ALICE results on the production of charged particles in pp, p-Pb, Xe-Xe and Pb-Pb collisions at the LHC

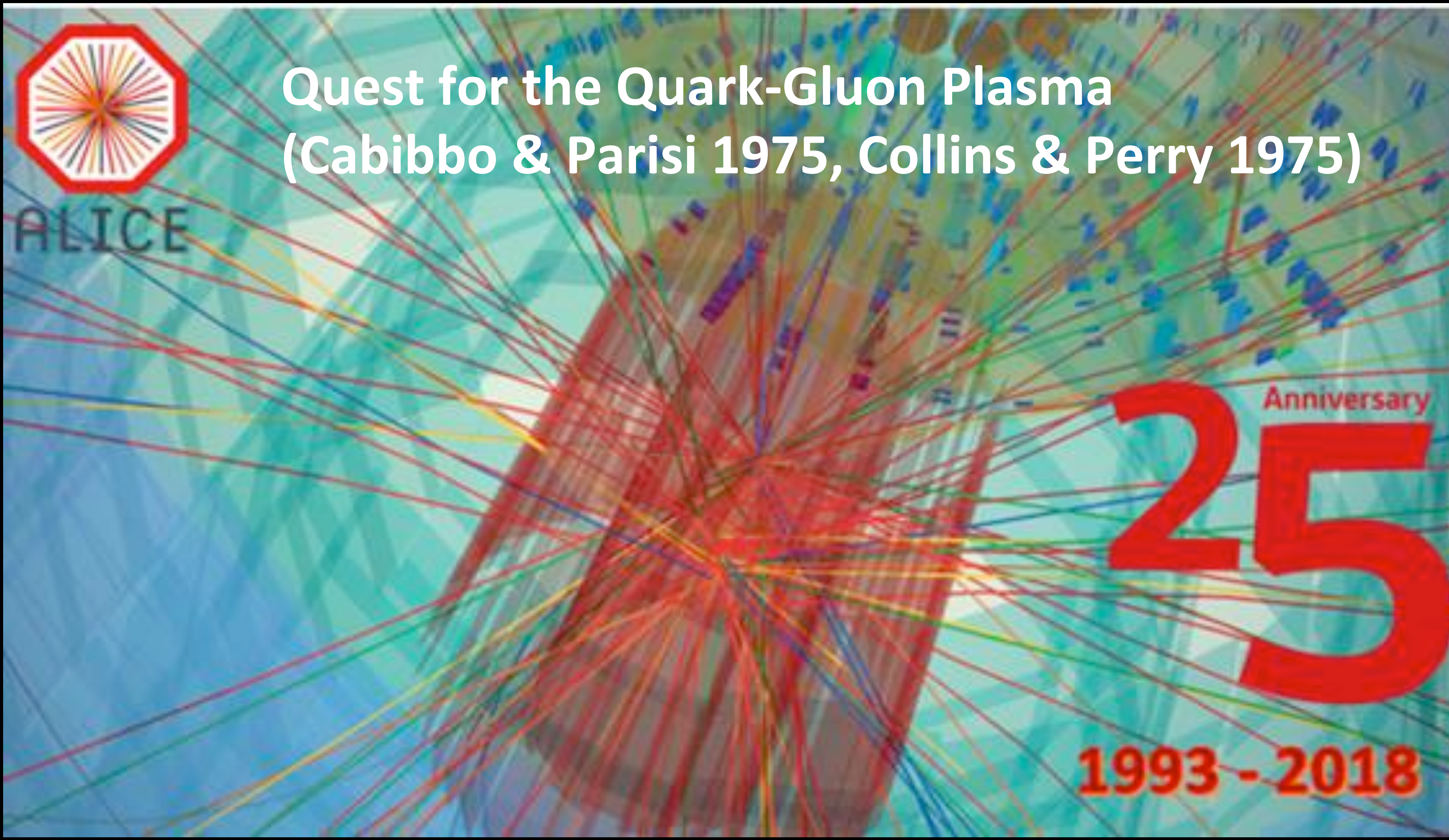
Jacek Otwinowski (IFJ PAN, Krakow)
On behalf of the ALICE Collaboration

XIV Polish Workshop on Relativistic Heavy-Ion Collisions: Interplay between soft and hard probes of heavy-ion collisions
6-7 April 2019

A Large Ion Collider Experiment
aliceinfo.cern.ch

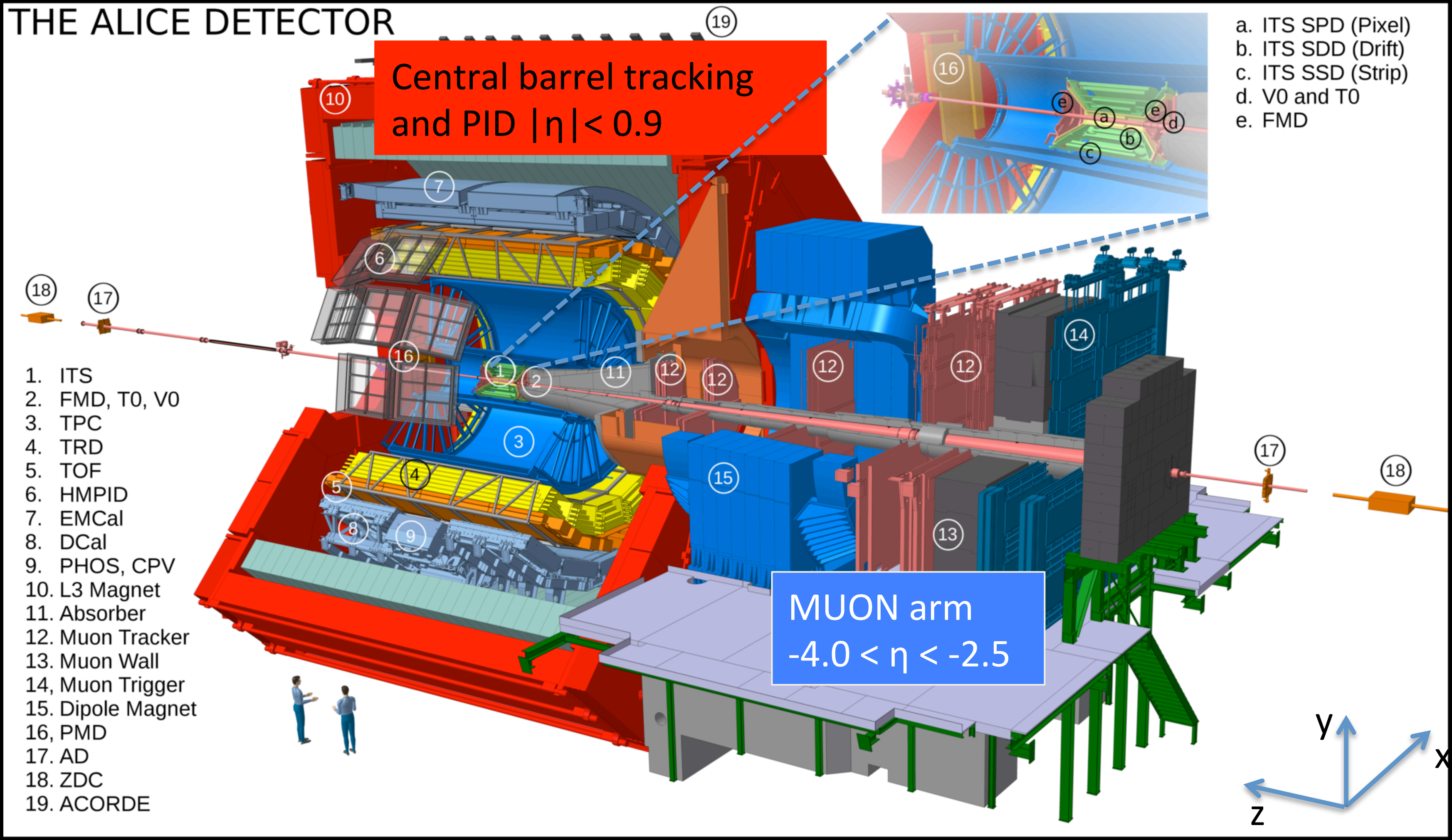
www.ifj.edu.pl

25 years of ALICE Collaboration



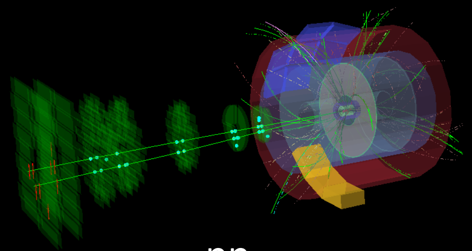
A Large Ion Collider Experiment

- Excellent particle identification capabilities in the large p_T range 0.1-20 GeV/c
- Good momentum resolution ~1-5% for p_T = 0.1-50 GeV/c

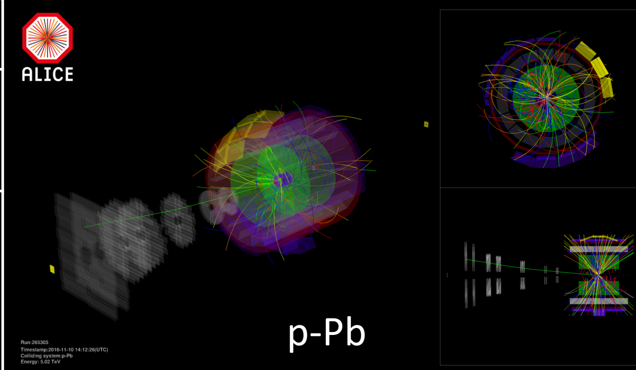


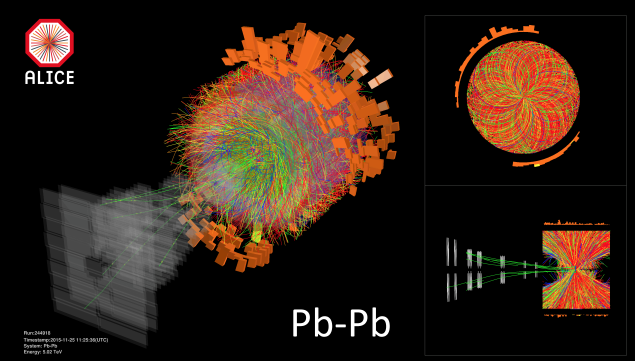
ALICE at work since 2009

System	Year	$\sqrt{s_{NN}}$ (TeV)	L_{int}
Pb-Pb	2010-2011 2015 2018	2.76 5.02 5.02	~75 μb^{-1} ~250 μb^{-1} ~0.9 nb^{-1}
Xe-Xe	2017	5.44	~0.3 μb^{-1}
p-Pb	2013 2016	5.02 5.02, 8.16	~15 nb^{-1} ~3 nb^{-1}, ~25 nb^{-1}
pp	2009-2013 2015-2018	0.9, 2.76, 7, 8 5.02, 13	~200 μb^{-1}, ~100 μb^{-1}, ~1.5 pb^{-1}, ~2.5 pb^{-1} ~1.3 pb^{-1} , ~59 pb^{-1}



pp





- Energy and system dependence studies of particle production are possible
- Large statistics of pp, p-Pb and Pb-Pb collisions at the same $\sqrt{s_{NN}}$

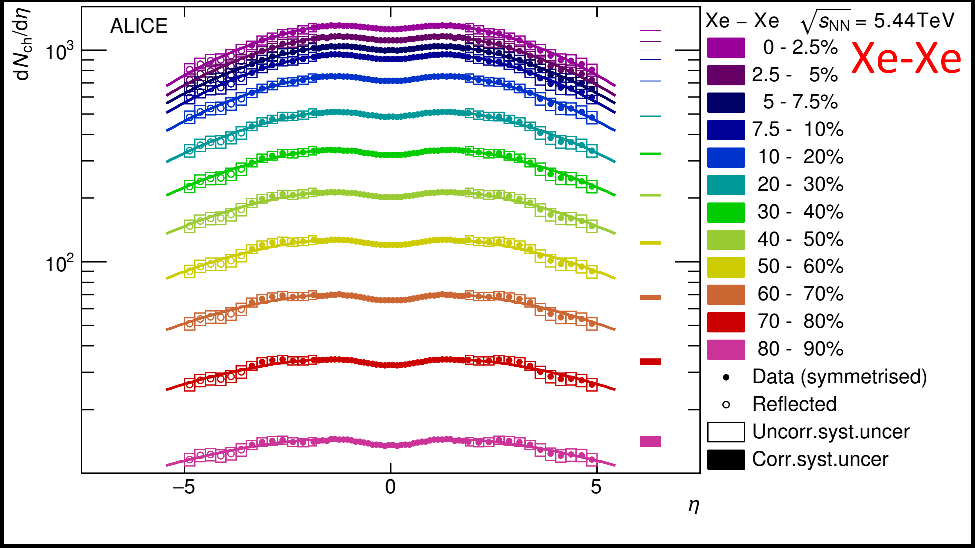
→ precise comparison studies

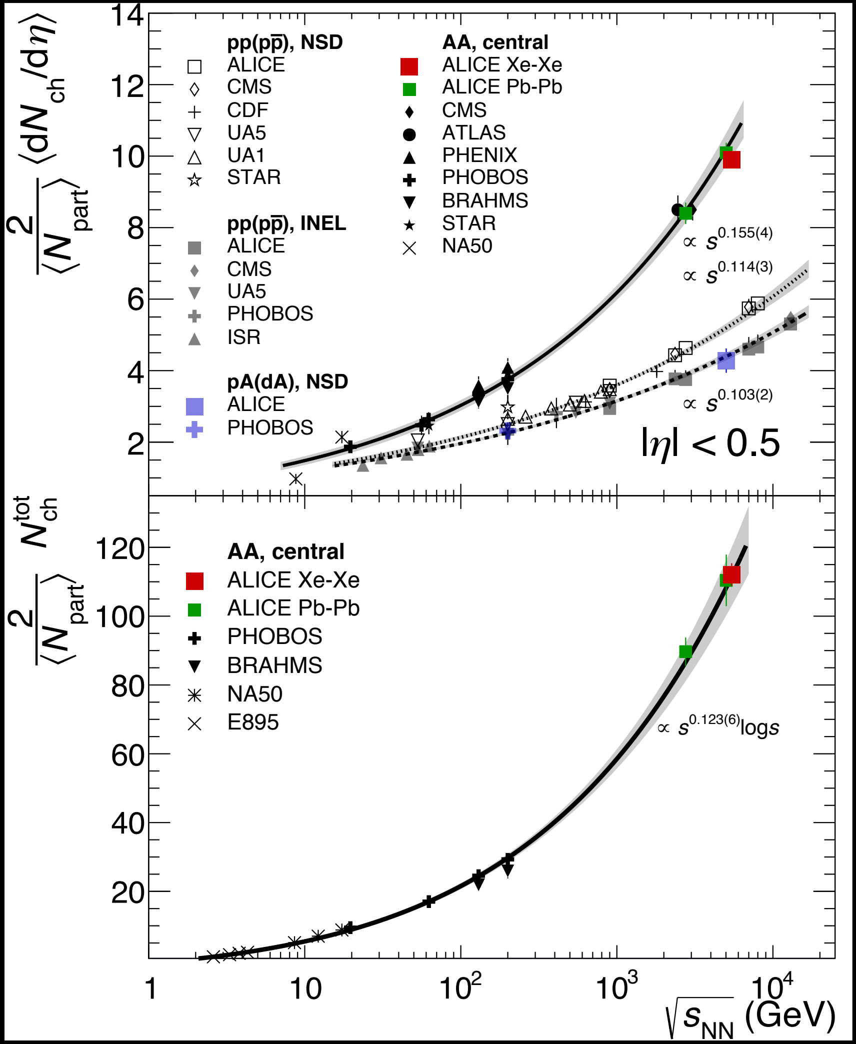
Outline

- Charged-particle multiplicity measurements in pp, p-Pb, Pb-Pb and Xe-Xe
  → Bulk matter properties
- Transverse momentum spectra and nuclear modification factors in p-Pb, Pb-Pb and Xe-Xe
  → Thermodynamic and transport properties of matter
- Outlook

Charged-particle multiplicity in pp, p-Pb, Pb-Pb and Xe-Xe

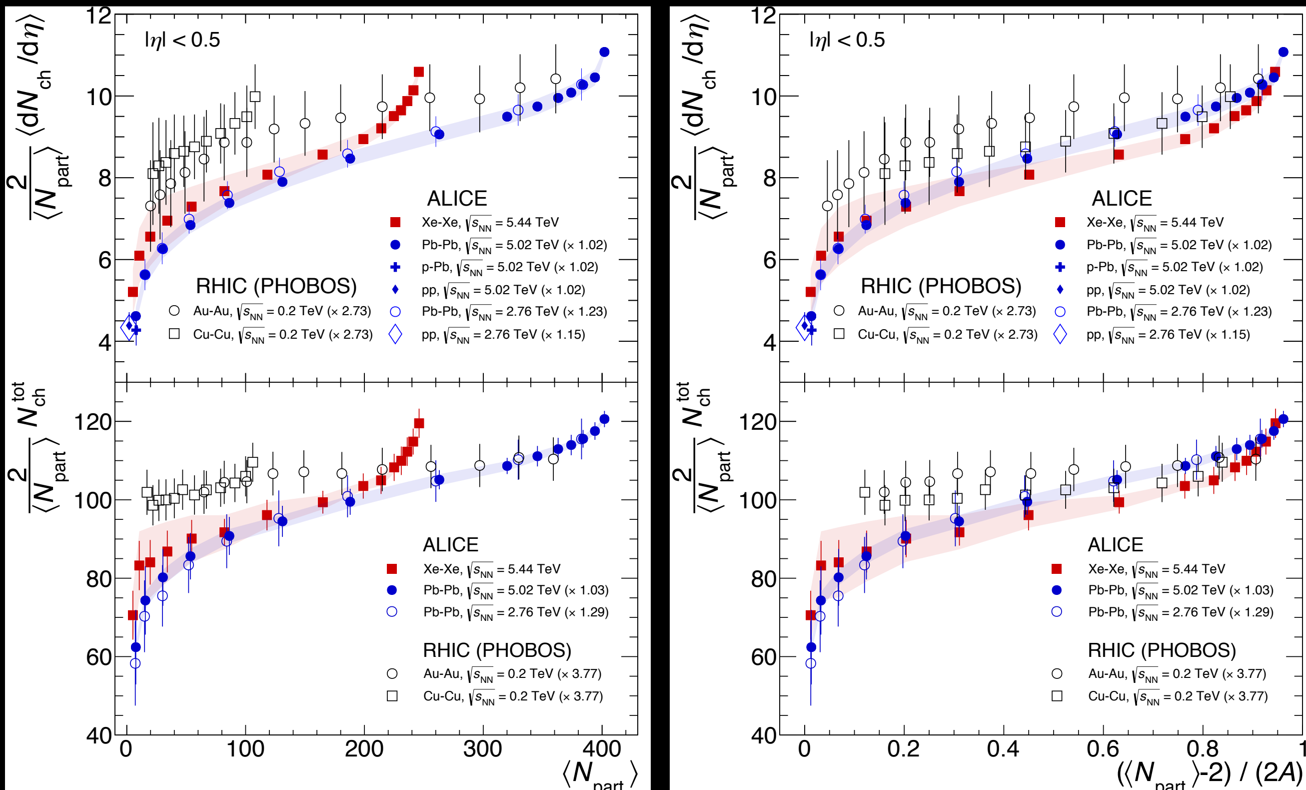
Phys. Lett. B 790 (2019) 35



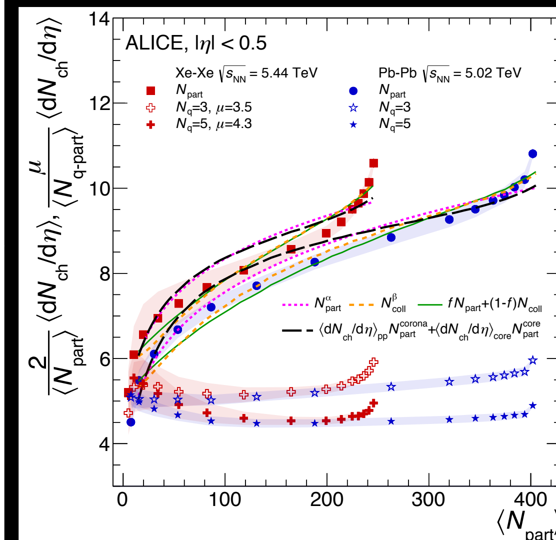


- Measurement in broad rapidity range and several centrality intervals
  - Fit assuming Gaussian shape of dN_{ch}/dy
- √s dependence in Xe-Xe similar to other AA systems and differs from pp and p-Pb
- Total charged-particle multiplicity from extrapolation to $\eta = \pm y_{beam}$

Charged-particle multiplicity vs N_{part} in pp, p-Pb, Pb-Pb and Xe-Xe



Phys. Lett. B 790 (2019) 35

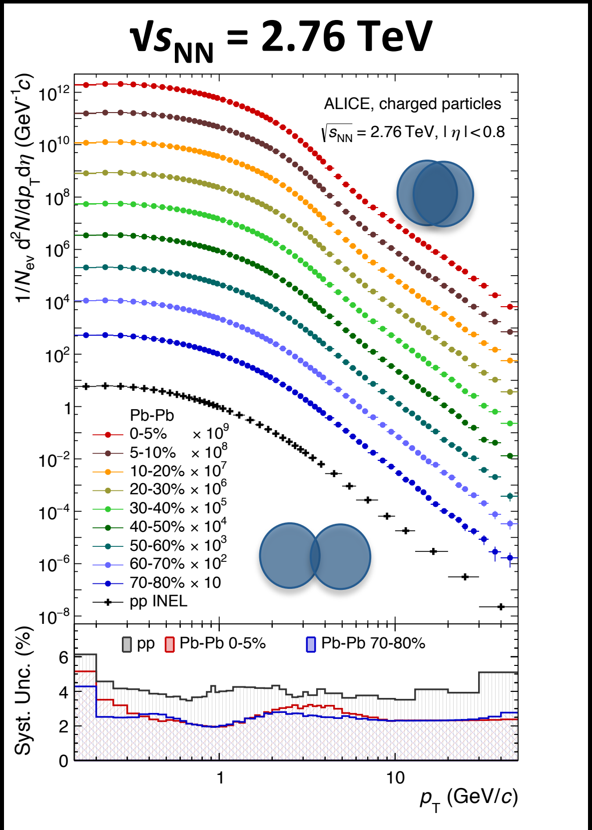


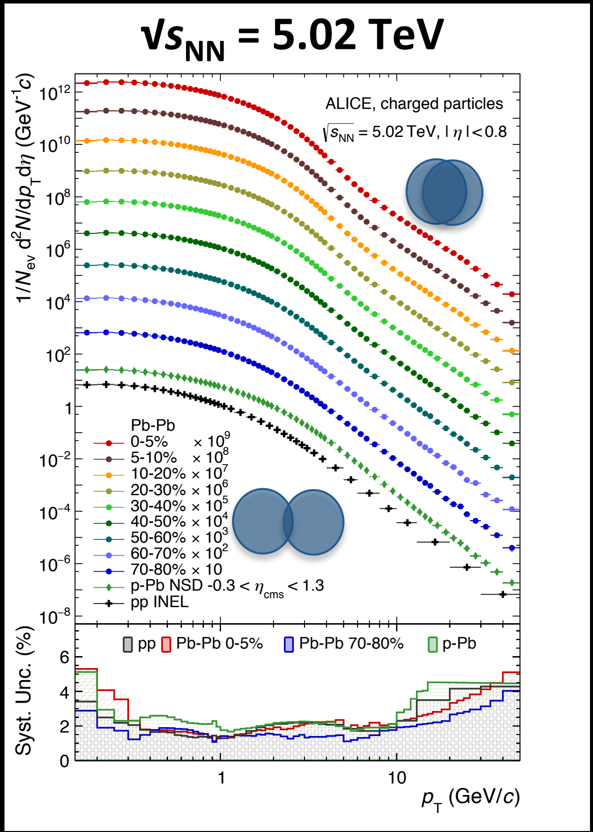
- Charge-particle multiplicity density and total multiplicity as a function of centrality
  - Deviation from N_{part} scaling (also seen at RHIC)
  - Steeper rise in most central Xe-Xe and Pb-Pb collisions
- Comparison to models shows that collision geometry plays an important role in particle production

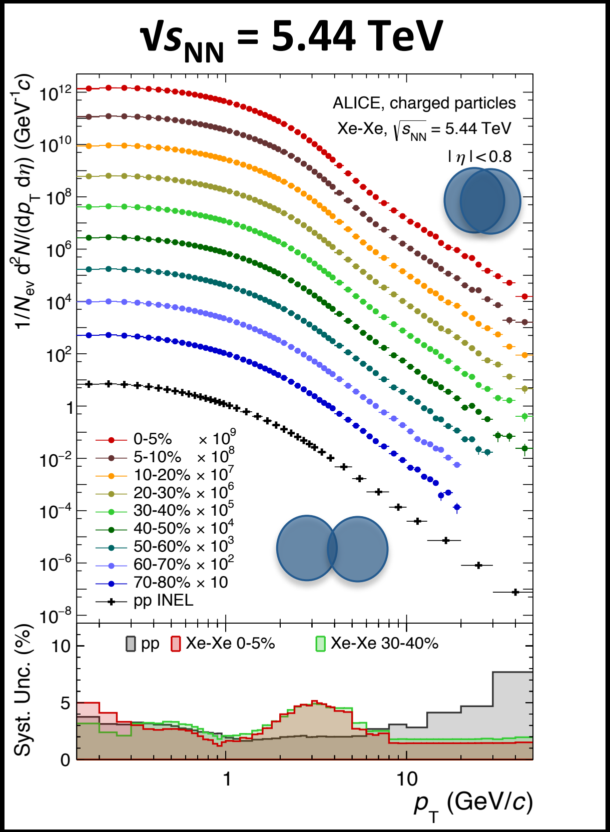
Charged-particle p_T spectra in pp, p-Pb, Pb-Pb and Xe-Xe

JHEP 1811 (2018) 013

Phys. Lett. B 788 (2019) 166





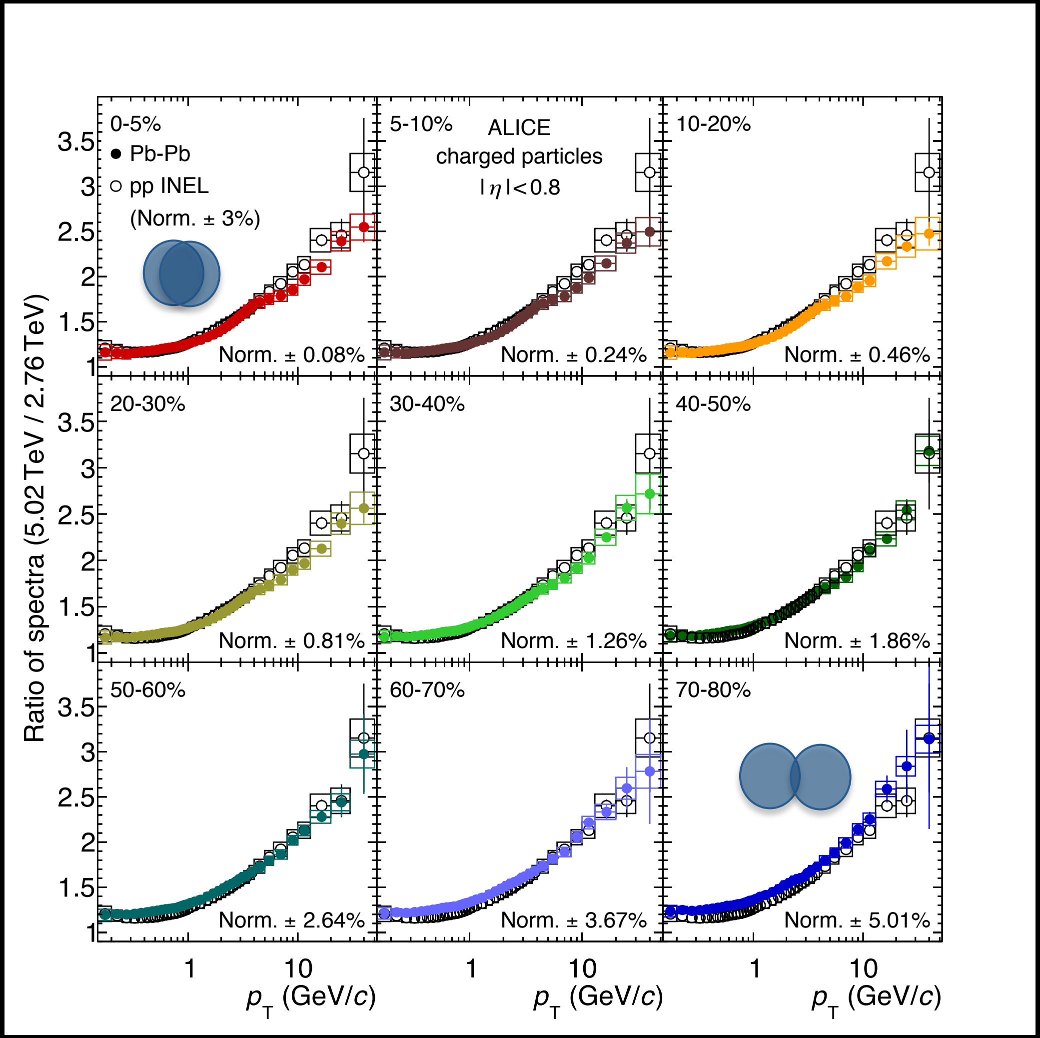


- p_T spectra in Pb-Pb and Xe-Xe measured in nine centrality intervals
- p_T reference spectra measured in pp and p-Pb collisions
- All spectra obtained using updated corrections (MC tuned on data)

PP, P-PB AND PB-PB COMPARISON

Ratios of spectra $\sqrt{s_{NN}}$ = 5.02 / 2.76 TeV

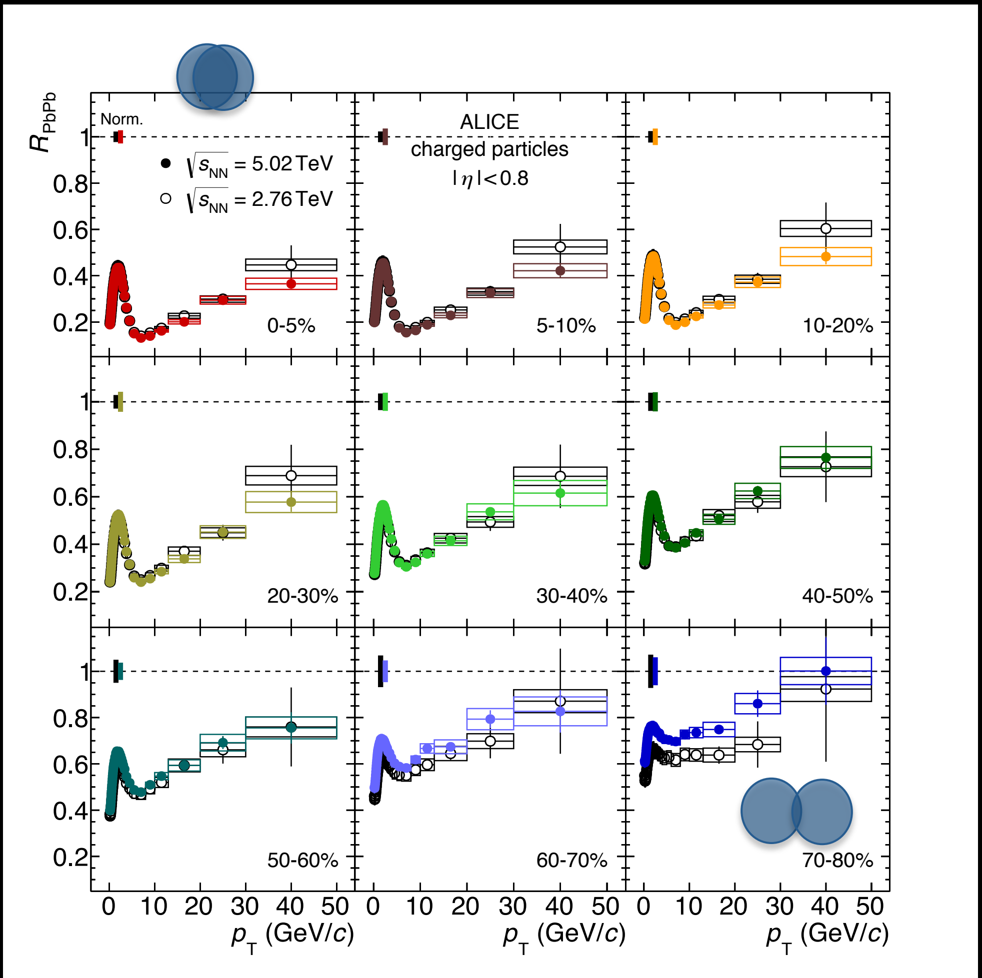
JHEP 1811 (2018) 013



- Spectra get significantly harder with collision energy
- Similar increase with energy in pp and peripheral Pb-Pb collisions
- Gradual reduction of the ratio towards central Pb-Pb collisions

Charged-particle R_{AA} at $\sqrt{s_{NN}}$ = 2.76 and 5.02 TeV

JHEP 1811 (2018) 013



$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T} \equiv \frac{[medium]}{[vacuum]}$$

Nuclear overlap function $\langle T_{AA} \rangle$ from Glauber MC

- Different suppression pattern depending on Pb-Pb collision centrality
- Maximum suppression by a factor ~7 ($6 < p_T < 7$ GeV/c) in 0-5% collisions
- No significant evolution with collision energy

→ Indication of larger parton energy loss at $\sqrt{s_{NN}}$ = 5.02 TeV

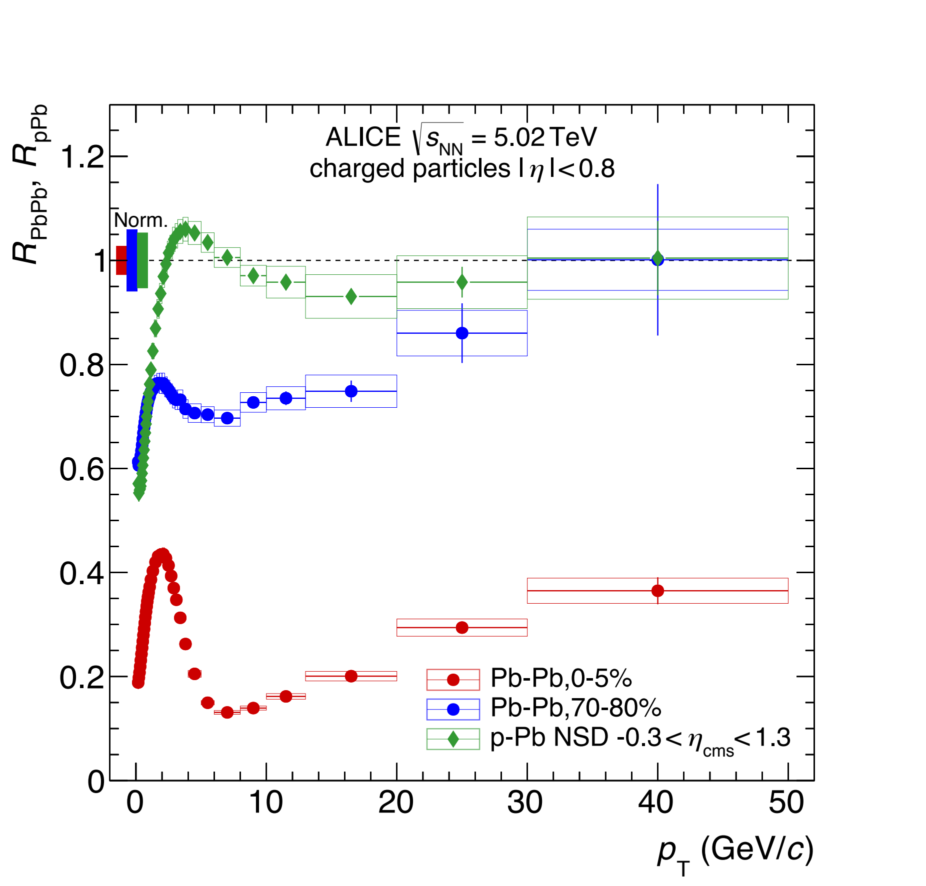
Charged-particle R_{pPb} and R_{PbPb} at $\sqrt{s_{NN}}$ = 5.02 TeV

For p_T > 7 GeV/c
- Strong suppression in central Pb-Pb collisions
- Small suppression in peripheral Pb-Pb collisions (possible due to biased centrality selection)
- No modification in p-Pb collisions (no centrality selection)

→ Suppression in central Pb-Pb collisions is due to final state effects!

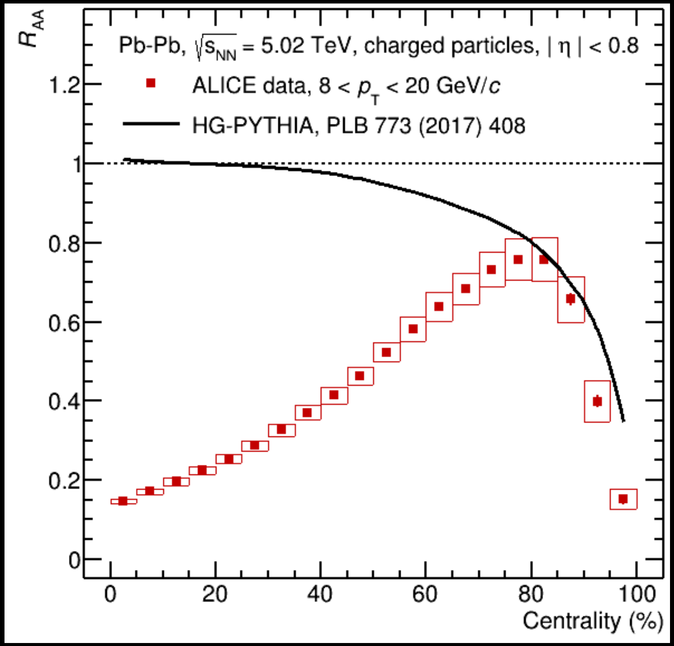
Confirmed also by jet measurements
ALICE, Phys. Lett. B749 (2015) 68

JHEP 1811 (2018) 013



Suppression in peripheral Pb-Pb collisions?

ALICE, arXiv:1805.05212



- R_{AA} average over $8 < p_T < 20$ GeV/c
- R_{AA} never reach unity

- HG-Pythia contains no nuclear effects

→ no need for jet quenching

→ centrality selection is biased by fluctuations in particle production towards smaller #MPIs

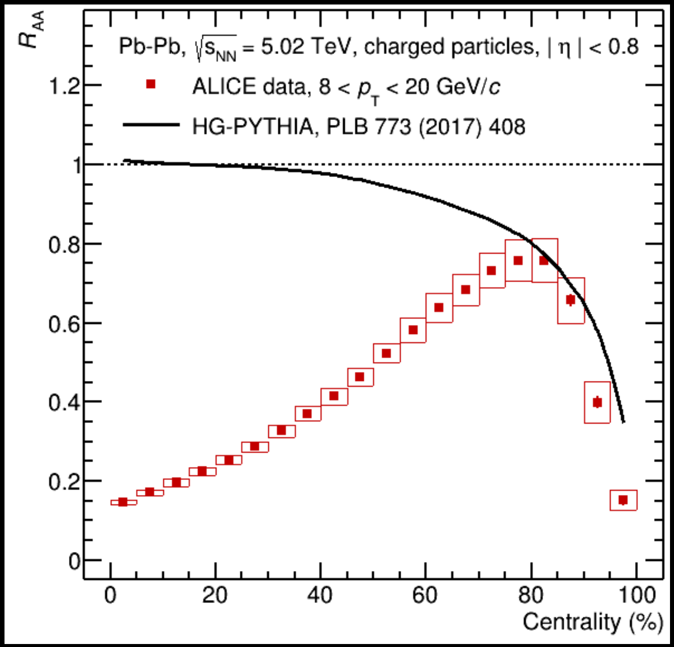
HG-Pythia model:

- incoherent superposition of Pythia pp collisions with #MPIs from HIJING-Glauber

A. Morsh & C. Loizides, PLB 773 (2017) 408

Suppression in peripheral Pb-Pb collisions?

ALICE, arXiv:1805.05212

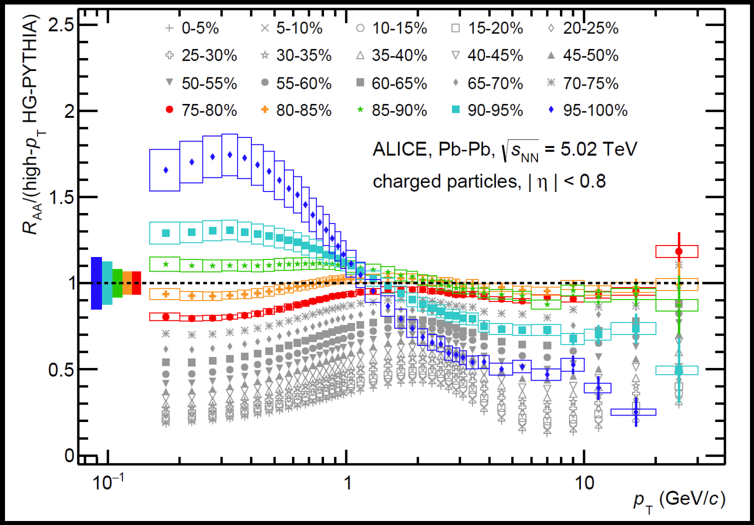


- R_{AA} average over 8 < p_T < 20 GeV/c
- R_{AA} never reach unity

- HG-Pythia contains no nuclear effects

→ no need for jet quenching

→ centrality selection is biased by fluctuations in particle production towards smaller #MPIs



HG-Pythia model:

- incoherent superposition of Pythia pp collisions with #MPIs from HIJING-Glauber

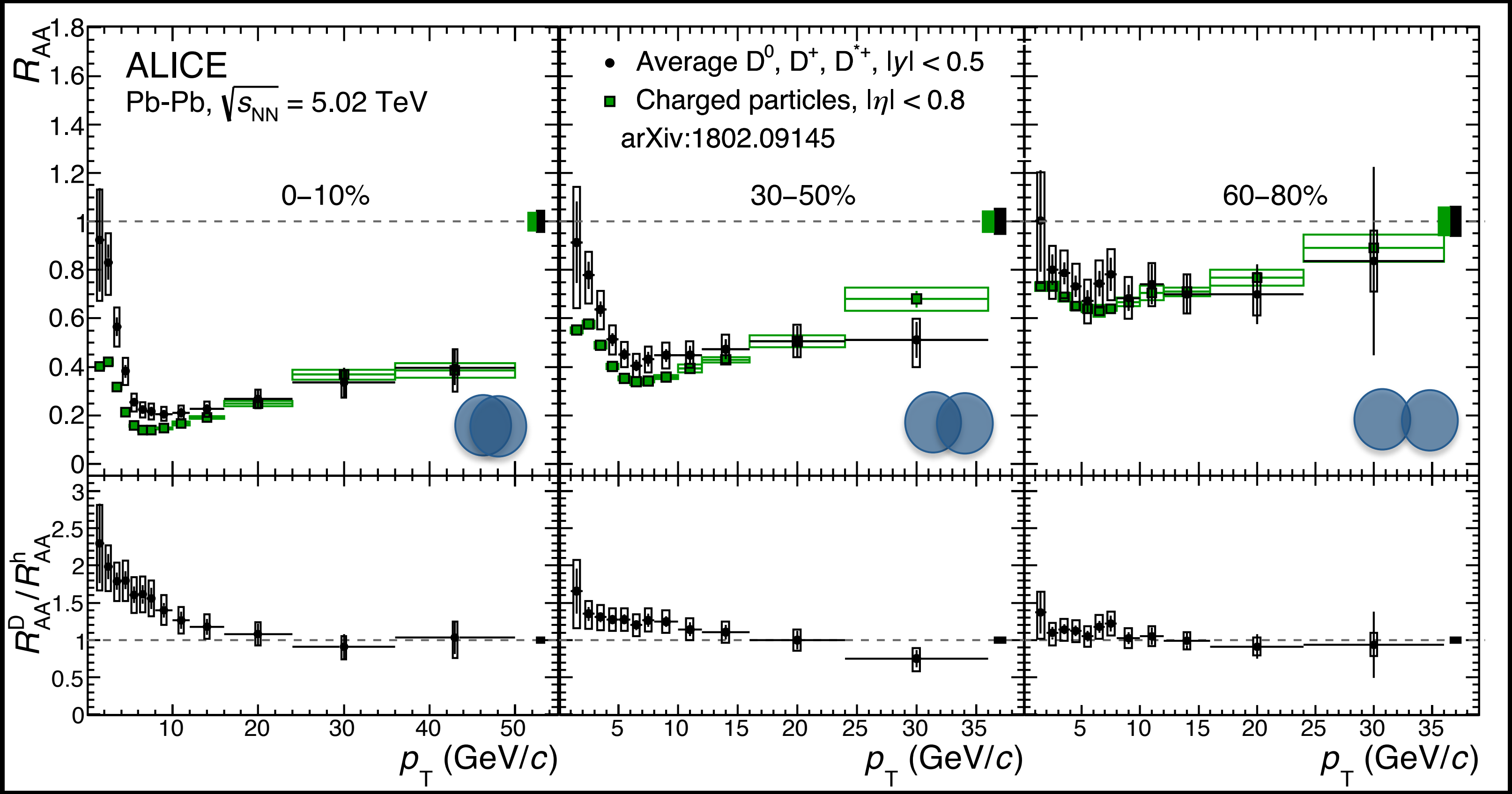
A. Morsh & C. Loizides, PLB 773 (2017) 408

R_{AA} scaled with high-p_T bias from HG-Pythia

→ Indication that R_{AA} ~ 1 for 75-90% central collisions

R_{AA} of D mesons and light hadrons in Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

JHEP10 (2018) 174

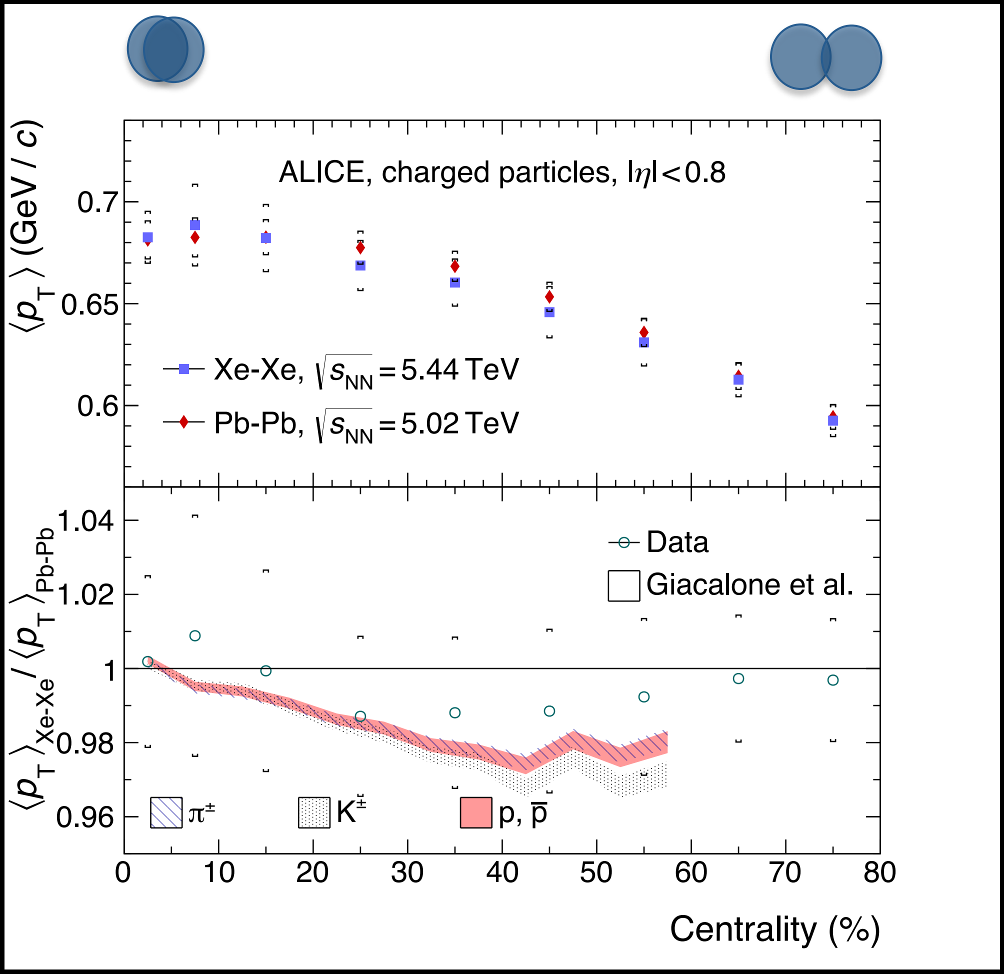


- For p_T > 10 GeV/c: the same suppression of light-flavor hadrons and D mesons in Pb-Pb collisions → similar energy loss of heavy and light partons in the QGP?
- For p_T < 10 GeV/c: smaller suppression of D mesons than light-flavor hadrons (difficult to interpret due to other effects e.g. radial flow, recombination,…)

XE-XE AND PB-PB COMPARISON

Mean p_T spectra in Xe-Xe and Pb-Pb

Phys. Lett. B 788 (2019) 166



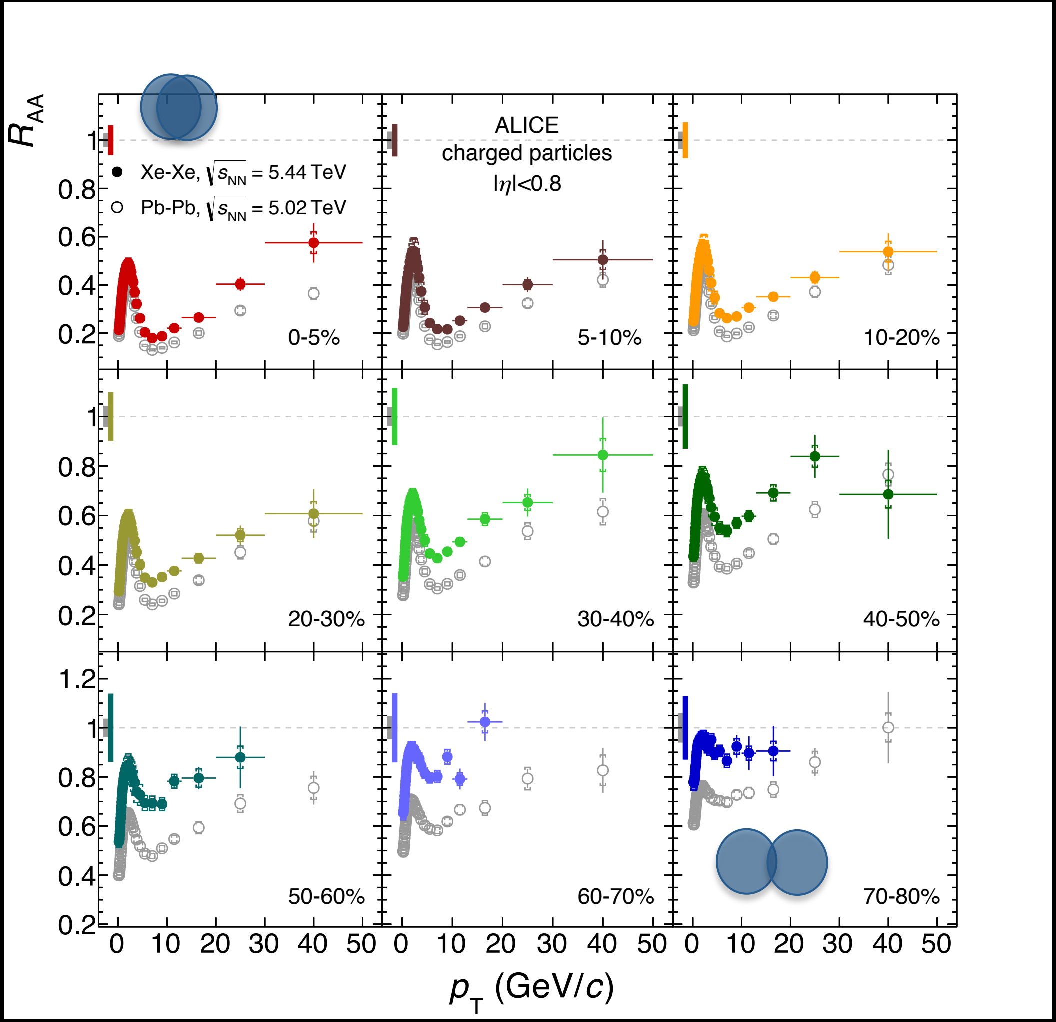
Testing system size (A) dependence

- Similar $<p_T>$ as function of centrality in Xe-Xe and Pb-Pb collisions
- $<p_T>$ increases with centrality due to radial flow
- Predictions by Giacalone et al. [Phys. Rev. C 97, 034904 (2018)] describes trend in the data
  - Event-by-event simulations: T_RENTo initial condition + viscous hydro

→ Strong constraints on the hydrodynamic evolution of the system

Charged-particle R_{AA} in Pb-Pb and Xe-Xe

Phys. Lett. B 788 (2019) 166

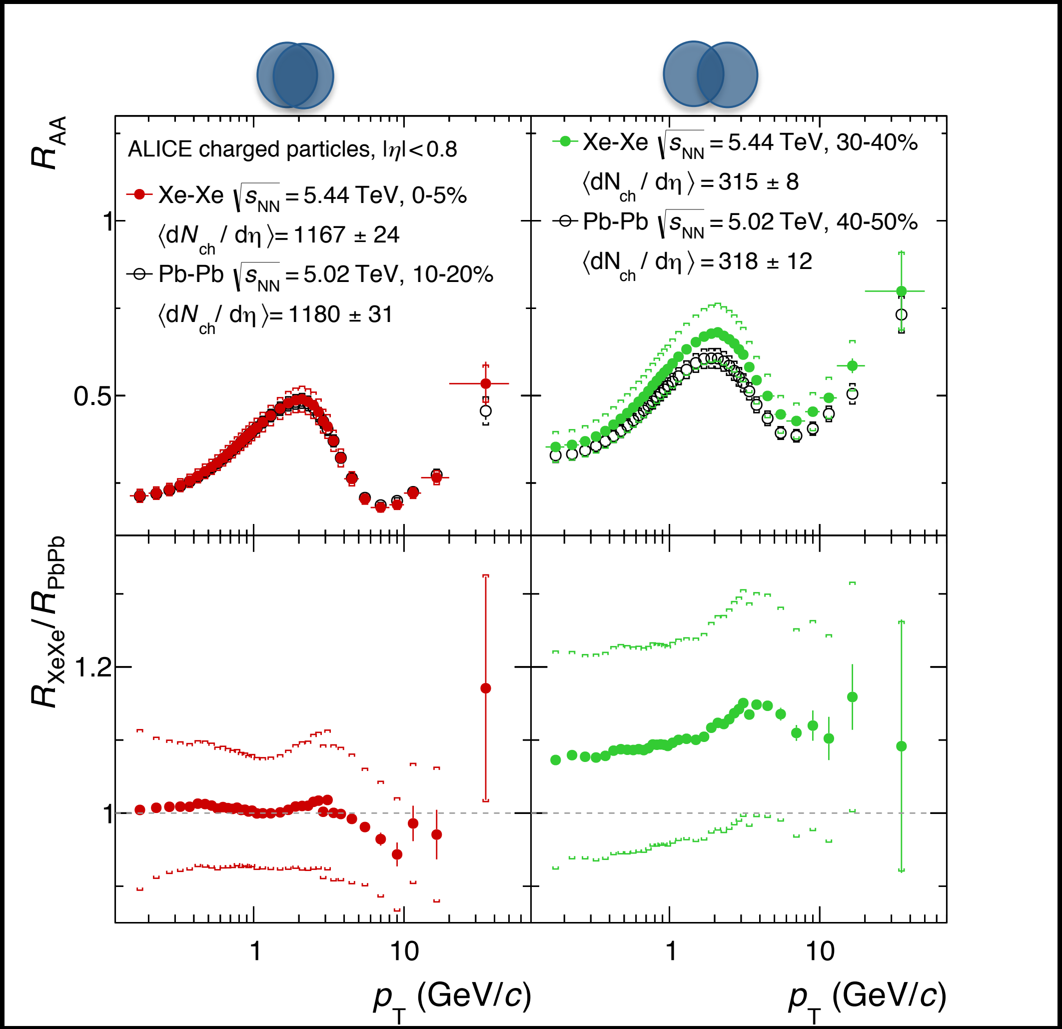


- Similar suppression pattern in Xe-Xe and Pb-Pb
- Larger suppression in Pb-Pb than in Xe-Xe collisions at high p_T at the same centrality
- Normalization uncertainty (T_{AA} and pp norm.) are much larger for Xe-Xe
  - less precisely known nuclear-charge-density distribution of deformed ^{129}Xe nucleus

→ Result of interplay between geometry and path length dependence of parton energy loss

Charged-particle R_{AA} in Xe-Xe and Pb-Pb

Phys. Lett. B 788 (2019) 166

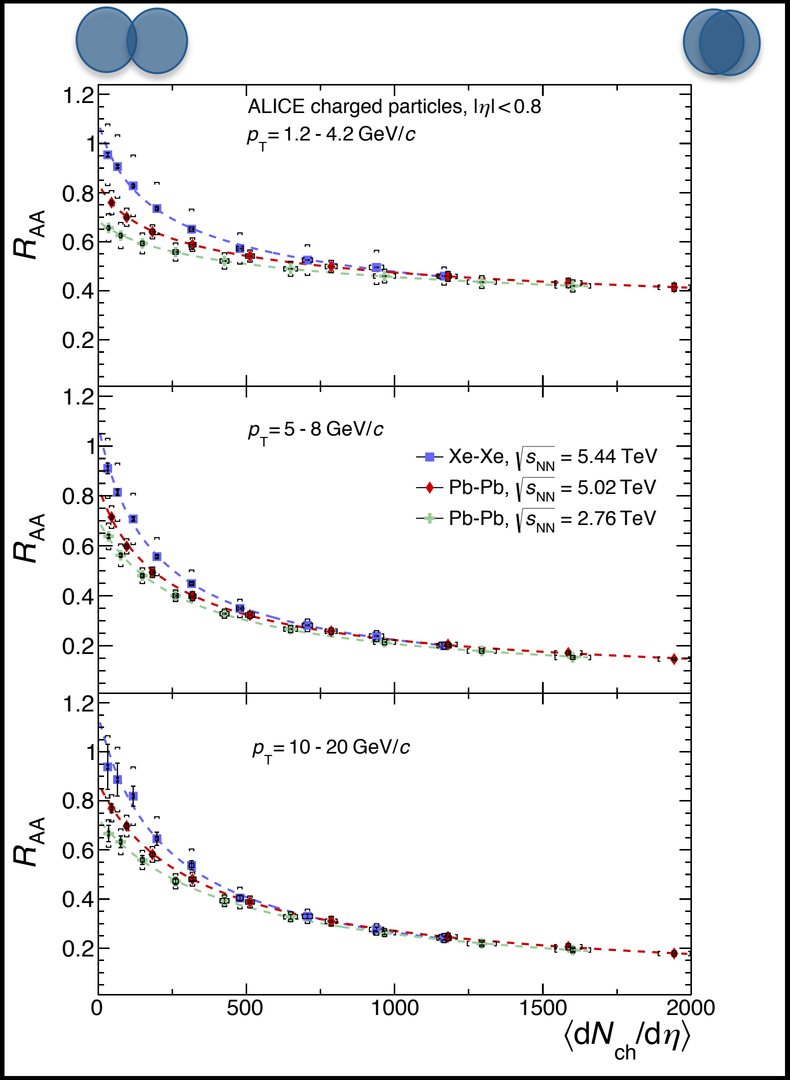


- Similar R_{AA} in central Xe-Xe and Pb-Pb collisions at similar multiplicity
- Different R_{AA} in more peripheral collisions

→ Result of interplay between geometry and path length dependence of parton energy loss

Charged-particle R_{AA} vs $dN_{ch}/d\eta$ in Xe-Xe and Pb-Pb

Phys. Lett. B 788 (2019) 166



- A remarkable similarity is found for all p_T ranges for $\langle dN_{ch}/d\eta\rangle > 400$
- Dashed lines are fits to the spectra

→ Result of interplay between geometry and path length dependence of parton energy loss

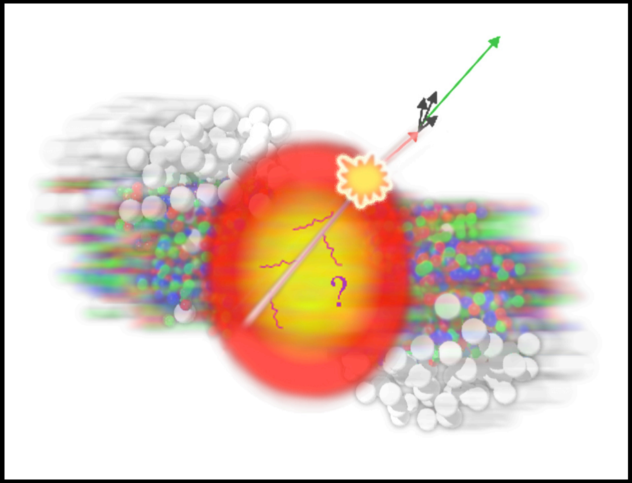
Outlook

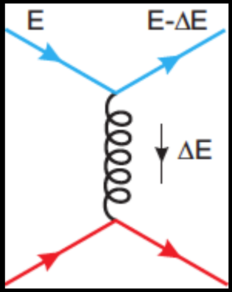
- Bulk matter properties
  - Deviation from N_{part} scaling at the LHC
  - The collision geometry plays an important role in particle production
  - The underlying mechanism to describe the increase of N_{ch} as function of N_{part} and $\sqrt{s}$ is still unknown

- p_T spectra and nuclear modification factors
  - Indication of larger energy loss at higher collision energy
  - Suppression in central Pb-Pb collisions is due to final state effects
  - Onset of suppression in peripheral Pb-Pb collisions is due to biases in centrality selection
  - Similar suppression is observed in central Pb-Pb and Xe-Xe at the same multiplicity, but smaller in Xe-Xe for more peripheral events
  - No mass dependence of parton energy loss at high p_T?

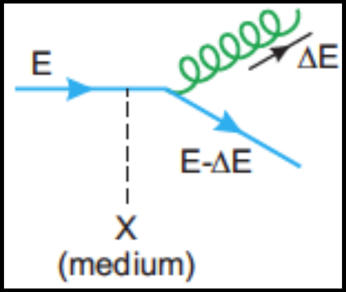
Backup

Parton energy loss and jet quenching





collisional



radiative

Radiative and collisional parton energy loss:

$\Delta E = \Delta E_{coll} + \Delta E_{rad}$, $\Delta E\,(E, m, C_R; \rho_g, \alpha_s, T, L)$

D. d'Enterria, arXiv:0902.2011

Radiative energy loss dominate at high-p_T:

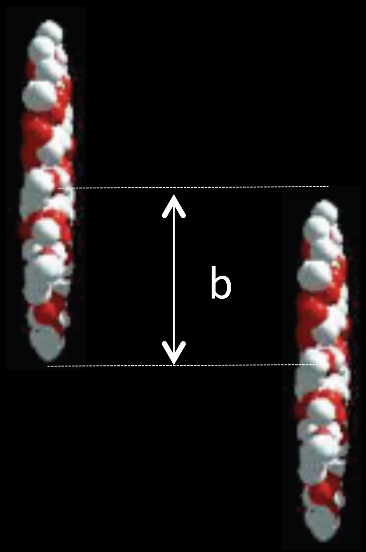
- Color charge dependence C_R: $C_{R,g} > C_{R,q,Q}$
  → $\Delta E_g > \Delta E_{q,Q}$
- Mass dependence "dead cone": gluon radiation suppression at $\Theta < m_Q/E$
  → $\Delta E_q > \Delta E_Q$
  L. Dokshitzer & D.E. Kharzeev, PLB 519 (2001) 199

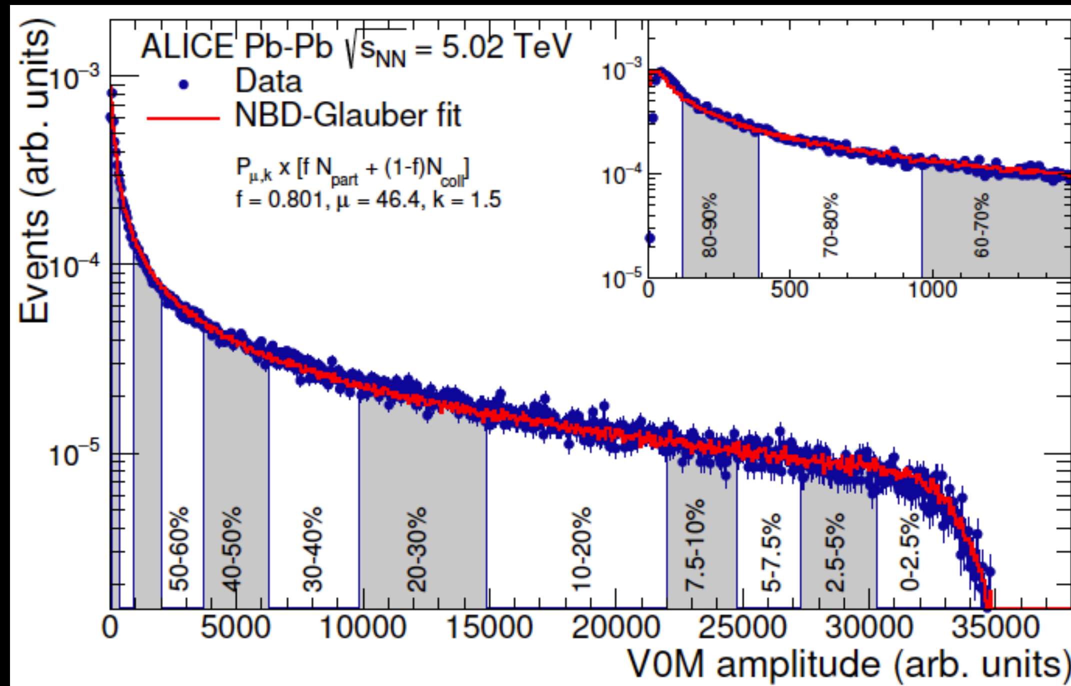
- In static medium: $\Delta E_{coll} \sim L$, $\Delta E_{rad} \sim L^2$
- Characterize medium transport properties via parton energy loss

$$\hat{q} \equiv \frac{m_D^2}{\lambda} = m_D^2 \rho \sigma$$

Event Centrality Selection

ALICE-PUBLIC-2018-011

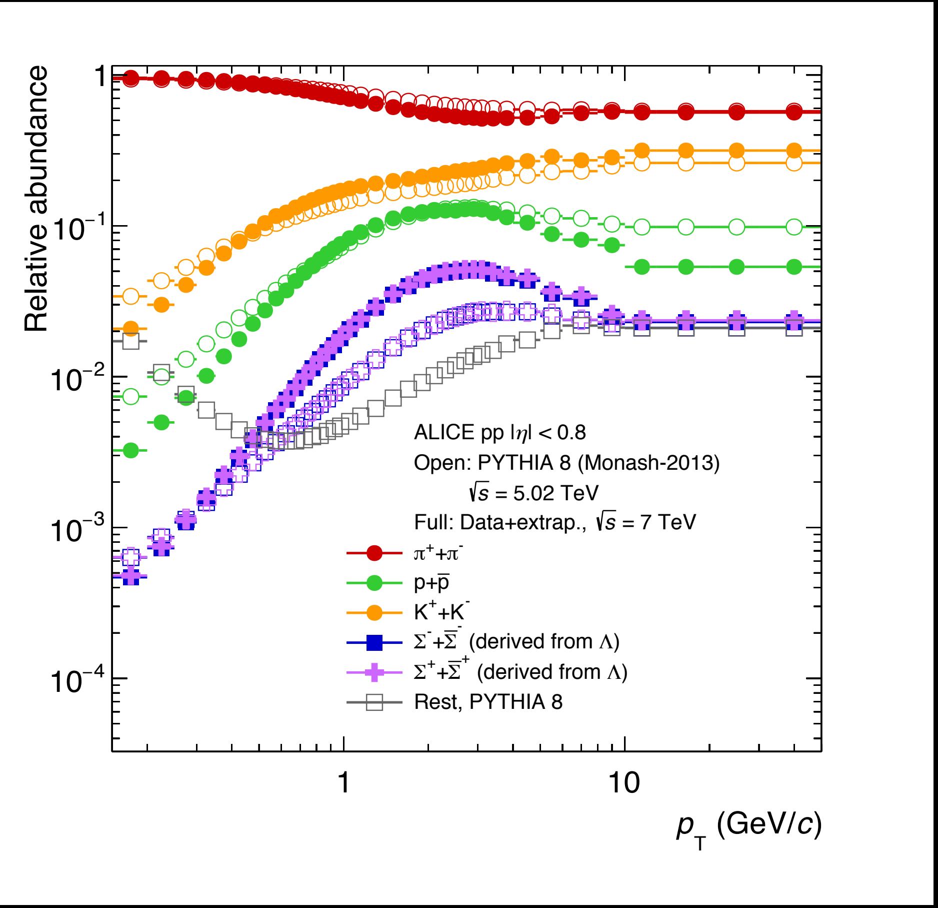




- Correlate particle multiplicity with collision geometry i.e. impact parameter, volume and shape (A. Białas et al. APPB 8 (1977) 389)
- N_{coll}, N_{part} and $T_{AA} = N_{coll} / \sigma^{NN}_{INEL}$ values determined by fitting NBD-Glauber coupled to two parameter model

Relative Particle Abundance

ALICE, arXiv:1802.09145

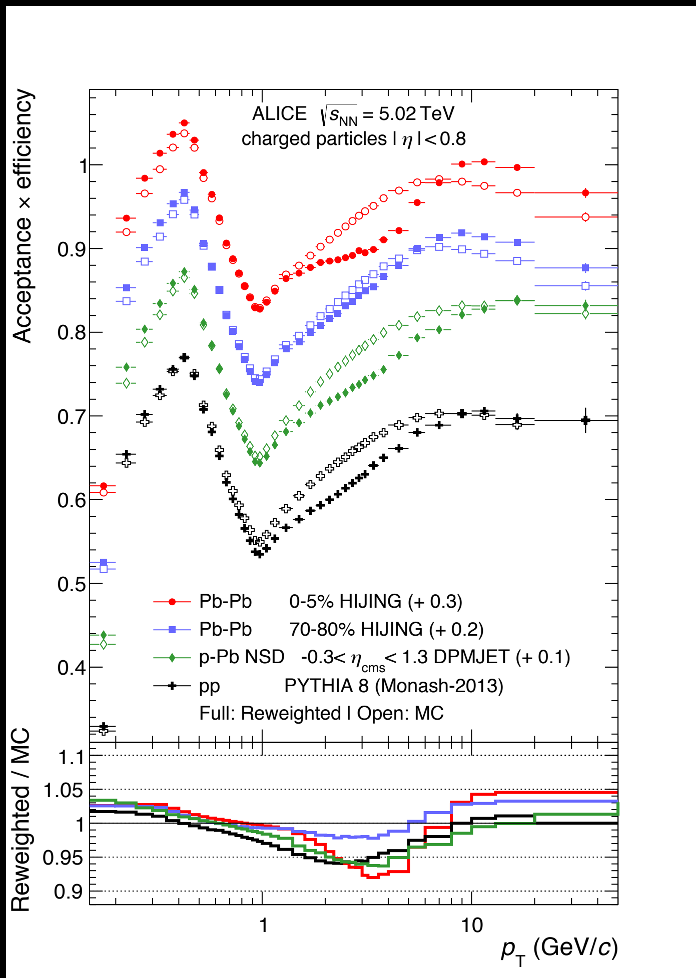


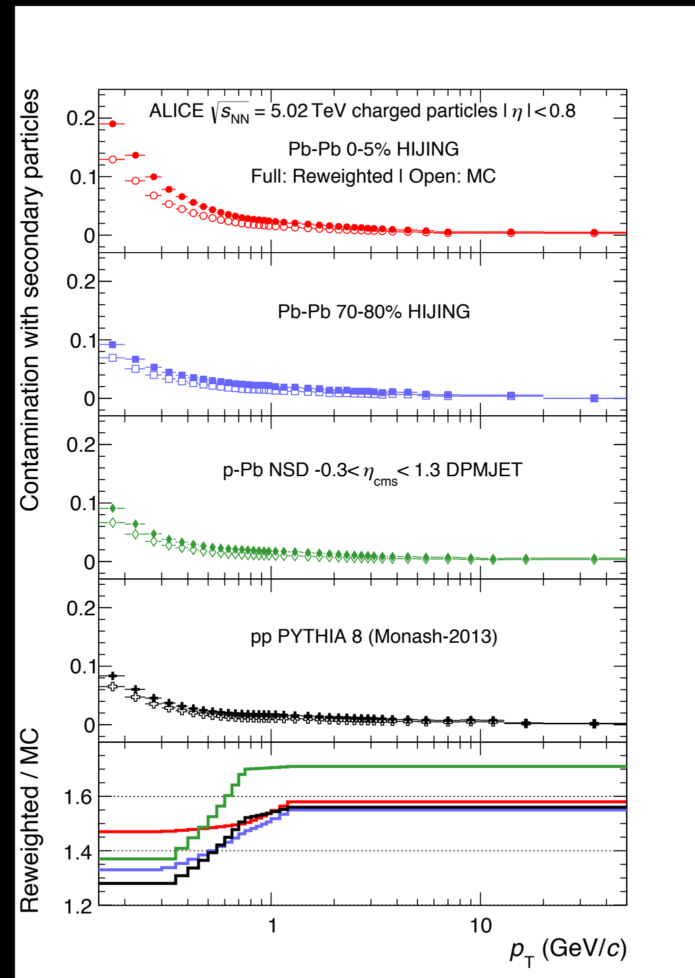
Relative particle abundance is not properly calculated in MC generators

Influences corrections to the spectra

Improvements to the p_T spectra analysis

ALICE, arXiv:1802.09145

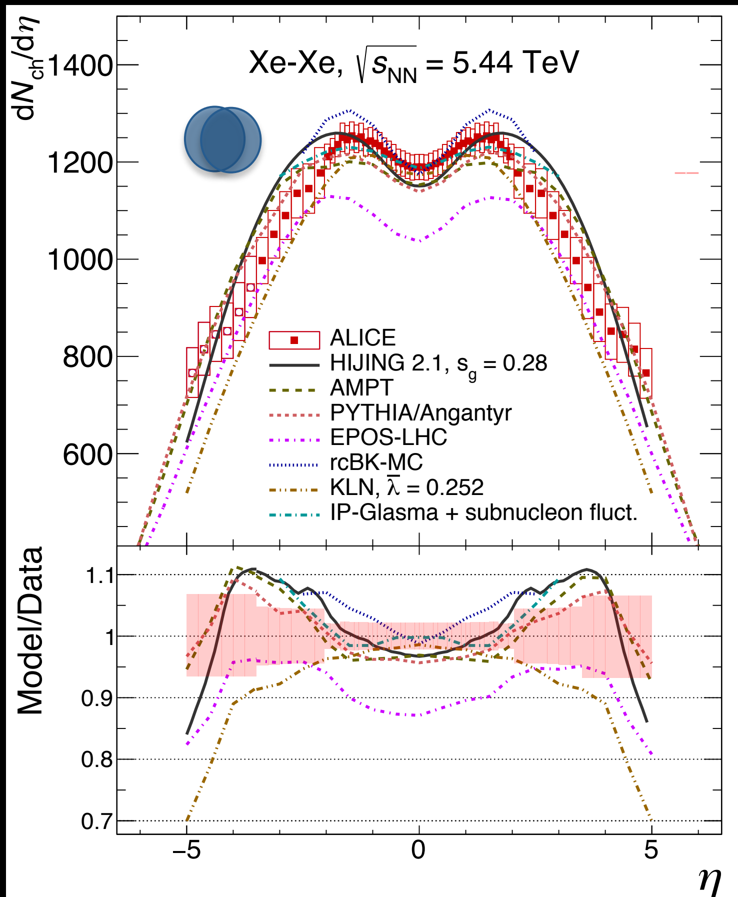


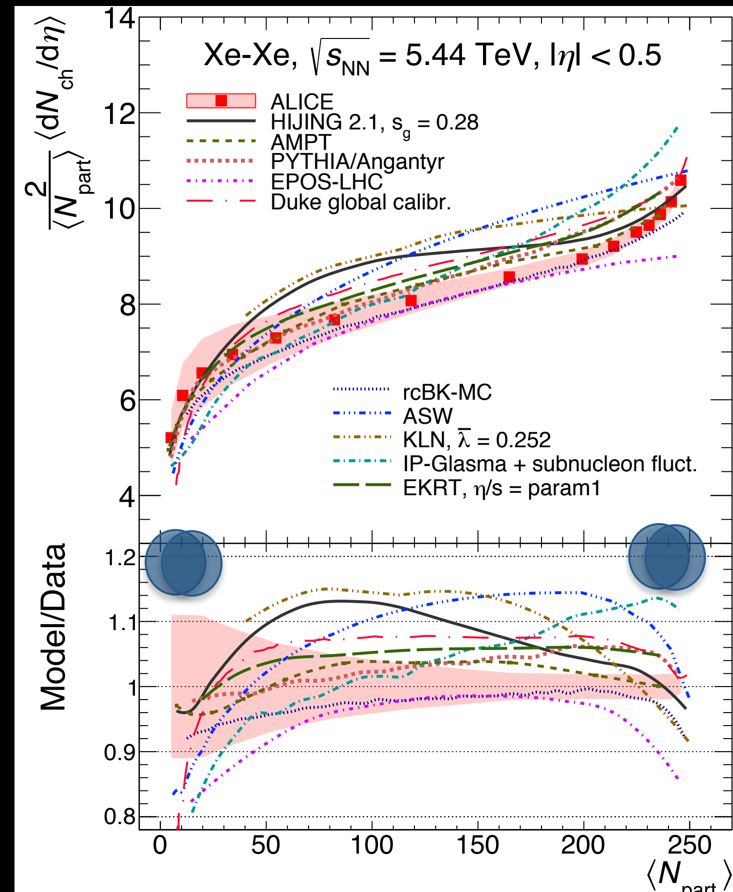


- Improved efficiency and contamination corrections based on measured particle species
  → Reduced systematic uncertainties by a factor of 2 as compared to previous analyses

Charged-particle multiplicity vs models in Xe-Xe

Phys. Lett. B 790 (2019) 35

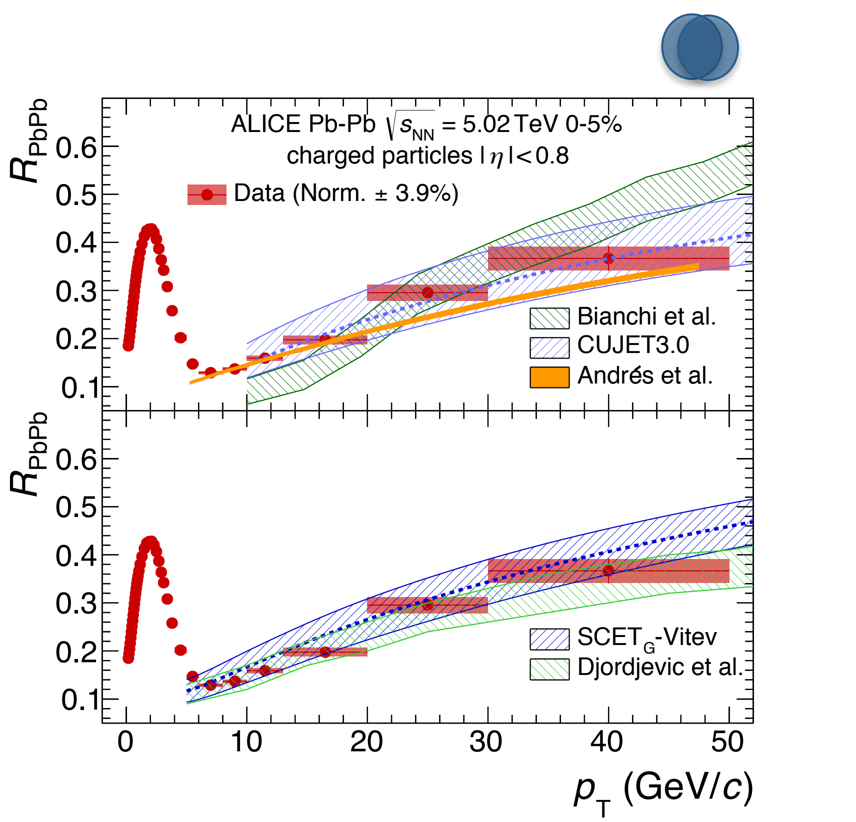




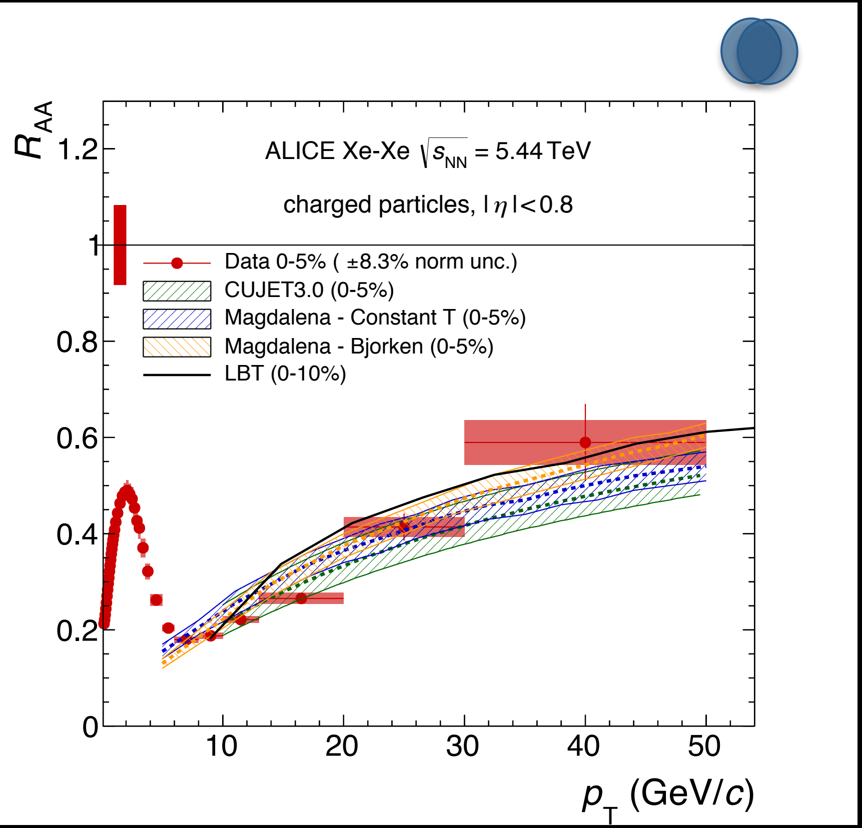
- Models do not describe charged-particle production in the whole rapidity range
- N_{part} dependence is best described by rcBK-MC: CGC saturation model based on Balitsky-Kovchegov gluon evolution equation

Charged-particle R_{AA} vs models in Pb-Pb and Xe-Xe

JHEP 1811 (2018) 013



Phys. Lett. B 788 (2019) 166



Models:

- All models include radiative energy loss
- CUJET3.0 and Magdalena Djordjevic models also include elastic energy loss
- Calculations are performed in dynamically expanding medium except that of Vitev et al.