Identified particles in pPb collisions by CMS

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for the CMS Collaboration

IS2013, Illa Da Toxa
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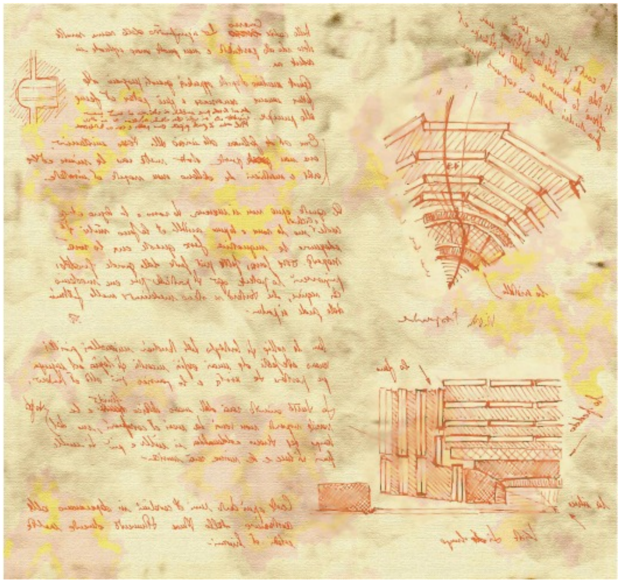
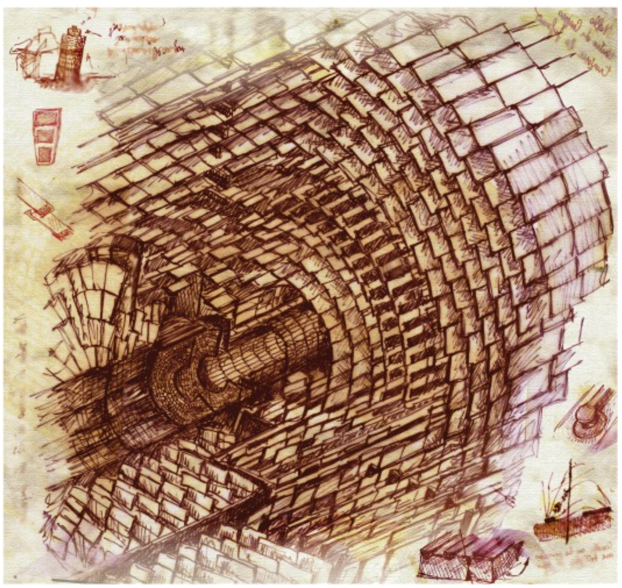
Outline





- Charged π, K, and p in pPb at $\sqrt{s_{NN}} = 5.02$ TeV
  - Results are public: arXiv:1307.3442 (hep-ex), submitted to EPJC, under review (+data points)

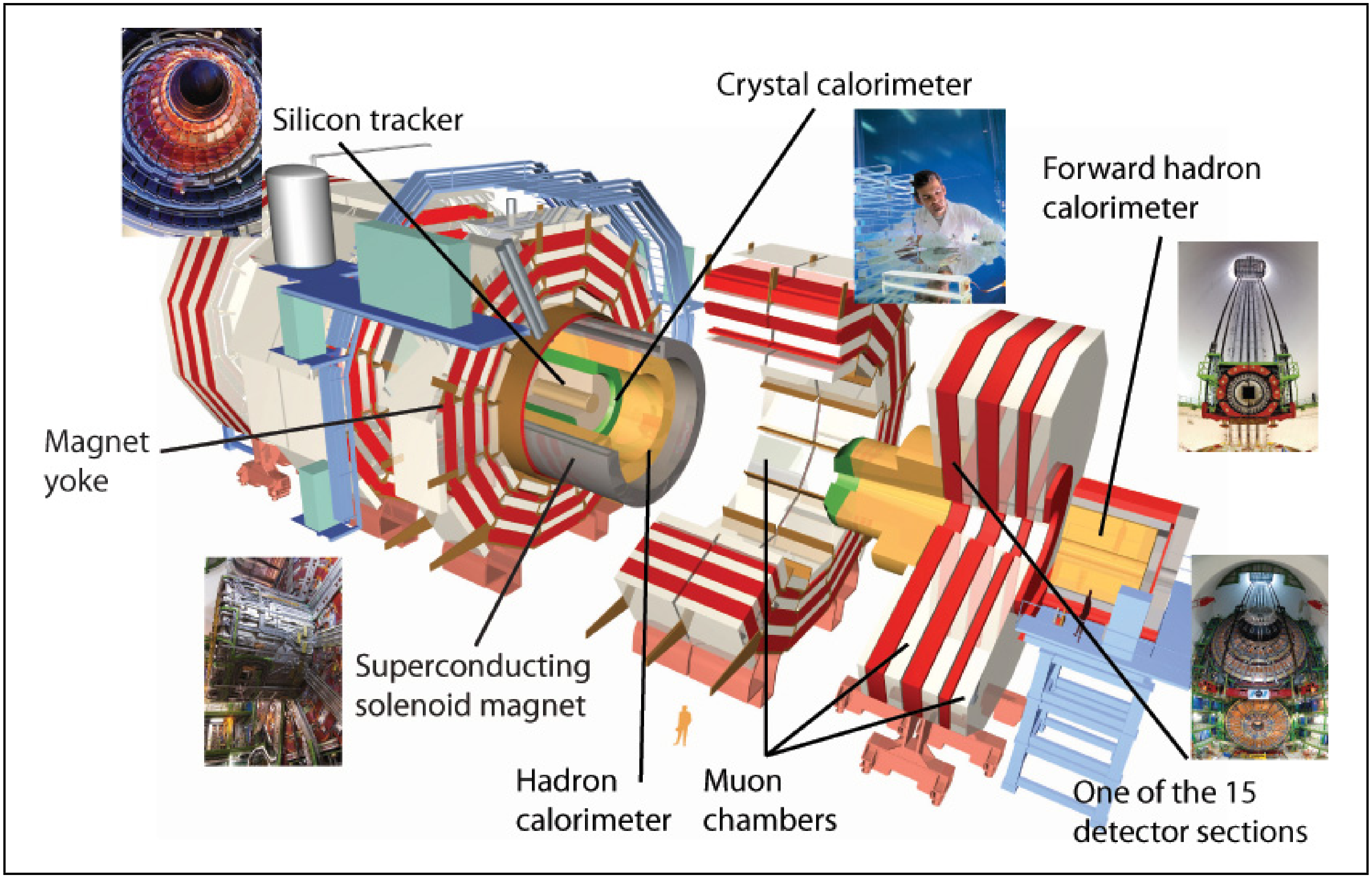
  - Trigger, tracking, vertexing
    $p_T > 0.1$ GeV/c; double sided trigger ($3 < |\eta| < 5$)
  - Energy deposits and energy loss rate
  - Determination of particle yields
  - Corrections

  - Inclusive measurements
  - Multiplicity-dependent measurements

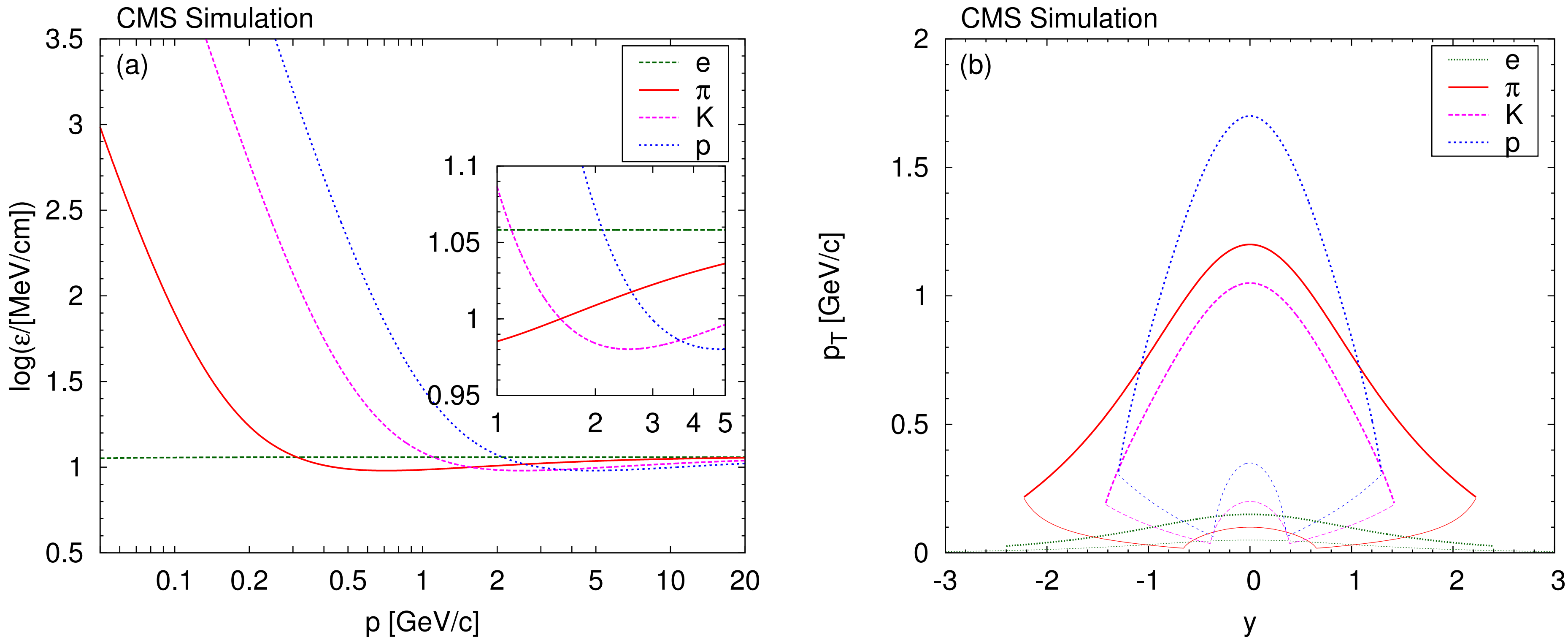
  - Comparisons to pp
    (CMS EPJC **72** (2012) 2164, +HepData)
    and to PbPb (ALICE arXiv:1303.0737) results

With emphasis on particle spectra and ratios

Analysis techniques



The scene



- Hadron spectra
  - Long history both in high energy particle and nuclear physics
  - One of the simplest and most relevant physics quantities
  - Scaling properties of particle production; predictions of models and generators
  - Origin of near-side ridge: needs radial flow or not
  - PID: $p < 1.20$ for $\pi^{\pm}$, $p < 1.05$ for $\mathrm{K}^{\pm}$, and $p < 1.70$ GeV/c for $\mathrm{p}/\overline{\mathrm{p}}$

Accessible region is also limited by η acceptance of the tracker

Final results are given for $|y_{\mathrm{lab}}| < 1$

Trigger, event definition

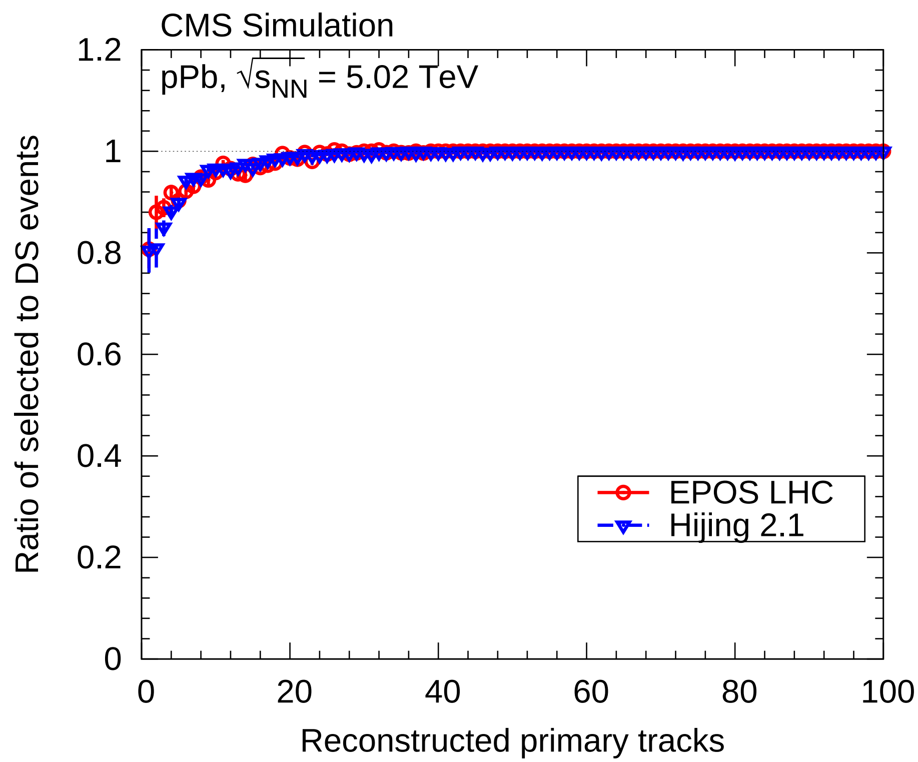
- Data
  - Low pile-up (0.15%) short run (about 4 hours) collected in Sep 2012
  - About 2 million events; uncertainties are dominated by systematics

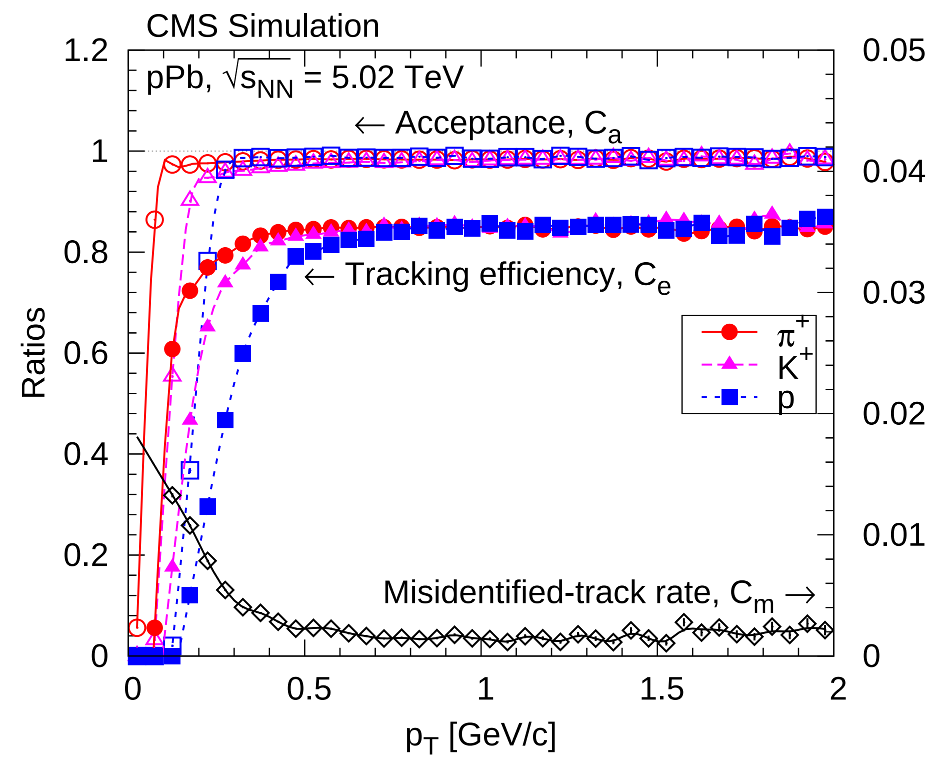
- Online and offline triggers
  - Coincidence of signals from both BPTX devices
  - At least one pixel track
  - Coincidence of at least one forward calorimeter (HF) tower with more than 3 GeV energy on each side
  - Beam-halo and beam-induced background events were suppressed

- We corrected to a **simple event definition**, closest to actual trigger
  - Double-sided selection (DS):
  - At least one particle with $E > 3$ GeV on both sides ($-5 < \eta < -3$ and $3 < \eta < 5$)
  - **With DS we select 94-97% of inelastic collisions**

Ranges from AMPT, EPOS LHC, Hijing

Trigger, tracking performance

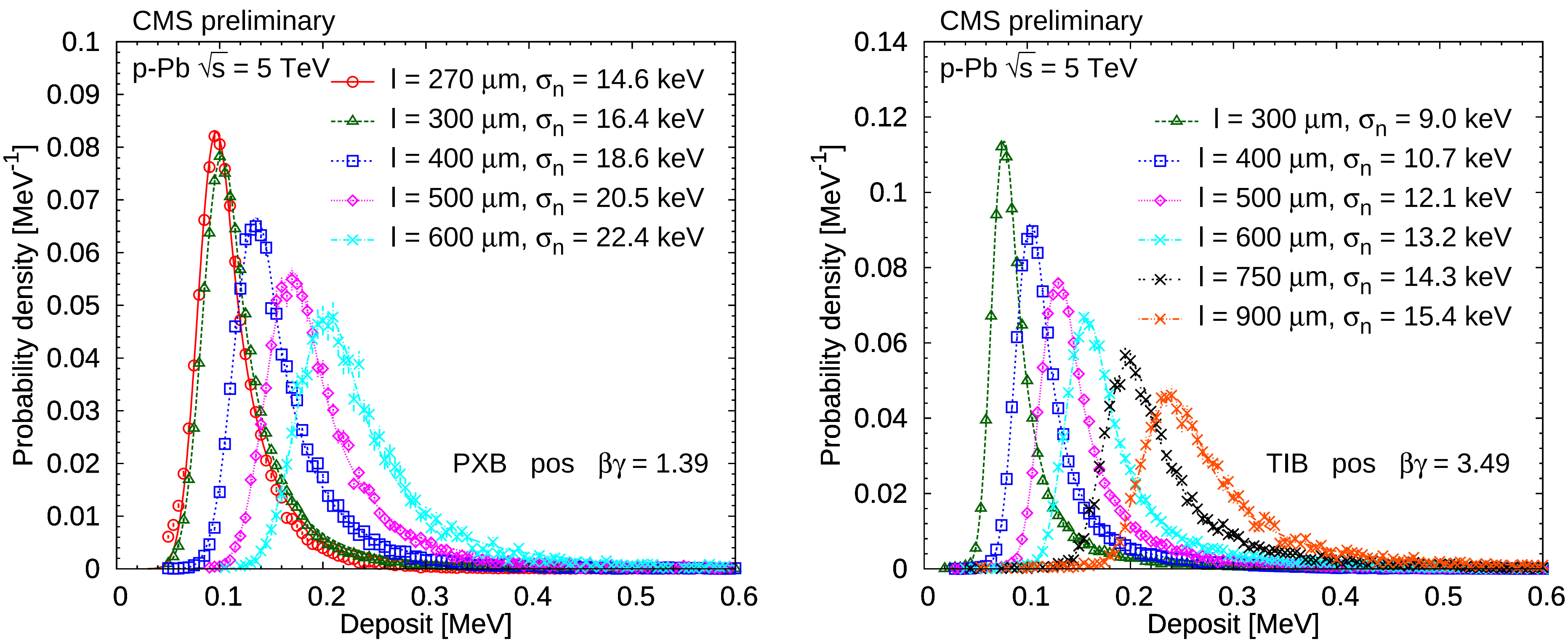




- Trigger corrections
  - The DS trigger efficiency is close to 1: EPOS, Hijing generators
- Tracking corrections
  - Acceptance, efficiency, fake tracks, unfolding p_T bias and resolution
- Non-primaries
  - Feed-down tuned with data via measuring $\mathrm{K^0_S}$ and $\Lambda/\overline{\Lambda}$ spectra; secondaries

Excellent tracking performance, for pions down to $p_T = 0.1$ GeV/c

Analytical energy loss parametrization – validation



The central quantity is the

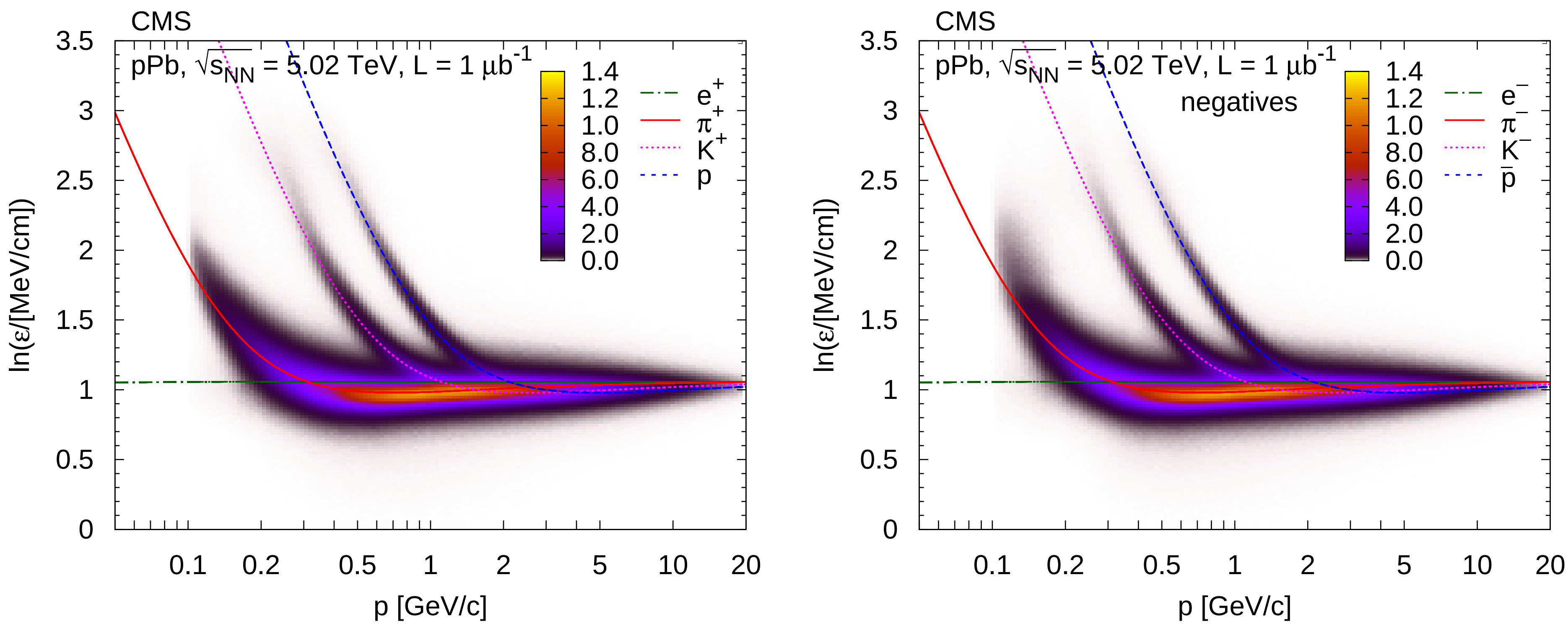
most probable energy loss rate ε along a reference length l_0

Probability of an energy loss y, along a path length l

$P(y|\varepsilon, l)$ has exponential and Gaussian parts

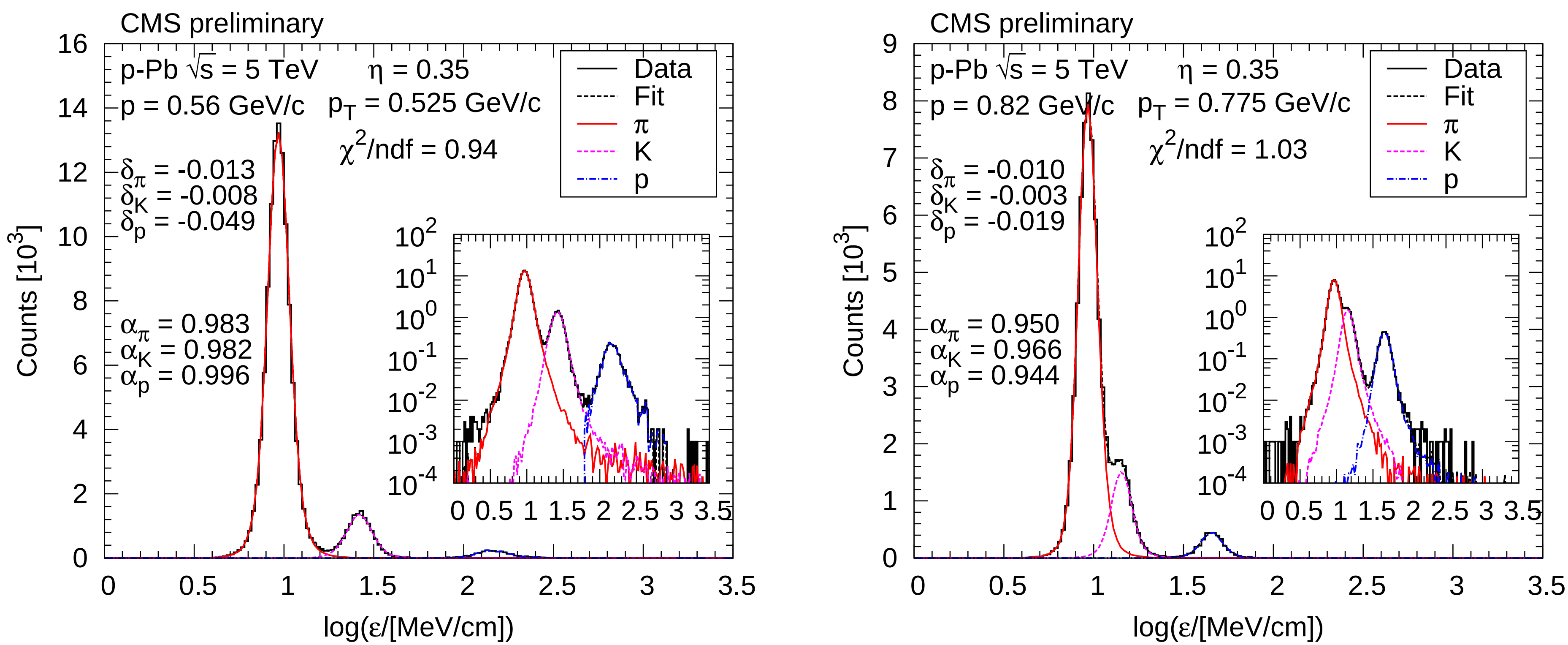
Analytical model with few (4) parameters; a very good match

Most probable energy loss rate ε



- Estimation of $\log\varepsilon$, for each track
  - We have the properly corrected deposits y_i along the trajectory
  - Minimize the joint energy-deposit χ^2 for a track
  - False hit removal (energy deposit outliers)
  - We get the estimate of $\log\varepsilon$

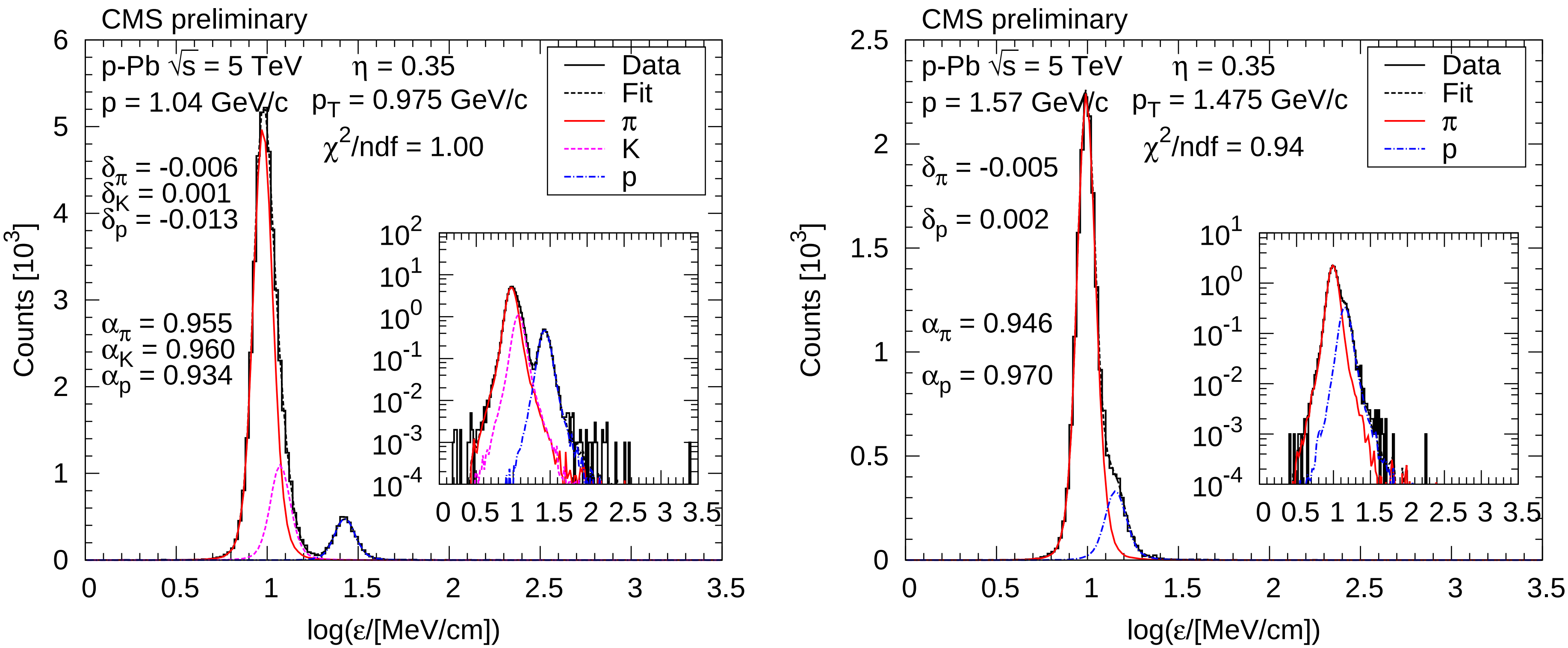
Fits in (η, p_T) bins



- Template fits
  - They are not Gaussians: use tracks in data
  - Keep all quantities, but regenerate energy deposits with the parametrization

High quality fits, good χ^2/ndf

Fits in (η, p_T) bins



Total momentum range used for physics is limited by systematic uncertainty

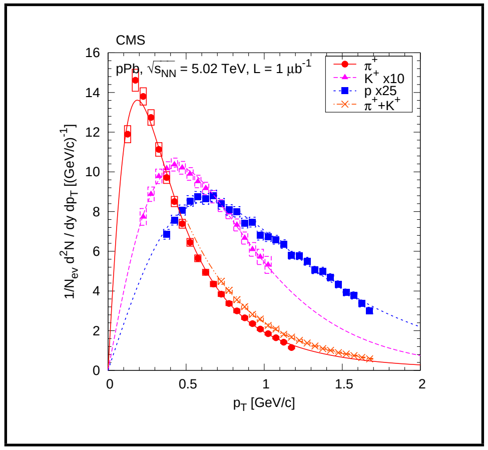
We give results in $|y_{\text{lab}}| < 1$ (dictated by PID capabilities)

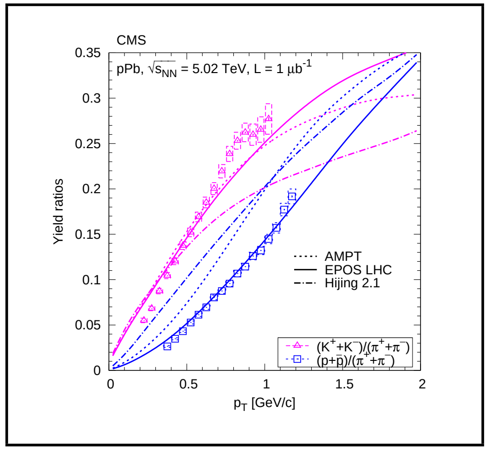
Systematic uncertainties

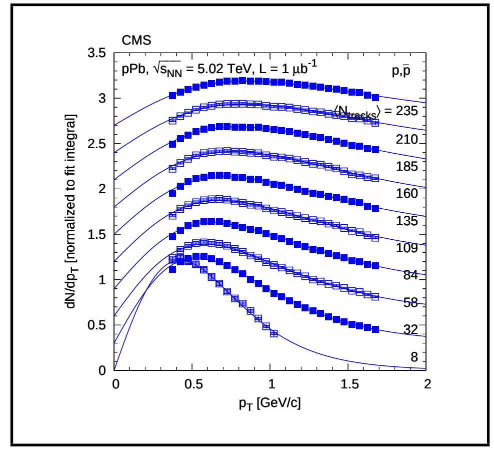
Source	*Uncertainty of the source* [%]	*Propagated yield uncertainty* [%]		
Fully correlated, normalisation				
Correction for event selection	3.0 (1.0)	3.0 (1.0)		
Pileup correction (merged and split vertices)	0.3			
Mostly uncorrelated				
Pixel hit efficiency	0.3	0.3		
Misalignment, different scenarios	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

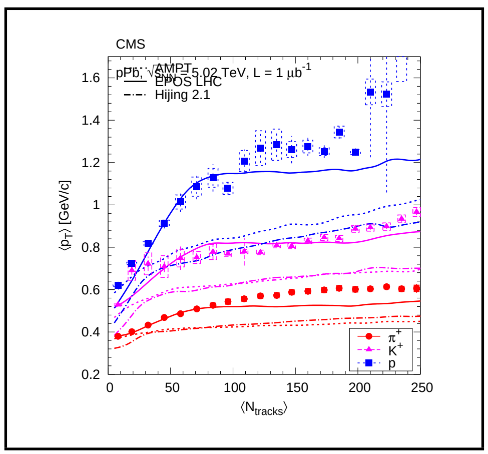
Consistent propagation of uncertainties (mapping, fits, unfolding, integration)

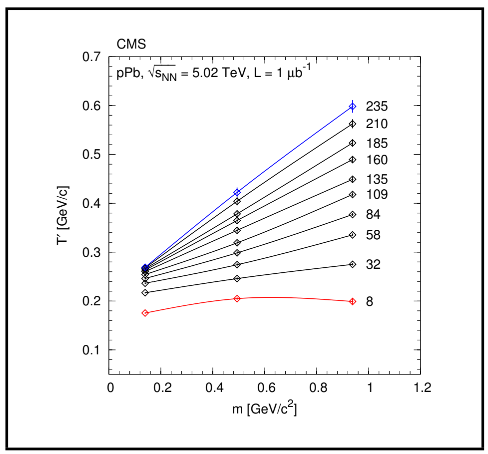
Physics results

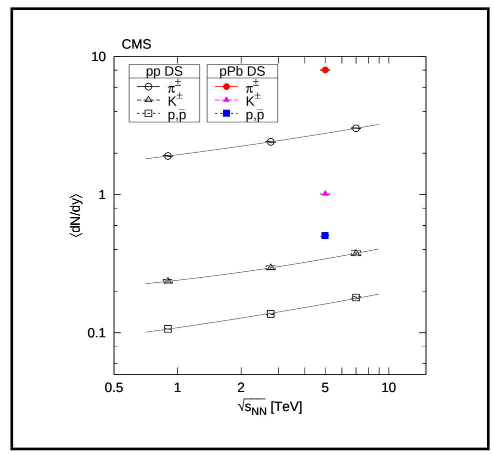




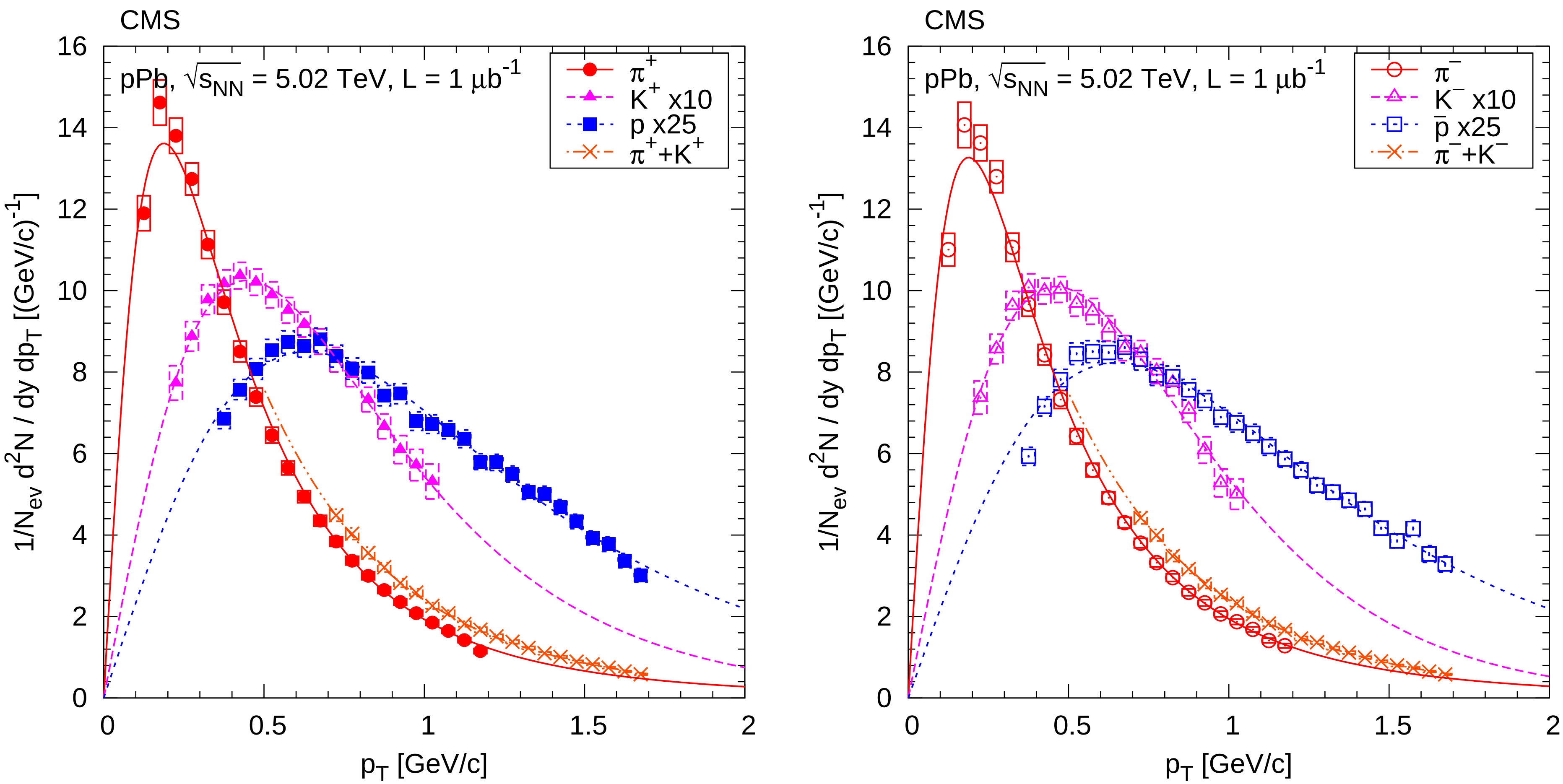








Results – p_T spectra



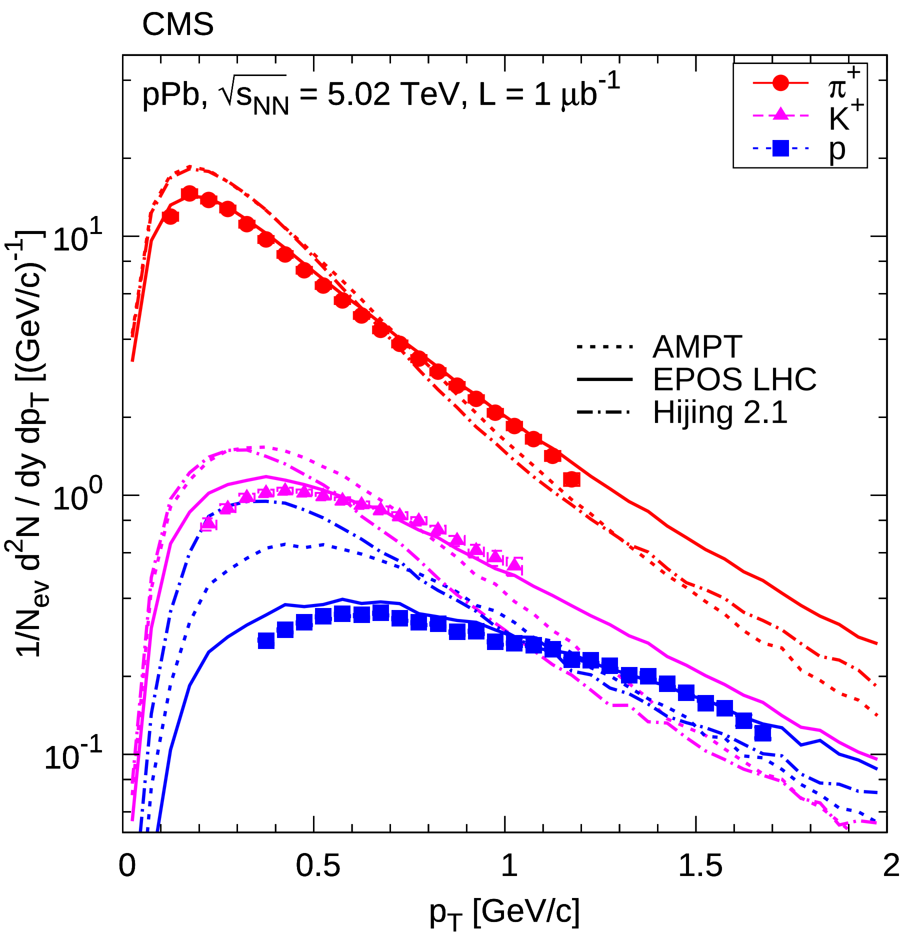
Statistical (error bars) and systematic uncertainties (boxes)

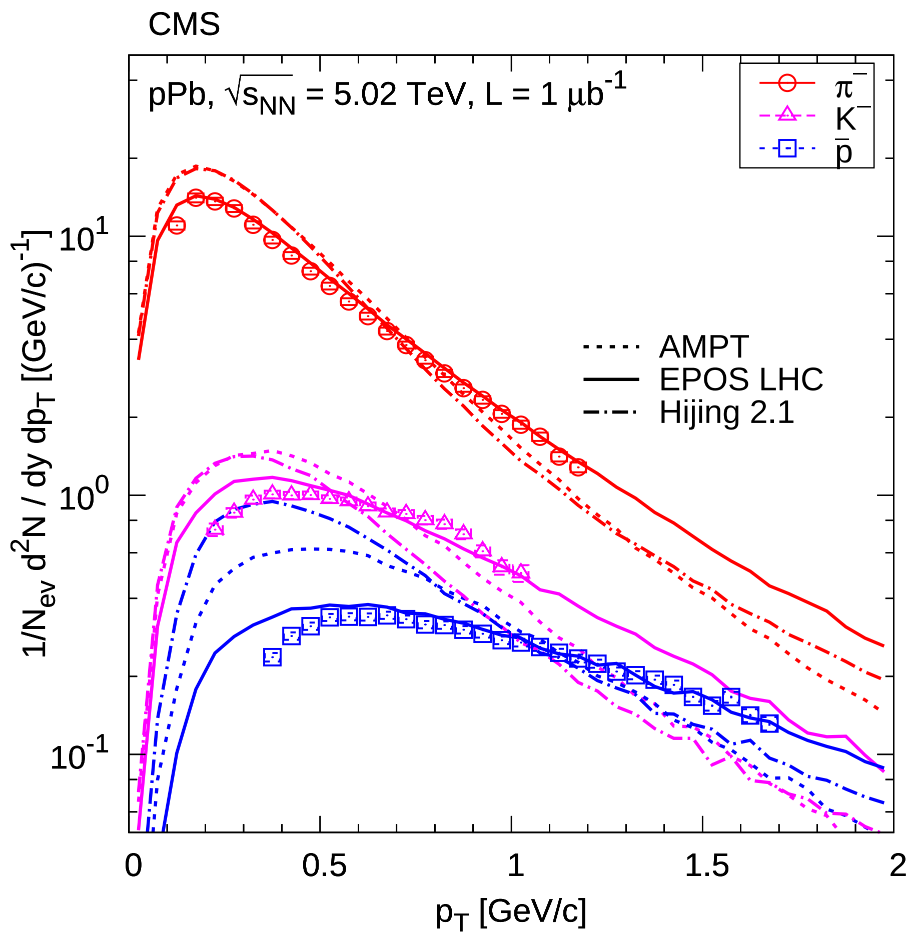
The fully correlated normalization uncertainty (not shown) is around 3.0%

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

The fits are of good quality

Results – p_T spectra

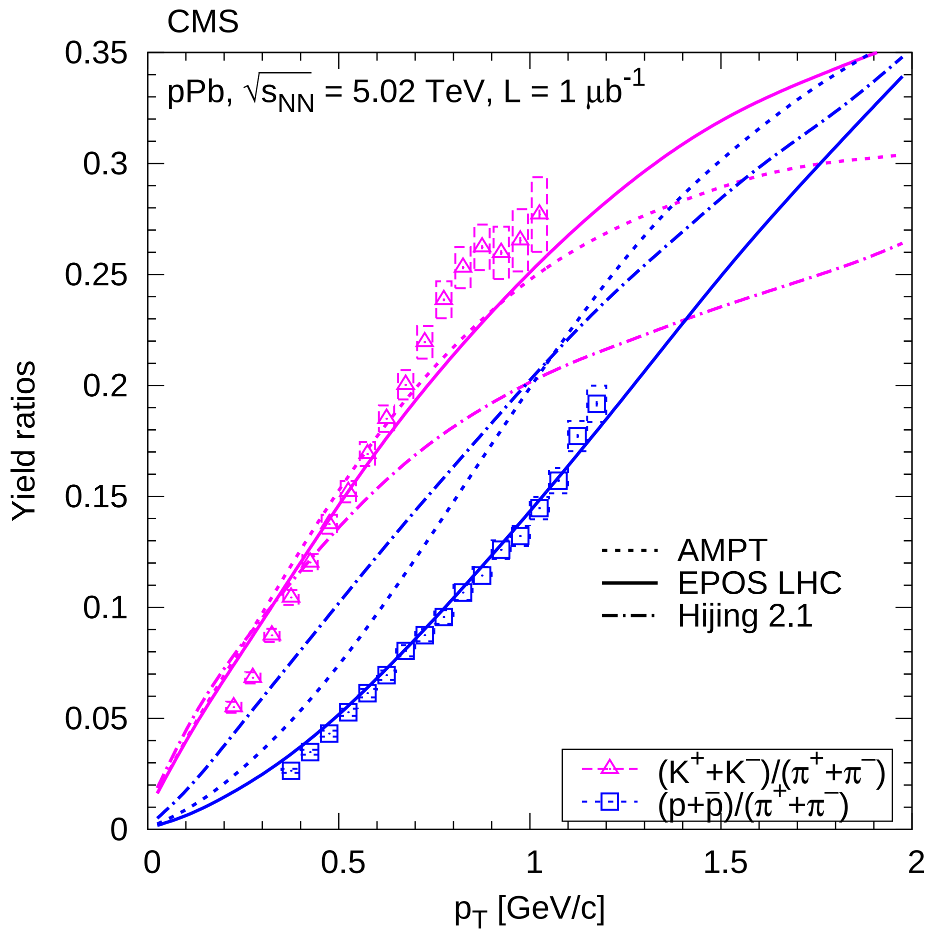


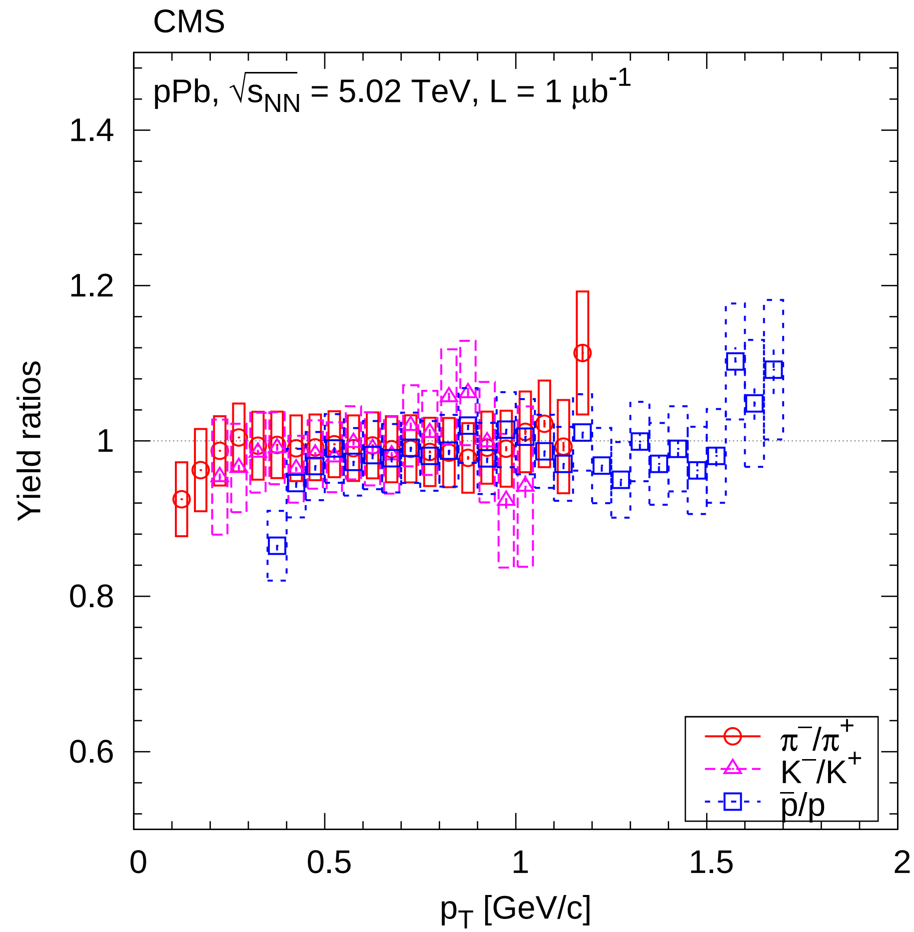


Logarithmic scale

Generators predict too steep p_T distributions, except EPOS LHC

Results – ratios vs p_T





- p_T dependence
  - K/π ratios are are well approximated by EPOS LHC
  - There are substantial deviations in case of p/π ratios
  - Ratios of opp charged pions and kaons are compatible with 1, indep of p_T

Track multiplicity classes

- How?
  - take the measured $d^2N/d\eta dp_T$ values
  - use adjusted MC corrections (take PID ratios from data)
  - correct for low p_T part ($p_T <$ 0.1 GeV/c), assuming a linear startup with p_T
  - no Tsallis fits are needed here

- The classes

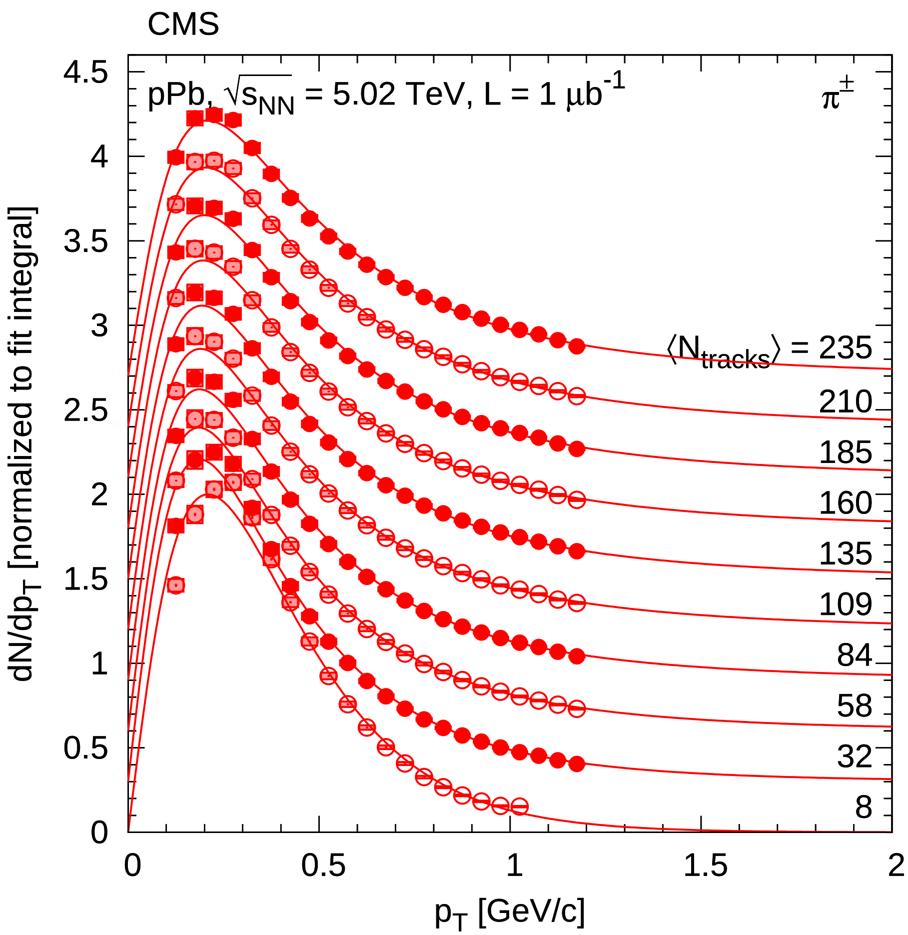
"peripheral" … "central"

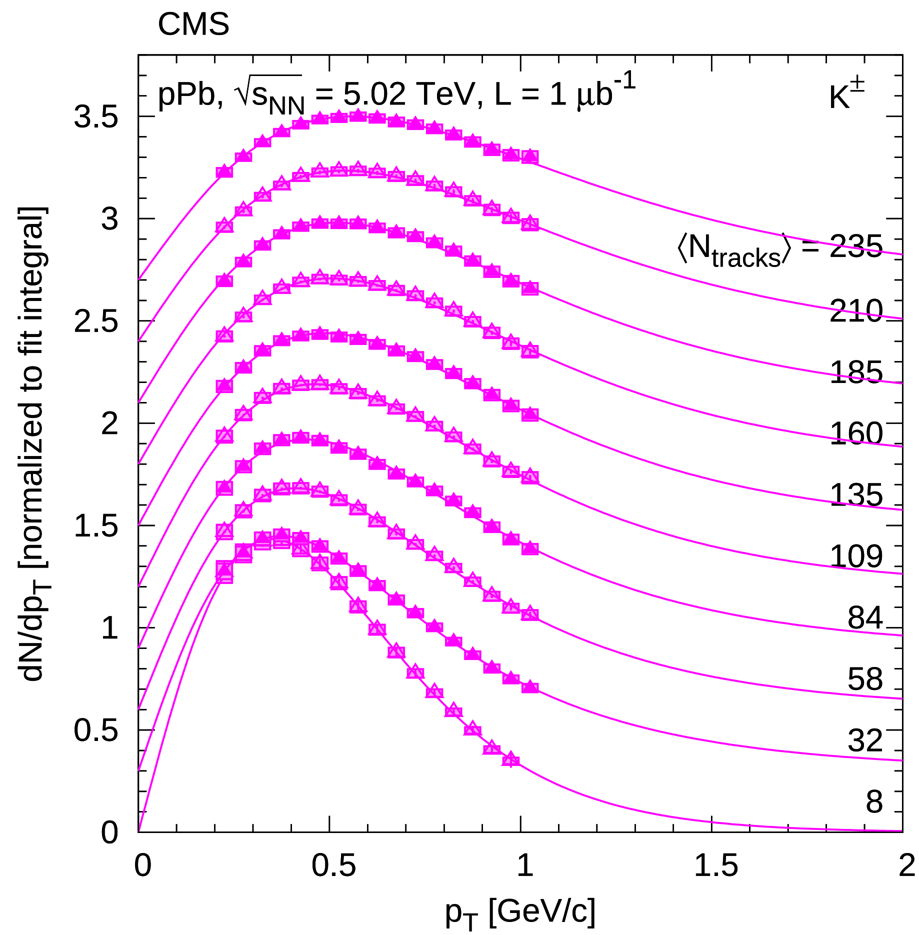
N_{rec}	0–9	10–19	20–29	30–39	40–49	50–59	60–69	70–79	80–89	90–99	100–109	110–119	120–129	130–139	140–149	150–159	160–169	170–179	180–189
$\langle N_{\text{tracks}} \rangle$	8	19	32	45	58	71	84	96	109	122	135	147	160	173	185	198	210	222	235
$\langle N_{\text{tracks}} \rangle_{p_T > 0.4\text{GeV/c}}$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

Collect data in N_{rec}, plot results in (theoretical) $\langle N_{\text{tracks}} \rangle$ bins
We give the corresponding fully corrected N_{tracks} values in $|\eta| < 2.4$

N_{tracks} – Poor man's centrality measure ;-)

Results – multiplicity dependence

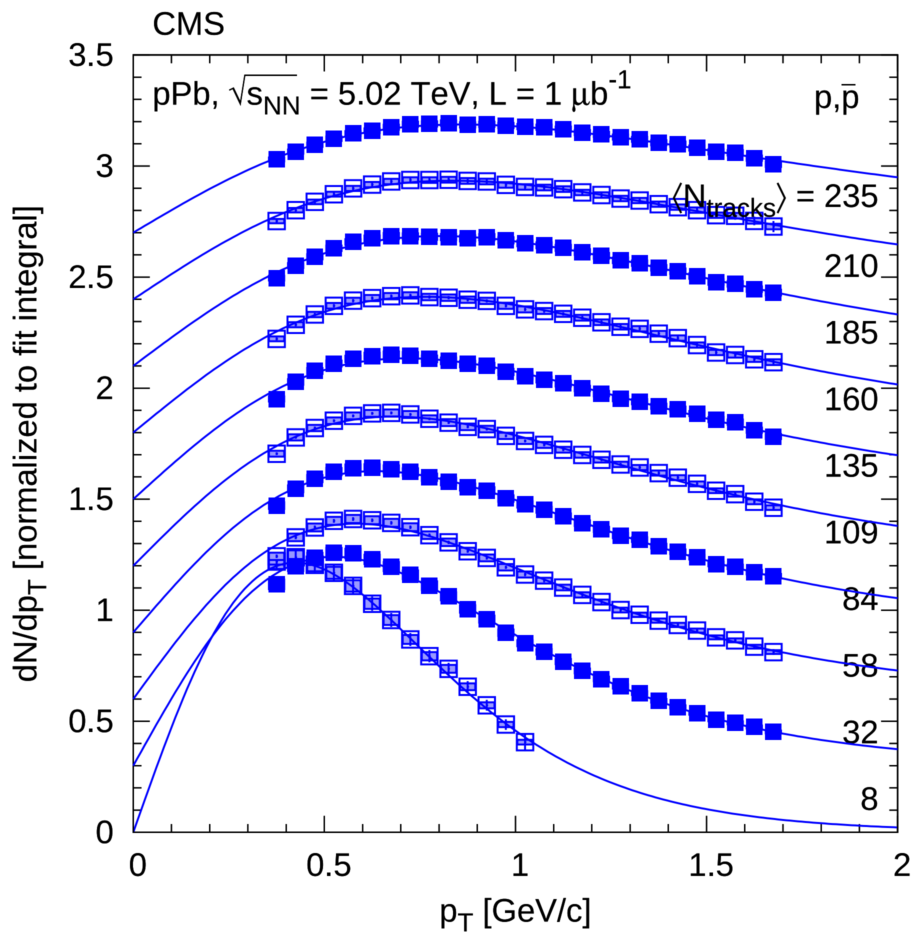




The values with increasing multiplicity are successively shifted by 0.1 units along the vertical axis

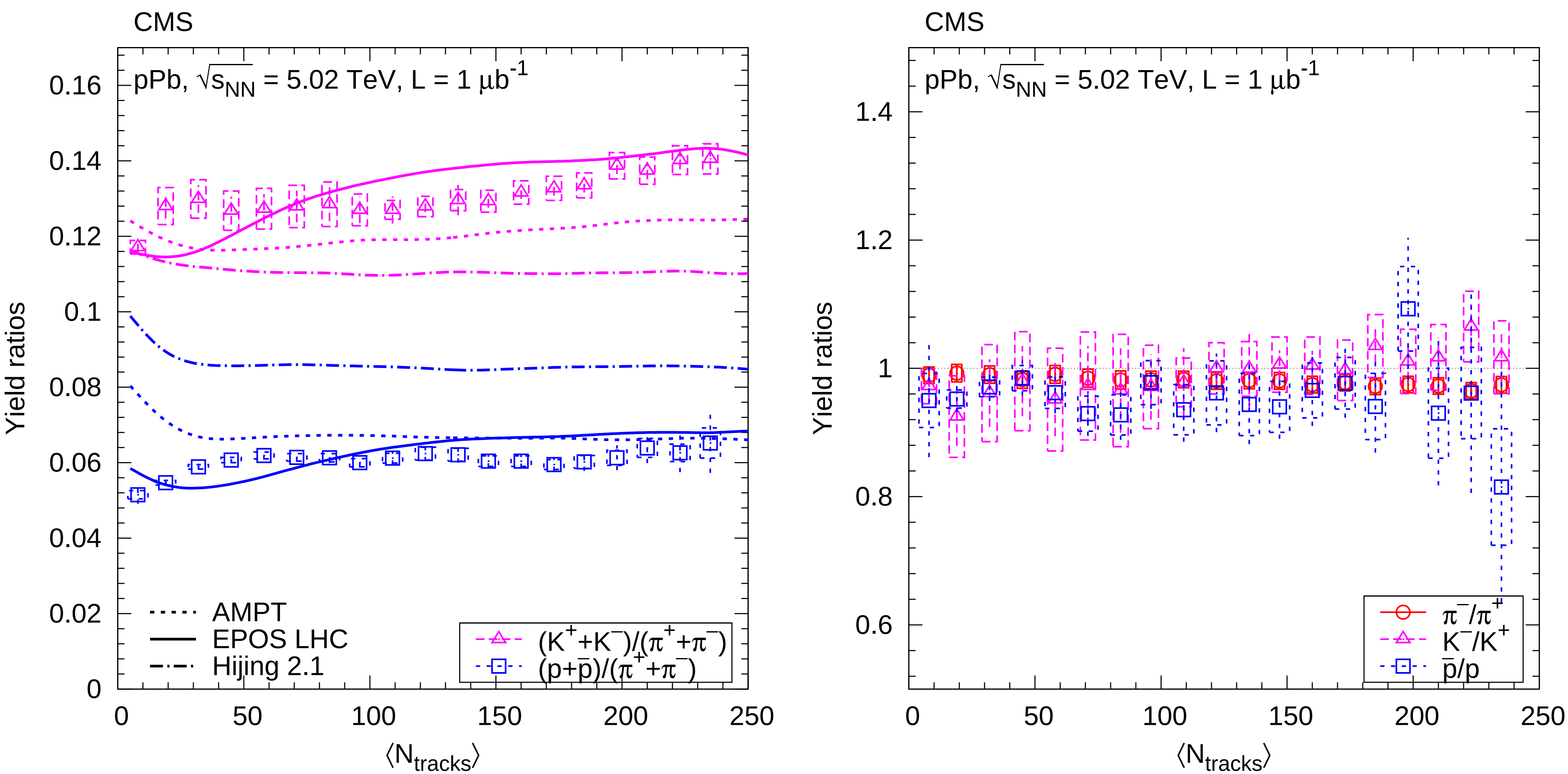
Unchanged (pion) vs changed shapes (kaons)

Results – multiplicity dependence



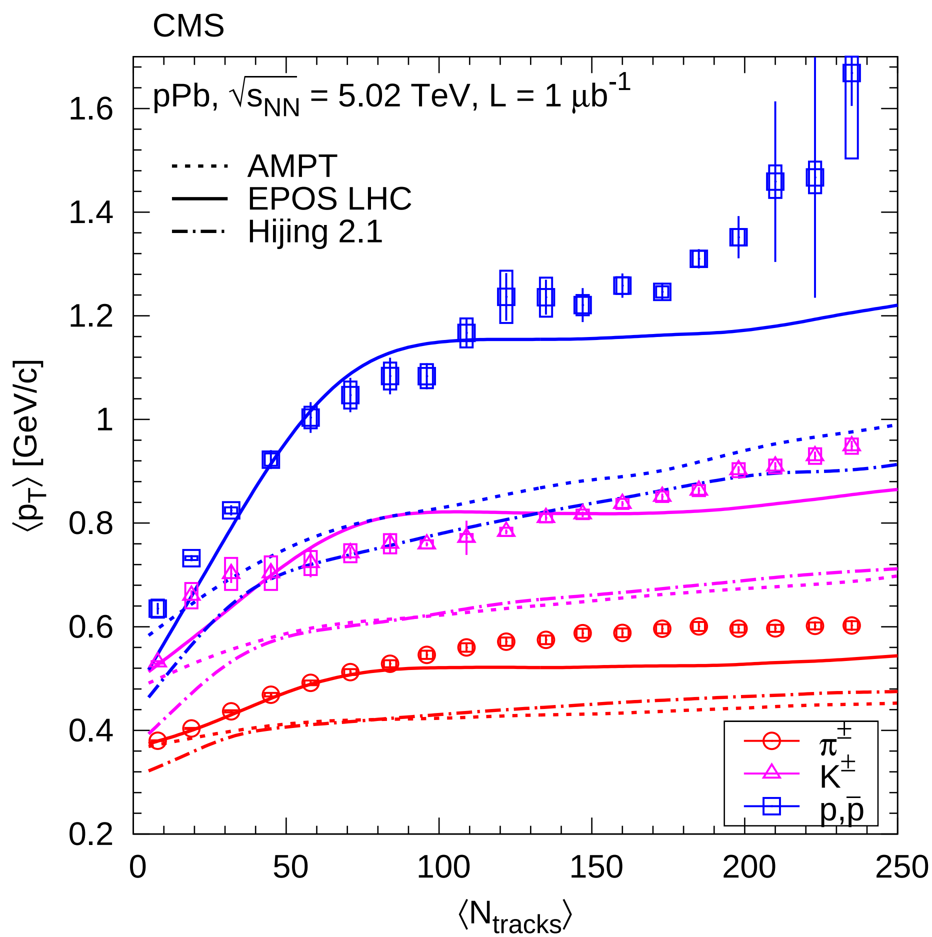
Strong change

Results – ratios – multiplicity dependence



- Cross ratios
  - K/π and p/π ratios are or slowly rising; EPOS LHC looks best
- Opposite charge ratios
  - The ratios are close to 1, no dependence on $\langle N_{\text{tracks}}\rangle$

Results – $\langle p_T \rangle$ – multiplicity dependence



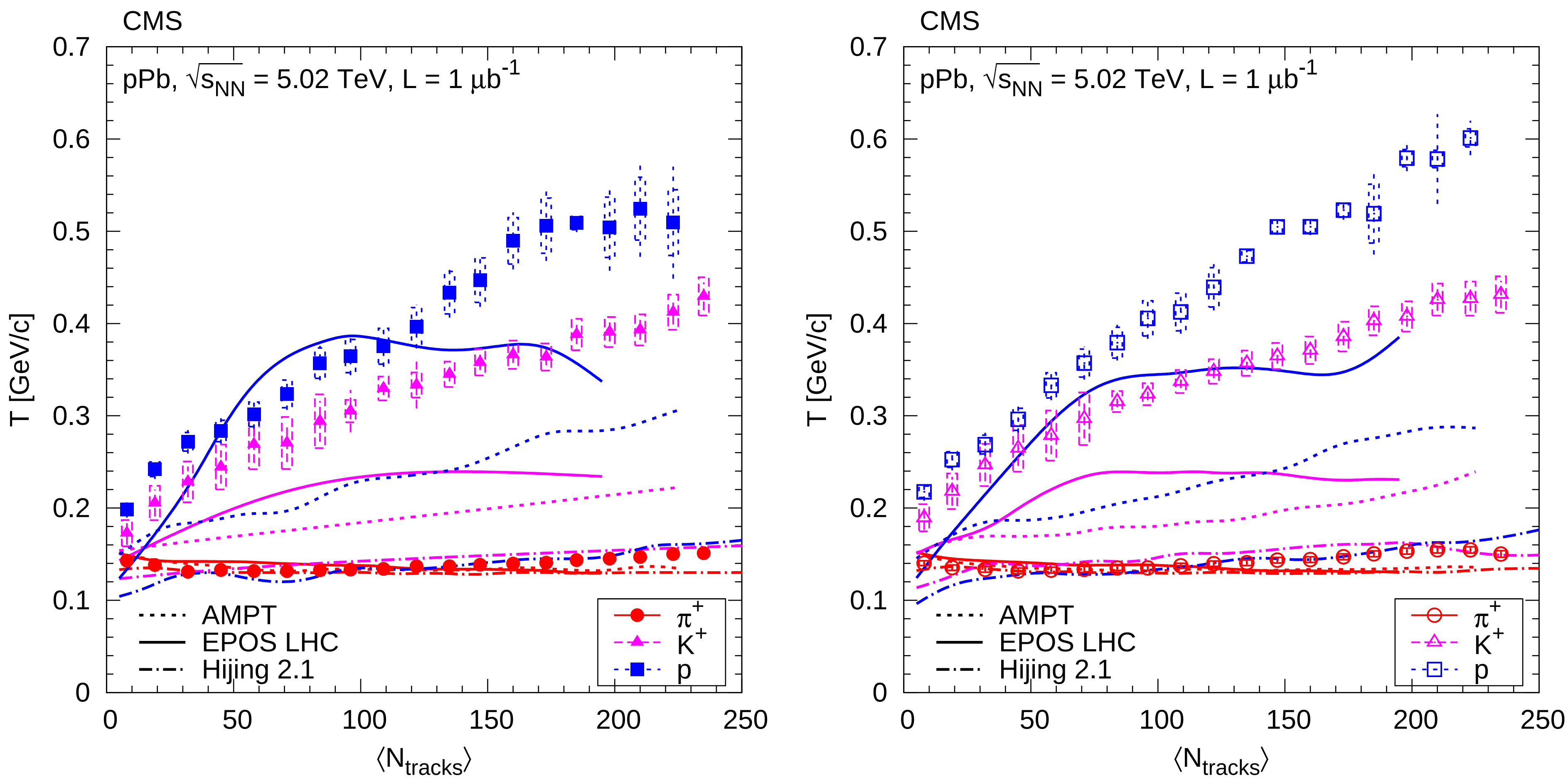
Calculated using MC technique followed by numerical integration

Error bars show the combined $\sqrt{\text{stat}^2 + \text{syst}^2}$ errors, boxes give systematic only

AMPT and Hijing 2.1 underpredict the measured values

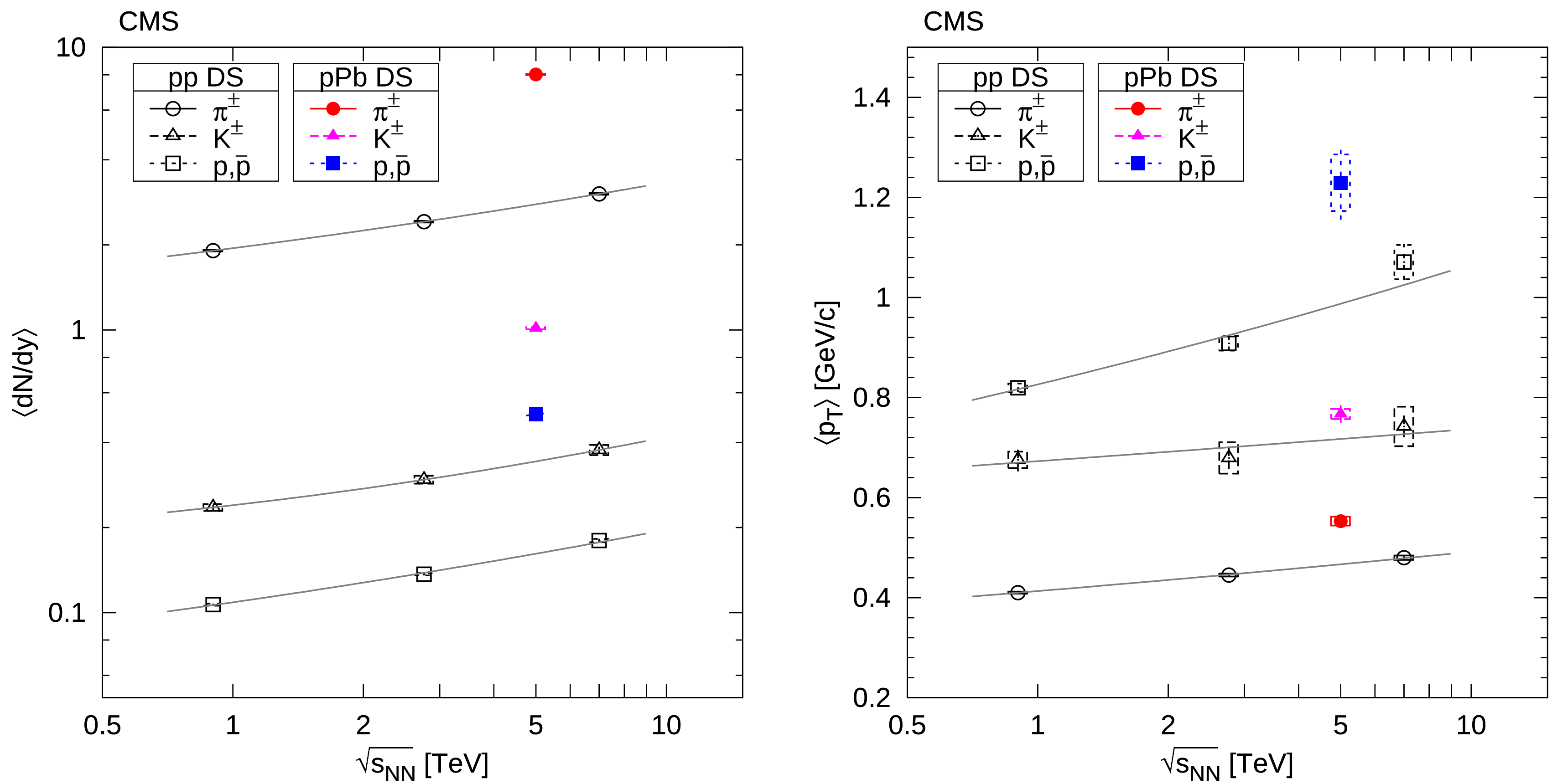
Good description by EPOS LHC: includes explicit hydrodynamic treatment

Results – T – multiplicity dependence



- Observations
  - Differences between data and generators
  - Pion T values are well described by models

Comparisons – $\sqrt{s}$ dependence – pp vs pPb



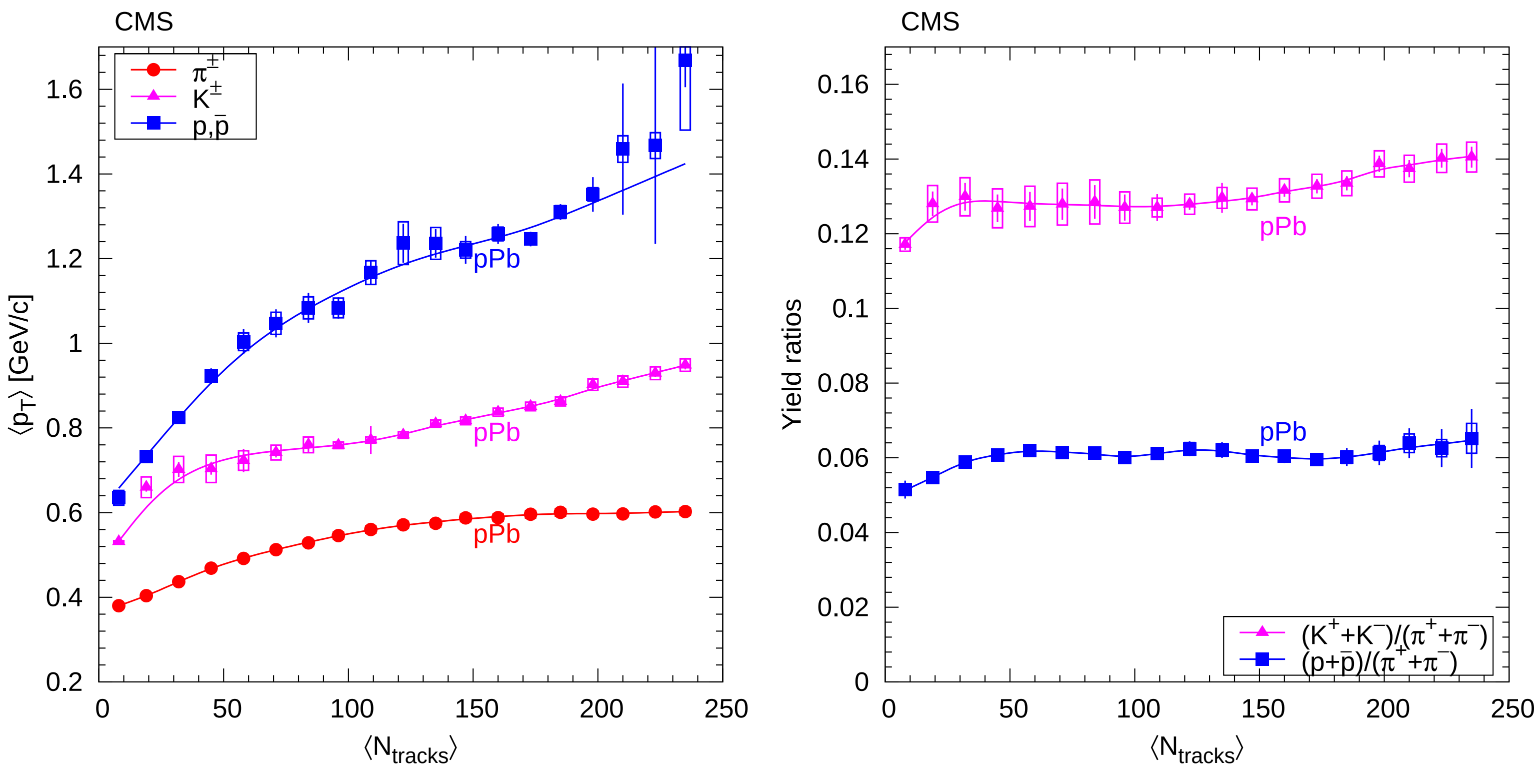
The curves show parabolic (dN/dy) or linear ($\langle p_T \rangle$) interpolation in log-log scale

Yields in pPb are generally three times higher than in pp at same $\sqrt{s}$

Consistent with $(\langle \nu \rangle + 1)/2$ expectation; $\langle \nu \rangle \approx 6$ (aver no of projectile collisions)

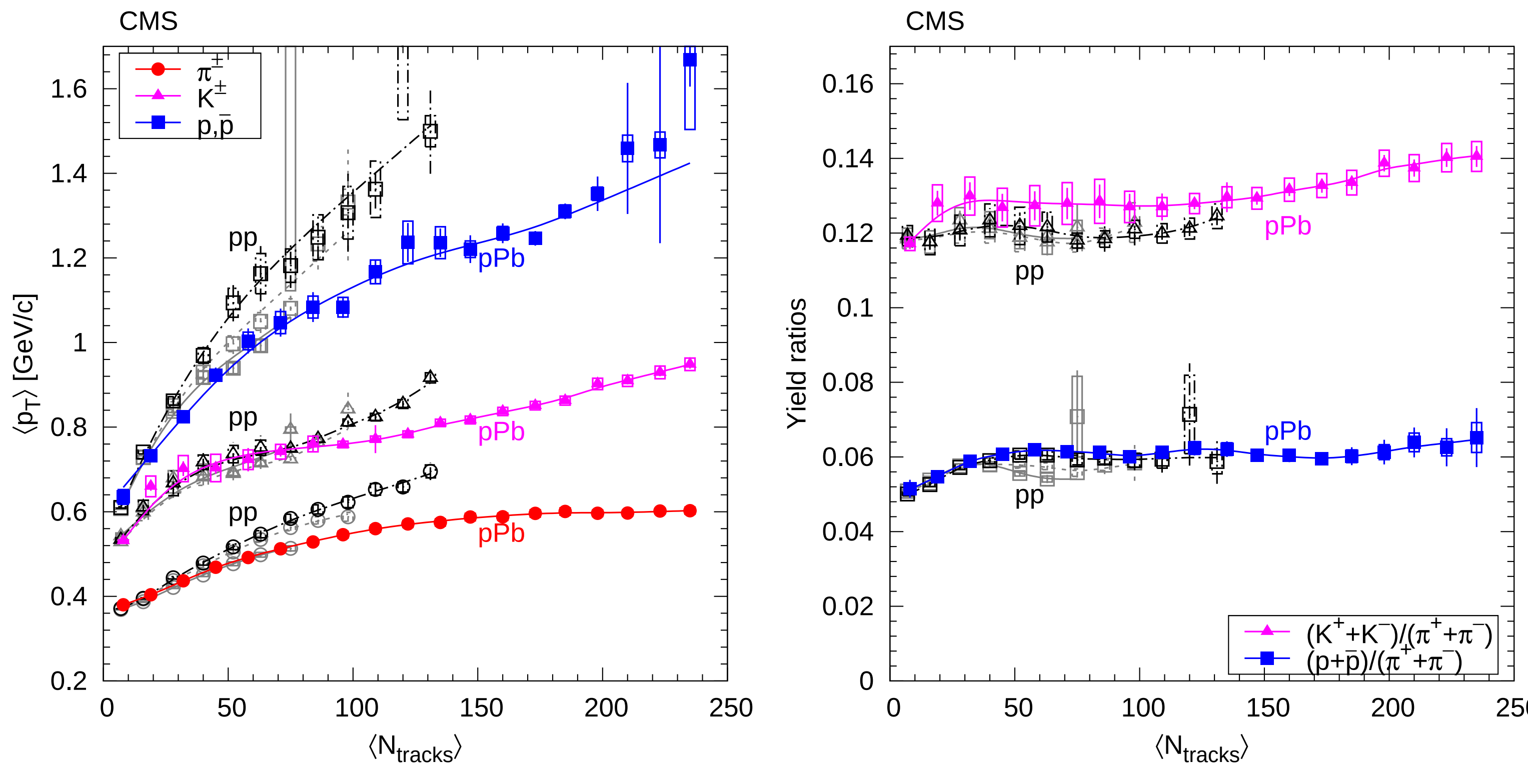
In case of $\langle p_T \rangle$, the increase is about 20% for pions and protons, 10% for kaons

Comparisons – $\sqrt{s}$ dependence – pPb



pPb (5.02 TeV)

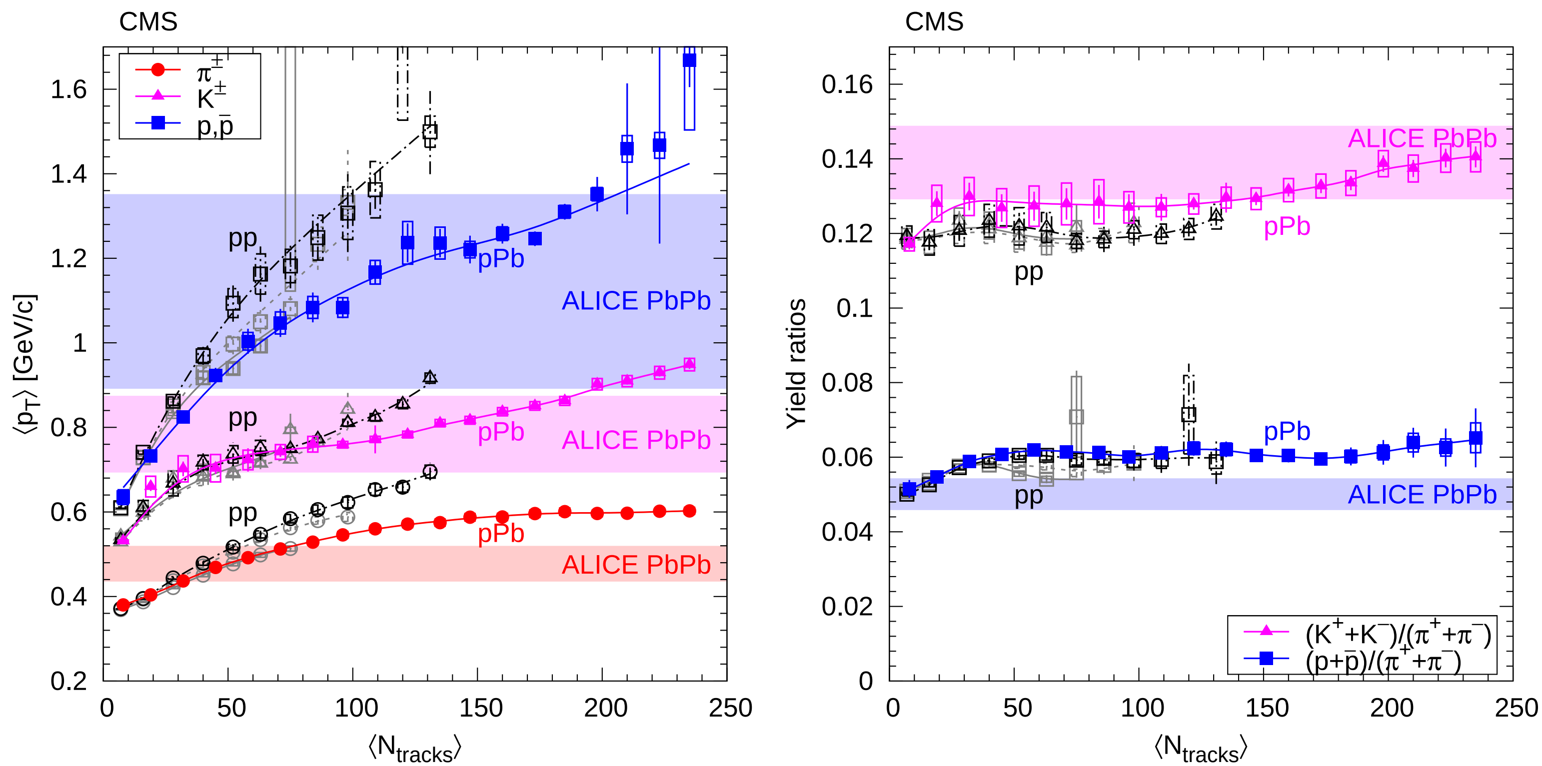
Comparisons – $\sqrt{s}$ dependence – pp vs pPb



pp (0.9, 2.76, 7 TeV), pPb (5.02 TeV)

- Observations
  - For low track multiplicity ($N_{\text{tracks}} \lesssim 40$), pPb behaves very similarly to pp
  - At higher multiplicities ($N_{\text{tracks}} \gtrsim 50$) the $\langle p_T \rangle$ curve for pPb gets flatter
  - This can be understood, since in the former case mostly peripheral pPb collisions are present with a few proton-nucleon collisions
  - By asking for more produced particles those collisions are chosen, where the projectile proton collided with the thick disk of the lead nucleus

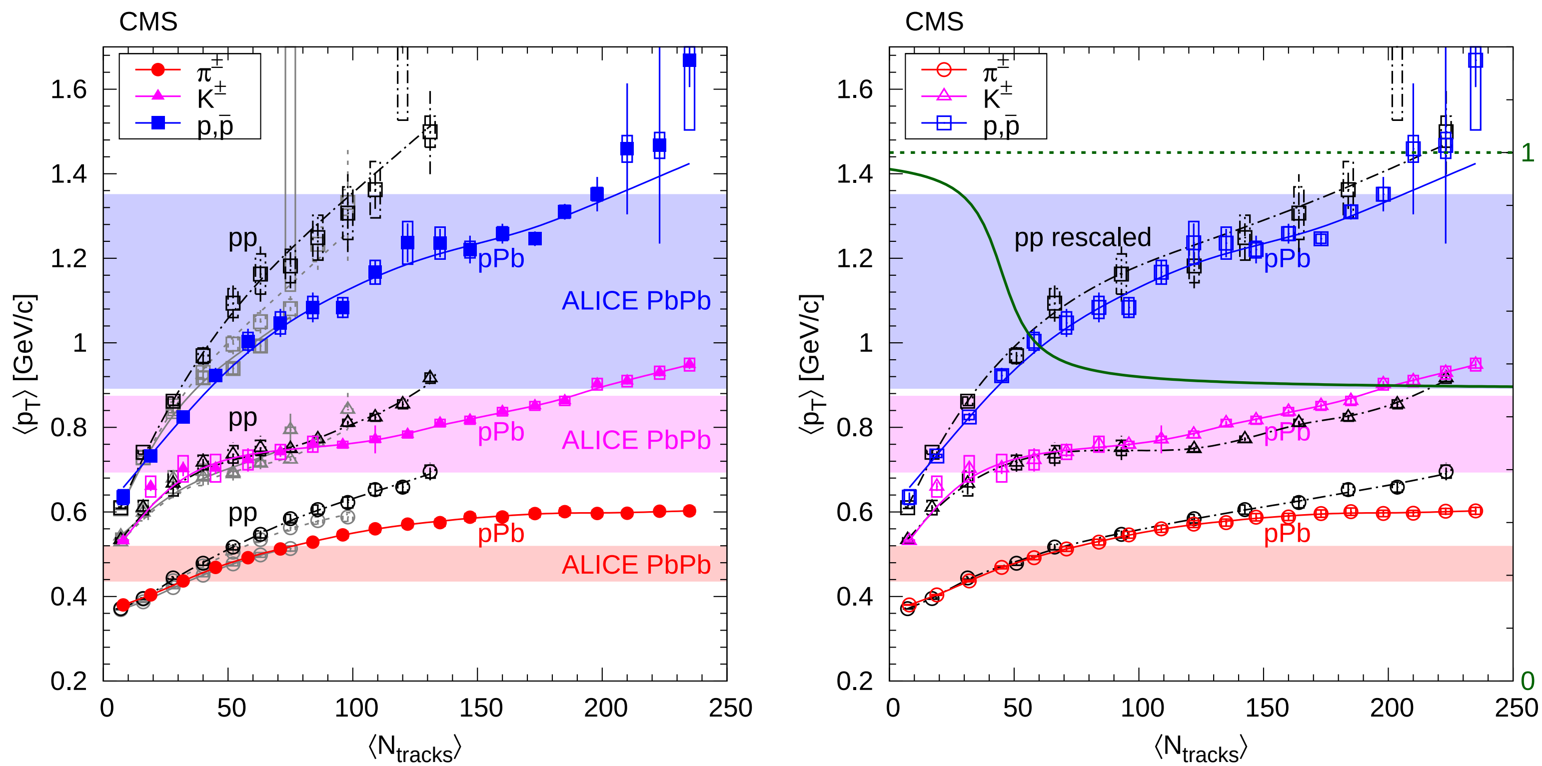
Comparisons – $\sqrt{s}$ dependence – pp vs pPb vs PbPb



pp (0.9, 2.76, 7 TeV), pPb (5.02 TeV), PbPb (2.76 TeV, periph to central bands)

- Observations
  - Highest multiplicity pPb interactions yield higher $\langle p_T \rangle$ than in central PbPb collisions (ALICE arXiv:1303.0737), or reach those values in case of pp
  - In the PbPb case even the most central collisions possibly contain a mix of soft and hard nucleon-nucleon interactions
  - In case of pp or pPb specifically the most violent interaction or sequence of interactions are selected

Comparisons – $\sqrt{s}$ dependence – pp vs pPb vs PbPb

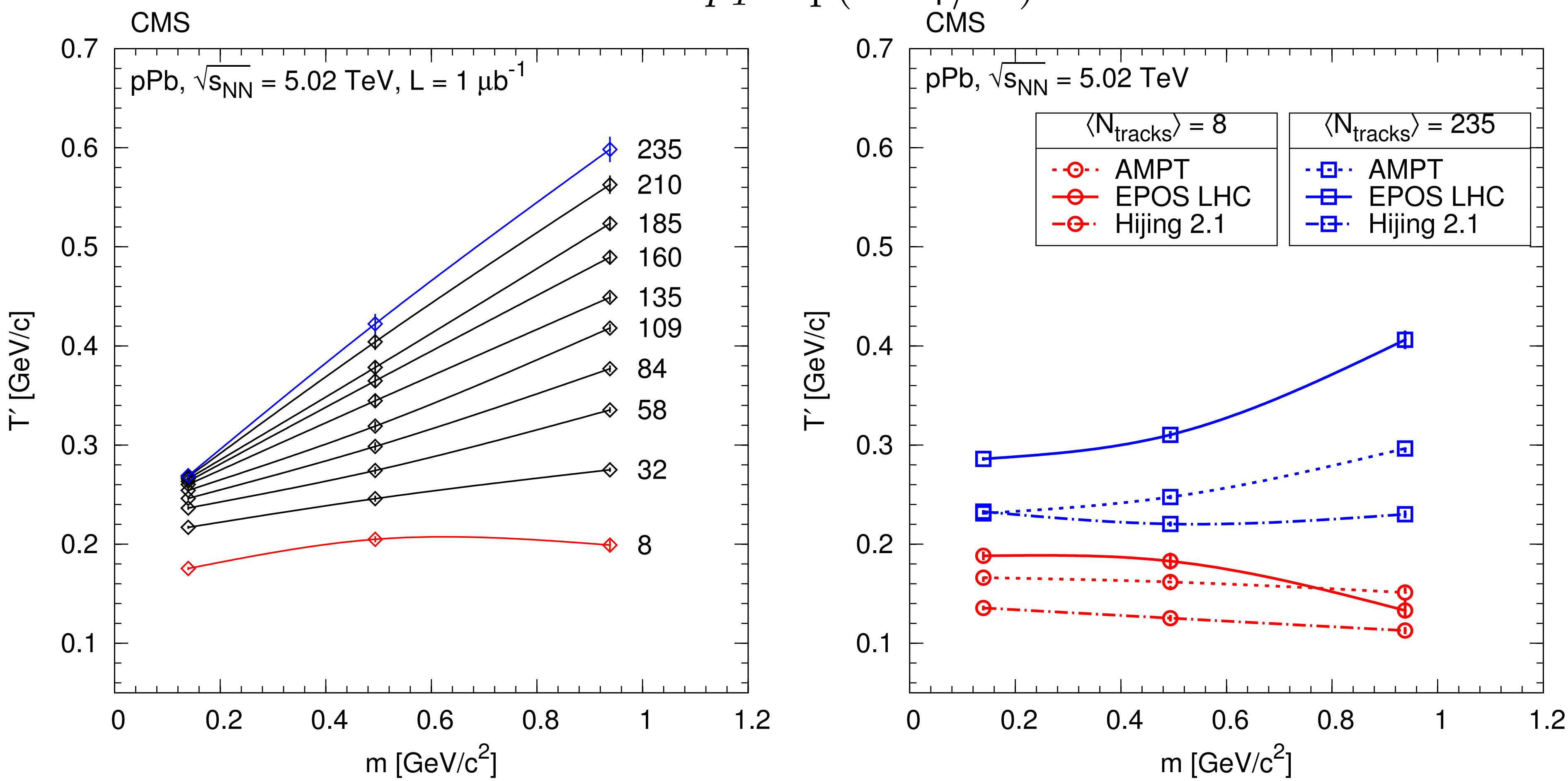


pp (0.9, 2.76, 7 TeV), pPb (5.02 TeV), PbPb (2.76 TeV, periph to central bands)

- Observations
  - Interestingly, at higher multiplicities, the pPb curves for all particles types can be reasonably approximated by taking the pp values and multiplying their N_{tracks} coordinate by a factor of 1.8
  - In other words, a pPb collision with a given N_{tracks} is similar to a pp collision with $0.55 \times N_{\text{tracks}}$ produced charged particles in the $|\eta| < 2.4$ range

Inverse slope parameters

Fit with $p_T \exp(-m_\mathrm{T}/T')$



Multiplicity dependence, data (left) vs MC (right)

Pions are only fitted if $p_T > 0.4$ GeV/c, kaons and protons for all p_T

Linear dependence on mass with a slope that increases with particle multiplicity

Interesting comparison to models (radial flow?); worked better for pp with Pythia

Summary

- Results
  - Measured spectra of identified charged hadrons with a double-sided trigger for in pPb $\sqrt{s_{NN}} = 5.02$ TeV; as a function of track multiplicity
- Conclusions
  - Particle production at LHC energies is strongly **correlated with event multiplicity in both pp and pPb,** rather than with the center-of-mass energy of the collision or with the masses of the colliding nuclei
  - Common underlying physics mechanism: at TeV energies, the characteristics of particle production are **constrained by** the amount of **initial parton energy** that is available in any given collision
  - At high multiplicities, **a pPb collision** with a given N_{tracks} **is similar to a pp** collision with $0.55 \times N_{\text{tracks}}$ produced charged particles in the $|\eta| < 2.4$ range
  - Highest multiplicity pPb interactions yield **higher $\langle p_T \rangle$ than in central PbPb** collisions, or reach those values in case of pp

Thank you for your attention!