Performance of the ALICE charged-particle veto detector in Pb-Pb and pp collisions at the LHC

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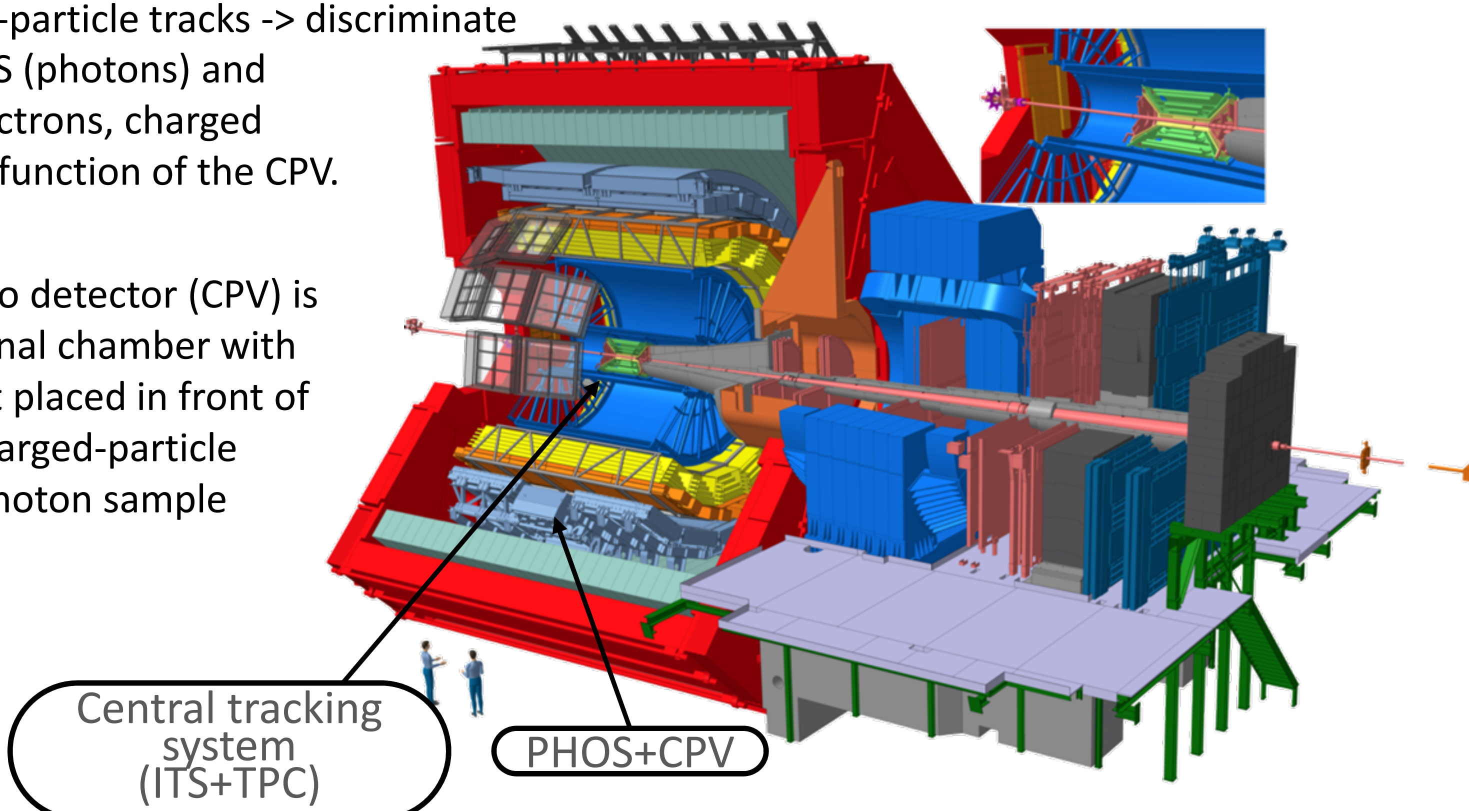
Introduction

- One of the aims of ALICE is to study photons emitted directly from pp or Pb-Pb collision, so-called "direct photons".
- ALICE is equipped with a high-precision photon spectrometer PHOS, consisting of 12544 $PbWO_4$ crystals each of size 2.2x2.2x18 cm.
- Photon identification is an important requirement to decrease systematical uncertainties in the direct photon spectra. There are several methods for this, one of which is anti-matching of PHOS clusters and charged-particle tracks -> discriminate neutral clusters PHOS (photons) and charged clusters (electrons, charged hadrons). This is the function of the CPV.

- **C**harged-**P**article **V**eto detector (CPV) is multi-wire proportional chamber with cathode pad readout placed in front of PHOS to suppress charged-particle background of the photon sample detected in PHOS.

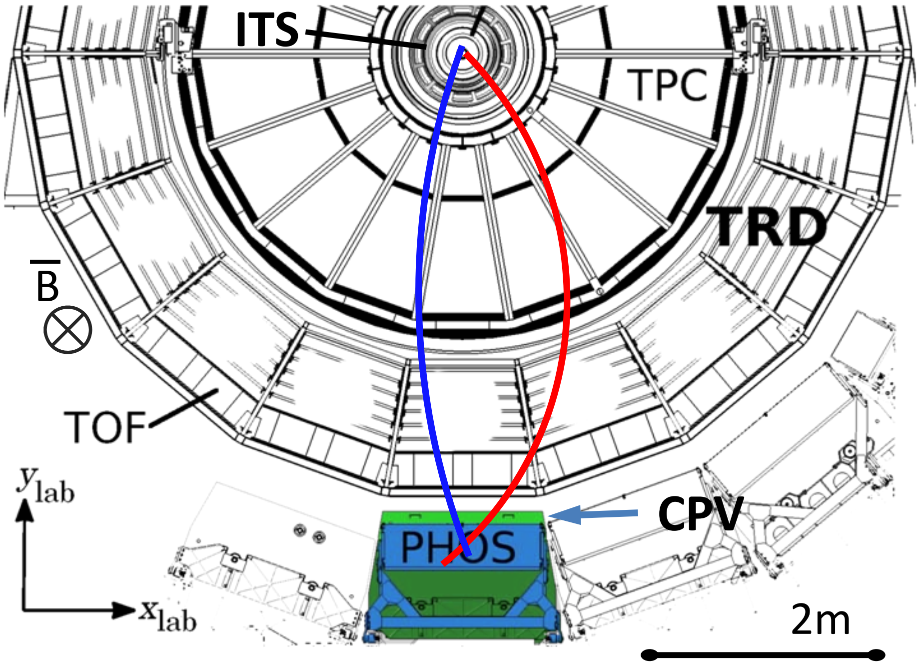


Performance tasks

- The first task is to calculate efficiency of charged-particle registration in CPV. Here efficiency refers to probability of registering a charged-particle.
- This can be estimated as $\epsilon = N_{CPV}(p_T)/N_{all}(p_T)$

  Where N_{CPV} is the number of tracks detected in CPV, p_T is transverse momentum of a track and N_{all} is the number of all tracks passing through CPV. The latter is found as propagation of track reconstructed in the central tracking system which has deposited a signal in PHOS.

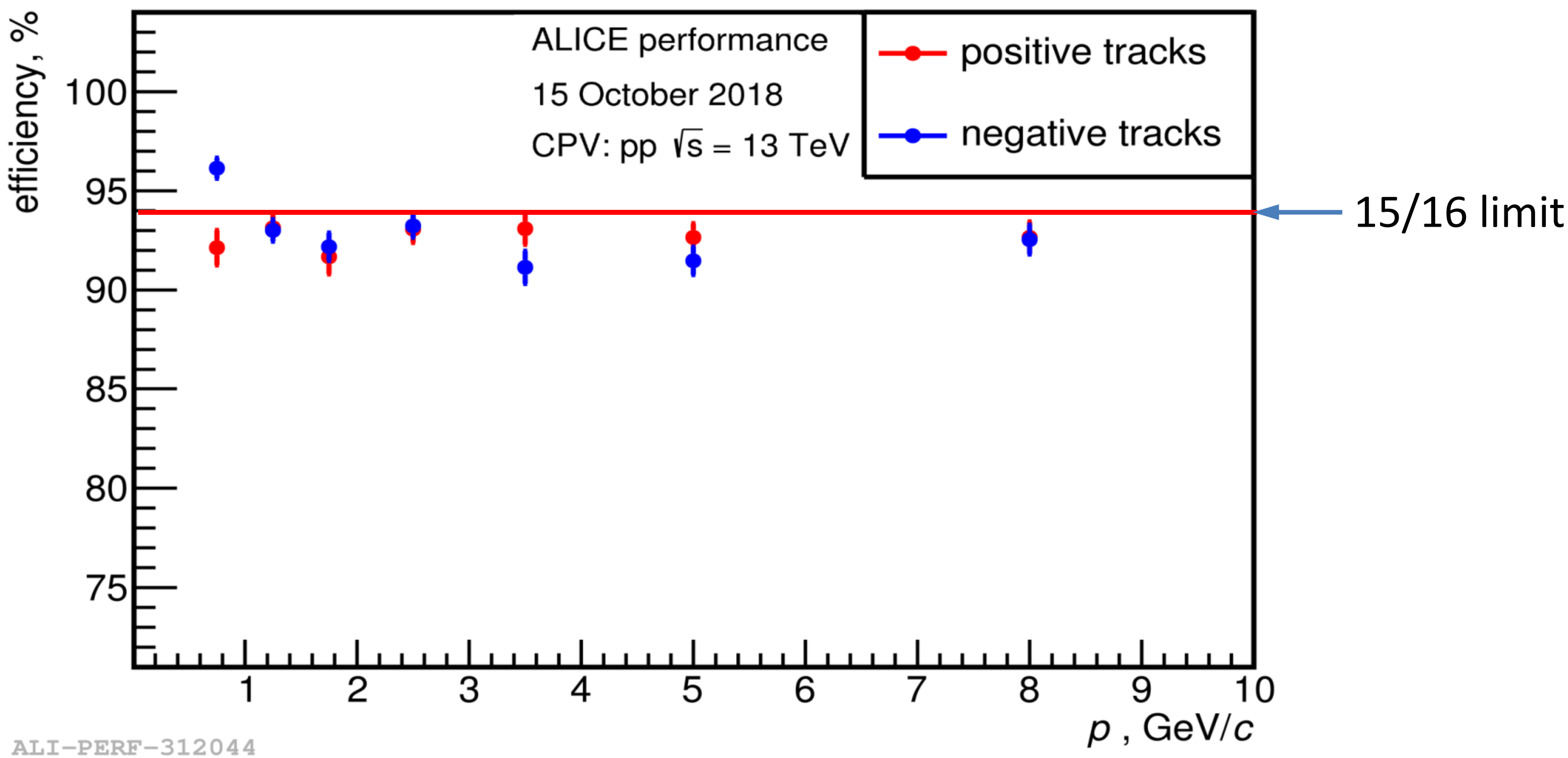
- Secondly, we want to actually use CPV to reject charged particles from PHOS events.
- These are found through correlations between cluster coordinates in PHOS and CPV and elaborate criteria for selecting PHOS clusters matching CPV ones.
- PHOS clusters matching corresponding CPV clusters are identified as charged clusters. PHOS clusters without a matching CPV cluster are neutral clusters.



- Thirdly, we use 2-gamma spectrum obtained by PHOS to estimate the impact on the photon identification. $\pi^0 \to \gamma\gamma$ peak is a convenient tool for this, because π^0 is neutral and shouldn't trigger CPV.

Efficiency of charged-particle registration

- Efficiency is close to its geometrical acceptance 15/16 (94%);
- For edge effects, when track is close to borders of sensitive volume of the CPV module, the registration efficiency is decreased by ~1-2%
- Obtained efficiency is almost independent from track momentum variation.
- Efficiency is defined as probability of the charged particle registration in CPV: $\epsilon = \frac{N_{registered}}{N_{total}}$



Criteria for cluster matching

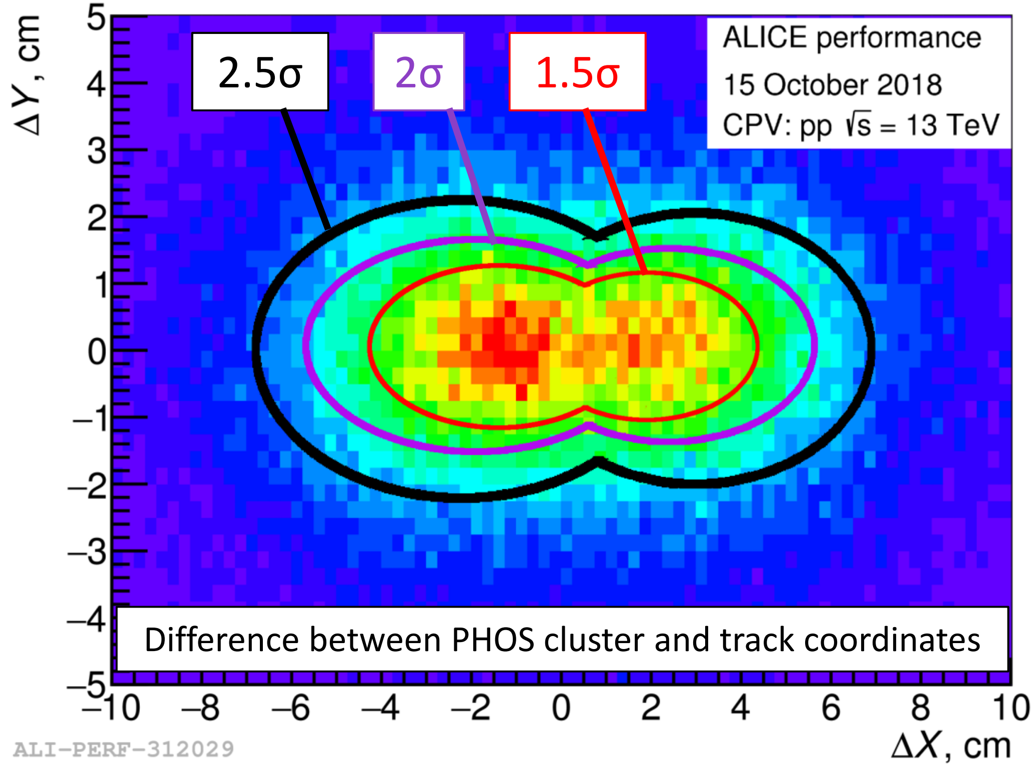
- Criteria to match PHOS and CPV clusters are geometrical: if distance between clusters is small enough, we call the pair matched. These criteria depend on energy of PHOS cluster. The same is used to match PHOS/CPV clusters with ITS-TPC track projection.
- There are 2 coordinates and we use 2d-Gaussian to define an oval-shaped window for the cut instead of simple rectangle. Distance is measured in number of σ of that Gaussian. This allows us to apply the same cut criteria to different PIDs to compare them. ($\mu_{x,z}$ and $\sigma_{x,z}$ are the Gaussian parameters)

$$\sqrt{\frac{(\Delta_x - \mu_x)^2}{\sigma_x^2} + \frac{(\Delta_z - \mu_z)^2}{\sigma_z^2}} < \sigma_{cut}$$

- Positive and negative tracks are bent oppositely in a magnetic field, hence the shape of the window for matching becomes a bit more complex.
- If the PHOS–CPV cluster pair is inside the window, we call it matched.

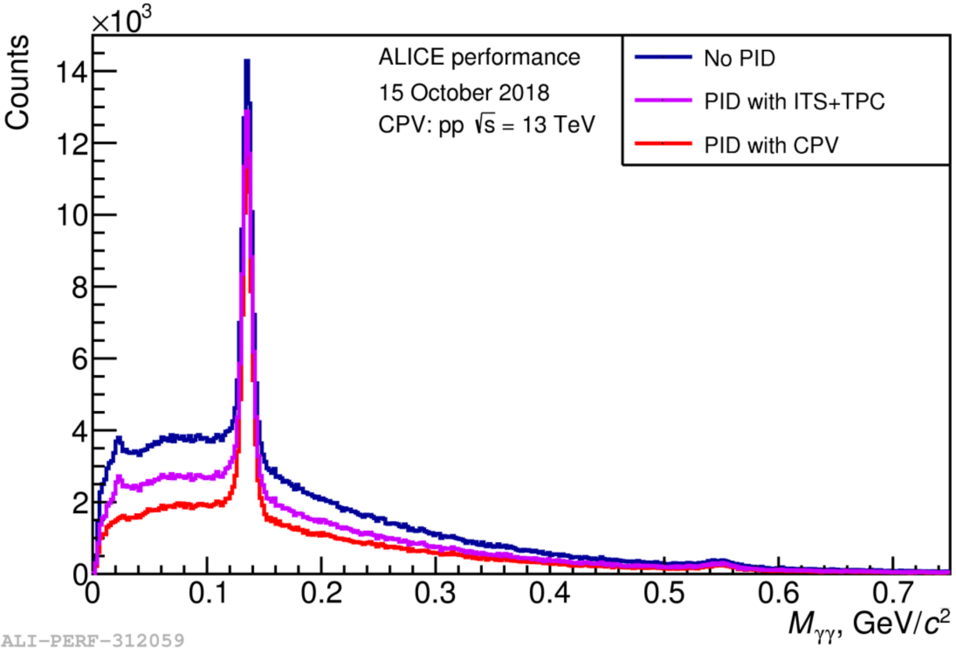
  (The same applies for the cluster-track projection matching)

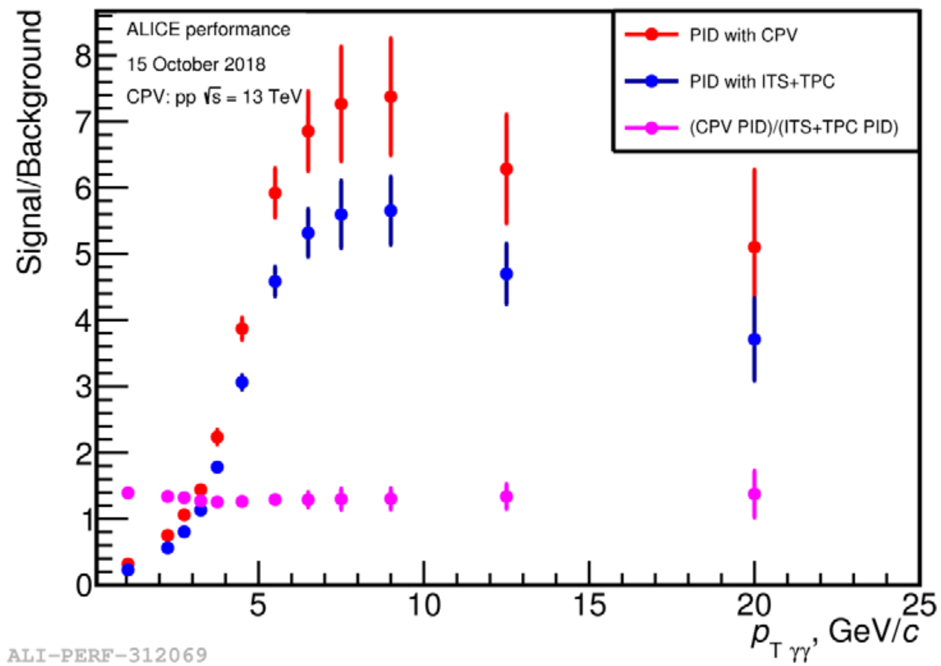
- At the moment we use 2.5σ cut, subject to optimization.



Improvement of signal/background (S/B) ratio in PHOS

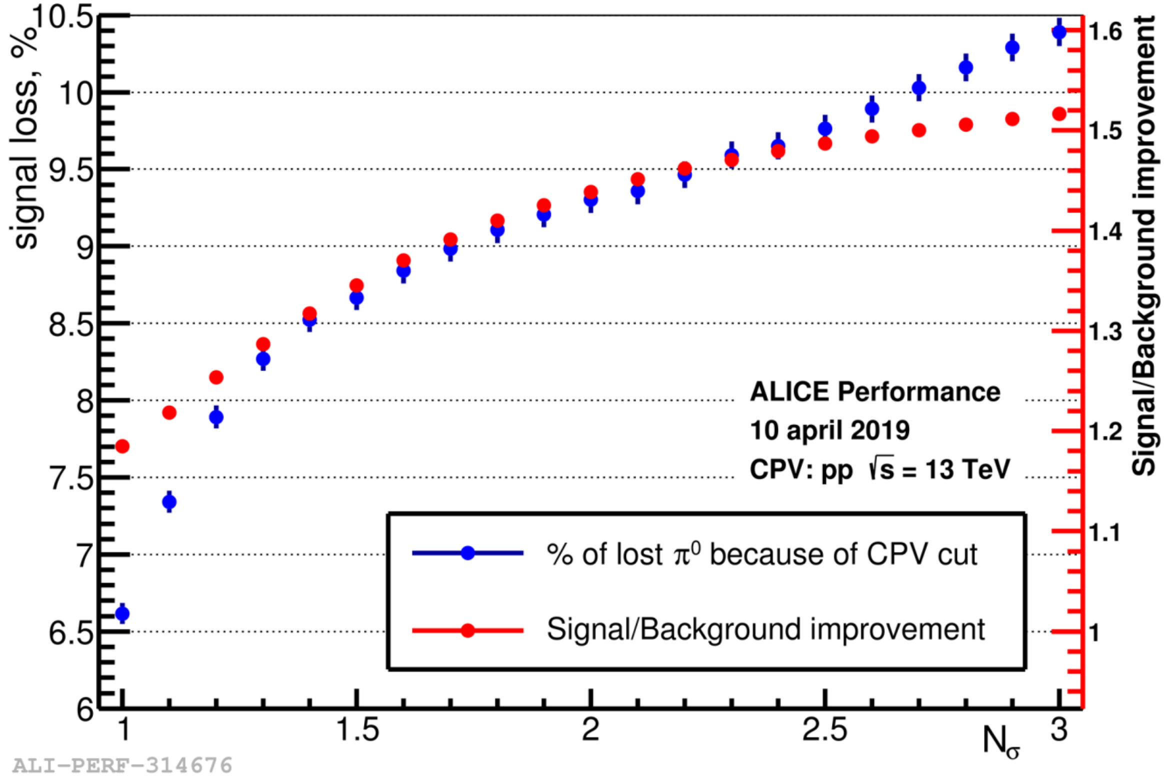
- Performance of CPV in terms of background suppression is studied by comparing signal/background ratio for $\pi^0 \to \gamma\gamma$ decays detected by PHOS;
- PHOS clusters can also be identified using the ALICE central tracking system. However, charged tracks created at radii beyond 1.8 m (late photon conversion of strange hadron decays) cannot be reconstructed, but do create a background in PHOS. CPV helps to eliminate such background.
- Some tracks may interact with the ALICE frame and not reach PHOS.
- CPV improves S/B ratio by factor 1.2 – 1.4 compared to tracking system identification;
- π^0 loss due to identification with CPV is at the level of 6% (9% compared to the spectrum without photon identification);





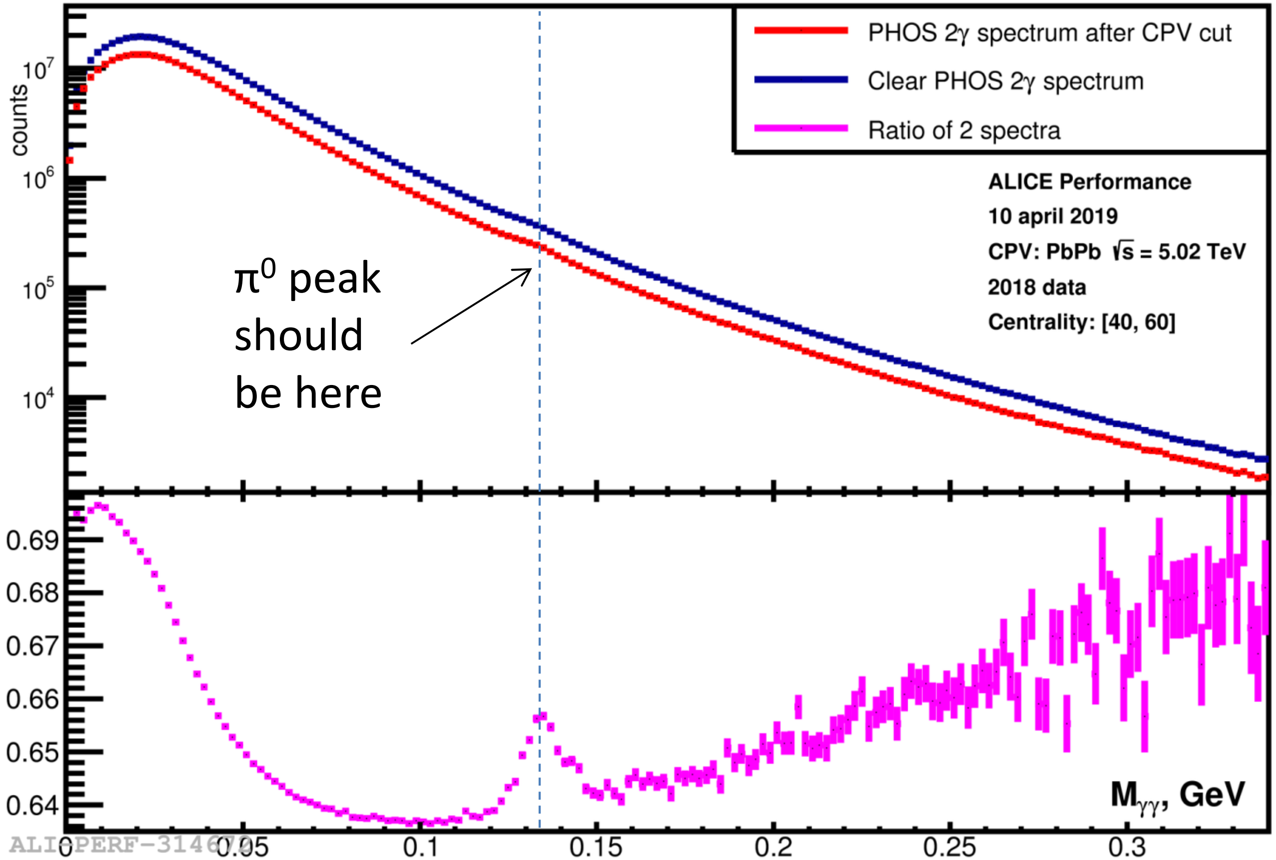
Dependence of signal loss on cut criteria

- There are some signal losses because of the CPV cut, about 9-10%. This may be caused by mismatches, e.g. when actual photon signal in PHOS is matched with a noisy cluster in CPV.
- As we increase the matching window (in sigma units), we cut away more background, thus improving the S/B ratio, but lose a fraction of π^0 signals.
- If we make cut more strict we can overlook some charged particles and mistake them as photons, especially in the low-p_T region.
- The optimal criteria are not obvious and balance between these two effects is still to be found.



Performance in Pb-Pb

- The exact same analysis as before can not be done here, because of high detector occupancy in Pb-Pb collisions resulting in large combinatorial background, π^0 peak is not seen. In this case one can use “mixed-event” technique to subtract background from the data.
- However, CPV helps to suppress background from charged particles which leads to a better visibility of the π^0 signal above combinatorial background in the 2γ spectrum. To estimate this effect as was done for pp, it’s necessary to subtract the combinatorial background.



Note on the amount of analyzed data

- ALICE, like all other LHC experiments, are at the leading edge of big data. For example, raw experimental data collected from Pb-Pb collisions in 2018, amounted to **4.6 Pbyte**.
- These data were reconstructed on the GRID system using 135 thousand CPU in parallel. This output of reconstruction resulted in **21 Tb** of disk space.
- Physics analysis of reconstructed data takes a few years of CPU time. In ALICE all analysis data were compressed down to **80 Gb** of relevant information needed for the CPV studies.

- Basic principles of big data analysis deployed by ALICE:
  Huge amount of raw data → parallelization of reconstruction on the GRID → data compression to a minimal significant volume → light and focused user analysis of compressed data.

Conclusion

- One module of the Charged-Particle Veto for PHOS spectrometer was in operation during the entire Run2;
- First results of its performance are obtained;
- We are ready to extract first direct photon measurements in Pb-Pb collisions obtained during Run2 of the LHC as CPV has proven abilities to reject charged-particle hits in PHOS.

Plans

- Dependency on detector parameters (gas mixture, high voltage) is still to be found;
- Analysis of Pb-Pb data is ongoing;
- 2 further modules are being prepared at CERN to be installed in the ALICE cavern in October 2019;
- FEE is being modified for the conditions of Run3. CPV will be suitable for high collision rates;
- Increase of acceptance and data taking speed will greatly increase integrated luminosity for direct photon measurements in Run3 of the LHC.

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Backup slides

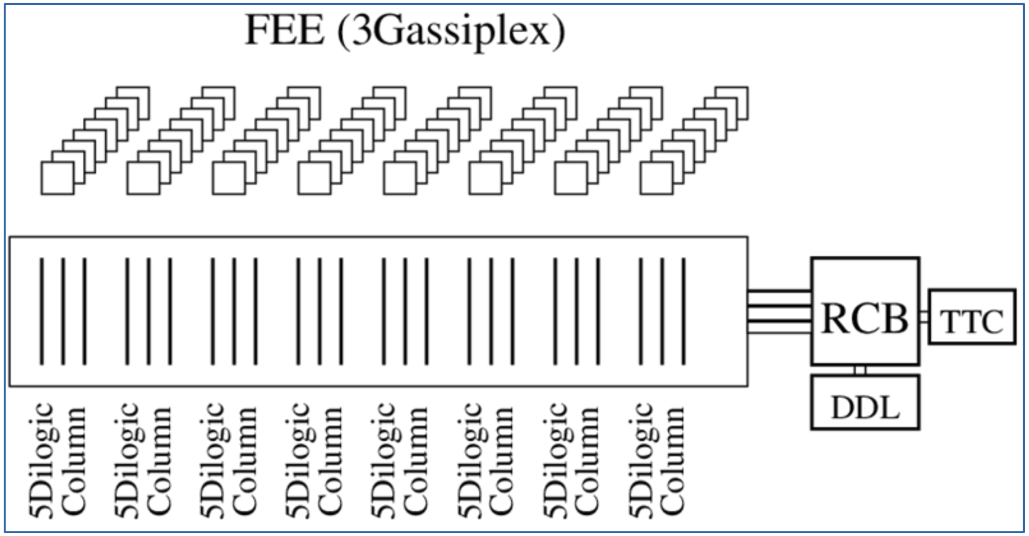
CPV main characteristics

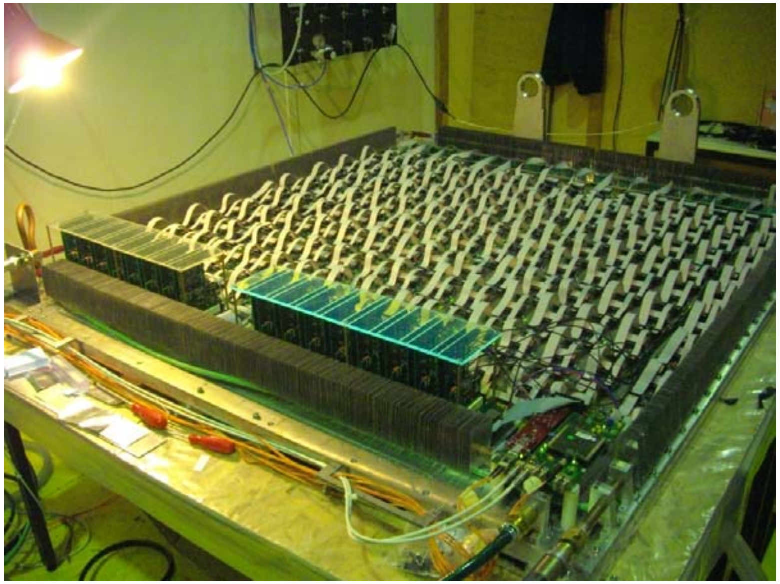
- Sensitive volume size: 140 x 123 x 1.4 cm^3
- Wire pitch – 5.6 mm
- Wire diameter – 28 μm
- Number of sensitive wires – 258
- Wire tension – 100 g
- Anode-cathode spacing – 7 mm
- Pad size – 21 x 10 mm^2
- Transverse segmentation: 128x60 pads
- Number of channels with charge-sensitive amplifiers – 7680
- Gas mixture – Ar(80%)+CO_2(20%)
- Nominal anode HV – 2.2 kV (+)
- Material budget – 5% X_0
- Designed coordinate resolution ≈1 mm

Readout

1 CPV module electronics consists of:

- 160 3Gassiplex cards – 48-channels charge-sensitive amplifiers
- 32 Dilogic cards – 5 ADC (12 bits) with sparse readout, each for multiplex readout of 48 channels
- 16 Column Controllers – readout controllers for 2 Dilogic cards each
- 2 Segment cards – readout controllers for 8 CC each
- 1 RCB card – optical DAQ interface (1 DDL) and optical(TTC)+ LVDS (L0+busy) trigger interface
- Readout time in Run2:
  - ≈ 200μs (low-multiplicity events)
  - ≈ 1800μs (fully occupied module)
- Data readout rate: 5 kHz in pp and 4 kHz in PbPb collisions

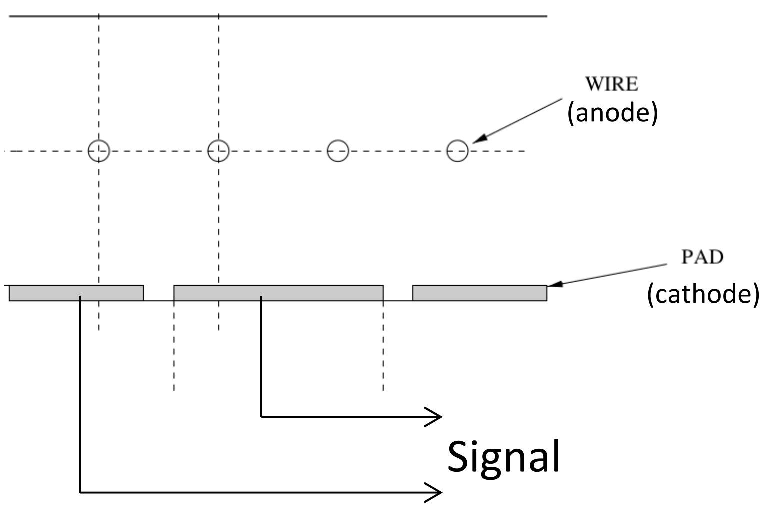




Construction

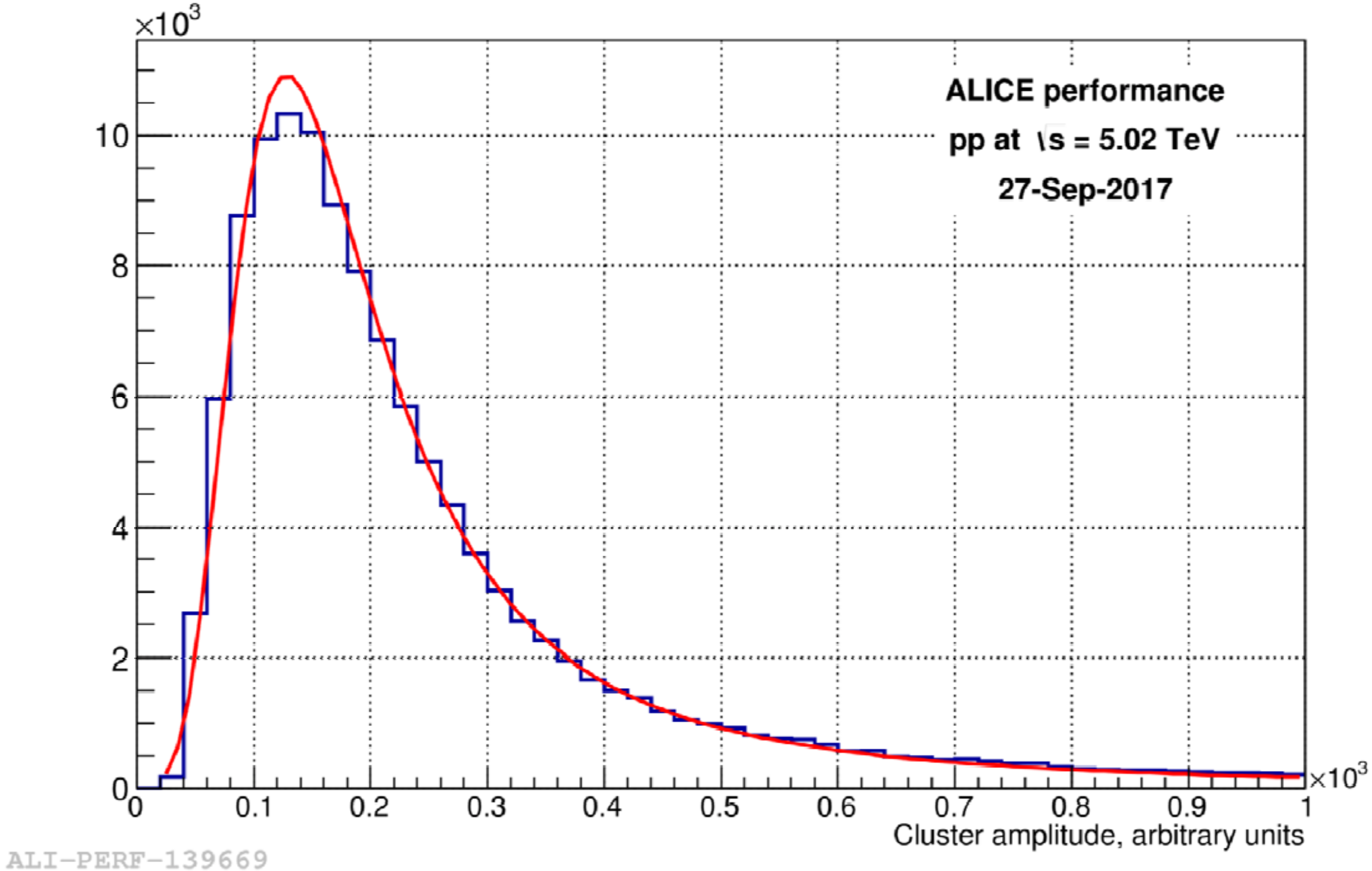
- CPV is a proportional chamber with cathode pad readout.
- Charged track passes through the CPV ionizing the gas mixture. Ions induce charge on the segmented cathode, which is detected by the readout electronics.
- Track coordinate is reconstructed from a cluster of induced charge distribution

- CPV measures charged track hits in (x,y) plane with resolution 0.7-1 mm
- CPV is positioned at 12 cm above the PHOS crystal surface, thus cluster matching in PHOS and CPV will be used for photon identification.
  - -- PHOS and CPV cluster matching means that PHOS cluster is produced by charged particle.
  - -- No matching of PHOS and CPV means that PHOS cluster is produced by neutral particle.
- Induced charge in each pad is measured by individual front-end channel with charged-sensitive amplifier.
- One CPV module was installed above one PHOS module before Run2.



Amplitude spectrum

- Amplitude spectrum of CPV clusters matched with charged tracks reconstructed in central tracking system in pp collisions at 5.02 TeV.
- CPV cluster has 3 and more pads. Measured induced charge is defined by ionization energy loss of charge particles punching the CPV which is well described by Landau distribution (red curve)



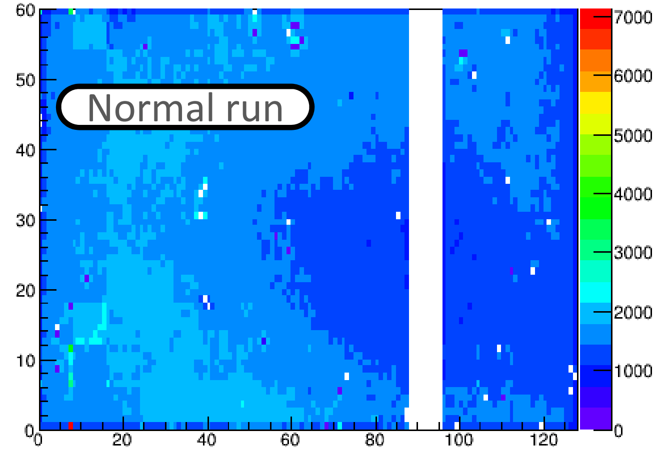
HV trips at high-luminosity and recovery

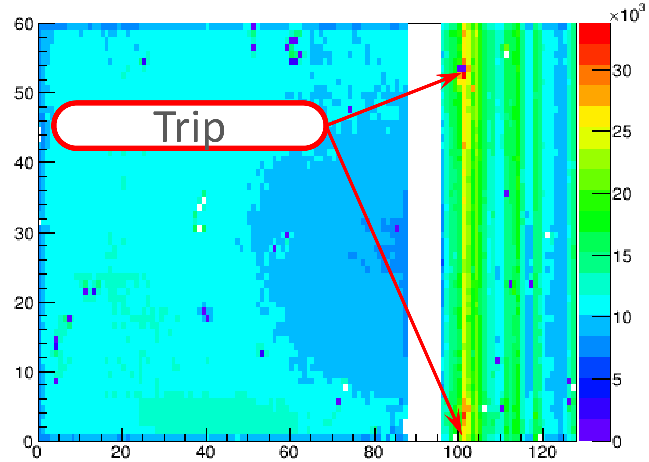
- HV trips are observed in runs with high particle flux: Pb-Pb, high-luminosity p-Pb and pp collisions.
- This first experience of CPV operation with collisions forced us to look for optimal detector conditions: nominal HV (2212V), gas relative concentration (83% Ar + 17% CO_2), gas flow (13.4 l/h).
- At the end of Pb-Pb run 2015, optimal conditions were found until the high luminosity pp-collisions at 700 kHz
- Stripes in the right part of the module, along the wires

- We had trips in pp runs at high luminosity 700 kHz, gas mixture is being attuned to fix this -> CO_2 percentage is increased up to 20%.

Map of CPV, each rectangle represents a single pad.

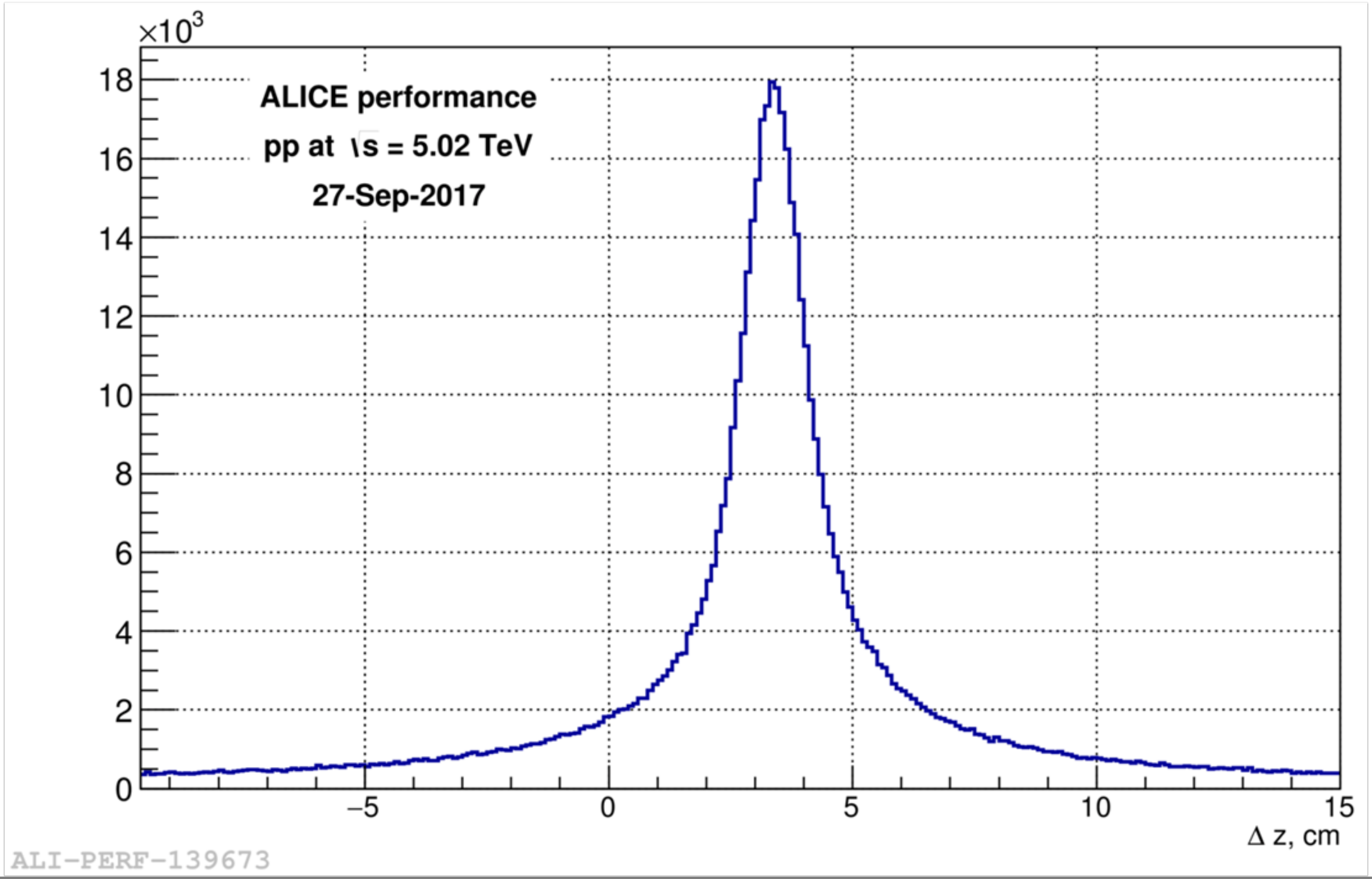
Color indicates total amplitude of signals, in arbitrary units.





Matching distance

- Matching distance along z axis between the CPV cluster and projection of the global track to the CPV surface. Analysis of pp at 5.02 TeV.
- Main peak on the distribution corresponds to clusters produced by reconstructed charged tracks, while background is clusters uncorrelated with global tracks.
- The peak position is displaced at 3.3 cm which is explained by the CPV misalignment with respect to the central tracking system.



Matching distance

• Matching distance along z axis between the CPV cluster and PHOS clusters at energy 1<E<2 GeV. Analysis of pp at 5.02 TeV.

• Main peak on the distribution corresponds to PHOS clusters produced by charged tracks which also generated a CPV cluster, while background is PHOS and CPV uncorrelated clusters.

• Photon is identified as cluster outside the width of this main peak or as cluster without a track.