Measurements of jets in ALICE

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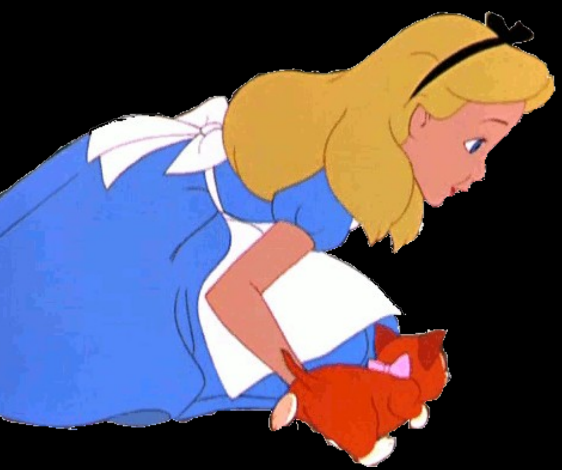
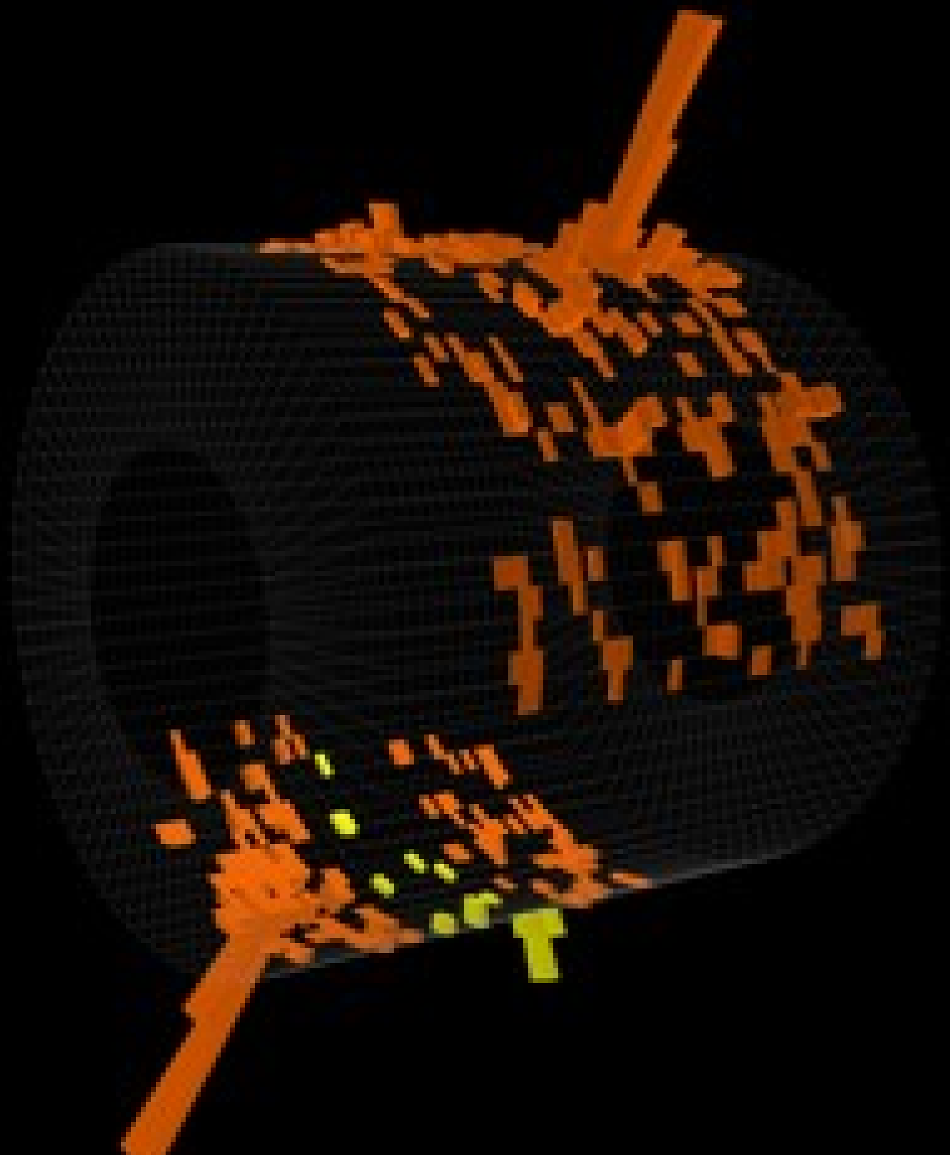


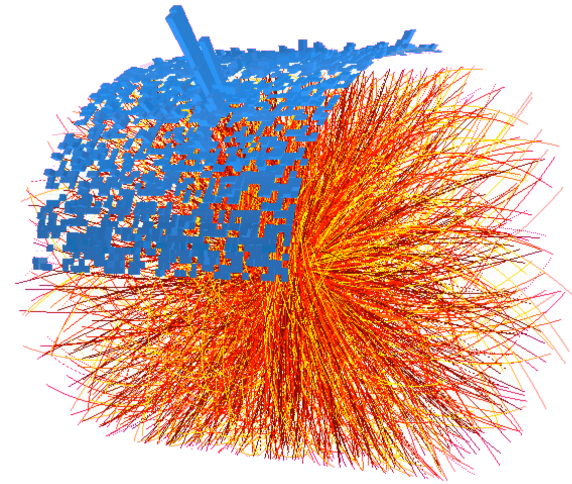


Observables

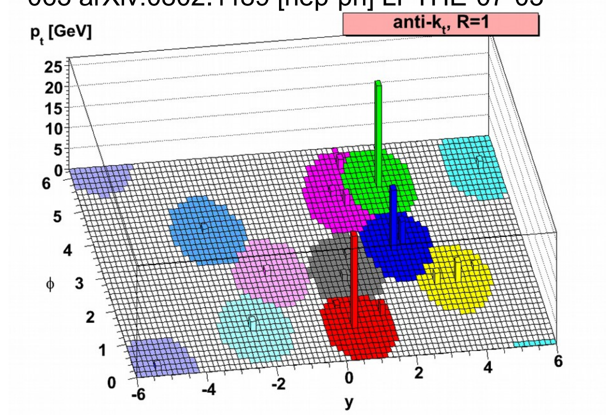
Jet spectra, R_{AA} → Production rates

Jet-hadron correlations → Average jet properties

New jet (shape) observables → Jet substructure

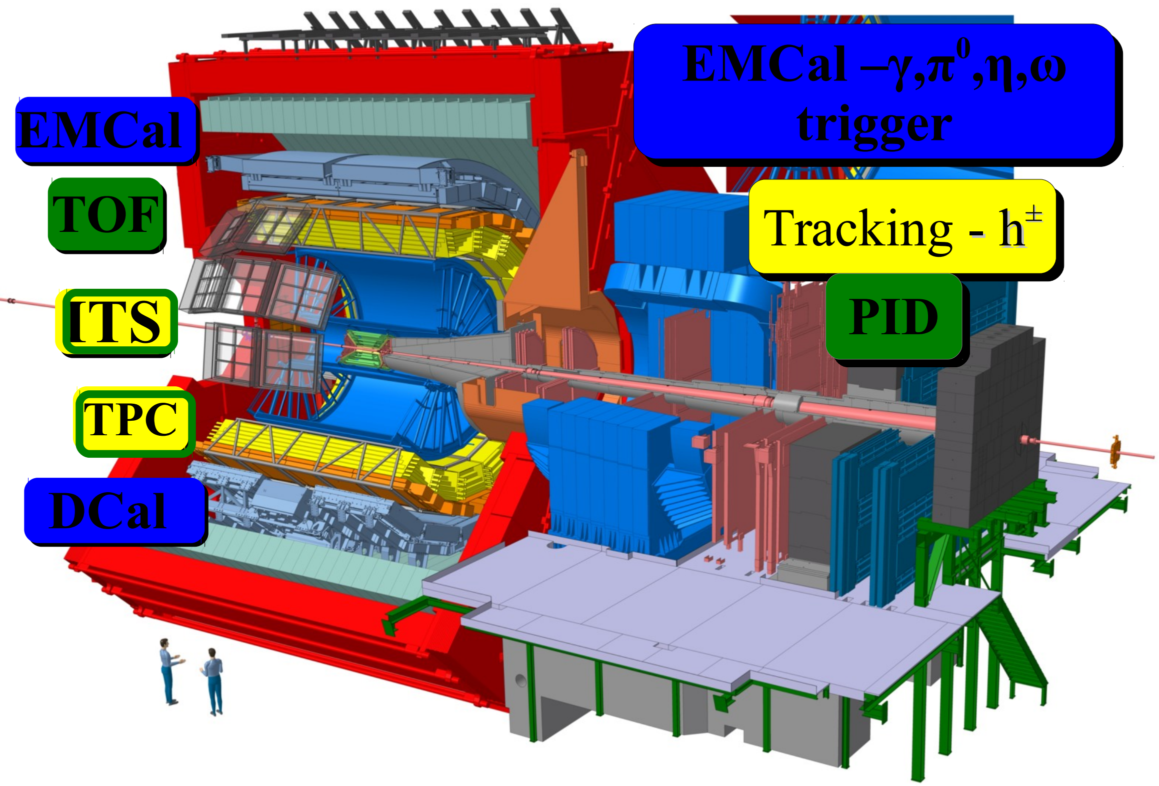


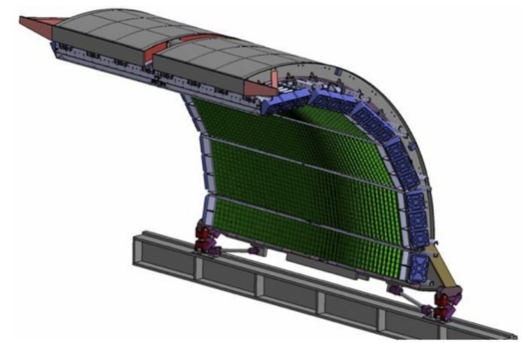
Cacciari, Matteo et al. JHEP 0804 (2008) 063 arXiv:0802.1189 [hep-ph] LPTHE-07-03



See also Alexandre Shabetai July 6 QCD & Hadronic Physics

Jets in ALICE



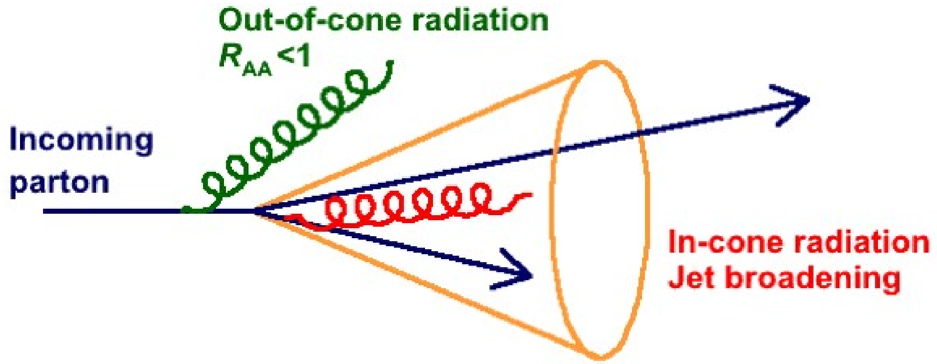


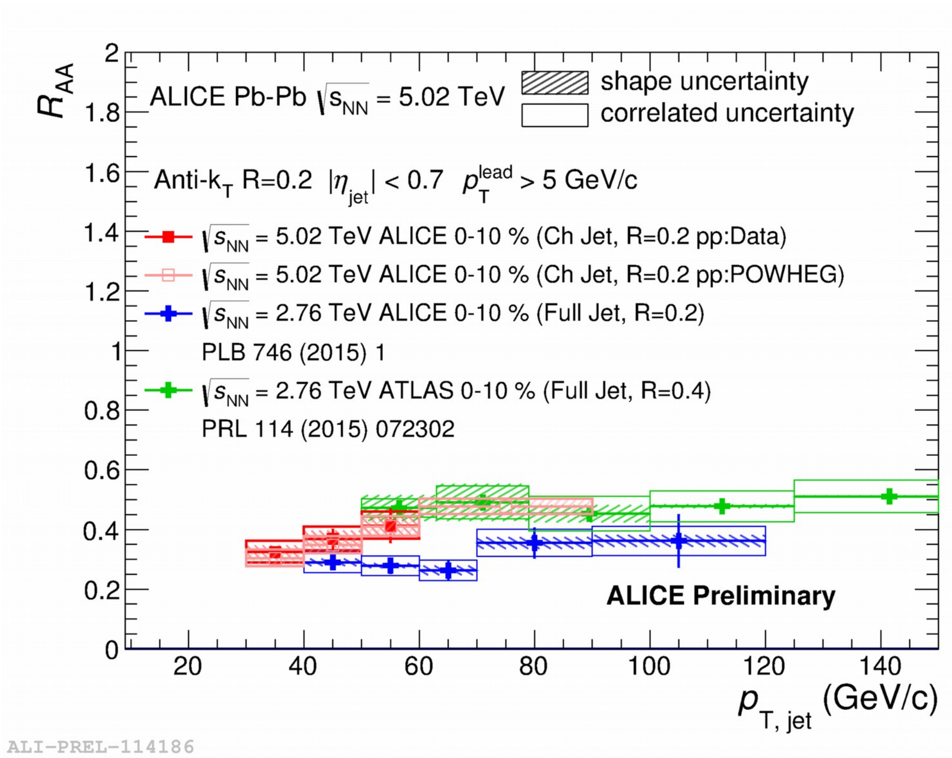
- EMCal Pb-scintillator sampling calorimeter:
  - $|\eta| < 0.7$, $1.4 < \varphi < \pi$
  - tower $\Delta\eta \sim 0.014$, $\Delta\varphi \sim 0.014$

Remove contamination from Charged particles → ***Neutral constituents*** → **Full jet**

Tracking: $|\eta| < 0.9$, $0 < \varphi < 2\pi$
TPC, ITS → ***Charged constituents*** → **Full jet**, **Charged jet**

Jet R_{AA}





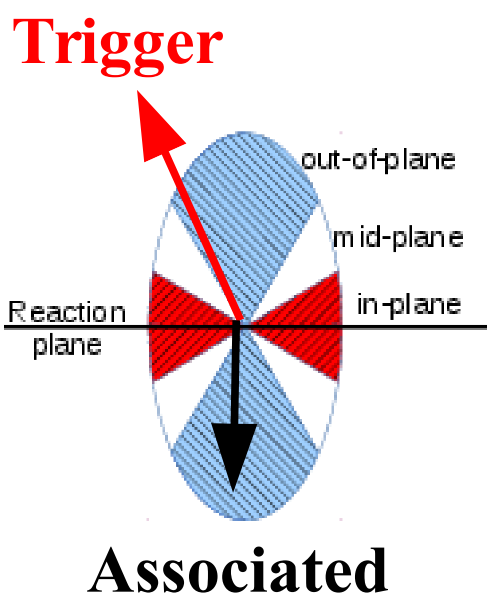
- Out-of-cone radiation: energy loss in jet cone
  - Jet yield suppression, di-jet energy imbalance, jet-jet/hadron-jet acoplanarity…
- In-cone radiation: medium modified fragmentation
  - Jet shape broadening, modification of transverse energy profile…
- Consistent with R_{AA} of charged particles and charged-jet R_{AA} at 2.76 TeV

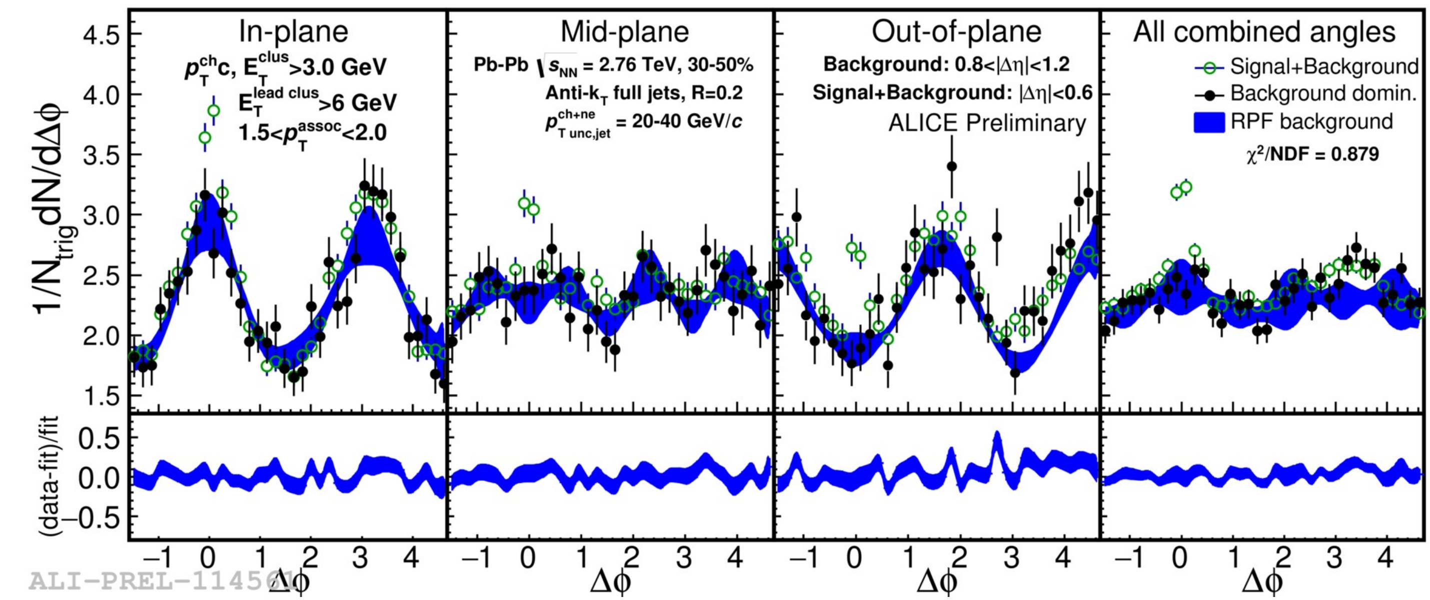
$$R_{AA}=\frac{dN_{AA}/dp_T}{T_{AA}\,d\sigma/dp_T}$$

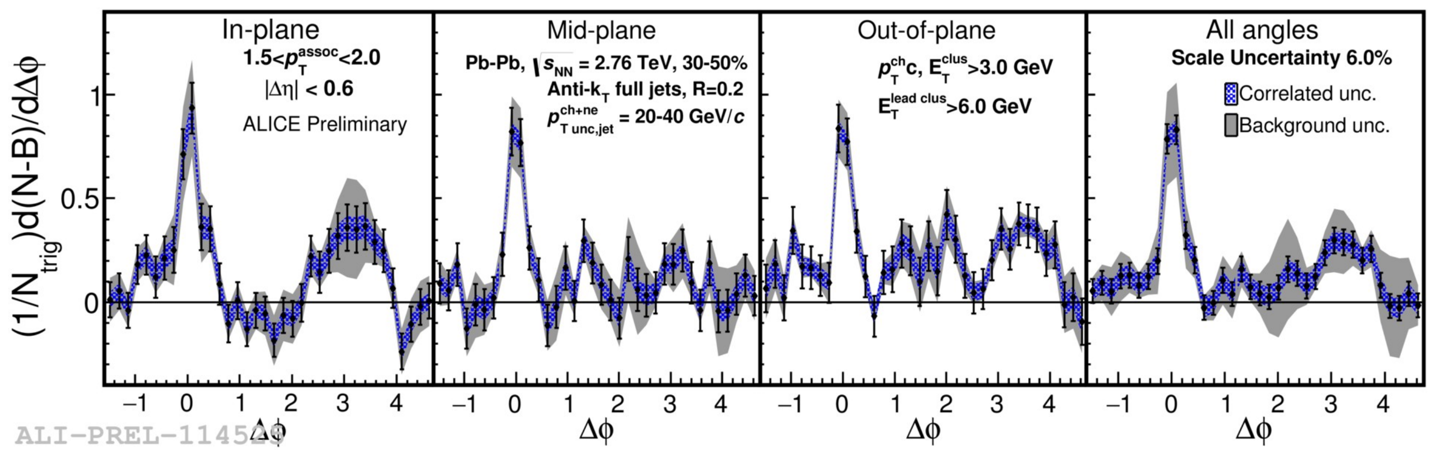
Jet-hadron correlations vs reaction plane

$1.5 < p_T^{assoc} < 2.0$ GeV/c

Full jets
1) signal+bkgd
2) bkgd dominated
3) bkgd RPF fit

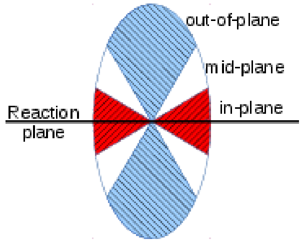






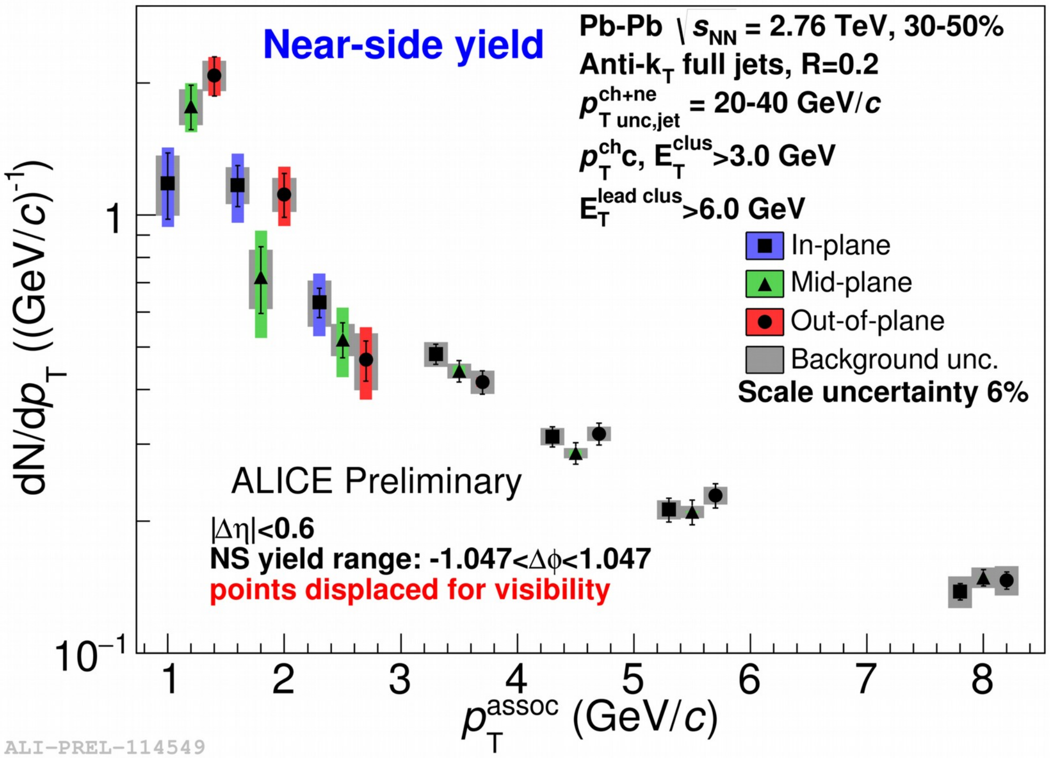
- Background uncertainty non-trivially correlated point-to-point
- Method described in Sharma, Mazer, Stuart, Nattrass Phys. Rev. C 93 (2016), 044915

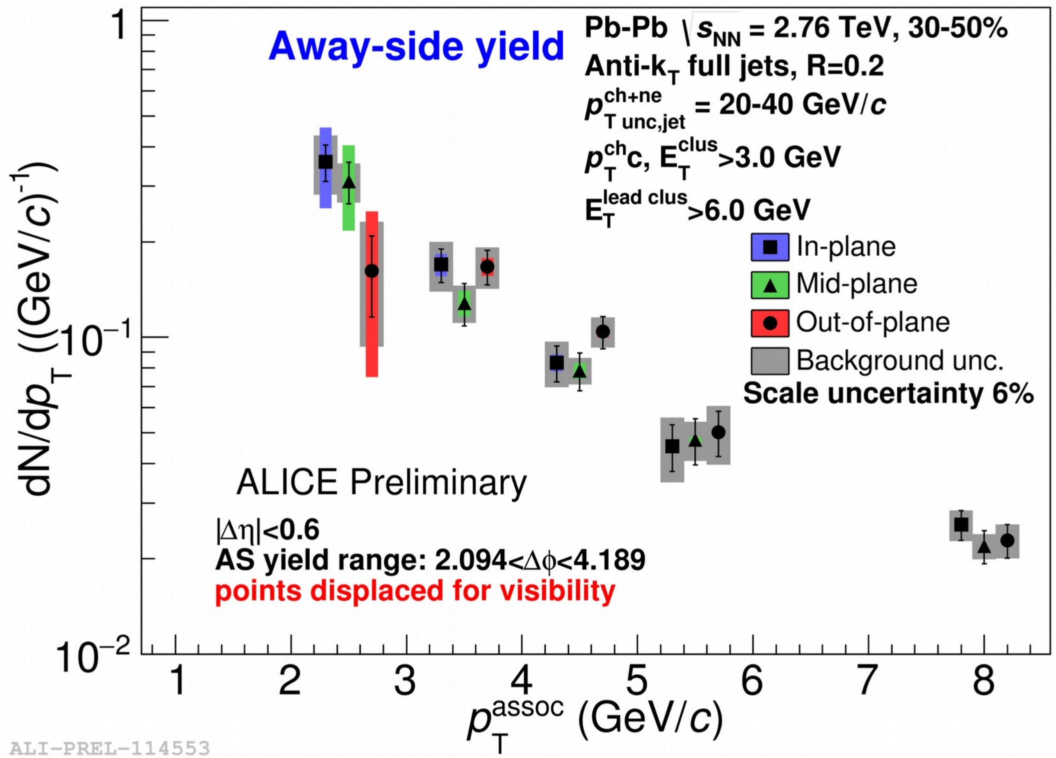
Near- and away-side yields



Full jet-hadron correlations vs reaction plane

Jets 20-40 GeV/c, 30-50% centrality



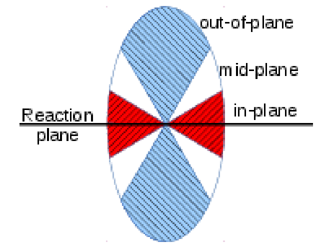


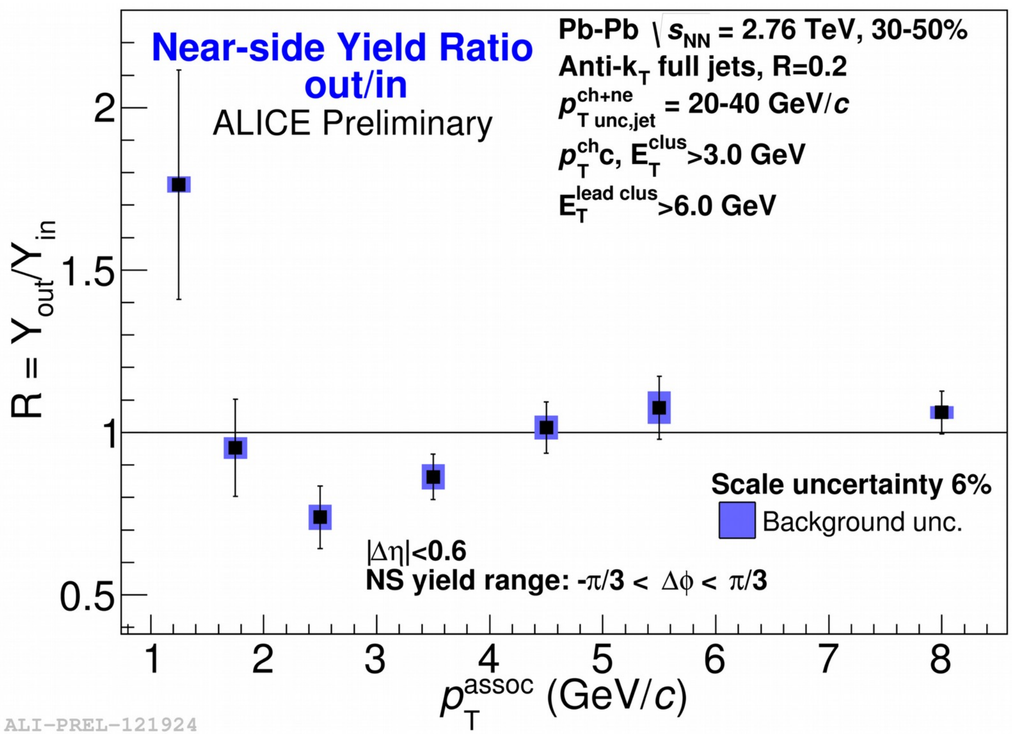
- Possible competing effects:
  - Quenching (decrease yield in → out)
  - Bremsstrahlung (increase yield in → out)
  - Jet-by-jet fluctuations in energy loss (Milhano & Zapp, Eur.Phys.J. C76 (2016) no.5, 288)

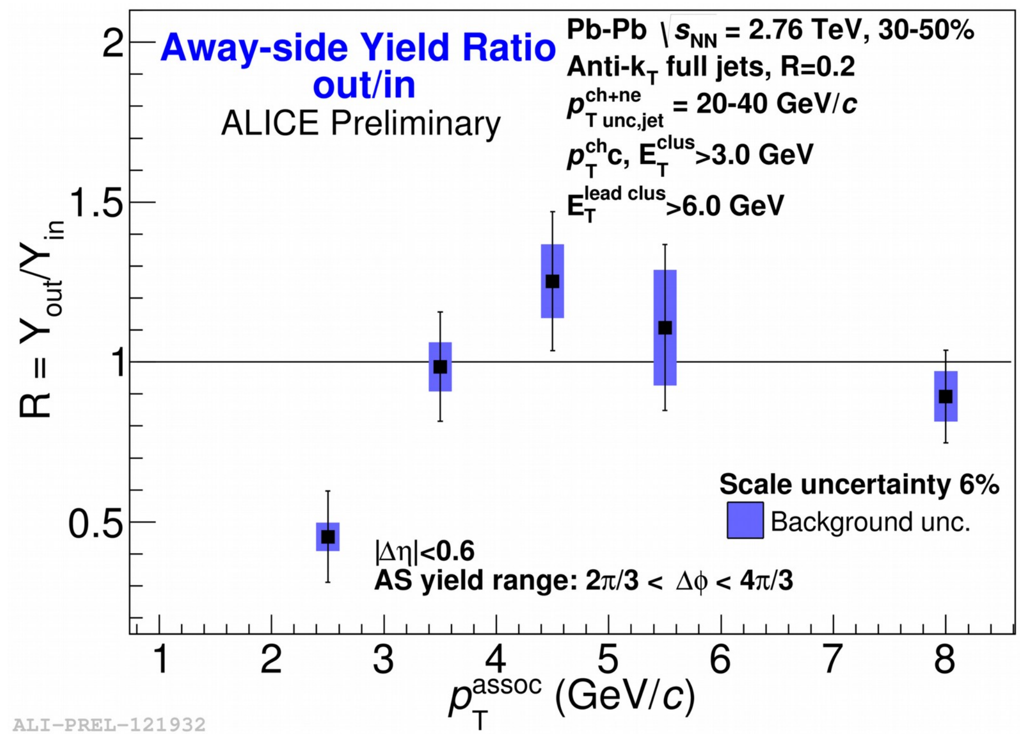
Near- and away-side yield ratio

Full jet-hadron correlations vs reaction plane

Jets 20-40 GeV/c, 30-50% centrality



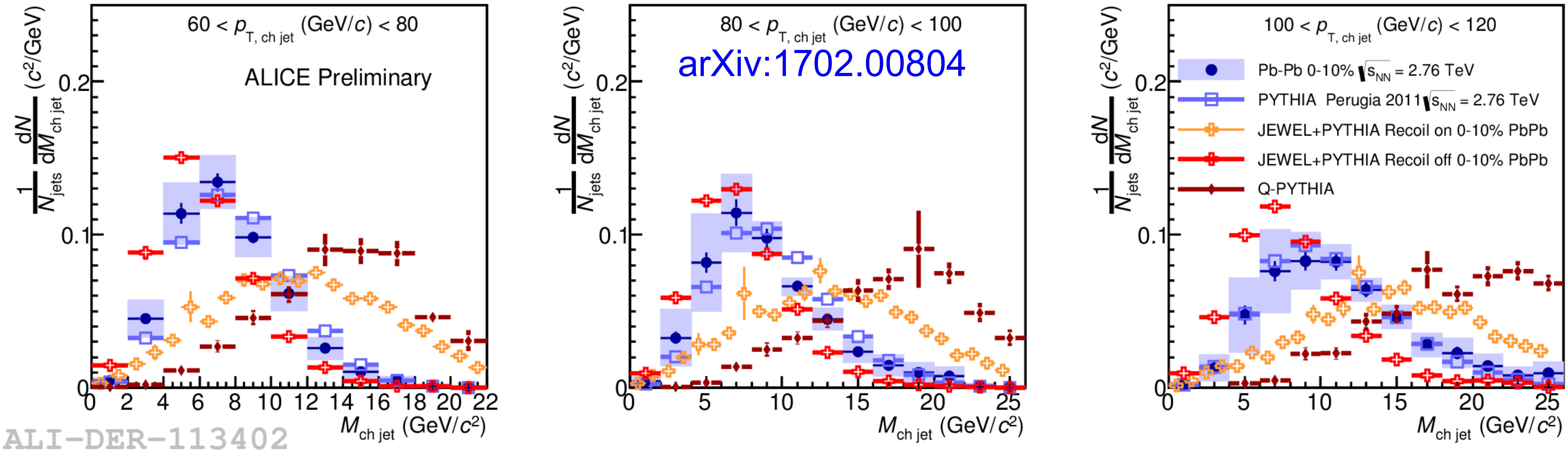




- Within uncertainties of current statistics, no event plane ordering
- **Indication that path-length is a secondary effect to fluctuations of jet energy loss in the medium**
- Consistent with reanalysis of STAR dihadron correlation data

Nattrass, Sharma, Mazer, Stuart, and Bejnood (Phys. Rev. C 94, 011901(R) 2016)

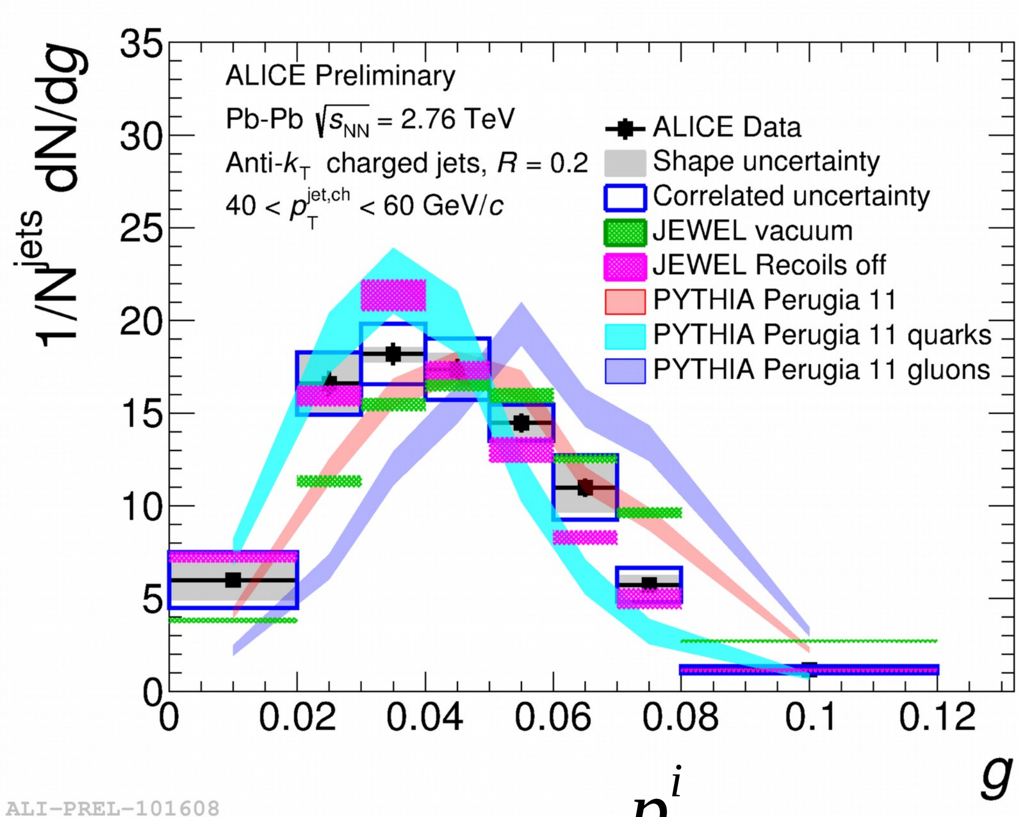
Jet mass

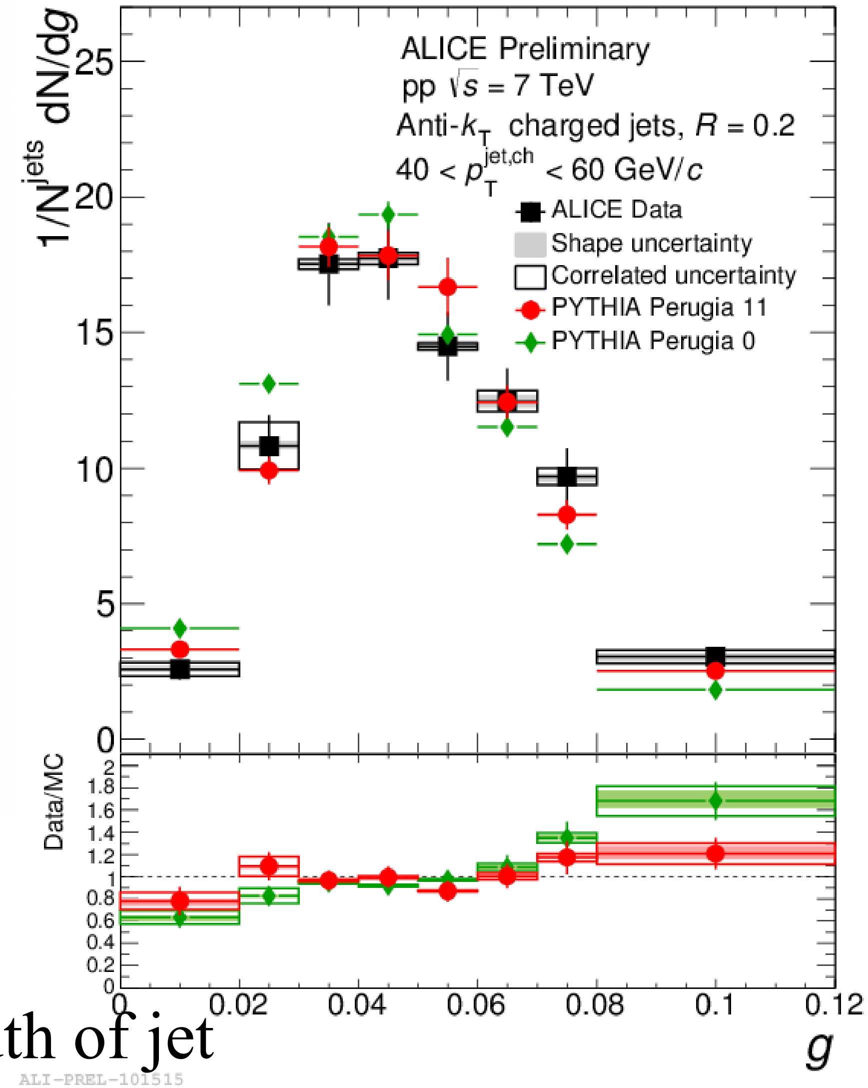


$$M = \sqrt{p^2 - p_T^2 - p_z^2} \qquad p = \sum_{i=1}^{n} p_{T_i} \cosh \eta_i \qquad p_z = \sum_{i=1}^{n} p_{T_i} \sinh \eta_i$$

- Quenching models (JEWEL, Q-PYTHIA) show a larger mass than pp-like PYTHIA jets
- Pb-Pb measurement can discriminate among these predictions

Girth g

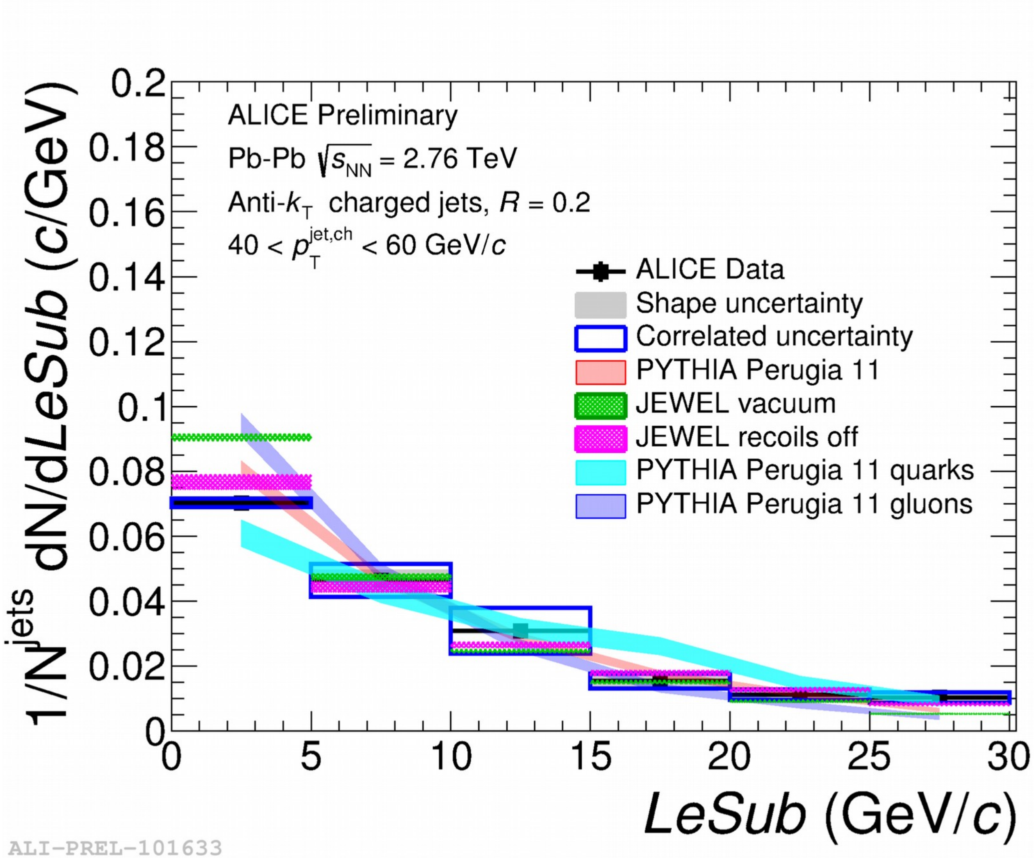


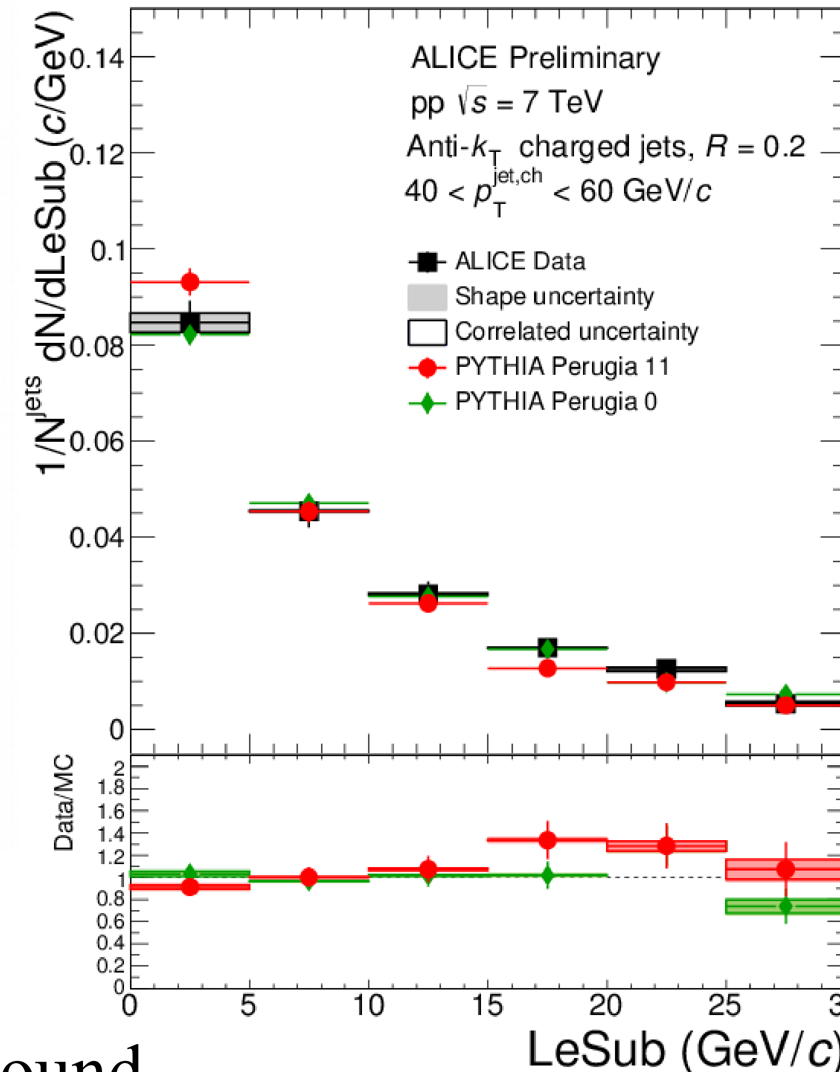


$$g = \sum_{i \in jet} \frac{p_T^i}{p_T^{jet}} r_i$$

- Radial moment g is p_T-weighted width of jet
- In pp collisions: g consistent with PYTHIA even for low R
- In Pb—Pb collisions: may be slightly more collimated

LeSub

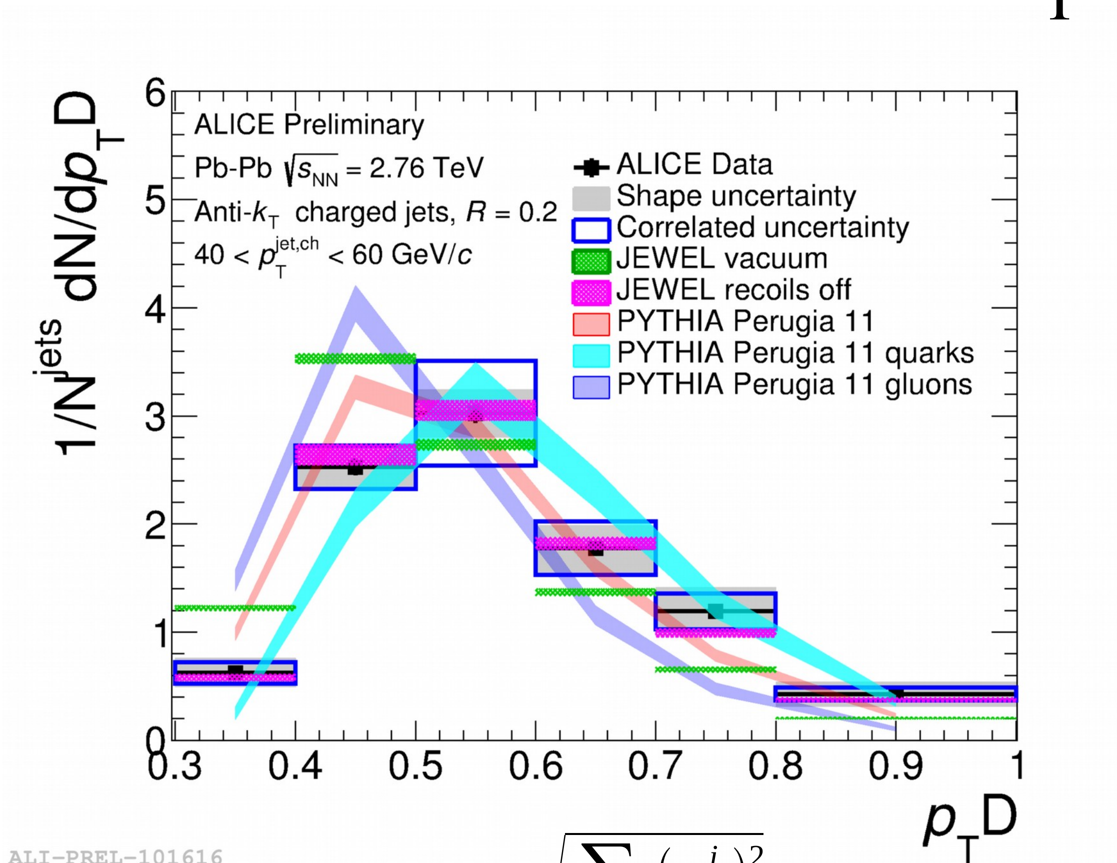




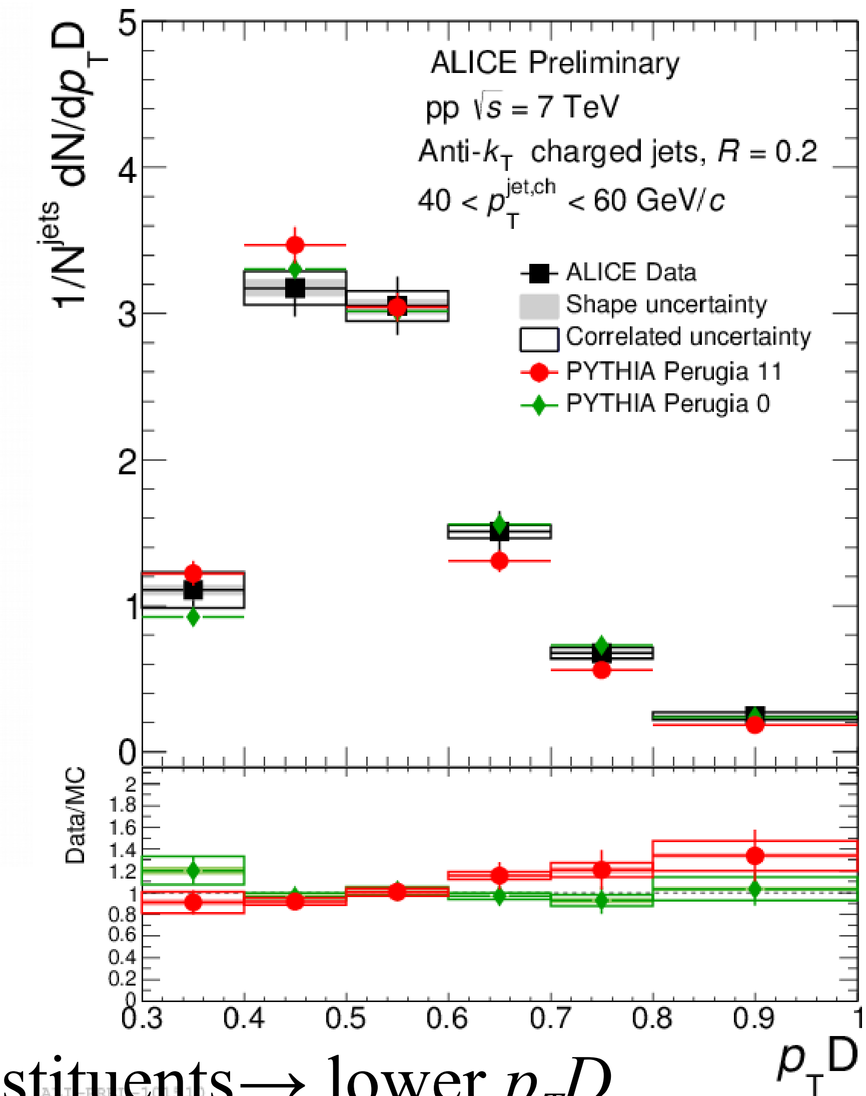
$$LeSub = p_T^{leading} - p_T^{subleading}$$

- Not IR-safe but robust to background
- In pp collisions: agrees with PYTHIA
- In Pb—Pb collisions: agrees with PYTHIA

Dispersion $p_T D$



$$p_T D = \frac{\sqrt{\sum_{i \in jet} (p_T^i)^2}}{\sum_{i \in jet} p_T^i}$$



- Measures dispersion – fewer constituents→ lower $p_T D$
- In pp collisions: agrees with PYTHIA
- In Pb—Pb collisions: slightly more collimated

Conclusions

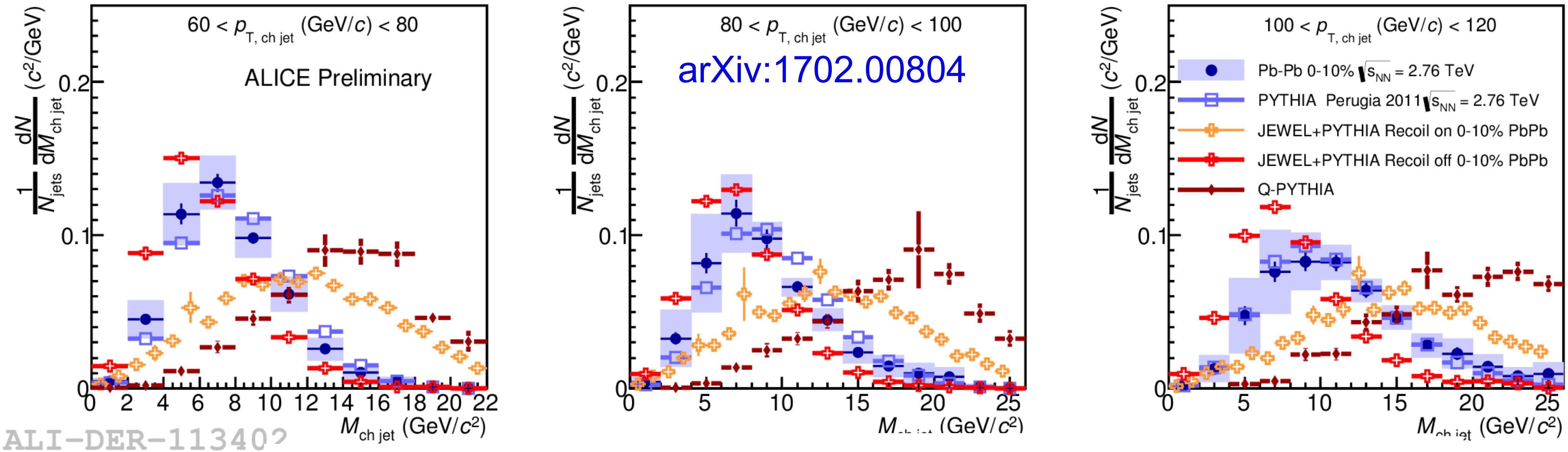
Jet spectra, R_{AA} → Jet suppression

Jet-hadron correlations → No rxn plane dependence → jet-by-jet fluctuations in energy loss significant?

New jet shape observables → Consistent with expectations from vacuum
Slight hints of more collimation in Pb—Pb

backup

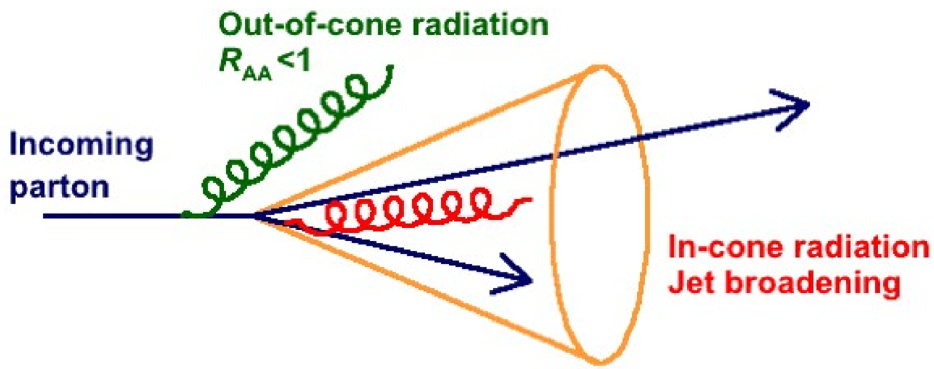
Jet mass



$$M = \sqrt{p^2 - p_T^2 - p_z^2} \qquad p = \sum_{i=1}^{n} p_{T_i} \cosh \eta_i. \qquad p_z = \sum_{i=1}^{n} p_{T_i} \sinh \eta_i$$

- Quenching models (JEWEL, Q-PYTHIA) show a larger mass than pp-like PYTHIA jets
  - JEWEL: 2→2 pQCD matrix elements with parton shower taking into account radiation. For charged jets the background subtraction is implemented by shifting the distribution considering the background estimated for full jets and the difference between full and charged jets in pp
  - Q-PYTHIA: PYTHIA with medium effects in the final state branching through an additive term in the splitting functions computed in the multiple-soft scattering approximation
- JEWEL with "recoil off" (removing recoil centres before hadronization) shows a depletion of the jet mass wrt pp due to less low-p_T fragments wrt recoil on
- Pb-Pb measurement can discriminate among these predictions

Jet R_{AA}



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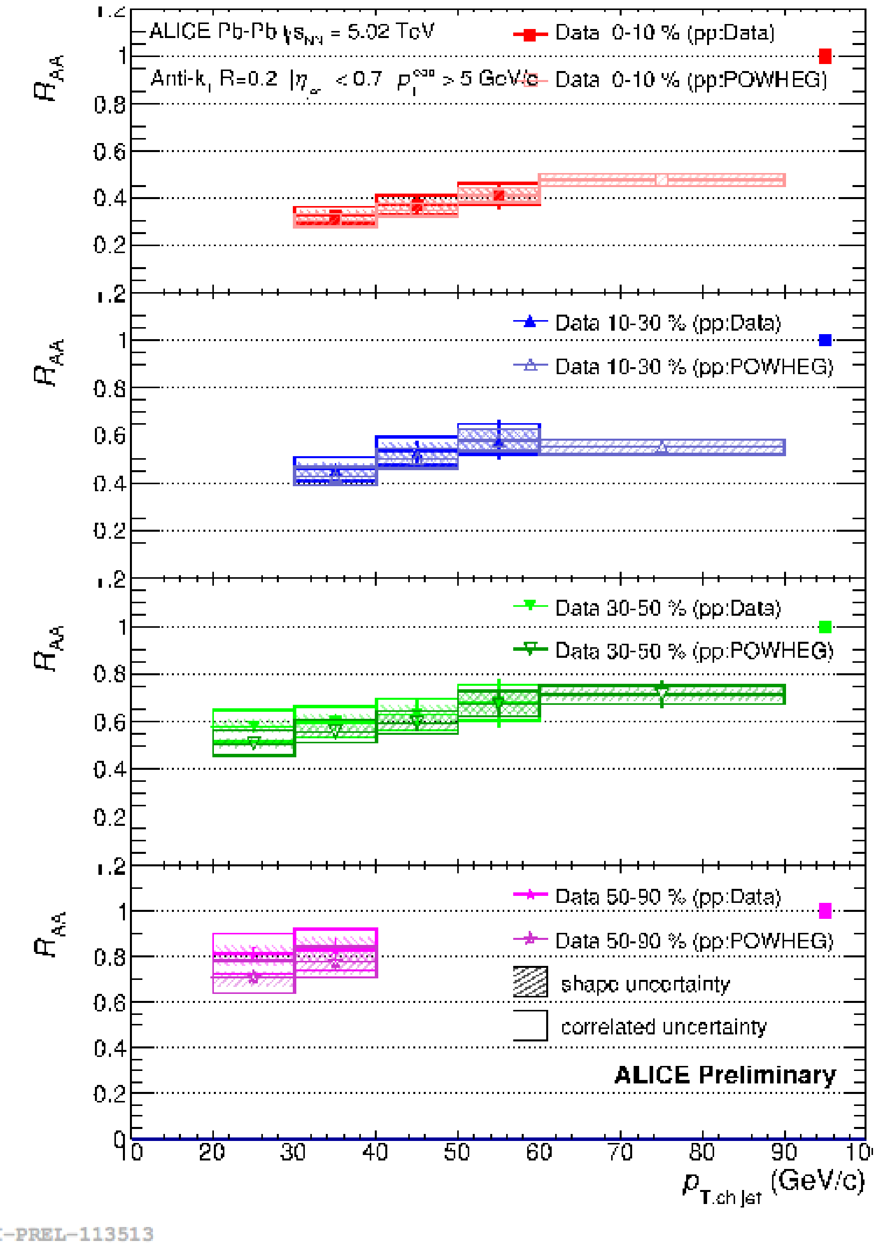
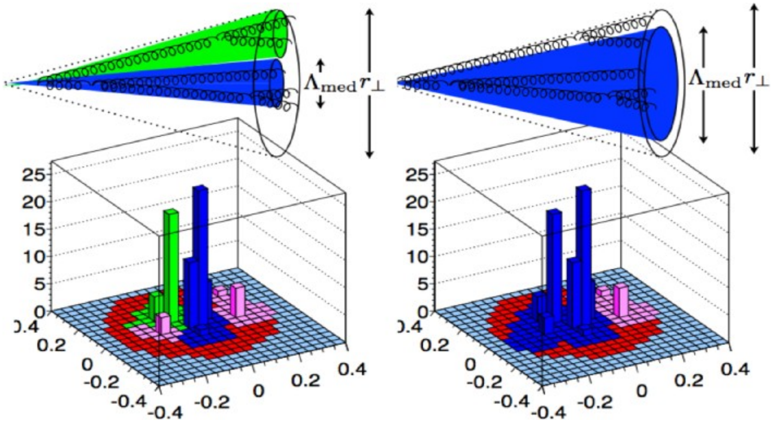


$$R_{AA} = \frac{d^2N_{AA}/dp_T d\eta}{T_{AA} d^2\sigma^{pp}/dp_T d\eta}$$

Nsubjettiness: search for color (de)coherence

Resolved subtructure **Unresolved subtructure**



Casalderrey-Solana, Mehtar-Tani, Salgado, Tywoniuk Phys.Lett.B 725 (2013) 357–360

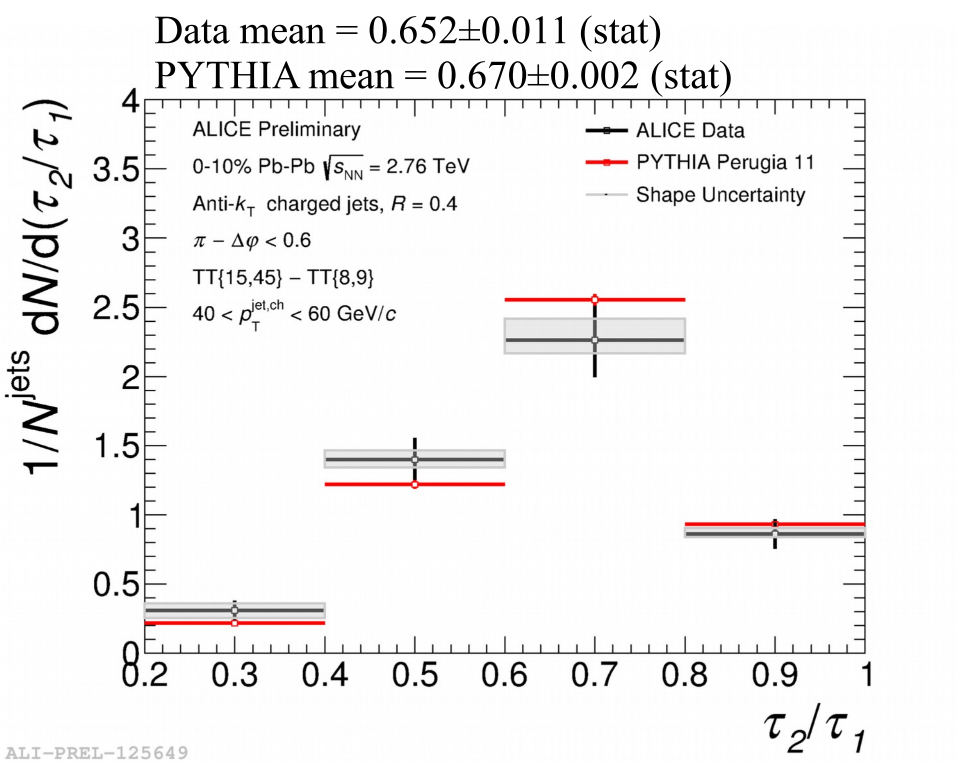
$$\tau_N = \frac{\sum_{i=1}^{M} p_T^i \, Min(\Delta R_{i,1}, \Delta R_{i,2} \ldots \Delta R_{i,N})}{R_0 \sum_{i=1}^{M} p_T^i}$$

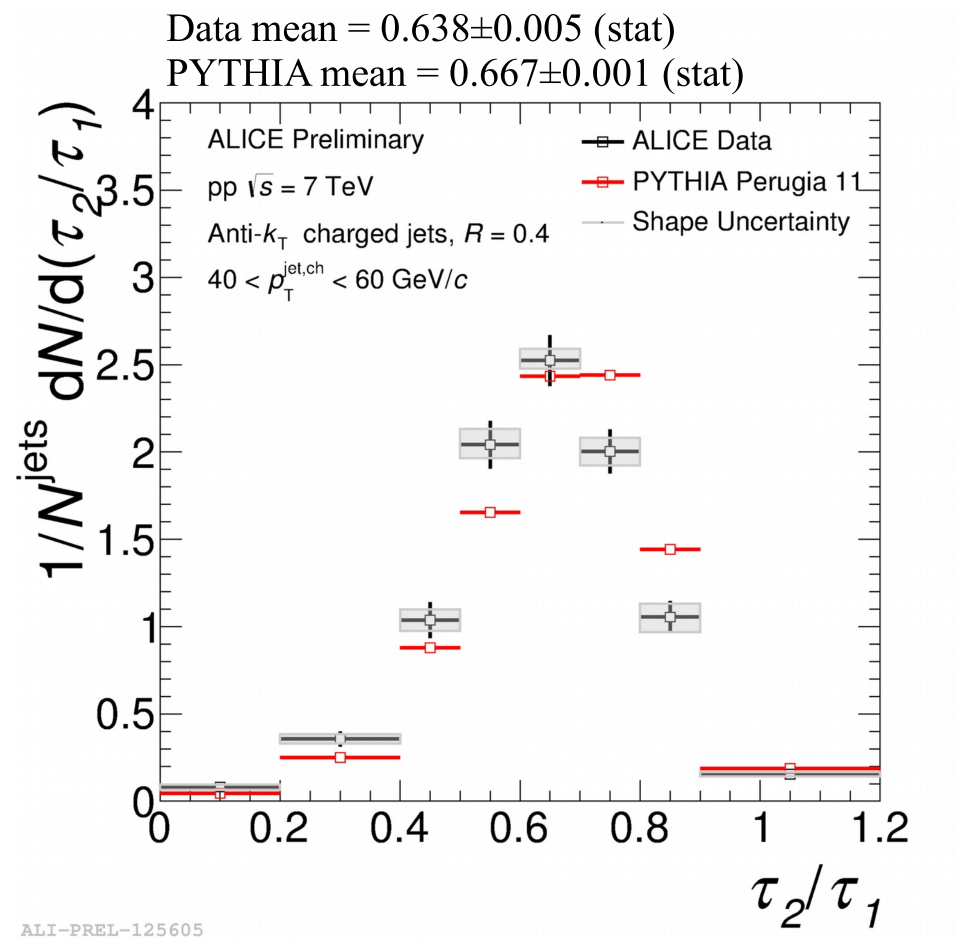
N: number of subjets
M: number of tracks
$\Delta R_{i,j}$: η-φ distance between track i and subjet j
R_0: jet resolution parameter

- Find jets with anti-k_T algorithm
- Run k_T algorithm over jet constituents
- Reverse the last merging τ_2

$\tau_N \rightarrow 0$: Jet has N or fewer cores
$\tau_N \rightarrow 1$: Jet has at least N+1cores
$\tau_N/\tau_{N-1} \rightarrow 0$: Jet has N cores
$\tau_2/\tau_1 \rightarrow 0$: Jet has 2 cores

Nsubjettiness

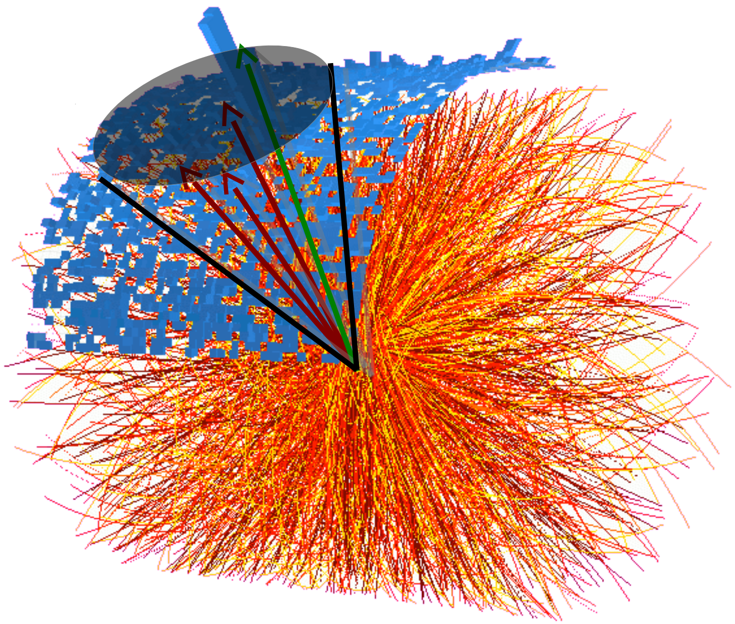




- τ_2/τ_1 measures alignment of radiation to two subjets
- No significant shift in τ_2/τ_1 to higher values→no significant change in alignment of radiation to the cores

Jet reconstruction

- Input to the jet finder
  - Assumed to be massless
  - Charged tracks (ITS+TPC) with $p_T > 150$ MeV/c
  - Cluster energies $E_{cluster} > 300$ MeV
  - EMCal cluster energies corrected for charged particle contamination with
    f = 100%



$$E^{cor}_{cluster} = E^{orig}_{cluster} - f \sum p^{Matched}, E^{cor}_{cluster} \geq 0$$

- ALICE measures
  - Full Jets (tracks + clusters) – corrected to include n, K^0_L...
  - Charged jets (tracks only) – corrected to charged particle energy only

Analysis details and correction procedure

Raw distributions:

Two Systems: pp MB at $\sqrt{s}$=7 TeV and Pb-Pb (0-10% central) at $\sqrt{s_{NN}}$=2.76 TeV

Charged particle tracks as input (TPC+ITS detectors), $p_{T,cutoff}^{const}$ = 0.15 GeV/*c*

anti-k_T algorithm, *R*=0.2, E-scheme

Background subtraction:

Uncorrelated average background removal from shape observables using new techniques:

- Area Subtraction *[G.Soyez et al, Phys.Rev.Lett 110 (2013) 16]* (default method)
- Constituents Subtraction *[P.Berta et al, JHEP 1406 (2014) 092]*

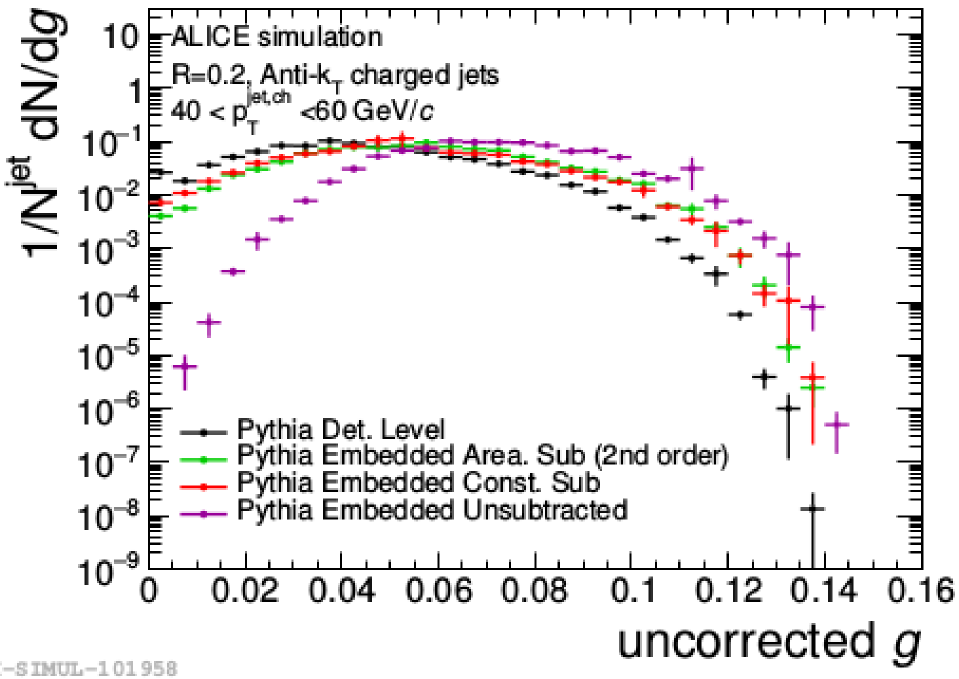
Unfolding of residual background fluctuations and detector effects:

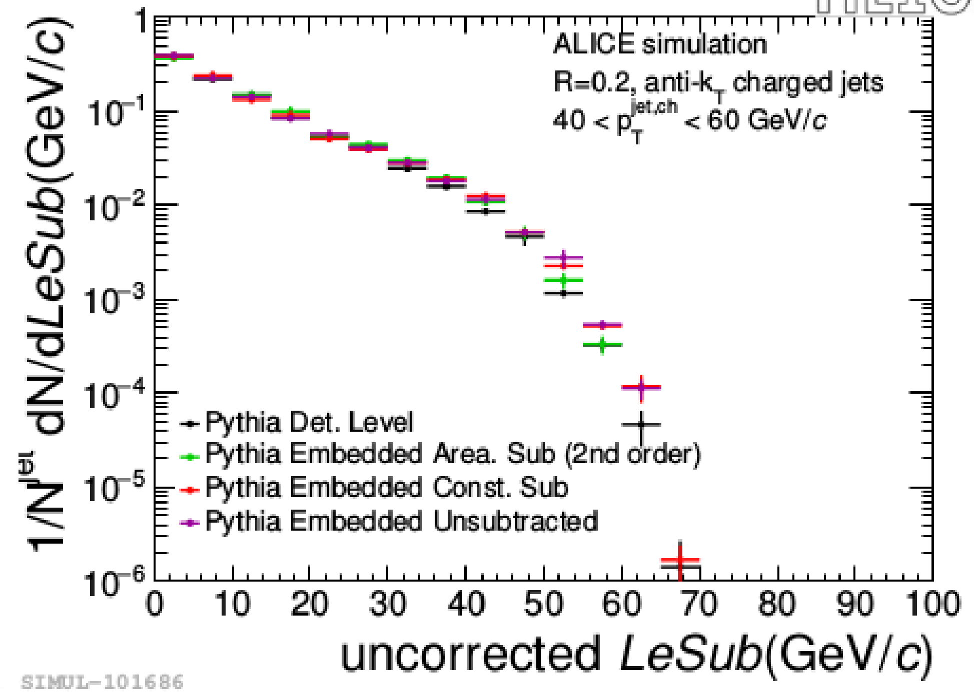
2D Bayesian techniques (*T.Adye, CERN-2011-006)2011) 13*)

are applied to unsmear the jet p_T and the shape simultaneously

Reported corrected p_T range: 40-60 GeV/*c* in both systems

Background subtraction performance in Pb-Pb





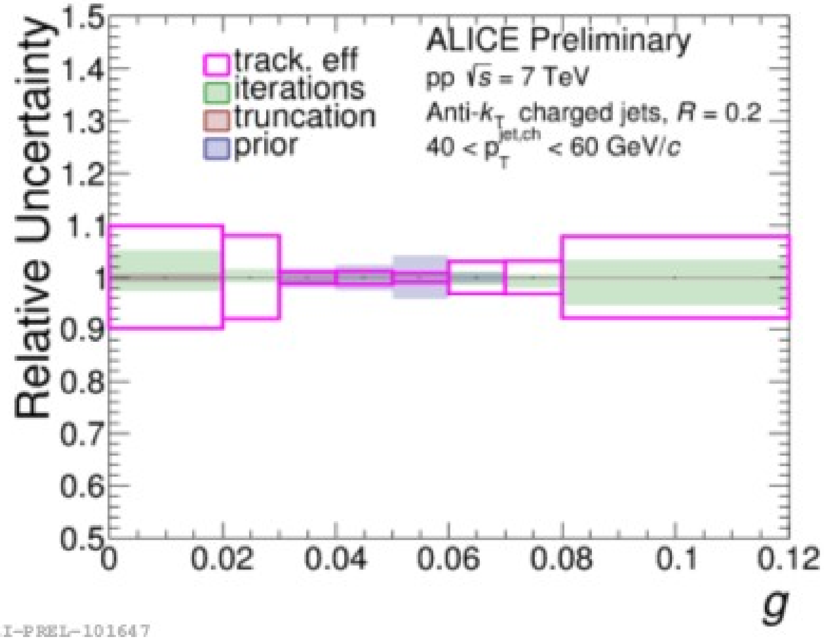
Pythia detector level jet embedded into Pb-Pb events and background subtracted

Subtracted jet shape approaches that of the original probe (compare black and red or green)
Residual differences between the shape in PYTHIA and that of the PYTHIA embedded subtracted come from background fluctuations that **need to be unfolded**

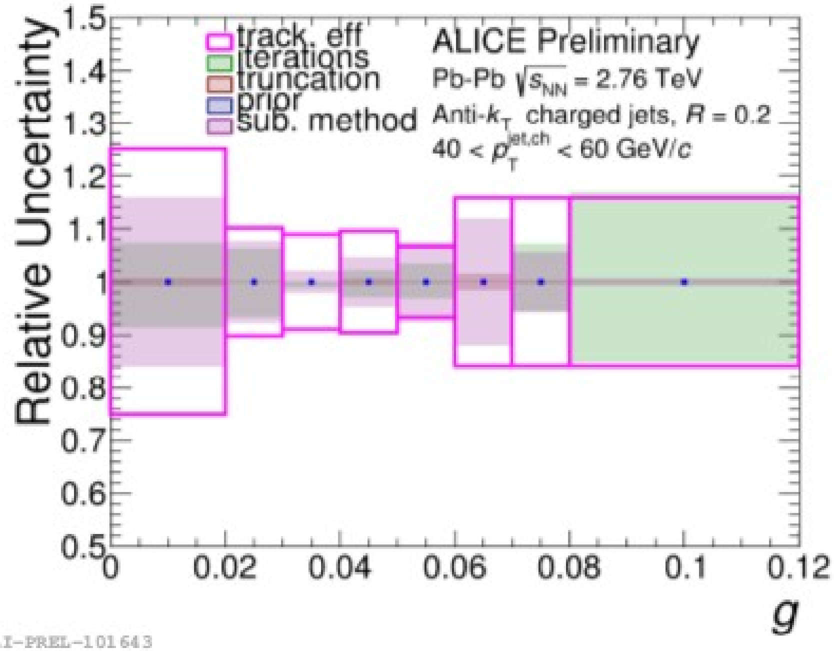
Note: *LeSub* is largely background invariant: very unlikely that an uncorrelated high p_T track replaces the leading or subleading jet tracks.

Uncertainties in the measurement

pp



Pb-Pb



Uncertainties:

-**Tracking efficiency** uncertainty of ±4% dominates the Jet Energy Scale uncertainty

-**Unfolding:**

Regularization variations of ±3 iterations

Truncation of the measured yield at a 10 GeV lower value (10 and 20 GeV/*c* in pp and Pb-Pb resp.)

Prior: intrinsic correlation between $p_T^{\text{jet,part}}$ and shape$^{\text{part}}$ with which response is built.

Default is PYTHIA Perugia 0, variation is a smearing of such correlation by 20%

-**Additional ingredient in Pb-Pb**: background subtraction method variation

Analysis Details and Correction Procedure

Raw distributions:

Two systems: pp Minimum Bias at $\sqrt{s}$=7 TeV and Pb-Pb (0-10% central) at $\sqrt{s_{NN}}$=2.76 TeV

Charged particle tracks as input, $p_T^{const} > 0.15$ GeV/c

anti-k_T algorithm, R=0.4, E-scheme

Background subtraction:

Average background removal from shape observables event-by-event using new techniques:

Derivative (Area based) Subtraction *[G.Soyez et al, Phys.Rev.Lett 110 (2013) 16]* .

Constituent Subtraction *[P.Berta et al, JHEP 1406 (2014) 092]* ***(default method)*****.**

Combinatorial background suppressed in Pb-Pb using hadron-jet coincidence technique.

Correction for residual background fluctuations and detector effects via unfolding:

2D Bayesian techniques (*T.Adye, CERN-2011-006)2011) 13*).

are applied to unsmear the jet p_T and the shape simultaneously.

Reported results in p_T range: 40-60 GeV/c in both systems.