Session of Nuclear Physics Division of Russian Academy of Science.
5-8.11.2013, Protvino

Nuclear matter studies with the ALICE experiment at LHC

Yuri Kharlov
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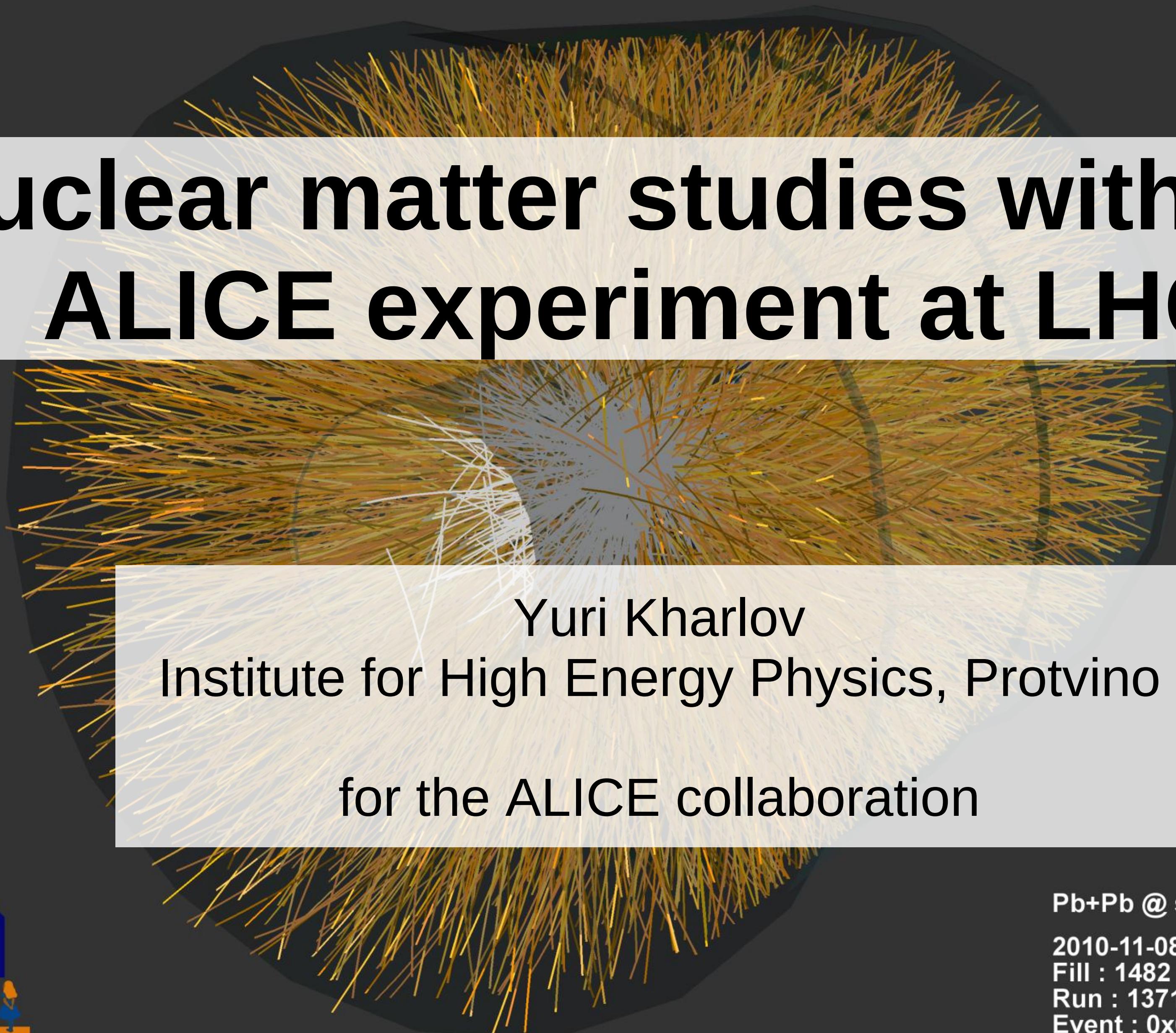
for the ALICE collaboration



Outline

- ALICE detector
- Global properties of heavy-ion collisions
- Anisotropic flow
- LF particle spectra
- HF spectra
- Quarkonia
- Hard probes
- Correlations
- Upgrade plans

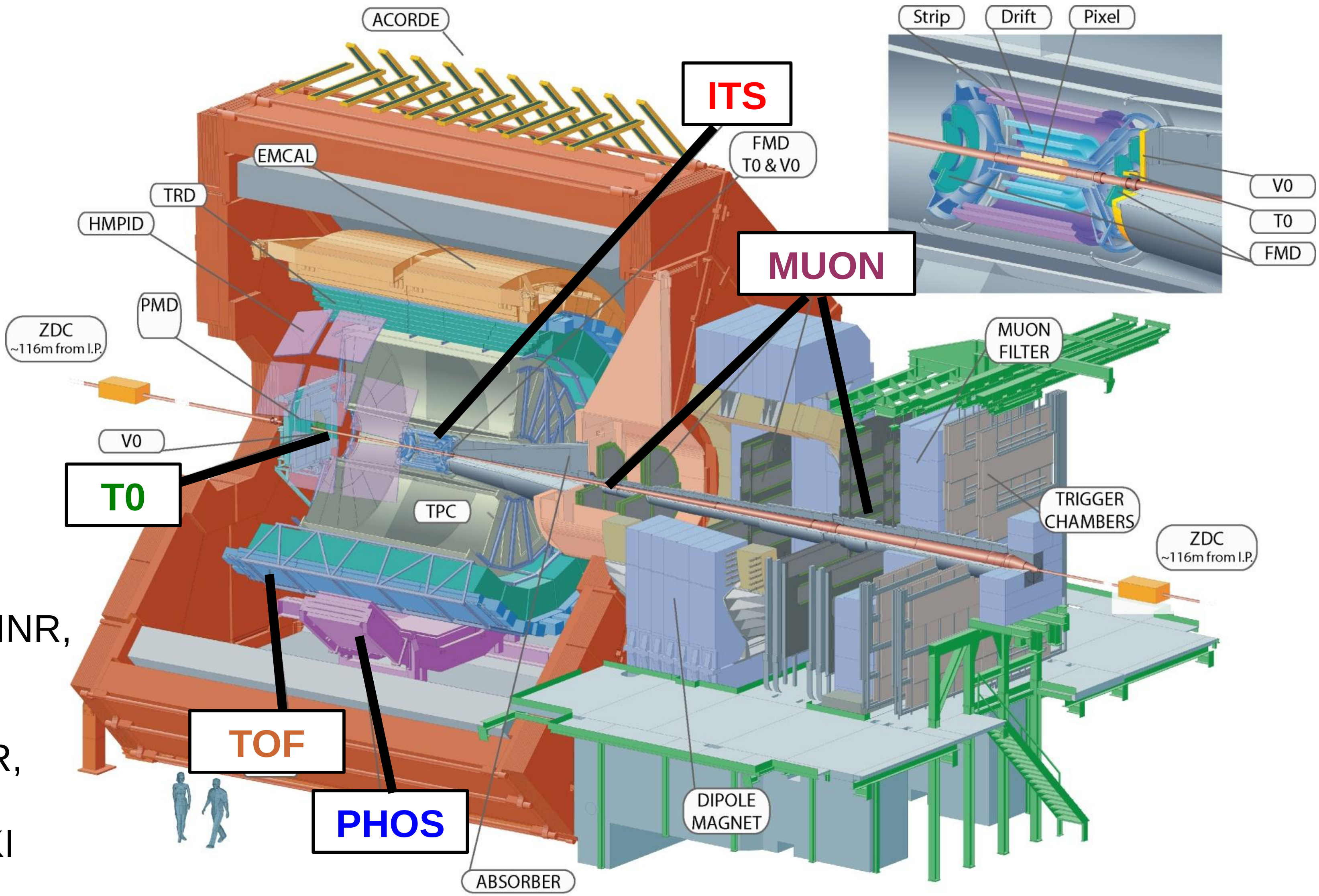
ALICE detector

ALICE numbers:

- 1200 members
- 131 institutes
- 36 countries

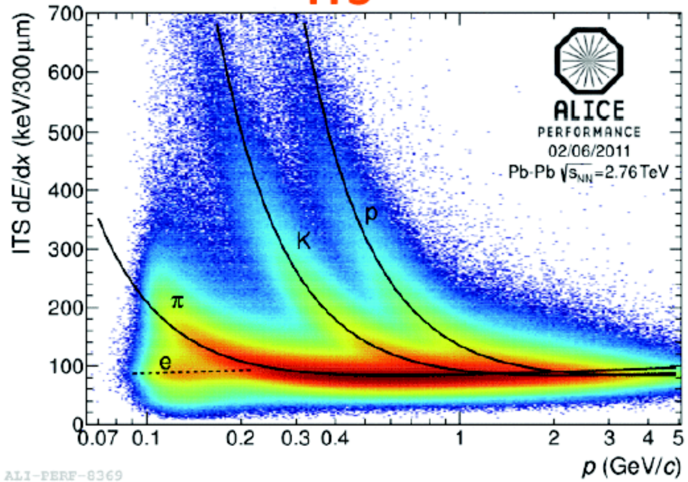
Russia in ALICE:

- **PHOS**: KI, IHEP, JINR, VNIIEF
- **TOF**: ITEP
- **MUON**: PINP, JINR, VNIIEF
- **T0**: INR, MEPHI, KI
- **ITS**: SpSU

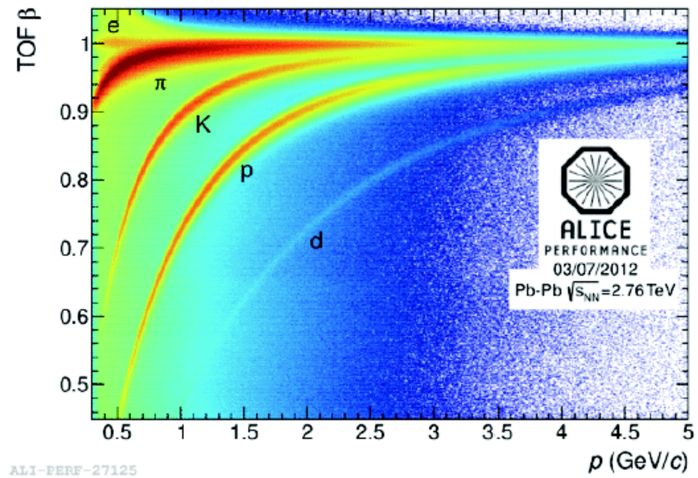


Charged particle identification in ALICE

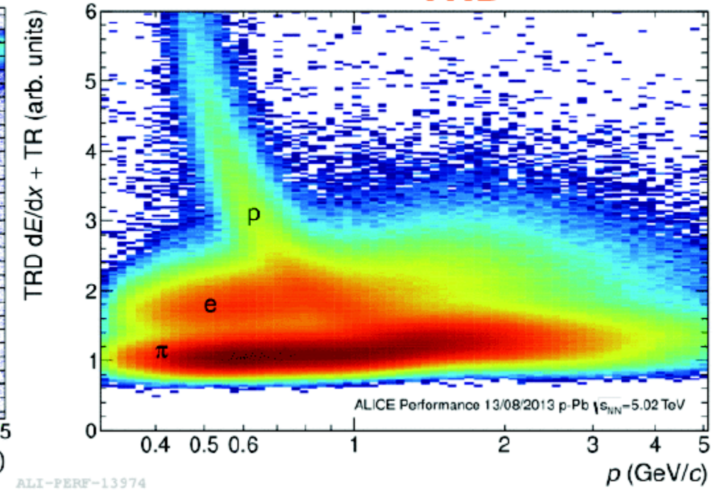
ITS



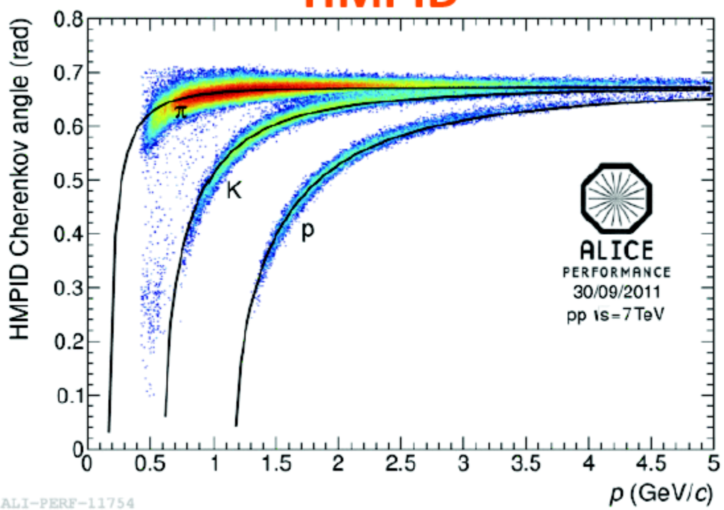
TOF



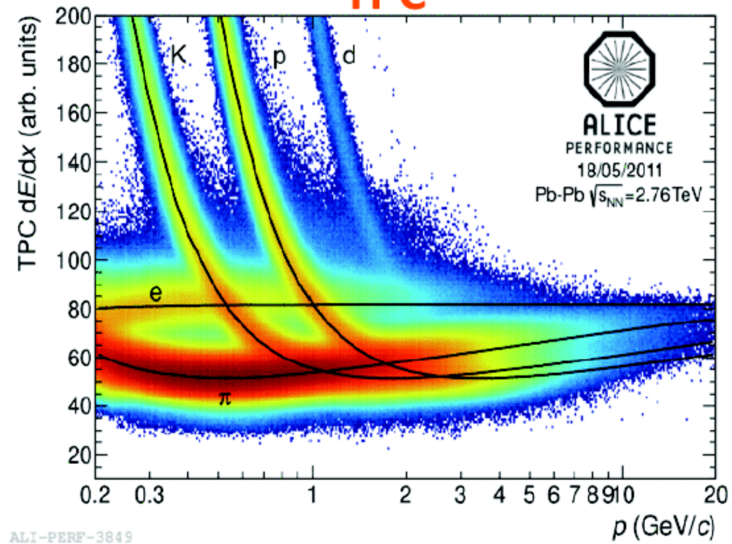
TRD



HMPID



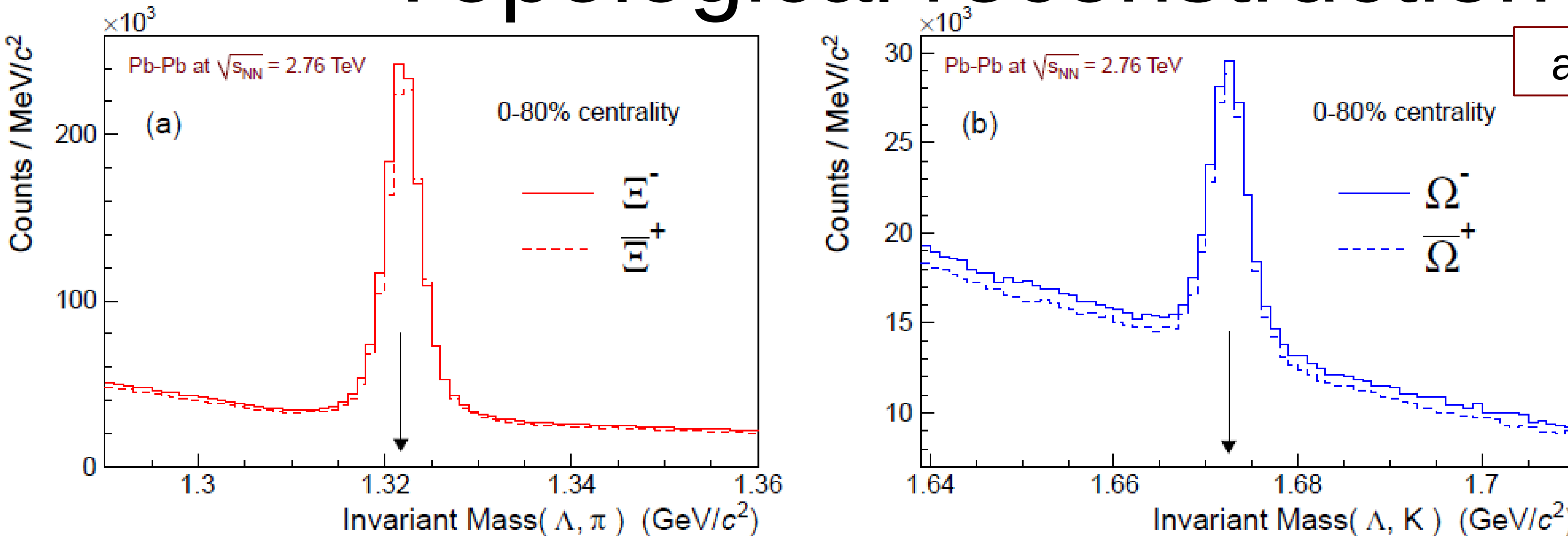
TPC



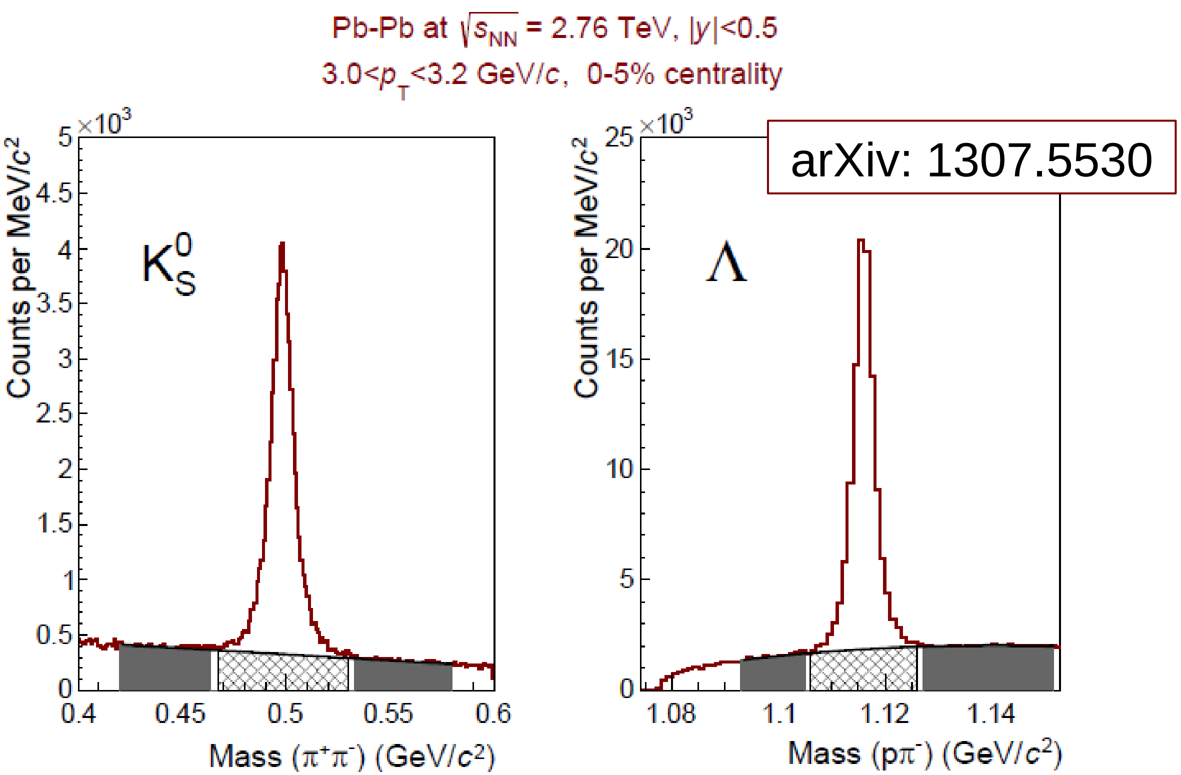
p_T range for PID:

- ITS: $p_T < 1$ GeV/c
- TOF: $p_T < 3$ GeV/c
- TRD (e): $p_T < 10$ GeV/c
- HMPID: $p_T < 5$ GeV/c
- TPC: $p_T < 20$ GeV/c

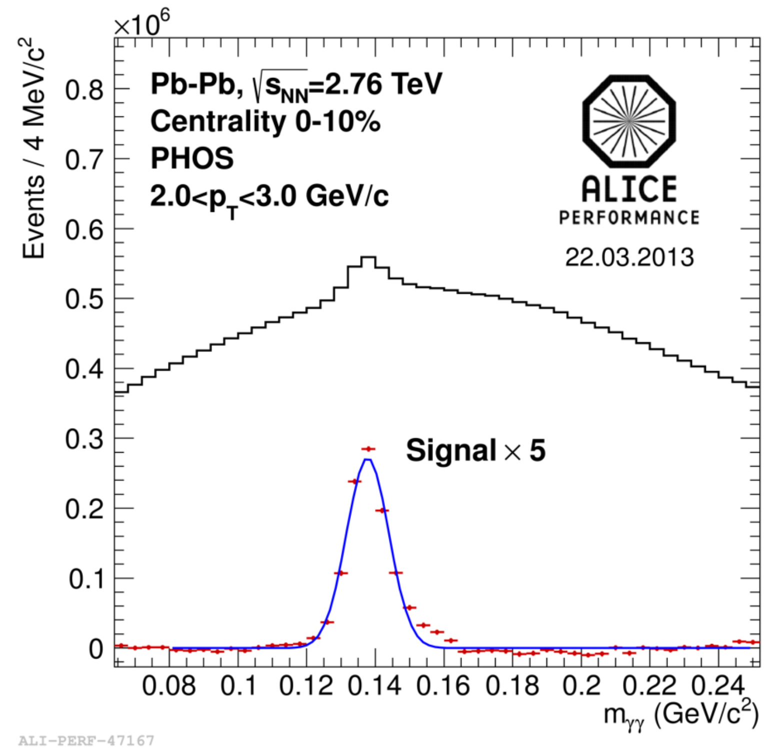
Topological reconstruction



arXiv: 1307.5543



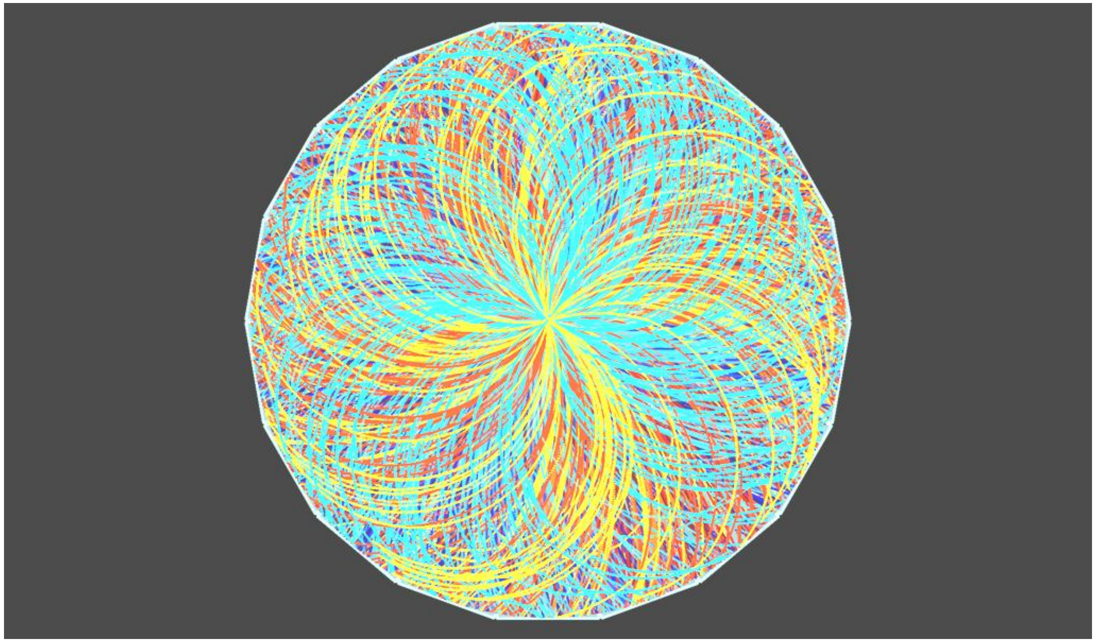
arXiv: 1307.5530



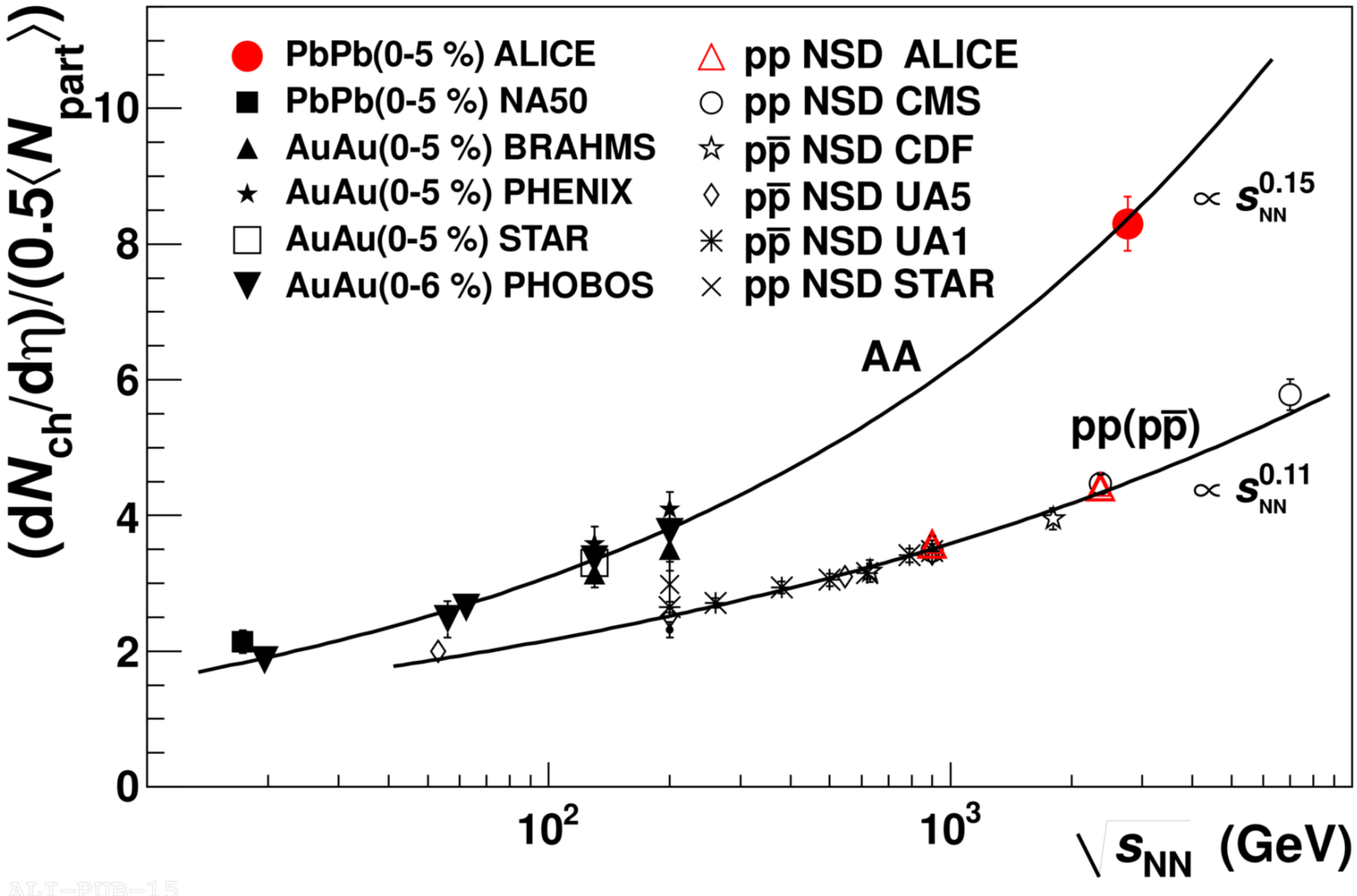
Datasets in Run1

Collision system, √s (TeV)	**2009**	**2010**	**2011**	**2012**	**2013**
pp 0.9 TeV	3 μb^{-1}	0.14 nb^{-1}			
pp 2.36 TeV	0.7 μb^{-1}				
pp 2.76 TeV			1.3 nb^{-1}		1.3 nb^{-1}
pp 7 TeV		10 nb^{-1}	1 pb^{-1}		
pp 8 TeV				8 pb^{-1}	
p-Pb 5.02 TeV					30 nb^{-1}
Pb-Pb 2.76 TeV		10 μb^{-1}	100 μb^{-1}		

Global event properties



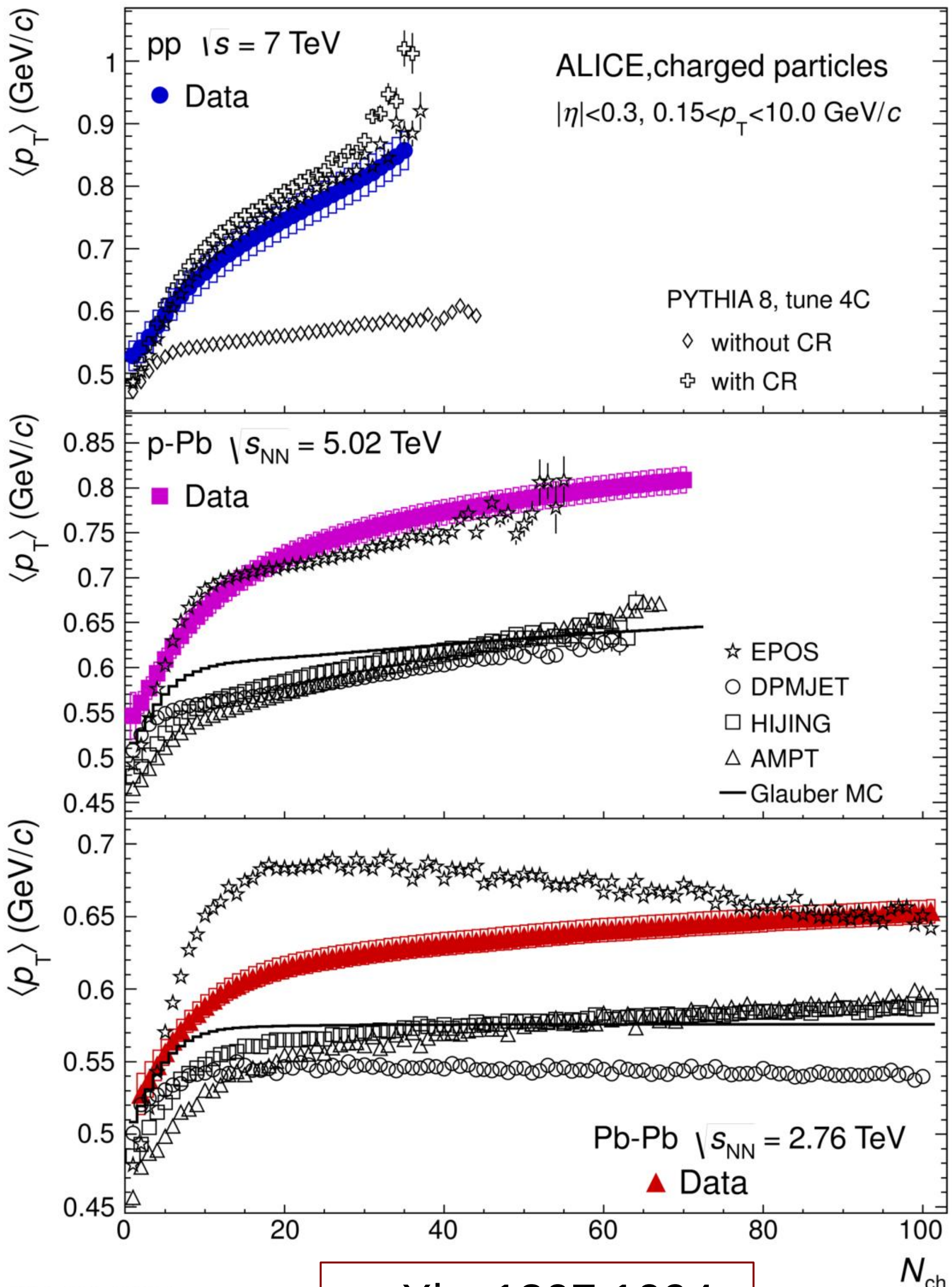
Charged multiplicity



Multiplicity ~ 2 x N_{RHIC}
Energy density ~ 3 x ε_{RHIC}

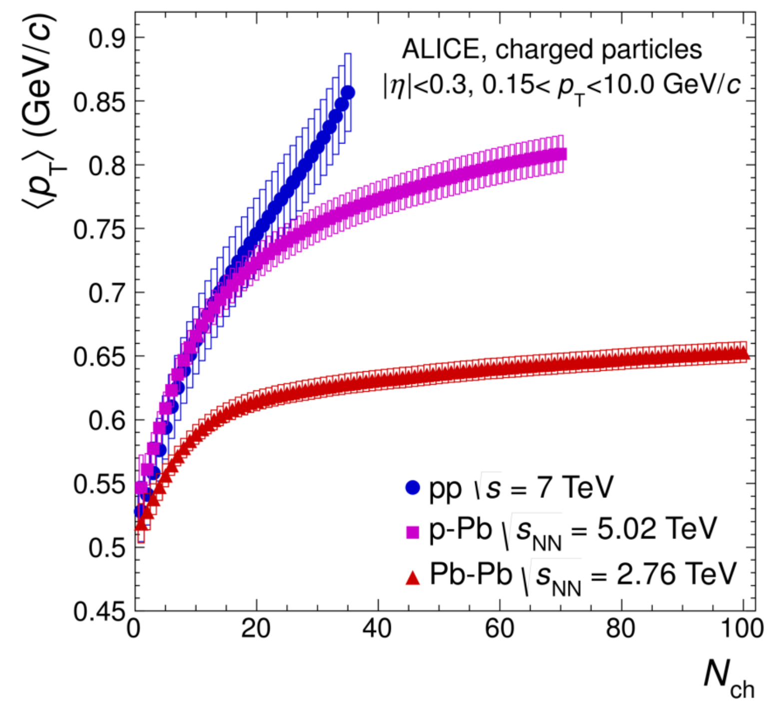
PRL 105 252301 (2010)

Mean transverse momentum



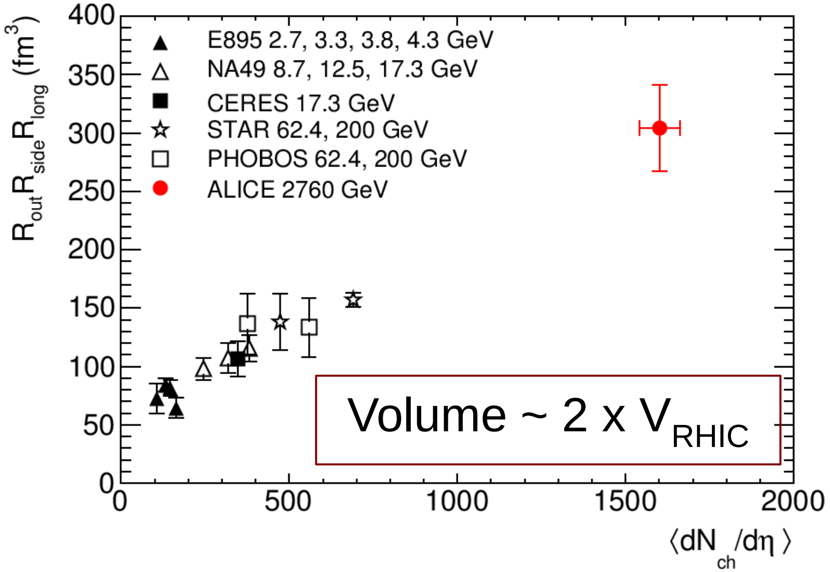
Comparison with models:

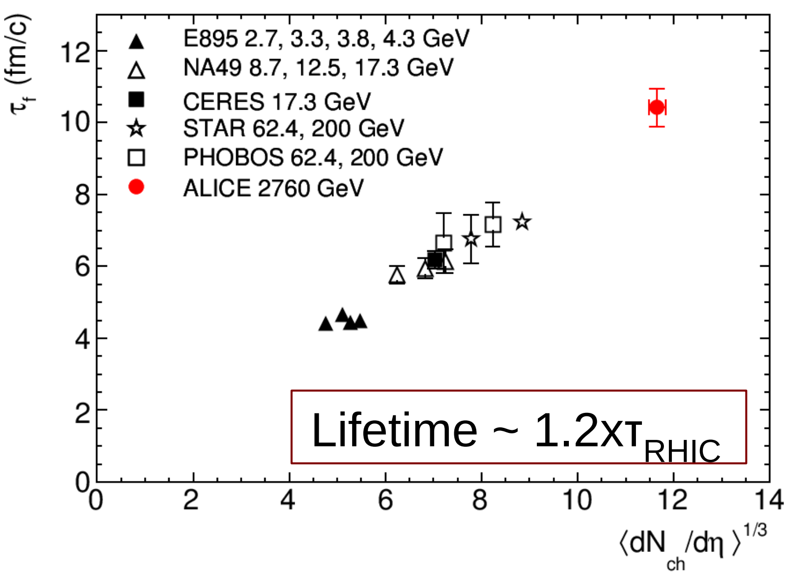
- **None** describe Pb-Pb
- **EPOS** describes **pp** and is consistent with **p-Pb** data but with tension (parametrizaions of collective effects)
- **PYTHIA8** with color reconnection (**CR**) consistent with **pp** data
- **Glauber MC** does not describe **p-Pb** data (incoherent superposition of NN collisions)



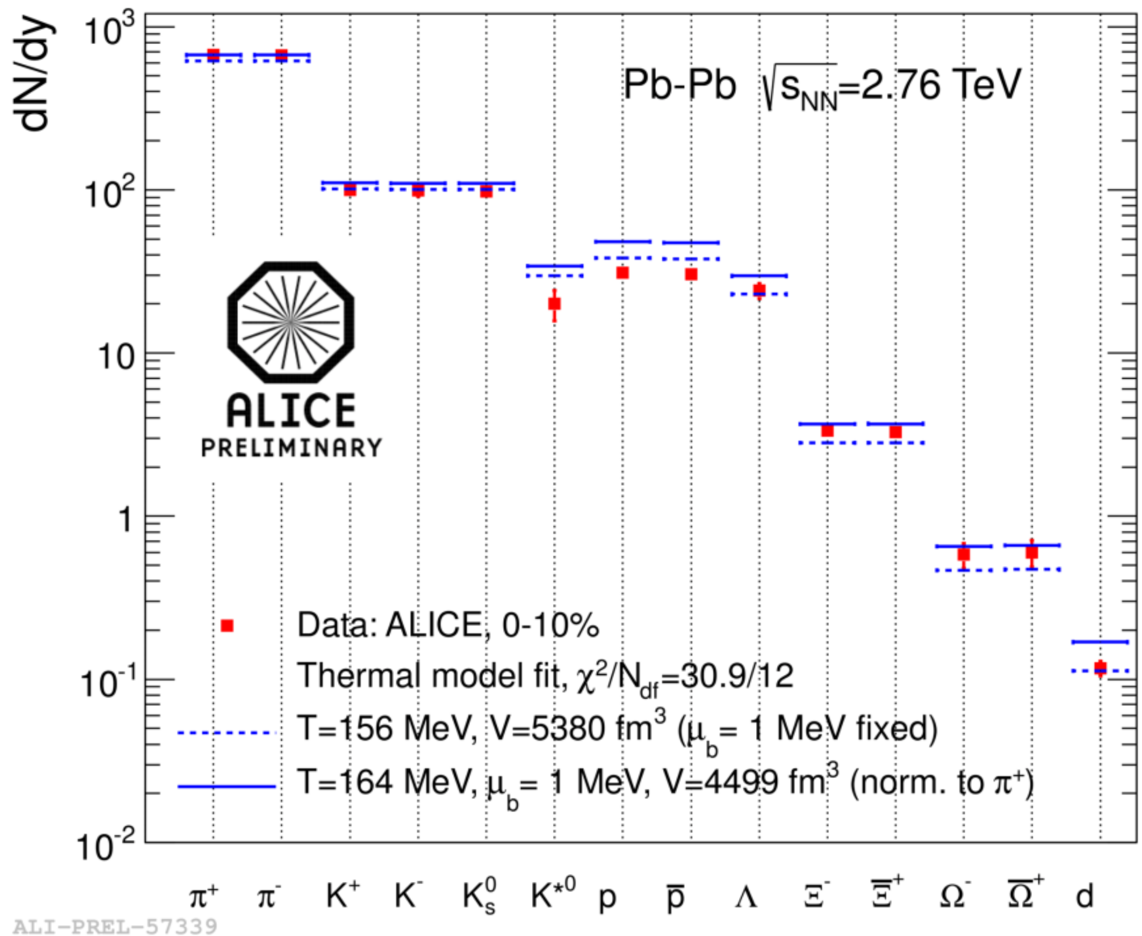
arXiv: 1307.1094

Size, lifetime, yields





PLB696 (2011) 328

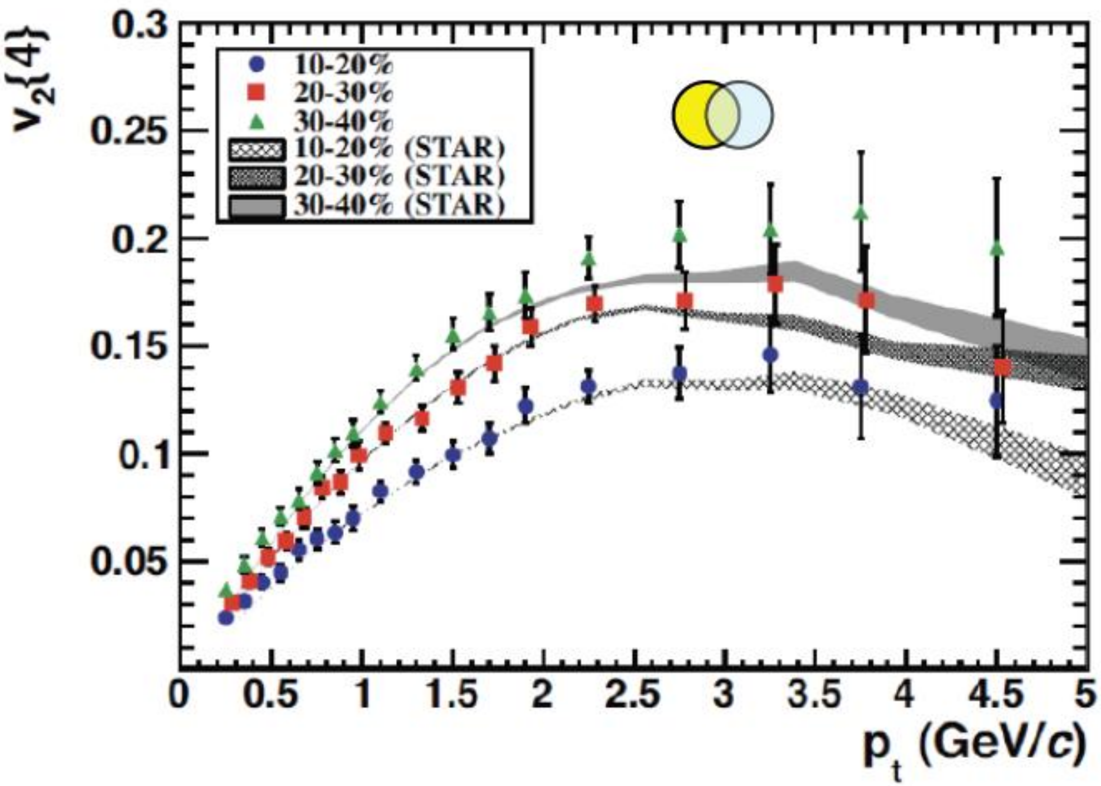


Hadron species abundances described by thermal model with T=156 MeV.
[A.Andronic et al., Nucl.Phys.A, 772 (2006), 167]

Anisotropic flow (1)

$$\frac{dN}{d(\varphi-\psi_{RP})} \propto 1+2\sum_{n=1} v_n \cos(n[\varphi-\psi_{RP}])$$

$$v_2 = \langle \cos[2(\varphi-\Psi_{RP})] \rangle$$

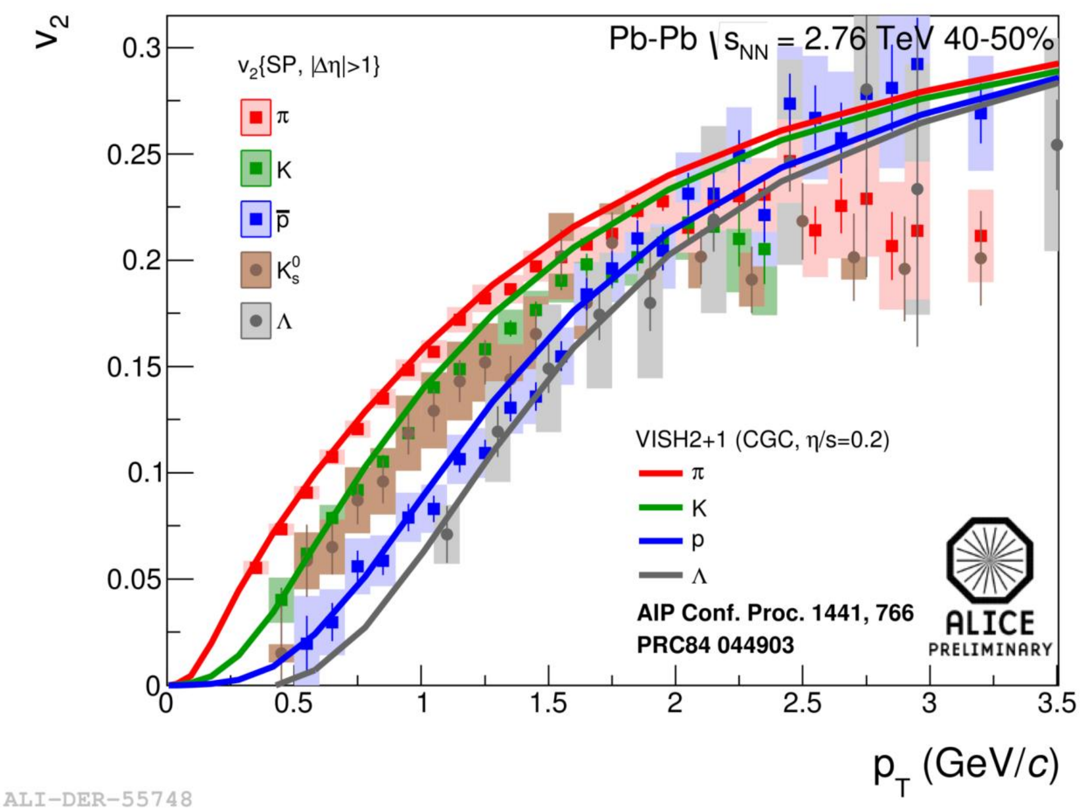


PRL 105, 252302 (2010)

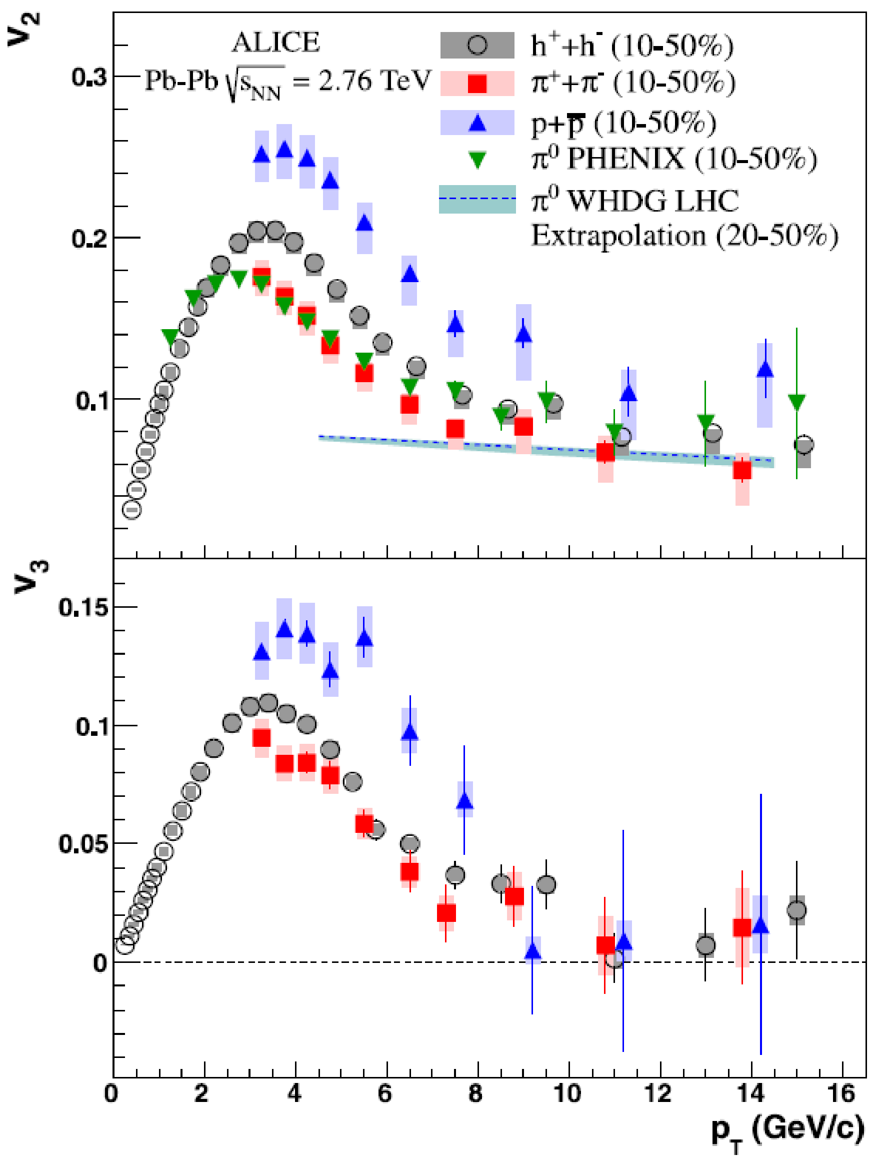
v_2 vs. p_T does not change between RHIC (200 GeV) and LHC (2.76 TeV) energy

the ~30% increase of p_T-integrated elliptic flow at LHC is then explained by higher mean p_T (stronger radial flow)

Anisotropic flow (2)



PLB 719 (2013) 18–28

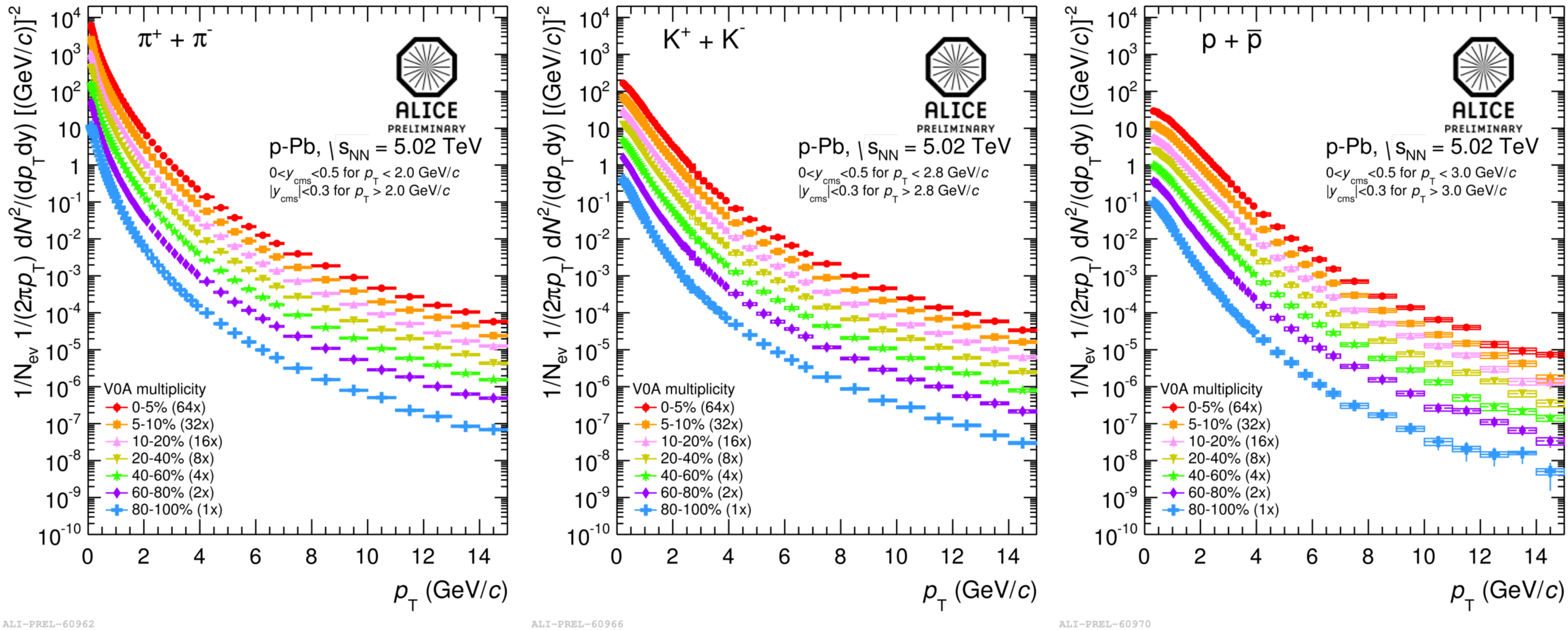


Identified particle elliptic flow

- Mass ordering at low p_T described by hydrodynamics
- Particle species dependence persists up to p_T~8 GeV/c

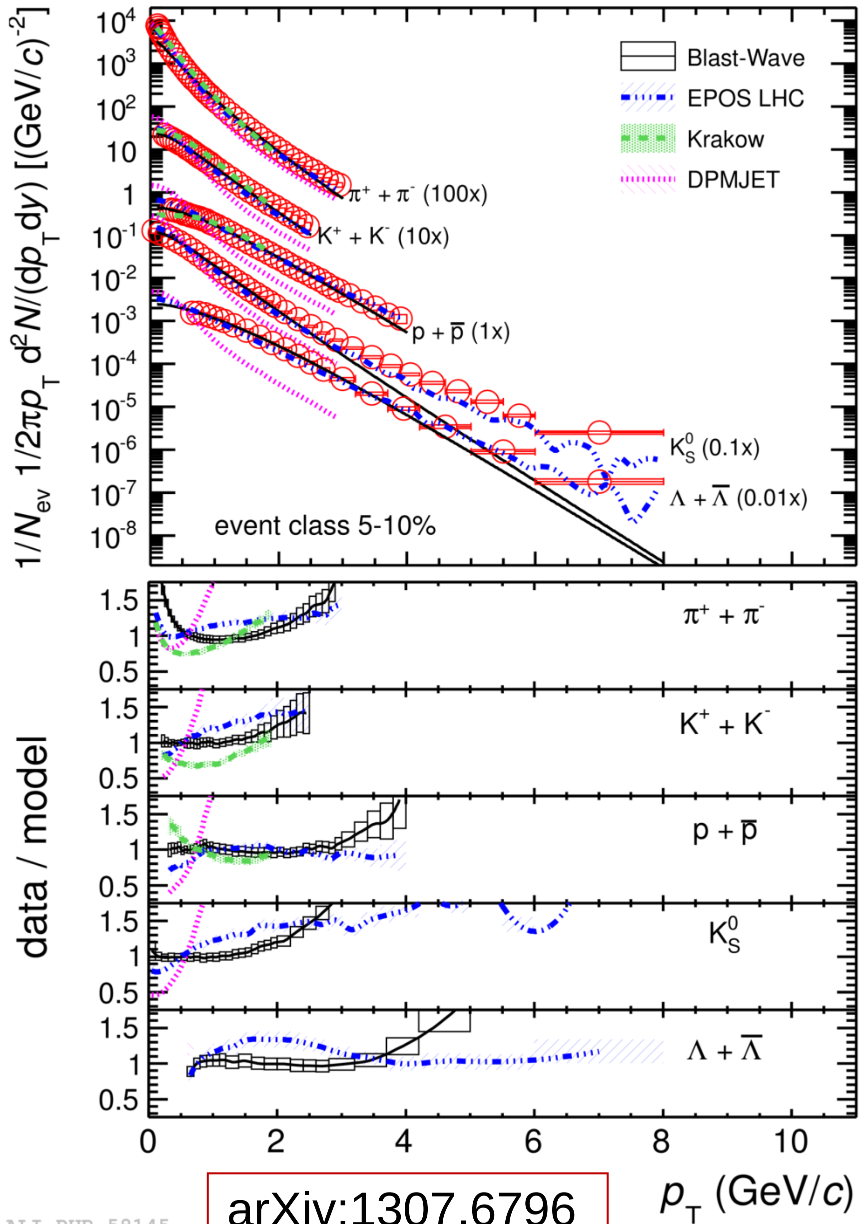
Light-flavor particle spectra

Identified hadron spectra in p-Pb



•Spectra become harder with increasing multiplicity and increasing particle mass

Identified hadron production in p-Pb



arXiv:1307.6796

Comparison with models:

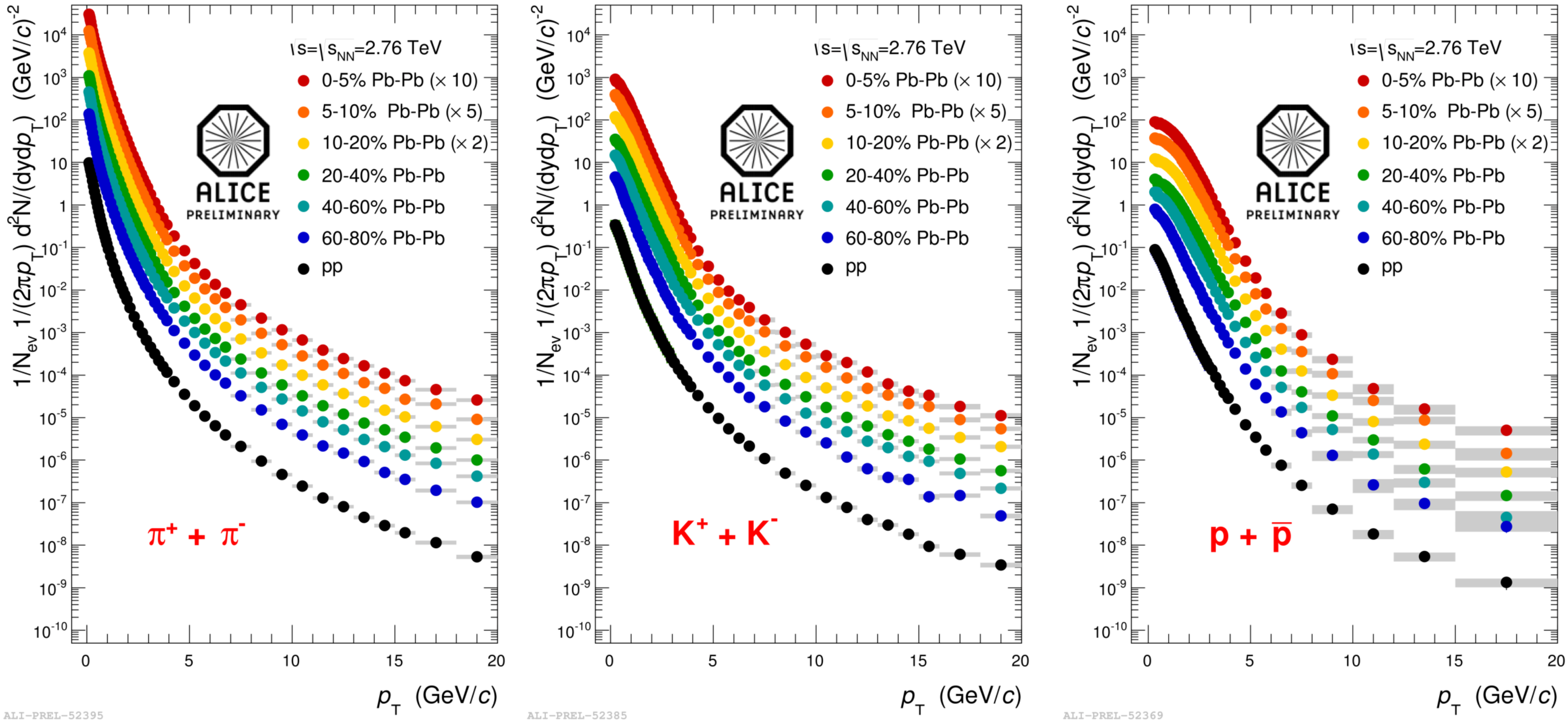
Blast-wave
- Hydro inspired model

EPOS LHC
- hard/soft scattering contribute to jet/bulk
- bulk matter described with hydro

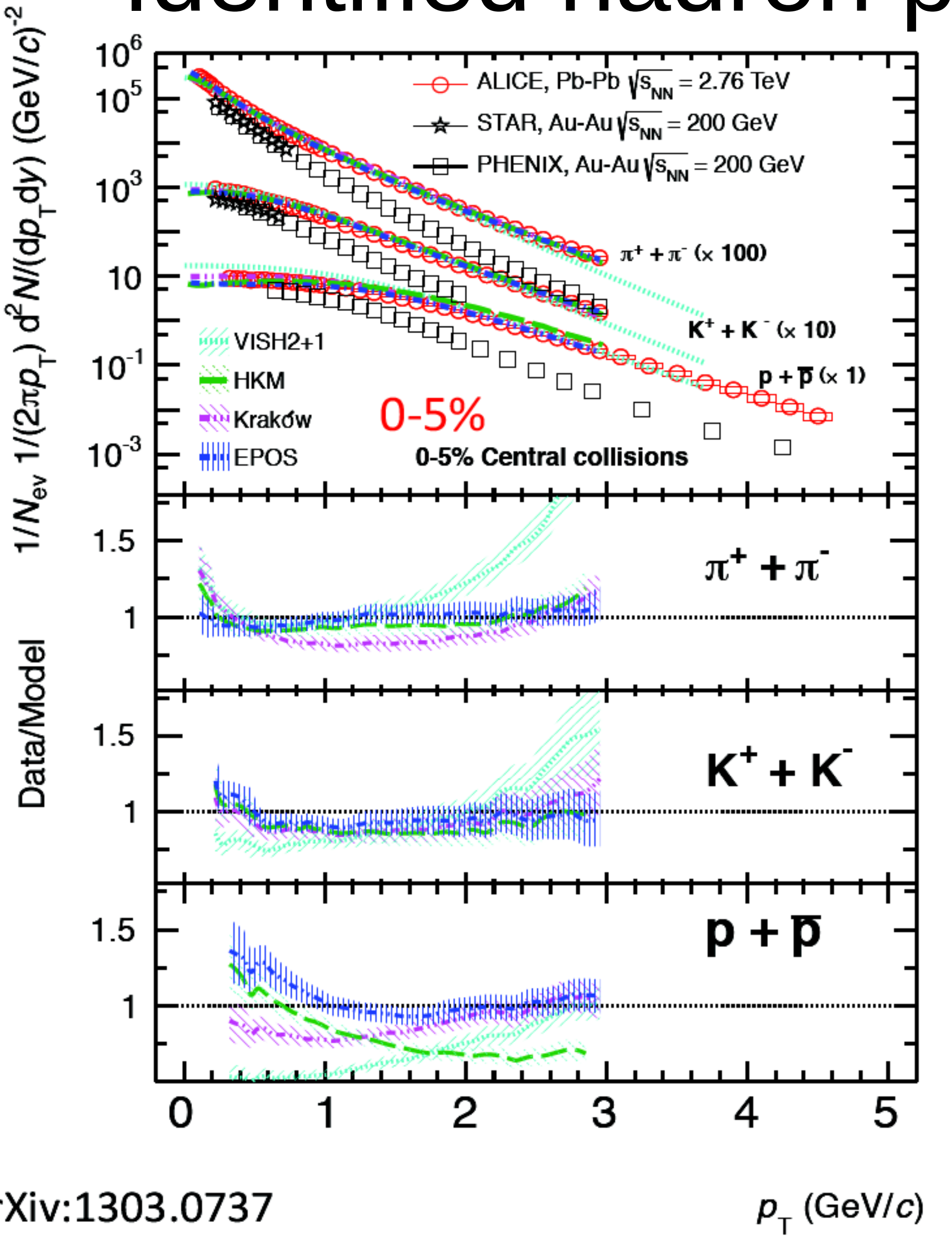
Krakow
- initial conditions from Glauber MC
- viscous hydrodynamic expansion
- statistical hadronization at freeze-out

DPMJET
- QCD-inspired model based on Gribov-Glauber Approach
- reproduces $dN_{ch}/d\eta$ in NSD p-Pb

Identified hadron spectra in Pb-Pb



Identified hadron production in Pb-Pb



arXiv:1303.0737

From comparison to RHIC and hydrodynamic models:

- large radial flow at the LHC

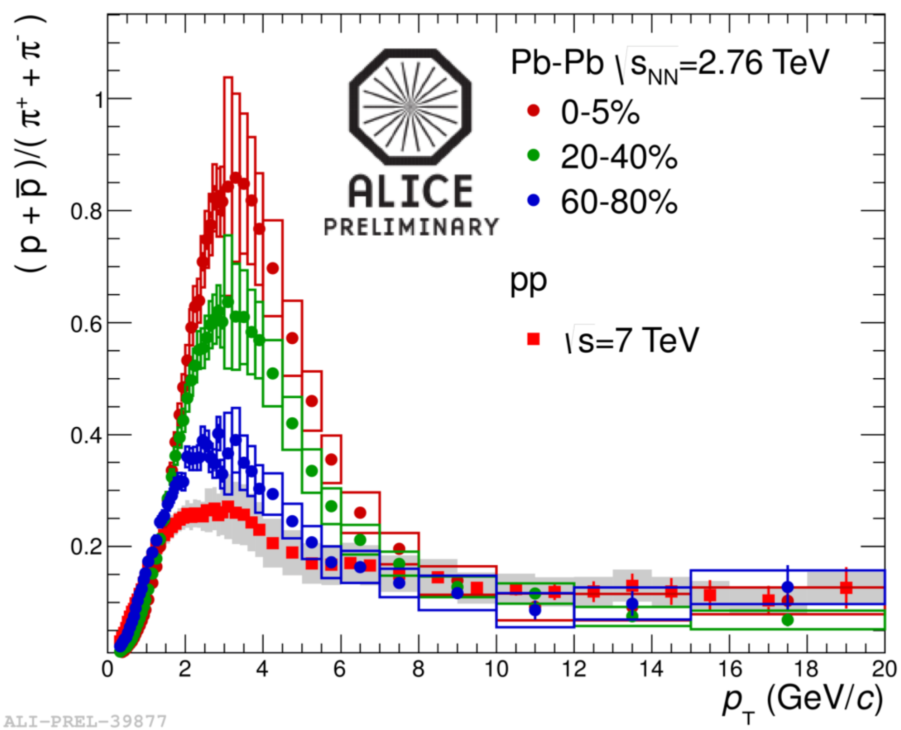
Hydrodynamic models:

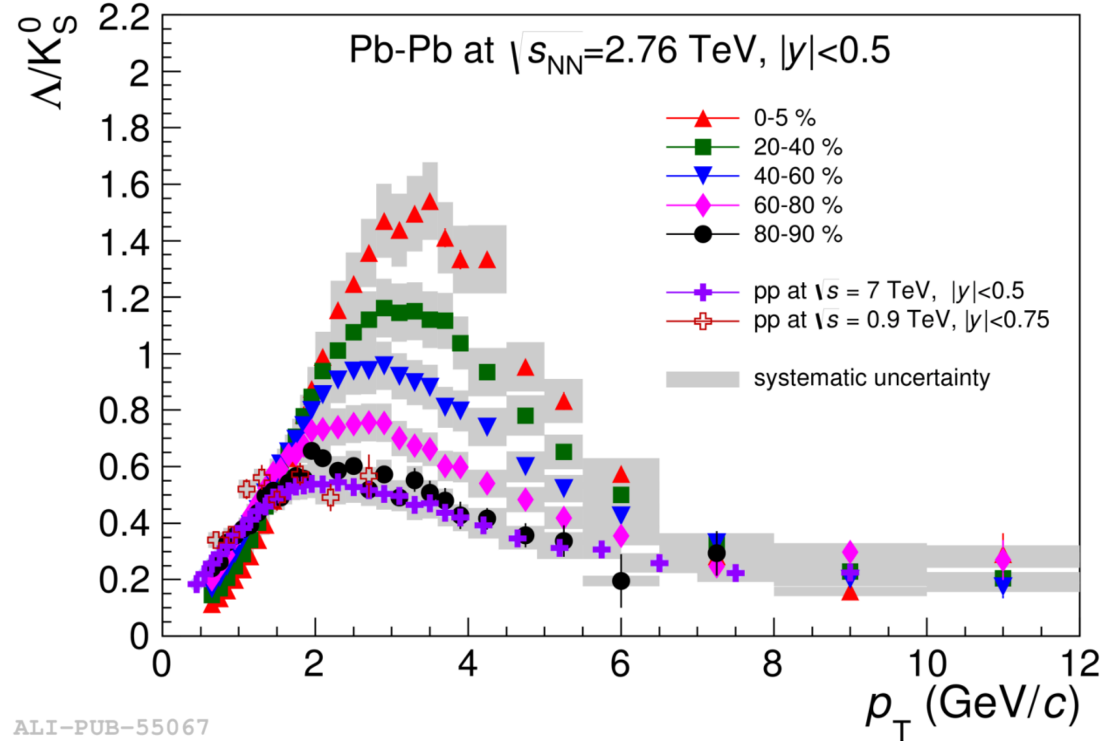
- VISH2+1 (viscous hydro)
- HKM (hydro+UrQMD)
- Krakow (viscous correctons)
- EPOS (hydro+UrQMD)

Are collective effect present in the system?

- Hydrodynamic flow exhibits a characteristic mass ordering
- QCD inspired models (DPMJET) cannot describe data
- Hydrodynamic models (EPOS, Krakow) are consistent with data

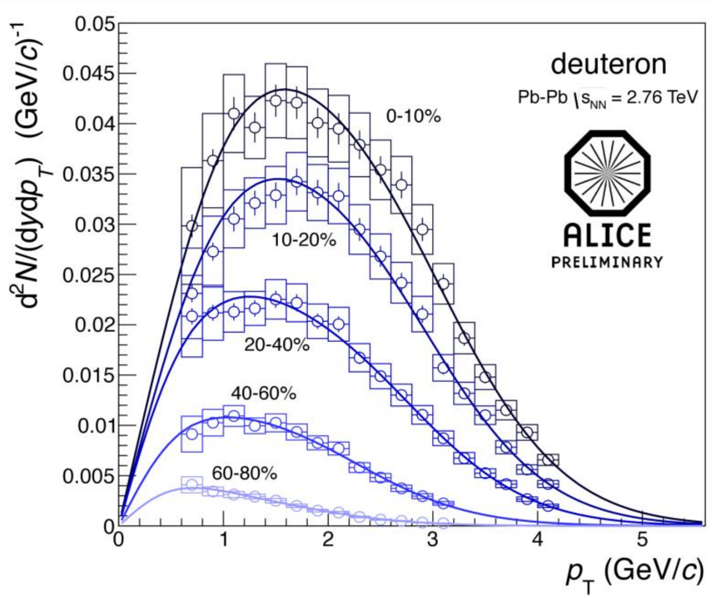
Baryon anomaly in Pb-Pb

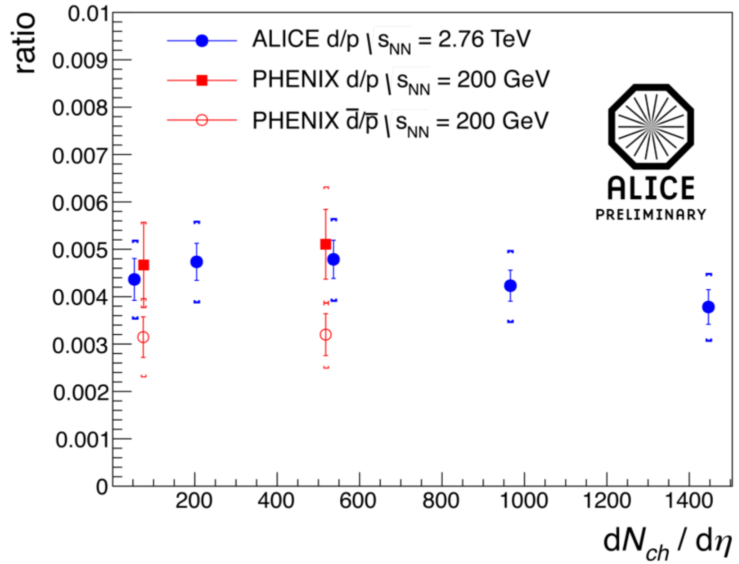




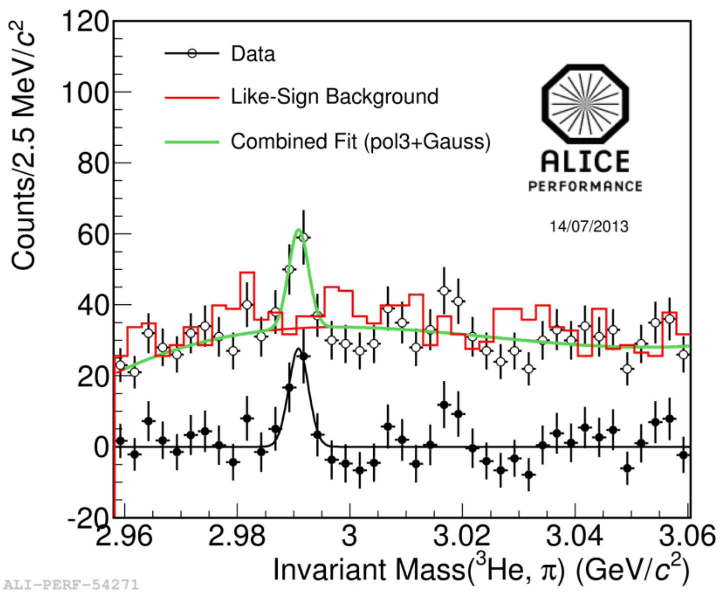
- Baryon to meson ratio increasing with centrality for p_T < 8 GeV/c.
  - Enhancement at moderate p_T is consistent with radial flow
  - May be explained by quark recombination from QGP (coalescence model)
- For p_T > 8 GeV/c no dependence on centrality and collision system
  - Consistent with fragmentation in vacuum

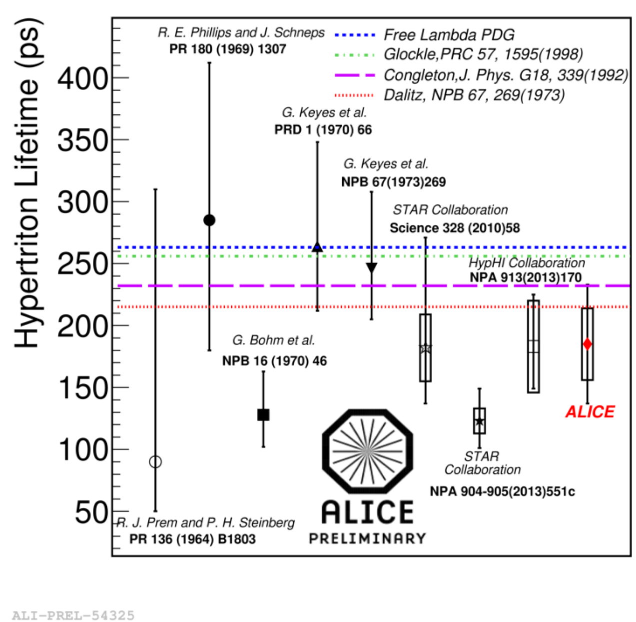
Nuclei and hyper-nuclei





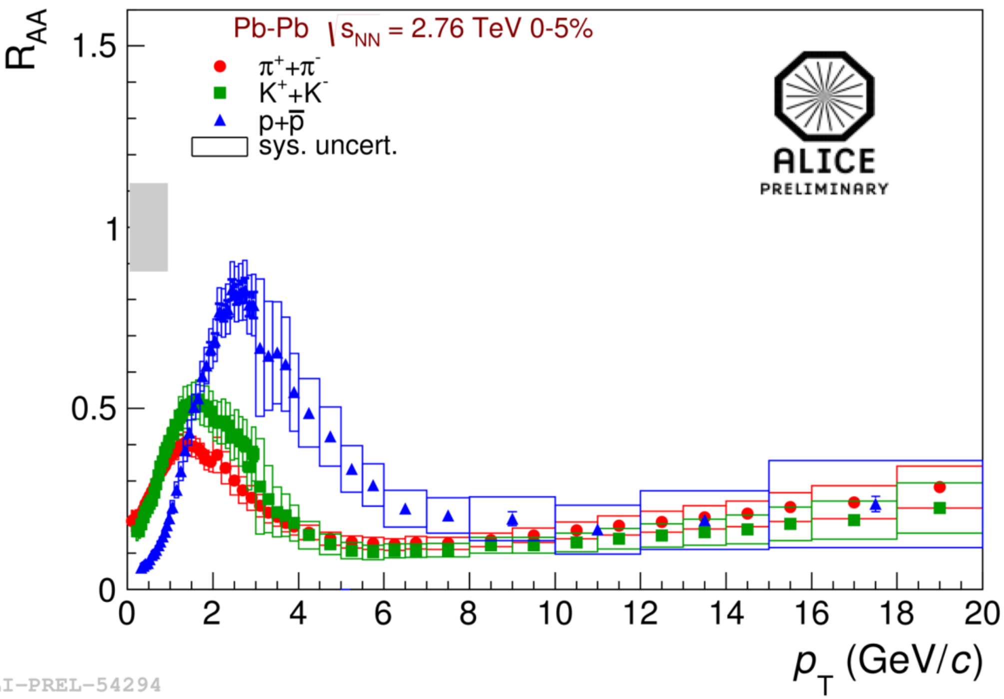
- Deuterons show hardening with increase of centrality (radial flow).
- d/p ratio does not depend on multiplcity.

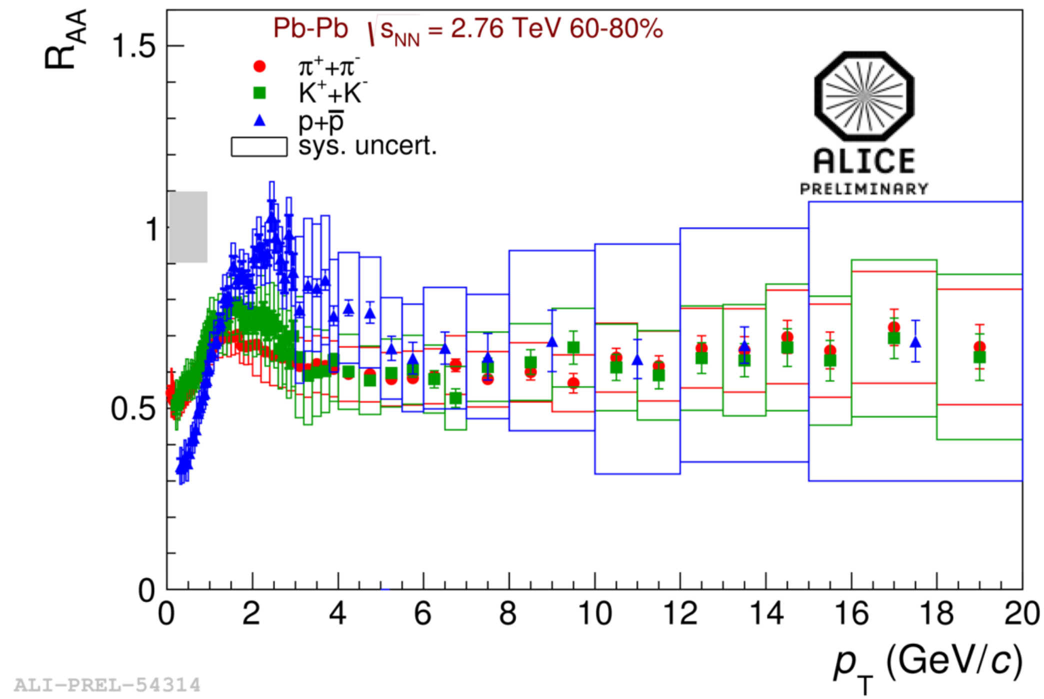




- Hypertriton (p,n,Λ) yield is measured in Pb-Pb collisions.
- Production rate of $^3{}_\Lambda H$ is described by thermal model.
- Lifetime measured.

R_{AA} of π, K, p

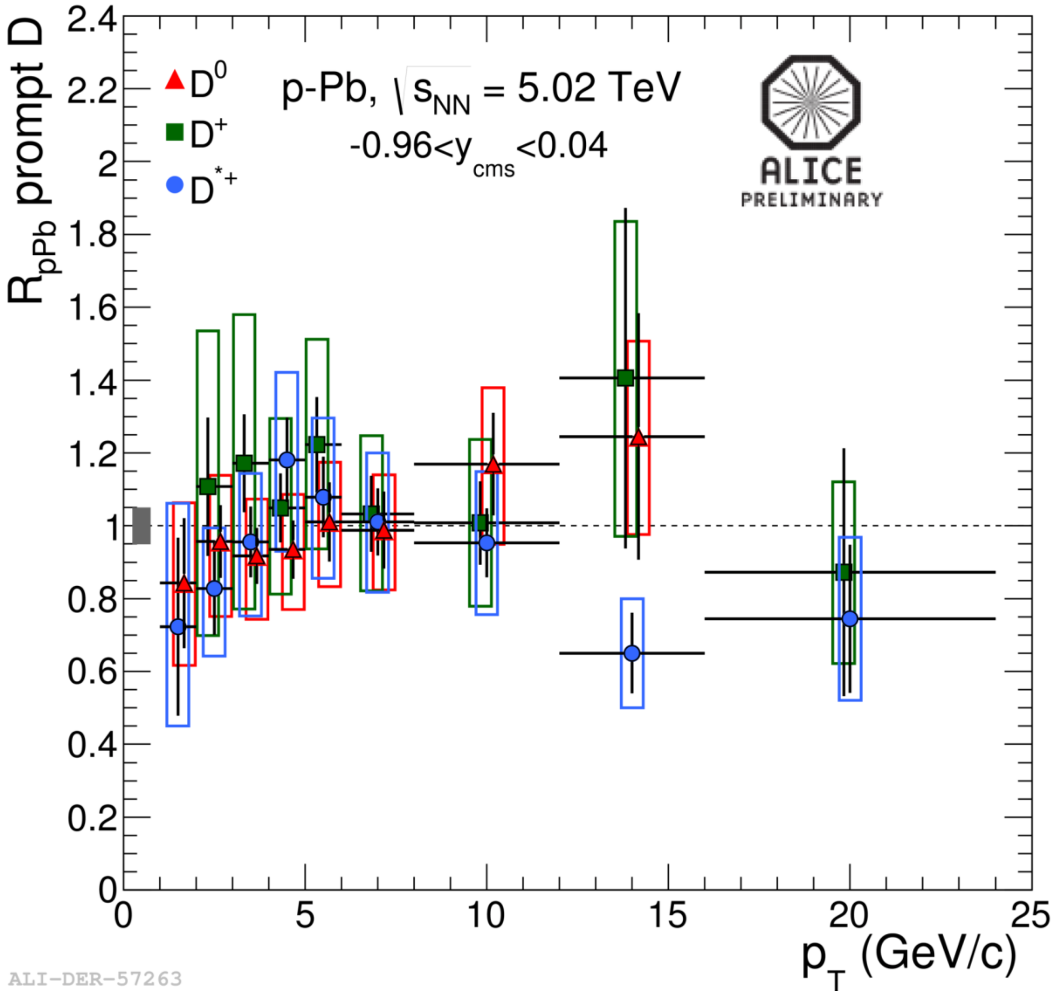


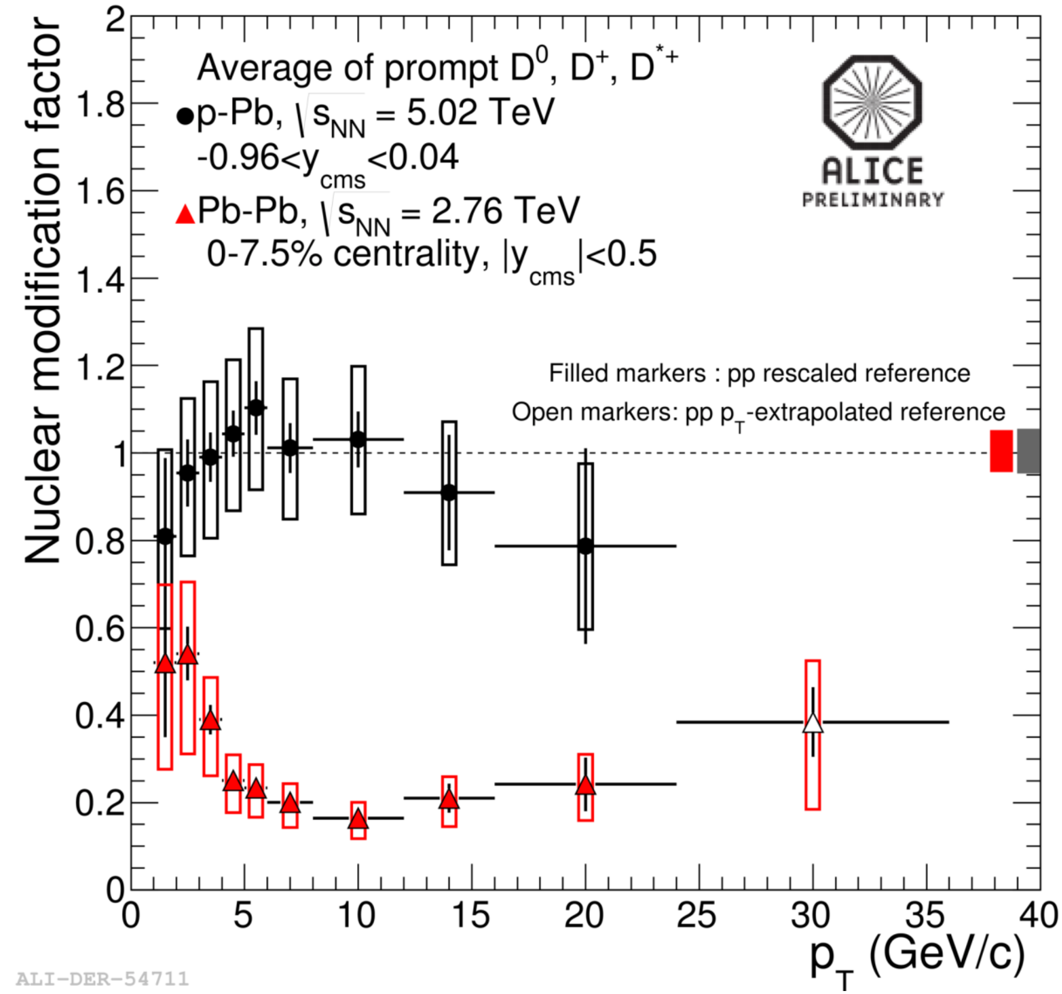


- p_T>8 GeV/c: strong suppression (factor 3-5) in central Pb-Pb collisions for all particle species
- Much smaller suppression in peripheral collisions

Heavy-flavor particle spectra

D-meson R_{pA}, R_{AA}



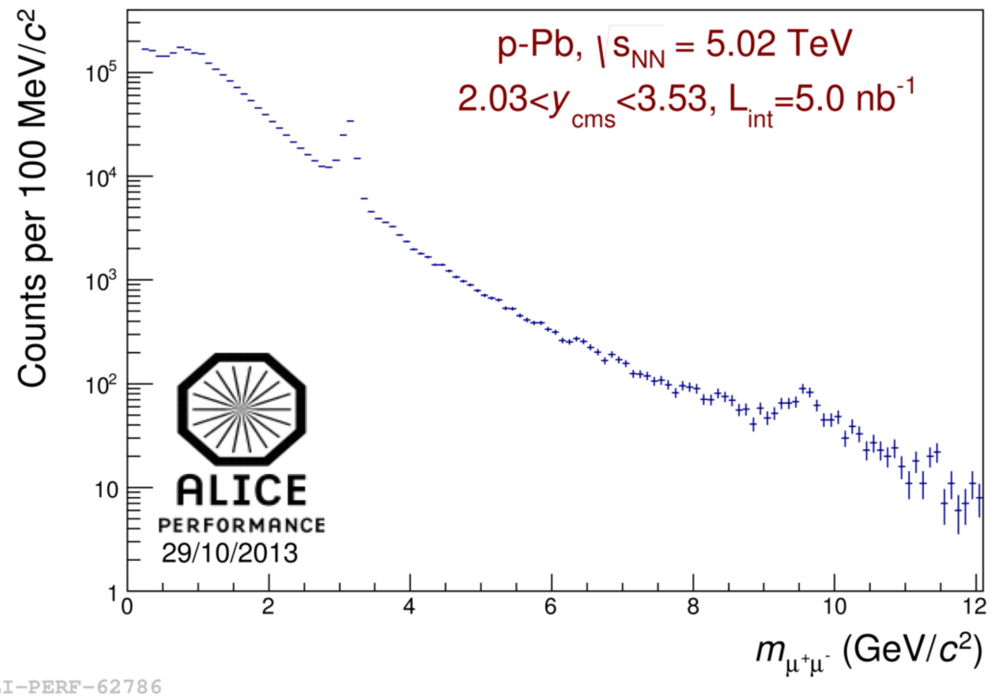


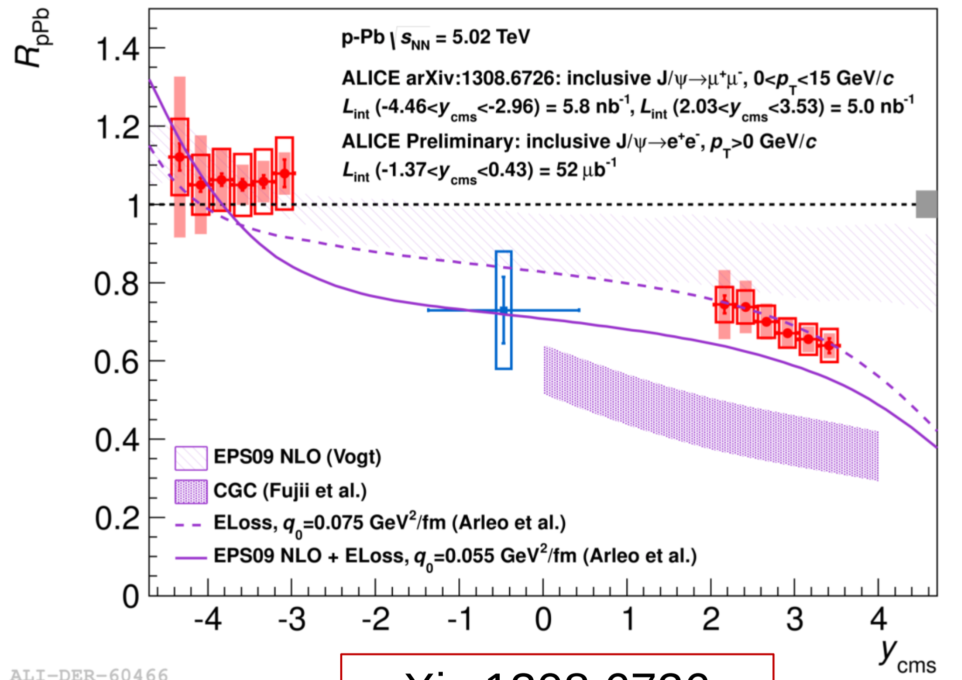
No suppression of D-meson is observed in p-Pb collisions.
All D-meson species are similar.
Initial state effects small!

D-meson are suppressed in central Pb-Pb collisions
Not an initial state effect!

Quarkonia

J/ψ production in p-Pb



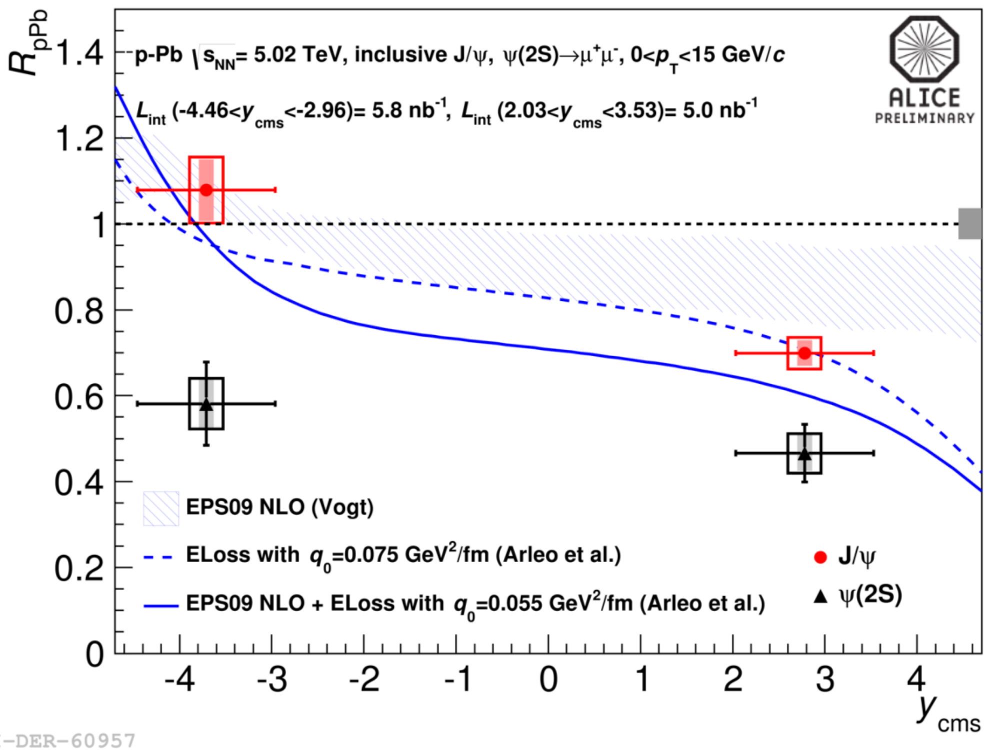


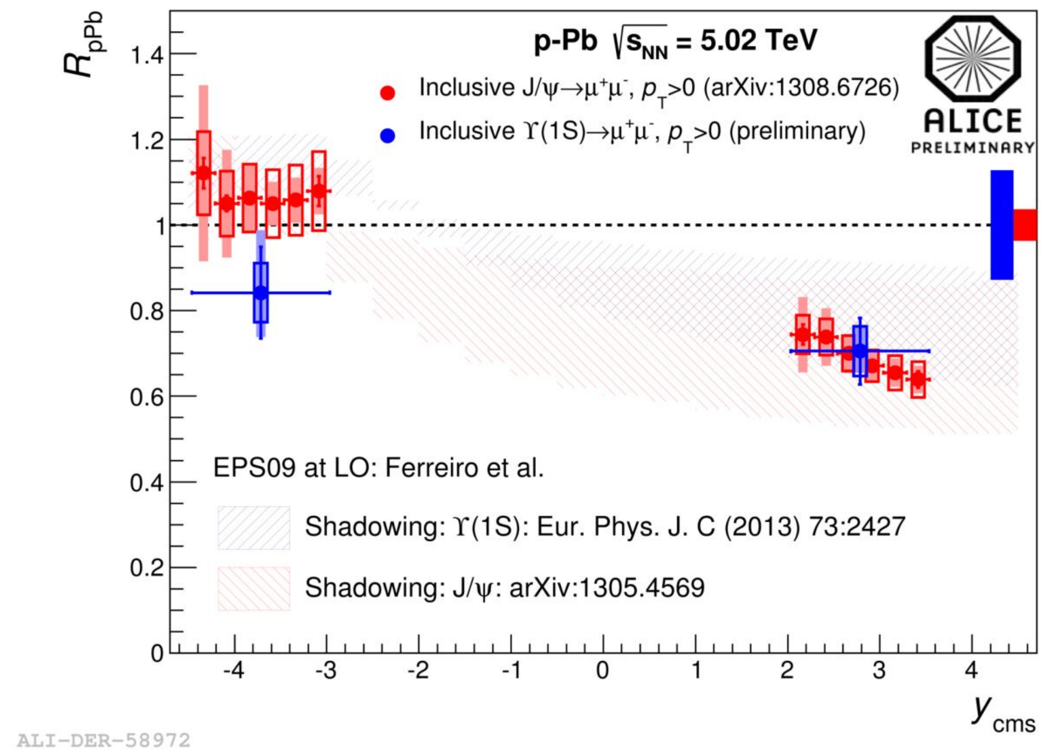
arXiv:1308.6726

Models:

- Shadowing model CEM + EPS09 NLO (Vogt)
  - backward rapidity data well reproduced, strong shadowing favoured at forward rapidity
- Coherent energy loss (Arleo et al.) with pp data parametrization
  - y-dependence well reproduced, better agreement with pure energy loss
- Gluon saturation (Fuji et al.): Color Glass Condensate framework with CEM LO
  - underestimate the data by a factor two

Ψ(2S), Υ(1S) in p-Pb

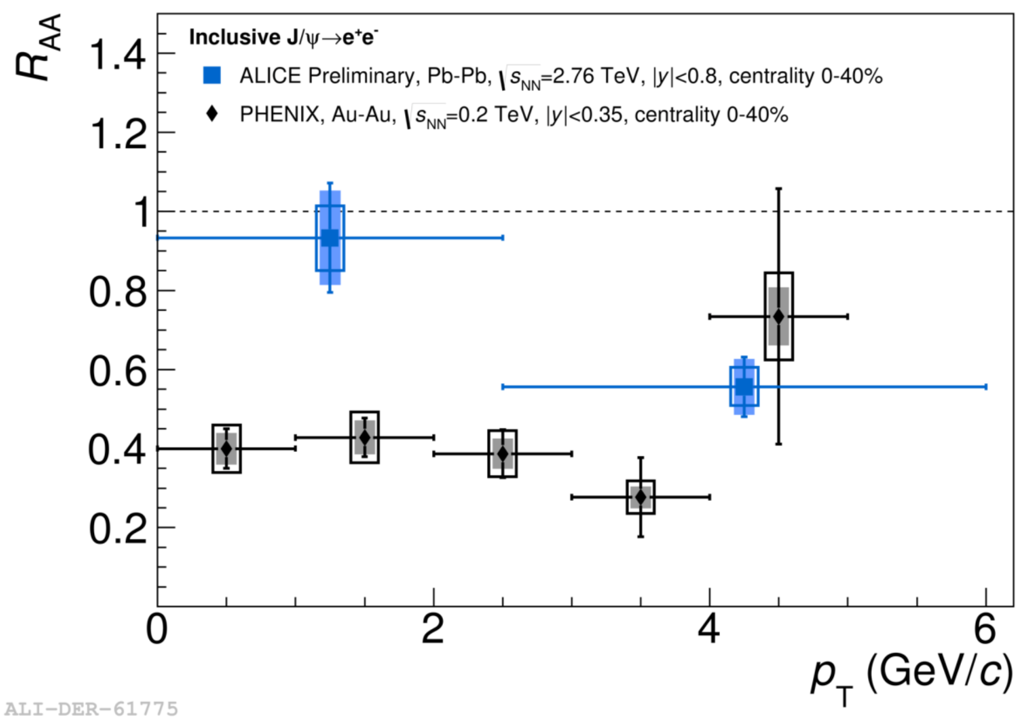


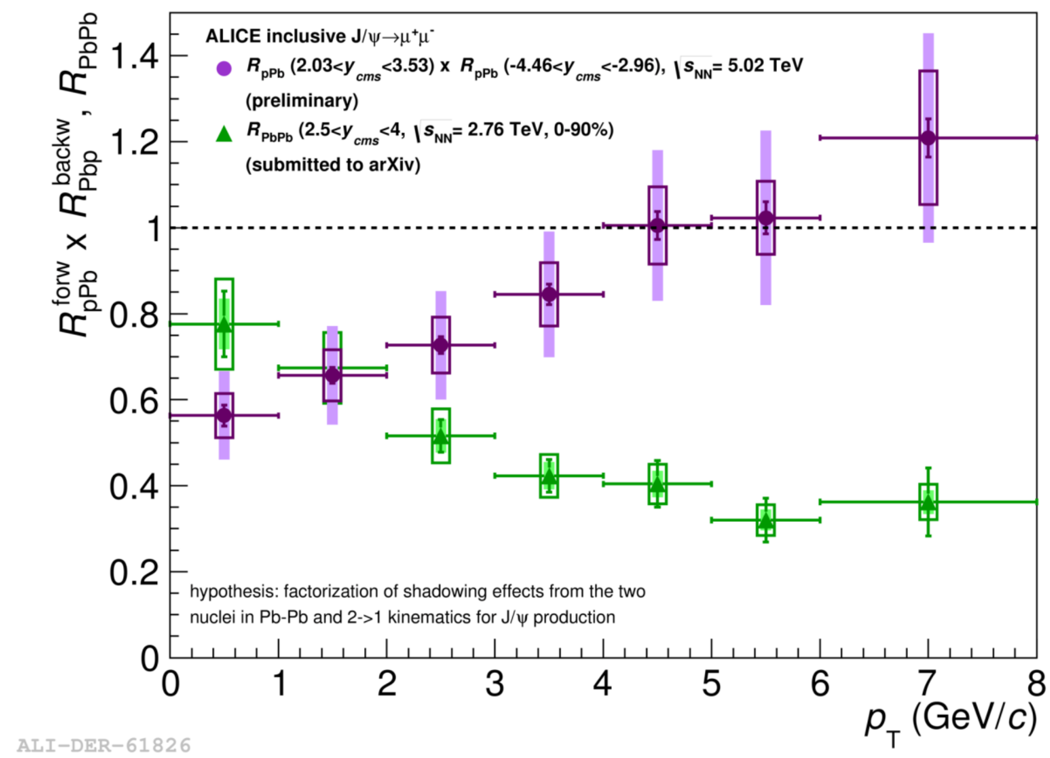


The stronger suppression of Ψ(2S) relatively to J/Ψ is not described by initial state CNM and coherent energy loss

Suppression of Υ(1S) is similar to that of J/Ψ, though uncertainties are still large

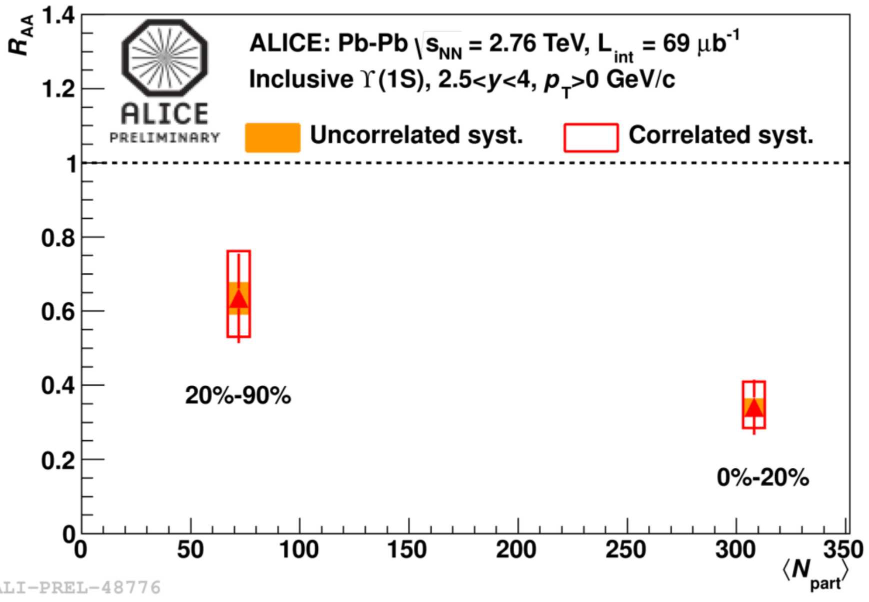
J/ψ production in Pb-Pb

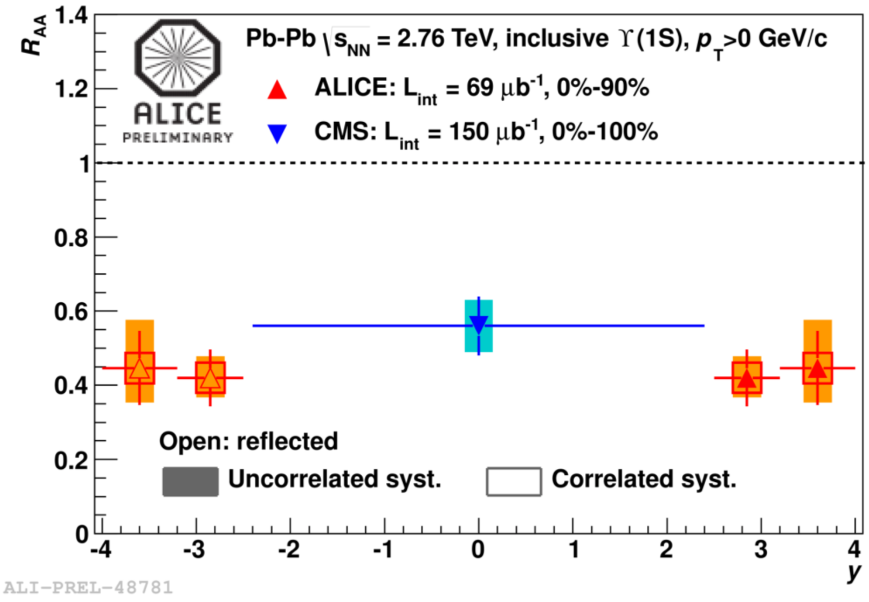




- J/Ψ less suppressed at low p_T than high p_T
- Different p_T dependence of R_{AA} at LHC and RHIC

Υ(1S) in Pb-Pb

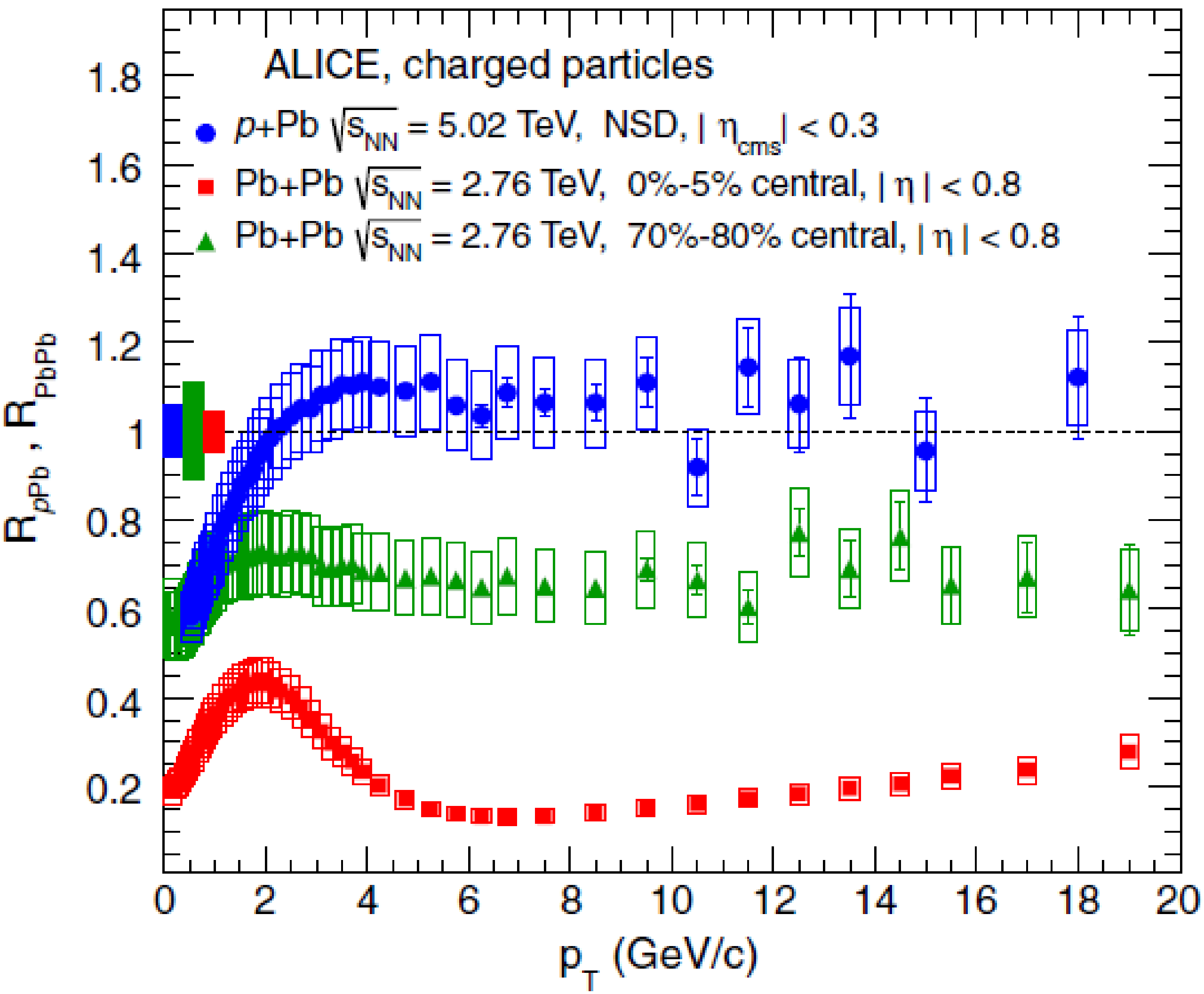


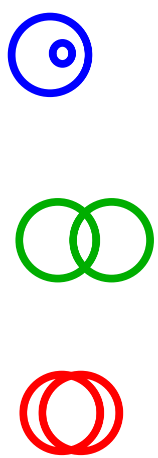


- Suppression increases for most central collisions
- Small rapidity dependence

Hard probes

Charged particle suppresion

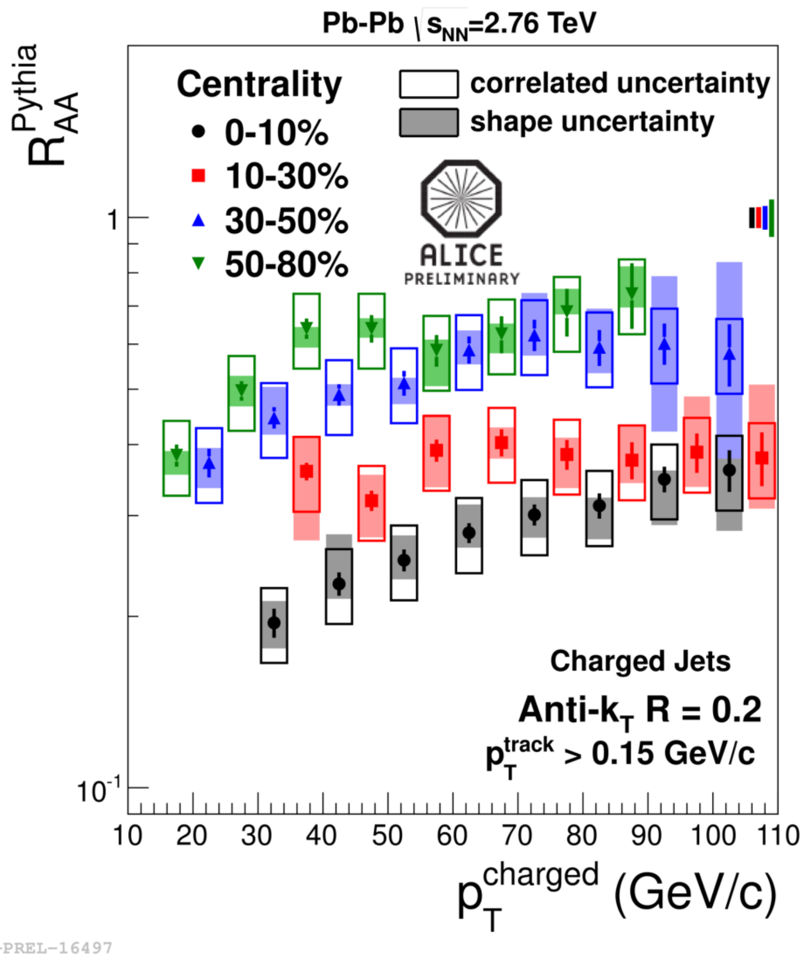


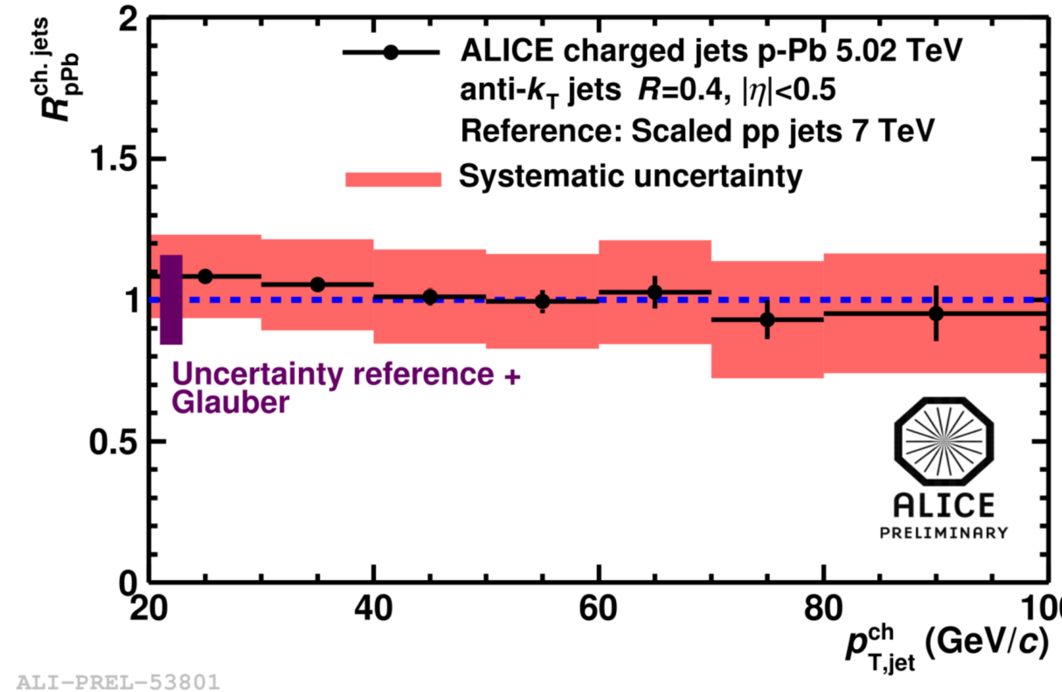


- Strong suppression in central Pb-Pb collisions is due to final-state effects (parton energy loss)
- Hadron suppression at high p_T is a reflection of jet quenching
- Nuclear modification of PDF is responsible for R_{AA} in p-Pb

PRL 110, 082302 (2013)

Jet quenching in Pb-Pb and p-Pb





Strong suppression in central Pb-Pb collisions

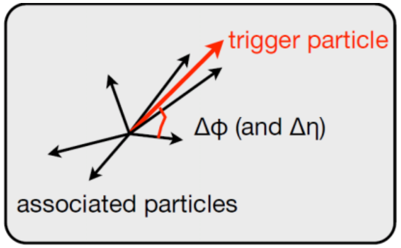
R_{pPb} = 1 for charged jets

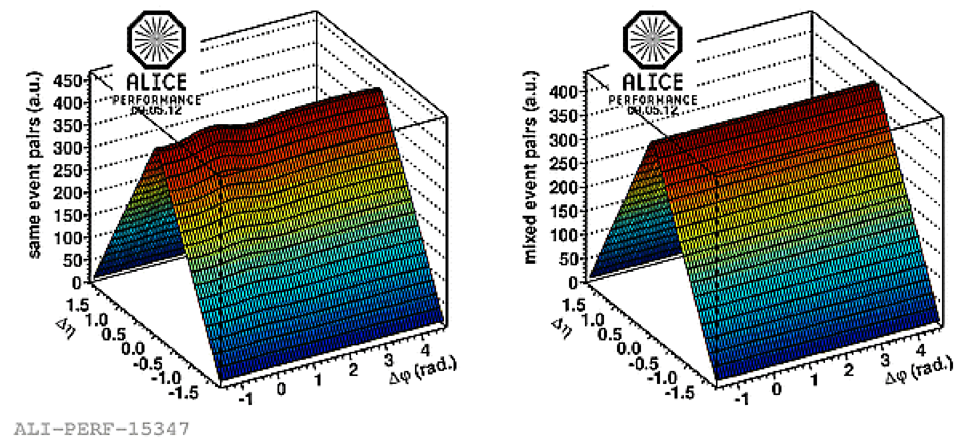
CNM have a negligible effect on the cross-section

- binary scaling holds

Correlations

Correlation functions: technique





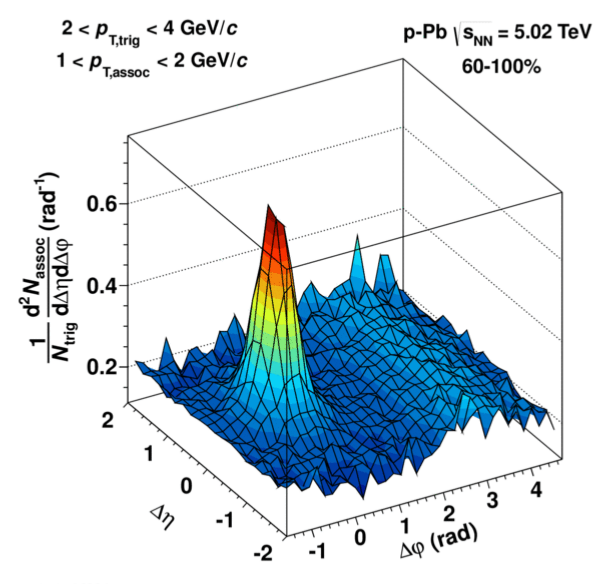
Signal (same event) pair yield

$$S(\Delta\eta, \Delta\varphi) = \frac{1}{N_{\mathrm{trig}}} \frac{\mathrm{d}^2 N_{\mathrm{same}}}{\mathrm{d}\Delta\eta\, \mathrm{d}\Delta\varphi}$$

summed over all events in event class, then divided

Background (mixed event) yield

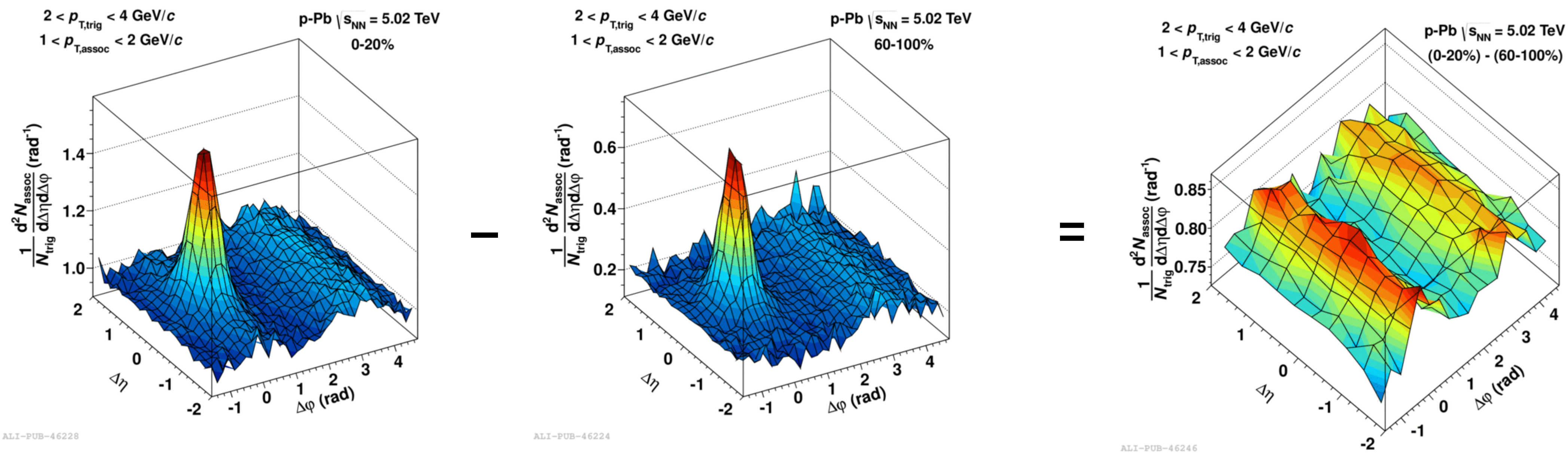
$$B(\Delta\eta, \Delta\varphi) = \frac{1}{B(0,0)} \frac{\mathrm{d}^2 N_{\mathrm{mixed}}}{\mathrm{d}\Delta\eta\, \mathrm{d}\Delta\varphi}$$



Associated yield per trigger particle

$$\frac{1}{N_{\mathrm{trig}}} \frac{\mathrm{d}^2 N_{\mathrm{assoc}}}{\mathrm{d}\Delta\eta\, \mathrm{d}\Delta\varphi} = \frac{S(\Delta\eta, \Delta\varphi)}{B(\Delta\eta, \Delta\varphi)}$$

Double ridge in p-Pb



pp and low-multiplicity p-Pb contain only jet-like correlations
- shape of jet-like correlations in all event classes is the same

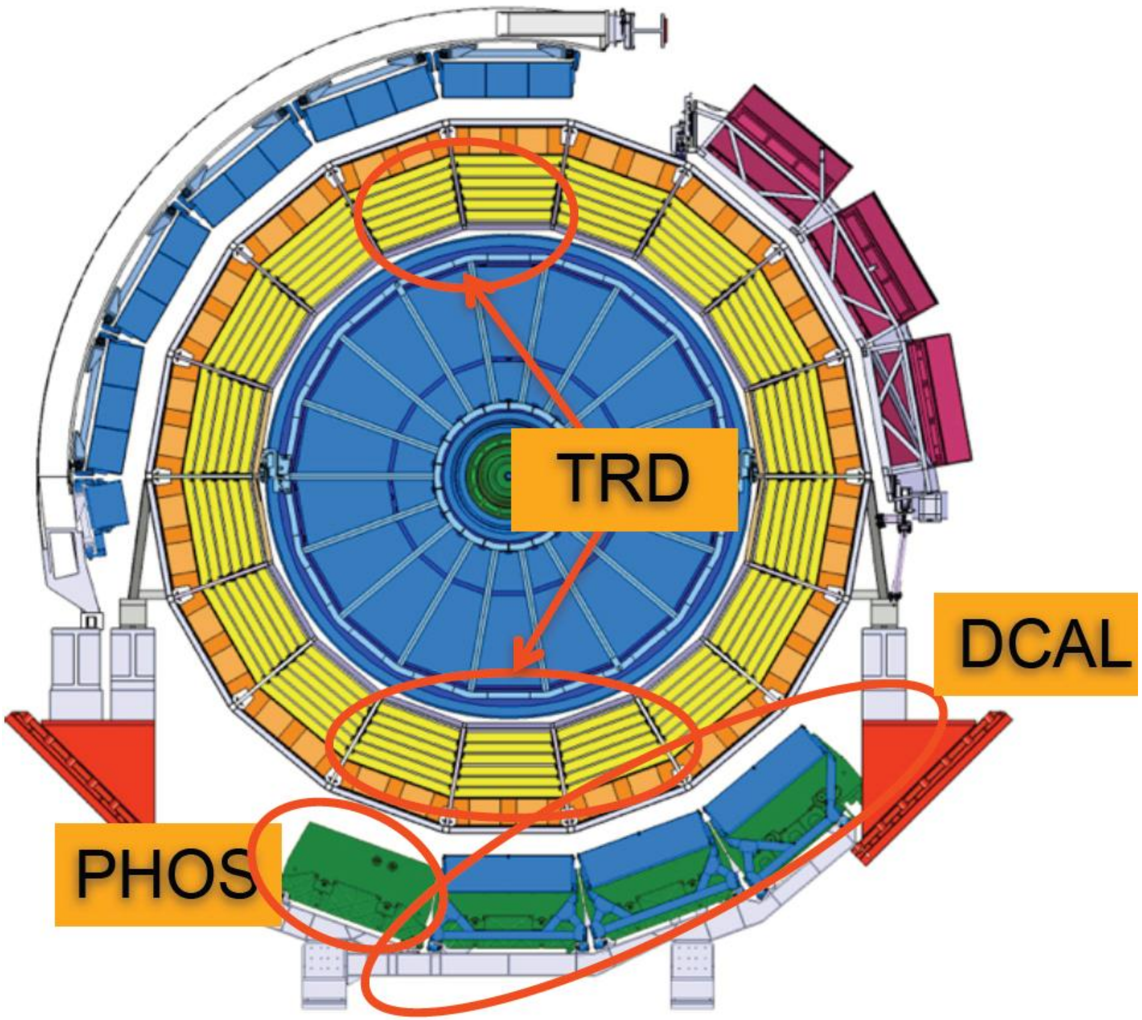
Subtraction high- minus low-multiplicity p-Pb events
- removes jet-like correlations
-reveals double ridge

Various explanations of the double ridge: from hydrodynamic flow to color-glass condensate

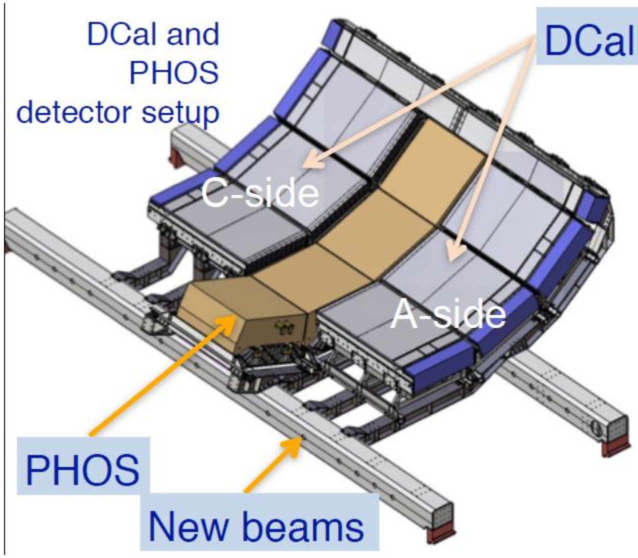
PLB 719 (2013) 29

Upgrade

LS1 progress



- Complete TRD (install 5 modules)
- Adding 1 PHOS module (4 in total)
- Installing1 CPV module
- Installing new calorimeter DCAL (8 supermodules)
- Numerous detector consolidation activity



LS2 and beyond

Physics goals:

- Detailed characterization of the QGP
- Measurement of heavy-quark transport parameters:
  - diffusion coefficient (QGP eq. of state, η/s) → RAA and azimuthal anisotropy of HF
- Measurement of low-mass and low-p_T di-electrons:
  - chiral symmetry restoration → ρ spectral function
  - γ production from QGP (temp.) → low mass di-lepton continuum
- J/ψ, ψ', and possibly χ_c states down to zero p_T
  - statistical hadronization vs. dissociation/recombination scenario
- Jets
  - Heavy-flavor tagged jets (gluon vs. quark induced jets and charm fragmentation)

Realization:

- New, high-resolution, low-material ITS
- Upgrade of TPC with replacement of MWPCs with GEMs and read-out electronics.
- New forward silicon tracker for the muon arm: MFT
- Run ALICE at collision rate 50 kHz
- Target integrated luminosity Pb-Pb: 10 nb^{-1}
- Preparations of all other detectors for readout at 50kHz (TRD, TOF, EMCAL, MCH, MTR, ZDC, V0/T0, PHOS) → "ALICE High Rate Detector Upgrade" TDR

Time scale:

- LS2 (2018-2019, 18 months)

Summary

- Complete dataset of pp, p-Pb, Pb-Pb collisions of Run1 and their classification on centrality allow one to study proterties of hot QCD matter in many details.
- Excellent PID capabilities of charged and neutral particles ensures precise studies of QCD properties vs flavor and mass.
- p-Pb and Pb-Pb data cannot be explained just by superposition of NN collisions
- Collective effects dominate in all observables at low and moderate p_T.
- Run2 and Run3 will bring ALICE to the precision level which will allow one to discriminate among the different models.