First physics with hadrons and the underlying event at CMS

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First physics with hadrons at CMS

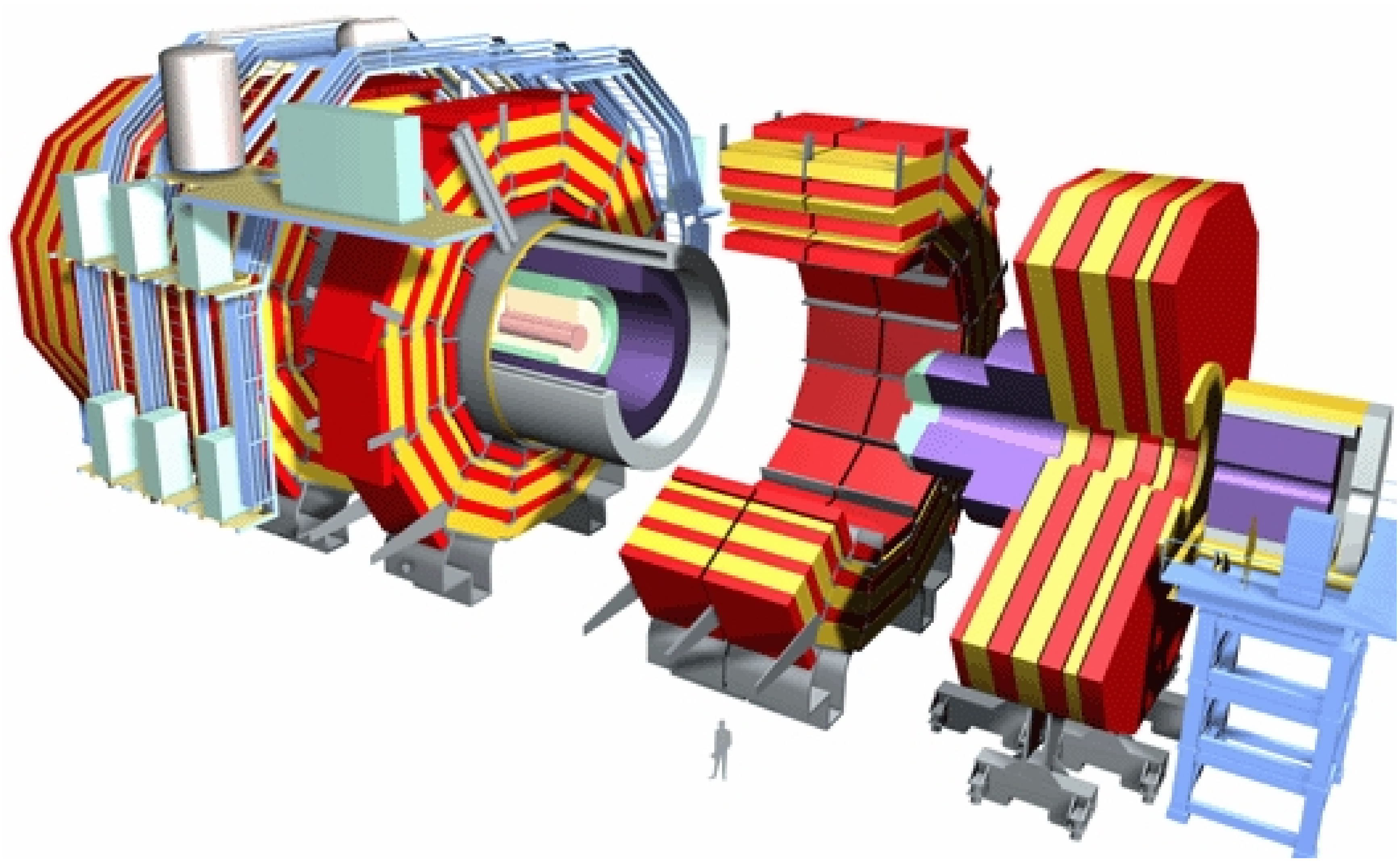
- Contents
  - The detector
  - First physics with hadrons
  - Triggers: Level-1 and HLT
  - Charged hadron rapidity density
  - Charged hadron spectra
  - Particle identification capabilities
    - charged hadrons via energy loss (dE/dx)
    - neutral hadrons via decay topology (V0)
  - Underlying event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

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

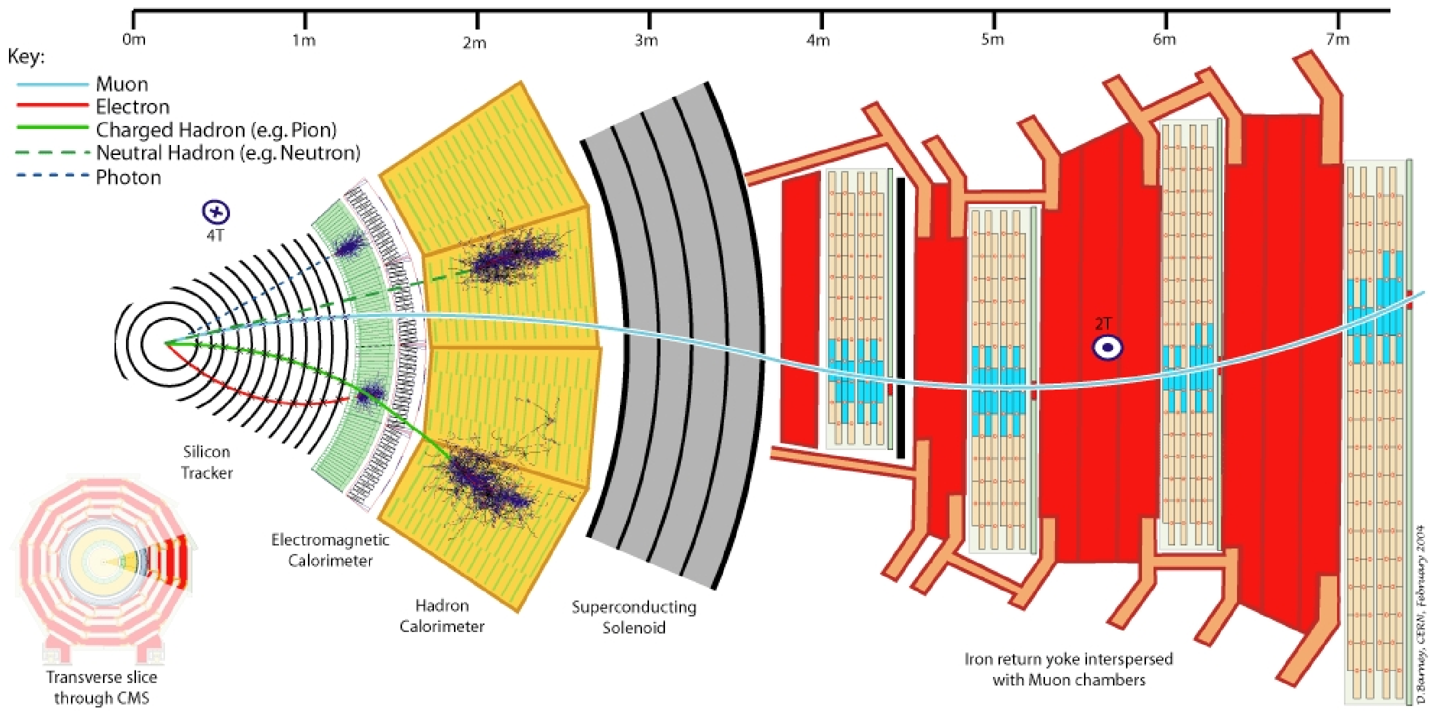
The CMS detector



Compact Muon Solenoid

One single detector combines global characterization and specific probes

The CMS detector – slice

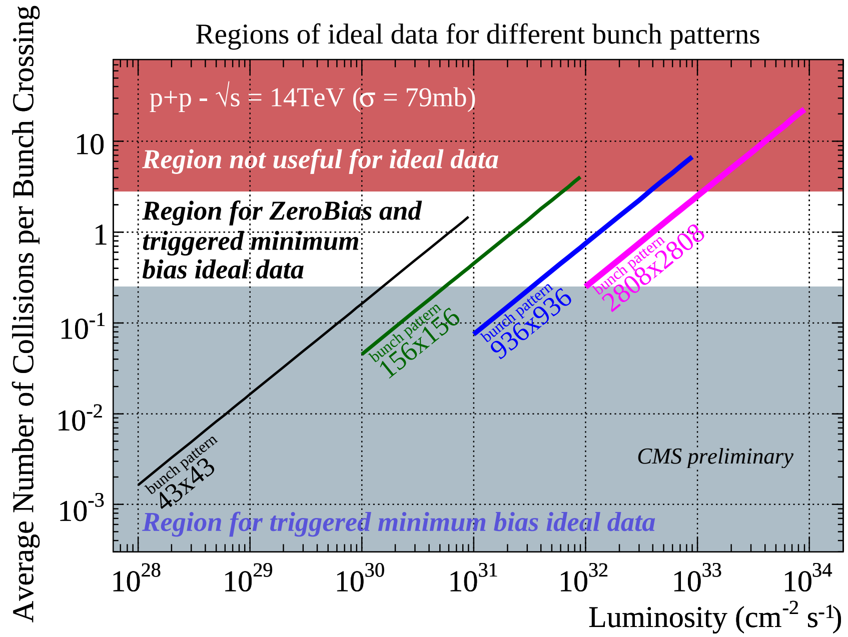


- Detectors
  - Silicon tracker: pixels and strips ($|\eta| < 2.4$)
  - Electromagnetic ($|\eta| < 3$) and hadronic ($|\eta| < 5$) calorimeters
  - Muon chambers ($|\eta| < 2.4$)
  - Extension with forward detectors (CASTOR $5.3 < |\eta| < 6.6$, ZDC $|\eta| > 8.3$)

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

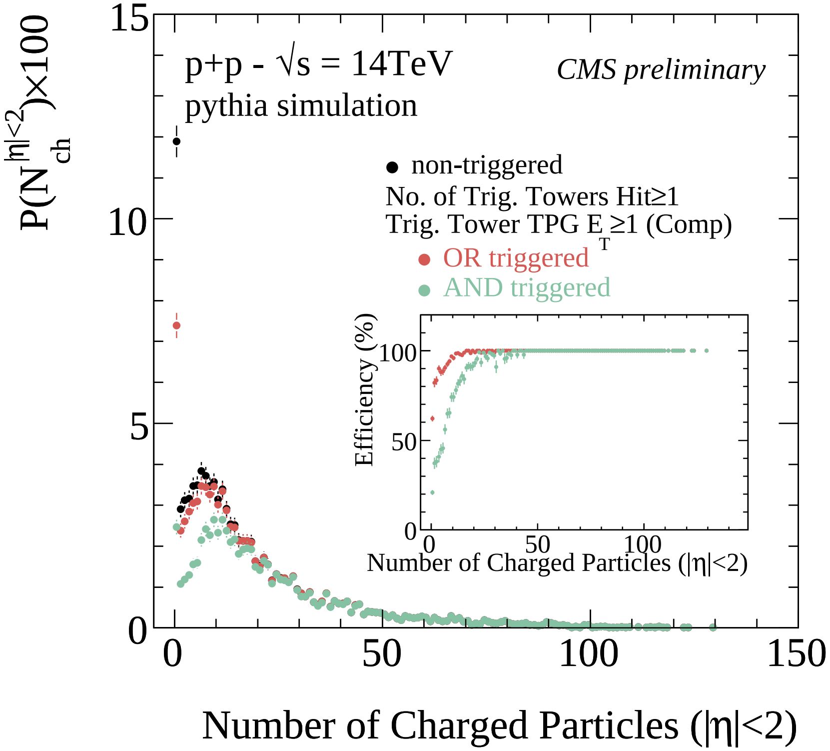
How to trigger? $\Rightarrow$ Low bias triggers

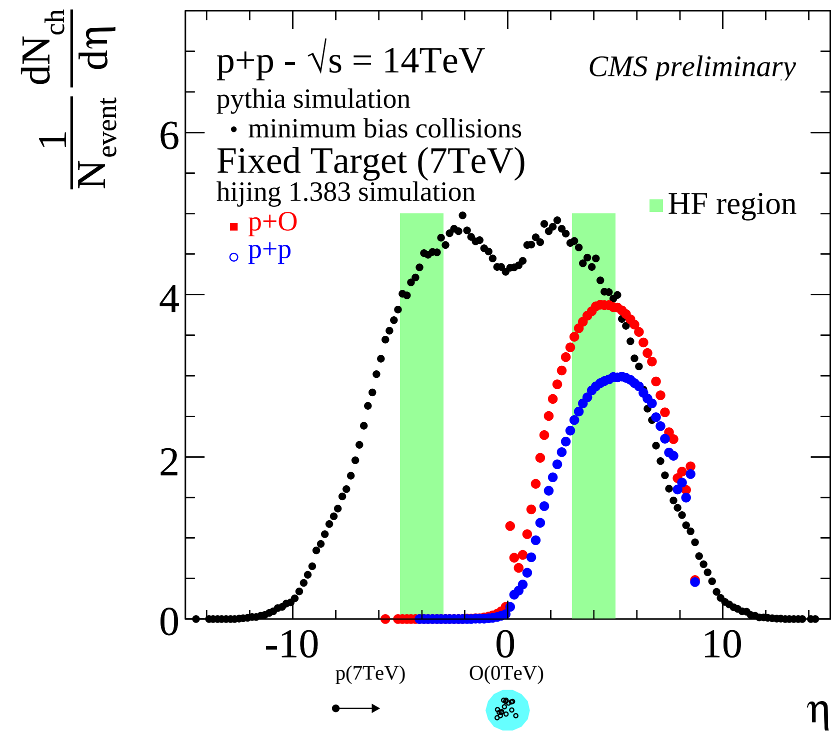
Minimum bias triggers – zero bias or pixel track



- 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



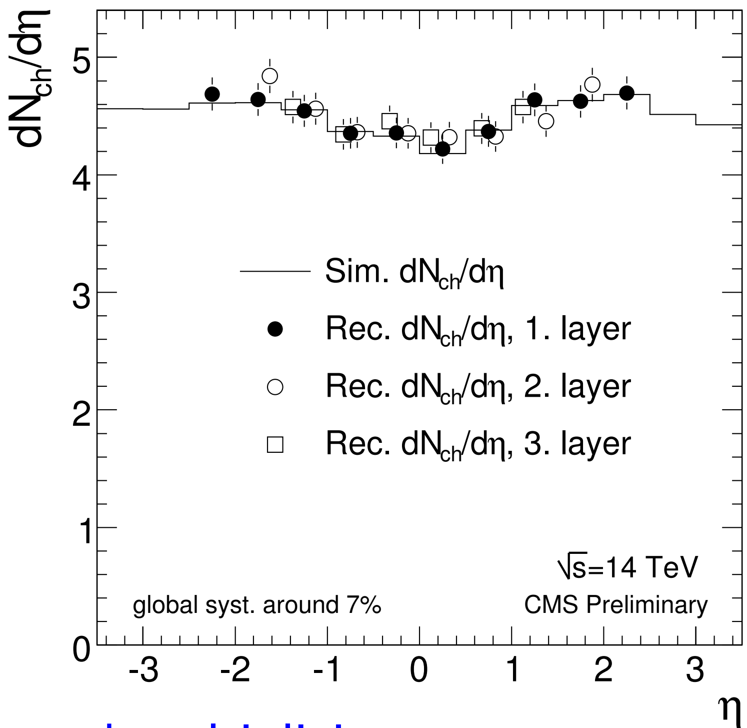


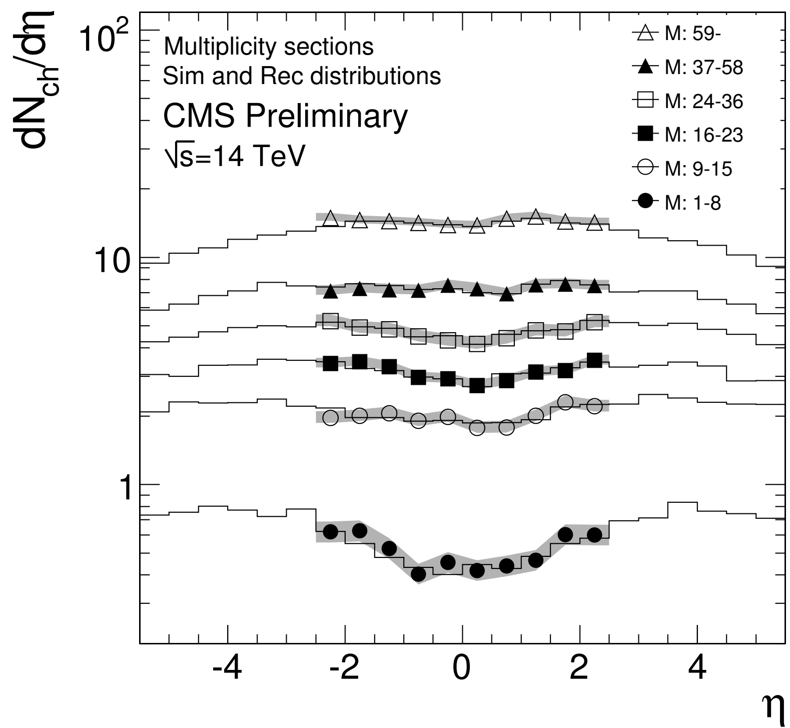
CMS PAS QCD-07-002

- 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)
  - 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



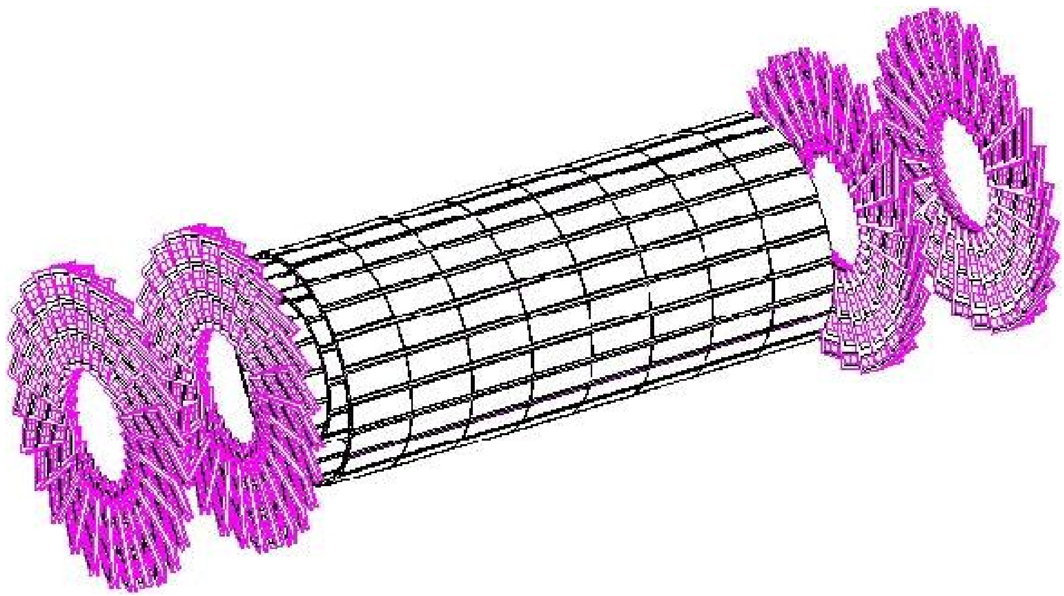


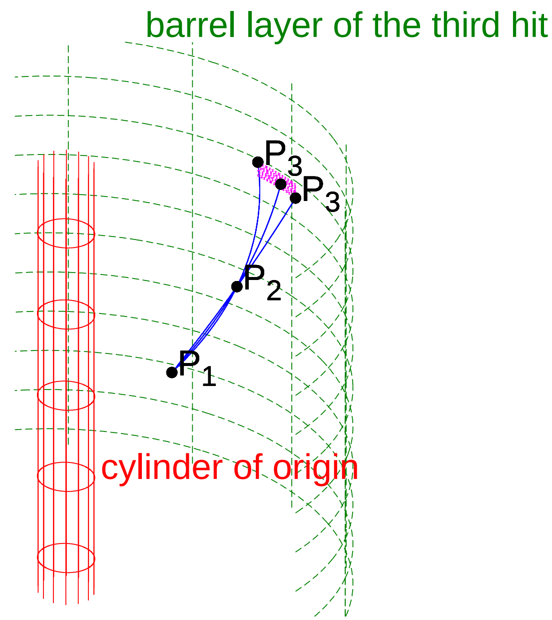
CMS PAS QCD-08-004

- 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



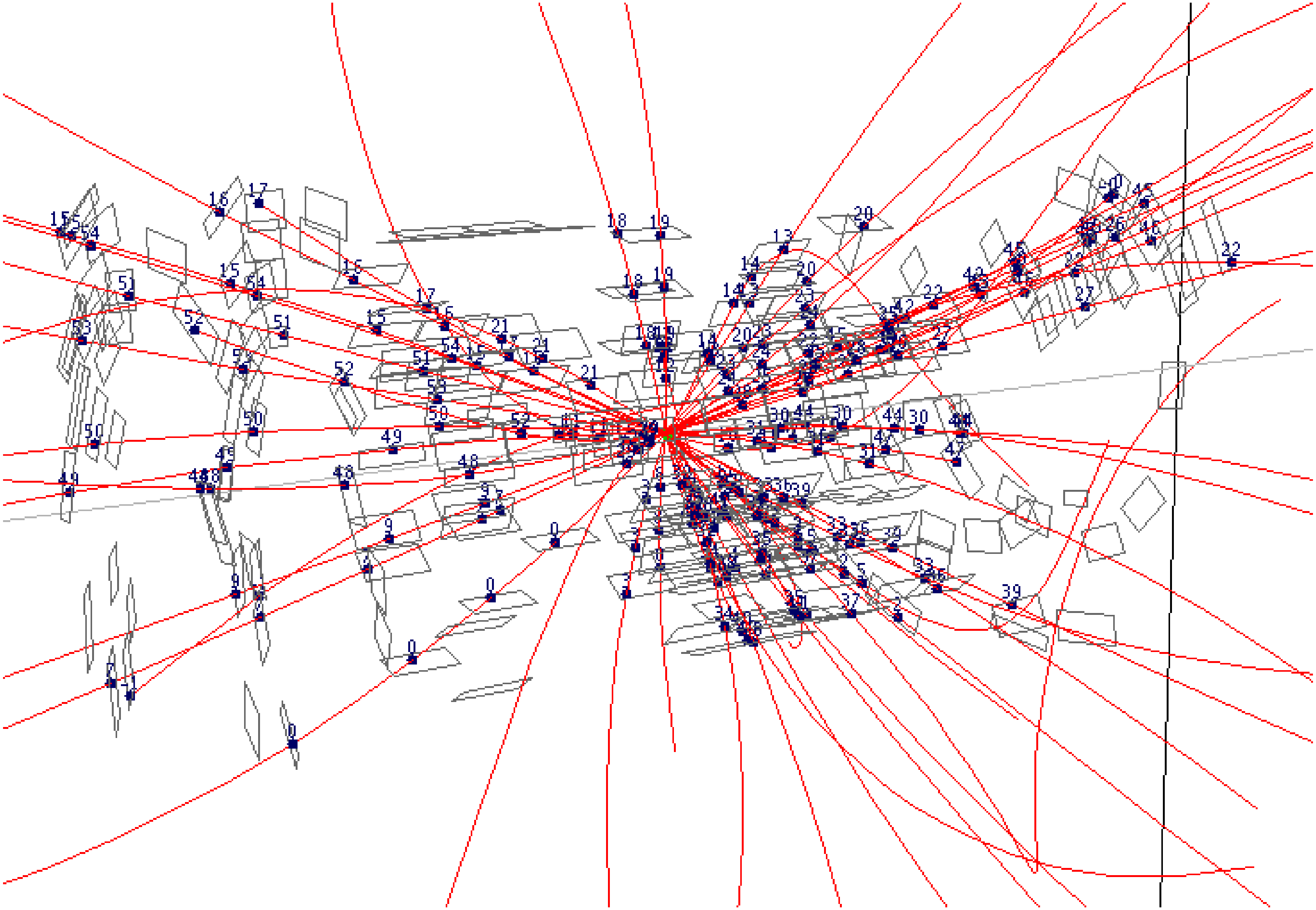


- Pixel detector
  - 3 barrel layers (4, 7 and 11 cm radii) and 2 endcaps on each side
- Hit triplets
  - Use pixel hit triplets instead of pairs, lower fake track rate
  - Modified triplet finding, reconstructing down to $p_T = 0.075$ GeV/c
  - Cluster shape must match trajectory direction, very low fake track rate

Tracking optimized for all p_T

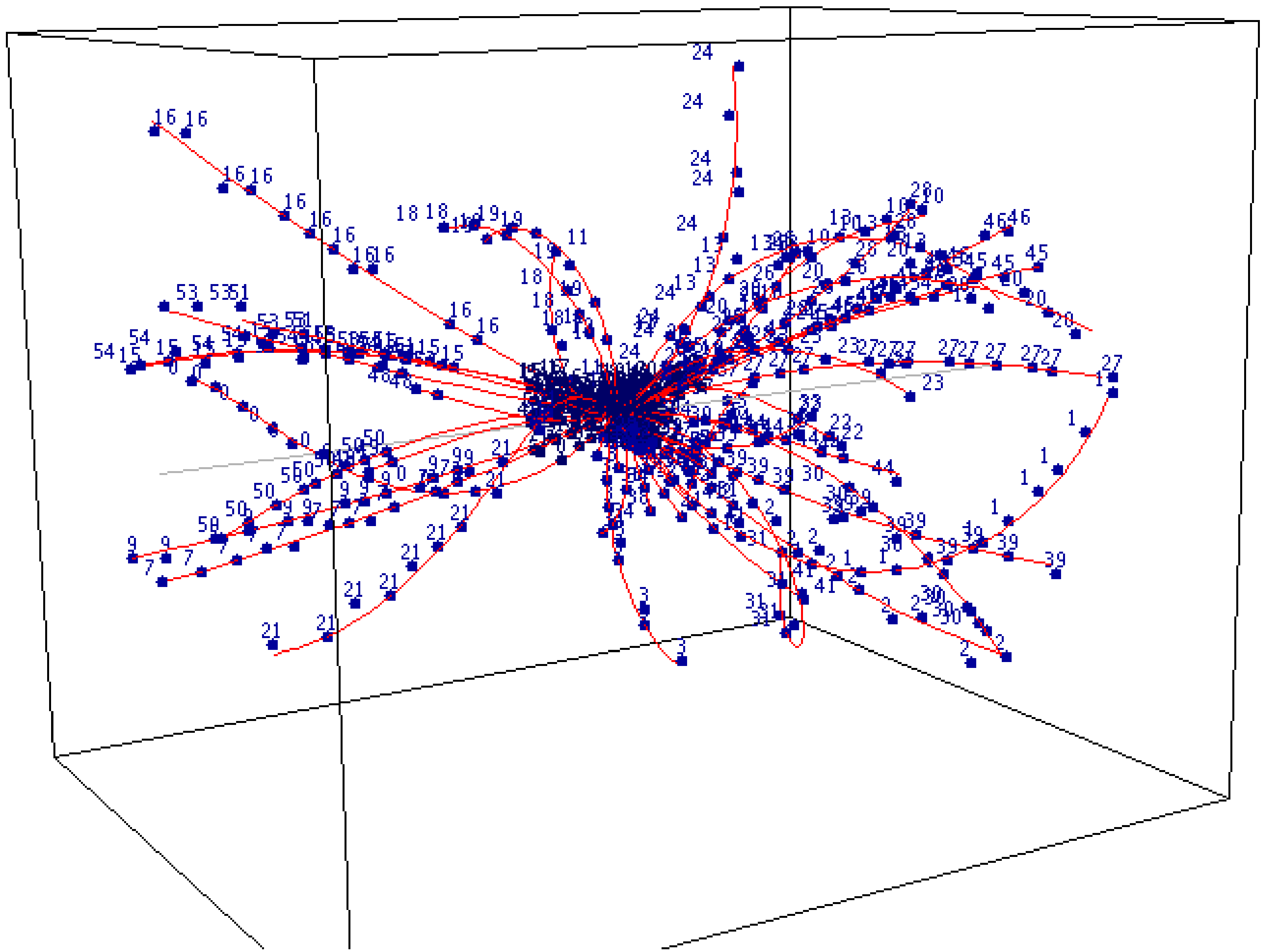
Charged particle tracking – pixel tracks

p-p @ 14 TeV (Pythia)



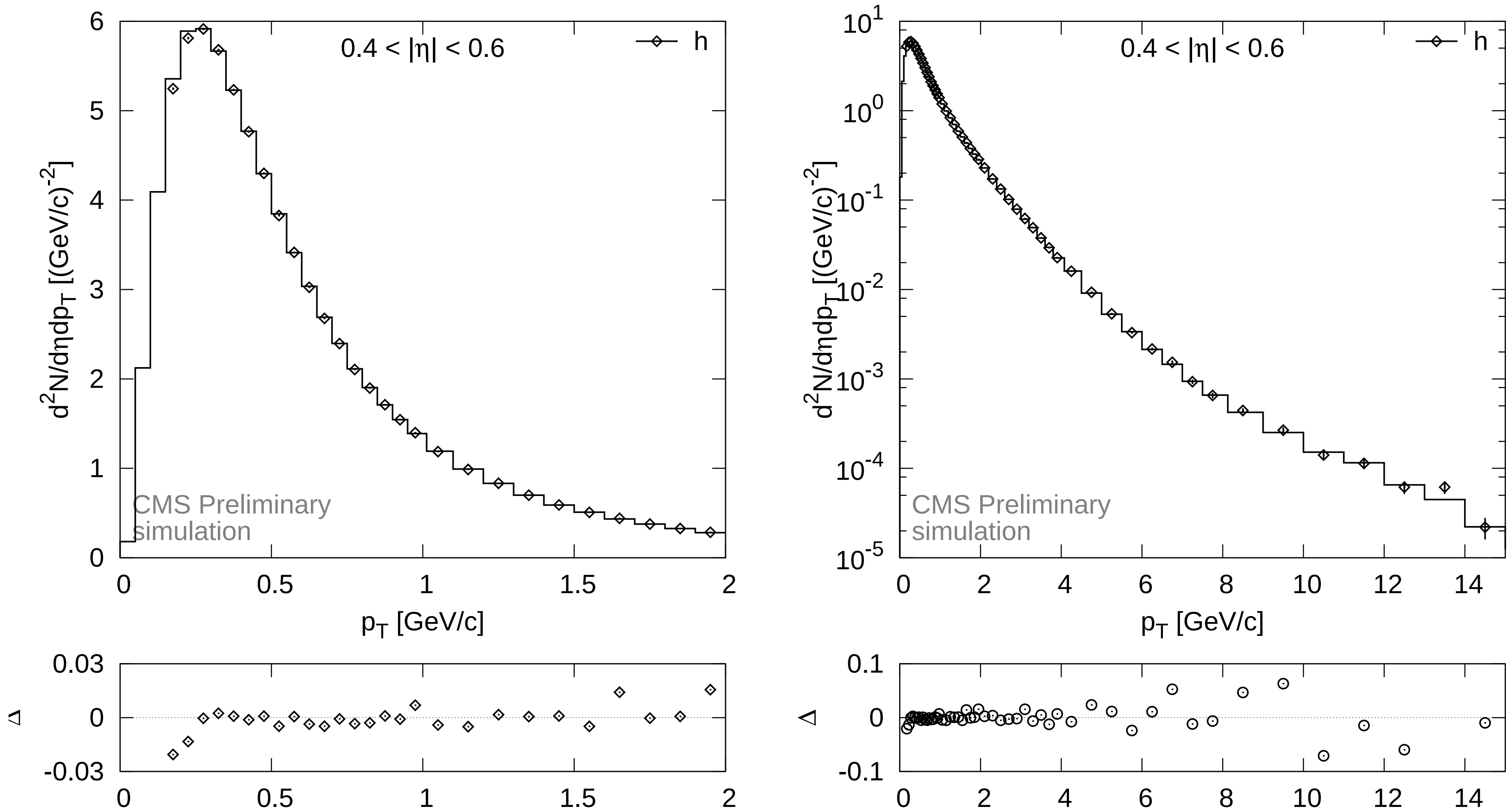
Charged particle tracking – global tracks

p-p @ 14 TeV (Pythia)



Charged particle tracking – spectra, comparisons

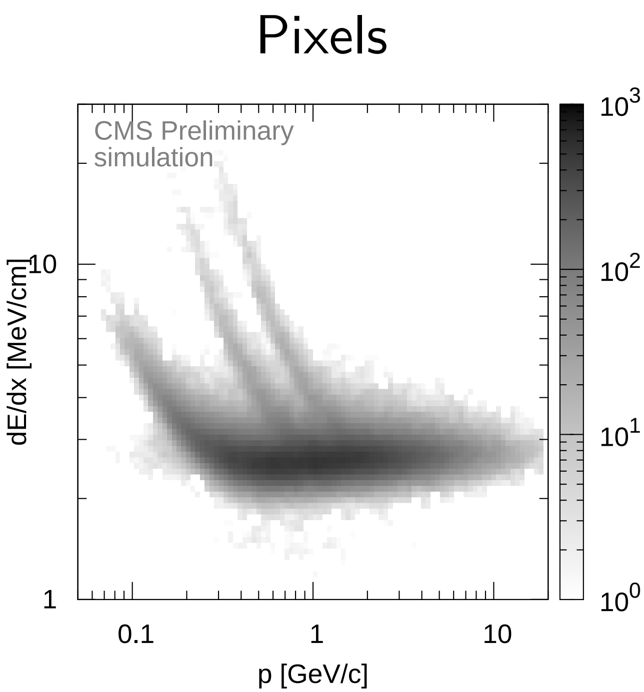
p-p @ 14 TeV (Pythia)

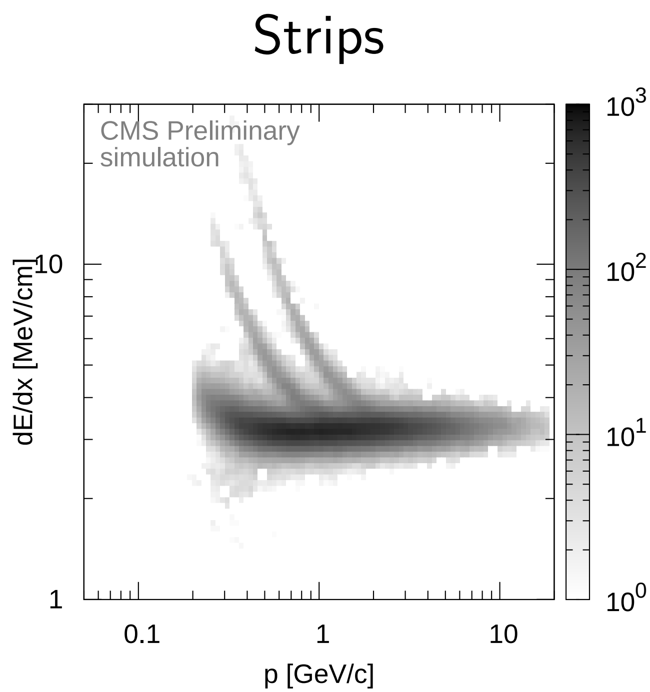


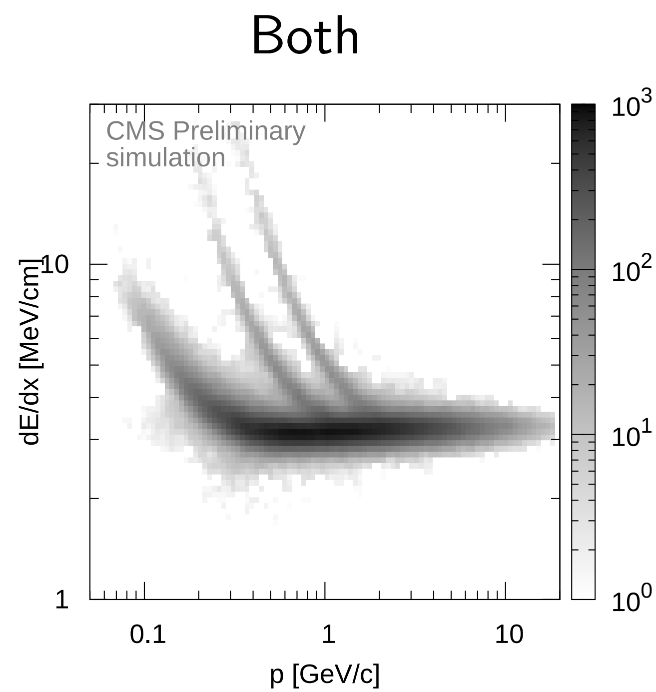
Comparison of simulated (histogram) and reconstructed (symbols), $0.4 < |\eta| < 0.6$

Can one identify these particles? ⇒ dE/dx

Particle identification – energy loss estimator



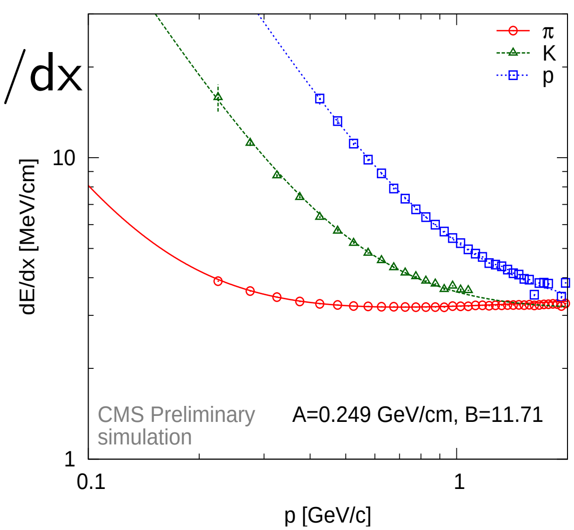




Truncated (average of lowest half) or weighted mean dE/dx
Proper treatment for overflows

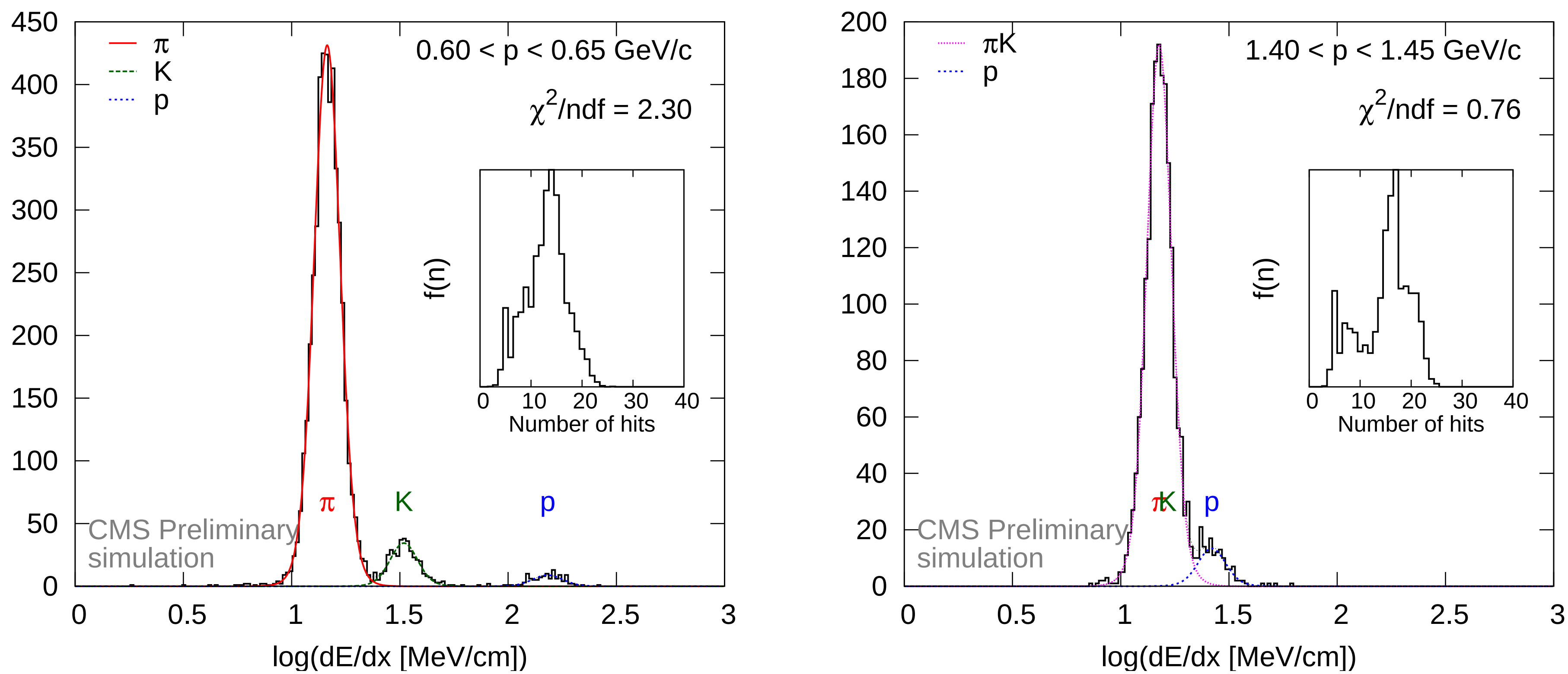
Combination of pixel and strip energy deposits

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 $\sigma \propto 1/\sqrt{n_{hits}}$

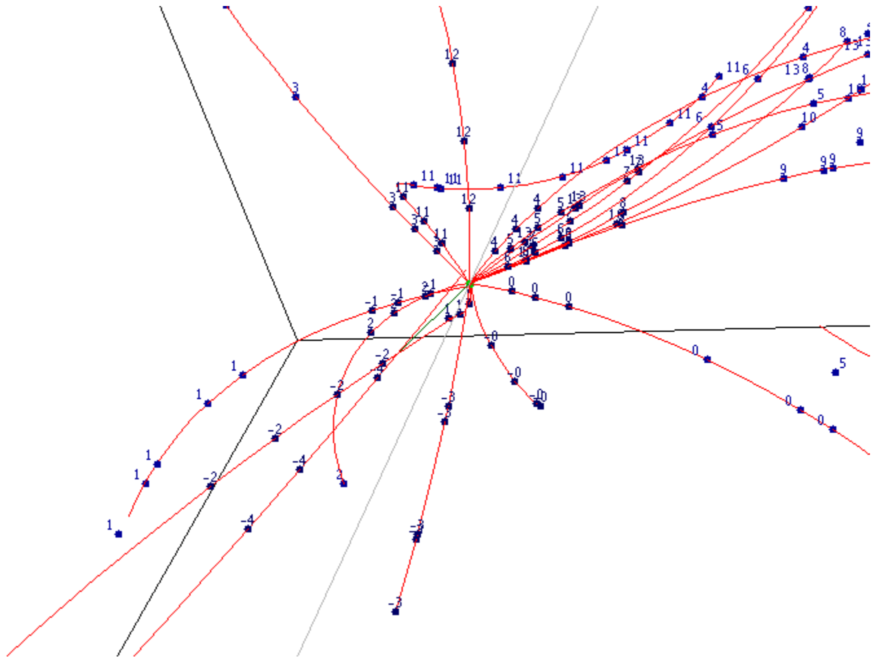
About 5-7% expected resolution, yields can be extracted

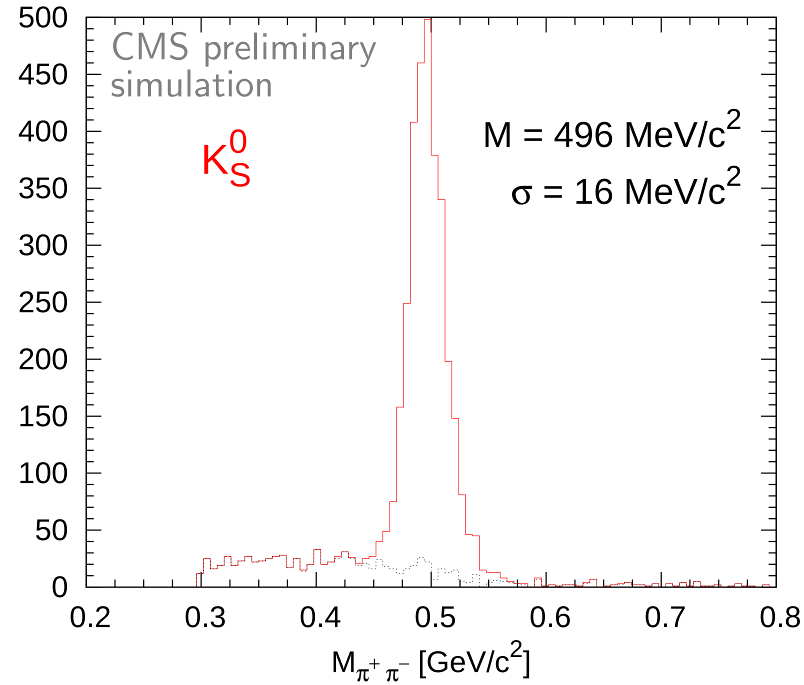
Momentum limit of yield extraction is set to 3σ separation

Could use $\beta\gamma$ scaling to fix parameters and push up limit

Particle identification – neutral particles

p-p @ 14 TeV (Pythia)



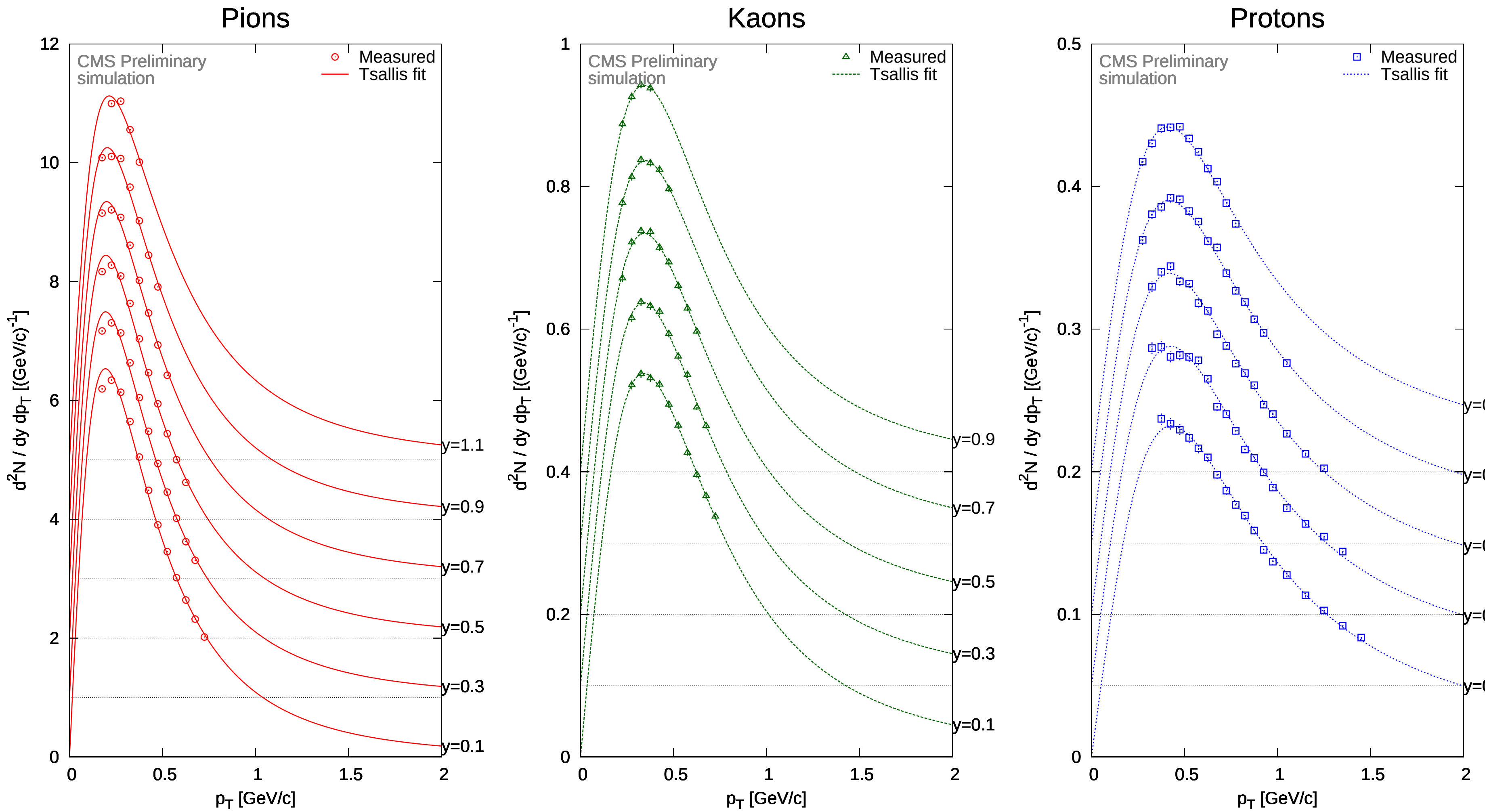


- Decay topology (V0)
  - Identified particle spectra and yields, neutrals: K_S^0, Λ, $\overline{\Lambda}$ and γ
  - Multi-strange baryons: Ξ^-, Ω^-

Access to neutral and multi-strange identified particles

Results – pions, kaons and protons

p-p @ 14 TeV (Pythia)



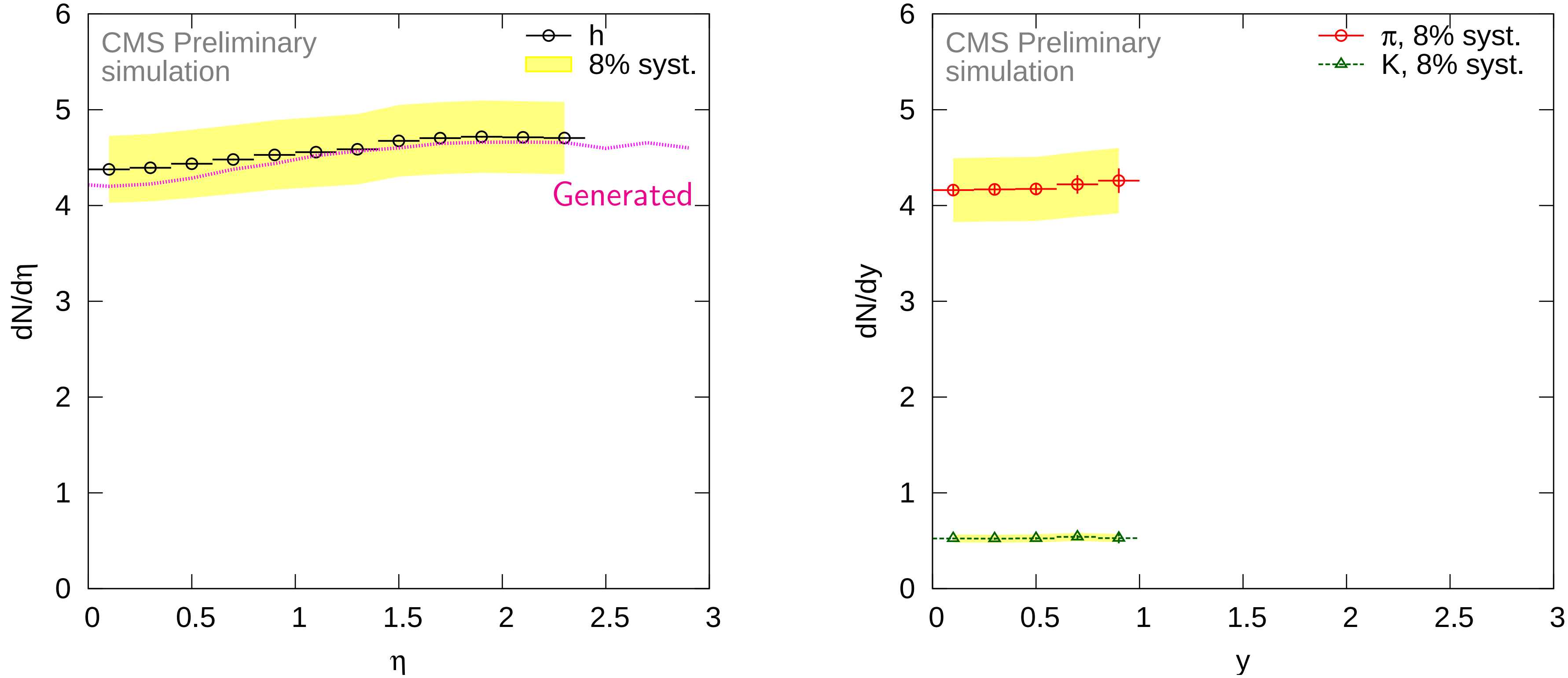
CMS PAS QCD-07-001

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

Rapidity dependence can be studied

Results – rapidity density

p-p @ 14 TeV (Pythia)



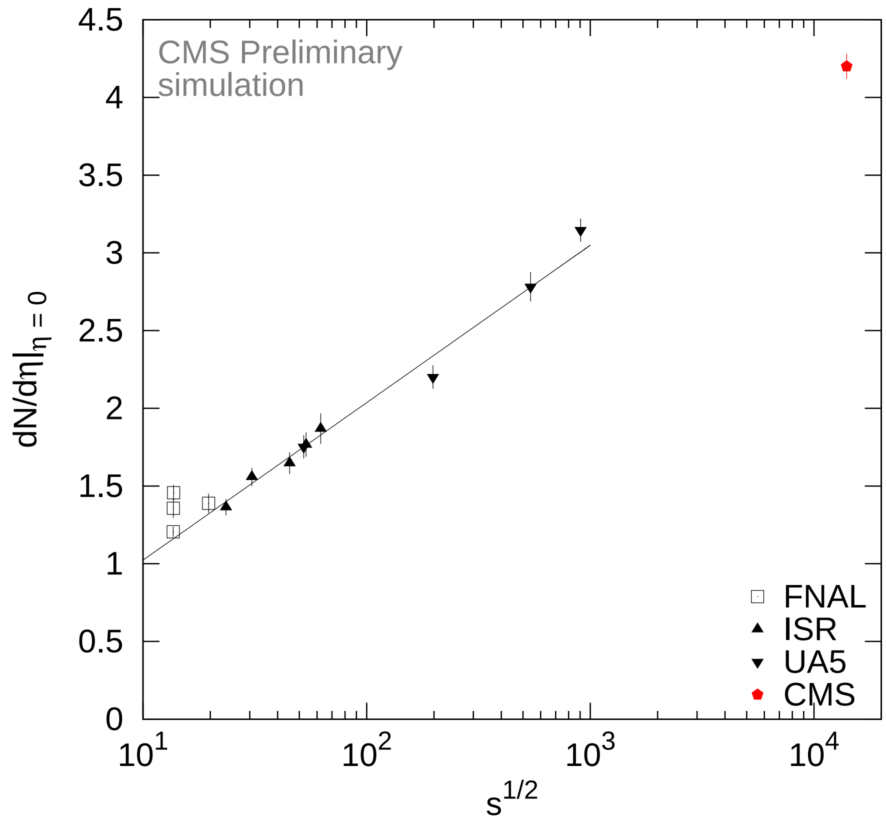
p_T spectrum is summed and integrated

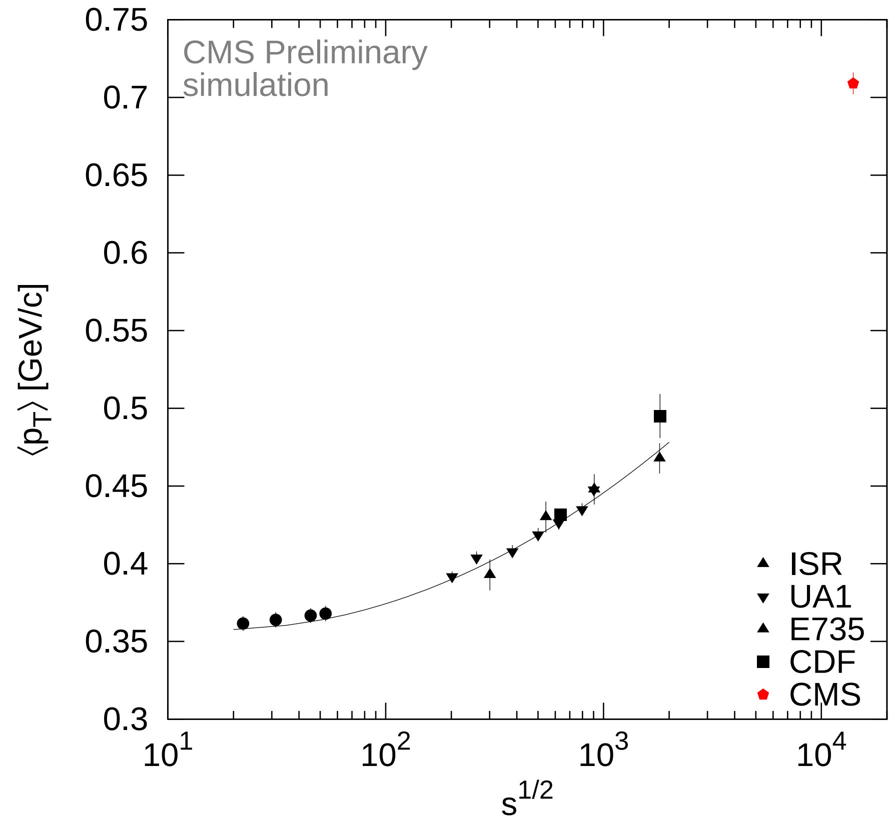
The acceptance of the tracker limits the accessible η/y range,
total number of produced charged particles cannot be measured

Total cross-section can be obtained using luminosity measurements

Results – energy dependence

p-p @ 14 TeV (Pythia)



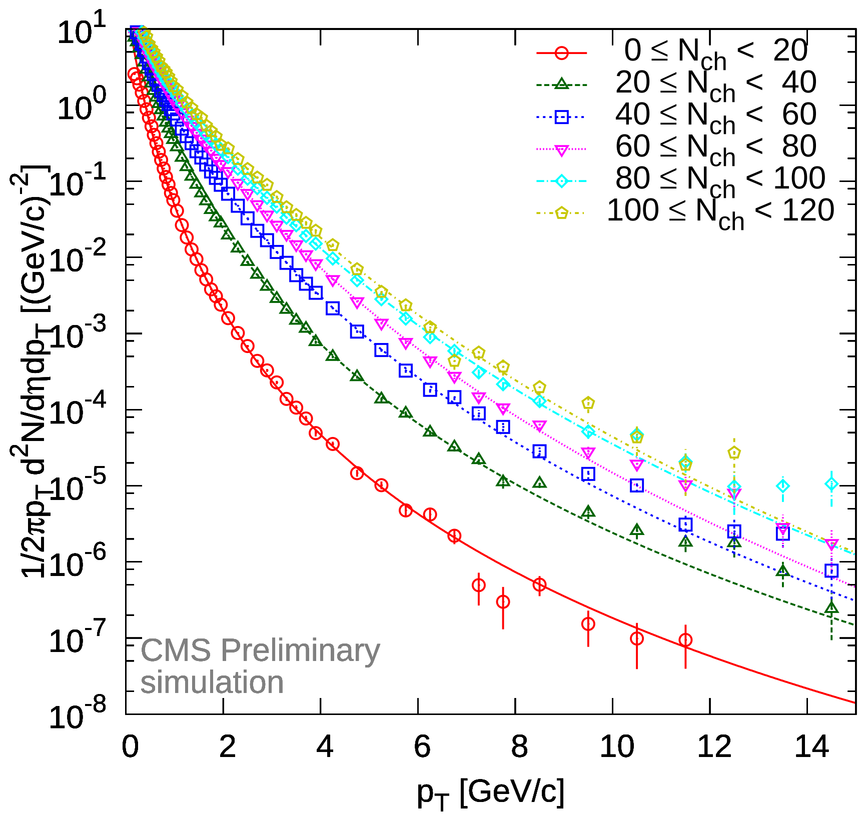


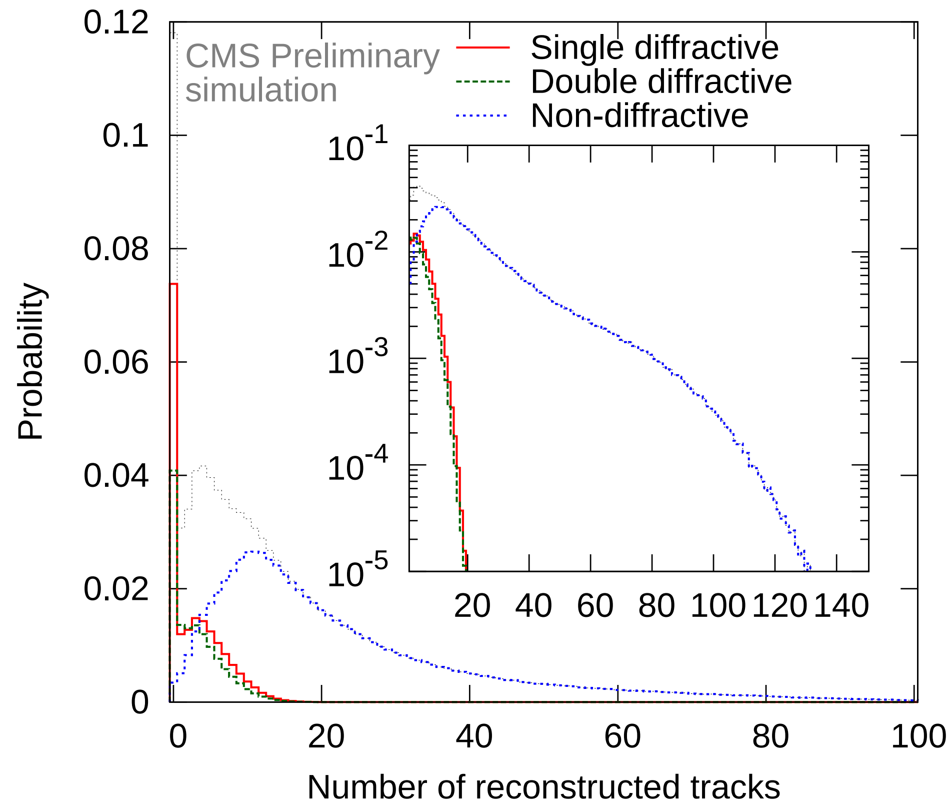
Comparison to lower energy measurements: FNAL, ISR, UA1, UA5, E735, CDF

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)



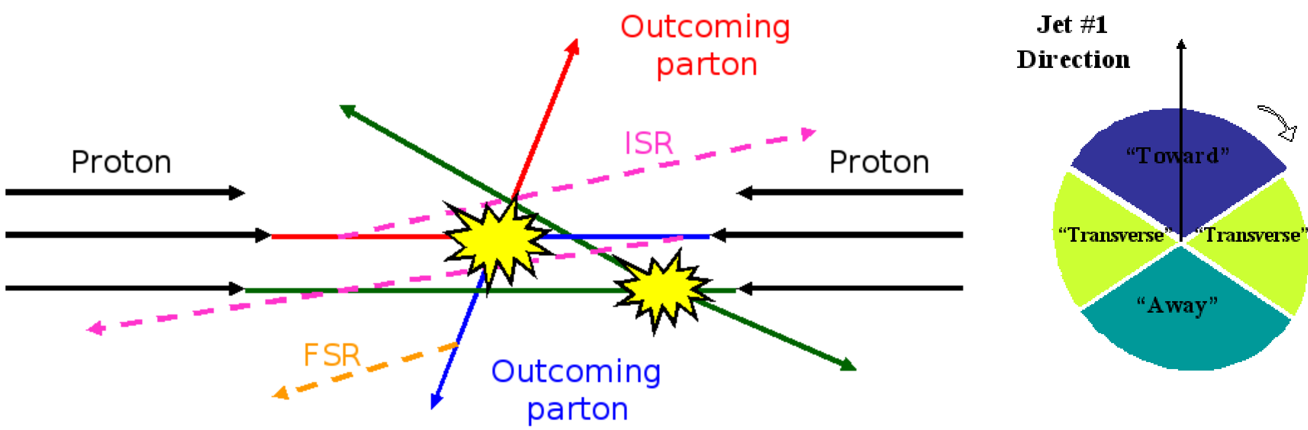


p_T distribution gets flatter
with increasing N_{ch}

After unfolding detector response
we can measure multiplicity distribution

Interesting physics (multiparton interactions, underlying event)

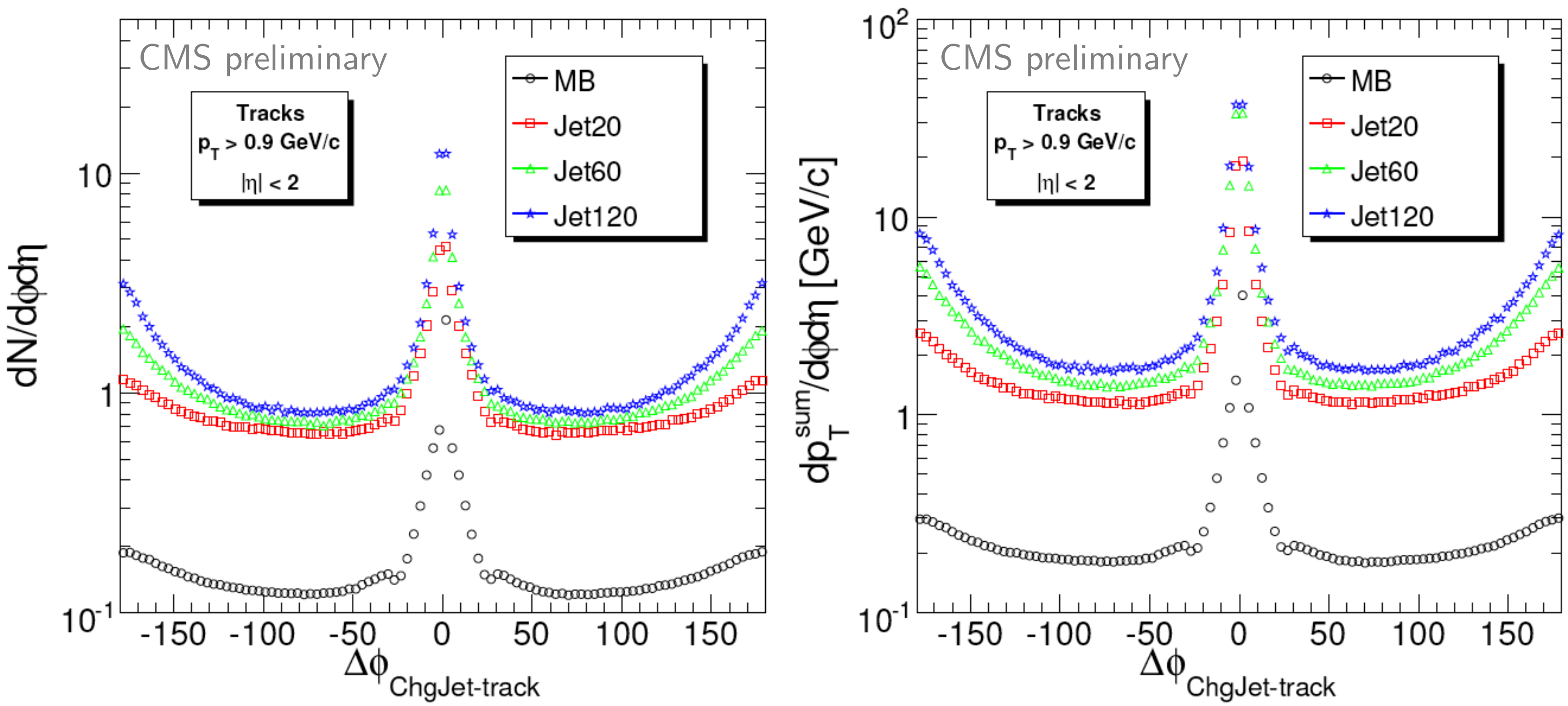
Underlying event studies



- What is underlying event (UE)?
  - All the activity of a single interaction on top of the "interesting" process
  - Initial and final state radiation, spectators, multiple parton interactions
  - UE is correlated with the interesting process: same vertex
  - Activity grows with the energy scale of the main interaction

- Why is it interesting?
  - Pythia tunes describe Tevatron data, but
  - Several differences extrapolating to LHC energy (14 TeV)

Underlying event studies

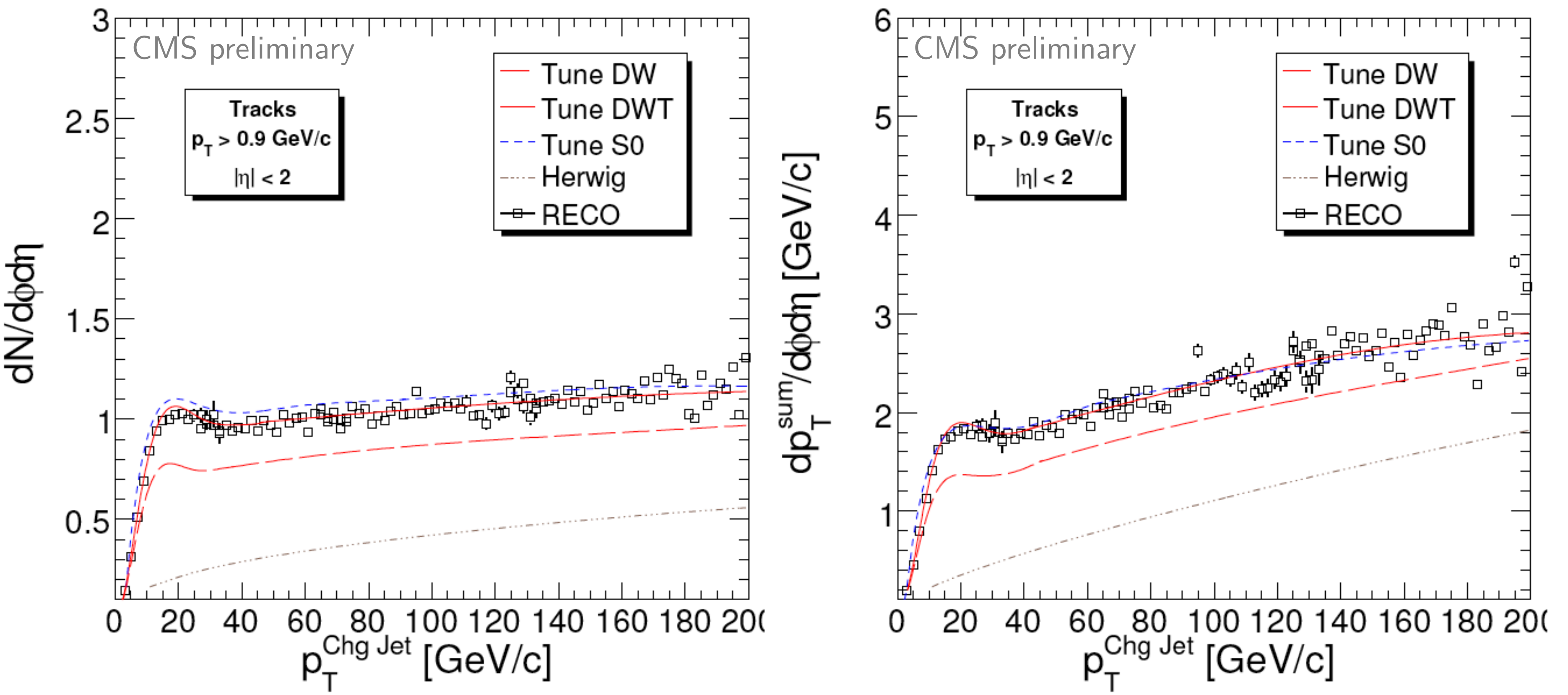


CMS PAS QCD-07-003

- Observables
  - Topology of proton-proton collision from charged jet, leading jet defines a direction in the ϕ plane
  - Charged density $dN/d\phi d\eta$
  - Energy density $dp_T^{sum}/d\phi d\eta$

The transverse region is particularly sensitive to UE

Underlying event studies

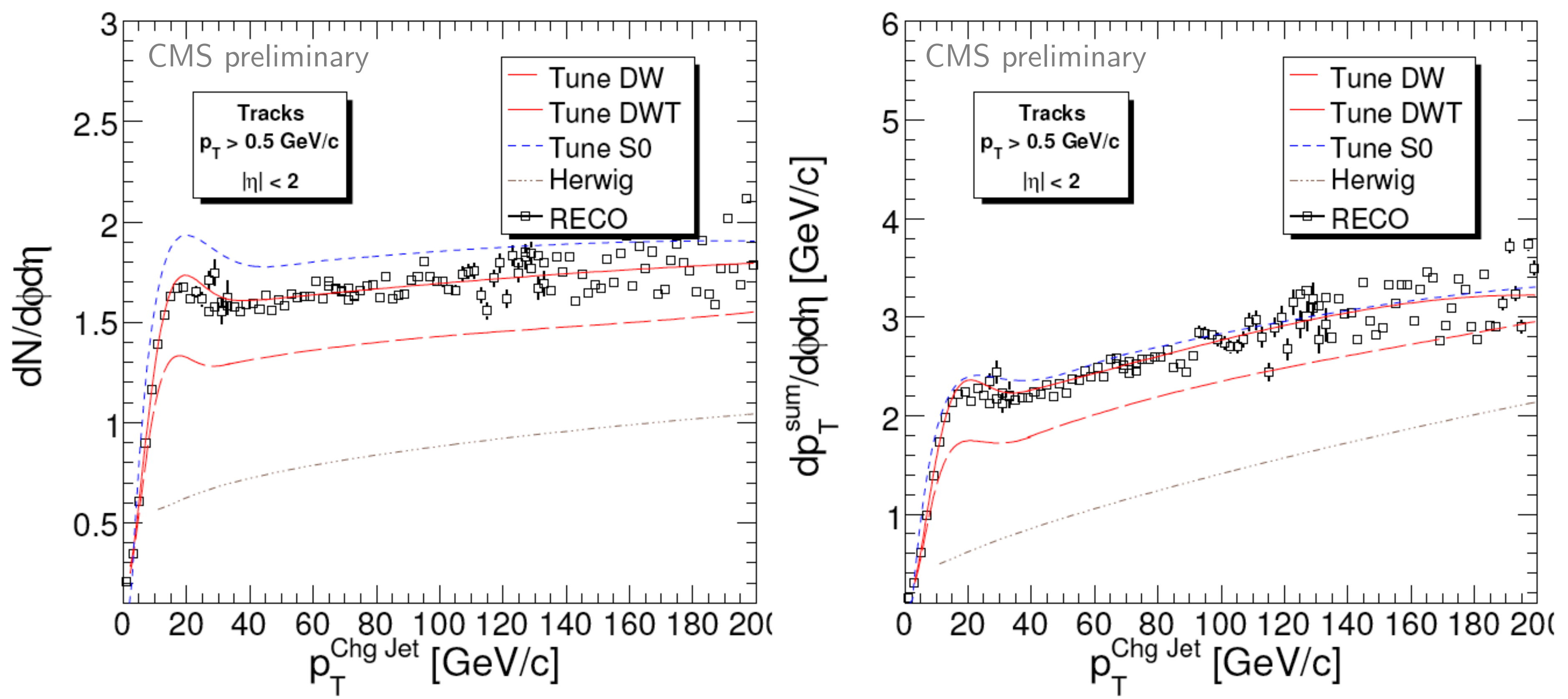


Comparison to several tunes, low p_T cut at 0.9 GeV/c

- Pythia tunes
  - DW: Q^2 ordered showers, Rick Field's tune
  - DWT: Q^2 ordered showers, Rick Field's tune with slower UE energy scaling
  - S0: interleaved p_T ordered showers, annealing color reconnections, Sandhoff-Skands Tune 0

Good discrimination power

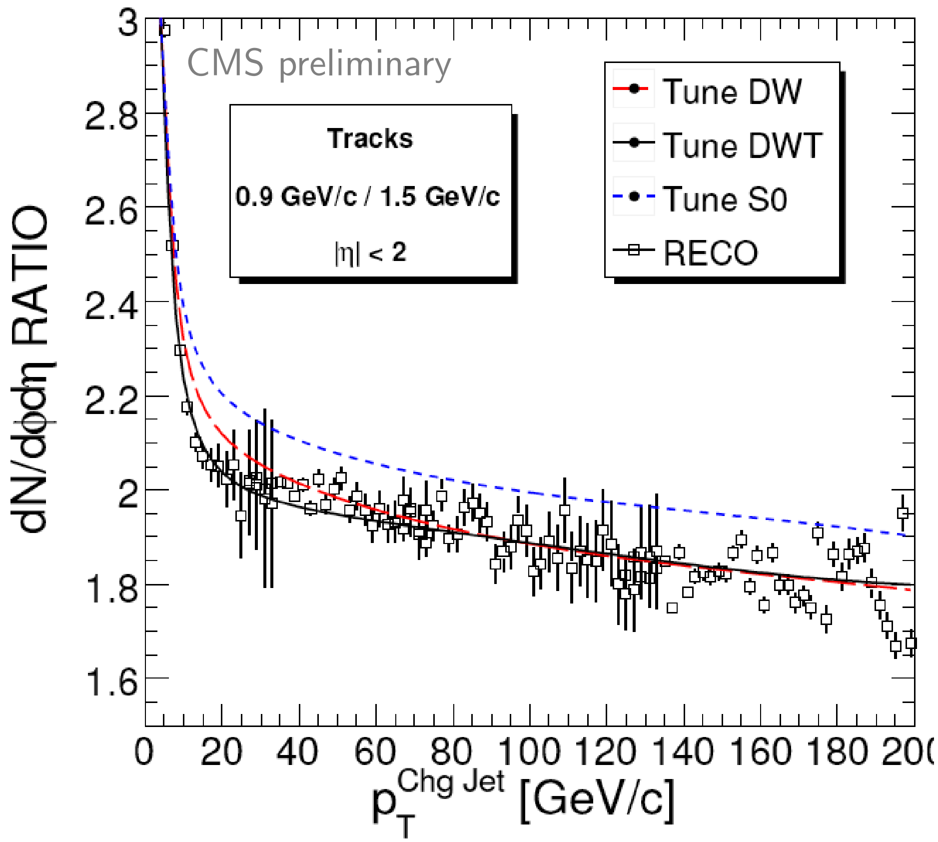
Underlying event studies

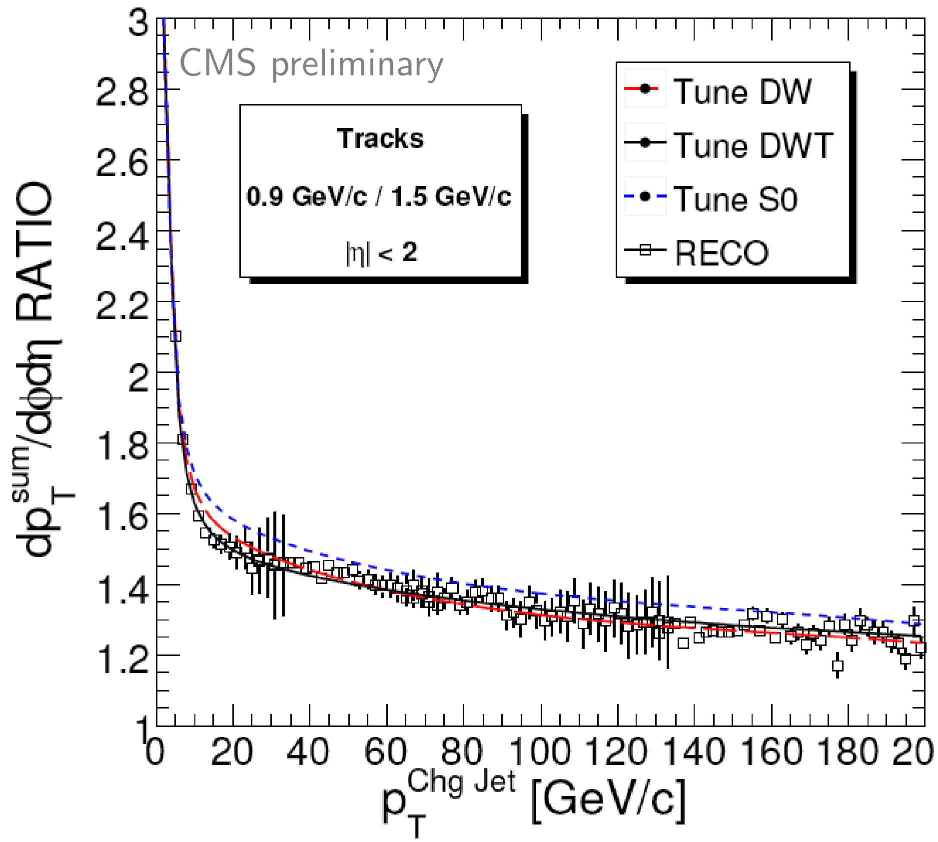


Comparison to several tunes, low p_T cut at 0.5 GeV/c
Mote Carlo based correction, event-by-event

Higher discrimination power

Underlying event studies





Ratios of observables using minimum p_T of 0.9 GeV/c and 1.5 GeV/c
Uncorrected data, but no need to apply corrections, absorbed in the ratio

Additional discrimination between tunes

Conclusions and outlook

- Inclusive hadron physics
  - Charged hadrons ($h^{\pm}$)
  - Identified charged particles via dE/dx ($\pi^{\pm}$, $K^{\pm}$, $p/\overline{p}$)
  - Identified neutral particles via decay (K^0_S, Λ, also Ξ^-, Ω^- and antiparticles)
  - Fundamental measurements (N, $dN/d\eta$, dN/dp_T), tests of models

- Underlying event physics
  - Tune energy dependence models (multiple parton interactions)
  - Improve the QCD understanding of p-p collisions

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

Interesting year ahead