Transverse momentum and pseudorapidity distributions of charged hadrons at CMS

PLHC 2010, Hamburg

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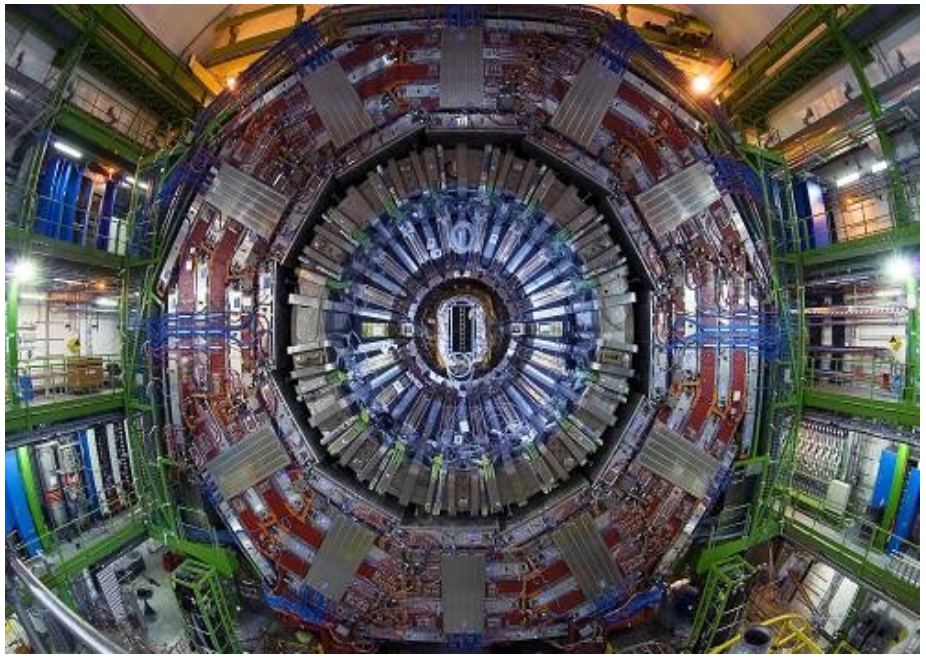
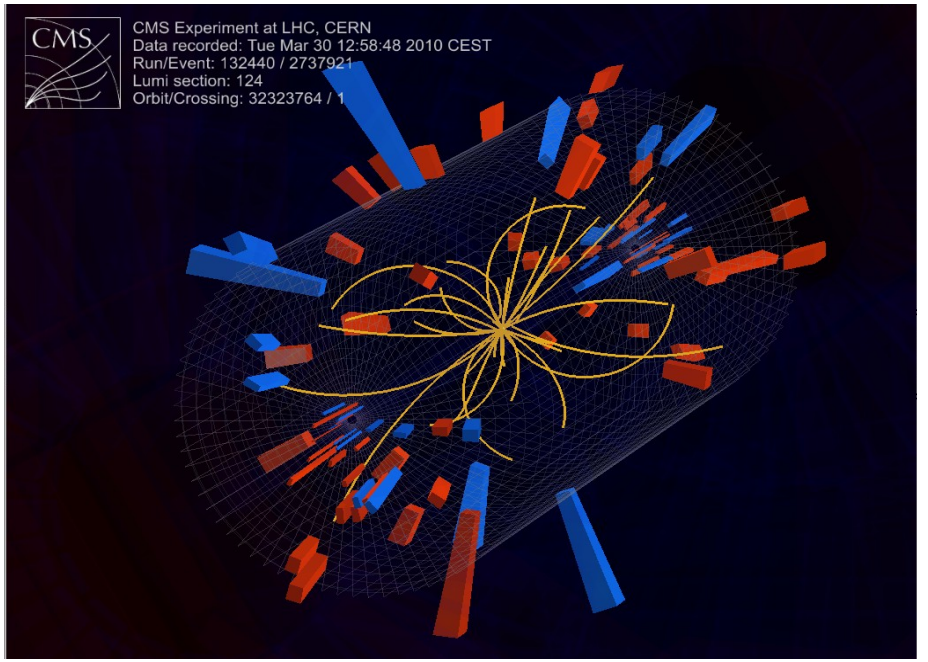
for the CMS Collaboration



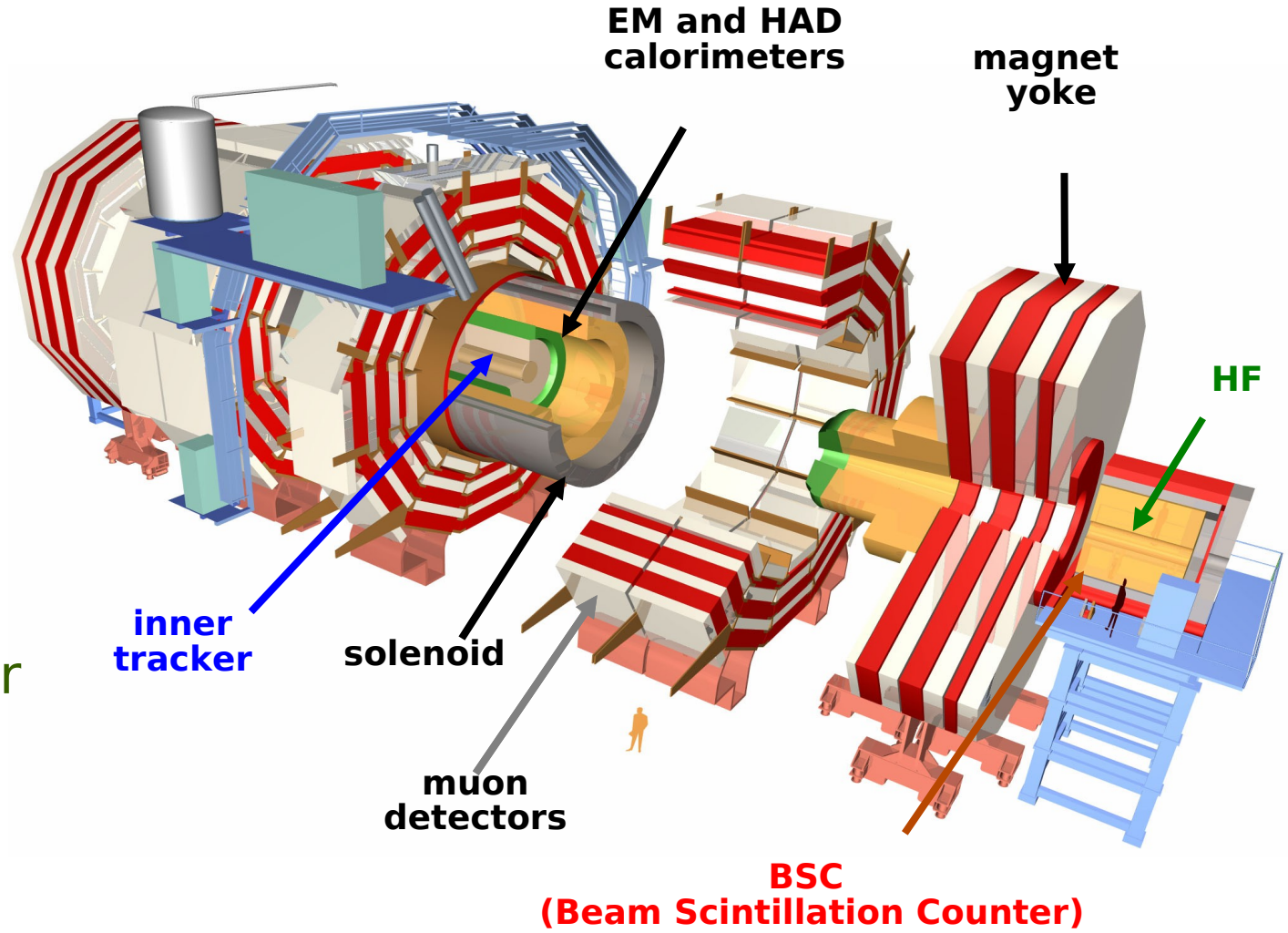


Introduction

- The bulk of the particles produced in pp collisions arise from soft interactions, which are modeled only phenomenologically.
- Soft processes contain: elastic scattering, single-diffractive, double-diffractive and non-diffractive (NSD) → to be presented today
- Results of $dN/d\eta$, dN/dp_T and $\langle p_T \rangle$ of charged hadrons at 0.9, 2.36, 7.0 TeV are presented.
- 7.0 TeV: Highest collision energy ever!
- Experimental results provide the critical guidance for tuning these widely-used models and event generators, and preparation for the high-luminosity runs at LHC.
- Provide important reference for the heavy ion collisions.

The CMS Detector

- Magnetic field: 3.8 Tesla
- Inner tracker: $|\eta| < 2.5$
- BSC $3.23 < |\eta| < 4.65$ partial coverage in the φ direction
- Forward Calorimeter (HF): $2.9 < |\eta| < 5.2$



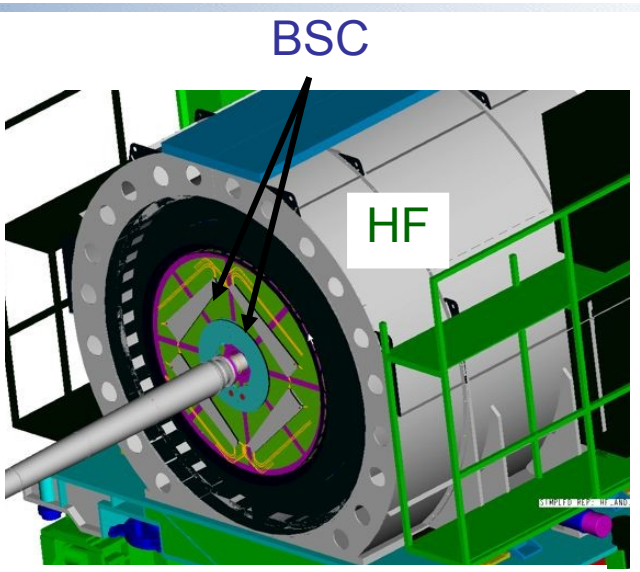
Trigger and Event Selection

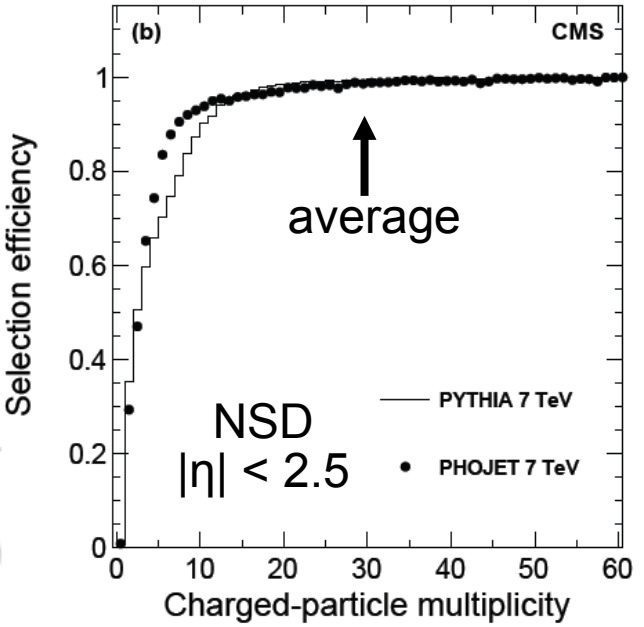
- Data sample used for the 7 TeV is 1.1/μb. Collision rate ~ 50 Hz "pileup" ~ 0.3% (neglected)

- Trigger: any hit in the Beam Scintillator Counters (BSC, $3.23 < |\eta| < 4.65$) AND a filled bunch passing the beam pickups (BPTX)

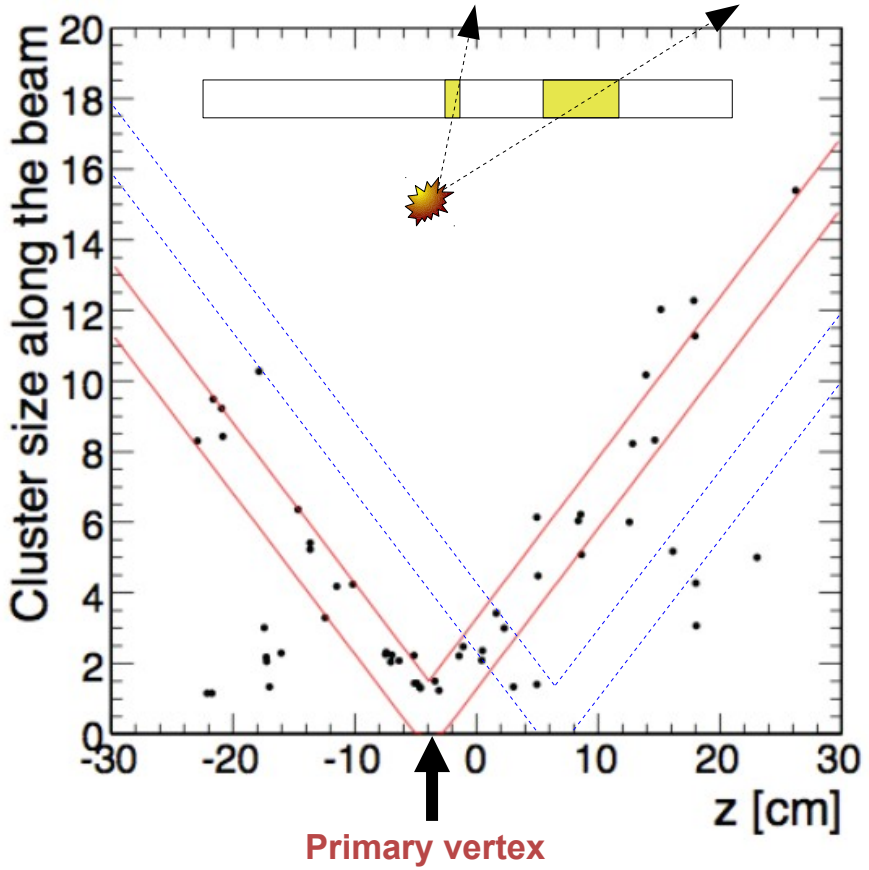
- Off-line event selection (NSD):
  - >3 GeV total energy on both sides in the Forward Calorimeter (HF $2.9 < |\eta| < 5.2$)
  - BSC Beam Halo rejection (BSC)
  - Dedicated beam background rejection
  - Collision vertex

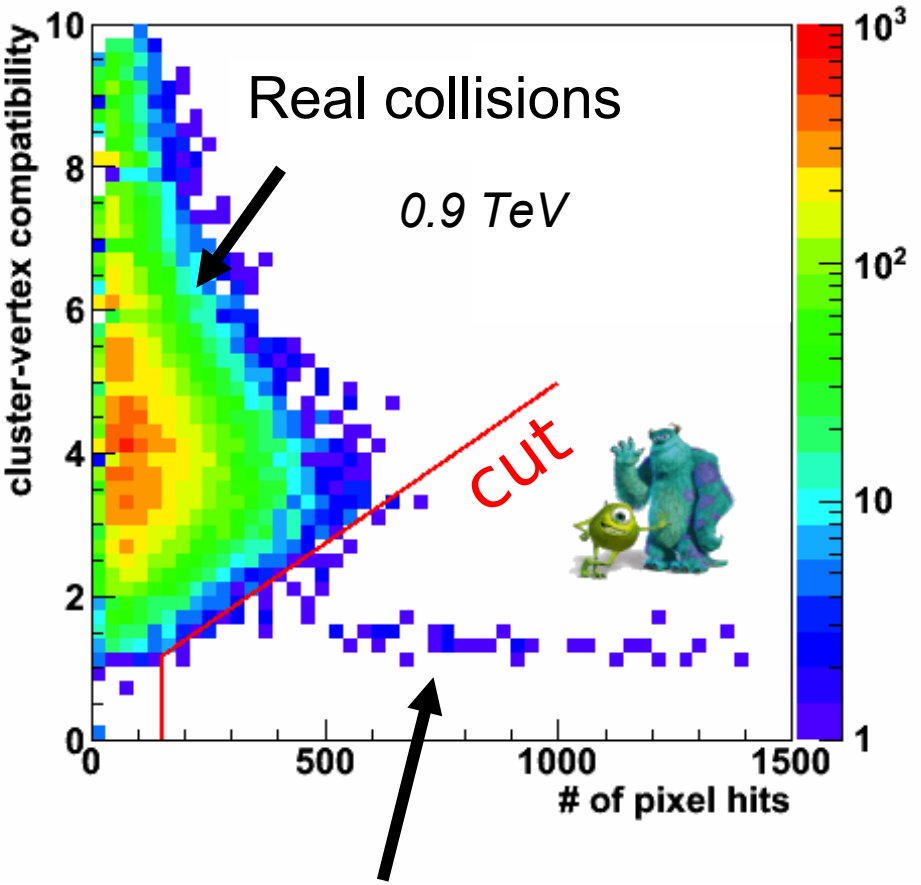
- 55100 events are selected after all cuts (7 TeV). Event selection efficiency is checked by MC and ZeroBias sample.





Beam gas event rejection





Vertex-cluster compatibility:
Ratio of $N_{clusters}$ in the V shape and
$N_{clusters}$ 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} (neglected)

Trigger Efficiencies

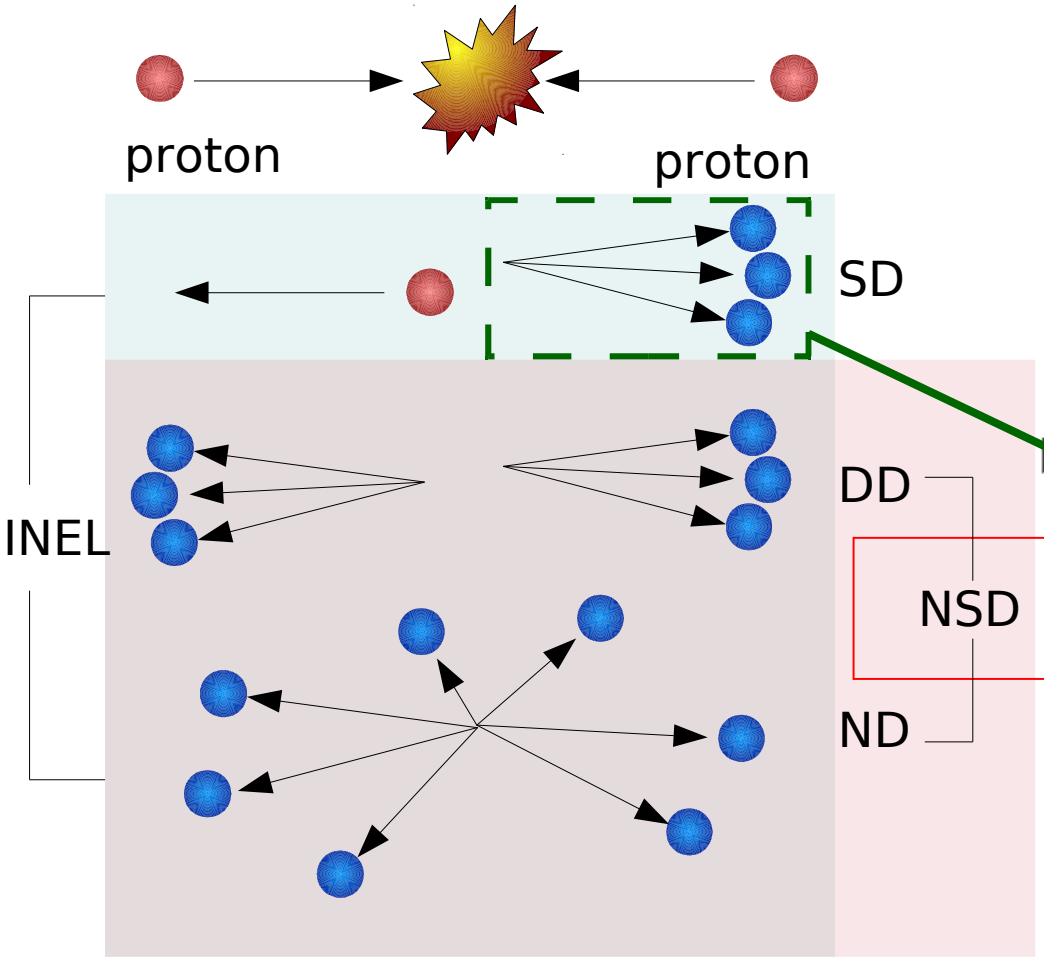
PYTHIA									
Energy	0.9 TeV			2.36 TeV			7.0 TeV		
	Frac.	Sel. Eff.	Sel. Frac.	Frac.	Sel. Eff.	Sel. Frac.	Frac.	Sel. Eff.	Sel. Frac.
SD	22.5%	16.1%	5.2%	21.0%	21.8%	6.3%	19.2%	26.7%	6.8%
DD	12.3%	35.0%	6.2%	12.8%	33.8%	5.9%	12.9%	33.6%	5.8%
ND	65.2%	95.2%	88.7%	66.2%	96.4%	87.8%	67.9%	96.4%	87.4%
NSD	77.5%	85.6%	94.8%	79.0%	86.2%	93.6%	80.8%	86.3%	93.1%

PHOJET									
Energy	0.9 TeV			2.36 TeV			7.0 TeV		
	Frac.	Sel. Eff.	Sel. Frac.	Frac.	Sel. Eff.	Sel. Frac.	Frac.	Sel. Eff.	Sel. Frac.
SD	18.9%	20.1%	4.9%	16.2%	25.1%	5.0%	13.8%	30.7%	5.0%
DD	8.4%	53.8%	5.9%	7.3%	50.0%	4.5%	6.6%	48.3%	3.8%
ND	72.7%	94.7%	89.2%	76.5%	96.5%	90.5%	79.6%	97.1%	91.2%
NSD	81.1%	90.5%	90.9%	83.8%	92.4%	89.5%	86.2%	93.4%	95.0%

- Predictions from PYTHIA and PHOJET are studied.
- High NSD trigger efficiency > 85%.
- SD Fraction after the event selection is 5% - 7%.
- Difference between PHOJET SD definition and PYTHIA is at 2% level.

Estimating the diffractive component from data

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

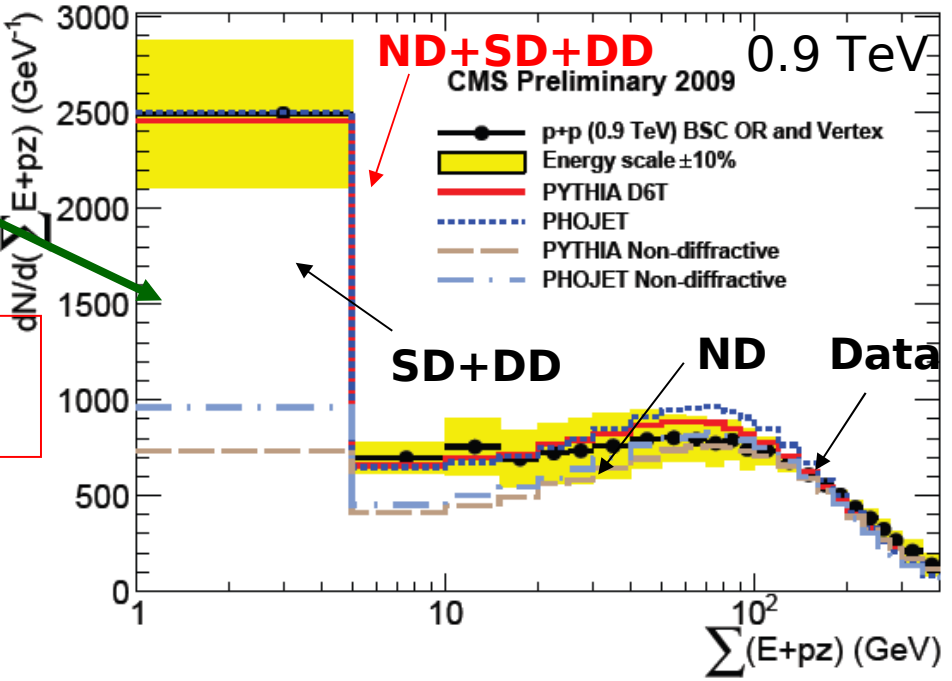


Variable used: $\Sigma(E+p_z) = \Sigma E(1+\cos\Theta) = \Sigma(p_T e^{\eta})$

The sum runs over the full calorimeter acceptance

Events below 5 GeV are mainly SD type:

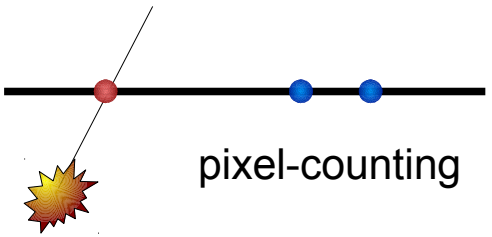
→ almost no forward energy on the +z side

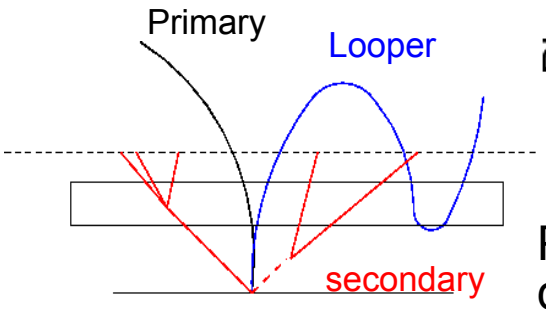


The calorimeter data is used to fit the SD+DD fraction in data using PYTHIA event shapes. PHOJET was also studied similarly.

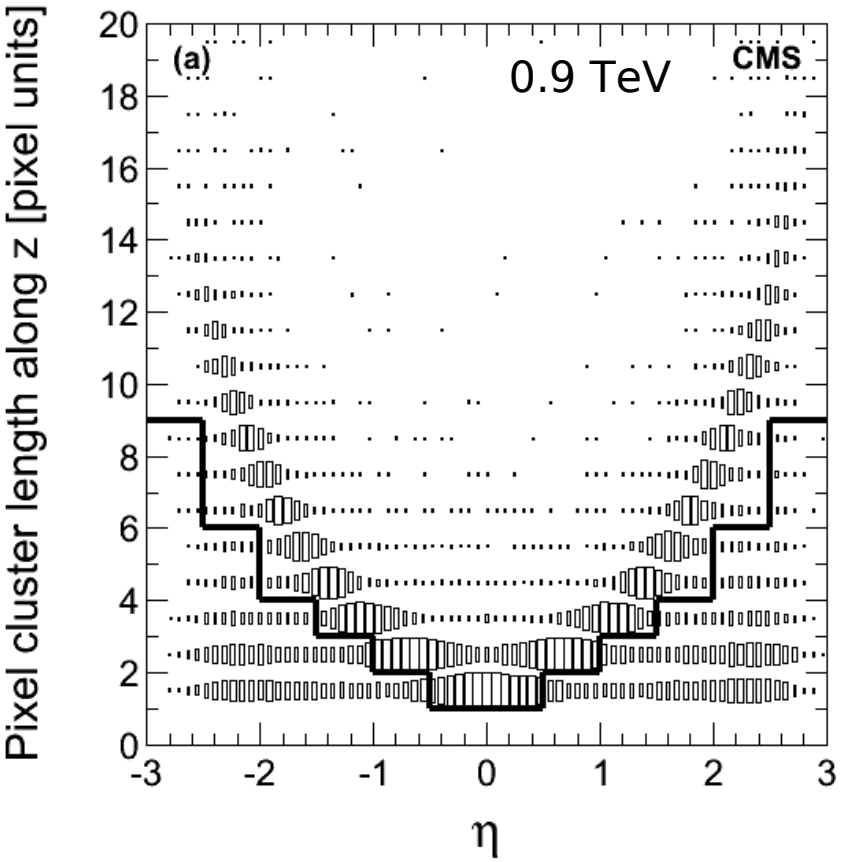
Cluster Counting Method

- 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!





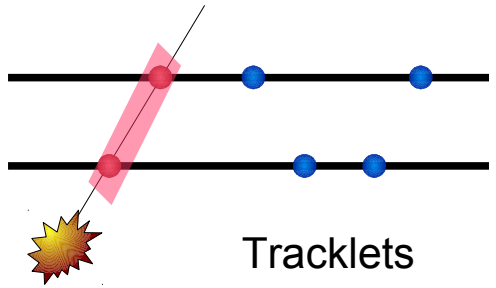
p_T-reach: down to 30 MeV/c



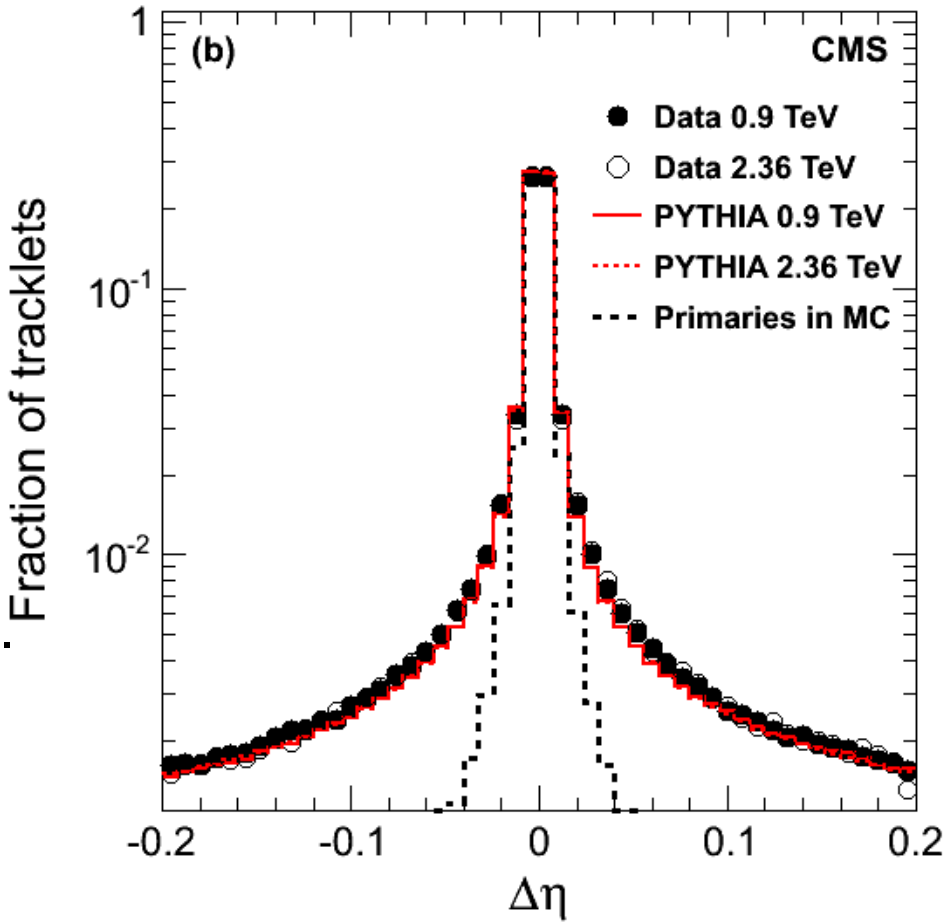
Pixel cluster length along the beam direction as a function of η. The solid line shows the cut applied.

Tracklet Method

- Tracklets: pairs of clusters on different pixel barrel layers
- The Δη and Δφ correlations between the 1st and 2nd clusters are used to separate the signal from background:
  $\Delta\eta = \eta_1 - \eta_2 \qquad \Delta\varphi = \varphi_1 - \varphi_2$
- A side-band in Δφ is used to subtract combinatorial background
- Corrections for efficiency, weak decays, secondaries.
- Independent result for all 3 layer pairs.
- Less sensitive to beam background



p_T-reach: down to 50 MeV/c

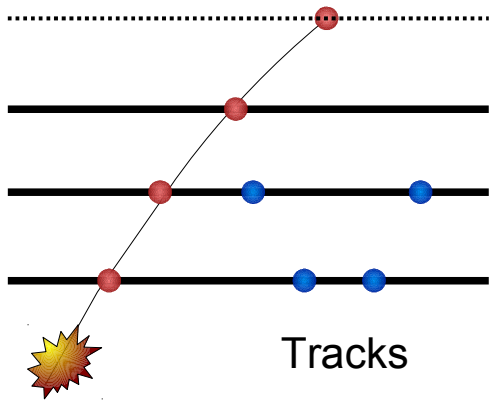


The Δη distribution of the two clusters of the tracklets

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



Result: P_T distribution at 7 TeV

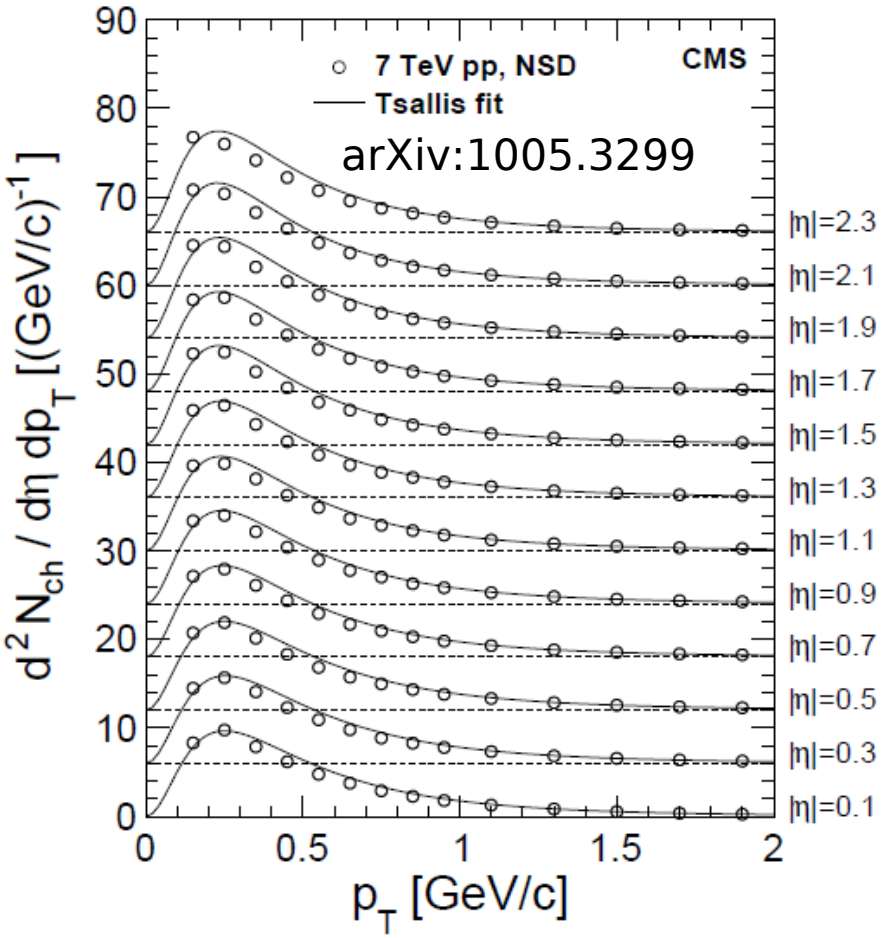
Measured down to 150 MeV
Important: turn-over of the yields

Fit with the Tsallis-function:

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

Behavior of the function:

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



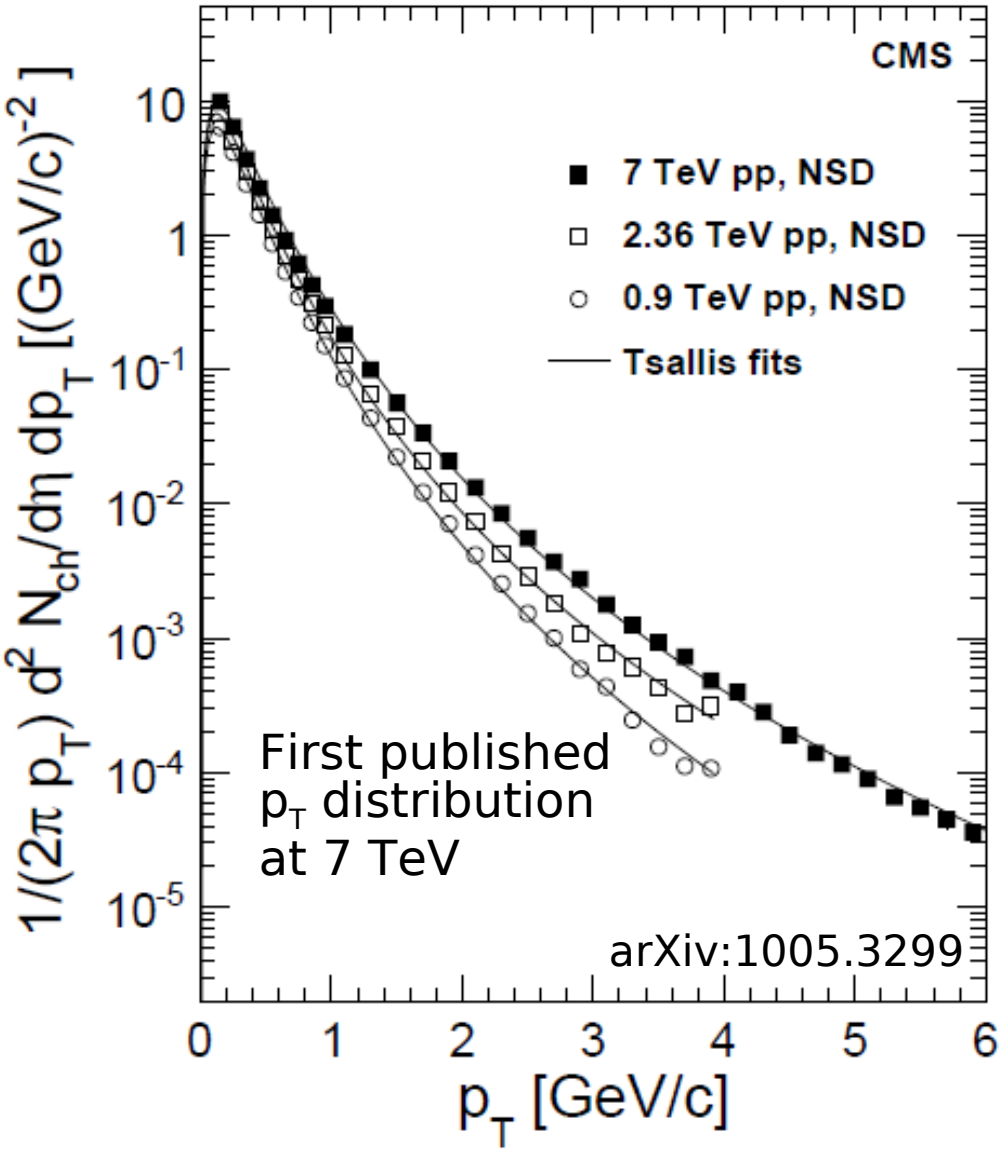
$\langle p_T \rangle$ = 545 ±5(stat) ±15(syst) MeV/c

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

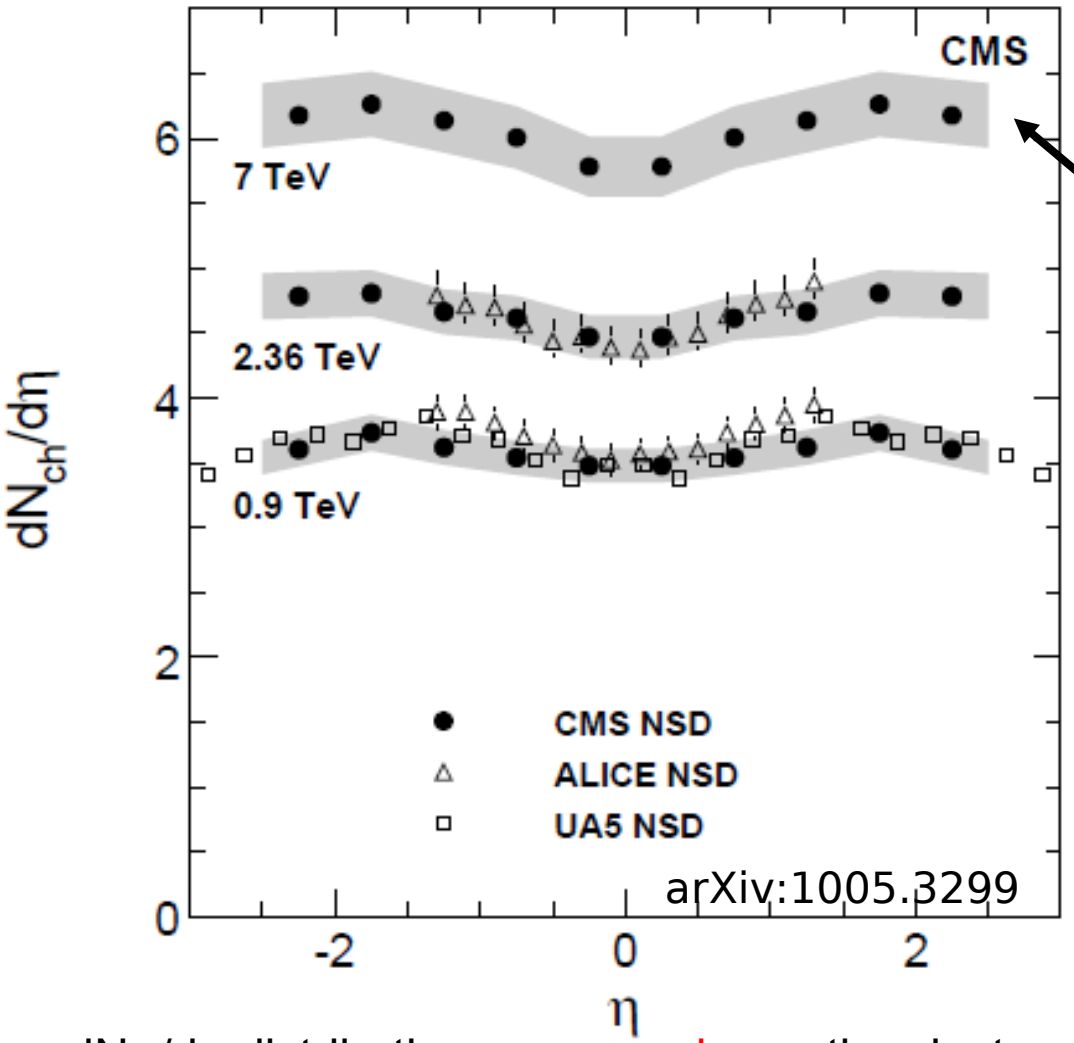
P_T-distribution at 7 TeV

- 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 phenomenologically.
- 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)!

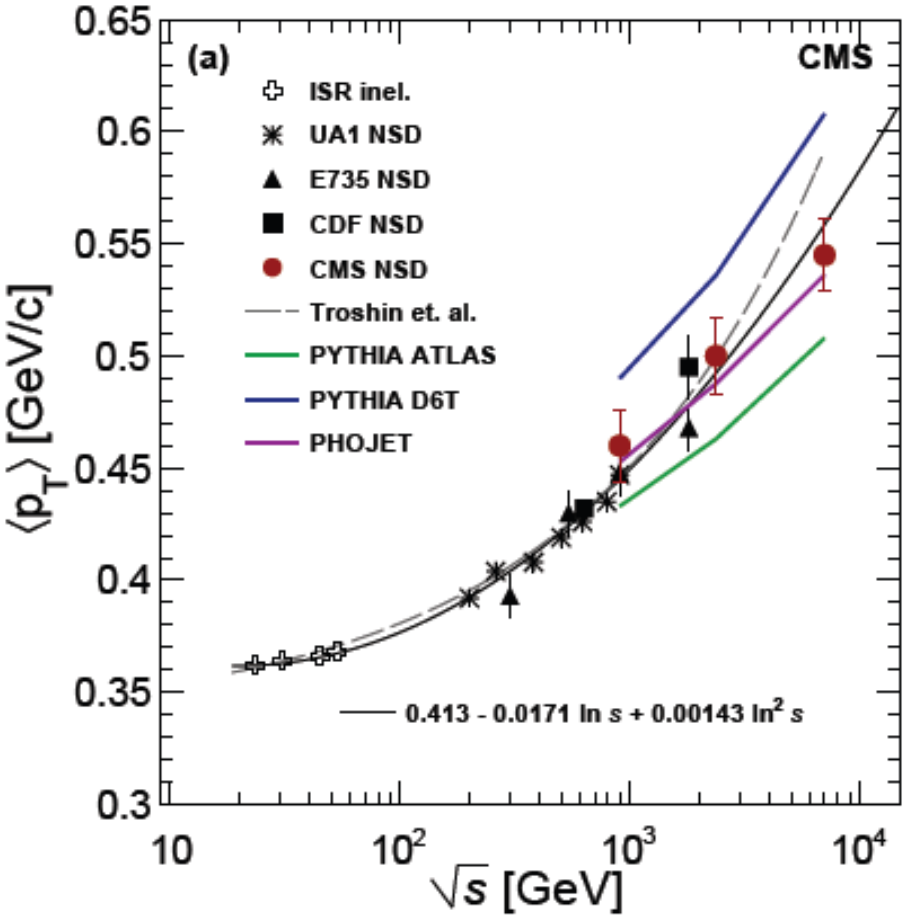
First published dN/dη distribution at 7 TeV

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

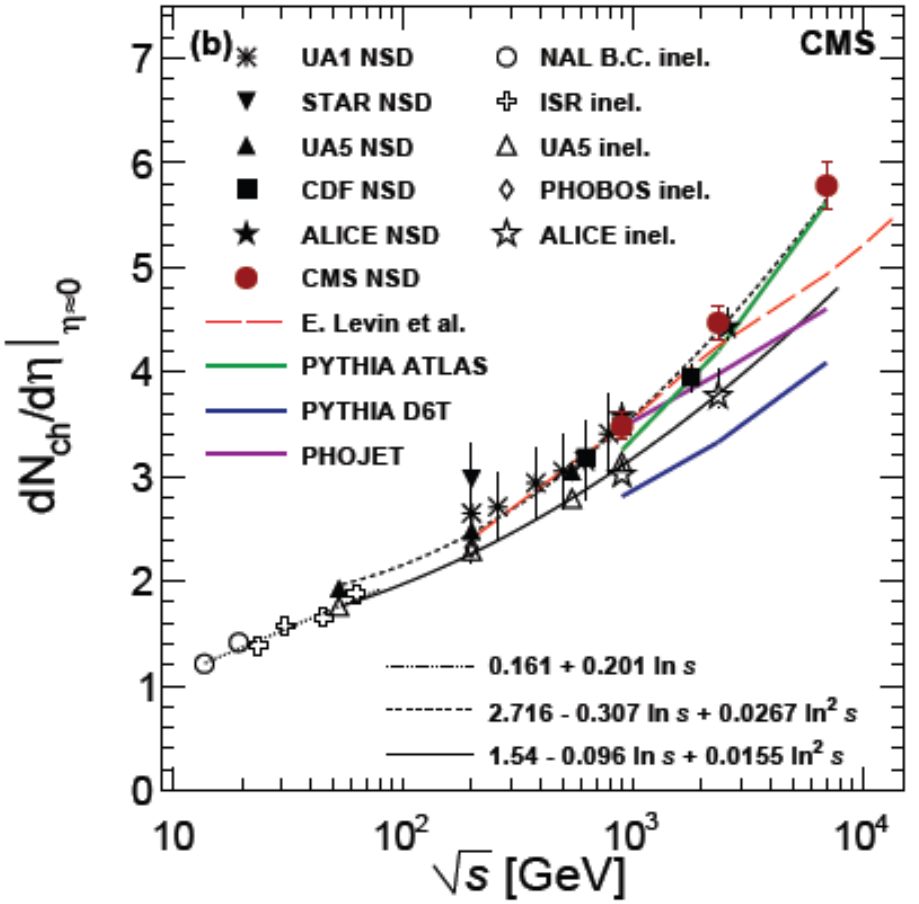
Results from 0.9 TeV and 2.36 TeV are consistent with UA5 and ALICE.
(1.5% difference due to the leptons)

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

Energy dependence Compared with Models

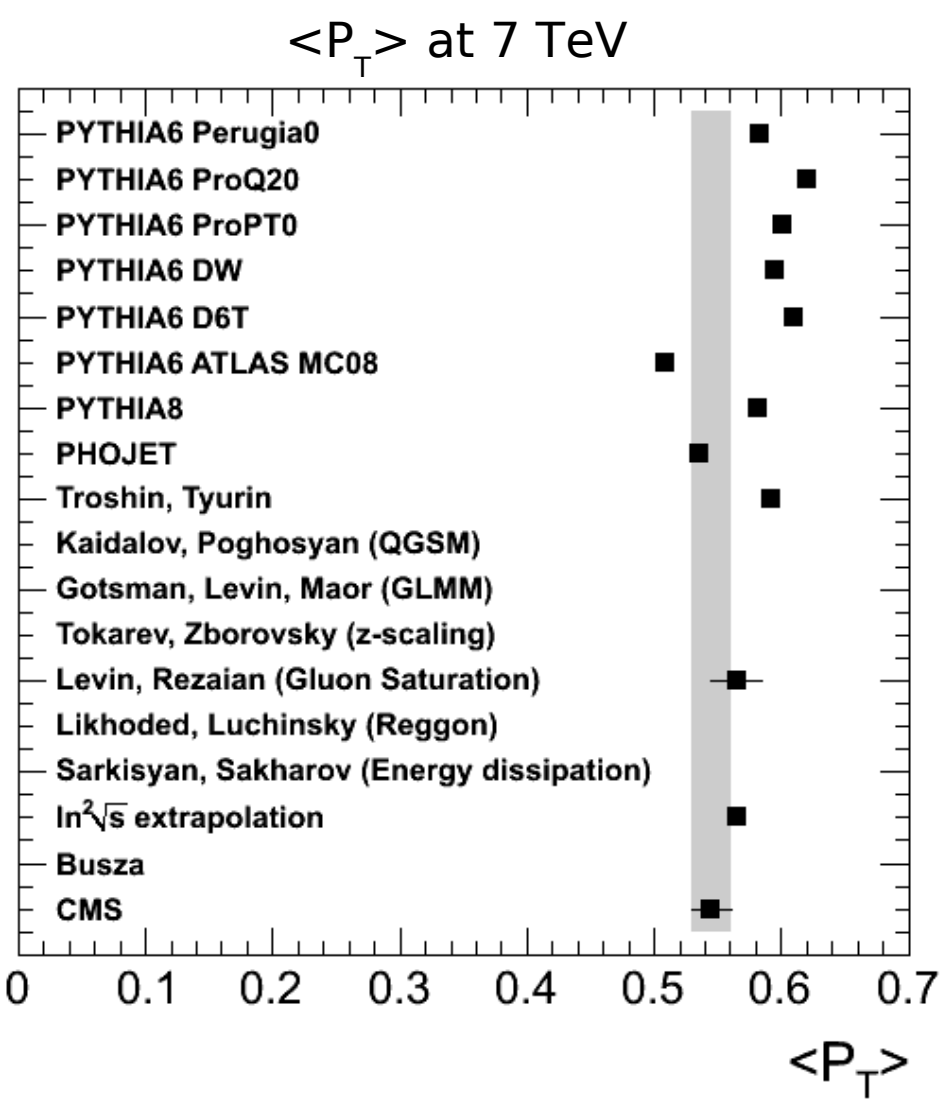


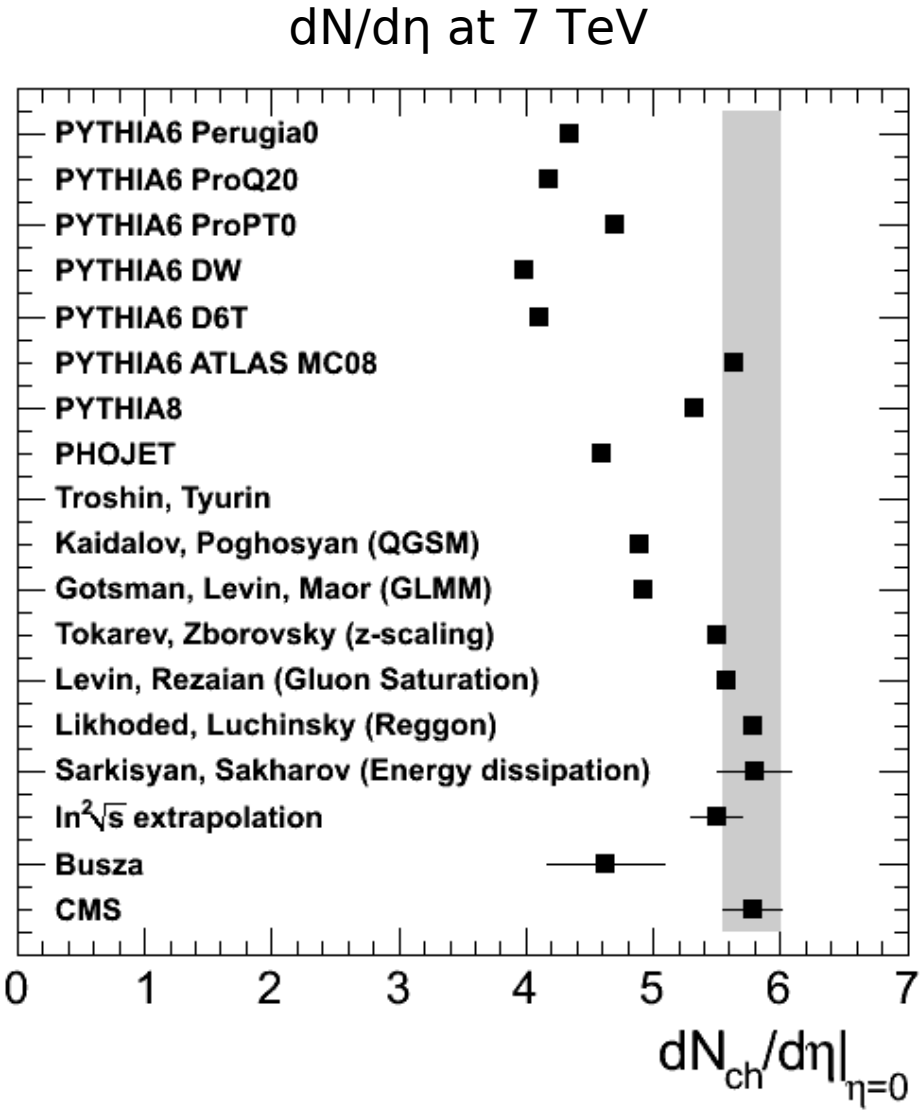
PHOJET describe <p_T> well in the three different energies.



Most tunes underestimate dN/dη at 7 TeV

Comparisons with models, MCs





dN/dη ratio

- Increase from 0.9 to 7 TeV:

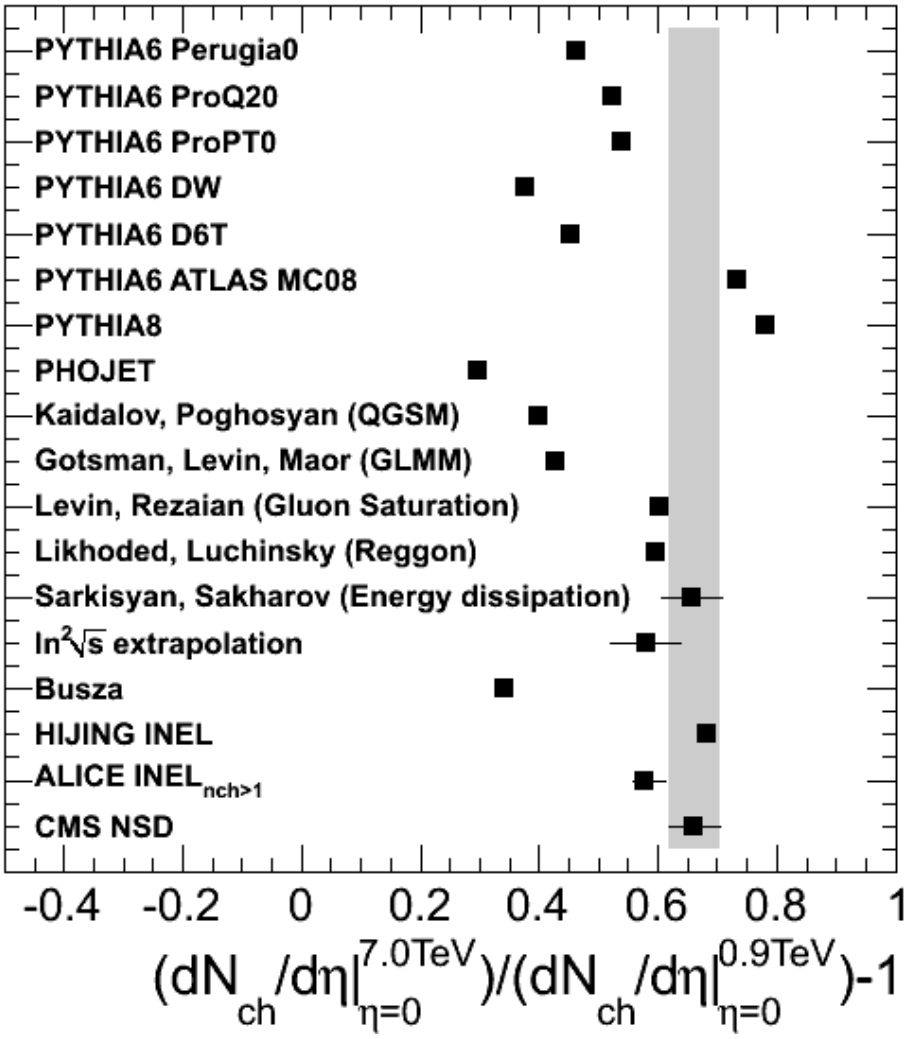
  (66.1 ±1.0(stat) ± 4.2(syst))%

- ALICE measurement: ($INEL_{nch>1}$)

  (57.6±0.4(stat.) $^{+3.6}_{-1.8}$ (syst.))%

- Most of the PYTHIA tunes predicted a lower increase in dN/dη.

Increase from 0.9 TeV to 7 TeV



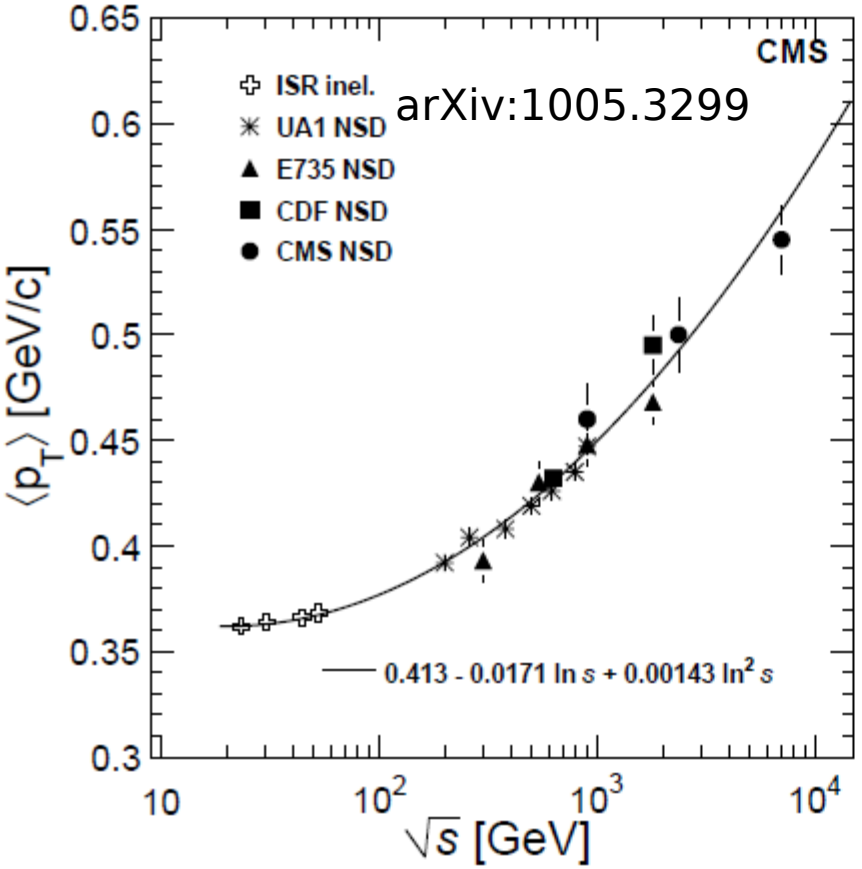
Summary

- CMS is an excellent detector for the minimum bias physics study: (Large coverage, MinBias triggers, low p_T reach).
- CMS has published two NSD $dN/d\eta$ and dN/dp_T papers which present the results from 0.9, 2.36 and 7.0 TeV.
  - Results are checked with PYTHIA tunes and PHOJET.
  - 7 TeV results are checked with B=0 data with tracklet method.
- The measured NSD $dN/d\eta$ and $\langle p_T \rangle$ are compared with predictions (postdictions) from various of phenomenological models.
- The measured $dN/d\eta$ is higher than the results from the commonly used PYTHIA tunes while $\langle p_T \rangle$ is lower than the predictions.

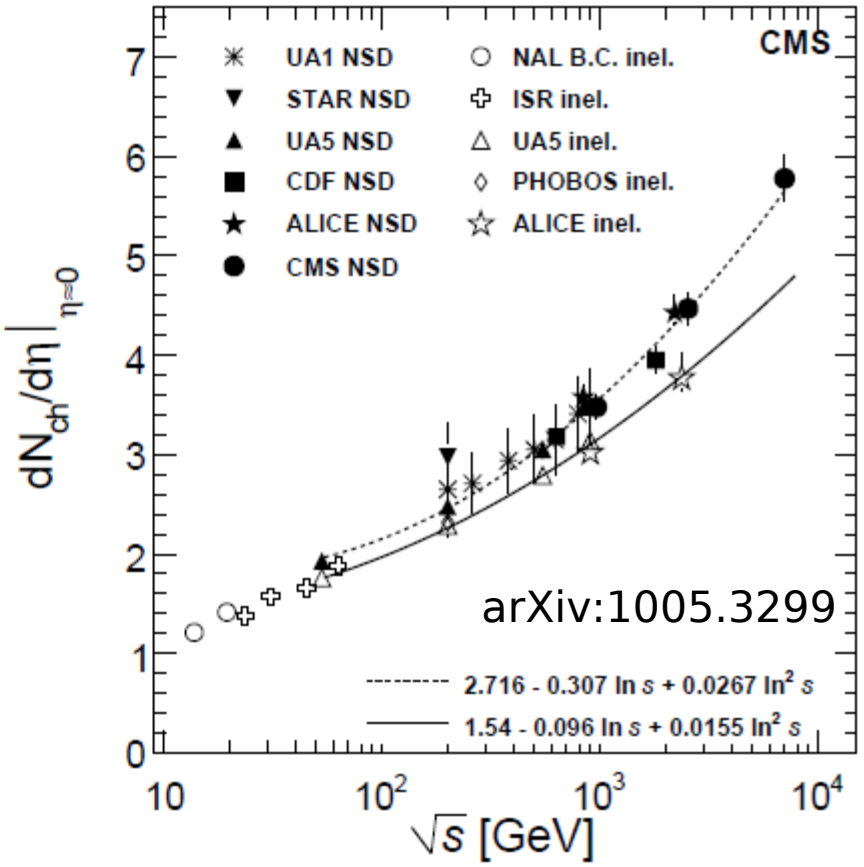
  → Input to the parameter tunning of the color reconnection and multiple parton interaction.

Backup slides

Results: energy dependence



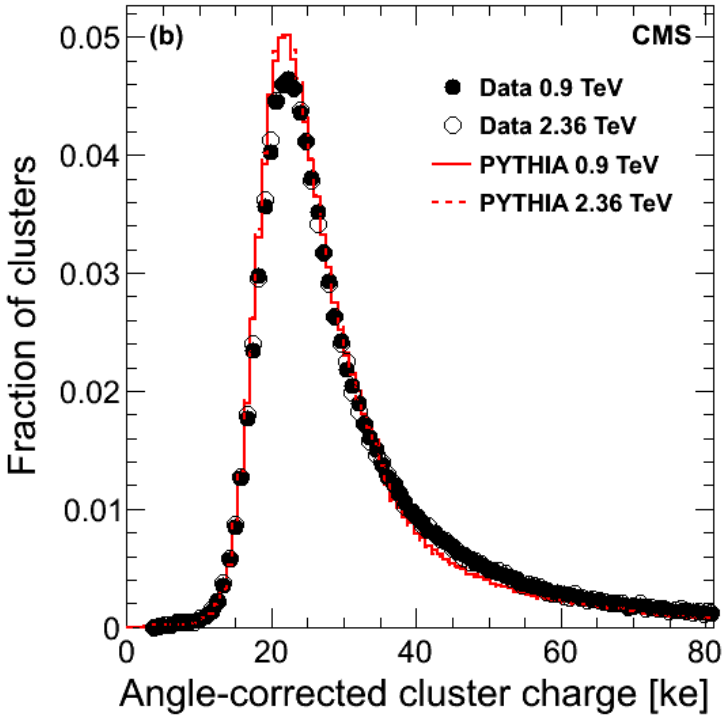
Collision energy dependence of average transverse momentum.



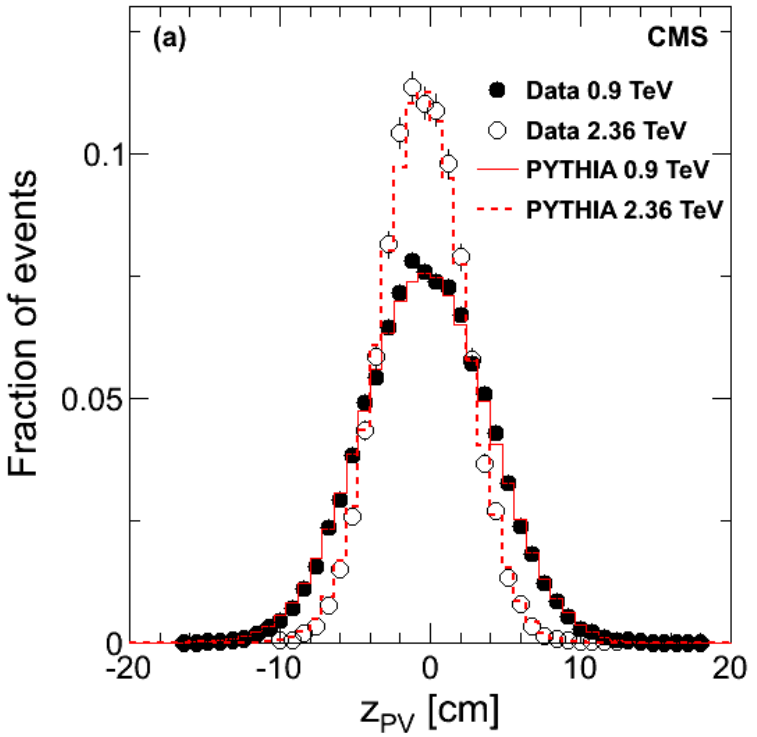
Charged particle pseudorapidity density as a function of collision energy.

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



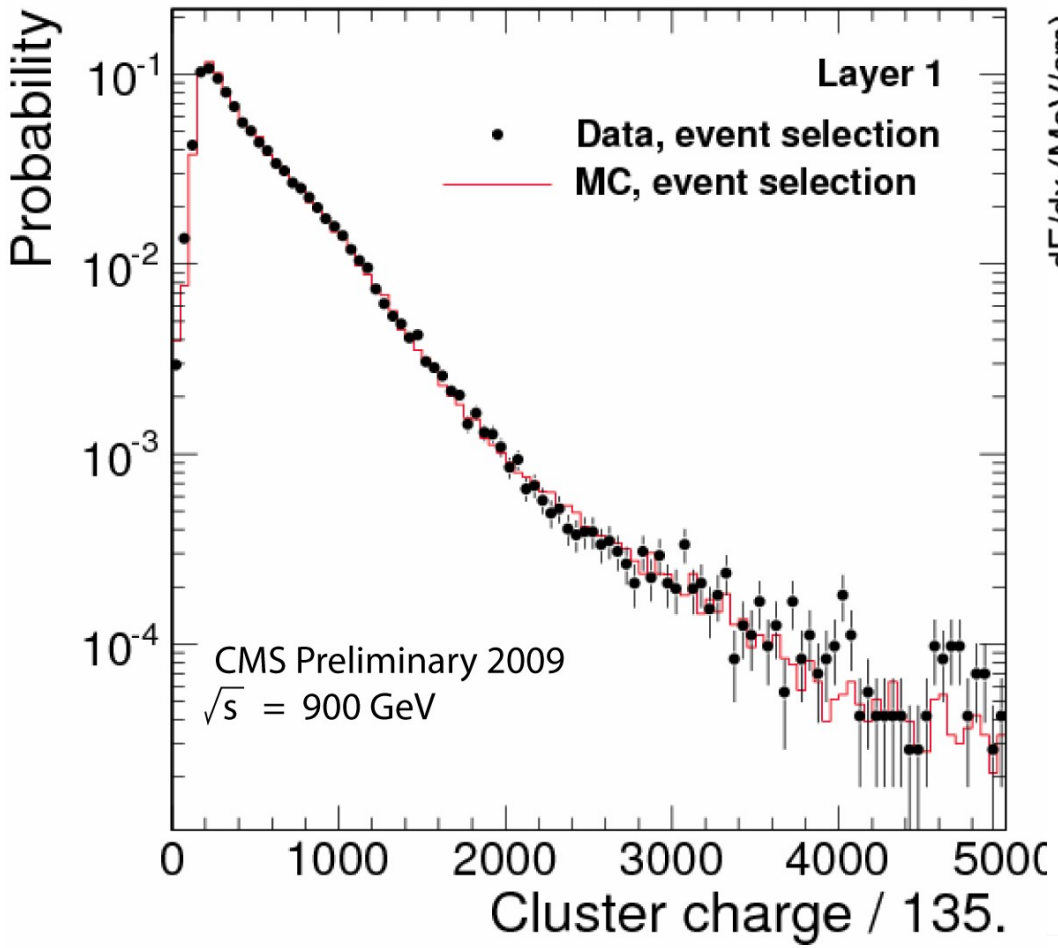
The energy loss in the tracker layers well described by MC



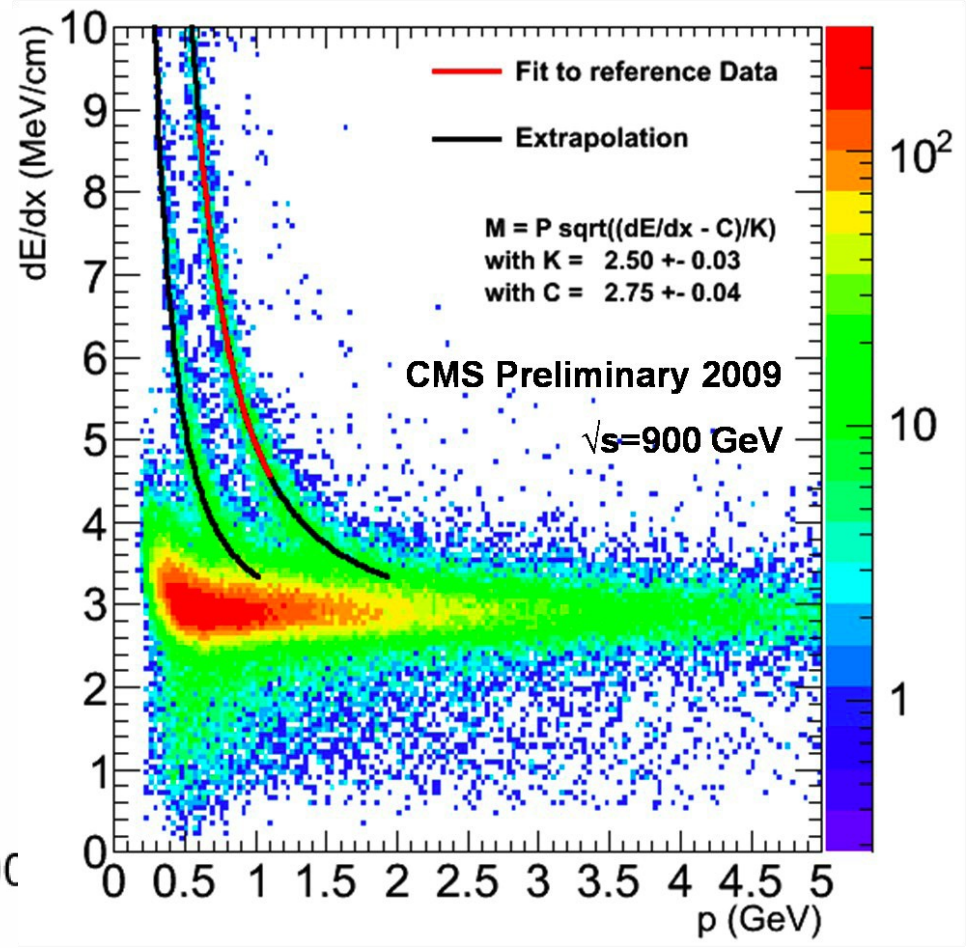
The vertex position distributions are clean Gaussians, with no tails

dE/dx information in the pixels

Silicon pixels



Silicon strips



Excellent agreement with simulations