Isolated photon-hadron correlations analysis in pp collisions at 7 TeV with ALICE at the LHC

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In this presentation

- Motivations
  - Parton energy loss
  - Energy redistribution
  - Energy loss measurement
- Analysis
  - Photons identification
  - Isolated photons purity
  - Underlying event subtraction
- Perspectives

Effects of QGP phase in HIC

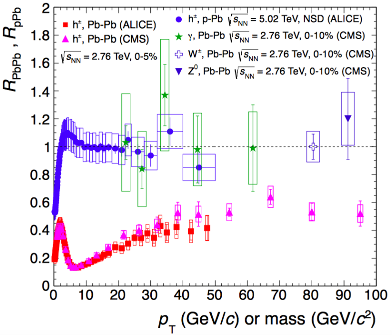
- QGP phase implies final state modification compared to pp collisions (i.e in vacuum)
  - Collective effects
  - Quarkonia melting
  - Suppression of high p_T particles
  - ...
- Aim: probing QGP $\Leftrightarrow$ quantify final state modification to better understand strong interaction in dense matter
- Observable for final state modification:

$$R_{AA} = \frac{\left(\frac{1}{N_{evt}^{AA}}\right)\frac{d^2N_{ch}^{AA}}{d\eta dp_T}}{< N_{coll} > \left(\frac{1}{N_{evt}^{pp}}\right)\frac{d^2N_{ch}^{pp}}{d\eta dp_T}}$$

- $R_{AA} = 1$ if AA collisions = n$\times$ pp collisions

High p_T particles suppression

- Hadrons:
  - suppressed in HIC compared to pp
  - unchanged in pA collisions compared to pp
- Photons, Z and $W^{\pm}$ unchanged

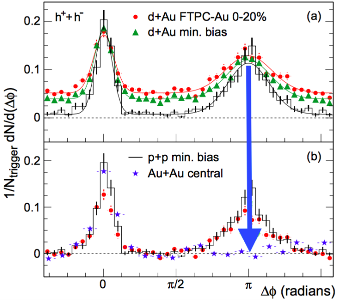


arXiv : 1405.2737

⇒High p_T particles suppression observed due to parton energy loss in medium

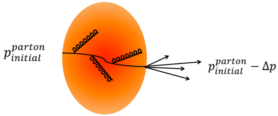
Jet quenching

- Tomographic information:
  - back-to-back jet is suppressed in HIC



PhysRevLett: 91,072304

- Parton loses energy by:
  - gluon radiation (can be dominant)
  - collisions

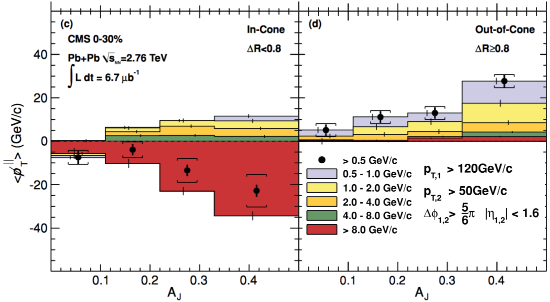


⇒What's the amount of energy lost and where does this energy go ?

Energy redistribution

- From jet analysis (CMS):
  - di-jet momentum imbalance measurement
  - In-cone imbalance corresponds to out-of-cone imbalance

$$\not{p}_T^{||} = \sum_i -p_T^i \cos(\phi_i - \phi_{\text{leading jet}}) \qquad (1)$$



PhysRevC: 84,024906

⇒ Energy is not recovered in the jet cone and is redistributed preferentially with low p_T particles

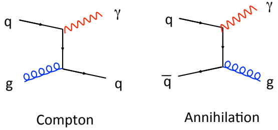
Energy loss measurement: observables

- Until now: proof of parton energy loss in medium
- Interest: quantify parton medium induced energy loss
- Several observables (from basic to subtle):
  - Single particle p_T spectrum (R_{AA}) : do not allow precise measurement of energy loss
  - Di-hadron correlations : biased measurement of initial parton energy
  - γ-hadron correlations : approximation of fragmentation fonction
  - γ-jet correlations : exact measurement of fragmentation function but only for higher p_T

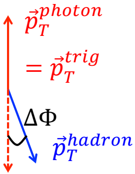
γ-hadron correlations = clean way to measure parton energy redistribution at low p_T

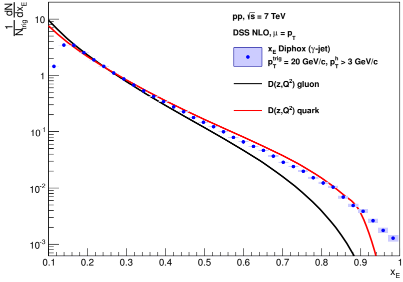
Energy loss measurement: pp reference

- Aim: Measurement of the Fragmentation Function D(z) using γ-jet events produced with hard processes
  - Compton: $q + g \rightarrow \gamma + q$
  - Annihilation: $q + \bar{q} \rightarrow \gamma + g$
- Initial parton energy known: $E^{parton}_{initial} \approx E_{\gamma}$
- Good approximation of the FF with the x_E distribution



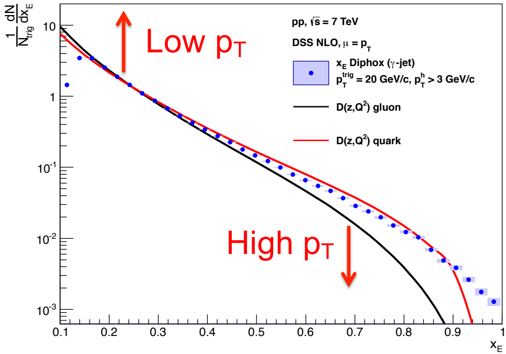
$$x_E = \frac{p_T^{hadron}}{p_T^{trig}} \cos \Delta\phi \approx z \qquad (2)$$





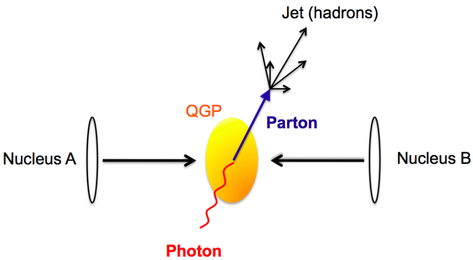
Energy loss measurement in Pb-Pb

- What we expect to see
  - Suppression of high p_T particles production
  - Modification of the x_E distribution depending on the medium properties

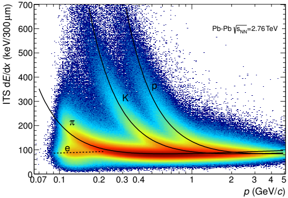


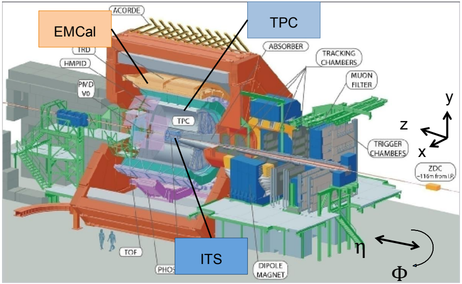
γ-hadron correlations: Method

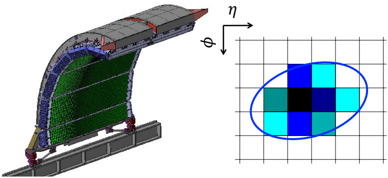
- Obtain the x_E distribution for isolated photons: $f(x_E) = \frac{1}{N^{\gamma}_{trig}} \frac{dN_h}{dx_E}$
- Need to identify:
  - Isolated photons (trigger particles)
  - hadrons coming from the opposite side parton



- ALICE designed for low p_T particles ID
- Charged particles : ITS and TPC
- Neutral particles : EMCal
  - acceptance: $|\eta| < 0{,}7$ et $\Delta\Phi = 107°$
  - Segmentation in lecture units: towers
  - Showers in EMCal = clusters

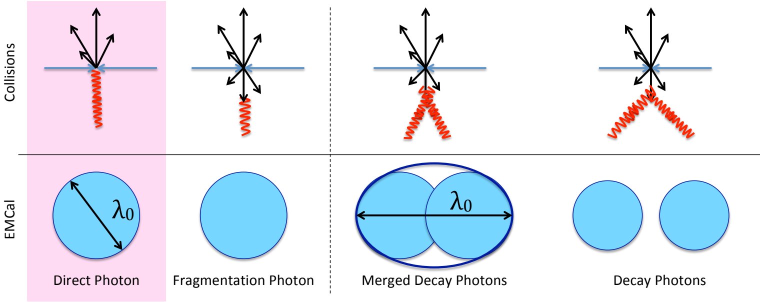






Photons background contributions

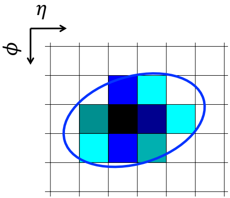
- Direct photons : isolated and circular clusters
- Several background contributions:
  - $\pi^0/\eta \to \gamma\gamma$ (2 photons merged in one single cluster)
  - Decay γ from π^0 or η
  - Fragmentation photons
  - Electrons or hadrons



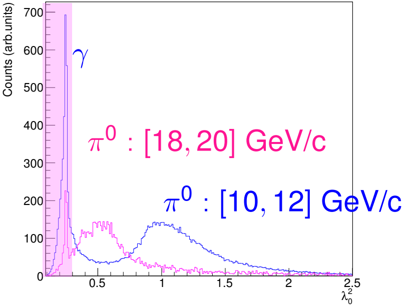
Isolated photons background suppression

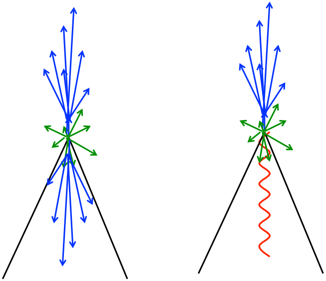
Apply cuts on the reconstructed EMCal clusters:

- Leading particle of the event
- Charged particles veto
- Round-shaped cluster ($\lambda_0^2 \in [0.10, 0.3]$)
- Isolation cut ($p_T^{max} < 0.5$ GeV/c)



After these cuts some contributions remain (at low p_T mostly decay γ)





Isolation Cone

Purity

Remaining background contributions (γ decays) have to be estimated to extract the isolated photons purity

- Purity definition:

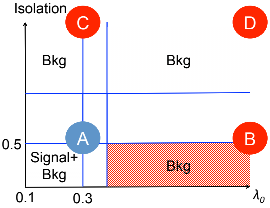
$$p = \frac{\text{direct photons clusters}}{\text{all isolated circular clusters}} = \frac{S_{<}^{isol}}{N_{<}^{isol}} = 1 - \frac{B_{<}^{isol}}{N_{<}^{isol}} \qquad (3)$$

- 2 different methods
  - MC correction method
  - Splitting method

Purity: MC correction method

- First assumption (QM 2012):

$$\frac{B_{<}^{isol}}{B_{<}^{\neq\, isol}} = \frac{B_{>}^{isol}}{B_{>}^{\neq\, isol}} \quad (4)$$



Proportion of isolated clusters is the same at low and high λ_0^2

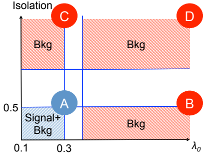
- Wrong assumption: the isolation fractions are NOT the same at low and high λ_0^2
- Try now to correct this purity estimate using:
  - jet-jet simulation: need to have no signal in B, C and D zones

$$p_2 = 1 - \left(\frac{N_{<}^{\neq\, isol}/N_{<}^{isol}}{N_{>}^{\neq\, isol}/N_{>}^{isol}}\right)_{data} \times \left(\frac{N_{<}^{isol}/N_{<}^{\neq isol}}{N_{>}^{isol}/N_{>}^{\neq isol}}\right)_{MC(JJ)} \quad (5)$$

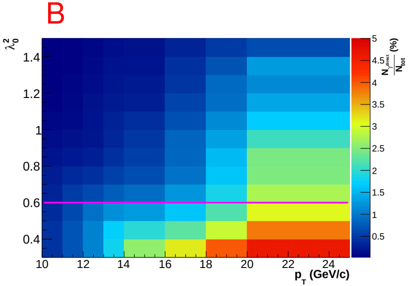
  - gamma-jet + jet-jet simulation: take into account possible signal contamination in B, C and D zones

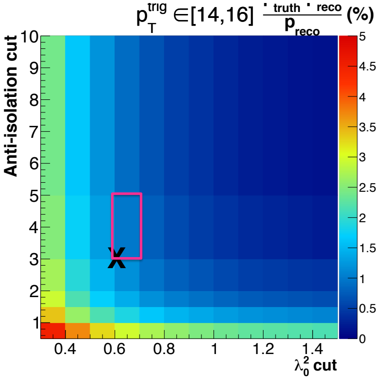
$$p_3 = 1 - \left(\frac{N_{<}^{\neq\, isol}/N_{<}^{isol}}{N_{>}^{\neq\, isol}/N_{>}^{isol}}\right)_{data} \times (1 - p_{MC}^{truth}) \left(\frac{N_{<}^{isol}/N_{<}^{\neq isol}}{N_{>}^{isol}/N_{>}^{\neq isol}}\right)_{MC(GJ+JJ)} \quad (6)$$

Purity: MC correction method results



- Choose proper cuts to define background regions B, C and D for each correction
  - Study signal contamination in B, C and D zones
  - Closure test : small difference between true purity and reconstructed with p_2





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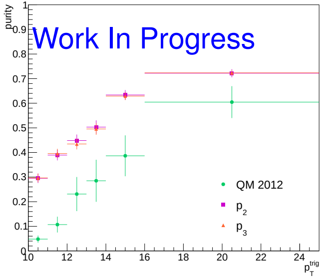
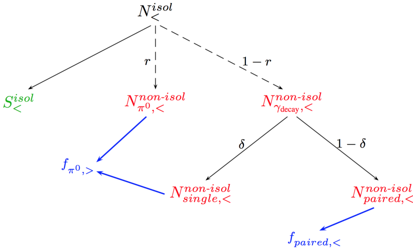


$\Rightarrow$ Both corrections give compatible results with higher purity estimate at low p_T compared to previous result

Purity: Splitting method

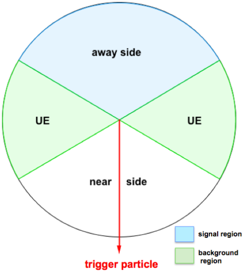
- Better understand background contributions
- Estimate each background contributions:
  - π^0 , η : 2 decay photons are merged in one cluster
  - Paired gamma decay (from π^0 and η): 2 separated clusters in isolation cone
  - Single gamma decay (from π^0 and η): 1 cluster in isolation cone, partner photon is outside the cone or not reconstructed

- Use several parameter to estimate purity:
  - Proportion of species $r^{iso}_{i,<}$ (MC)
  - Isolation fraction $f_{i,<}$ (data)
  - Fraction of single gamma decays δ_i (MC)



Underlying Event (UE) subtraction

- UE: Not all the hadrons of the event are coming from the hard process ⇒ some hadrons have to be disregarded for x_E calculation
- In pp collisions: particles production is isotropic in azimuth ⇒ UE is the same in different ϕ region
- To avoid jet contamination (coming from opposite side parton), UE is estimated in cones orthogonal to trigger particle



x_E distribution

The x_E distribution for isolated photons is defined as:

$$f(x_E)^{\gamma} = \frac{1}{p} f(x_E)^{clusters} - \frac{1-p}{p} f(x_E)^{\pi^0} - f(x_E)^{UE} \quad (7)$$

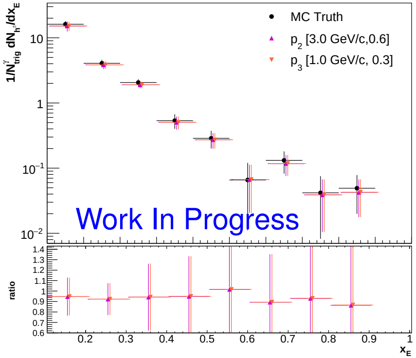
- $f(x_E)^{clusters}$: all isolated and circular clusters
- $f(x_E)^{\pi^0}$: estimated with high λ_0^2 π^0 clusters
- $f(x_E)^{UE}$: estimated in cones orthogonal to trigger particle

x_E distribution: first result

Compare x_E distributions with black one (use true purity from MC)

- p_2: compatible with MC truth
- p_3: compatible with MC truth

No visible difference on x_E when using p_2 or p_3



Slope of x_E distributions is one of the relevant parameter to compare as this is the one used to make comparison with theoretical predictions

$\Rightarrow$ Slopes are compatible

Perspectives: p-Pb and Pb-Pb

- p-Pb:
  - Do not expect differences wrt pp analysis: CNM effects do not affect the fragmentation function
  - Same analysis strategy: use the cones method to estime UE
  - Slope could be compatible with pp result (very preliminary analysis already done)
- Pb-Pb:
  - UE plays a part in:
    - Isolation condition: higher multiplicity ($\approx 10^3$ particles) $\rightarrow$ the UE has to be subtracted event by event to be able to apply isolation cut on trigger particle
    - x_E distribution: UE contribution is estimated assuming ϕ isotropic particle production in pp $\rightarrow$ take into account anisotropic flow for Pb-Pb

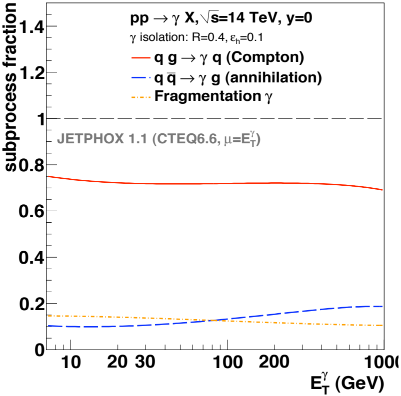
Conclusions

- Isolated photon - hadron correlation is a useful tool to access some medium properties
- The strategy of the analysis has evolved, especially for the purity estimate
- The analysis is still ongoing but almost done in pp collisions
- p-Pb analysis should be very similar to pp one, as shown by the preliminary analysis
- Pb-Pb analysis will require more investigation: the subtraction of the UE and the direct photon identification promise to be challenging

BACK UP

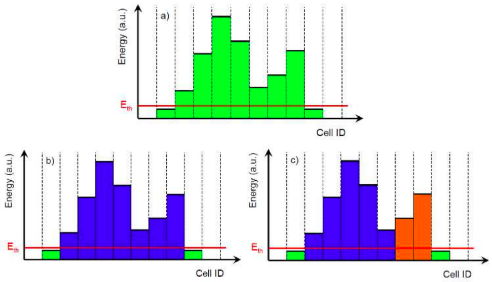
Production fraction of hard processes

Dominant processus : Compton diffusion $\Rightarrow x_E$ distribution slope approximate the quark FF

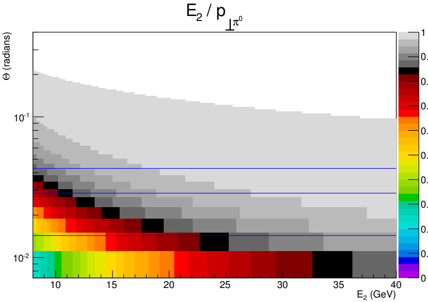


EMCal : clusterization

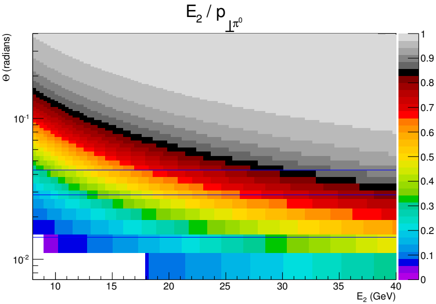
Several types of clusterization to reconstruct particles in EMCal : V1, V2, NxM, V1+Unfolding



Neutral mesons kinematics



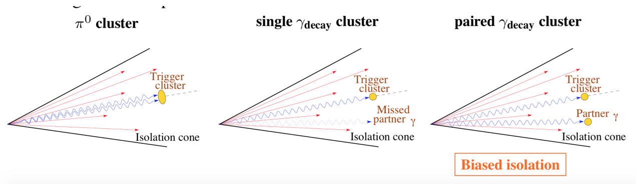
For π^0



For η

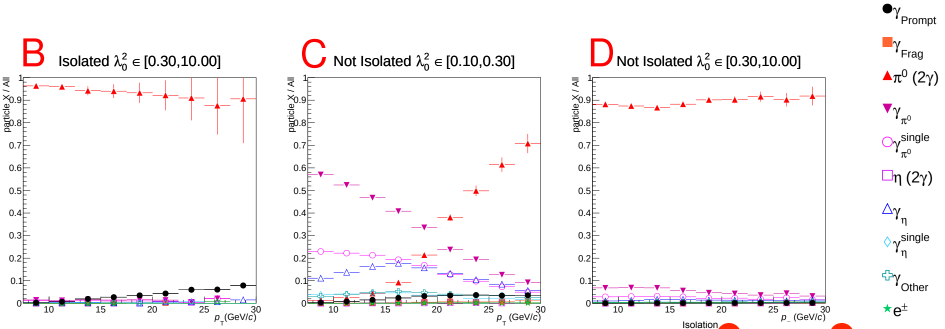
Assumption bias

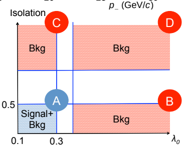
- Paired gamma decays : present only at low λ_0^2
- MCC : at high λ_0^2



Particles proportions

Proportion of each particle type in background zone B, C and D





- zone B : close to 10% (grows with p_T)
- zone C : close to 5% (grows with p_T)
- zone D : close to 0 $\rightarrow$ we neglect signal contribution in this zone

Closure test

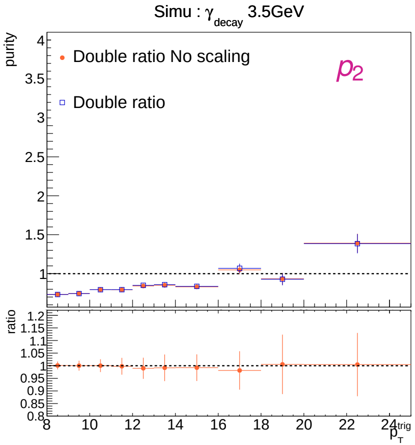
Try to get back to MC truth by replacing data with gamma-jet + jet-jet cocktail

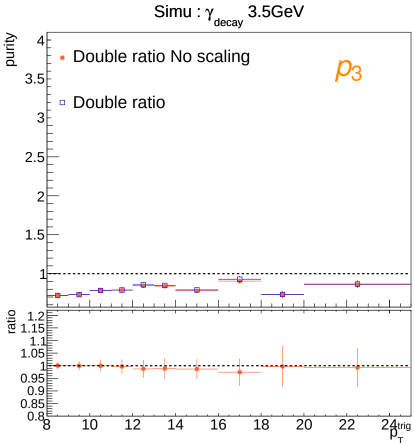
- p_2: $\left(\frac{N_<^{\neq \text{isol}}/N_<^{\text{isol}}}{N_>^{\neq \text{isol}}/N_>^{\text{isol}}}\right)_{data} \rightarrow \left(\frac{N_<^{\neq \text{isol}}/N_<^{\text{isol}}}{N_>^{\neq \text{isol}}/N_>^{\text{isol}}}\right)_{MC_{GJ+JJ}}$

  $p_2 = 1 - \frac{S_<^{isol}}{N_<^{isol}} = p_{MC}^{truth}$
- p_3: $\left(\frac{N_<^{\neq \text{isol}}/N_<^{\text{isol}}}{N_>^{\neq \text{isol}}/N_>^{\text{isol}}}\right)_{data} \rightarrow \left(\frac{N_<^{\neq \text{isol}}/N_<^{\text{isol}}}{N_>^{\neq \text{isol}}/N_>^{\text{isol}}}\right)_{MC_{GJ+JJ}}$

  $p_3 = p_{MC}^{truth}$ by construction

Correction term



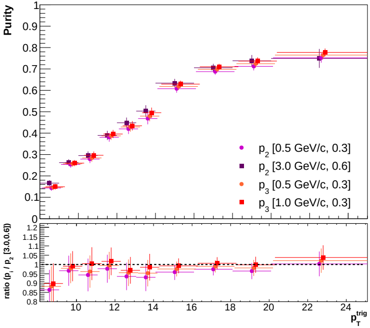


Correction term is close to 1 $\Rightarrow$ the bias is not too big

Comparison p_2 vs p_3

p_3 should be compatible with p_2 if p_3 correctly deal with signal contamination

- p_2 loose cuts: bias due to signal contamination in bkg regions
- p_3 loose cuts: little bias. some hypothesis made for p_3 may break down at low pT
- p_3 standard cuts: compatible with p_2 tight cuts
- p_3 tight cuts (see back-up): quasi-perfect match



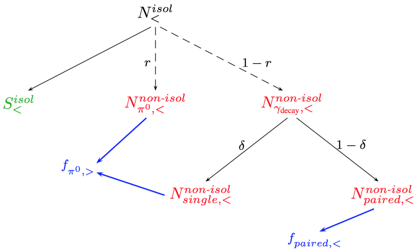
$\Rightarrow$ small discrepancy with p_2 at low p_T : the signal contamination is not perfectly reproduced in GJ+JJ simulation compared to data

$\Rightarrow$ Even with GJ+JJ correction one needs to be careful with the choice of anti-isolation and λ_0^2 cuts

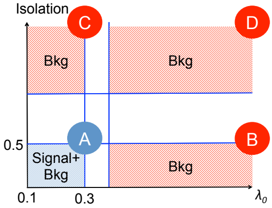
Splitting method : formula

▶ Split the background contributions

- Proportion of species $r^{iso}_{i,<} = N^{iso}_{i,<} / N^{iso}_{tot,<}$ (MC)
- Isolation fraction $f_{i,<} = N^{iso}_{i,<} / N^{iso+\neq iso}_{i,<}$ (data)
- Fraction of single gamma decays $\delta_i = N^{single}_i / N^{single+paired}_i$ (MC)



$$p_4 = 1 - \frac{N^{non\text{-}isol}_{<}}{N^{isol}_{<}} \left[\frac{f^{isol}_{\pi^0,<}}{1 - f^{isol}_{\pi^0,<}} r^{non\text{-}isol}_{\pi^0,<} - \left(\frac{f^{isol}_{single\,\pi^0,<}}{1 - f^{isol}_{single\,\pi^0,<}} \delta_{\pi^0} + \frac{f^{isol}_{paired\,\pi^0,<}}{1 - f^{isol}_{paired\,\pi^0,<}} (1 - \delta_{\pi^0}) \right) r^{\neq isol}_{\gamma_{\pi^0},<} - \left(\frac{f^{isol}_{single\,\eta,<}}{1 - f^{isol}_{single\,\eta,<}} \delta_{\eta} + \frac{f^{isol}_{paired\,\eta,<}}{1 - f^{isol}_{paired\,\eta,<}} (1 - \delta_{\eta}) \right) r^{\neq isol}_{\gamma_{\eta},<} \right] \quad (8)$$



Estimate of UE in Pb-Pb collisions

- High multiplicity : trigger particle never isolated
- Subtract UE, then apply isolation cut
- Estimate in the same ϕ band as the isolation cone