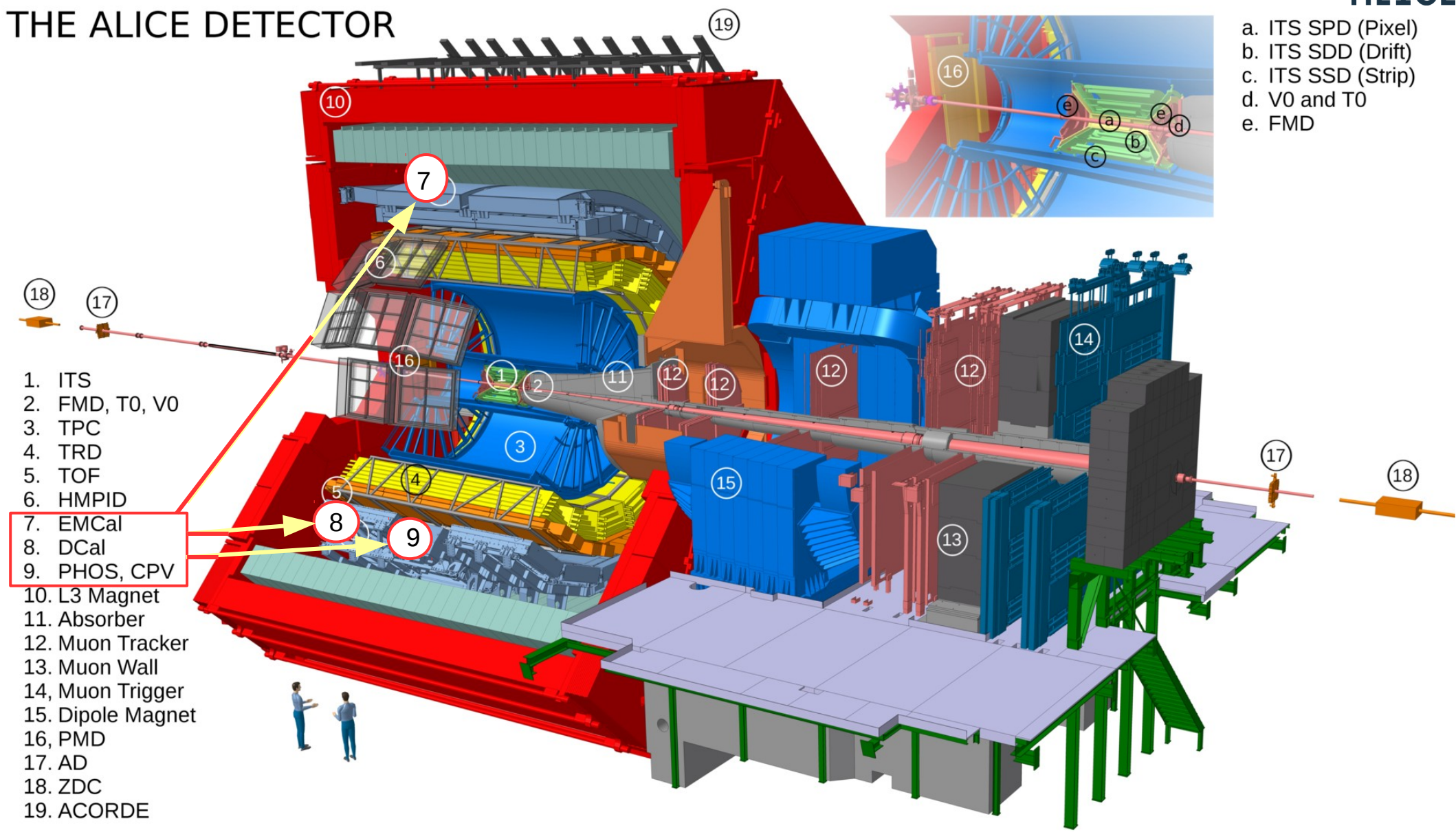
Performance of calorimeters in ALICE

Yuri Kharlov
For ALICE collaboration
NRC “Kurchatov institute” - IHEP

ALICE experiment



EMCal and DCal represent one detector, hereafter referred to as “EMCal"

Physics with ALICE calorimeters

- PHOS is designed to study thermal properties of hot QCD matter created in AA collisions via measuring direct photon yield.
- Other subjects to study with PHOS: precise neutral meson and direct photon spectra, photon-hadron correlations in pp, pA and AA collisions.
- EMCal due to its large acceptance but less granularity is suitable to study parton energy loss in hot QCD matter via measuring jet spectra.
- EMCal provides reconstruction of neutral fraction of jets.
- EMCal also studies direct photons at high p_T, electrons, neutral mesons, photon-jet correlations in pp, pA, AA collisions.

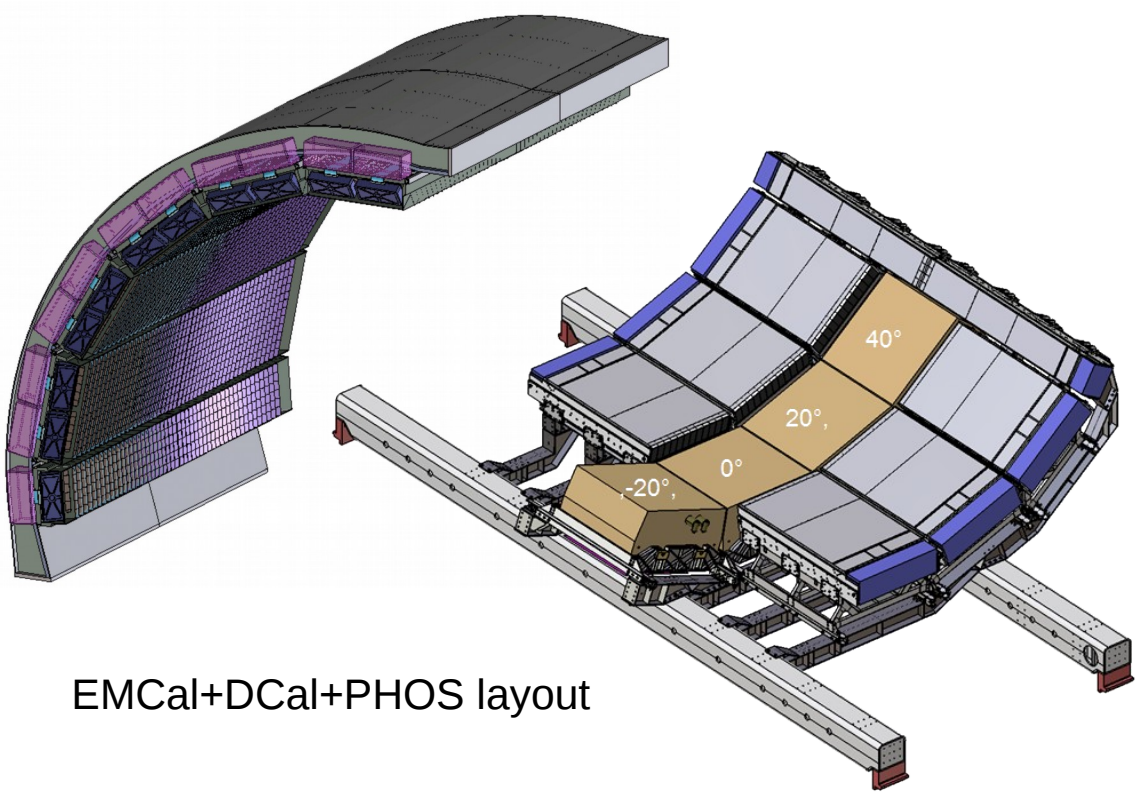
ALICE calorimeters

	EMCal/DCal	PHOS
Active element	Sampling 77 layers (1.44 mm Pb, 1.6 mm Sci) with WSF light collection	Homogeneous crystals $PbWO_4$
Moliere radius	3.2 cm	2.0 cm
Photodetector	APD 5x5 mm^2	APD 5x5 mm^2
Depth	$20X_0$	$20X_0$
Acceptance	EMCal: $\|y\|<0.7$, $\Delta\varphi=107°$ DCal: $0.22<\|y\|<0.7$, $\Delta\varphi=67°$	$\|y\|<0.13$, $\Delta\varphi=70°$
Granularity	Cell 6x6 cm2, $\Delta\varphi\cdot\Delta\eta=0.0143\cdot0.0143$	Cell 2.2x2.2 cm, $\Delta\varphi\cdot\Delta\eta=0.0048\cdot0.0048$
Modularity	EMCAL: 10+2(1/3) modules DCAL: 6(2/3)+2(1/3) modules 17664 cells	3+1/2 modules 12544 cells
Dynamic range	0-250 GeV	0-100 GeV
Energy resolution	$\sigma_E/E = 4.8\%/E \oplus 11.3\%/\sqrt{E} \oplus 1.7\%$	$\sigma_E/E = 1.8\%/E \oplus 3.3\%/\sqrt{E} \oplus 1.1\%$
Distance from IP	428 cm, 0.7-0.9X_0	460 cm, 0.2X_0

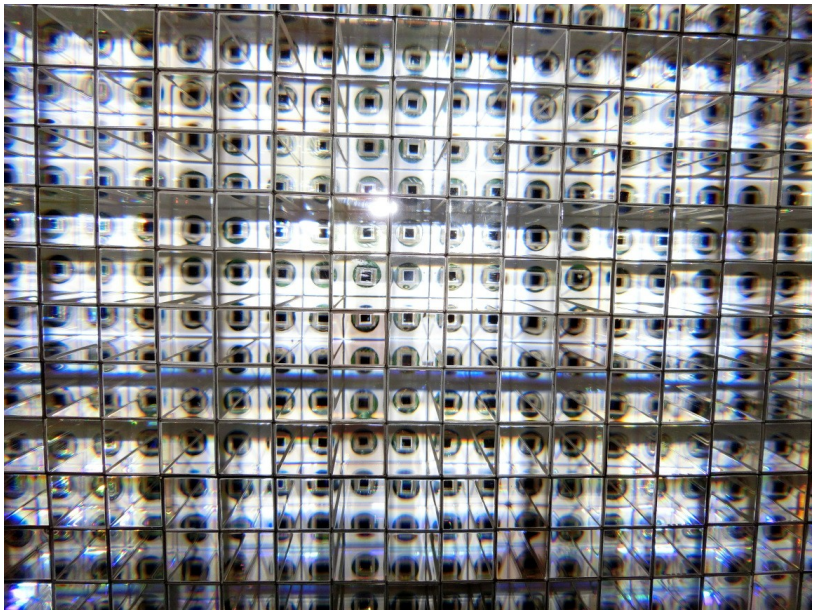
PHOS and EMCAL components

4 EMCAL cells bound in 1 module

PHOS cell – crystal + APD



EMCal+DCal+PHOS layout



PHOS crystal matrix

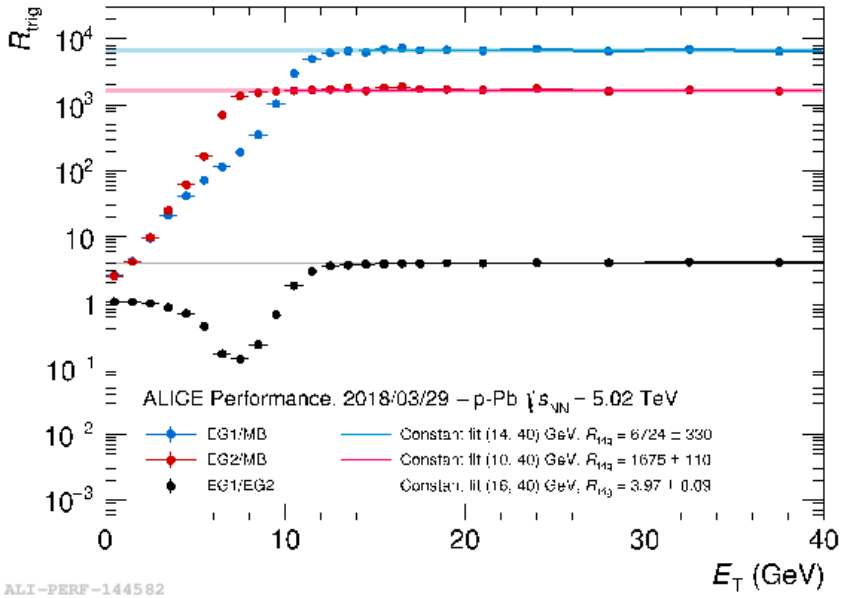
Trigger system

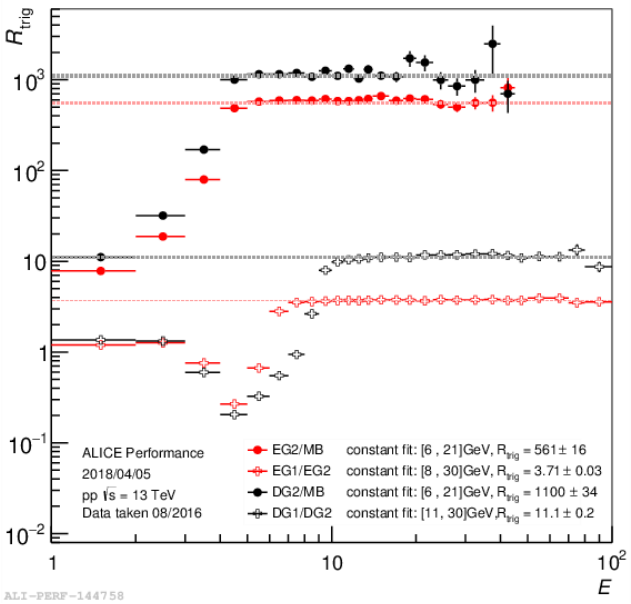
ALICE calorimeters provide triggers of levels L0 (1.2 μs) and L1 (7 μs).

- EMCal and PHOS L0: trigger on 4x4 clusters within trigger region units with energy sum above a threshold
- PHOS L1: trigger on photons with 3 thresholds.
- EMCal L1:
  - trigger on photons with 2 thresholds.
  - Trigger on jets with 2 thresholds which can cope with uncorrelated background for jets in Pb-Pb
- Thresholds are adjustable depending on collision rate, trigger rejection factor, readout time.
- Typical thresholds:
  - 2.5-9 GeV for photon L0 and L1 triggers
  - 16-20 GeV for L1 jets

- J.Kral et al., L0 trigger for the EMCal detector of the ALICE experiment, NIM. A693 (2012) 261-267
- O.Bourrion et al., The ALICE EMCal L1 trigger first year of operation experience, JINST 8 (2013) C01013

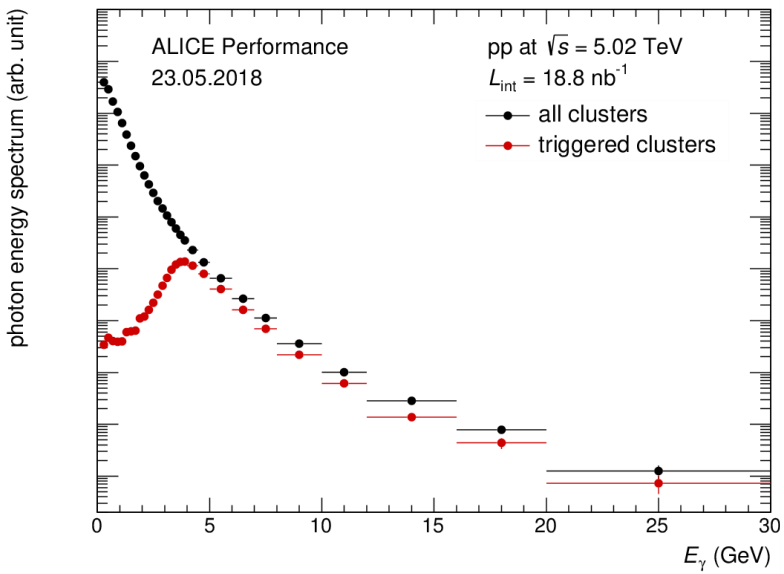
Trigger performance

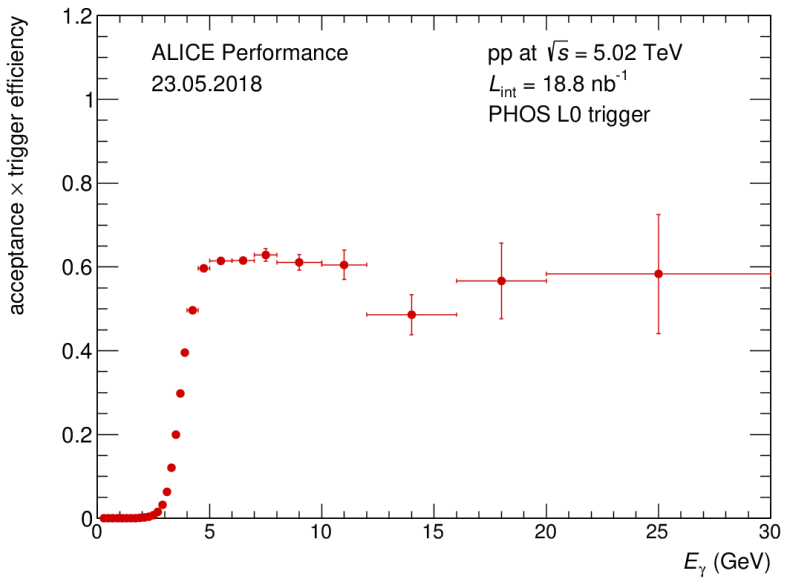




EMCal L1 triggers are bootstrapped:

Triggers with higher rejection factor are treated w.r.t. triggers with low rejection factor.

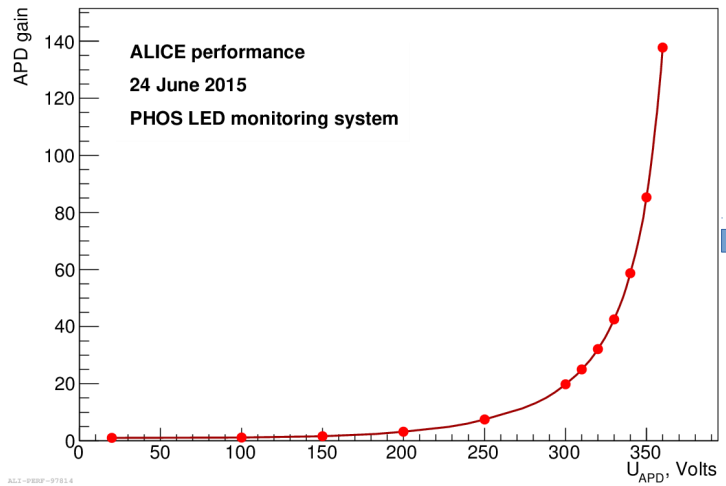


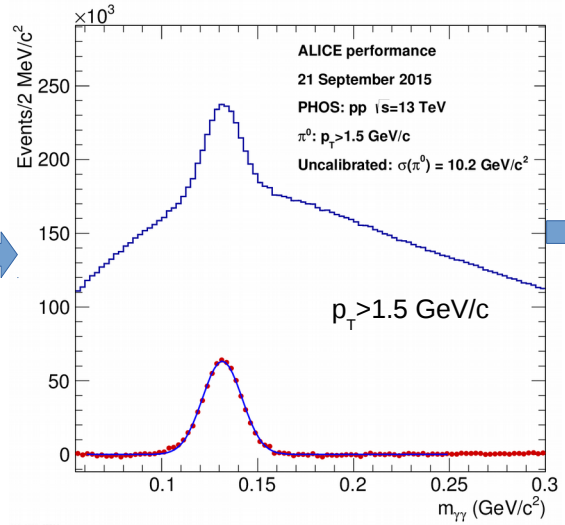


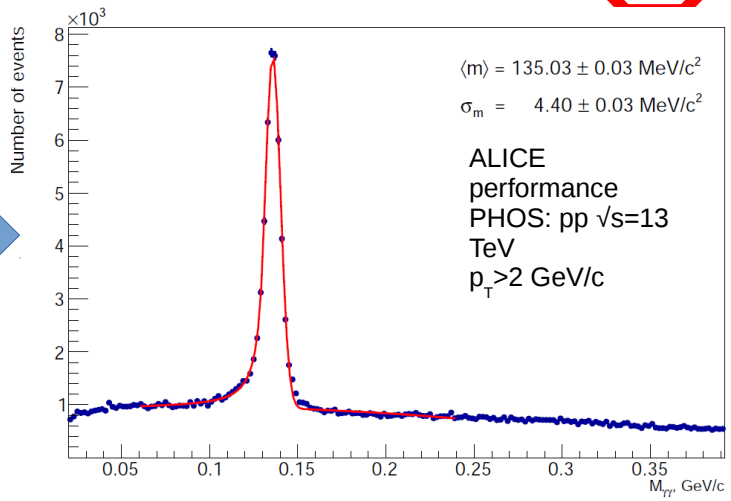
In pp collisions, only PHOS L0 trigger is enough due to low trigger rate.

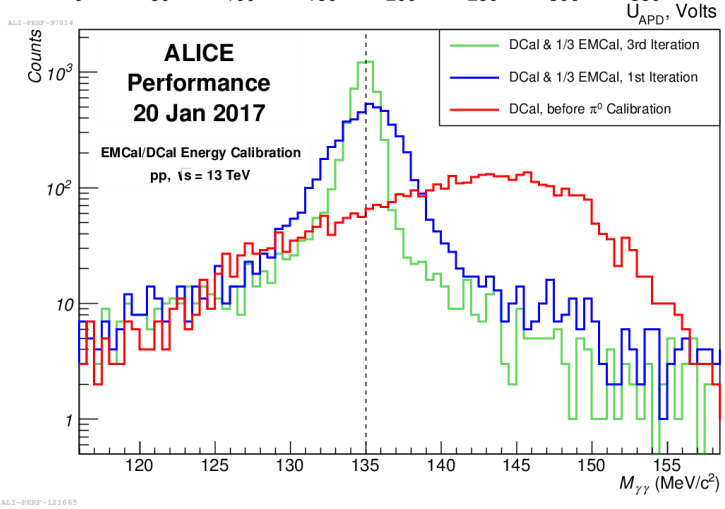
In Pb-Pb collisions, L1 triggers become effective.

Energy calibration

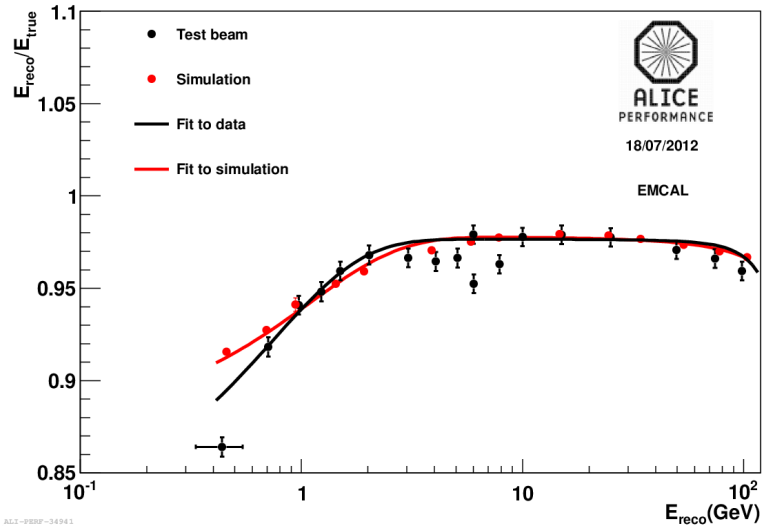








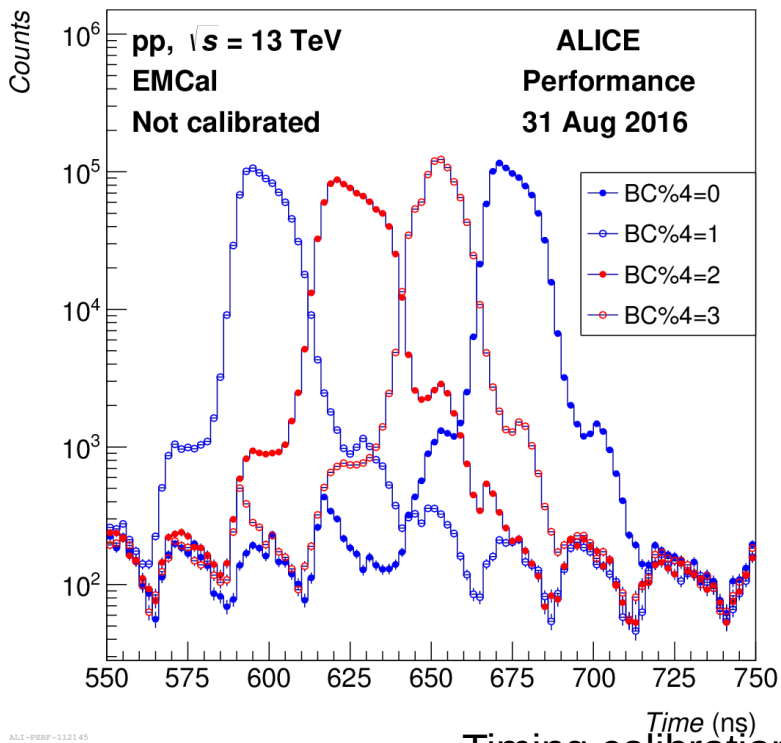
- Pre-calibration: voltage is adjusted in every APD to provide the same gain → π^0 peak visible.
- In-situ calibration with physics data by π^0 mass per-cell equalization:
  - High statistics is needed: ~100M events triggered by calorimeters ~ months of data taking.

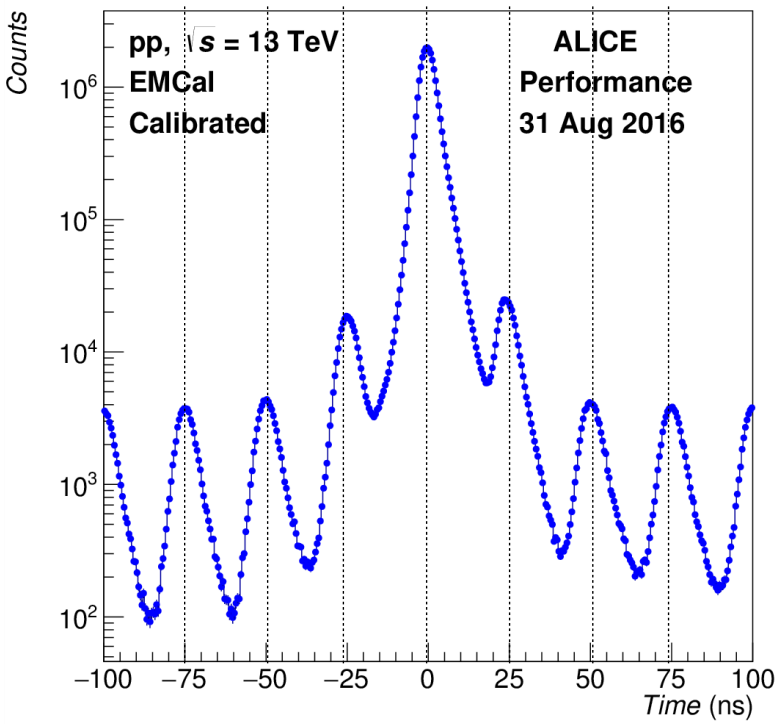


- Further improvement of calibration is correction for non-linear response of calorimeters
- Simulations do not reproduce all detector effects.
- Only data-driven algorithms are reliable:
  - Test-beam data;
  - Dependence of reconstructed π^0 mass on p_T;
  - Dependence of electron E/p ratio on p_T.

Timing calibration

- Front-end electronic parameters:
  - Rather long integration time: 2 μs for EMCAL and 4 μs for PHOS.
  - FEE sampling clock: 10 MHz (100 ns) is synchronized with LHC clock 40 MHz (25 ns), but phase remains unknown.
- Minimal bunch crossing (BC) interval at LHC is 25 ns.
- Good timing calibration is important to discriminate photons produced in triggered BC and in the following BCs (out-BC pileup).



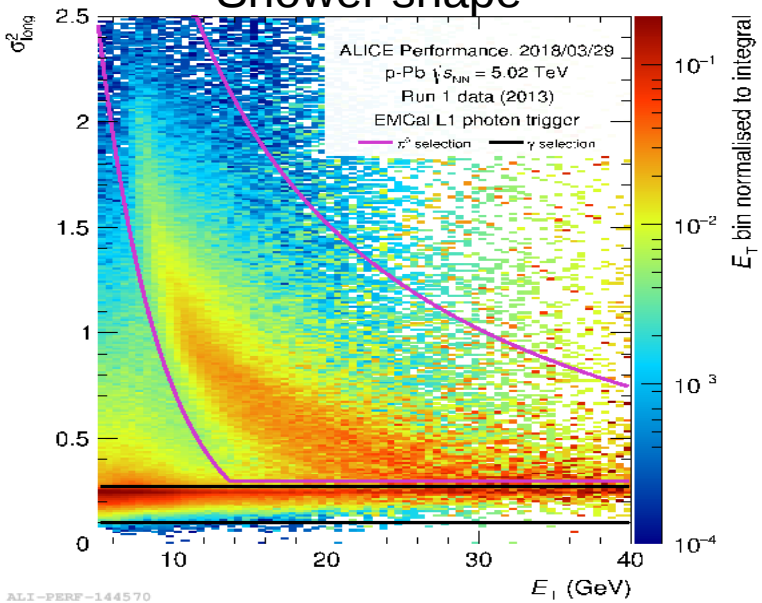


Timing calibration is based on physics data

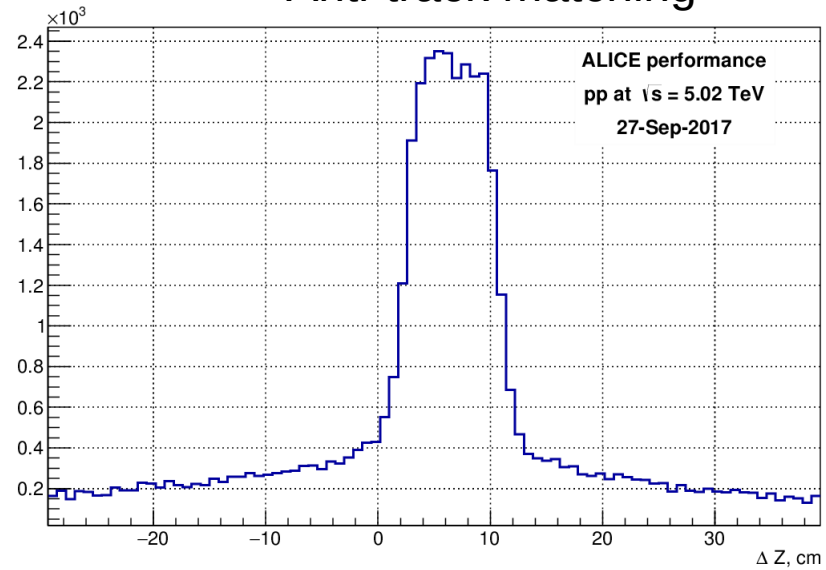
Photon identification

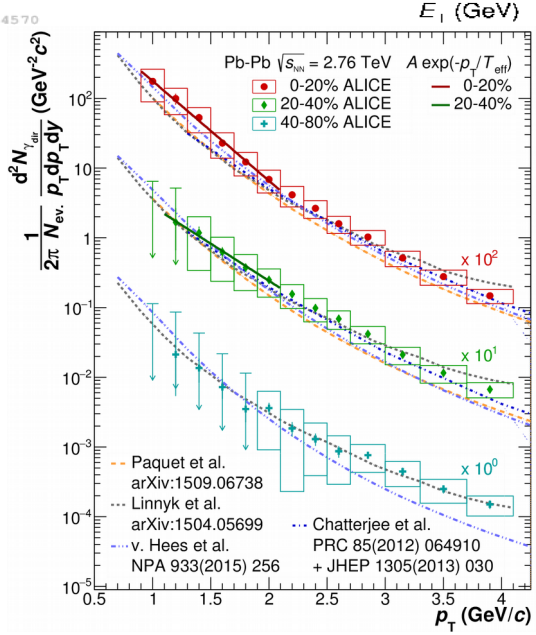
Photon identification in EMCal and PHOS is implemented by two criteria

Shower shape



Anti-track matching





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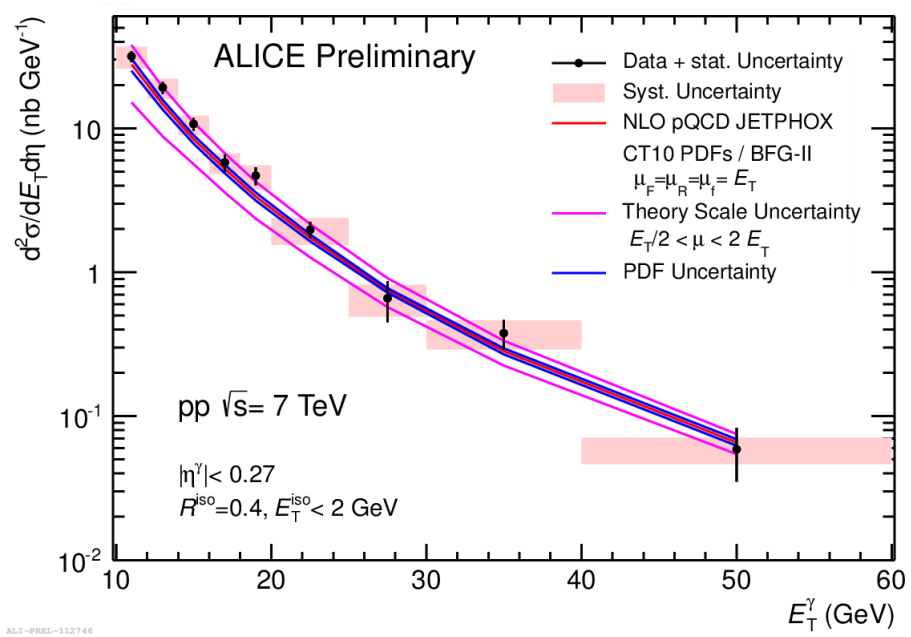
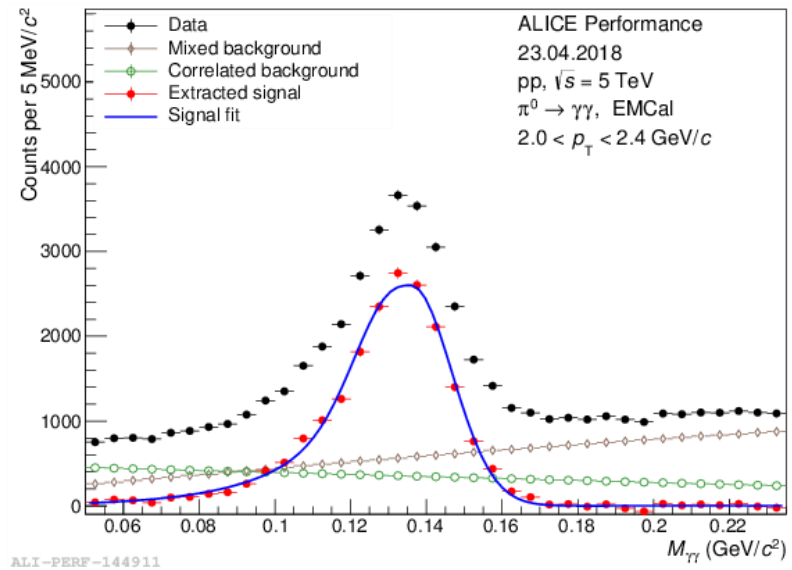


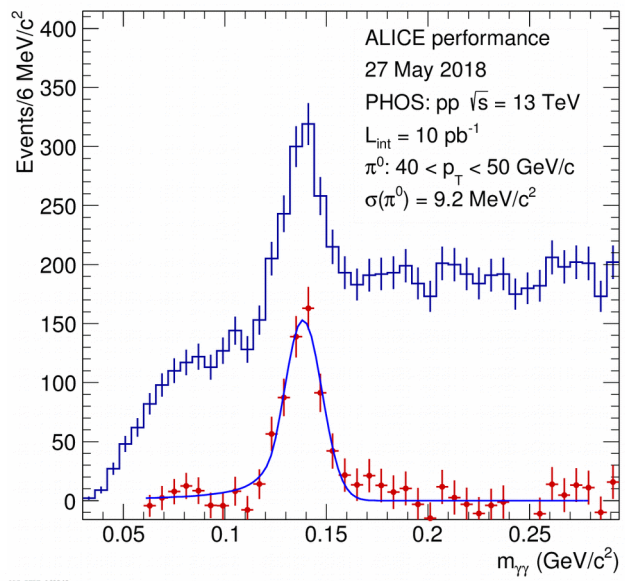
Neutral meson measurements

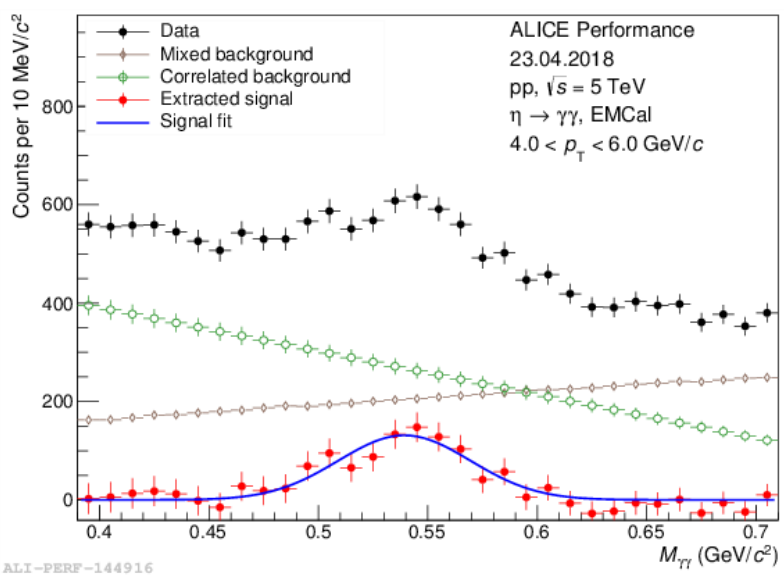
- For ALICE calorimeters, neutral meson measurements is one of the primary task prior to a more elaborated analysis (direct photons, electrons, jets).
  - π^0 and η are dominant source of background for direct photons;
  - π^0 and η are sensitive probes to study hard parton energy loss in QCD medium via R_{AA};
  - π^0 and η in pp collisions can be measured over much wider p_T range than any other identified hadrons → study QCD in vacuum and thus be used for tuning QCD parameters;
  - π^0 and η are also a good tool for calorimeter calibration due to their large cross sections.
- EMCal and PHOS, complemented by ALICE central tracking system, measure differential yields of neutral mesons in mid-rapidity in all collision systems.

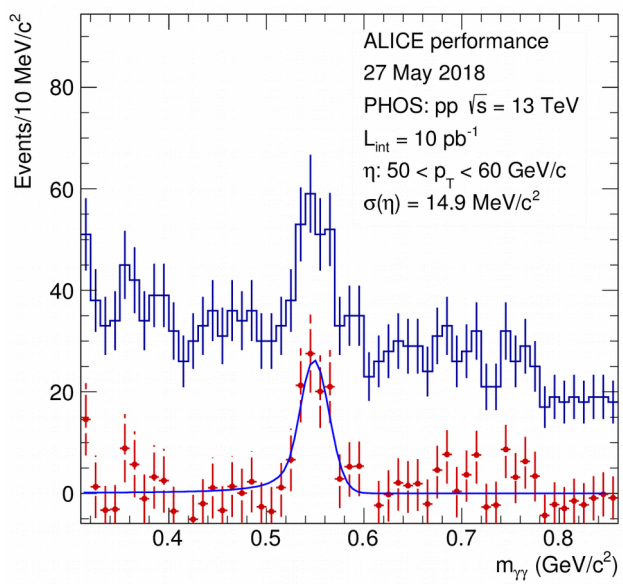
Neutral mesons in pp collisions

Invariant mass spectra of photon pairs and combinatorial background subtraction









Due to low detector occupancy, photon identification criteria are minimal.

At p_T=50 GeV/c decay photons from π^0 are separated by 1 cell in PHOS:

- It is a limit of invariant-mass analysis.

For EMCAL, this limit is p_T=20 GeV/c.

π^0 at higher p_T can be measured using shower shape analysis.

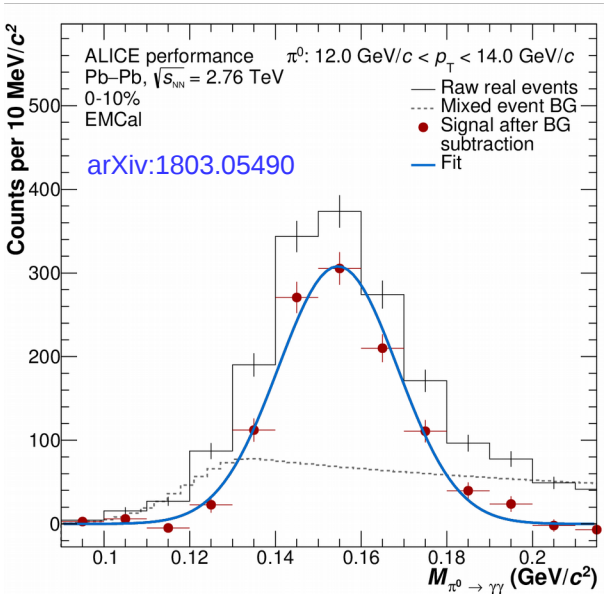
Neutral mesons in Pb-Pb collisions

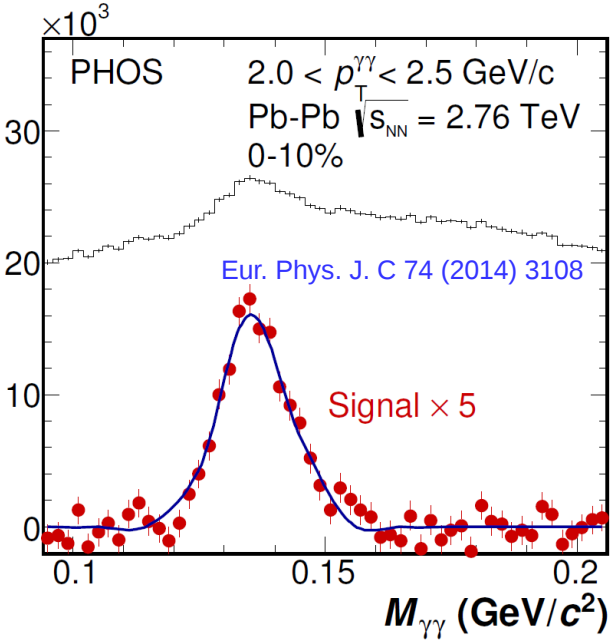
Detector occupancy in central Pb-Pb collisions is high →

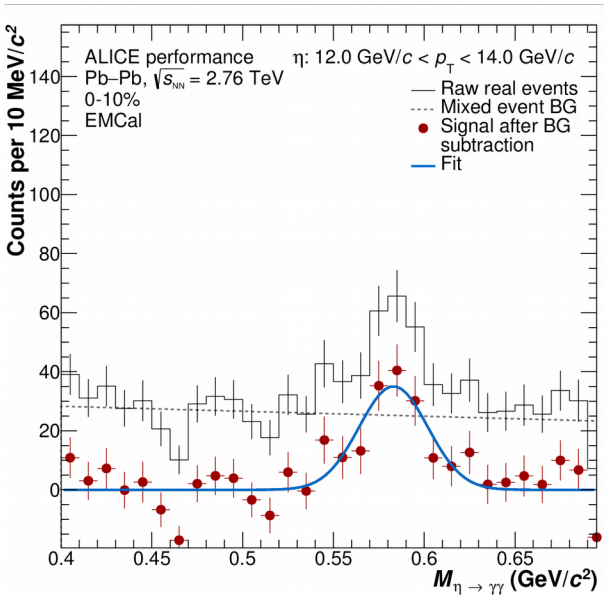
- Large combinatorial background;
- Cluster overlap;
- Signal extraction becomes challenging.

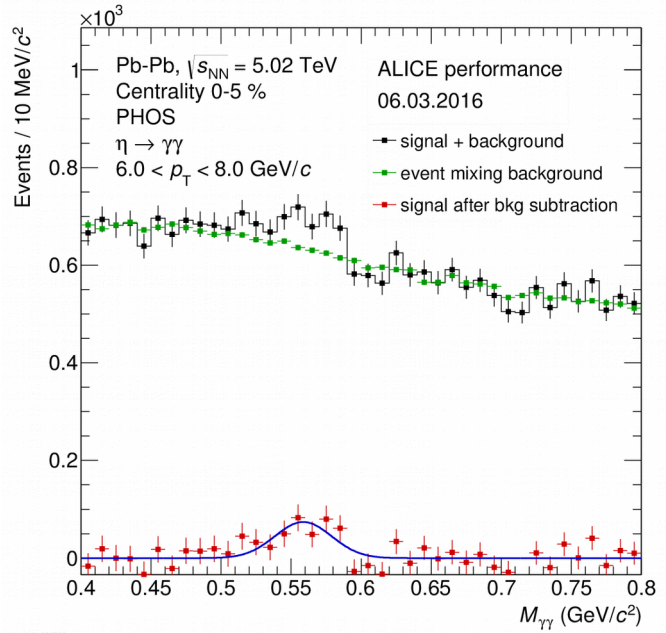
Photon identification is applied:

- shower shape to select electromagnetic showers;
- Anti-track matching to select neutral clusters.









ALICE results on neutral mesons

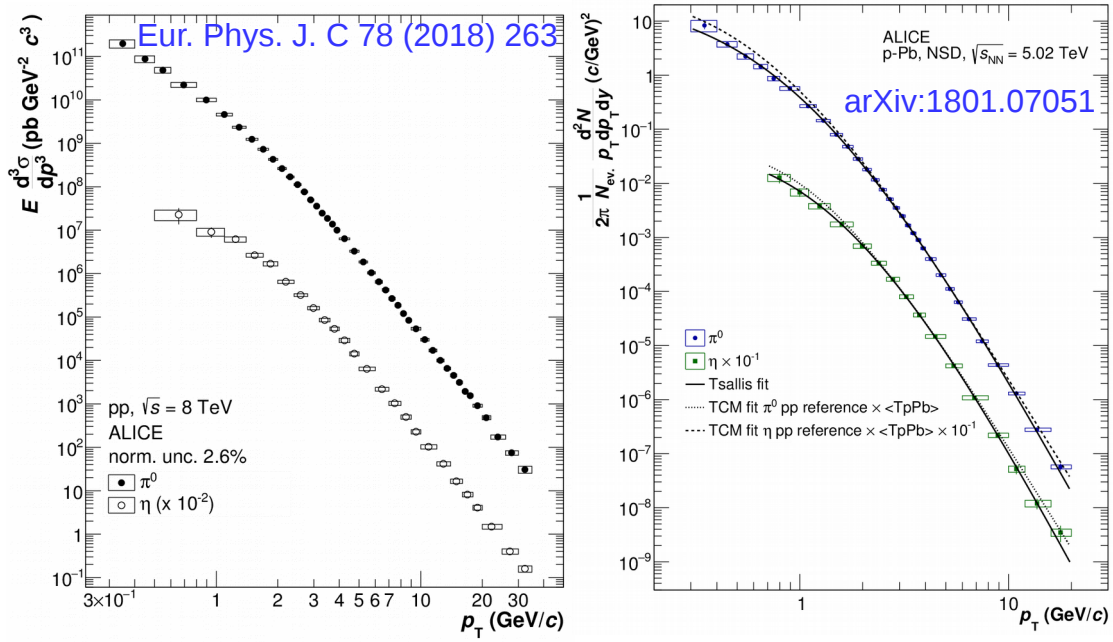
EMCal and PHOS already contributed to ALICE measurements of π^0 and η:

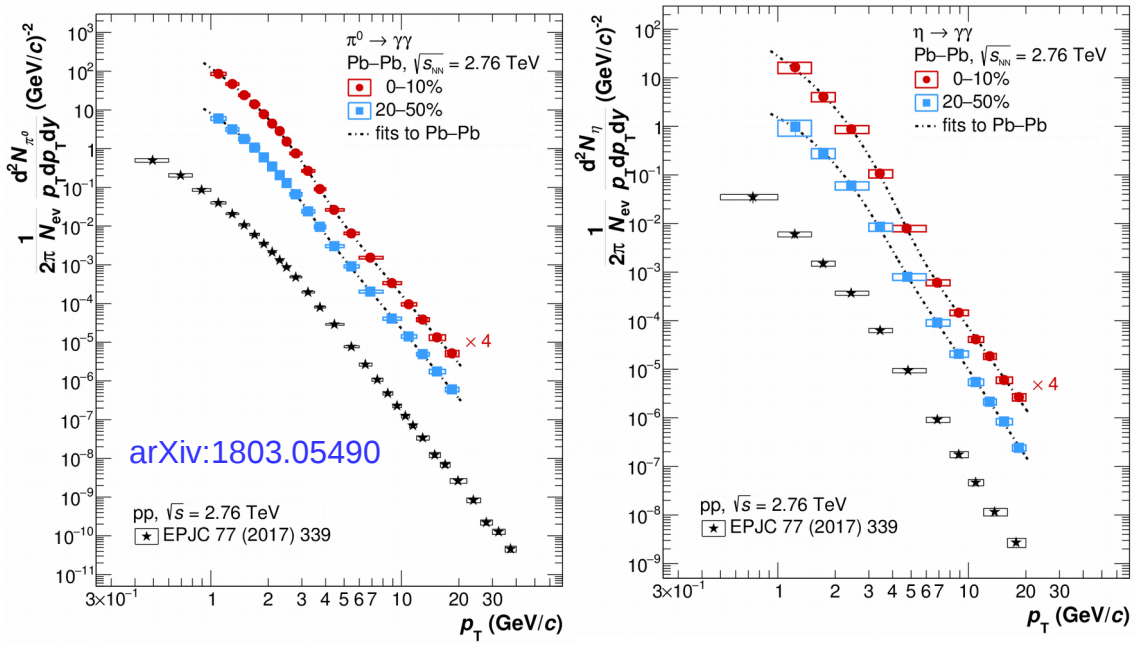
- pp at $\sqrt{s}$=0.9, 2.76, 7, 8 TeV
- p-Pb at $\sqrt{s_{NN}}$=5.02 TeV (Run1)
- Pb-Pb at $\sqrt{s_{NN}}$=2.76 TeV

Ongoing alanyses:

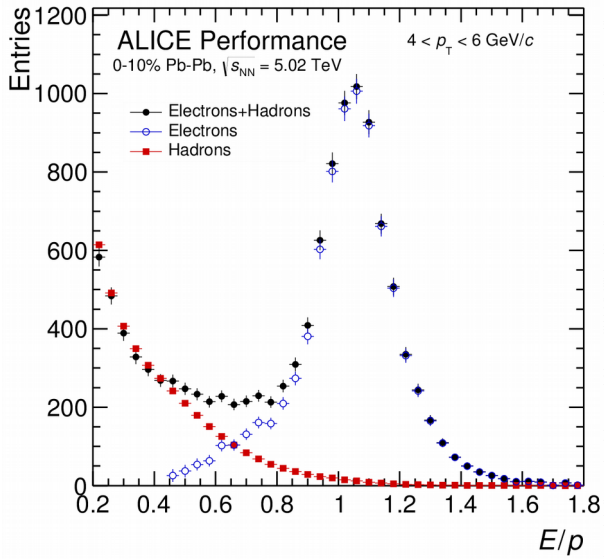
- pp at $\sqrt{s}$=5.02, 13 TeV
- p-Pb at $\sqrt{s_{NN}}$=5.02 TeV (Run2)
- p-Pb at $\sqrt{s_{NN}}$=8.16 TeV
- Pb-Pb at $\sqrt{s_{NN}}$=5.02 TeV

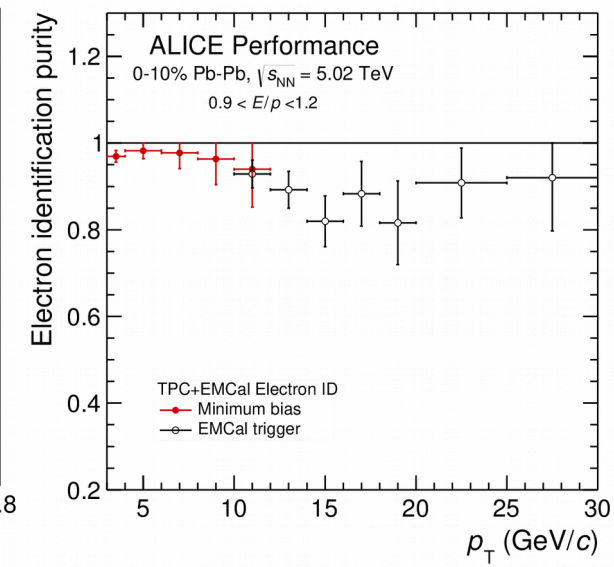
High-p_T range of measurements with neutral mesons (0.8-35 GeV/c) is unbeatable compared to identified charged hadrons.





Electrons

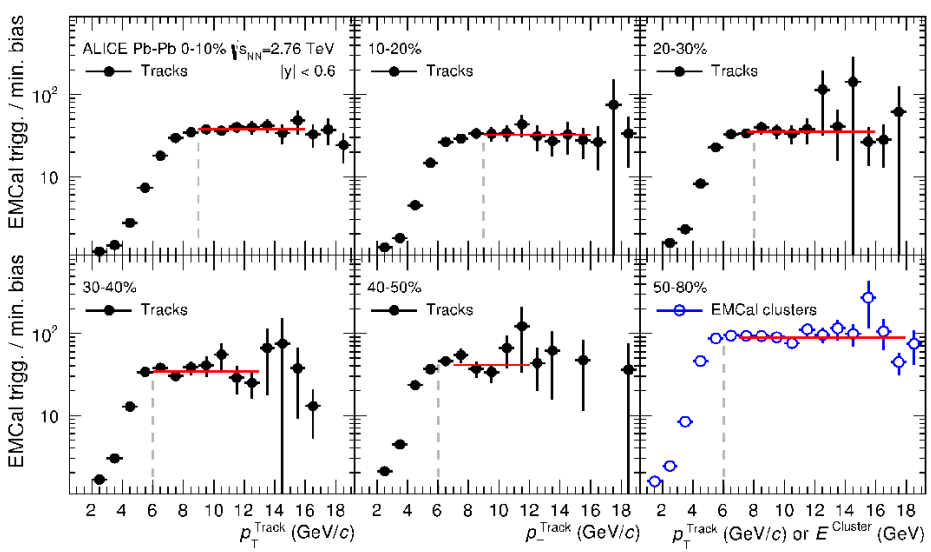


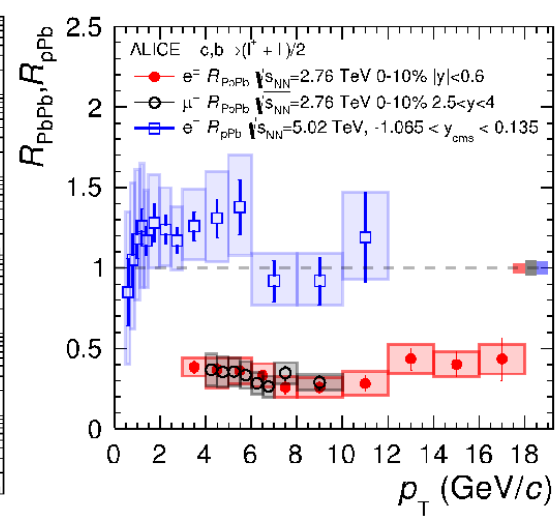


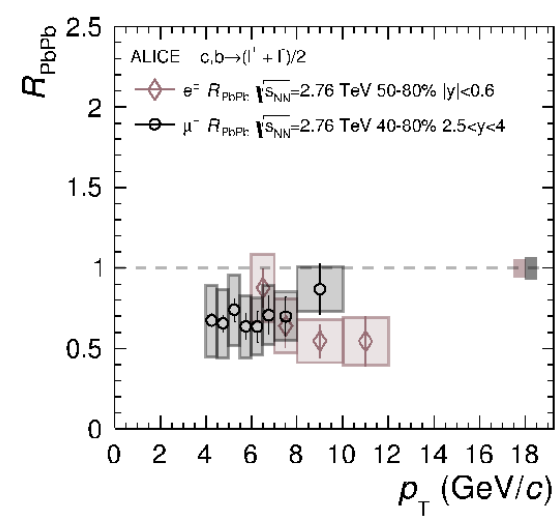
Electrons are identified with high purity in calorimeters by E/p ratio in conjunction with tracking system via dE/dx.

Due to wide acceptance and trigger on high-energy electrons, EMCal contributes to electron measurements at high p_T with high integrated luminosity.

Electrons from HF decays







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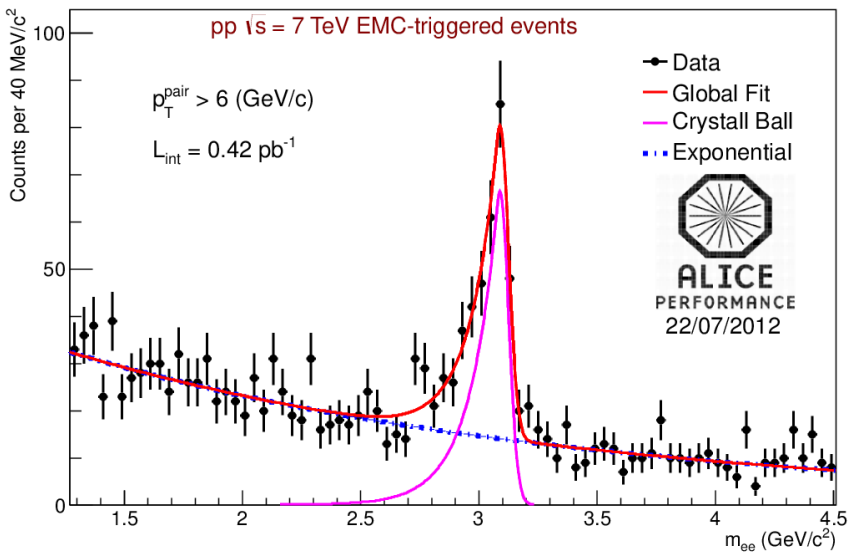
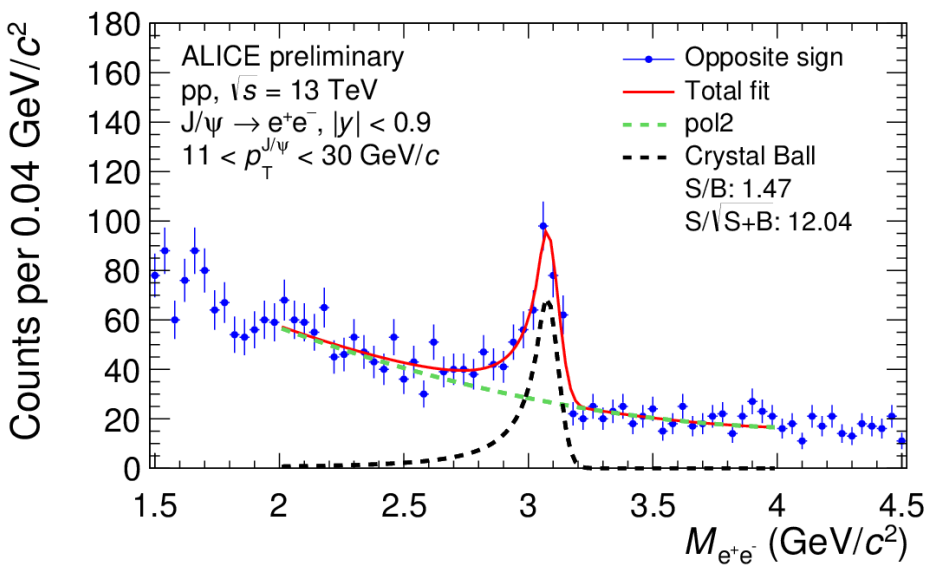
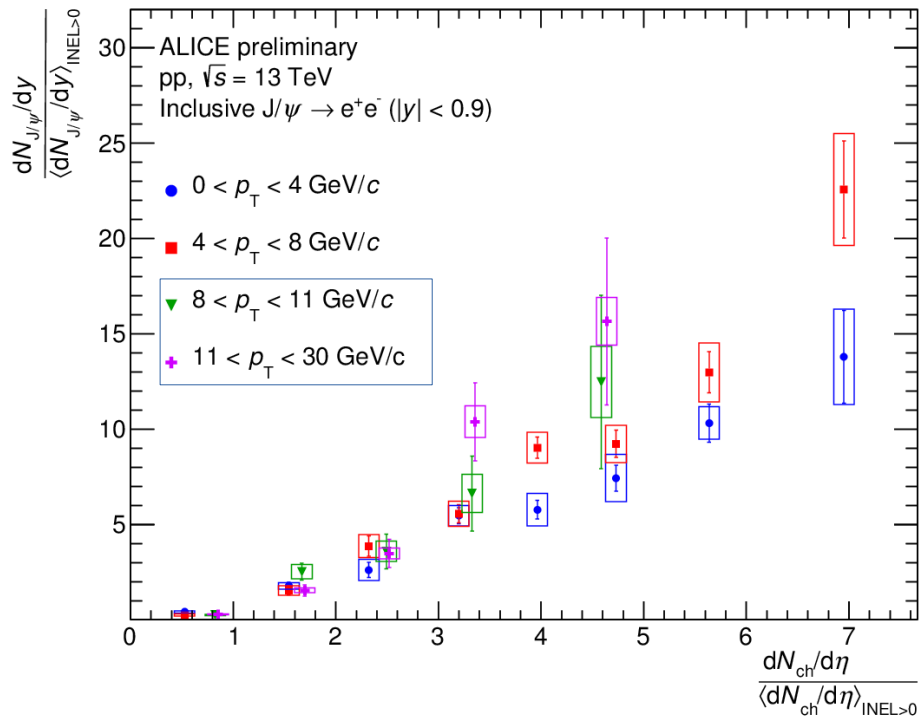
Electrons from J/ψ decay





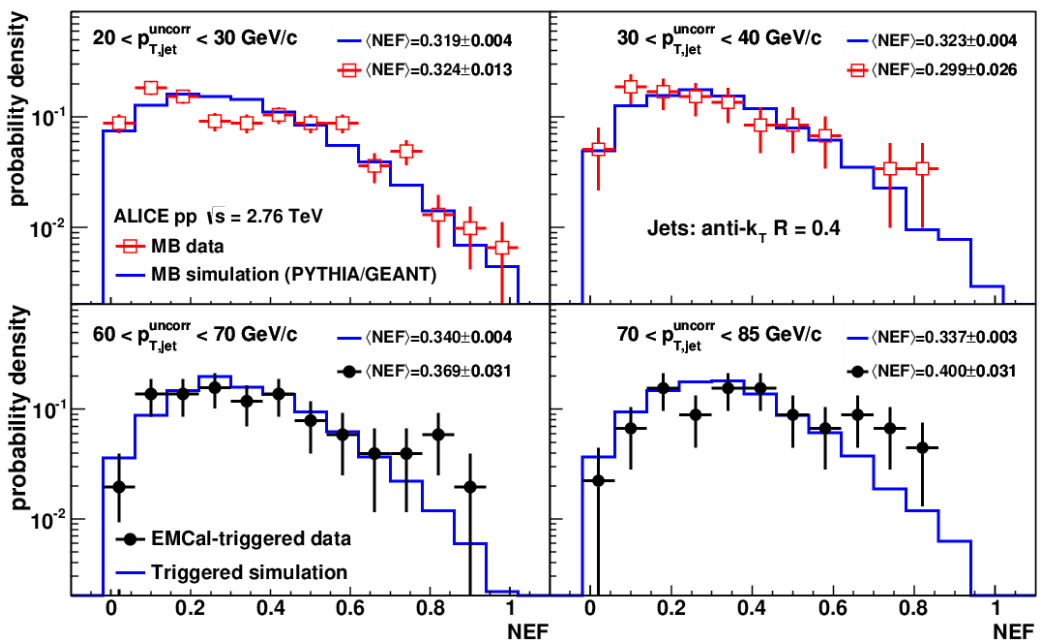


J/ψ yield at |y|<0.9 as a function of $dN_{ch}/d\eta$.

p_T=8-11, 11-30 GeV/c from EMCal analysis

Jets

One of the goals of EMCal is to trigger on jets and to measure neutral energy of jets.



Jet neutral energy fraction (NEF) in pp at √s=2.76 TeV is 0.3-0.4 with slight jet energy dependence.

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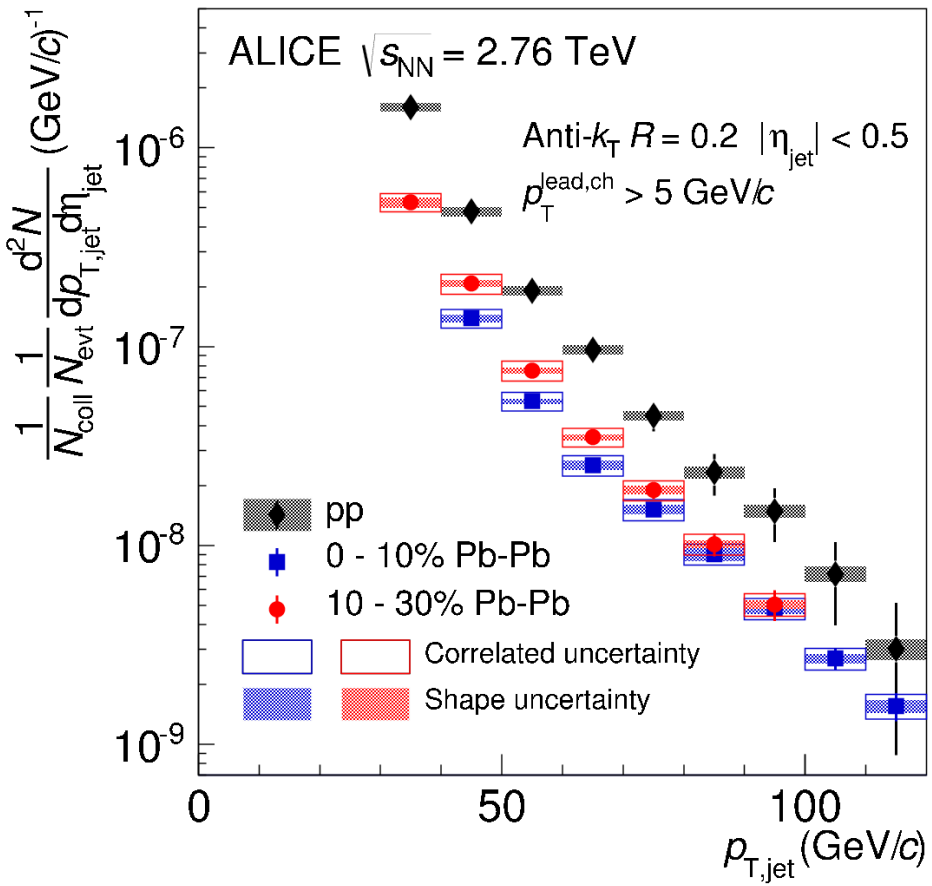

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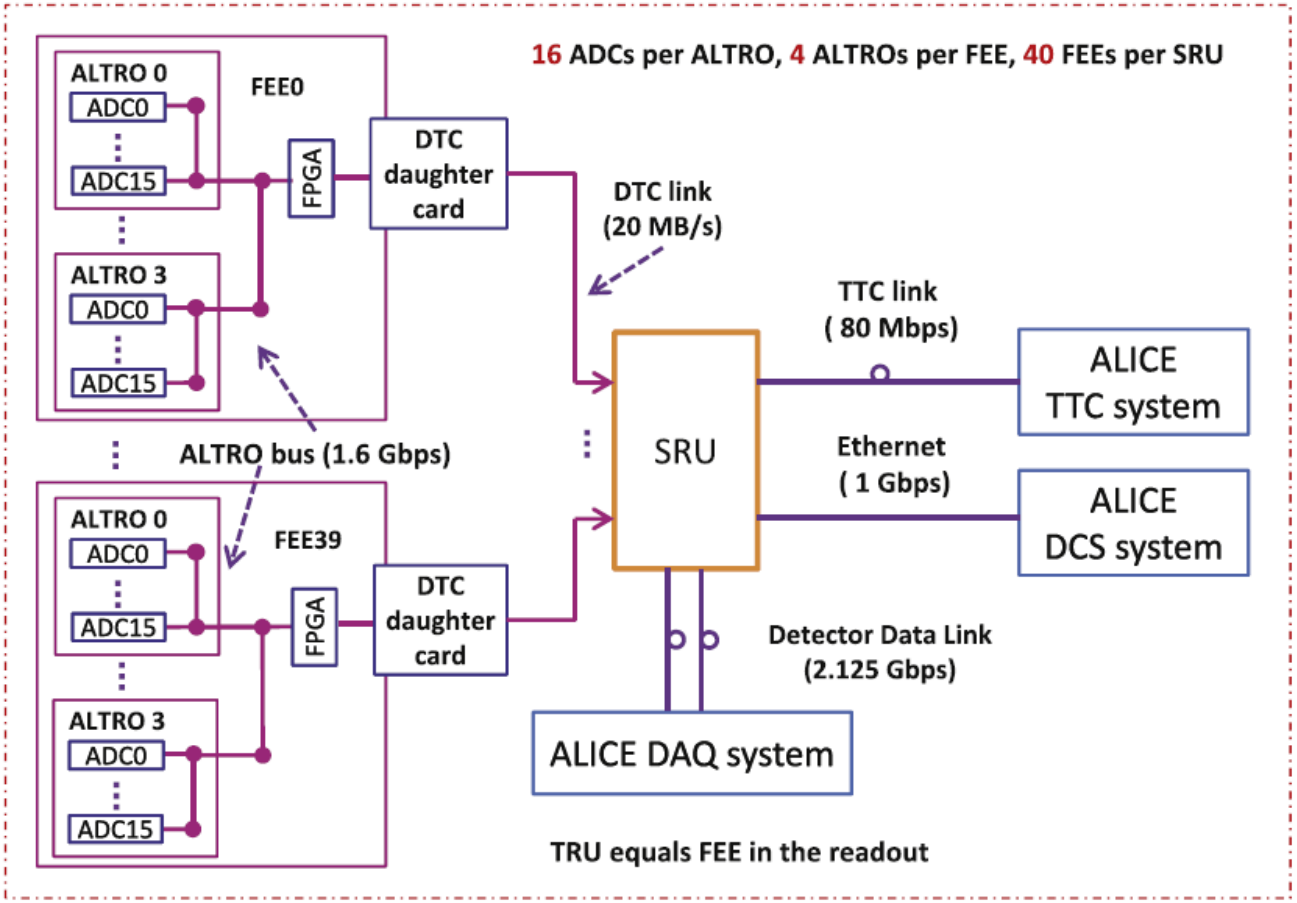
Summary

- ALICE electromagnetic calorimeters contribute to ALICE physics program with photon, neutral meson, electron, jet measurements in pp, pA and AA collisions.
- Trigger system of calorimeters allows ALICE to enhance collected data of event samples with observables of interest.
- Calorimeters are calibrated using the same data used for physics measurements.
- Photon, neutral pion and electron identification is elaborated towards high purity and efficiency.

Backup slides

Readout system

- EMCAL and PHOS have unified readout system:
- Scintillator light is collected to photodetector: APD 5x5 mm^2;
- APD signal pass to preamplifier and shaper;
- Signals are digitized by sampling ADC ALTRO and pass to scalable readout units (SRU) via 20-Mb/s p2p links.



Readout time: 172 μs independent from event size.

[F.Zhang et al./NIM A735(2014)157-162]