Study of Lambda polarization at the MPD

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MPD Polarization Meeting
«Vorticity and Polarization in Heavy-Ion Collisions»

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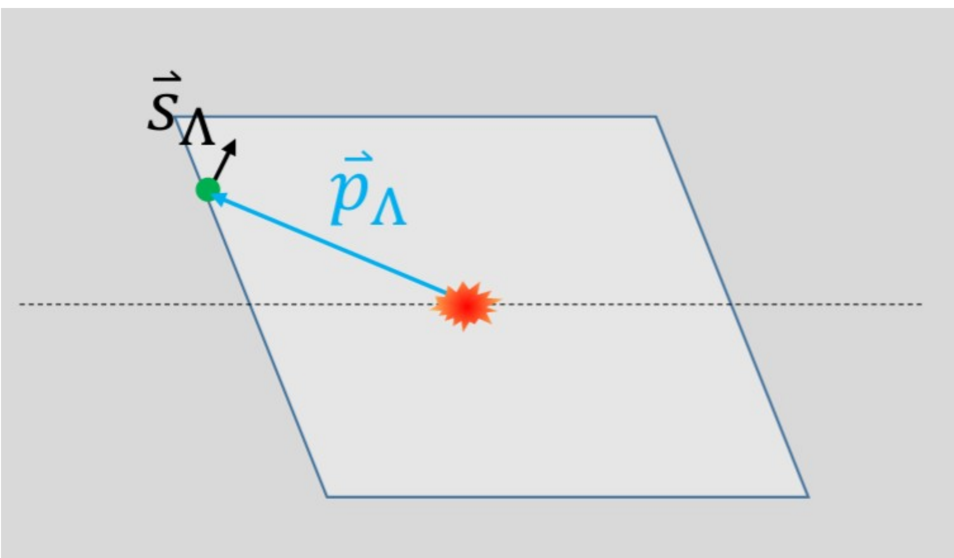
[3] Institute of Applied Physics, Chisinau, Moldova

Outline

- Introduction
  - Lambda polarization
  - Motivation
  - MPD detector
- Analysis method
  - Inclusive polarization
  - Global polarization
- Results
  - Feasibility test of polarization extraction
- Conclusion

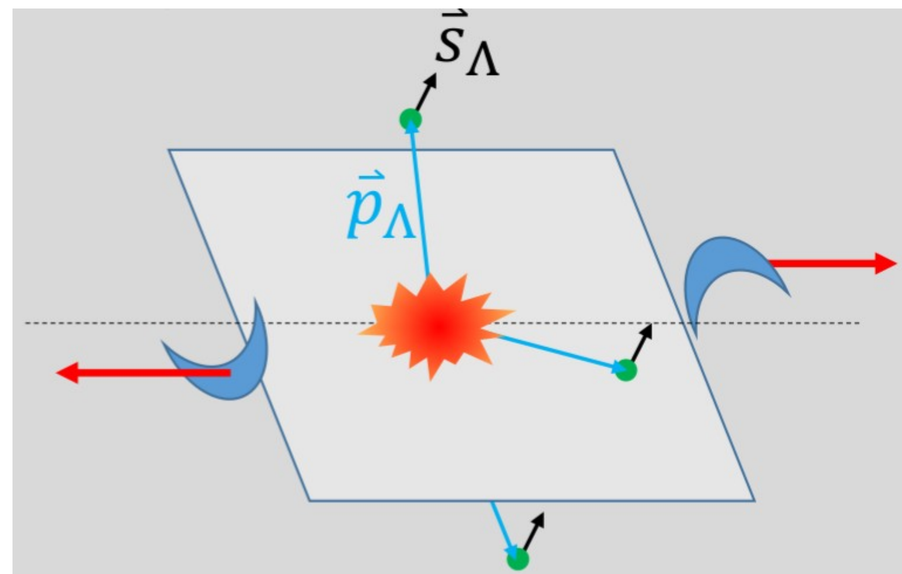
$\Lambda(\bar{\Lambda})$ hyperon polarization

- **Inclusive polarization**[3,4]
  - w.r.t scattering (production) plane
  - Measured in pp and pA collisions
  - In HIC can be diluted due to the rescattering in the QCD medium



Spanned by beam direction and $\vec{p}_\Lambda$

- **Global polarization**[1,2]
  - w.r.t reaction plane
  - Emerges in HIC due to the system angular momentum
  - Sensitive to parity-odd characteristics of QCD medium and QCD anomalous transport



Spanned by beam direction and $\vec{b}$

[1] Z. Liang, X. Wang, PRL 94, 102301 (2005)
[2] L. Adamczyk et al., Nature 548, 62 (2017)
[3] A. Lesnik et al., Phys. Rev. Lett. 35, 770 (1975)
[4] G. Bunce et al., PRL 36, 1113 (1976)

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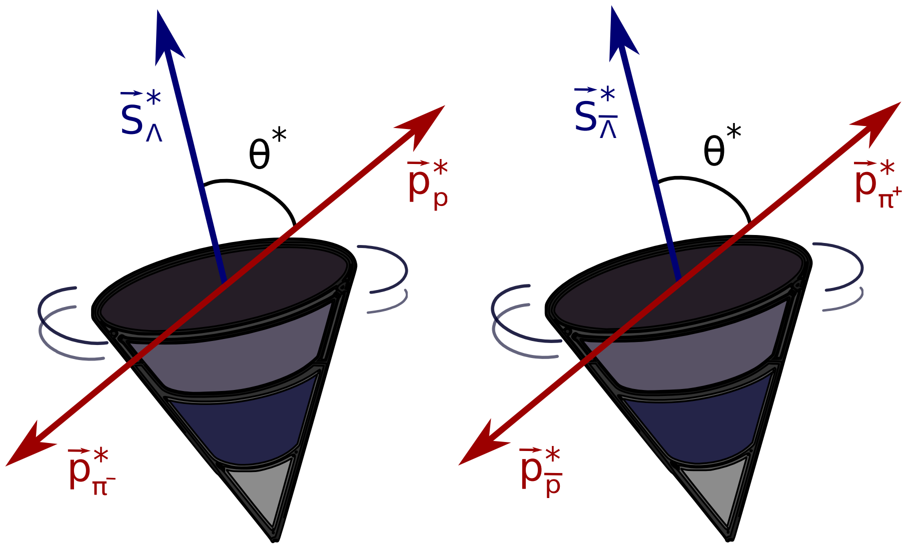
Can be measured through the weak decay: $\Lambda \to p + \pi^-$

$\bar{\Lambda} \to \bar{p} + \pi^+$

$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*} = 1 + \alpha_\Lambda P_\Lambda \cos\theta^*$$

* indicates the scattering plane

$\alpha_\Lambda = -\alpha_{\bar{\Lambda}} \simeq 0.642$ (decay asymmetry)



1 Z. Liang, X. Wang, PRL 94, 102301 (2005)
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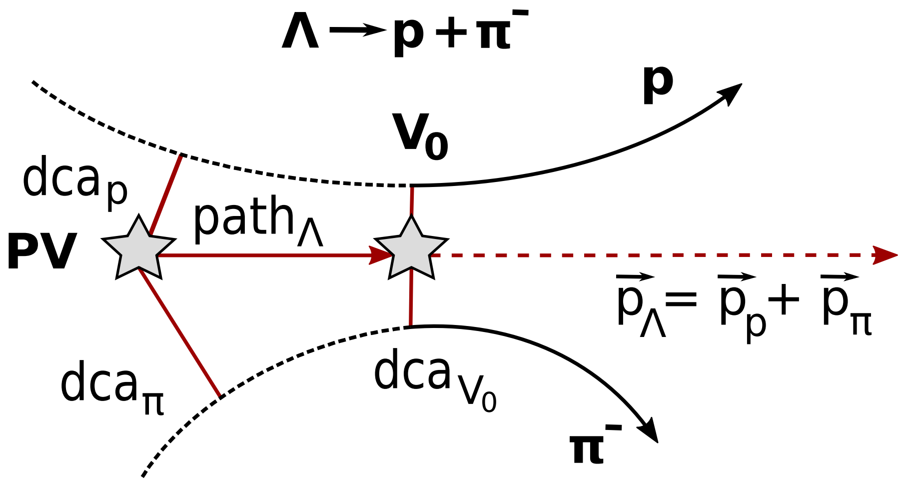
$\Lambda(\bar{\Lambda})$ hyperon polarization



- PV — primary vertex
- V_0 — vertex of hyperon decay
- dca — distance of closest approach
- path — decay length

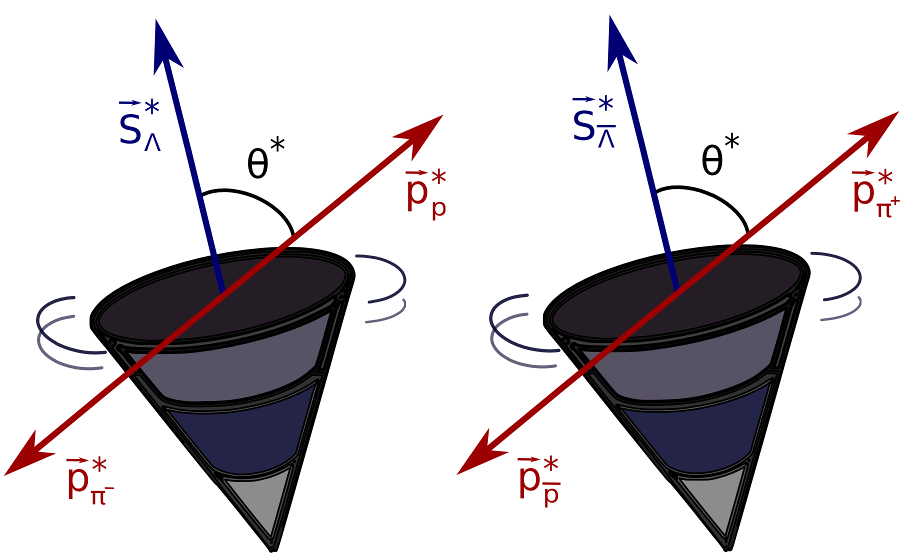
- In the case of global polarization one needs to calculate event plane and account for its resolution (R^1_{EP}):

$$\overline{P}_{\Lambda/\bar{\Lambda}} = \frac{8}{\pi\alpha}\frac{1}{R^1_{\mathrm{EP}}}\left\langle \sin(\Psi^1_{EP} - \phi^*_p)\right\rangle$$

- ϕ^*_p is the azimuthal angle of p

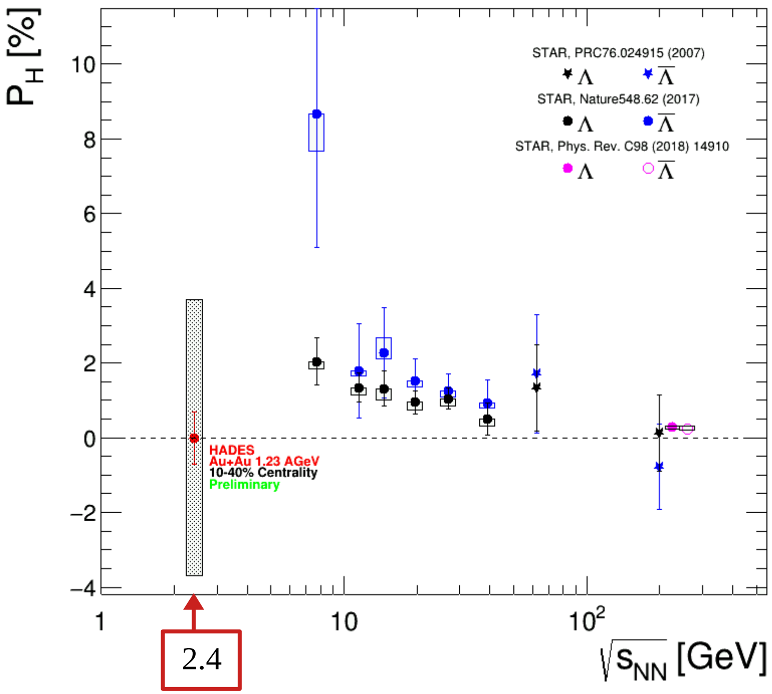
$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*} = 1 + \alpha_\Lambda P_\Lambda \cos\theta^*$$

- θ^* — angle between the decay particle and $\vec{n} = \vec{p}_{\mathrm{beam}} \times \vec{p}_\Lambda$
- P_Λ — inclusive polarization (w.r.t. production plane of Λ)



Motivation

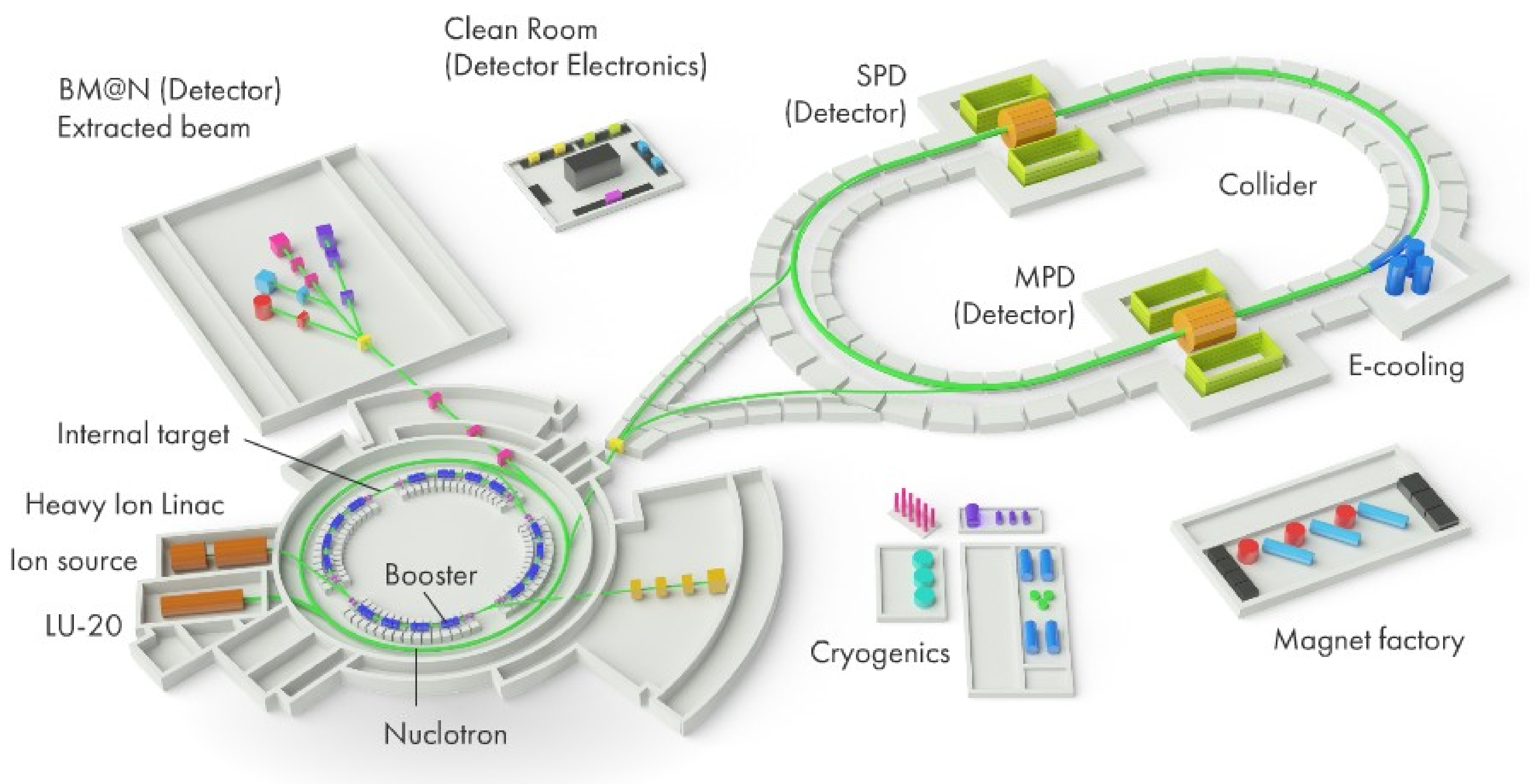
- Predicted[1] and observed[2] global polarization signals rise as the collision energy is reduced:
  - NICA energy range will provide new insight
  - Possible drop-off seen at $\sqrt{s_{NN}} = 2.4$ in HADES experiment[3]
- New value of decay asymmetry α_Λ found in BES-III experiment[4]
  - Effect could be studied at NICA
- $\Lambda(\bar{\Lambda})$-splitting of global polarization, connection to the radial flow of $\Lambda(\bar{\Lambda})$



Possible drop-off at low energies?[3]

[1] O. Rogachevsky, A. Sorin, O. Teryaev, Phys.Rev. C 82, 054910 (2010)
[2] J. Adam et al. (STAR Collaboration), Phys. Rev. C 98, 014910 (2018)
[3] F. Kornas for the HADES Collaboration, SQM 2019, Bari, Italy (11.06.19)
[4] Ablikim M, et al., Nature Phys. 15:631 (2019)

NICA complex

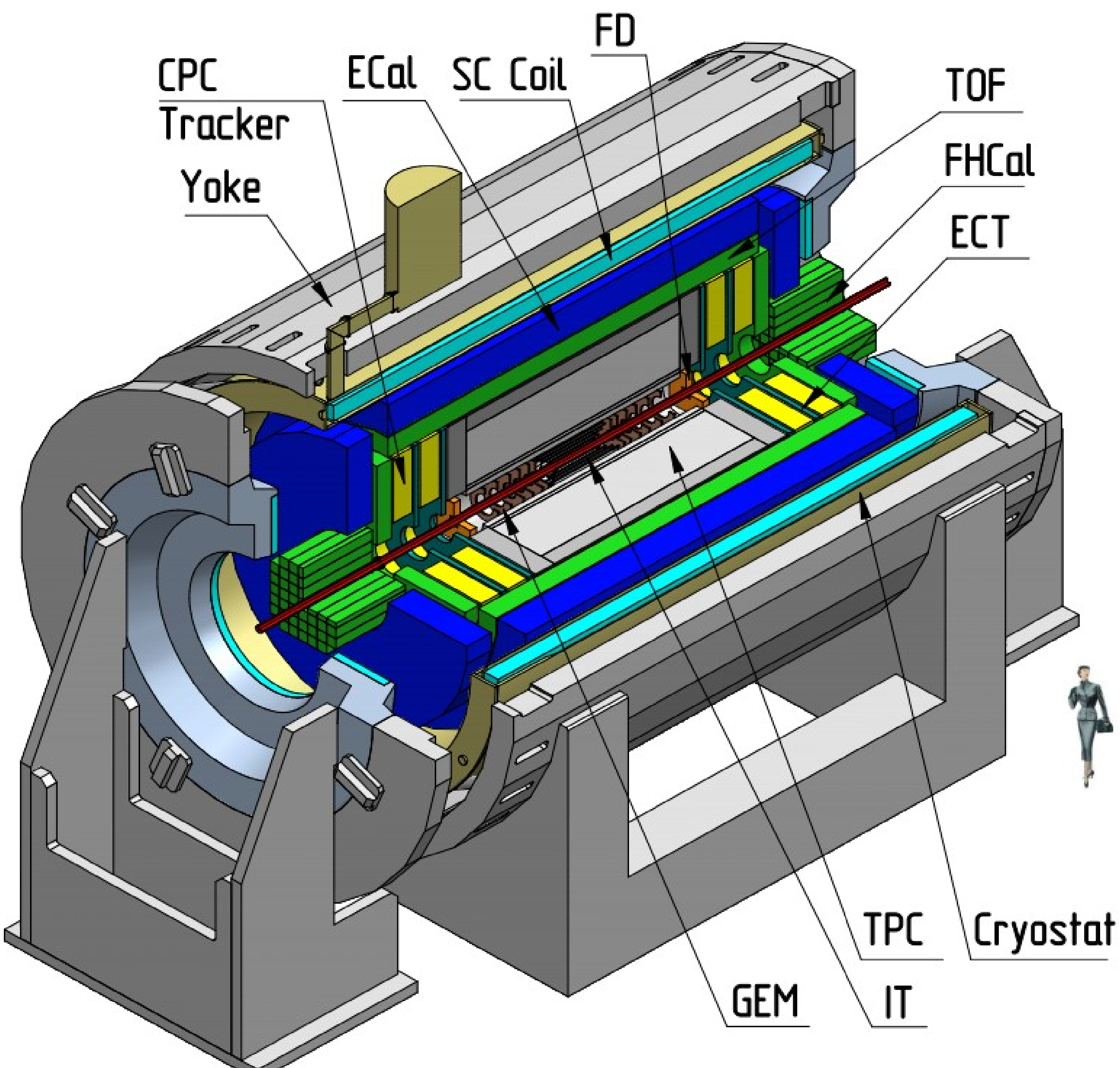


- Beams:
  - p (d) →
  - Au →
- Luminosity:
  - $L = 10^{32}$ $cm^{-2}s^{-1}$
  - $L = 10^{27}$ $cm^{-2}s^{-1}$

MPD detector

Multi-Purpose Detector (MPD)

- energy and system size scan from 4 to 11 GeV (HI beams) to measure a variety of signals



- 2π acceptance in azimuth
- 3-D tracking (TPC)
- Powerful PID (TPC, TOF, ECAL):
  - π/K up to 1.5 GeV/c
  - K/p up to 3 GeV/c
  - γ, e: 0.1 < p < 3 GeV/c
- High event rate
  - Up to ~ 6 kHz

- Stage I:
  - TPC, TOF, ECAL, FHCAL, FFD
- Stage II:
  - IT (ITS) + EndCap (CPC, Straw, TOF, ECAL)

Analysis method

- Inclusive polarization
- Data: MC simulation using DCM-QGSM generator[1]
  - Au-Au, $\sqrt{s_{NN}} = 9$ GeV, ~100000 events, b=0 fm
  - Inclusive Λ polarization (transverse to the scattering plane)
    - DeGrand-Markkanen-Miettinen approach[2]
    - No $\bar{\Lambda}$ polarization
- Track selection criteria:
  - Number of TPC hits: $N_{hits} > 10$
  - $|\eta|<1.3$

$$P = -\left(\frac{12p_T}{\Delta x_0 M^2}\frac{1-\xi(x)}{(1+3\xi(x))}\right)^2$$

$$\xi(x) = \frac{1-x}{3} + 0.1x, \; x = p_\Lambda/p_{\text{beam}}$$

$$M^2 = \left[\frac{m_D^2 + p_{TD}^2}{1-\xi(x)} + \frac{m_s^2 + p_{Ts}^2}{\xi(x)} - (m_\Lambda^2 + p_T^2)\right]$$

[1] V.D. Toneev, K.K. Gudima, Nucl. Phys. A 400, 173 (1983)
[2] T.A. Degrand, J. Markkanen, H.I. Miettinen, Phys. Rev. D: Part. Fields 32, 2445 (1985)

Analysis method

MC simulation
DCM-QGSM

↓

Detector simulation
GEANT 3

↓

Event reconstruction
MPD

↓

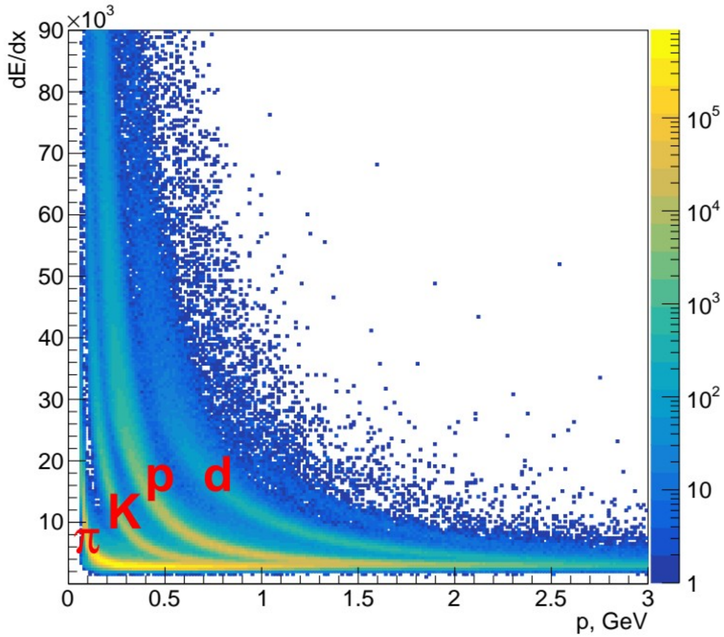
$\Lambda(\bar{\Lambda})$ reconstruction
Analysis

- Realistic Monte-Carlo simulation using DCM-QGSM generator (inclusive Λ polarization)
- Simulation of polarization effects in the detector via GEANT 3 (anisotropic decay of Λ hyperons) — can be switched on/off to study the effect
- Event reconstruction using realistic PID within mpdroot framework
- $\Lambda(\bar{\Lambda})$ reconstruction through the weak decay channel $\Lambda \rightarrow p + \pi^-$

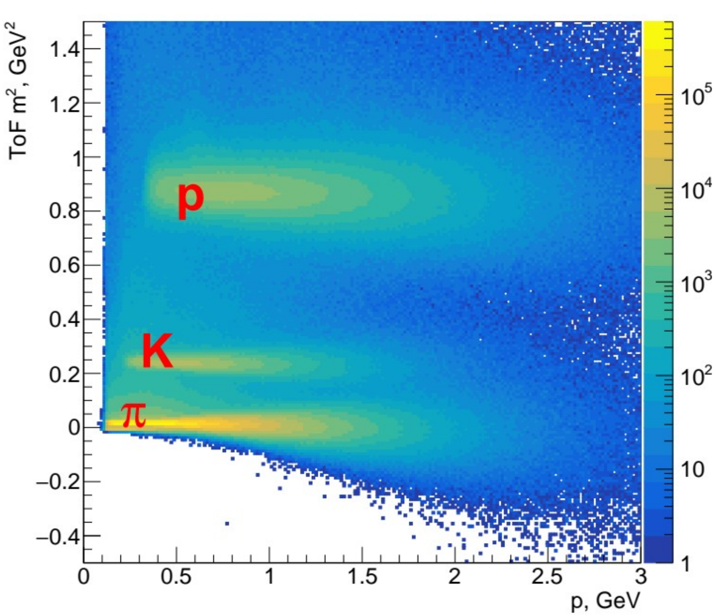
Results

MPD PID for the analysis

dE/dx as a function of momentum

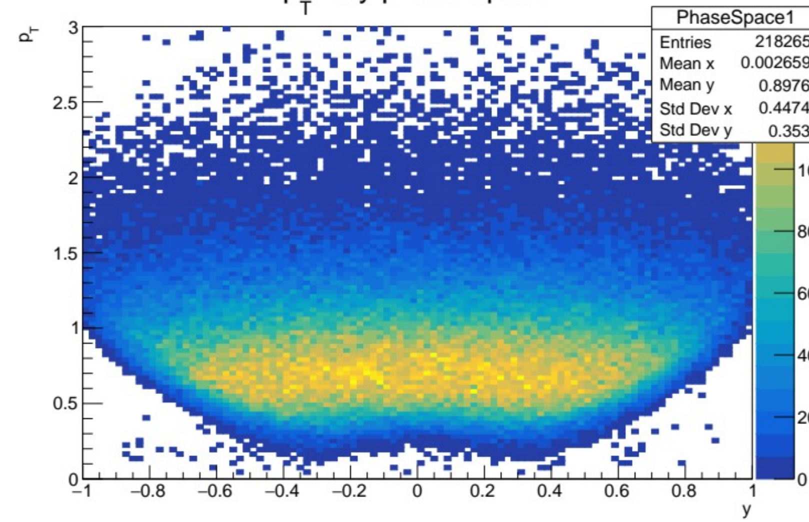


ToF m^2 as a function of momentum



Phase space for Λ hyperon

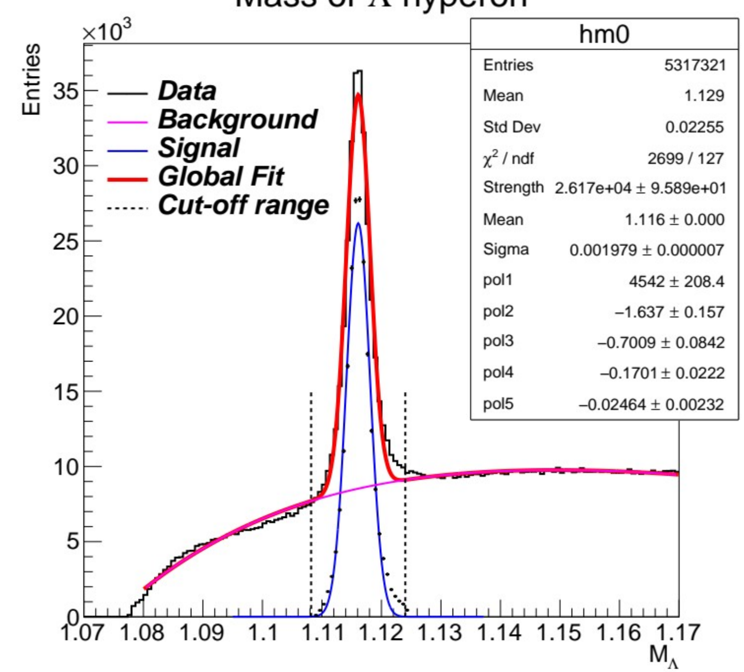
p_T vs y phase space



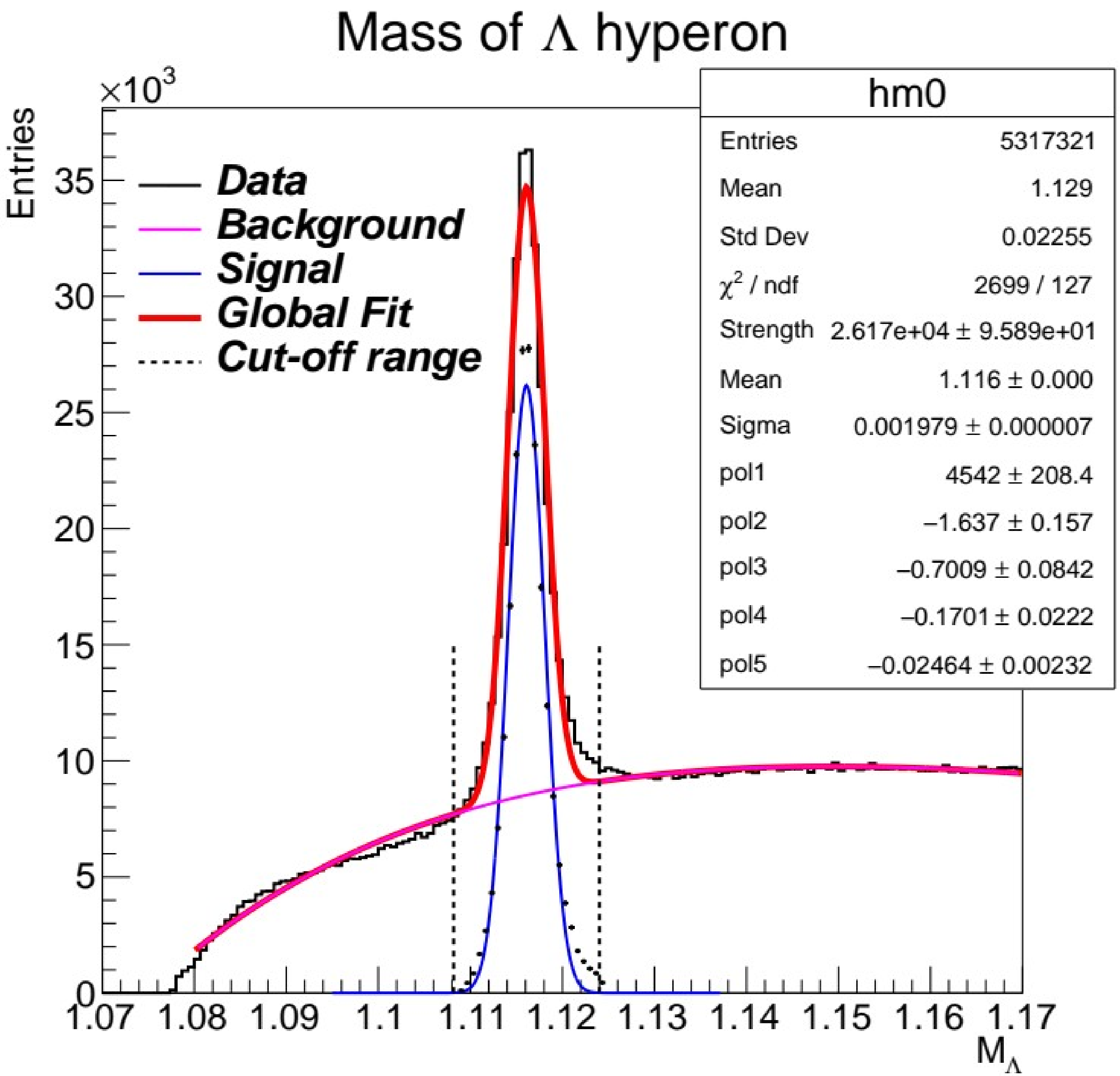
$$\Lambda \rightarrow p + \pi^-$$

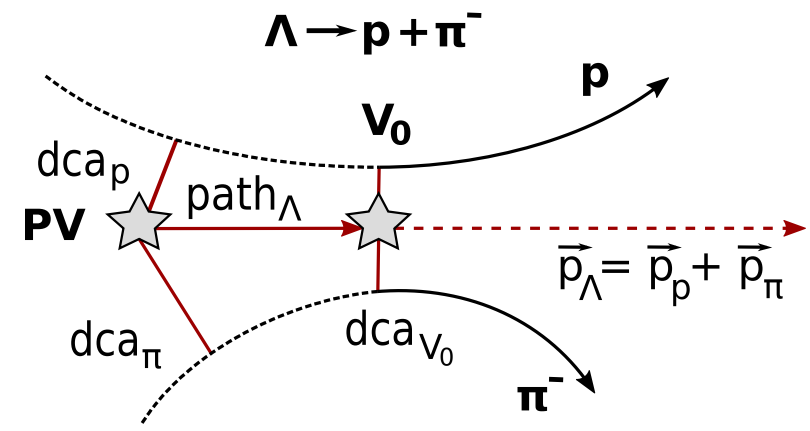
Invariant mass distribution of Λ hyperon

Mass of Λ hyperon



Results



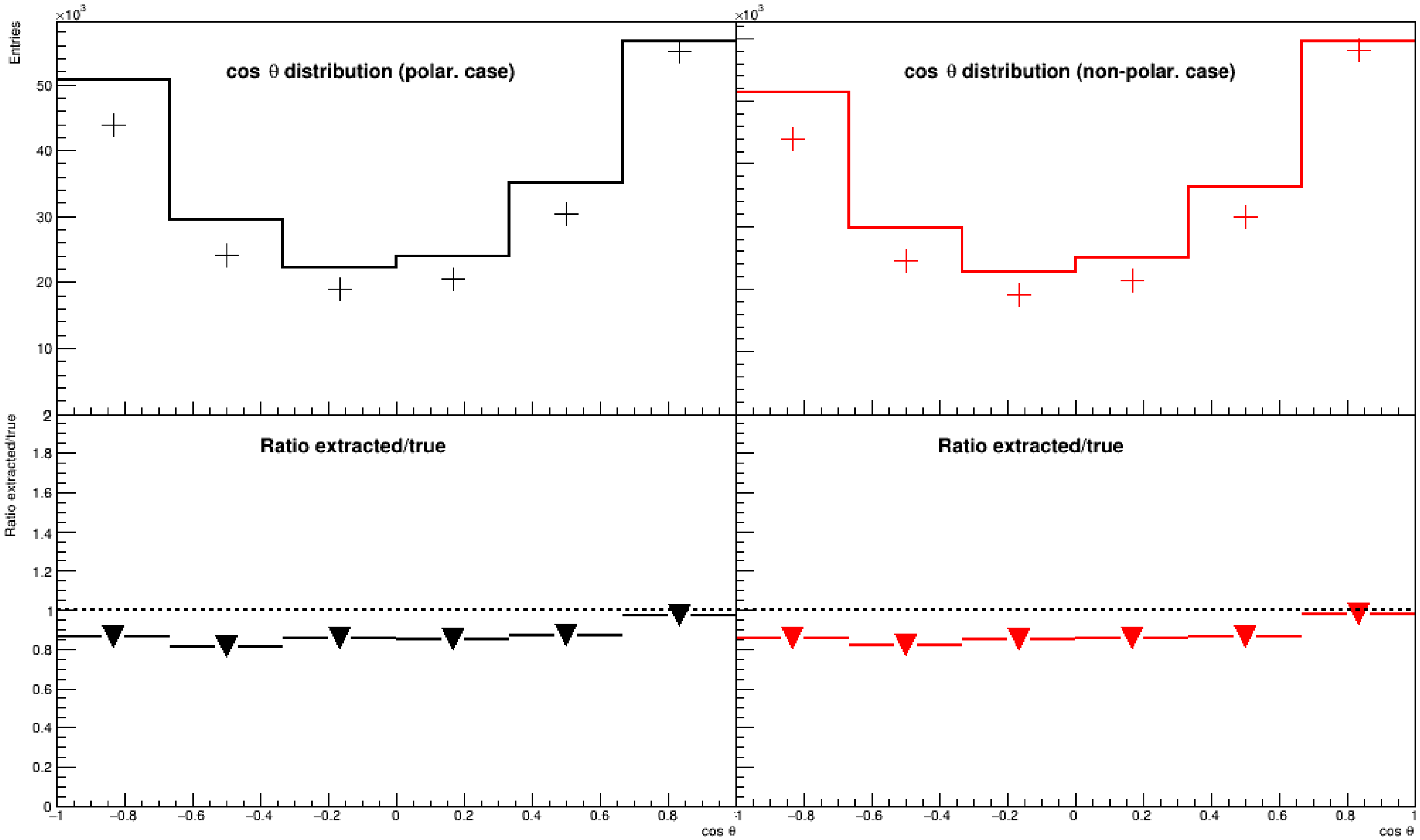


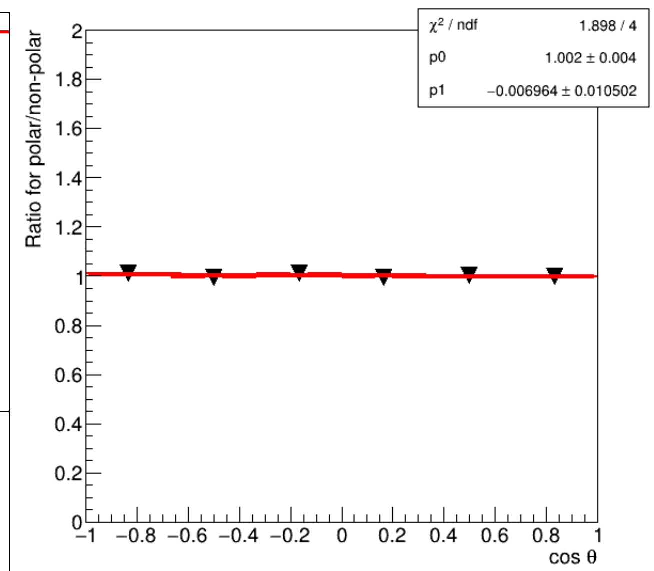
Fitting function:

- Gauss for signal
- Legendre polynomials (L_n) for Background
- Cut-off: $\langle M_\Lambda \rangle \pm 4\sigma$
- DCA and track-separation cuts

$$f(x) = [0]\exp\left(\frac{(-0.5(x-[1]))^2}{[2]^2}\right) + [3](L_0 + [4]L_1 + [5]L_2 + [6]L_3 + [7]L_4)$$

Results



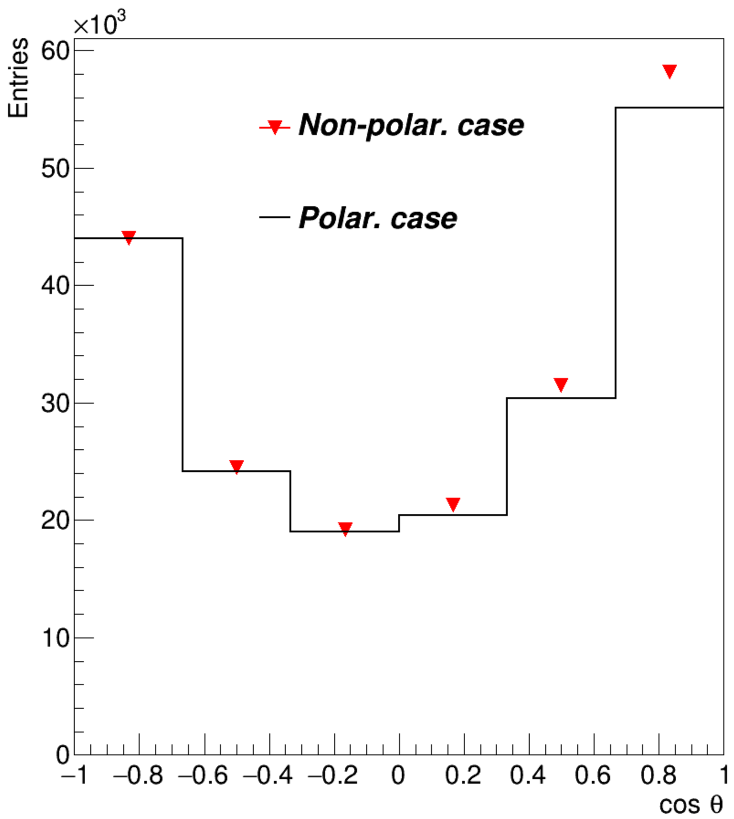


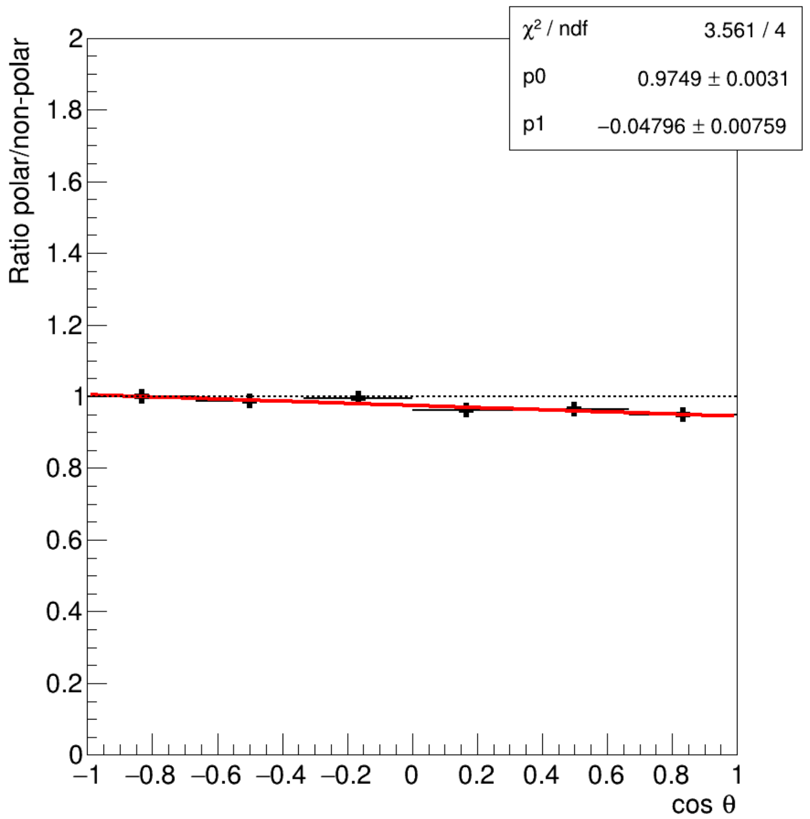
Check of the extraction technique

Comparison of extracted angular distributions (from invariant mass) with the true distributions (for «polarized» and «non-polarized» case)
→ shows detector acceptance effects

+ (black)	Extracted (polarized case)	+ (red)	Extracted (non-polarized case)
— (black)	True (polarized case)	— (red)	True (non-polarized case)

Results





Accounting for detector acceptance

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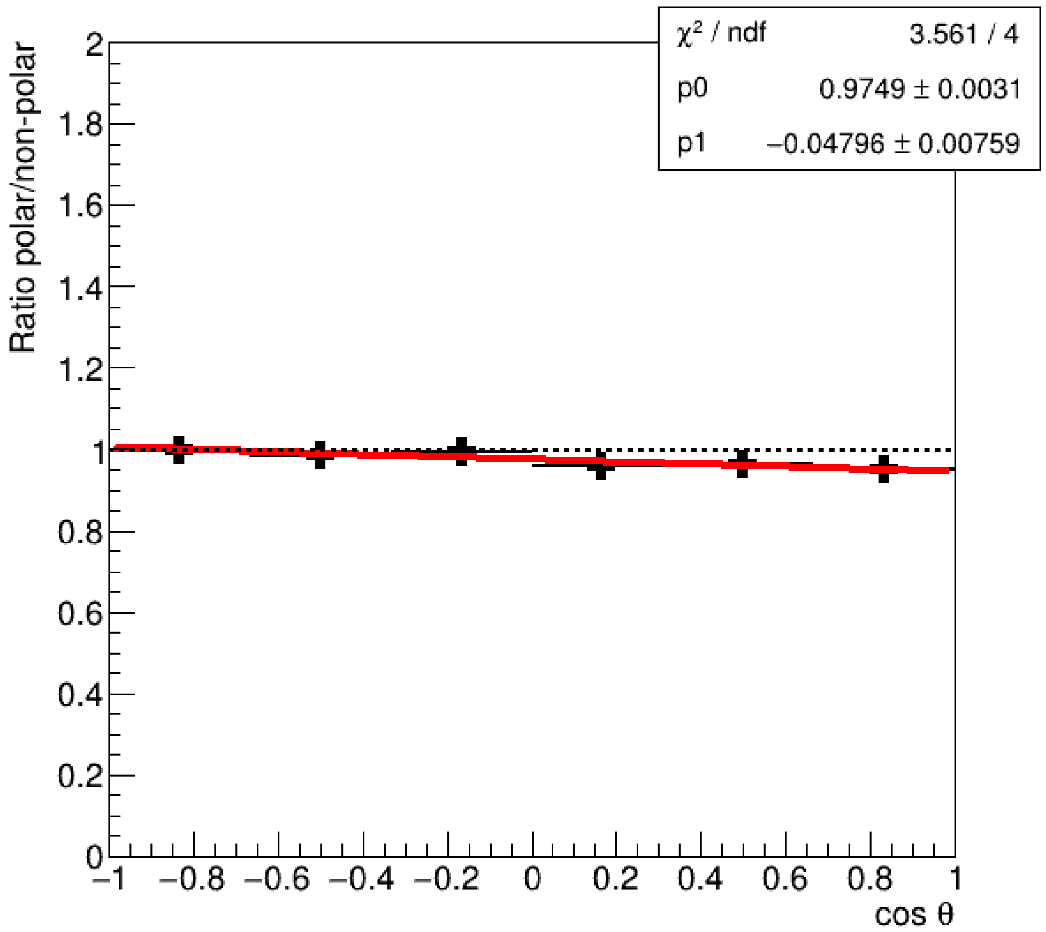
Net effect of polarization

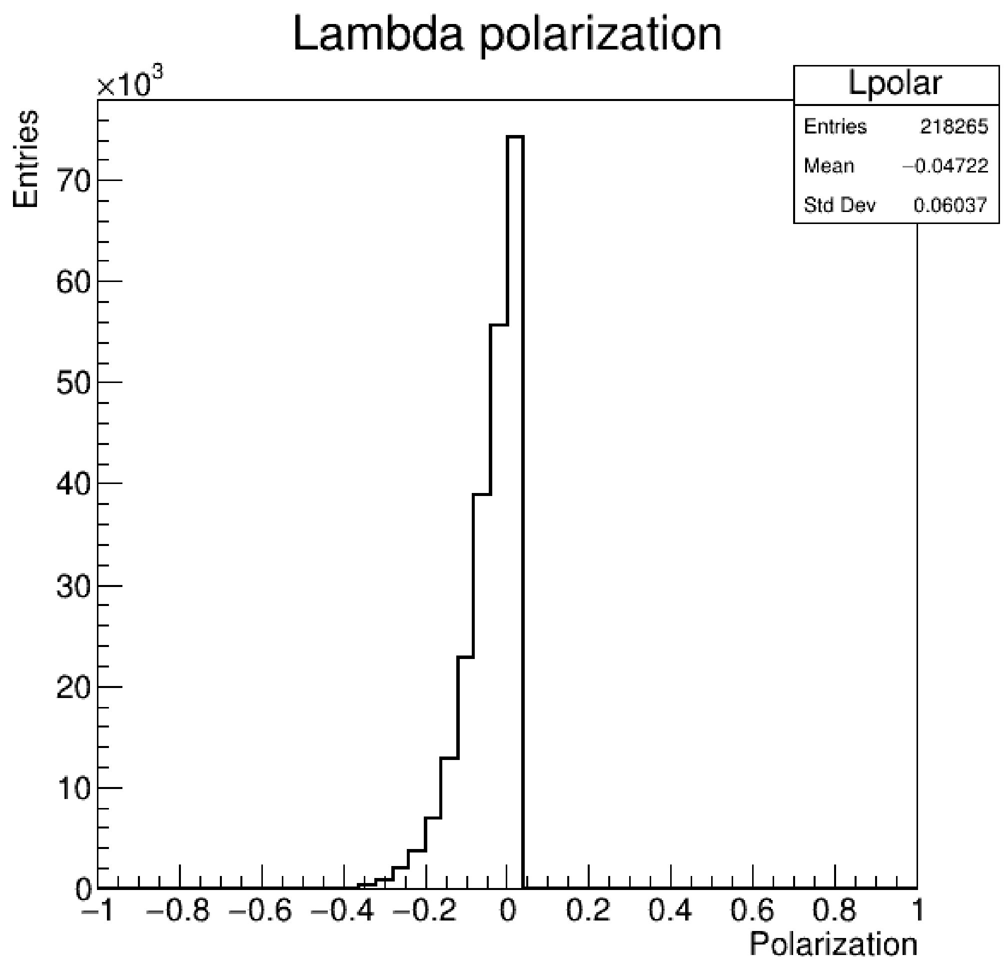
Dividing extracted angular distributions obtained from polarized/non-polarized case (with or w/o anisotropic decay)

- Accounts for the detector acceptance → shows net effect due to polarization of Λ hyperons

$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*} = 1 + \alpha_\Lambda P_\Lambda \cos\theta^*$$

Results



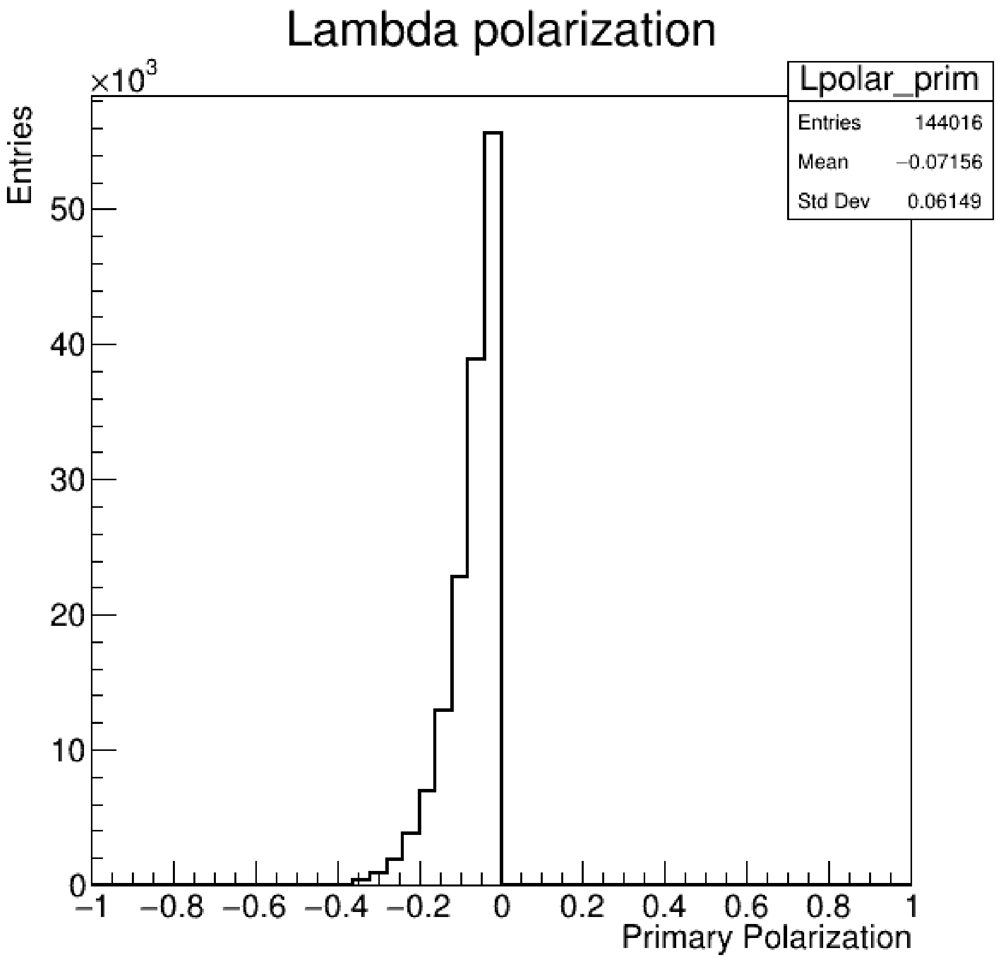


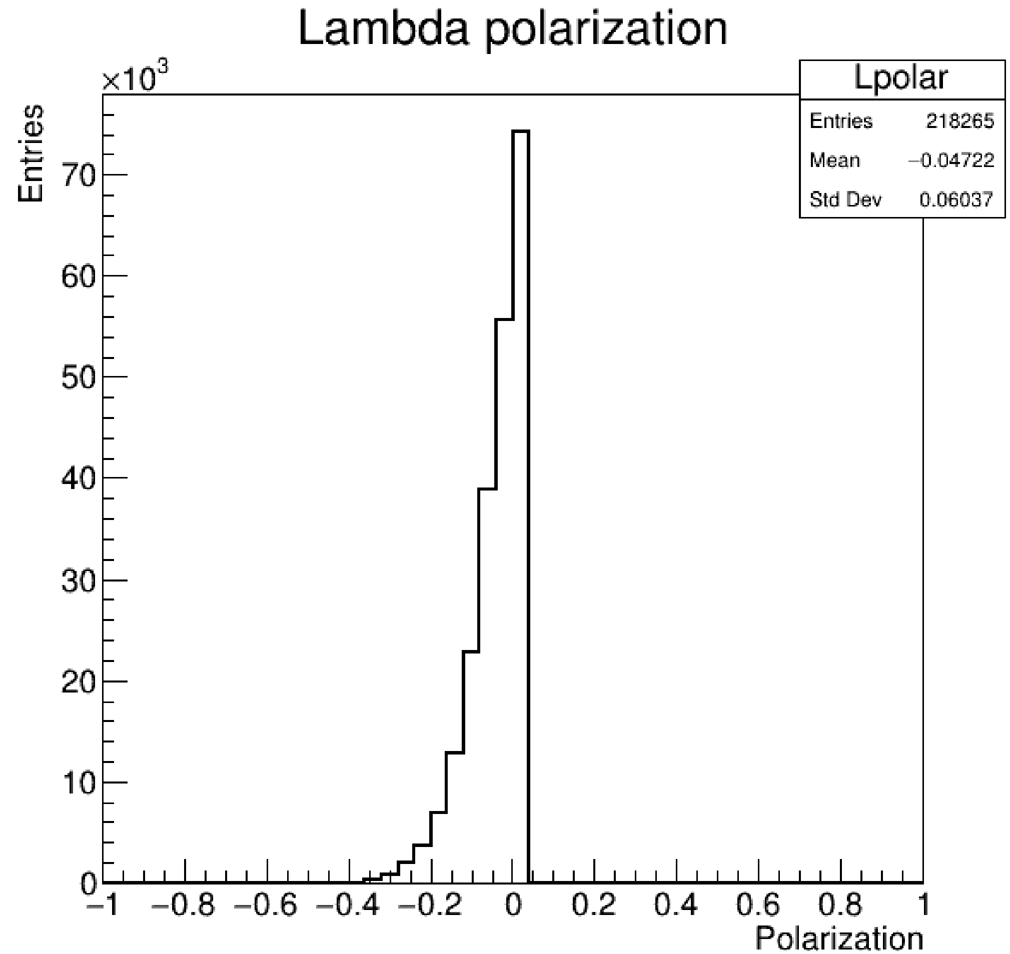
p_1 (slope parameter) → extracted polarization value:

- $p_1 = -0.04796 \pm 0.00759$

<P> (mean polarization) → true mean polarization (full Λ):

- $\langle P \rangle = -0.0472 \pm 0.00013$





$<P>$ (mean polarization) → true mean polarization is smeared towards 0 due to non-polarized secondary Λ:

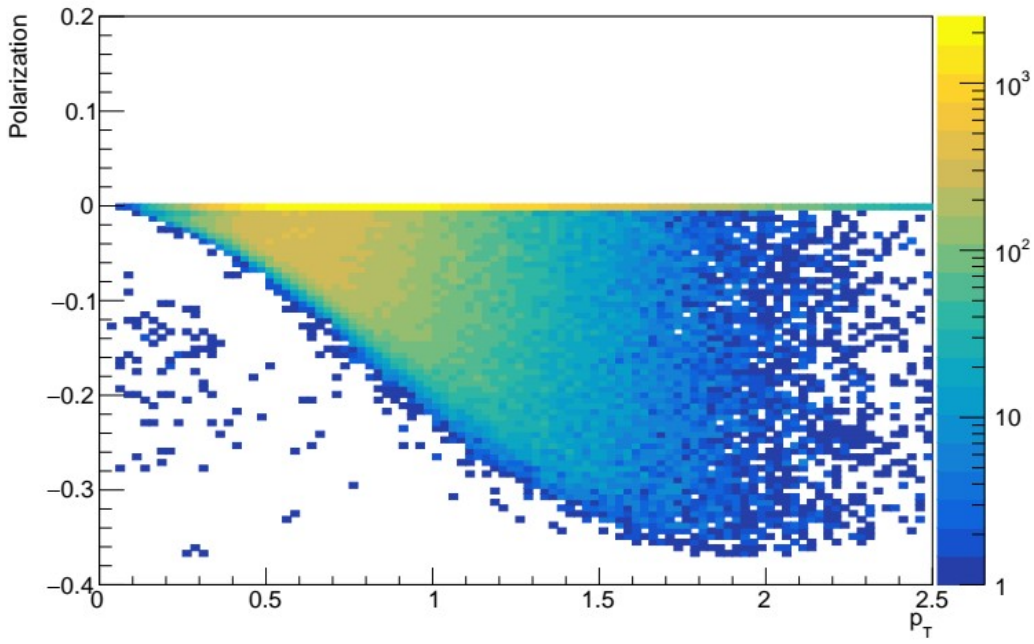
- $<P> =$ -0.0471 $\pm$ 0.00013 (full)
- $<P> =$ -0.0714 $\pm$ 0.00016 (only primary Λ)

Major contributions from decays:

$\Sigma^* \to \Lambda\pi \quad \Xi \to \Lambda\pi$

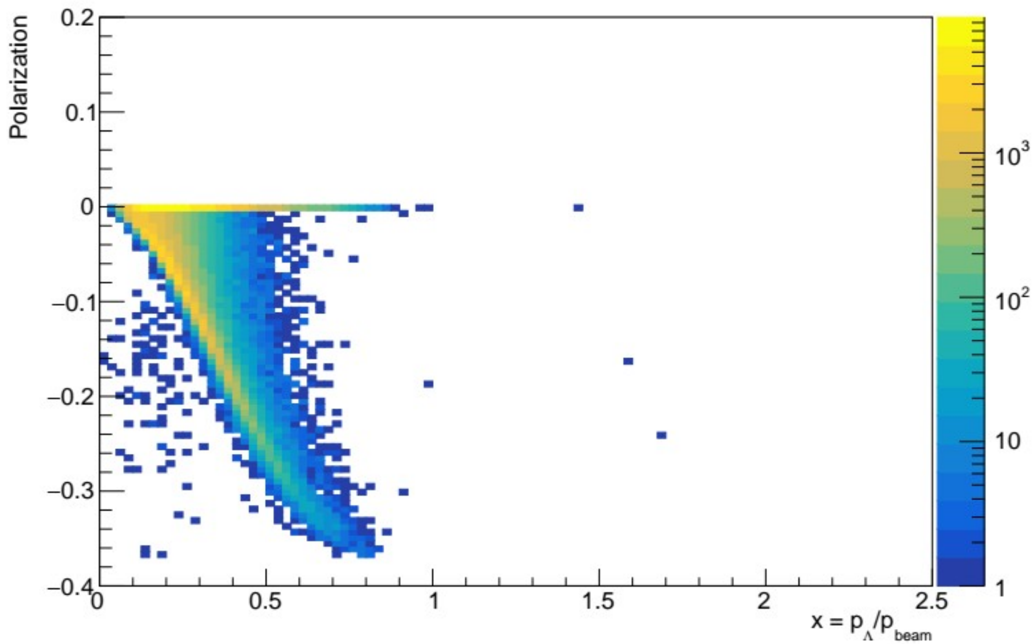
$\Sigma^0 \to \Lambda\gamma$

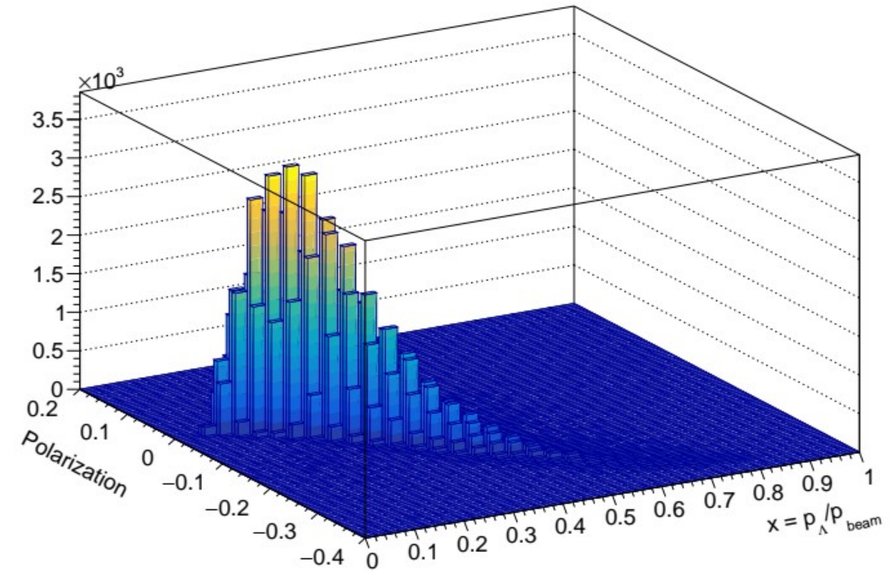
Results



Polarization dependence on p_T (top) and $x = p_\Lambda/p_{beam}$ (bottom).

- Large fraction of non-polarized secondary Λ
- Reaches maximum at intermediate values of p_T and x
- Warrants a study in different regions of p_T (x)





Conclusions

- Feasibility test of polarization extraction within the framework of the MPD experiment
  - Good sensitivity of the detector to inclusive Λ polarization
  - Reasonable extraction of Λ-hyperons via the weak decay
  - Upper limit on the value of inclusive Λ polarization
  - Need to account for secondary Λ-hyperons
- Outlook:
  - Study the technique in different regions of p_T (x)
  - Perform feasibility test on MC simulation of global polarization
  - Estimate the sensitivity of the detector towards global polarization of Λ and anti-Λ hyperons
  - Include polarization effects for other hyperons and account for rescattering

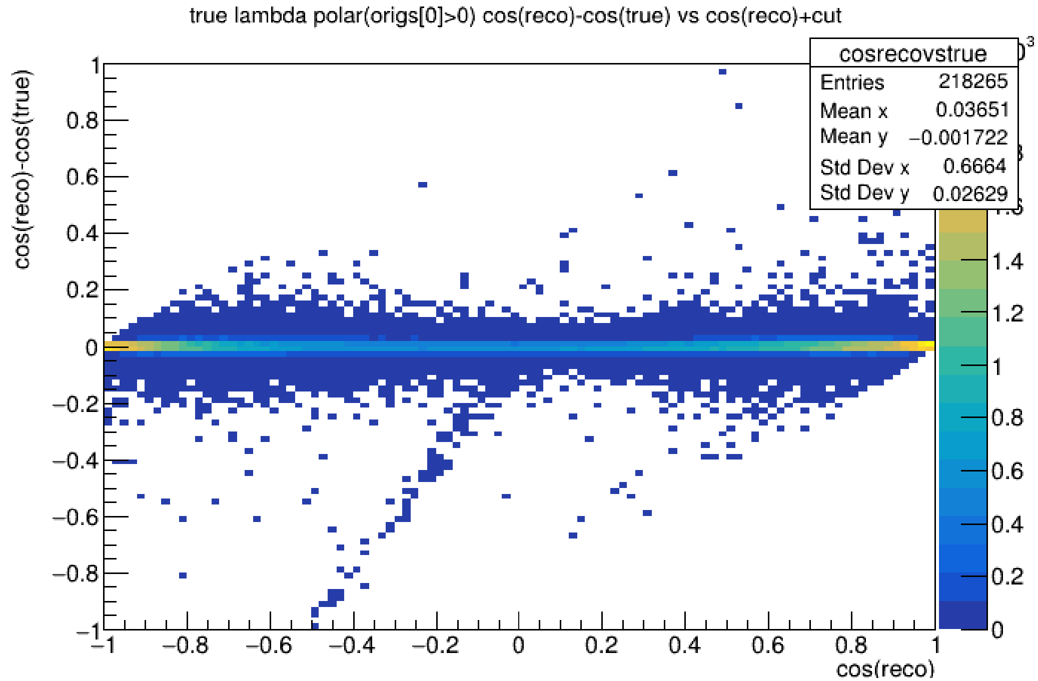
Outlook

- Global polarization
- Data: MC simulation using PHSD generator[1]
  - Au-Au, $\sqrt{s_{NN}} = 7.7; 9$ GeV, ~1.5M MB events
  - Global $\Lambda(\bar{\Lambda})$ polarization
    - Becattini approach
- Track selection criteria:
  - Number of TPC hits: $\mathrm{N}_{\mathrm{hits}} > 10$
  - $|\eta|<1.3$

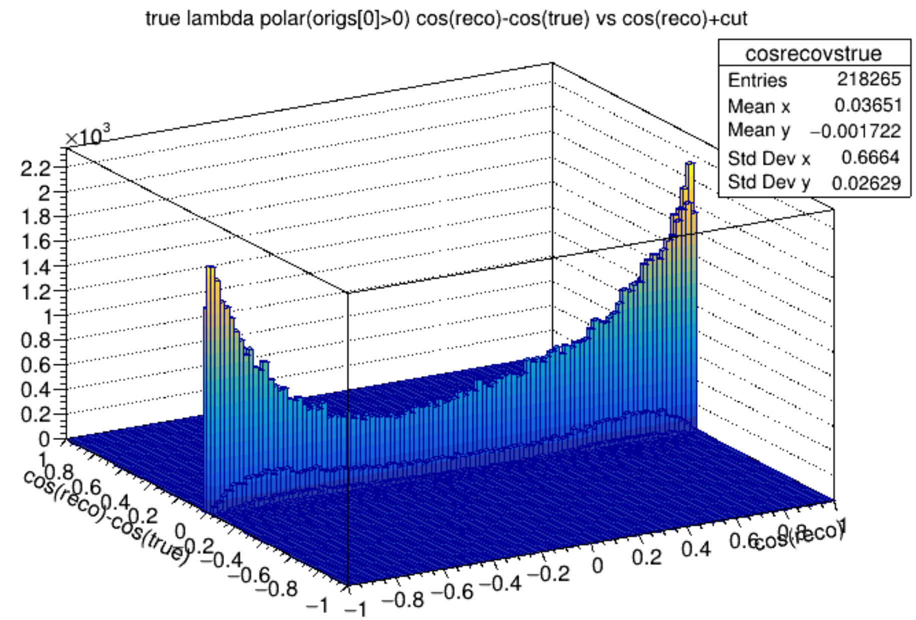
The End

Thank you for your attention!

Back Up



true lambda polar(origs[0]>0) cos(reco)-cos(true) vs cos(reco)+cut
cosrecovstrue
Entries 218265
Mean x 0.03651
Mean y −0.001722
Std Dev x 0.6664
Std Dev y 0.02629
cos(reco)-cos(true)
cos(reco)



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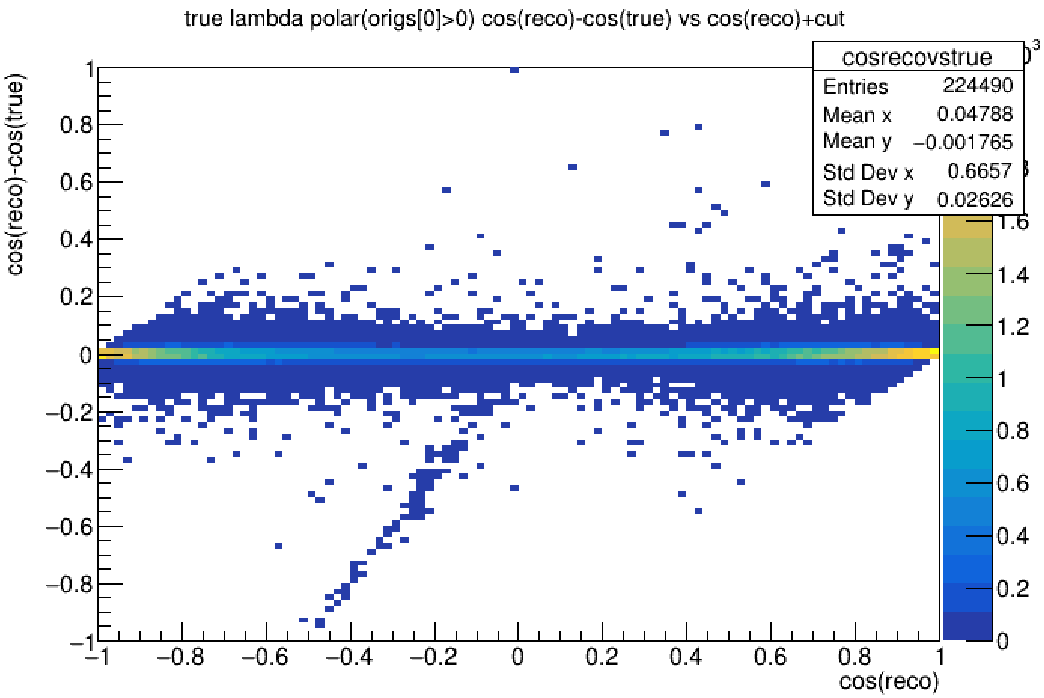

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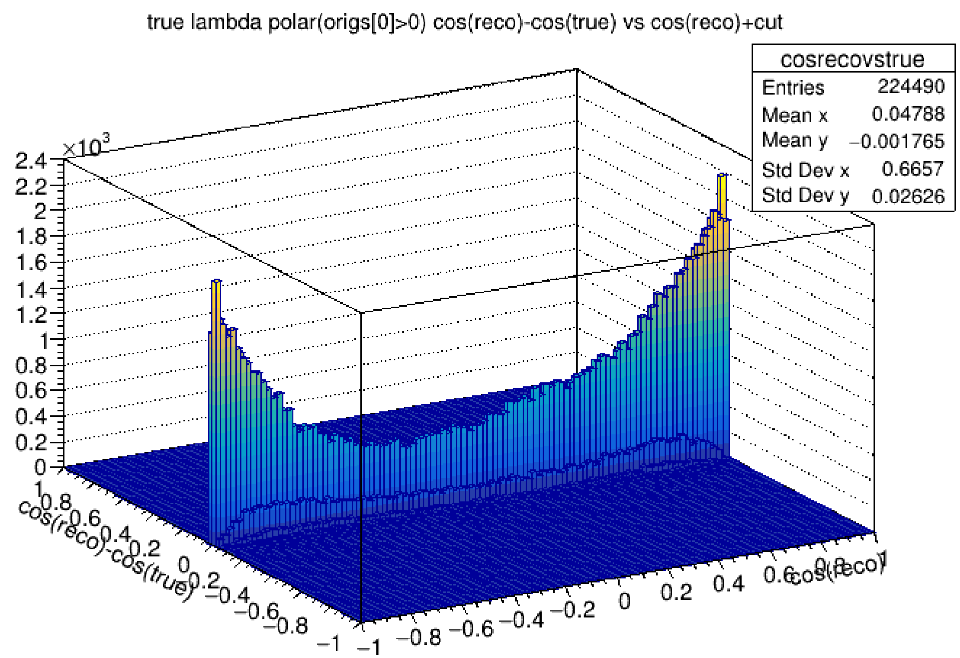
cos(reco)



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