CMS: minimum bias studies

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MPI@LHC'08, Perugia, Italy
October 28, 2008

CMS: minimum bias studies

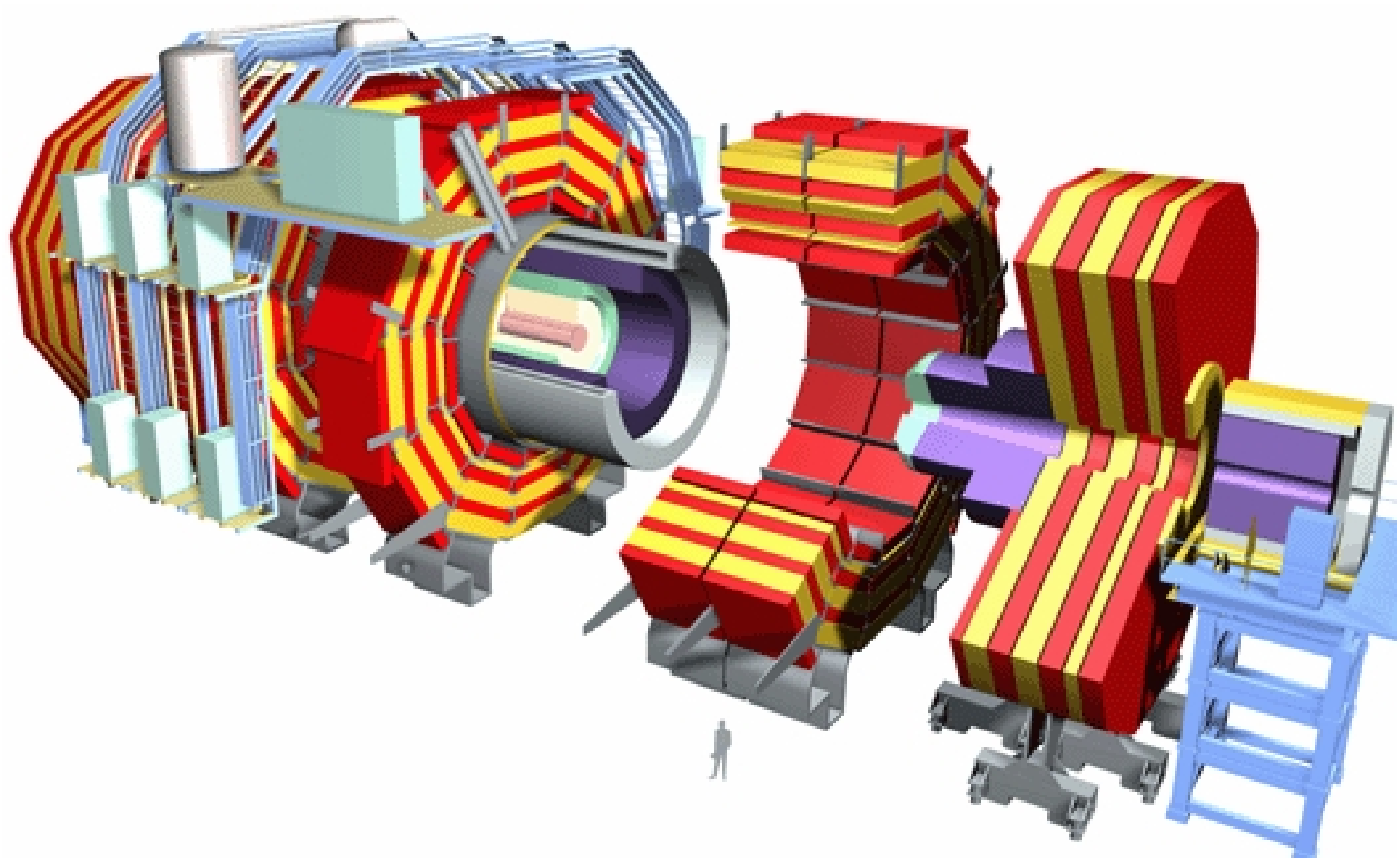
- Contents
  - The detector
  - First physics with hadrons
  - Triggers: Level-1 and HLT
  - Charged hadron rapidity density
  - Charged hadron spectra
  - Particle identification capabilities
    - ∗ charged hadrons via energy loss (dE/dx)
    - ∗ neutral hadrons via decay topology (V0)

First analyses based on silicon pixel detector and strip tracker

Early physics, constrain QCD models of hadron production
Also important for MC tuning, backgrounds, pile-up
Calibration and understanding of the detector, basis for exclusive physics

This talk: preparations, results of analysis exercises

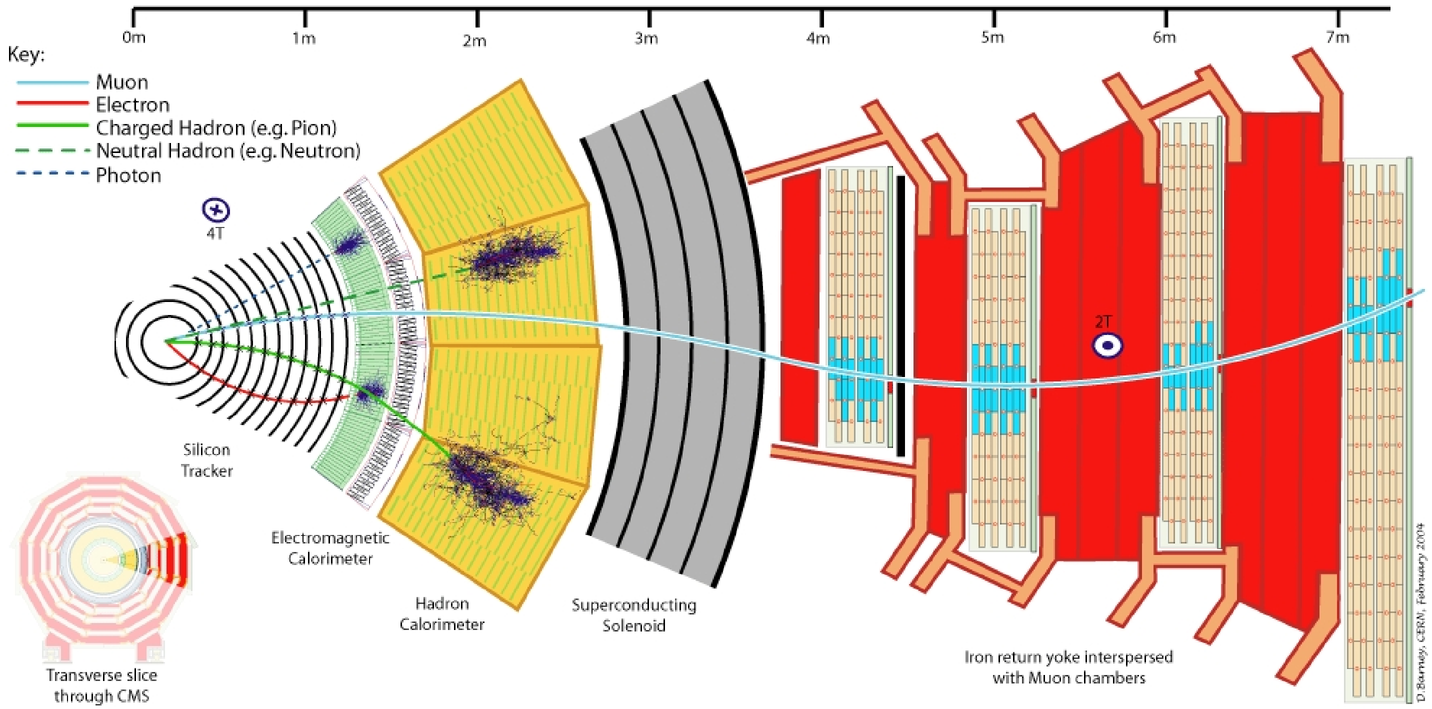
The CMS detector



Compact Muon Solenoid

One single detector combines global characterization and specific probes

The CMS detector – slice

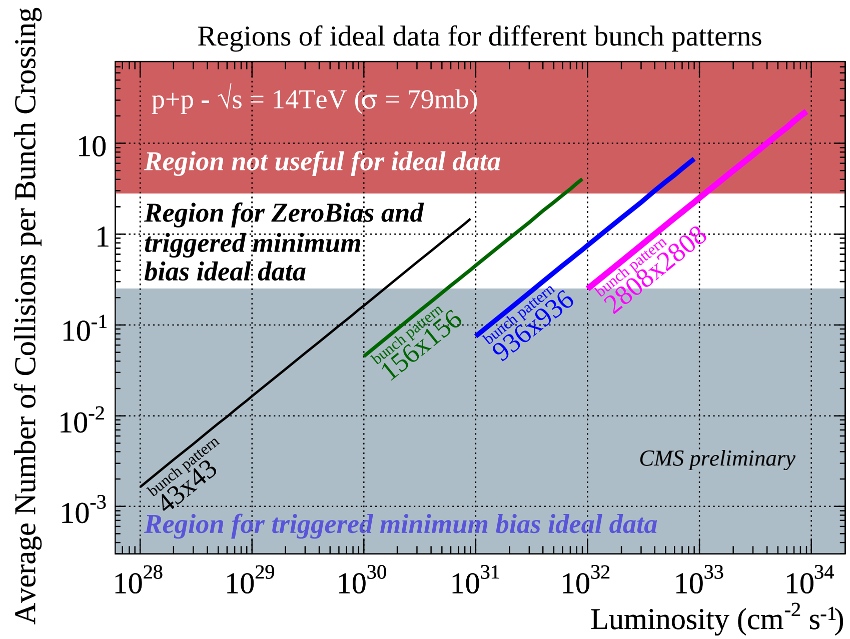


- Detectors
  - Silicon tracker: pixels and strips ($|\eta| < 2.4$)
  - Electromagnetic ($|\eta| < 3$) and hadronic ($|\eta| < 5$) calorimeters
  - Muon chambers ($|\eta| < 2.4$)
  - Extension with forward detectors (CASTOR $5.3 < |\eta| < 6.6$, ZDC $|\eta| > 8.3$)

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

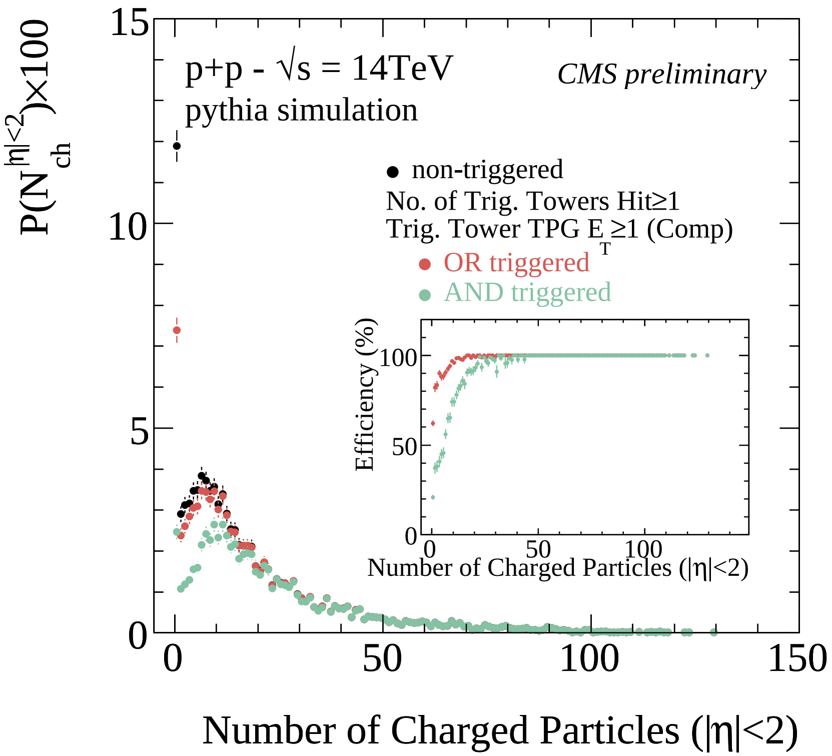
How to trigger? $\Rightarrow$ Low bias triggers

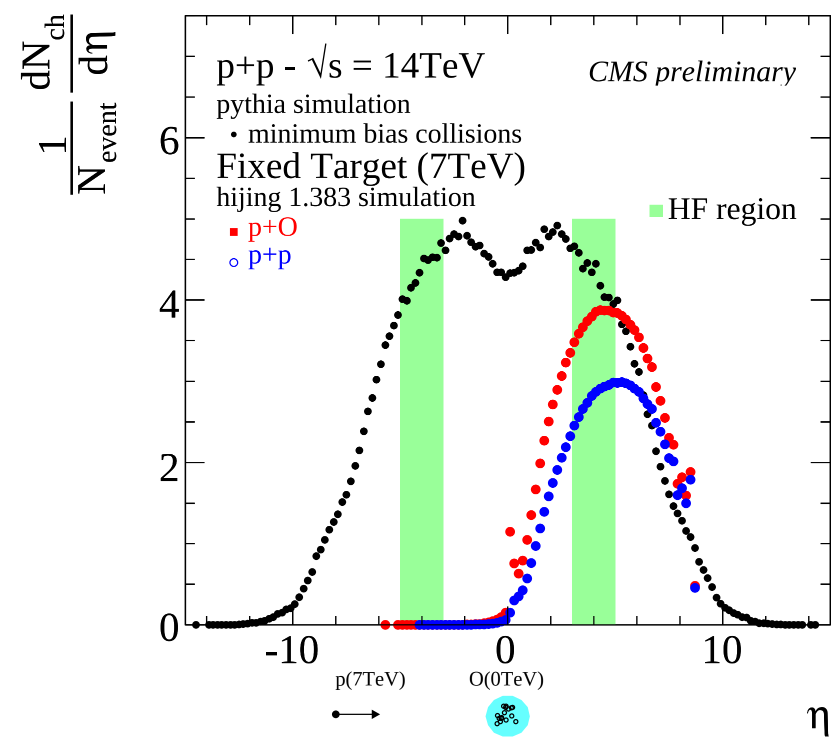
Minimum bias triggers – zero bias or pixel track



- Random trigger, Level-1
  - zero bias: trigger on crossing of filled bunches
  - optimal for moderate intensity, heavily prescaled
- At least one track in the pixel detector, HLT
  - very low bias, optimal for very low intensity running (e.g. @ 900 GeV)
  - efficiencies: 88% IN; 99% ND, 69% DD, 59% SD (@ 14 TeV)
  - can be completed by offline vertex trigger

Minimum bias triggers – forward calorimeters

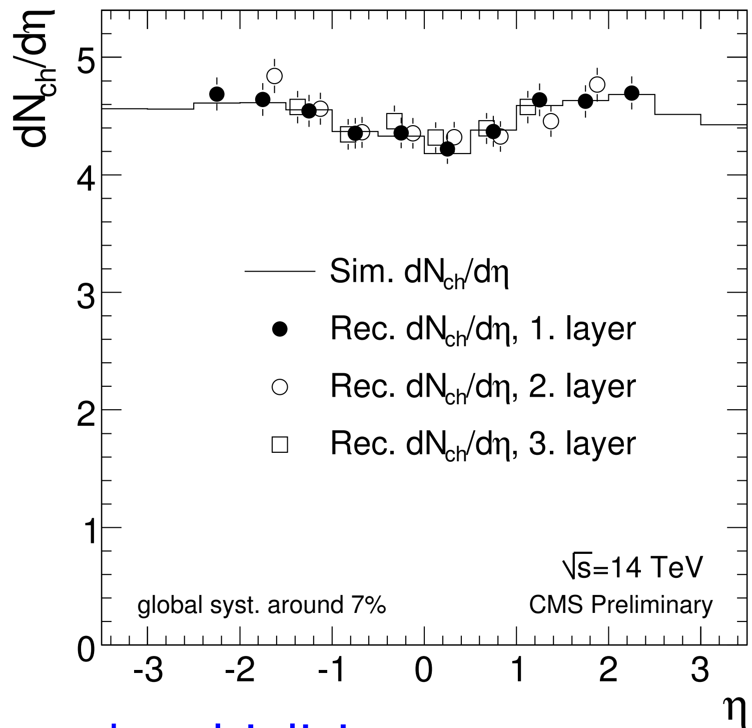


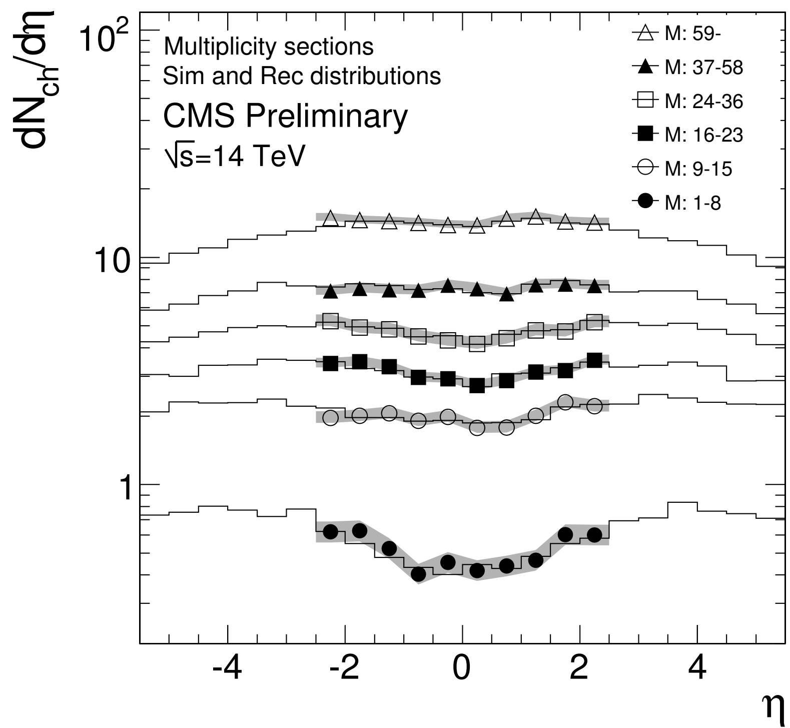


- Forward hadronic calorimeters, Level-1
  - count towers with $E_T^C > 1$GeV in the forward calorimeters (HF, $3 < |\eta| < 5$)
  - require hits on one side (OR triggered)
    efficiency: 89% IN (@ 900 GeV); 97% ND, 79% DD, 71% SD (@ 900 GeV)
  - require hits on both sides (AND triggered)
    less efficient (59% IN), but not sensitive to beam-gas background

Usability of triggers depend on bunch pattern and luminosity

Charged particle rapidity density



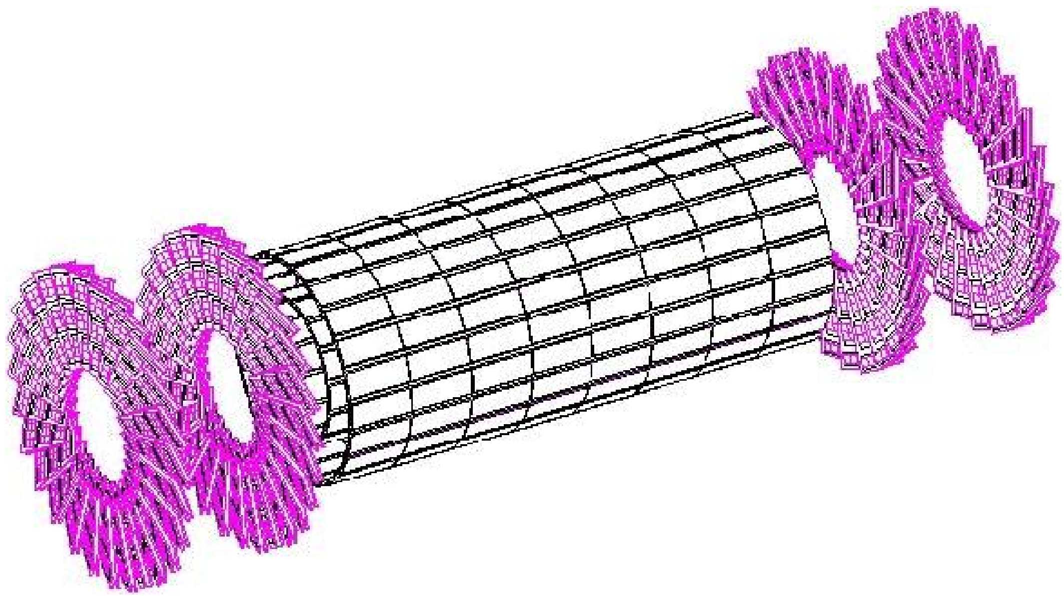


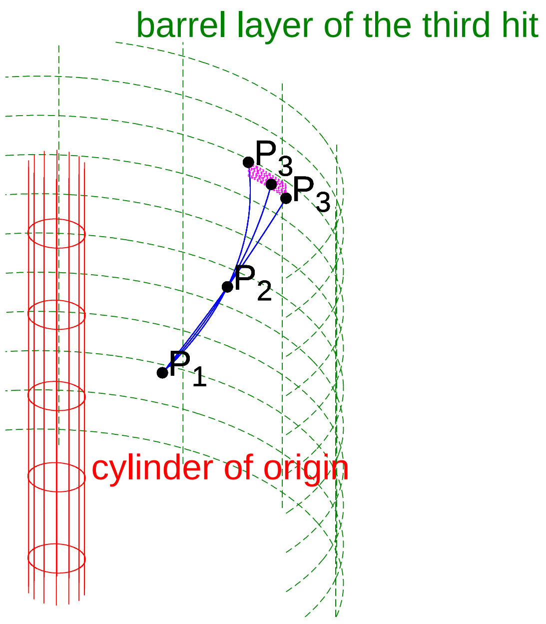
CMS PAS QCD-08-004

- Charged multiplicity
  - Count clusters in the pixel barrel layers, as done in PHOBOS
  - Use pixel cluster size information to
    - estimate z position of the interaction vertex
    - remove hits at high η from non-primary sources
  - Correction for loopers, secondaries, expect systematics below 10%
  - No need for tracking, alignment; sensitivity down to p_T of 30 MeV/c

Important cross check with particle spectra from tracking

Charged particle tracking – pixel detector



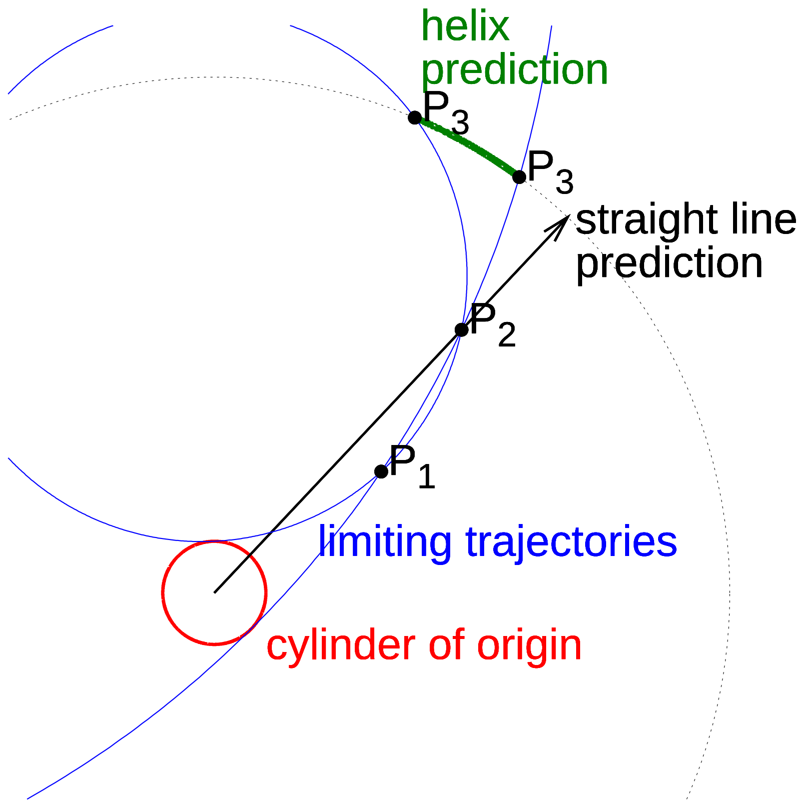


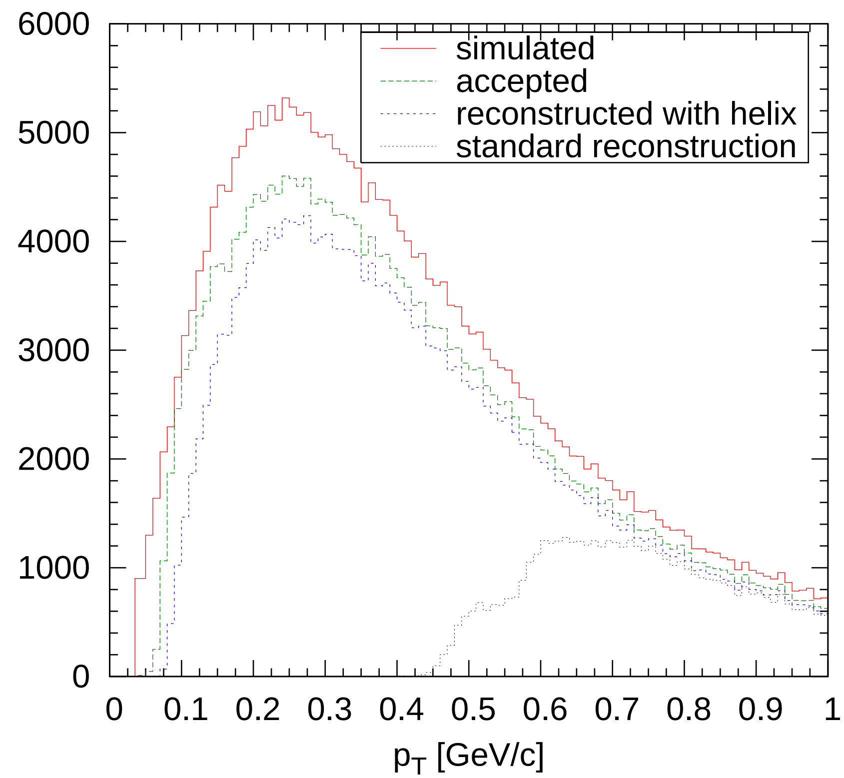
- Pixel detector
  - 3 barrel layers (4, 7 and 11 cm radii) and 2 endcaps on each side
  - $100 \times 150\ \mu\text{m}^2$ pixels, 2% occupancy even at $dN/d\eta_{ch} = 5000$

- Hit triplets
  - Use pixel hit triplets instead of pairs, lower fake track rate
  - Modified triplet finding, reconstructing down to $p_T = 0.075$ GeV/c

Tracking optimized for all p_T

Charged particle tracking – pixel triplets



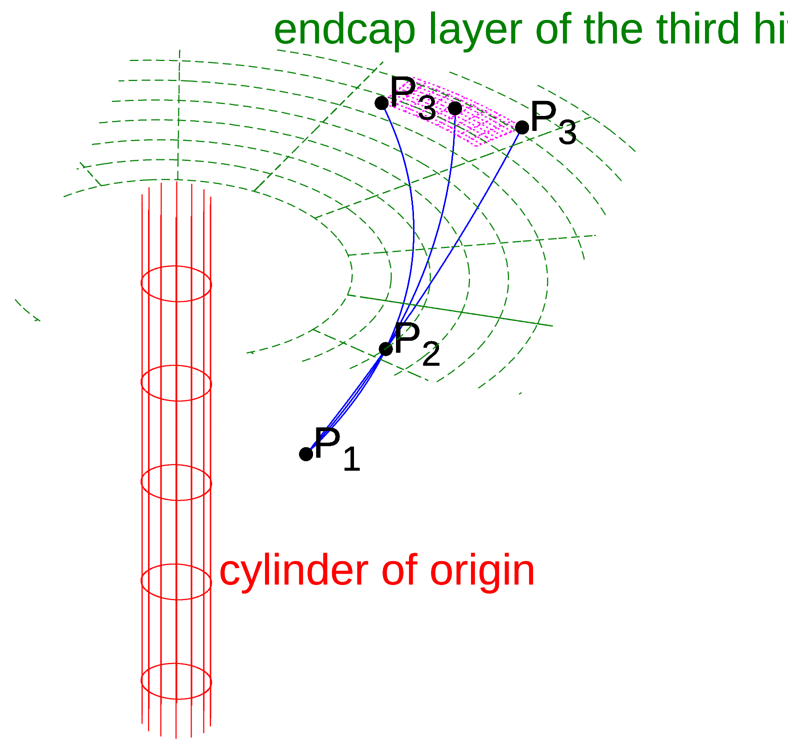


CMS-TDR-008.2-add-1
J Phys G **34** (2007) 2307-2455

- Modified method
  - Hit pair finding, then prediction for the third hit
  - "origin": the track must come from the cylinder of origin
  - "minimum": the p_T of the track must be above the minimal value
  - "third": the track must be able to reach the third layer (barrel or endcap)

How? Limiting circles in planar projection

Charged particle tracking – allowed ranges



Intercepts of three special trajectories on the layer form a curve

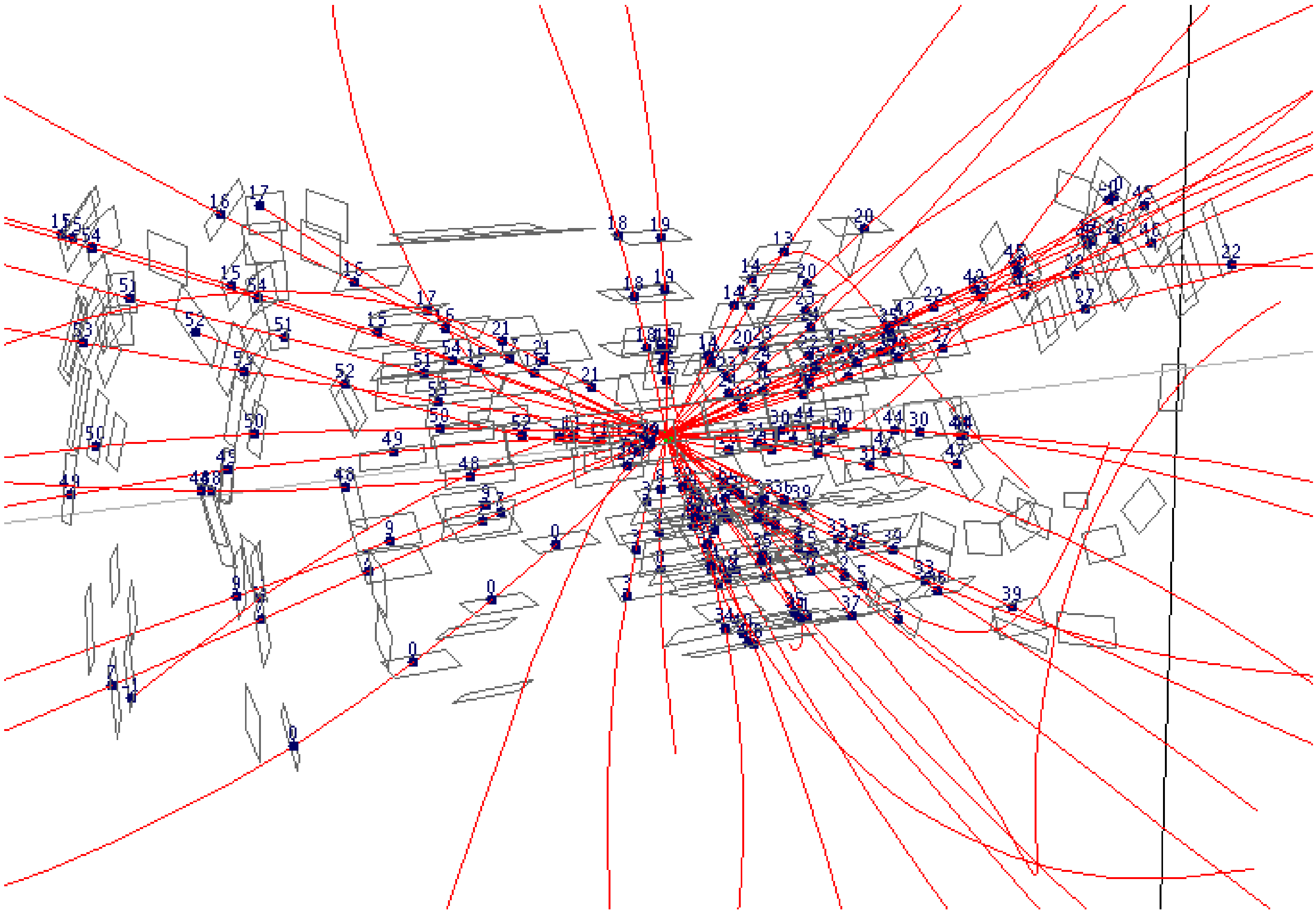
Three points ⇒ parabola ⇒ rectangular envelope

How to select third hits?

Check if position is compatible with multiple scattering

Charged particle tracking – pixel tracks

p-p @ 14 TeV (Pythia)

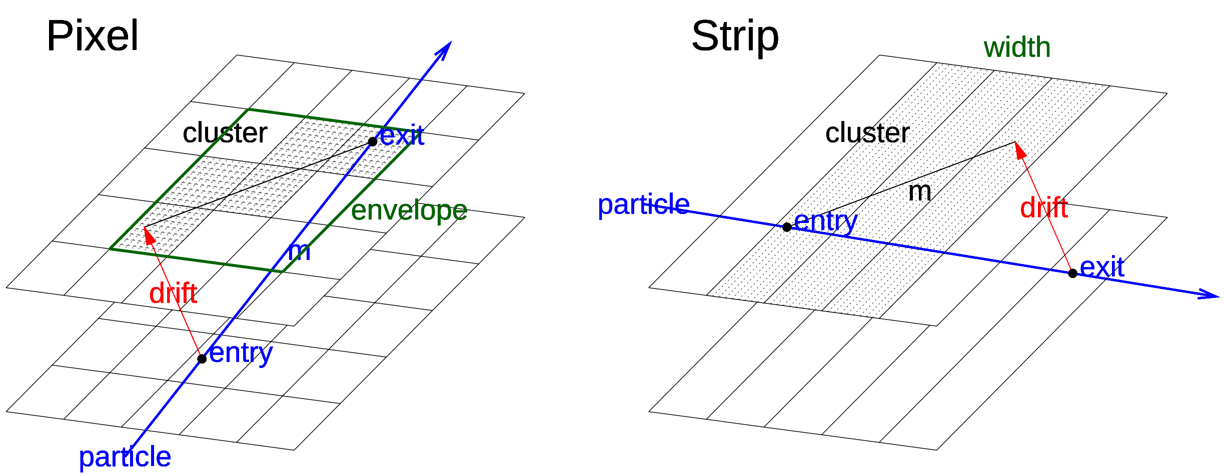


Charged particle tracking

- 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

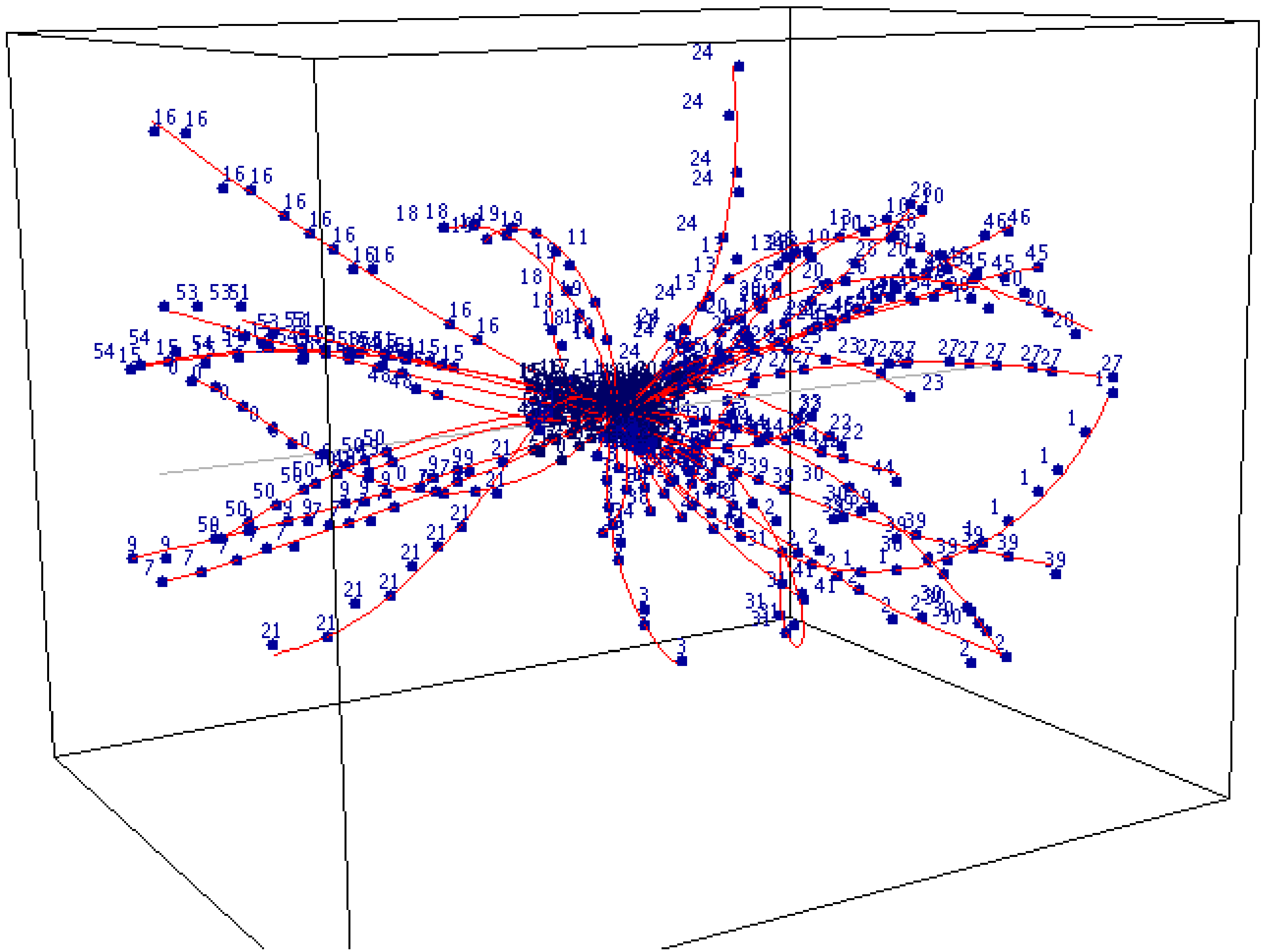


Cluster shape must match trajectory direction

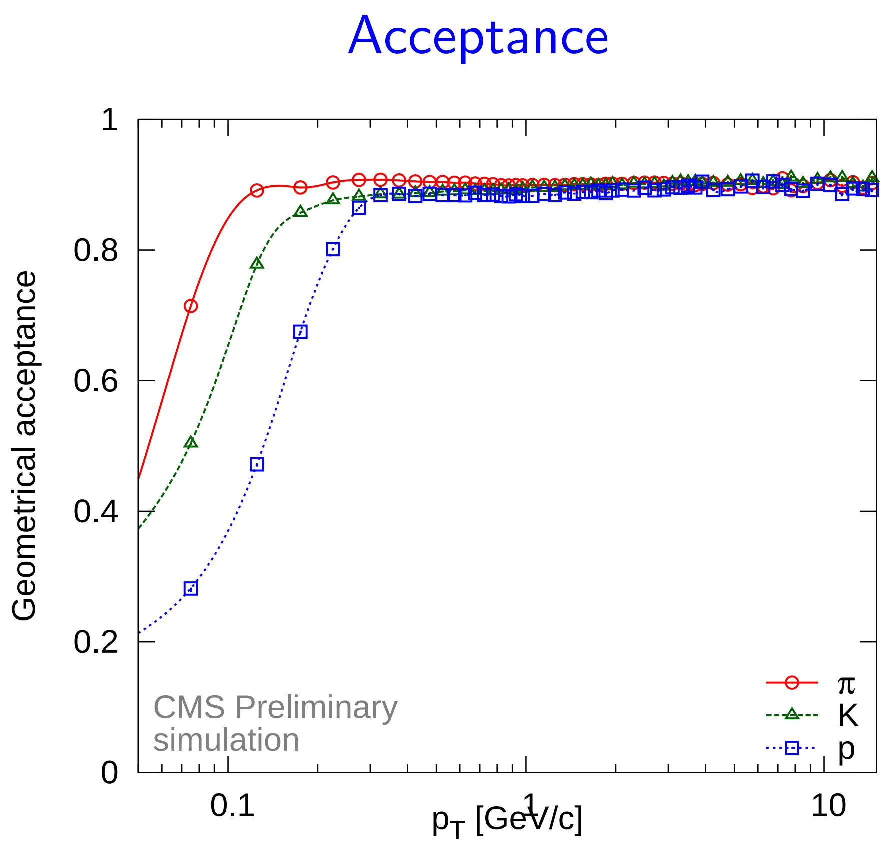
Essential for reducing the fake track rate

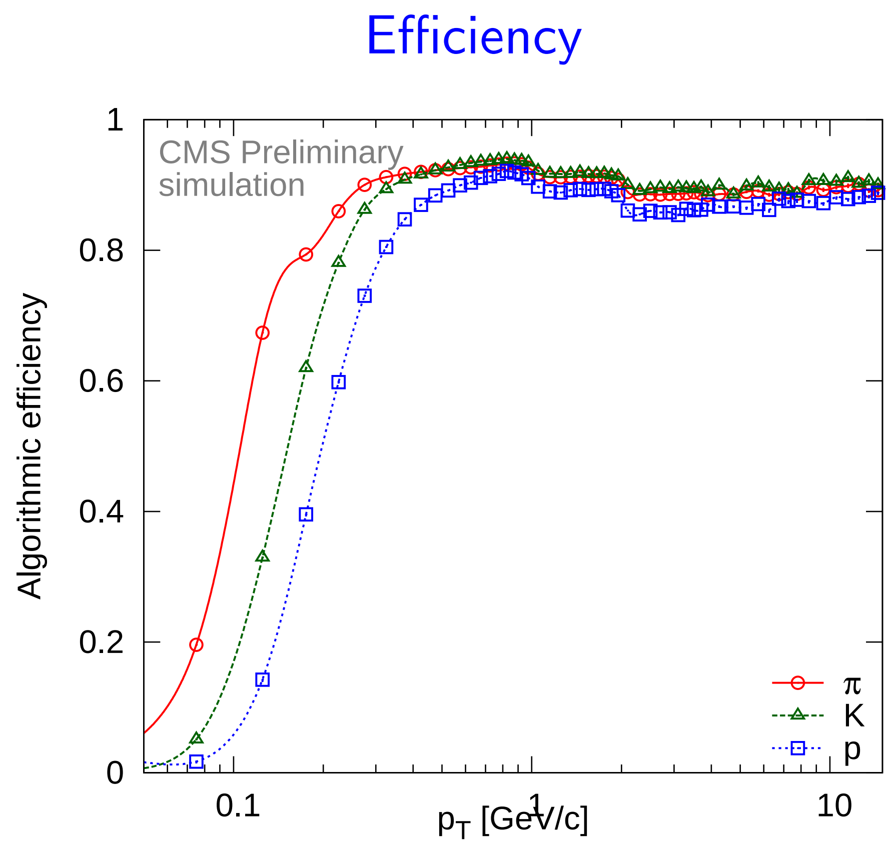
Charged particle tracking – global tracks

p-p @ 14 TeV (Pythia)



Charged particle tracking – acceptance and efficiency



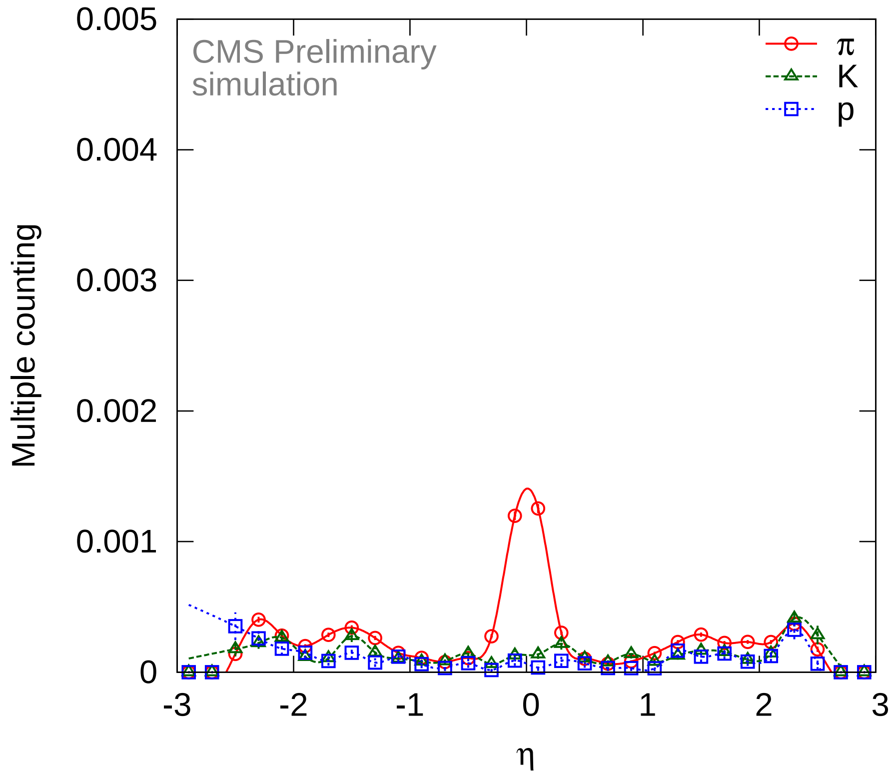


Different for low p_T for particles with different mass
Steps at 1 and 2 GeV/c are due to stricter requirements (points on track)
Close to flat and smooth in the mid-rapidity region

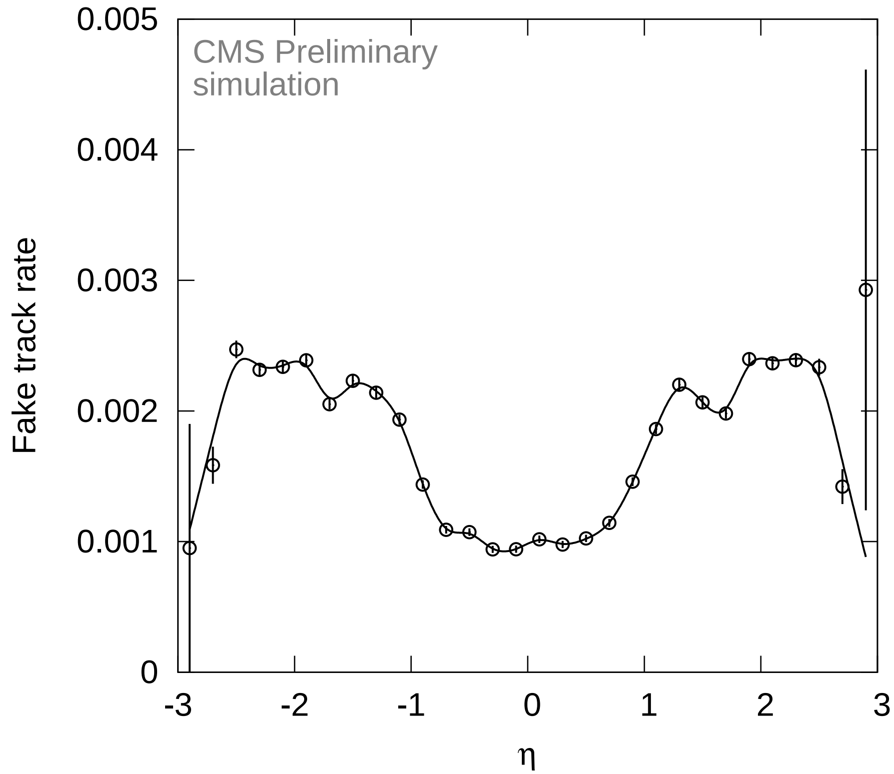
Multiple track counting and fake track rate are around per mille level

Charged particle tracking – multiple and fake

Multiple counting



Fake track rate

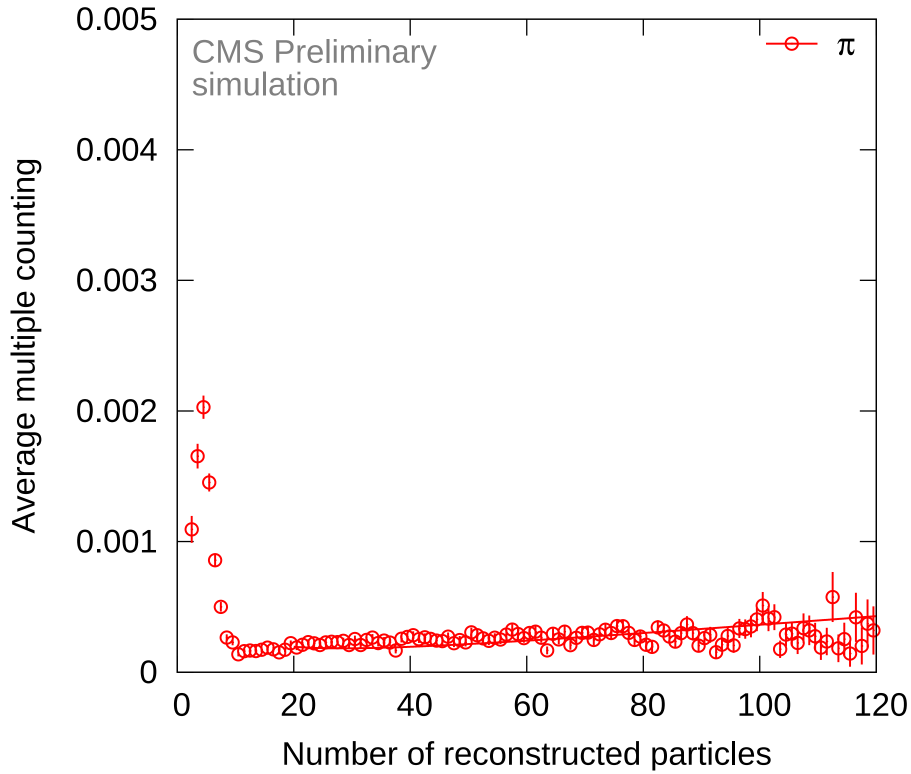


Note the looping pions at $\eta \approx 0$

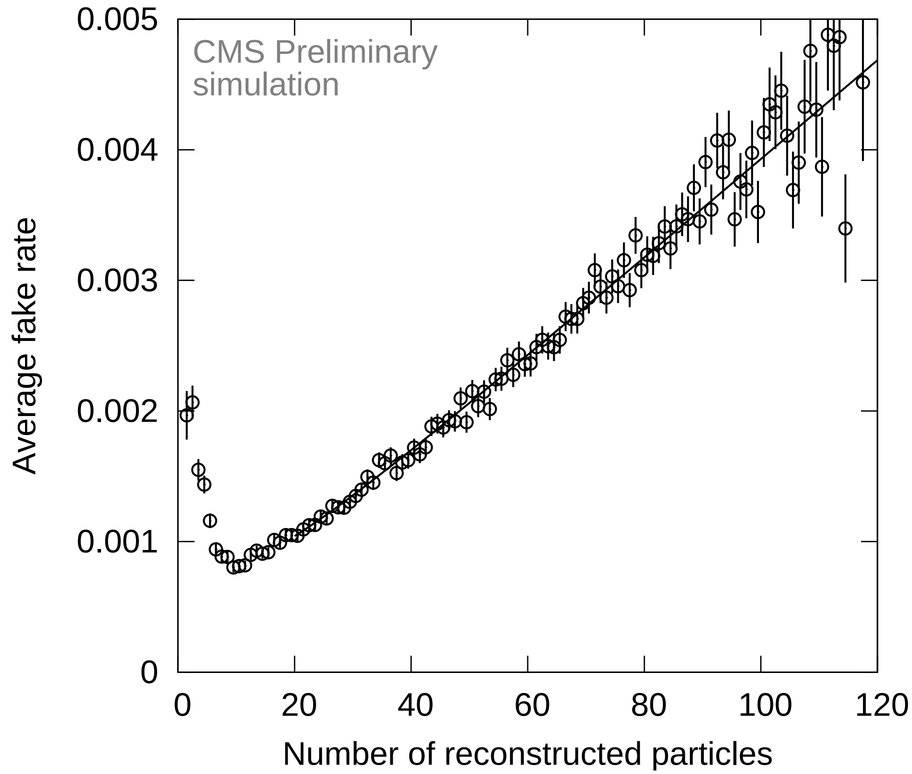
Very small, at per mille level

Corrections – multiplicity dependence

Multiple counting



Fake track rate



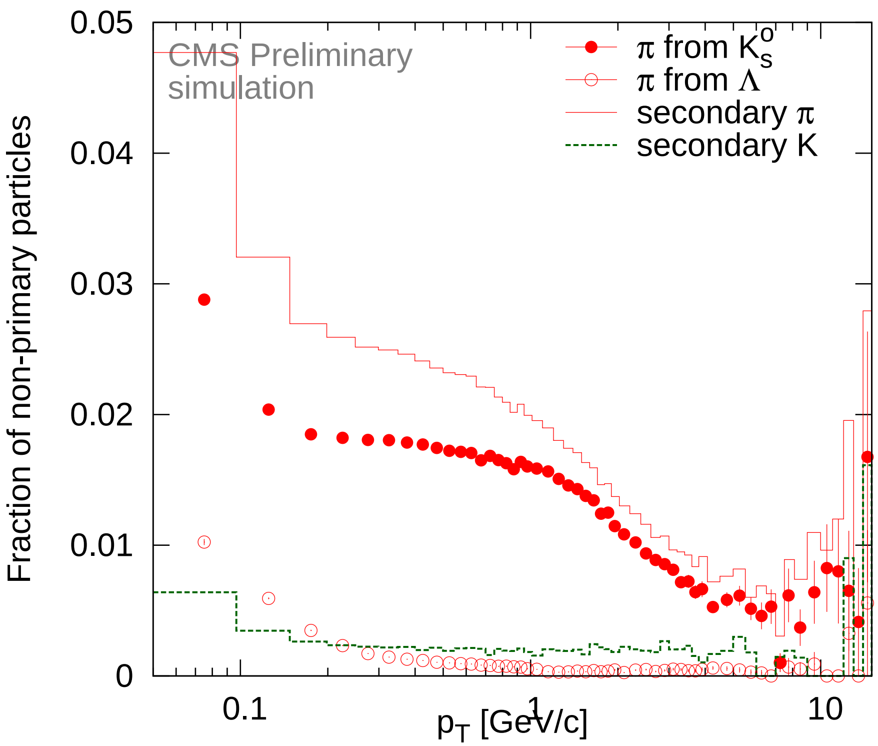
In case of no vertex (low multiplicity) averages go up

Linear dependence on multiplicity also in pile-up

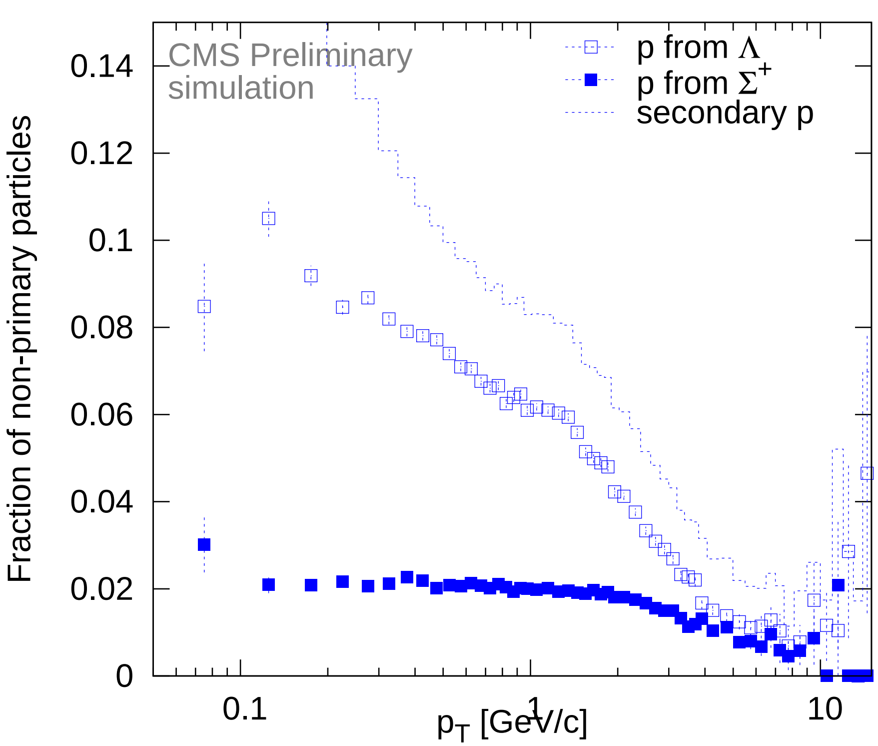
Multiplicity dependent correction

Corrections – feed-down

Pions



Protons

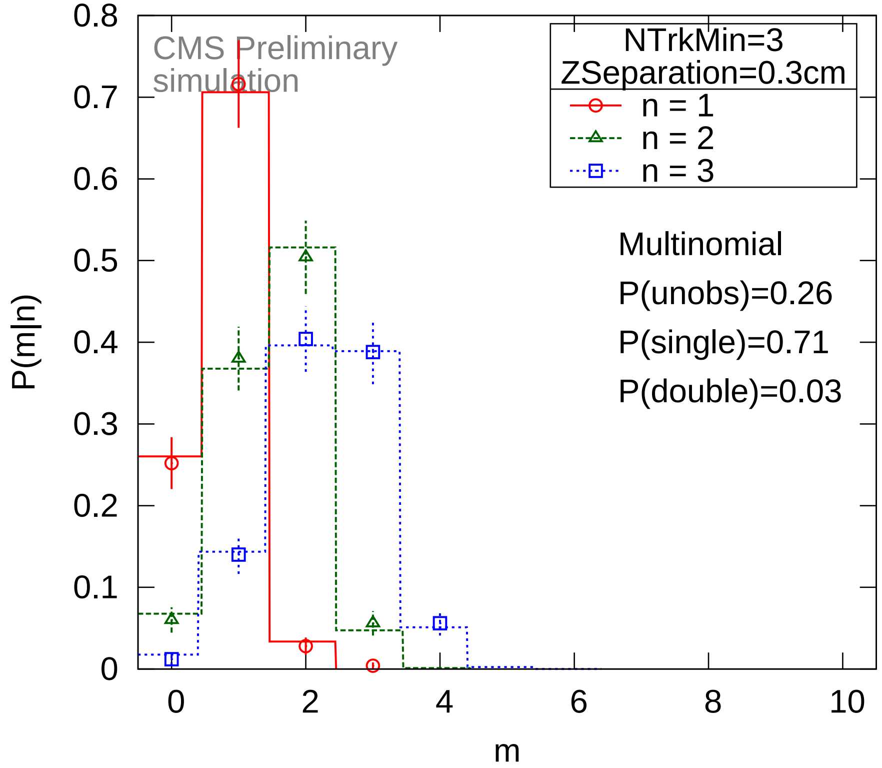


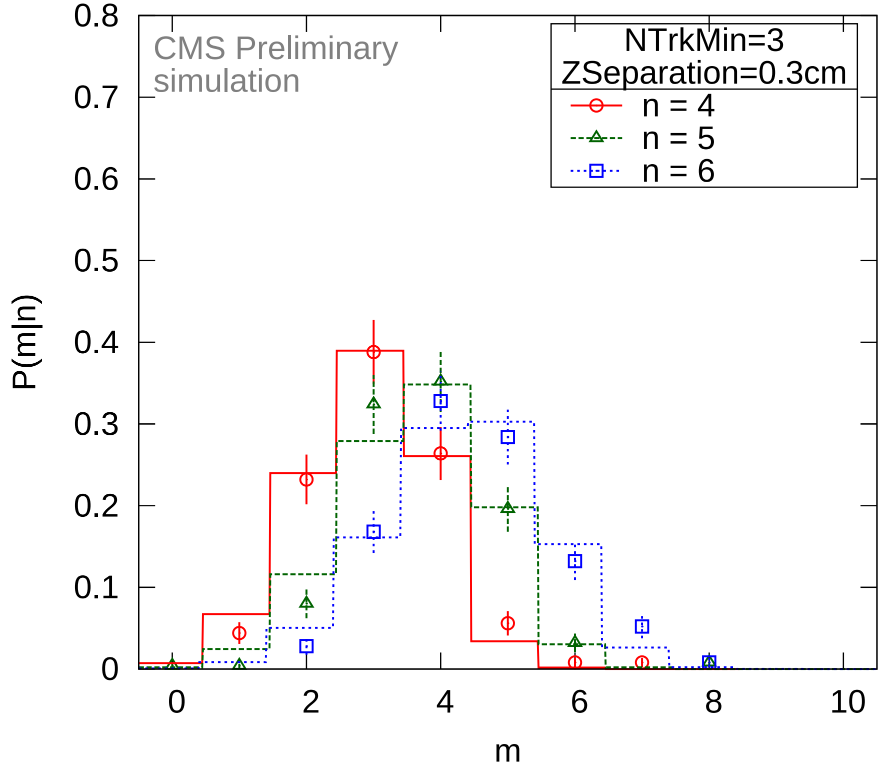
Resonance	Decay	Branching	$c\tau$ [cm]
K^0_S	$\pi^+\pi^-$	69.2%	2.68
$\Lambda/\overline{\Lambda}$	$p\ \pi^-$ / $\overline{p}\ \pi^+$	63.9%	7.89
$\Sigma^+/\overline{\Sigma}^-$	$p\ \pi^0$ / $\overline{p}\ \pi^0$	51.6%	2.40

Sizeable correction for protons from Λ decays

Later: get the correction from direct measurement of K^0_S, $\Lambda,\overline{\Lambda}$, even Σ^+ and $\overline{\Sigma}^-$

Vertexing





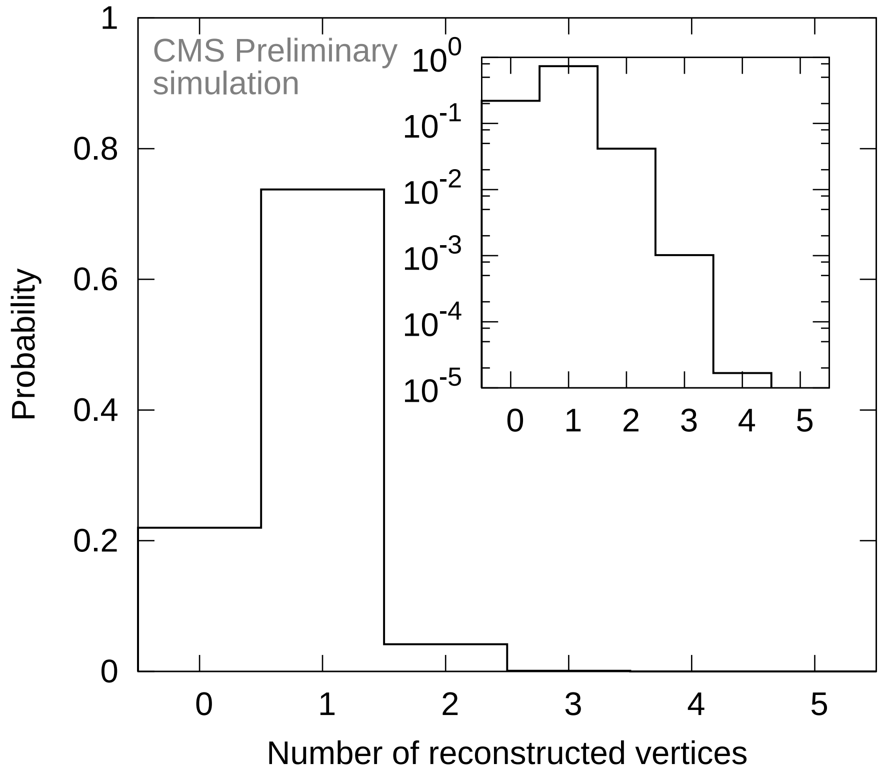
If there are n interactions, how many vertices (m) can we detect?

Multinomial distribution, about 3/4 of the inelastic events get a vertex

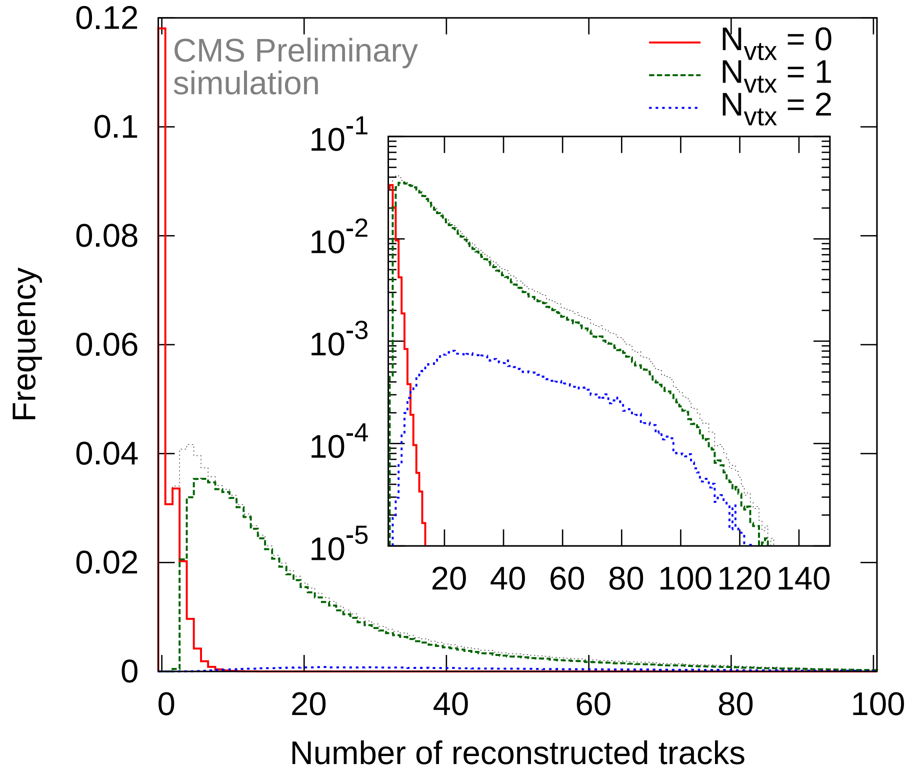
Vertex finding is an independent process ⇒ can treat pile-up

Vertexing, triggers

Vertices



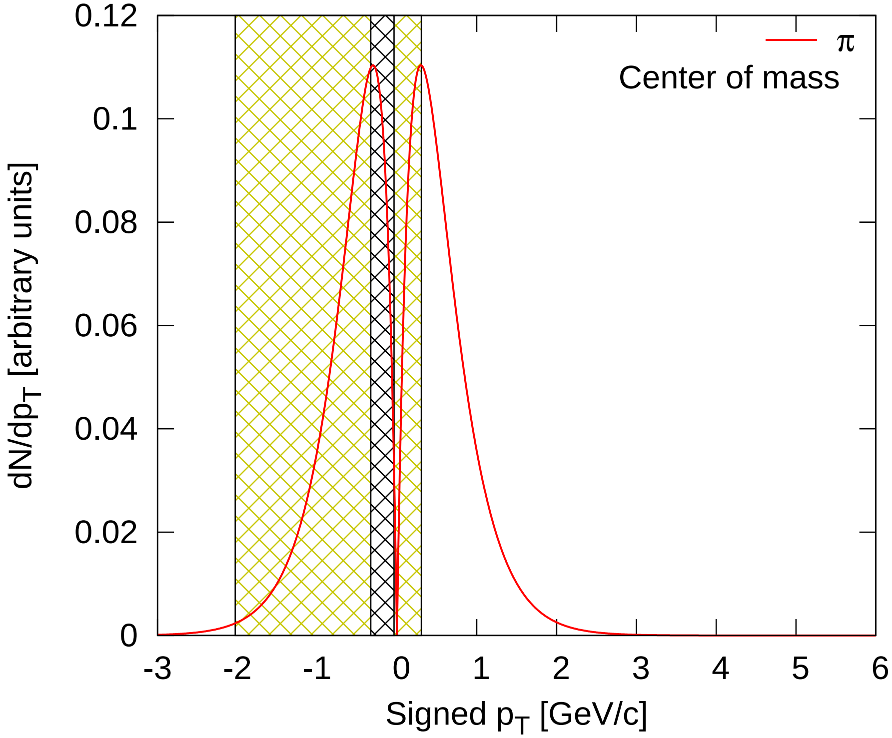
Tracks

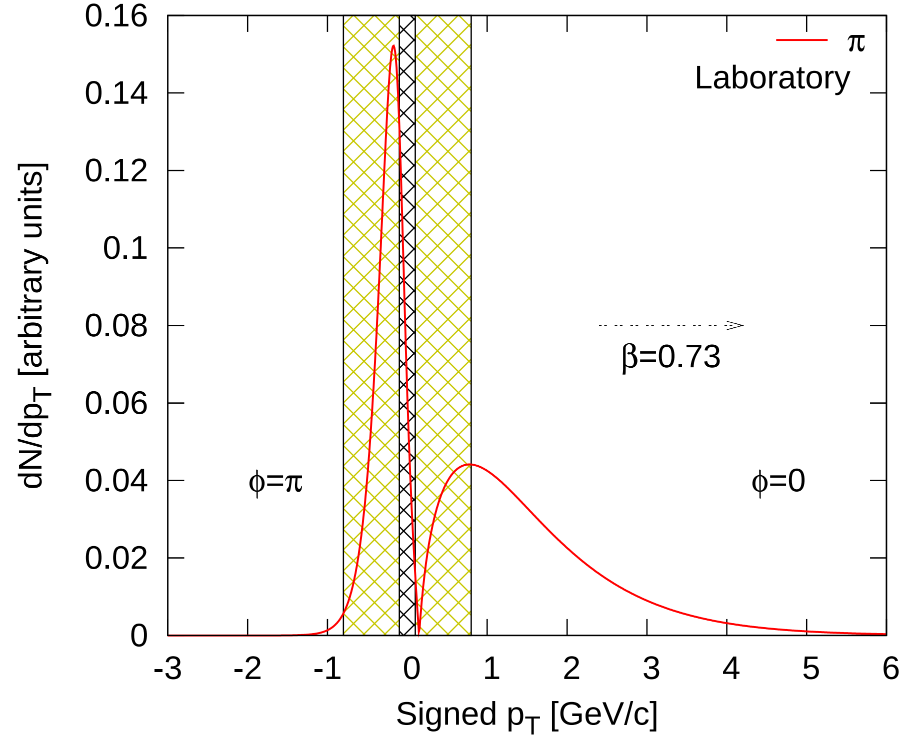


- Zero-bias off-line triggers
  - Track trigger : the event has at least one reconstructed track
  - Vertex trigger: the event has at least one reconstructed primary vertex

Probability to reconstruct 0, 1 or 2 interaction vertices are 22%, 74% and 4%

Other considerations – beam crossing angle





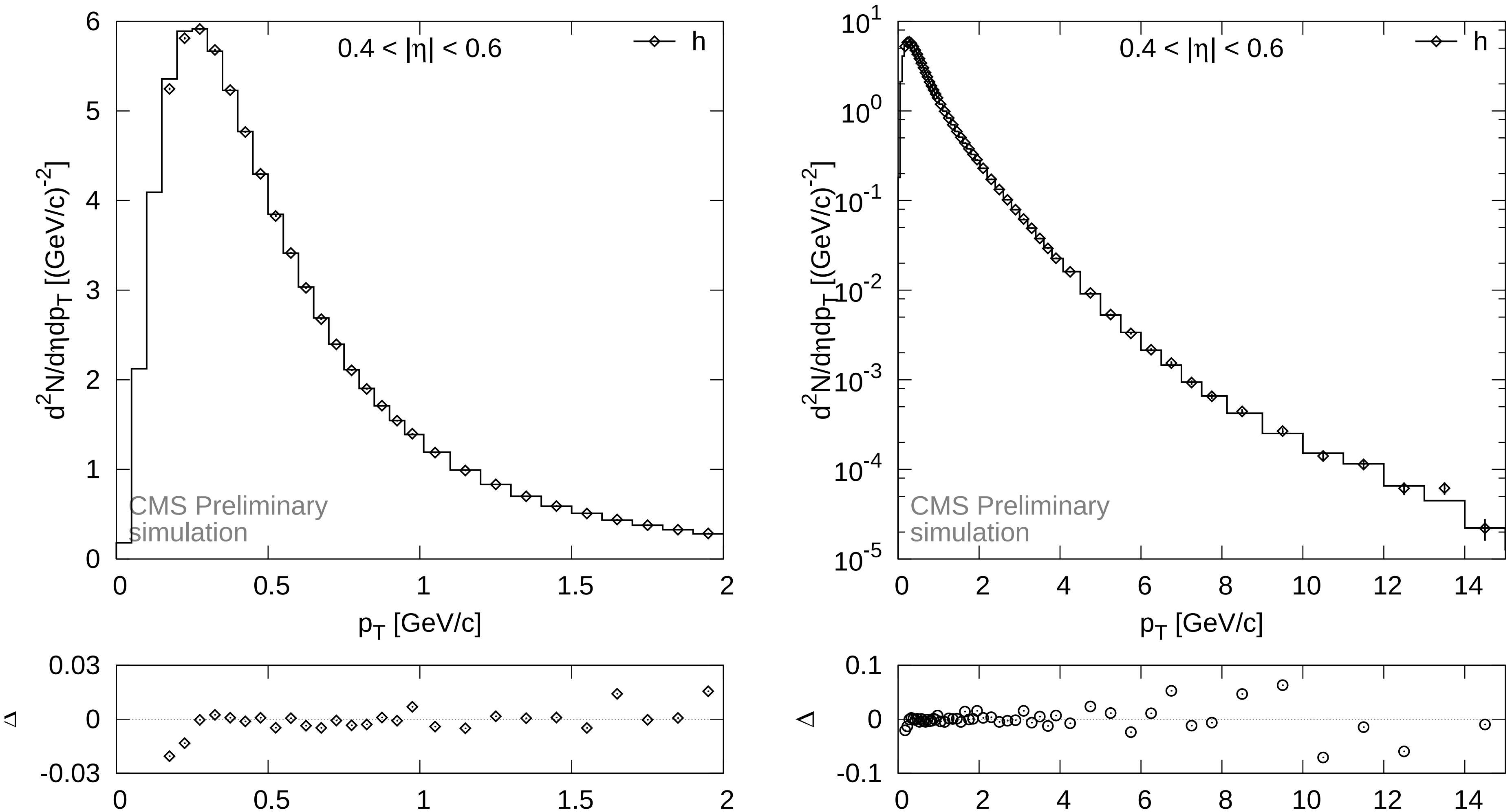
p_{beam}	450 GeV	7 TeV
beam crossing half-angle	142 μrad	
β	0.07	0.73
γ	1.00	1.46

Acceptance+efficiency window (black) shifted

Interesting possibilities if beam crossing angle is not zero

Charged particle tracking – spectra, comparisons

p-p @ 14 TeV (Pythia)

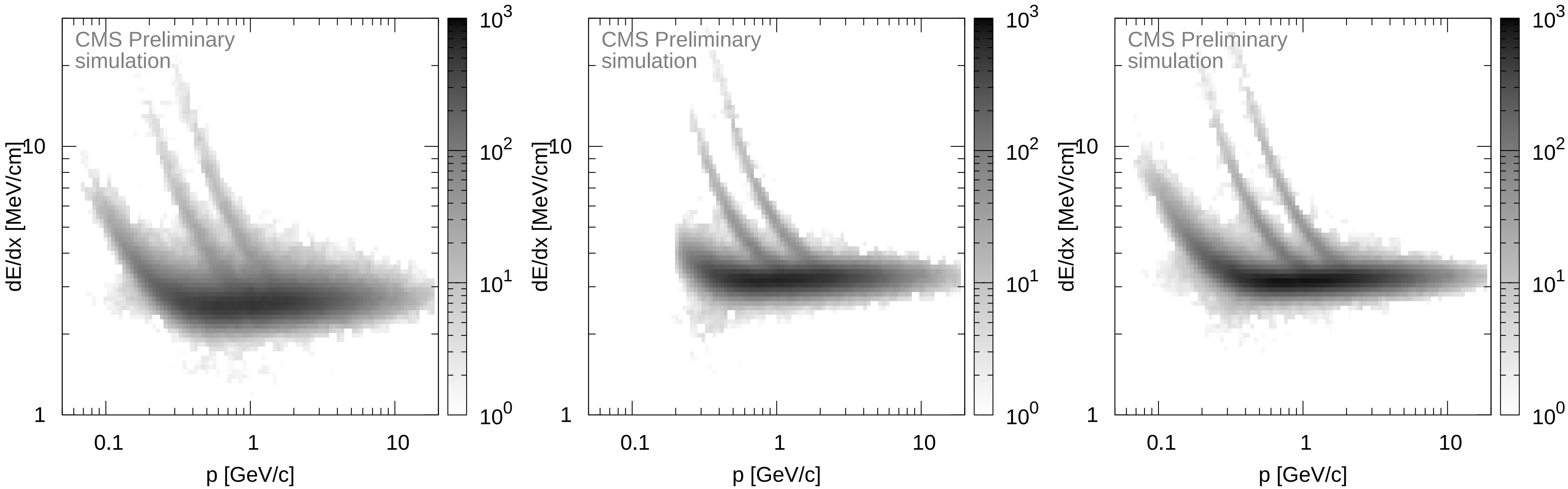


Comparison of simulated (histogram) and reconstructed (symbols), $0.4 < |\eta| < 0.6$

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

Particle identification – energy loss estimator

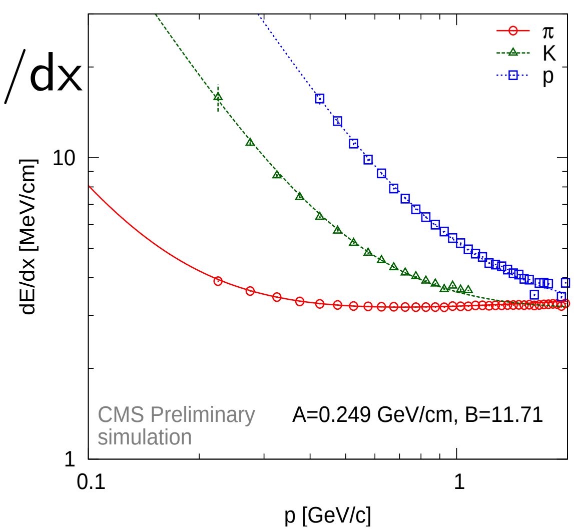
Pixels | Strips | Both



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

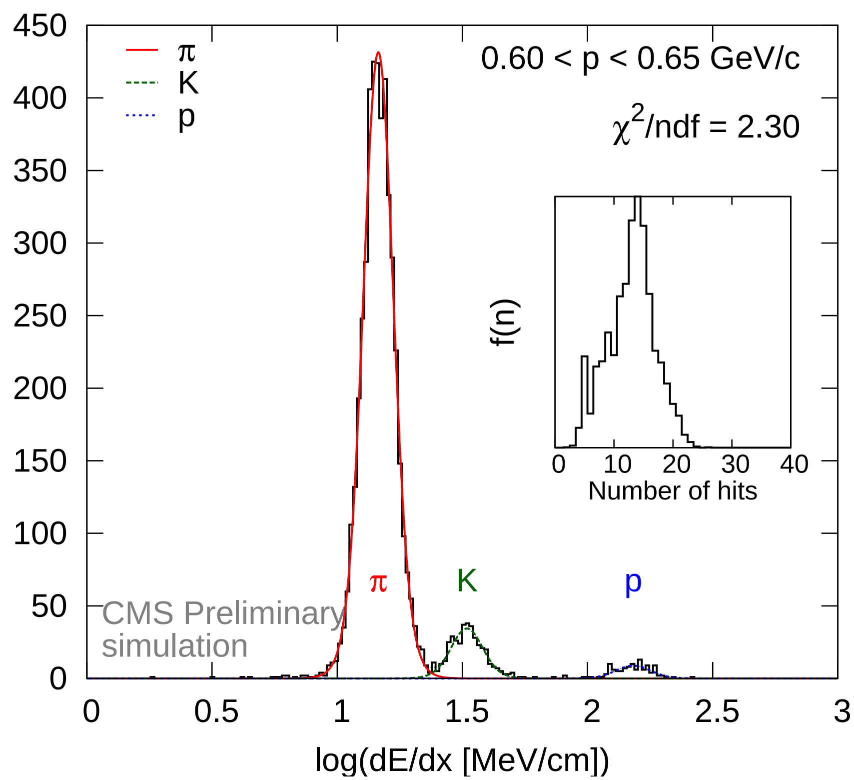
Combination of pixel and strip energy deposits

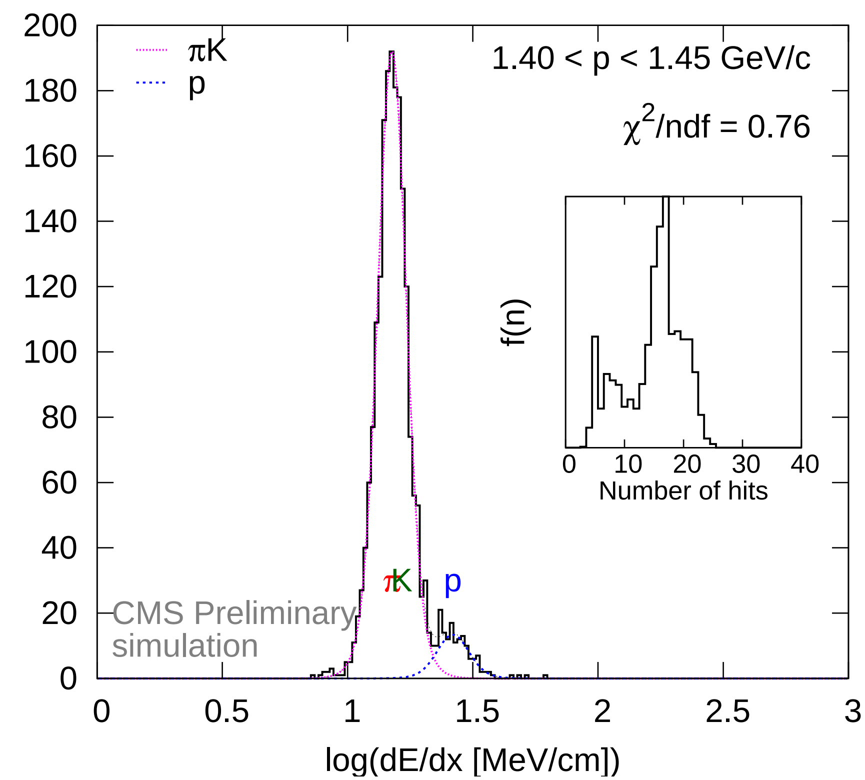
PID expected for pions and kaons ($p < 0.9$ GeV/c)
and protons ($p < 1.8$ GeV/c)



Particle identification – energy loss fits

p-p @ 14 TeV (Pythia)



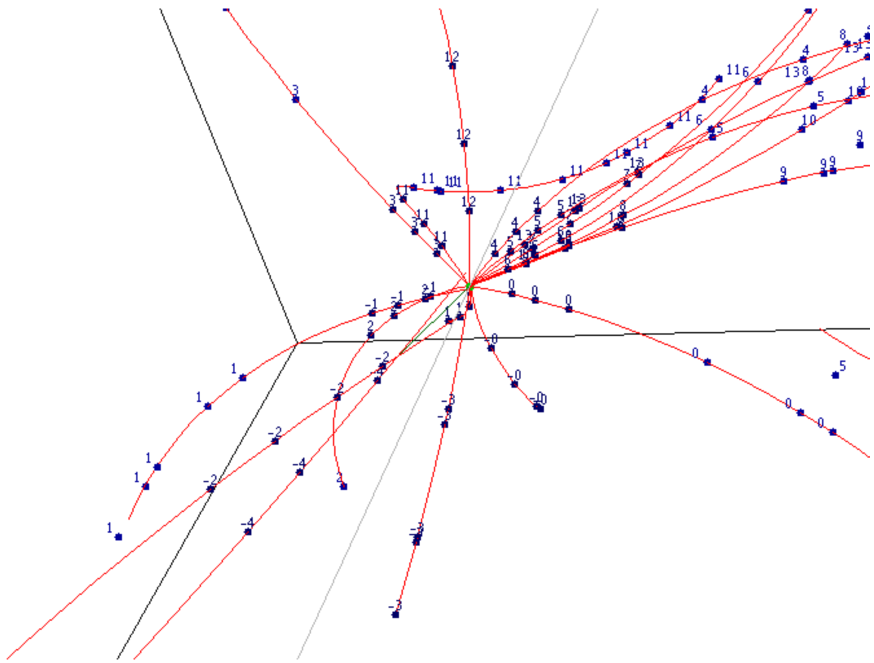


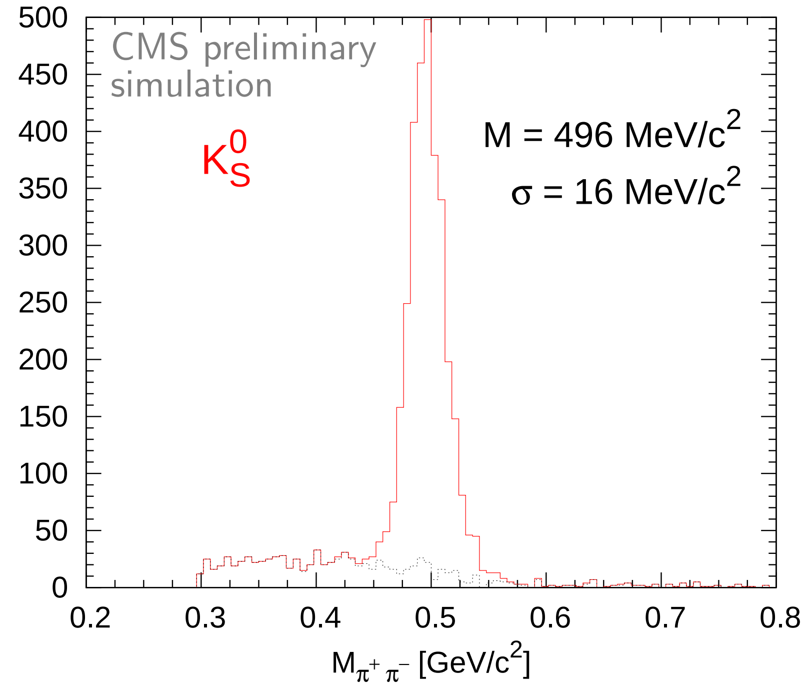
Combined fit using sum of many gaussians, where $\sigma \propto 1/\sqrt{n_{hits}}$
About 5-7% expected resolution, yields can be extracted

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

Particle identification – neutral particles

p-p @ 14 TeV (Pythia)





- Decay topology (V0)
  - Identified particle spectra and yields, neutrals: K_S^0, Λ, $\overline{\Lambda}$ and γ
  - Multi-strange baryons: Ξ^-, Ω^-

Access to neutral and multi-strange identified particles

Results – variables, fit functions

Invariant yields

$$E\frac{d^3N}{dp^3} = \frac{d^3N}{d\phi\, dy\, p_T\, dp_T} = \frac{1}{2\pi p_T}\frac{d^2N}{dy\, dp_T} \tag{1}$$

Interpolation to y

$$\frac{d^2N}{dy\, dp_T} = \frac{E}{p}\,\frac{d^2N}{d\eta\, dp_T} \tag{2}$$

Empirical fit function (Tsallis or Levy) from UA1, Tevatron, RHIC

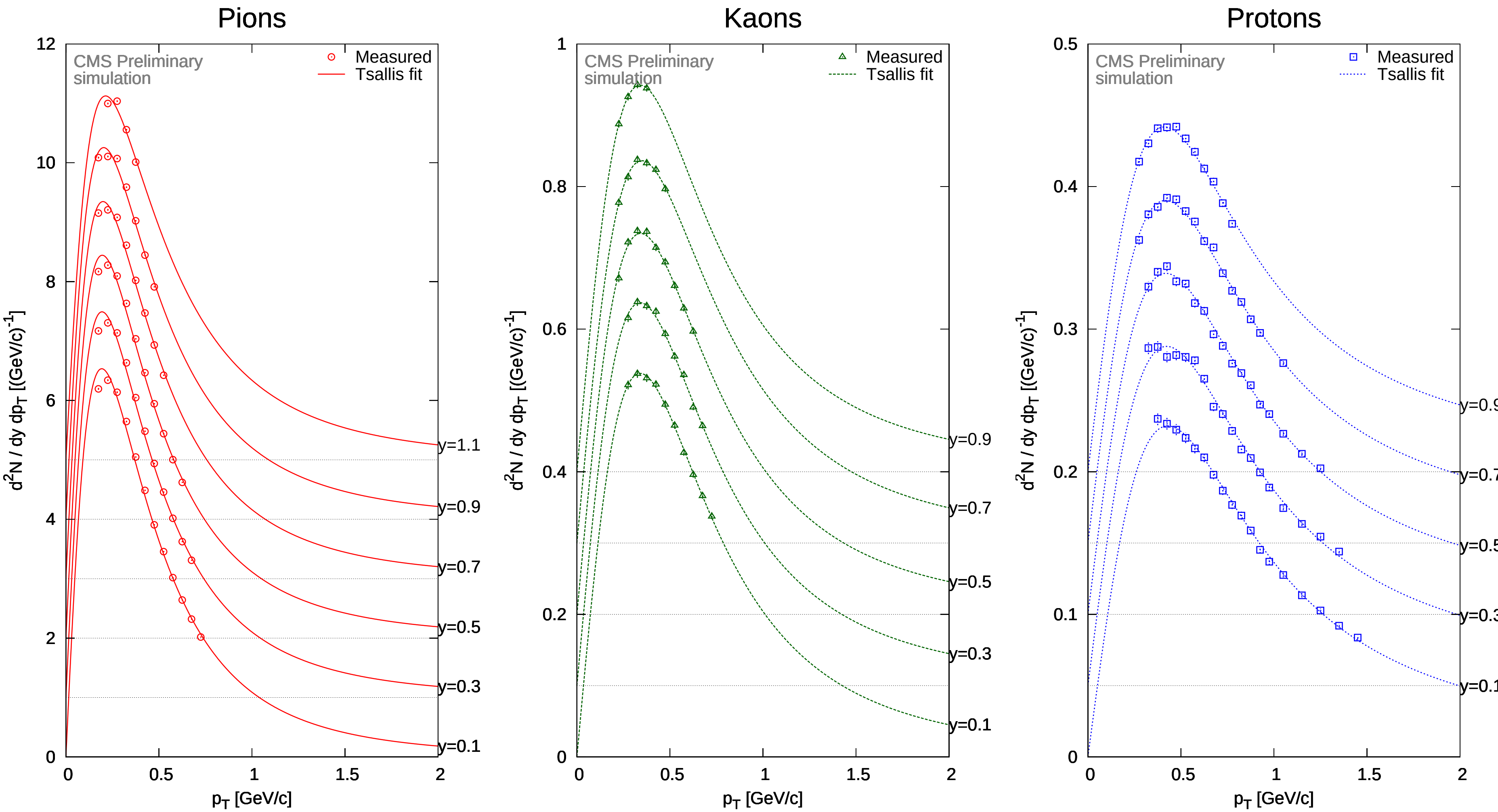
$$E\frac{d^3N}{dp^3} = \frac{dN}{dy}\,\frac{(n-1)(n-2)}{2\pi\, nT\,[nT+(n-2)m]}\,\left[1+\frac{E_T(p_T)}{nT}\right]^{-n} \tag{3}$$

Thermal and power-law function in low and high p_T limits

Good description of data

Results – pions, kaons and protons

p-p @ 14 TeV (Pythia)



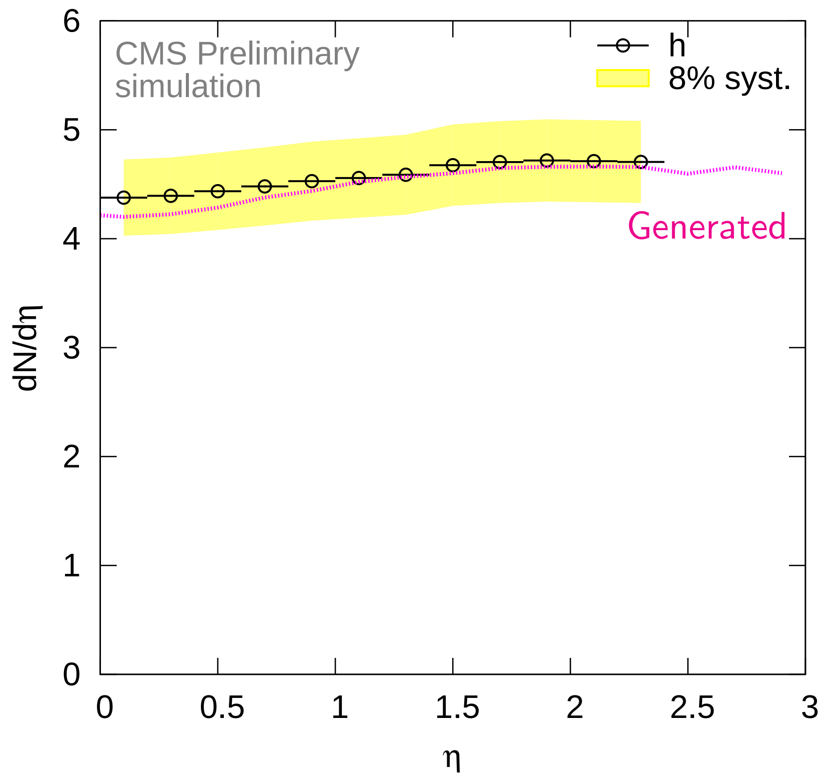
CMS PAS QCD-07-001

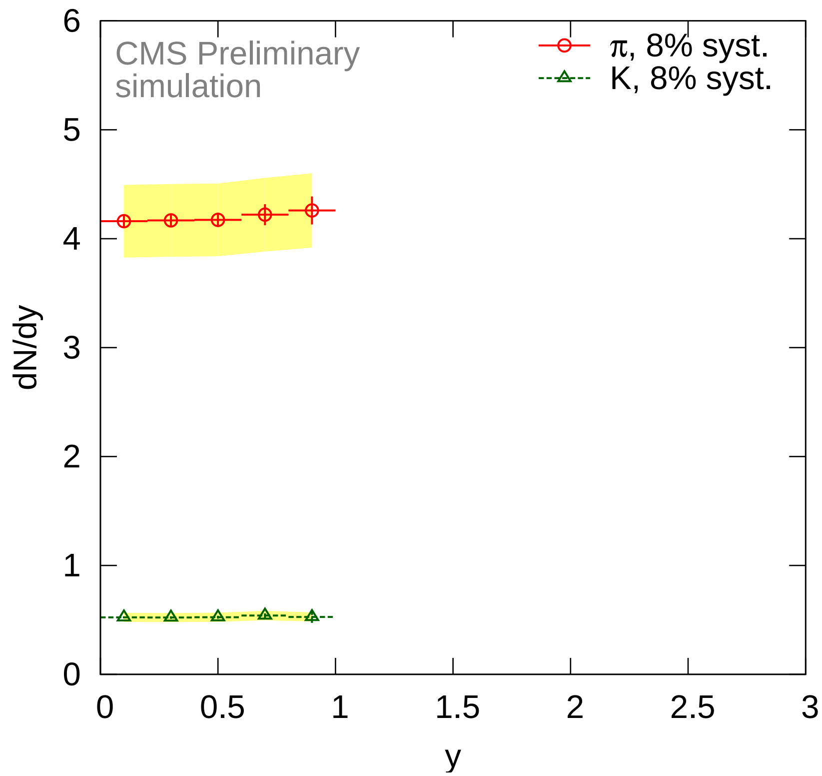
Exponent of the power-law is taken from unidentified spectra

Rapidity dependence can be studied

Results – rapidity density

p-p @ 14 TeV (Pythia)





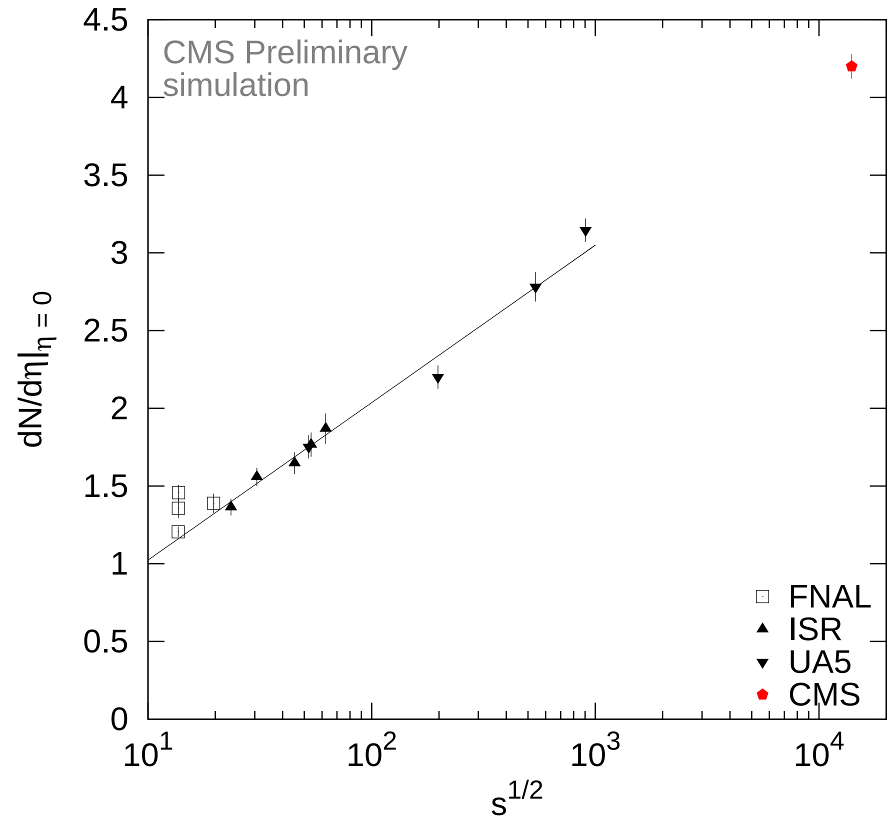
p_T spectrum is summed and integrated

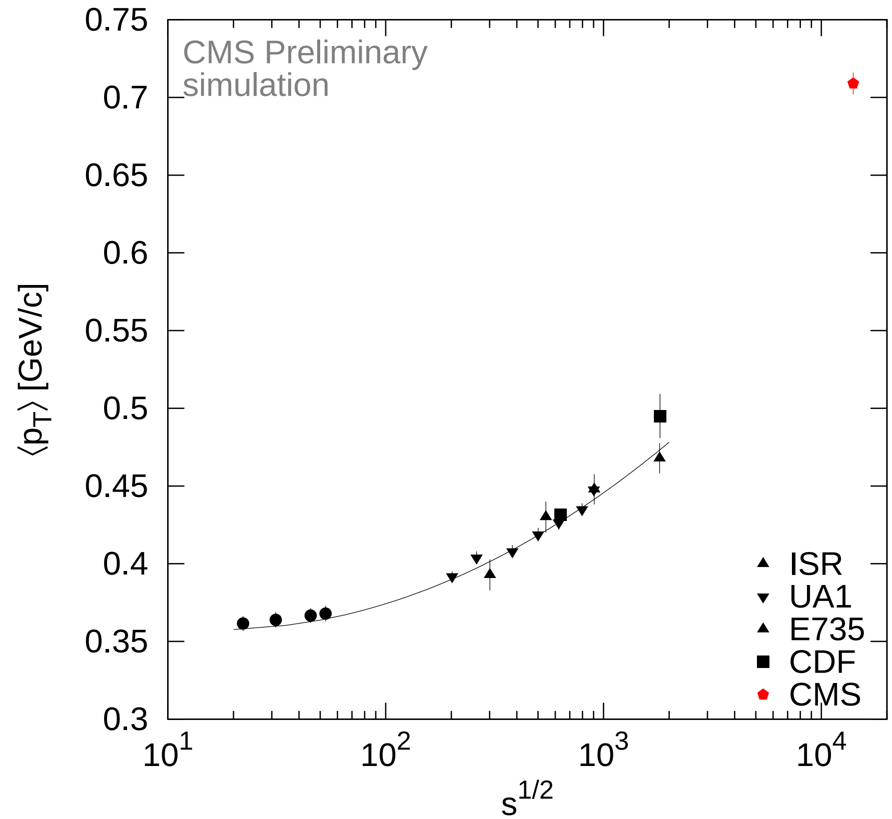
The acceptance of the tracker limits the accessible η/y range,
total number of produced charged particles cannot be measured

Total cross-section can be obtained using luminosity measurements

Results – energy dependence

p-p @ 14 TeV (Pythia)





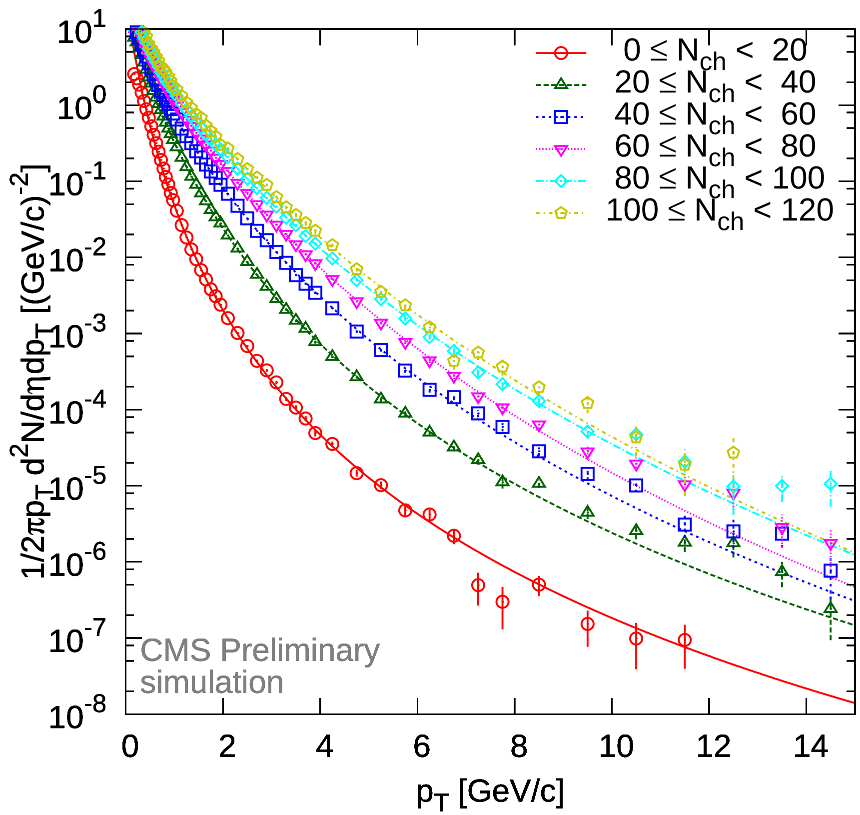
Comparison to lower energy measurements: FNAL, ISR, UA1, UA5, E735, CDF

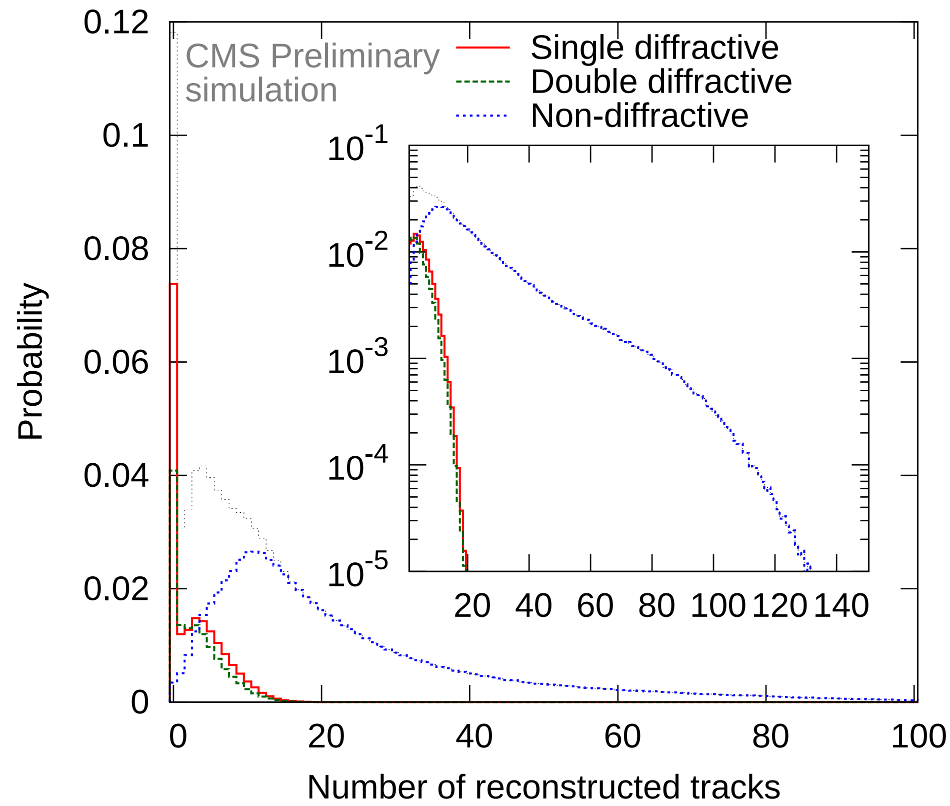
We can verify if $dN/d\eta|_{\eta=0}$ continues its linear increase in $\log\sqrt{s}$

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}

After unfolding detector response we can measure multiplicity distribution

Interesting physics (multiparton interactions, underlying event)

Conclusions and outlook

- Inclusive hadron physics with CMS
  - Charged hadrons ($h^\pm$)
  - Identified charged particles via dE/dx ($\pi^\pm$, $K^\pm$, $p/\bar{p}$)
  - Identified neutral particles via decay (K^0_S, Λ, also Ξ^-, Ω^- and antiparticles)
  - On-vertex resonances (ρ, K^*, ϕ)
  - Add calorimetry: extend η range, provide medium or high momentum PID

Fundamental measurements (N, $dN/d\eta$, dN/dp_T), tests of models

Now: preparing for 900 GeV, 10 TeV and 14 TeV data taking

Busy year ahead