Jet physics overview in ALICE

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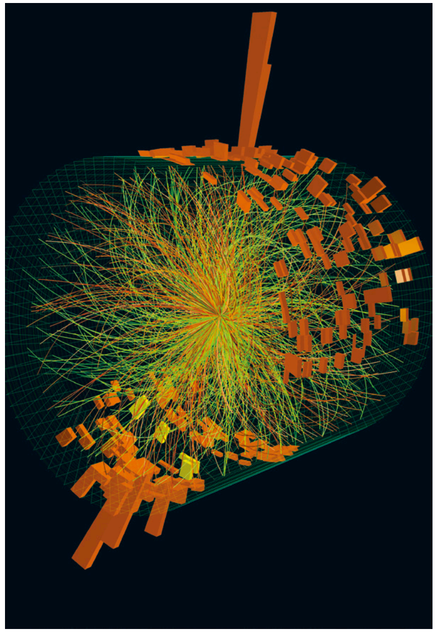
(for the ALICE collaboration)



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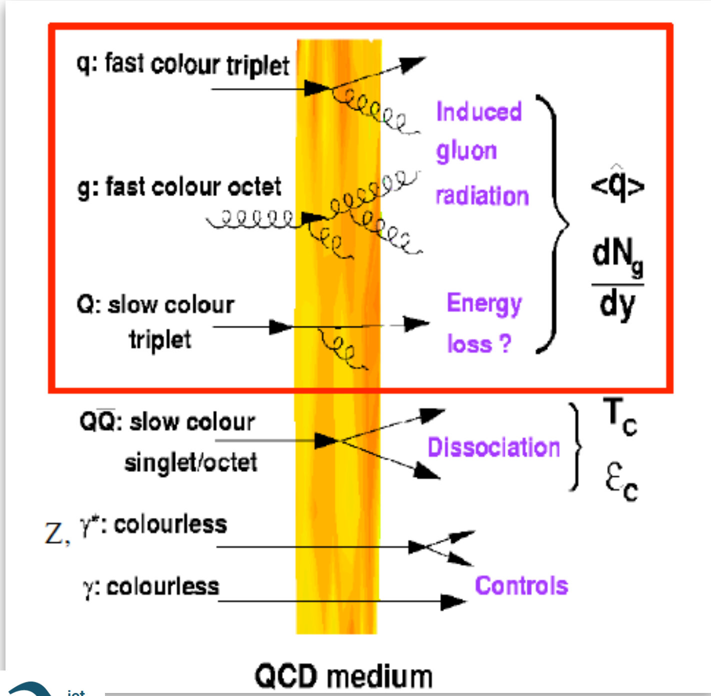
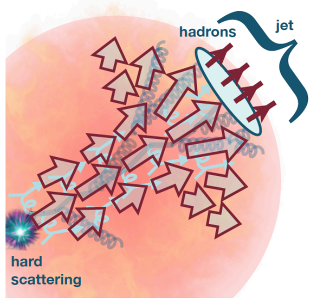
Opportunities and Challenges with Jets at LHC and beyond, June 10-12, 2018, CCNU, Wuhan, China

Hard probes for QGP

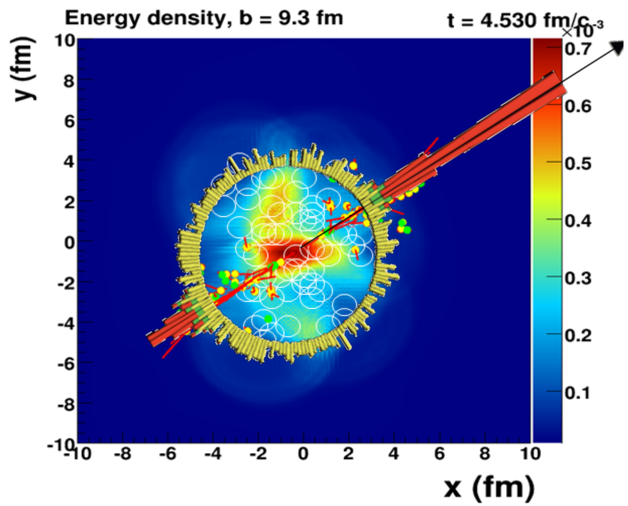
- **Hard probes:**
  - originated hard scattering parton (large Q^2), prior to QGP formation time ($1/Q \ll 1$ fm/c).
  - well calibrated (pQCD), self generated probe
  - jets: experienced the whole evolution of the system (strongly interacting with medium)
- **Access to the medium properties:**
  - dE/dx of partons (g, q (uds, c, b)) & *L* dep.)
  - Medium response (large angle emission)
  - Jet tomography by different probes & techniques.



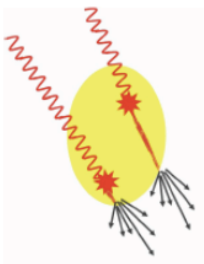
side by D. d'Enterria (slide at QGPWS, 2008)



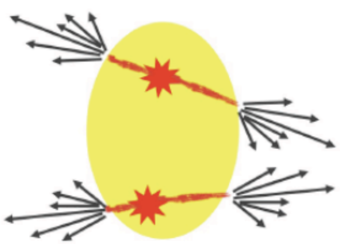
Picture form Y. Tachibana (Heavy Ion Cafe 2017)



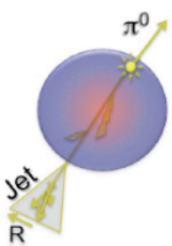
γ-Jet



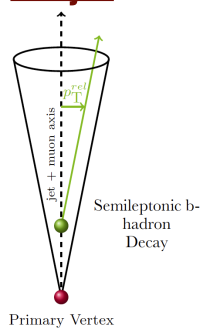
Di-jet



π⁰-Jet

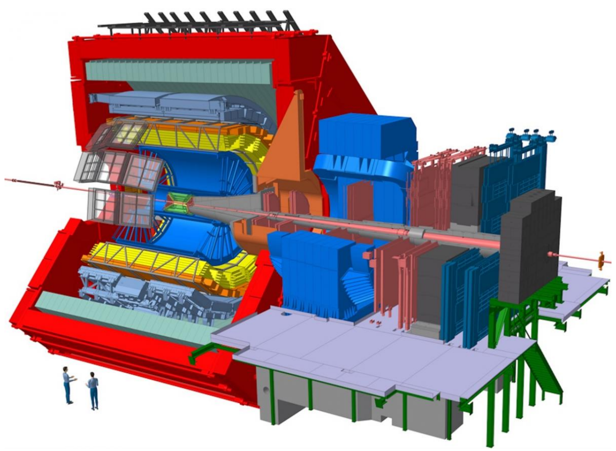


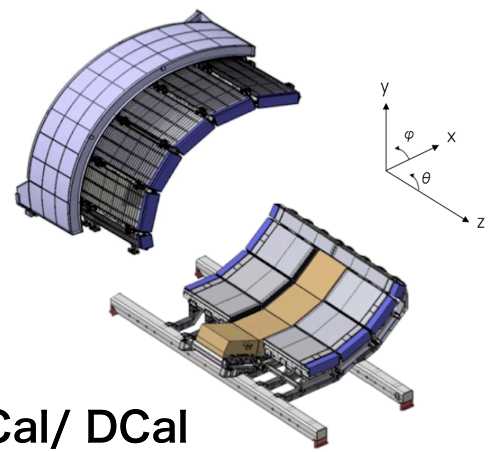
HF jet



Jet in ALICE

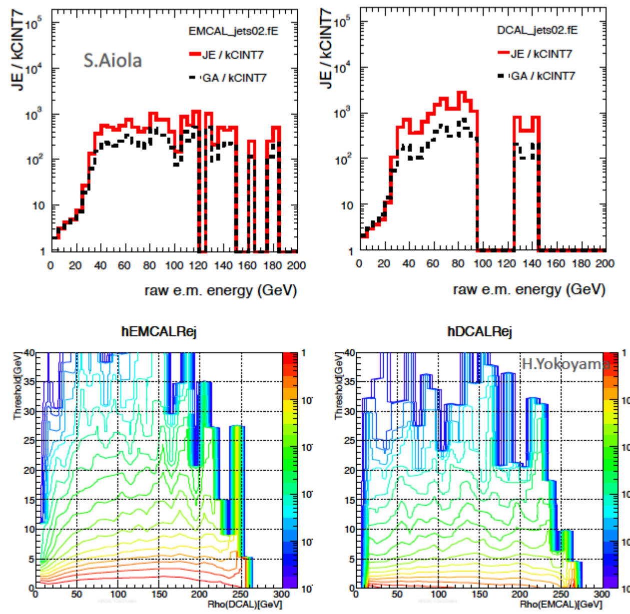
- Jet reconstruction by tracking (TPC+ITS) + calorimetry (EMC)
- Go to **low jet p_T and low constituent p_T** (> 0.15 GeV) in large HI background
  - ✓ Detailed characterization of background fluctuations (JHEP 1203 (2012), 053
  - ✓ gamma and jet triggers by EMCal/DCal, PHOS for high p_T
- **Measurements:**
  - ✓ high p_T hadrons
  - ✓ Inclusive jet
  - ✓ jet + h correlations (soft hadron, w/ PID)
  - ✓ gamma-jet correlations, c/b taged jets, jet-jet
  - ✓ jet substructure





EMCal/ DCal

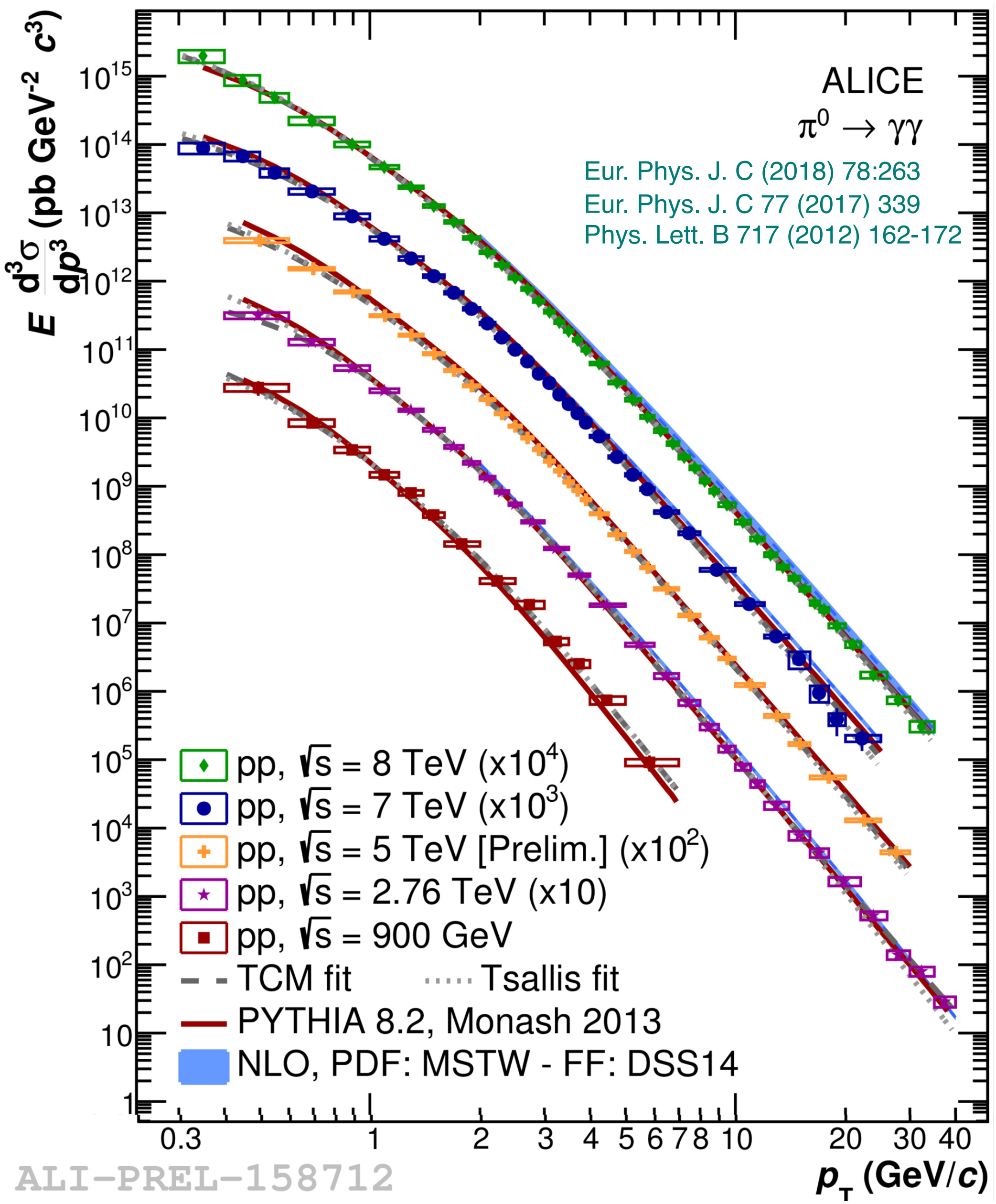
gamma, jet trigger in Run-2 Pb-Pb

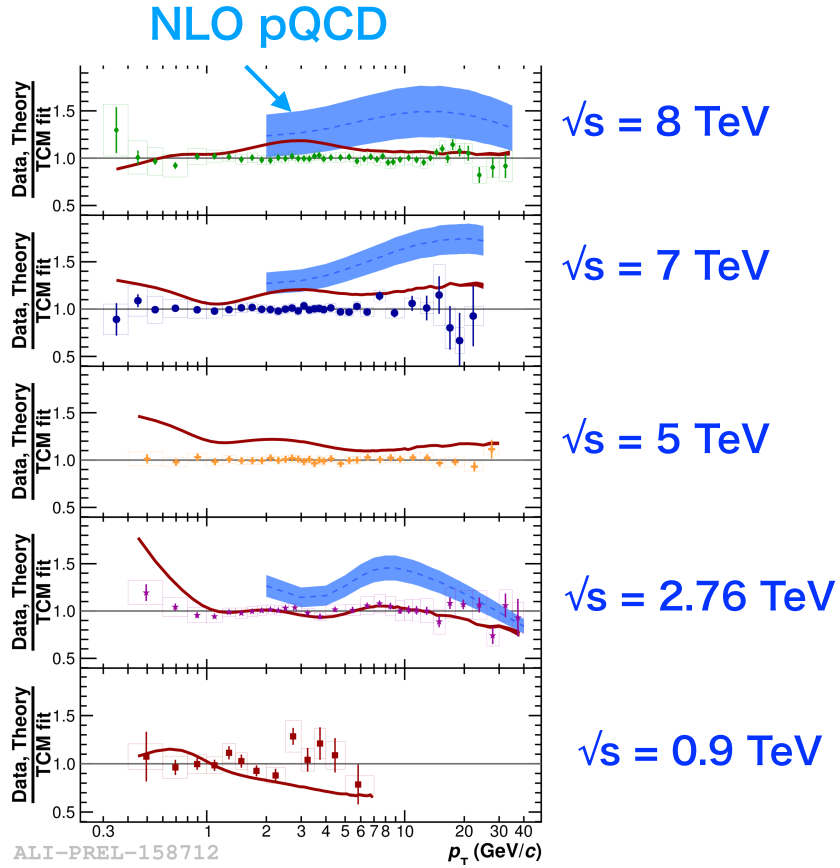


Colors: Rejection factor

Single hadrons @ high p_T

Baseline: π⁰ spectra in pp from 0.9 - 8 TeV



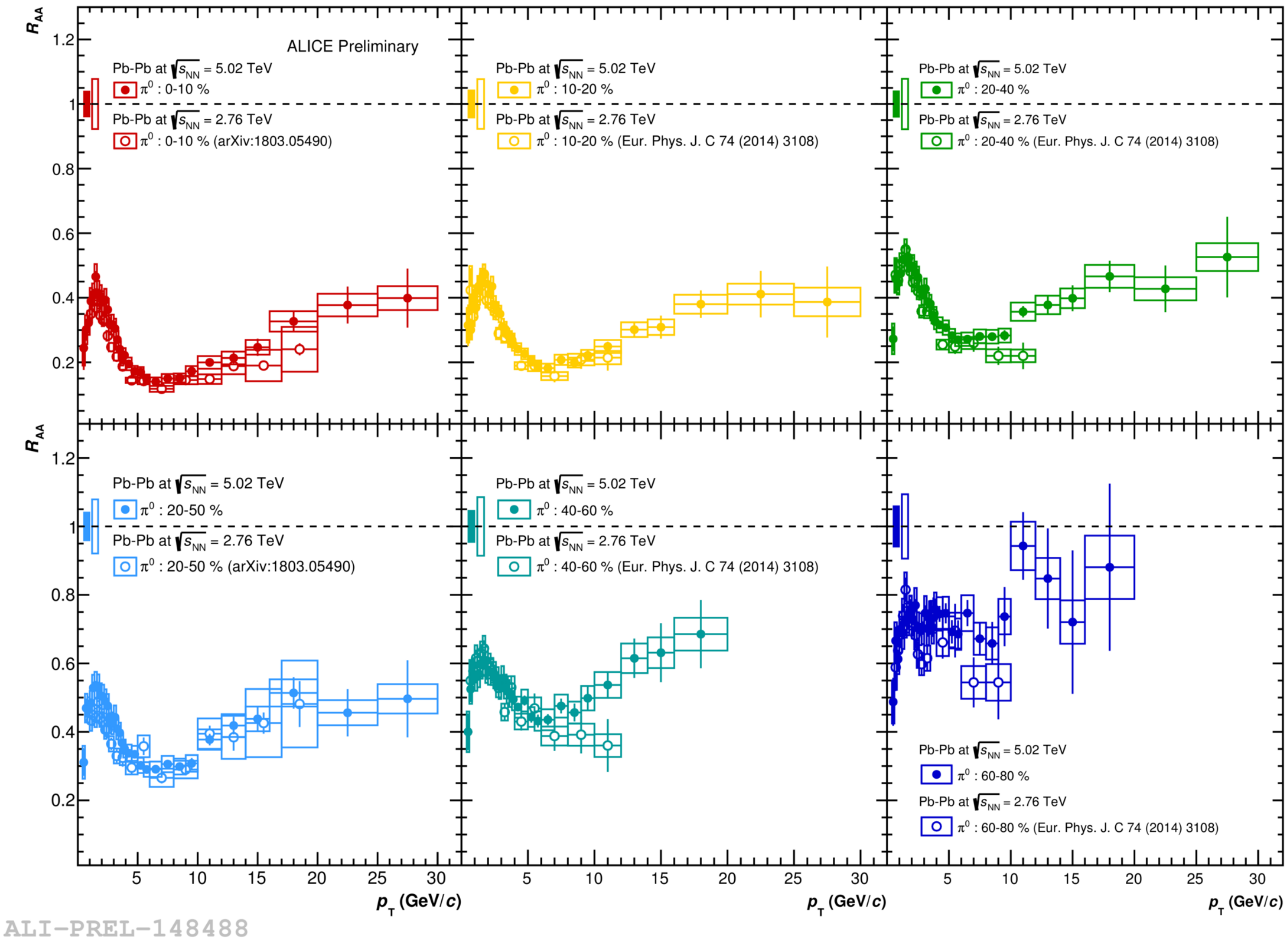


- Identified neutral pions in pp, up to 40 GeV
- With increasing of energy (harder spectrum), deviation from NLO pQCD
- Better agreement by PYTHIA (LO + parton shower)

• Suggested importance of FF and parton shower for spectra

R_{AA}: π^0 in Pb-Pb @ 5.02 TeV

0-10% 10-20% 20-40%

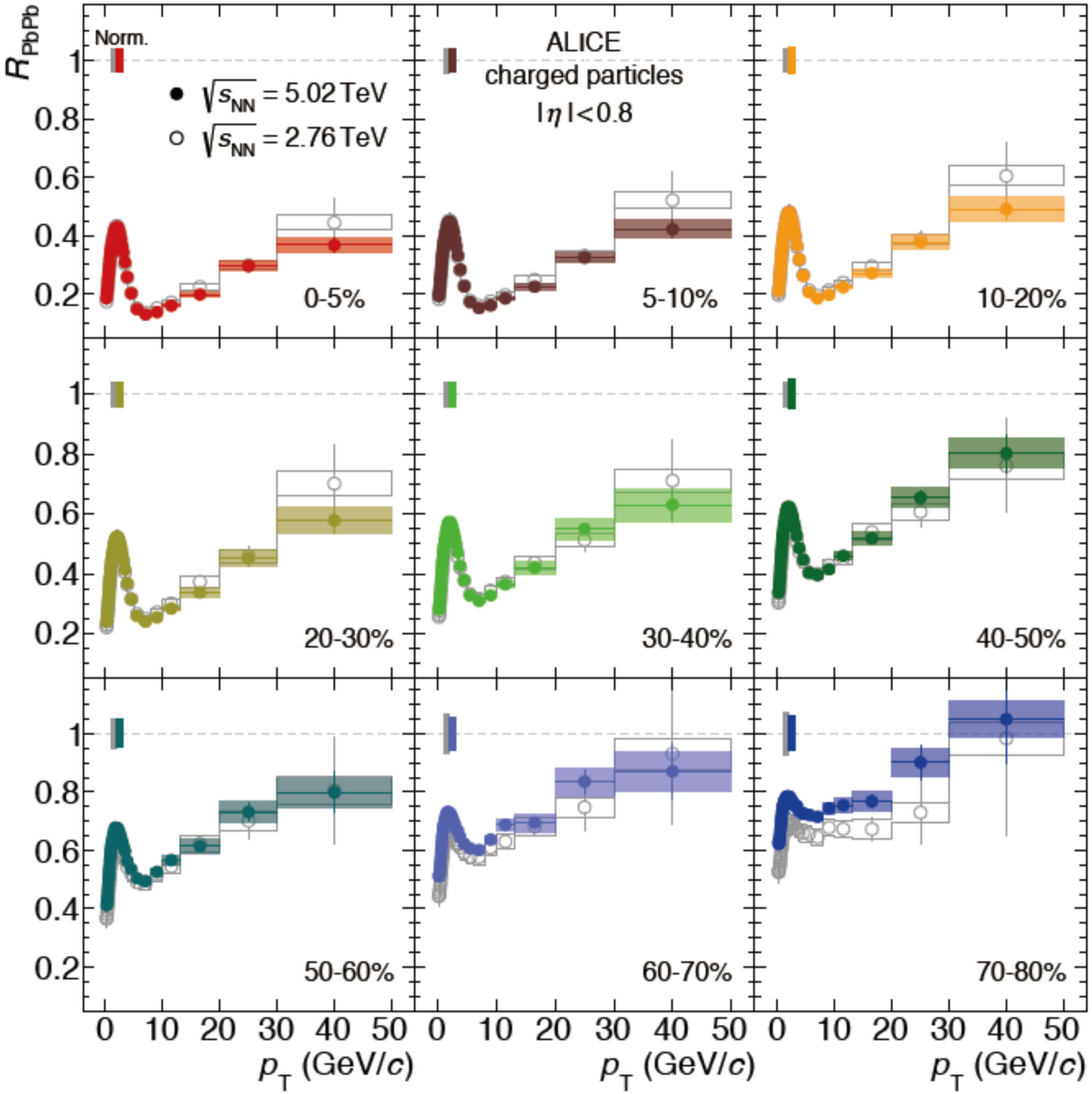


20-50% 40-60% 60-80%

- Well defined FF for an identified hadron, compared to inclusive charged particles
- Strong centrality dependence
- Similar R_{AA} for two energies

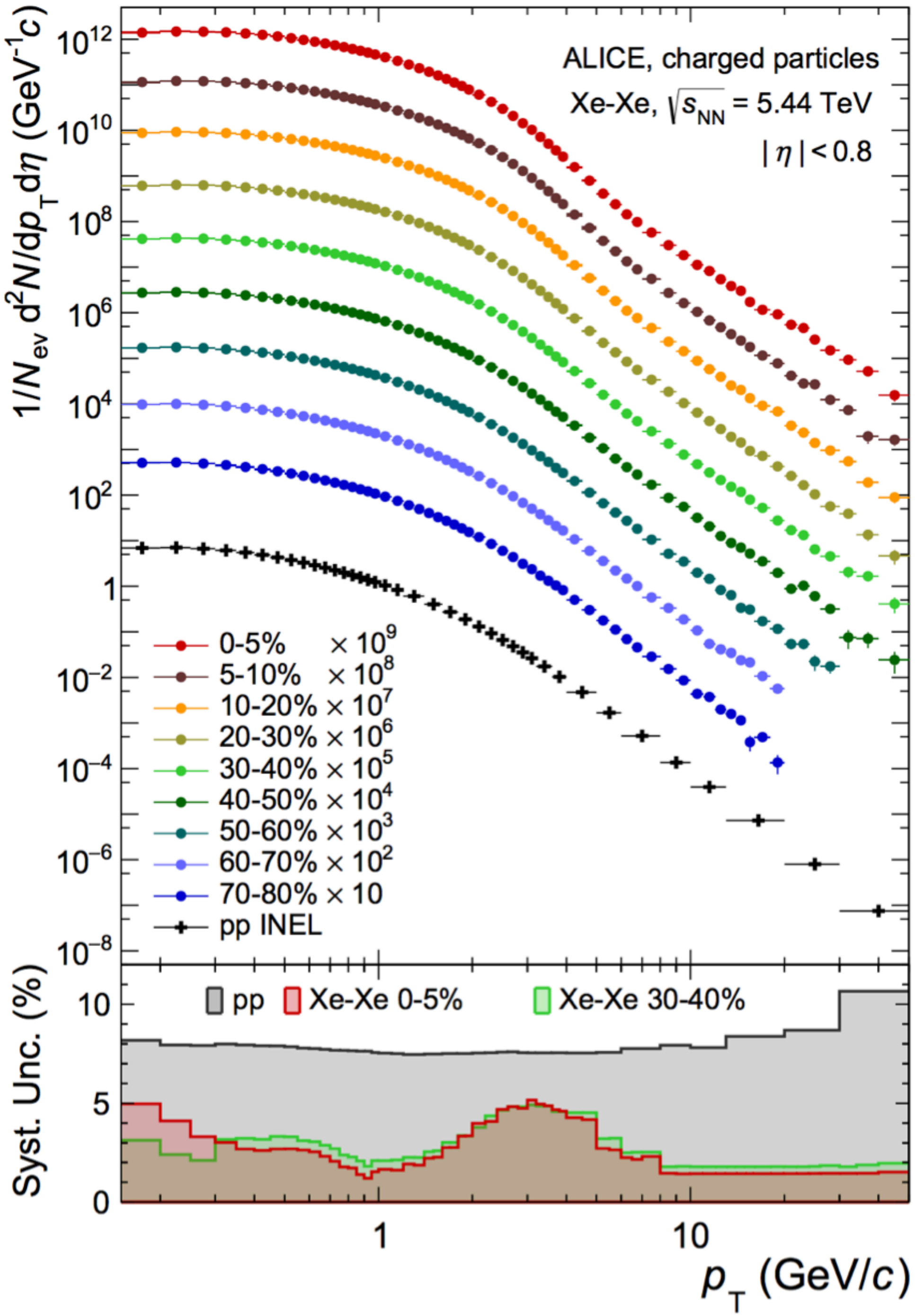
R_{AA}: Charged hadron in Pb-Pb @ 5.02 TeV

arXiv:1802.09145

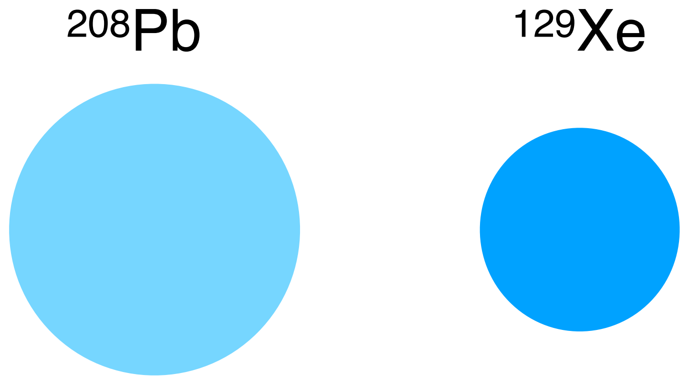


- Significantly reduced systematic uncertainties compared to Run 1
- Statistical uncertainty determined by pp baseline (update soon)
- Similar picture up to 50 GeV.
- No significant difference between 2.76 and 5 TeV.

Charged hadron: Xe-Xe @ 5.44 TeV



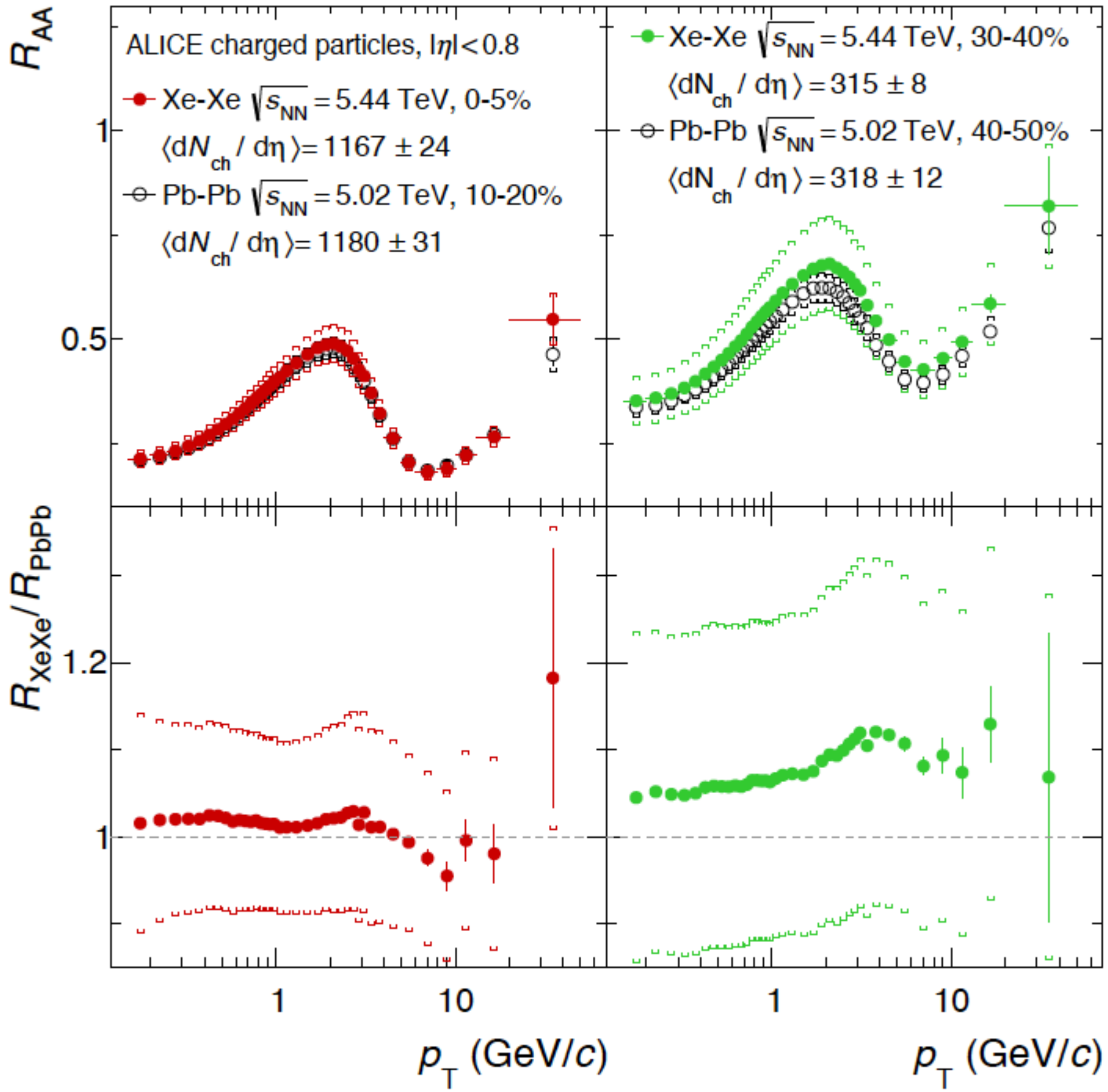
arXiv:1805.04399



- For systematic study of system size and geometry dependence, complementary for centrality dependence in Pb-Pb.
- pp baseline at √s = 5.44 TeV
  - interpolation of the measured spectra at √s = 5.02 and 7 TeV.

R_{AA} in Xe-Xe and Pb-Pb at similar $dN_{ch}/d\eta$

arXiv:1805.04399



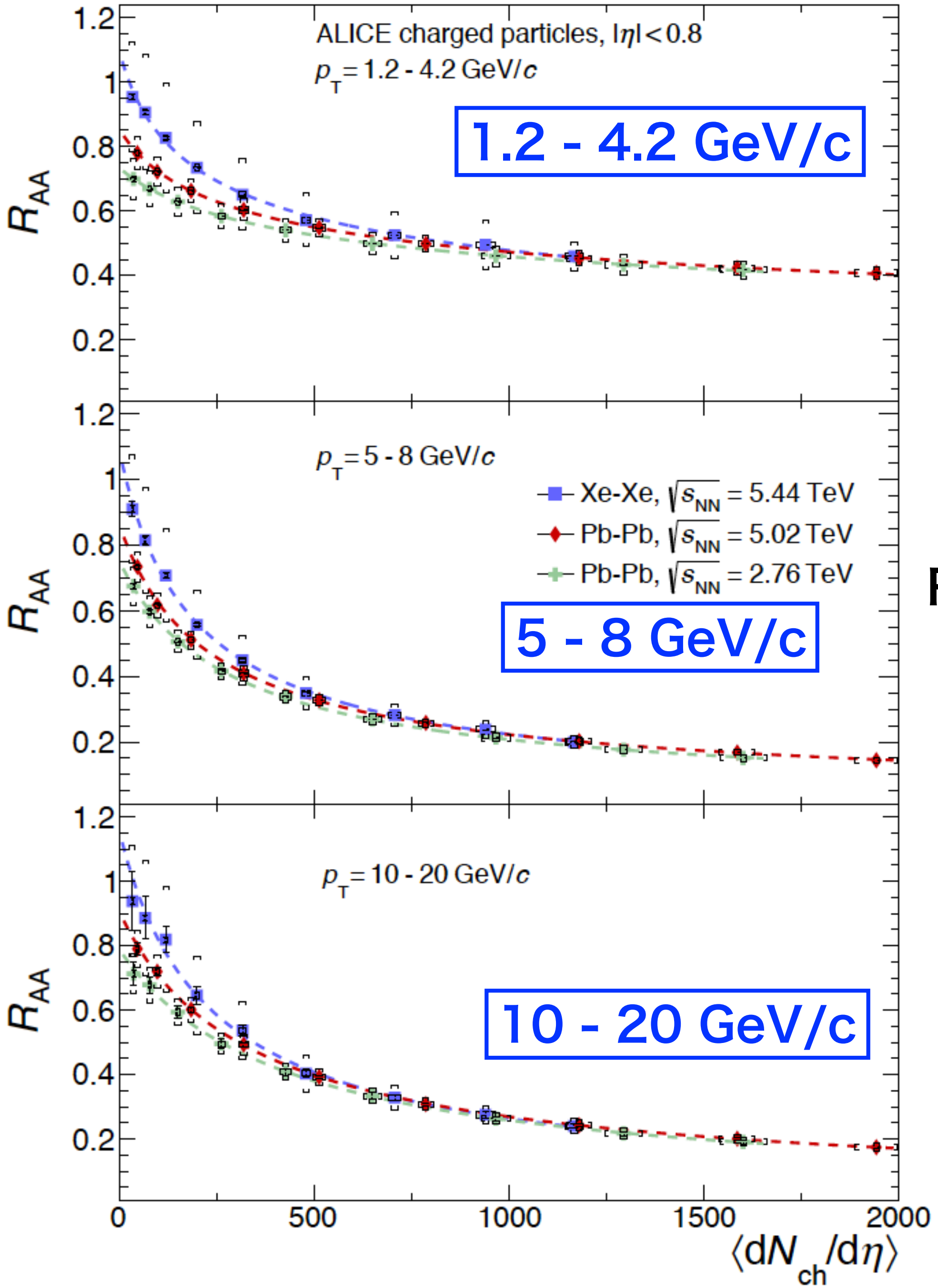
- Similar R_{AA} in the most central Xe-Xe collisions to that in 10-20% Pb-Pb collisions over the entire p_T range.

- Agreement of R_{AA} between 30-40% Xe-Xe and 40-50% Pb-Pb.

centrality	N_{part}
0-5% Xe-Xe	236 ± 2
10-20% Pb-Pb	263 ± 4
30-40% Xe-Xe	82.2 ± 3.9
40-50% Pb-Pb	86.3 ± 1.7

Testing Geometry: Xe-Xe vs. Pb-Pb

arXiv:1805.04399



Flow dominant

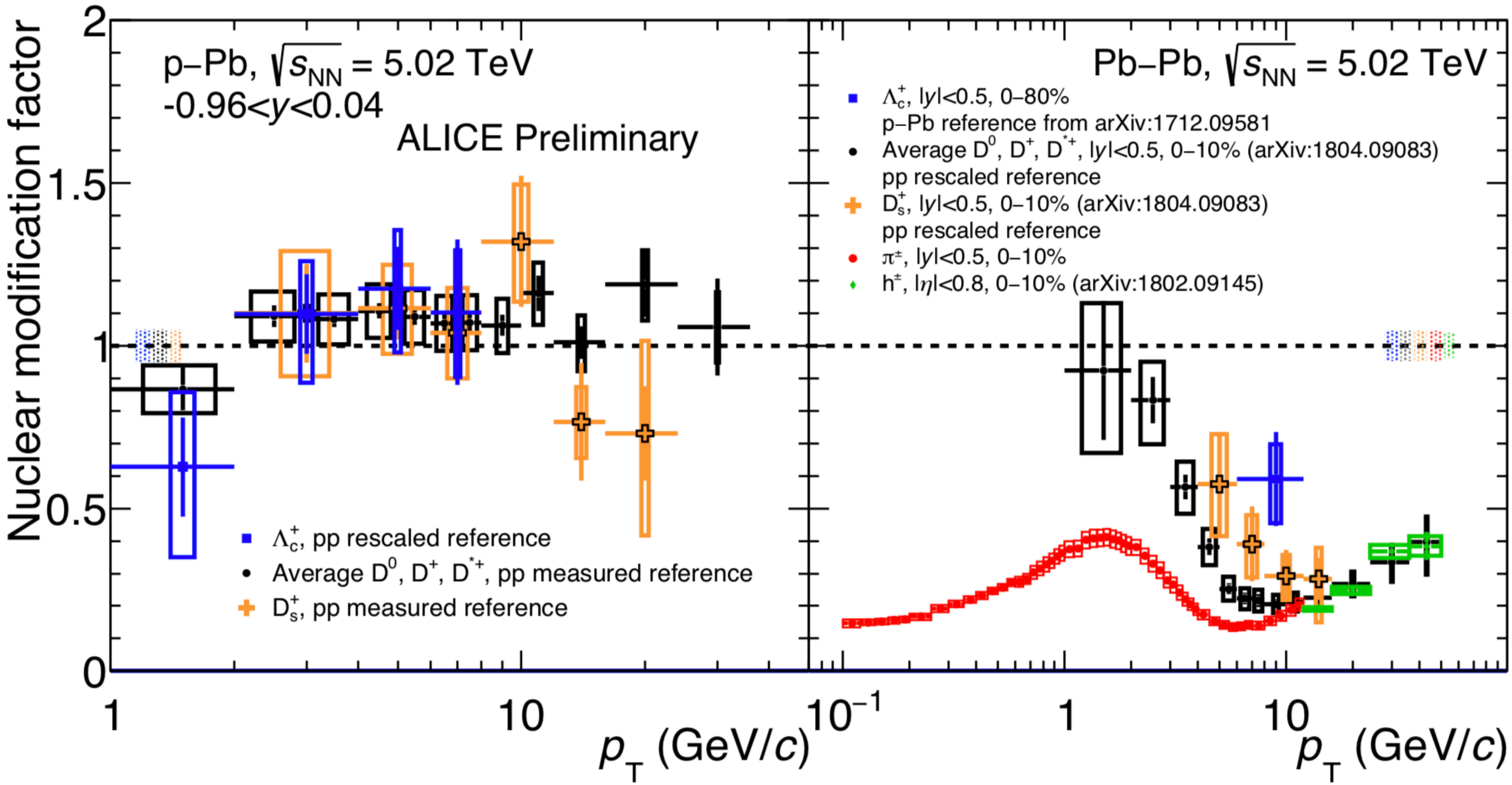
Recombination dominant

Energy loss dominant

High dN/dη (> 400): A remarkable similarity between Xe-Xe and Pb-Pb

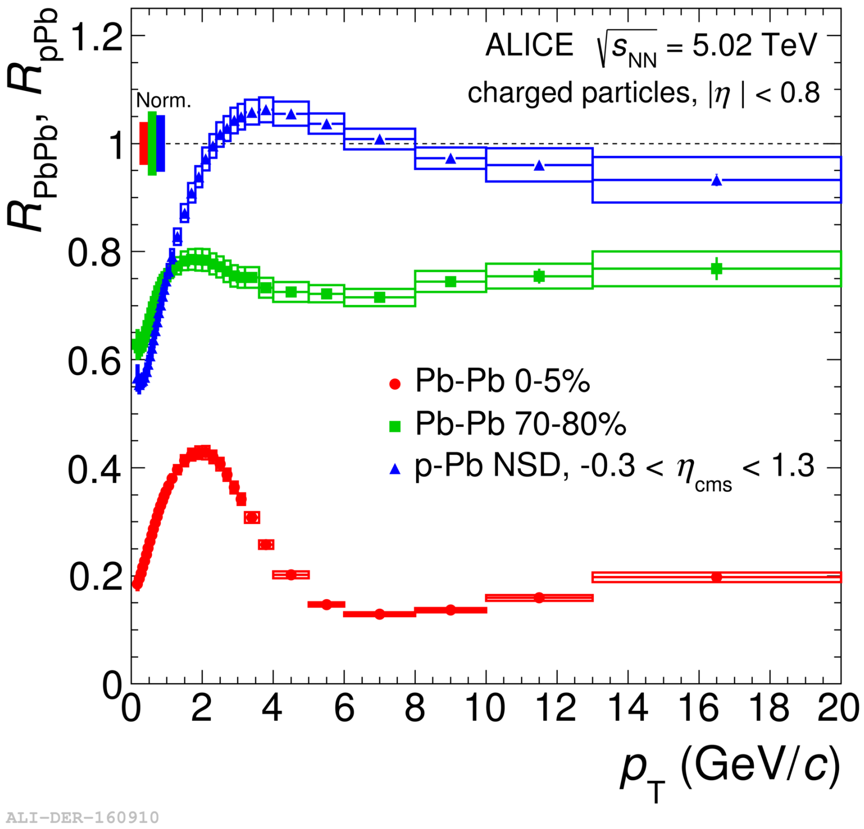
Low dN/dη (< 400): Differences between Xe and Pb geometry (irrespective of mechanism)

Heavy Flavor's R_{AA}



- Unity in p-Pb.
- Ordering for intermediate p_T in Pb-Pb $\pi < D < D_s < \Lambda_c$
- Consistent with recombination (+strangeness enhancement)

Jet quenching in peripheral Pb-Pb?



In p-Pb high multiply events:

- **long range correlations (ridge and v_2)**
- **mass ordering of v_2 for identified hadrons**
- **strangeness enhance enhancement.**

But still no evidence for jet quenching

- System is too small to quench jet?

R_{AA} ≈ 70% in peripheral Pb-Pb

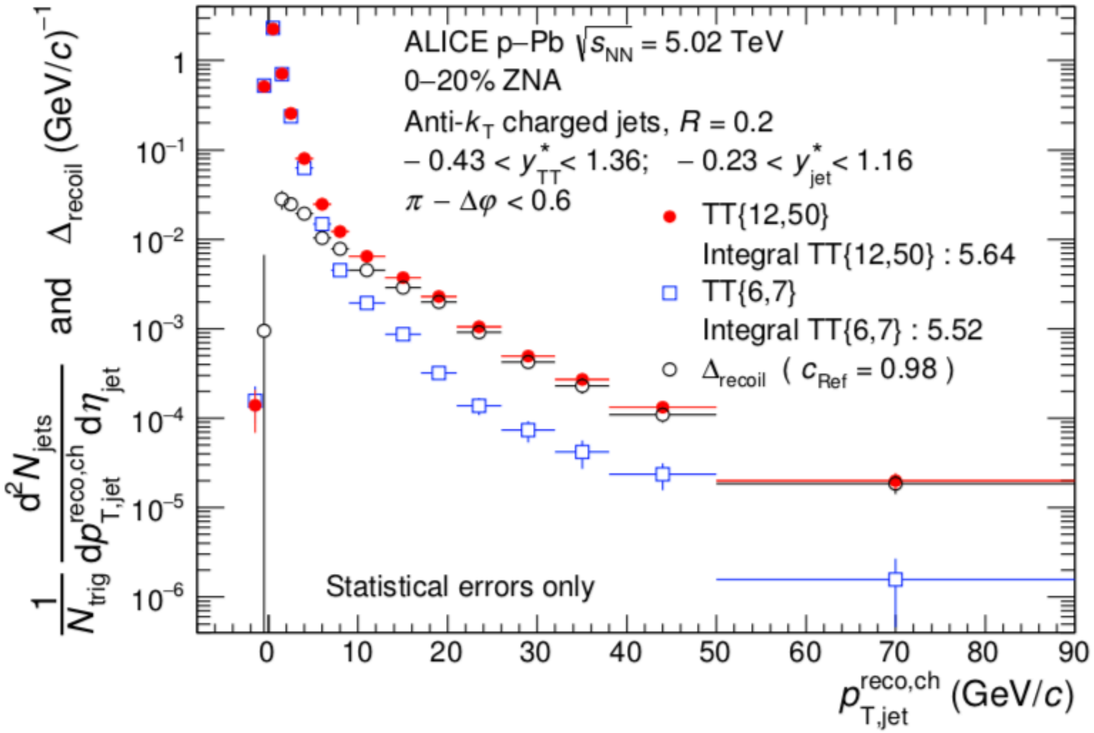
However, from N_{coll}, N_{part}, dN/dη:
70 – 80% Pb-Pb ≈ 0 – 5% p – Pb
80 – 90% Pb-Pb ≈ 0 – 100% p – Pb

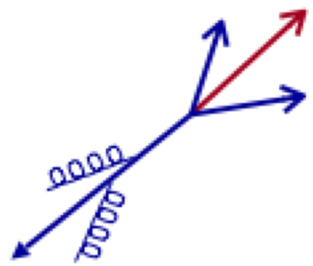
No jet quenching in p-Pb: recoil jet

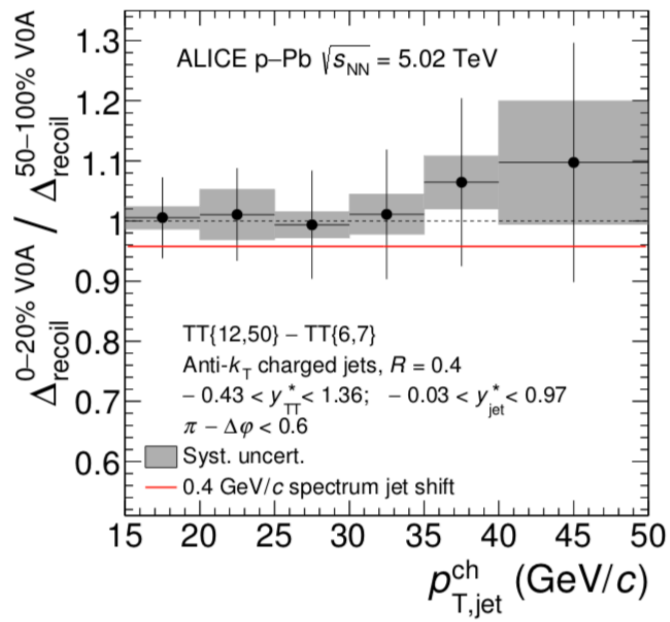
- **Semi-inclusive recoil-jet distribution**
- Jet recoiling against a trigger high p_T hadron
- To subtract uncorrelated combinations:

Δ_{recoil} = high pT trigger (12-50 GeV)
- low pT trigger (6-7 GeV/c)

- Self normalized coincidence.

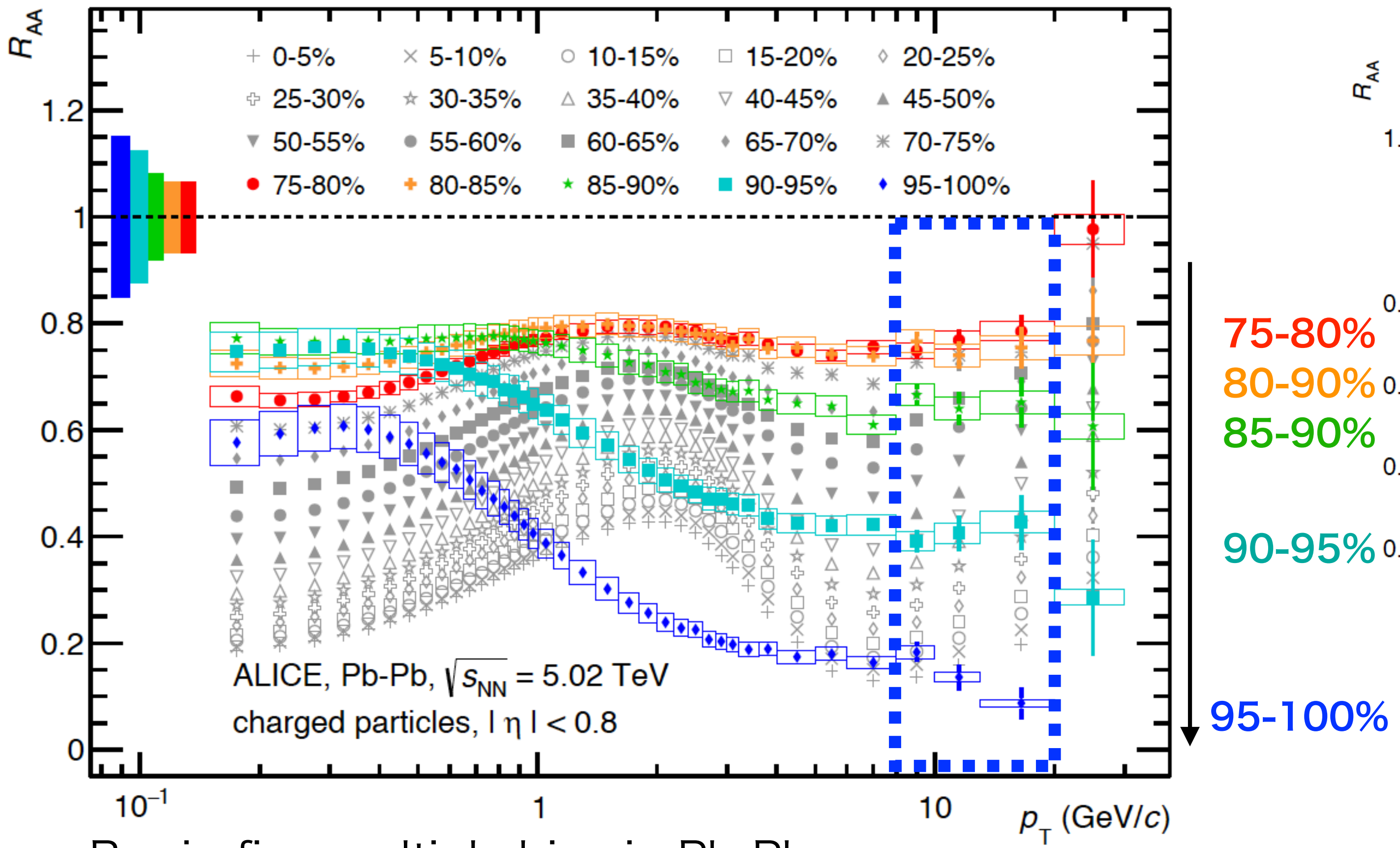




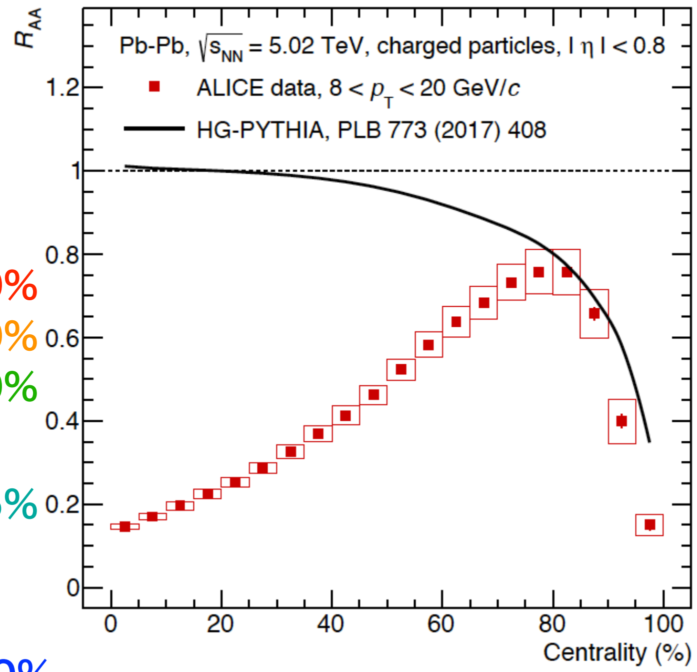


Divided central / peripheral:
no significant modification (ΔE < 0.4 GeV)

Revisit peripheral Pb-Pb



arXiv:1805.05212

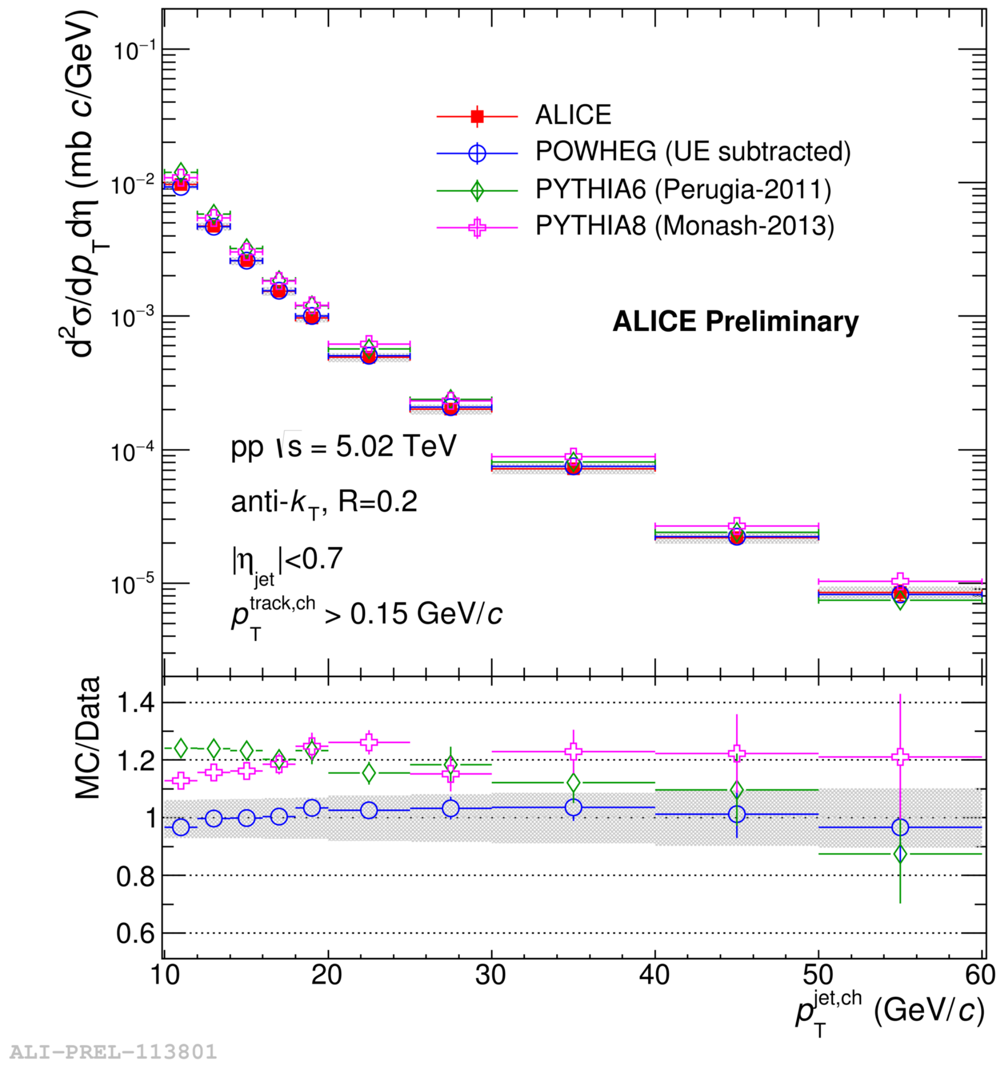


- R_{AA} in fine multiply bins in Pb-Pb
- Change of behavior for peripheral collisions : > 80% centrality -> “suppression”
- **Explained by geometry, selection biases**
  - ✓ **Larger average b_{NN} leads to less MPI per binary NN in peripheral**
  - ✓ **nuclear density/geometry bias**
- **Reproduced by PYTHIA based model : geometry and event biases, no nuclear modifications**

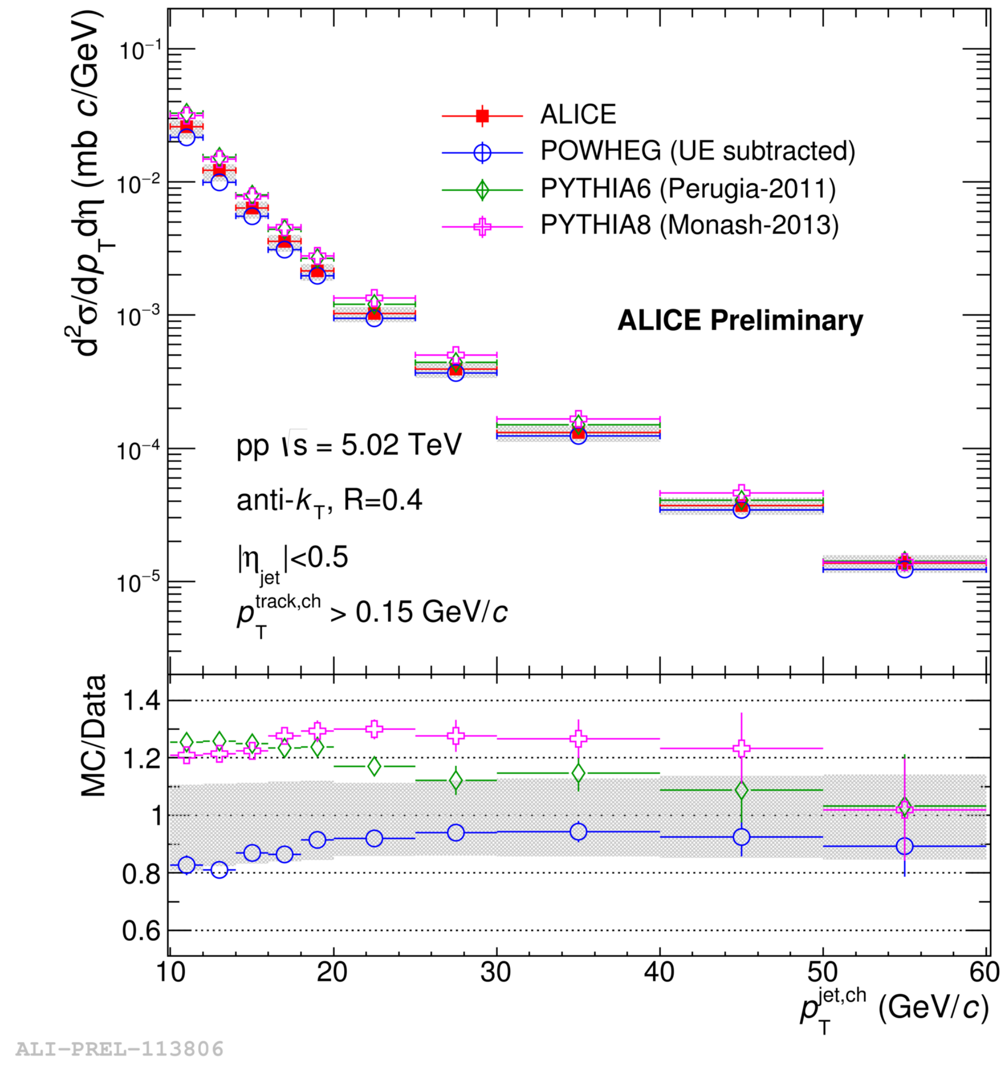
Inclusive jet spectra

Baseline: Inclusive jet spectra in pp @ 5 TeV

R = 0.2

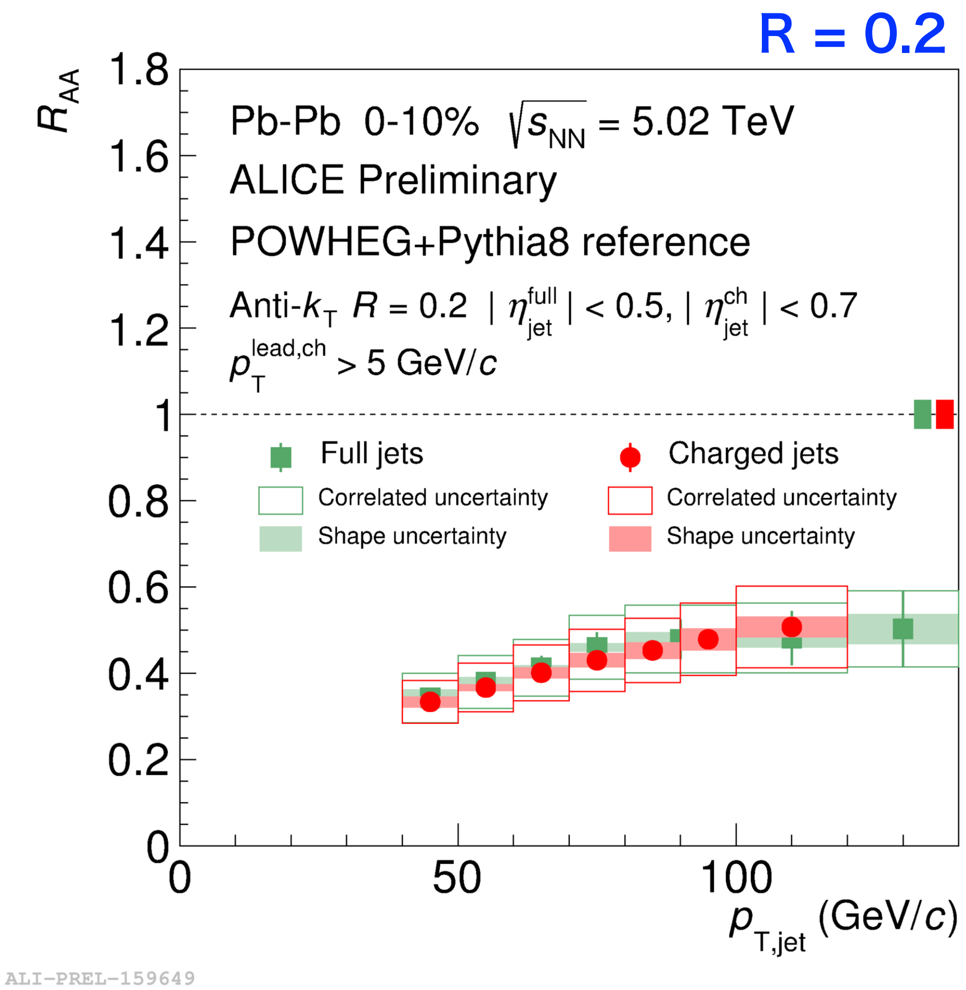


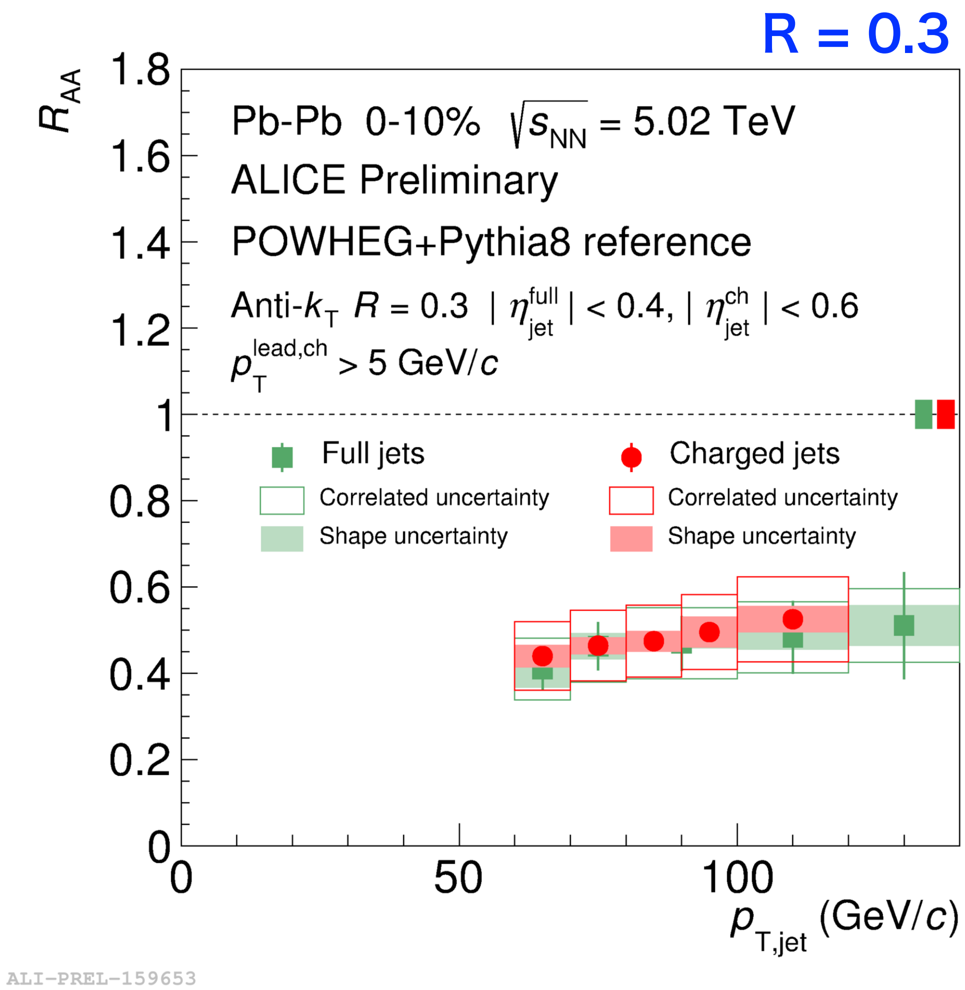
R = 0.4



Well described by POWHEG+Pythia8 prediction for both R=0.2, 0.4
(NLO pQCD + parton shower, hadronization)

R_{AA}: charged vs. full jet



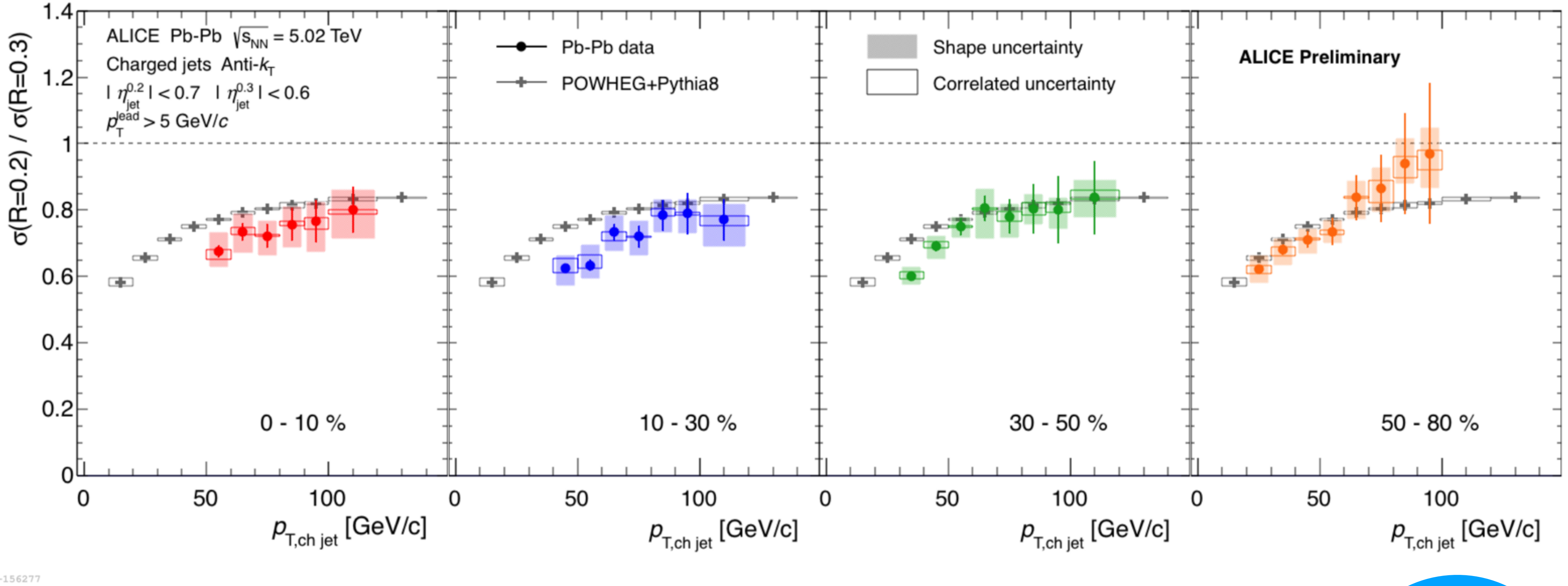


- **Strong jet suppression in central Pb-Pb for both R=0.2 and 0.3**
- **Charged vs. full jets are consistent.**
- **pp data at the same beam energy in ALICE been analyzed**

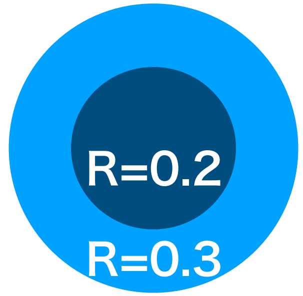
Cross section ratio: (R=0.2) / (R=0.3)

Central → Peripheral

0-10% 10-30% 30-50% 50-80%

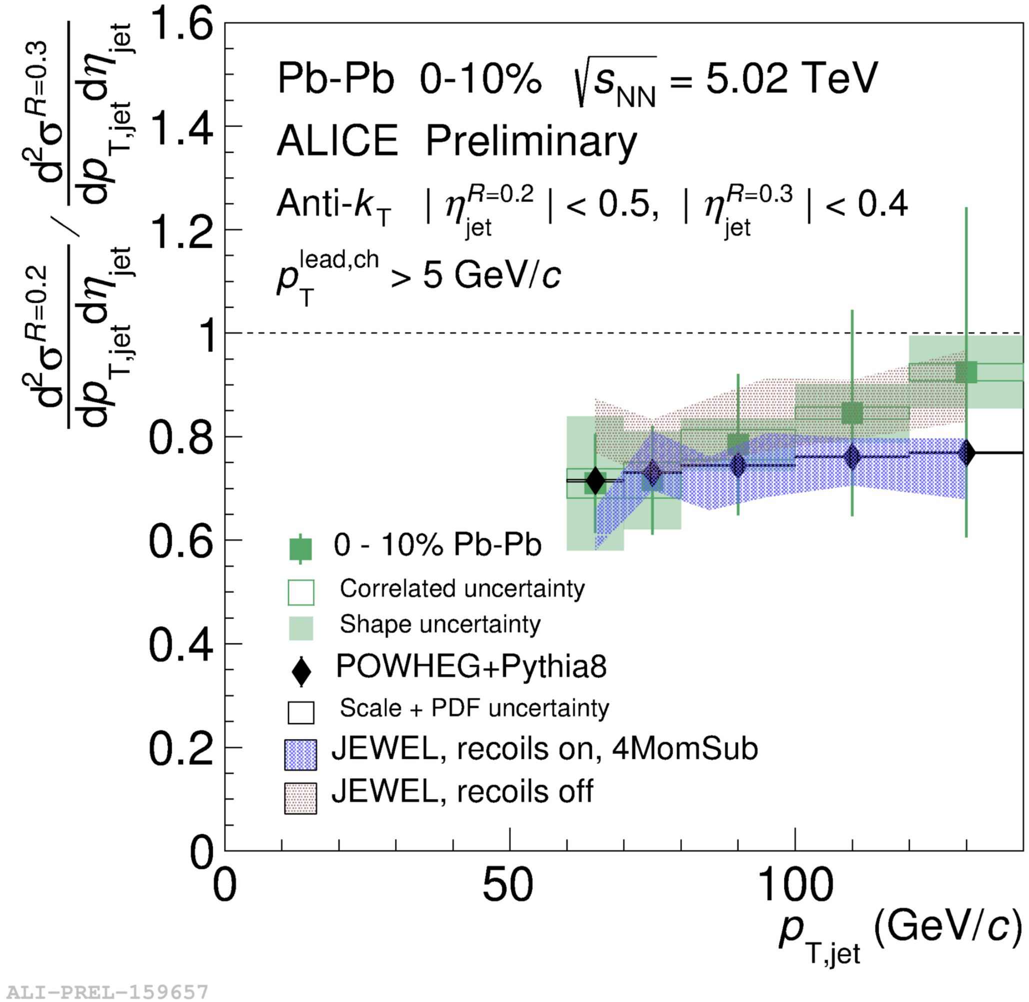


- Cross section ratio: sensitive to the jet radial profile
  - ✓ Decrease: More energy in R = 0.3 and/or less in R = 0.2
  - ✓ Increase: Collimation



- No significant difference with jets in vacuum (POWHEG+PYTHIA8)
- Small difference at low p_T in central collisions
  → Hints for stronger broadening @ low p_T

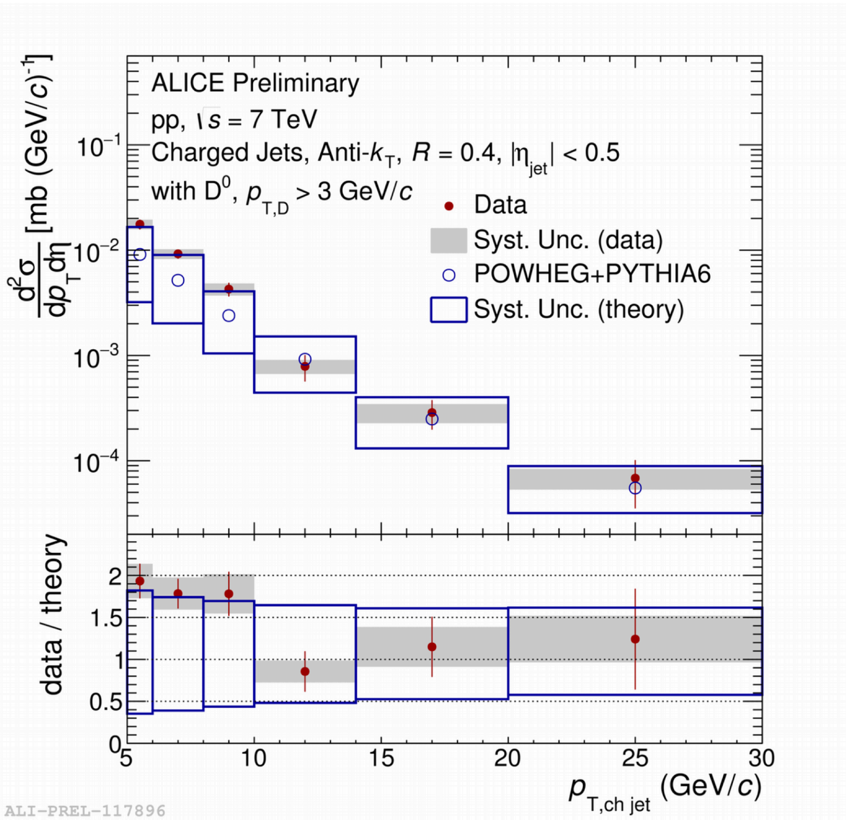
Cross section ratio: Comparison with model

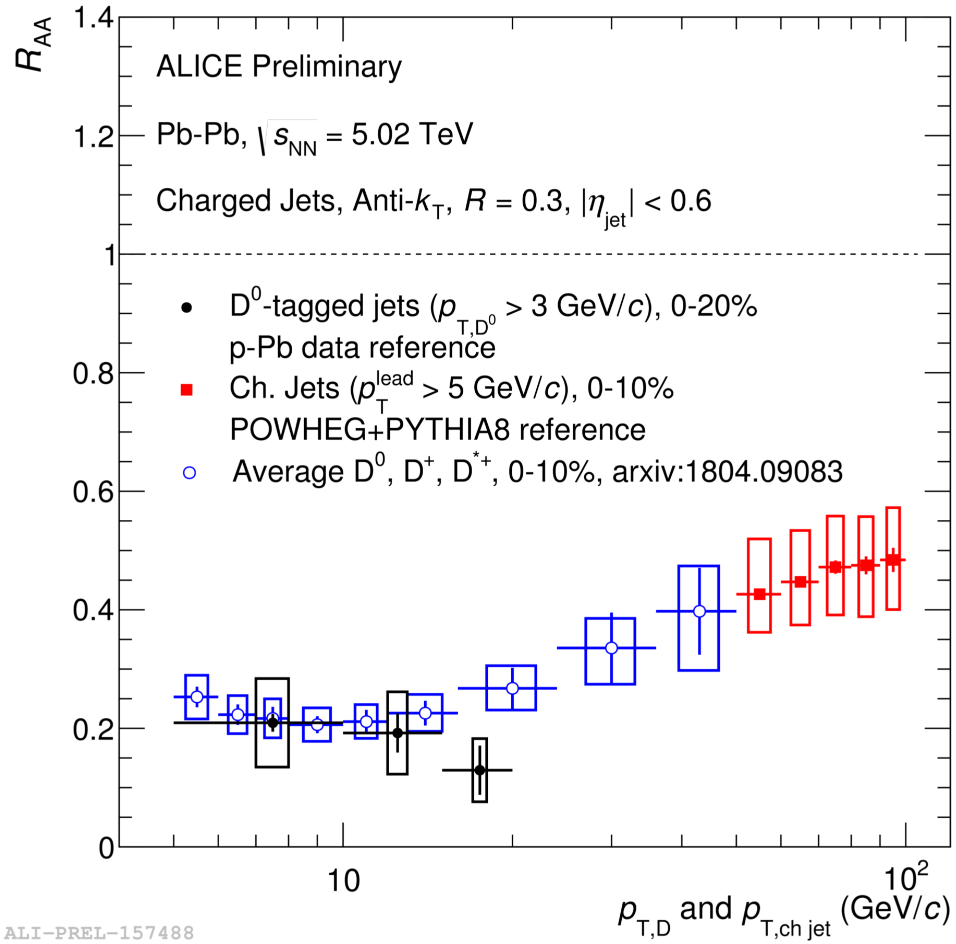


- No significant difference between the vacuum (POWHEG+PYTHIA) and JEWEL.
- JEWEL predictions agree with data.

Comparison with D⁰ tagged jets

pp @ 7 TeV





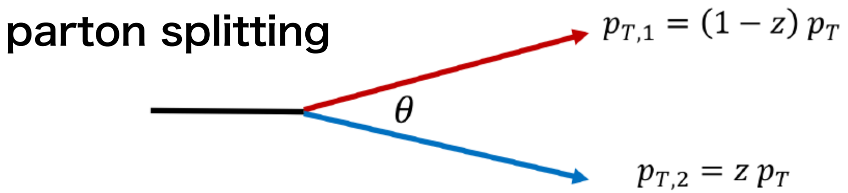
D-meson tagged jets agree with pQCD predictions in pp
⇒ well understood baseline for Pb-Pb collisions.

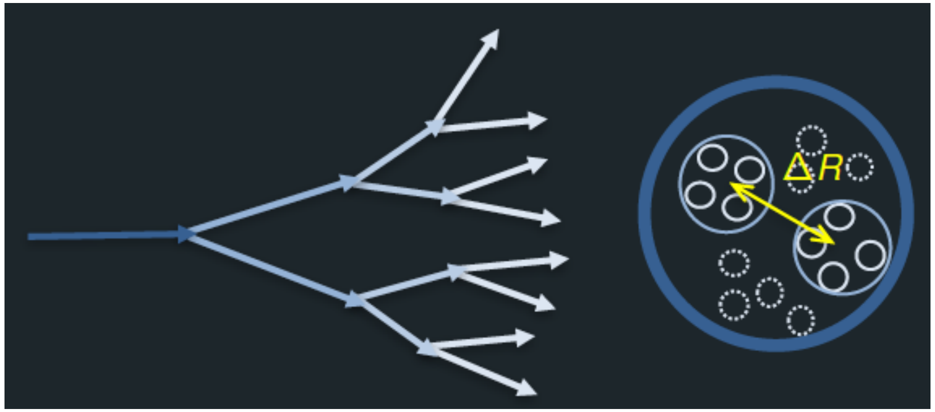
- **Similar suppression found for D^0-tagged jets as for D^0-mesons.**

Groomed jet

Mapping jet substructure: Groomed jet

- **Iterative de-clustering**
– Recluster found jet (e.g. with C/A) and unwind
– Each (sub)jet consists of 2 sub-jets

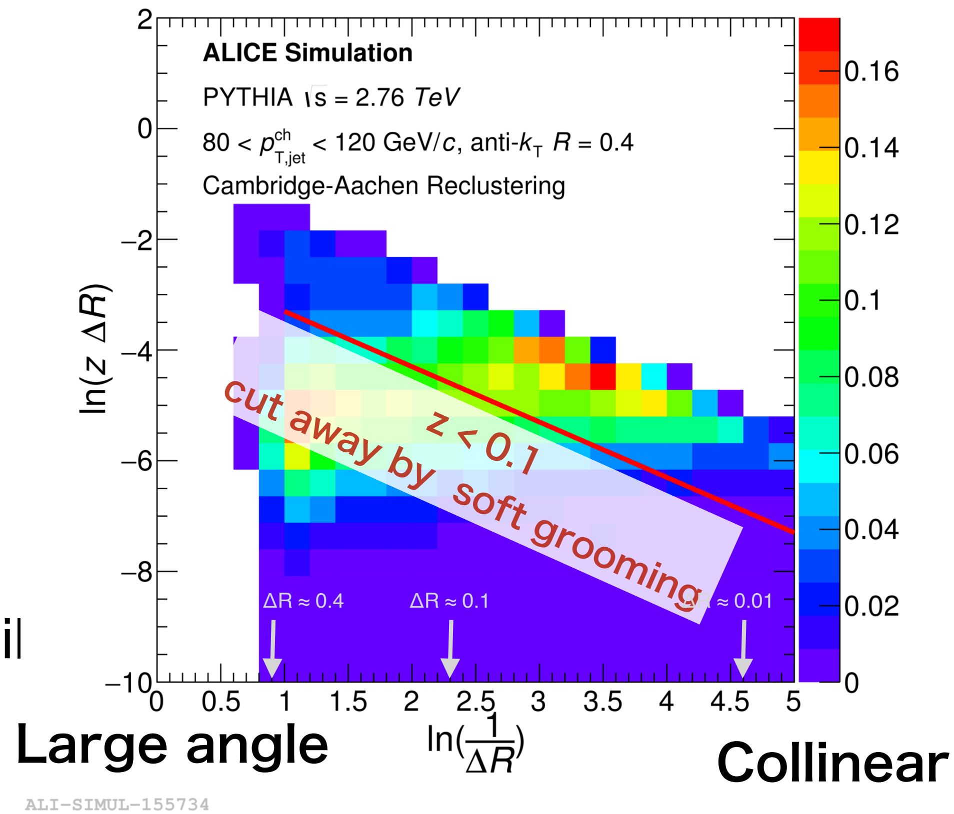




- **Lund diagram**
– Phase space of all splittings
– Momentum fraction vs. opening angle
– Isolate different regions for medium effects

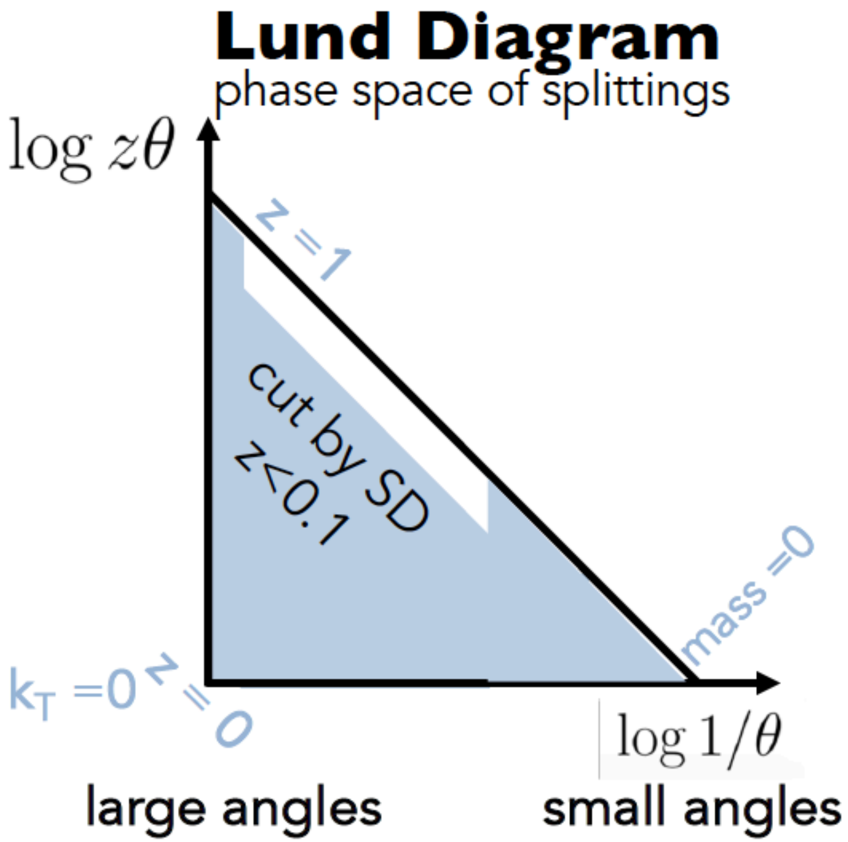
- **Grooming**
– Impose phase space cuts to enhance regions of interest
– Soft drop: unwind, follow the largest pT until

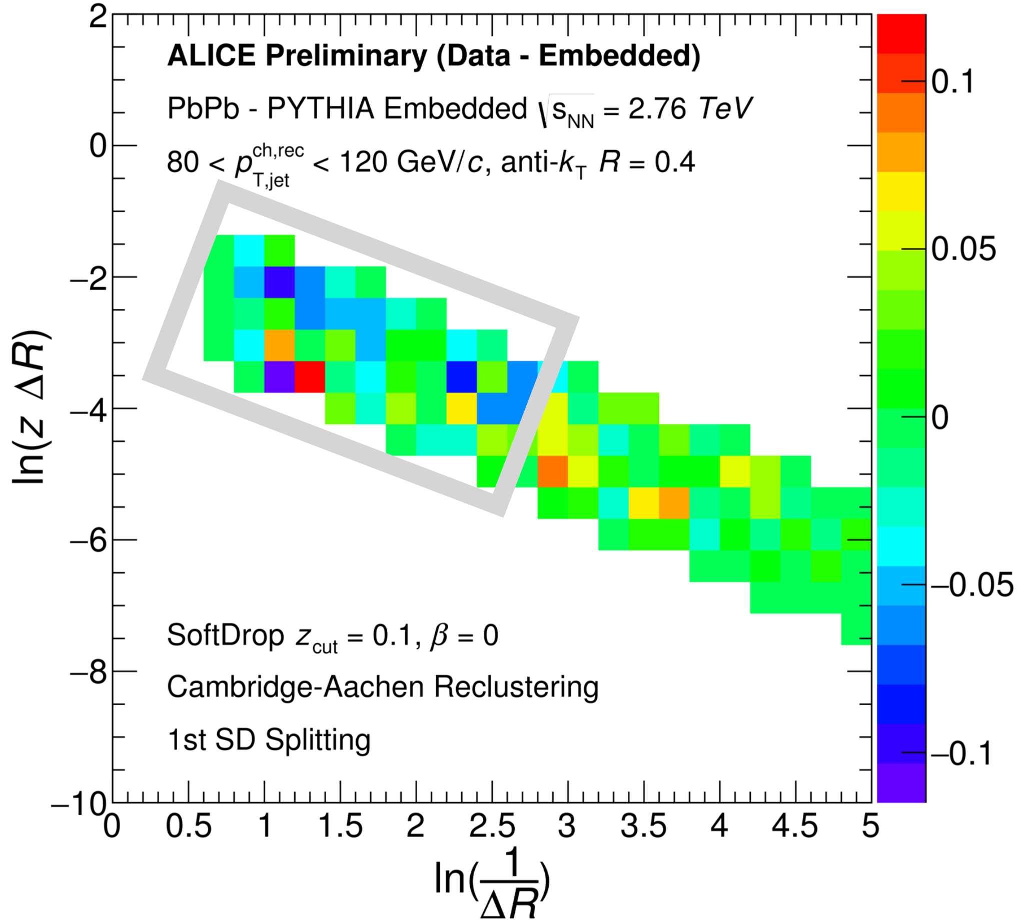
$$z > z_{cut} \cdot (\Delta R)^{\beta}$$



Lund Diagram in real data (Pb-Pb, 2.76 TeV)

from E. Epple





ALI−PREL−148246

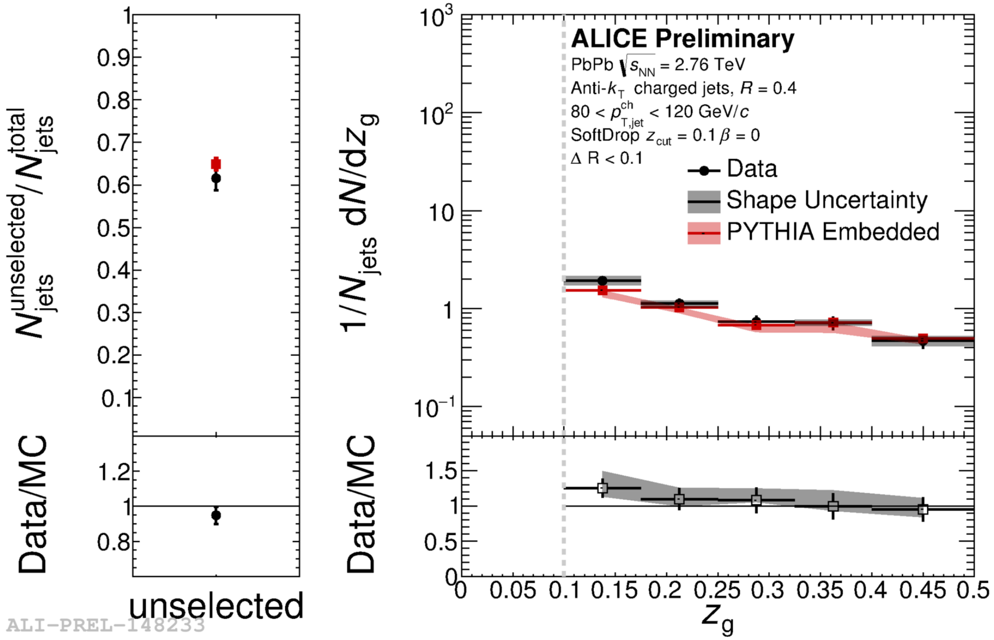
- Lund diagram for first hard splitting
- Subtracted Pb-Pb jets and embedded PYTHIA jets

Hint for a depletion of large angle first-splittings in Pb-Pb

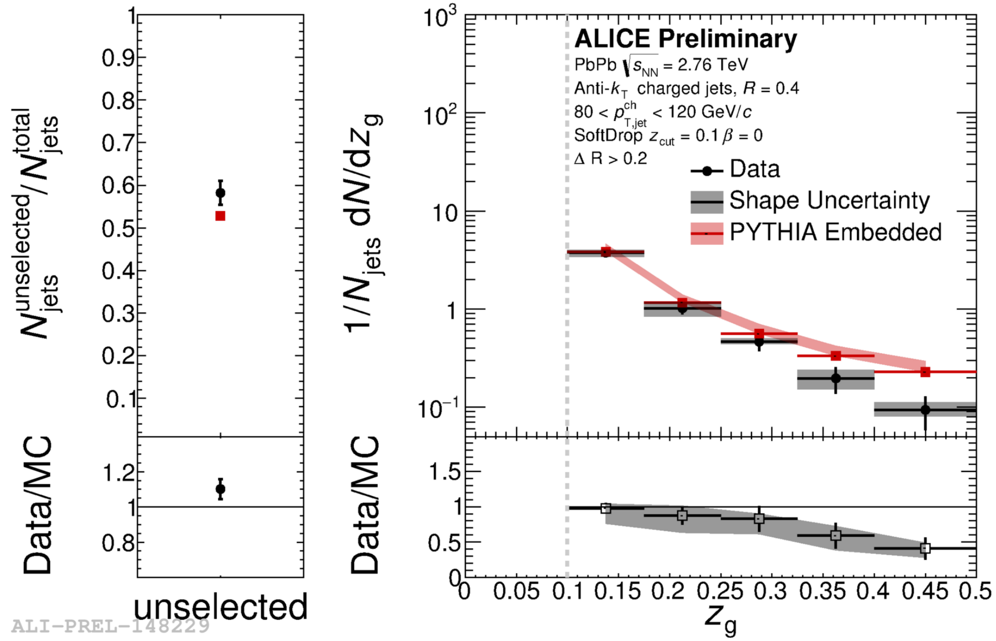
Groomed jet (z_g distributions)

Extreme angular limits of collimated and large angle splittings

ΔR < 0.1 (small, collimated angle)



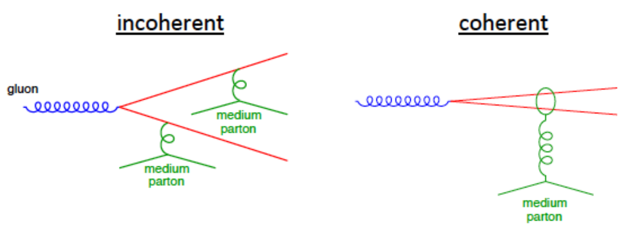
ΔR > 0.2 (large angle)



Slight enhancement of collimated first- splittings.

suppression of large angle first (symmetric) splittings.
In large angle limit, no evidence for excess of low z splittings.

sensitive to coherence of energy loss



z_g: shared momentum fraction of the first groomed splitting

$$z_g = \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}},$$

Summary and outlook

Exploring differential picture of parton energy loss by jet at LHC

- **R_{AA} of hadrons**: reaching at precision measurements.
- **jet spectra**: new data using the new high interaction rate data in Pb-Pb
  - a hit of stronger brooding at lower p_T, central Pb-Pb.
- **Groomed jets**:
  - Detailed picture of parton shower provided by Lund Plane
  - A tool to select substructures
  - Showed suppression of large angle splittings and slight enhancement of collinear splittings compared to embedded PYTHIA

- **Outlook**
  - Jet spectra →towards larger *R* and low jet p_T
  - Recoil jets, tagged jets (c, b) →jet-h, h-jet correlations w/ trigger data
  - Groomed jets and jet sub-structure
  - Jet mass, Dijet-kT
  - Di-jet, gamma-jet
  - Di-jet + soft hadron (PID)
  - …

Harvest of jet physics in ALICE !

Thank you !