CMS Minimum Bias and Diffraction Measurements

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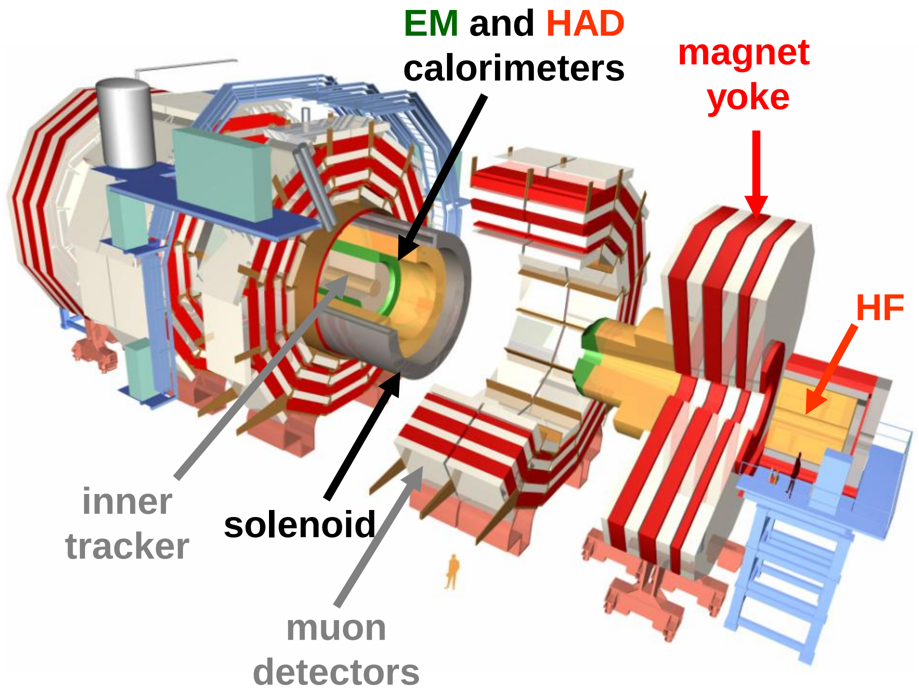
Minimum Bias and Underlying Event Working Group Meeting
CERN, 31 May, 2010

Talks related to CMS data today

- Minimum bias measurements* and observation of diffractive events (G.V.)
- Underlying event** studies (Klaus Rabbertz)
- Correlation* analyses – clusters, BEC (Wei Li)
- Early MB&UE measurements – what have we learned? (Rick Field)



* submitted to PRL

** approved, will be submitted soon

Introduction

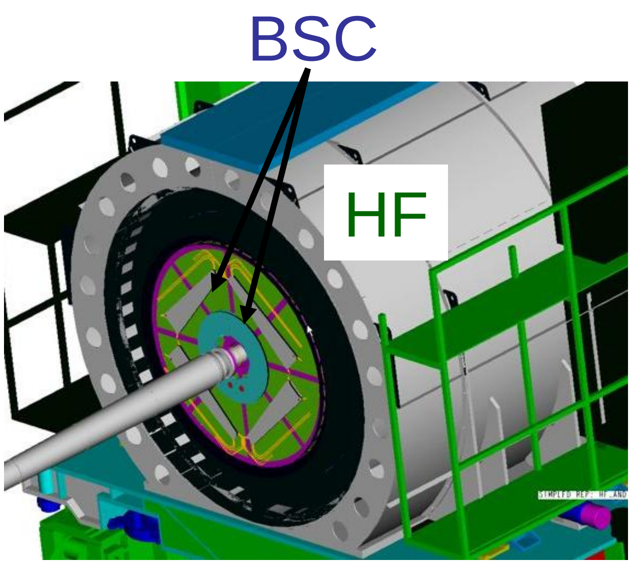
- The majority of the pp collisions are soft,
  with no hard parton scattering
- Modeling soft hadron production is done
  phenomenologically (hadronization, fragmentation, …)
- Various processes: elastic, single-diffractive (SD),
  double-diffractive (DD) + non-diffractive: NSD
- $dN/d\eta$ and dN/dp_T distributions of primary charged hadrons
  are measured, **per NSD event**
- 7 TeV: results at the highest-ever collision energy
- Important for high-luminosity LHC runs with event pileup
- Also important as a reference for heavy ion collisions

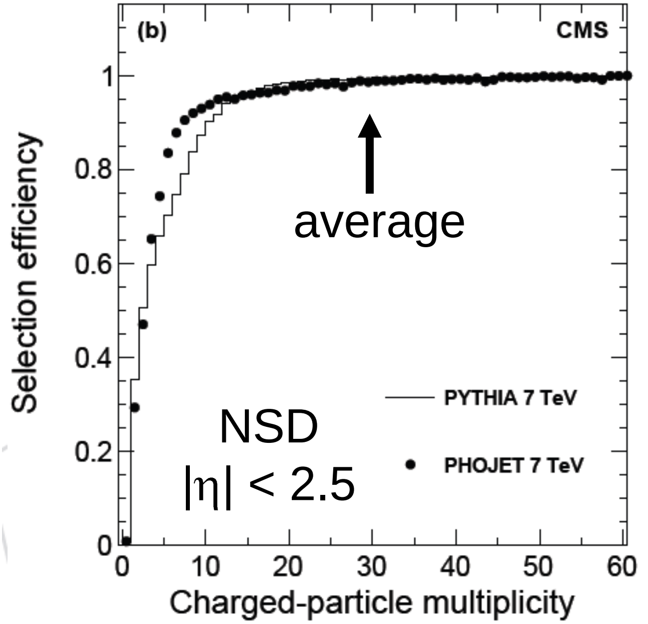
LHC startup at 7 TeV

- First collisions at 7 TeV:
  30 March, 2010 (“media event”)
- First preliminary dN/dη results ready in a few minutes
- The 7 TeV publication on dN/dη uses 1.1 μb^{-1} (less than one hour) of the first, “media event” run

Trigger and event selection

- Collision rate ≈ 50 Hz
  "pileup" ≈ 0.3% (neglected)
- Trigger: any hit in the Beam Scintillator Counters ($BSC, 3.23 < |\eta| < 4.65$) AND a filled bunch passing the beam pickups (BPTX)
- Off-line event selection:
  - >3 GeV total energy on both sides in the Forward Calorimeter ($HF\ 2.9 < |\eta| < 5.2$)
  - Beam Halo rejection (BSC)
  - Dedicated beam background rejection
  - Collision vertex



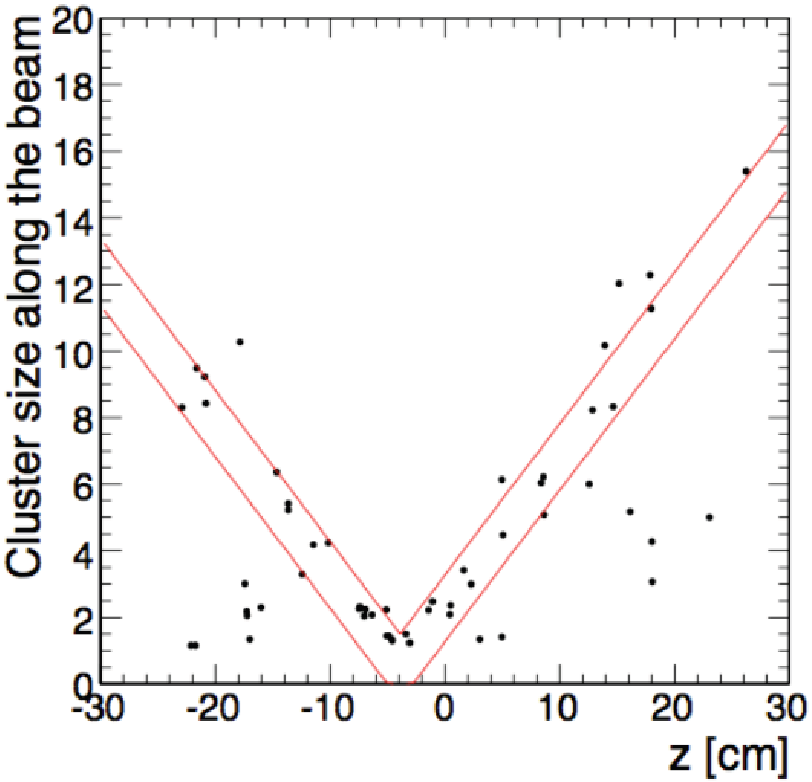


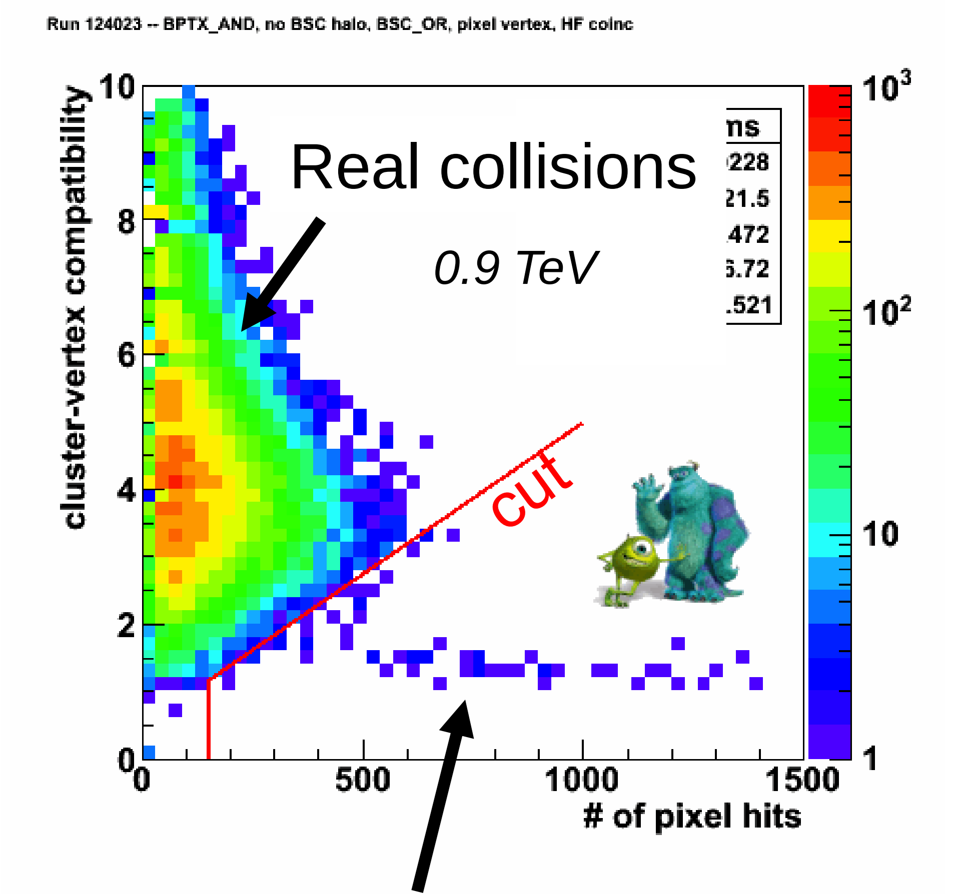
Efficiencies:

NSD:	~86 %
SD:	~27 %
DD:	~34 %

55100 events remain after all cuts

Rejecting beam-gas events





Vertex-cluster compatibility:
Ratio of #clusters in the V shape and #clusters in the V-shape offset by ±10 cm

Beam-scraping events have a lot of pixel hits but ill-defined vertex

Remaining beam-gas fraction: 2×10^{-5}

Trigger efficiencies

Based on event generators (MC)

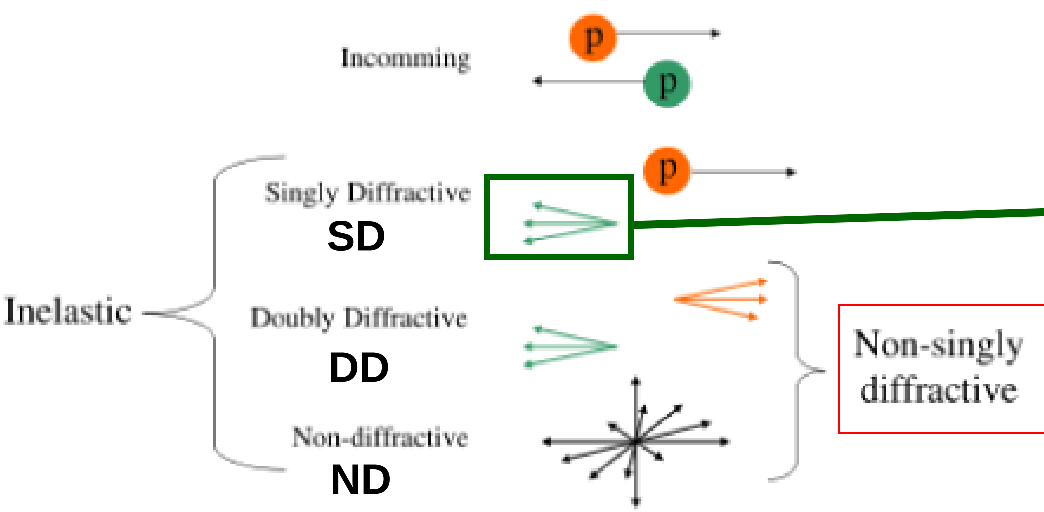
	PYTHIA				PHOJET			
Energy	0.9 TeV		2.36 TeV		0.9 TeV		2.36 TeV	
	Frac.	Sel. Eff.	Frac.	Sel. Eff.	Frac.	Sel. Eff.	Frac.	Sel. Eff.
SD	22.5%	16.1%	21.0%	21.8%	18.9%	20.1%	16.2%	25.1%
DD	12.3%	35.0%	12.8%	33.8%	8.4%	53.8%	7.3%	50.0%
ND	65.2%	95.2%	66.2%	96.4%	72.7%	94.7%	76.5%	96.5%
NSD	77.5%	85.6%	79.0%	86.2%	81.1%	90.5%	83.8%	92.4%

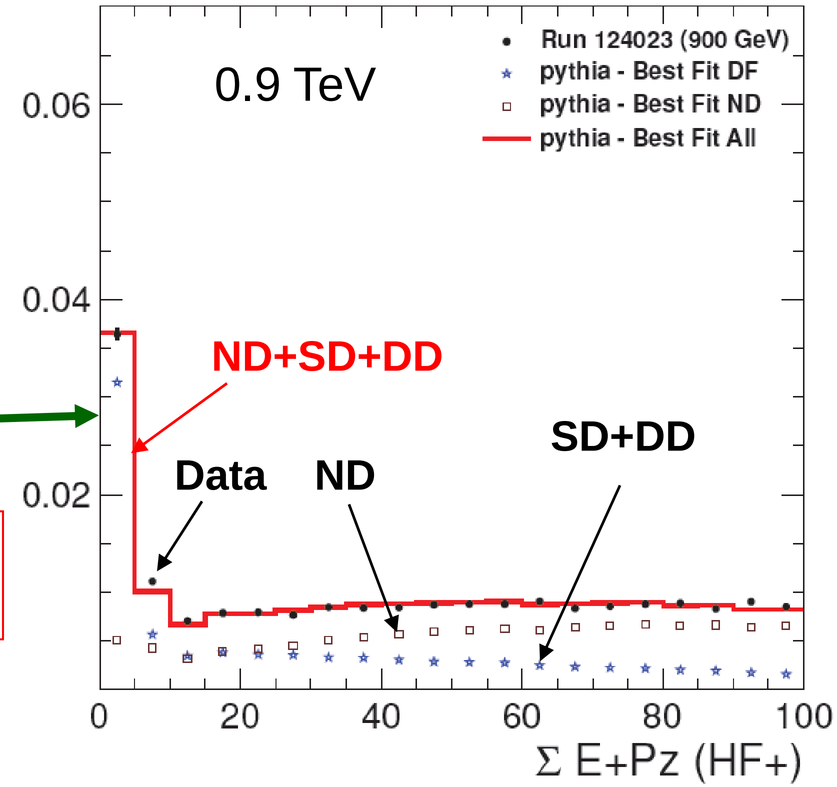
7 TeV	PYTHIA		PHOJET	
	Frac.	Sel. eff.	Frac.	Sel. eff.
SD	19.2%	26.7%	13.8%	30.7%
DD	12.9%	33.6%	6.6%	48.3%
ND	67.9%	96.4%	79.6%	97.1%
NSD	80.8%	86.3%	86.2%	93.4%

≈7% of our selected events are single diffractive

Estimating the diffractive component from data

Our measurement is corrected for inel. non-single-diffractive events!

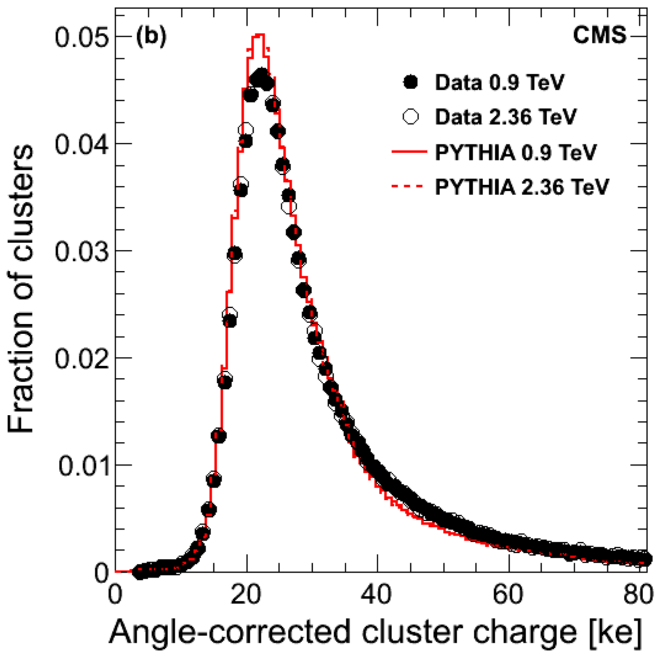




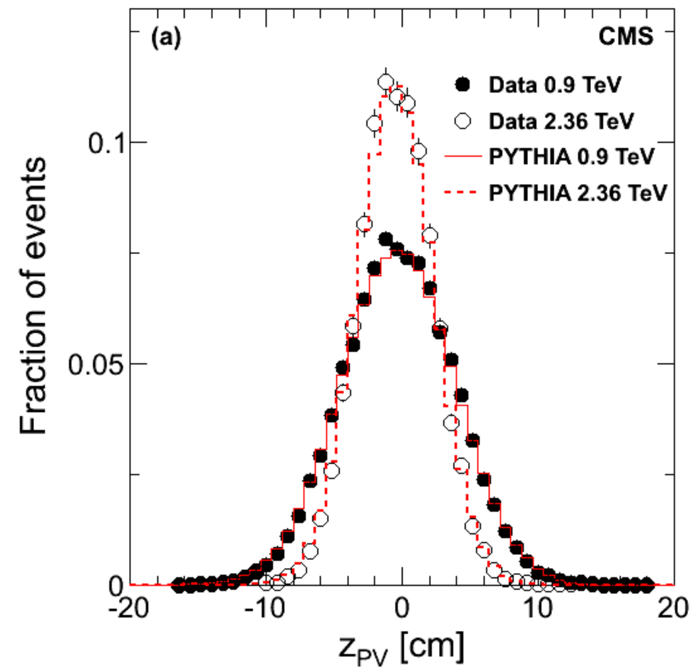
The HF calorimeter data is used to fit the SD+DD fraction in data using PYTHIA event shapes. PHOJET was also studied similarly.

Detector 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



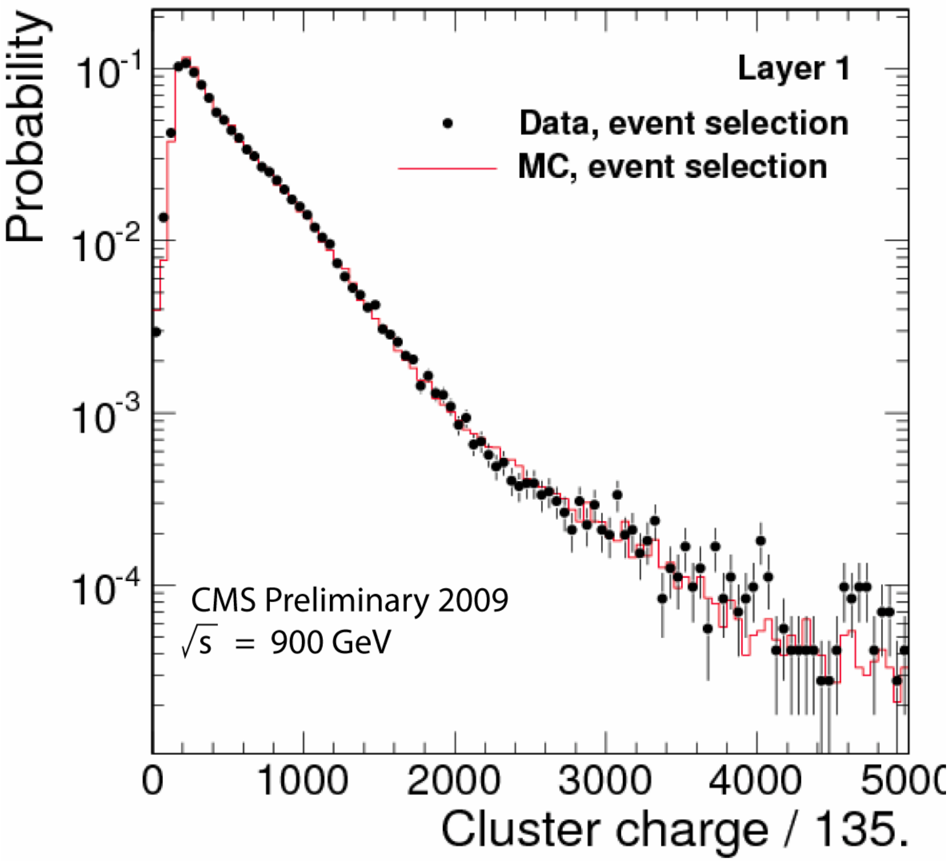
The energy loss in the tracker layers well described by MC



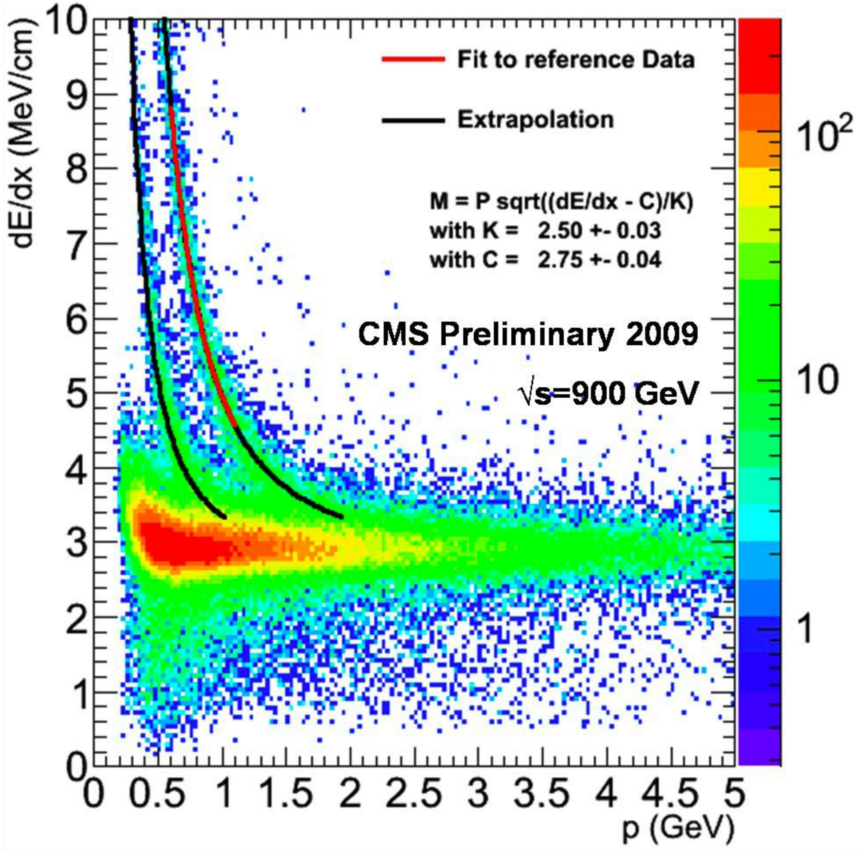
The vertex position distributions are clean Gaussians, with no tails

dE/dx information in the pixels

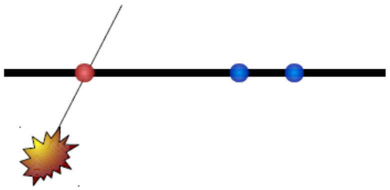
Silicon pixels



Silicon strips



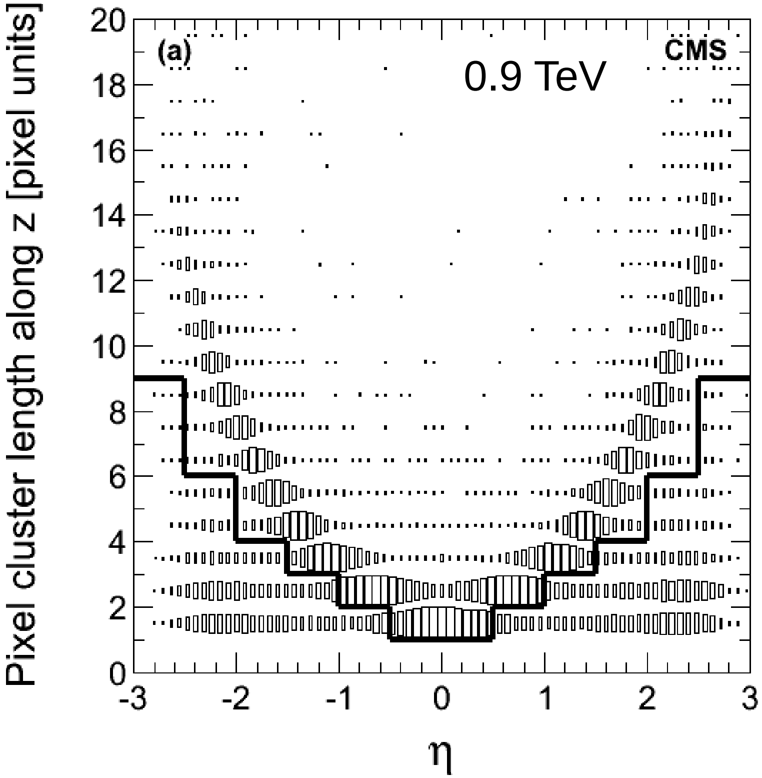
Excellent agreement with simulations



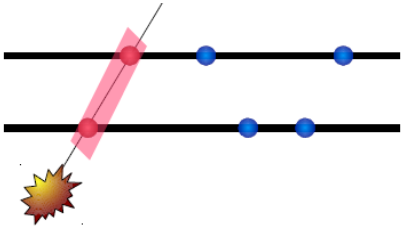
Cluster counting method

- Counting hits (clusters of pixels) in the pixel barrel layers
- Cluster length ~ |sinh(η)|
- Shorter clusters are eliminated (loopers, secondaries)
- Corrections for loopers, weak decays, secondaries
- Independent result for all 3 layers
- Immune to detector misalignment
- Sensitive to beam background
- Note: our detector is noise-free!

p_T-reach: down to 30 MeV/c

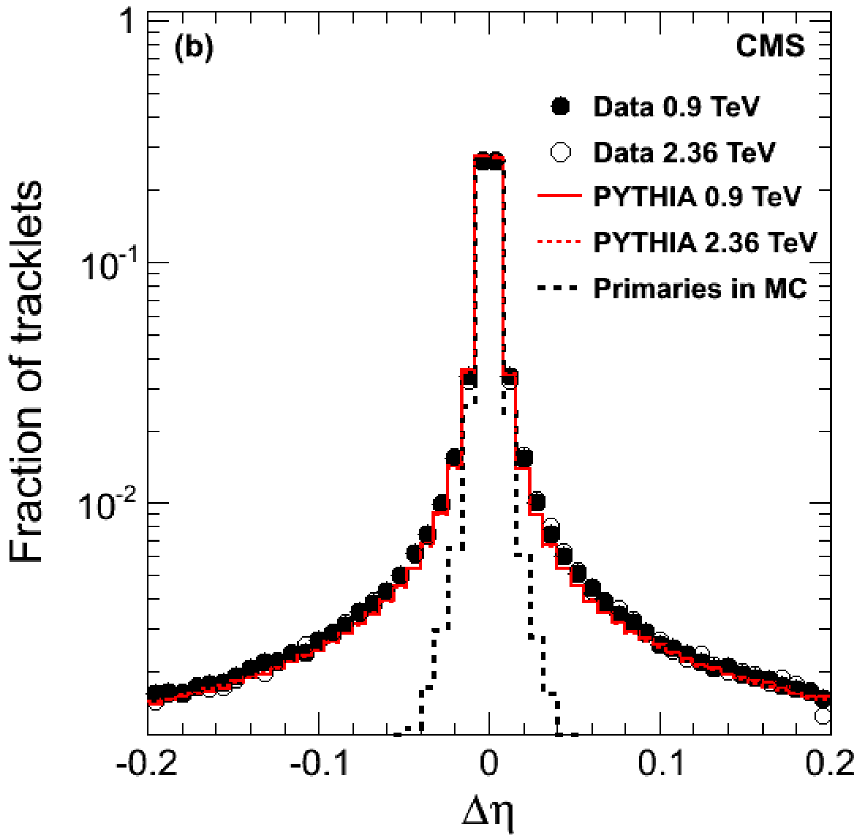


Pixel cluster length along the beam direction as a function of η. The solid line shows the cut applied.



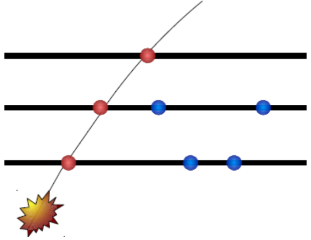
Tracklet method

- Tracklets: pairs of clusters on different pixel barrel layers
- The $\Delta\eta$ and $\Delta\varphi$ correlations are used to separate the signal
- A side-band in $\Delta\varphi$ is used to subtract combinatorial background
- Corrections for efficiency, weak decays, secondaries
- Independent result for all 3 layer pairs
- Less sensitive to beam background



The $\Delta\eta$ distribution of the two clusters of the tracklets

p_T-reach: down to 50 MeV/c



Tracking method

- Uses all pixel and strip layers
- Builds particle trajectories iteratively
- Low fake rate achieved with cleaning based on cluster shapes
- Primary vertex reconstructed from tracks
  – agglomerative vertexing
- Compatibility with beam spot and primary vertex required
- Immune to background
- More sensitive to beam spot position and detector alignment

p_T-reach: down to 100 MeV/c

Results: p_T –distribution at 7 TeV

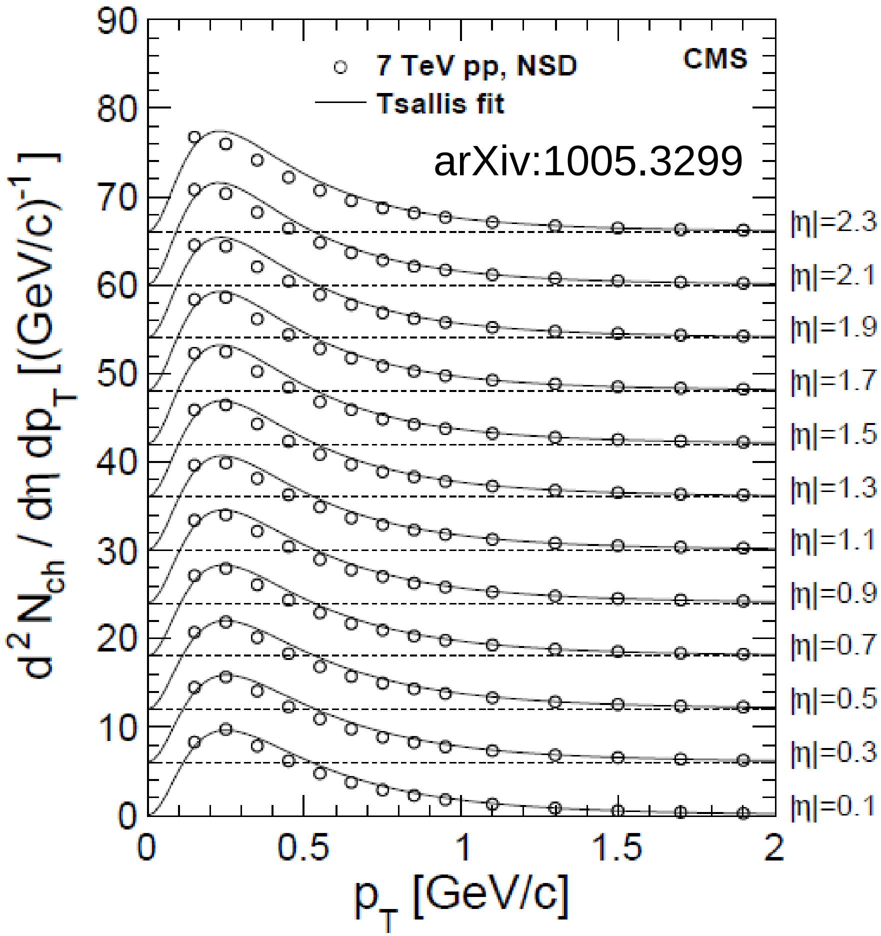
Measured down to 150 MeV
Important: turn-over of the yields

Fit with the Tsallis-function:

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

Behavior of the function:

- exponential at low p_T
- power-law at high p_T



$\langle p_T \rangle$ = 545 ±5(stat) ±15(syst) MeV/c

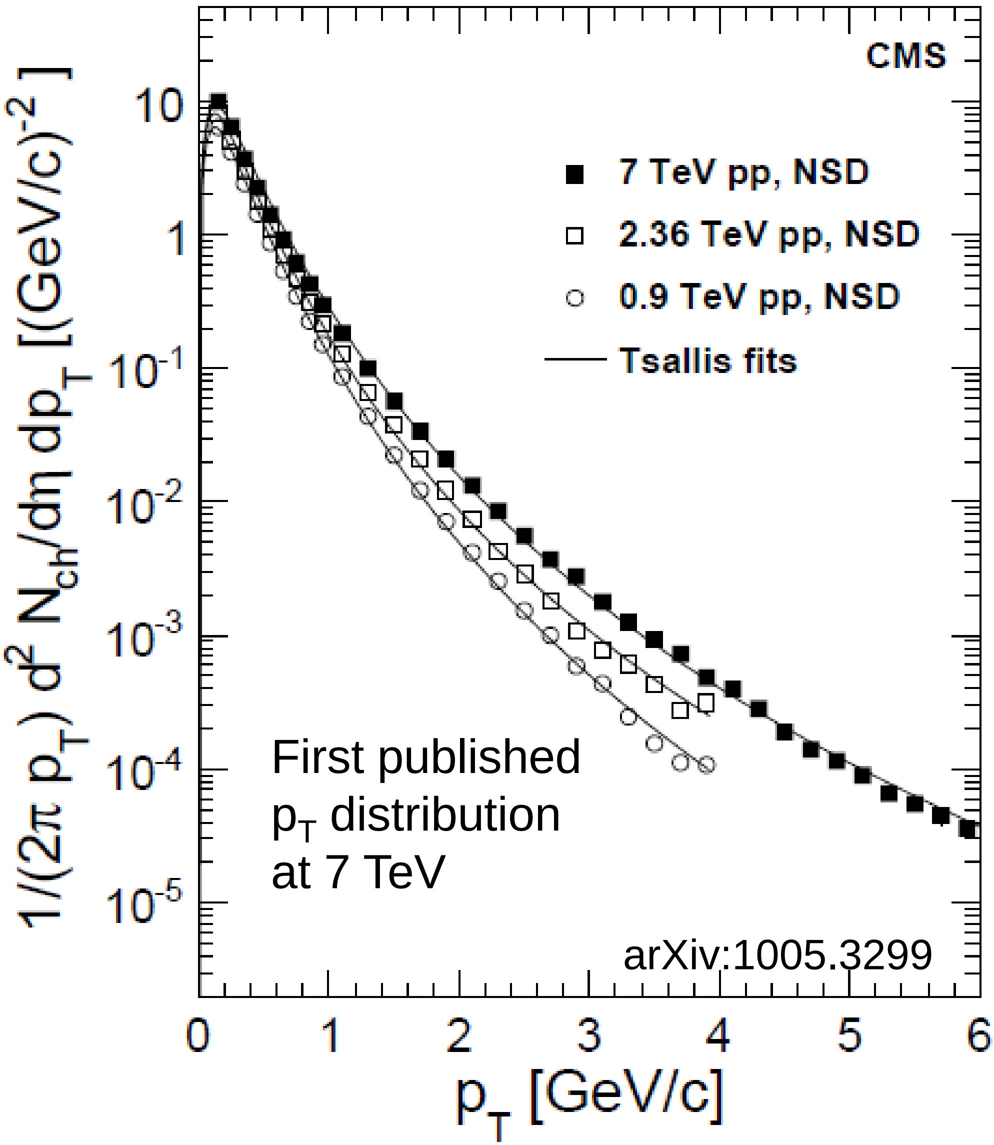
Differential yield of charged hadrons in the range $|\eta|<2.4$ The η bins are shifted by six units vertically.

p_T-distribution at 7 TeV

• The transverse-momentum distribution of charged hadrons was measured up to 6 GeV/c.

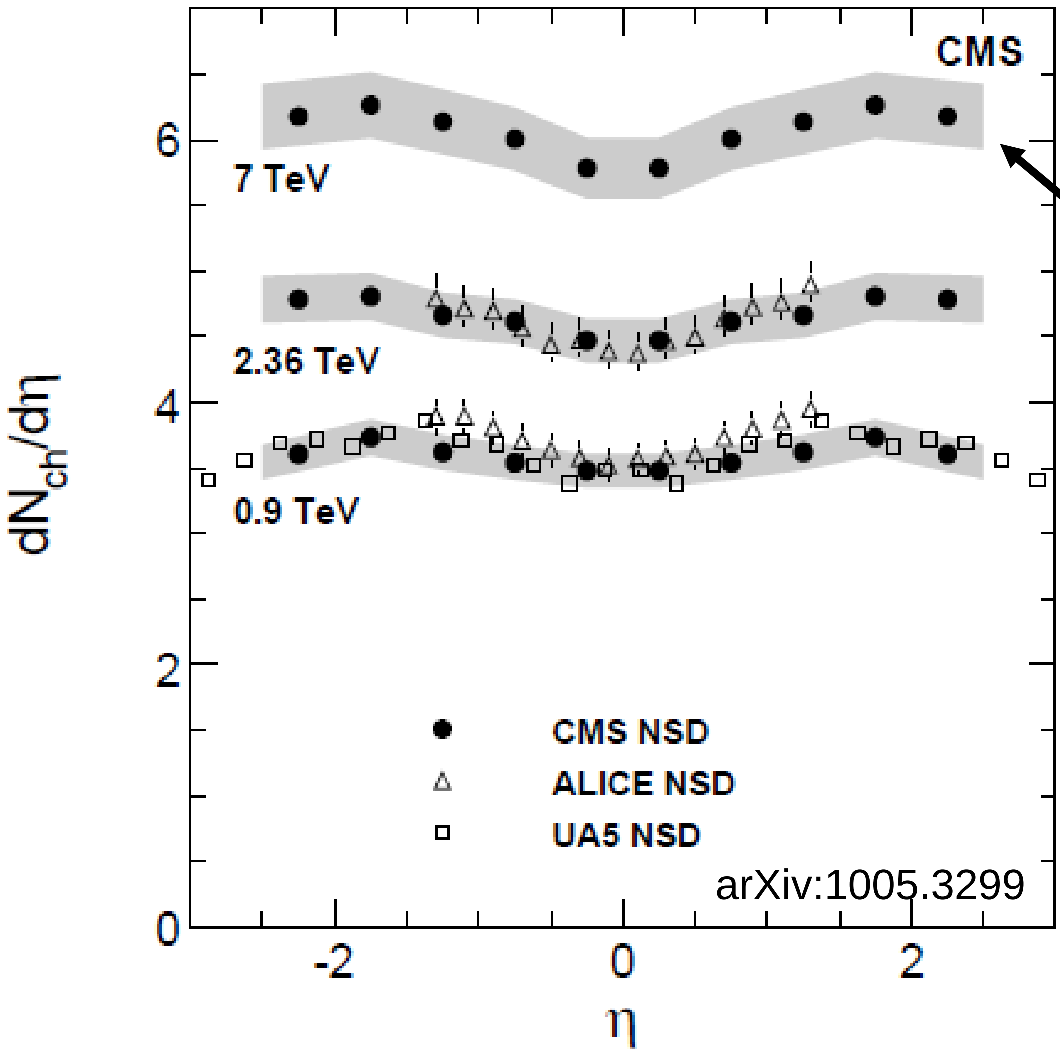
• Well described by the Tsallis-function combining a low-p_T exponential with a high-p_T tail

• With increasing energy, the p_T-spectrum gets “harder” (as expected)



Measured yield of charged hadrons for $|\eta| < 2.4$, fit with the Tsallis function.

Results: dN/dη



Cross-checked with B=0 data at 7 TeV (tracklets)!

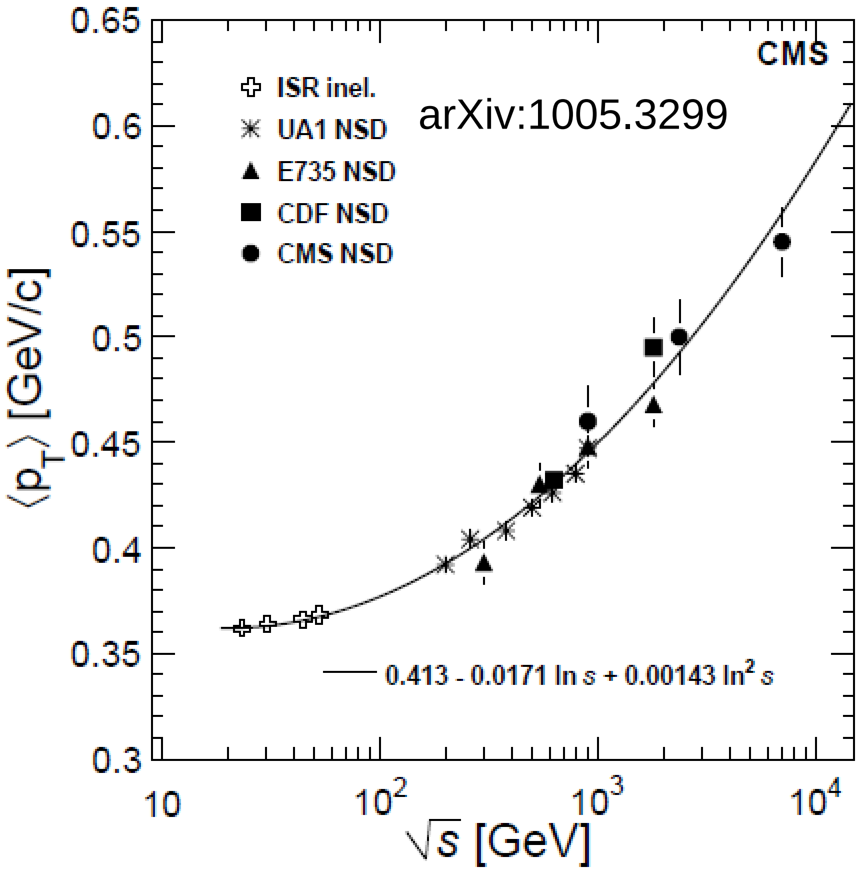
First published dN/dη distribution at 7 TeV

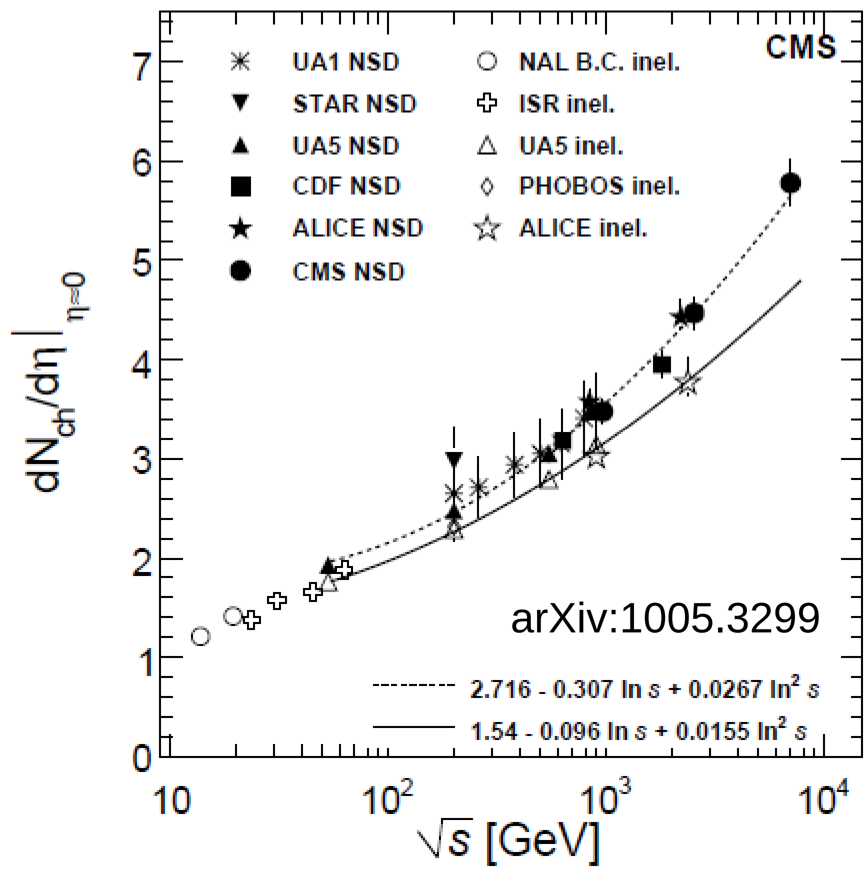
dN/dη(|η|<0.5) =
5.78 ±0.01(stat) ±0.23(syst)

Increase from 0.9 to 7 TeV:
(66.1 ±1.0(stat) ±4.2(syst))%

$dN_{ch}/d\eta$ distributions averaged over the cluster counting, tracklet and global track methods and symmetrized in η. The shaded band represents systematic uncertainties.

Results: energy dependence

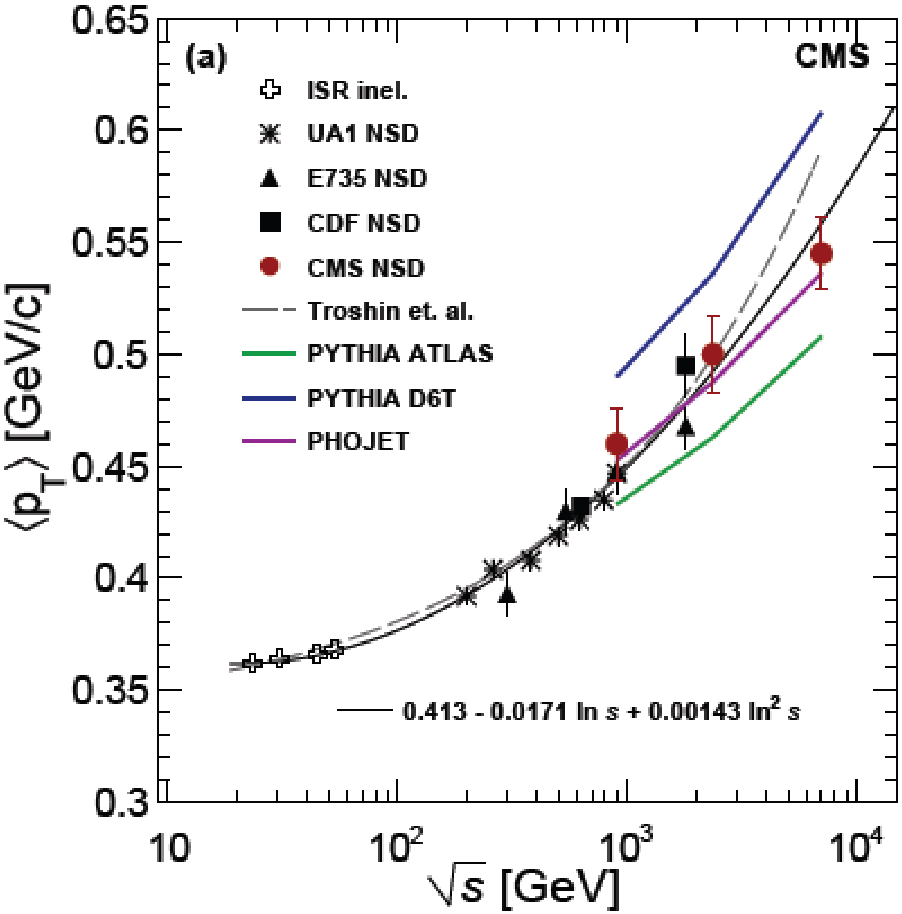


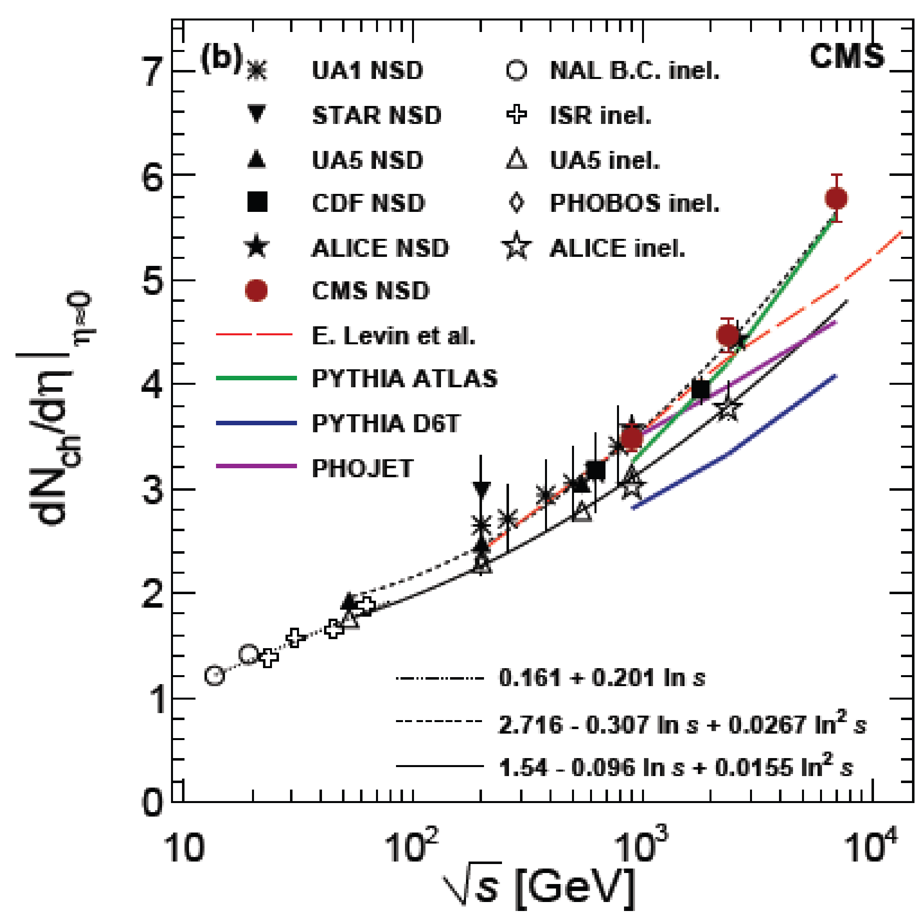


Collision energy dependence of average transverse momentum.

Charged particle pseudorapidity density as a function of collision energy.

Comparisons with models, MCs



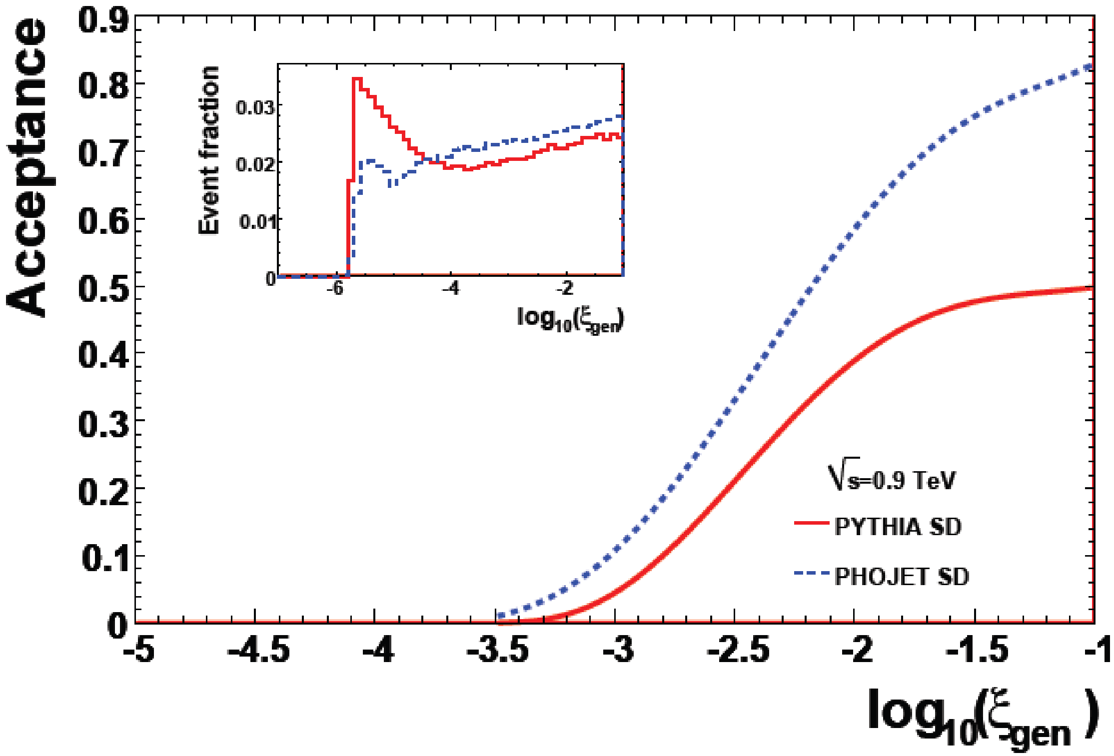


PHOJET describes $\langle p_T \rangle$ well

Most tunes underestimate dN/dη at 7 TeV

Diffractive events in CMS

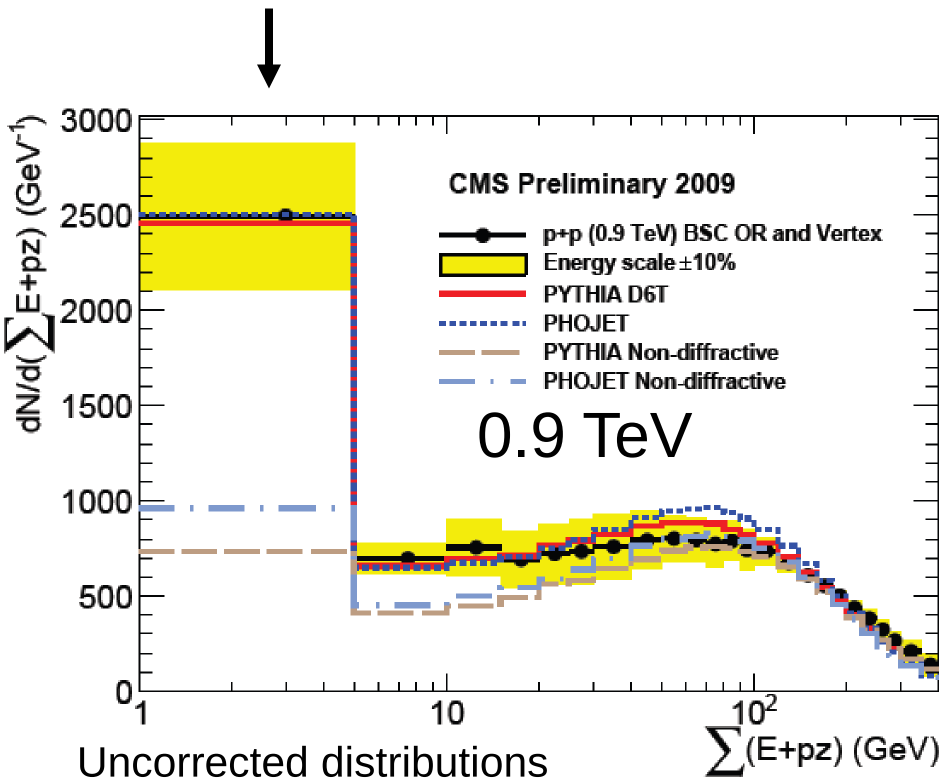
- Acceptance for single diffractive events is high enough to clearly observe them
- The acceptance is clearly model-dependent (event multiplicity and topology)
- The CMS calorimeters are used with coverage of $-5<\eta<5$

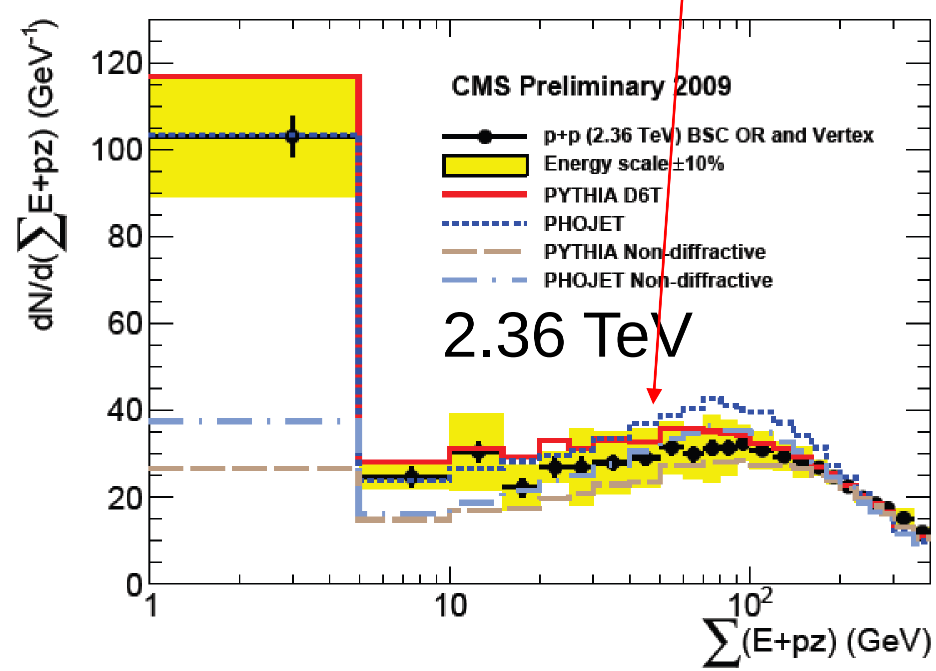


Observation of SD events I.

Variable used: $\Sigma(E+p_z) = \Sigma E(1+\cos\theta) = \Sigma(p_T e^{\eta})$
The sum runs over the full calorimeter acceptance
Events below 5 GeV are mainly SD type:
almost no forward energy on the +z side

PYTHIA describes the ND part better than PHOJET





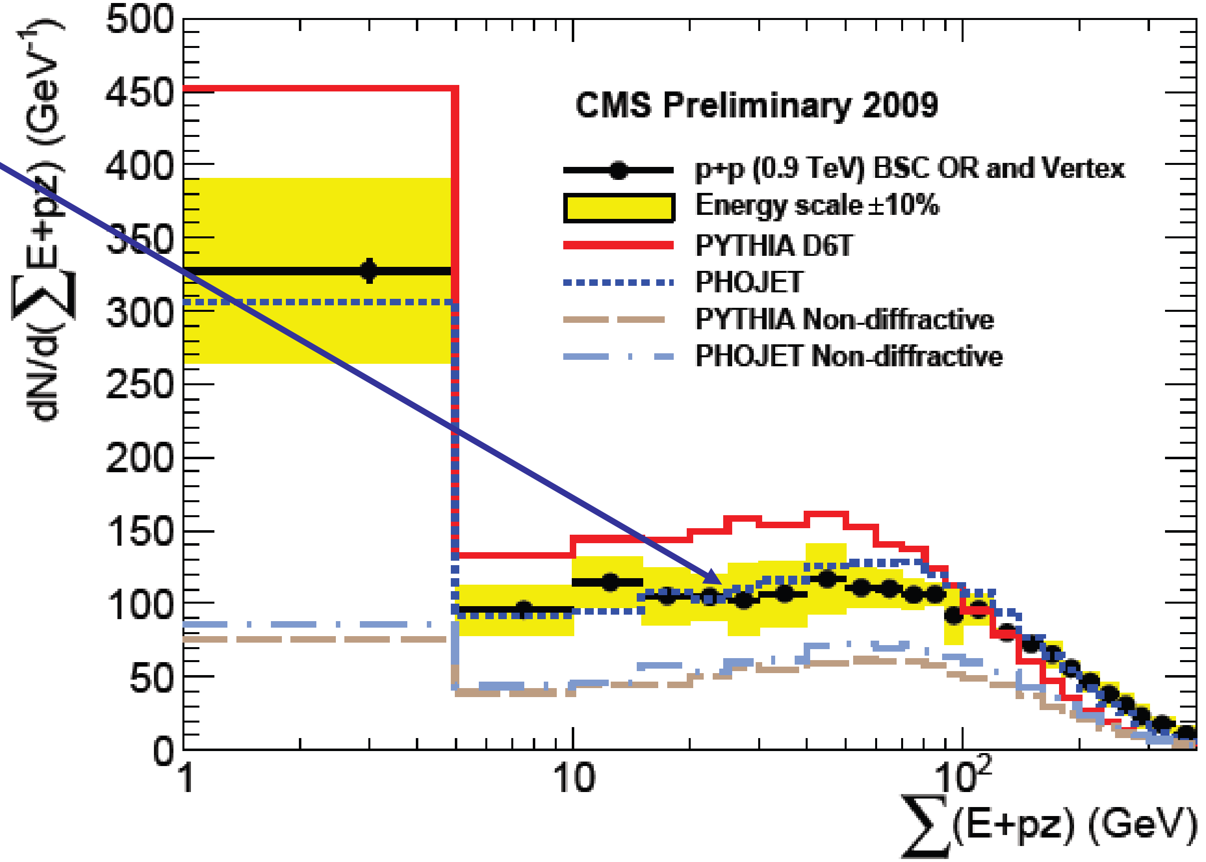
Uncorrected distributions

Observation of SD events II.

Enhancing SD events:

E_{HF-}<8 GeV was required (LRG over HF-)

PHOJET agrees better with the data (for high-mass SD)



Conclusions

- CMS has published three **papers** on Minimum Bias data so far:
  - $dN/d\eta$ and dN/dp_T at 0.9 and 2.36 TeV
  - $dN/d\eta$ and dN/dp_T at 7 TeV
  - Bose-Einstein Correlations
- CMS has used its calorimeters (10 units of η) to observe **single-diffractive** events
- Other upcoming results/publications:
  - **Underlying event** studies
  - Cluster properties in two-particle **correlations**
  - **Multiplicity distributions**, $\langle p_T \rangle$ vs multiplicity, KNO scaling
  - Many other topics
- CMS is an **excellent detector** to study minimum bias physics and diffraction (large coverage, MB triggers, low p_T-reach)
- CMS analysis groups are also working on **MBUEWG recommendations** on event and track selections to compare between experiments
- Exciting **prospects** to learn about multiparticle production, soft QCD, UE!