Neutral Meson Measurements in pp Collisions with ALICE

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outline

(1) ALICE & relevant detectors

(2) pp collisions @ 8 TeV

    I.   neutral meson (π^0, η) analysis...

        a) ...using EMCal

        b) ...using PCM - EMCal "hybrid"
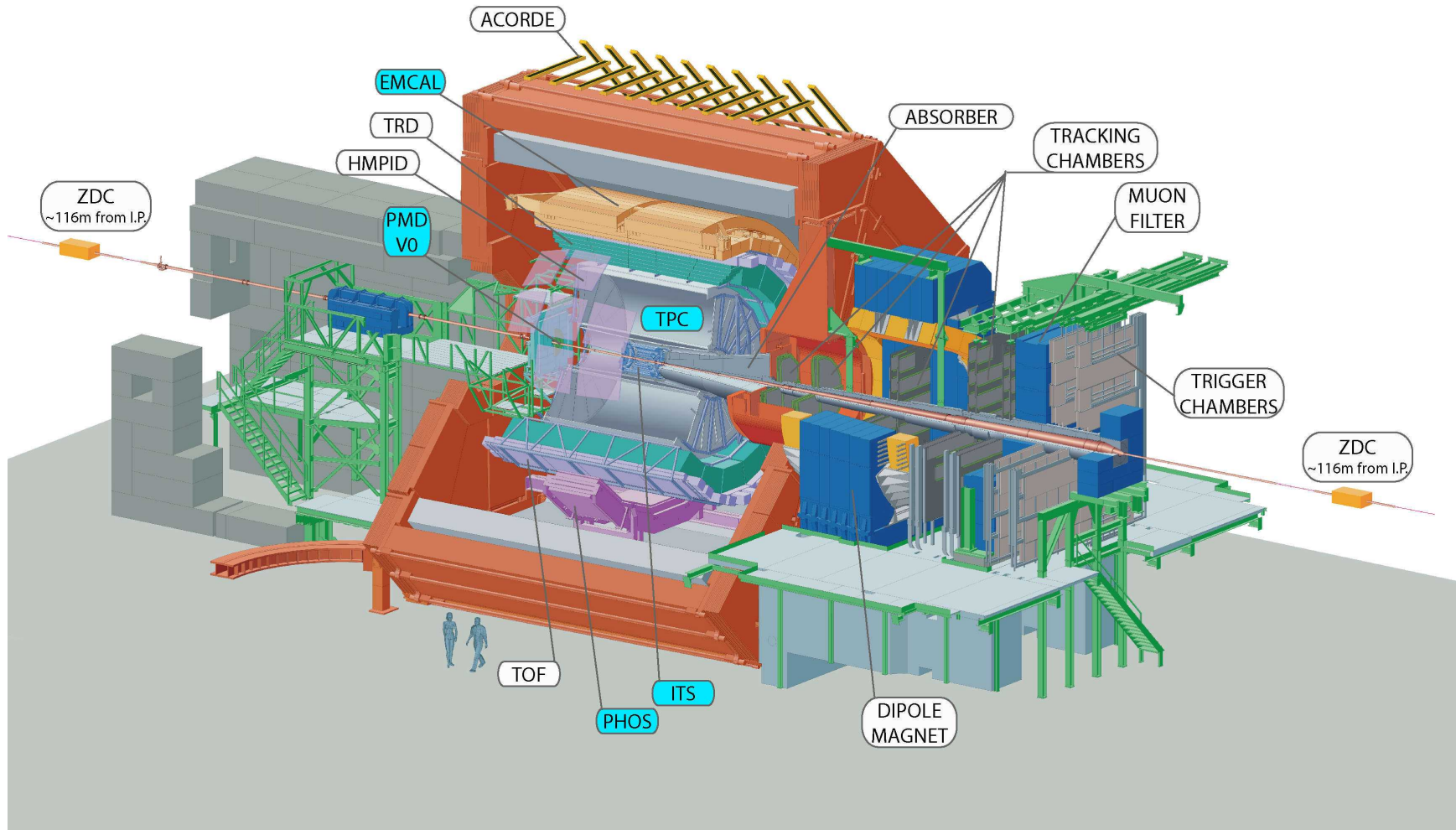
    II. results

        a) invariant cross sections

        b) η/π^0 ratio

(3) direct photons → "π^0 – tagging"

(4) ω(782) reconstruction: pp @ 7 TeV, 8 TeV

(5) outlook

ALICE

photon reconstruction in ALICE

three different methods/detectors available:

(1) ... Photon Conversion Method (PCM)

  – very high resolution, but limited in statistics (e.g. P_{conv})
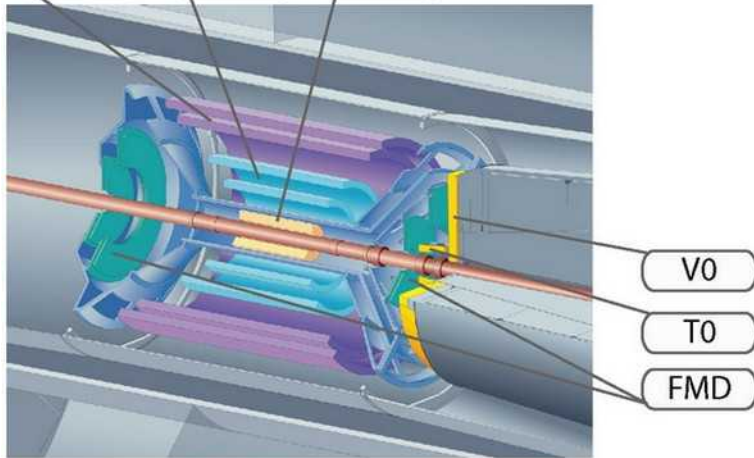
(2) ... Electromagnetic Calorimeter (EMCal)

  – trigger capabilities, decent acceptance,
    but resolution worse compared to other two systems
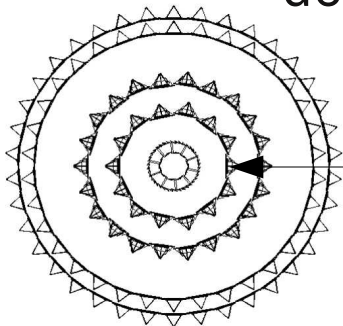
(3) ... Photon Spectrometer (PHOS)

  – good resolution, but very limited acceptance

ALICE detectors - ITS & TPC
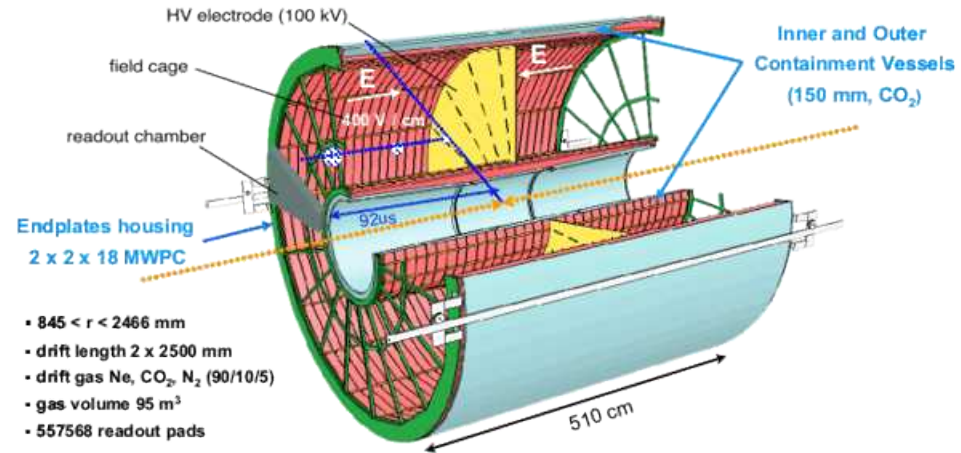
ITS – consists of three parts:

SSD   SDD   SPD

TPC
→ main tracking and PID detector

- Strip
- Drift
- Pixel

- V0
- T0
- FMD

HV electrode (100 kV)

field cage

readout chamber

Endplates housing
2 x 2 x 18 MWPC

Inner and Outer
Containment Vessels
(150 mm, CO_2)

- 845 < r < 2466 mm
- drift length 2 x 2500 mm
- drift gas Ne, CO_2, N_2 (90/10/5)
- gas volume 95 m³
- 557568 readout pads

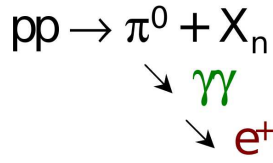510 cm

➢ tracks particles
down to 100 MeV/c

ITS radial structure,
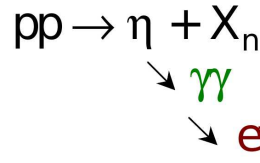as seen in beam direction

➢ currently filled with 95 m³
Ar-CO2

➢ tracks particles down to 100
MeV/c (primary) or 50 MeV/c
(secondary) up to 100 GeV/c
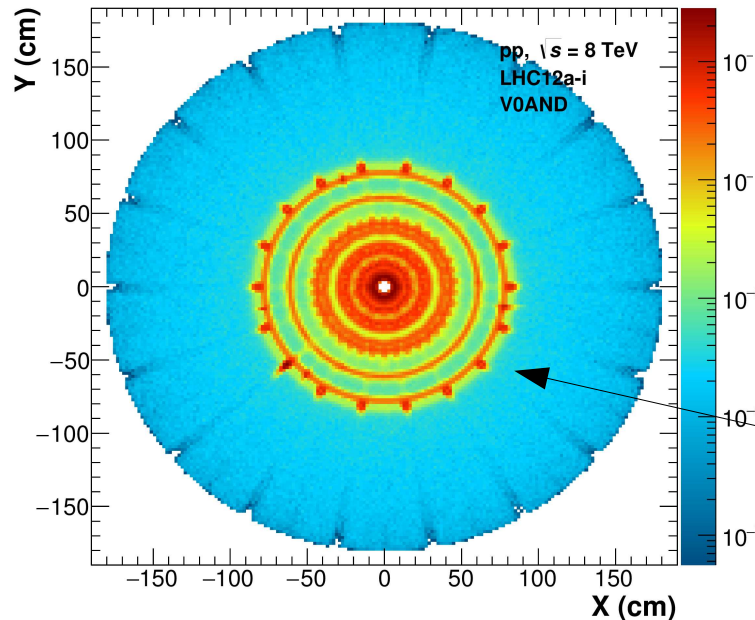
Photon Conversion Method (PCM)

$$pp \rightarrow \pi^0 + X_n$$
$$\searrow \gamma\gamma$$
$$\searrow e^+e^-\ e^+e^-$$

$(m_{\pi^0} = 0.135\ \text{GeV}/c^2,\ BR_{\gamma\gamma} = 0.988)$

$$pp \rightarrow \eta + X_n$$
$$\searrow \gamma\gamma$$
$$\searrow e^+e^-\ e^+e^-$$

$(m_\eta = 0.548\ \text{GeV}/c^2,\ BR_{\gamma\gamma} = 0.393)$

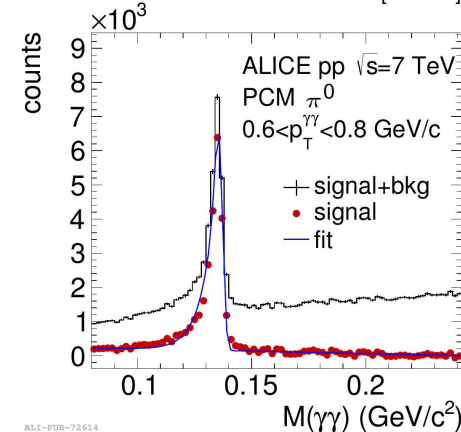Perf. of the ALICE Experiment at the CERN LHC
arXiv:1402.4476 [nucl-ex]

> high resolution
> high momentum reach depending on statistics
> conversion probability (~8.5%)
> acceptance

$$|\eta| < 0.9, 0 < \phi < 2\pi$$

(X/Y) of photon conversions

pp, $\sqrt{s}$ = 8 TeV
LHC12a-i
V0AND

ALICE pp $\sqrt{s}$=7 TeV
PCM π^0
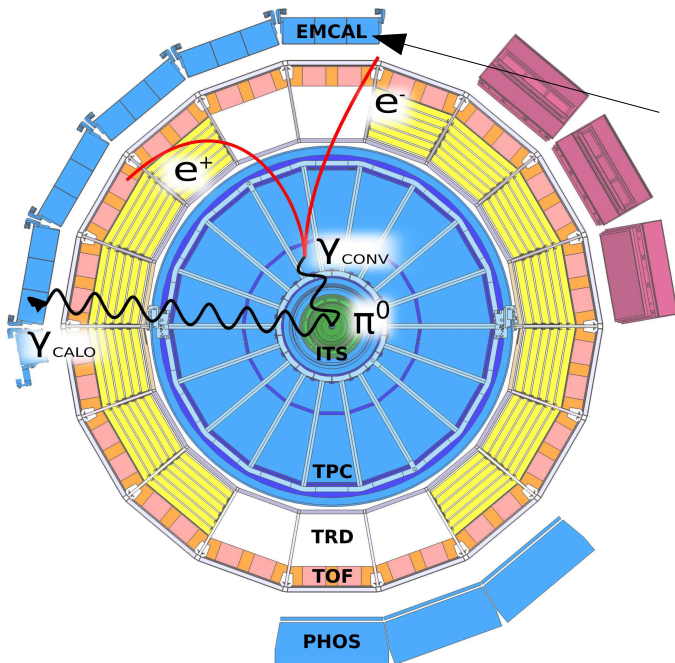$0.6 < p_T^{\gamma\gamma} < 0.8$ GeV/c

+ signal+bkg
• signal
— fit

$$\sigma_{\pi^0} \approx 2\,\text{MeV}/c^2$$

"detector tomography" using photon conversions

ALICE detector - EMCal

➢ shashlik calorimeter

  ◆ alternating layers of scintillator/lead, in total ~25 cm $(X_0 \approx 20)$

➢ 10 active super modules composed of 24 x 12 modules, every module → 4 towers → each ~6cm x 6cm (in total 11520 towers)
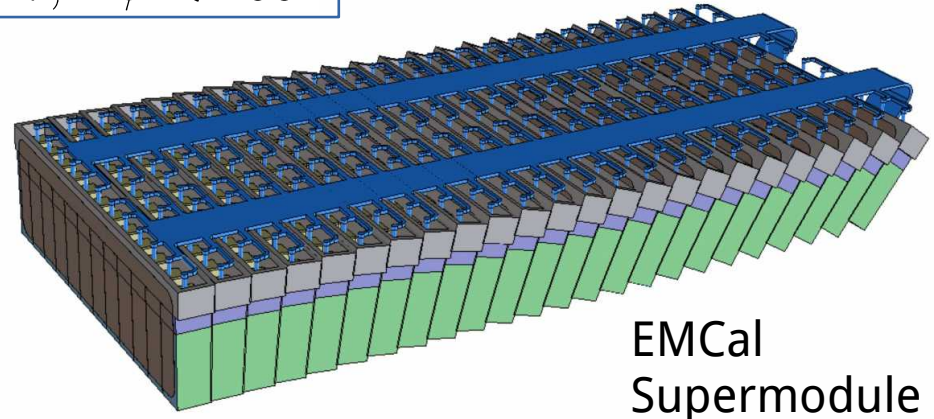

ALICE with EMCal, acceptance:

$$|\eta| < 0.7, \Delta\phi < 100°$$

EMCal Module

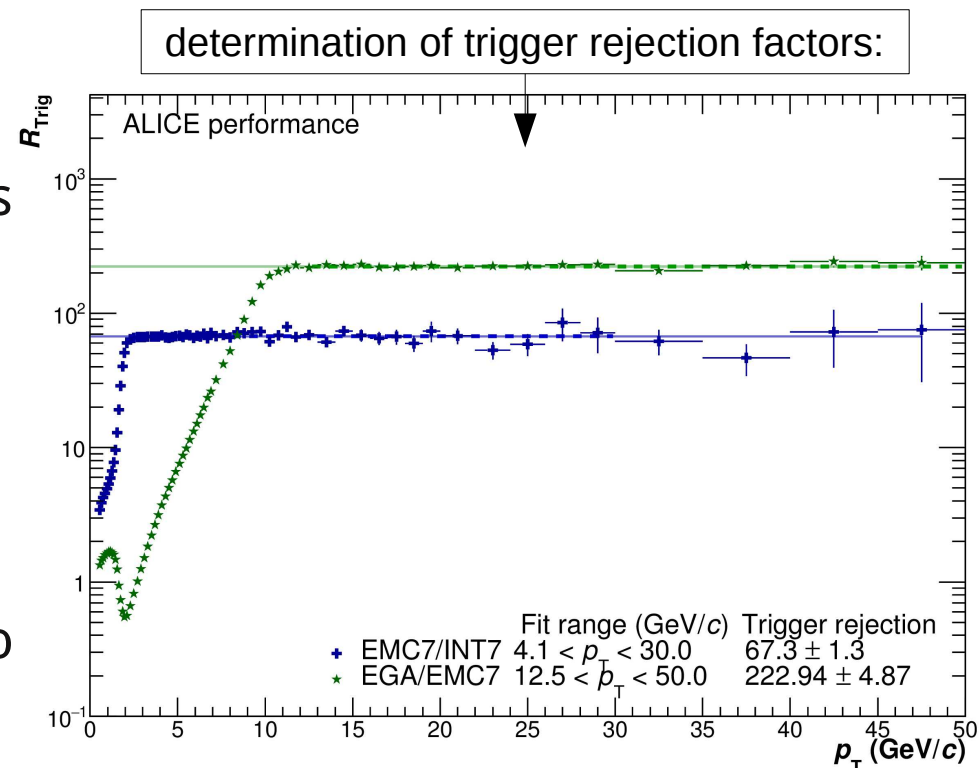EMCal Supermodule

Electromagnetic Calorimeter (EMCal)

➢ improved energy calibration of EMCal by making use of good resolution of PCM photon with PCM-EMCal "hybrid"

➢ signals on cell level need to be grouped into so-called 'clusters'
→ clusterizer (V1, V2, …)

■ using V2-clusterizer
  i. starts with cluster seeds
  ii. adding adjacent cells with certain minimum energy, do not add cell if energy raises again

■ shower shape
→ axes of surface ellipse

$$(\lambda_0^2, \ \lambda_1^2)$$

v2

550 MeV	
450 MeV	
350 MeV	
250 MeV	
150 MeV	
40 MeV	
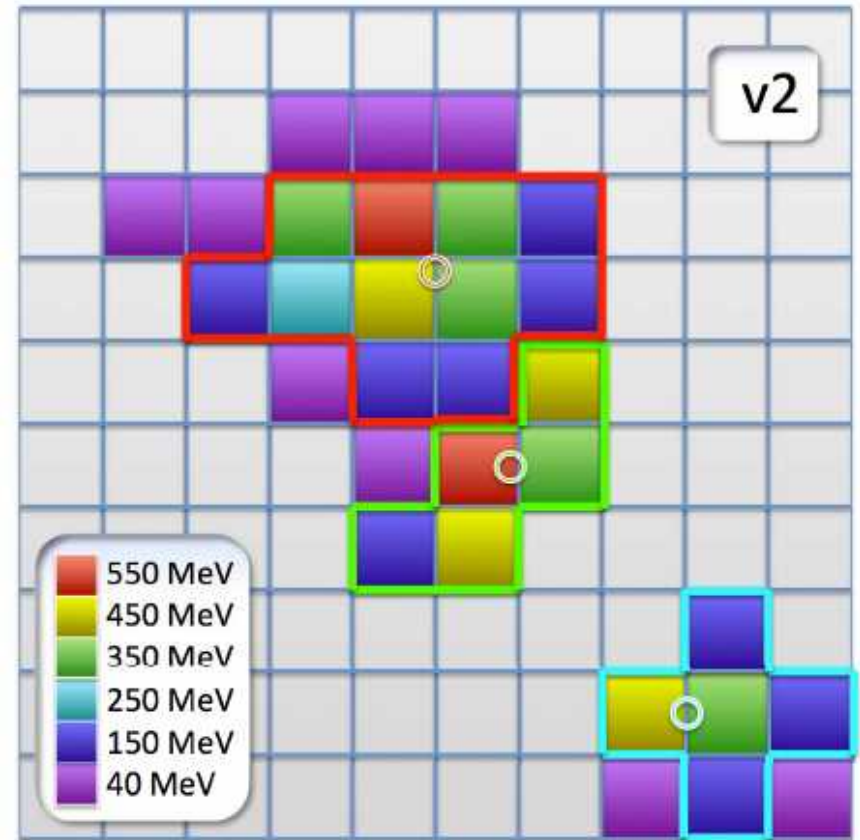
pp @ 8 TeV: data sets & triggers

➤ data taken in 2012: pp collisions @ 8 TeV, bunch spacing 50 ns

– 120 million minimum bias (V0AND, INT7)

→ recorded high statistics of EMCal triggers:

– 40 million L0 (EMC7, ~2 GeV)

– 2,5 million L1 (EGA, ~ 10 GeV)

➤ Monte Carlo simulations, min bias Pythia8 and Phojet

– in total 535 million events

– JetJet Pythia8 MC in p_T-hard bins is also available
→ need enough statistics at higher transverse momenta to be able to use triggered data

determination of trigger rejection factors:

ALICE performance

|	Fit range (GeV/c)	Trigger rejection
EMC7/INT7	$4.1 < p_T < 30.0$	67.3 ± 1.3
EGA/EMC7	$12.5 < p_T < 50.0$	222.94 ± 4.87

neutral meson analysis ...using EMCal

➢ invariant mass analysis, combining two distinct EMCal clusters

➢ mixed events → background subtraction

➢ fit Gaussian+Exponential, bin counting to determine signal

➢ corrections for
  ➔ secondaries (weak decays, material interactions)
  ➔ acceptance
  ➔ reconstruction efficiency
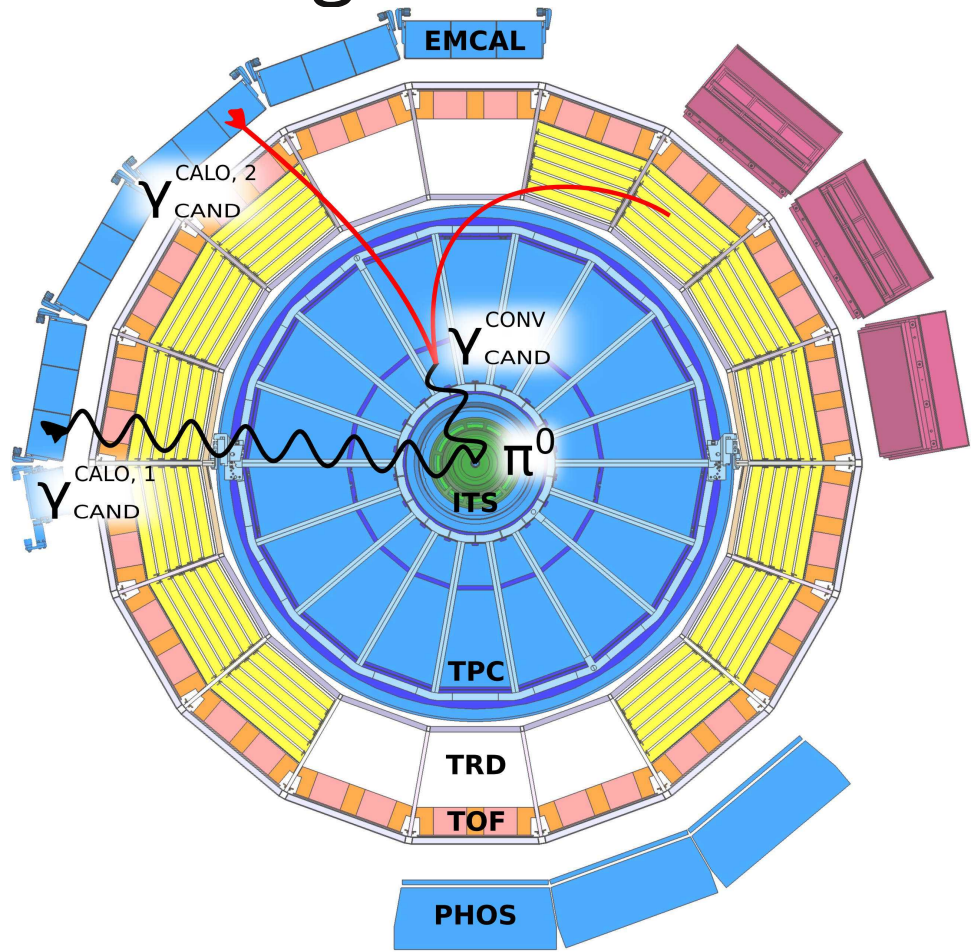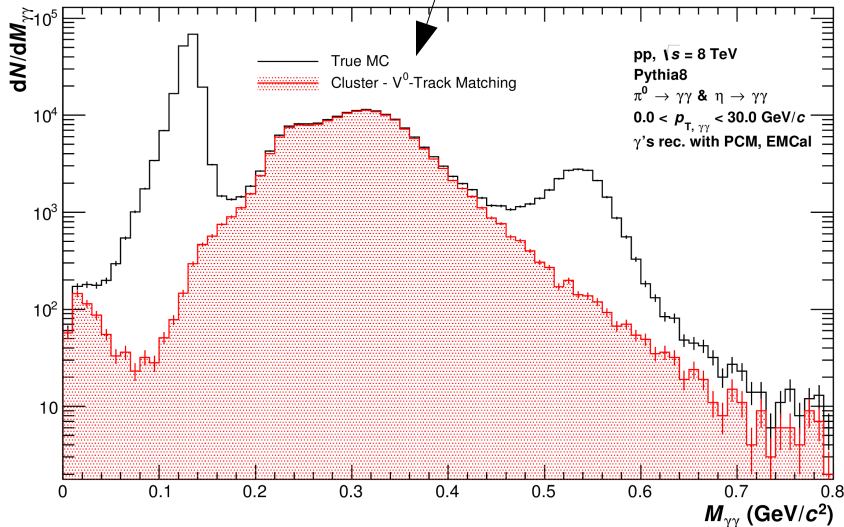 ➔ track multiplicity
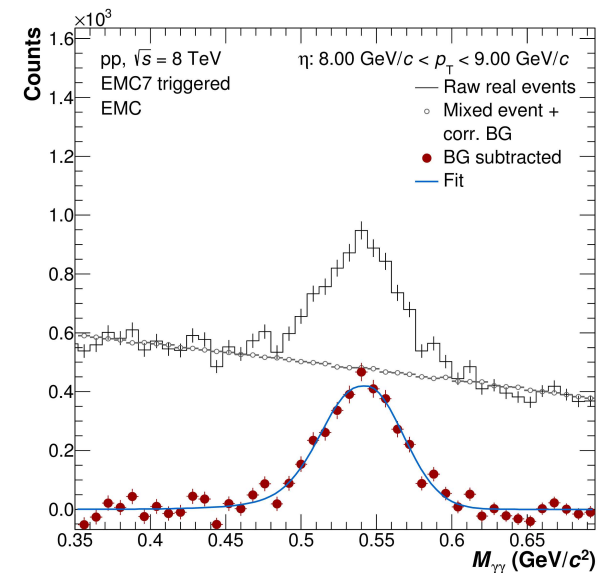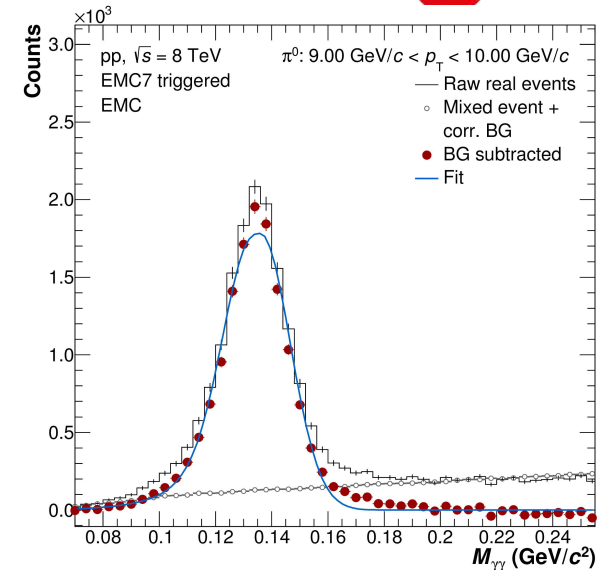
neutral meson analysis ...using PCM - EMCal

➢ invariant mass analysis, combining PCM photon candidate + EMCal cluster

    ➔ combining strengths of both systems

➢ same steps as for EMCal analysis

➢ need additional cluster ↔ V0-track matching

EMCal & PCM-EMCal:

➢ analyses performed for 'INT7', 'EMC7', 'EGA'

  – combination of different triggers using BLUE (Best Linear Unbiased Estimator)

  – determination of correlation factors for systematic errors; statistical errors fully uncorrelated
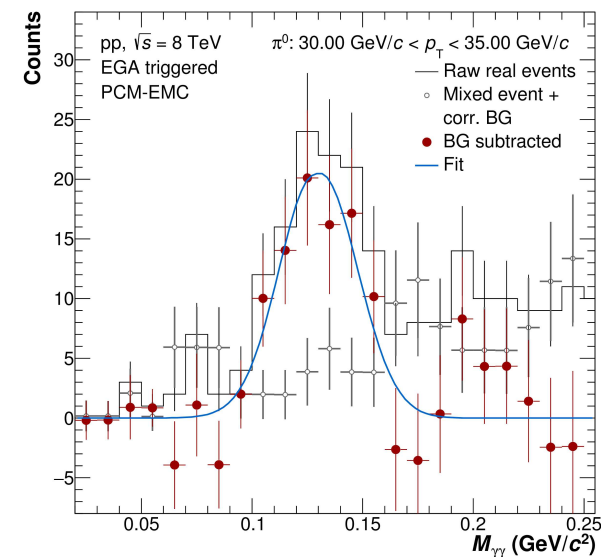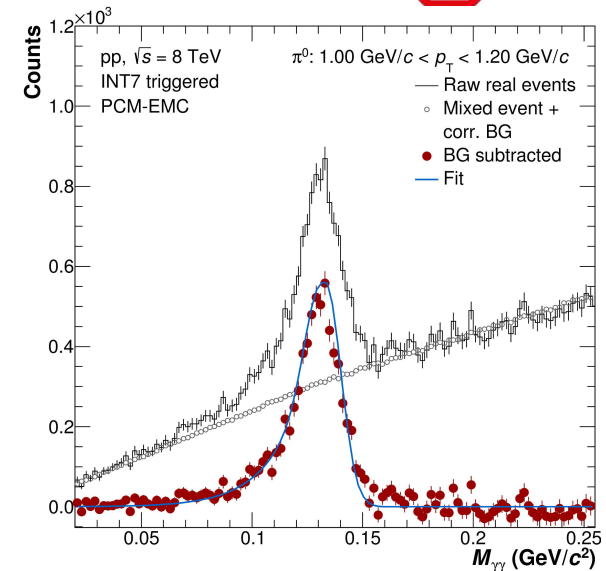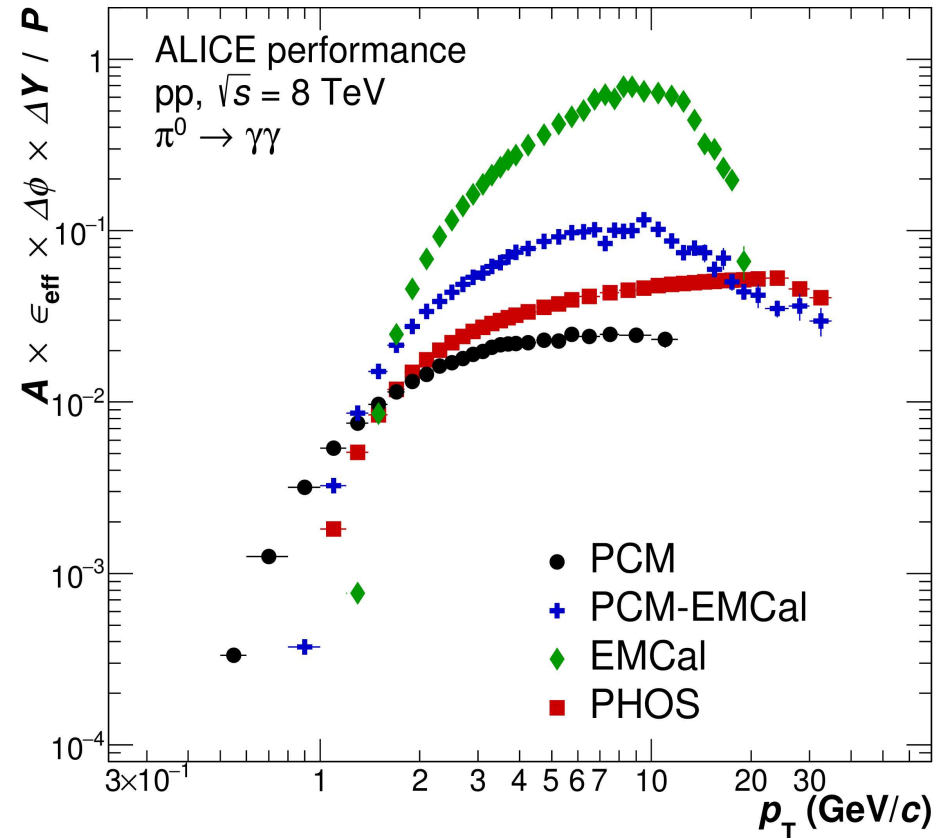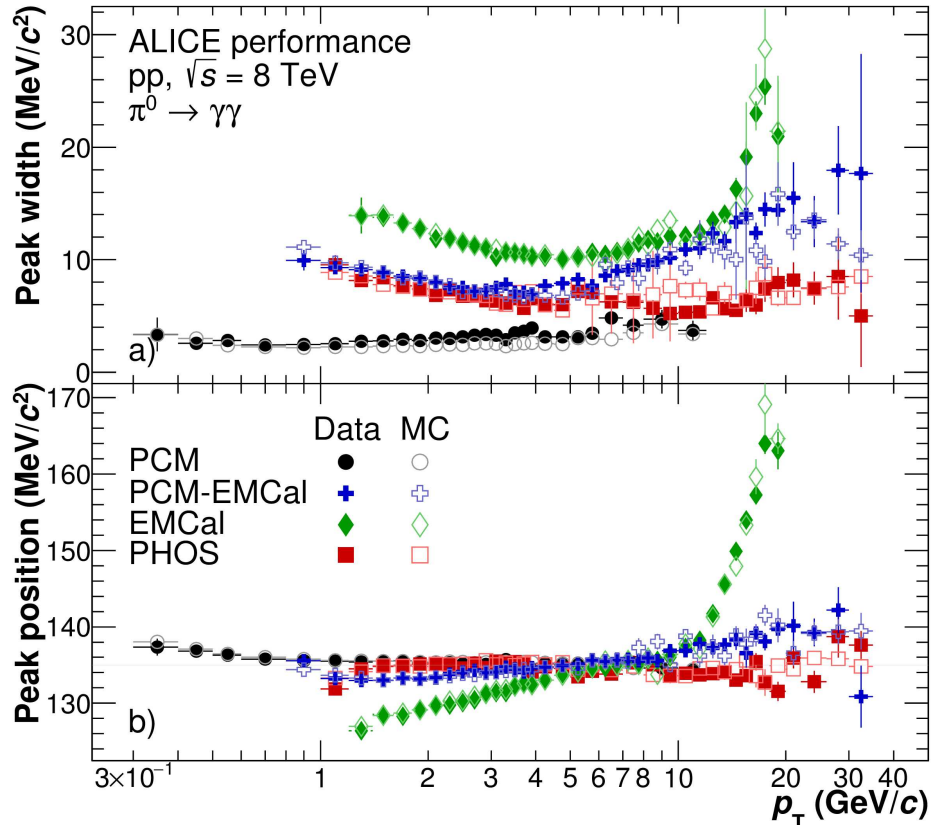
neutral meson analysis with PCM-EMCal ...cluster ↔ V0-track matching

➤ real signal

$$\rightarrow \gamma_{\mathrm{cand}}^{\mathrm{calo\ 1}} + \gamma_{\mathrm{cand}}^{\mathrm{conv}}$$

➤ but also combinations of type:

$$\rightarrow \gamma_{\mathrm{cand}}^{\mathrm{calo\ 2}} + \gamma_{\mathrm{cand}}^{\mathrm{conv}}$$

● cause broad peak between mesons:

Figure legend: True MC; Cluster - V0-Track Matching

pp, √s = 8 TeV
Pythia8
$\pi^0 \rightarrow \gamma\gamma$ & $\eta \rightarrow \gamma\gamma$
$0.0 < p_{\mathrm{T},\ \gamma\gamma} < 30.0$ GeV/c
γ's rec. with PCM, EMCal

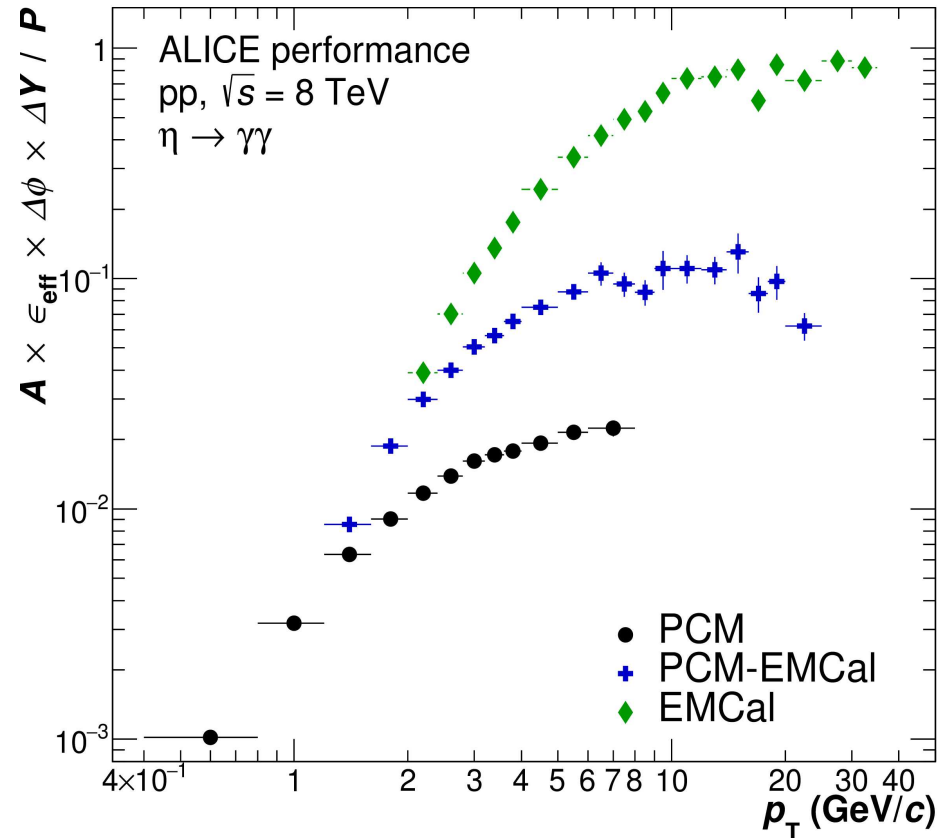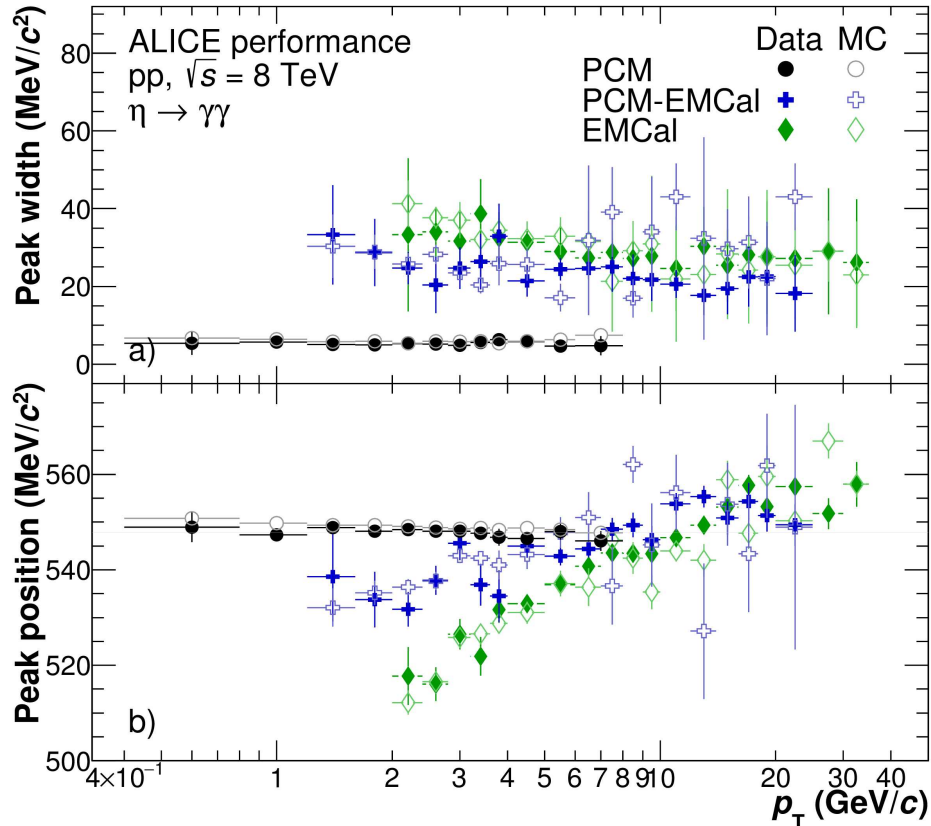# results – neutral pion

> width "ordering" (PCM < PCM-EMC < EMC)
> very reasonable agreement of data &
> Monte Carlo within errors

> lower towards high momenta due to
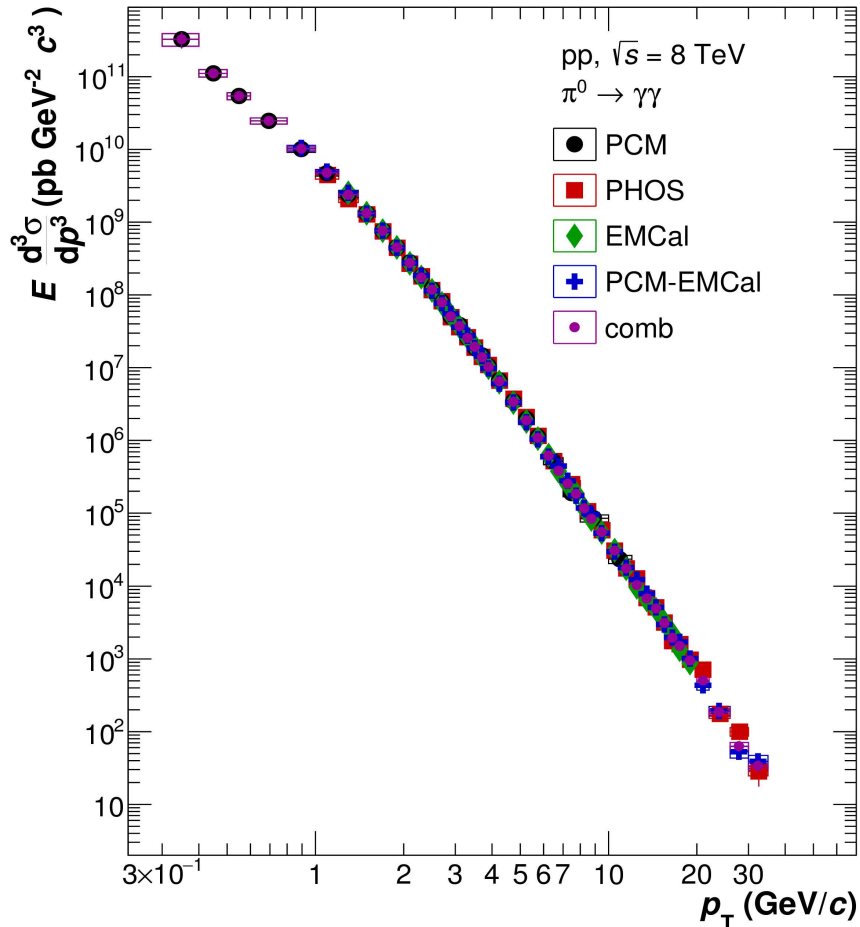> cluster merging (EMCal) &
> track matching (PCM-EMCal)

results – eta meson

ALICE performance
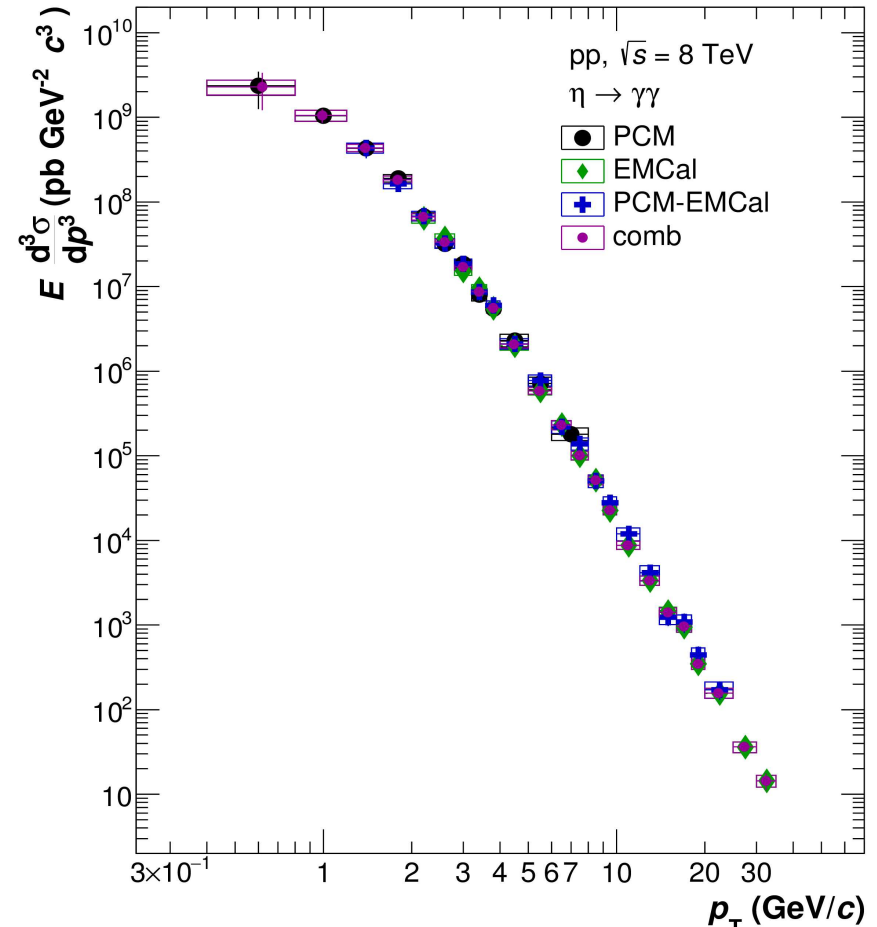pp, $\sqrt{s}$ = 8 TeV
$\eta \rightarrow \gamma\gamma$

- ➤ width "ordering" (PCM < PCM-EMC < EMC)
- ➤ very reasonable agreement of data & Monte Carlo within errors

- ➤ compared to pion no lowering at high pT
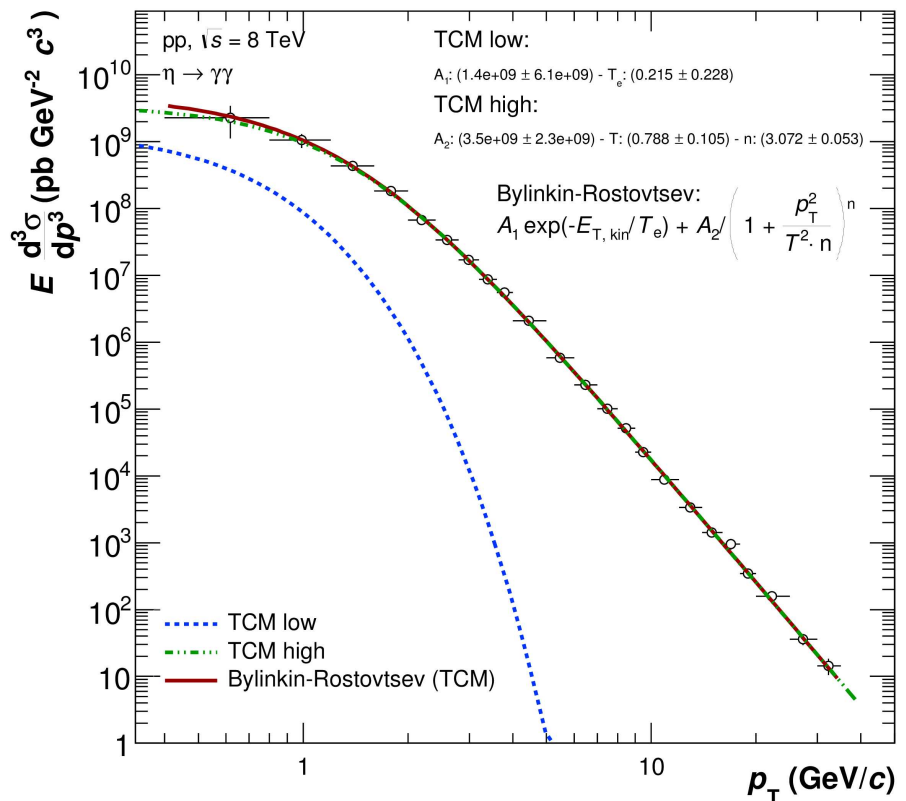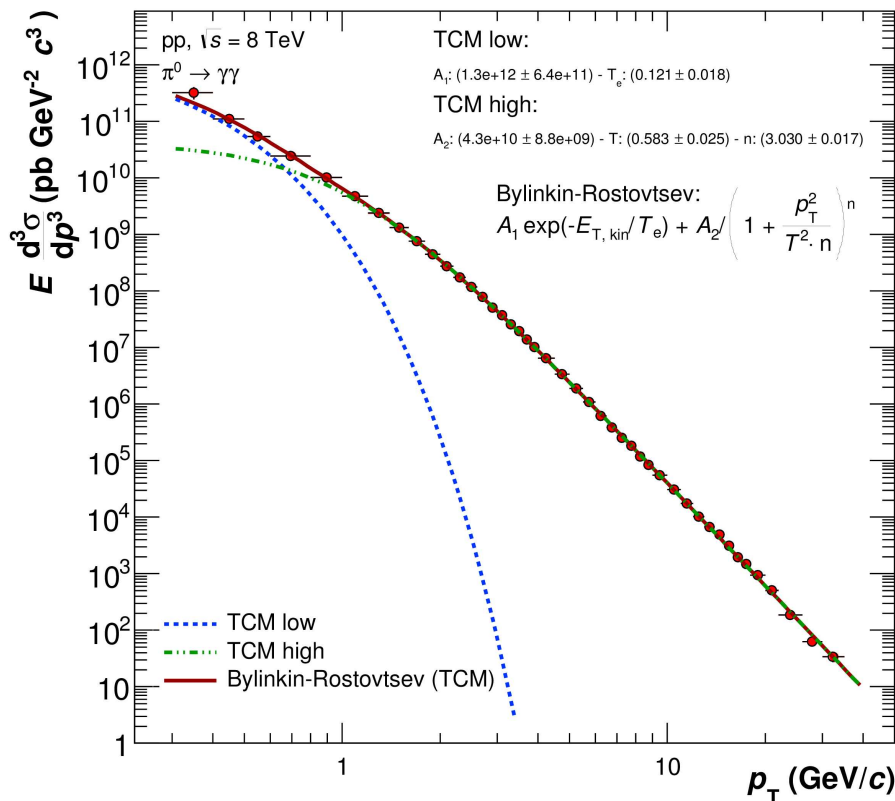
results – invariant cross sections

➢ combined pion momentum reach: $0.3 < p_T < 35.0$ GeV/c

➢ combined eta momentum reach: $0.4 < p_T < 35.0$ GeV/c
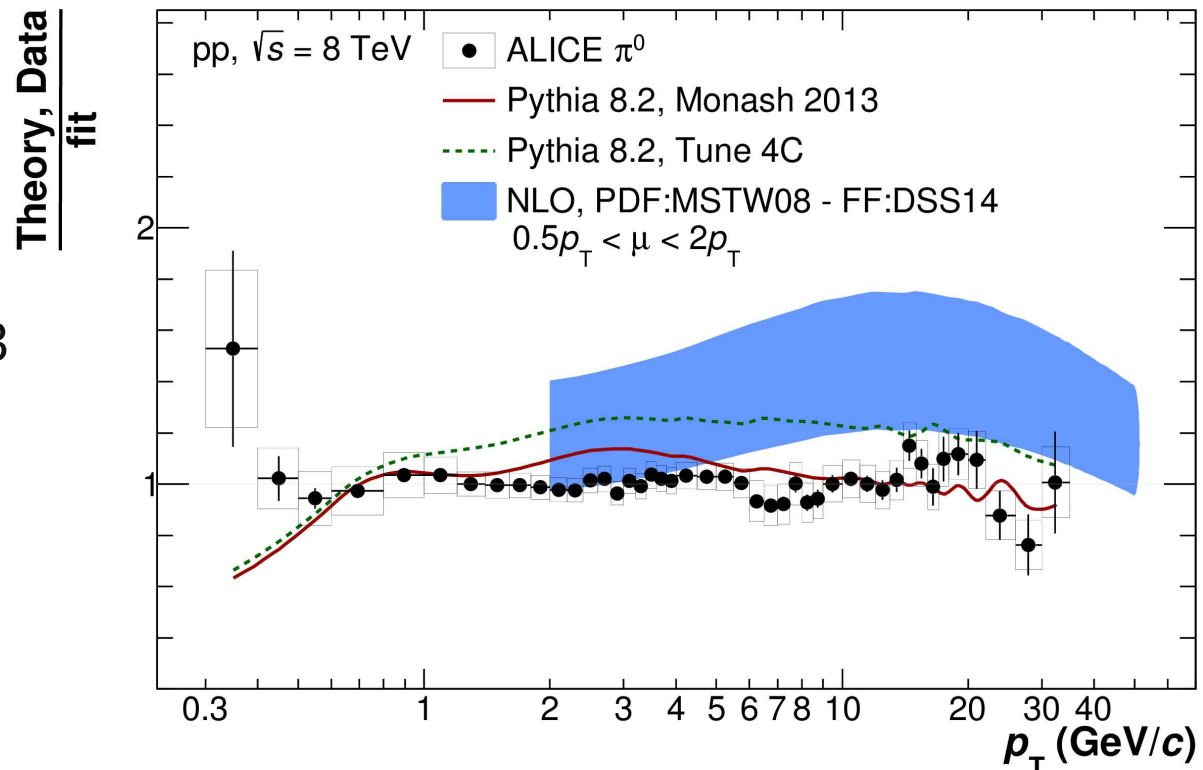
results – TCM fits to combined spectra

➢ neutral meson spectra fitted with Two-Component Model (TCM) by A. Bylinkin and A. Rostovtsev

➢ bin shift corrections (in 'X'; for upcoming η/π⁰ in 'Y') already applied

results - comparison with fit&theory

➢ invariant cross section fitted with Bylinkin-Rostovtsev (TCM, two component model)

➢ plot shows ratio of combined data points to fit & theory to fit

➢ Pythia8.2, Monash 2013 with best agreement as expected

➢ NLO calculation does decent job with FF:DSS14 (with DSS07 bigger overestimation)

pp, $\sqrt{s}$ = 8 TeV
- ● ALICE π^0
- Pythia 8.2, Monash 2013
- Pythia 8.2, Tune 4C
- NLO, PDF:MSTW08 - FF:DSS14
  $0.5p_T < \mu < 2p_T$

$\dfrac{\text{Theory, Data}}{\text{fit}}$
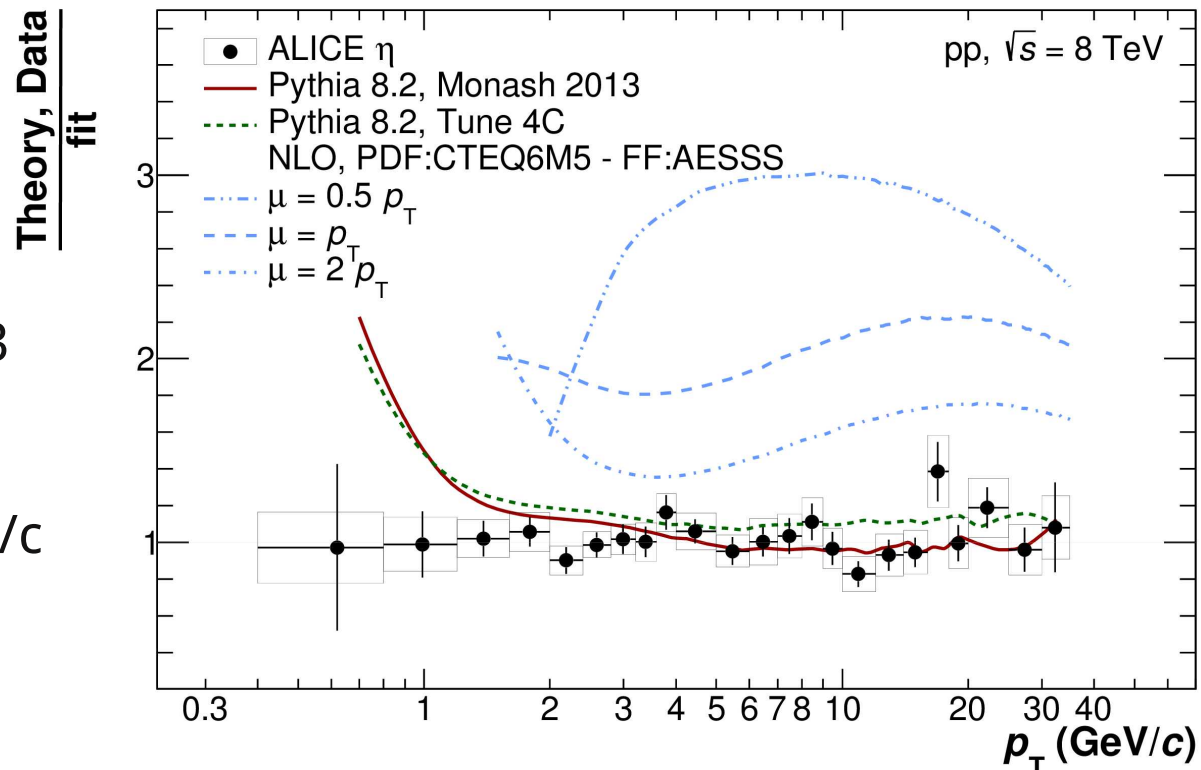
p_T (GeV/c)

results - comparison with fit&theory

➢ invariant cross section fitted with Bylinkin-Rostovtsev (TCM, two component model)

➢ plot shows ratio of combined data points to fit & theory to fit

➢ Pythia8.2, Monash 2013 with best agreement as expected, but clear deviation below ~1 GeV/c

➢ NLO calculation with FF:AESSS clearly overestimates yield

results – η/π⁰ ratio

- ➢ available for momentum range of $0.4 < p_T < 25.0$ GeV/c in 8 TeV

- ➢ η/π⁰ ratio compared with other ALICE measurements at different energies, good agreement within errors

- ➢ η/π⁰ ratio compared with available theory calculation

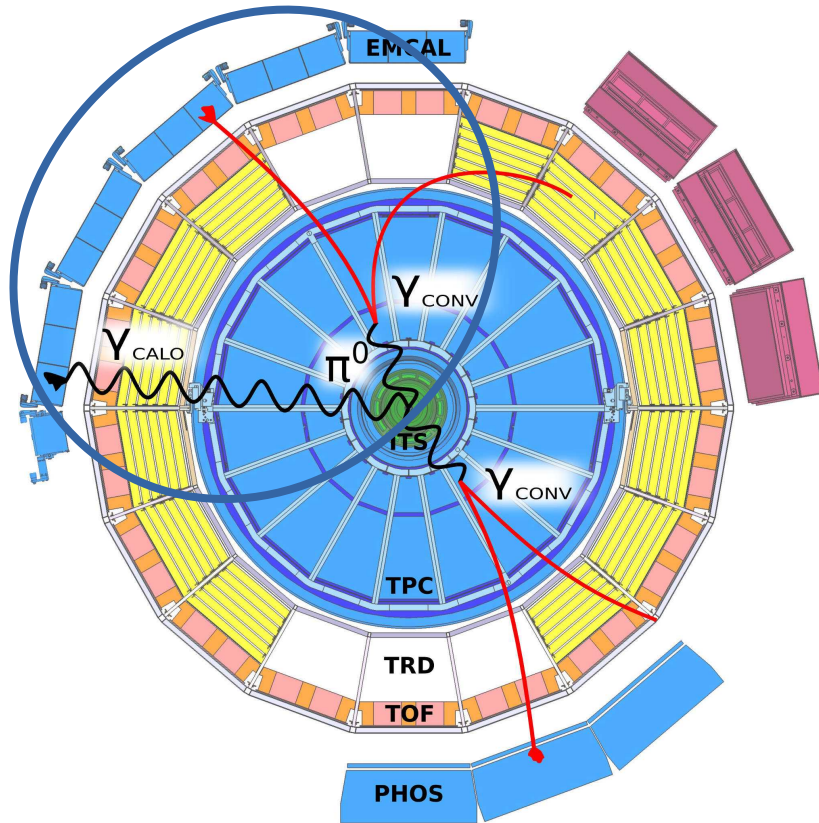- ➢ data indicates little higher ratio than calculations
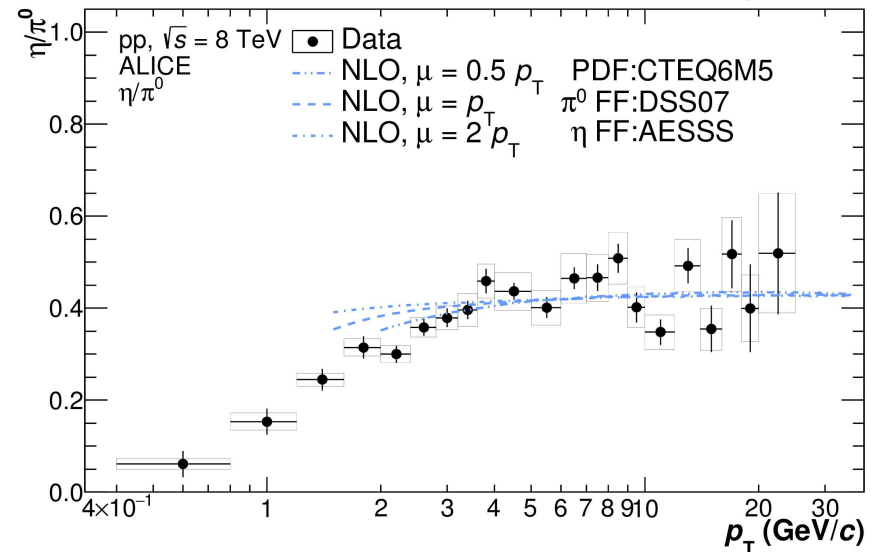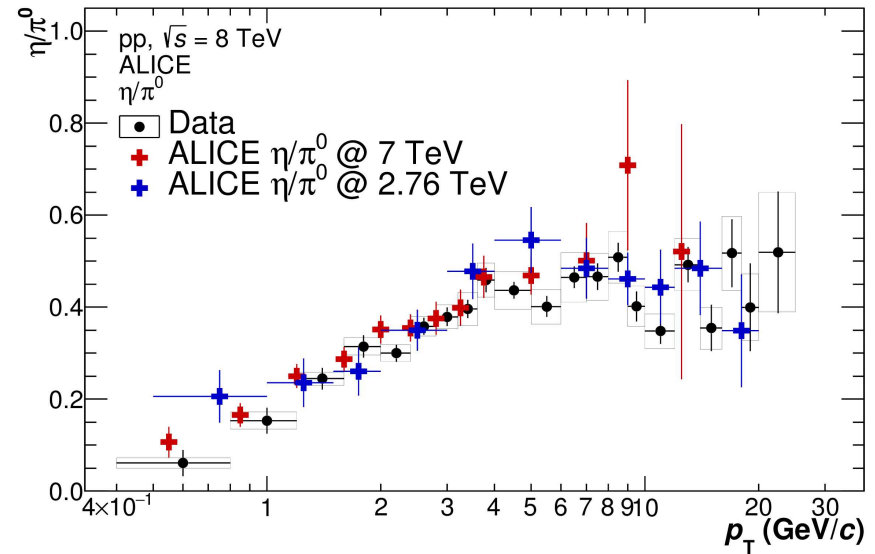
single EMCal cluster analysis, pp@8TeV

➢ momentum reach will be extended up to 70 GeV/c for neutral pion
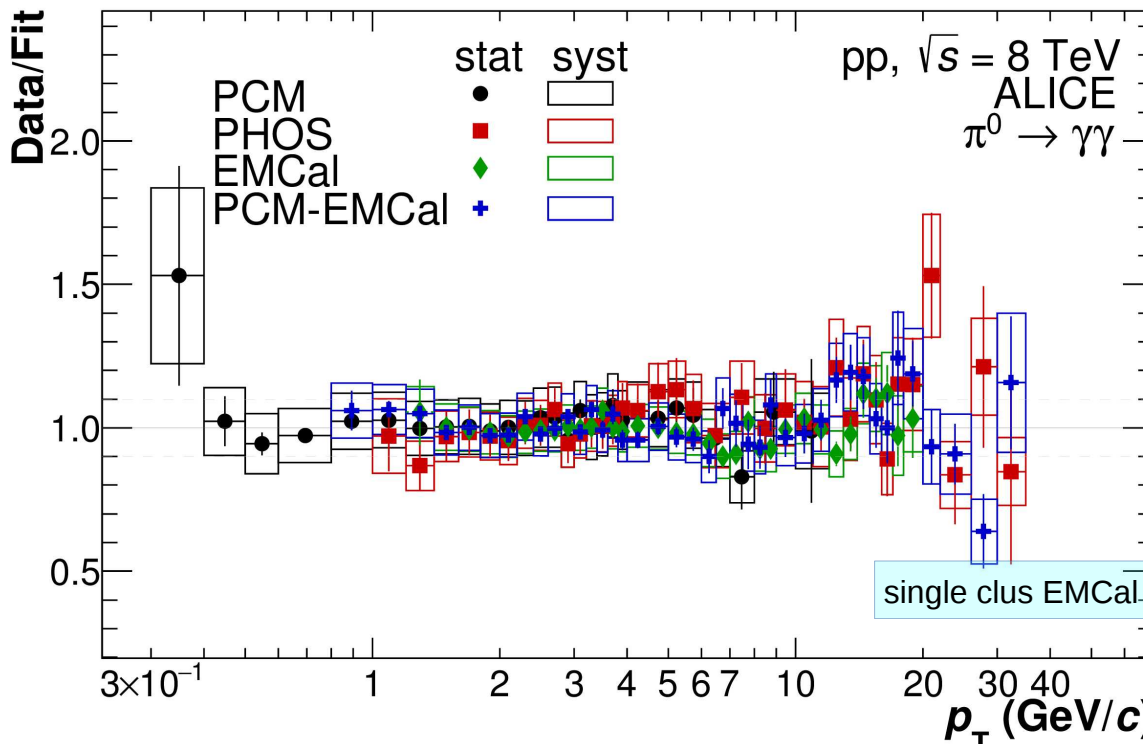
➢ currently in systematics evaluation + analysis note preparations

π⁰ - tagging: direct photons

➢ goal: determine R_γ
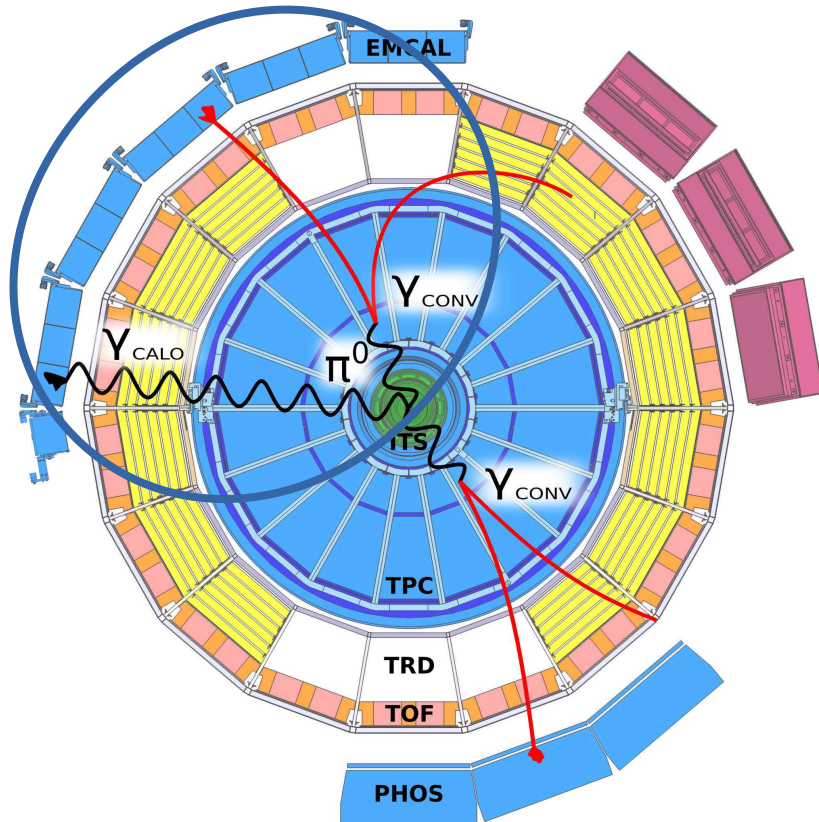
$$R_\gamma = \frac{\gamma^{\mathrm{incl}}}{\gamma^{\mathrm{hadron}}}$$

i. inclusive conversion photon measurement

$$N_\gamma^{\mathrm{incl}} \overset{(1)}{=} \epsilon_{\mathrm{pur}} \, P_{\mathrm{conv}} \, \epsilon_{\gamma,\mathrm{eff}} \, A_\gamma \, \gamma^{\mathrm{incl}}$$

ii. neutral pion reconstruction using PCM-EMCal "hybrid", reconstructed in conversion photon transverse momentum bins

$$N_\gamma^{\pi^0_{\mathrm{Tag}}} \overset{(2)}{=} <\epsilon_\gamma f> \, P_{\mathrm{conv}} \, \epsilon_{\gamma,\mathrm{eff}} \, A_\gamma \, \gamma^{\pi^0}$$

π⁰ - tagging: direct photons

$$R_\gamma = \frac{<\epsilon f> \left(\frac{N_\gamma^{\text{incl}}}{N_\gamma^{\pi^0,\text{Tag}}} \right)_{\text{Data}}}{\left(\frac{N_\gamma^{\text{hadron}}}{N_\gamma^{\pi^0}} \right)_{\text{Sim}}}$$

> ➤ "tagging efficiency": $<\epsilon_\gamma f>$
>   ➜ conditional acceptance & probability to rec. 2$^{\text{nd}}$ photon
> ➤ material budget error cancels, but EMCal related errors enter
> ➤ comparable reach in pT as PCM-EMCal neutral pion measurement

ω(782) reconstruction

➢ motivation: ω(782) measurement would lower errors of decay photon cocktail; measurement of particle ratios including omega

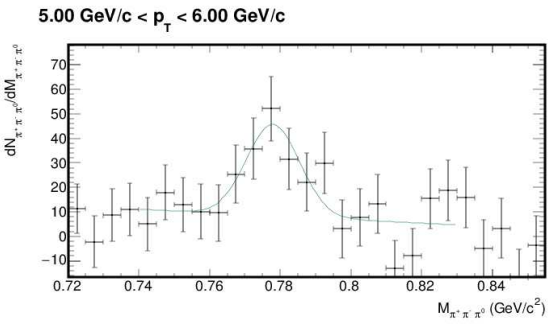 ■ 3ʳᵈ highest contribution behind pions and etas

  (a) $\omega \to \pi^0 \pi^+ \pi^-$ ◄——— F. Jonas & K. Ueberholz (Bachelor students)

  (b) $\omega \to \pi^0 \gamma$ ◄——— Z. Zhang (DAAD Rise student)

(a) result for 7 TeV, reconstructing with PCM; including EMCal will push to higher transverse momenta
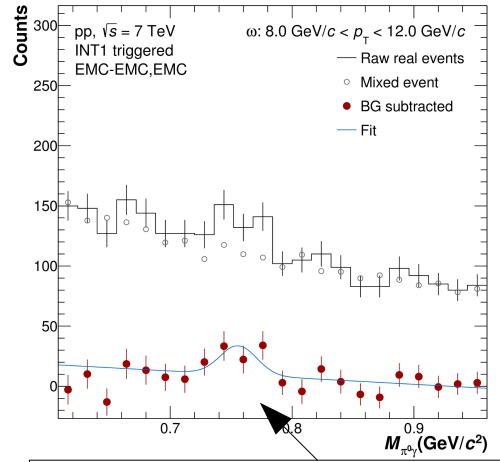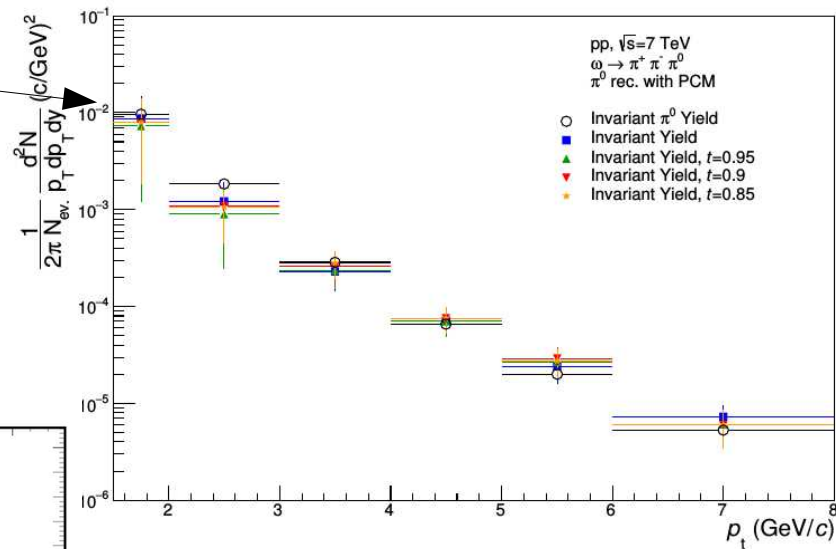
(b) result for 7 TeV, 8 TeV + pPb ongoing

summary & outlook

➢ neutral mesons in pp @ 8 TeV

  ◆ presented combined results (EMCal, PCM-EMCal, PCM, PHOS)

   • covering 0.3 GeV/c - 35 GeV/c (up to 70 GeV/c with upcoming single cluster EMCal analysis) for neutral pion

   • covering 0.4 GeV/c - 35 GeV/c for eta meson

  ◆ finalizing analysis/combination notes

  ◆ paper preparations ongoing: draft & public note

➢ "π^0 - tagging" to obtain R_γ

  ◆ very promising method

➢ ongoing efforts to also establish ω(782) measurement