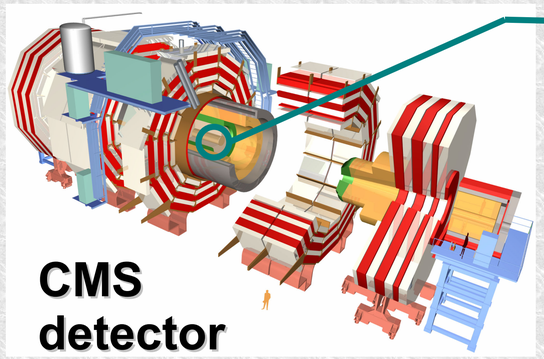
Soft QCD Results from CMS

Yuan CHAO* for the CMS Collaboration

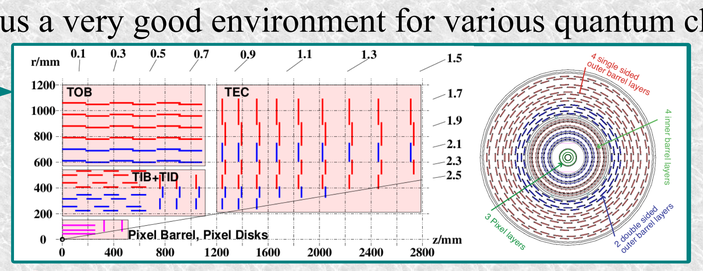
* National Taiwan University, R.O.C.

Introduction

The frontier energy scale of LHC and the general purpose CMS detector provide us a very good environment for various quantum chromodynamics (QCD) studies.

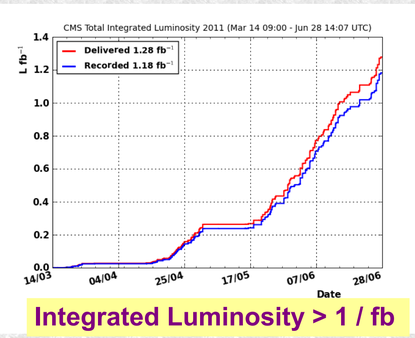


- General purpose detector
- Dimension: 15x15x21.6 m; Weight: 12.5 kT
- Tracker & Calorimeter inside S.C. Solenoid
- Optimized for p^T and Energy measurement
- Muon system sandwiched in return york
- First muon system outside solenoid
- Big lever arm for p^T measurement



CMS Tracker

- Under 3.8 Tesla magnetic field
- Pure solid state tracking system
- p^T resolution: 0.7 % at $\eta = 0$; 2.0 % at $|\eta| = 2.5$



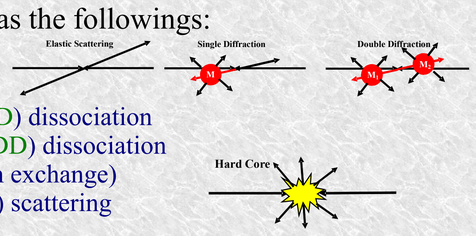
Integrated Luminosity > 1 / fb

Basic Low pT QCD measurements

Charged Hadron Measurements

Soft collision defined as the followings:

- Elastic scattering
- Inelastic scattering
  - Single-diffractive (SD) dissociation
  - Double-diffractive (DD) dissociation (inc. double-pomeron exchange)
  - Non-diffractive (ND) scattering

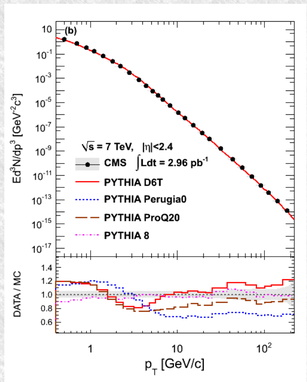


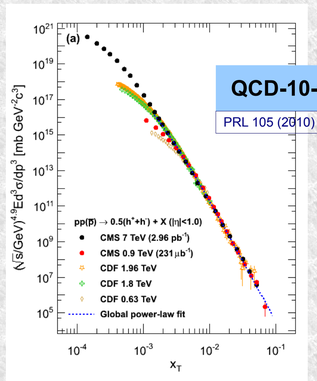
The studies focus on the non-single diffractive (NSD) interactions, which based on triggered events retaining large fraction of ND and DD, disfavoring SD.

Charged particles defined as:

- Decay products of particles with proper lifetime < 1cm
- Production of secondary interactions excluded
- Correction applied for prompt leptons

p^T distribution of charged hadrons





QCD-10-008
PRL 105 (2010) 022002

$$E\frac{d^3\sigma}{dp^3} = F(x_T)/P_{p_T}^{n(x_T,\sqrt{s})} = F'(x_T)/\sqrt{s}^{\,n(x_T,\sqrt{s})}$$

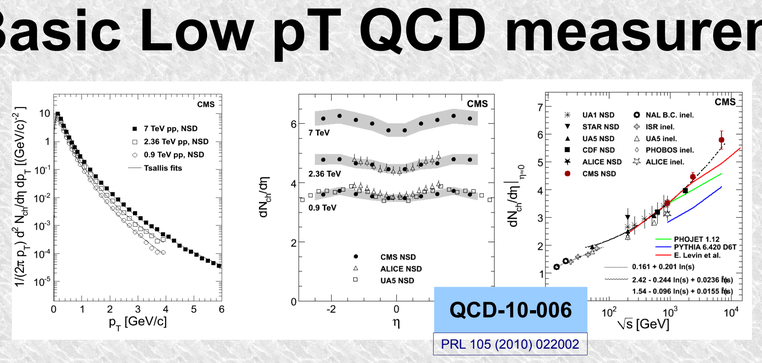
- Most compatible with PYTHIA 8 while PYTHIA 6 is worse
- Empirical $x_T = 2\,p_T / \sqrt{s}$ match differential cross sec. at high x_T

η distribution of charged hadrons

The $dN_{ch}/d\eta$ distributions obtained with 3 methods:

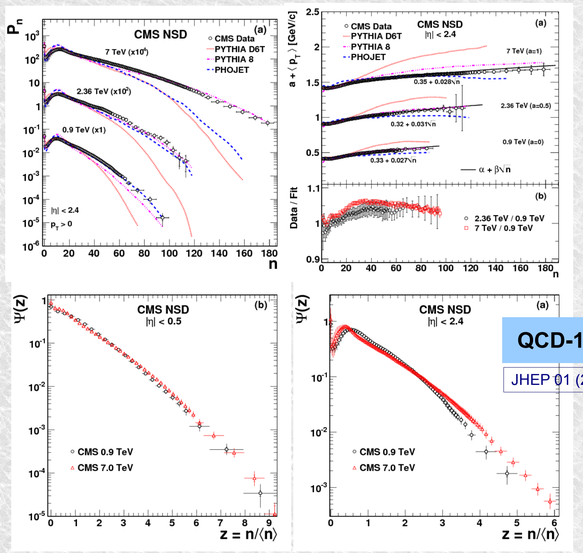
- Reconstructed clusters in barrel pixel (p_T^{MIN} = 30 MeV)
- Tracklets in two barrel pixel layers (p_T^{MIN} = 50 MeV)
- Tracks reconstructed in full tracker (p_T^{MIN} = 100 MeV)

CMS measurements in agreement with other experiments.
However densities are higher than most models and pre-LHC MC at high energy.



QCD-10-006
PRL 105 (2010) 022002

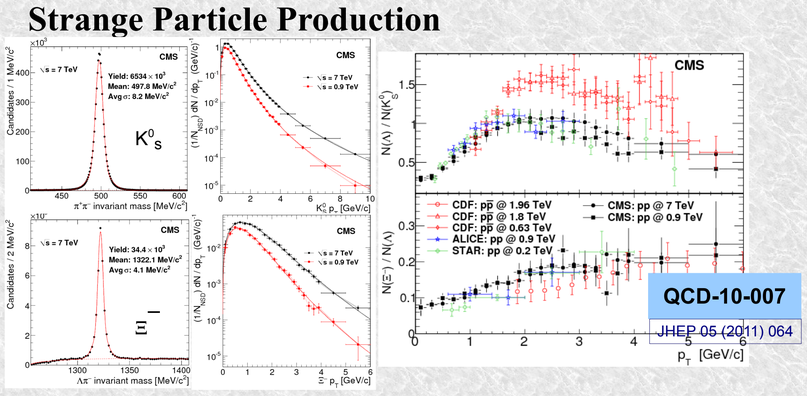
Charged multiplicity N_{ch}



QCD-10-004
JHEP 01 (2011) 079

KNO scaling violation for $|\eta| < 2.4$
-> connected to the presents of multiple parton interaction

Strange Particle Production

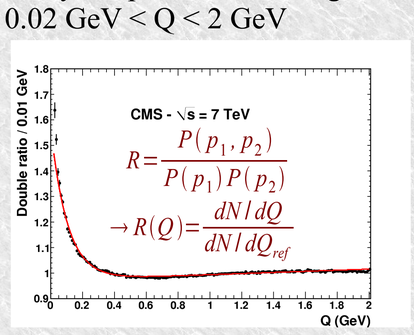


QCD-10-007
JHEP 05 (2011) 064

The production ratios $N(\Lambda)/N(K^0s)$ and $N(\Xi^-)/N(\Lambda)$ stays approximately constant to centre-of-mass energy.

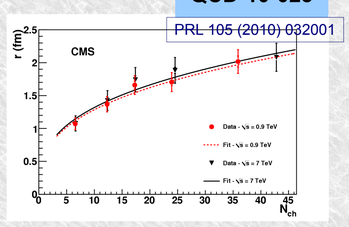
Bose-Einstein Correlation

Study on pairs of same-signed charged particle with $0.02\ \text{GeV} < Q < 2\ \text{GeV}$



$$R = \frac{P(p_1,p_2)}{P(p_1)P(p_2)} \rightarrow R(Q) = \frac{dN/dQ}{dN/dQ_{ref}}$$

QCD-10-023
PRL 105 (2010) 032001



√s	0.9 TeV	7 TeV
r (fm)	1.56 ± 0.02 ± 0.15	1.89 ± 0.02 ± 0.21
λ	0.616 ± 0.011 ± 0.029	0.618 ± 0.009 ± 0.042

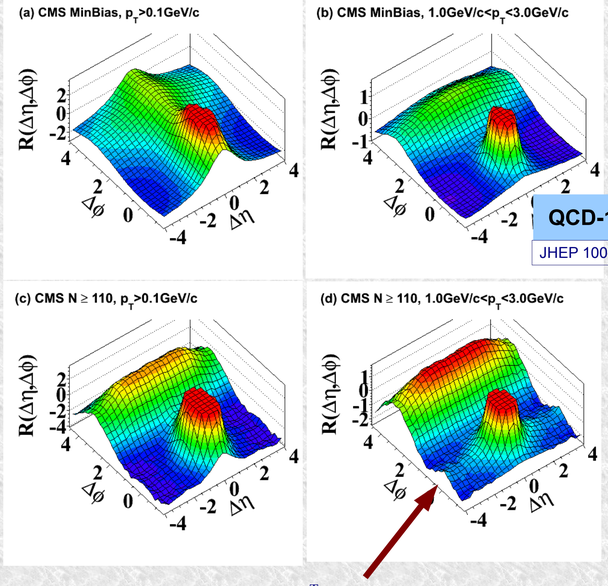
$$R(Q) = C[1 + \lambda\Omega(Qr)](1 + \delta Q)$$

$\Omega(Qr)$: Fourier transform of emission region of effective size r
λ : BEC strength δ : Long distance correlations

- BEC effective emission region grows with √s while strength is similar
- BEC effective emission region grows with N_{ch}, as observed by previous experiments

Near-side Long-range Correlation in pp data

First surprise in LHC data



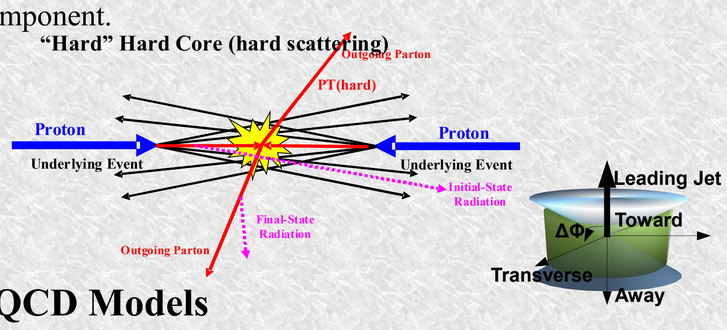
QCD-10-002
JHEP 1009 (2010) 091

Ridge most evident for 2 GeV < p^Ttrig < 6 GeV, but disappeared at high p^T

Underlying Events Measurements

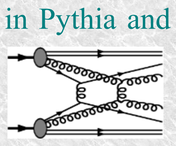
Introduction

The "Underlying Events" (UE) is everything in a single proton-proton interaction except for the hard scattering component.



pQCD Models

- Initial / final state radiation, spectators ... not enough for observed multiplicities & p^T spectra
- Multiple parton interaction (MPI) adopted in Pythia and other general MC generators
- Main parameter: p^T cut-off p^{T0}
  - Cross section regularization for $p^T \rightarrow 0$
  - As inverse effective color screening
  - Control the number of interactions



Pythia Tunes

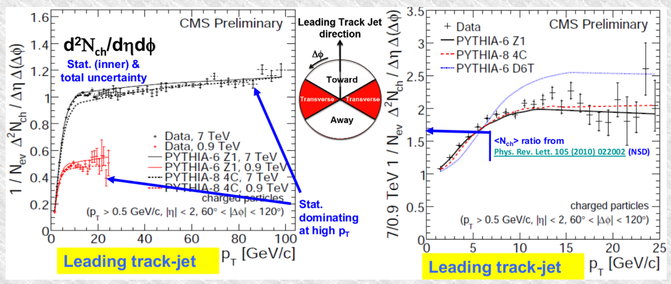
$$\sigma(\widehat{P_T}) \rightarrow \sigma(\widehat{P_T}) \cdot \frac{(\widehat{P_T})^4}{((\widehat{P_{T0}})^2 + (\widehat{P_T})^2)^2}$$

- Virtuality ordered shows, old MPI
  - CTQ5L DW, CTEQ6LL D6
- New MPI with interleaved pT ordered shower
  - CTQ5L Z1, CTEQ6LL Z2
- Pythia 8, new MPI with interleaved pT ordered shower
  - CTQ5L Tune 1, CTEQ6LL Tune 2C, 4C...

Underlying Event Study with Trackjet

Looking at the transverse region of the referencing leading trackjet direction. The UE sensitive observables are checked.

7 TeV and 900 GeV results with Z1 and 4C tune MC



Fast rise attributed for the increase of MPI, followed by a plateau-like region.

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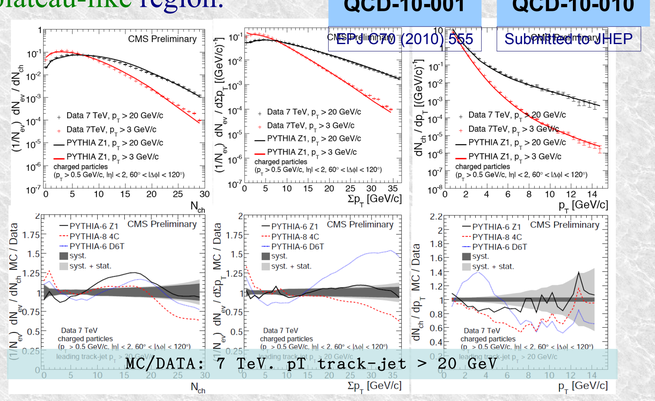
EPJ C70 (2010) 555

QCD-10-010
Submitted to JHEP



Unfolded results compared with MC of various tunes

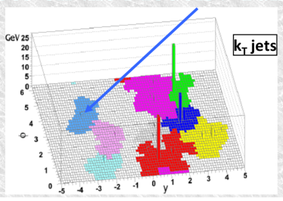
UE Study with Jet Area

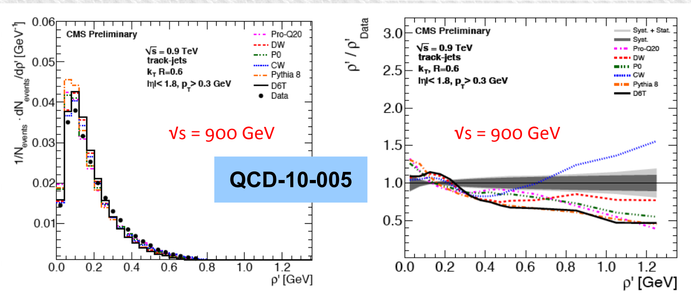
Event & Track Selection identical to the traditional UE measurement at 900 GeV

Clear sensitivity to the differences on the Models / Tunes

$$\rho' = \underset{j \in \text{physical jets}}{\text{median}} \left[\left\{ \frac{p_{Tj}}{A_j} \right\} \right] \cdot C$$

$$C = \frac{\sum_{j \in \text{physical jets}} A_j}{A_{tot}}$$





QCD-10-005

Conclusion

- Various soft QCD analysis performed at 0.9, 2.36, 7 TeV
- Charged hadron distribution from NSD studied. KNO scaling violation observed.
- Two particle correlation measured and can not be reproduced by current MC model.
- BEC observed at 0.9 and 7 TeV.
- UE analyzed at 7 TeV, unfolded results compared with many MC tunes.