Investigating jet modifications using di-hadron correlations in Pb-Pb collisions with ALICE

May. 24th 2019

Heavy Ion Meeting

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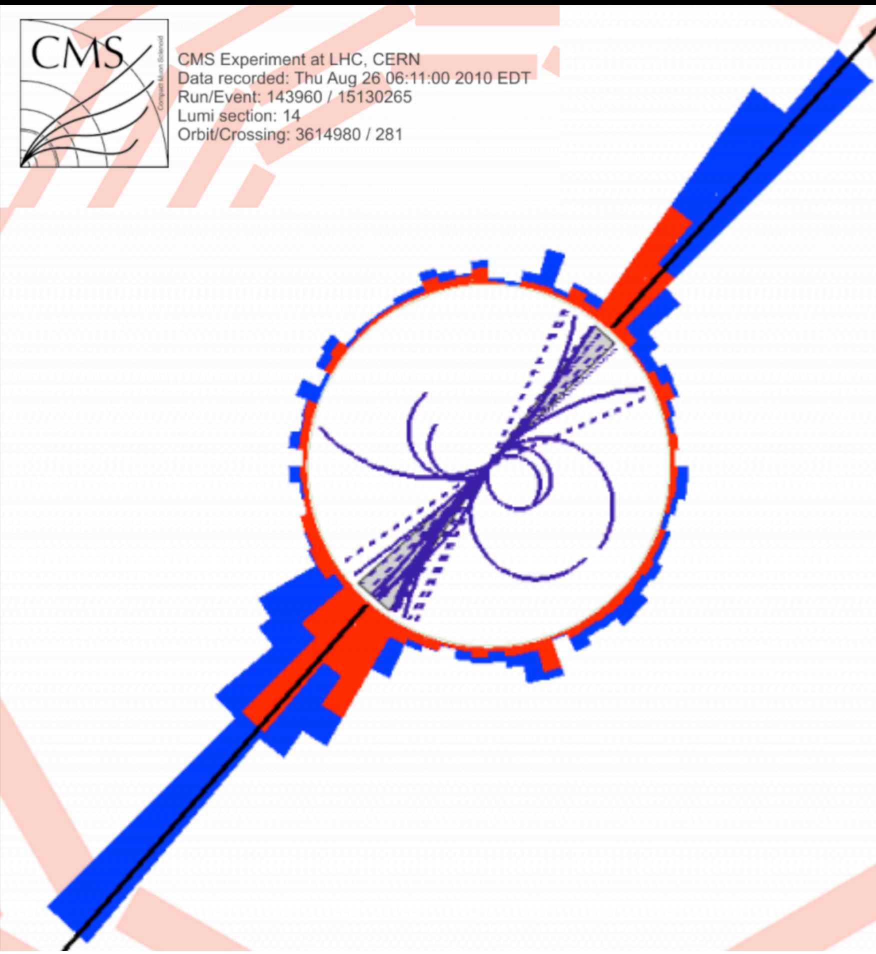
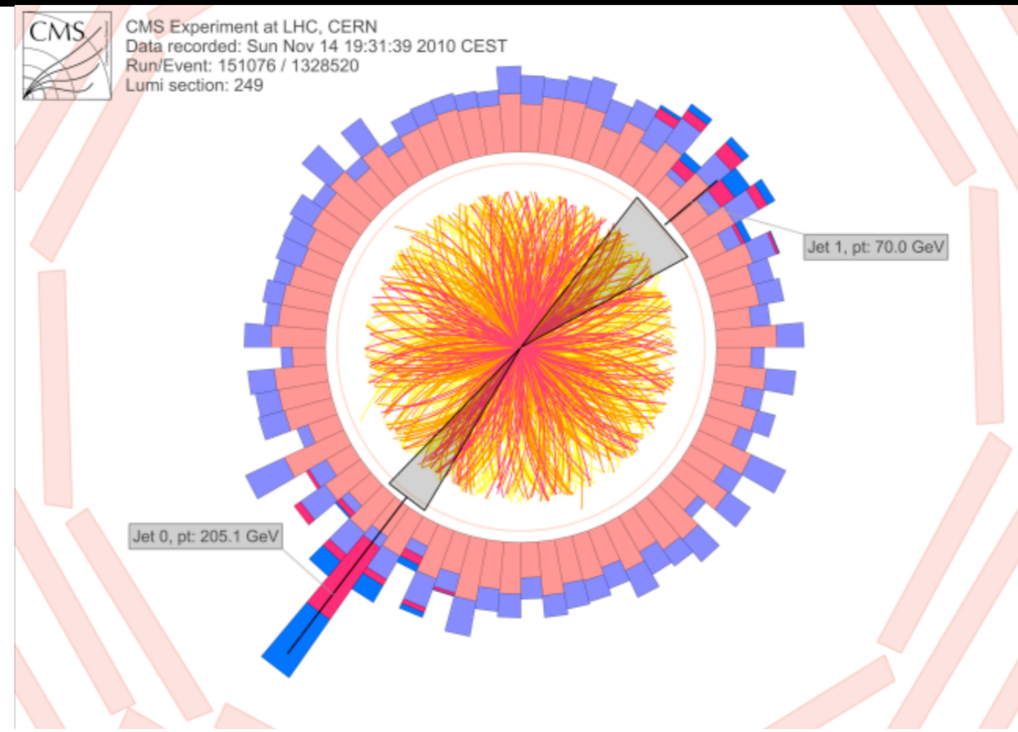
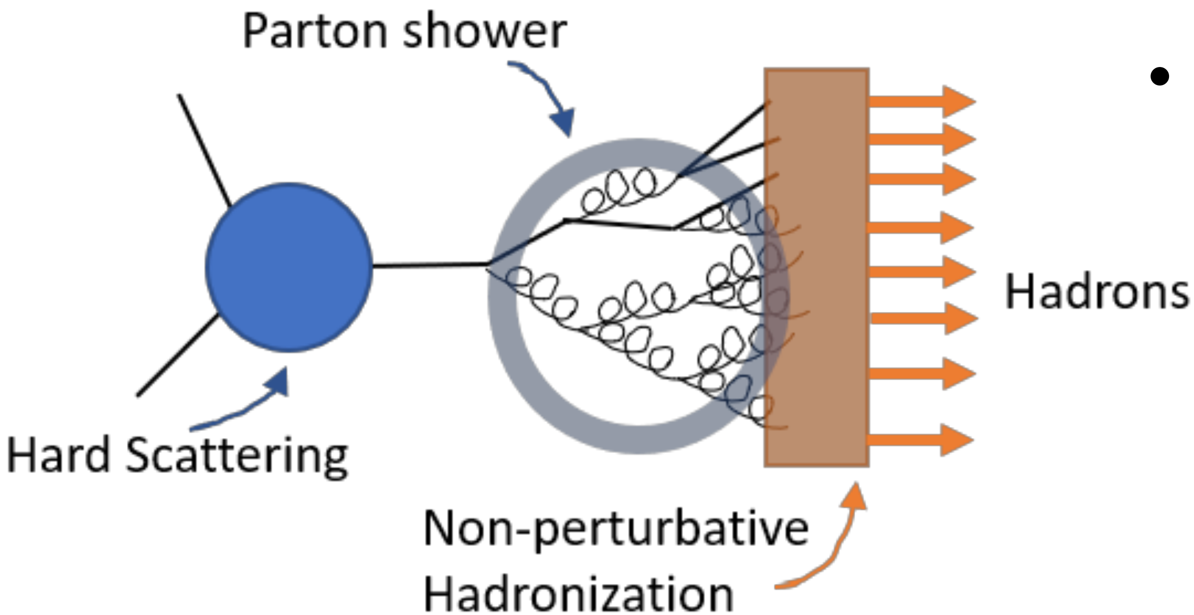
Jets in heavy-ion collisions





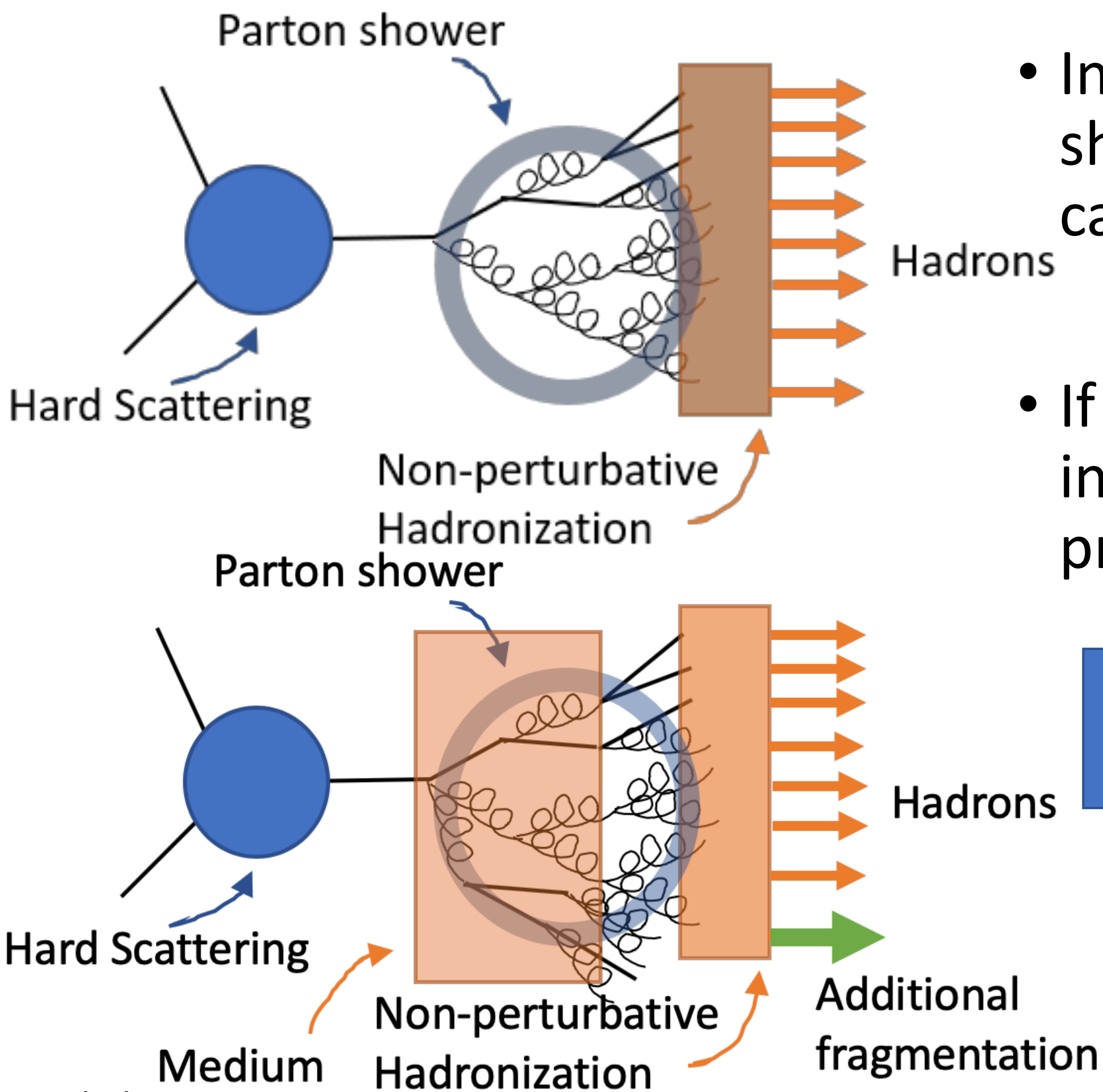
- Hard scattering between partons produces a shower of softer partons having similar direction
- Jets interact with the medium and induces energy loss

Jets in heavy-ion collisions



- In a vacuum, the showering process can be simplified as

Jets in heavy-ion collisions

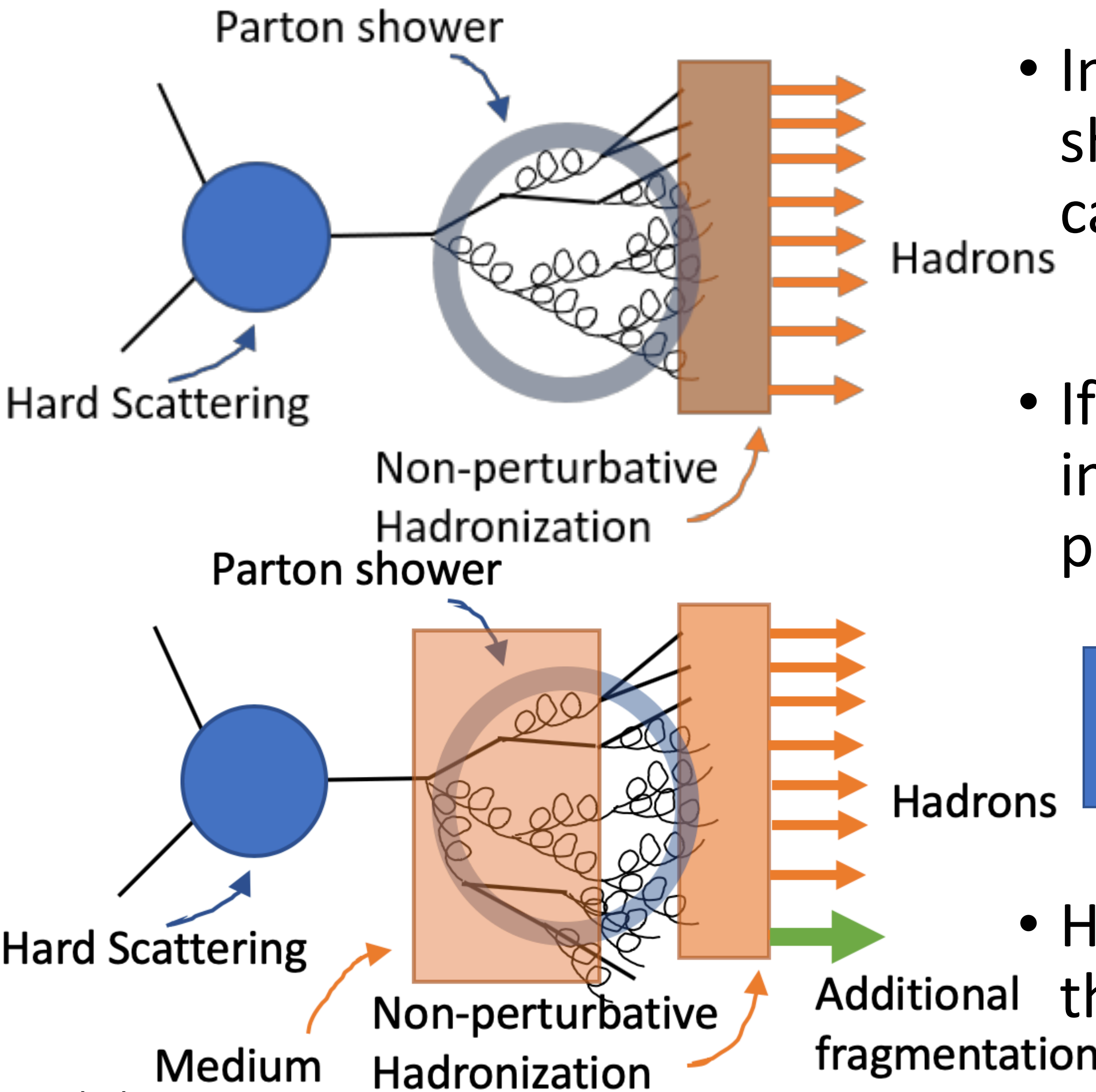


- In a vacuum, the showering process can be simplified as

- If we add a medium in the parton shower process...

Propagation of the jets are modified

Jets in heavy-ion collisions



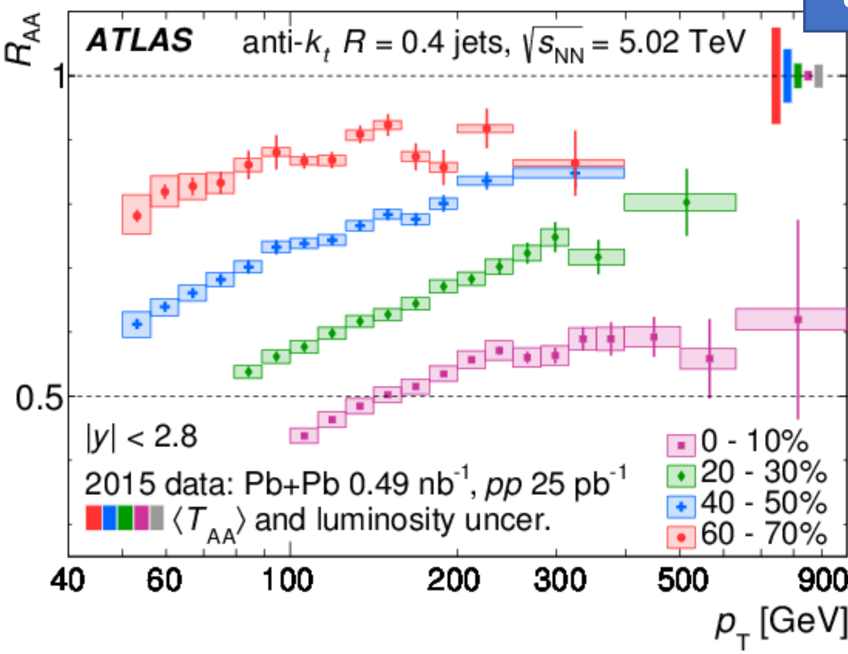
- In a vacuum, the showering process can be simplified as
- If we add a medium in the parton shower process…

Propagation of the jets are modified

- How do we observe the modifications?

Jet Suppression

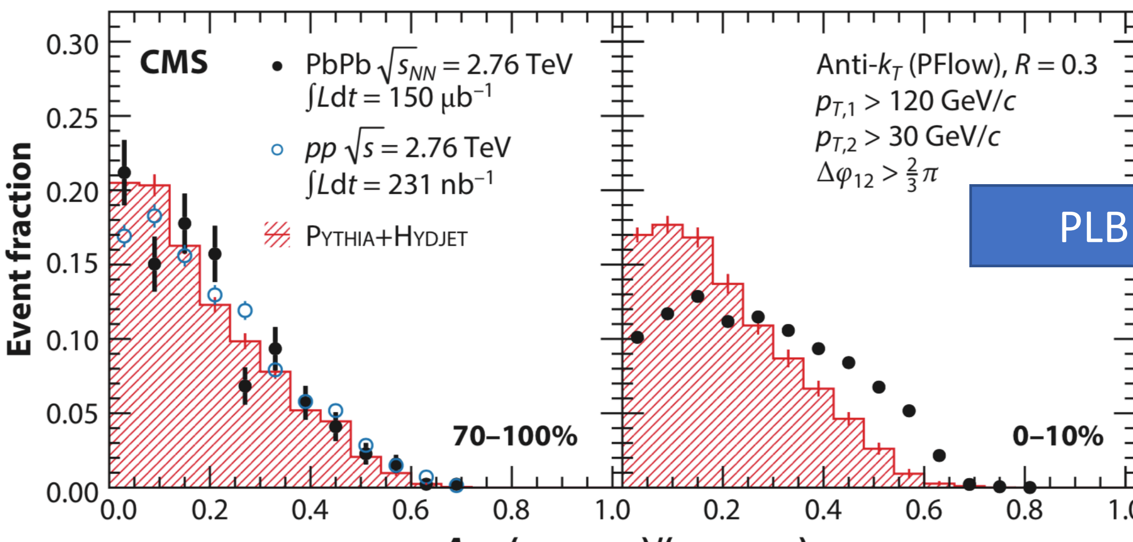
arXiv:1805.05635



- Strong jet quenching is observed in heavy-ion collisions

$$R_{AA} = \frac{dN^{AA}\ /dp_T}{\langle N_{coll} \rangle dN^{pp}/dp_T}$$

$\langle N_{coll} \rangle$: number of binary collisions in pp estimated in Glauber simulation



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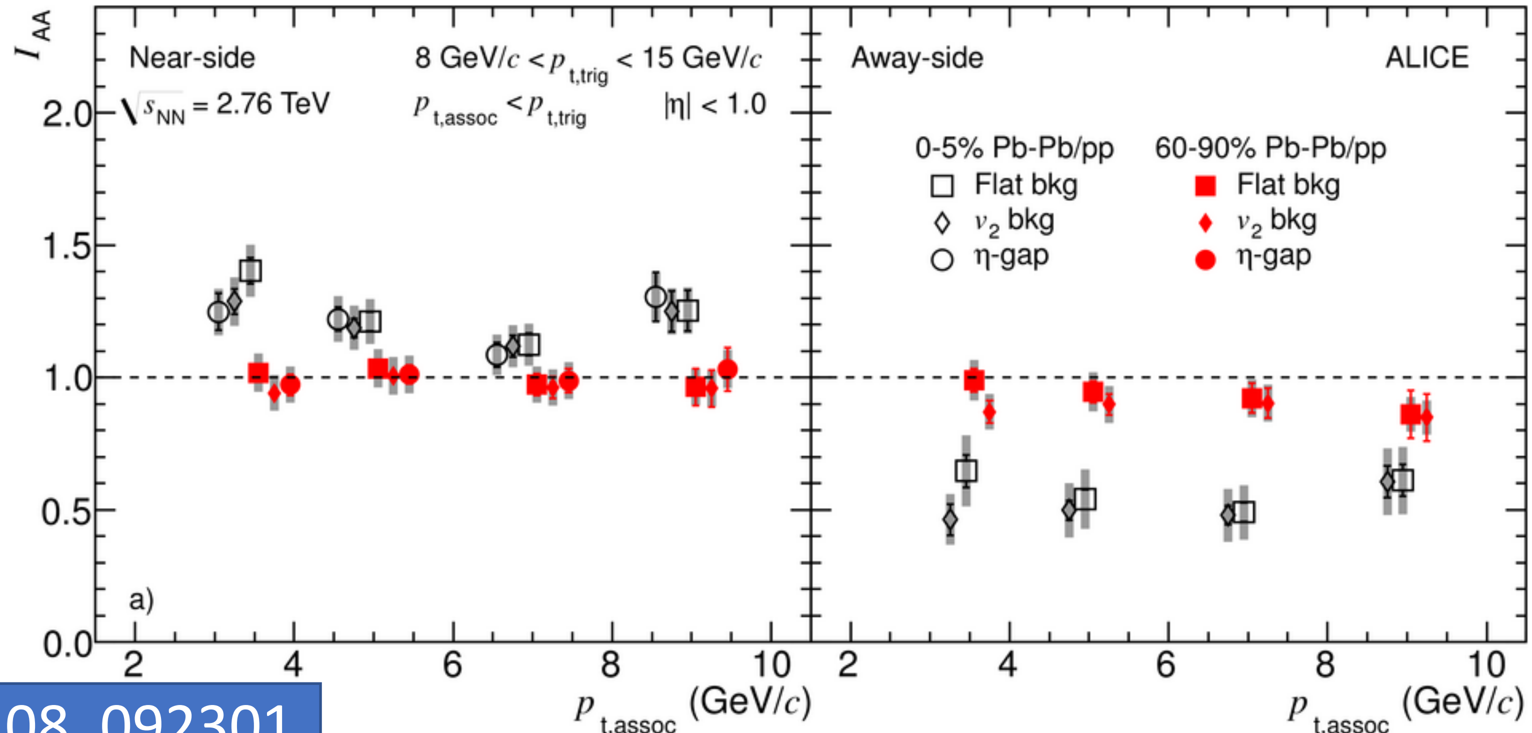
- Strong dijet asymmetry also observed in most central collisions
- Indication of E_{loss} may depend on the jet shape or its traverse length

Jets from Angular Correlation

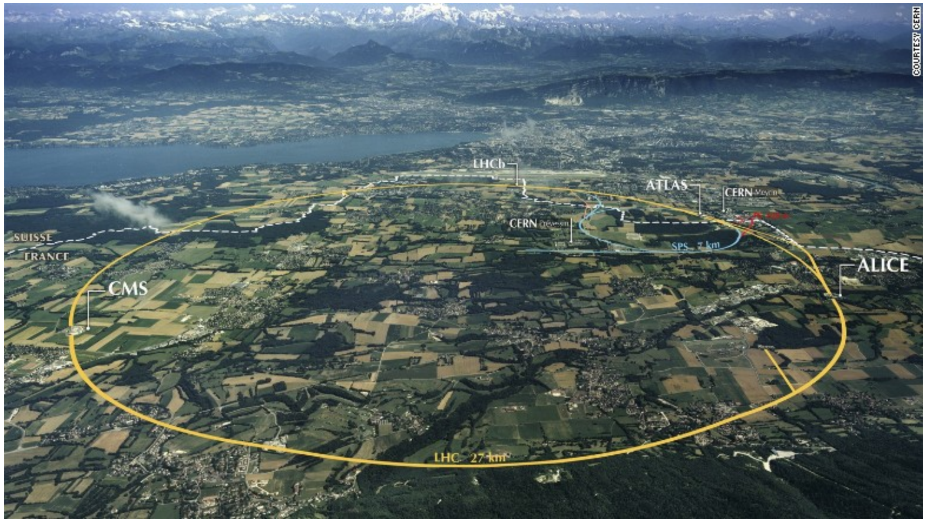


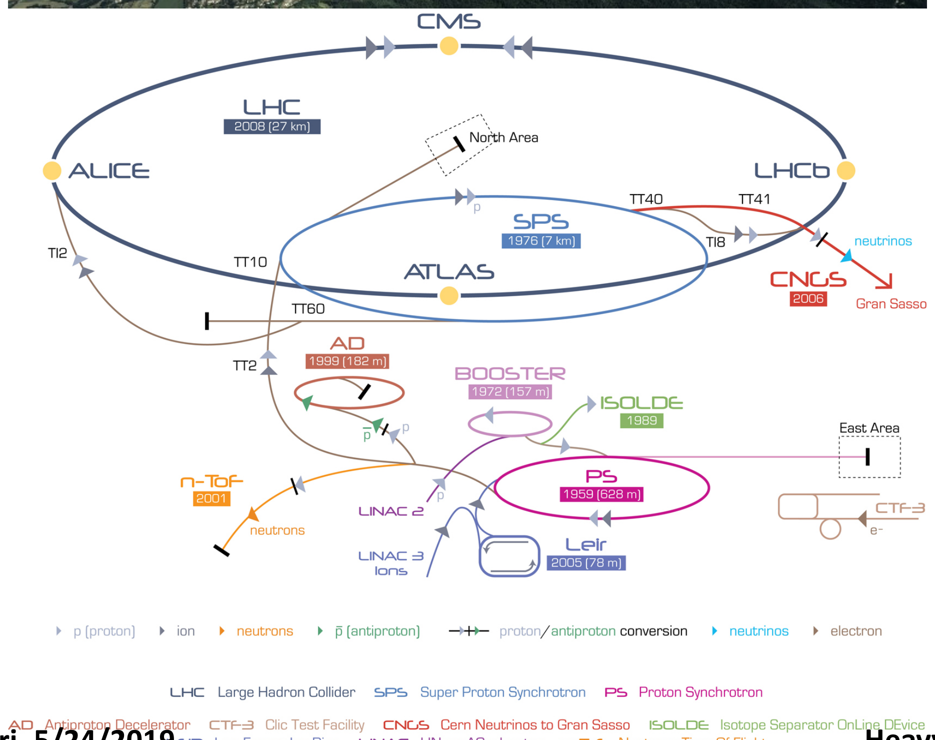
PRL108, 092301

- Can provide additional information on jet properties
- I_{AA} measurement in ALICE
  - Modification of a fragmentation function
  - Modification of a quark/gluon jet ratio
  - Bias on the parton p_{T} distribution after energy loss due to the trigger selection

$I_{AA} = \frac{Y_{PbPb}}{Y_{pp}}$ where Y is the per-trigger yield of jets

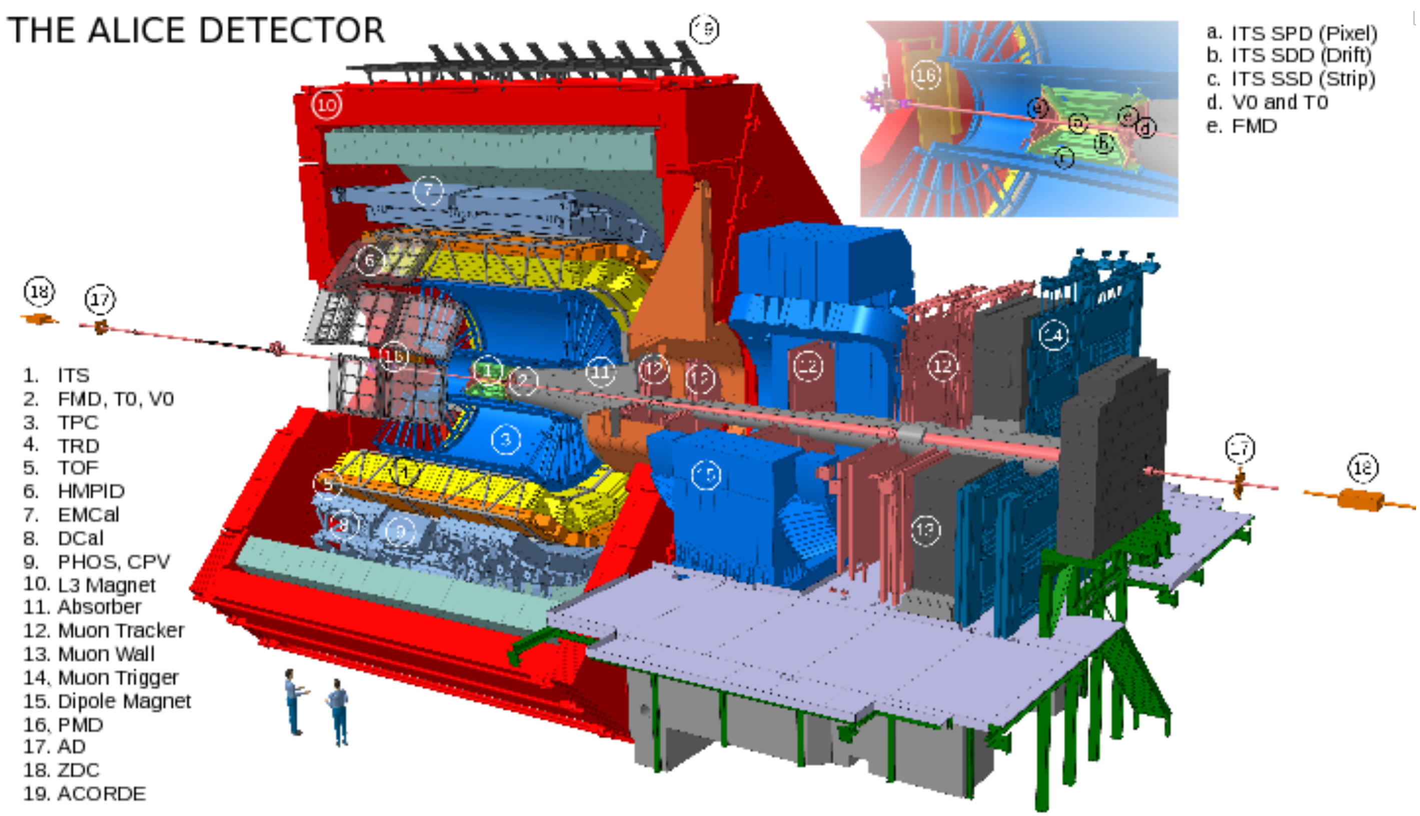
Large Hadron Collider





- Located at border of France and Switzerland
- Accelerator ring of 27km circumference
- *pp* collision's maximum energy $\sqrt{s_{NN}} = 13$ TeV
  Pb—Pb collision with $\sqrt{s_{NN}} = 5.02$ TeV
- 4 collision points
  - ALICE, ATLAS, CMS, LHCb

A Large Ion Collider Experiment



- Dedicated to study heavy-ion physics
- Tracking
  - ITS and TPC : Specialized in low p_T measurements and particle identification
    Full azimuthal acceptance with $|\eta| < 0.9$
- Trigger detector
  - VZERO : Also used as an event plane and centrality estimator

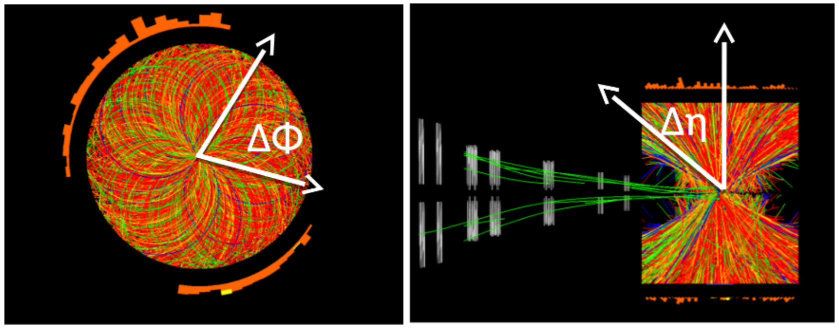
Two particle correlation

- Another useful tool to measure jet properties

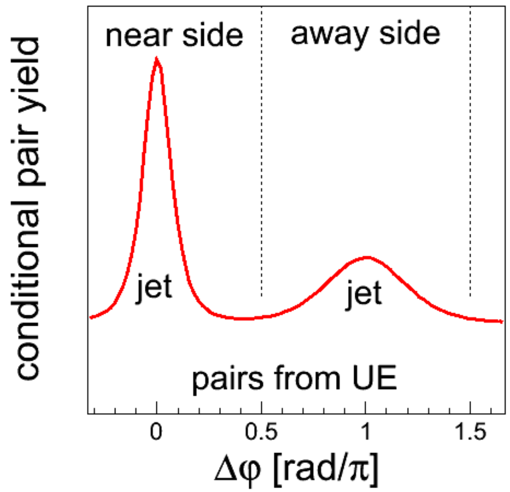
Basic quantities

$$\Delta\varphi = \varphi_{\mathrm{trig}} - \varphi_{\mathrm{assoc}}$$

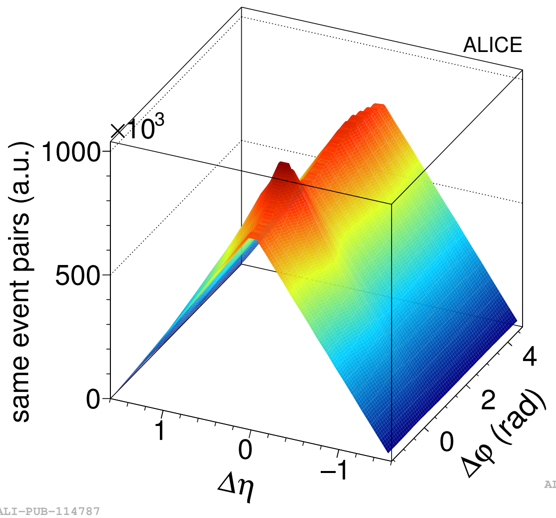
$$\Delta\eta = \eta_{\mathrm{trig}} - \eta_{\mathrm{assoc}}$$

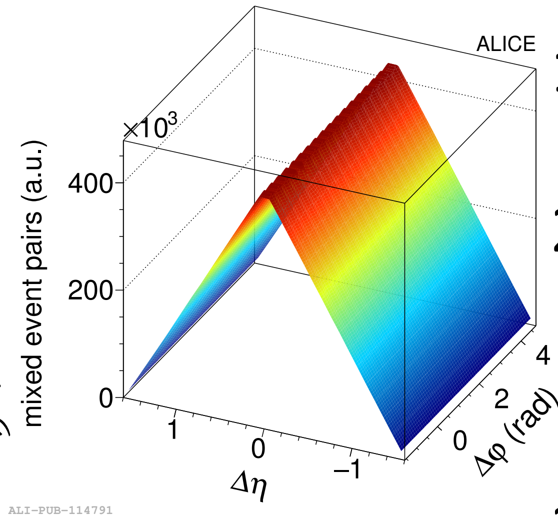


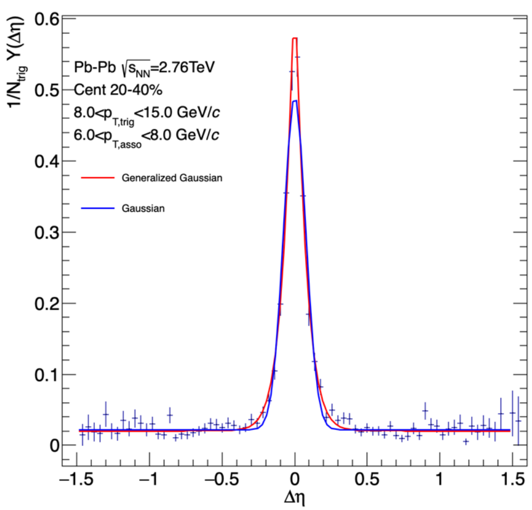
- Near side jet : Single jet properties
  - Jet fragmentation
- Away side jet : Di-jet properties
  - Acoplanarity + momentum imbalance due to k_{T}
  - Additional medium induced modification

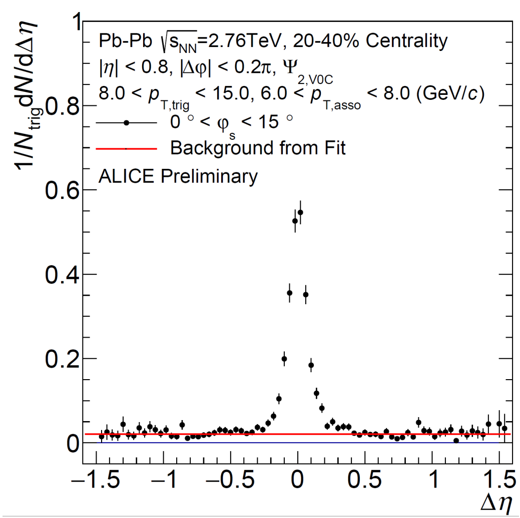


I_{AA} Analysis Method



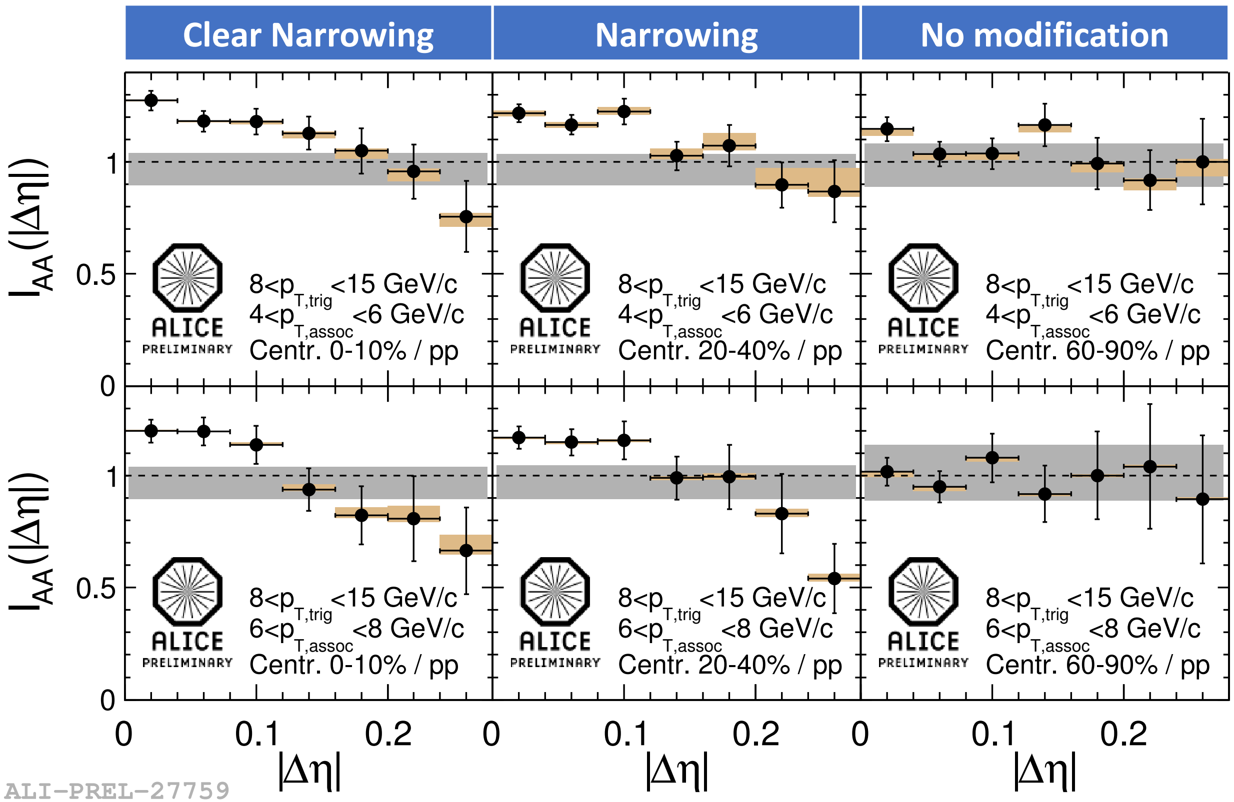


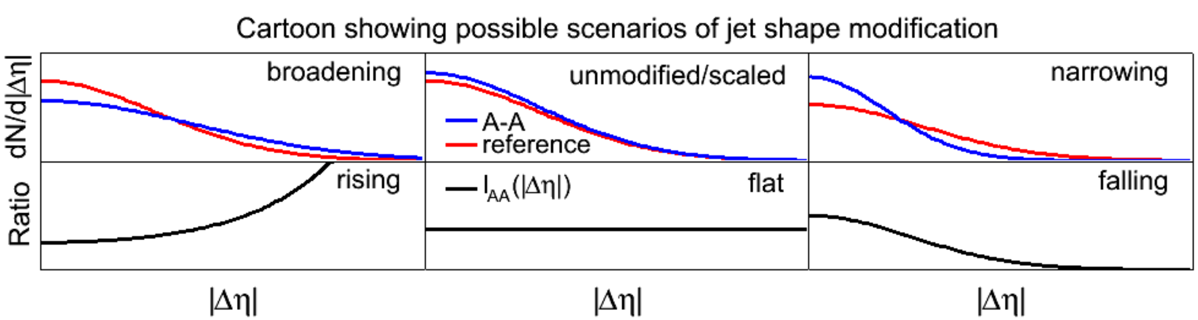




1. Construct same and mixed event distributions
2. Correct the experimental effects
   - Tracking efficiency
   - Resonance decays
3. Background level is estimated by fit
4. Extract the yield $1/N_{trig}\,\mathrm{dN}/\mathrm{d}\Delta\eta$ in jet peak region
5. Evaluate the ratio between Pb-Pb and pp $I_{\mathrm{AA}} = Y^{\mathrm{Pb-Pb}}/Y^{\mathrm{pp}}$

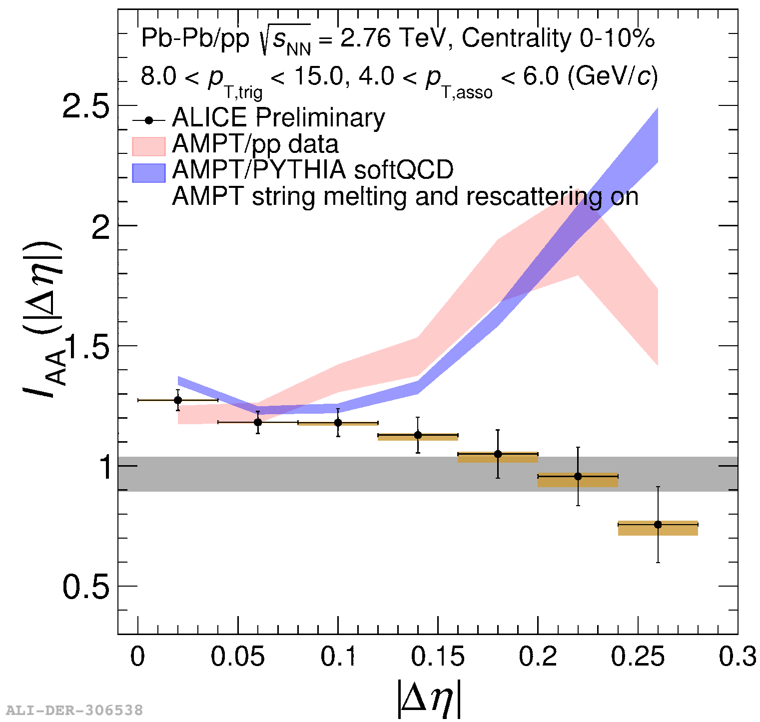
Jet shape modification and I_{AA}

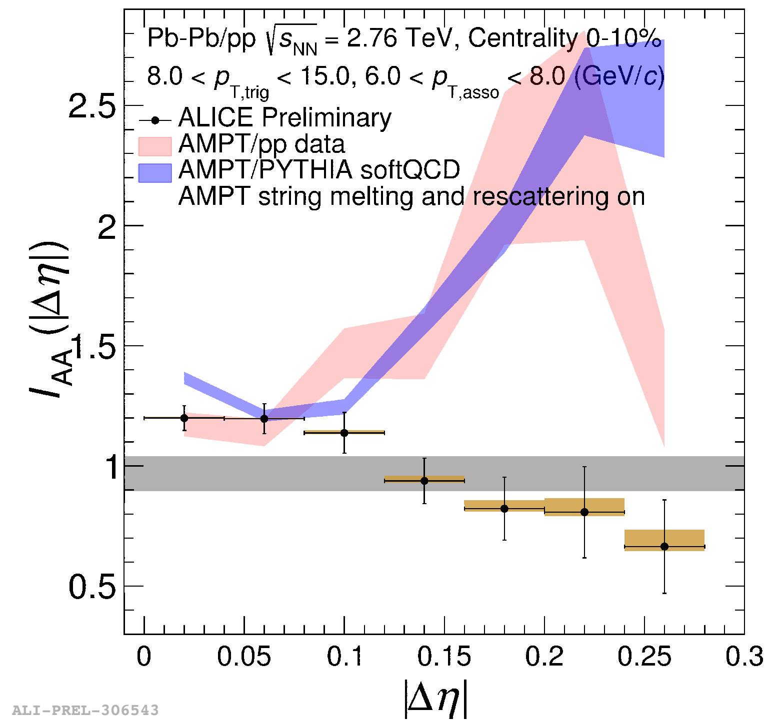




- Trend of I_{AA} shows a possible onset of jet shape modification in $\Delta\eta$ (narrowing), in most central collisions with $8 < p_{T,trig} < 15$ & $4 < p_{T,asso} < 8$ (GeV/c)
- Cartoon describes possible scenarios of modification, in terms of I_{AA}

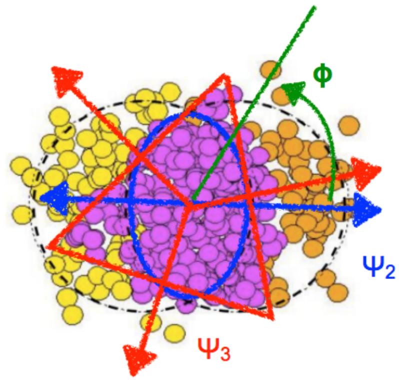
Model comparison on shapes

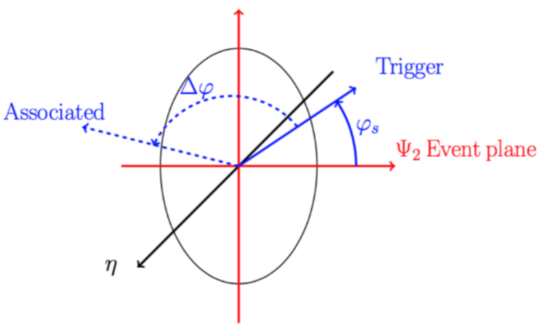


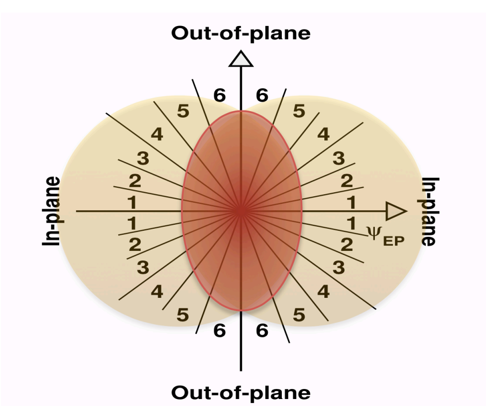


- Comparison with AMPT model, string melting on with hadronic rescattering
  - pp reference – Data or PYTHIA (softQCD setting)
- Very large broadening at $|\Delta\eta| > 0.1$
- I_{AA} is overestimated by AMPT

Event plane and path-length dependence





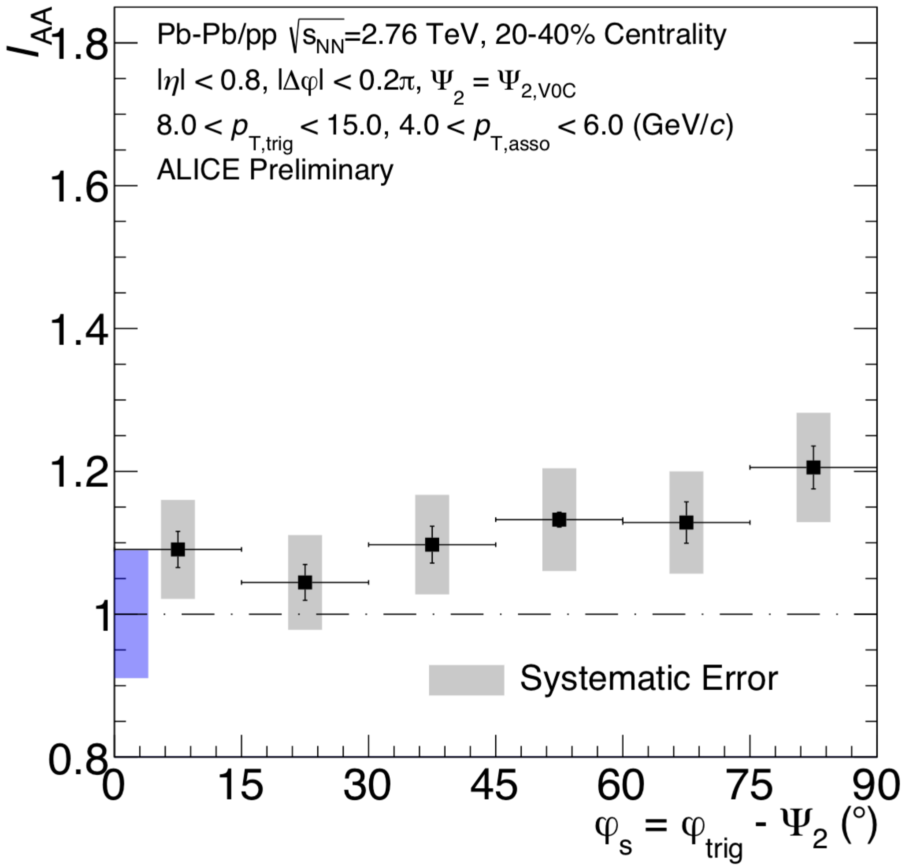


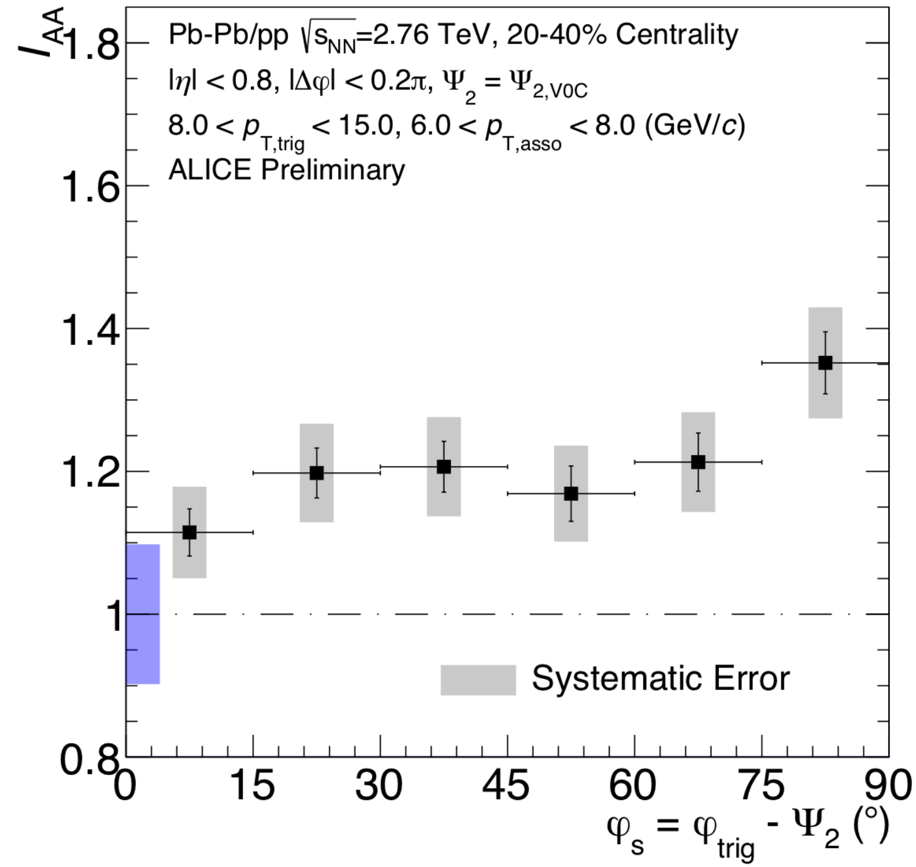
- Spatial anisotropy from initial collision geometry and event-by-event fluctuations
- For each event, the trigger particle's direction is constrained

$$\varphi_s = \varphi_{\mathrm{trig}} - \Psi_2$$

- Amount of interaction through the medium depends on the direction
- Can be interpreted as path-length dependence of jets
- φ_s is divided into 6 planes

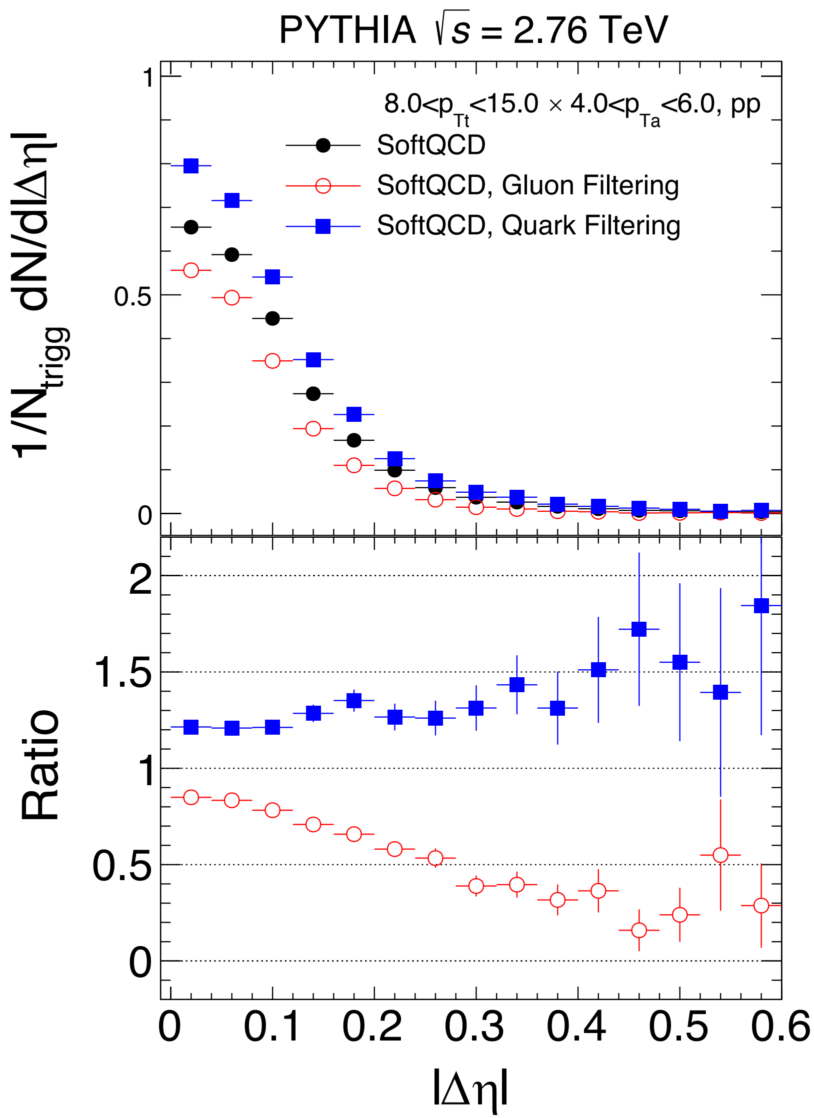
Path-length dependence of I_{AA}





- Weak path-length dependence observed in $p_{T,assoc} < 8.0$ GeV/c
  - Competing effect that comes from quenching / bremsstrahlung

Jets interacting with medium



- Casimir scaling gives color charge dependence of jet suppression in heavy ion collisions
  - Strong gluon jet suppression can explain the narrowing
  - Tested with PYTHIA in same kinematic region
- Relative quark and gluon jet suppressions and modification of their fragmentation functions play a role
  - Gives constraints to models

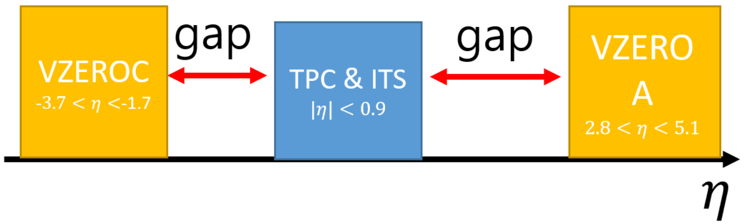
Conclusions and Outlook

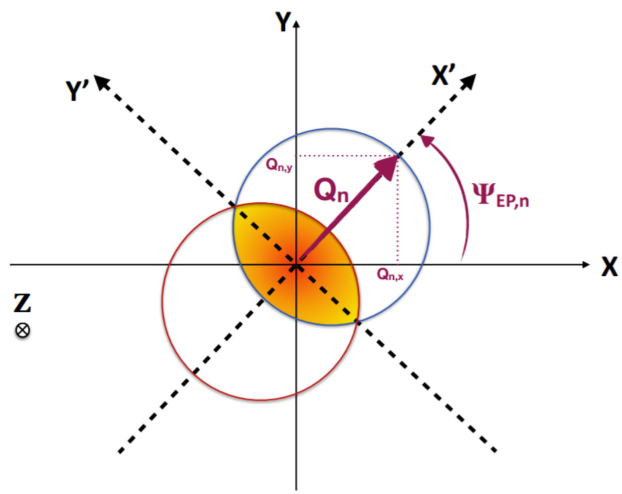
- I_{AA} shape modification
  - Possible onset of narrowing is observed
  - AMPT shows very large broadening in $|\Delta\eta| > 0.1$, contrary to the data
  - I_{AA} is also overestimated by AMPT, in $|\Delta\eta| < 0.3$
- The I_{AA} as a function of φ_s can estimate the path length dependence of jets
  - Weak path length dependence is observed at $4.0 < p_{\mathrm{T,asso}} < 8.0$ (GeV/c)
  - No significant path-length dependence observed at $8.0 < p_{\mathrm{T,asso}}$ (GeV/c)
  - AMPT Model does not describes the data qualitatively
- Other model studies are to be done in near future

Thank you!

Backups

Event plane determination





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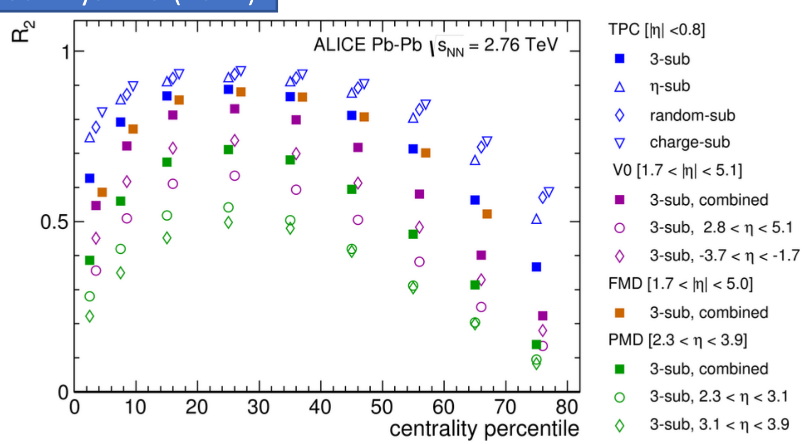


- Large η gap between TPC and VZERO
  - To reduce non-flow correlation contributions from TPC-V0 (i.e. jets in TPC does not show in V0)
- Nth order event plane (Ψ_n) is determined via Q-vector method:

$$\Psi_n = \left(\tan^{-1}\frac{Q_y^n}{Q_x^n}\right)/\mathrm{n}$$

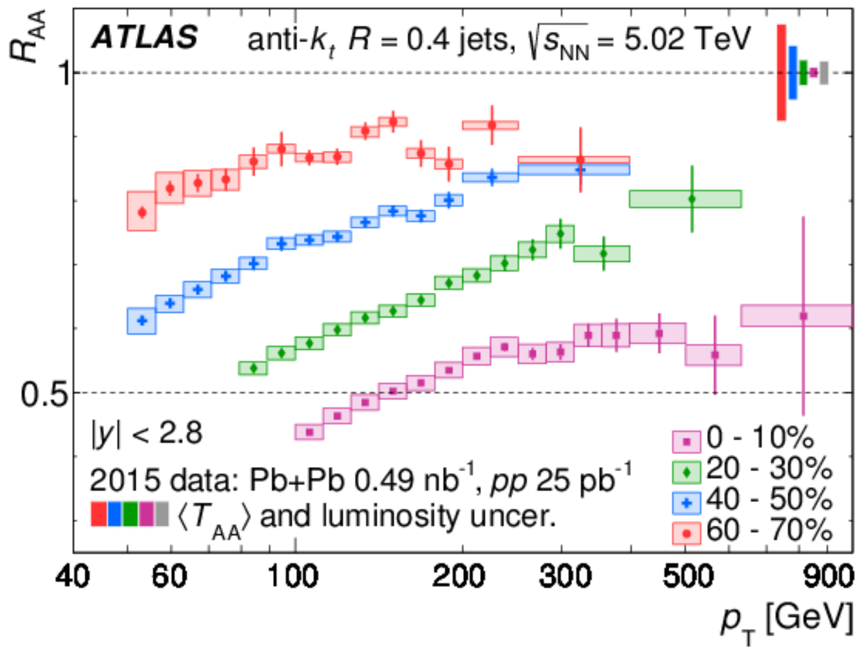
$$Q_x^n = \sum_i w_i^n \cos(n\varphi_i)\,,\, Q_y^n = \sum_i w_i^n \sin(n\varphi_i)$$

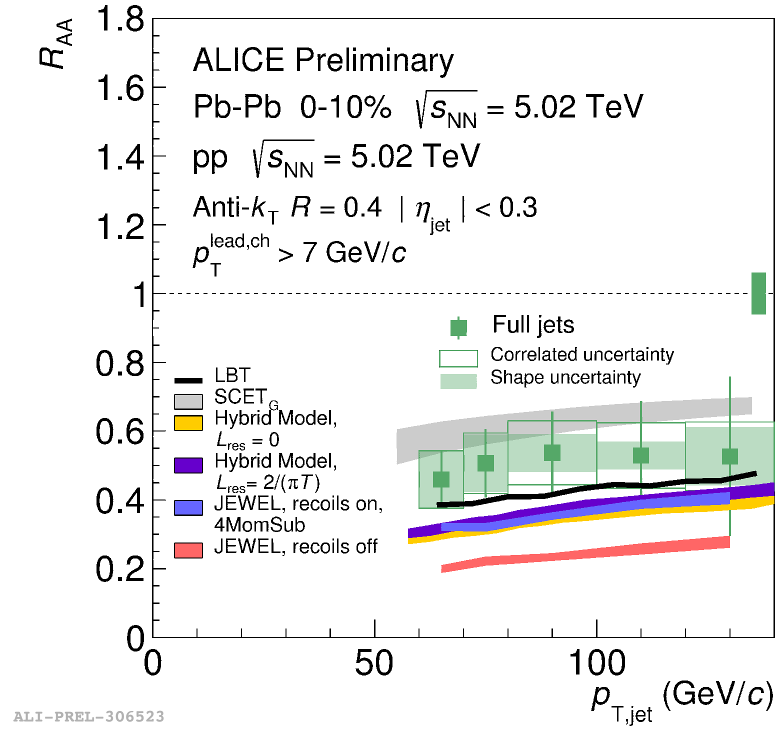
where i denotes the particles in event, w_i^n is the weight for different detector

- Due to the finite multiplicity, the event-plane resolution is also needed to be calculated
  - Detector A's Resolution at nth event plane is determined using 3-sub detector method

$$Res_n^A = \sqrt{\frac{\langle\cos n(\Psi_n^A - \Psi_n^C)\rangle\langle\cos n(\Psi_n^A - \Psi_n^B)\rangle}{\langle\cos n(\Psi_n^B - \Psi_n^C)\rangle}}$$

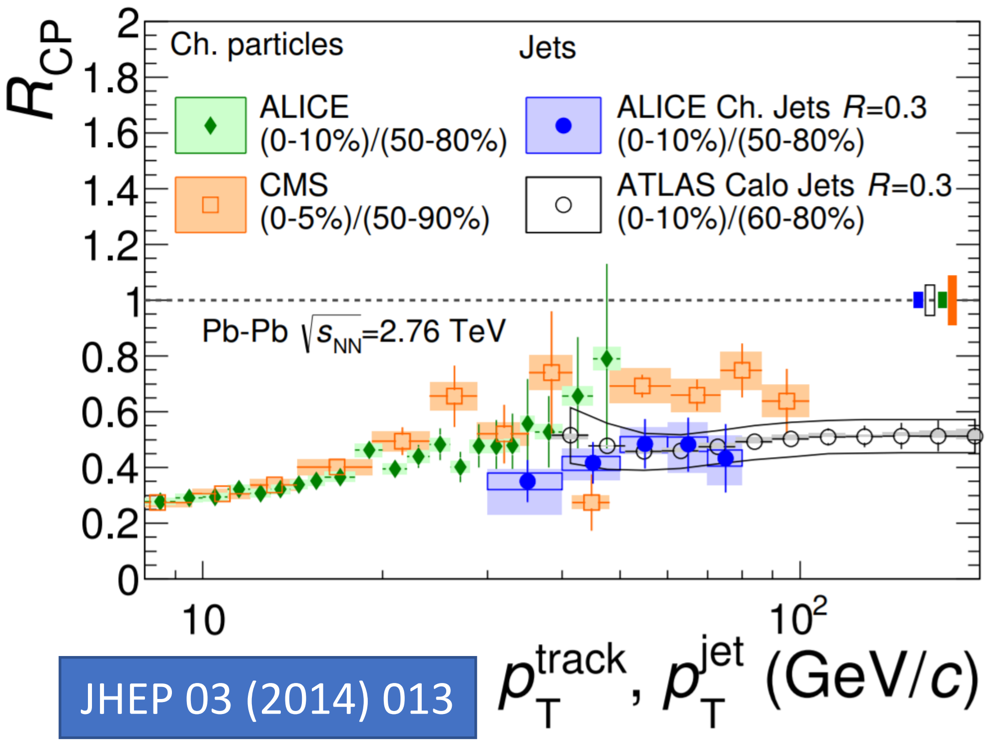
Path-length dependence





- Path-length dependence of jet E_{loss} is indirectly observed by comparing R_{AA} of different centrality
- However, the details of the jet quenching process is not yet well understood

Path-length dependence



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$$R_{CP} = \frac{\langle T_{AA}\rangle d^2\sigma_{pp}/dp_T d\eta|_{\text{central}}}{\langle T_{AA}\rangle d^2\sigma_{pp}/dp_T d\eta|_{\text{peripheral}}}$$

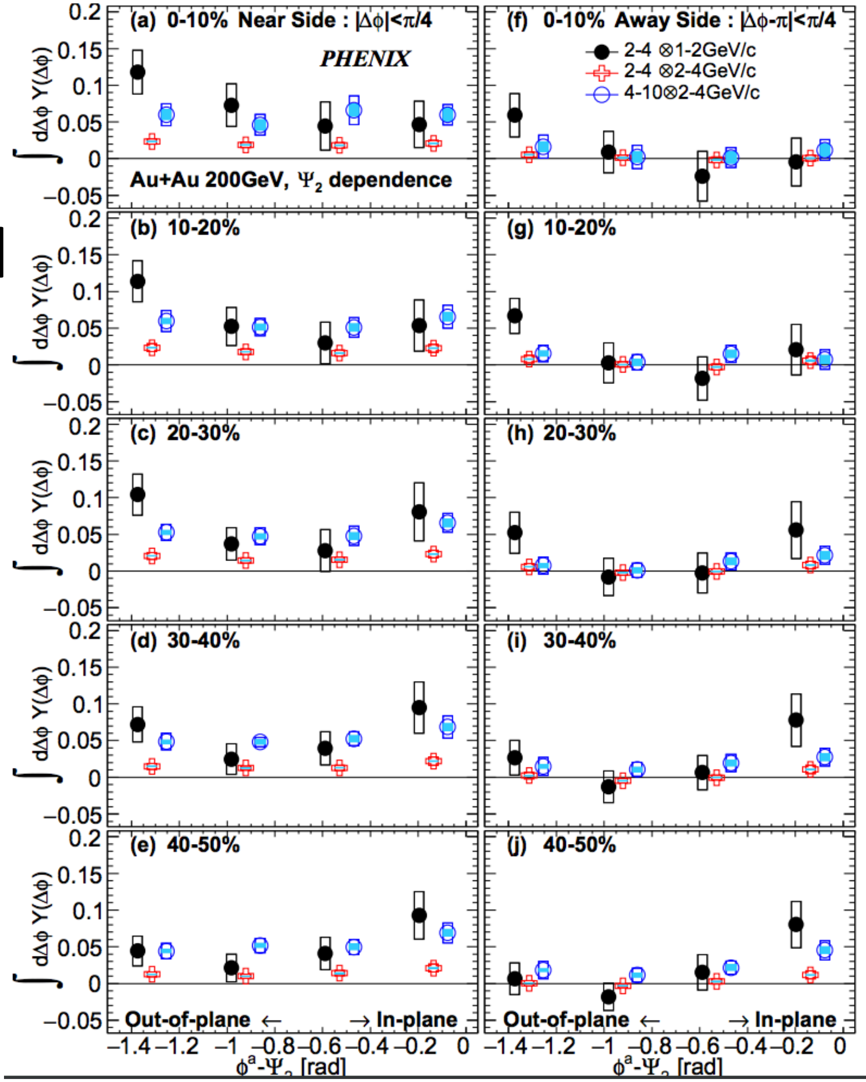
Nuclear Overlap function $\langle T_{AA}\rangle$

- Full jet reconstruction is made
- No significant difference between R_{CP} of charged particles and jets
  - Momentum redistribution is made outside of the jet radius (R=0.3)

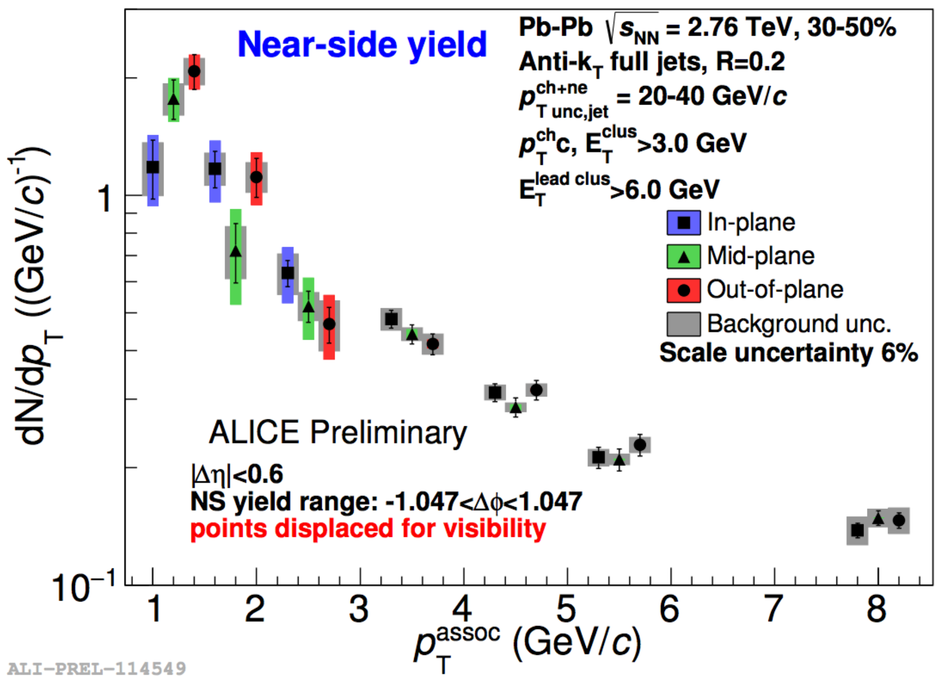
- Path-length dependence of jet E_{loss} is indirectly observed by R_{CP}
- However, the details of the jet quenching process is not yet well understood

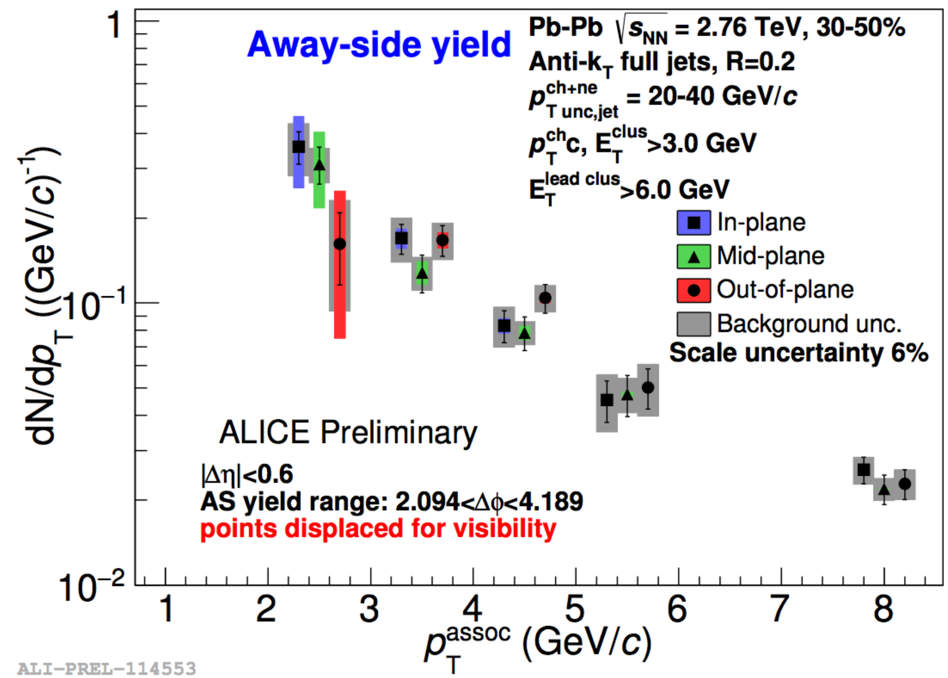
Other event plane dependence studies

- [PHENIX, arXiv:1803.01749]
- No significant 2nd order plane dependence of per-trigger yield
  - At $2 < p_{T,trig} < 10$ with $2 < p_{T,asso} < 4$ (GeV/c)
- Weak 2nd order dependence of per trigger yield
  - At $2 < p_{T,trig} < 4$ with $1 < p_{T,asso} < 2$ (GeV/c)



Other event plane dependence studies





- [ALICE, Nucl.Phys.A 967(2017) 500]
- No significant 2nd order plane dependence of yields in jet-hadron correlation