HARD PROBES 2018

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

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On behalf of the ALICE Collaboration

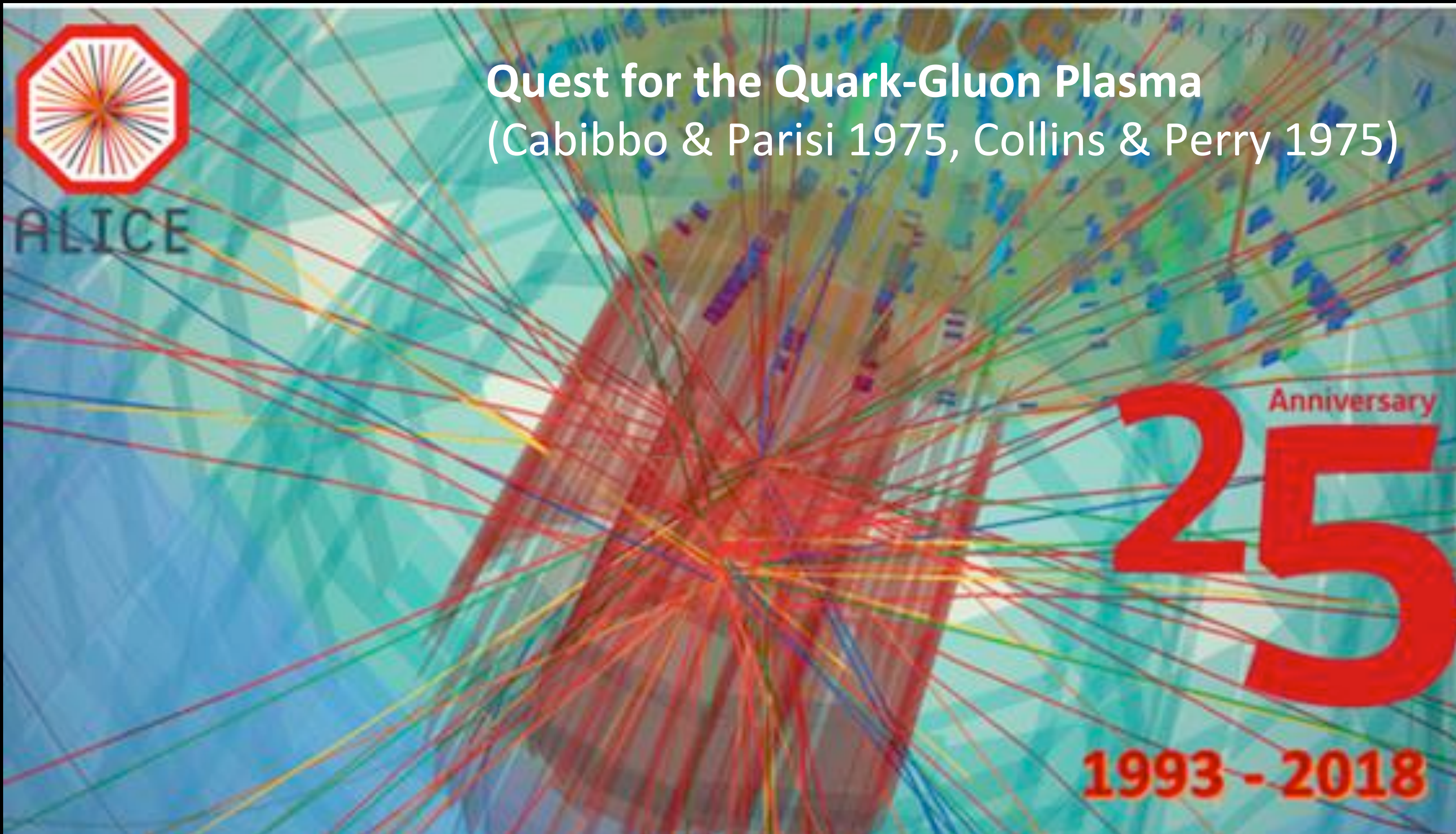
Hard Probes 2018, Aix-Les-Bains, Savoie, France

ALICE

A Large Ion Collider Experiment
aliceinfo.cern.ch

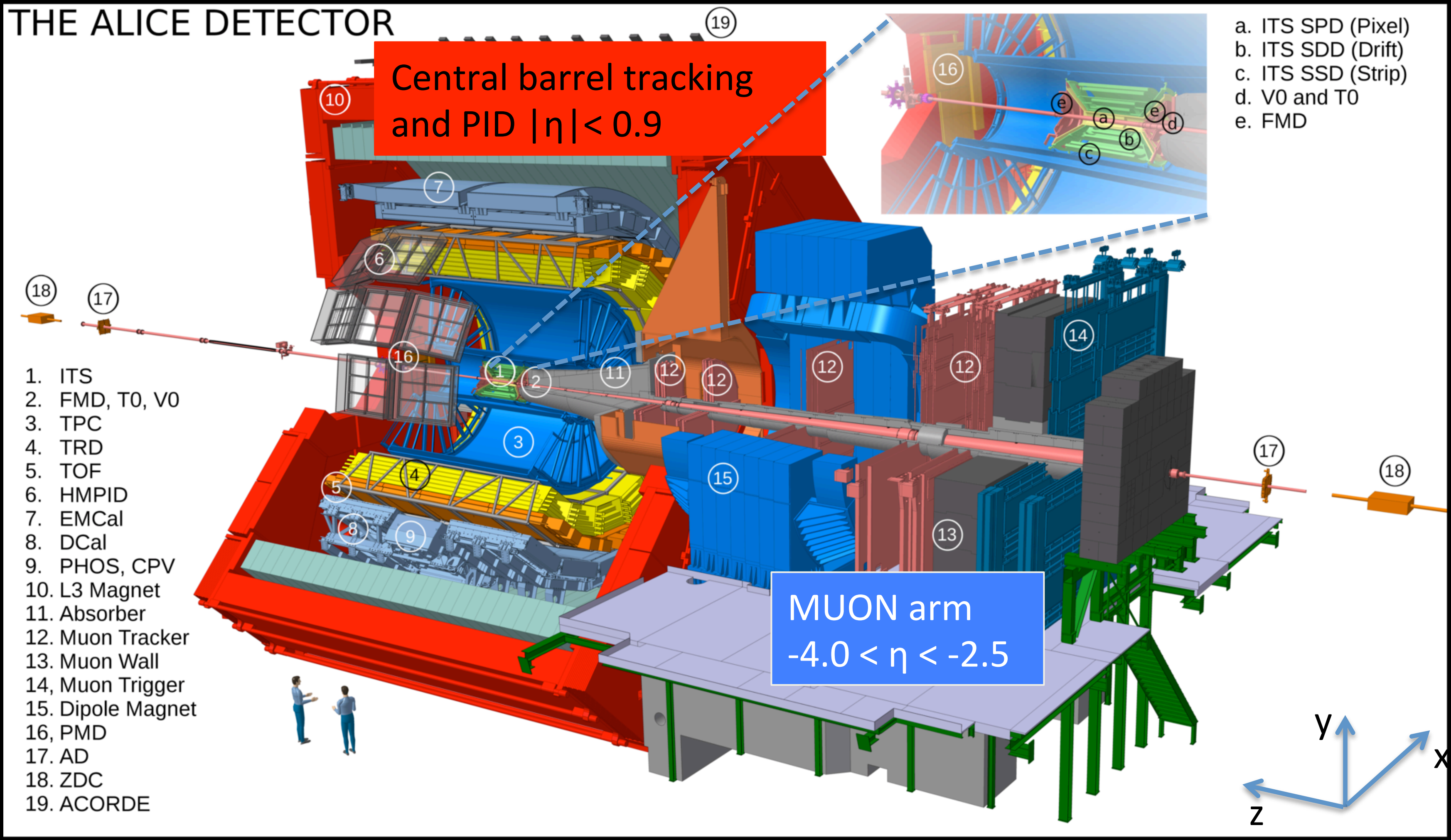
www.ifj.edu.pl

25 years of ALICE Collaboration



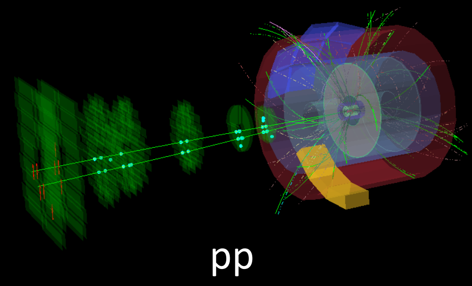
A Large Ion Collider Experiment

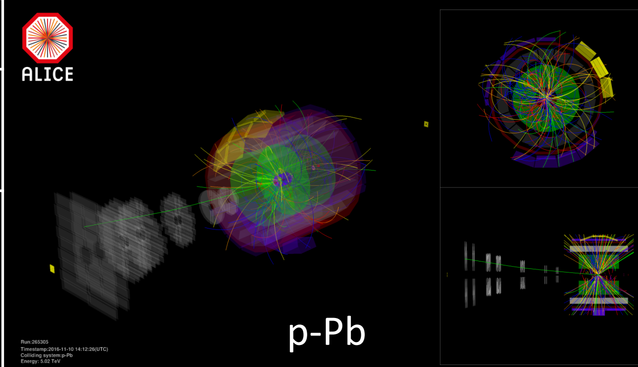
- Excellent particle identification capabilities in the large p_T range 0.1-20 GeV/c
- Good momentum resolution ~1-5% for p_T = 0.1-50 GeV/c

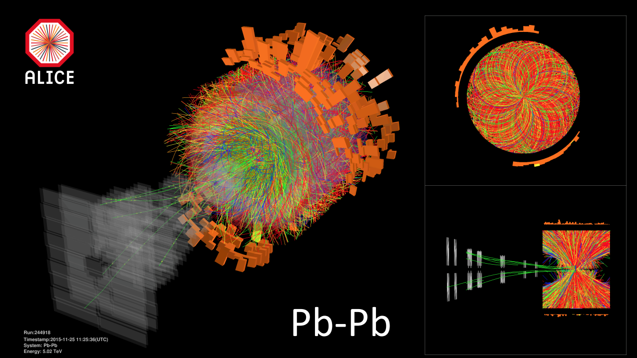


ALICE at work since 2009

System	Year	$\sqrt{s_{NN}}$ (TeV)	L_{int}
Pb-Pb	2010-2011 2015 by the end of 2018	2.76 5.02 5.02	~75 μb^{-1} ~250 μb^{-1} ~1 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 2015-2017	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} , ~25 pb^{-1}







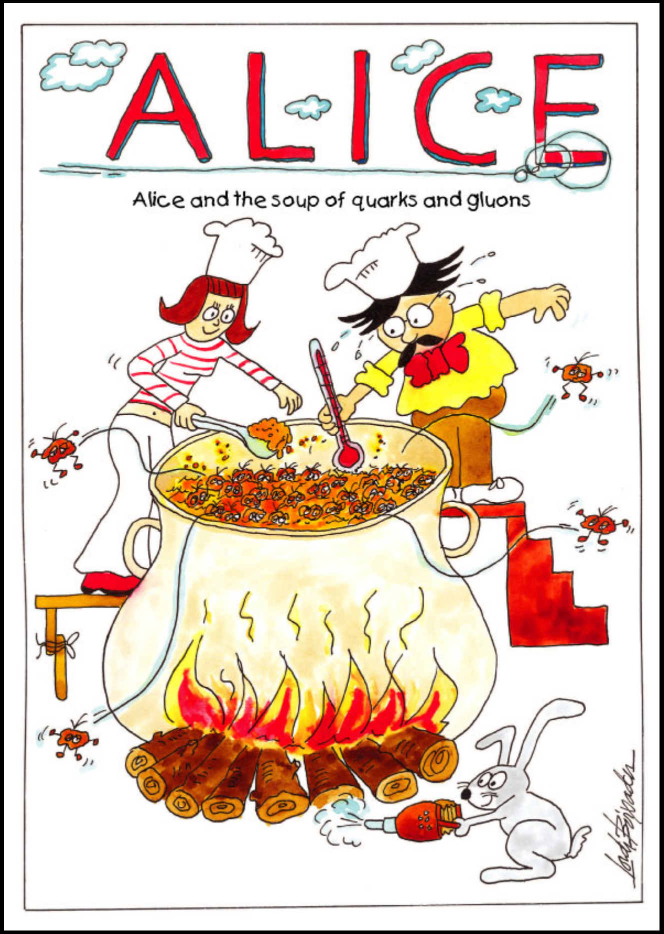
- Energy and system dependence studies of particle production are possible
- Large statistics of pp, p-Pb and Pb-Pb collisions at the same $\sqrt{s_{NN}}$

→ precise comparison studies

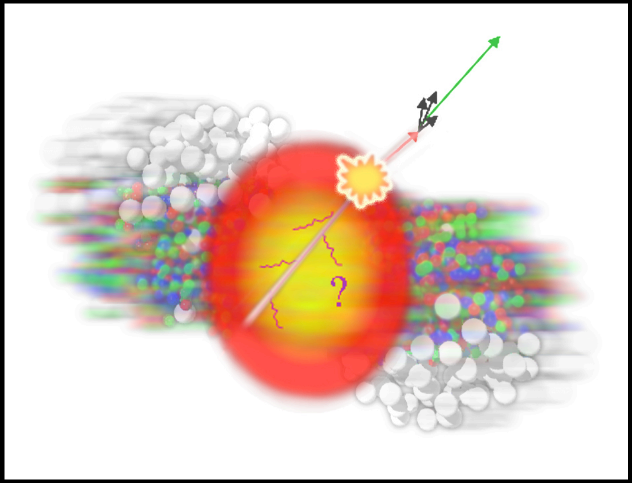
Outline

Focus on particle production at high p_T

- Parton energy loss and jet quenching
- Improvements to the p_T spectra analysis
- Nuclear modification factors
    - Energy and system dependence
    - Light vs. heavy-flavor hadrons
    - Comparison with models of parton energy loss
- Outlook



Parton energy loss and jet quenching



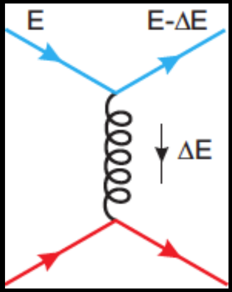
Radiative and collisional parton energy loss:

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

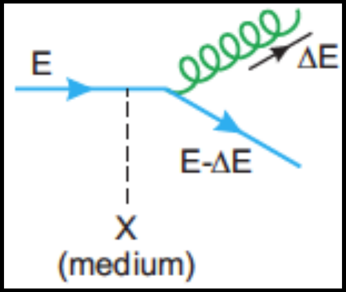
D. d'Enterria, arXiv:0902.2011

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



collisional



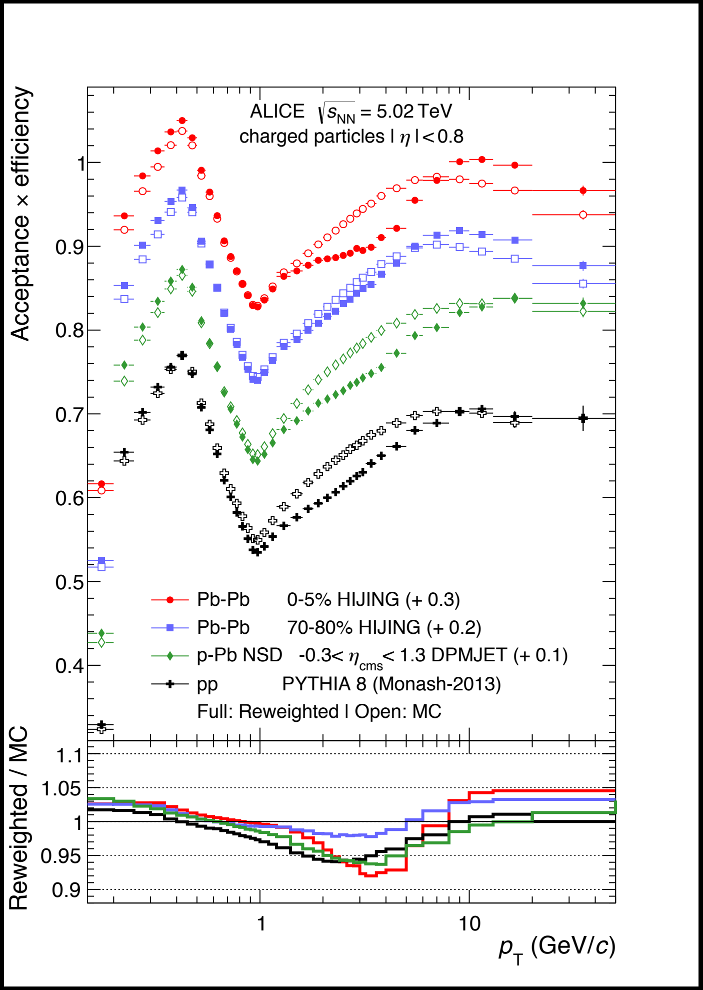
radiative

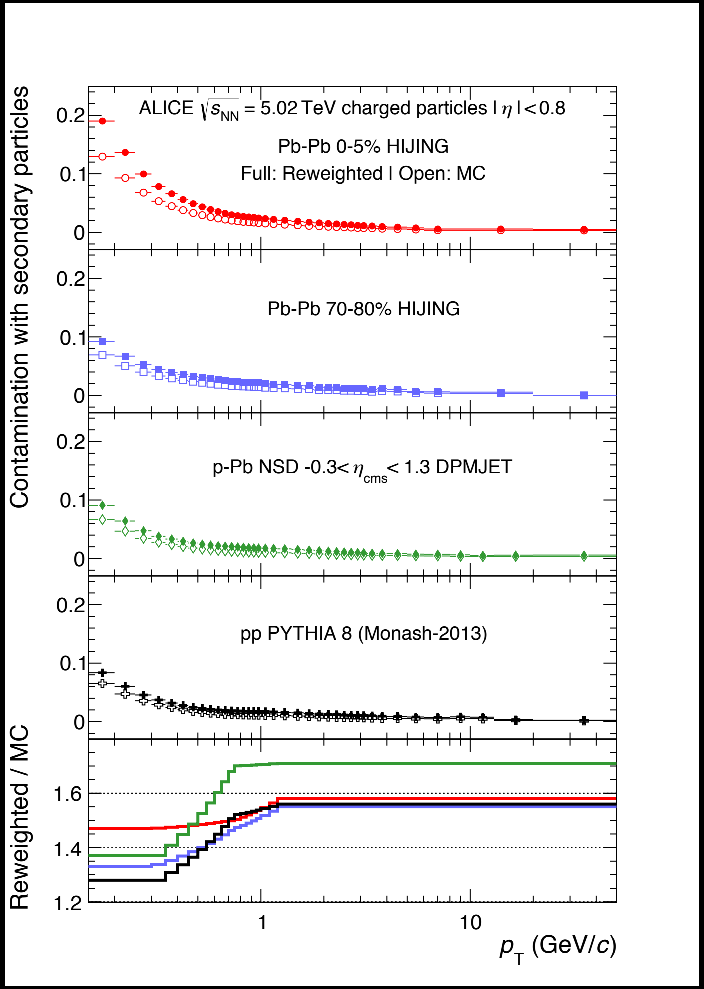
- In static medium: $\Delta E_{coll} \sim L$, $\Delta E_{rad} \sim L^2$
- Characterize medium transport properties via parton energy loss

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

Improvements to the p_T spectra analysis

ALICE, arXiv:1802.09145



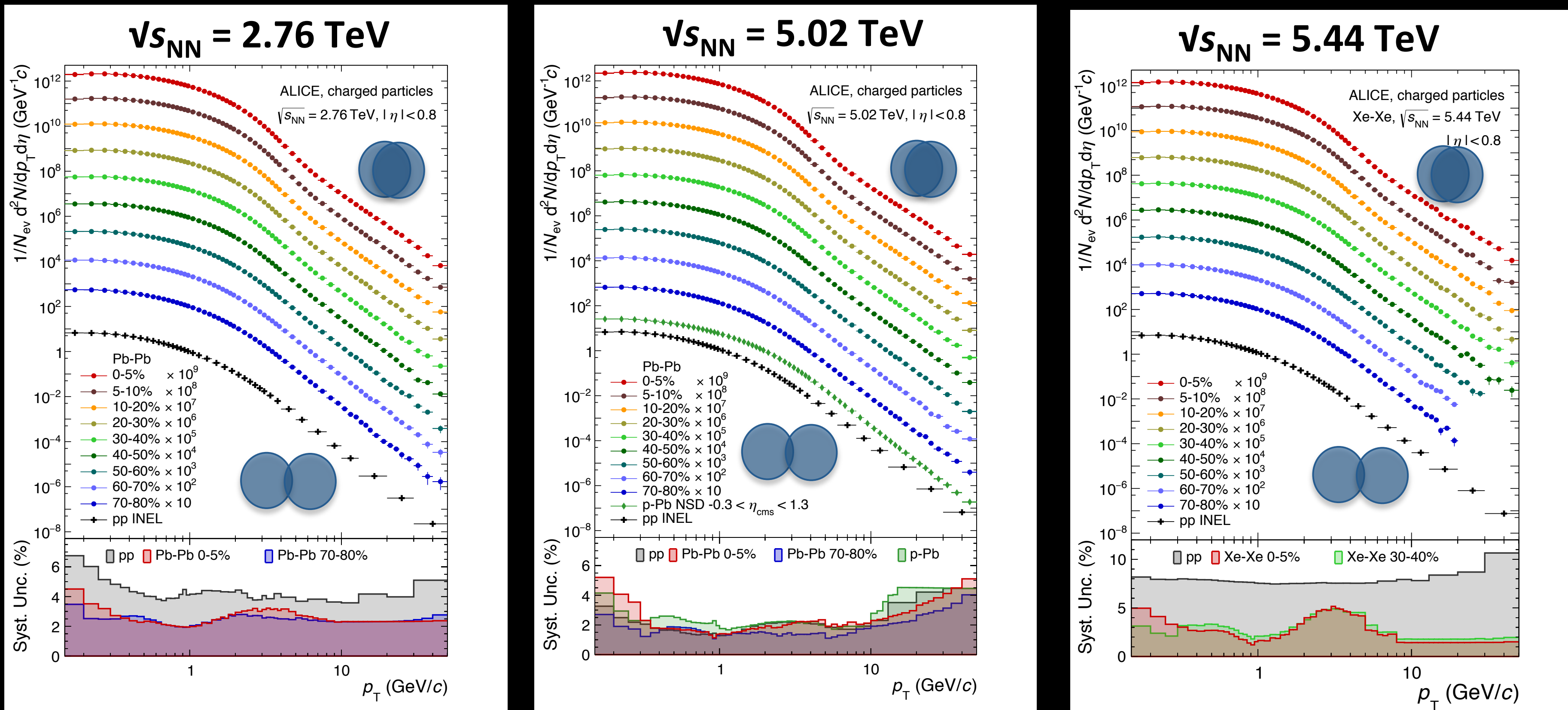


- Improved efficiency and contamination corrections based on measured particle species
  → Reduced systematic uncertainties by a factor of 2 as compared to previous analyses

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

ALICE, arXiv:1802.09145

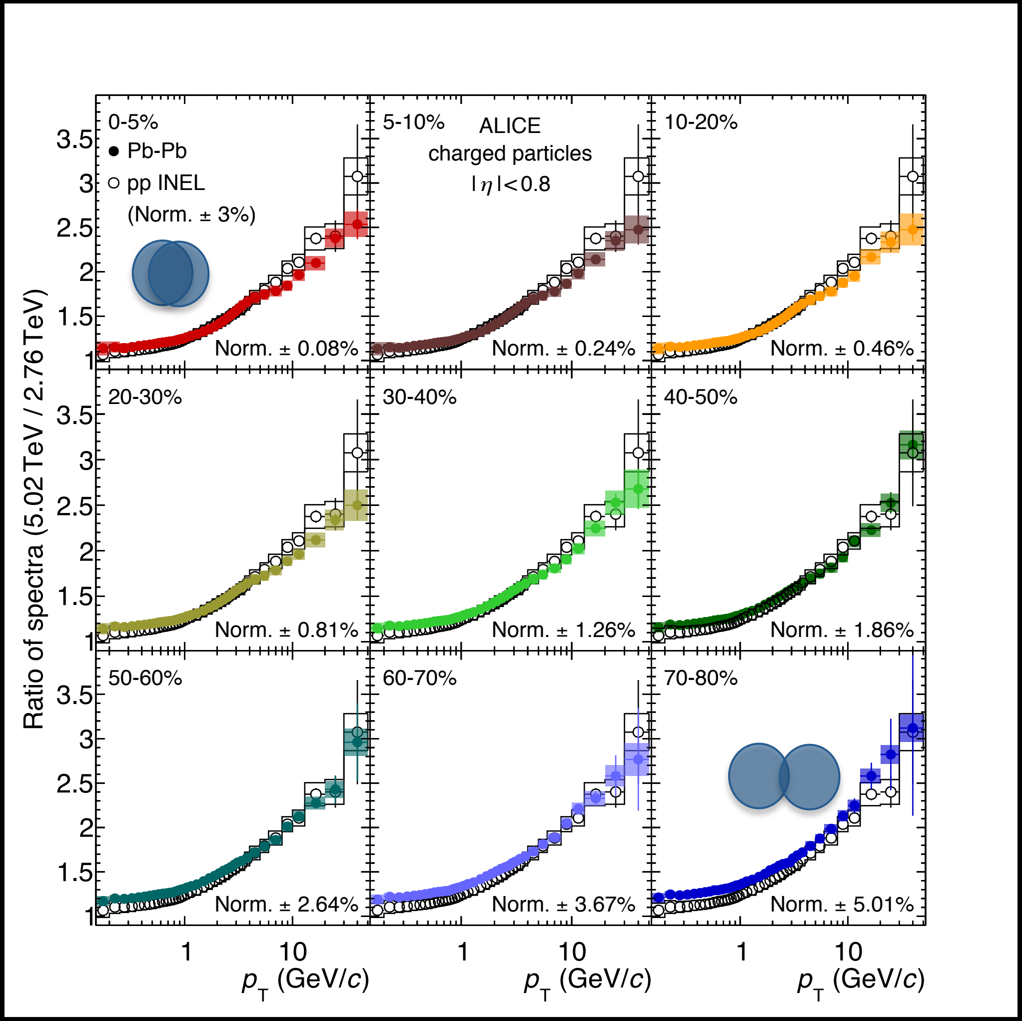
ALICE, arXiv:1805.04399



- 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

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

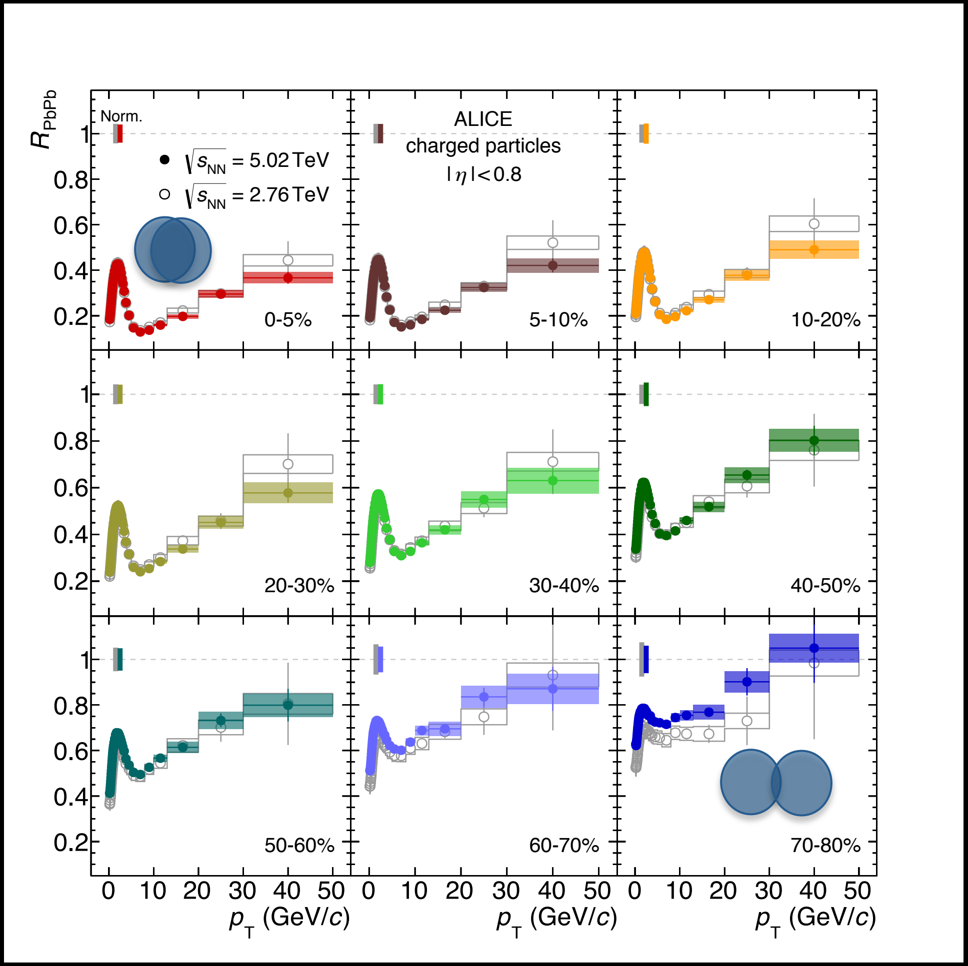
ALICE, arXiv:1802.09145



- 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

ALICE, arXiv:1802.09145



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

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

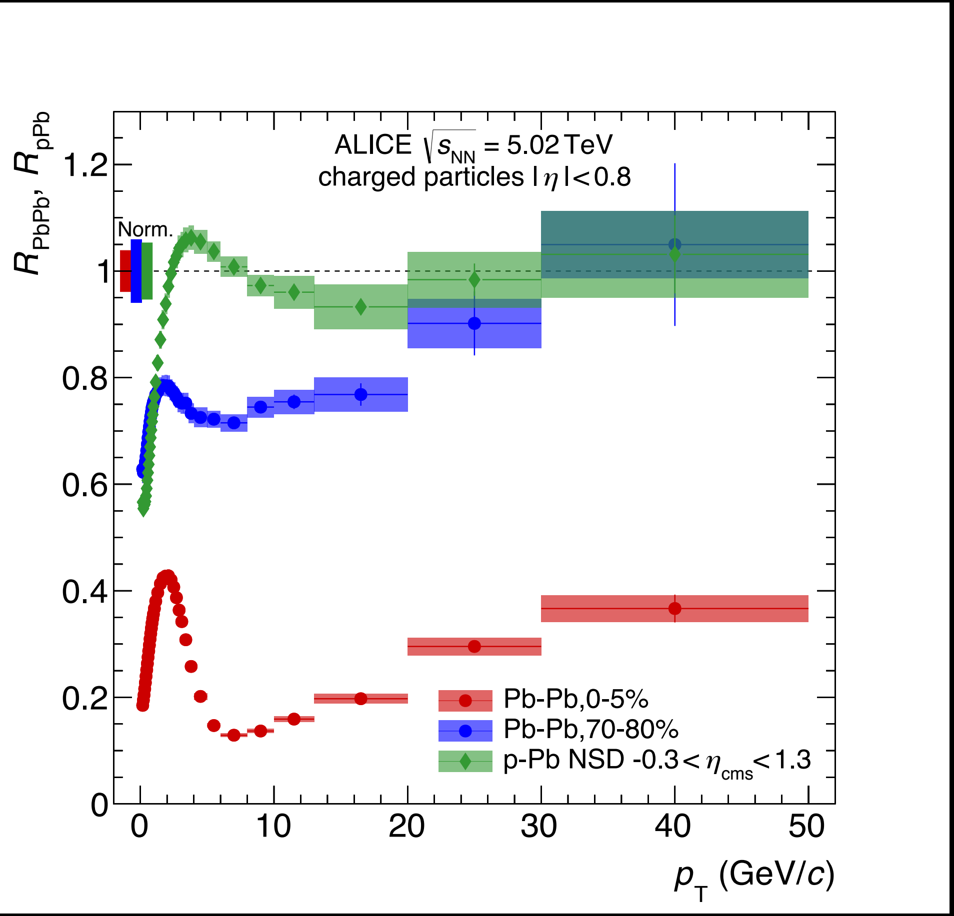
ALICE, arXiv:1802.09145

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)

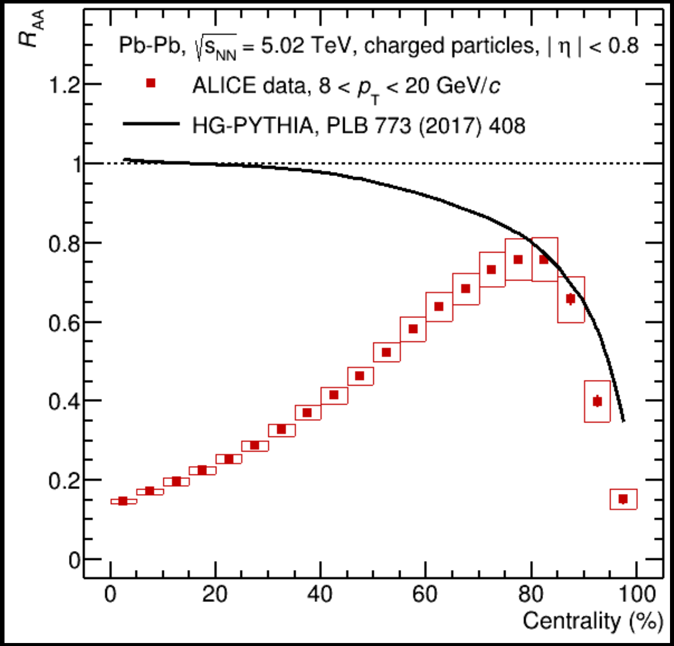
→ Suppression in central Pb-Pb collisions is due to final state effects!

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



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

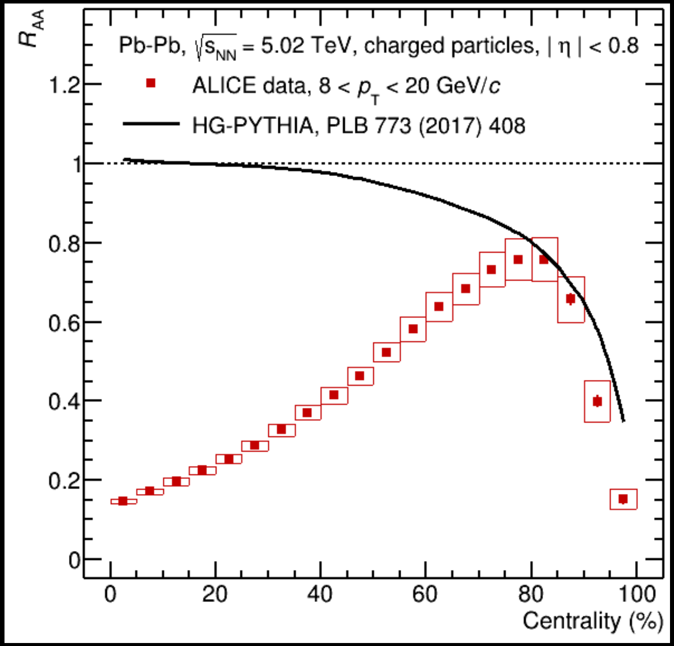
HG-Pythia model:

- 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



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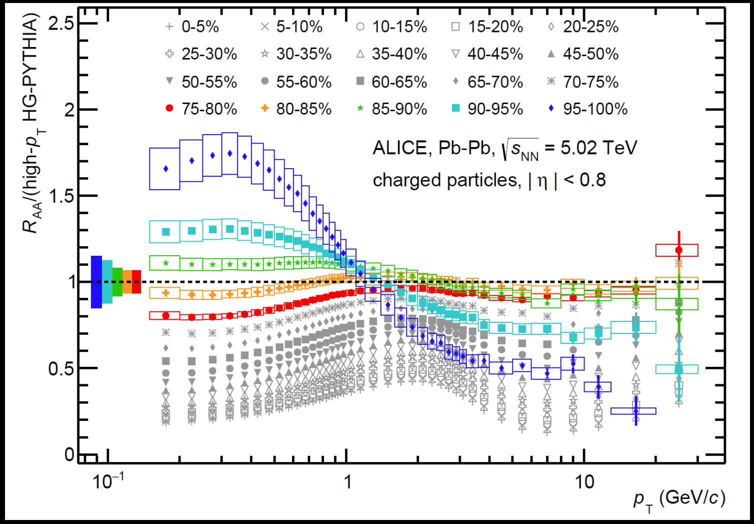

HG-Pythia model:

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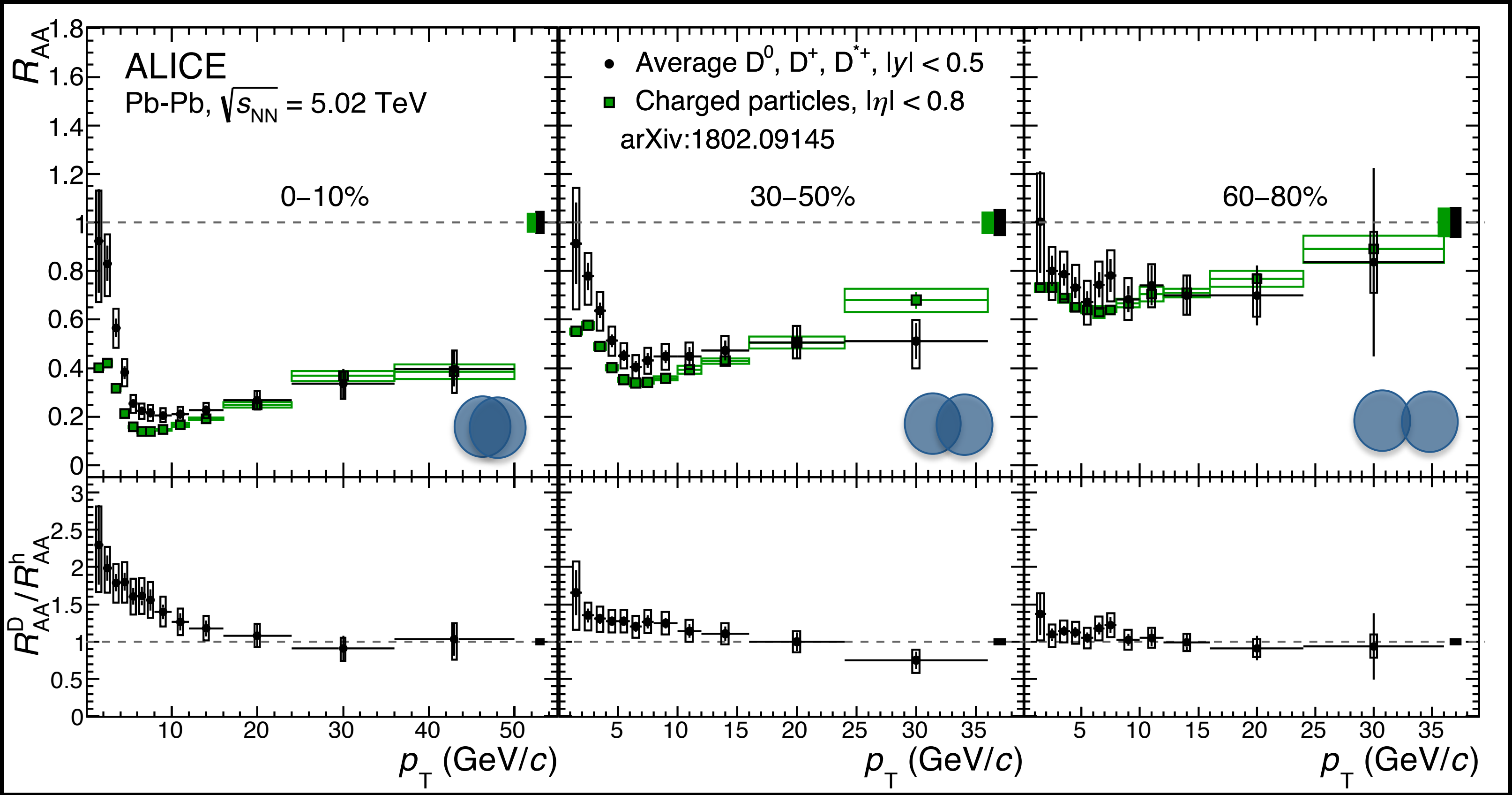
A. Morsh & C. Loizides, PLB 773 (2017) 408

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

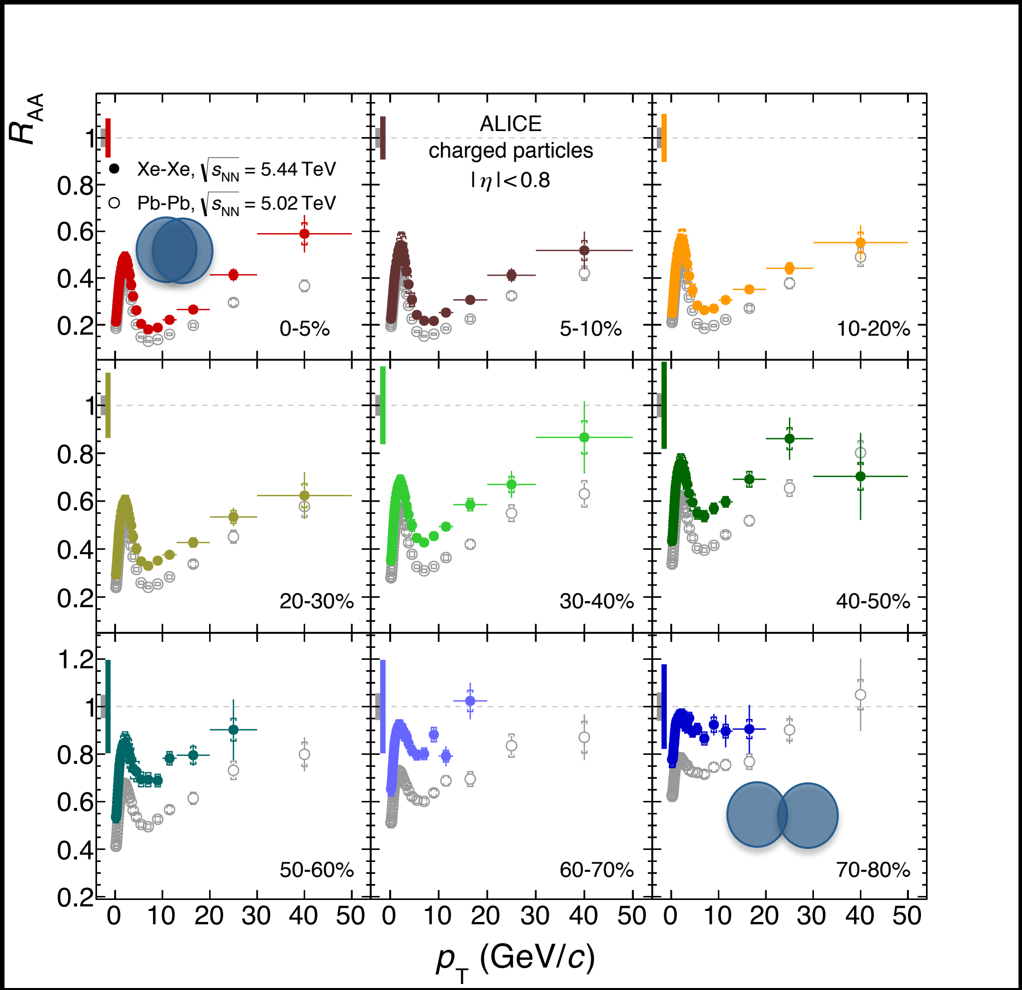
ALICE, arXiv:1804.09083



- 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,…)

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

ALICE, arXiv:1805.04399

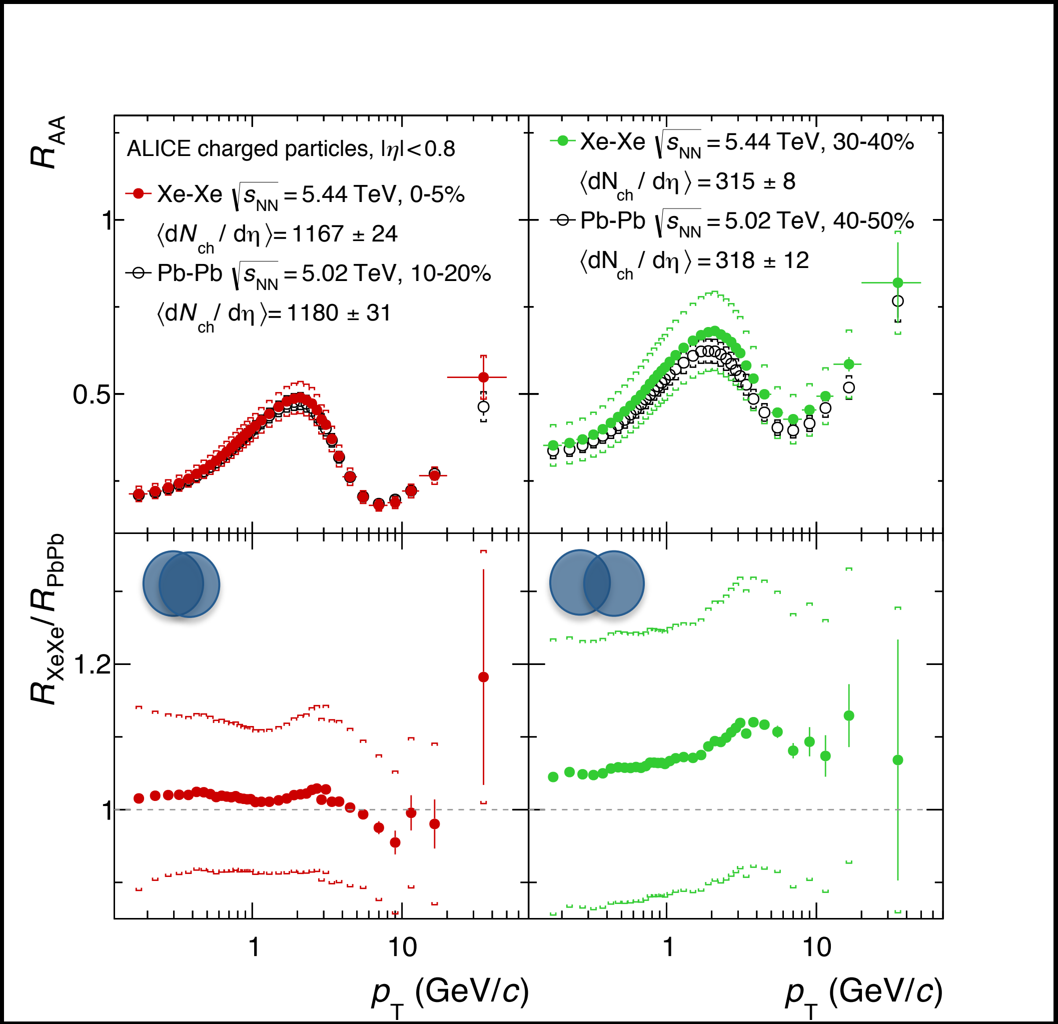


- Similar suppression pattern in Xe-Xe and Pb-Pb
- Larger suppression in Pb-Pb than in Xe-Xe collisions at high p_T at the same centrality
- Normalization uncertainty (T_{AA} and pp norm.) are much larger for Xe-Xe
  - less precisely known nuclear-charge-density distribution of deformed ^{129}Xe nucleus

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

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

ALICE, arXiv:1805.04399

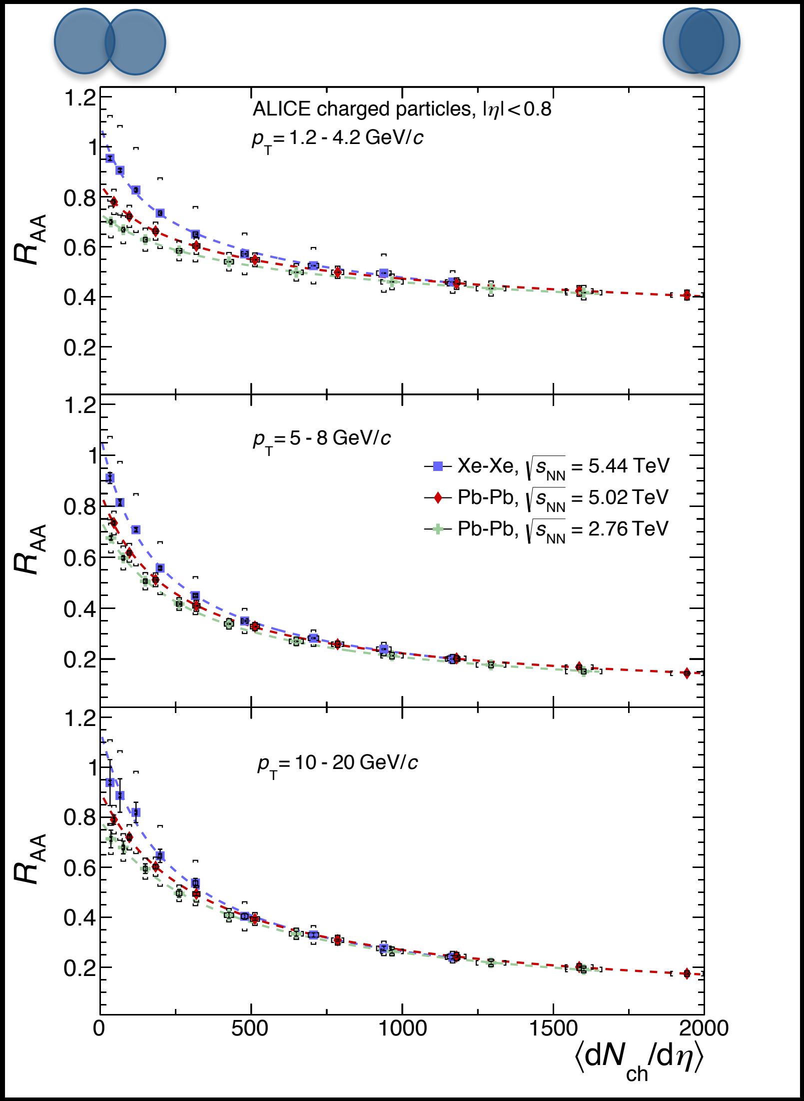


- Similar R_{AA} in central Xe-Xe and Pb-Pb collisions at similar multiplicity
- Different R_{AA} in more peripheral collisions

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

Charged-particle R_{AA} vs dN_{ch}/dη in Xe-Xe and Pb-Pb

ALICE, arXiv:1805.04399

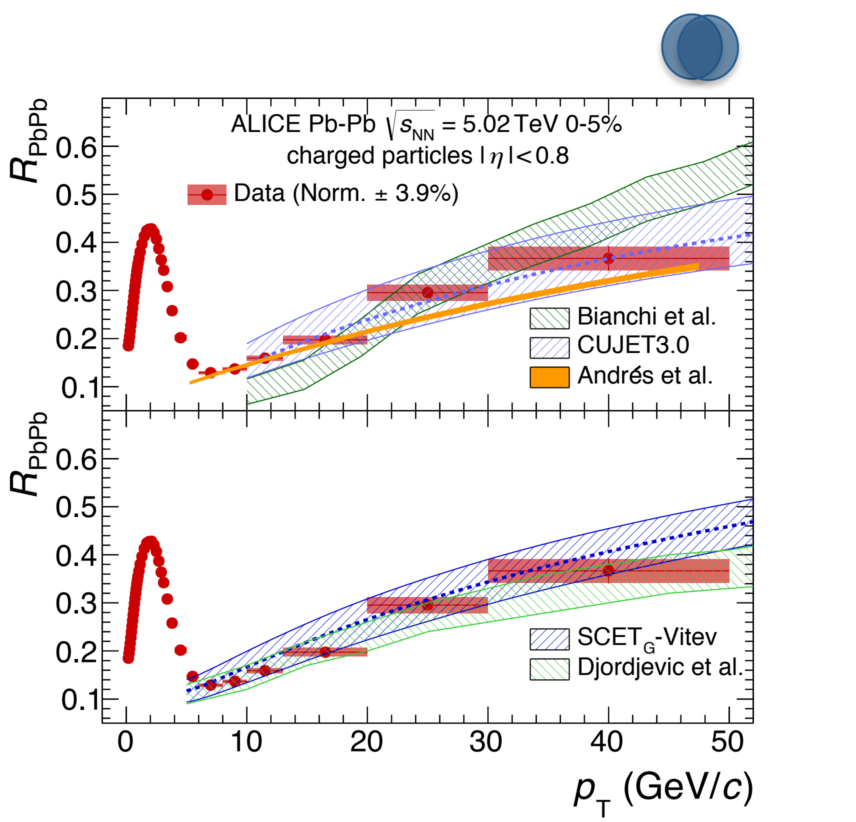


- A remarkable similarity is found for all p_T ranges for <dN_{ch}/dη> > 400
- Dashed lines are fits to the spectra

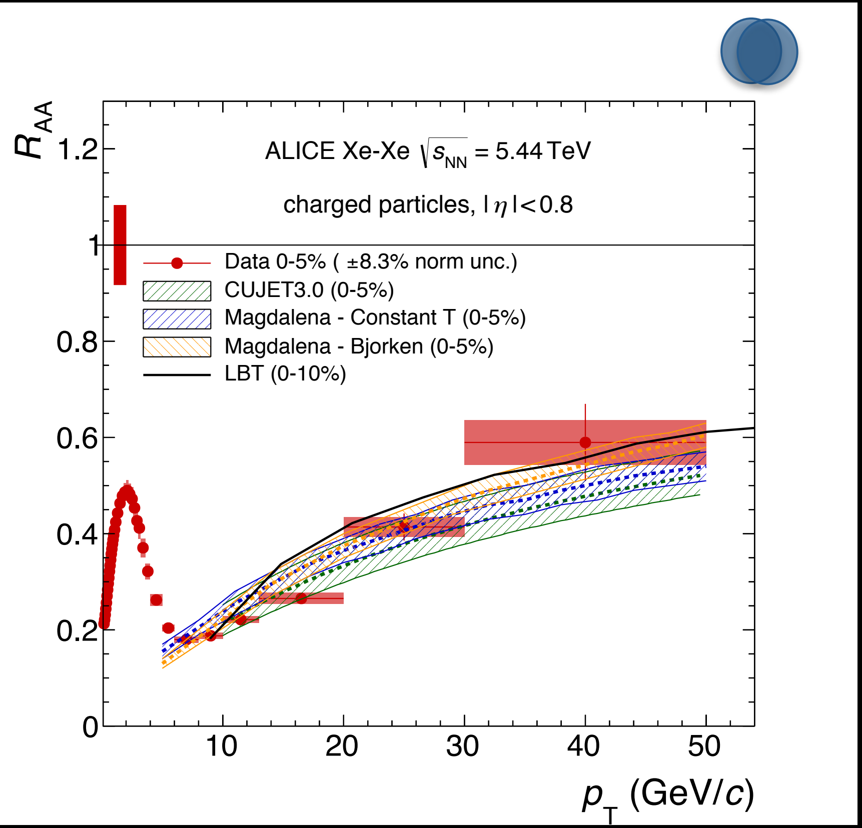
→ Result of interplay between geometry and path length dependence of parton energy loss

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

ALICE, arXiv:1802.09145



Data: ALICE, arXiv:1805.04399

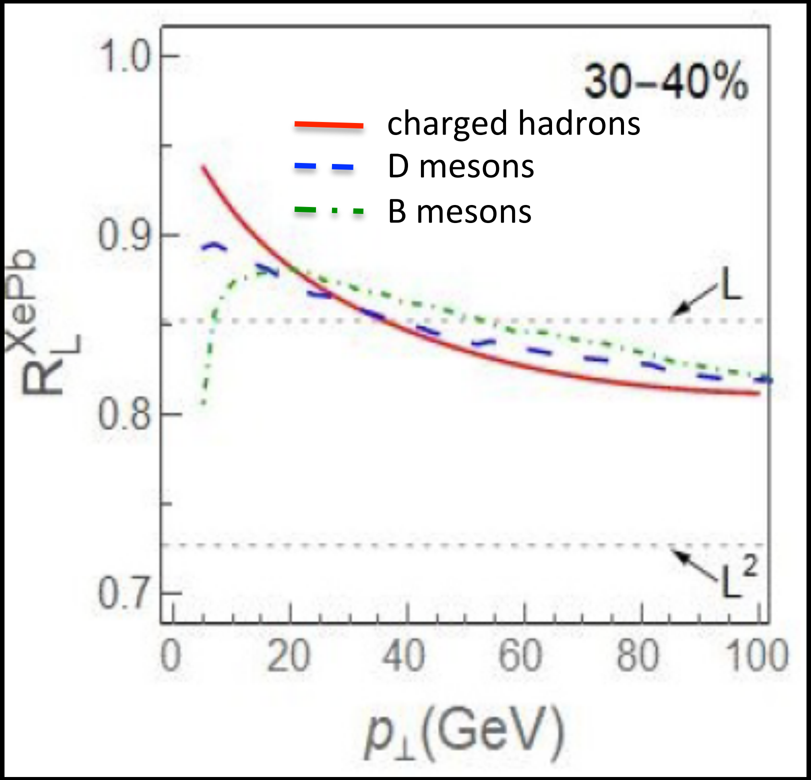


Models:

- 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.

Path-length sensitive suppression ratio

M. Djorjevic et al., arXiv:1805.04030



Assuming fractional energy loss (*T* - average temperature, *L* path-length)

$$\Delta E/E \sim \eta T^a L^b$$

for small ΔE/E one obtains

$$R_{AA} \approx (1 - \xi T^a L^b)$$

where ξ depends on initial p_T spectrum

$$R_L^{XePb} \equiv \frac{1 - R_{XeXe}}{1 - R_{PbPb}} \approx \left(\frac{A_{Xe}}{A_{Pb}}\right)^{b/3}$$

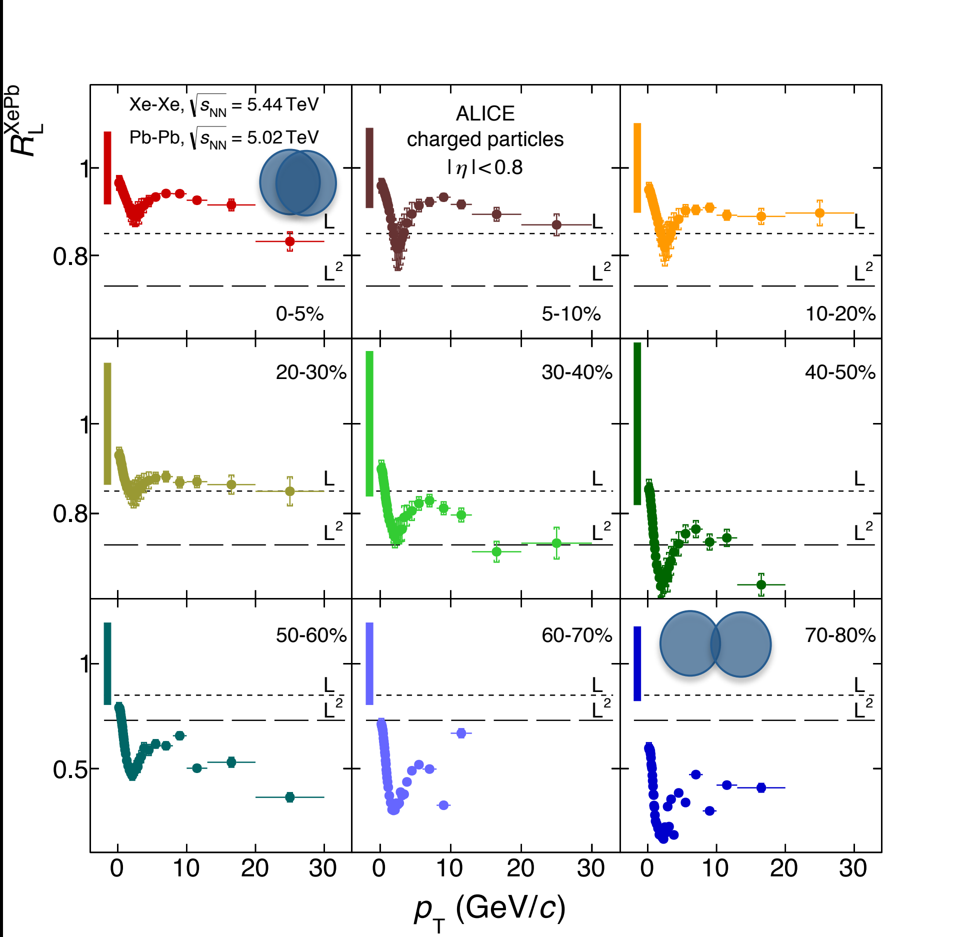
→ observable supposed to be sensitive to path- length dependence

→ work best for peripheral collisions

Model calculations:

- Elastic and radiative energy loss in the static medium at constant temperature *T*

Path-length sensitive suppression ratio



Flattens above 5 GeV/c in central and semi-central collisions ~ *L*, … but calculations assuming the static medium

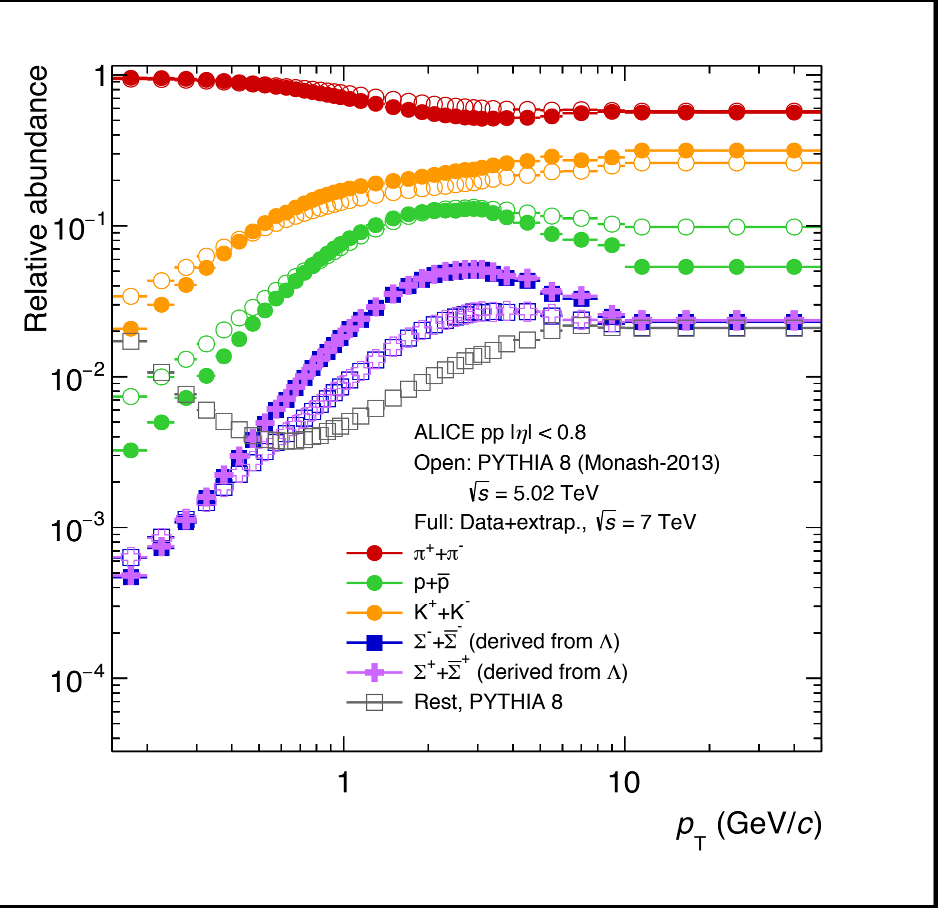
Outlook

- Similar suppression pattern in Pb-Pb and Xe-Xe collisions
- Similar R_{AA} measured in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 and 5.02 TeV
  → Indication of larger energy loss at higher collision energy
- R_{pPb} is around unity at high p_T
  → Suppression in central Pb-Pb collisions is due to final state effects
- Onset of suppression in peripheral Pb-Pb collisions is due to bias 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
  → Interplay between geometry and path length dependence of parton energy loss
- Similar R_{AA} of D mesons and light-flavor hadrons at high p_T
  → No mass dependence of parton energy loss at high p_T?
- Path-length sensitive suppression ratio is a new observable to be tested against models

Backup

Relative Particle Abundance

ALICE, arXiv:1802.09145

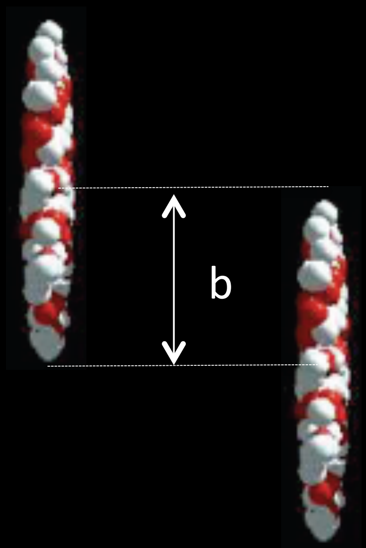


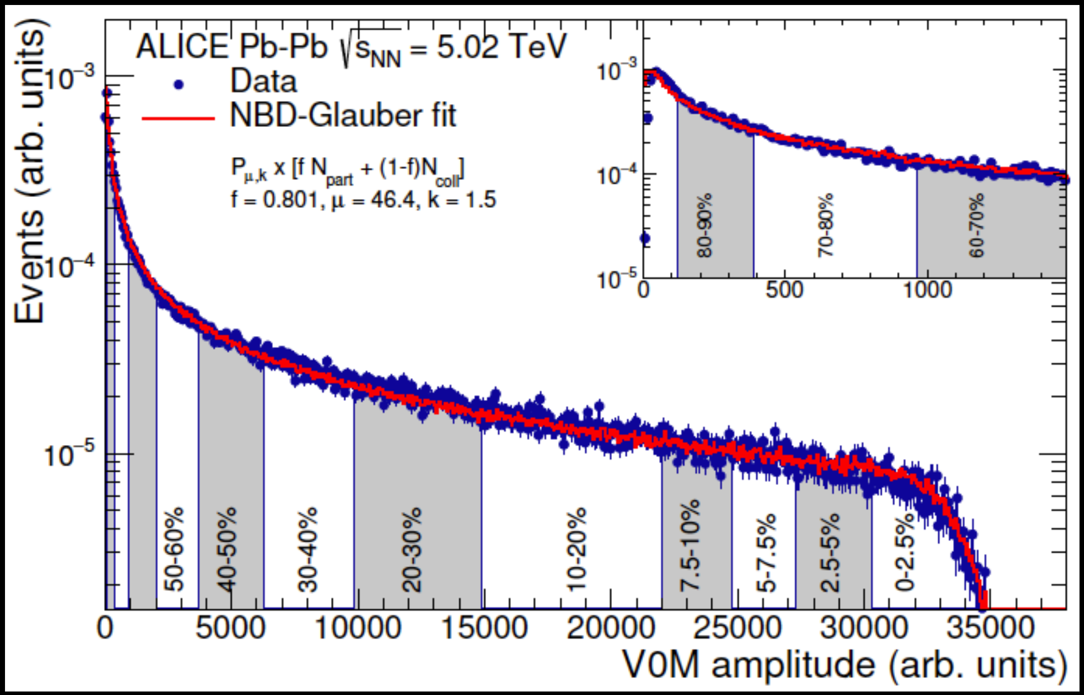
Relative particle abundance is not properly calculated in MC generators

Influences corrections to the spectra

Event Centrality Selection

ALICE-PUBLIC-2018-011

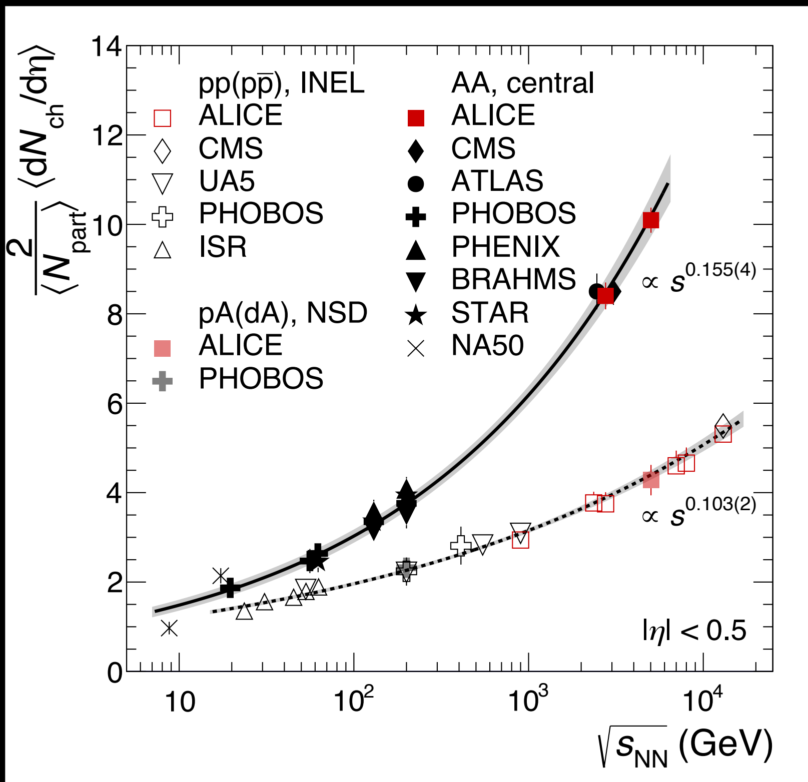


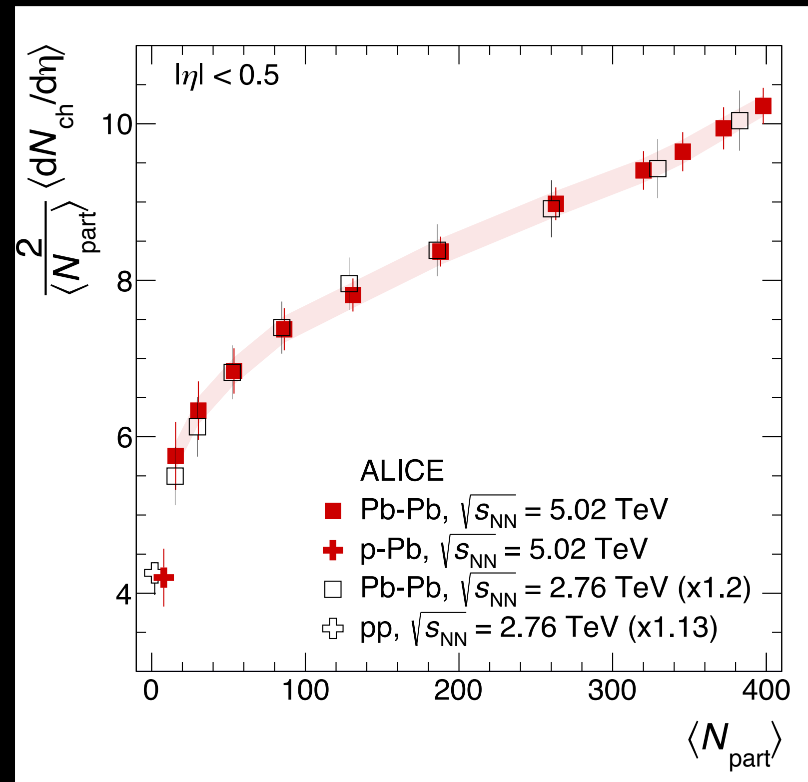


- Correlate particle multiplicity with collision geometry i.e. impact parameter, volume and shape (A. Białas et al. APPB 8 (1977) 389)
- N_{coll}, N_{part} and $T_{AA} = N_{coll} / \sigma^{NN}_{INEL}$ values determined by fitting NBD-Glauber coupled to two parameter model

Charged Particle Multiplicity

ALICE, Phys. Rev. Lett. 116, 222302 (2016)





- About 20% increase in the charged particle density from $\sqrt{s_{NN}}$ = 2.76 to 5.02 TeV