π^0-hadron correlations in pp and Pb–Pb collisions measured at the ALICE experiment

Xinye Peng

on the behalf of the ALICE Collaboration

Central China Normal University, China

Padova University & INFN, Italy

EPS-HEP - July 7, 2017

Outline

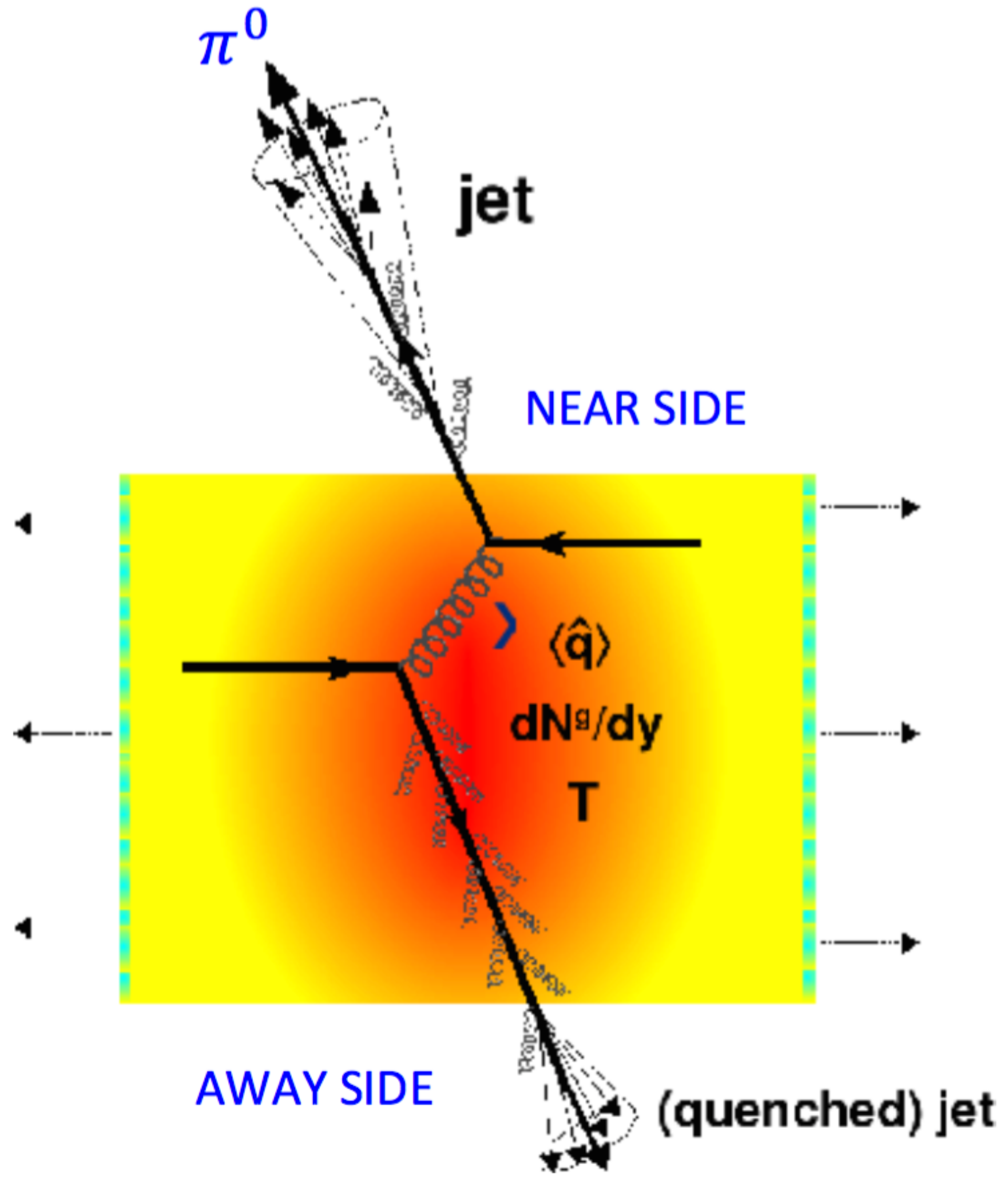
- Physics Motivation
- ALICE Setup
- Analysis strategy
- Results: pion-hadron correlations PLB 763 (2016) 238-250
- Conclusion and Outlook

Physics motivation 1/3

- **Heavy-ion collisions**: hot, dense, deconfined and strongly interacting QCD medium (**the Quark-Gluon Plasma**) is formed

- **Jet quenching** (strong evidence for **QGP** formation) can be investigated via:
  - inclusive hadron and jet production
  - di-jet energy imbalance
  - modification of jet fragmentation functions
  - **two-particle azimuthal correlations**

Results from **RHIC** to **LHC**

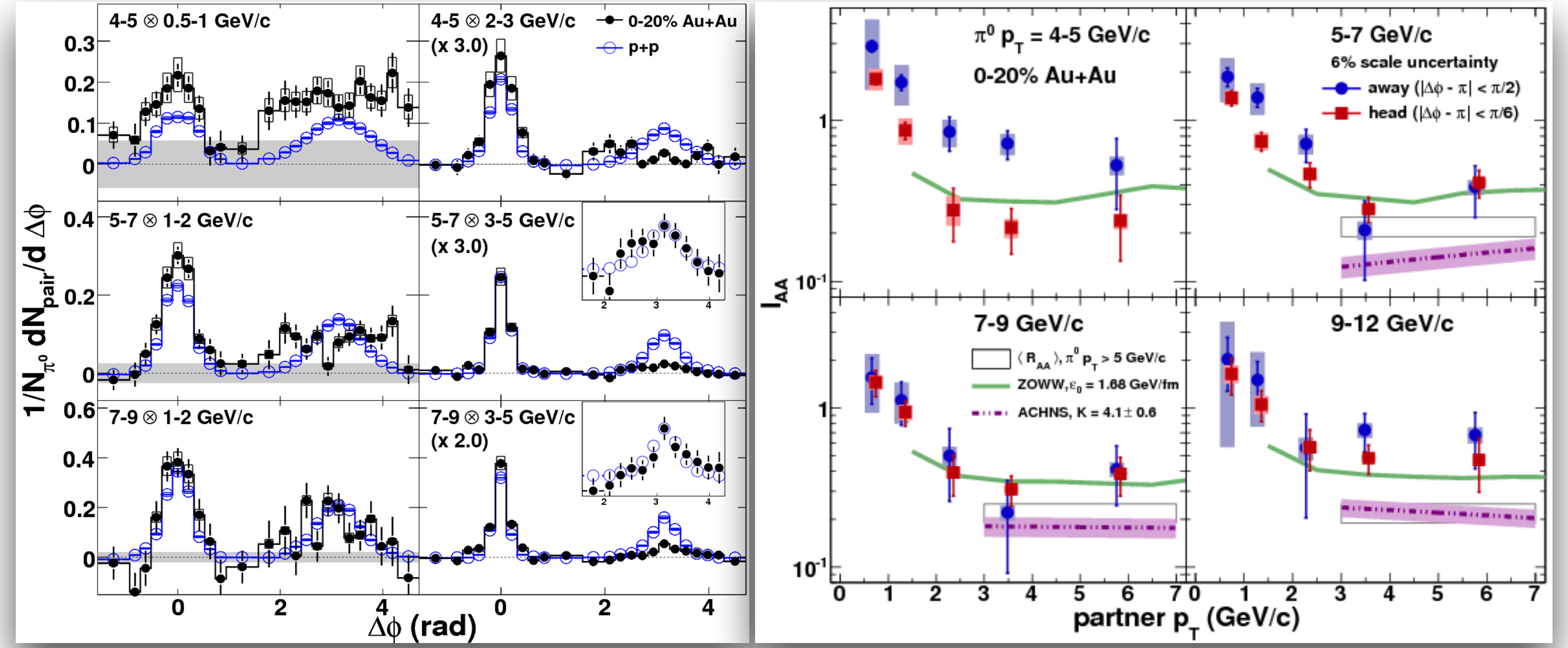


Physics motivation 2/3

- Two main observables:
  - Azimuthal correlations: $C = \frac{1}{N_{trig}} \frac{dN^{pair}}{d\Delta\varphi}$, $J = C - B$ (flat or v_n background)
  - Modification of the yield in the correlations: $Y = \frac{1}{N_{trig}} \int J d\Delta\varphi$, $I_{AA} = \frac{Y_{Pb-Pb}}{Y_{pp}}$ or $I_{CP} = \frac{Y^{central}_{Pb-Pb}}{Y^{peripheral}_{Pb-Pb}}$

RHIC

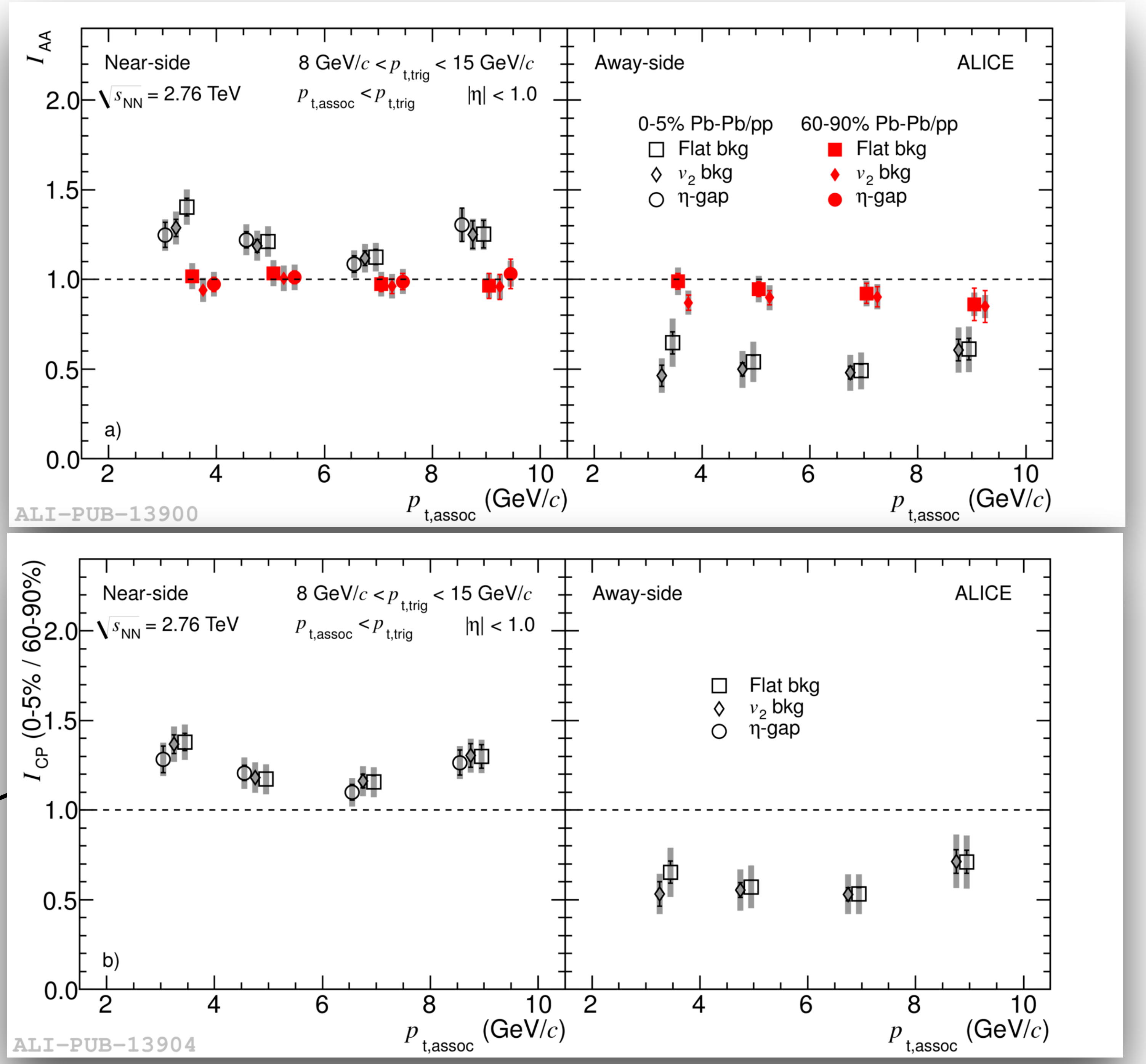
PHENIX measurements



Phys. Rev. Lett. 104 (2010) 252301

LHC

ALICE di-hadron measurements



Phys. Rev. Lett. 108 (2012) 092301

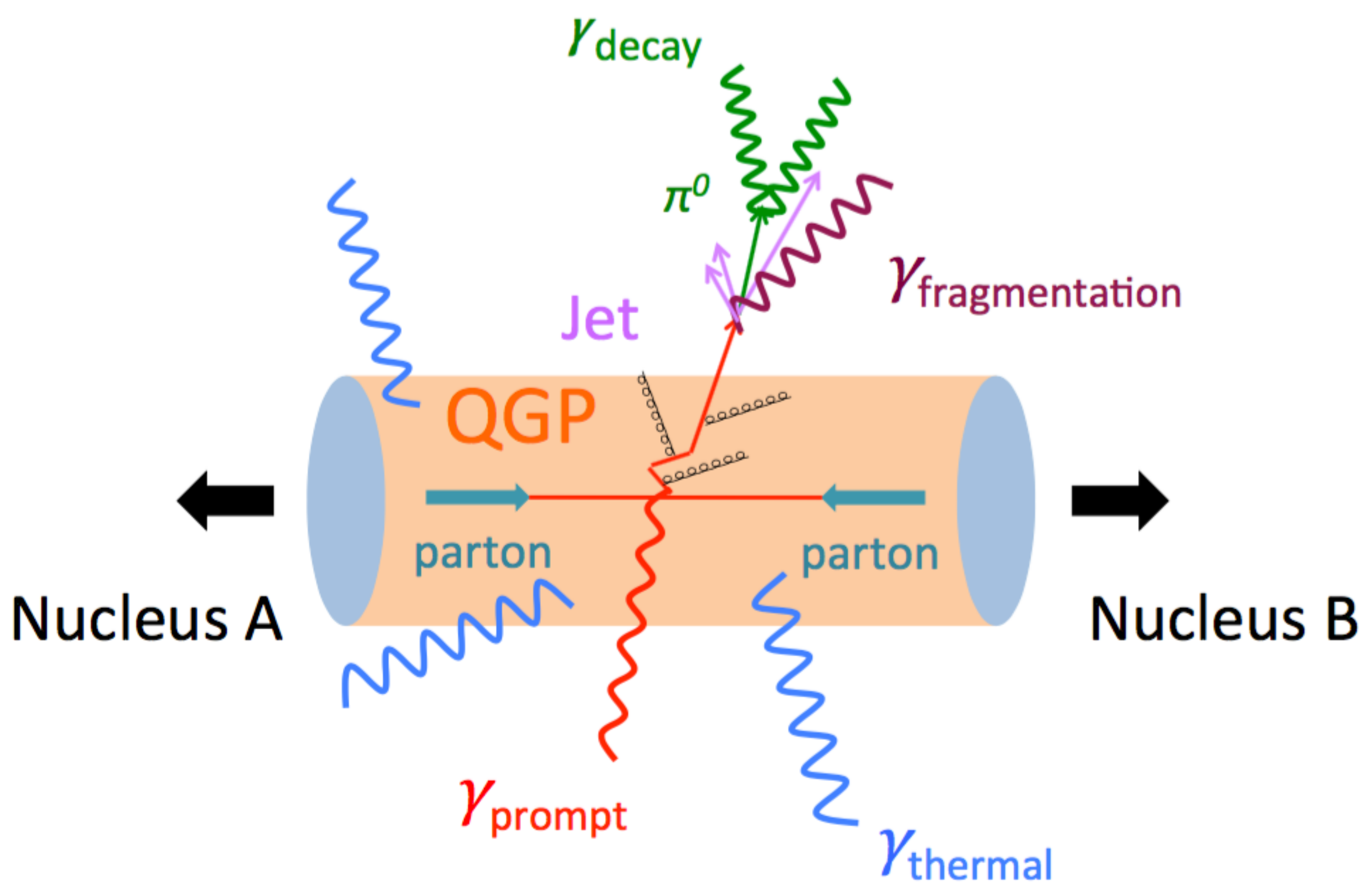
interesting to extend the result to low p_T region !

Physics motivation 3/3

- **Heavy-ion collisions**: hot, dense, deconfined and strongly interacting QCD medium (**the Quark-Gluon Plasma**) is formed

- **Jet quenching** (strong evidence for **QGP** formation) can be investigated via:
  - inclusive hadron and jet production
  - di-jet energy imbalance
  - modification of jet fragmentation functions
  - **pion-hadron correlations**
    - constraints on parton energy loss
    - provide a gauge for the background

  in gamma-hadron correlations



ALICE setup

- ITS (Inner Tracking System)

six cylindrical layers of silicon detectors, |η|< 0.9
  - localize the primary and secondary vertices.
  - track and identify particles down to $p_{\mathrm{T}} \sim$100 MeV/c

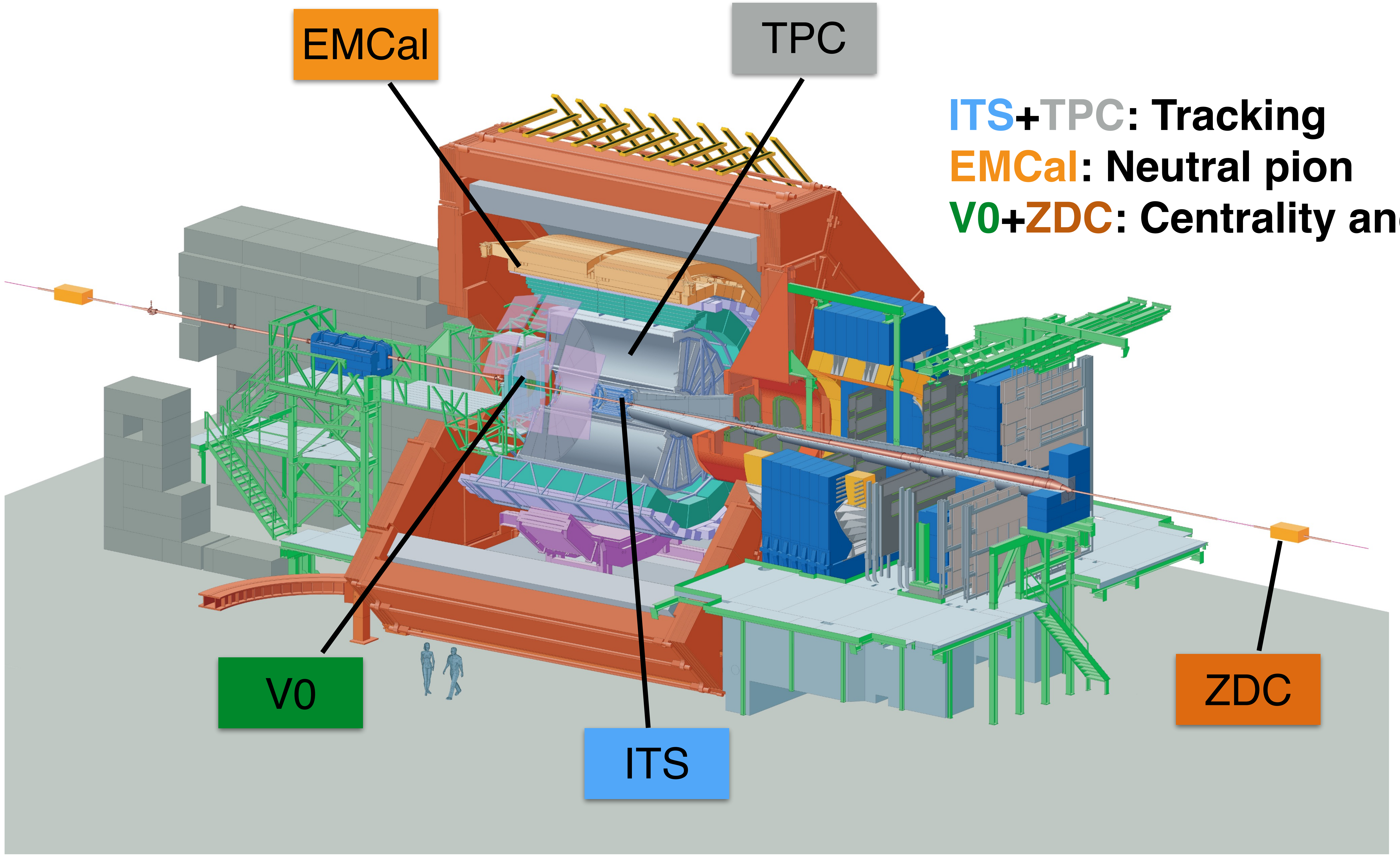
- TPC (Time Projection Chamber)

a cylindrical gas detector, |η|< 0.9
  - charged particle momentum (0.15 < p_{T} < 100 GeV/c)
  - particle identification (dE/dx resolution better than 10%)

- EMCal (Electro Magnetic Calorimeter)

a lead-scintillator sampling calorimeter,

|η|< 0.7, $\frac{\sigma_E^2}{E^2} = A^2 + \frac{B^2}{E} + \frac{C^2}{E^2}$ (dσ/dE resolution better than 4% above 10 GeV/c)
  - trigger capabilities
  - high energy jets
  - high-p_{T} neutral mesons, photons and electrons



Nucl.Instrum.Meth.A615:6-13,2010

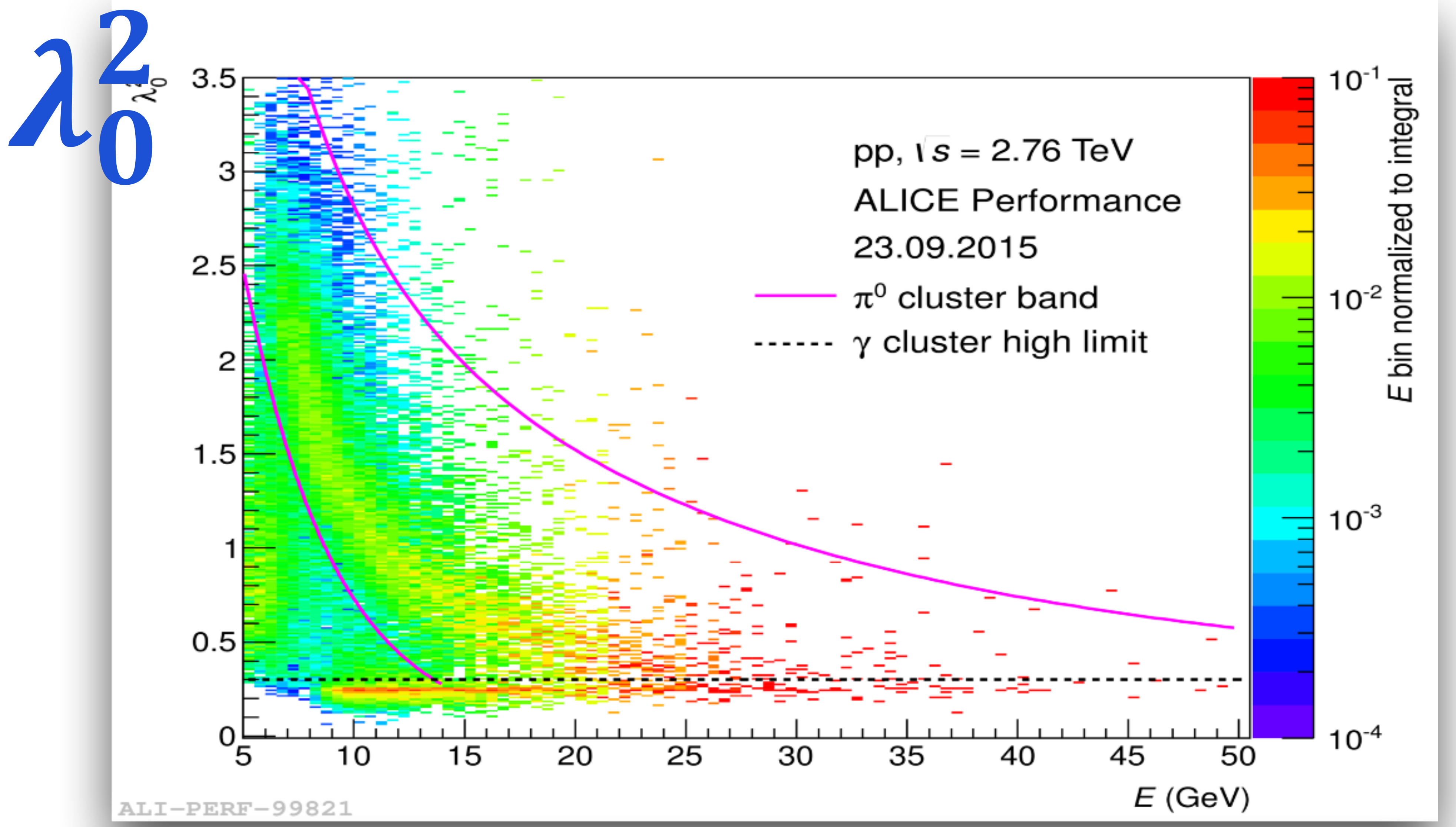
ITS+TPC: Tracking
EMCal: Neutral pion
V0+ZDC: Centrality and event

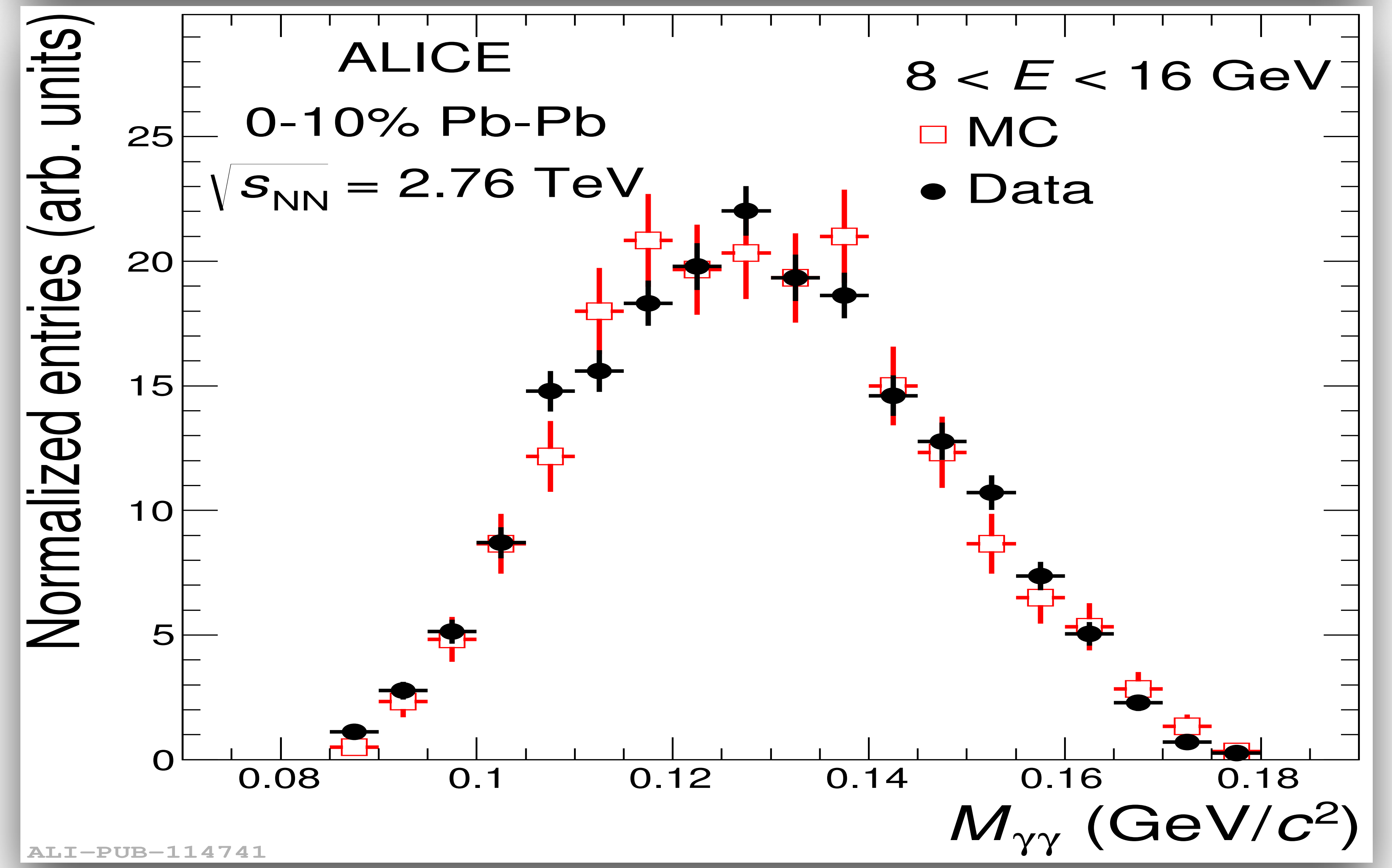
data taken in the year 2011;
440K (5.2 M) events in pp (Pb-Pb) collision at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV

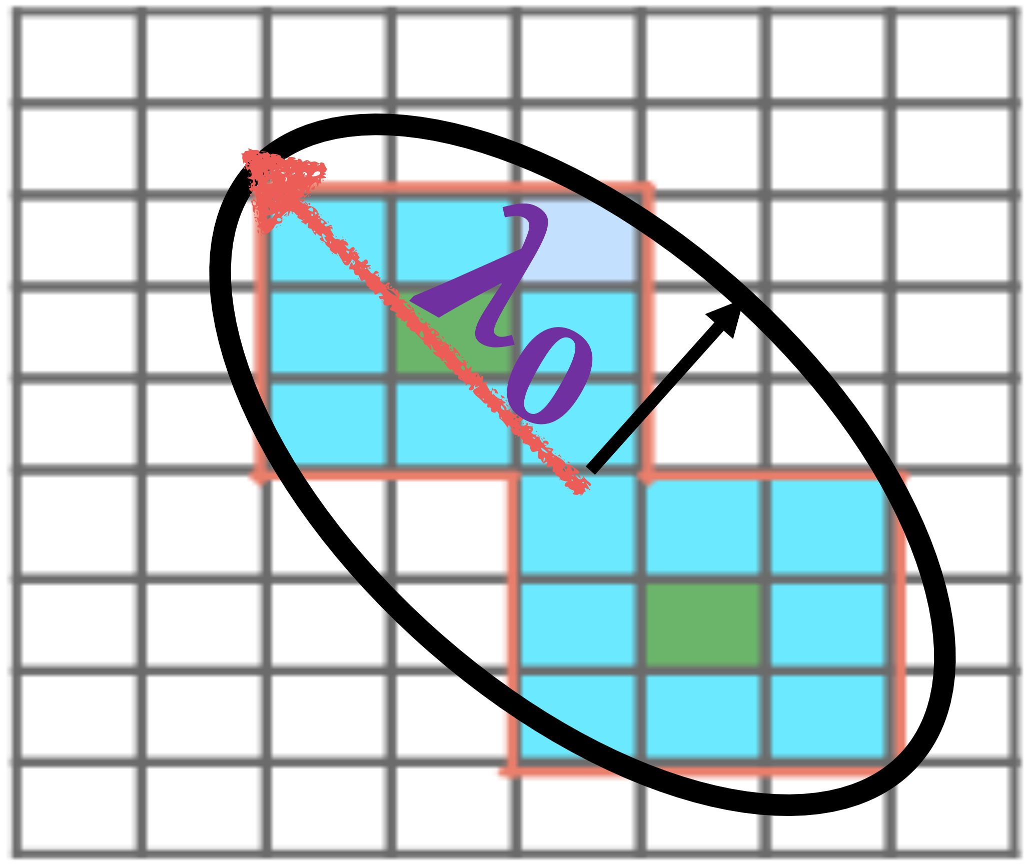
Analysis strategy

- π^0 measurement
  - ✓ select π^0 candidate cluster with Shower Shape cut
  - ✓ split cluster into two clusters, calculate the invariant mass
- charged particles are detected by the central tracking system ITS + TPC
- correlate π^0 with charged particles
- corrections
- background subtraction

Pion identification



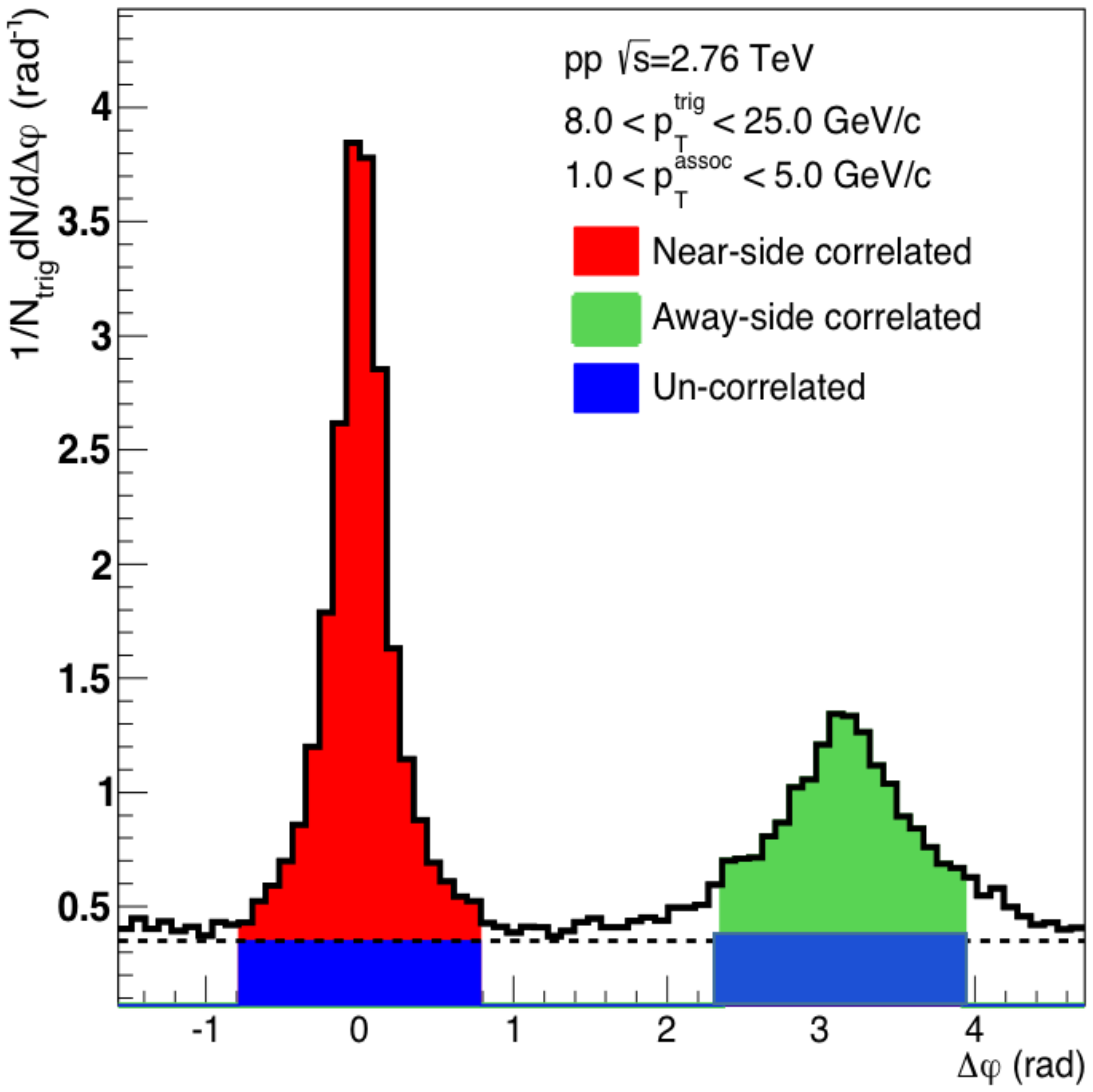




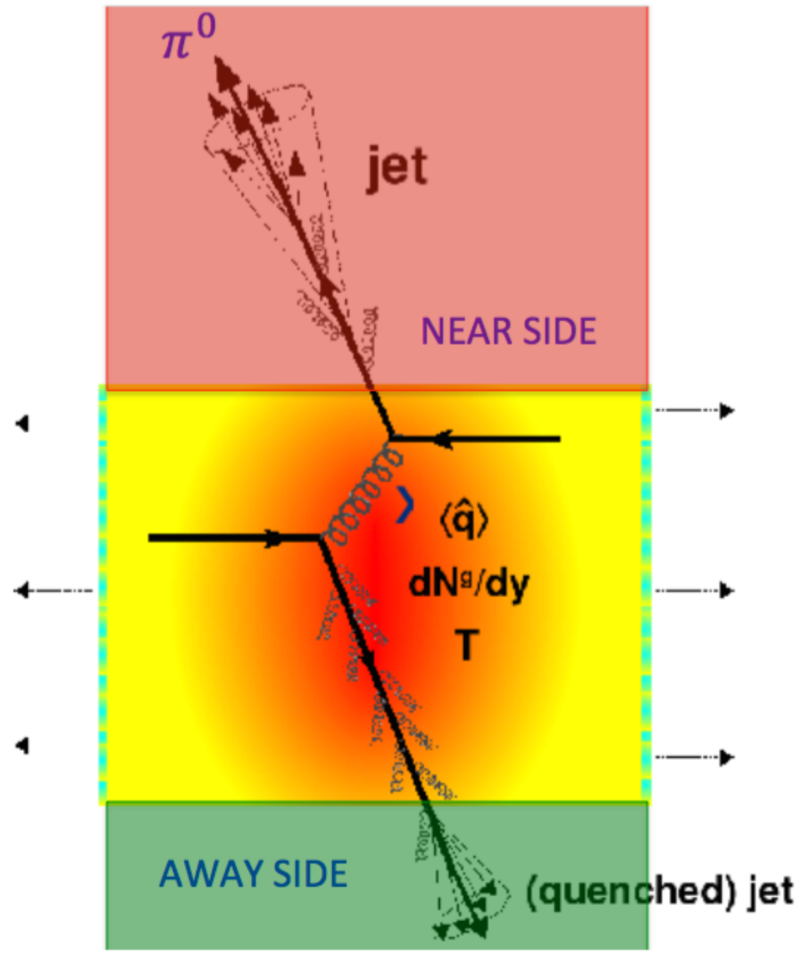
π^0 decay photons start to merge for $E > 6$ GeV

- Select clusters with elongated λ_0^2 shower shape
- A cluster is split in 2 sub-clusters, the seed are the 2 highest energy cells or local maxima. Select cells around
- Select those with invariant mass at 3 sigma of the π^0 mass

Background subtraction



red, green: Correlated
blue: Un-correlated



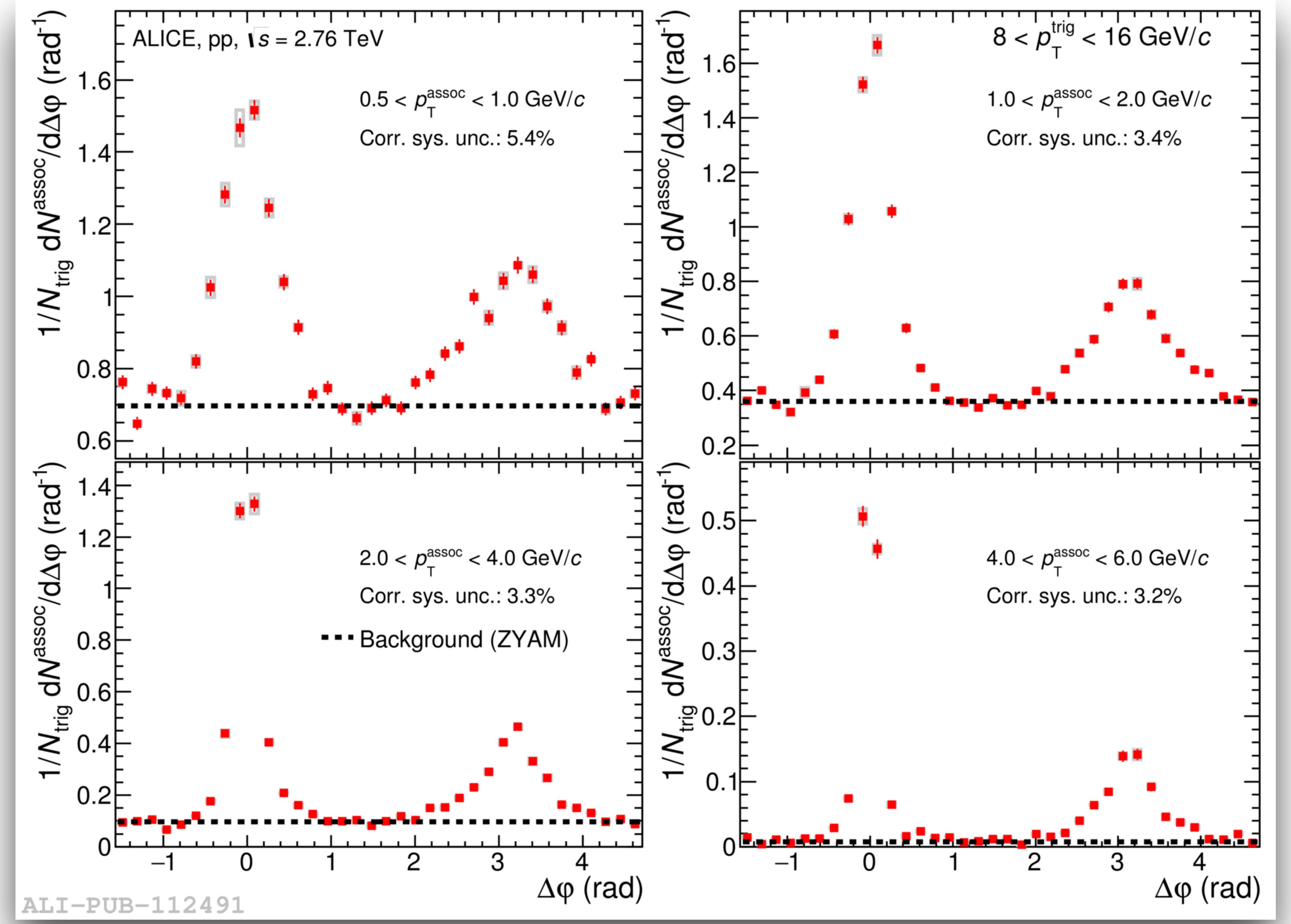
- Per-trigger yield in two regions
  - ✓ Near side: $|\Delta\varphi| < 0.7$ rad
  - ✓ Away side: $|\Delta\varphi - \pi| < 1.1$ rad
- Subtract the background with ZeroYieldAtMinimum
  - ✓ Flat background (pp)
  - ✓ v_n background (Pb-Pb)

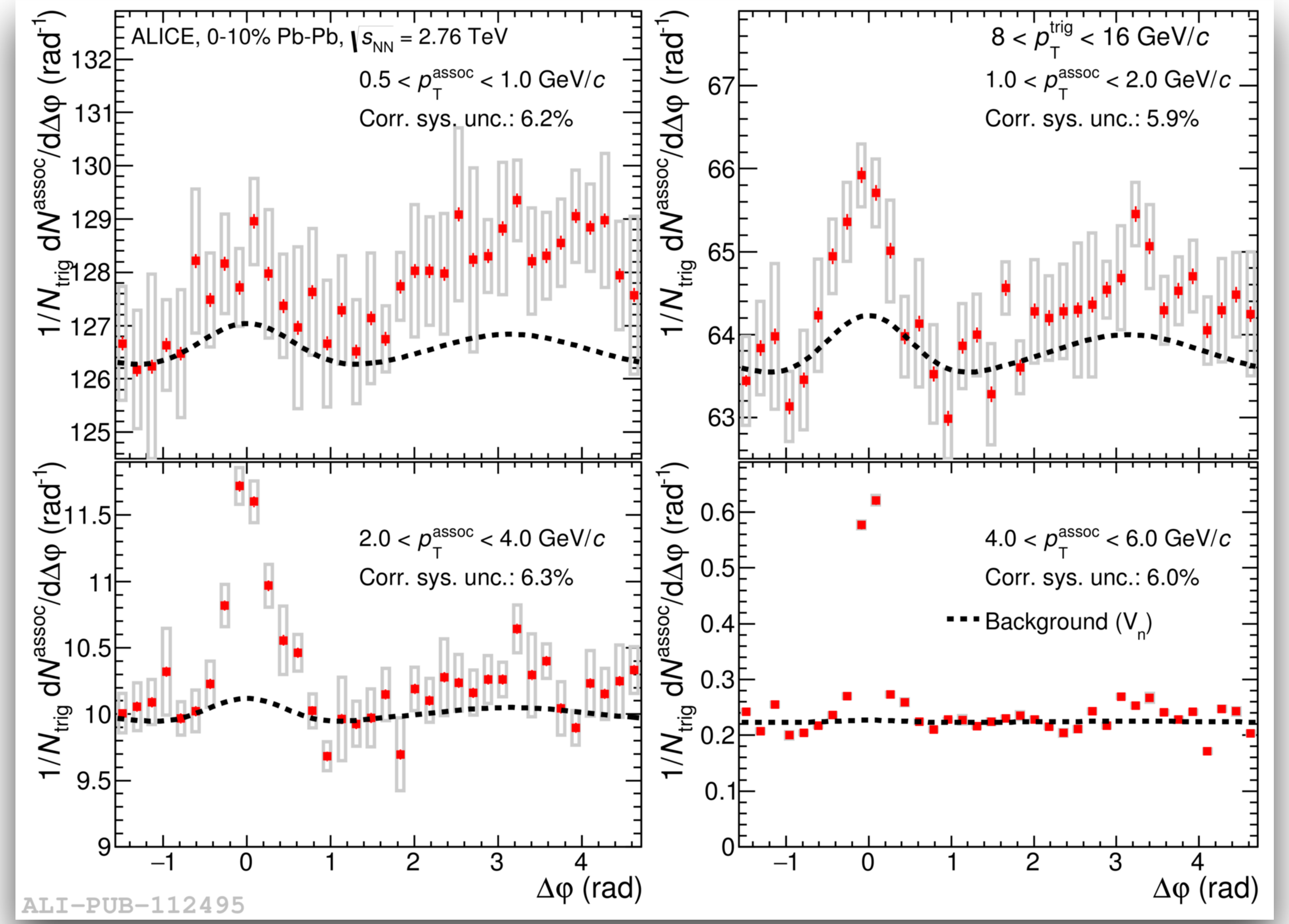
$$J(\Delta\varphi) = C(\Delta\varphi) - b_0\left(1 + 2\sum_{n=2}^{5} < v_n^{trig} >< v_n^{assoc} > \cos(n\Delta\varphi)\right)$$

Results: azimuthal distributions in pp and Pb-Pb

pp $\sqrt{s}$ = 2.76 TeV

0-10% Pb-Pb $\sqrt{s_{\rm NN}}$ = 2.76 TeV

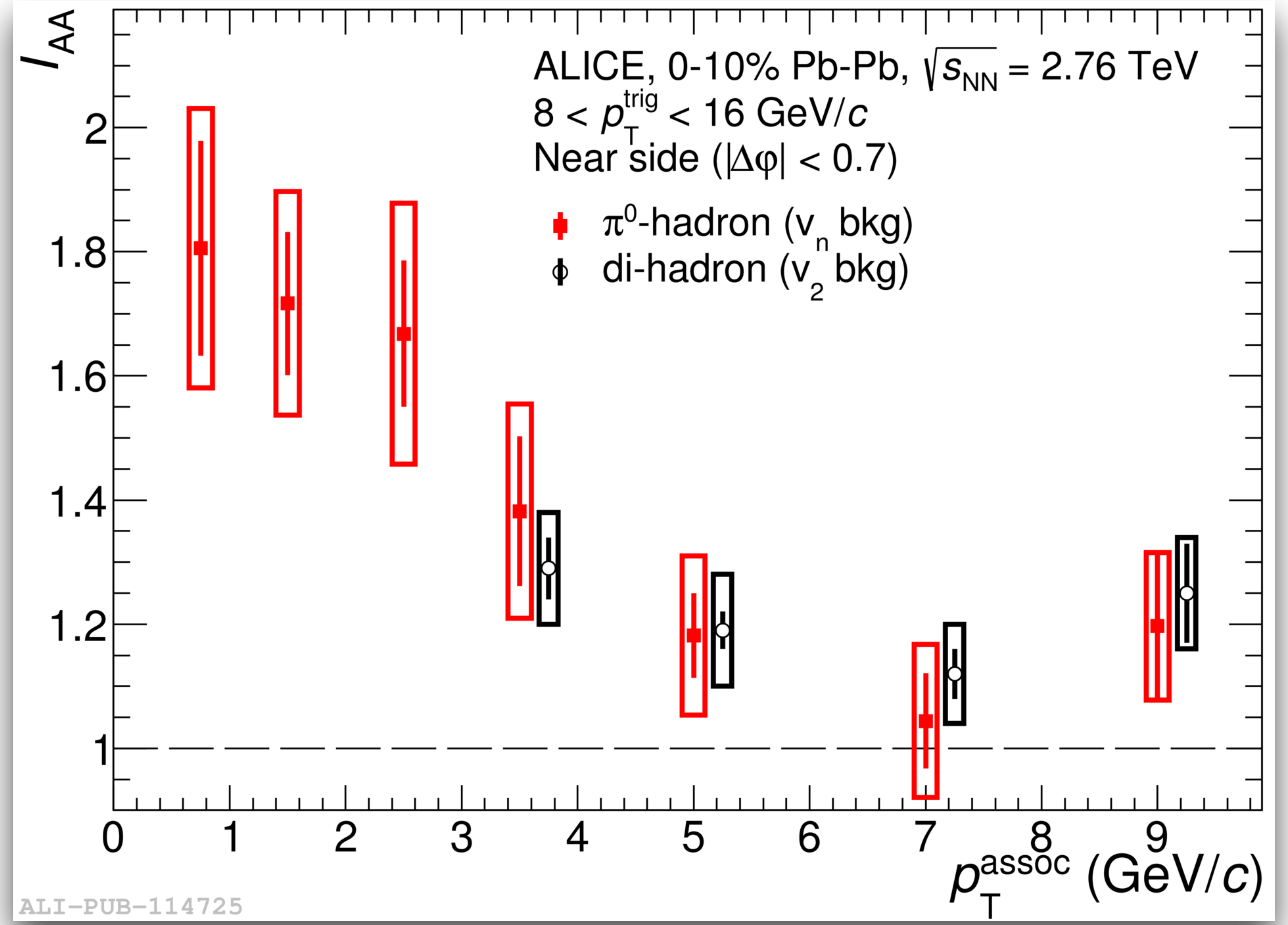




PLB 763 (2016) 238-250

- Trigger π^0 : $8 < p_{\rm T}^{trig} < 16$ GeV/c
- Associated charged hadron: $0.5 < p_{\rm T}^{assoc} < 6.0$ GeV/c with several bins

Results: modification factor I_{AA} (Near side)

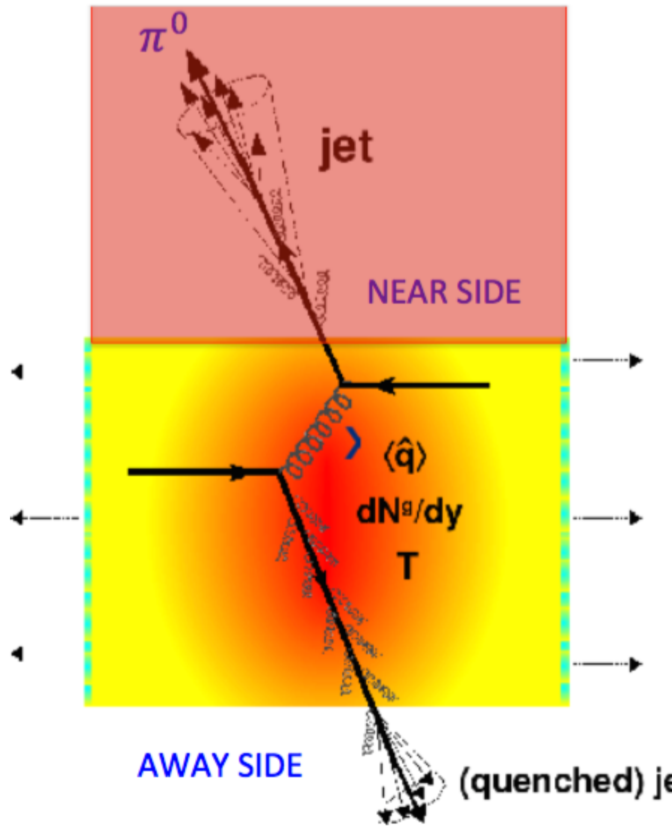


pion-hadron: PLB 763 (2016) 238-250

di-hadron: Phys. Rev. Lett. 108 (2012) 092301

agreement at high p_T

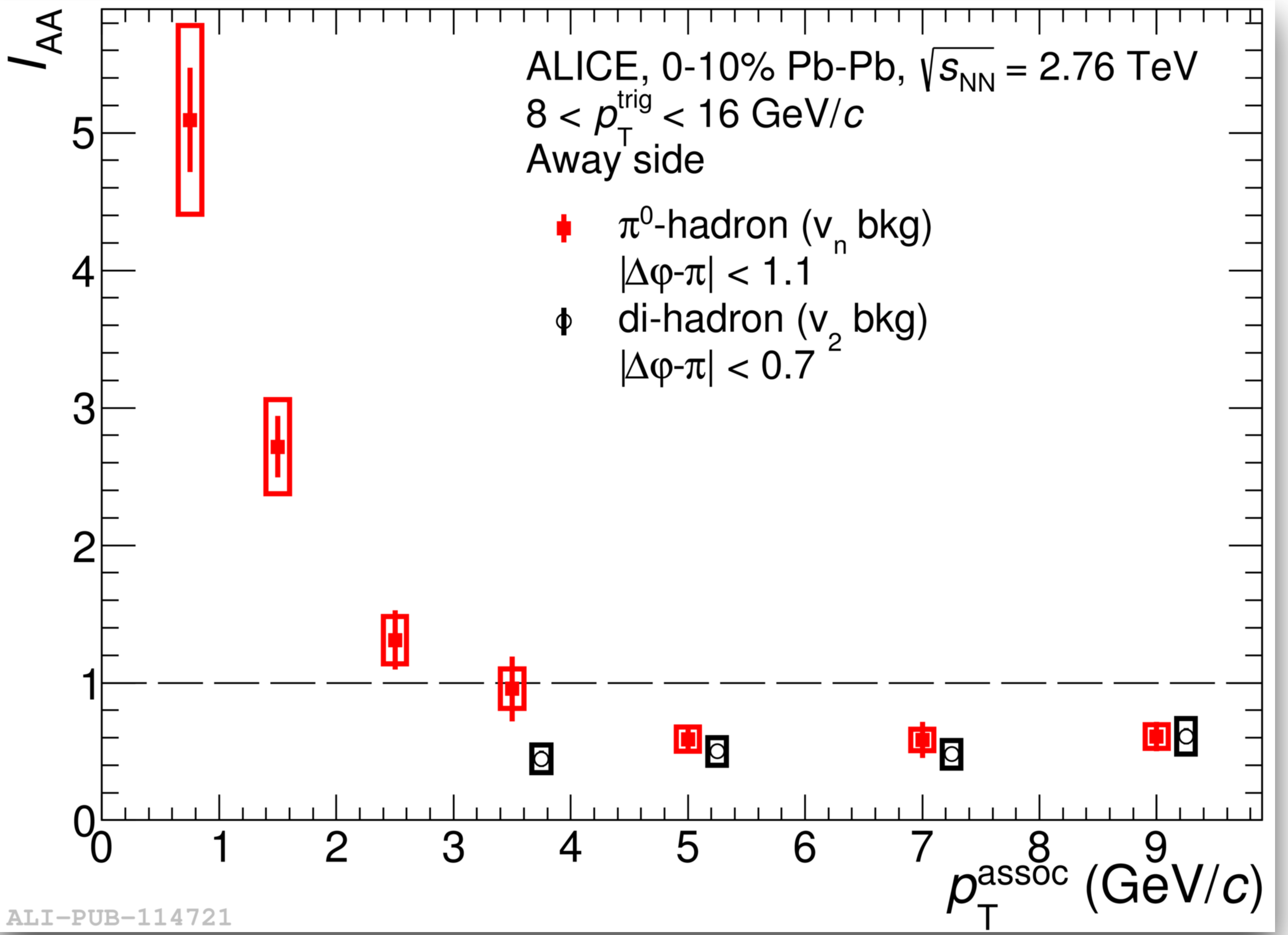
$$Y = \frac{1}{N_{trig}} \int J d\Delta\varphi \quad \Rightarrow \quad I_{AA} = \frac{Y_{Pb-Pb}}{Y_{pp}}$$



Near-side enhancement at high p_T ($I_{AA} \sim 1.2$), $I_{AA} \sim$ 1.2 to 1.8 at low p_T

- ✓ Change of the fragmentation function?
- ✓ Change of the quark vs gluon jet ratio?
- ✓ Bias on the parton p_T spectrum?

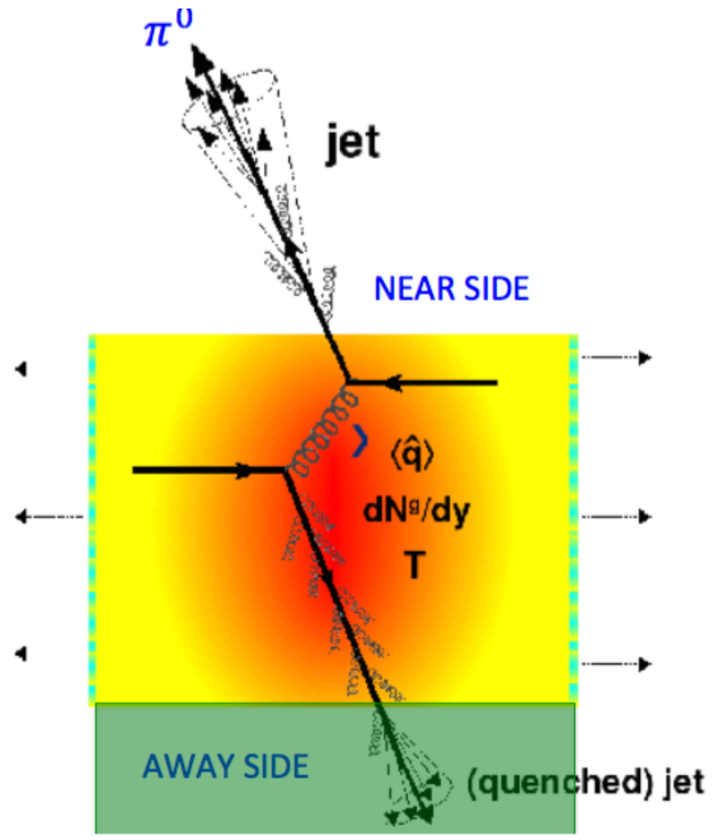
Results: modification factor I_{AA} (Away side)



pion-hadron: PLB 763 (2016) 238-250

di-hadron: Phys. Rev. Lett. 108 (2012) 092301

$$Y = \frac{1}{N_{trig}} \int J d\Delta\varphi \Rightarrow I_{AA} = \frac{Y_{Pb-Pb}}{Y_{pp}}$$



Away-side suppressed at high p_T ($I_{AA} \approx 0.6$)

- ✓ Energy loss in medium

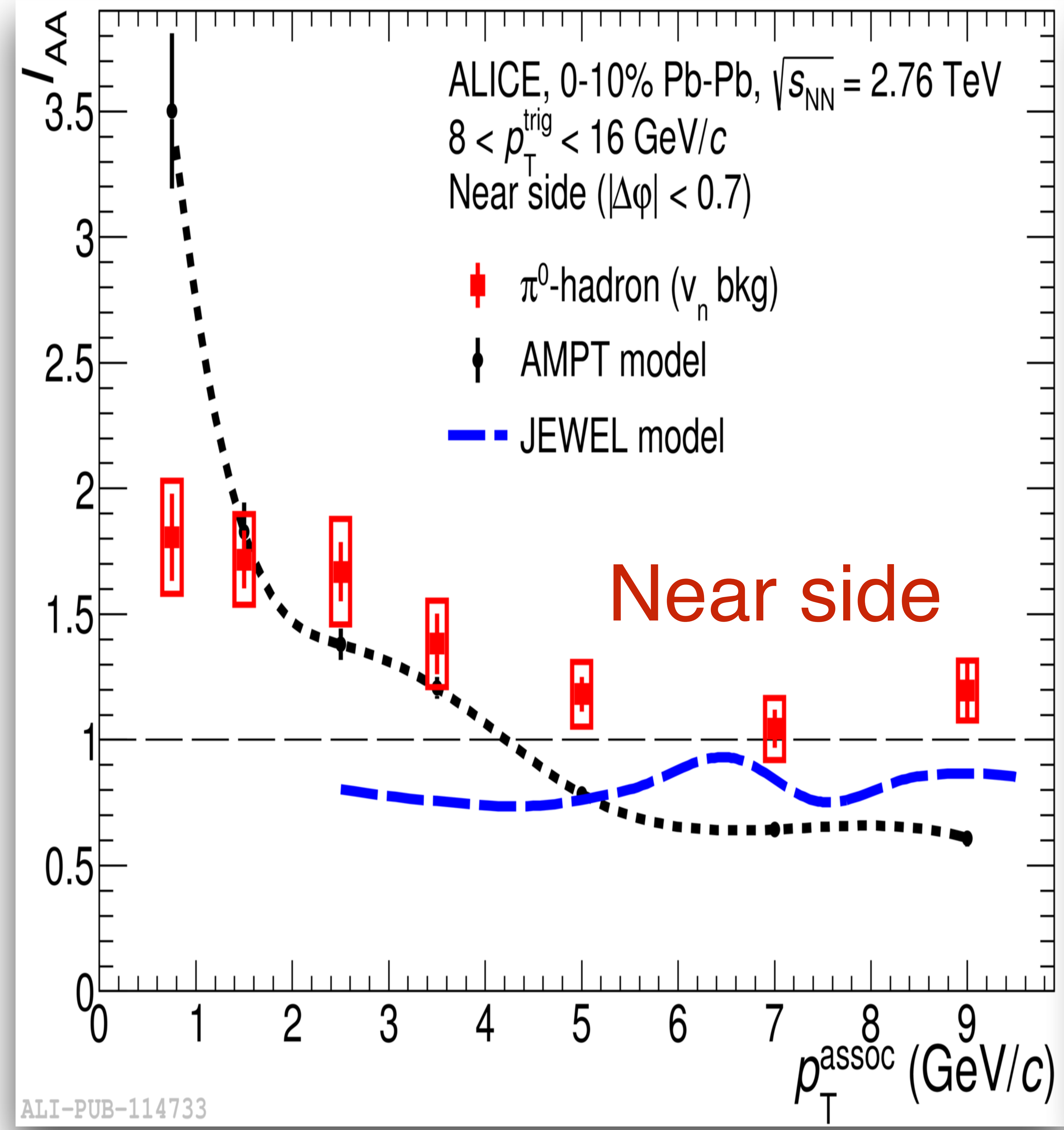
Enhancement up to $I_{AA} \sim 5$ at low p_T

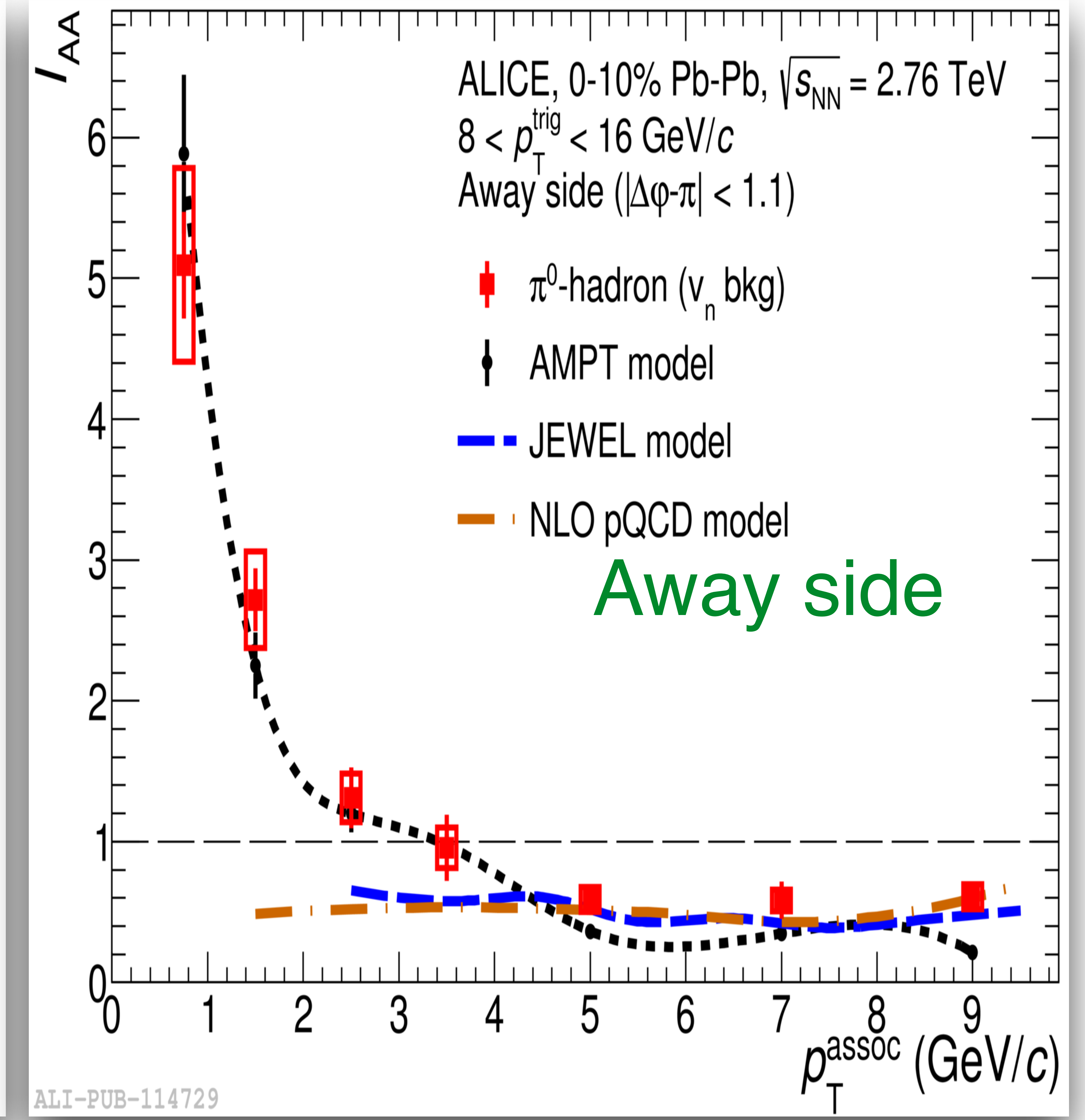
- ✓ k_T broadening?
- ✓ medium-excitation?
- ✓ fragments from radiated gluons?

jet-medium interaction

agreement at high p_T

Results: I_{AA} compared with models





AMPT: *Phys. Rev. Lett. 106 (2011) 162301*

NLO pQCD: *Phys. Rev. Lett. 98 (2007) 212301*

JEWEL: *JHEP 03 (2013) 080*

- Near-side
  - ✓ Only AMPT model can qualitatively describe the enhancement at low p_T (except the lowest p_T bin)
- Away-side
  - ✓ All can qualitatively describe the suppression at high p_T
  - ✓ Only AMPT model can qualitatively describe the enhancement at low p_T

PLB 763 (2016) 238-250

In AMPT the low-p_T^{assoc} enhancement is attributed to the increase of soft particles as a result of the jet-medium interactions

Conclusion and Outlook

- π^0-hadron correlations as a function of azimuthal angle difference $\Delta\varphi$ at midrapidity in pp and central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV have been measured
- The per-trigger yield modification factor, I_{AA}, has been measured for the near and away side in 0–10% most central Pb–Pb collisions
  - ✓ Extend the results to low p_{T}, both near and away side show enhancement
  - ✓ Measured I_{AA} comparison to models, away-side suppression reproduced by JEWEL, NLO and AMPT but enhancement on near and away side only qualitatively reproduced by AMPT

Perspectives:

- Study this phenomenon further and in depth with different collision systems (p-Pb) and energies
- Ultimate goal: gamma-hadron correlations

BACK UP

systematic uncertainties

Source	$Y(\Delta\varphi)$ pp	$Y(\Delta\varphi)$ Pb–Pb	I_{AA} (NS)	I_{AA} (AS)
Tracking efficiency	5.4%	6.5%	8.5%	8.5%
MC closure	1.0%	2.0%	1.2%	1.2%
TPC-only tracks	1.0%	3.5%	4.3%	3.8%
Track contamination	1.0%	0.9%	1.1%	1.1%
Shower shape (λ_0)	1.2%	0.7%	3.4%	2.6%
Invariant mass window	1.3%	1.0%	3.5%	3.3%
Neutral pion purity	0.3%	1.1%	0.6%	0.5%
Pair p_T resolution	1.0%	1.1%	0.3%	0.3%
Pedestal determination	–	–	9.4%	11.7%
Uncertainty on v_n	–	–	7.1%	5.1%
Total	6.7%	7.4%	12.6%	15.0%

Details for model calculation

- AMPT:
  - Parton and hadron cascades with elastic scattering
  - String melting and parton recombination for hadronization
  - Use a standard triggered jet technique which is a part of HIJING for Pb-Pb
- JEWEL:
  - Parton-medium interactions with microscopic description of transport coefficient q hat
  - Hard scatter from Glauber collision geometry
  - Elastic and radiative energy loss implement by LPM interference effects
- NLO-pQCD:
  - Nuclear parton distribution functions for initial-state cold nuclear matter effects
  - Phenomenological model for medium-modified fragmentation functions
  - 3+1 dimensional ideal hydrodynamic model for the evolution of bulk medium