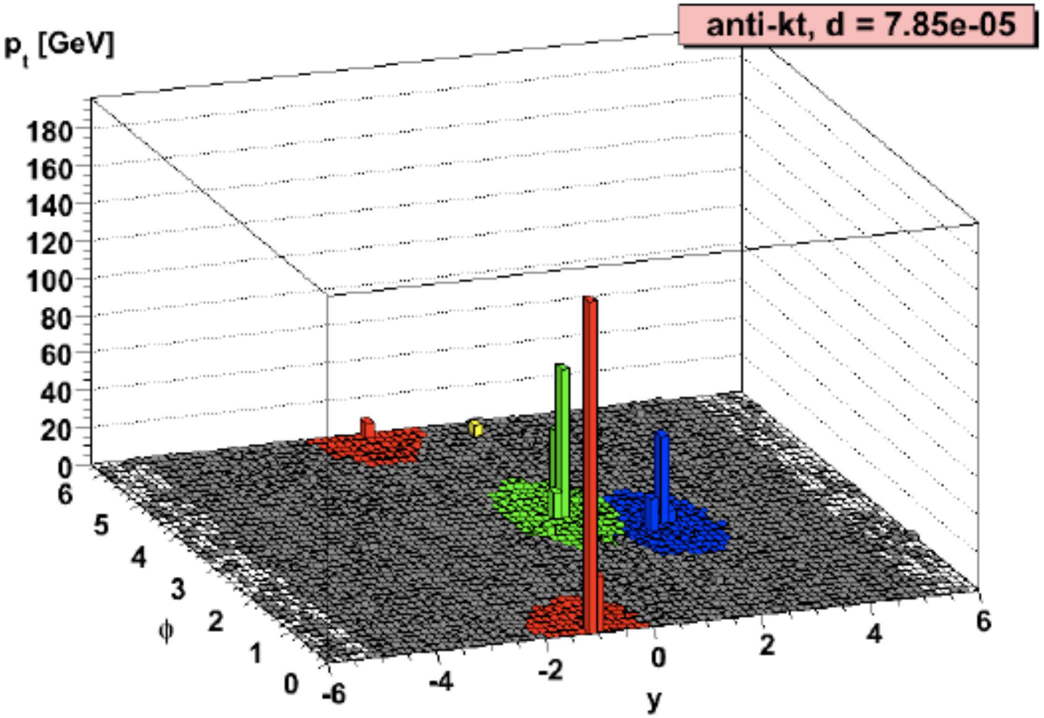

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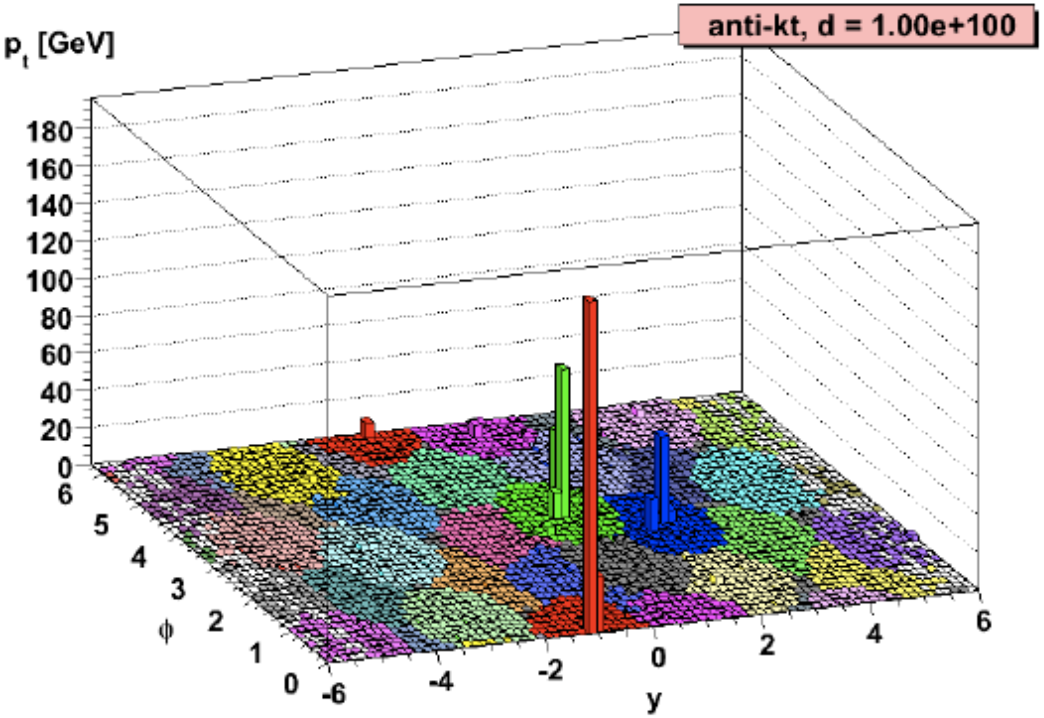


anti-k$_t$ gives cone-like jets without using stable cones

A full set of IRC-safe jet algorithms

Generalise inclusive-type sequential recombination with

$$d_{ij} = \min(k_{ti}^{2p}, k_{tj}^{2p})\Delta R_{ij}^2/R^2 \qquad d_{iB} = k_{ti}^{2p}$$

	Alg. name	Comment	time
$p = 1$	k_t CDOSTW '91-93; ES '93	Hierarchical in rel. k_t	$N \ln N$ exp.
$p = 0$	Cambridge/Aachen Dok, Leder, Moretti, Webber '97 Wengler, Wobisch '98	Hierarchical in angle Scan multiple R at once $\leftrightarrow$ QCD angular ordering	$N \ln N$
$p = -1$	anti-k_t Cacciari, GPS, Soyez '08 $\sim$ reverse-k_t Delsart	Hierarchy meaningless, jets like CMS cone (IC-PR)	$N^{3/2}$
SC-SM	SISCone GPS Soyez '07 + Tevatron run II '00	Replaces JetClu, ATLAS MidPoint (xC-SM) cones	$N^2 \ln N$ exp.

All these algorithms coded in (efficient) C++ at
`http://fastjet.fr/` (Cacciari, GPS & Soyez '05-08)

Thus, Snowmass is solved.

But that was the problem of the 1990s ...

What are the problems
we **should** be trying to solve
in the LHC epoch ?

Which jet definition(s) to use for LHC ?

choice of ***algorithm*** (kt, anti-kt, SISCone, ...)
choice of ***parameters*** (R, ...)

can we address these questions systematically i.e. scientifically ?

what R is best to isolate a jet ?

E.g. to reconstruct $m_X \sim (p_{tq} + p_{t\bar{q}})$

PT radiation:

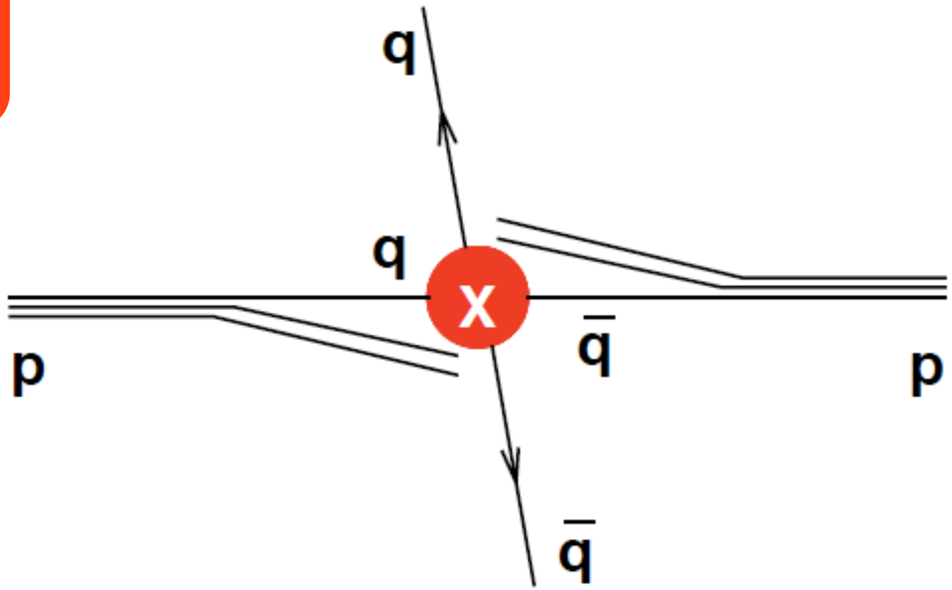
$$q: \quad \langle \Delta p_t \rangle \simeq \frac{\alpha_s C_F}{\pi} p_t \ln R$$

Hadronisation:

$$q: \quad \langle \Delta p_t \rangle \simeq -\frac{C_F}{R} \cdot 0.4 \text{ GeV}$$

Underlying event:

$$q, g: \quad \langle \Delta p_t \rangle \simeq \frac{R^2}{2} \cdot 2.5\text{–}15 \text{ GeV}$$



Minimise fluctuations in p_t

Use crude approximation:

$$\langle \Delta p_t^2 \rangle \simeq \langle \Delta p_t \rangle^2$$

in small-R limit (?!)

cf. Dasgupta, Magnea & GPS '07

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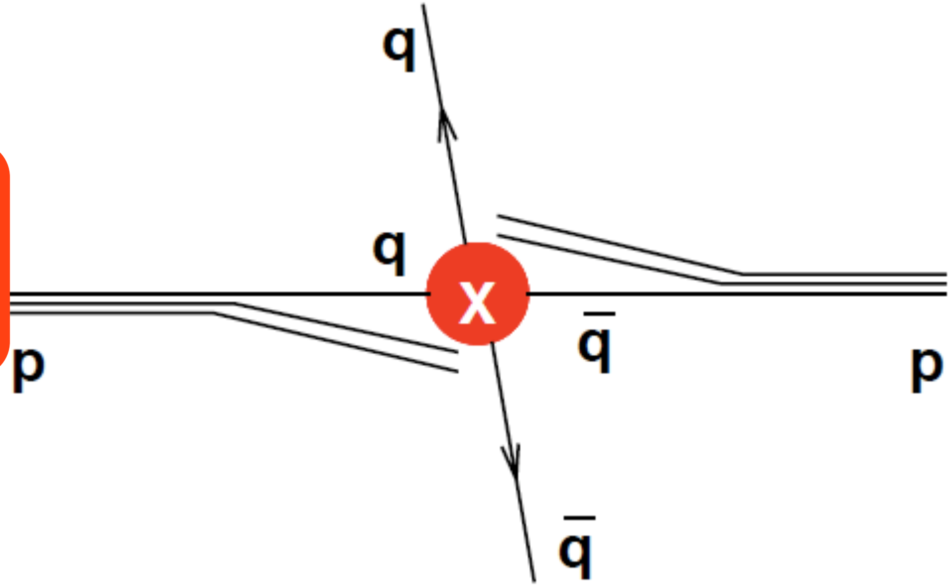

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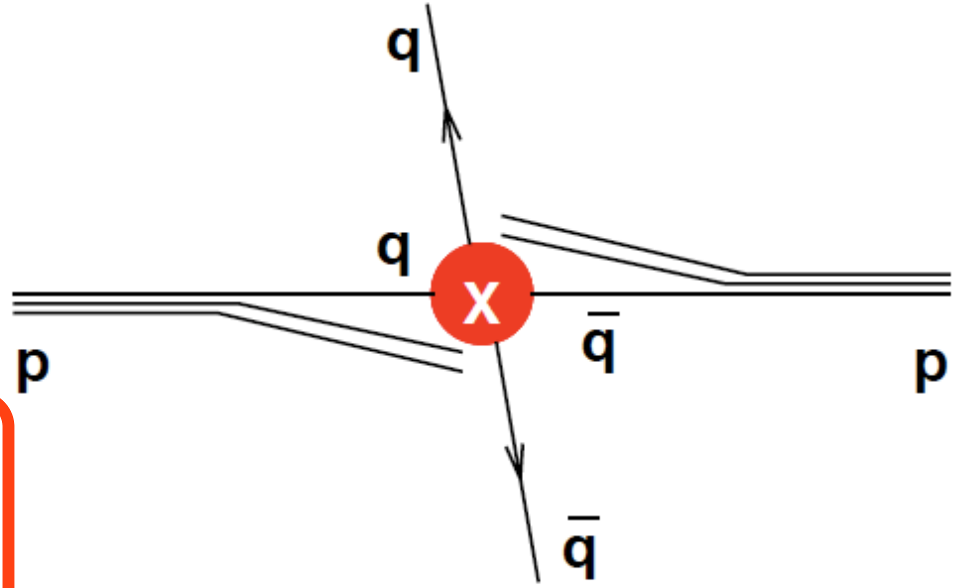

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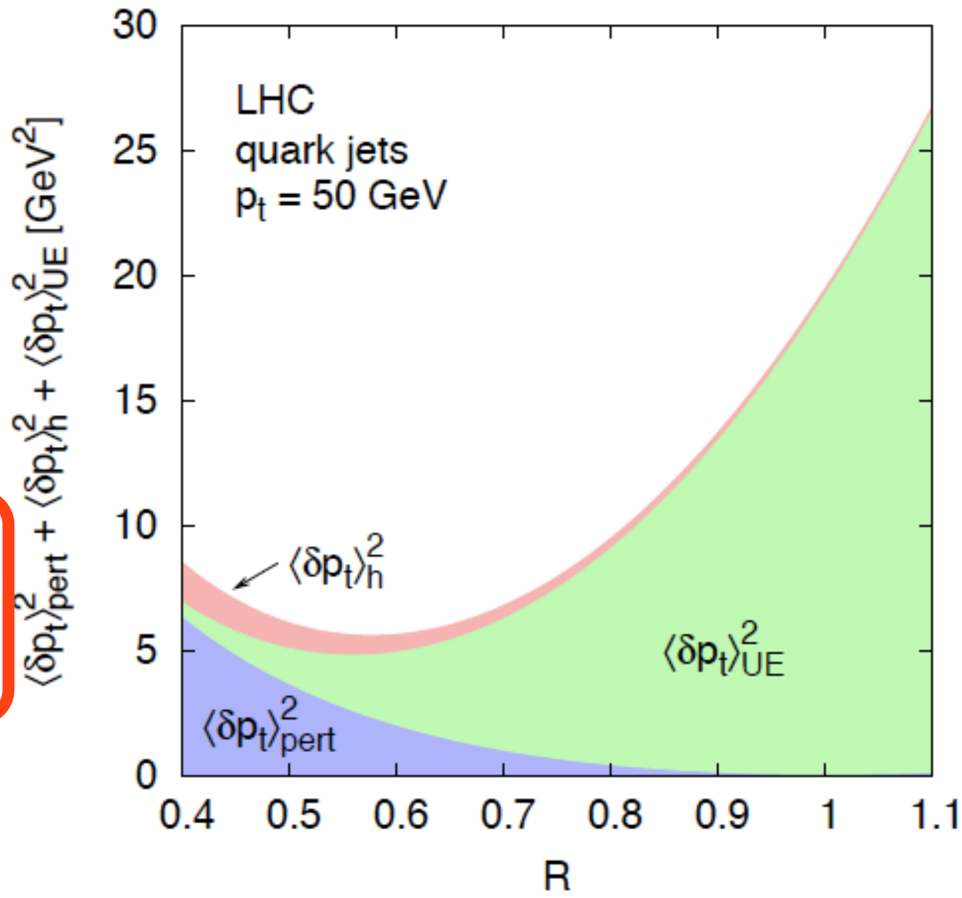
50 GeV quark jet



in small-R limit (?!)

cf. Dasgupta, Magnea & GPS '07

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Minimise fluctuations in p_t

Use crude approximation:

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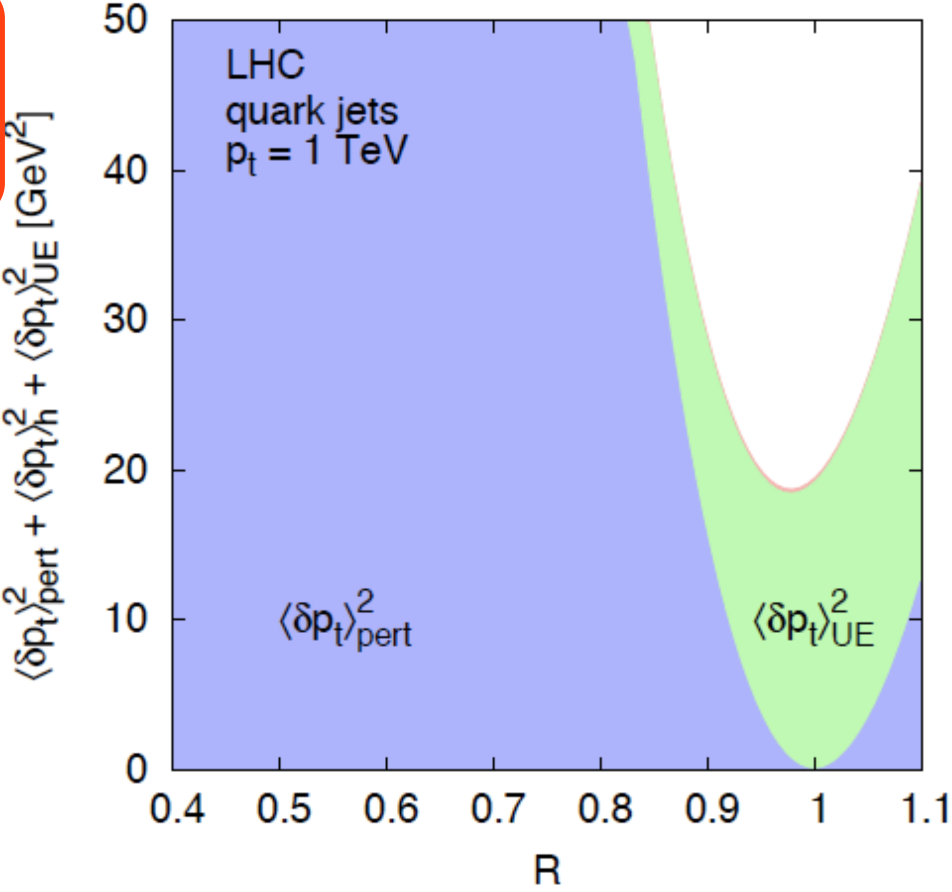
1 TeV quark jet



in small-R limit (?!)

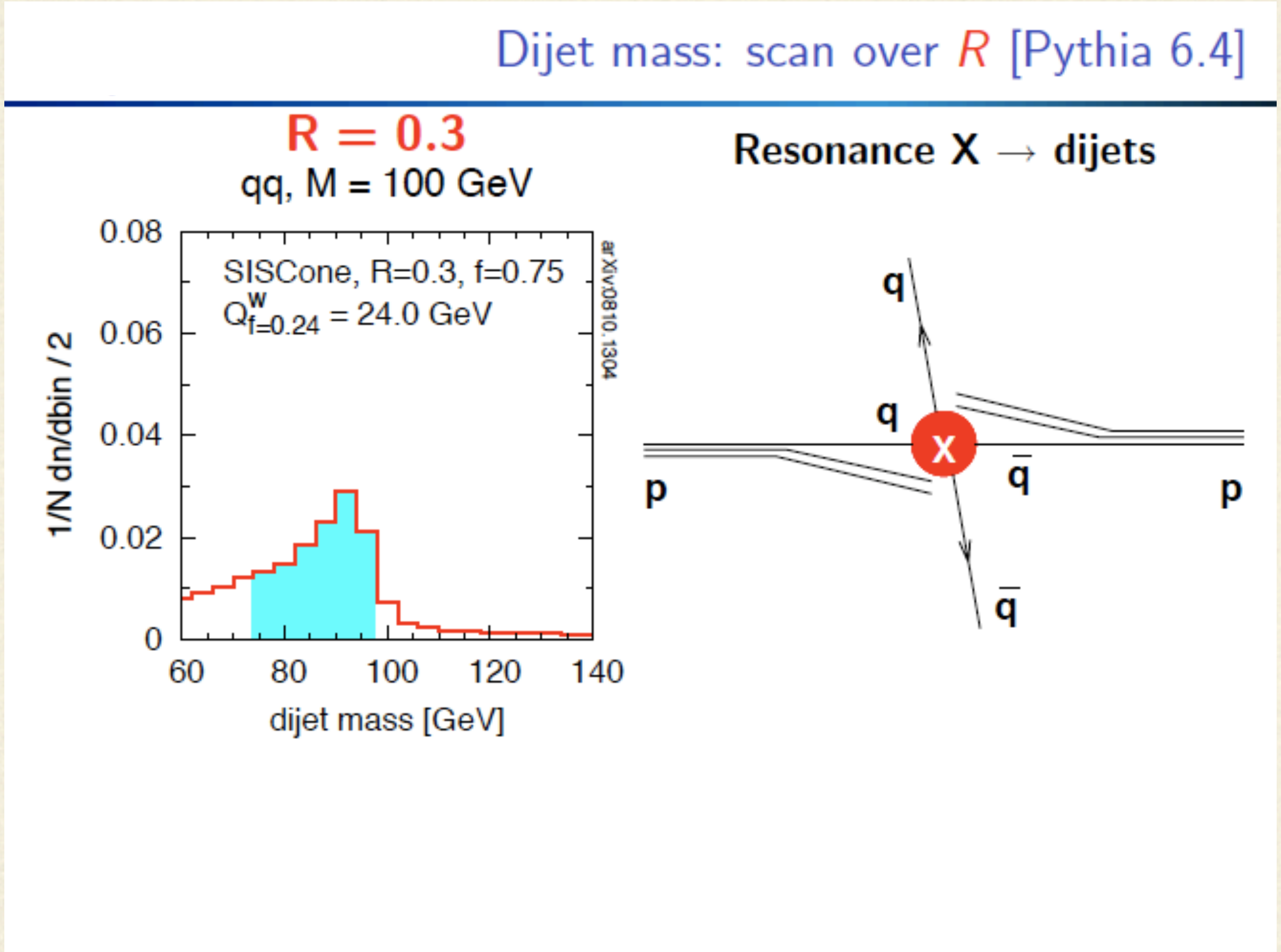
cf. Dasgupta, Magnea & GPS '07

what R is best to isolate a jet ?

At low p_t, small R limits relative impact of UE

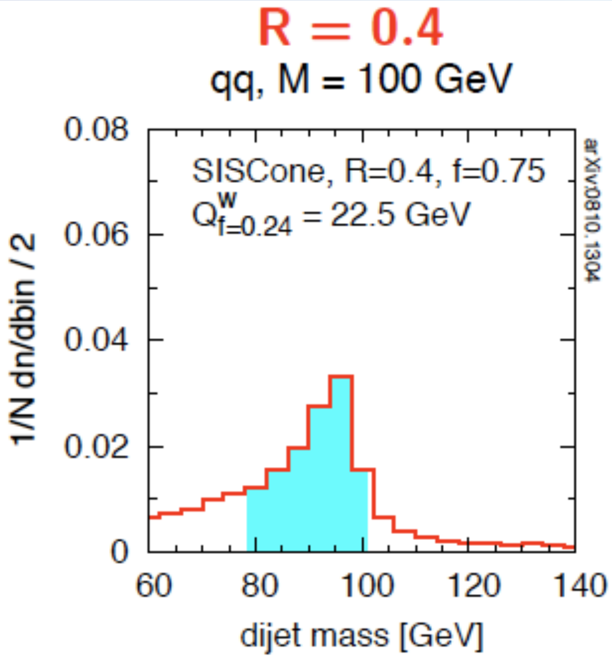
At high p_t, perturbative effects dominate over non-perturbative $\rightarrow R_{best} \sim 1$.

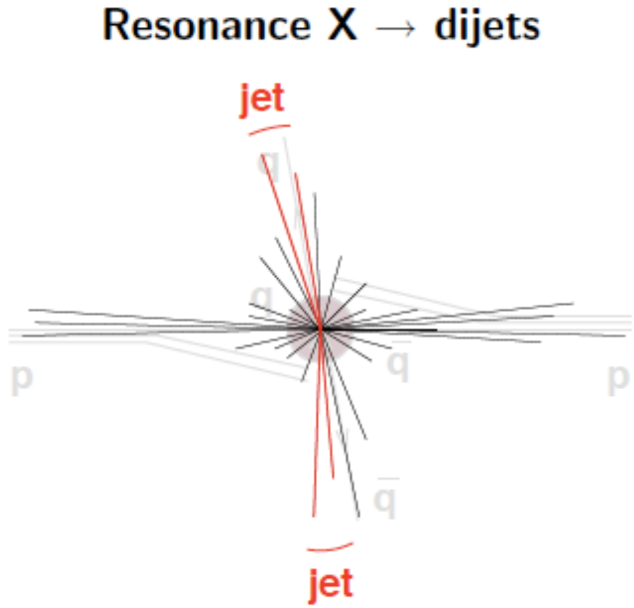
fate of a resonance peak



fate of a resonance peak

Dijet mass: scan over *R* [Pythia 6.4]





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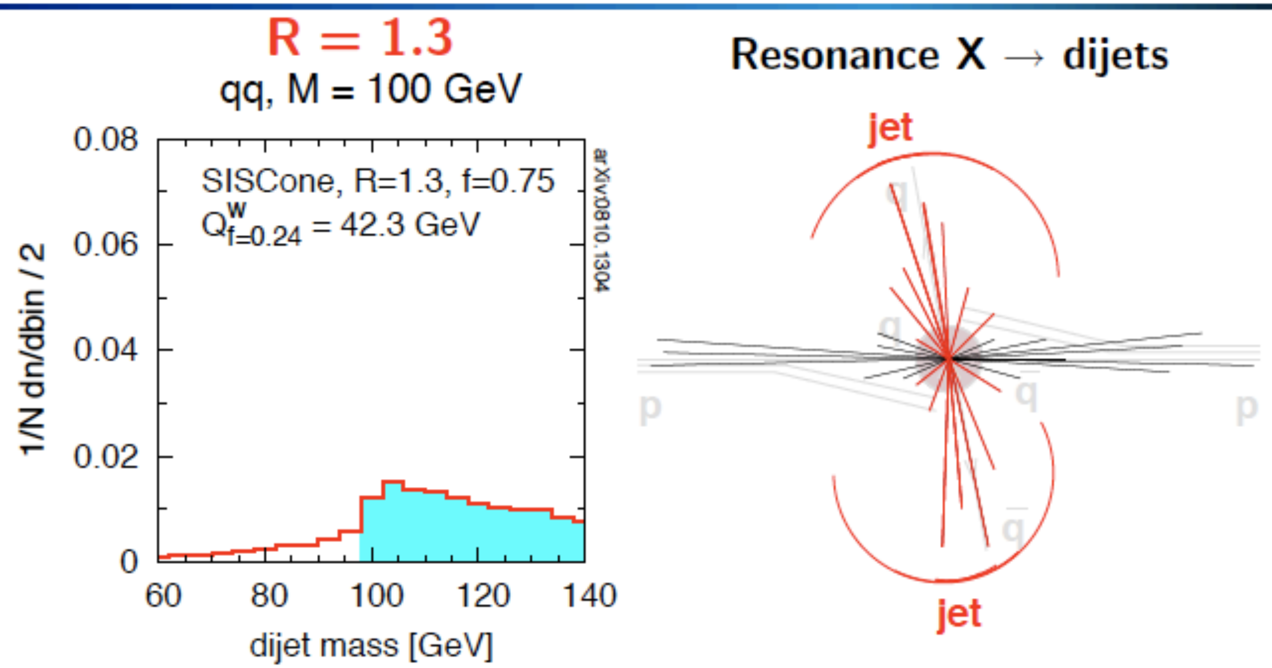

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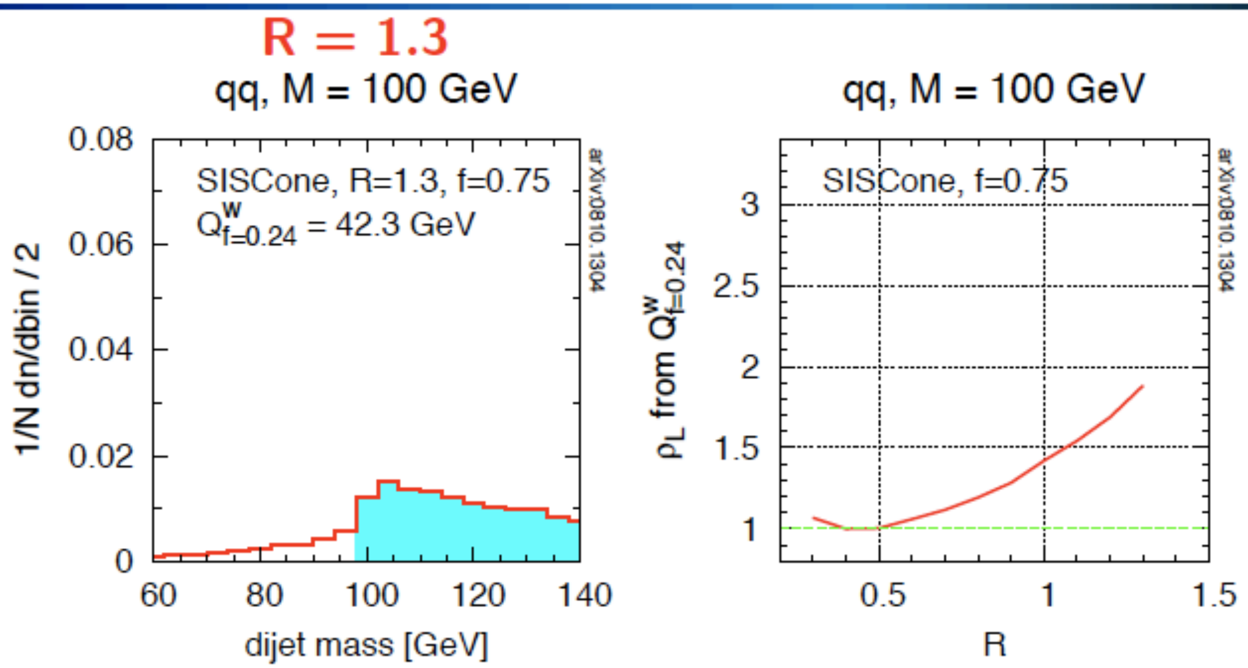
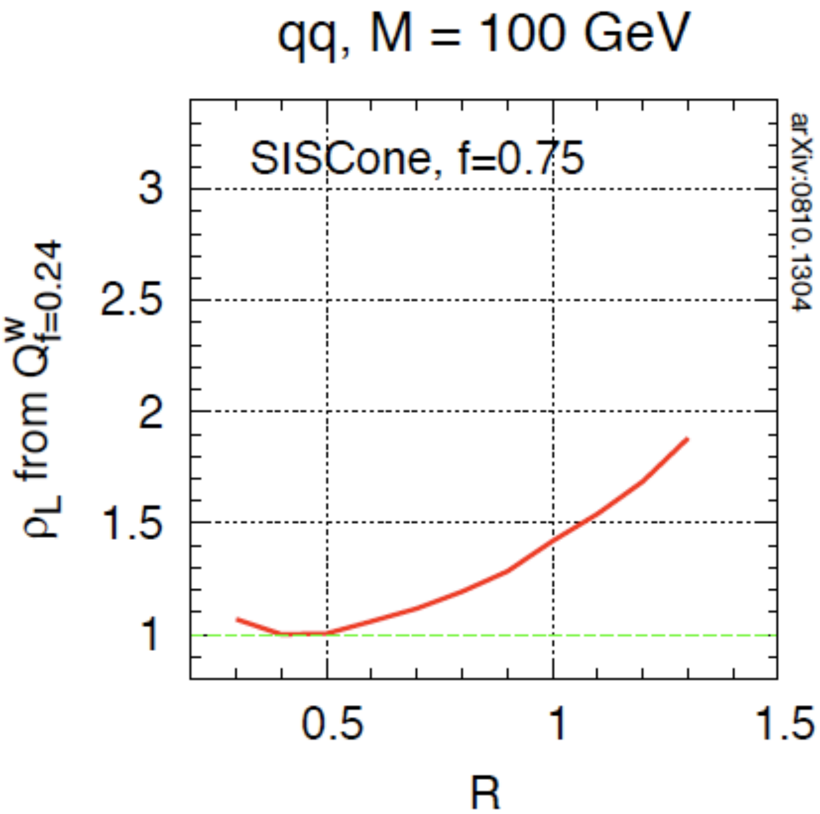


After scanning, summarise "quality" v. *R*. Minimum ≡ BEST

picture not so different from crude analytical estimate

Scan through $q\bar{q}$ mass values

$\mathbf{m_{qq} = 100\ GeV}$



Best R is at minimum of curve

- Best R depends strongly on mass of system
- Increases with mass, just like crude analytical prediction

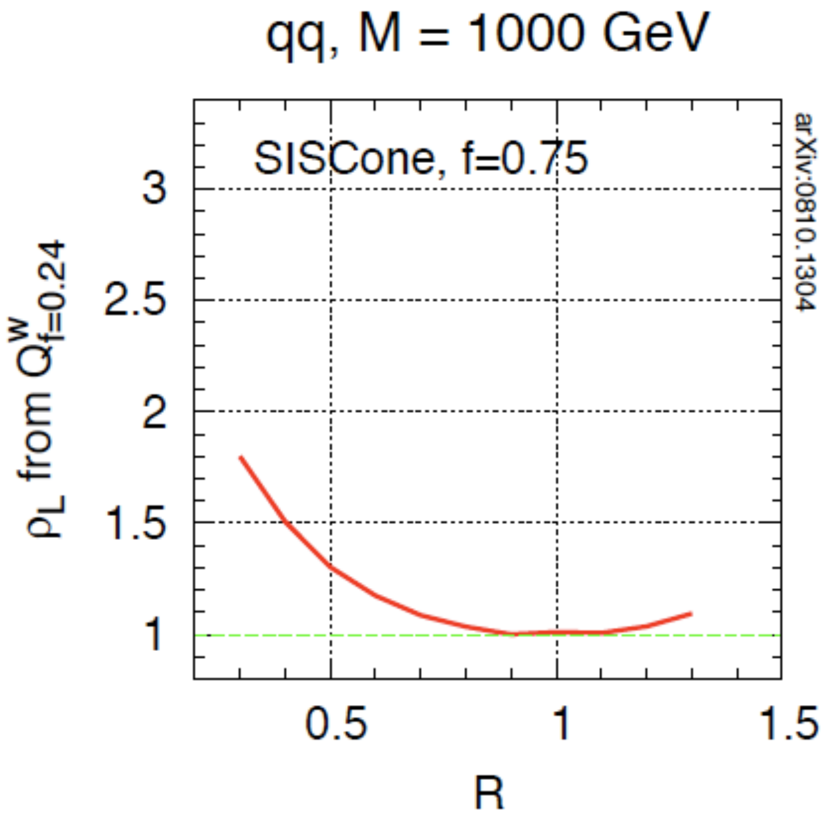
  NB: current analytics too crude

BUT: so far, LHC's plans involve running with fixed smallish R values

e.g. CMS arXiv:0807.4961

Scan through $q\bar{q}$ mass values

$\mathbf{m_{qq} = 1000\ GeV}$



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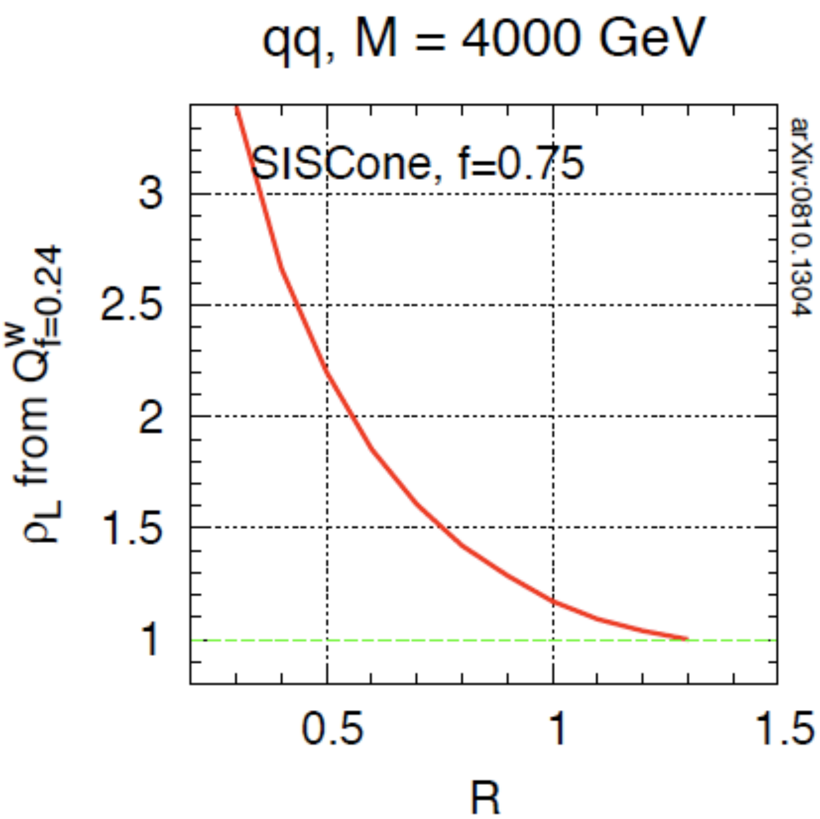
e.g. CMS arXiv:0807.4961

Scan through $q\bar{q}$ mass values

$\mathbf{m_{qq} = 4000\ GeV}$



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BUT: so far, LHC's plans involve running with fixed smallish R values

e.g. CMS arXiv:0807.4961

NB: 100,(... sonances

from http ... Soyez '08

about 100,000 plots for various jet algorithms, narrow ***qq*** and ***gg*** resonances can be found at **http://quality.fastjet.fr**

Cacciari, Rojo, Salam & Soyez, 2008

http://quality.fastjet.fr/

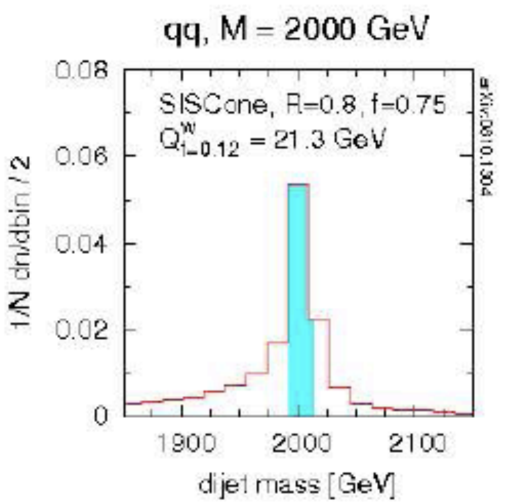
File Edit View History Bookmarks Tools Help

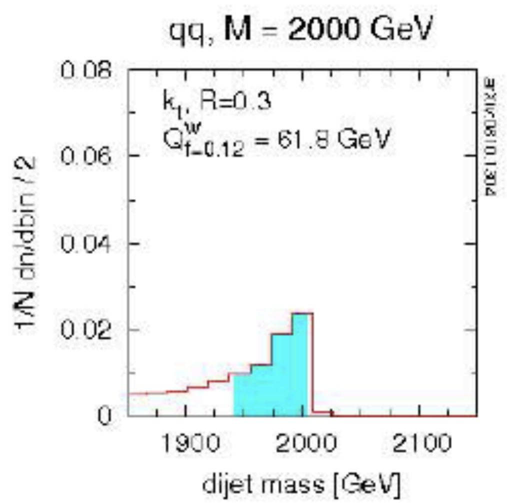
http://www.lpthe.jussieu.fr/~salam/jet-quality/

Testing jet definitions: qq & gg c...

Testing jet definitions: qq & gg cases

by M. Cacciari, J. Rojo, G.P. Salam and G. Soyez, arXiv:0810.1304





○ k_t ○ C/A ○ anti-k_t ◉ SISCone ○ C/A-filt	◉ k_t ○ C/A ○ anti-k_t ○ SISCone ○ C/A-filt
- R = 0.8 + →all R	- R = 0.3 + →all R
◉ $Q^{W}_{f=z}$ ○ $Q^{1/f}_{W=x\sqrt{M}}$ ☐ x 2	◉ $Q^{W}_{f=z}$ ○ $Q^{1/f}_{W=x\sqrt{M}}$ ☐ x 2
- rebin = 2 +	- rebin = 2 +
◉ qq ○ gg	◉ qq ○ gg
- mass = 2000 +	- mass = 2000 +
pileup: ◉ none ○ 0.05 ○ 0.25 mb^{-1}/ev	pileup: ◉ none ○ 0.05 ○ 0.25 mb^{-1}/ev
subtraction: ☐	subtraction: ☐

This page is intended to help visualize how the choice of jet definition impacts a dijet invariant mass reconstruction at LHC.

The controls fall into 4 groups:

- *the jet definition*
- *the binning and quality measures*
- *the jet-type (quark, gluon) and mass scale*
- *pileup and subtraction*

The events were simulated with Pythia 6.4 (DWT tune) and reconstructed with FastJet 2.3.

For more information, view and listen to the ***flash demo****, or click on individual terms.*

This page has been tested with Firefox v2 and v3, IE7, Safari v3, Opera v9.5, Chrome 0.2.

Reset

doing physics with jets : boosted heavy particles

How about task of resolving separate jets from separate partons?

Illustrate in context of boosted $H \to b\bar{b}$ reconstruction

example : "Higgsstrahlung" - WH/ZH @ LHC

- Signal is $W \to \ell\nu$, $H \to b\bar{b}$
- Backgrounds include $Wb\bar{b}$, $t\bar{t} \to \ell\nu b\bar{b}jj$, ...

Studied e.g. in ATLAS TDR

example : "Higgsstrahlung" - WH/ZH @ LHC

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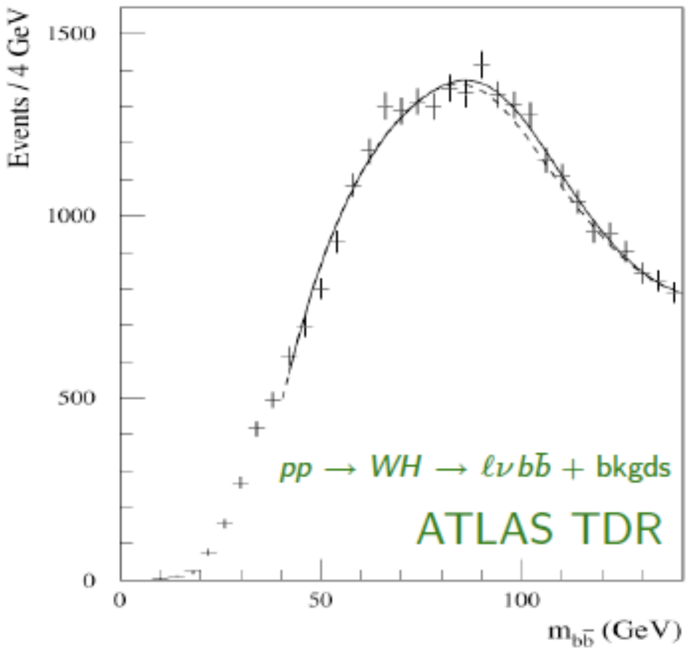
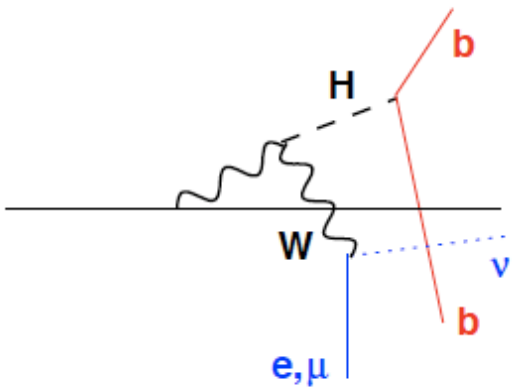


Difficulties, e.g.

- $gg \to t\bar{t}$ has $\ell\nu b\bar{b}$ with **same intrinsic mass scale**, but much higher partonic luminosity
- Need exquisite control of bkgd shape



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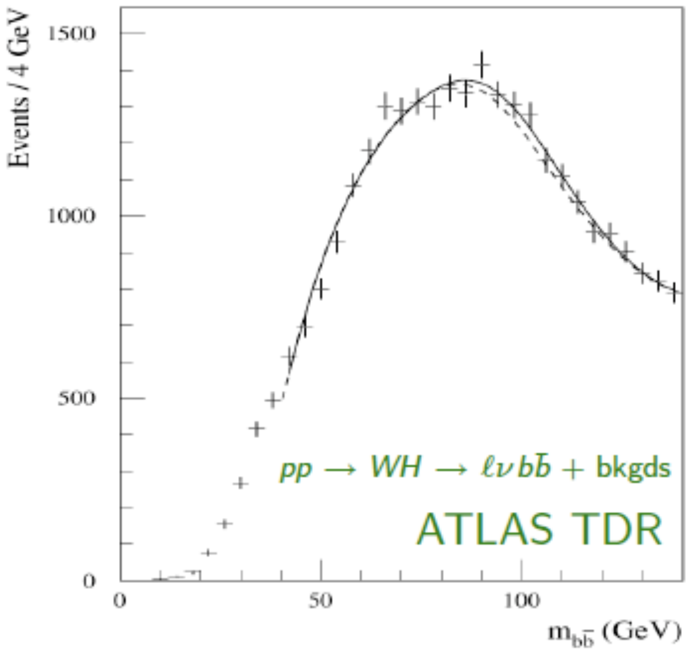
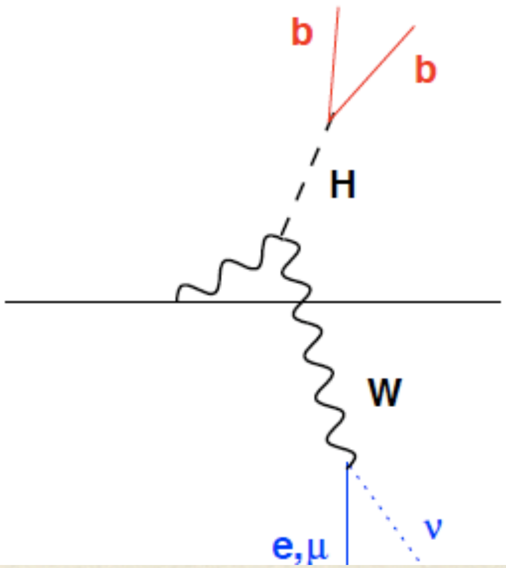
- Backgrounds include $Wb\bar{b}$, $t\bar{t} \to \ell\nu b\bar{b}jj$, ...

Studied e.g. in ATLAS TDR



Difficulties, e.g.

- $gg \to t\bar{t}$ has $\ell\nu b\bar{b}$ with **same intrinsic mass scale**, but much higher partonic luminosity
- Need exquisite control of bkgd shape



Try a long shot?

- Go to high p_t ($p_{tH}, p_{tV} > 200$ GeV)
- Lose 95% of signal, but more efficient?
- Maybe kill $t\bar{t}$ & gain clarity?

example : “Higgsstrahlung” - WH/ZH @ LHC

Question:

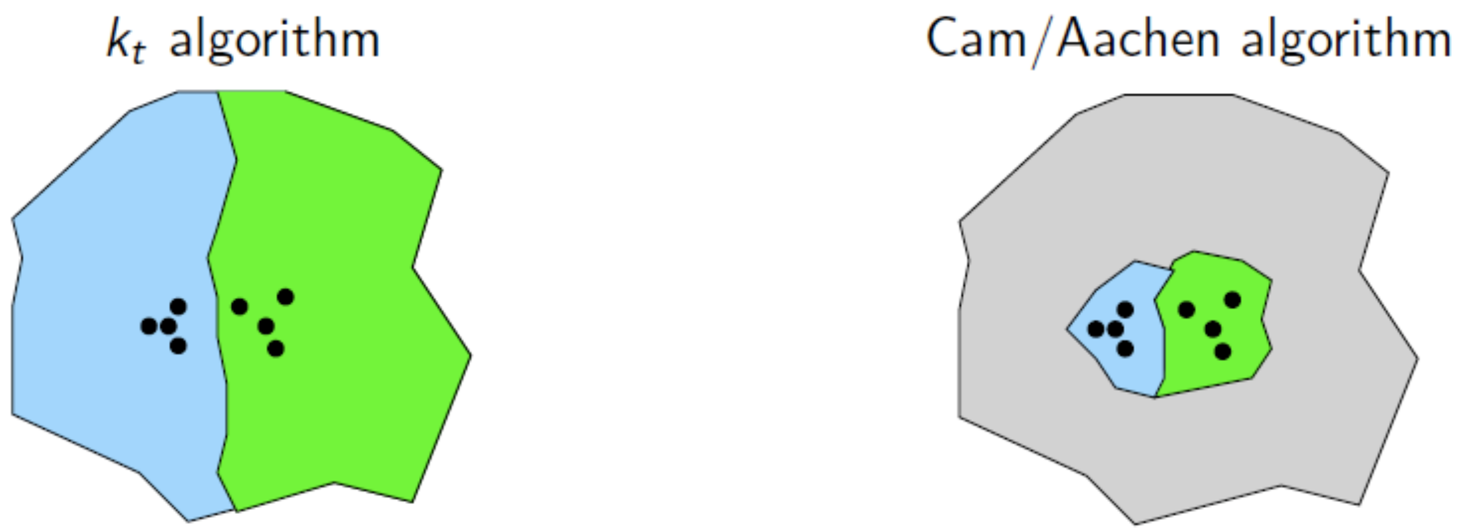
What’s the best strategy to identify the two-pronged structure of the boosted Higgs decay?

the tool

The Cambridge/Aachen jet alg. Dokshitzer et al '97
Wengler & Wobisch '98

Work out $\Delta R_{ij}^2 = \Delta y_{ij}^2 + \Delta \phi_{ij}^2$ between all pairs of objects i, j;
Recombine the closest pair;
Repeat until all objects separated by $\Delta R_{ij} > R$. [in FastJet]

Gives "hierarchical" view of the event; work through it backwards to analyse jet

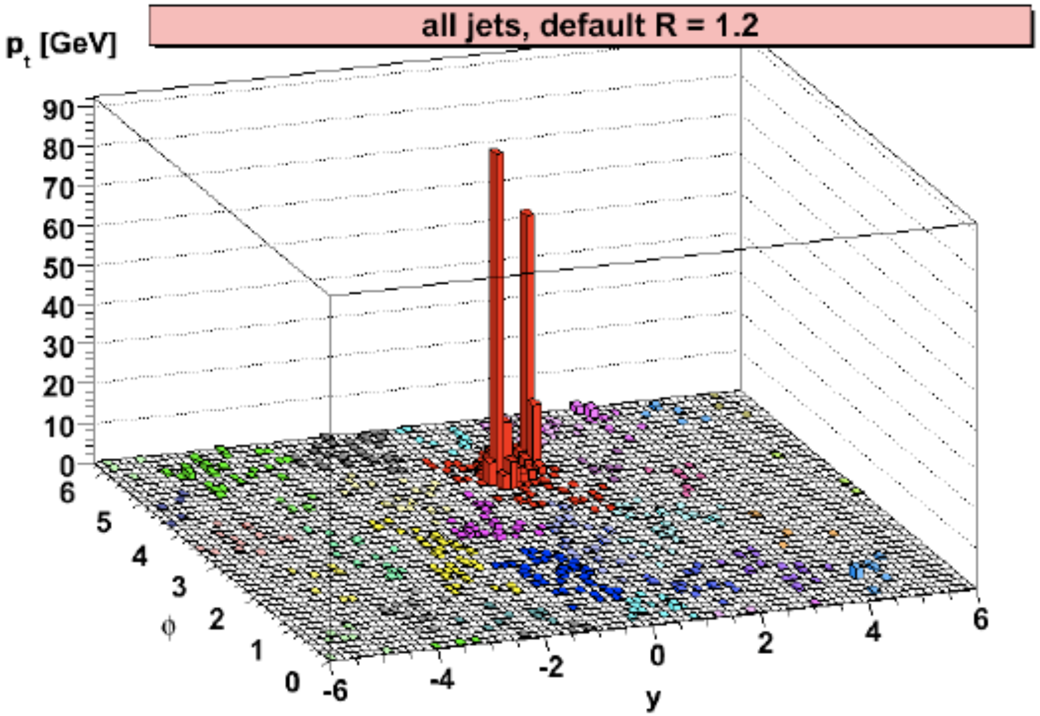


Allows you to "dial" the correct R to keep perturbative radiation, but throw out UE

$pp \to ZH \to \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

SIGNAL

Herwig 6.510 + Jimmy 4.31 + FastJet 2.3



Zbb BACKGROUND

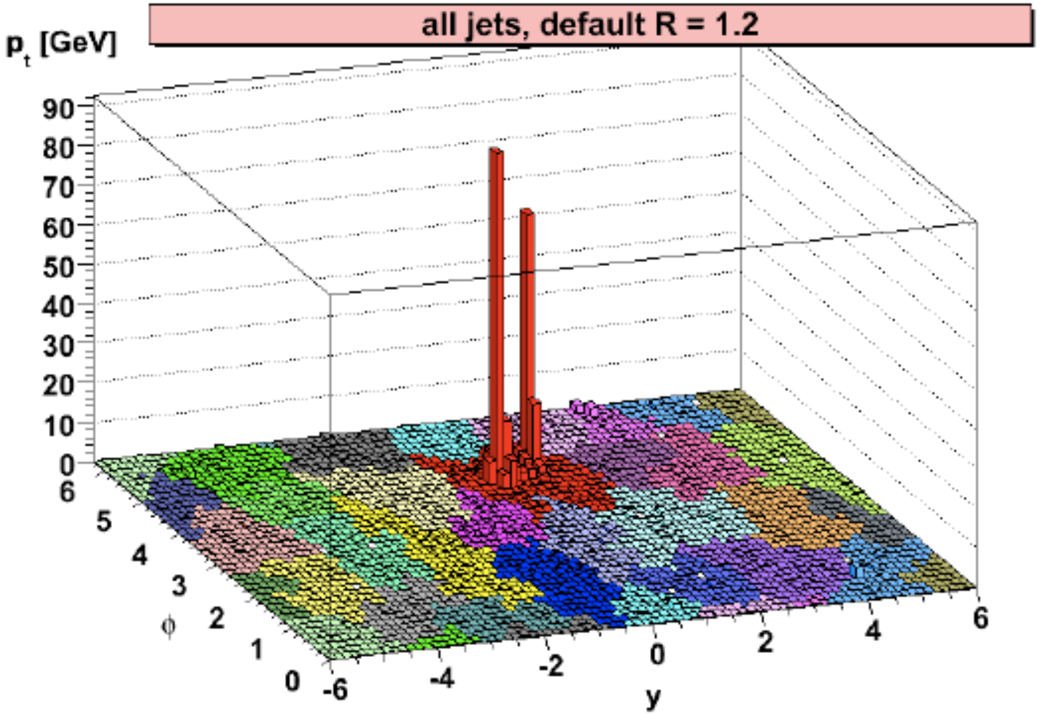
Cluster event, C/A, R=1.2

arbitrary norm.

$pp \to ZH \to \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

SIGNAL

Herwig 6.510 + Jimmy 4.31 + FastJet 2.3



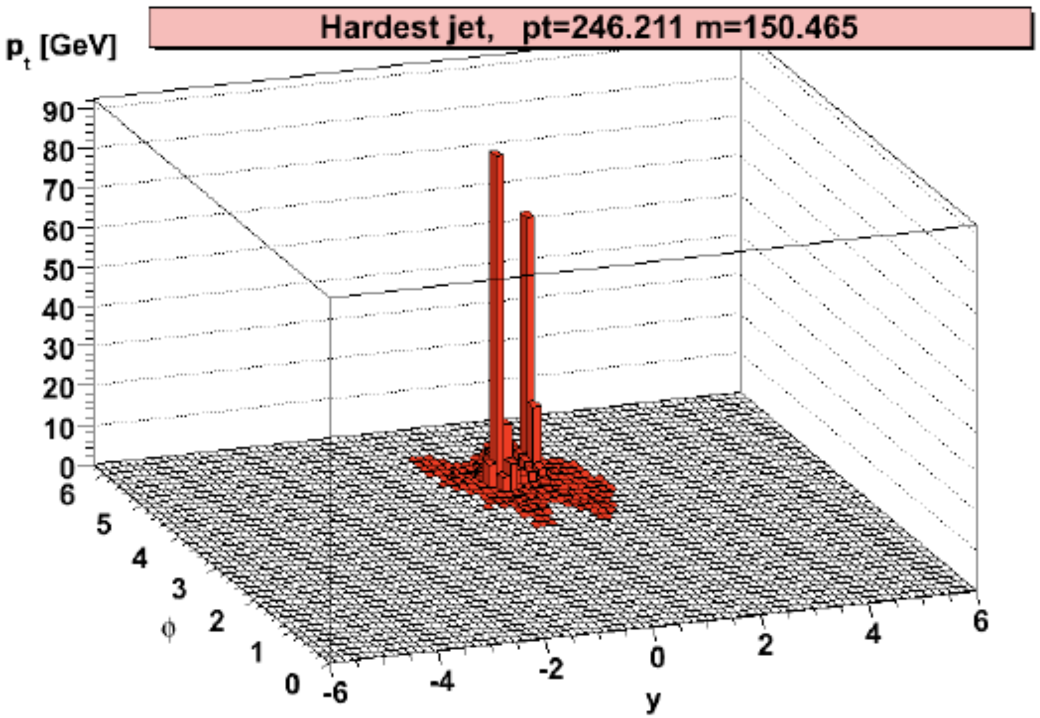
Fill it in, → show jets more clearly

Zbb BACKGROUND

arbitrary norm.

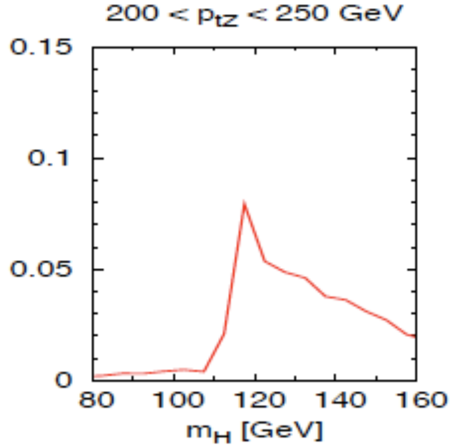
$pp \to ZH \to \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

Herwig 6.510 + Jimmy 4.31 + FastJet 2.3

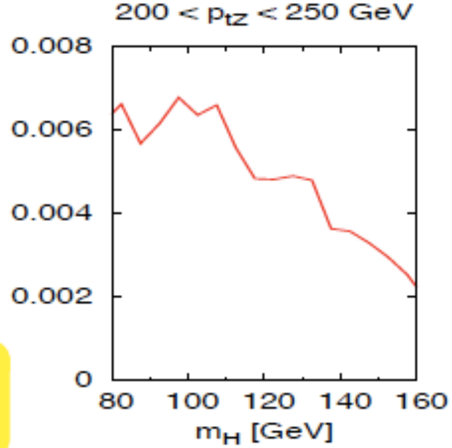


Consider hardest jet, $m = 150$ GeV

SIGNAL



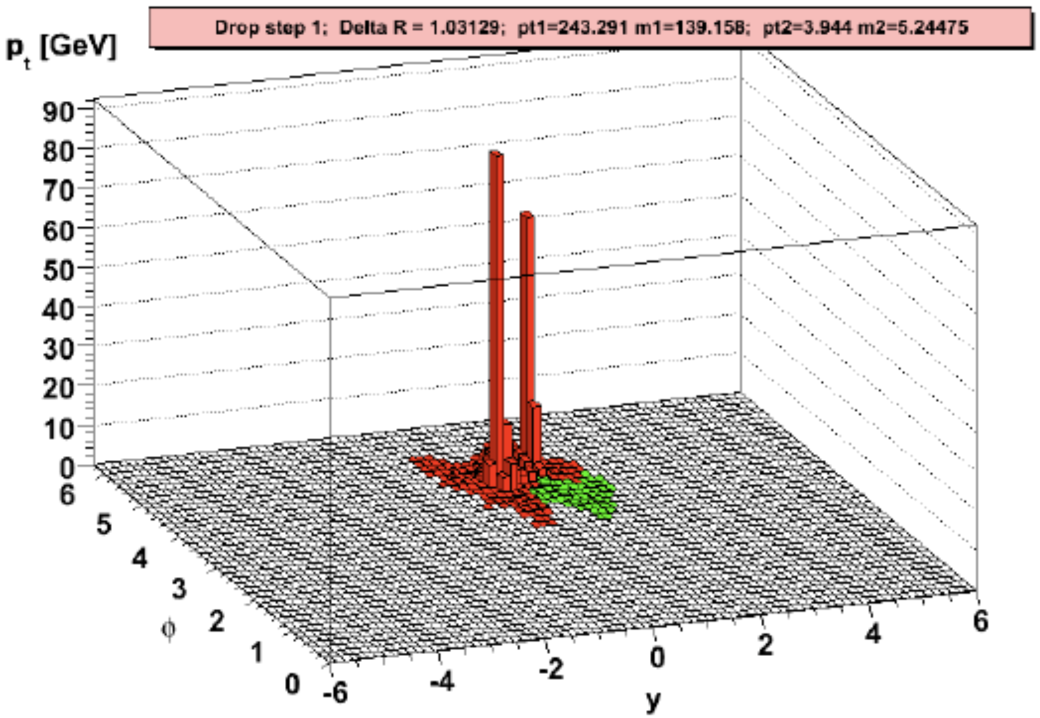
Zbb BACKGROUND



arbitrary norm.

$pp \to ZH \to \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

Herwig 6.510 + Jimmy 4.31 + FastJet 2.3



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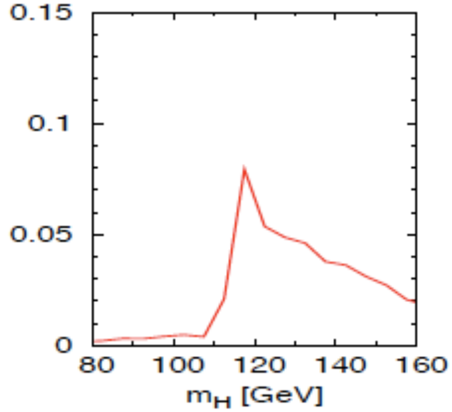
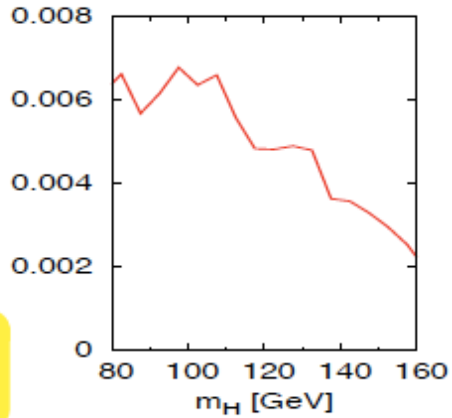


Zbb BACKGROUND

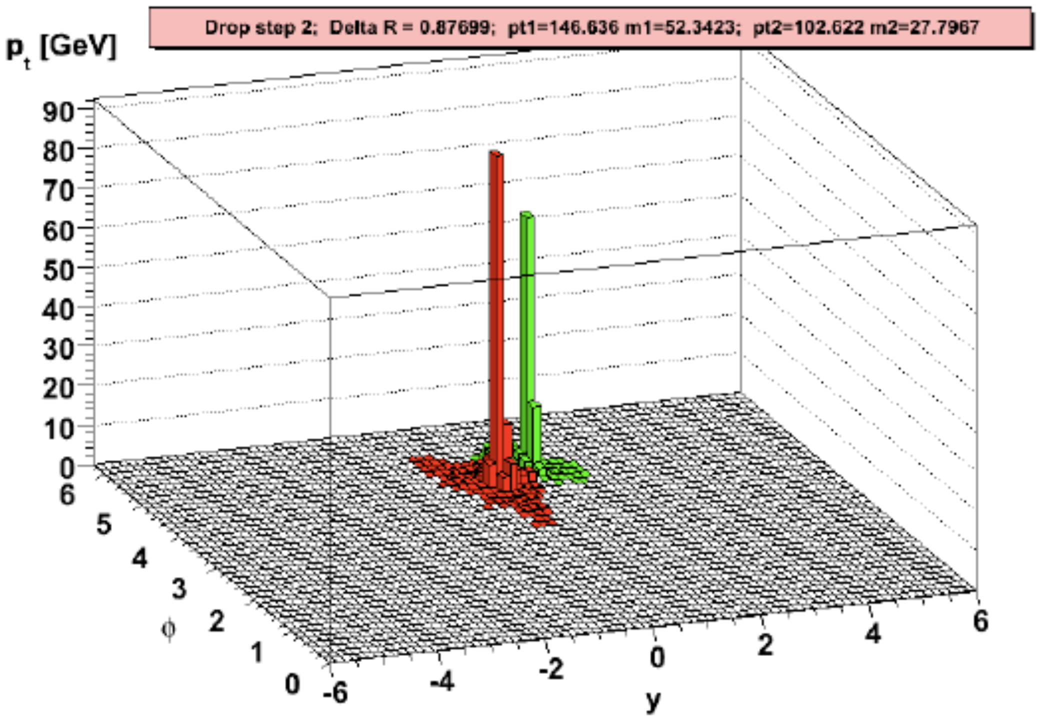


split: $m = 150$ GeV, $\frac{\max(m_1, m2)}{m} = 0.92 \to$ repeat

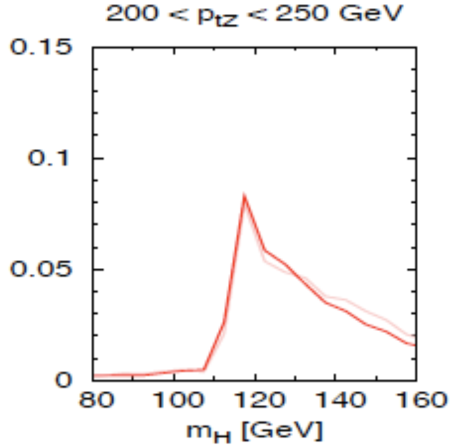
arbitrary norm.

$pp \to ZH \to \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

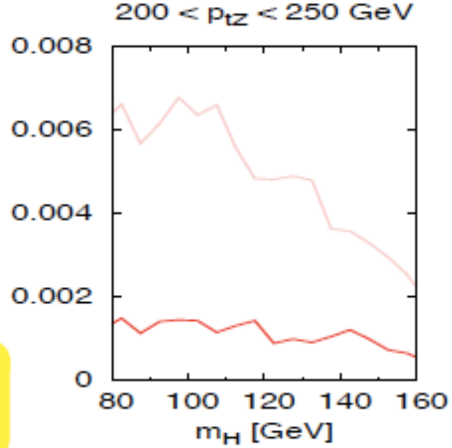
Herwig 6.510 + Jimmy 4.31 + FastJet 2.3



SIGNAL



Zbb BACKGROUND

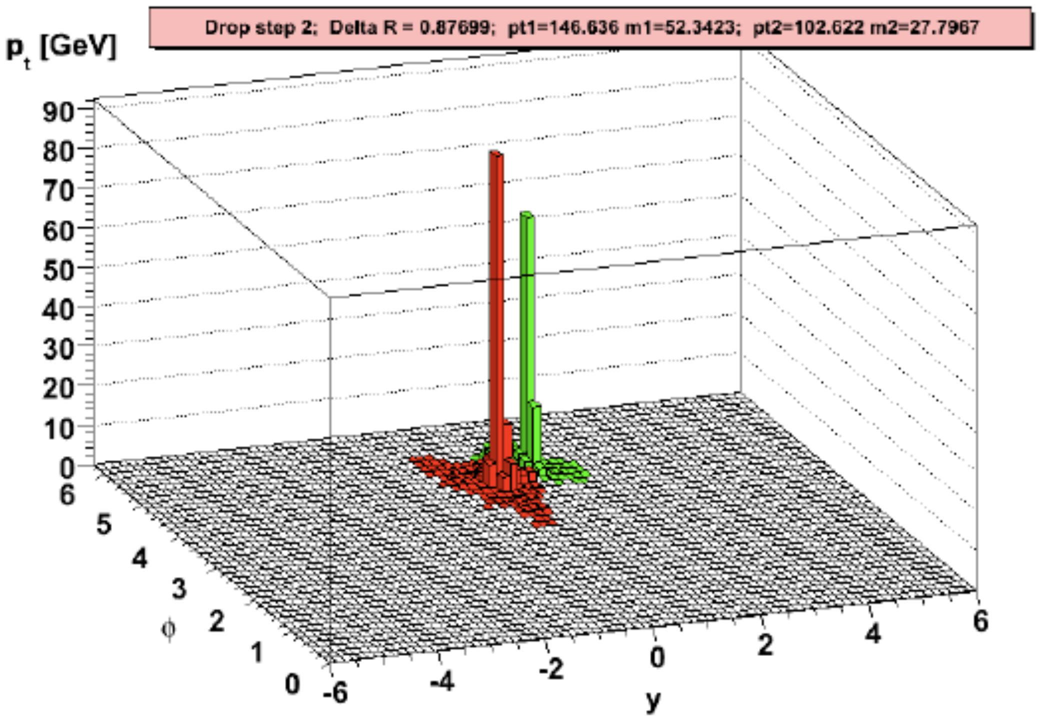


split: $m = 139$ GeV, $\frac{\max(m_1, m2)}{m} = 0.37 \to$ mass drop

arbitrary norm.

$pp \to ZH \to \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

Herwig 6.510 + Jimmy 4.31 + FastJet 2.3



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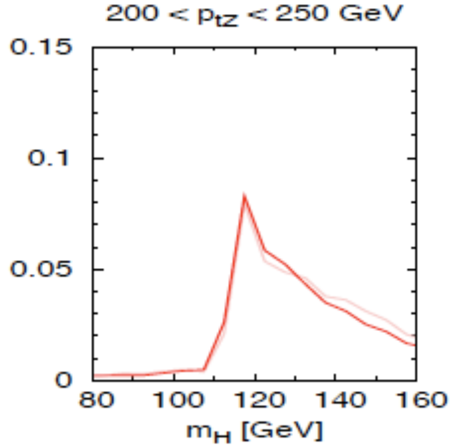

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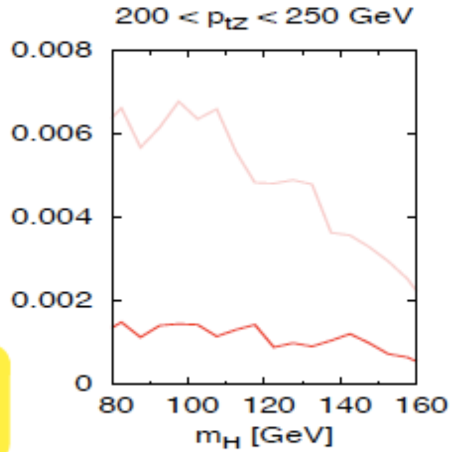
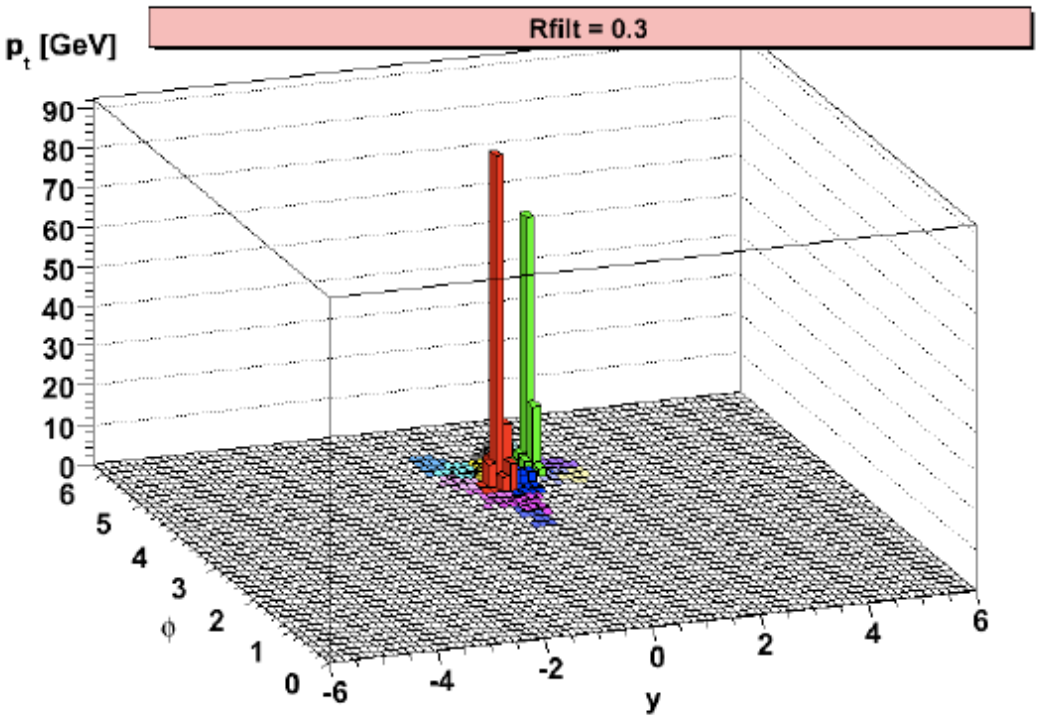


check: $y_{12} \simeq \frac{p_{t2}}{p_{t1}} \simeq 0.7 \to$ OK + 2 b-tags (anti-QCD)

arbitrary norm.

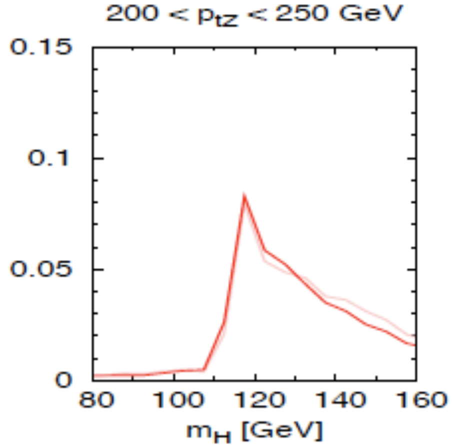
$pp \to ZH \to \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

Herwig 6.510 + Jimmy 4.31 + FastJet 2.3

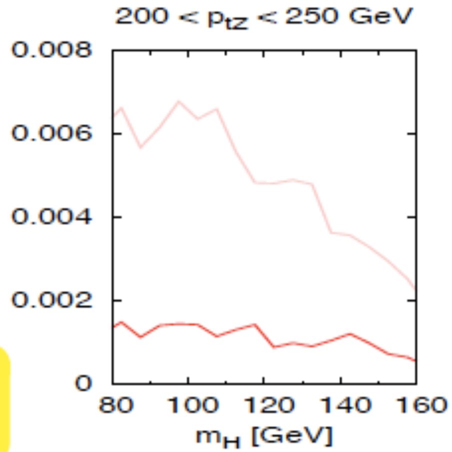


$R_{filt} = 0.3$

SIGNAL



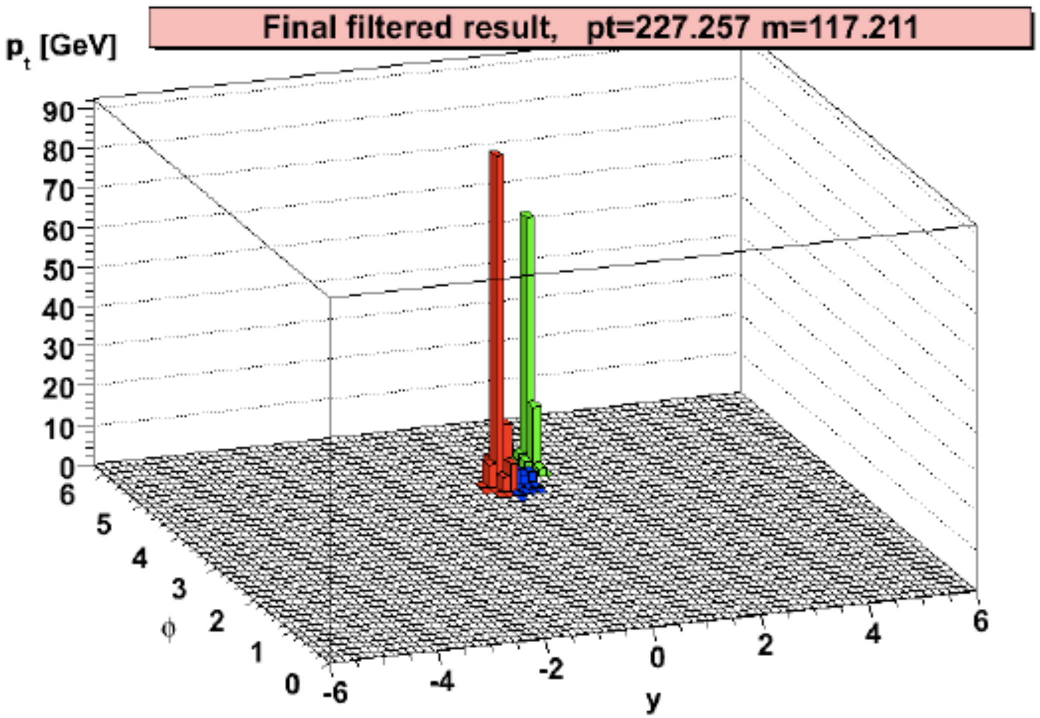
Zbb BACKGROUND



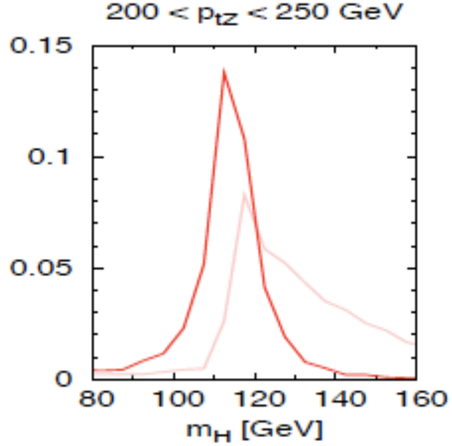
arbitrary norm.

$pp \to ZH \to \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

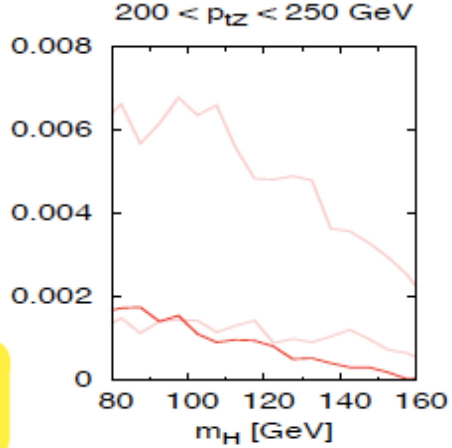
Herwig 6.510 + Jimmy 4.31 + FastJet 2.3



SIGNAL



Zbb BACKGROUND



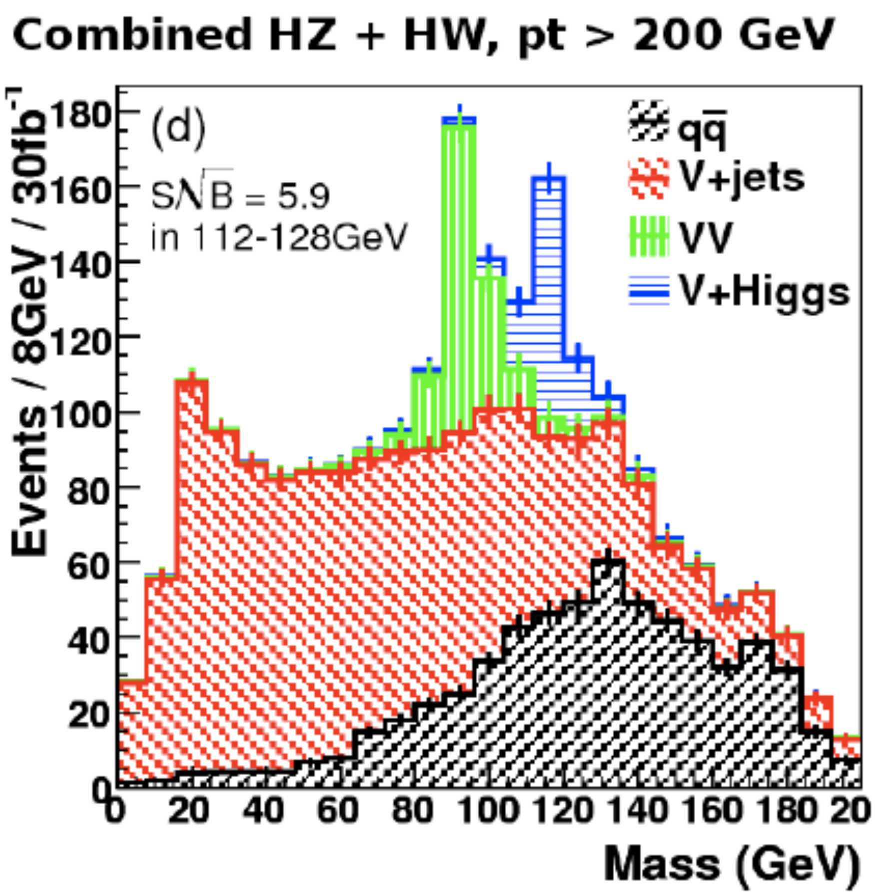
$R_{filt} = 0.3$: take 3 hardest, **m = 117 GeV**

arbitrary norm.

comparing jet algorithms

Cross section for signal and the Z+jets background in the leptonic Z channel for $200 < p_{TZ}/\text{GeV} < 600$ and $110 < m_J/\text{GeV} < 125$, with perfect b-tagging; shown for our jet definition (C/A MD-F), and other standard ones close to their optimal R values.

Jet definition	σ_S/fb	σ_B/fb	$S/\sqrt{B \cdot \text{fb}}$
C/A, $R = 1.2$, MD-F	0.57	0.51	0.80
k_t, $R = 1.0$, y_{cut}	0.19	0.74	0.22
SISCone, $R = 0.8$	0.49	1.33	0.42
anti-k_t, $R = 0.8$	0.22	1.06	0.21



- Take $Z \to \ell^+\ell^-$, $Z \to \nu\bar{\nu}$, $W \to \ell\nu$ $\quad \ell = e, \mu$
- $p_{tV}, p_{tH} > 200$ GeV
- $|\eta_V|, |\eta_H| < 2.5$
- Assume real/fake b-tag rates of 0.7/0.01.
- Some extra cuts in HW channels to reject $t\bar{t}$.
- Assume $m_H = 115$ GeV.

At $\sim 5\sigma$ for 30 fb^{-1} this looks like a competitive channel for light Higgs discovery. **Deserves serious exp. study!**

conclusions

conclusions

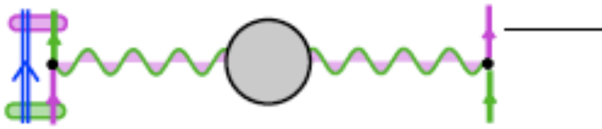
- "eternal" fight btw **kt** and **cone** jet finding algorithms is finally over
- competitive and theoretically sound **SIScone** (**S**eedless **I**nfrared **S**afe) cone algorithm constructed
- fast (the fastest !) **kt** jet finder **FastJet** is working
- choosing cleverly **jet algorithm** and dialing its **parameters** one significantly increases potential for searches for **new physics**

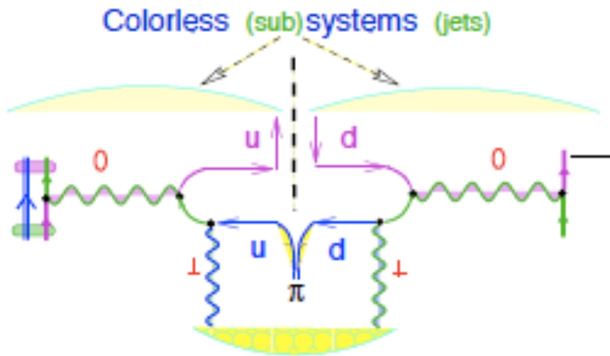
lot of work ahead for noble causes:
to better understand and to better use QCD

extras

the only existing dynamical model
of the vacuum breakup
has been developed by
Volodya Gribov in the 90's

What happens with the Coulomb field when the sources move apart?





Bearing in mind that virtual quarks live in the background of gluons (zero fluctuations of $A_\perp$ gluon fields) what we look for is a mechanism for binding (negative energy) *vacuum quarks* into *colorless hadrons* (positive energy physical states of the theory)

V.Gribov suggested such a mechanism — the supercritical binding of light fermions subject to a Coulomb-like interaction. It develops when the coupling constant hits a definite "critical value" (Gribov 1990)

Phasis Publishing House
Moscow (2002)

www.prospero.hu/gribov.html

FastJet web logs (2008)

In 2008: about 10 000 page loads from 2 000 IP addresses, in ∼ 800 locations.

[After exclusion of robots]