Antineutron reconstruction and identification in electromagnetic calorimeter

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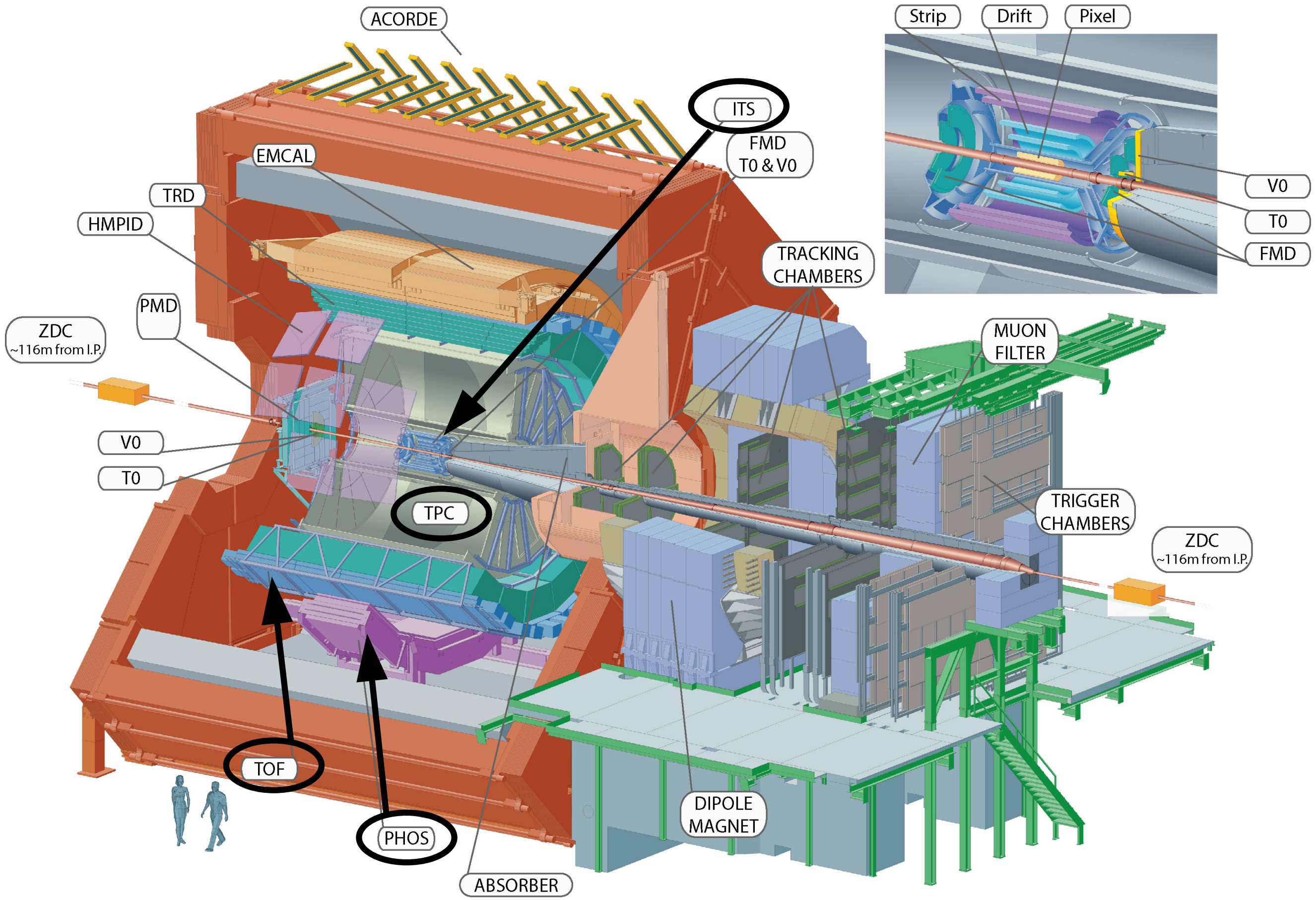
The ALICE detector

- ITS, TPC and TOF are mainly used for reconstruction and identification of tracks

- PHOS - high granularity photon spectrometer based on PbWO4 crystals located at the bottom of the ALICE
- The PHOS is dedicated to the search for electromagnetic radiation from the hot strongly interacting matter in nucleus-nucleus interactions at high energies, as well as for measurements of meson specra via their decays on photons
- Distance to IP = 4.6 m



Motivation

Measurement of antineutron

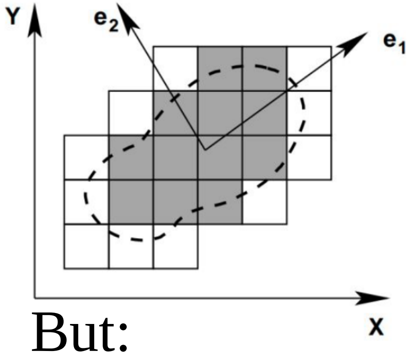
- Measurement of antineutron-hadron interaction
- Search for (anti)neutron bound states (di-anti-neutron/tetra-anti-neutron)

- Measurement of $\bar{\Sigma}$ to validate method of antineutron identification and get insight into hyperon production mechanisms
- Measurement of the p-$\bar{\Sigma}$ interaction via the femtoscopic method to understand the hyperon-nucleon interaction (important for astrophysics)
- Cross-check between different methods is important to reduce systematic uncertainties and verify results

Antineutron identification in PHOS

How we can identify $\bar{n}$:

- Deposited energy of annihilation
- Neutrality
- Dispersion of cluster (M20, M02 – eigenvalues of S matrix)



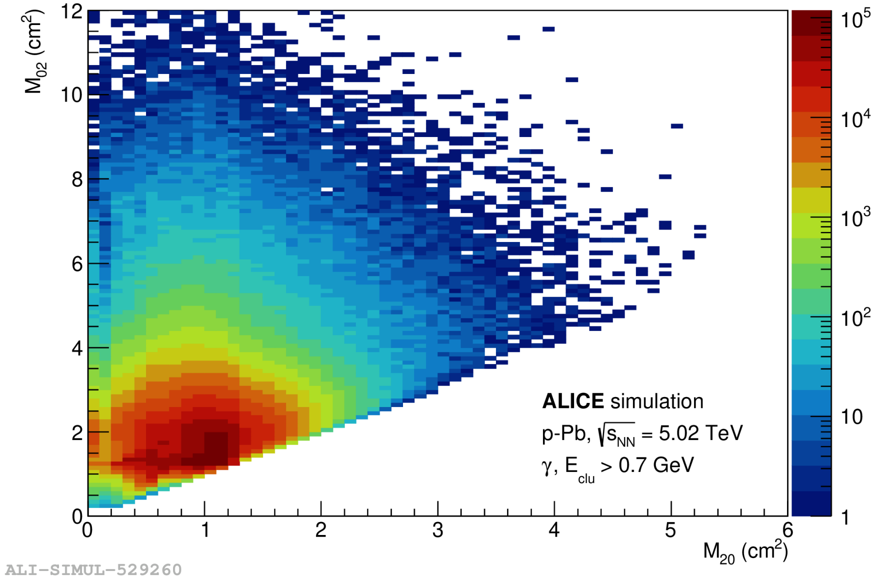
$$S = \begin{pmatrix} s_{xx} & s_{xz} \\ s_{zx} & s_{zz} \end{pmatrix}$$

$$s_{xx} = \langle (x - \bar{x})^2 \rangle$$

$$s_{xz} = \langle (x - \bar{x})(z - \bar{z}) \rangle$$

But:

- Cannot measure momentum based on deposited energy
- Use Time-of-Flight to reconstruct antineutron momentum



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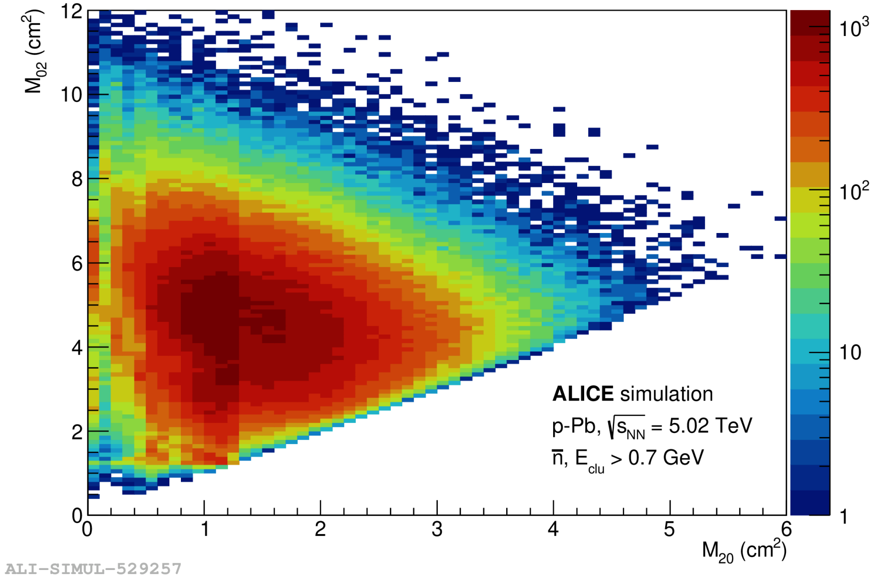

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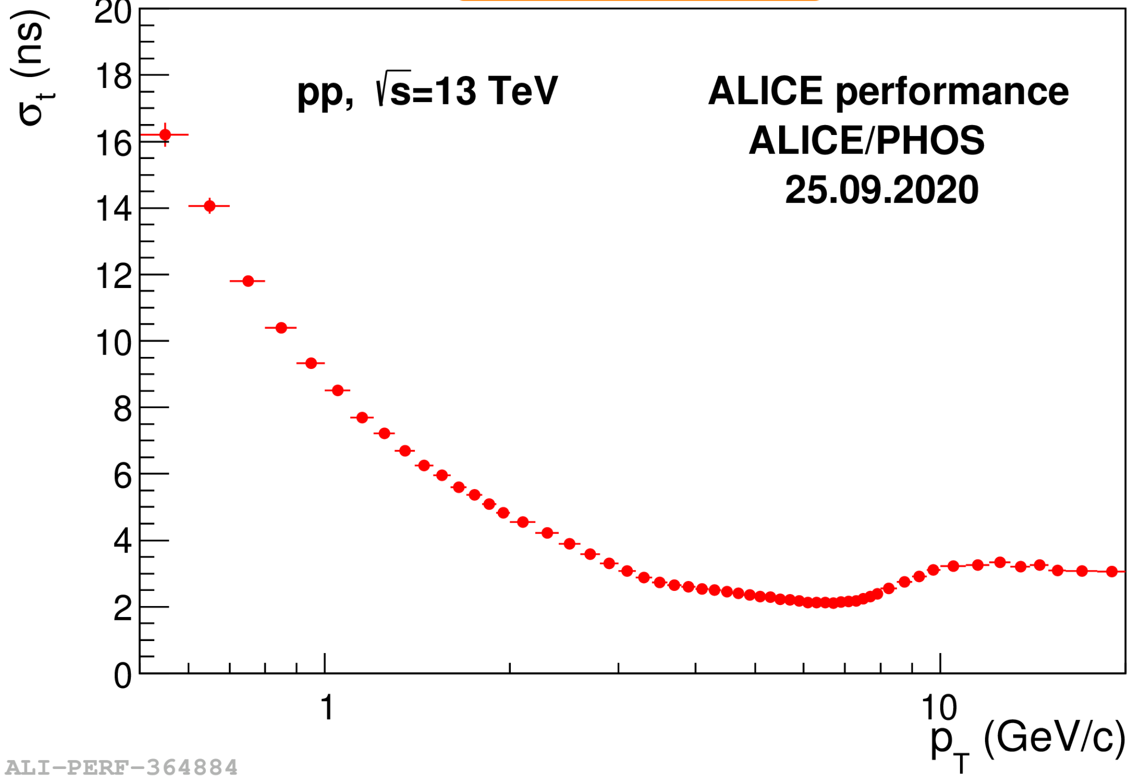
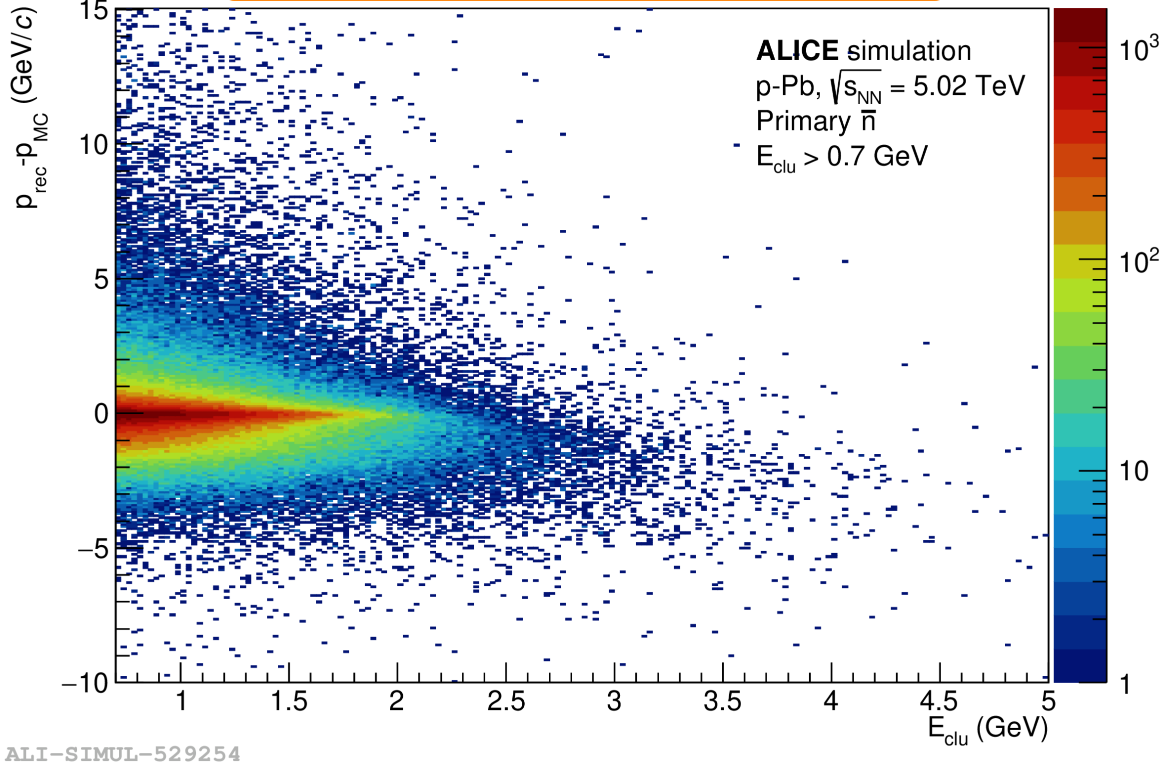
Reconstruction of $\bar{n}$ momentum

PHOS time resolution



Momentum reconstruction from time of flight



$$p_{\text{rec}} = \frac{m_{\bar{n}}}{\sqrt{\left(\frac{t_{\text{TOF}} \cdot c}{L}\right)^2 - 1}}$$

L - distance between primary vertex and cluster coordinate in PHOS, m (about 4.6 m)

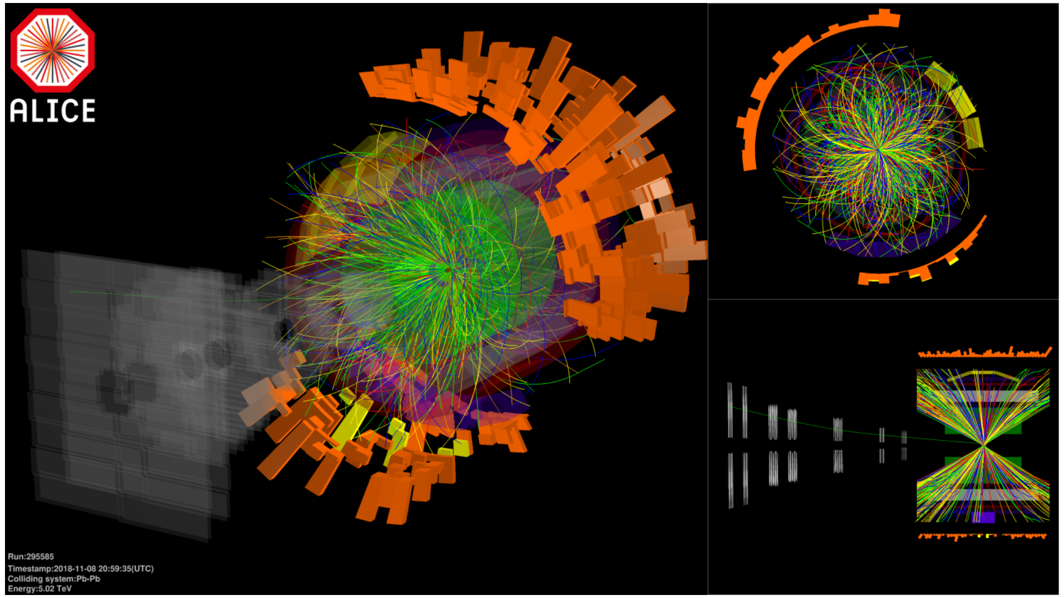
$m_{\bar{n}}$ - antineutron mass, $0.939485\ \text{GeV}/c^2$

t_{TOF} - time of flight, s

Event selection

$\Sigma^+ = \mathrm{uus}$
$m = 1189.37 \pm 0.07\ \mathrm{MeV}/c^2$
$\Sigma^+ \to p\pi^0 (51.57 \pm 0.30)\ \%$
$\Sigma^+ \to n\pi^+ (48.31 \pm 0.30)\ \%$
$\boxed{\bar{\Sigma}^- \to \bar{n}\pi^-}$

$\Sigma^- = \mathrm{dds}$
$m = 1197.449 \pm 0.030\ \mathrm{MeV}/c^2$
$\Sigma^- \to n\pi^- (98.848 \pm 0.005)\ \%$
$\boxed{\bar{\Sigma}^+ \to \bar{n}\pi^+}$



- p-Pb collisions at $\sqrt{s} = 5.023$ TeV
- |Vertex z position| ≤ 10 cm
- Pile-up rejection
- MC and Data were analysed

Particle selections

$\bar{\Sigma}$

$\bar{n}$ π

Clusters in calorimeter:

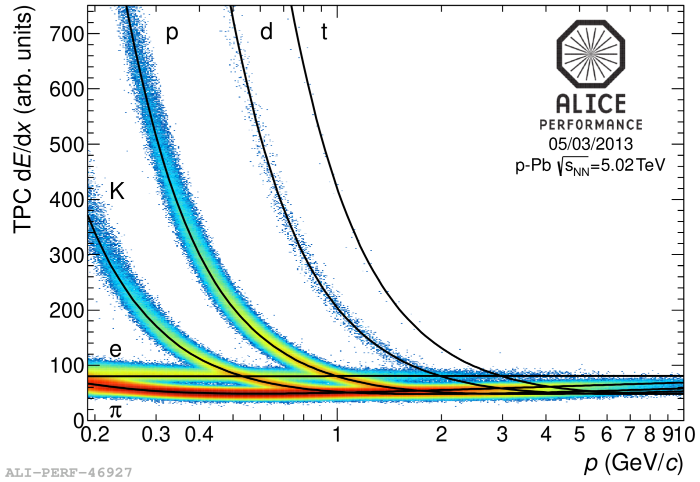
- $E_{\mathrm{clu}} > 0.7$ GeV
- $\mathrm{M02} > 0.2\ \mathrm{cm}^2$
- $N_{\mathrm{cells}} > 2$
- $\mathrm{CPV} > 2.5\sigma$

Dispersion cut for $\bar{n}$:

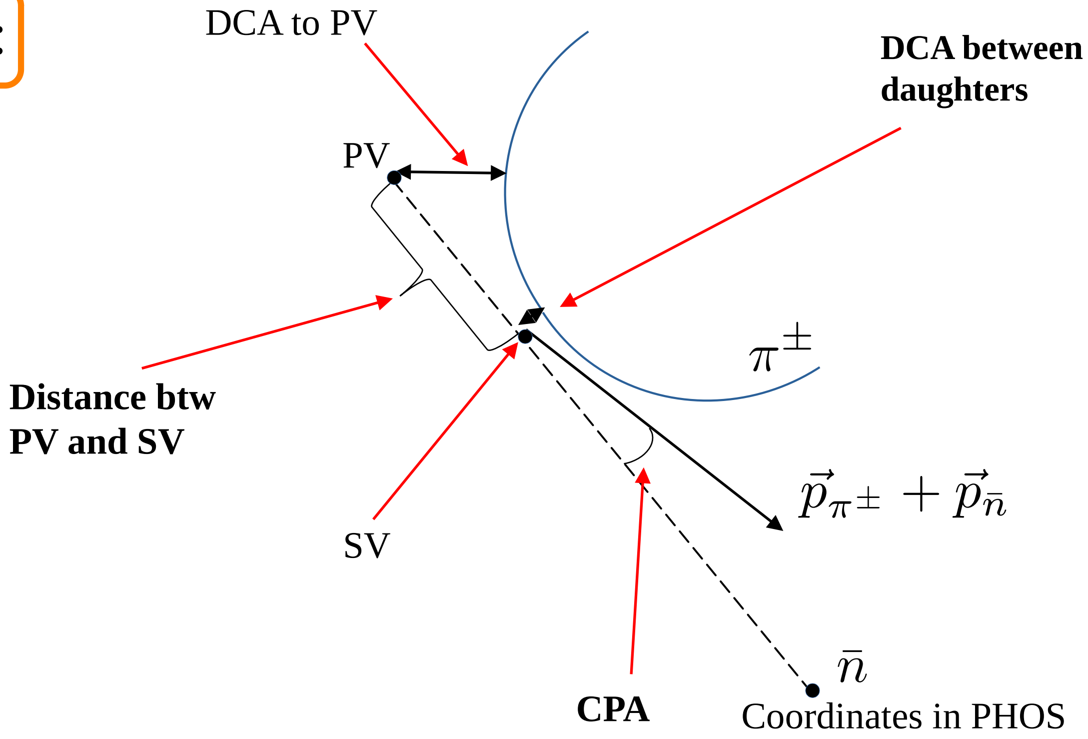
- $\mathrm{M02} > -\mathrm{M20} + \mathrm{B}$
- $\mathrm{B} = \begin{cases} 4.5, E_{\mathrm{clu}} < 2.0\ \mathrm{GeV} \\ 4.0, E_{\mathrm{clu}} \geq 2.0\ \mathrm{GeV} \end{cases}$

Tracks in tracking system:

- $|\eta| < 0.8$
- TPC dE/dx: 3σ band around π line



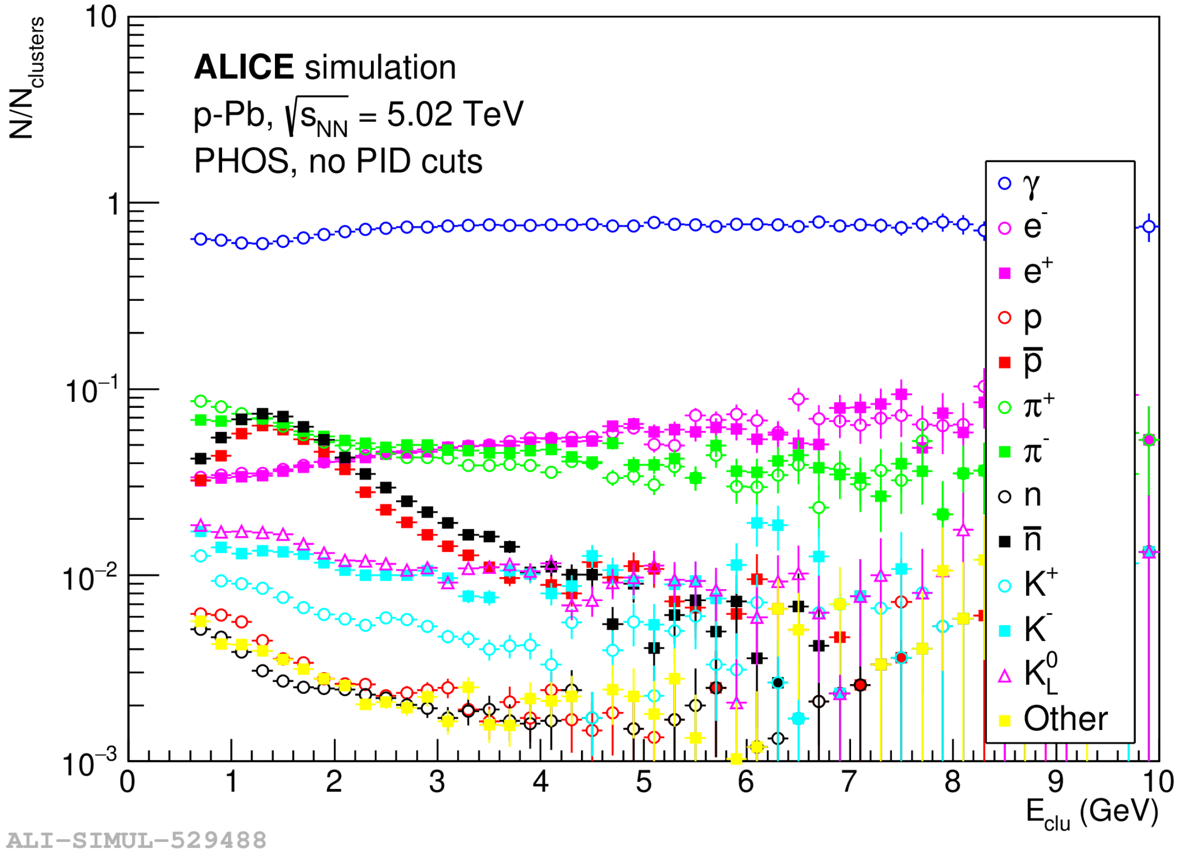
Topological selections



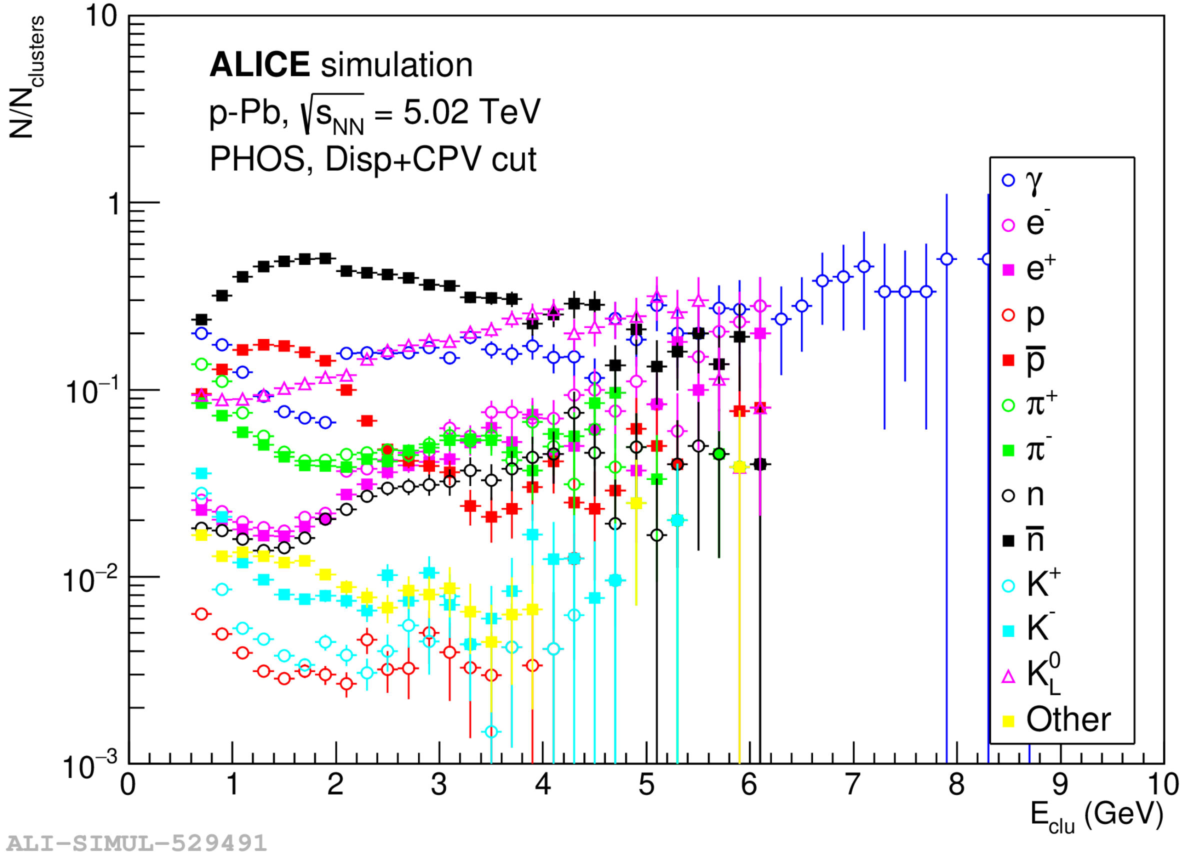
Topological selections in backup slides

Fraction of different type of clusters

- After applying CPV and Dispersion cuts the fraction of antineutron clusters reaches ~50%



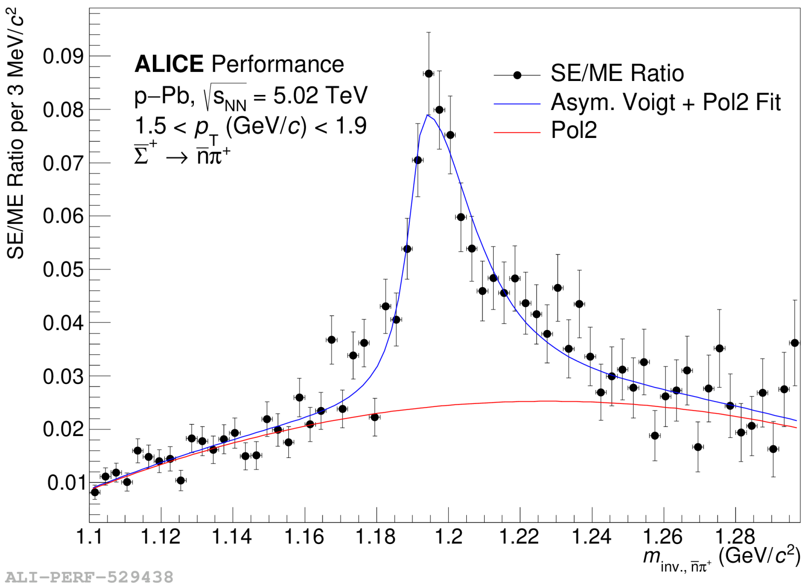
Without CPV and Dispersion cuts

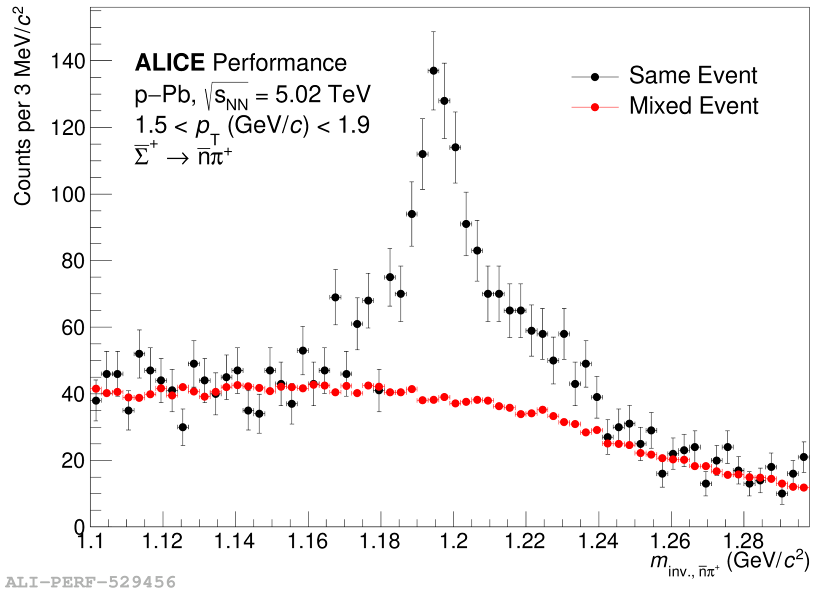


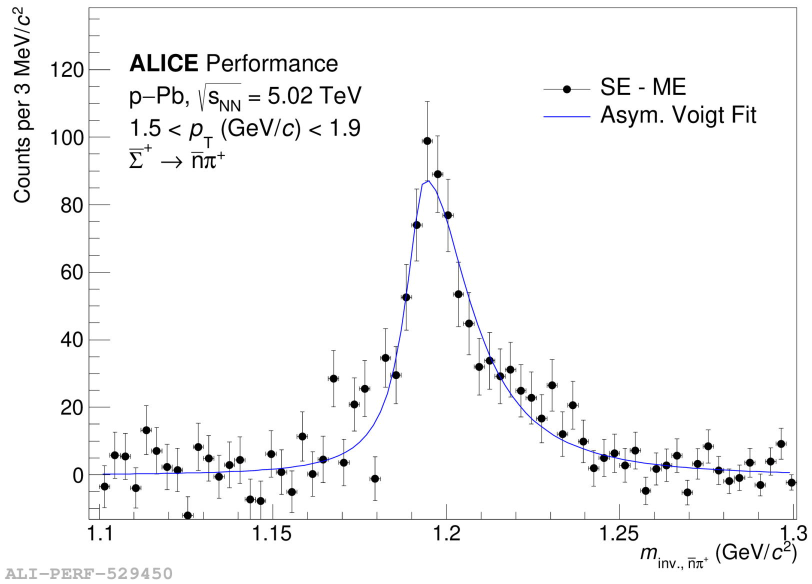
With CPV and Dispersion cuts

Signal extraction. $\bar{\Sigma}^{+}$

- Applying all the obtained cuts, the distribution of the invariant mass for pairs of a track (pi-meson) and a cluster in the calorimeter (antineutron) is constructed
- Same Event and Mixed Event distributions are obtained







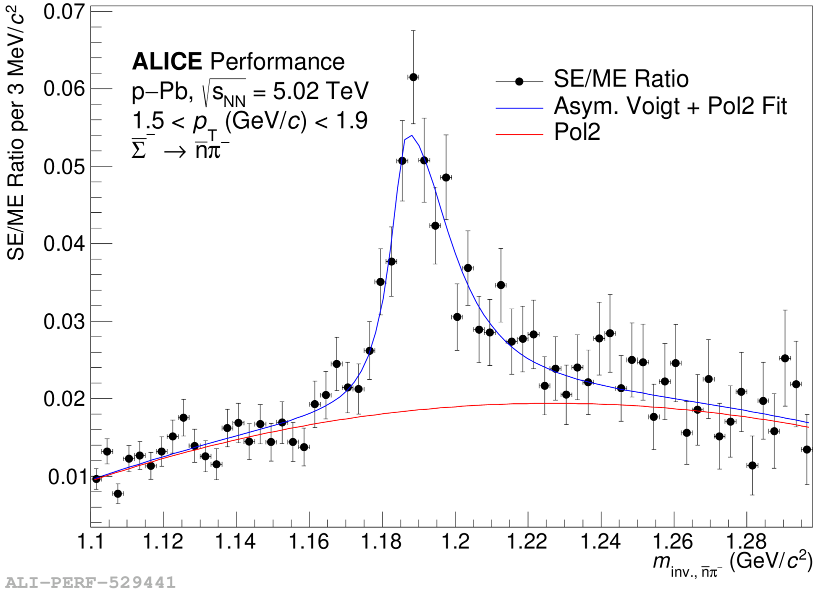
SE to ME ratio fitted with Pol2 and Asymmetric Voigt function

SE and ME. ME is normalized on second order polynom obtained from SE/ME fit

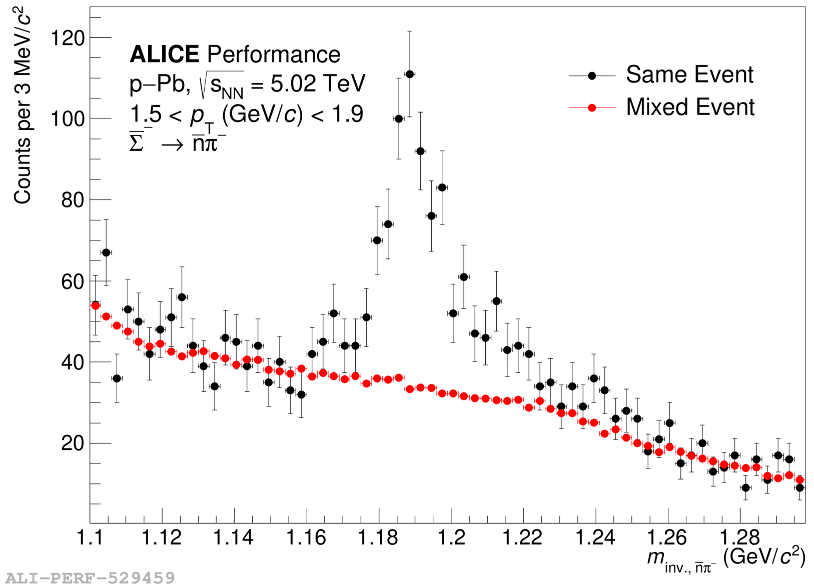
SE after the ME subtraction. Peak fit performed with Asymmetric Voigt function

Signal extraction. $\bar{\Sigma}^{-}$

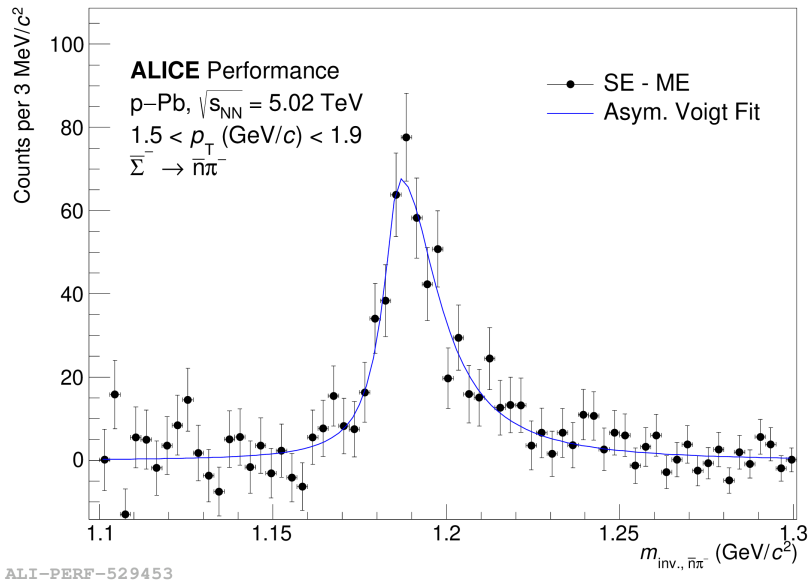
- The same procedure performed for a negatively charged track and a cluster in the calorimeter
- The peak is smaller due to the fact that BR of this channel is lower than for $\bar{\Sigma}^{+}$



SE to ME ratio fitted with Pol2 and Asymmetric Voigt function



SE and ME. ME is normalized on second order polynom obtained from SE/ME fit

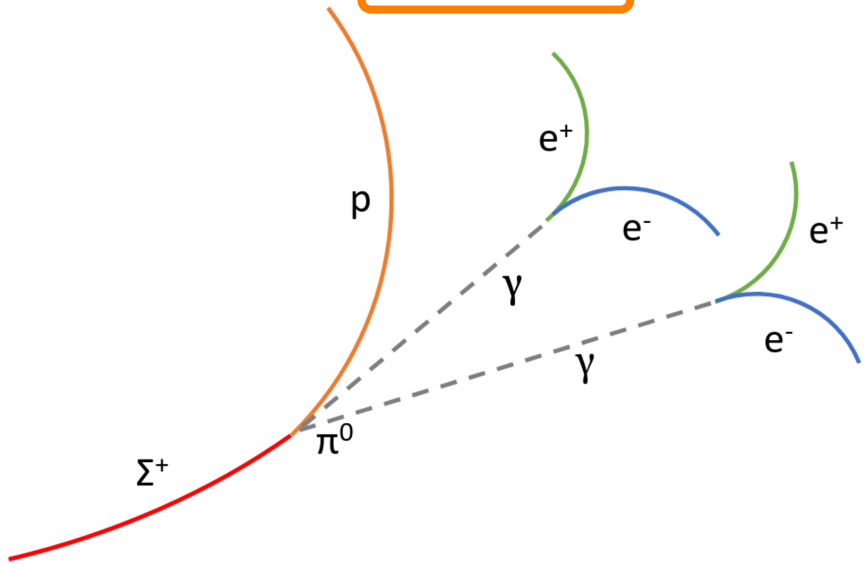


SE after the ME subtraction. Peak fit performed with Asymmetric Voigt function

Alternative method

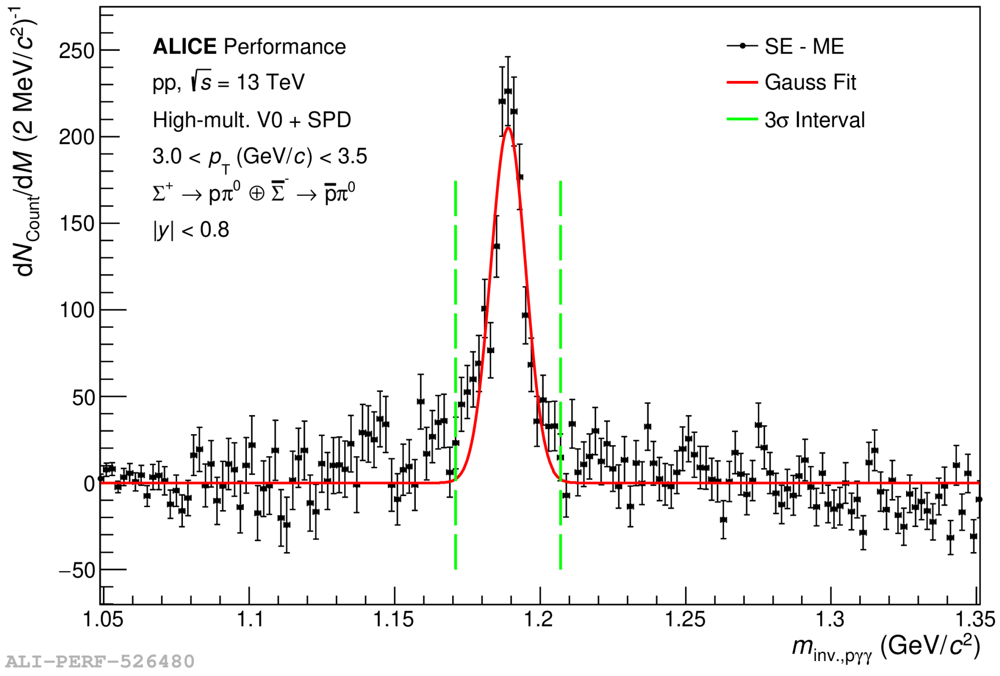
$$\Sigma^+ = \mathrm{uus}$$
$$m = 1189.37 \pm 0.07\ \mathrm{MeV}/c^2$$
$$\Sigma^+ \to p\pi^0 (51.57 \pm 0.30)\ \%$$
$$\bar{\Sigma}^- \to \bar{p}\pi^0$$

Decay topology



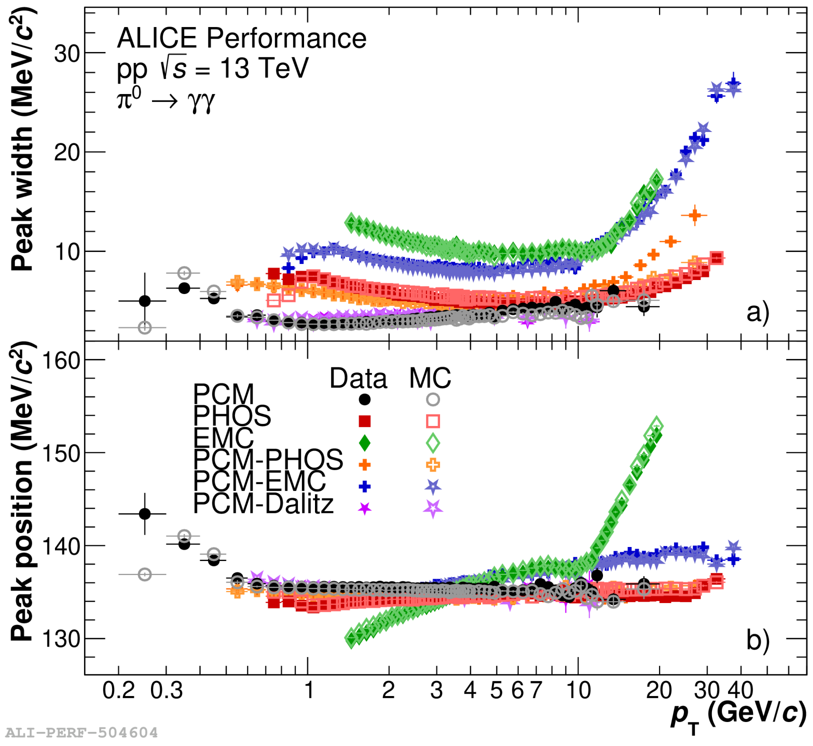
- 2 photons were observed using PCM and High Multiplicity Trigger
- Peak is visible after background subtraction
- Only Σ^+ ($\bar{\Sigma}^-$) can be measured, but not $\Sigma^-(\bar{\Sigma}^+)$
- Widths of $\bar{\Sigma}^-$ peak for both methods are comparable
- Systematic uncertainties are mostly independent
- Both methods complement each other
- Further analysis is progress

SE after the ME subtraction

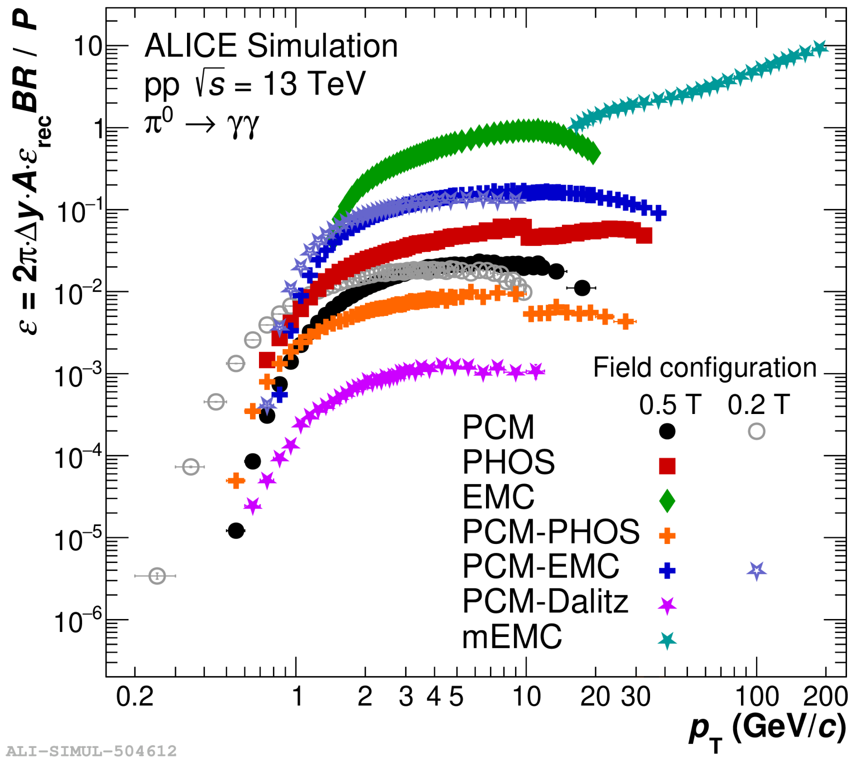


Alternative method. PCM vs PHOS

- 2 photons can be observed using PHOS
- For low p_T PCM have smaller width
- PCM and PHOS have comparable efficiencies



Neutral pion peak position and width



Neutral pion acceptance times efficiency

Conclusion

- For the first time, a method for antineutron reconstruction was proposed
- Reconstruction of antineutrons by the time-of-flight allows to obtain momentum values up to ~2 GeV/c for the current time resolution of PHOS
- The method can be used to reconstruct $\bar{\Sigma}^{+}$, by a single channel of decay to the antineutron and pion
- The existing method ($\bar{\Sigma}^{-} \rightarrow \bar{p}\pi^{0}$) and the new one proposed, nicely complement each other

- Further analysis is ongoing

Thank you for your attention!

Backup

Signal extraction

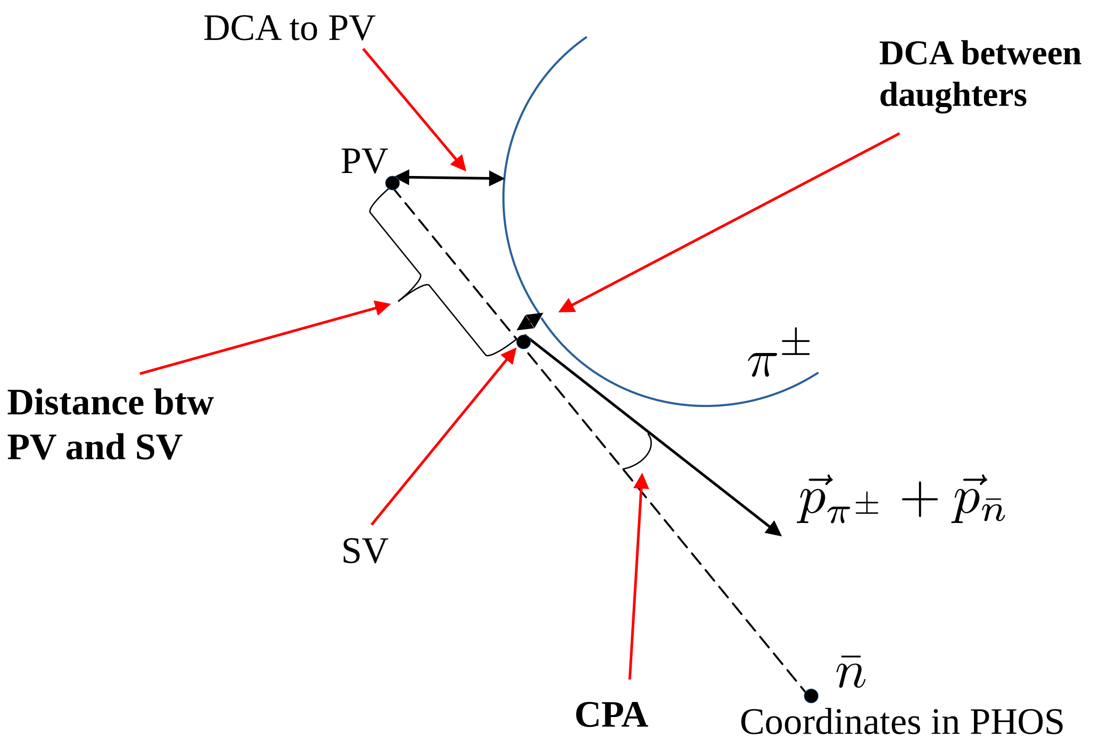
- For signal extraction we use Asymmetric Voigt function with different widths on the left and right side and Pol2 for background

$$f(x, m, \sigma, w_1, w_2) = \begin{cases} c_0 \cdot \dfrac{\exp\left(-\dfrac{(x-m)^2}{2\sigma^2}\right)}{((x-m)^2 + w_1)}, x - m < 0 \\ c_0 \cdot \dfrac{w_2}{w_1} \cdot \dfrac{\exp\left(-\dfrac{(x-m)^2}{2\sigma^2}\right)}{((x-m)^2 + w_1)}, x - m \geq 0 \end{cases}$$

Topological cuts

- PV – Primary Vertex
- SV – Secondary Vertex
- DCA – Distance to Closest Approach
- CPA – Cosine of Pointing Angle

Topological selections



Topological selections in backup slides

Topological cuts

$$\mathrm{DCA}_{\mathrm{daug}} < 0.029393 - \frac{0.023081}{(p_{\mathrm{T}} - 0.184449)}$$

$$\mathrm{CPA} > 0.998790 - \frac{3.69242 \cdot 10^{-3}}{(p_{\mathrm{T}} - 0.296266)}$$

$$\mathrm{DBV}^{+} > 4.15714 - \frac{14.5387}{p_{\mathrm{T}} + 3.85203}$$

$$\mathrm{DBV}^{-} > 1.43437 - \frac{0.782708}{p_{\mathrm{T}} + 0.634462}$$