Direct photon measurements in ALICE

Alexis Mas for the ALICE collaboration

Outline

I - Physics motivations for direct photon measurements

II – Direct photon measurements in ALICE

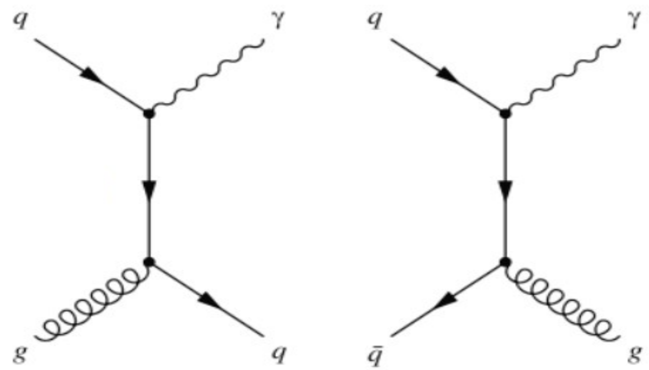
i - Subtraction method with TPC and ITS (p_T 0.5-14 GeV/*c*)

ii - Isolation method with EMCal (p_T 10-60 GeV/*c*)

III - Conclusions

Direct photon production

In pp and Pb-Pb collisions



Compton scattering and **annihilation**

Independent of fragmentation functions (FF)

➡ **Their measurement constrains parton distribution functions (PDFs)**

Fragmentation photons: production can be affected by parton energy loss in Pb-Pb

Only in Pb-Pb collisions

Thermal photons: from QGP or hadron gas:

➡ **Direct information on the hot and dense medium**

Photons from interactions between hard partons and the medium:

- bremsstrahlung of partons
- $q_{hard} + g_{QGP} \rightarrow q + \gamma$

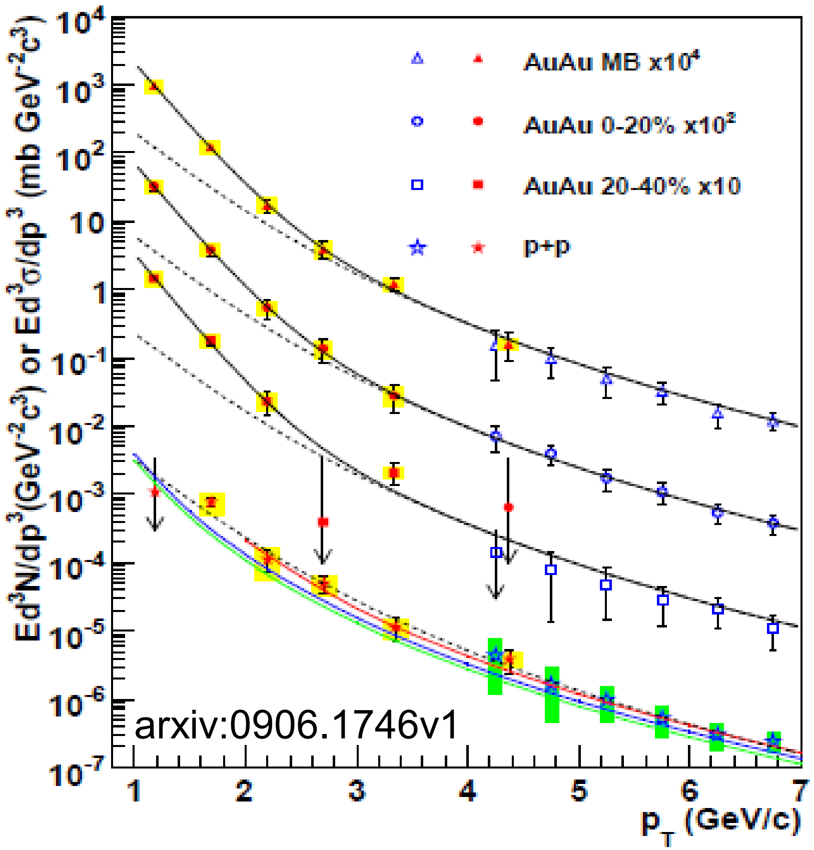
Electromagnetic probes do not interact with the color field

➡ Ideal to study HI collisions

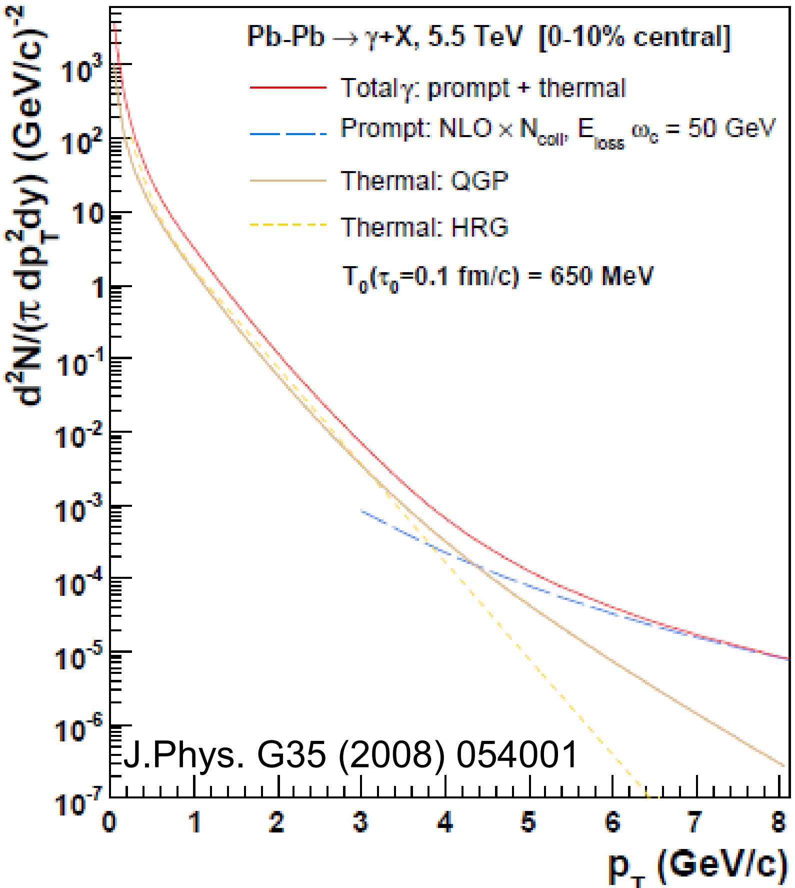
A medium thermometer: thermal photons

In heavy-ion collisions, low p_T direct photon production is dominated by QGP and hadron gas radiation => Access to medium properties

The "excess" seen at RHIC



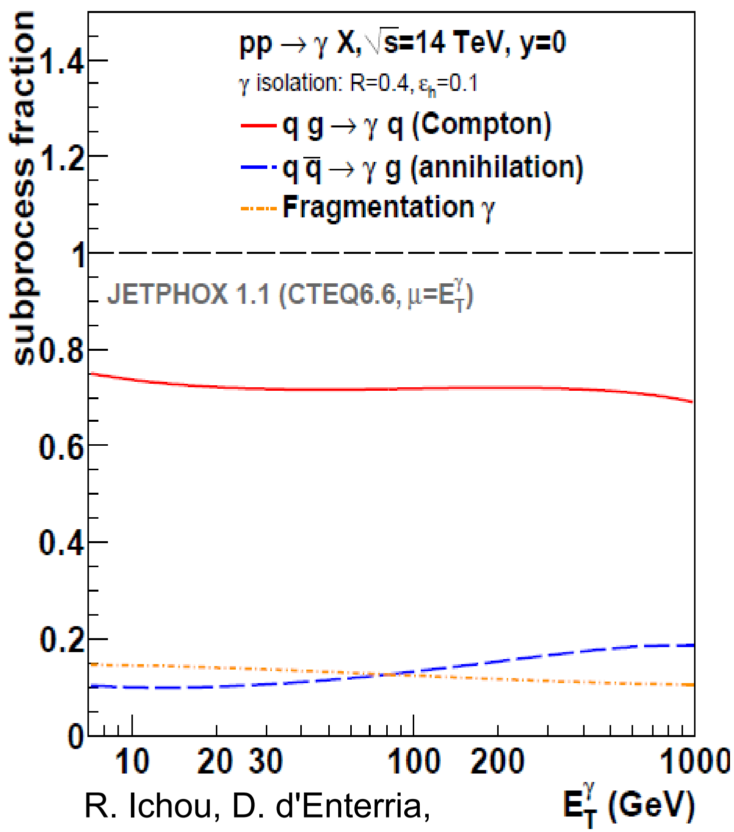
Prediction for the LHC



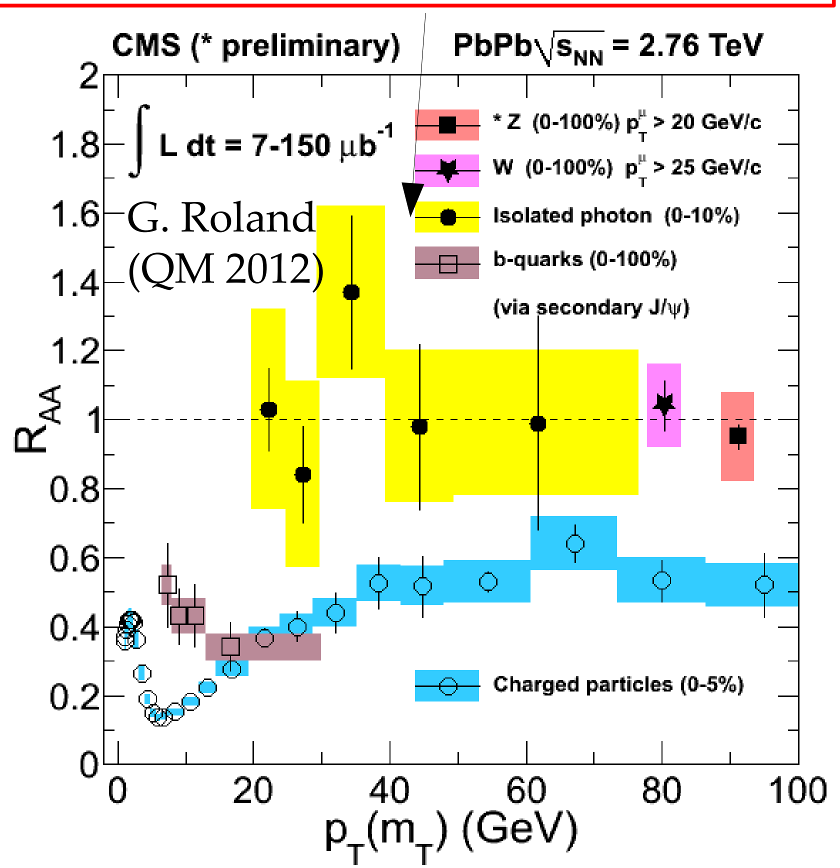
Isolated direct photons: an ideal probe

Compton scattering is the dominant channel of **high p_T** isolated direct photon at LHC
➡ constraints on gluon PDF

Unlike hadron production, **high p_T** isolated photon one is not affected by the medium created in HI collisions
➡ ideal reference for PDF and FF modification studies



R. Ichou, D. d'Enterria, Phys.Rev D 82(2010)014015



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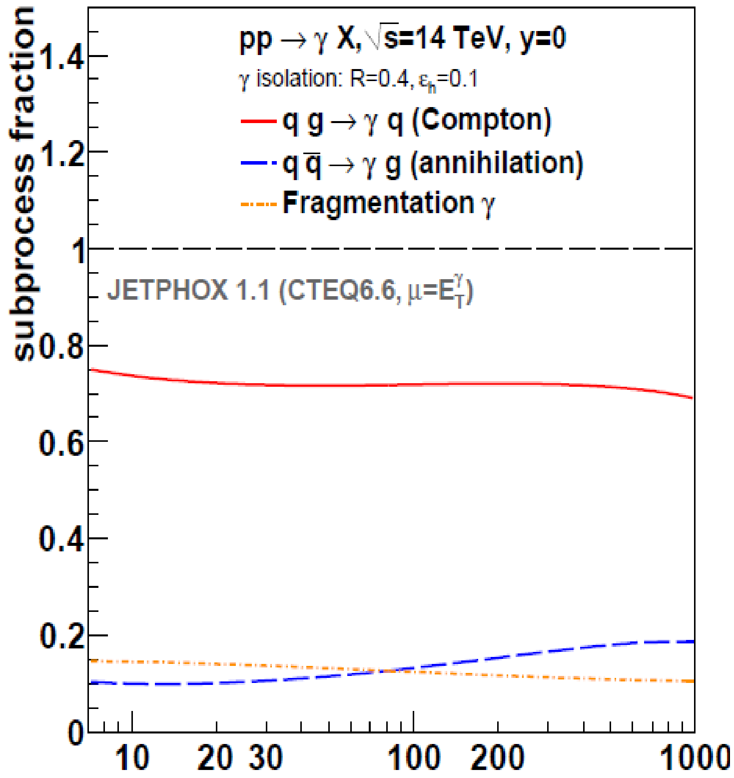

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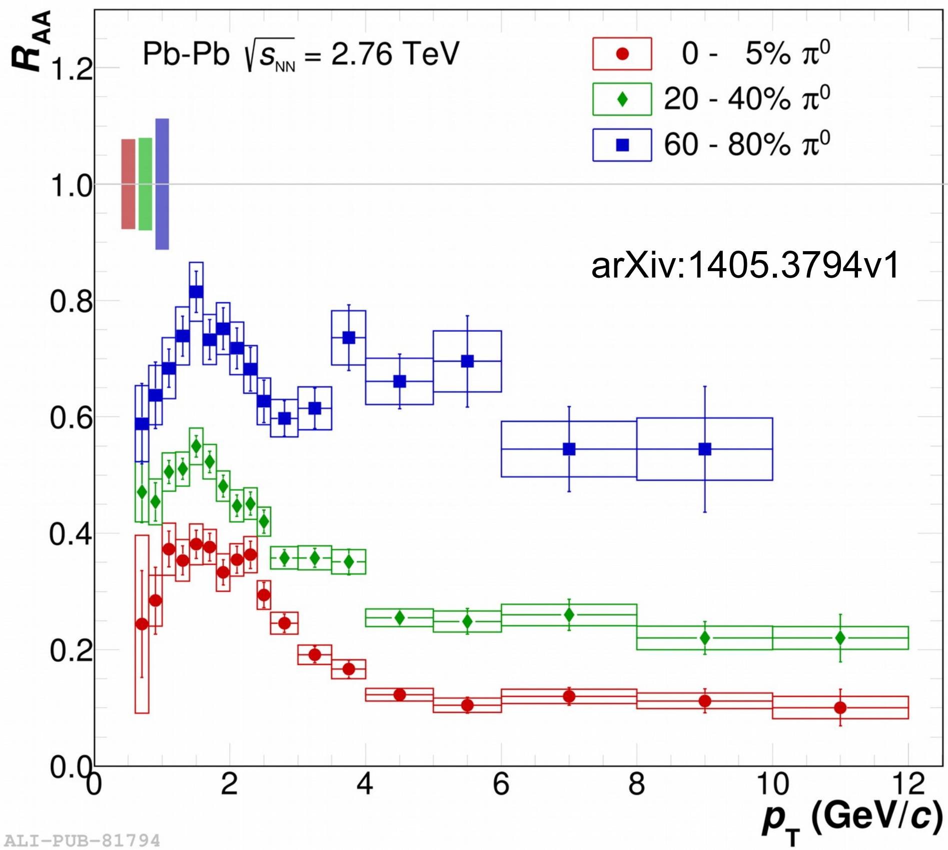


Direct photon measurement: an experimental challenge

Photon production is completely dominated by hadron decays

The $\pi^0 \rightarrow \gamma\gamma$ channel contributes for more than 80% of those decay photons

➡ **Direct photon signal extraction is challenging**

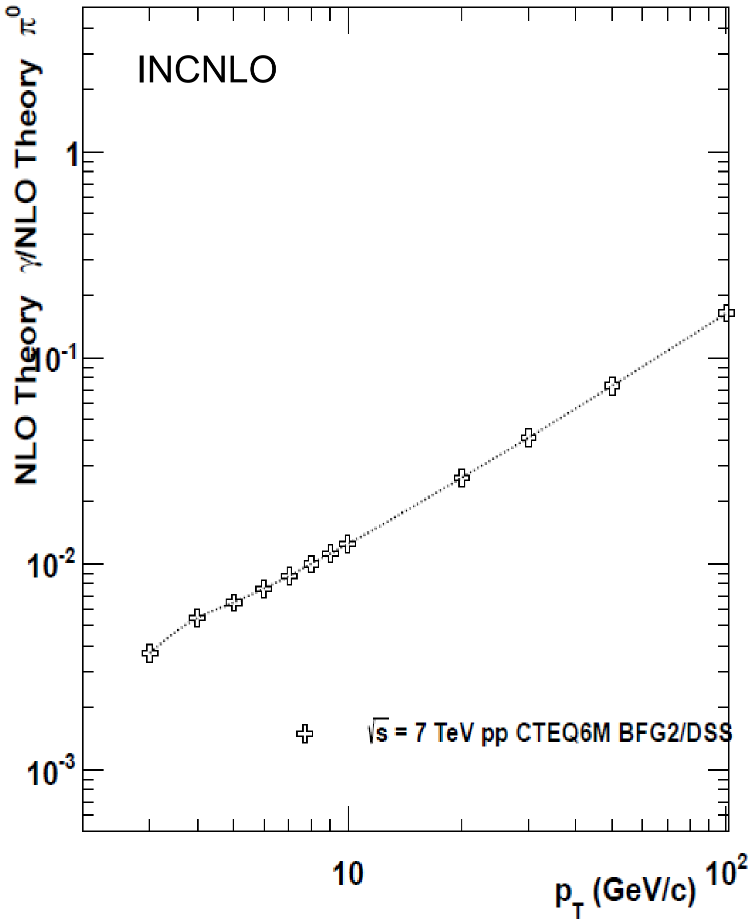
1st approach, **decay photon subtraction**:

$$\gamma_{dir} = \gamma_{inc} - \gamma_{decay}$$

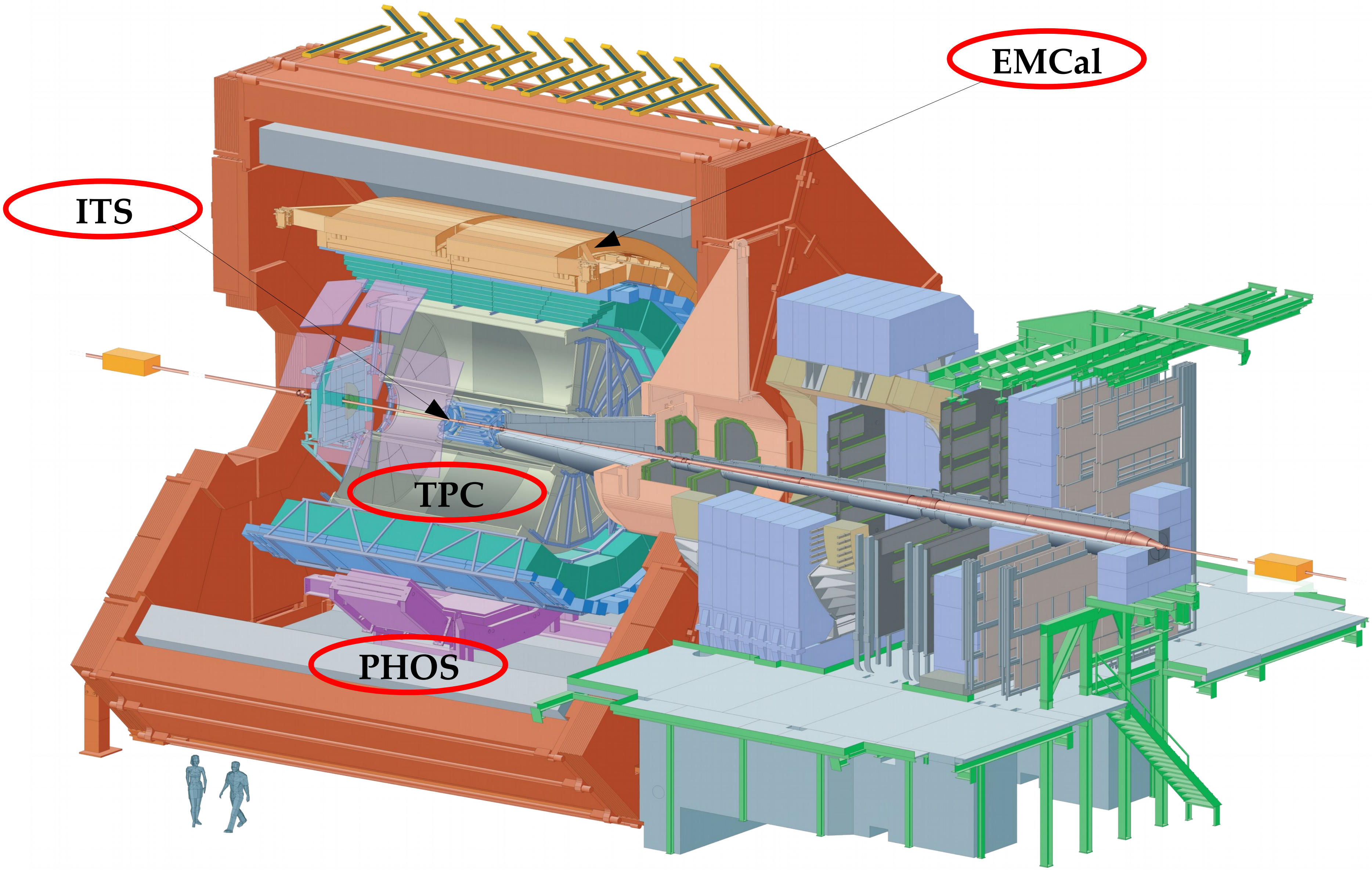
Used in the **subtraction method**

2nd approach, **direct photon identification**:

Used in the **isolation method**



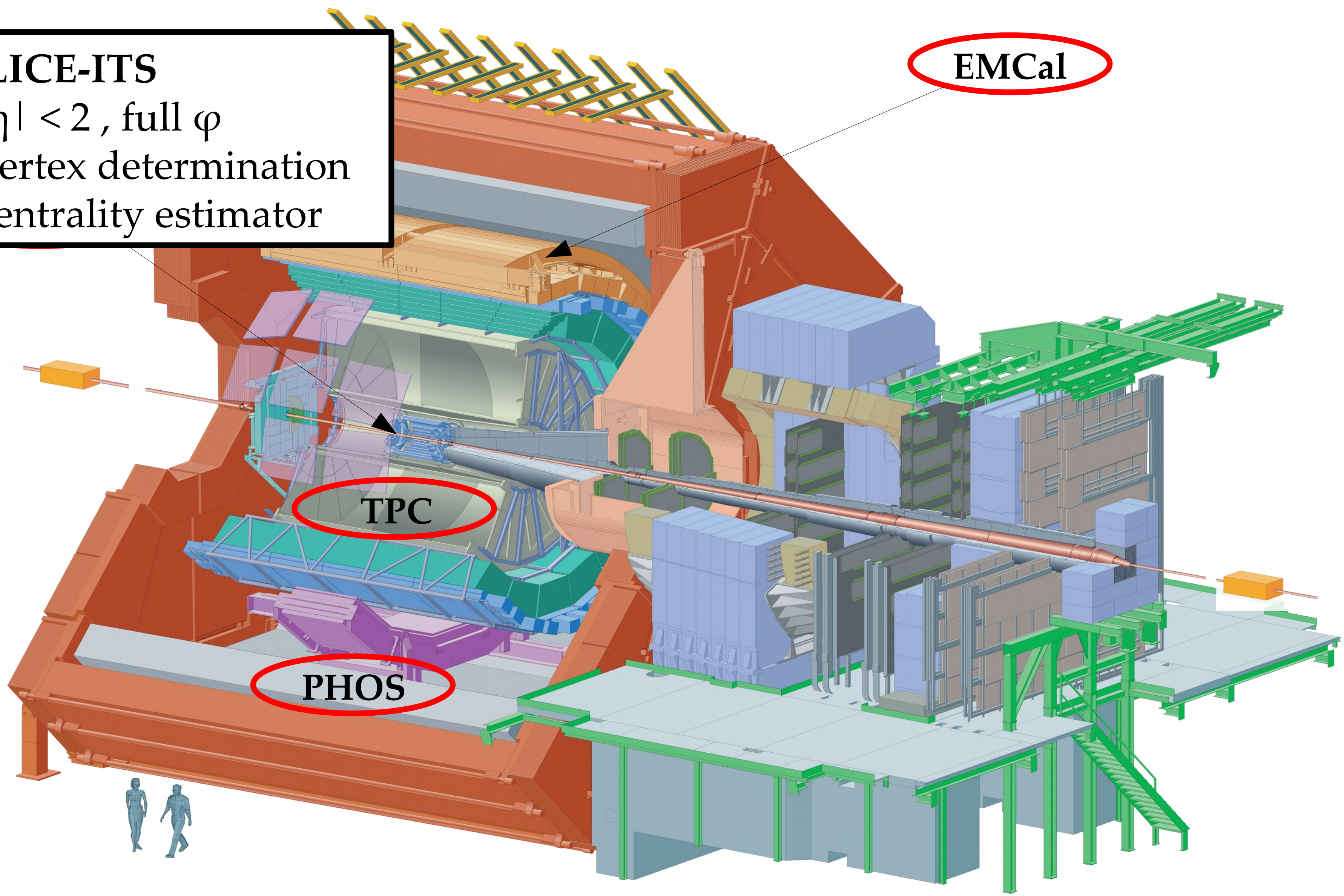
ALICE Detector Setup



ALICE Detector Setup

ALICE-ITS

- $|\eta| < 2$, full φ
- vertex determination
- centrality estimator



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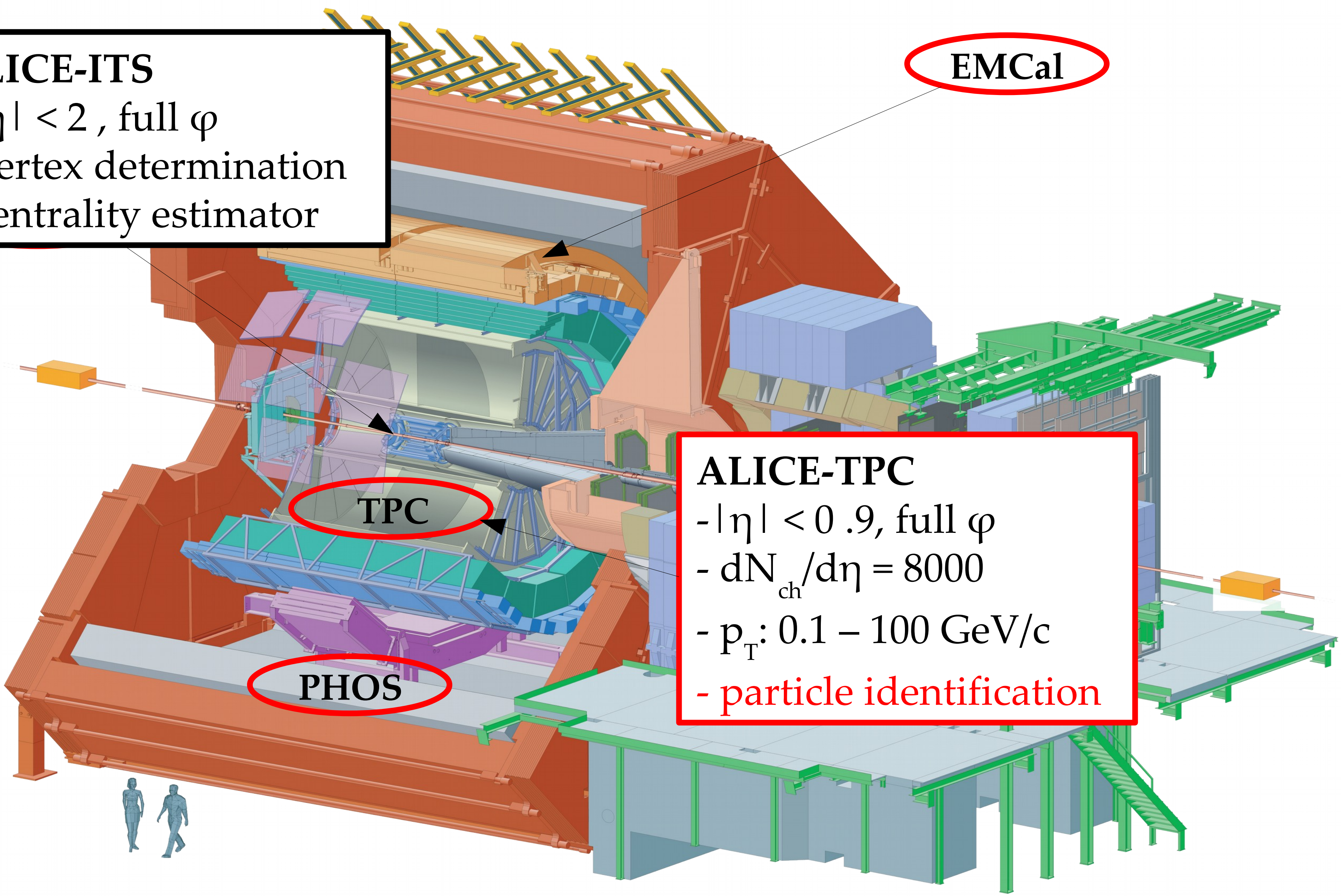
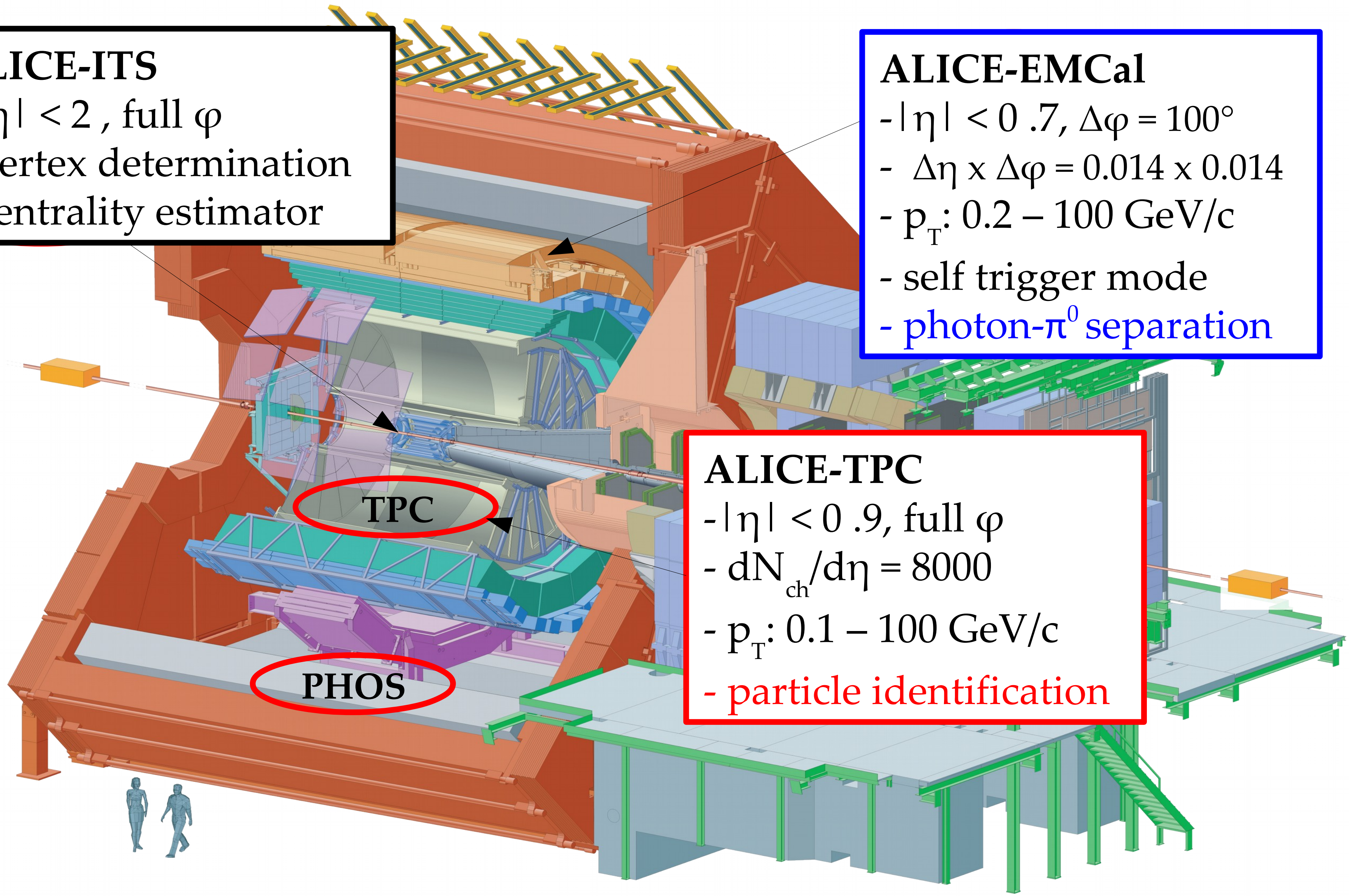


ALICE-TPC
- $|\eta| < 0.9$, full φ
- $dN_{ch}/d\eta = 8000$
- p_T: 0.1 – 100 GeV/c
- particle identification

ALICE Detector Setup



ALICE-ITS
- $|\eta| < 2$, full φ
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ALICE-EMCal
- $|\eta| < 0.7$, $\Delta\varphi = 100°$
- $\Delta\eta \times \Delta\varphi = 0.014 \times 0.014$
- p_T: 0.2 – 100 GeV/c
- self trigger mode
- photon-π^0 separation

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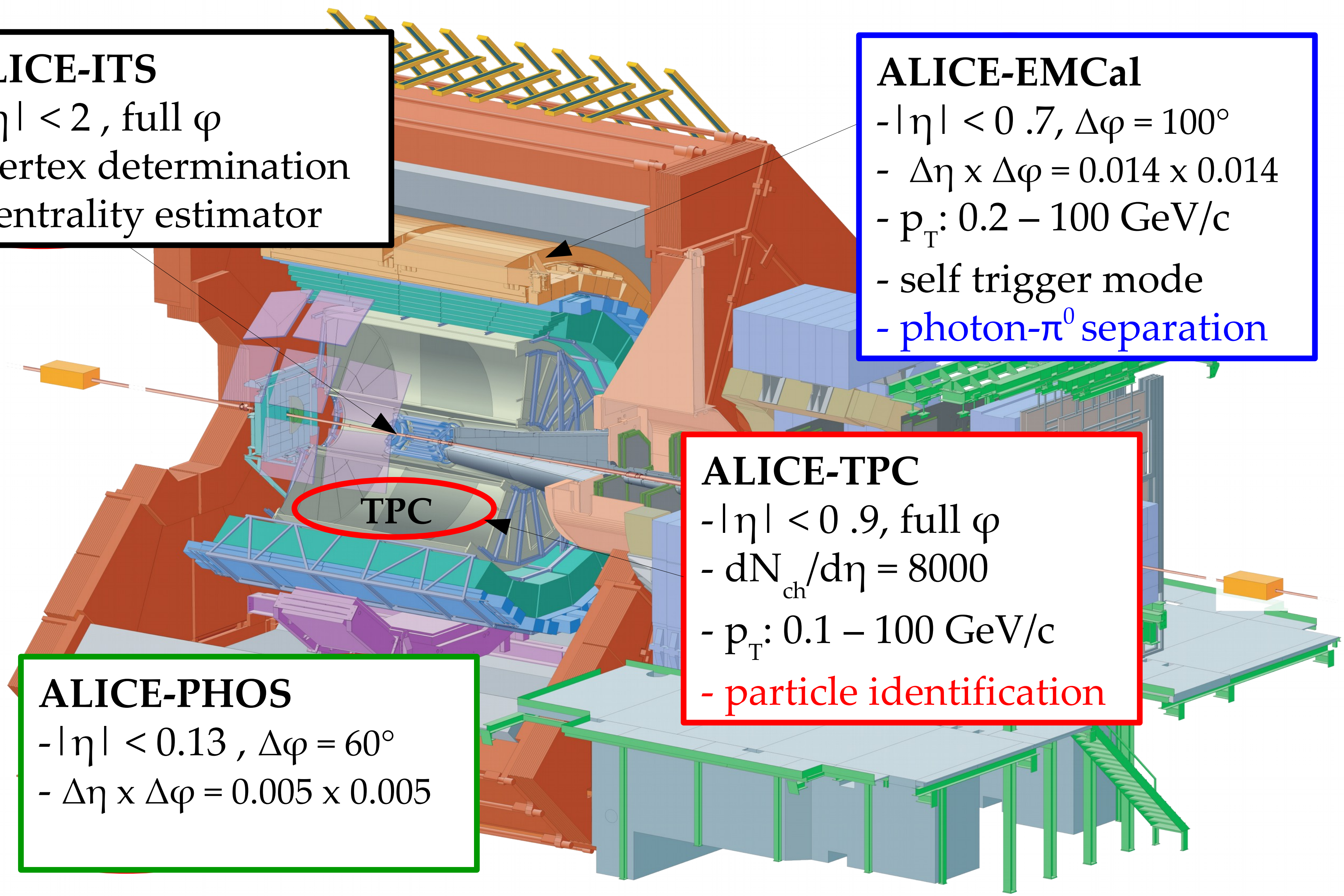

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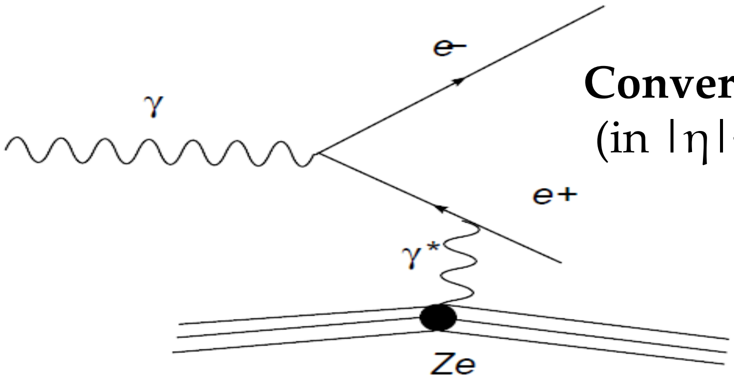
- particle identification

ALICE-PHOS
- $|\eta| < 0.13$, $\Delta\varphi = 60°$
- $\Delta\eta \times \Delta\varphi = 0.005 \times 0.005$

1st measurement: Subtraction method with TPC and ITS

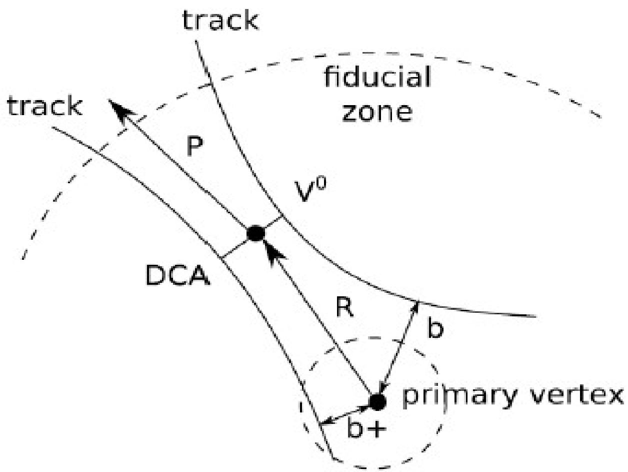
Photon Conversion Method

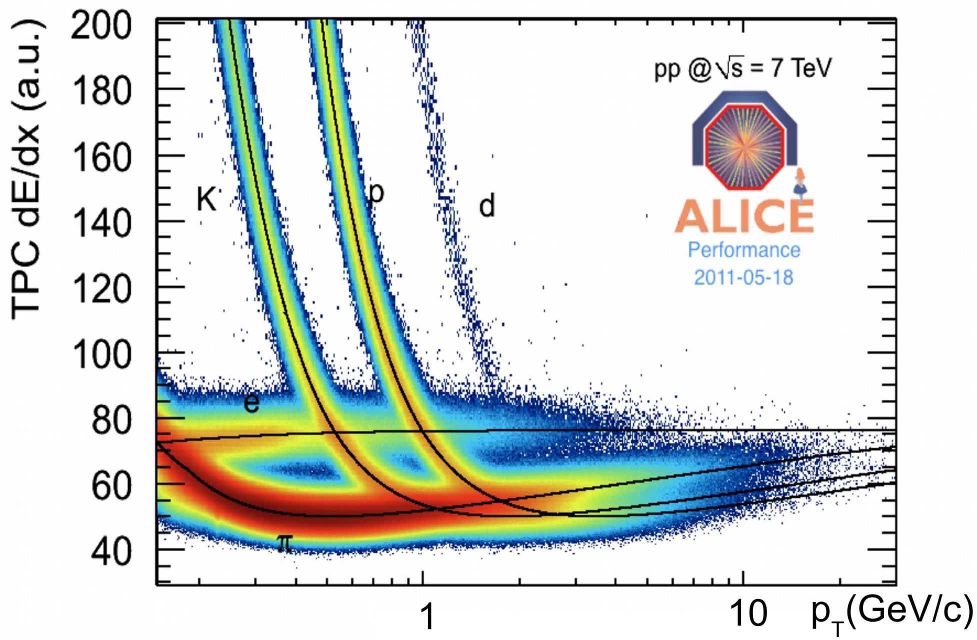


Conversion probability in ALICE inner material = 8.5 %
(in $|\eta| < 0.9$ to R=180 cm)

Remove other V0 sources (K^0_s, Λ, $\bar{\Lambda}$)
- cut on opening angle
- cut on dE/dx of the tracks

Track selection (V0 candidates)
- Large impact parameter (avoid primary particles)
- Small DCA





Contamination from combinatorial background estimated from MC simulation

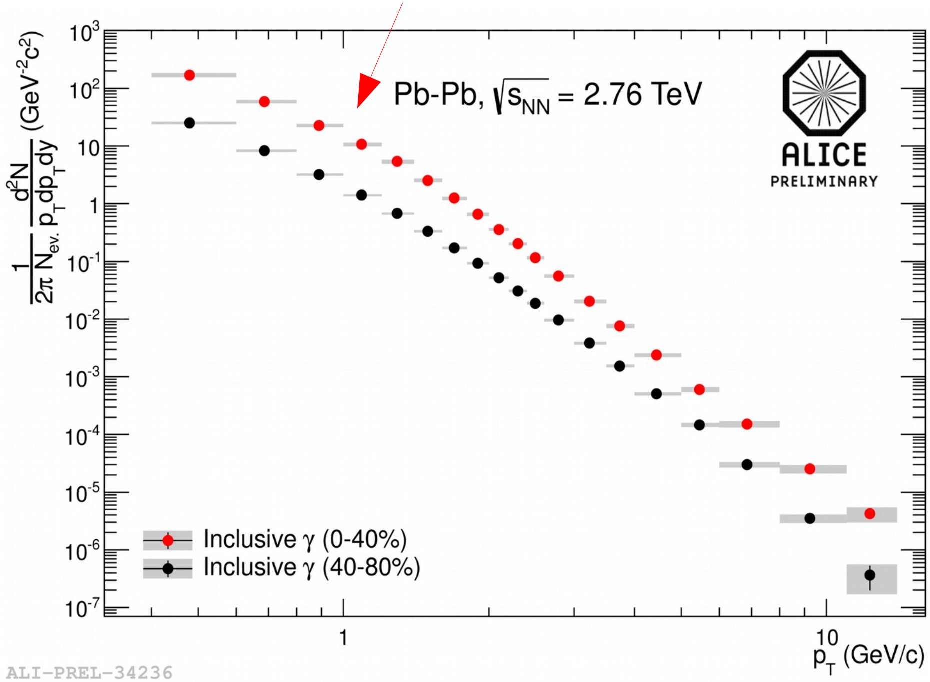
Analysis strategy

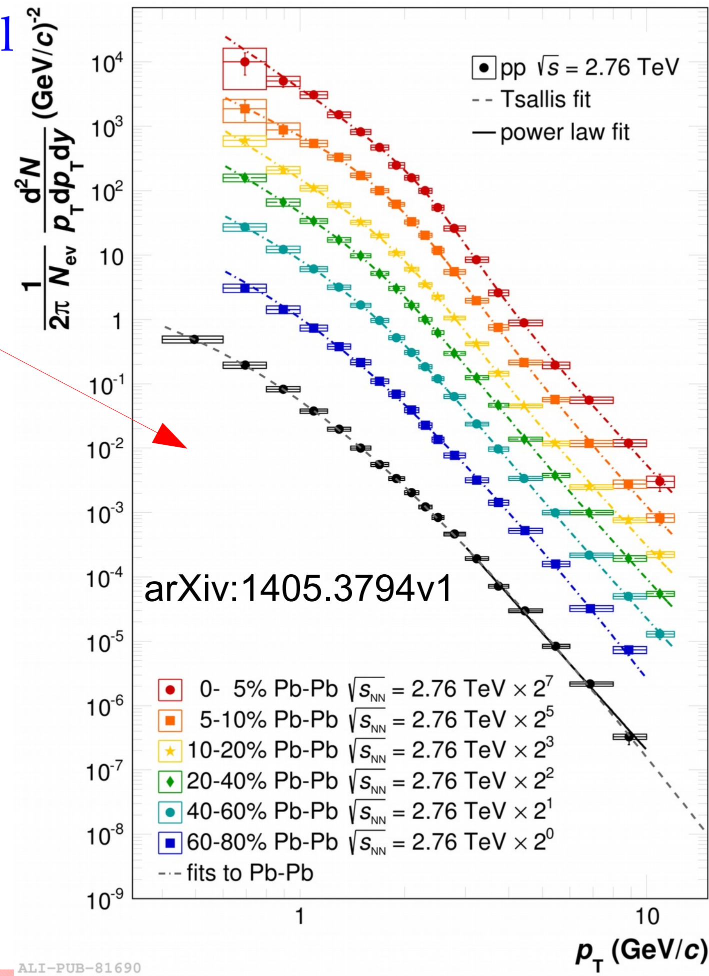
Direct photon contribution is obtained from inclusive spectrum by:

$$\gamma_{dir} = \gamma_{inc} - \gamma_{decay} = \gamma_{inc} \times (1 - \frac{\gamma_{decay}}{\gamma_{inc}})$$

with : $\dfrac{\gamma_{inc}}{\gamma_{decay}} \simeq \boxed{\dfrac{\gamma_{inc}}{\pi^0}} / \boxed{\dfrac{\gamma_{decay}}{\pi^0_{param}}}$ from cocktail (next slide)

measured from converted photons in CTS and PHOS





Cocktail generator

A part from π^0 and η (in pp), **decay photon spectra are computed.**

Cocktail generator is based on the m_T- scaling of π^0 spectrum

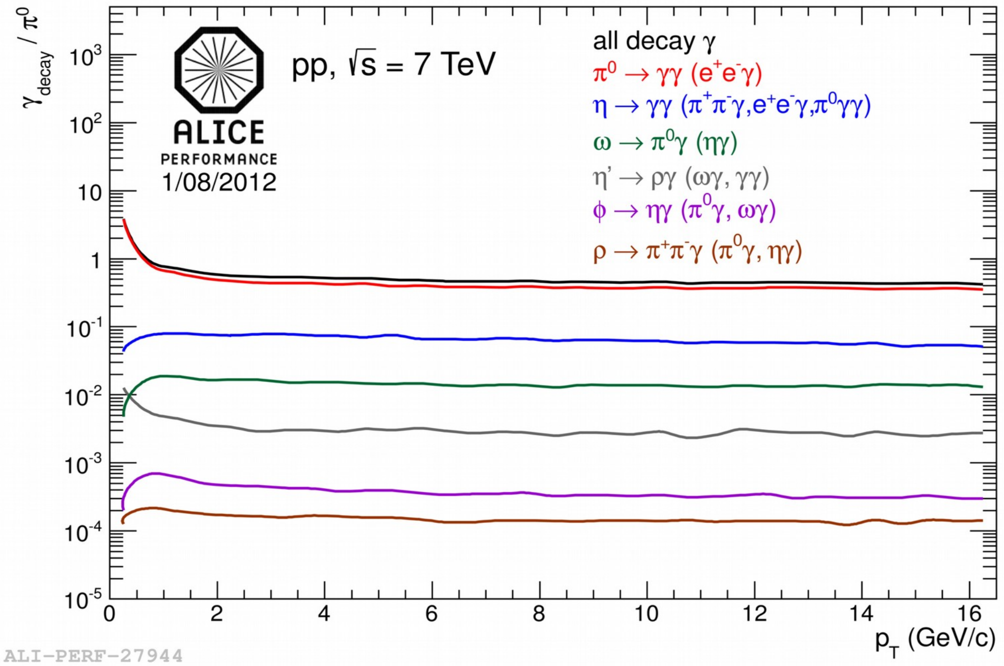
m_T- scaling ($m_T = \sqrt{m^2 + p_T^2}$)

Same shape of cross-section $f(m_T)$ of various mesons:

$$\frac{Ed^3\sigma_m}{dp^3} = \boxed{C_m} \times f(m_T)$$

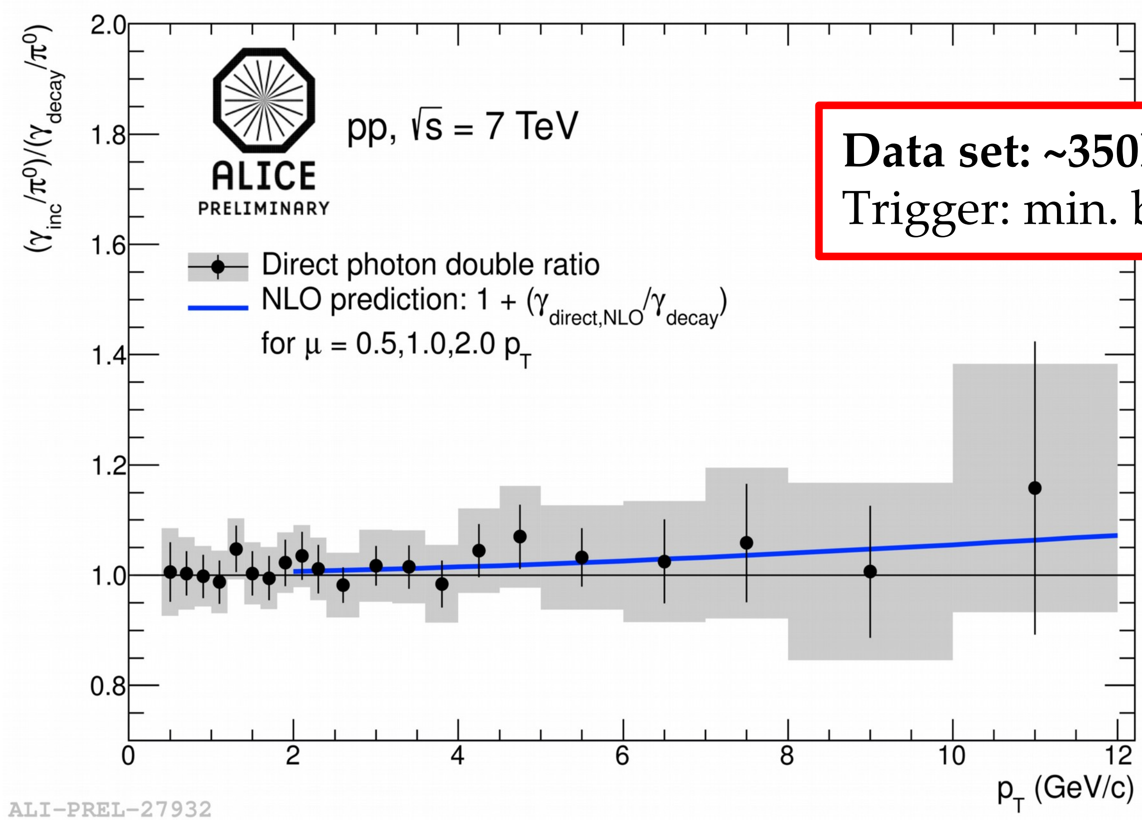
Normalization factors

Considered mesons: π^0, η, η', ω, ϕ and ρ_0



Meson (C_m)	Mass	Decay Branch	B. Ratio
π^0	134.98	$\gamma\gamma$ $e^+e^-\gamma$	98.789% 1.198%
η (0.48)	547.3	$\gamma\gamma$ $\pi^+\pi^-\gamma$ $e^+e^-\gamma$	39.21% 4.77% $4.9 \cdot 10^{-3}$
ρ^0 (1.0)	770.0	$\pi^+\pi^-\gamma$ $\pi^0\gamma$	$9.9 \cdot 10^{-3}$ $7.9 \cdot 10^{-4}$
ω (0.9)	781.9	$\pi^0\gamma$ $\eta\gamma$	8.5% $6.5 \cdot 10^{-4}$
η' (0.25)	957.8	$\rho^0\gamma$ $\omega\gamma$ $\gamma\gamma$	30.2% 3.01% 2.11%

Results for pp collisions at $\sqrt{s}$ = 7 TeV



Data set: ~350M events (2010 data)
Trigger: min. bias

$$\frac{\gamma_{inc}}{\gamma_{decay}} \simeq \frac{\gamma_{inc}}{\pi^0} / \frac{\gamma_{decay}}{\pi^0_{param}}$$

The double ratio leads to the **cancellation of some systematics errors** (efficiency, normalization, π^0 spectrum)

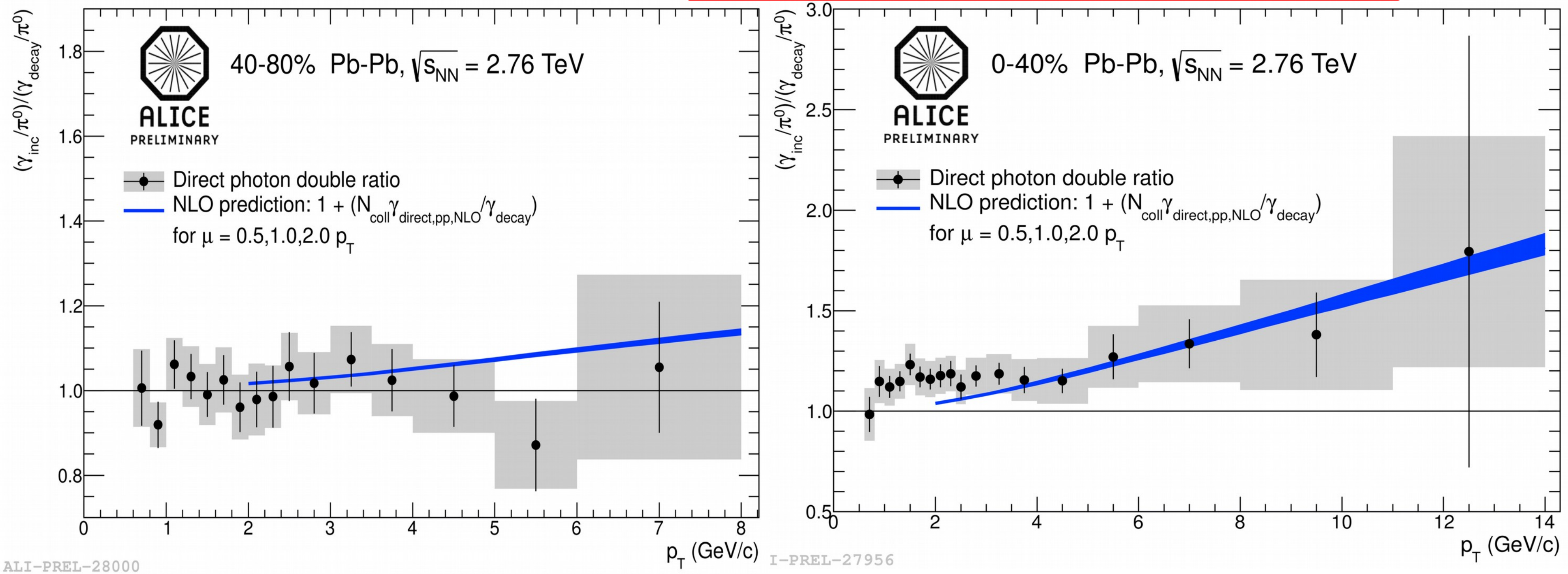
- No significative direct photon signal

- The result is compatible with NLO predictions

Results for Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

$$\frac{\gamma_{inc}}{\gamma_{decay}} \simeq \frac{\gamma_{inc}}{\pi^0} / \frac{\gamma_{decay}}{\pi^0_{param}}$$

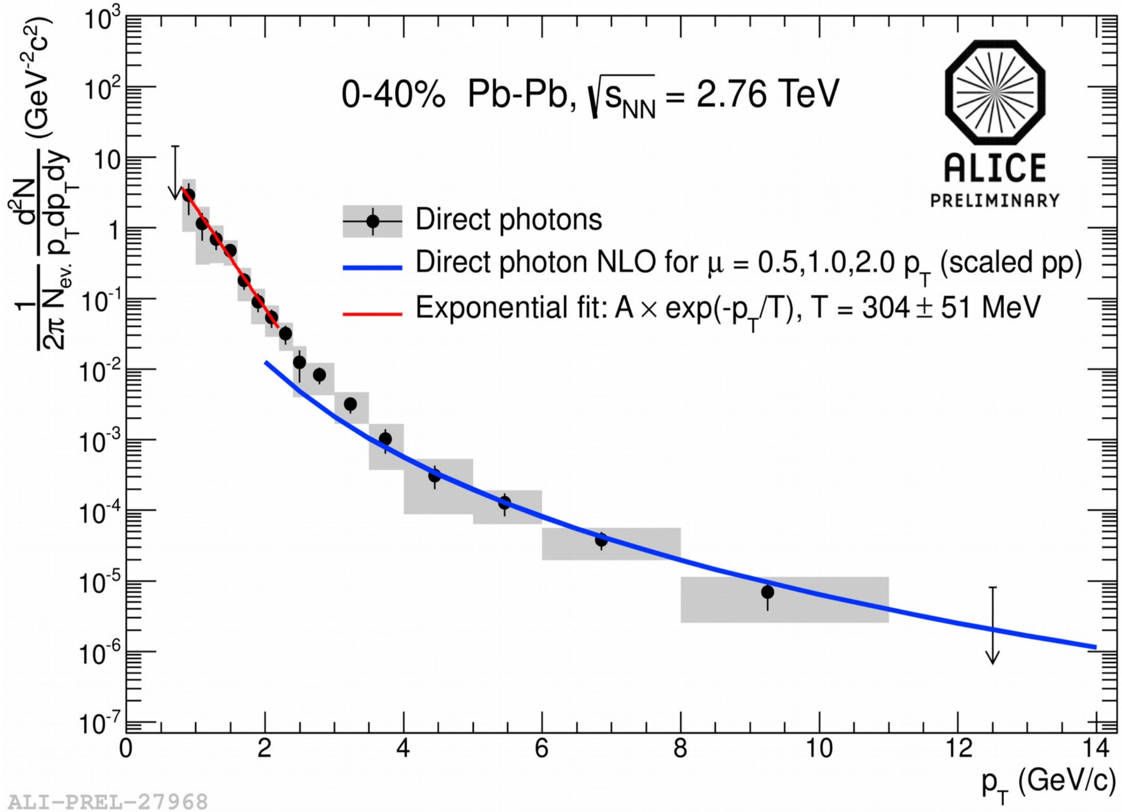
Data set: ~17M events (2010 data)
Trigger: min. bias



- Above 4 GeV/c, in both peripheral and central collisions, results are consistent with NLO predictions

- We see a **direct photon signal at low p_T in central collisions**

Direct photons in central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV



The direct photon yield is extracted from:

$$\gamma_{dir} = \gamma_{inc} \times \left(1 - \boxed{\frac{\gamma_{decay}}{\gamma_{inc}}}\right)$$

Using the double ratio:

$$\frac{\gamma_{inc}}{\gamma_{decay}} \simeq \frac{\gamma_{inc}}{\pi^0} \Big/ \frac{\gamma_{decay}}{\pi^0_{param}}$$

- At $p_T < 2.2$ GeV/c, the spectrum is fitted with an exponential with a slope parameter: $\boxed{T = 304 \pm 51^{stat+syst}\ \mathrm{MeV}}$

- The excess is comparable to the one measured at RHIC:

$$T = 221 \pm 19^{stat} \pm 19^{syst}\ \mathrm{MeV}$$

(Au-Au centrality 0-20%)

2[nd] measurement: Isolation method with EMCal

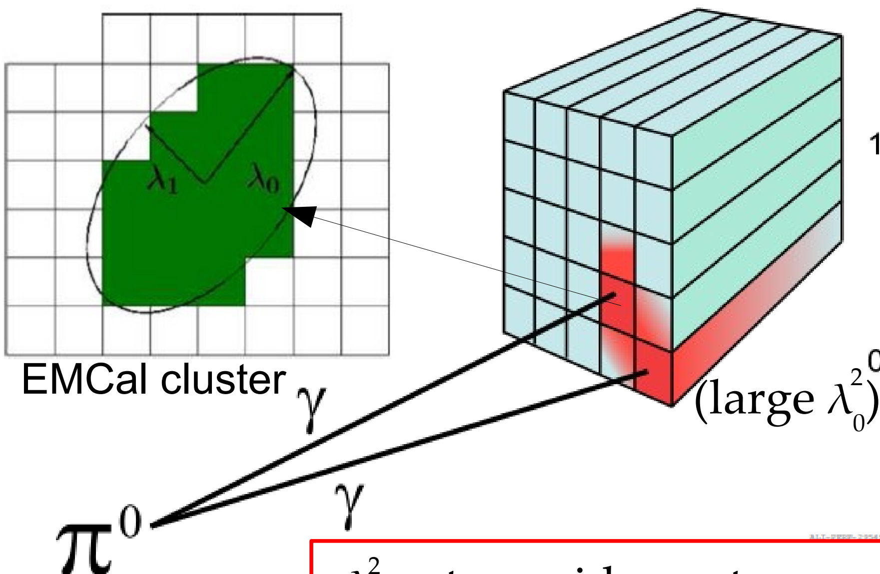
Photon identification with EMCal

I – Charged particle veto (CPV)

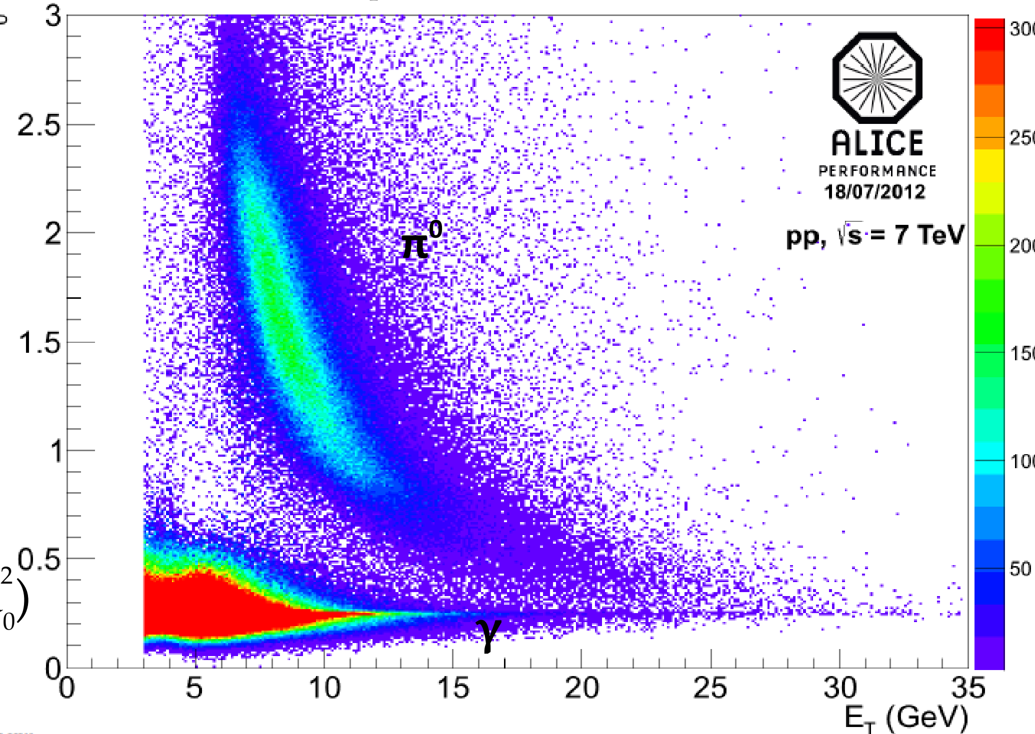
Selection of clusters that are not matching a track (matched if $\Delta\eta < 0.02$ & $\Delta\varphi < 0.03$)

II – Shower shape discrimination ($\lambda_0^2 < 0.3$)

λ_0 measures, in cell unit, the energy dispersion with respect to the longer axis of the cluster

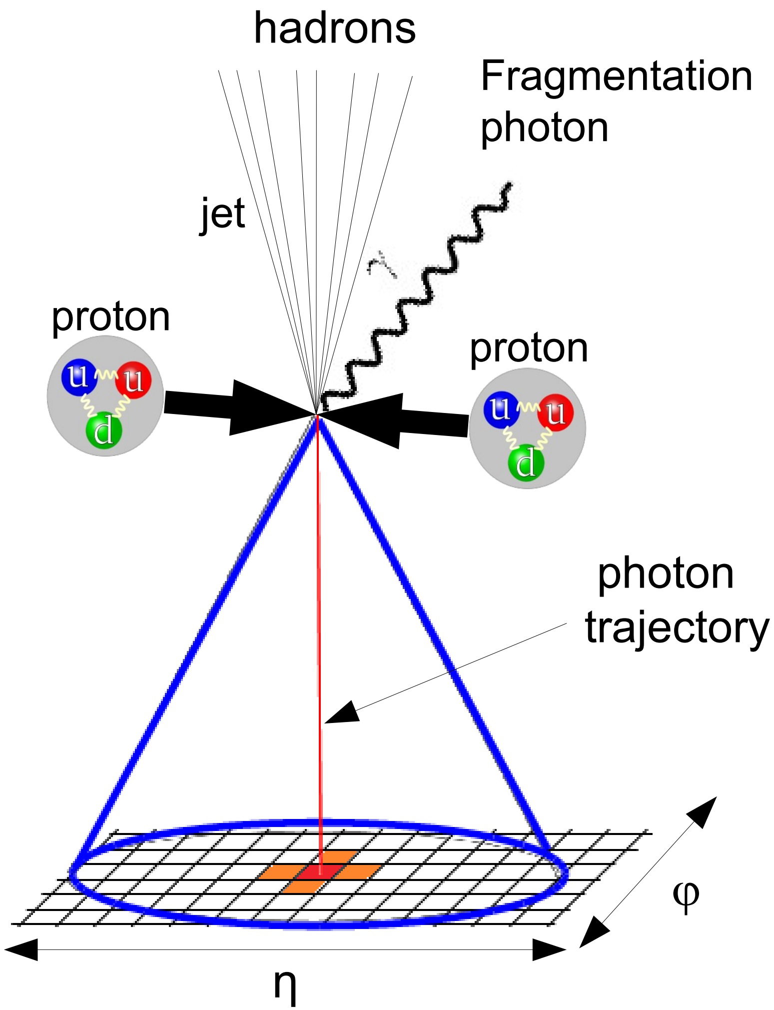


λ_0^2 vs E_T of clusters (after CPV)

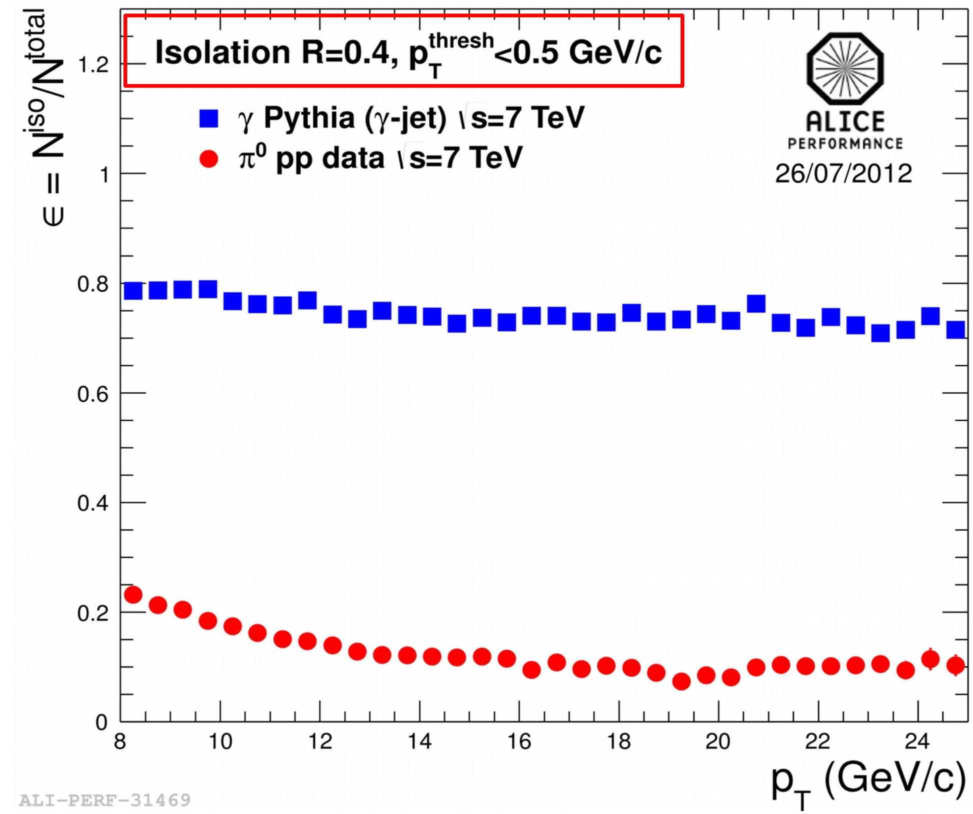


λ_0^2 cut provides a strong π^0 rejection between 5 and 60 GeV

Photon isolation



$$R = \sqrt{\Delta\varphi^2 + \Delta\eta^2}$$



- The isolation technique strongly reduces the residual π^0 contamination

- Fragmentation photons are also strongly suppressed since they are surrounded by hadronic activity

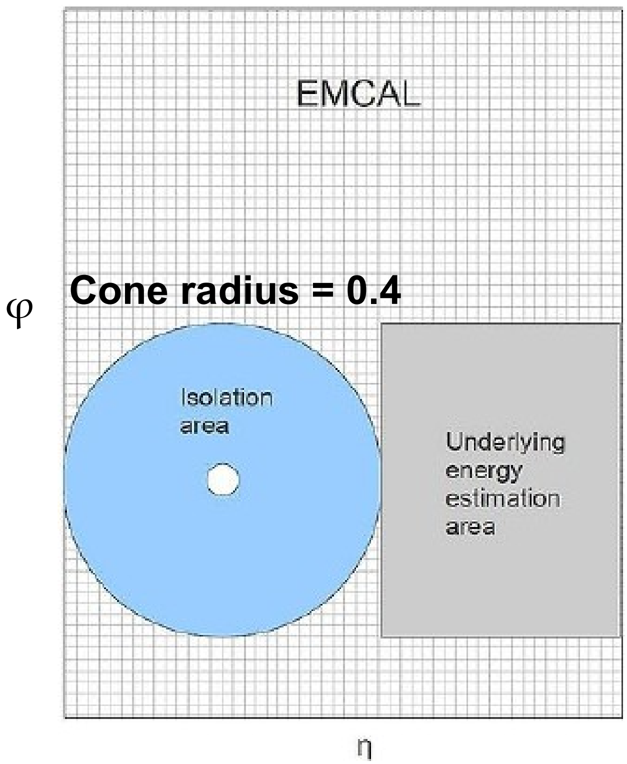
Isolation method: signal extraction

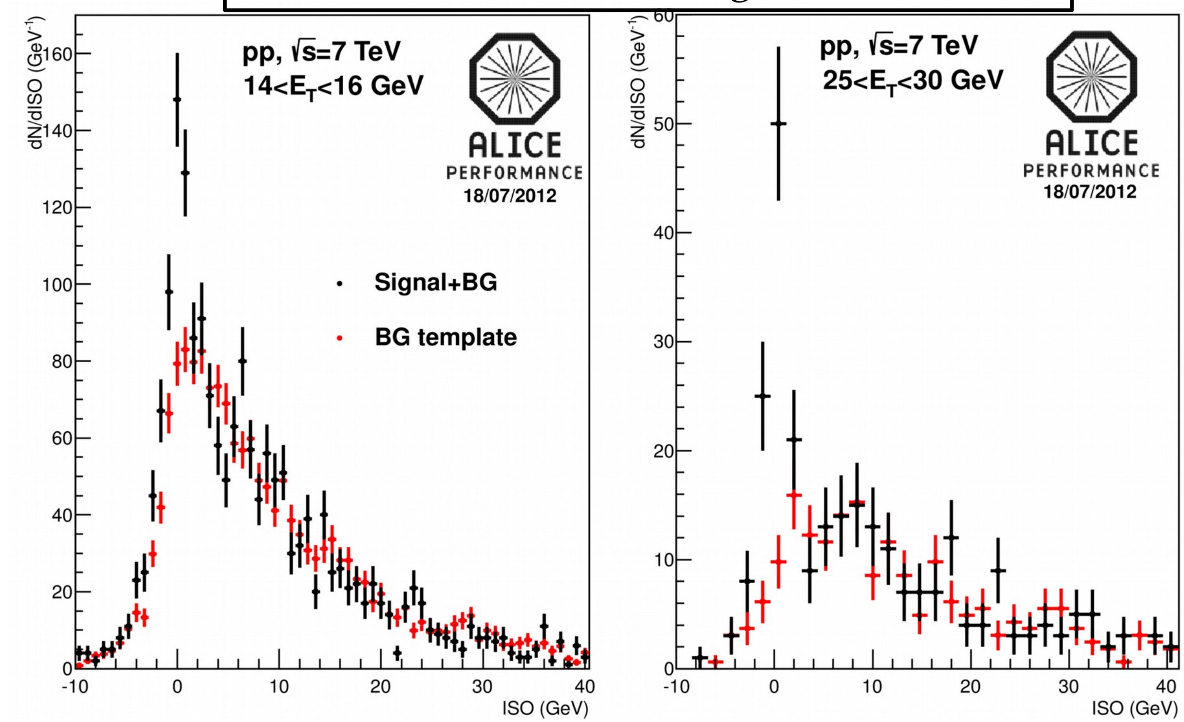
Computation of $\boxed{ISO = E_T^{Cone} - E_T^{UE}}$ for:

- BG template: clusters with $0.5 < \lambda_0^2 < 2$ (normalized using distribution tails: ISO>15 GeV)

- Signal+BG: clusters with $0.1 < \lambda_0^2 < 0.3$

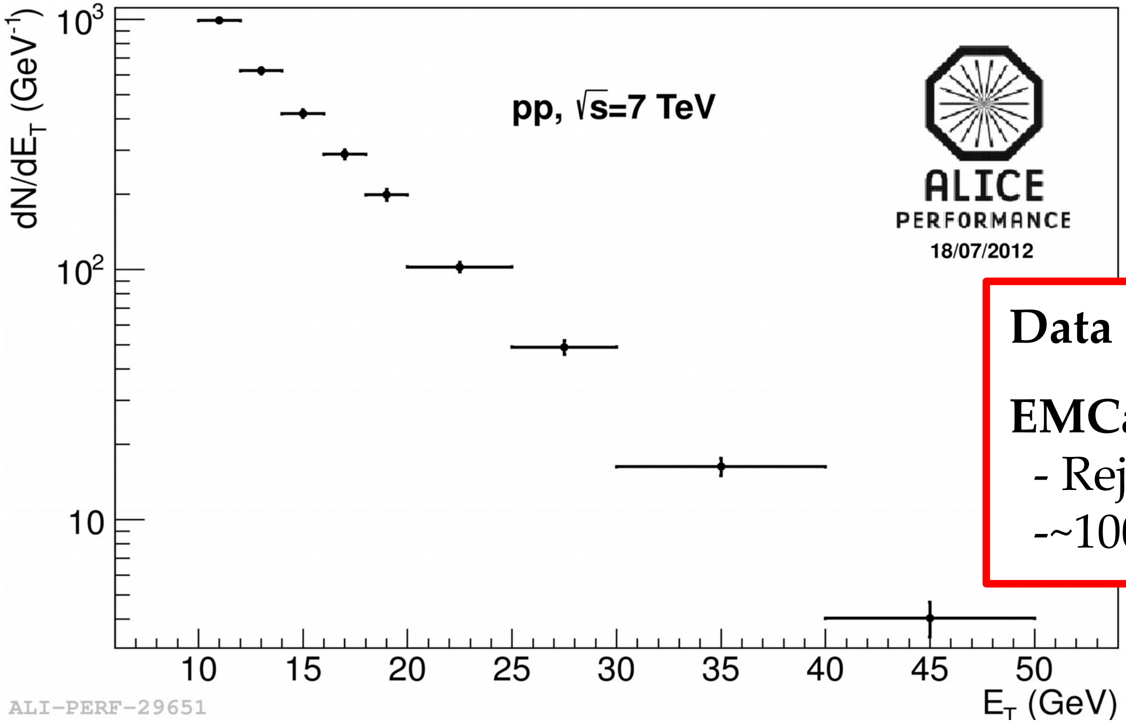
Yield is extracted substracting the BG ISO distribution from Signal + BG one





ISO distributions for 2 E_T bins

Isolated photons in pp collisions at $\sqrt{s}$ = 7 TeV



Data set: ~10M events (2011 data)

EMCal Trigger (threshold ≈ 5 GeV)
- Rejection factor ~3000
- ~100 x more luminosity

- E_T range covered is complementary with ATLAS and CMS measurements

	p_T range (GeV/c)	η range	reference
CMS	21-300 / 25–400	$\|\eta\| < 1.45$ / < 2.5	Phys.Rev.Lett.106 082001 /Phys.RevD84 052011
ATLAS	15-100 / 45-400 100-1000	$\|\eta\| < 1.81$ / < 2.37 $\|\eta\| < 1.37$	Phys.Rev.D83 052005/ Phys.Lett. B706 150-167 Moriond 2013
ALICE (in EMCal)	10 - 60	$\|\eta\| < 0.3$	ALICE

Conclusions

ALICE can measure direct photons using two complementary methods:

Subtraction method (0.5 – 14 GeV)

- No significative direct photon signal in pp and Pb-Pb peripheral (consistent with NLO)
- Low p_T excess in central Pb-Pb is interpreted as thermal photon production with: $T = 304 \pm 51^{stat+syst}$ MeV

Isolation method (10 – 60 GeV)

- Measurement of raw isolated photons spectrum in pp at 7 TeV
- Outlook: extraction of direct photon cross-section (work ongoing)

GENERAL PERSPECTIVES

- Measurement in Pb-Pb and p-Pb with both approaches
- Measurement of the nuclear modification factor of direct photons

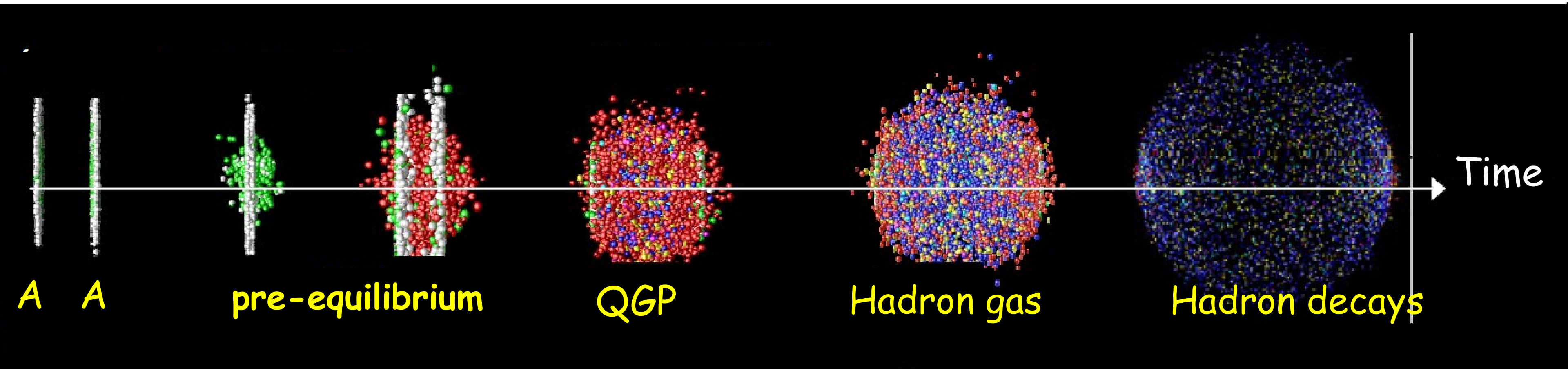
BACK UP

Photon production in HI collisions

Prompt photons:
From **hard processes** between partons

Fragmentation photons: from parton fragmentation

Decay photons from π^0 , η , ω ...

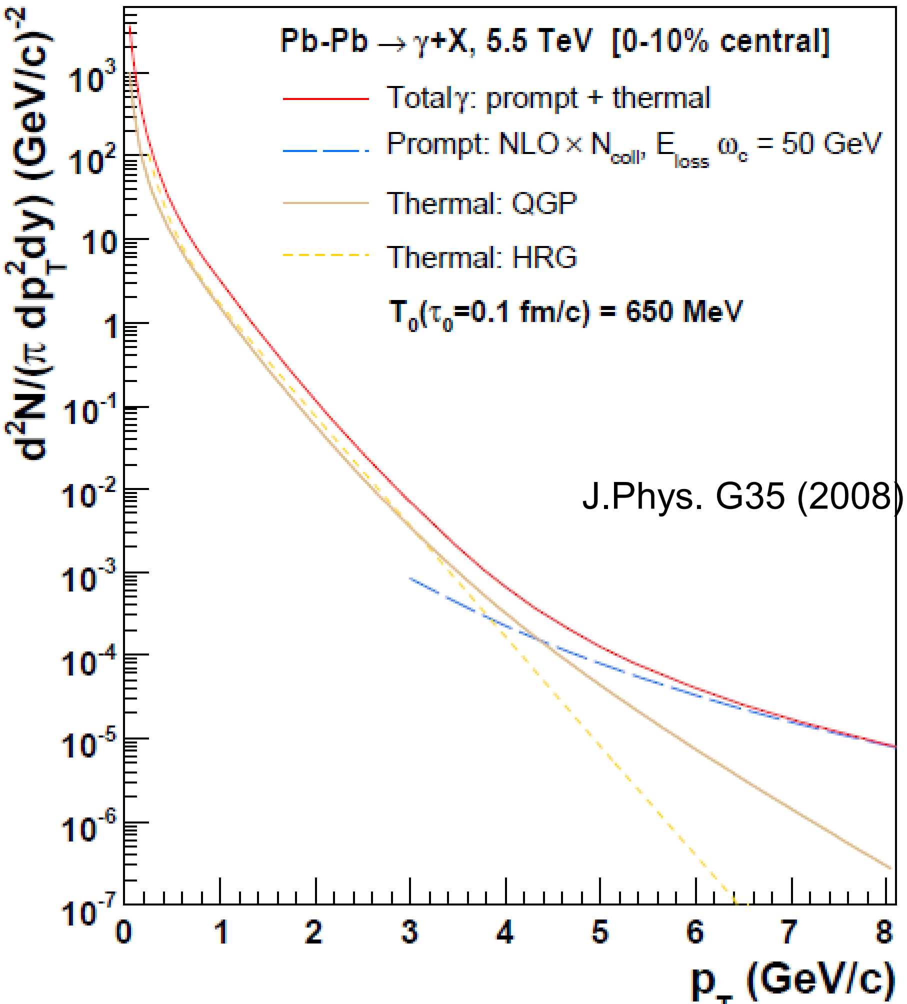


Photons from interactions between hard partons and the medium

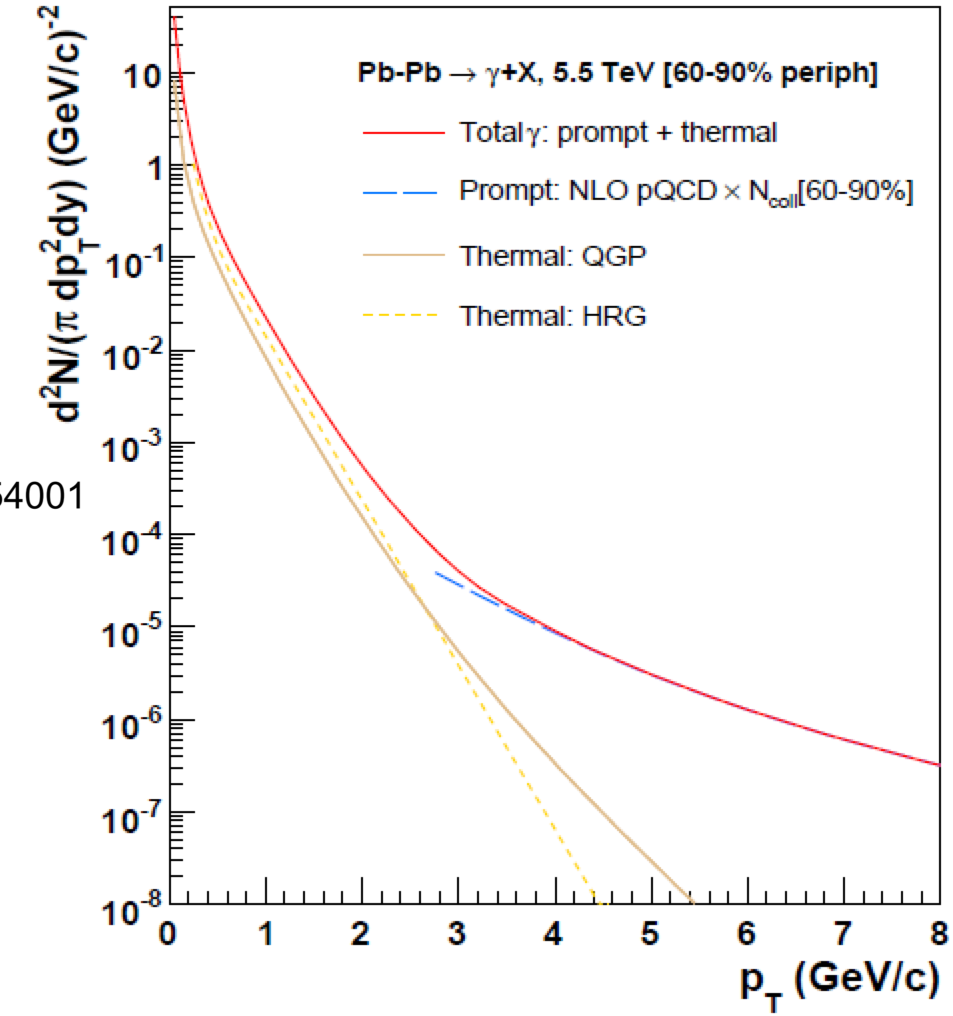
Thermal photons: from QGP or hadron gas

Direct photons: all photons that are not coming from hadron decays

Thermal photon in Pb-Pb (central vs peripheral)



J.Phys. G35 (2008) 054001



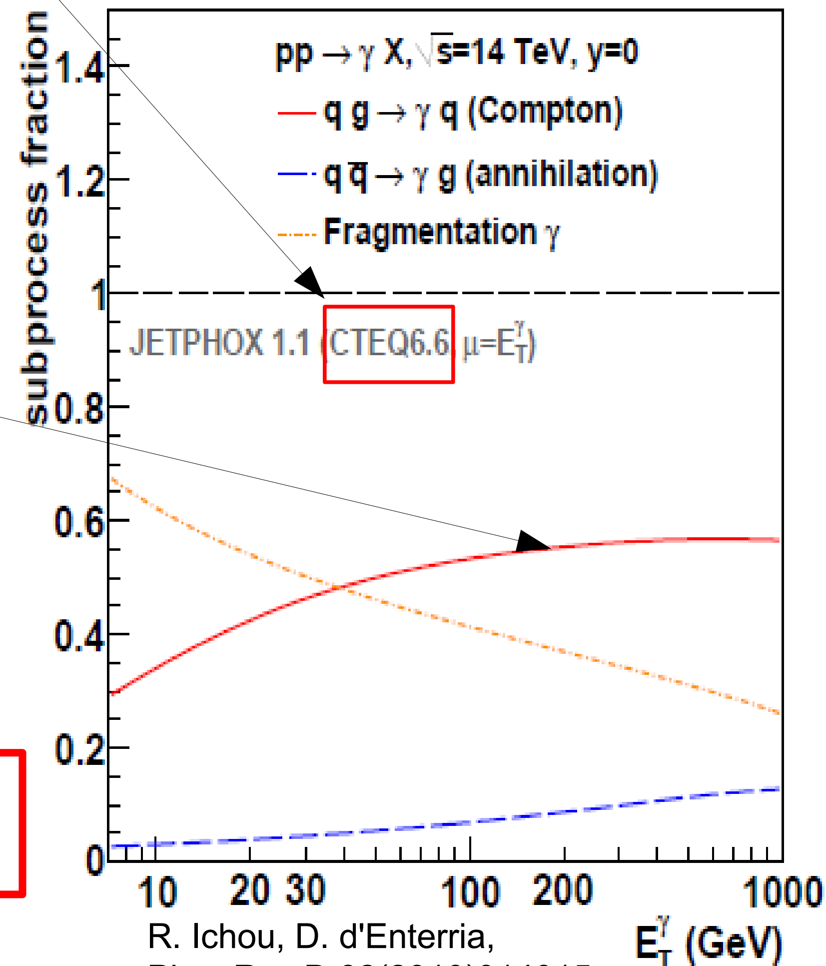
- A less important thermal photon signal is expected in peripheral collisions compared to central ones

Direct photon production: PDF constraint

- PDFs constraints ➡ accurate pQCD calculation

- Gluon has one of the least constrained PDF

Compton process is the dominant channel of direct photon production at LHC energy



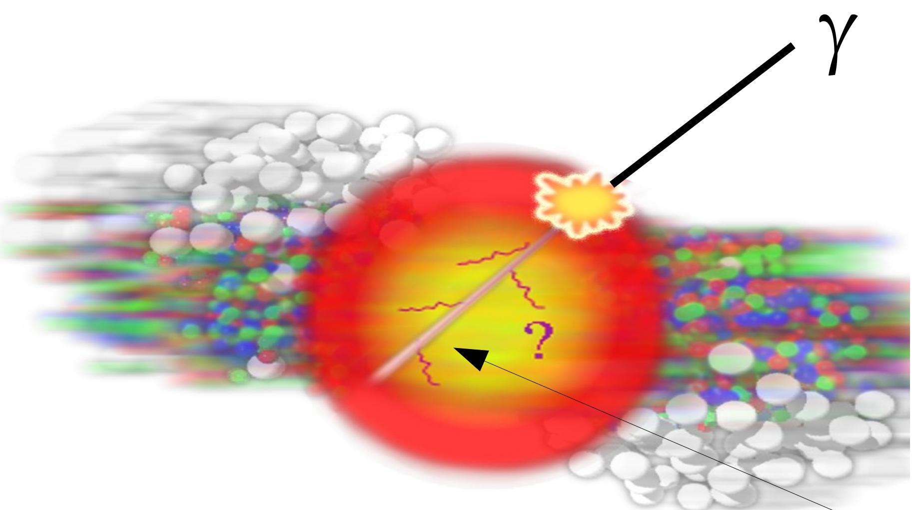
R. Ichou, D. d'Enterria, Phys.Rev D 82(2010)014015

Direct photon measurement gives a strong constraint of gluon PDF

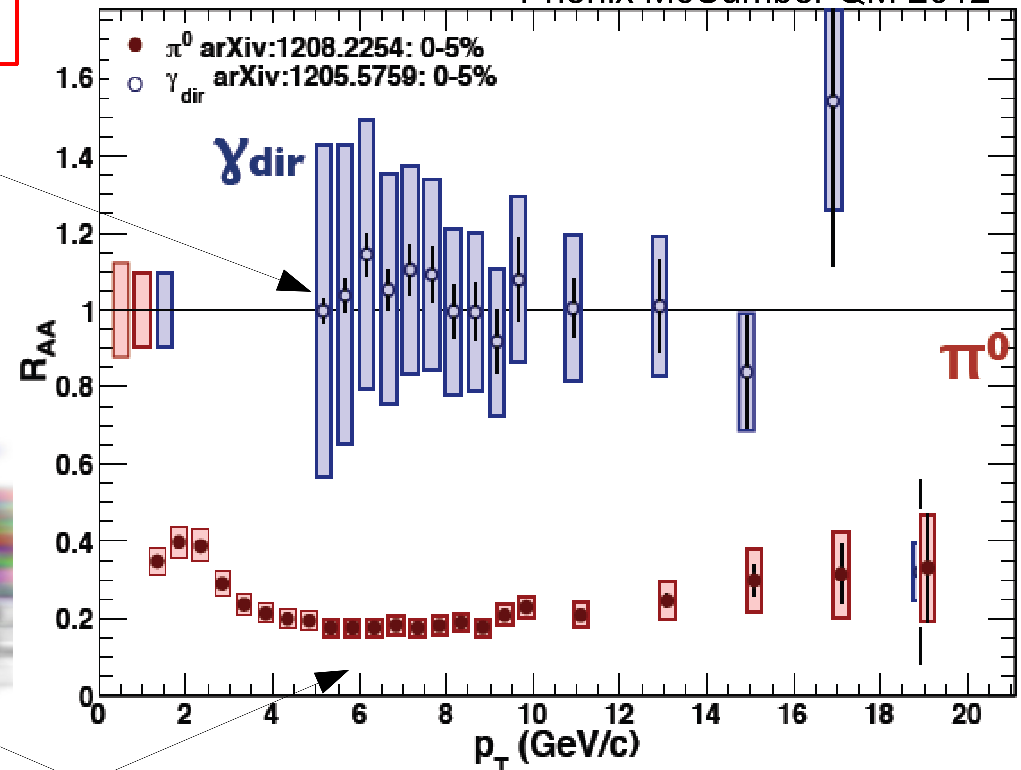
Direct photon production & jet quenching

$$R_{AA}(p_T) = \frac{d^2N_{AA}/dy\,dp_T/\langle N_{bin}\rangle}{d^2\sigma_{pp}/dy\,dp_T/\sigma_{pp}^{inel}}.$$

Photons do not interact strongly with the plasma: **access to the energy of initial hard process**

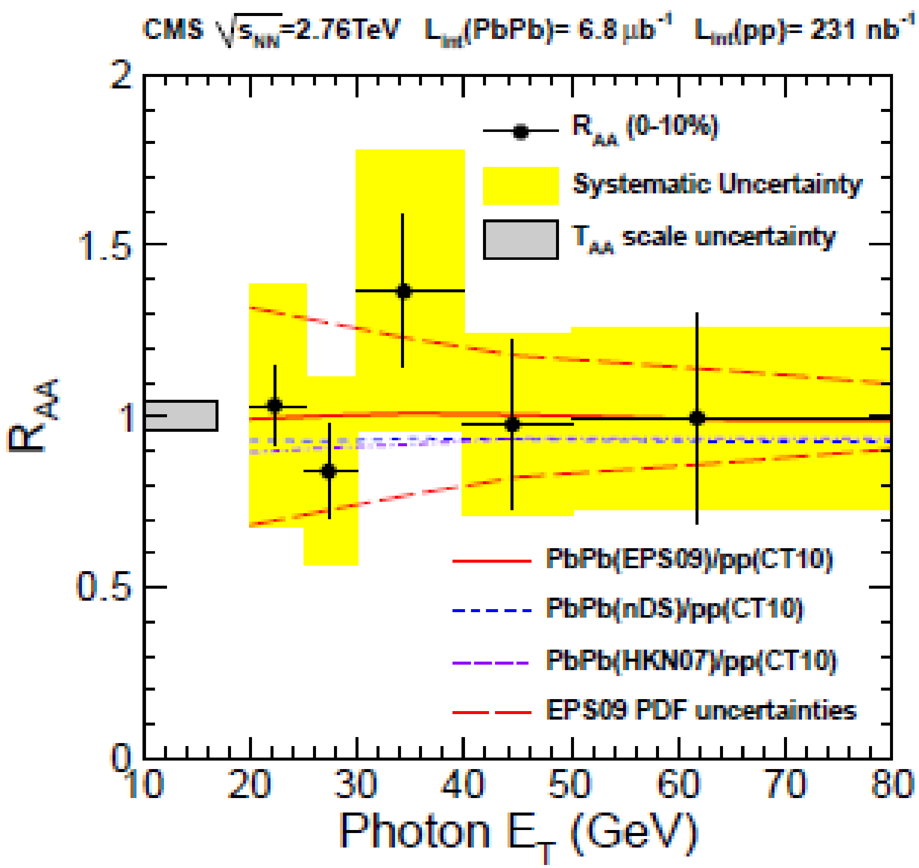


Phenix McCumber QM 2012



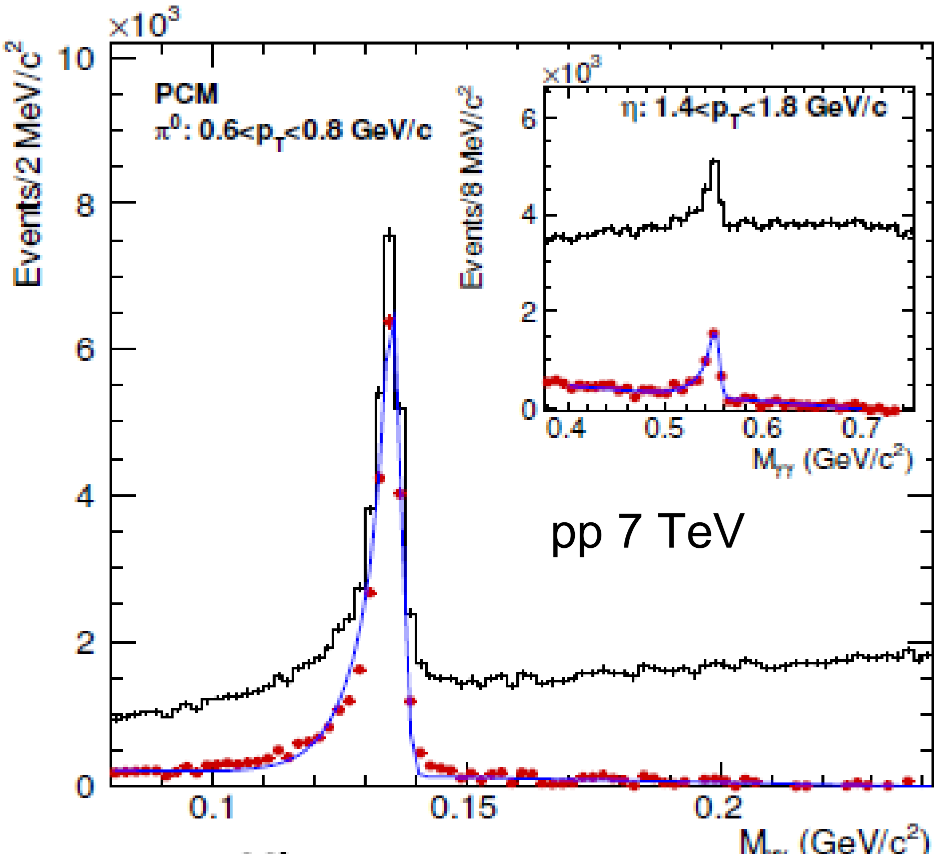
« Jet quenching »: partons loose their energy interacting with the medium **modifying their fragmentation**

R_{AA} isolated photon CMS



$$R_{AA}(p_T) = \frac{d^2N_{AA}/dy\,dp_T/\langle N_{bin}\rangle}{d^2\sigma_{pp}/dy\,dp_T/\sigma_{pp}^{inel}}.$$

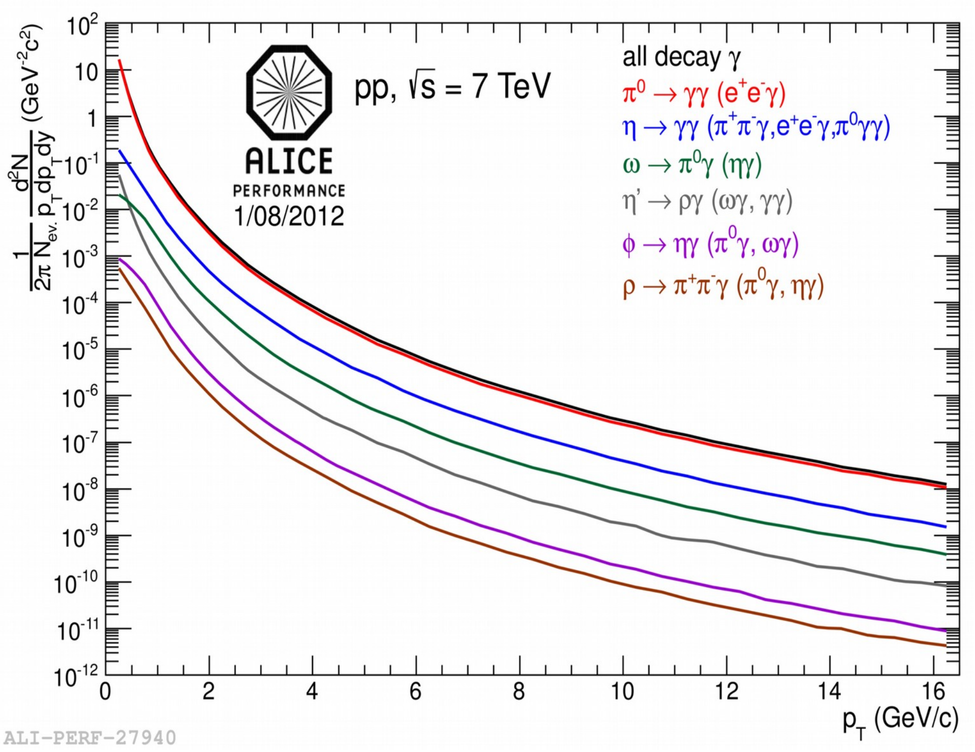
Neutral meson measurements via conversion



arXiv:1205.5724v1

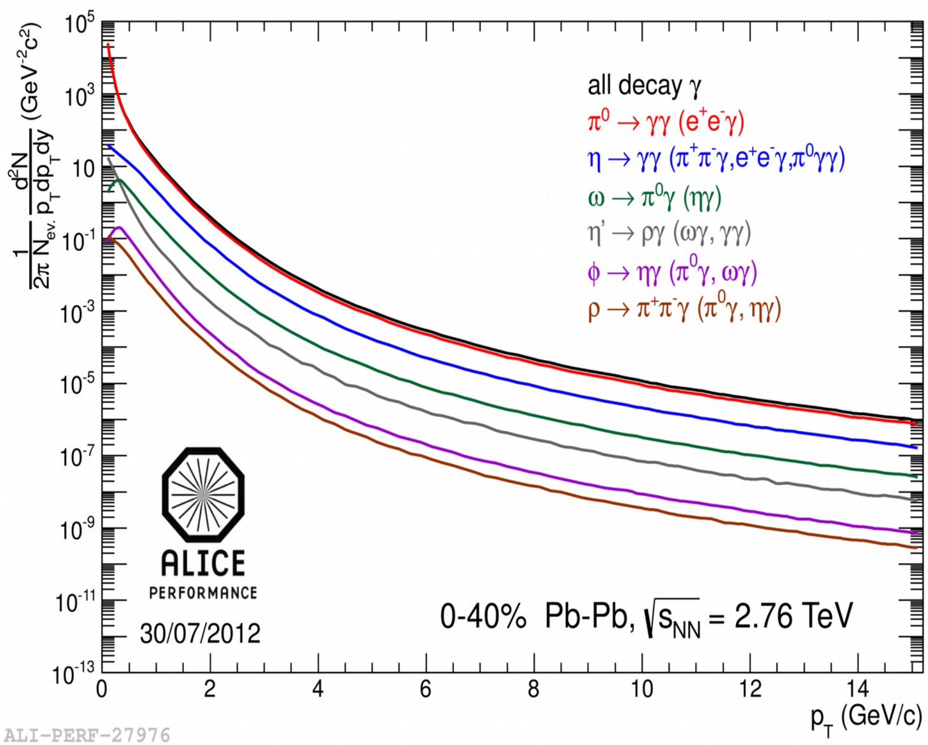
- Invariant mass spectra using conversion method

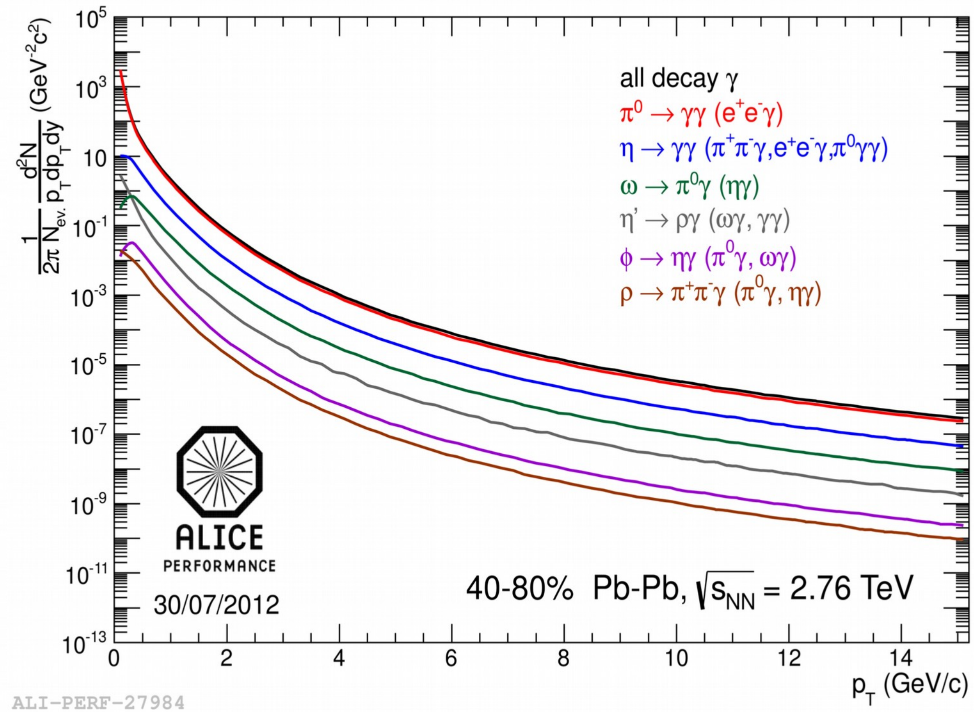
Cocktail generator pp



- Decay photon spectra from the cocktail generator (pp)

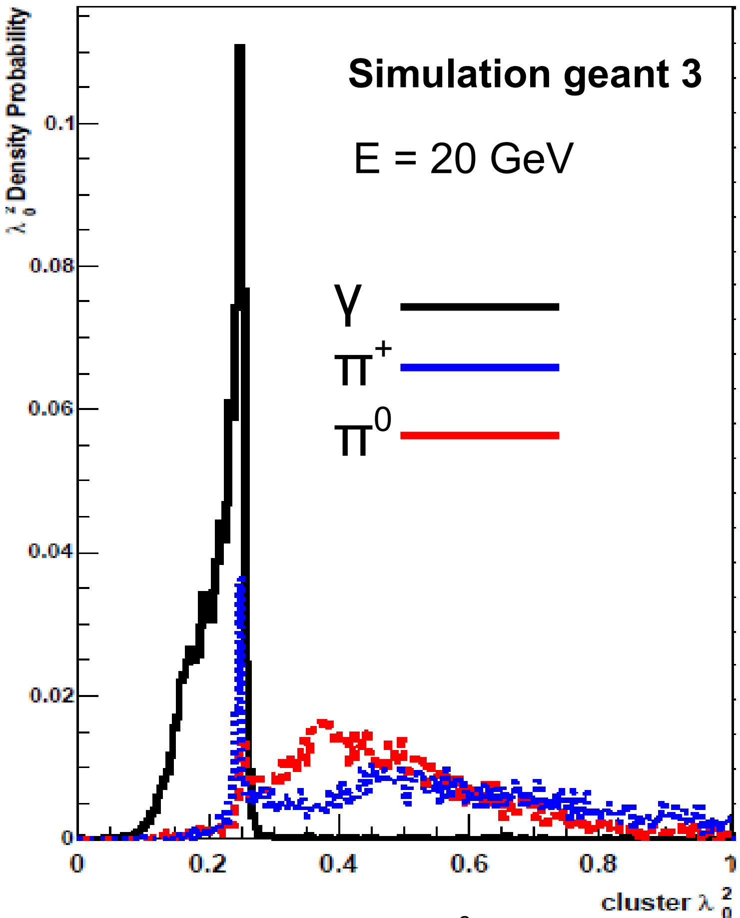
Cocktail generator Pb-Pb





- Decay photon spectra from the cocktail generator (Pb-Pb)

Photon identification

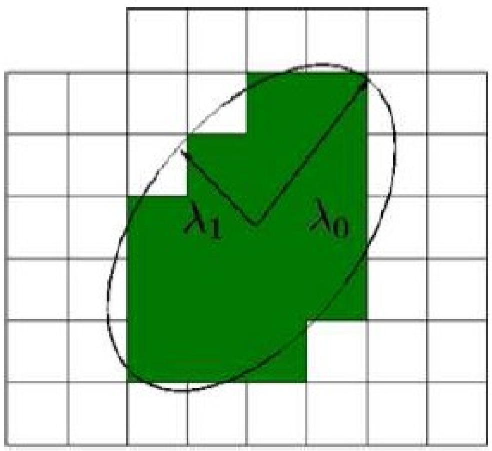


Density of probability of λ_0^2

$$\lambda_0^2 = 0.5*(d_{xx} + d_{zz}) + \sqrt{(0.25*(d_{xx} - d_{zz})^2 + d_{xz}^2}$$

$$d_{AB} = \frac{\sum_i w_i A_i B_i}{\sum_i w_i} - \frac{(\sum_i w_i A_i)(\sum_i w_i B_i)}{(\sum_i w_i)^2}$$

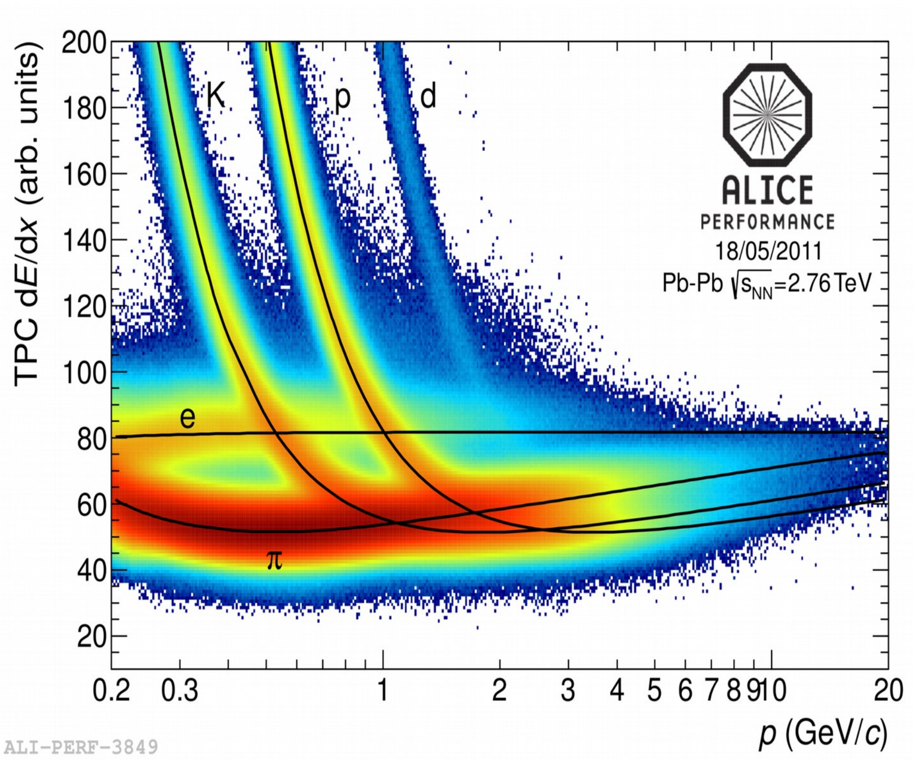
$$w_i = 4.5 - \log(\frac{E_i}{E_{cluster}})$$

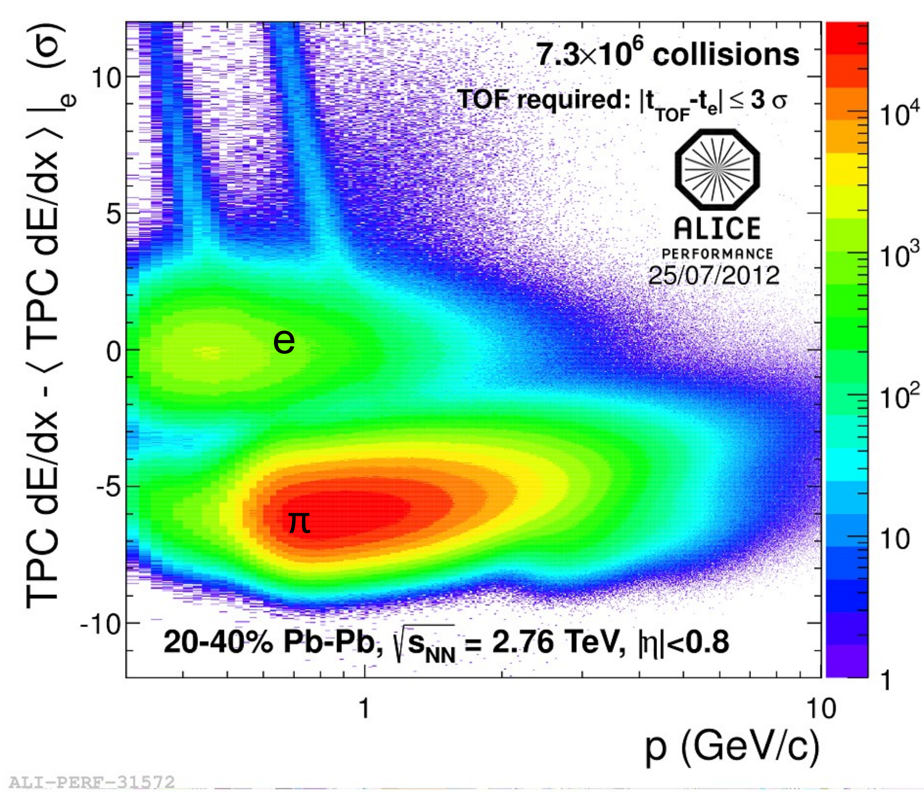


EMCal cluster

Particle identification Pb Pb

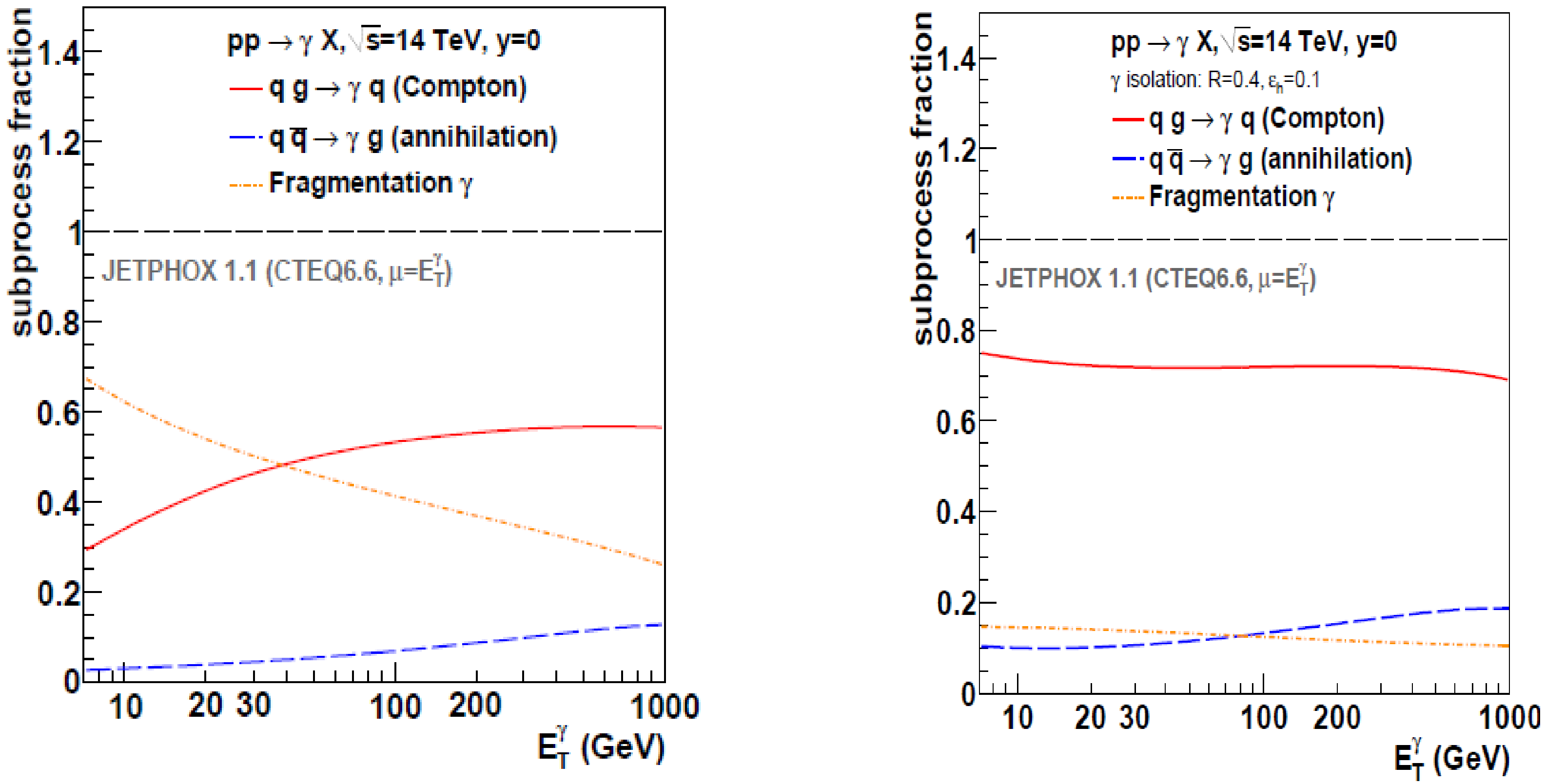
- The energy loss study allows a good seperation between electrons and pions





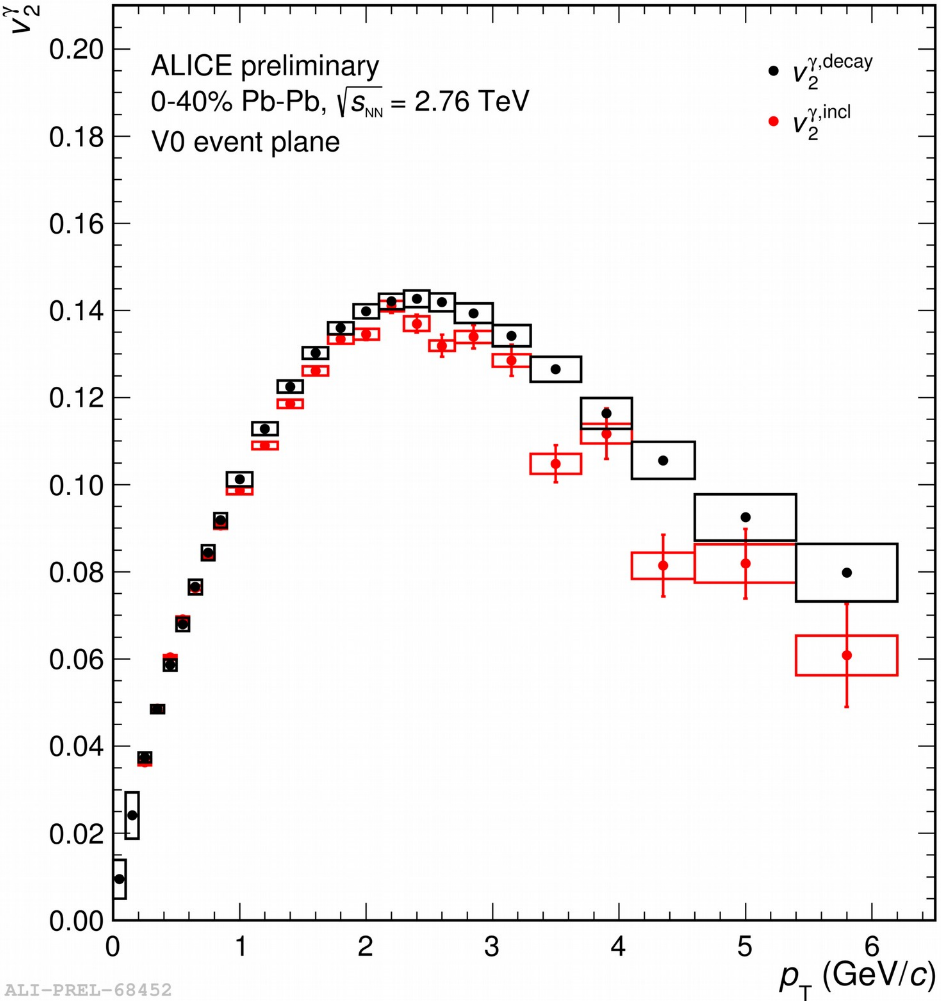
Fragmentation photon and isolation

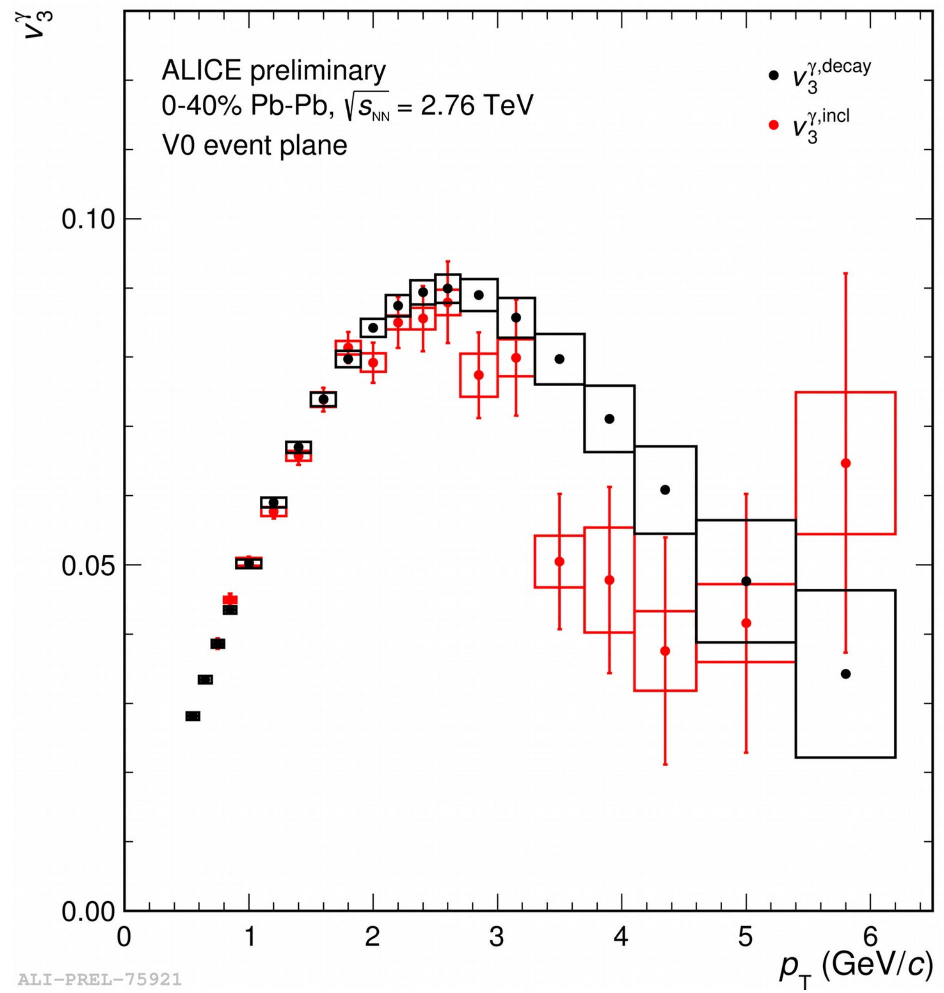
R. Ichou, D. d'Enterria, Phys.Rev D 82(2010)014015



- The isolation strongly suppress the fragmentation photon

V2 and V3 of photons





- v_2 of decay photons is higher than v_2 of inclusive photons