Identified Hadron Production in pp and pPb with CMS

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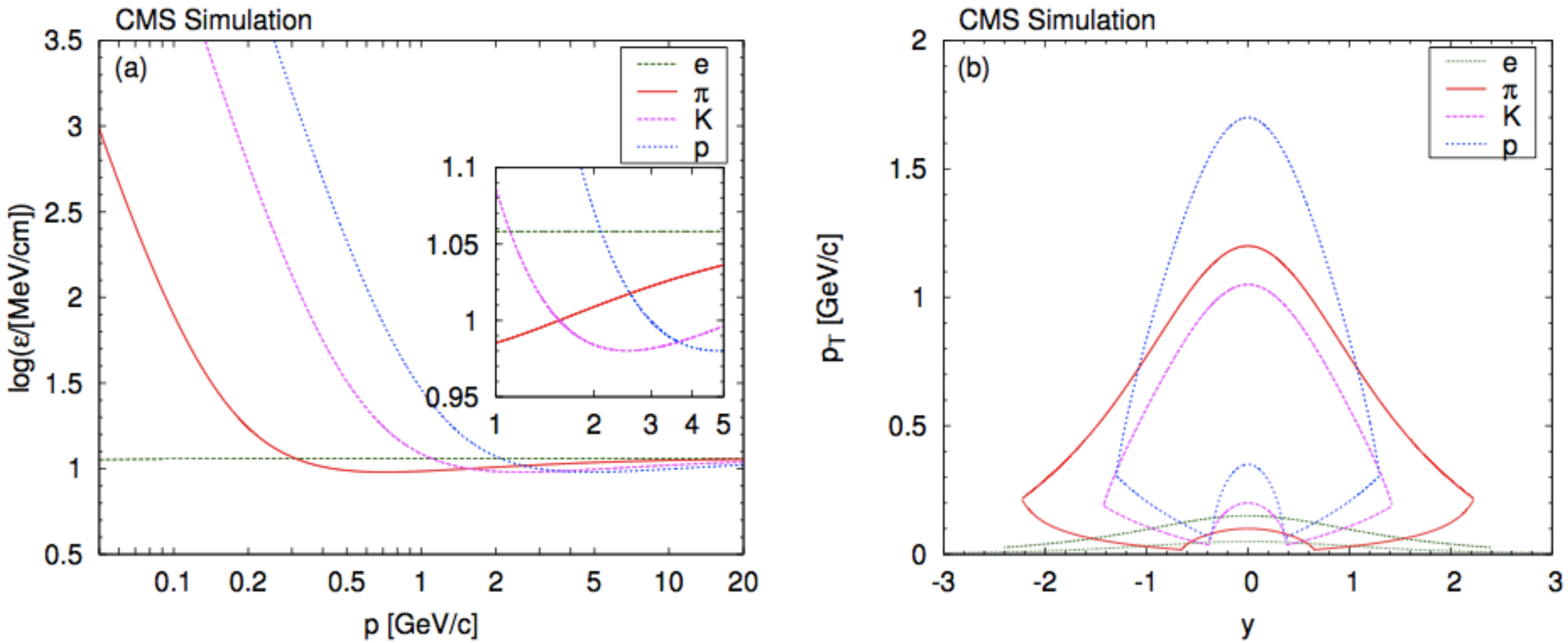
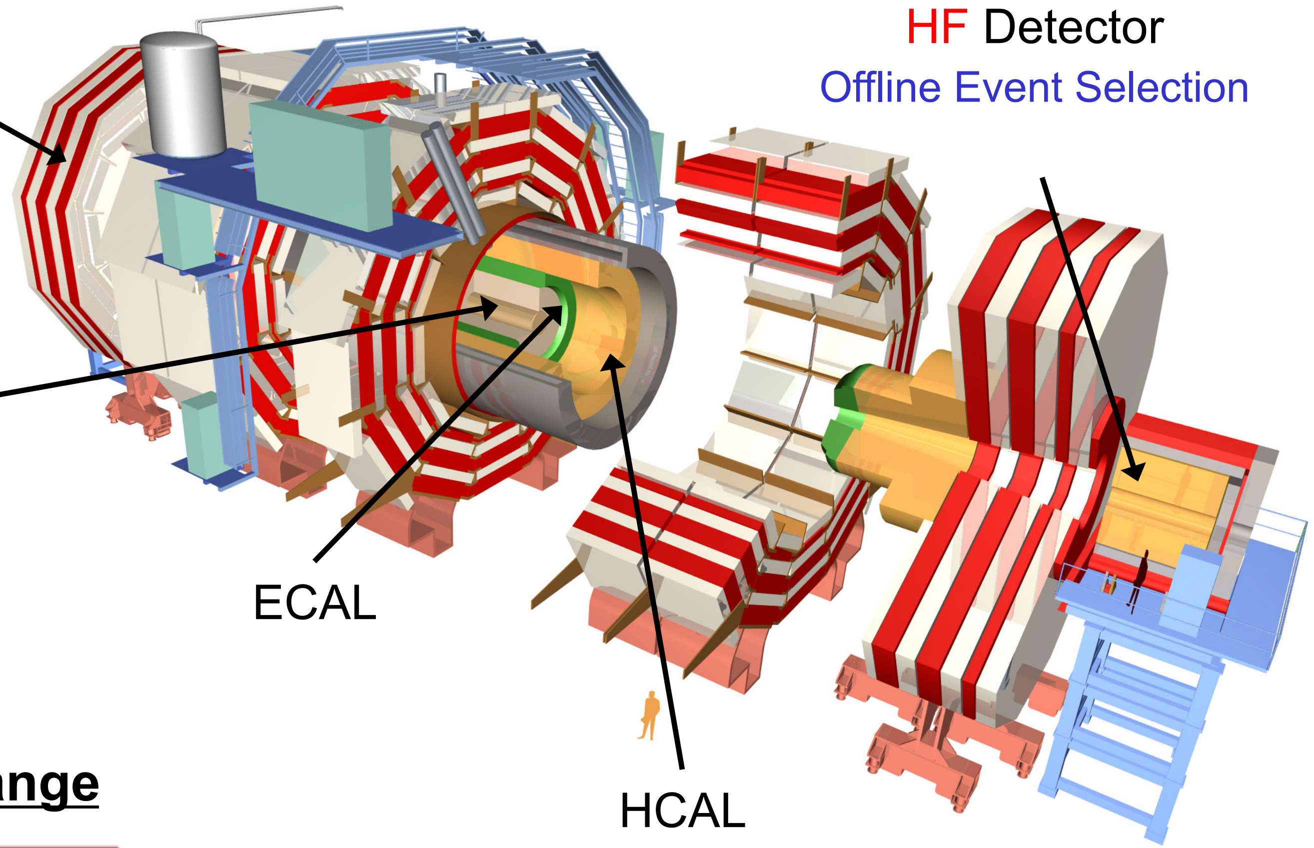
Introduction

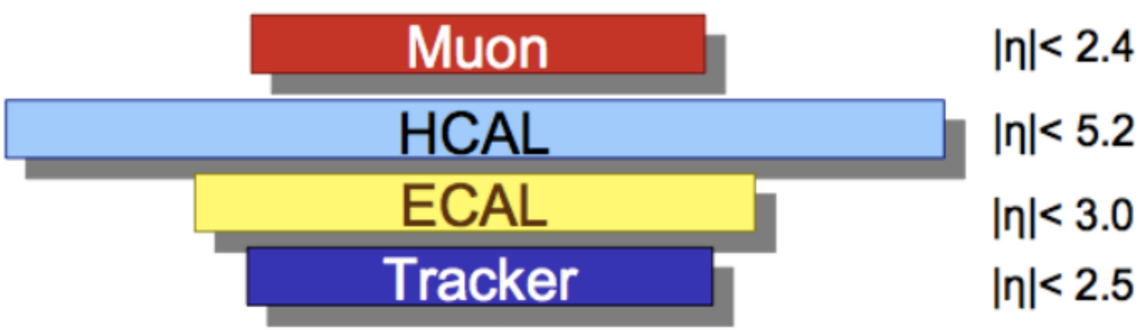


- Hadron Spectra
  - Test implementations of non-perturbative QCD processes in MC generators
  - Reference for heavy ion collisions, understanding of near-side pp ridge
- Particle Identification Capabilities
  - p<1.20 GeV/c for $\pi^{\pm}$, p<1.05 GeV/c for $K^{\pm}$, p<1.70 GeV/c for p/p-bar
  - Accessible region limited in η by the tracker, results given in |y| < 1

The CMS Detector

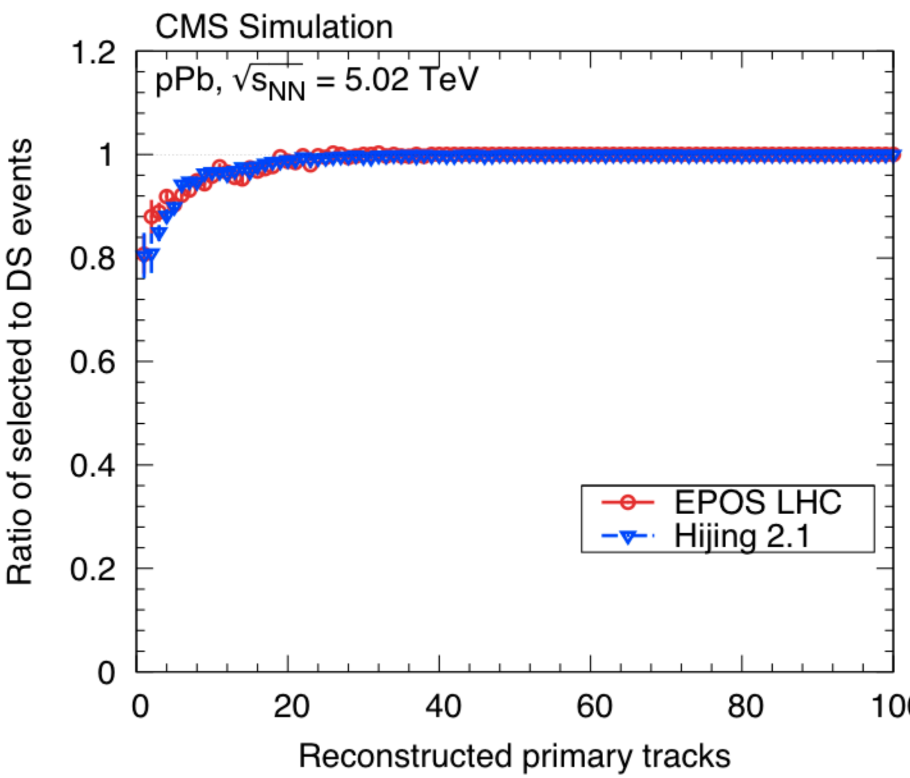


Pseudorapidity Range



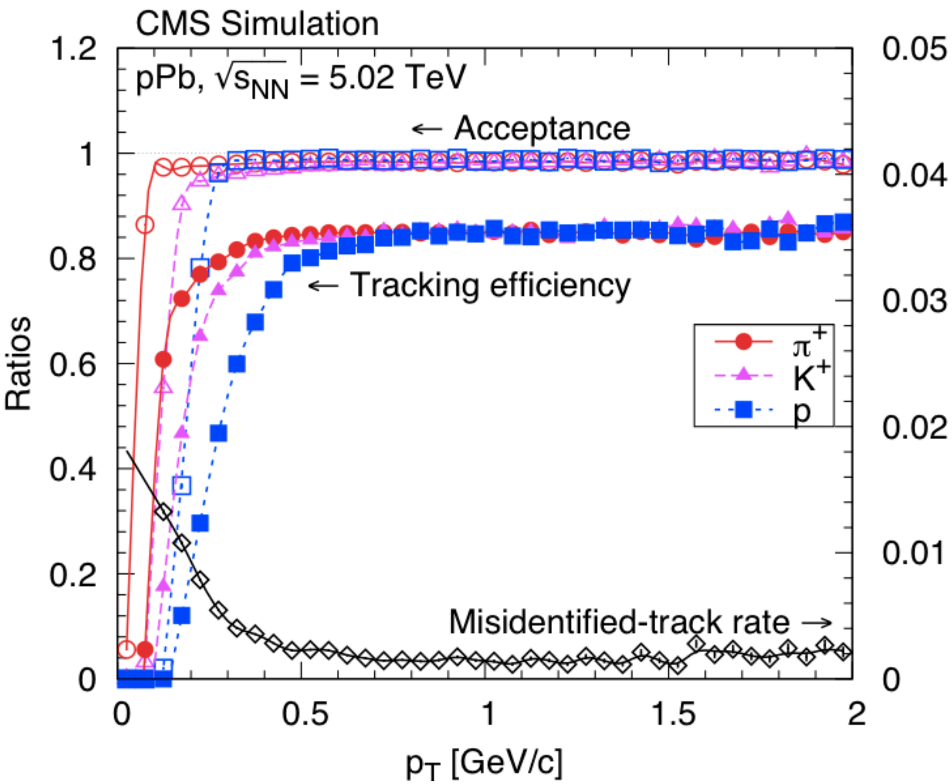
Data Sample and Event Selection

- **Data Sample**
  - Low-luminosity 4 hour test run from 2012
  - ~ 2M events, uncertainties dominated by systematics
- **Online and Offline Selection**
  - Coincidence of beam pickup device signals indicating bunch presence
  - Single pixel track (p_T > 400 MeV/c)
  - At least one HF calorimeter tower with E > 3 GeV on either side
  - Suppression of beam-halo and beam-background events.



- **Corrected to Simple Event Definition: "Double Sided" (DS)**
  - DS: At least one particle with E > 3 GeV in -5<η<-3, and in 3<η<5
  - Trigger efficiency close to 1 for DS events
  - DS represents 94-97% of inelastic collisions

Tracking Performance

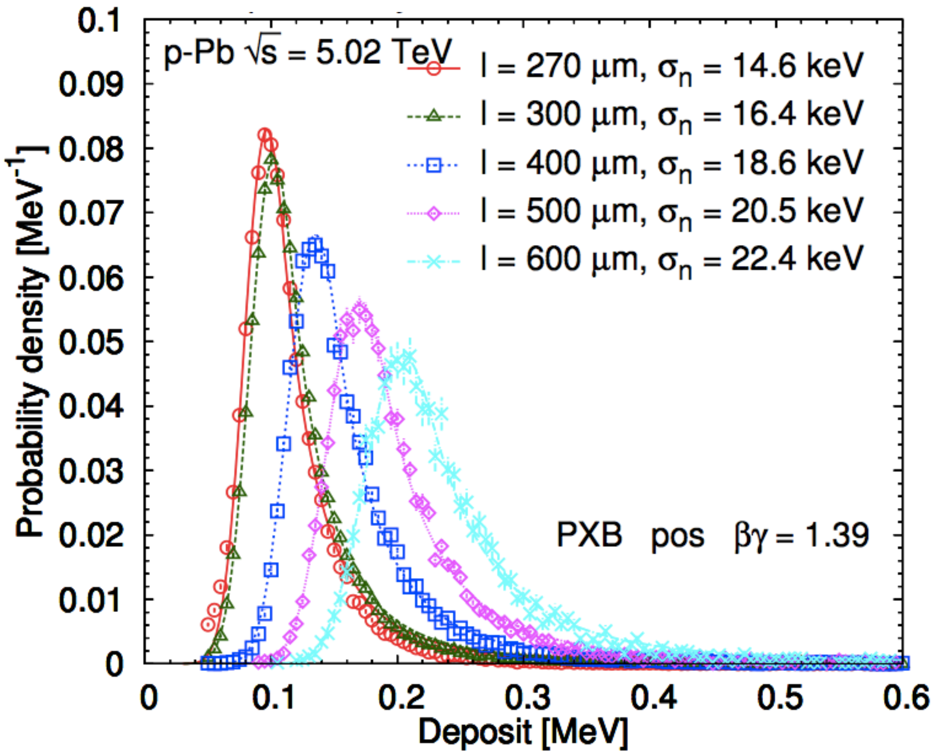


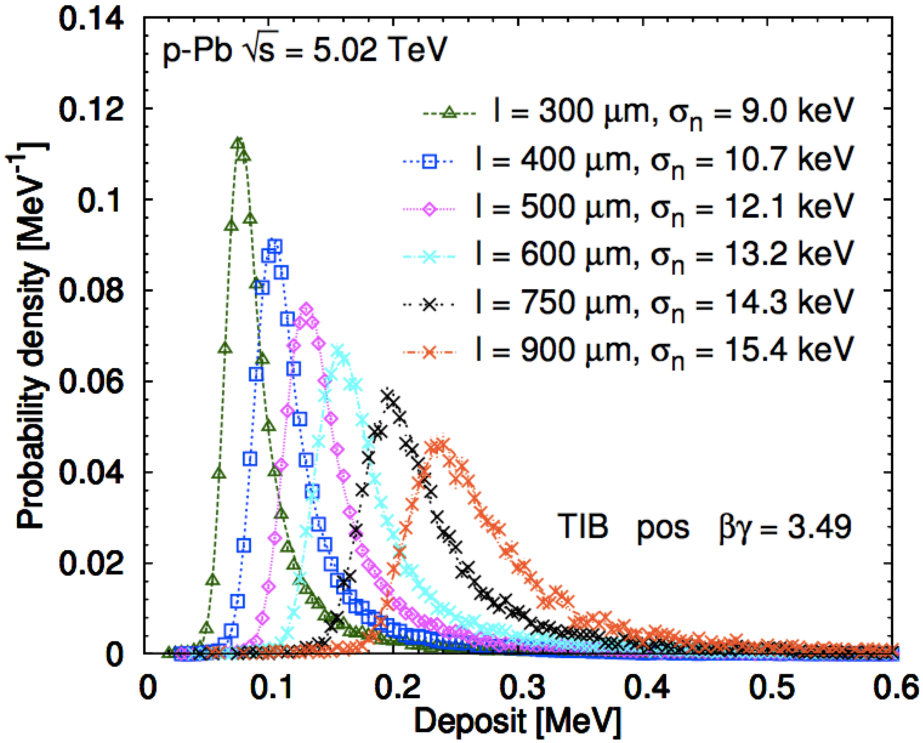
Tracking Performance

Special algorithm reconstructs pions down to p_T > 100 MeV/c

- **Tracking Corrections**
  - Acceptance, algorithmic efficiency, and misidentified-track rate
  - Unfolding p_T bias and resolution
  - Secondary (Feed-Down) correction tuned with data via measured K^0_S and $\Lambda/\overline{\Lambda}$ spectra

Validation of Energy Loss Parameterization

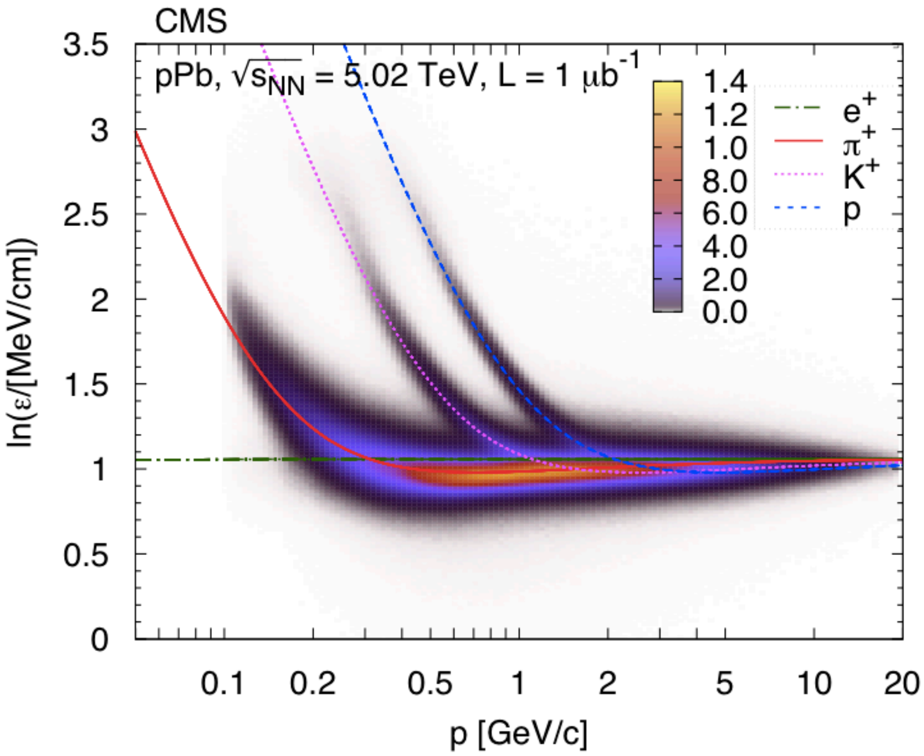




4 Parameter Analytical Parameterization of Energy Loss

- Model has Gaussian and exponential parts, [see F. Siklér, *Nucl. Instrum. Meth. A* **691** (2012) 16)]
- Determine probability distribution P(Δ | ε,l)
- Energy deposit Δ given path length l and known most probable energy loss ε
- Very good match

Most Probable Energy Loss Rate



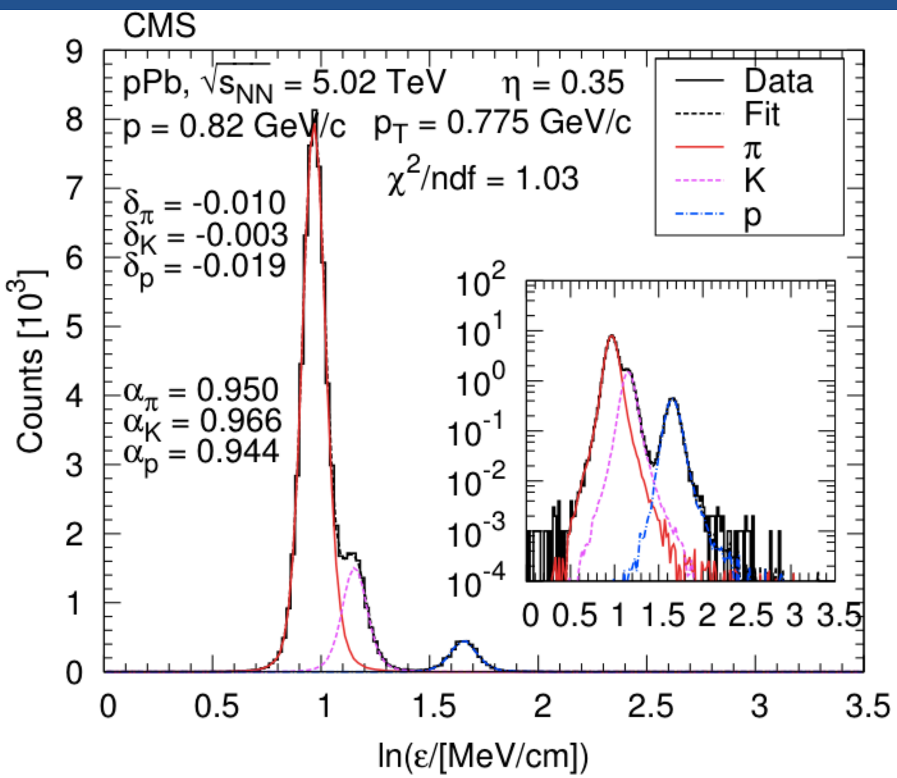
Determine value of ε to minimize the negative log likelihood over all hits on the track:

$$\chi^2 = -2\sum_i \ln P(\Delta_i|\varepsilon, l_i)$$

Δ_i is the corrected energy deposit and l_i the path length of the *i*th hit.

Energy deposit outliers from false hits removed, affecting 1.5% of tracks

Template Fits in (η, p_T) Bins



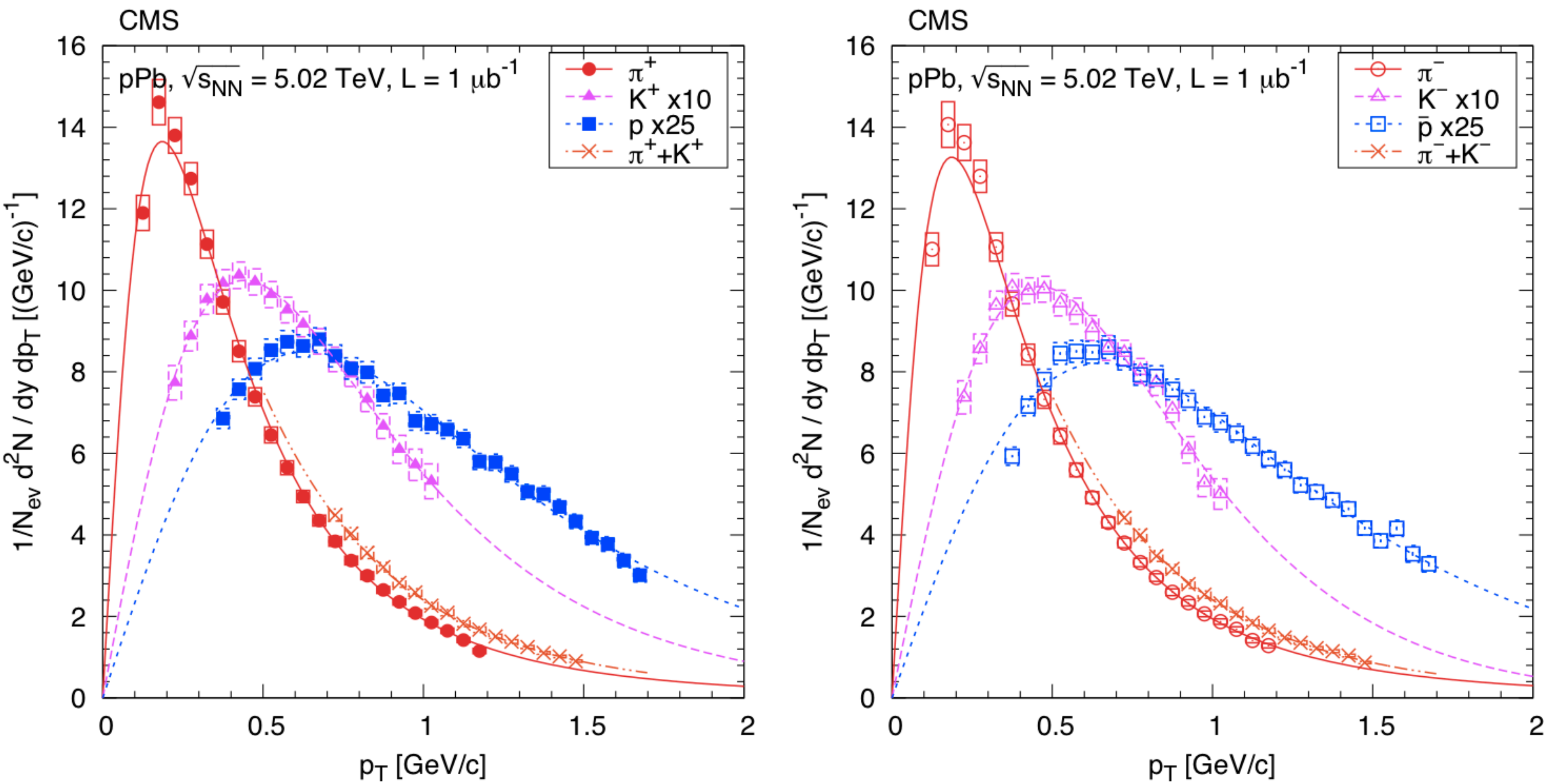
- Non-gaussian shape distributions for each species
- Track-level residual correction: $\ln \varepsilon \to \alpha \ln \varepsilon + \delta$, determined by enhanced particle samples
- High quality fits, good χ^2 / ndf

Systematic Uncertainties

Source	*Uncertainty of the source* [%]	*Propagated yield uncertainty* [%]		
Fully correlated, normalisation				
Correction for event selection	3.0 (1.0)	3.0 (1.0)		
Pileup correction (merged and split vertices)	0.3			
Mostly uncorrelated				
Pixel hit efficiency	0.3	0.3		
Misalignment, different scenarios	0.1			
Mostly uncorrelated, (y, p_T) dependent		π	K	p
Acceptance of the tracker	1–6	1	1	1
Efficiency of the reconstruction	3–6	3	3	3
Multiple-track reconstruction	50% of the corr.	–	–	–
Misreconstructed-track rate	50% of the corr.	0.1	0.1	0.1
Correction for secondary particles	20% of the corr.	0.2	–	2
Fitting $\log \varepsilon$ distributions	1–10	1	2	1

Results

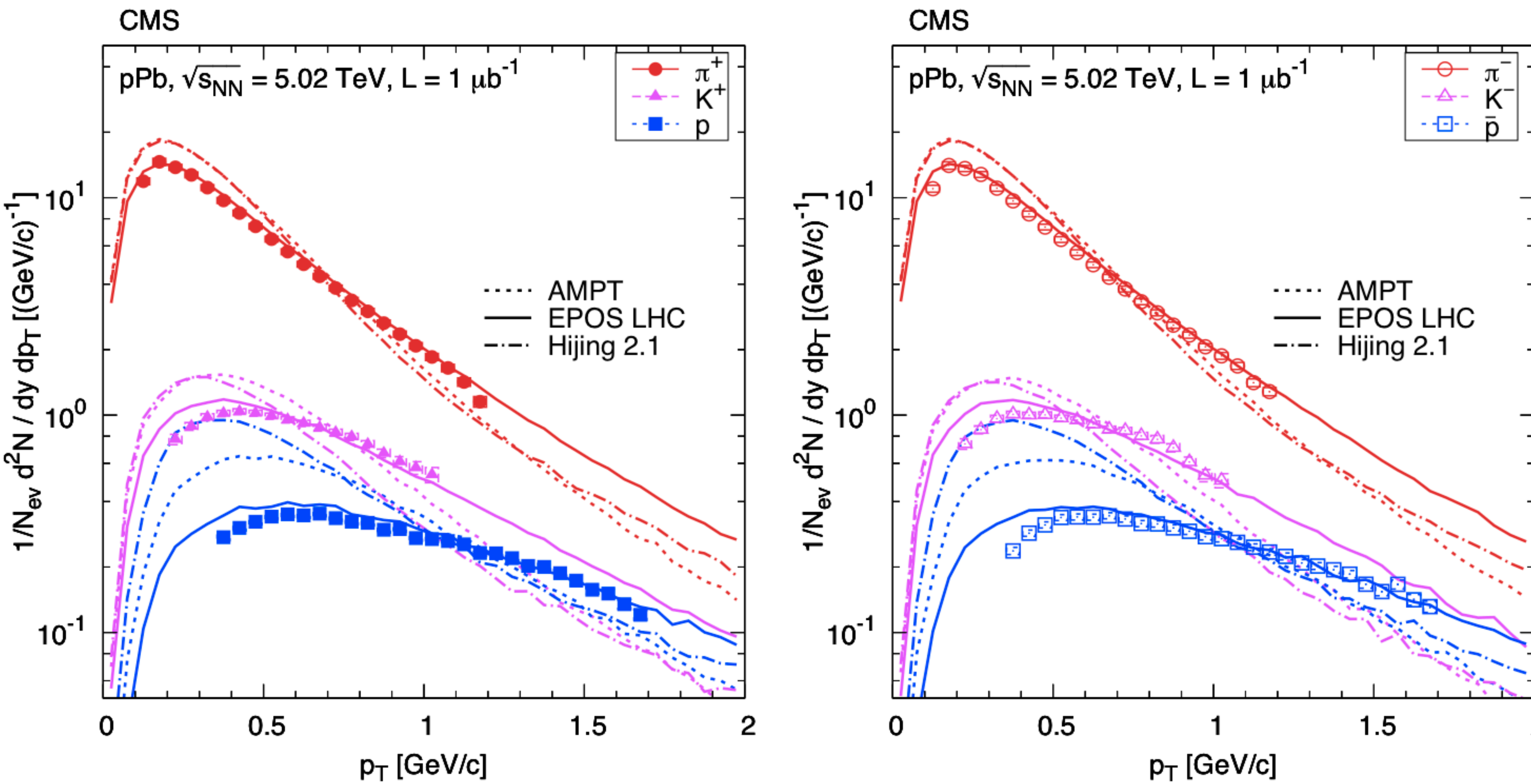
p_T Spectra



Tsallis-Pareto Type Fit: $$\frac{d^2N}{dy\,dp_T} = \frac{dN}{dy} \cdot C(m,n,T) \cdot p_T \left[1 + \frac{(m_T - m)}{nT}\right]^{-n}$$

Fully correlated normalization uncertainty (3%) is not shown.

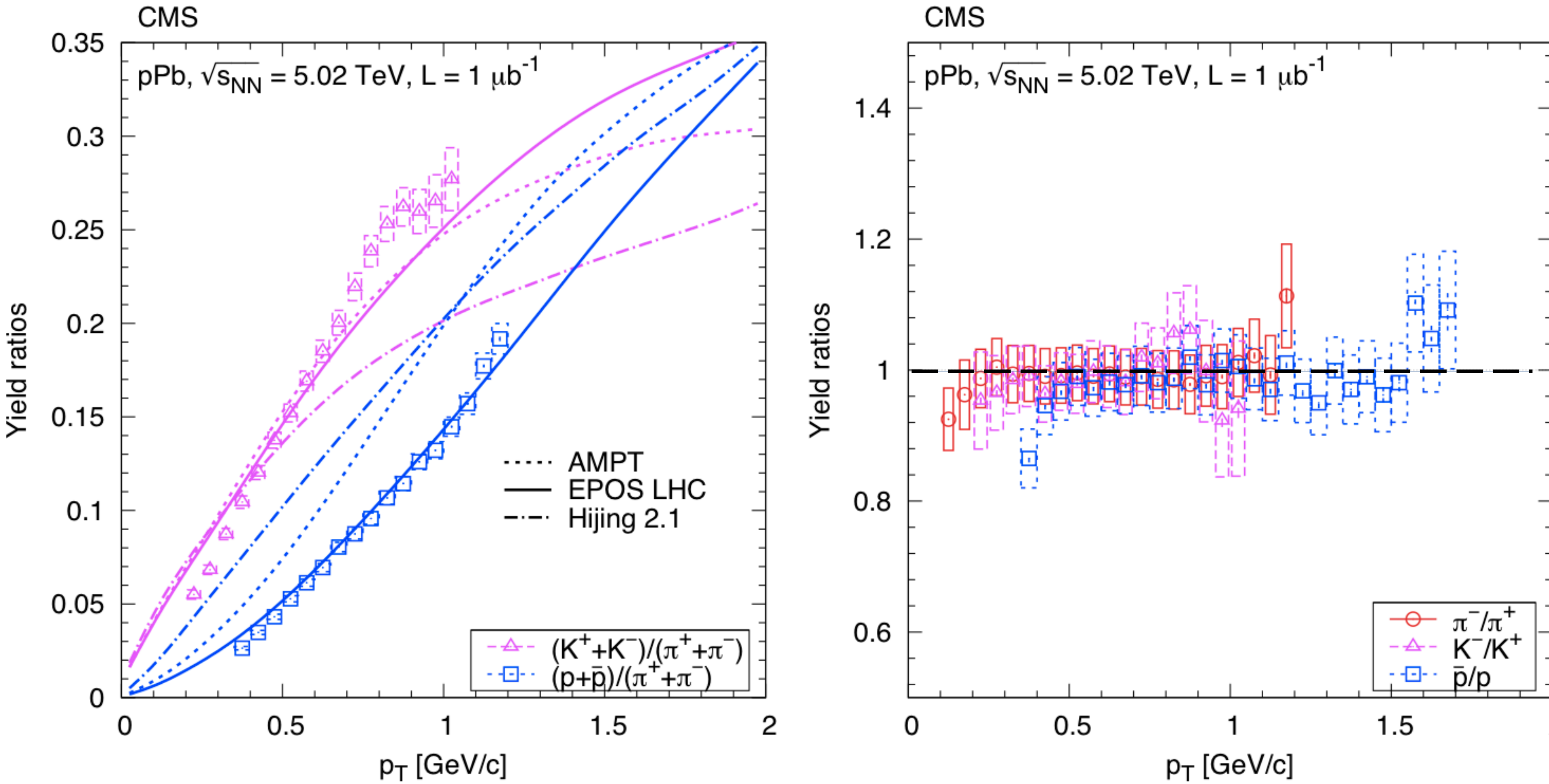
p_T Spectra



EPOS LHC describes the spectra well,

AMPT and Hijing predict steeper p_T distributions than in data

p_T Dependence of Relative Yields



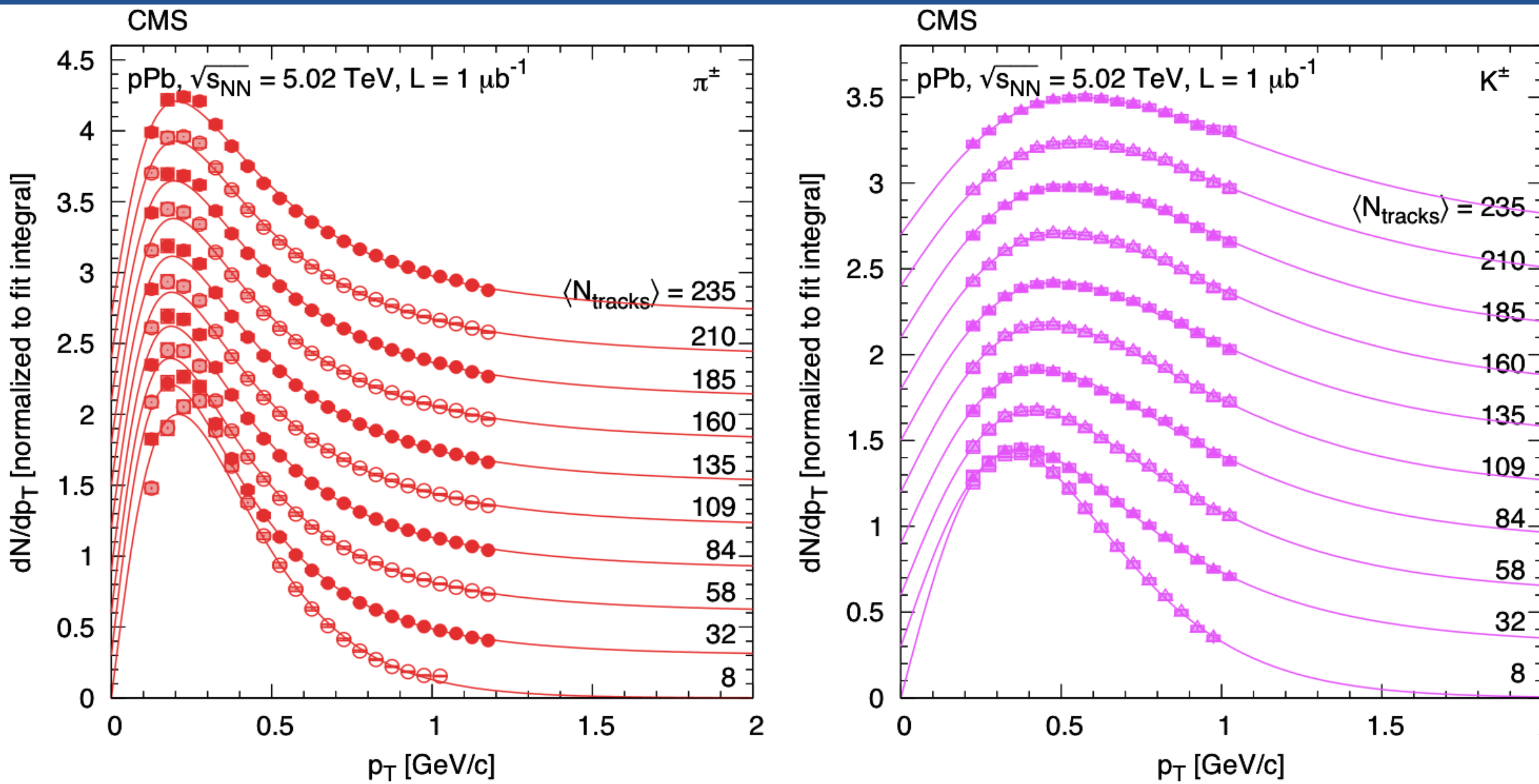
- AMPT decribes K/π, but only EPOS LHC describes both K/π and p/π
- Ratios of oppositely charged particles are close to 1

Event Multiplicity Classes

- Take the measured $d^2N/d\eta dp_T$ values
- Use MC corrections adjusted using PID ratios from data
- Correct for p_T<100 MeV/c assuming a linear startup
- The fully corrected number of hadrons is given in $|\eta|<2.4$: $\langle N_{tracks} \rangle$

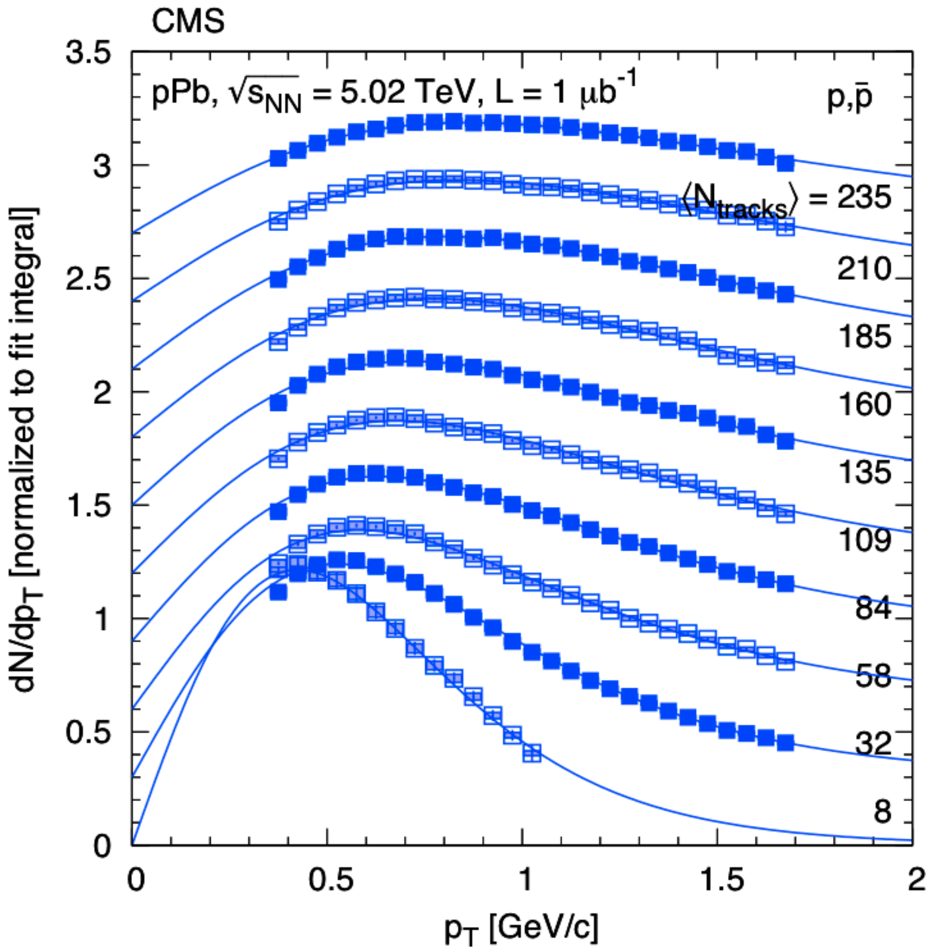
N_{rec}	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-99	100-109	110-119	120-129	130-139	140-149	150-159	160-169	170-179	180-189
$\langle N_{tracks} \rangle$	8	19	32	45	58	71	84	96	109	122	135	147	160	173	185	198	210	222	235
$\langle N_{tracks} \rangle_{p_T > 0.4\,GeV/c}$	3	8	15	22	29	36	43	50	58	65	73	80	87	95	103	110	117	125	133

Multiplicity Classes – p_T Spectra



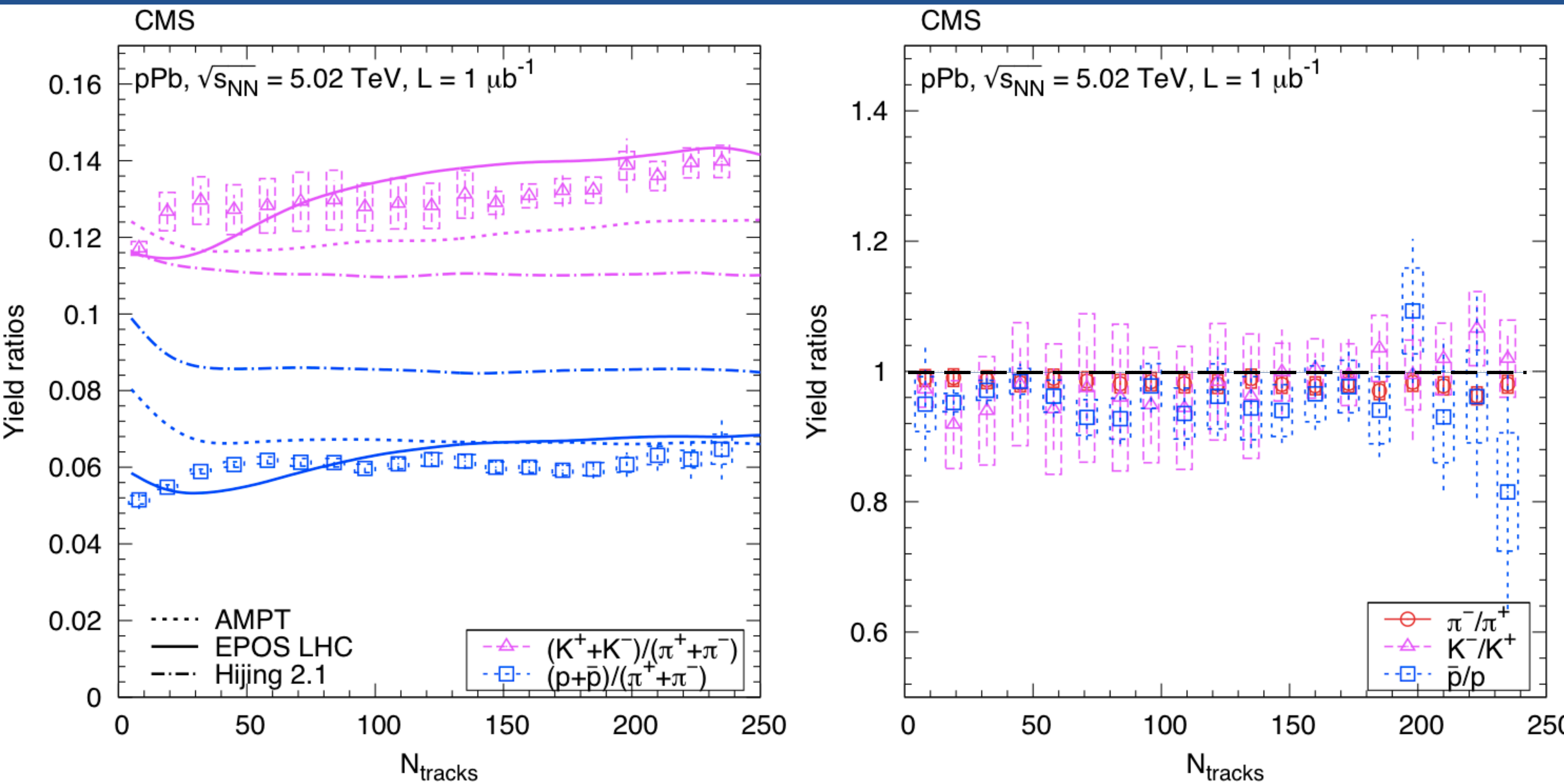
- Values with increasing multiplicity are shifted vertically by 0.3 units
- Tsallis-Pareto fits are shown
- Spectral shape changes for kaons, but not significantly for pions.

Multiplicity Classes – p_T Spectra



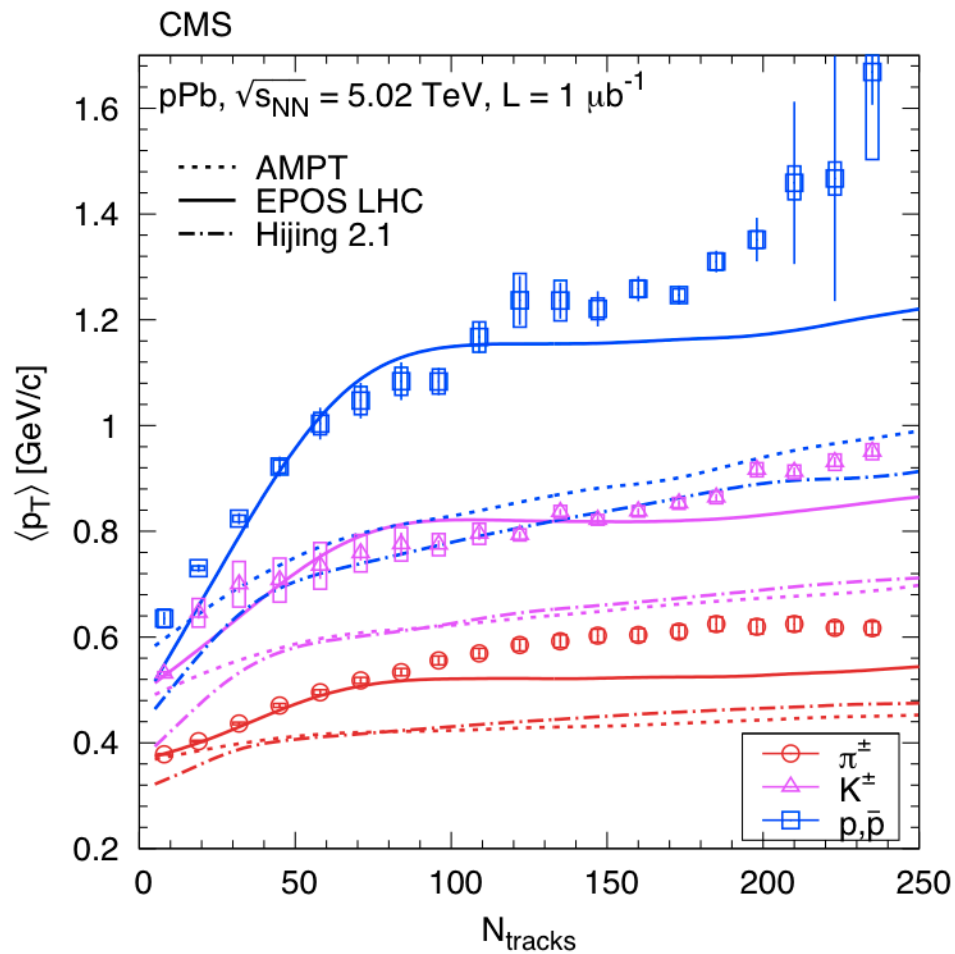
- Spectral shape changes strongly for protons.

Multiplicity Classes – Yield Ratios



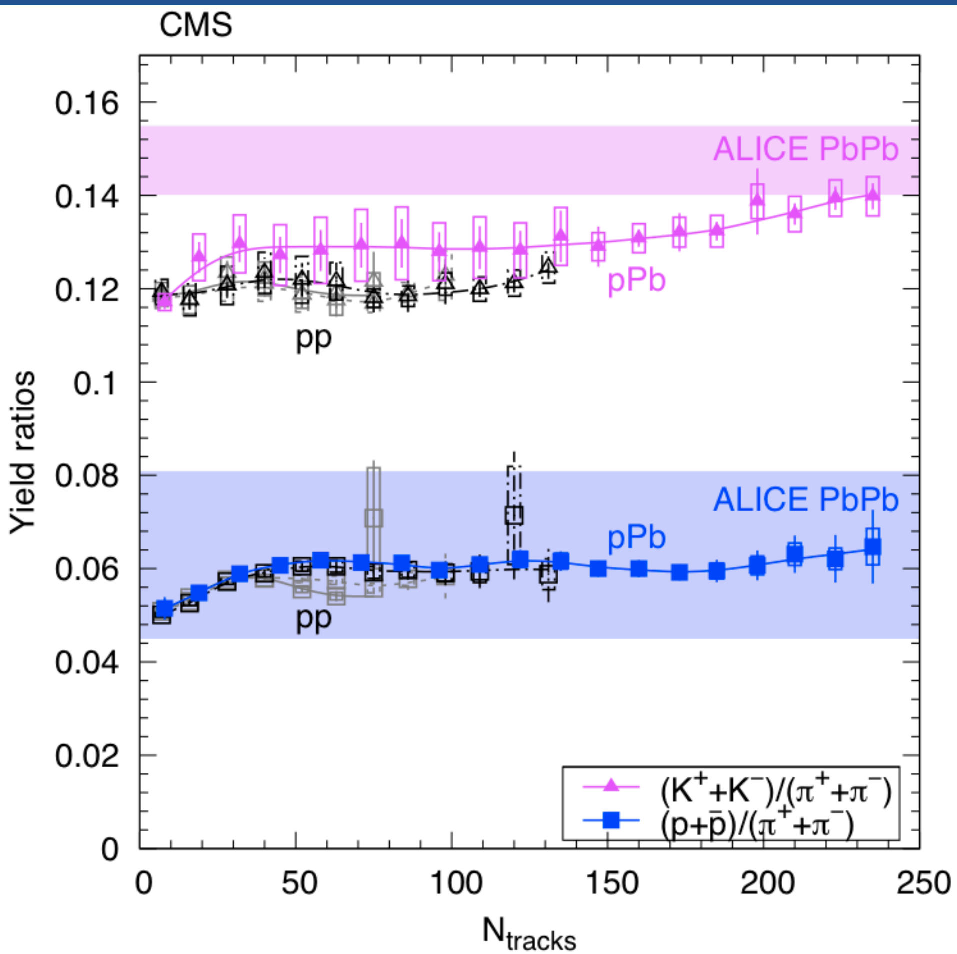
- K/π and p/π are slowly rising, EPOS LHC describes them best
- Ratios of oppositely charged particles are close to 1

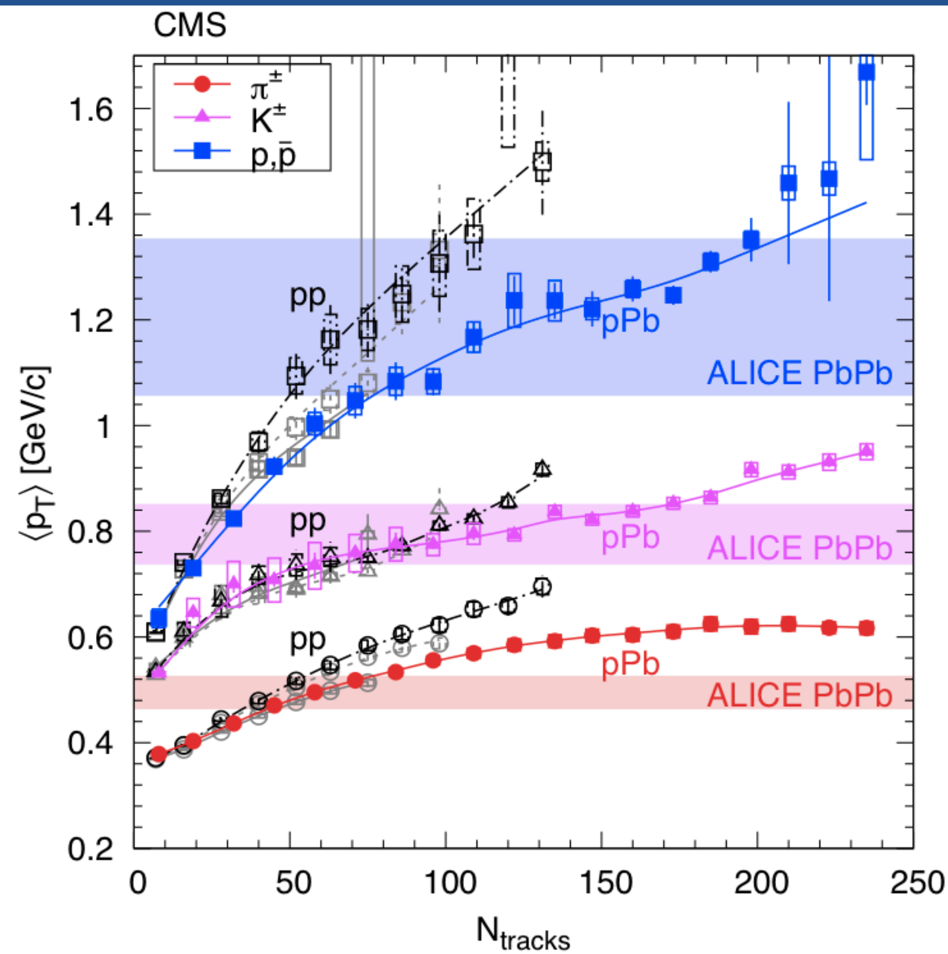
Multiplicity Classes – $\langle p_T \rangle$



- Average p_T values are much higher in data than AMPT or HIJING

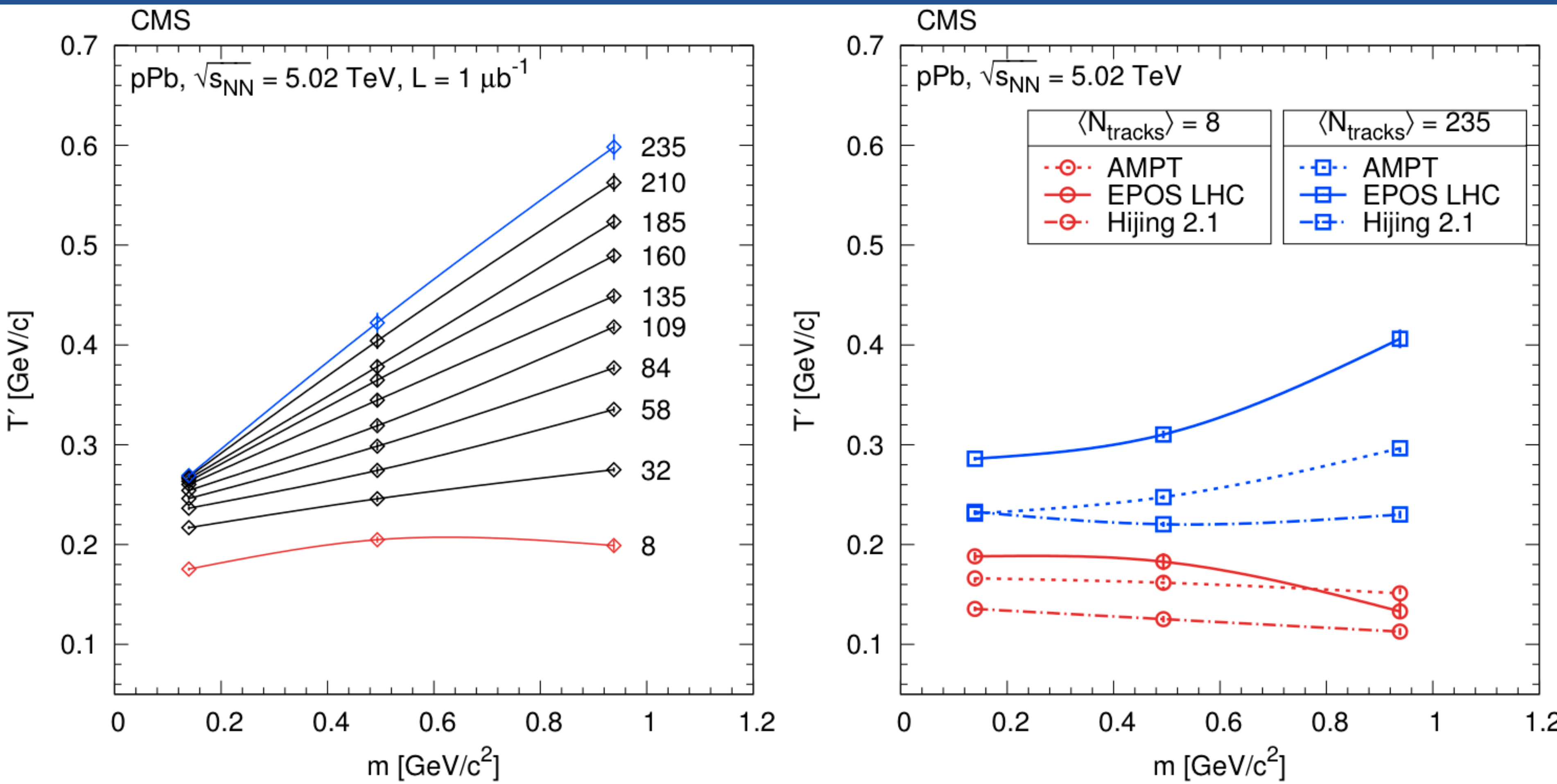
Comparison – pp – pPb - PbPb





- Yield ratios: similar in pp and pPb
- $<p_T>$: pPb behaves similar to pp for $N_{track}<40$, but it is flatter for $N_{tracks}>50$
- $<p_T>$: grows higher for pPb than for PbPb, most violent collisions selected in pPb

Inverse Slope Parameter



- Inverse slope parameter taken from $p_T \exp(-m_T/T')$ fits
- Linear dependence on mass with a slope that increases with particle multiplicity
- Generator predictions are flatter than data for high multiplicity events

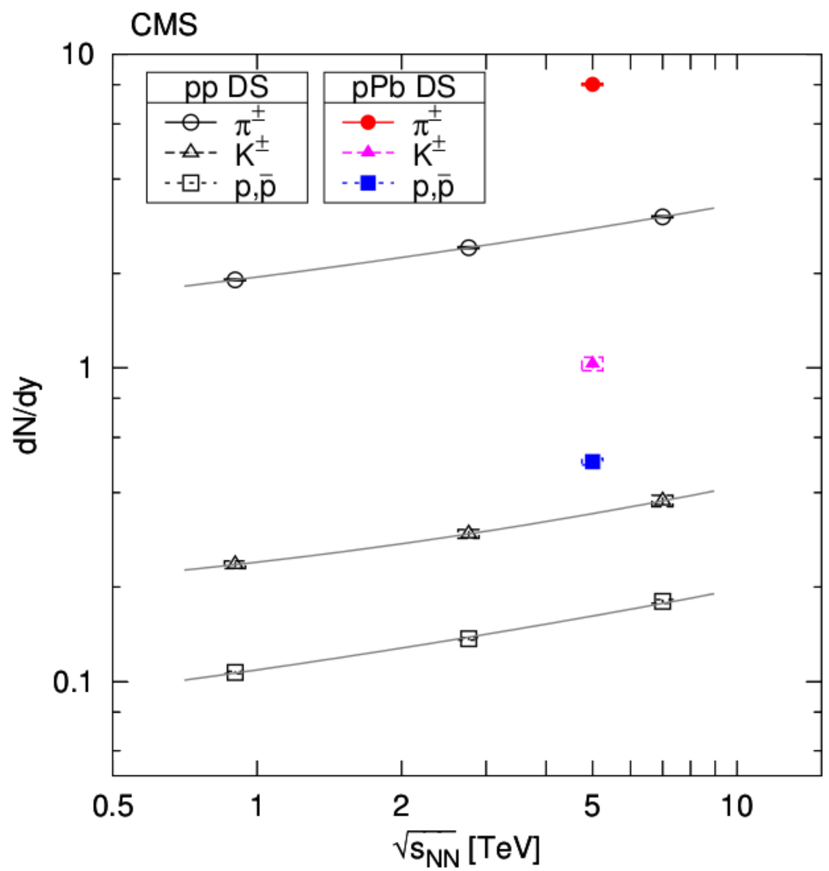
Summary

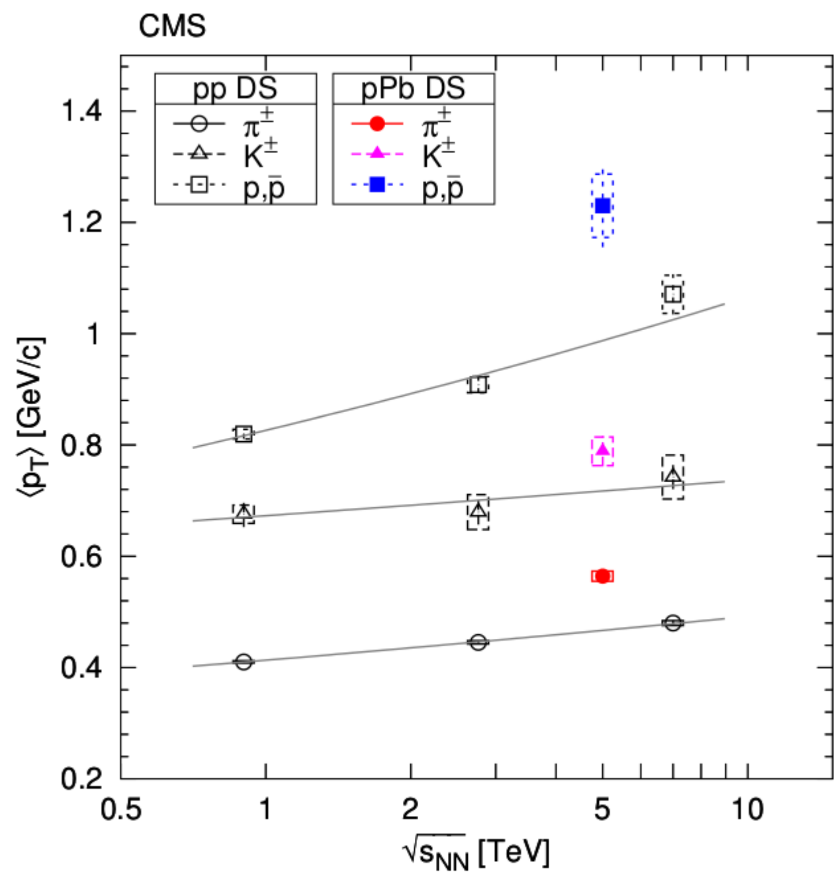
- Measured spectra of identified charged hadrons in pPb collisions with $\sqrt{s_{NN}}$ = 5.02 TeV as a function of multiplicity
- Particle production is strongly correlated with event multiplicity, rather than collision energy or the mass of the colliding nuclei
- Highest multiplicity pPb interactions yield higher p_T hadrons than central PbPb
- Inverse slope parameter shows a linear dependence on particle mass
- Paper - arXiv:1307.3442 – submitted to EPJC

Backup

BACKUP

Yield and <p_T>





- **pp and pPb data are for laboratory rapidity**

- **Parabolic (dN/dy) and linear (<p_T>) parameterizations on log-log scale**