Study of the underlying event with the CMS detector at the LHC

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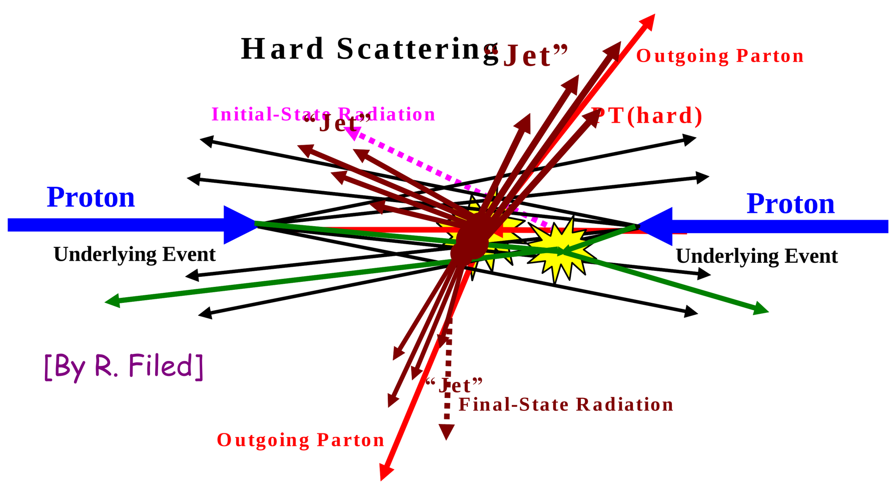
On behalf of the CMS Collaboration

Introduction

In a proton-proton hard process the hadronic final state can be described as the superposition of different contributions:



- -production of the partonic hard scattering
- -initial and final state radiation
- -"beam-beam remnants" (BBR) resulting from the hadronization of the partonic constituents that did not participate in other scatters
- -hadrons produced in additional multiple parton interaction (MPI).

MPI and BBR form the "**Underlying Event**", which cannot be uniquely separated from initial and final state radiation.

The goal is to understand the UE kinematics and dynamics (the energy dependence evolution).

A good description of UE properties is needed for a proper final state modelling and hence for any precision SM measurement and new physics search.

The UE observables have been measured for integrated luminosity of 1 nb^{-1} at 7 TeV.

Monte Carlo description

We present 0.9 and 7 TeV data in comparison with different MC predictions after full detector simulation (different PYTHIA 6 tunes and PYTHIA 8)

To regularize the formal divergence of the leading order partonic scattering PYTHIA introduces a p_T cut-off parameters (p^4_T):

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

p^2_{T0} is parameterized as:

$p^2_{T0}(\sqrt{s}) = p^2_{T0}(\sqrt{s_0})\,(\sqrt{s}/\sqrt{s_0})^{\varepsilon}$

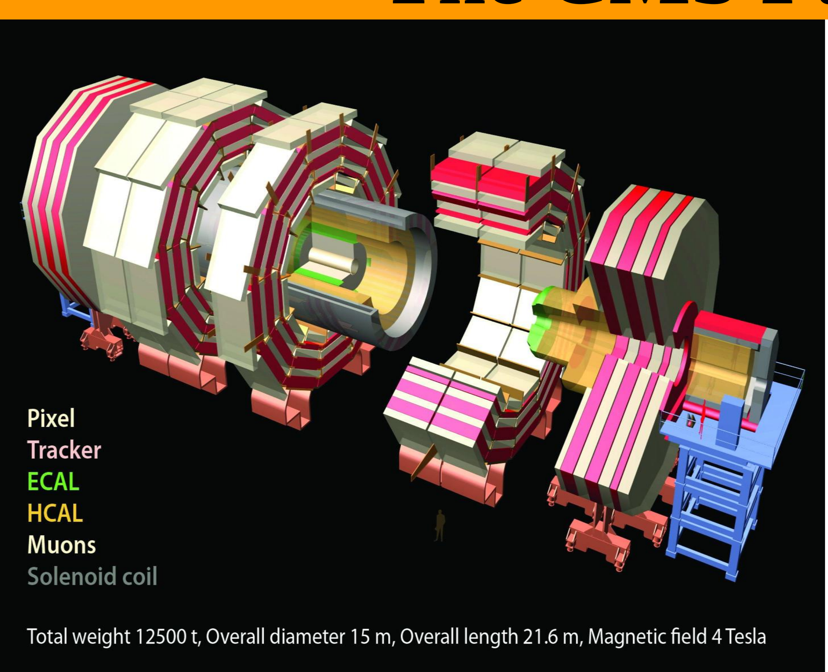
where $\sqrt{s_0}$ is the reference energy (1.8 TeV) at which p^2_{T0} is determined and ε is a parameter describing of the energy dependence.

PYTHIA 6 tunes are all compatible with data taken at CDF.

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 Δφ
P0	2 GeV/c	0.26	Professor fit program using LEP data for fragmentation+ new PYTHIA MPI model + pT-ordered shower
CW	1.8 GeV/c	0.3	Maximizes MPI at 900 GeV, still compatible with Tevatron

Reference: CDF Collaboration, "The underlying event in hard interaction at the Tevatron p - antip collisions at 1.8 TeV", **Phys. Rev D65 (2002) 092002**. doi:10.1103/PhysRevD.65.092002

The CMS Full Silicon Tracker



The Compact Muon Solenoid is a general purpose detector designed to study proton proton and ion-ion collisions at the LHC.

The Silicon Tracker, inside the 3.8 Tesla superconducting solenoid, is designed for the best reconstruction of charged particles (momentum, position and decay vertices)

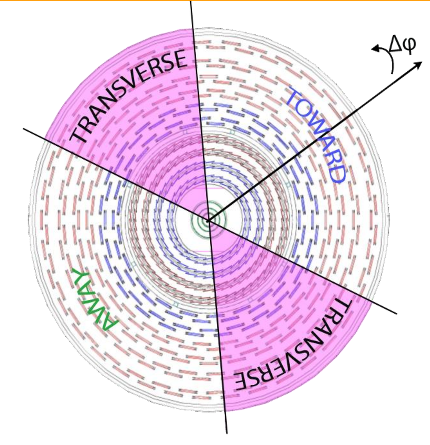
The CMS Tracker is made of a Silicon Pixel vertex detector and a Silicon Microstrip Tracker

- (100 x 150) μm² pixel, the resolution is 10 (rφ) x 20 (z) μm²
- 81 – 172 μm pich in microstrip sensors, the resolution change from 25 μm to 140 μm

Track momentum resolution is: $\sigma(p_T)/p_T \sim 2\%$ for track with $|\eta| < 1.4$

Reference: CMS Collaboration, "Tracking and Vertexing Results from First Collisions", **CMS PAS TRK-10-001 (2010)**

Analysis strategy



Reconstructed tracks are used as input for a SISCone clustering algorithm, forming track-jets. The leading track-jet provides an energy scale and defines a direction in the φ plane.

The azimuthal distance between track and leading track-jet direction define 3 regions (same size):

Toward	$|\Delta\phi| < 60^0$
Away	$|\Delta\phi| > 120^0$
Transverse	$60^0 < |\Delta\phi| < 120^0$

Main observables are:

$d^2N_{ch}/d\eta d(\Delta\phi)$ charged multiplicity

$d^2\Sigma p_T/d\eta d(\Delta\phi)$ energy density

UE contribution is maximized in the transverse region.

Event and Track Selection

Event Selection:

- -Beam Scintillator Counter (BSC) (L1)
- -Good primary vertex
- -presence of leading track-jet (offline)

Event Sel.	DATA	MC (D6T)
7TeV	36.8%	28.4%
0.9TeV	16.1%	15.9%

Track Selection:

- -Kinematics cuts $p_T > 0.5$ GeV/c, $|\eta| < 2$
- -Association of tracks to primary vertex
- -Good quality tracks (relative p_T error < 5 %)

Track Sel.	DATA	MC (D6T)
7TeV	97.2%	97.0%
0.9TeV	97.2%	96.9%

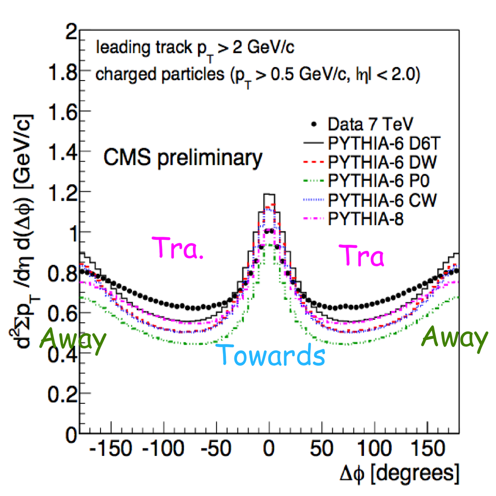
Systematic uncertainties

Several sources of systematic uncertainties have been considered:

- -Track Selection (evaluated by applying different cuts)
- -Contribution from misalignment, beam spot position, dead channels map and material budget background contamination from secondaries and photon conversion
- -Trigger uncertainty (complementary strategy)

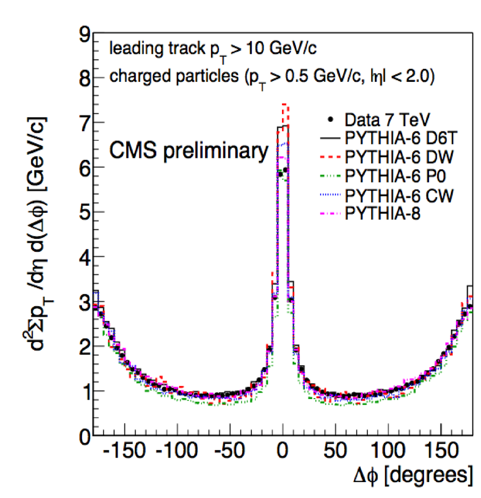
		Er.Total
$d^2N_{ch}/d\eta d(\Delta\phi)$	(pT=20 GeV/c)	1.8%
$d^2\Sigma p_T/d\eta d(\Delta\phi)$	(pT=20 GeV/c)	2.0%
dN_{ev}/dN_{ch}	(N_{ch}=4)	1.0%
$dN_{ev}/d\Sigma p_T$	(Σp_T=4.5GeV/c)	1.3%
dN_{ch}/dp_T	(p_T=1 GeV/c)	2.3%

Results



Average scalar sum of transverse momentum of charge particles versus the azimuthal angle difference |Δφ| relative to the leading track.

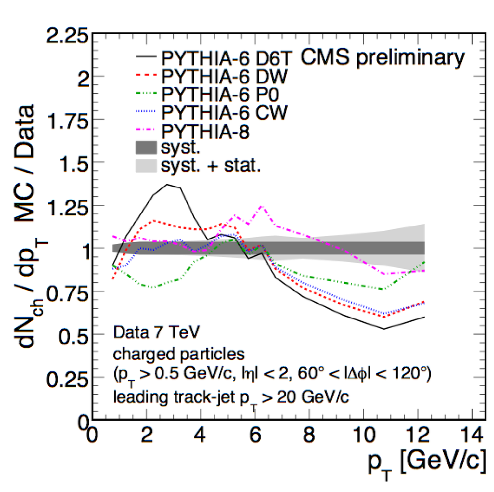
For lower scale p_T > 2 GeV/c in towards region PYTHIA8 describes the data better, in away region all predictions are essentially below the data. In transverse region the prediction of all tunes are significantly below the data.

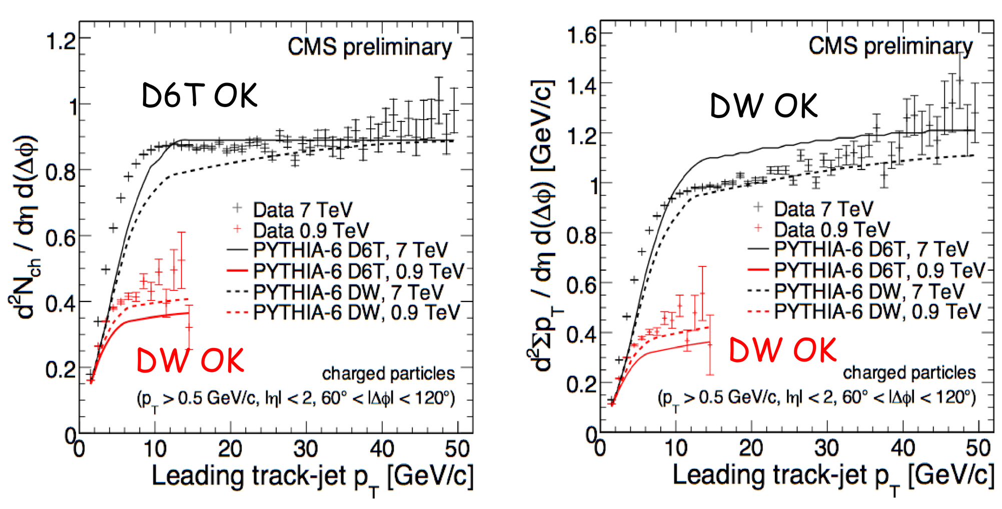


For high scale p_T >10 GeV/c the predictions of the models are above the data for |Δφ| close to zero, except for P0, which thus provides the best description of the fragmentation at high z.

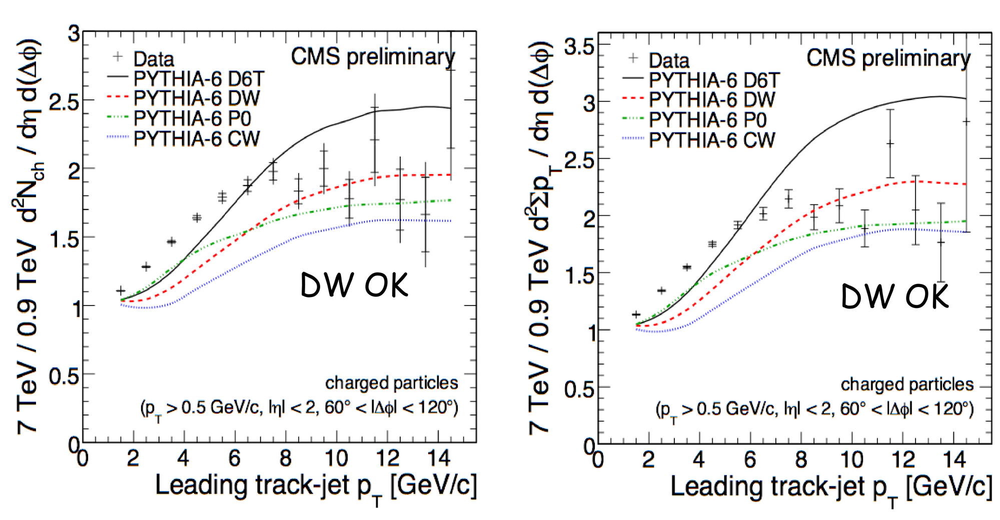
For this scale, all tunes provide a good description of the away and transverse region, expect for P0, which is 10% below the data.

Ratios MC/DATA of various tunes of p_T spectra at 7TeV. Models have been compared to the data in the transverse region for event selection with low (p_T > 3 GeV/c) and high scale (p_T> 20 GeV/c). For high scale the agreement from MC tunes and data is better.



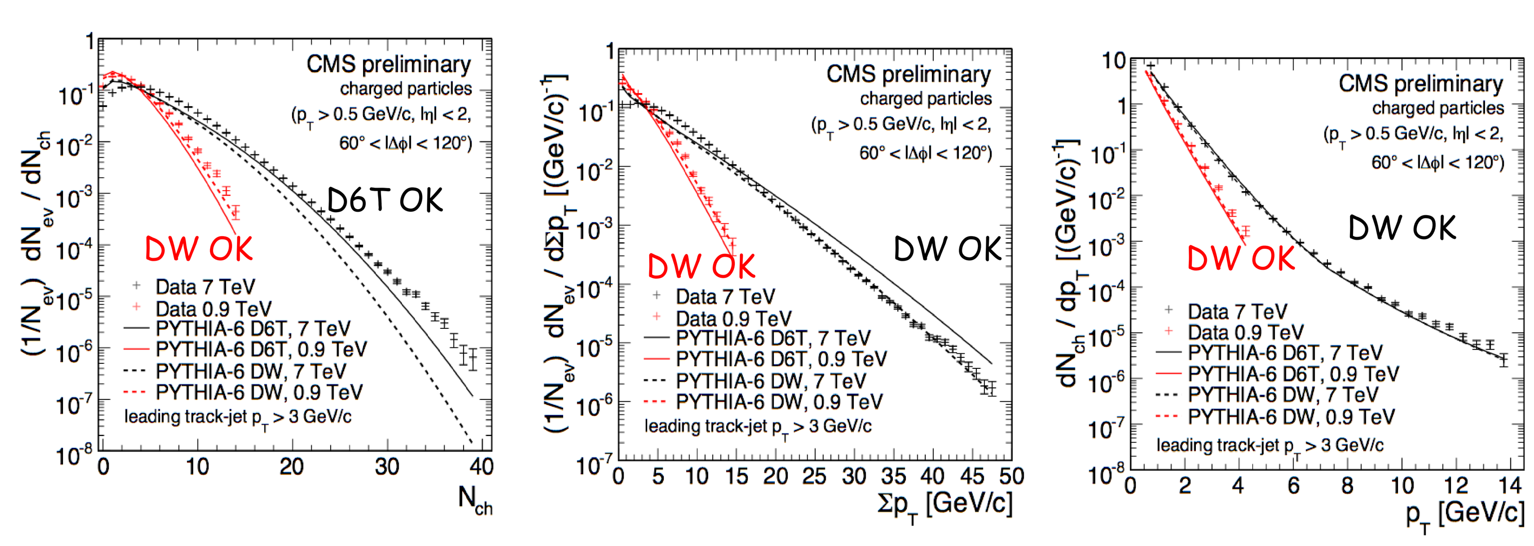


Average multiplicity (left) and average Σp_T (right) versus the p_T of the leading track jet, the inner error bars indicate the statistical uncertainties, the outer error bars the statistical and systematic uncertainties added in quadrature. A factor of two increase of the underlying events is observed at 7 TeV with respect to 900 GeV.
D6T and DW are taken here as representatives of slow and fast energy dependence of the p_T-cutoff.



Ratio UE observable between 7 and 0.9 TeV.
All tunes predicts ratios that are below the data up p_T ~ 6-8 GeV/c, for large values of the scale, the agreement in the ratio is improved.
The best predictions, for both observables, are provided by the DW, whereas the predictions of D6T lie much above the data.

Normalized multiplicity distribution, normalized average Σp_T and p_T spectra



The best predictions are provided by DW (D6T behaving better just for charged multiplicity at 7 TeV)

Conclusions:

Two components are visible for both UE observables : a fast rise for p_T < 8 GeV/c at 7 TeV and for p_T < 4 GeV/c at 0.9 TeV, attributed mainly to the increase of MPI activity, followed by a plateau-like region with nearly constant average number of selected particles and slow increase of Σp_T.
The strong growth of UE activity with √s is also striking in the comparison of the normalized distribution of charge particle multiplicity and of scalar Σp_T as well as in p_T spectra.
The present study, with a comparison of data taken at 0.9 and 7 TeV, favour a relatively strong √s dependence of p_T-cutoff, as in tune DW, compared to a lower value as in tune D6T.

References:
[1] CMS Collaboration, "The underlying event in proton proton collision at 900 GeV" **CERN-PH-EP/2010-014**
[2] CMS Collaboration, "Measurement of the Underlying Event Activity at the LHC with √s =7 TeV and comparison with √s = 0.9 TeV " **CMS-PAS-QCD-10-010 (2010)**

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