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

A 10hp Project Presentation at Group Meeting

1st March 2022

UPPSALA
UNIVERSITET

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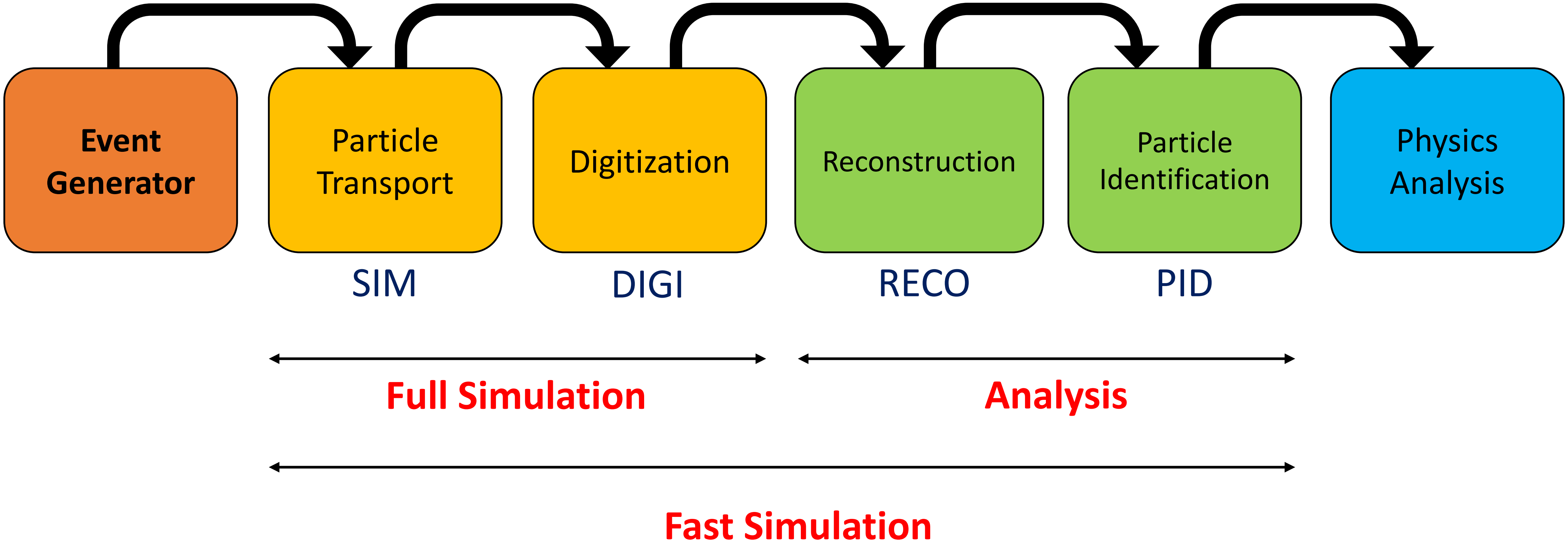
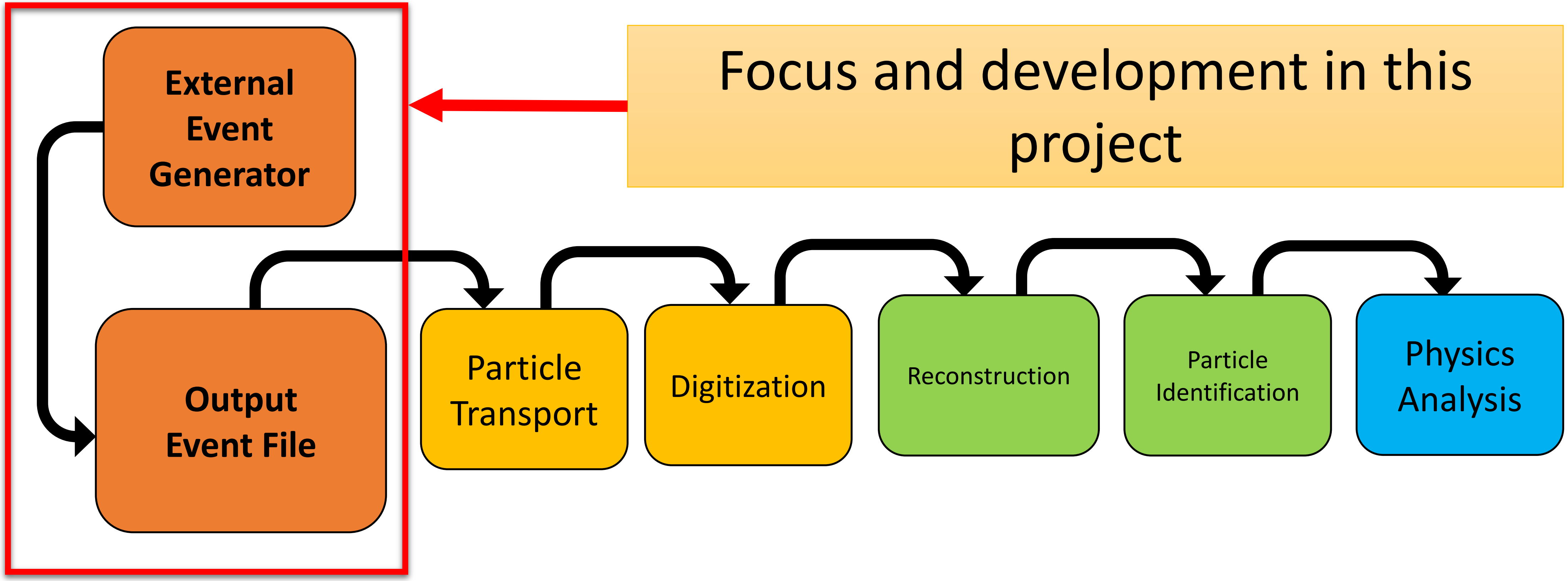
Outline

Introduction

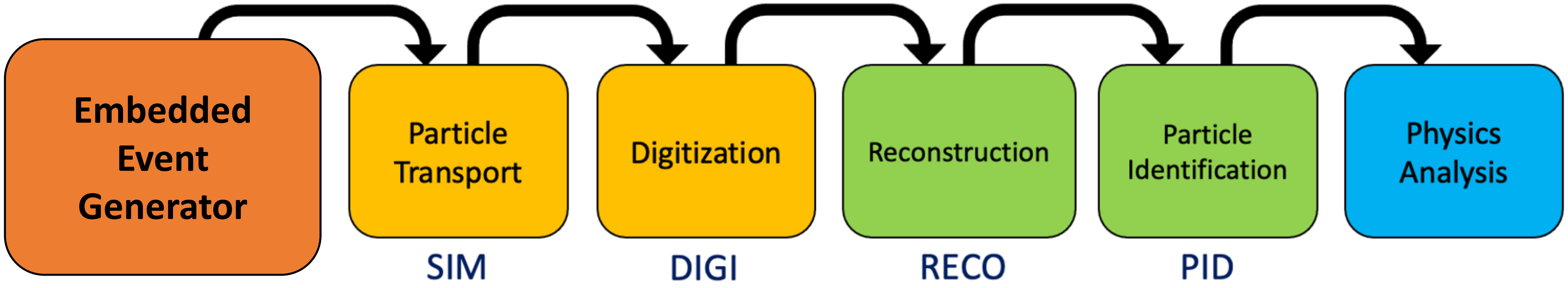
- PANDA experiment at FAIR
- PandaRoot
- Embedded MC Event Generator
- Light-weight external MC Event Generator

Main Framework of PandaRoot




External Event Generator
Output Event File
Focus and development in this project
Particle Transport
Digitization
Reconstruction
Particle Identification
Physics Analysis

vs.


Embedded Event Generator
Particle Transport
Digitization
Reconstruction
Particle Identification
Physics Analysis
SIM
DIGI
RECO
PID

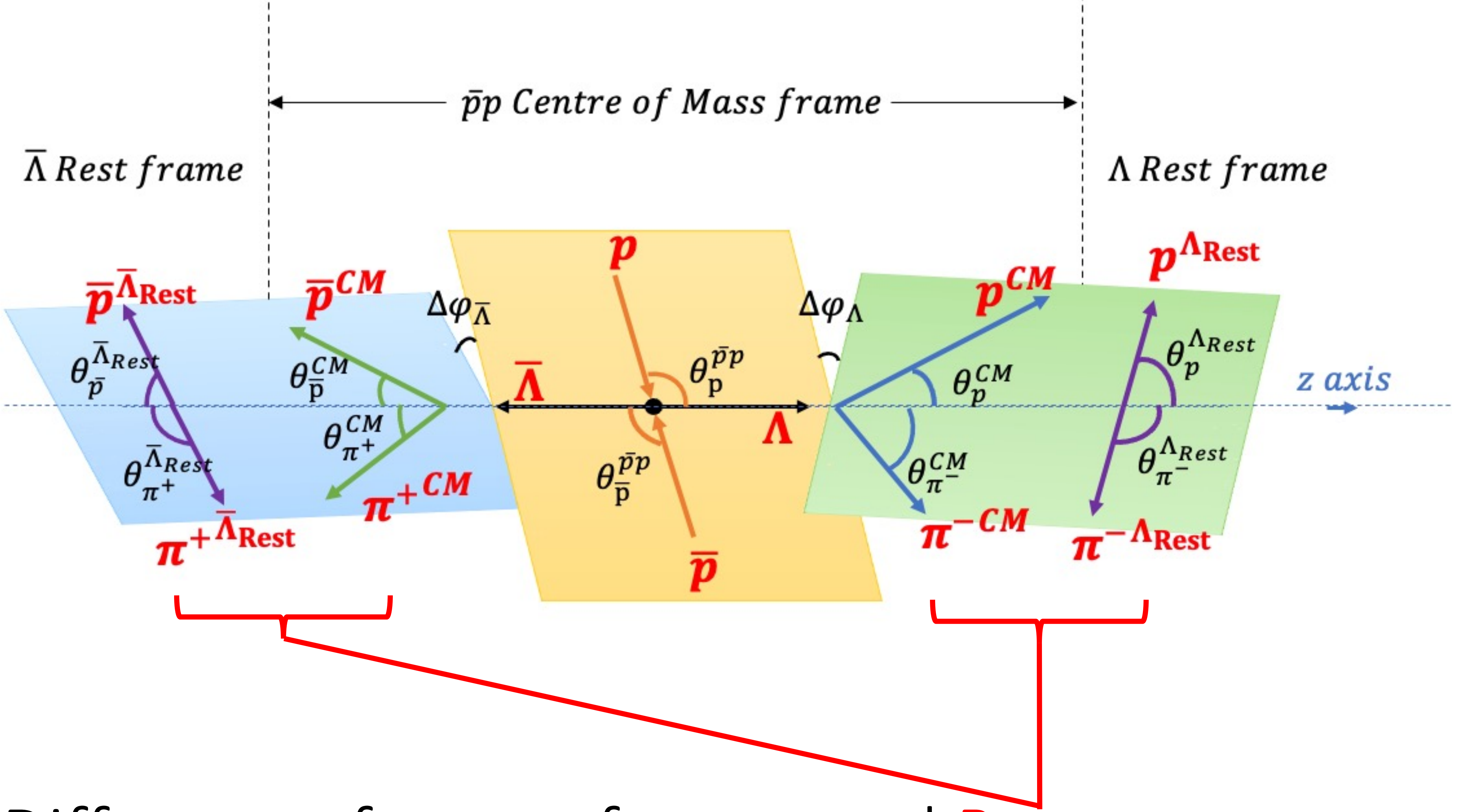
$$\bar{p} + p \rightarrow \bar{\Lambda} + \Lambda \rightarrow p^{-}\pi^{+} + p\pi^{-}$$

Kinematics (4-vectors)

Metheodology

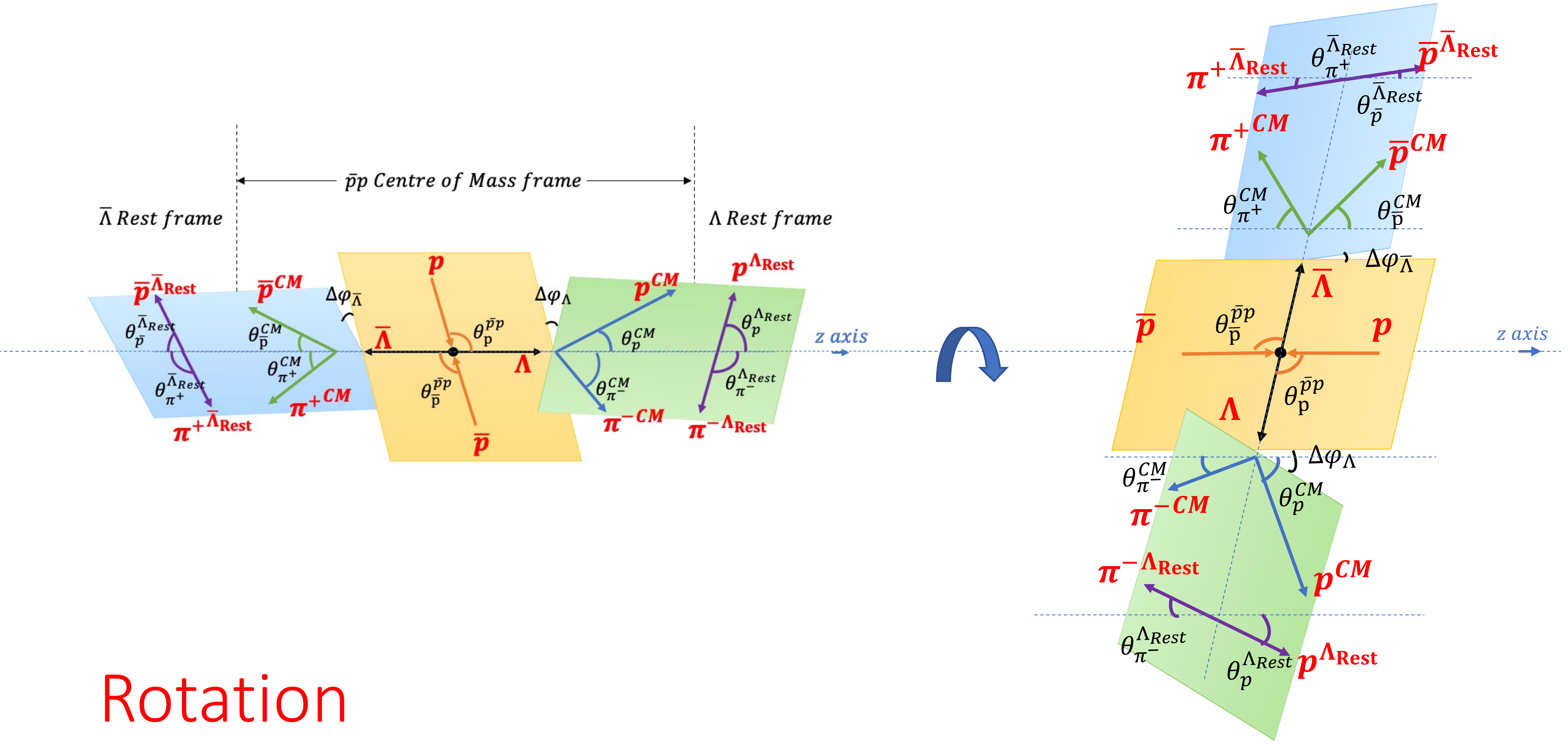
$$p_A^2 \equiv E_A^2 - \boldsymbol{p}_A^2 = m_A^2$$

To p.10



Different reference frames and Boost

To p.12, p.14, p.16, p.17, p.19, p.21



Rotation

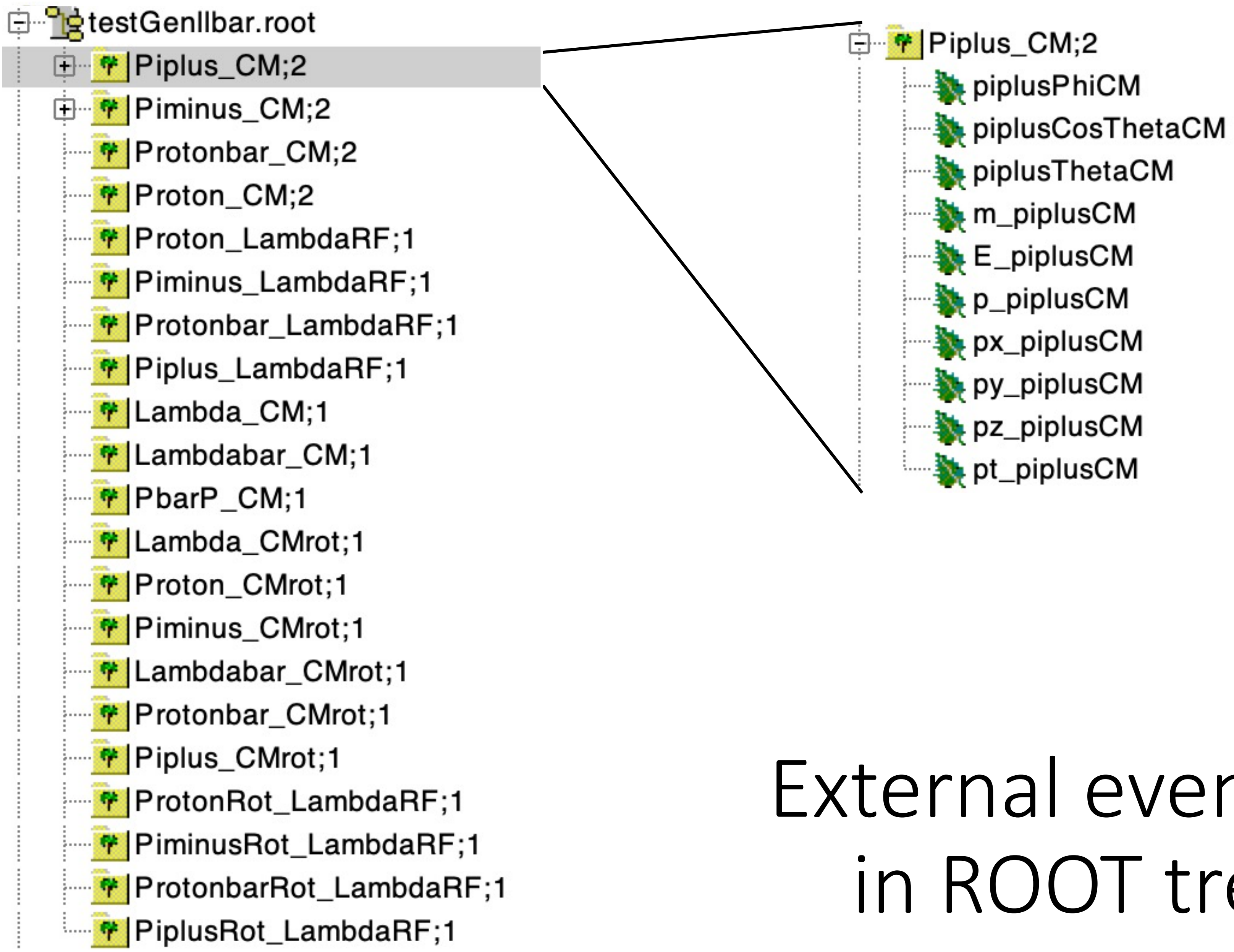
m_Λ	m_p	m_{π^-}	p_{beam}
1.115 GeV/c^2	0.9383 GeV/c^2	0.1396 GeV/c^2	1.64 GeV/c

$$\bar{p} + p \rightarrow \overline{\Lambda} + \Lambda \rightarrow p^-\pi^+ + p\pi^-$$

The developing of an external Event Generator

The brief introduction of the developing framework

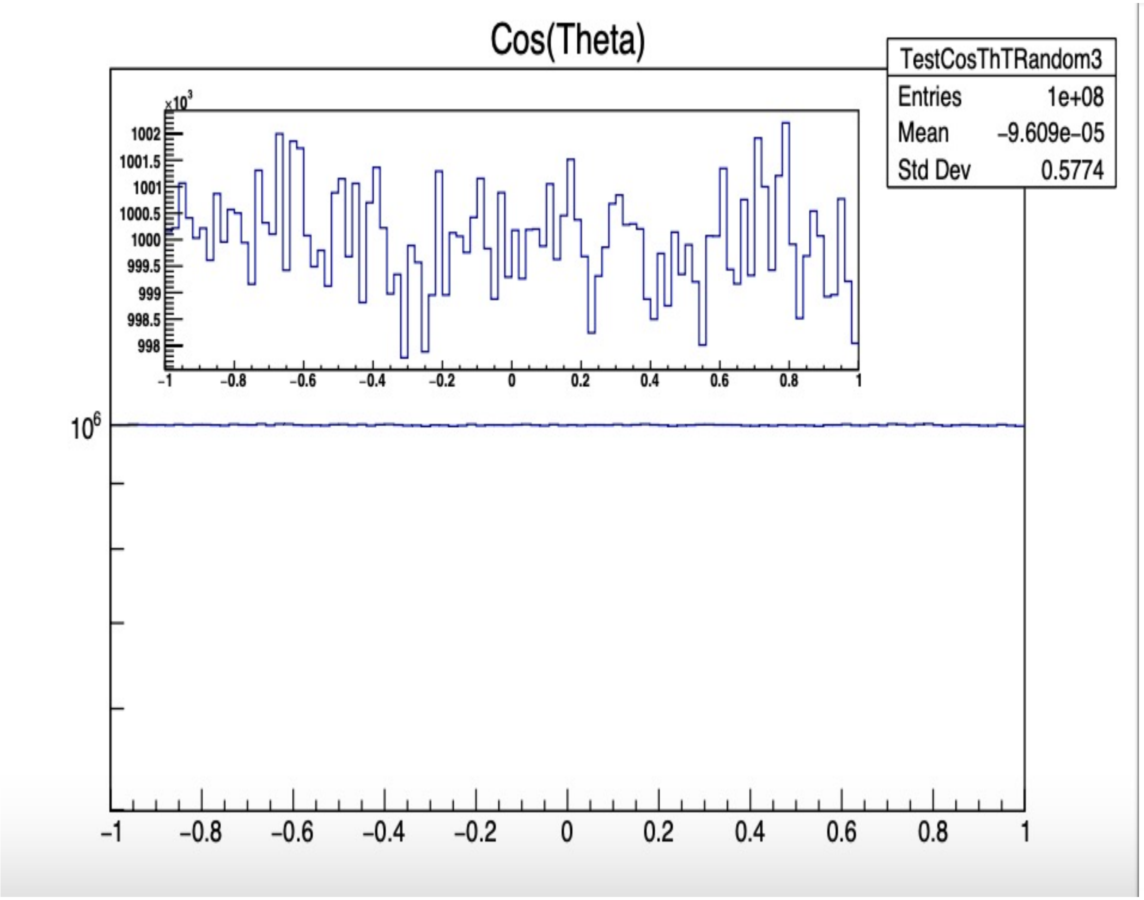
and the testing results of angular distribution

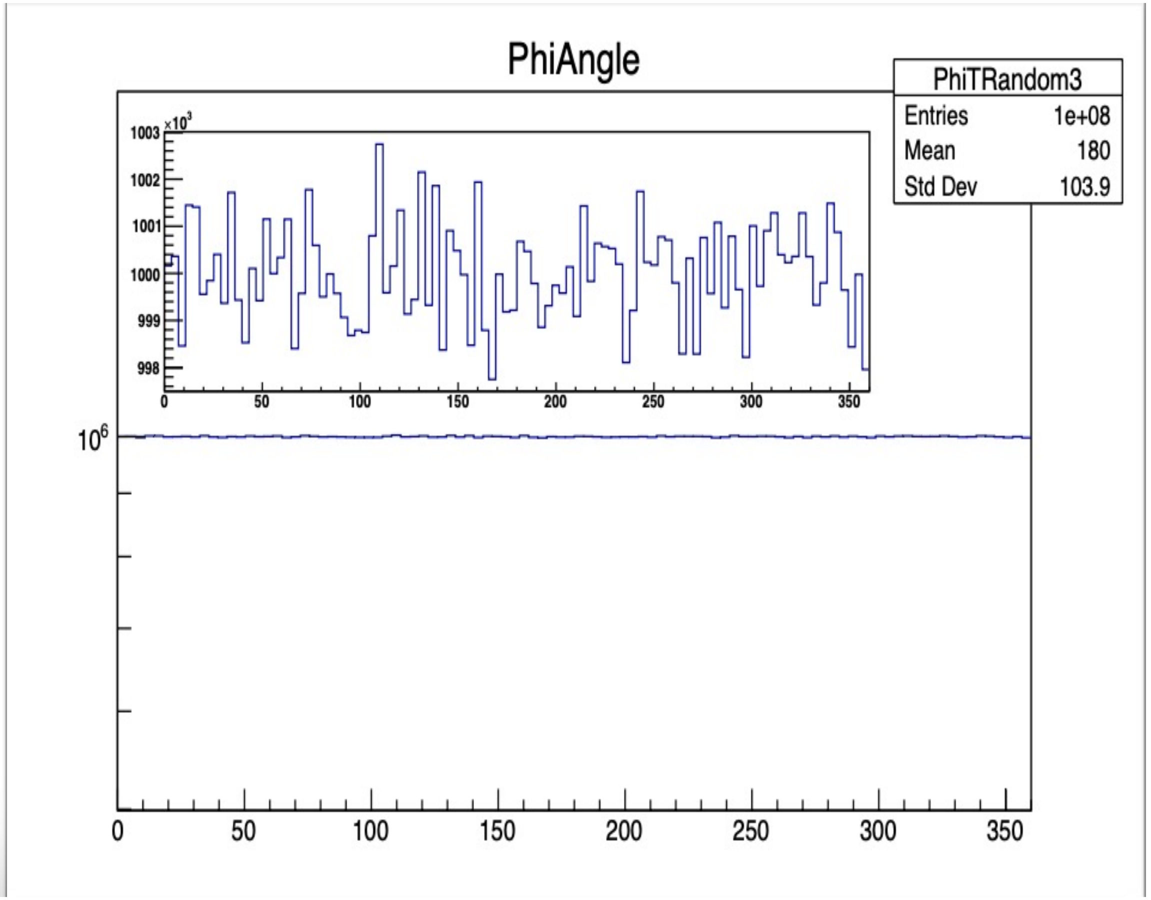


External event generator in ROOT tree format

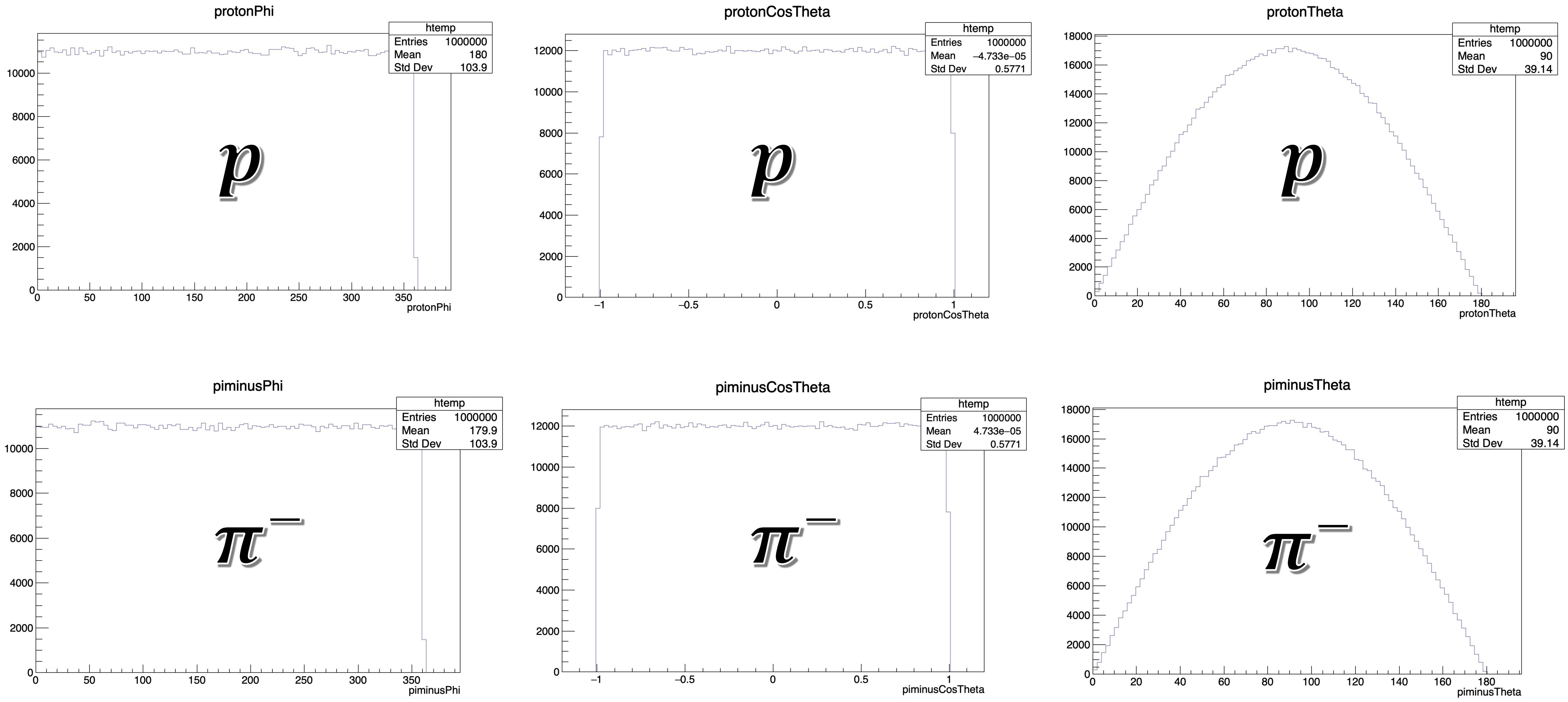
To p.6

Test for uniform distribution



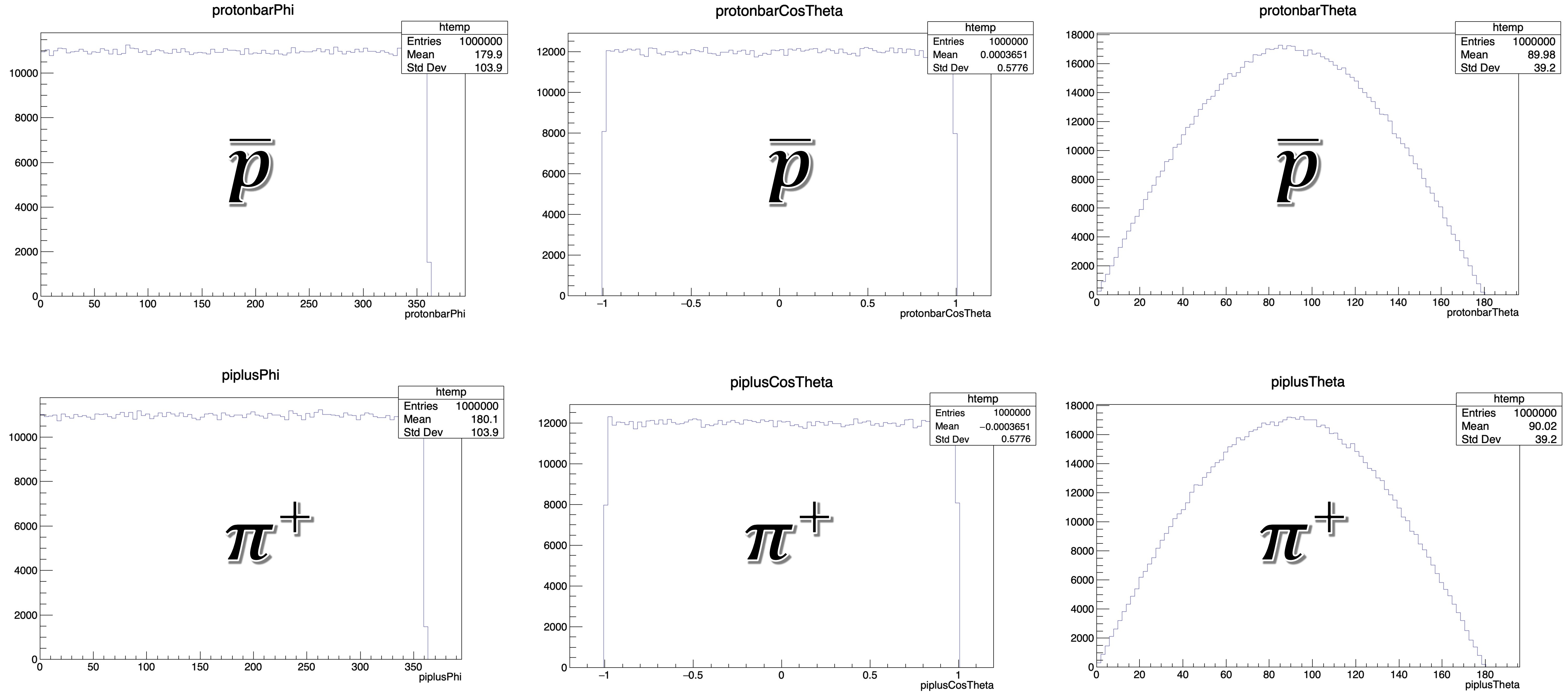


Λ rest frame

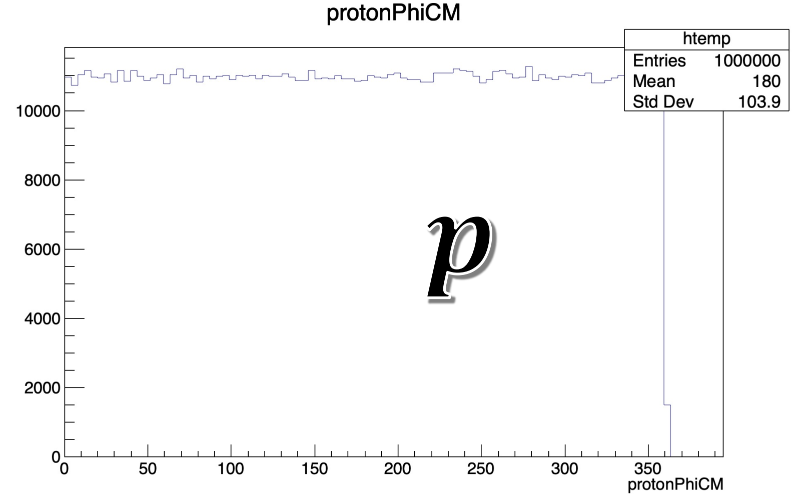


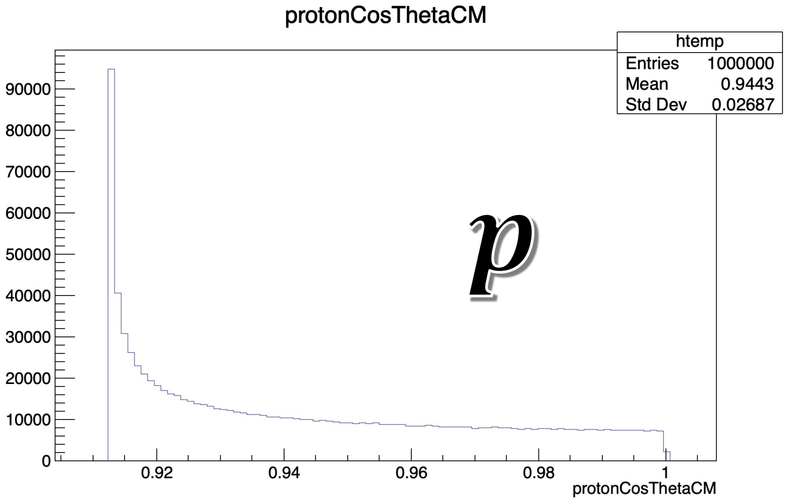
To p.7

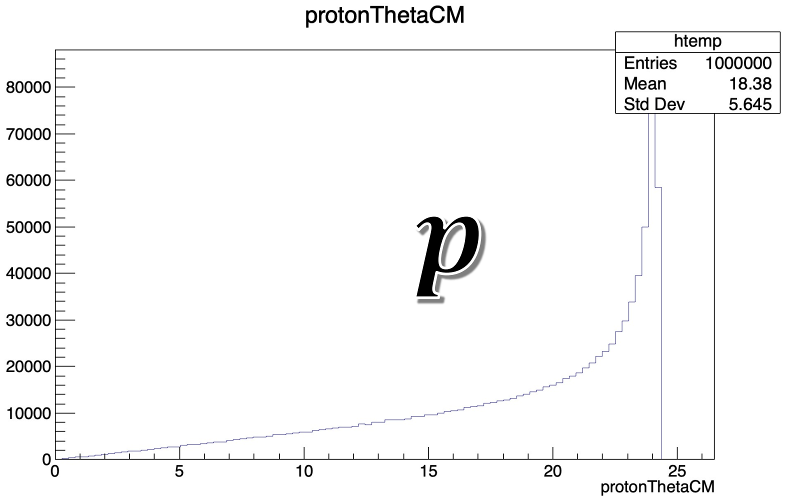
$\bar{\Lambda}$ rest frame

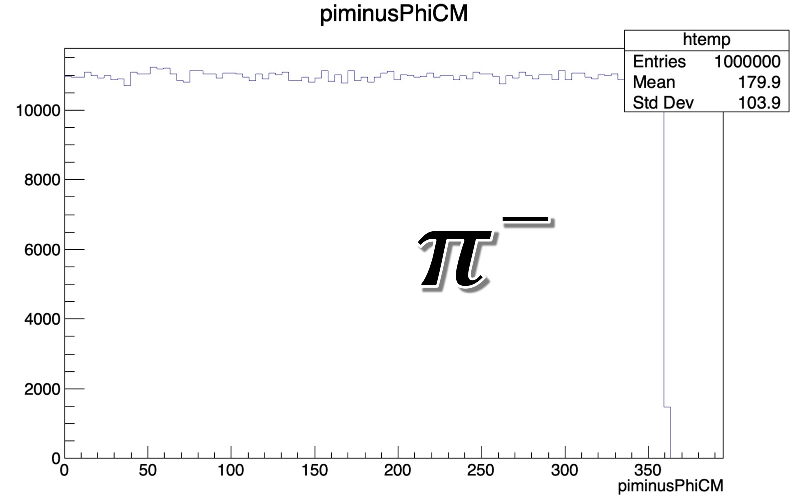


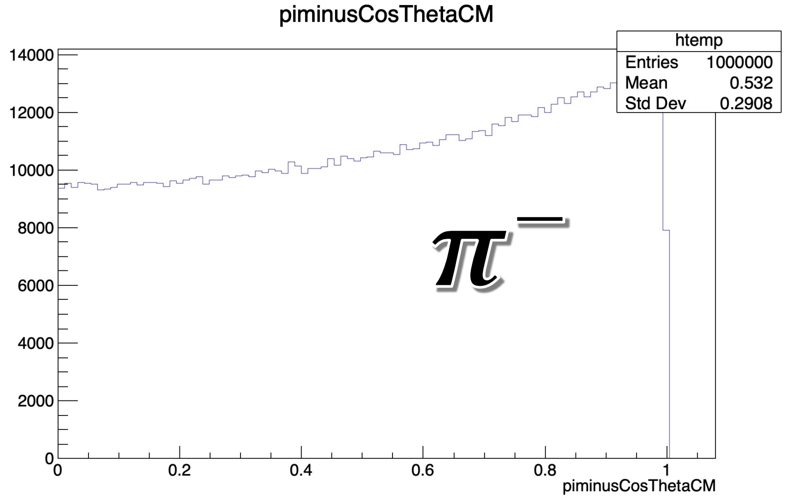
$\bar{p}p$ CM frame

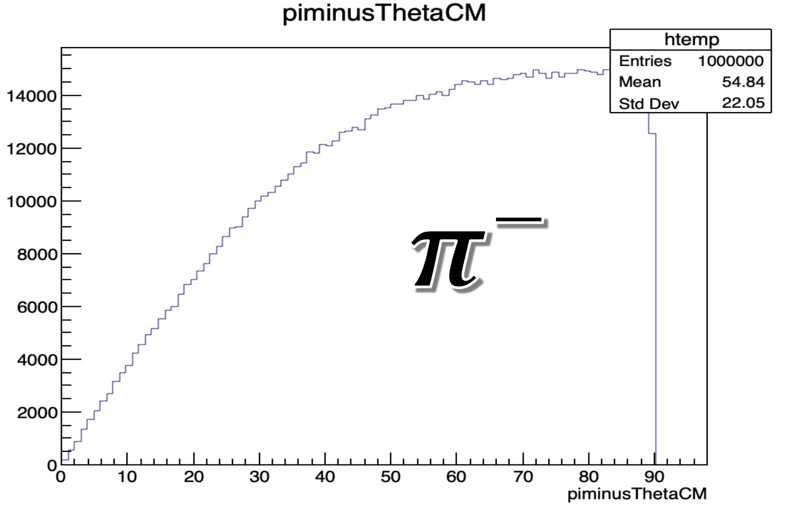






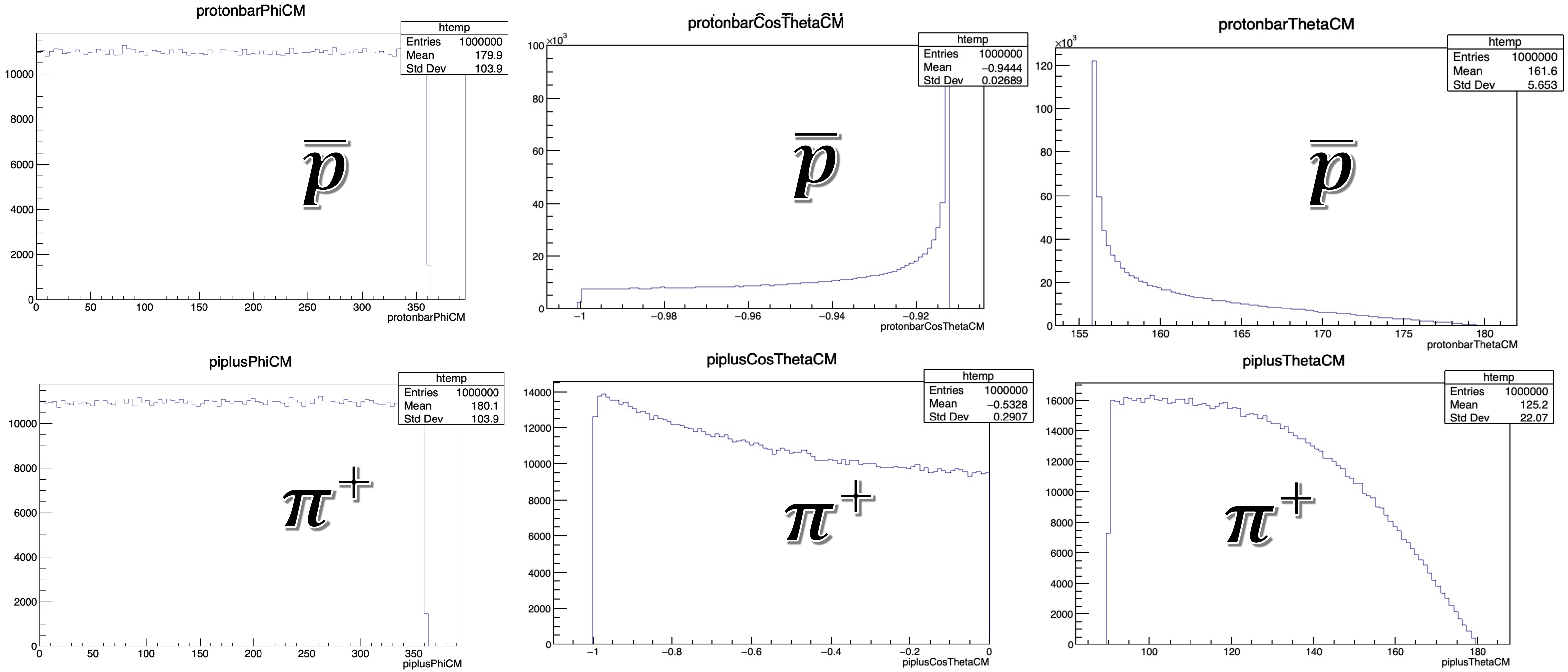




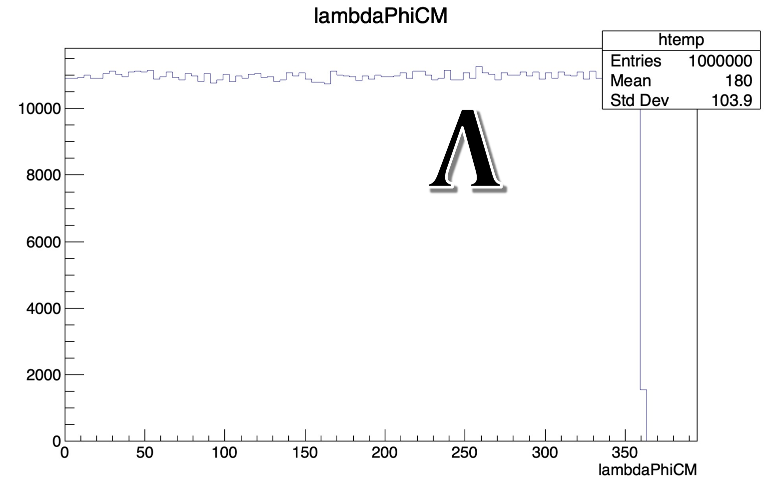


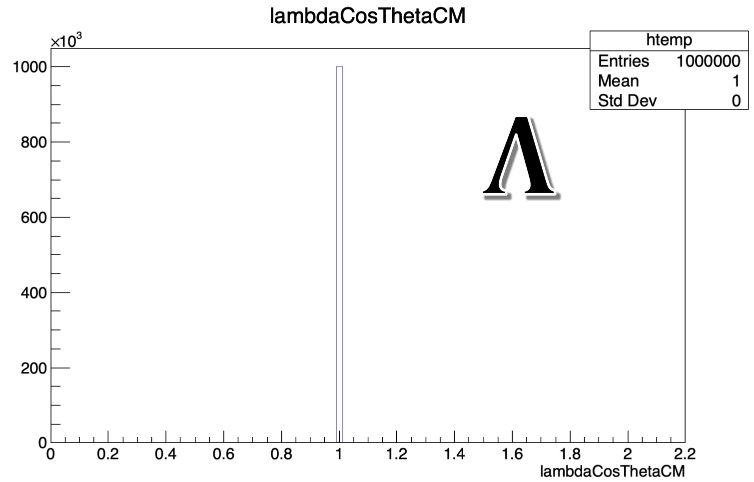
To p.7

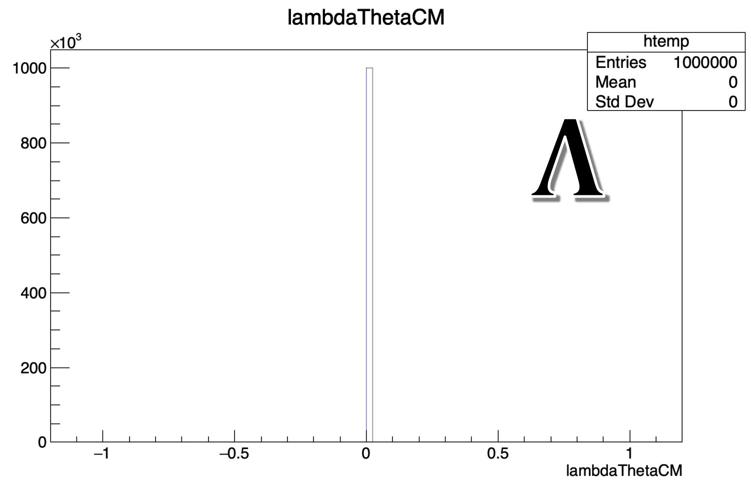
$\bar{p}p$ CM frame

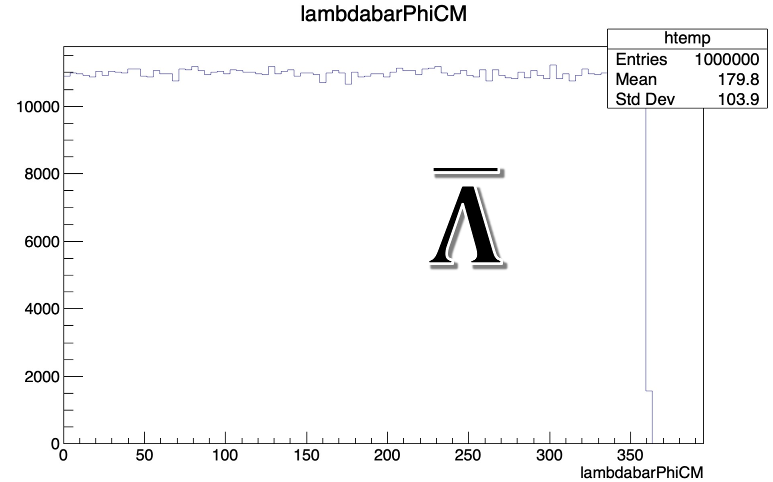


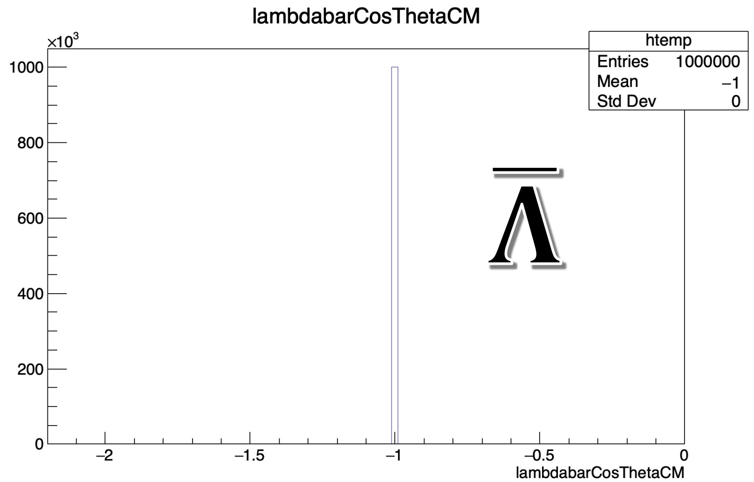
$\bar{p}p$ CM frame

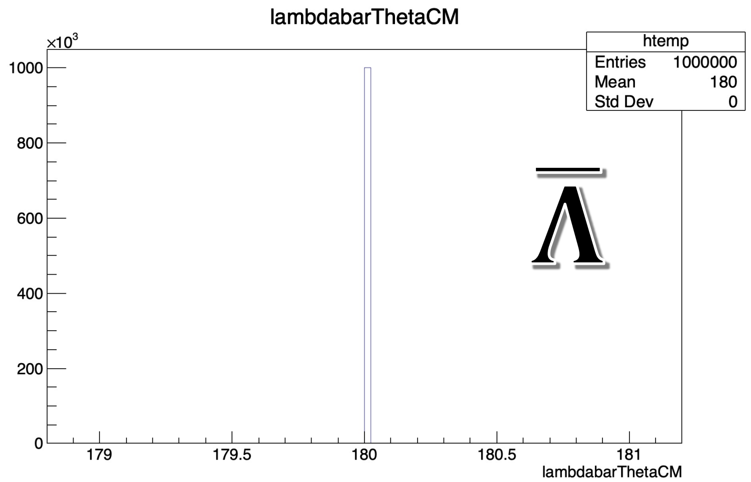






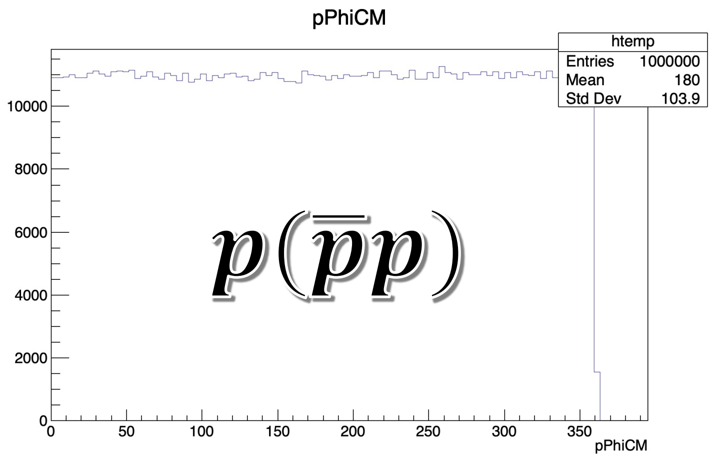


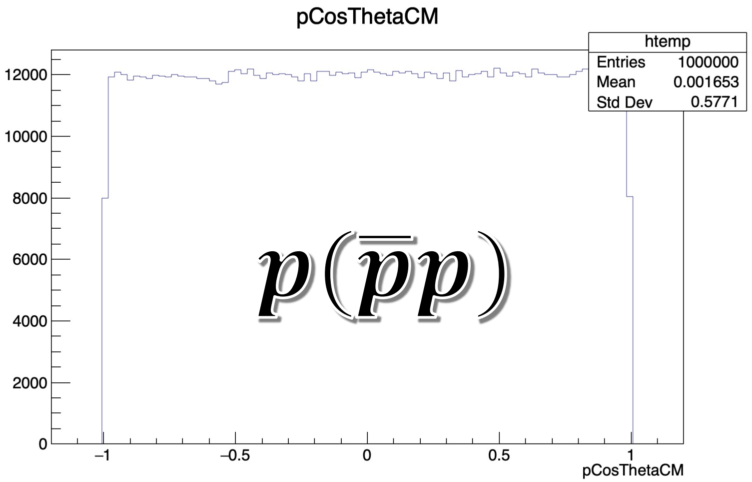


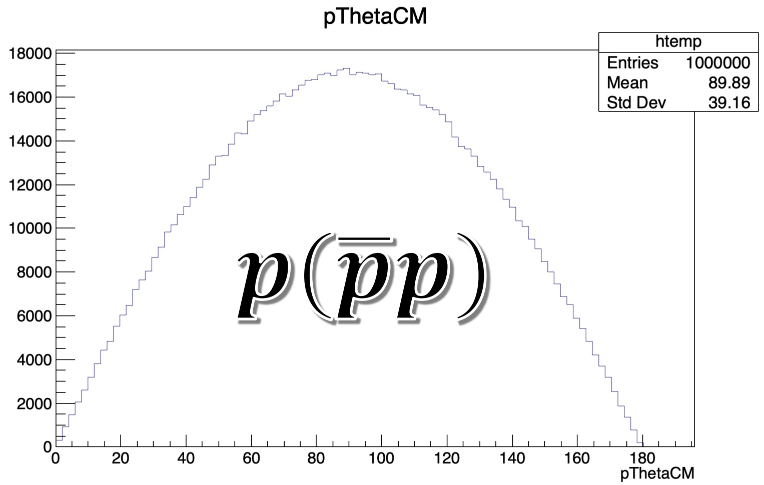


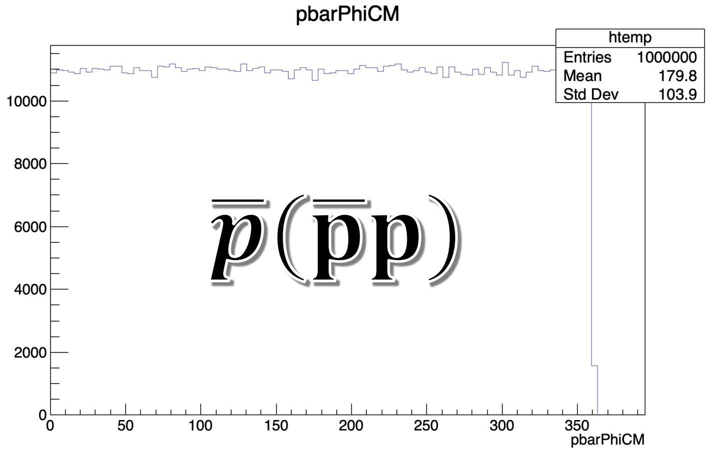
To p.7

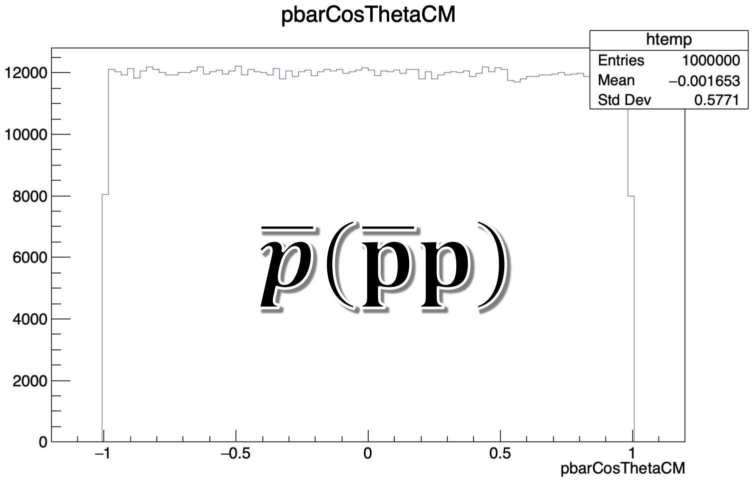
$\bar{p}p$ CM frame

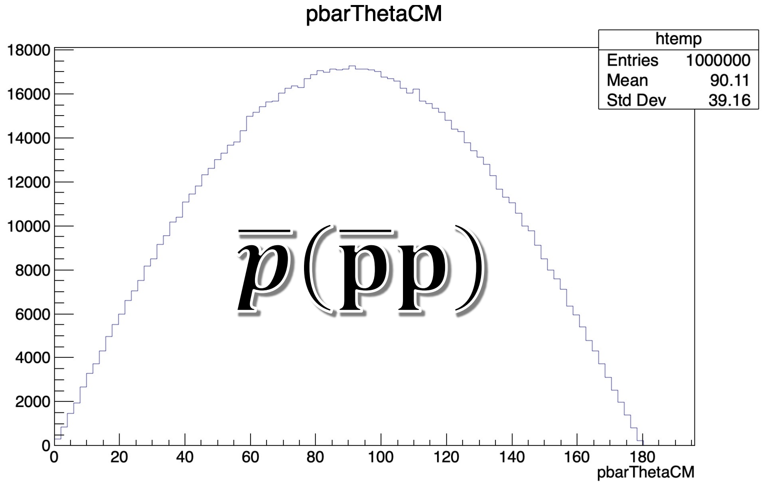






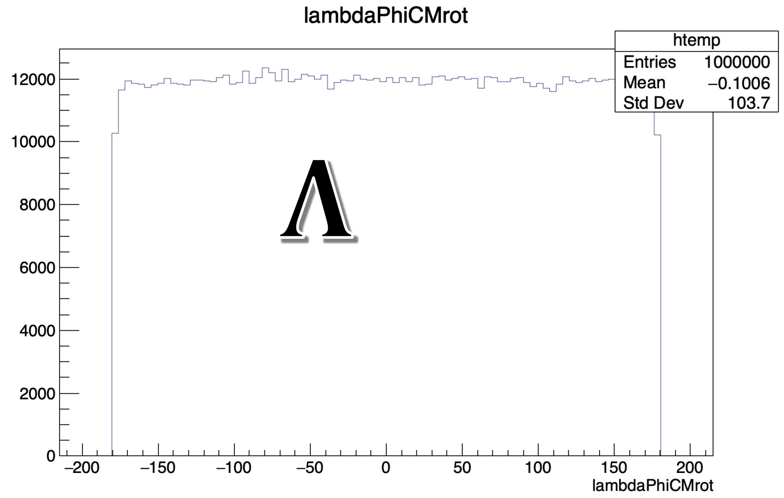


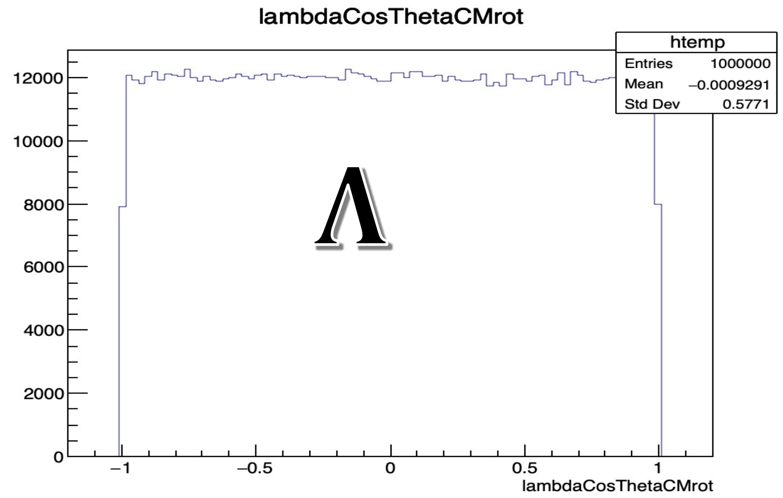


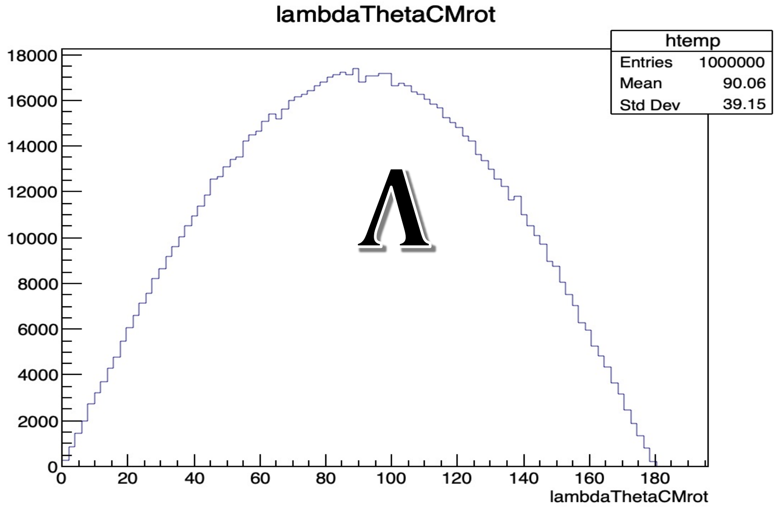


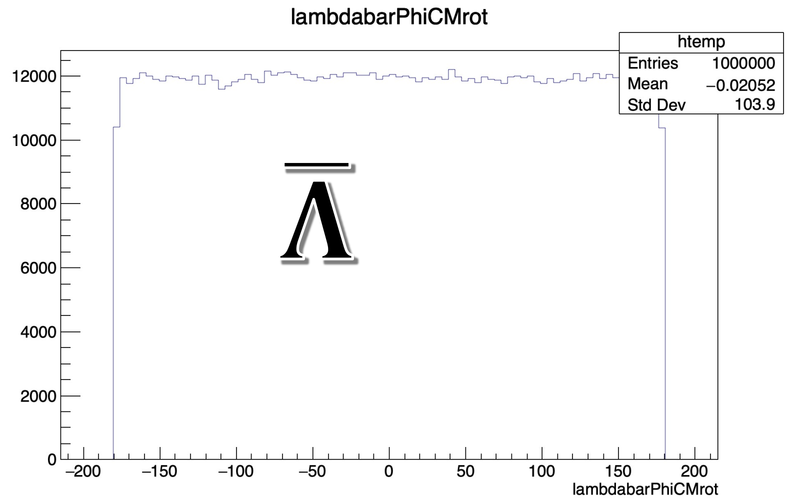
To p.7

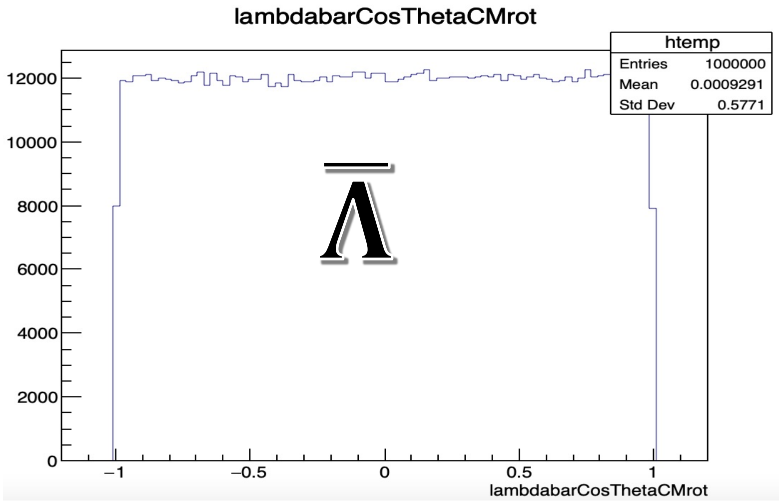
$\bar{p}p$ CM frame (Rotation)

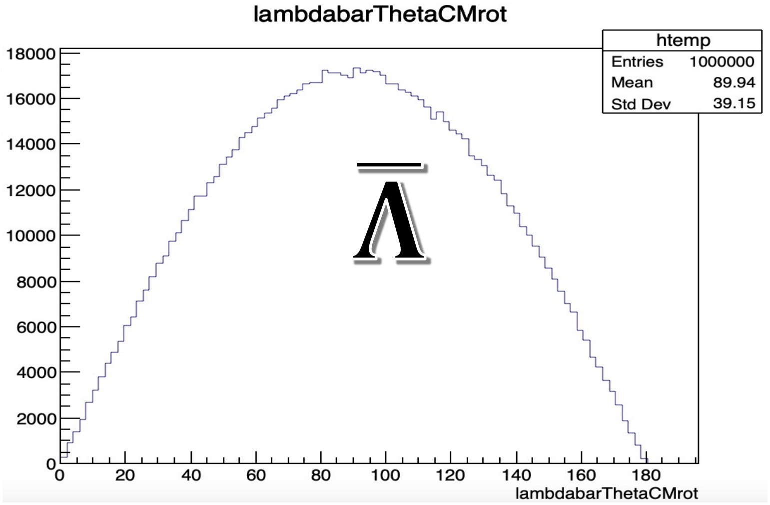




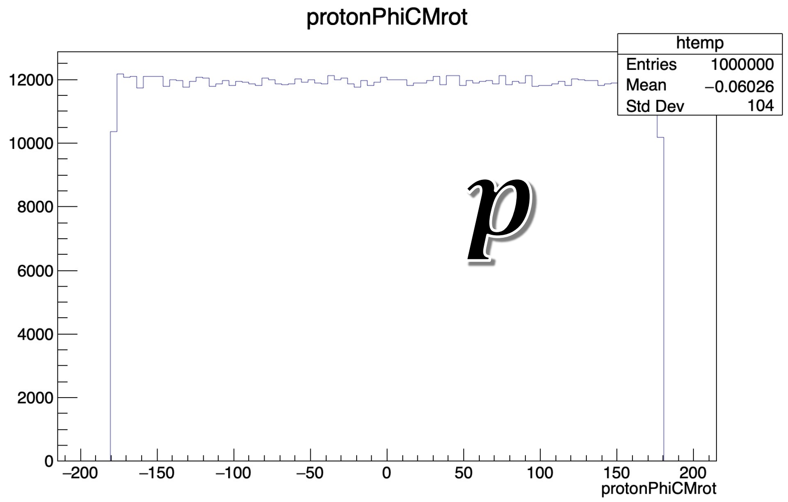


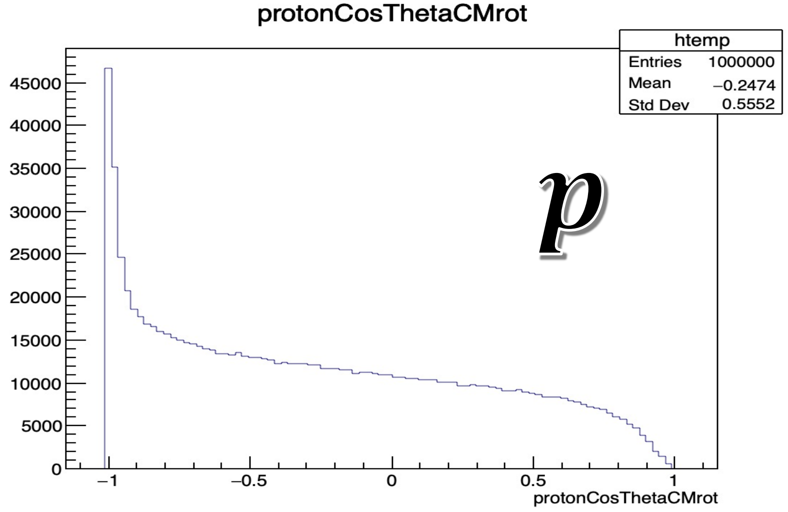


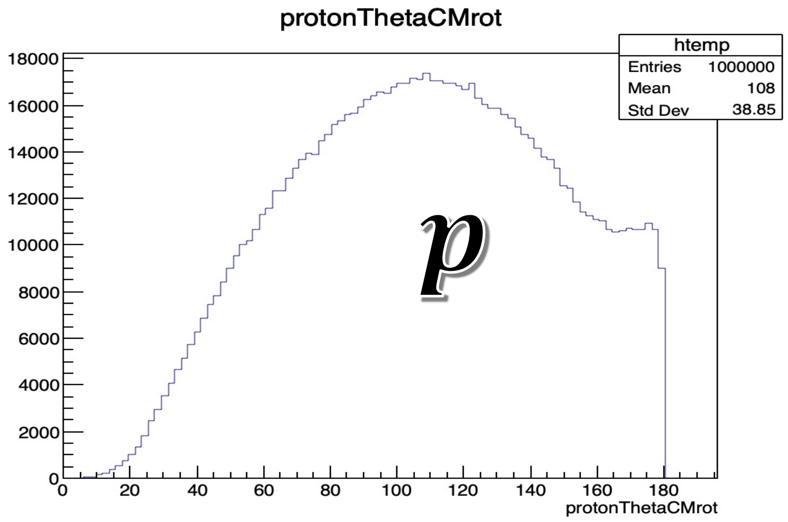


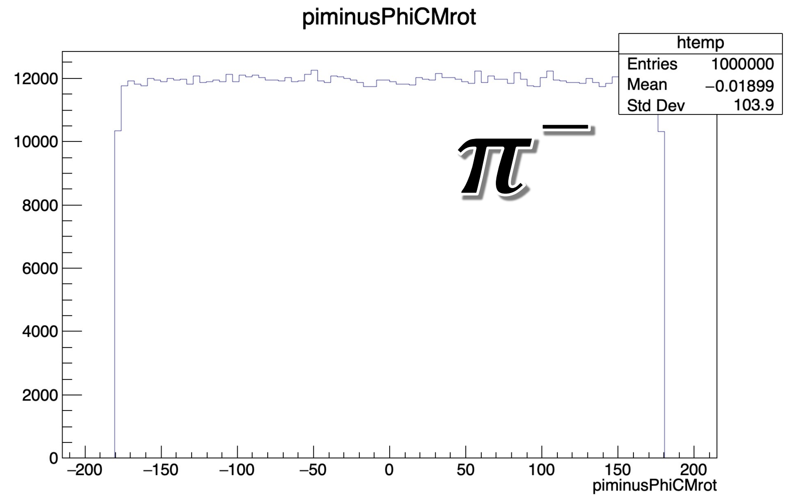


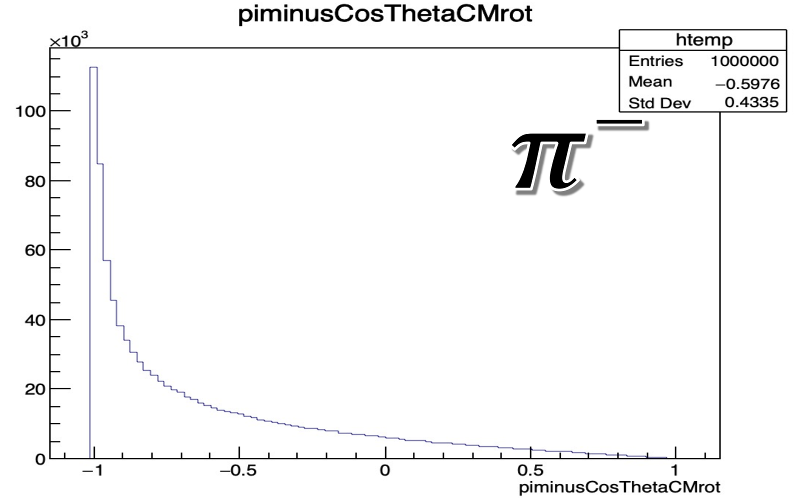
$\bar{p}p$ CM frame (Rotation)

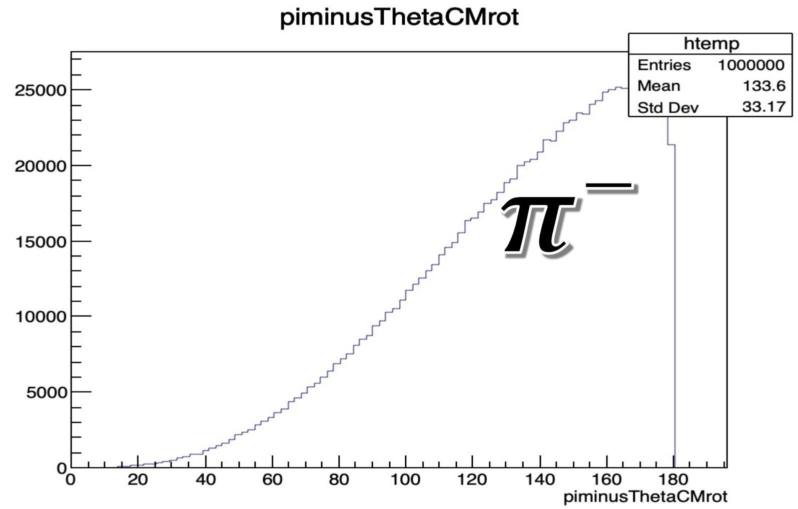






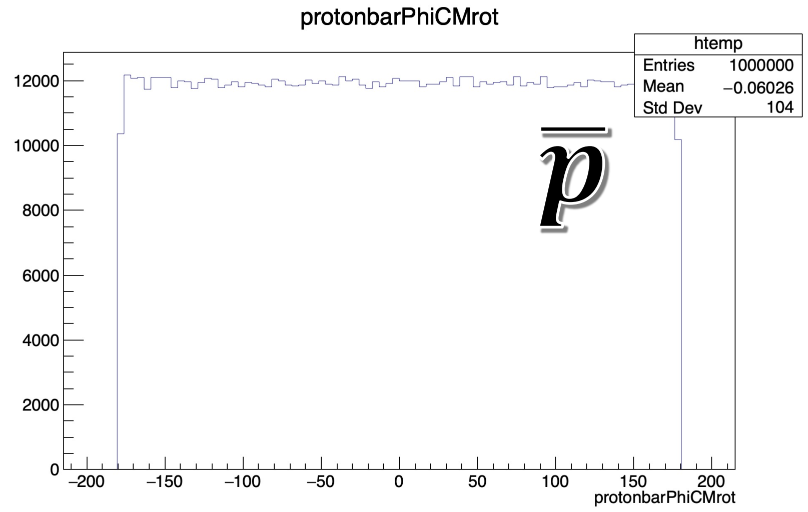


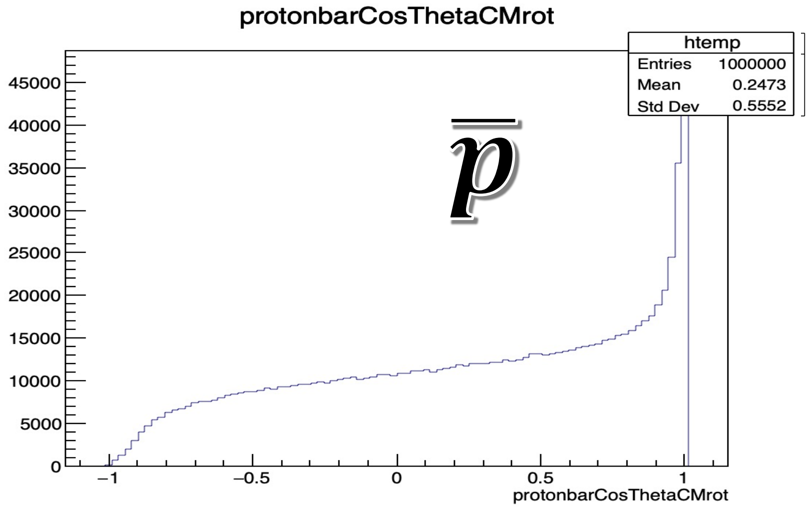


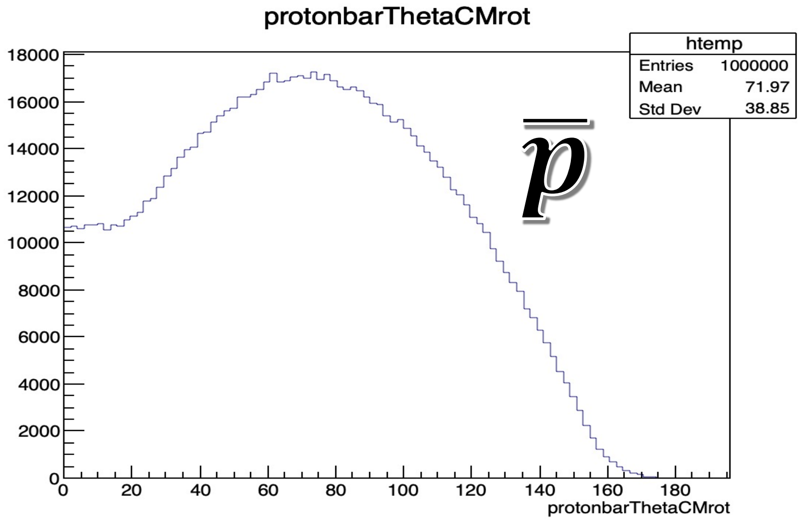


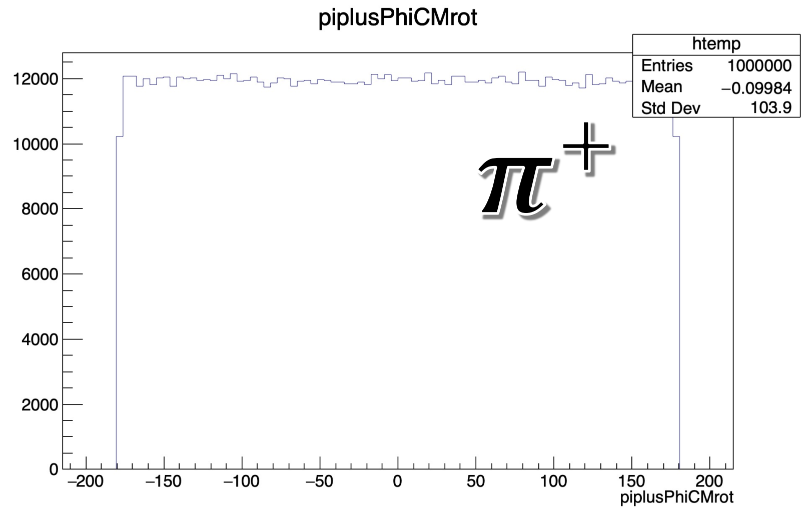
To p.7

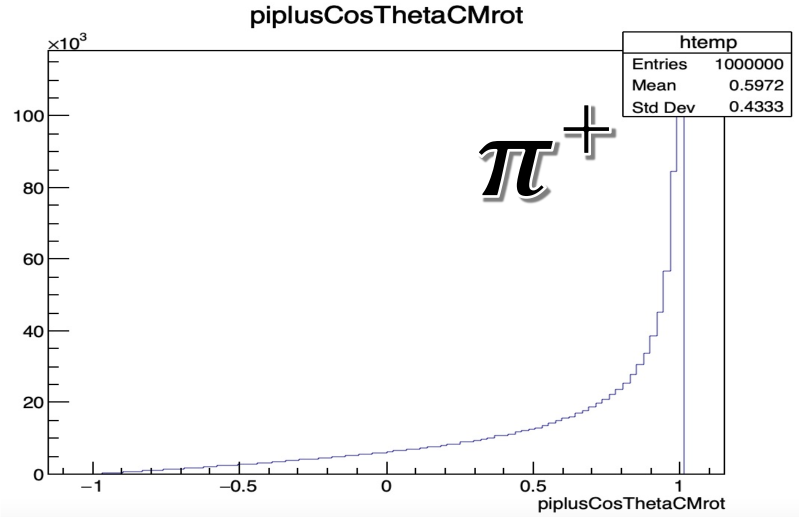
$\bar{p}p$ CM frame (Rotation)

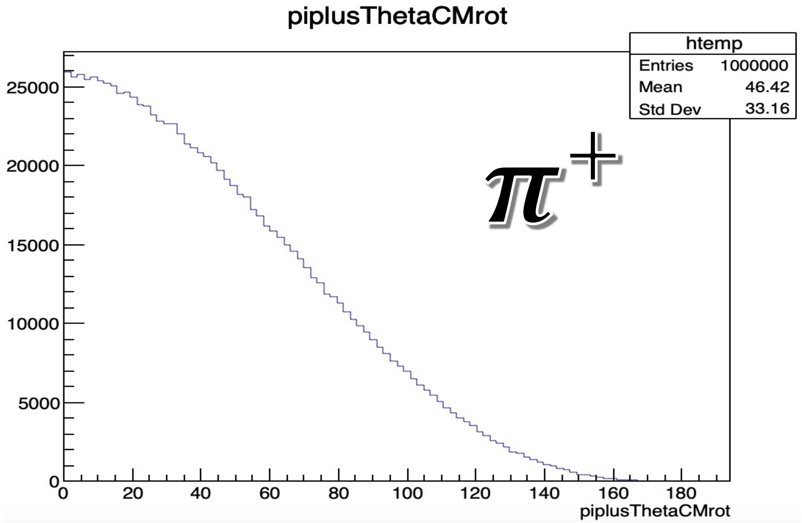




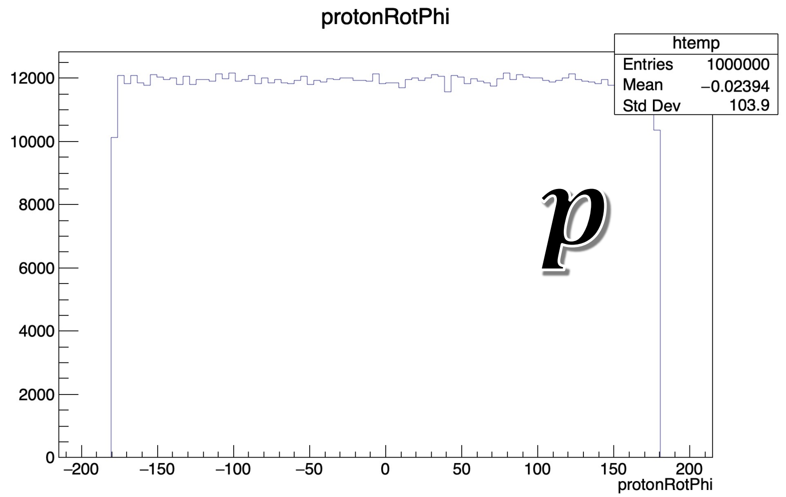


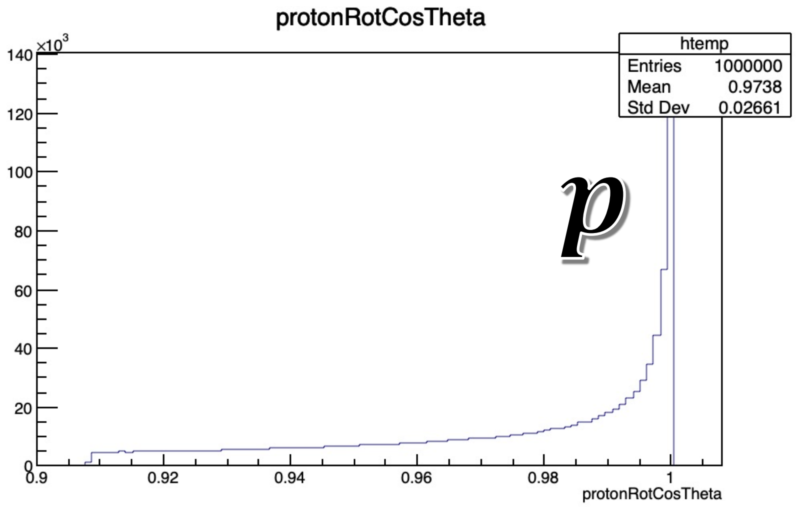


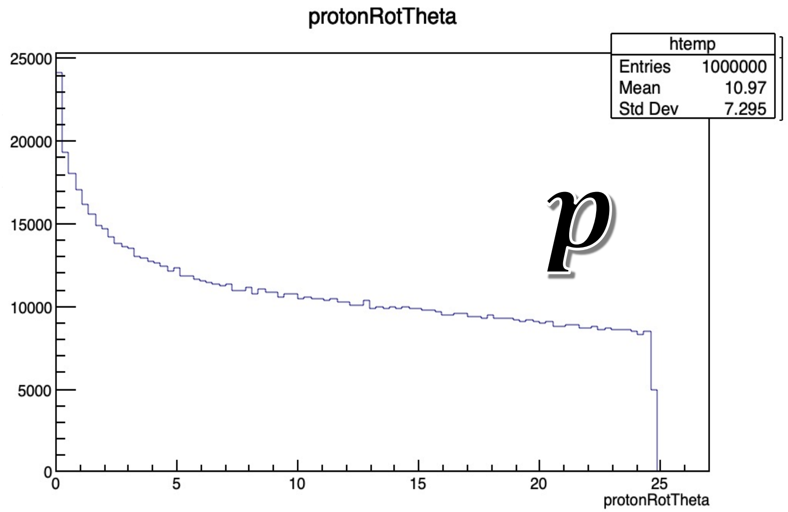


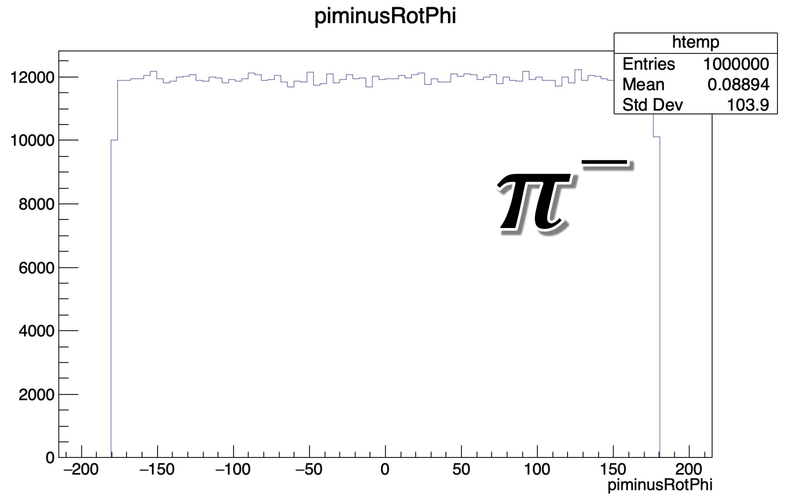


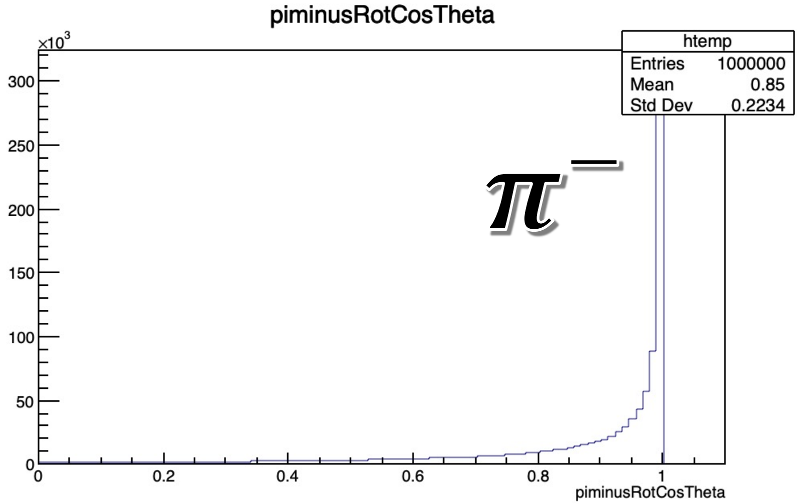
Λ rest frame (Rotation)

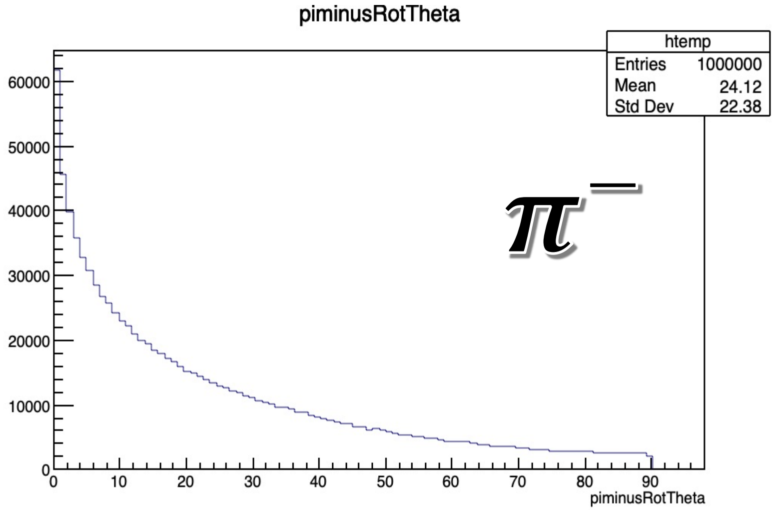






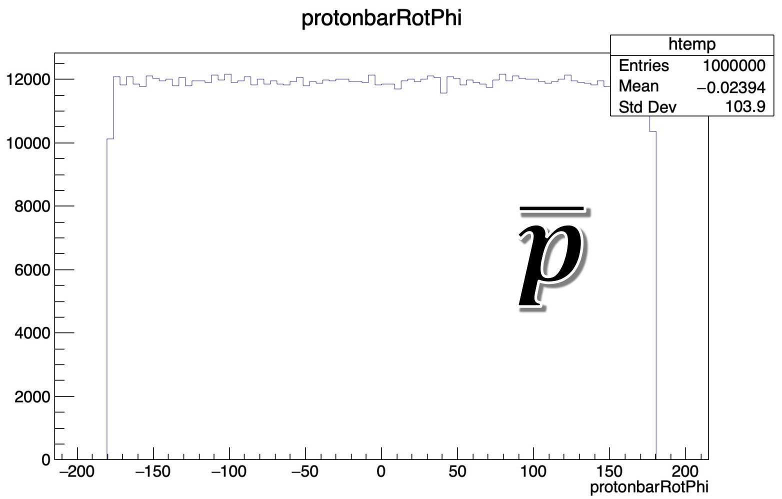


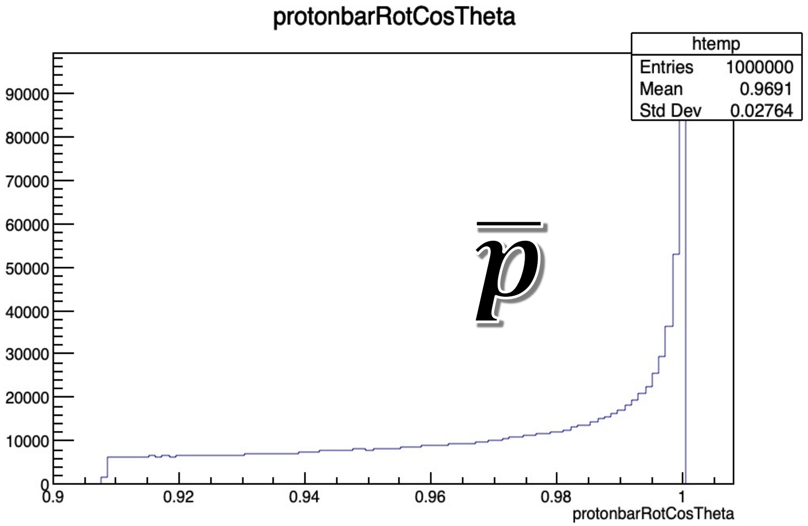


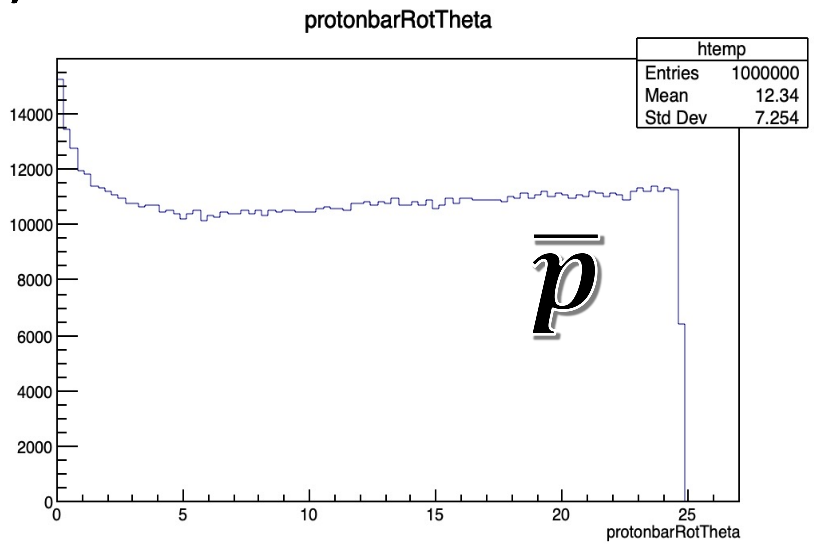


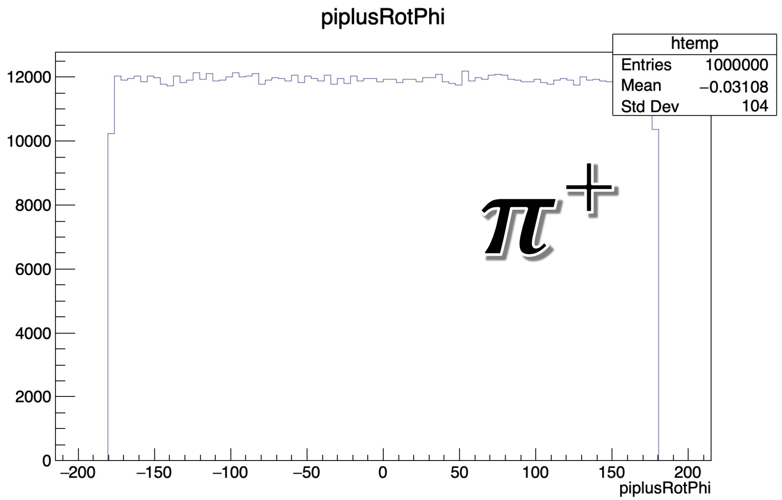
To p.7

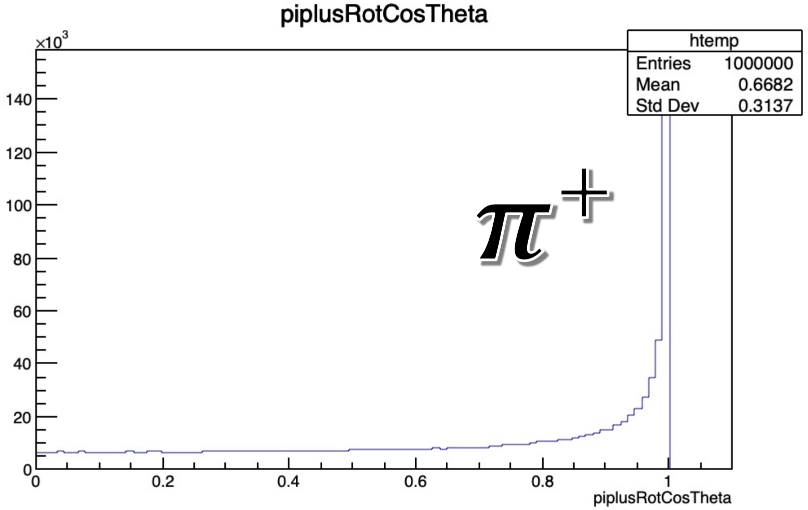
$\bar{\Lambda}$ rest frame (Rotation)

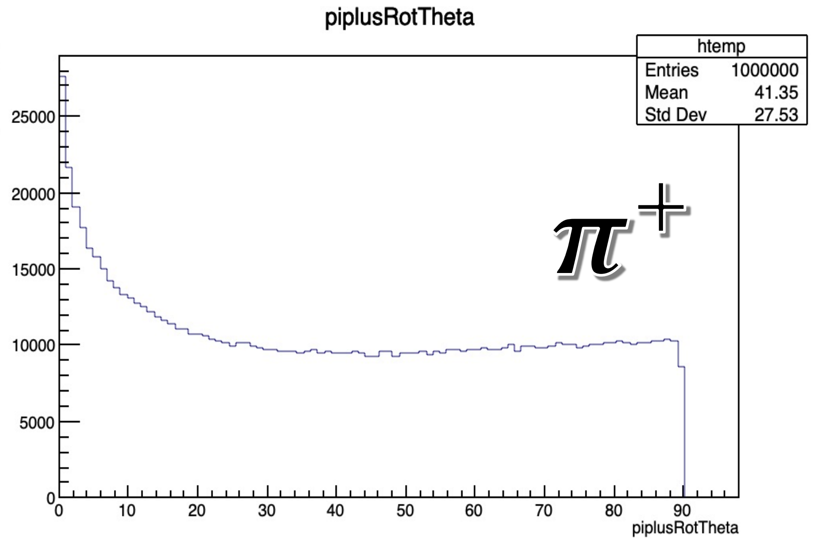












Conclusion & Outlook

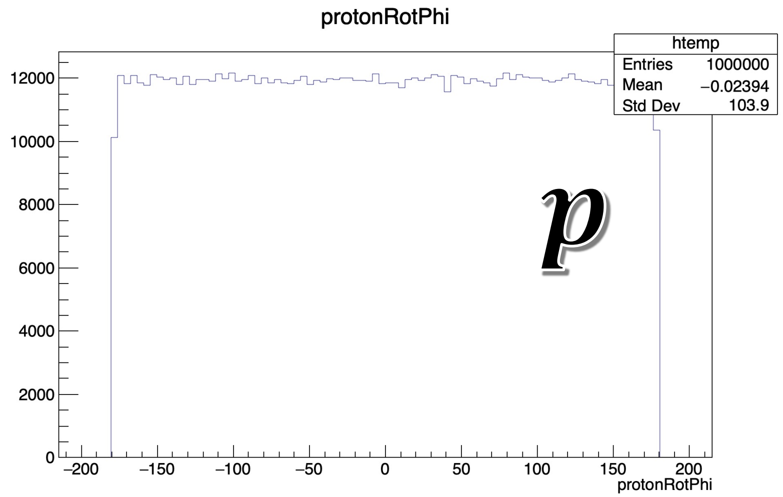
- External Monte-Carlo Event Generator
  - $\bar{Y}Y$ pair production in $\bar{p}p$ annihilation
  - $\bar{p} + p \rightarrow \bar{\Lambda} + \Lambda \rightarrow p^{-}\pi^{+} + p\pi^{-}$
  - Kinematics relations of 4-vectors
  - Angular distribution

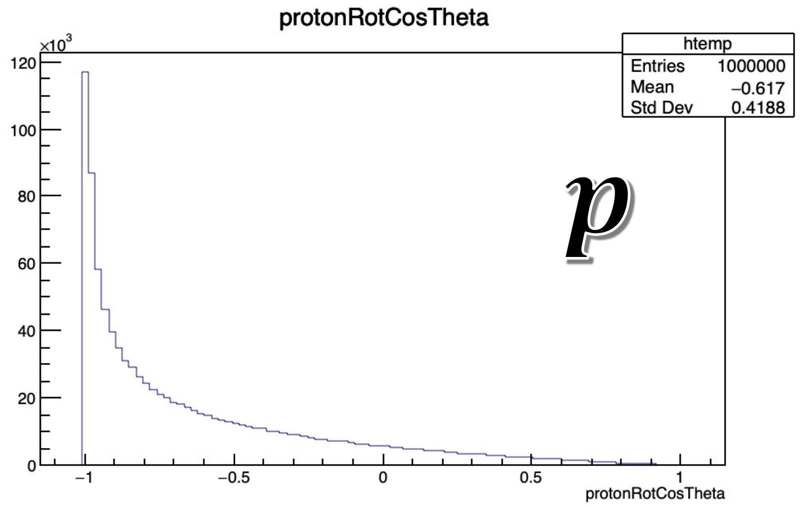
- Future development outlook
  - Implementation the testing of new models or formalisms about polarisation and spin-observables studies in the external MC event generator

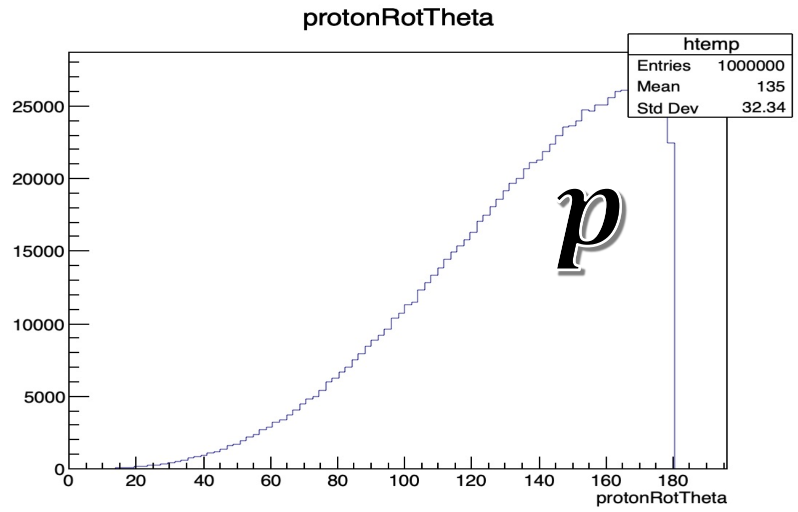
Appendix

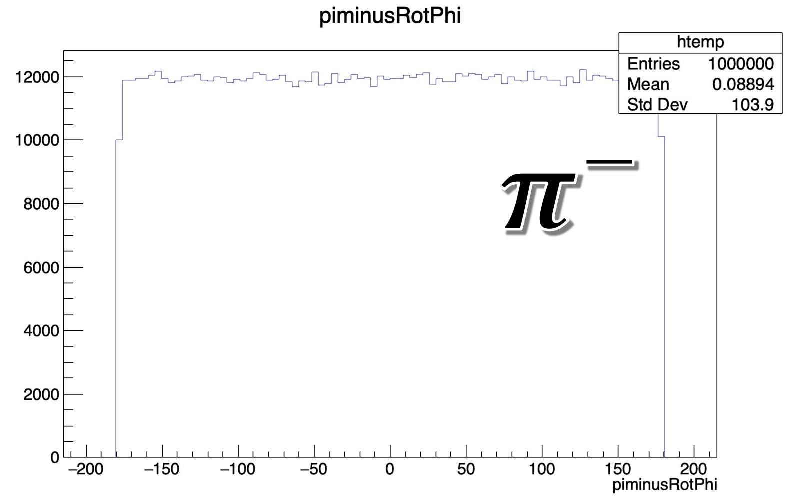
Previous version

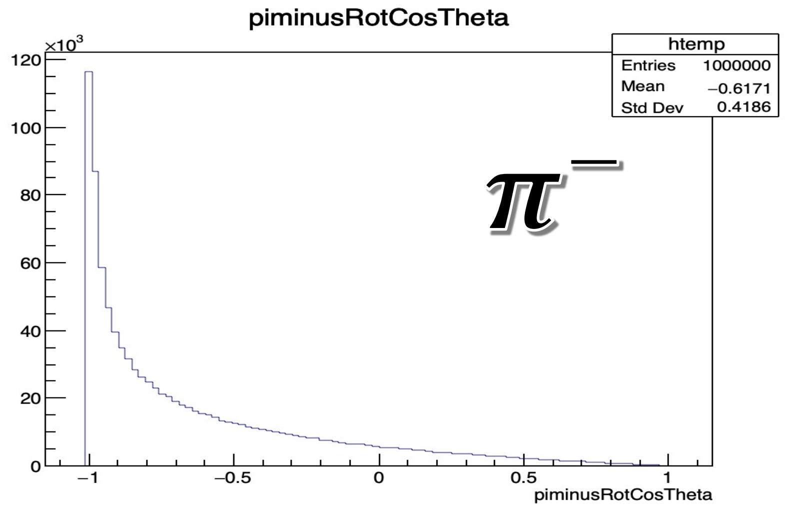
Λ rest frame (Rotation)

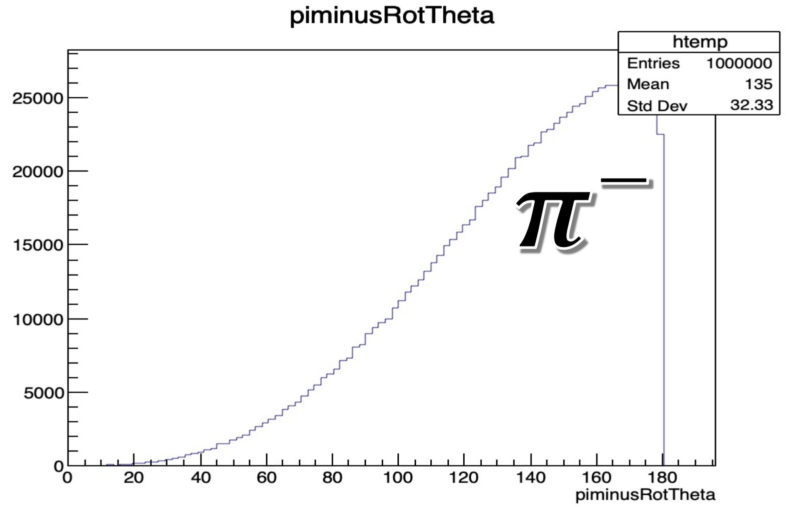






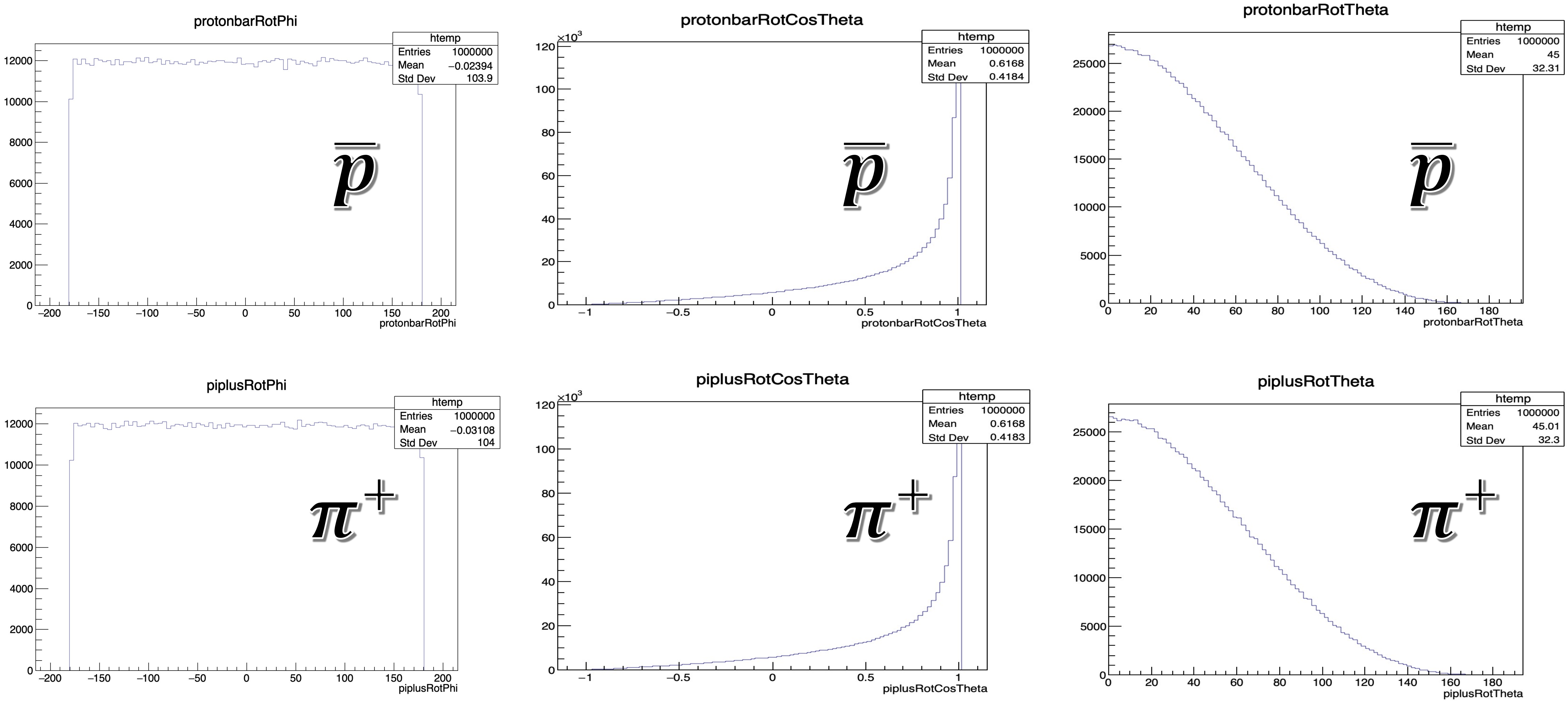






Previous version

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



4-vector

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

$$\begin{pmatrix} E_A \\ p_{A_x} \\ p_{A_y} \\ p_{A_z} \end{pmatrix} + \begin{pmatrix} E_B \\ p_{B_x} \\ p_{B_y} \\ p_{B_z} \end{pmatrix} = \begin{pmatrix} E_C \\ p_{C_x} \\ p_{C_y} \\ p_{C_z} \end{pmatrix} + \begin{pmatrix} E_D \\ p_{D_x} \\ p_{D_y} \\ p_{D_z} \end{pmatrix}$$

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

and the mass

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

The energy of the daughter particels 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

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

The momentum form $|\boldsymbol{p_1}| = \sqrt{E_1^2 - m_1^2}$ and obtains

$$|\boldsymbol{p_1}| = \frac{\sqrt{(M^2 + m_1^2 - m_2^2)^2 - 4M^2 m_1^2}}{2M} = \frac{\sqrt{(M^2 - m_1^2 - m_2^2)^2 - 4m_1^2 m_2^2}}{2M}$$

$$\begin{cases} p^*_{p_x} = p^*_p sin\theta^* \\ p^*_{p_z} = p^*_p cos\theta^* \end{cases}$$

Similarly we have

$$\begin{cases} p^*_{\pi^-_x} = -p^*_{p_x} \\ p^*_{\pi^-_z} = -p^*_{p_z} \end{cases}$$

While the energy of them can also be found

$$\begin{cases} E^*_p = \frac{m^2_\Lambda + m^2_p - m^2_\pi}{2m_\Lambda} \\ E^*_\pi = m_\Lambda - E^*_p \end{cases}$$

Considering

$$E_\Lambda = \sqrt{p^2_\Lambda + m^2_\Lambda}$$

Also the γ factor and velocity

$$\gamma_\Lambda = \frac{E_\Lambda}{m_\Lambda}$$
$$v_\Lambda = \frac{p_\Lambda}{E_\Lambda}$$

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

$$\begin{cases} p_{p_x} = p^*_{p_x} \\ p_{p_z} = \gamma_\Lambda(p^*_{p_x} + v_\Lambda E^*_p) \\ tan\theta_p = \frac{p_{px}}{p_{pz}} \end{cases}$$

and simlarily 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

$$\begin{cases} x = rcos\varphi sin\theta \\ y = rsin\varphi sin\theta \\ z = rcos\theta \end{cases}$$

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^2)	Decay
Λ	uds	7.89	2.632×10^{-10}	1.116	$p\pi^-$ (63.9%) $n\pi^0$ (35.8%)
Σ^+	uus	2.404	8.018×10^{-11}	1.189	$p\pi^0$ (51.57%) $n\pi^+$ (48.31%)
Σ^0	uds	2.22×10^{-9}	7.4×10^{-20}	1.193	$\Lambda\gamma$ (100%)
Σ^-	dds	4.434	1.479×10^{-10}	1.197	$n\pi^-$ (99.848%)
Ξ^0	uss	8.71	2.0×10^{-10}	1.315	$\Lambda\pi^0$ (99.524%)
Ξ^-	dss	4.91	1.639×10^{-10}	1.322	$\Lambda\pi^-$ (99.887%)
Ω^-	sss	2.461	8.21×10^{-11}	1.672	ΛK^- (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].

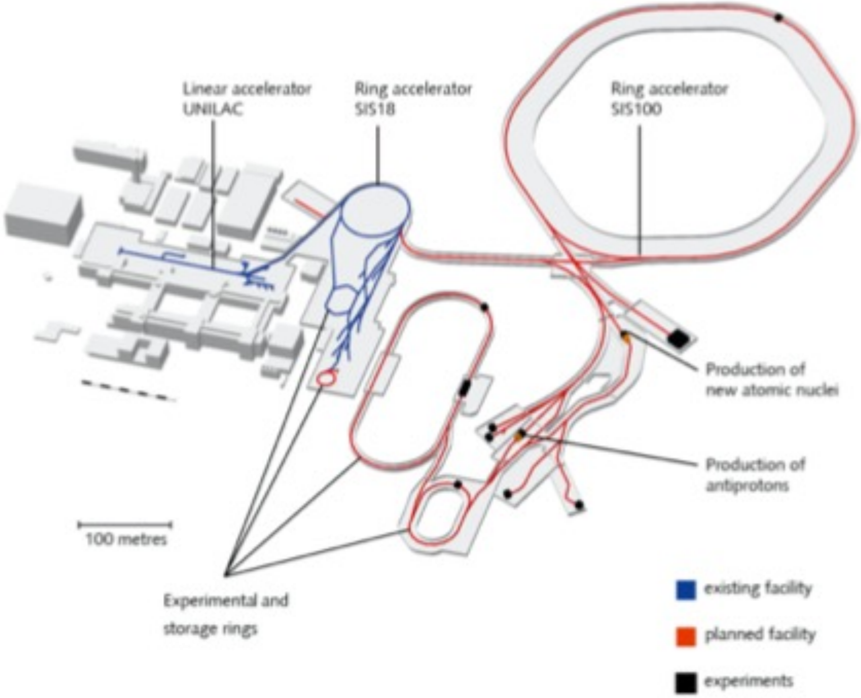


Figure 1.1: The Accelerator Facility of FAIR [2]

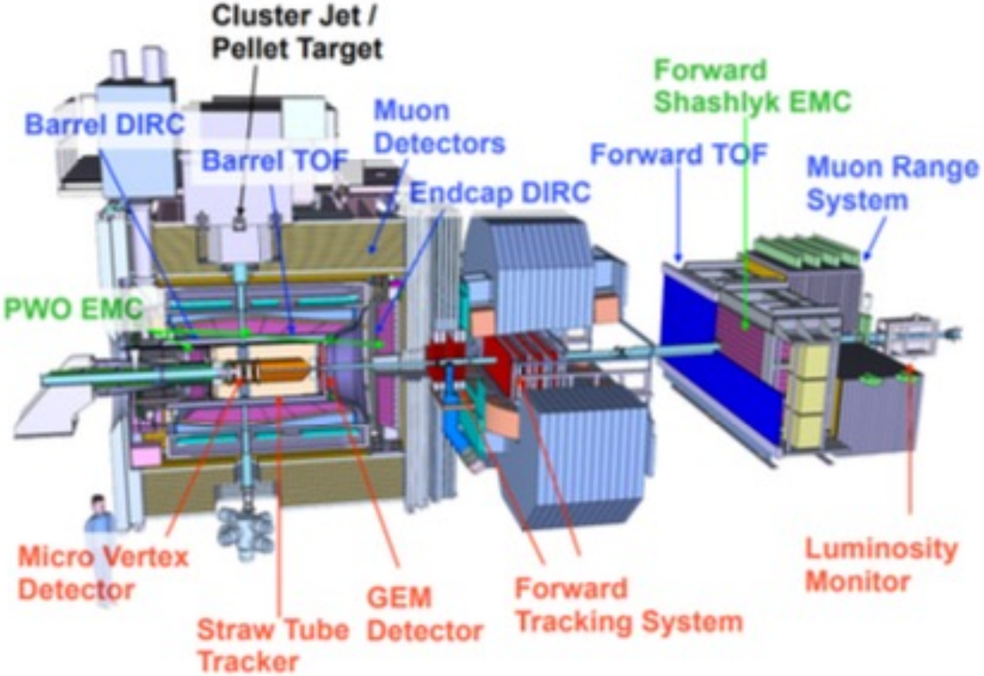


Figure 1.2: The Detector of PANDA [1]