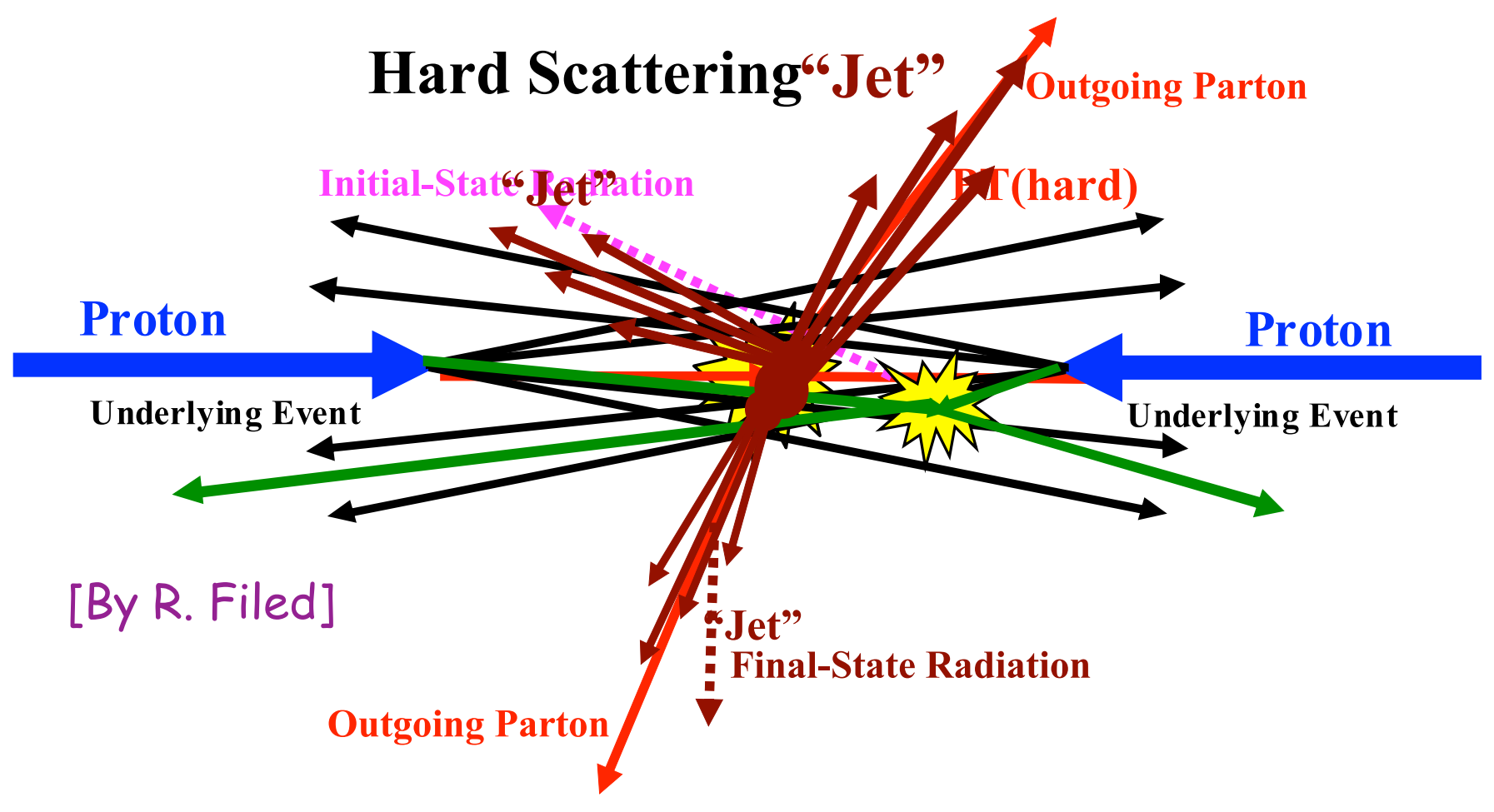
# Measurement of the Underlying Event Activity at the LHC with √s = 7 TeV and Comparison with √s = 0.9 TeV

Andrea Lucaroni INFN Perugia, CERN
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 contribution:



-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**" (UE), 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.

## Monte Carlo description

We present **0.9 and 7 TeV** data, the distribution are fully corrected for detector effects.

To regularize the formal divergence of the leading orden parton 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.

**Pythia 6.420**

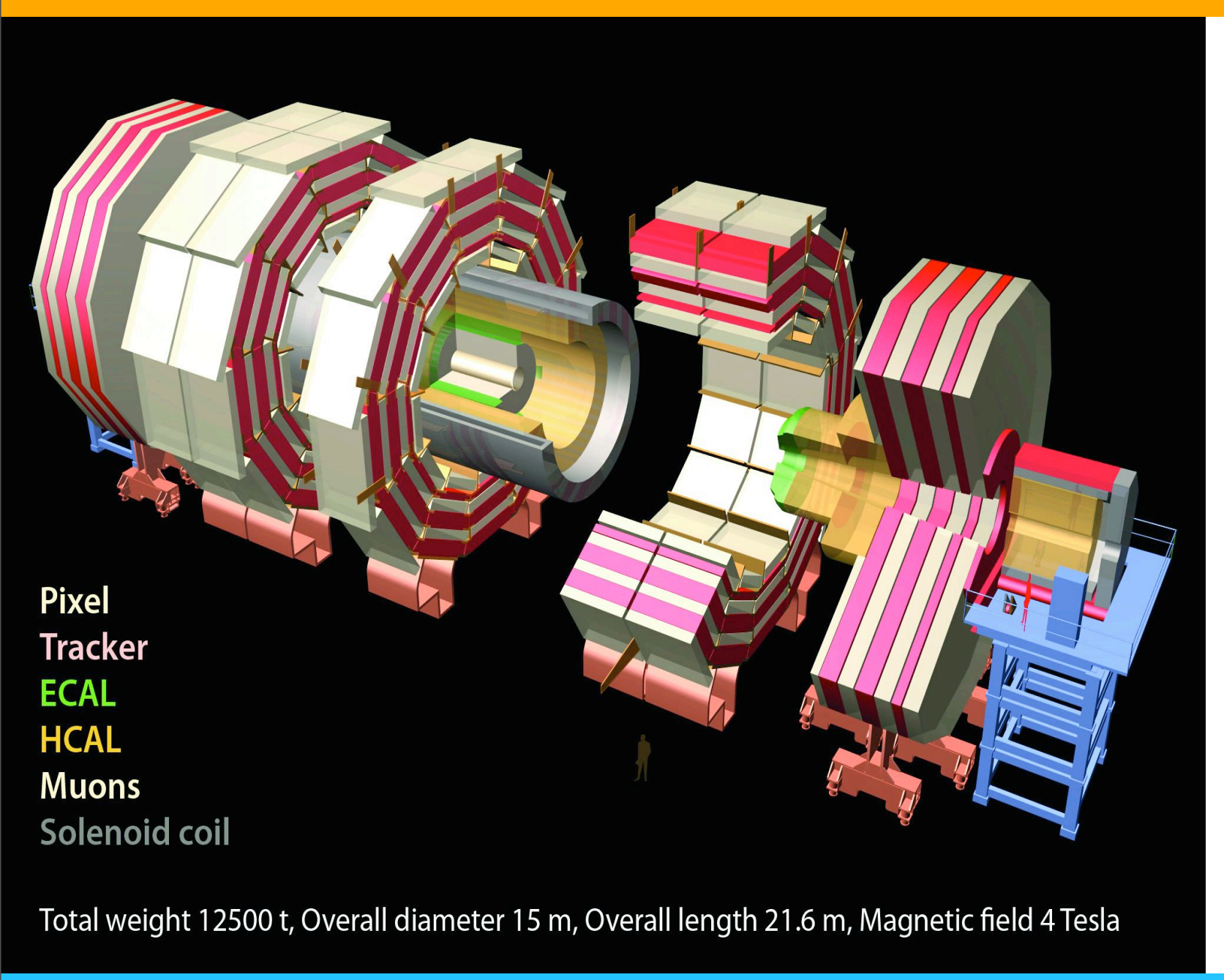
| Tune | $p_{T0}$ | ε | notes/other features |
|---|---|---|---|
| Z2 | 1,8 GeV/c | 0,27 | Tool using LHC data, new PYTHIA MPI model and CTEQ6L |
| Z1 | 1,9 GeV/c | 0,27 | Tool using LHC data, new PYTHIA MPI model and CTEQ5L |
| D6T | 1,8 GeV/c | 0,16 | Energy dependence from UA5 at SppS. Uses CTEQ6L, tune pre LHC |

**Pythia 8.145**

| Tune | $p_{T0}$ | ε | notes/other features |
|---|---|---|---|
| C4 | 2.0 GeV/c | 0,20 | Tool using LHC data, new PYTHIA MPI model with rescatering and CTEQ6L1 |

Reference: R. Corke and T Sjostrand, "Interleaved Parton Showers and Tuning Prospects", arXiv:1011.1759v1, 2010

## 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 4 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

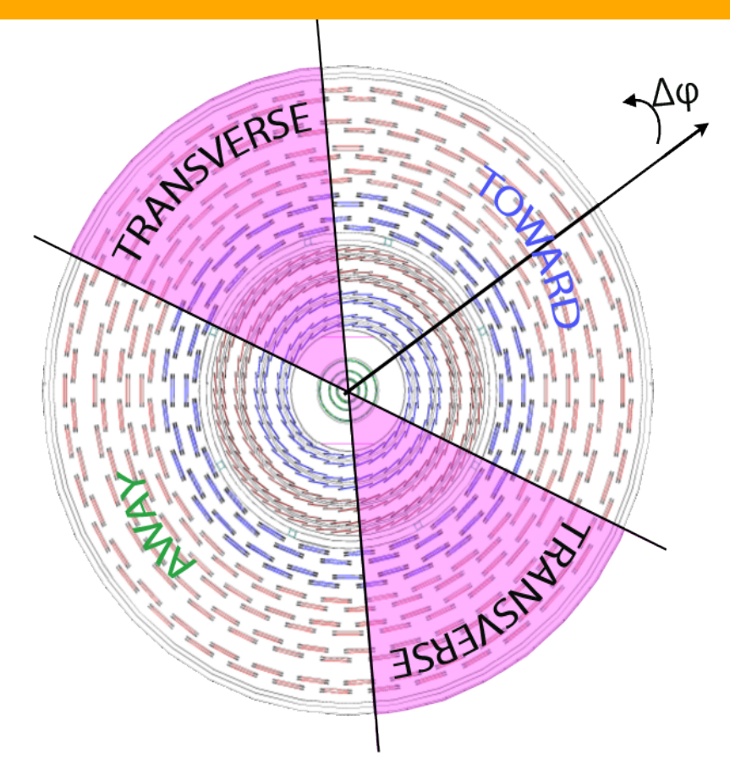
- (100 x 150) μm² pixel, the resolution is 10 (rφ)x20 (z) μm
- 320 – 500 μm thick microstrip sensors, the resolution change from 25 μm to 140 μm

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

$d^2\Sigma pT/d\eta d(\Delta\phi)$ 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)

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 %)

Corrected for detector :

The distribution present are corrected, unfolding the detector effect

| N. Events | 1 GeV/c | 3 GeV/c | 20 GeV/c |
|---|---|---|---|
| 7TeV (x10³) | 18x10³ | 6x10³ | 19 |
| 0.9TeV (x10³) | 5x10² | 783 | 5.8 |

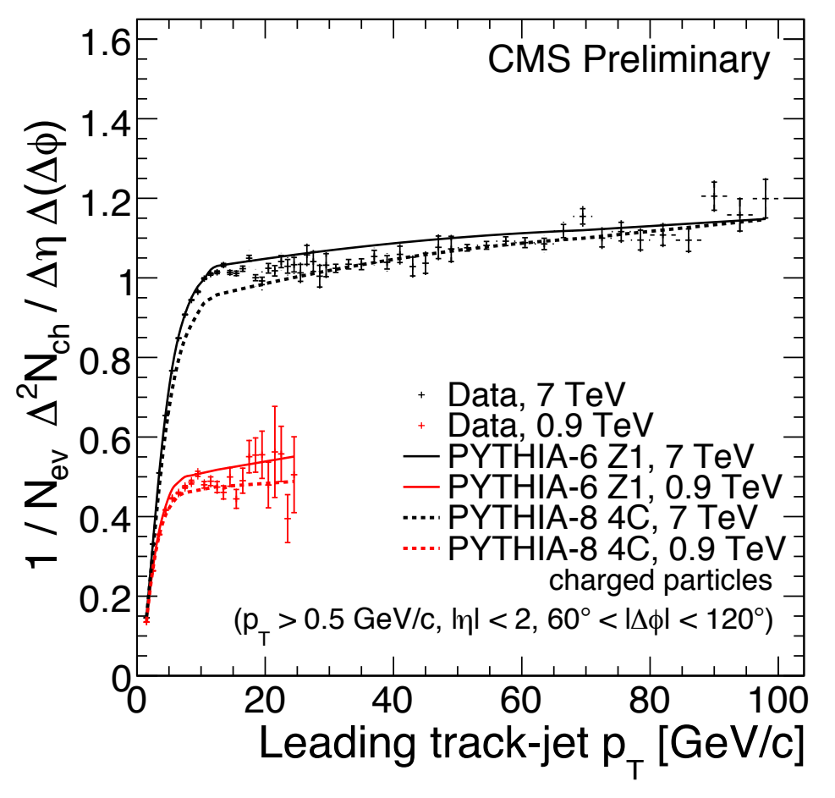
## Systematic uncertainties

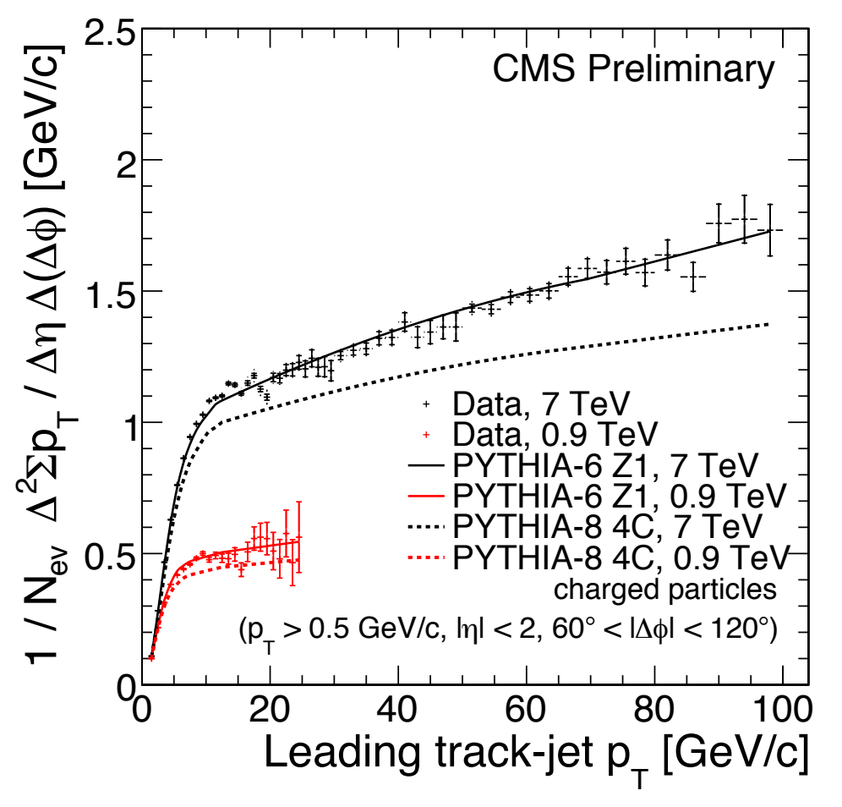
Several sources of systematic uncertainties have been considered:

-Track Selection (evaluated by applying different cuts)
-Contribution from misalignment, beam spot position, dead channels map and material budget
- Correction different model
- Trigger uncertainty (complementary strategy)

| 7 TeV | | Er.Total |
|---|---|---|
| $d^2N_{ch}/d\eta d(\Delta\phi)$ | ($p_T$=20 GeV/c) | 1.5% |
| $d^2\Sigma p_T/d\eta d(\Delta\phi)$ | ($p_T$=20 GeV/c) | 1.6% |
| $dN_{ev}/dN_{ch}$ | (4 $p_T$ > 3 GeV/c) | 2.5% |
| $dN_{ev}/d\Sigma p_T$ | ($\Sigma p_T$=4.6GeV/c) | 3.2% |
| $p_T$ | ($p_T$=1 GeV/c) | 2.6% |

## Results

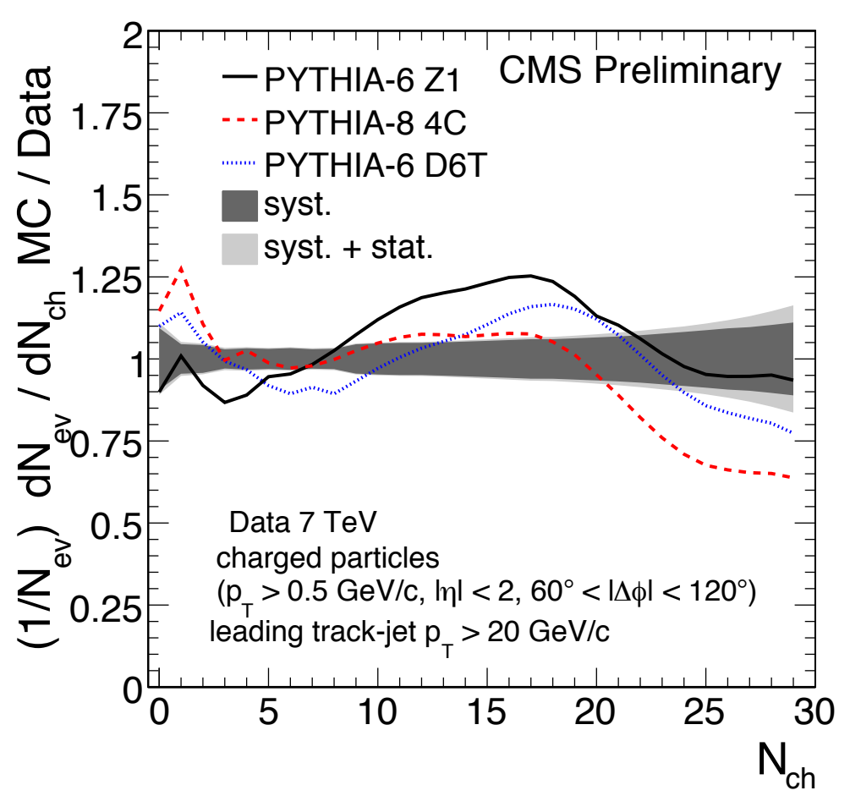


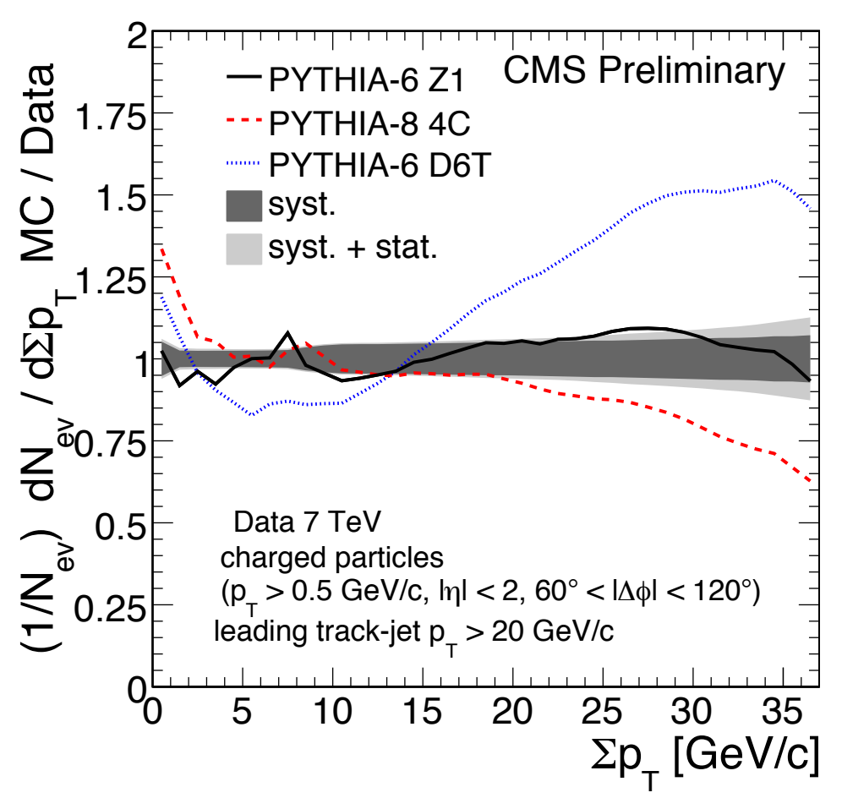


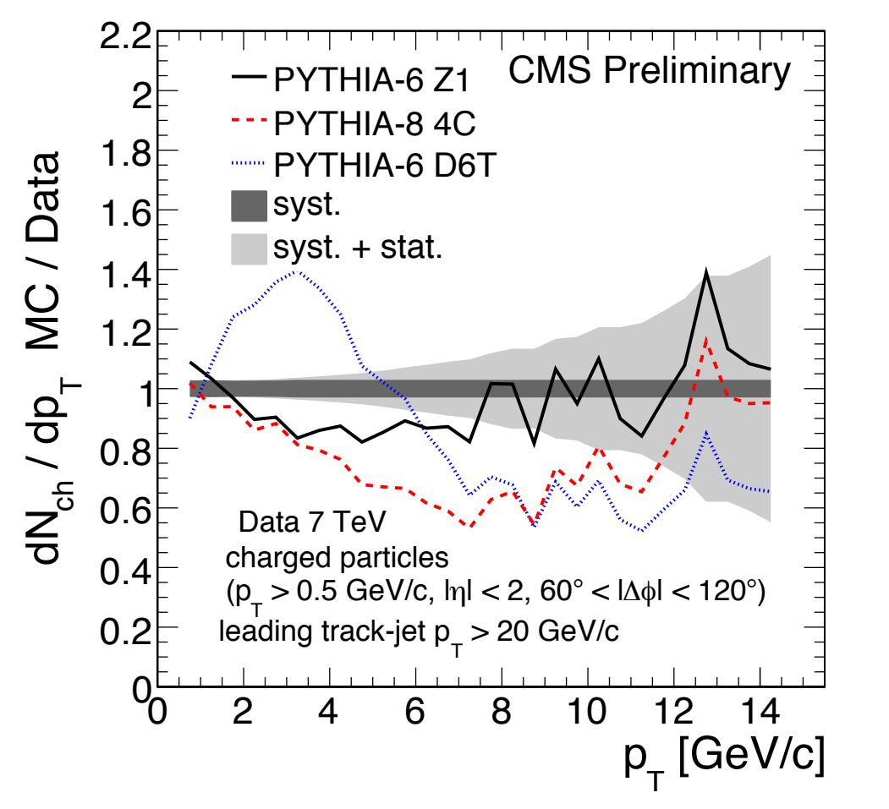
The inner error bars indicate the statistical uncertainties affecting the outer error bars represent the statistical and systematic uncertainties added in quadrature; statistical errors dominate at large values of the observables.

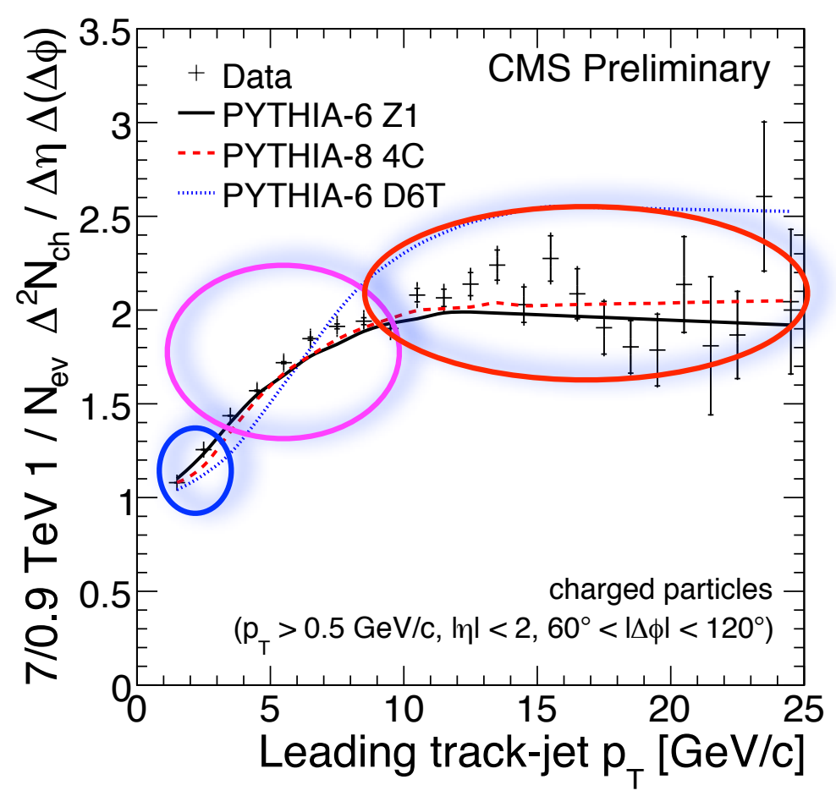
Very good description of the most distribution at √s = 7 and 0.9 TeV is provided by the Tune Z1

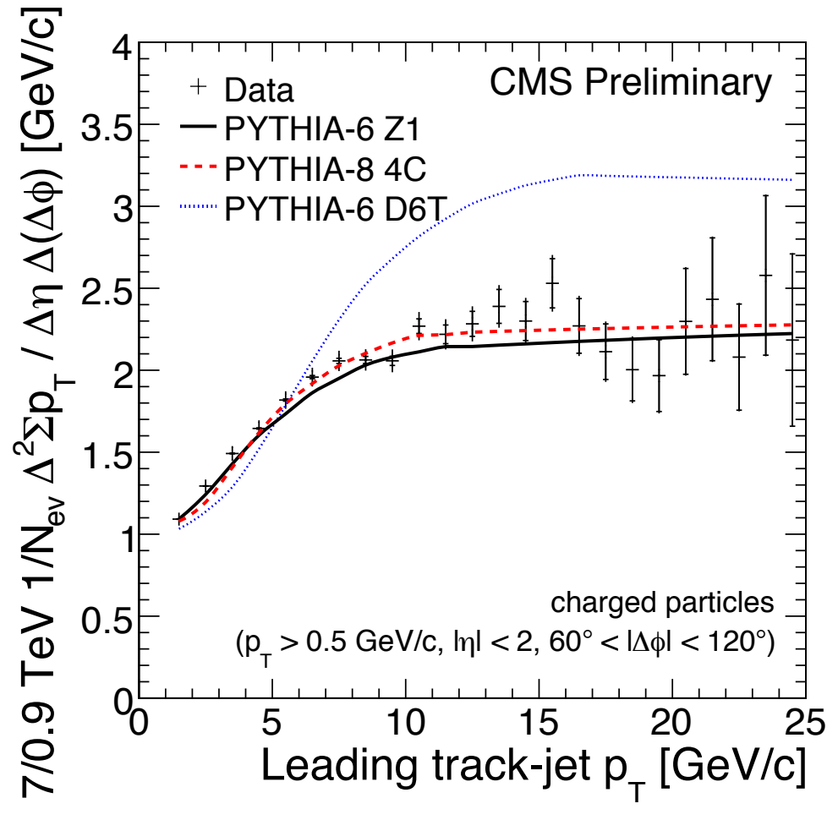
Ratio MC/DATA of normalized multiplicity distribution, normalized average $\Sigma p_T$ and $p_T$ spectra







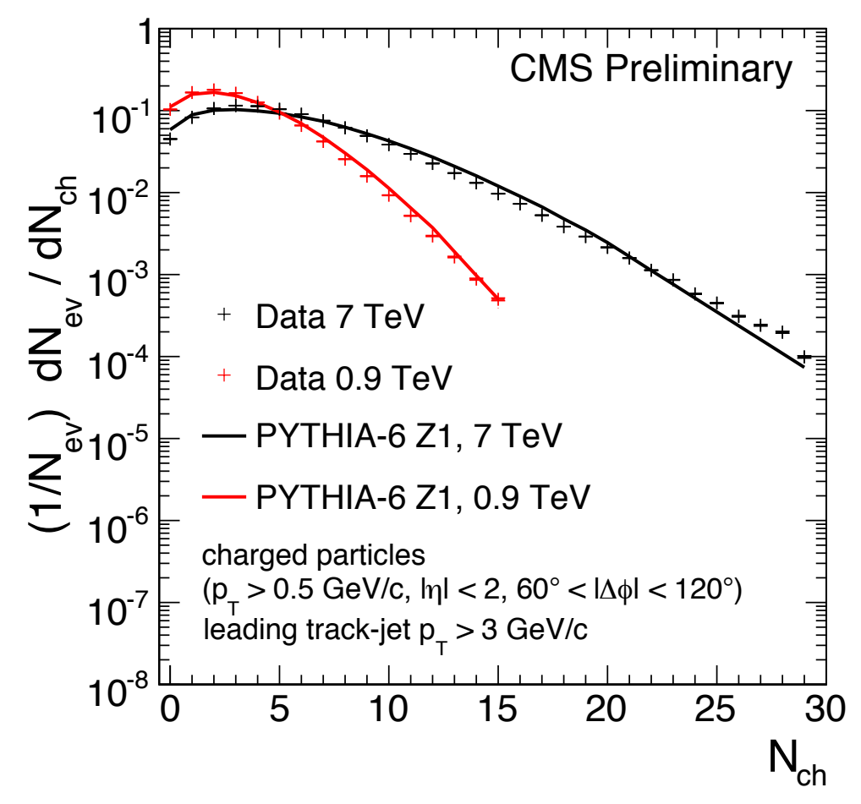


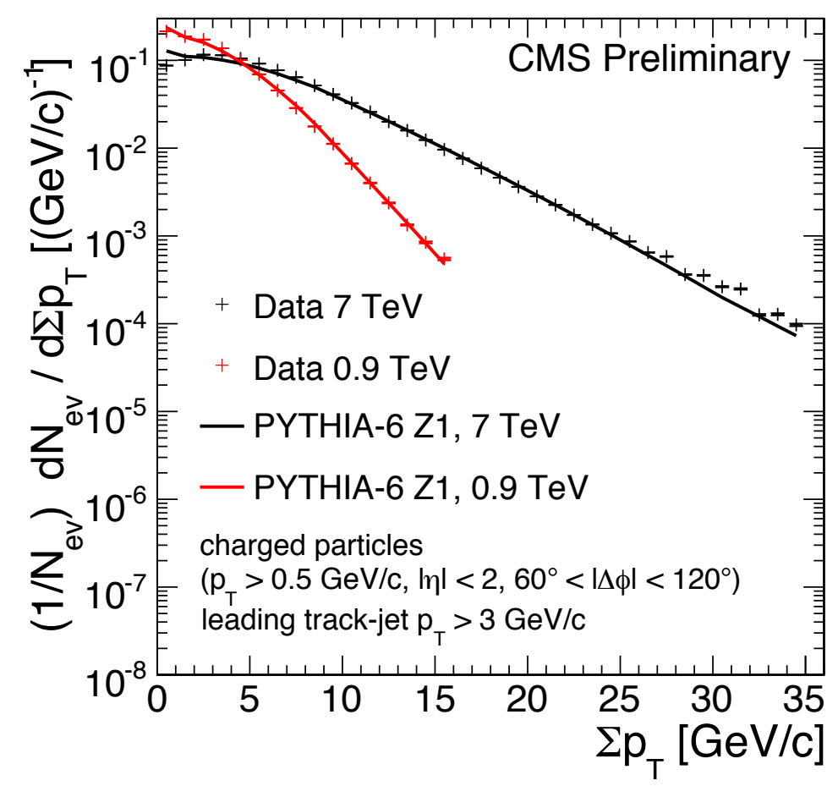


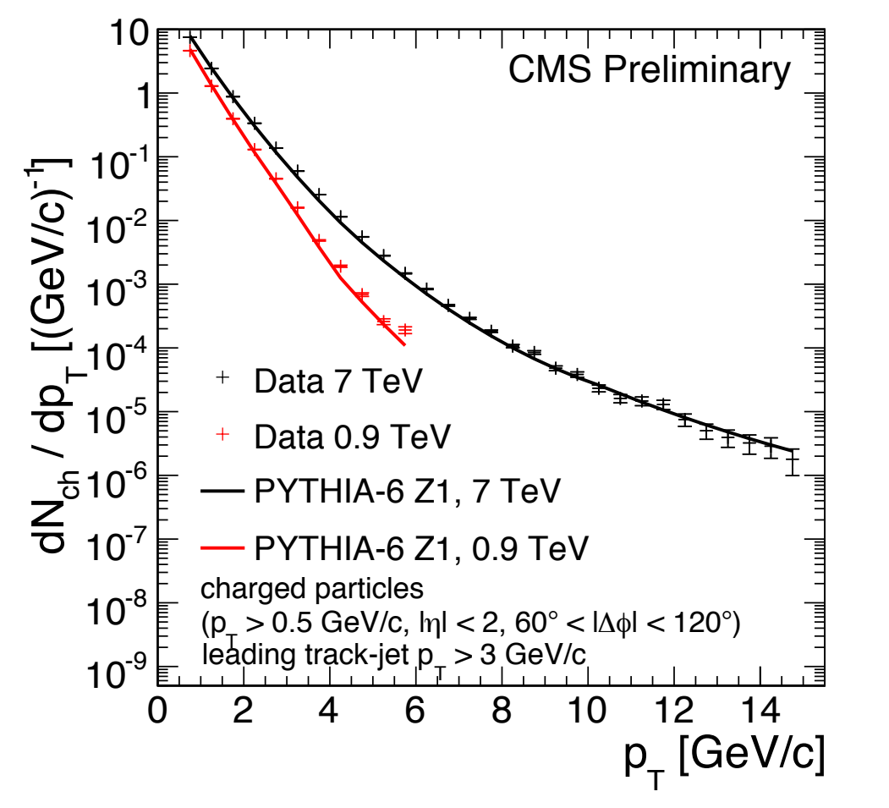
soft
peripheral collision independent ~ √s
semi-soft
mix central and peripheral collision
hard
mainly central collision, hight parton density regions for the two √s domains

The distributions are overall rather well described by the selected MC models over several orders of magnitude, in presence of a hard scale (a leading track-jet with $p_T$ > 20 GeV/c), the Z1 and 4C tunes describe the data remarkably well in view of the steeply falling character of the distribution. The distributions within 10-15% over most of the domain, except for 4C for small Nch (Nch < 5) and $\Sigma p_T$. Data description by D6T is worse.

Normalized multiplicity distribution, normalized average $\Sigma p_T$ and $p_T$ spectra







An increase of the scale implies an increasing contribution of central interactions, the central region with higher parton density and larger MPI probability is wider at larger √s. The evolution of the UE activity at 7 TeV and 0.9 TeV is remarkably well described by the tune Z1.

Conclusion:

Two components are visible for both UE observables : a fast rise for $p_T$< 8 GeV/c at 7TeV 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 $\Sigma p_T$.

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 $\Sigma p_T$ as well as in $p_T$ spectra.

**The prediction of the new tunes Z1 and 4C have been compared to the measurements. The models differ in the PDF description, in the implementation of radiation and multiple parton interaction, in particular in the √s dependence. Tunes adopting CTEQ6L may need a smoother increase of the $p_T$-cut-off with increasing energy with respect CTEQ5L.**
**The good descriptions of most distribution both energies is provided by the tune Z1.**

References:

[1] CMS Collaboration, "The underlying event in proton proton collision at 900 GeV" **EPJC Volume 70, Issue 3 (2010), Page 555**
[2] CMS Collaboration, "Measurement of the Underlying Event Activity at the LHC with √s =7 TeV and comparison with √s = 0.9 TeV " **CMS-QCD-10-010 (2011)**

Andrea.Lucaroni@cern.ch