UNIVERSITY of GLASGOW

The Underlying Event in Jet Physics at TeV Colliders

Arthur M. Moraes

University of Glasgow

PPE – ATLAS

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Outline:

I. LHC and ATLAS;

II. Hadron collisions: how can we model them?

- Describing soft hadronic interactions.

III. The underlying event in jet analysis;

IV. LHC predictions;

V. Conclusions.

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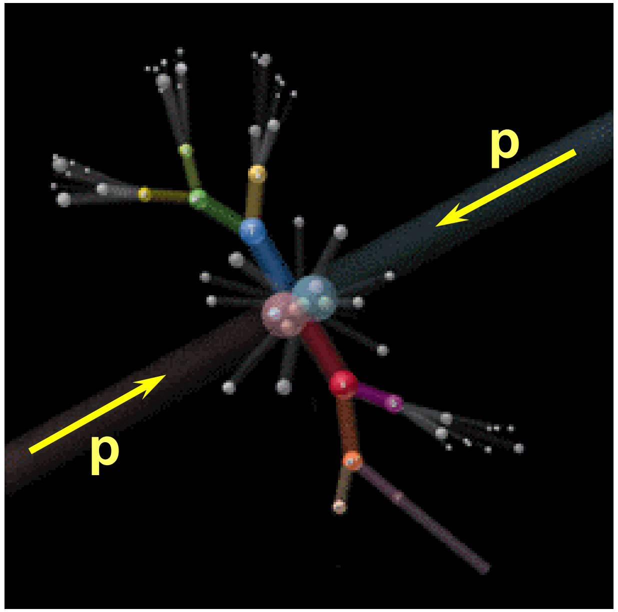
Proton-proton collisions at the LHC

- p-p collisions at $\sqrt{s}$ = 14TeV
  - *low-luminosity*: L ≈ 2 x $10^{33}cm^{-2}s^{-1}$ ($\mathcal{L}$ ≈ 20 fb^{-1}/year)
  - *high-luminosity*: L ≈ $10^{34}cm^{-2}s^{-1}$ ($\mathcal{L}$ ≈ 100 fb^{-1}/year)



- Essentially all physics at LHC are connected to the interactions of *quarks* and *gluons* (small & large transferred momentum).
  - *Hard processes (high-pT)*: well described by perturbative QCD
  - *Soft interactions (low-pT)* : require non-perturbative phenomenological models *(strong coupling constant, $\alpha_s(Q^2)$, saturation effects,…)*

The ***underlying event*** is dominated by ***"soft"*** partonic interactions.

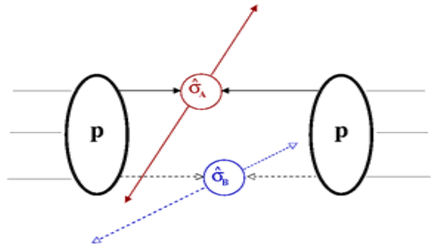
Models for soft hadronic interactions

- **Uncorrelated soft scatter – HERWIG/UA5 model (S.U.E.)**
  (http://hepwww.rl.ac.uk/theory/seymour/herwig/)

Questionable modelling for:

1. Energy dependence;
2. Minimum-bias and UE hard component;

- **Multiple interactions:**



Soft partonic scatters matched to hard 2 → 2 scatters:

• *PYTHIA (several options)*
(http://www.thep.lu.se/~torbjorn/Pythia.html)

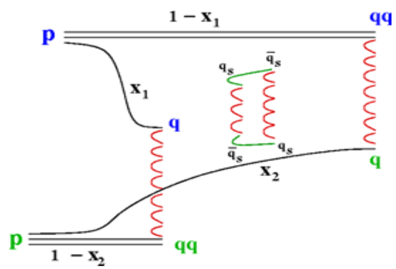
$$\sigma_{\text{int}} = \int_{p_{t_0}}^{s/4} \frac{d\sigma}{dp_t^2} dp_t^2$$

$n \sim \sigma_{\text{int}}$
$\downarrow pt_0 \; \uparrow n$
(and vice-versa)

• *JIMMY (multiple parton interactions – b-space picture)*
(http://jetweb.hep.ucl.ac.uk/JIMMY/index.html)

$$\sigma_n = \int d^2b \frac{(A(b)\sigma^{inc})^n}{n!} \exp(-A(b)\sigma^{inc})$$

• *PHOJET (based on DPM)*
(http://www-ik.fzk.de/%7Eengel/phojet.html)



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Underlying event in charged jet evolution

(CDF analysis – Run I data) *Phys. Rev. D, 65 092002 (2002)*

- **All particles from a single particle collision *except* the process of interest.**
- Sometimes, the underlying event can also be defined as everything in the collision except the hard process.
- *It is not* only minimum bias event!
- The underlying event has **hard** (multiple "semi-hard" parton scatterings) and **soft** components (beam-beam remnants).

CDF analysis:

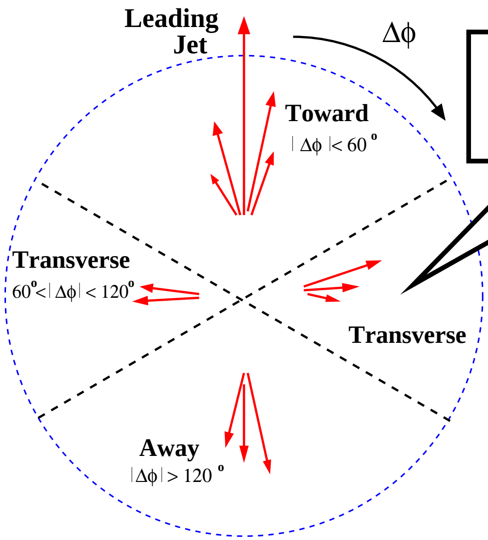
- charged particles:

p_t>0.5 GeV and |η|<1

- **cone jet finder:**

$$R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.7$$

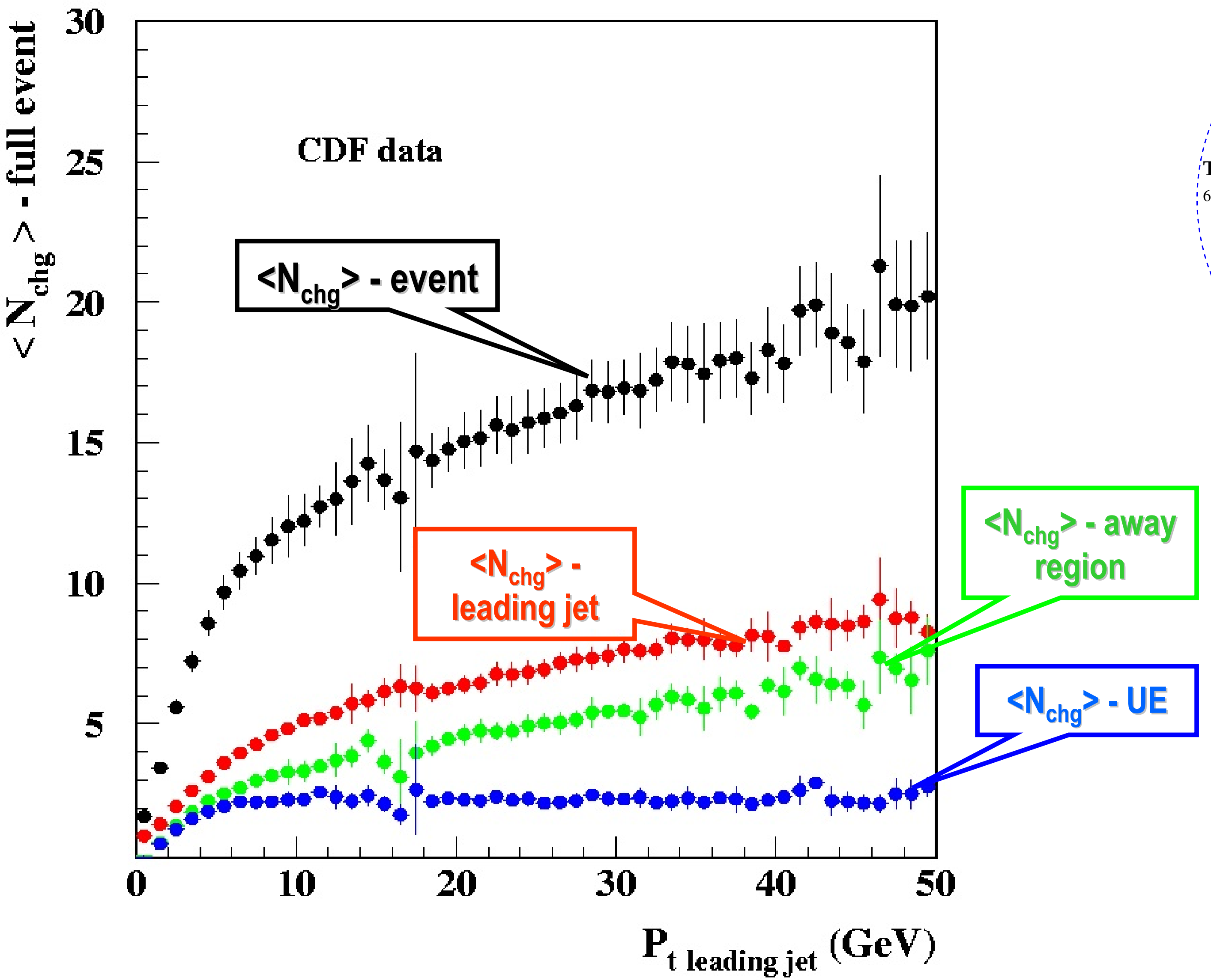
$$\Delta\phi = \phi - \phi_{ljet}$$

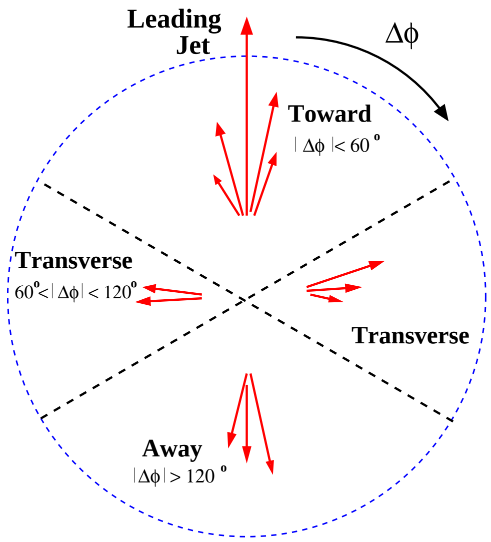


UE is defined as the Transverse Region

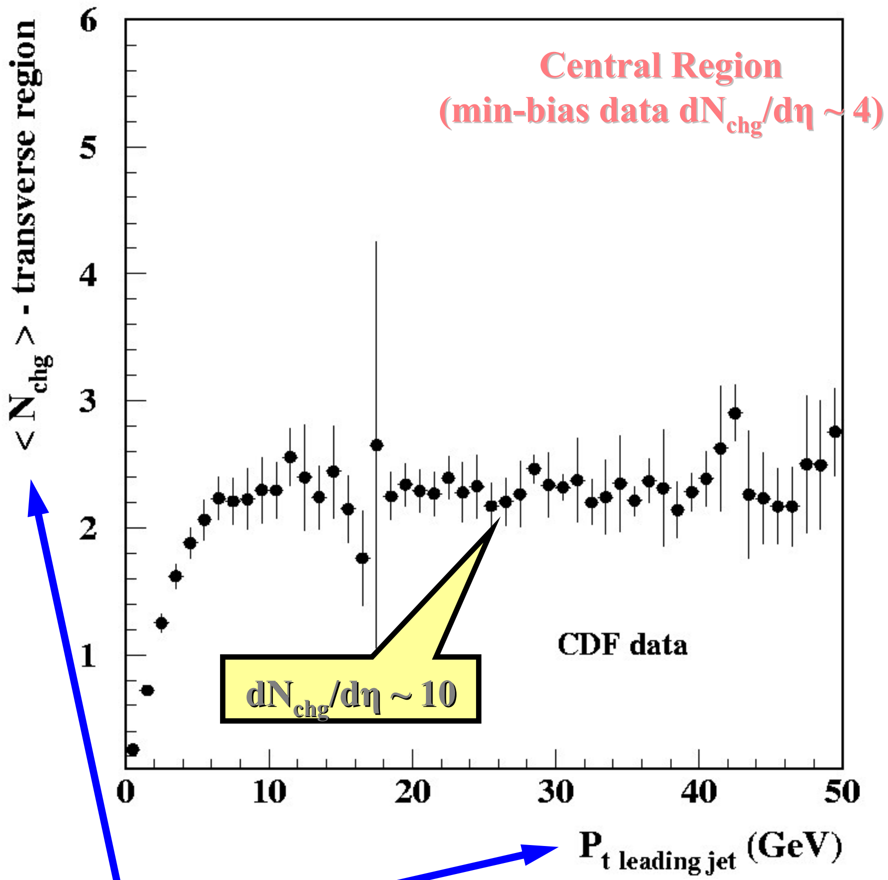
Phys. Rev. D, 65 092002 (2002)

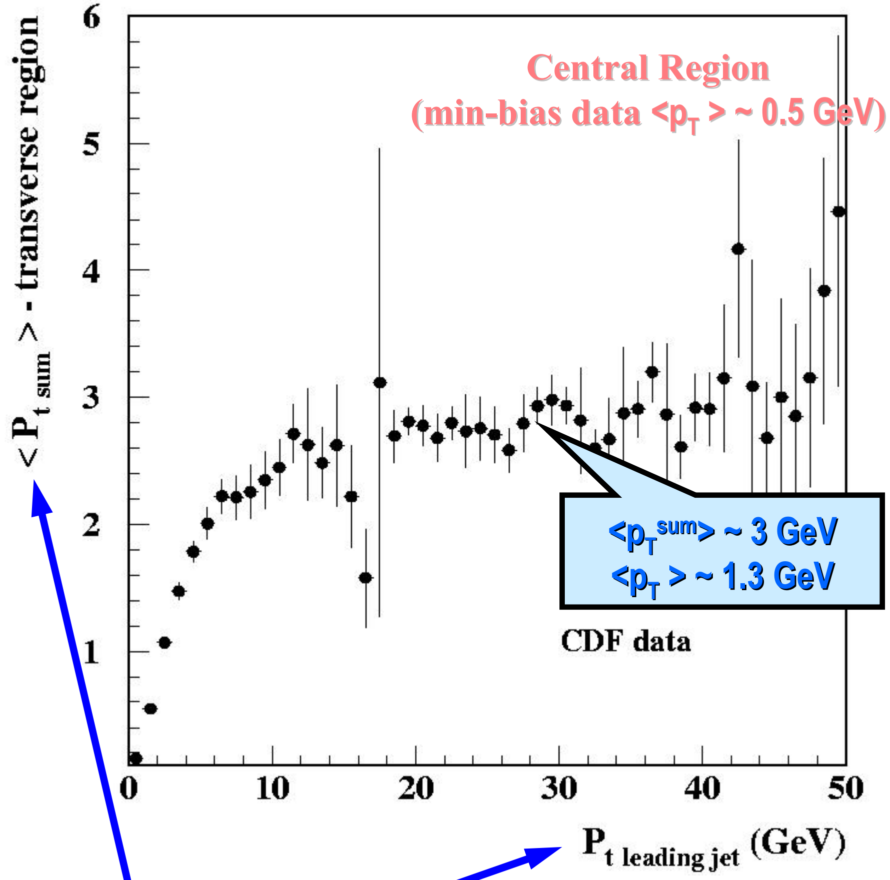
$<N_{chg}>$ distributions
(particles from different angular regions)





$\langle N_{chg} \rangle$ and $\langle p_T^{sum} \rangle$ distributions (particles from the underlying event)

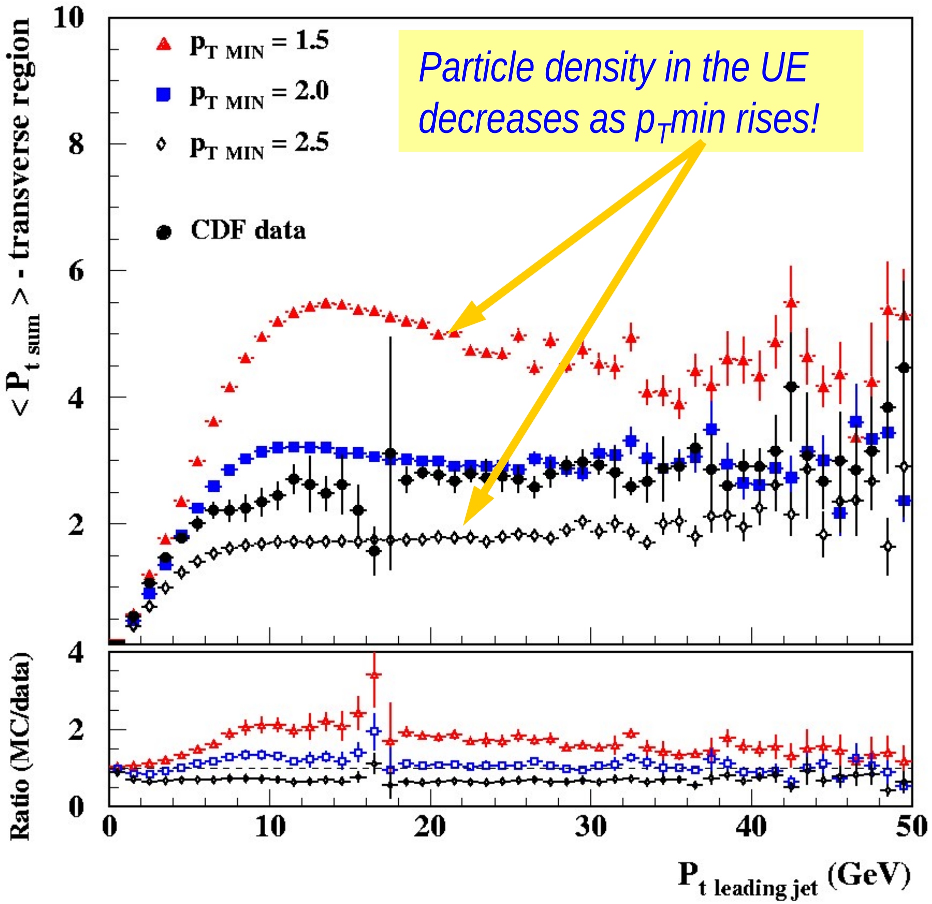




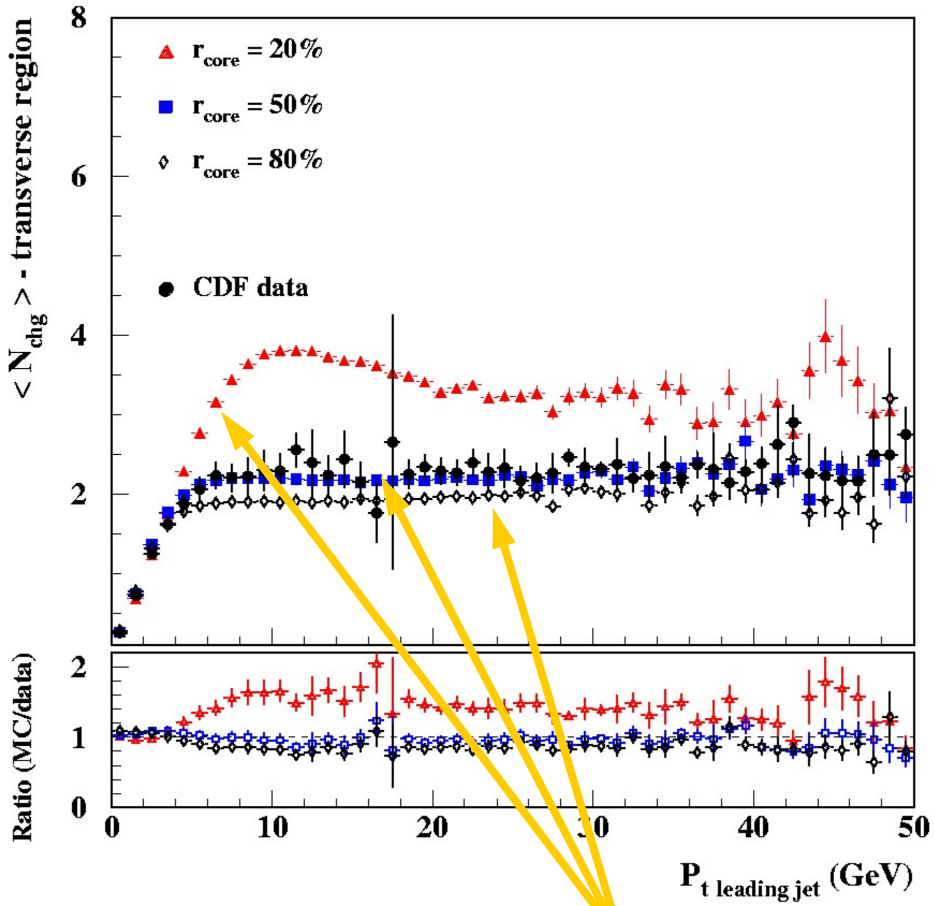
Average multiplicity of charged particles in the underlying event associated to a leading jet with $\mathbf{P_t^{ljet}}$ (GeV).

Average $\mathbf{p_T^{sum}}$ (GeV) of charged particles in the underlying event associated to a leading jet with $\mathbf{P_t^{ljet}}$ (GeV).

Tuning models to the underlying event



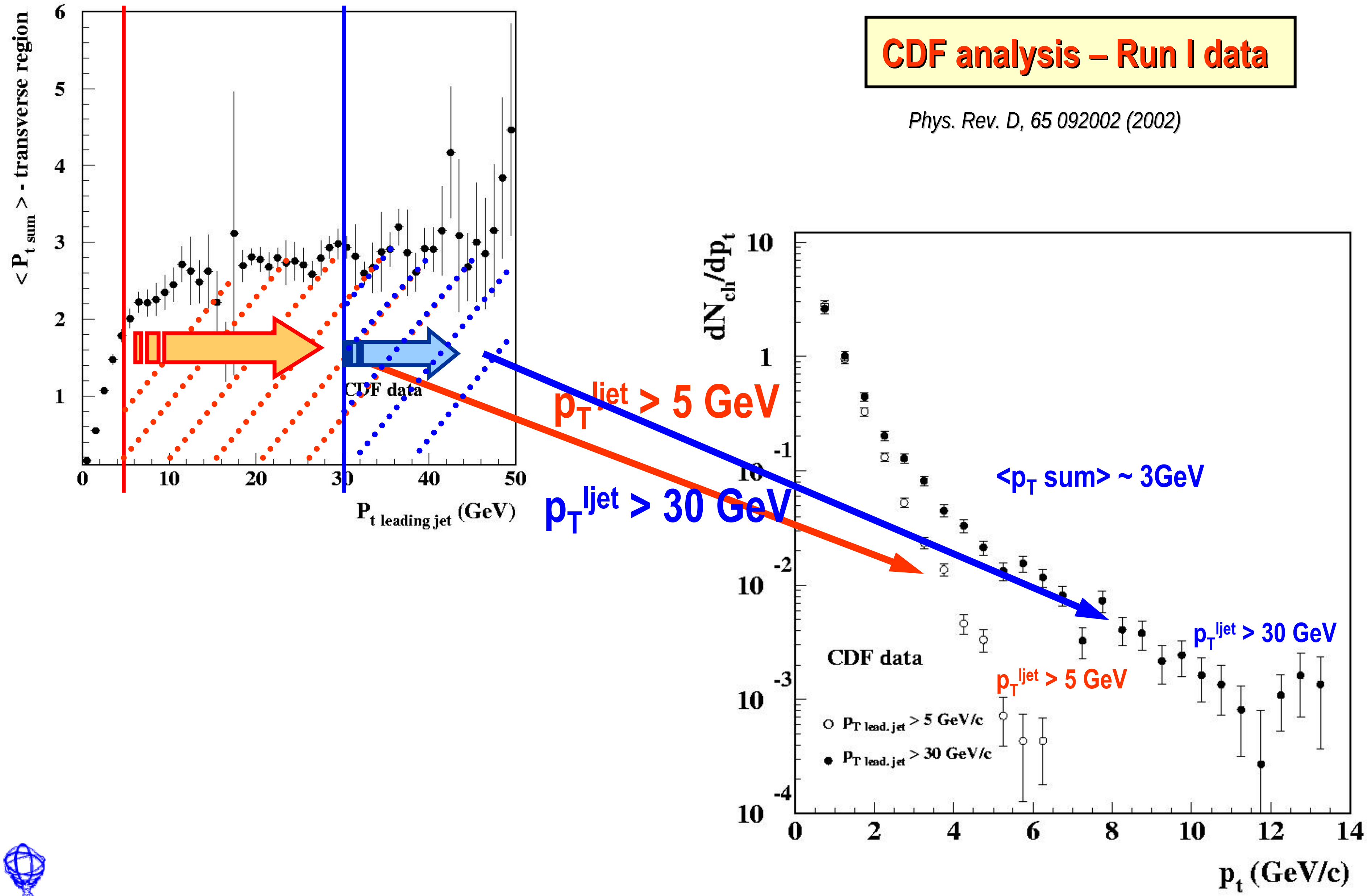
Particle density in the UE decreases as $p_T$min rises!



Similarly to the observed for min-bias distributions, varying the lower p_T cut-off also changes the particle density (and p_T density) in the UE.

Small, dense core-size generates more multiplicity in the UE.

Measurements recently made available for tuning models



CDF analysis – Run I data

Phys. Rev. D, 65 092002 (2002)

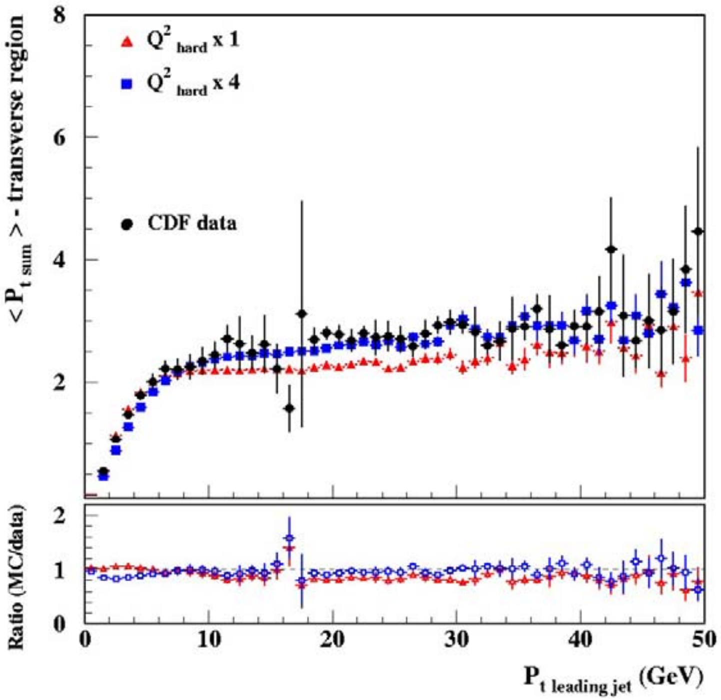
$p_T^{ljet} > 5$ GeV

$p_T^{ljet} > 30$ GeV

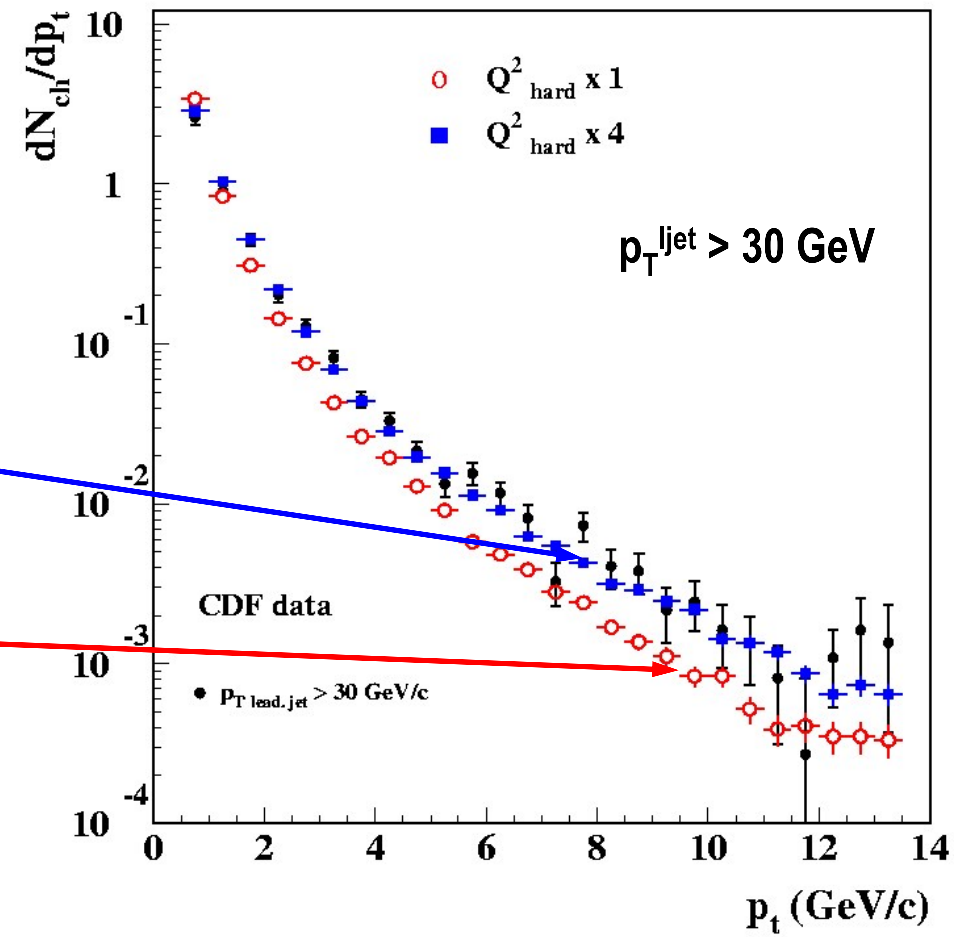
$<p_T$ sum$>$ ~ 3GeV

$p_T^{ljet} > 30$ GeV

$p_T^{ljet} > 5$ GeV



Q^2 scale of the hard scattering is multiplied by a factor λ to define the *maximum parton virtuality allowed in showers*.



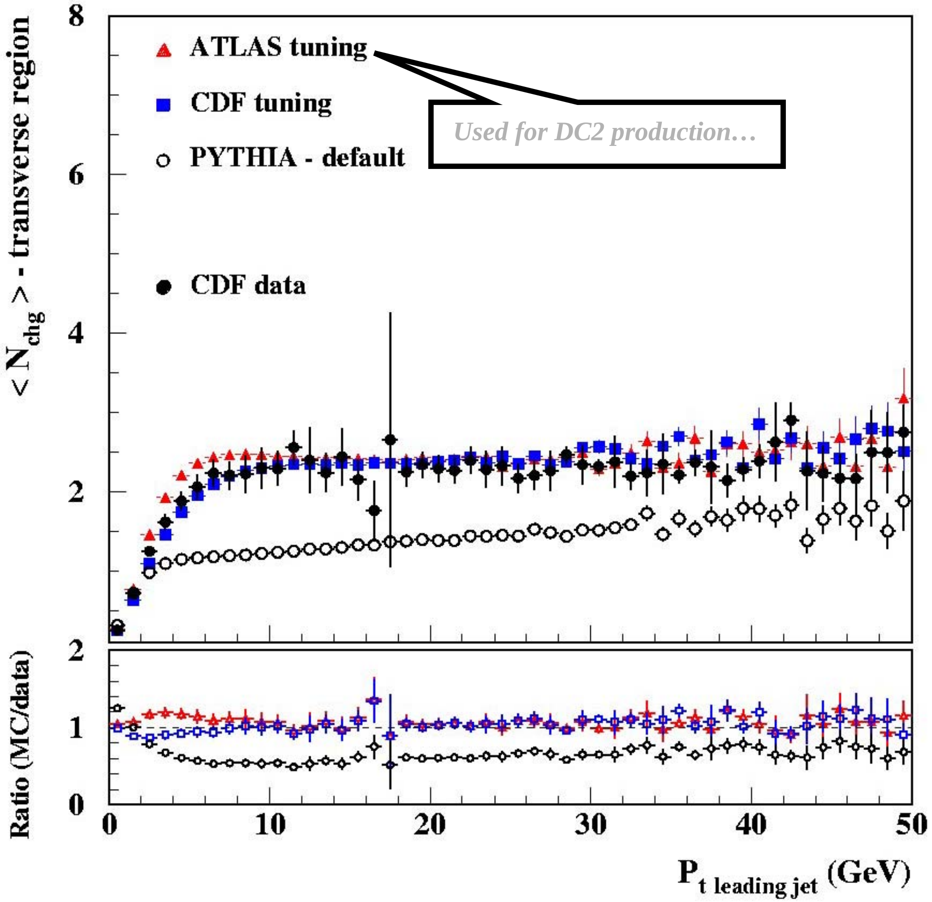
λ = 4

harder p_T spectrum

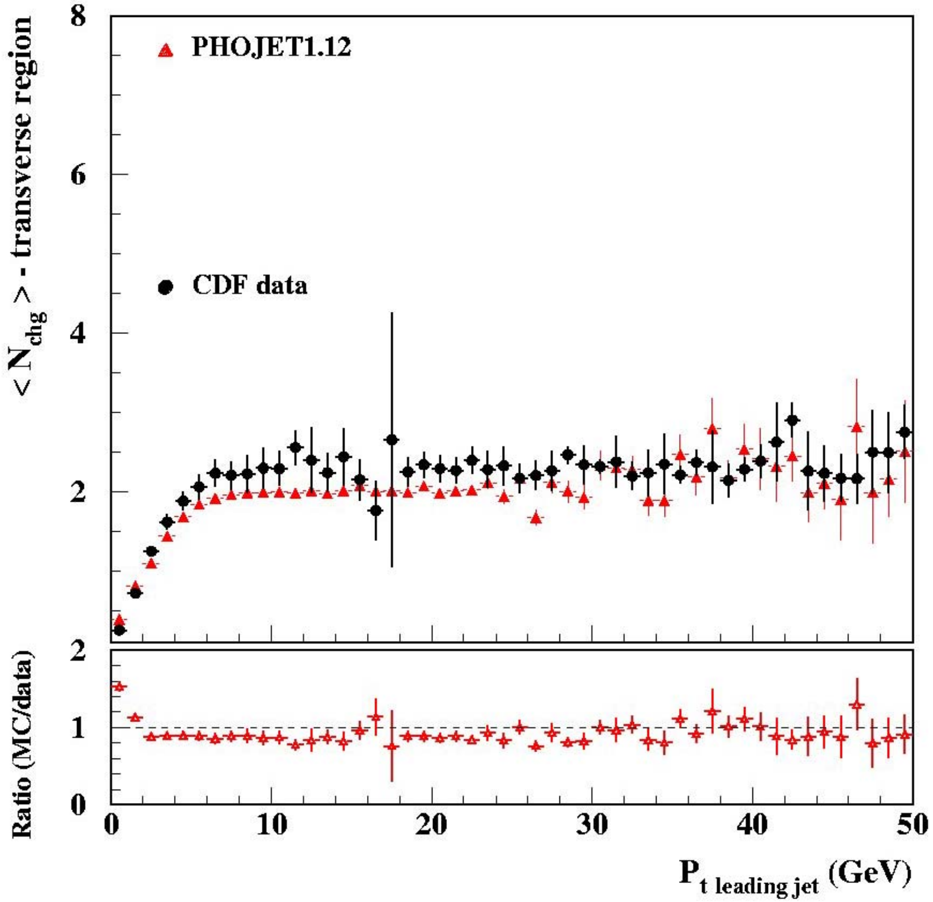
λ=1

Examples of MC tunings for the UE

PYTHIA6.2 tunings



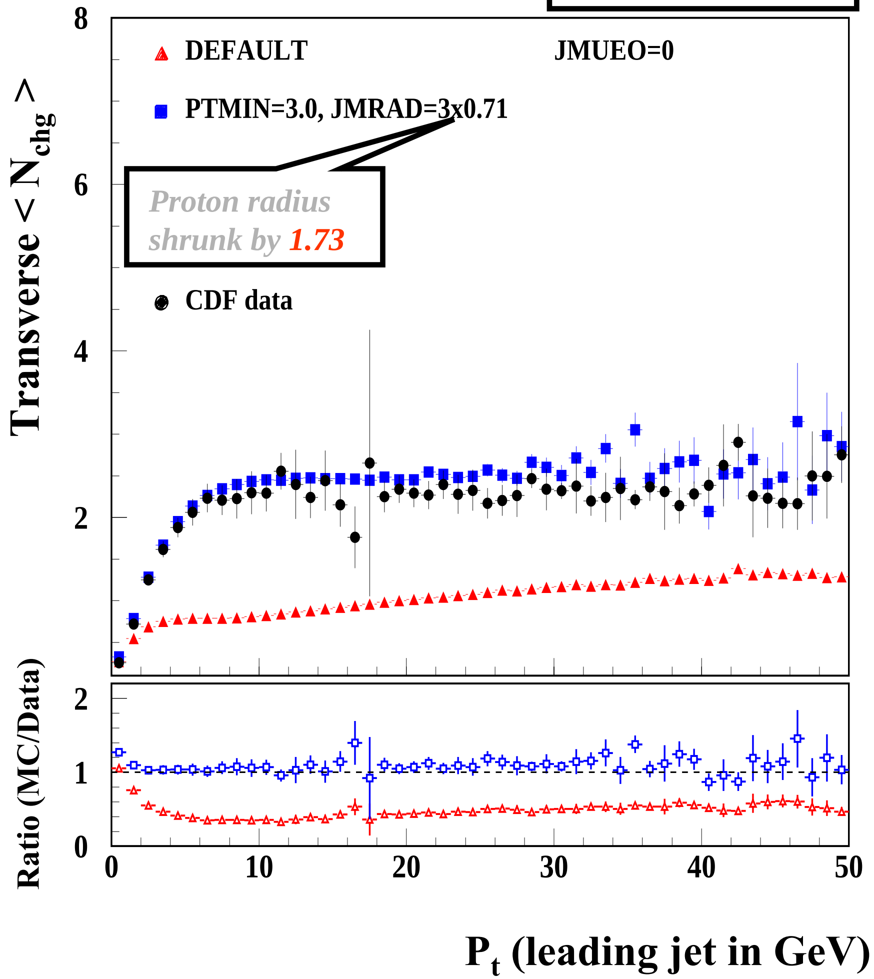
PHOJET1.12



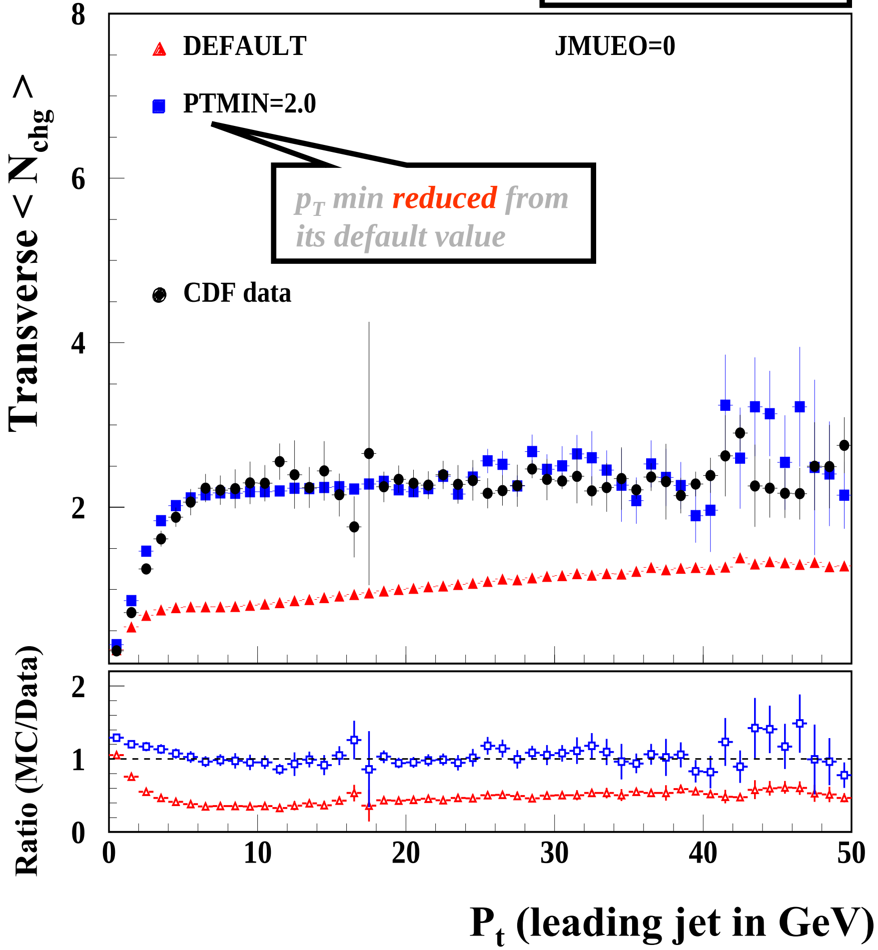
HERWIG6.5 + JIMMY4.1 tunings

(http://jetweb.hep.ucl.ac.uk/)

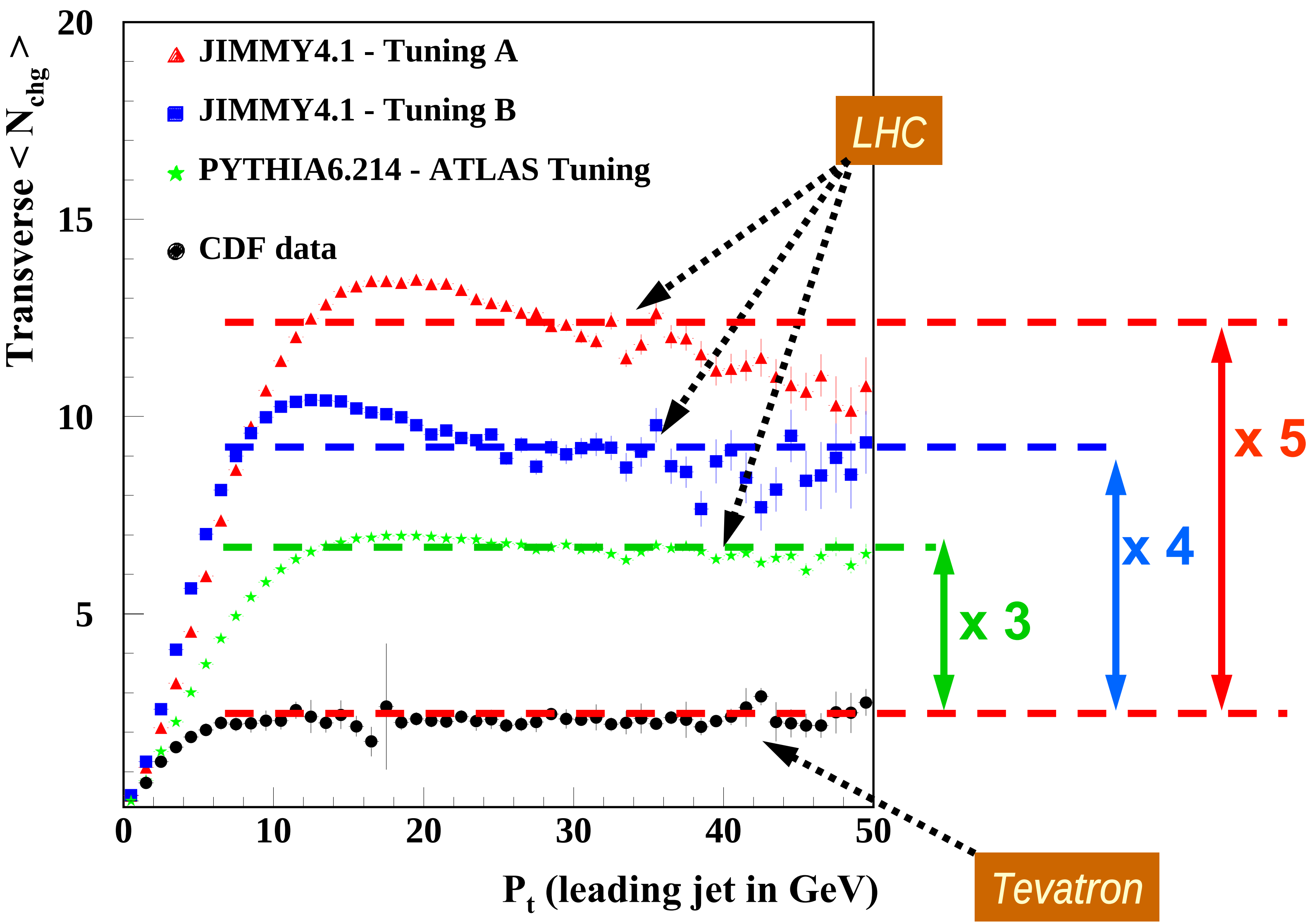
JIMMY4.1 – Tuning A



JIMMY4.1 – Tuning B



LHC predictions: JIMMY4.1 Tunings A and B vs. PYTHIA6.214 – ATLAS Tuning



Predictions for the UE: from Tevatron to LHC energies

	Measurement	JIMMY4.1 Tuning A	JIMMY4.1 Tuning B	PYTHIA6.214 ATLAS Tuning	PYTHIA6.214 CDF Tuning	PHOJET1.12	Data
Tevatron	$\langle N_{chg} \rangle$ $p_{T\,ljet} > 10$ GeV	2.4	2.3	2.4	2.3	2.1	**2.3**
	$\langle p_{T\,sum} \rangle$ $p_{T\,ljet} > 10$ GeV	2.5	2.1	2.3	2.6	2.0	**2.6**
LHC	$\langle N_{chg} \rangle$ $p_{T\,ljet} > 10$ GeV	**12.2**	**9.2**	**6.6**	**4.7**	**3.0**	"?"
	$\langle p_{T\,sum} \rangle$ $p_{T\,ljet} > 10$ GeV	**11.5**	**8.5**	**7.5**	**6.5**	**3.5**	"?"

x 5 x 4

x 3 x 2

x 1.5

x "?"

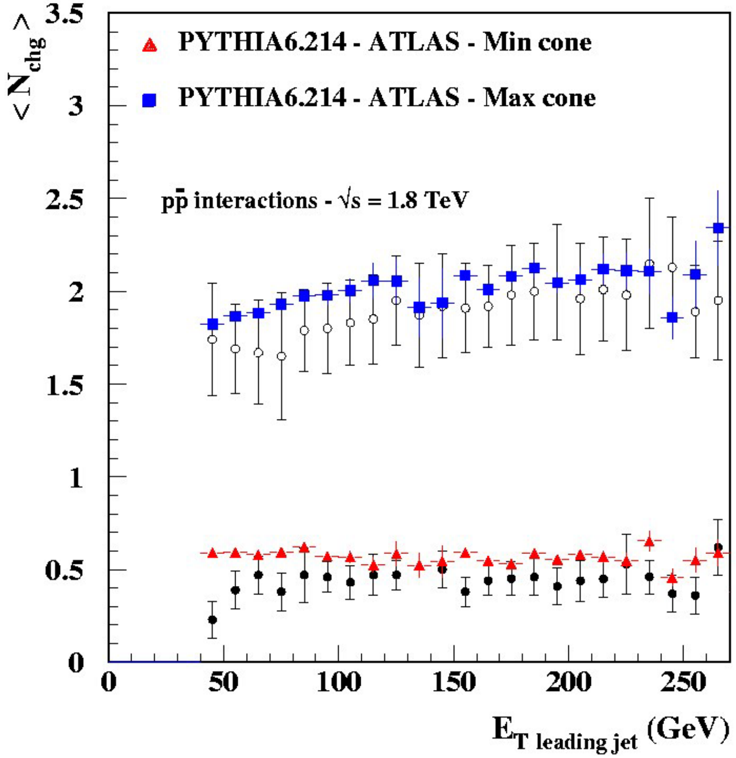
LHC

Measurements recently made available for tuning models

CDF analysis – Run I data

The underlying event in Hard Interactions at the Tevatron ppbar collider, **CDF Collaboration, PRD 70, 072002 (2004).**

"MAX/MIN analysis"



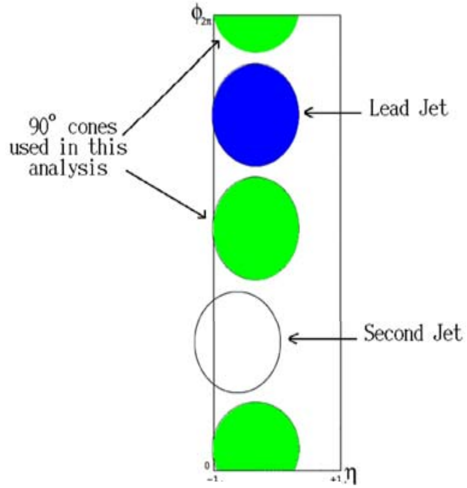
- **Two cones in η–ϕ space are defined:**

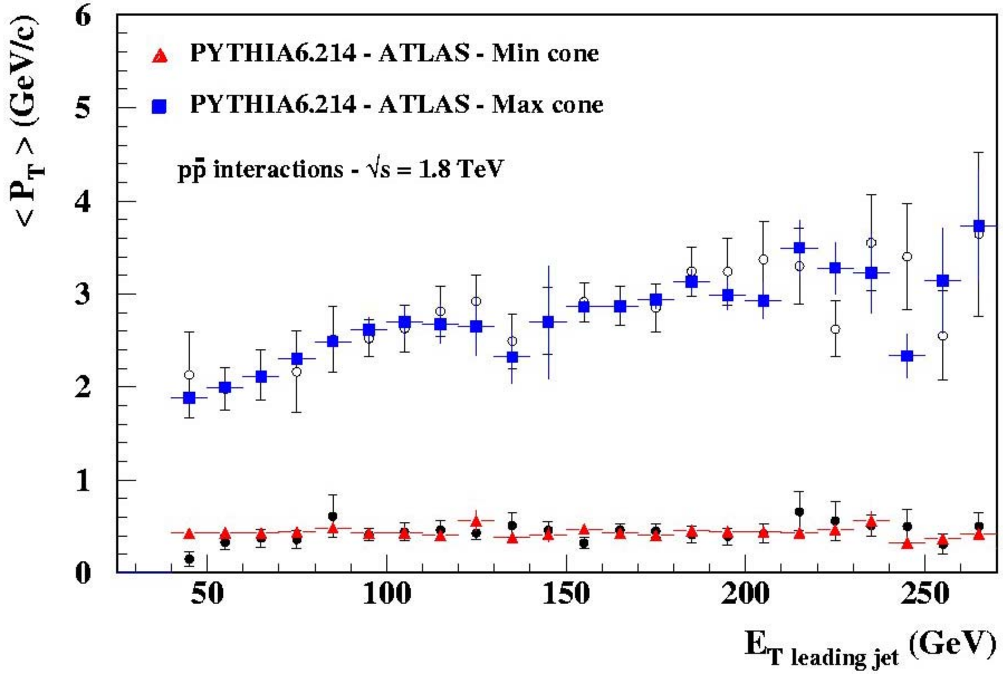
$\eta=\eta_{ljet}$ *(same as the leading jet)*

$\phi=\phi_{ljet} \pm 90°$

R=0.7

P_T^{90max} and P_T^{90min}





"MAX/MIN analysis"

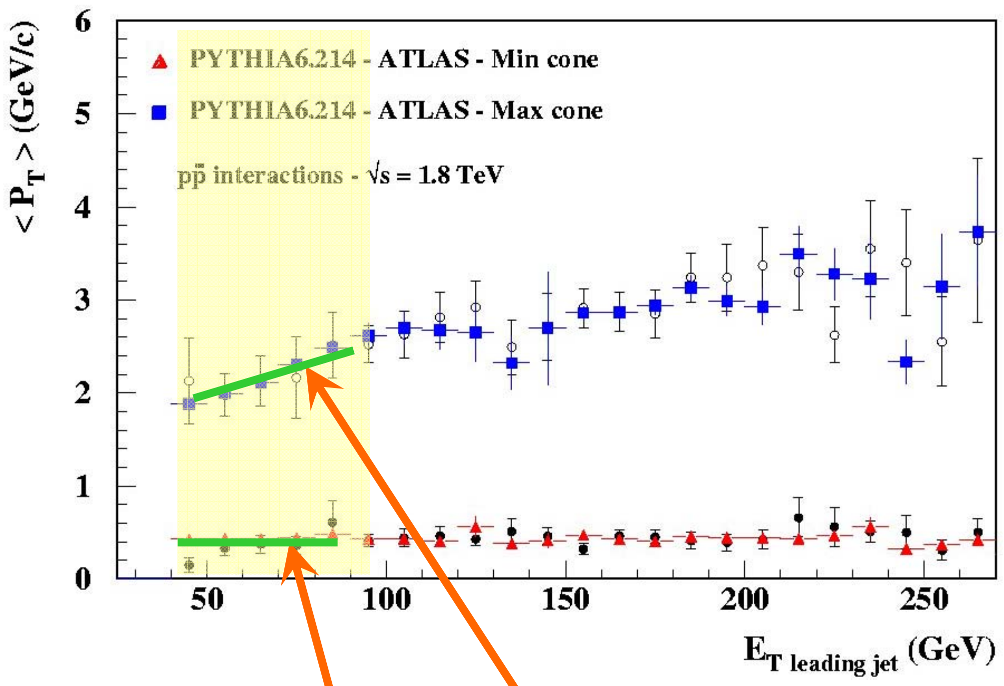
- The underlying event is measured for jet events at two different colliding energies: 630 GeV and 1800 GeV.

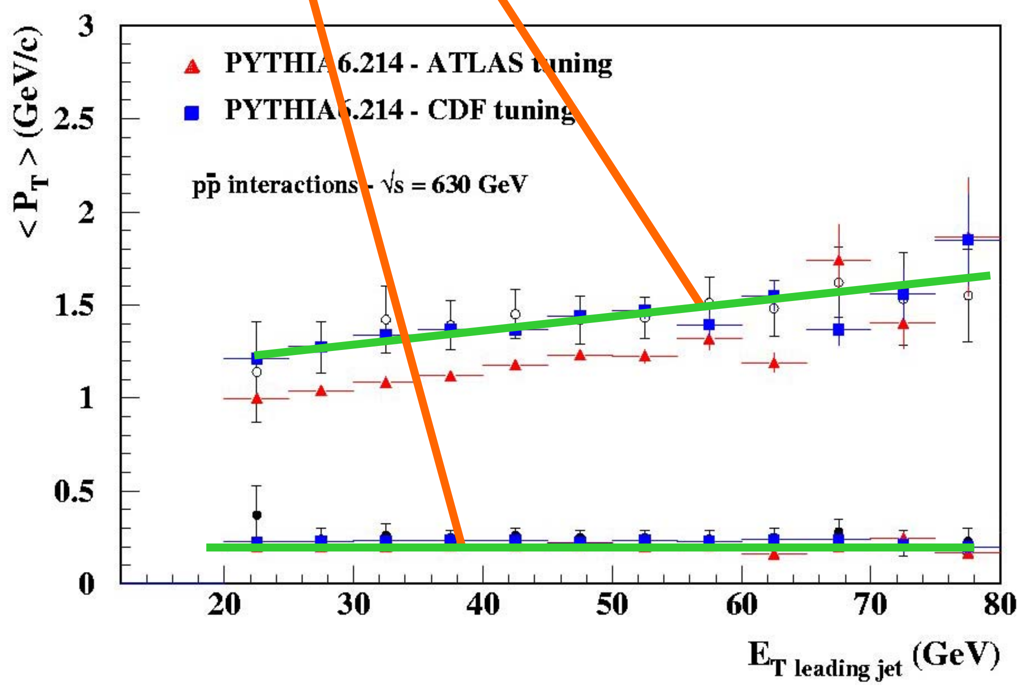
- This will provide important information on how to model the energy extrapolation in UE models.

$\sqrt{s}$ = 630 GeV √

$\sqrt{s}$ = 1.8 TeV √

$\sqrt{s}$ = 14 TeV ?





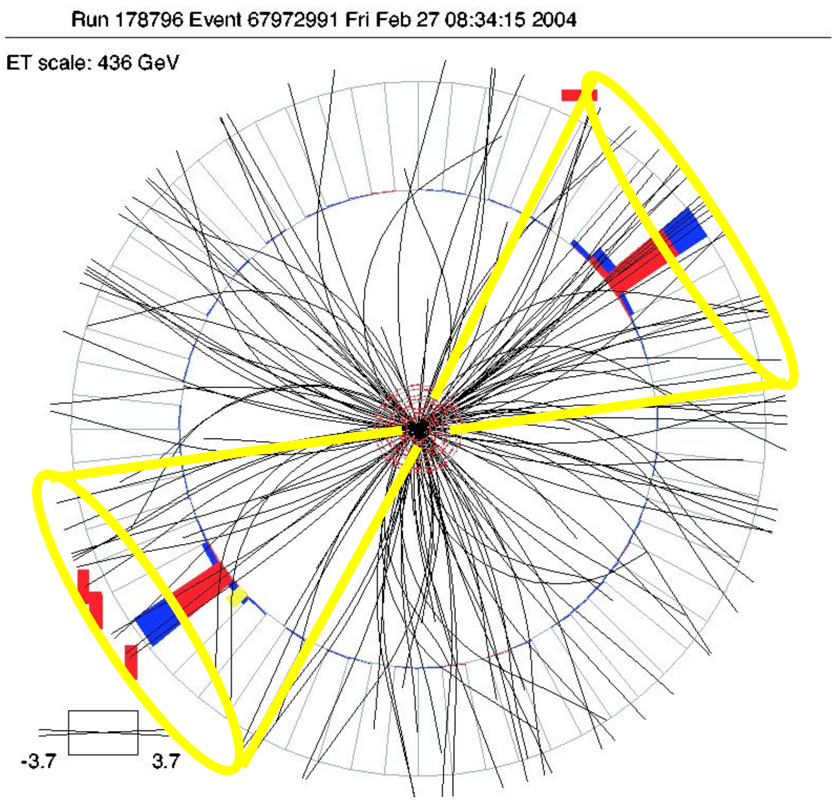
Conclusions:

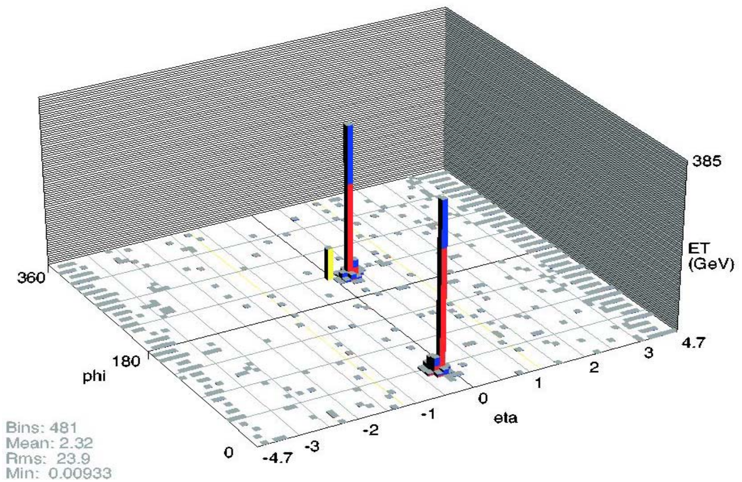
- Current underlying event data can be described with appropriate tunings (*PYTHIA, PHOJET and HERWIG+JIMMY*).
- There are sizeable uncertainties in LHC predictions generated by different models.
- We need to understand better how to tune the energy dependence of the event activity: multiple parton scattering rate?
- New MC models *(e.g. PYTHIA6.3)* and measurements can provide us with more tools to understand minimum-bias and the UE, and also to estimate more precisely this physics at the LHC.
- At the LHC, the best chance to the UE is at the low (very low?) luminosity runs. We are currently studying strategies to perform these measurements at ATLAS.

Backup…

Dijet azimuthal decorrelation

hep-ex/0409040 Sep. 2004





Jets are defined in the central region using seed-based cone algorithm (R=0.7)

leading jet $p_T^{max} > 75$ GeV
second leading jet $p_T^{max} > 40$ GeV
both leading p_T jets: $|y_{jet}| < 0.5$

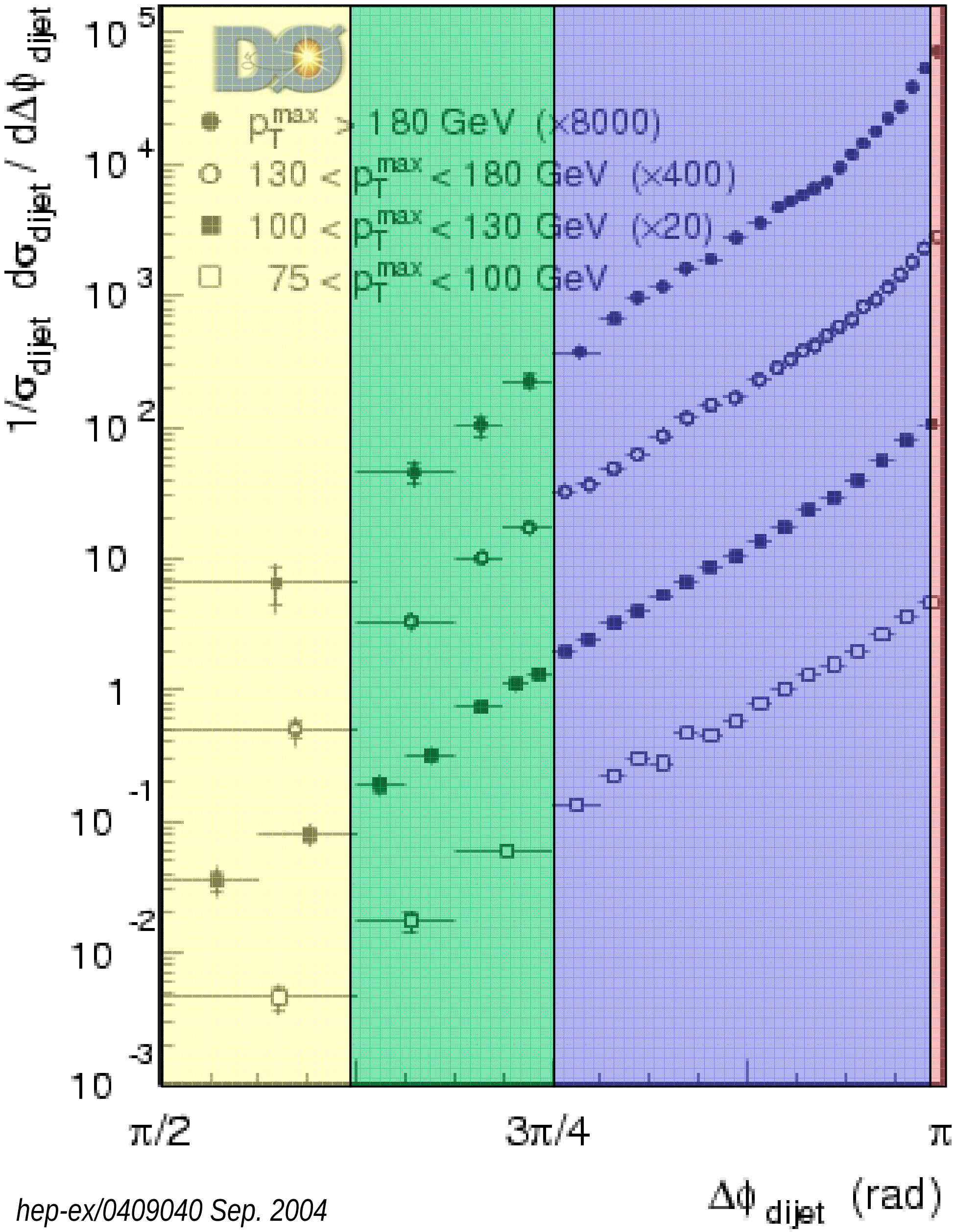
Dijet production in hadron-hadron collisions result in $\Delta\phi_{dijet} = |\phi_{jet1} - \phi_{jet2}| = \pi$ in the absence of radiative effects.

$\Delta\phi_{dijet} = \pi$ $\rightarrow$ exactly two jets, no further radiation

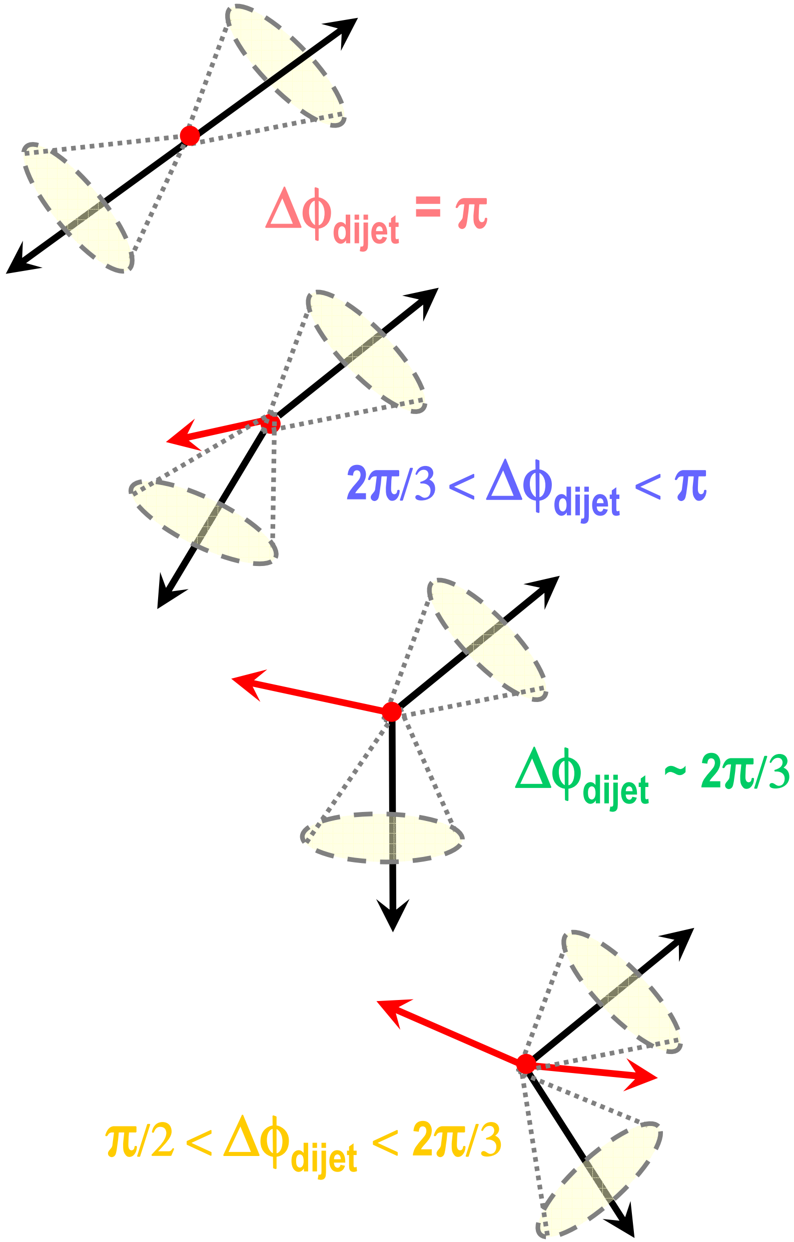
$\Delta\phi_{dijet}$ small deviations from π $\rightarrow$ additional soft radiation outside the jets

$\Delta\phi_{dijet}$ as small as $2\pi/3$ $\rightarrow$ one additional high-p_T jet

small $\Delta\phi_{dijet}$ – no limit $\rightarrow$ multiple additional hard jets in the event



hep-ex/0409040 Sep. 2004



Dijet azimuthal decorrelation: ISR

PARP(67) defines the maximum parton virtuality allowed in ISR showers
(PARP(67) x hard scale Q^2)

PARP(67)=1 (default): distributions underestimate the data! Need to increase the decorrelation effect, i.e. increase radiative and multiple interaction effects.

Increasing PARP(67) (from 1 to 4) the azimuthal decorrelation is increased.

Best value is somewhere between PARP(67)= 1 and 4!