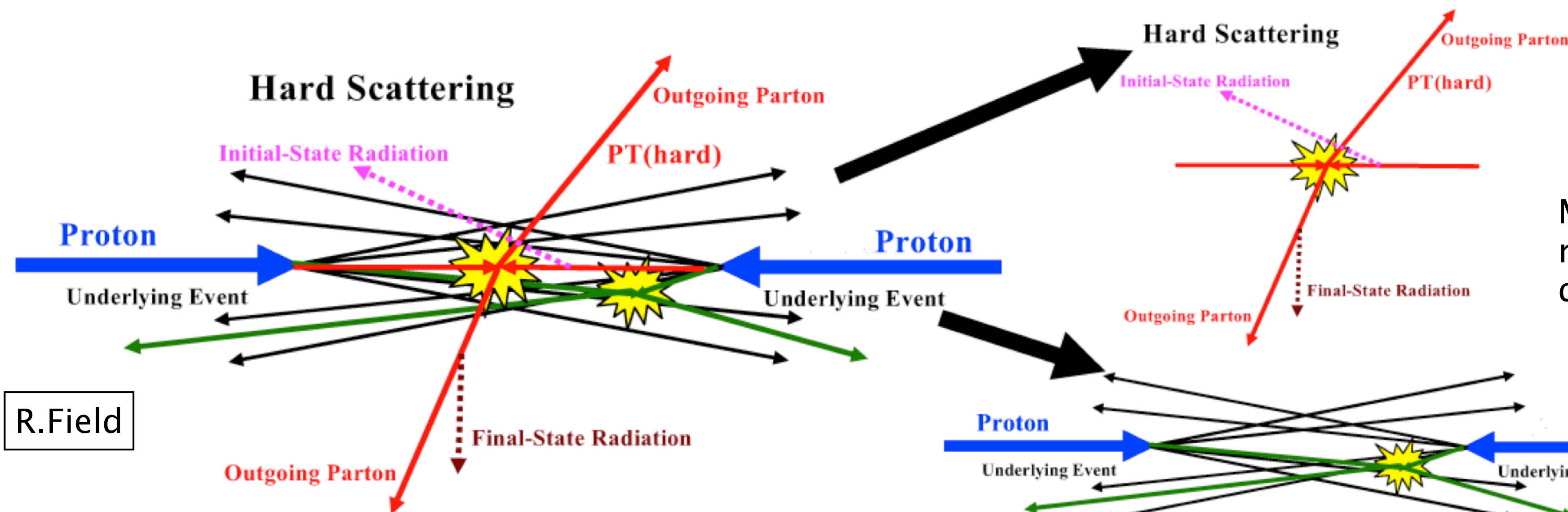
The Underlying Event in pp Collisions at 900 GeV

PLHC2010 - June 11, 2010 - DESY, Hamburg

Giuseppe Cerati (INFN–MIB and CERN)
on behalf of the CMS collaboration

The Hard Scattering in p-p collisions can be sketched as the sum of a hard 2-to-2 parton collision (including initial and final state radiation) and the Underlying Event (UE), given by beam-beam remnants plus multiple parton interactions.



MPI, BBR, ISR, FSR not uniquely differentiable

The study of UE properties and the MC tuning is crucial for the precise measurement of SM processes and the search for physics beyond SM. The study of its properties already with 900 GeV p-p collisions provides interesting information about the energy dependence of MPI.

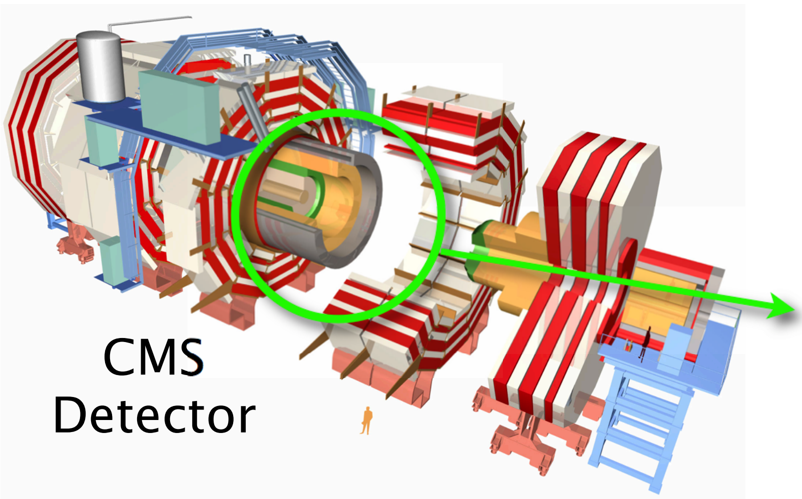
PYTHIA tunes

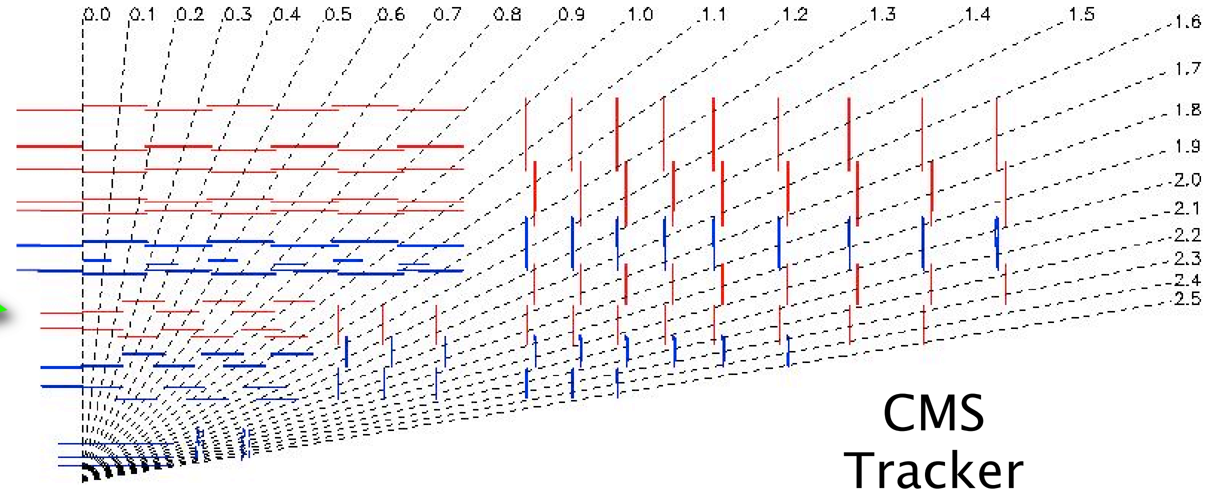
- Several PYTHIA tunes considered, differing in the description of parton fragmentation and multiple parton interaction.
- PYTHIA regularizes the $1/p_T^4$ divergence for final state parton $p_T \rightarrow 0$ using a cut-off parameter p_{T0}, used both for hard-scattering and MPI.
- The energy dependence of the cut-off is given by: $p_{T0}(\sqrt{s}) = p_{T0}(\sqrt{s_0}) \cdot (\sqrt{s}/\sqrt{s_0})^\varepsilon$
- All considered tunes are compatible with Tevatron data.

Tune	p_{T0}(1.8TeV)	ε	notes/other features
D6T	1.8 GeV/c	0.16	Energy dependence from UA5 Minimum Bias data at SppS. Uses CTEQ6L.
DW	1.9 GeV/c	0.25	"Best fit" of Tevatron data: $p_T(Z)$ and di-jet $\Delta\phi$
Pro-Q20	1.9 GeV/c	0.22	Professor fit program using LEP data for fragmentation
P0	2 GeV/c	0.26	As above + new PYTHIA MPI model + pT-ordered shower
CW	1.8 GeV/c	0.3	Maximizes MPI at 900 GeV, still compatible with Tevatron

Analysis strategy

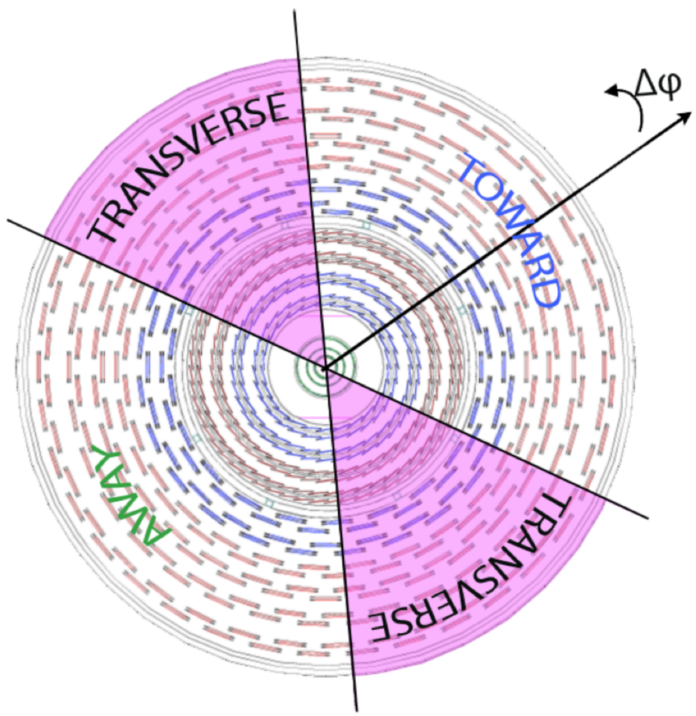
Comparison of 900 GeV CMS data with detector level simulation





The scale of the hard-interaction is defined by:
- the leading track
- the leading tracker-jet

This defines two complementary analysis approaches.



The hard-interaction direction identifies three regions (same size):
- **toward**: $|\Delta\phi|<60°$
- **away**: $|\Delta\phi|>120°$
- **transverse**: $60<|\Delta\phi|<120°$

The UE is best studied in the transverse region.

Event and Track Selection

- Trigger: coincidence of both Beam Pick-up Timing for eXperiments (BPTX) with a hit in Beam Scintillator Counters (BSC)
- Primary vertex
- Leading tracker-jet or track above p_T threshold

Event selection	Data (nb. of events)	Data [%]	MC [%]
triggered	255 122	100	100
+ 1 primary vertex	239 038	93.7	92.9
+ 15 cm vertex z window	238 977	93.6	92.8
+ at least 3 tracks associated	230 611	90.4	88.7
leading track, $p_T > 0.5$ GeV/c	216 215	93.8	93.2
$p_T > 1.0$ GeV/c	131 421	60.8	55.0
$p_T > 2.0$ GeV/c	28 210	21.5	19.5
leading tracker jet, $p_T > 1.0$ GeV/c	155 005	67.2	62.9
$p_T > 3.0$ GeV/c	24 928	16.1	15.9

Fairly good Data-MC agreement

- Kinematic Cuts:
  - p_T>0.5 GeV/c, $|\eta|$<2
- Primary vtx compatibility:
  - IP significance < 5
- Good quality tracks:
  - p_T error<5%
  - "highPurity" flag

Track selection	Data (nb. tracks)	Data [%]	MC [%]
no requirement	4826701	100	100
+ $p_T > 0.5$ GeV/c	1986805	41.2	42.0
+ $\|\eta\| < 2.5$	1950269	98.2	98.1
+ $\|\eta\| < 2$	1588177	81.4	81.1
+ $d_{xy}/\sigma(d_{xy}) < 5$	1376042	86.6	87.5
+ $d_z/\sigma(d_z) < 5$	1260249	91.6	94.2
+ $\sigma(p_T)/p_T < 5\%$	1201941	95.4	95.2
+ high purity algorithm	1168530	97.2	97.4
Total	1168530	24.2	25.5

Systematic Uncertainties

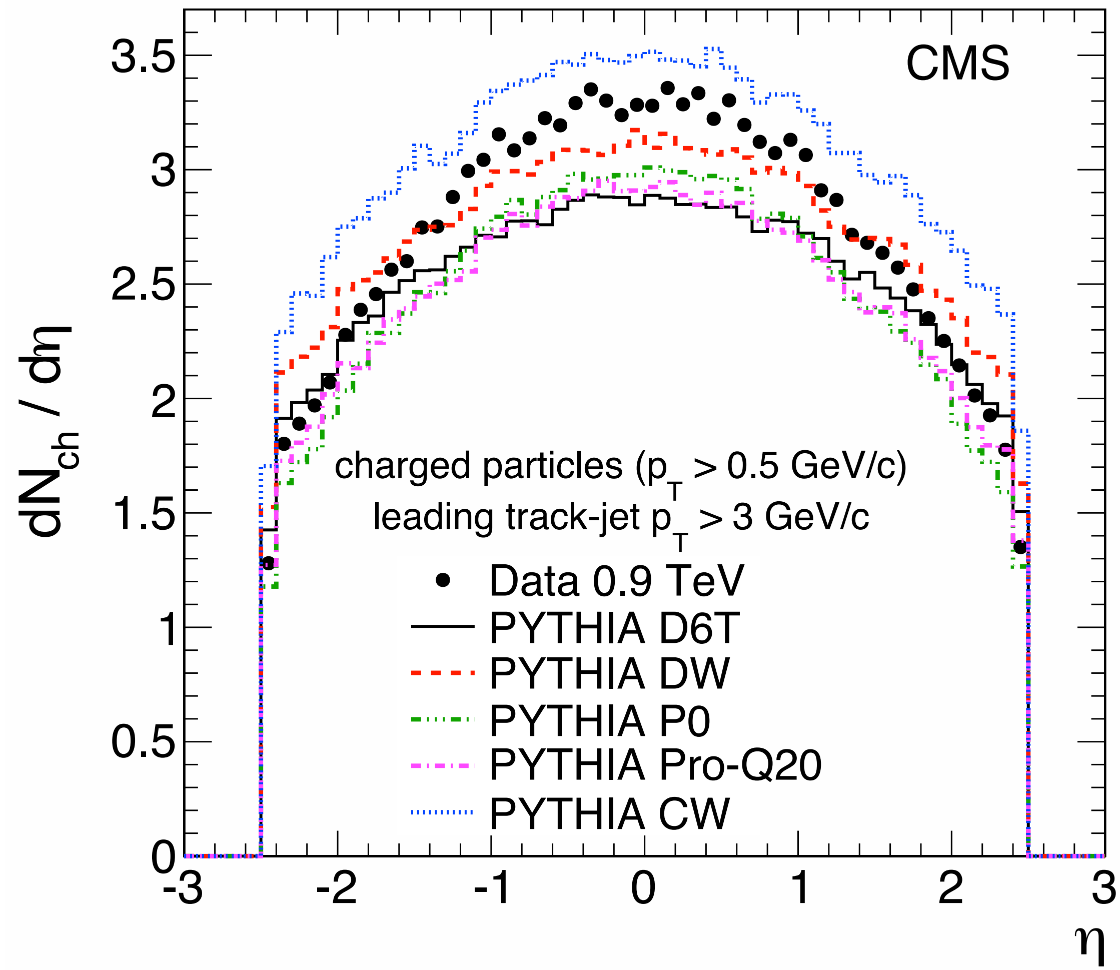
- A very detailed study of systematic uncertainties has been performed, investigating all possible sources of data-MC disagreement.
- Tested MC samples with altered scenarios for: alignment, beam spot, dead channels and material description.
- The underestimation of the rates of K_S, Λ and conversions in MC has been accounted.
- Results with different track selection criteria have been compared.
- Trigger uncertainty tested with complementary HF trigger.
- All results are quite stable, leading to a total error O(2%)
  - the CMS simulation is very accurate;
  - the reconstruction algorithms are very robust.
- Commissioning of standard CMS tracking for a physics analysis.

	track sel.	tracker align.	tracker matter	bg. cont.	trigger	dead ch.	beam spot	total
$d^2N_{ch}/d\eta d\phi$ ($p_T = 3.5$ GeV/c)	0.3	0.3	1.0	0.8	0.6	0.1	0.5	1.8
$d^2\Sigma p_T/d\eta d\phi$ ($p_T = 3.5$ GeV/c)	0.4	0.3	1.0	0.8	1.1	0.1	0.5	1.8
dN_{ev}/dN_{ch} ($N_{ch} = 4$)	0.6	0.6	1.2	1.0	1.2	0.2	0.6	2.3
$dN_{ev}/d\Sigma p_T$ ($\Sigma p_T = 4.5$ GeV/c)	0.5	0.2	0.6	0.5	1.2	0.2	0.4	1.6
dN_{ch}/dp_T ($p_T = 1$ GeV/c)	0.8	0.6	1.0	0.8	1.0	0.2	0.5	2.0

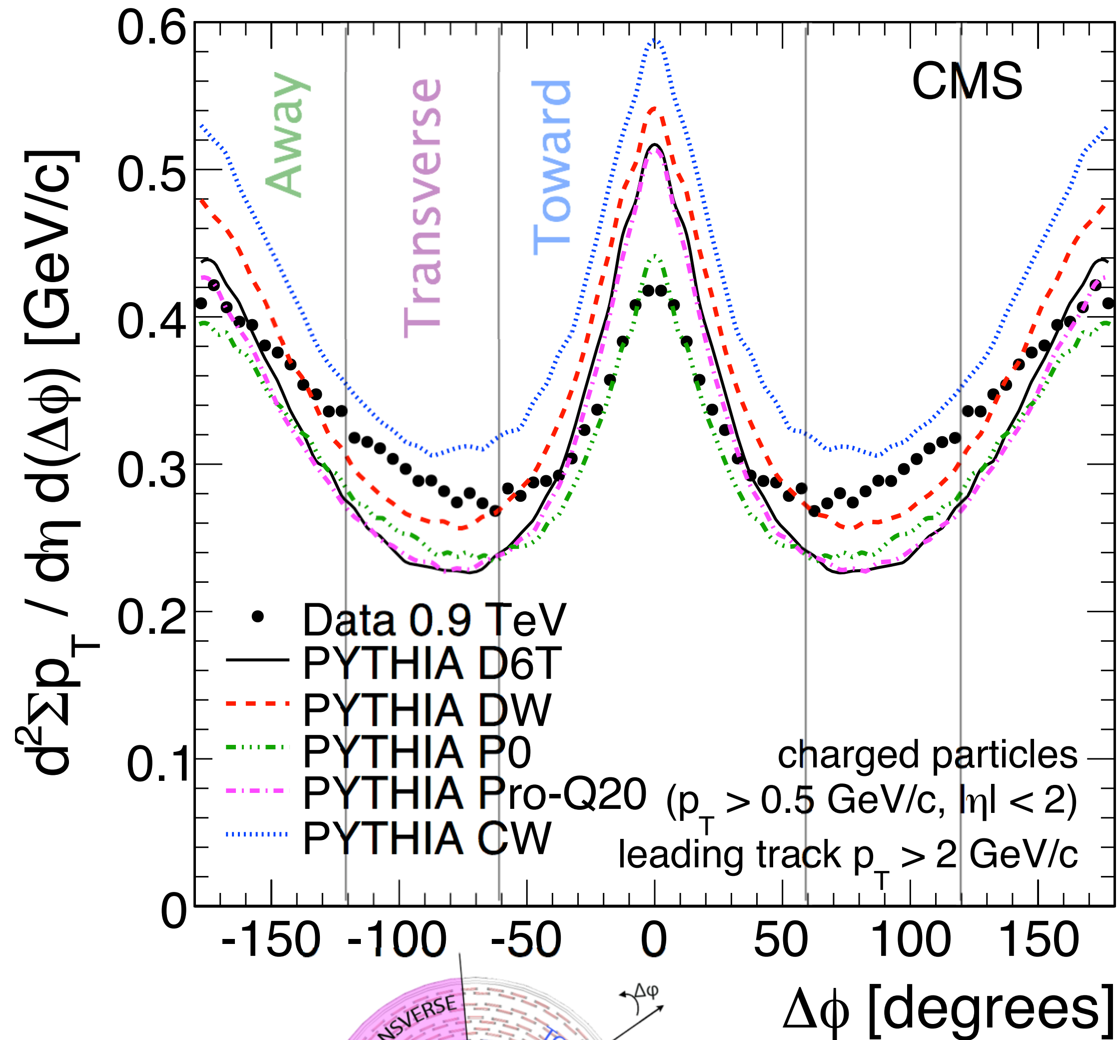
Pseudorapidity

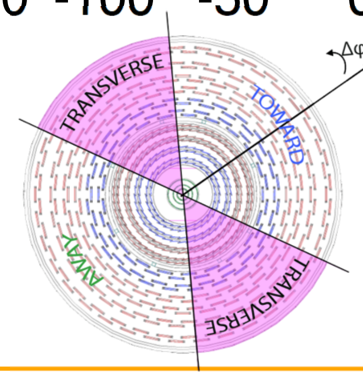
- The tunes describe the features of data within 10–15%
- No tune shows a satisfactory agreement
- The multiplicity depends on the interaction scale, increasing with the p_T of the tracker-jet.
- The shape is better described by Pro-Q20 and P0.
- Normalization:
  - CW too high
  - D6T, P0 and Pro-Q20 too low
  - DW high at large |η| and low at small |η|

Shown for all regions!



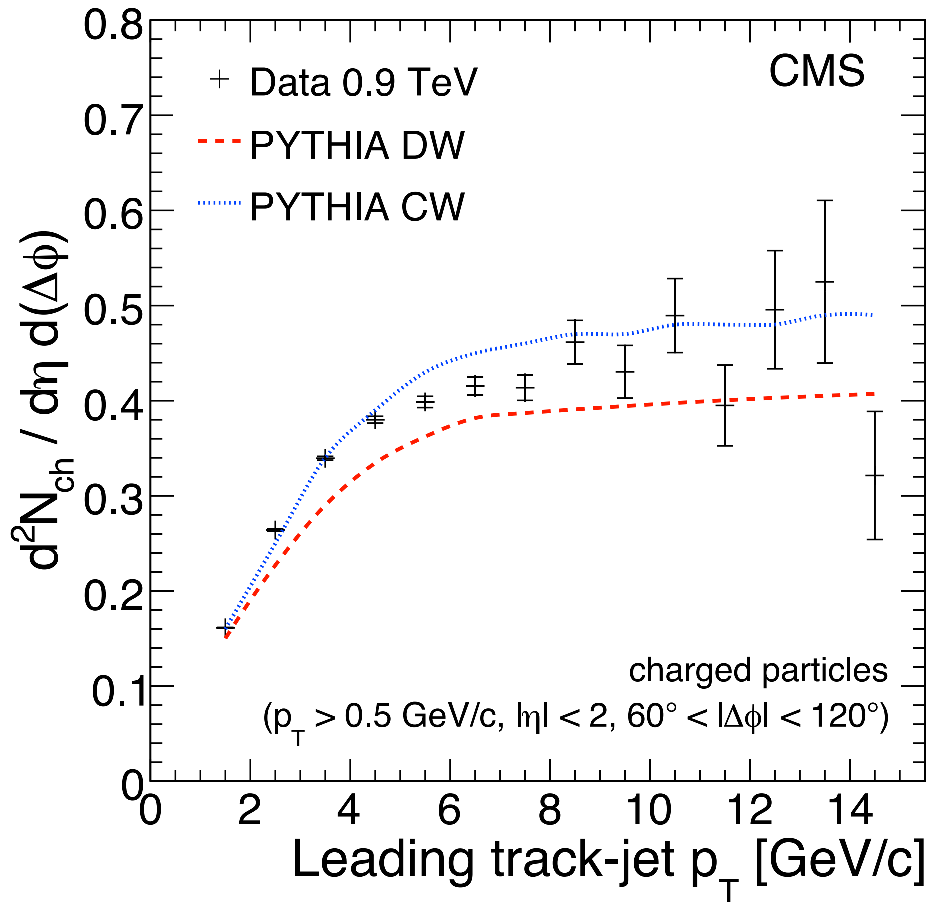
- Toward: all tunes are above data except P0 (new MPI modeling, p_T-ordered showering, fragmentation from LEP).
  - the tracker-jet analysis, less sensitive to the showering model, shows a better agreement for all tunes in this region
- Away: only DW and CW overshoot the data.
- Transverse - this is the region sensitive to UE properties: data is embraced by CW and DW tunes.

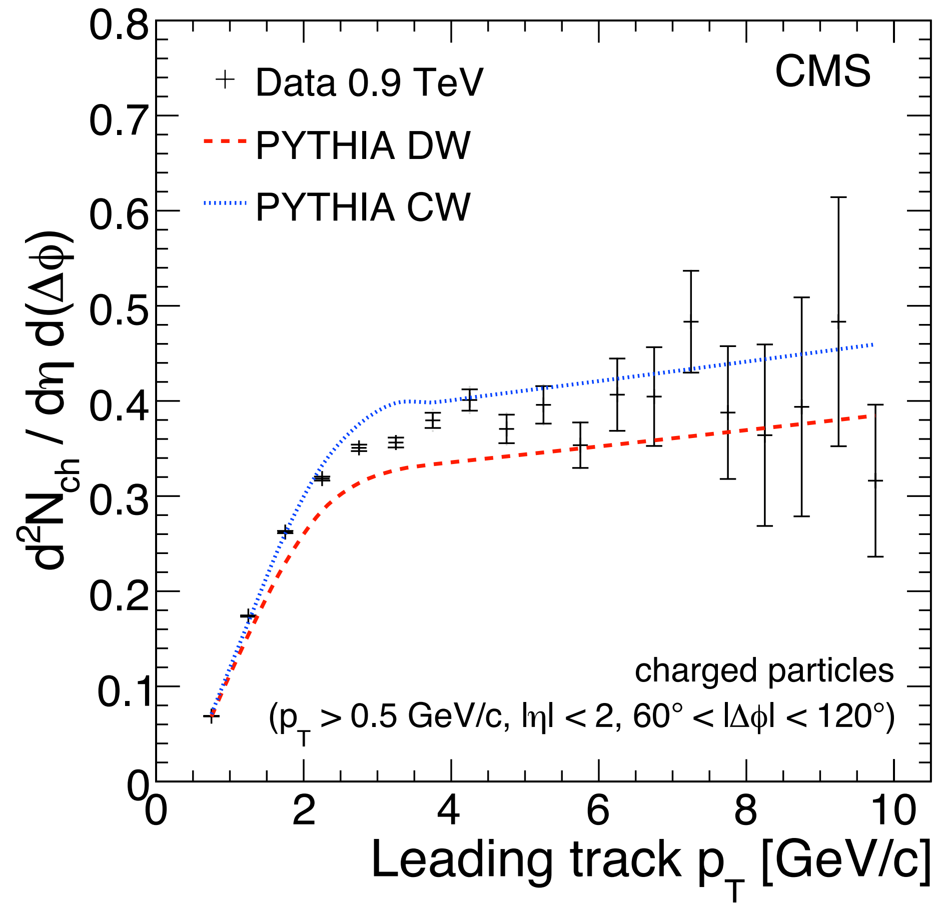




Leading track p_T NOT included!

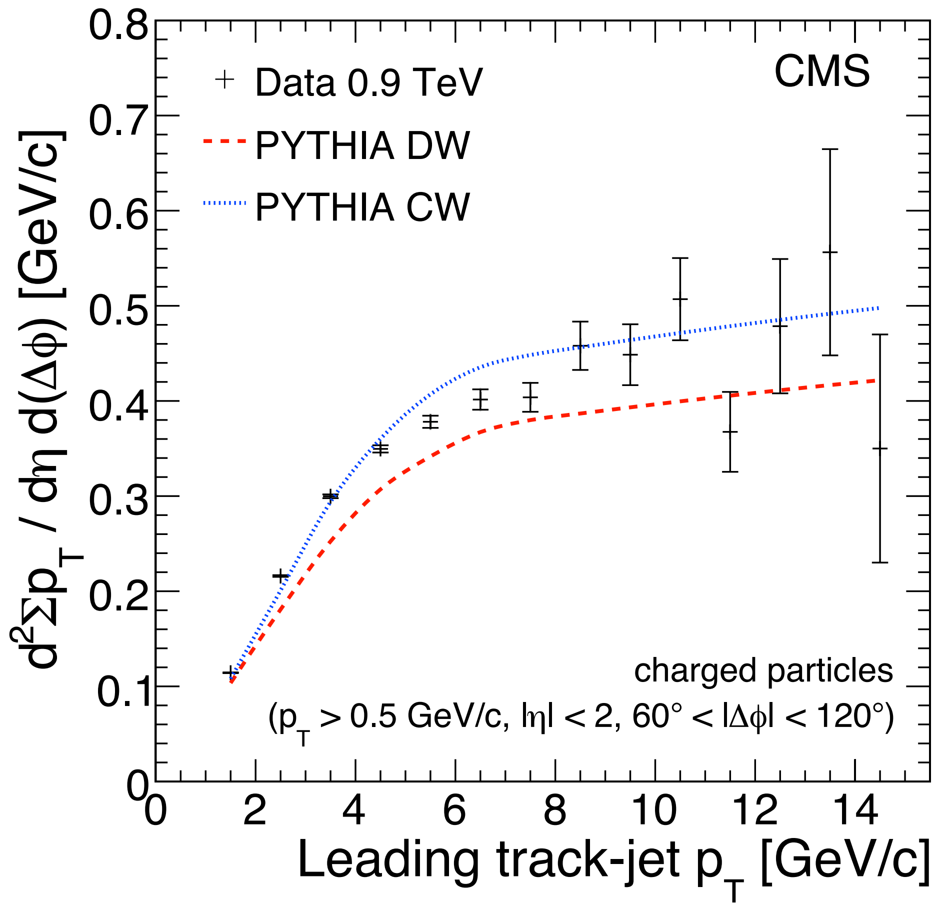
Charge density in the Transverse Region

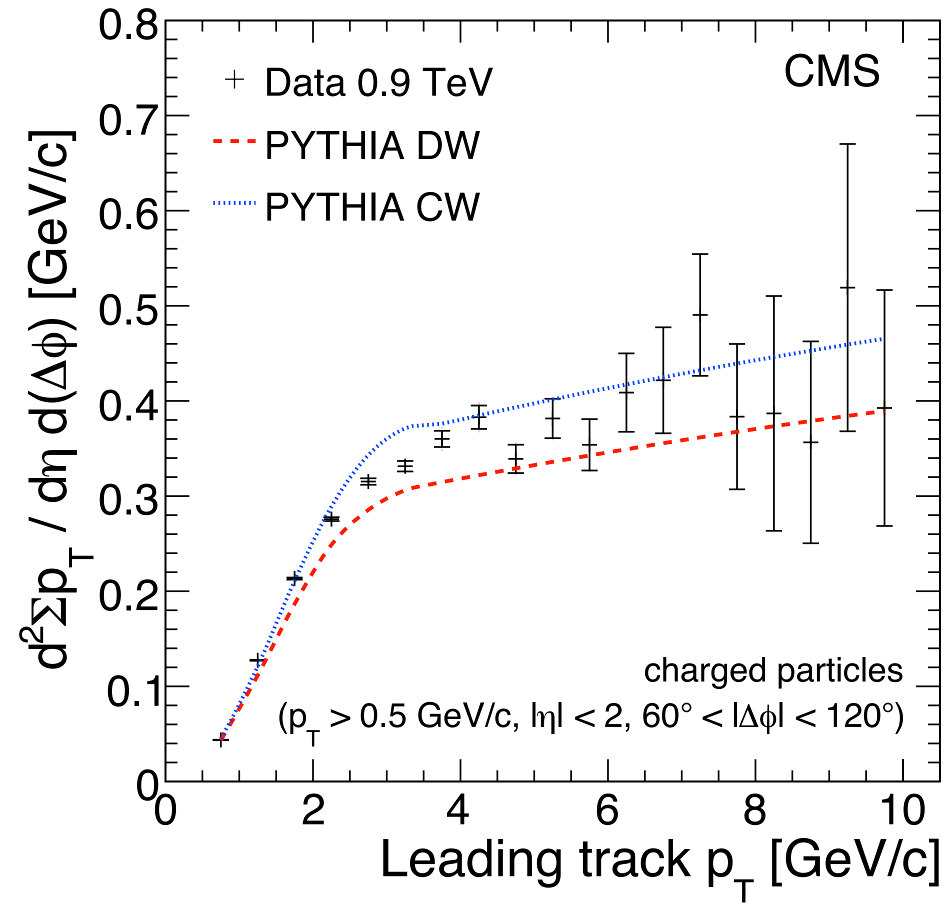




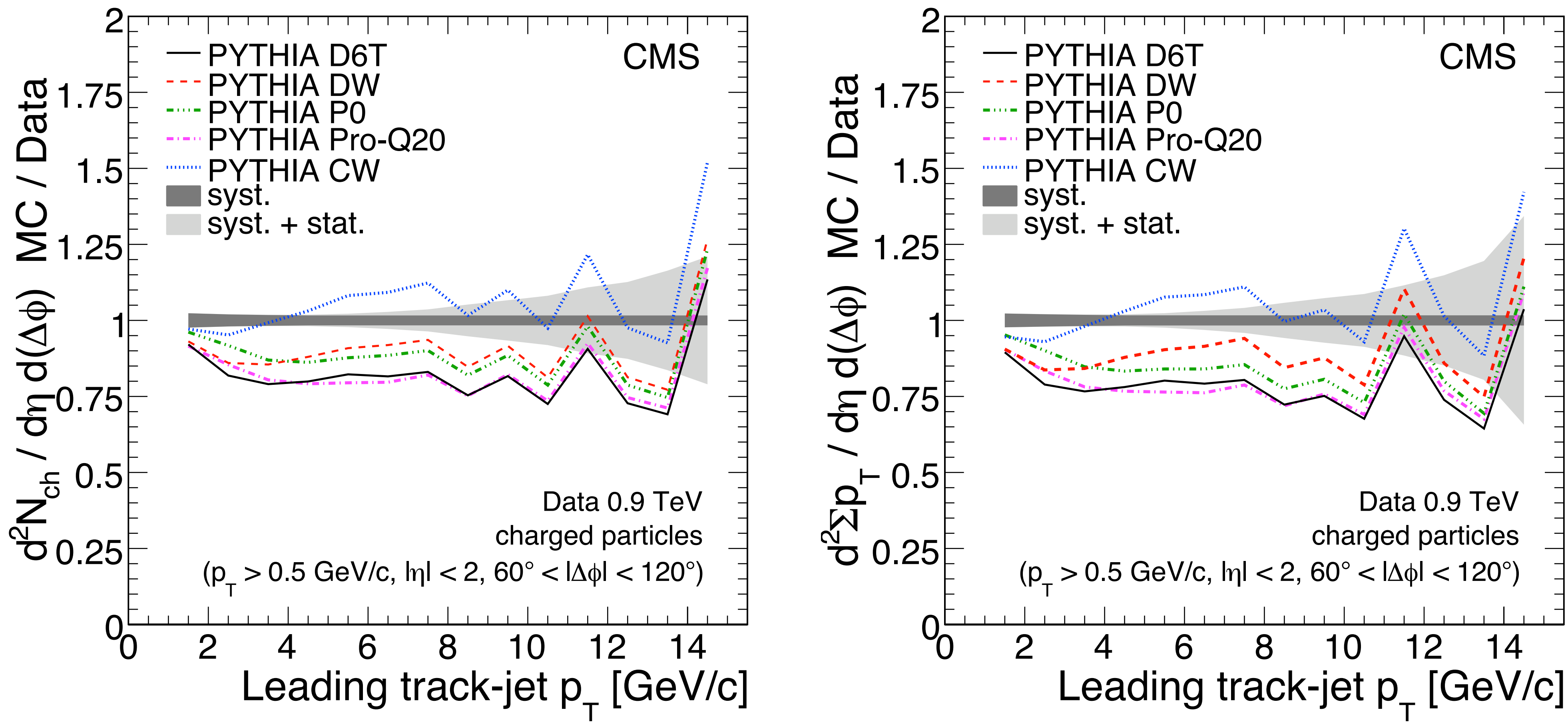
Charge density in the transverse region shown
as a function of the interaction scale.
Same features observed in data and all MC tunes:
fast rise at low p_T (MPI) followed by a slower increase (radiation) above ~3 GeV/c and ~5 GeV/c for leading track and jet analyses respectively.

Energy density in the Transverse Region



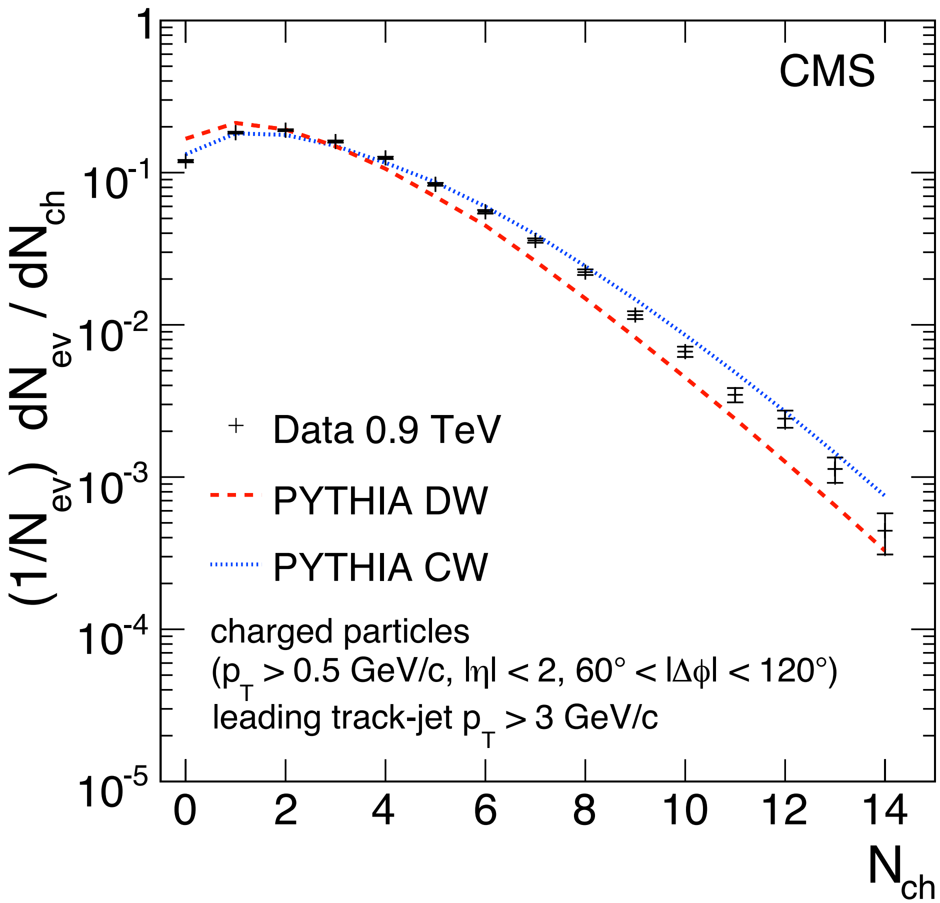


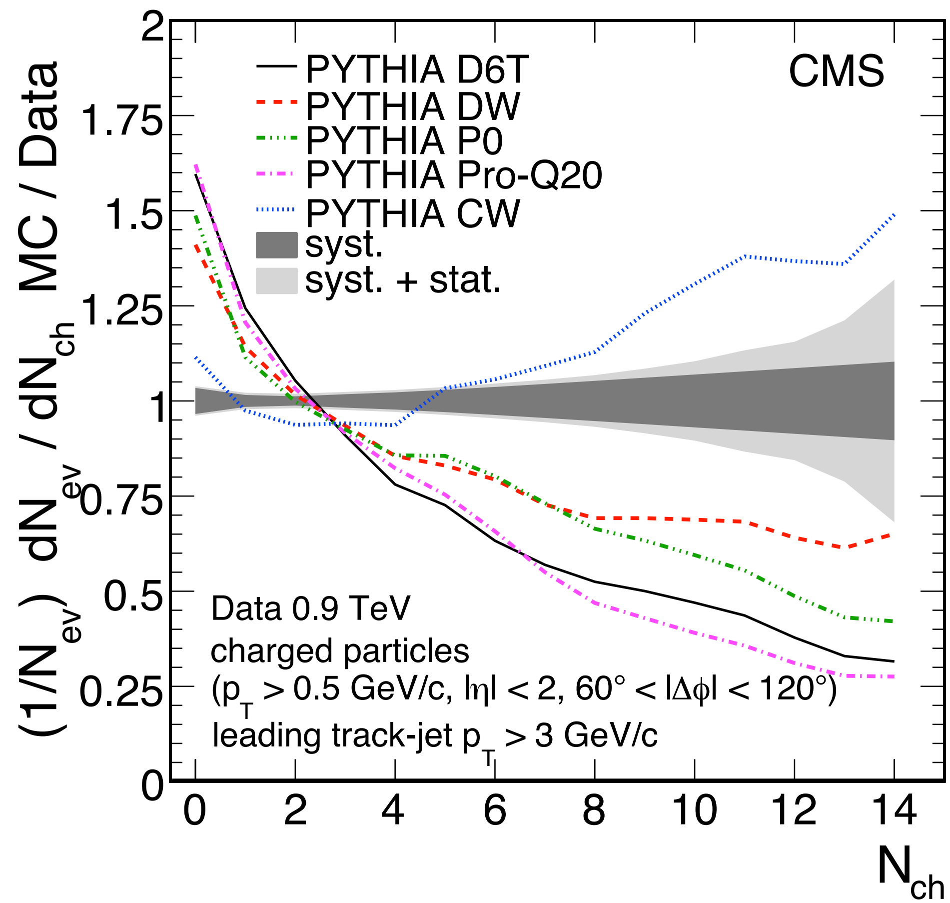
Energy density in the transverse region shown as a function of the interaction scale.
Same features observed in data and all MC tunes:
fast rise at low p_T (MPI) followed by a slower increase (radiation) above ~3 GeV/c and ~5 GeV/c for leading track and jet analyses respectively.



The transverse region is better described by DW and CW, with CW overestimating the UE activity and DW underestimating it.

Charged Particles Multiplicity (Transv. Reg.)



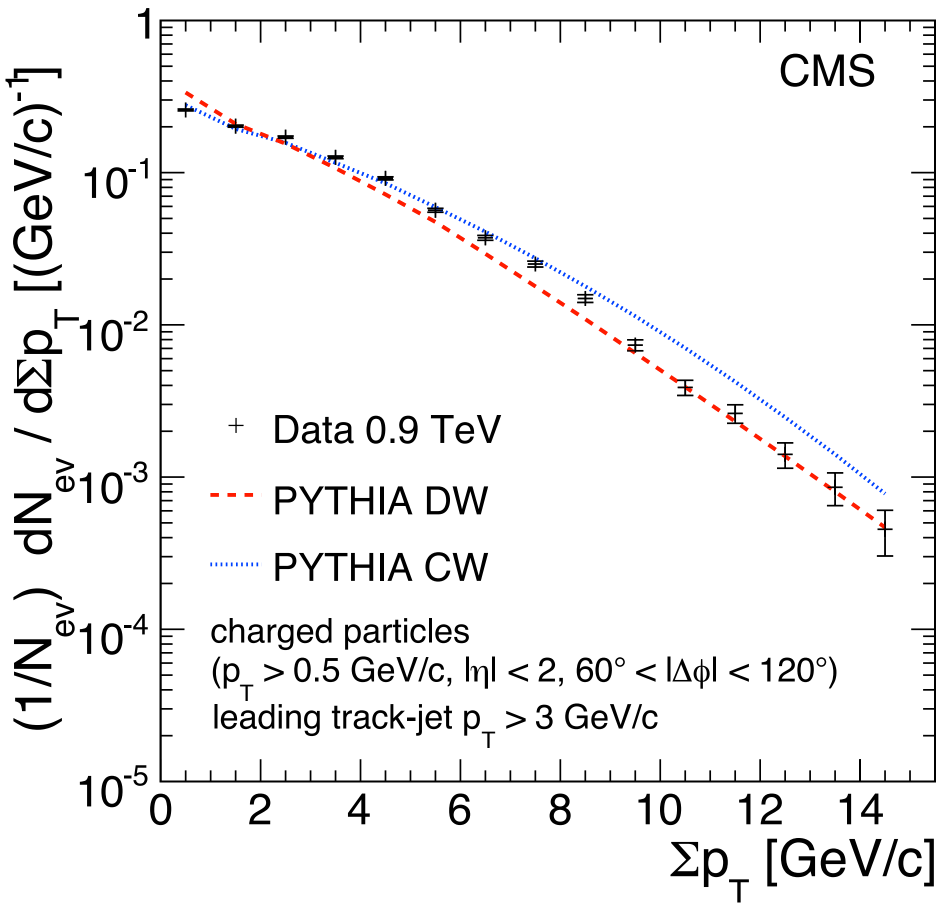


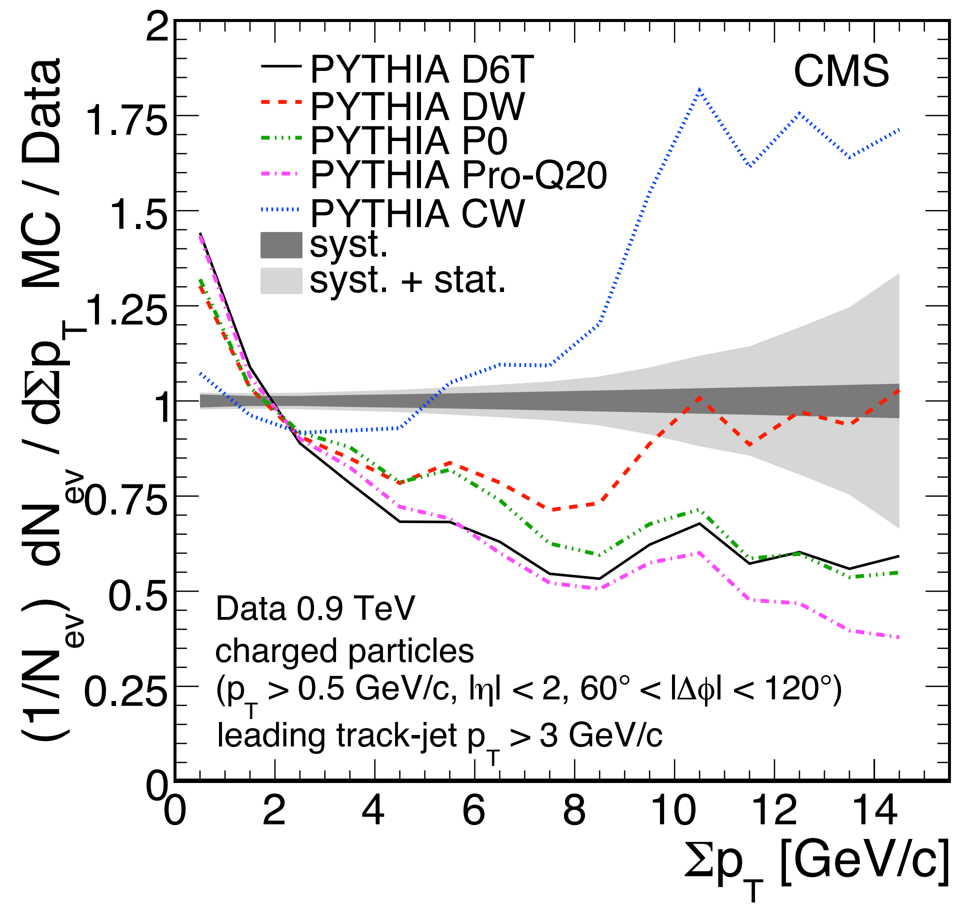
Probability distribution of track multiplicity in the transverse region for events with a tracker-jet with p_T>3 GeV/c.

Steep decrease after first bins.

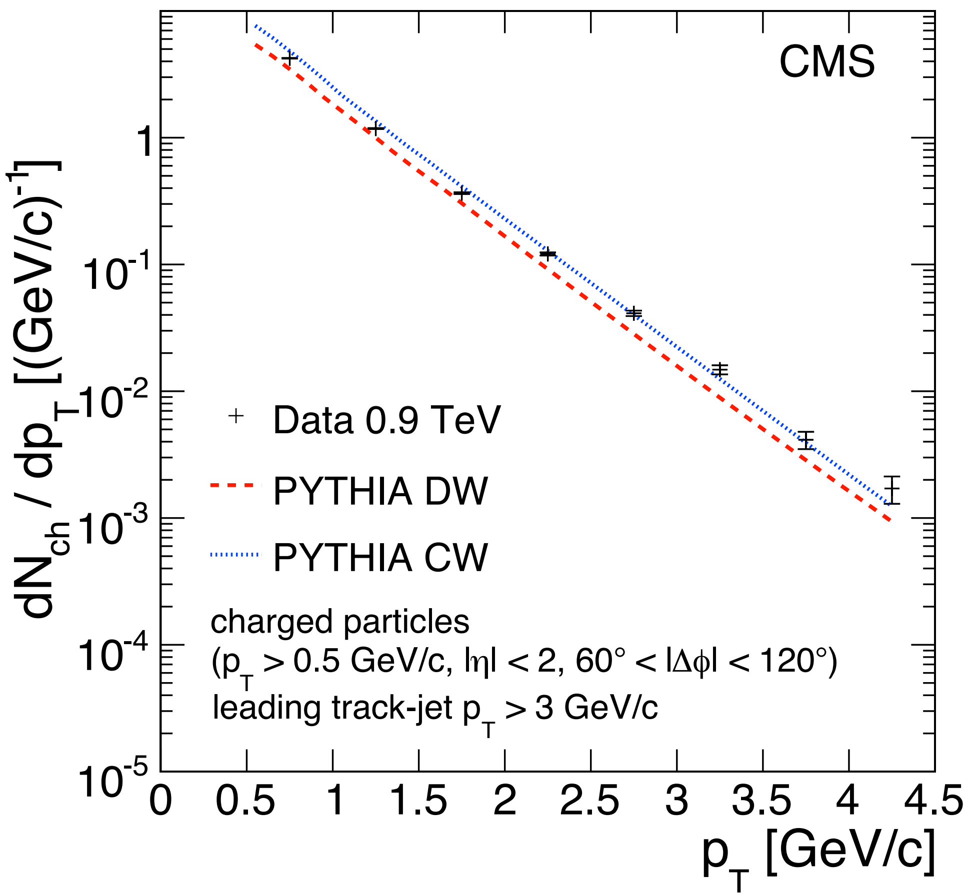
D6T and Pro-Q20 quickly diverge (too many events with low multiplicity).

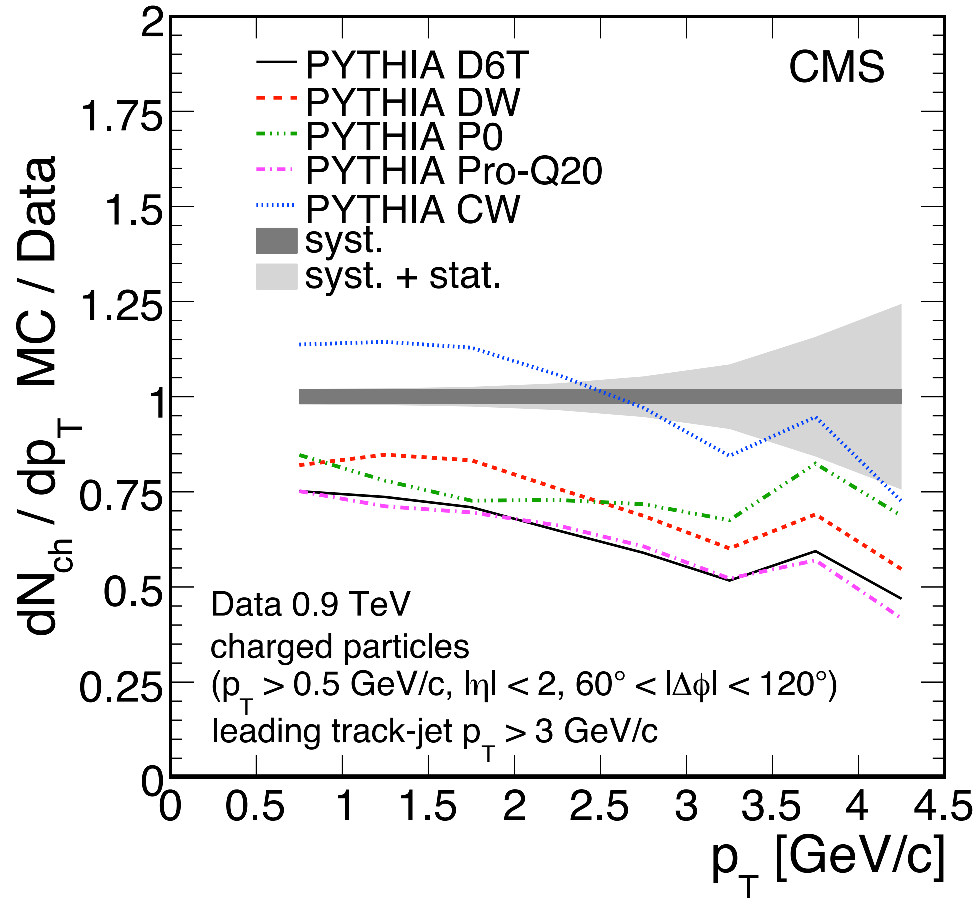
Scalar Σp_T (Transverse Region)





Probability distribution of scalar p_T sum in the transverse region for events with a tracker-jet with p_T>3 GeV/c.
Fluctuations at large Σp_T due to data.





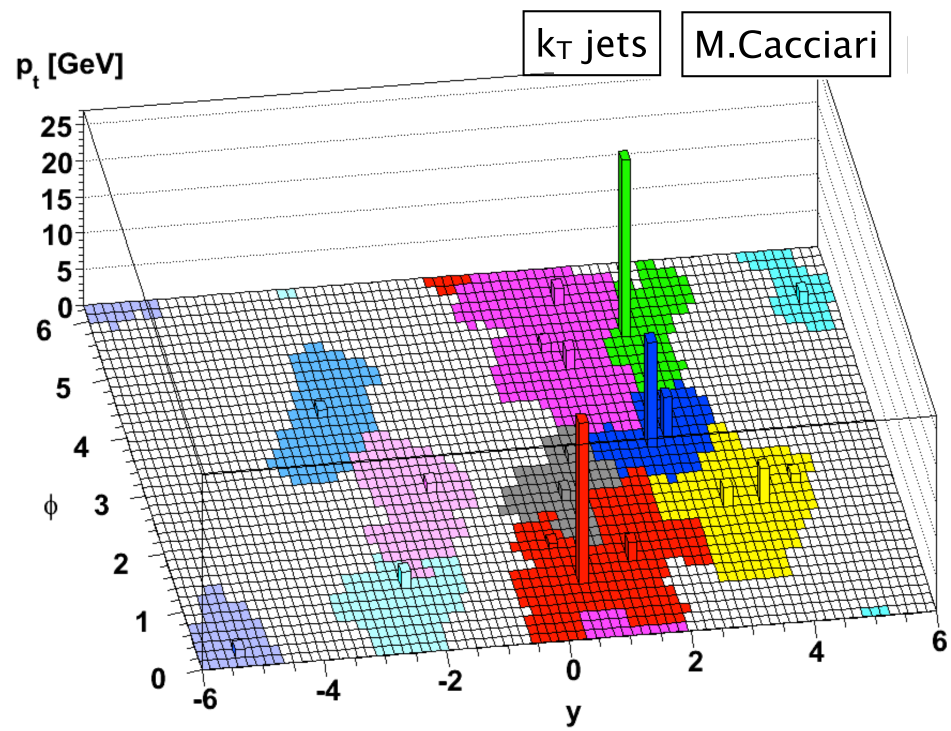
Track p_T distribution in the transverse region for events with a tracker-jet with p_T>3 GeV/c.
Almost exponential spectrum.
P0 is close to data at high p_T and shows a flatter ratio.

Another Approach to UE: Jet Area/Median

- Based on the paper: "On the characterisation of the underlying event"; JHEP04(2010)065; M. Cacciari, G. Salam, S. Sapeta
- Few hard jets have large values of transverse momentum divided by the area, while most of the others have small ratio values.
- The underlying event activity is given by $\rho = \text{median}\{p_T/A\}$
  - the median is less sensitive to outliers, i.e. hard jets
- Track jets using k_T jet algorithm with R=0.6
- Adjusted observable for low occupancy events:

$$\rho' = \underset{j \in \text{physical jets}}{\text{median}} \left[\left\{ \frac{p_{T,j}}{A_j} \right\} \right] * C$$

$$C = \frac{\Sigma_j A_j}{A_{tot}}$$



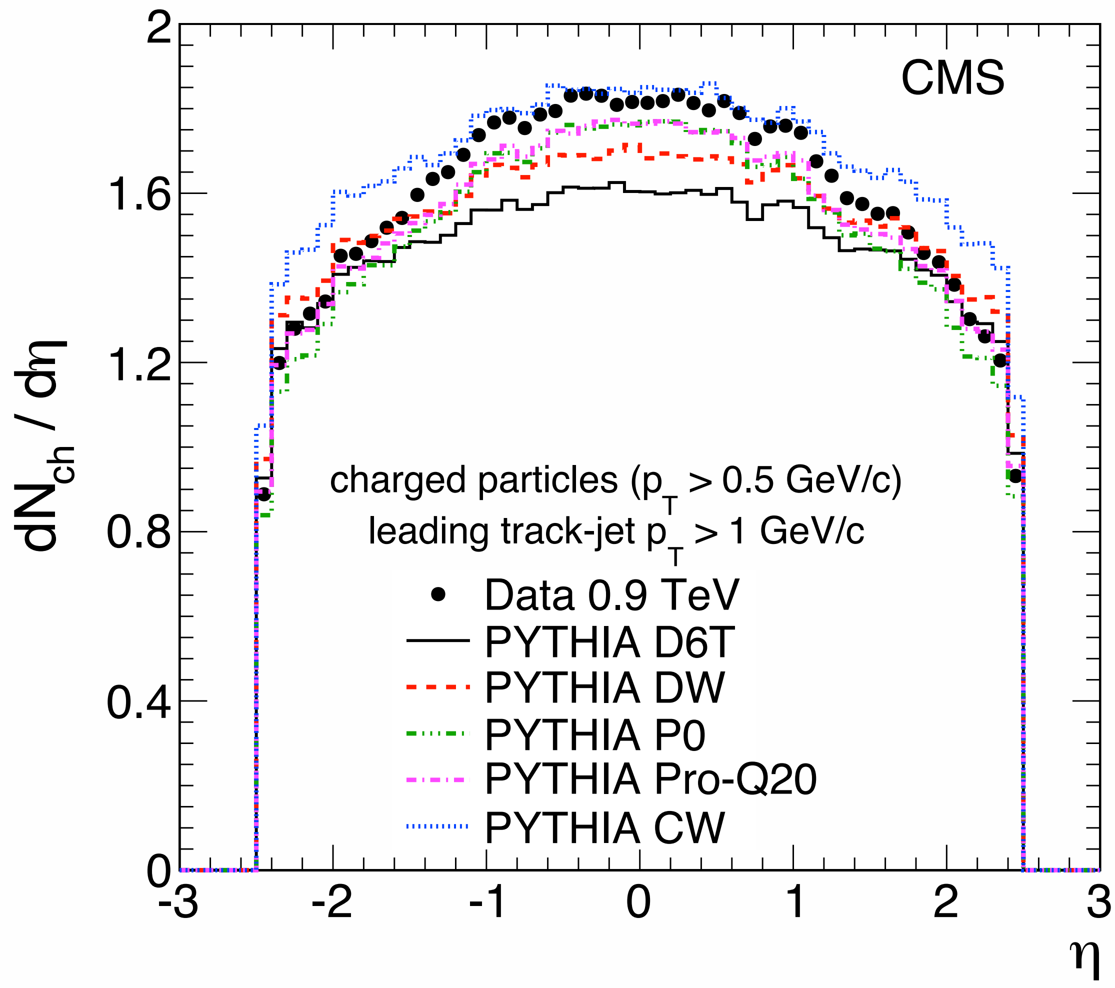
- Similar event and track selection and systematic uncertainty estimation as previous method
- Comparison of data with several PYTHIA tunes
- Results are almost ready...

Conclusions and Outlook

- The first study of hadron production at the LHC with $\sqrt{s} = 900$ GeV at a scale provided by the leading track or the leading tracker-jet has been presented.
- This work is essential for precision measurements of Standard Model processes and for the search for new physics at the LHC!
- The predictions of several PYTHIA tunes, after full detector simulation, have been compared to data with particular interest in the transverse region.
- They describe CMS data within 10 − 15%, but in the transverse region they predict too little hadronic activity (except CW).
- Data favor an energy dependence of the cut-off parameter like DW ($\epsilon = 0.25$) or even stronger ($\epsilon = 0.30$ as CW).
- Lower values are disfavored (i.e. D6T $\epsilon = 0.16$).
- Interesting features are shown by the P0 tune.
- Just submitted for publication: arXiv:1006.2083v1.
- More results are coming: new tunes, generator-level results both at 0.9 and 7 TeV.
- A new approach for complementary results has been developed.

Backup

- Lower interaction scale w.r.t. slide 7
- The charge density is significantly lower



Toward, Away and Transverse Regions/2

- Lower interaction scale w.r.t. slide 8
- P0 shows a worse agreement with data in the toward region
- CW shows a better agreement in the Transverse region