A Large Ion Collider Experiment

ALICE

Light flavour p_T spectra and N_{ch} dependence of $\langle p_T \rangle$ in pp, p–Pb, and Pb–Pb collisions at the LHC

Marco Marquard
University of Frankfurt
for the ALICE collaboration

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HGS-HIRe for FAIR
Helmholtz Graduate School for Hadron and Ion Research

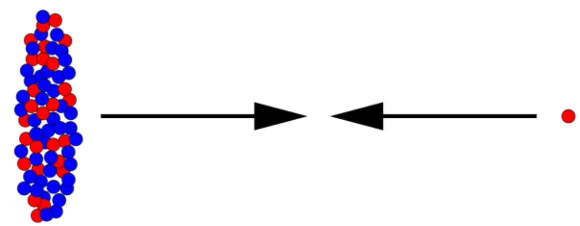
H-QM Helmholtz Research School Quark Matter Studies

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

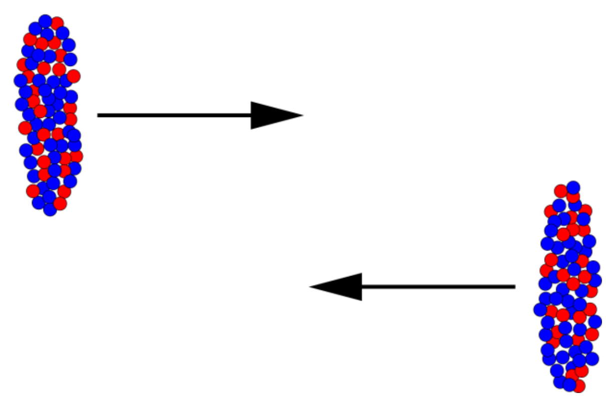
IKF Institut für Kernphysik Frankfurt

Motivation

- pp collisions
  - pQCD describes data well
  - Baseline for comparison to other collision systems
  - Well defined system size



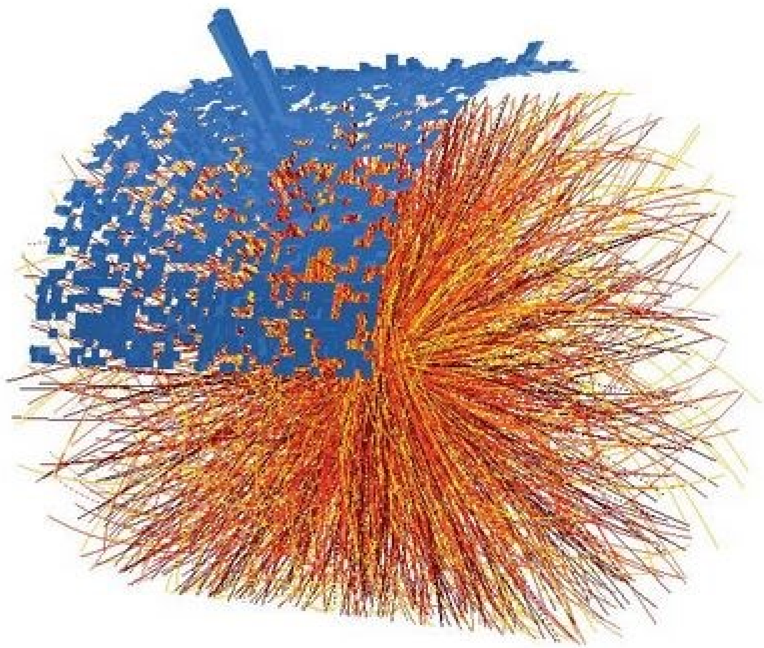
- p-Pb collisions
  - Multiple nucleon-nucleon collisions
  - Study of initial-state effects (cold nuclear matter)
  - We look for collective effects



- Pb-Pb collisions
  - Large variation of system size (centrality)
  - Quark-Gluon Plasma (hot nuclear matter)
  - Collective effects

Motivation

- Different collision systems
  - System size differs
  - Study effects with increasing number of participants
- High p_T particles
  - Created in initial hard scattering / pQCD processes
  - Information about medium properties
- Low p_T particles
  - Bulk particle production a non-pertubative QCD process and needs to be modelled
  - Contains information about underlying event structure

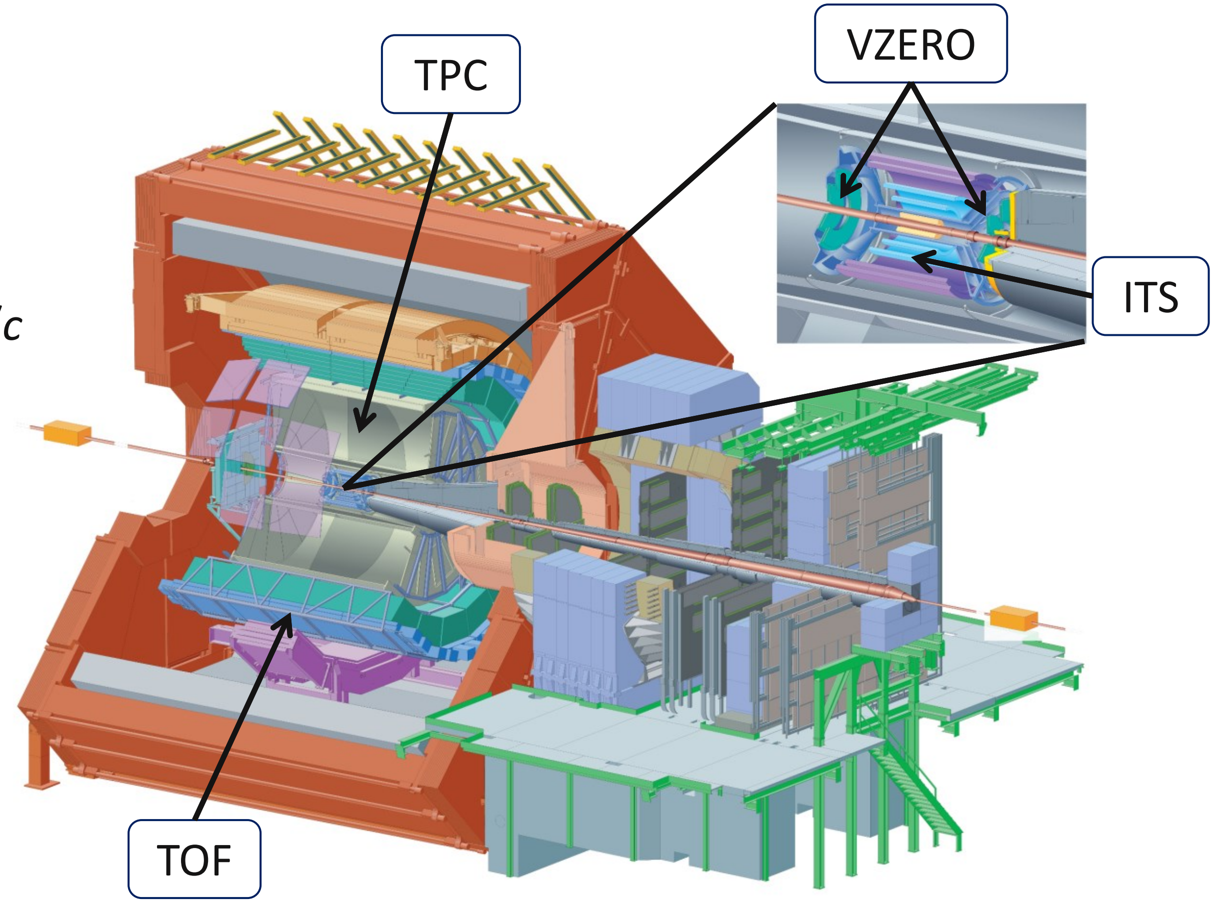


The ALICE detector

Usage of different detectors

Trigger	VZERO
Tracking	ITS, TPC
PID	ITS, TPC, TOF
Centrality	VZERO

- Tracking down to p_{T} = 0.15 GeV/c
- PID over a large momentum range
  - $\pi^{+}\ \pi^{-}$ up to p_{T} = 20 GeV/c
  - $K^{+}\ K^{-}$ up to p_{T} = 20 GeV/c
  - $\bar{\mathrm{p}}$ p up to p_{T} = 20 GeV/c
  - Statistical limitation
- Statistical analysis in high p_{T} regime



Light flavour spectra

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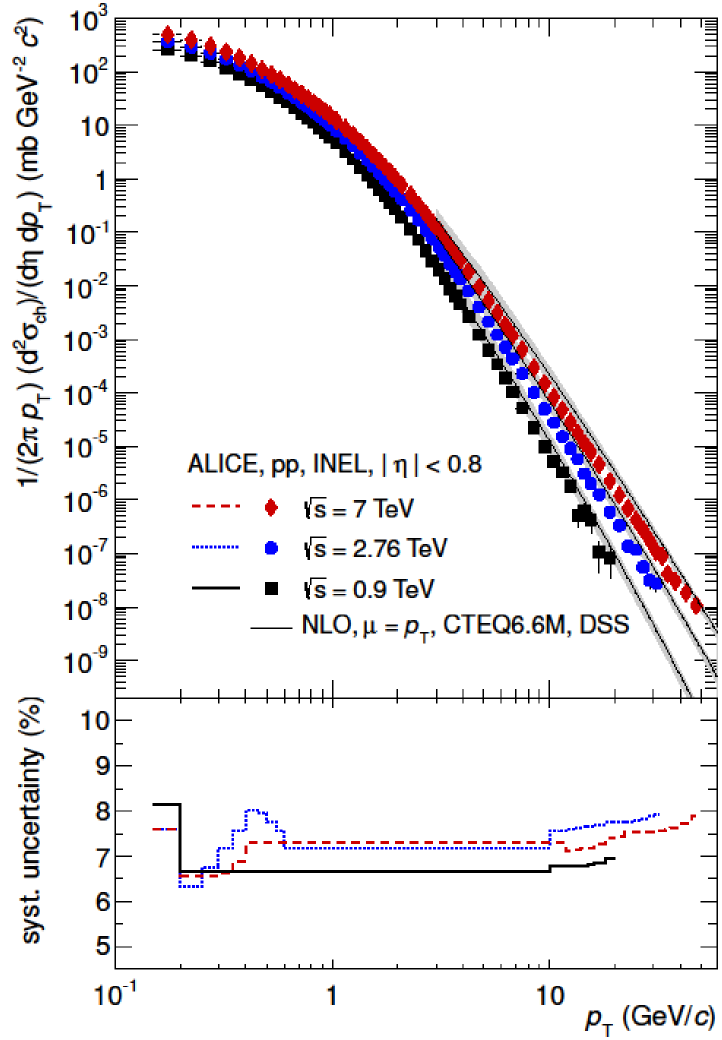
Particle spectra in pp collisions

- Bulk of particles is produced in the low p_T regime
- Spectral shape varies for different collision energies
- Energy dependence larger at high p_T
- NLO-pQCD calculation over-predicts data by factor 2



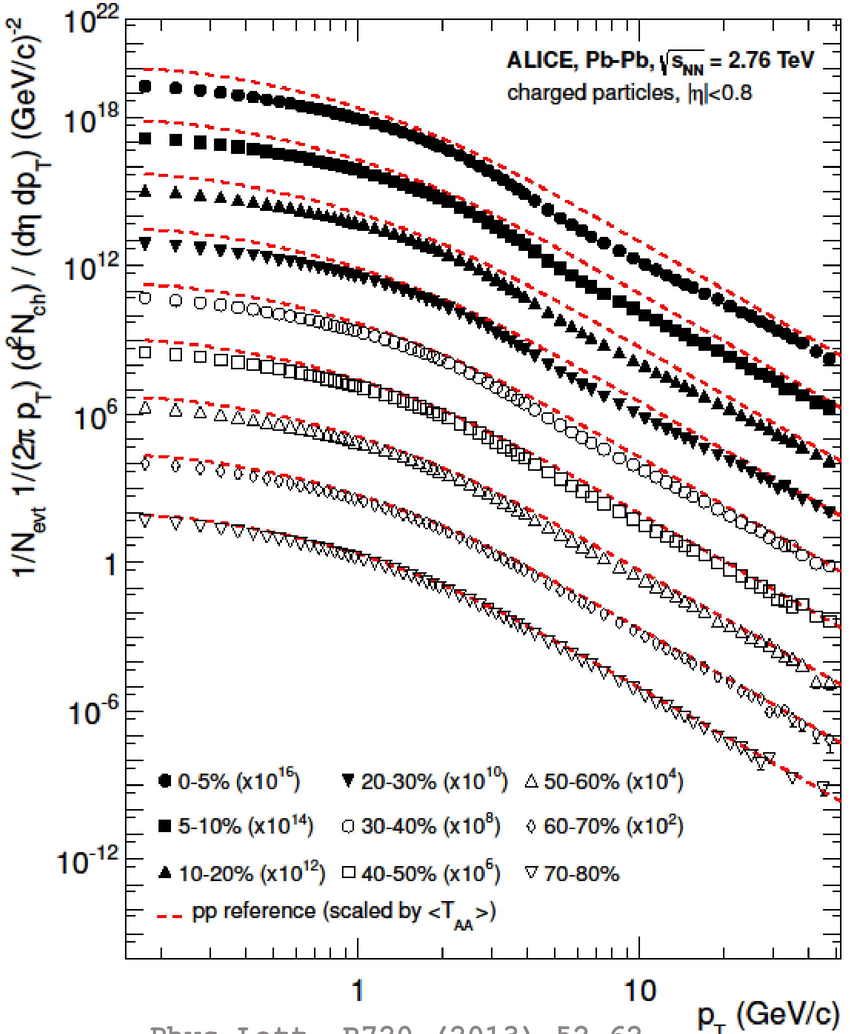
ALI-PUB-60518 Eur. Phys. J. C (2013) 73:2662

Particle spectra in Pb-Pb

- pp reference scaled with $\langle T_{AA} \rangle = \langle N_{coll} \rangle / \sigma_{inel}^{NN}$
- Spectral shape of scaled pp agrees with peripheral Pb-Pb
- Progressive deviation in shape and magnitude towards more central events
- Quantified in terms of the nuclear modification factor:

$$R_{AA} = \frac{N_{ch}^{AA}}{\langle N_{coll} \rangle N_{ch}^{pp}}$$

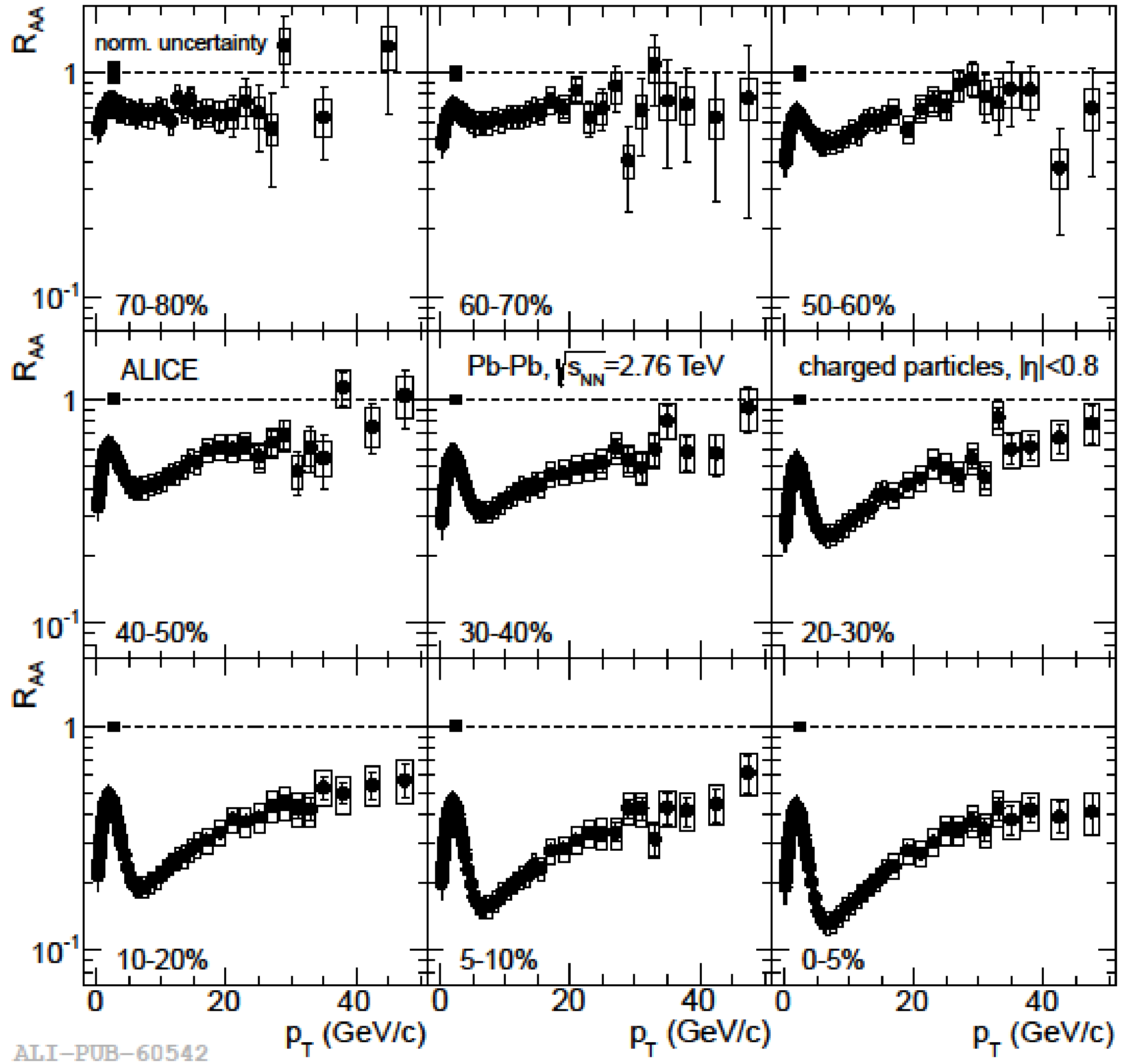
- $R_{AA} = 1$: no effect of the medium



Phys.Lett. B720 (2013) 52-62

R_{AA} of inclusive charged particles

- Suppression for all centrality intervals
- Larger suppression for more central events
- Minimum around p_T = 6 GeV/c
- Less suppression for higher p_T
- High p_T limit not constrained yet: Does R_{AA} become constant?



Phys.Lett. B720 (2013) 52-62

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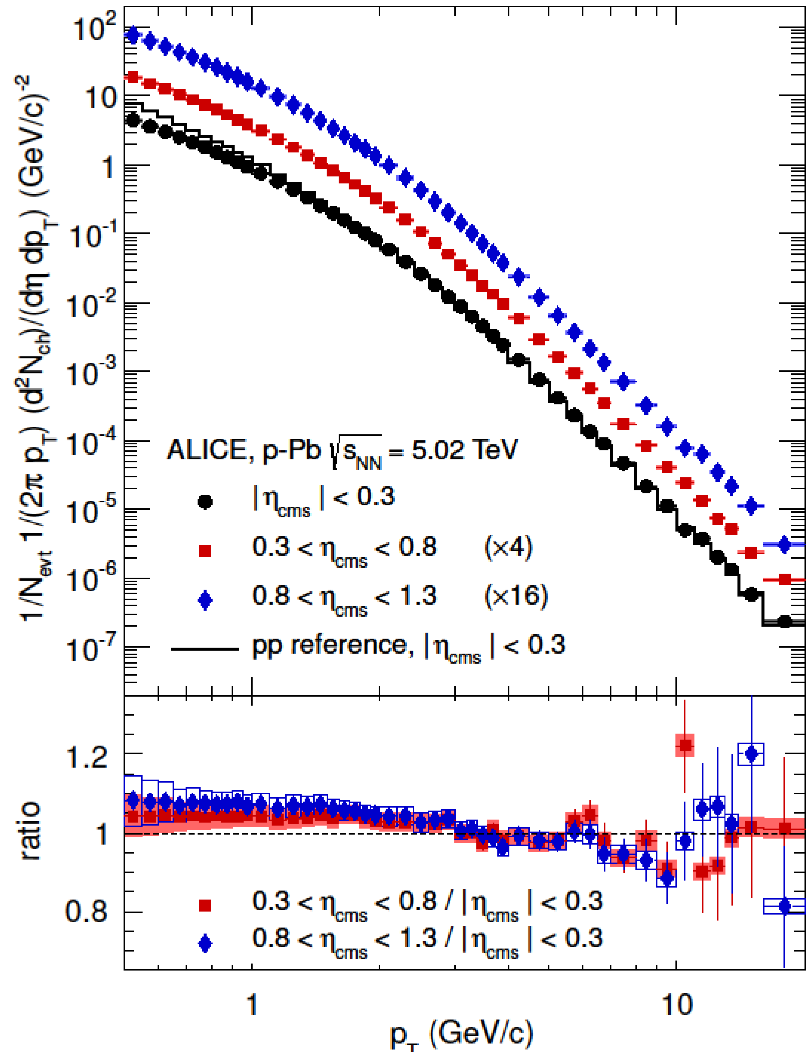
Particle spectra in p-Pb

- Spectra of scaled pp agrees with p-Pb above 1 GeV/*c*
- Shifted centre-of-mass system due to asymmetric collision system
- No deviation between mid and forward rapidity measured
- Nuclear modification factor:

$$R_{pA} = \frac{N_{\mathrm{ch}}^{\mathrm{pA}}}{\langle N_{coll} \rangle N_{\mathrm{ch}}^{\mathrm{pp}}}$$



Phys. Rev. Lett. 110, 082302 (2013)

Comparison of R_{AA} and R_{pA}

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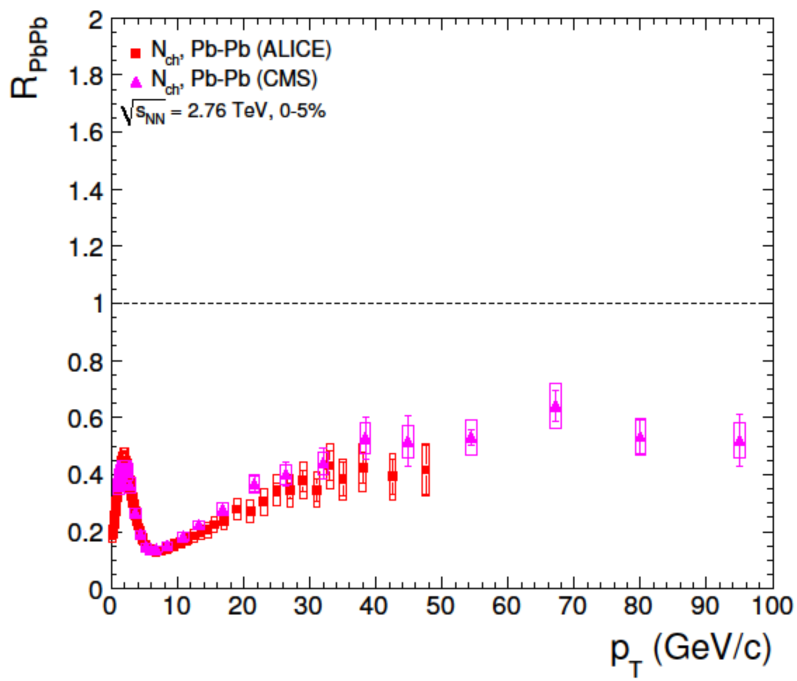
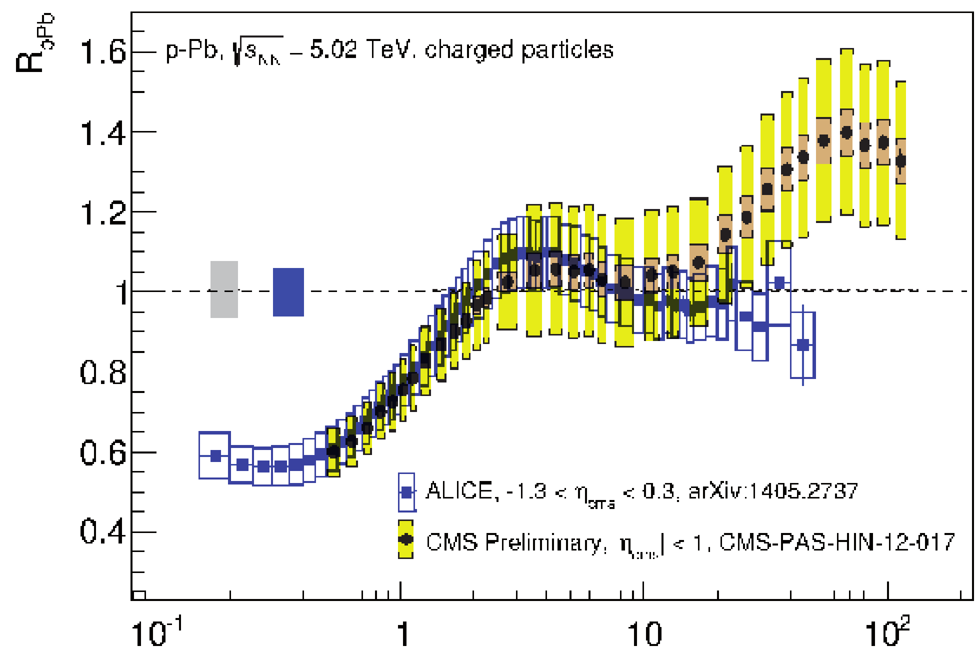
R_{AA}



ALI-DER-45654 ALICE, Phys. Lett. B720 (2013)52-62
CMS, Eur. Phys. J. C (2012) 72:1945

- Good agreement between ALICE and CMS
- Compare to R_{pA} for origin of suppression

R_{pA}



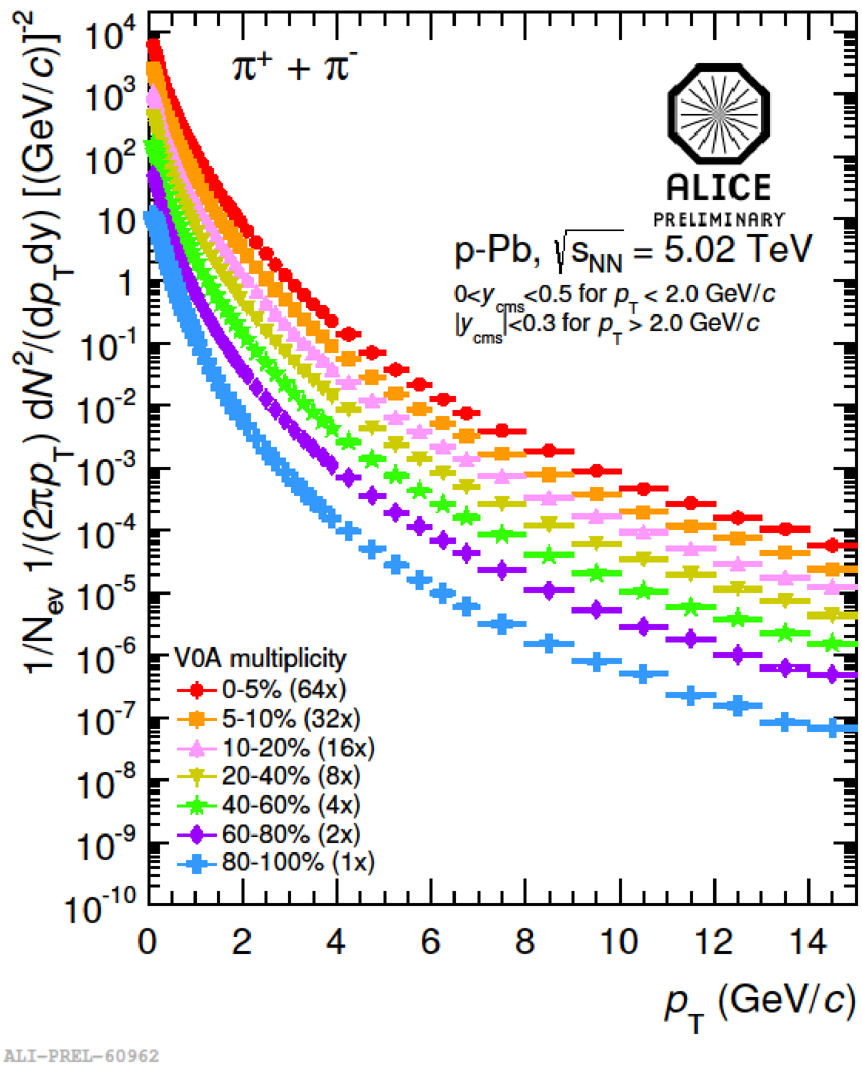
p_T (GeV/c)

ALICE, arxiv:1405.2737
CMS, CDS: CMS-PAS-HIN-12-017
ALI-DER-77092

- $R_{pA} \sim 1$, suppression is not an initial-state effect
- Different visual impression between ALICE and CMS
- Main difference in interpolated reference spectra

Spectra of identified particles

- $\pi^+ \pi^-, K^+ K^-$, $p \bar{p}$ measured up to 15 GeV/c
- Decreasing yield for higher mass particles



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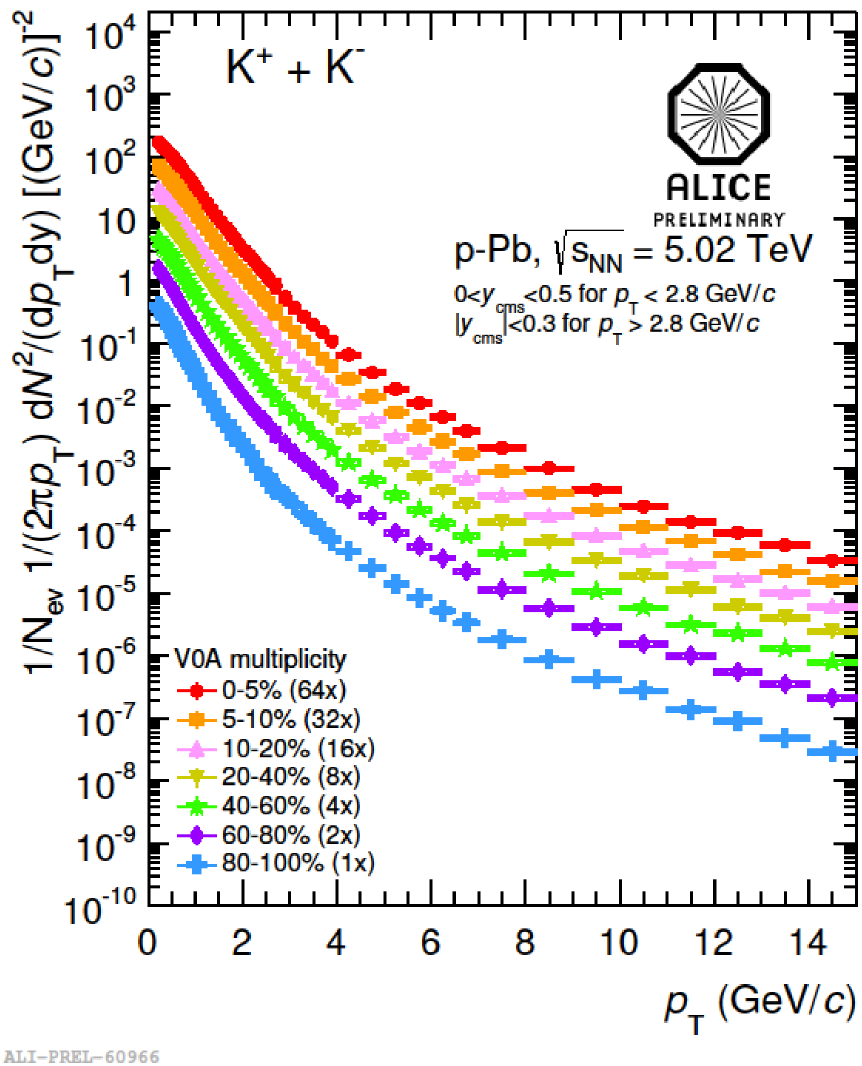

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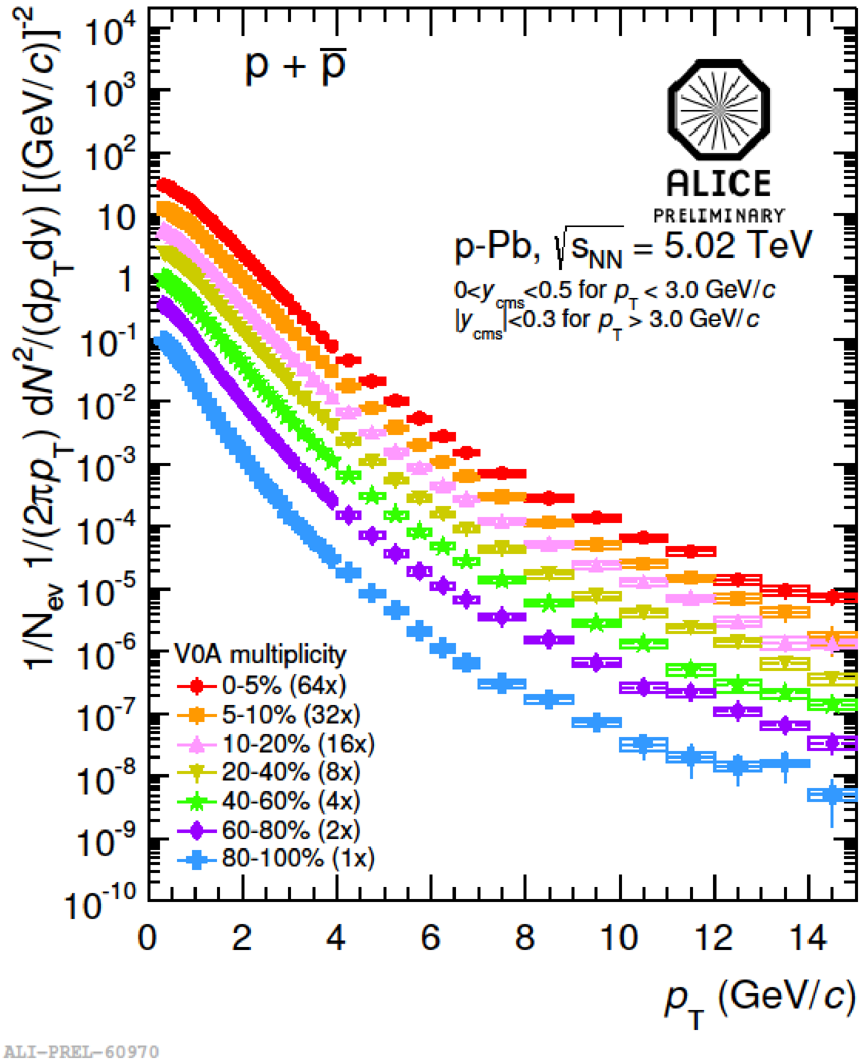
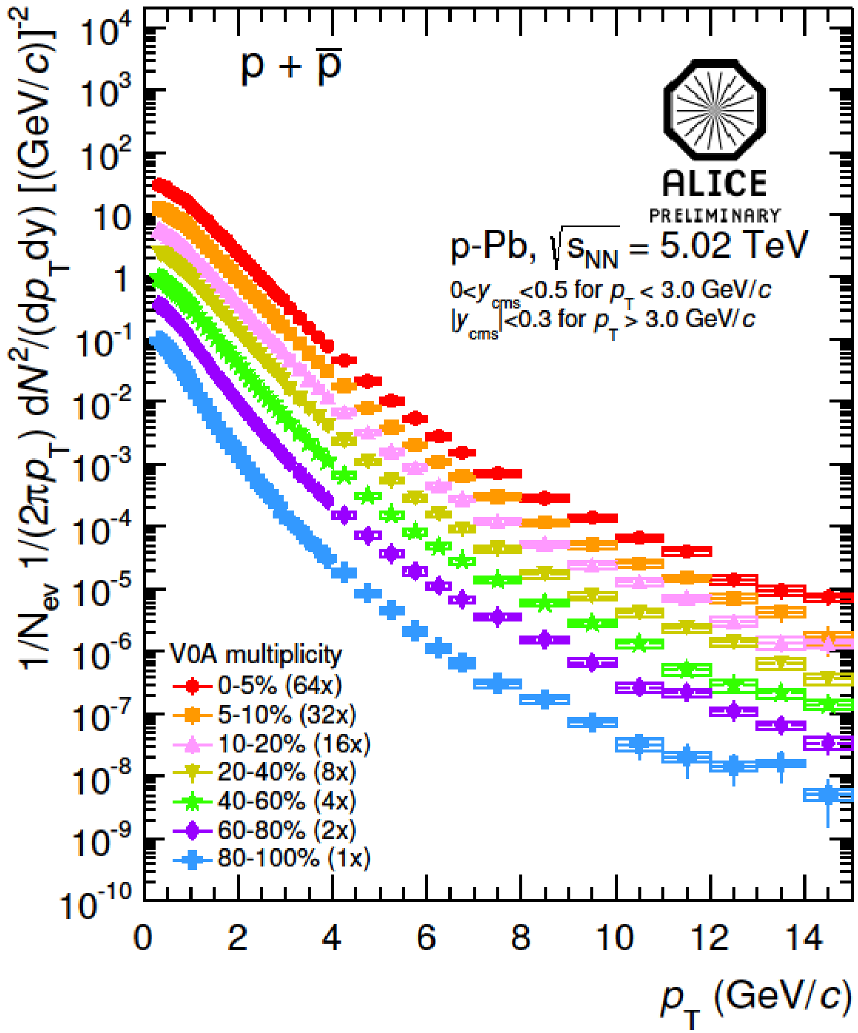


Spectra of identified particles

- $\pi^+\pi^-$, K^+K^-, $p\,\bar{p}$ measured up to 15 GeV/*c*
- Decreasing yield for higher mass particles
- Spectra get harder with increasing multiplicity
- Effect is more pronounced for heavier particles
- Reminiscent of the phenomenology in Pb-Pb



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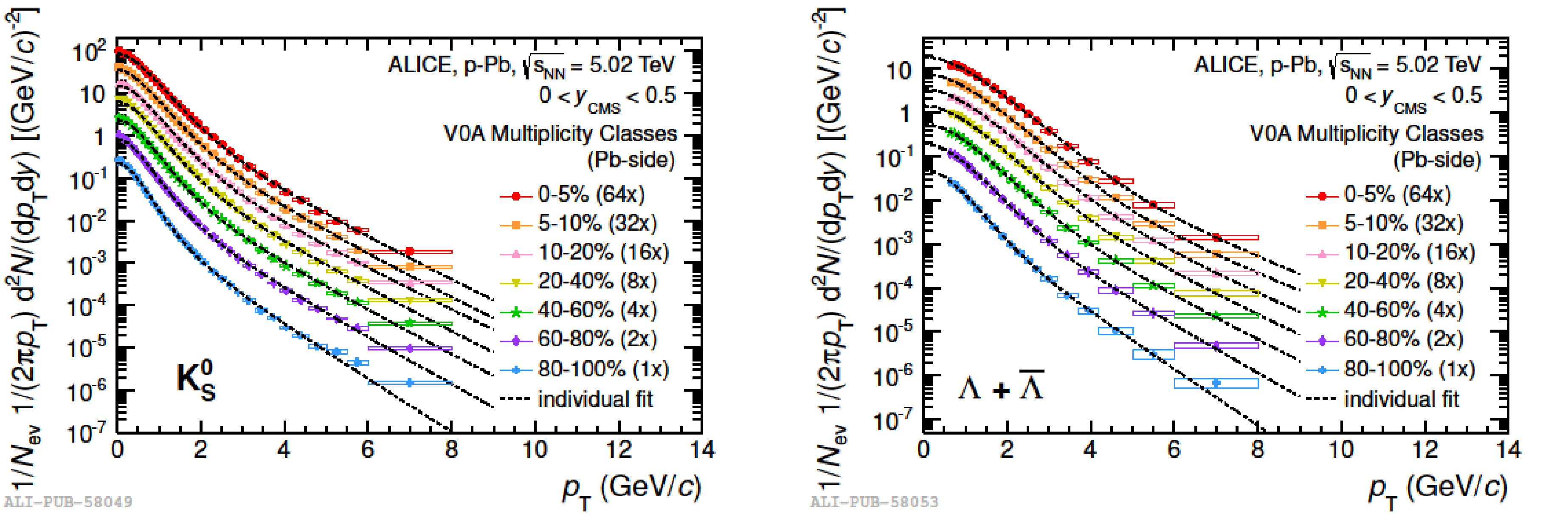
Spectra of identified particles



Phys.Lett. B728 (2014) 25-38

- Same effect for strange particles
- Decreasing yield for higher mass particles
- Spectra get harder with increasing multiplicity
- Effect is more pronounced for heavier particles

Comparison of identified particle spectra to models

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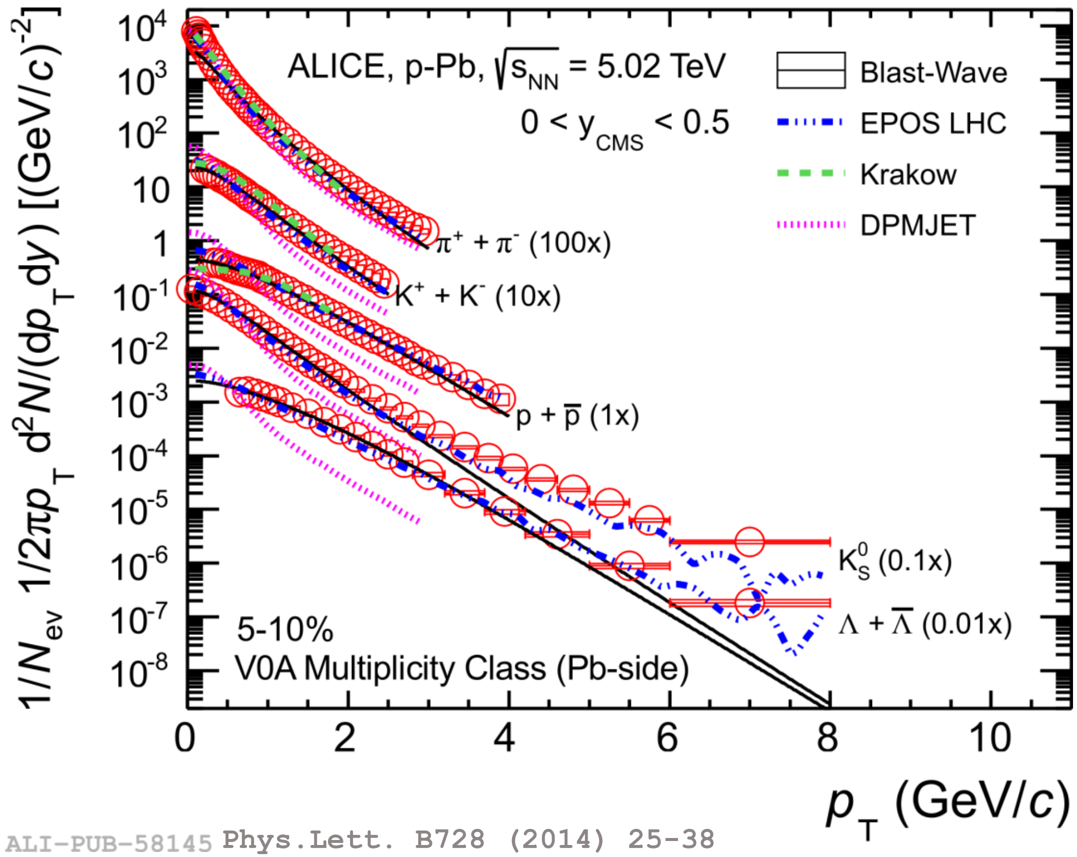
- DPMJET
  - QCD based model
- EPOS
  - Coherence effects via flux tubes
  - Includes a flow parameterisation
- Kraków
  - Hydrodynamical model
  - Glauber MC used for initial state fluctuations



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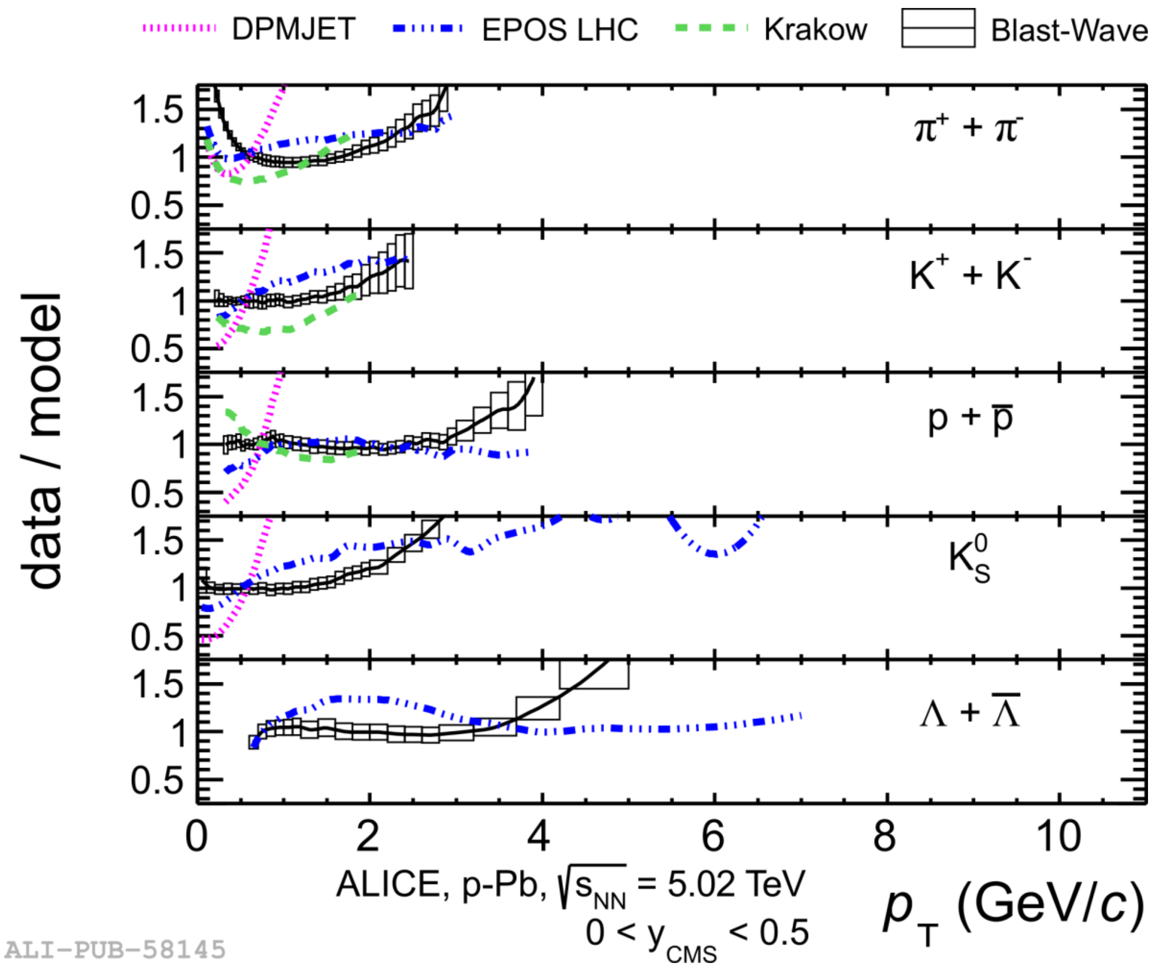
Comparison of identified particle spectra to models

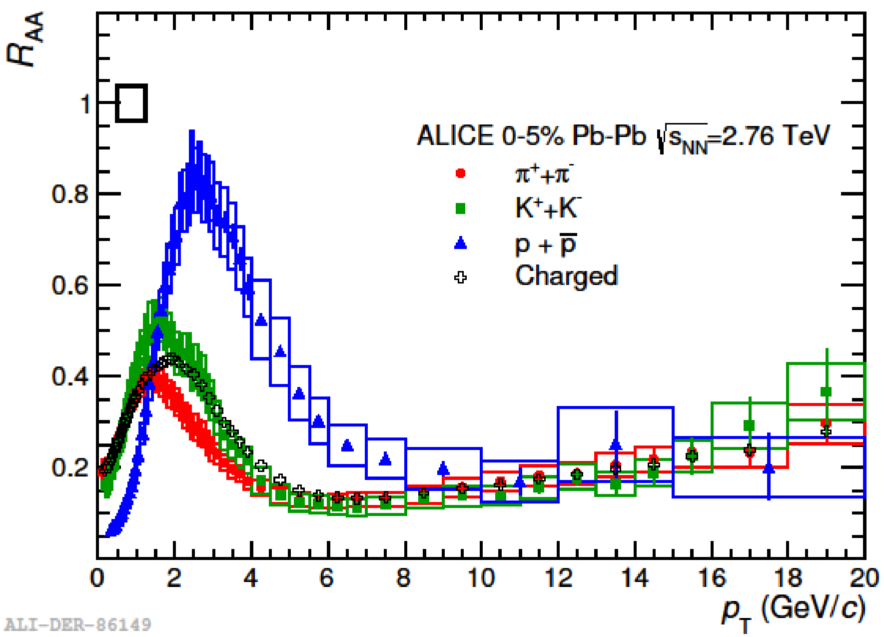
- Pure QCD based model without flow does not describe the data
- Models with flow in good agreement with p-Pb data



ALI-PUB-58145
Phys.Lett. B728 (2014) 25-38

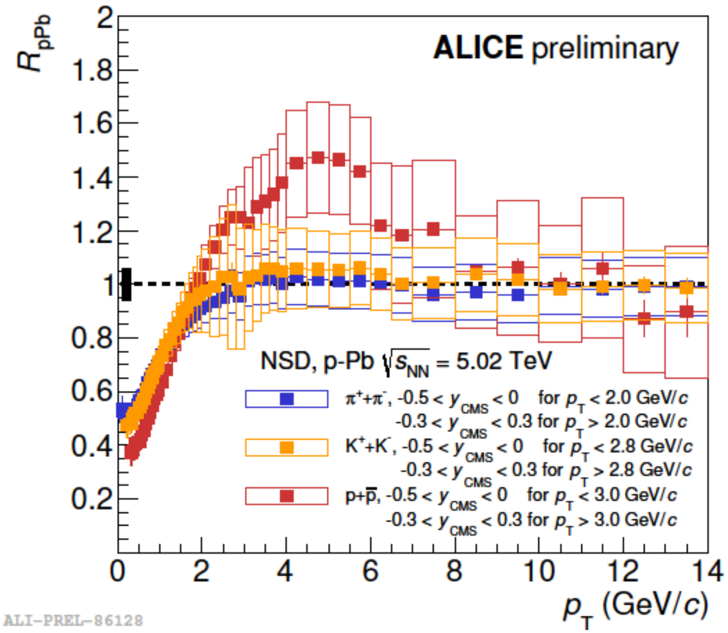
R_{AA} and R_{pA} of identified charged hadrons

R_{AA}



Phys.Lett. B736 (2014) 196-207

R_{pA}

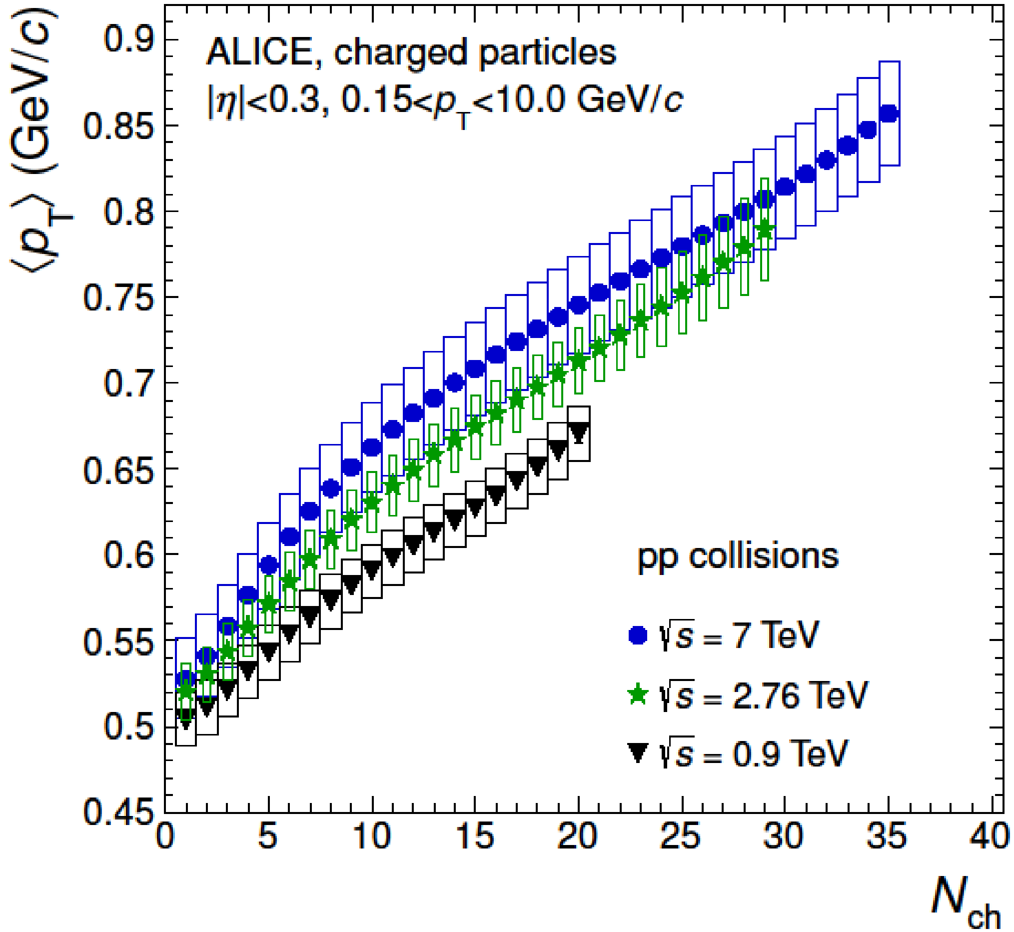


- Less suppression of $\mathrm{p} + \bar{\mathrm{p}}$ at intermediate p_T in Pb-Pb
  - Effect of radial flow
- $\mathrm{p} + \bar{\mathrm{p}}$ enhanced un p-Pb

Average transverse momentum

Average p_T of inclusive charged particles in pp

- Small collision energy dependence of $\langle p_T \rangle$
- Similar shape for all energies
- Change of slope at $N_{ch} \approx 10$

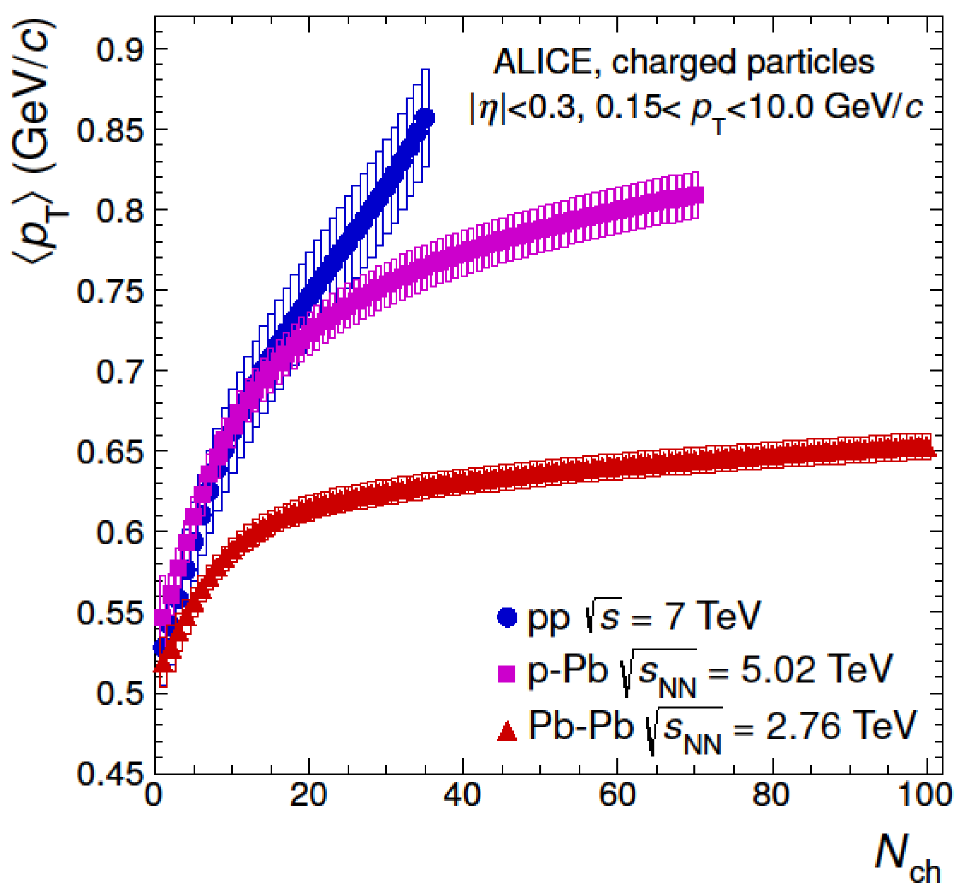


ALI-PUB-55936

Phys.Lett. B727 (2013) 371-380

$\langle p_T \rangle$ comparison for pp, p-Pb and Pb-Pb

- Pb-Pb differs entirely from pp and p-Pb
- N_{ch} covers only peripheral Pb-Pb
- Same trend for pp and p-Pb up to $N_{ch} \approx 14$
- Strong increase of $\langle p_T \rangle$ up to highest multiplicities in pp
- High multiplicity p-Pb events show flattening (similar to Pb-Pb)

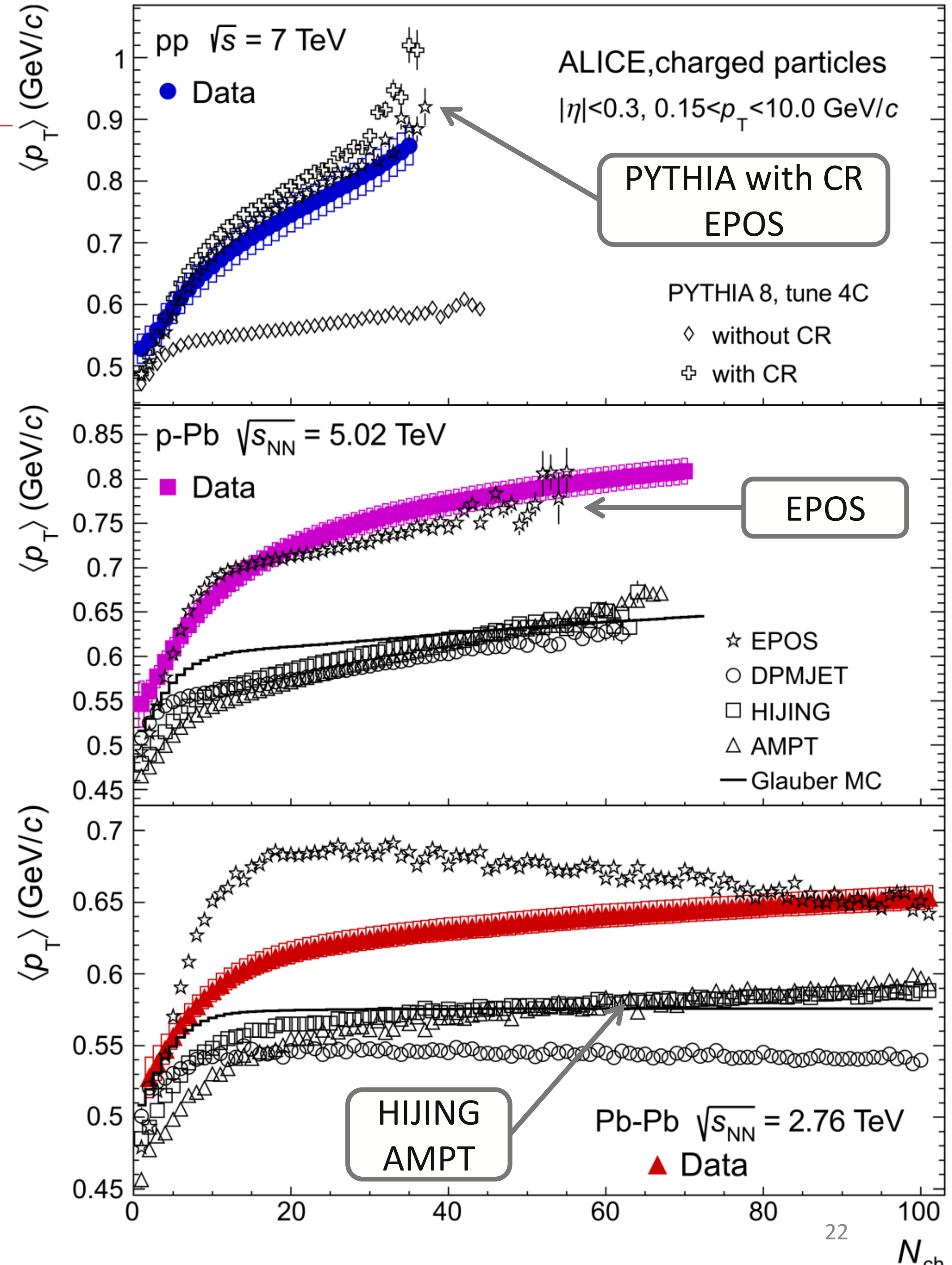


ALI-PUB-55941

Phys.Lett. B727 (2013) 371-380

Comparison of <p_T> to Models

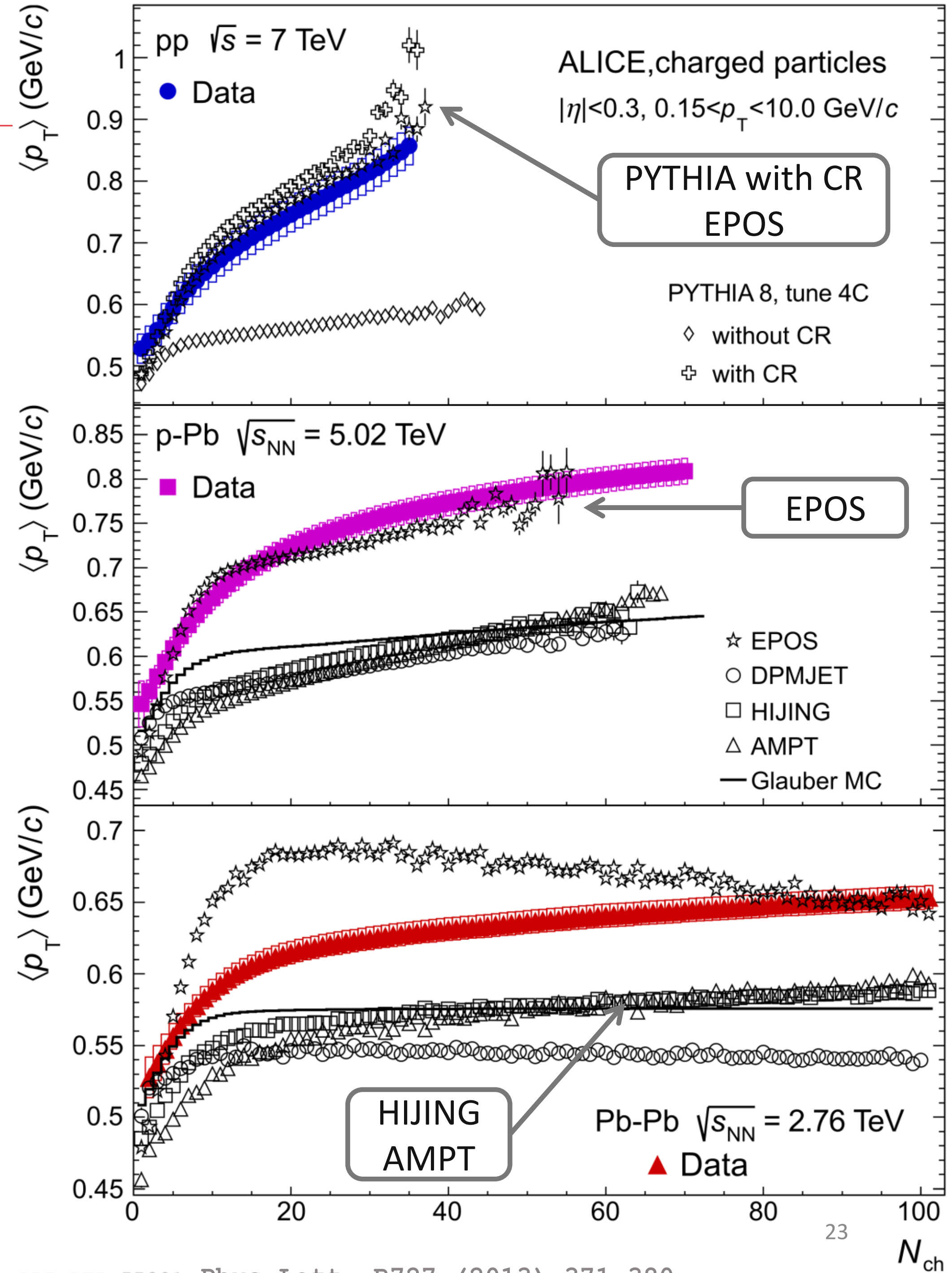
- HIJING
  - pQCD model for jet production
  - Multistring phenomenology for low p_T
- AMPT
  - Initial collision created by HIJING
  - Different parton cascade (ZPC) used (v2.x / string melting)
- Glauber MC
  - Data based
  - Superposition of $\sqrt{s} = 7$ TeV pp collisions



Phys.Lett. B727 (2013) 371-380

Comparison of <p_T> to Models

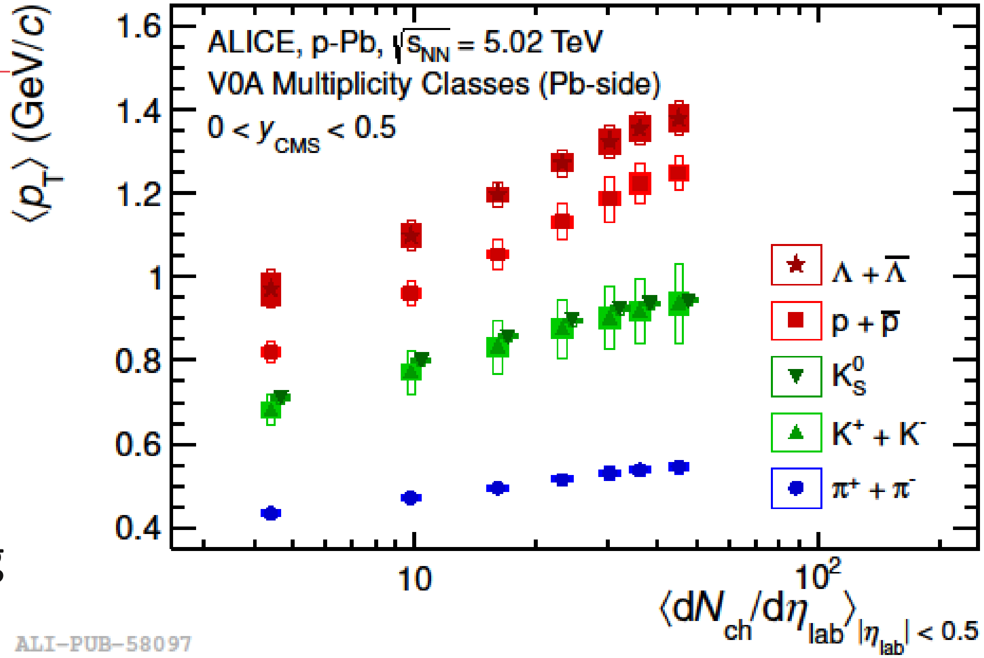
- pp data can only be described with coherence effects (color reconnection) or collective effects (flow)
- EPOS describes the correlation between <p_T> and N_{ch} in p-Pb
- In Pb-Pb AMPT and HIJING have a similar N_{ch} dependence as data but underestimate the magnitude
- No universal model description



ALI-DER-55991 Phys.Lett. B727 (2013) 371-380

Mass ordering of <p_T>

- Mean p_T increases with particle mass and multiplicity
- In Pb-Pb, radial flow equals velocity of particles and thus could explains the mass ordering



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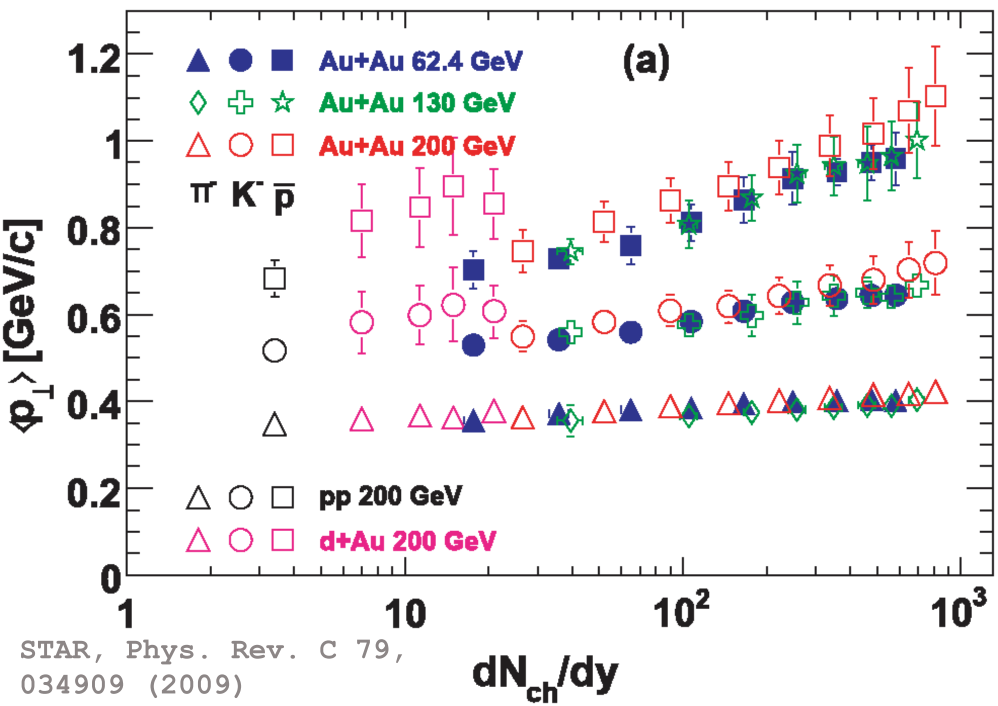

STAR, Phys. Rev. C 79, 034909 (2009)

- In p-Pb, we observe the same trend (seen already at RHIC)
- Origin of p-Pb not yet understood, is it flow or color reconnection like?

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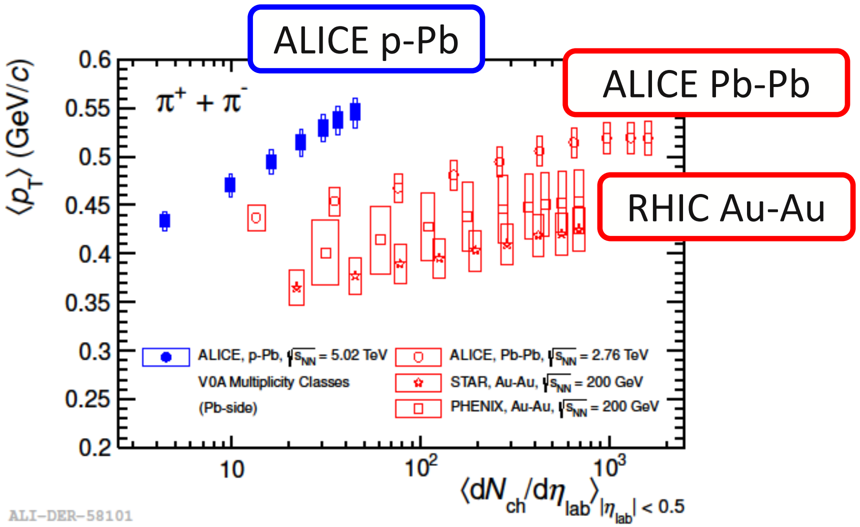
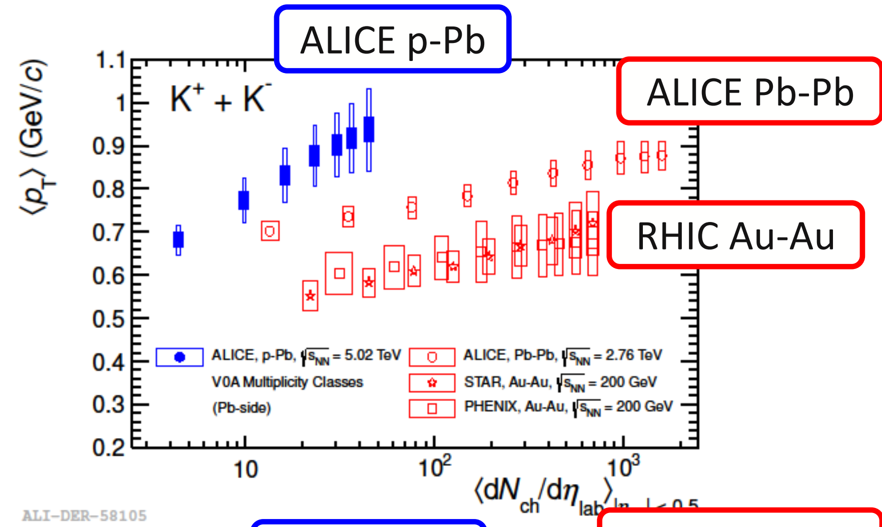
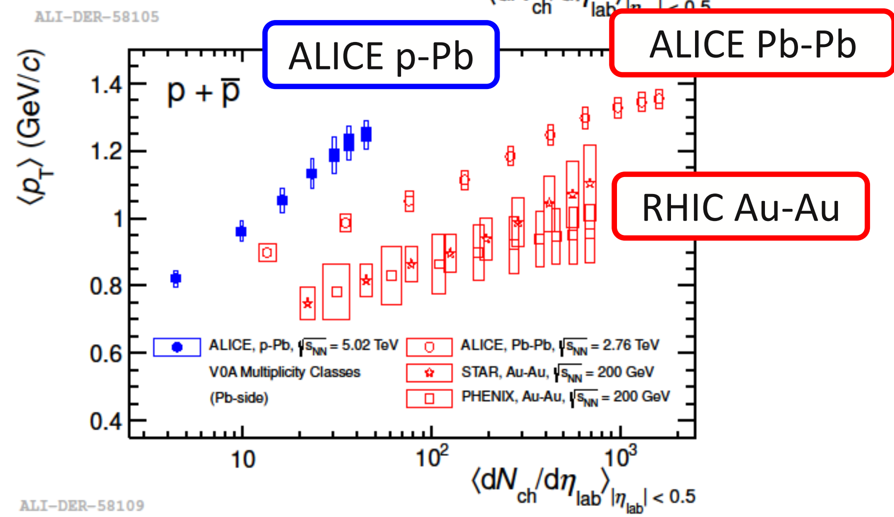
Comparison to RHIC data





- AA:
  - Slight difference between RHIC and LHC, but 10 x larger $\sqrt{s}$
- p-A:
  - Significant difference to Pb-Pb
  - Similar behaviour as inclusive charged particles



PHENIX, Phys. Rev. C 69, 03409 (2004), ALICE, Phys. Rev. C 88, 044910 (2013)
STAR, Phys. Rev. C 79, 034909 (2009), STAR, Phys. Rev. Lett. 108, 072301 (2012)

Conclusion

- Spectra of inclusive and identified charged particles measured
- Suppression at high p_T in Pb-Pb is a medium induced effect and not an initial state effect
- Identified p-Pb spectra described by models with hydro
- pp, p-Pb and Pb-Pb have different $\langle p_T \rangle$ shapes with increasing N_{ch}
- Clear mass ordering of $\langle p_T \rangle$
- $\langle p_T \rangle$ of pp and p-Pb can be described by models with collective or coherent effects
- Same trend for $\langle p_T \rangle$ over large $\sqrt{s}$ range at LHC and RHIC, also same collision system dependence

Backup

Comparison of particle identification capabilities in AA collisions

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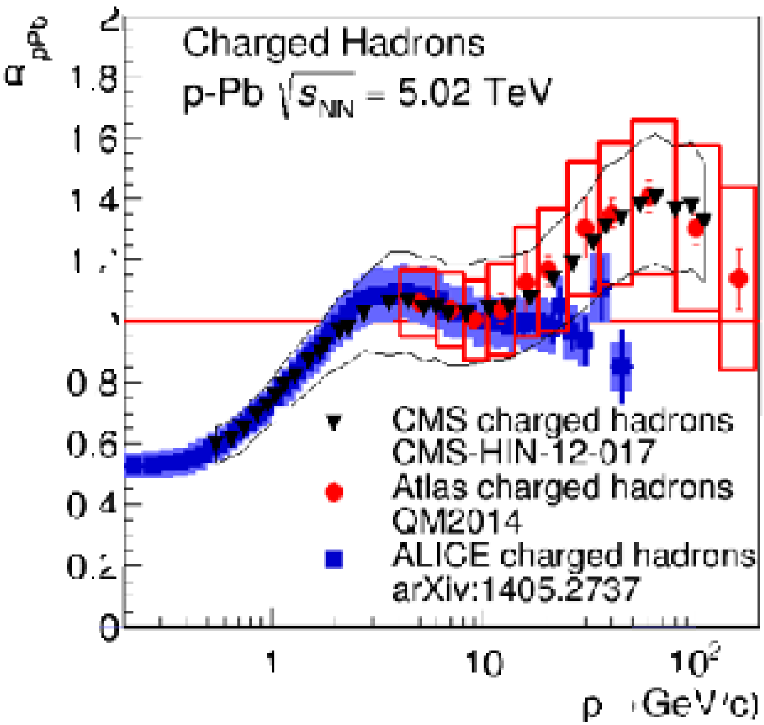
Experiment	coverage		$\pi^{\pm}$		$K^{\pm}$		$p^{\pm}$	
	Δy $\Delta\eta$	$\Delta\phi$	low p_T (GeV/c)	high p_T (GeV/c)	low p_T (GeV/c)	high p_T (GeV/c)	low p_T (GeV/c)	high p_T (GeV/c)
ALICE	1.0	360°	0.1	3.0	0.2	3.0	0.3	4.6
ALICE (statistical)	1.6	360°		20.0		20.0		20.0
PHENIX	0.7	45°	0.2	3.0	0.4	2.0	0.6	4.5
STAR	0.2	360°	0.2	0.7	0.2	0.7	0.35	1.2

R_{pPb} comparison between ATLAS, CMS and ALICE



Anne Sickles, Talk QuarkMatter 2014