Soft physics capabilities of CMS in p-p at 14 TeV and Pb-Pb at 5.5 TeV

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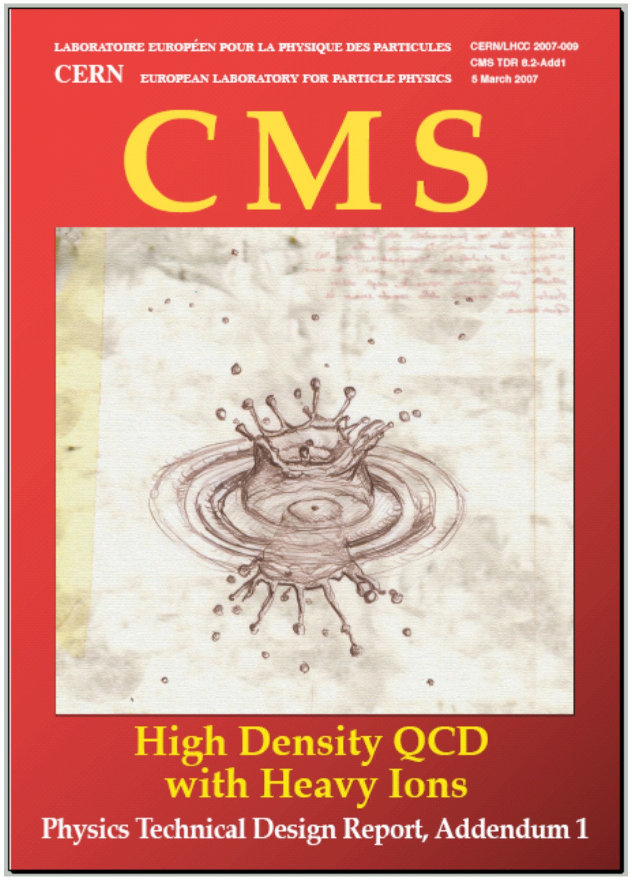
Soft physics

- Contents
  - The detector
  - Level-1 trigger
  - Centrality selection
  - Charged hadron rapidity density
  - Charged hadron spectra
  - Particle identification capabilities
    - ∗ charged hadrons via energy loss (dE/dx)
    - ∗ neutral hadrons via decay topology (V0)
  - Azimuthal asymmetry, flow
  - Summary



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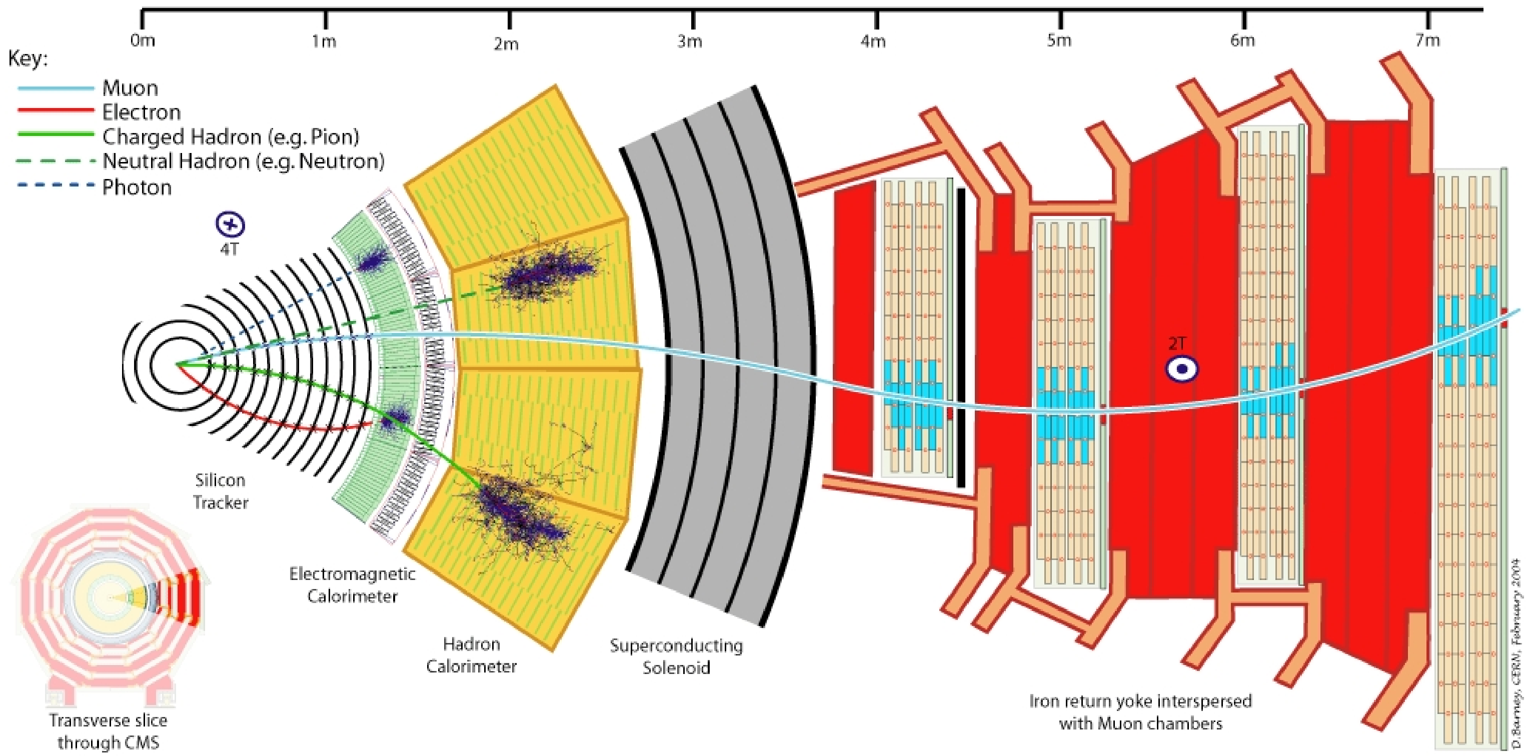
Proton-proton program: analysis exercise, first measurements
Heavy-ion program: study of QCD matter under extreme conditions

One single detector combines **global** characterization and **specific** probes

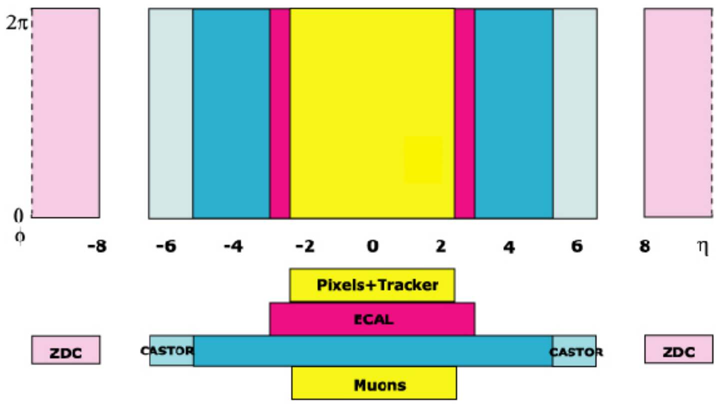
The CMS detector – slice



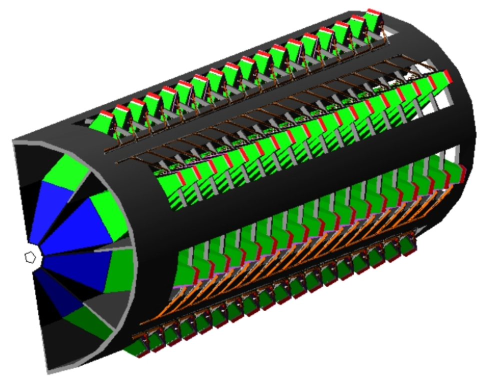
- Detectors
  - Silicon tracker: pixels and strips ($|\eta| < 2.4$)
  - Electromagnetic ($|\eta| < 3$) and hadronic ($|\eta| < 5$) calorimeters
  - Muon chambers ($|\eta| < 2.4$)
  - Extension with forward detectors (next slide)

Can measure leptons (e, μ), hadrons (π, K, p), charged and neutrals (n, γ)

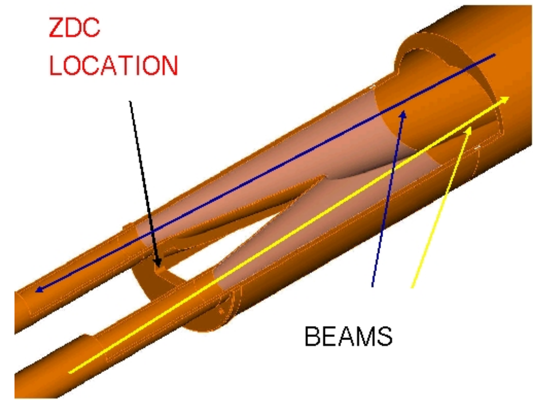
The CMS detector – forward



CASTOR



ZDC



- CASTOR
  - tungsten and quartz plates ($5.3 < |\eta| < 6.6$)
  - covers region where baryon density is expected to be maximal in Pb-Pb

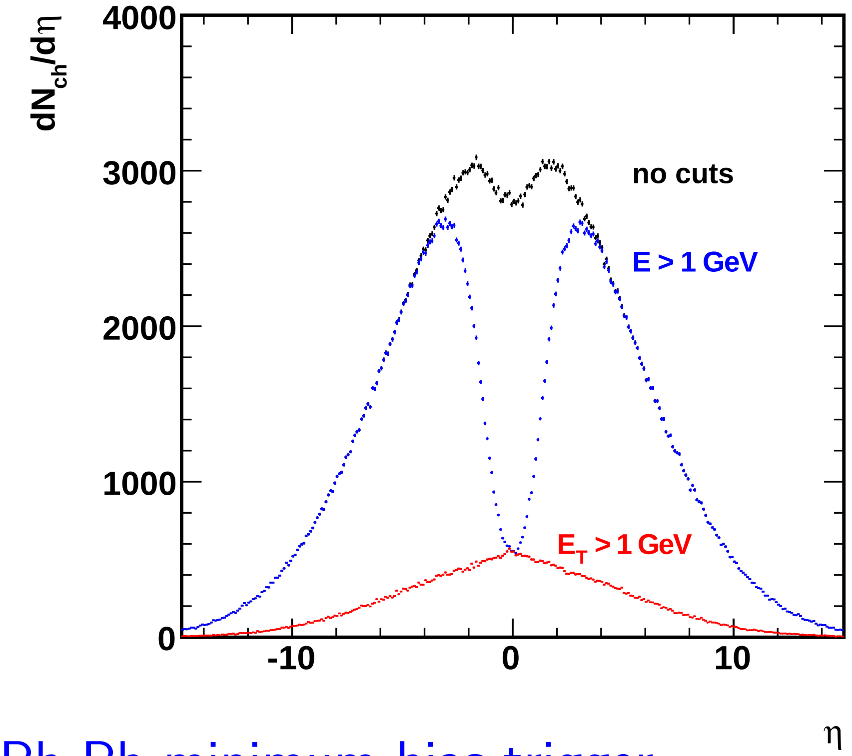
  ⇒ See poster of P. Katsas: "Performance studies of the final prototype for the CASTOR forward calorimeter at the CMS experiment"

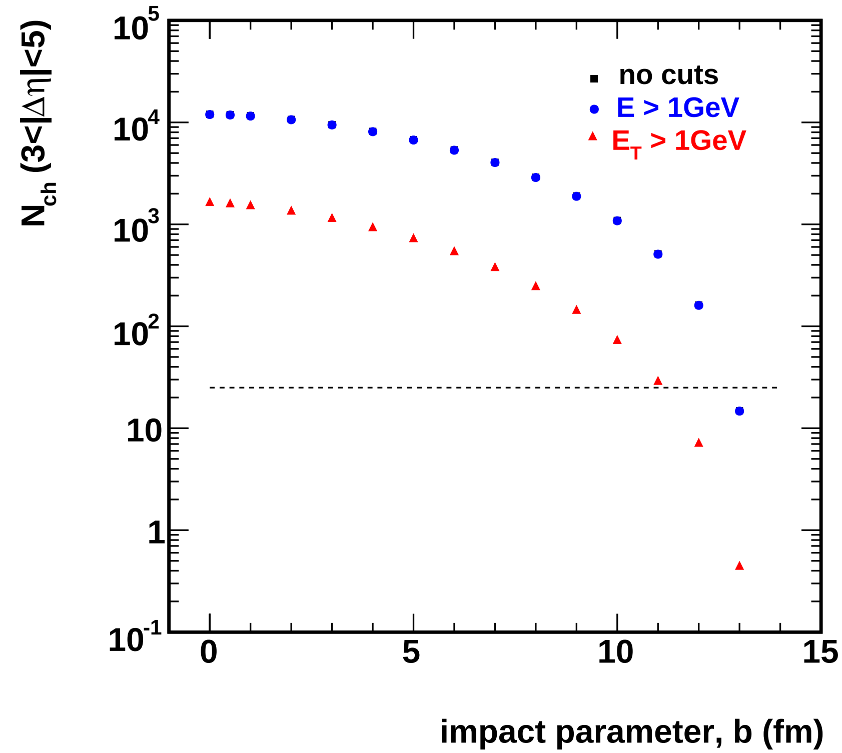
- ZDC
  - quartz fibers in a tungsten matrix, 140 m away from the IP ($|\eta| > 8.3$)
  - measures spectator neutrons and forward photons

  ⇒ See poster of E. Garcia: "Zero degree calorimeters for beam monitoring and forward physics measurements at the LHC"

Very wide acceptance

Level-1 trigger – minimum bias p-p and Pb-Pb

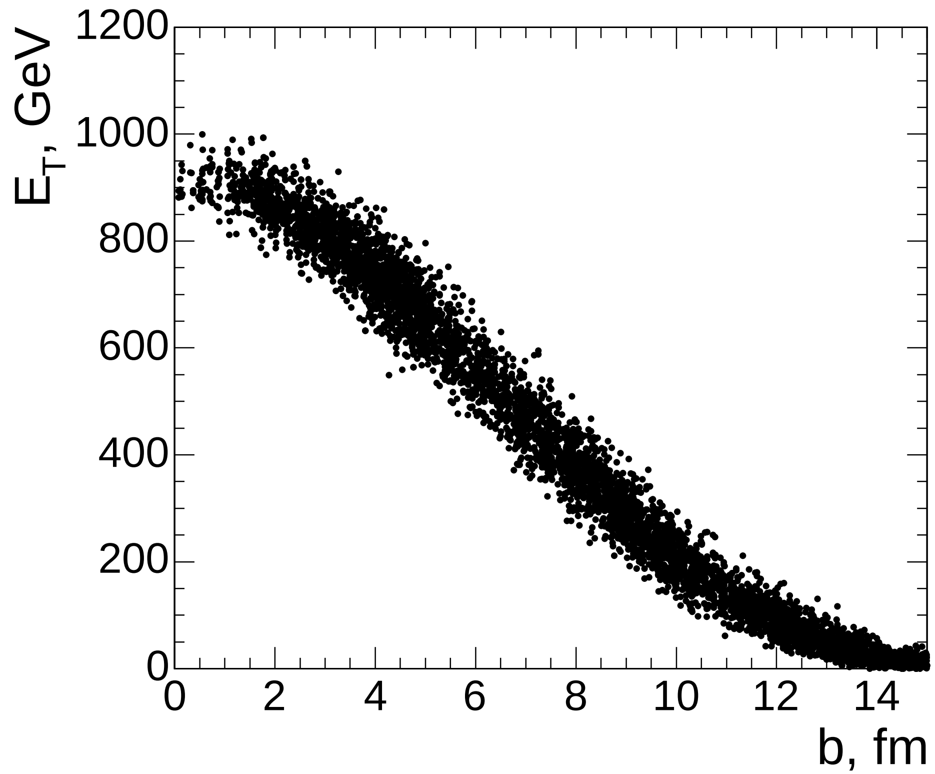




- Pb-Pb minimum bias trigger
  - count hits in the hadronic forward calorimeters (HF, $3 < |\eta| < 5$)
  - there are many particles in that region
  - good efficiencies over all centralities
- p-p random trigger
  - zero bias: trigger on beam crossing if intensity is low

Same scheme should work for both p-p and Pb-Pb

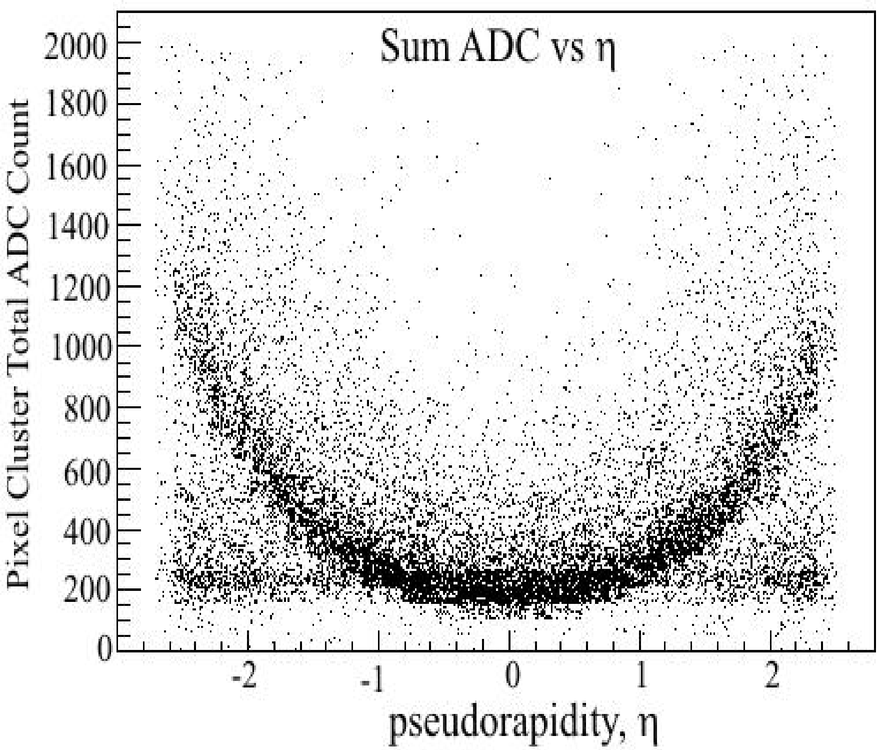
Centrality determination in Pb-Pb

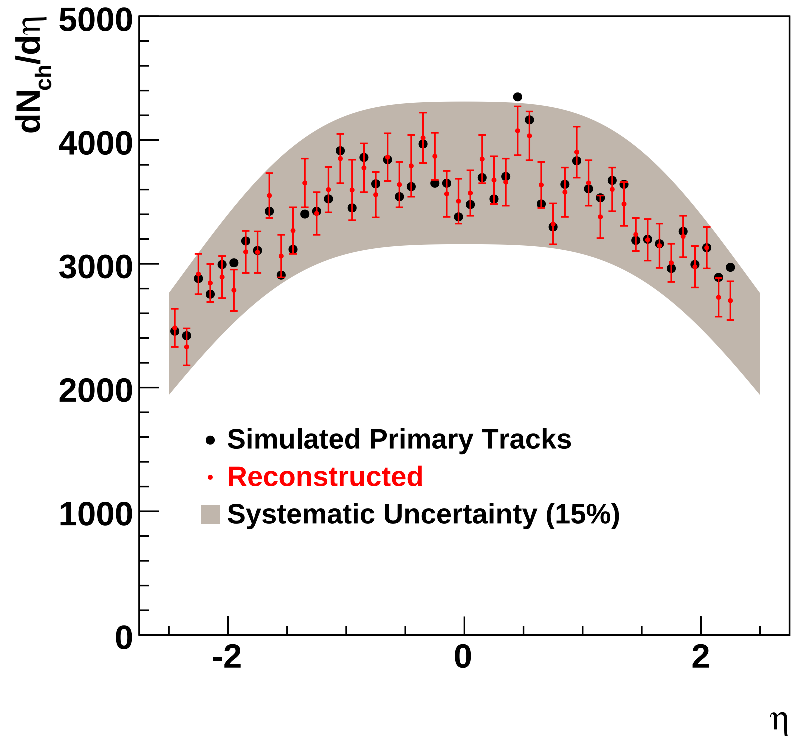


- Combine information from various independent measurements
  - The very forward region is expected to be nearly free of final-state rescattering
  - E_T from both CASTOR and HF
  - Forward energy of spectator forward neutrons measured in both ZDCs
  - Goal: determine impact parameter with a resolution of few tenths of fm

$\Rightarrow$ See poster of S. Ozturk: "Determination of Pb-Pb event centrality using HF and CASTOR calorimeters in CMS"

Charged particle rapidity density in Pb-Pb



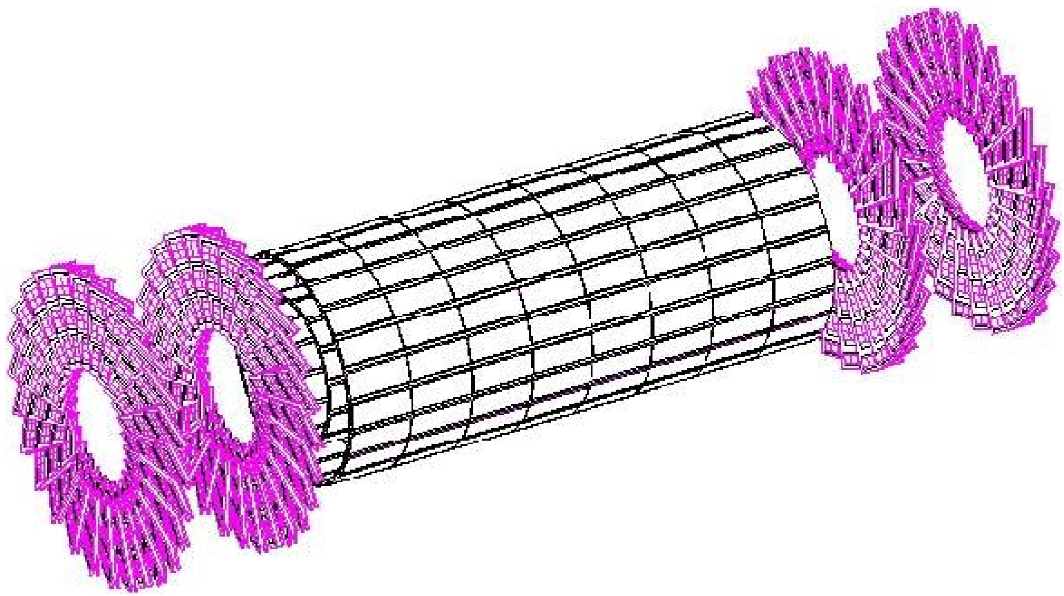


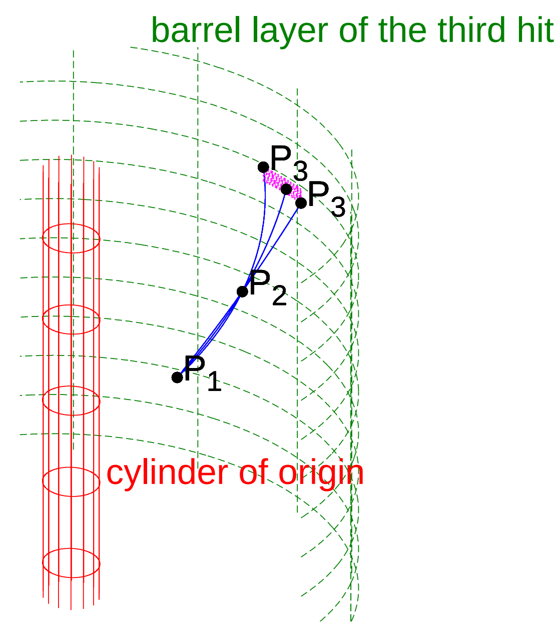
- Total event-by-event multiplicity
  - Counting hits in the innermost pixel layer, as done in PHOBOS
  - Expect systematics below 10%
  - Correction for loopers, secondaries
  - Use ADC information to remove hits at high η from non-primary sources

Final Pb-Pb multiplicity – initial number of released gluons

Important cross check for particle spectra

Charged particle tracking



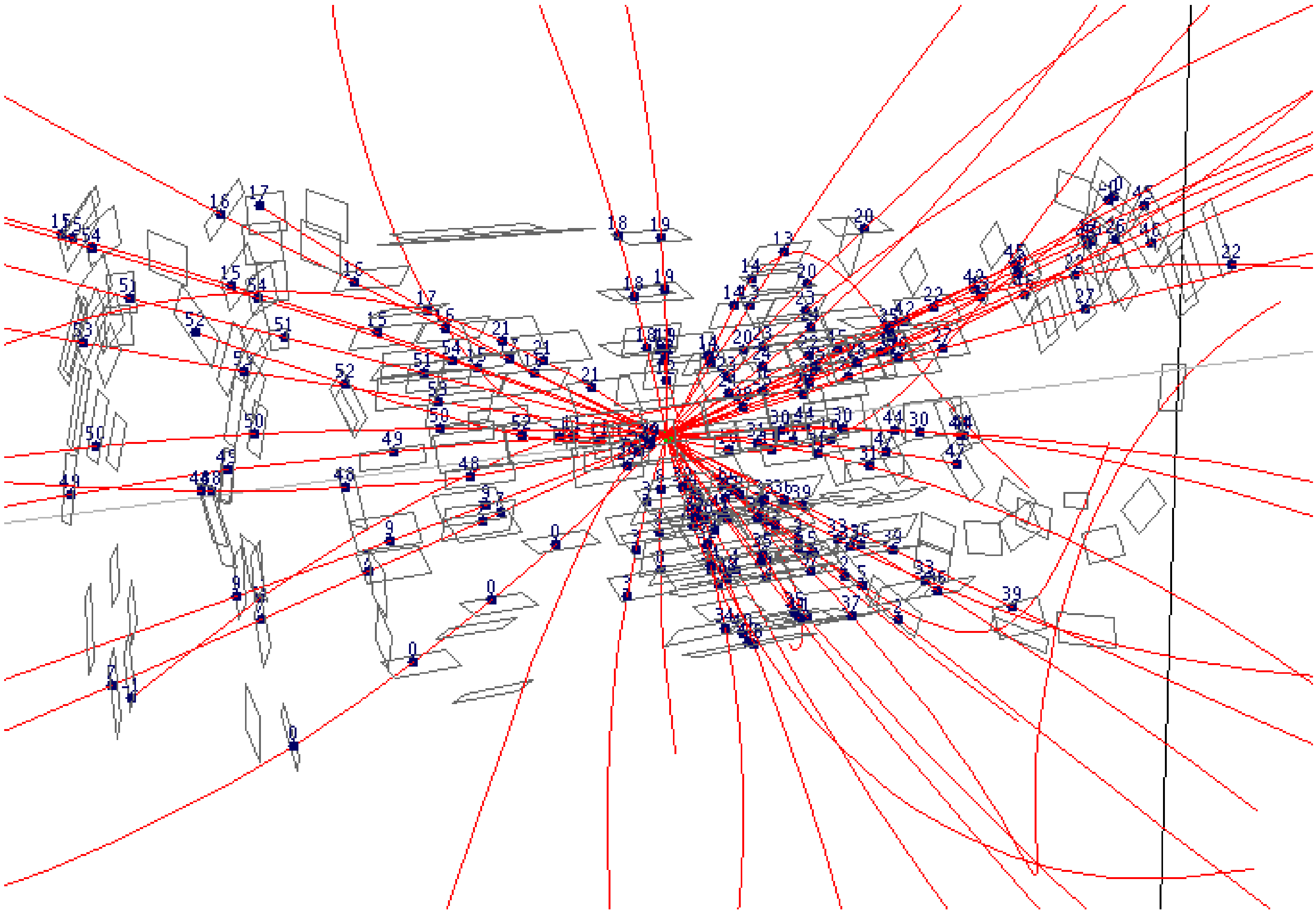


- Pixel detector
  - 3 barrel layers (4, 7 and 10 cm radii) and 2 endcaps on each side
  - $100 \times 150\ \mu\text{m}^2$ pixels, 2% occupancy even at $dN/d\eta_{ch} = 5000$
- Hit triplets
  - Use pixel hit triplets instead of pairs, loss of acceptance but lower fake rate
  - Modified triplet finding, reconstructing down to $p_T = 0.075$ GeV/c

Tracking optimized for the p-p analysis exercise, 2M events

Charged particle tracking – pixel tracks

p-p @ 14 TeV (Pythia)

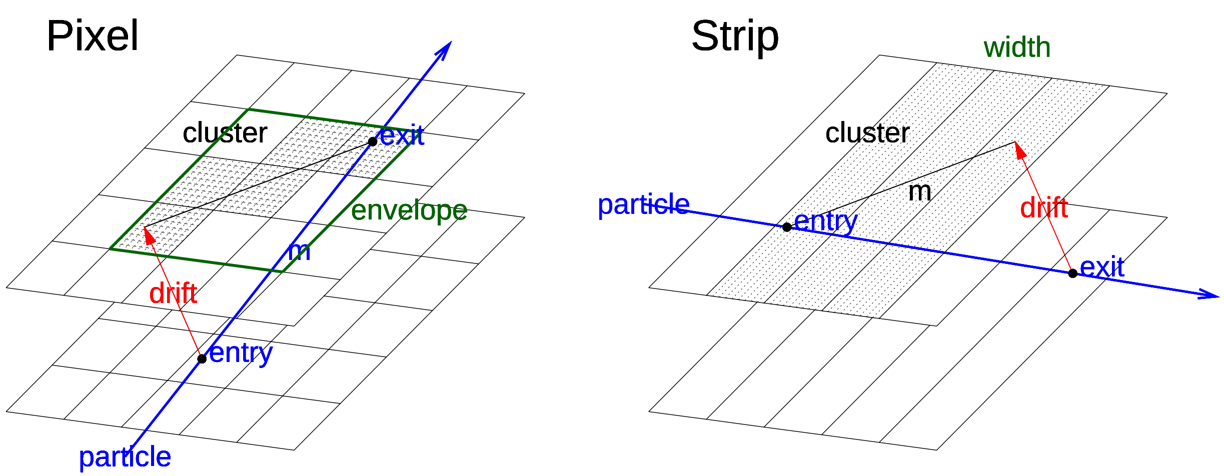


Charged particle tracking

- Strategy
  - Seed generation: triplets tracks
  - Determination of primary vertex (or vertices)
  - Seed re-generation: constrain triplets with previously found primary vertex
  - Trajectory building by successively including strip hits, final fit

Note: **global tracks** include both pixel and strip hits

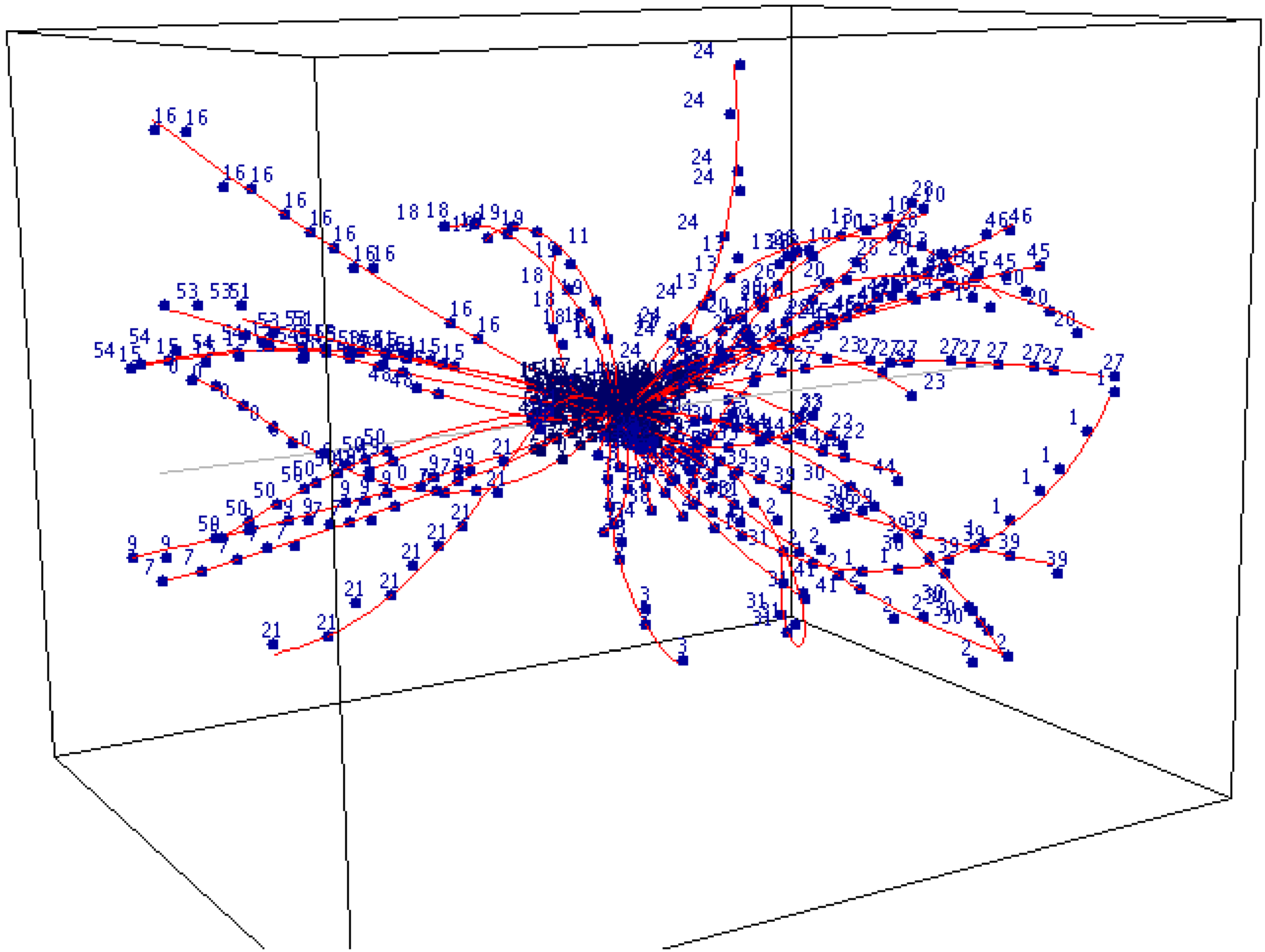
- Cluster shape filters



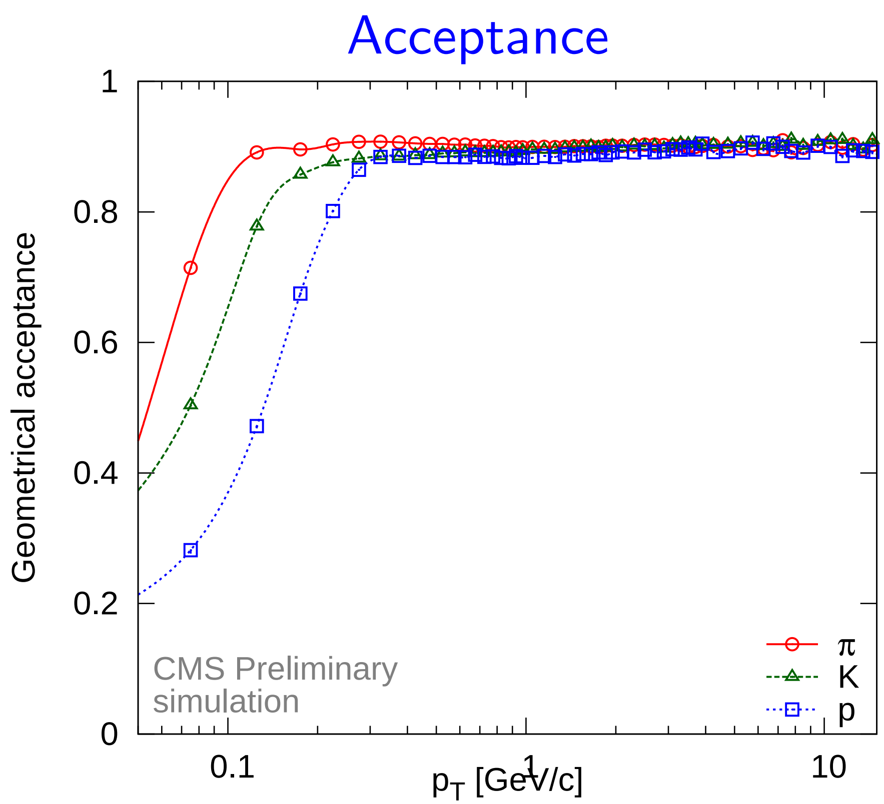
Cluster shape must match trajectory direction
Essential for reducing the fake track rate

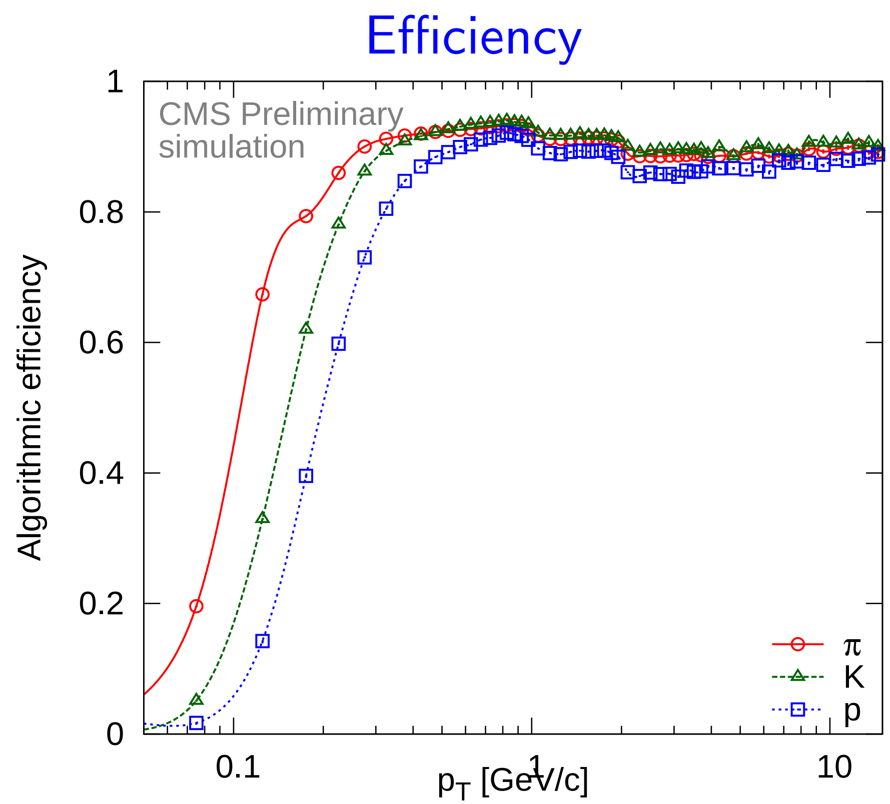
Charged particle tracking – global tracks

p-p @ 14 TeV (Pythia)



Charged particle tracking – acceptance and efficiency



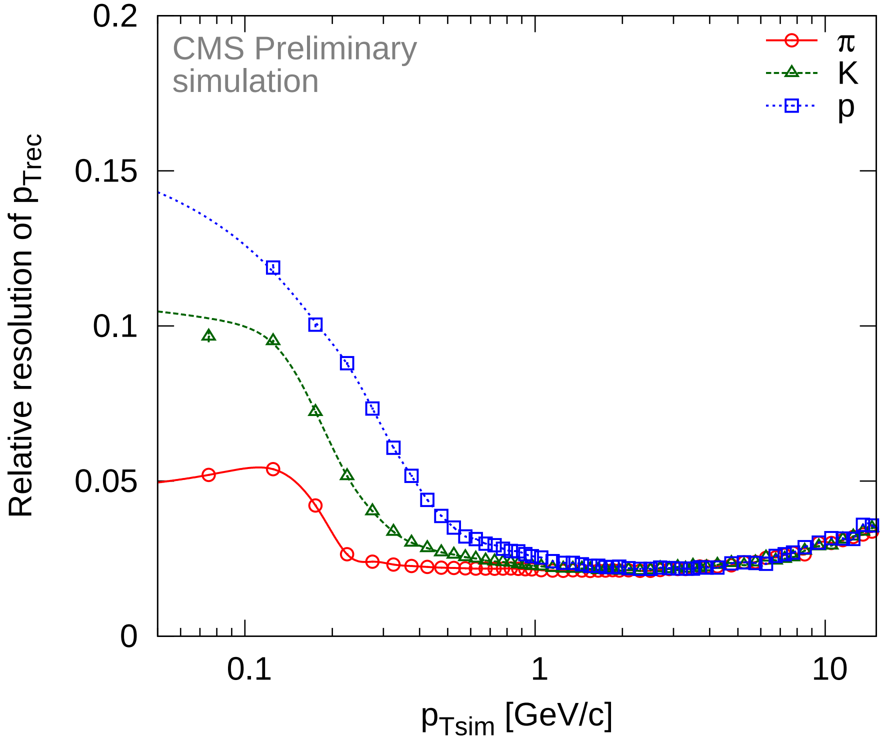


Different for low p_T for particles with different mass
Steps at 1 and 2 GeV/c are due to stricter requirements (points on track)
Close to flat and smooth in the mid-rapidity region

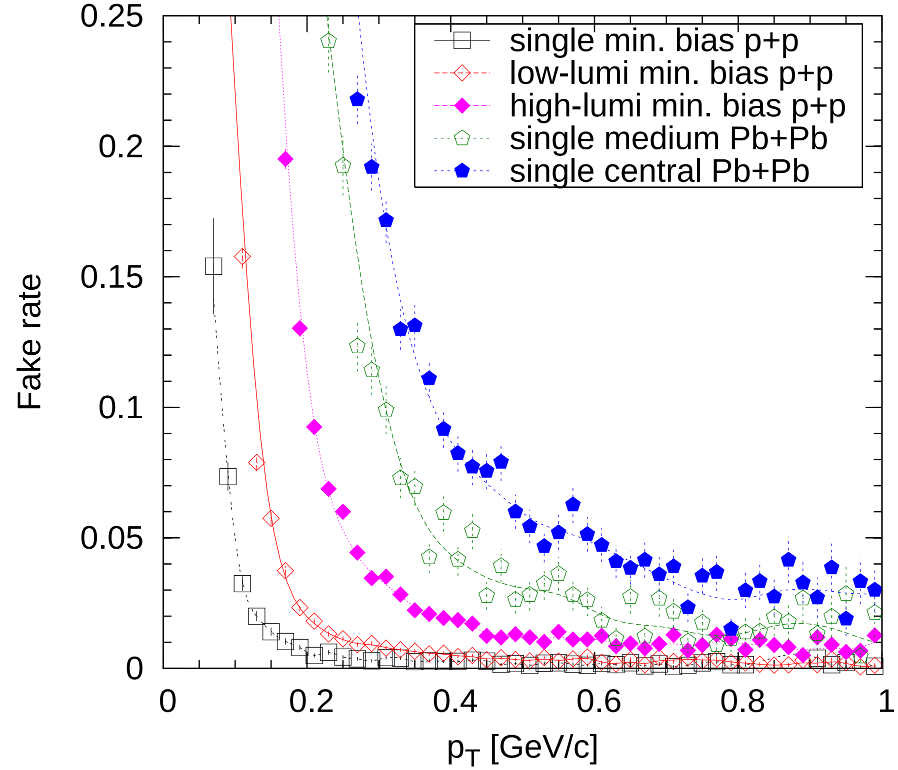
Multiple track counting and fake track rate are around per mille level

Corrections – p_T resolution, fake rate

Relative p_T resolution (all η)



Pixel-only fake rate

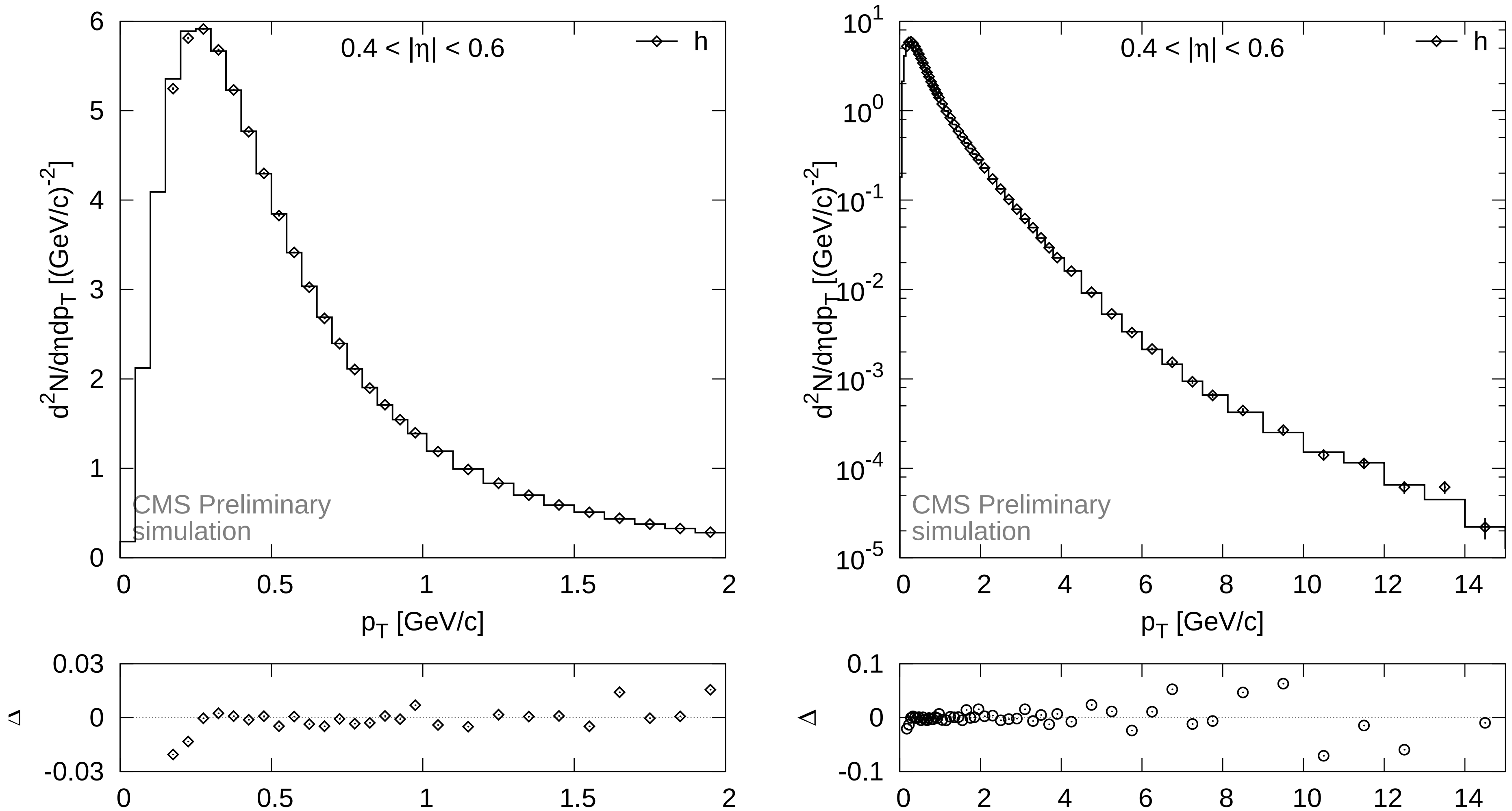


The p_T resolution is about 1-2%
in the barrel region

Fake rate is below 10%
in central Pb+Pb for $p_T > 0.4$ GeV/c

Charged particle tracking – spectra, comparisons

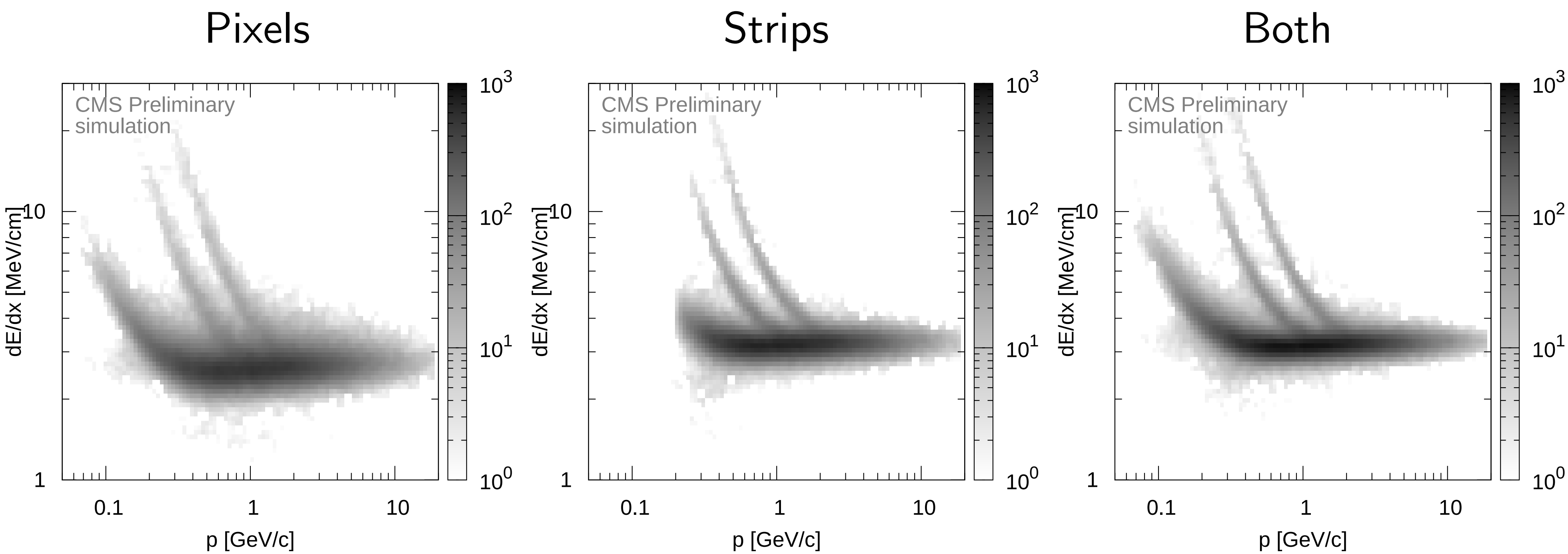
p-p @ 14 TeV (Pythia)



Comparison of simulated (histogram) and reconstructed (symbols), $0.4 < |\eta| < 0.6$

Can one identify these particles? $\Rightarrow$ dE/dx

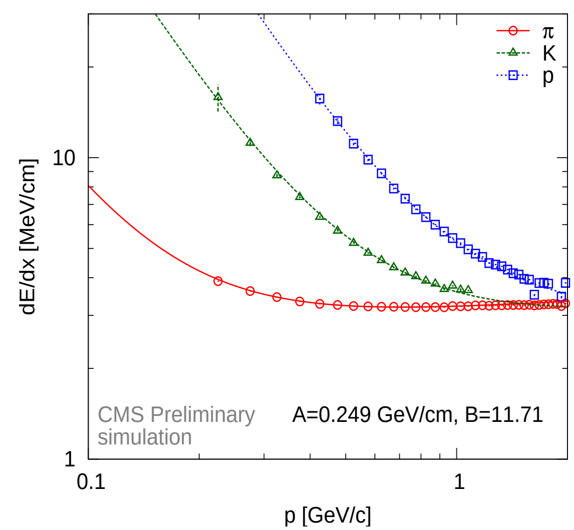
Particle identification – energy loss estimator



Truncated mean dE/dx (average of lowest half)
Proper treatment for overflows

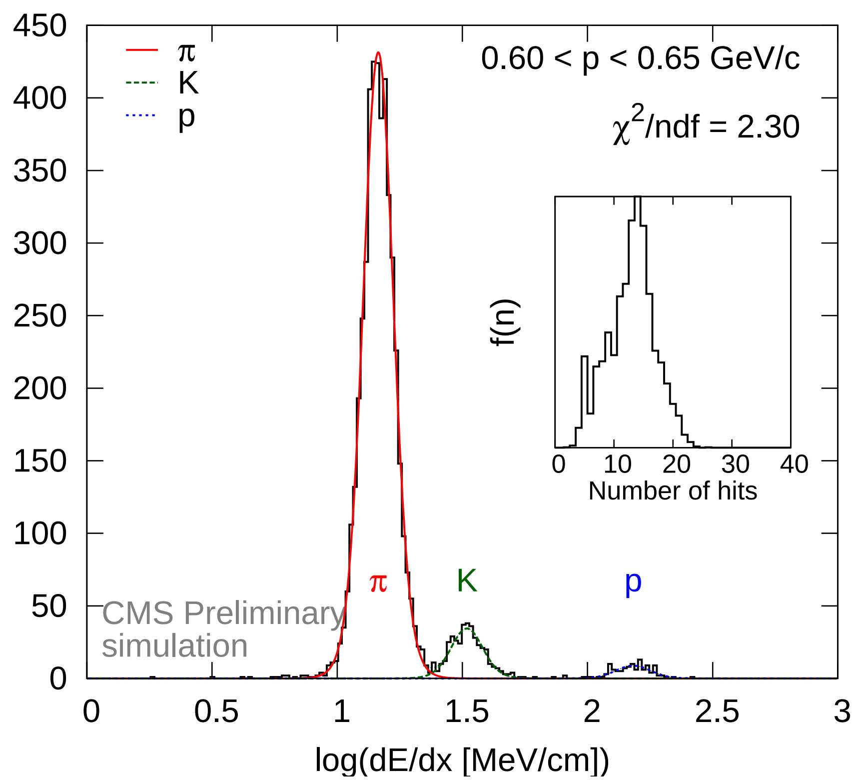
Combination of pixel and strip energy deposits

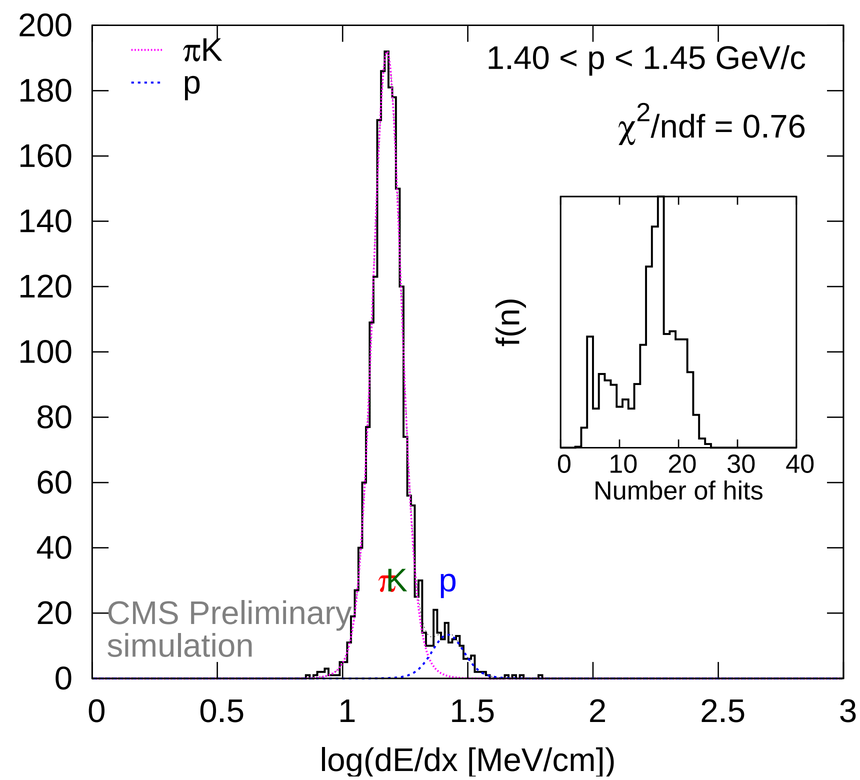
PID expected for pions and kaons ($p < 0.8$ GeV/c)
and protons ($p < 1.5$ GeV/c)



Particle identification – energy loss fits

p-p @ 14 TeV (Pythia)



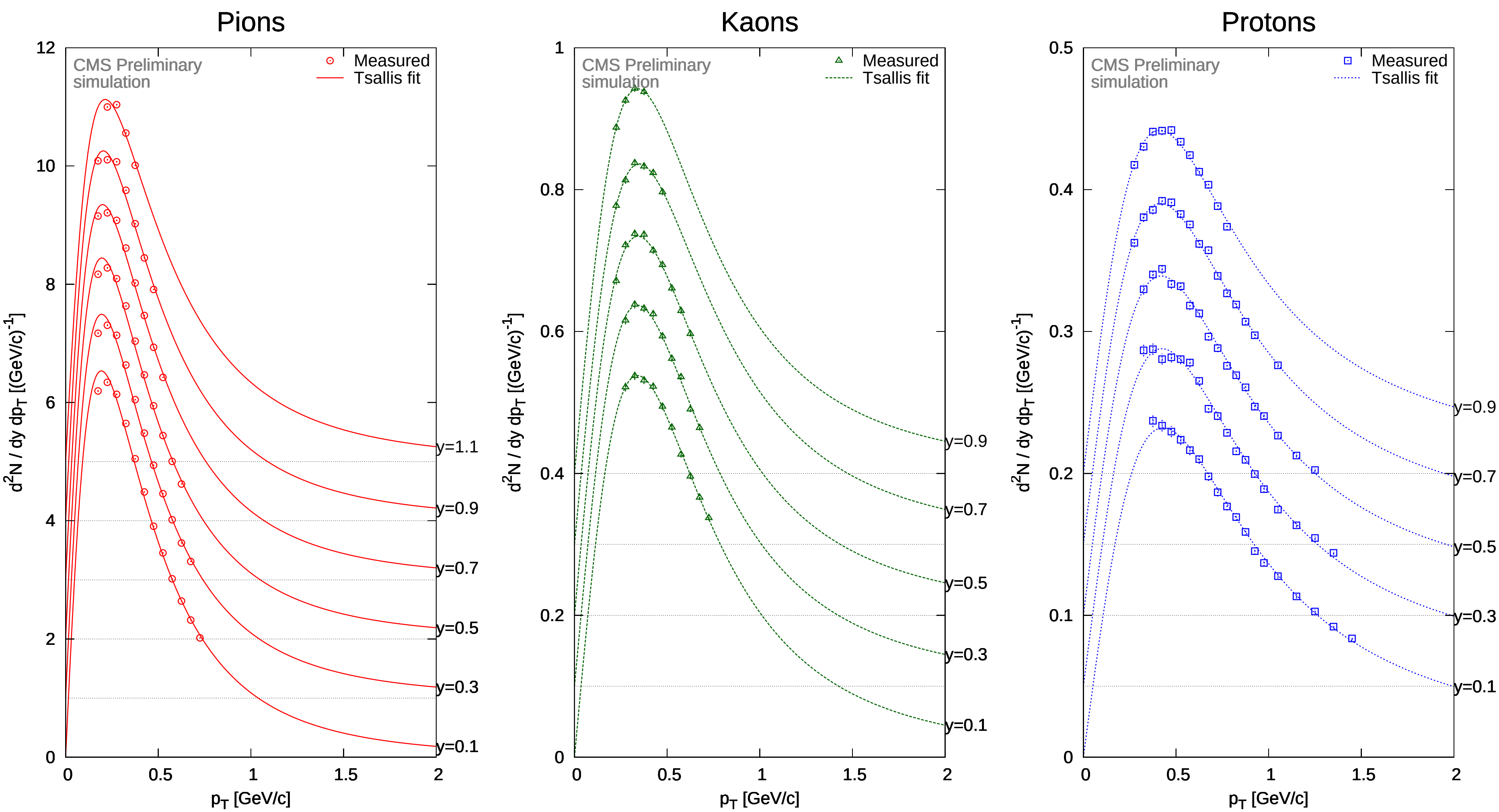


Combined fit using sum of many gaussians, where $\sigma \propto 1/\sqrt{n_{hits}}$
About 5-7% expected resolution, yields can be extracted

Momentum limit of yield extraction is set to 3σ separation
Could use $\beta\gamma$ scaling to fix parameters and push up limit

Results – pions, kaons and protons

p-p @ 14 TeV (Pythia)

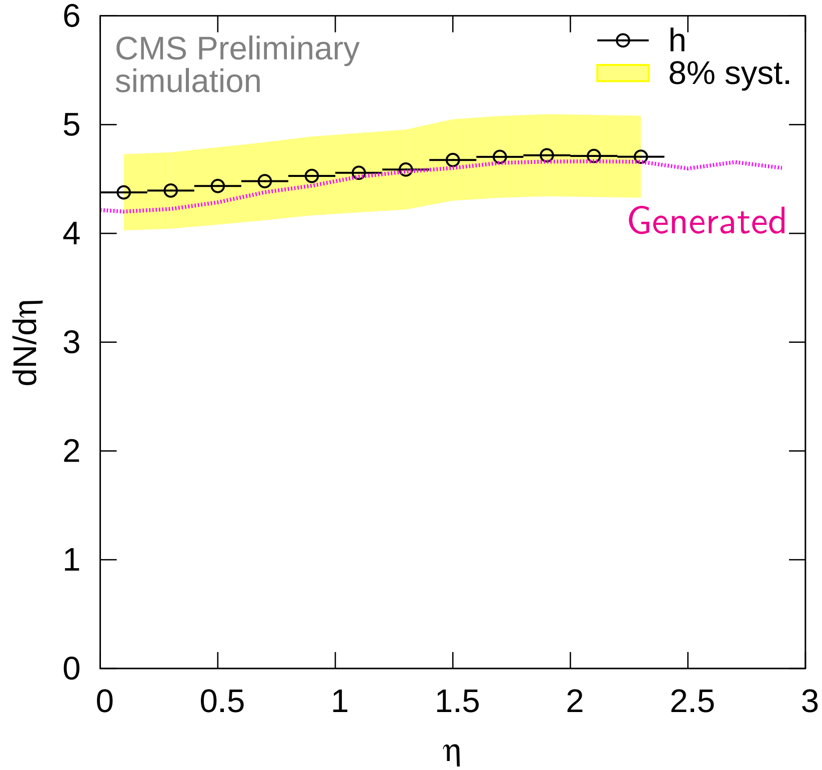


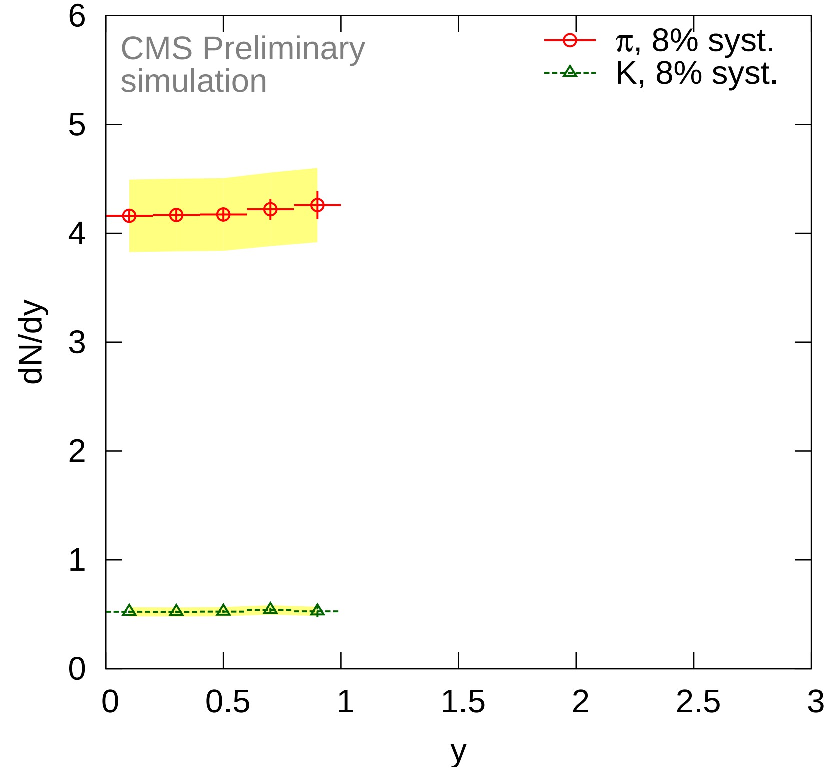
Empirical (Tsallis) fit: $E\frac{d^3N}{dp^3} = \frac{dN}{dy}\,\frac{(n-1)(n-2)}{2\pi\, nT\,[nT+(n-2)m]}\left[1+\frac{E_T(p_T)}{nT}\right]^{-n}$

η dependence can be studied

Results – rapidity density

p-p @ 14 TeV (Pythia)





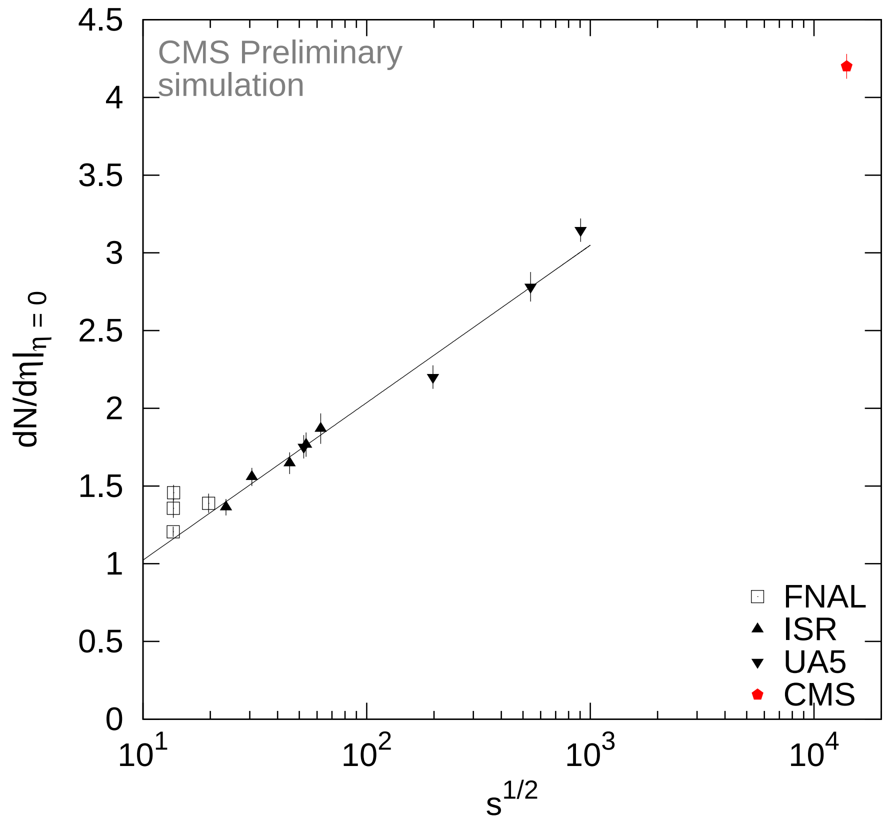
p_T spectrum is summed and integrated

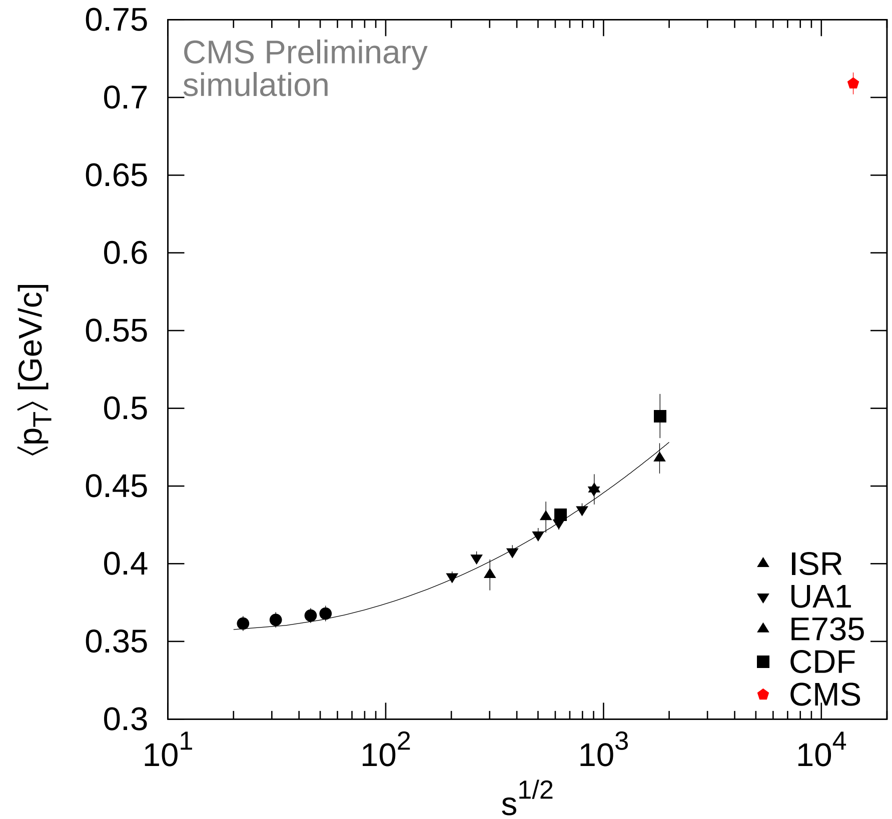
The acceptance of the tracker limits the accessible η/y range,
total number of produced charged particles cannot be measured

Total cross-section can be obtained using luminosity measurements

Results – energy dependence

p-p @ 14 TeV (Pythia)

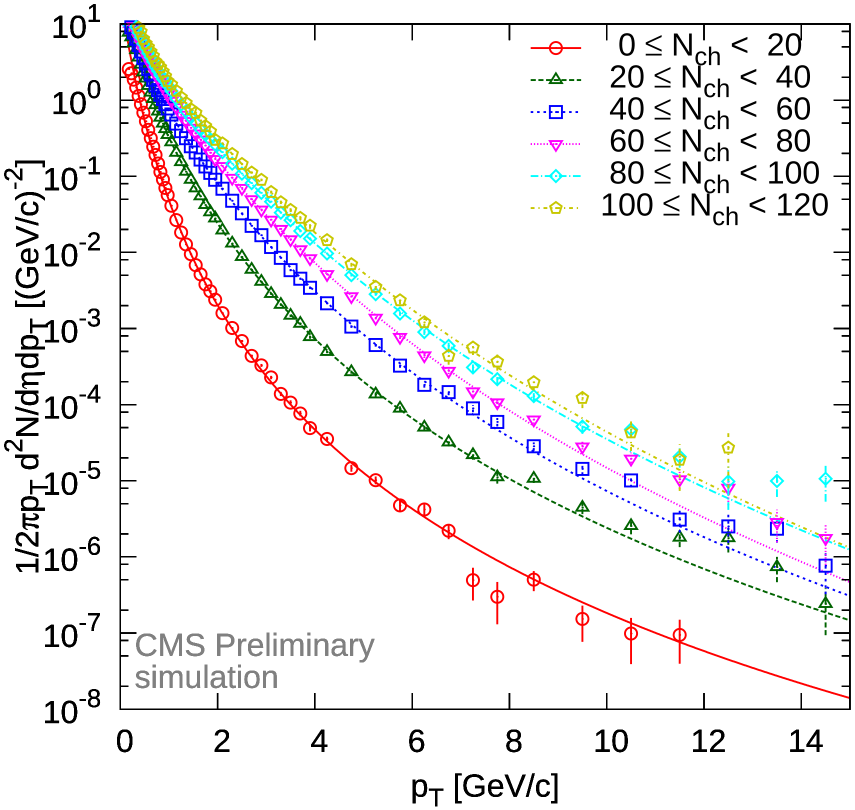




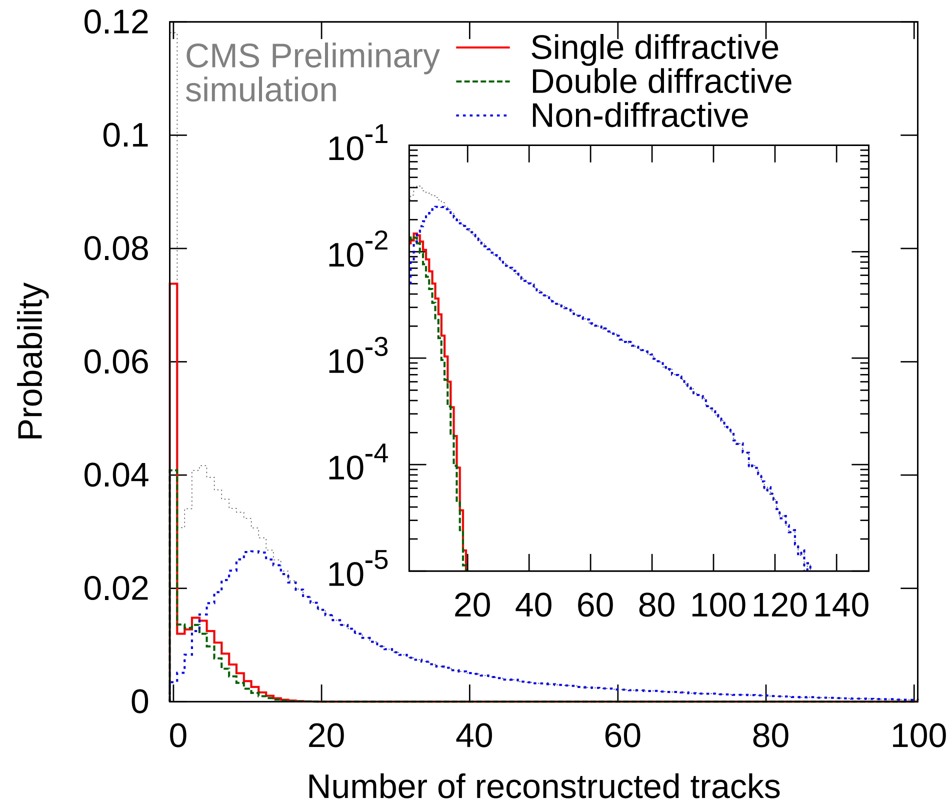
Comparison to lower energy measurements: FNAL, ISR, UA1, UA5, E735, CDF

We can verify if $dN/d\eta|_{\eta=0}$ continues its linear increase in $\log\sqrt{s}$
A Strong, non-linear increase of $\langle p_T \rangle$ is expected

Results – multiplicity



p-p @ 14 TeV (Pythia)

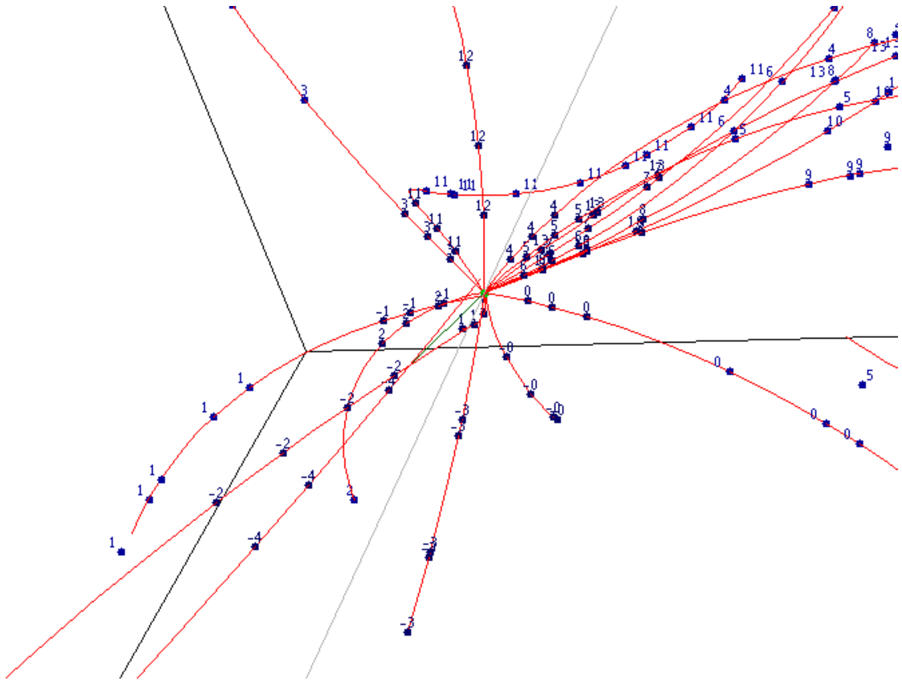


p_T distribution gets flatter with increasing N_{ch}

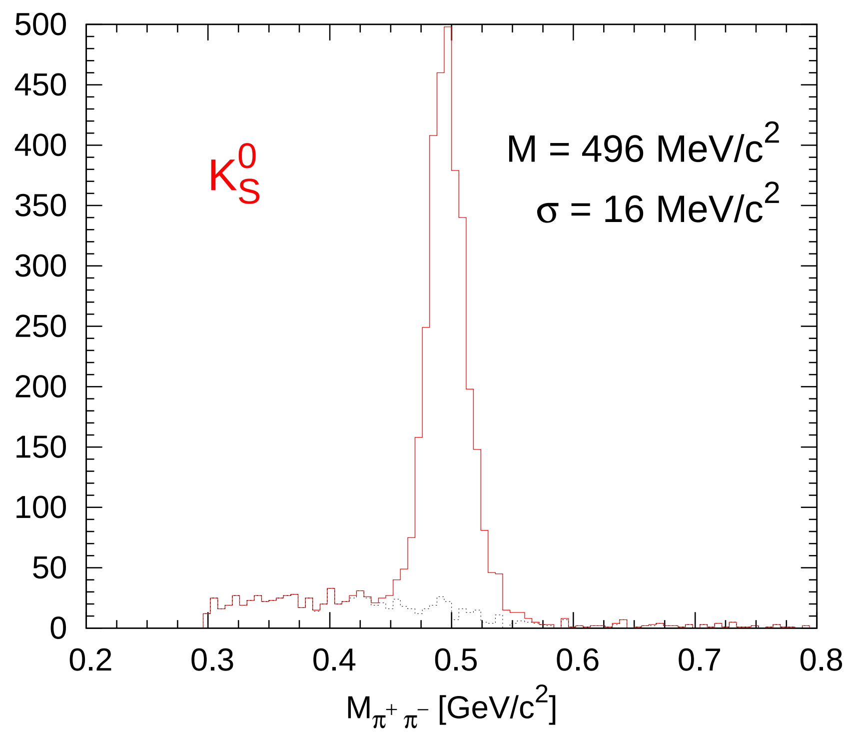
We can measure multiplicity distributions

Interesting physics (multiparton interactions, underlying event)

Particle identification – neutral particles



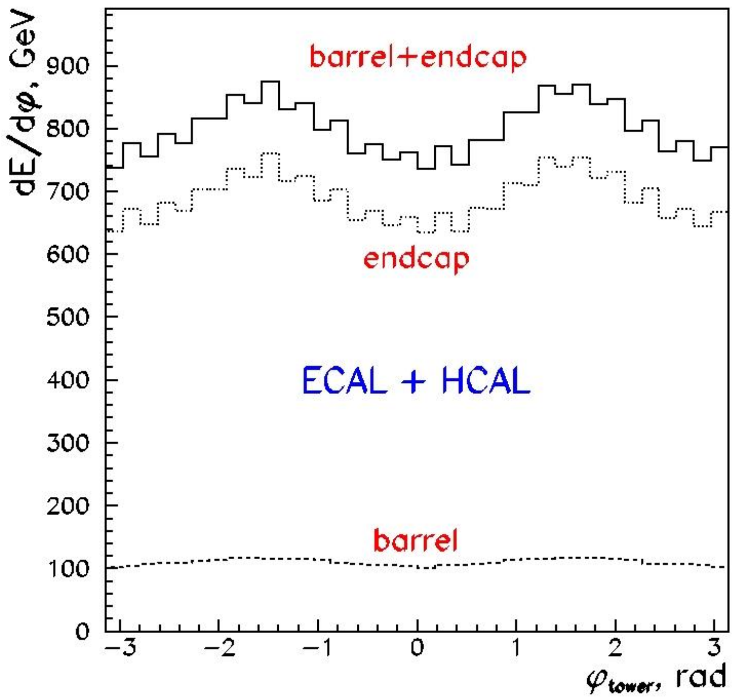
p-p @ 14 TeV (Pythia)

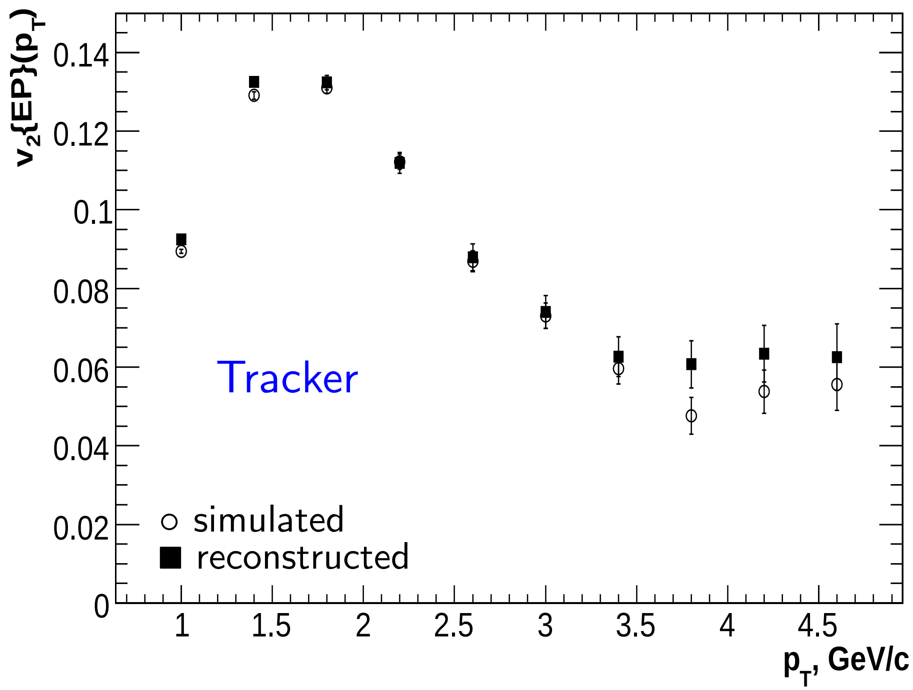


- Decay topology (V0)
  - Identified particle spectra and yields, neutrals: K^0_S, Λ, $\overline{\Lambda}$, γ
  - Multi-strange baryons: Ξ^-, Ω^-
  - Open charm (D^0, D^{*+}) and open beauty ($B \rightarrow J/\psi + K$)

Access to neutral and multi-strange identified particles

Elliptic flow in Pb-Pb

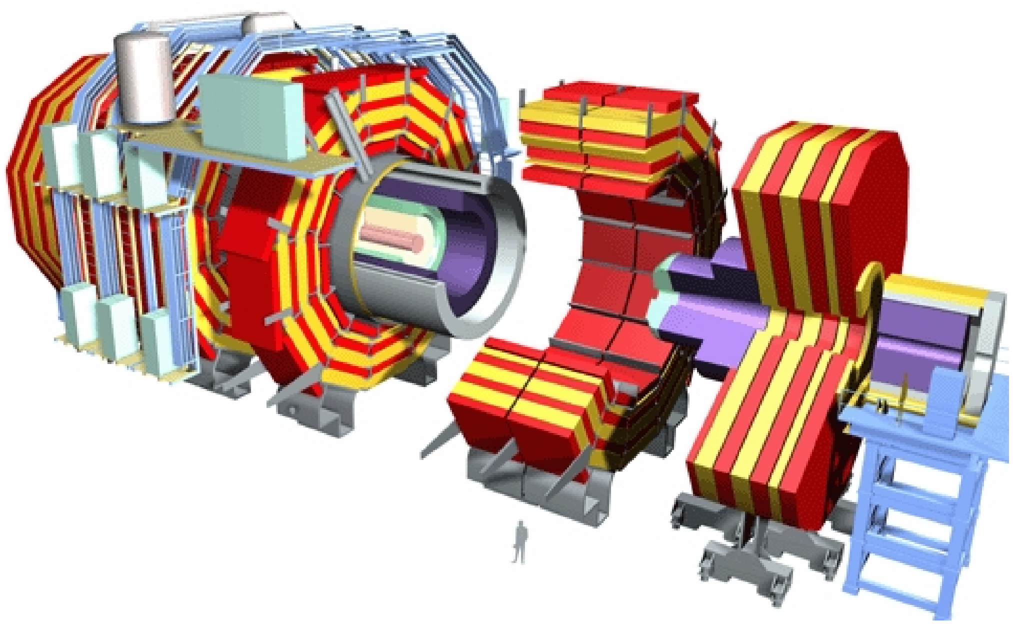




- Reconstruction of the event plane using calorimetry
  - Good event plane resolution (about 0.37 rad), at b = 9 fm
- Elliptic flow coefficient using tracker
  - Estimated systematic error of v_2 is below 3%, at b = 9 fm
  - Forward detectors will also be used

⇒ See poster of G. Eyyubova: "v_2 measurement using the CMS detector"

CMS soft physics – conclusions and outlook



- Summary of first measurements with CMS in p-p mode
  - Charged hadron spectra
  - Identified charged particles via energy loss ($\pi^{\pm}$, $K^{\pm}$, $p/\overline{p}$)
  - Identified neutral particles via decay (K^0_S, Λ, also Ξ^-, Ω^- and antiparticles)
  - On-vertex resonances (ρ, K^*, ϕ)
  - Not yet studied in detail
    - use calorimetry data to extend rapidity range of some measurements
    - provide PID capabilities in the momentum range 1–5 GeV/c

Now we prepare for data taking: p+p @ 14 TeV and Pb+Pb @ 5.5 TeV