Isolated γ, π^0-hadrons and π^0-jets correlations in ALICE

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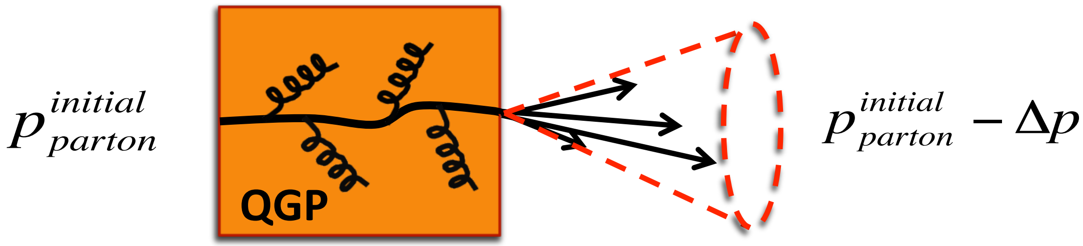
Results presented at QM2014, collaboration with China and Japan
and results from N. Arbor thesis (not final)

ALICE
A JOURNEY OF DISCOVERY
LPSC Grenoble
Laboratoire de Physique Subatomique et de Cosmologie
cnrs IN2P3 Les deux infinis

Introduction

- At the initial stages of the heavy-ion collision, hard probes (partons) are produced
- Partons traverse the hot, dense and colored **QCD** medium, the Quark-Gluon Plasma (**QGP**)



  - Partons lose energy via radiative (gluon emission) and collisional processes in the **QGP**: *Jet-quenching*
- Is their production mechanism modified with respect to collisions without **QGP**? References:
  - pp collisions: in any case measurement interesting for pQCD test
  - p-Pb collisions: consider initial state effects

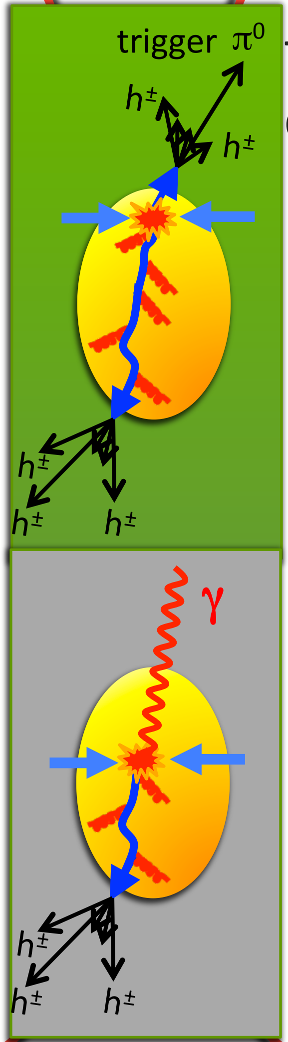
Experimental observables

Single hadron and jet production yields: the *Nuclear Modification Factor*

$$R_{AA,pA}(p_T, y) = \frac{d^2N_{AA,pA} / dydp_T}{\langle N_{coll} \rangle \times d^2N_{pp} / dydp_T}$$

$$\langle N_{coll} \rangle = \langle T_{AA} \rangle \sigma_{pp}^{INEL}$$

- $R_{AA,\ pA}$ = 1, if no medium or initial state effect
- Particle identification can help to understand energy loss dependences (quark vs gluon, quark mass, …)



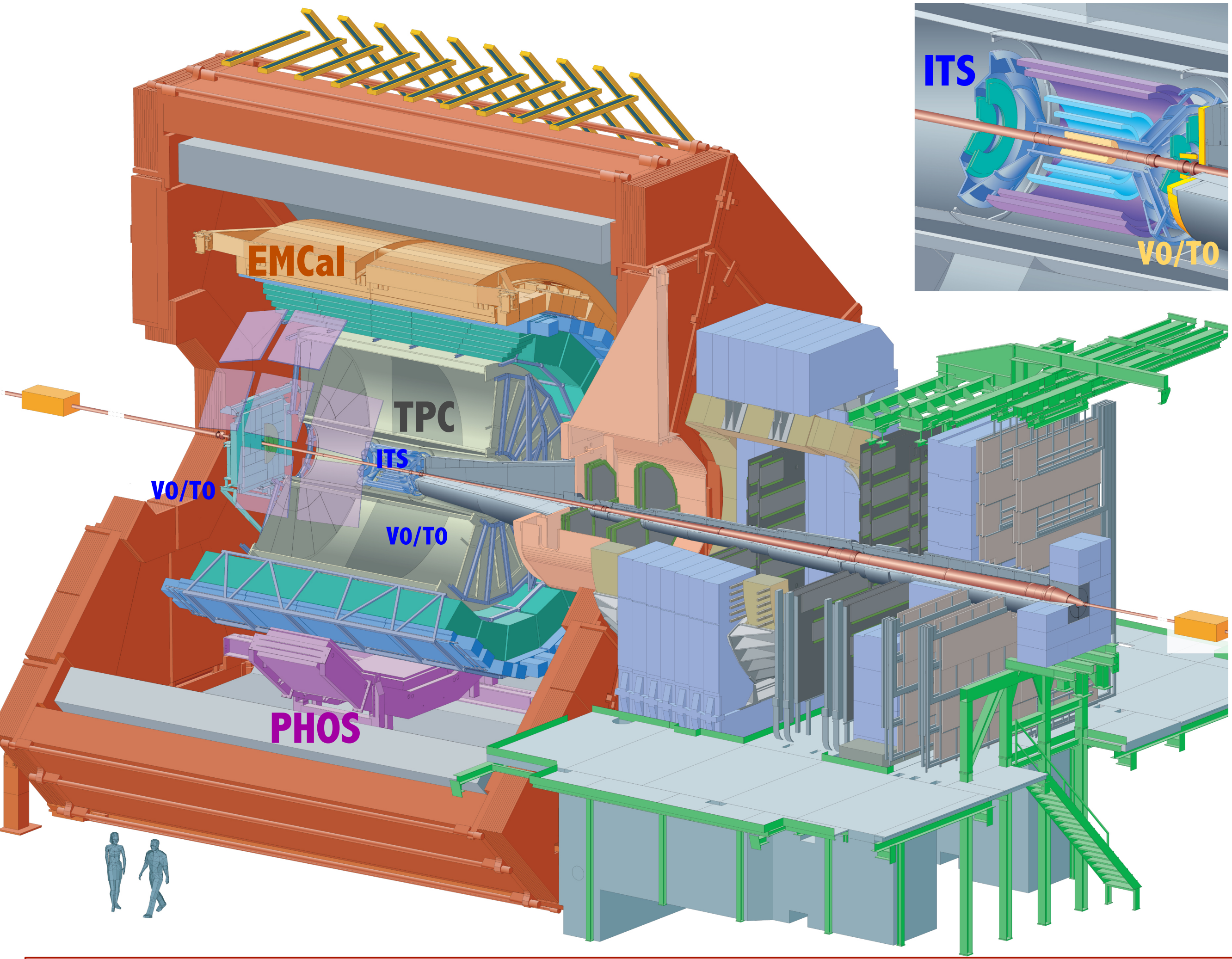
Parton fragmentation: Jet fragmentation function, hadron conditional yields

$$I_{AA,pA} = \frac{1/N_{AA,pA}^{trigger} \quad dN_{AA,pA}^{assoc}}{1/N_{pp}^{trigger} dN_{pp}^{assoc}}$$

with $N(p_T \ or \ z_T \ or \ x_E)$

- If parton traverses medium, redistribution of jet energy. I_{AA}=1 if no medium.
- Di-hadron correlation, high p_T trigger
  - Surface bias, mainly gluons
- Prompt γ-hadron correlation
  - Probe all volume with quarks
  - Access to energy of parton before **QGP**

- Relevant detectors for high-p_T particles and jets:



- Trigger and centrality determination
  - V0 & T0
- Trackers: TPC & ITS
  - PID
    - $\pi^\pm/K/p/e^\pm$ via *dE/dx*
    - $\gamma/\pi^0/\eta$ via conversions
  - Charged jets components
- Calorimeters: EMCal & PHOS
  - PID: $\gamma/\pi^0/\eta/e^\pm$
  - Neutral jets components (EMCal)

Results presented here measured by ALICE in pp collisions at at $\sqrt{s_{NN}}$ = 2.76, 7 TeV and Pb-Pb col. at $\sqrt{s_{NN}}$ = 2.76 TeV

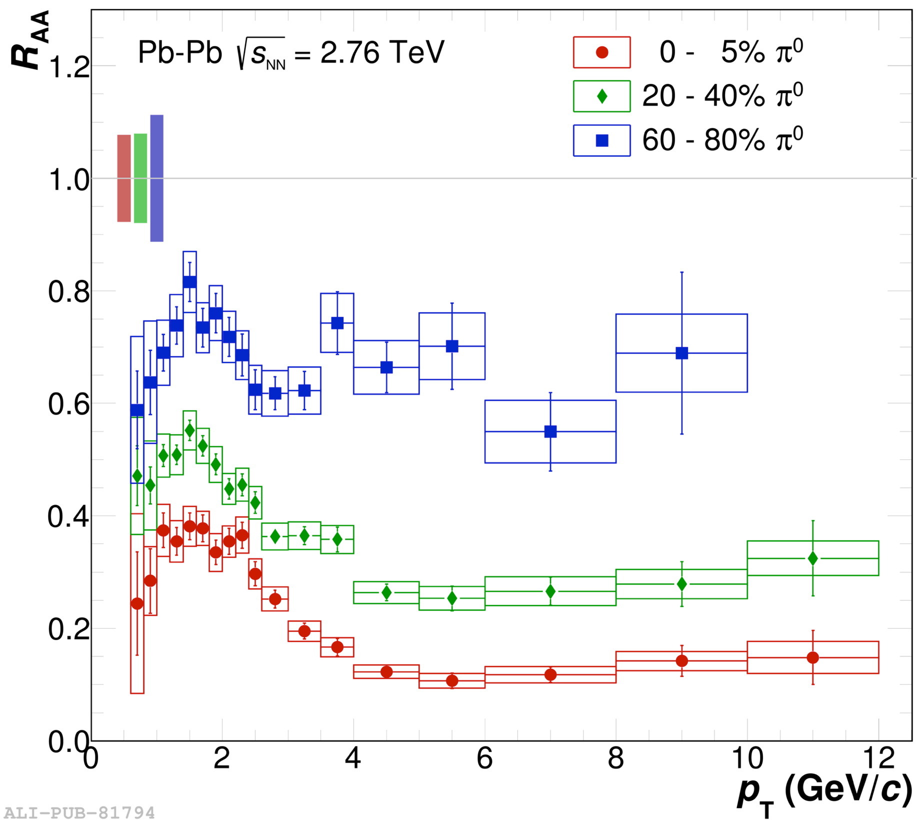
See talk from Astrid M. on neutral mesons in ALICE

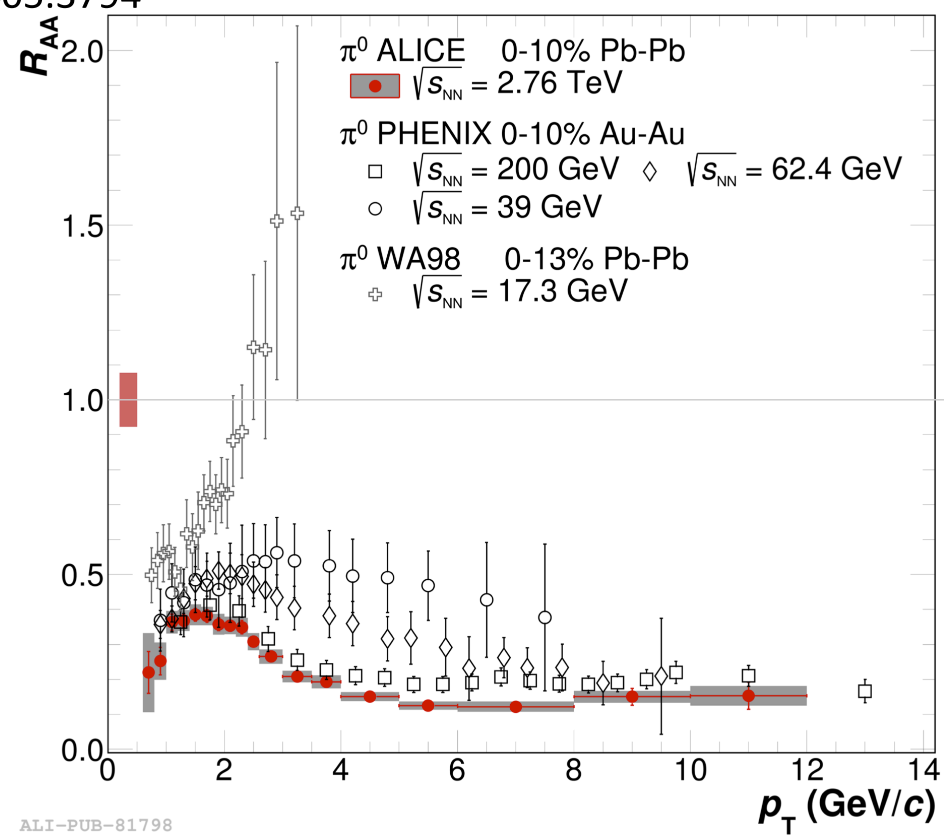
Low p_T π^o R_{AA}

- π^0 : invariant mass analysis, combined measurement of PHOS calorimeter and trackers
  - 10 times more statistics waiting on tape
- Same result as for $\pi^{\pm}$

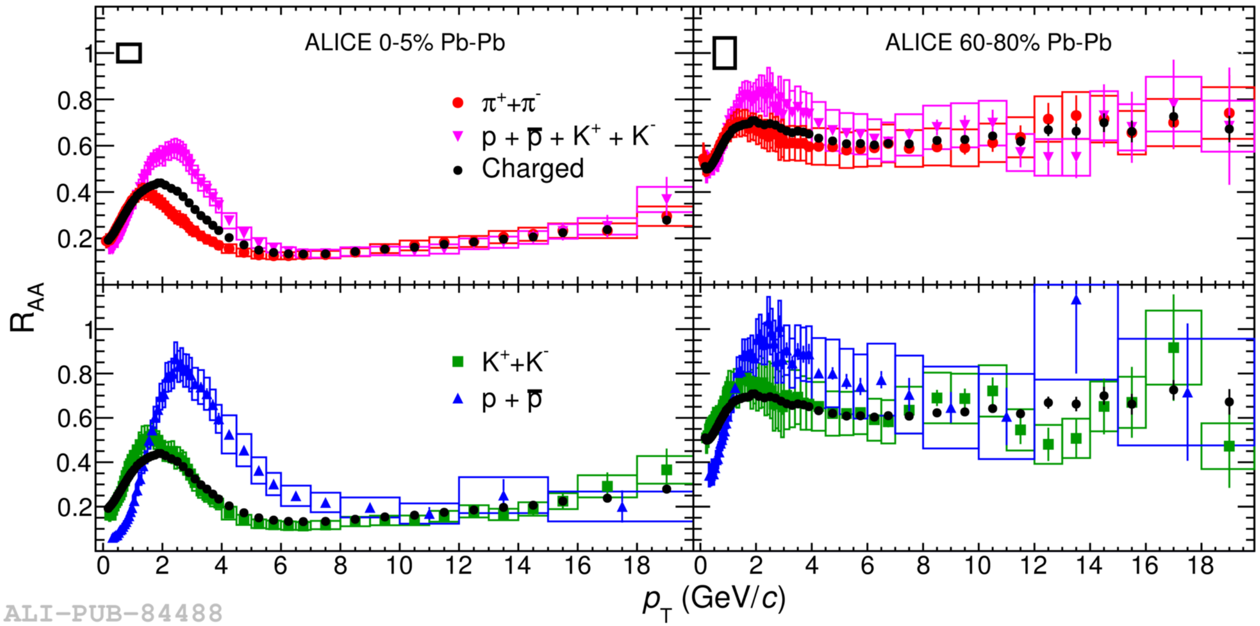
- Evolution with respect √s from SPS to LHC:
  - Increasing √s leads to more suppression

arXiv:1405.3794





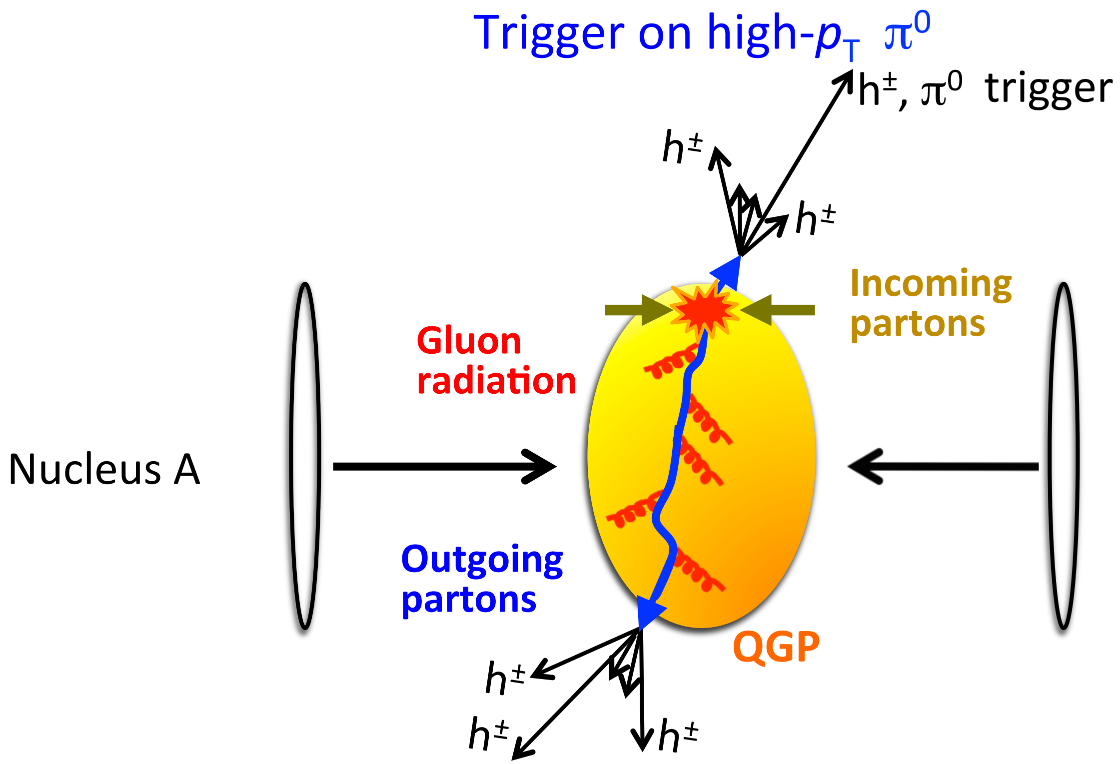
Identified particle R_{AA}



arXiv:1401.1250

- Mesons and baryons show a different behavior for $p_T < 10$ GeV/c
  - Radial flow plays an important role in this region
- Same behavior above 10 GeV/c
  - Chemical composition of high-p_T jet fragments in the medium is similar to that of vacuum jets
- Then, why charged hadron and π^0 triggers in correlation analysis?
  - Can trigger (hardware) and identify π^0 at high p_T
  - Cross check with 2 different systems measuring the trigger: Trackers vs Calorimeter

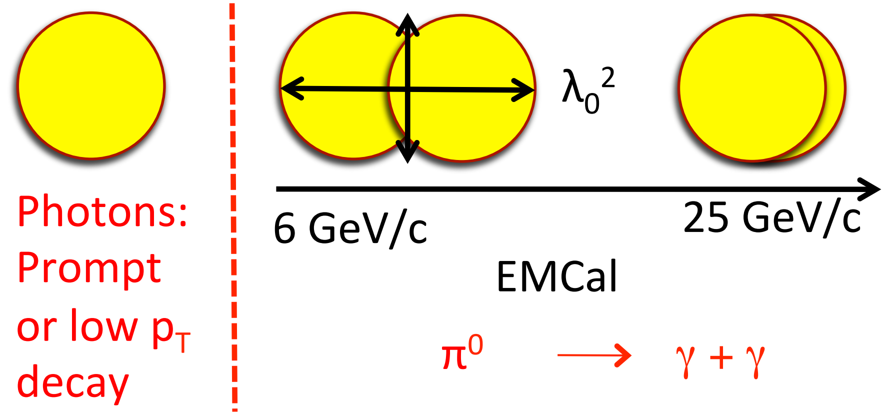
π^0-hadrons/jets azimuthal correlations



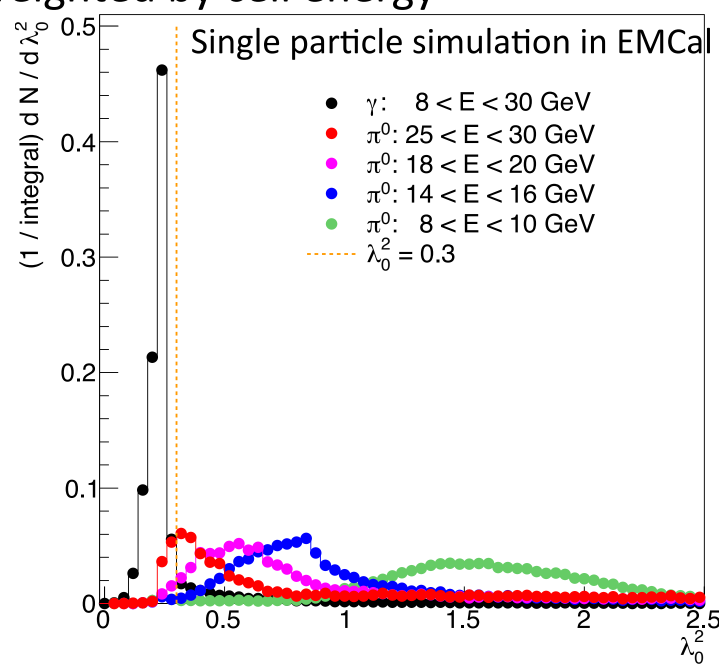
- π^0 trigger is quenched: Select high-p_T particles at the surface of medium
- Analysis of EMCal triggered events, π^0 identified in EMCal (trigger), charged hadrons / charged jets measured in TPC+ITS

High p_T π^o and γ identification in EMCal

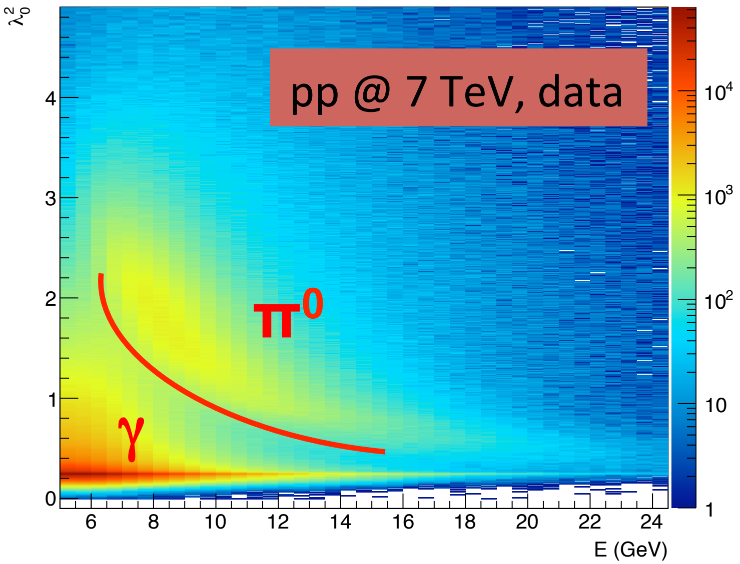
- Photon identification in calorimeters
  - Track veto: neutral clusters
  - Shower shape: 2D distribution of particle cluster energy in the calorimeter cells
    - Circular shape
  - Prompt photons: Isolation
- Neutral mesons identification in calorimeters, 2 ways
  - 2 separated neutral clusters invariant mass
  - Merged clusters splitting + shower shape
    - Ellipsoidal shape
    - Split sub-clusters invariant mass



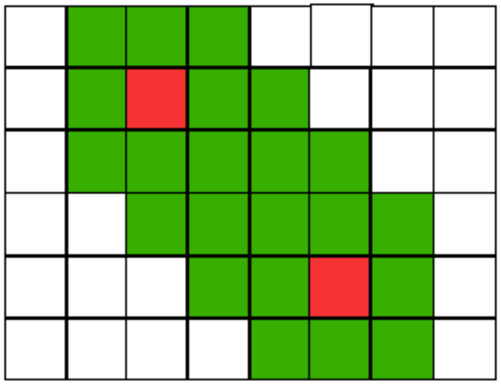
λ_0 ≈ main axis of the ellipse in cell units weighted by cell energy

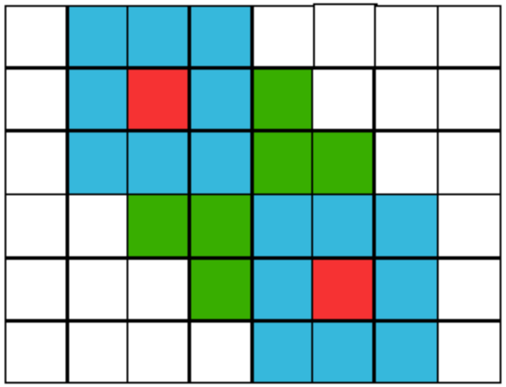


High p_T π^0 identification in EMCal



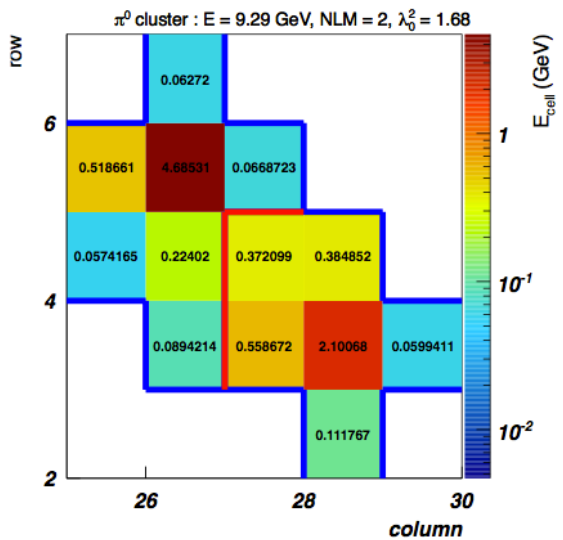
- π^0 and γ bands well visible in λ_0^2 from data
- How to select π^0 clusters from merged decays with high purity
  - Select clusters with large λ_0^2 (>0.3 or over the red line)
  - Split the clusters depending on their local maxima (LM):



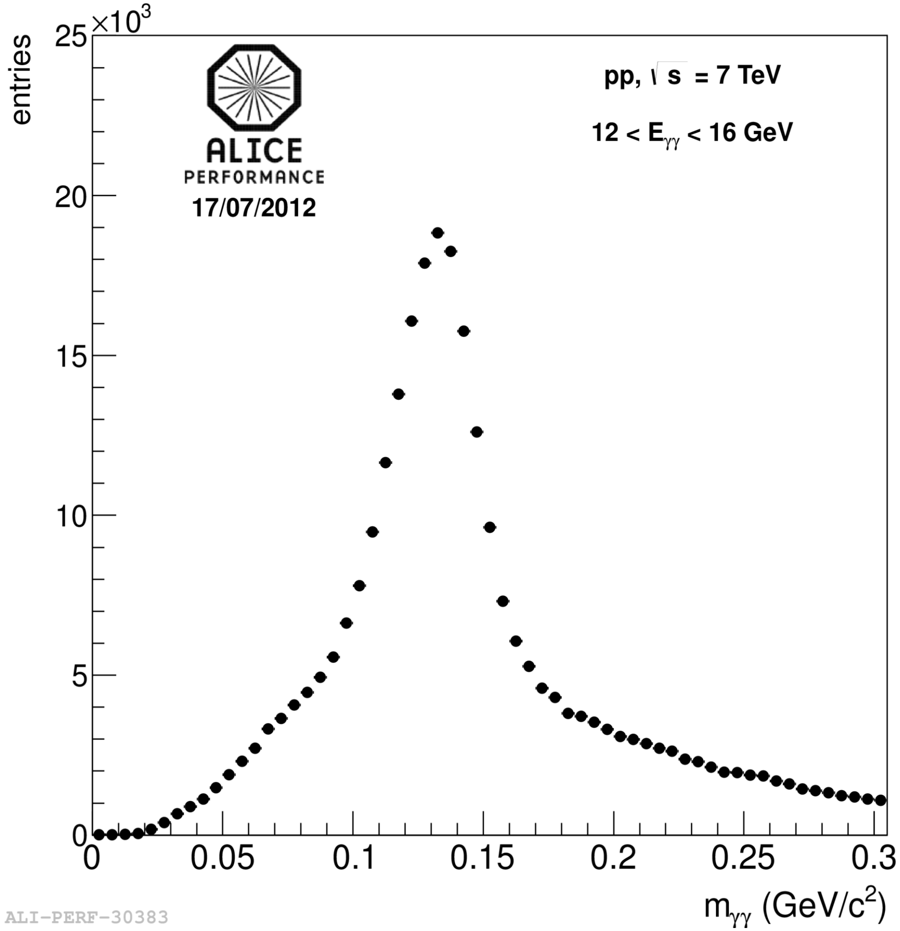


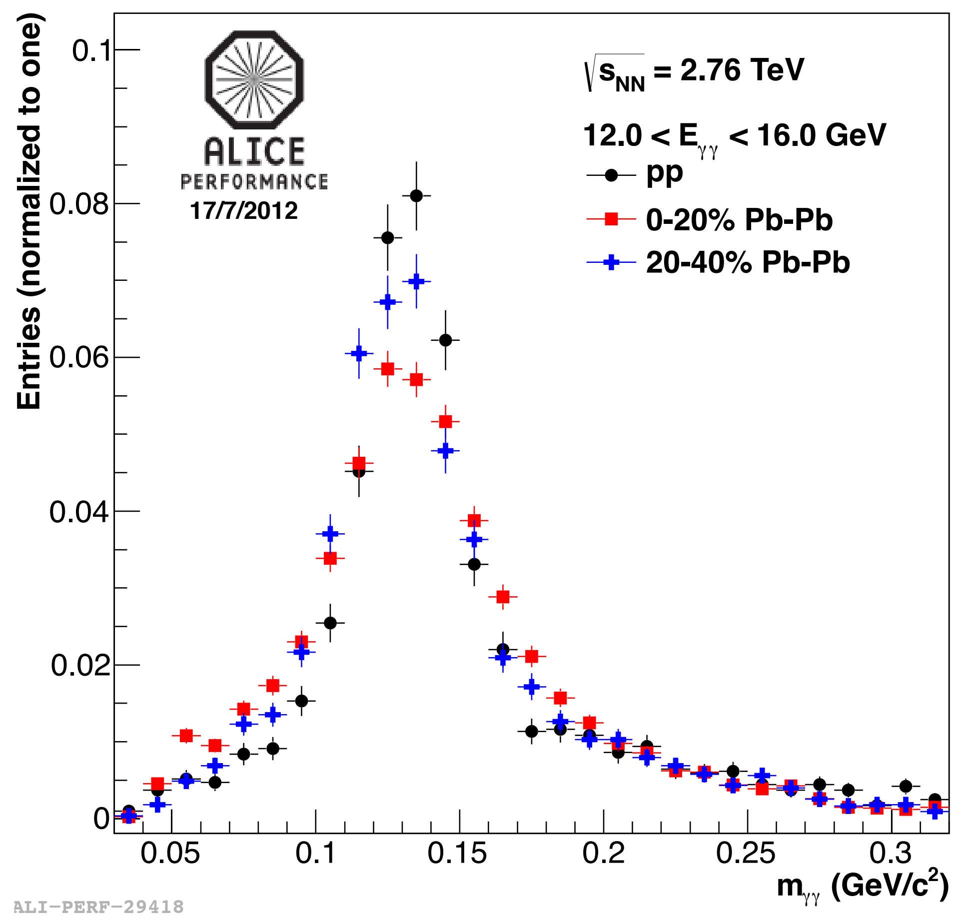
    - E_{LM}(candidate) - E(neighbor cell) > 30MeV
    - E_{LM}(seed) = 100 MeV (pp) – 200 MeV (Pb–Pb)
  - Form sub-clusters with 3x3 cells around LM
  - Select clusters with split Invariant mass, 3σ, Identification up to p_T=40-50 GeV/c

Merged pi0 cluster candidate in data



High p_T π^0 identification in EMCal

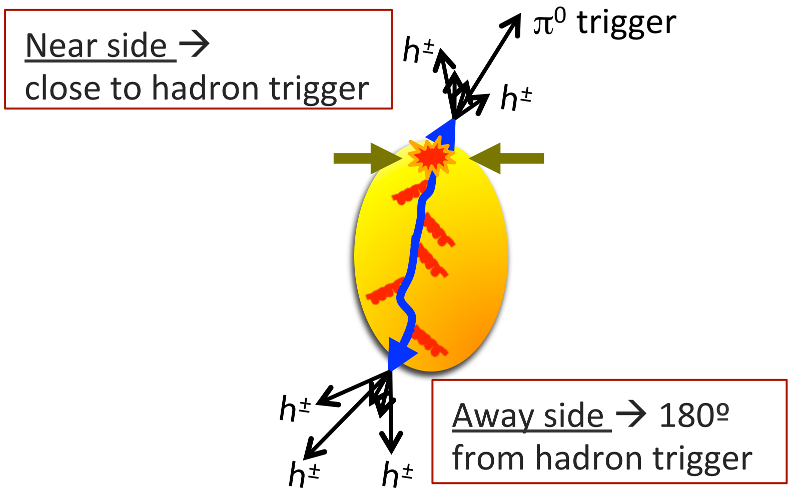


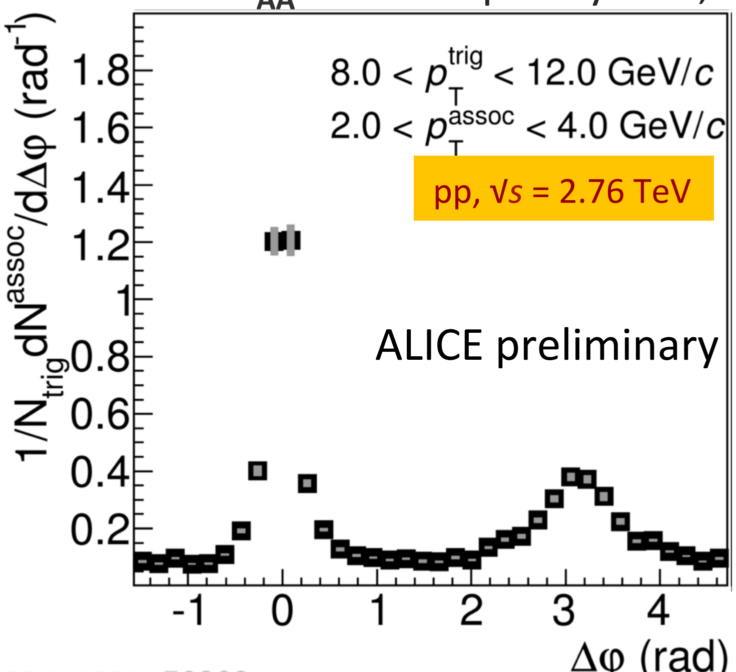


- Select merged clusters with Mass=Mean Peak±3σ
- Purity of the selection for E > 10 GeV of 95-90% in pp and Pb-Pb
  - Contamination mainly from unmerged decay γ: very asymmetric decays with $E(\gamma) > 0.8E(\pi^0)$

π^0-hadron azimuthal correlations

- Trigger on high-p_T π^0 (EMCal)
  - Select mostly jets produced close to the surface of the fireball
- Correlate with charged hadrons in azimuth
- How to quantify modifications on correlation?
  - Remove combinatorial yield under the peaks
  - Obtain I_{AA}: Ratio of peak yields, Pb-Pb over pp





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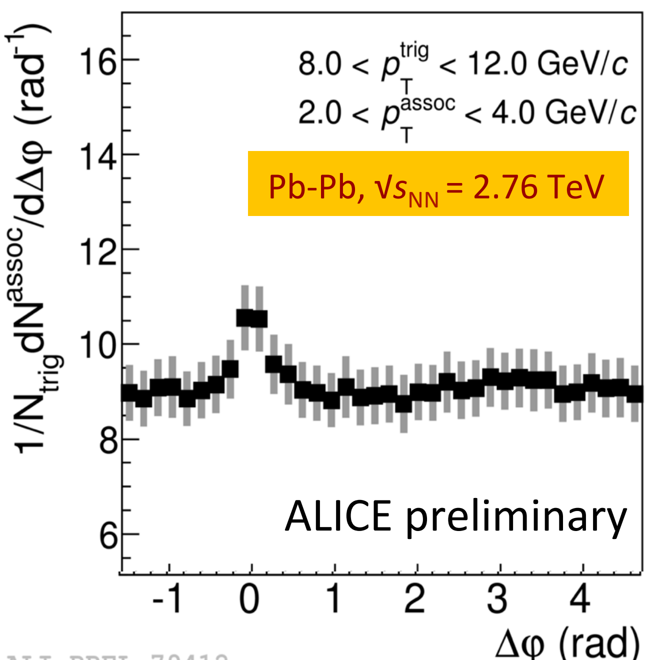

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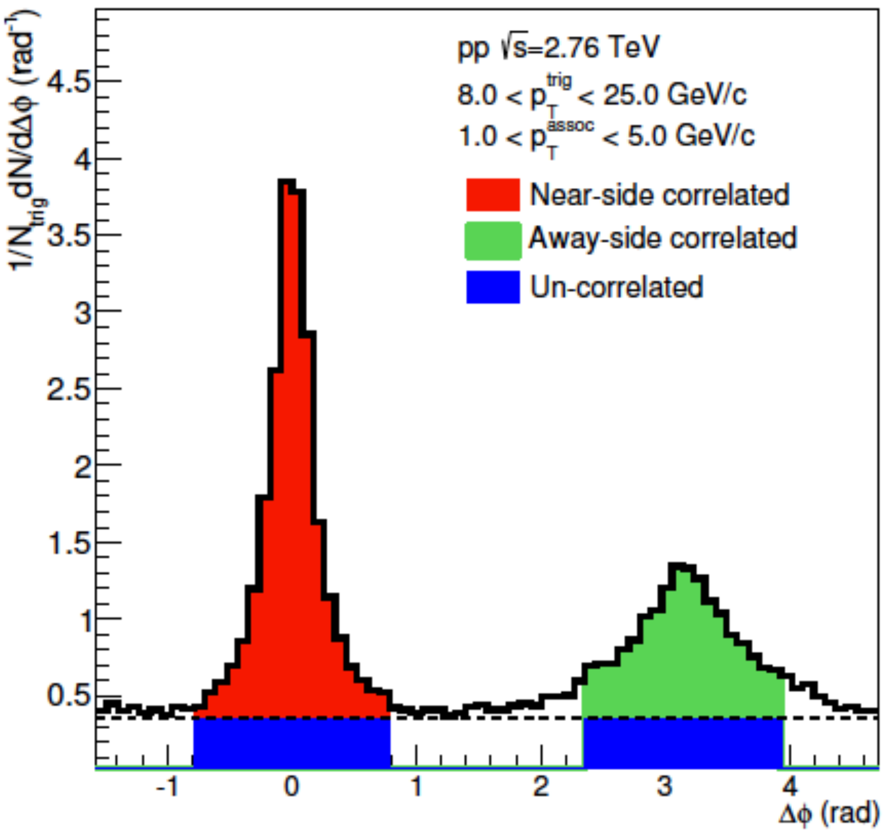
π^0-hadron per trigger yields extraction



red, green: Correlated

blue: Un-correlated

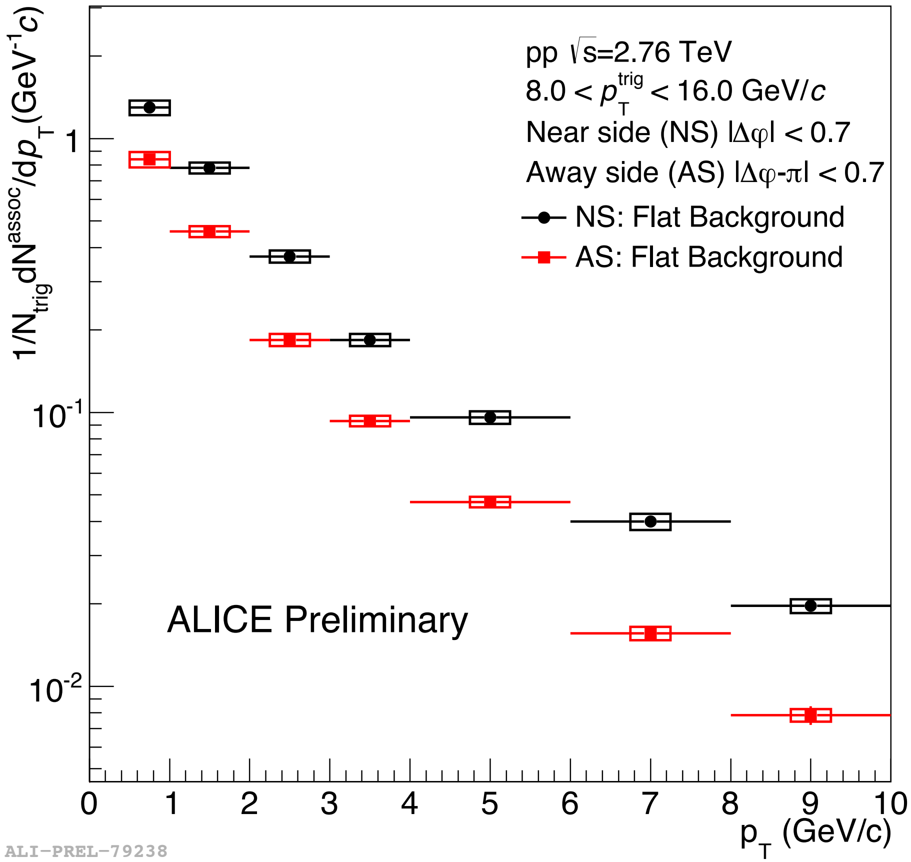
- Per trigger yields in 2 regions
  - Near side $|\Delta\phi| < 0.7$
  - Away side $|\Delta\phi - \pi| < 0.7$
- Subtract the background with ZYAM (Zero Yield At Minimum). Two corrections considered
  - Flat background: pp and Pb-Pb
  - Flow background: Pb-Pb

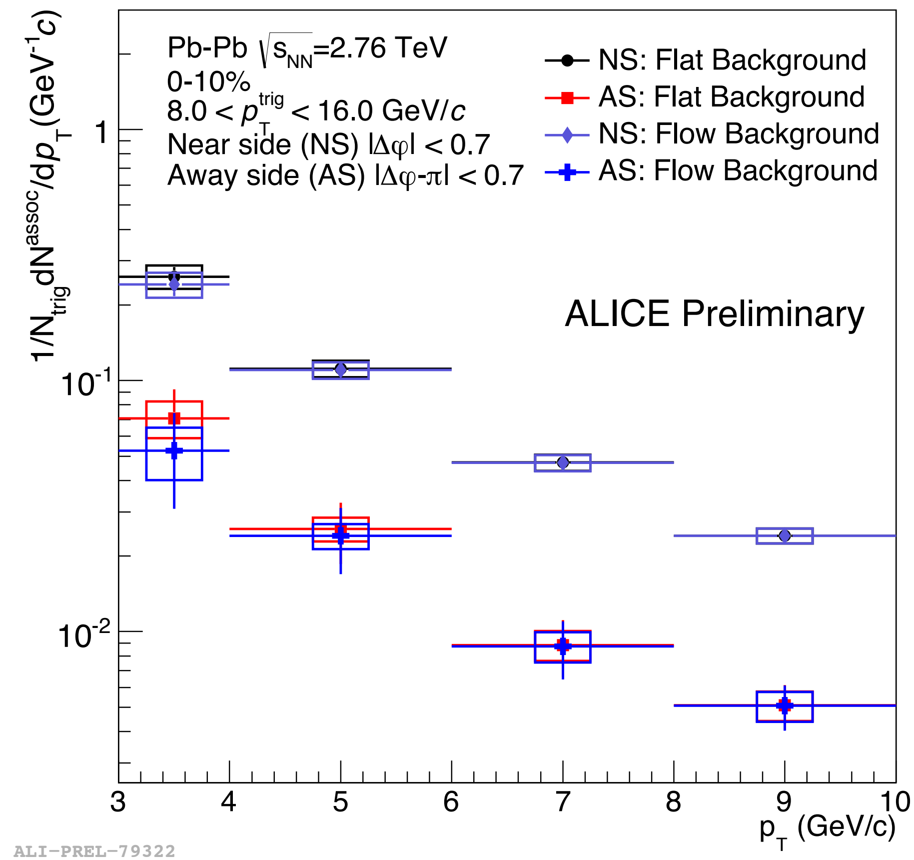
$$J(\Delta\varphi) = C(\Delta\varphi) - b_0(1 + 2\langle v_2^{trig} v_2^{assoc}\rangle \cos(2\Delta\varphi))$$

- Use charged pions v_2

Xiangrong Zhu thesis

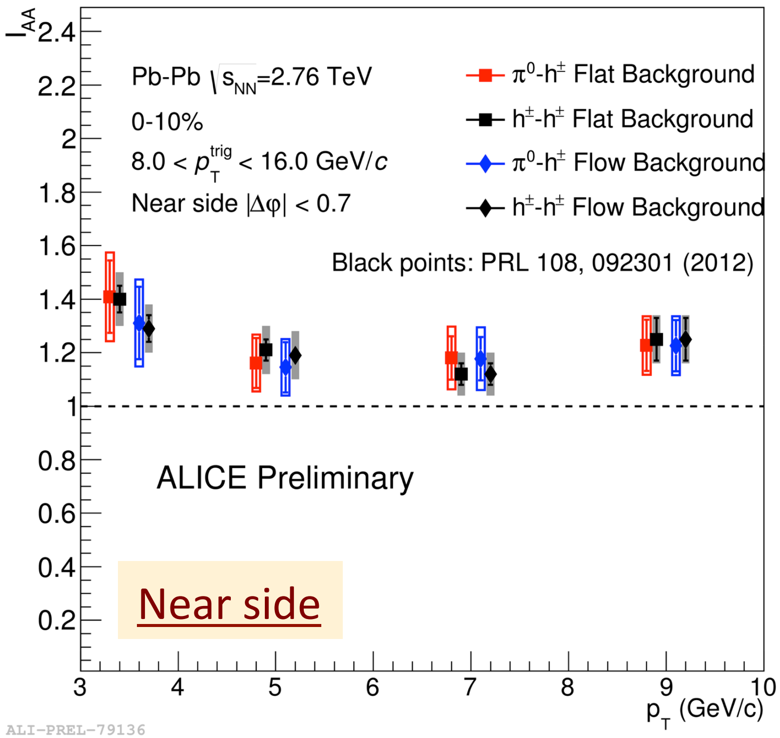
π^0-hadron per trigger yields

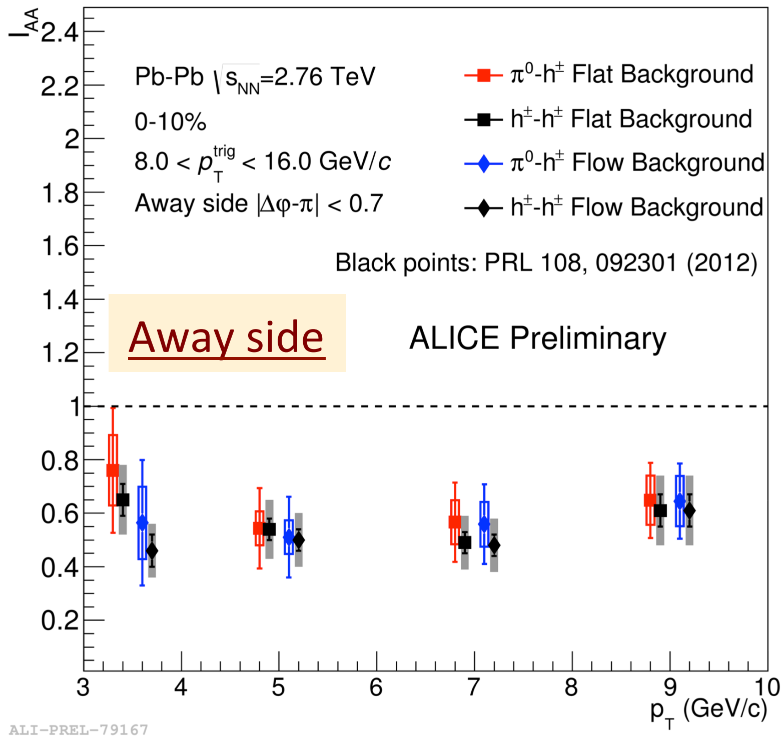




- Corrected per trigger yield of all detector effects
- Background subtracted with flat and flow estimations: Both give similar yields due to small flow at high p_T

π^0-hadron and di-hadron I_{AA}

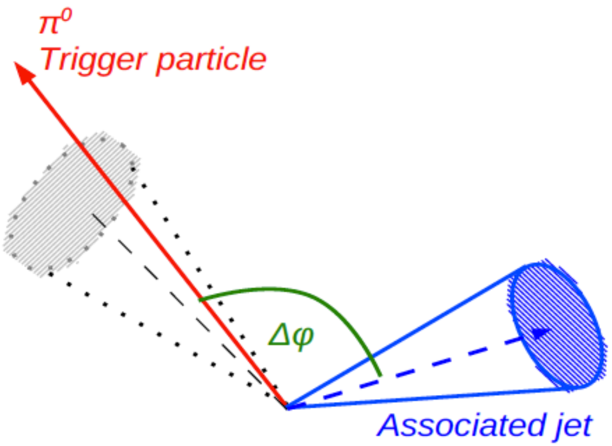


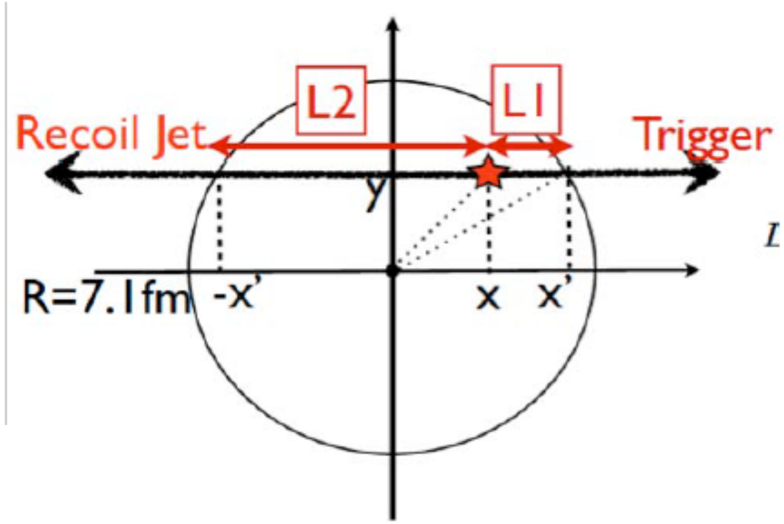


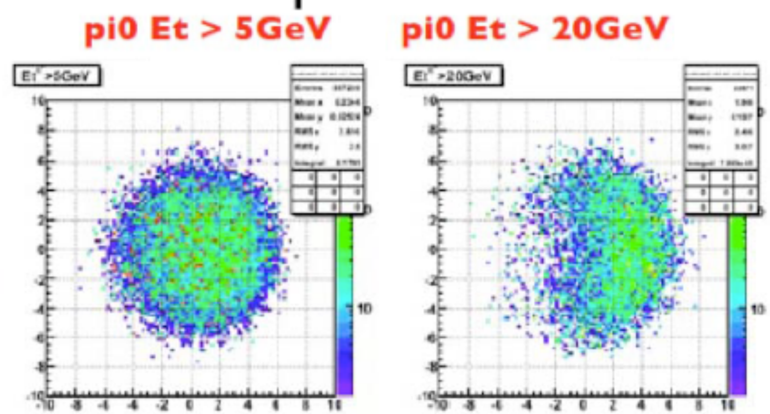
- Enhancement of charged hadrons conditional yield on the near side
- Suppression of charged hadrons conditional yield on the away side
- Same result with hadron-hadron and π^0-hadron
  - Different data sets, di-hadrons is year 2010 and π^0–hadrons is year 2011

Daisuke Watanabe analysis

π^0-jet azimuthal correlations



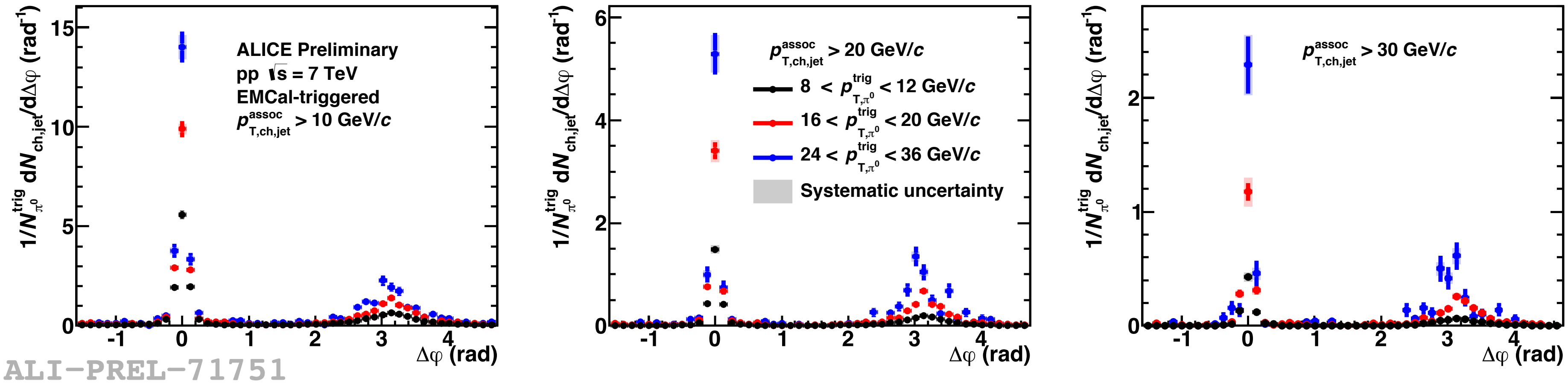




CERN-LHCC-2010-011, ALICE-TDR-014-ADD-1)

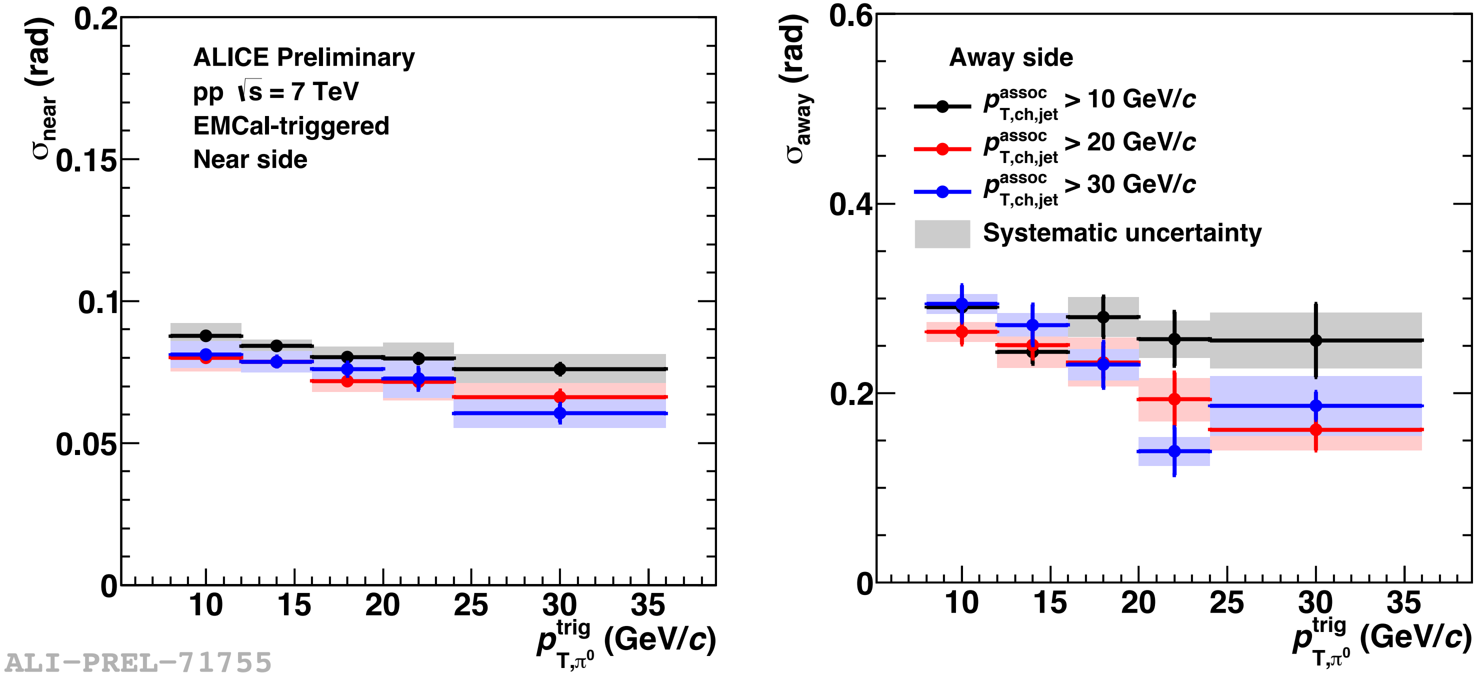
- Trigger on π^0, correlate with charged jets:
  - Control parton path length
  - The higher the p_T of the π^0 the longer the parton path length
- Preliminary pp results @ 7 TeV, Pb-Pb next
- Charged Jet reconstruction:
  - Anti kT, R=0.4
  - p_T^{charge} > 150 MeV/c, p_T^{jet} > 10 GeV/c
  - Jet axis: $|\eta|$<0.5, full azimuth

π^0-jet azimuthal correlations



- 2 clear jet-peaks are observed at near- and away-side
  - π^0 production is correlated with jet-production
  - jet-yields increase with trigger p_T
- Using jets - direct access to jet-modification
  - comparing to π^0-hadron: we may compare jet-matter and hadron-matter interaction influence on π^0 production

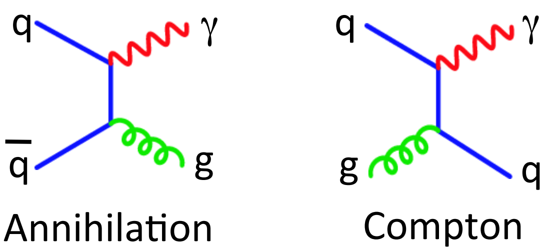
Width of π⁰-jet azimuthal correlations

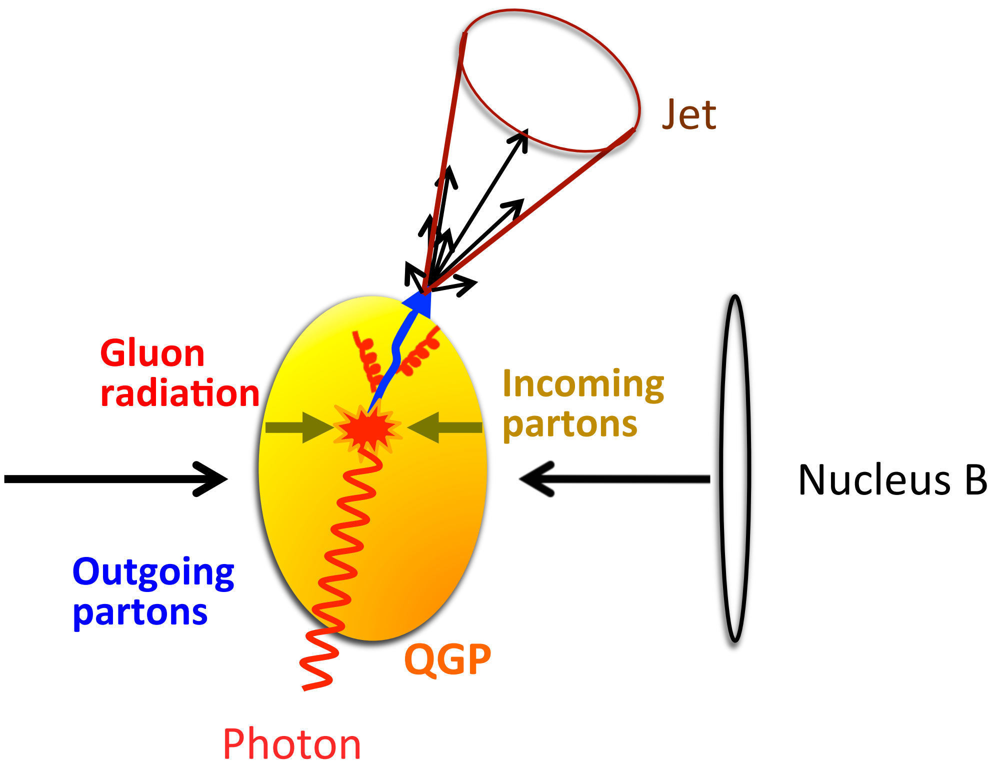


- The widths are decreasing with increasing π^0 p_T,
  - π^0 is produced close to jet-axis
  - π^0 produced in jet-fragmentation
- No clear difference for different jet p_T
- Baseline for Pb–Pb to study modification of π^0 fragmentation in a jet

γ-hadrons correlation

Isolated photon – TPC charged tracks

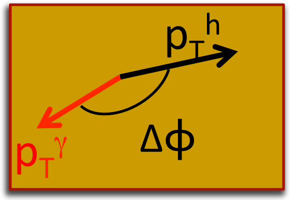




Photon is not modified by the colored medium
Analysis of EMCal triggered data in pp collisions at 7 TeV

See talk from Denise MdG. on gamma-jet correlations in ALICE

Why γ-hadrons correlation



Approximate reconstruction of jet fragmentation function

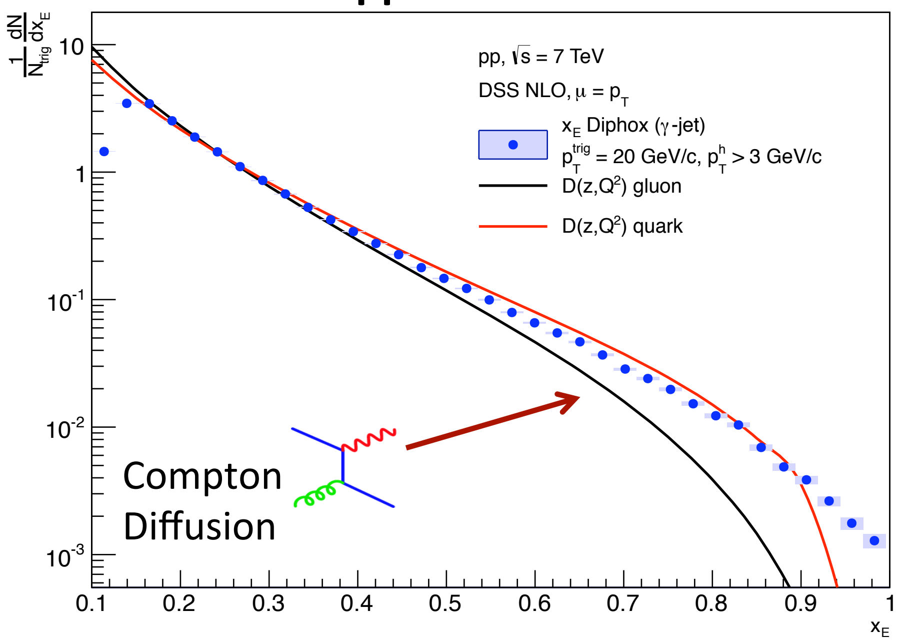
$$x_E = -\frac{p^h{}_T}{p^\gamma{}_T}\cos\Delta\Phi \quad \xrightarrow{p_T^\gamma \approx p_T^{parton}} \quad x_E \approx z_T = \frac{p_T^{hadron}}{p_T^{parton}}$$

cos Δ ϕ → Give more weight to charged hadrons at 180 degrees from trigger

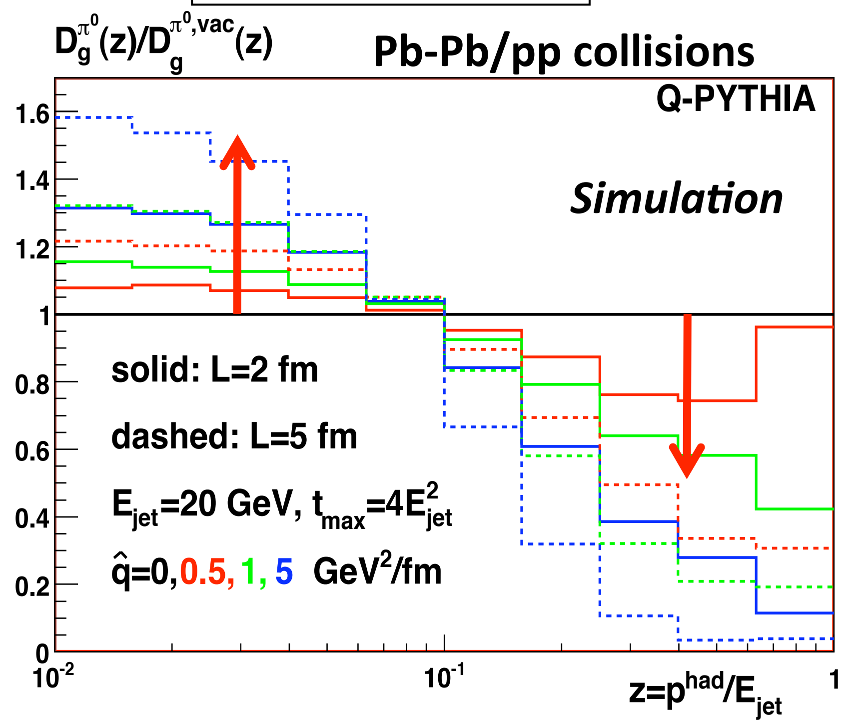
Distribution in x_E :

$$f(x_E) = \frac{1}{N_{photon}}\frac{dN}{dx_E}$$

pp collisions

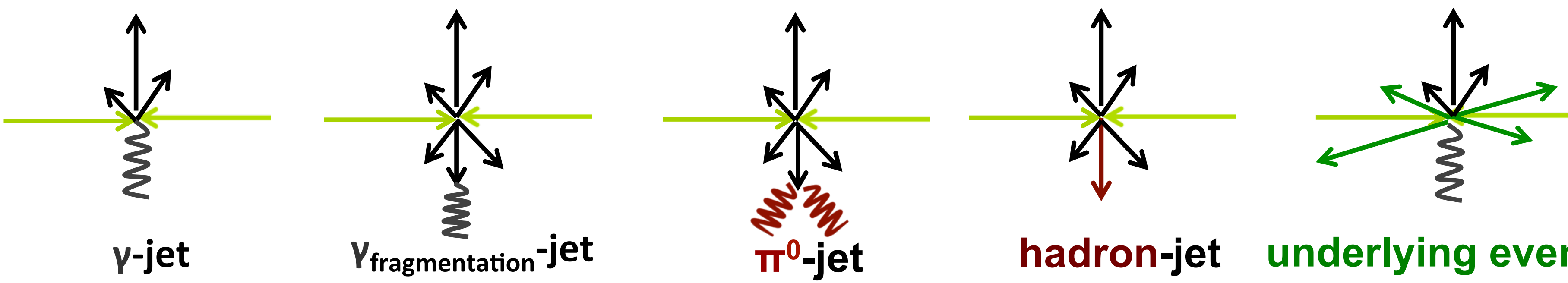


Pb-Pb/pp collisions



γ-hadrons analysis strategy

Inclusive photons clusters | **UE**



Purity : p = S/(S+B)

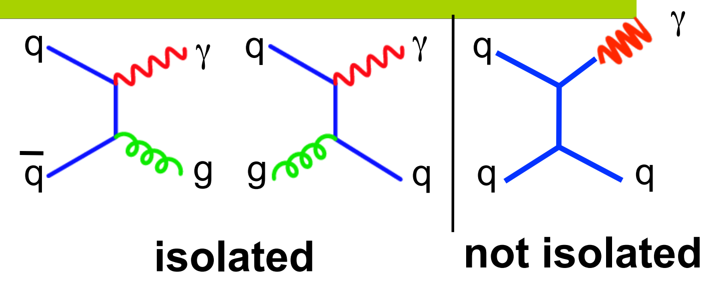
Background (B) dominated by π^0

Signal | **Background** | **UE**

$$f(x_E^{\gamma\ iso}) = \frac{1}{p} f(x_E^{clusters\ iso}) - \frac{(1-p)}{p} f(x_E^{\pi^0\ iso}) - f(x_E^{UE})$$

$x_E^{\pi^0} \approx x_E^{hadron}$

Prompt γ identification in EMCal

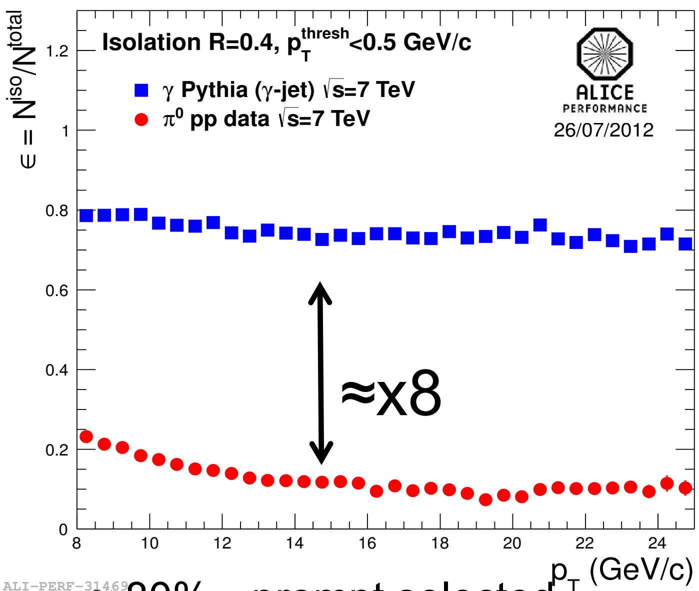


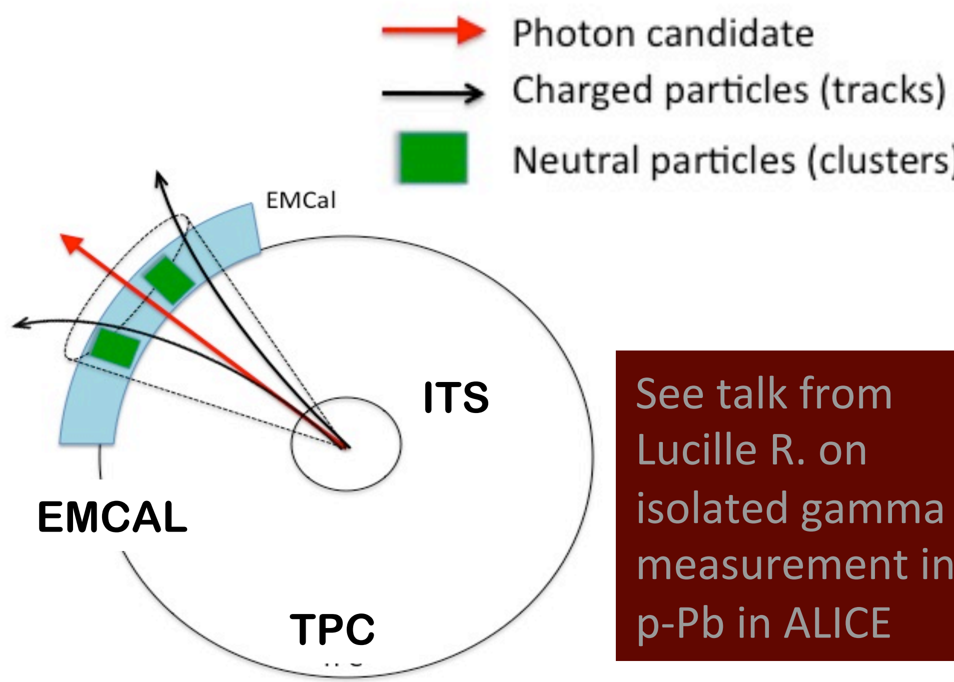
Most direct photons are isolated

While most decay photons are not (jet)

Isolated photons selection:

- Isolation cone radius $R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.4$
- Apply isolation cut on hadronic energy
  - on each particle : $p_T < 0.5$ GeV/c
  - energy sum : $\Sigma p_T < 1$ GeV/c





See talk from Lucille R. on isolated gamma measurement in p-Pb in ALICE

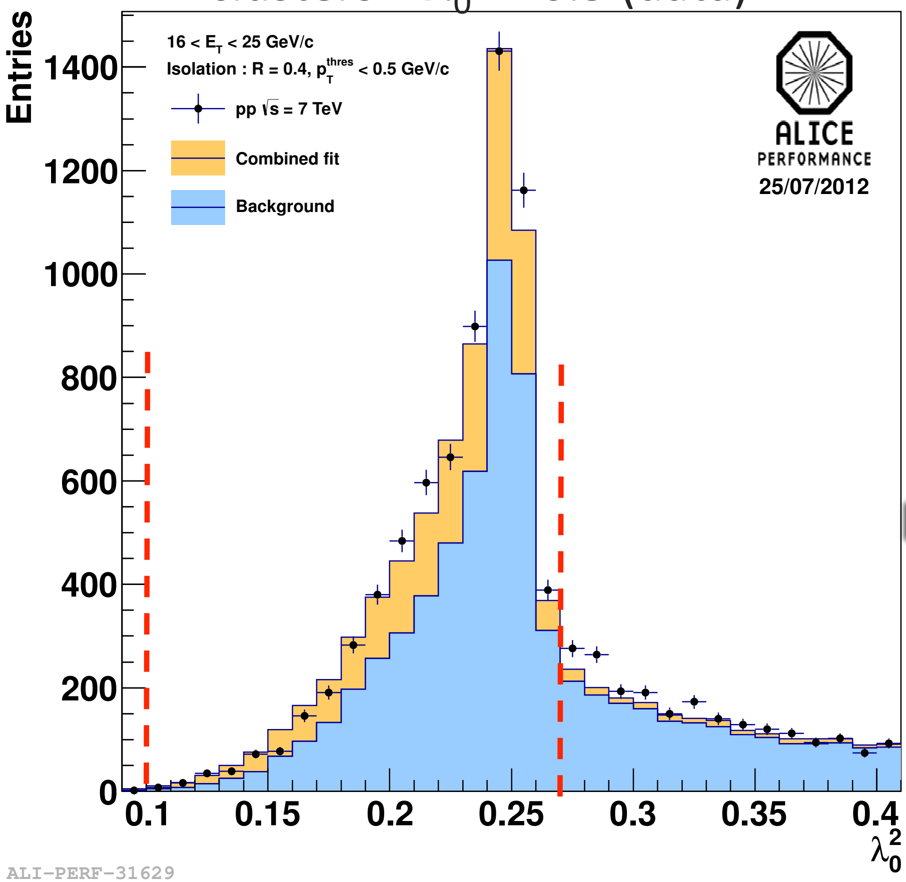
≈ 80% γ prompt selected

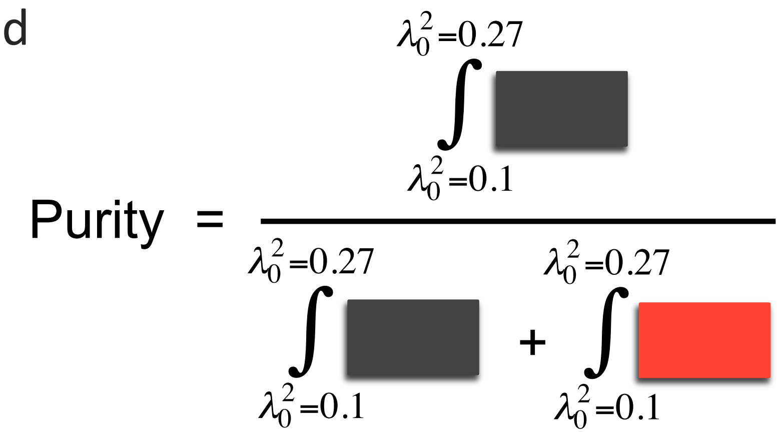
≈ 80% γ from decay rejected → Still a large contribution below 15 GeV/c

Purity

Isolated photons + background clusters

- Binned likelihood fit of the λ_0^2 distributions
  - Template : signal (MC) + background clusters $\lambda_0^2 > 0.5$ (data)



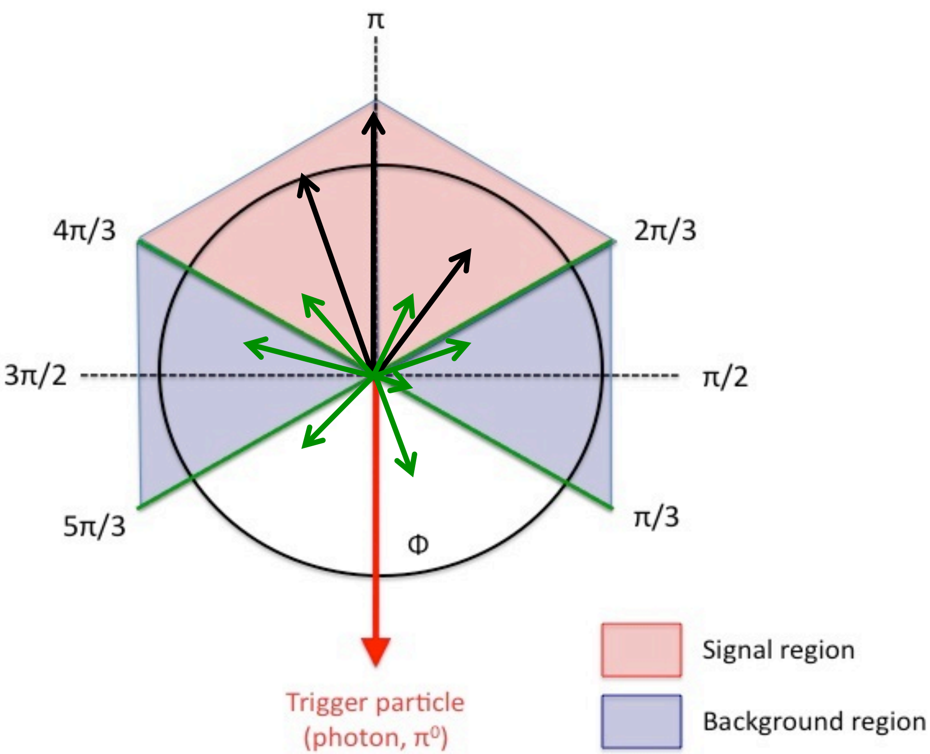


p_T (GeV/c)	Purity
8-12	0.08 ± 0.01
12-16	0.31 ± 0.05
16-25	0.59 ± 0.04

Underlying event (UE)

x_E estimation in 2 regions perpendicular ($\Delta\phi$) to the photon

$$f(x_E^{\gamma}) = \frac{1}{p} f(x_E^{cluster\ iso}) - \frac{(1-p)}{p} f(x_E^{\pi 0\ iso}) - f(x_E^{UE})$$



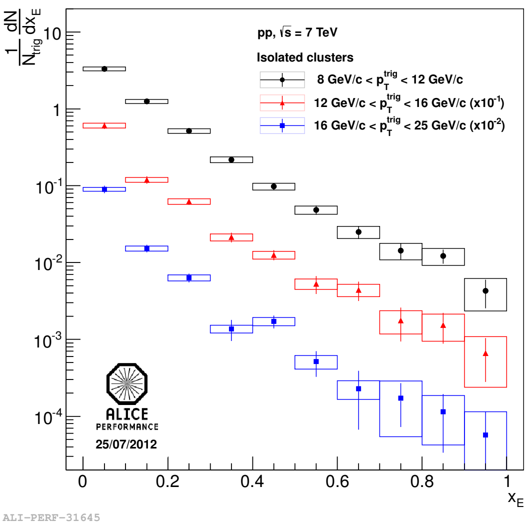
It only affects significantly for x_E<0.2

Nicolas Arbor thesis

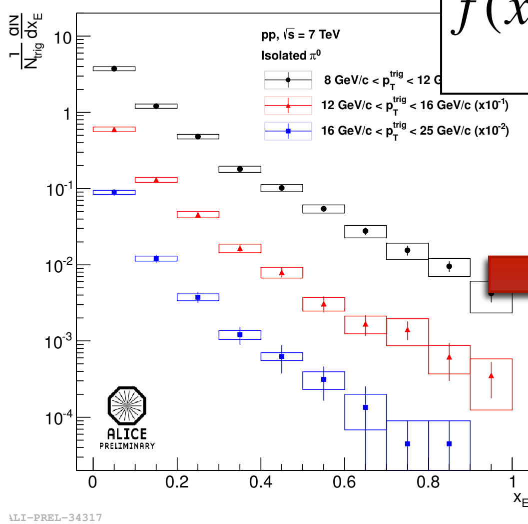
Isolated clusters x_E

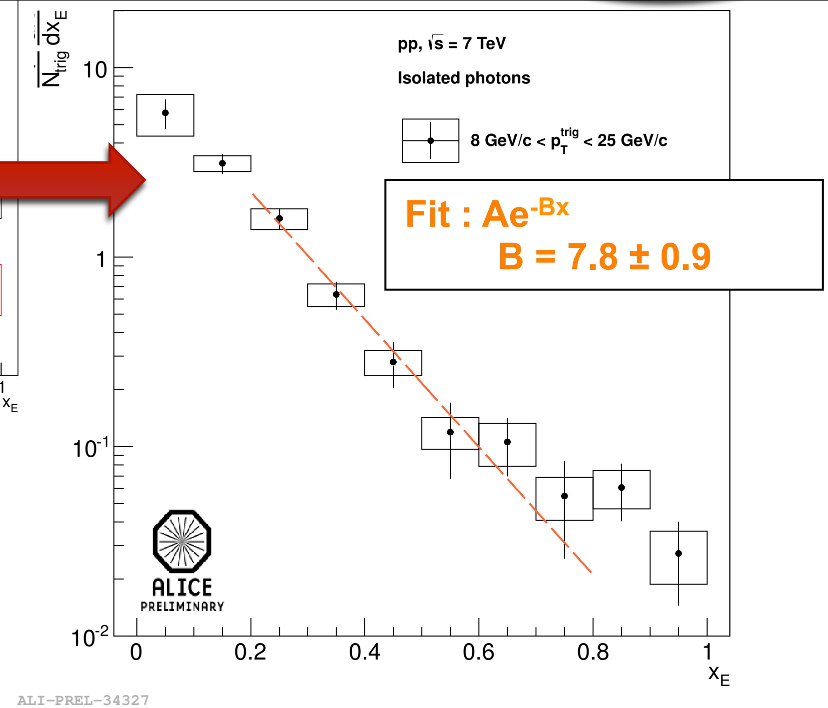
$$f(x_E^{\gamma\ iso}) = \frac{1}{p} f(x_E^{clusters\ iso}) - \frac{(1-p)}{p} f(x_E^{\pi^0\ iso})$$

Isolated cluster



Isolated π^0





- Underlying event subtracted and experimental effects corrected
- Systematics: background (UE), detector correction, purity, π^0-hadron
- Compatible results between π^0-hadron et cluster-hadron ($\lambda_0^2 < 0.27$)

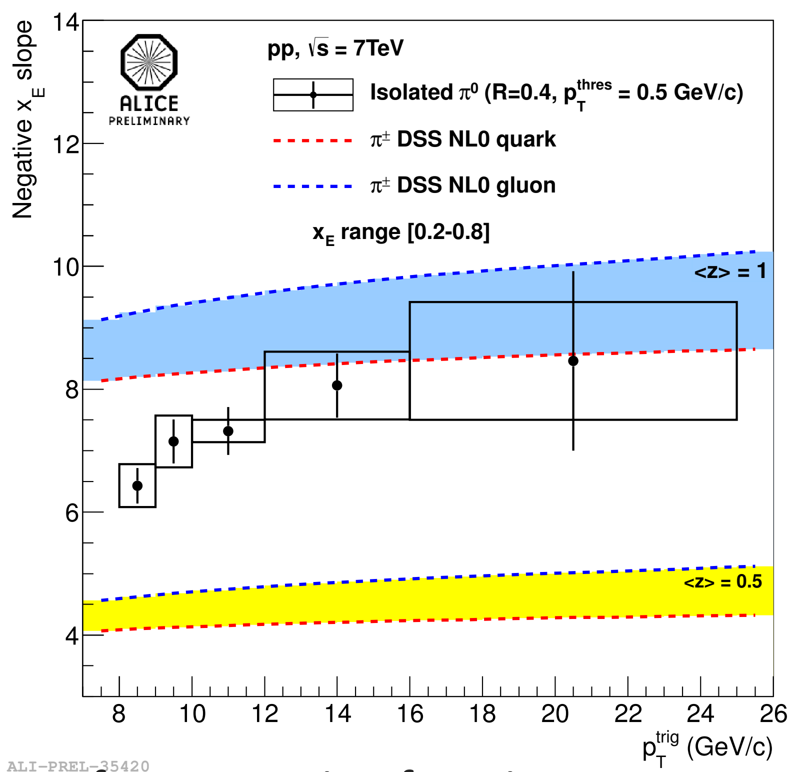
- Main limiting factor, statistics
- Systematic uncertainties and purity are being reevaluated
- **Baseline for Pb-Pb**

Nicolas Arbor thesis

π^o x_E slope

$z = p_T^{trig}/p_T^{parton}$

- π^0 isolated-hadrons



$\langle z \rangle$ photon

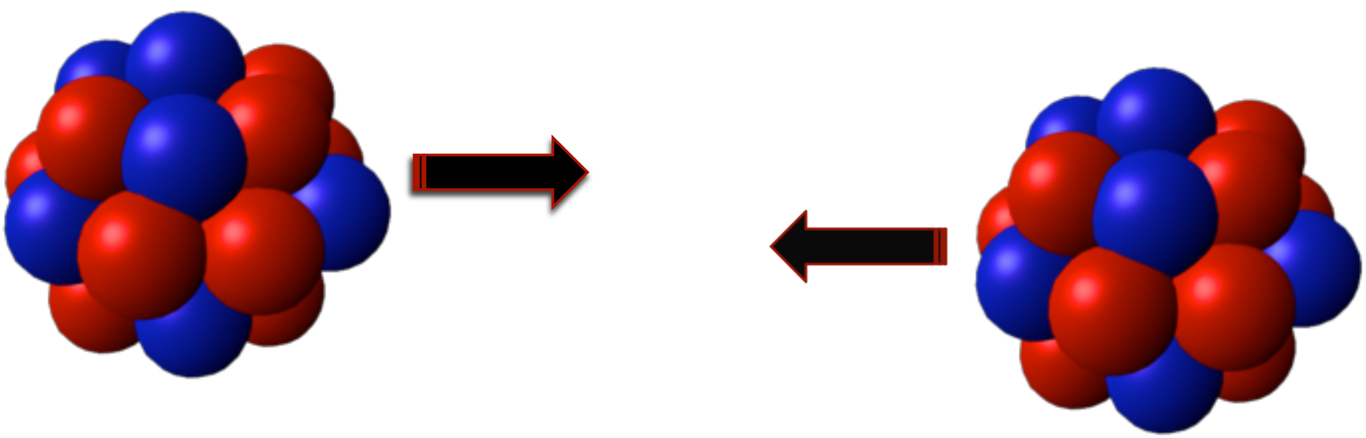
$\langle z \rangle$ π0 iso ≈ 0.8

$\langle z \rangle$ π0 no-iso

- Bands: quark and gluon fragmentation functions
- photon-hadron : slope in agreement with fragmentation function, $\langle z \rangle = 1$
  - Large uncertainties(!!)
- π^0-hadron : slope close to fragmentation functions but deviation visible, $\langle z \rangle < 1$

γ-hadrons correlation in Pb-Pb

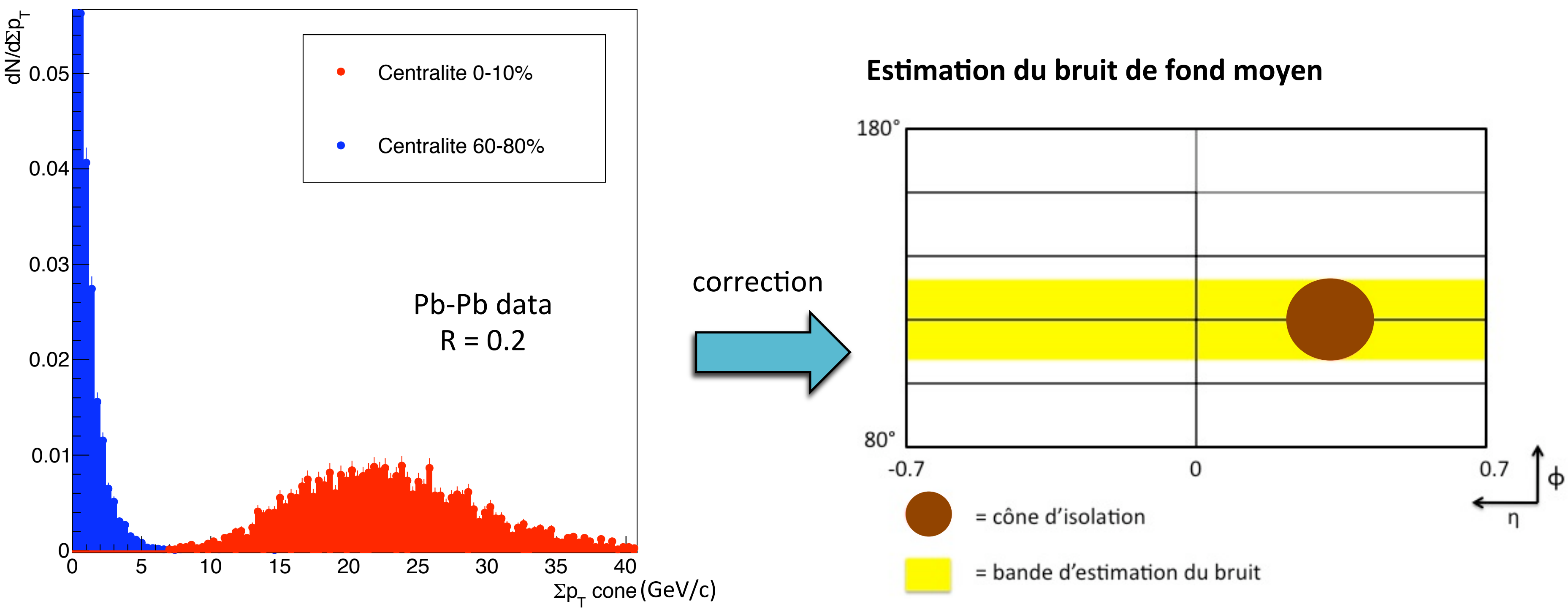
Pb-Pb collisions @ $\sqrt{s_{NN}}$ = 2.76 TeV
A very very preliminary analysis



Triggered EMCal data, 0-10% central

Isolation: background

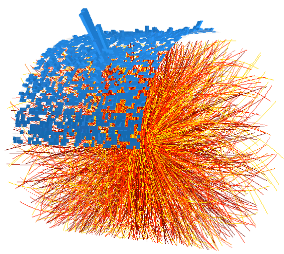
- UE very significant in Pb-Pb collisions
- UE depends strongly on centrality
  - We have to subtract the UE from the isolation cone

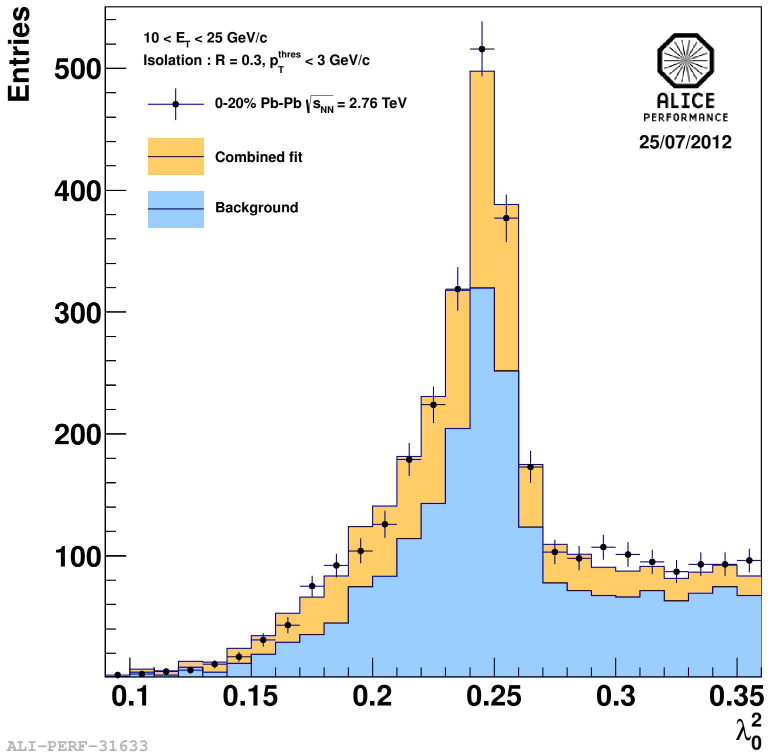


- Chosen parameters for now: R=0.2 and UE subtracted Σp_T < 3 GeV/c
  - ~85% of γ and ~ 20% of the π^0 pass the selection

Purity

- Photon cluster shape similar in pp and central Pb-Pb
  - Apply same selection cut, $\lambda_0^2 < 0.27$
- Estimation of purity in a high multiplicity environment:
  - Prompt photons can be measured





Summary

π^0-hadrons/jets correlation

- ALICE can identify high p_T π^0s with shower shape and splitting techniques
- Di-hadron correlation observations (charged trigger in TPC) confirmed when using π^0 measured with the calorimeter
  - Suppression in the away side
  - Enhancement on the near side
- π^0-jet correlations base line for Pb-Pb established

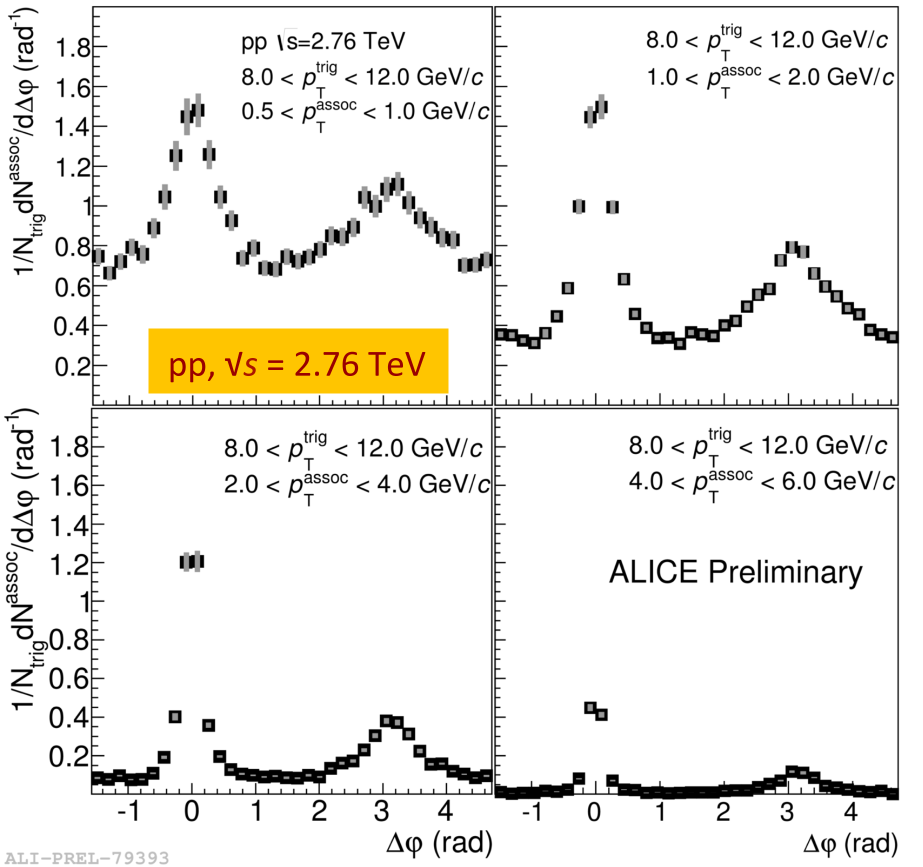
γ-hadrons correlation

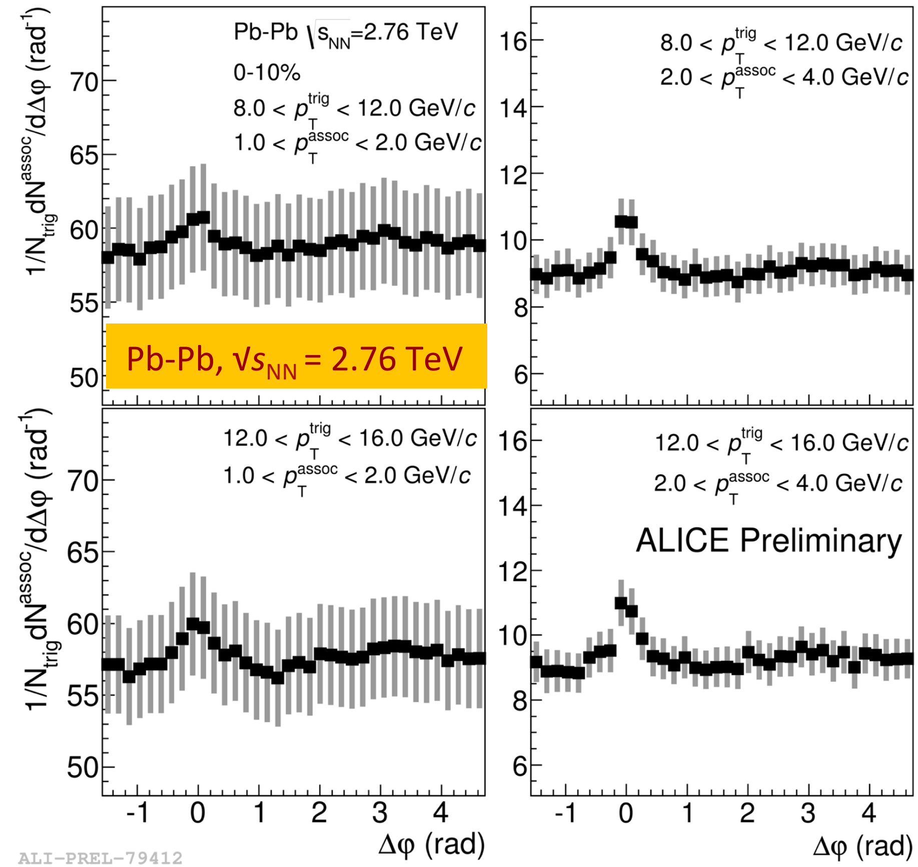
- ALICE can measure prompt photons with shower shape and isolation techniques
- γ-hadron x_E distribution is a measurement of the fragmentation function
- pp baseline is almost ready
- Preliminary Pb-Pb analysis
  - Difficulty of the measurement due to the large UE showed
  - It seems feasible but needs careful studies

π^0-hadron azimuthal correlations

- Trigger on high-p_T π^0 (EMCal)
- Select mostly jets produced in the surface of the fireball
- Correlate with charged hadrons in azimuth

- Near side → close to hadron trigger
- Away side → 180º from hadron trig.

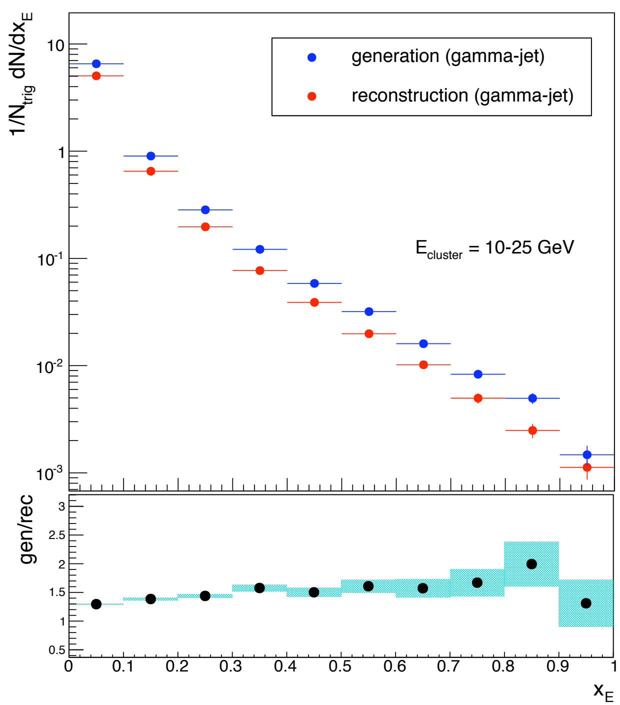




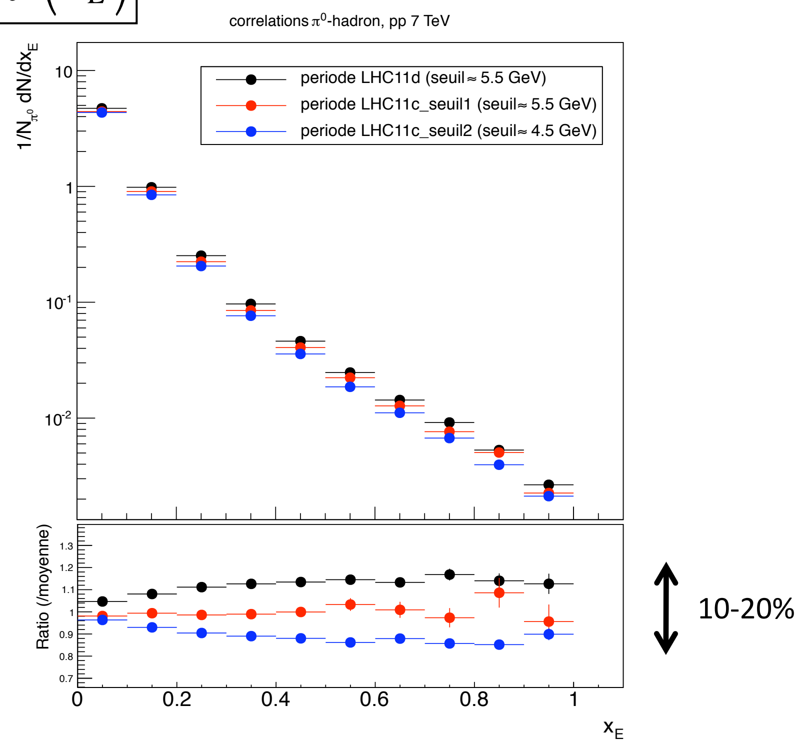
Correction : effets de détecteurs

- Corriger des effets expérimentaux : résolution en énergie (EMCal), efficacité reconstruction traces (TPC, ITS), résolution en impulsion (TPC, ITS)
- Utilisation information Monte-Carlo (avec ou sans effets de détecteurs)
- Incertitudes systématiques : corrections différentes selon la période

$$f\left(x_E^{\gamma}\right)^{corr} = \alpha^{corr} \times f\left(x_E^{\gamma}\right)$$

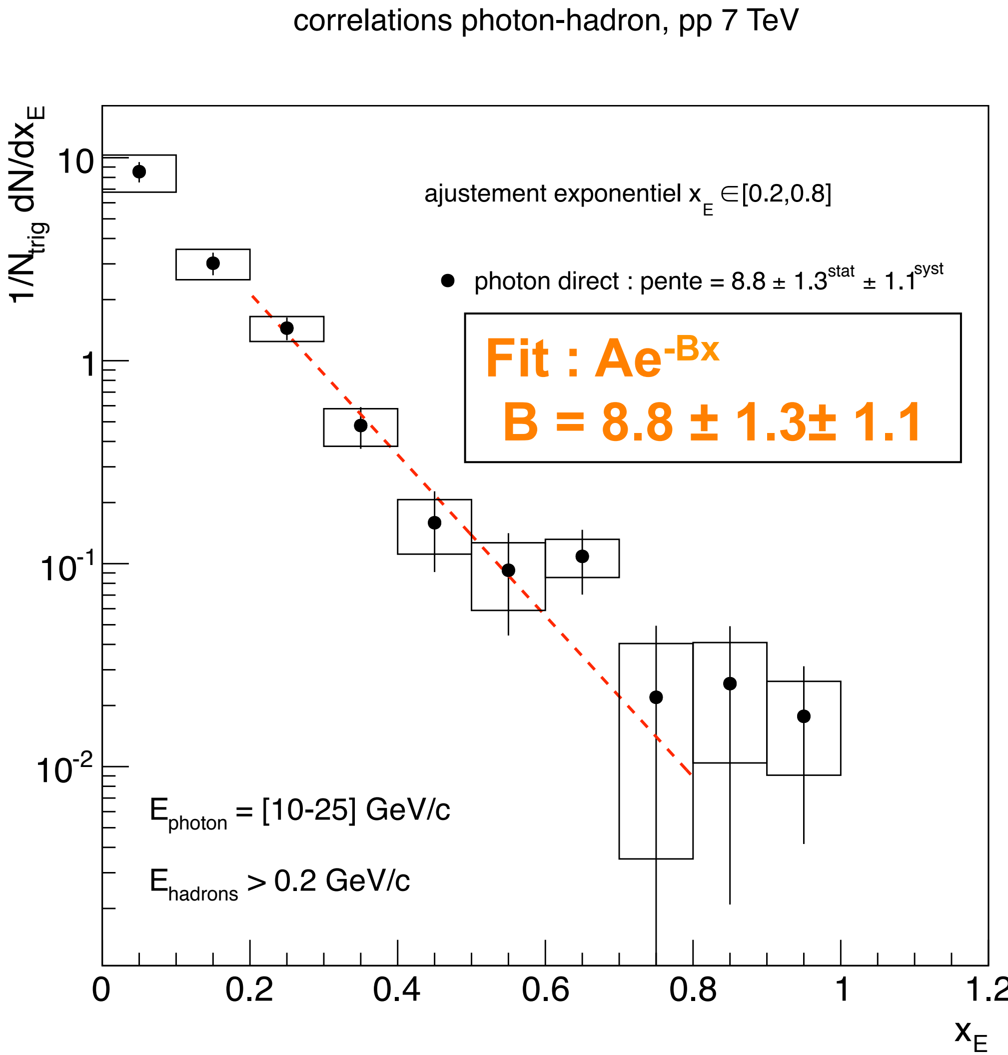


Facteur de correction (α^{corr})



$f(x_E)$ pour différentes périodes

Isolated Photons x_E



Baseline for Pb-Pb

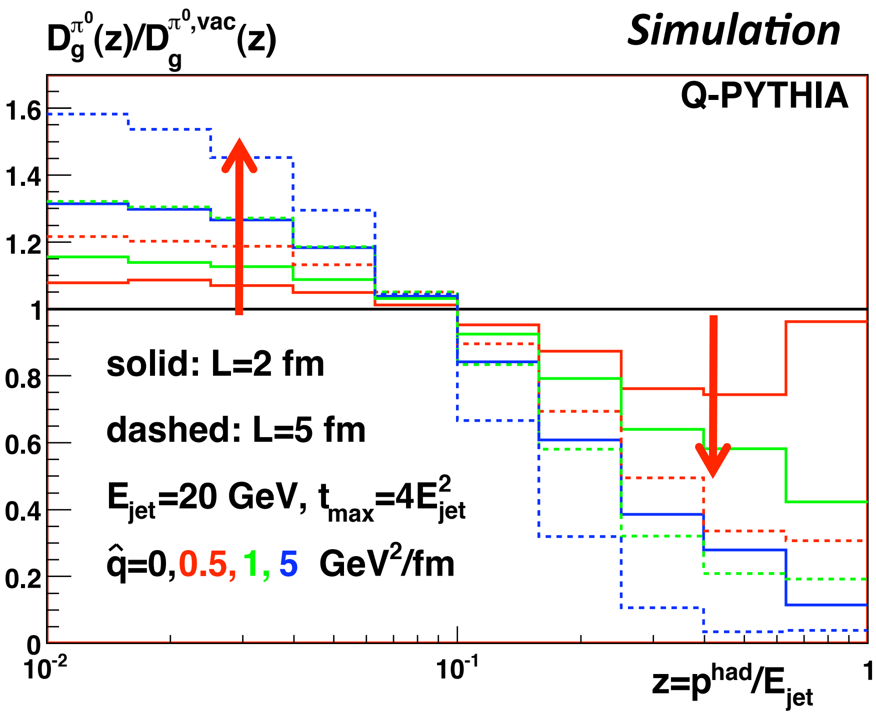
Uncertainties are being reevaluated

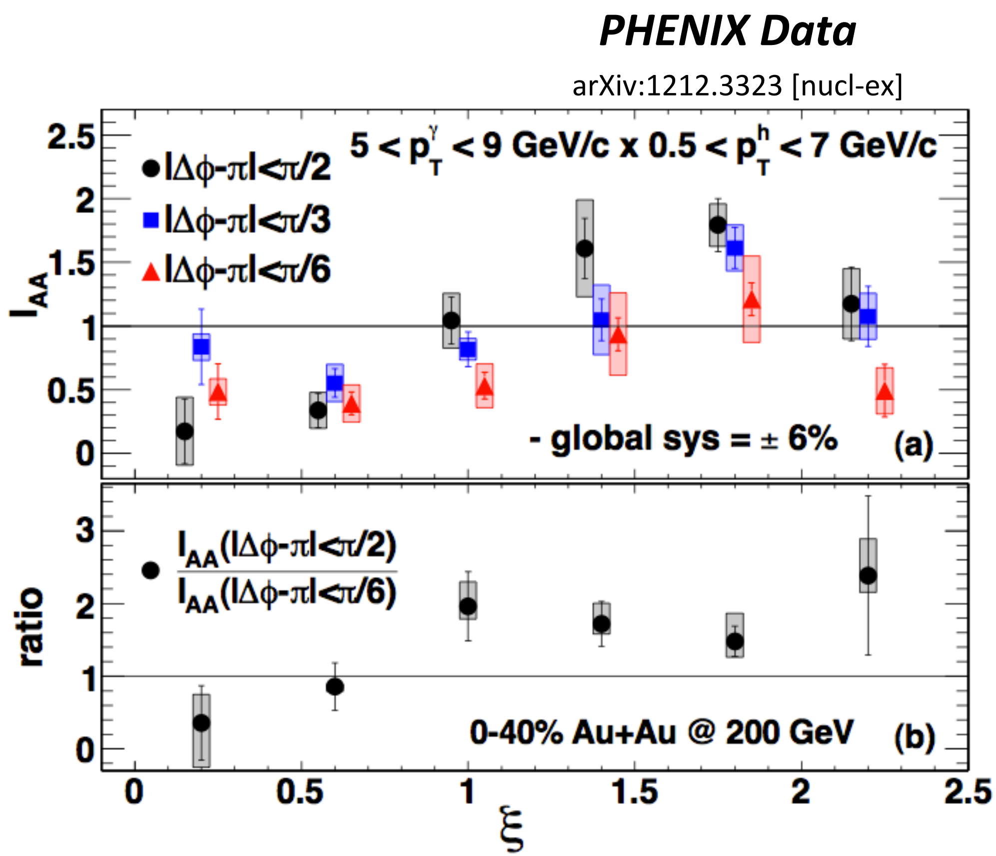
Contributions (%) to total uncertainty

x_E	stat	UE	α_{corr}	purity	π^0
0-0.1	25	<1	57	11	6
0.1-0.2	36	<1	48	5	10
0.2-0.3	45	<1	35	7	12
0.3-0.4	55	<1	24	5	15
0.4-0.5	67	<1	8	4	19
0.5-0.6	68	<1	9	4	19
0.6-0.7	73	<1	7	3	17
0.7-0.8	69	<1	6	4	19
0.8-0.9	70	<1	8	4	17
0.9-1.0	71	<1	10	3	16

Why γ-hadrons correlation

- If medium is present, redistribution of energy expected





We want to do this in ALICE