CMS Results relevant for MC tuning

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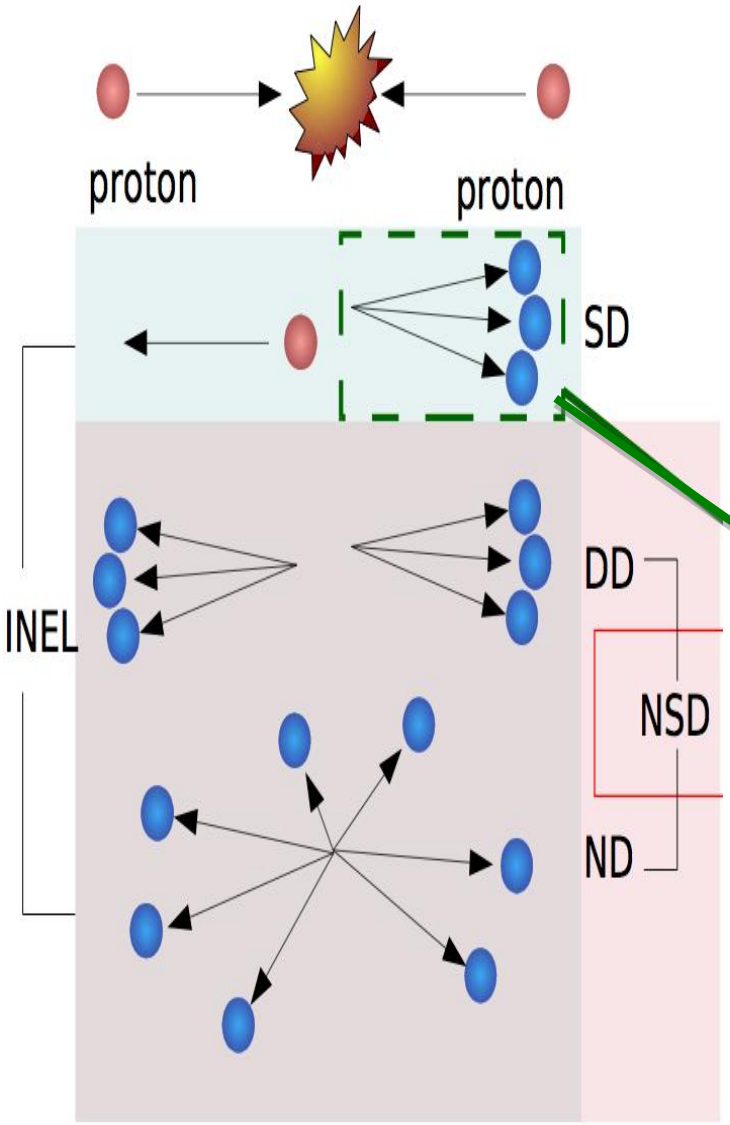
Input to MC tuning

1. Diffractive events at $\sqrt{s} = 0.9$ & 2.36 TeV
2. Bose-Einstein Correlations at $\sqrt{s} = 0.9$ & 2.36 TeV
3. Strange Particle Production at $\sqrt{s} = 0.9$ & 7 TeV
4. Charged Particle Multiplicities at $\sqrt{s} = 0.9$, 2.36, & 7.0 TeV
5. Charged Particle Transverse Momentum Spectra at 7 TeV
   ➔ Emphasis on large p_T
6. Transverse-Momentum and Pseudorapidity Distributions of Charged Hadrons at $\sqrt{s} =$ 0.9, 2.36 & 7 TeV
   ➔ $dN/d\eta$, dN/dpT and $\langle pT \rangle$ of charged hadrons
   ➔ Emphasis on low p_T
7. Underlying Event

Disclaimer



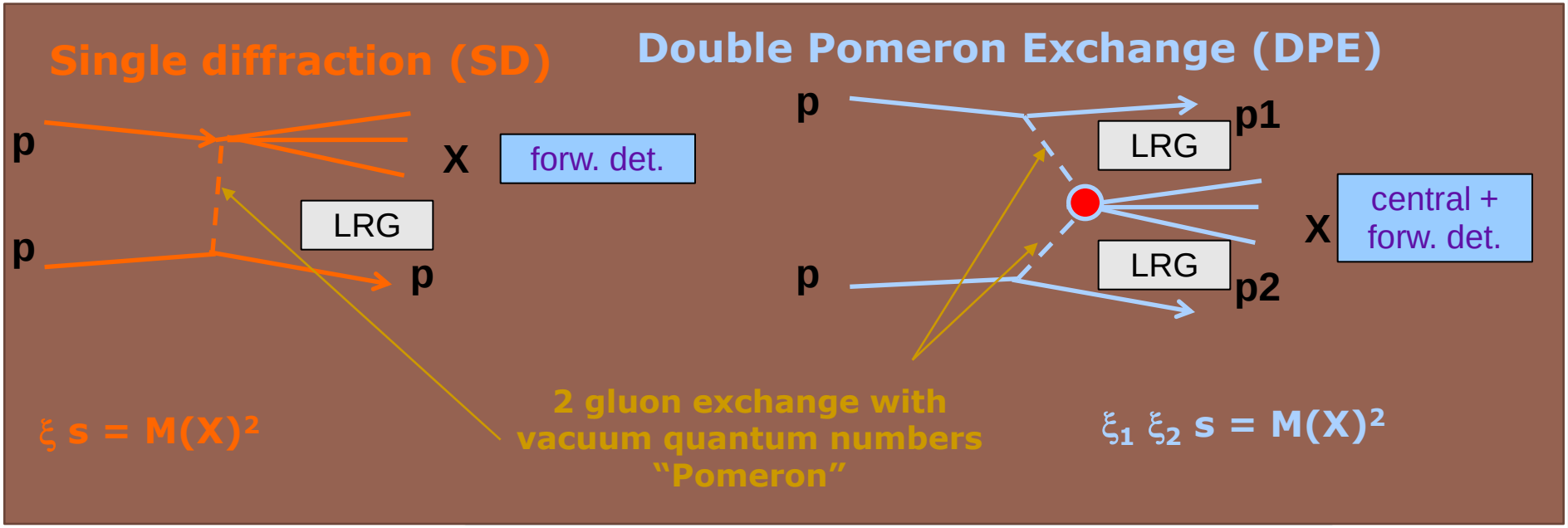
- Not all soft processes are kept in the analyses to be discussed (3-6):
  - elastic scattering
  - single-diffractive
  } excluded
  - double-diffractive
  - non-diffractive
  } used NSD
- Single–Diffraction (**SD**) was observed with an independent analysis … let's look at those results first

Observation of diffraction in proton-proton collisions at 900 and 2360 GeV

CMS PAS FWD-10-001

Diffraction

- Diffractive reactions in *p p* collisions: reactions $p\,p \to X\,Y$ in which the systems *X* and *Y* are separated by a Large Rapidity Gap

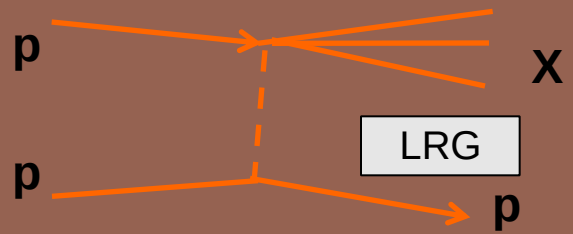


- Diffractive events contribute significantly to Minimum Bias data set (~ 30 % of the total *p p* cross section)
- Modelling of soft diffraction is generator dependent

➔Info on proton structure (dPDFs and GPDs), discovery physics, MPI, …

Strategy for Single Diffraction Detection at CMS

Single diffraction (SD)



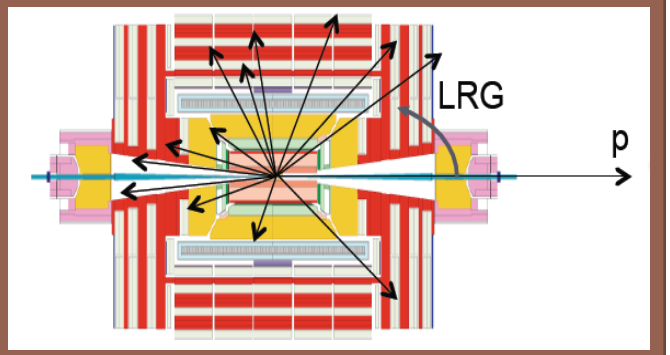
$\xi = M_X^2 / s$

$\sigma \approx 1 / \xi$

$\Delta y \approx - \ln \xi$

$\xi \approx \Sigma_i (E_i \pm p_{z,i}) / \sqrt{s}$

No measurement of the proton → rely on Large Rapidity Gaps



LOOK FOR A SD PEAK @ low $\xi \approx \Sigma_i (E_i \pm p_{z,i}) / \sqrt{s}$

Sum runs over all the Calo Towers:

$p_{z,I} = E_i \cos \vartheta_i$

Hadron Forward:

- @11.2m from interaction point
- rapidity coverage: $3 < |\eta| < 5$
- Steel absorbers/ quartz fibers (Long +short fibers)
- 0.175x0.175 η/φ segmentation

CONFIRM SD PEAK @ low $E_{HF\pm}$, $N_{HF\pm}$

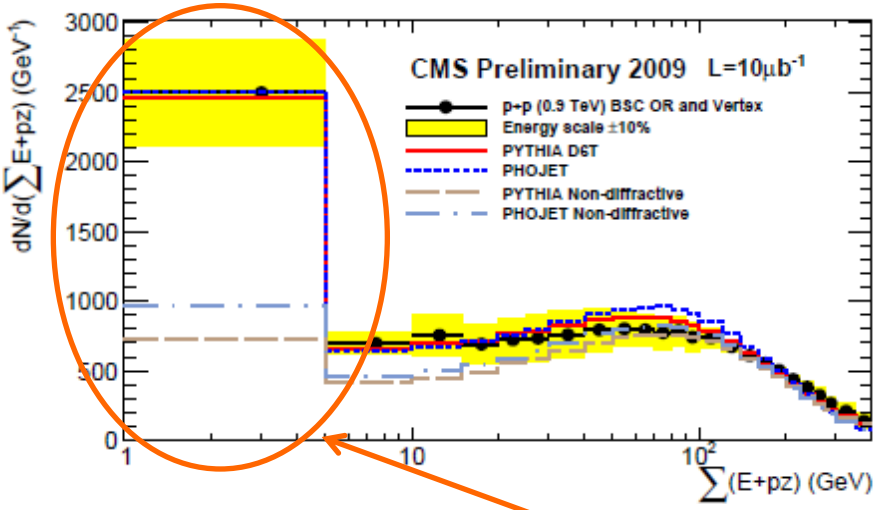
$E_{HF\pm}$ = energy deposition in HF±

$N_{HF\pm}$ = multiplicity of towers above threshold in HF±

Observation of Single Diffraction at CMS

(Results at 7 TeV to become public in the near future)

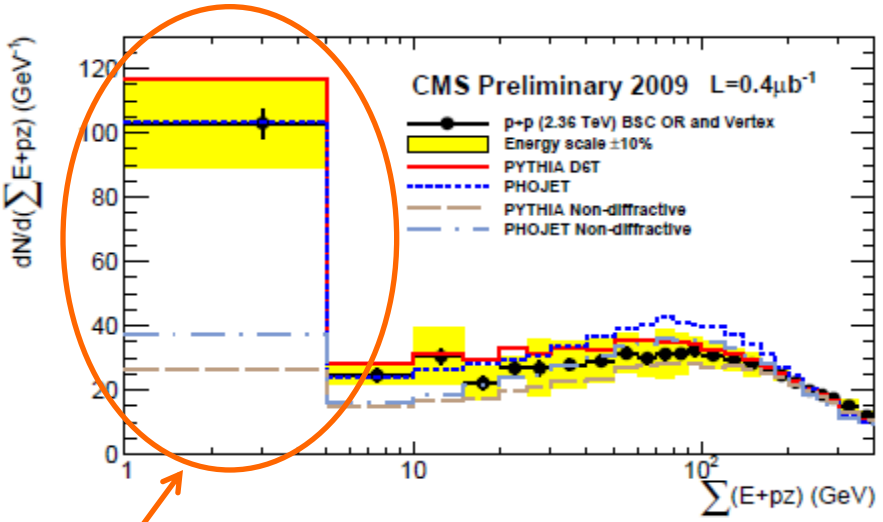
900 GeV (10 μb^{-1})



Systematic uncertainty dominated by energy scale

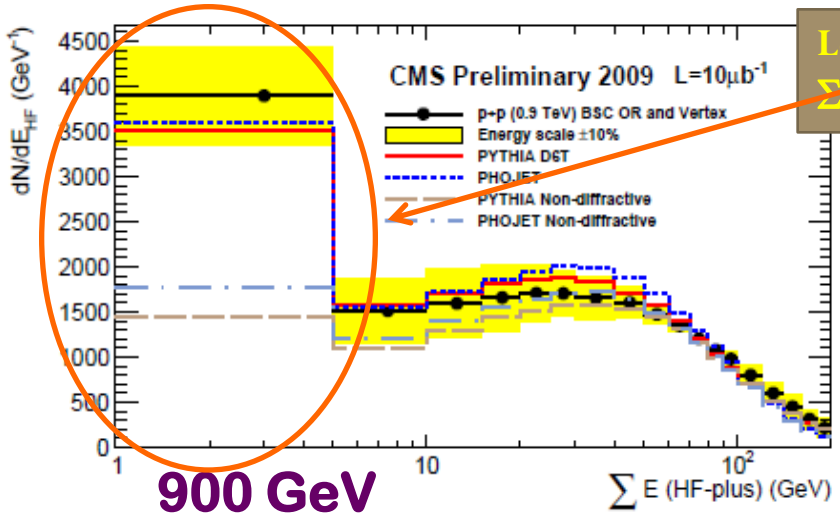
Acceptance for SD ~ 20%
For NSD ~80% (PYTHIA)

2360 GeV (0.4 μb^{-1})



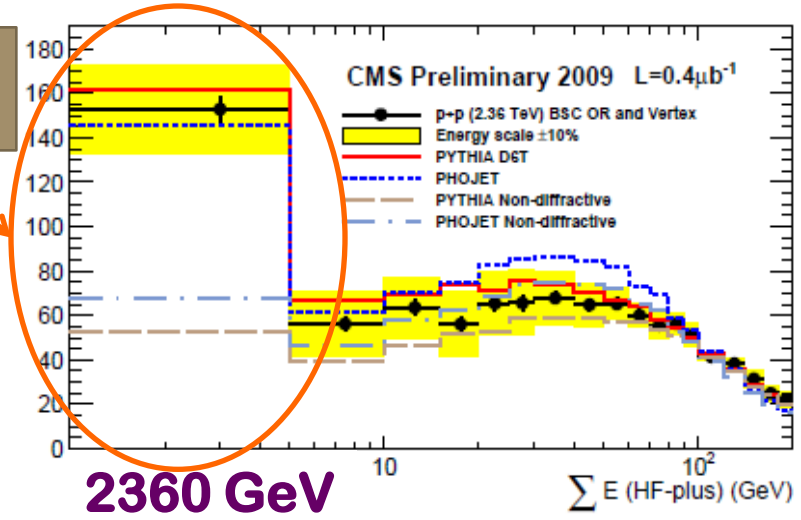
SD seen in Σ E+pz distribution due to cross section peaking at small values of ξ

Observation of Single Diffraction at CMS

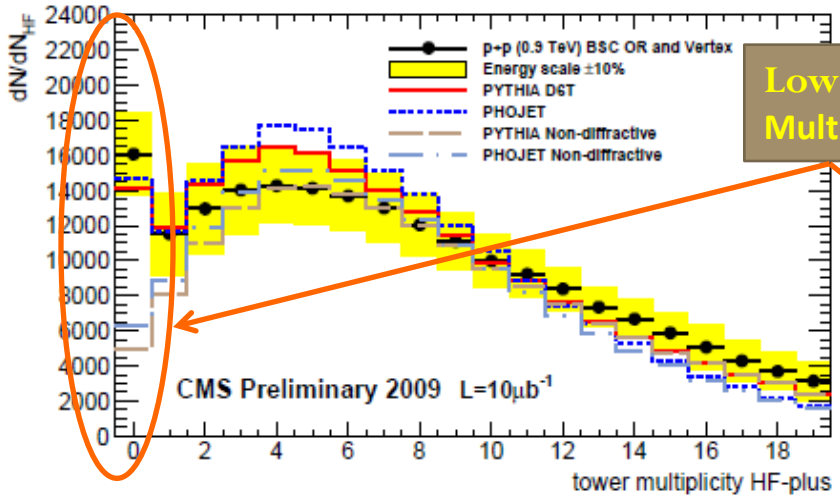


900 GeV

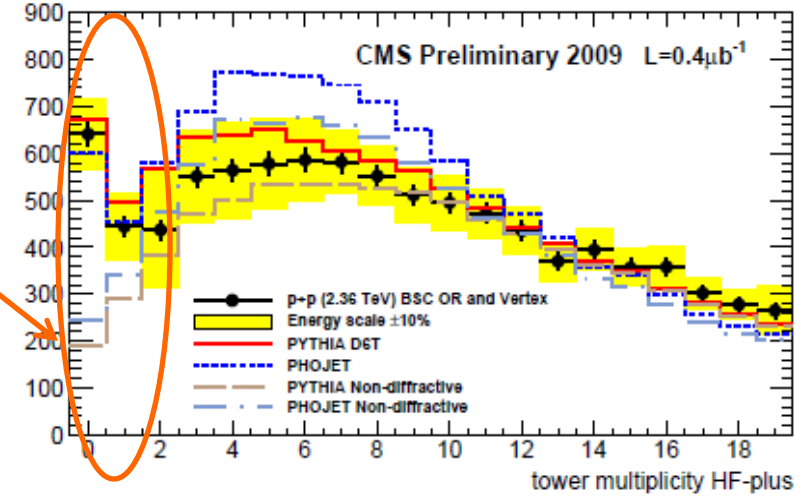
Low $\sum E(HF+)$



2360 GeV

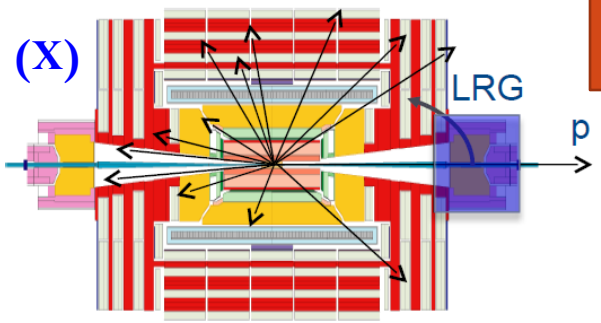


Low HF+ Multiplicity



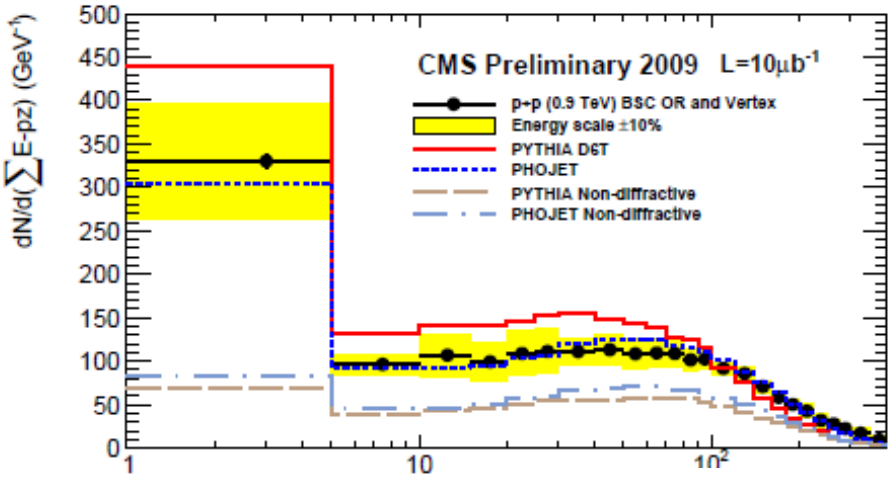
SD signature confirmed by the absence of forward hadronic activity (presence of a LRG)

Enriched SD Sample ➔ E(HF+) < 8 GeV

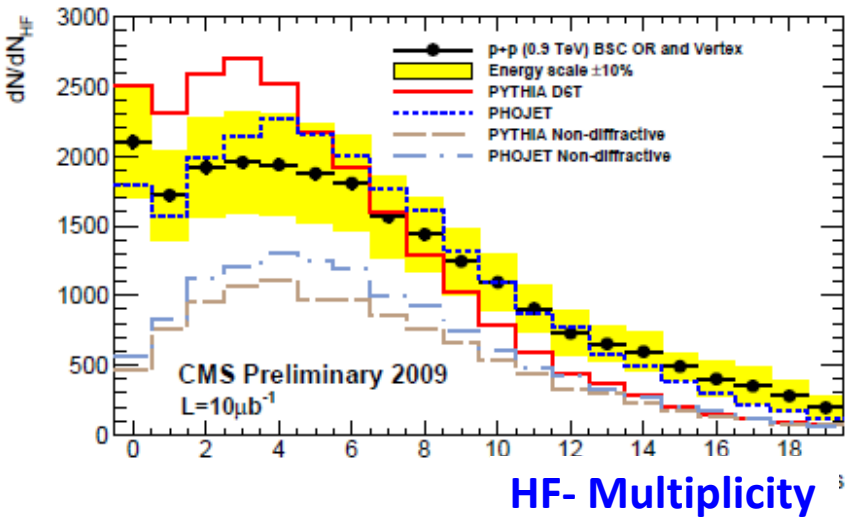


Requirement of low Activity in one side of CMS

SD component of the data
LRG in z+ direction
Concentrating on the fragmenting object
(X) boosted in z- direction



$\xi = \Sigma_i (E_i \pm p_{z,i})$



HF- Multiplicity

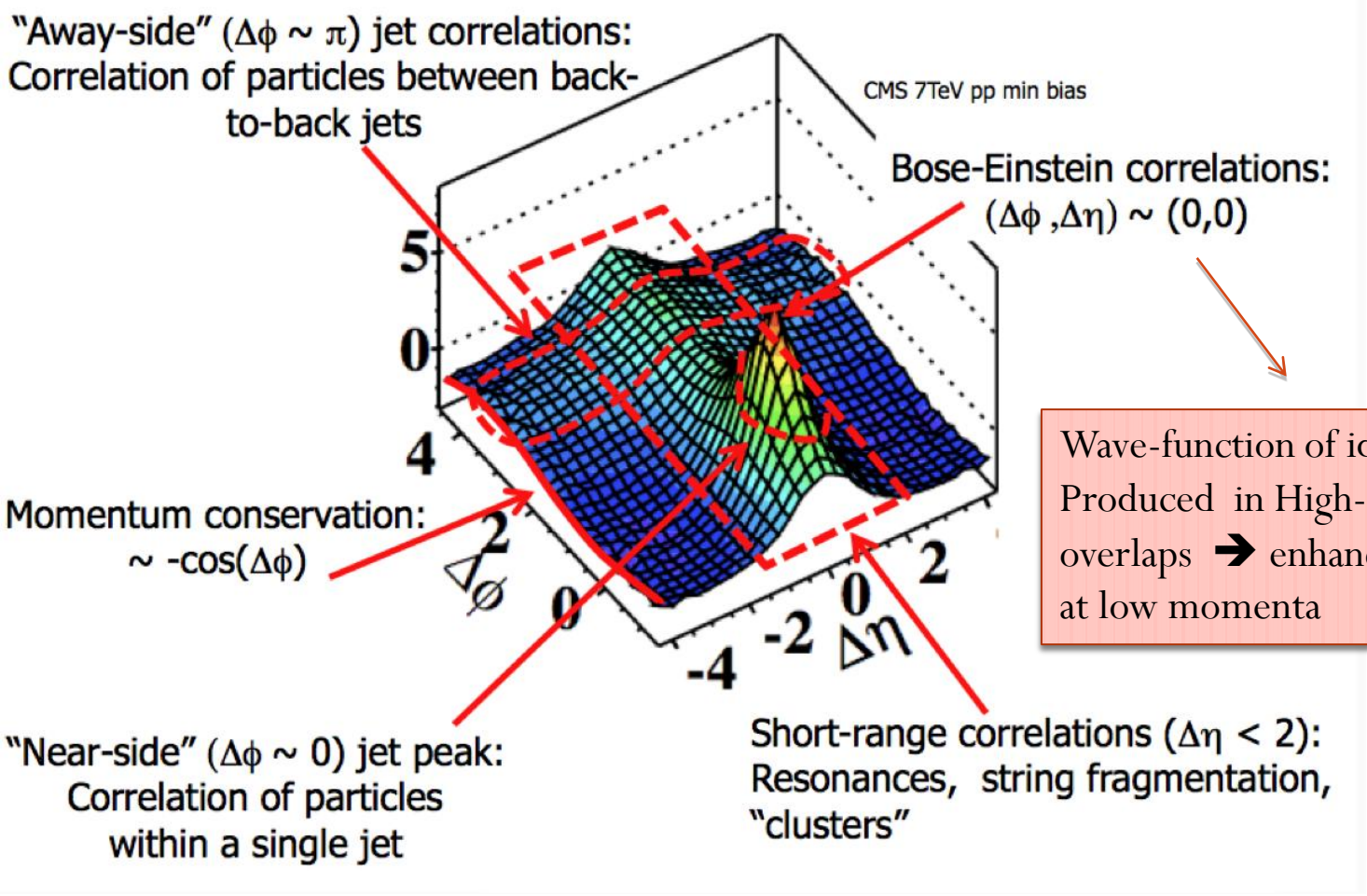
➔ *Now fit the data better than DT6*

First Measurement of Bose–Einstein Correlations in proton-proton Collisions at $\sqrt{s}$ = 0.9 and 2.36 TeV at the LHC

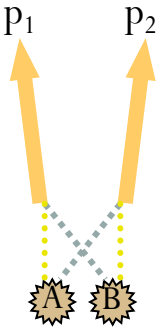
CMS PAS QCD-10-003

PRL 105, 032001 (2010)

Angular correlation analysis…Good if we could get all details - including BEC



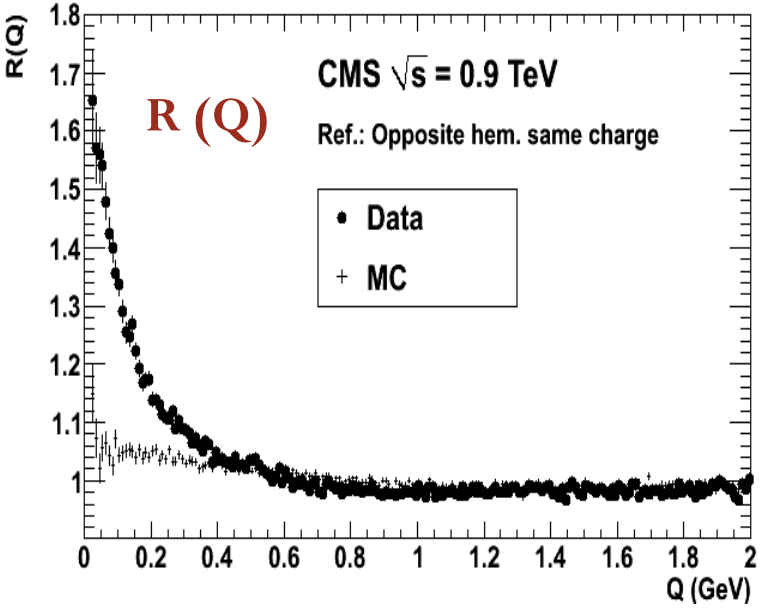
Particles



Wave-function of identical bosons
Produced in High-Energy Collision
overlaps ➔ enhancement
at low momenta

BEC for charged pions

PRL 105, 032001 (2010)



$$R = \frac{\text{joint prob. for identical boson emission}}{\text{independent prob. for identical boson emission}}$$

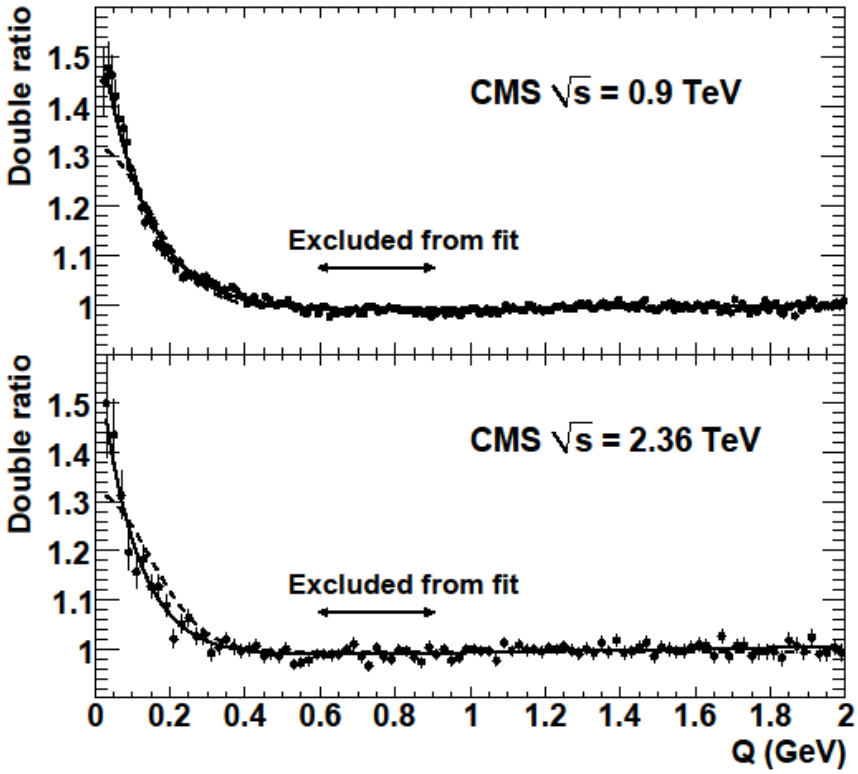
Experimentally the proximity in phase space can be quantified by the Lorentz-inv. parametrization

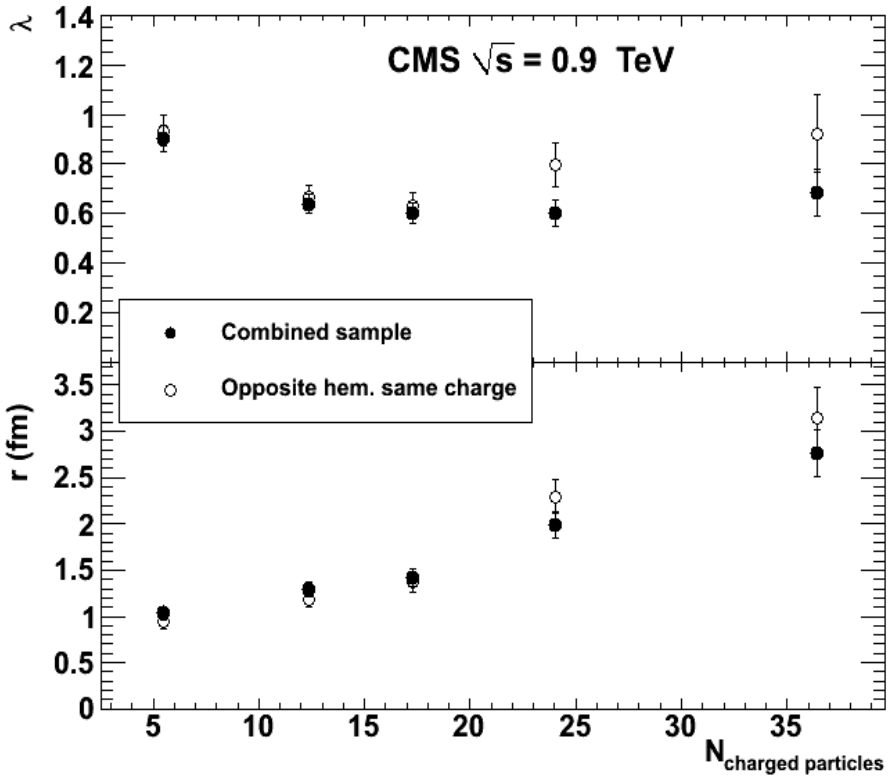
$$Q^2 = -(p_1 - p_2)^2 = M^2_{inv} - 4m^2_\pi$$

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

- Ω is the Fourier transform of the spatial distribution of the emission region (static models)
- λ is the strength of the emission source
- r is the radius of the emission source
- δ accounts for long range Q correlations

Exponential fit *exp(-Qr)* to enhancement at low Q, fits our data better than Gaussian





- Small dependence of **λ** from N_{CH}
- Significant increase of the size of the emission region **r** as the charged track multiplicity increases

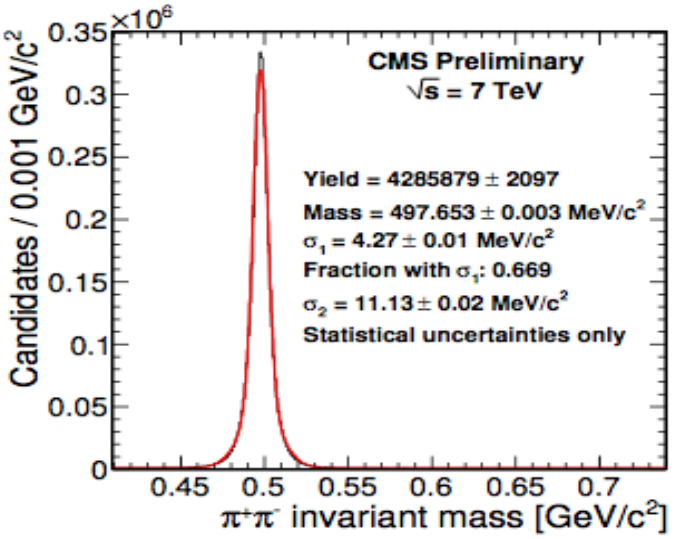
Strange Particle Production

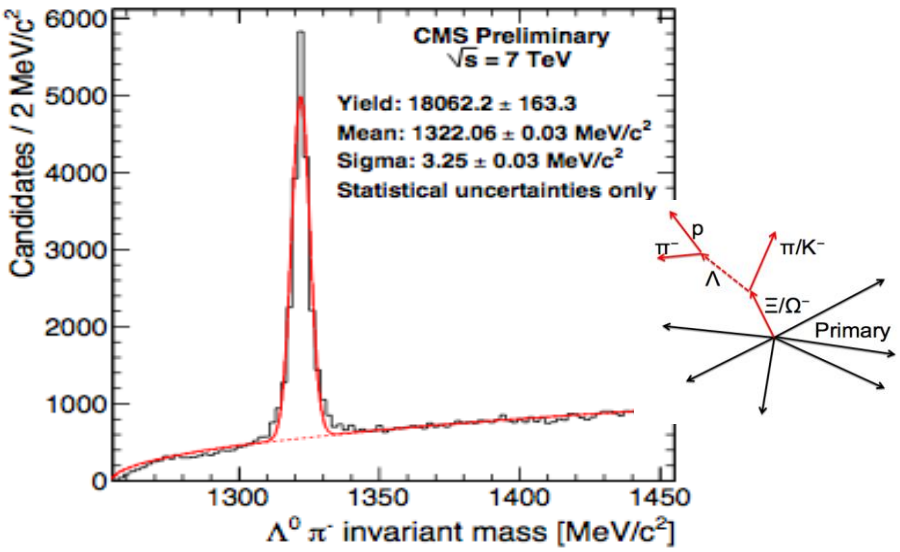
Ks, Λ & Ξ

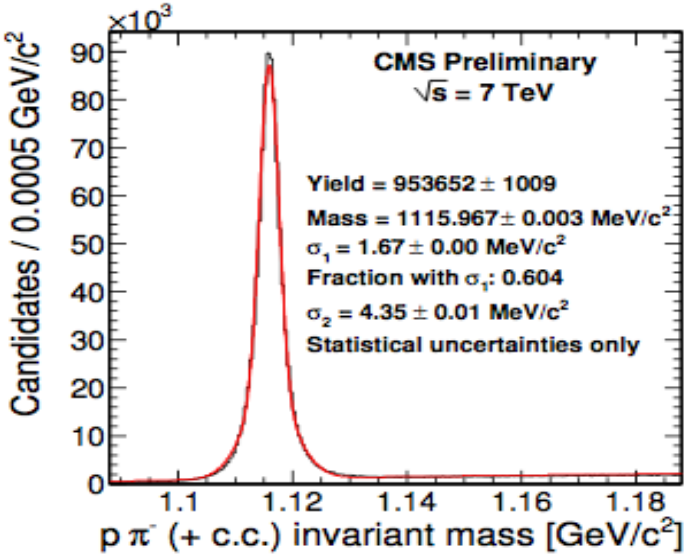
CMS PAS QCD-10-007

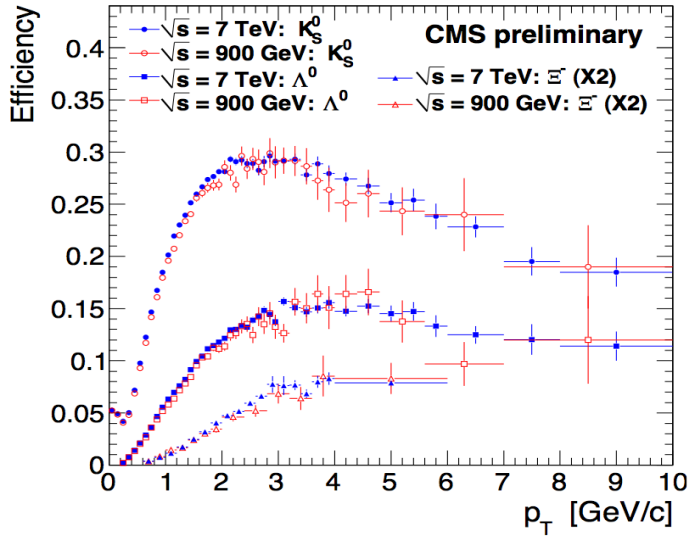
➔ Proper interaction for Anti-Proton needed in Physics list before ratios of Λ / Anti-Λ , etc can be reported

Strange Particles Decays

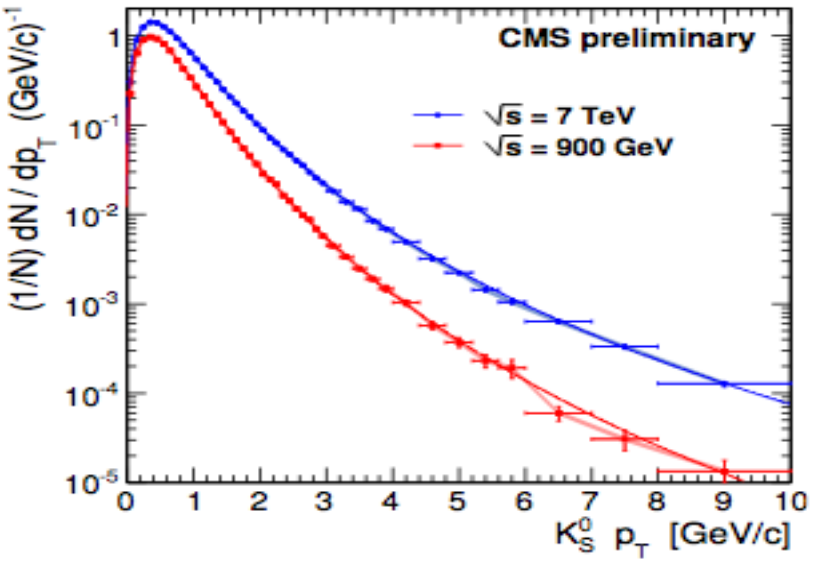


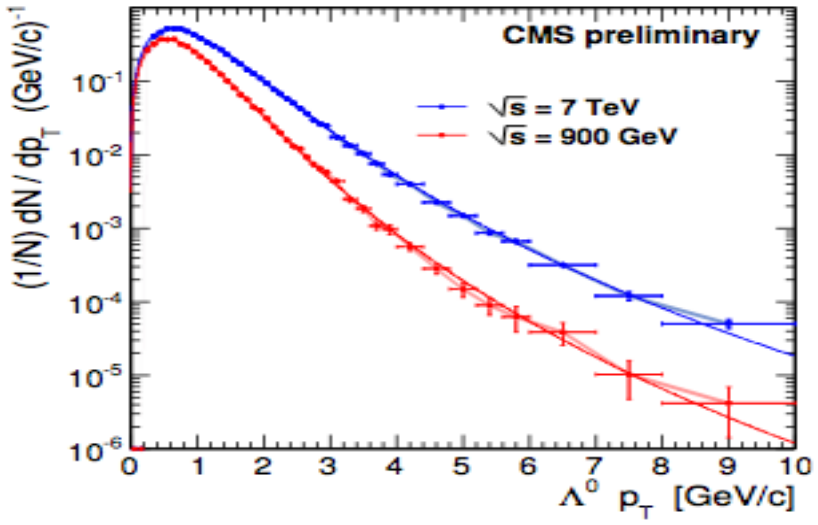




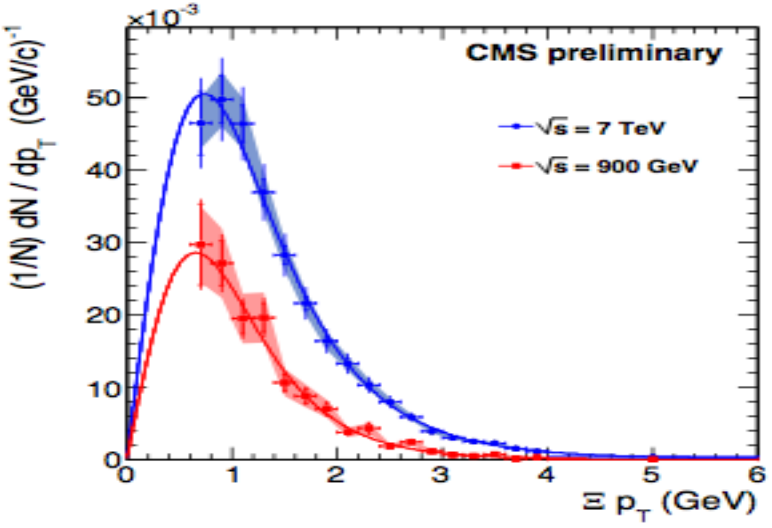


Strange Hadron Spectra

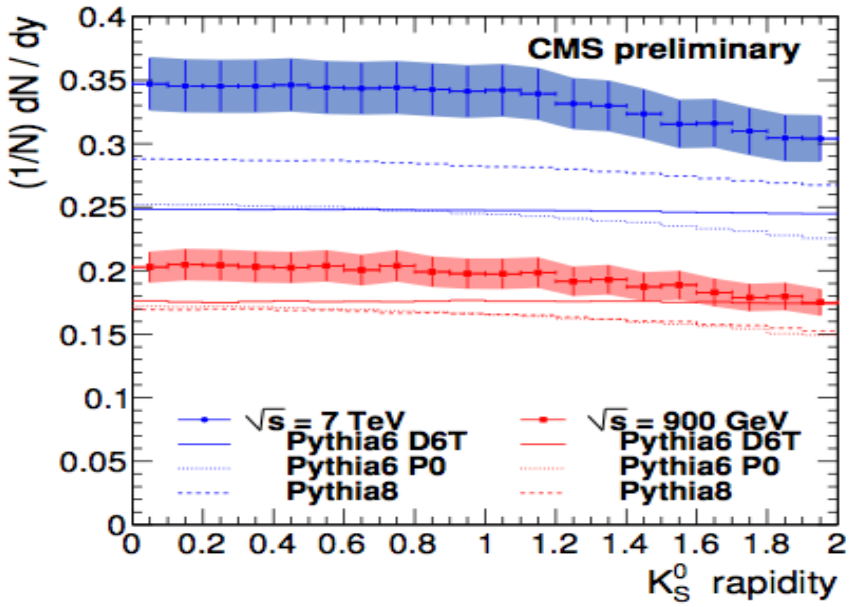




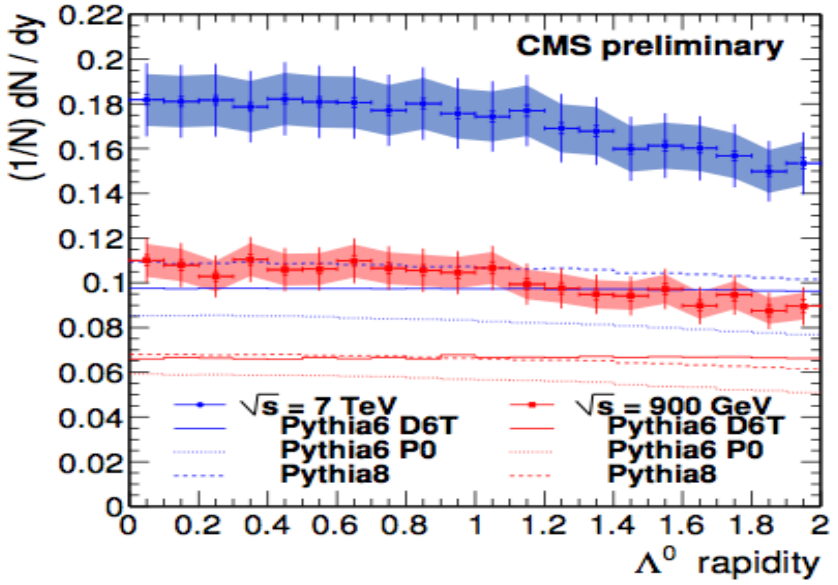
- Only NSD interactions
- Normalized to number of NSD
- Solid line is a fit to Tsallis function
- Band error due to normalization

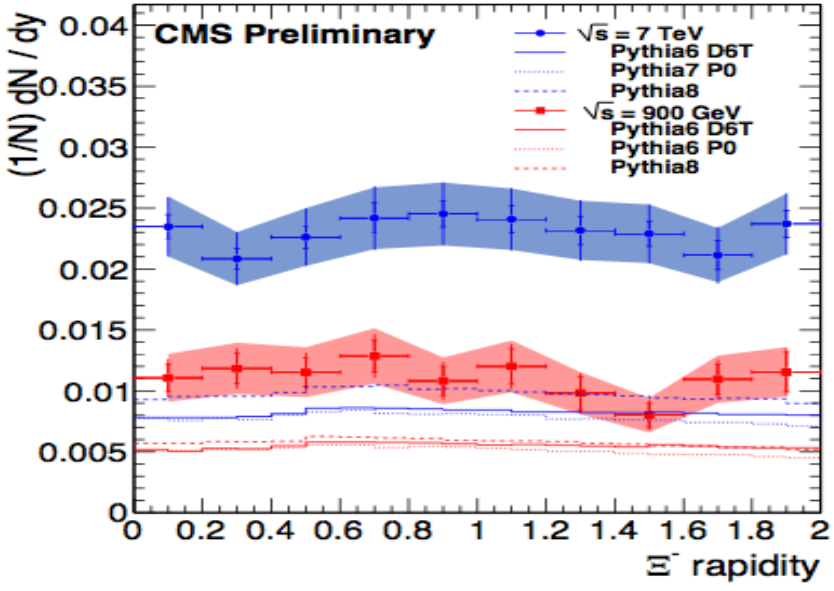


Comparison with various generators



- All generators underestimate the amount of Strange Particles produces at both 0.9 and 7 TeV





Comparison with previous experiments & event Generator

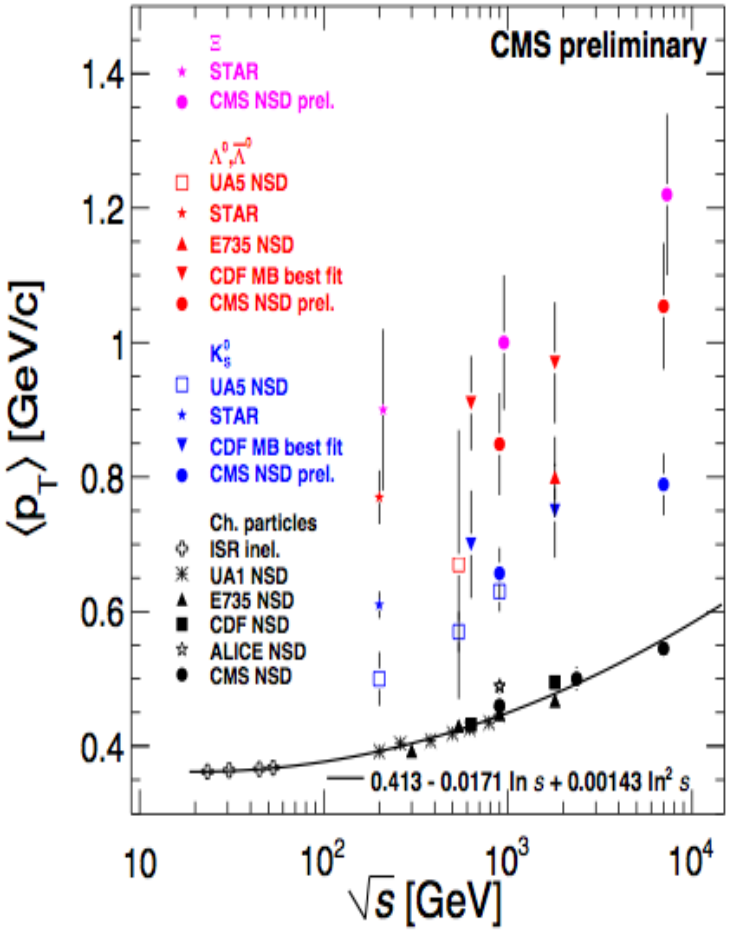
Simulation

Particle	$\sqrt{s} = 0.9$ TeV				$\sqrt{s} = 7$ TeV			
	T (GeV)	n	$\langle p_T \rangle_{\text{Tsallis}}$ (GeV/c)	$\langle p_T \rangle_{\text{true}}$ (GeV/c)	T (GeV)	n	$\langle p_T \rangle_{\text{Tsallis}}$ (GeV/c)	$\langle p_T \rangle_{\text{true}}$ (GeV/c)
PYTHIA 6 (D6T) K^0_S	0.156	7.41	0.581	0.579	0.183	5.71	0.753	0.754
PYTHIA 8 K^0_S	0.141	6.93	0.550	0.550	0.171	5.67	0.713	0.711
PYTHIA 6 (P0) K^0_S	0.150	6.73	0.585	0.582	0.168	5.39	0.730	0.726
PYTHIA 6 (D6T) Λ^0	0.152	6.07	0.756	0.756	0.216	5.11	1.064	1.069
PYTHIA 8 Λ^0	0.112	5.04	0.666	0.669	0.168	4.68	0.933	0.928
PYTHIA 6 (P0) Λ^0	0.124	5.33	0.695	0.694	0.163	4.64	0.921	0.910
PYTHIA 6 (D6T) Ξ^-	0.123	4.90	0.759	0.763	0.213	4.70	1.167	1.162

Simulation & Data

Particle	$\frac{dN}{dy}\|_{y=0}(7\text{ TeV})$ / $\frac{dN}{dy}\|_{y=0}(0.9\text{ TeV})$		$\frac{dN}{dy}\|_{y=0}(\text{PYTHIA D6T})$ / $\frac{dN}{dy}\|_{y=0}(\text{Data})$	
	Data	PYTHIA D6T	0.9 TeV	7 TeV
K^0_S	$1.71 \pm 0.02 \pm 0.20$	1.41	$0.87 \pm 0.01 \pm 0.07$	$0.72 \pm 0.01 \pm 0.06$
Λ^0	$1.65 \pm 0.04 \pm 0.26$	1.48	$0.60 \pm 0.01 \pm 0.07$	$0.54 \pm 0.01 \pm 0.06$
Ξ^-	$2.09 \pm 0.09 \pm 0.27$	1.47	$0.48 \pm 0.05 \pm 0.09$	$0.33 \pm 0.02 \pm 0.05$

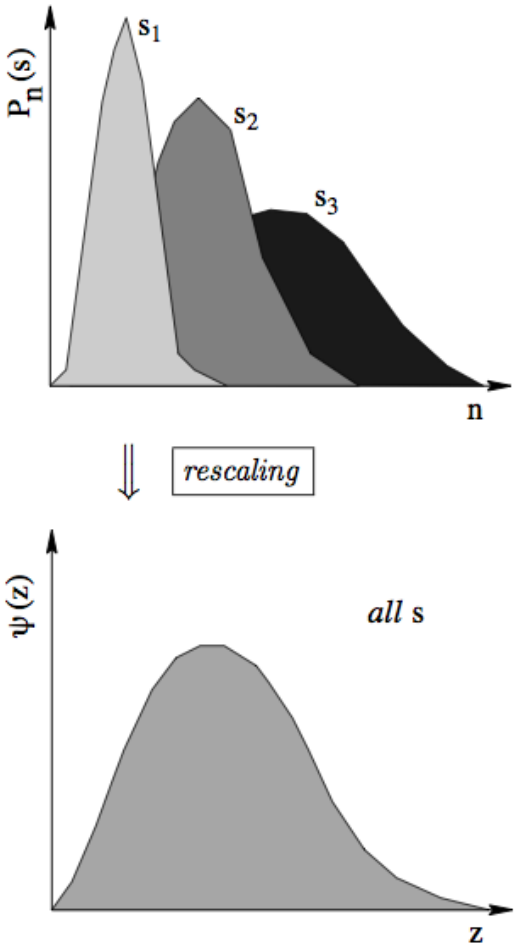
Data



Charge Multiplicities

CMS PAS QCD-10-004

KNO Scaling and C_q Moments



- Probability distributions $P_n(s)$ of producing n particles at collision energy s :

$$P_n(s) = \frac{1}{\langle n(s) \rangle} \psi\left(\frac{n}{\langle n(s) \rangle}\right)$$

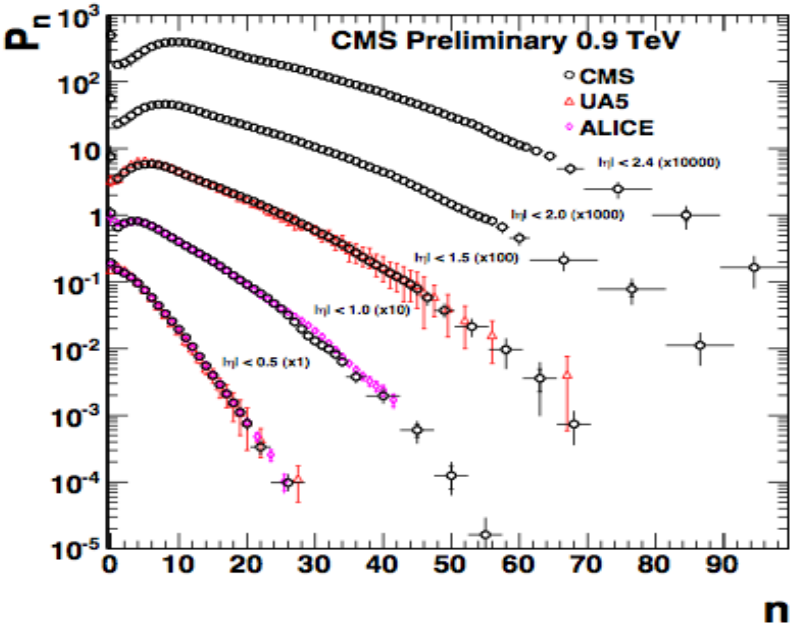
- Scaling function:

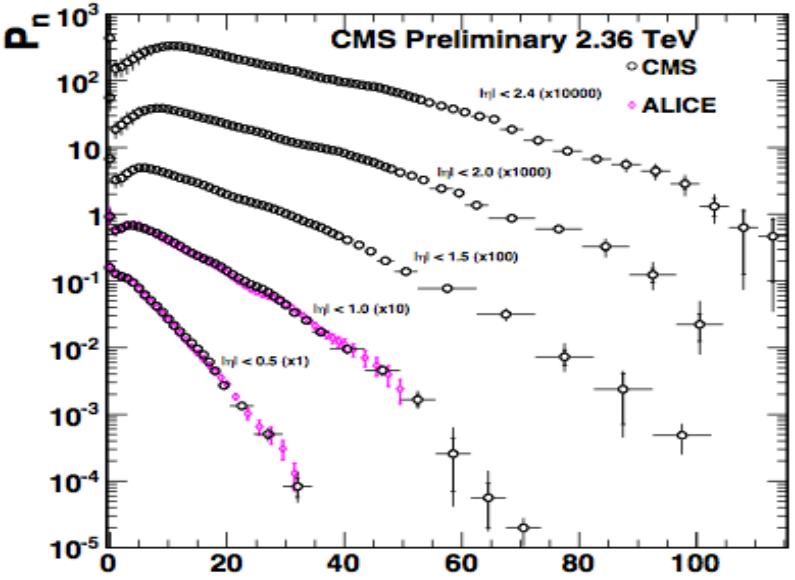
$$\Psi(z) = \langle n \rangle P_n, \text{ with } z = n/\langle n \rangle$$

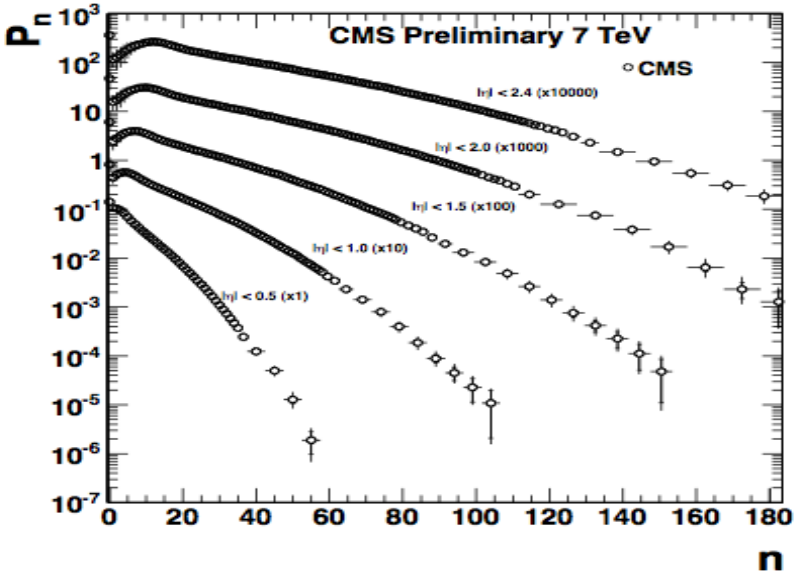
- Moments:

$$C_q = \langle n^q \rangle / \langle n \rangle^q$$

Results for the Probability Distributions



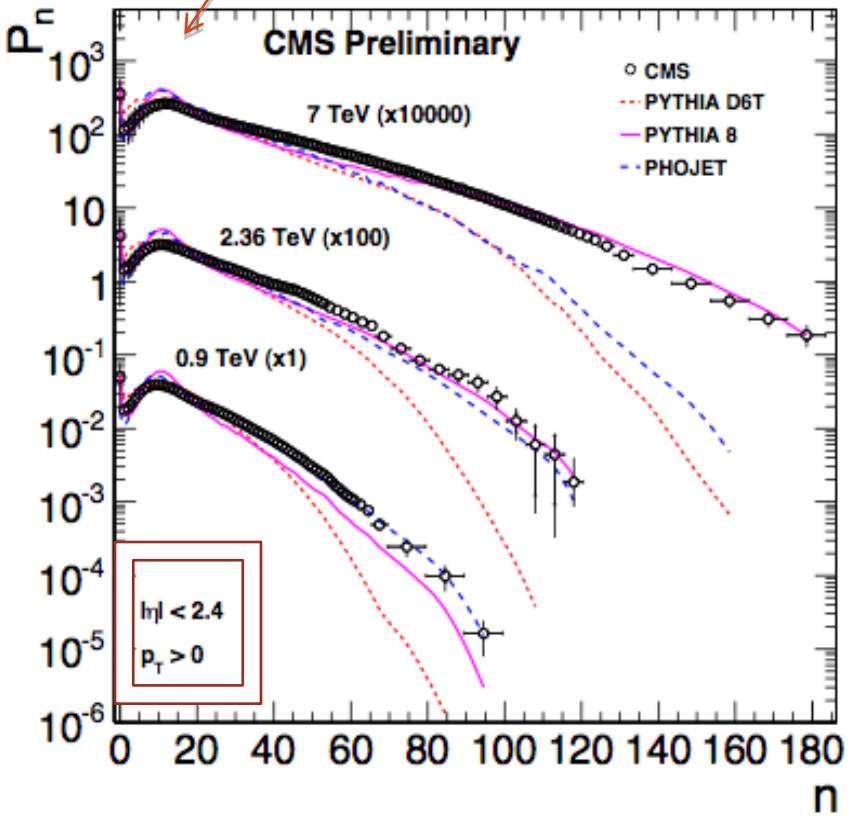


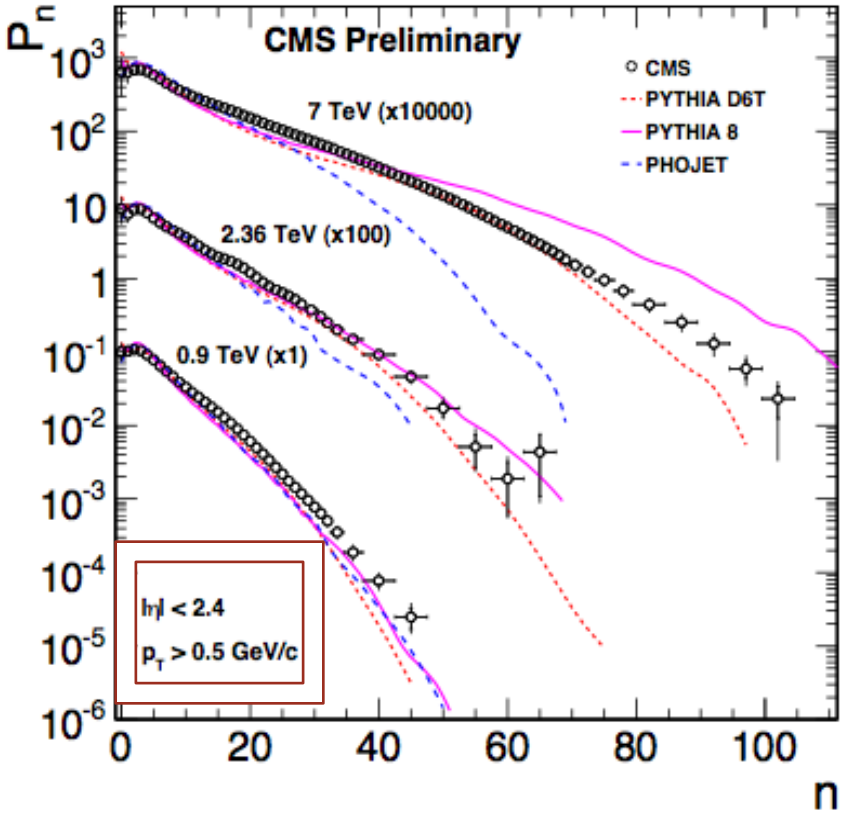


- $P_n = \sigma_n / \sigma$, where σ normalization taken from NSD events
- p_T > 100 MeV, then extrapolate to 0 MeV .The fraction of charged hadrons that is added by extrapolation correction ranges between 5% and 7%

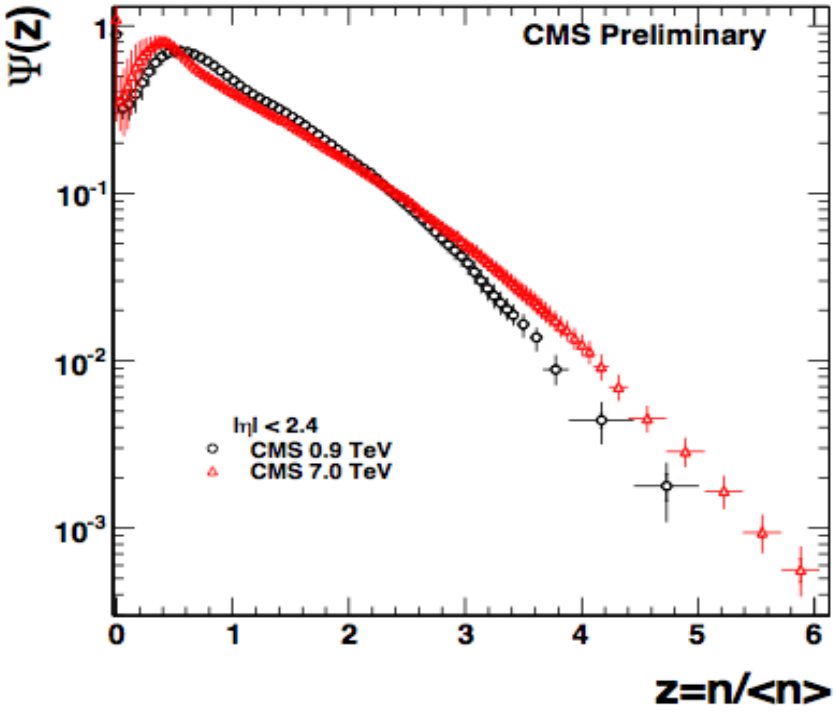
Comparison with Generators

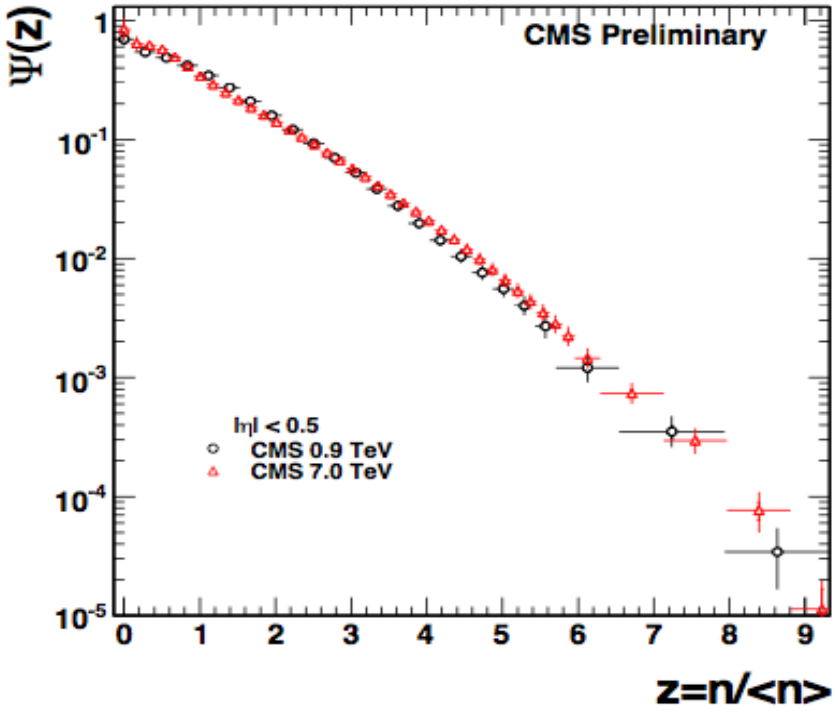
Soft vs Semi hard scatters
& Multi Parton Interactions





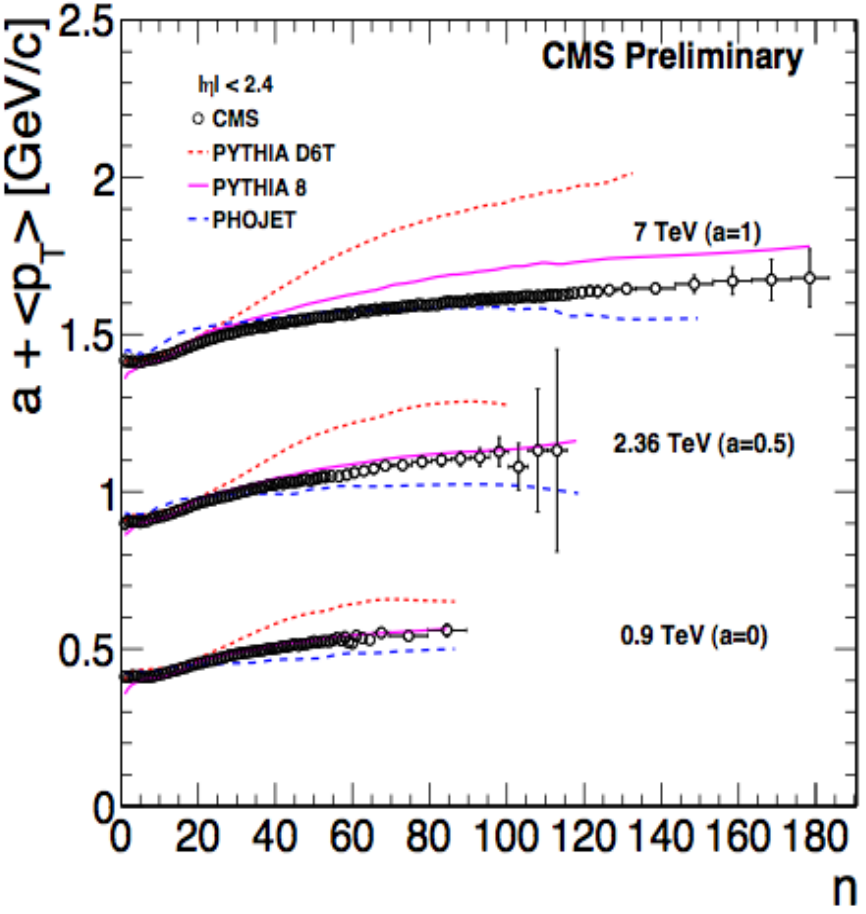
Scaling Functions Results

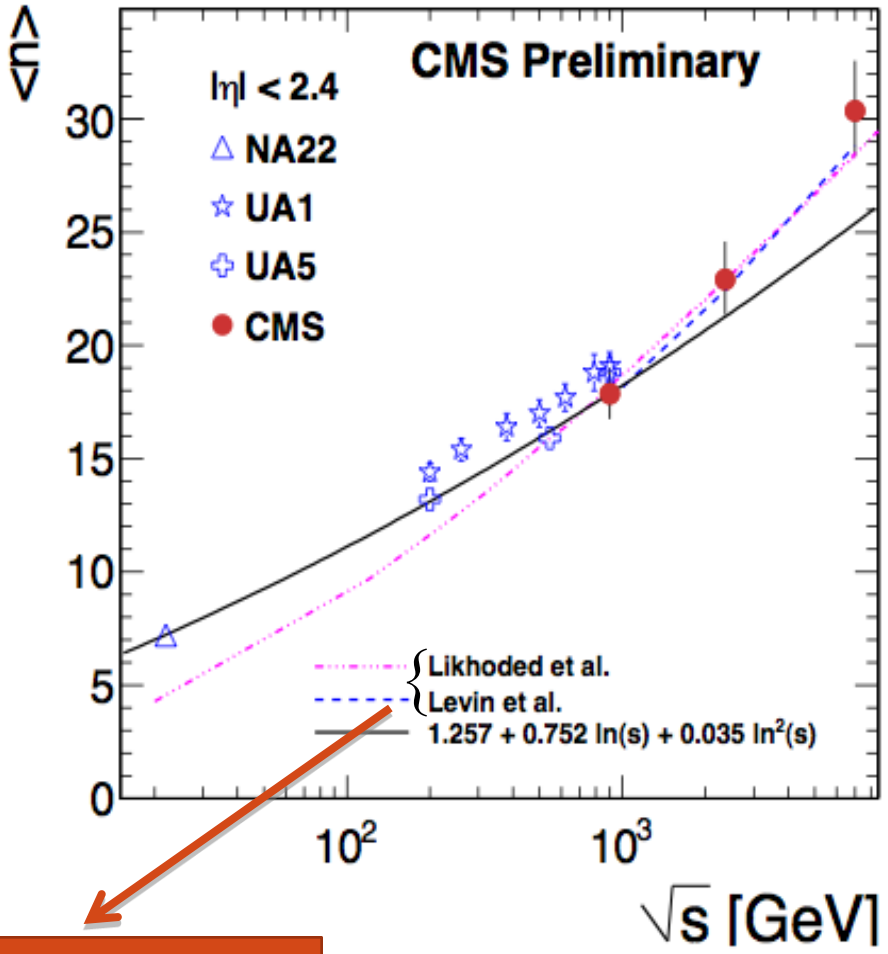




Difference in scaling between $|\eta| < 2.4$ and $|\eta| < 0.5$

Other useful distributions

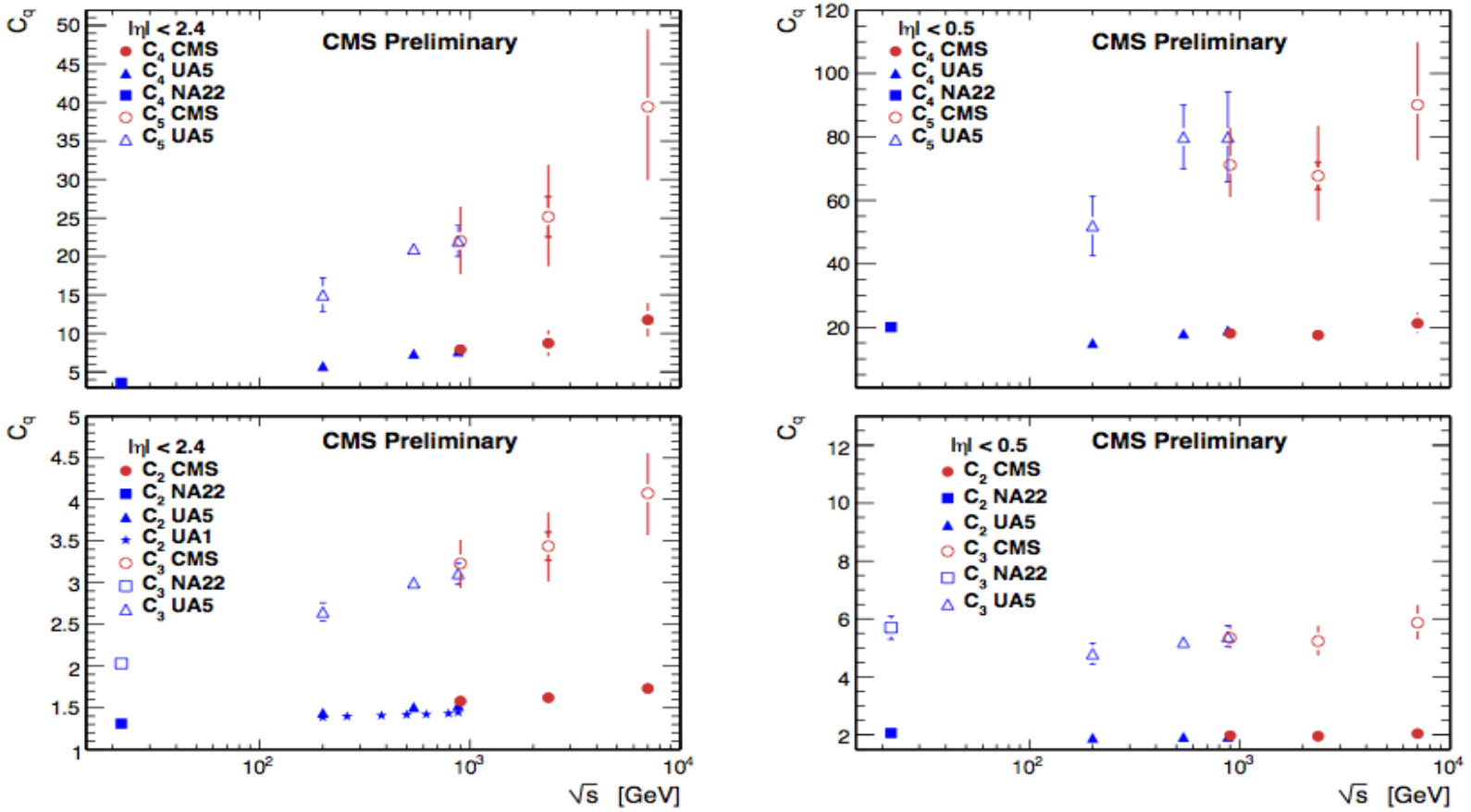




2010 – Recent Theoretical work

C_q Energy Dependence - Scaling Violations

➔ Correlations between particles produced



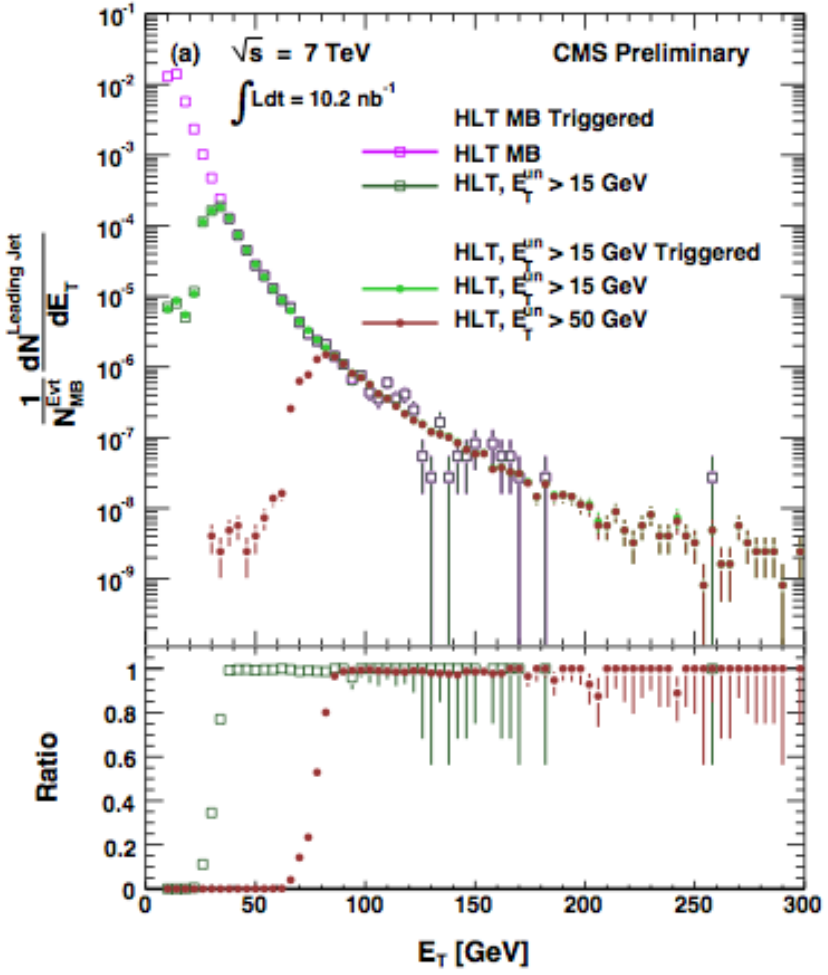
C_q moments increase nearly linearly with log (√s) for 0.5< |η|< 2.4

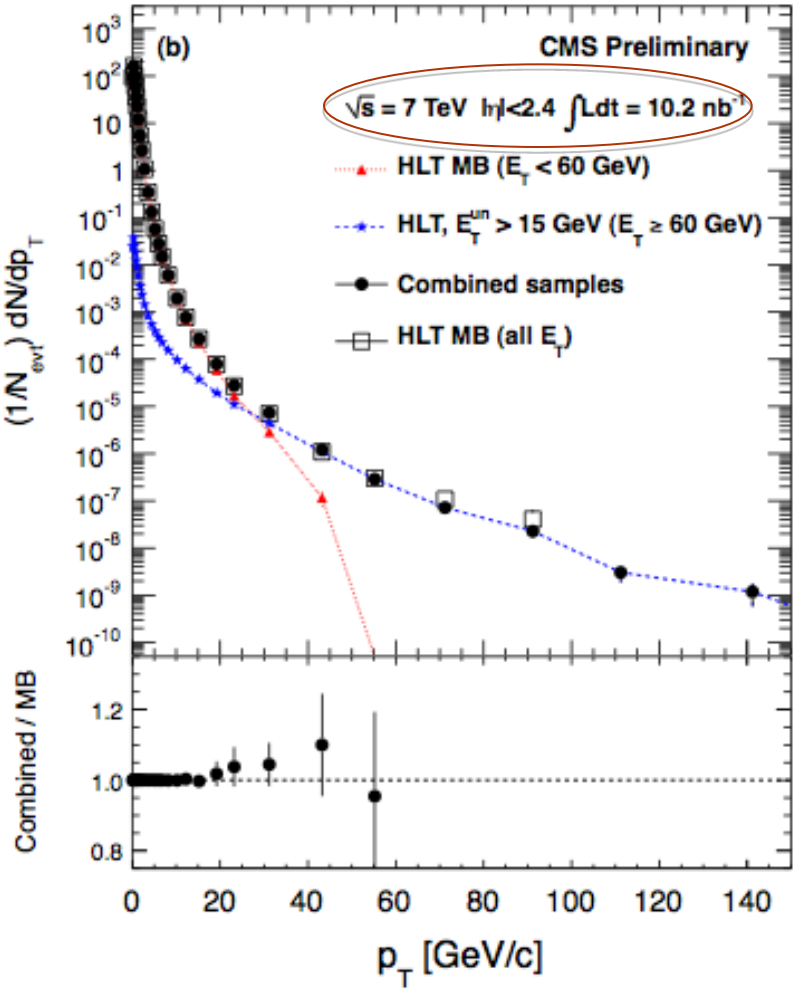
Charged particle transverse momentum spectra

Jet Triggered: CMS PAS QCD-10-008

Minimum Bias: CMS PAPER QCD-10-006 (PRL)

Using Jet Trigger & Minimum Bias

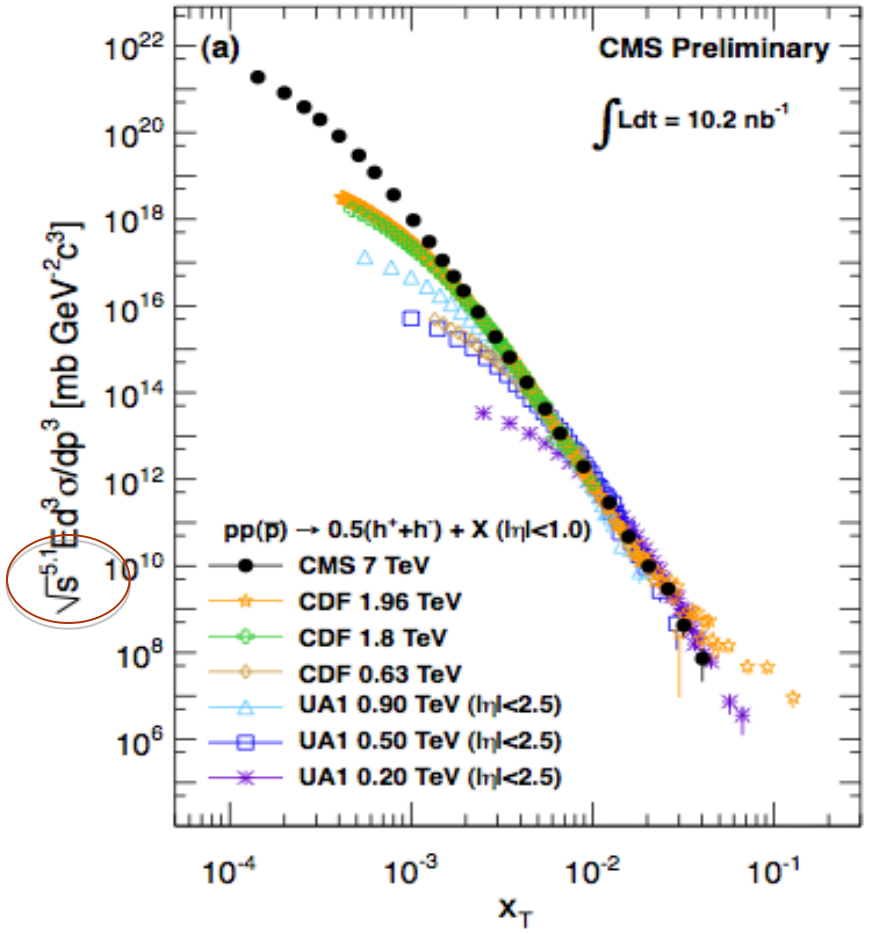


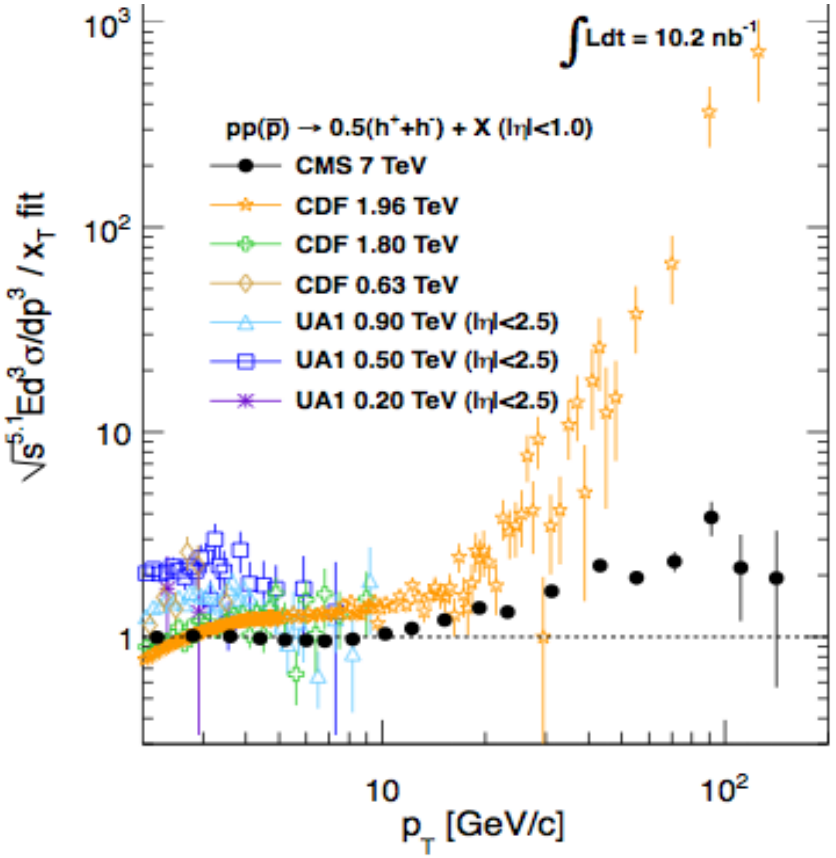


➔ High-E_T jet triggers are employed to enhance yields at high p_T

Comparison of Differential Yield with Previous Experiments:

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

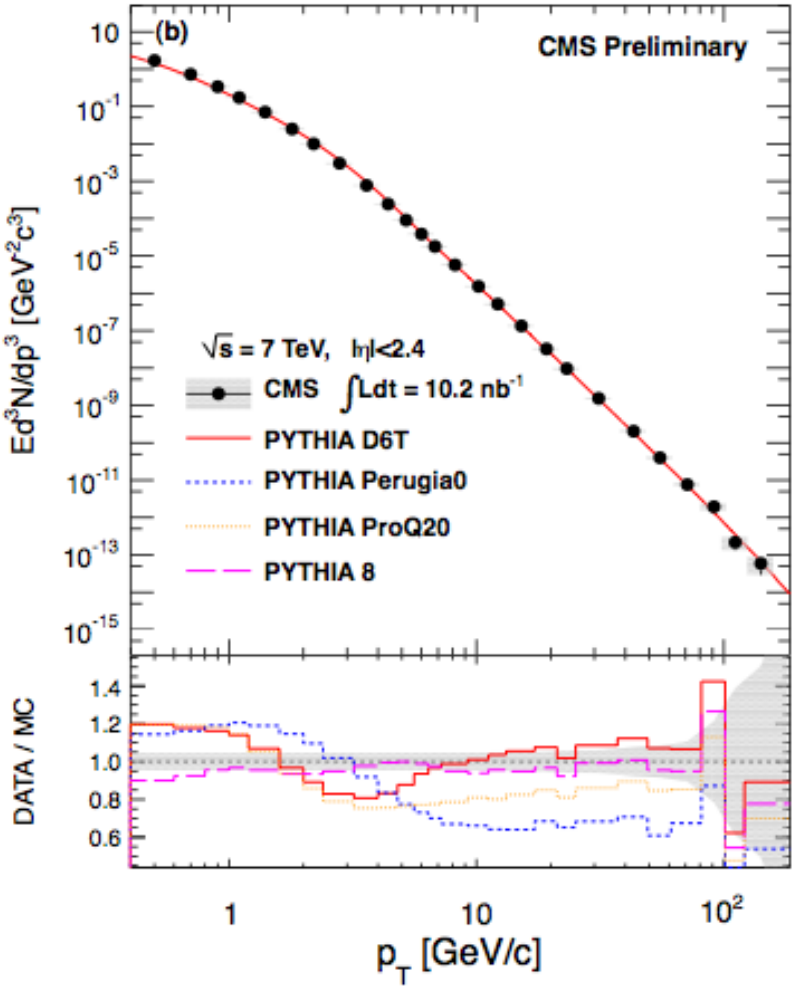




A robust prediction of pQCD hard processes is the power-law scaling of the inclusive invariant cross section with $x_T \equiv 2p_T/\sqrt{s}$

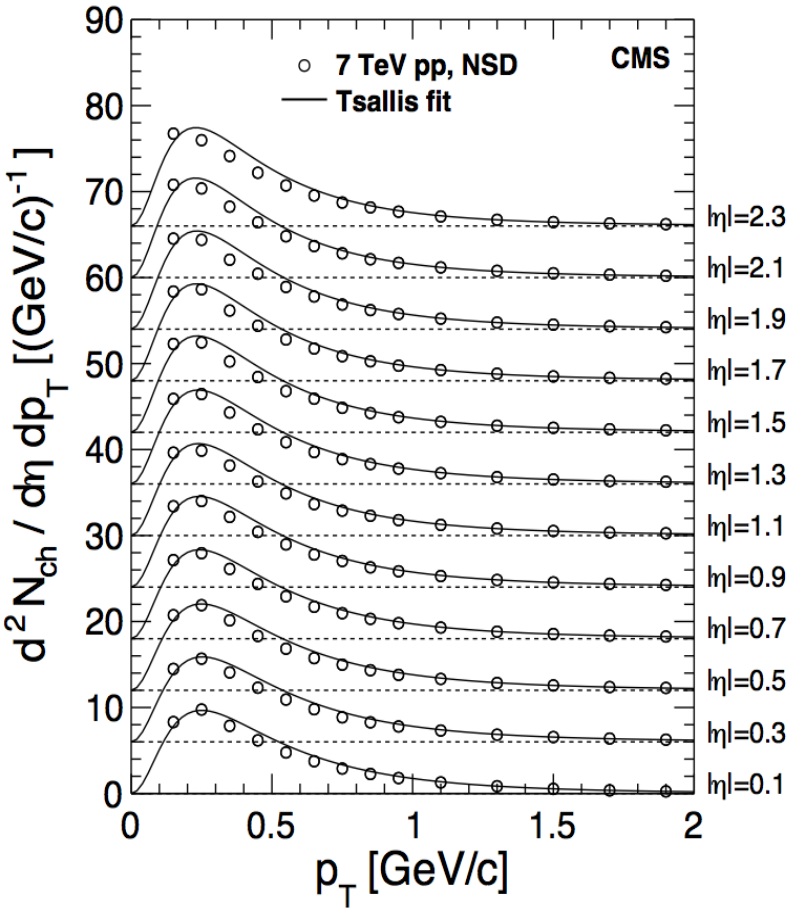
➔ Expected to be valid for $p_T > 2$GeV

Comparison of Differential Yield with Generators including the low p_T



- **The gray band corresponds to statistical plus systematic errors in quadrature.**
- **Pythia – 8 in reasonable agreement**
- **Jet Triggered data note: CMS PAS QCD-10-008**

Differential Yield of Charged Hadrons @ low p_T



Based on Minimum Bias PRL

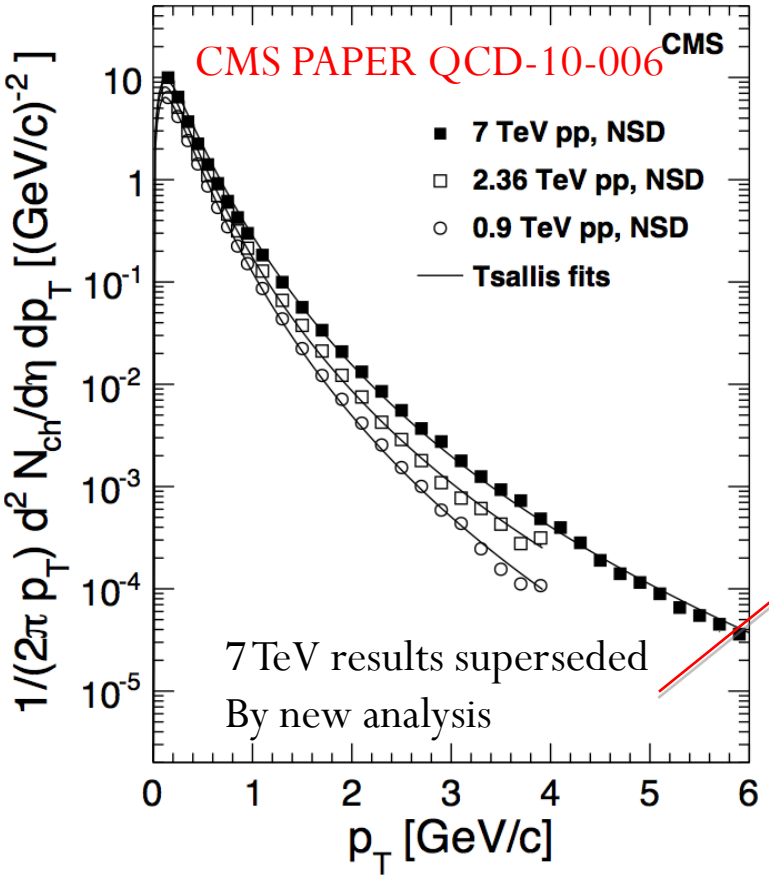
- Minimum p_T 150 MeV
- Fit with Tsallis-Function:

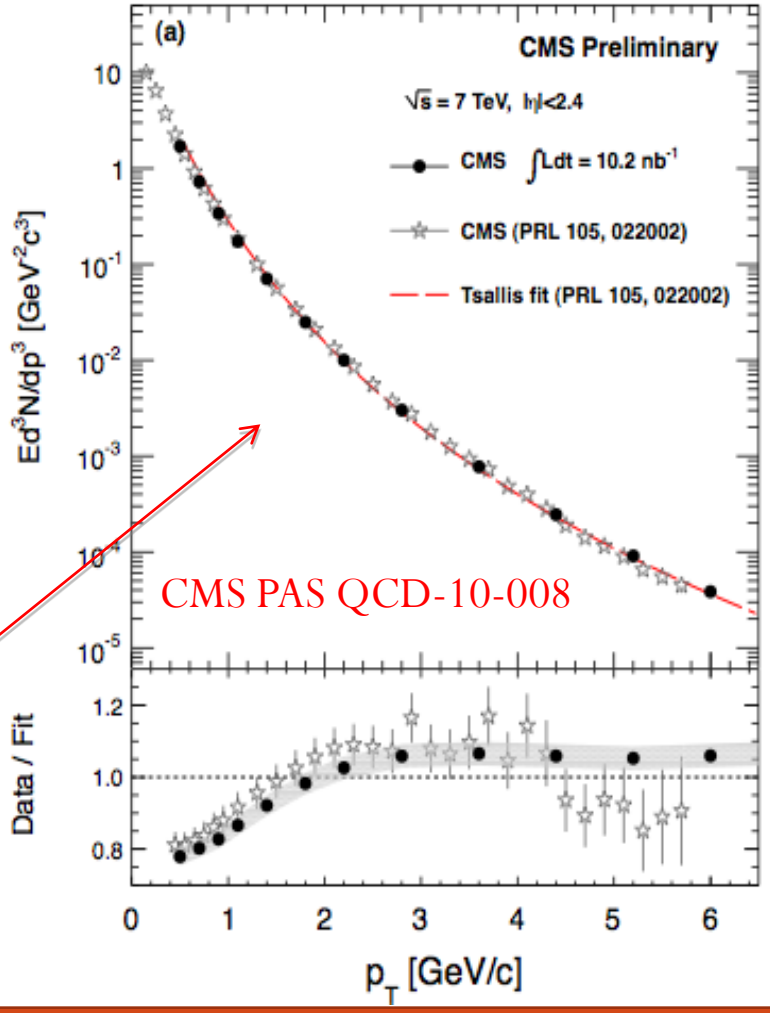
$$E\frac{d^3N_{ch}}{dp^3} = \frac{1}{2\pi p_T}\frac{E}{p}\frac{d^2N_{ch}}{d\eta\, dp_T} = C\frac{dN_{ch}}{dy}\left(1+\frac{E_T}{nT}\right)^{-n}$$

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

- Exponential at low p_T
  - Beam-beam remnant
- Power Law at high p_T
  - Hard parton-parton scattering

As expected: p_T Spectrum gets harder at higher energies

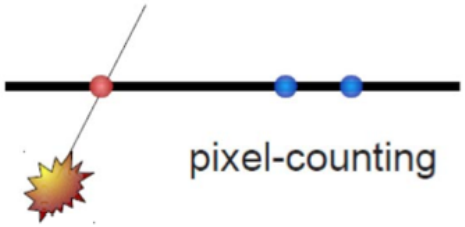


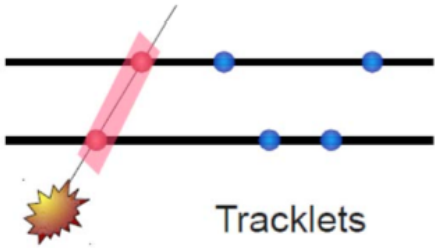


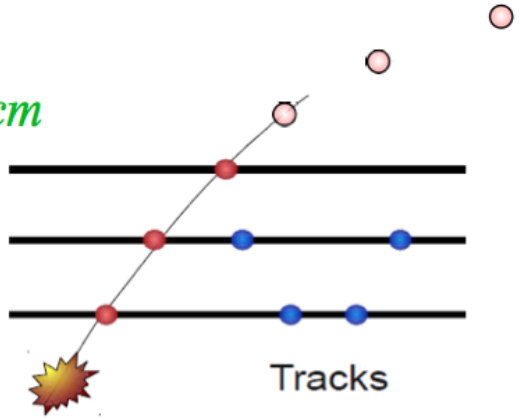
Invariant differential yield for the new analysis (solid circles) & the previous CMS 7 TeV measurement (stars) over the limited p_T range of the earlier result. (Lower) Ratio of the new (solid circles) & previous (stars) CMS results to a Tsallis fit of earlier measurement.

Difference between "new" and "old" result…Further tuning of tracking in 3rd method

Pixel detector: *53.3cm long, 3 layers with radii: 4.4, 7.3, 10.2 cm*







$p_T > 30$ MeV/c

Clusters per layer
$|\eta|<2$
3 measurements of dN/dη
Immune to mis-alignment
Simplest method
Requires noise-free detector

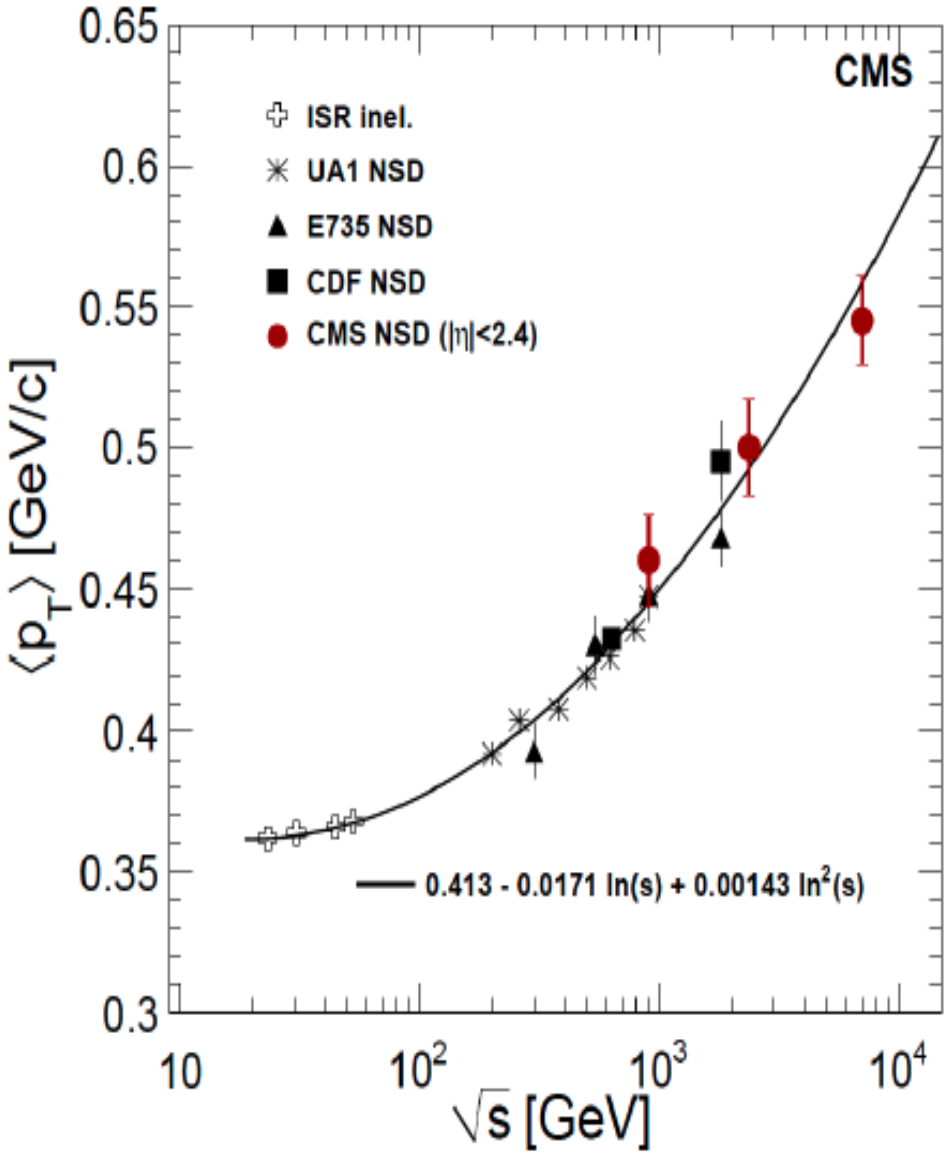
$p_T > 75$ MeV/c

2 of 3 pixel layers
$|\eta|<2$
3 measurements of dN/dη
Sensitive to mis-alignment

Over 50% Efficient for $p_T >$ *0.1, 0.2, 0.3 GeV/c for π, K, p*

Full tracks (pixel and strips)
$|\eta|<2.4$
dN/dη and dN/dp_T
Sensitive to mis-alignment
Most complex

Average p_T of Charged Hadrons

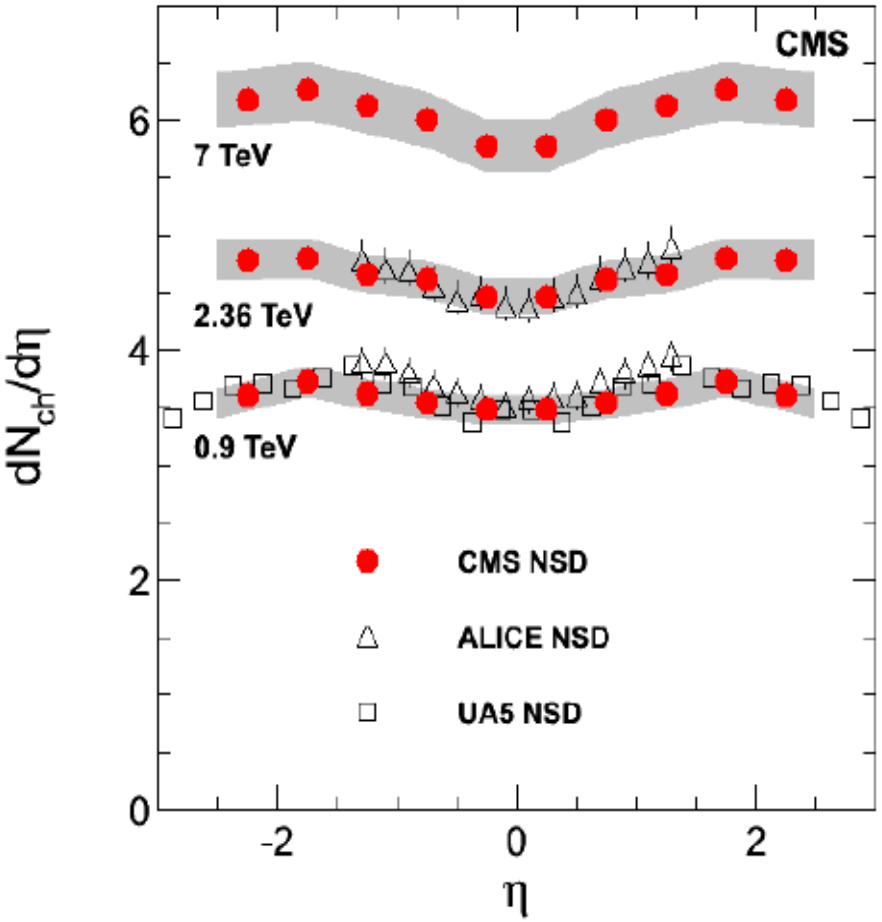


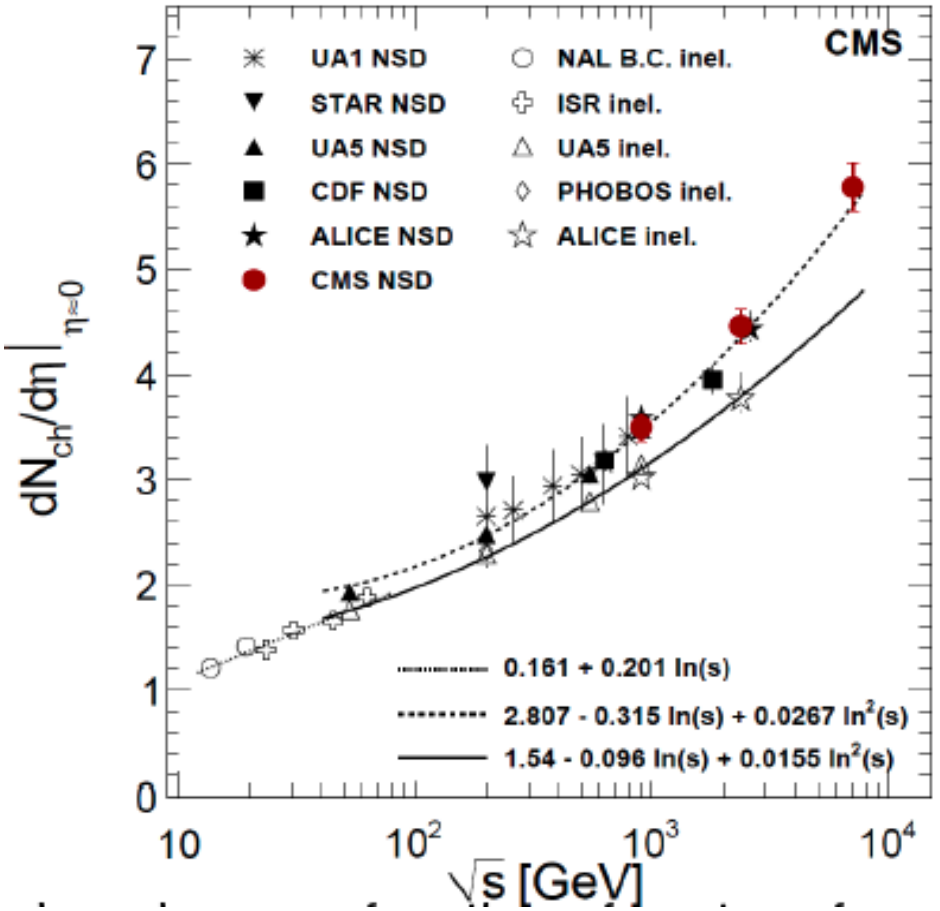
- **The energy dependence of the average charged-hadron p_T can be described by a quadratic function of ln(s)**
- **Minimum Bias: CMS PAPER QCD-10-006 (PRL)**

Charged particle pseudorapidity distributions

Minimum Bias: CMS PAPER QCD-10-006 (PRL)

Pseudorapidity Distributions of Charged Hadrons for NSD Events





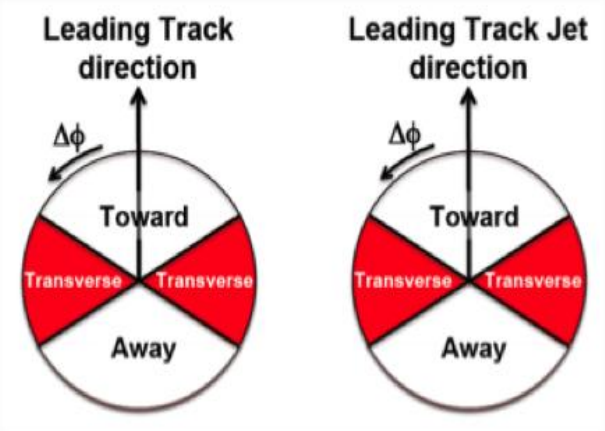
Rise of the particle density at 2.36 & 7 TeV steeper than in model predictions … new analysis for MC tunning underway

Underlying Event

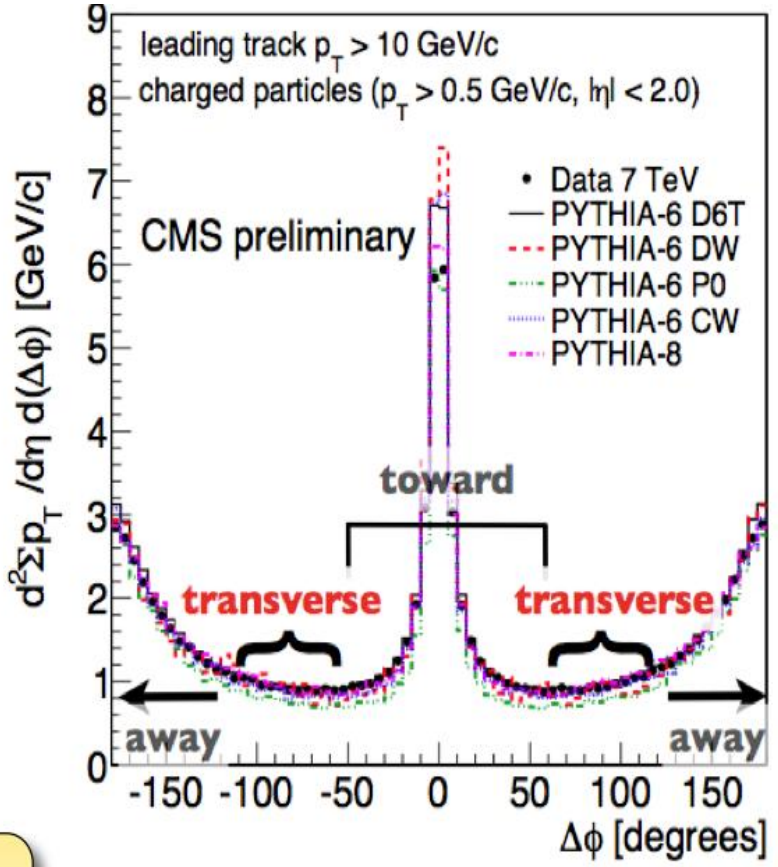
PAS-QCD-10-001

PAS-QCD-10-010

Basic Information



- Traditional approach (R. Field)
  - **Leading Track or Leading Track-Jet** define a direction in the phi plane
  - Track or Track-jet p_T provide an energy scale



Main observables, built from Tracks:

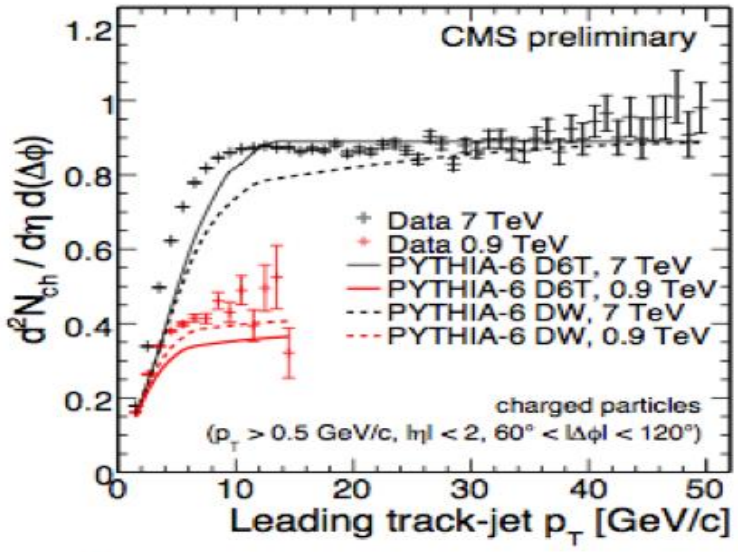
$d^2N_{ch}/d\eta d\Phi$	charged mult. density
$d^2Sum(PT)/d\eta d\Phi$	energy density

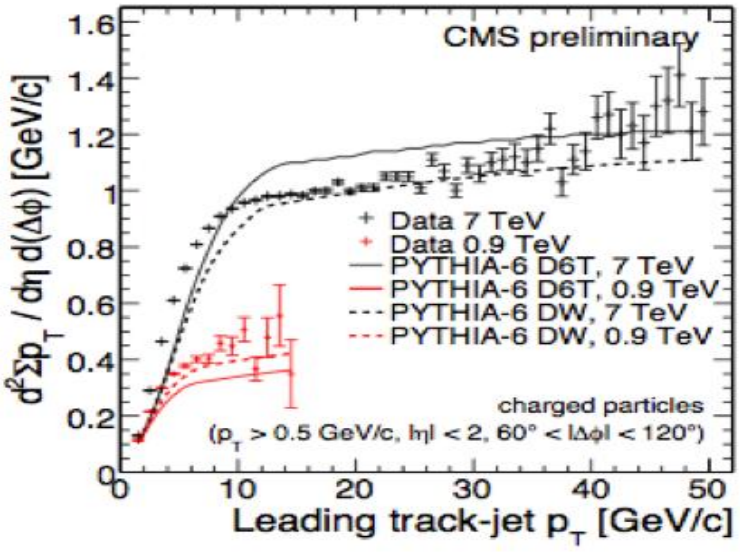
Note : so far data were not corrected for detector effects. Efforts in this direction under way

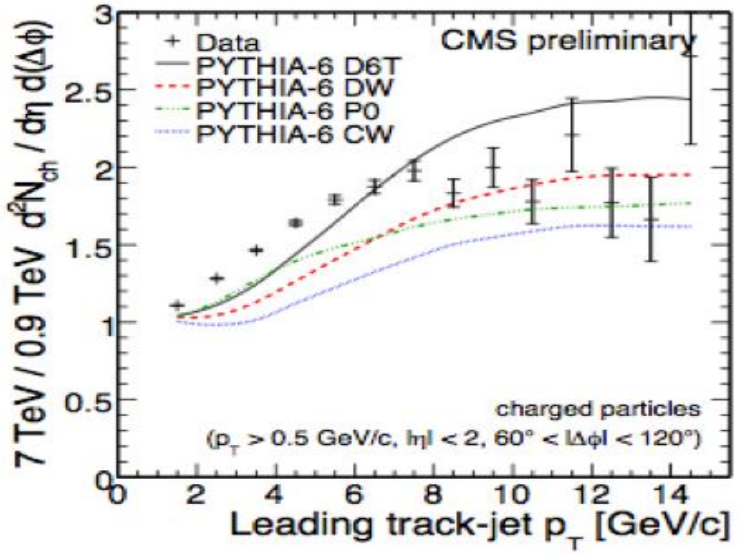
- Transverse region expected to be particularly sensitive to the UE

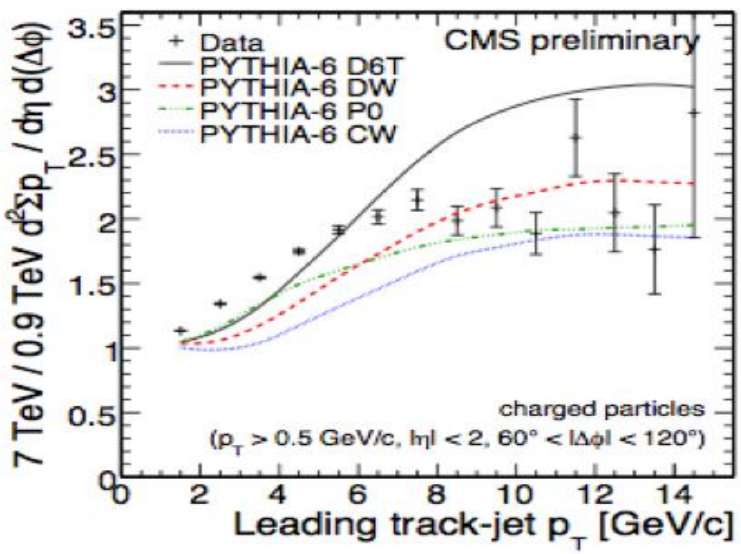
see QCD-10-001 and QCD-10-010

Energy Dependence









Conclusions...

- Strange Particle:
  - production at all energies is underestimated by available generator
  - …so is the relative increase between 0.9 and 7 TeV
- Charged Particle Multiplicity
  - Scaling violations observed - Cq grows linearly with log ($\sqrt{s}$)
  - Reasonable agreement with Pythia-8 for 0.9 and 2.36 TeV, but overestimates multiplicity at 7 TeV
- Charged Particle Transverse momentum spectra at 7 TeV
  - At high p_T behaves as expected by pQCD contrary to CDF results
  - At low p_T our new results are superseed previous CMS results
- Charged Particle Pseudorapidity distributions
  - Underestimated by current models, but empirical fit possible
- SD unambiguously observed

➔ Good references for MC tuning & for future suppression measurements in Dense QCD medium produced in PbPb collision are now available