Implications of First LHC Data: Underlying Event Measurements

Mohammed Zakaria

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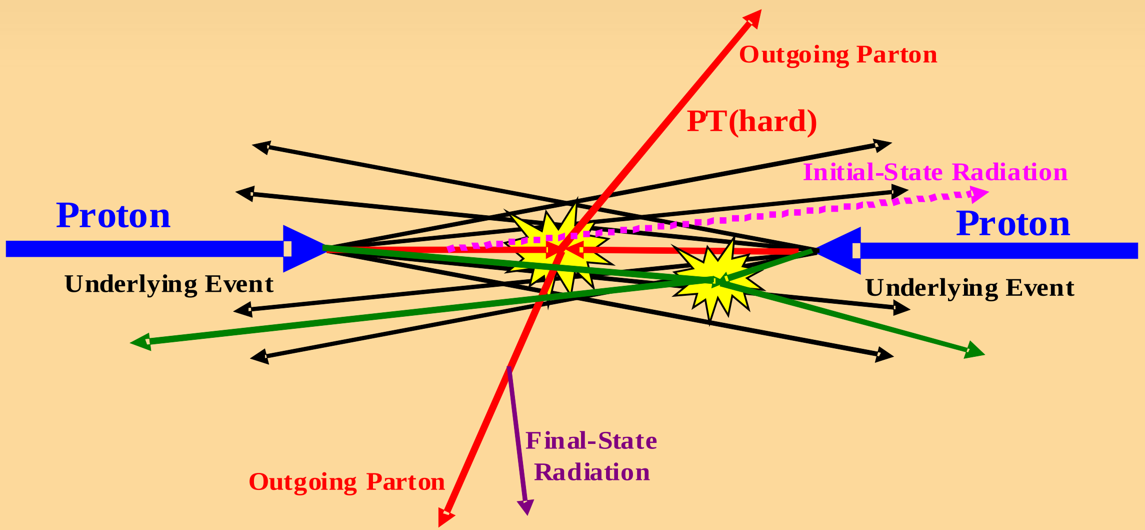
The Undelying Event in p-p collisions

- Introduction to the UE.
- How to calculate the UE?
- Experimental procedure.
- Results.

What is the The UE?

- The Underlying Event is the part of the p-p collision that doesn't participate in the hard scattering.



Why should we care about the UE?

- The UE is an unavoidable background for most collider observables.
- It has large effect on other physics process (example: inclusive jet cross section).
- We need to have a good understanding of the UE to isolate it from signals (more precise measurements).
- It helps us in modelling MPI and BBR.
- It might be even sensitive to new physics!

How to calculate the UE activity?

- The UE represents the soft component of QCD processes. The transverse momentum (p_T) is too small for perturbative QCD as p_T goes to zero.
- Instead, we use MC simulations: PYTHIA, SHERPA, HERWIG++ etc.
- There are two approches for measuring the UE:
    - Traditional approach.
    - Jet-Area/median approach.

How to calculate The UE activity

- PYTHIA regulates the cross section by including a smooth cut-off p_{T0} which regulates the 2-to-2 scattering divergence

$$\frac{1}{\hat{p}_T^{\,4}} \rightarrow \frac{1}{(\hat{p}_T^{\,2} + \hat{p}_{T0}^{\,2})^2}$$

- $\hat{p}_{T0}$ can be interpreted as the inverse of effective colour screening length.

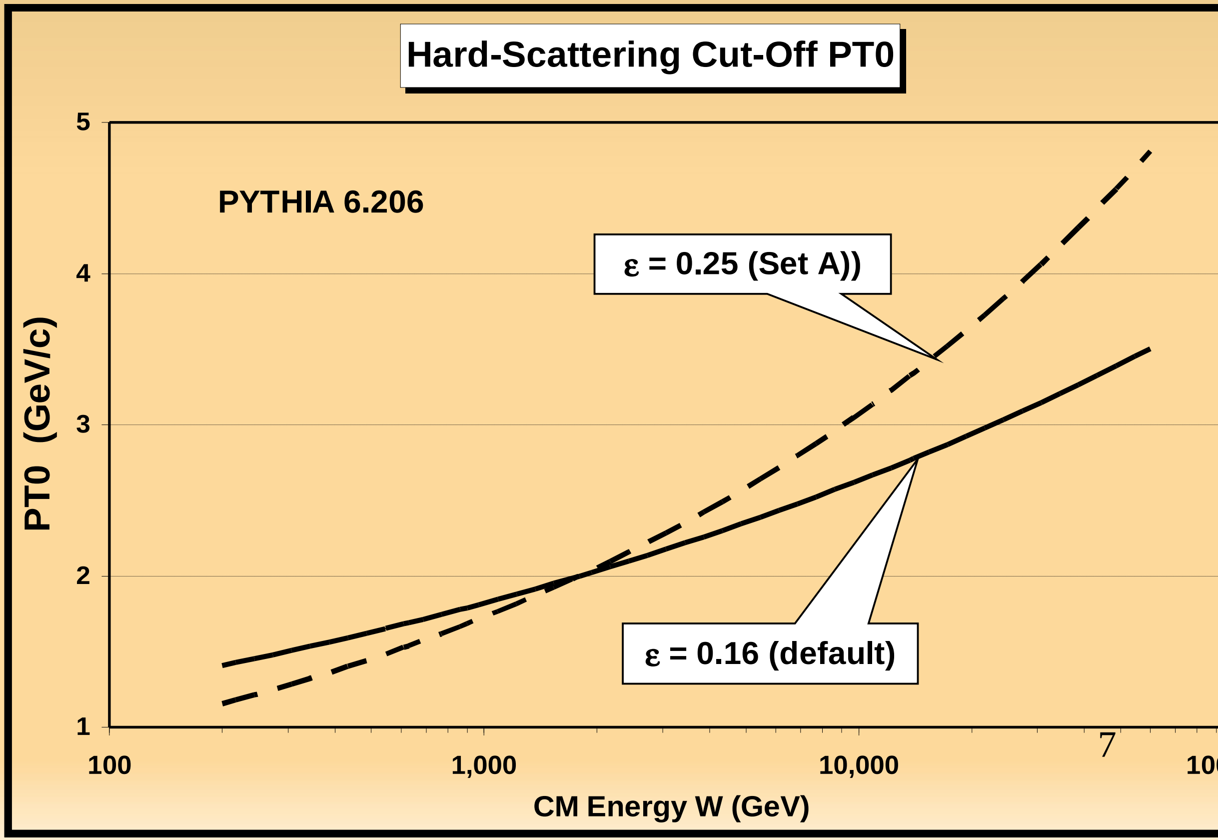
How to calculate the UE activity

- The energy dependence of the cut-off $\hat{p}_{T0}$ as

$$\hat{p}_{T0}(E_{cm}) = \hat{p}_{T0} \cdot (E_{cm}/E_0)^{\varepsilon}$$

- In PYTHIA:
  - PARP(82) = $\hat{p}_{T0}$
  - PARP(90) = ε

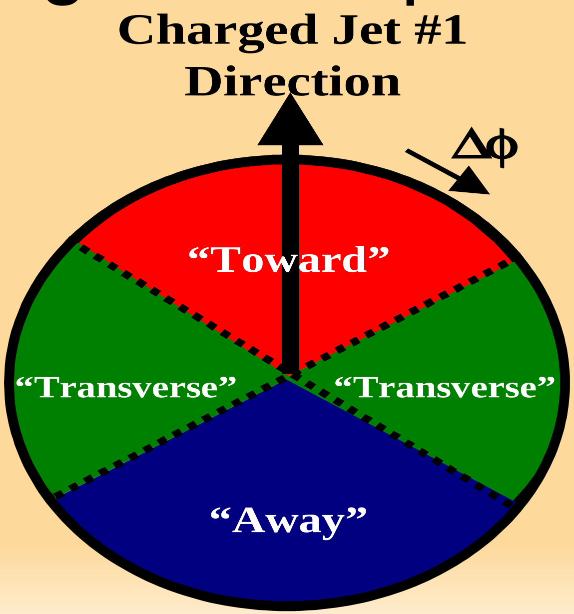
Tune	p_{T0}(1.8TeV)	ε
D6T	1.8 GeV/c	0.16
DW	1.9 GeV/c	0.25
Pro-Q20	1.9 GeV/c	0.22
P0	2 GeV/c	0.26
CW	1.8 GeV/c	0.3



Where to look for answers?

- We utilize the jet structure of hadron-hadron collisions to find regions sensitive to the UE activity.
- Our leading object defines 3 regions in space and sets the scale.
- The Transverse region:

  $60° < |\Delta\Phi| < 120°$.

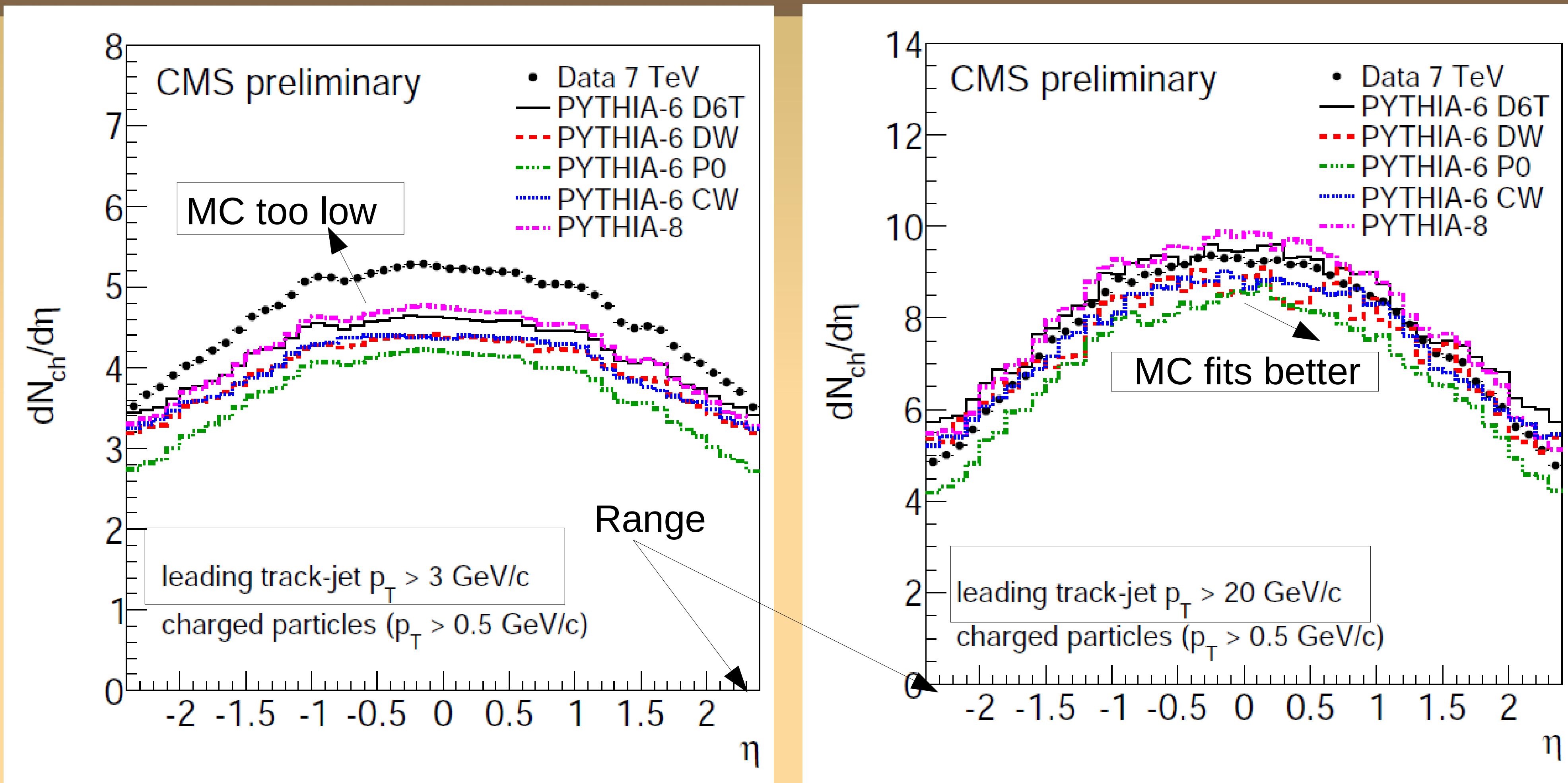


Cuts and Track selections

- Predictions from the models are compared to uncorrected data, after a full detector simulation with the following cuts:
  - p_T > 0.5 GeV/c (reduces the diffractive component).
  - $|\eta| < 2$.

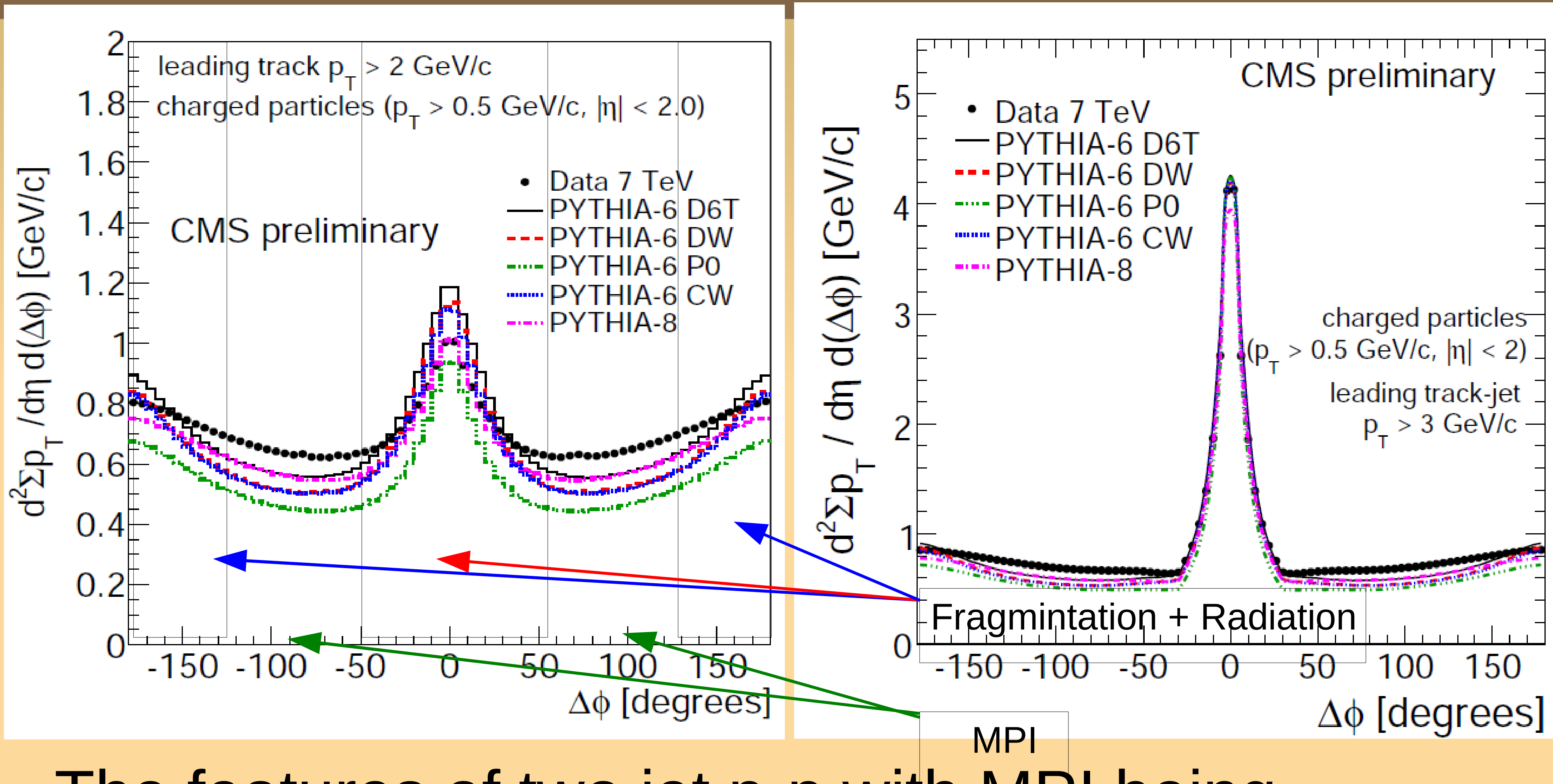
Track Selection	Data	Data[%]	MC[%]
triggered	28 475 724	100	100
+1 real Vertex	27 104 779	95.18	96.12
+ (+/-10cm) vertex z window	27 045 773	99.78	99.95
+ vertex n.d.o.f. > 4	24 772 528	91.59	87.39
Leading jet p_T > 3 GeV/c	9 103 746	36.75	28.35
Leading jet p_T > 20 GeV/c	37 296	0.41	0.44

Average N_{ch} Multiplicity per η



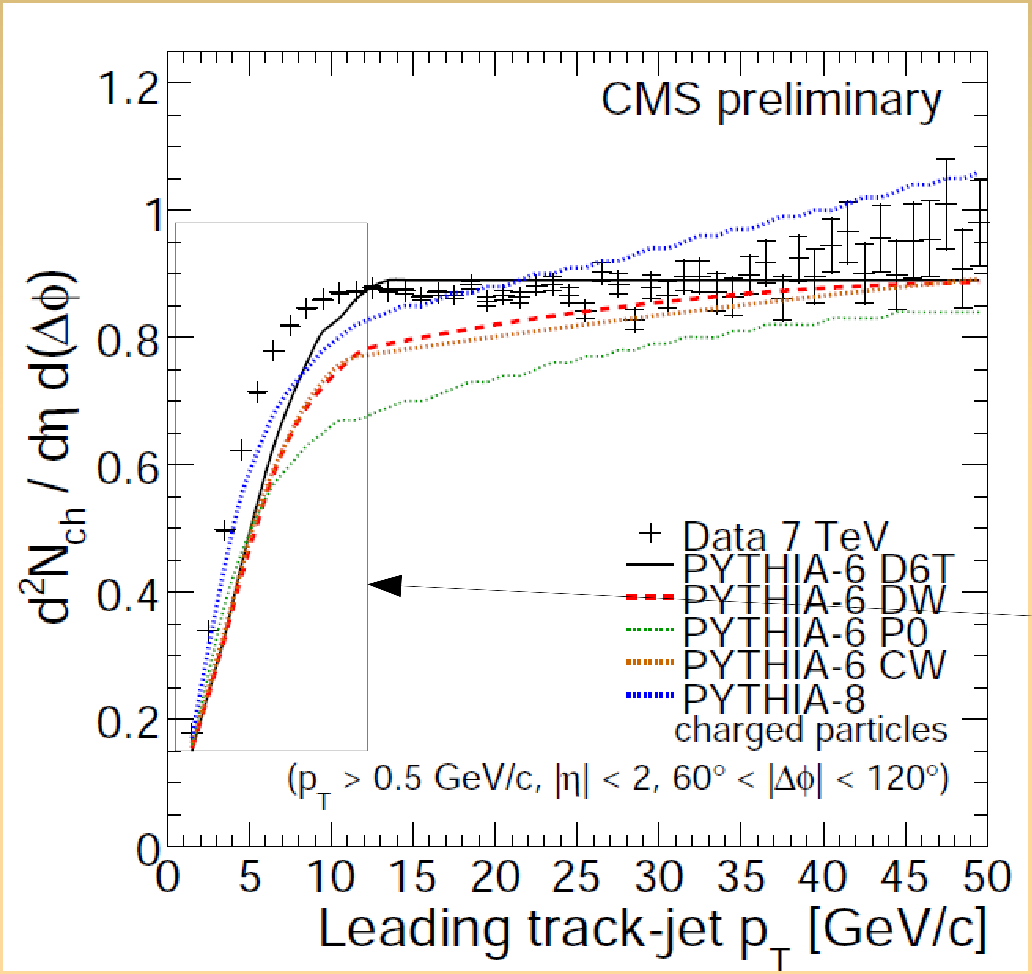
Both figures: MC is less central than Data.
Probably due to frgamentation, radiation, and UE

Average scalar Σp_T per η and Φ



- The features of two jet p-p with MPI being imposed are observed.

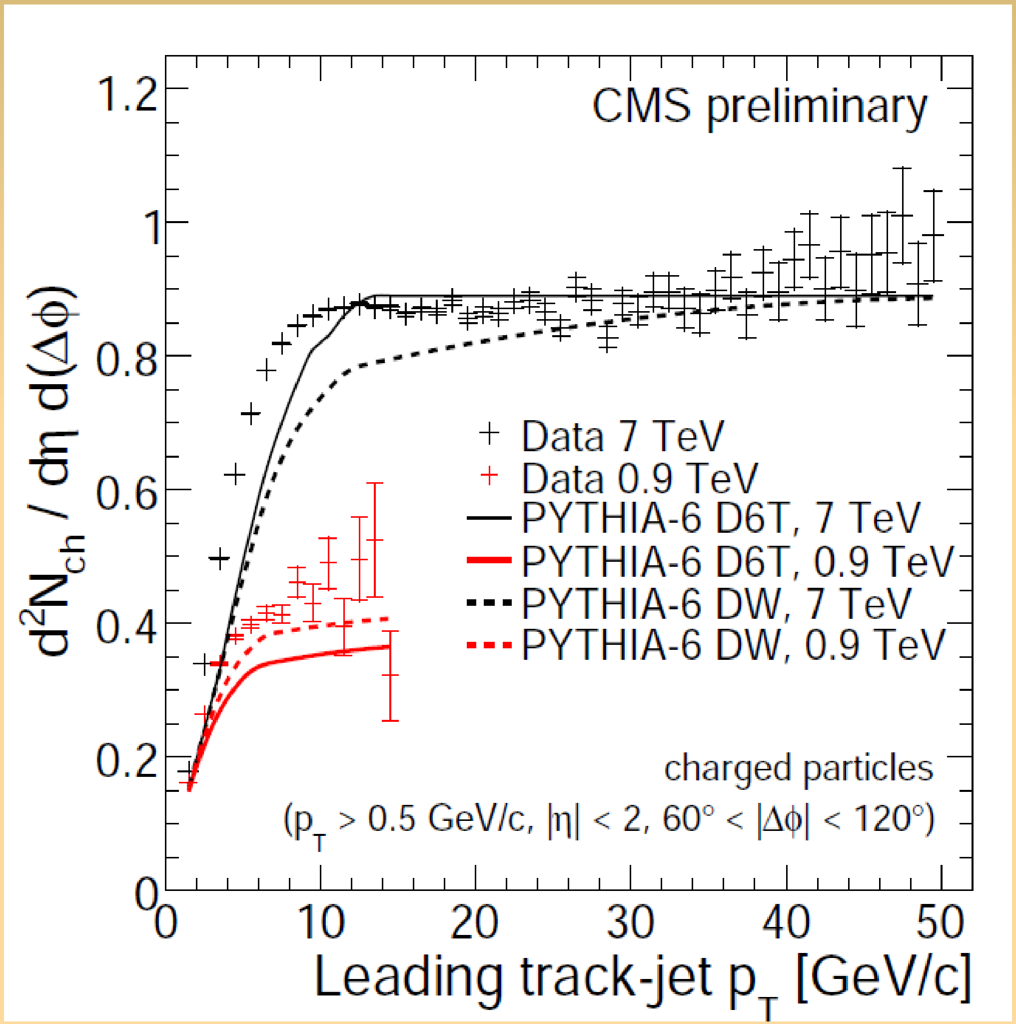
Transverse Charged Track Density



- We see the MC tunes mimic the behaviour at the of the data with various degrees of success.

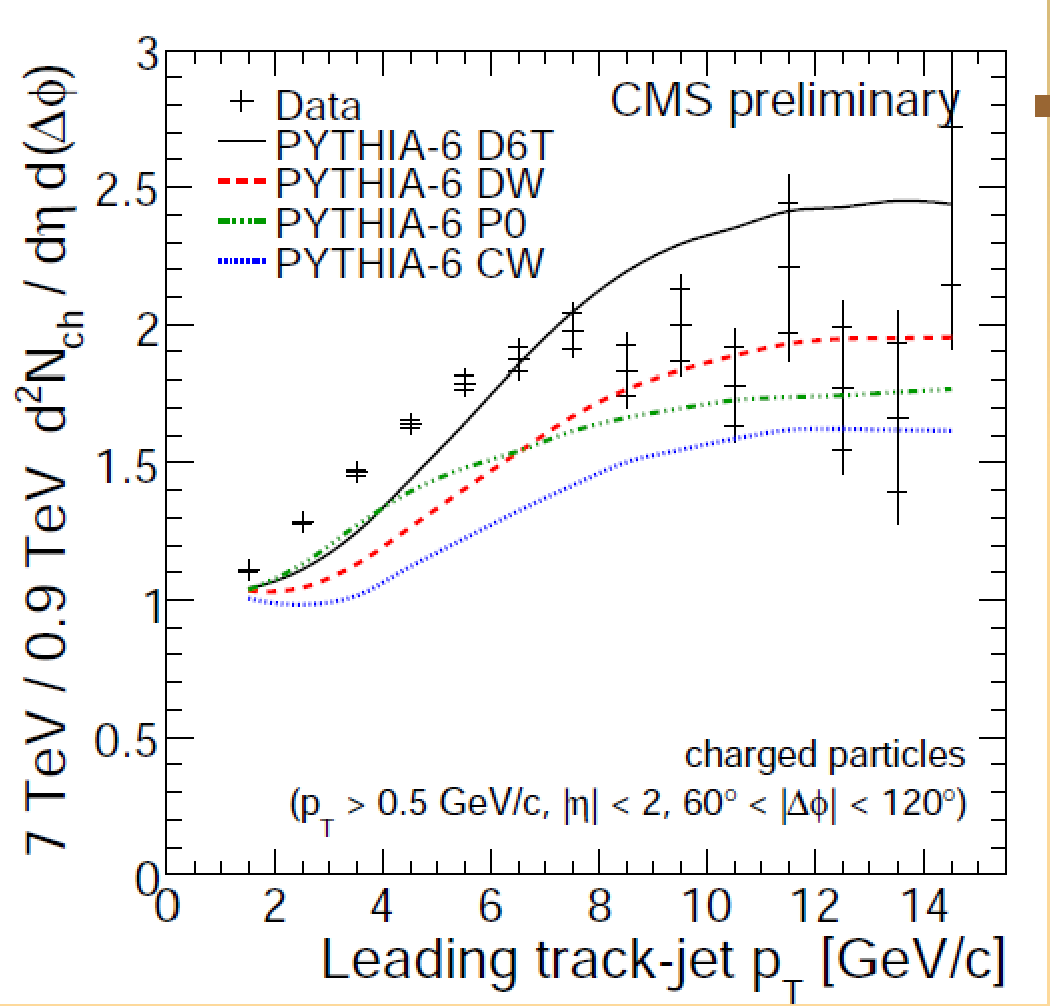
Increase of MPI activity

Transverse Charged Track Density



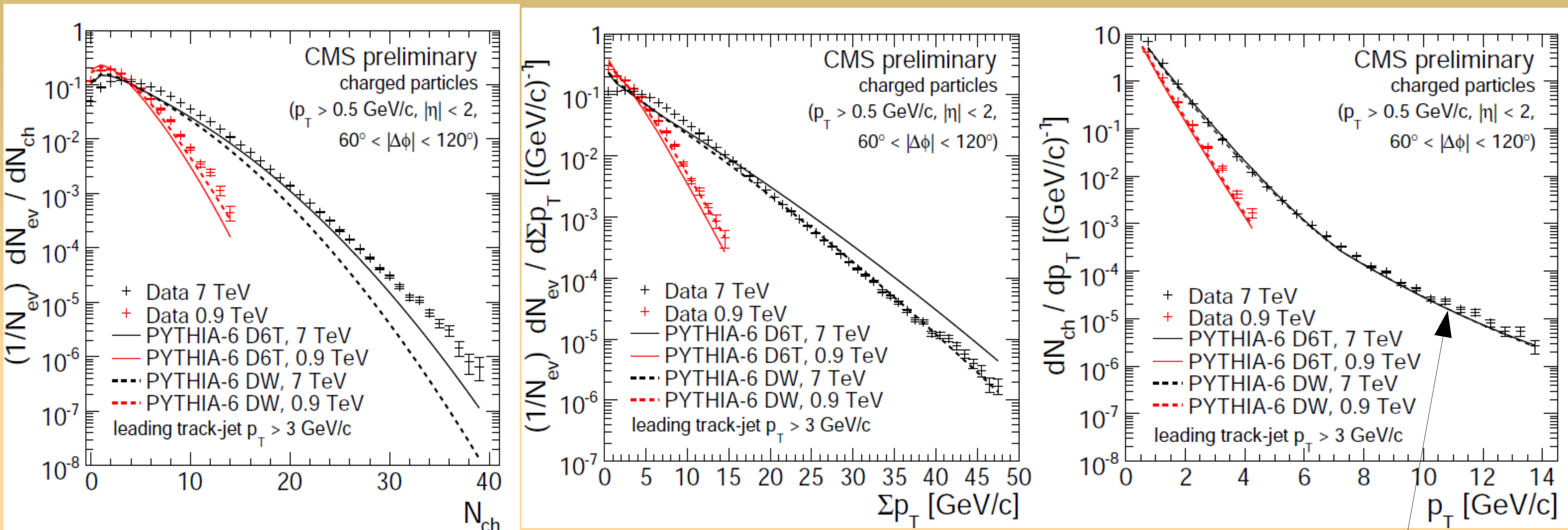
- Comparison between 7 TeV and 0.9 TeV.

Comparing 0.9 TeV and 7 TeV



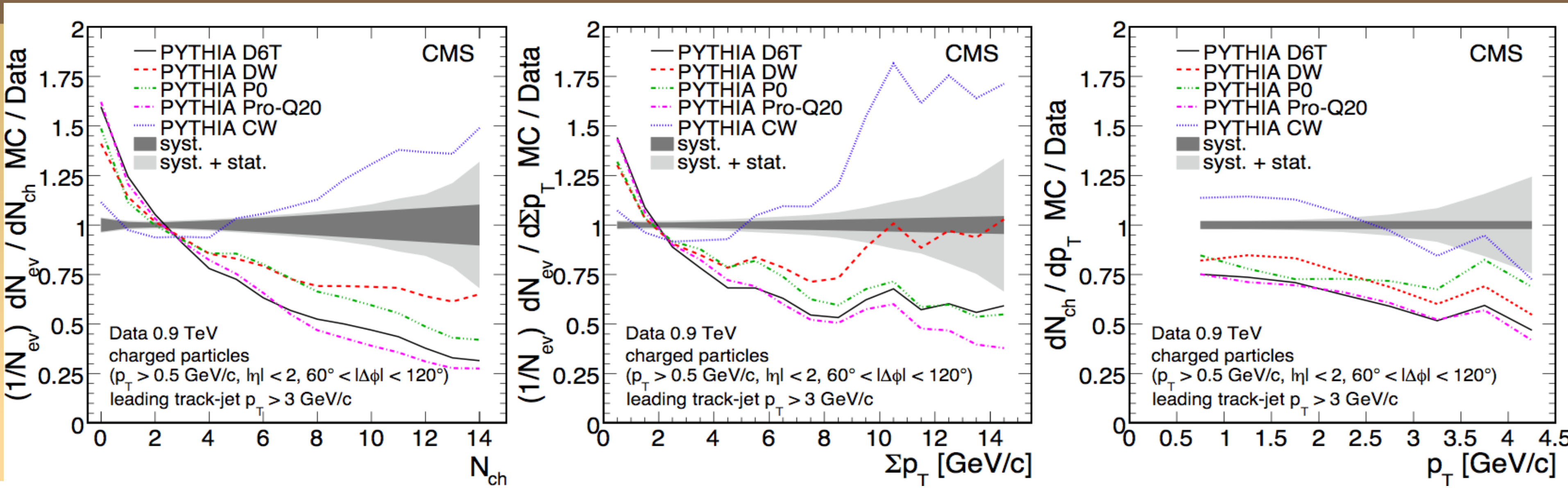
- MC tunes don't reproduce the behaviour of the data as we move from 0.9 TeV to 7 TeV.

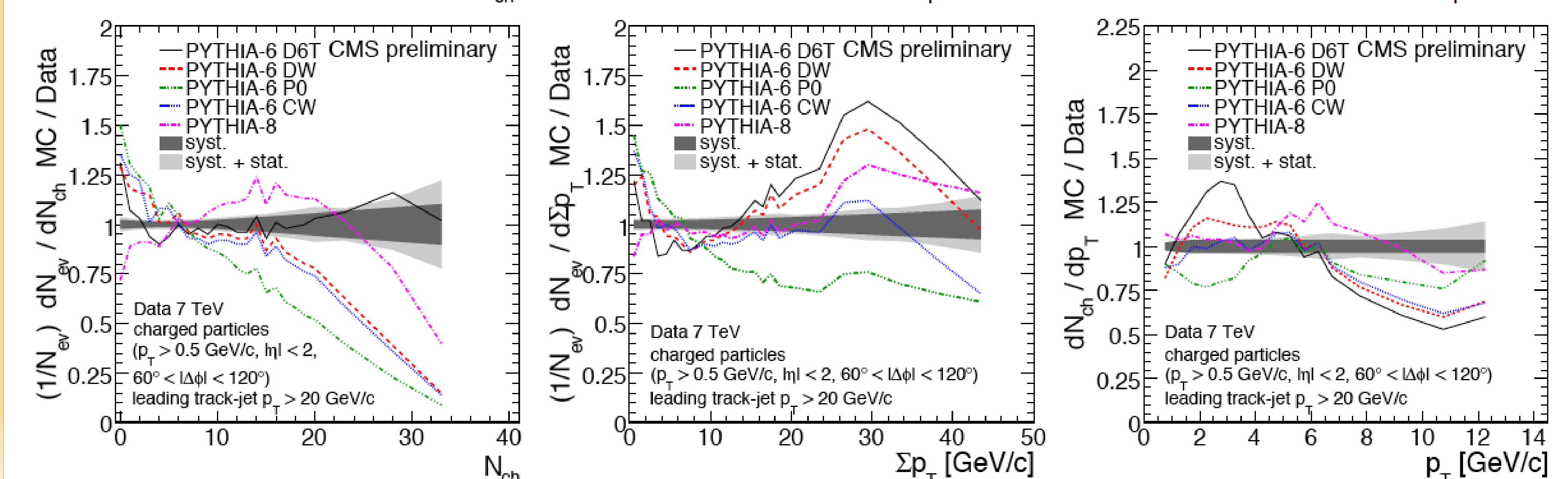
N_{ch}, p_T, and Σp_T distributions



- MC gives a good description of Data throughout the large range.
- Indications for having hard components in the transverse region.

N_{ch}, p_T, and Σp_T distributions





Conclusions about UE at 7 TeV

- Growth of UE activity with the scale of interaction
  - MC reproduced the main features but lacked in accuracy.
- Increase of UE activity with the increase centre of mass energy
  - MC reproduced the main features with inaccurate values.
- Detailed studies of various distributions in the transverse region
  - Favours a stronger value of ε (around 0.25).

The Jet-Area/median approach

Adjusted observable for low occupancy events: $\rho' = \underset{j \in physical\ jet}{median} [\{\frac{p_{Tj}}{A_j}\}] . C$ with $C = \frac{\sum A_j}{A_{tot}}$

- Event & Track Selection identical to the traditional UE measurement at 900 GeV, only differences:
  - p_T track > 0.3 GeV instead of 0.5 GeV/c
  - |η| track < 2.3 instead of 2.5
  - |η| track-jet < 1.8 instead of 2.0

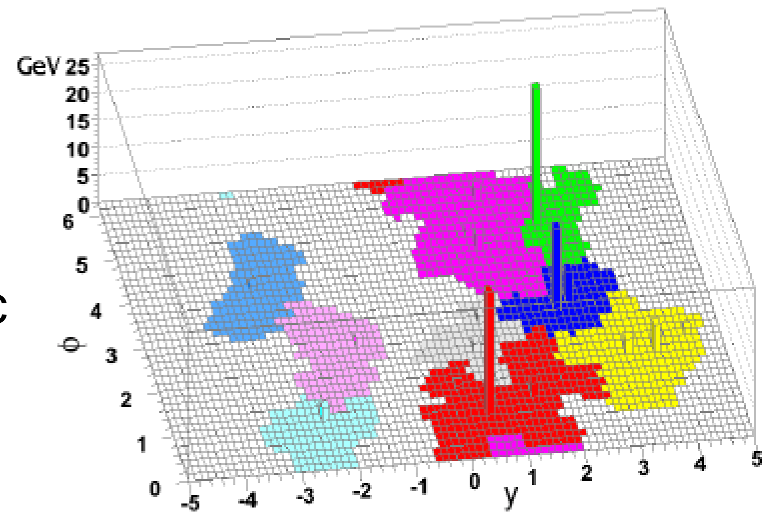
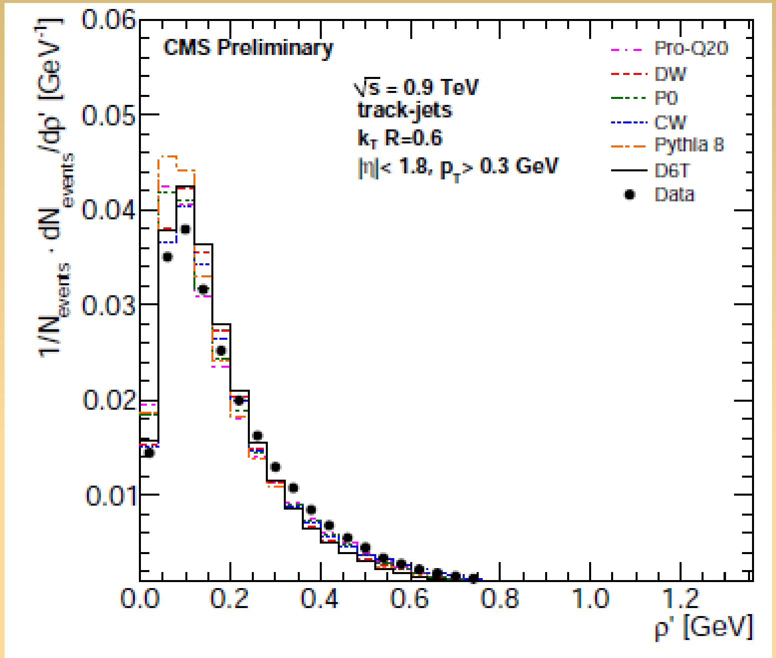
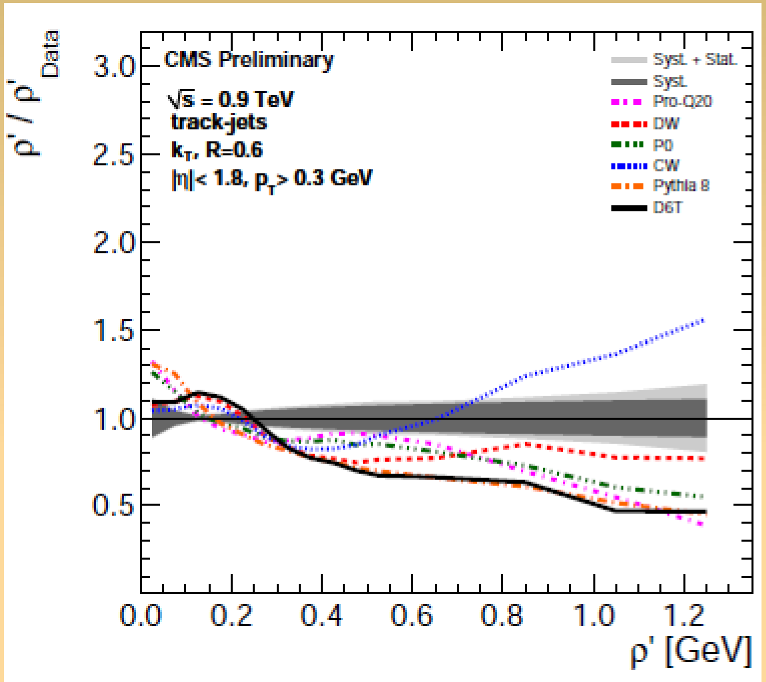


Figure 4: Active area for the same event as in figure 3, once again clustered with the k_t algorithm and $R = 1$. Only the areas of the hard jets have been shaded — the pure 'ghost' jets are not shown.

Based on the "On the characterisation of the underlying event"; JHEP04(2010)065; M. Cacciari, G. Salam, S. Sapeta.

Results





- Complementary approach to evaluate the UE activity, robust and flexible against different topologies, additional observables for MC tuning.

References

PAS QCD-10-001 & CERN-PH-EP/2010-014, submitted to EPJC: “First Measurement of the Underlying Event Activity at the LHC with $\sqrt{s}$ = 0.9 TeV”.

PAS QCD-10-010: “Measurement of the Underlying Event Activity at the LHC with $\sqrt{s}$ = 7 TeV and Comparison with $\sqrt{s}$ = 0.9 TeV”.

PAS QCD-10-005: “Measurement of the Underlying Event Activity with the Jet Area/Median Approach at 0.9 TeV”.

Paolo Bartalini: ”Underlying Event Studies and Forward Physics at CMS”-ICHEP2010

Future Steps

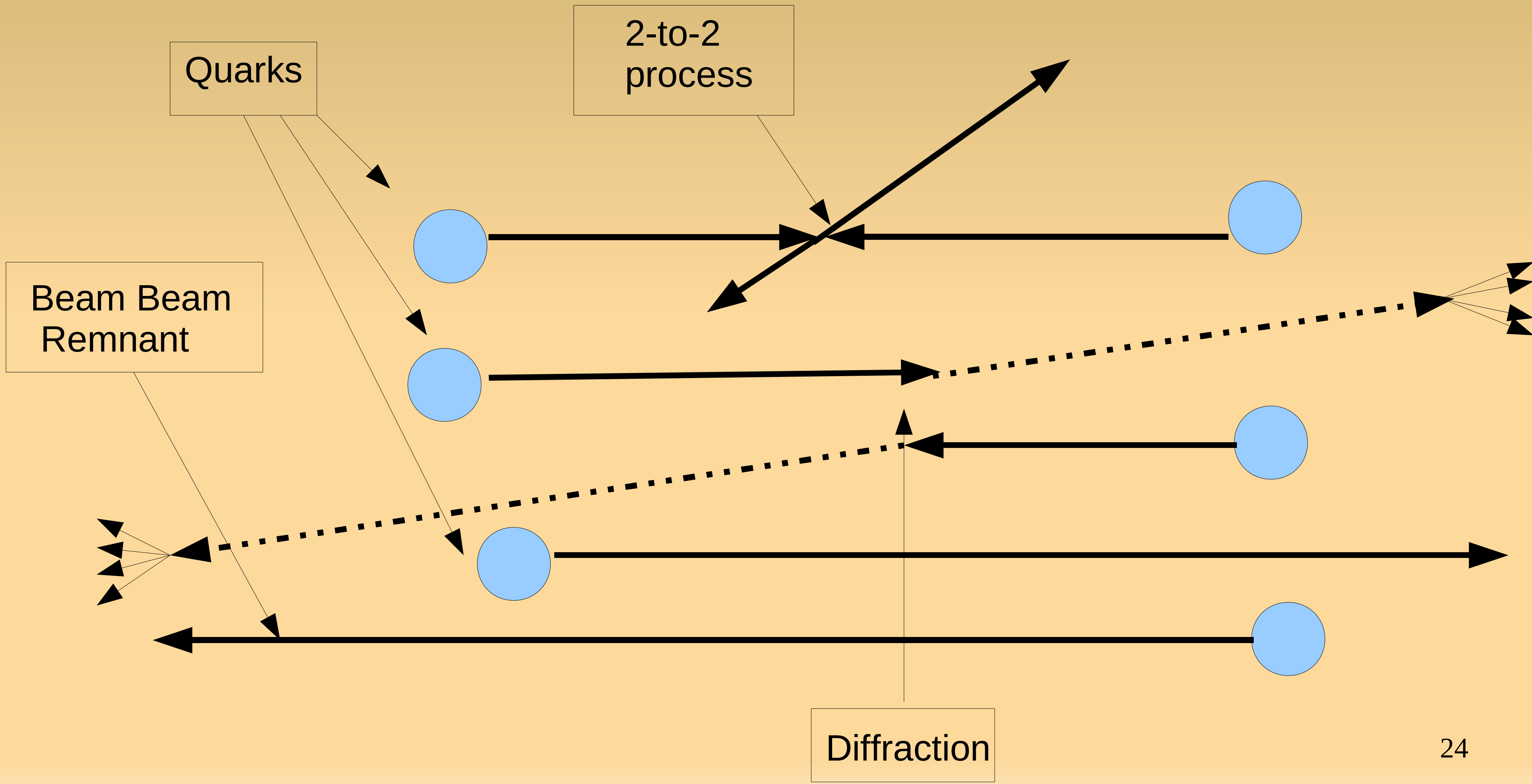
- Include more data at 0.9 TeV.
- Correcting the results with respect to detector effects.

Stay Tuned!

Thank You!

Back up slides

What is the UE?



The Traditional Approach

- The transverse momentum of outgoing parton in p-p center of mass frame $\hat{p}_T$ is crucial in determining the UE cross section.
- The perturbative 2-to-2 cross section diverges as $\frac{1}{\hat{p}_T^4}$ when $\hat{p}_T \to 0$.

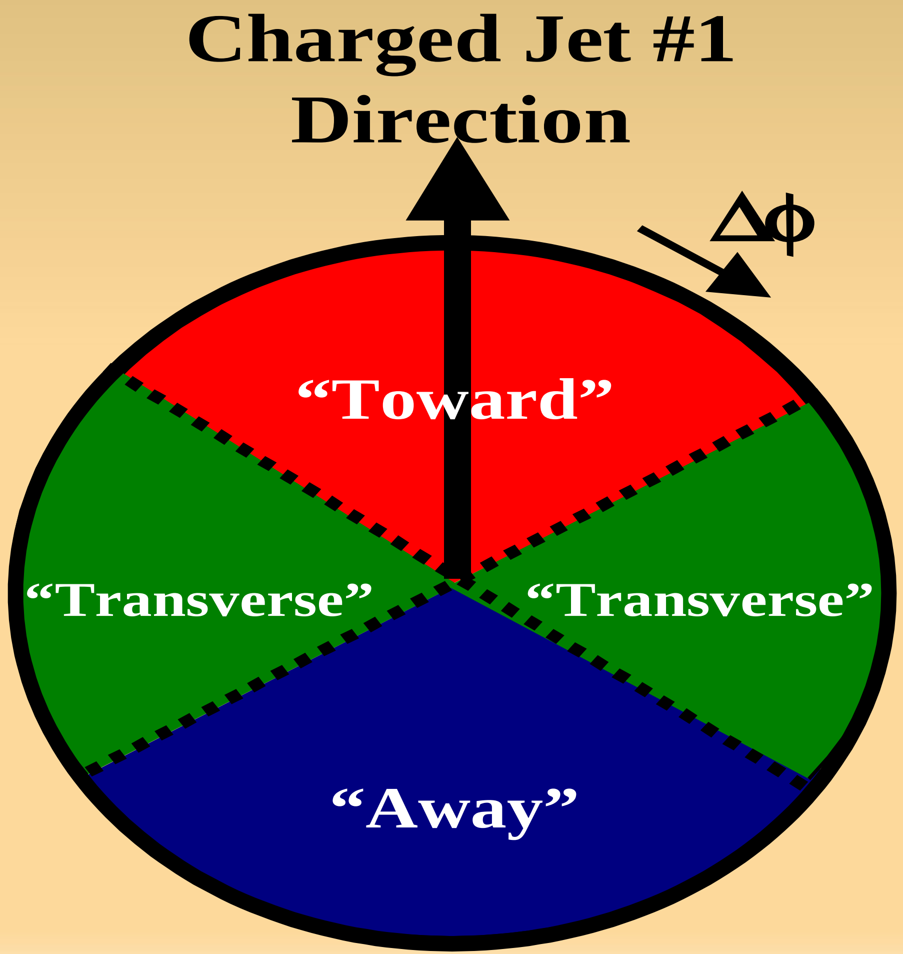
PYTHIA parameters

	Parameter	Default	Description
	PARP(83)	0.5	Double-Gaussian: Fraction of total hadronic matter within PARP(84)
	PARP(84)	0.2	Double-Gaussian: Fraction of the overall hadron radius containing the fraction PARP(83) of the total hadronic matter.
	PARP(85)	0.33	Probability that the MPI produces two gluons with color connections to the “nearest neighbors.
	PARP(86)	0.66	Probability that the MPI produces two gluons either as described by PARP(85) or as a closed gluon loop. The remaining fraction consists of quark-antiquark pairs.
	PARP(89)	1.8 TeV	Determines the reference energy E_0.
1	PARP(82)	1.9 GeV/c	The cut-off P_{T0} that regulates the 2-to-2 scattering divergence $1/PT^4 \rightarrow 1/(PT^2+P_{T0}^2)^2$
2	PARP(90)	0.16	Determines the energy dependence of the cut-off P_{T0} as follows $P_{T0}(E_{cm}) = P_{T0}(E_{cm}/E_0)^{\varepsilon}$ with ε = PARP(90)
	PARP(67)	1.0	A scale factor that determines the maximum parton virtuality for space-like showers. The larger the value of PARP(67) the more initial-state radiation.

Differnet Tunes

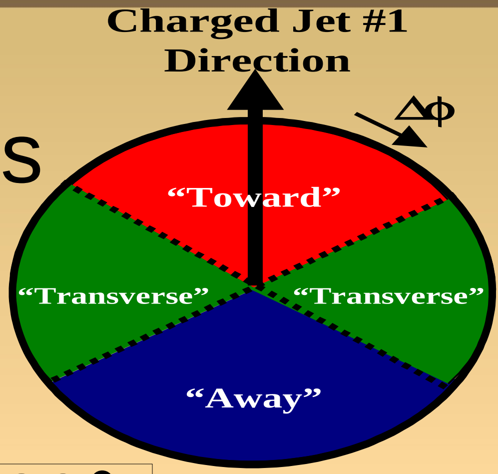
- All tunes used in this study were used to describe the UE activities at CDF.
- DW, P0 (only Minbias) , Pro-Q20 (UE + Min-bias) has ε = 0.25, 0.26, 0.22 respectively.
- D6T has ε = 0.16 and CTEQ6L.
- P0 and Pro-Q20 use LEP Fragmentation.
- CW was modified for this analysis to have p_{T0} = 1.8GeV/c and ε = 0.30
- P8: Only one tune (close to P0), ε = 0.25

Where to look?



- UE properties are convineintly analyzed with reference to the particle or jet with the highest $\hat{p}_T$.
- This leading object reflects the direction of the outgoing partons in 2-to-2 process.

The Transverse Region



- The Φ space is divided into 3 regions depending on $\Delta\Phi = \Phi - \Phi1$
  - The Toward region: $|\Delta\Phi| < 60°$.
  - The Transverse region: $60° < |\Delta\Phi| < 120°$.
  - The Away region: $|\Delta\Phi| > 120°$.
- The Tranverse region is the most sensitive region to the UE.

The Jet-Area/median approach

- Cluster the event using inclusive k_T jet algorithm.
- Each jet 'j' is assigned a jet area A_j by including a large number of ghost particles to the event.
- A_j is then proportional to the number of ghosts it contains.
- The underlying event activity is given by $\rho = \text{median}\{p_T/A\}$.
- The median is less sensitive to outliers, i.e. hard jets

Cuts (0.9 TeV)

Event Selection	Data	Data[%]	MC[%]
triggered	255122	100	100
+1 real Vertex	239038	93.7	92.9
+15cm window	238977	93.6	92.8
+3 tracks associated	230611	90.4	88.7
Leading jet pT > 1 GeV/c	155702	67.2	56.0
Leading jet pT > 3 GeV/c	24881	10.8	9.0

The UE Observables

- We can decide which model is better by studying a few observables:
  - Transverse charge density.
  - Transverse charged $\sum p_T$ density.
  - Transevere charge multiplicity and transverse momenta distributions.