γ-hadrons correlation in pp collisions at $\sqrt{s}$ = 7 TeV with ALICE at the LHC

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ALICE
A JOURNEY OF DISCOVERY

In this presentation

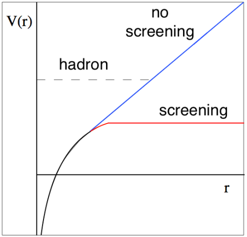
- Physics motivations
- ALICE experiment
- Analysis strategy and status
- Conclusions and outlook


$\rightarrow$ my work

Diving into the theory ...

- Standard model: describes elementary particles and their interactions
- Quantum Chromo-Dynamics (QCD): strong interaction between partons (i.e. quarks or gluons)
- Interaction potential between partons: $V(r) = -\frac{A(r)}{r} + Kr$
  - small r: "weak" interaction $\rightarrow$ asymptotic freedom
  - large r: second term is dominant $\rightarrow$ confinement in hadrons
- Color screening: appears at high color charge density $\rightarrow$ the partons are not confined anymore

$\Rightarrow$ Quark and Gluon Plasma (QGP)

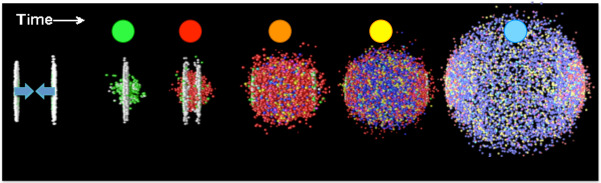


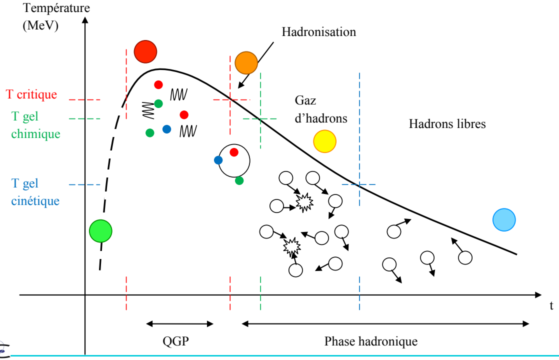
QGP in practice

- Phase transition predicted at T $\approx$ 175 MeV et $\epsilon \approx$ 5 GeV/fm^3 (0.4 GeV/fm^3 for hadronic matter)
- But what is QGP ?
  - Hot and deconfined medium
  - In thermodynamical equilibrium
  - In a defined volume
  - State of the universe $\approx$ 1 μs after the Big Bang
- Now accessible with accelerators (LHC, RHIC) through ultra relativistic heavy-ion (Pb or Au) collisions

Heavy ion collisions: the evolution

Björken scenario:

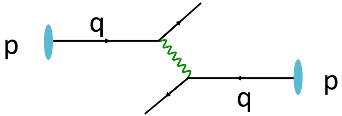




- Pre equilibrium : hard processes
- QGP phase : violent expansion
- Hadronisation : kinetic and chemical freeze-out

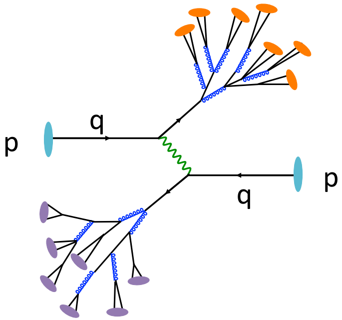
Parton fragmentation and jet

- Hard process: very high energy taking part in interaction



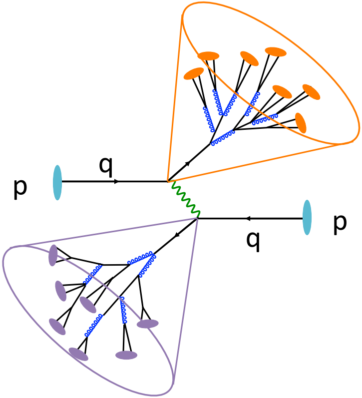
Parton fragmentation and jet

- Hard process: very high energy taking part in interaction
- Fragmentation: described by the fragmentation function D(z).
  $z = p_T^{\text{hadron}} / p_T^{\text{parton}}$



Parton fragmentation and jet

- Hard process: very high energy taking part in interaction
- Fragmentation: described by the fragmentation function D(z).
  $z = p_T^{\text{hadron}} / p_T^{\text{parton}}$
- Jet: hadrons form a particles jet in a finite size cone



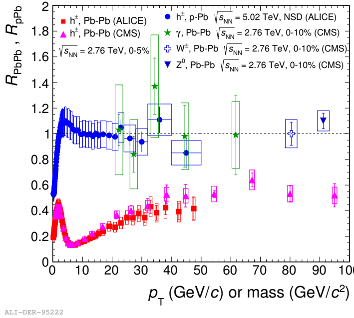
Effects due to QGP phase

- QGP phase implies final state modifications compared to pp collisions (i.e in vacuum)

- Relevant observable: Nuclear modification factor

$$R_{AA} = \frac{N_{AA}}{<N_{coll}> \times N_{pp}}$$

- R_{AA} = 1: γ, Z/W$^{\pm}$
- R_{AA} < 1: hadrons



⇒High p_T particles suppression is attributed to parton energy loss in QGP

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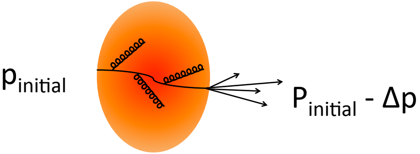
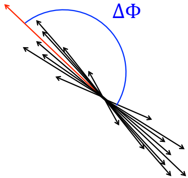
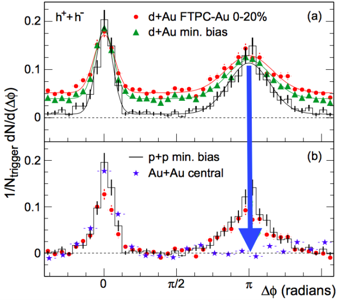


$\Rightarrow$ High p_T particles suppression is attributed to parton energy loss in QGP

Jet quenching

- Angular distribution between particles
- Recoiling jet is suppressed in heavy ion collisions





PhysRevLett: 91,072304
(results from RHIC)

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

Jet quenching

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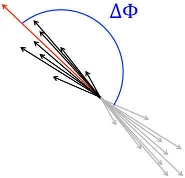
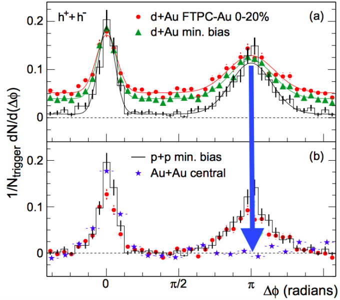
- Recoiling jet is suppressed in heavy ion collisions





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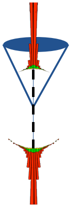
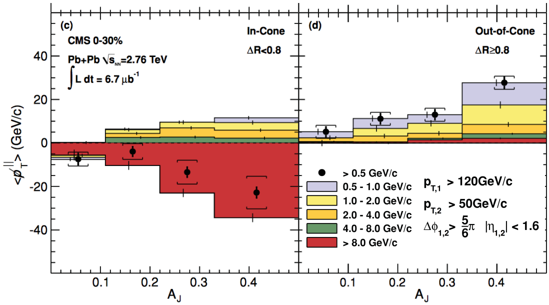
⇒What's the amount of energy lost and where does this energy go ?

Energy redistribution

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

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





PhysRevC: 84,024906

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

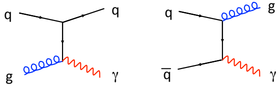
Energy loss measurement: observable

- Until now: proof of parton energy loss in medium
- Interest: quantify parton medium induced energy loss

γ-hadrons correlations = clean way to measure parton energy redistribution at low p_{T}

Energy loss measurement: pp reference

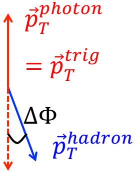
- Aim: Measurement of the Fragmentation Function D(z) using γ-jet events produced with hard processes
  - Compton: $q + g \rightarrow \gamma + q$
  - Annihilation: $q + \bar{q} \rightarrow \gamma + g$

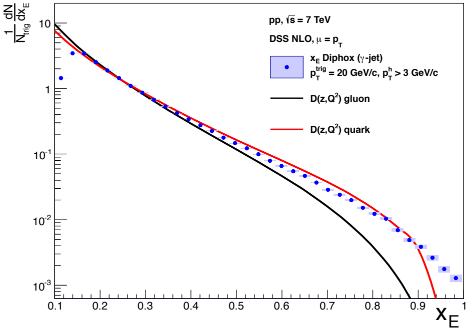


Compton　　Annihilation

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

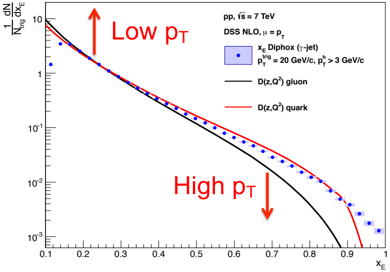
$$x_E = \frac{p_T^{hadron}}{p_T^{trig}} \cos \Delta\phi \approx z \qquad (2)$$

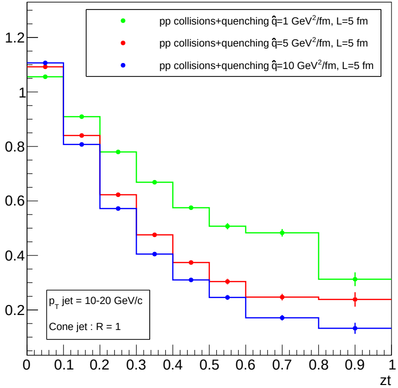




Energy loss measurement in Pb-Pb

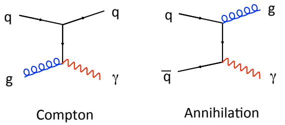
- What we expect to see
  - Suppression of high p_T particles
  - Modification of the x_E distribution depending on the medium properties

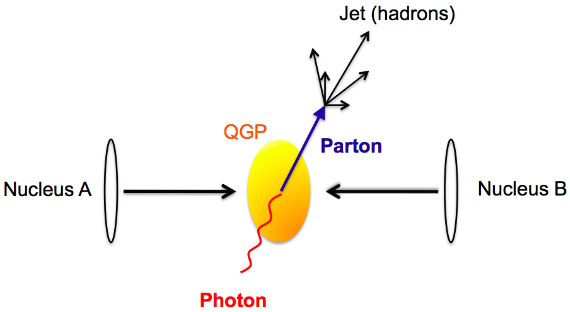




γ-hadrons correlations: Method

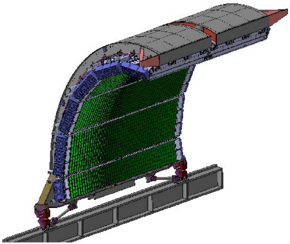
- Obtain the x_E distribution for isolated photons: $f(x_E) = \frac{1}{N^{\gamma}_{trig}} \frac{dN_h}{dx_E}$
- Need to identify:
  - Isolated photons (trigger particles)
  - hadrons coming from the opposite side parton fragmentation

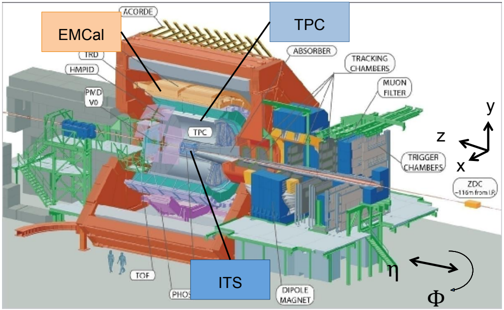


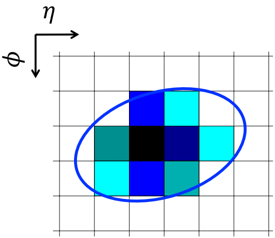


ALICE and EMCal

- 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 (0.014 $\times$ 0.014 rad)
  - Showers in EMCal = clusters

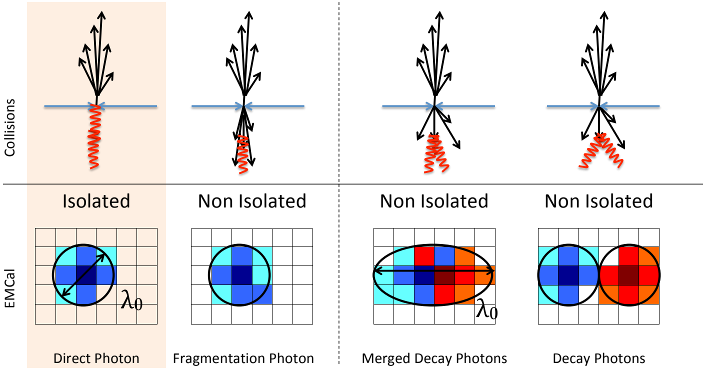






Photons background contributions

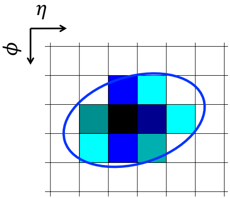
- Direct photons : isolated and circular clusters
- Several background contributions:
  - $\pi^0/\eta \rightarrow \gamma\gamma$ (2 photons merged in one single cluster)
  - Decay γ from π^0 or η
  - Fragmentation photons
  - Electrons or hadrons



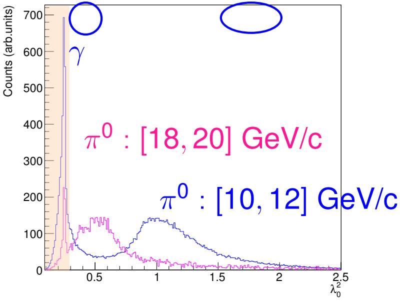
Isolated photons background suppression

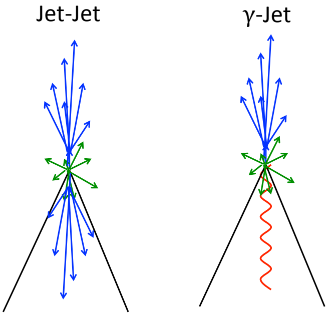
Apply cuts on the reconstructed EMCal clusters:

- Leading particle of the event
- Charged particles veto
- Round-shaped cluster ($\lambda_0^2 \in [0.10, 0.3]$)
- Isolation cut ($\sum p_{\mathrm{T}}^{\text{in cone}} < 1.0$ GeV/c)



After these cuts some contributions remain (at low p_{T} mostly decay γ)



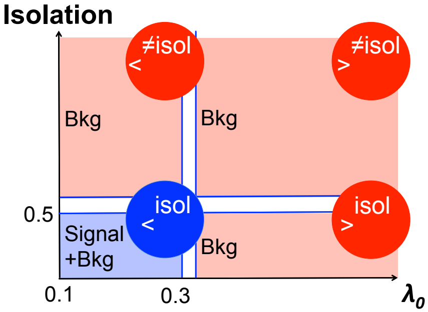


Purity

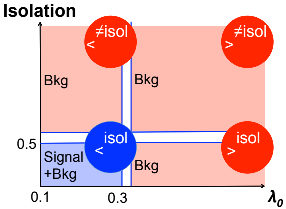
Remaining background contributions (decay photons) have to be estimated to extract the isolated photons purity

- Purity definition:

$$p = \frac{\text{direct photons clusters}}{\text{all isolated circular clusters}} = \frac{S^{isol}_{<}}{N^{isol}_{<}} = 1 - \frac{B^{isol}_{<}}{N^{isol}_{<}} \quad (3)$$



Purity estimate



- First assumption:

$$\frac{B^{\mathrm{isol}}_{<}}{B^{\neq\,\mathrm{isol}}_{<}} = \frac{B^{\mathrm{isol}}_{>}}{B^{\neq\,\mathrm{isol}}_{>}} \iff \frac{B^{\mathrm{isol}}_{<} / B^{\neq\,\mathrm{isol}}_{<}}{B^{\mathrm{isol}}_{>} / B^{\neq\,\mathrm{isol}}_{>}} = 1 \qquad (4)$$

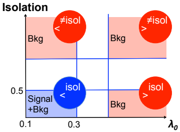
Proportion of isolated clusters is the same at low and high λ_0^2

- Wrong assumption: bias at low λ_0^2 , the double ratio falls around 0.8

- Cannot access B in data: estimate double ratio with simulation

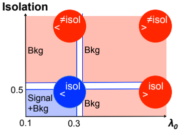
Purity estimate: 2 methods (p_2 and p_3)

- p_2: only background
  - No signal in background regions in data



⇒Set of cuts defining background regions: [3.0 GeV/c, 0.6]

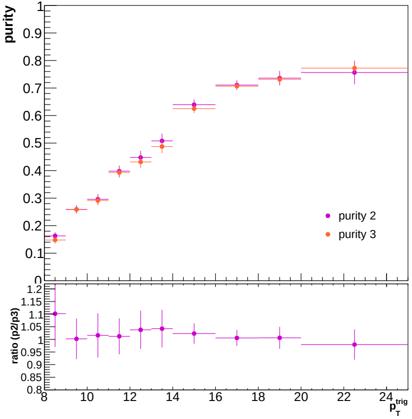
- p_3: signal + background
  - Signal contamination in background regions is the same in data and MC



⇒Cannot be verified completely: systematic taken into account

Purity estimate: results

Final results for p_2 and p_3 (statistical uncertainties only)

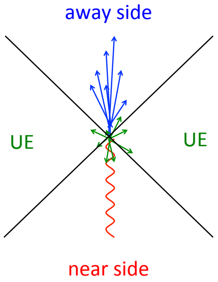


$\Rightarrow$ Purity grows from 30% to 80%

The systematics are around 5%

Underlying Event (UE) subtraction

- UE: Some hadrons do not come from the hard process
- In pp collisions: particles production is isotropic in azimuth
- Avoid jet contamination: UE is estimated in cones orthogonal to trigger particle



x_E distribution

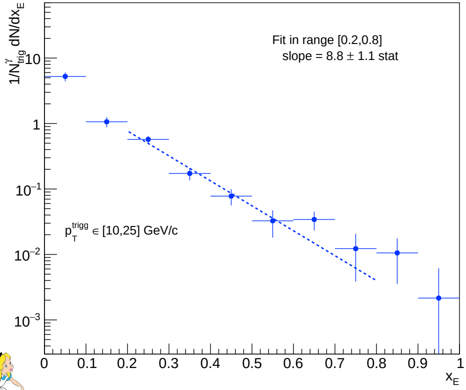
The x_E distribution for isolated photons is defined as:

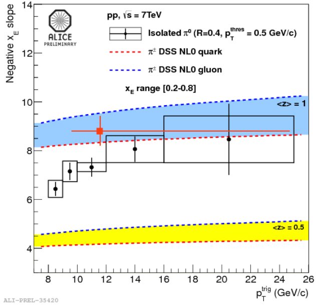
$$f(x_E)^{\gamma} = \frac{1}{p} f(x_E)^{clusters} - \frac{1-p}{p} f(x_E)^{\pi^0} - f(x_E)^{UE} \quad (5)$$

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

x_E distribution: result

- x_E distribution for isolated photons using p_3

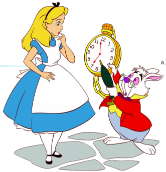




Conclusions

- The parton energy loss mechanism in QGP is not well understood
- The fragmentation function can be approach with the γ-hadrons correlations using the x_E distribution
- Direct photons identification:
  - First set of cuts to remove most of direct photons background
  - Purity estimate: need to rely on MC – the two methods developed give compatible results
- Underlying event subtracted statistically based on the isotropy of particles production
- x_E distribution has been presented

Outlook for next months



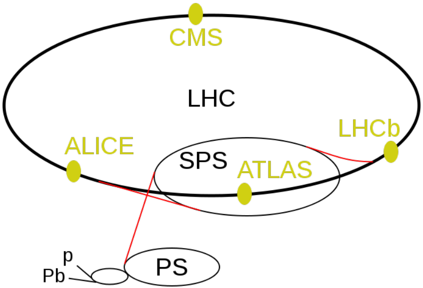
- Analysis in pp collisions:
  - Finalize the systematic studies on x_E distribution (purity already done)
  - Finalize the related analysis note to be submitted to the ALICE collaboration as a first step for a paper
  - Compare the x_E distribution with models
- EMCal calibration: finalize calibration of EMCal and DCal for 2015 data
- Analysis in p-Pb collisions:
  - Change of strategy for UE ?
  - Besides UE the analysis strategy should be unchanged: should be faster than pp analysis

BACK UP

LHC

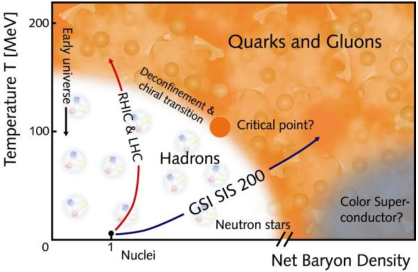
4 main experiences

- ATLAS and CMS : new physics searches
- LHCb : matter/anti-matter, CP violation
- ALICE : hadronic physics



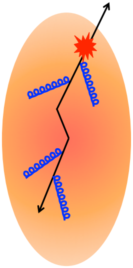
Nuclear phase diagram

Phase transition: increase T and/or μ_B



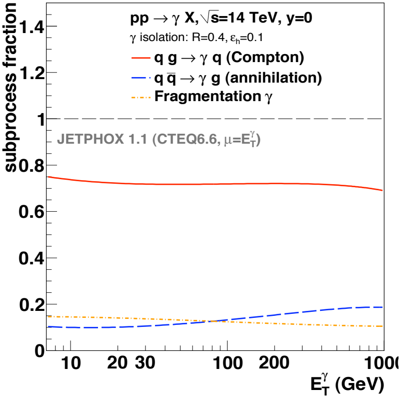
Surface bias

- The highest momentum particle is taken as trigger particle:
  - comes from a parton that did not pass through a lot of QGP
  - the opposite side parton passed through a lot of QGP and is completely attenuated



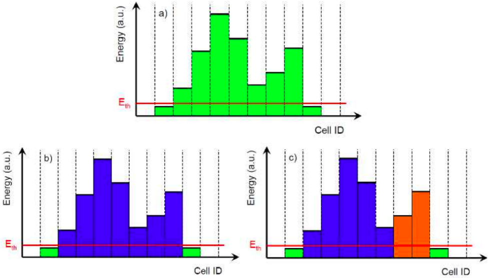
Production fraction of hard processes

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

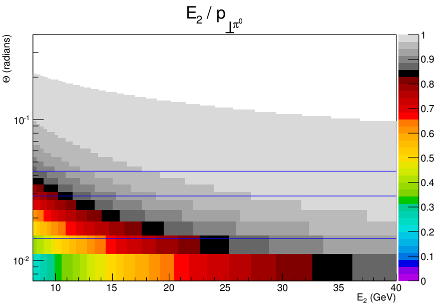


EMCal : clusterization

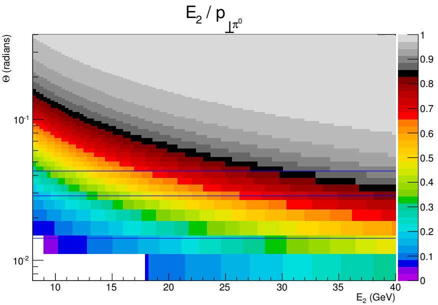
Several types of clusterization to reconstruct particles in EMCal : V1, V2, NxM, V1+Unfolding



Neutral mesons kinematics



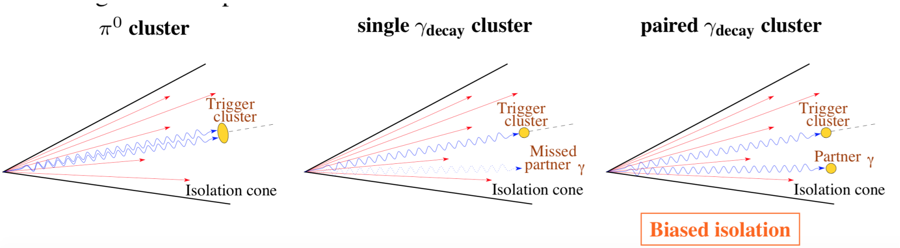
For π^0



For η

Assumption bias

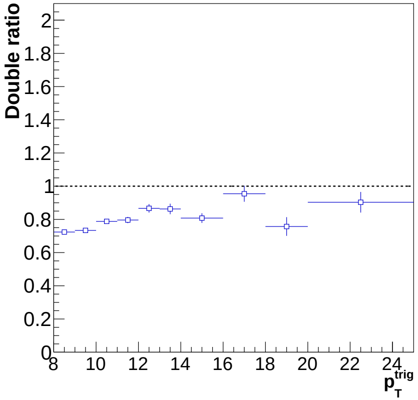
- Paired gamma decays : present only at low λ_0^2
- MCC : at high λ_0^2



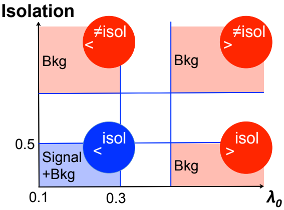
Background double ratio

Result from simulation as we cannot access the double ratio in data: bias is quite small

$$\frac{B_{<}^{\text{isol}} / B_{<}^{\neq\ \text{isol}}}{B_{>}^{\text{isol}} / B_{>}^{\neq\ \text{isol}}}$$



MC JJ correction



- Estimates the background isolation fraction ratio at low and high λ_0^2 :

$$\left(\frac{B_<^{isol}/B_<^{\neq isol}}{B_>^{isol}/B_>^{\neq isol}}\right)_{data} = \left(\frac{B_<^{isol}/B_<^{\neq isol}}{B_>^{isol}/B_>^{\neq isol}}\right)_{MC(JJ)}$$

- Hypothesis:
  - No signal in B, C and D areas in data and jet-jet simulation $\rightarrow$ cut at high λ_0^2 and anti isolation
  - Isolation fractions are constant in high λ_0^2 region

$$p_2 = 1 - \left(\frac{B_<^{\neq\ \mathrm{isol}}/B_<^{\mathrm{isol}}}{B_>^{\neq\ \mathrm{isol}}/B_>^{\mathrm{isol}}}\right)_{data} \times \left(\frac{B_<^{isol}/B_<^{\neq isol}}{B_>^{isol}/B_>^{\neq isol}}\right)_{MC(JJ)} \quad (6)$$

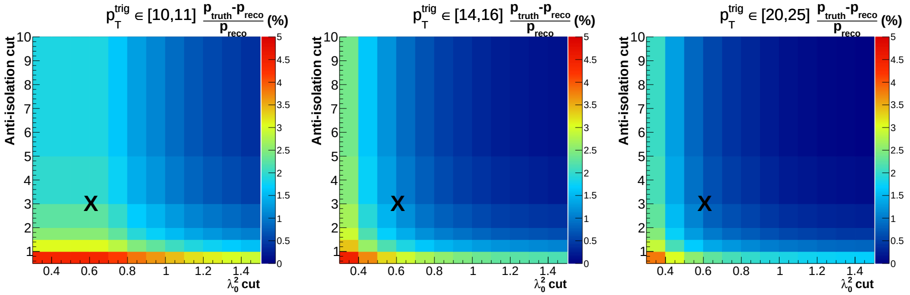
Hypothesis 1: No signal in B, C and D zones 1/2

- Closure test: check difference between p_{MC}^{truth} and p_{reco}
- p_{reco}: found by replacing data term in p_2 with a GJ + JJ simulation
- If no signal in B, C and D zones: $p_{reco} = p_{MC}^{truth}$

$$p_{2,reco} = 1 - \left(\frac{B_{<}^{\neq \text{ isol}} / B_{<}^{\text{isol}}}{B_{>}^{\neq \text{ isol}} / B_{>}^{\text{isol}}} \right)_{GJ+JJ} \times \left(\frac{B_{<}^{isol} / B_{<}^{\neq isol}}{B_{>}^{isol} / B_{>}^{\neq isol}} \right)_{MC(JJ)} \tag{7}$$

Hypothesis 1: No signal in B, C and D zones 2/2

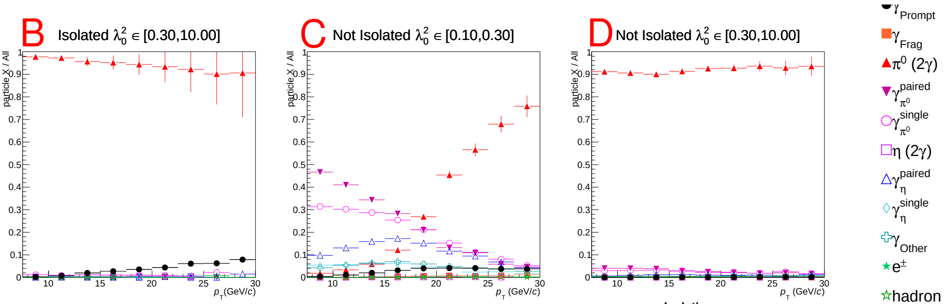
- When p_{reco} very close from p_{MC}^{truth} no signal in B, C and D zones

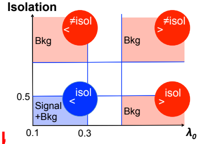


$\Rightarrow$ A good agreement (less than 2 % difference) is found between the true purity and the corrected one for the whole p_T range for the set of tight cuts [3.0 GeV/c, 0.6]

Particles proportions

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



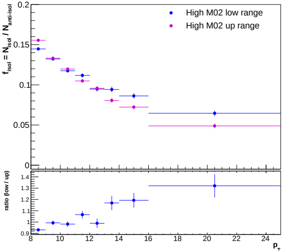


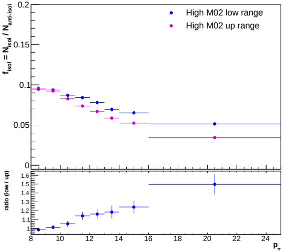
- zone B : close to 10% (grows with p_T)
- zone C : close to 5% (grows with p_T)
- zone D : close to 0 → we neglect signal contrib

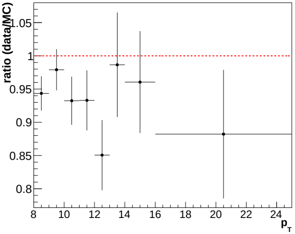
Hypothesis 2: Isolation fraction at high λ_0^2

- Use of tight cuts: the isolation fractions have to be the same in the whole range of high λ_0^2
  if not their evolution have to be the same in data and MC (use of double ratio)
- Divide the high λ_0^2 region into 2 subregions with same statistic

data simu JJ



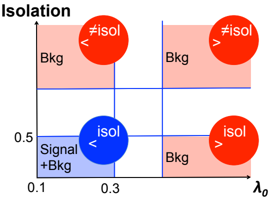




⇒ Difference is not the same in data and MC: lead to a systematic (not presented today)

MC GJ+JJ correction 1/2

Try to get rid of hypothesis 2
(constant isolation fractions at high λ_0^2)



- Assume $B_i^j = k_i^j N_i^j$

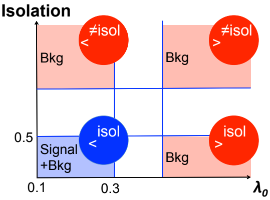
$$\left(\frac{B_<^{isol}/B_<^{\neq isol}}{B_>^{isol}/B_>^{\neq isol}}\right)_{data} = \left(\frac{B_<^{isol}/k_<^{\neq isol}N_<^{\neq isol}}{k_>^{isol}N_>^{isol}/k_>^{\neq isol}N_>^{\neq isol}}\right)_{data}$$

and

$$\left(\frac{B_<^{isol}/B_<^{\neq isol}}{B_>^{isol}/B_>^{\neq isol}}\right)_{GJ+JJ} = \left(\frac{B_<^{isol}/k_<^{\neq isol}N_<^{\neq isol}}{k_>^{isol}N_>^{isol}/k_>^{\neq isol}N_>^{\neq isol}}\right)_{GJ+JJ}$$

- Hypothesis:
  - Assume $(k_i^j)_{data} = (k_i^j)_{MC(GJ+JJ)}$, i.e. signal contamination in B, C and D zones are the same in MC (GJ+JJ) and data (new compared to p_2)

MC GJ+JJ correction 2/2



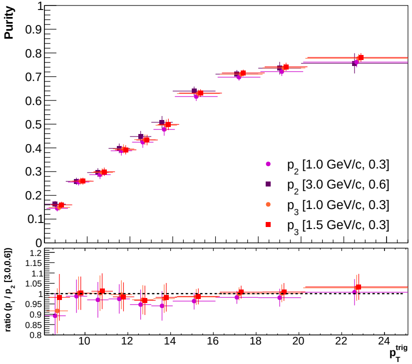
The hypothesis leads to:

$$\left(\frac{B^{isol}_{<}/N^{\neq isol}_{<}}{N^{isol}_{>}/N^{\neq isol}_{>}}\right)_{data} = \left(\frac{B^{isol}_{<}/N^{\neq isol}_{<}}{N^{isol}_{>}/N^{\neq isol}_{>}}\right)_{MC(GJ+JJ)}$$

$$p_3 = 1 - \left(\frac{N^{\neq\,\mathrm{isol}}_{<}/N^{\mathrm{isol}}_{<}}{N^{\neq\,\mathrm{isol}}_{>}/N^{\mathrm{isol}}_{>}}\right)_{data} \times (1 - p^{truth}_{\mathrm{MC}}) \left(\frac{N^{isol}_{<}/N^{\neq isol}_{<}}{N^{isol}_{>}/N^{\neq isol}_{>}}\right)_{MC(GJ+JJ)} \quad (8)$$

Comparison p_2 vs p_3

- Signal contamination in B, C and D zones could be not well reproduced ($(k_i^j)_{data} \neq (k_i^j)_{MC(GJ+JJ)}$)
- Compare p_3 with p_2 to avoid bias from signal contamination



$\Rightarrow$No signal contamination bias for p_3 with set of cuts [1.5 GeV/c, 0.3]

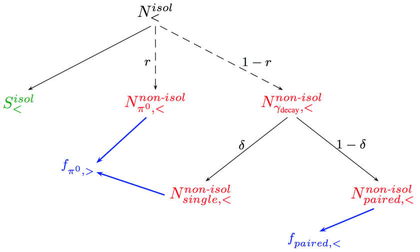
Purity systematics

- Signal contamination
- k factors
- Smearing

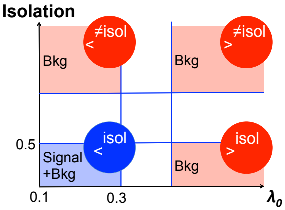
Splitting method : formula

- 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)



$$p_4 = 1 - \frac{N^{non\text{-}isol}_{<}}{N^{isol}_{<}} \left[\frac{f^{isol}_{\pi^0,<}}{1 - f^{isol}_{\pi^0,<}} r^{non\text{-}isol}_{\pi^0,<} - \left(\frac{f^{isol}_{single\pi^0,<}}{1 - f^{isol}_{single\pi^0,<}} \delta_{\pi^0} + \frac{f^{isol}_{paired\pi^0,<}}{1 - f^{isol}_{paired\pi^0,<}} (1 - \delta_{\pi^0}) \right) r^{\neq isol}_{\gamma_{\pi^0},<} - \left(\frac{f^{isol}_{single\eta,<}}{1 - f^{isol}_{single\eta,<}} \delta_\eta + \frac{f^{isol}_{paired\eta,<}}{1 - f^{isol}_{paired\eta,<}} (1 - \delta_\eta) \right) r^{\neq isol}_{\gamma_\eta,<} \right] \tag{9}$$



x_E formula

$$f(x_E)^{\gamma} = \frac{1}{\sum_i p_i N_{trig,i}^{clusters}} \sum_i p_i N_{trig,i}^{clusters} \Bigg\{ \frac{1}{p_i} f(x_E)_i^{clusters}$$

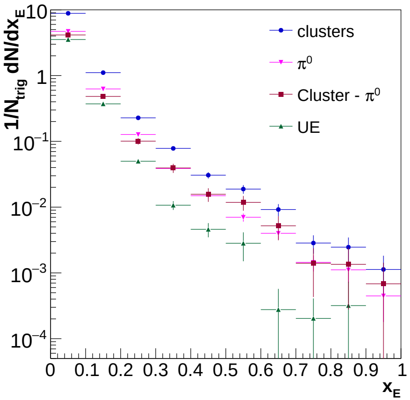
$$- \frac{1-p_i}{p_i} \Bigg(r_{\pi^0,i} f(x_E)_i^{\pi^0} + r_{\gamma^{\pi^0},i} \Big[(1-\delta_{\pi^0,i}) f(x_E)_i^{\gamma^{\pi^0}_{paired}} + \delta_{\pi^0,i} f(x_E)_i^{\gamma^{\pi^0}_{single}} \Big]$$

$$+ r_{\eta,i} f(x_E)_i^{\eta} + r_{\gamma^{\eta},i} \Big[(1-\delta_{\eta,i}) f(x_E)_i^{\gamma^{\eta}_{paired}} + \delta_{\eta,i} f(x_E)_i^{\gamma^{\eta}_{single}} \Big] \Bigg) \Bigg\}$$

where $f(x_E)_i^{j,measured} = f(x_E)_i^{j,wanted} + f(x_E)_i^{j,UE}$

x_E distribution contributions

UE important at low p_T



x_E systematics

- Tracking system resolution
- Hybrid tracks
- Isolation
- λ_0^2

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