EMCal/DCal calibration
γ-hadron correlations in pp collisions status and outlook

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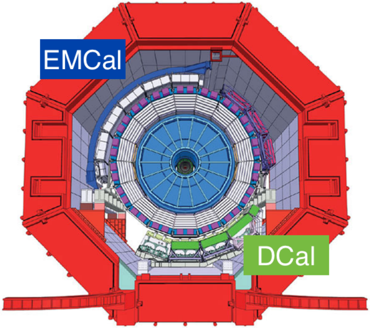
ALICE
A JOURNEY OF DISCOVERY

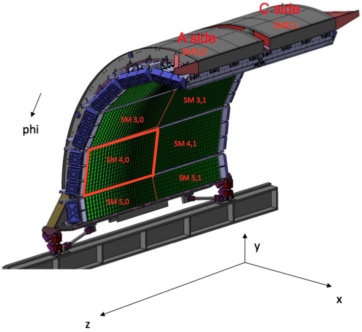
In this presentation

- EMCal/DCal 2015 calibration
  - Status
  - Related studies
- γ-hadron correlations analysis in pp collisions:
  - Physics motivation
  - Results
  - Persepctives

EMCal/DCal detectors

- EMCal and DCal composed of Super Modules (SMs)
- Each SM is composed of towers which are elementary lecture units





EMCal/DCal calibration status

- In-situ energy calibration tower by tower with π^0 invariant mass:
  - Reconstruct π^0 invariant mass distribution for each tower of EMCal and DCal
  - Apply offline coefficients to put fitted π^0 masses at π^0 PDG mass with iterative process

- Few iterations more needed for analyses

EMCal/DCal calibration related studies

- In 2015 largest dataset ever for energy calibration: use this opportunity to better understand EMCal and DCal
- Several tasks have been started:
  - Test the accuracy reachable by the current calibration method - next slides
    - Statistics
    - Systematics
  - Test the stability of the detector
  - Understand large amount of electronic noise observed in 2015 data

EMCal/DCal calibration accuracy (statistics)

- Specification: the calibration has to reach 1% accuracy for each tower
- Find how many events are needed to reach n% of statistical uncertainty on the π^0 mass with the calibration
  - Calibrate one sample and apply coefficients on another one
  - Uncertainty on the fitted mass as a function of tower stat = statistical uncertainty

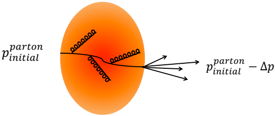
$\Rightarrow$ Aim to obtain a typical SM map with the statistics needed to calibrate all towers with 1% accuracy

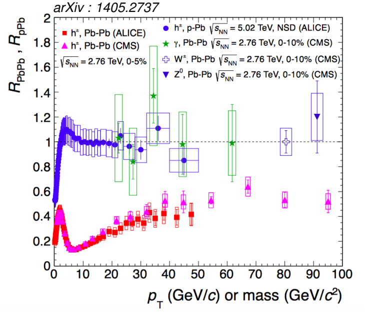
EMCal/DCal calibration accuracy (systematics)

- Test uncertainty coming from different pieces of the calibration procedure:
  - new trigger configuration: compare fitted means with and without new trigger configuration - no bias
  - alignement: compare invariant mass distributions for 2γ in same SM and 2γ in different SMs - bias for DCal
  - combinatorial background shape: compare fitted means after changing bkg shape - no bias

High p_T particles suppression and jet quenching

- QGP phase induces final state modification compared to pp collisions
- High p_T particles suppression observed due to parton energy loss in medium
- Parton loses energy by:
  - gluon radiation
  - collisions



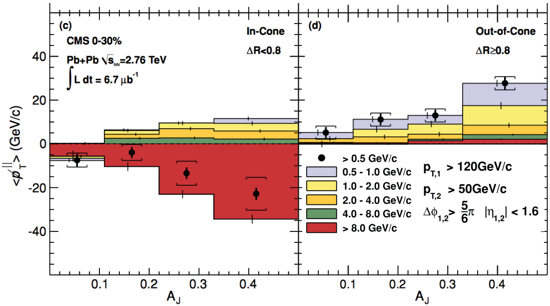


$\Rightarrow$ What's the amount of energy lost and where does this energy go ?

Energy redistribution

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

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



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

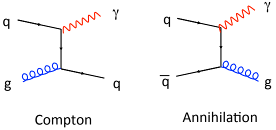
Energy loss measurement: observables

- Until now: proof of parton energy loss in medium
- Need more observables to constrain theoretical models
- Several observables:
  - Single particle p_T spectra (R_{AA}) : do not allow precise measurement of energy loss
  - Di-hadron(jet) correlations : bias on initial parton energy
  - γ-jet correlations : exact measurement of fragmentation function
  - γ-hadron correlations : approximation of fragmentation fonction but possible at lower p_T

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

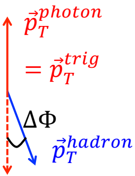
Energy loss measurement: pp reference

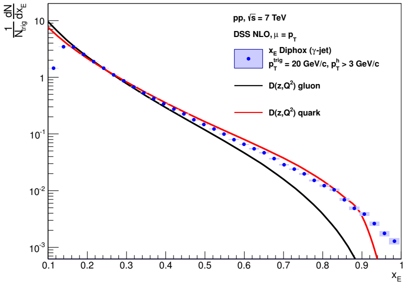
- Aim: Approximate the Fragmentation Function D(z) using γ-jet events produced with hard processes
  - Compton: $q + g \rightarrow \gamma + q$
  - Annihilation: $q + \bar{q} \rightarrow \gamma + g$



- Initial parton energy known: $E_{initial}^{parton} \approx E_{\gamma}$
- Good approximation of the FF with the x_E distribution

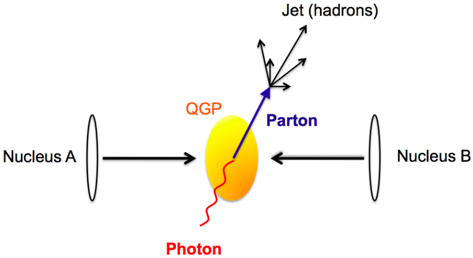
$$x_E = \frac{p_T^{hadron}}{p_T^{trig}} \cos \Delta\phi \approx z \qquad (2)$$





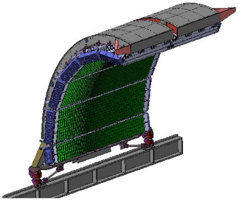
γ-hadron correlation: Method

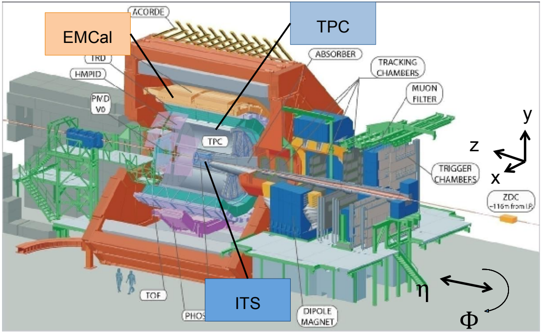
- Obtain the x_E distribution for isolated photons: $f(x_E) = \frac{1}{N^{\gamma}_{trig}} \frac{dN_h}{dx_E}$
- Need to identify:
  - Isolated photons (trigger particles)
  - hadrons coming from the opposite side parton

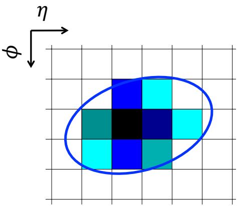


ALICE and EMCal

- 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

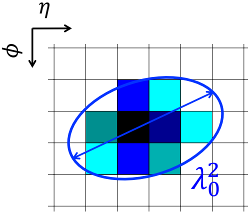


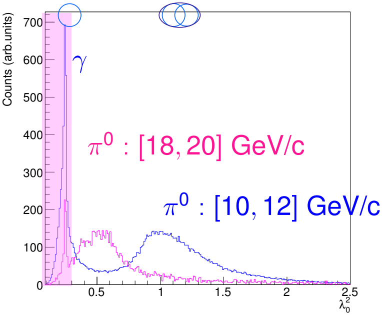


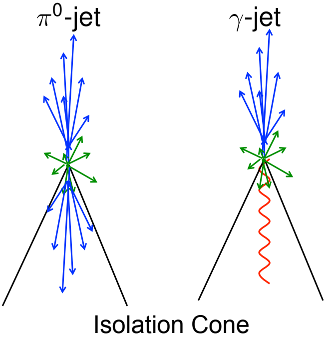


Isolated photons background suppression

- Main background contribution is $\pi^0 \to \gamma\gamma$
- Apply cuts on the reconstructed EMCal clusters:
  - Leading particle of the event
  - Charged particles veto
  - Round-shaped cluster ($\lambda_0^2 \in [0.10, 0.27]$)
  - Isolation cut ($\sum p_{\mathrm{T}}^{\text{in cone}} < 1$ GeV/c)







Isolated photons purity

- After cuts on clusters, background remains $\rightarrow$ purity estimate
- Purity definition:

$$\mathbb{P} = \frac{\text{direct photons clusters}}{\text{all isolated circular clusters}} \tag{3}$$

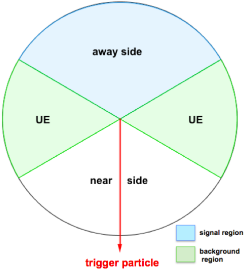
- Two methods to estimate isolated photons purity both using simulation

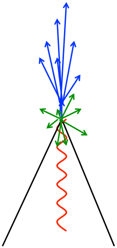
Isolated photons purity: Systematics

- All parameters involved in purity estimate have been variated
- Most of them do not lead to a systematic uncertainty
- Systematic uncertainties come from the discrepancy between data and MC for λ_0^2 (cluster shape) and isolation

Underlying Event (UE) subtraction

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





Isolated photon x_E distribution

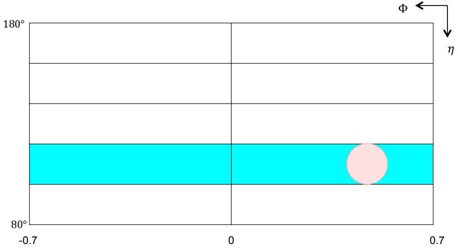
The x_E distribution for isolated photons is defined as:

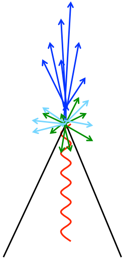
$$f(x_E)^{\gamma} = \alpha_{corr}^{away}\left(\frac{1}{\mathbb{P}}f(x_E)^{clusters} - \frac{1-\mathbb{P}}{\mathbb{P}}f(x_E)^{\pi^0}\right) - \alpha_{corr}^{UE}f(x_E)^{UE} \quad (4)$$

γ-hadron correlations in p-Pb and Pb-Pb (1/2)

Two main issues raise in p-Pb an Pb-Pb collisions :

- The isolation of the trigger particle in high multiplicity environment
  - $\sum p_{\mathrm{T}}^{\text{in cone}} \approx 2$ GeV/c in p-Pb collisions
  - $\sum p_{\mathrm{T}}^{\text{in cone}}$ up to 40 GeV/c in Pb-Pb collisions
  - Estimate in η band around the isolation cone allows to get rid of collective effects

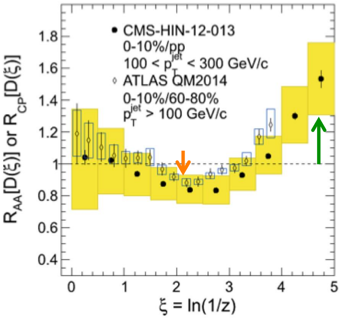


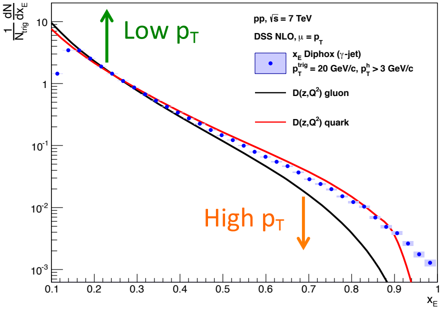


- The subtraction of the UE in the away side
  - Parton energy loss recovered far from the parton axis
    $\rightarrow$ could bias the UE estimate towards high value

γ-hadron correlations in p-Pb and Pb-Pb (2/2)

- What we expect to see
  - No change in p-Pb collisions
  - Modification of the x_E distribution depending on the medium properties in Pb-Pb collisions





⇒ The first bins are the most important

γ-hadron correlations analysis improvement

- With run II data: systematics will be the dominant uncertainties
- Dominant systematic at low x_E comes from purity
- Need to improved purity estimate method:
  - Reach a better agreement between data and Monte-Carlo for λ_0^2 and $\sum p_{\mathrm{T}}^{\text{in cone}}$ distributions
  - Improve isolation method

What future after γ-hadron correlations?

- Numerous measurements will be needed to constrain theoretical models
- γ-hadron correlations is just the beginning: allows to understand UE and isolated photons purity and access plenty of different variables
- Access parton energy loss and energy redistribution with differential studies:
  - Parton energy loss vs energy — run II
  - Parton energy redistribution — run II
    - γ-jet allows to access to other informations than di-jet
  - Medium length dependency — run II
    - Study for different centrality classes
  - Mass and color charge dependency — run III
    - quark vs gluon = γ-jet vs π^0 -jet
    - Will need heavy quark jet tagging

Conclusions

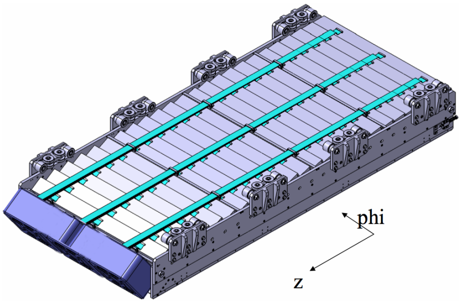
- Better understanding of EMCal and DCal with the estimate of the statistical and systematic uncertainties
- Fragmentation function and parton medium induced energy loss can be approach with γ-hadron correlations
- γ-hadron correlations analysis in pp collisions is close to final
- The two main difficulties of the analysis (purity and UE) are now better understood
- For the future:
  - First step with p-Pb collisions then Pb-Pb collisions
  - Second step: move to all the other observables accessible to probe the QGP

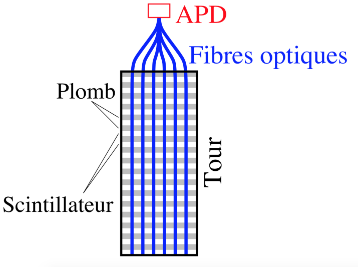
$\Longrightarrow$ Still lots of exiting work to measure parton energy loss and to understand quantitatively the medium induced modification of the fragmentation process

BACK UP

EMCal/DCal segmentation

- EMCal (DCal) = 10 + 2/3 SMs (6 + 2/3)
- 1 SM = 24 stripmodules
- 1 stripmodules = 12 $\times$(2 $\times$ 2) towers





EMCal/DCal energy calibration procedure

Reconstruct π^0 invariant mass for each tower with

$$m_{\pi^0} = \sqrt{2E_1E_2 \times (1 - \cos\theta_{12})} \tag{5}$$

- Combined all clusters from 1 tower with all clusters from the event in the same SM $\rightarrow$ signal + combinatorial background
- Fit the distribution obtained with gauss (signal) + pol2 (bkg)
- Peak position = tower decalibration
- Offline coefficient to correct
- Iterative procedure because of the two photons (i.e. two clusters, towers) involved in m_{π^0}
- Coefficients can be used to recalculate HVs

EMCal/DCal tower gain and HVs

- APD change light from optic fibers to electric signal
- Each APD has a gain which depends on the HVs applied: $G(U) = A + Be^{kU}$
- Changing HVs change APD gain $\rightarrow$ change number of ADC (i.e energy) collected for a same generated light

EMCal/DCal electronic noise

- In 2015 data electronic noise is observed
- Discriminate noise and true π^0 with absolute time cut
- No change with pair difference time cut $\rightarrow$ the electronic noise is correlated
- Energy spectra can help to detect which tower of a duo is the bad one

EMCal/DCal gain variation

- Several peaks observed for the same tower
- Is it due to gain change with time?
- Study on detector stability should answer

EMCal/DCal calibration statistical uncertainty

- Aim: determine fitted mass uncertainty as a function of the number of π^0 for each tower
- Theory: $\sigma_\mu = 1/\sqrt{N_{\pi^0}}$
- But there is combinatorial background
- Method used:
  - Calibrate 1 data sample with few iteration automatically
  - Apply coefficients found on another data sample
  - Extract the fitted mean relative difference between the two samples for tagged good towers
  - Discretize as a function of the average number of π^0

EMCal/DCal new trigger configuration

- New trigger configuration was tested during 2015 calibration data taking
- New configuration allows to populate more at the edges than the center of the SMs
- Aim: be able to calibrate towers that are at the edges of SMs
- Compare fitted mass obtain for flagged good towers with and without the special trigger configuration

$\Rightarrow$ There is no bias observed due to the special trigger

EMCal/DCal background shape bias

- The background is part of the fit used to obtain π^0 mass
- Structure is observed as per the χ^2 of the fit
- Does the mis-reproduction of the background shape by the fit induce a bias in the π^0 mass estimate ?
- Use typical difference between the fit and the real background shape to deteriorate good towers
- Compare the fitted mass between good towers and deteriorated background towers

$\Rightarrow$ Bias smaller than statistical uncertainty observed

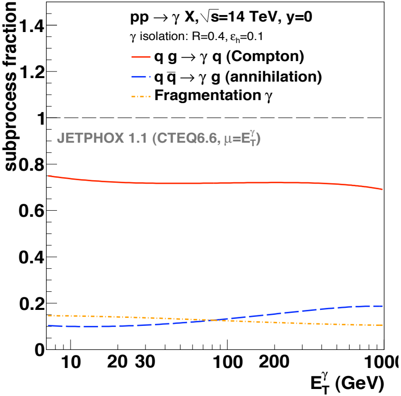
EMCal/DCal alignement

- To avoid any bias from bad SMs alignement the two photons used to build π^0 mass have to be in the same SM
- To collect more statistics at the edges we would like to open up this cut
- Alignement is better for EMCal than DCal
- Compare fitted mass for 2 photons in the same SM and two photons in different SMs

$\Rightarrow$ Bias observed for DCal

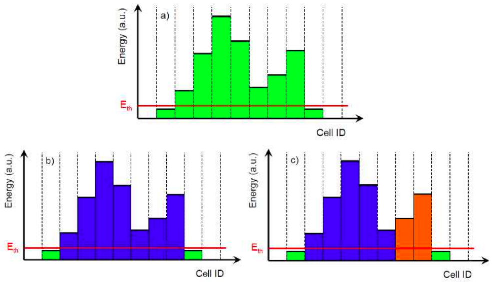
Production fraction of hard processes

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

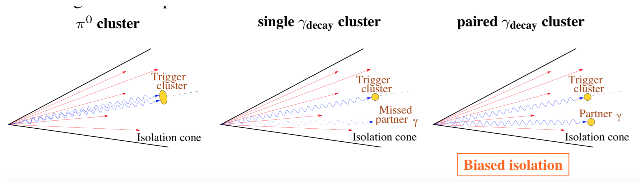
For π^0

For η

$\Rightarrow$ π^0 are asymmetric decays and η are more symmetric

Bias assumption

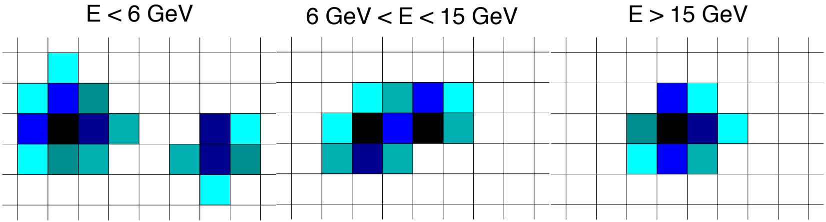
- Paired gamma decays : present only at low λ_0^2
- MCC : at high λ_0^2



Cluster shape

- Cluster shape described by λ_0^2 parameter
- Photons: 1 circular cluster
  $0.1 < \lambda_0^2 < 0.27$
- $\pi^0 \rightarrow \gamma\gamma$ (background for direct photons):
  - E < 6 GeV: 2 circular clusters
  - 6 GeV < E < 15 GeV: 1 elongated cluster
  - E > 15 GeV: 1 almost circular cluster

  Energy dependence for λ_0^2 cuts applied for selecting π^0

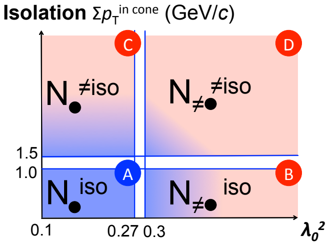


Isolation

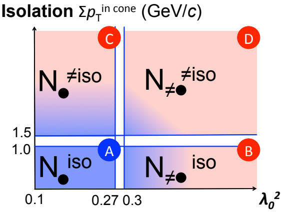
- Measure hadronic activity in isolation cone, with $R = 0.4$, around the cluster candidate
- Direct photons from γ-jet events have to be isolated
- Isolation criteria: $\sum p_{\mathrm{T}} < 1$ GeV/c
- Anti-isolation criteria: $\sum p_{\mathrm{T}} > 1.5$ GeV/c (used for bkg study)

Isolation and λ_0^2 space phase

- Isolation and λ_0^2 cuts divide space phase into 4 areas:
  - A: mainly signal region (isolated photons) + background
  - B, C and D: mainly background regions (π^0) + signal
- Estimate the purity of direct photons in A zone



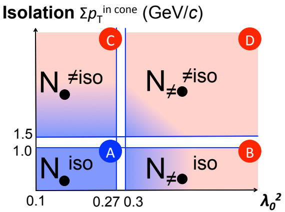
Notations and definitions



- Amount of particles:
  - S: direct photons
  - B: background
    (π^0 , η , gamma decays (π^0 , η), ...)
  - N = S + B
- Isolation criteria:
  - isol: isolation cone activity $\sum p_T < 1$ GeV/c (A, B)
  - $\neq$ isol: isolation cone acitivity $\sum p_T > p_T^{thres}$ (C, D)
- Circularity of the clusters:
  - $\bullet$: round shape cluster $\lambda_0^2 < 0.27$ (A, C)
  - $\neq \bullet$: elliptic cluster $\lambda_0^2 > f^{thres}(p_T^{trig})$ (B, D)
- Purity = number of clusters coming from isolated photons in our isolated and round shape clusters sample

$$\mathbb{P} = \frac{S_\bullet^{isol}}{N_\bullet^{isol}} = 1 - \frac{B_\bullet^{isol}}{N_\bullet^{isol}} \qquad (6)$$

Purity estimate: data method



- Assume background isolation fractions are the same at low and high λ_0^2

$$\frac{B_\bullet^{\text{isol}}/B_\bullet^{\neq\text{ isol}}}{B_{\neq\bullet}^{\text{isol}}/B_{\neq\bullet}^{\neq\text{ isol}}} = 1 \qquad (7)$$

$$\mathbb{P}_1 = 1 - \frac{B_\bullet^{\neq\text{ isol}}/N_\bullet^{\text{isol}}}{B_{\neq\bullet}^{\neq\text{ isol}}/B_{\neq\bullet}^{\text{isol}}} \qquad (8)$$

- The isolation fractions ratio between low and high λ_0^2 deviates significantly from 1 due to the presence of gamma decays and MultiContribution Clusters

$\Rightarrow$ Try now to correct this purity estimate using simulation

Purity estimate: Corrections 1/2

- $\mathbb{P}_2$ using JJ simulation:
  - Assume no signal in background zones
  - Correct only bias from gamma decays and MultiContribution Clusters

$$\left(\frac{B_{\bullet}^{isol}/B_{\bullet}^{\neq isol}}{B_{\neq\bullet}^{isol}/B_{\neq\bullet}^{\neq isol}}\right)_{data} = \left(\frac{B_{\bullet}^{isol}/B_{\bullet}^{\neq isol}}{B_{\neq\bullet}^{isol}/B_{\neq\bullet}^{\neq isol}}\right)_{MC(JJ)} \tag{9}$$

Replacing $B_{\bullet}^{isol}$ in $\mathbb{P}$:

$$\mathbb{P}_2 = 1 - \left(\frac{B_{\bullet}^{\neq\text{ isol}}/N_{\bullet}^{\text{isol}}}{B_{\neq\bullet}^{\neq\text{ isol}}/B_{\neq\bullet}^{\text{isol}}}\right)_{data} \times \left(\frac{B_{\bullet}^{isol}/B_{\bullet}^{\neq isol}}{B_{\neq\bullet}^{isol}/B_{\neq\bullet}^{\neq isol}}\right)_{MC(JJ)} \tag{10}$$

$\mathbb{P}_2$ hypothesis 1: No signal in B, C and D zones 1/2

- Closure test: check difference between $\mathbb{P}^{truth}_{MC}$ and $\mathbb{P}_{reco}$
- $\mathbb{P}_{reco}$: found by replacing data term in $\mathbb{P}_2$ with a GJ + JJ simulation
- If no signal in B, C and D zones: $p_{reco} = p^{truth}_{MC}$

$$\mathbb{P}_{2,reco} = 1 - \left(\frac{B^{\neq \text{ isol}}_{\bullet} / B^{\text{isol}}_{\bullet}}{B^{\neq \text{ isol}}_{\neq\bullet} / B^{\text{isol}}_{\neq\bullet}} \right)_{GJ+JJ} \times \left(\frac{B^{isol}_{\bullet} / B^{\neq isol}_{\bullet}}{B^{isol}_{\neq\bullet} / B^{\neq isol}_{\neq\bullet}} \right)_{MC(JJ)} \tag{11}$$

Purity estimate: Corrections 2/2

- $\mathbb{P}_3$ using GJ+JJ simulation:
  - Correction of $\mathbb{P}_2$: take into account signal in background region
  - $B_i^j = \mathscr{C}_i^j \times N_i^j$

$$\left(\frac{B_{\bullet}^{isol} / B_{\bullet}^{\neq isol}}{B_{\neq\bullet}^{isol} / B_{\neq\bullet}^{\neq isol}}\right)_{data} = \left(\frac{B_{\bullet}^{isol} / B_{\bullet}^{\neq isol}}{B_{\neq\bullet}^{isol} / B_{\neq\bullet}^{\neq isol}}\right)_{MC(GJ+JJ)} \text{ and } \left(\frac{\mathscr{C}_{\neq\bullet}^{\neq isol}}{\mathscr{C}_{\bullet}^{\neq isol}\mathscr{C}_{\neq\bullet}^{isol}}\right)_{data} = \left(\frac{\mathscr{C}_{\neq\bullet}^{\neq isol}}{\mathscr{C}_{\bullet}^{\neq isol}\mathscr{C}_{\neq\bullet}^{isol}}\right)_{MC(GJ+JJ)} \quad (12)$$

$$\Leftrightarrow \left(\frac{B_{\bullet}^{isol} / N_{\bullet}^{\neq isol}}{N_{\neq\bullet}^{isol} / N_{\neq\bullet}^{\neq isol}}\right)_{data} = \left(\frac{B_{\bullet}^{isol} / N_{\bullet}^{\neq isol}}{N_{\neq\bullet}^{isol} / N_{\neq\bullet}^{\neq isol}}\right)_{MC(GJ+JJ)} \quad (13)$$

Replacing $B_{\bullet}^{isol}$ in $\mathbb{P}$:

$$\mathbb{P}_3 = 1 - \left(\frac{N_{\bullet}^{\neq\, isol} / N_{\bullet}^{isol}}{N_{\neq\bullet}^{\neq\, isol} / N_{\neq\bullet}^{isol}}\right)_{data} \times \left(\frac{B_{\bullet}^{isol} / N_{\bullet}^{\neq isol}}{N_{\neq\bullet}^{isol} / N_{\neq\bullet}^{\neq isol}}\right)_{MC(GJ+JJ)} \quad (14)$$

- $\mathbb{P}_3$ will be used for final purity estimate while signal contamination reproduction will be tested with $\mathbb{P}_2$

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

$\mathbb{P}_3$ results in data

- Two JJ simulations are available:
  - γ_{decay} $p_T > 3.5$ GeV/c in EMCal: valid in all analysis p_T range
  - γ_{decay} $p_T > 7$ GeV/c in EMCal: unbiased only after 16 GeV/c
- Apply the GJ+JJ correction anti-isolation cut at 1.5 GeV/c and high λ_0^2 cut at 0.3 on data and simulation

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$\Rightarrow$ Purity grows from almost 30% at 10 GeV/c to 80% at high p_T

Cross check with p2

- $\mathbb{P}_3$ should be compatible with $\mathbb{P}_2$ if the signal contamination is properly reproduce
- Compare $\mathbb{P}_3$ with $\mathbb{P}_2$ with no signal in background region (see backup and presentation *here*)

- $\mathbb{P}_2$ [1 GeV/c,0.3]: bias due to signal contamination in bkg regions
- $\mathbb{P}_3$ [1 GeV/c, 0.3]: little bias
- $\mathbb{P}_3$ [1.5 GeV/c,0.3]: compatible with $\mathbb{P}_2$ tight cuts

$\Rightarrow$No signal contamination bias for $\mathbb{P}_3$ with our set of cuts

Systematics sources

The systematic uncertainties come from hypotheses made for $\mathbb{P}_3$:

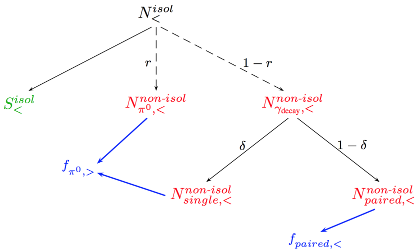
$$\left(\frac{B^{isol}_{\bullet} / B^{\neq isol}_{\bullet}}{B^{isol}_{\neq\bullet} / B^{\neq isol}_{\neq\bullet}}\right)_{data} = \left(\frac{B^{isol}_{\bullet} / B^{\neq isol}_{\bullet}}{B^{isol}_{\neq\bullet} / B^{\neq isol}_{\neq\bullet}}\right)_{MC(GJ+JJ)} \text{ and } \left(\frac{\mathscr{C}^{\neq isol}_{\neq\bullet}}{\mathscr{C}^{\neq isol}_{\bullet}\,\mathscr{C}^{isol}_{\neq\bullet}}\right)_{data} = \left(\frac{\mathscr{C}^{\neq isol}_{\neq\bullet}}{\mathscr{C}^{\neq isol}_{\bullet}\,\mathscr{C}^{isol}_{\neq\bullet}}\right)_{MC(GJ+JJ)} \tag{15}$$

- Signal proportion in GJ+JJ simulation: 0.5 to 1 %
- Smearing (see backup and presentation *here*) of λ_0^2 in simulation ($\mathscr{C}^{isol}_{\neq\bullet}$): 1 to 1.5 %
- Sensibility to $\mathscr{C}^{\neq isol}_{\bullet}$: $\leq$ 0.5 %
- Uncertainties on background isolation fractions ratio: $\leq$ 8%

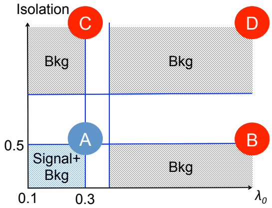
Splitting method : formula

- 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 $\delta_i = N_i^{single} / N_i^{single+paired}$ (MC)



$$p_4 = 1 - \frac{N^{non\text{-}isol}_{<}}{N^{isol}_{<}} \left[\frac{f^{isol}_{\pi^0,<}}{1 - f^{isol}_{\pi^0,<}} r^{non\text{-}isol}_{\pi^0,<} - \left(\frac{f^{isol}_{single\pi^0,<}}{1 - f^{isol}_{single\pi^0,<}} \delta_{\pi^0} + \frac{f^{isol}_{paired\pi^0,<}}{1 - f^{isol}_{paired\pi^0,<}} (1 - \delta_{\pi^0}) \right) r^{\neq isol}_{\gamma_{\pi^0},<} - \left(\frac{f^{isol}_{single\eta,<}}{1 - f^{isol}_{single\eta,<}} \delta_{\eta} + \frac{f^{isol}_{paired\eta,<}}{1 - f^{isol}_{paired\eta,<}} (1 - \delta_{\eta}) \right) r^{\neq isol}_{\gamma_{\eta},<} \right] \quad (16)$$



π^0 x_E systematics: α^i_{corr}

Propagate analytically uncertainties on α^i_{corr} to x_E distribution

Parton energy loss

$$\Delta E \approx \alpha_s C_R \hat{q} L^2 \quad (17)$$

where

- C_R is the Casimir factor (3/4 for q, 3 for g)
- $\hat{q}$ is the medium transport coefficient
- L is the le