



XXIV **QUARK MATTER**
DARMSTADT 2014

Production of light flavor hadrons at intermediate and high p_T measured with ALICE

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Universität Heidelberg

May 19, 2014



H-QM | Helmholtz Research School
Quark Matter Studies



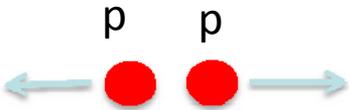
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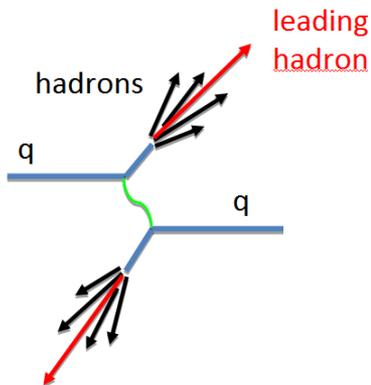
ALICE

Particle production at intermediate and high p_T

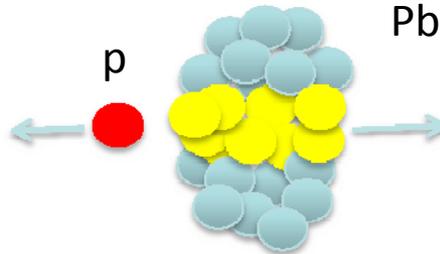
pp



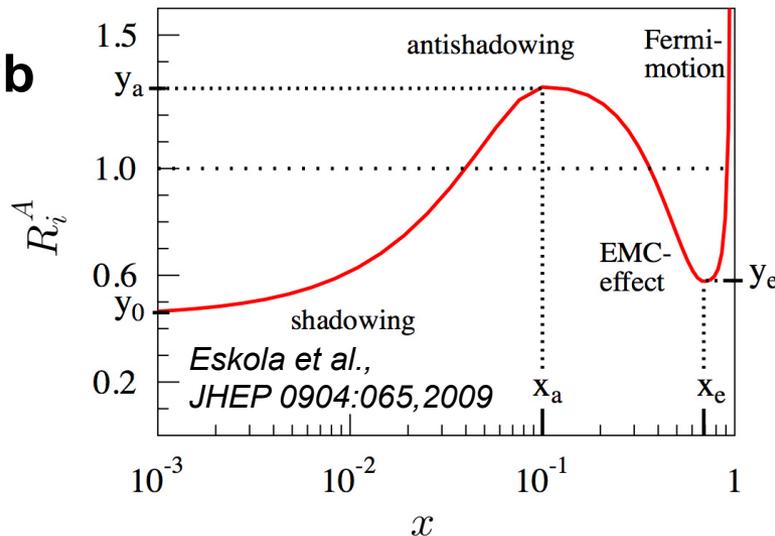
- test of pQCD
- fragmentation functions
- tuning of MC generators
- reference for p-Pb and Pb-Pb



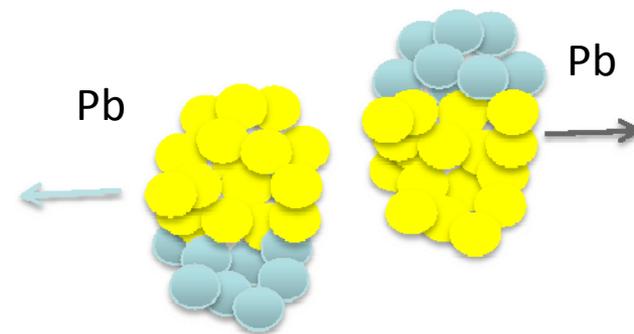
p-Pb



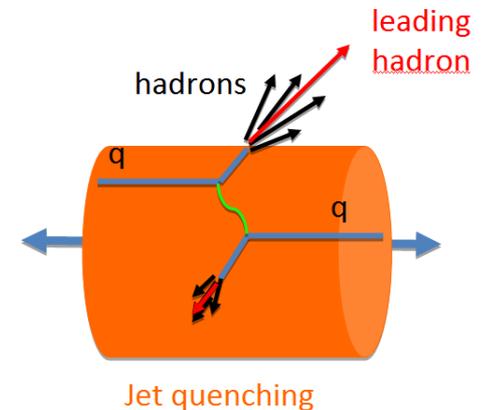
- initial and final state cold nuclear matter effects
- collective effects?
- reference for Pb-Pb



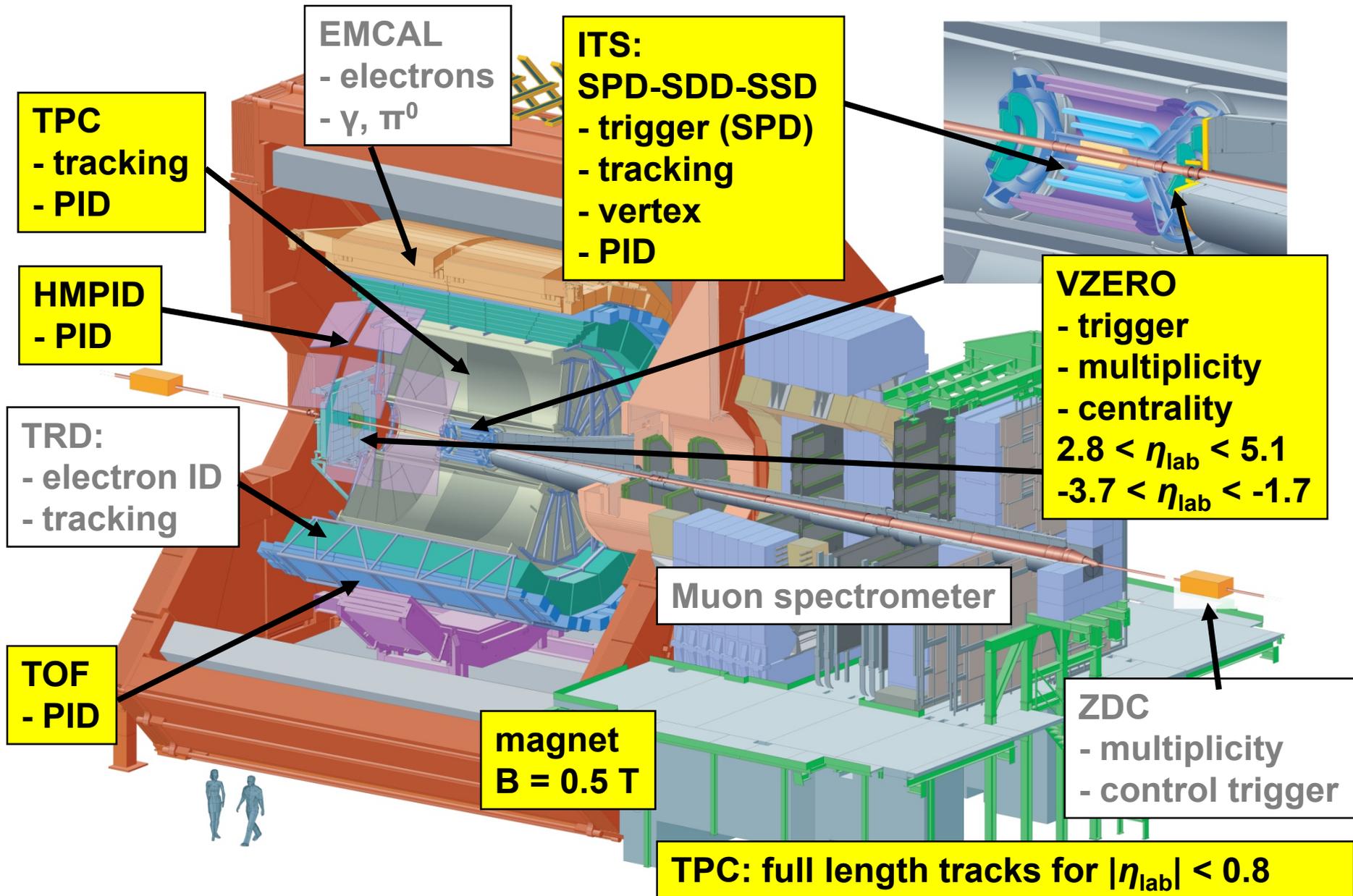
Pb-Pb



- collective effects
- parton energy loss
- modified fragmentation?

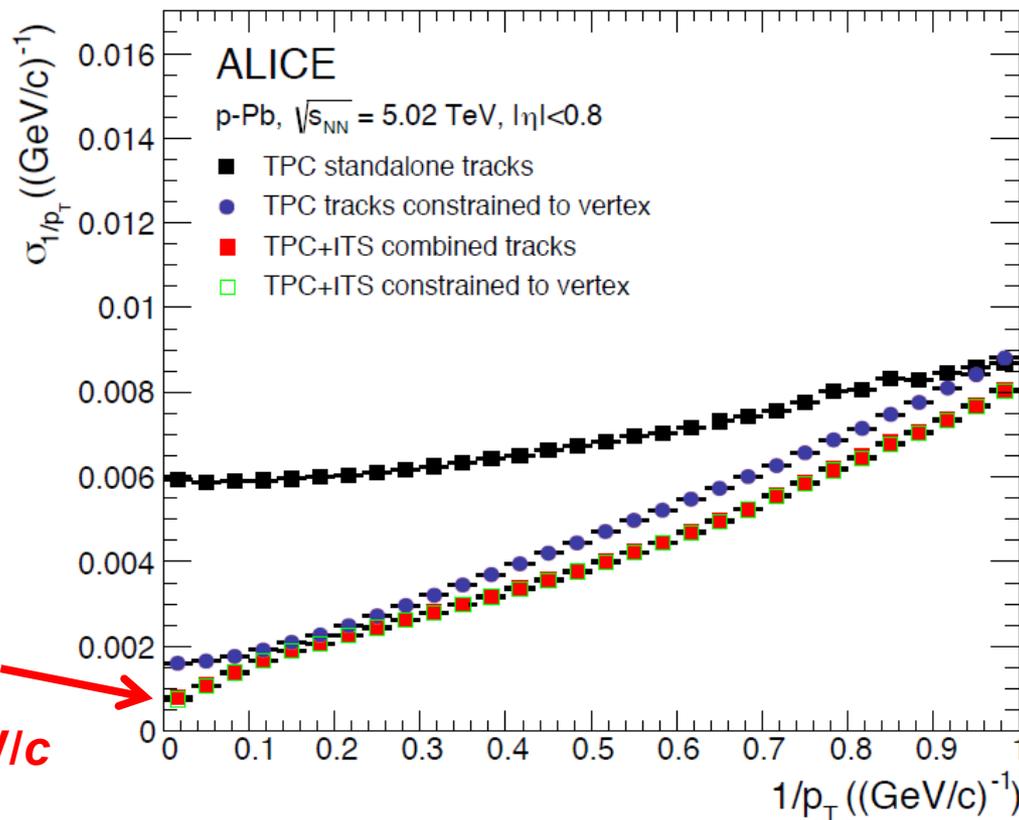


The ALICE detector



p_T resolution with ALICE detector

- best p_T resolution with combined TPC+ITS tracking
- currently: $\sigma(p_T)/p_T \sim 10\%$ at $p_T = 50$ GeV/c (pp, Pb-Pb)
- p-Pb: improved reconstruction, expected also for pp and Pb-Pb



$$\frac{\sigma_{p_T}}{p_T} = p_T \sigma_{1/p_T}$$

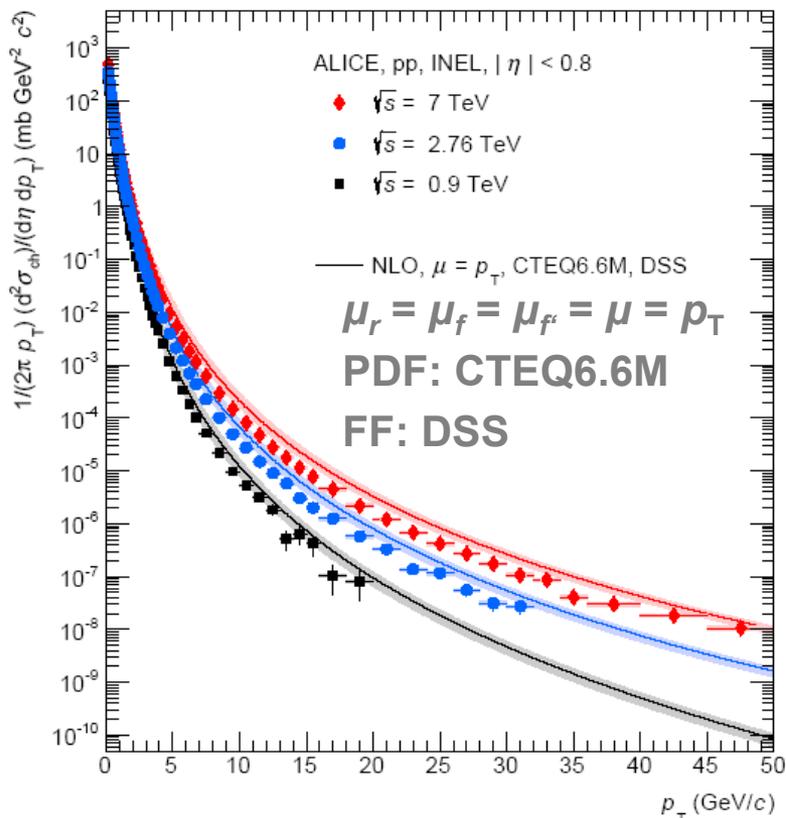
$\sigma(p_T)/p_T \sim 1\%$
at $p_T = 1$ GeV/c

$\sigma(p_T)/p_T \sim 3\%$
at $p_T = 50$ GeV/c

ALICE Collaboration, arXiv:1402.4476 [nucl-ex]

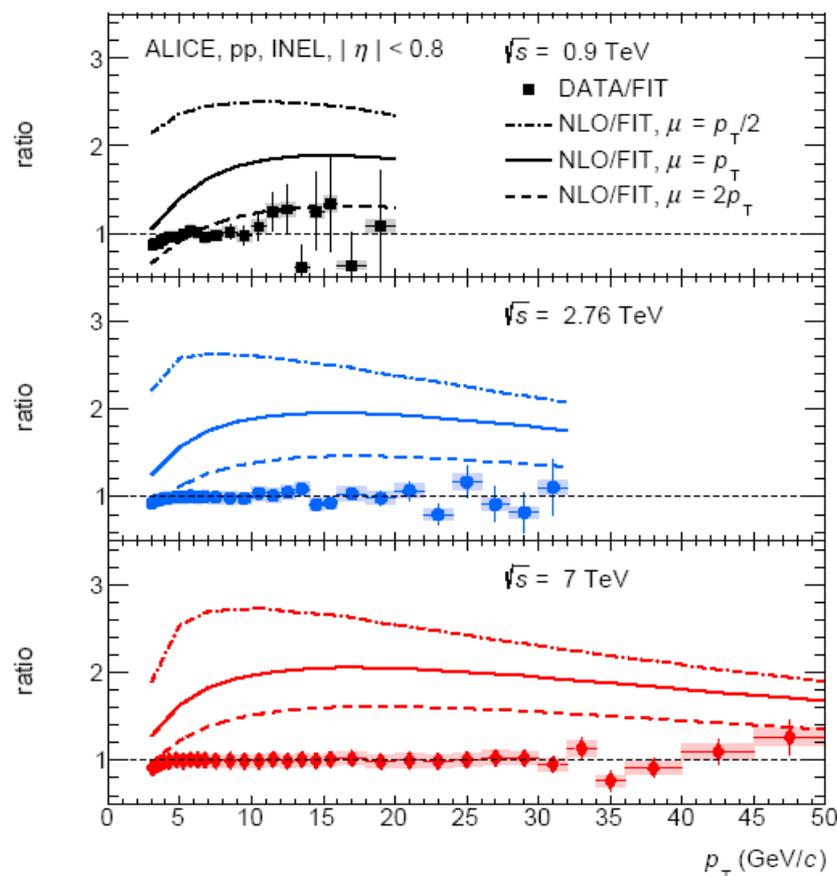


Charged particles in pp



- pp is not simple pQCD
- uncertainties of NLO only from scale variations $\mu = 2p_T$, $\mu = p_T/2$
- PDF and FF uncertainties not included

- NLO overpredicts the cross section by up to a factor 2
 - jet spectra are well described e.g. ALICE, Phys. Lett. B 722(2013) 262-272
- ⇒ FF too hard at LHC energy



ALICE Collaboration, Eur.Phys.J.C (2013) 73:2662
 NLO: Sassot, Zurita, Stratmann, Phys.Rev D 82, 074011 (2010)



pp reference for p-Pb

for R_{pPb} a pp reference spectrum is needed ($\sqrt{s} = 5.02$ TeV)

- ratio of pp cross sections at different energies well described by NLO

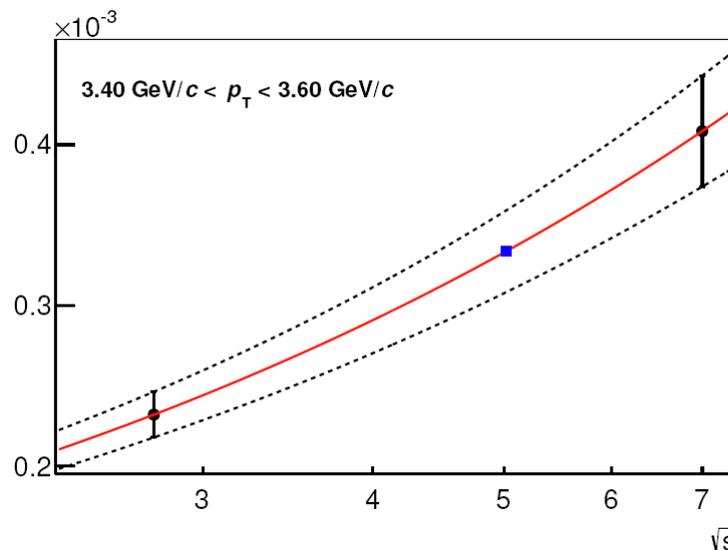
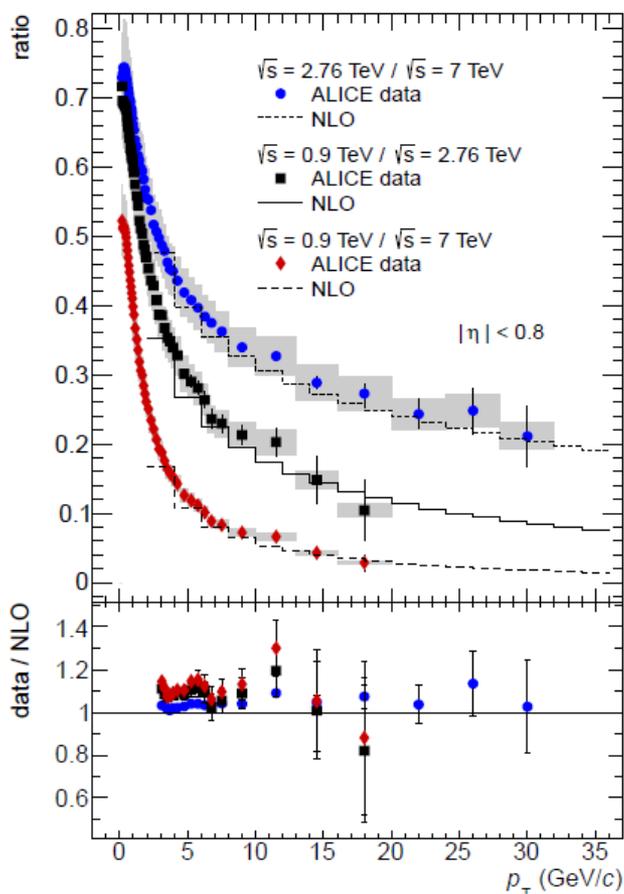
NLO scaling:

- charged particles $p_T > 5$ GeV/c

$$\left(\frac{d^2\sigma_{ch}^{pp}}{d\eta dp_T} \right)_{5.02\text{TeV}} = \frac{\left(\frac{d^2\sigma_{ch}^{pp}}{d\eta dp_T} \right)_{\text{NLO},5.02\text{TeV}}}{\left(\frac{d^2\sigma_{ch}^{pp}}{d\eta dp_T} \right)_{\text{NLO},7\text{TeV}}} \times \left(\frac{d^2\sigma_{ch}^{pp}}{d\eta dp_T} \right)_{7\text{TeV}}$$

power law interpolation in \sqrt{s} :

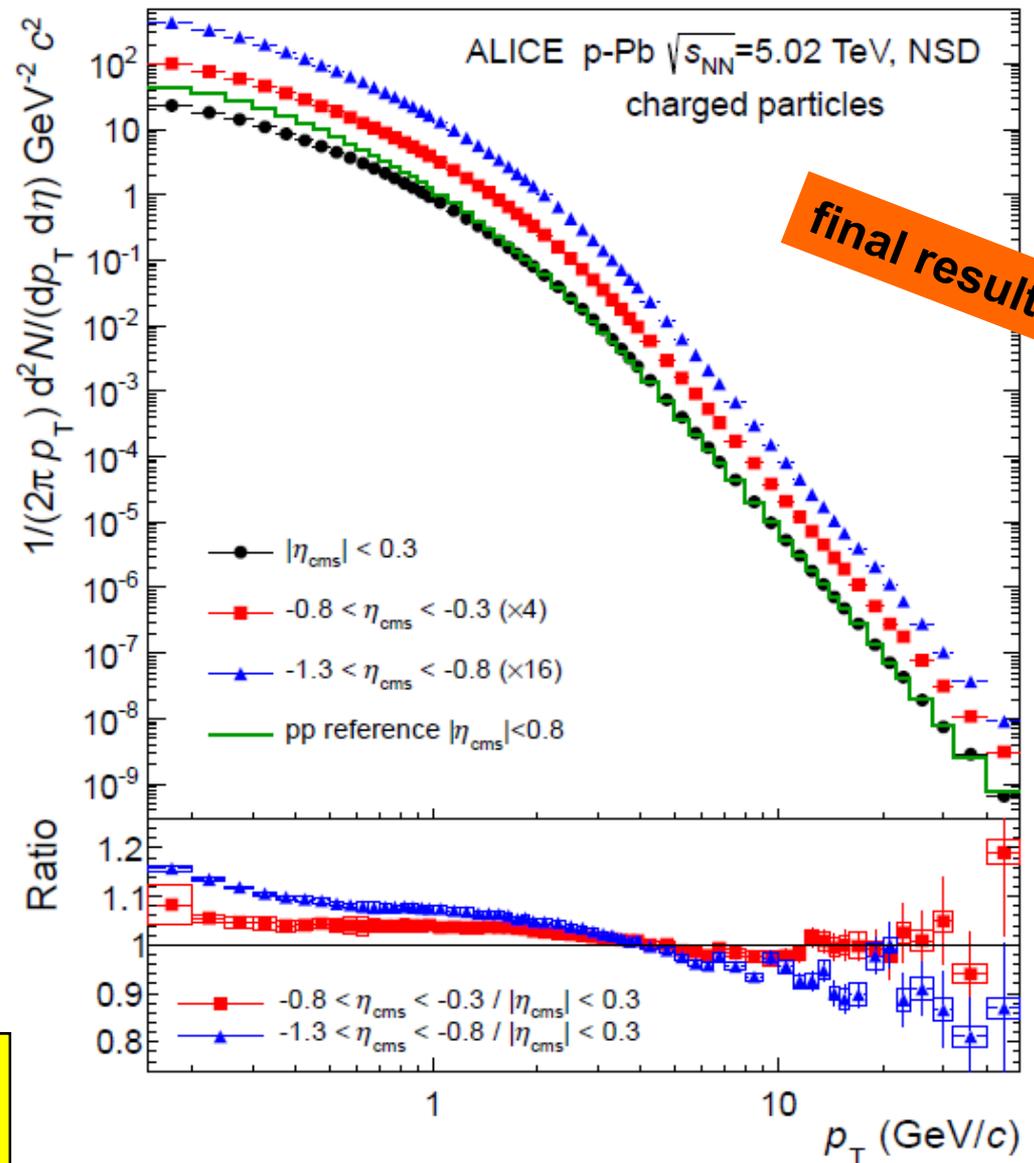
- charged particles $p_T < 5$ GeV/c
- π, K, p



Charged particles in p-Pb

- minimum bias trigger
- NSD collisions
- 2013 data, $L_{\text{int}} = 50.7 \mu\text{b}^{-1}$
- $0.15 < p_T < 50 \text{ GeV}/c$
- reduced systematic uncertainties
- softer spectrum at backward rapidity (Pb side)
- in the ratio of η intervals many systematic uncertainties cancel

sign convention:
proton goes to $y > 0$, $\eta_{\text{cms}} > 0$



ALICE Collaboration, arXiv:1405.2737 [nucl-ex]



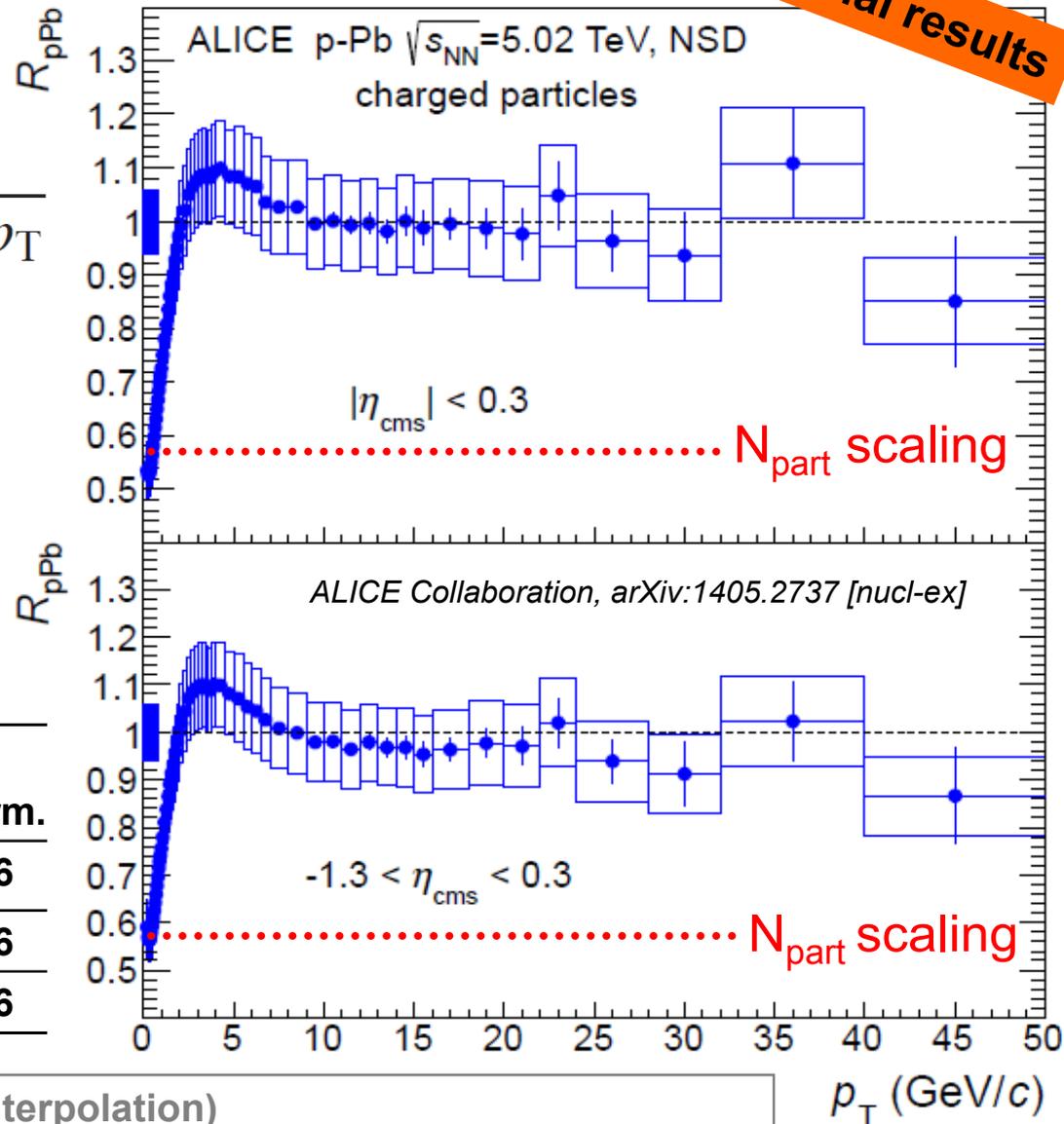
R_{pPb} of charged particles

nuclear modification factor:
(pp reference: $\eta < 0.8$)

$$R_{pPb}(p_T) = \frac{d^2 N^{pPb} / d\eta dp_T}{\langle T_{pPb} \rangle d^2 \sigma^{pp} / d\eta dp_T}$$

- N_{coll} scaling at high p_T
- N_{part} scaling at low p_T
- small Cronin-like enhancement at intermediate p_T

p_T (GeV/c)	$\langle R_{pPb} \rangle$ $ \eta_{cms} < 0.3$	\pm stat.	\pm syst.	\pm norm.
10-20	0.995	0.007	0.084	0.06
20-28	0.990	0.031	0.090	0.06
28-50	0.969	0.056	0.090	0.06



final results

$$\langle T_{pPb} \rangle = \langle N_{coll} \rangle / \sigma_{NN}; \sigma_{NN} = 70 \pm 5 \text{ mb (interpolation)}$$

$$\Rightarrow \sigma_{tot} = 2.1 \text{ b}; \langle b \rangle = 5.56 \text{ fm}; \langle N_{coll} \rangle = 6.9 \pm 0.6; \langle T_{pPb} \rangle = 0.0983 \pm 0.0035 \text{ mb}^{-1}$$

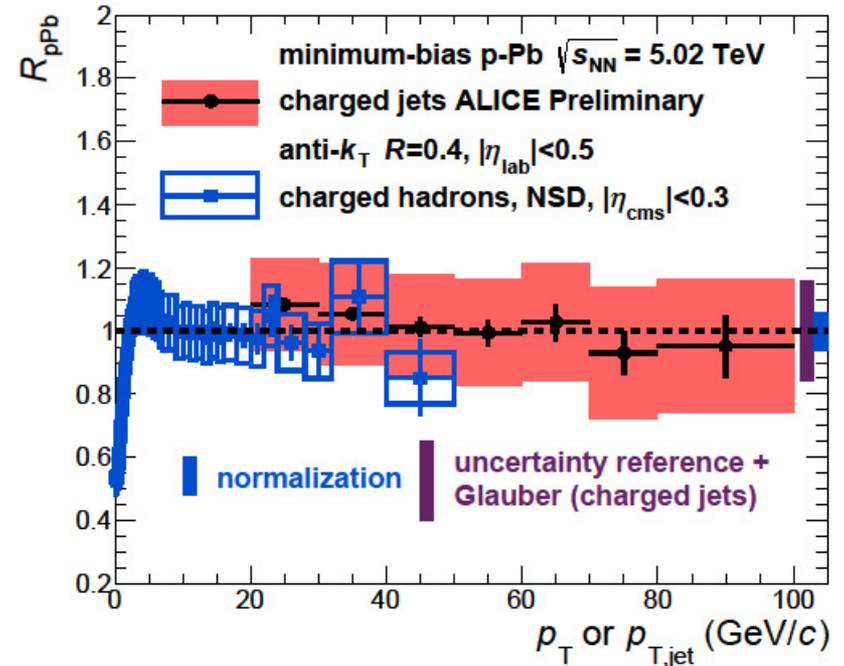
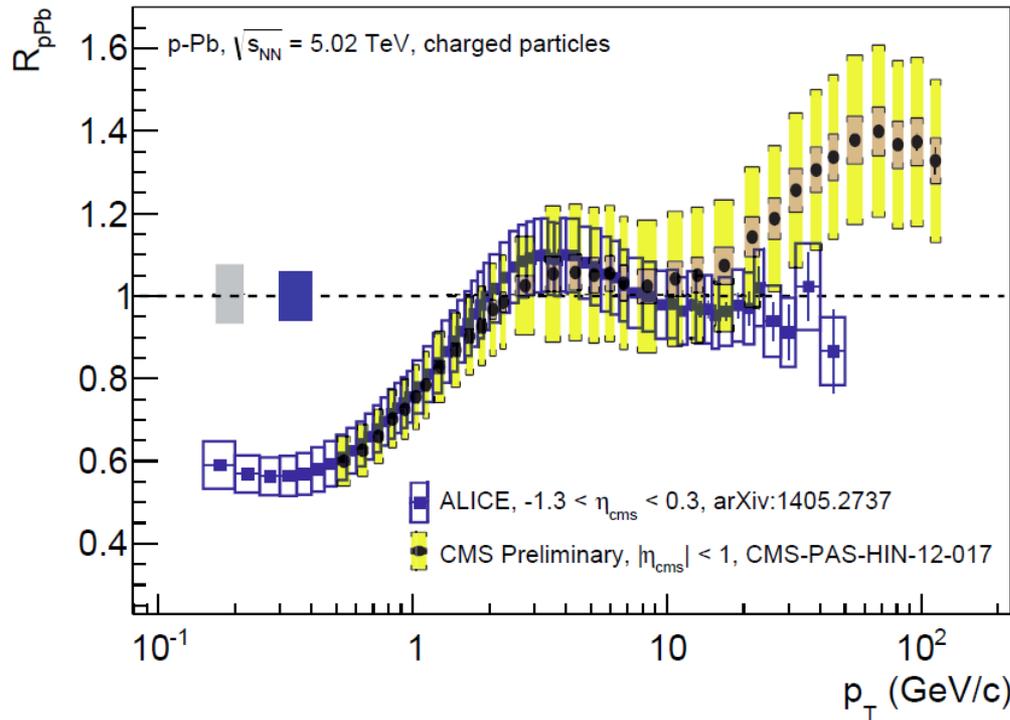


Comparison of R_{pPb} to other measurements

- **CMS:**
strong anti-shadowing at large p_T
– not seen in ALICE data
- also pp references are different

- **ALICE charged jets R_{pPb}**
consistent with unity up to
 $p_{T,jet} = 100 \text{ GeV}/c$

jet R_{pPb} : M. Connors (poster E-06)
R. Haake (poster E-09)



- **ATLAS (0-90%, $p_T < 22 \text{ GeV}/c$) R_{pPb} in agreement with ALICE**



R_{pPb} compared to models

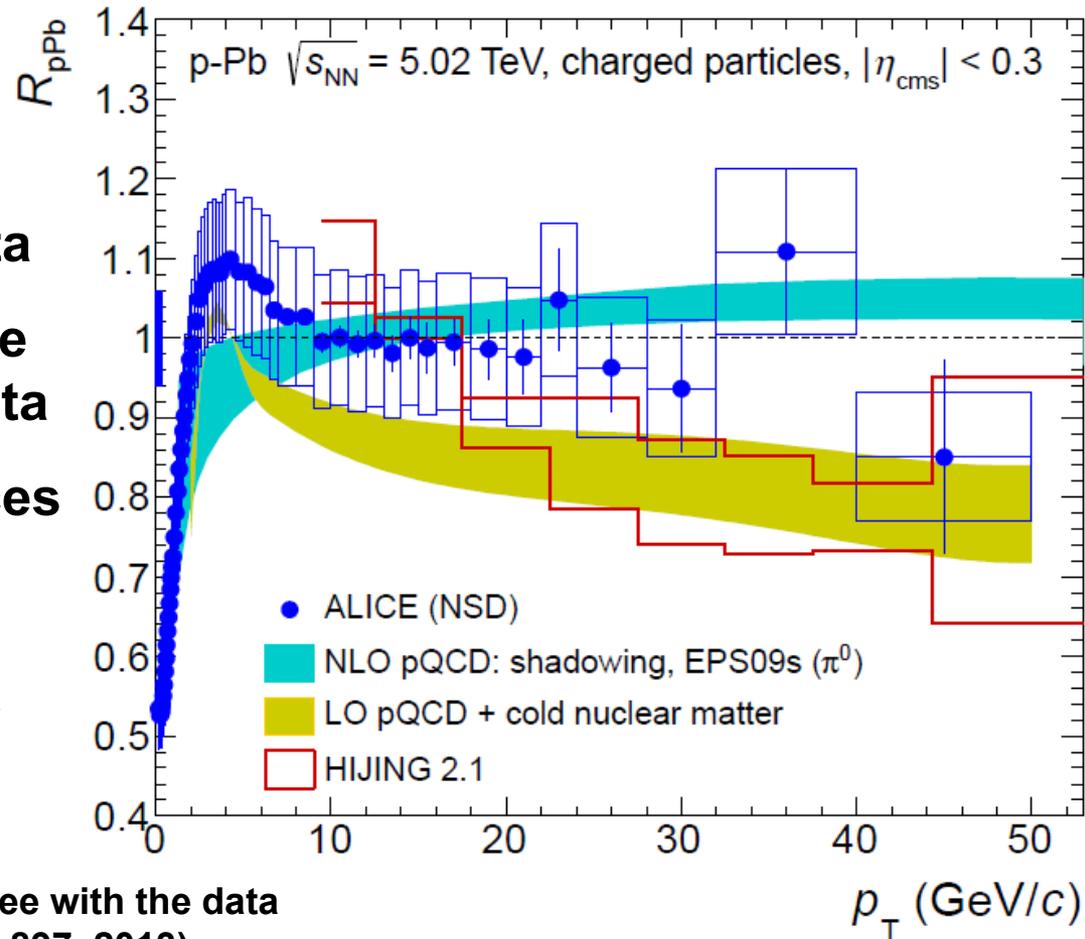
ALICE Collaboration, arXiv:1405.2737 [nucl-ex]

- NLO with EPS09s nPDF: agrees for $p_T > \sim 6$ GeV/c
- LO with cold nuclear matter effects: not supported by data
- HIJING 2.1: stronger decrease of R_{pPb} with p_T not seen in data
- none of the models reproduces the Cronin enhancement

NLO+EPS09s: Helenius et al., JHEP 1207 (2012) 073
LO+CNM: Kang et al., Phys.Lett. B718 (2012) 482-487
HIJING: Xu et al., Phys.Rev. C86 (2012) 051901

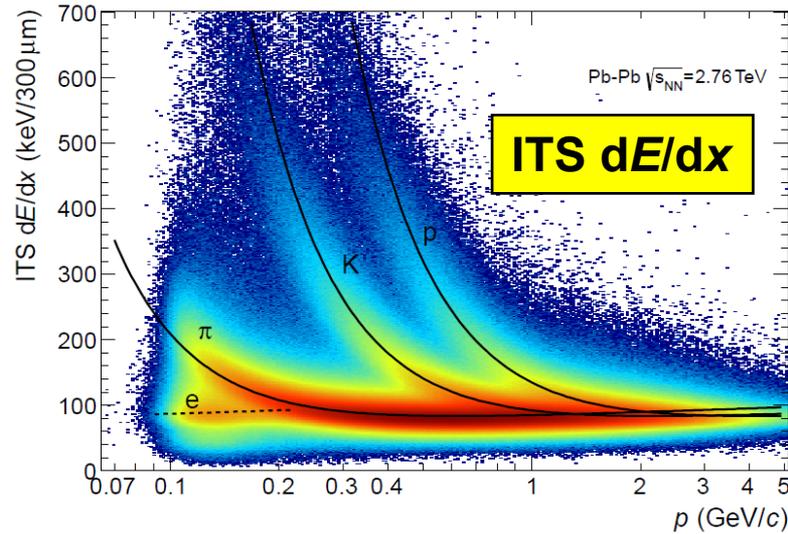
not included in the Figure:

- CGC predictions are for low p_T and agree with the data (rcBK-MC, Albacete et al. Nucl. Phys. A 897, 2013)
- EPOS3 with hydro describes R_{pPb} and the spectra (within $\sim 20\%$) (K. Werner et al., arXiv:1312.1233)
- PHSD transport model does not describe the spectra for $p_T > 2$ GeV/c (V. P. Konchakovski et al., arXiv:1401.4409)

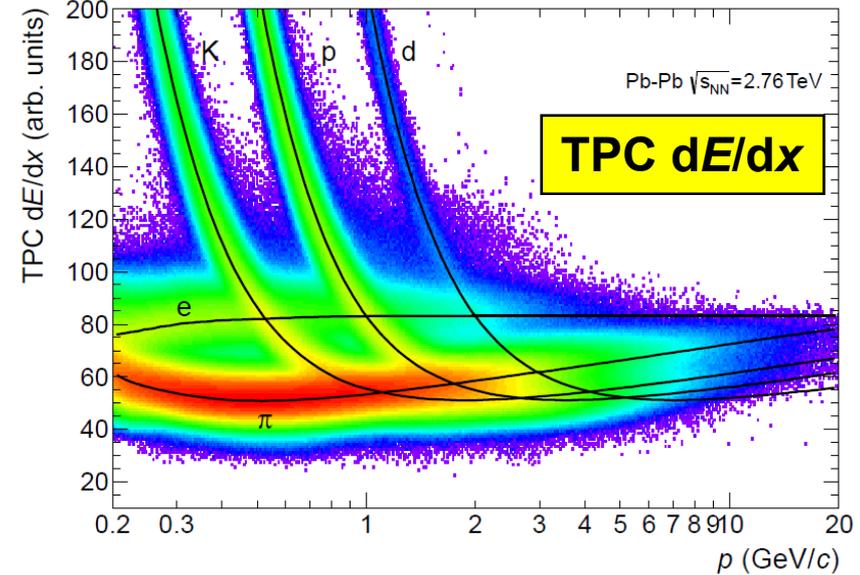


Particle Identification in ALICE

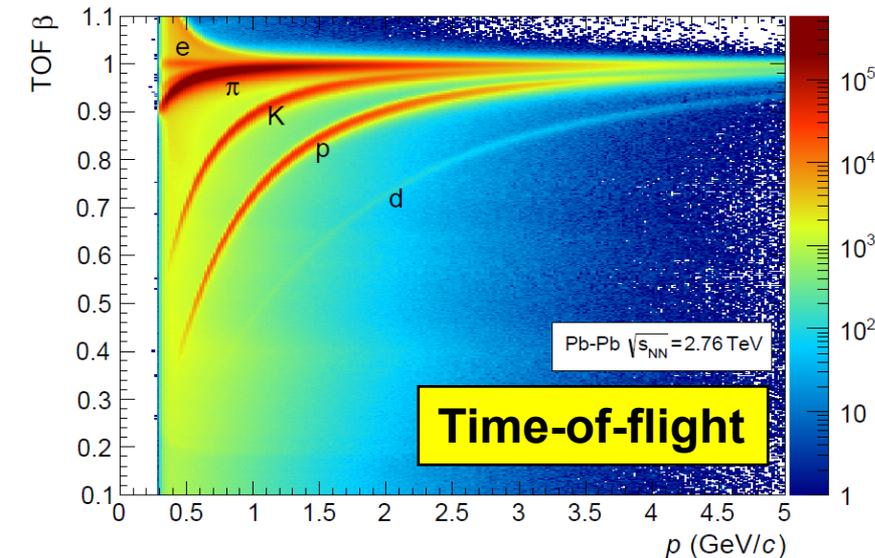
ALICE Collaboration, arXiv:1402.4476 [nucl-ex]



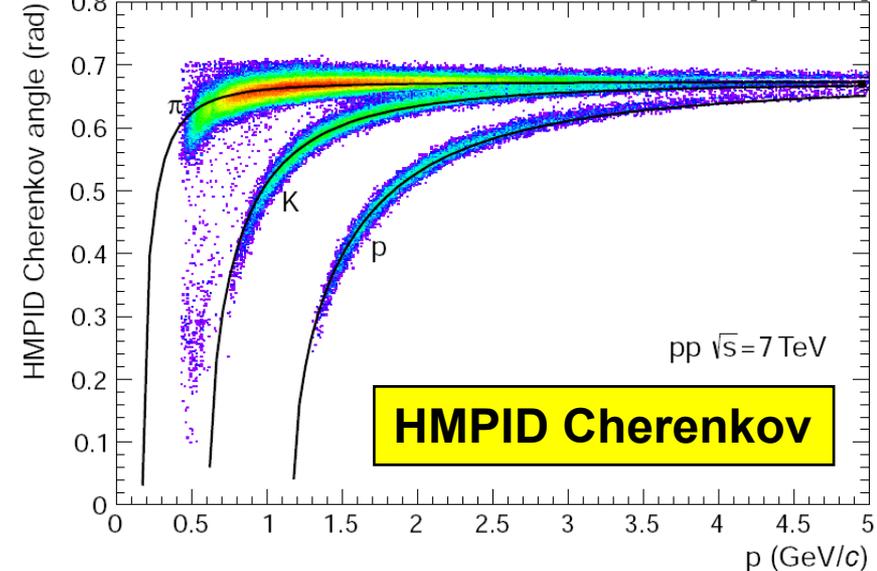
ALICE Collaboration, arXiv:1402.4476 [nucl-ex]



ALICE Collaboration, arXiv:1402.4476 [nucl-ex]

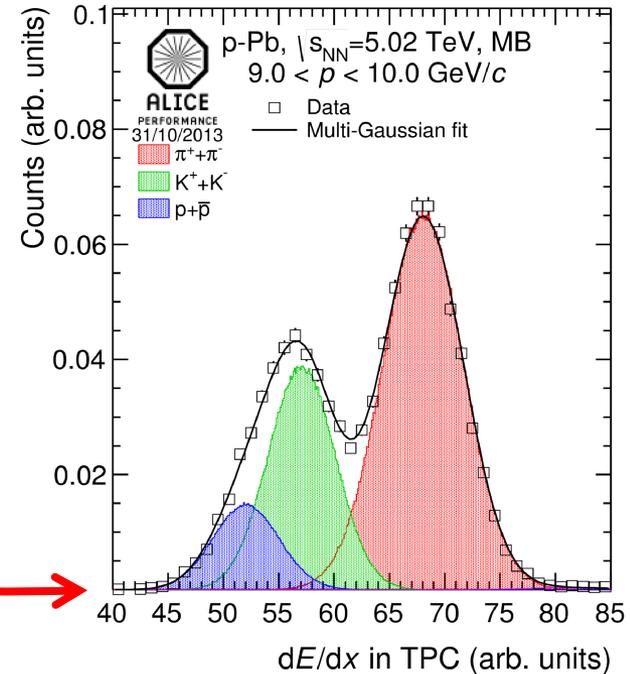
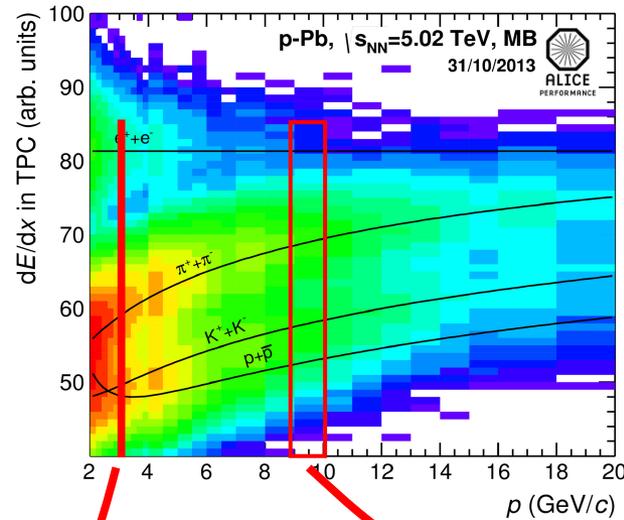
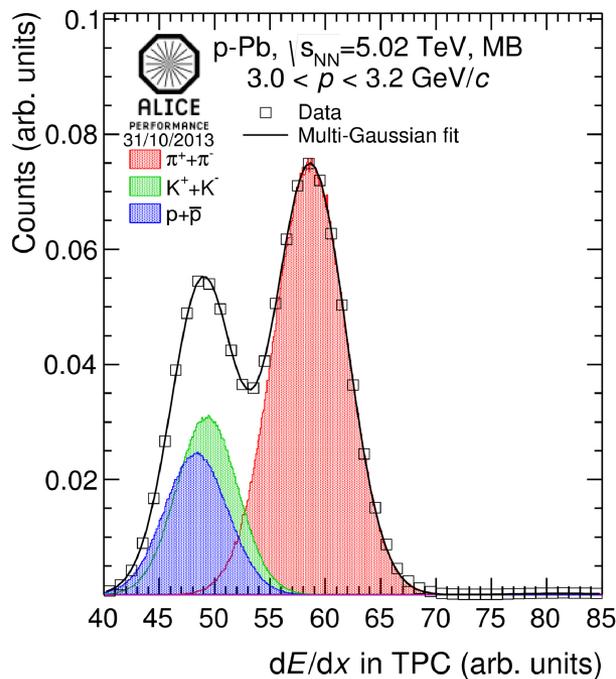


ALICE Collaboration, arXiv:1402.4476 [nucl-ex]



TPC relativistic rise dE/dx

- fit of 4 Gaussians (π , K, p, e) in intervals of η and p_T
- peak positions and width fixed from identified particles
- π , K, p spectra on statistical basis for $3 < p_T < 20$ GeV/c



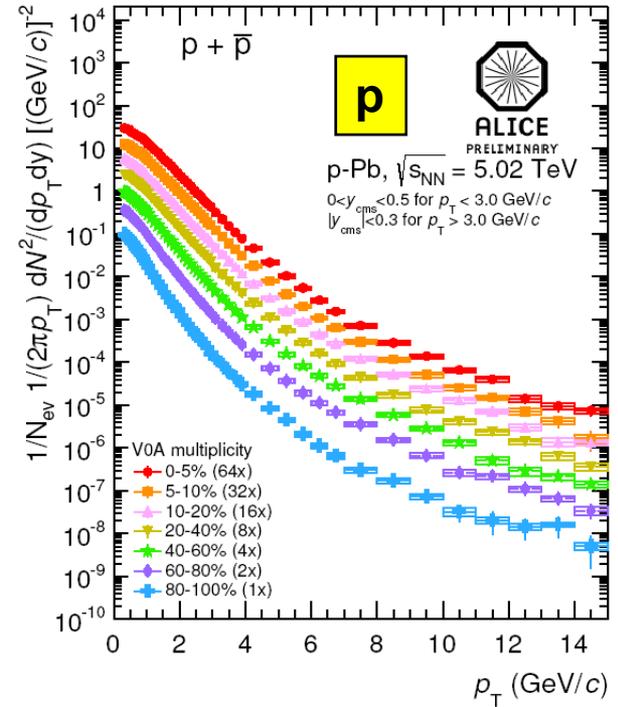
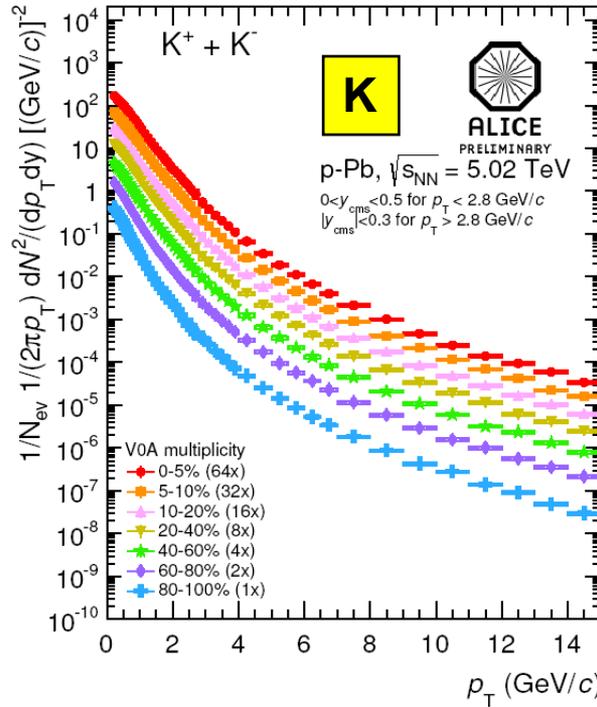
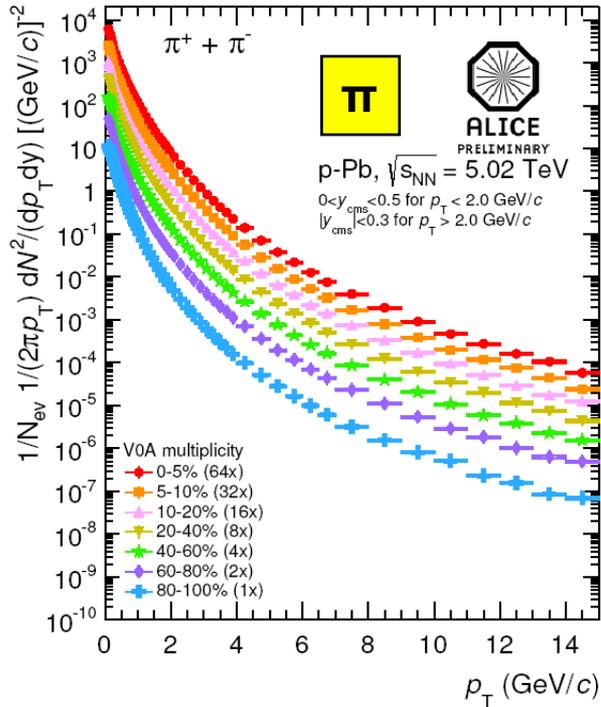
$$\frac{d^2 N_\pi}{dy dp_T} = \frac{E}{p} \frac{d^2 N_{ch}}{d\eta dp_T} \times \frac{\epsilon_\pi}{\epsilon_{ch}} \times \frac{N_\pi}{N_{ch}} \leftarrow \text{from TPC } dE/dx$$



Identified hadron spectra in p-Pb collisions

p-Pb

- multiplicity classes from V0A detector
- spectra combined from low- p_T and high- p_T analysis



- harder spectra for higher multiplicities
- mass ordering of π , K, p: harder spectra \leftrightarrow larger mass

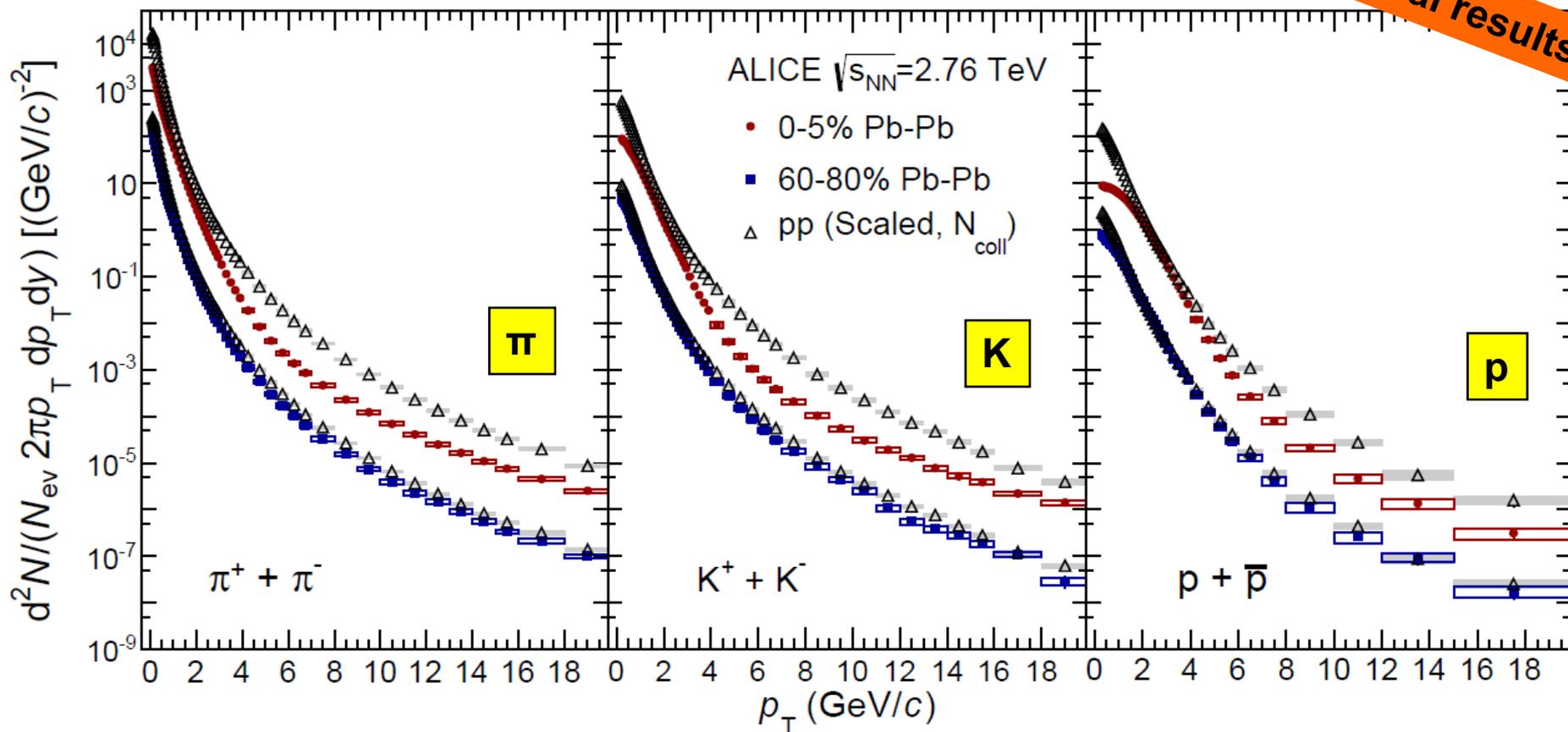


Identified hadron spectra in Pb-Pb collisions

- shape of the spectrum in Pb-Pb differs from pp reference
- difference most pronounced in central collisions

Pb-Pb

final results



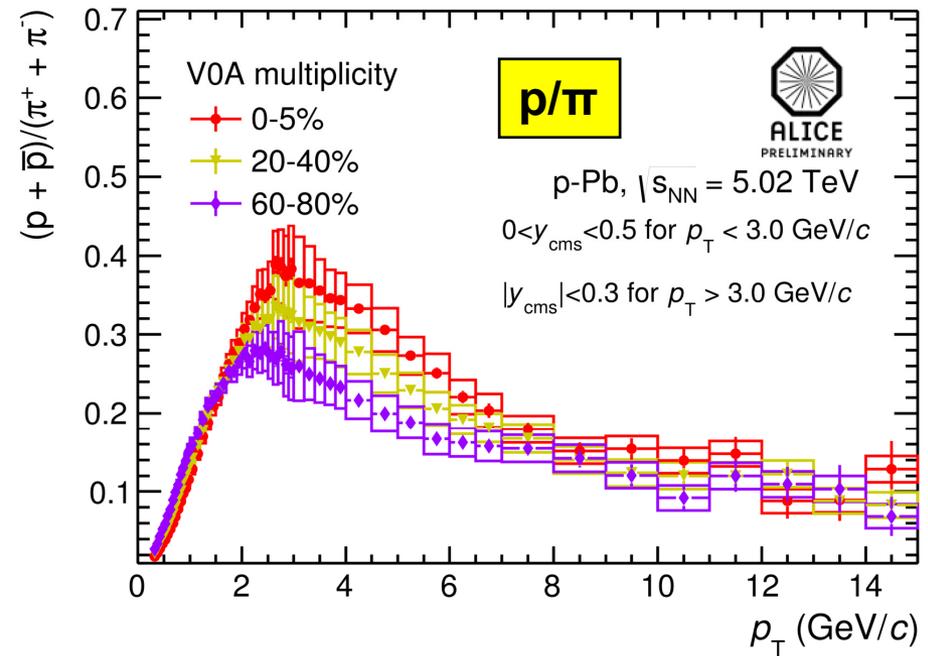
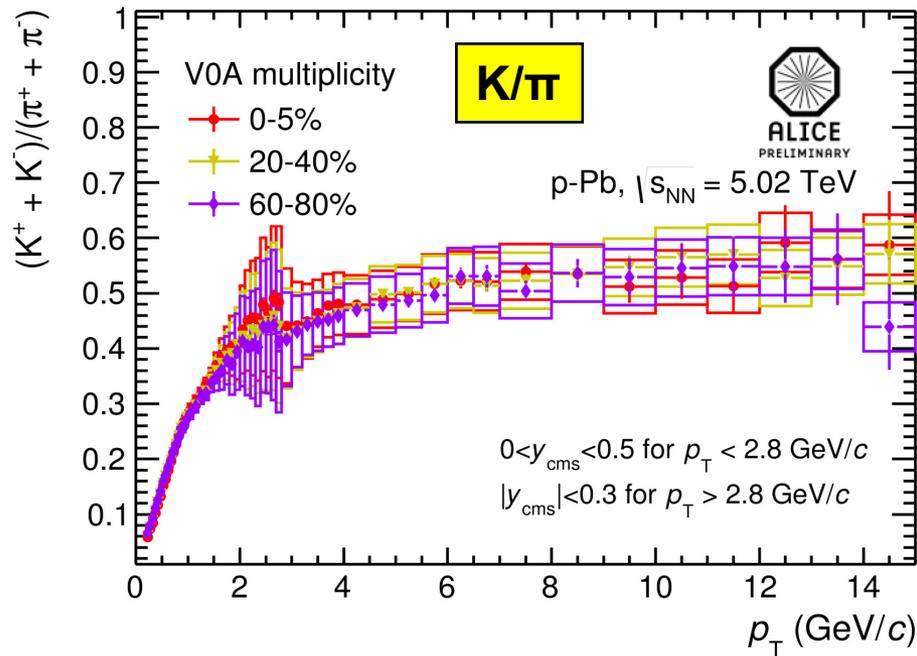
ALICE Collaboration, arXiv:1401.1250 [nucl-ex]



Identified hadron ratios p-Pb

p-Pb

- no multiplicity dependence in K/π
- K/π ratio reaches ~ 0.55 at high p_T



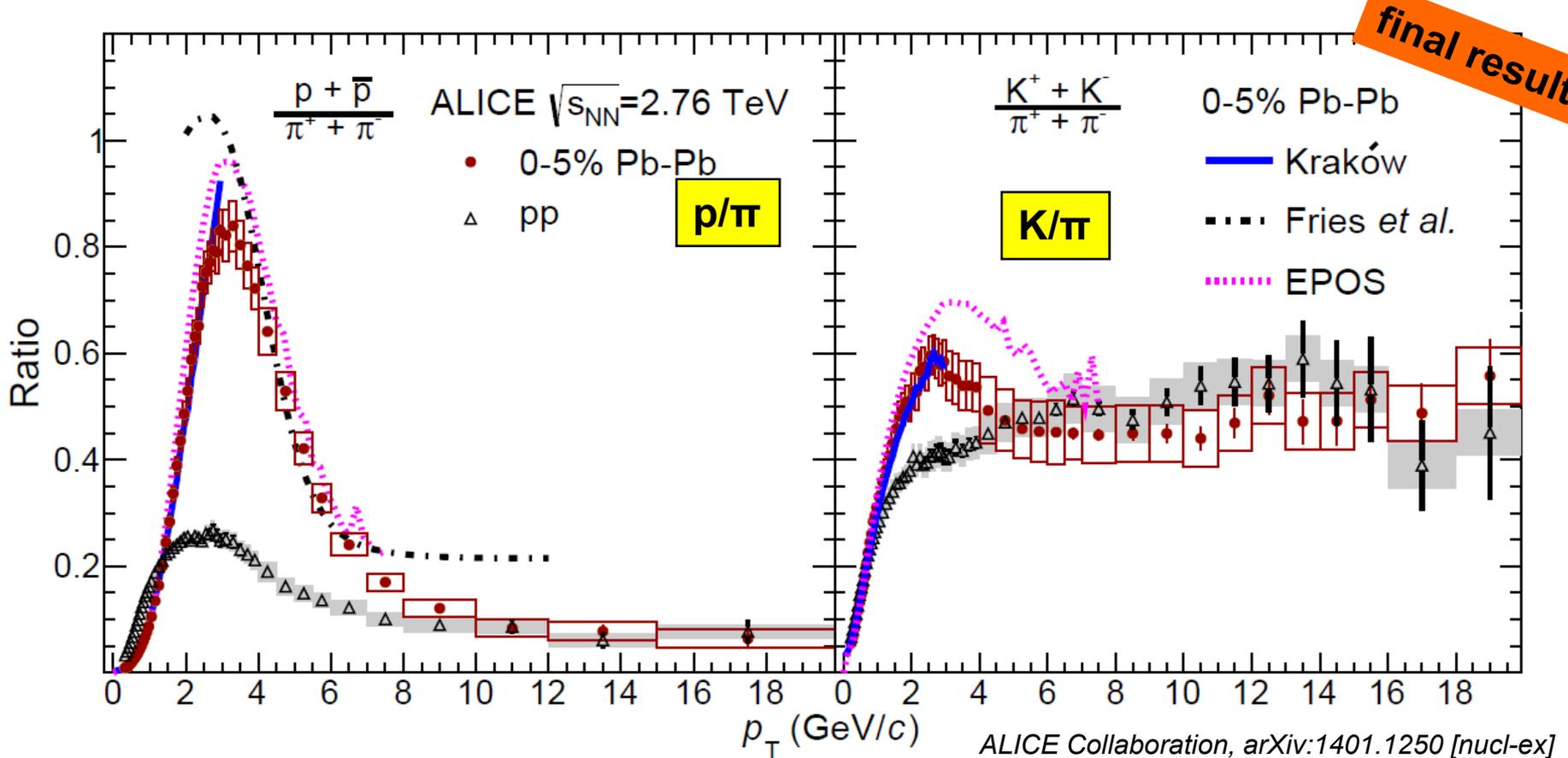
- enhancement of protons at intermediate p_T (2-6 GeV/c)
- p/π ratio ~ 0.1 at high p_T
- results from low- p_T (< 3 GeV/c) and high- p_T (> 3 GeV/c) analysis



Identified hadron ratios in Pb-Pb collisions

- p/π up to ~ 0.8 around $p_T = 3$ GeV/c (central 0-5%)
- K/π and p/π different from pp at intermediate p_T (radial flow)
- at large p_T particle fractions do not differ from those in pp

Pb-Pb

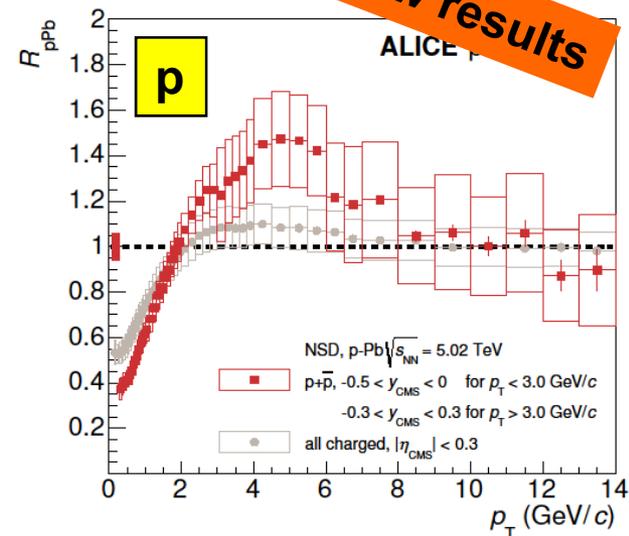
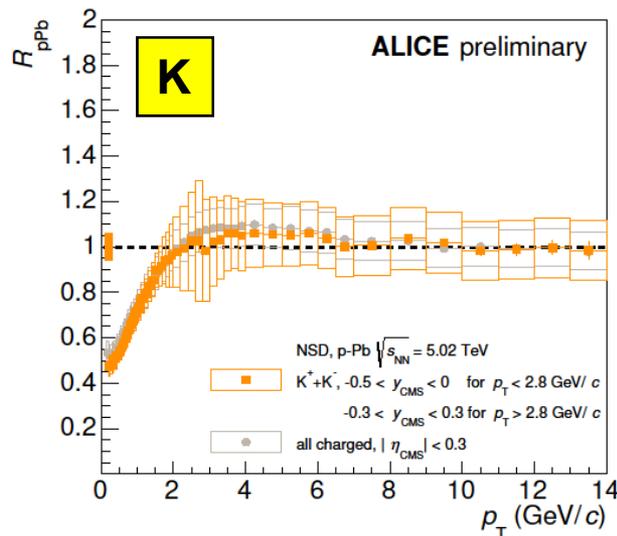
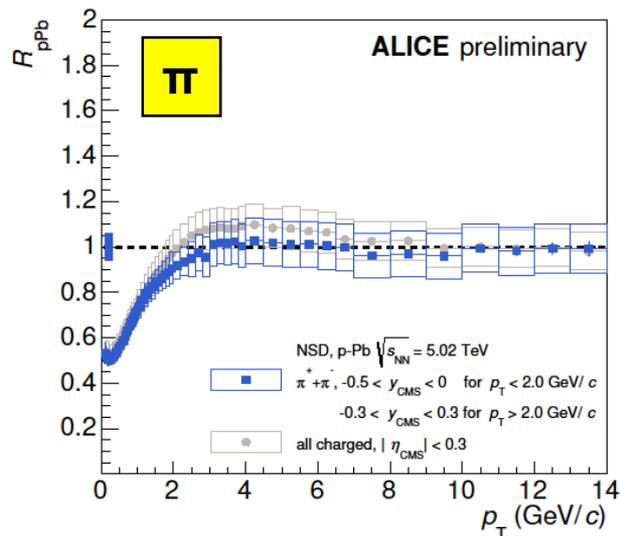


Identified hadron R_{pPb}

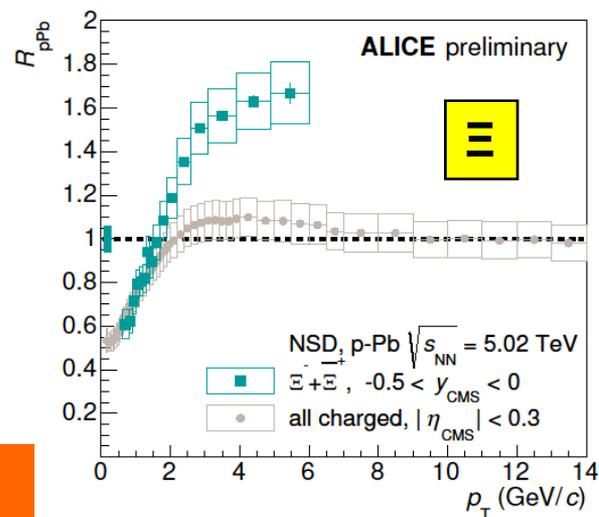
- pp reference from interpolation
- π , K not different charged particle R_{pPb}

p-Pb

new results



- mass ordering in the Cronin-region: π , K, p, Ξ
- notable enhancement for p, Ξ
- Cronin peak in charged R_{pPb} from protons
- R_{pPb} of π , K, p consistent with unity at large p_T



strange baryons: D. Alexandre, Wed 9:00

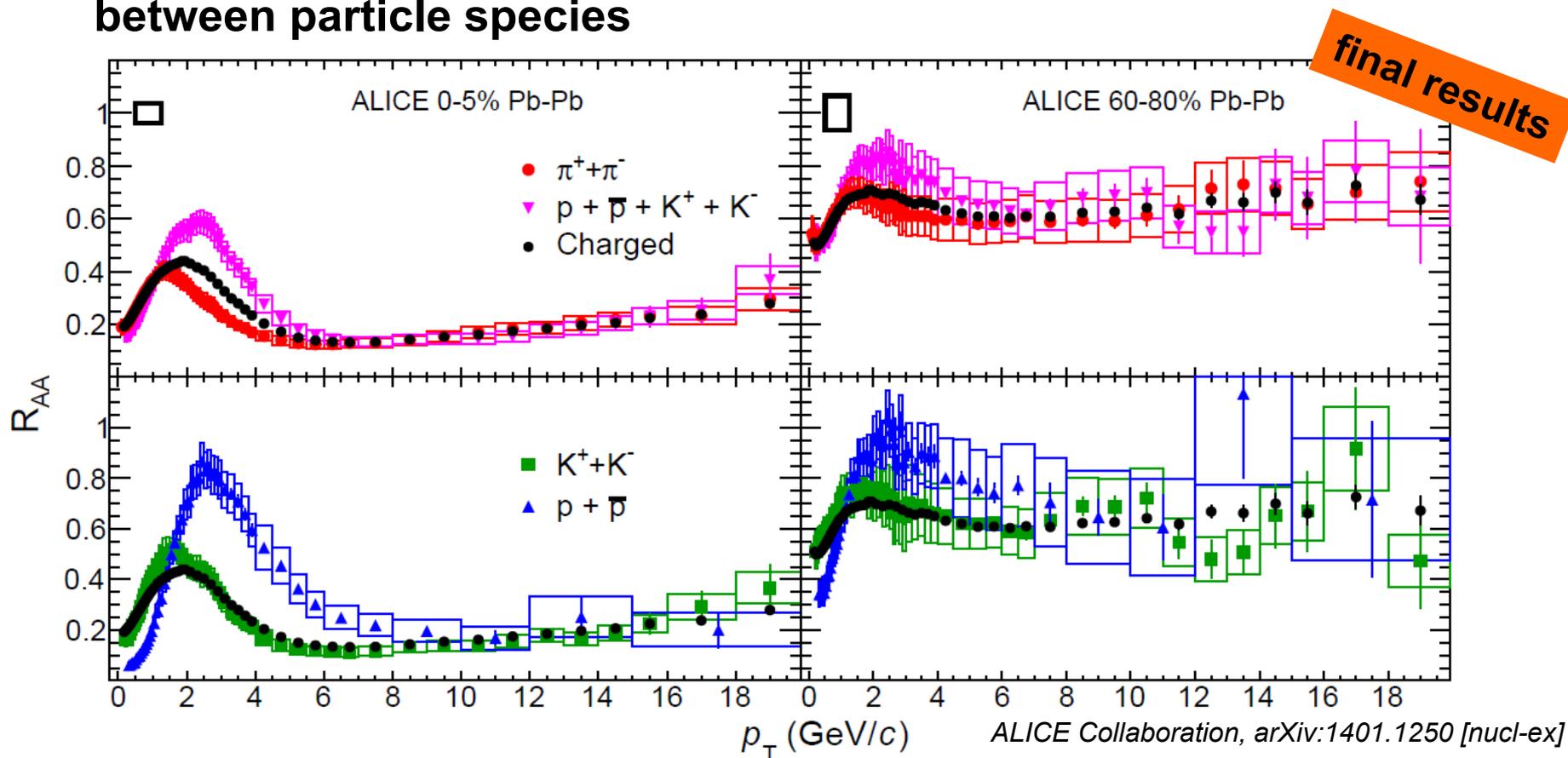


Identified hadron R_{AA}

- mass ordering at intermediate p_T
- less suppression of protons at intermediate p_T
- at large p_T (> 8 GeV/c) no difference between particle species

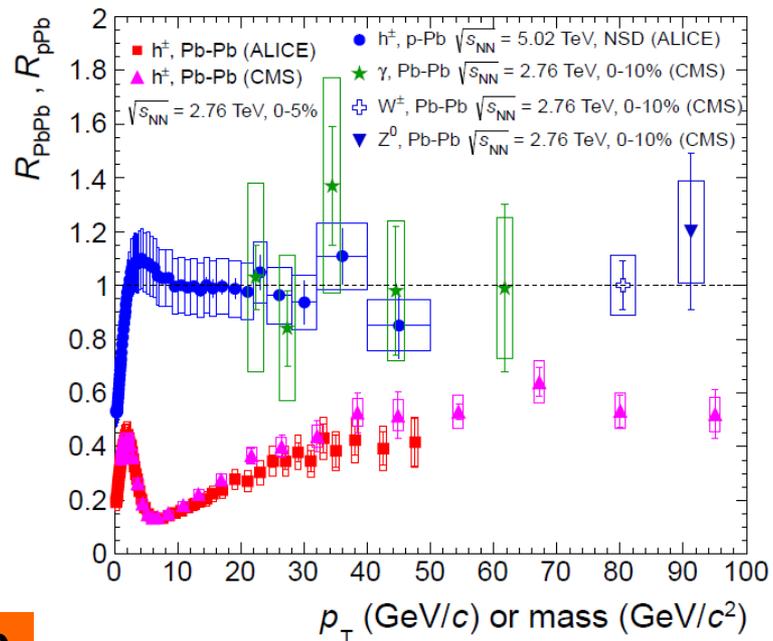
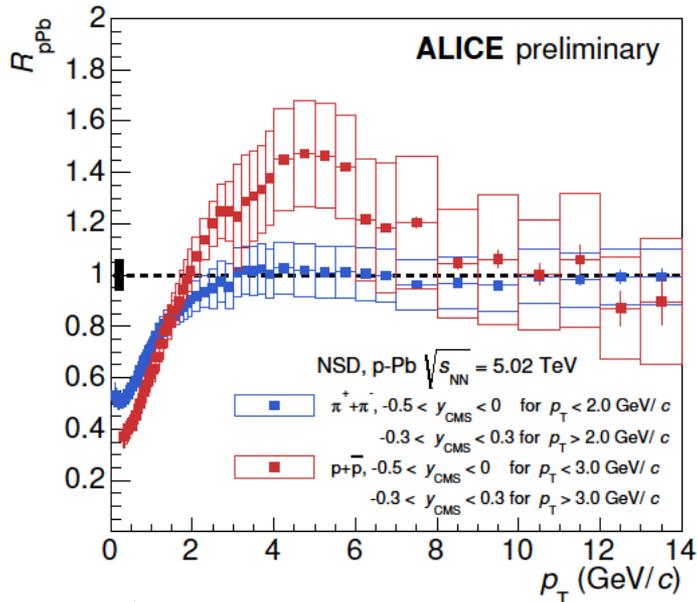
Pb-Pb

$$R_{AA}(p_T) = \frac{d^2 N^{AA} / d\eta dp_T}{\langle T_{AA} \rangle d^2 \sigma^{pp} / d\eta dp_T}$$



Summary/Conclusion

- no deviation from N_{coll} scaling in high p_T p-Pb
- at large p_T R_{pPb} and R_{AA} universal for hadron species
particle ratios not different from pp \Rightarrow vacuum fragmentation
- mass ordering at intermediate p_T similar in p-Pb and Pb-Pb (flow?)
- Cronin enhancement in p-Pb caused by protons
- description of R_{pPb} over full p_T range remains a challenge for models



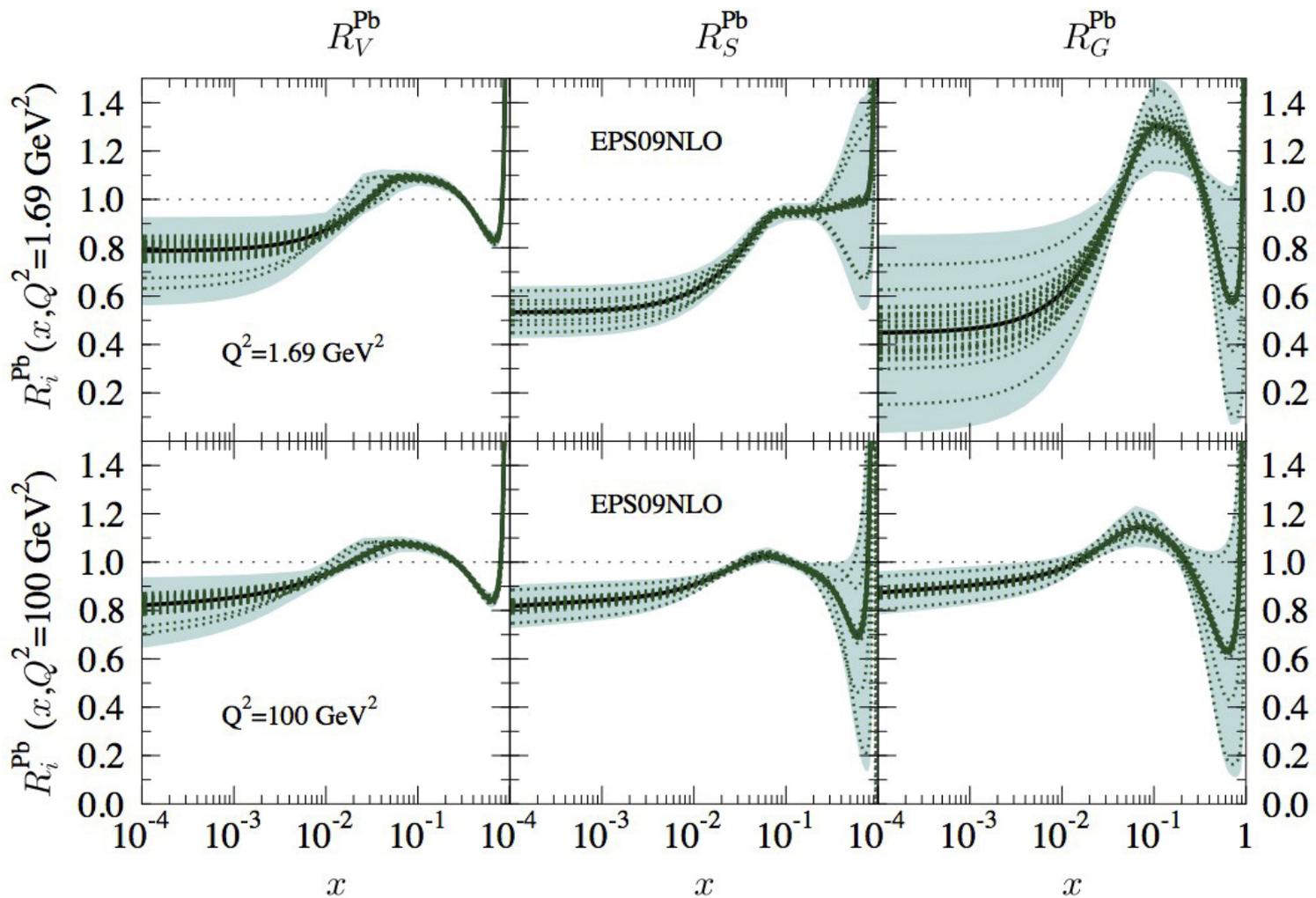
ALICE, Phys. Lett. B 720 (2013) 52-62
 CMS, Eur. Phys. J. C 72 (2012) 1945
 ALICE, arXiv:1405.2737 [nucl-ex]
 CMS, Phys. Lett. B 710 (2012) 256
 CMS, Phys. Lett. B 715 (2012) 66
 CMS, Phys.Rev.Lett. 106:212301, 2011

collective effects: C. Andrei, Mon 12:00



Additional Slides

EPS09 nPDF for Pb nuclei

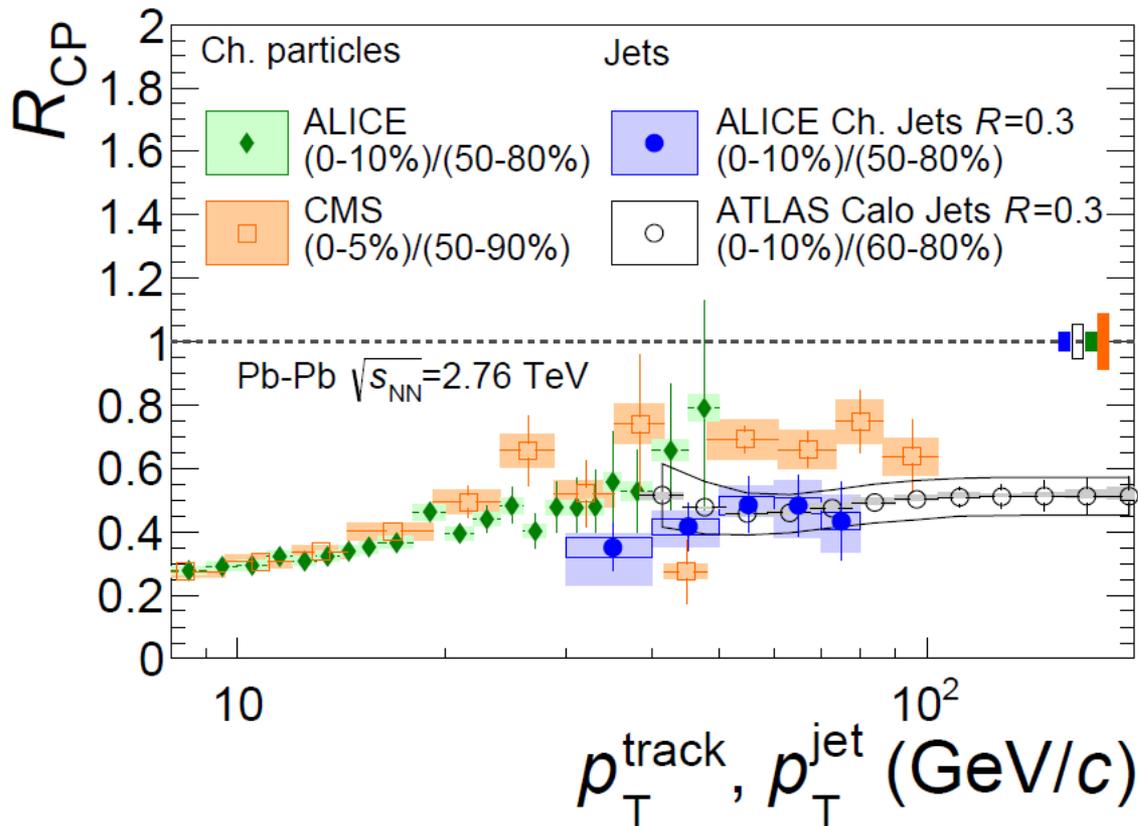


Eskola et al., JHEP 0904:065,2009



R_{CP} of jets and charged particles

- R_{CP} of charged jets similar to R_{CP} of charged hadrons at comparable parton p_T



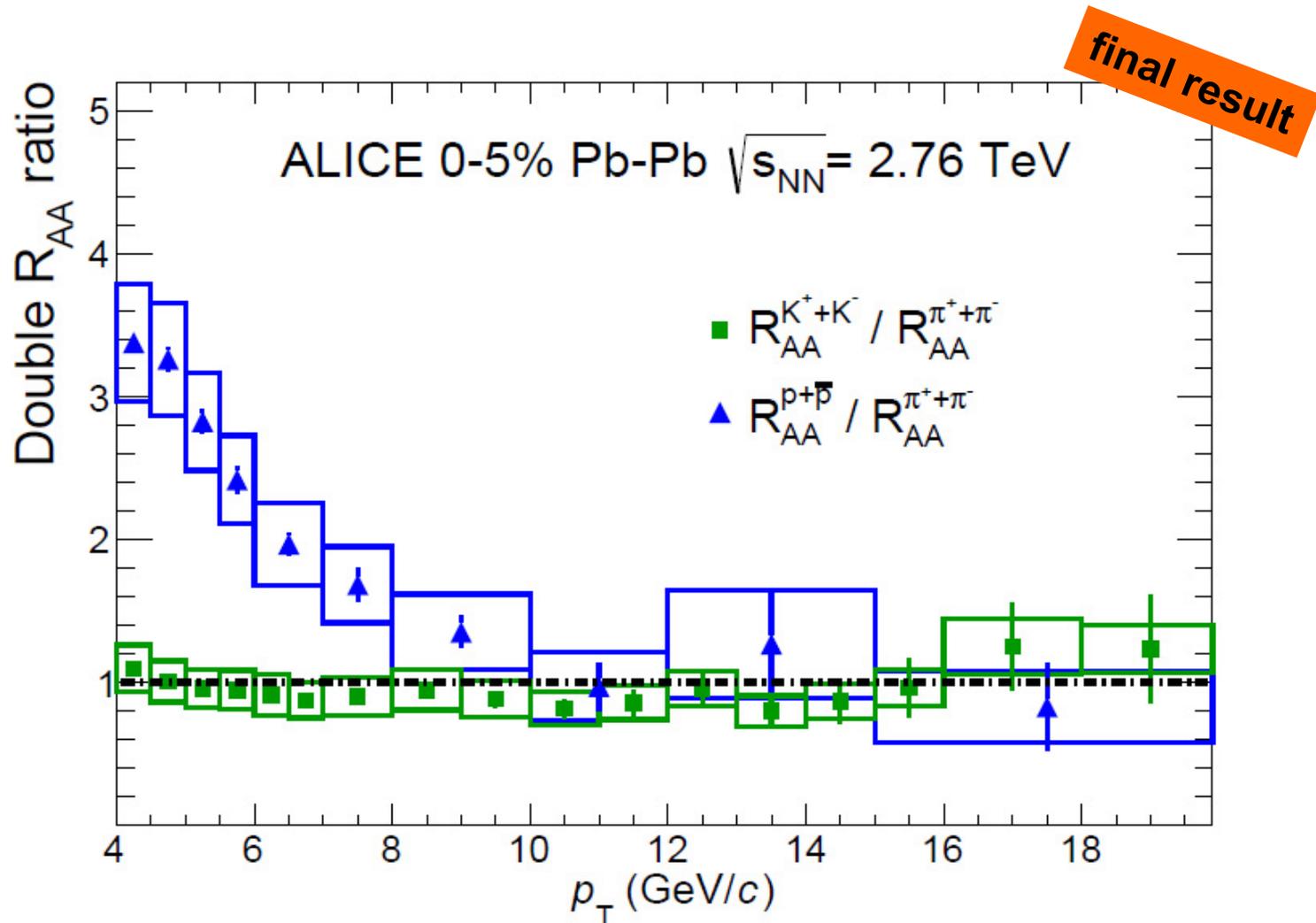
$$R_{CP}(p_T) = \frac{\langle N_{coll}^P \rangle}{\langle N_{coll}^c \rangle} \frac{d^2 N_{ch}^c / d\eta dp_T}{d^2 N_{ch}^P / d\eta dp_T}$$

ALICE Collaboration, arXiv:1405.1849 [nucl-ex]
 ALICE Collaboration, Phys.Lett. B720 (2013) 52-62
 ATLAS Collaboration, Phys.Lett. B719 (2013) 220-241
 CMS Collaboration, Eur.Phys.J. C72 (2012) 1945



R_{AA} double ratio

- partial cancellation of systematic uncertainties

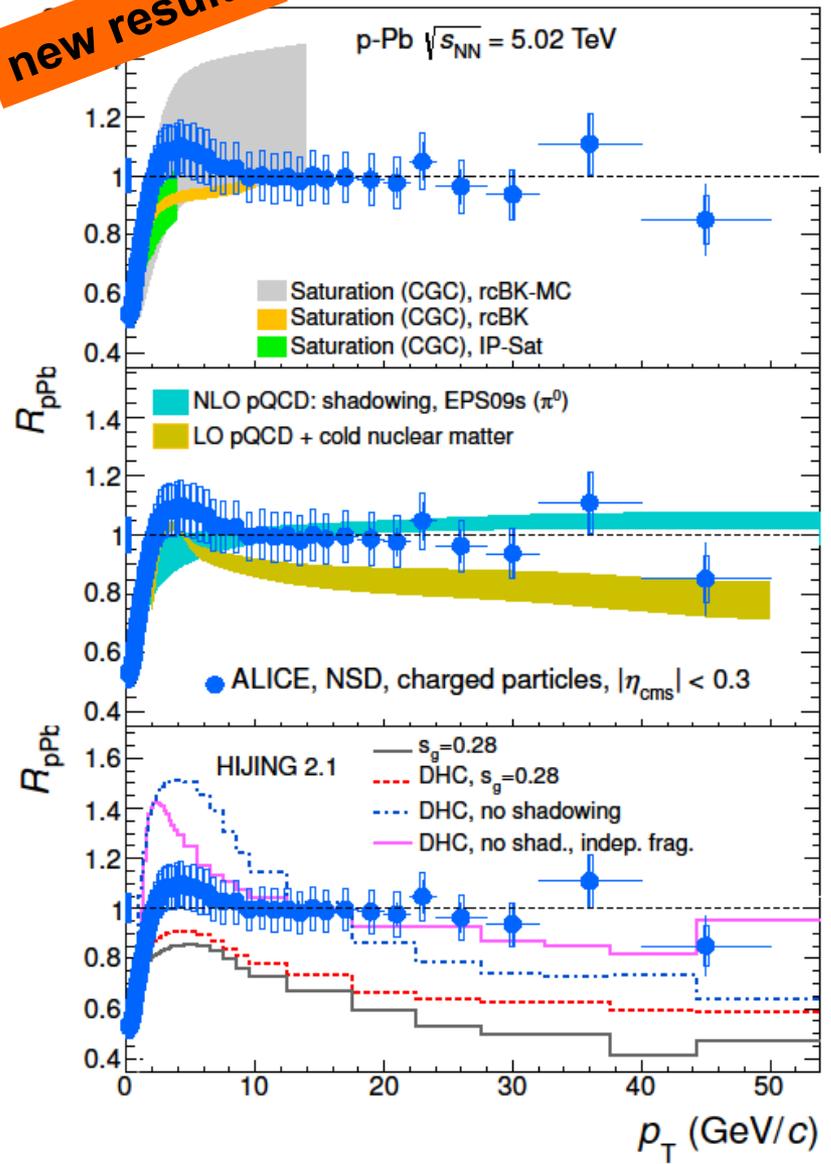


ALICE Collaboration, arXiv:1401.1250 [nucl-ex]



R_{pPb} compared to predictions

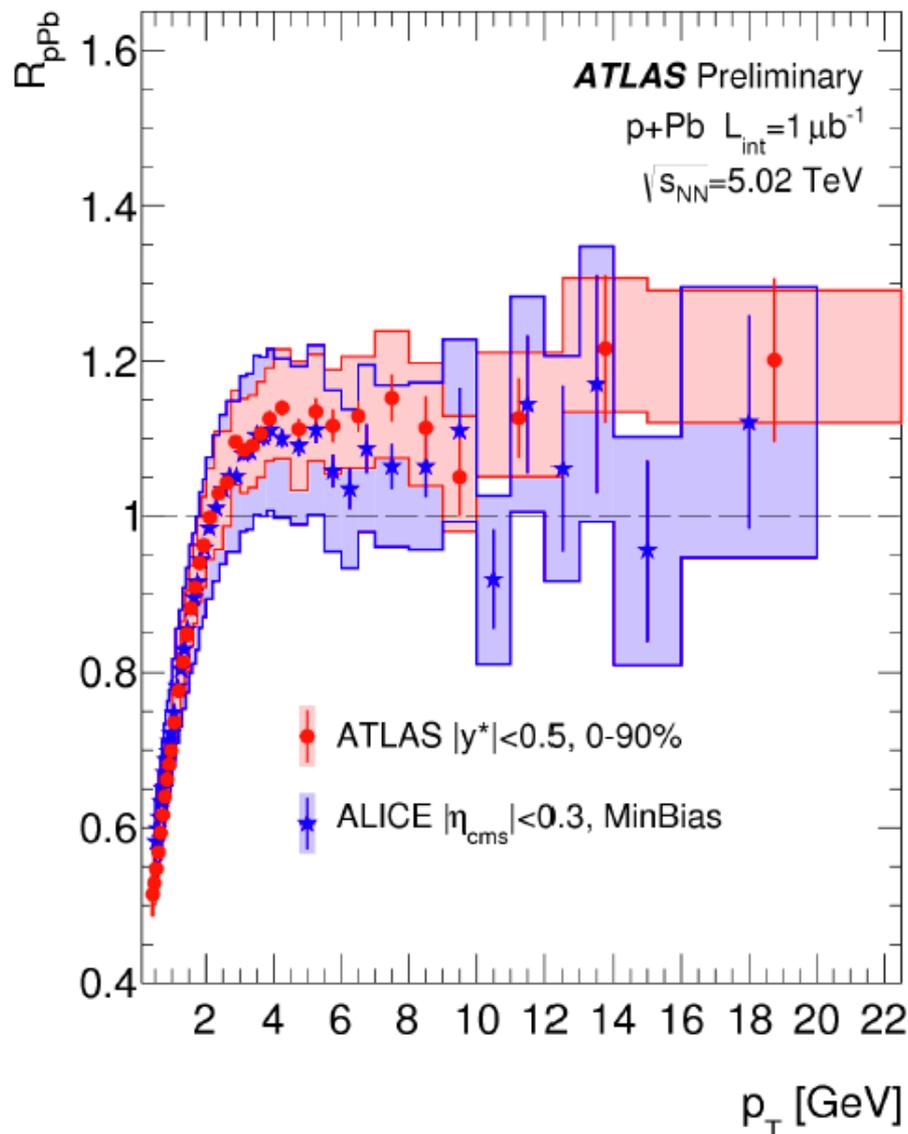
new results



- gluon saturation models (CGC) are in agreement with the data
- NLO with EPS09s PDF and DSS fragmentation functions are also in agreement
- LO pQCD + cold nuclear matter: too low at high p_T
- none of the HIJING 2.1 predictions are consistent with the data in the full p_T range
- DPMJET (not shown) describing $dN/d\eta$ very well, but fails to describe R_{pPb}



R_{pPb} : comparison to ATLAS



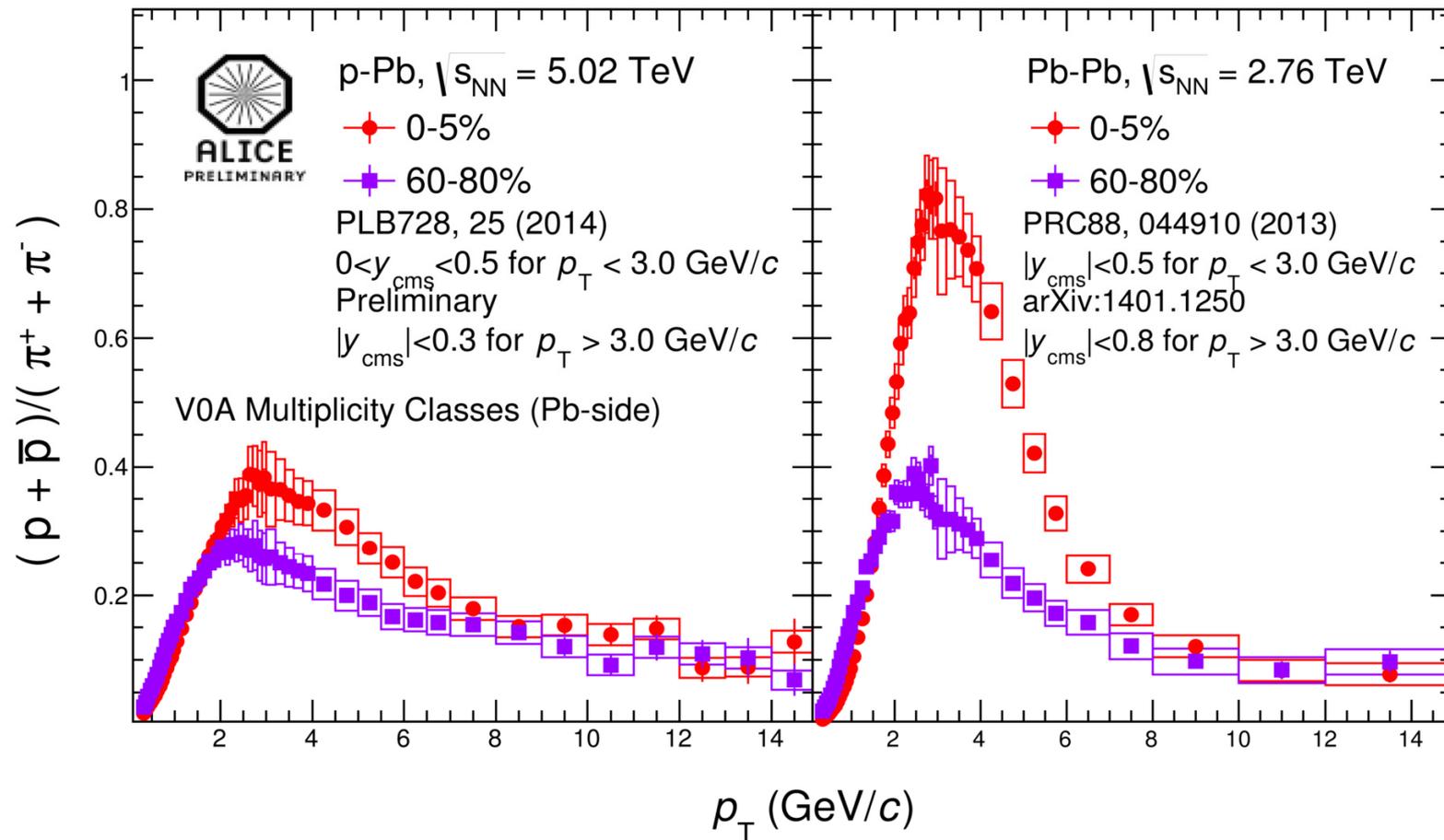
ATLAS Collaboration, ATLAS-CONF-2013-107

- **pilot run data**
ALICE: Phys.Rev.Lett. 110 (2013)
- **ATLAS 0-90% centrality**
- **consistent within uncertainties**
- **no sign of Cronin-enhancement in ATLAS data**



p/π ratio in p-Pb and Pb-Pb

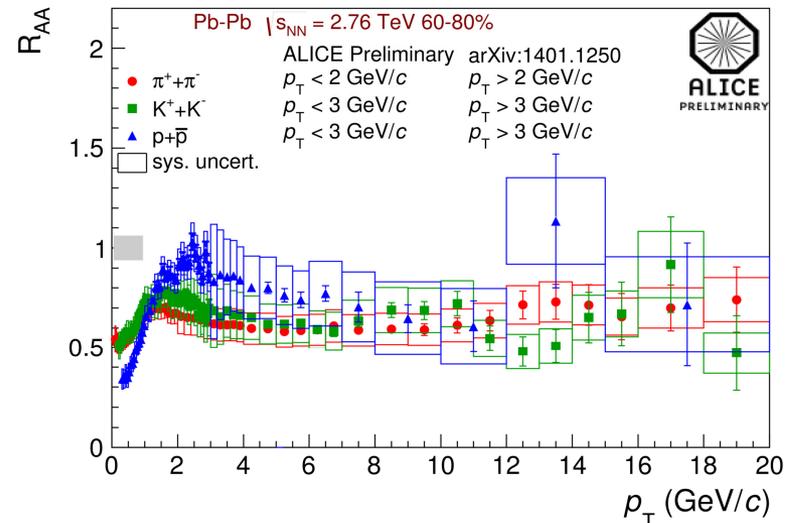
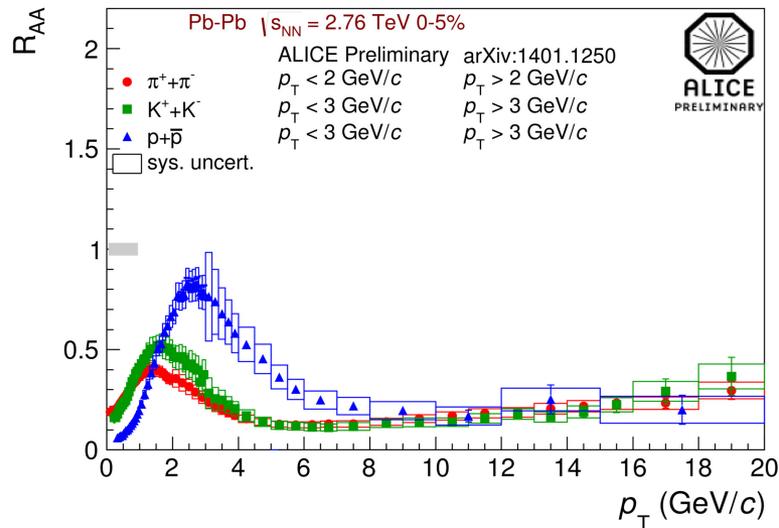
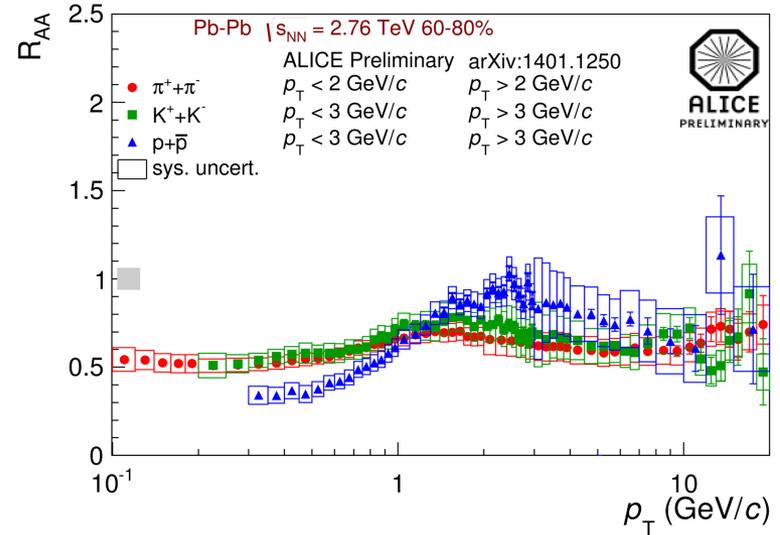
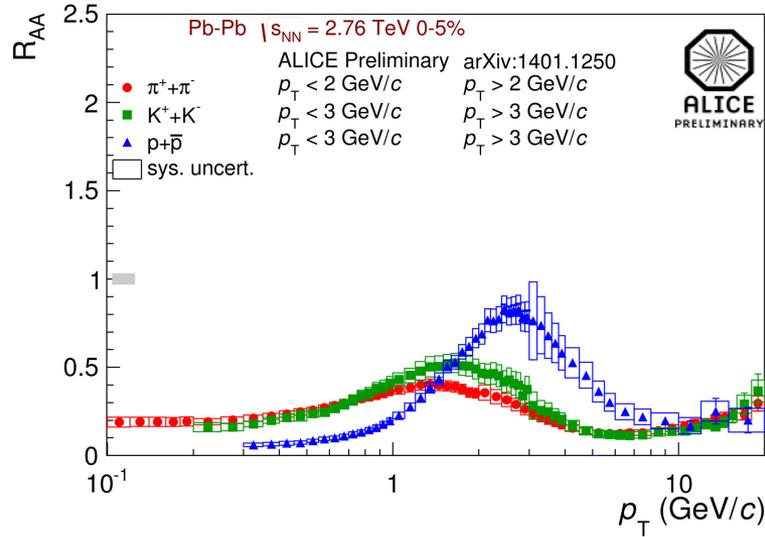
- similar trend vs. centrality/multiplicity
- much stronger „baryon enhancement“ in Pb-Pb



R_{AA} of charged π , K, p

0-5% central

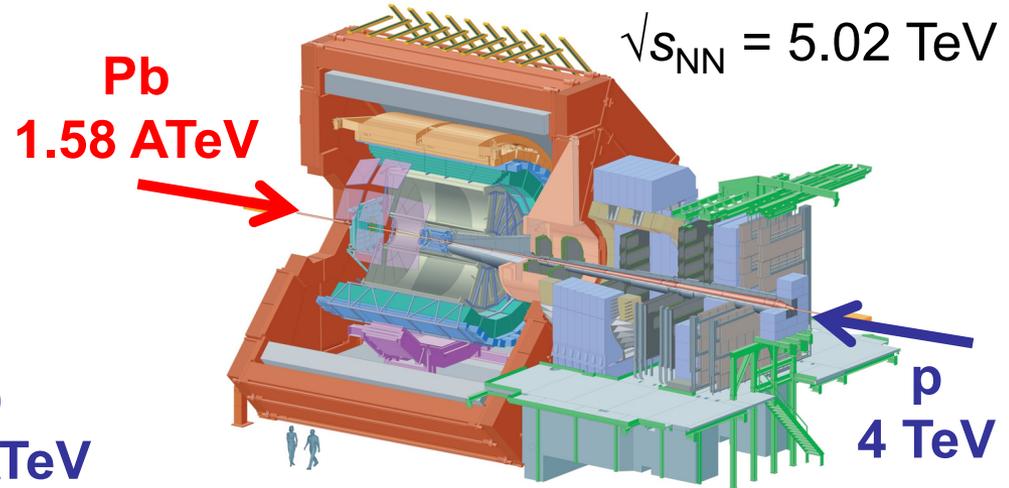
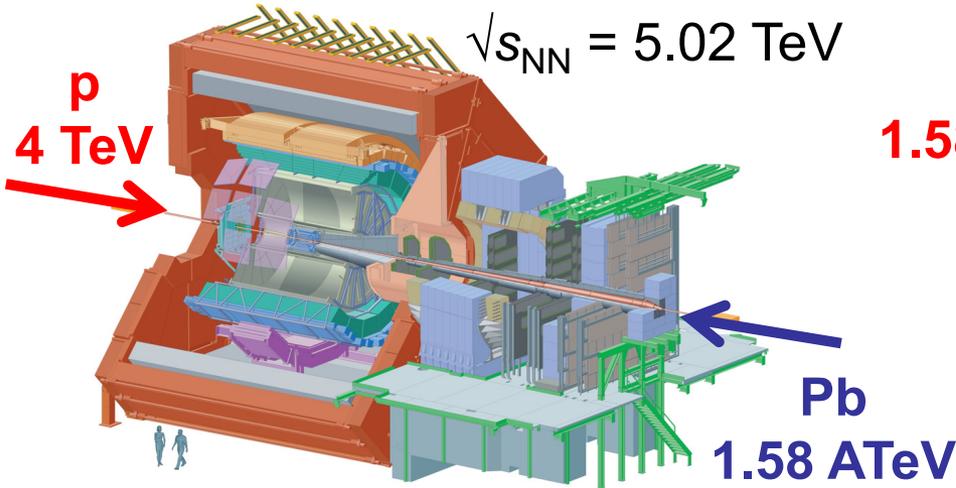
60-80% central



p-Pb collision geometry

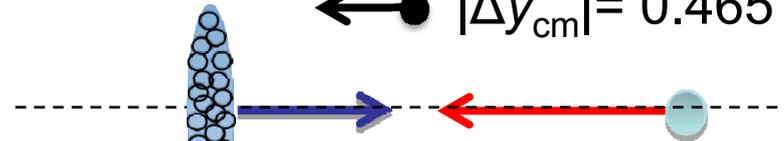
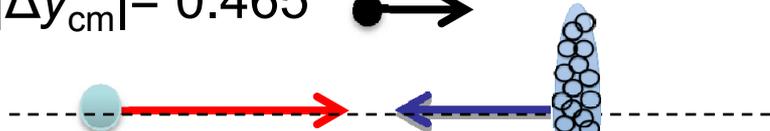
p-Pb

Pb-p



$|\Delta y_{cm}| = 0.465$ $\bullet \rightarrow$

$\leftarrow \bullet$ $|\Delta y_{cm}| = 0.465$



p
 $\eta_{lab} < 0$
 $y > 0$
 $\eta_{cms} > 0$

Pb
 $\eta_{lab} > 0$
 $y < 0$
 $\eta_{cms} < 0$

Pb
 $\eta_{lab} < 0$
 $y < 0$
 $\eta_{cms} < 0$

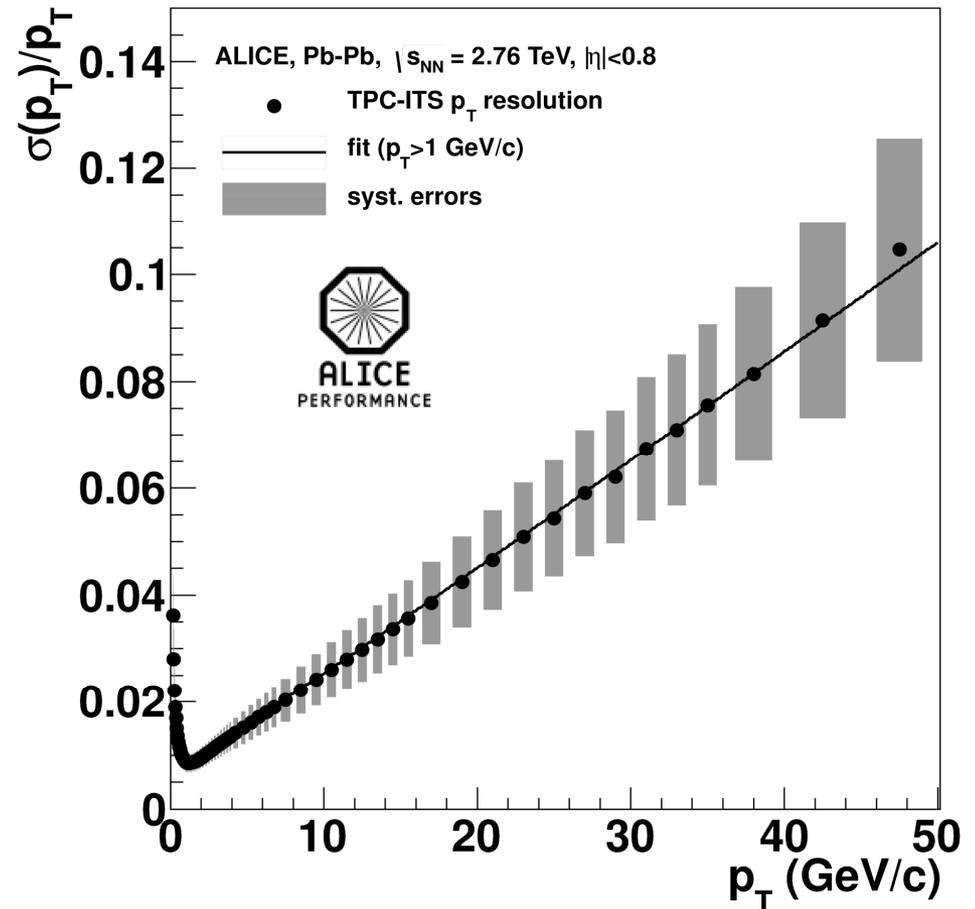
p
 $\eta_{lab} > 0$
 $y > 0$
 $\eta_{cms} > 0$

the direction for the proton is always at positive $y \equiv y_{cms}$ and positive η_{cms}



Transverse momentum resolution in Pb-Pb

- p_T resolution almost independent of multiplicity
- same performance in pp and Pb-Pb
- resolution estimated from covariance matrix of the Kalman Filter algorithm used for tracking
- verified with invariant mass analysis of $K^0 \rightarrow \pi^+\pi^-$ and cosmic ray measurements
- syst. uncertainty on the resolution $\sim 20\%$

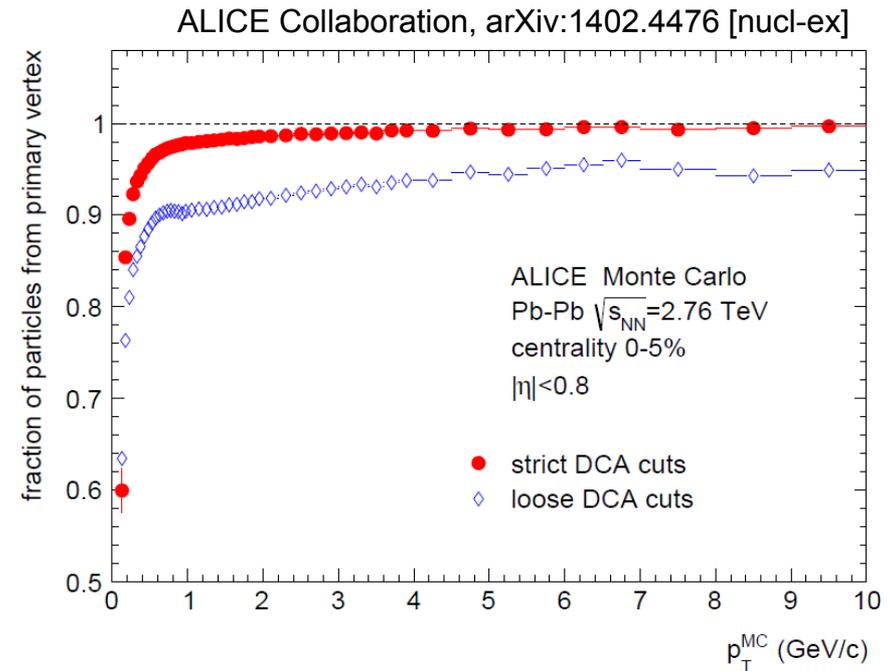
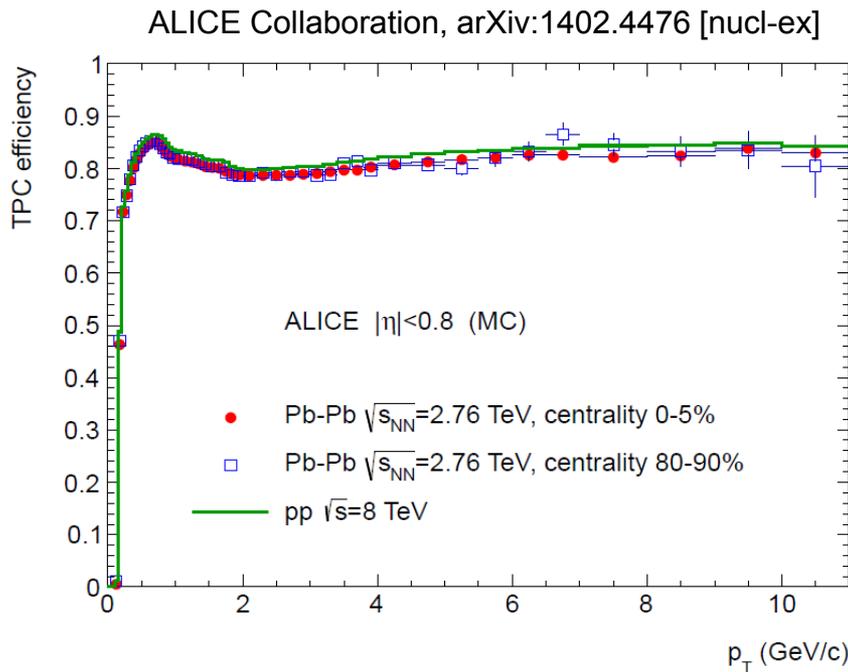


resolution: $\sigma(p_T)/p_T \sim 10\%$ at 50 GeV/c



Track selection & ALICE performance

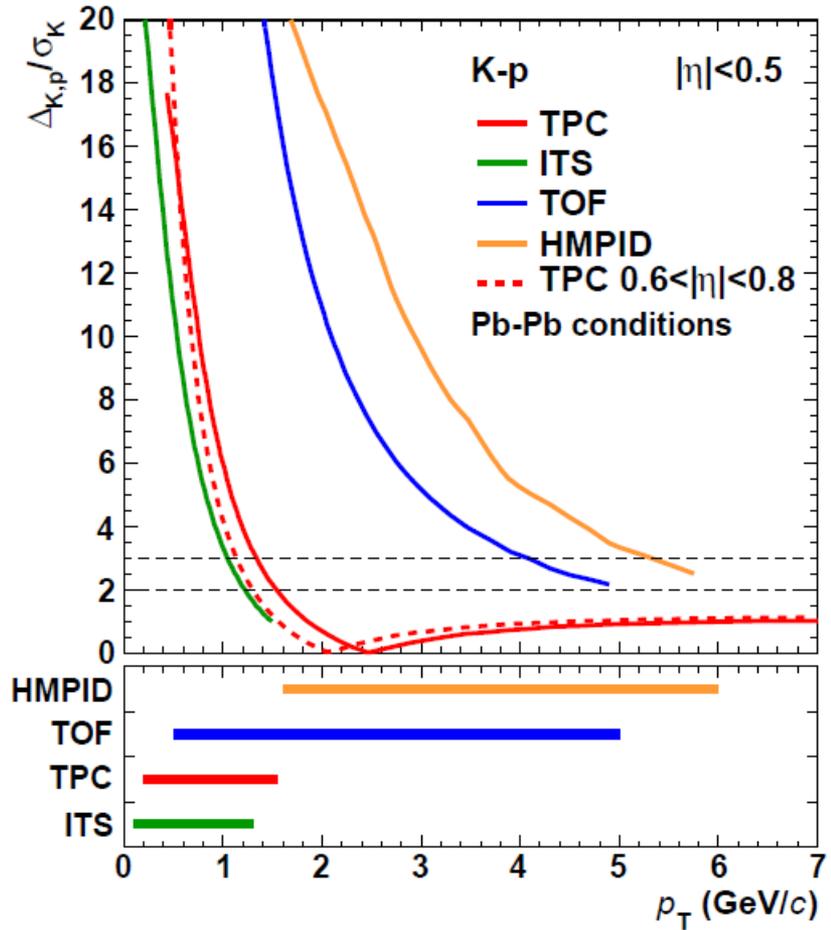
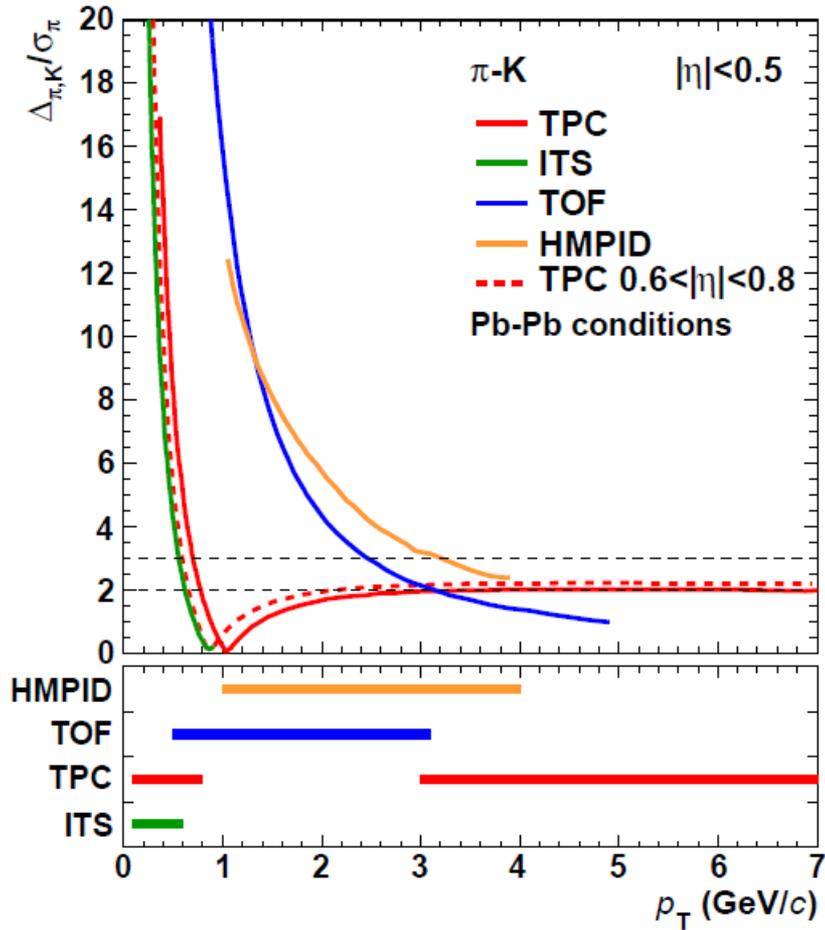
- tracking based on combined information from TPC and ITS
- two hits in the ITS, one in the innermost two layers (SPD)
- long tracks in the TPC selected (resolution at high p_T)
- tracks must point to the primary vertex



- overall acceptance \times efficiency lower than TPC efficiency
- contamination corresponds to strict DCA cuts



PID in ALICE



ALICE Collaboration, arXiv:1402.4476 [nucl-ex]

