QCD Physics from CMS

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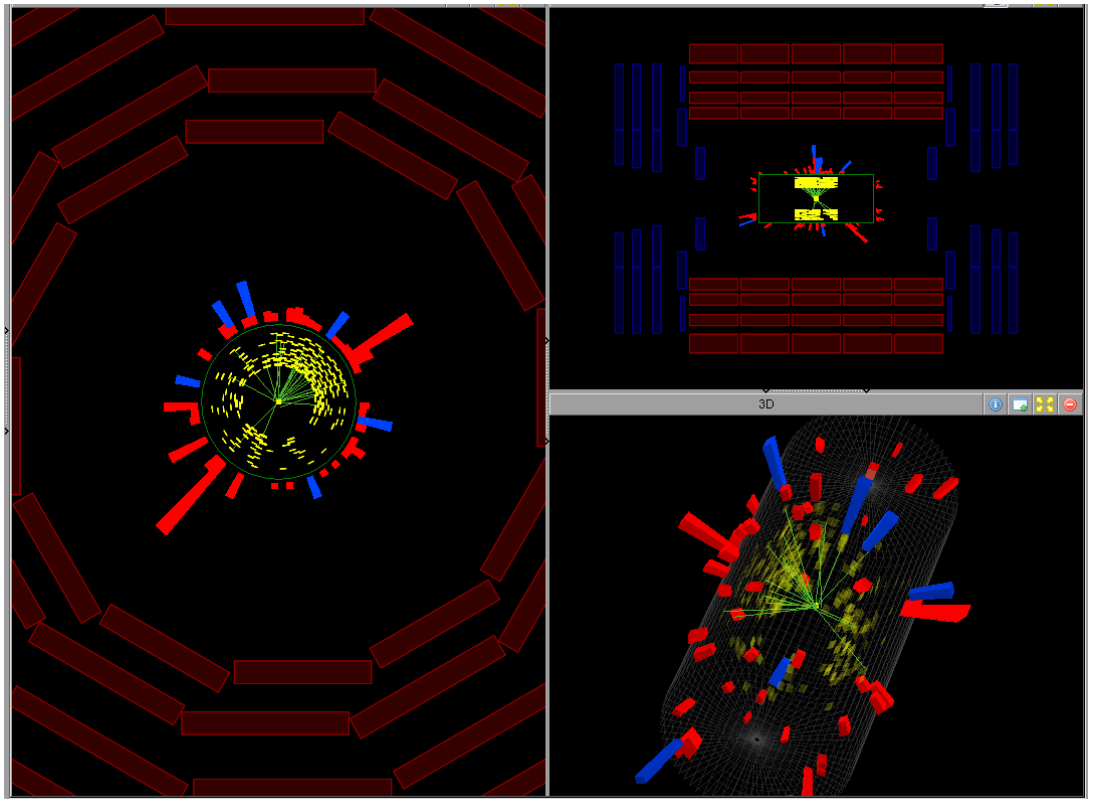


DIS 2010

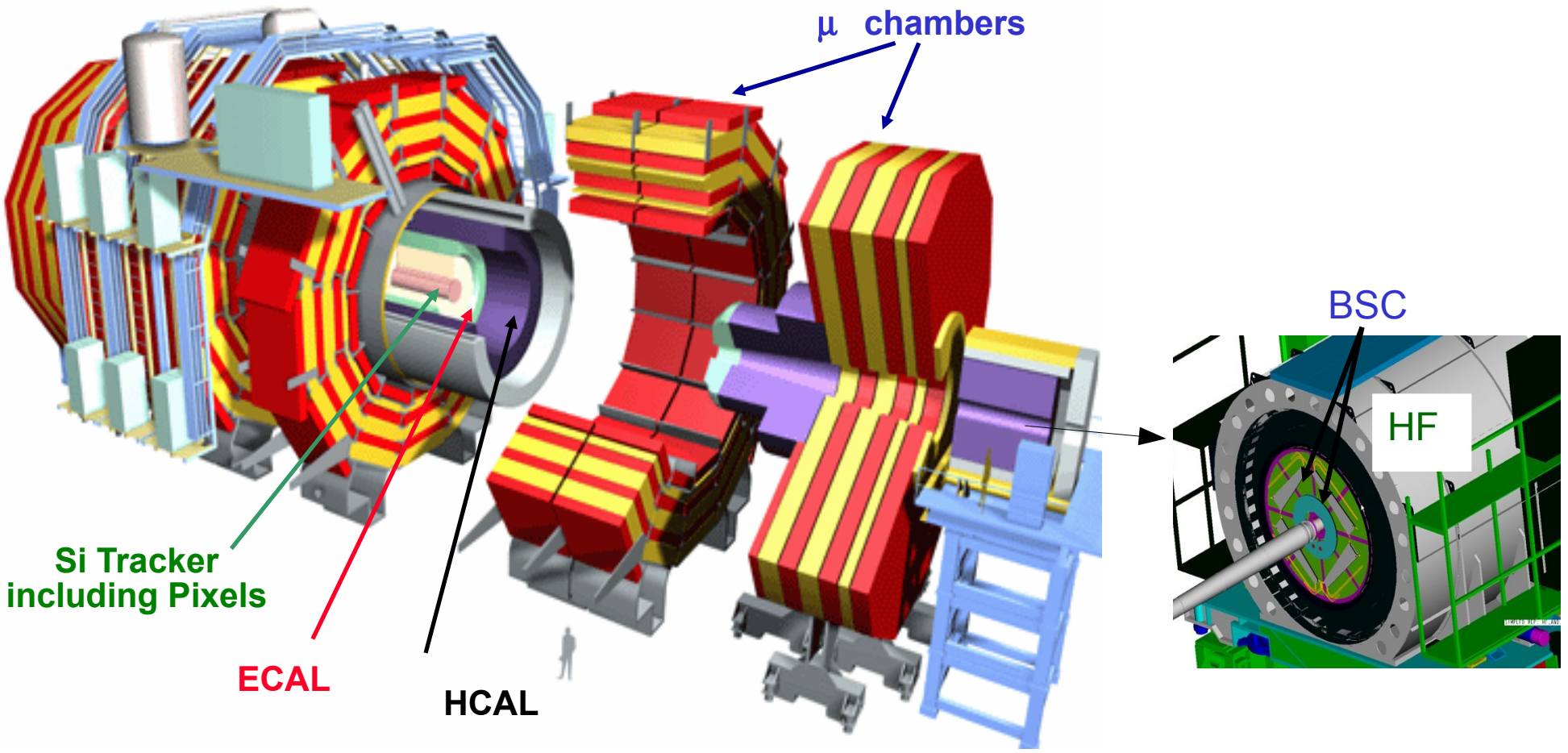
Florence, Italy, 2010

QCD results from CMS

- Public QCD results from CMS:
  - Charged hadron spectra at 0.9 and 2.36 TeV [1]
    - Transverse momentum spectra
    - Average p_T
    - Angular distributions
    - Collision energy dependence of these
  - Evidence of Bose-Einstein correlations at 0.9 and 2.36 TeV [2]
    - Size of the interference region
    - Strength of the effect
    - Dependence of these on momentum
- Data: first physics runs in December, 2009

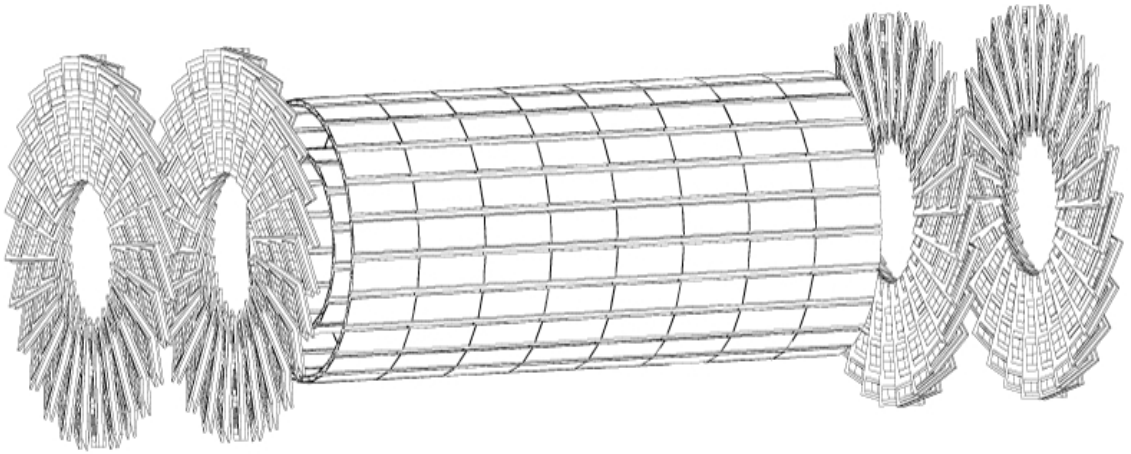
The CMS detector

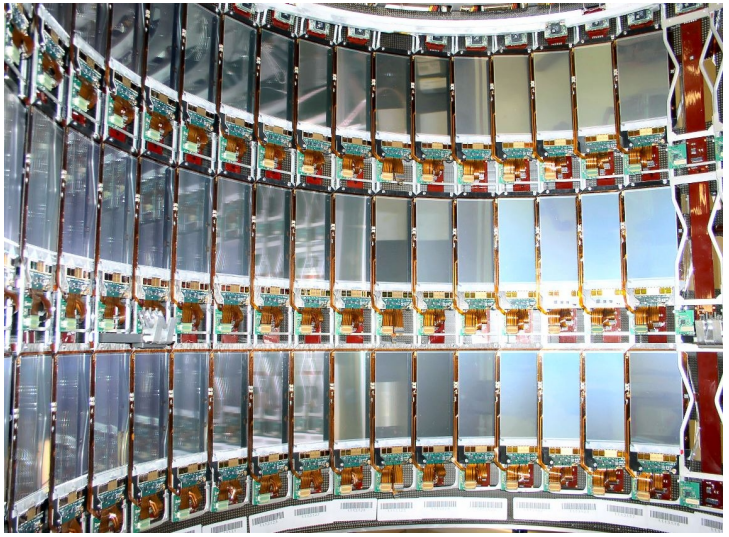
The CMS detector



- Large acceptance tracker
- Hermetic calorimetry
- Excellent muon spectrometer

Tracking system





- Silicon tracker including pixels and strips (|η|<2.4)
- Pixels:
  - 150x100 μm^2, closest to the interaction point
  - 3 barrel layers (4, 7 and 10 cm radii) and 2 endcaps on each side
- Strips:
  - Larger silicon modules, refine momentum resolution

The complete tracker layout in backup

Charged Hadron Spectra at 0.9 and 2.36 TeV

Charged particle spectra

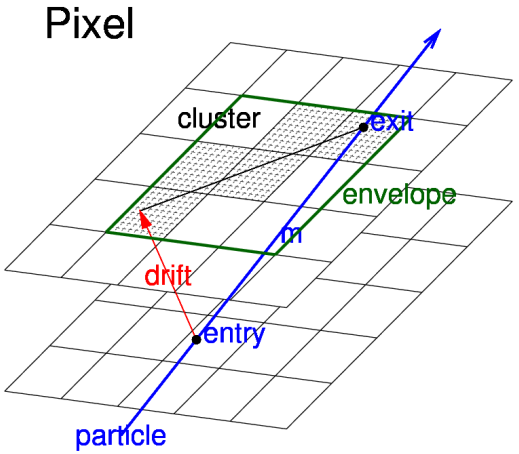
- The majority of the pp collision events are soft
  - No hard parton scattering
  - Phenomenological models: hadronization, fragmentation, …
- Various processes:
  - Elastic
  - Single-diffractive, double-diffractive (pomeron exchange)
  - Non-diffractive
- Measurement: $dN/d\eta$ and dN/dp_T of primary charged hadrons corrected for non-single-diffractive collisions
- First results at 2.36 TeV, first measurements at the LHC with momentum reconstruction
- Important reference for heavy-ion collisions

Different approaches

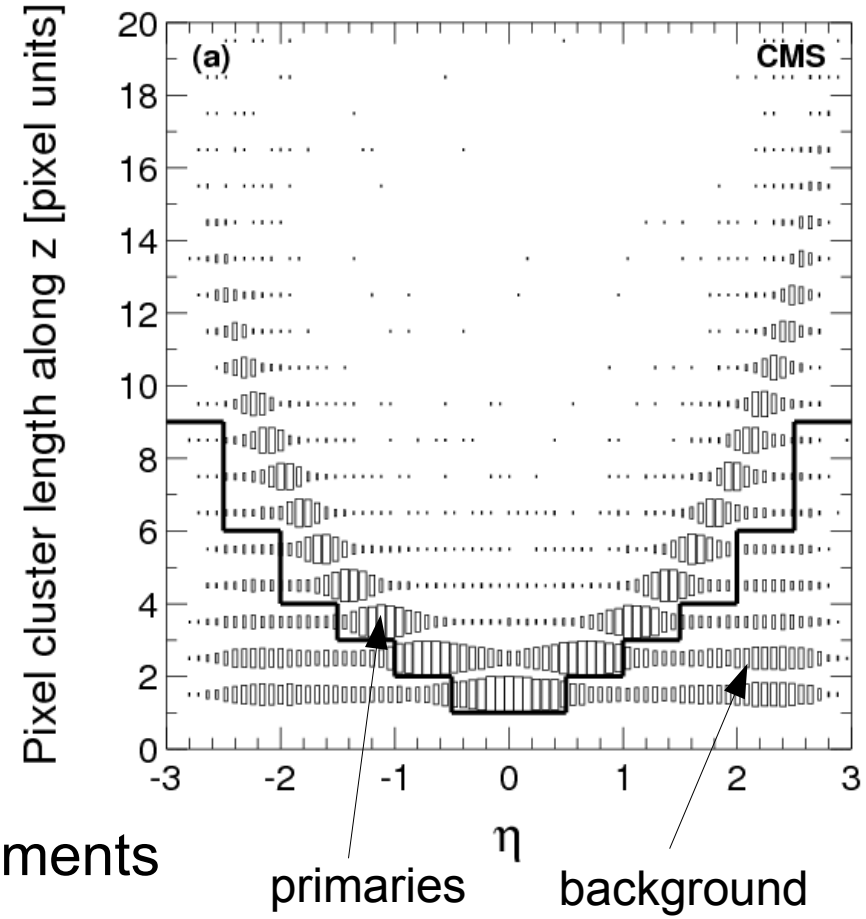
- Aim:
  - Measure primary charged hadrons
  - Use various methods
- Different approaches to measure charged spectra:
  - Use only 1 pixel layer (clusters): dN/dη
  - Use only 2 pixel layers (tracklets): dN/dη
  - Use all 3 pixel + strip layers (tracks): dN/dp_T, dN/dη
- Each of them have their own pros and cons
- Common issues:
  - Triggering, event selection (which events to take)
  - Vertexing (where is the interaction point)

Pixel clusters

- Method: calculate the η of every cluster wrt the vertex, reject background, correct results to hadrons
- Background rejection:
  - Pixel clusters: 2D objects

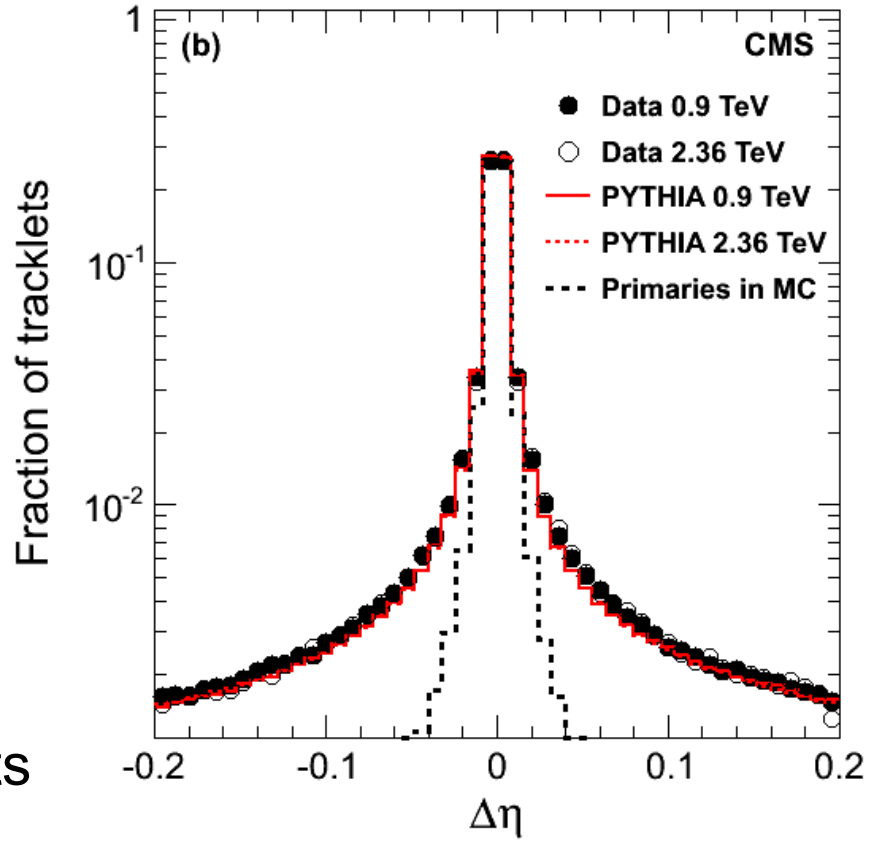


  - Cluster length ~ |sinh(η)|
- 3 layers → 3 independent measurements



Pixel tracklets

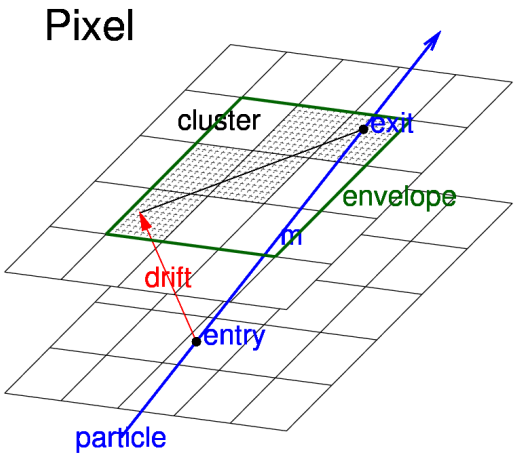
- Method: prepare pairs of pixel hits with vertex contraint, subtract the combinatorial background, correct the results to hadrons
- Combinatorial background:
  - $\Delta\eta=\eta_1-\eta_2$ and $\Delta\Phi=\Phi_1-\Phi_2$
  - Primary particles: spike at $\Delta\eta=0$ and $\Delta\Phi=0$
  - Define regions: signal and background regions in $\Delta\Phi$
  - Data driven procedure
- 3 layer pairs
  → 3 independent measurements

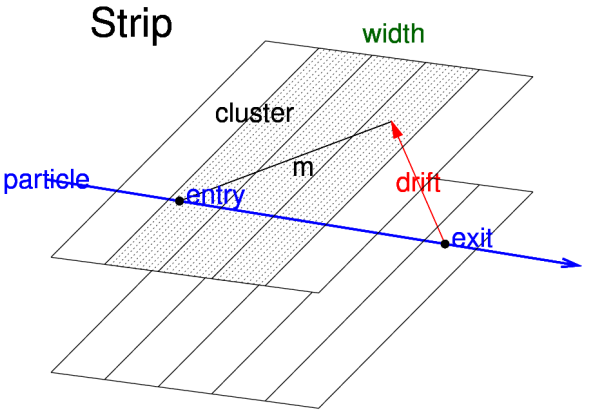


The Δη distribution of the two clusters of the tracklets

Full tracks

- Uses all pixel and strip layers
- Build trajectories interatively:
  - Reduces combinatorics, fake rate
- Clean trajectories based on cluster shapes
  - Low fake rate
- Primary vertex reconstructed from tracks:
  - Agglomerative vertexing
- Compatibility with beam spot and primary vertex required
  - Immune to background
  - More sensitive to beam spot and alignment





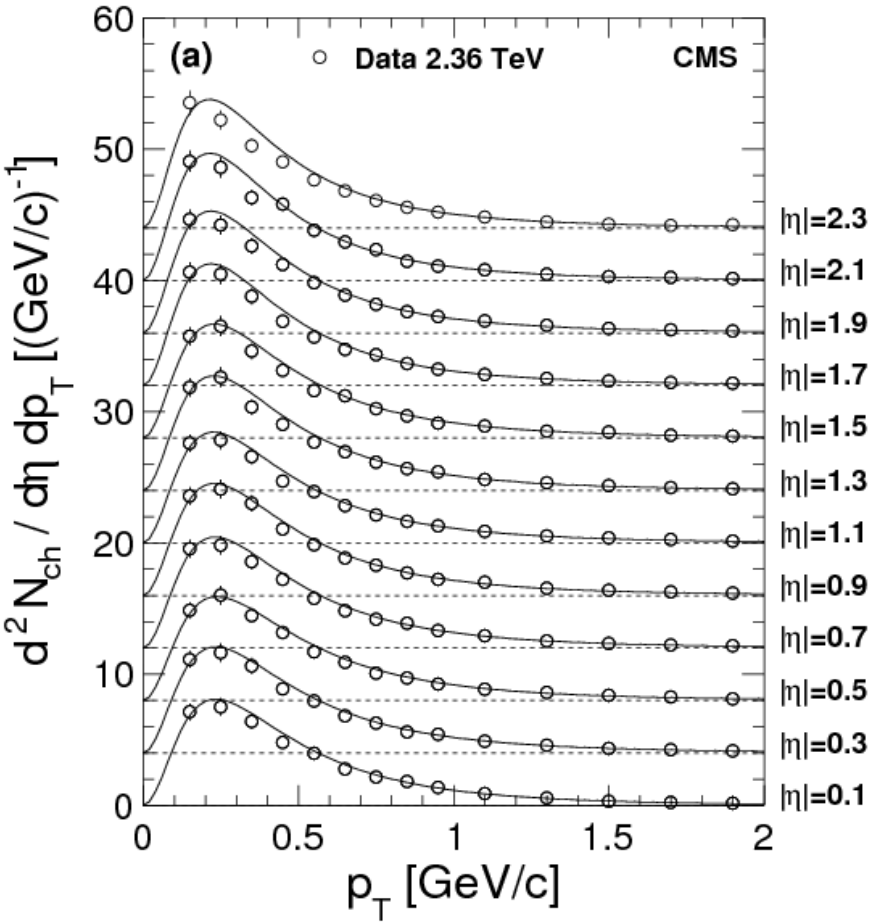
Differential yields

- Measured differential yields of charged hadrons, fitted by the Tsallis function
- Tsallis function:

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

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

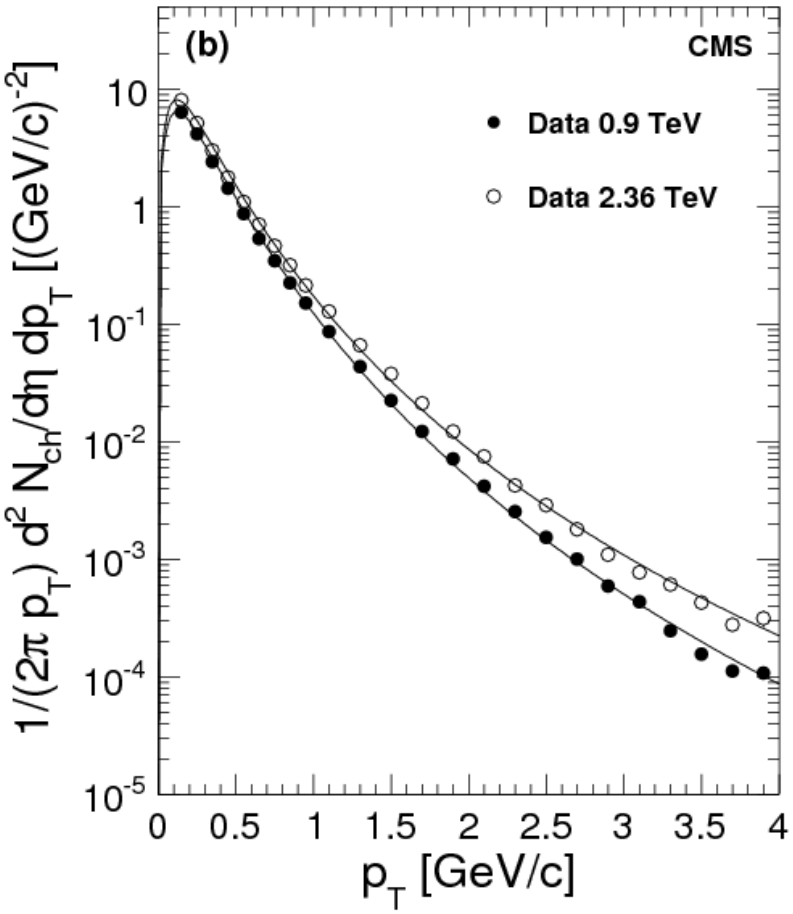
- Only a small change in the parameters as a function of η



Differential yields in various η bins

Invariant yields

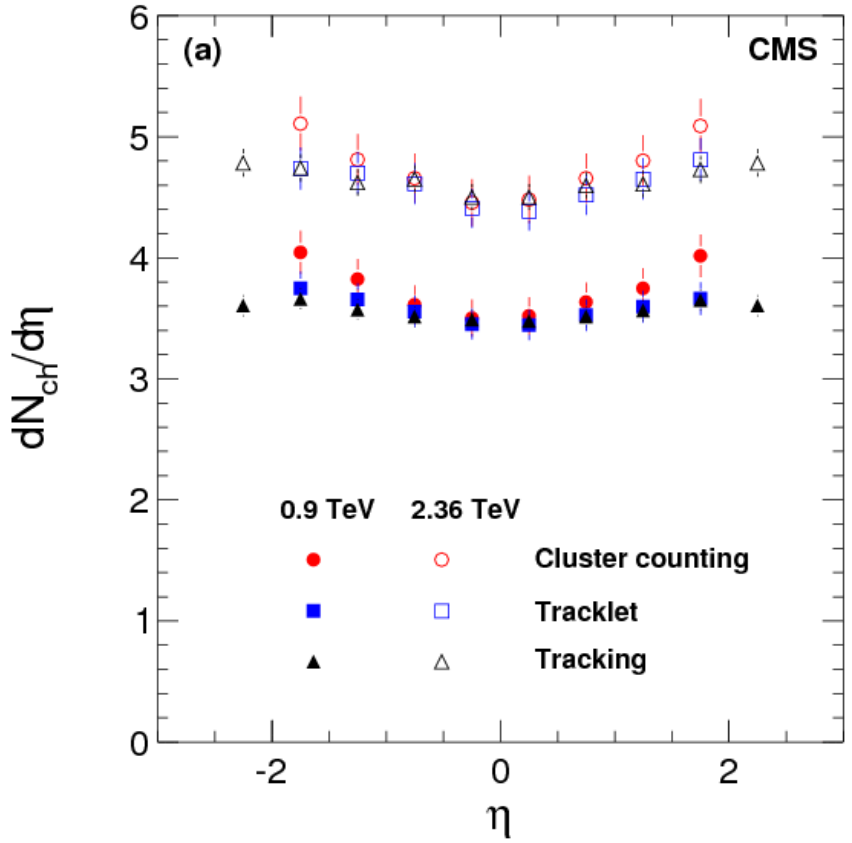
- Measured yields of charged hadrons, fitted by the Tsallis function
- With increasing energy the p_T-spectrum gets harder
- Measured parameters of the Tsallis fit:
  - 900 GeV:
    - T = 0.13 ± 0.01 GeV
    - n = 7.7 ± 0.2
  - 2.36 TeV:
    - T = 0.14 ± 0.01 GeV
    - n = 6.7 ± 0.2



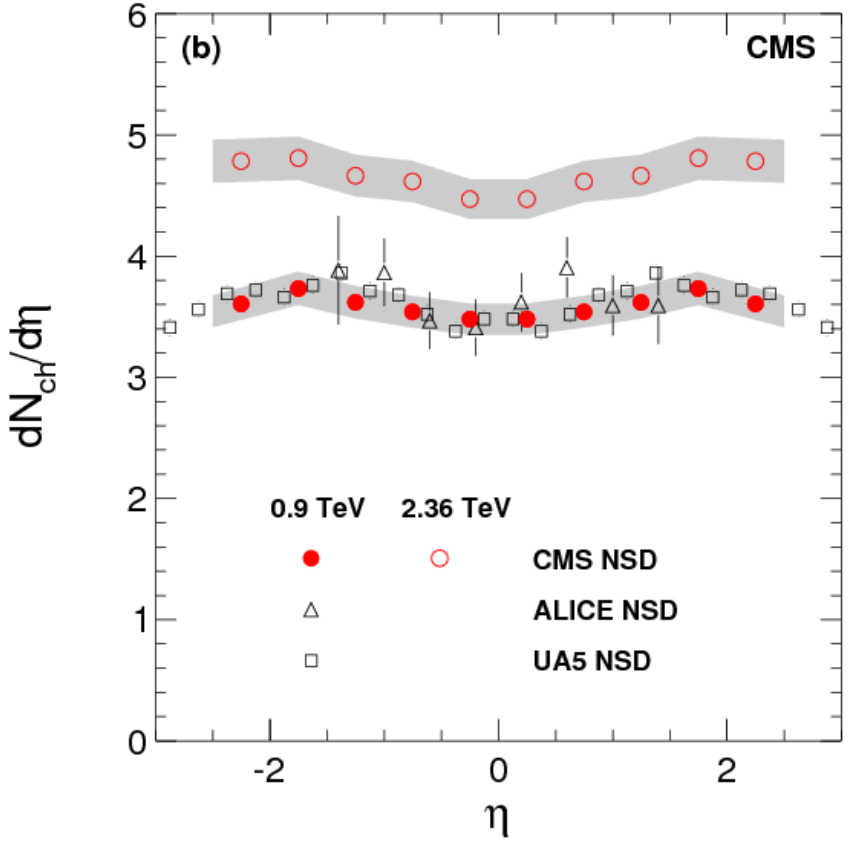
Measured yield within |η|<2.4

Measured dN/dη distributions

- Measured dN/dη distributions of primary charged hadrons for non-single-diffractive collisions at 0.9 and 2.36 TeV



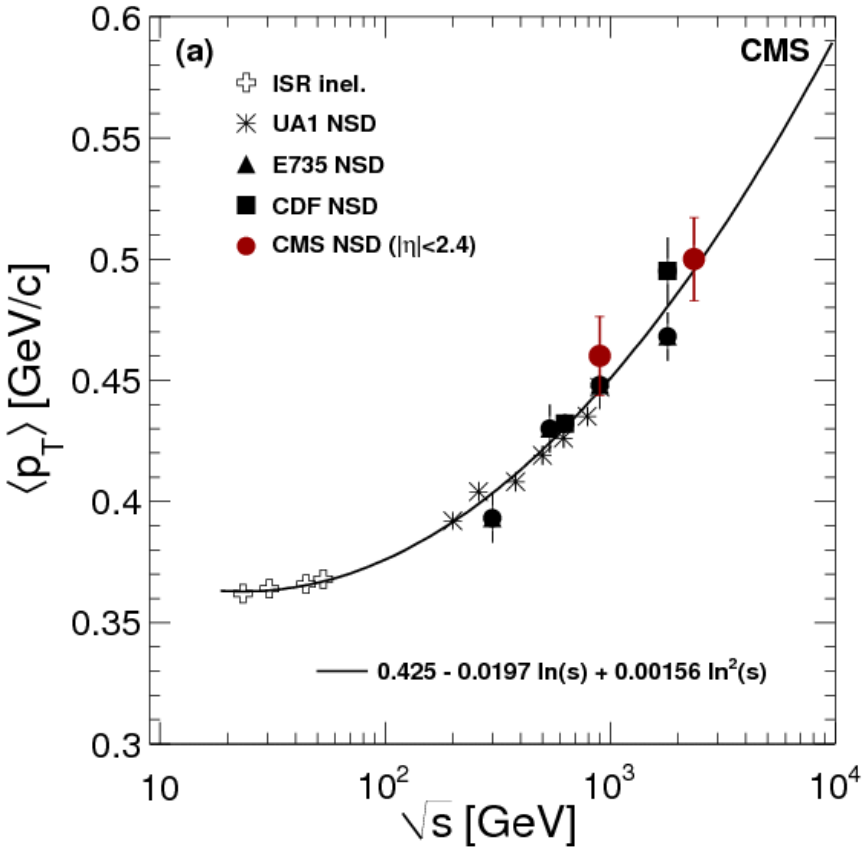
dN/dη distributions obtained with the three methods, common systemtic errors excluded



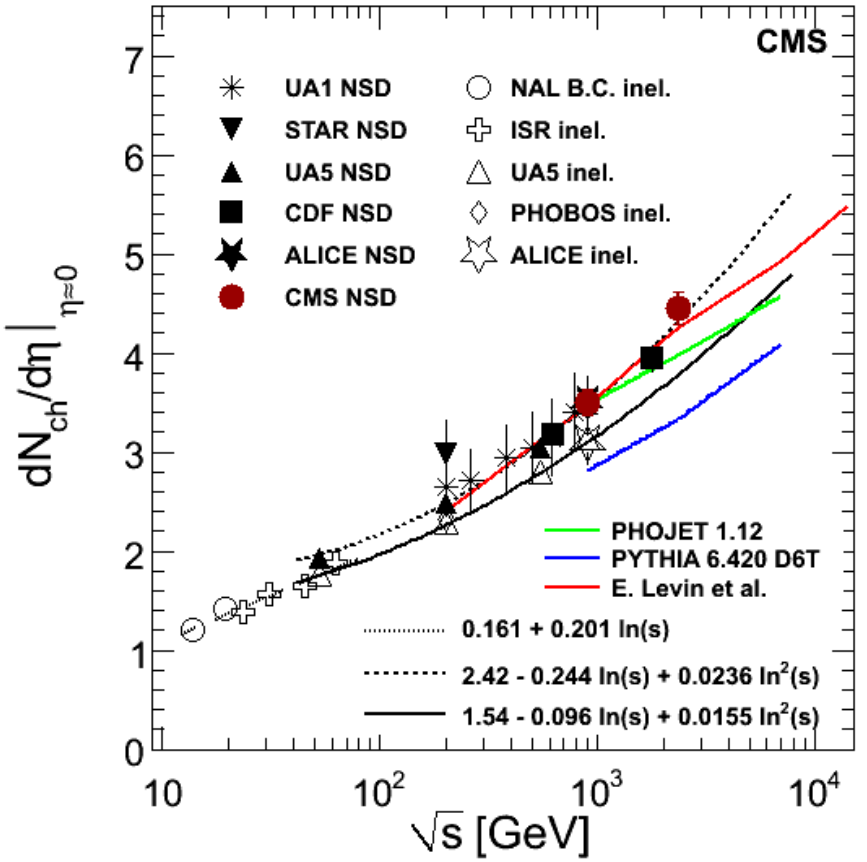
Averaged and symmetrized dN/dη distributions, systematic uncertainties are shown

Energy dependence

- Energy dependence of the average p_T and the $dN/d\eta|_{\eta=0}$ of primary charged hadrons



Error bars include systematic uncertainties



Error bars include systematic uncertainties

Bose-Einstein Correlations at 0.9 and 2.36 TeV

Bose-Einstein correlation

- A correlation in production of light hadrons of integer spin is expected from the constructive interference of the multi-particle wave function
- The effect can be observed: regions of phase space where bosons have very similar momenta
- Parametrizations:
  - Ratio between the joint probability and individual probabilities:

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

  - *R* may be expressed as a function of the pair Q-value:

$$R = \frac{dN/dQ}{dN/dQ_{ref}} \quad \text{where} \quad Q = \sqrt{(M^2_{\pi\pi} - 4\mathrm{m}^2_{\pi})}$$

Measurement

- Experimental measurement of *R*:
  - Quantity: Q-value distribution of pairs of identical bosons divided by a similar distribution of non-interferencing pairs
  - Signal: enhancement of *R* from unity in the low-*Q* region
- Lorentz-invariant form of *R* for emission from a spherical region:

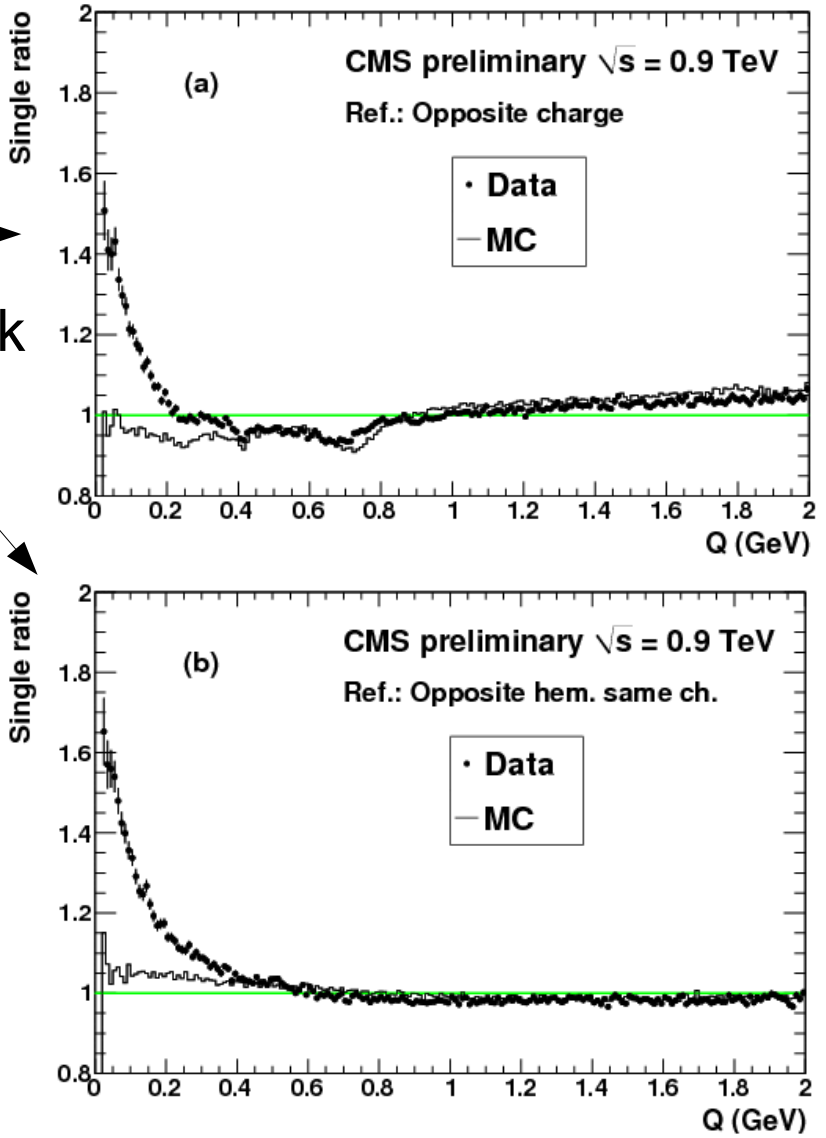
$$R(Q) = C[1 + \lambda\, \Omega(Qr)](1 + \delta\, Q)$$

where

  - $\Omega(Qr)$ is the Fourier transform of the emission region
  - whose effective size is *r*
  - λ is a strength parameter
  - δ allows slight biases in the *Q* distribution of the reference
- Different forms for $\Omega(Qr)$: gaussian, exponential

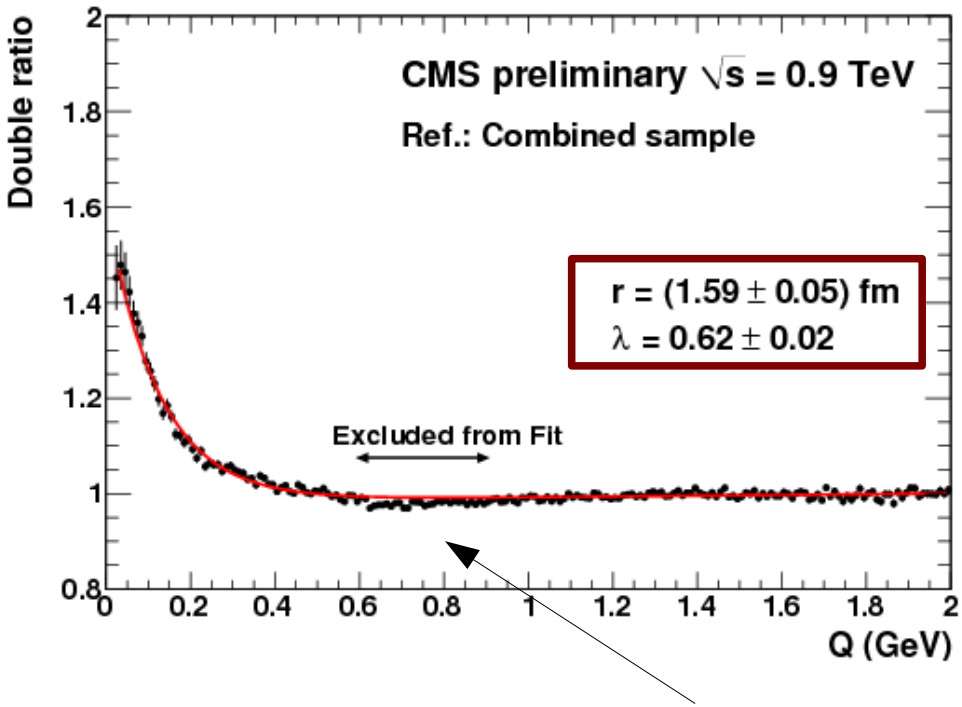
Reference samples

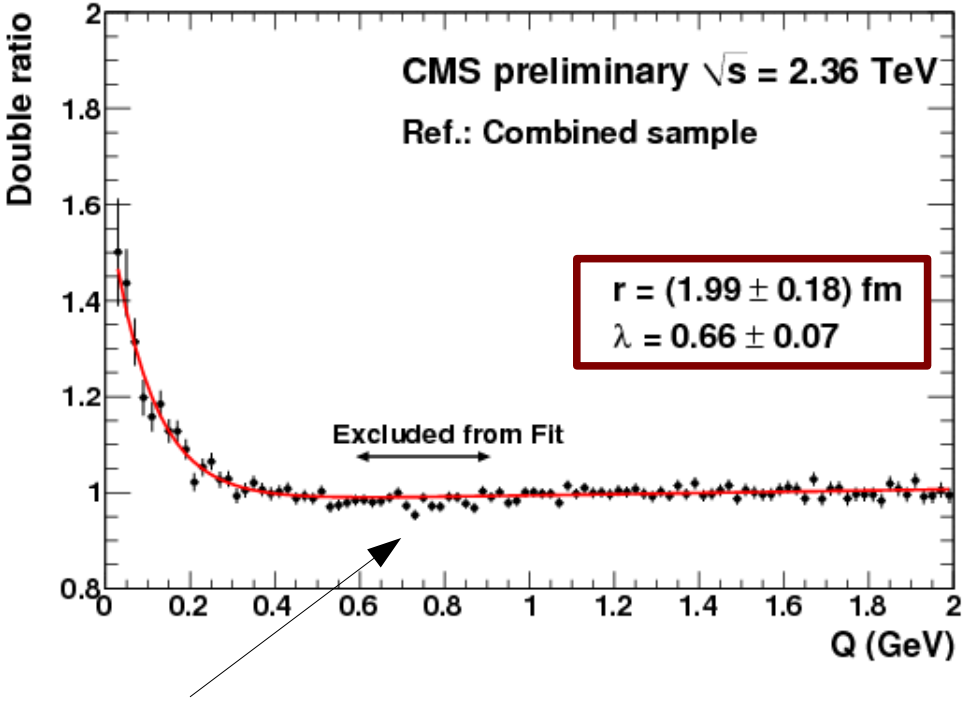
- Samples which don't contain the correlation (7 methods):
  - Opposite-charge pairs
  - Same-charge pairs where one track has inverted three-momentum
  - Event mixing
  - …
- Use these as reference samples in data and in MC
- The single ratios show the signal, but contain some long range biases
- Double ratio: $\varrho = \frac{R}{R_{MC}}$



Measured correlation

- Combined results: new reference ← average all the 7 reference samples
- Fit with exponential parametrization (favoured by data)

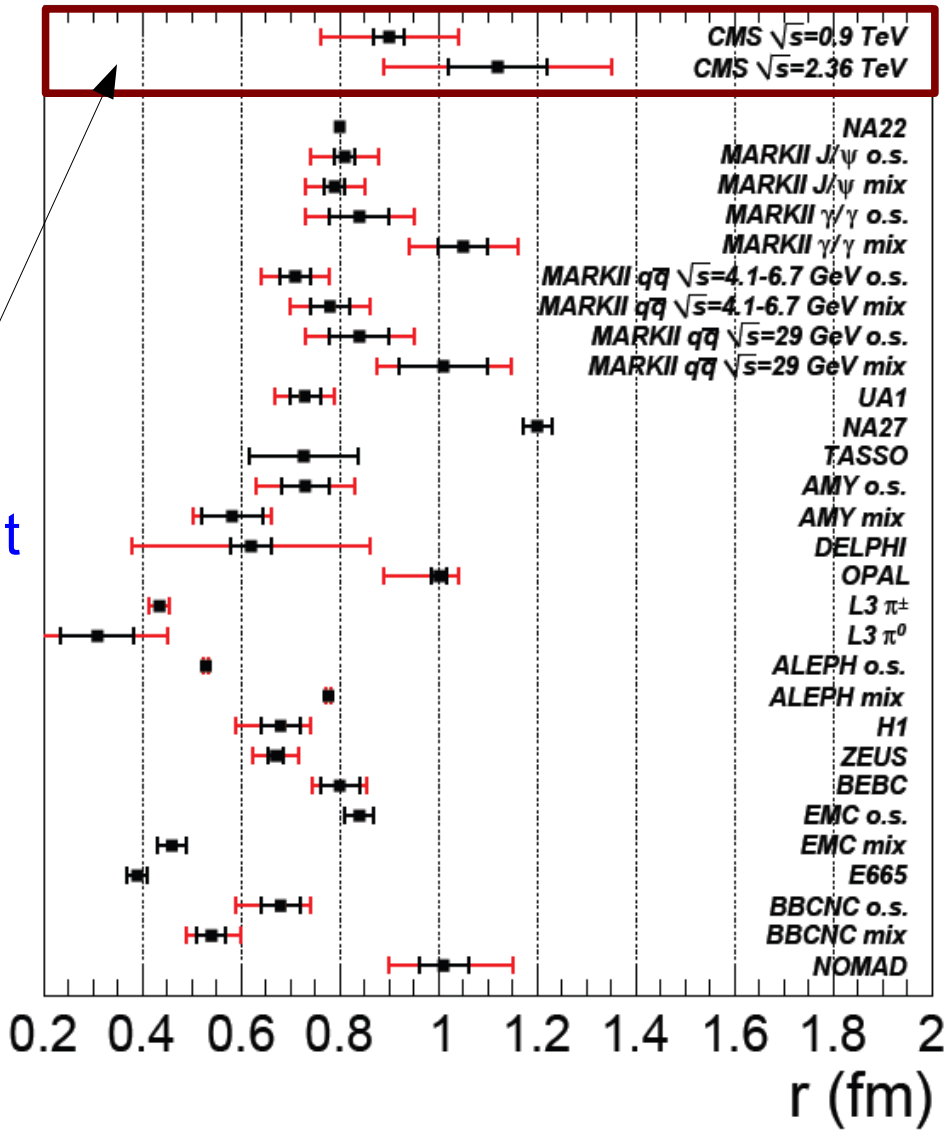




Corresponds to the ρ^0 resonance (0.6-0.9 GeV)

Context

- Results for *r* with gaussian interpretation
- CMS values:
  - obtained from the exponential fit
  - Scaled by $1/\sqrt{\pi}$
- Both statistical end systemtics errors are shown



Summary

Collection of results

- Charged hadron spectra:
  - Average transverse momentum for NSD collisions:
    - 0.9 TeV: 0.46±0.01(stat.)±0.01(syst.) GeV/c
    - 2.36 TeV: 0.50±0.01(stat.)±0.01(syst.) GeV/c
  - dN/dη for NSD collisions:
    - 0.9 TeV: 3.48±0.02(stat.)±0.13(syst.)
    - 2.36 TeV: 4.47±0.04(stat.)±0.16(syst.)
- Bose-Einstein correlation:
  - Size of the emission region:
    - 0.9 TeV: 1.59±0.05(stat.)±0.19(syst.) fm
    - 0.23 TeV: 1.99±0.18(stat.)±0.24(syst.) fm
  - Strength parameter:
    - 0.9 TeV: 0.625±0.021(stat.)±0.046(syst.)
    - 2.36 TeV: 0.663±0.073(stat.)±0.048(syst.)

Summary

- CMS already published a set of interesting results on the field of QCD
- More results will become public in the near future:
  - Underlying event in leading charged jets and leading charged tracks at 0.9 TeV
  - Charged particle multiplicities at 0.9 and 2.36 TeV
  - Transverse-momentum and pseudorapidity distributions of charged hadrons in pp collisions at 7 TeV
  - ...

CMS already produces valuable results, much more to come!

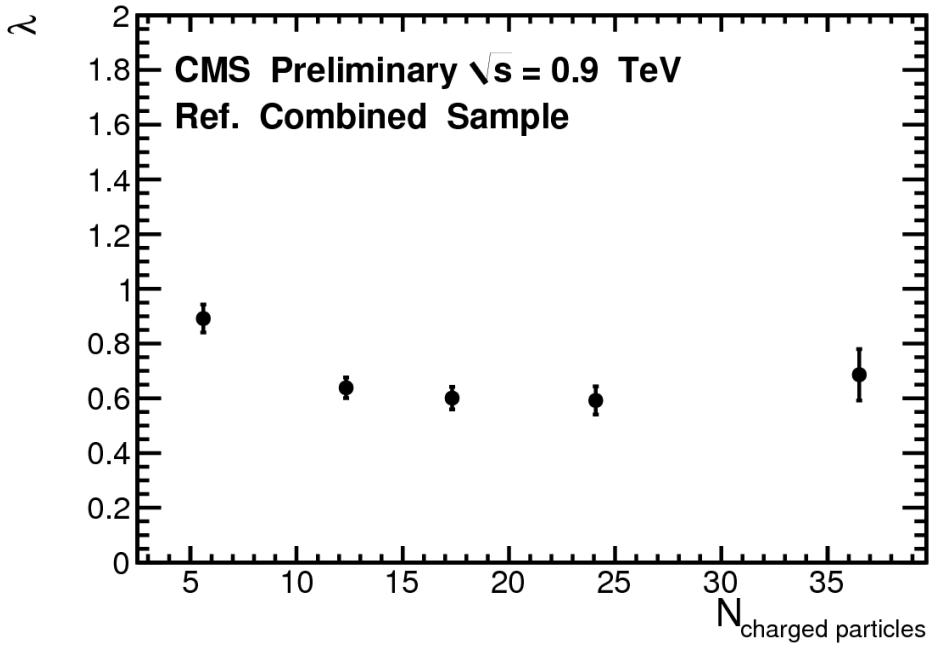
- References:

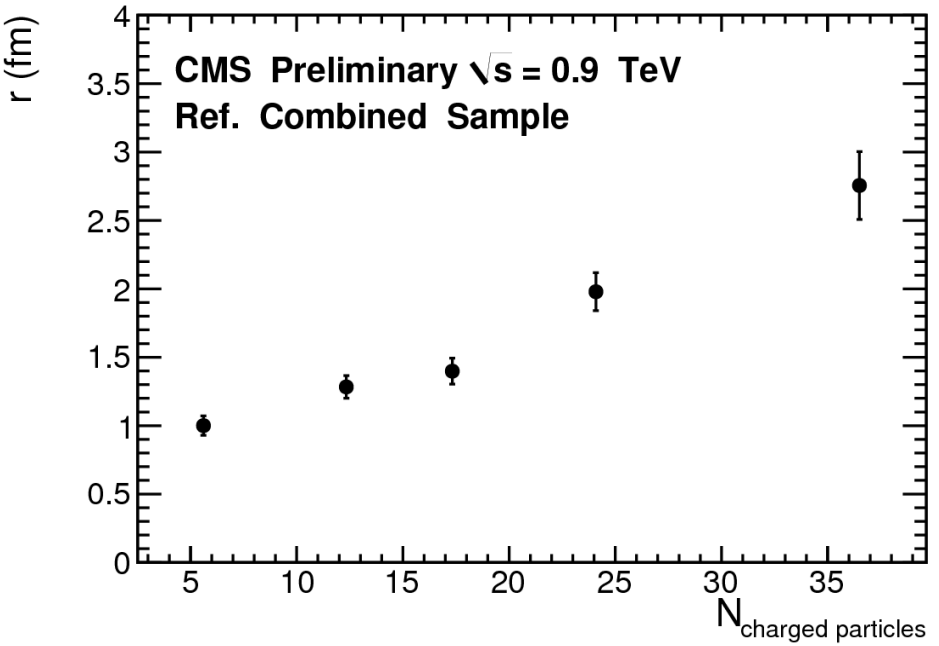
[1] JHEP 02 (2010) 041

[2] CMS-PAS-QCD-10-003

BACKUP SLIDES

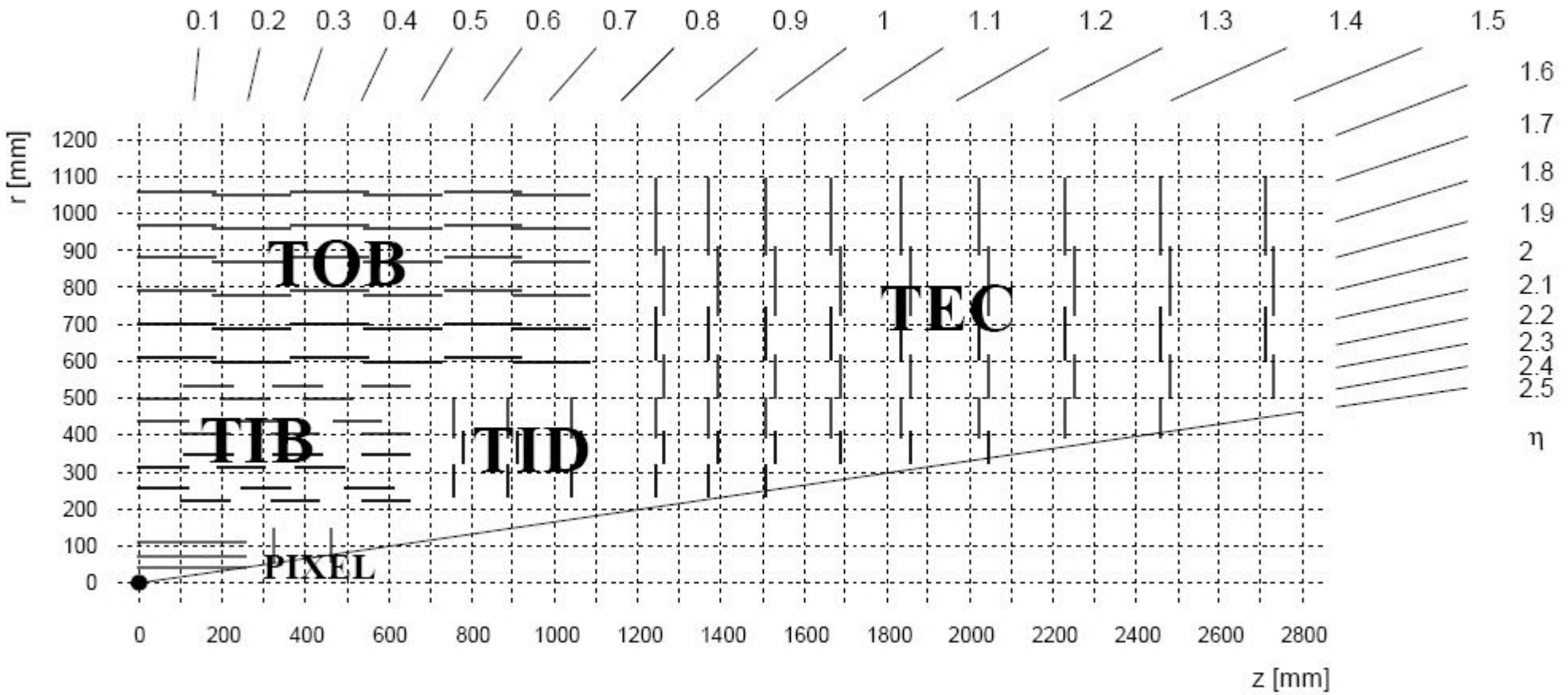
N_{ch} dependence of λ and r



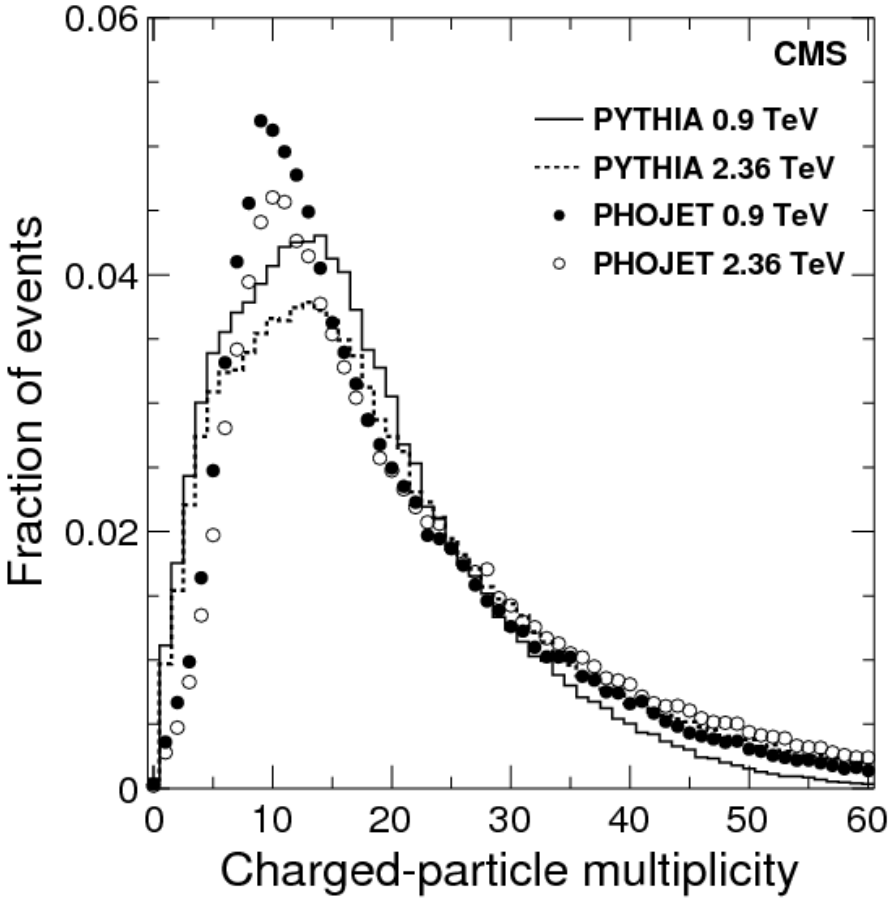


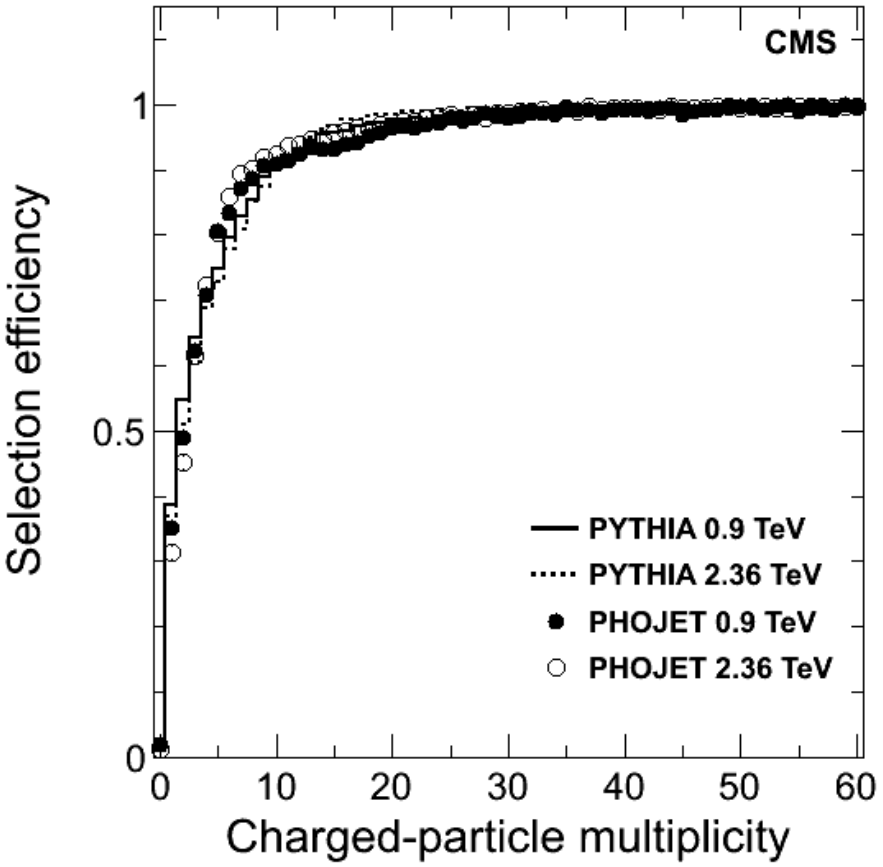
Errors are statistical only

Tracker layout

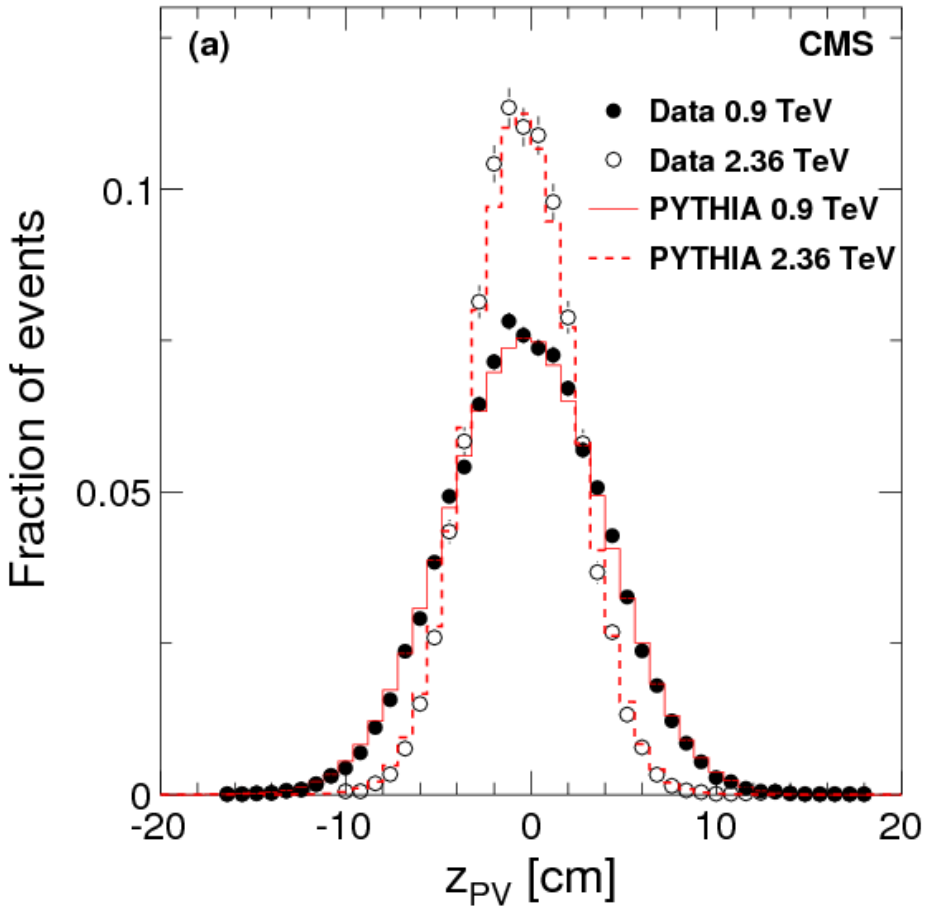


Event selection

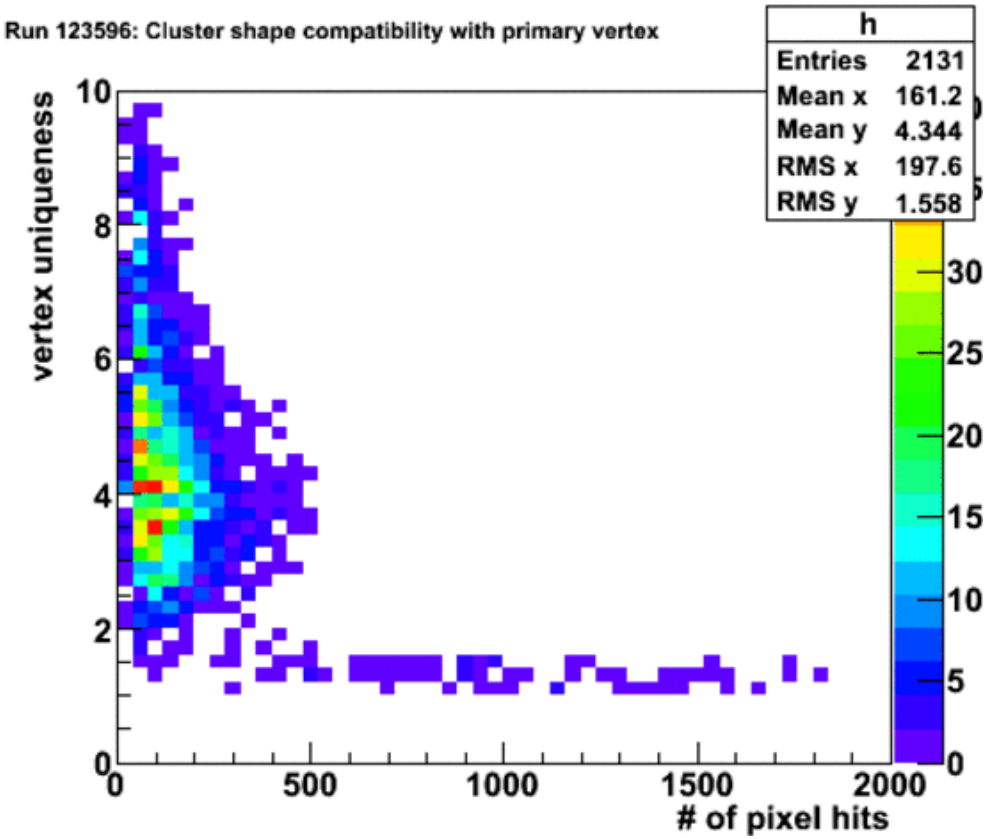


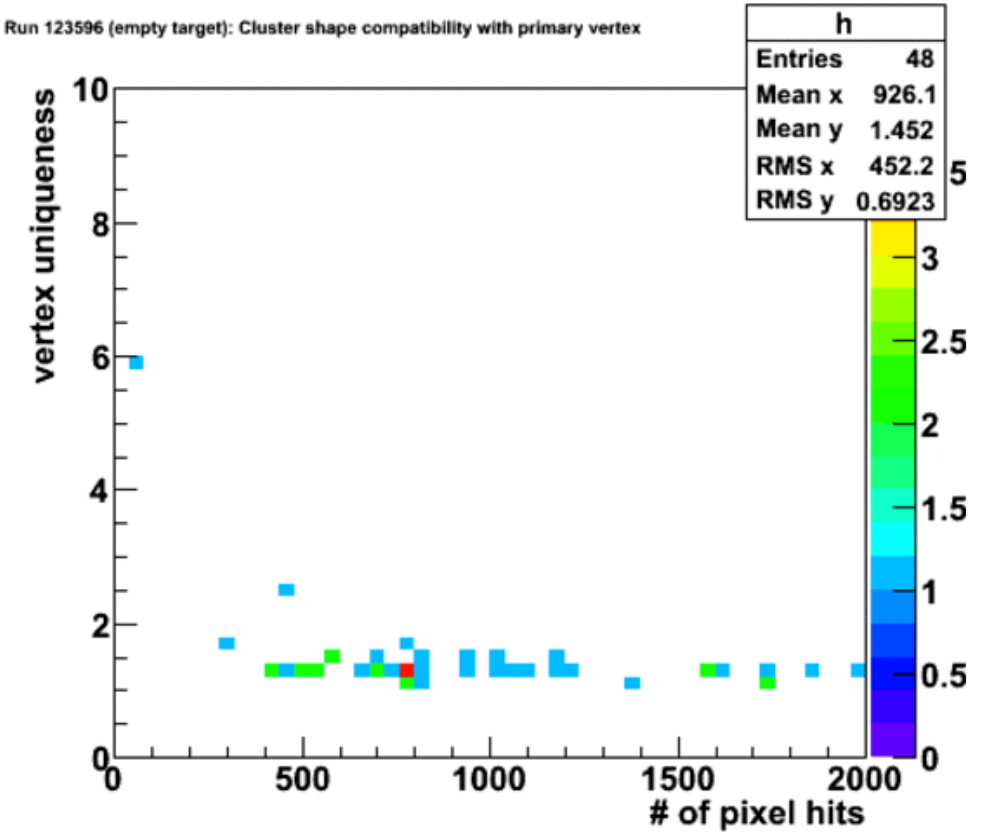


Vertex positions

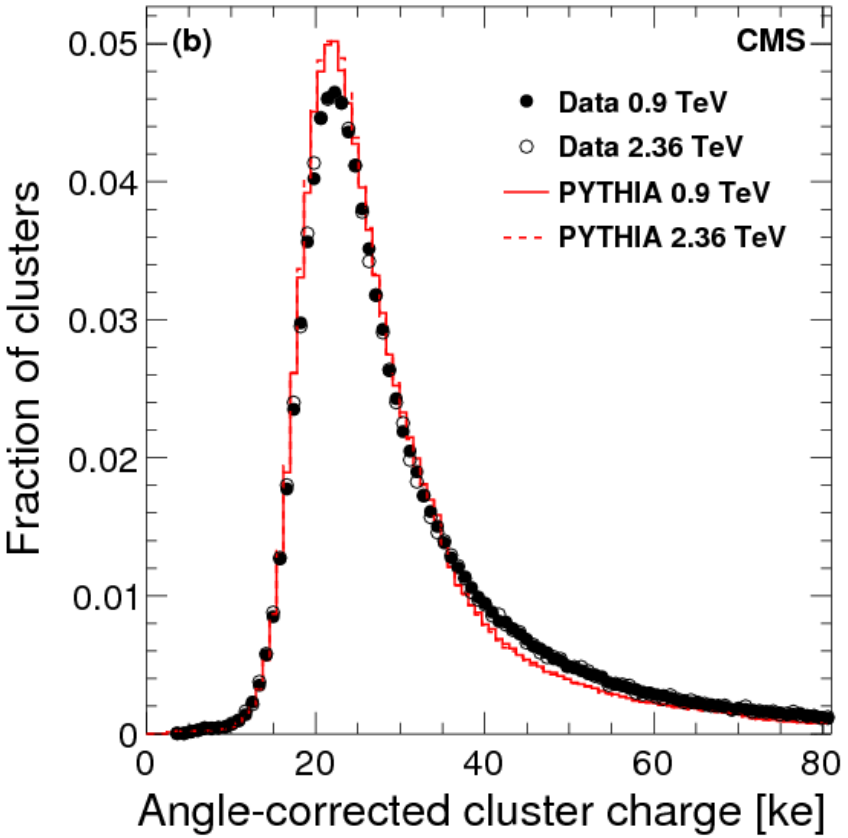


Cluster-vertex compatibility

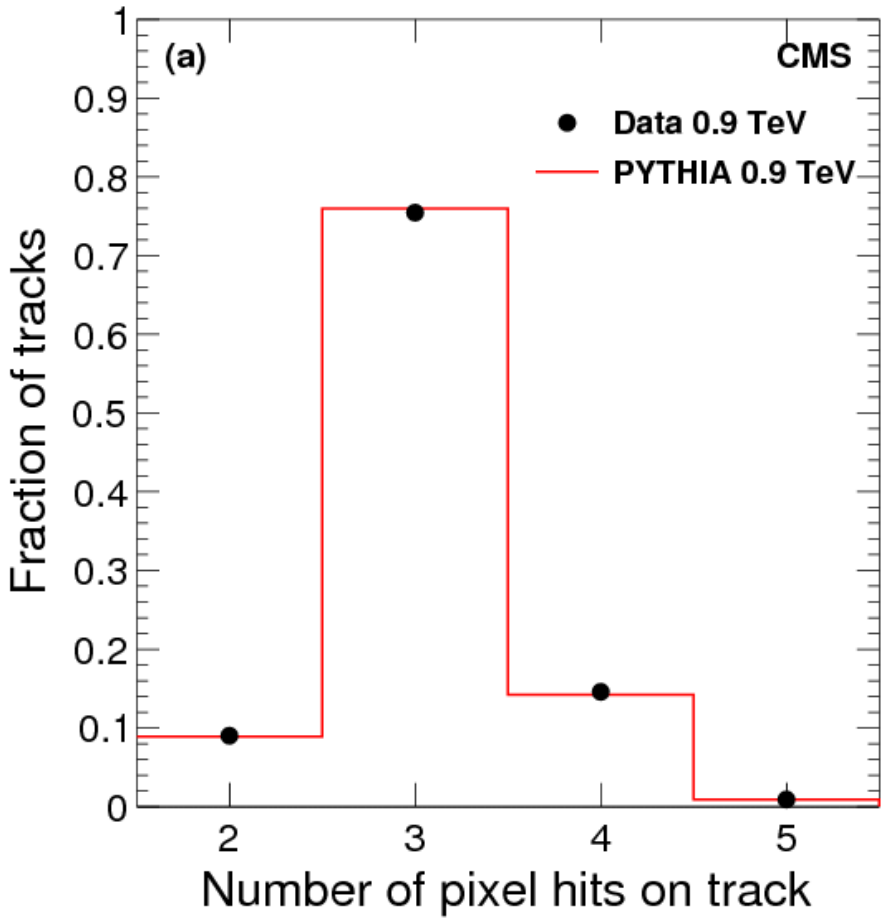


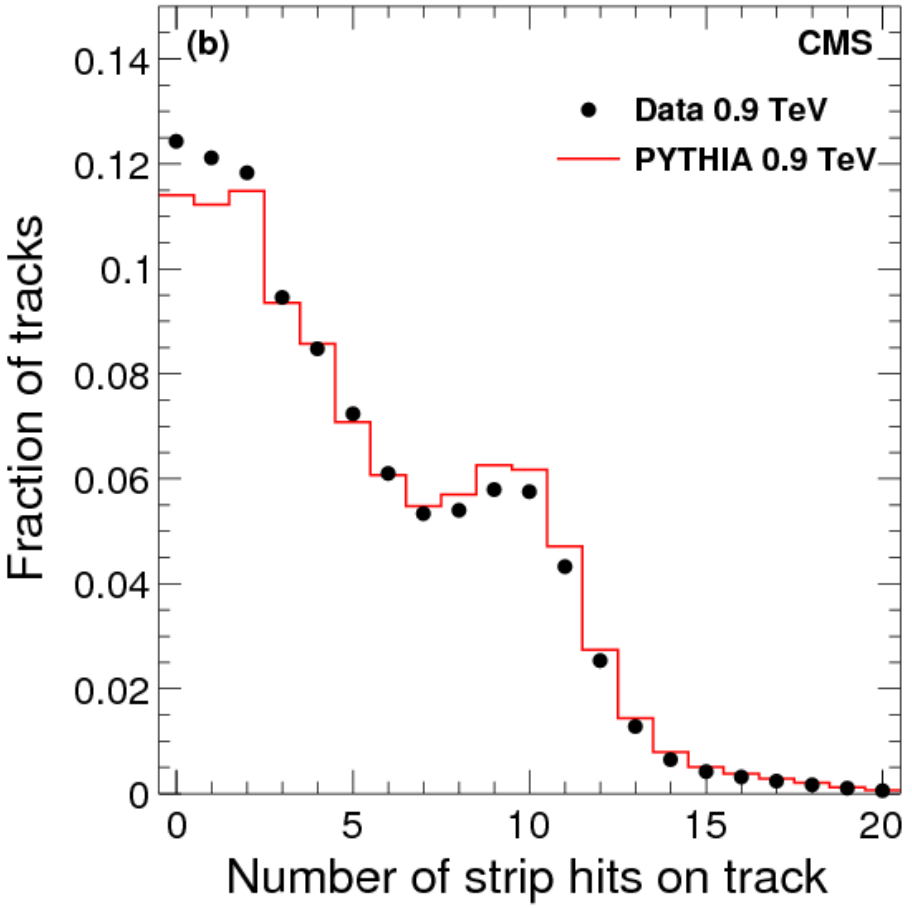


Cluster charge distribution

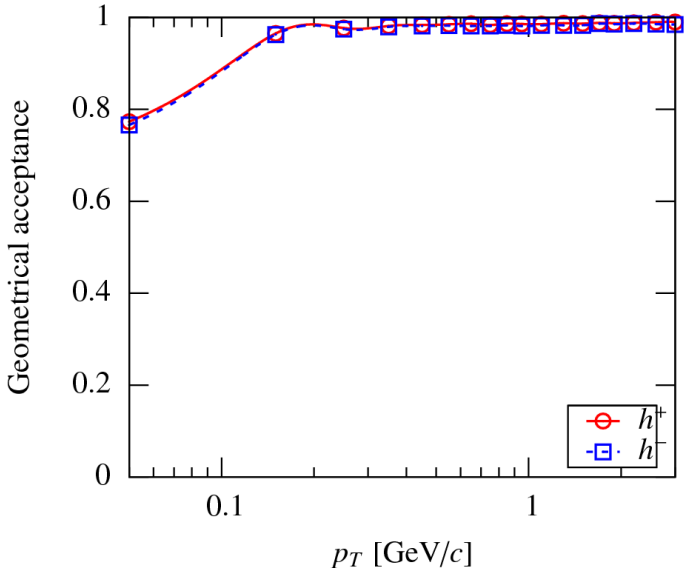


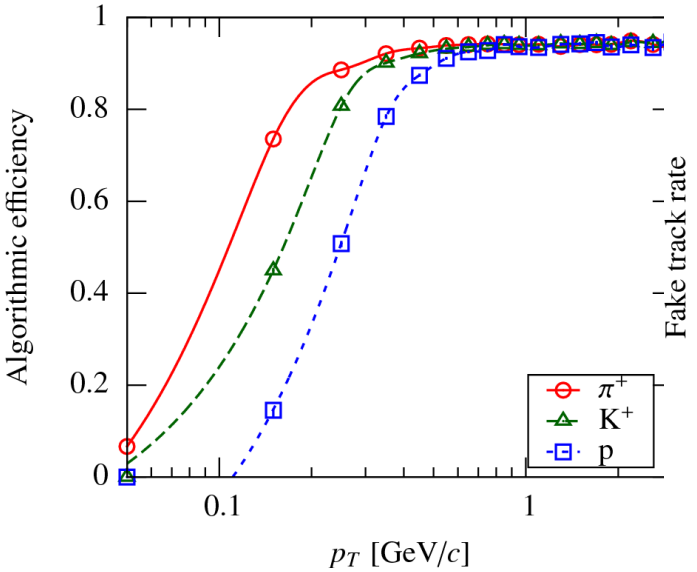
Number of hits on tracks

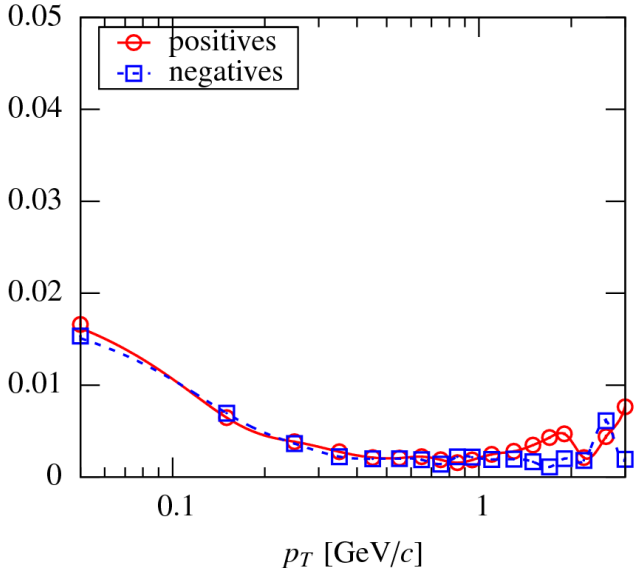


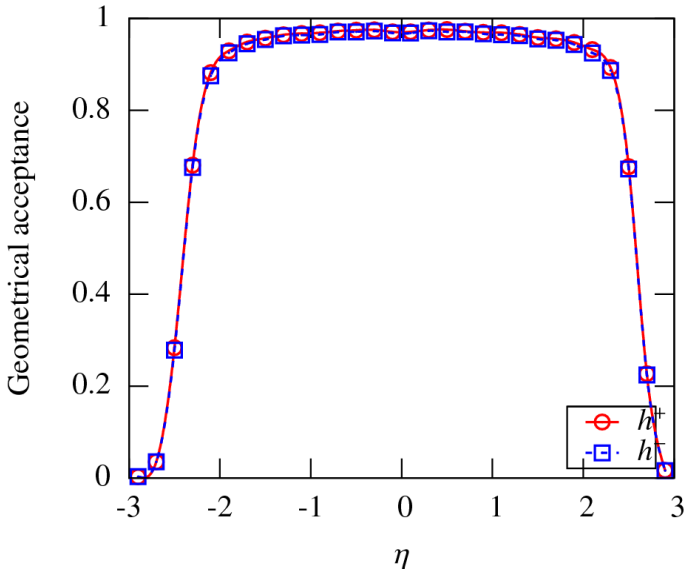


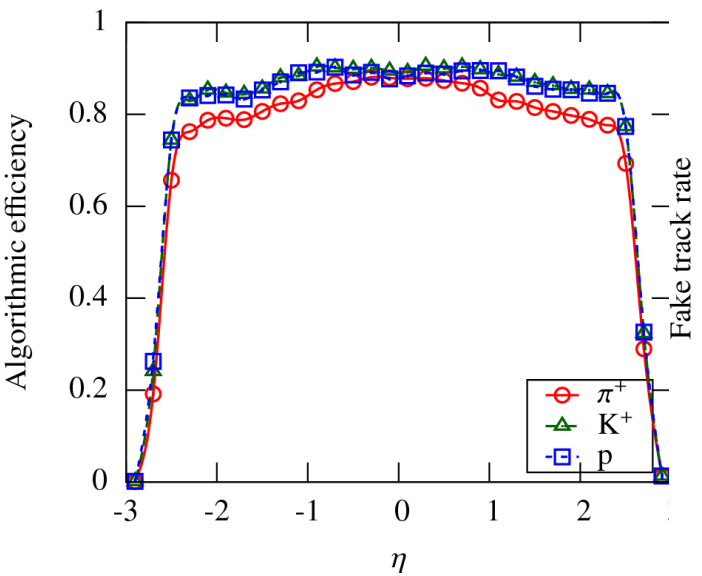
Tracking performance

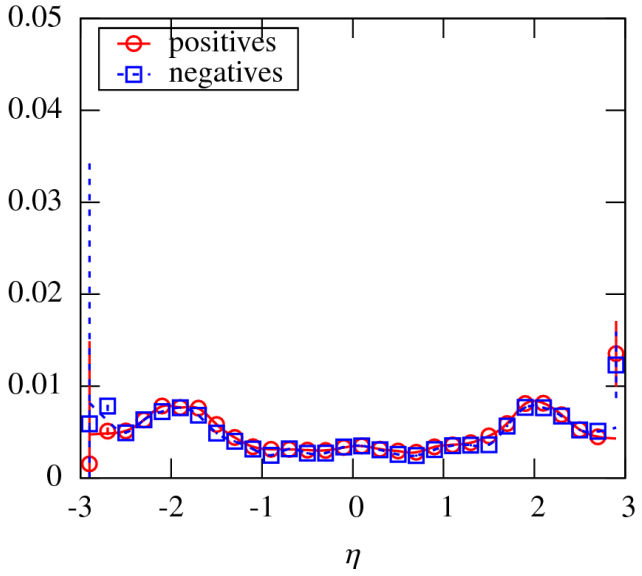




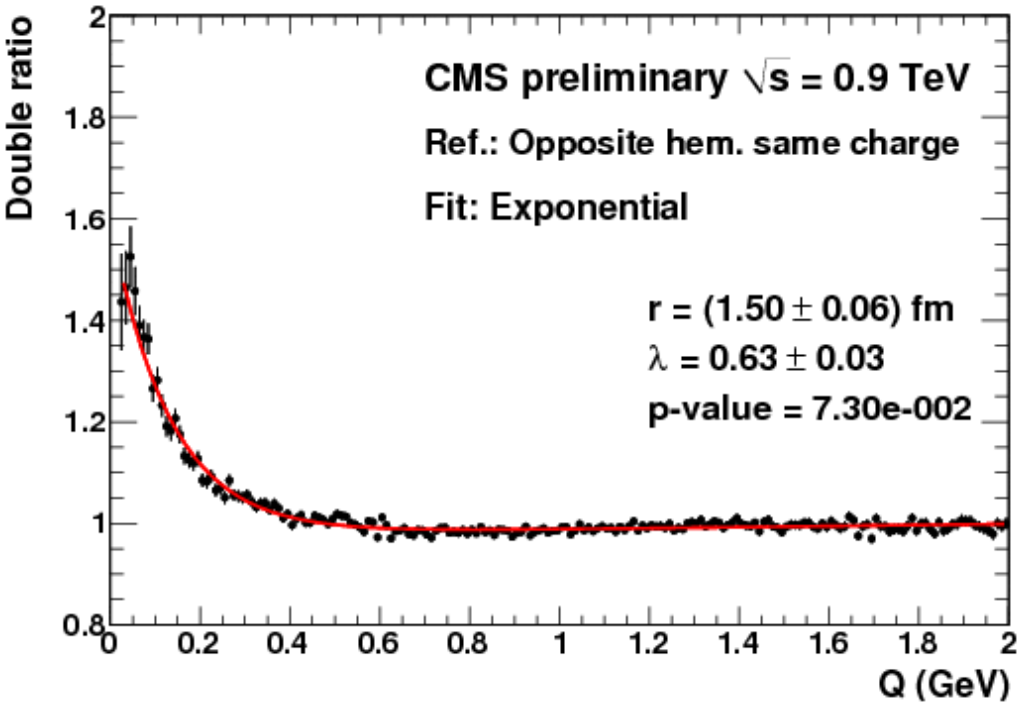
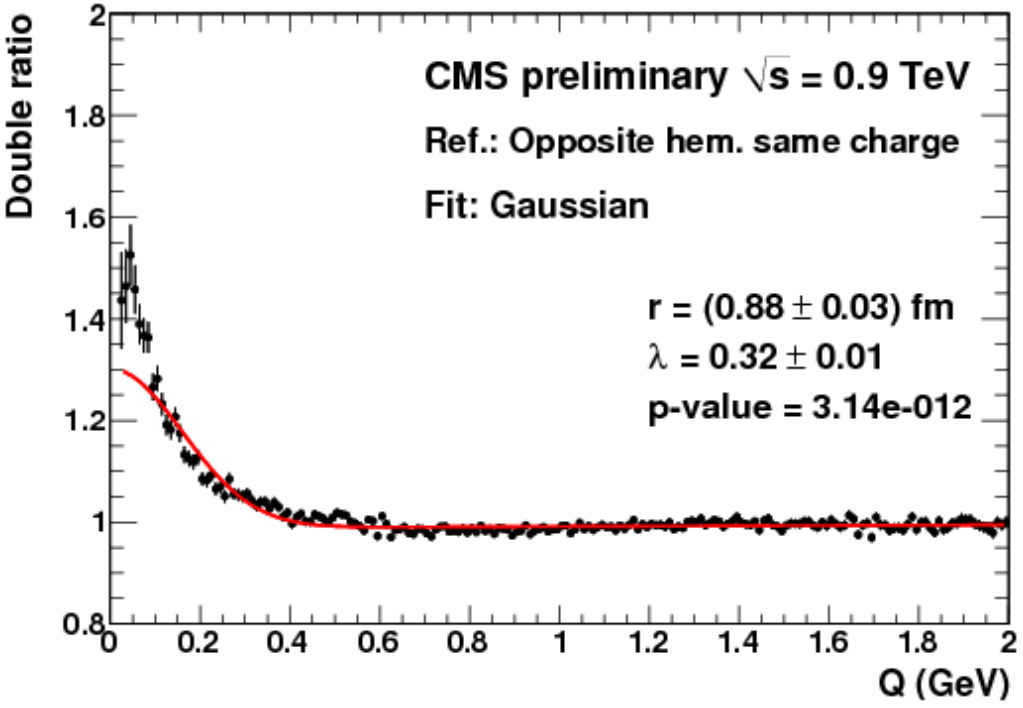








List of reference samples

- Opposite-charge pairs: natural choice but contains resonances (η,ρ)
- Opposite-hemisphere pairs: particle pairs are constructed after inverting in space the three-momentum of one of the two particles
- Rotated particles: a statistically-independent reference sample is constructed by inverting x and y components of the particle three-momentum
- Mixing events: particles from different events are combined:
  - Events are paired at random
  - Events with similar similar charged particle density in different η regions are selected
  - Events with an invariant mass of all charged particles similar to that of the signal are paired

Exponential vs gaussian fit