CMS - first results

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QCD@Work - International Workshop on QCD - Theory and Experiment

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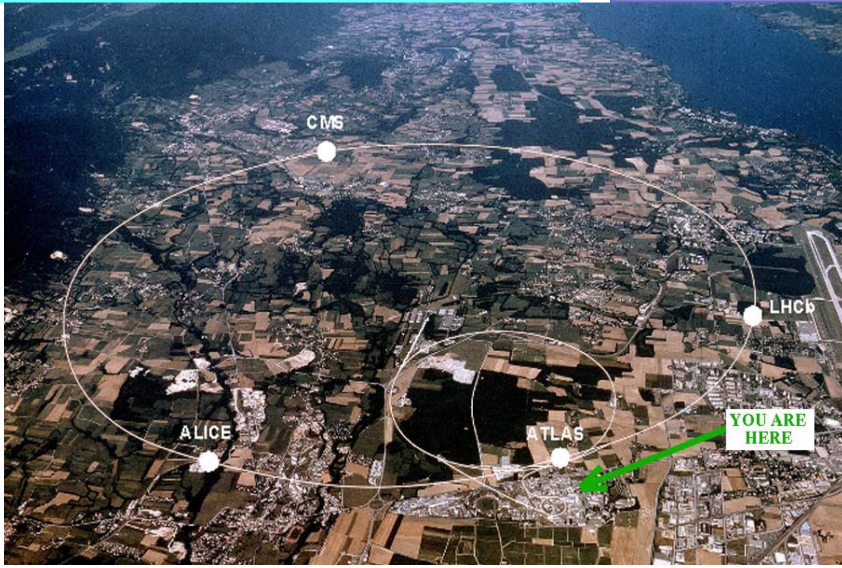


- **LHC and CMS**
- **Detector performance**
- **QCD Physics results**

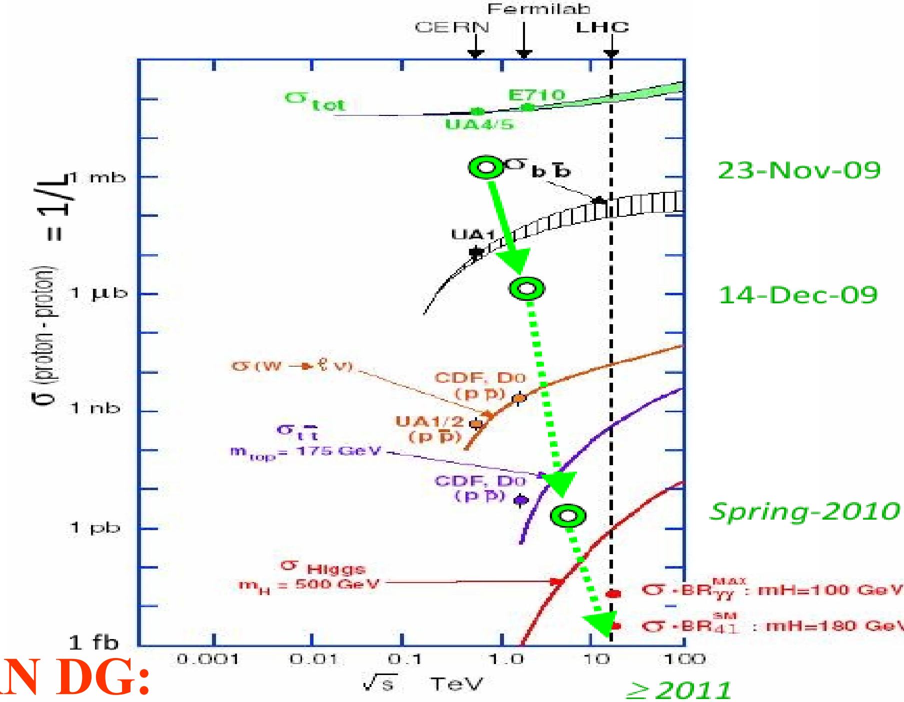
  - Charged particle multiplicity and p_t spectra
  - Bose Einstein Correlation
  - Angular correlations
  - Underlying Events
  - Diffraction (just approved) +…..

  } model comparison

- **Conclusions**

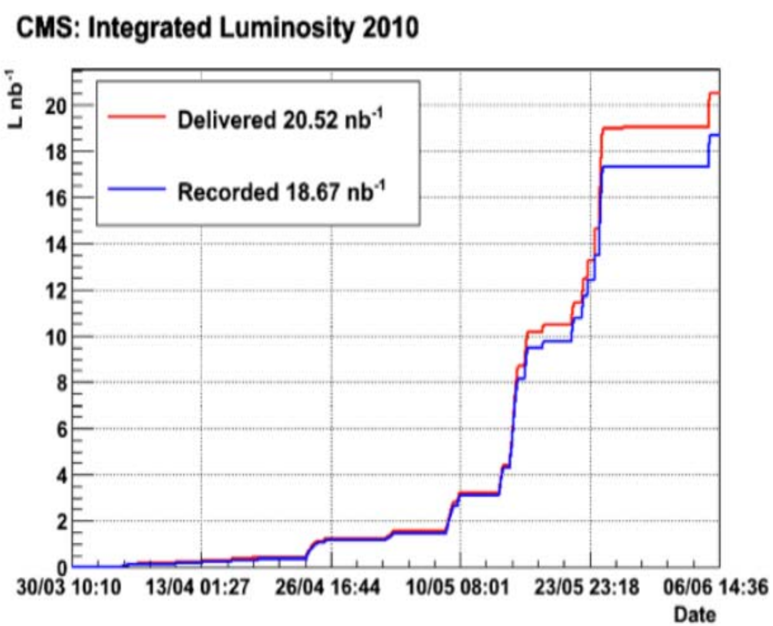
LHC and CMS

After 2009 startup
(0.9 TeV and few 2.36 TeV data)
with first Physics results



2010-2011 Physics program:
~1 fb^{-1} at 7 TeV c.m.

started successfully

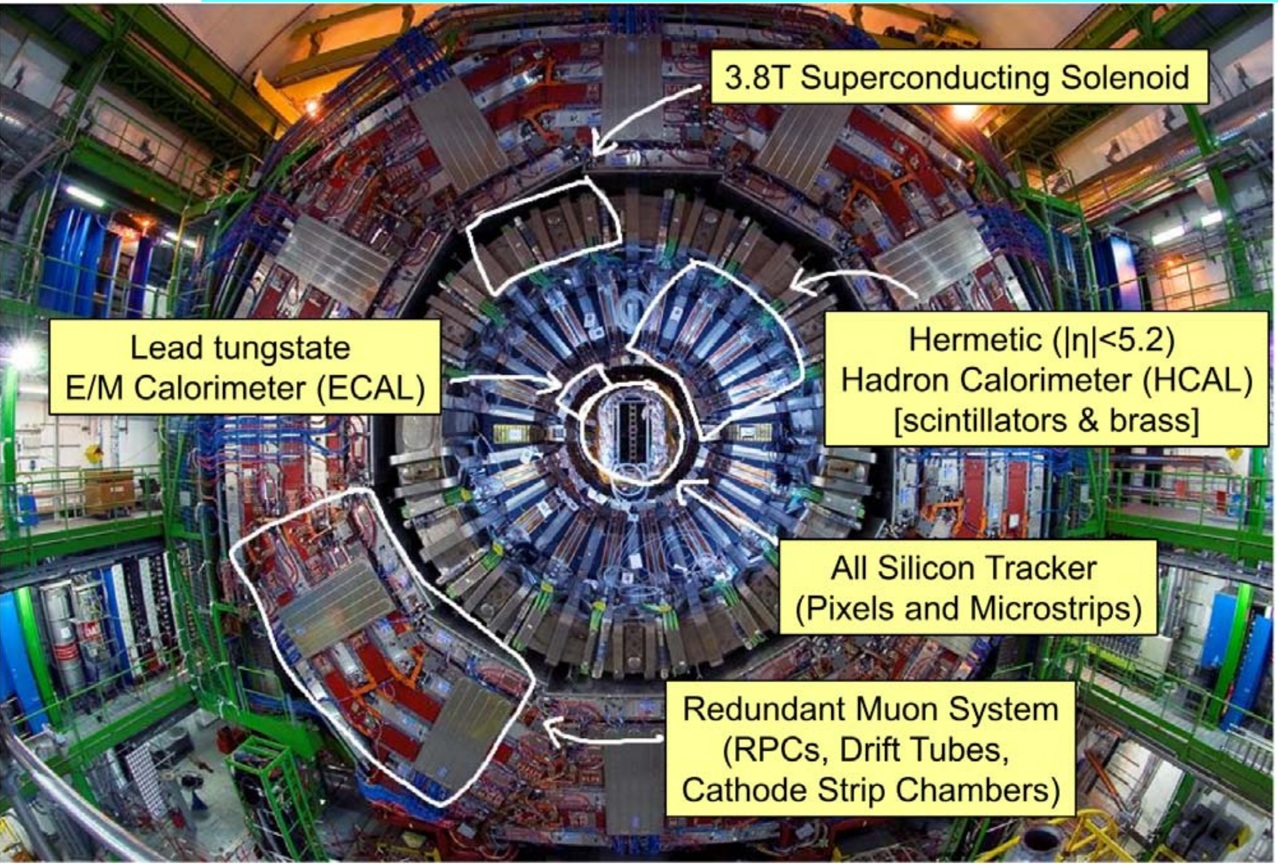


CERN DG:

One step towards these goals is for the LHC to run smoothly with bunches at the design intensity, that is, with 1.1×10^{11} protons per bunch. The first collisions at 3.5 TeV between bunches at this intensity were achieved successfully.., but in order for collisions at this intensity to become a routine operation, the LHC teams need to continue development work.

We have therefore decided, ….. to focus fully on the beam development work for at least the coming week.

LHC and CMS



Total weight: 12000 tons

Diameter: 15 m

Length 22 m

Superconducting coil:

3.8 T

All subdetectors working properly!!!
>99% of detector channels operational

Physic results from the very early data

The CMS tracker

Silicon pixel detector surrounded by silicon strip detectors

$|\eta|<2.5$ [$\eta = -\ln(\tan(\theta/2))$]

Pixel

- 3 barrel layers (R=4, 7, 11 cm),
- 2 endcap disks
- ~1 m^2 of Si sensors,
- 66M channels,
- 1440 modules

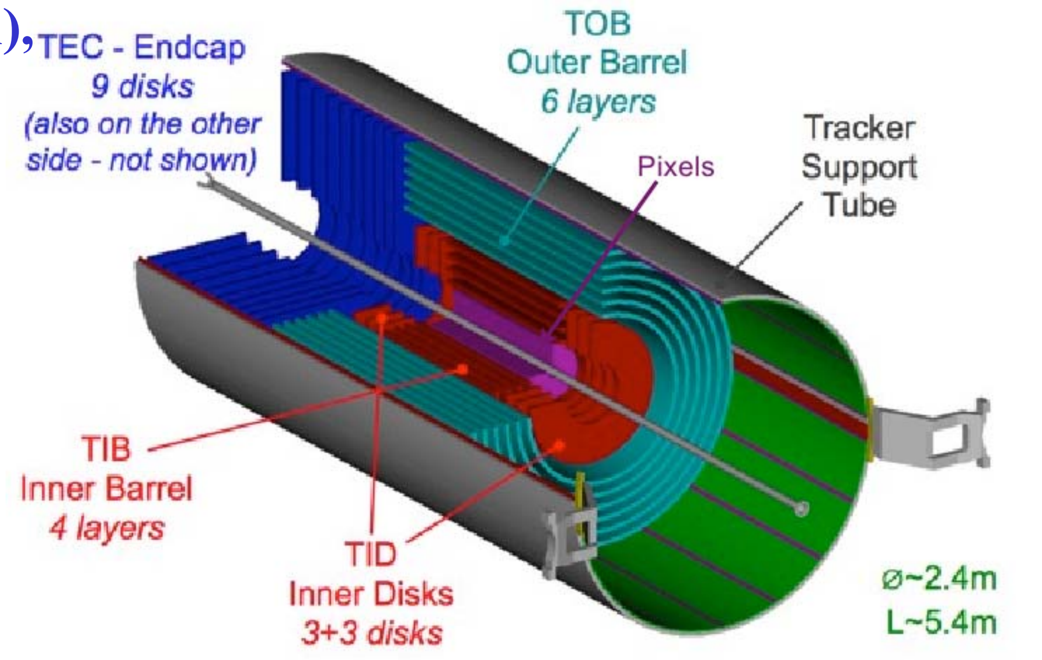
Strips

- 10 barrel layers,
- 9+3 endcap wheels per side
- ~198 m^2 of Si sensors,
- ~9.6M channels,
- 15148 modules

fine pixel granularity ⇒ 2-track separation ~ 1mrad

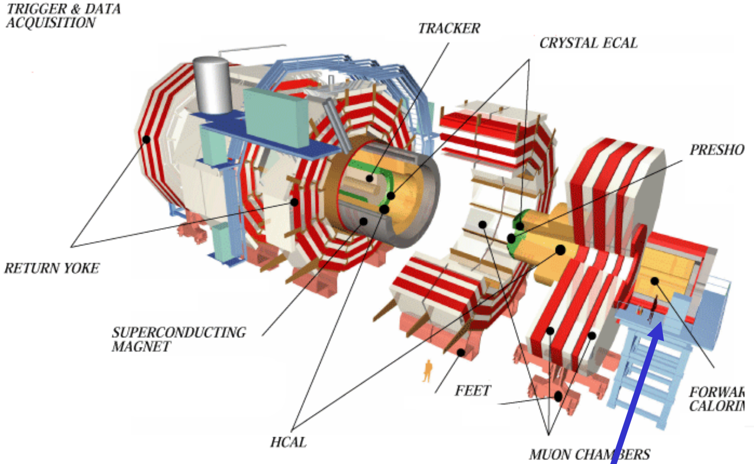
≥ 3 hits @ p_t > 100 MeV

$\Delta p_t/p_t$ 1-2% @ 1 GeV

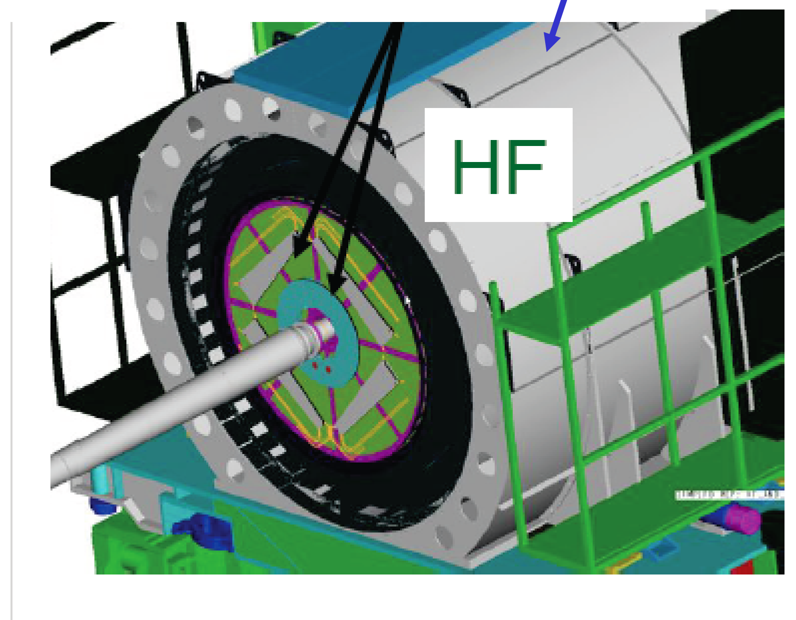


LHC and CMS

The CMS Hadron Forward Calorimenter



covers the range $2.9 < |\eta| < 5.2$
~11 m from interaction point
Steel – Cherenkov quartz fiber
Fast readout
η, φ segmentation of 0.175x0.175

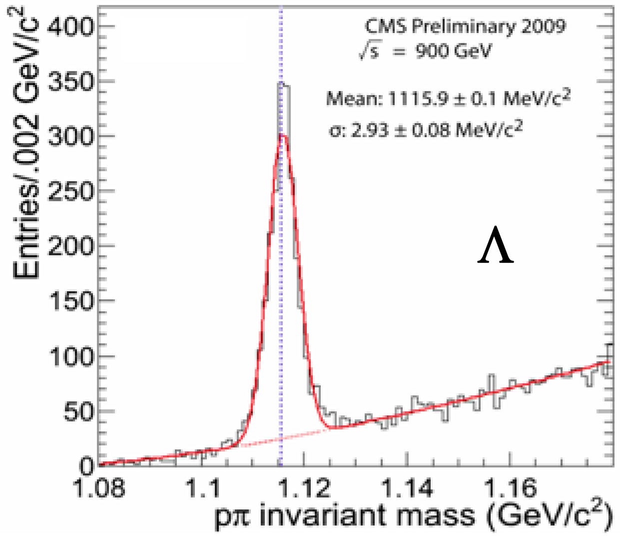


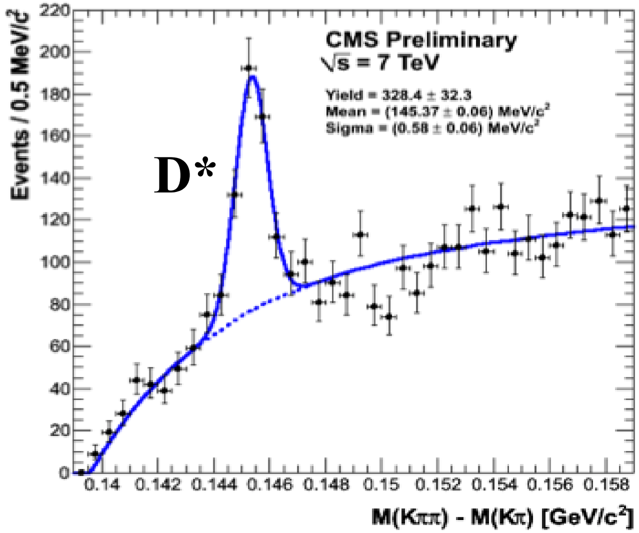
Embedded Beam Scintillation Counters (BSC) used to trigger on collision events

Detector performance

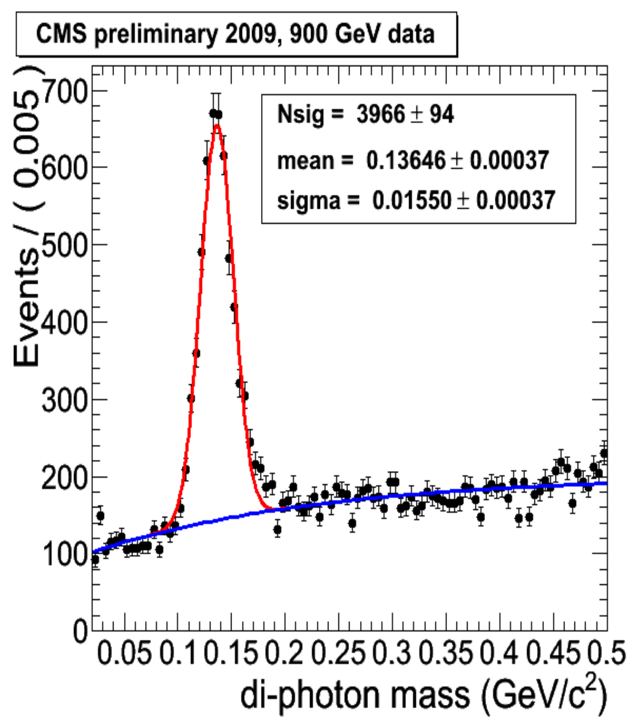
Excellent detector performance: a few examples

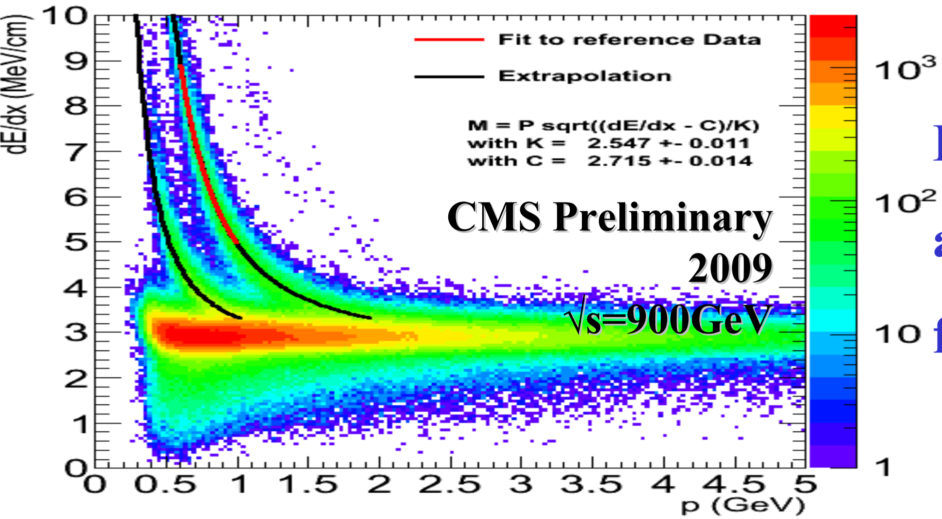
Tracker





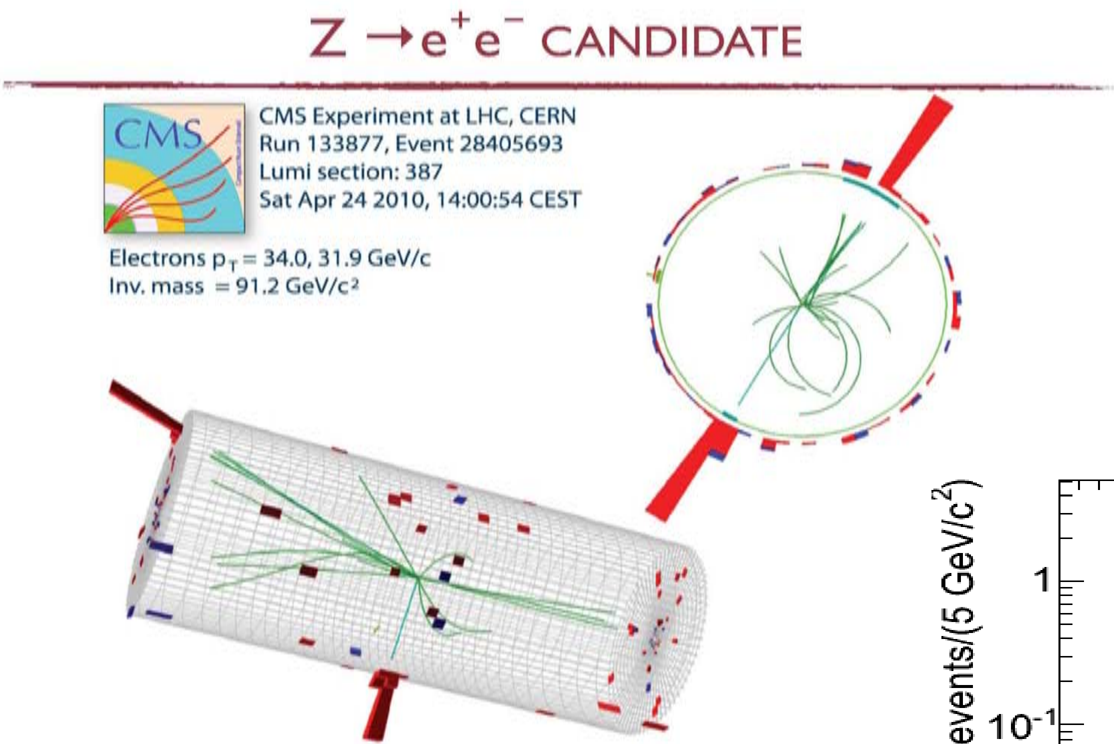
Ecal



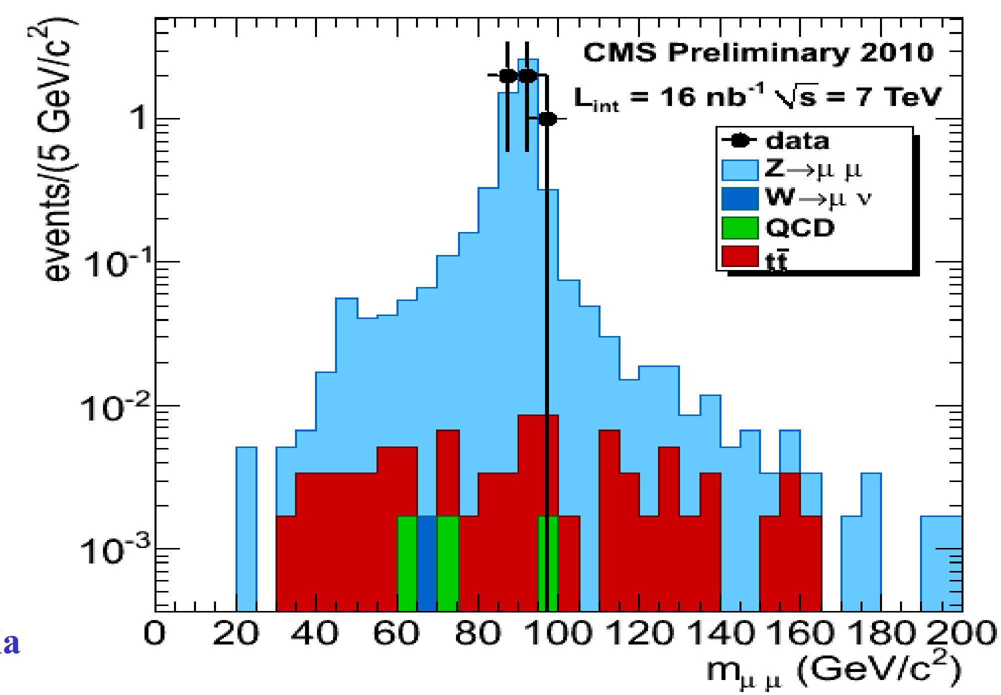


Particle id at low p from dE/dx

Detector performance



$Z \rightarrow \mu^+\mu^-$



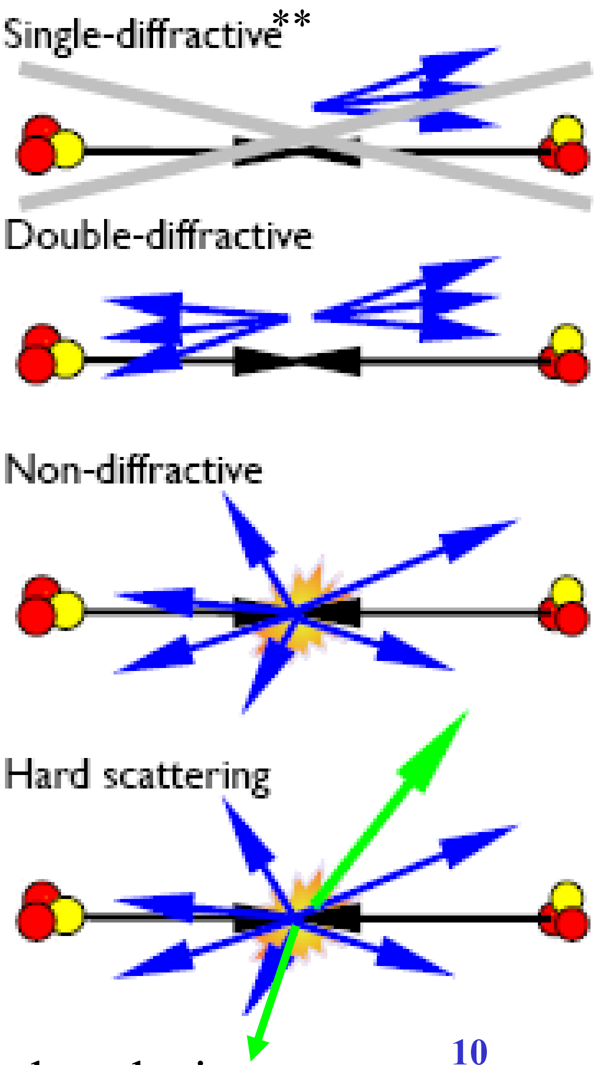
Good detector gives…

Physics results

- **Charged particle multiplicity and p_t spectra**
  JHEP 02 (2010) 041, arXiv:1005.3299: 0.9, 2.36, 7 TeV
- **Bose-Einstein correlations**
  arXiv:1005.3294 0.9, 2.36 TeV
- **Angular correlations**
  CMS PAS QCD-10-002 (2010): 0.9, 2.36, 7 TeV
- **Underlying event**
  CMS PAS QCD-10-001 (2010): 0.9, 2.36 TeV
- **Diffraction**
  CMS PAS FWD -10-001: 0.9, 2.36 TeV

Physics results

Minimum bias trigger and selection



Collision events are selected from
BSC BPTX
(Beam Pick-up Timing for experiments)*

Collisions:

BSC and BPTX coincidence in both sides+

Rejection of beam halo and beam background

Some analyses use only Non single Diffractive (NSD) events selected requiring at least one tower with E>3 GeV in each side of HF

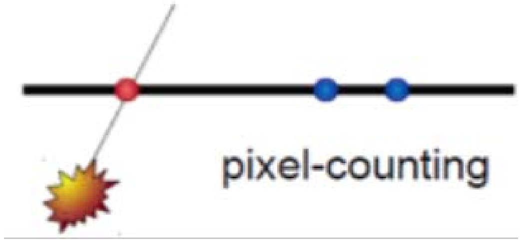
* two detectors at 175 m from i.p. to measure the beam presence

**for dedicated analysis

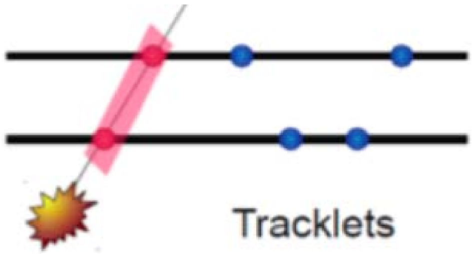
Charged particle multiplicity and p_t spectra*

Three methods:

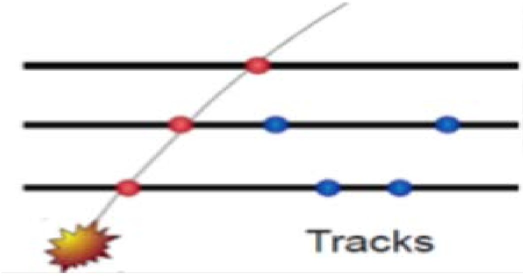
Single hit (pixels only) p_t>30 MeV



Tracklets (pixels only) p_t>50 MeV



Tracks (pixels+strips) p_t>100 MeV



*1st CMS paper (2009 data), 7 TeV accepted by PRL

Charged particle multiplicity and p_t spectra

Single pixel

Count pixel hits in single layer

Pixel size $\propto$ |sinh η|

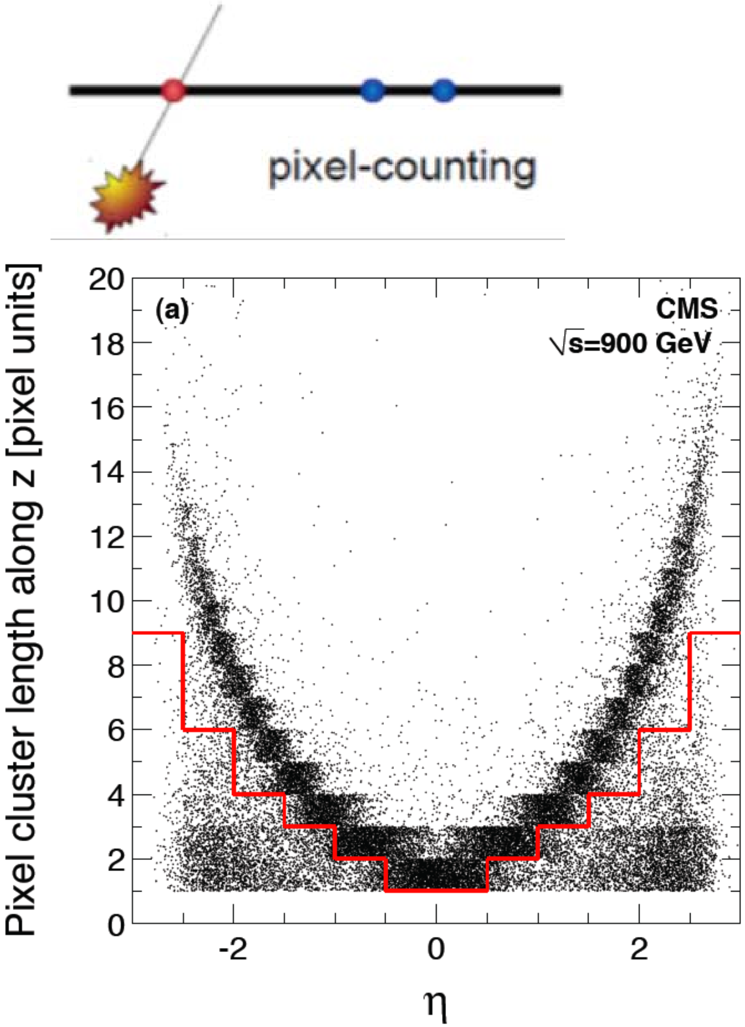
Down to 30 MeV p_t

short clusters (loopers, sec.) removed

but

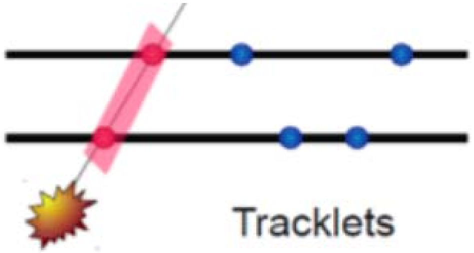
Does not measure p_t

Need MC to subtract secondaries, decays etc.



Charged particle multiplicity and p_t spectra

Tracklets



Pair hits from different pixel layers and

look for compatibility along η,φ

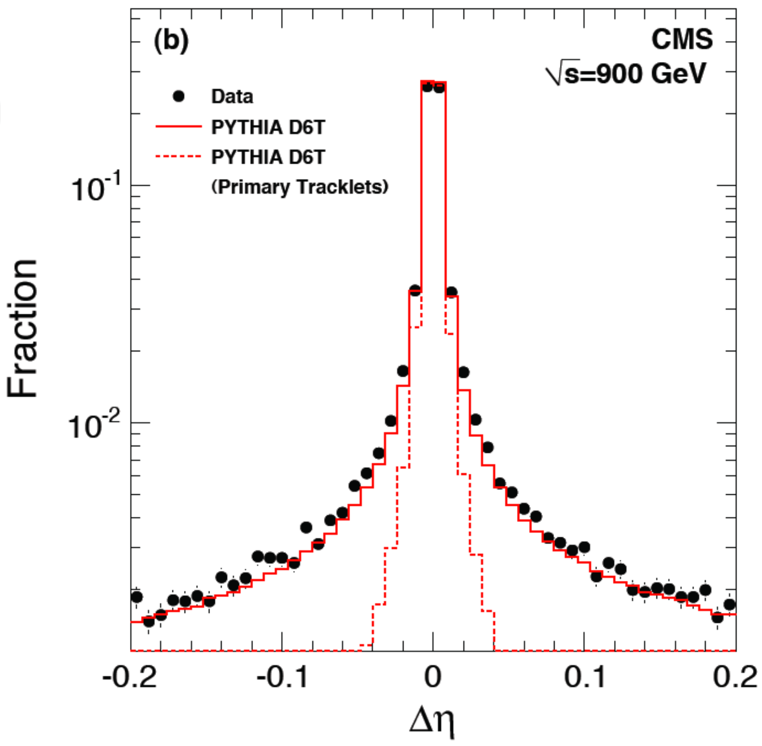
Subtract background using $\Delta\varphi$ sidebands ($1<|\Delta\varphi|<2$)

Down to **50 MeV** p_t

but

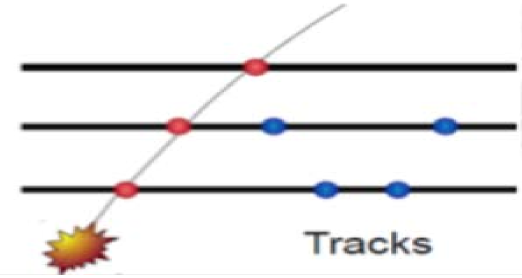
Does not measure p_t

Need MC for acceptance, to subtract secondaries, decays, pixel splitting etc.



Charged particle multiplicity and p_t spectra

Tracks



Iterative algorithm
≥ 3 hits in pixel + strips
compatibility with primary vertex

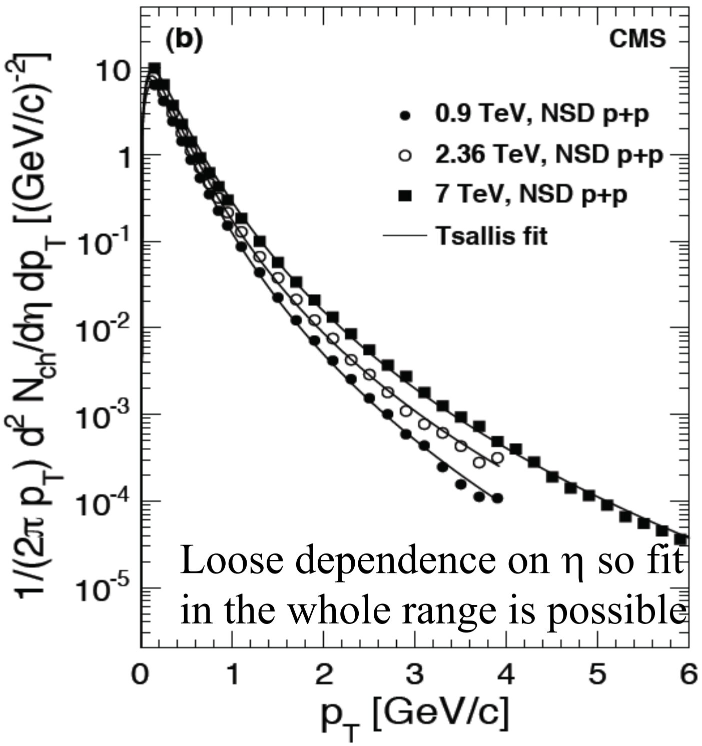
low fake rate (ghosts < 1%)

Measure p_t

but

No low p_t (>100 MeV)

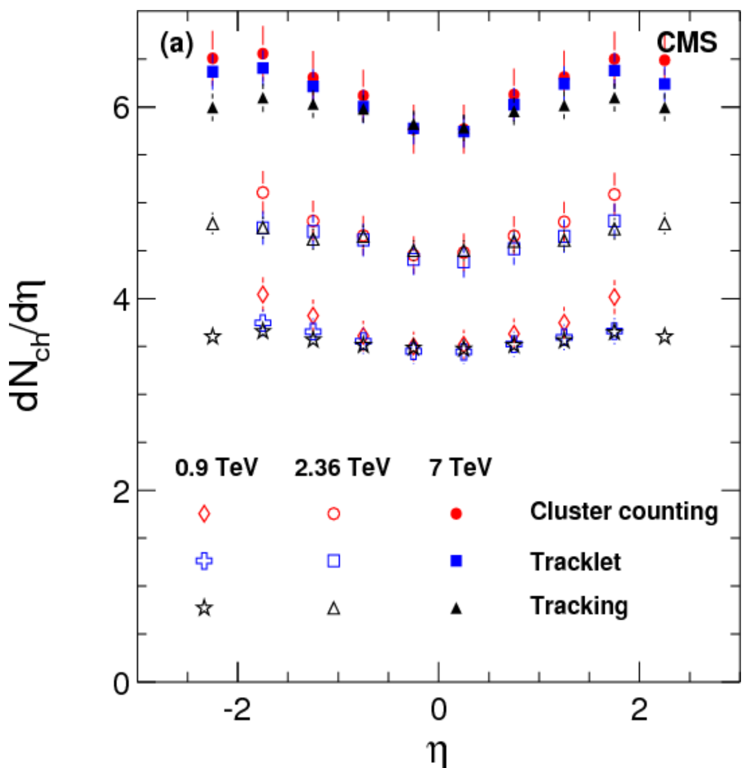
Sensitive to alignment, beam spot



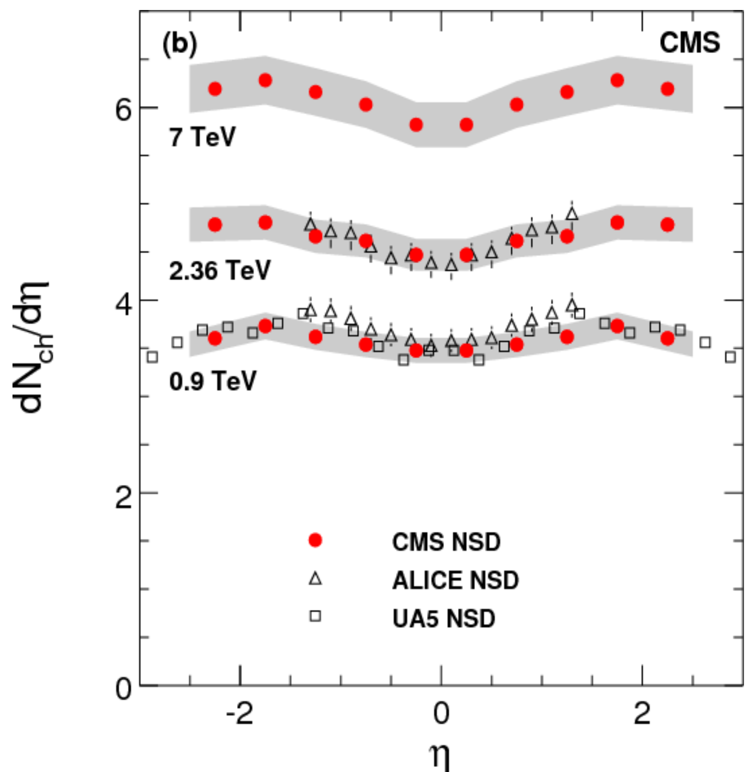
Charged particle multiplicity and p_t spectra

Results

Results obtained with the three methods for NSD events **compatible within the errors**



averaged results compared ALICE and UA5. **Systematic** uncertainties mainly coming from trigger, event selection, reconstruction efficiencies **~5%**

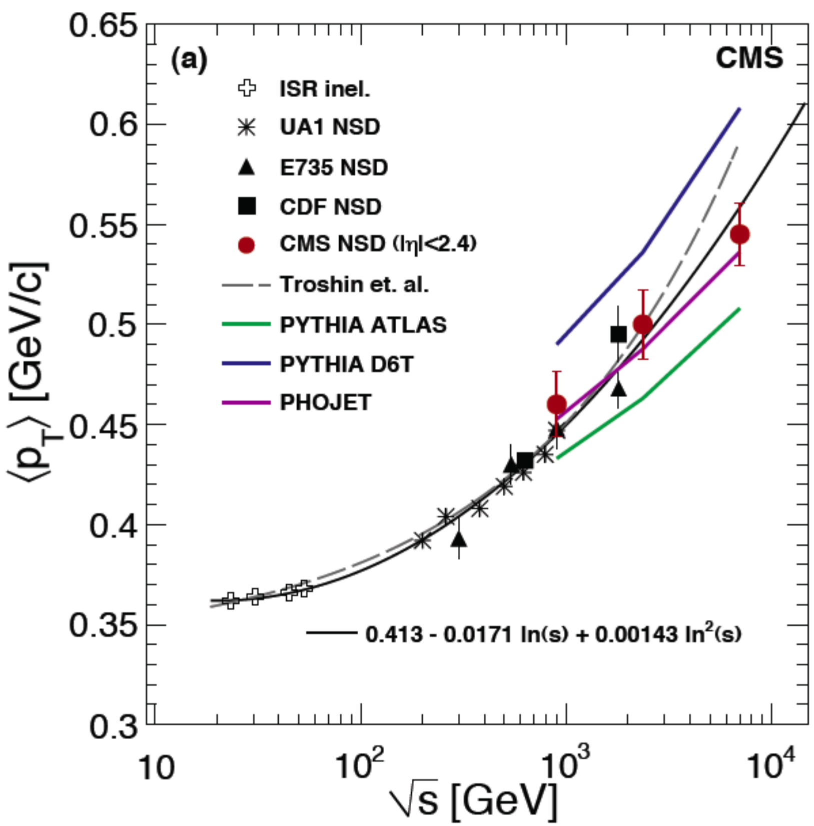


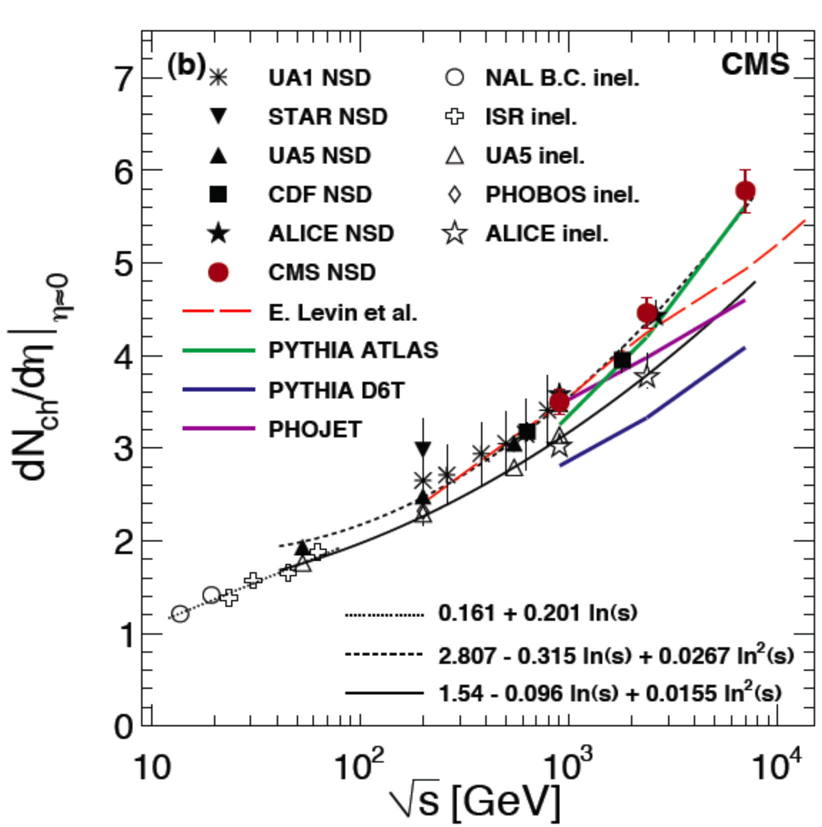
Charged particle multiplicity and p_t spectra

Energy dependence

Steep multiplicity increase at 7 TeV

Significantly higher than most event generator prediction





Bose-Einstein correlation

•Bose statistics **enhances the probability for identical bosons to have similar momenta with respect the uncorrelated case** (reference)

$$R(p_1 p_2) = \frac{P(p_1, p_2)}{P(p_1)P(p_2)}$$

•BEC gives information on the size of the primary source

$$R(Q) = \left(\frac{dN_{signal} / dQ}{dN_{reference} / dQ} \right)$$

•*R* is expressed in term of particle pair *Q* value:

$$Q = \sqrt{M_{\pi\pi}{}^2 - 4m_\pi{}^2}$$

• and parametrized as:

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

• Ω is the Fourier transform of the spatial distribution of the emission region (static models)

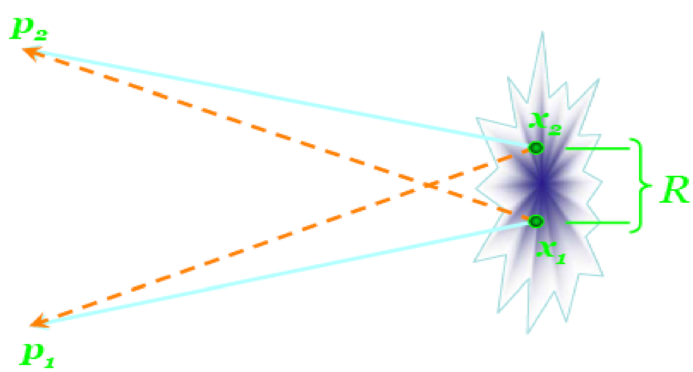
• λ is the BEC strength for boson emission from independent sources

• r is the radius of the emission source

• δ accounts for long range Q correlations

several parametrization for $\Omega(Qr)$:

exponential e^{-Qr}, Gaussian $e^{-(Qr)^2}$ …

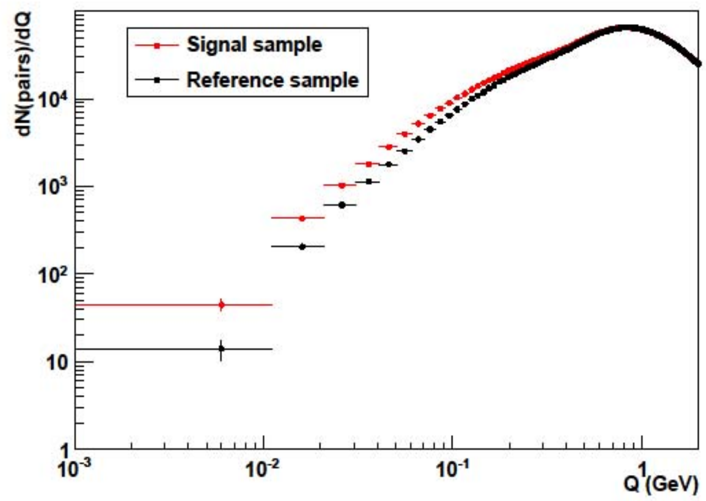


Bose-Einstein correlation

Signal and Reference Samples

Signal: pairs of particles with the same charge

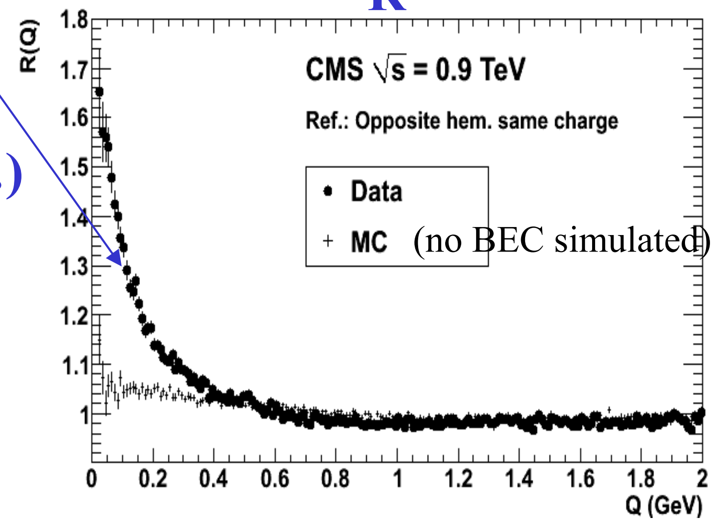
dN/dQ



No golden reference, several (7) used and combined

BEC evidence!

R



- -Opposite-charge pairs (natural but resonances…)
- -3-momentum invertion(p → -p for one track)
- -Rotated [px , py , pz] → [-px , -py , pz]
- -Mixing events (randomly, with comparable multiplicity, with comparable mass)

Bose-Einstein correlation

Double ratio

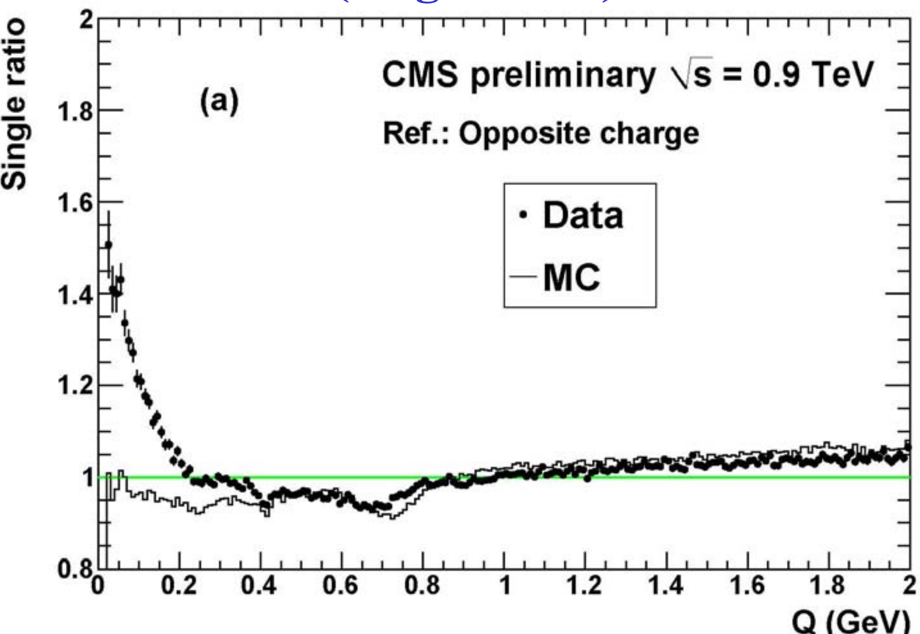
In order to reduce the bias due to the reference sample construction a double ratio $\mathcal{R}$ is defined:

$$\mathcal{R} = \frac{R}{R_{MC}} = \frac{\left(\frac{dN_{signal}/dQ}{dN_{reference}/dQ}\right)}{\left(\frac{dN_{MC,signal-like}/dQ}{dN_{MC,reference}/dQ}\right)}$$

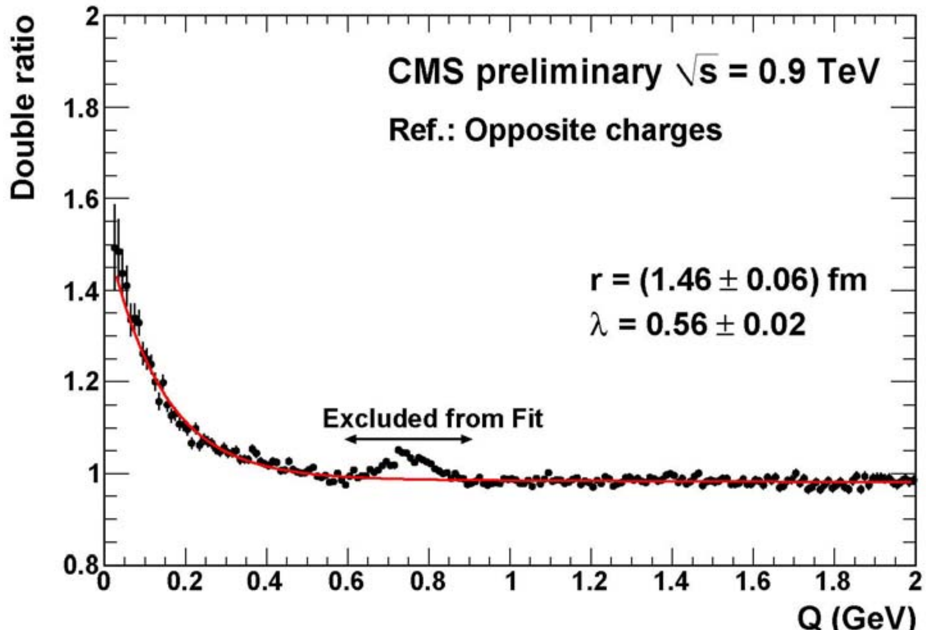
Improves fit quality

Reduces r.m.s. spread among results

R (single ratio)



$\mathcal{R}$ (double ratio)



Bose-Einstein correlation

Combined reference sample*

The parameters of the correlation function were obtained using a "combined " reference sample

$$\left(\frac{dN}{dQ}\right)_{comb} = \sum_{i=1}^{7}\left(\frac{dN}{dQ}\right)_{ref\_i}$$

r.m.s. from each individual fit provides the systematic error contribution

Exponential form describe the data much better than the Gaussian one

Results

900 GeV

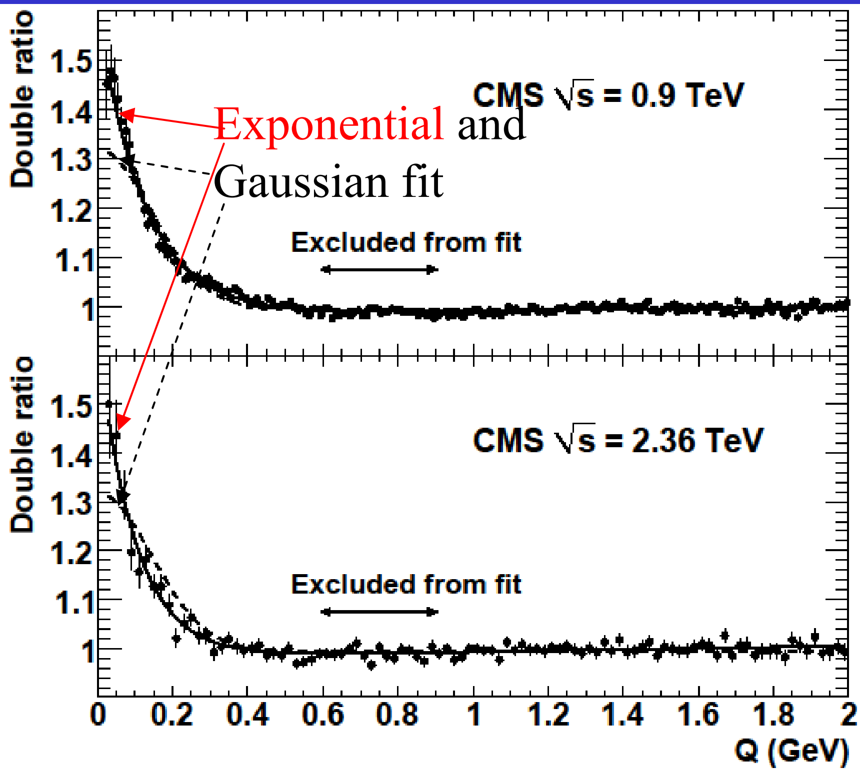
$\lambda = 0.625 \pm 0.021_{stat} \pm 0.046_{sys}$

$r = 1.59 \pm 0.05_{stat} \pm 0.19_{sys}$

2.36 TeV

$\lambda = 0.662 \pm 0.073_{stat} \pm 0.048_{sys}$

$r = 1.99 \pm 0.18_{stat} \pm 0.24_{sys}$



*results from all the ref. samples are given

Bose-Einstein correlation

Dependencies and comparisons

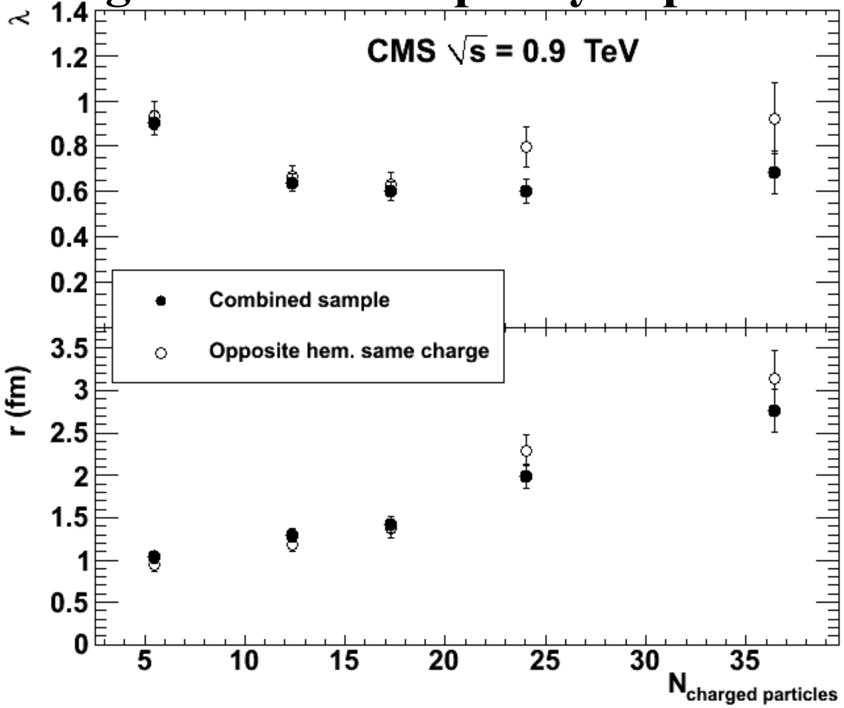
r grows with N_{ch}

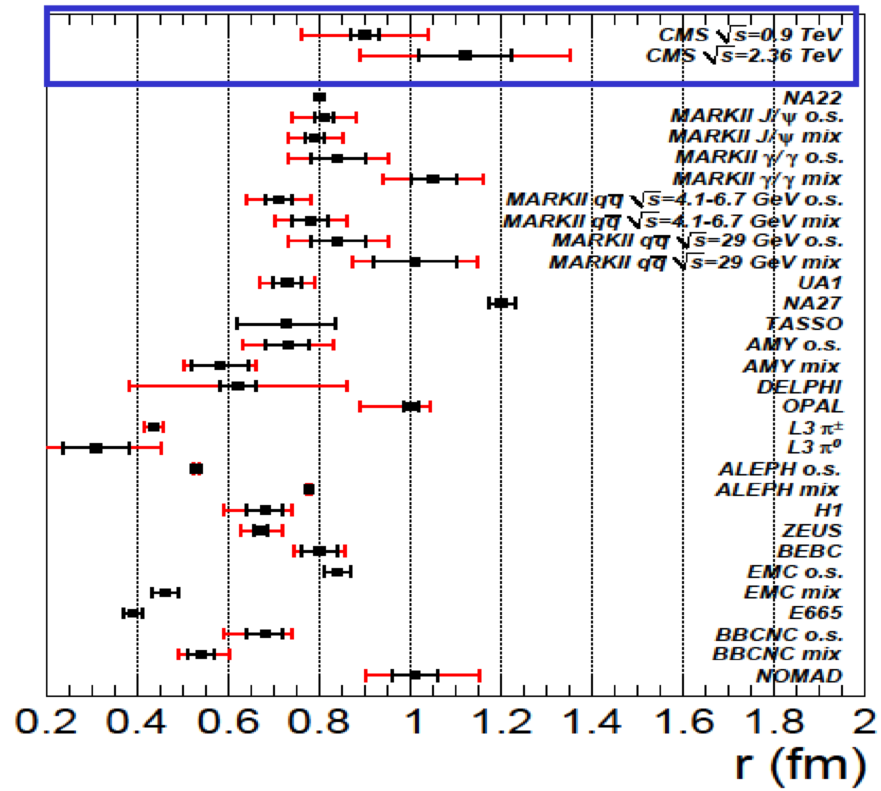
λ slight decrease

Consistent with previous measurements

For comparison,
CMS result scaled: $r_G = r/\sqrt{\pi}$

Charged track multiplicity dependence





Angular correlations

- Particle produced in clusters

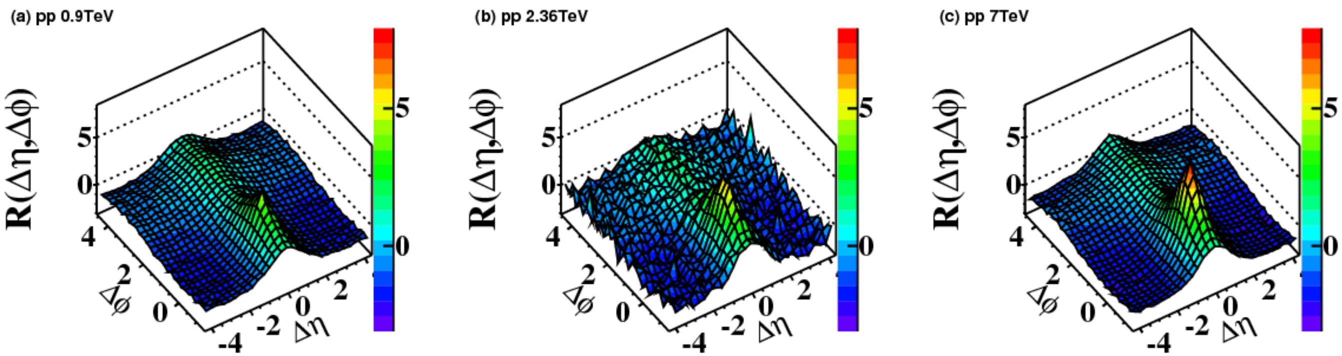
•Clusters characterized by:

"size": number of particle in cluster

"width": angular separation between particles

•Quantitative comparison with model prediction

EVIDENCE



20/06/2010

Angular correlations

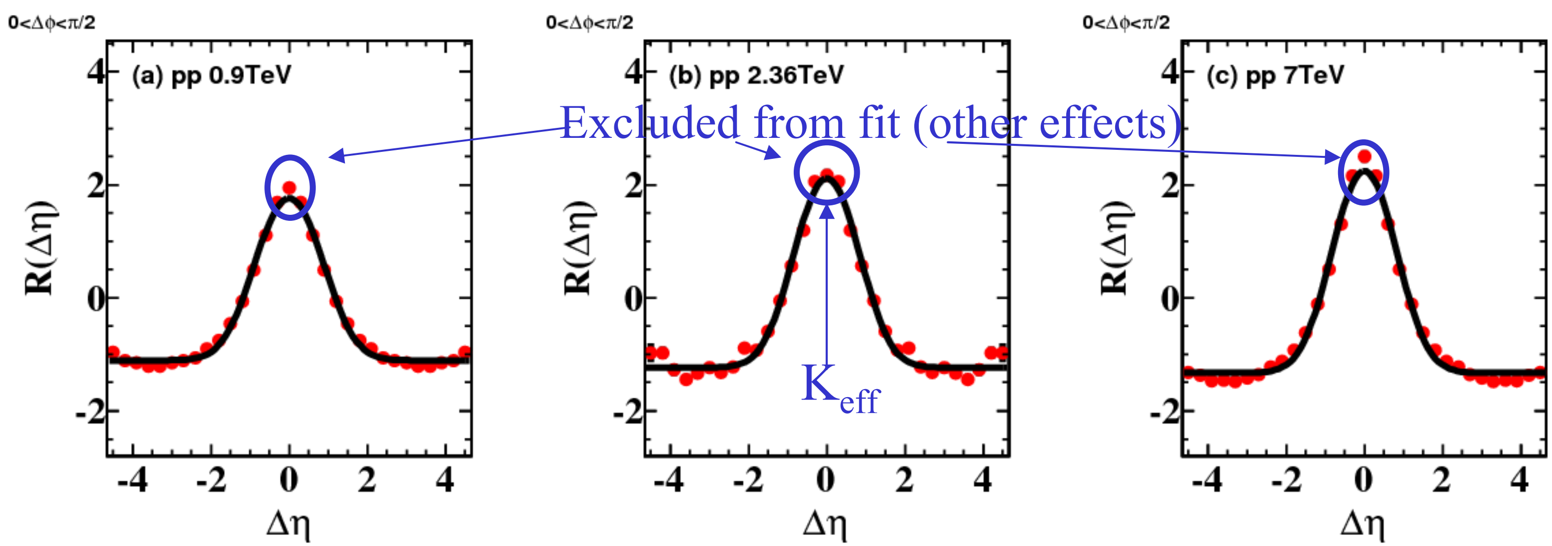
The method

$$R(\Delta\eta,\Delta\phi) = \left\langle (N-1)\left(\frac{S_N(\Delta\eta,\Delta\phi)}{B_N(\Delta\eta,\Delta\phi)} - 1\right)\right\rangle_N$$

Signal events

Reference sample (uncorrelated: mixed events)

Fit $\Delta\eta$ projections in the near ($\Delta\varphi < \pi/2$) and far ($\Delta\varphi > \pi/2$) sides with a Gaussian function $f(\Delta\eta) = K_{eff} \exp[-(\Delta\eta)^2/(4\delta^2)]$
Measure size (K_{eff}) and width (δ)

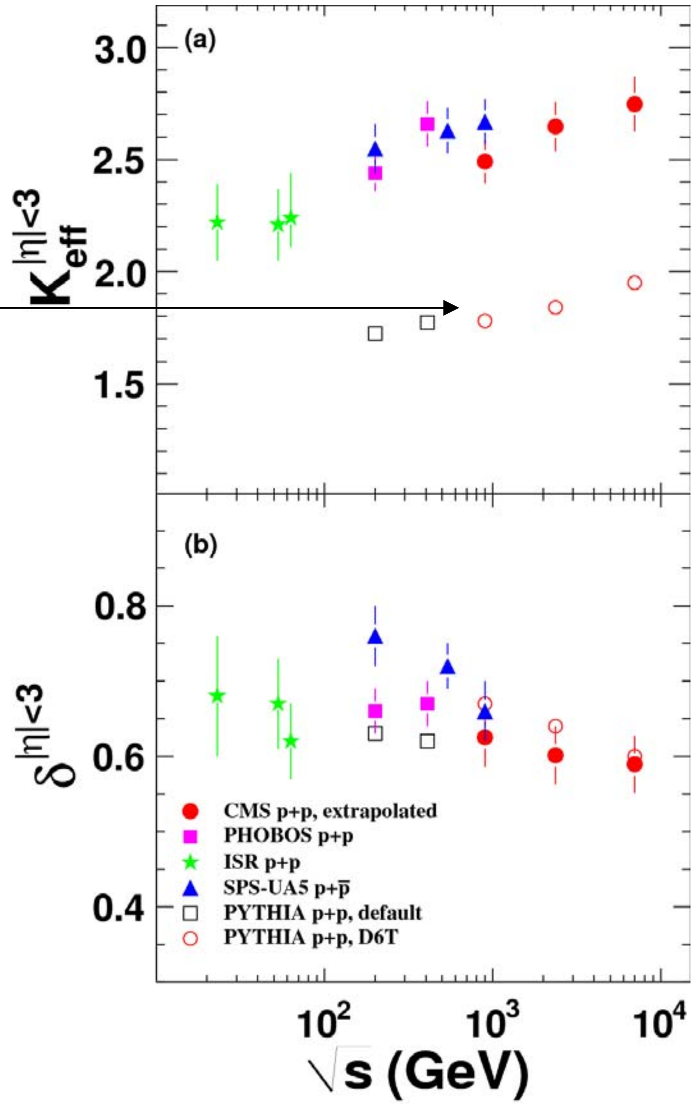


Angular correlations

Results

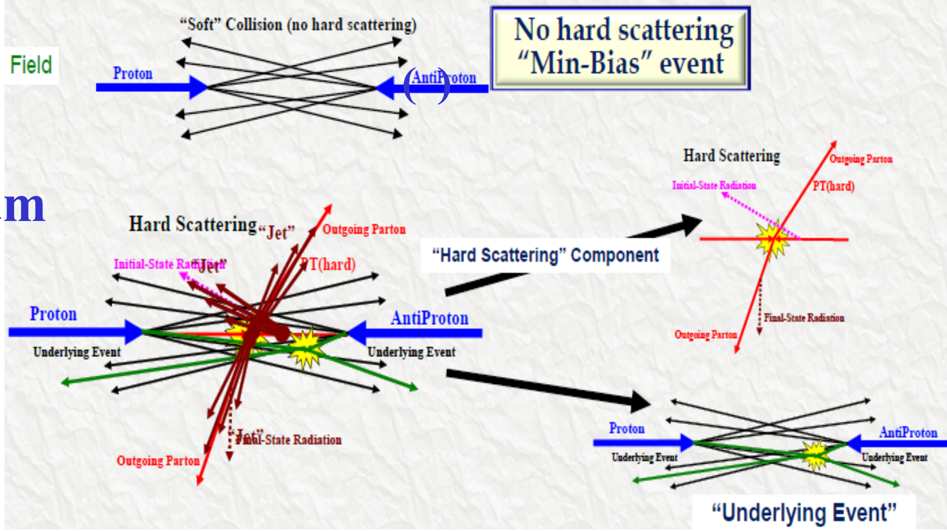
- Size increase with Energy
  - Already seen at low energies
  - Increase concentrated at near side $\Delta\varphi < \pi/2$
- Only qualitatively reproduced by Pythia
- Width is almost constant
- well reproduced by simulation

•Systematics mainly from event selection,
tracking/acceptance efficiency,
model dependency on the
corrections (~4%)



Underlying event

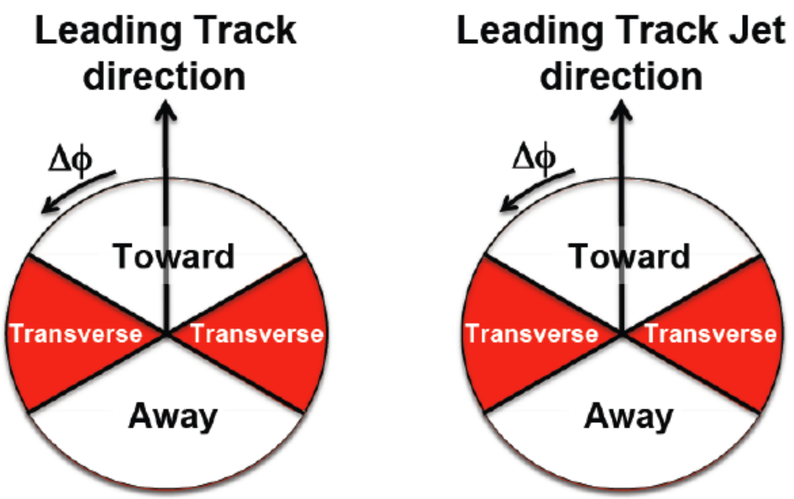
At (L)HC the "hard" parton scattering accompanied by:



- Additional "soft" interactions among beam partons (Multi Parton Interactions)
- Hadronization of non interacting beam partons (Beam Beam Remnants)
- Products of MPI and BBR form Underlying Event
- UE knowledge crucial for MC tuning, precision SM measurements and searches bejond SM

Starting from leading track (jet)"

- "Toward" (|Δφ|<60°): hard interaction
- "Away" (|Δφ|>120°): recoiling jet
- "Transverse" dominated by UE



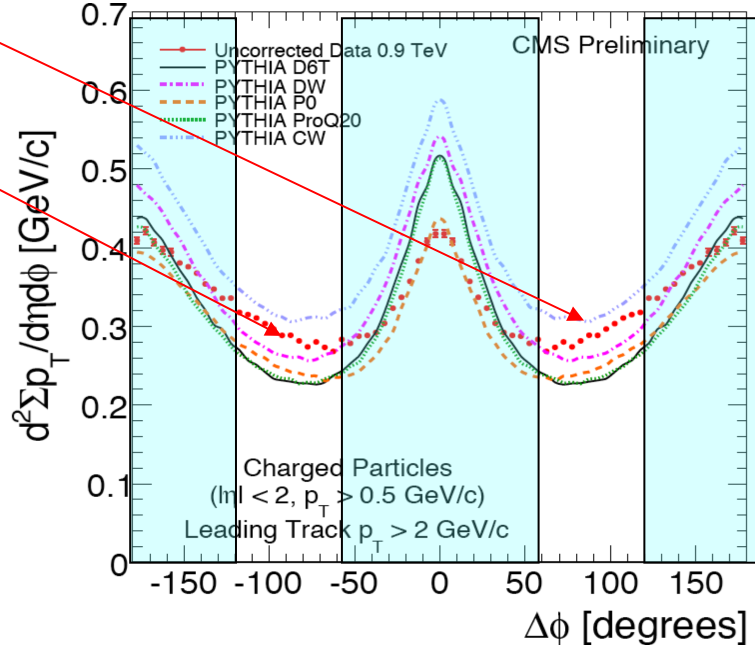
Underlying event

measurement

Track selection: |η|<2 , p_t>0.5 GeV   Hard parton: track/jet with p_t> 1/2/3 GeV

- **In toward and away regions, high activity due to radiation and to the fragmentation of the two outgoing partons**
- **Non-null activity in transverse region is attributed to UE**
- **No Pythia tune models accurately the data**

  CW and DW closest description



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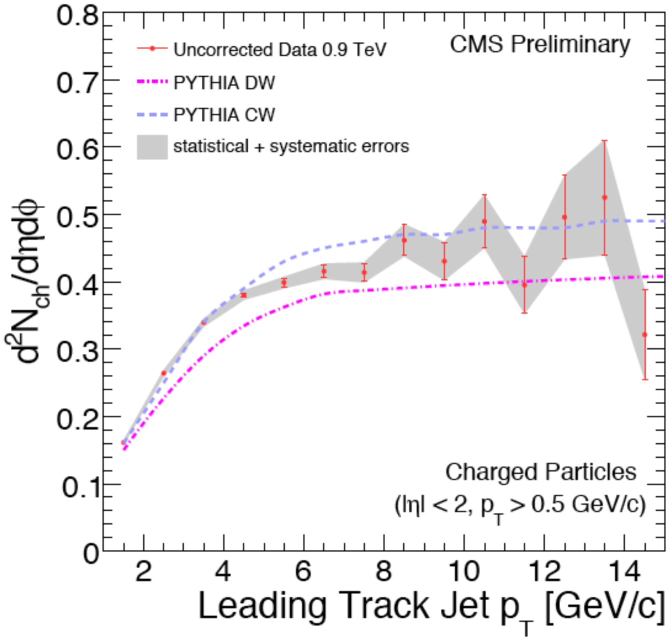
Underlying event

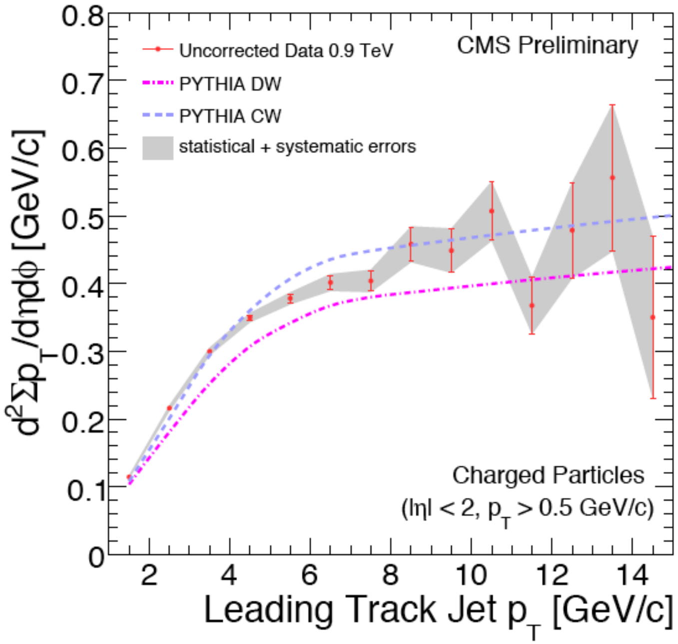
UE activity (multiplicity and average momentum) increases with leading jet / leading track p_t

Slower increase for jet p_t>4 GeV (track p_t>3 GeV)

Well-reproduced by simulation (data between CW and DW tunes)

Bands are statistical+systematic errors (material budget, background contamination, selection)





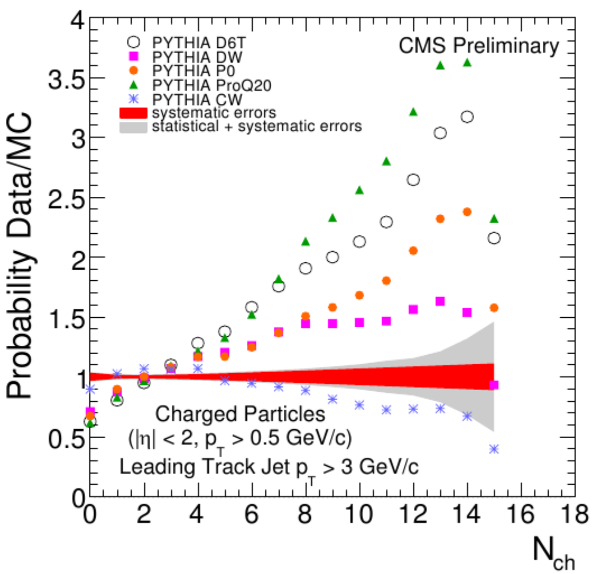
Underlying event

Comparison with MC

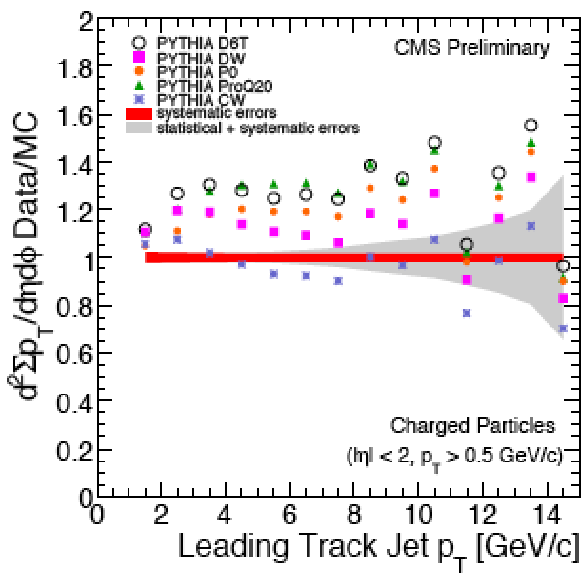
Models fail to represent the data (absolute values and trends)

These measurements allow for a better MC tuning

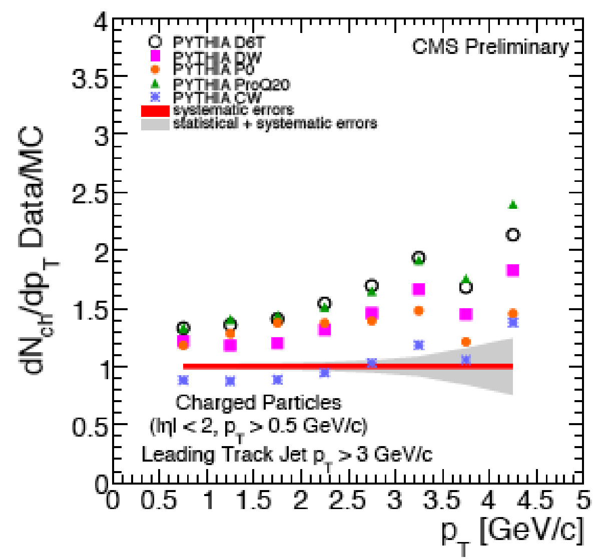
Data/MC ratio



multiplicity



Σp_t vs. leading jet p_t

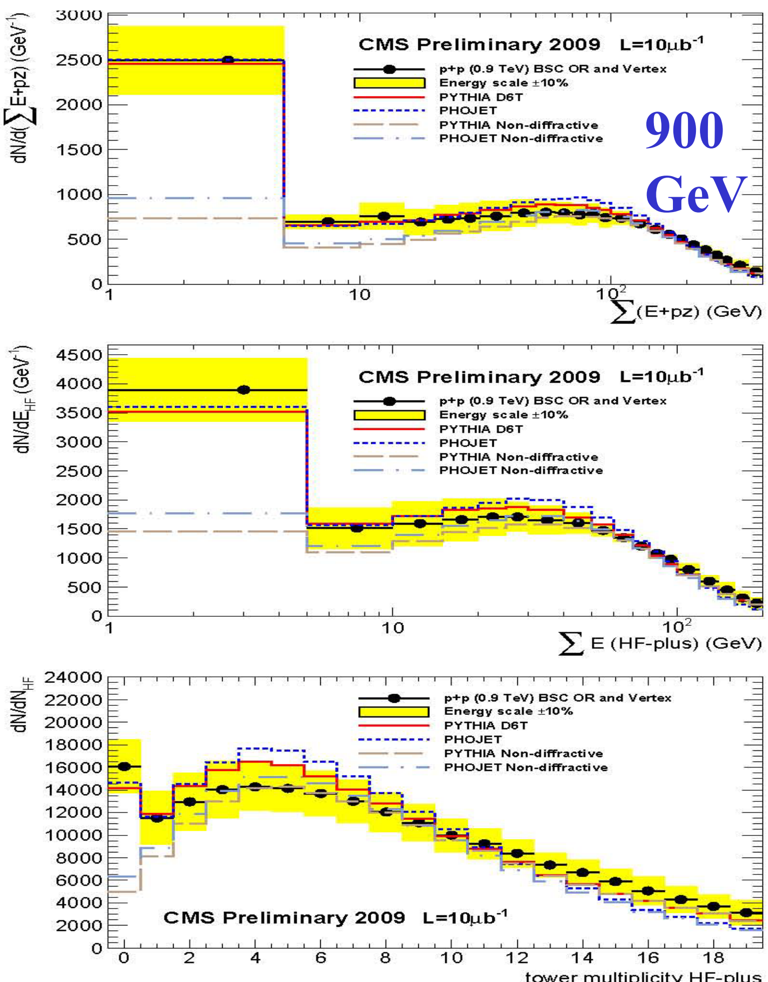


N_{ch} vs. leading jet p_t

Diffraction

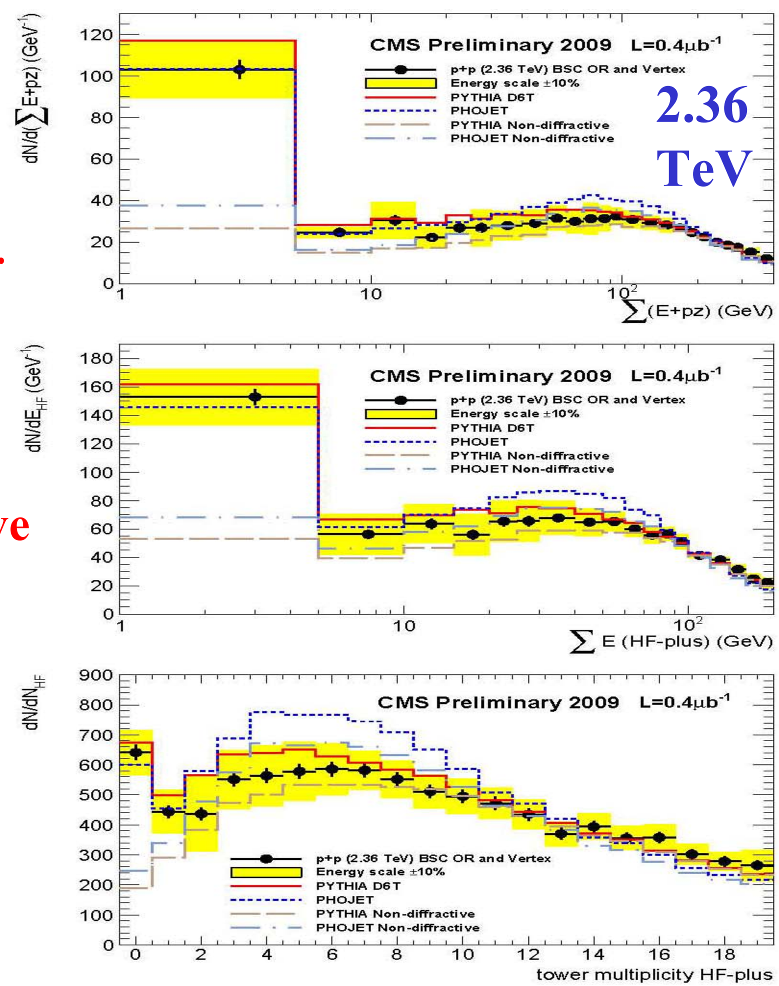
pp→*XY* with *XY* *p* or low-mass system with $p \sim p_{beam}$. Single Diffractive *pp*→*Xp*

SD: a peak at small $E \pm p_z \propto \zeta$ the proton fractional energy loss (diffractive cross section goes as $1/\zeta$) and on the HF low Energy and multiplicity



PYTHIA better for ND

PHOJET for Diffractive region



Conclusions

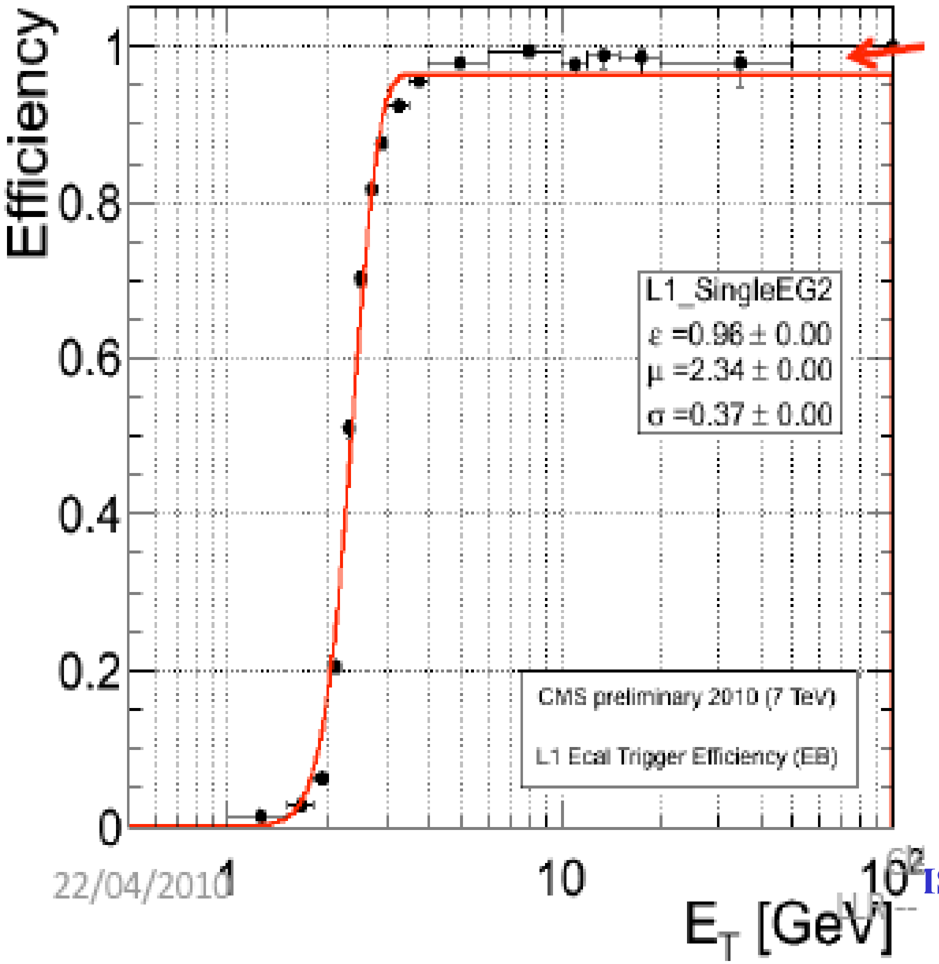
- LHC (re)started providing good quality data
- CMS startup with impressive performance
- Physic results from the very early data in a fast and efficient way
- Soft hadron Dynamics measurements in the new energy domain reveal problems of phenomenological models and allow to tune MC generators in view of hard scattering processing
- A long list (~50) of other Physics results coming soon (or just approved)
- Increasing luminosity could provide competitive results in a short time

Backup slides

Detector performance

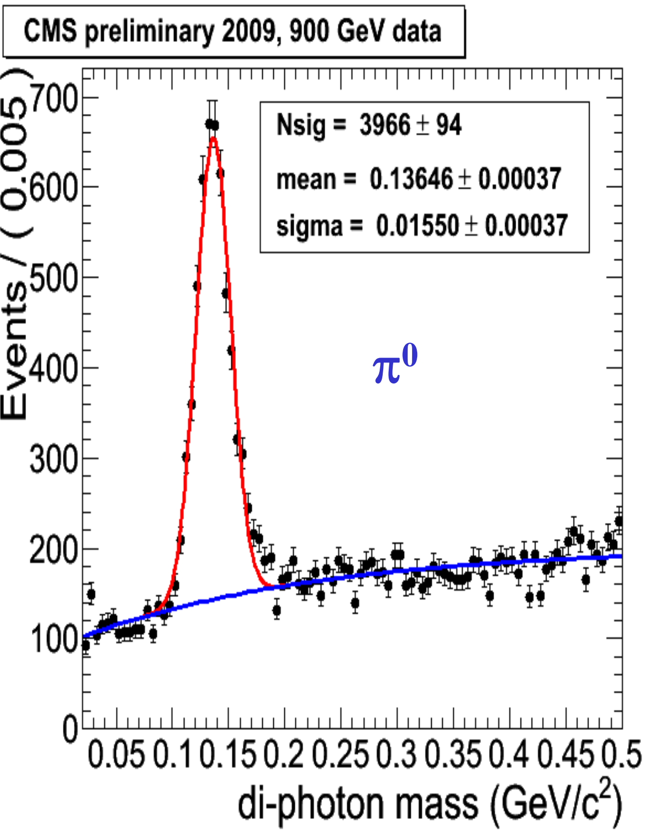
Trigger

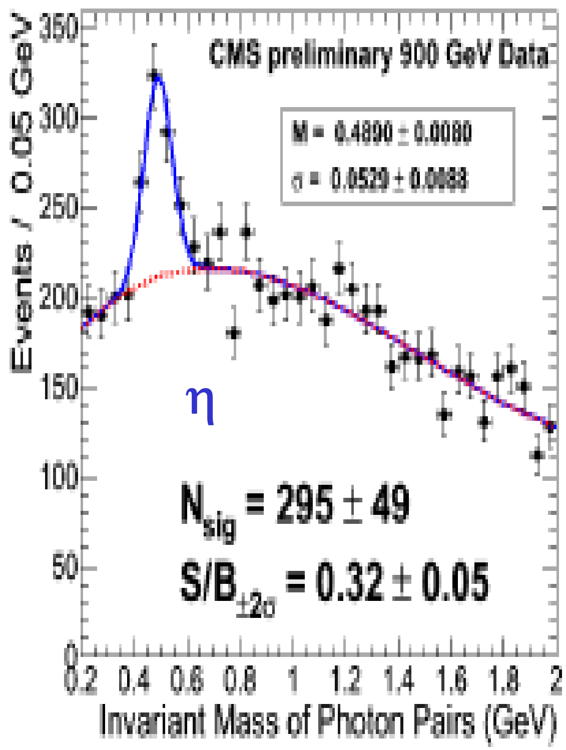
the low Pt triggers can be validated with MB events.

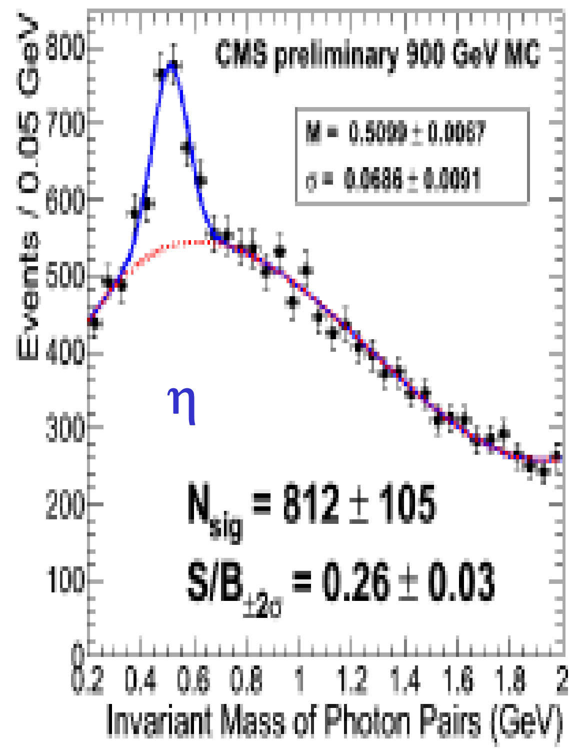


Detector performance

Ecal







Coulomb correction

Coulombian interactions between pairs of charged particles affect the low-Q region.

Effect is different (of course!) for different-sign and same-sign pairs

Can be parametrized by Gamow factors:

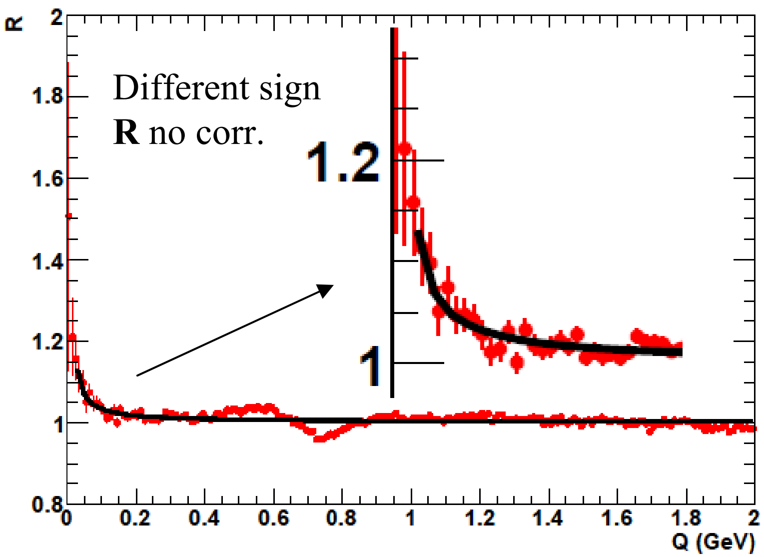
$$W_{SS}(\eta) = \frac{e^{2\pi\eta} - 1}{2\pi\eta}, W_{OS}(\eta) = \frac{1 - e^{-2\pi\eta}}{2\pi\eta}$$

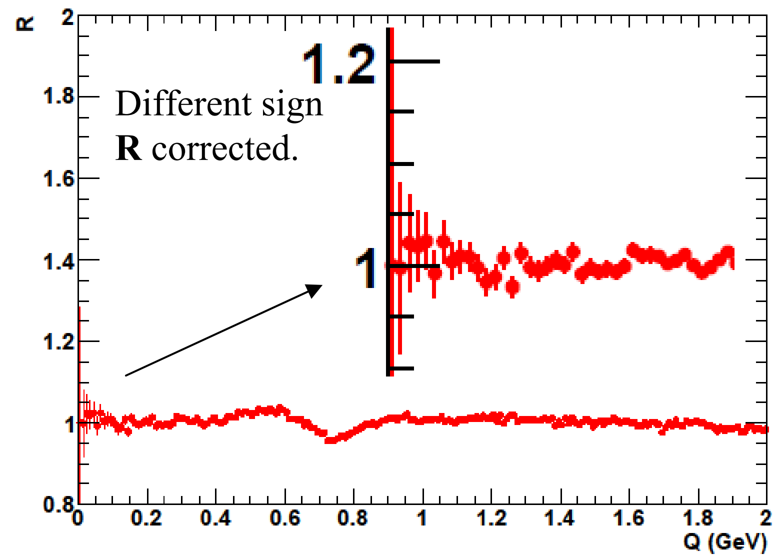
$$(\eta = \alpha_{em} m_{\pi} / Q)$$

- Leaving same-charge pairs alone (they are affected by BE correlations in the region where Coulomb interactions act) we may study opposite-charge pairs

Take the ratio R=dN/dQ(data)/dN/dQ(MC) and compare to inverse of applicable Gamow factor → small excess at low-Q, fully understood as coming from Coulomb effect. Note: the MC does not simulate the interaction.

After a correction, data/MC ratio for different-charge pairs becomes flat as expected (ignore wiggles due to ρ region)





Bose-Einstein correlation

Results

900 GeV

Results of fits to 0.9 TeV data

Reference sample	p value (%)	C	λ	r (fm)	δ (10^{-3} GeV^{-1})
Opposite charge	21.9	0.988 ± 0.003	0.56 ± 0.03	1.46 ± 0.06	-4 ± 2
Opposite hem. same ch.	7.3	0.978 ± 0.003	0.63 ± 0.03	1.50 ± 0.06	11 ± 2
Opposite hem. opp. ch.	11.9	0.975 ± 0.003	0.59 ± 0.03	1.42 ± 0.06	13 ± 2
Rotated	0.02	0.929 ± 0.003	0.68 ± 0.02	1.29 ± 0.04	58 ± 3
Mixed evts. (random)	1.9	1.014 ± 0.002	0.62 ± 0.04	1.85 ± 0.09	-20 ± 2
Mixed evts. (same mult.)	12.2	0.981 ± 0.002	0.66 ± 0.03	1.72 ± 0.06	11 ± 2
Mixed evts. (same mass)	17.0	0.976 ± 0.002	0.60 ± 0.03	1.59 ± 0.06	14 ± 2
Combined	2.9	0.984 ± 0.002	0.63 ± 0.02	1.59 ± 0.05	8 ± 2

2.36 TeV

Results of fits to 2.36 TeV data

Reference sample	p value (%)	C	λ	r (fm)	δ (10^{-3} GeV^{-1})
Opposite charge	57	1.004 ± 0.008	0.53 ± 0.08	1.65 ± 0.23	-16 ± 6
Opposite hem. same ch.	42	0.977 ± 0.006	0.68 ± 0.11	1.95 ± 0.24	15 ± 5
Opposite hem. opp. ch.	46	0.969 ± 0.005	0.70 ± 0.11	2.02 ± 0.23	24 ± 5
Rotated	42	0.933 ± 0.007	0.61 ± 0.07	1.49 ± 0.15	58 ± 6
Mixed evts. (random)	23	1.041 ± 0.005	0.74 ± 0.15	2.78 ± 0.36	-40 ± 4
Mixed evts. (same mult.)	35	0.974 ± 0.005	0.63 ± 0.10	2.01 ± 0.23	20 ± 5
Mixed evts. (same mass)	73	0.964 ± 0.005	0.73 ± 0.11	2.18 ± 0.23	28 ± 5
Combined	89	0.981 ± 0.005	0.66 ± 0.07	1.99 ± 0.18	13 ± 4

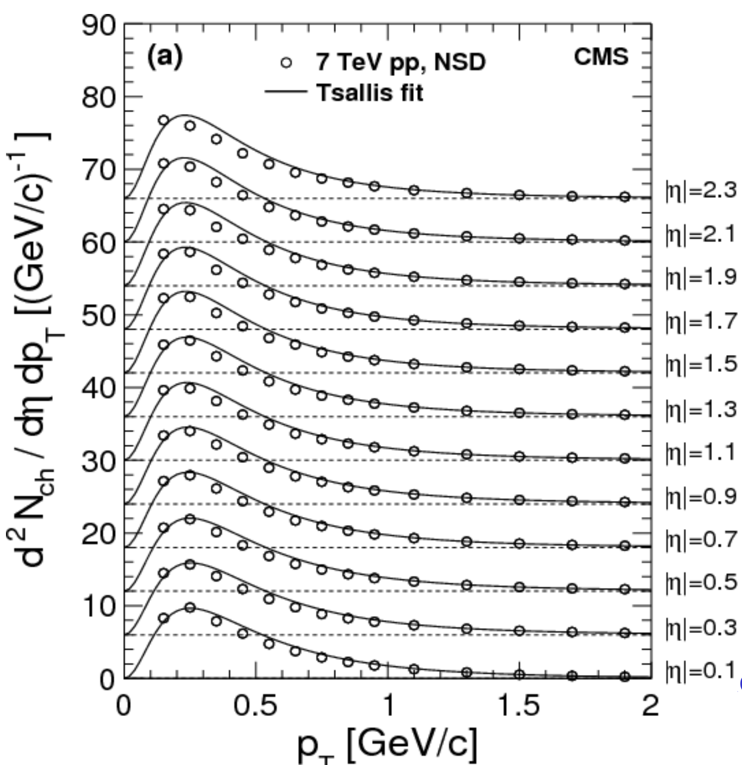
Charged particle multiplicity and p_t spectra

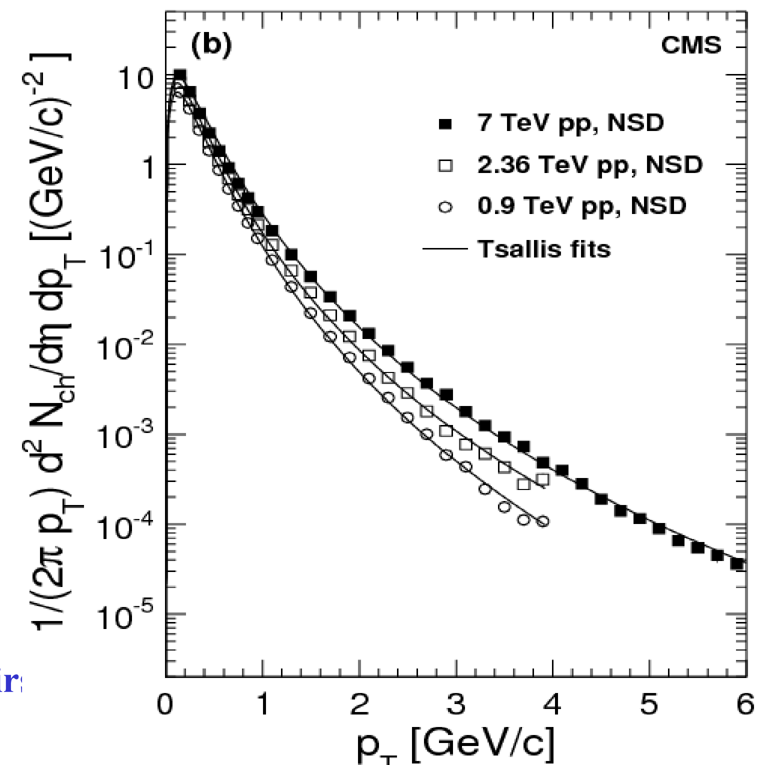
Results: p_t

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

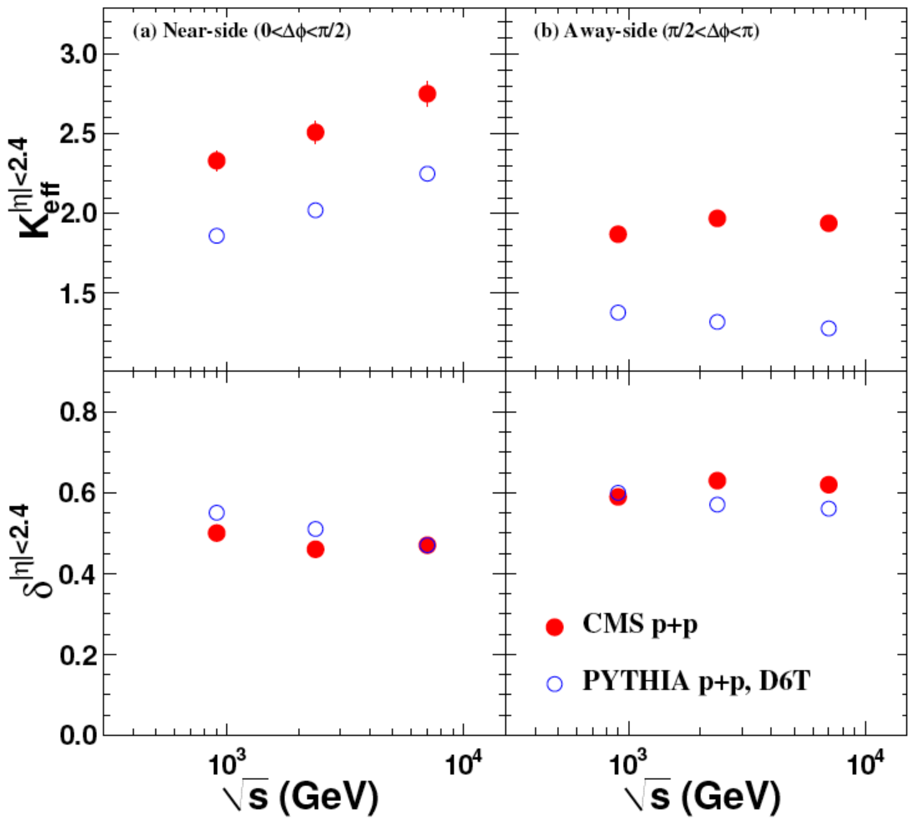
Tsallis function

Loose dependence on η so fit in the whole range is possible





Angular correlations



Diffraction

Experimental details

- Trigger in any BSC counter in coincidence with BPTX
- primary vertex with |z|<15 cm and d_t <2 cm and > 2 tracks
- beam-halo rejection
- >25% high-quality tracks in events with >10 tracks
- reject HCAL noisy events