# Calibrating QCD MC models to the early LHC data

**Arthur Moraes**

**University of Glasgow**

(on behalf of the ATLAS Collaboration)

# Outline:

I. Introduction:

a. Examples of previous ATLAS tunings;

b. Updating the UE prediction/MC tuning for ATLAS.

- Transverse region distributions,
- MAX and MIN cone distributions

  ($\sqrt{s}$=630 GeV and $\sqrt{s}$=1800 GeV)

II. LHC predictions:

- $\sqrt{s}$=10 TeV and $\sqrt{s}$=14 TeV

III. Tuning MC generators to “early” LHC data

IV. Summary

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- Minimum bias distributions:

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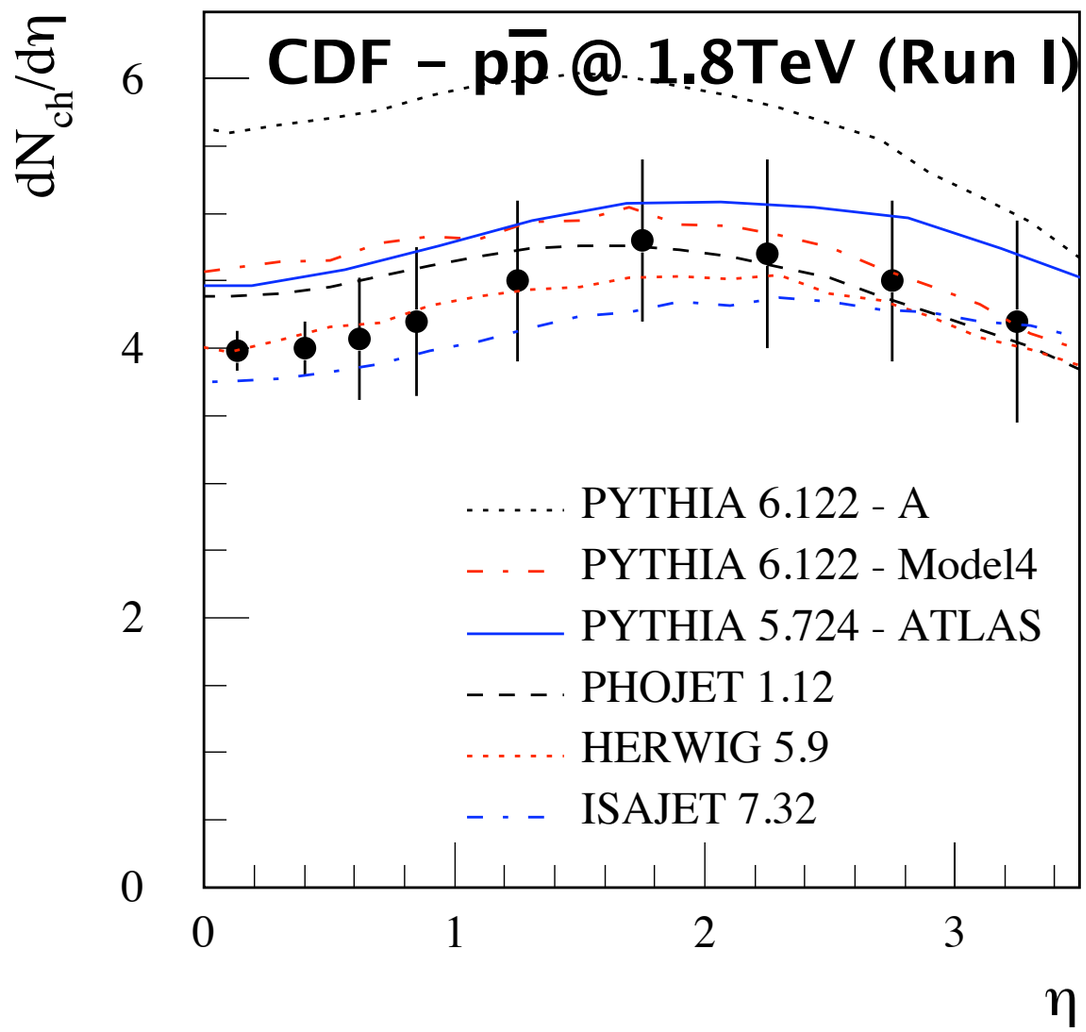


ATL-PHYS-99-019

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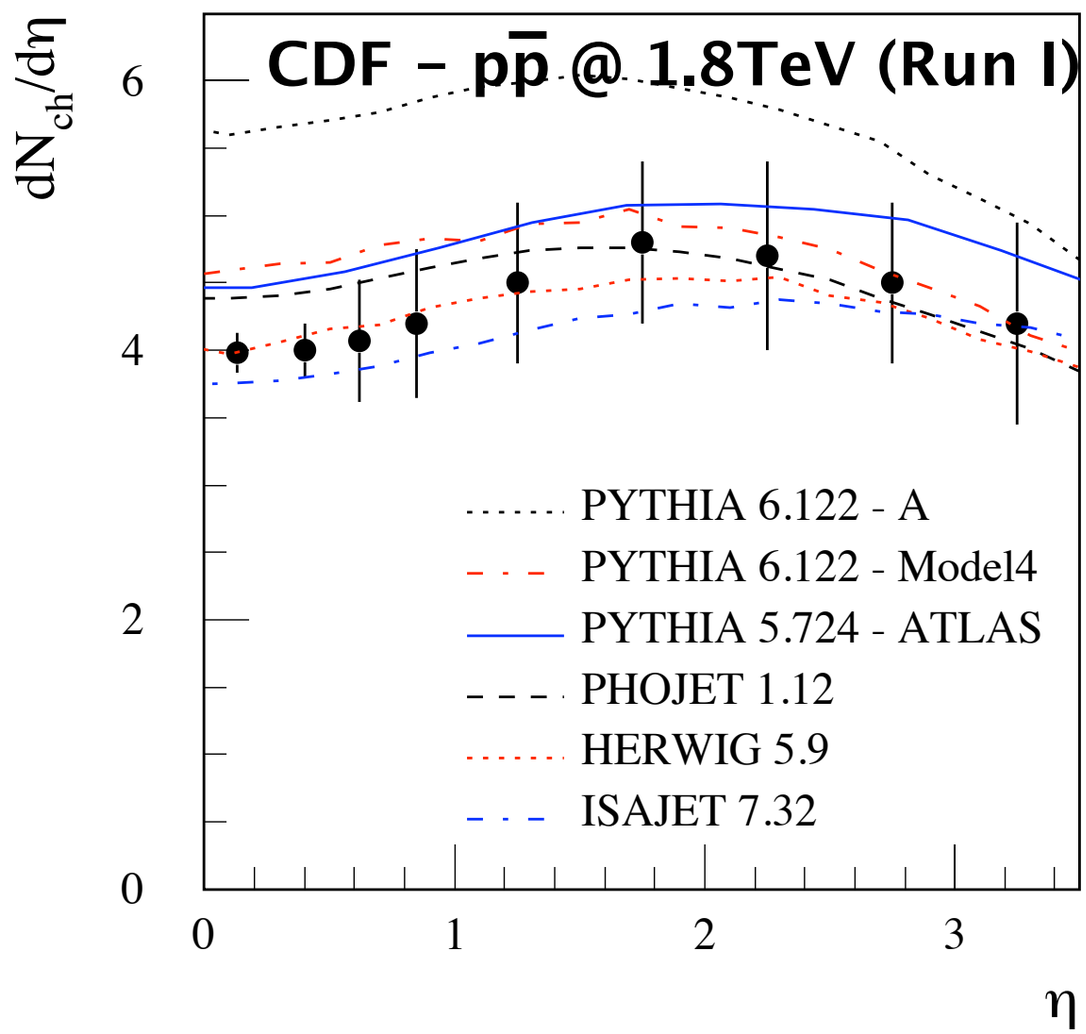


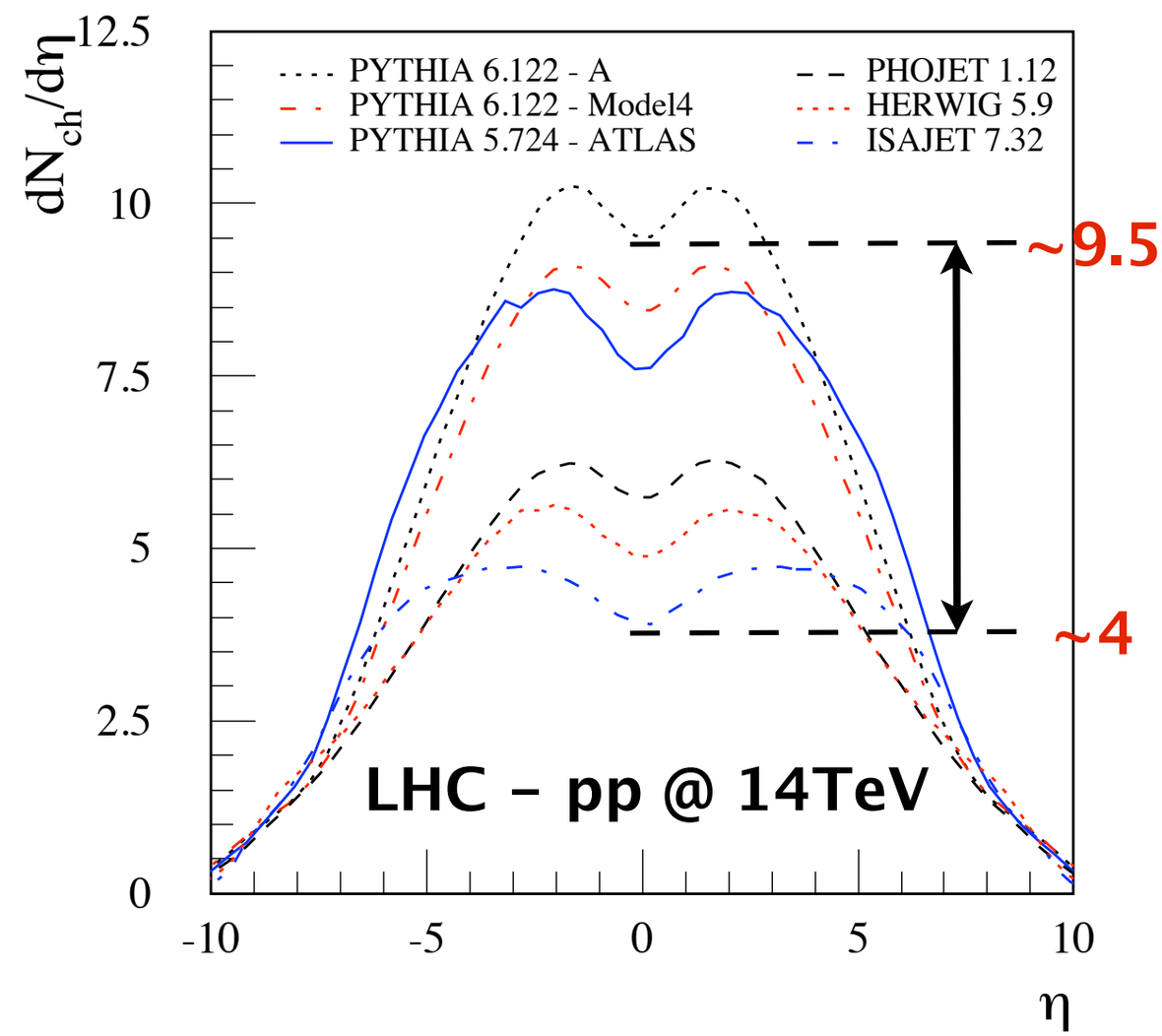


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# Introduction:

- Minimum bias and underlying event measurements were used for a "new" round of MC tunings.

| Comments | ATLAS – TDR (PYTHIA5.7) | PYTHIA6.214 - ATLAS |
|---|---|---|
| Generated processes (QCD + low-pT) | Non-diffractive inelastic (MSEL=1) | Non-diffractive + double diffraction (MSEL=0, ISUB 94 and 95) |
| p.d.f. | CTEQ 2L (MSTP(51)=9) | CTEQ 5L (MSTP(51)=7) |
| Multiple interactions models | MSTP(81) = 1<br>MSTP(82) = 4 | MSTP(81) = 1<br>MSTP(82) = 4 |
| $p_T$ min | PARP(82) = 1.55<br>no energy depend. | PARP(82) = 1.8<br>PARP(89) = 1 TeV<br>PARP(90) = 0.16 |
| Core radius | 20% of the hadron radius (PARP(84) = 0.2) | 50% of the hadron radius (PARP(84) = 0.5) |
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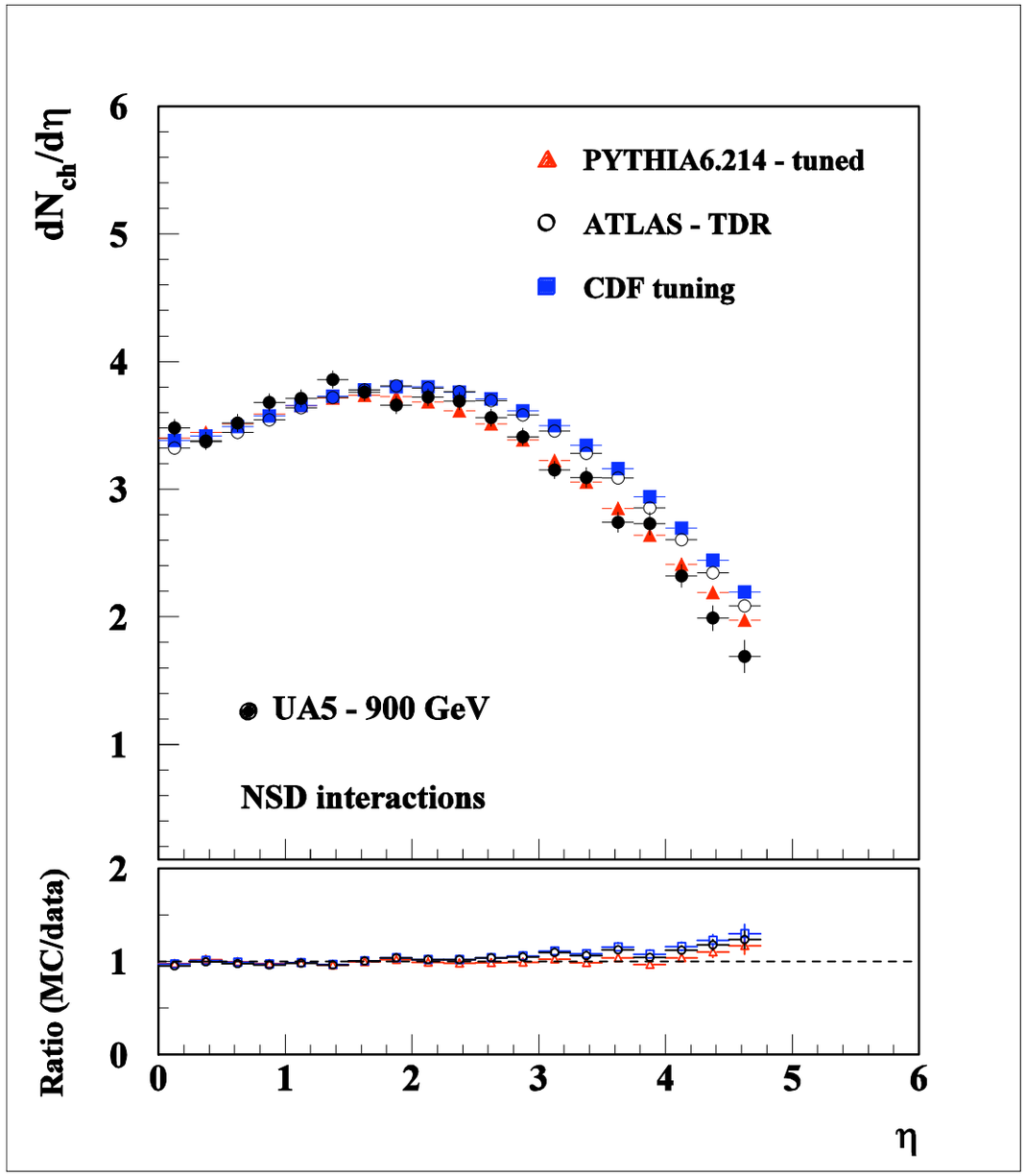


EPJ C 50, 435 (2007)

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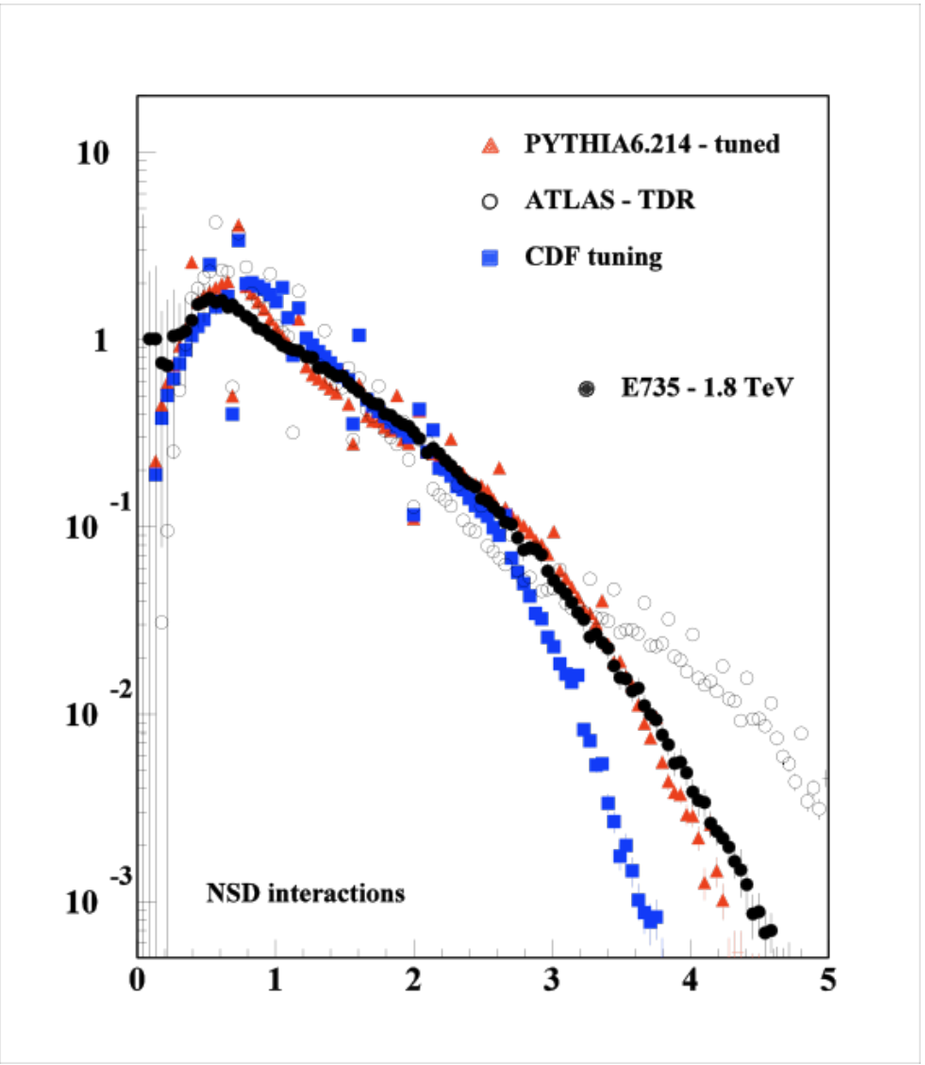


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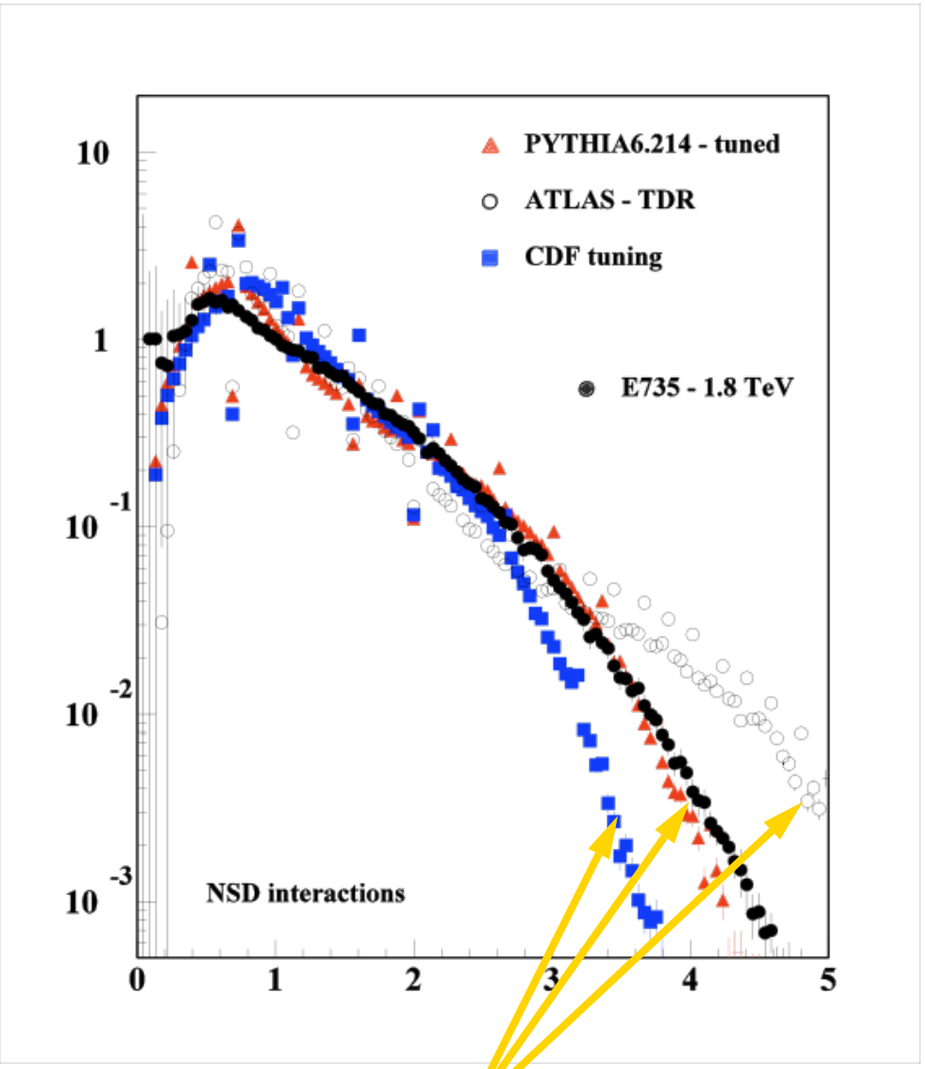


*High-multiplicity events are described differently by each tuning*

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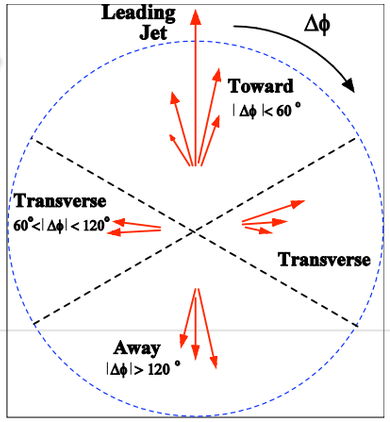
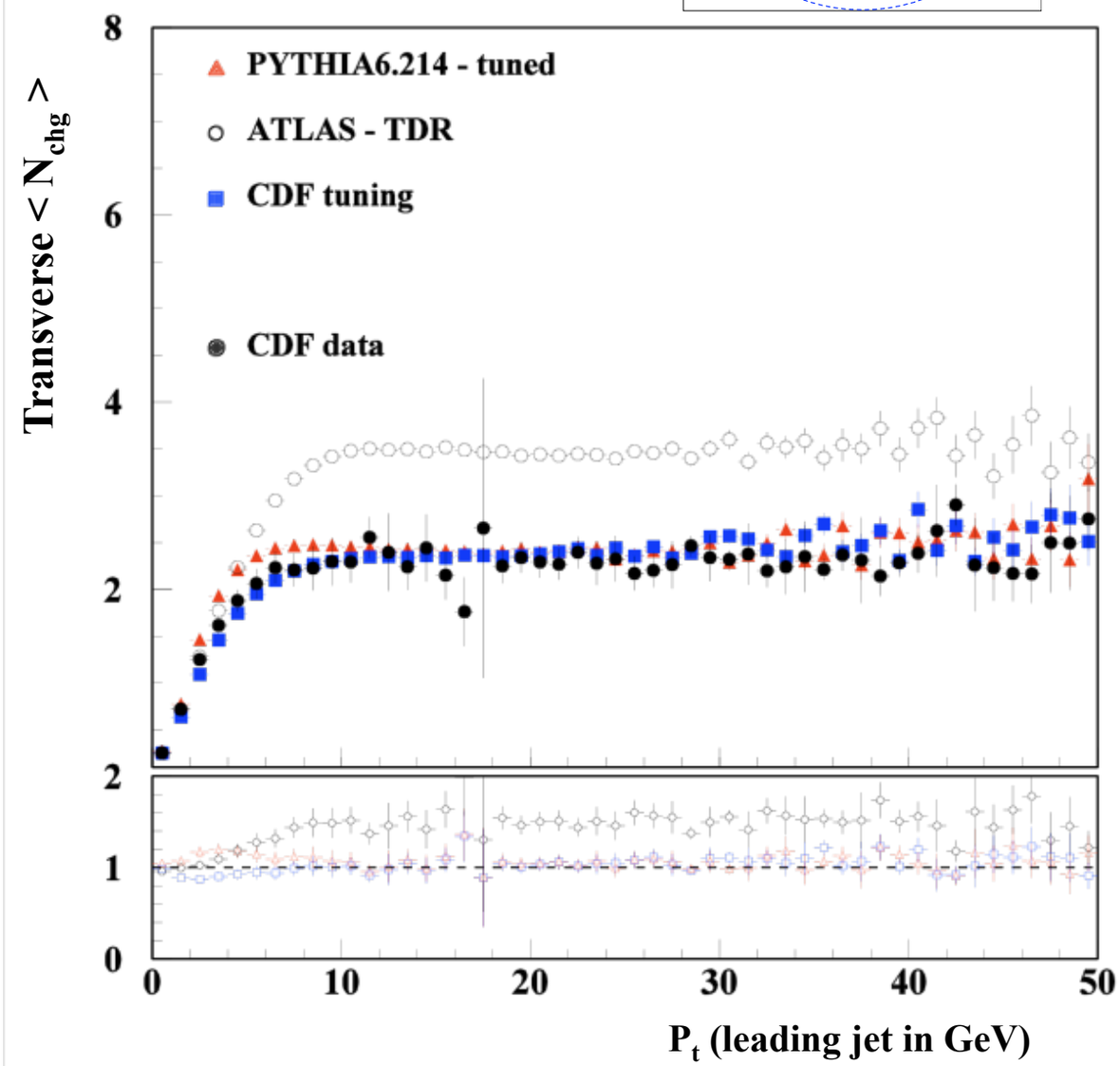
**CDF - Run I "Style"**

**Charged particles:**
**$p_t$>0.5 GeV and |η|<1**

**UE particles come from region transverse to the leading jet.**



# Updating the UE prediction/tuning for ATLAS.

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- ATLAS simulations: for most samples, the underlying event activity is generated with **PYTHIA** or **JIMMY** (HERWIG).
  - PYTHIA6.4: http://projects.hepforge.org/pythia6/
  - JIMMY4.31: http://projects.hepforge.org/jimmy/

- PYTHIA version used by ATLAS has recently been updated (new bug fixes & improvements required for the next round of simulated sample production).
  - Re-tuning the underlying event parameters was necessary!

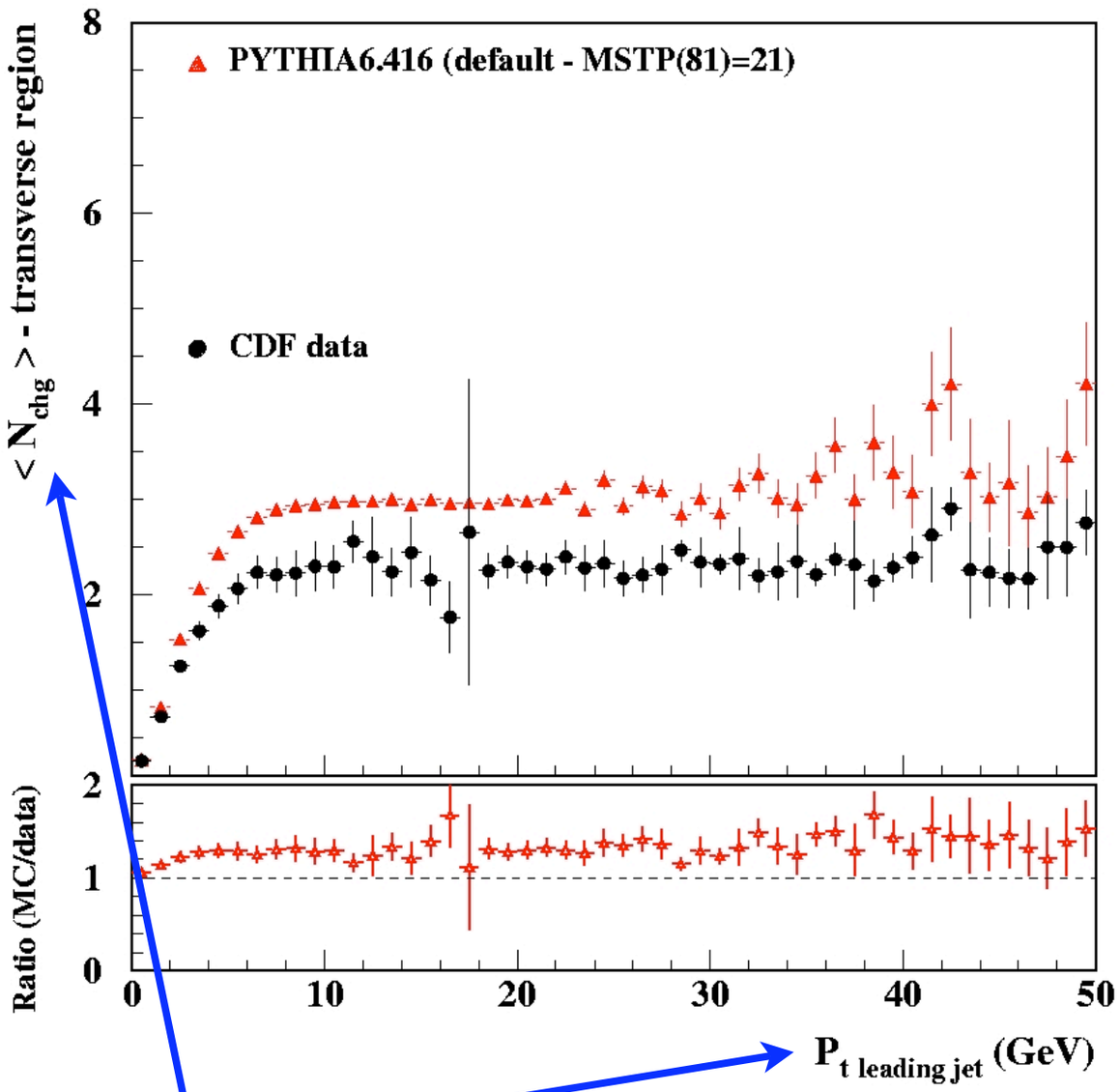
- Guidelines followed for re-tuning PYTHIA:
  - use CTEQ6ll (this means that most of tunes already available in PYTHIA - MSTP(5) aren't suitable);
  - try to keep as many default settings as possible;
  - do not touch ISR/FSR parameters if at all possible!

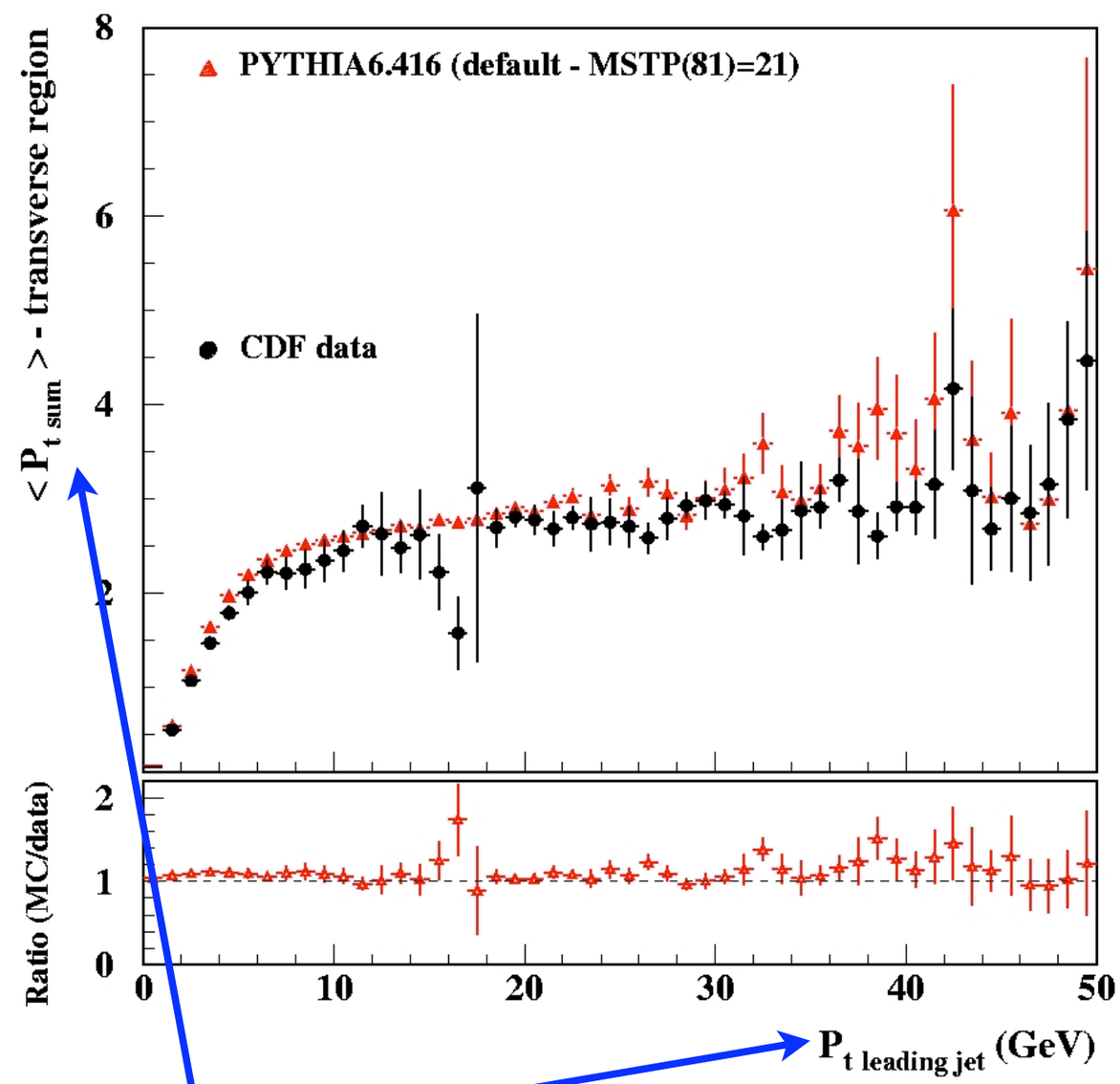
# Updating the UE prediction/tuning for ATLAS.

- JIMMY: no immediate need to update the tune currently used by ATLAS. hep-ph/0604120 – LH2005: SM & Higgs WG report

- Data distributions used to check model predictions:
  - $\langle N_{chg} \rangle$ and $\langle P_T^{sum} \rangle$ in the region transverse to the leading jet (CDF Run I data @ $\sqrt{s}$ = 1.8 TeV). Phys. Rev. D65, 092002 (2002)
  - $dN_{chg}/dp_T$ spectrum of particles in the underlying event (same CDF data as above). Phys. Rev. D65, 092002 (2002)
  - MAX/MIN cones transverse to the leading jet (CDF Run I data @ $\sqrt{s}$ = 630 GeV and $\sqrt{s}$ = 1.8 TeV) Phys. Rev. D70, 072002 (2004)

# PYTHIA6.416: describing the region transverse to the leading jet




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

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

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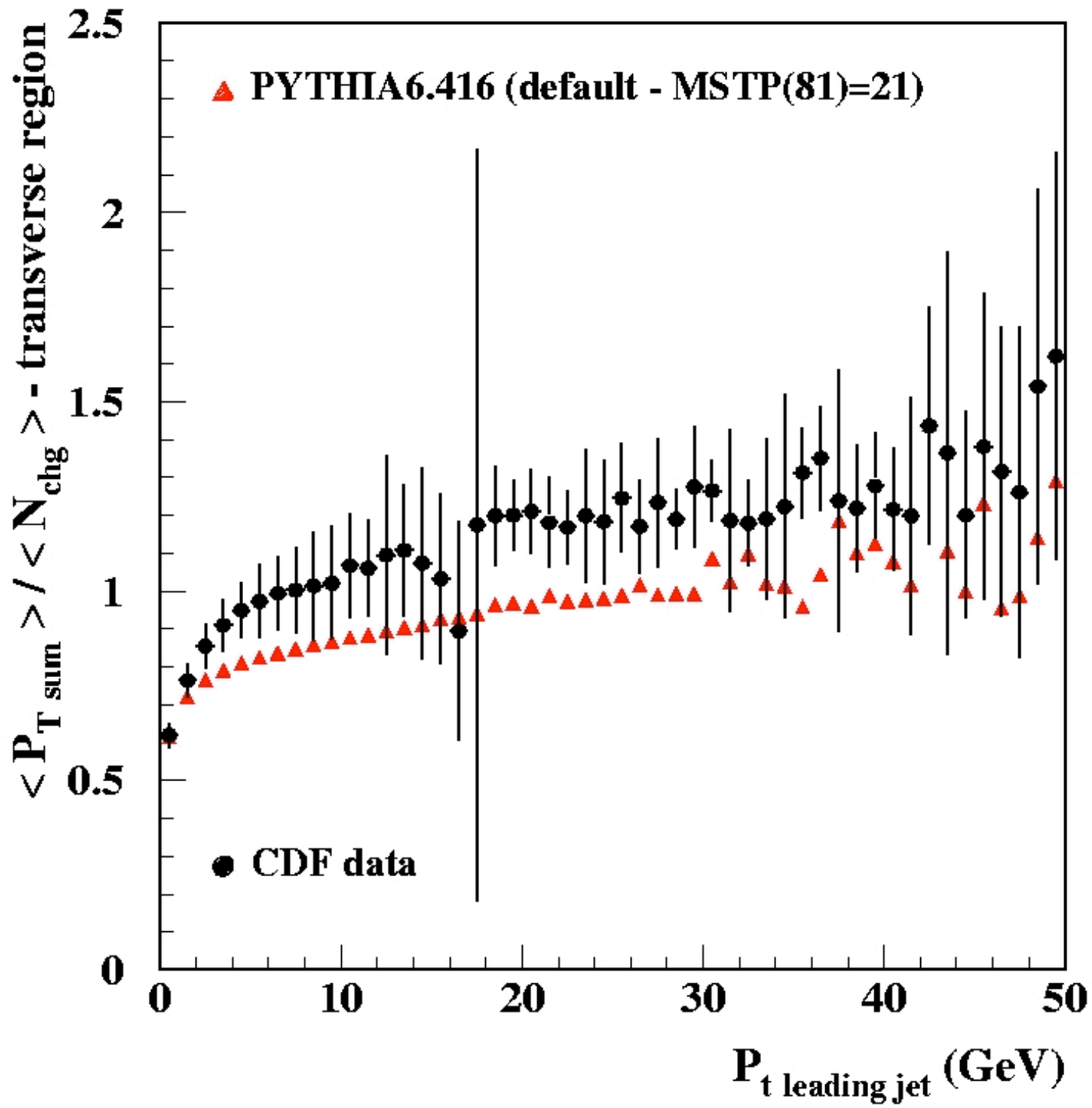


- PYTHIA6.416 – default generates the UE with particles too soft!
- $p_T$ ($n_{chg}$) needs to be increased!

# Parameters tuned:

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**PYTHIA6.416 - PYEVNT** CTEQ6ll (LO fit with LO $\alpha_s$) → LHAPDF (set number 10042)

| | Default: | Tuned: | |
|---|---|---|---|
| | MSTP(81)=21 | | new multiple interaction model & new parton shower selected! |
| MPI | MSTP(82)=4 | | |
| ISR | MSTP(84)=1 | | allowed ISR and FSR after first (hardest) interaction |
| FSR | MSTP(85)=1 | | |
| MPI | MSTP(86)=2 | | |
| colour reconnection | MSTP(87)=4 | | |
| | MSTP(88)=1 | | |
| | MSTP(89)=1 | | |
| | MSTP(90)=0 | | |
| | MSTP(95)=1 | MSTP(95)=2 | minimize the total string length |
| | PARP(78)=0.025 | PARP(78)=0.3 | regulates the number of attempted colour reconnections (choose shorter strings) |
| $p_{T0}$ scale | PARP(82)=2.0 | PARP(82)=2.1 | |
| matter distribution | PARP(83)=0.5 | PARP(83)=0.8 | |
| | PARP(84)=0.4 | PARP(84)=0.7 | |
| $p_{T0}$ scale | PARP(89)=1800 | | |
| | PARP(90)=0.16 | | |

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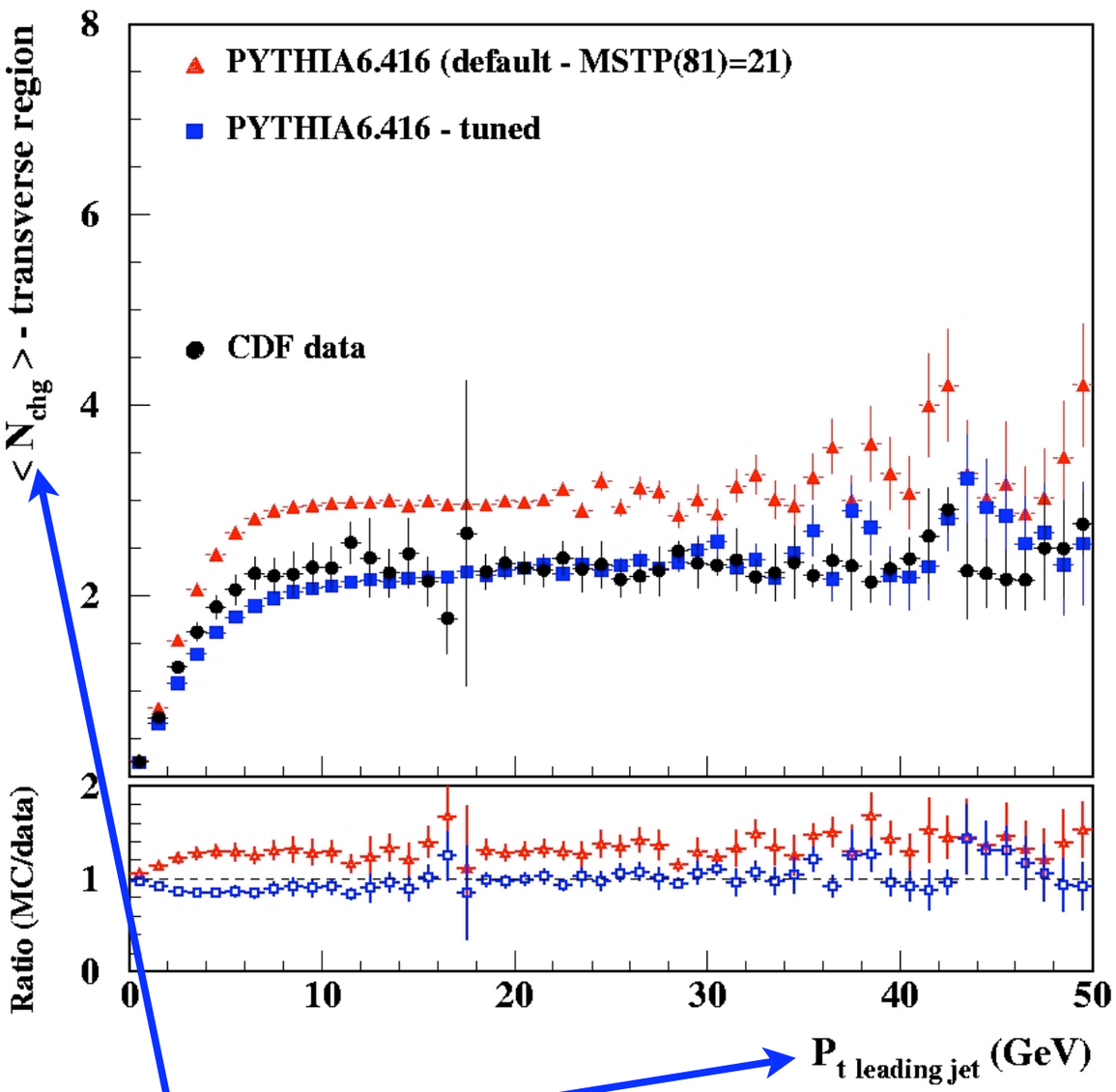


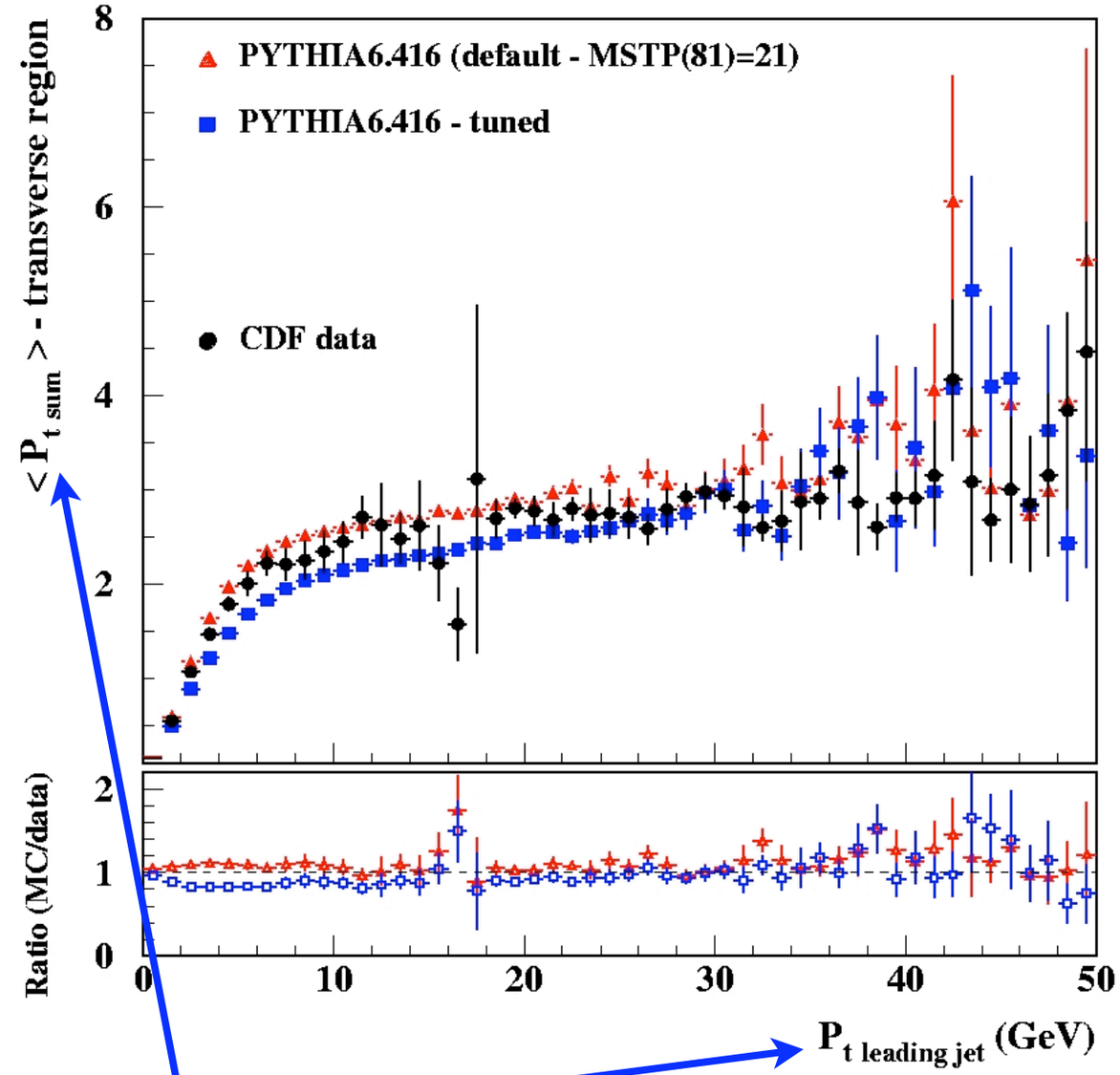


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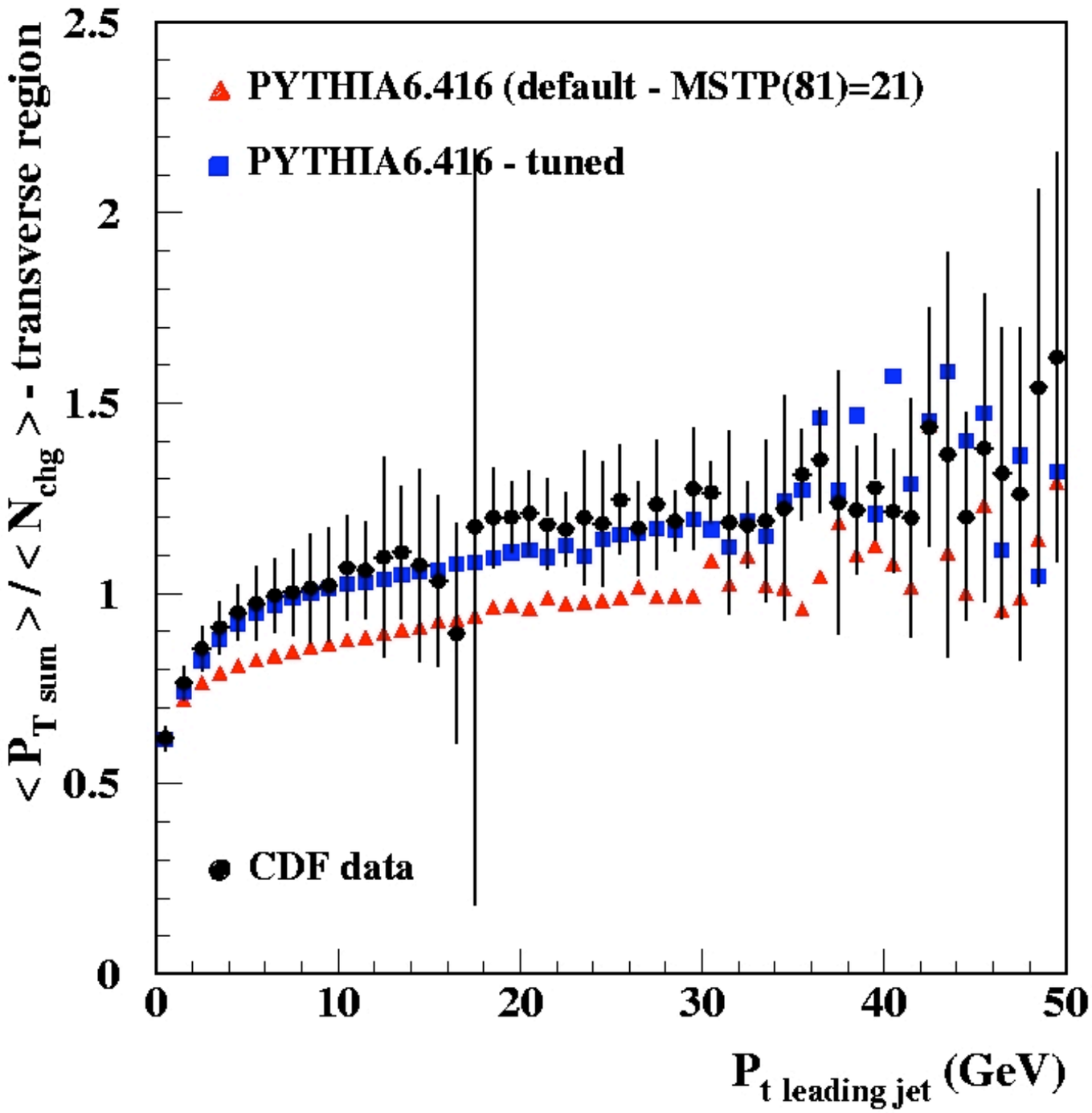
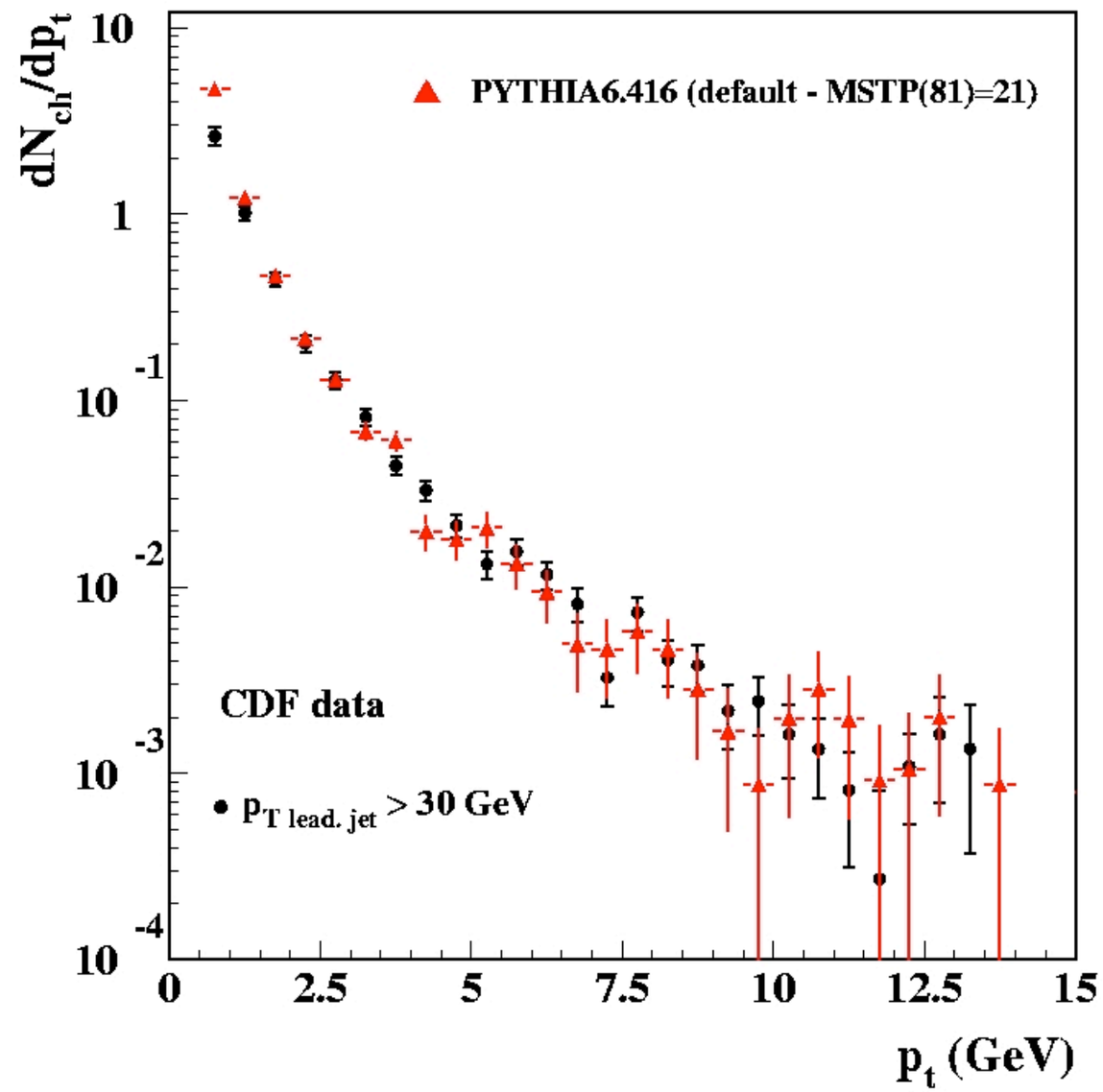



- Better $p_T$ ($n_{chg}$) is obtained by "forcing" more colour reconnections with the hard scattering system, and less with the beam remnant.

# PYTHIA6.416: describing the region transverse to the leading jet

**$dN_{chg}/dp_T$ spectrum:**
charged particles in the underlying event for $p_T^{\text{leading jet}} > 30$ GeV.



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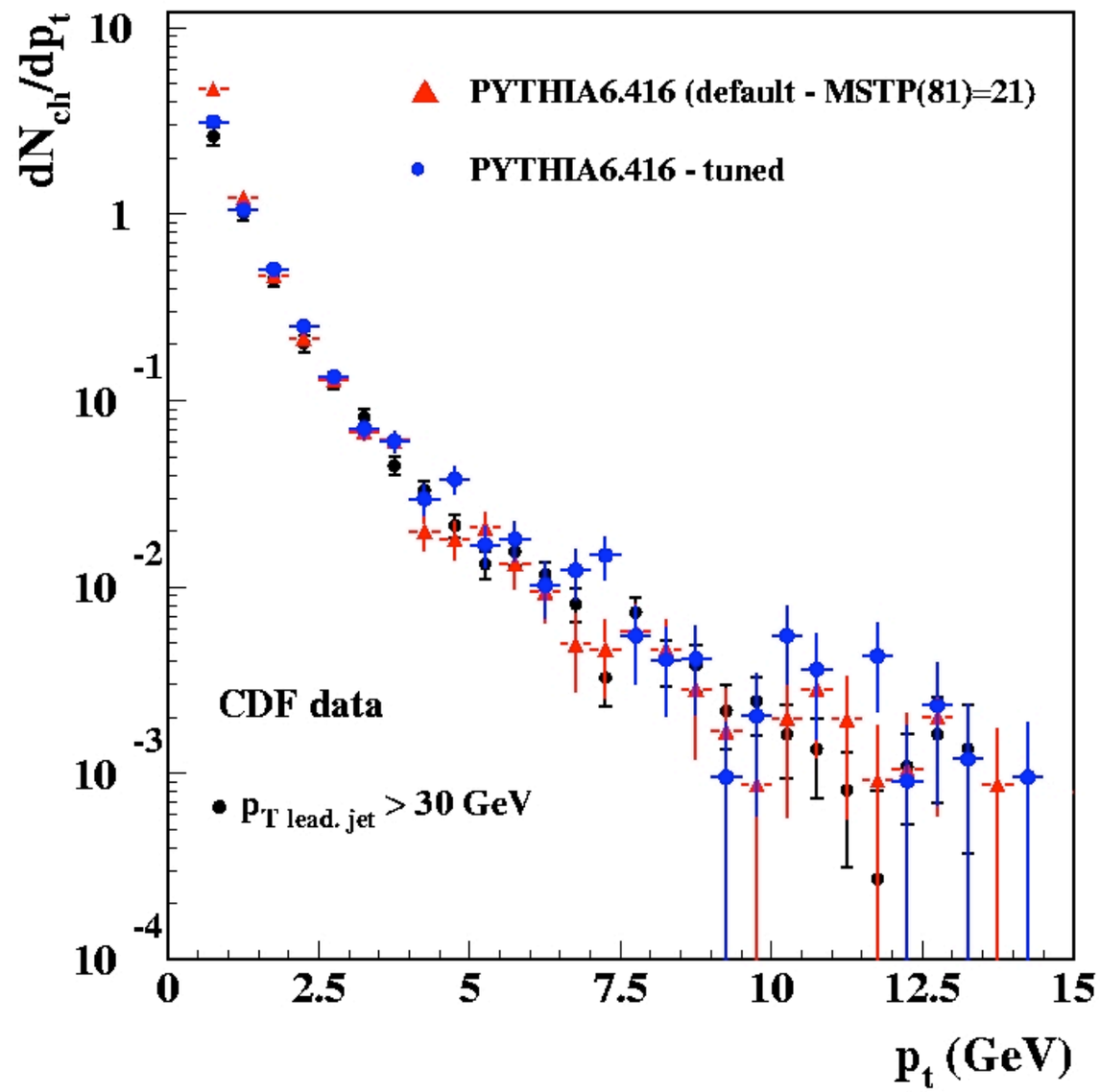
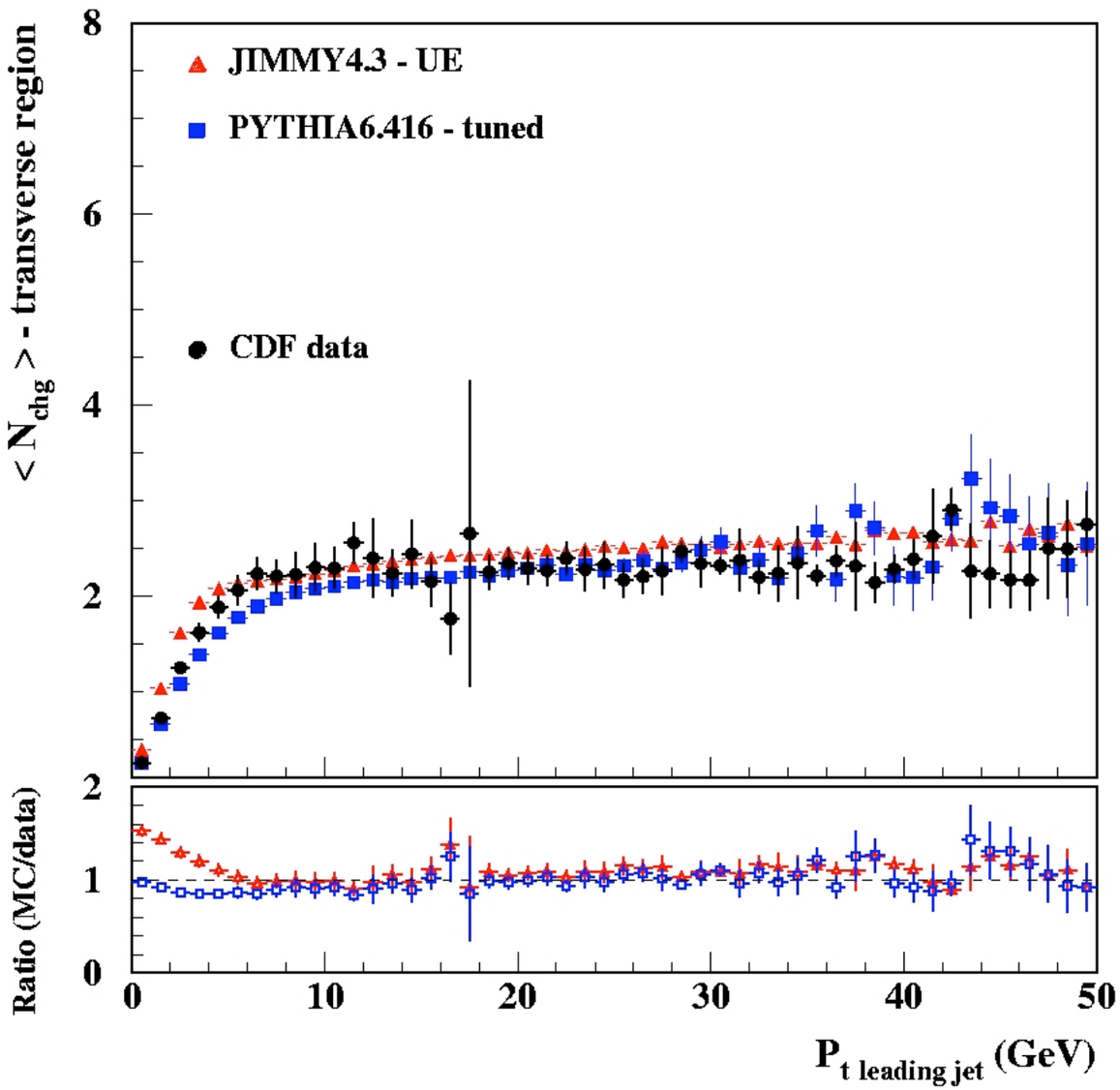
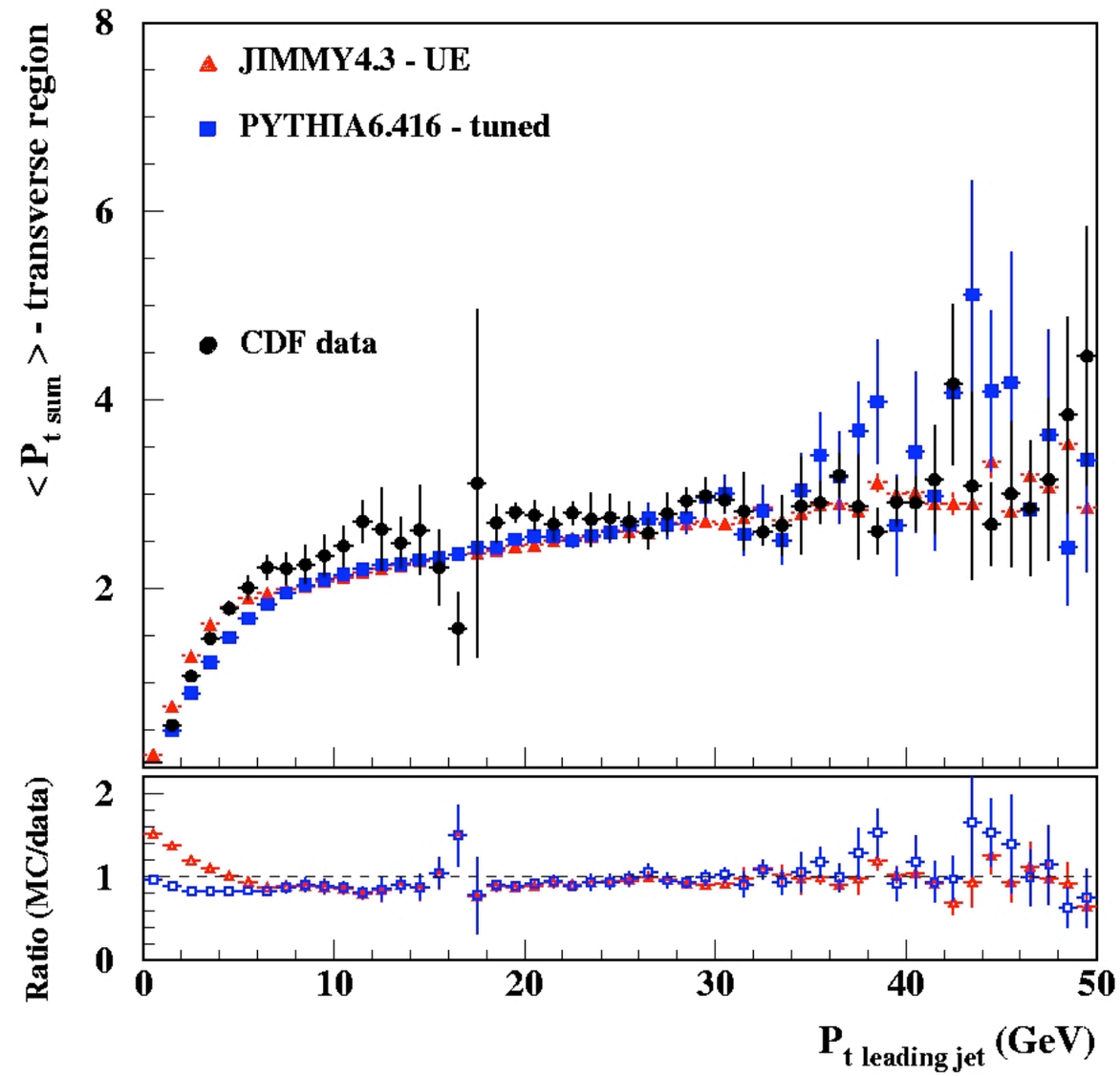


# PYTHIA6.416 – tuned vs. JIMMY4.3



# "MAX / MIN analysis" (CDF analysis – Run I data)

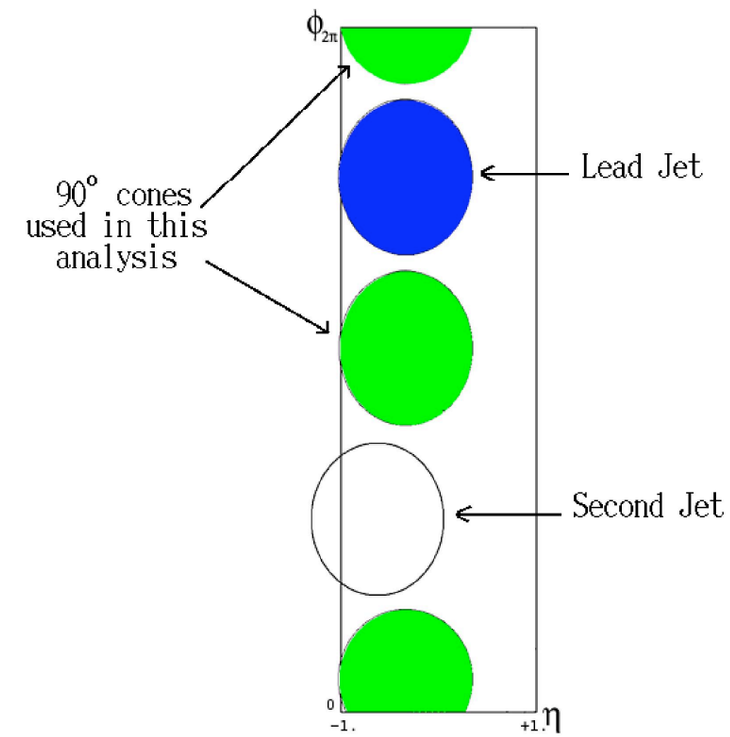
- Two cones in $\eta-\phi$ space are defined:

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

$\phi=\phi_{ljet} \pm 90°$

$R=0.7$

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

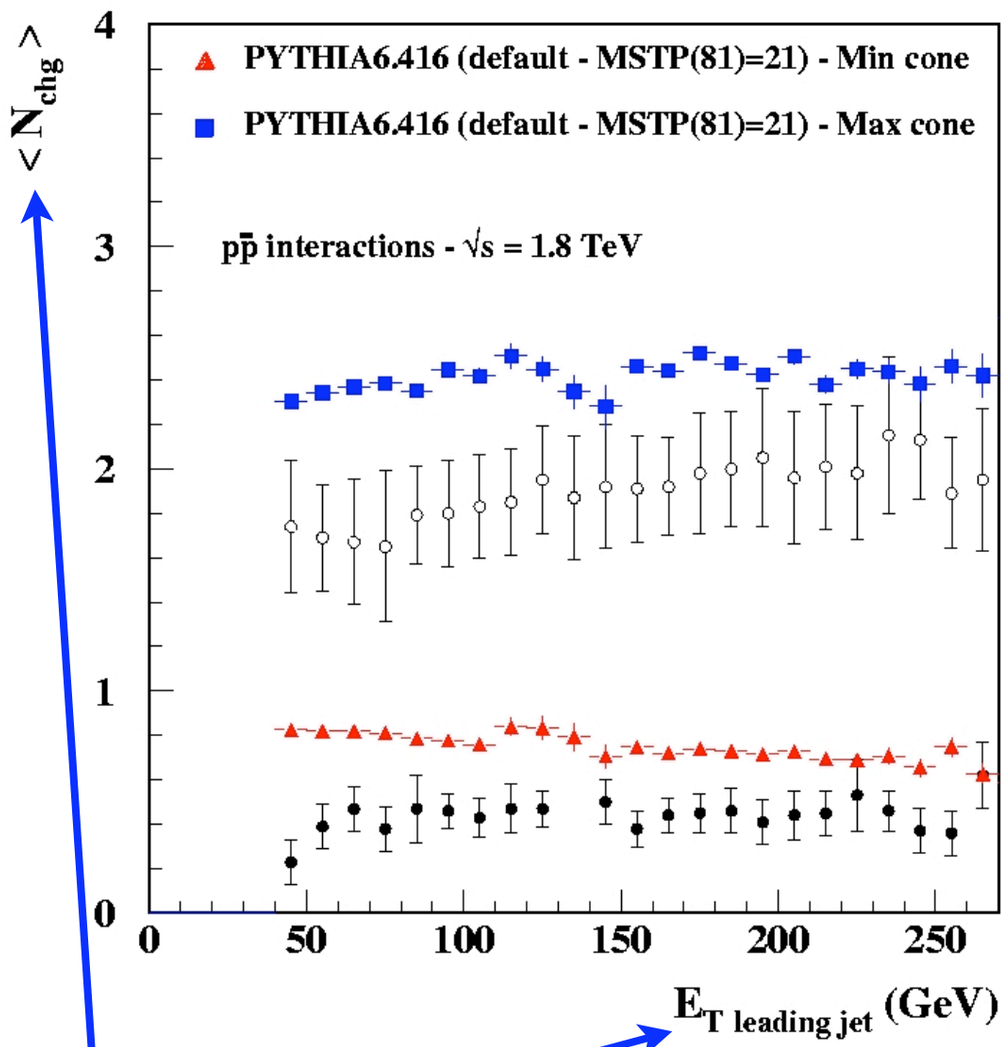


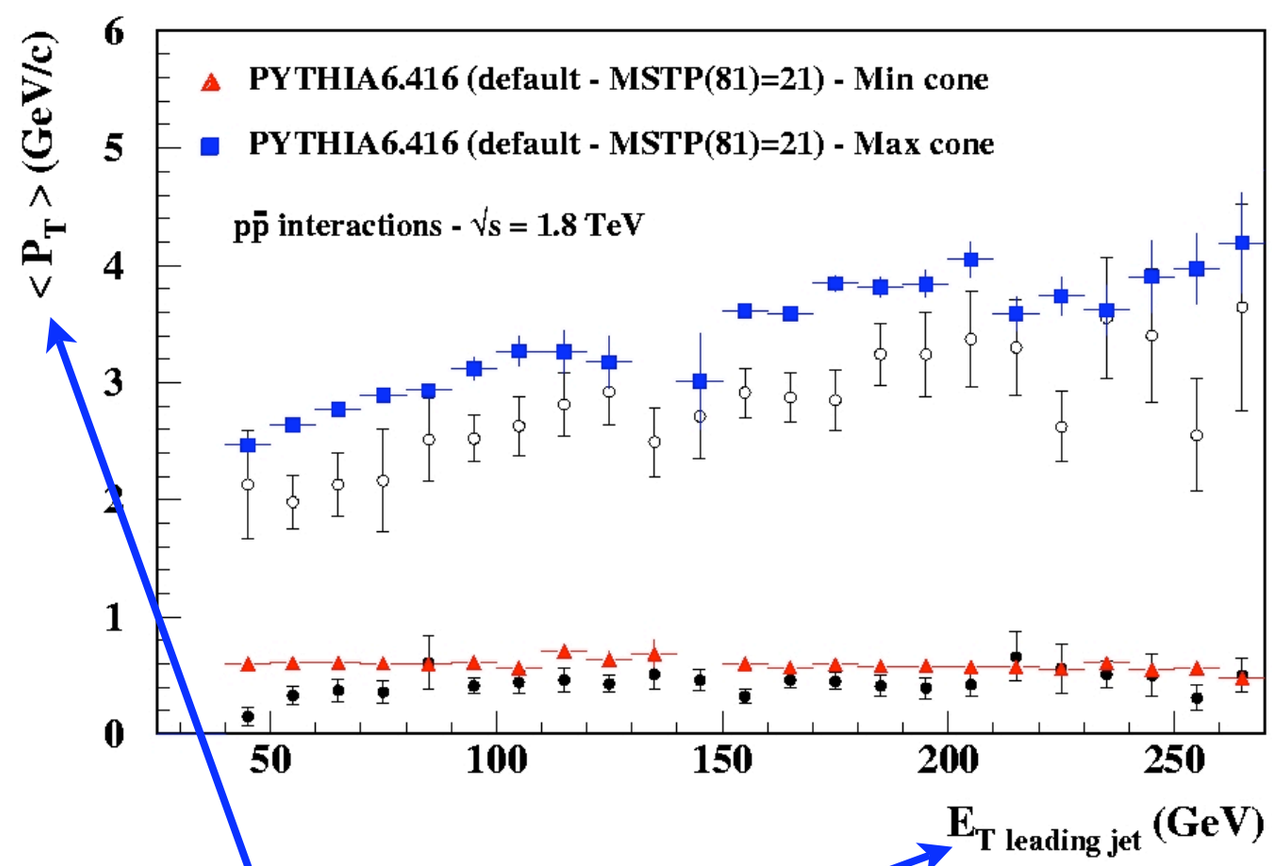

- The underlying event is measured for jet events at two different colliding energies: $\sqrt{s}=630$ GeV and $\sqrt{s}=1800$ GeV.

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

D. Acosta et al., The CDF Collaboration, Phys. Rev. D70, 072002 (2004).

# "MAX / MIN analysis": √s=1.8 TeV
## PYTHIA6.416 – default (MSTP(81)=21)

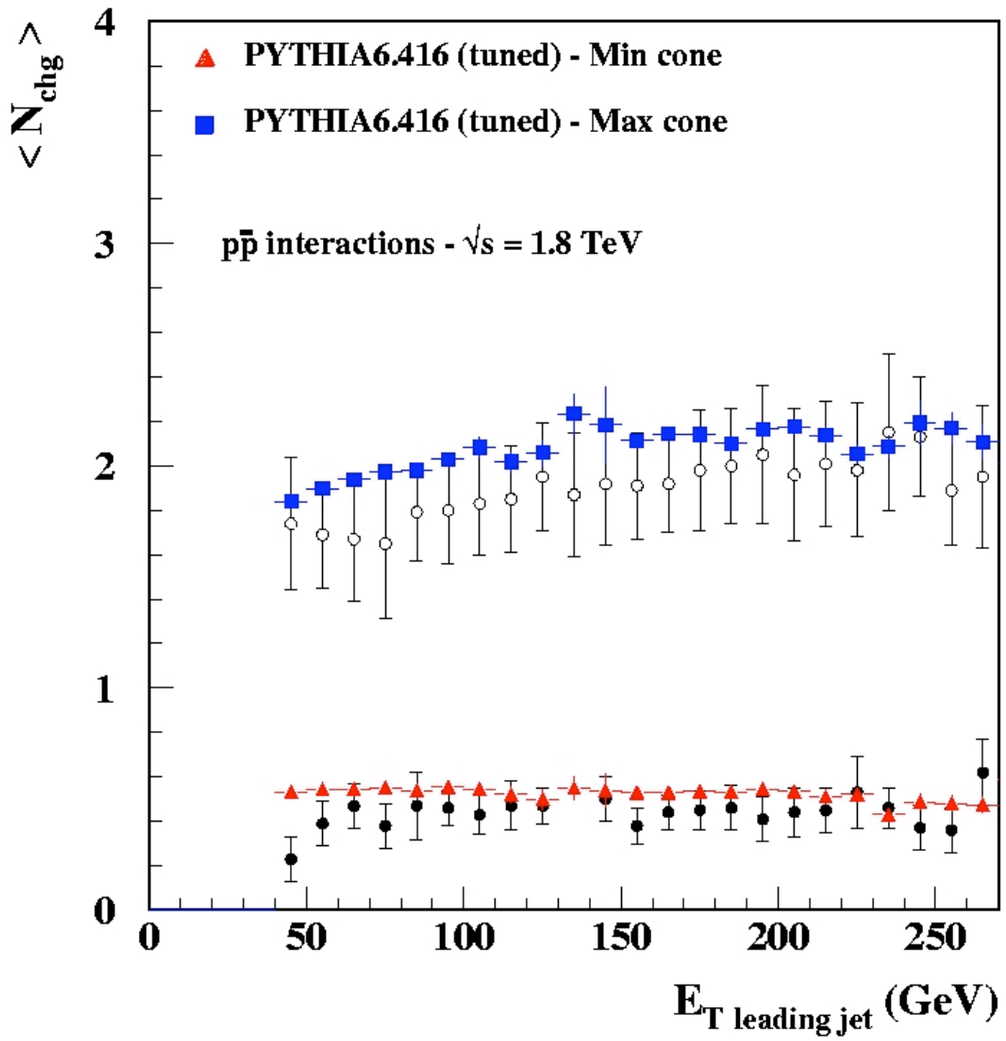


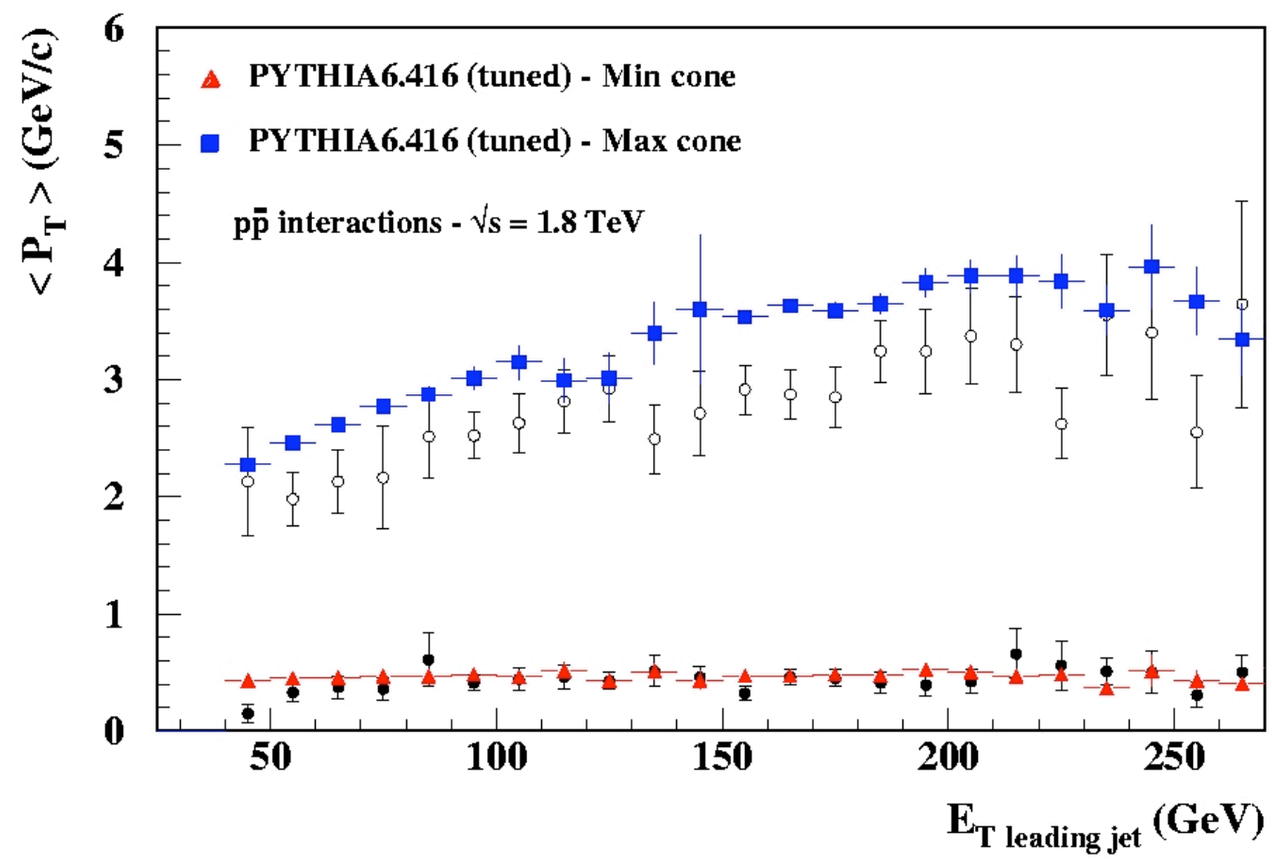




**Average multiplicity** of charged particles in the transverse cones (MAX and MIN) associated to the leading jet – $E_t^{ljet}$ (GeV).

**Average $p_T$** (GeV) of charged particles in the transverse cones (MAX and MIN) associated to the leading jet – $E_t^{ljet}$ (GeV).

# "MAX / MIN analysis": √s=1.8 TeV
## PYTHIA6.416 – tuned

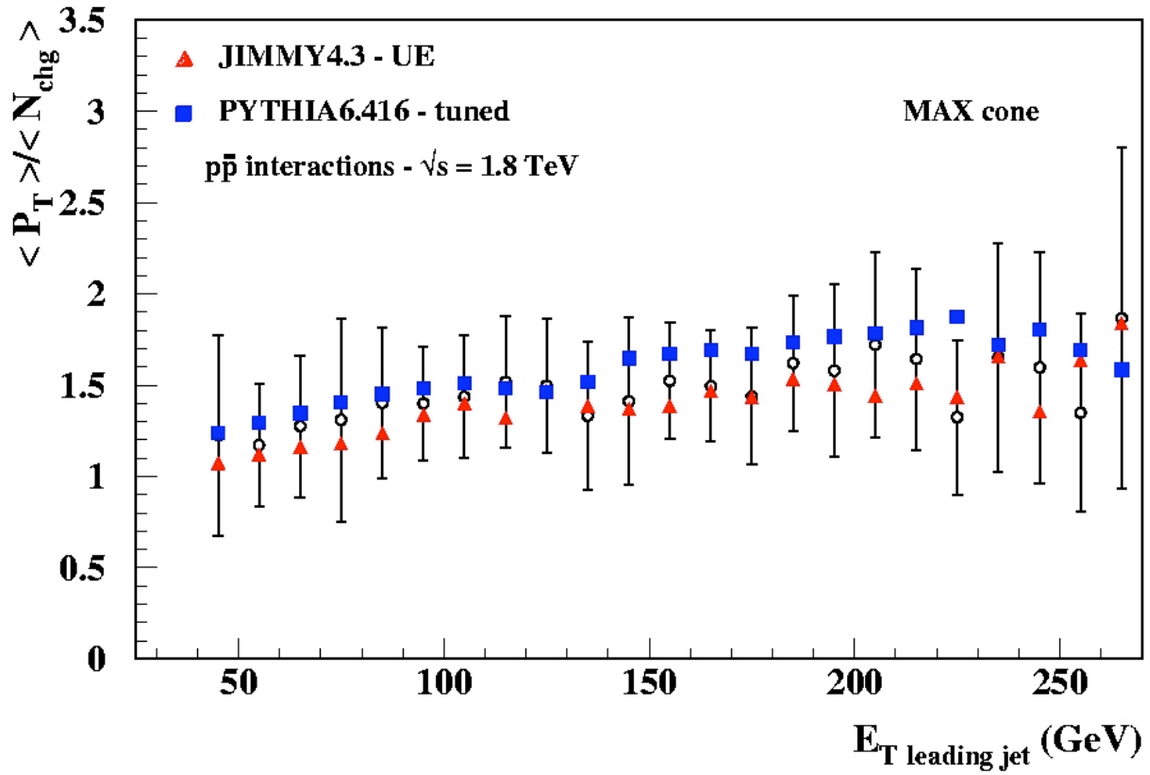


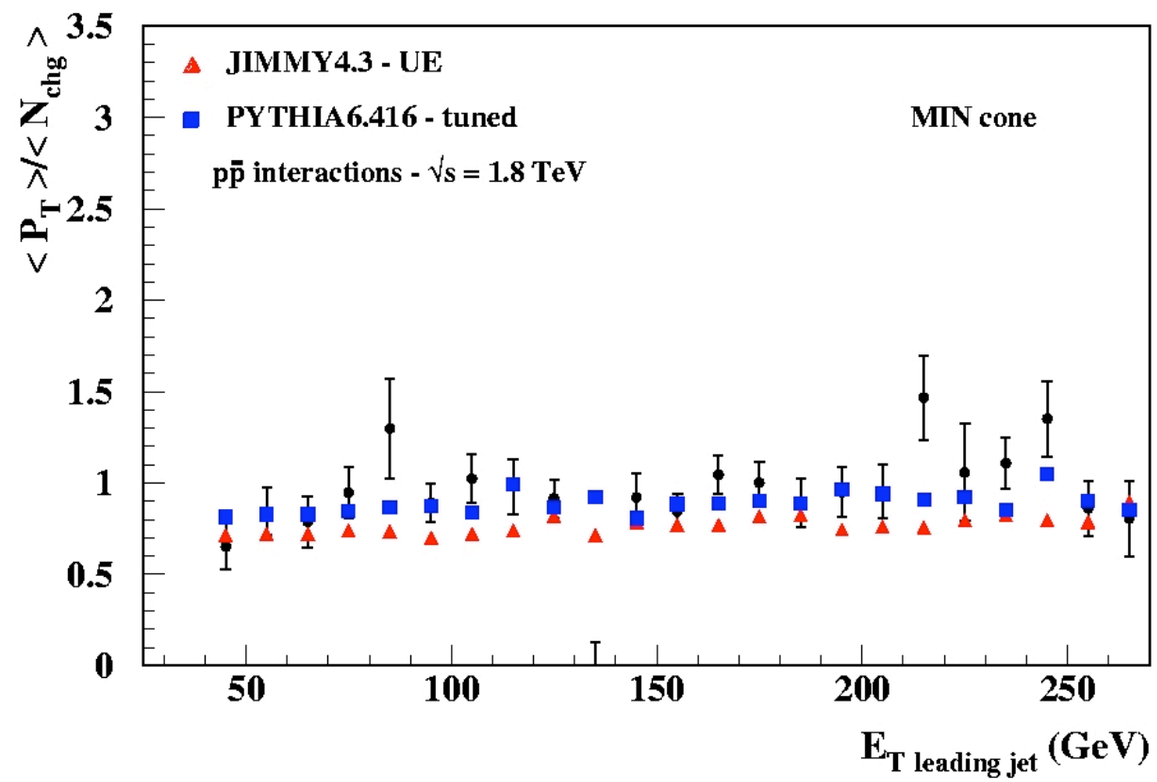




- **Better description of the ratio $\langle P_T \rangle / \langle N_{chg} \rangle$ (for both MAX and MIN cones)**

# "MAX / MIN analysis"

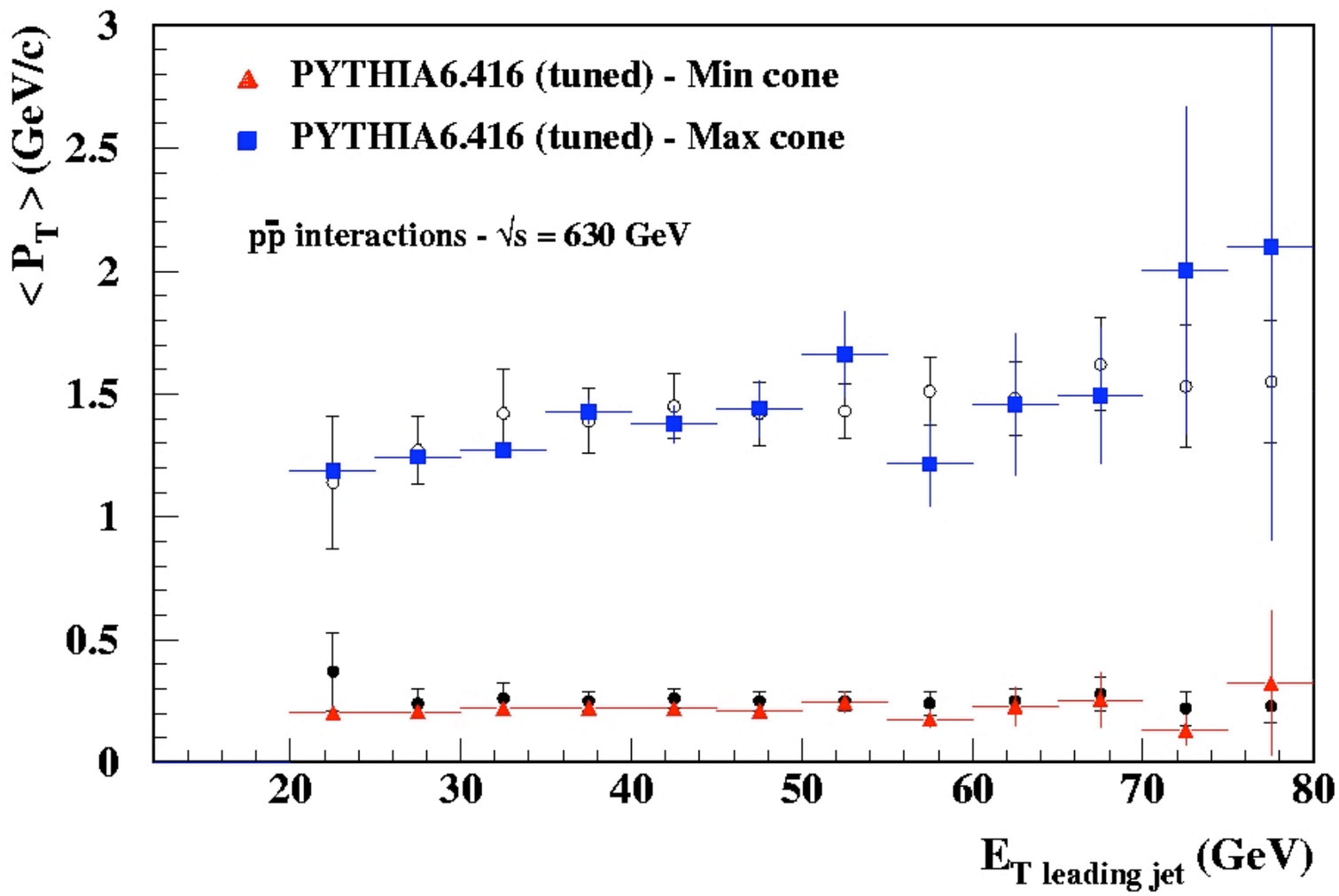
- Ratio (for each cone): $\langle P_T \rangle / \langle N_{chg} \rangle$
- Compare: PYTHIA6.416 – tuned to JIMMY4.3
- Note that these are ratios of average quantities.
- It will be important to measure the properties of MAX and MIN cones in more detail at the LHC!



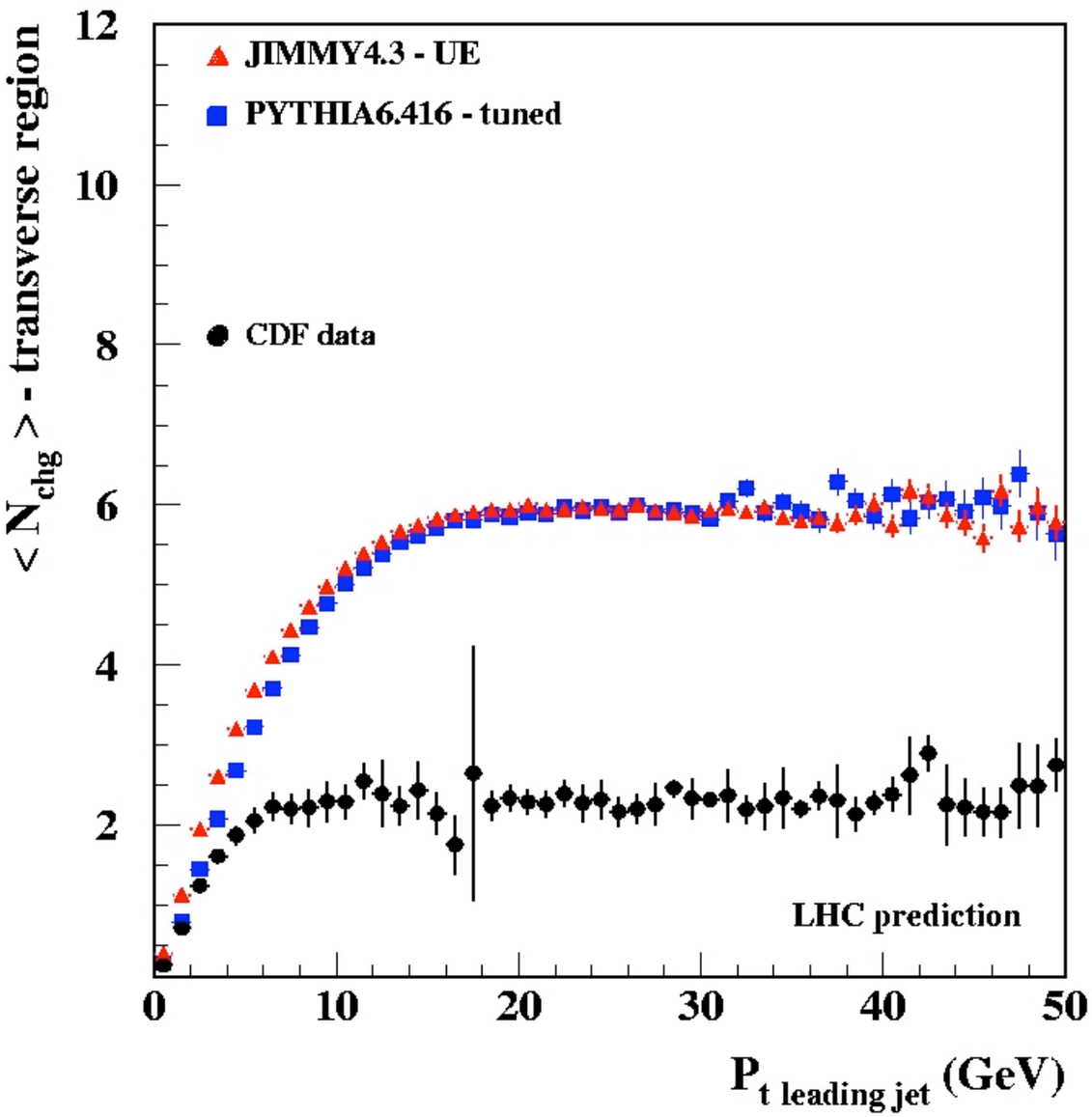
# "MAX / MIN analysis"

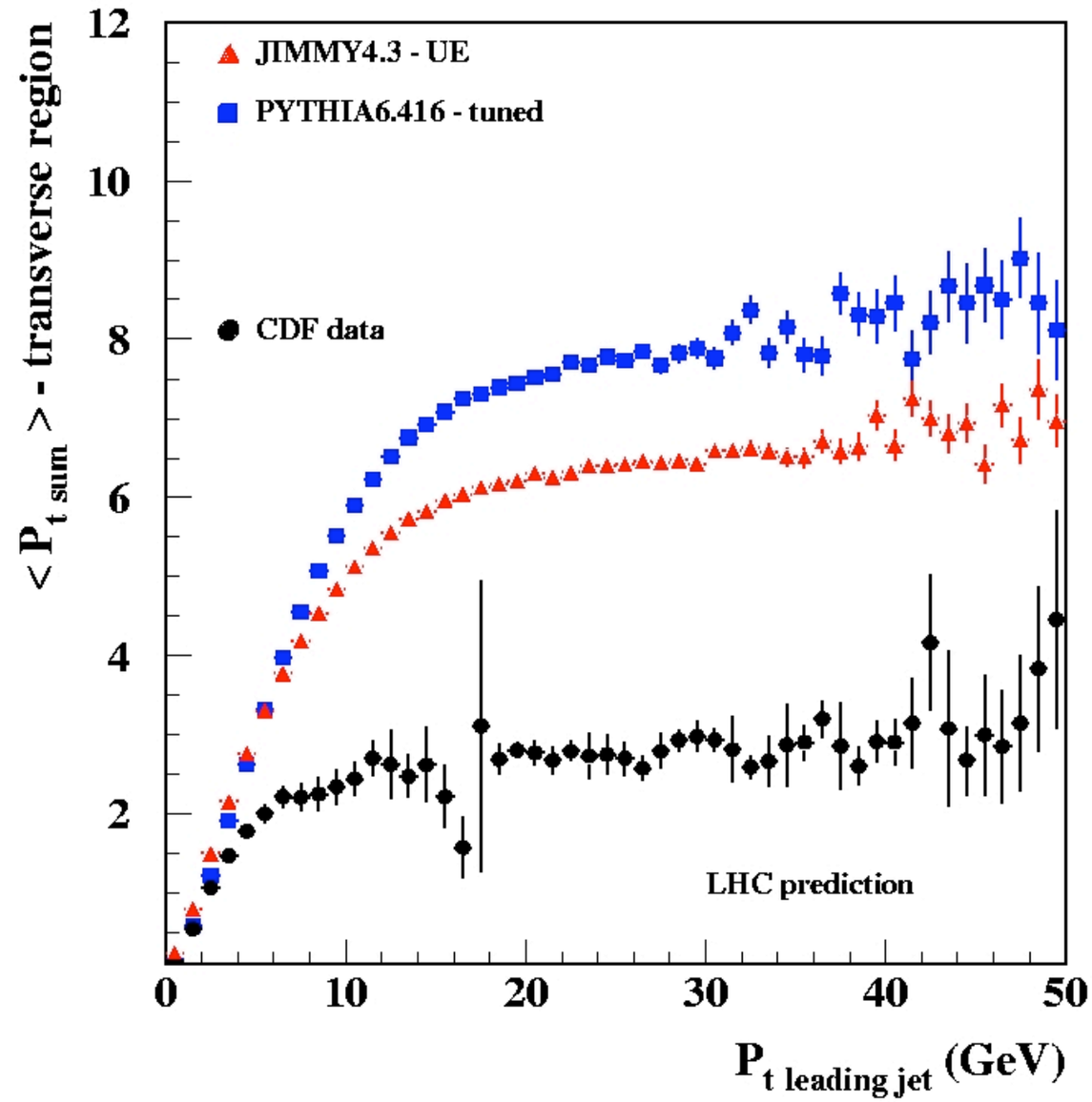
## $p\bar{p}$ @ $\sqrt{s}$=630 GeV




- **Lower CM energy data: important for tuning parameters which need to be regulated for energy extrapolation** (eg. multiple "semi-hard" parton scattering cross-section)**.**

# LHC Predictions: describing the region transverse to the leading jet




- **$<N_{chg}>$ distribution:** PYTHIA6.416 – tuned and JIMMY4.3 – UE predict same particle density at $\sqrt{s}$=14 TeV.
- **$<P_{T\ SUM}>$ distribution:** PYTHIA6.416 – tuned generates harder particles!

# Tuning MC generators with early LHC data

- **Initial remarks:**

  - This will not be a discussion on “new physics”. Focus on some examples of early QCD measurements.

  - I will assume that the early data measurements to be used in the MC tuning will be presented with error bars (at least) comparable to what has been published by past experiments.

  - I will also assume that the early data measurements will be presented corrected back to the hadron level (ie. corrected for detector effects – can be directly compared to MC generators).

# Tuning MC generators with early LHC data

- Based on the experiences of other large collaborations, it seems fair to expect several iterations before achieving an optimum tuning.
  - tuning to the "global" observables (distributions of average properties – largely dominated by "soft" interactions).
  - detailed tuning to specific distributions (calibrate generators to describe tails of distributions and shapes)

**Minimum bias data** (example)

| Experiment | References | Colliding beams |
|---|---|---|
| CERN – ISR | Phys. Rev. D **30** 528 (1984) | pp at $\sqrt{s}$ = 30.4, 44.5, 52.6 and 62.2 GeV |
| UA5 – SPS | Phys. Rep. **154**(5,6) 247 (1987)<br>Z. Phys. C **37**, 191 (1988)<br>Z. Phys. C **43**, 357 (1989) | $p\bar{p}$ at $\sqrt{s}$ = 200, 546 and 900GeV |
| CDF - Tevatron<br>E735 - Tevatron | Phys. Rev. D **41** 2330 (1990)<br>Phys. Lett. B **435** 453 (1998) | $p\bar{p}$ at $\sqrt{s}$ = 1.8TeV |

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  - tuning to the "global" observables (distributions of average properties)
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- MC tunings done with ISR, SppS and Tevatron data can be used as a template for the LHC measurements.
  - example: **EPJ C 50, 435 (2007)**.

- Should possibly tune more than one MC generator to describe global observables.
  - the use of an alternative generator is important for assessing systematic uncertainties.
  - encourage the use of tools that allow fast check of new tunings (eg. Rivet).

# What can be done with early data?

- $\mathcal{L} < 1\text{pb}^{-1}$ – Minimum Bias measurements

- At the LHC, studies on minimum-bias **are planned to be done early on**. Low luminosity is ideal as the effect of overlapping proton-proton collisions is removed (or at least reduced)!

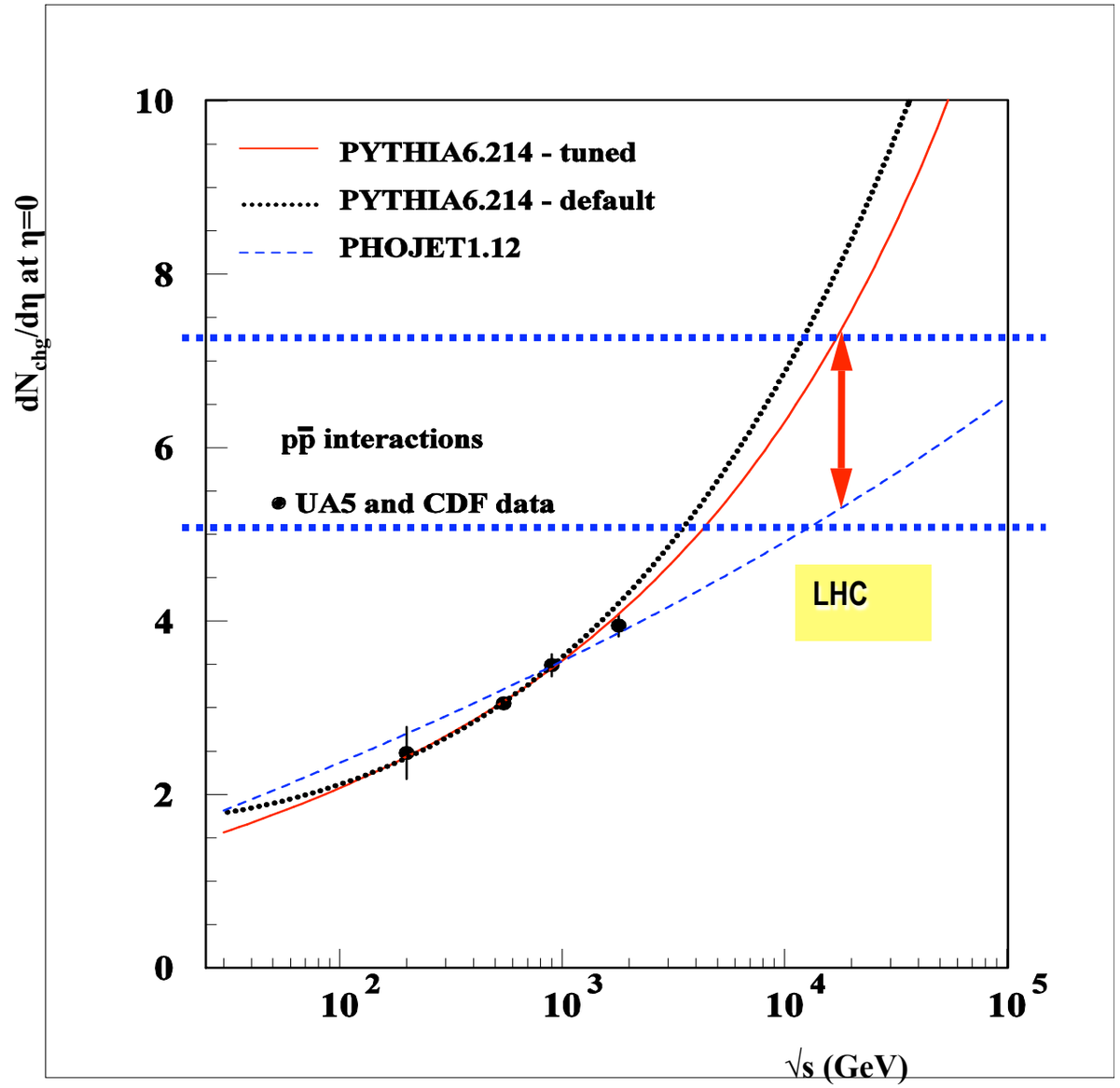
- Modeling of minimum bias pile-up and underlying event **necessary tool for high $p_T$ physics!**

  - "Minimum bias" is usually associated to **non-single-diffractive events** (NSD), e.g. ISR, UA5, E735, CDF,...

$$\sigma_{tot} = \sigma_{elas} + \sigma_{s.dif} + \underbrace{\sigma_{d.dif} + \sigma_{n.dif}}_{\text{minimum bias event}}$$

$\sigma_{tot} \sim 102 - 118$ mb (PYTHIA) (PHOJET)

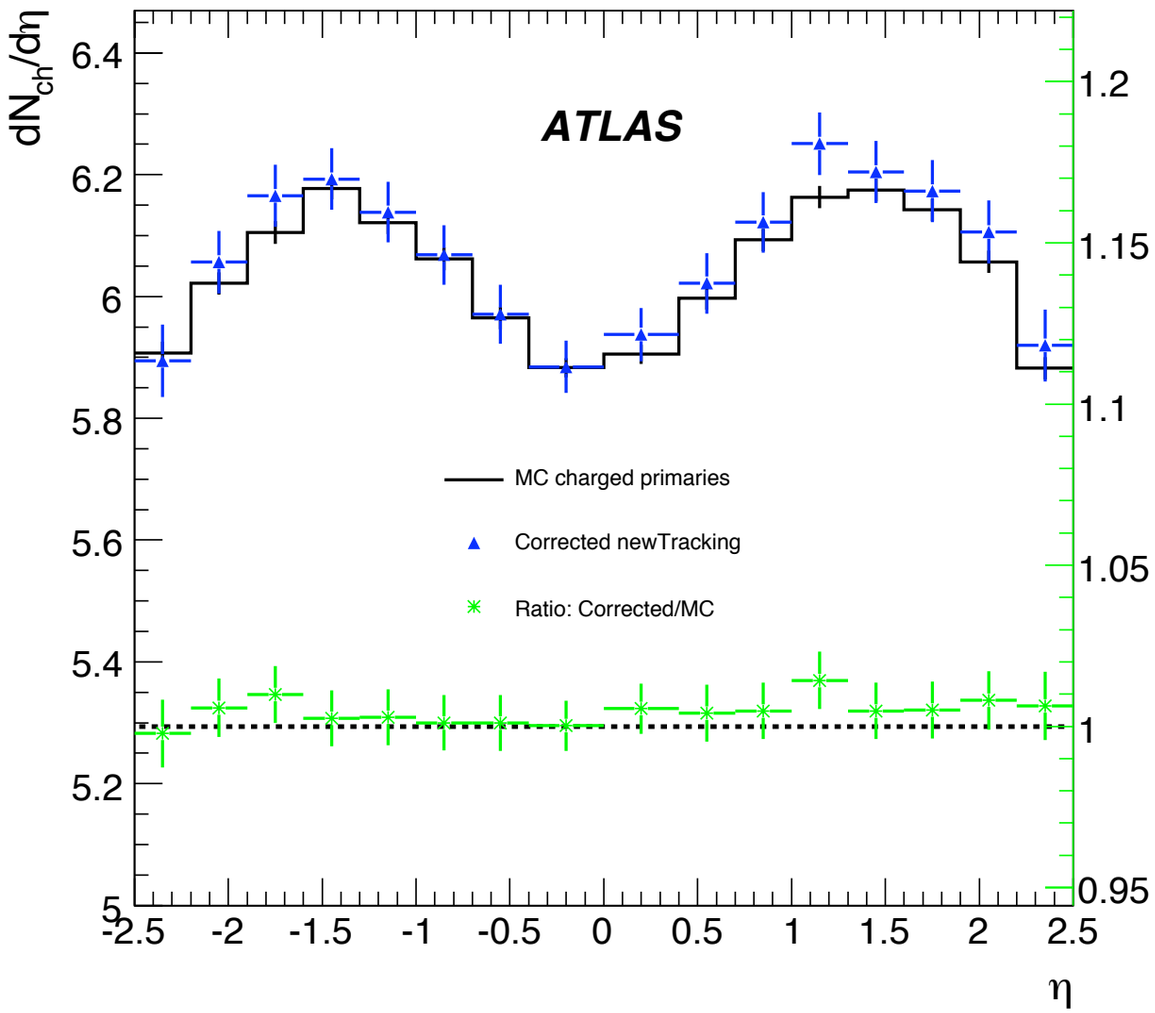
$\sigma_{NSD} \sim 65 - 73$ mb (PYTHIA) (PHOJET)




- PYTHIA models favour $\ln^2(s)$;
- PHOJET suggests a $\ln(s)$ dependence.

- Estimating how well ATLAS minimum bias events can be reconstructed (see SM chapter on CSC book).

**MC charged primaries & track $p_T$ > 150MeV**



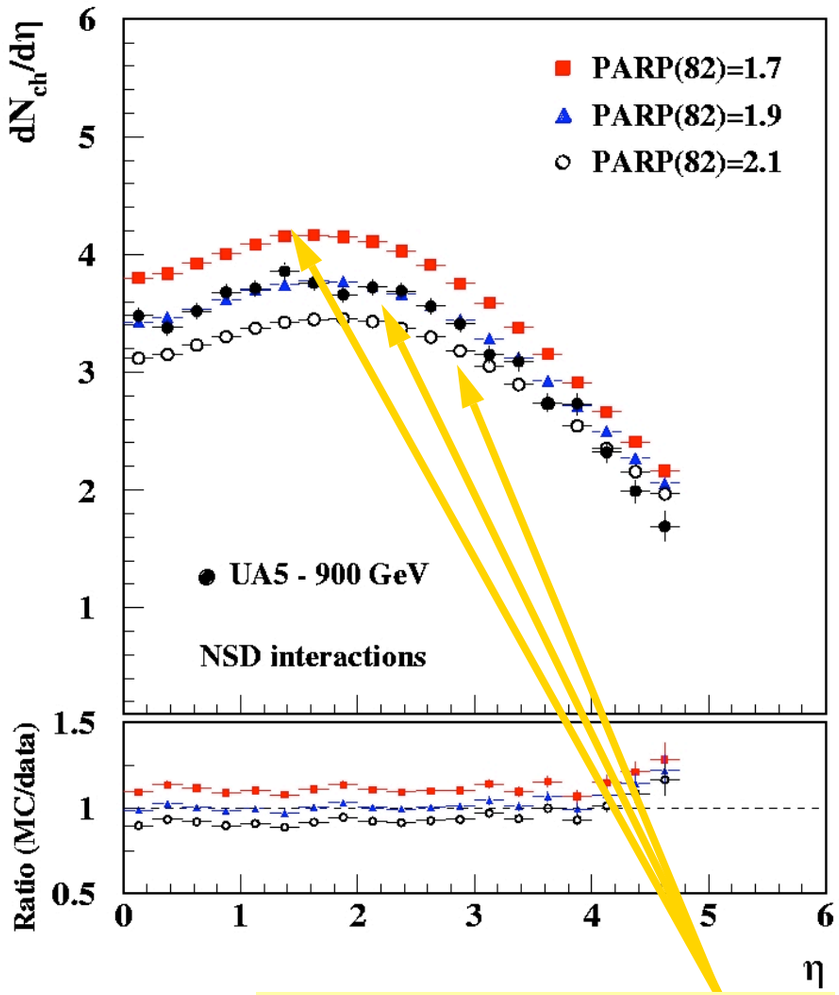

**Summary of systematic uncertainties**

| | |
|---|---|
| Track selection cuts | 2% |
| Mis-estimate of secondaries | 1.5% |
| Vertex reconstruction | 0.1% |
| Mis-alignment | 6% |
| Beam-gas & pile-up | 1% |
| Particle composition | 2% |
| Diffractive cross-sections | 4% |
| **Total:** | **8%** |

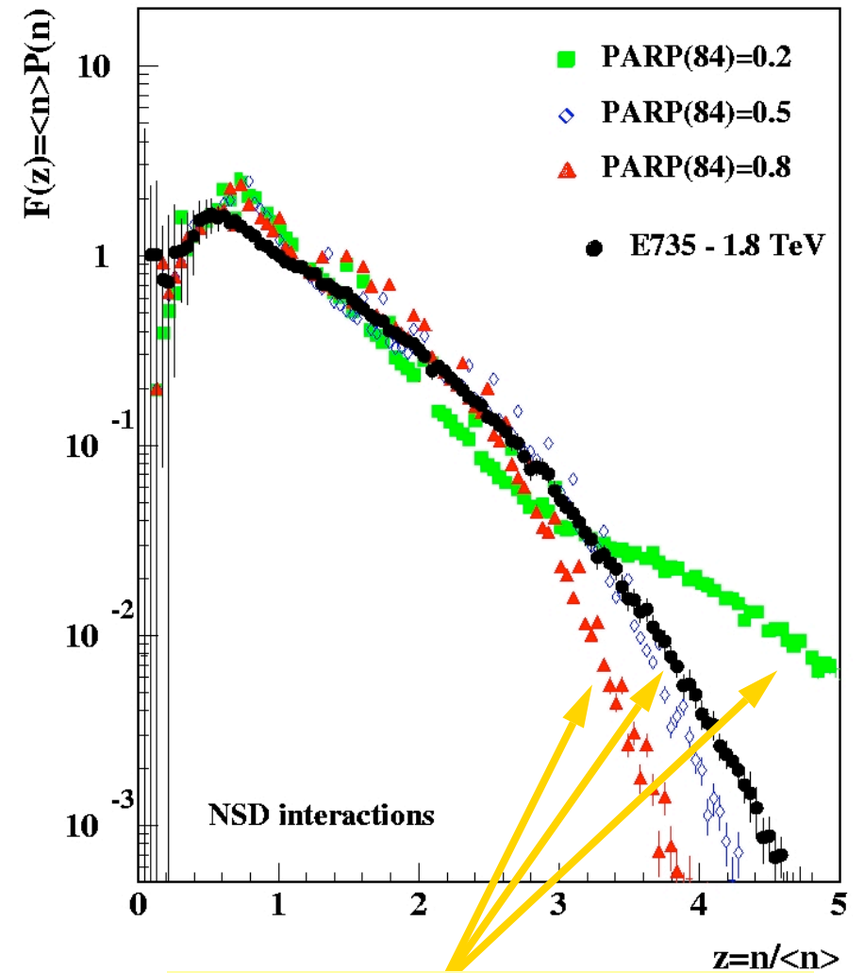
- Reconstructed distribution for non-single diffractive inelastic events (for $p_T$ > 150MeV)
- This can be directly compared to previous measurements from UA5 and CDF for example.

ATLAS Collaboration, *Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics*, CERN-OPEN-2008-020, Geneva, 2008, to appear.

# Tuning models to minimum-bias data




Lower $p_T$ cut-off determines the average particle density.



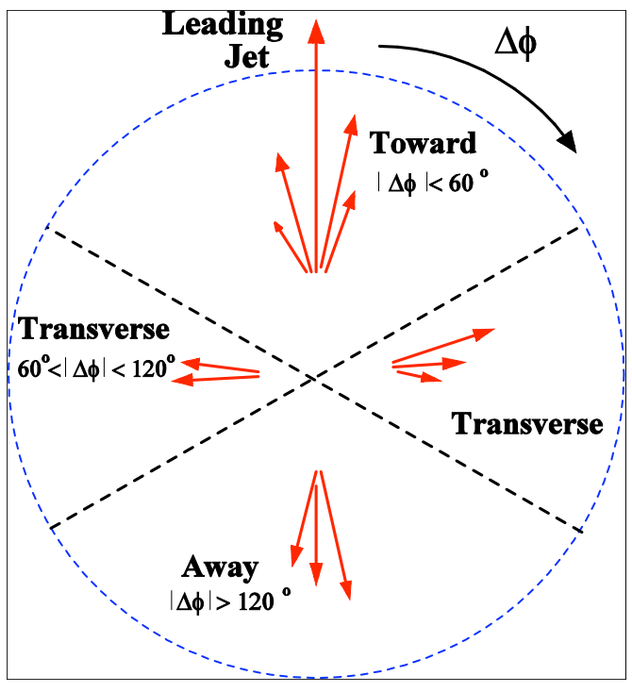

High-multiplicity events are described differently by each tuning.

## 1 pb$^{-1}$ < $\mathcal{L}$ < 10 pb$^{-1}$ – Underlying event associated to jets (depending on how far in Jet $E_T$ one wants to explore)

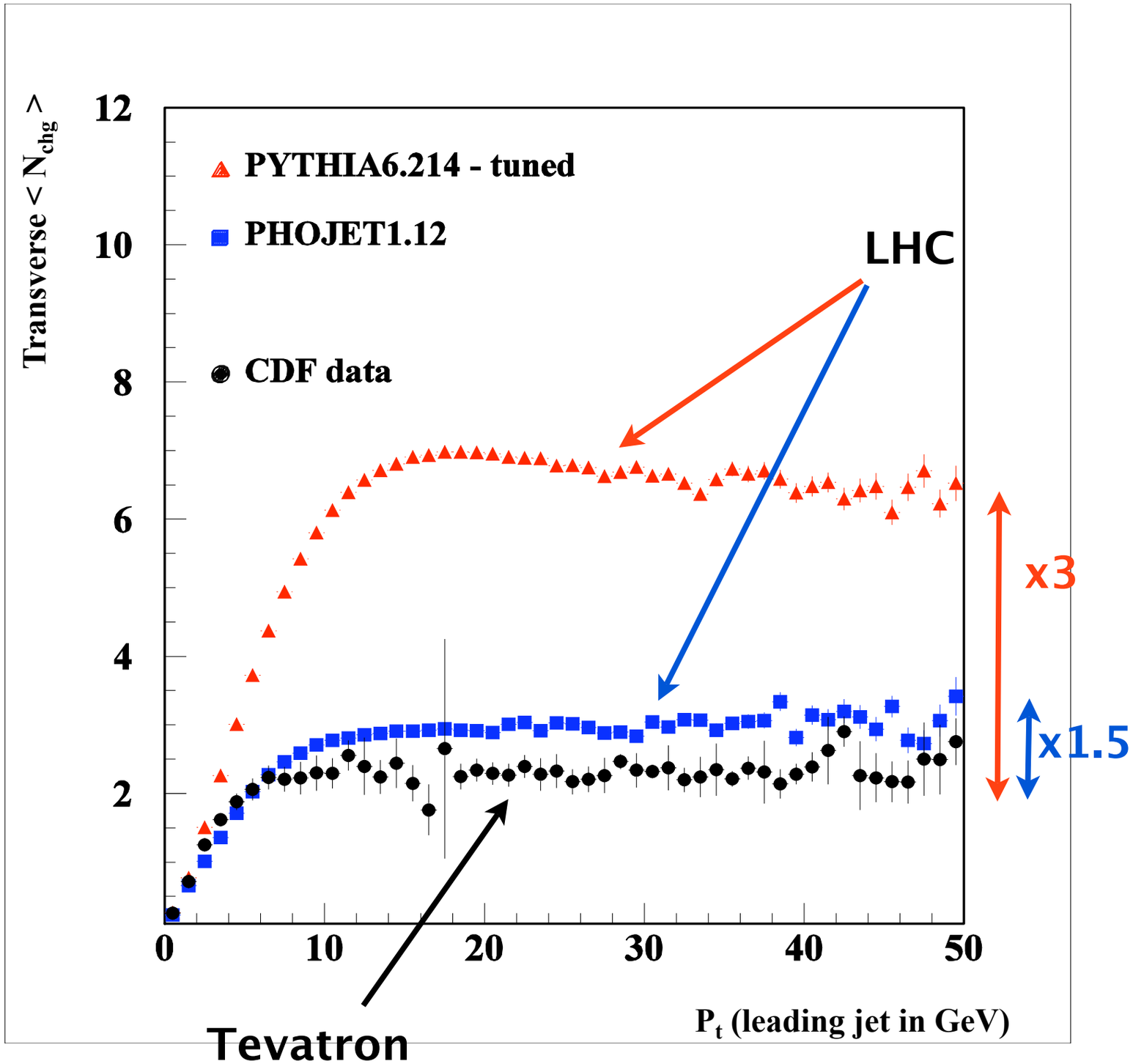
**CDF - Run I "Style"**

**Charged particles:**
**$p_t$>0.5 GeV and |η|<1**

**Cone jet finder: R=0.7**




UE particles come from region transverse to the leading jet.




EPJ C 50, 435 (2007)

- Estimating how well ATLAS can reconstruct the underlying event (see ATL-PHYS-PUB-2005-015).

**Selecting the underlying event:**

**i. Jet events:**

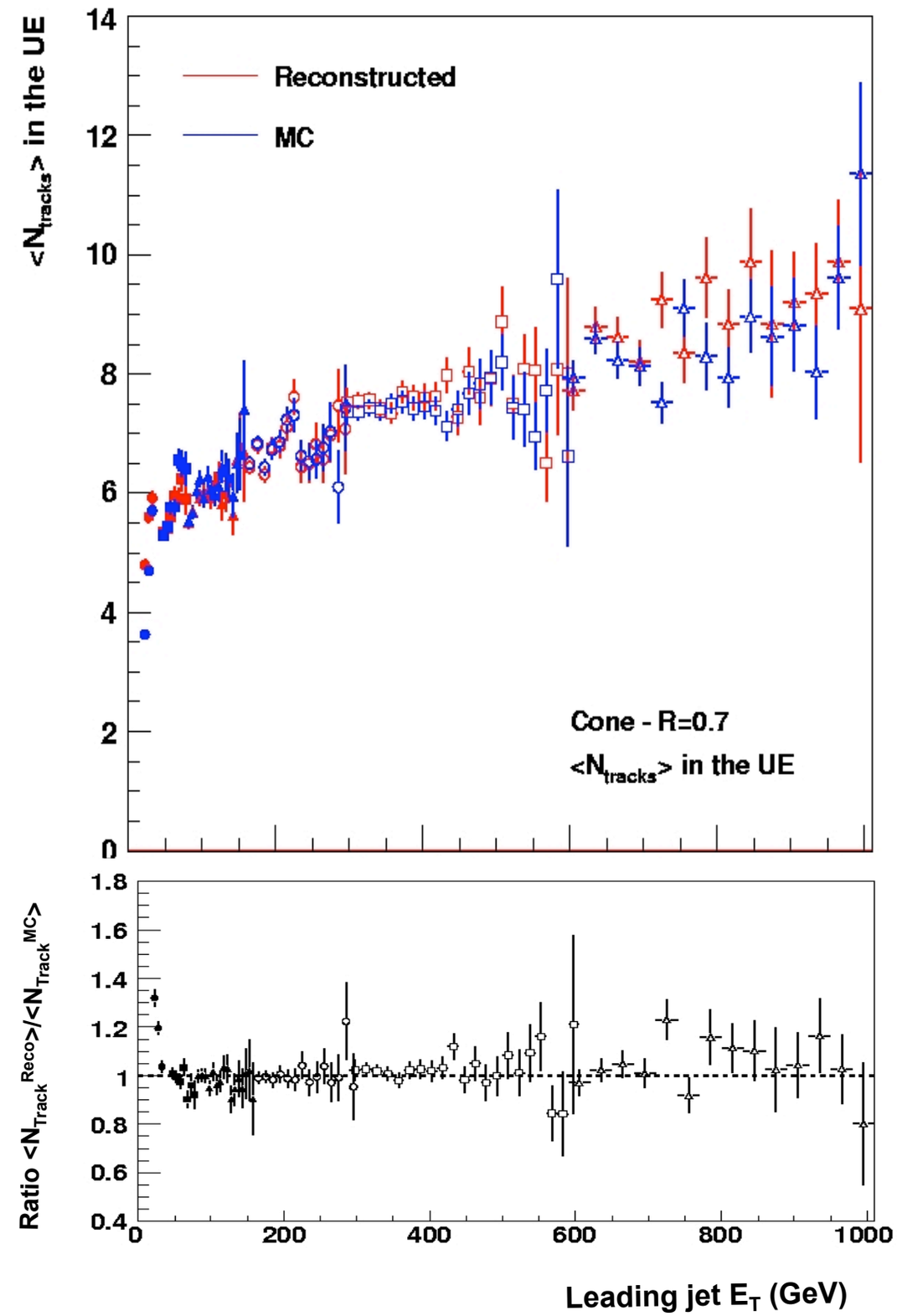
$N_{jets} > 1$,
$|\eta_{jet}| < 2.5$,
$E_T^{jet} > 10$ GeV,

**ii. Tracks:**

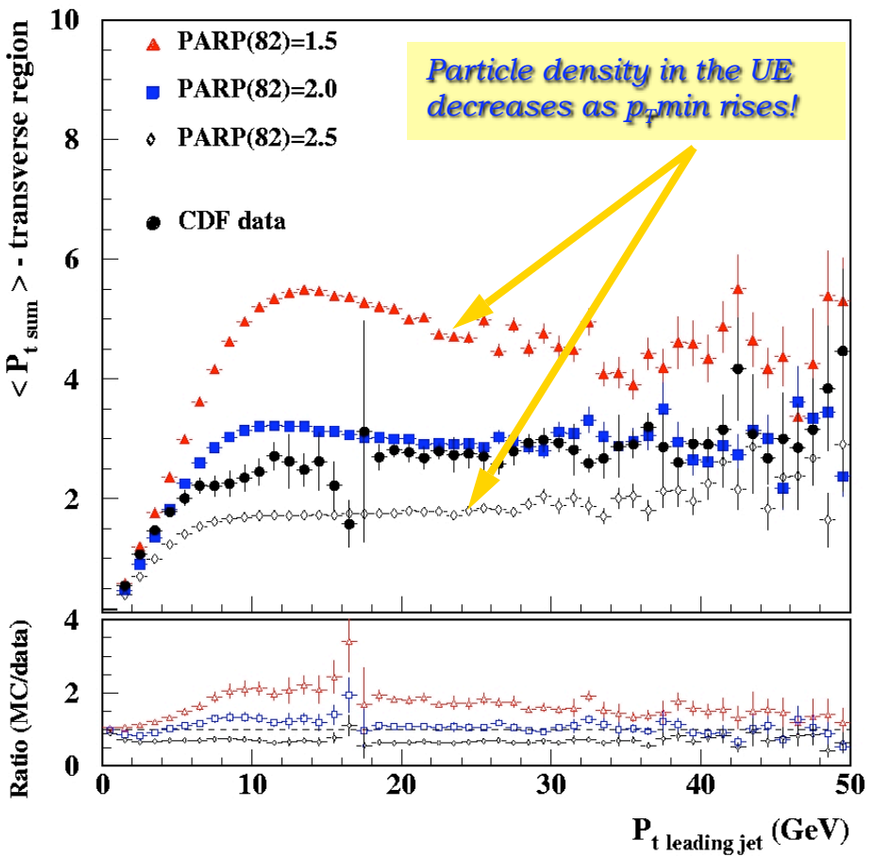
$|\eta_{track}| < 2.5$,
$p_T^{track} > 1.0$ GeV/c

- **Jet measurements with early data at ATLAS will extend considerably our knowledge of the underlying event!**

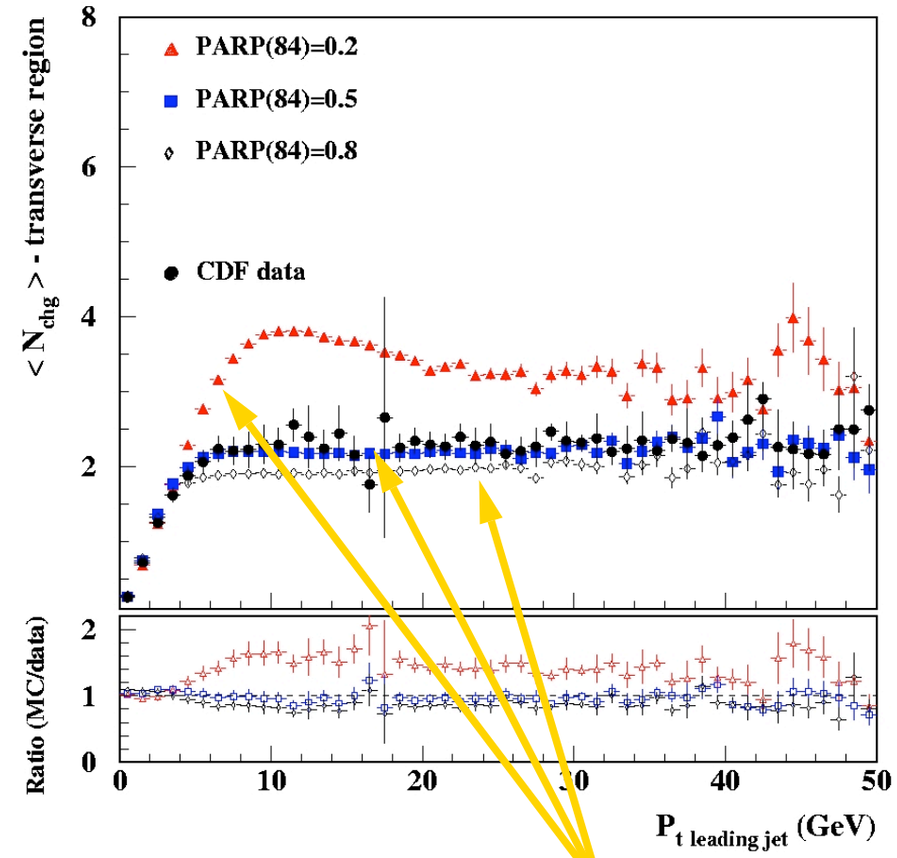
- **This study used ~ 60 pb$^{-1}$ of integrated luminosity (few days at $L=10^{32}cm^{-2}s^{-1}$, $\varepsilon=50\%$)!**



# Tuning models to the underlying event




*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.***

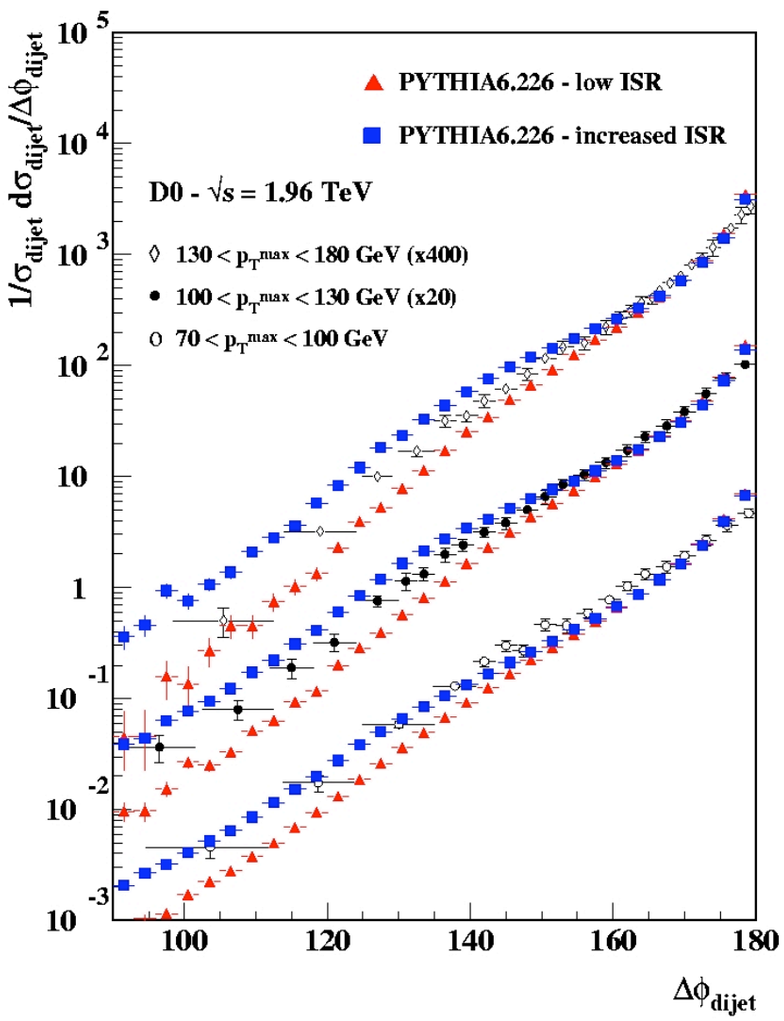
# Dijet azimuthal decorrelation

- $1\ pb^{-1} < \mathcal{L} < 50\ pb^{-1}$

hep-ex/0409040 Sep. 2004
PRL **94**, 221801 (2005)

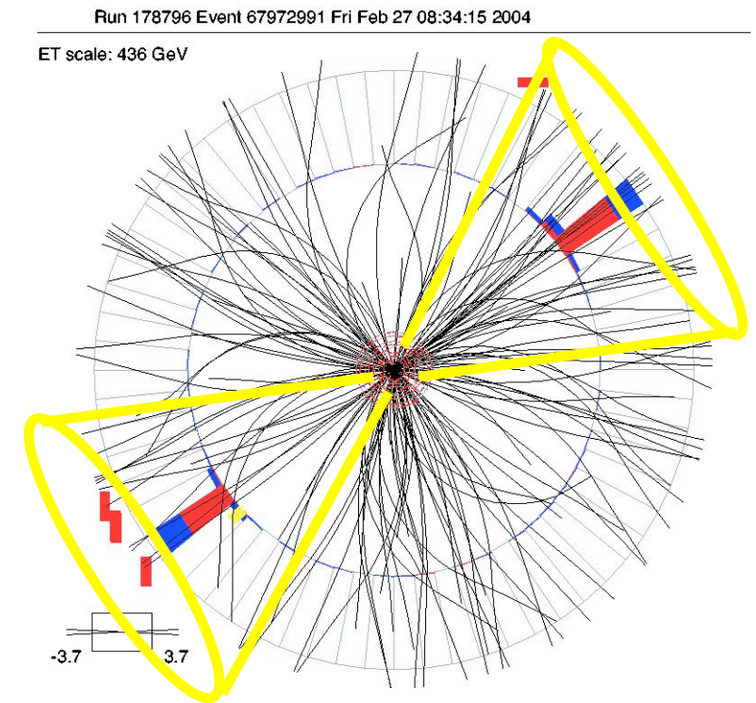
Jets are defined in the central region using seed-based cone algorithm (MidPoint - R=0.7)

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




PYTHIA predictions for $\Delta\phi_{dijet}$ depend on the modelling of radiation associated to ISR.

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




(see also ATL-PHYS-PUB-2006-013).

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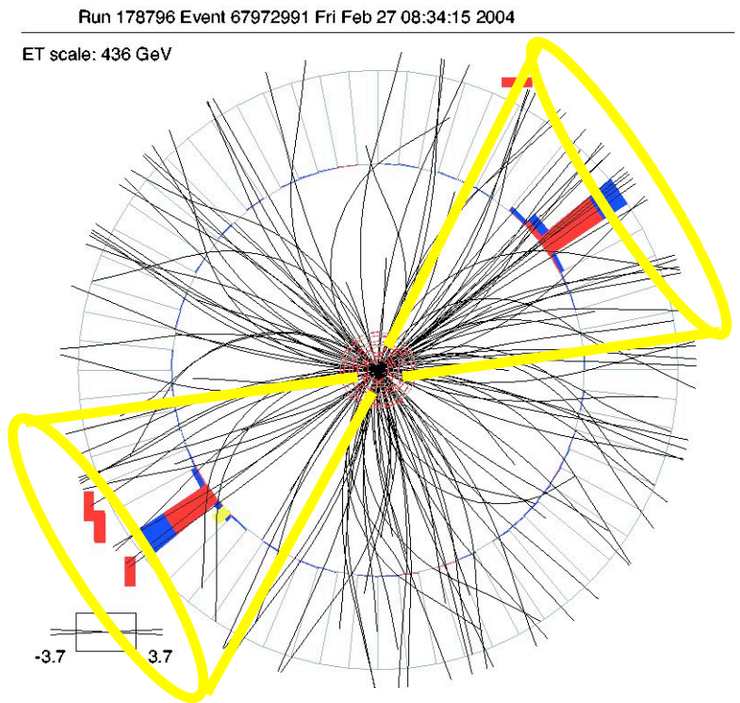


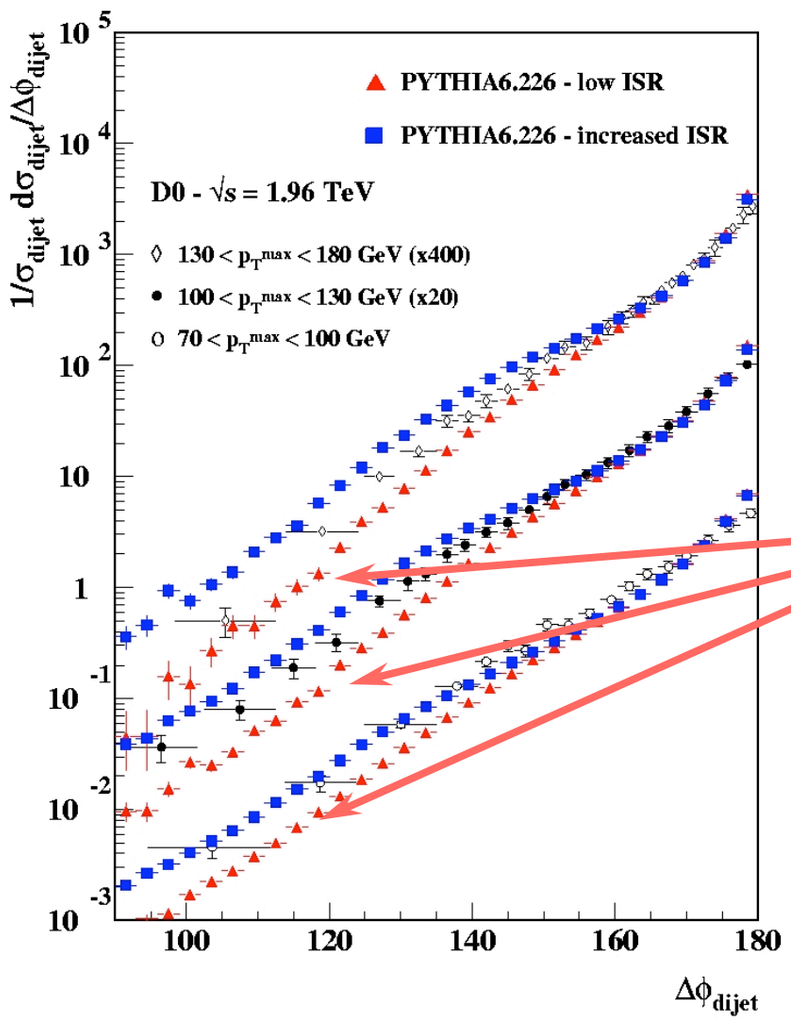


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Need to increase the decorrelation effect, i.e. increase radiative and multiple interaction effects.

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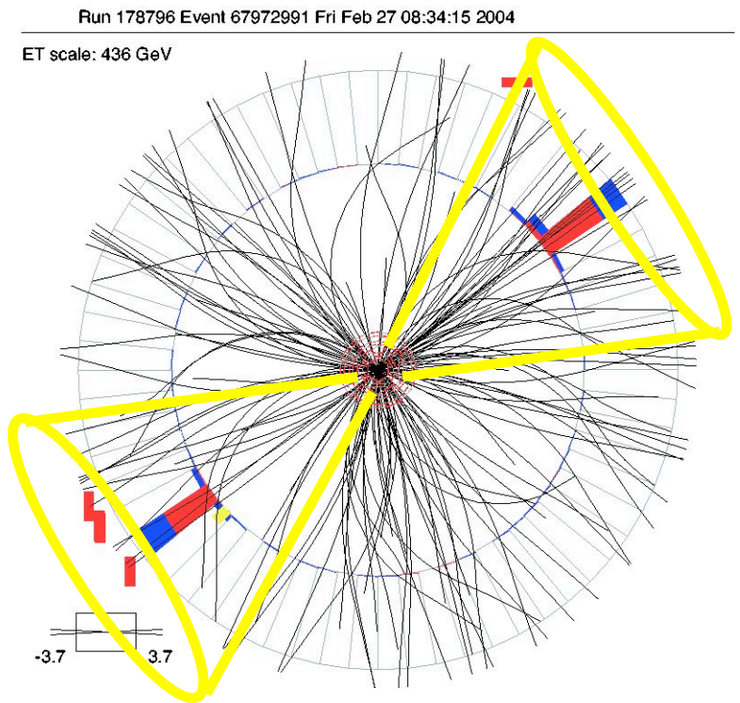


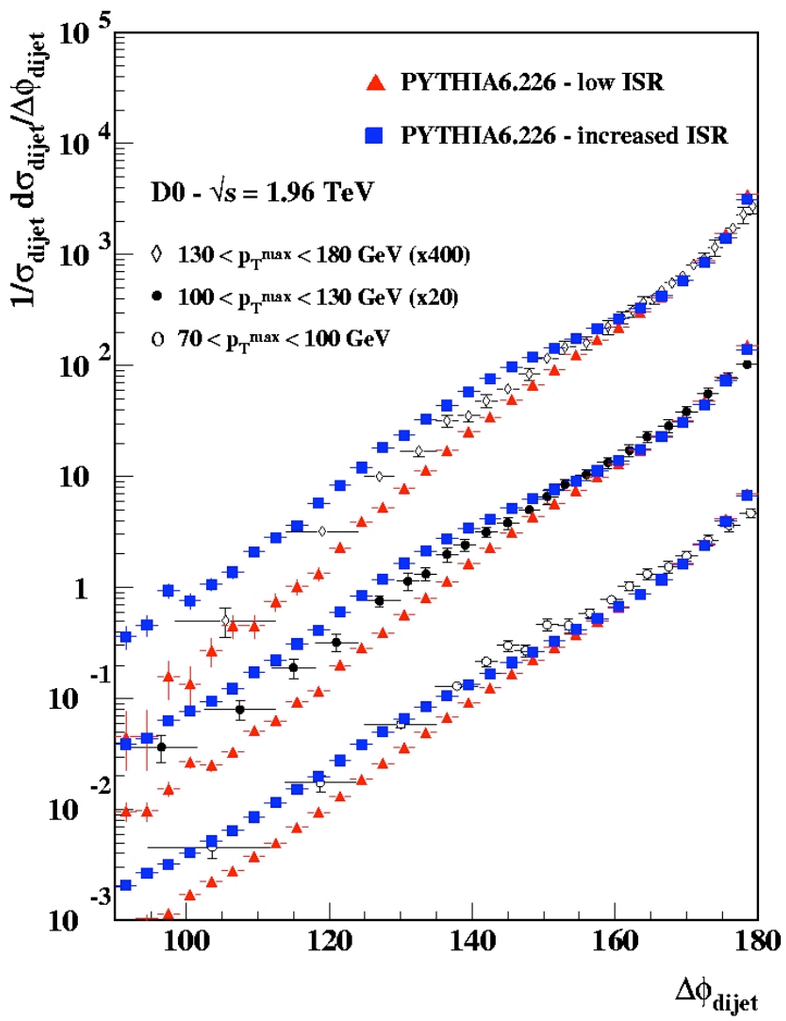


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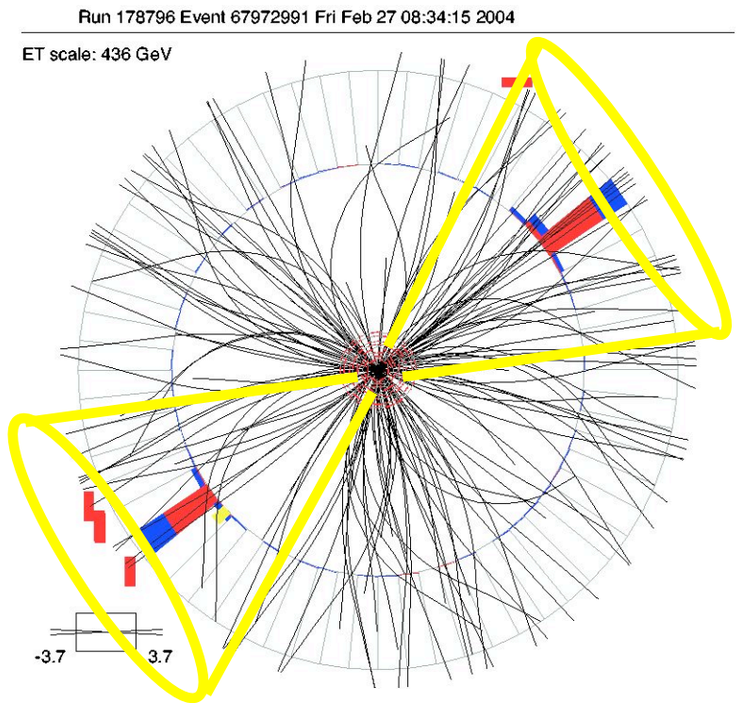


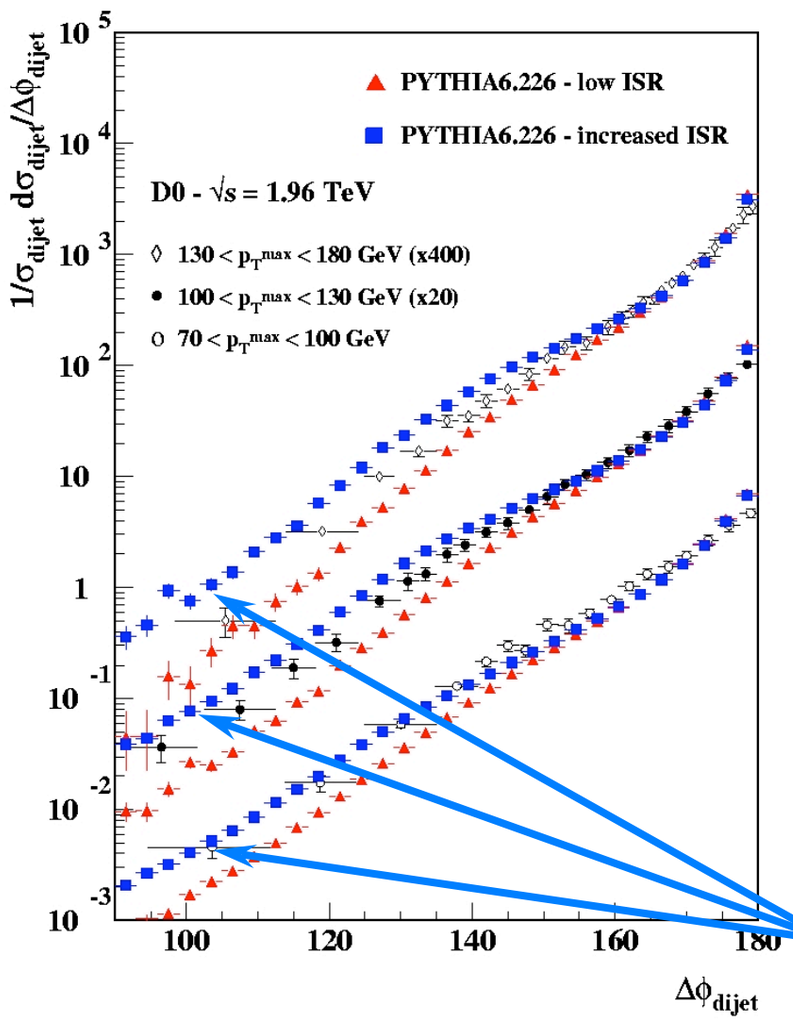


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PYTHIA6.226 - PARP(67)=4 ("increased ISR") : Changing PARP(67) from 1 to 4, the azimuthal decorrelation is *increased*.

(see also ATL-PHYS-PUB-2006-013).

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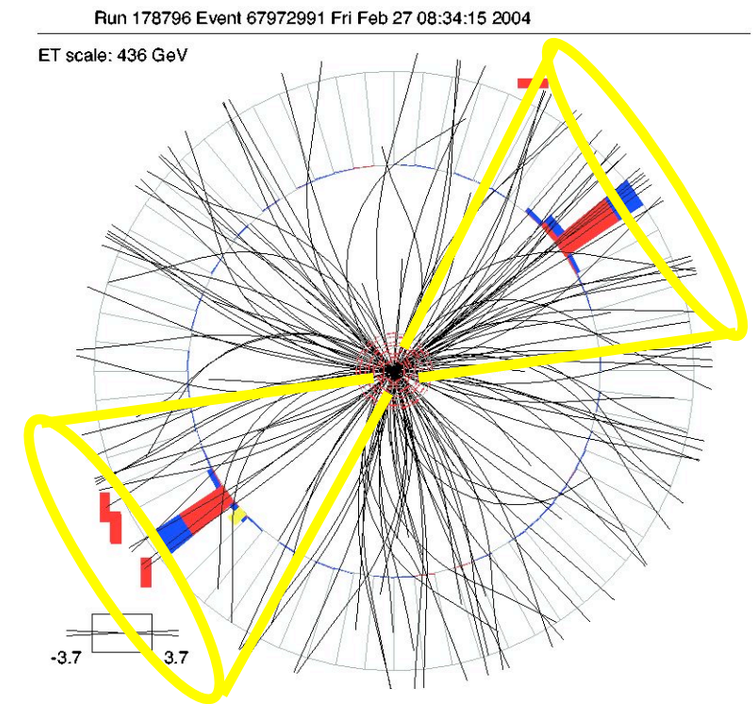


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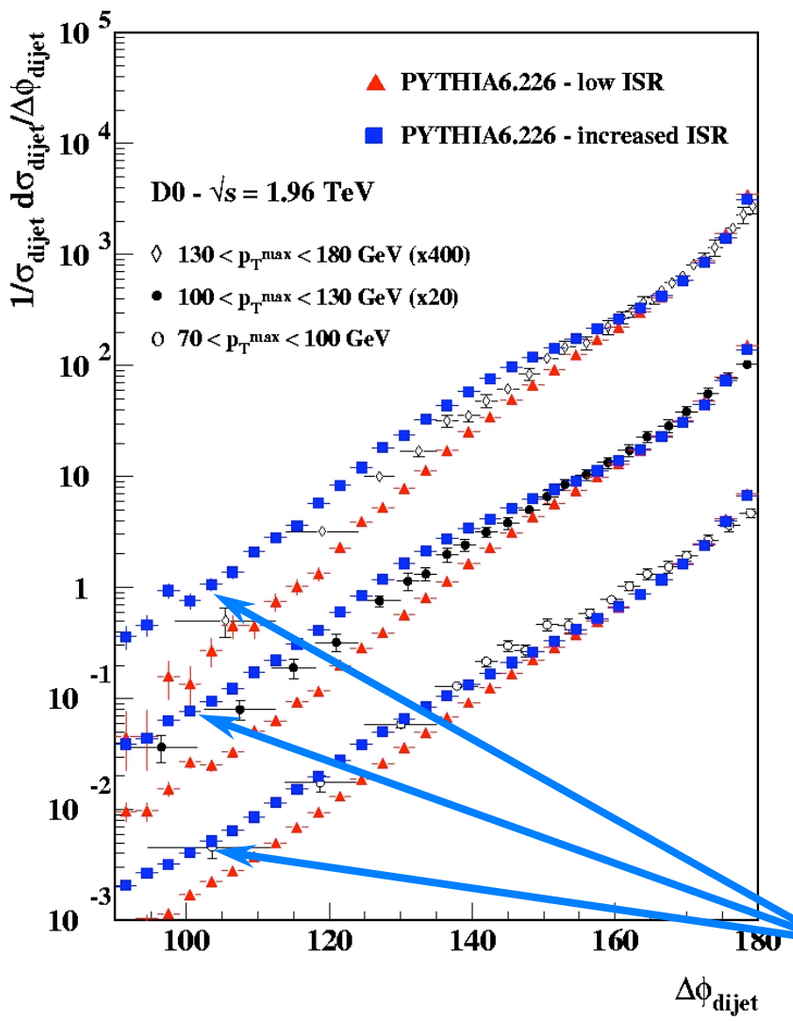


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***Best value is somewhere between PARP(67)= 1 and 4!***

(see also ATL-PHYS-PUB-2006-013).

# Summary & Outlook:

- As part of the preparations for LHC measurements, ATLAS is continuously reviewing and updating its MC generator versions (and tunings).
  - A new PYTHIA tune for the underlying event has been developed for PYTHIA6.416.
  - This tune was obtained with as few changes as possible to the default settings.
  - Results are comparable to those obtained with previous tunings (c.f. **EPJ C 50, 435 (2007)**).
  - $\langle p_T \rangle / N_{chg}$ has improved (requiring shorter strings and more connections to the hard scatter system).

# Summary & Outlook:

- **ATLAS is preparing a strategy to calibrate MC generators to the early LHC data.**

- **Re-calibrating MC generators with early LHC data will be extremely important!**
  - List expected "global" observables we plan to measure. Input / involvement of experts from Physics groups very important.
  - List MC generators we will prioritize in the first round(s) of tuning (PYTHIA, PYTHIA++, HERWIG+JIMMY, HERWIG++, PHOJET, ??? )
  - Before collision data is ready to be used, we need to decide on generator versions, PDF sets, etc.

- **"Longer" term strategy:**
  - The need to re-tune generators will probably be dictated by the availability of measurements.

- **Interaction between LHC experiments can be very beneficial!**
  - As a Collaboration, we will certainly want an ATLAS tuning, but we would probably be better off having an additional LHC tuning.

# Backup

# Underlying event in charged jet evolution (CDF analysis – Run I data)

University of Glasgow

- **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!**

**CDF analysis:**

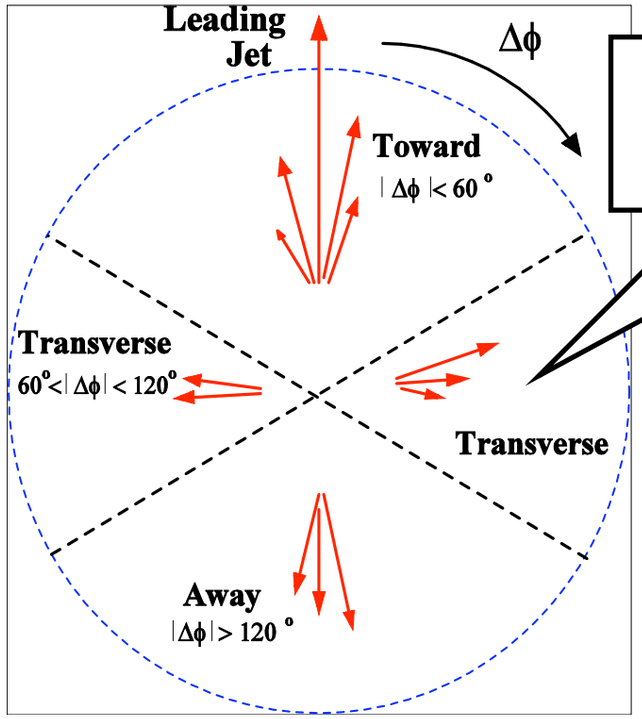
- charged particles:

$p_t$>0.5 GeV and $|\eta|$<1

- **cone jet finder:**

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

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

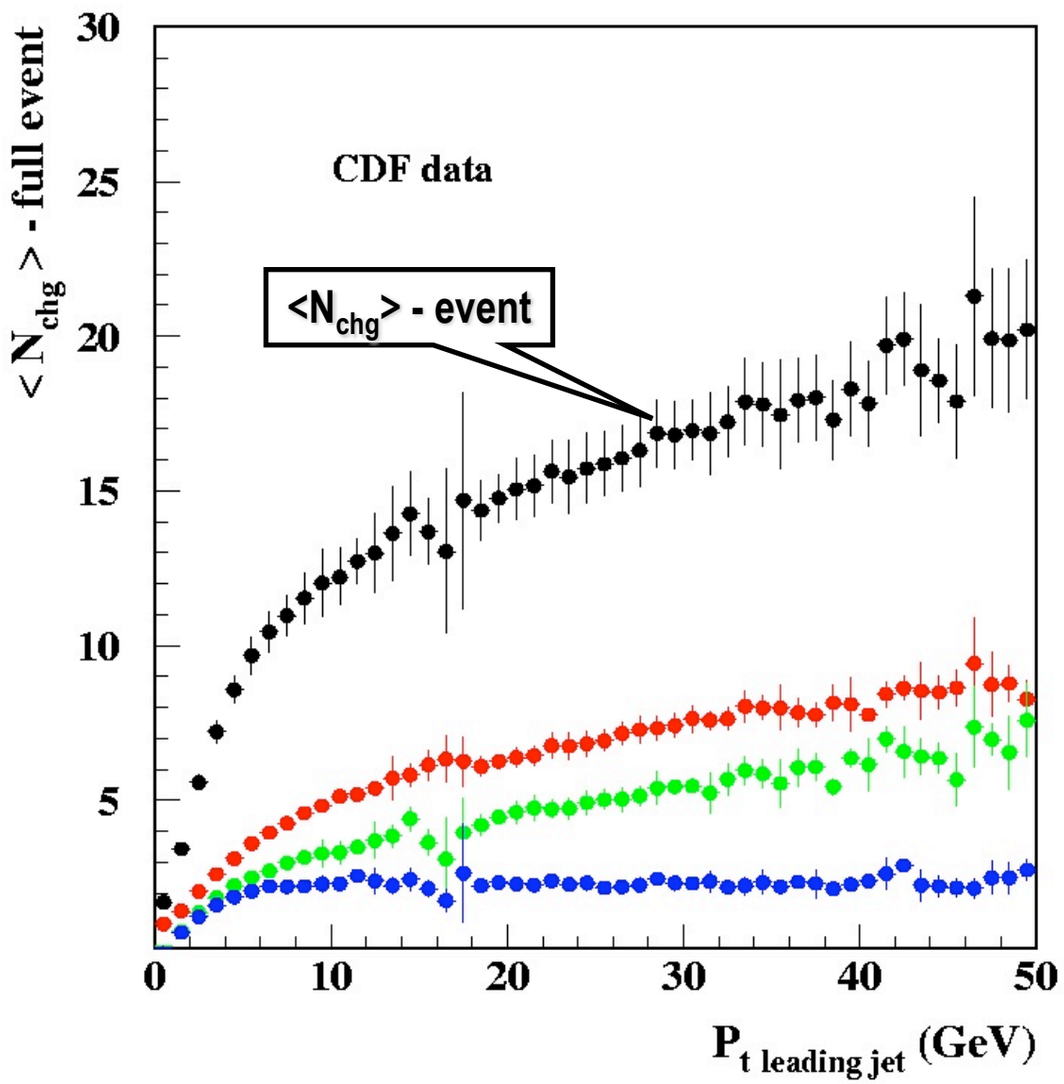


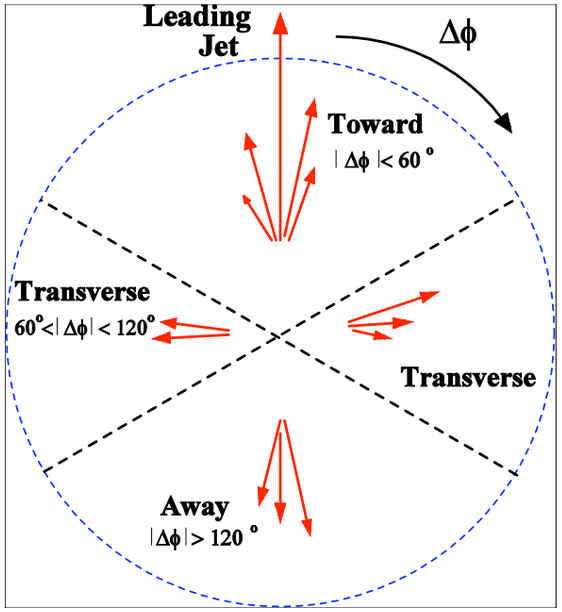

UE is defined as the Transverse Region

T. Affolder et al., The CDF Collaboration, Phys. Rev. D65, 092002 (2002).

Phys. Rev. D, **65** 092002 (2002)

# $\langle N_{chg} \rangle$ distributions (particles from different angular regions)



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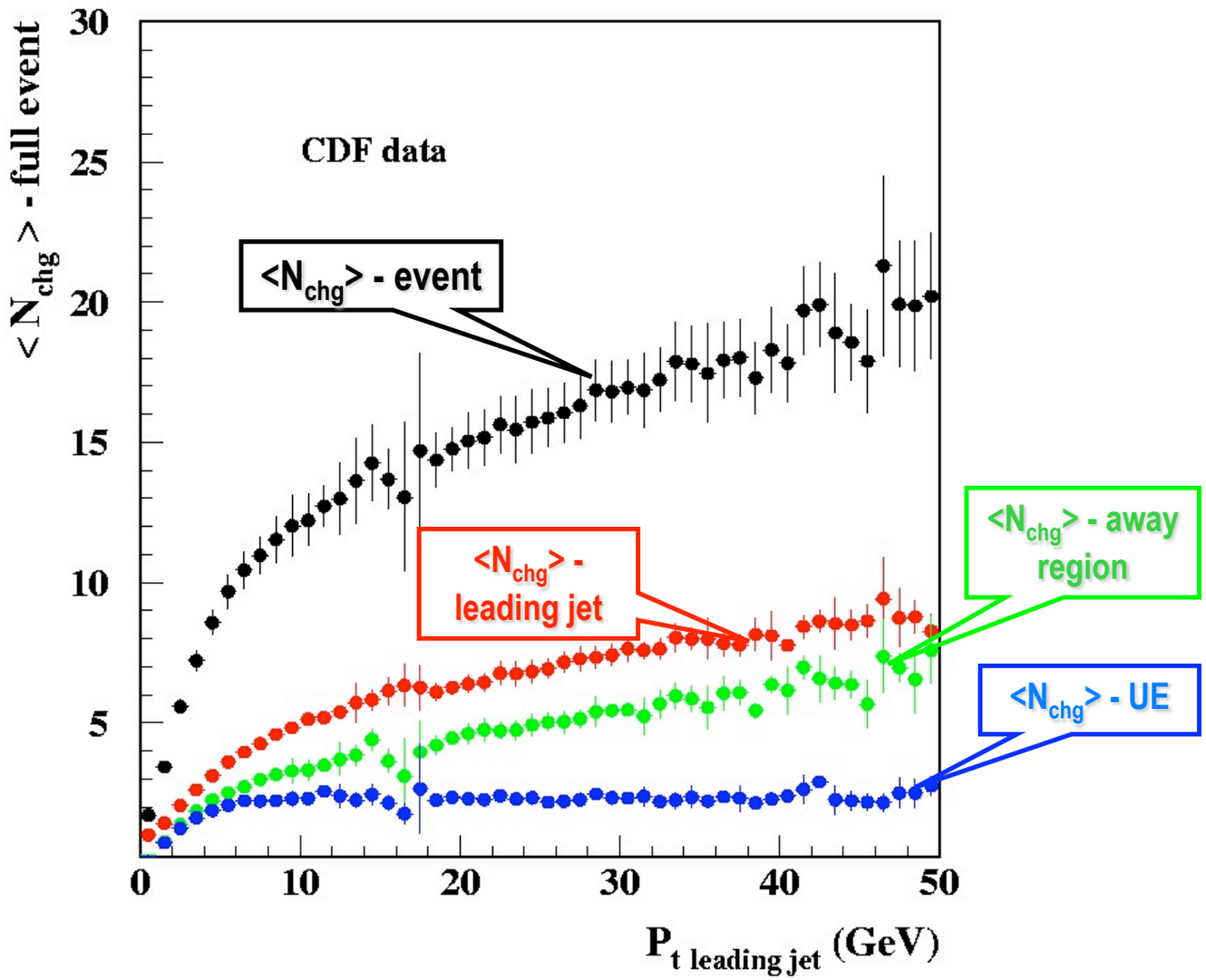
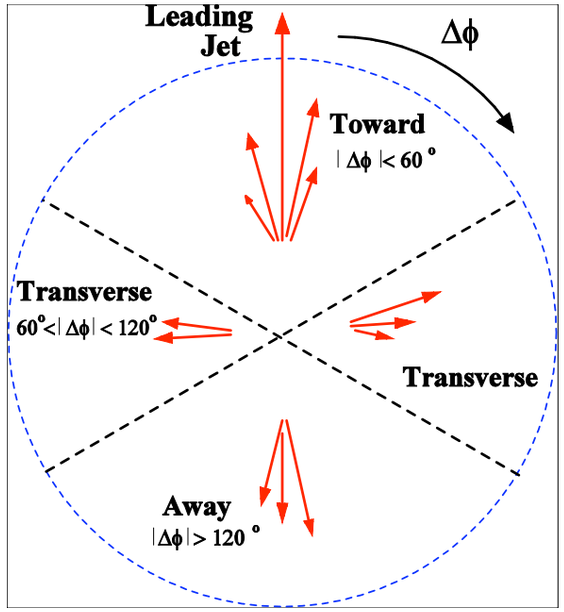
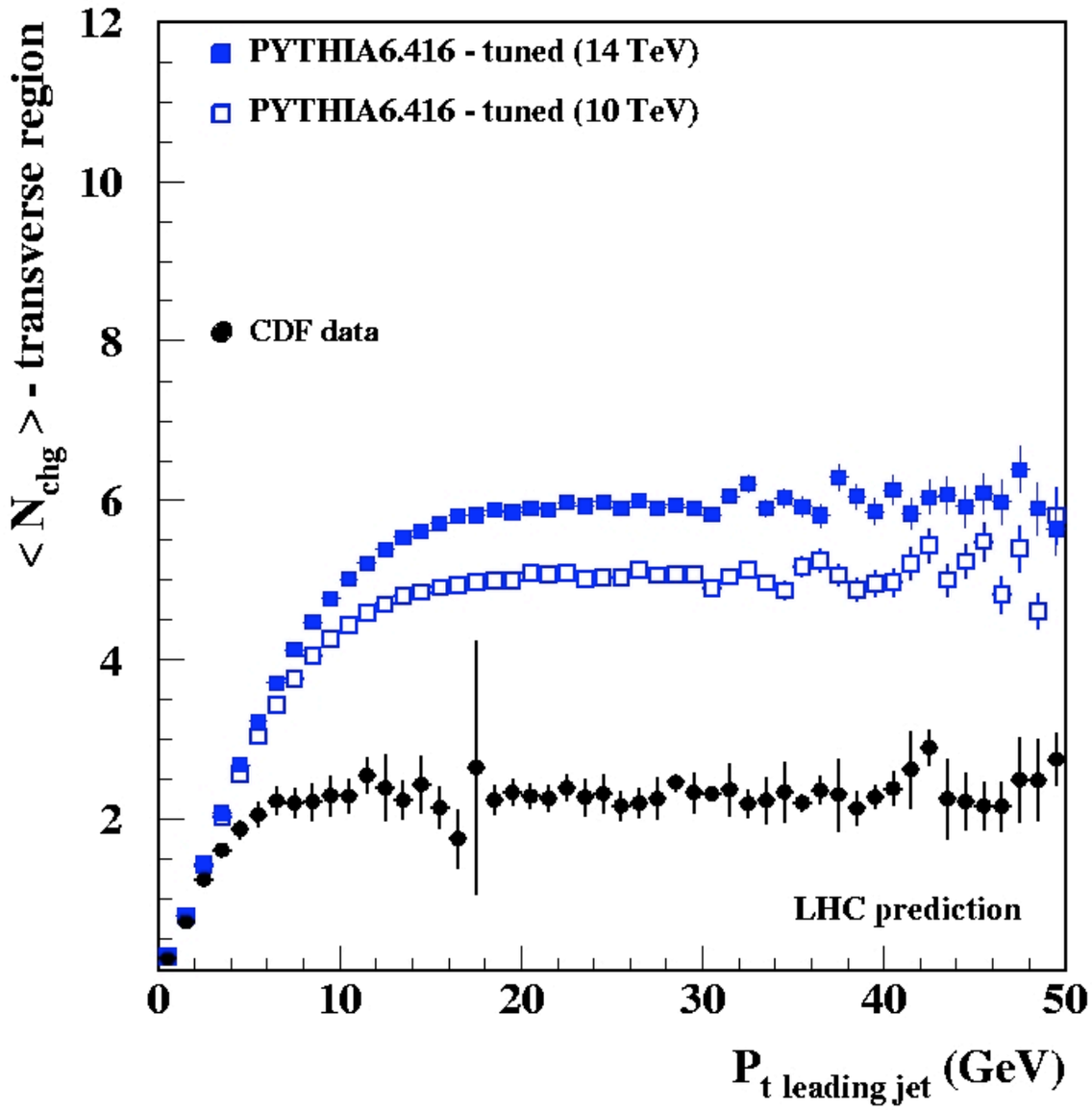
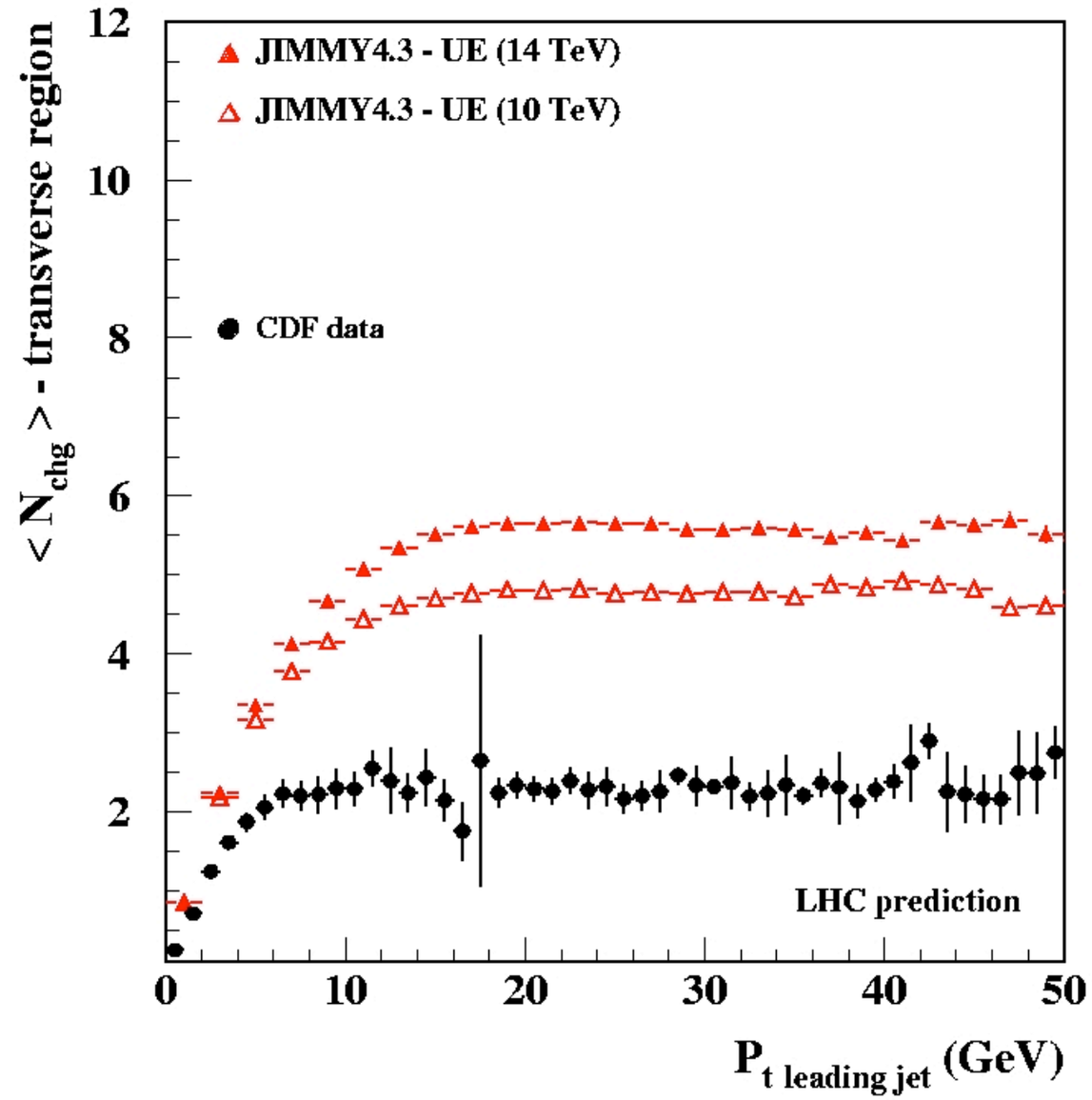


# LHC Predictions: describing the region transverse to the leading jet



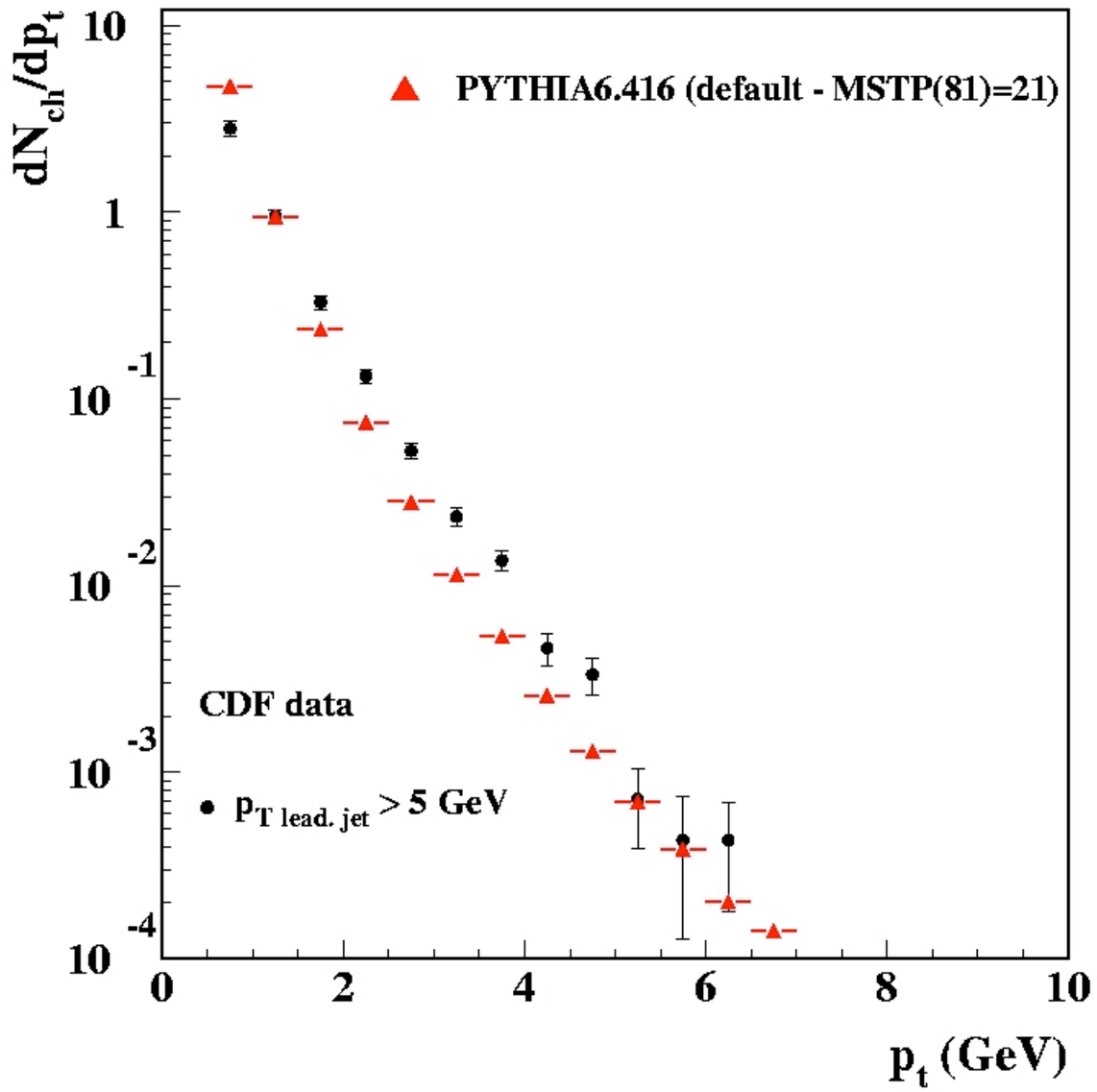




- Measurements of the particle density in the UE at $\sqrt{s}$=10TeV are predicted to reach a plateau ~2 times higher that what has been measured at the Tevatron.

- Measurements at different colliding energies will be very useful to tune energy dependence parameters in MC models. Big challenge to get models that will be able to describe data all the way from SppS to LHC!

# PYTHIA6.416: describing the region transverse to the leading jet

**$dN_{chg}/dp_T$ spectrum:**
charged particles in the underlying event for $p_T^{\text{leading jet}} > 5$ GeV.



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