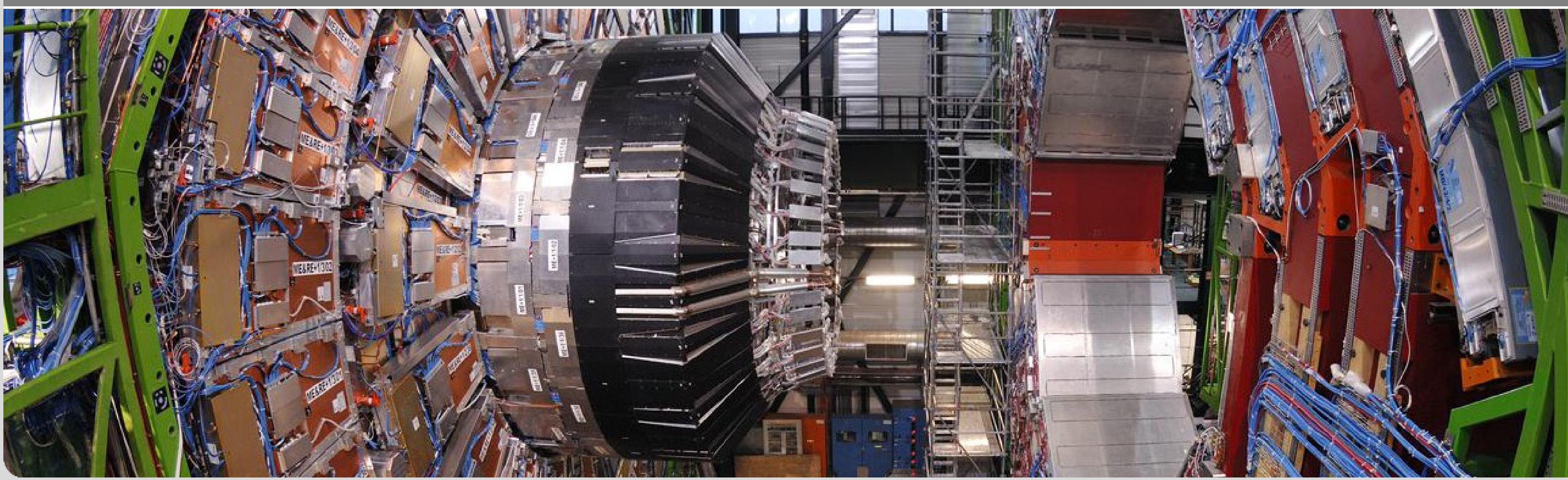
Karlsruhe Institute of Technology

Measurements of Hadron Production and Underlying Event Studies at CMS

XL ISMD
ANTWERP - BELGIUM

Danilo Piparo for the CMS collaboration

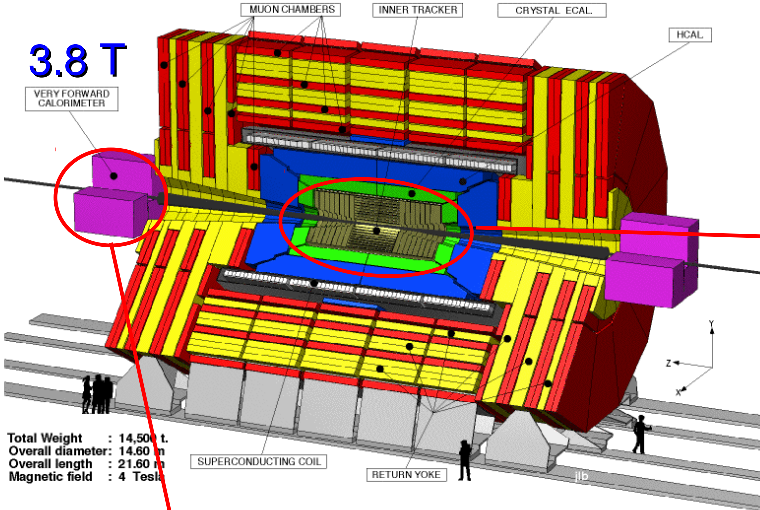
INSTITUTE OF EXPERIMENTAL PARTICLE PHYSICS (EKP) · PHYSICS FACULTY

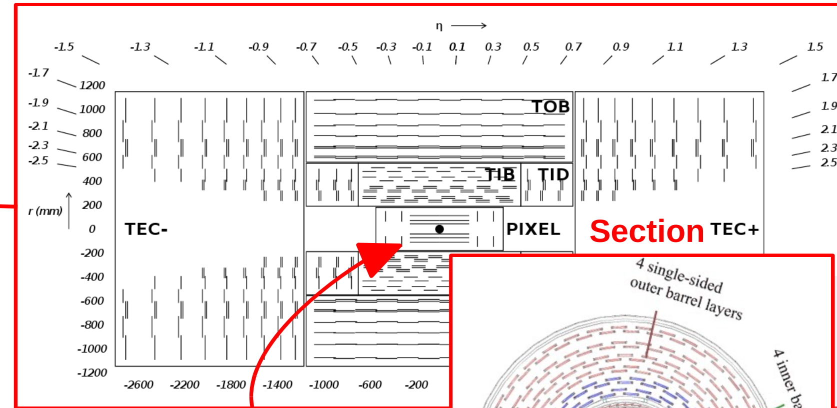


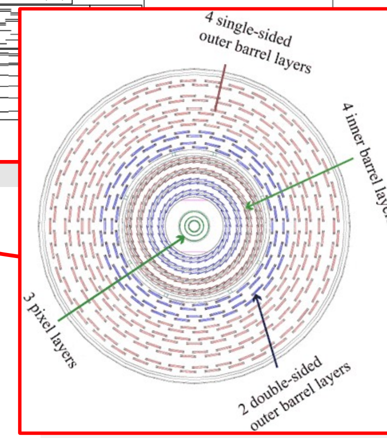
Outline

- Trigger and tracker
- Charged hadrons spectra
  - Strange hadrons
  - Reaching higher p_T using jet triggers
- Underlying event:
  - Traditional approach
  - Jet area/median approach
- Single diffractive peak observation

CMS, the Tracker and the Trigger System



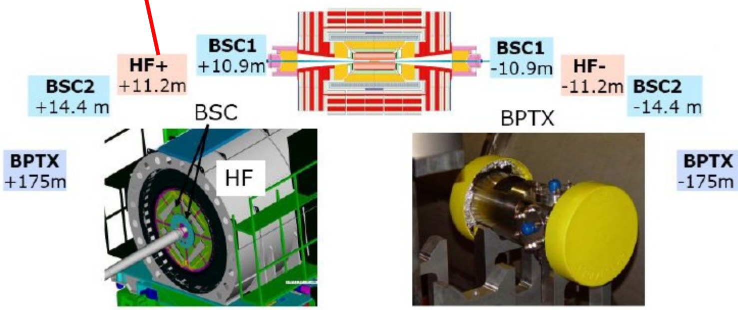




Track P_T resolution

@1 GeV (TRK-10-001):

- |η|~0 → 0.7%
- |η|~2.5 → 2.5%



Beam Scintillator Counters
- ± 10.86m (14.4m) from interaction point
- Hit and coincidence rates (beam-halo rejection)

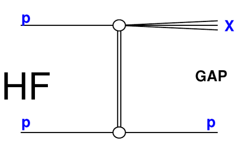
Beam **P**ick-up **T**iming for the e**X**periments
- Bunch structure
- Timing of beam

Time resolution better 2ns!

For MB events

Online L1 requirements:
- Any Hit in BSC *and* Filled bunch seen by BPTX

Offline requirements:
- Single Diffractive Rejection using both HF
- Beam Halo Rejection
- At least one proper vertex identified
- Beam induced background rejection (pixel cluster shapes)



Part One

Charged Hadrons Pseudorapidity distributions

Charged Hadrons Multiplicity distributions

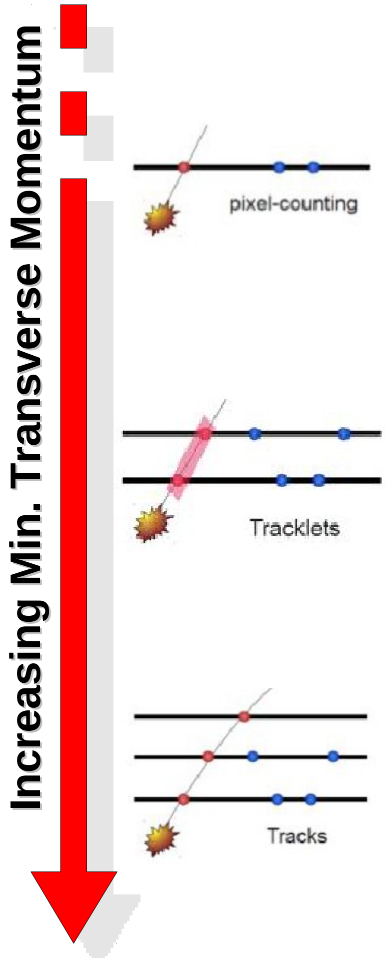
Charged Hadrons Transverse momenum distributions

Monte Carlo Comparison

Tracking Performance

CMS QCD-09-010

- Three methods to reconstruct charged particles
  - Different features, cross-check efficiencies



Pixel Counting
- Number of clusters per layer
- Min P_T = 30 MeV
- Insensitive to alignment
- Sensitive to bkg:
  - Noise + Loopers

Sys: 4.4% (3% from cluster selection)

Tracklets
- 2 out of 3 pixel layers
- Data driven bkg subtraction
- Min P_T = 50 MeV

Sys: 2.9% (1.9% reco efficiency)

Tracks
- Robust (Kalman Filter)
- Low bkg (< 5%)
- Min P_T = 100 MeV
- Efficiency > 70%
- Fakes only at lowest Pt

Sys: 2.4% (2.0% reco efficiency)

Three CM energies
0.9, 2.36, 7 TeV

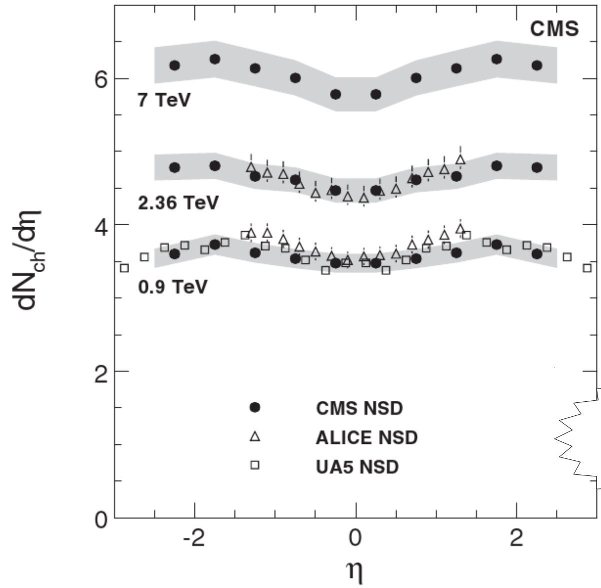
Three methods – consistency at three C.M. energies

Pseudorapidity distributions 2/2

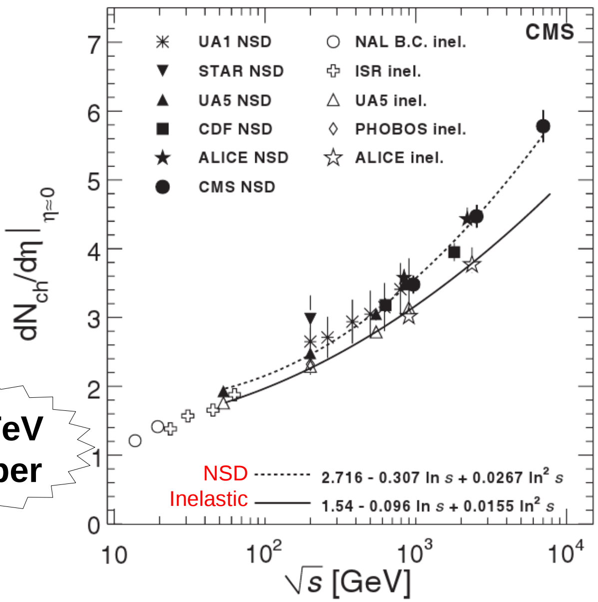
Phys. Rev. Lett. 105, 022002 (2010)

Charged Hadrons

- Average three methods
- Successful comparisons: pp and ppbar measurements and different energies



Early 7 TeV CMS Paper



Average on the 3 methods
UA5 (ppbar): stat error only
ALICE error bars: systematic
Gray band: CMS systematic

Systematic uncertainties when available
pp and ppbar collisions
NSD and inelastic compared

$$dN_{ch}/d\eta_{\eta<0.5} = 5.78 \pm 0.01(stat) \pm 0.23(syst)$$

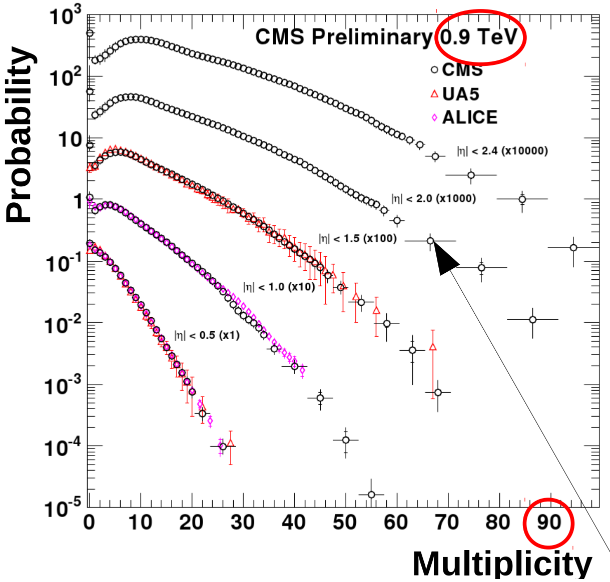
7 TeV

$$dN_{ch}/d\eta \; increase \; 0.9\text{TeV} \rightarrow 7\text{TeV} = [66.1 \pm 1.9(stat) \pm 4.2(syst)]\,\%$$

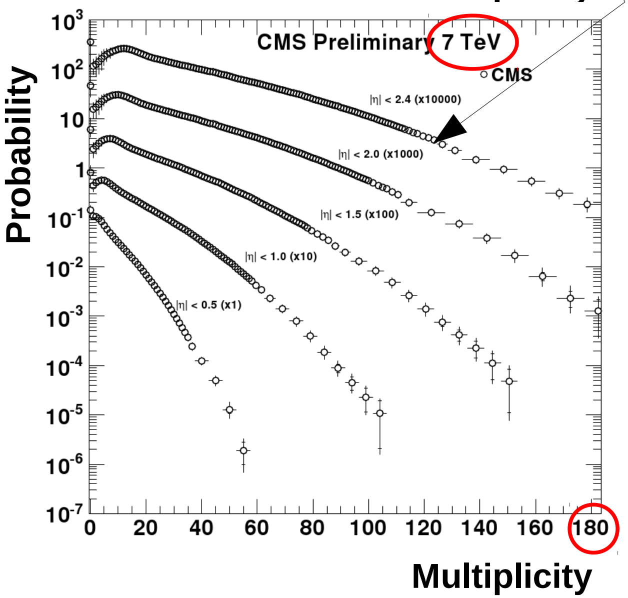
Consistency among experiments and CM energies

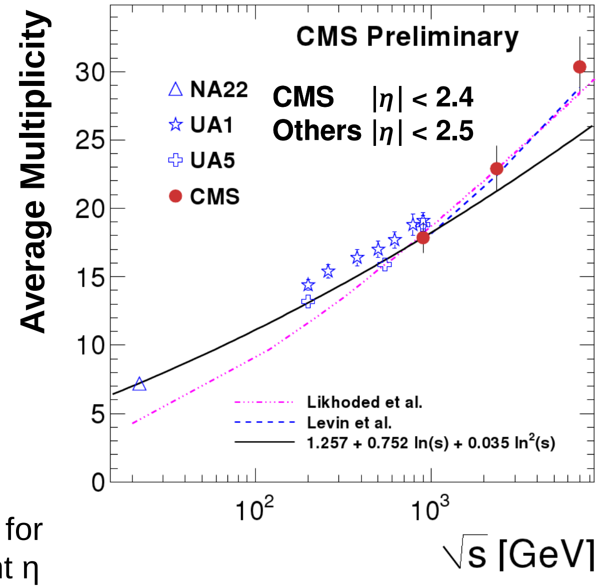
Multiplicity distributions - 1/2

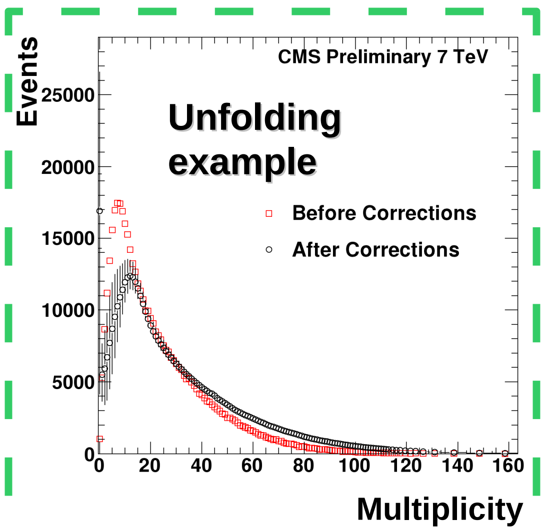
CMS QCD-10-004



Shifted for different η ranges







Charged Hadrons

Bayesian Unfolding Method by D'Agostini

Nucl. Instrum. Meth. A362 (1995) 487-498

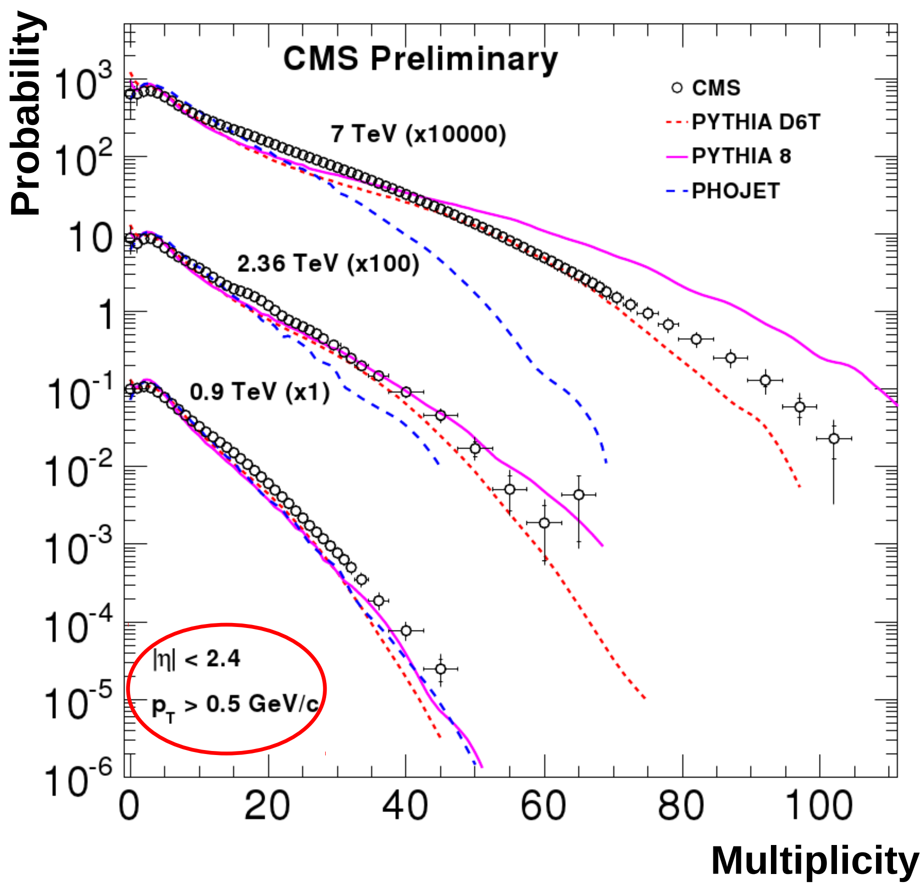
- All spectra unfolded
- Bayesian Unfolding
- Extrapolated to P_T>0
- Crosscheck with
  - Tracklets
  - B=0T data

- Multiplicity spectra measured at different energies
- Agreement with other measurements

Multiplicity distributions - 2/2

CMS QCD-10-004

Charged Hadrons



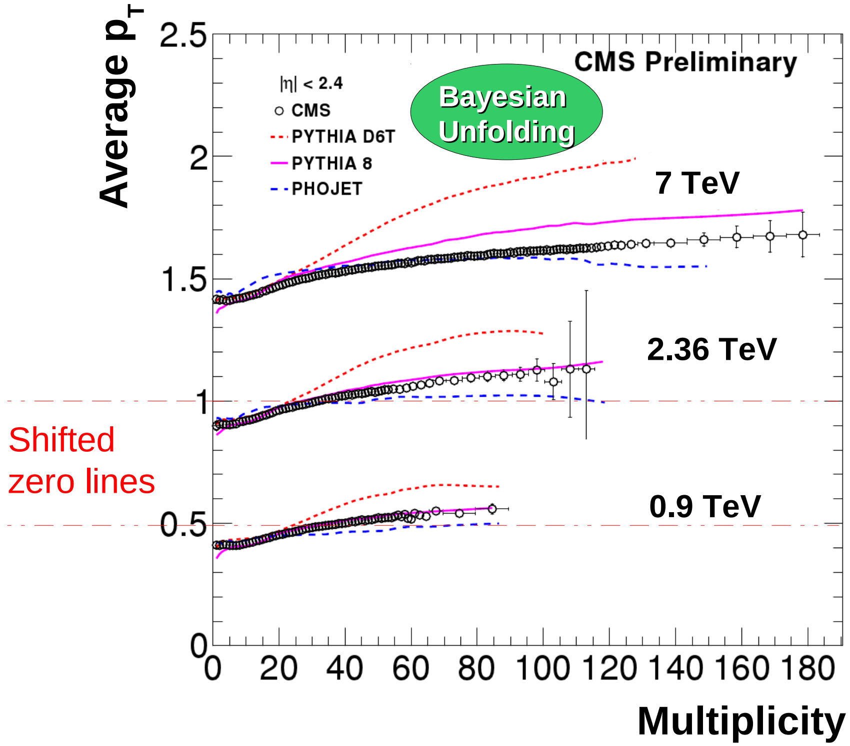
- **Monte Carlo comparisons** in different η ranges
- Several Monte Carlo Generators studied

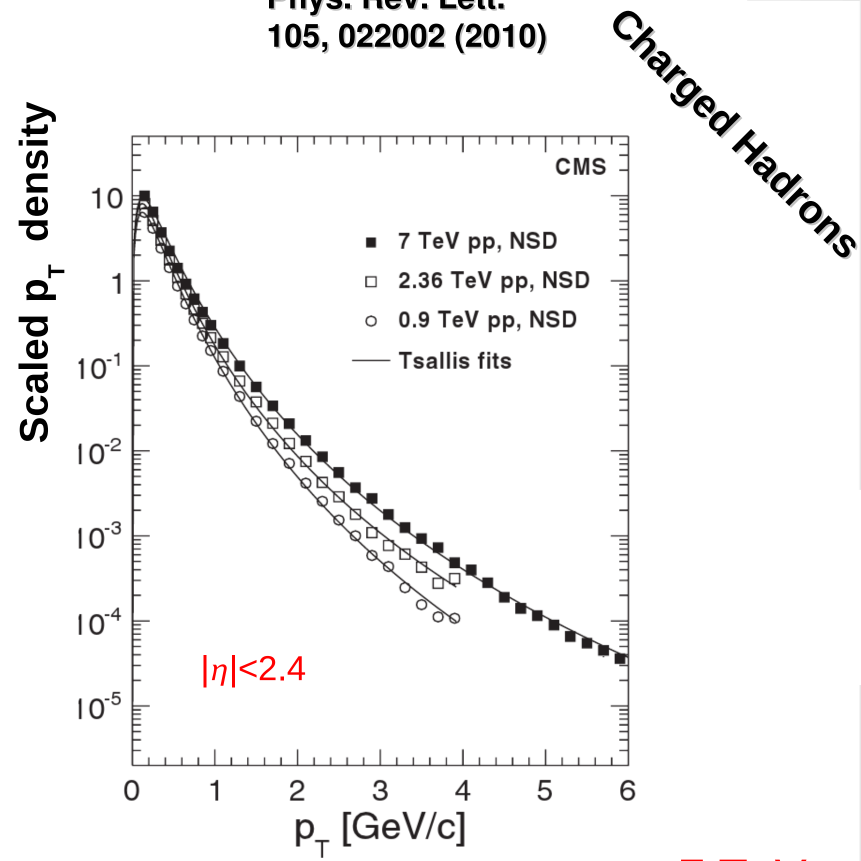
- No tune describes all multiplicities at all energies

P_T Distributions

CMS QCD-10-004

Phys. Rev. Lett. 105, 022002 (2010)





$$\bar{p}_T = 0.545 \pm 0.005(stat) \pm 0.015(syst)\, GeV/c$$ **7 TeV**

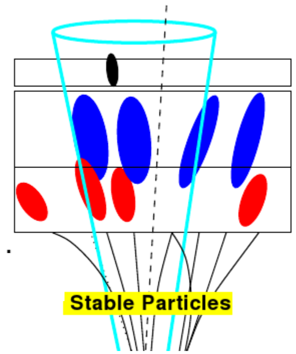
Tsallis Parametrisation, J. Stat. Phys **52**, 479 (1988)

$$E\frac{d^3N_{\mathrm{ch}}}{dp^3} = \frac{1}{2\pi p_T}\frac{E}{p}\frac{d^2N_{\mathrm{ch}}}{d\eta\, dp_T} = C\frac{dN_{\mathrm{ch}}}{dy}\left(1+\frac{E_T}{nT}\right)^{-n}$$

- Expected increase in multiplicity
- No tune describes average momentum at all energies

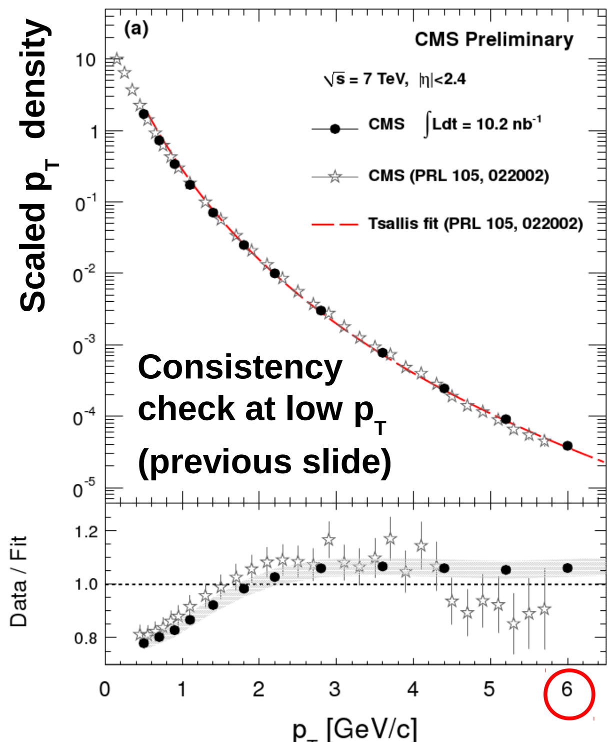
Extending Pt Reach with Calo Jets Triggers

Charged Hadrons

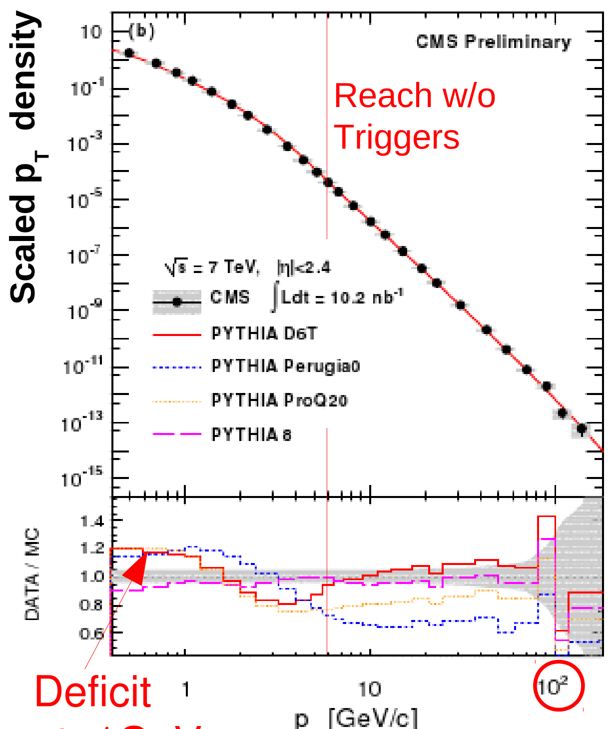


Hadron Calorimeter deposits
E.M. Calorimeter deposits

- Exploit CMS HLT for Calorimeter Jets (anti-kt R=0.5 algo)
  - Different thresholds of jet p_T
  - Event energy scale set by the jet
  - HLT efficiency curves with Monte Carlo
  - Consistency with MB events ensured



Consistency check at low p_T (previous slide)



Reach w/o Triggers

Deficit pt<1GeV

140 GeV/c

- p_T < 1 GeV: deficit Pythia 6
- High pt, Pythia 8 and Pythia 6 D6T tune: consistency within 10%

Gray band: systematic uncertainty

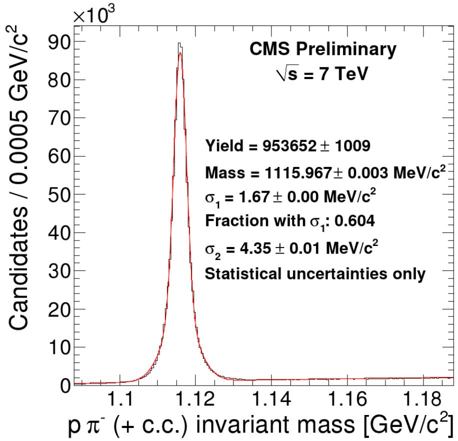
CMS QCD-10-008

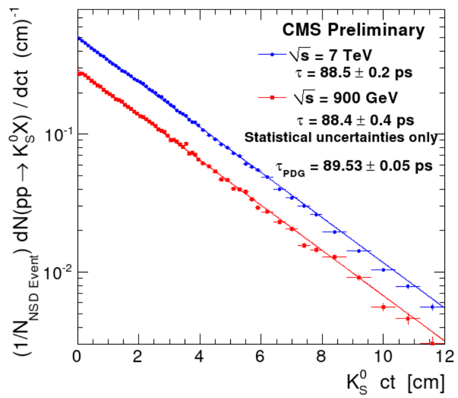
Strange Hadrons

CMS QCD-10-007

- Three neutral states considered

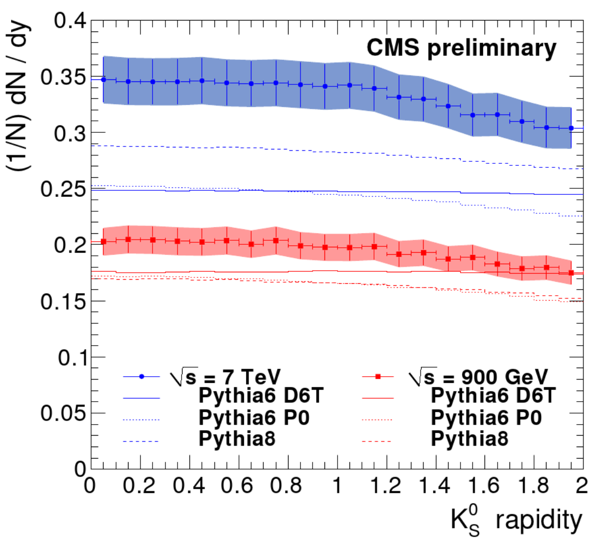
Topologies and lifetimes reconstructed with extreme precision!

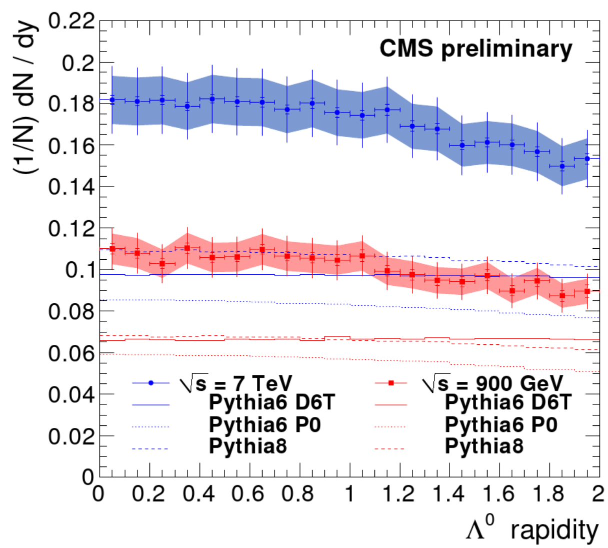


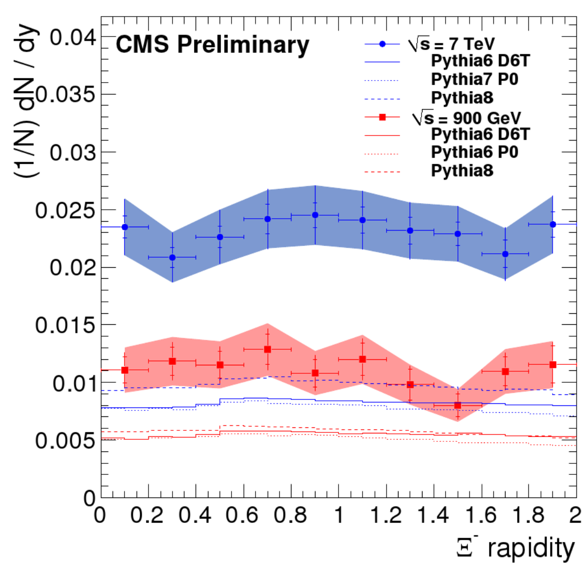


- K^0_s, mass≃497 MeV, s=1
- Λ^0, mass≃1115 MeV, s=1
- $\Xi^{\pm}$, mass≃1314 MeV, s=2

- Identification of strange hadrons
- Monte Carlo: Lower multiplicity
- Increasing CM energy and strangeness: larger discrepancy





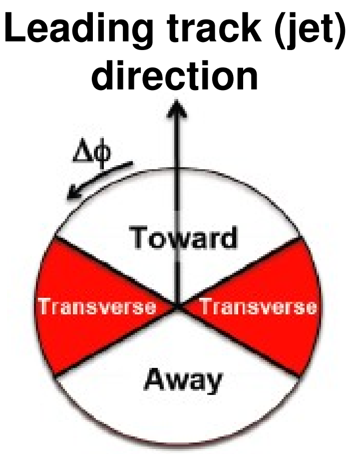


Part Two

Underlying Event

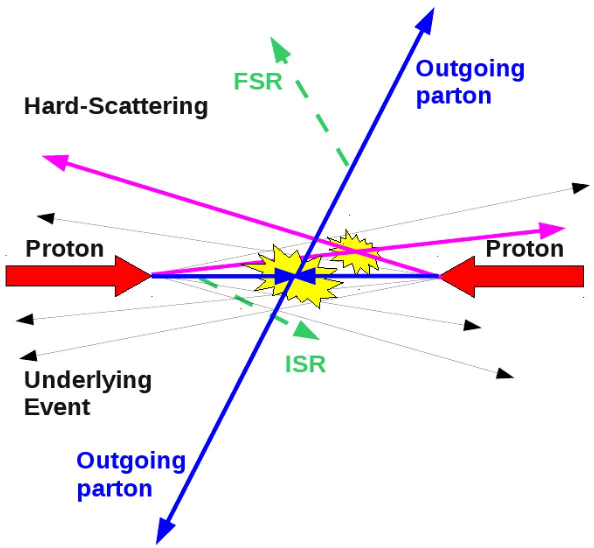
Monte Carlo Comparison

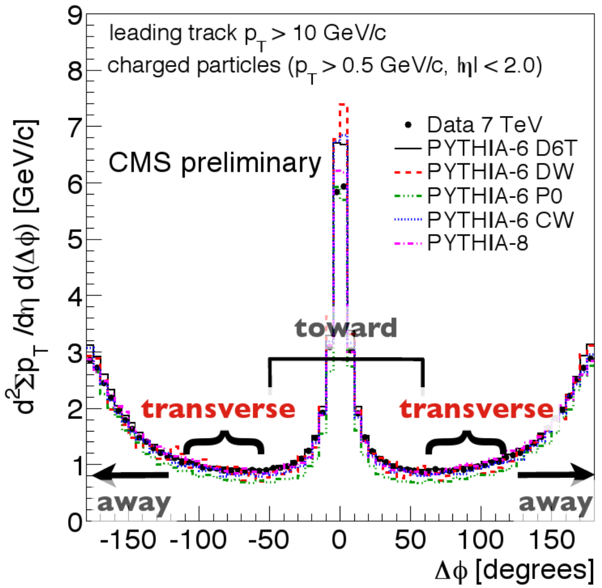
Underlying Event



Traditional approach:

- Leading object (track/track-jet)
  - Defines direction
  - Sets an energy scale
- Observables from charged particles
  - $d^2N_{ch}/d\eta d\phi$: multiplicity density
  - $d^2\Sigma pt/d\eta d\phi$: momentum density





A road for CMS MC tuning

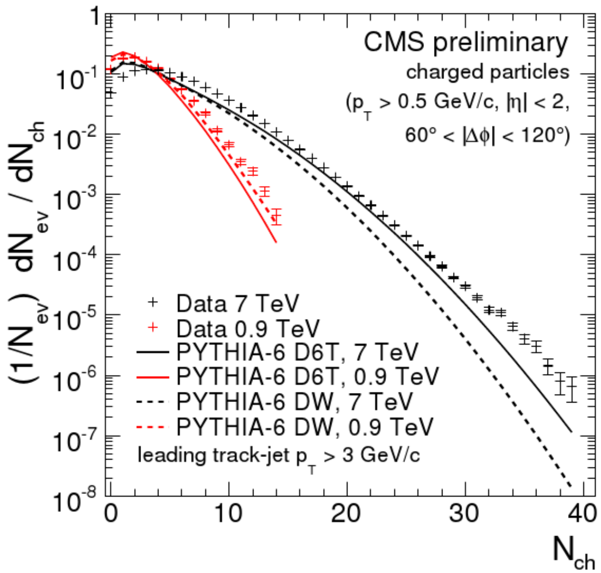
Program to measure Multiple Parton Interactions @ LHC

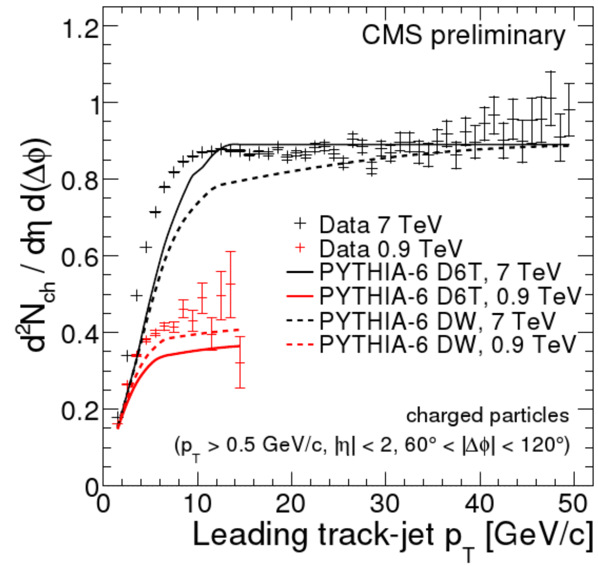
Difference wrt preceding analyses: 1 single vertex

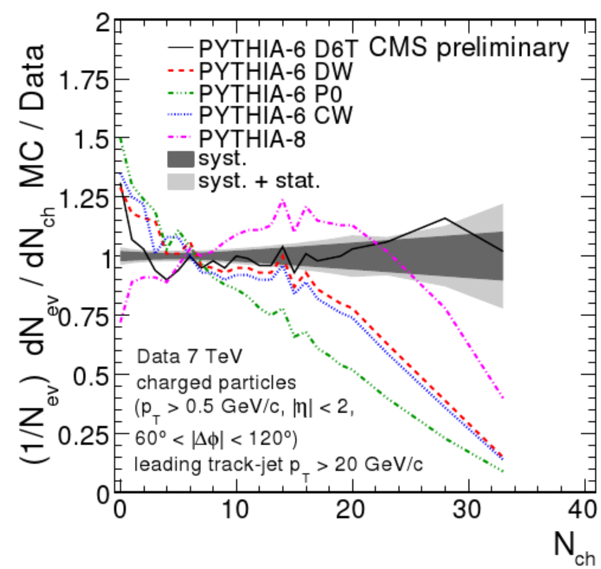
UE Traditional Approach

CMS QCD-10-010

- Results shown for 0.9 and 7 TeV
- Several PYTHIA 6 tunes and PYTHIA 8

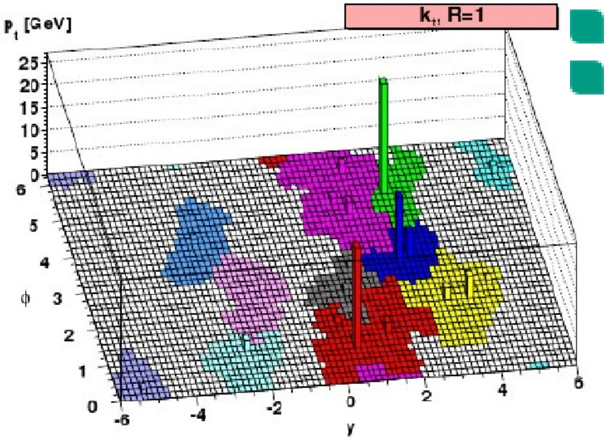






- Strong growth between 0.9 and 7 TeV
- Multiplicity raise described by Pythia 6
  - plateau with variable success
- Giant step towards UE understanding after the Tevatron era

New Jet Area Median Approach



- Use track-jets, kt R=0.6 algorithm – Infrared and collinear safe
- Relies on active jet-area concept
  - Add grid of artificial soft objects (pt~10^{-100} GeV) called *ghosts*
  - Cluster them with physical tracks
    → Infra-red: physics does not vary!
  - Area of jet proportional to the contained ghosts

- Underlying activity estimator
- Occupancy "C":
  - Recovers "empty" events (900 GeV) dominated by *ghost-jets*

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

- Complementary to traditional approach
  - UE measured with infrared and collinear safe quantities
  - Look at all the event (not only transverse region)
  - No need for leading object!
- Fundamental for pile-up and UE jet energy corrections

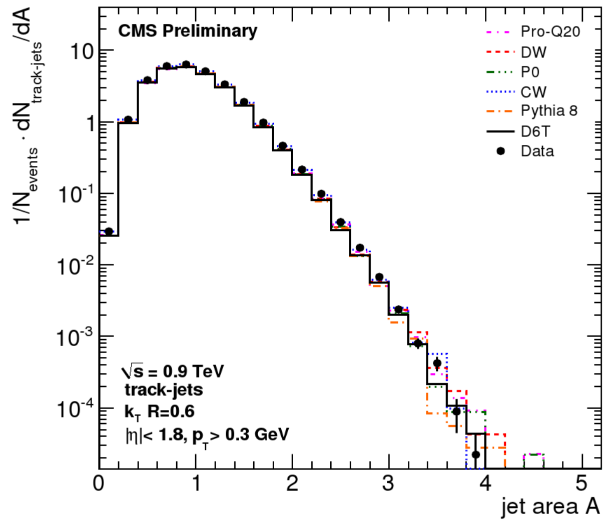
Areas with FastJet
www.fastjet.fr

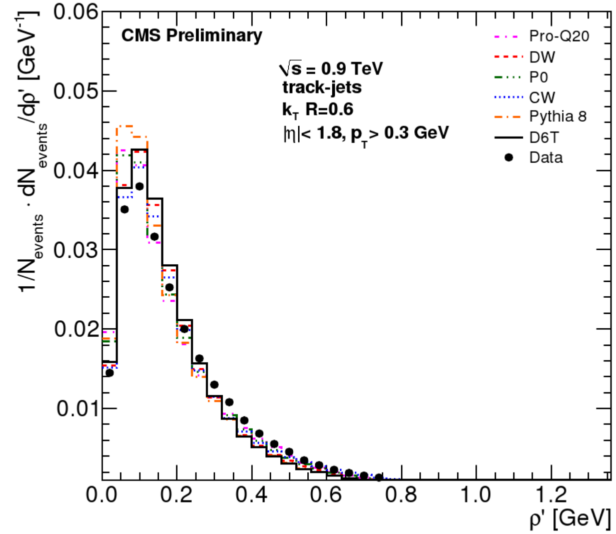
Areas of kt jets are not round. They depend on the surrounding topology

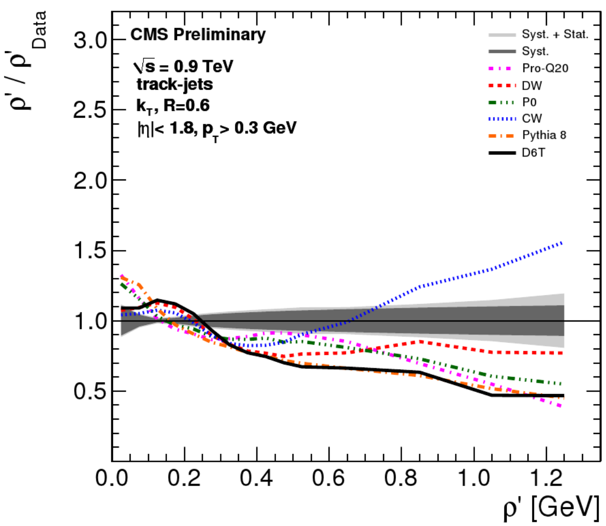
Based on the paper: "On the characterisation of the underlying event" JHEP04(2010)065; M. Cacciari, G. Salam, S. Sapeta.

UE with JA/Median approach

CMS QCD-10-005







- No Monte Carlo describes rho'
- Jet Area: very good description
  → tune independent

- Complementary UE approach
- Consistent with traditional patterns
- Towards UE and pile-up jet energy corrections

Part Three

Forward Physics

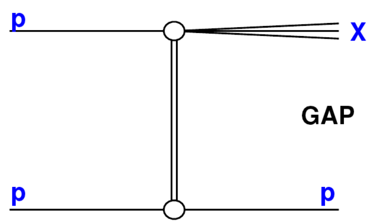
Monte Carlo Comparison

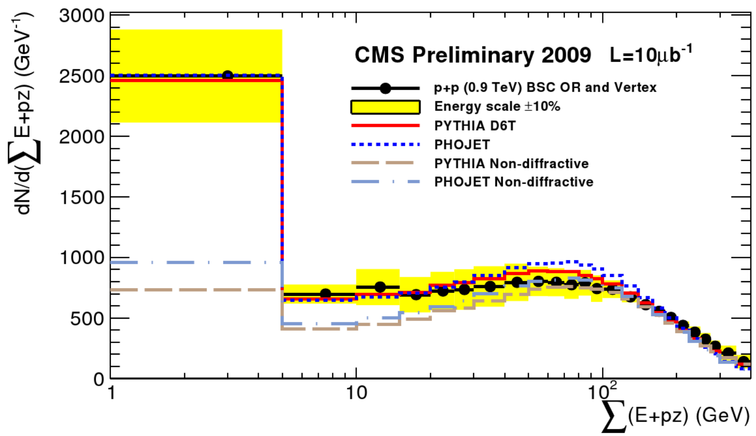
Forward processes

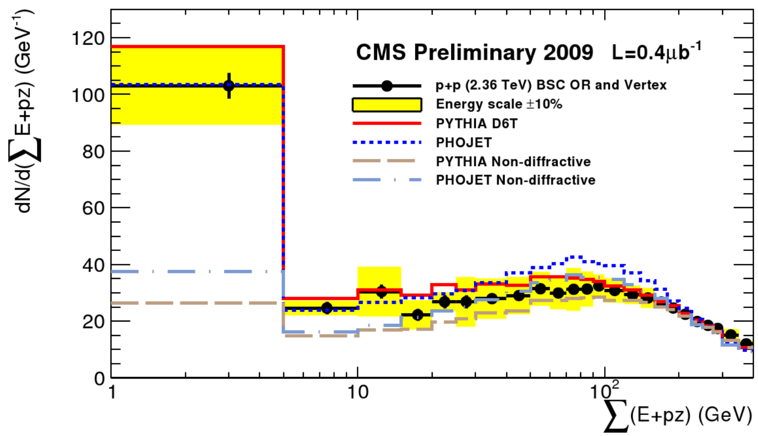
- Single Diffraction peak observation
- To describe it: ξ (proton fractional energy loss)
- Features:
  - Large Rapidity Gap (LRG) - colourless pomeron
  - Final states p and X have ~same energy of incoming particles

→ Require low activity on one side of CMS

$\xi = M_X^2 / s$
$\sigma \approx 1 / \xi$
$\Delta y \approx - \ln \xi$
$\xi \approx \Sigma_i (E_i \pm p_{z,i})$







- Evidence of SD peak
- Dominant Uncertainty: Jet Energy Scale
- Pythia describes better non-diffractive component
- Phojet accurately reproduces diffractive component

Summary

- CMS data @ 0.9, 2.36 and 7 TeV
  - Efficient trigger and precise tracking system
- Eta, pt and multiplicity charged particles distributions
  - Diverse tracking strategies established
  - Bayesian unfolding already in place
  - Calorimeter jet triggers to extend pt range
  - General Monte Carlo deficit, especially at low pt
  - Strange hadrons: deficit for increasing mass and strangeness
- Underlying Event studied @ 0.9, 2.36 and 7 TeV
  - Traditional and Jet Area/Median approaches
  - Input for improvement of Monte Carlo predictions
  - Step towards UE and pileup jet energy corrections
- Forward processes
  - Single diffractive peak observed
  - Diffractive component critical for Monte Carlo generators

Bibliography

- **QCD-09-010**

"Transverse-Momentum and pseudorapidity distributions of charged hadrons in pp collisions at $\sqrt{s}$ = 0.9 and 2.36 TeV"

- **Phys. Rev. Lett. 105, 022002 (2010)**

"Transverse-Momentum and pseudorapidity distributions of charged hadrons in pp collisions at $\sqrt{s}$ =7 TeV"

- **QCD-10-004**

"Charged multiplicities in pp interactions at $\sqrt{s}$ = 0.9, 2.36 and 7 TeV"

- **QCD-10-008**

"Jet-triggered charged particle transverse momentum spectra in pp collisions at 7 TeV"

- **QCD-10-010**

"Measurement of the Underlying Event Activity at the LHC with $\sqrt{s}$ =0.9 TeV and Comparison with $\sqrt{s}$ =7 TeV"

- **QCD-10-005**

"Measurement of the Underlying Event Activity with the Jet Area/Median Approach at 0.9 TeV"

- **FWD-10-001**

"Observation of diffraction in proton-proton collisions at 900 and 2360 GeV centre-of-mass energies at the LHC"

- **TRK-10-001**

"Tracking and Vertexing Results from First Collisions"

Backup

Backup 1

- Pippo

$$y = 0.5\ln[(E+p_z)/(E-p_z)],\ E_T = \sqrt{m^2 + p_T^2}$$

TABLE II. Fractions of SD, DD, ND, and NSD processes obtained from the PYTHIA and PHOJET event generators before any selection, and the corresponding selection efficiencies determined from the MC simulation.

	PYTHIA		PHOJET	
	Fractions	Selection efficiencies	Fractions	Selection efficiencies
SD	19.2%	26.7%	13.8%	30.7%
DD	12.9%	33.6%	6.6%	48.3%
ND	67.9%	96.4%	79.6%	97.1%
NSD	80.8%	86.3%	86.2%	93.4%