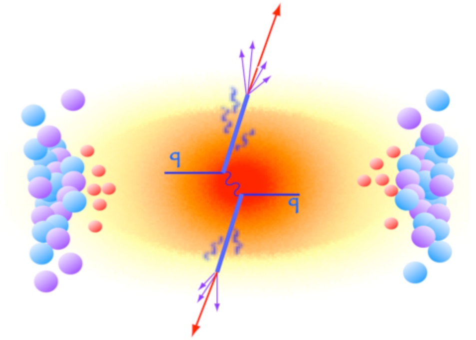

Recent results on jets in ALICE

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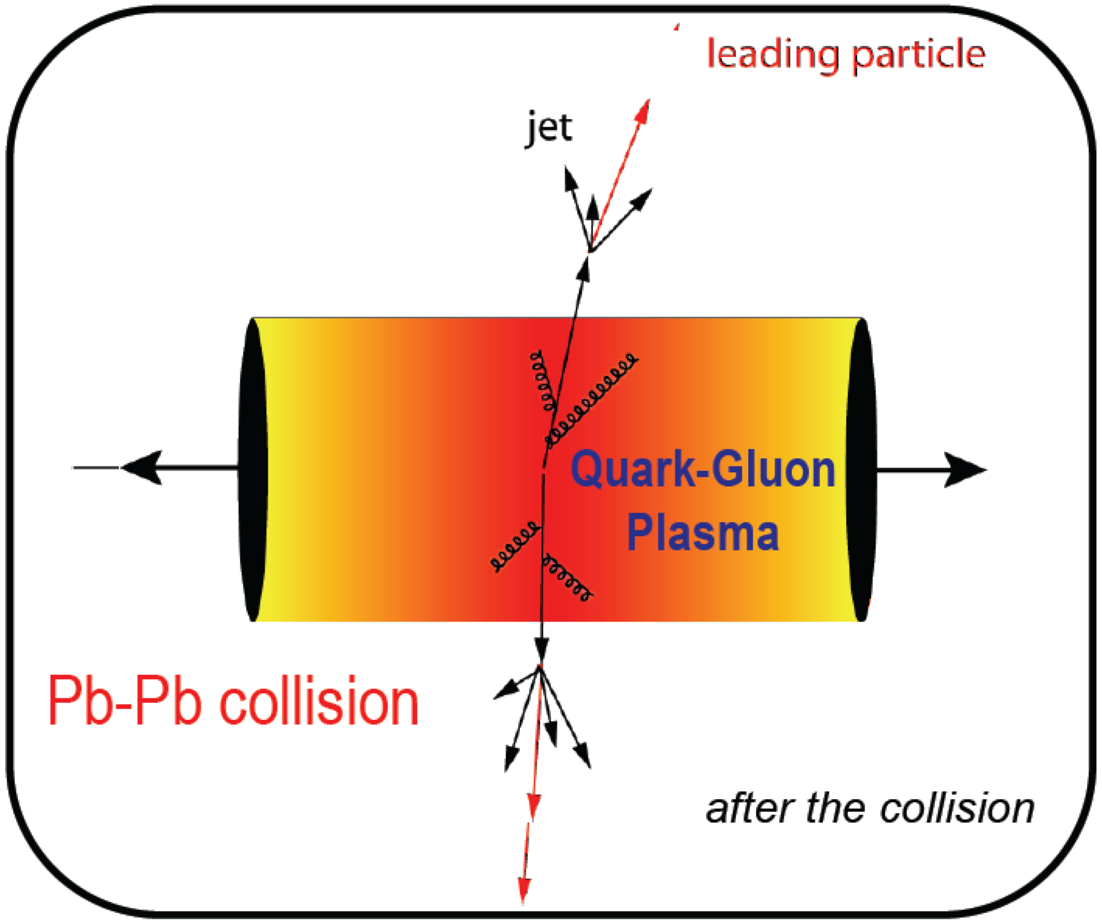
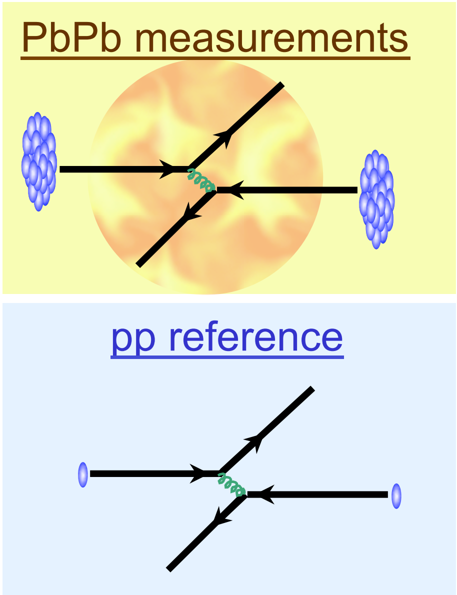
Central China Normal University

11th France China Particle Physics Laboratory Workshop (FCPPL2018)
Marseille, France 22-25 May, 2018

Probing hot QCD matter with hard probes

- Hard probes serve as calibrated probe (pQCD)
- Hard probes traverse through the medium and interact strongly with the hot QCD matter
- Suppression pattern provides density measurements
- General picture: parton energy loss through medium-induced gluon radiation and collisions with medium constituents
- Quantify the medium effects with nuclear modification factor

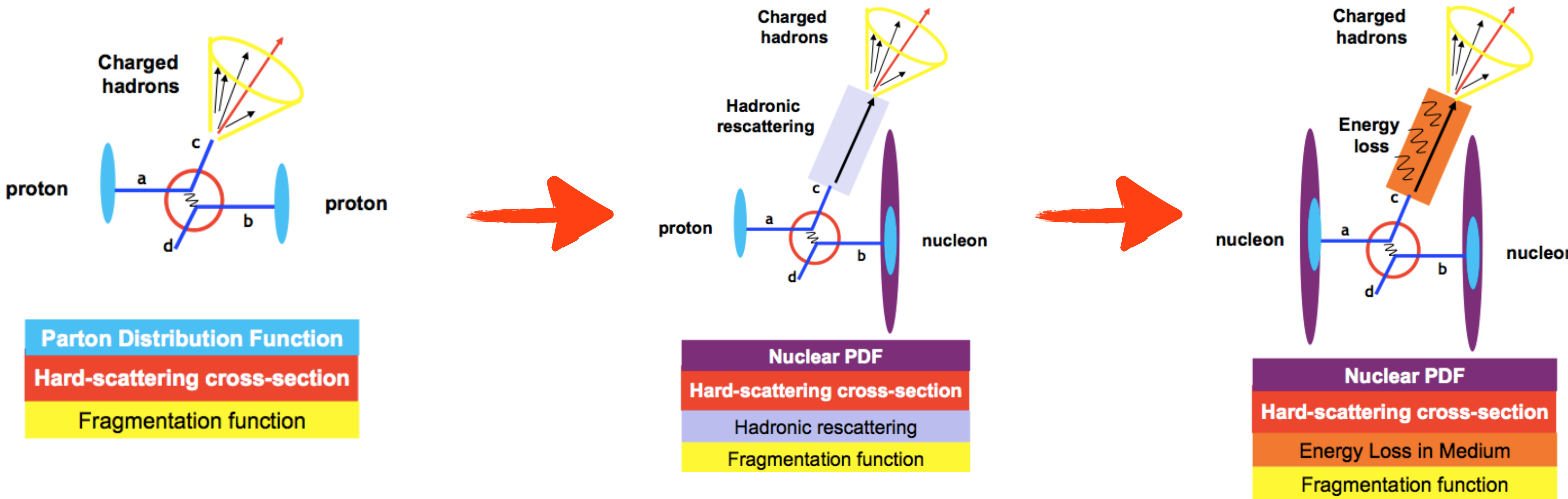




$$= R_{AA} = \frac{\sigma_{pp}^{inel}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dp_T d\eta}{d^2\sigma_{pp}/dp_T d\eta}$$

- $R_{AA} > 1$ (enhancement)
- $R_{AA} = 1$ (no medium effect)
- $R_{AA} < 1$ (suppression)

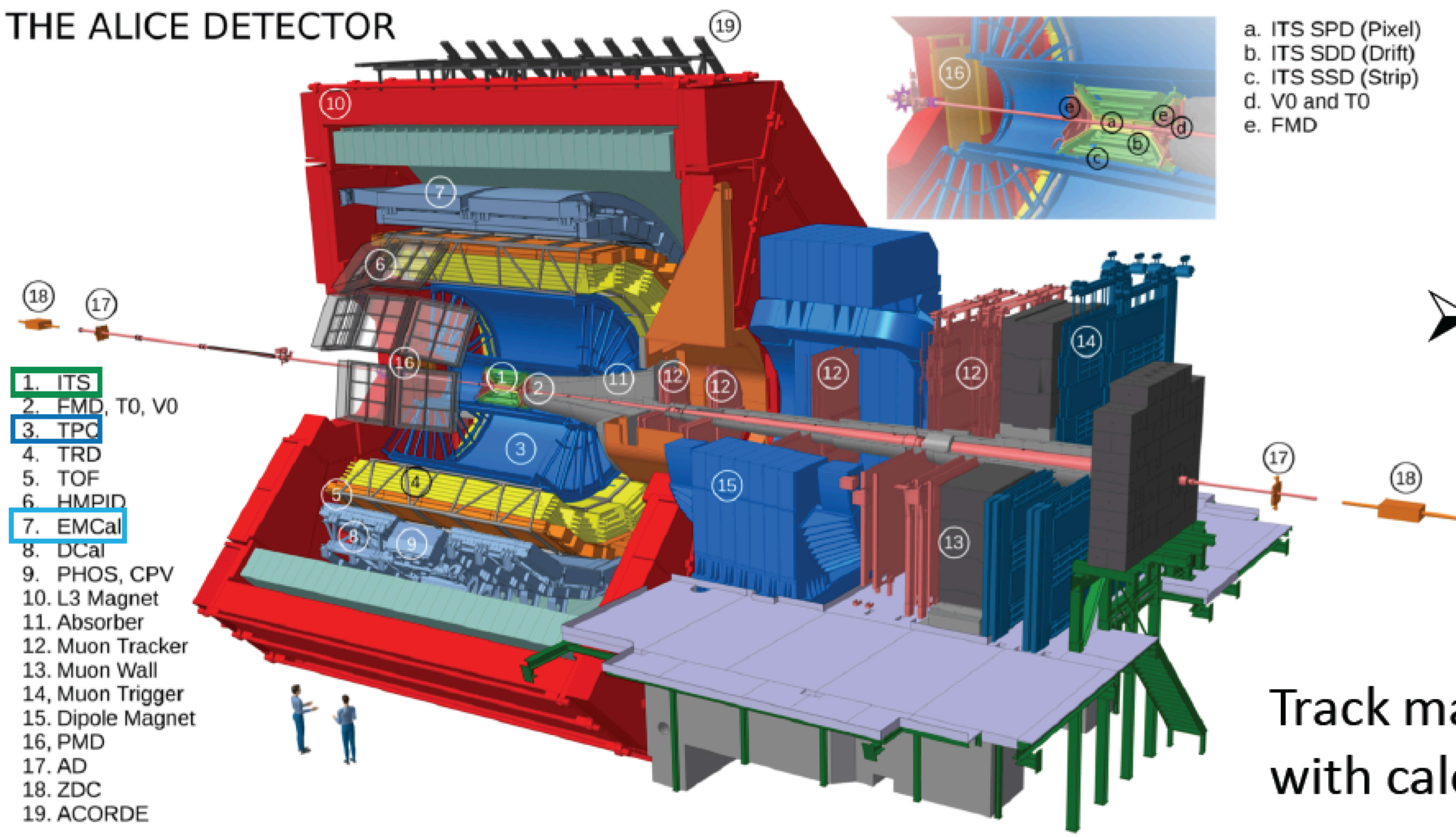
Nuclear effects probed by hard process (jets)



- Disentangle initial and final state effects
- Characterize nuclear PDFs
- Significant increase in integrated luminosity allows more precise investigation of statistic hungry probes

systems	years	$\sqrt{s_{NN}}$ (TeV)	L_{int}
Pb-Pb	2010-201111	2.76	~75 μb^{-1}
	2015	5.02	~250 μb^{-1}
	by end of 2018	5.02	~1 nb^{-1}
Xe-Xe	2017	5.44	~0.3 μb^{-1}
p-Pb	2013, 2016	5.02	~18 nb^{-1}
	2016	8.16	~25 nb^{-1}
p-p	2009-2013	0.9, 2.76, 7, 8	~200 μb^{-1}, ~100 nb^{-1} ~1.5 pb^{-1}, ~2.5 pb^{-1}
	2015, 2017	5.02	~1.3 pb^{-1}
	2015-2017	13	~25 pb^{-1}

Jet measurements in ALICE



- EM calorimeter
  - Sampling calorimeter with Pb-scintillator
  - Acceptance: $80° < \varphi < 188°$, $|\eta|<0.7$

- Charged particle tracking
  - ITS (Inner tracking system)
    - Consists of three silicon detectors (SPD,SSD,SDD)
    - Acceptance: $0 < \varphi < 2\pi$, $|\eta|<0.9$
  - TPC (Time projection chamber)
    - Gas detector
    - 3D tracking
    - Acceptance: $0 < \varphi < 2\pi$, $|\eta|<0.9$

Track matching with calorimeter

Remove charged particle contributions

Neutral constituents

$E_{cluster} > 0.3$ GeV

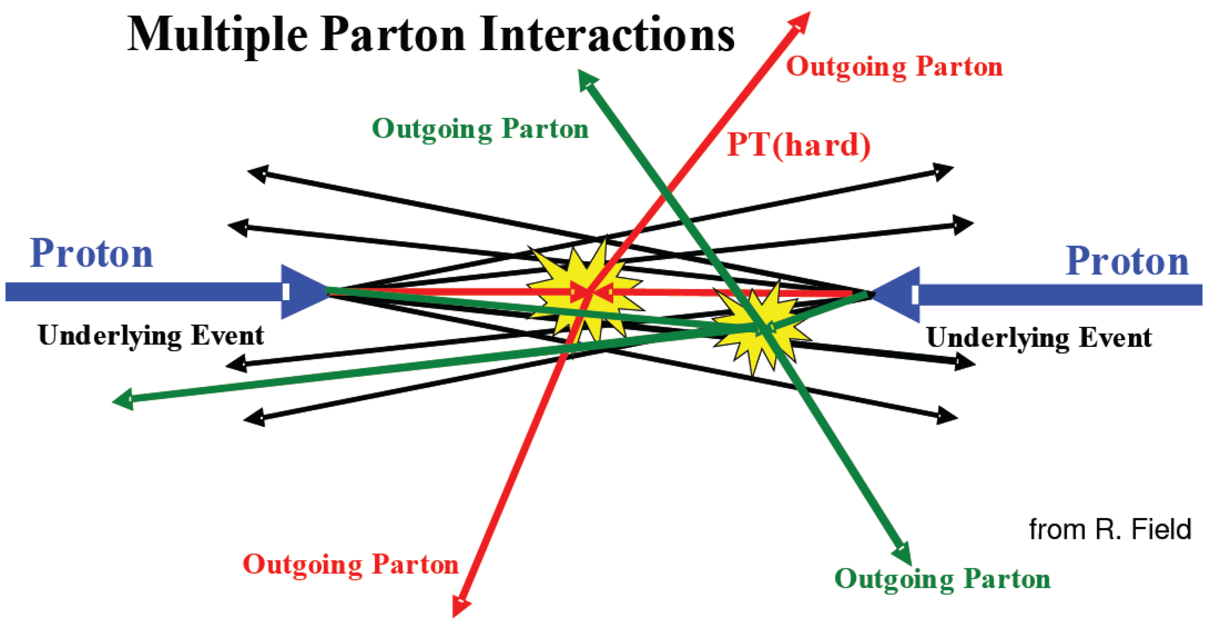
Charged constituents

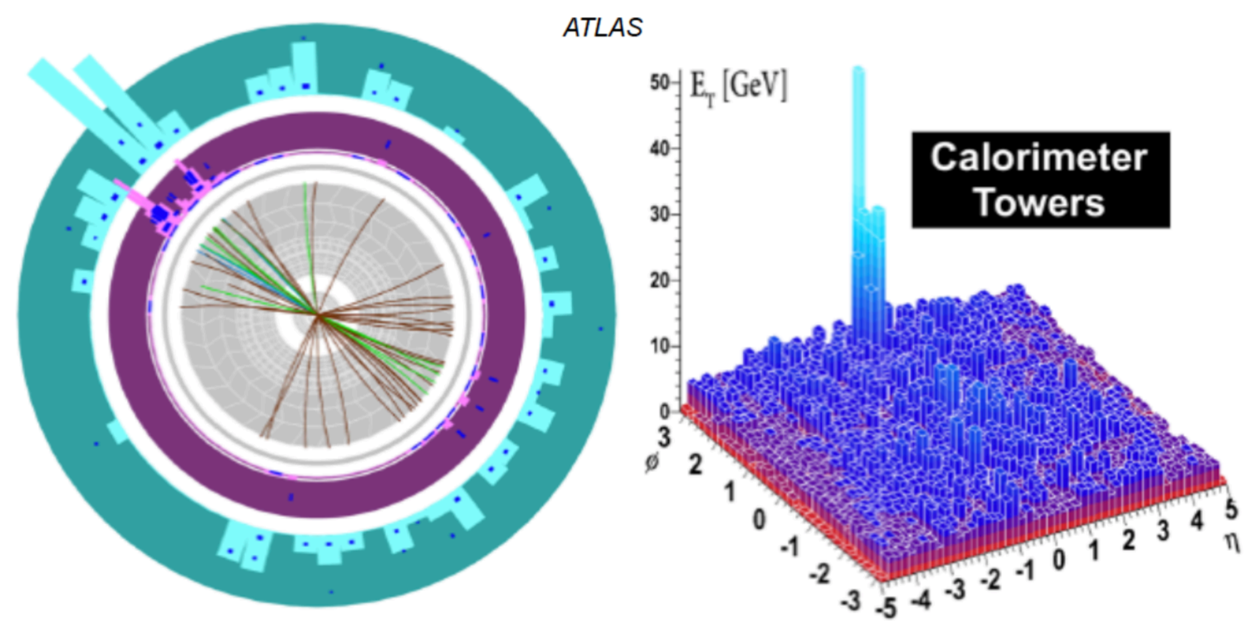
Full Jets

$p_{T,track} > 0.15$ GeV/c

Charged Jets

Underlying Event (UE) in jet reconstruction

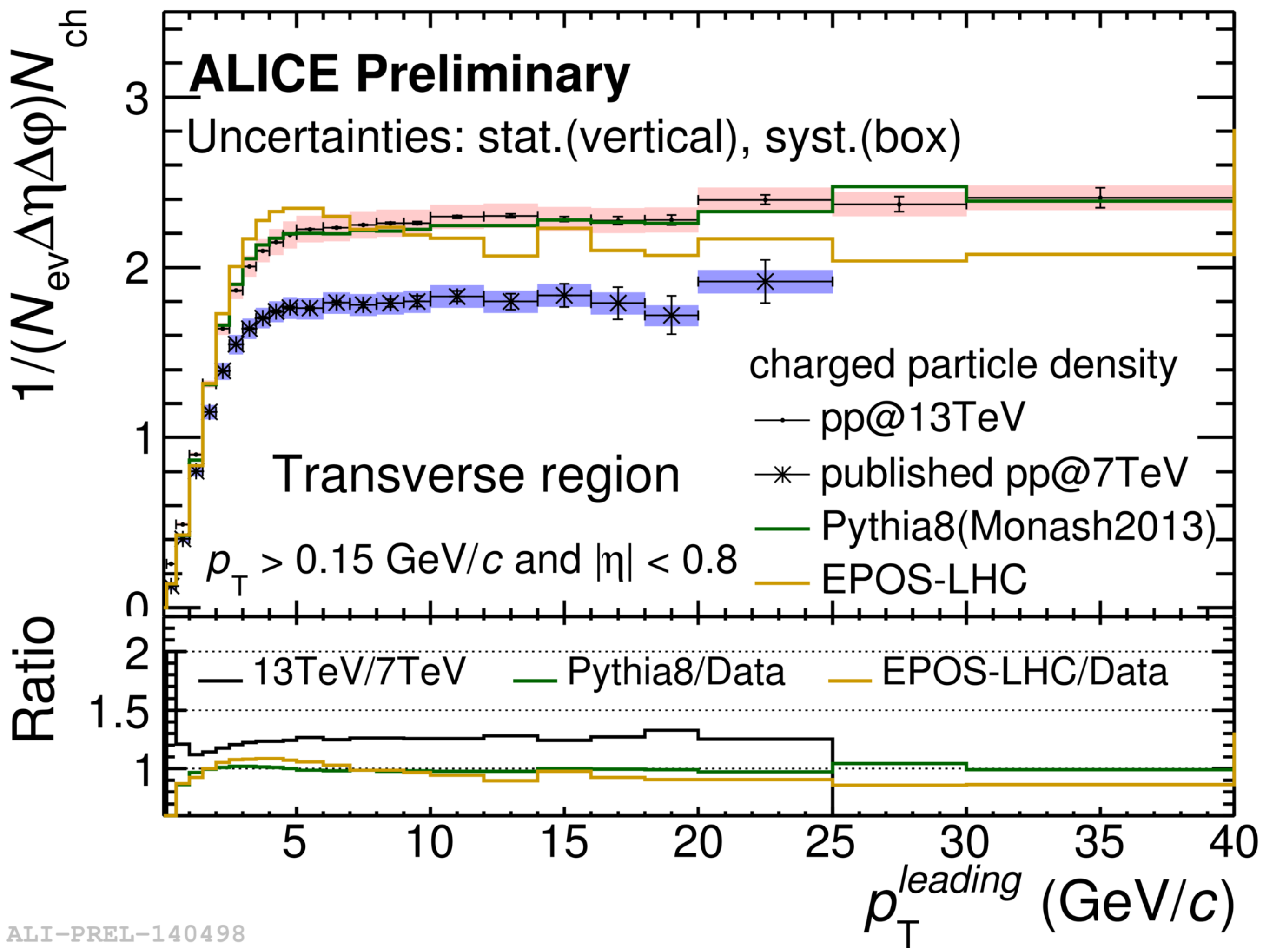




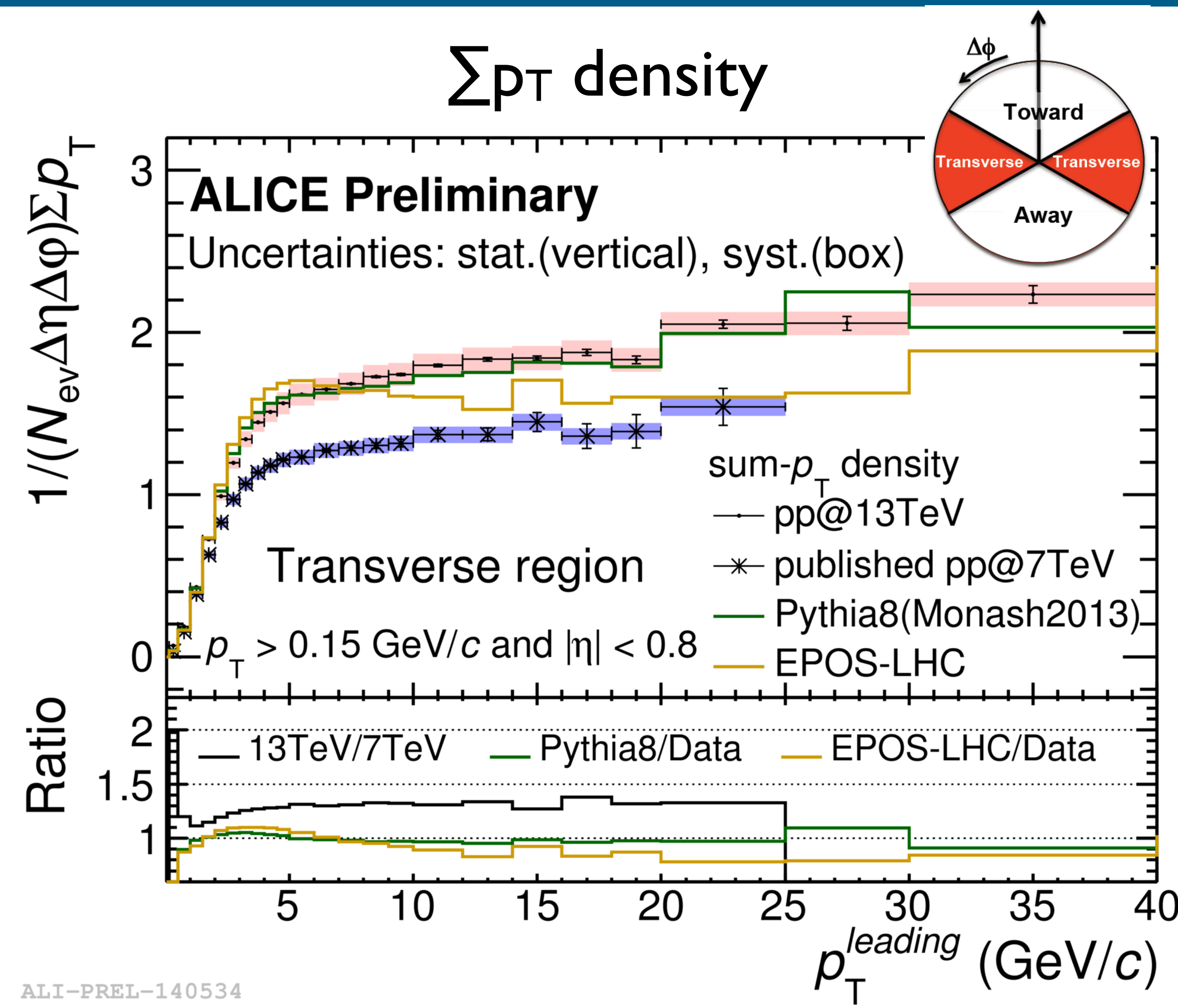
- Background gets clustered into jets, need to decide which particles are part of jets and which belong to UE
- Good control of UE allows to access deep information of the hadronic structure and hard probes
- Two strategies:
  - cluster jets and subtract observable-by-observable
  - subtract UE on entire event, then cluster jets

Underlying event study

charged particle density

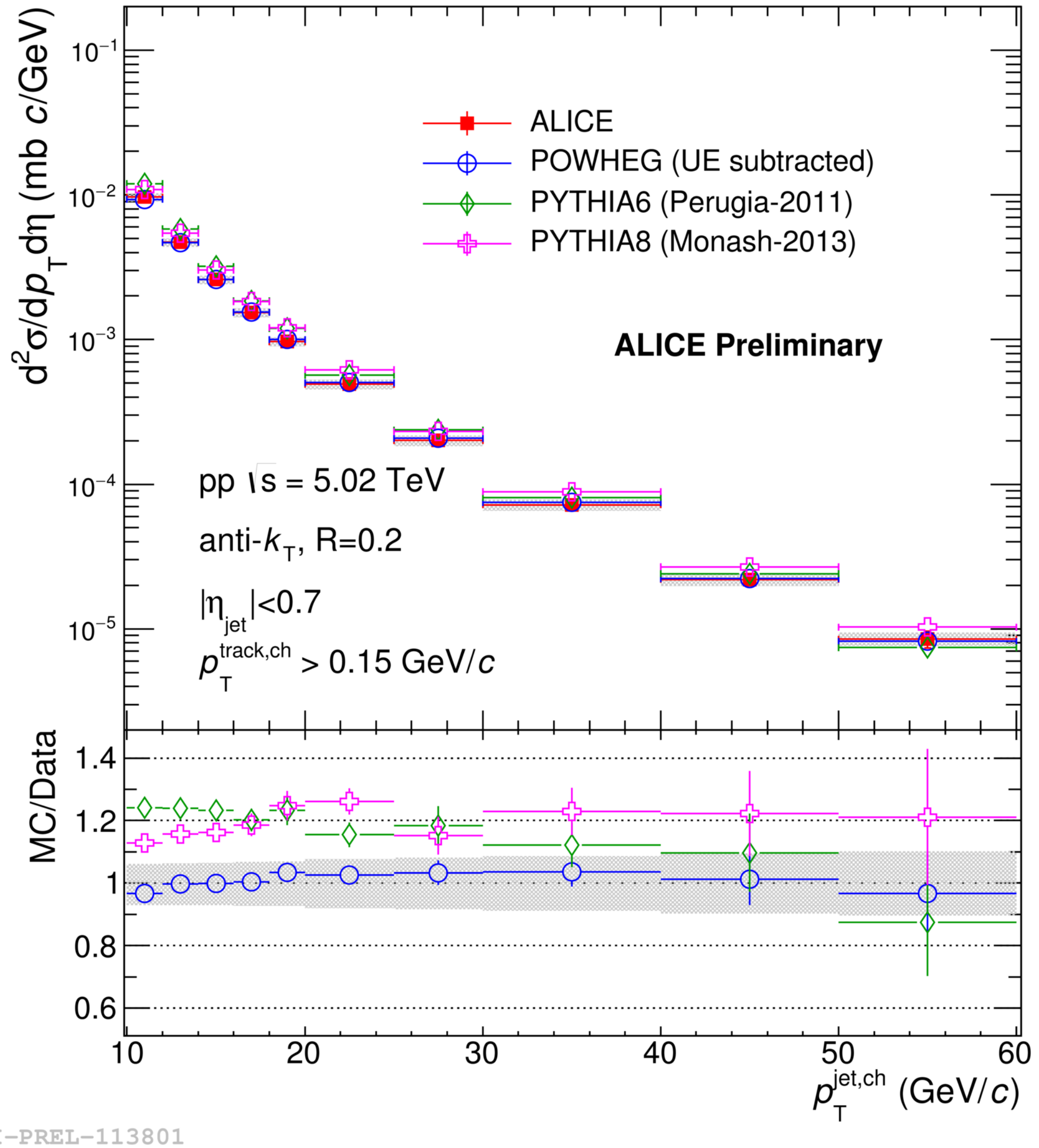


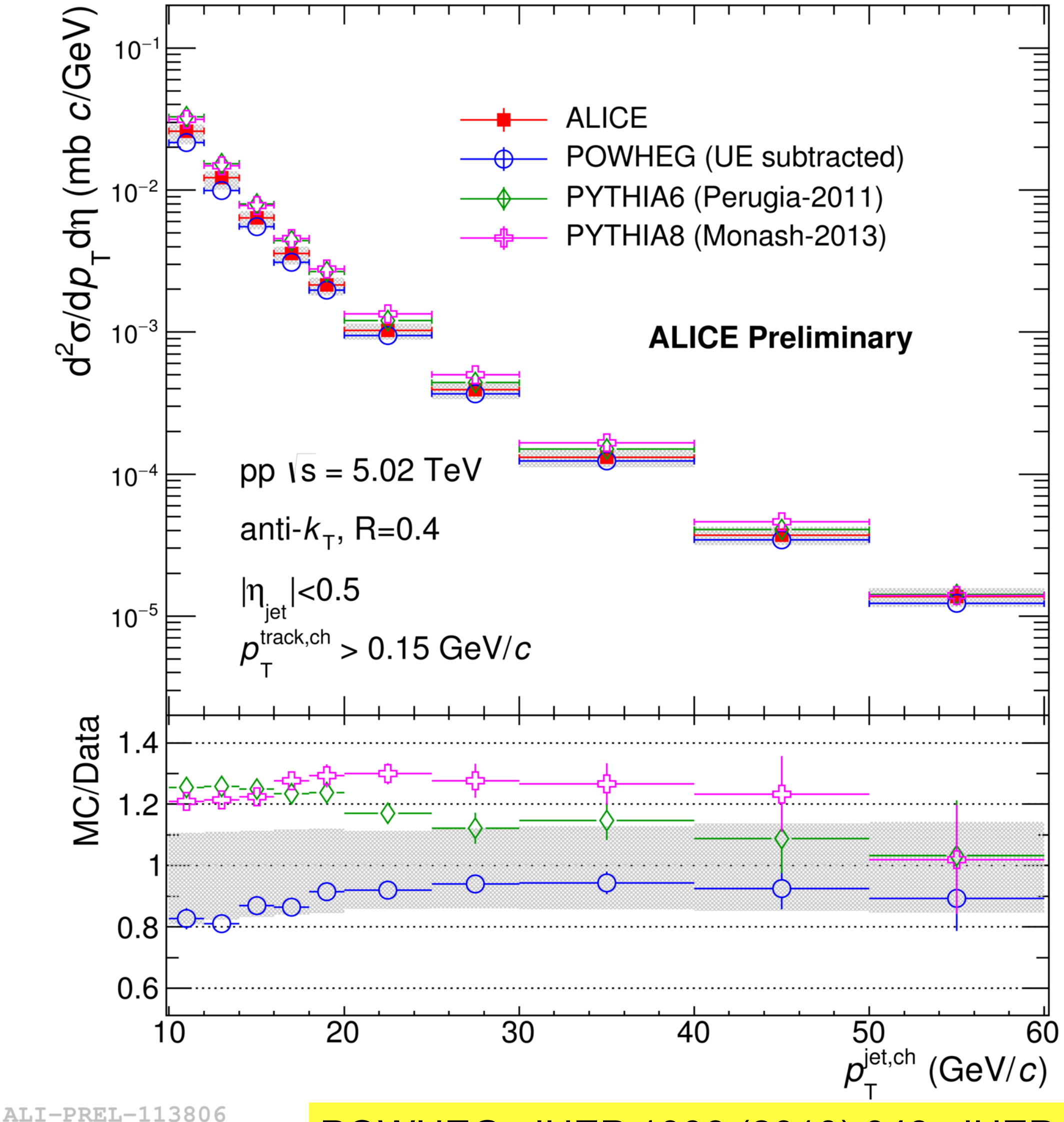
$\sum p_T$ density



- Similarity of UE behavior at different collision energies
  - Fast rise for p_T < 5 GeV/c, mostly attributed to the increase of MPI rate, followed by a plateau-like region
  - Higher collision energy generates larger charged particle density
  - UE level can be retroduced by PYTHIA8 generator

Charged jet cross section in pp collisions

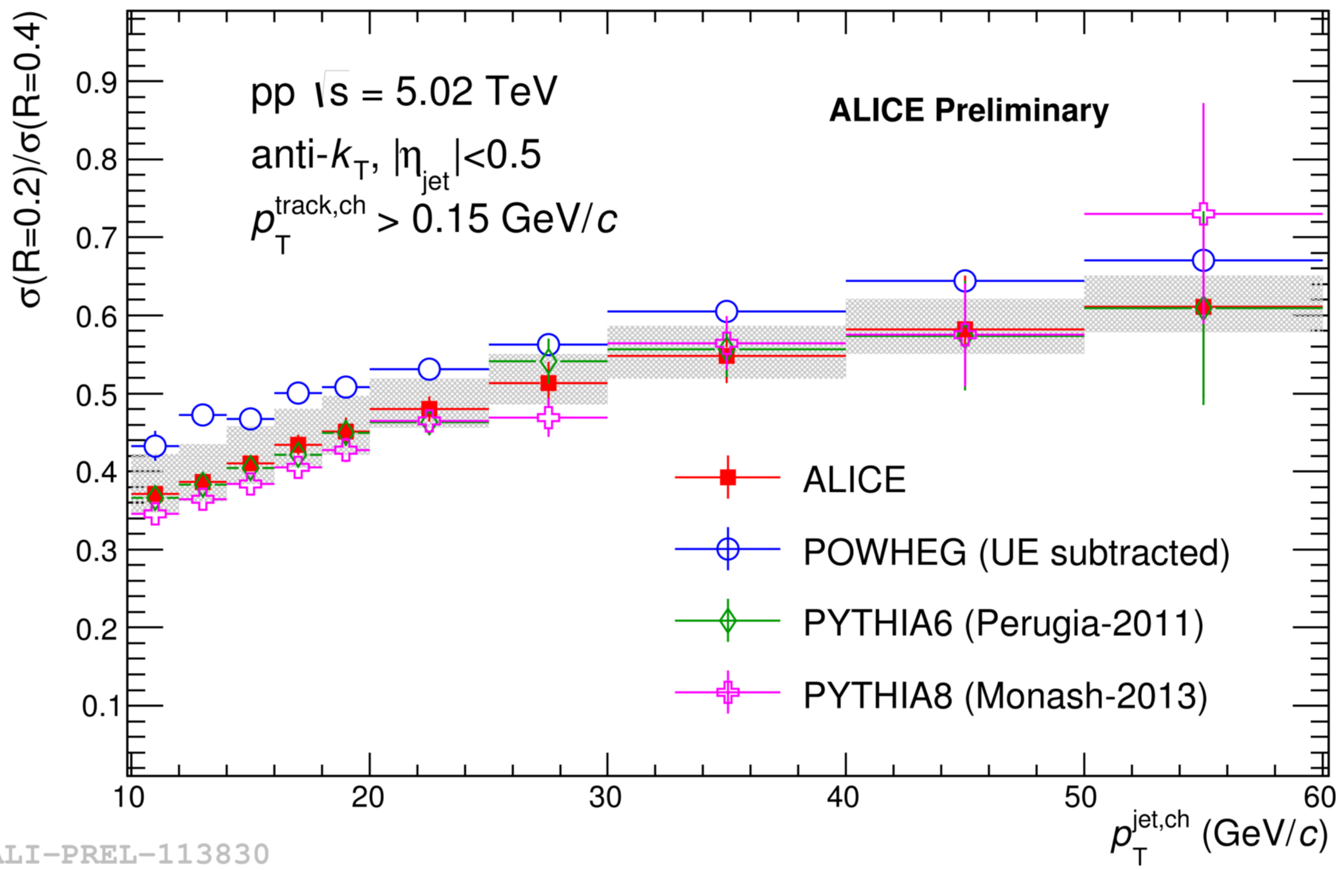


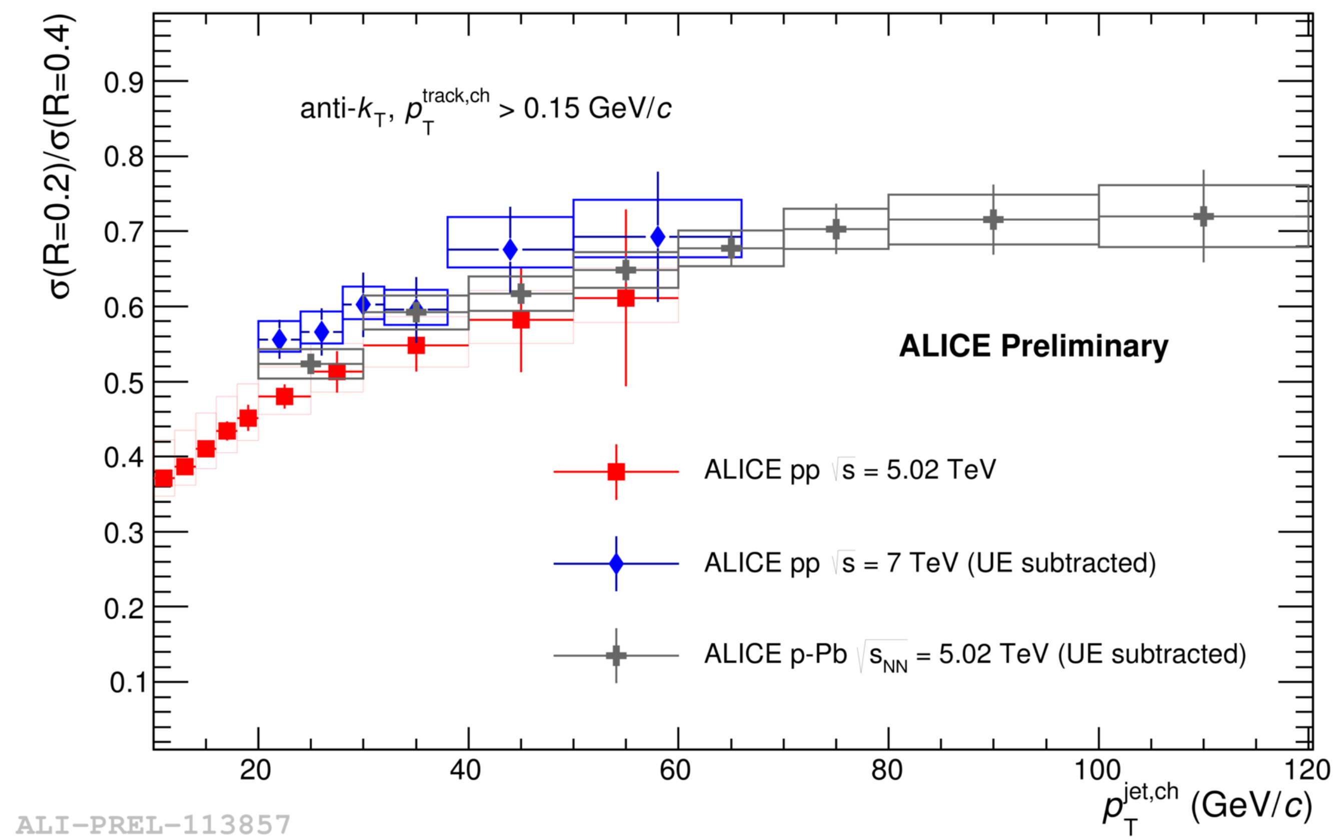


POWHEG: JHEP 1006 (2010) 043; JHEP 1104 (2011) 081
PYTHIA8: Comput. Phys. Commun. 191 (2015) 159

- Charged jets are reconstructed using different resolution parameters and down to low p_T
- Jet cross section is well described by POWHEG+PYTHIA8 predictions (NLO pQCD+parton shower+hadronization) within systematic uncertainties

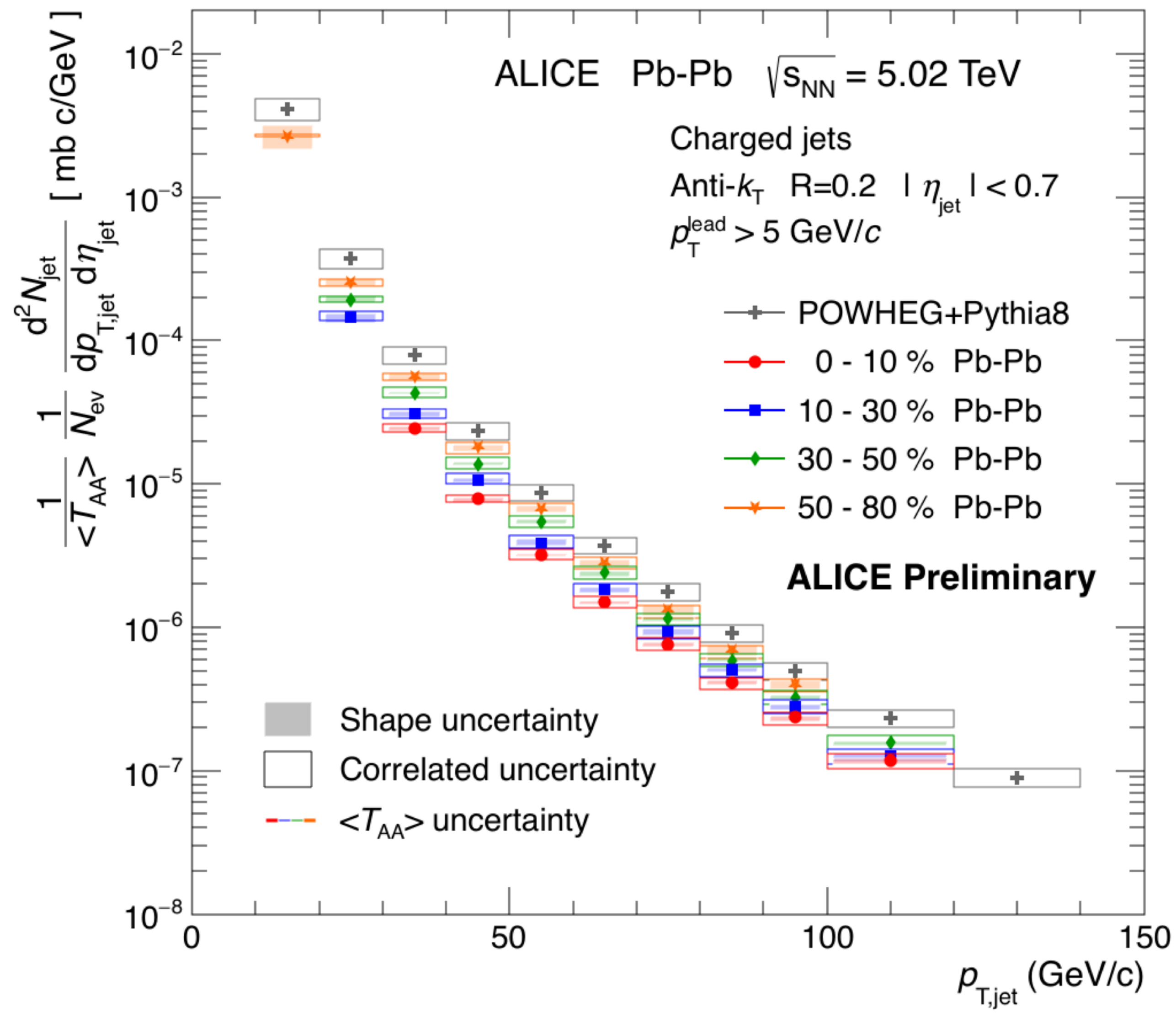
Jet cross section ratio



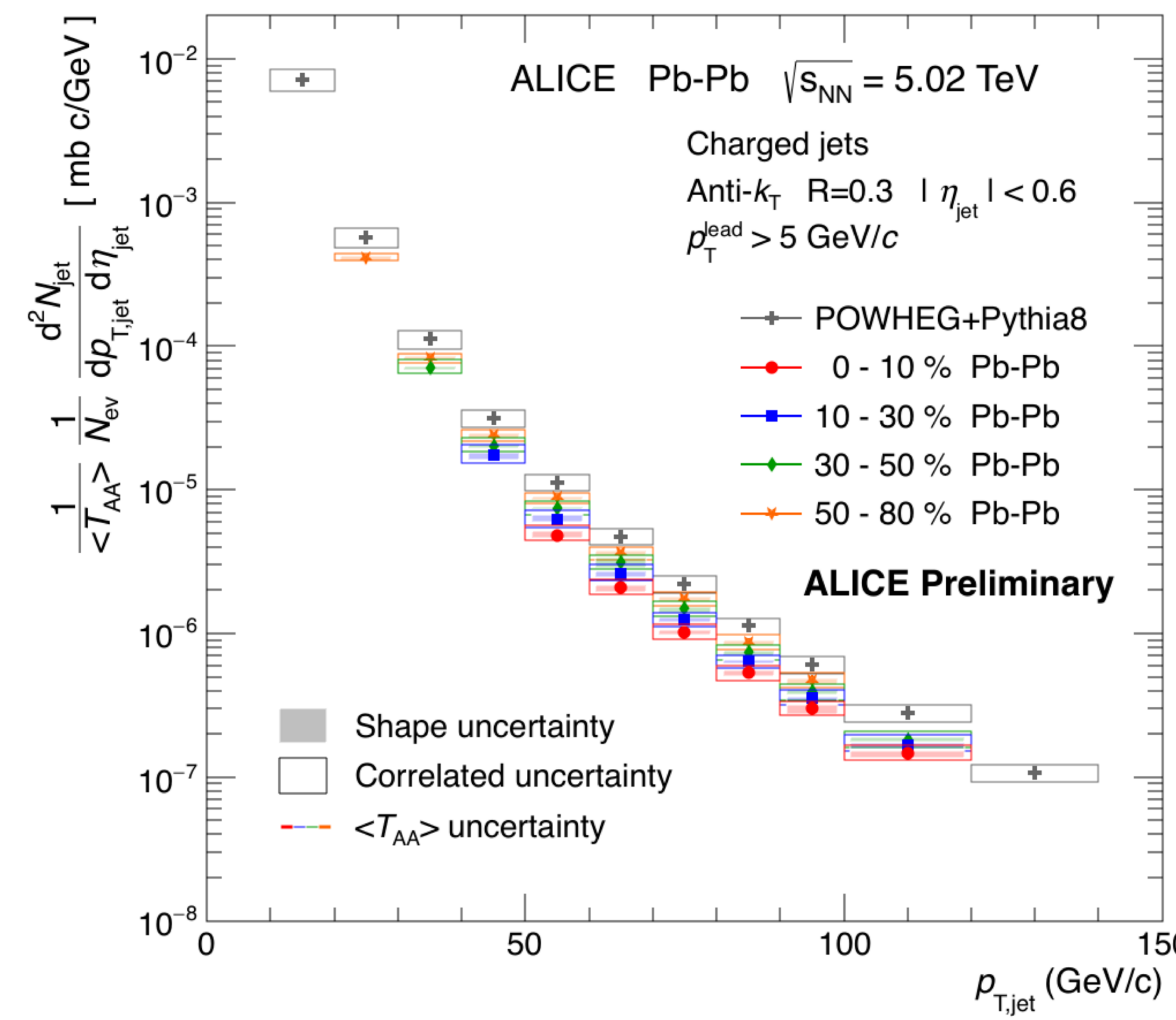


- Jet cross section ratio measurements are the reflection of jet collimation
- Different jet cross section ratio is consistent with Monte Carlo simulation
- Jet cross section ratio is consistent with different $\sqrt{s}$, slightly increasing with jet p_T

Inclusive charged jet spectra in Pb-Pb collisions



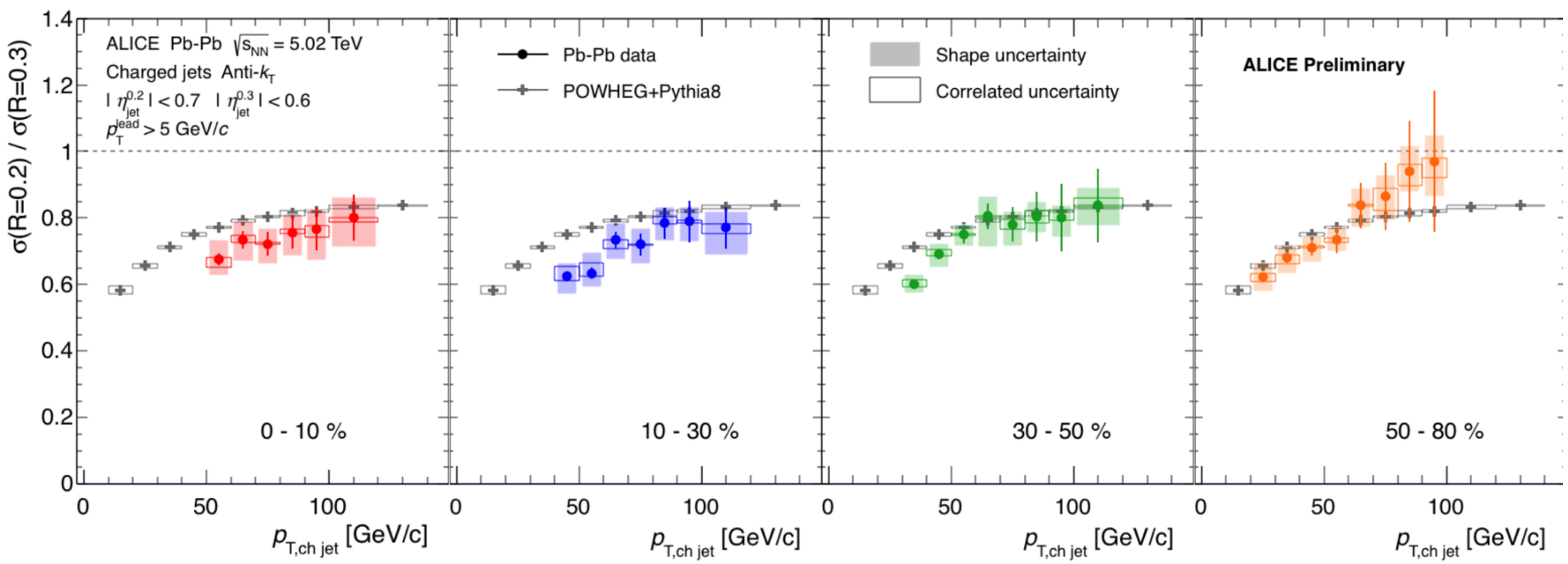
ALI-PREL-156109

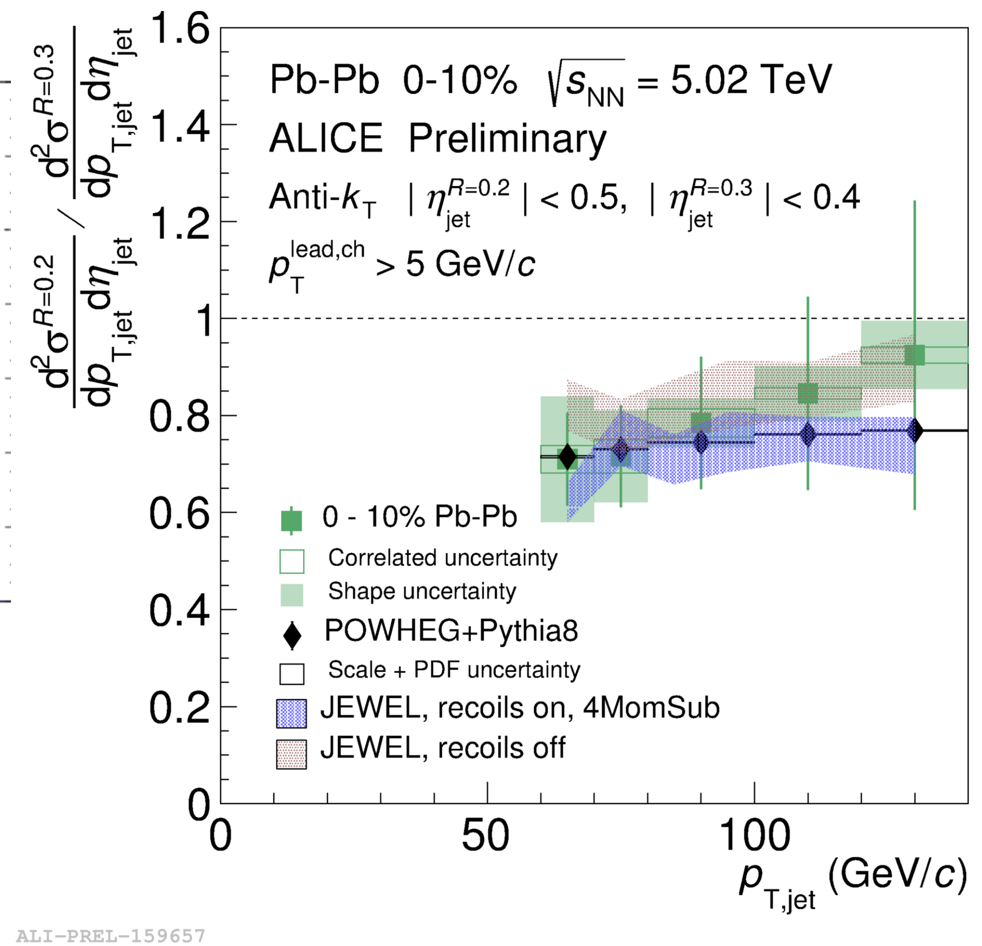


ALI-PREL-156116

- Charged jet spectra in different centrality intervals are measured in Pb-Pb collisions with different cone radii
- Centrality ordered jet production yield are observed after T_{AA} scaling

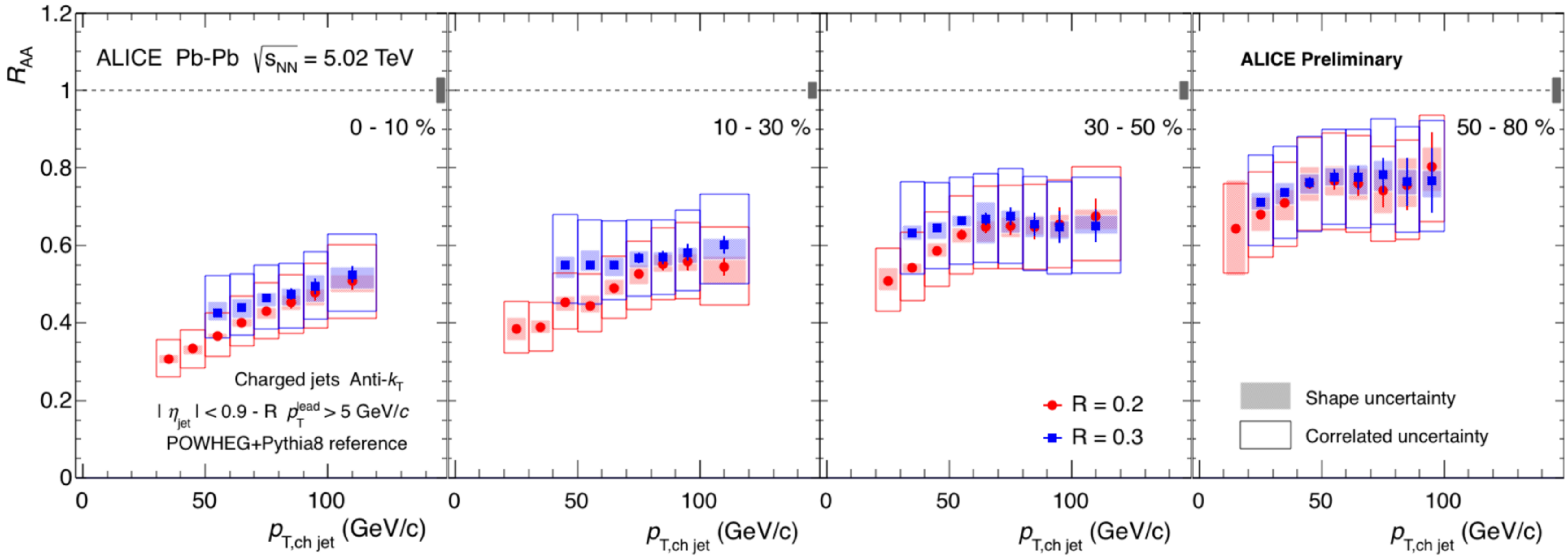
Jet cross section ratio in Pb-Pb collisions





- Ratio of charged jet cross section between R = 0.2 and R = 0.3 for different centrality intervals
- No significant difference with jets in vacuum (POWHEG+PYTHIA reference)
- Small difference at low p_T for most central collisions → hints for stronger broadening at low p_T ?
- JEWEL predictions agree with data

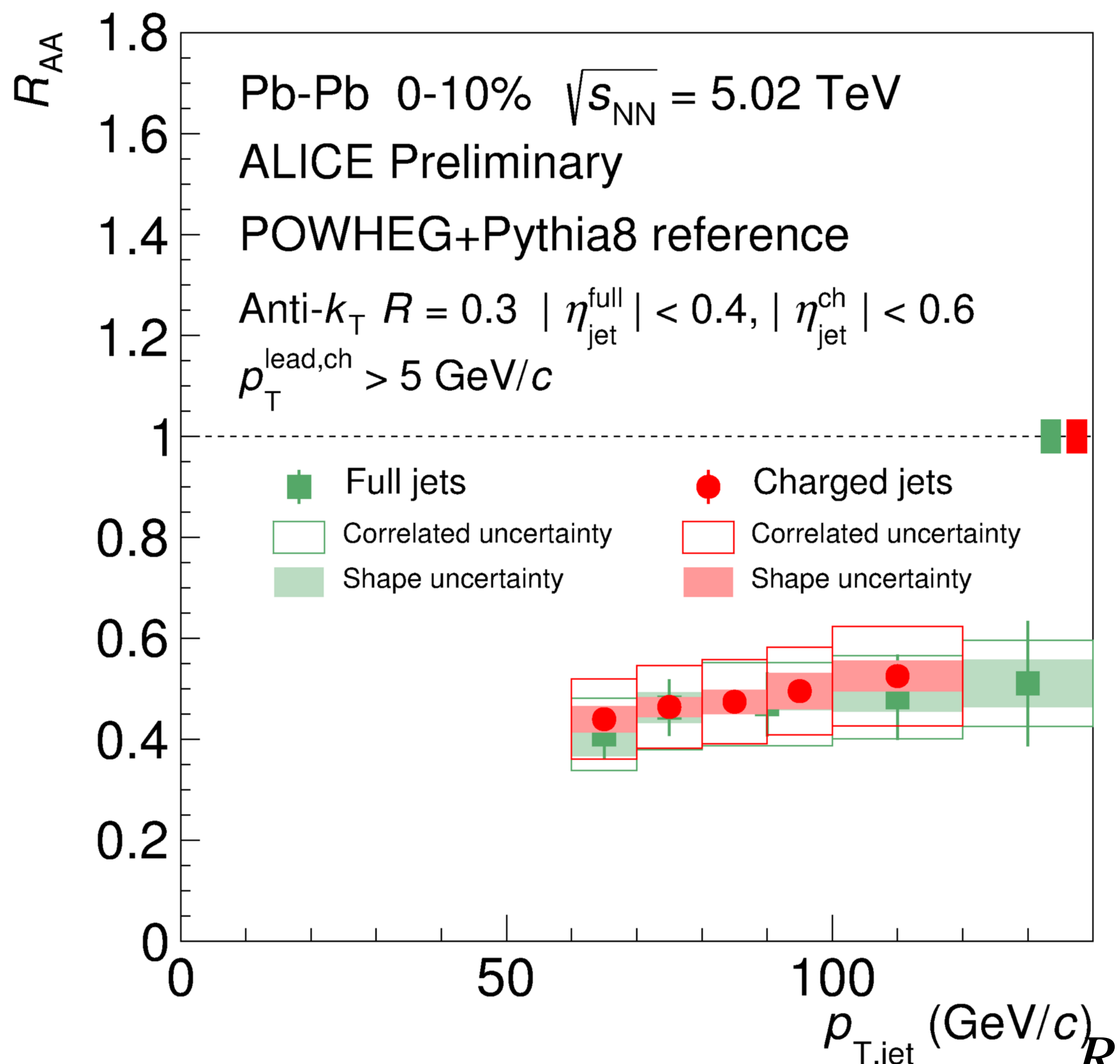
Jet nuclear modification factor R_{AA}



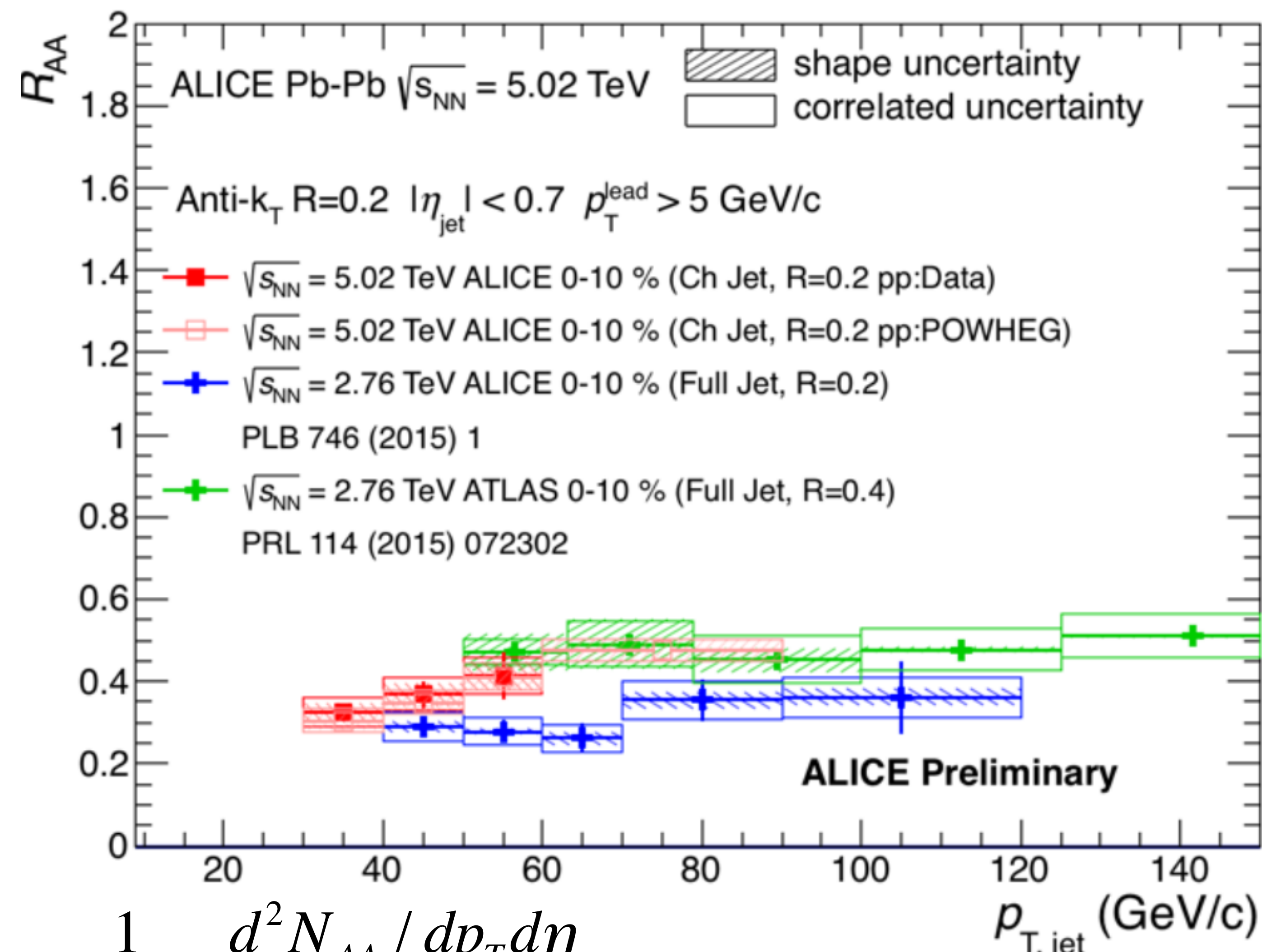
$$R_{AA} = \frac{1}{<T_{AA}>} \frac{d^2N_{AA}/dp_T d\eta}{d^2\sigma_{pp}/dp_T d\eta}$$

- Strong suppression of jet yield in most central collisions
- Less suppression for peripheral events
- R_{AA} of different radius jets are consistent with systematic errors
- POWHEG+PYTHIA8 is used as pp reference to enlarge to higher jet p_T range

Jet R_{AA} comparison



ALI-PREL-159653

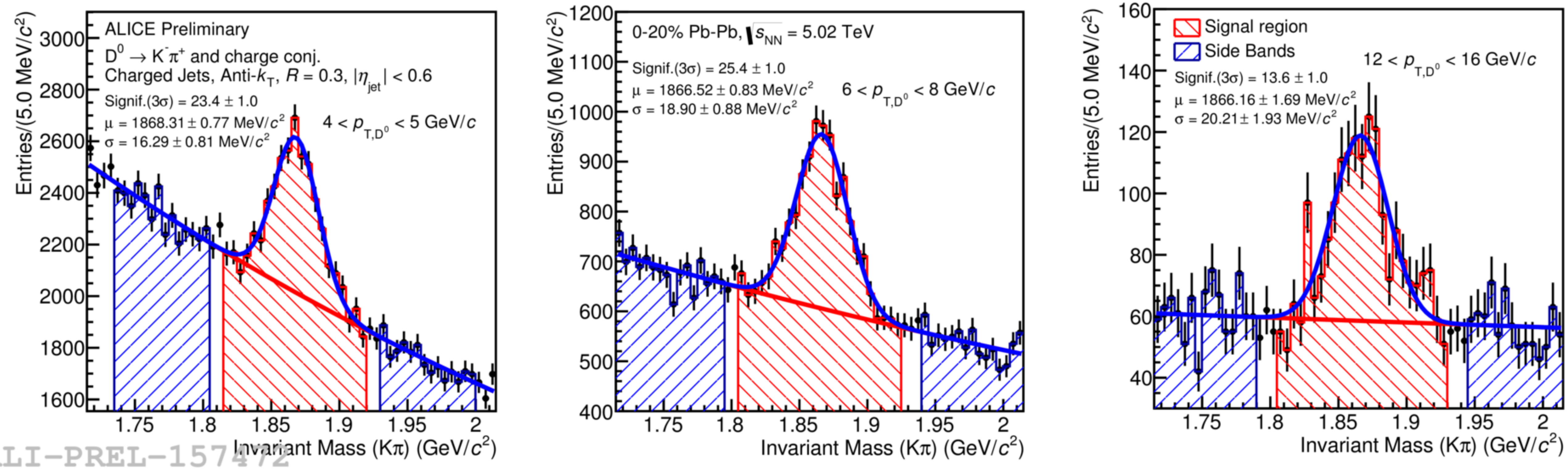


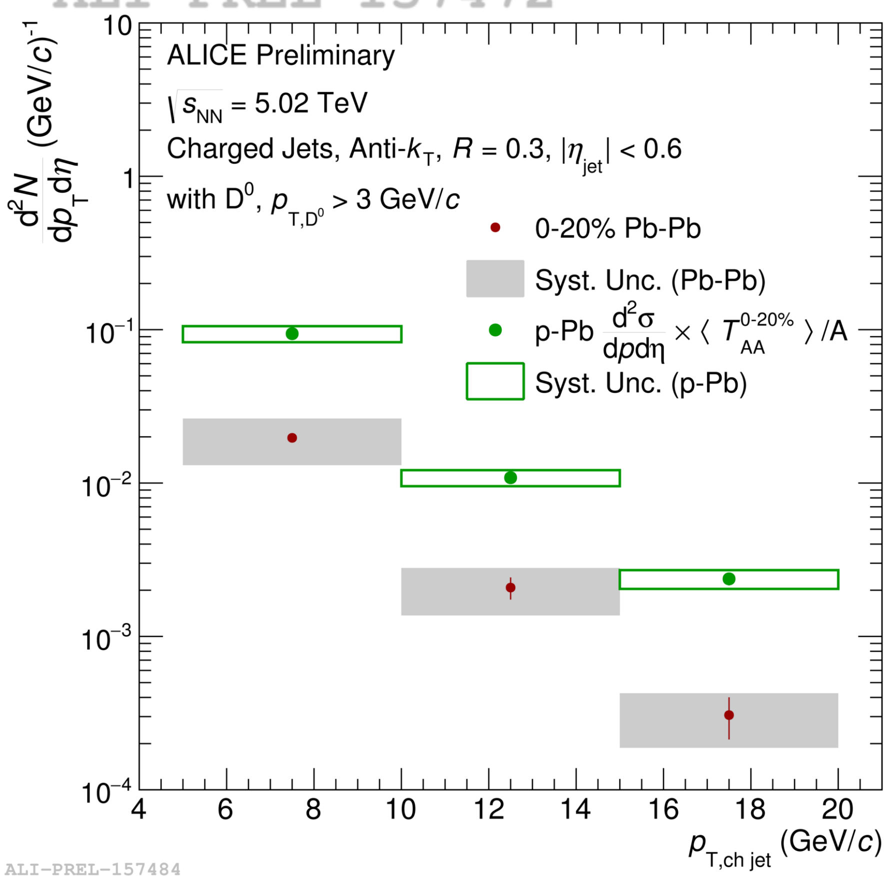
$$R_{AA} = \frac{1}{<T_{AA}>} \frac{d^2N_{AA}/dp_T d\eta}{d^2\sigma_{pp}/dp_T d\eta}$$

- Full jets and charged jets are suppressed similarly
- R_{AA} at 5.02 TeV similar to 2.76 TeV
  - ➡ "compensation" between increasing suppression and change of the shape of the spectra

Heavy-Quark (c-)jet tagging

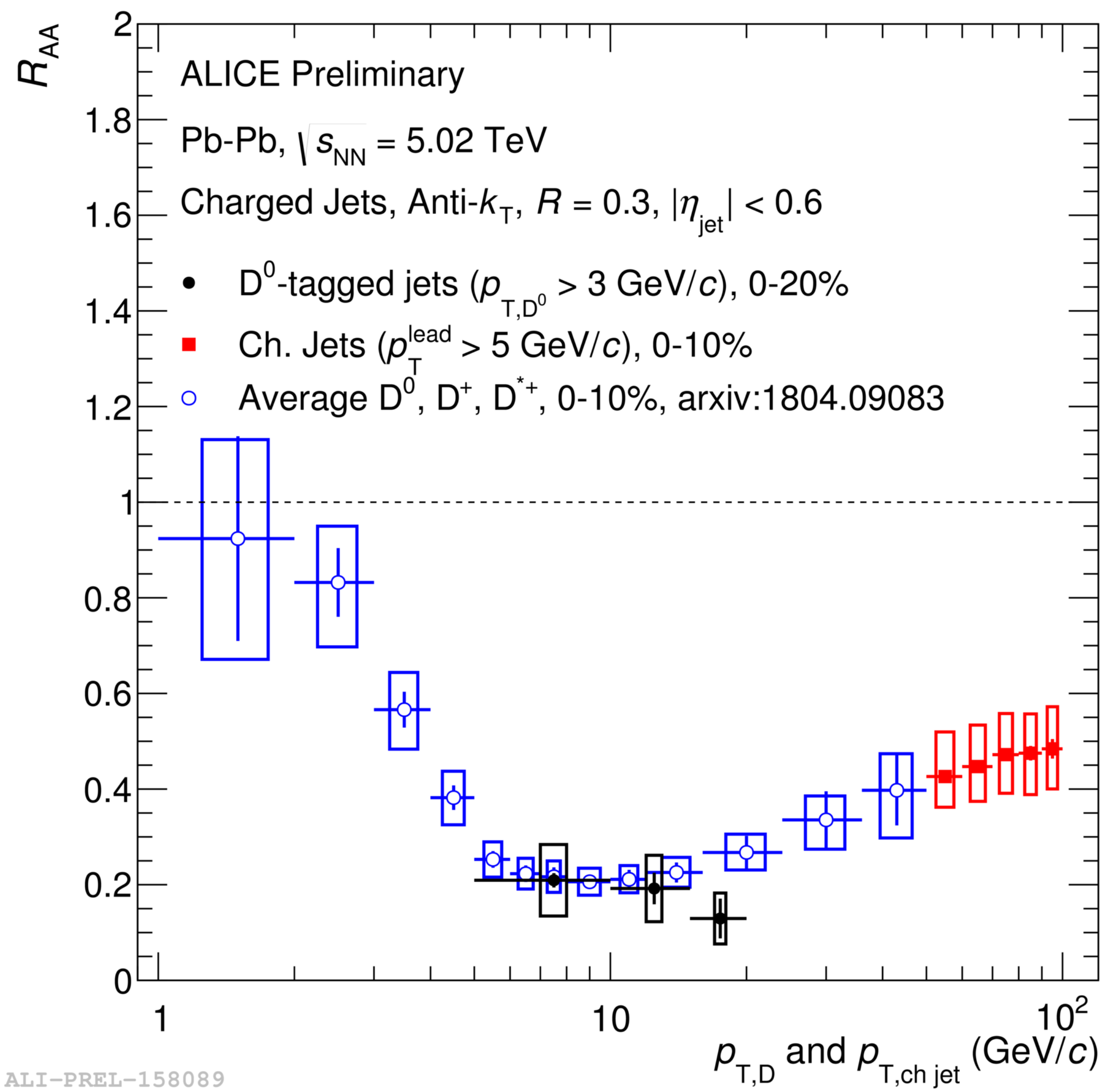
- Charged jet containing a D meson as one of the constituents





- Invariant mass analysis to extract D-jet raw spectrum
  - Background spectrum from side bands
- Corrected jet p_T spectra unfolded for detector effects and background fluctuations
- D^0-tagged jets are measured down to 5 GeV/c
  - D^0 mesons must come from hard scattering
  - Jets from charm quarks are measured selectively

Jet R_{AA}: inclusive vs. tagged D^0-jet

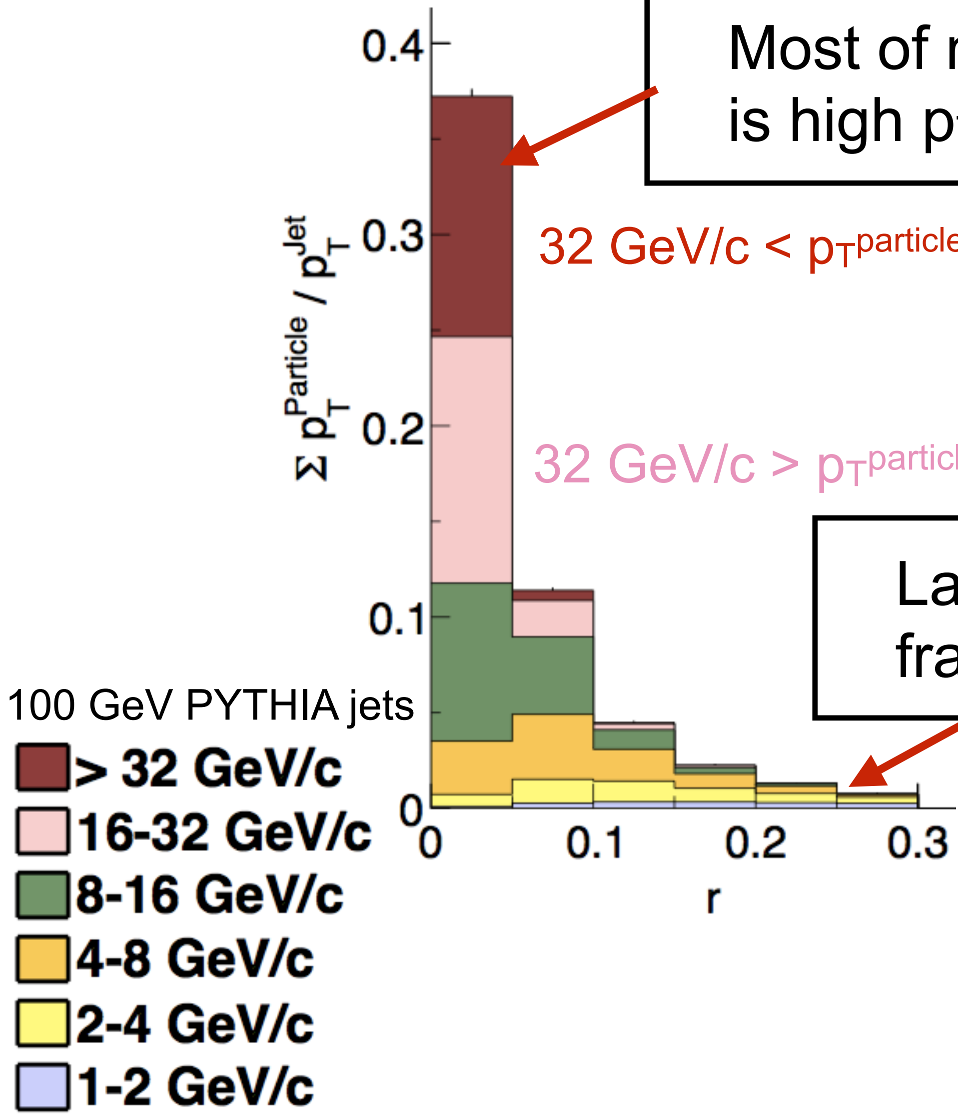


$$R_{AA} = \frac{1}{< T_{AA} >} \frac{d^2N_{AA} / dp_T d\eta}{d^2\sigma_{pp} / dp_T d\eta}$$

- Strong suppression of D^0-tagged jets in most central collisions
  - ➡ Hints of more suppression at low p_T D^0-tagged jets than inclusive jets at higher p_T
  - ➡ Similar to D meson R_{AA}
  - ➡ Importance of collisional energy loss for heavy flavor jets
- Promising results in view of this year Pb-Pb run and run 3,4
  - ➡ Improved precision and extended jet p_T reach
  - ➡ jet shape and momentum fraction measurements

Jet anatomy

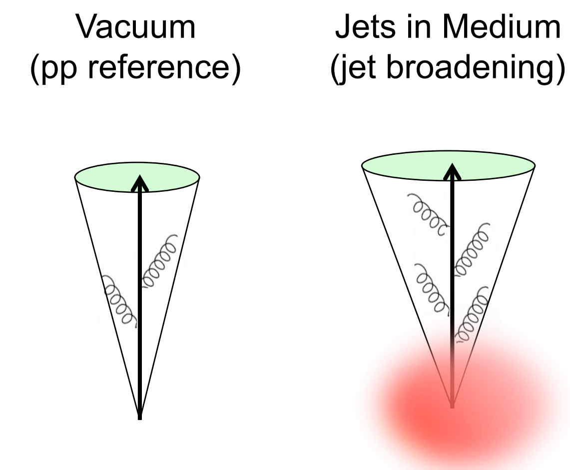
- Jet are extended objects with momentum and angular structure

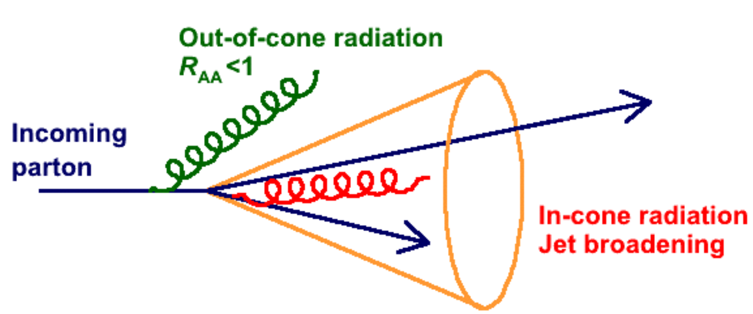


Most of momentum found close to jet axis is high p_T particles (p_T > O(10 GeV))

Large angle component of jet contains small fraction of jet p_T in soft particles (p_T > O(1GeV))

$r = \sqrt{(\eta_{jet}-\eta_{ch})^2+(\varphi_{jet}-\varphi_{ch})^2}$

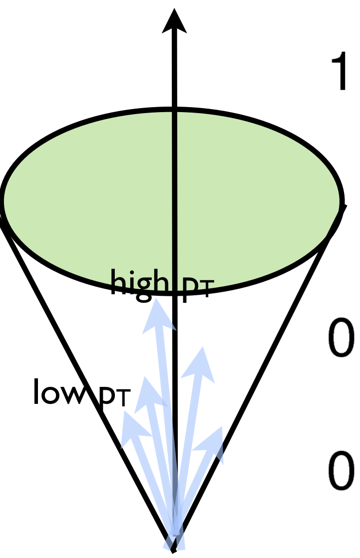


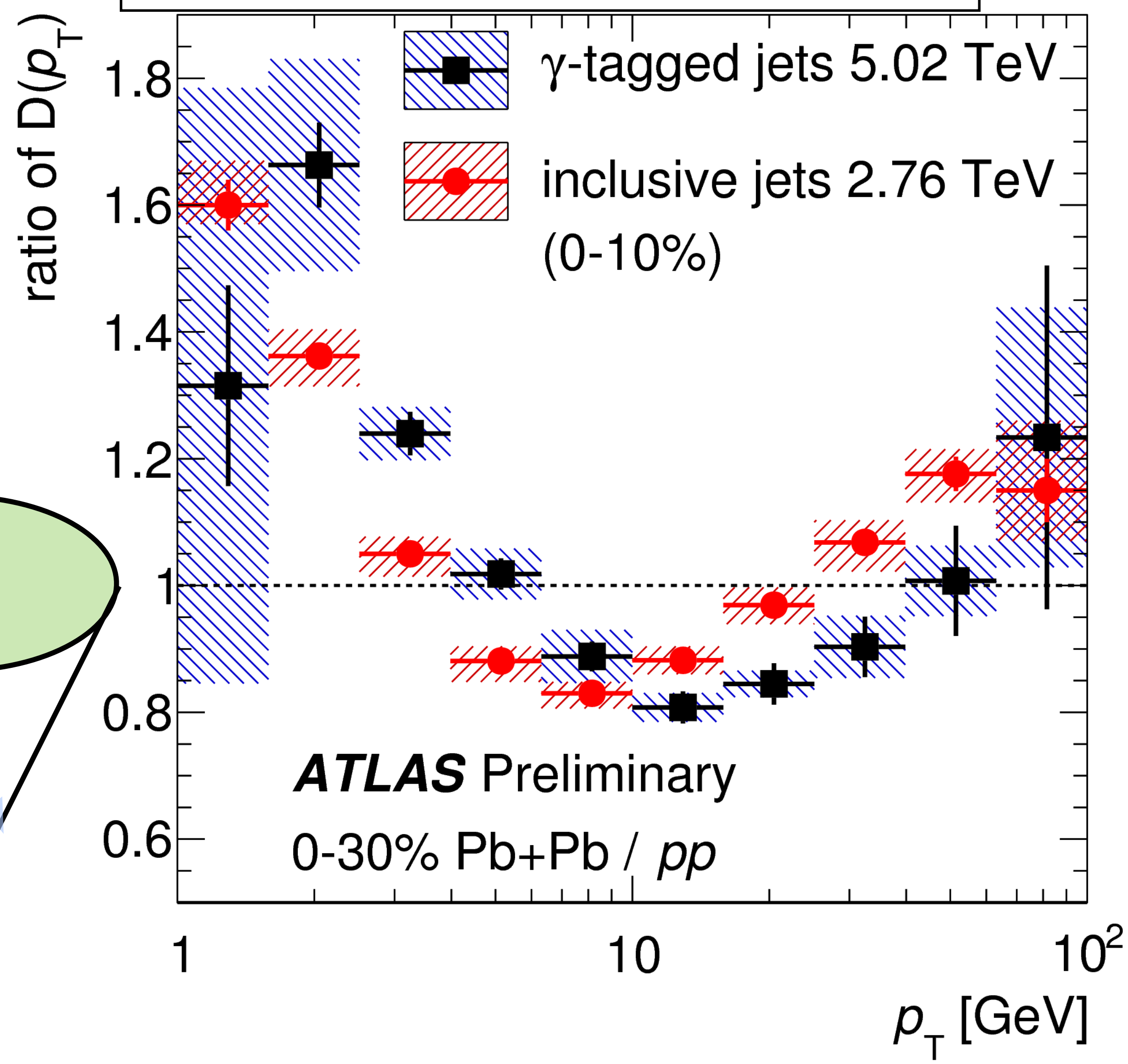


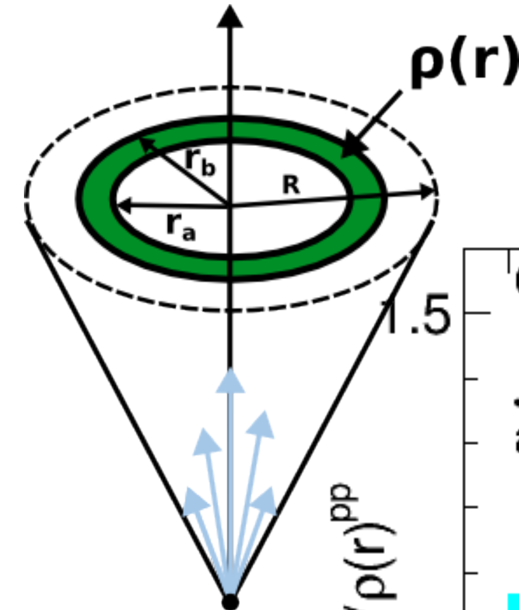
- How the parton shower modified?
- What is the mechanism modifying the shower?
- Can we relate to shower modifications to medium properties?

Modification of jet fragmentation patterns

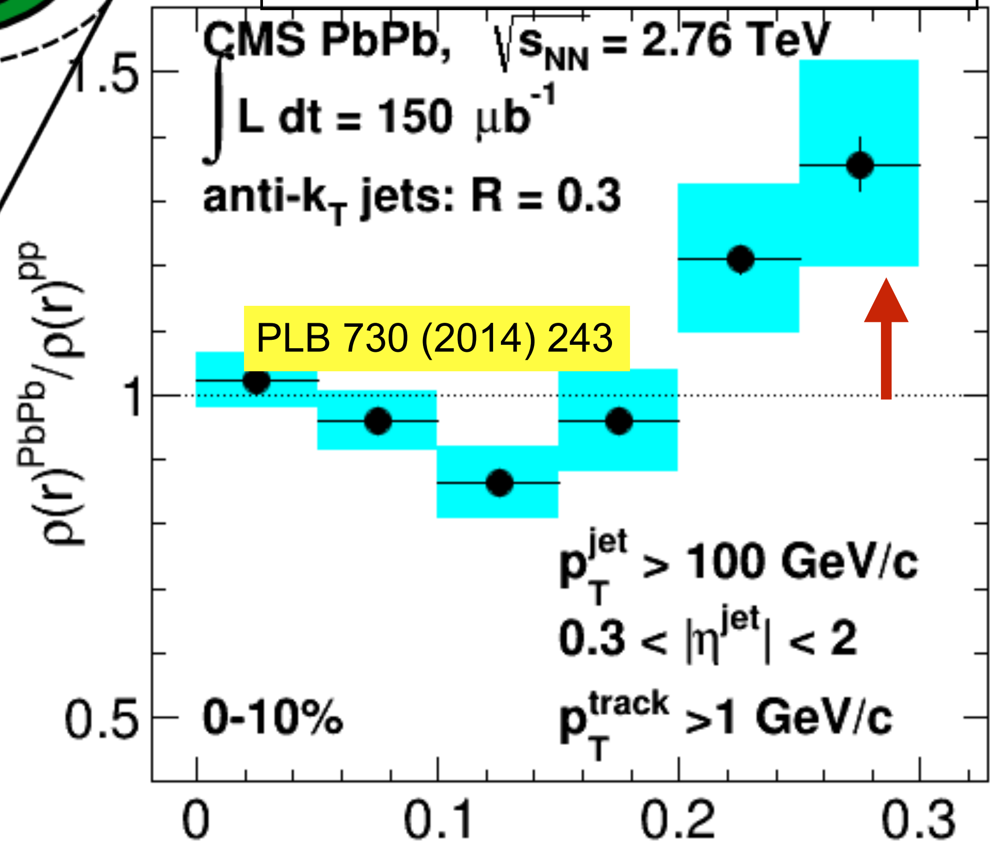
jet FF: momentum redistribution







radial profile:
energy flow redistribution

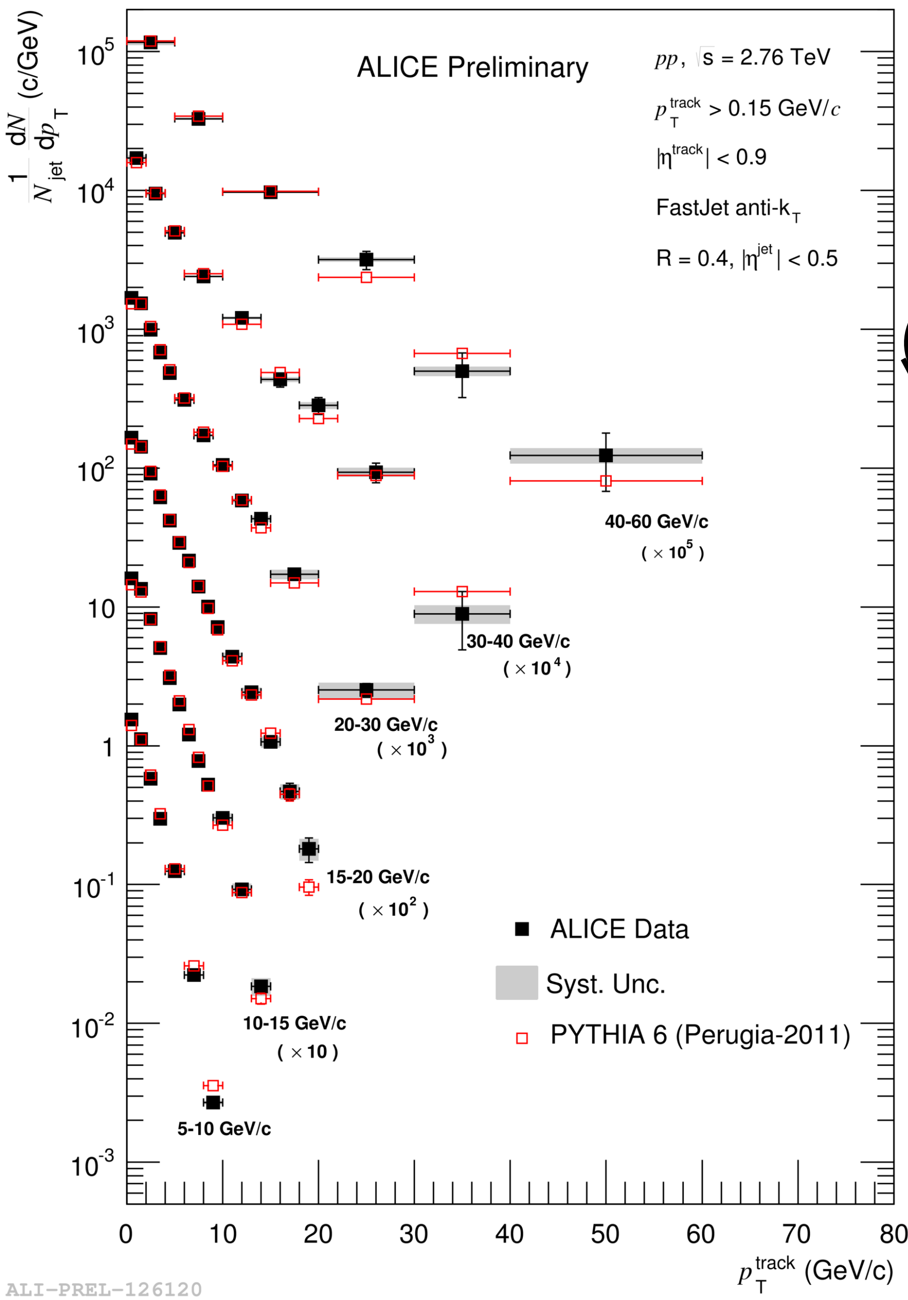


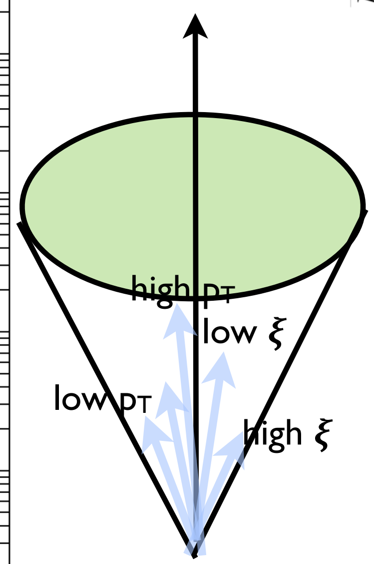
$$\rho(r) = \frac{1}{f_{ch}}\frac{1}{\delta r}\frac{1}{N_{jet}}\sum_{jets}\frac{p_T(r-\delta r/2, r+\delta r/2)}{p_T^{jet}},$$

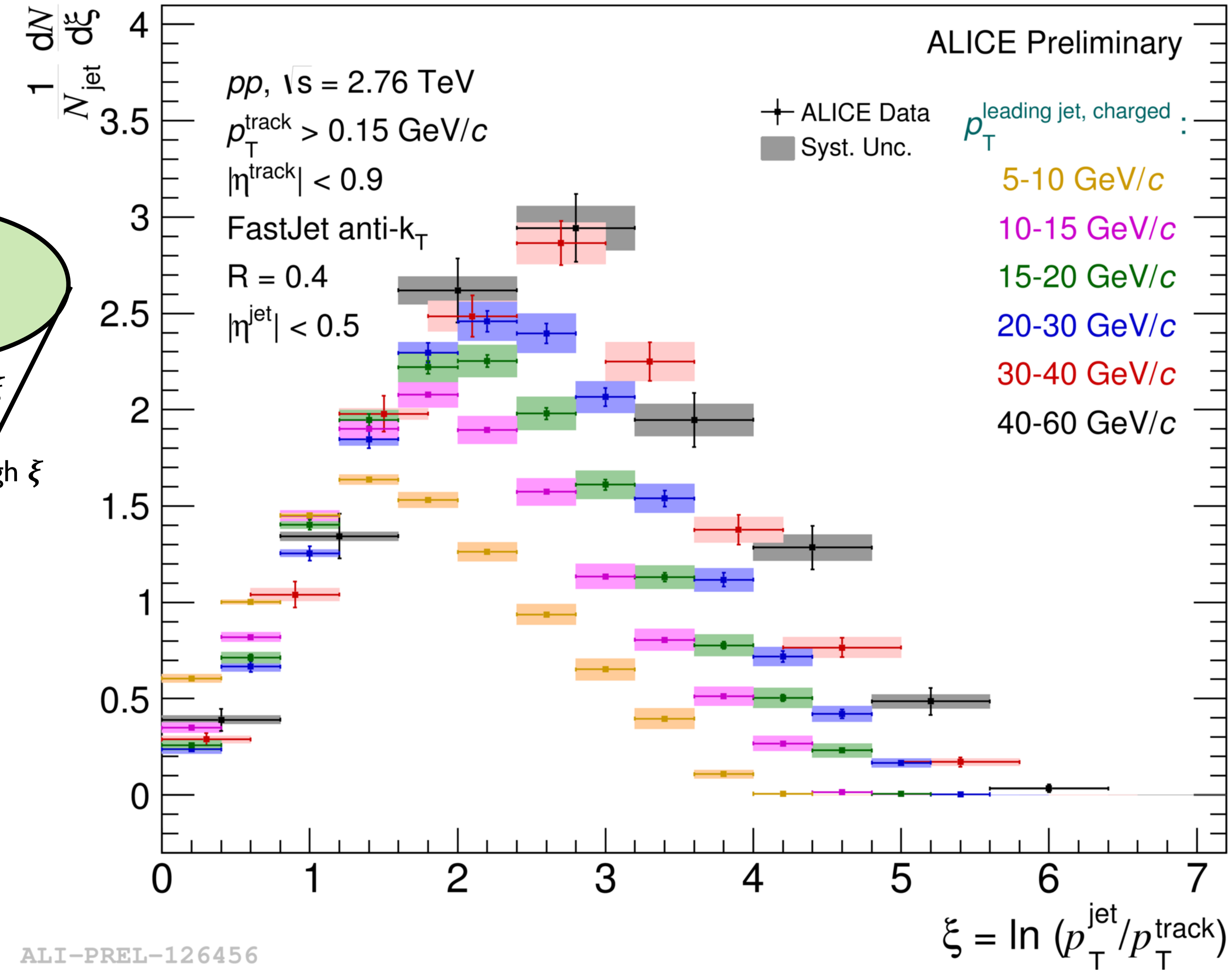
- Excess at low p_T and large angular distance → jet broadening
- Suppression in intermediate p_T and radii → jet quenching

➡ Investigate low p_T jet fragmentation patterns with ALICE

Jet fragmentation function (FF) measurements

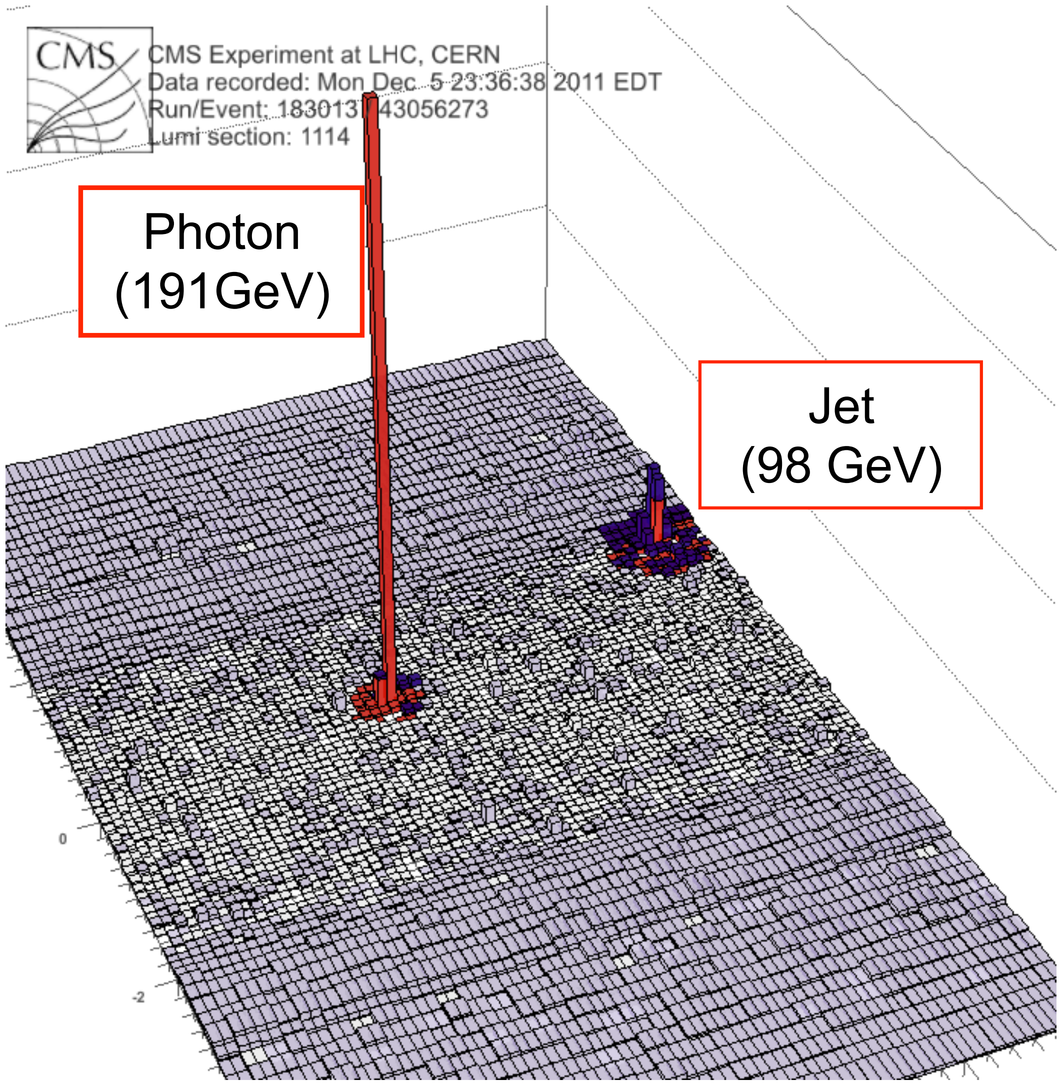


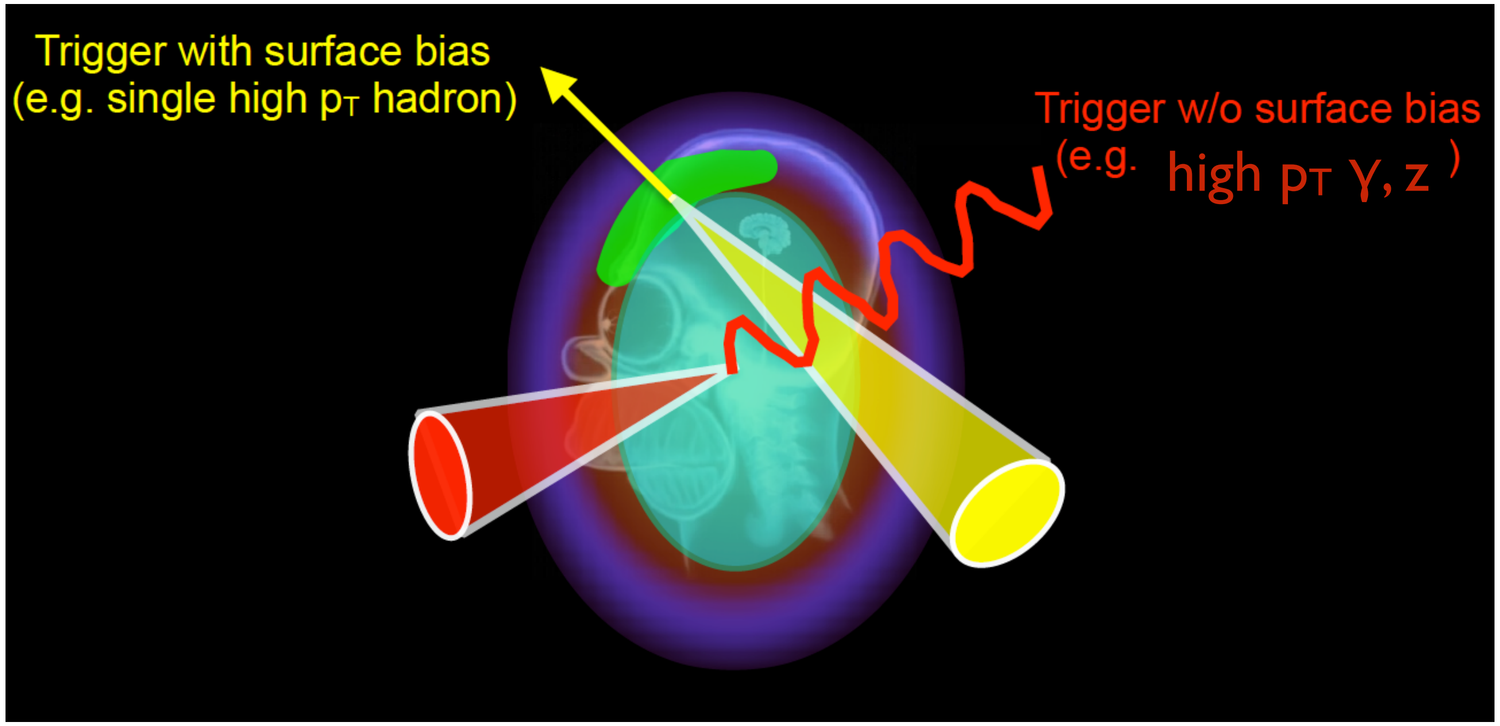


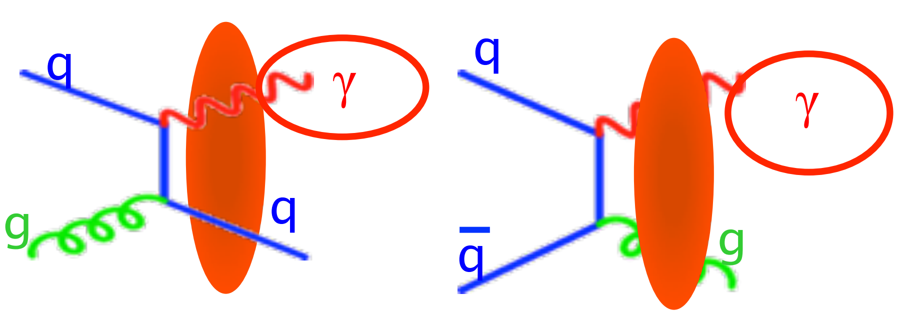


- Focus on low p_T jet fragmentation properties (later with identified particle FF)
- Analysis in Pb-Pb collision is ongoing to study jet modifications

γ+jet: "golden" probe for energy loss

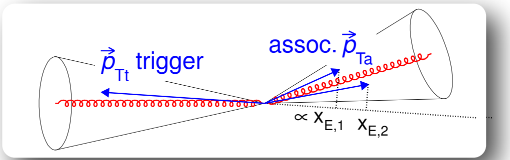






- Photon tagging:
  - Sets the reference of the hard process
  - Provide the calibrated energy of the jet opposite
  - Identify quark jets by photon tagging
  - Decay photons from π^0 dominate the background

π^0-hadron azimuthal correlations



pp

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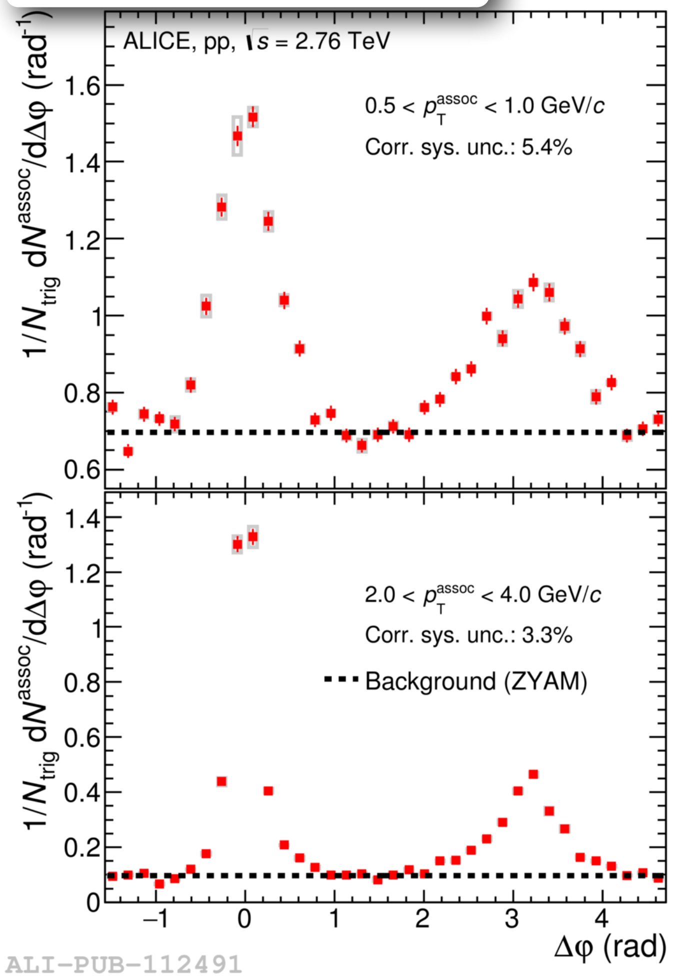
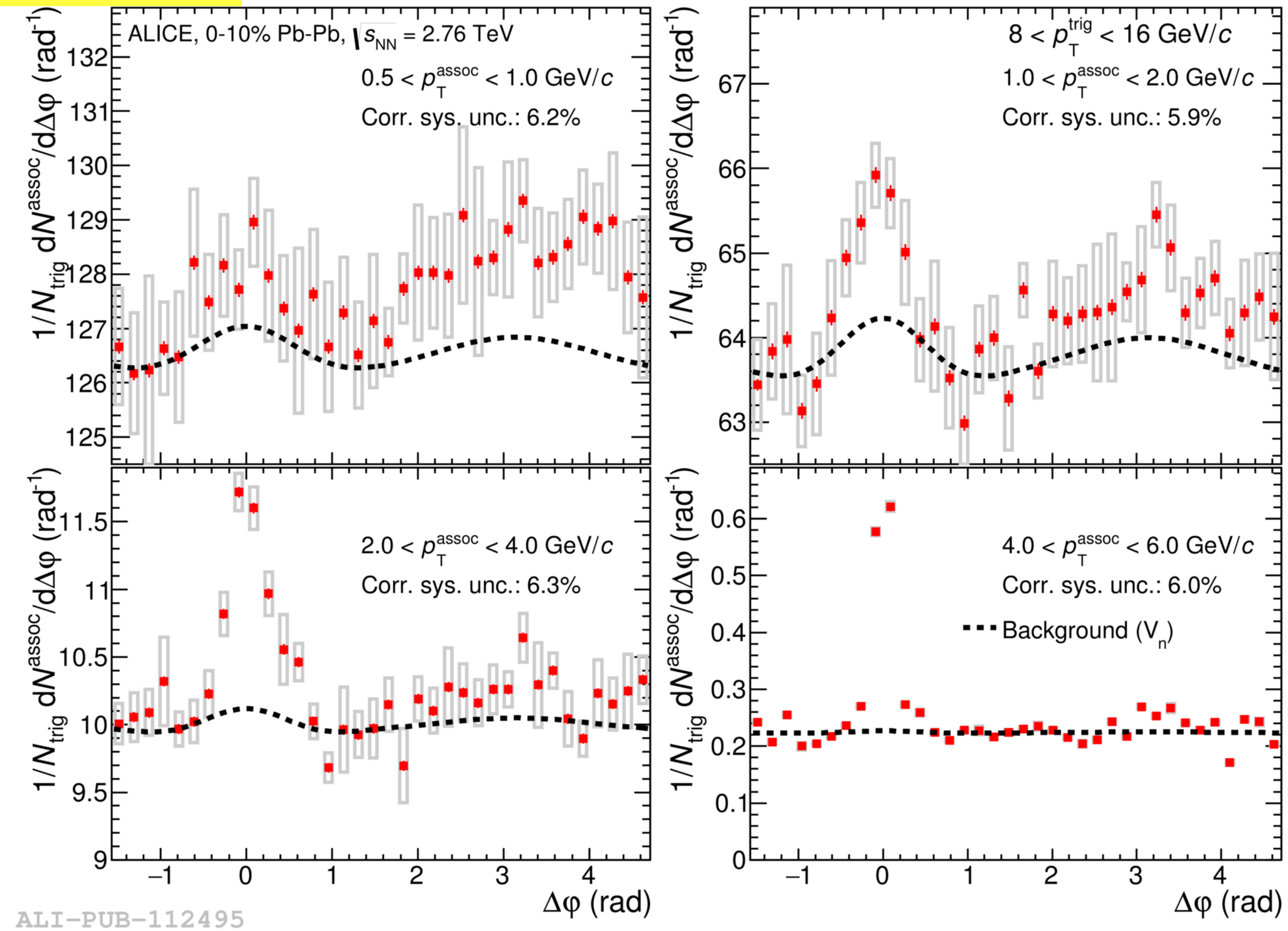
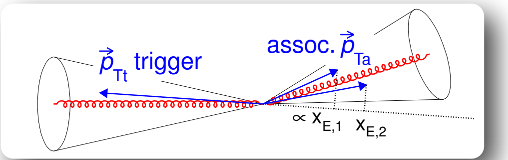
PbPb





- Double peaks observed → di-jet structure
- Near side peak width broader in PbPb compared to pp → jet broadening
- Away side peak in central PbPb collision is strongly suppressed → jet quenching

π⁰-hadron correlation distributions



near side

$$I_{AA} = \frac{Y_{\text{Pb-Pb}}}{Y_{\text{pp}}} \qquad Y = \int \frac{dN_{assoc}}{d\Delta\varphi} d\Delta\varphi$$

away side

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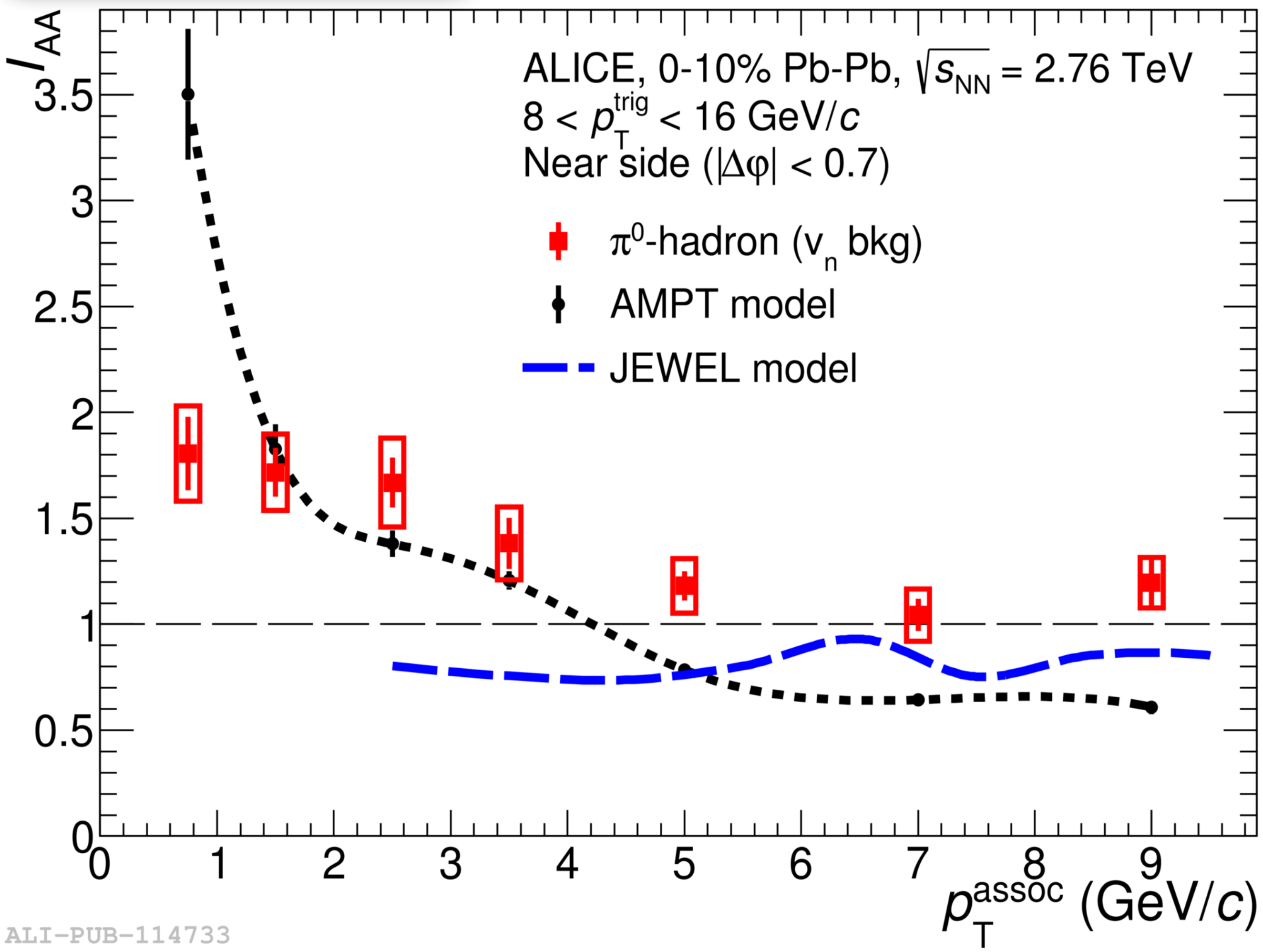
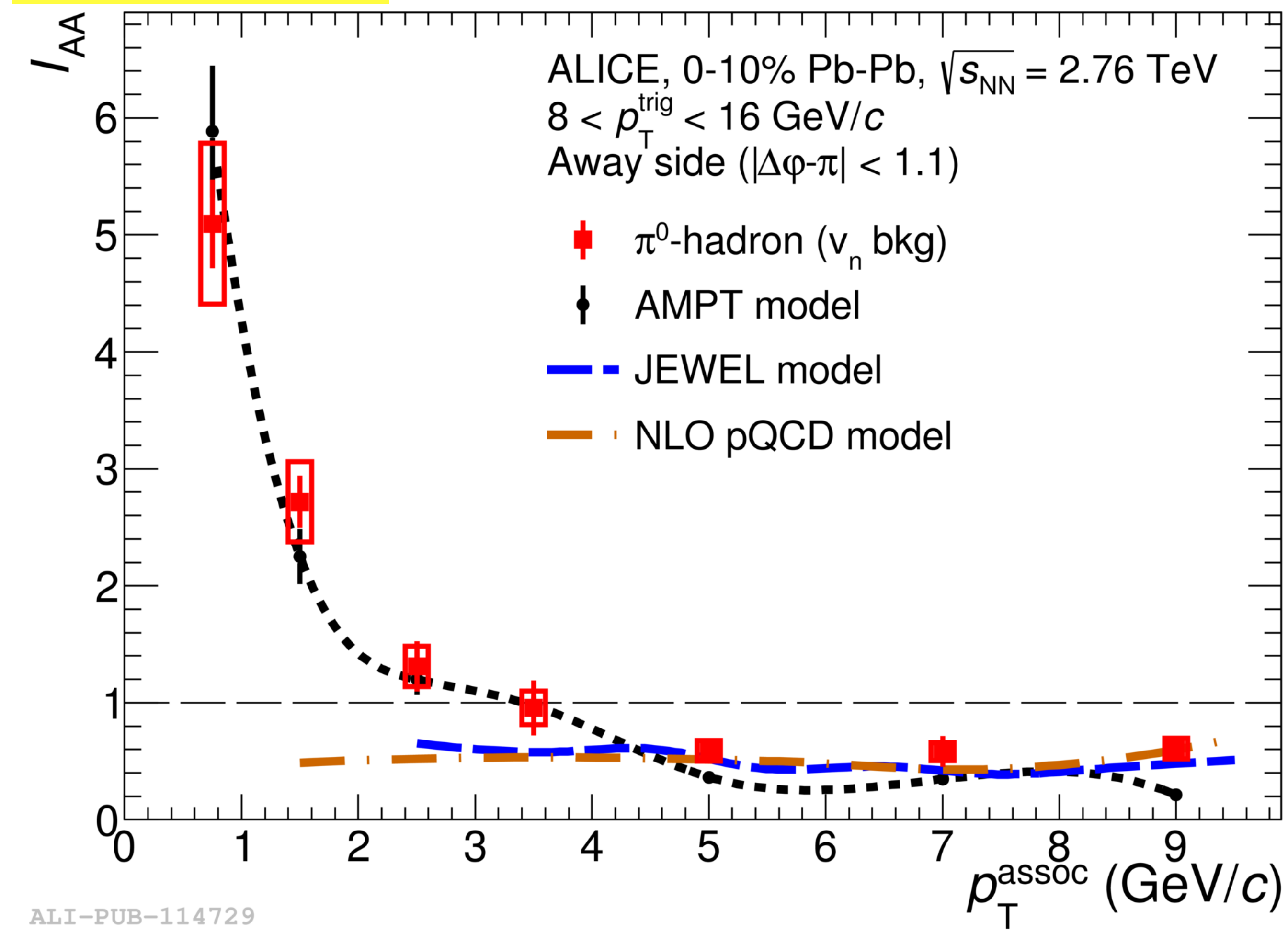
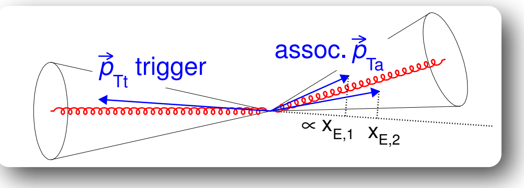




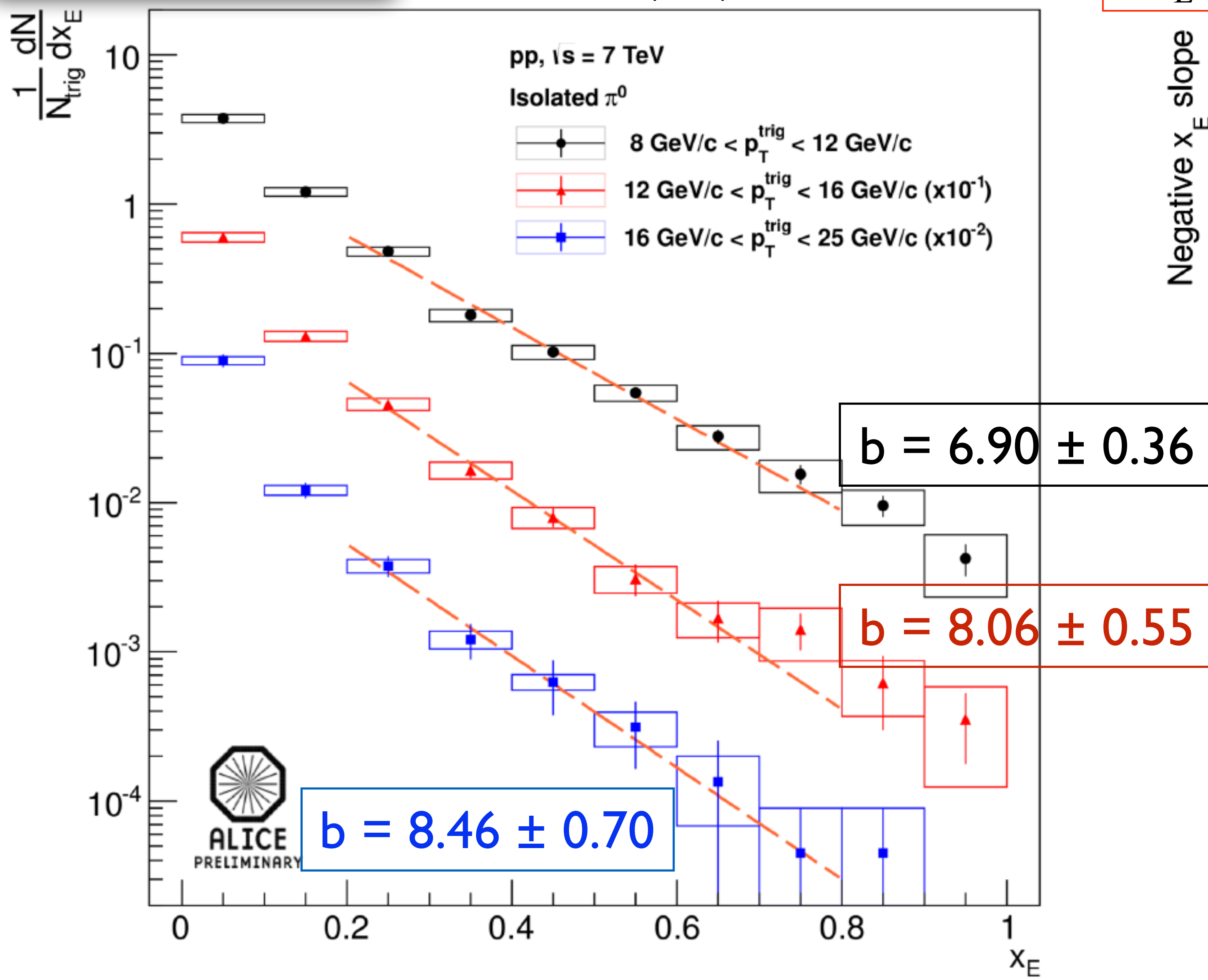
- Enhancement at very low p_T, indicating extra particles excess → consistent with low p_T broadening (soften of fragmentation functions? excited by medium?)
- Suppression on the away side for high p_T → consistent with jet quenching

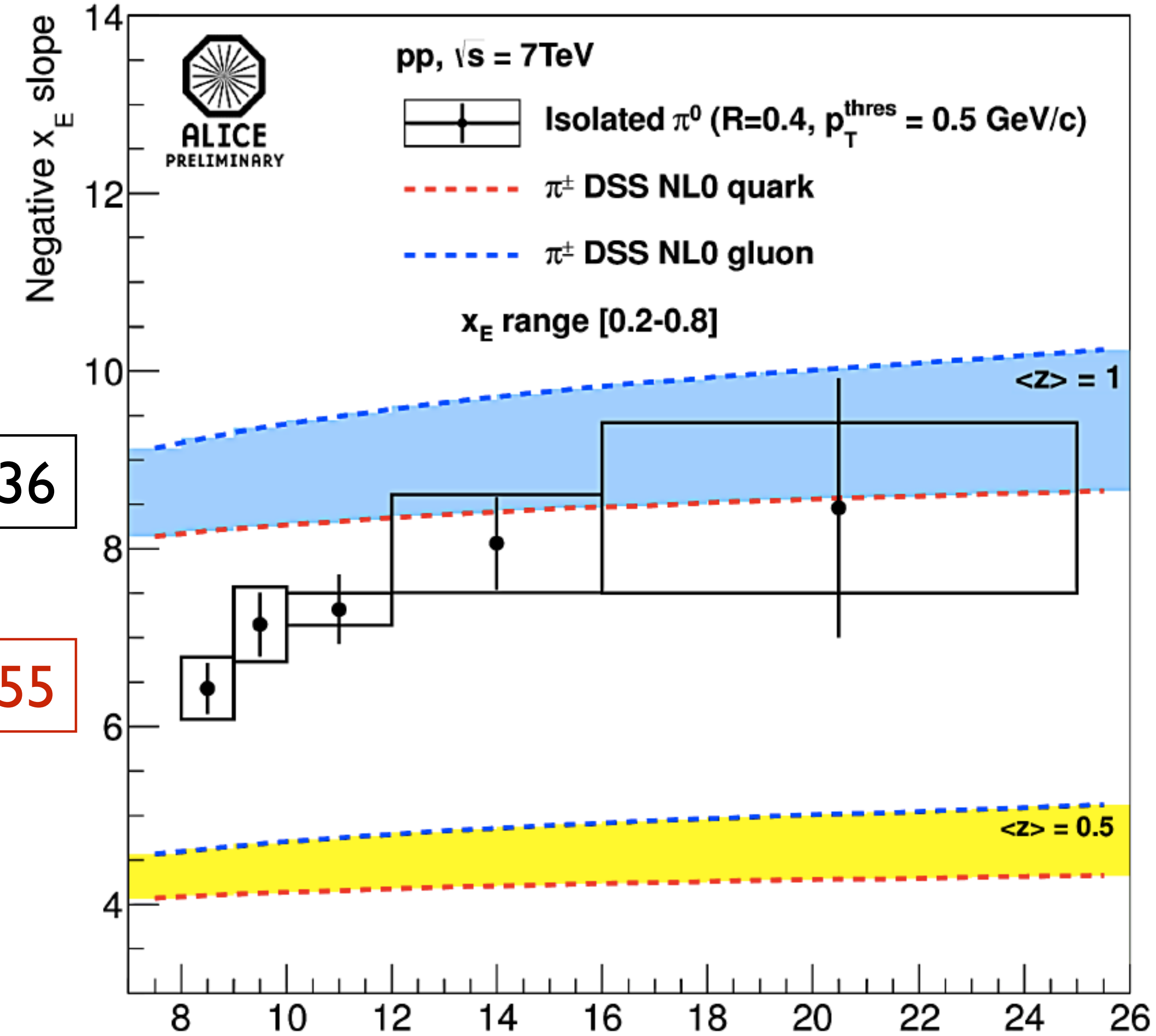
Isolated π^0-hadron x_E distributions



$$x_E = -\frac{\vec{p}_{Tt} \cdot \vec{p}_{Ta}}{\left|\vec{p}_{Tt}\right|^2} = -\frac{p_{Ta}}{p_{Tt}} \cos(\Delta\phi)$$

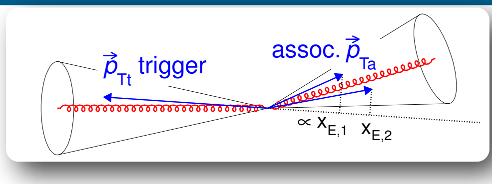
$$\frac{dN}{dx_E} = N e^{-b x_E}$$





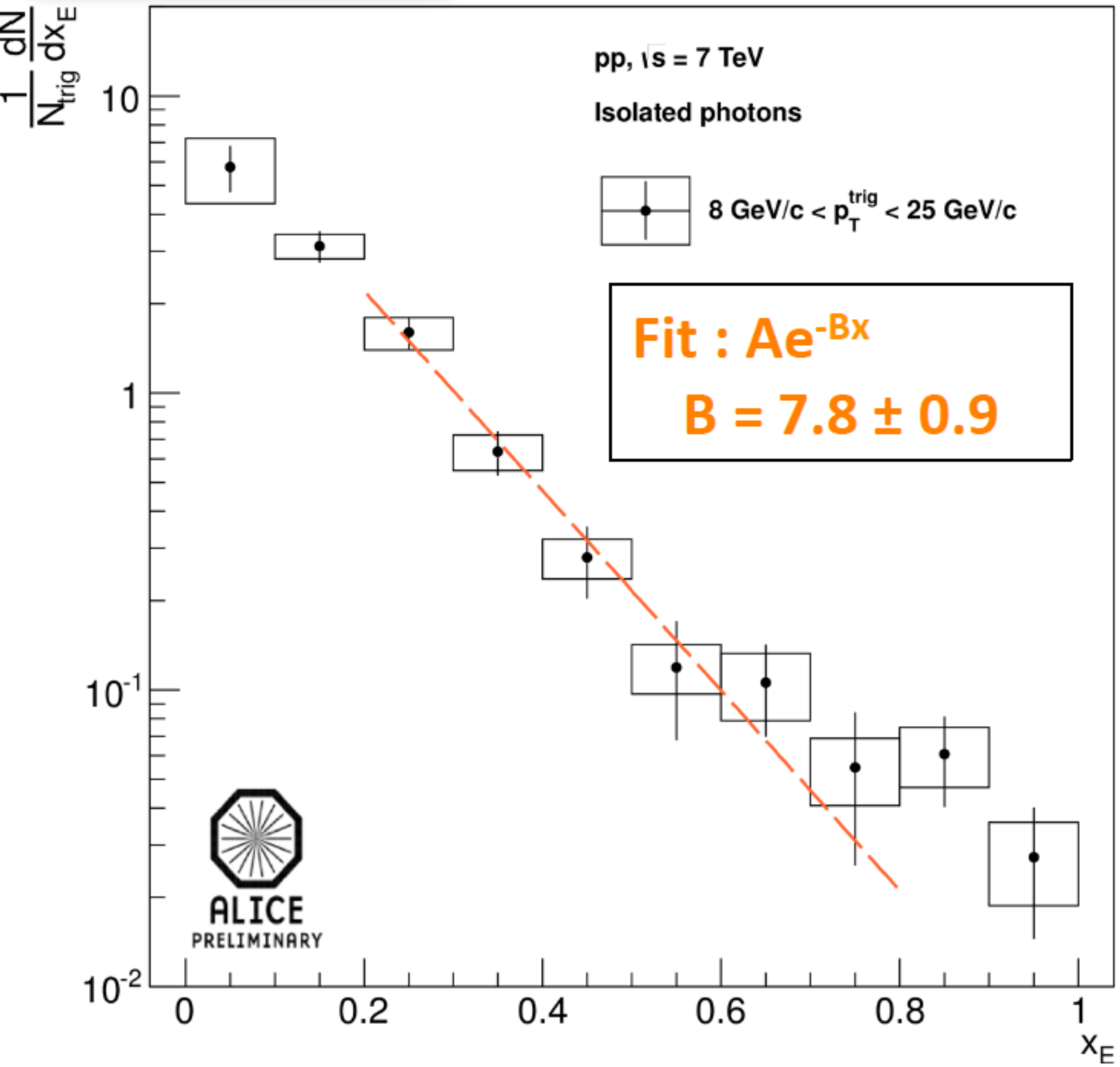
- x_E slope moves towards to <z> =1 direction → isolated π^0 samples a large fraction of jet energy
- Very limited statistics and large uncertainties from Run1 analysis

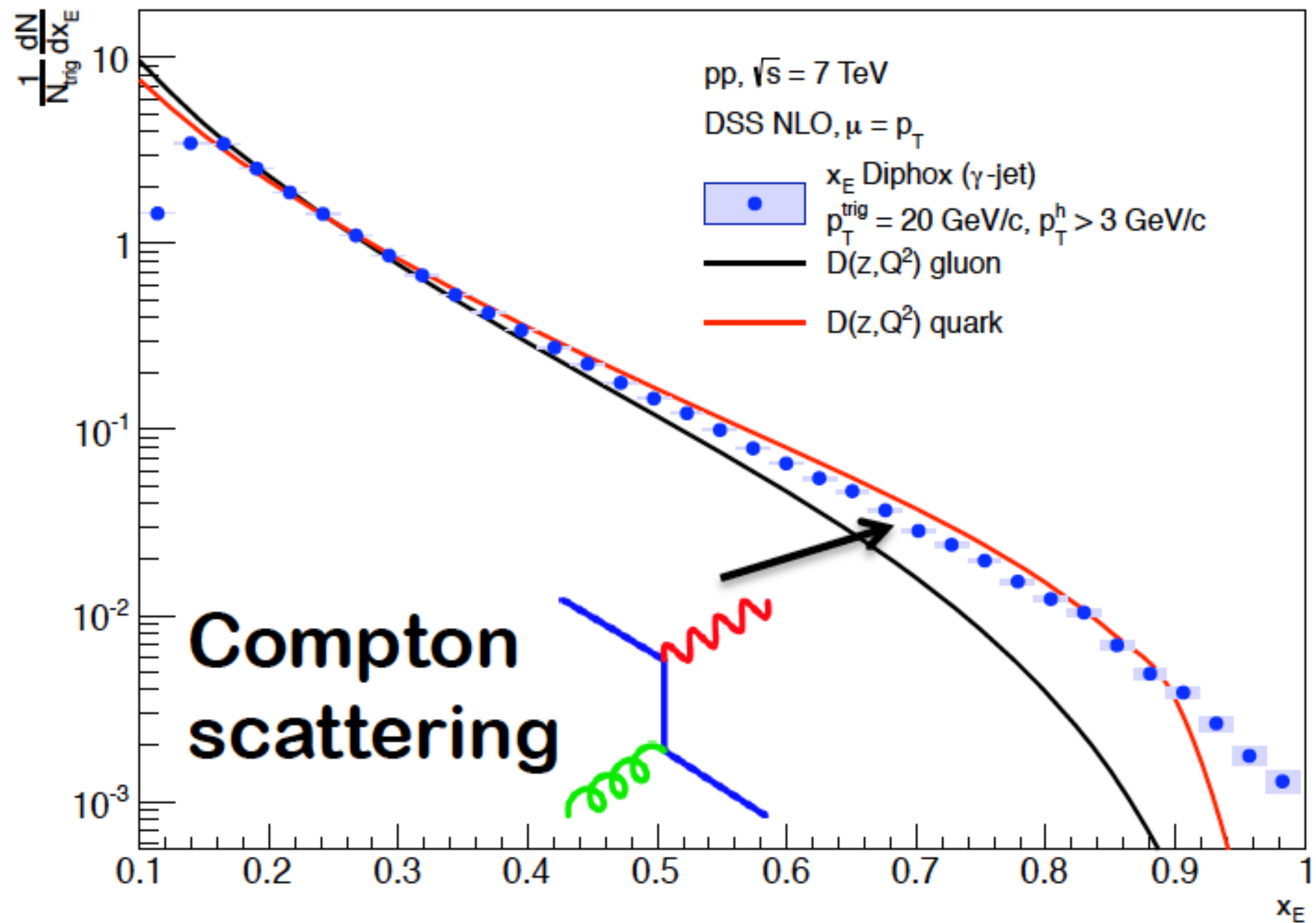
Isolated γ-hadron x_E distributions



$$x_E = -\frac{\vec{p}_{Tt}\cdot\vec{p}_{Ta}}{|\vec{p}_{Tt}|^2} = -\frac{p_{Ta}}{p_{Tt}}\cos(\Delta\phi)$$

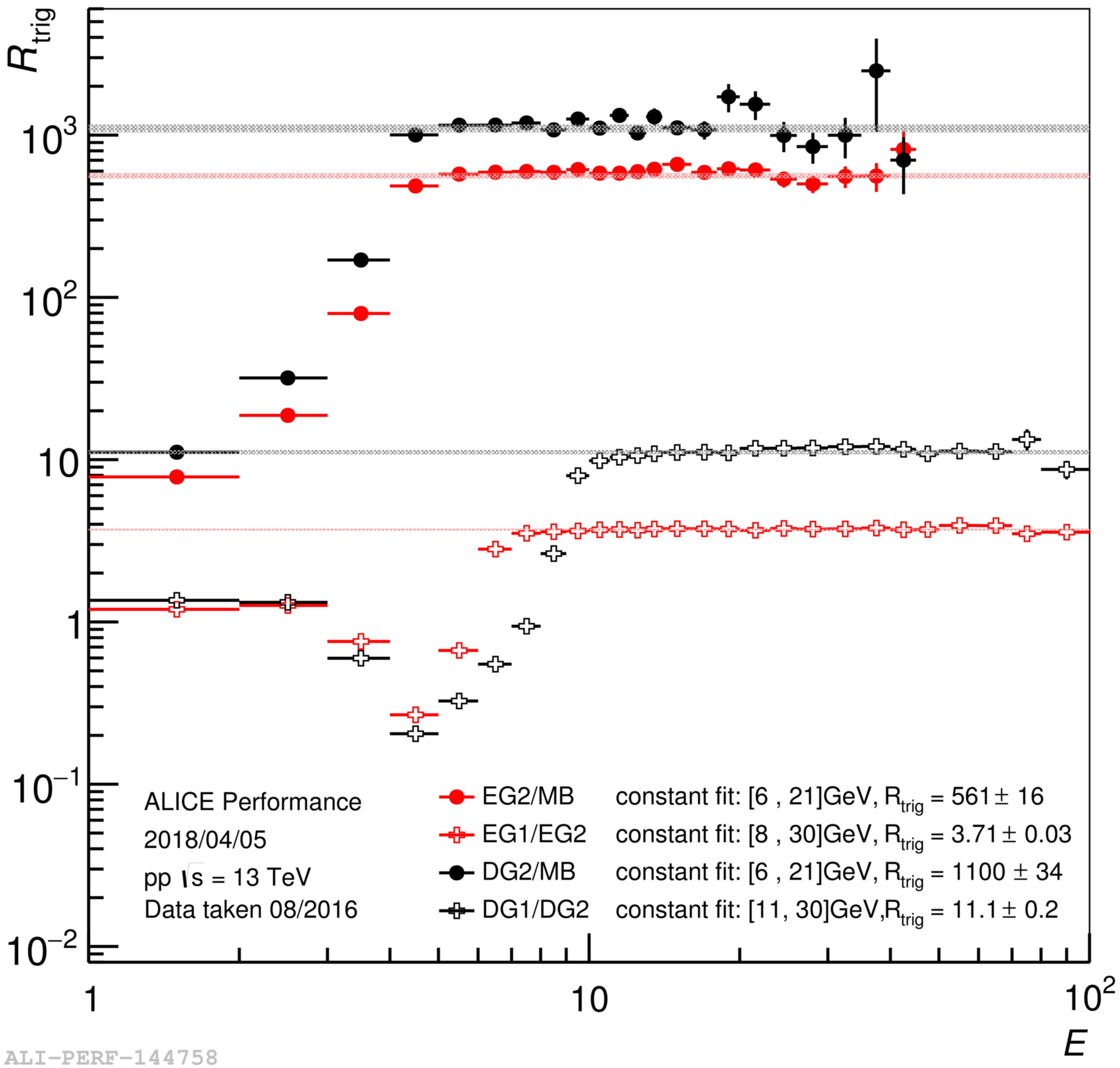
$$\frac{dN}{dx_E} = Ne^{-bx_E}$$

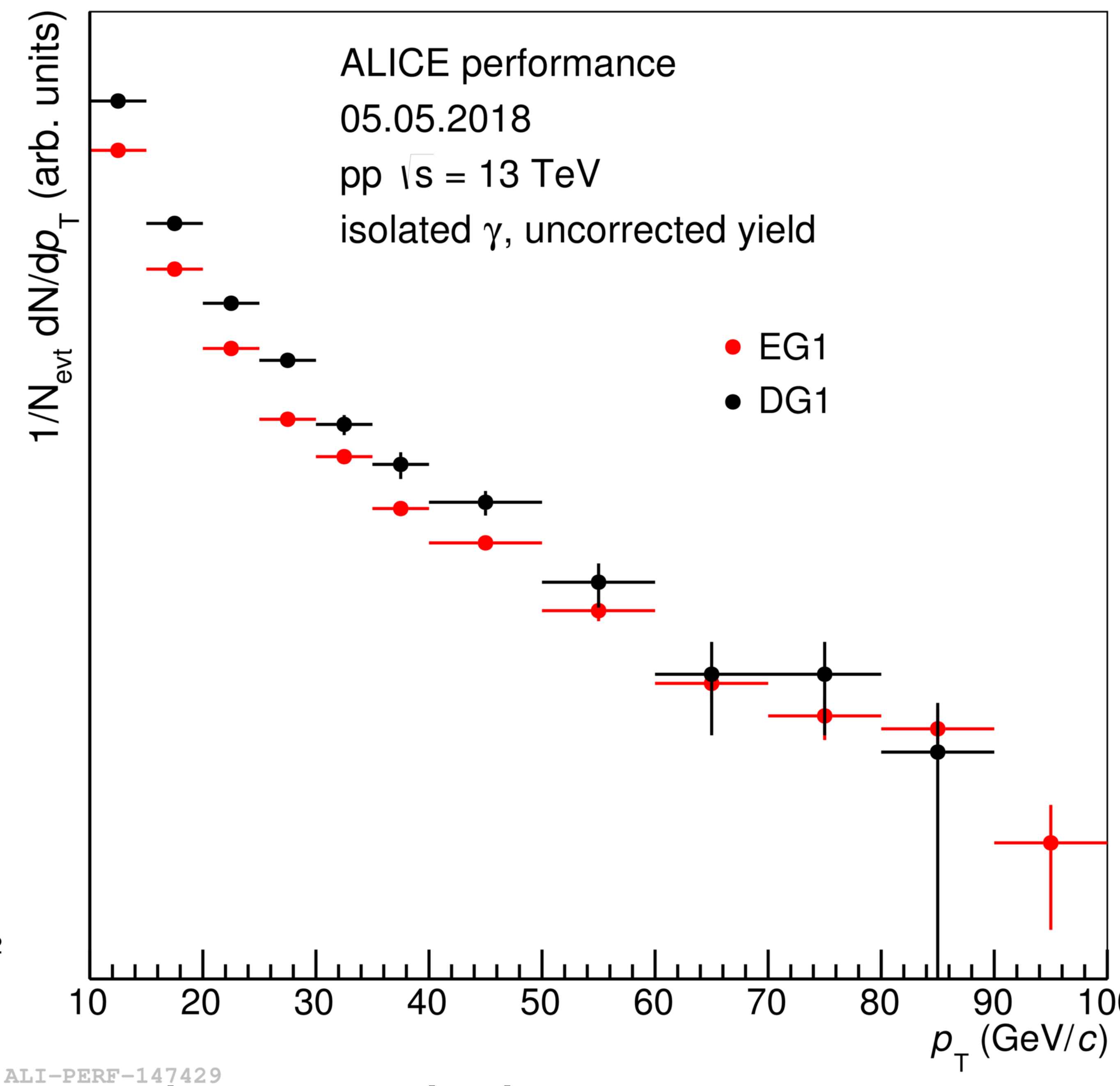




- Isolated γ-hadron x_E distributions in favour of quark jet FF
- Unable to perform such tagging study due to limited statistics in Run I

Kinematics enlarged by using Run2 triggers





- With Run2 triggers, isolated γ can reach to very high p_T
- Different detector triggers performed the same way

➡ Promising results in view of Run2 data analysis are coming soon

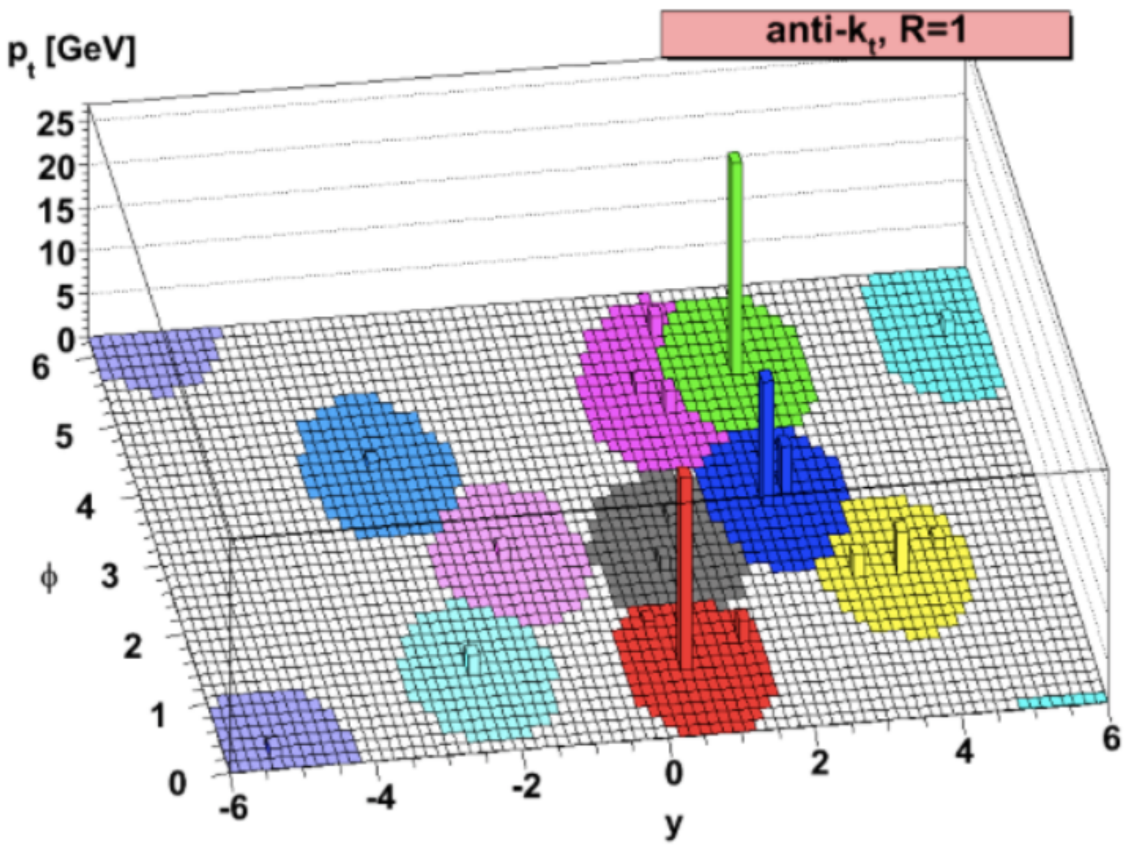
Summary and outlook

- A consistent picture about jet quenching in PbPb collisions at LHC
  - high p_T jets/particles strongly suppressed
  - charm quark jets suppressed similarly as inclusive jets
- Jet properties can be studied using triggered particle correlations
  - isolated trigger particle correlations can be used as a proxy to study light quark jet fragmentation pattern
  - low p_T particle enhanced and away side high p_T suppressed, consistent picture for jet quenching
- Improving understanding on jet thermalization and resolving power of jets using jet tagging and anatomy
  - ➡ A joint proposal on HF-tagged jet was submitted to FCPPL2018 proposal

Thank you for your attention!

backup

Jet reconstruction



2008: Fastjet revolution

Cacciari, Salam, Soyez, JHEP 0804 (2008) 063

"anti-kT" replaced zoo of prior algorithms:

- conceptually simple
- theoretically sound
  - infrared safe
  - collinear safe
- computationally efficient & robust
- part of Fastjet package

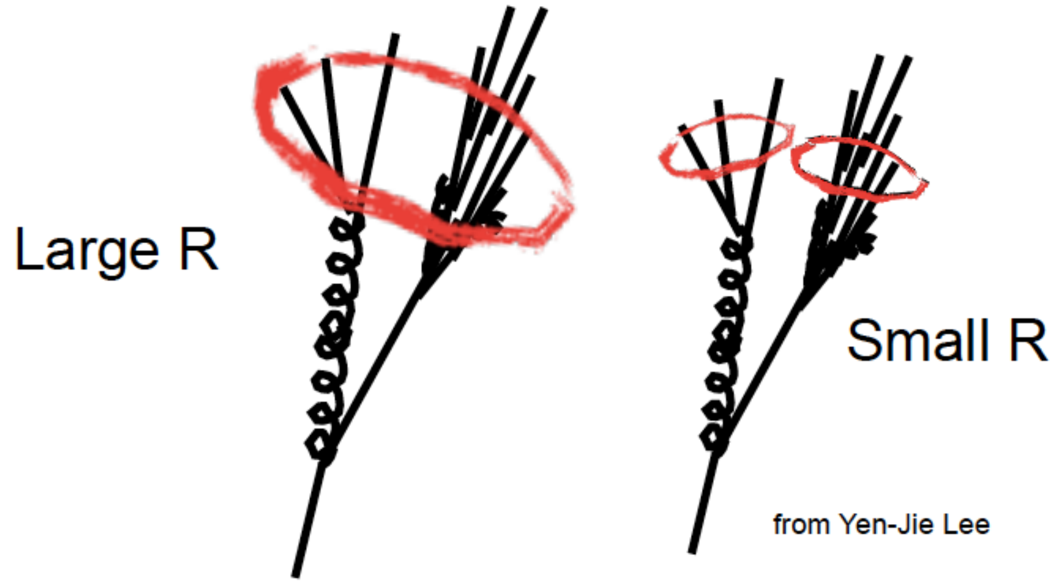
Anti-k_T:

Sequential clustering of objects in event (calo towers, tracks etc) with a particular distance measure:

$$d_{ij} = \min(k_{ti}^{2p}, k_{tj}^{2p}) \frac{\Delta_{ij}^2}{R^2},$$

$$d_{iB} = k_{ti}^{2p}, \quad p=-1$$

Results in cone-shaped, approximately R-sized jets



Which jets are found depends on anti-k_T resolution parameter