Latest CMS Minimum Bias Results

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MBUEWO

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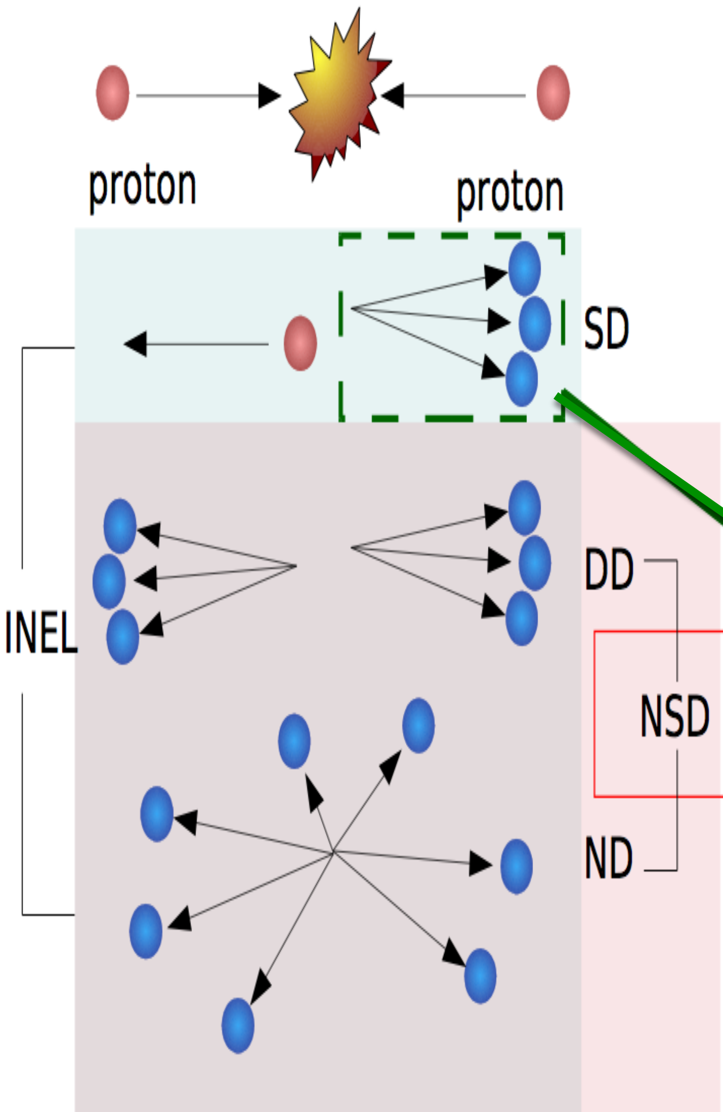
Introduction I

- Majority of the particles produced in pp collisions arise from soft interactions, which are only modeled phenomenologically
  - models must tuned/validated with experimental results

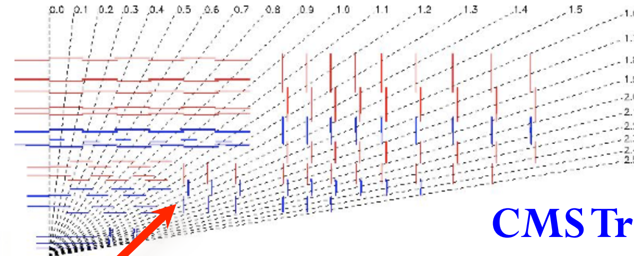
- Today, we will present a new set of results to be used as input to that modeling work and event generator tuning based on minimum bias data collected at CMS in pp collisions:
  1. Strange Particle Production at $\sqrt{s} = 0.9$ & 7 TeV
  2. Charged Particle Multiplicities at $\sqrt{s} = 0.9$, 2.36, & 7.0 TeV
  3. Charged Particle Transverse Momentum Spectra at 7 TeV
     ➔ Emphasis on large p_T
  4. 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

Introduction II



- Data used has a natural admixture of soft, semi-hard, hard scatters and multiple particle interactions
- Not all soft processes are kept in the analyses to be discussed (1-4):
  - elastic scattering
  - single-diffractive } excluded
  - double-diffractive
  - non-diffractive } included NSD
- Single–Diffraction (**SD**) was observed with an independent analysis and results will be presented today as well

CMS Detector

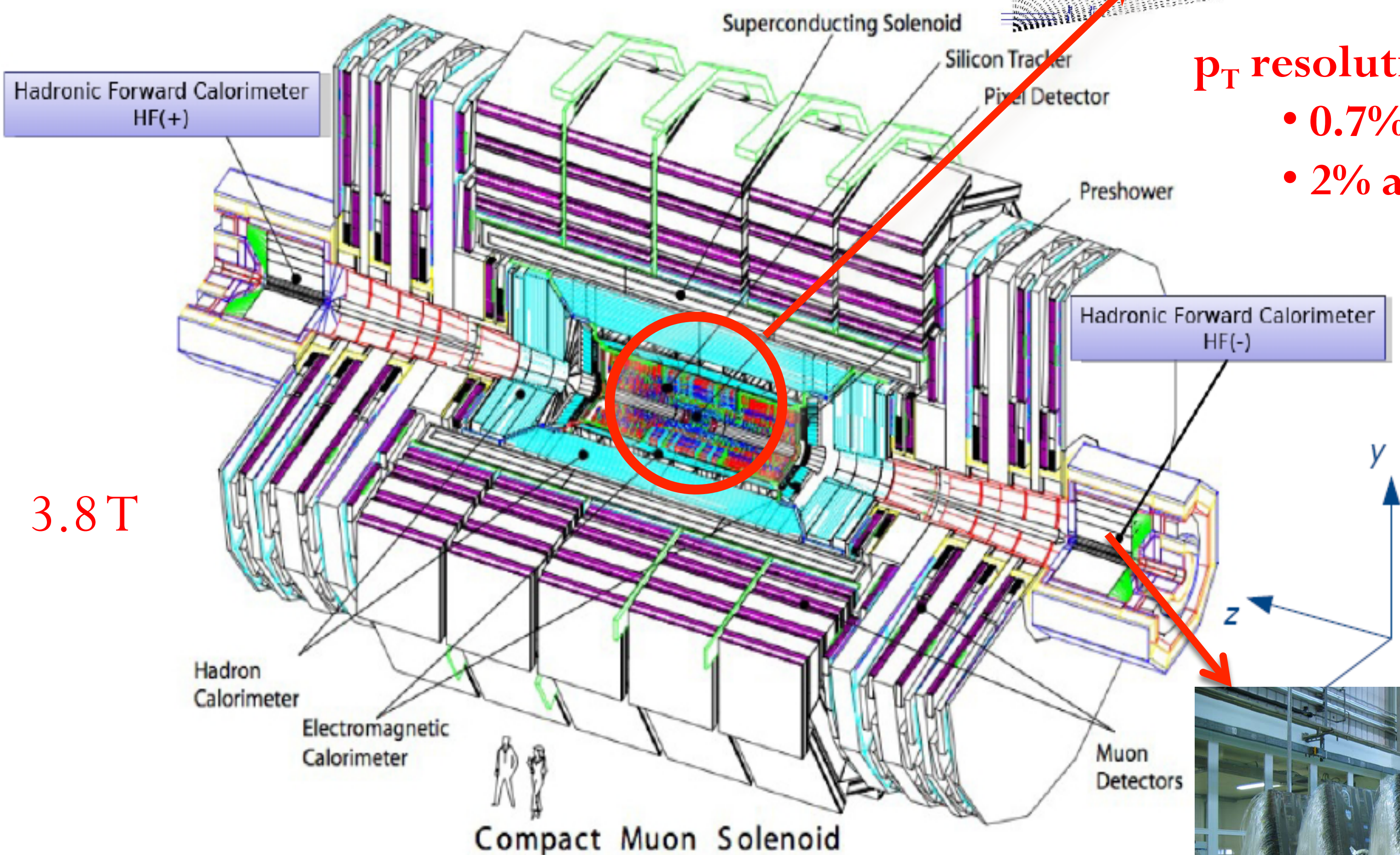


CMS Tracker

p_T resolution @ 1 GeV/c:

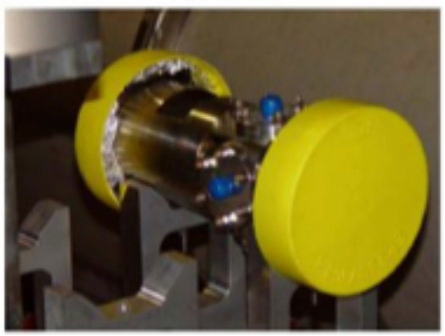
- 0.7% at $\eta = 0$
- 2% at $|\eta| = 2.5$

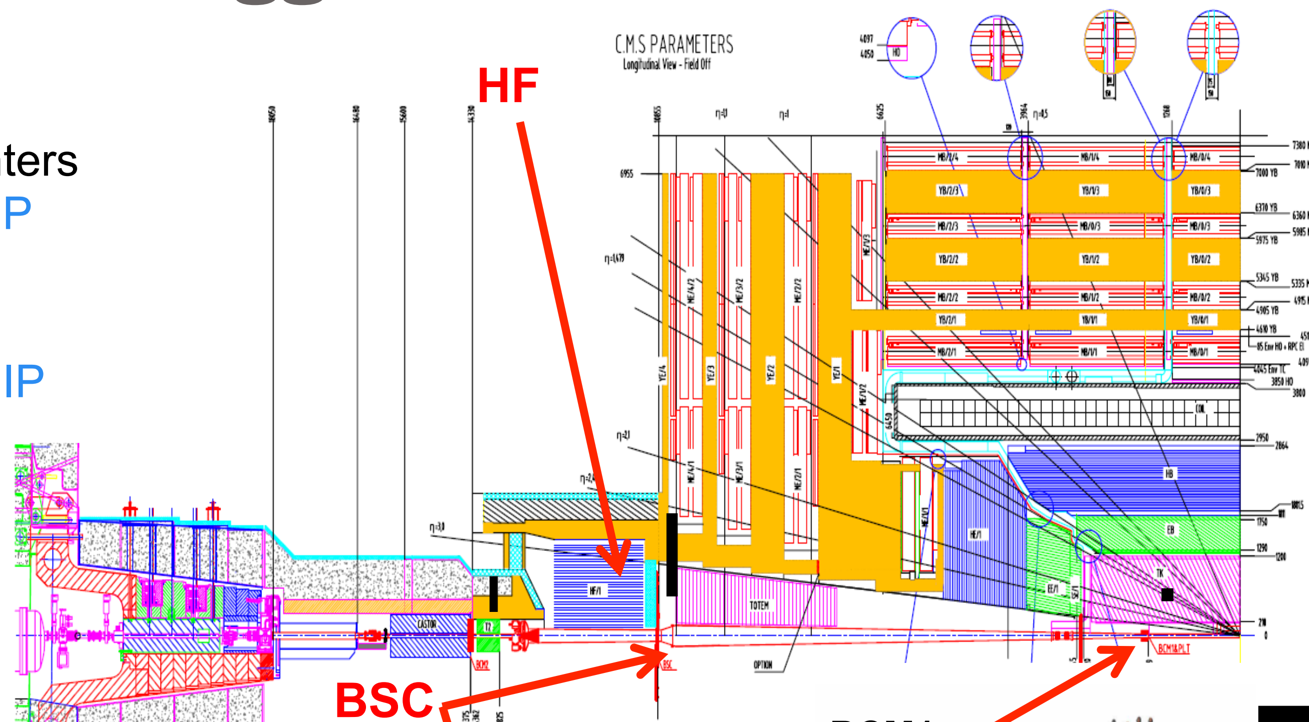
3.8 T

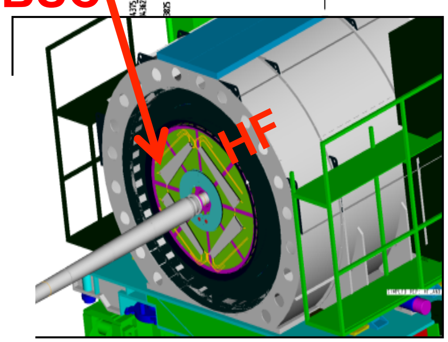


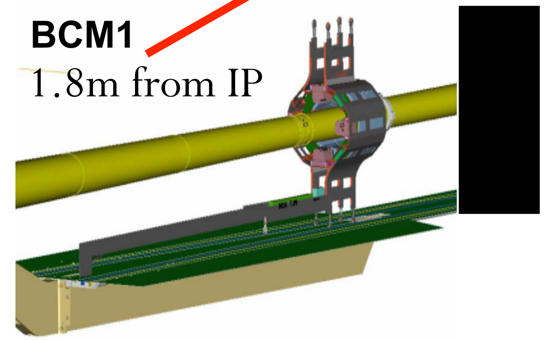
Minimum Bias Trigger and FW HCal

- HCAL Forward
  - HF: $2.9 \leq |\eta| \leq 5.$
- Beam Scintillator Counters
  - BSC: ± 10.5 m from IP
  - $3.23 \leq |\eta| \leq 4.65$
- Beam Pick-up Timing
  - BPTX: ± 175 m from IP









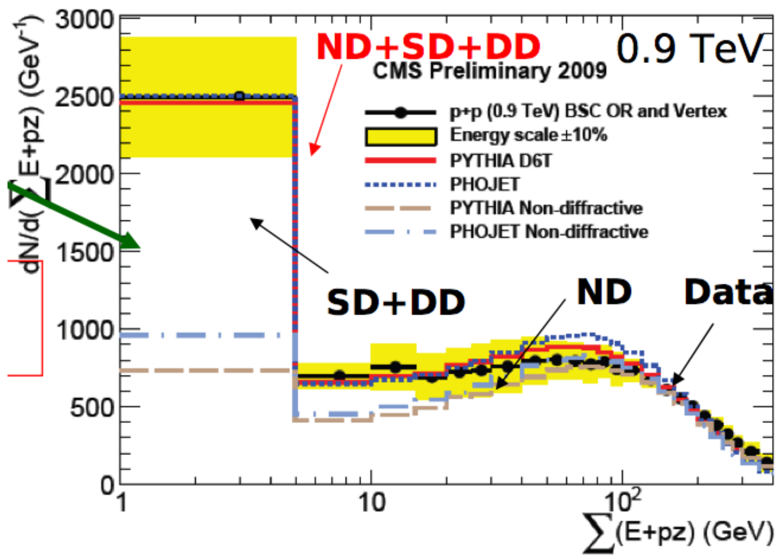
- Trigger: Min Bias & Zero Bias
  - L1 Beam Scintillator Counters “BSC”
  - L1 Trigger “BPTX”
- Minimum Bias selection:
  - BPTX+BSC(OR)+ vertex: $\epsilon \sim 90\%$
  - HF (E > 3 GeV both sides): $\epsilon \sim 90\%$
  - !(BSC Halo) + track quality for further rejection of beam gas interactions

Main requirement to reject single-diffraction (SD) events and define Non-diffracting (NSD) signal

Trigger and data selection NSD & rejection of SD

Checks with data

$$\Sigma(E+p_z) = \Sigma E(1+\cos\Theta) = \Sigma(p_T e^{\eta})$$

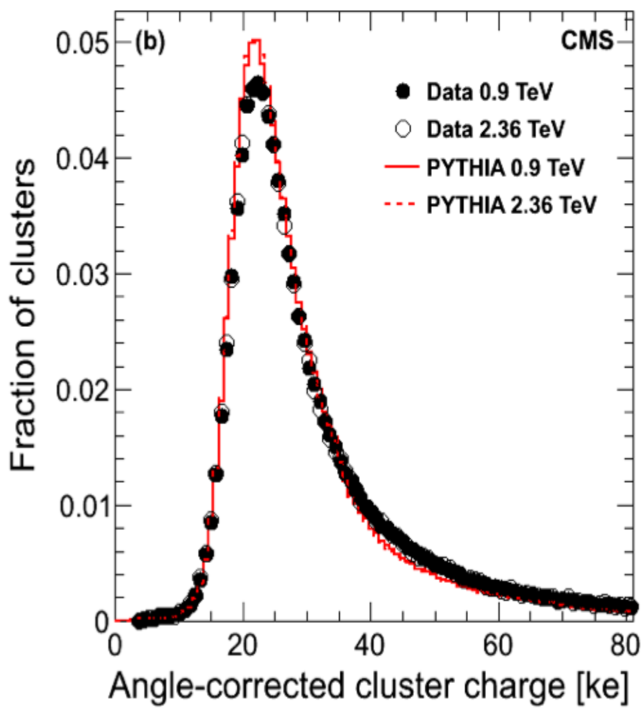


Checks with MC

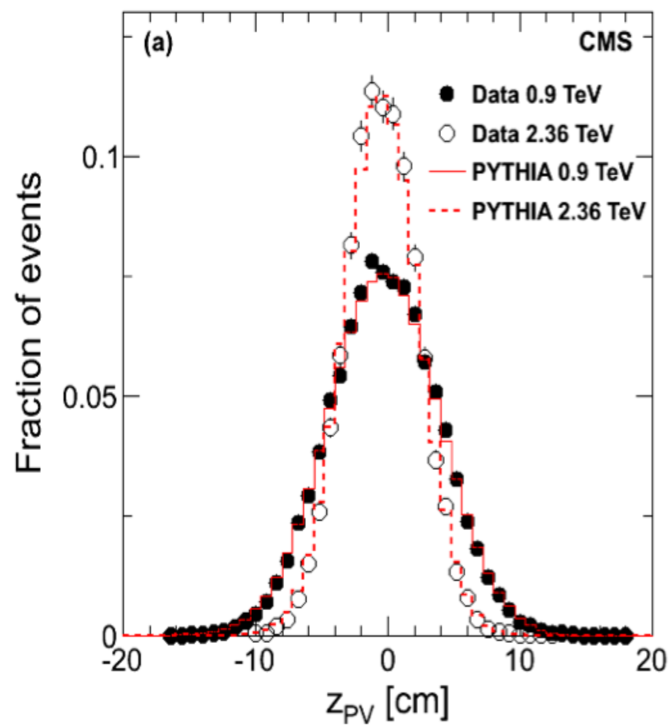
- High NSD trigger acceptance > 85%
- SD contamination after event selection 5-6%
- Difference between Phojet SD definitions and Pythia is at the level of 2%

Tracker Performance

- The CMS silicon pixel and strip tracker detectors were used
- Pixels: three 53.3 cm long layers with radii 4.4, 7.3, 10.2 cm
- >97% of all channels were operational, hit efficiency optimized



The energy loss in the tracker layers well described by MC



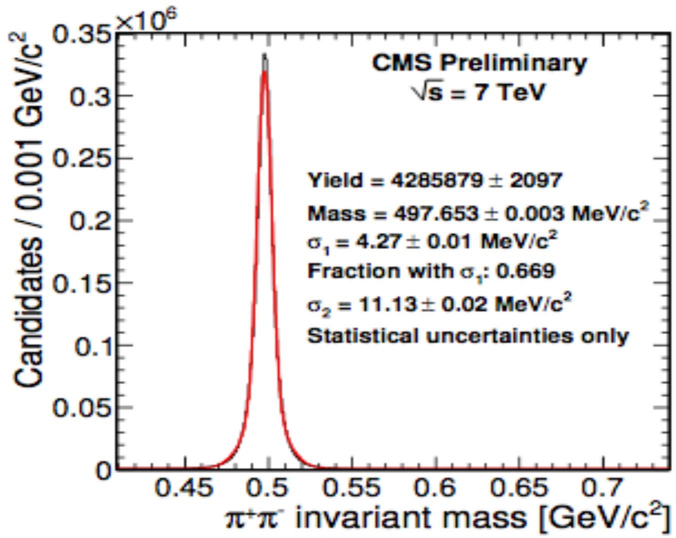
The vertex position distributions are clean Gaussians, with no tails

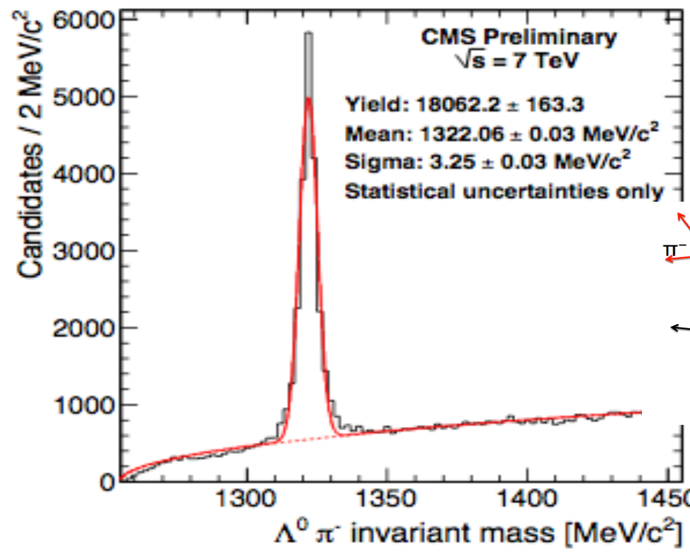
Strange Particle Production

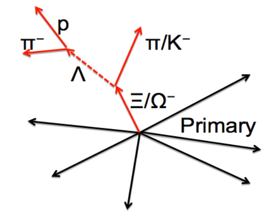
Ks, Λ & Ξ

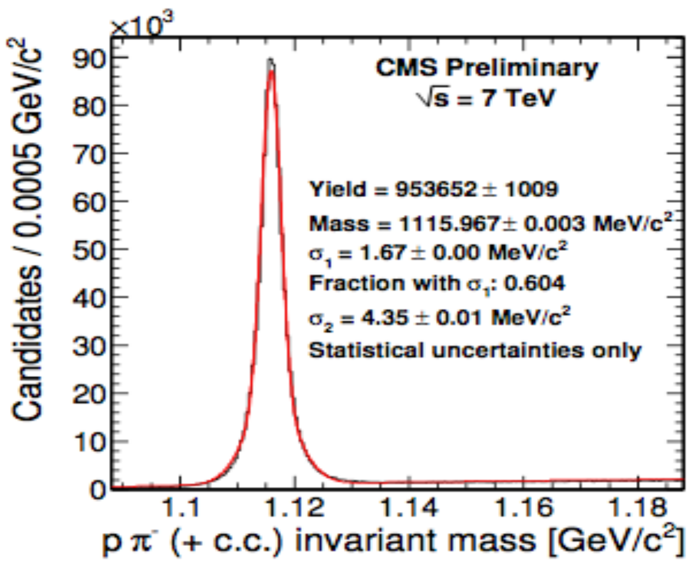
CMS PAS QCD-10-007

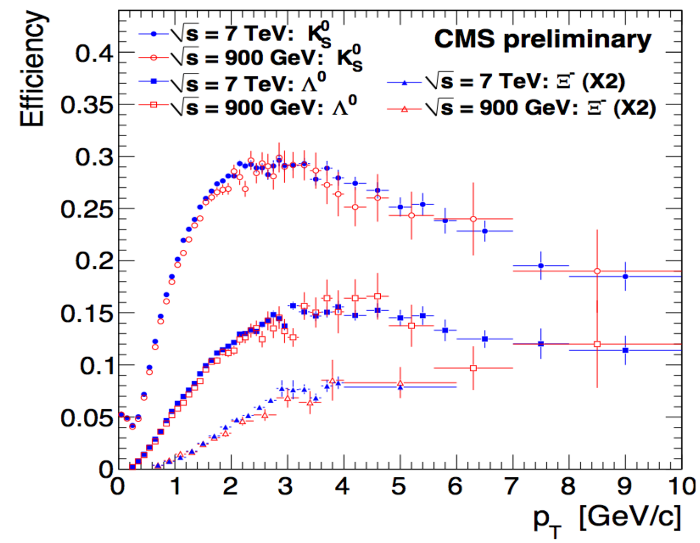
Strange Particles Decays



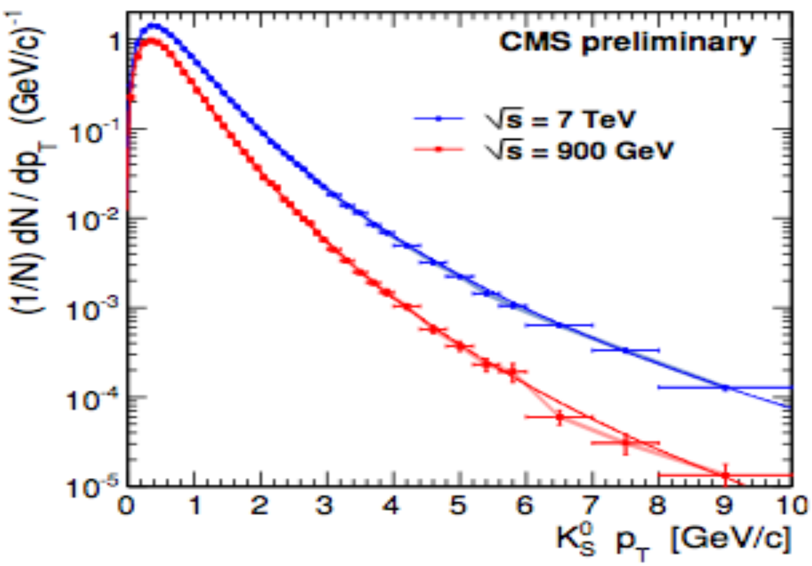




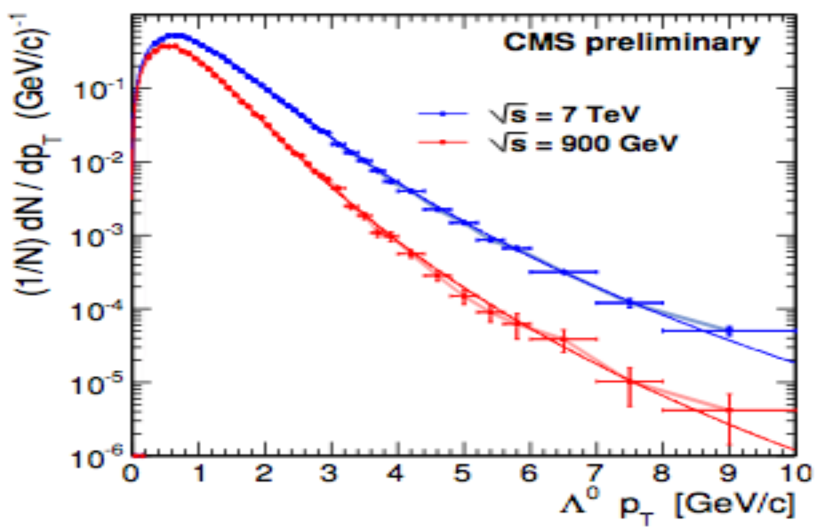


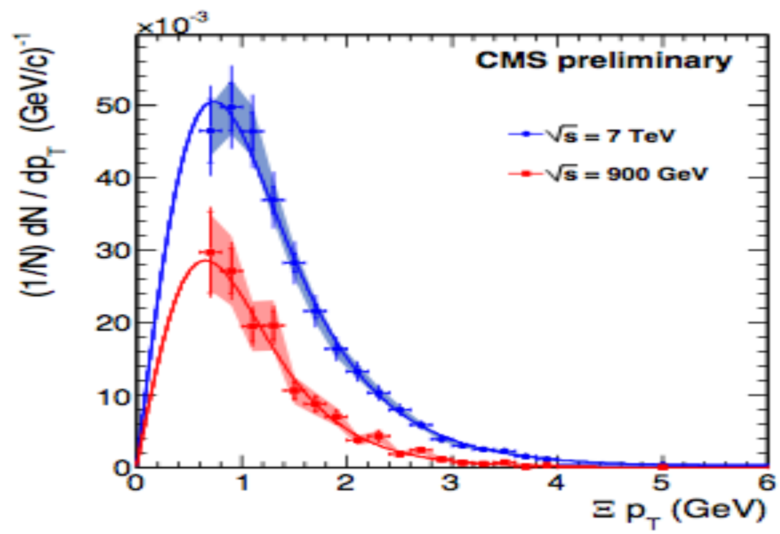


Strange Hadron Spectra

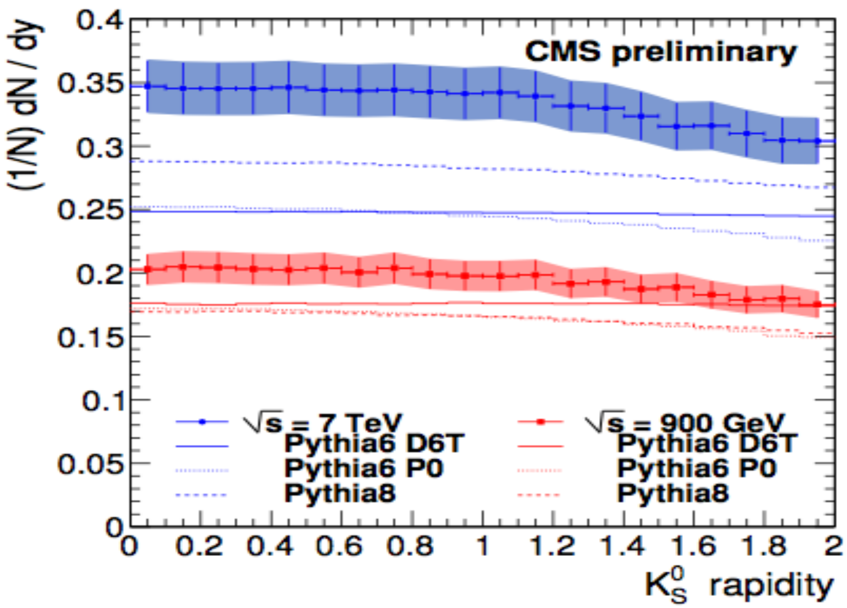


- Only NSD interactions
- Normalized to number of NSD
- Solid line is a fit to Tsallis function
- Band error due to normalization

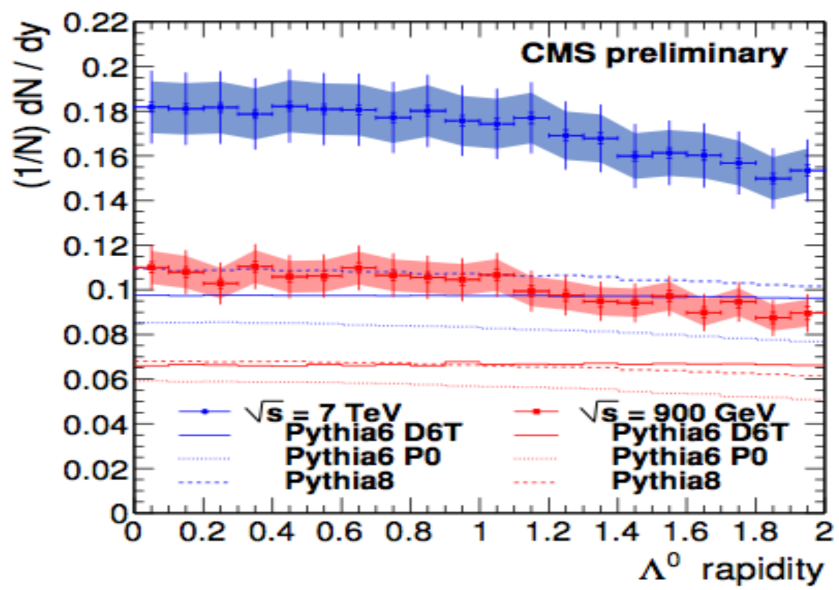


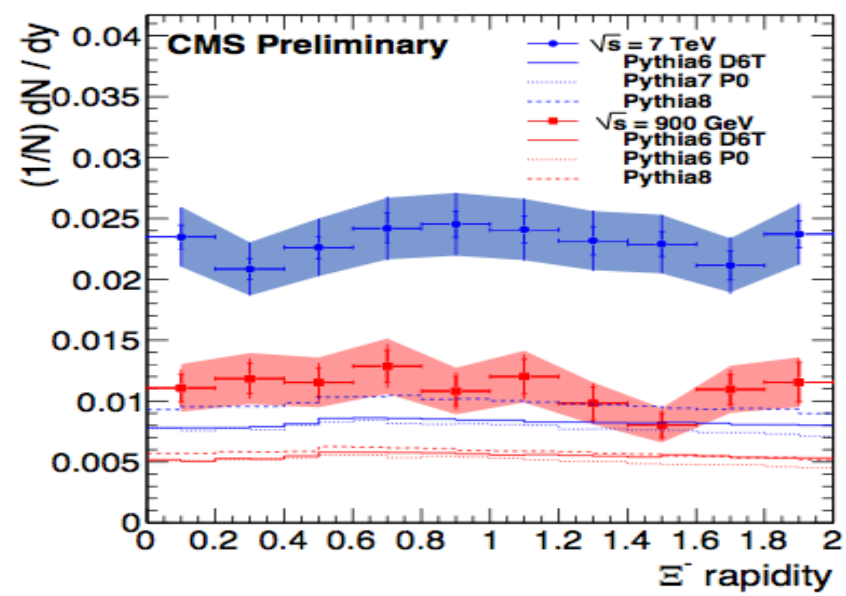


Comparison with various generators



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





Comparison with previous experiments & event Generator

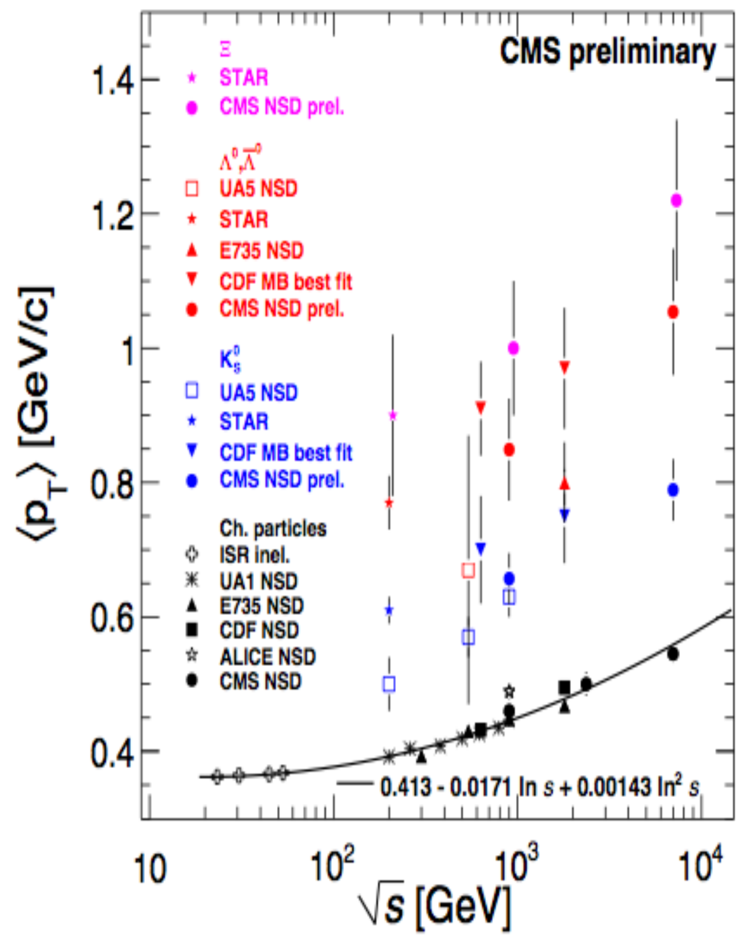
Simulation

Particle	$\sqrt{s} = 0.9$ TeV: T (GeV)	n	$<p_T>_{\text{Tsallis}}$ (GeV/c)	$<p_T>_{\text{true}}$ (GeV/c)	$\sqrt{s} = 7$ TeV: T (GeV)	n	$<p_T>_{\text{Tsallis}}$ (GeV/c)	$<p_T>_{\text{true}}$ (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	$\frac{dN}{dy}\|_{y=0}(7\,\text{TeV}) / \frac{dN}{dy}\|_{y=0}(0.9\,\text{TeV})$: Data	PYTHIA D6T	$\frac{dN}{dy}\|_{y=0}(\text{PYTHIA D6T}) / \frac{dN}{dy}\|_{y=0}(\text{Data})$: 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	$0.48 \pm 0.05 \pm 0.09$	$0.33 \pm 0.02 \pm 0.05$

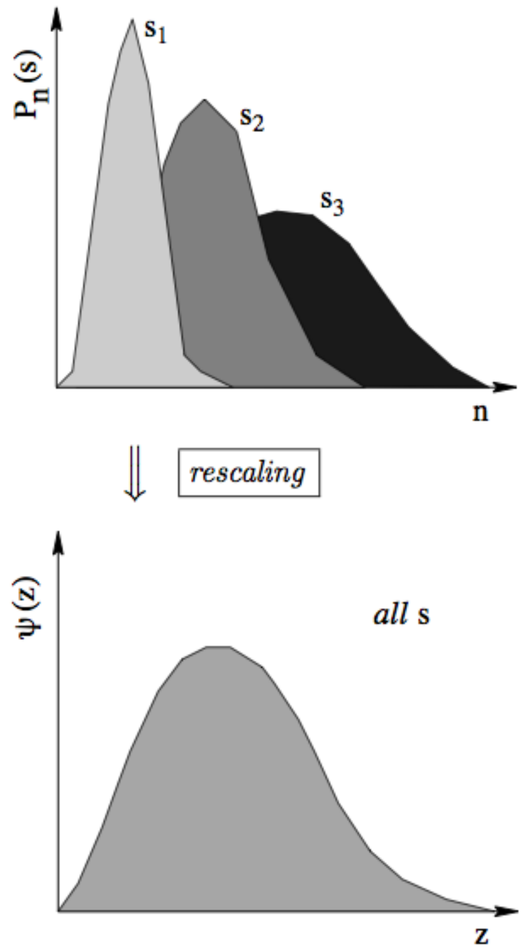
Data



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 :

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

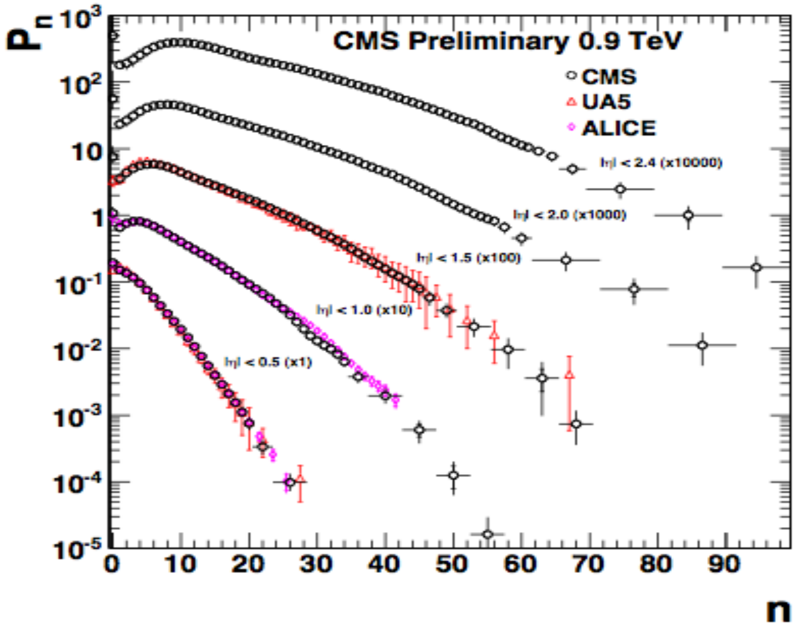
- Scaling function:

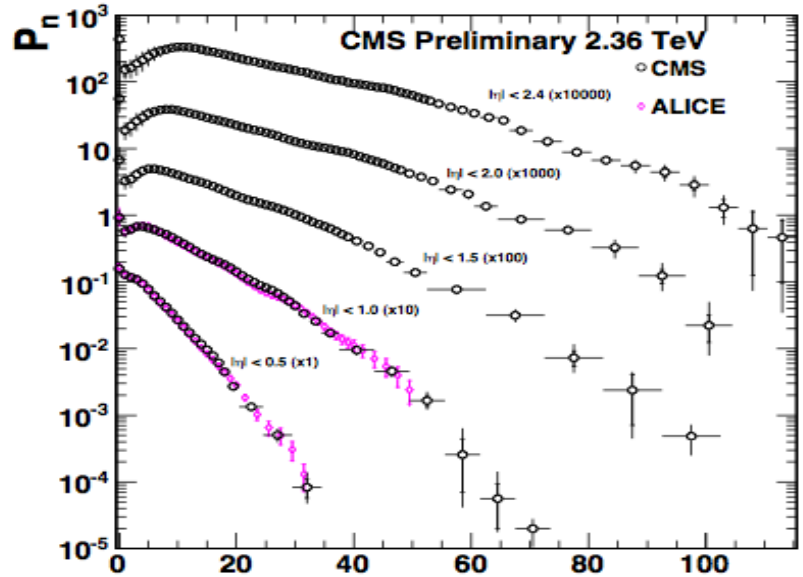
$$\Psi(z) = \langle n\rangle P_n, \text{ with } z = n/\langle n\rangle$$

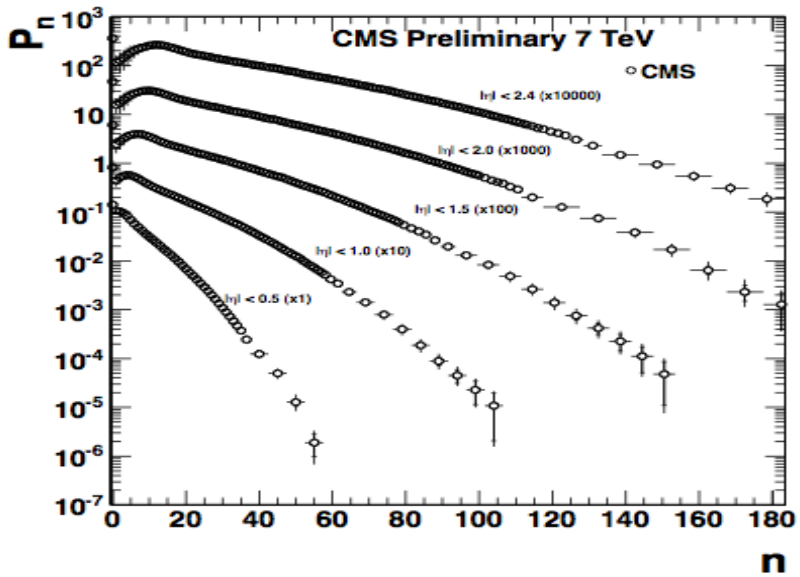
- Moments:

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

Results for the Probability Distributions



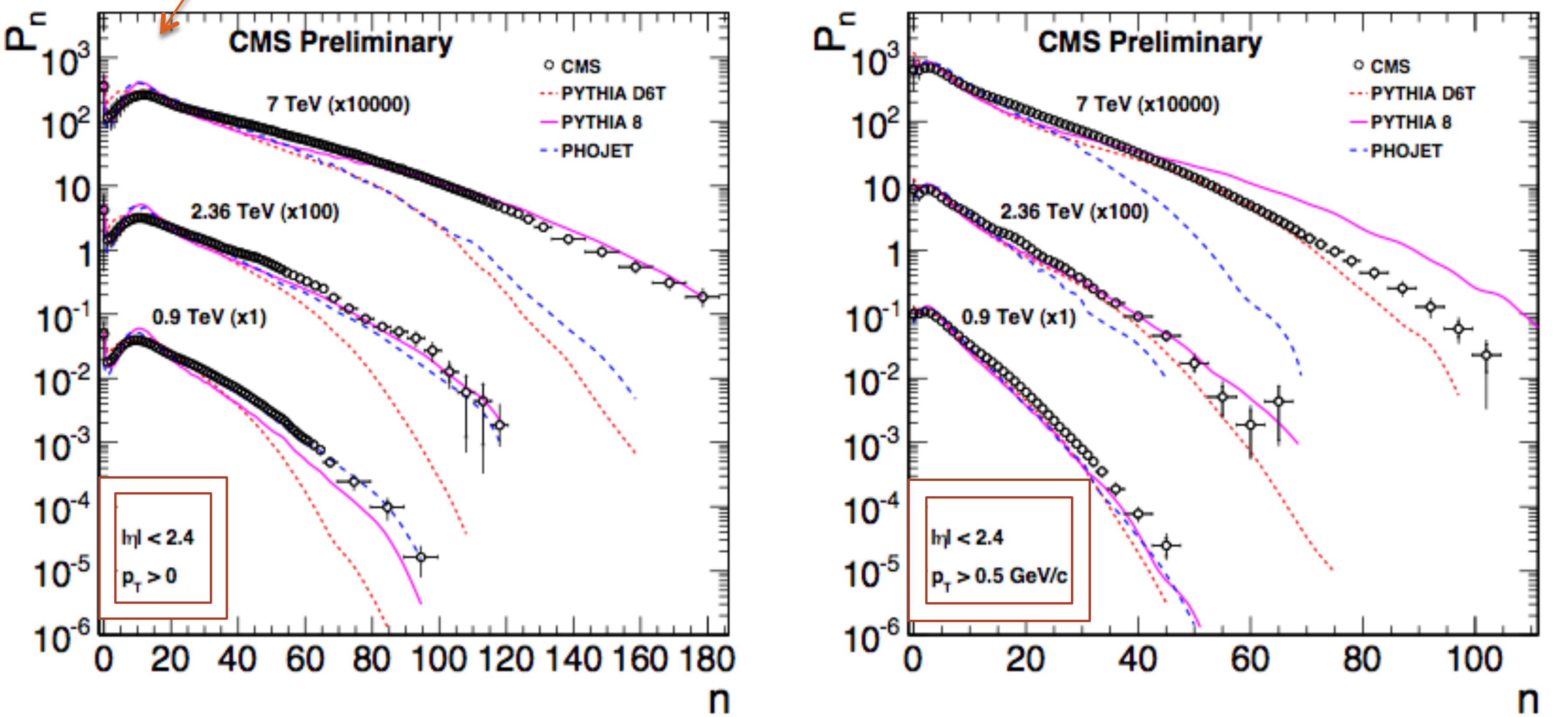




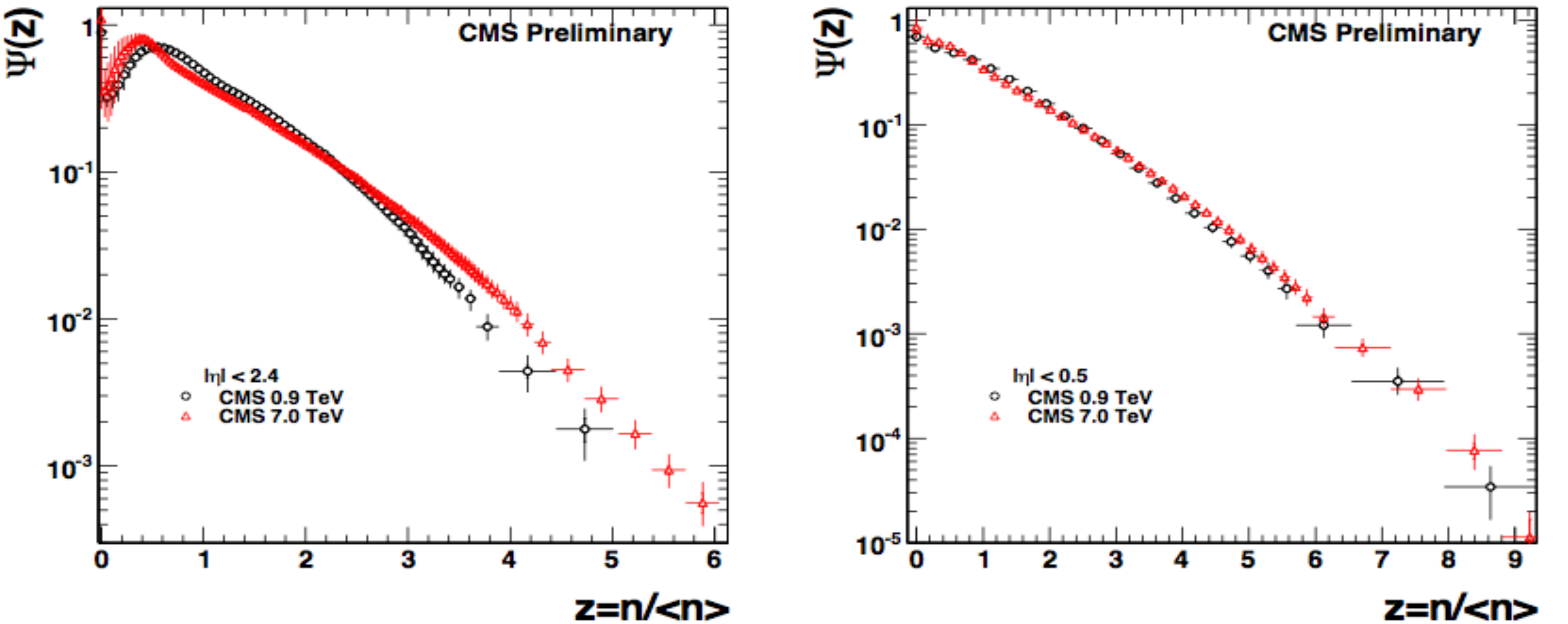
- $P_n = \sigma_n / \sigma$, where σ normalization taken from NSD events
- $p_T > 100$ MeV, then extrapolate to 0 MeV .The fraction of charged hadrons that is added by extrapolation correction ranges between 5% and 7%

Comparison with Generators

Soft vs Semi hard scatters
& Multi Parton Interactions

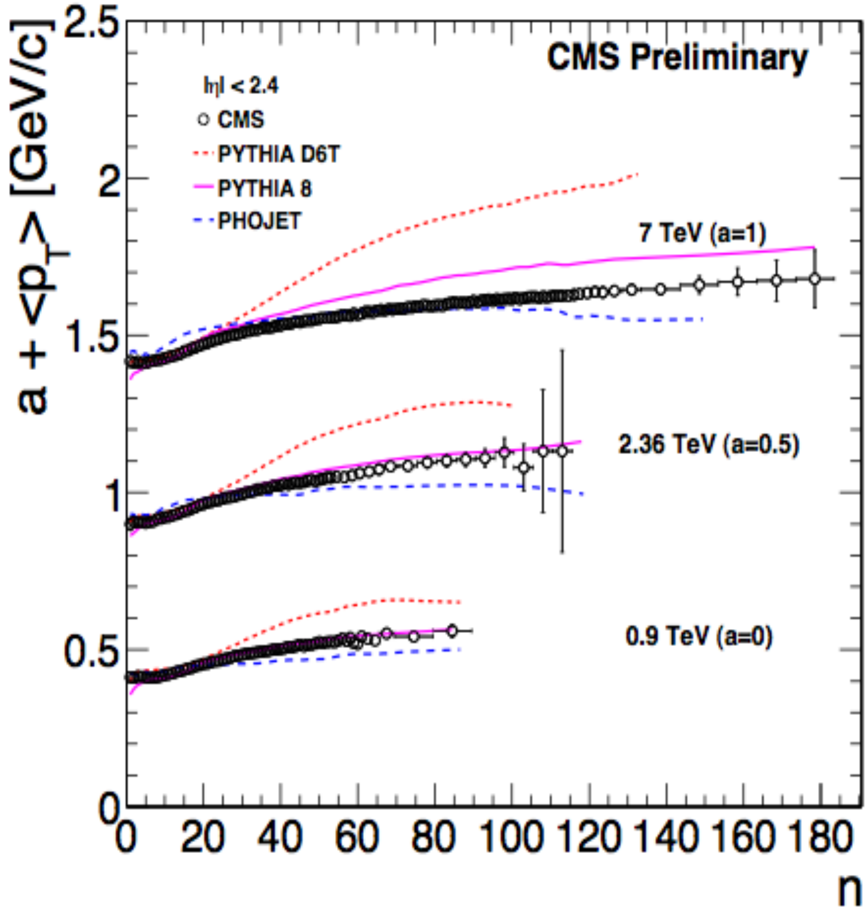


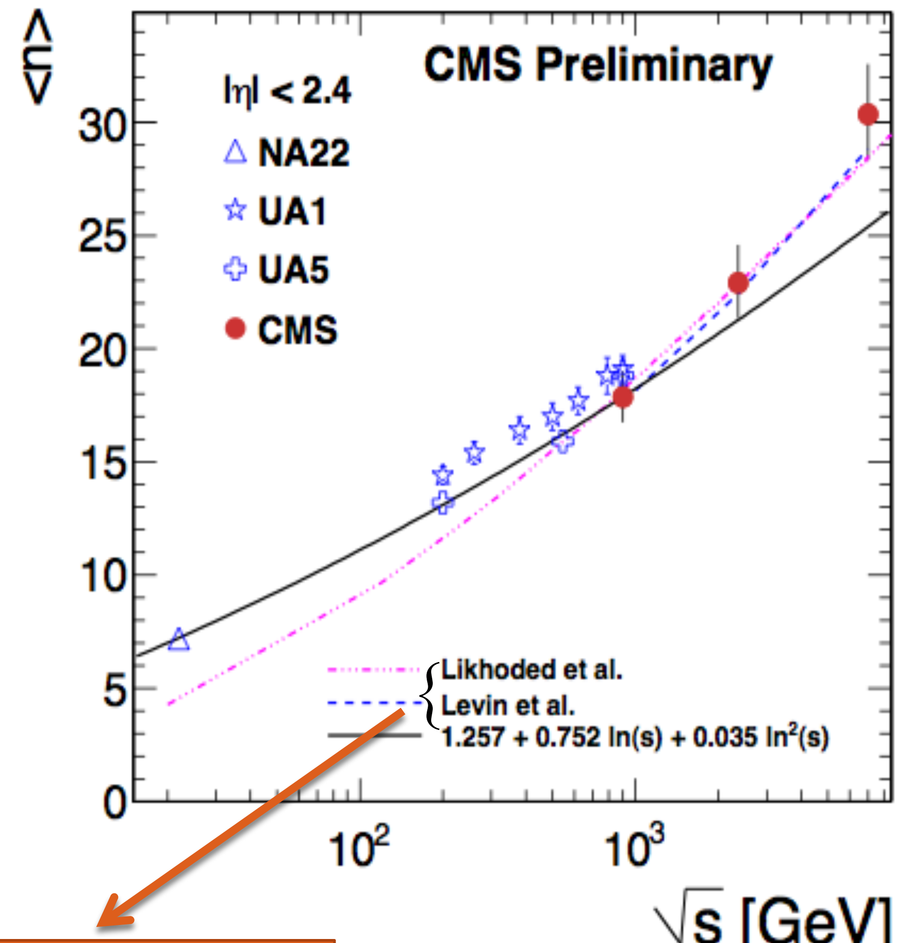
Scaling Functions Results



Difference in scaling between |η|< 2.4 and |η| <0.5

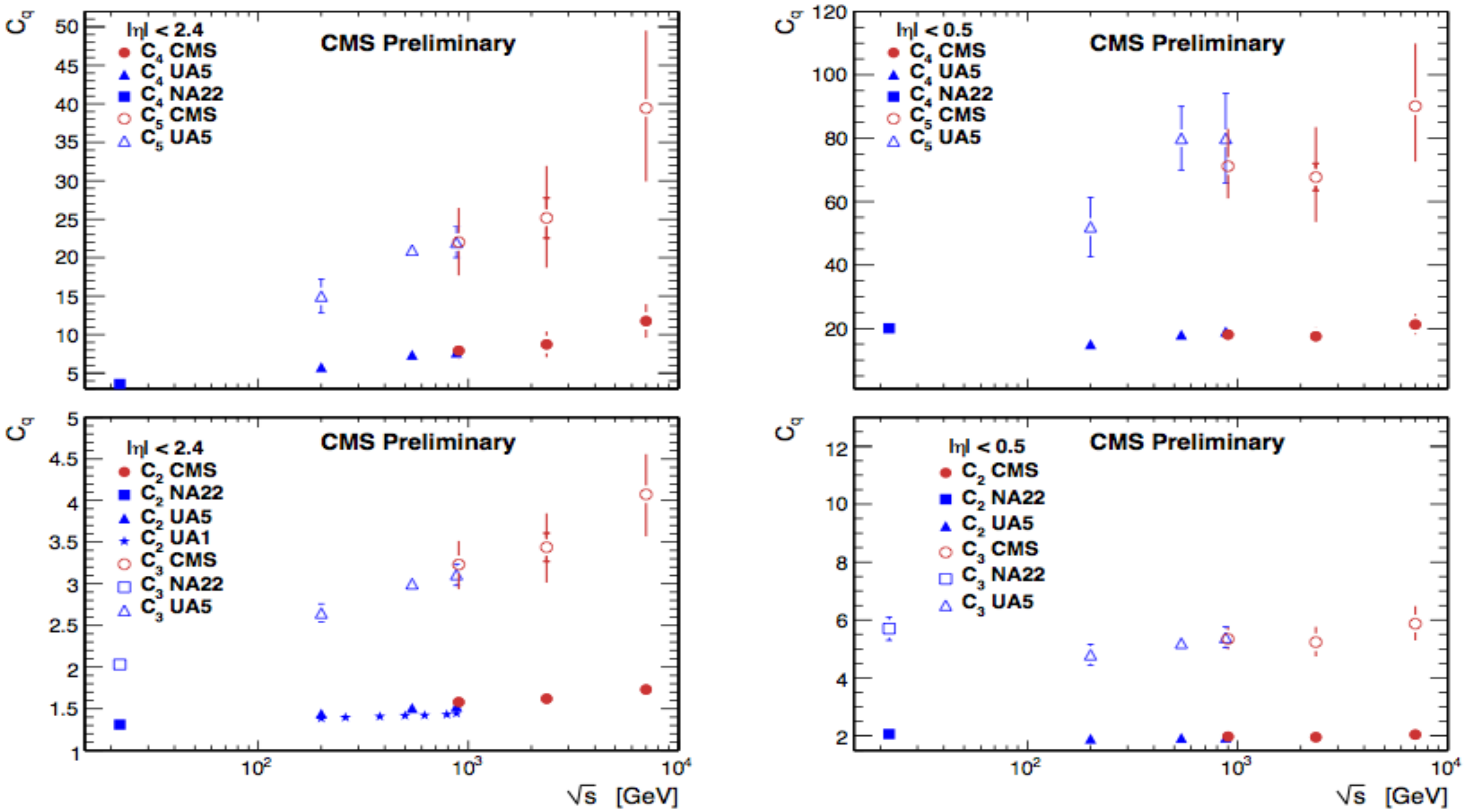
Other useful distributions





2010 – Recent Theoretical work

C_q Energy Dependence - Scaling Violations ➔ Correlations between particles produced



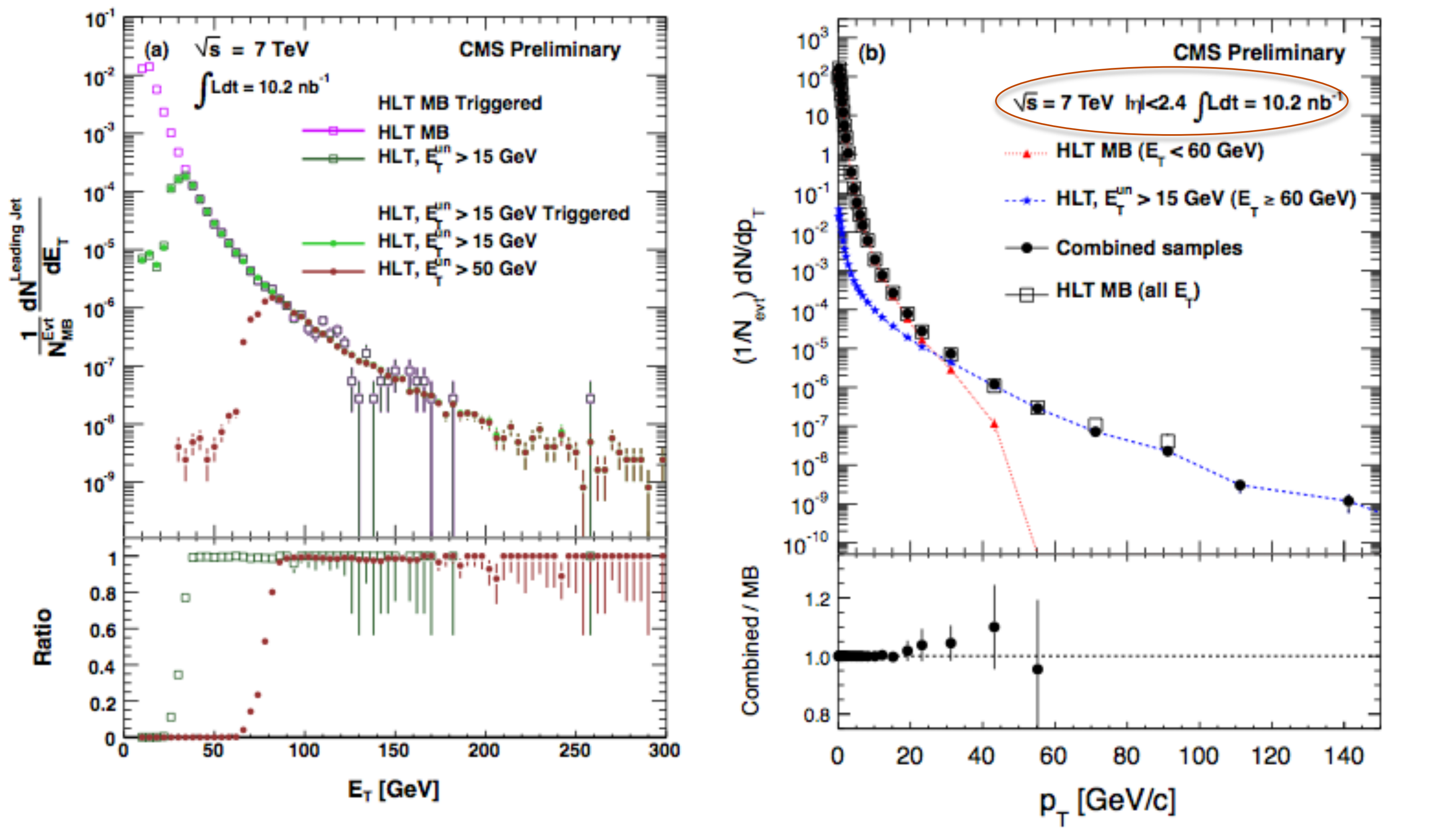
C_q moments increase nearly linearly with log (√s) for 0.5< |η|< 2.4

Charged particle transverse momentum spectra

Jet Triggered: CMS PAS QCD-10-008

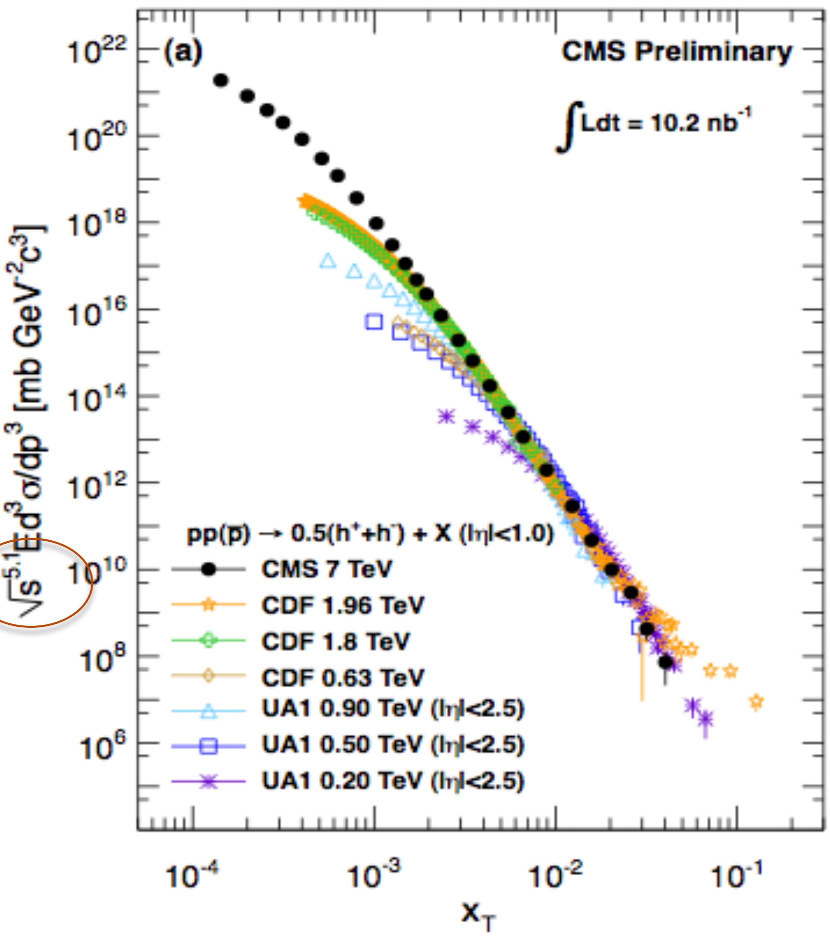
Minimum Bias: CMS PAPER QCD-10-006 (PRL)

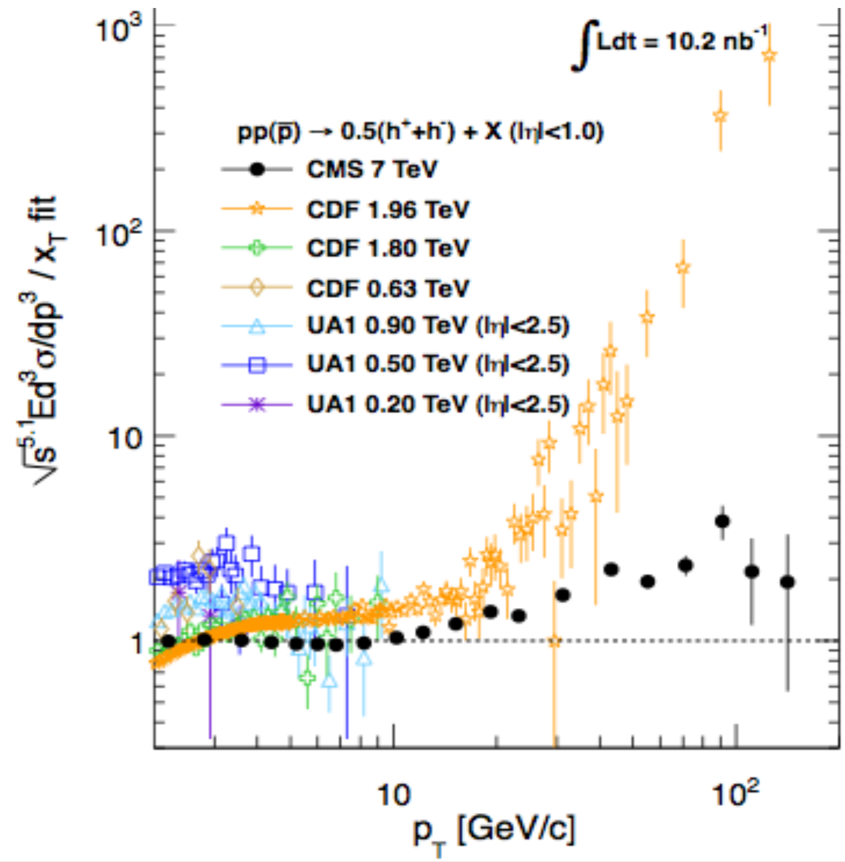
Using Jet Trigger & Minimum Bias



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

Comparison of Differential Yield with Previous Experiments: $E\frac{d^3\sigma}{dp^3} = F(x_T)/p_T^{n(x_T,\sqrt{s})} = F'(x_T)/\sqrt{s}^{n(x_T,\sqrt{s})}$

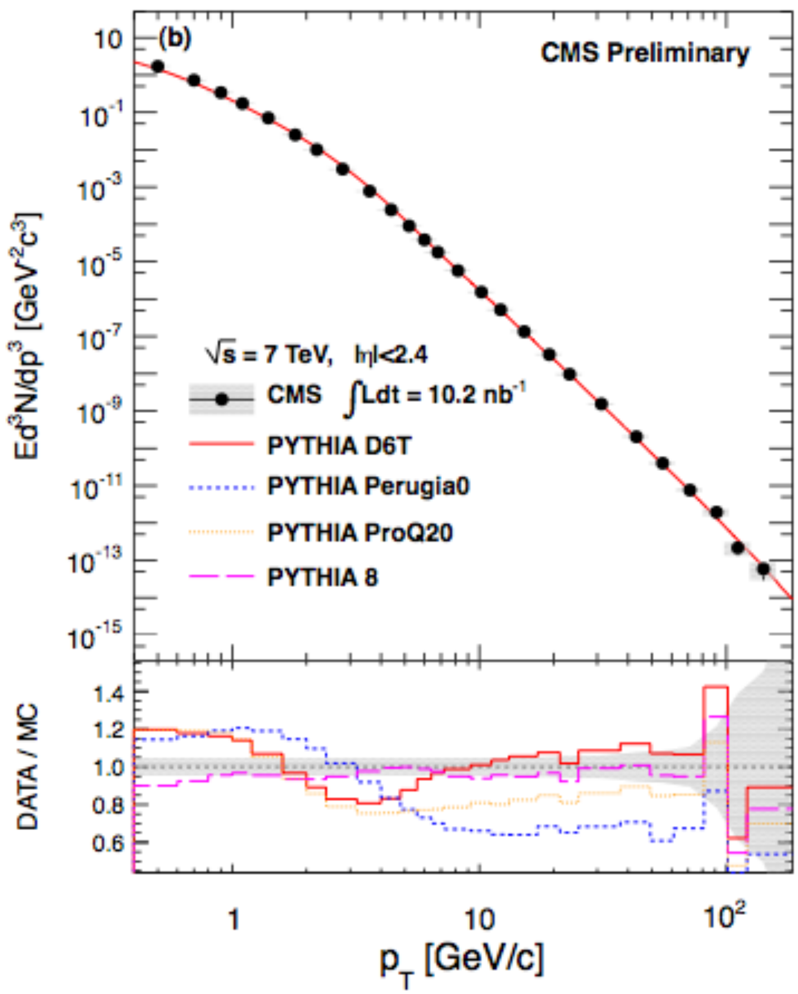




A robust prediction of pQCD hard processes is the power-law scaling of the inclusive invariant cross section with $x_T \equiv 2p_T/\sqrt{s}$

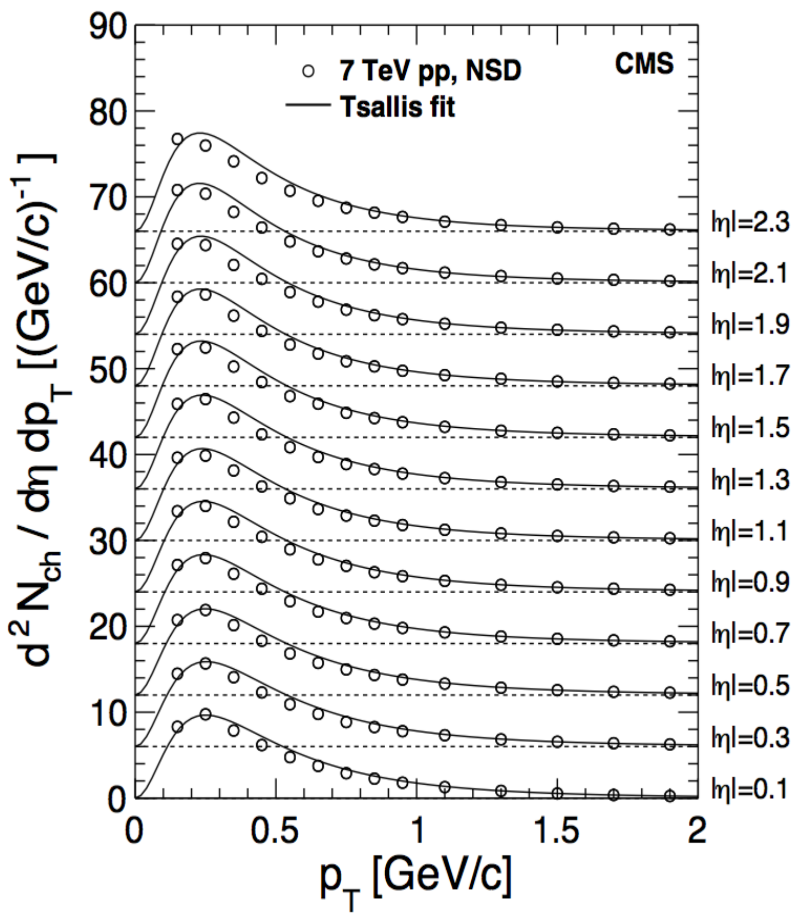
➔ Expected to be valid for $p_T > 2\text{GeV}$

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

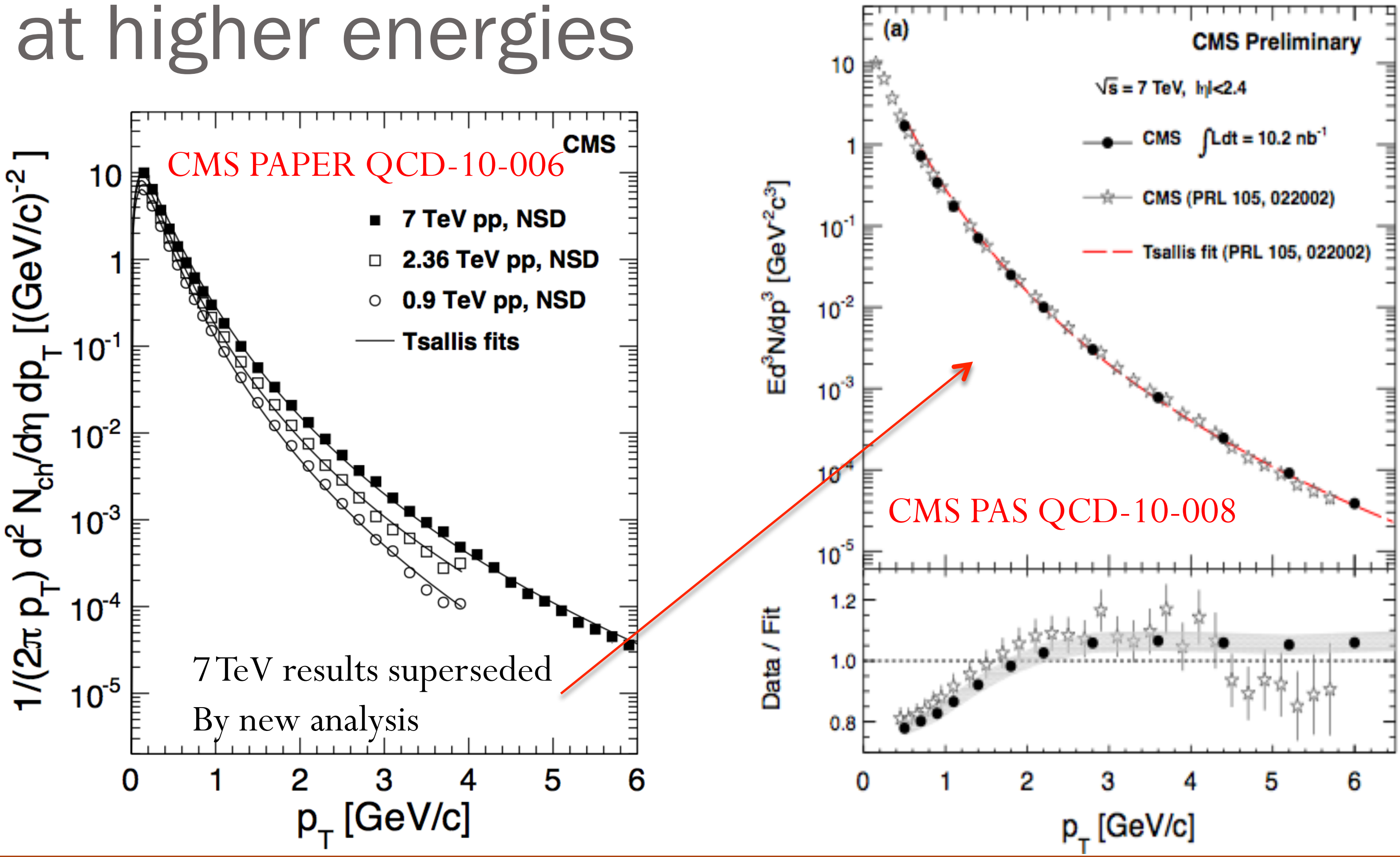
- **Minimum p_T 150 MeV**
- **Fit with Tsallis-Function:**

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

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

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

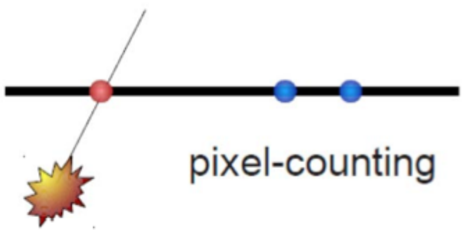
As expected: p_T Spectrum gets harder at higher energies



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.

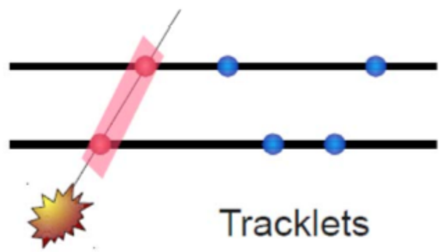
Difference between "new" and "old" result… Further tuning of tracking in 3rd method

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



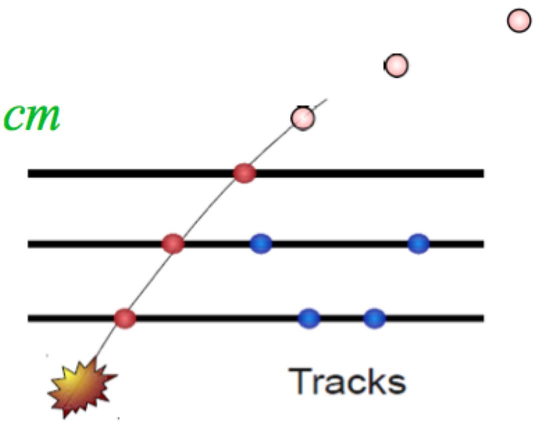
$p_T > 30$ MeV/c

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



$p_T > 75$ MeV/c

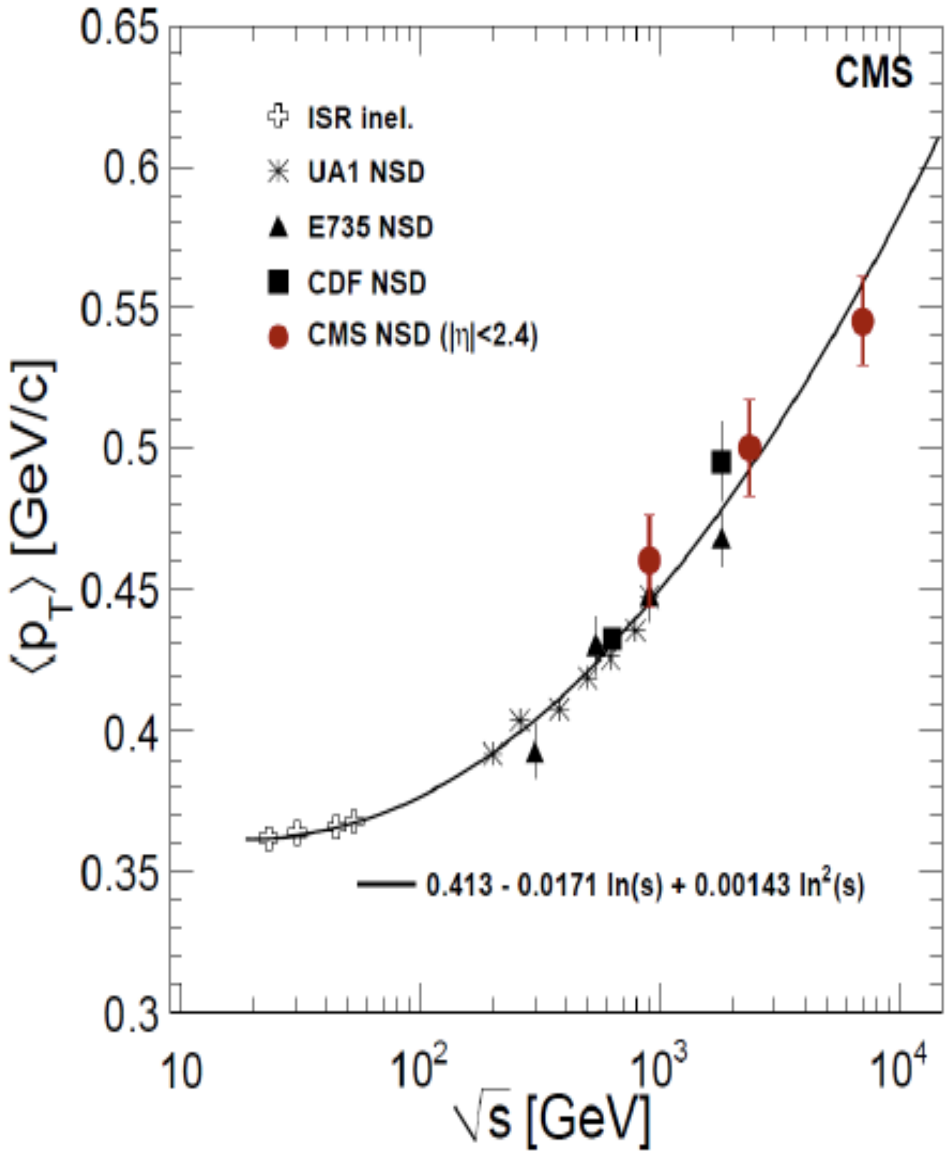
2 of 3 pixel layers
$|\eta|<2$
3 measurements of $dN/d\eta$
Sensitive to mis-alignment



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

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

Average p_T of Charged Hadrons

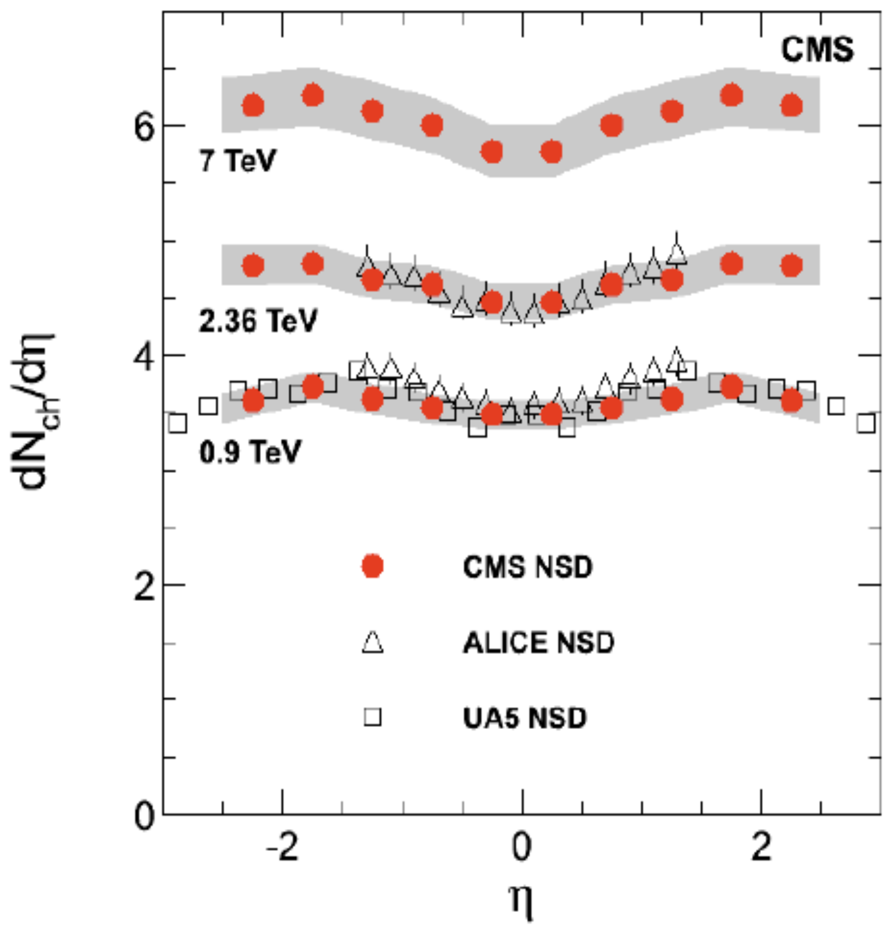


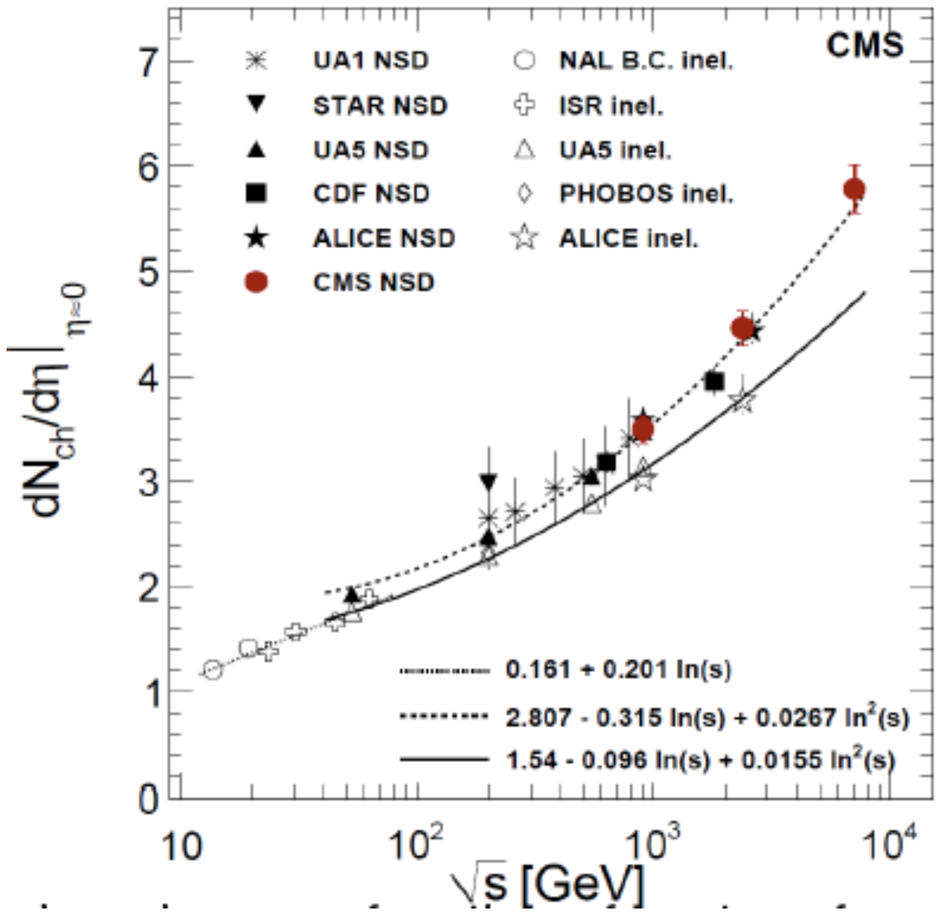
- **The energy dependence of the average charged-hadron p_T can be described by a quadratic function of ln(s)**
- **Minimum Bias: CMS PAPER QCD-10-006 (PRL)**

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.

What is next for this type of measurements?

- Finish all the analysis requested by the MBUEWG for $dN/d\eta$, dN/dp_T, etc.
- Some of the main differences with analyses shown today:
  - Do not reject SD events
  - Minimum p_T of 500 MeV and require at least one track in the central region
- Still some open questions to WG
  - Definition/Correction of "primary" charged particles

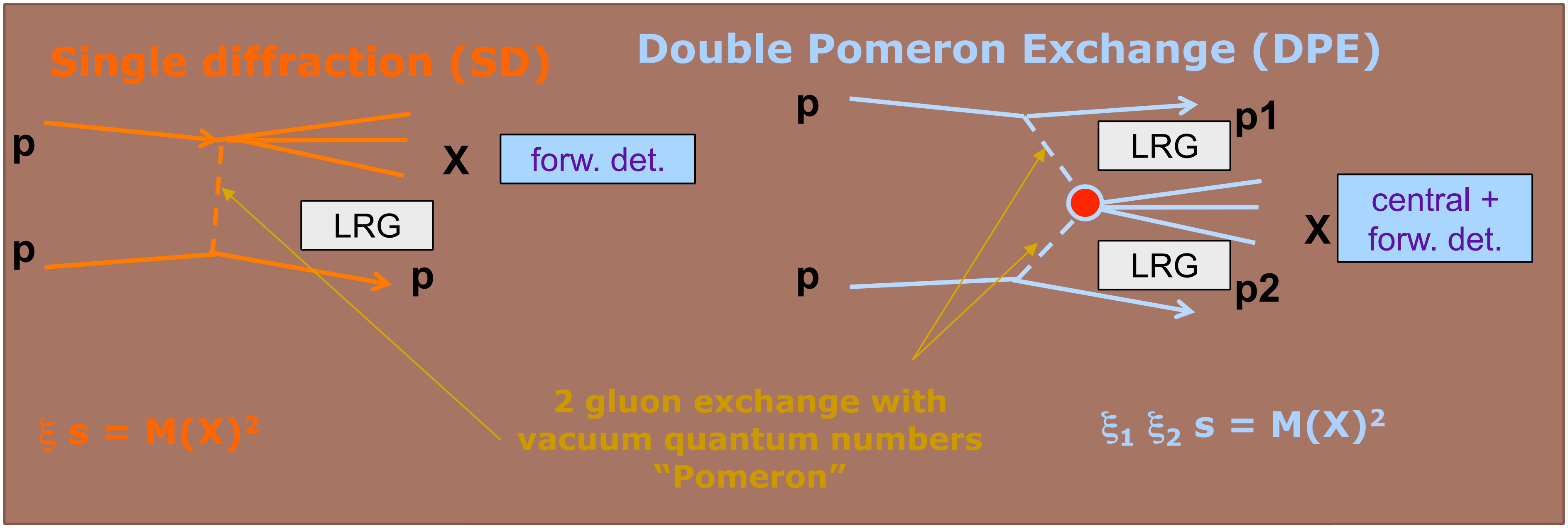
➔ More discussion in close section

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 $p\,p \rightarrow X\,Y$ in which the systems *X* and *Y* are separated by a Large Rapidity Gap

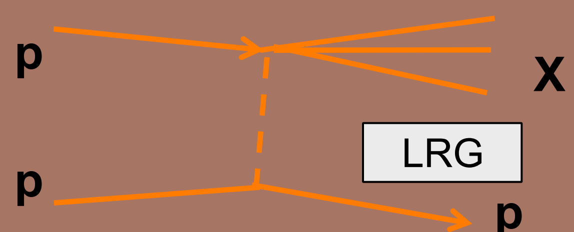


- Diffractive events contribute significantly to Minimum Bias data set (~ 30 % of the total *p p* cross section)
- Modelling of soft diffraction is generator dependent

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

Strategy for Single Diffraction Detection at CMS

Single diffraction (SD)



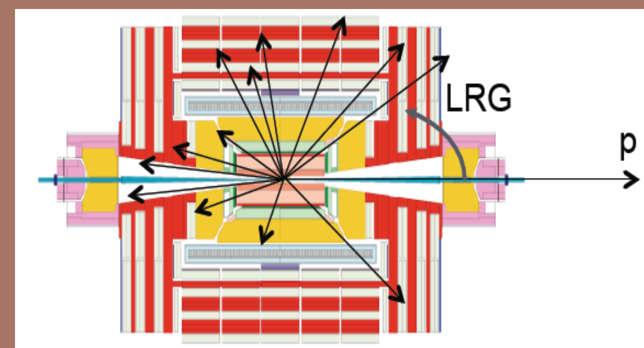
$\xi = M_X^2 / s$

$\sigma \approx 1/\xi$

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

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

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 $E_{HF\pm}$, $N_{HF\pm}$

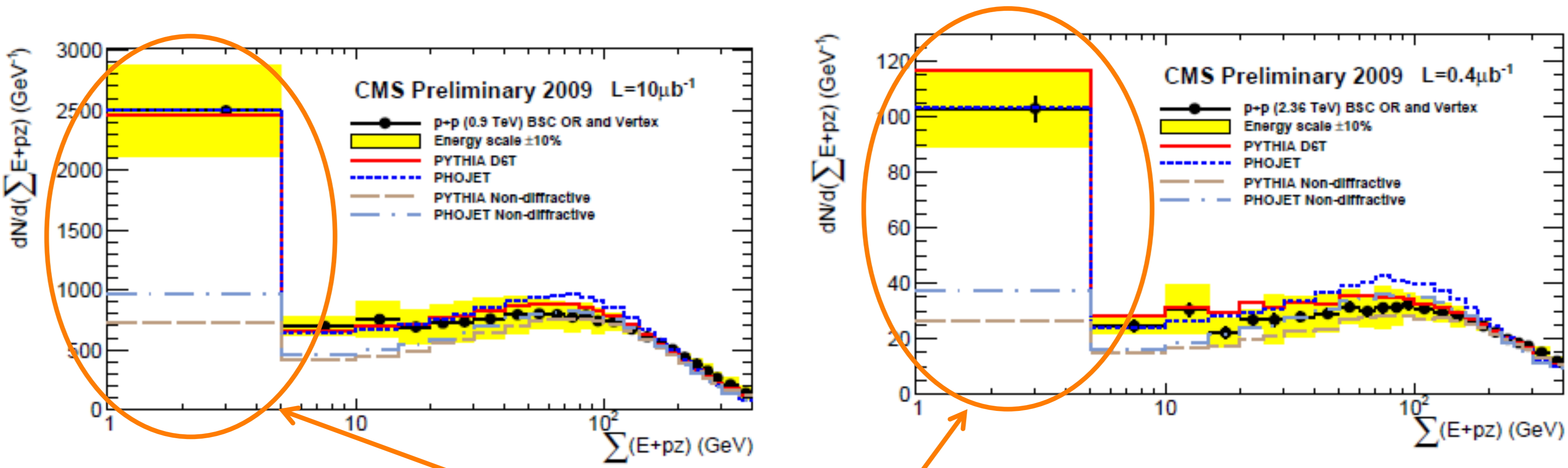
$E_{HF\pm}$ = energy deposition in HF±

$N_{HF\pm}$ = 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}) **2360 GeV (0.4 μb^{-1})**

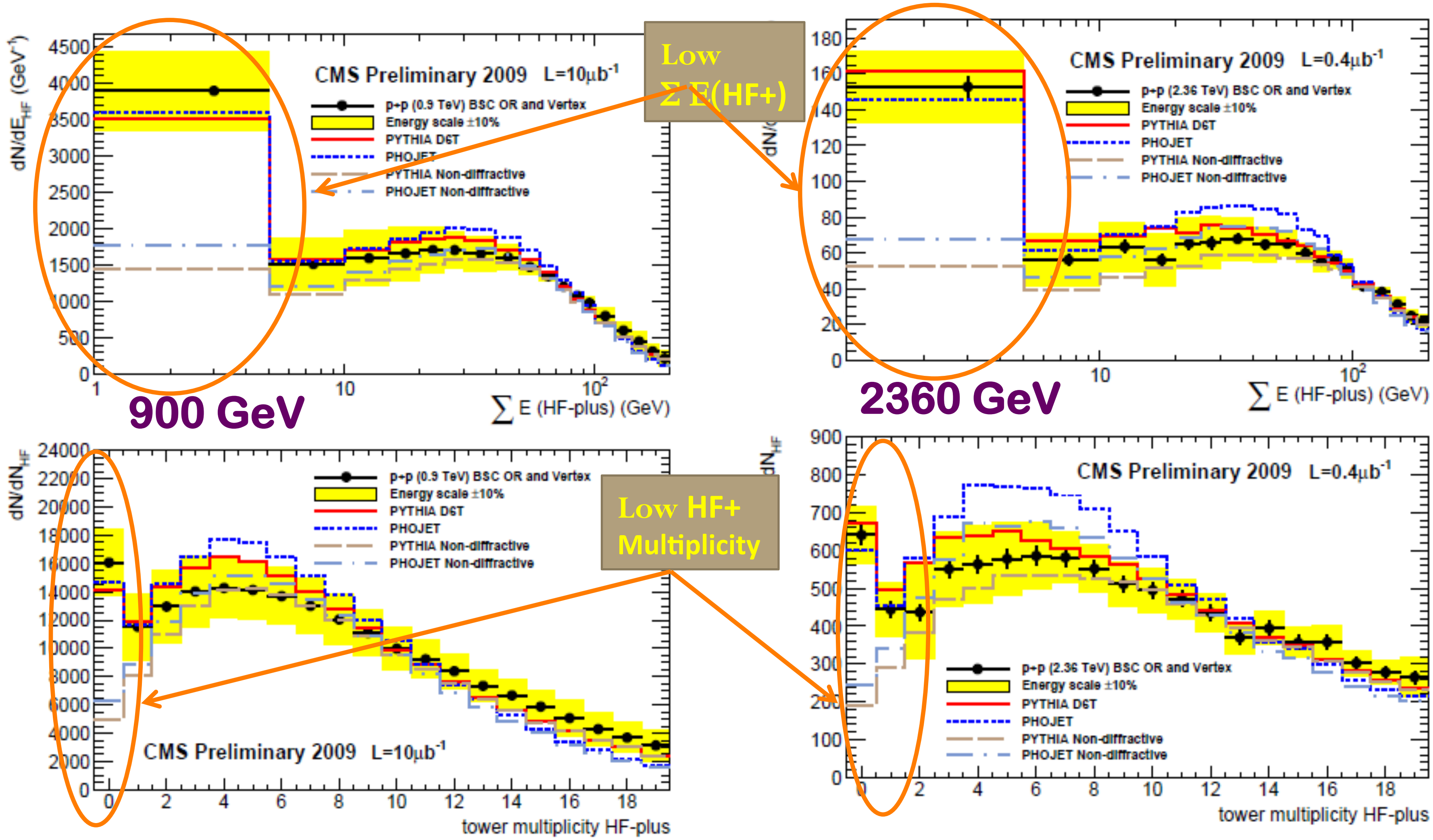


Systematic uncertainty dominated by energy scale

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

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

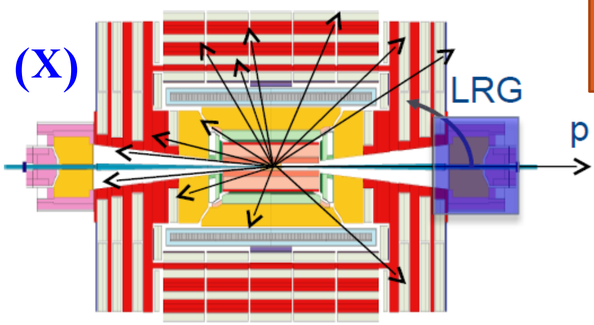
Observation of Single Diffraction at CMS



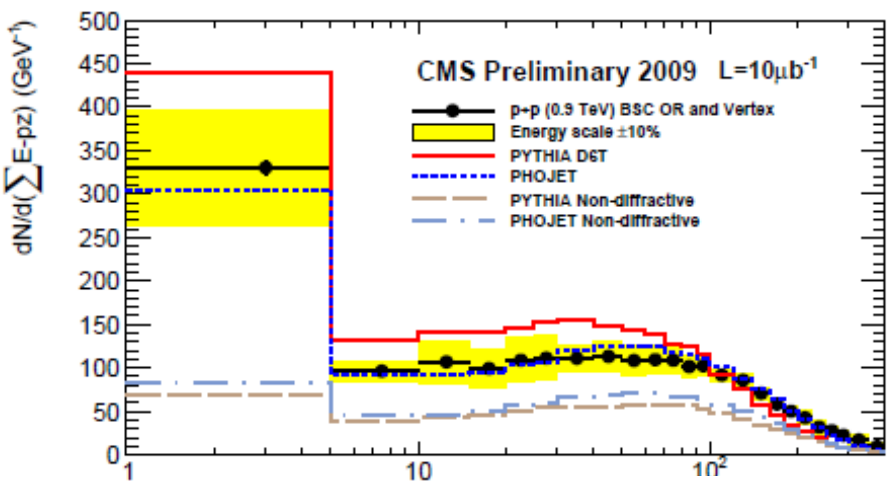
SD signature confirmed by the absence of forward hadronic activity (presence of a LRG)

Enriched SD Sample ➔ E(HF+) < 8 GeV

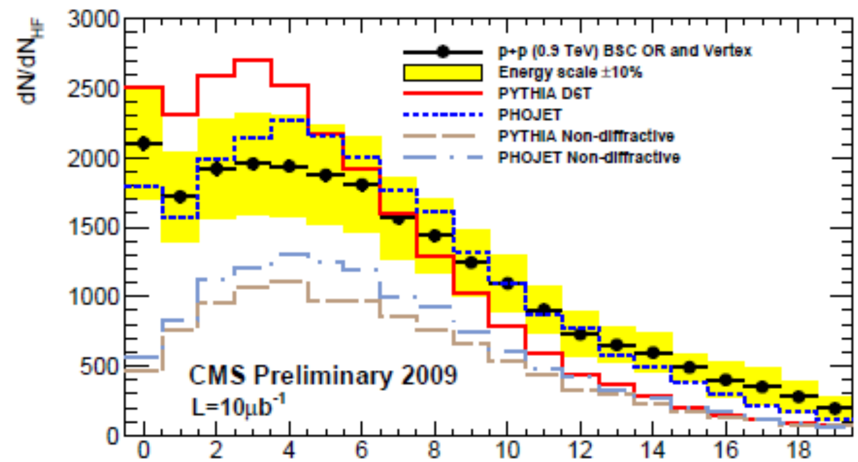
Requirement of low Activity in one side of CMS



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

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