

# Development of an event generator for antihyperon-hyperon pair production in antiproton-proton collisions

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10hp Project Presentation at Uppsala PANDA/HADES Group Meeting

Presented on 1<sup>st</sup> March 2022

Revised on 2<sup>nd</sup> May 2022



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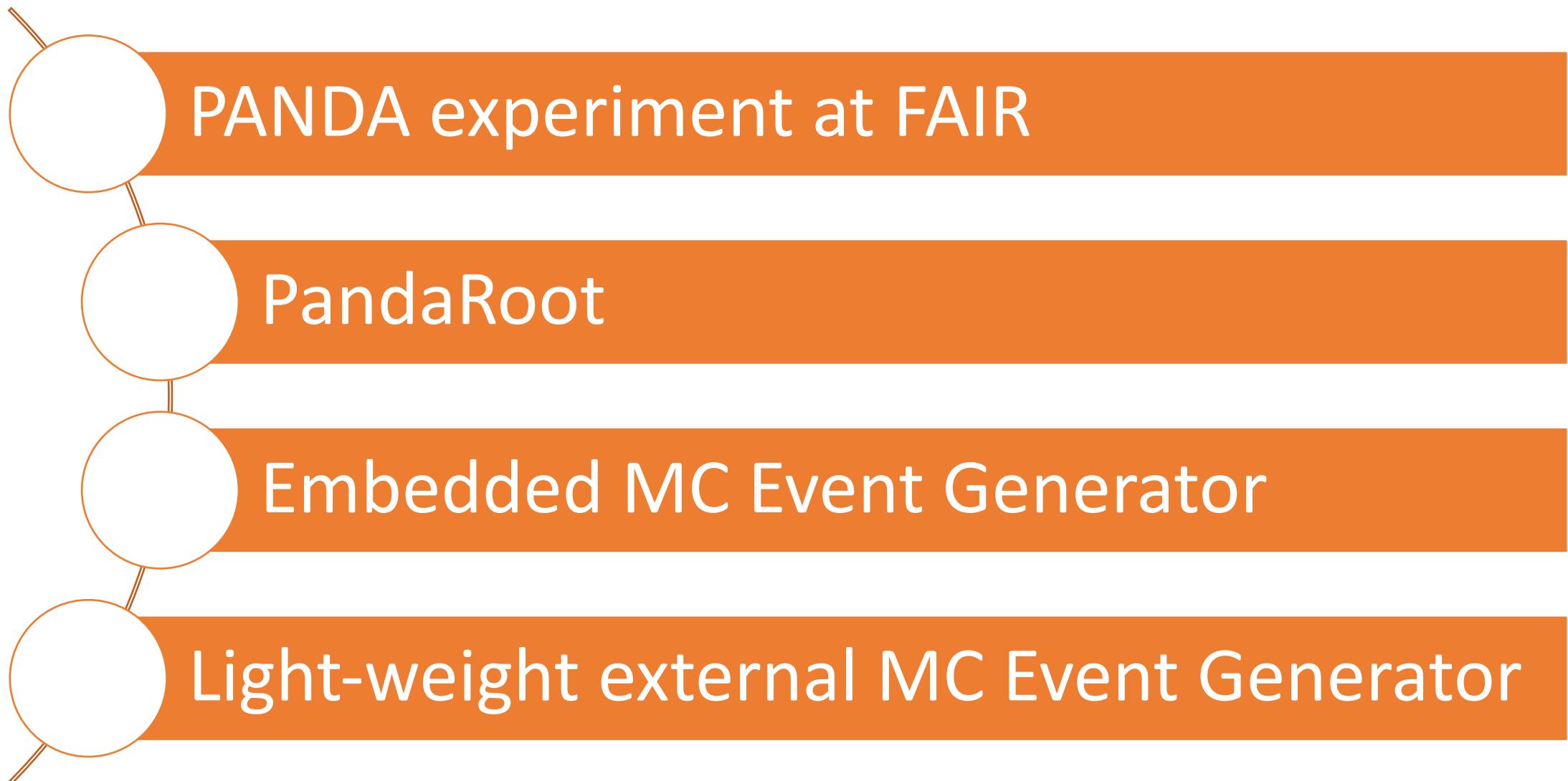
Presenter: Vitor José Shen

Supervisor: Michael Papenbrock

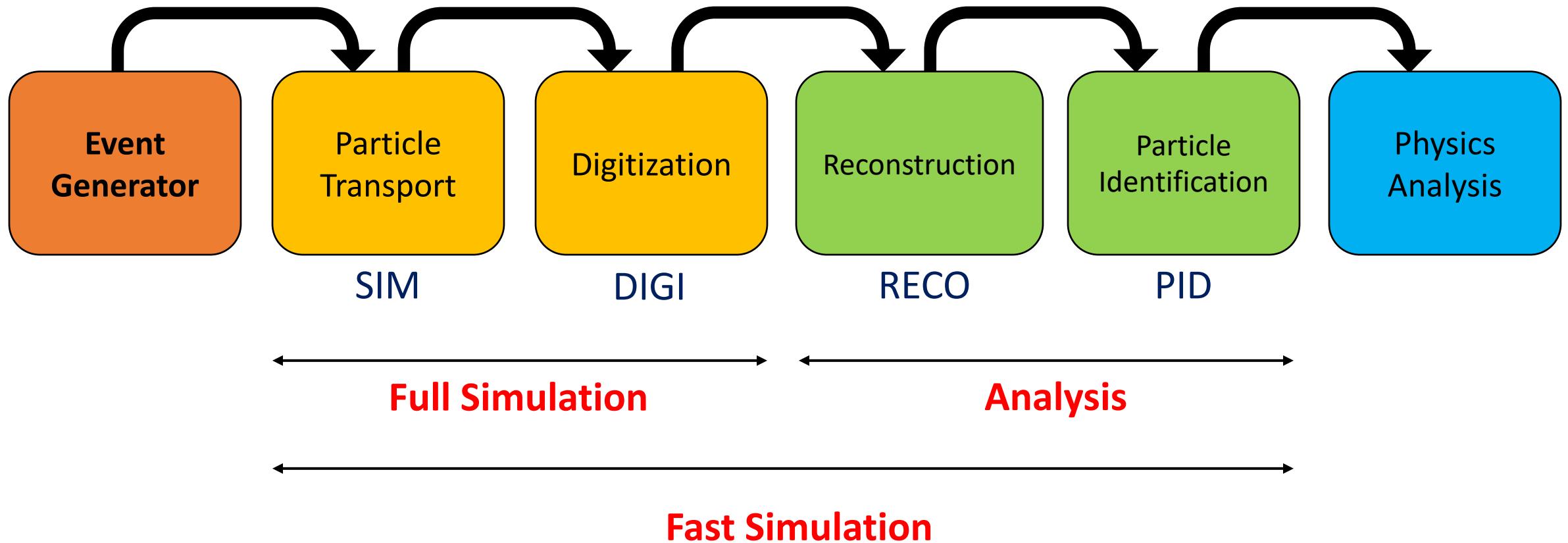
# Outline

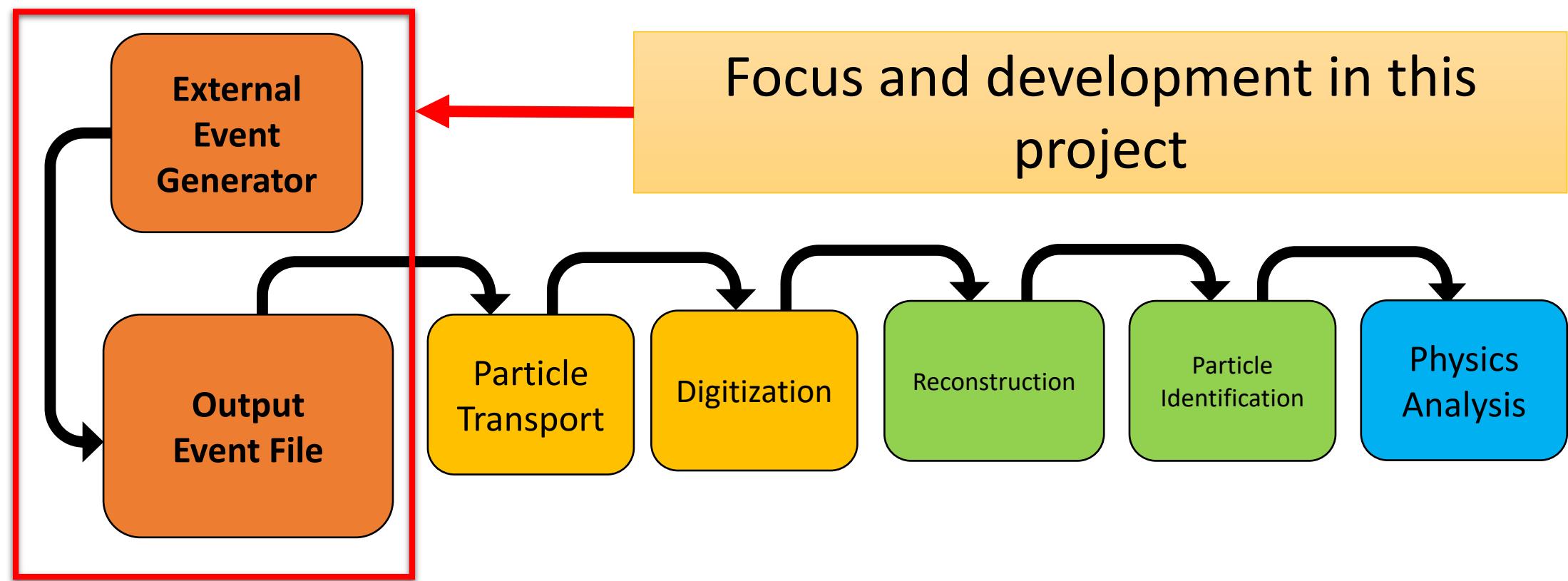
- Introduction p.2
- Main Framework of PandaRoot
  - External Event Generator & embedded event generator p.3
- Kinematics
  - Different reference frame and Lorentz boost p.5
  - Lorentz rotation
- The developing of an external Event Generator
  - ROOT tree format framework p.8
  - The testing results of angular distribution
- Conclusion & outlook p.22

# Introduction

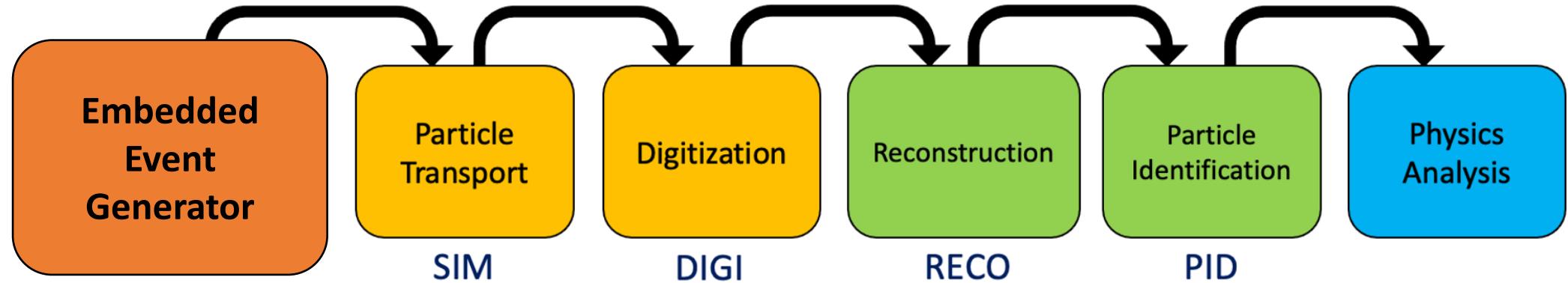


# Main Framework of PandaRoot





VS.

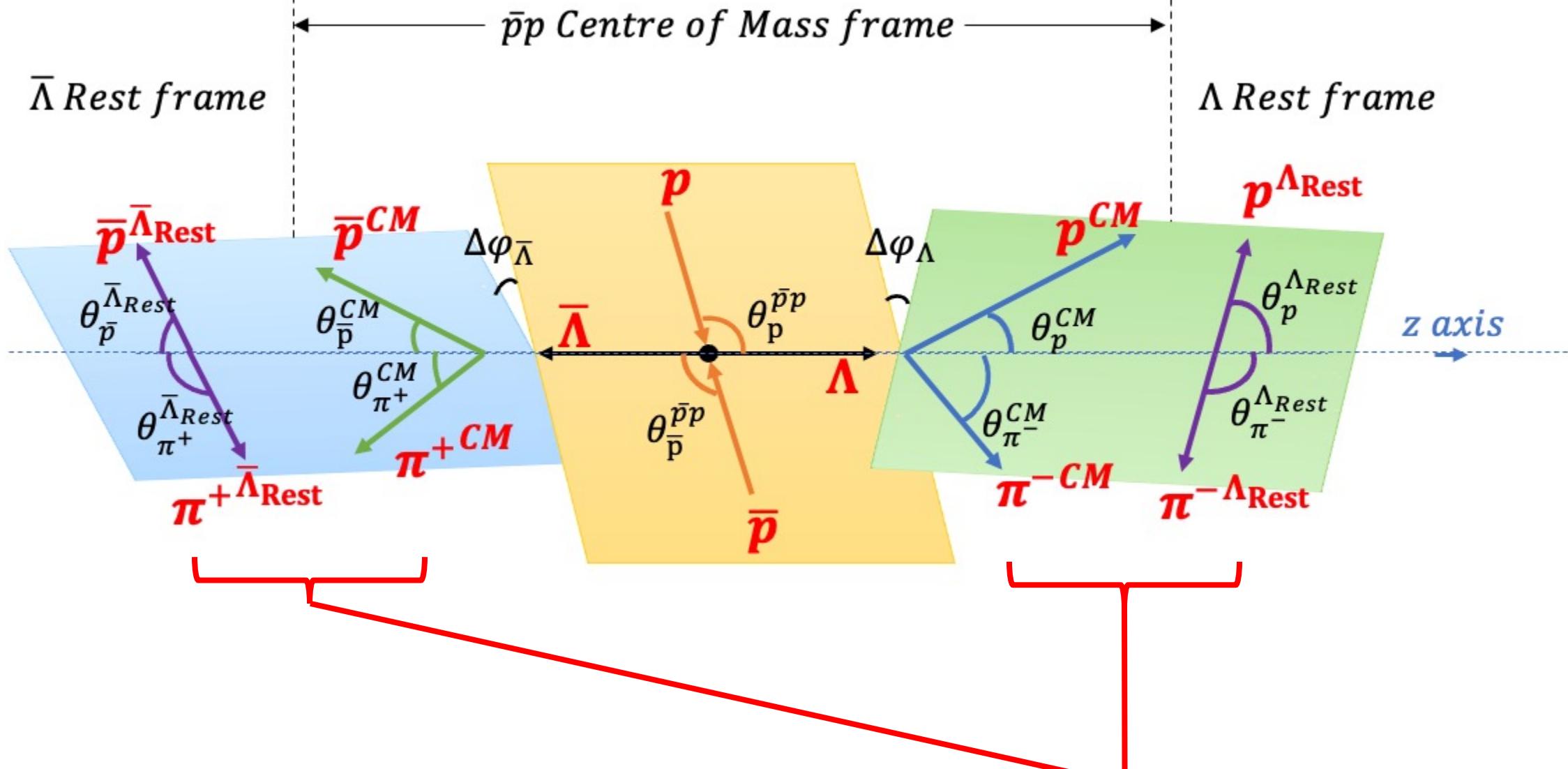




# Kinematics (4-vectors)

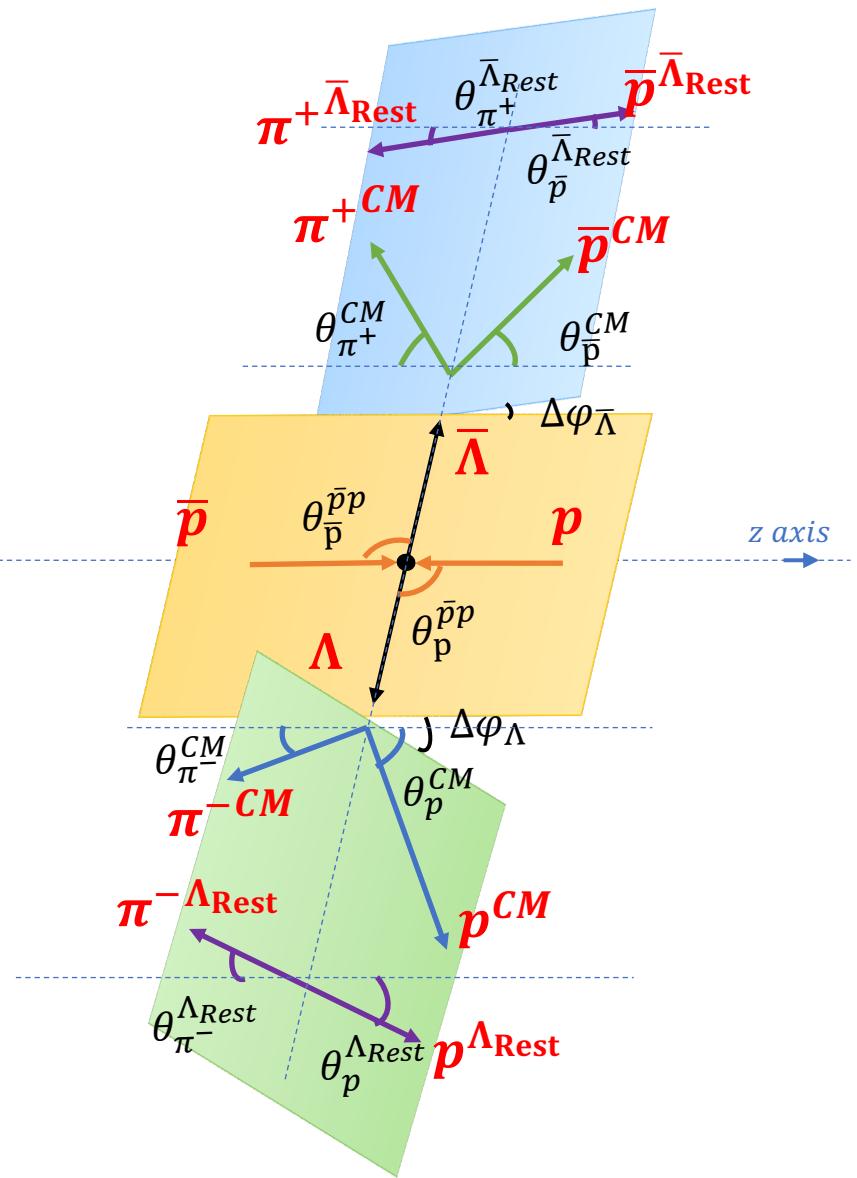
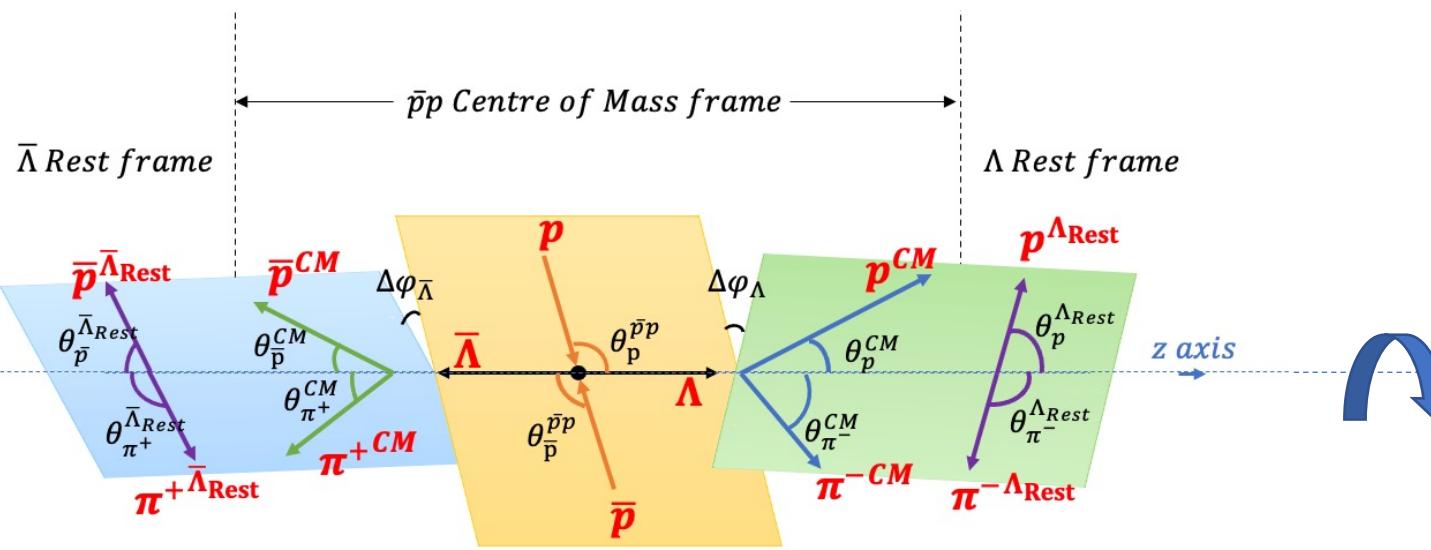
Methedology

$$p_A^2 \equiv E_A^2 - \mathbf{p}_A^2 = m_A^2$$



Different reference frames and Boost

To [p.12](#), [p.14](#), [p.16](#), [p.17](#), [p.19](#), [p.21](#)



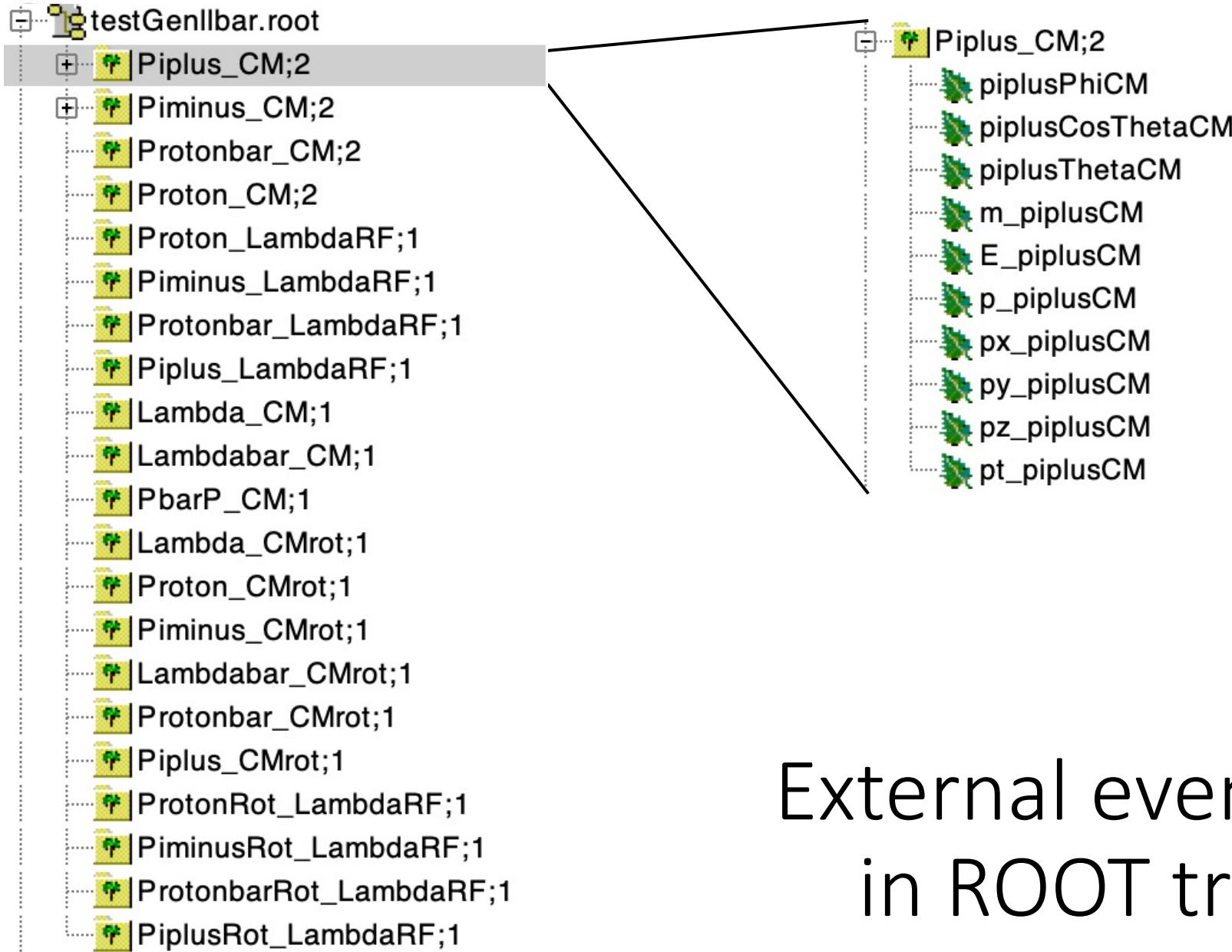
# Rotation

$m_\Lambda$	$m_p$	$m_{\pi^-}$	$p_{beam}$
1.115 GeV/c <sup>2</sup>	0.9383 GeV/c <sup>2</sup>	0.1396 GeV/c <sup>2</sup>	1.64 GeV/c



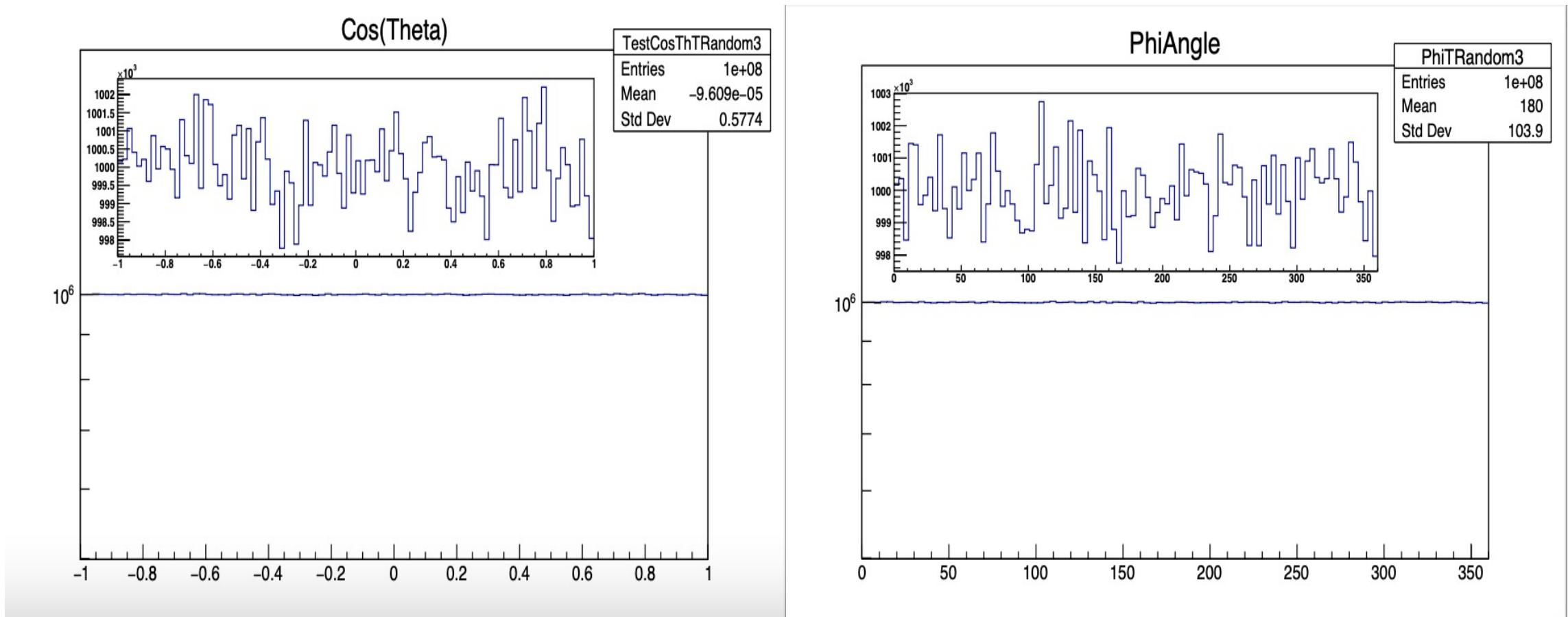
# The developing of an external Event Generator

The brief introduction of the developing framework  
and the testing results of angular distribution



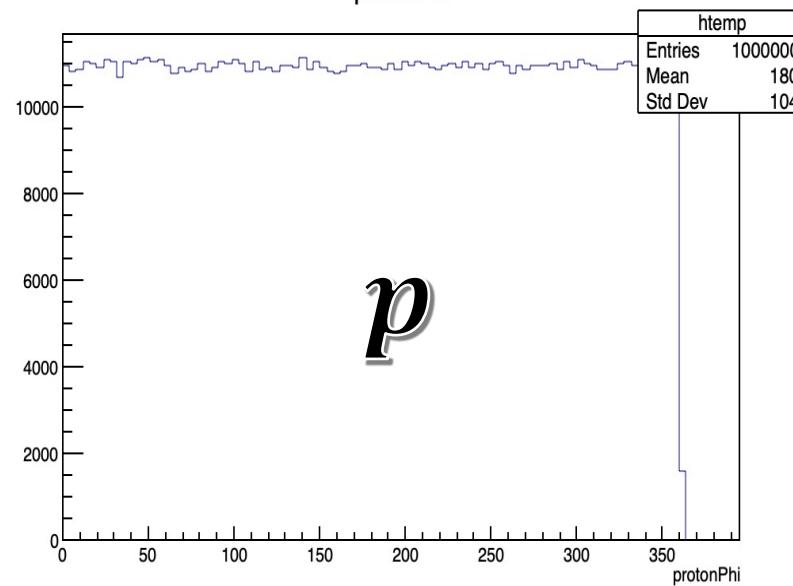
External event generator  
in ROOT tree format

# Test for uniform distribution

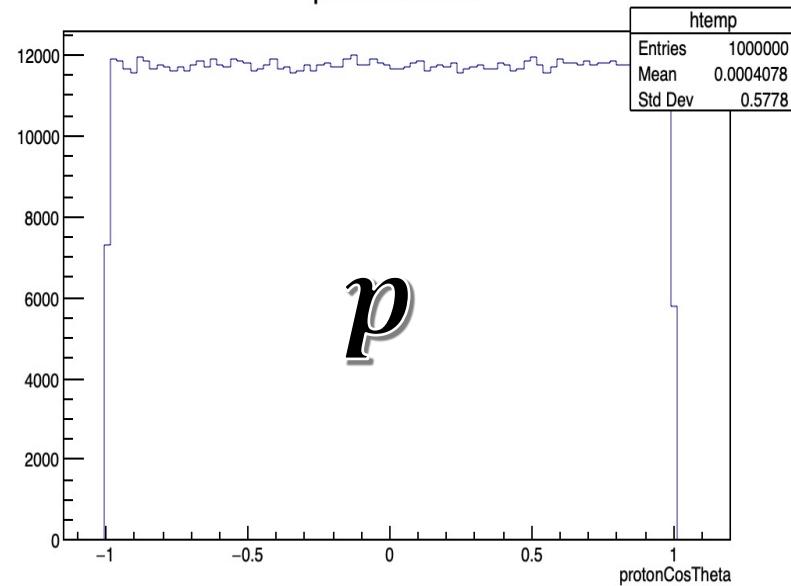


# $\Lambda$ rest frame

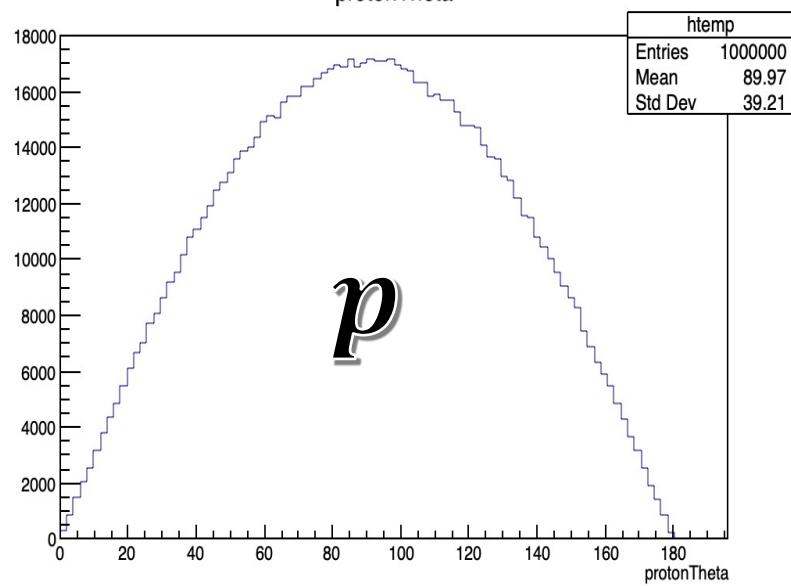
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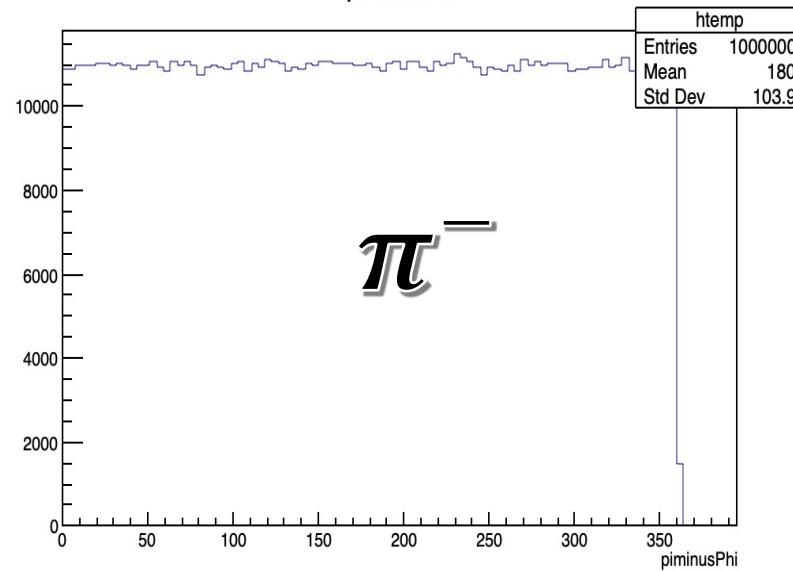
protonCosTheta



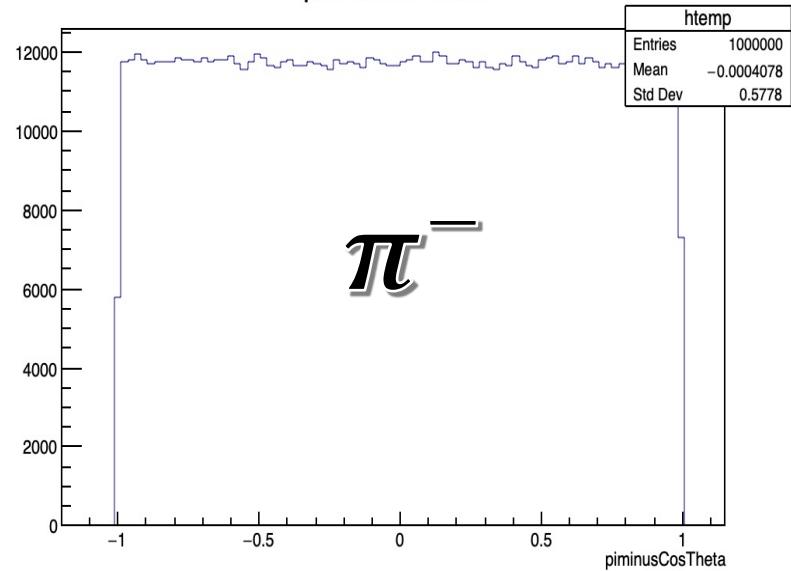
protonTheta



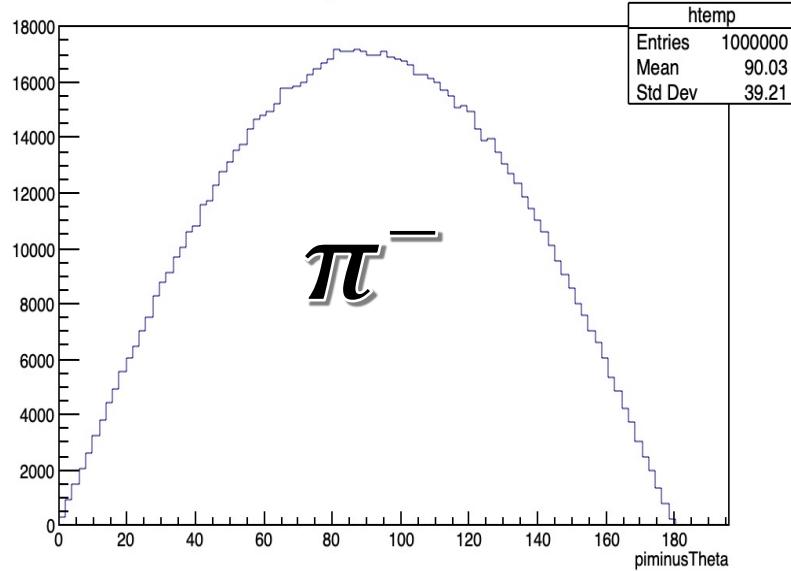
pminusPhi



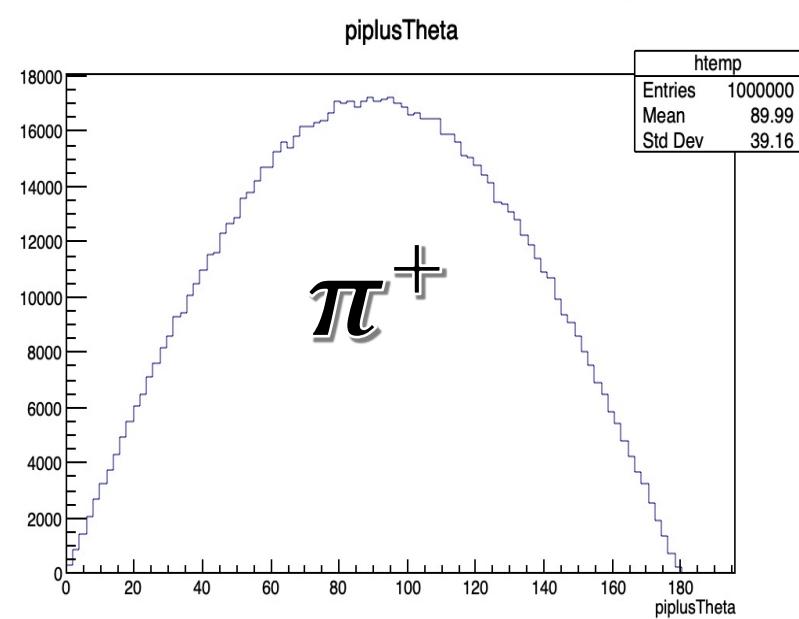
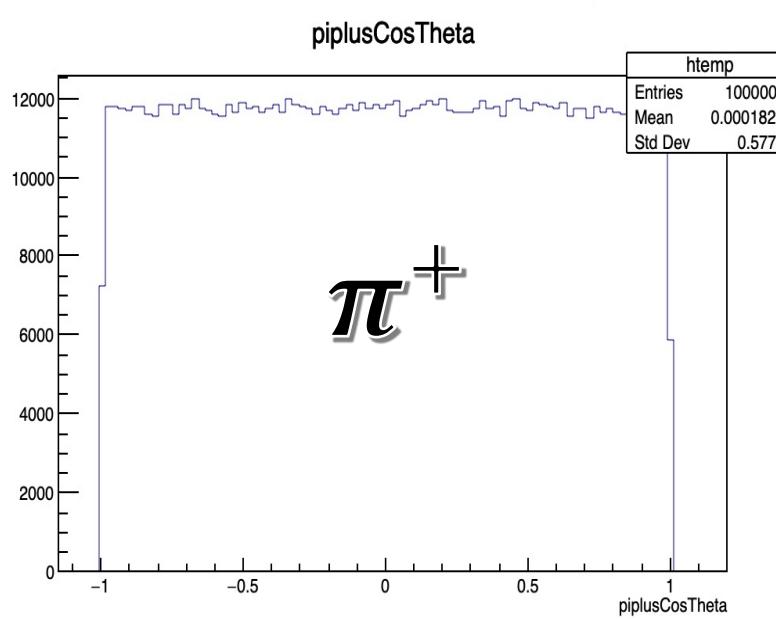
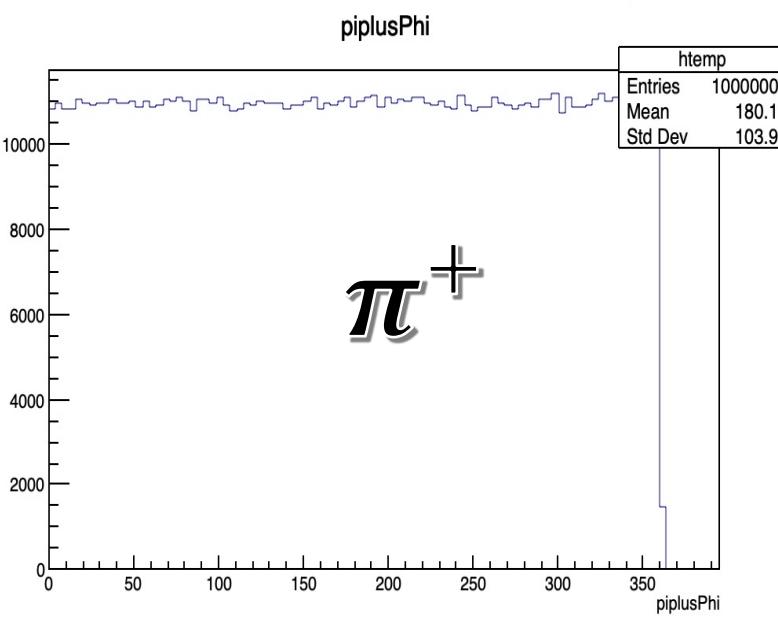
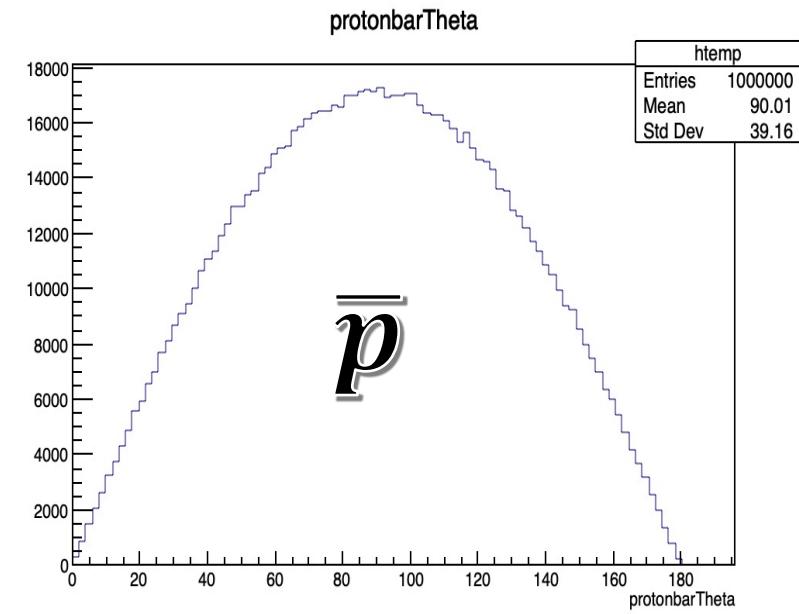
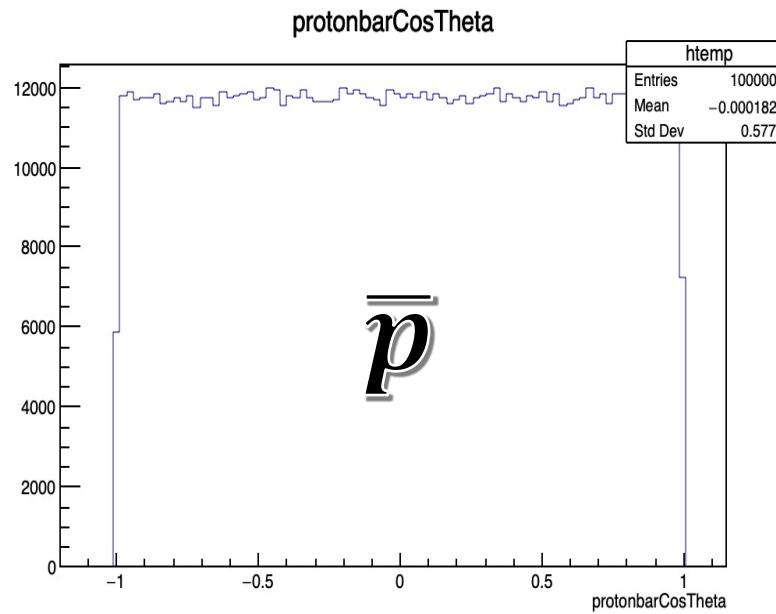
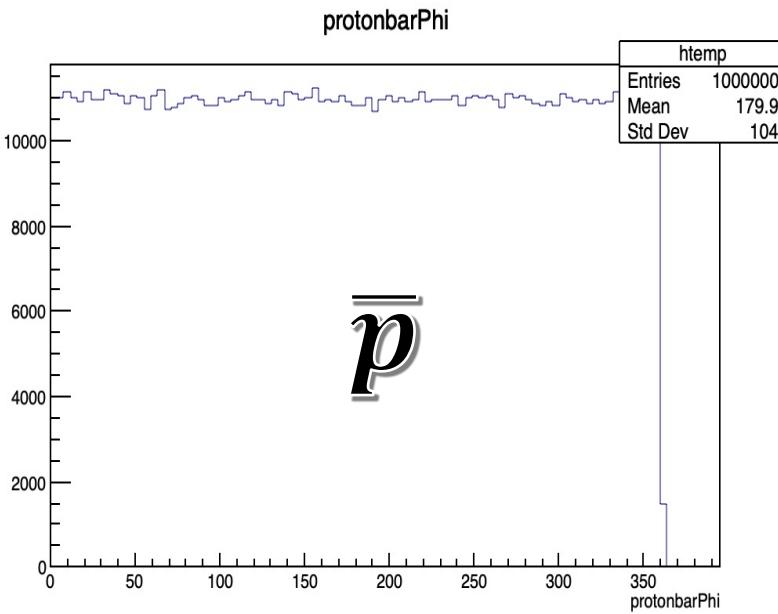
pminusCosTheta



pminusTheta

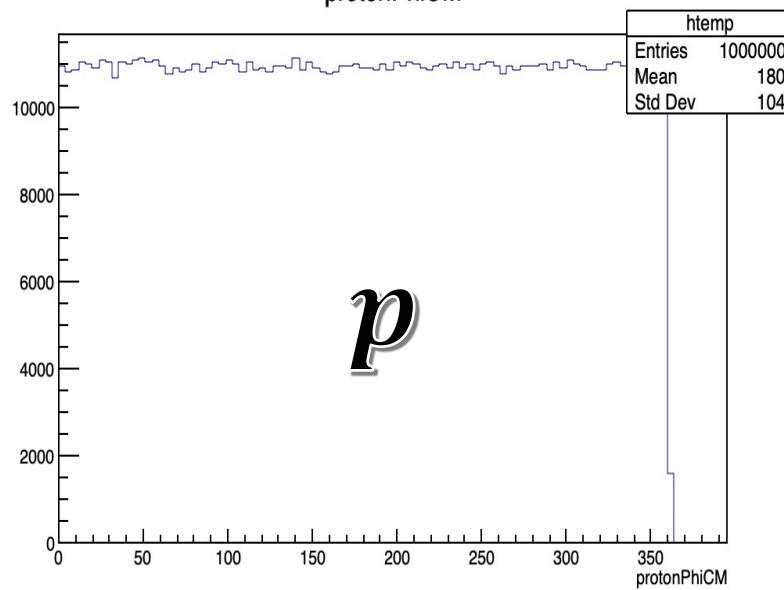


# $\bar{\Lambda}$ rest frame

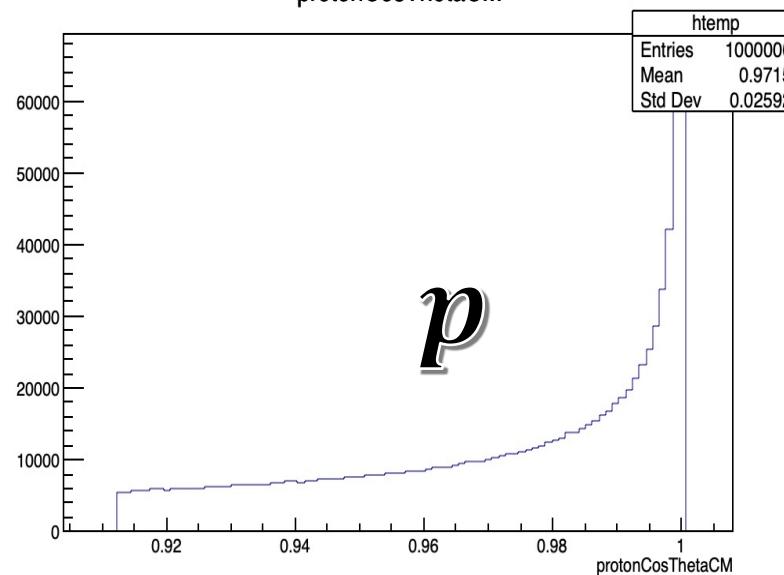


# $\bar{p}p$ CM frame

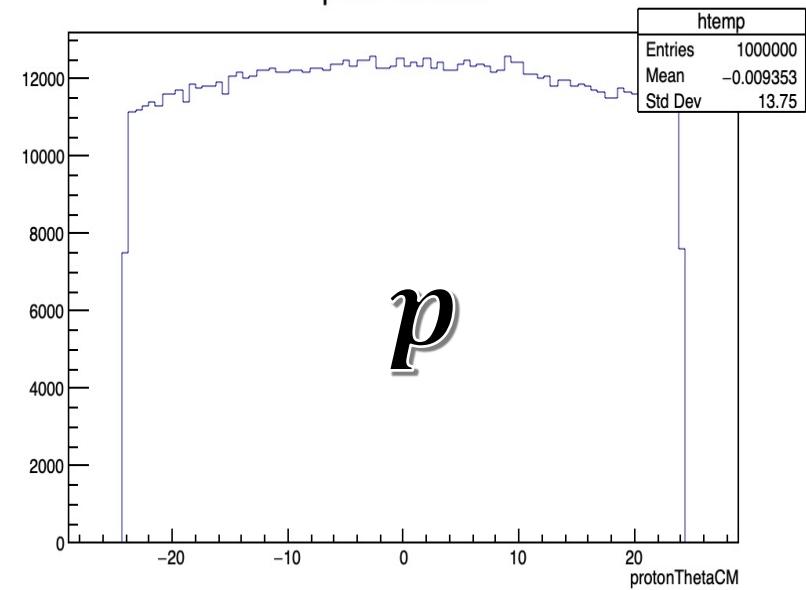
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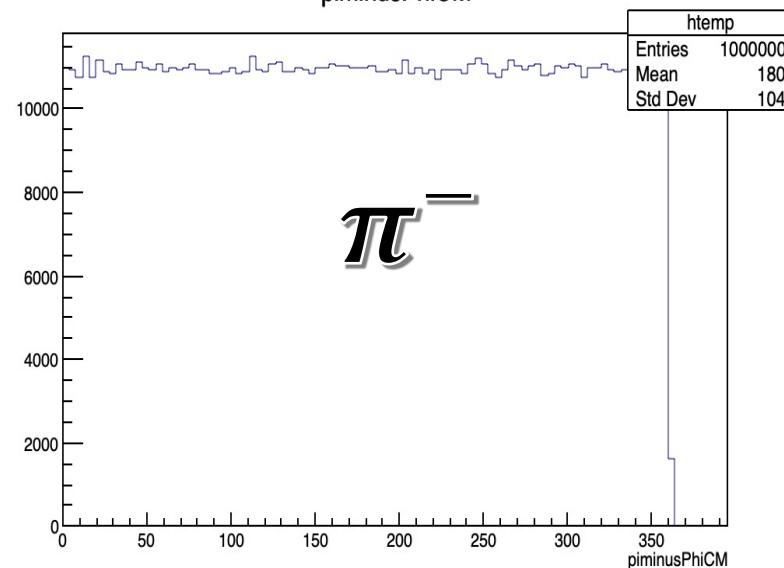
protonCosThetaCM



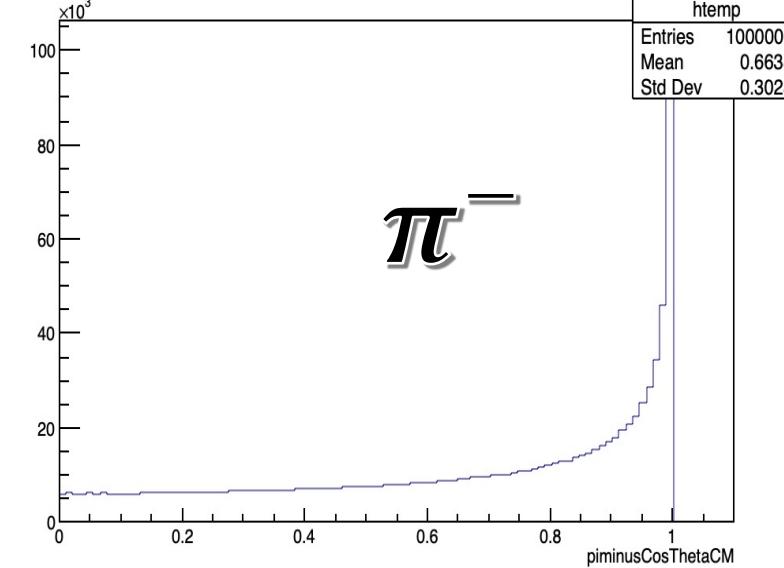
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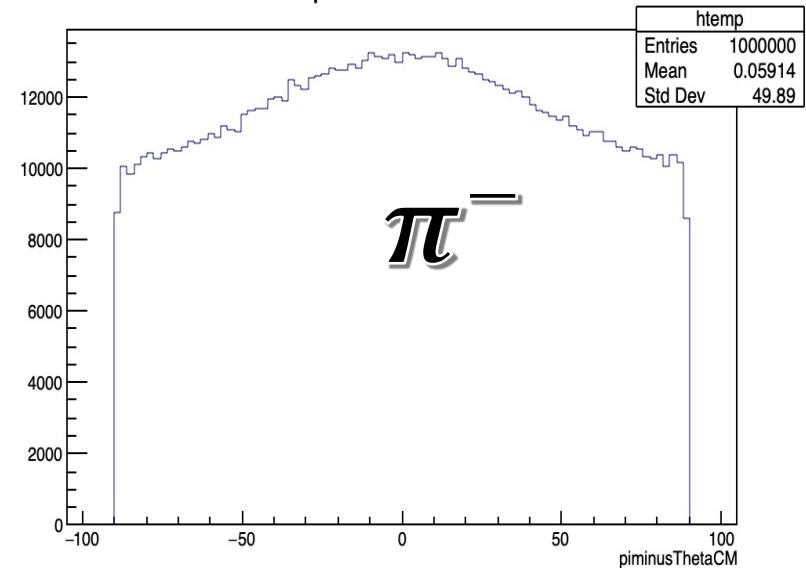
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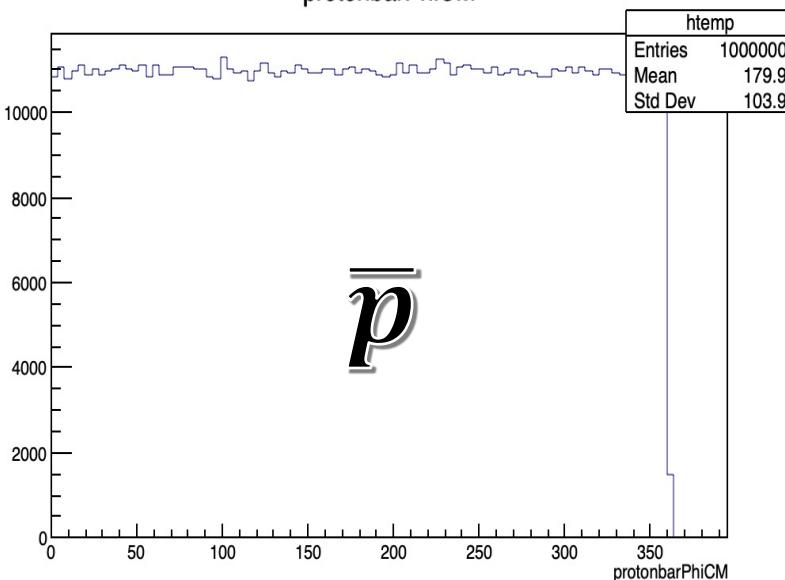


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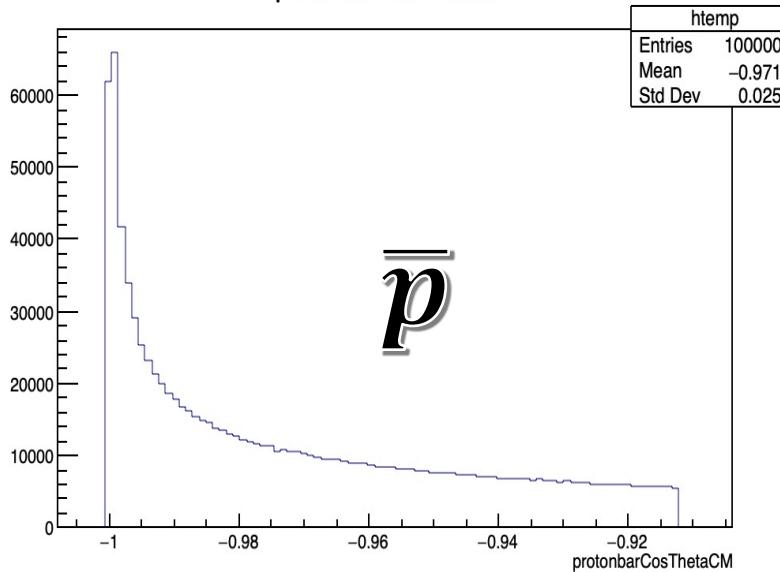


# $\bar{p}p$ CM frame

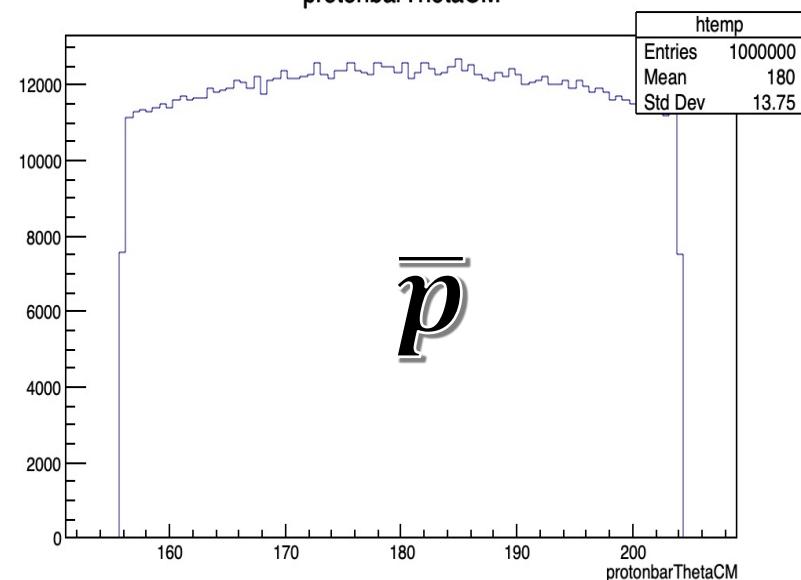
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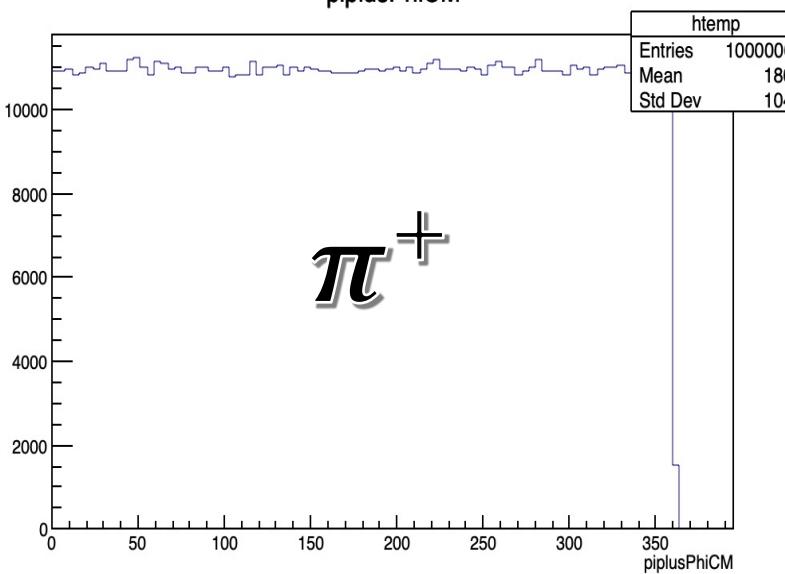
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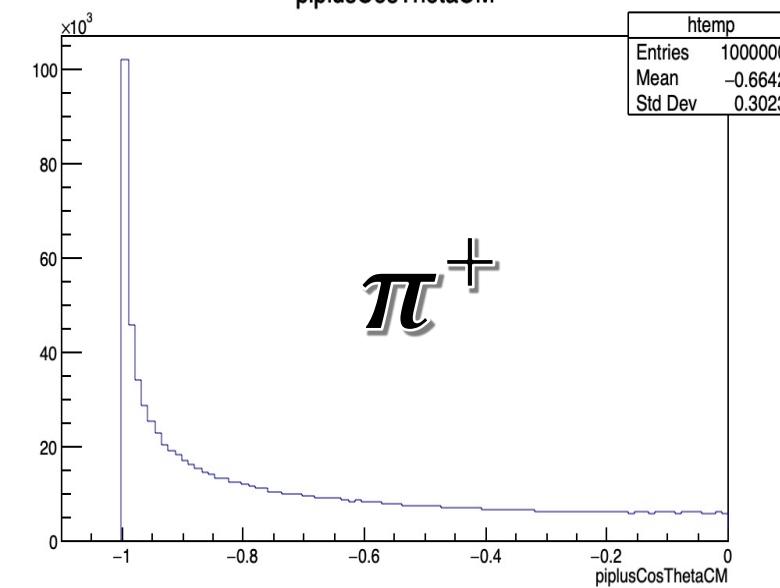
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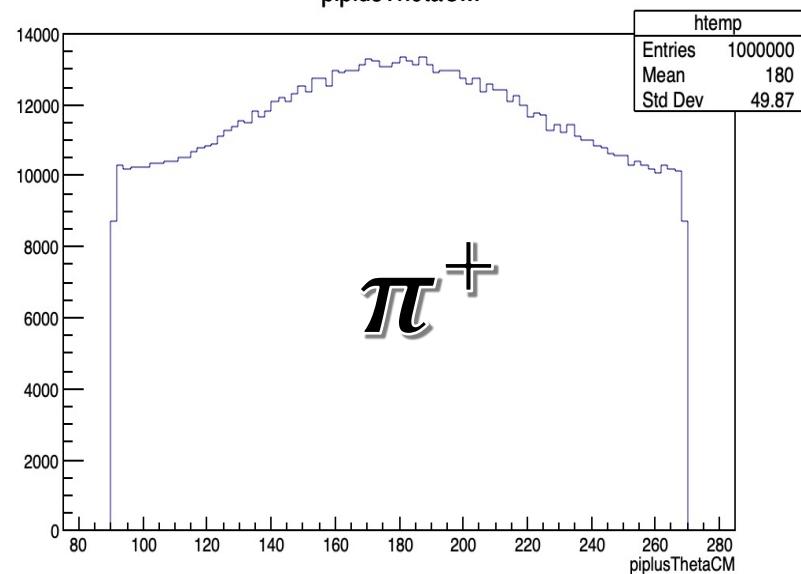
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piplusCosThetaCM

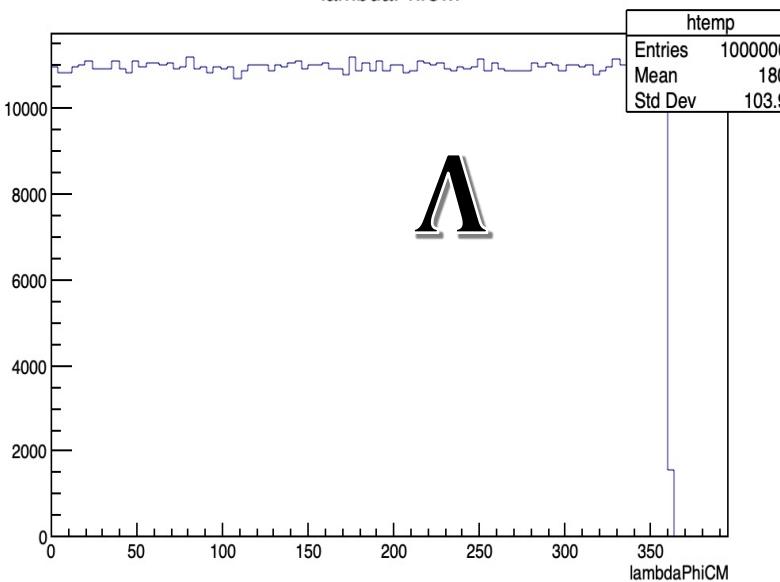


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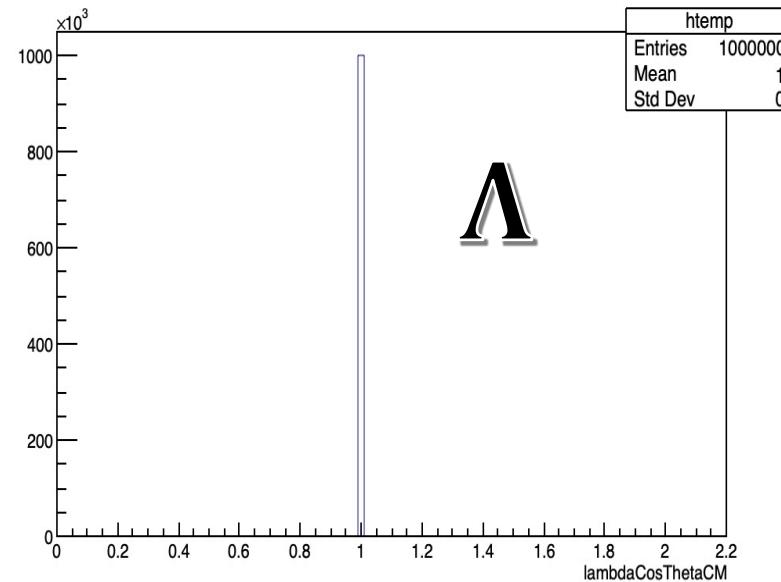


# $\bar{p}p$ CM frame

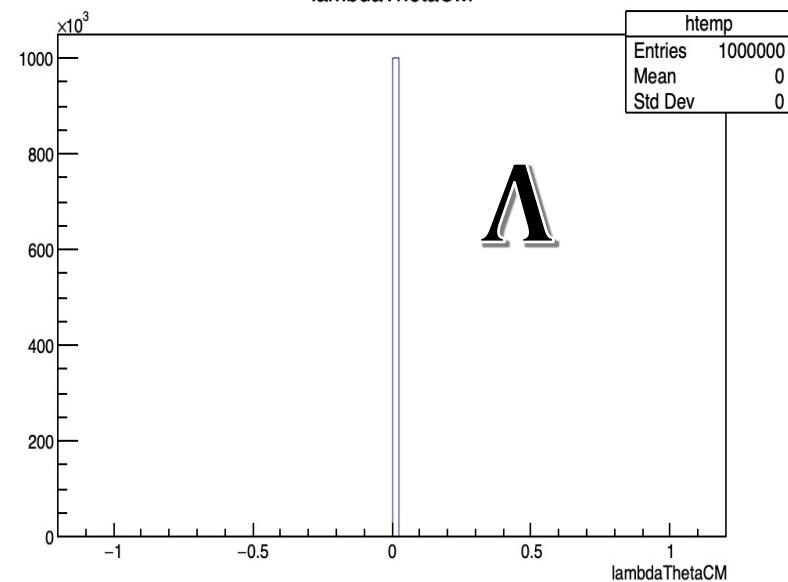
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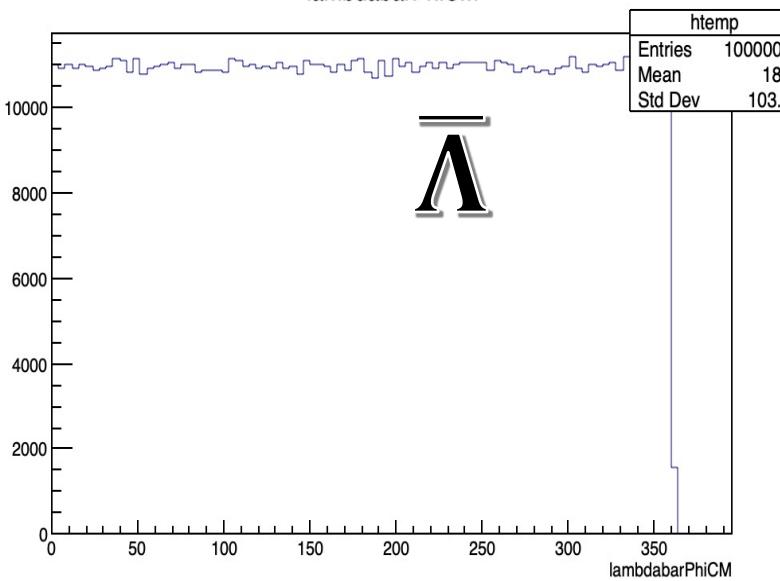
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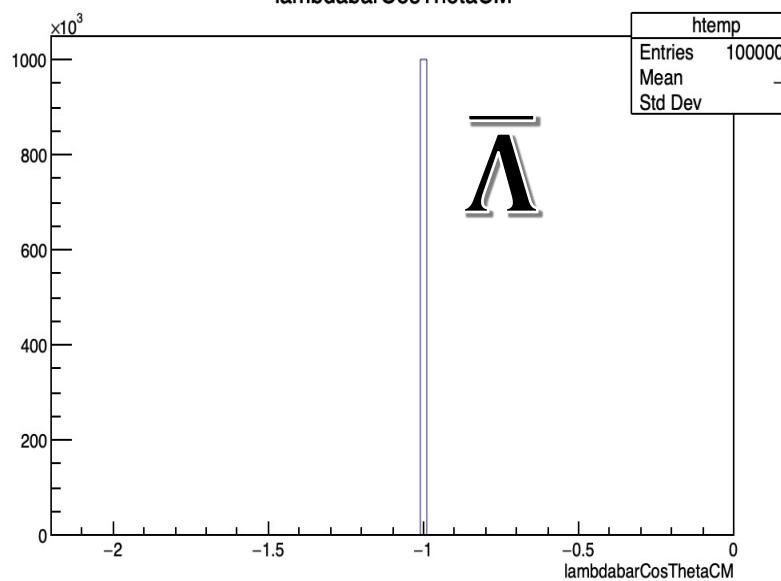
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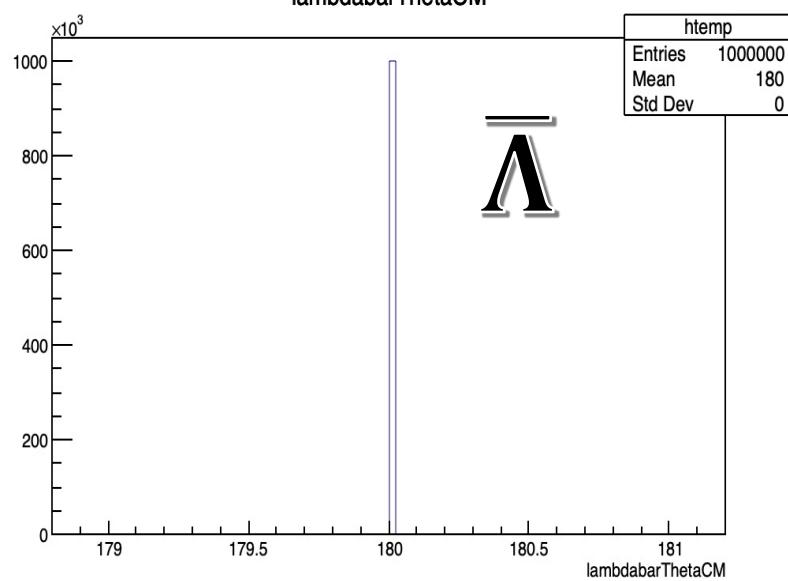
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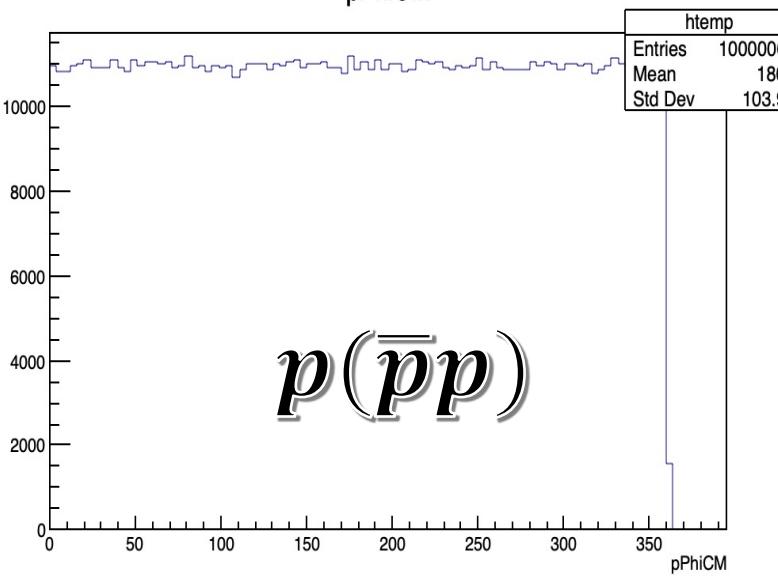


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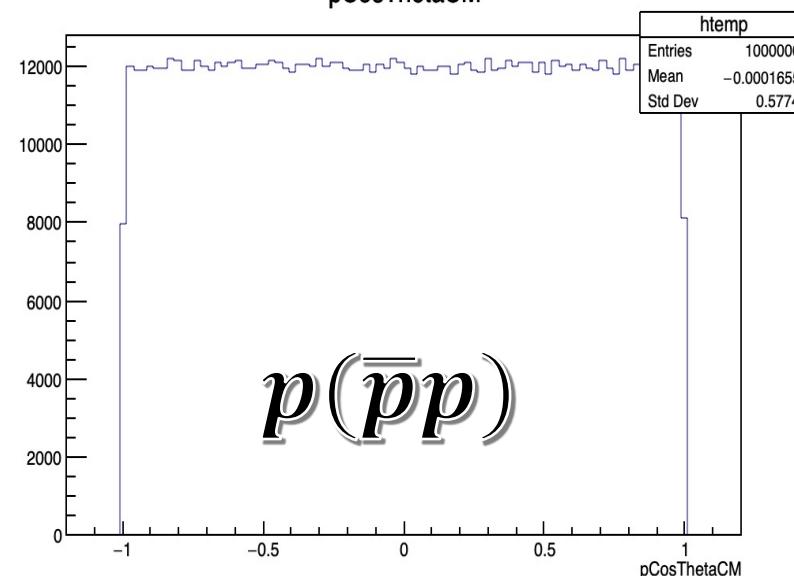


# $\bar{p}p$ CM frame

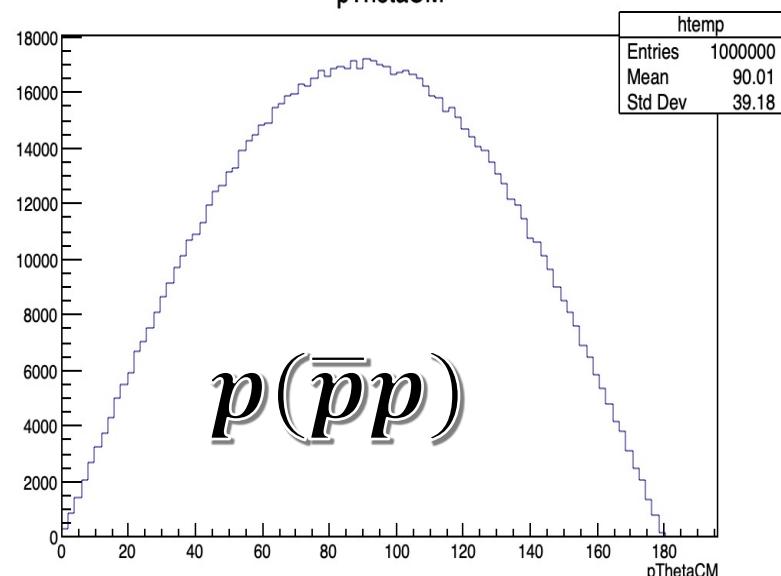
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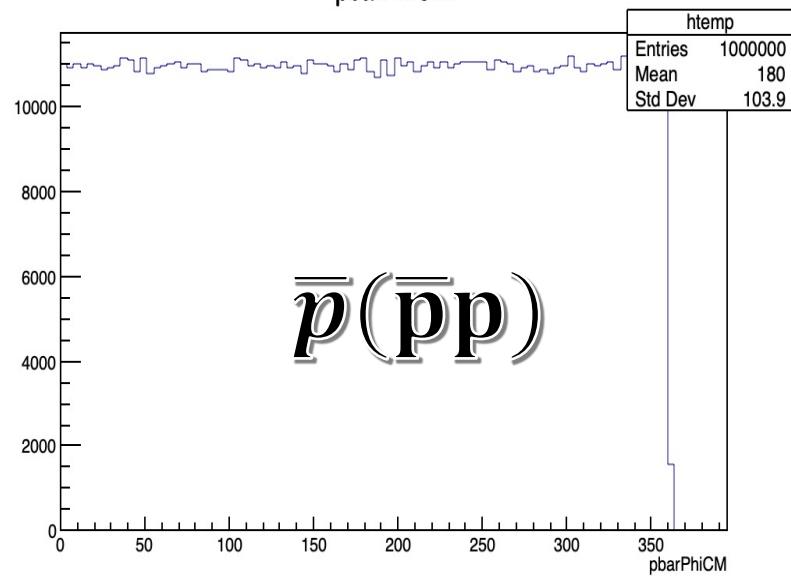
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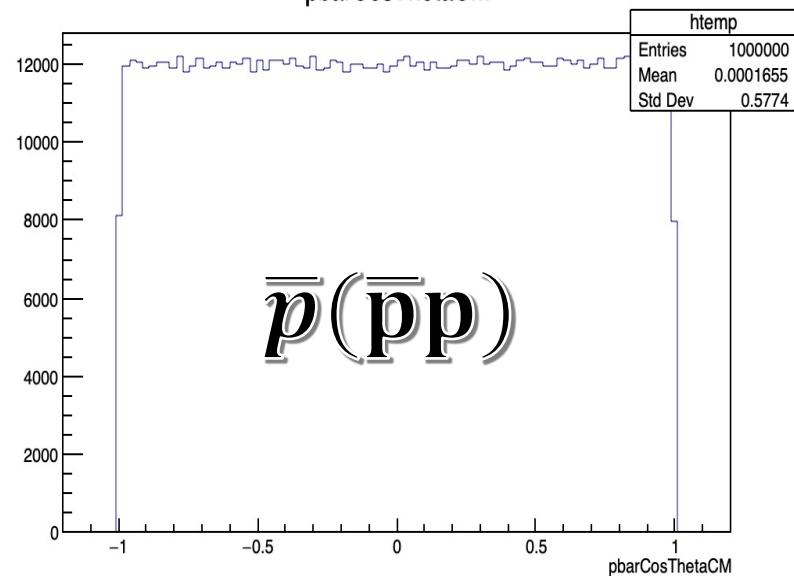
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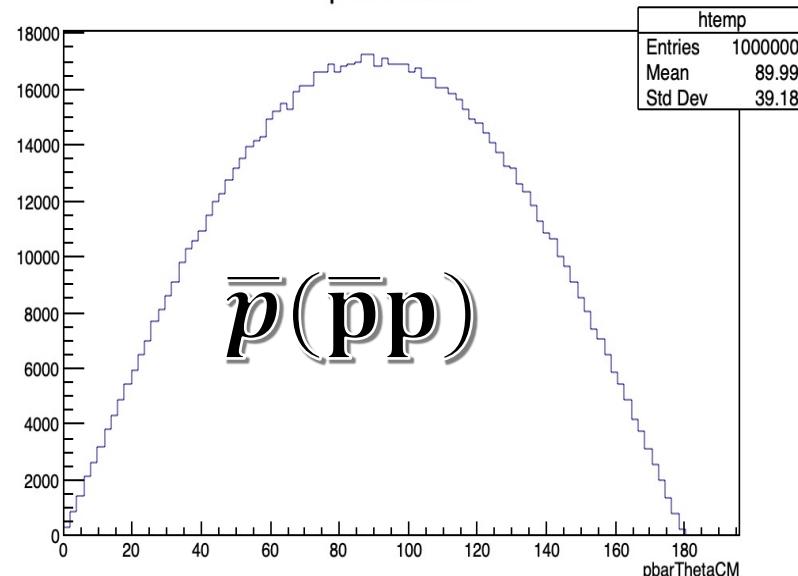
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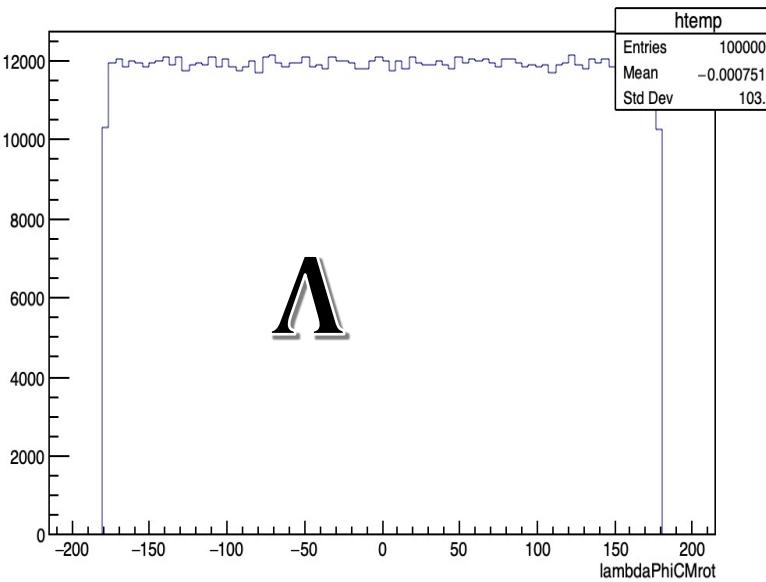


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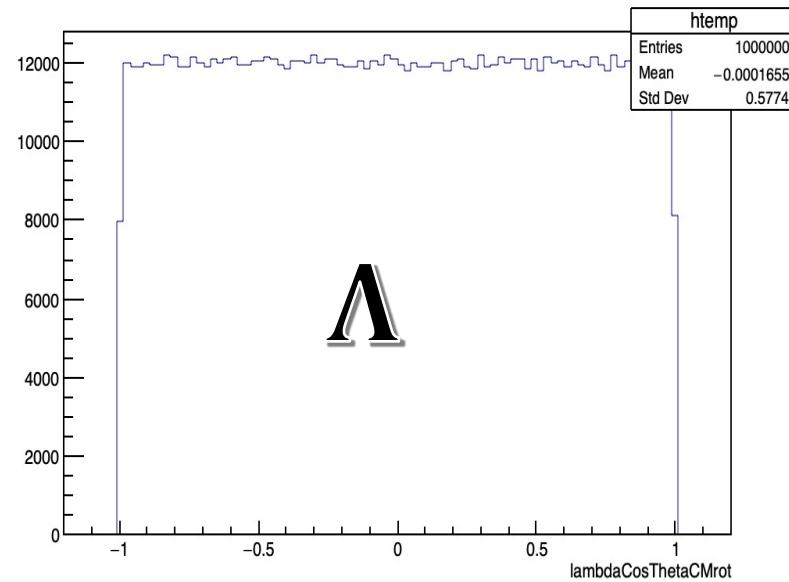


# $\bar{p}p$ CM frame (Rotation)

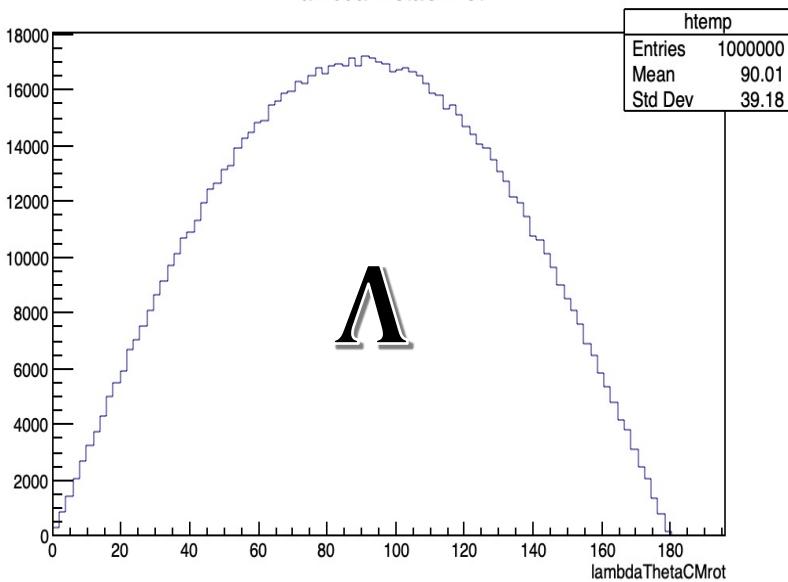
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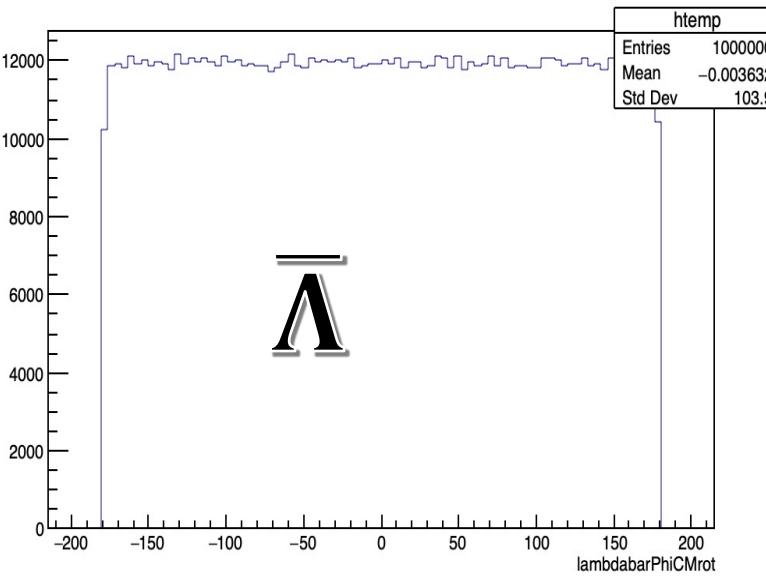
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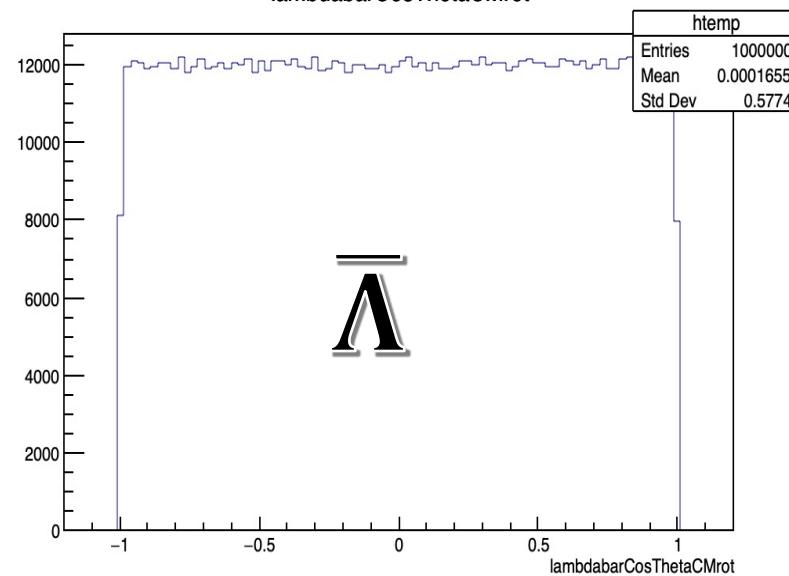
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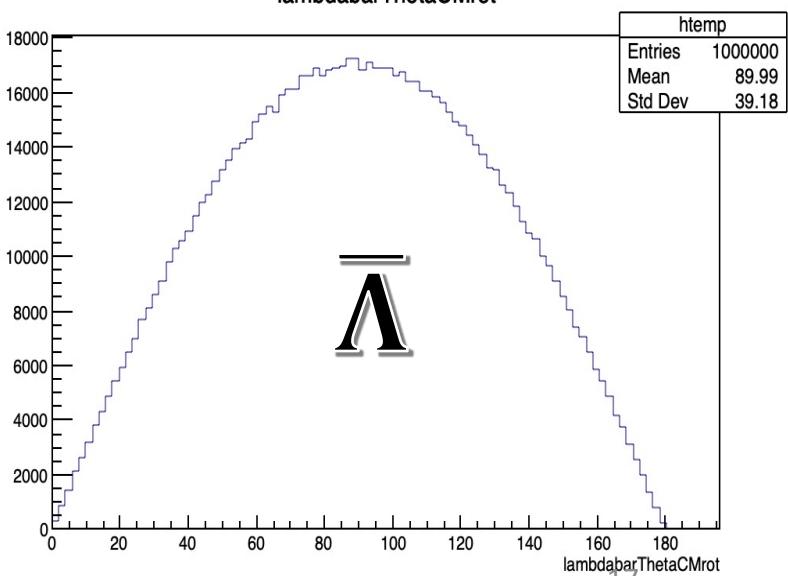
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lambdabarCosThetaCMrot

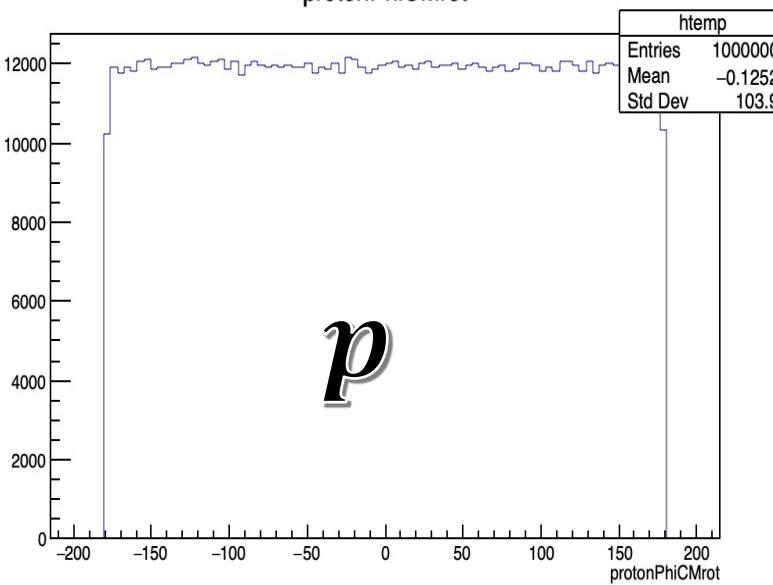


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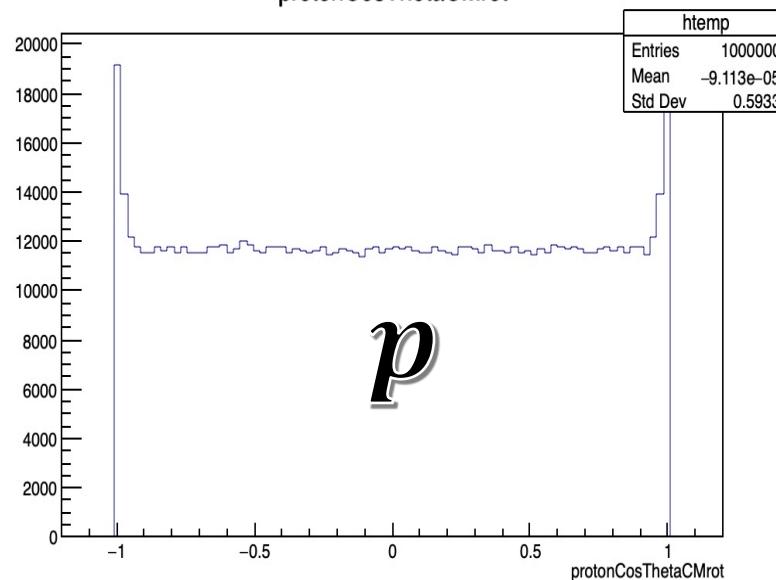


# $\bar{p}p$ CM frame (Rotation)

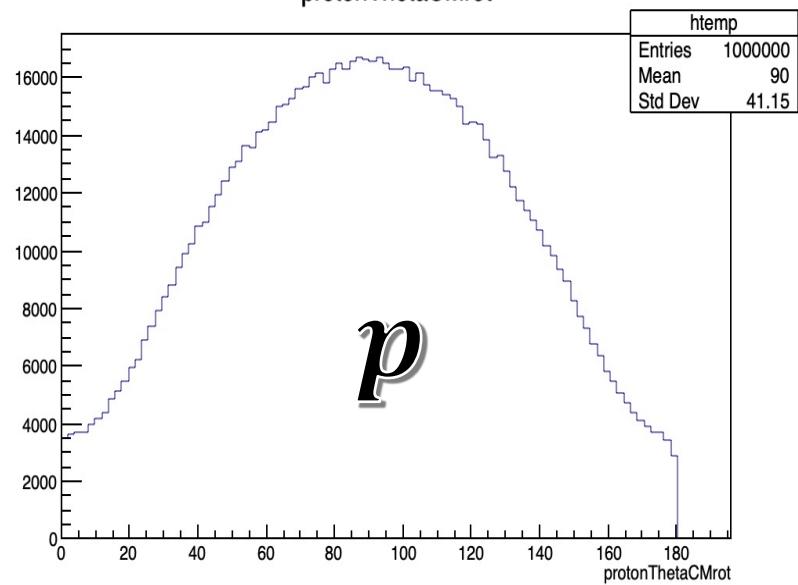
protonPhiCMrot



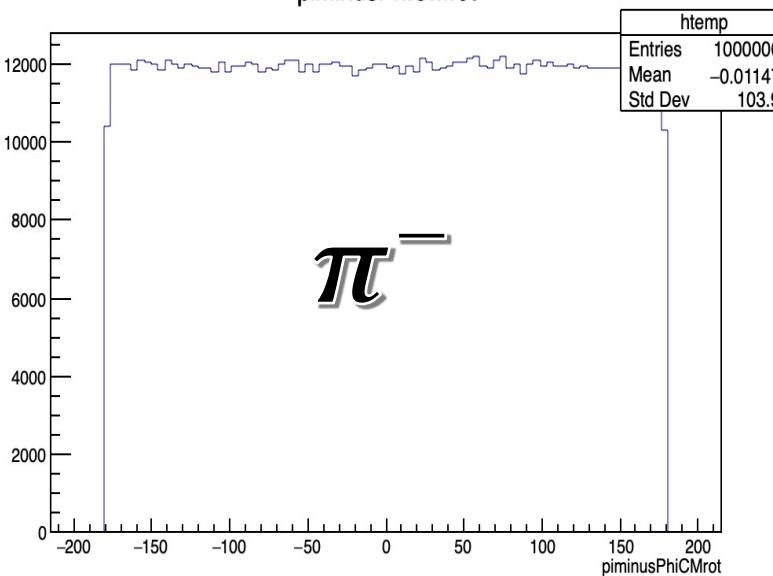
protonCosThetaCMrot



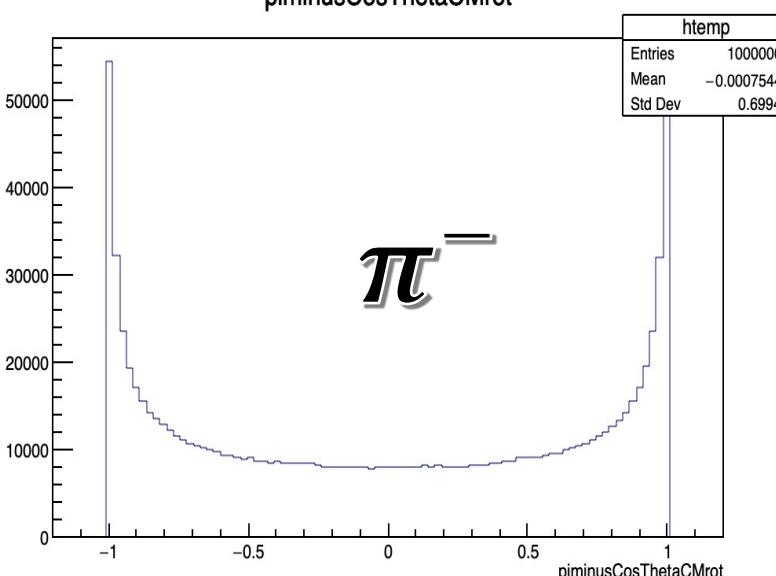
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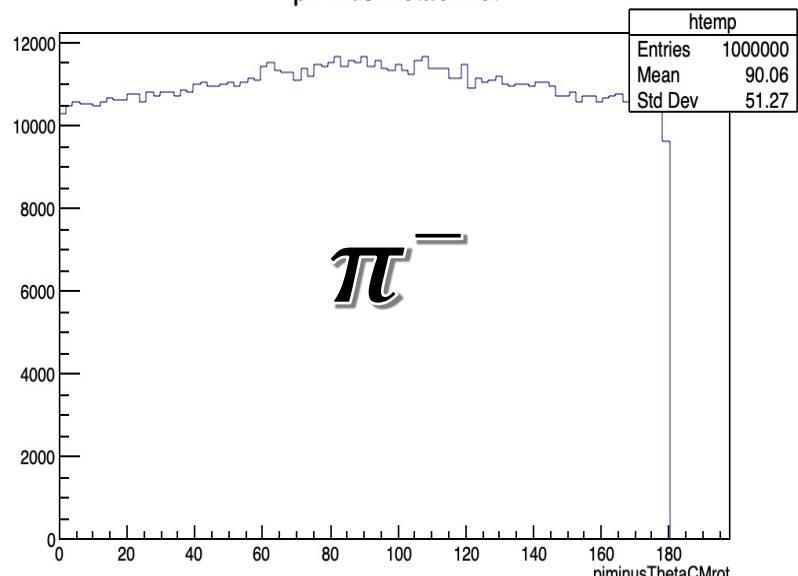
piminusPhiCMrot



piminusCosThetaCMrot

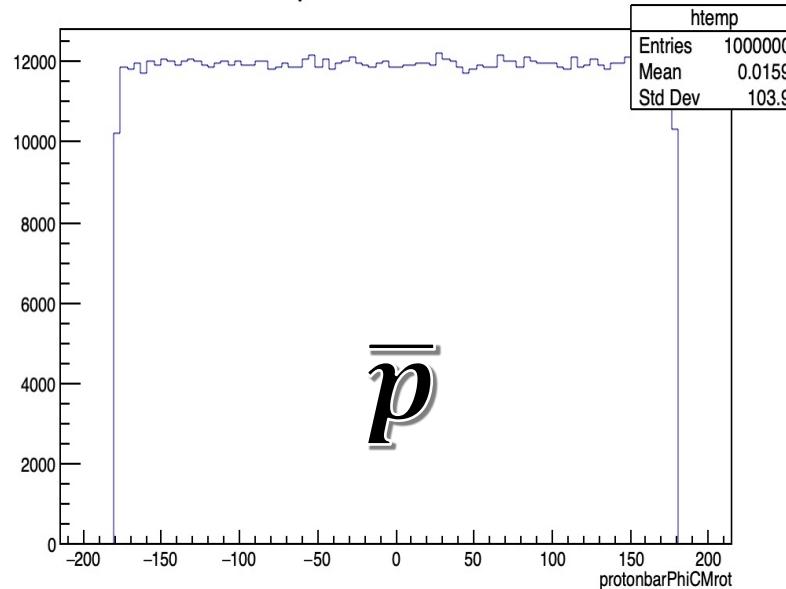


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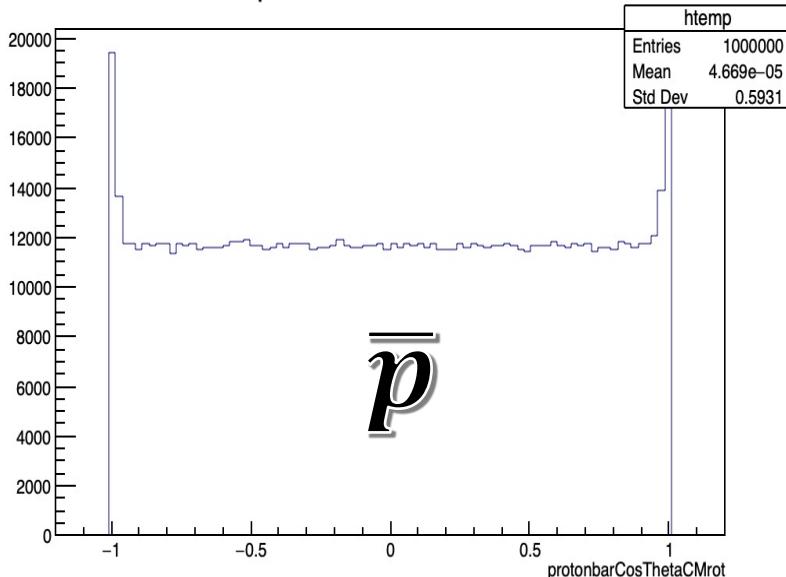


# $\bar{p}p$ CM frame (Rotation)

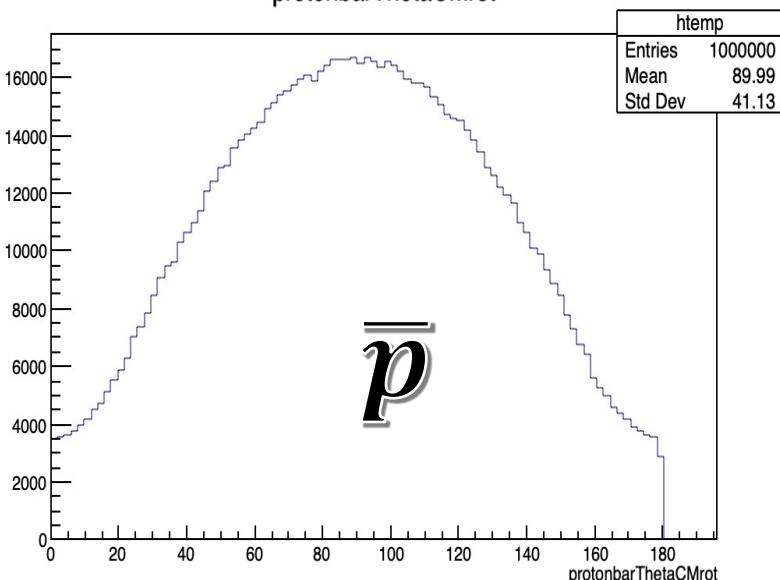
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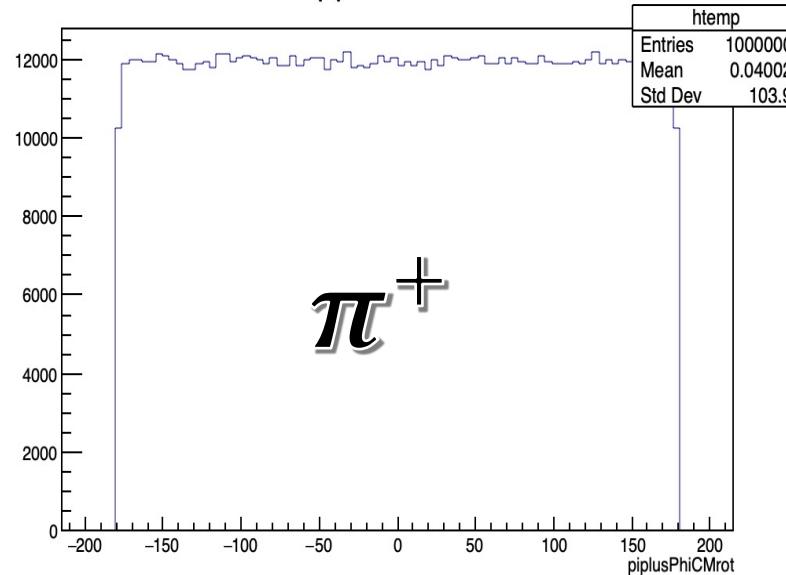
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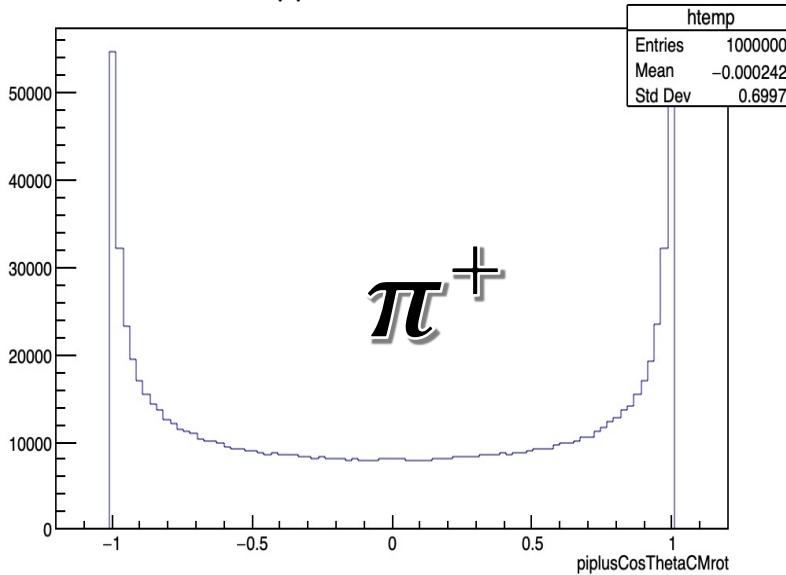
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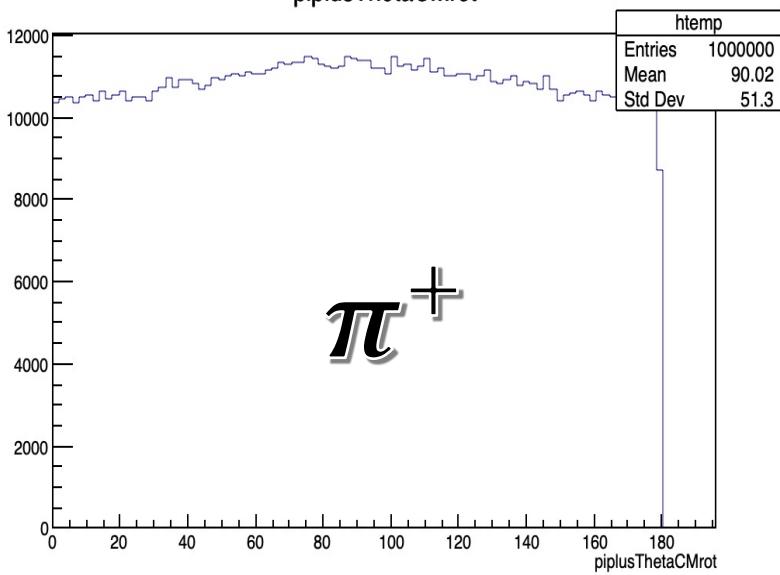
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piplusCosThetaCMrot

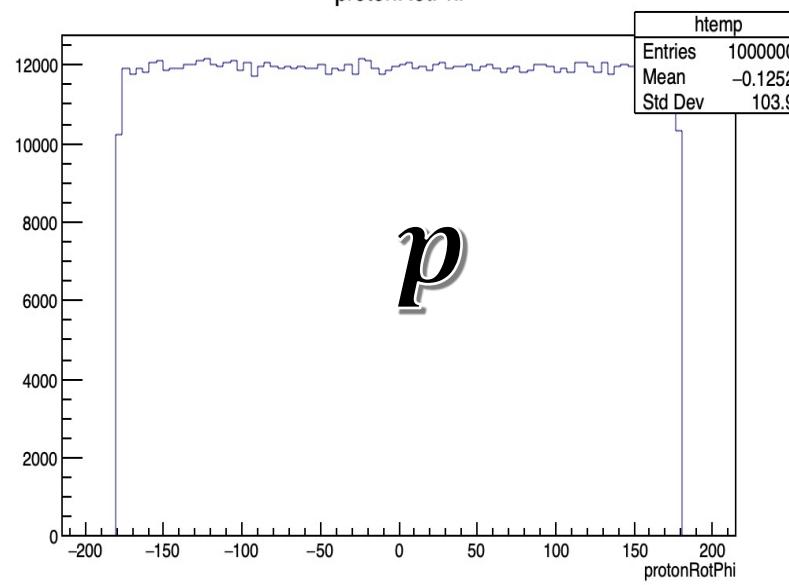


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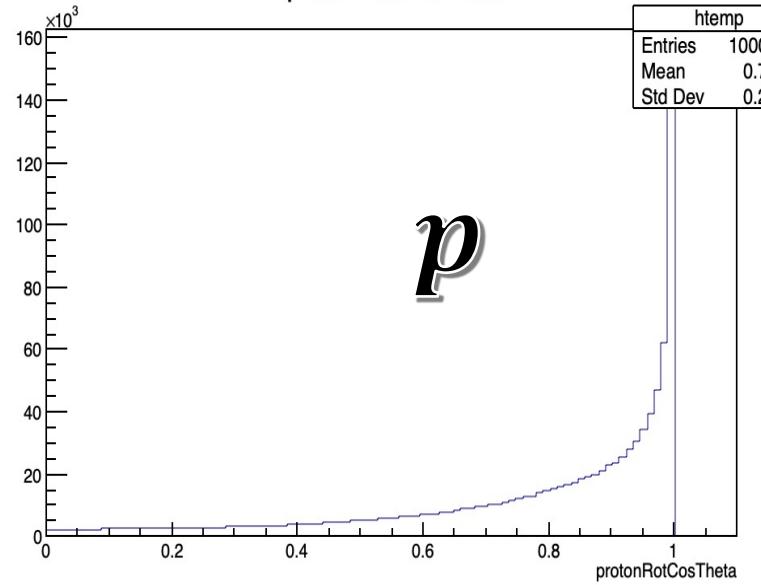


# $\Lambda$ rest frame (Rotation)

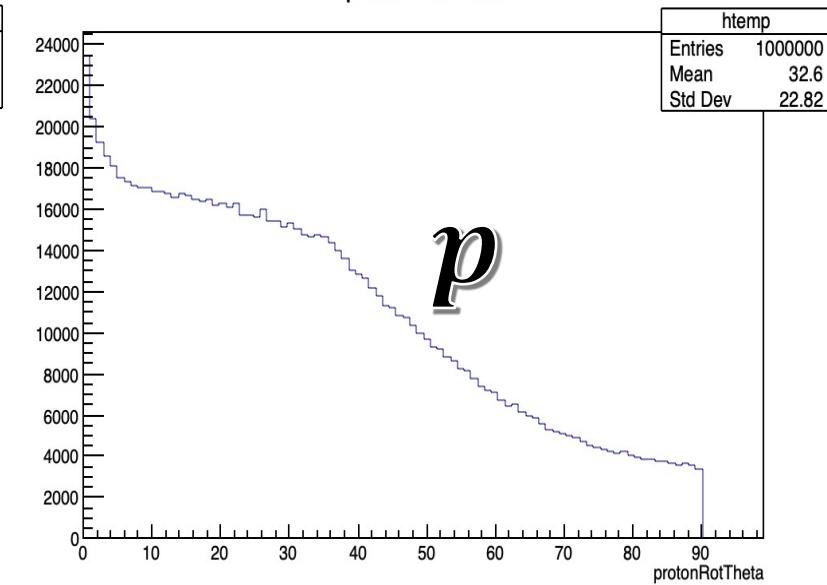
protonRotPhi



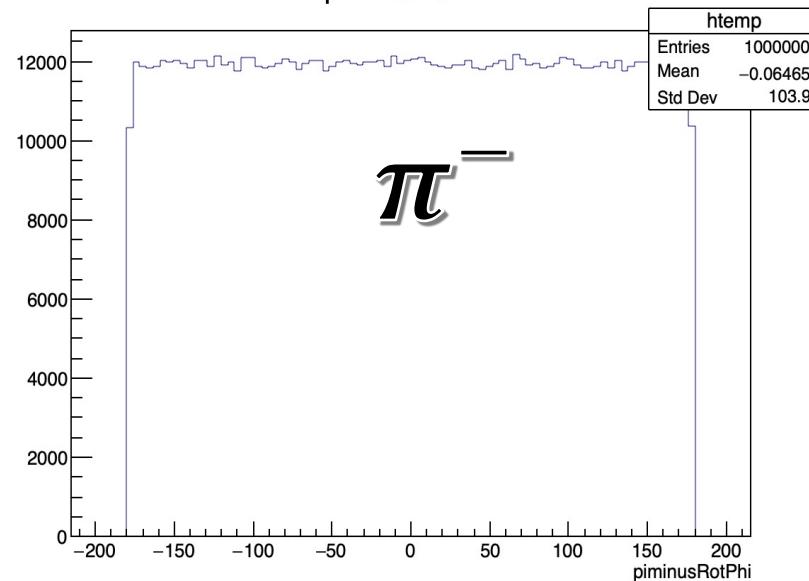
protonRotCosTheta



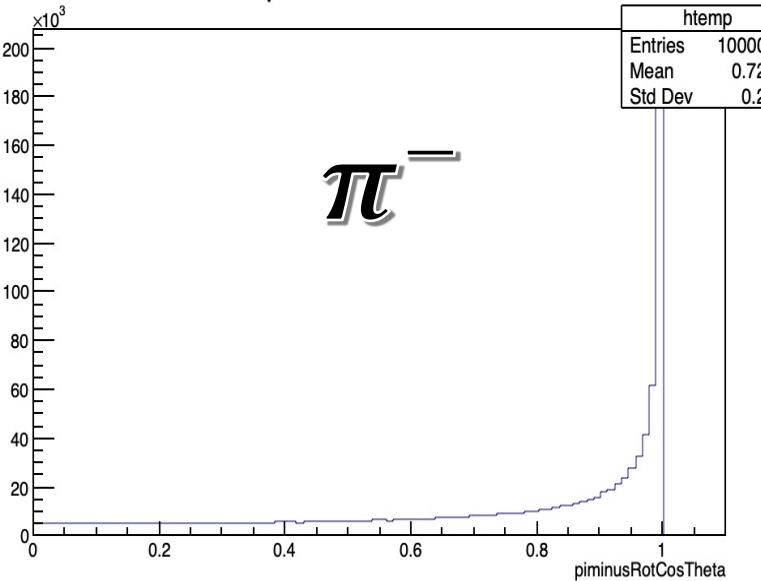
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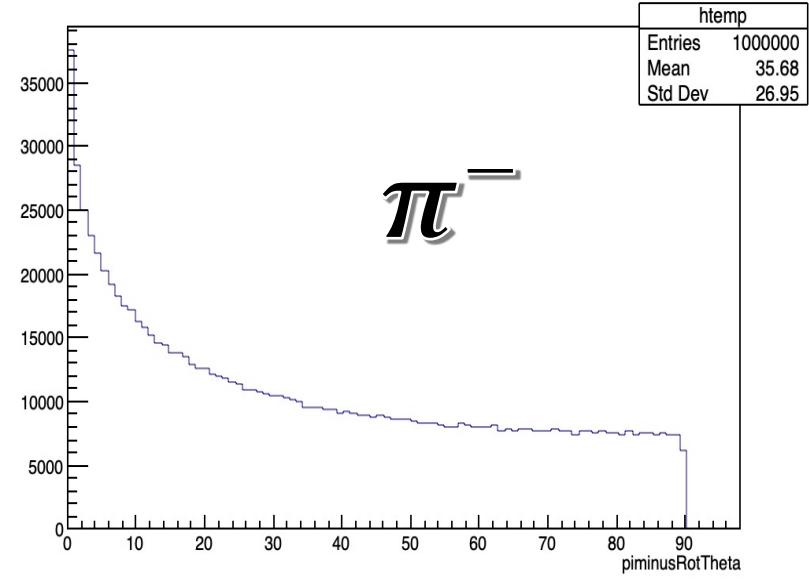
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piminusRotCosTheta



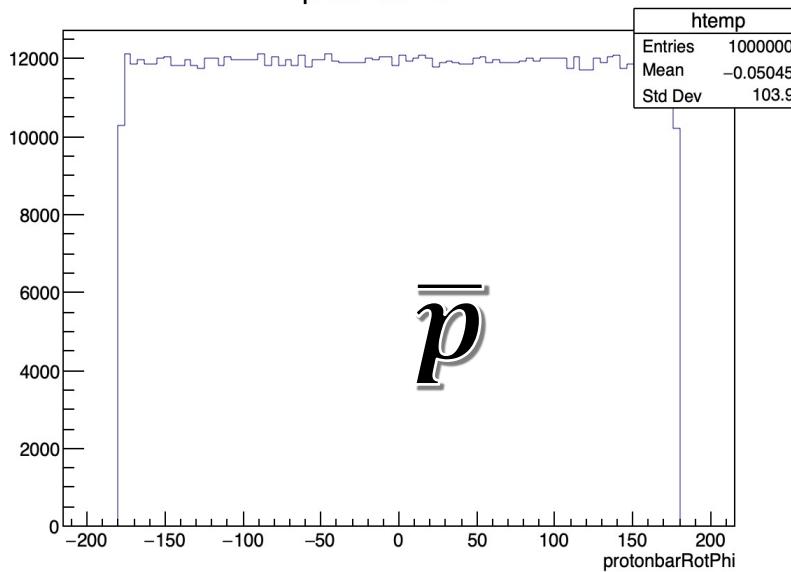
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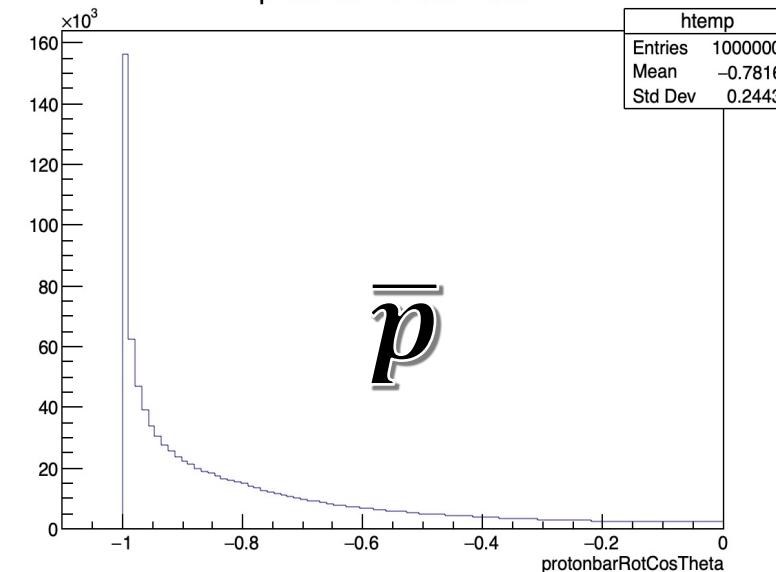
# $\bar{\Lambda}$ rest frame (Rotation)

To [p.7](#)

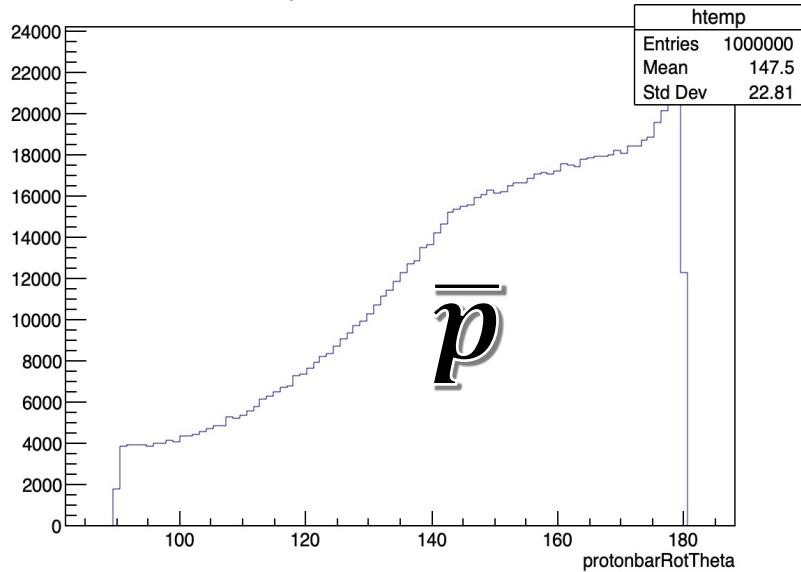
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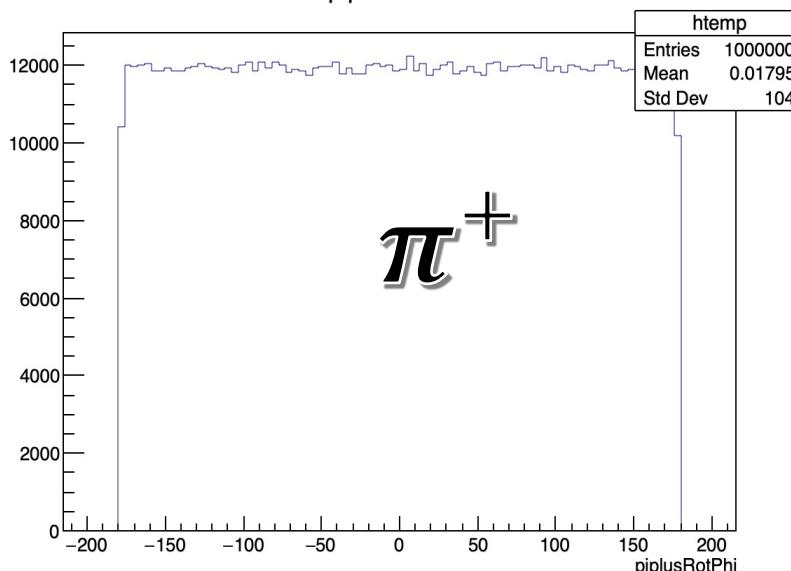
protonbarRotCosTheta



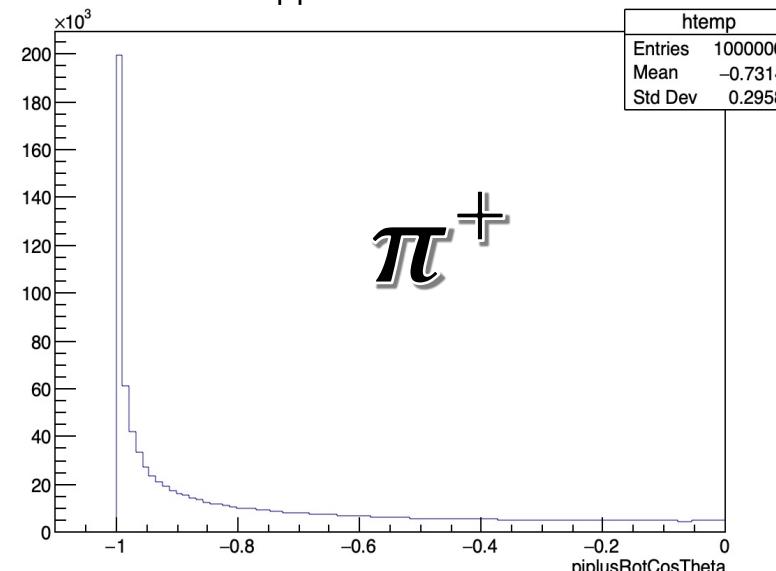
protonbarRotTheta



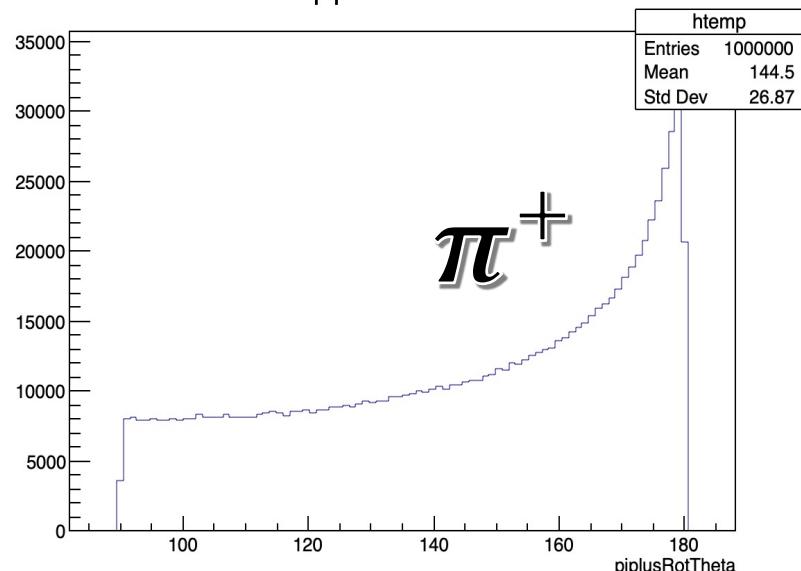
piplusRotPhi



piplusRotCosTheta



piplusRotTheta



# Conclusion & Outlook

- **External Monte-Carlo Event Generator**
  - $\bar{Y}Y$  pair production in  $\bar{p}p$  annihilation
    - $\bar{p} + p \rightarrow \bar{\Lambda} + \Lambda \rightarrow p^-\pi^+ + p\pi^-$
    - Kinematics relations of 4-vectors
  - Beam momentum as input
  - Fast MC simulation with light-weight software package
  - Comprehensive set of angles and momentum in CM and helicity frame
- **Future development outlook**
  - Testing of models and formalisms of spin-observables
    - Implementation arbitrary angular distribution
    - Implementation of Decay length

# Appendix

# 4-vector

$$p_2^2 = (P - p_1)^2 = P^2 - 2P \cdot p_1 + p_1^2$$

and the mass

$$p_A^2 \equiv E_A^2 - \mathbf{p}_A^2 = m_A^2$$

$$m_2^2 = M^2 - 2ME_1 + m_1^2$$

The energy of the daughter particles can be solved

$$E_1 = \frac{M^2 + m_1^2 - m_2^2}{2M}$$

and using the relation of  $E_2 = M - E_1$  in this case parent's rest frame

$$E_2 = \frac{M^2 + m_2^2 - m_1^2}{2M}$$

$$\begin{pmatrix} E_A \\ p_{Ax} \\ p_{Ay} \\ p_{Az} \end{pmatrix} + \begin{pmatrix} E_B \\ p_{Bx} \\ p_{By} \\ p_{Bz} \end{pmatrix} = \begin{pmatrix} E_C \\ p_{Cx} \\ p_{Cy} \\ p_{Cz} \end{pmatrix} + \begin{pmatrix} E_D \\ p_{Dx} \\ p_{Dy} \\ p_{Dz} \end{pmatrix}$$

The momentum form  $|\mathbf{p}_1| = \sqrt{E_1^2 - m_1^2}$  and obtains

$$|\mathbf{p}_1| = \frac{\sqrt{(M^2 + m_1^2 - m_2^2)^2 - 4M^2m_1^2}}{2M} = \frac{\sqrt{(M^2 - m_1^2 - m_2^2)^2 - 4m_1^2m_2^2}}{2M}$$

$$\begin{cases} p_{p_x}^* = p_p^* \sin\theta^* \\ p_{p_z}^* = p_p^* \cos\theta^* \end{cases}$$

Considering

$$E_\Lambda = \sqrt{p_\Lambda^2 + m_\Lambda^2}$$

Similarly we have

$$\begin{cases} p_{\pi_x^-}^* = -p_{p_x}^* \\ p_{\pi_z^-}^* = -p_{p_z}^* \end{cases}$$

Also the  $\gamma$  factor and velocity

$$\begin{aligned} \gamma_\Lambda &= \frac{E_\Lambda}{m_\Lambda} \\ v_\Lambda &= \frac{p_\Lambda}{E_\Lambda} \end{aligned}$$

While the energy of them can also be found

$$\begin{cases} E_p^* = \frac{m_\Lambda^2 + m_p^2 - m_\pi^2}{2m_\Lambda} \\ E_\pi^* = m_\Lambda - E_p^* \end{cases}$$

Ultimately the Lorentz transformation (LT) can be done by multiply the factors above

$$\begin{cases} p_{p_x} = p_{p_x}^* \\ p_{p_z} = \gamma_\Lambda(p_{p_x}^* + v_\Lambda E_p^*) \\ \tan\theta_p = \frac{p_{p_x}}{p_{p_z}} \end{cases}$$

and similarly for the other daughter particle

$$\begin{cases} p_{p_{\pi^-}} = p_{p_{\pi^-}}^* \\ p_{p_{\pi^-}} = \gamma_\Lambda(p_{p_{\pi^-}}^* + v_\Lambda E_{\pi^-}^*) \\ \tan\theta_{\pi^-} = \frac{p_{p_{\pi^-}}}{p_{\pi_z^-}} \end{cases}$$

To perform the rotation, the relation of angles in spherical coordinates

$$\begin{cases} x = r \cos\varphi \sin\theta \\ y = r \sin\varphi \sin\theta \\ z = r \cos\theta \end{cases}$$

Also the rotation matrix can be considered to perform this operation.

$$R_x = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{pmatrix}$$

$$R_y = \begin{pmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{pmatrix}$$

$$R_z = \begin{pmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

And in general

$$R = R_z(\alpha)R_y(\beta)R_x(\gamma)$$

A list of typical hyperons is summarised below.

Y	q	$c\tau$ (cm)	T (s)	M (GeV/c <sup>2</sup> )	Decay
$\Lambda$	uds	7.89	$2.632 \times 10^{-10}$	1.116	$p\pi^-$ (63.9%)
					$n\pi^0$ (35.8%)
$\Sigma^+$	uus	2.404	$8.018 \times 10^{-11}$	1.189	$p\pi^0$ (51.57%)
					$n\pi^+$ (48.31%)
$\Sigma^0$	uds	$2.22 \times 10^{-9}$	$7.4 \times 10^{-20}$	1.193	$\Lambda\gamma$ (100%)
$\Sigma^-$	dds	4.434	$1.479 \times 10^{-10}$	1.197	$n\pi^-$ (99.848%)
$\Xi^0$	uss	8.71	$2.0 \times 10^{-10}$	1.315	$\Lambda\pi^0$ (99.524%)
$\Xi^-$	dss	4.91	$1.639 \times 10^{-10}$	1.322	$\Lambda\pi^-$ (99.887%)
$\Omega^-$	sss	2.461	$8.21 \times 10^{-11}$	1.672	$\Lambda K^-$ (67.8%)
					$\Xi^0\pi^-$ (23.6%)
					$\Xi^-\pi^0$ (8.6%)

Table 1.1: Strange ground state hyperons. The name of hyperon, its quark content, mean decay length, mean lifetime, mass, and main decay with branching ration are shown, and they are denoted by Y, q,  $c\tau$ , T, M, and Deca [7].

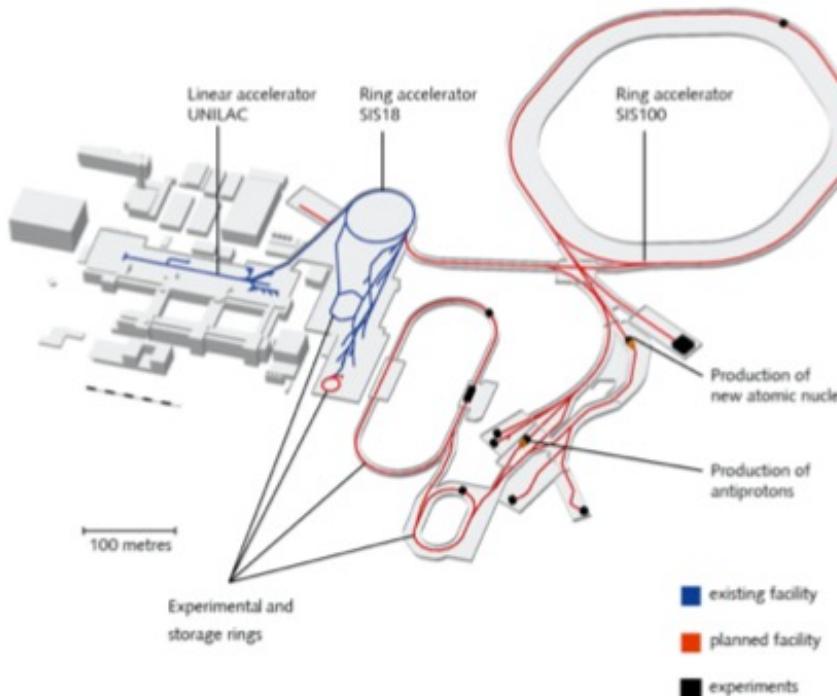


Figure 1.1: The Accelerator Facility of FAIR [2]

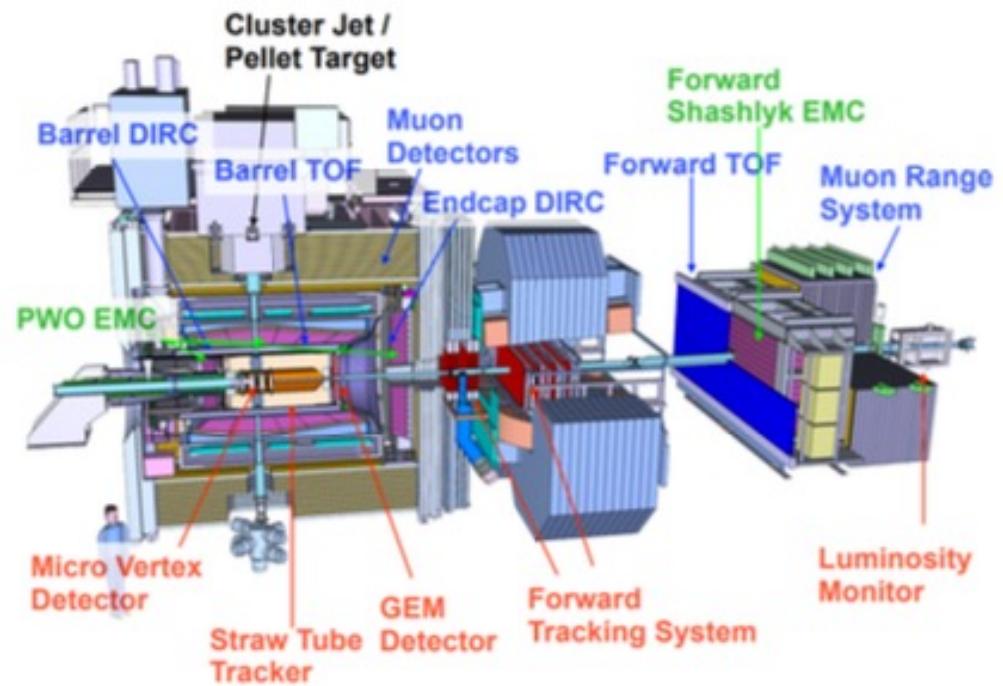


Figure 1.2: The Detector of PANDA [1]