BEAM ASYMMETRY Σ FOR:

$\gamma\, p \rightarrow \eta\, p$ $\gamma\, p \rightarrow \eta'\, p$

WORK IN PROGRESS

η/η' DECAYING INTO:

$\eta \rightarrow 2\gamma$ $\eta' \rightarrow 2\gamma$

$\eta \rightarrow 3\pi^0 \rightarrow 6\gamma$ $\eta' \rightarrow \pi^0\pi^0\eta \rightarrow 6\gamma$

$\eta \rightarrow \pi^+ \pi^- \pi^0$ $\eta' \rightarrow \pi^+ \pi^- \eta$

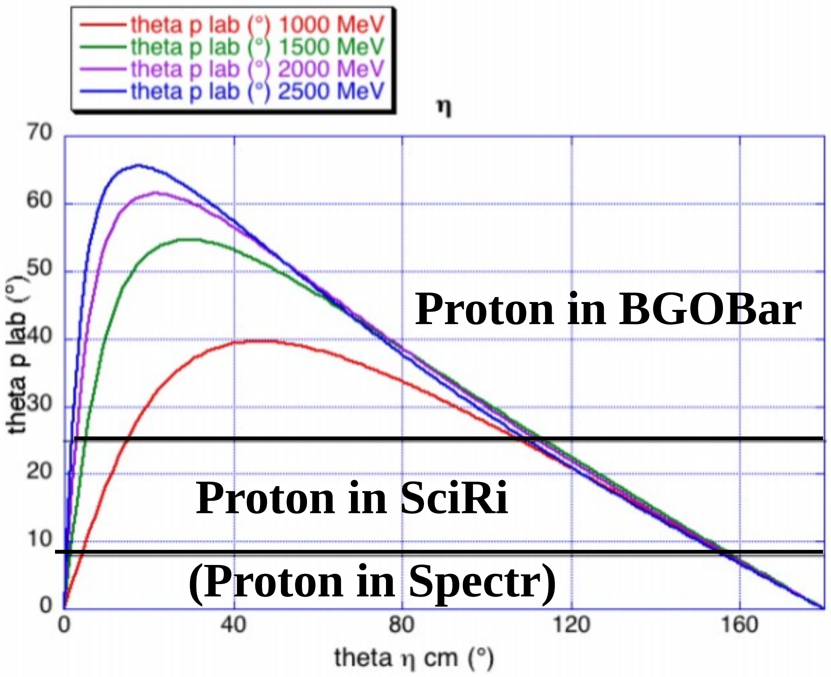
Conception of a new technique for the simultaneous analysis of:
- several data taking periods
- several meson decay channels
with different efficiencies
(also different polarization degrees)

Particle identification also in BGO-Barrel required for the analysis of charged multi-pion final states
$\rightarrow$ barrel calibration
$\rightarrow$ proton/pion discrimination (dE/dx vs. Ene_{BGO})

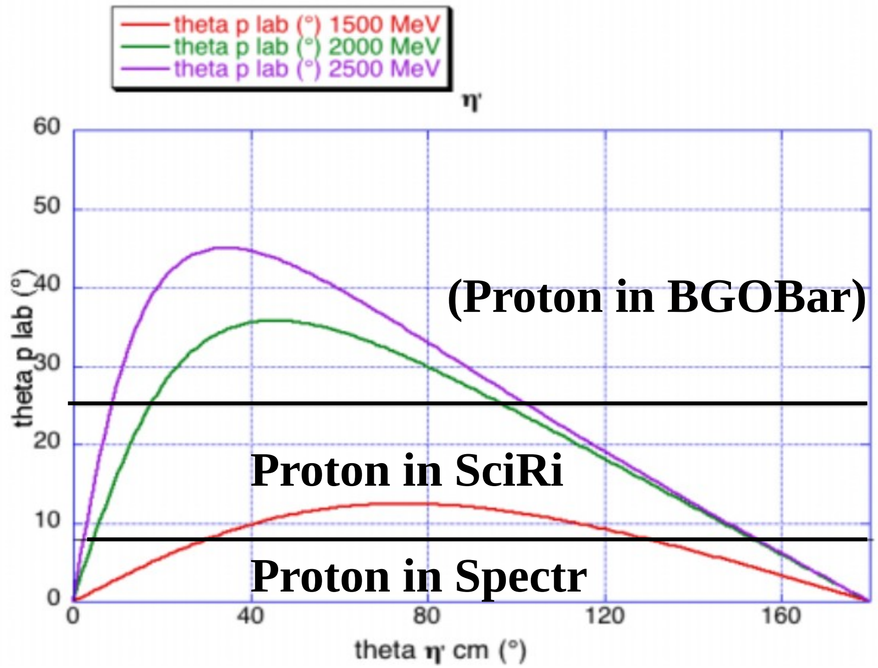
Kinematical reconstruction technique based on energy and momentum conservation

Extraction of the polarization degree of new data taking periods

η KINEMATICS



η' KINEMATICS



Central proton → BGOBar
Interm proton → SciRi
(Forward proton → Spectr)

Interm proton → SciRi
Forward proton → Spectr

TWO OR MORE DATA TAKING PERIODS *Pi* WITH DIFFERENT POLARIZATION DEGREES AND EFFICIENCIES Ex. *P1* AND *P2* WITH

$$P^{P1}_{Pol\pm} \neq P^{P2}_{Pol\pm} \quad \text{AND} \quad \varepsilon^{P1} \neq \varepsilon^{P2}$$

IDEAL SOLUTION

- Extract the asymmetry from each single period

- Make the weighted average of the results

BUT

if the statistics of each period is not enough

=> Another strategy:

- Sum up the statistics of each period IN A PROPER WAY (see after)

- Extract the asymmetry

ONE DATA TAKING PERIOD *P* WITH:
$\boldsymbol{P^P_{Pol+} = P^P_{Pol-} = P^P}$

$$N^P_{Pol\pm} = F^P_{Pol+}\left(\frac{d\sigma}{d\Omega}\right)_{UNP}\varepsilon^P(\varphi)\,N_{SC}\left(1 \pm P^P\Sigma\cdot\cos(2\varphi)\right) \qquad (1a)$$

where: P = period

$$N^P_{UNP,norm} = \frac{N^P_{Pol+}}{F^P_{Pol+}} + \frac{N^P_{Pol-}}{F^P_{Pol-}} \propto 2\varepsilon(\varphi) \qquad (1b)$$

$$\frac{\dfrac{N^P_{Pol+}}{F^P_{Pol+}}}{\dfrac{N^P_{Pol+}}{F^P_{Pol+}} + \dfrac{N^P_{Pol-}}{F^P_{Pol-}}} = \frac{\cancel{\left(\frac{d\sigma}{d\Omega}\right)_{UNP}}\,\cancel{\varepsilon^P}(\varphi)\,\cancel{N_{SC}}\left(1 + P^P\Sigma\cdot\cos(2\varphi)\right)}{\cancel{\left(\frac{d\sigma}{d\Omega}\right)_{UNP}}\,\cancel{\varepsilon^P}(\varphi)\,\cancel{N_{SC}}\,2}$$

NUMERATOR

DENOMINATOR

$$\boxed{\frac{\dfrac{N^P_{Pol+}}{F^P_{Pol+}}}{N^P_{UNP,norm}} = \frac{1}{2}\left(1 + P^P\Sigma\cdot\cos(2\varphi)\right)} \qquad (2)$$

ONE DATA TAKING PERIOD *P* WITH:
$P^{P}_{Pol+} \neq P^{P}_{Pol-}$

NUMERATOR → $\dfrac{N^{P}_{Pol+}}{F^{P}_{Pol+}}$

where: P = period

DENOMINATOR → $$N^{P}_{UNP,norm} = \frac{2}{P^{P}_{Pol+} + P^{P}_{Pol-}} \left(P^{P}_{Pol-} \frac{N^{P}_{Pol+}}{F^{P}_{Pol+}} + P^{P}_{Pol+} \frac{N^{P}_{Pol-}}{F^{P}_{Pol-}} \right) \qquad (3)$$

which has no dependence on cos(2φ). It only depends on φ through the efficiency ε:

$$N^{P}_{UNP,norm} \propto 2\,\varepsilon^{P}(\varphi) \qquad (4)$$

NUMERATOR →

DENOMINATOR →

$$\boxed{\frac{\dfrac{N^{P}_{Pol+}}{F^{P}_{Pol+}}}{N^{P}_{UNP,norm}} = \frac{1}{2}\left(1 + P^{P}_{Pol+}\,\Sigma \cdot \cos(2\varphi)\right)} \qquad (5)$$

TWO (OR MORE) DATA TAKING PERIODS *Pi* WITH DIFFERENT POLARIZATION DEGREES AND EFFICIENCIES Ex. *P1* AND *P2* WITH $P^{P1}_{Pol\pm} \neq P^{P2}_{Pol\pm}$ AND $\varepsilon^{P1} \neq \varepsilon^{P2}$

NUMERATOR →

$$\frac{N^{P1}_{Pol+}}{F^{P1}_{Pol+}}+\frac{N^{P2}_{Pol+}}{F^{P2}_{Pol+}} \qquad (6)$$

The (6) has the following behaviour in the azimuthal angle:

$$\frac{N^{P1}_{Pol+}}{F^{P1}_{Pol+}}+\frac{N^{P2}_{Pol+}}{F^{P2}_{Pol+}} \propto [\varepsilon^{P1}(\varphi)+\varepsilon^{P2}(\varphi)]\left[1+P^{W}_{Pol+}\Sigma\cos(2\varphi)\right] \qquad (7)$$

$$P^{W}_{Pol+}=\frac{\varepsilon^{P1}P^{P1}_{Pol+}+\varepsilon^{P2}P^{P2}_{Pol+}}{\varepsilon^{P1}+\varepsilon^{P2}} \qquad (8)$$

DENOMINATOR →

$$N^{P1}_{UNP,norm}+N^{P2}_{UNP,norm} \propto 2[\varepsilon^{P1}(\varphi)+\varepsilon^{P2}(\varphi)] \qquad (9)$$

where: $$N^{Pi}_{UNP,norm}=\frac{2}{P^{Pi}_{Pol+}+P^{Pi}_{Pol-}}\left(P^{Pi}_{Pol-}\frac{N^{Pi}_{Pol+}}{F^{Pi}_{Pol+}}+P^{Pi}_{Pol+}\frac{N^{Pi}_{Pol-}}{F^{Pi}_{Pol-}}\right)$$

$$N^{Pi}_{UNP,norm} \propto 2\varepsilon^{Pi}(\varphi)$$

where: *Pi = i-th period*

NUMERATOR

DENOMINATOR

$$\boxed{\frac{\dfrac{N^{P1}_{Pol+}}{F^{P1}_{Pol+}}+\dfrac{N^{P2}_{Pol+}}{F^{P2}_{Pol+}}}{\sum N^{Pi}_{UNP,norm}}=\frac{1}{2}\left(1+P^{W}_{Pol+}\,\Sigma\cos(2\varphi)\right)} \qquad (10)$$

$$P^{W}_{Pol+}=\frac{\varepsilon^{P1}P^{P1}_{Pol+}+\varepsilon^{P2}P^{P2}_{Pol+}}{\varepsilon^{P1}+\varepsilon^{P2}} \qquad (11)$$

Problem:

$P^{W}{}_{Pol+}$ depends on the azimuthal angle φ through the efficiencies

Solution:
We can show that this dependency is quite smooth

→ We can average $P^{W}{}_{Pol+}$ on all angles φ

The hypothesis is quite reasonable because:
1) we are simultaneously analysing several η decay channels which have different efficiencies (see after)
2) In the extraction of the weighted polarization only relative efficiencies are relevant

Followed procedure:

$$N^{Pi}_{UNP,norm}(E_\gamma,\theta^{C.M.}_\eta)=\frac{2}{P^{Pi}_{Pol+}+P^{Pi}_{Pol-}}\left(P^{Pi}_{Pol-}\frac{N^{Pi}_{Pol+}}{F^{Pi}_{Pol+}}+P^{Pi}_{Pol+}\frac{N^{Pi}_{Pol-}}{F^{Pi}_{Pol-}}\right)$$

$$N^{Pi}_{UNP,norm}(E_\gamma,\vartheta^{C.M.}_\eta)\propto\varepsilon^{Pi}(\varphi)$$

- in the formula

$$P^{W}_{Pol+}=\frac{\varepsilon^{P1}P^{P1}_{Pol+}+\varepsilon^{P2}P^{P2}_{Pol+}}{\varepsilon^{P1}+\varepsilon^{P2}} \qquad (11)$$

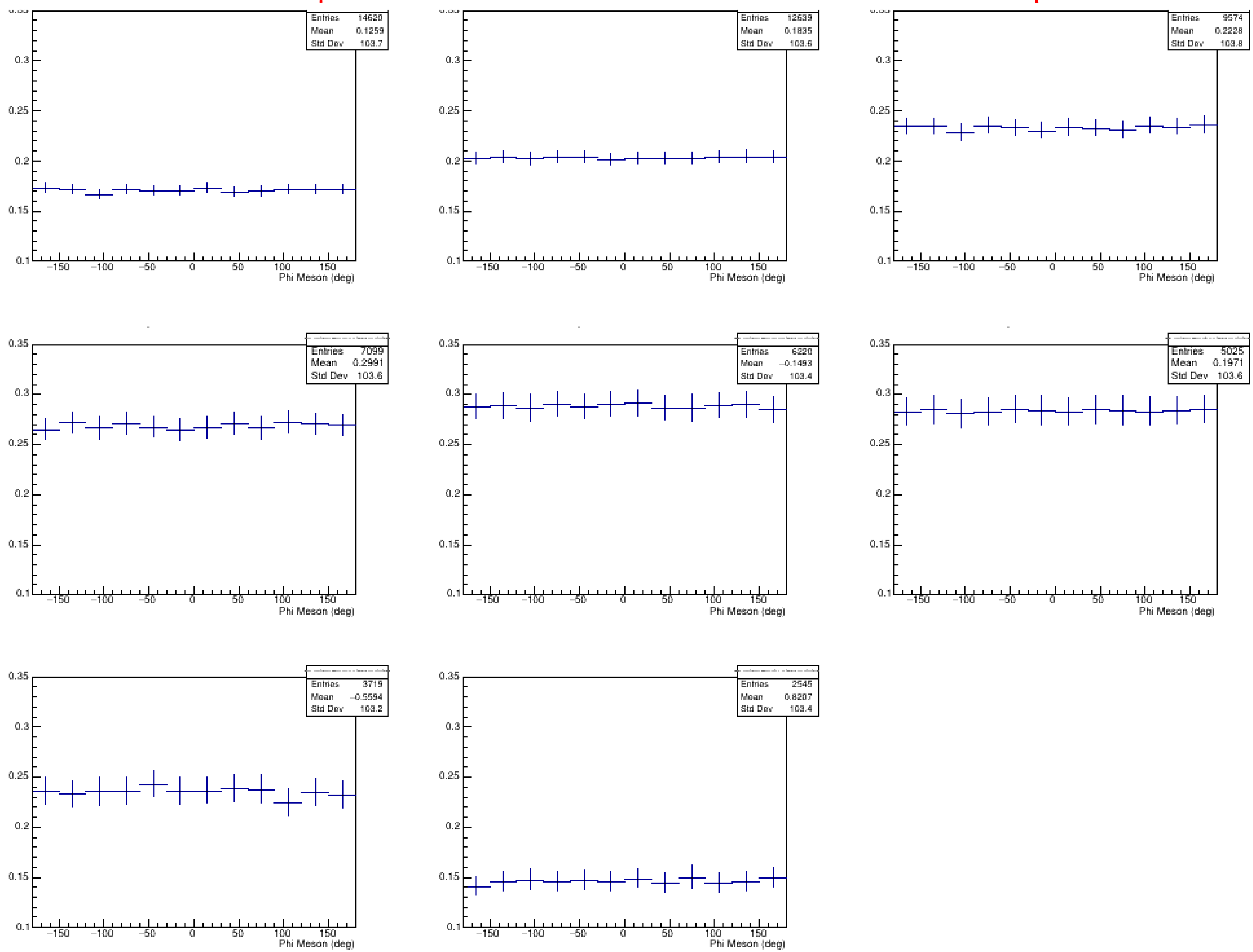
we replace:

$$\varepsilon^{Pi}(\varphi)\rightarrow N^{Pi}_{UNP,norm}(E_\gamma,\theta^{C.M.}_\eta)$$

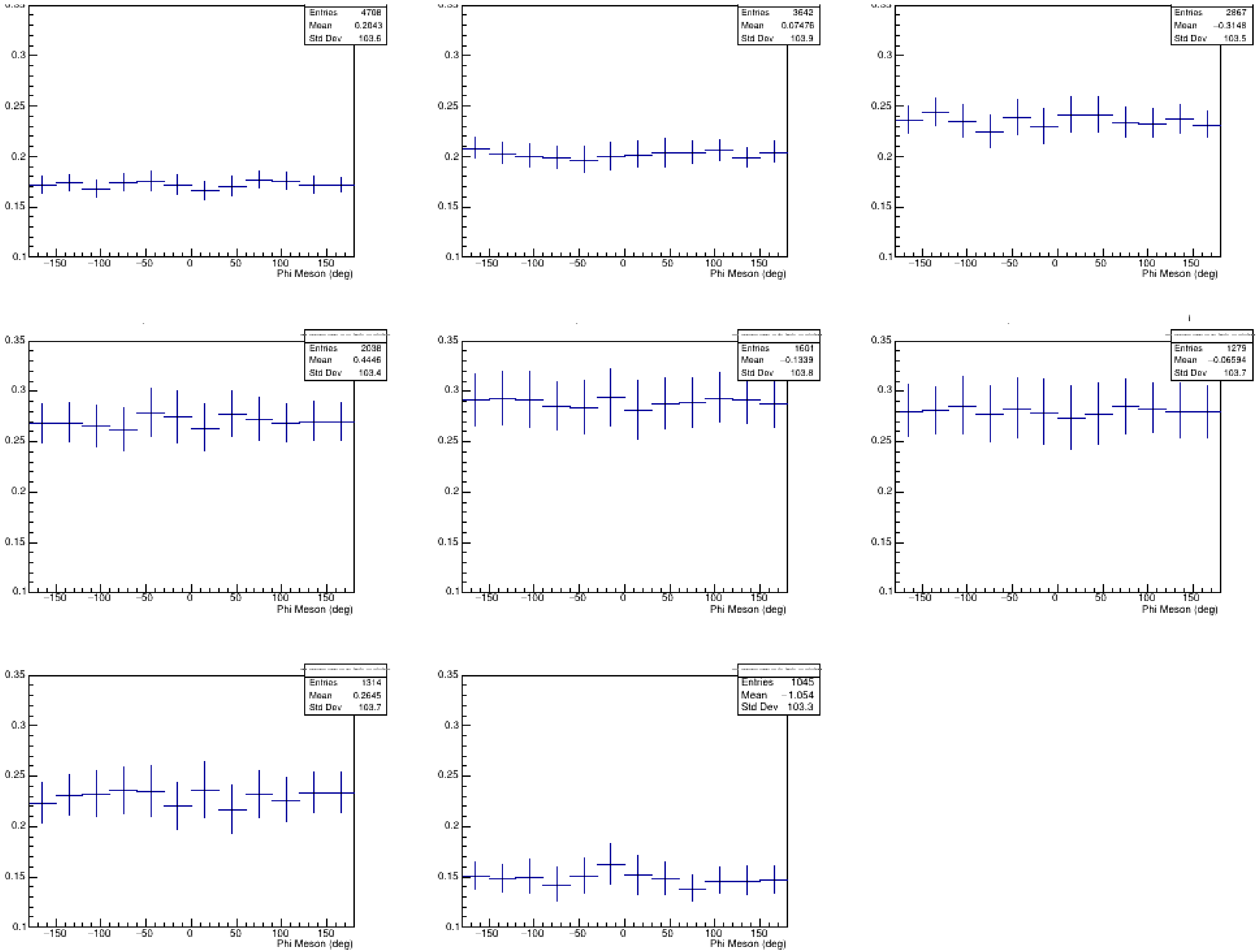
- We extract $P^{W}{}_{Pol+}$ for every E_γ and η polar angle $\theta_\eta^{C.M.}$ in the c.m.
- make the average on all φ bins N_φ:

$$\overline{P^{W}_{Pol+}(E_\gamma)}=\frac{1}{N_\varphi}\sum_\varphi P^{W}_{Pol+}(E_\gamma,\varphi) \qquad (21)$$

$P^{W}_{Pol-}(E_{\gamma}, \varphi)$ - POLMINUS – CENTRAL PROTON - $\theta_{\eta}^{CM} = 68°-83°$



$P^{W}_{Pol-}(E_{\gamma}, \varphi)$ - POLMINUS – PROTON IN SciRi - θ_{η}^{CM} = 130°-140°



ONE PERIOD *P* AND SEVERAL η DECAY CHANNELS *C1, C2, …* WITH DIFFERENT EFFICIENCIES:

$$\varepsilon^{P,C1} \neq \varepsilon^{P,C2}$$

POL. DEGREES AND FLUXES ARE THE SAME FOR ALL CHANNELS:

$$P^{P,C1}_{Pol\pm} = P^{P,C2}_{Pol\pm} = P^{P}_{Pol\pm} \qquad \textbf{BUT} \qquad P^{P}_{Pol+} \neq P^{P}_{Pol-}$$

$$F^{P,C1}_{Pol\pm} = F^{P,C2}_{Pol\pm} = F^{P}_{Pol\pm}$$

Decay channels of one period can be summed up as follows:

$$\frac{\dfrac{N^{P,C1}_{Pol+}}{F^{P}_{Pol+}} + \dfrac{N^{P,C2}_{Pol+}}{F^{P}_{Pol+}}}{N^{P,C1}_{UNP,norm} + N^{P,C2}_{UNP,norm}} = \frac{\cancel{(\varepsilon^{P,C1}(\varphi)+\varepsilon^{P,C2}(\varphi))}(1+P^{P}_{Pol+}\Sigma\cos(2\varphi))}{2\cancel{(\varepsilon^{P,C1}(\varphi)+\varepsilon^{P,C2}(\varphi))}} = \frac{1}{2}(1+P^{P}_{Pol+}\Sigma\cos(2\varphi))$$

In general for more than two channels:

$$\frac{\sum_{Cj} \dfrac{N^{P,Cj}_{Pol+}}{F^{P}_{Pol+}}}{\sum_{Cj} N^{P,Cj}_{UNP,norm}} = \frac{1}{2}(1+P^{P}_{Pol+}\Sigma\cos(2\varphi)) \qquad (22)$$

TWO OR MORE PERIODS *Pi* AND SEVERAL η DECAY CHANNELS *C1, C2, …* WITH DIFFERENT EFFICIENCIES:

$$\varepsilon^{Pi,C1} \neq \varepsilon^{Pi,C2}$$

$$\frac{\sum_{Pi} \sum_{Cj} \dfrac{N_{Pol+}^{Pi,Cj}}{F_{Pol+}^{Pi}}}{\sum_{Pi} \sum_{Cj} N_{UNP,norm}^{Pi,Cj}} = \frac{1}{2}\left(1 + P_{Pol+}^{W} \Sigma \cos(2\varphi)\right)$$

$$P_{Pol+}^{W} = \frac{\varepsilon^{P1}(\varphi) P_{Pol+}^{P1} + \varepsilon^{P2}(\varphi) P_{Pol+}^{P2}}{\varepsilon^{P1}(\varphi) + \varepsilon^{P2}(\varphi)}$$

$$\varepsilon^{P1}(\varphi) = \varepsilon^{P1,C1}(\varphi) + \varepsilon^{P1,C2}(\varphi) \qquad \varepsilon^{P2}(\varphi) = \varepsilon^{P2,C1}(\varphi) + \varepsilon^{P2,C2}(\varphi)$$

Procedure for the extraction of the asymmetry: Summary

- for each period separately: **sum up** the contribution of all decay channels (**number of polarized events normalized to flux**) →

$$\sum_{Cj} \frac{N^{Pi,Cj}_{Pol+}}{F^{P}_{Pol+}}$$

- for each period separately: extract the **average efficiency** of the period ε^{Pi} (proportional to the number of unpolarized and normalized events) →

$$N^{Pi}_{UNP,norm}(E_\gamma, \vartheta^{C.M.}_\eta) \propto \varepsilon^{Pi}(\varphi)$$

- calculate the **weighted Polarization** →

$$P^{W}_{Pol+} = \frac{\varepsilon^{P1}(\varphi) P^{P1}_{Pol+} + \varepsilon^{P2}(\varphi) P^{P2}_{Pol+}}{\varepsilon^{P1}(\varphi) + \varepsilon^{P2}(\varphi)}$$

- calculate the **average on** the azimuthal angle **φ of Weighted Polarization** →

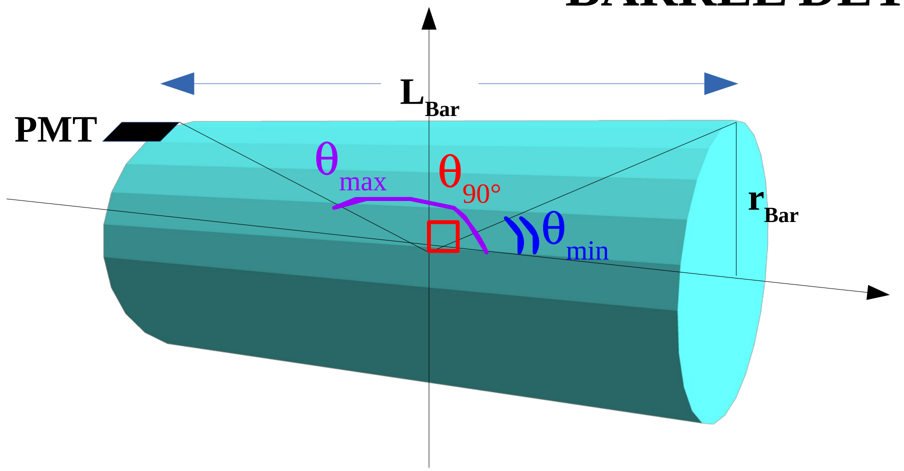
$$\overline{P^{W}_{Pol+}(E_\gamma)} = \frac{1}{N_\varphi} \sum_{\varphi} P^{W}_{Pol+}(E_\gamma, \varphi)$$

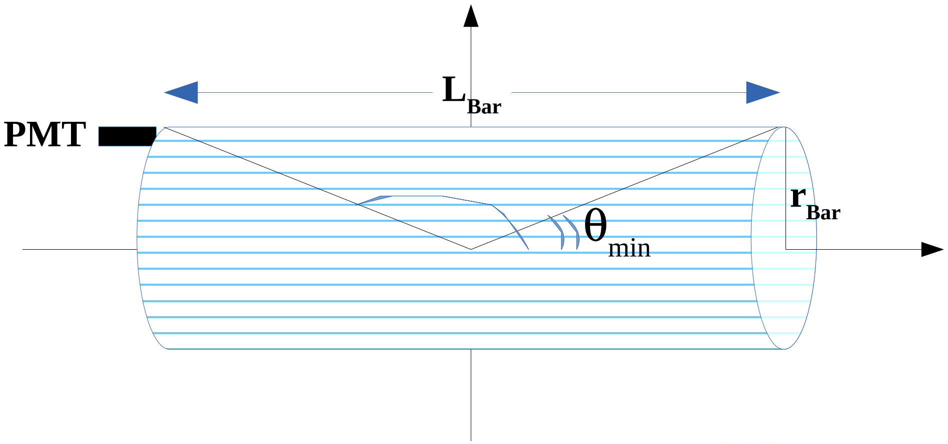
- extract the beam asymmetry from the fit:

$$\frac{\sum_{Pi} \frac{N^{Pi}_{Pol+}}{F^{Pi}_{Pol+}}}{\sum_{Pi} N^{Pi}_{UNP,norm}} = \frac{1}{2}\left(1 + \overline{P^{W}_{Pol+}}\, \Sigma \cos(2\varphi)\right) \qquad (23)$$

BARREL CALIBRATION

BARREL DETAILS





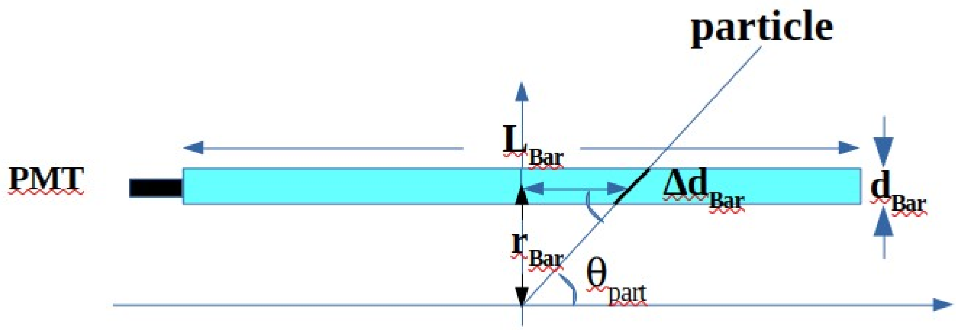
Polar Angle in LAB	Travelled distance To the PM
$\theta_{min} = 25°$	$\Rightarrow x(\theta_{min}) = L_{Bar}$
$\theta_{max} = 155°$	$\Rightarrow x(\theta_{max}) = 0$
$\theta_{90°} = 90°$	$\Rightarrow x(\theta_{90°}) = L_{Bar}/2$

Barrel Length

$L_{bar} = 43.4$ cm

Barrel Radius

$r_{Bar} = L_{Bar}/2 * tg(\theta_{min})$



$$\Delta d_{Bar} = \frac{d_{Bar}}{\sin\theta_{part}}$$

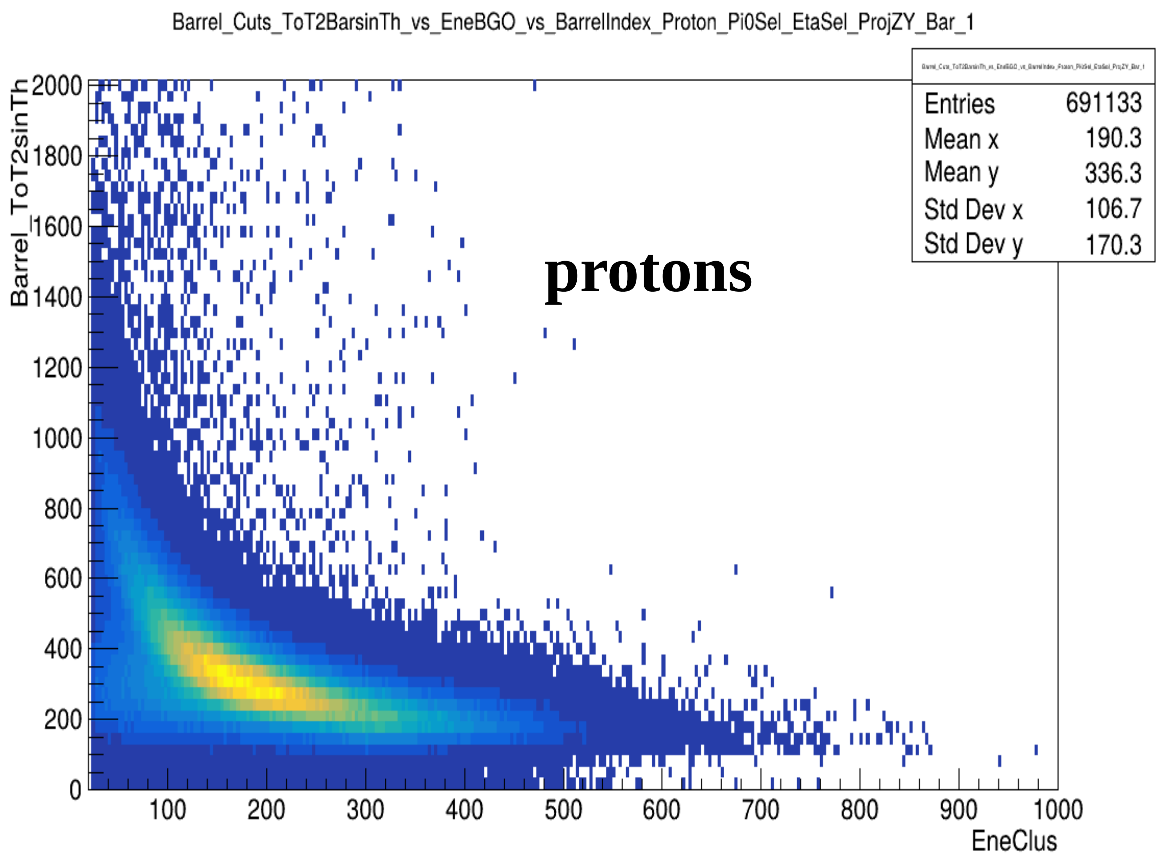
$$ToT2_{Bar} \propto \frac{1}{\sin\theta_{part}}$$

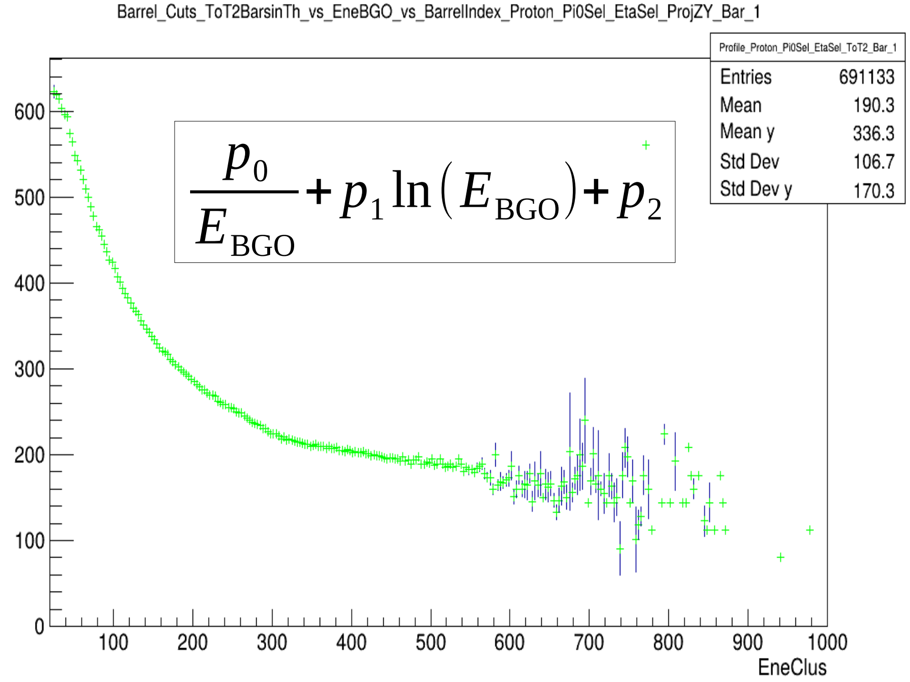
If we multiply the $ToT2_{Bar}$ by $\sin(\theta)$ we get free of this dependence

CUTS ON $ToT2_{Bar}*\sin(\theta)$ vs. E_{BGO}

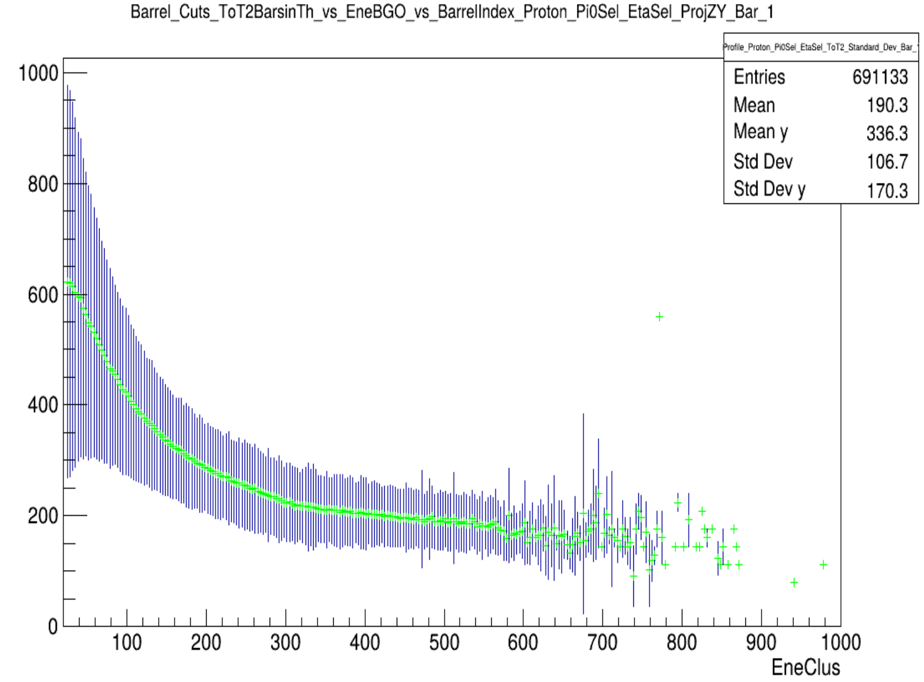
FOR:

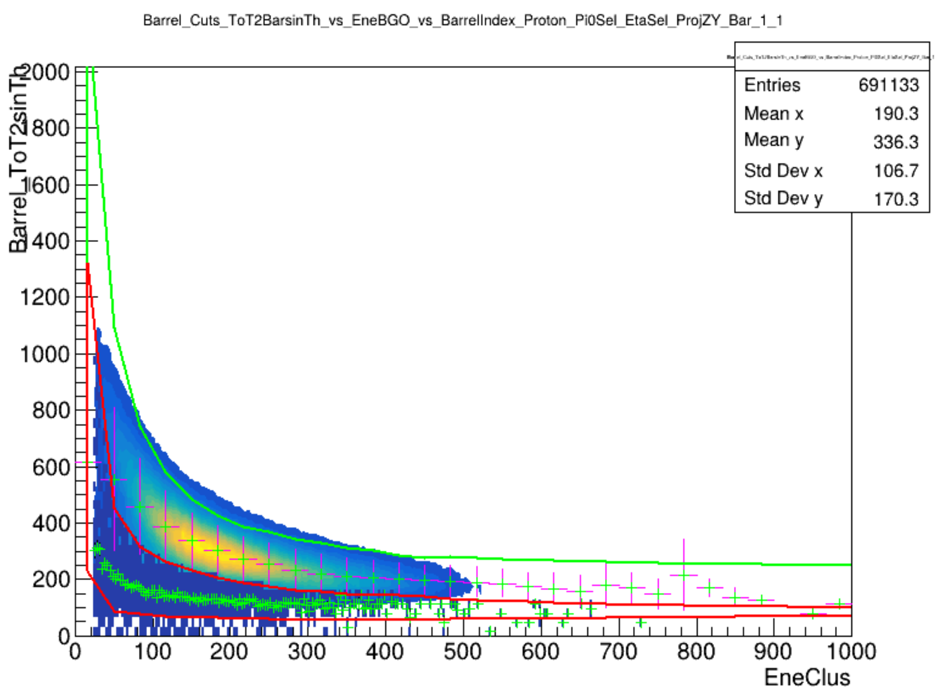
- **protons** from: $\gamma p \rightarrow \pi^0 p \rightarrow 2\gamma p$
- **pions** from: $\gamma p \rightarrow \eta p \rightarrow \pi^+ \pi^- \pi^0 p$





$$\frac{p_0}{E_{\mathrm{BGO}}} + p_1 \ln\left(E_{\mathrm{BGO}}\right) + p_2$$





CALIBRATION OF BARREL ADC

WITH:

- pions@MIP from: $\gamma\, p \rightarrow \pi^+\, n$

BARREL CALIBRATION

$$\Delta\, E_{Bar}\,(i_{Bar}) = c.c.(i_{Bar}) * ToT2_{Bar}(i_{Bar})$$

Technique

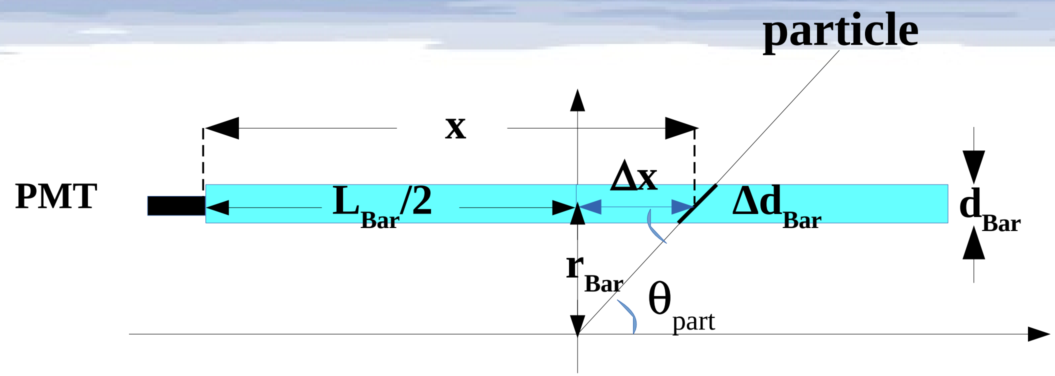
Choose a reaction for which energy deposited by a charged particle in the BGO and in the barrel (plastic EJ248) is fixed

$$\gamma\, p \;\rightarrow\; \pi^{+}\, n$$

in energy range where the pion is a MIP particle both in BGO and in barrel.

BGO $$E_{\mathrm{BGO}}^{\mathrm{MIP}} = \left(\frac{dE}{dx}\right)_{\mathrm{BGO}}^{\mathrm{MIP}} \mathrm{L}_{\mathrm{BGO}} = 213.2\, MeV$$

BARREL $$\left(\frac{dE}{dx}\right)_{\mathrm{Bar}}^{\mathrm{MIP}} = 2.0\,\frac{MeV}{g}\,cm^{2} * \rho_{\mathrm{Bar}} = 2.0\,\frac{MeV}{g}\,cm^{2} * 1.023\,\frac{g}{cm^{3}} = 2.046\,\frac{MeV}{cm}$$



- Energy loss of a particle emitted at a polar angle θ_{part} depends on crossed material thickness Δd_{Bar}, i.e. on θ_{part}:

$$(\Delta E)^{MIP}_{Bar} = 2.046 \frac{MeV}{cm} * \Delta d_{Bar}(\theta_{part})$$

$$\Delta d_{Bar} = \frac{d_{Bar}}{\sin\theta_{part}}$$

- Distance x travelled by light before collection in PMT causes light exponential attenuation and can be expressed in terms of the polar angle θ_{part} (see picture):

$$x = \frac{L_{Bar}}{2} + \Delta x = \frac{L_{Bar}}{2} + r_{Bar}\frac{\cos\theta_{part}}{\sin\theta_{part}}$$

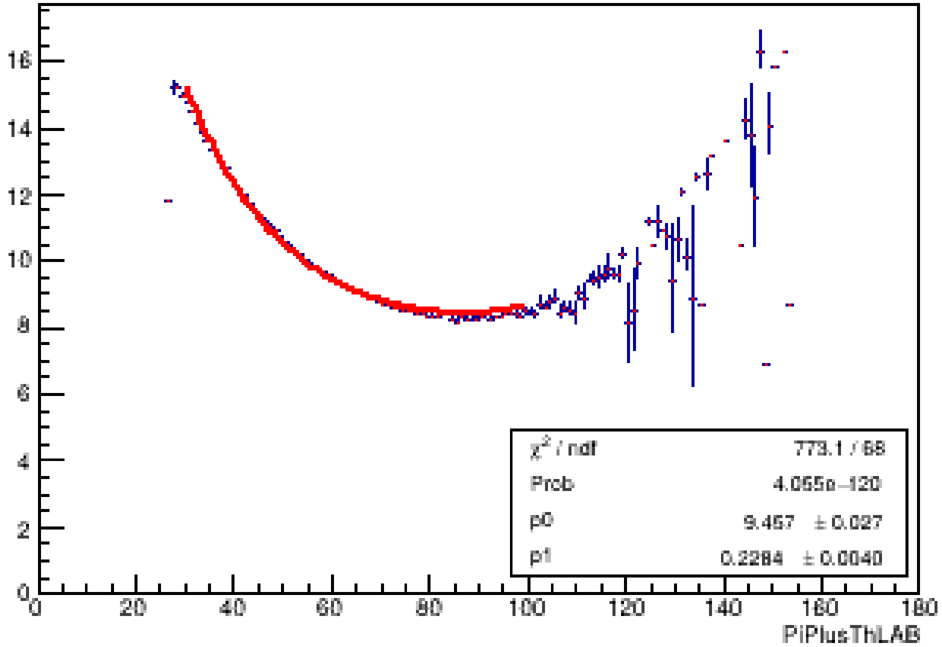
➡ Barrel ToT2 can be parametrized as follows:

$$ToT2_{Bar,\pi} = \frac{A}{\sin\theta_{\pi}} \exp\left(-\frac{B}{L_{Bar}} x\right) \Rightarrow ToT2_{Bar,\pi} = \frac{A}{\sin\theta_{\pi}} \exp\left[-\frac{B}{L_{Bar}}\left(\frac{L_{Bar}}{2} + r_{Bar}\frac{\cos\theta_{\pi}}{\sin\theta_{\pi}}\right)\right]$$

Parameters ***A*** and ***B*** can be derived from data.

$$ToT\,2_{\mathrm{Bar},\pi} = \frac{A}{\sin\theta_\pi} \exp\left[-\frac{B}{\mathrm{L_{Bar}}}\left(\frac{L_{\mathrm{Bar}}}{2} + r_{\mathrm{Bar}}\frac{\cos\theta_{\mathrm{part}}}{\sin\theta_{\mathrm{part}}}\right)\right]$$

ToT2



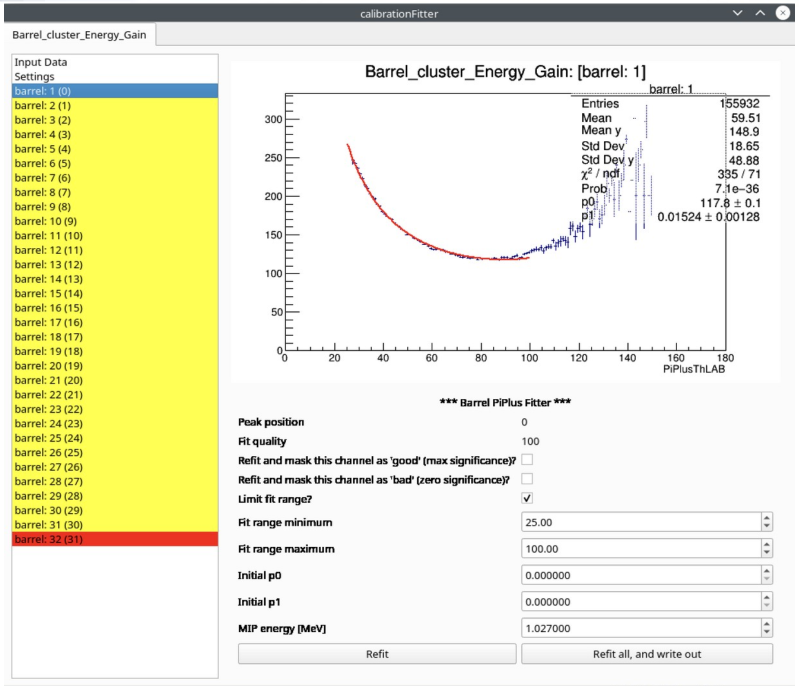
- Fit procedure has been implemented inside a **calibrationFitter program** (similar to the BGO calibration one) → production of the calibration file necessary for the database

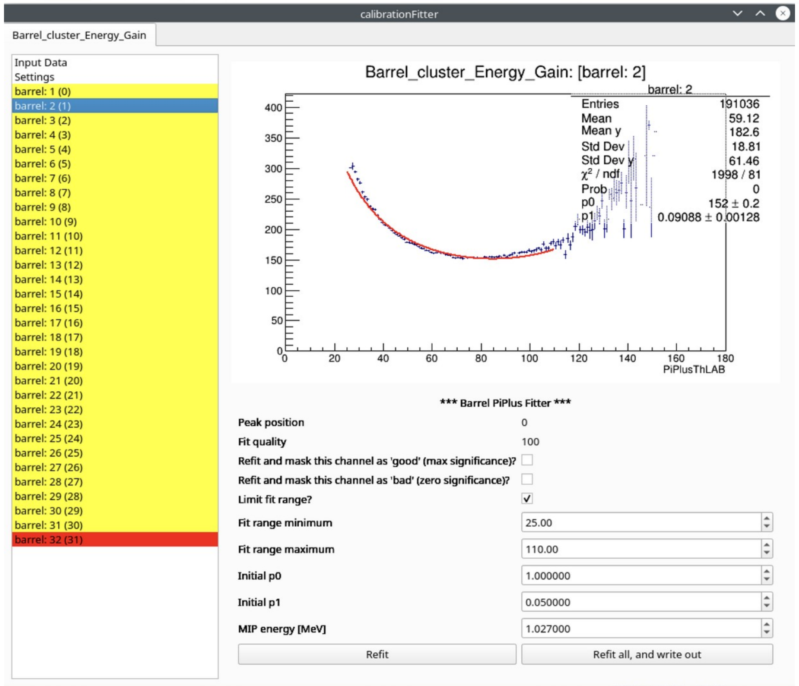
- Analysis outputs are provided to this program in the form of 3D histos

$ToT2_{Bar}$ vs. $\theta_{\pi+,\mathrm{LAB}}$ vs. Barrel Index

BUT

We still have to find how to read in explora barrel calibration constants from database


calibrationFitter
Barrel_cluster_Energy_Gain
Input Data
Settings
barrel: 1 (0)
barrel: 2 (1)
barrel: 3 (2)
barrel: 4 (3)
barrel: 5 (4)
barrel: 6 (5)
barrel: 7 (6)
barrel: 8 (7)
barrel: 9 (8)
barrel: 10 (9)
barrel: 11 (10)
barrel: 12 (11)
barrel: 13 (12)
barrel: 14 (13)
barrel: 15 (14)
barrel: 16 (15)
barrel: 17 (16)
barrel: 18 (17)
barrel: 19 (18)
barrel: 20 (19)
barrel: 21 (20)
barrel: 22 (21)
barrel: 23 (22)
barrel: 24 (23)
barrel: 25 (24)
barrel: 26 (25)
barrel: 27 (26)
barrel: 28 (27)
barrel: 29 (28)
barrel: 30 (29)
barrel: 31 (30)
barrel: 32 (31)
Barrel_cluster_Energy_Gain: [barrel: 1]
barrel: 1
Entries 155932
Mean 59.51
Mean y 148.9
Std Dev 18.65
Std Dev y 48.88
χ² / ndf 335 / 71
Prob 7.1e−36
p0 117.8 ± 0.1
p1 0.01524 ± 0.00128
PiPlusThLAB
*** Barrel PiPlus Fitter ***
Peak position 0
Fit quality 100
Refit and mask this channel as 'good' (max significance)?
Refit and mask this channel as 'bad' (zero significance)?
Limit fit range?
Fit range minimum 25.00
Fit range maximum 100.00
Initial p0 0.000000
Initial p1 0.000000
MIP energy [MeV] 1.027000
Refit
Refit all, and write out


calibrationFitter
Barrel_cluster_Energy_Gain
Input Data
Settings
barrel: 1 (0)
barrel: 2 (1)
barrel: 3 (2)
barrel: 4 (3)
barrel: 5 (4)
barrel: 6 (5)
barrel: 7 (6)
barrel: 8 (7)
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barrel: 11 (10)
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barrel: 14 (13)
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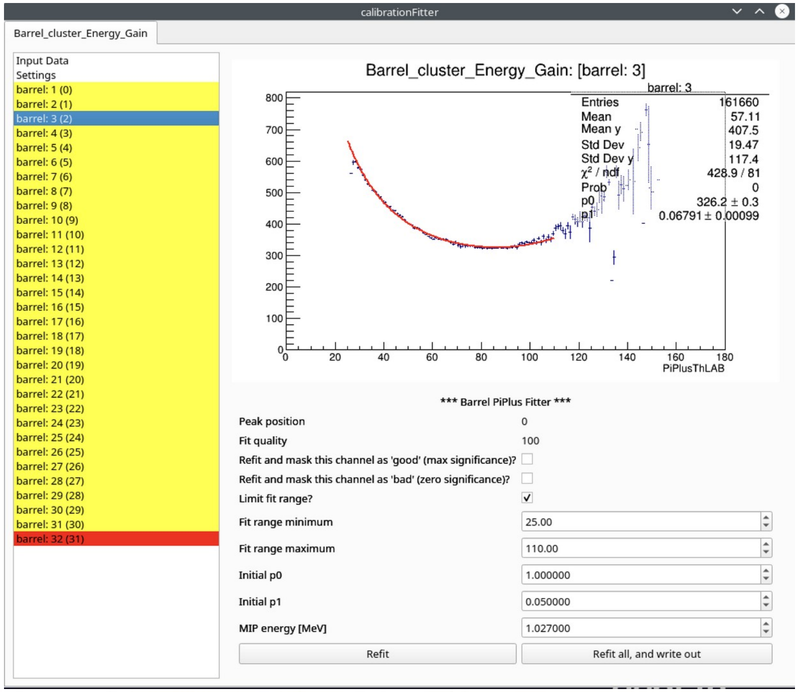
barrel: 21 (20)
barrel: 22 (21)
barrel: 23 (22)
barrel: 24 (23)
barrel: 25 (24)
barrel: 26 (25)
barrel: 27 (26)
barrel: 28 (27)
barrel: 29 (28)
barrel: 30 (29)
barrel: 31 (30)
barrel: 32 (31)
Barrel_cluster_Energy_Gain: [barrel: 2]
barrel: 2
Entries 191036
Mean 59.12
Mean y 182.6
Std Dev 18.81
Std Dev y 61.46
χ² / ndf 1998 / 81
Prob 0
p0 152 ± 0.2
p1 0.09088 ± 0.00128
PiPlusThLAB
*** Barrel PiPlus Fitter ***
Peak position 0
Fit quality 100
Refit and mask this channel as 'good' (max significance)?
Refit and mask this channel as 'bad' (zero significance)?
Limit fit range?
Fit range minimum 25.00
Fit range maximum 110.00
Initial p0 1.000000
Initial p1 0.050000
MIP energy [MeV] 1.027000
Refit
Refit all, and write out


calibrationFitter
Barrel_cluster_Energy_Gain
Input Data
Settings
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barrel: 2 (1)
barrel: 3 (2)
barrel: 4 (3)
barrel: 5 (4)
barrel: 6 (5)
barrel: 7 (6)
barrel: 8 (7)
barrel: 9 (8)
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barrel: 11 (10)
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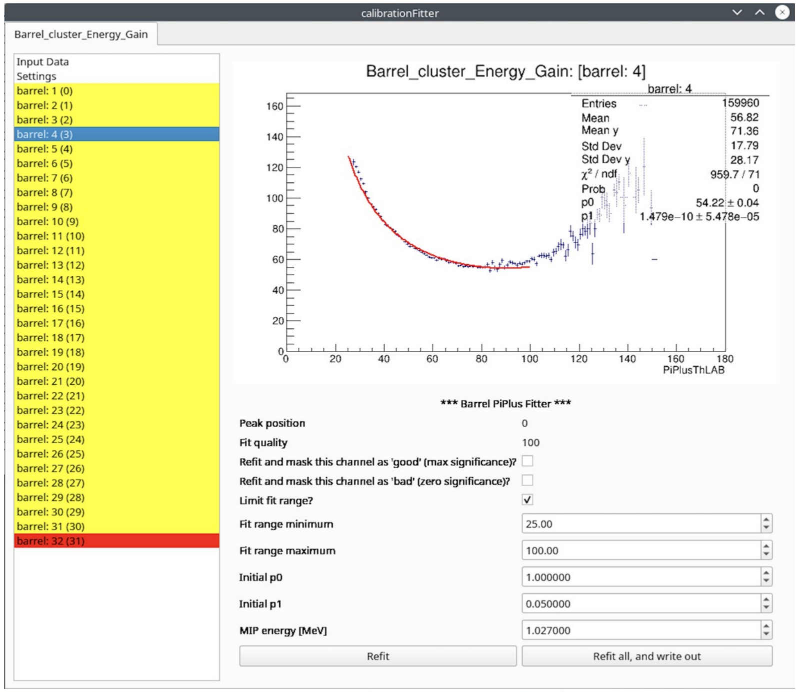
barrel: 25 (24)
barrel: 26 (25)
barrel: 27 (26)
barrel: 28 (27)
barrel: 29 (28)
barrel: 30 (29)
barrel: 31 (30)
barrel: 32 (31)
Barrel_cluster_Energy_Gain: [barrel: 3]
barrel: 3
Entries 161660
Mean 57.11
Mean y 407.5
Std Dev 19.47
Std Dev y 117.4
χ² / ndf 428.9 / 81
Prob 0
p0 326.2 ± 0.3
p1 0.06791 ± 0.00099
PiPlusThLAB
*** Barrel PiPlus Fitter ***
Peak position 0
Fit quality 100
Refit and mask this channel as 'good' (max significance)?
Refit and mask this channel as 'bad' (zero significance)?
Limit fit range?
Fit range minimum 25.00
Fit range maximum 110.00
Initial p0 1.000000
Initial p1 0.050000
MIP energy [MeV] 1.027000
Refit
Refit all, and write out


calibrationFitter
Barrel_cluster_Energy_Gain
Input Data
Settings
barrel: 1 (0)
barrel: 2 (1)
barrel: 3 (2)
barrel: 4 (3)
barrel: 5 (4)
barrel: 6 (5)
barrel: 7 (6)
barrel: 8 (7)
barrel: 9 (8)
barrel: 10 (9)
barrel: 11 (10)
barrel: 12 (11)
barrel: 13 (12)
barrel: 14 (13)
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barrel: 16 (15)
barrel: 17 (16)
barrel: 18 (17)
barrel: 19 (18)
barrel: 20 (19)
barrel: 21 (20)
barrel: 22 (21)
barrel: 23 (22)
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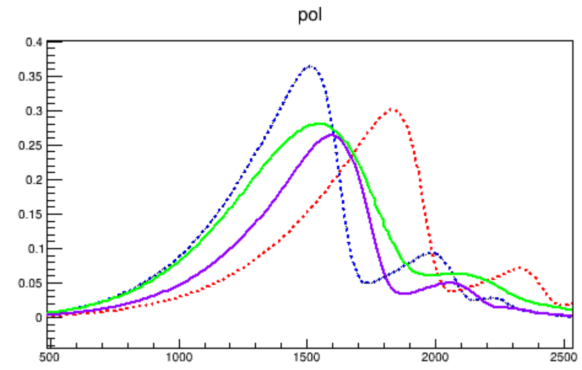
barrel: 29 (28)
barrel: 30 (29)
barrel: 31 (30)
barrel: 32 (31)
Barrel_cluster_Energy_Gain: [barrel: 4]
barrel: 4
Entries 159960
Mean 56.82
Mean y 71.36
Std Dev 17.79
Std Dev y 28.17
χ² / ndf 959.7 / 71
Prob 0
p0 54.22 ± 0.04
p1 1.479e−10 ± 5.478e−05
PiPlusThLAB
*** Barrel PiPlus Fitter ***
Peak position 0
Fit quality 100
Refit and mask this channel as 'good' (max significance)?
Refit and mask this channel as 'bad' (zero significance)?
Limit fit range?
Fit range minimum 25.00
Fit range maximum 100.00
Initial p0 1.000000
Initial p1 0.050000
MIP energy [MeV] 1.027000
Refit
Refit all, and write out

BEAM ASYMMETRY Σ FOR:

$\gamma\, p \rightarrow \eta\, p$

- Analysis of 3 data taking periods
(OctNov2015, AprMay2017, NovDec2018)

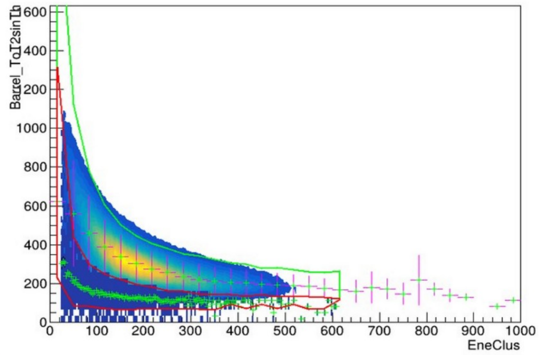
- **Different efficiencies**
- **Different polarization degrees**



- Analysis of 3 decay channels
$\eta \rightarrow 2\gamma \quad \eta \rightarrow 3\pi^0 \rightarrow 6\gamma \quad \eta \rightarrow \pi^+ \pi^- \pi^0$

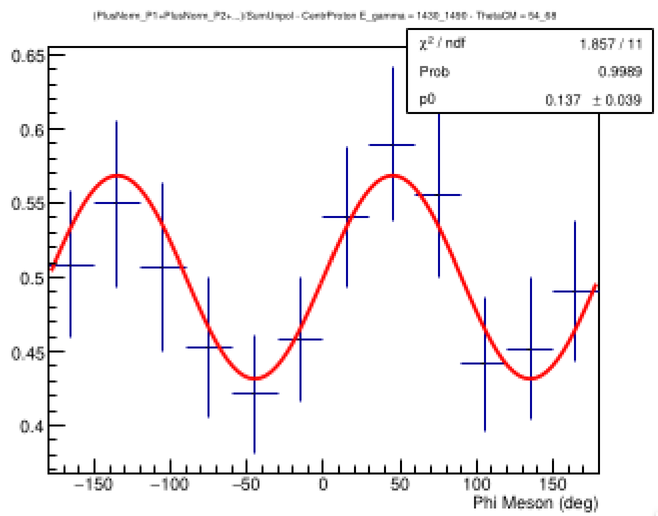
With proton in BGO/Bar and in SciRi

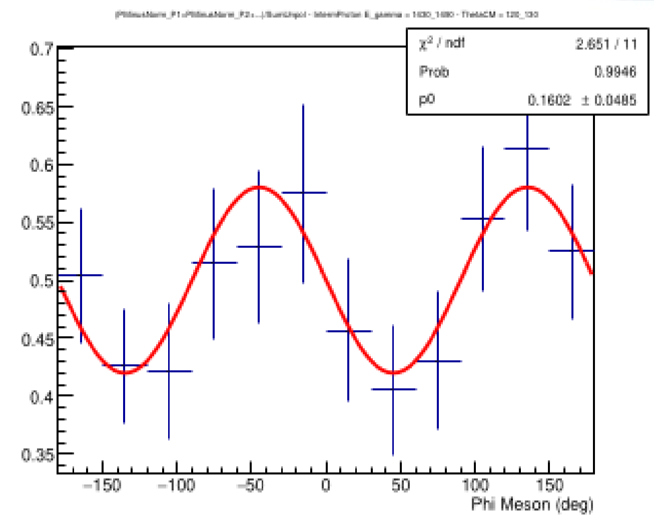
- Calibration constants not yet applied
→ Only cuts ToT2*sin(θ_{CM}) vs. Ene$_{BGO}$

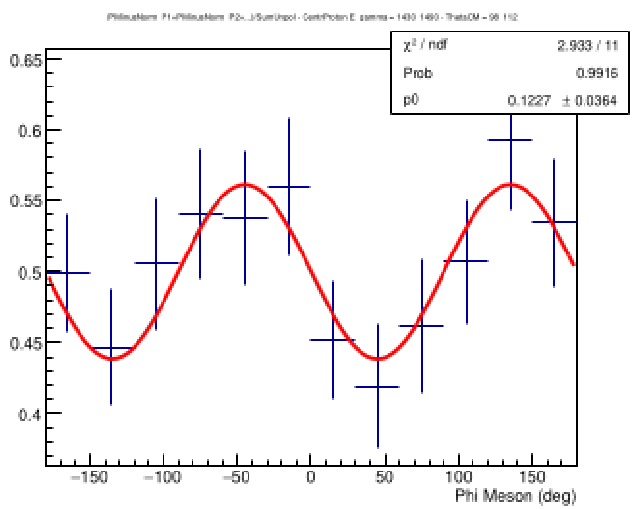


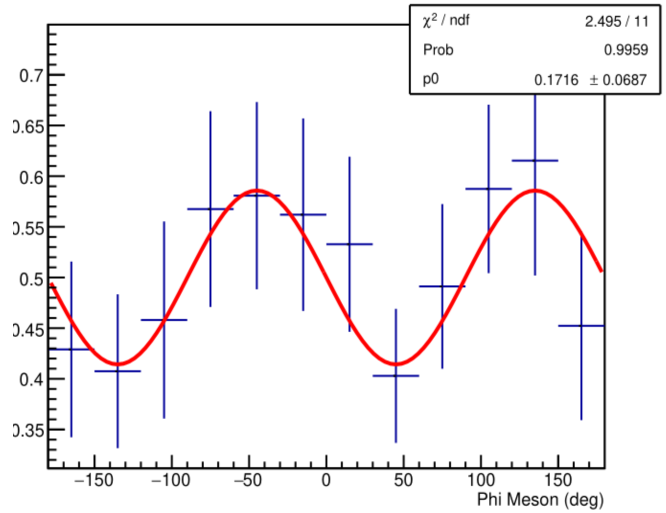
COMPARISON EFFICIENCY DATA TAKING PERIODS - H2

		Jun15	Oct15	AprMay17	NovDec18
		CENTRAL	PROTON	AND $\eta \rightarrow 2\gamma$	
$E\gamma > 0.5$GeV					
	#η/Flux	$0.3\ 10^{-8}$	$0.4\ 10^{-8}$	$1.6\ 10^{-8}$	$2.3\ 10^{-8}$
$E\gamma > 1.2$GeV					
	#η/Flux	$0.6\ 10^{-8}$	$0.6\ 10^{-8}$	$2.2\ 10^{-8}$	$3.\ 10^{-8}$
		INTERM.	PROTON	AND $\eta \rightarrow 2\gamma$	
$E\gamma > 0.5$GeV					
	#η/Flux	$0.5\ 10^{-8}$	$0.6\ 10^{-8}$	$2.3\ 10^{-8}$	$2.7\ 10^{-8}$
$E\gamma > 1.2$GeV					
	#η/Flux	$0.2\ 10^{-8}$	$0.2\ 10^{-8}$	$0.8\ 10^{-8}$	$0.7\ 10^{-8}$



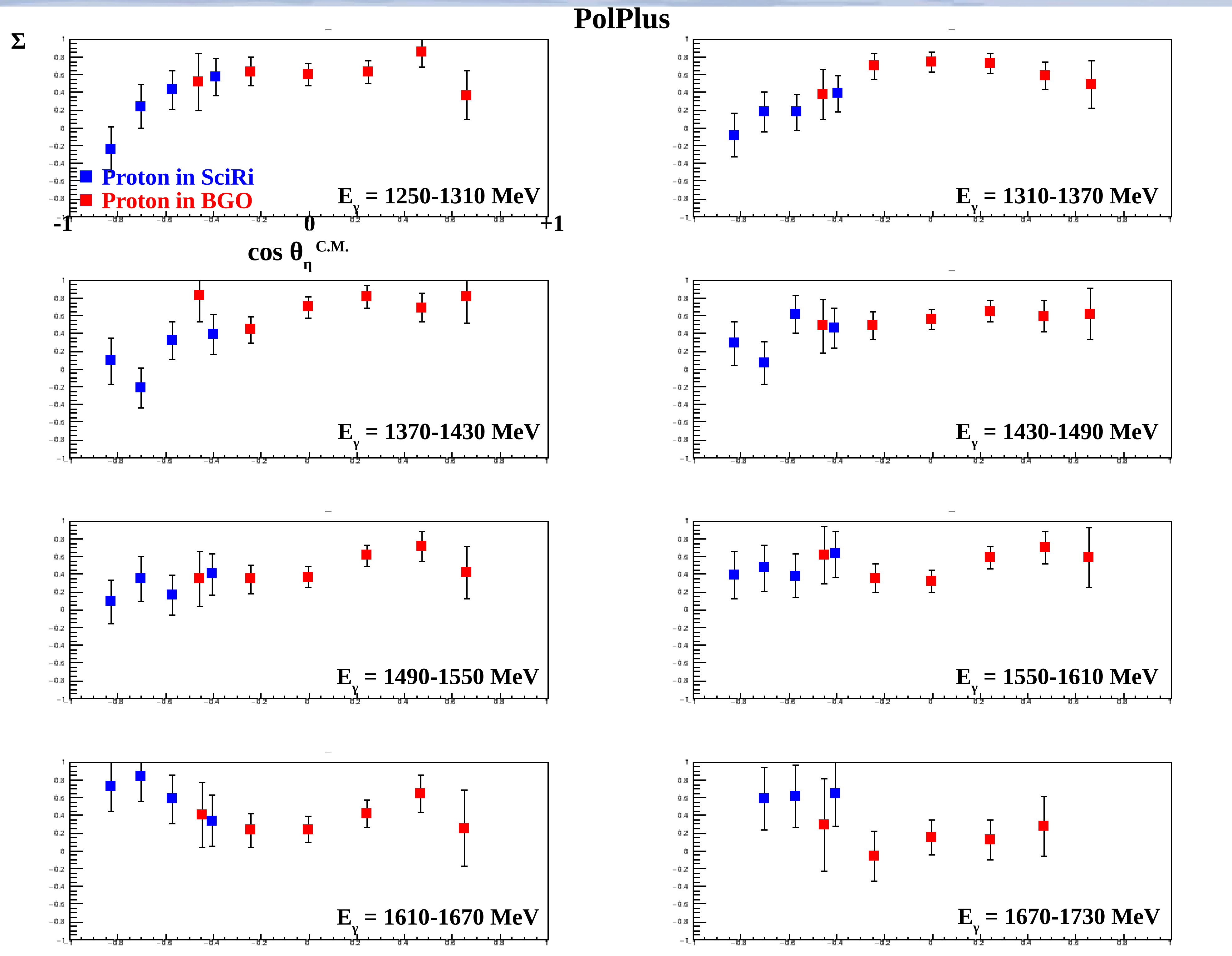






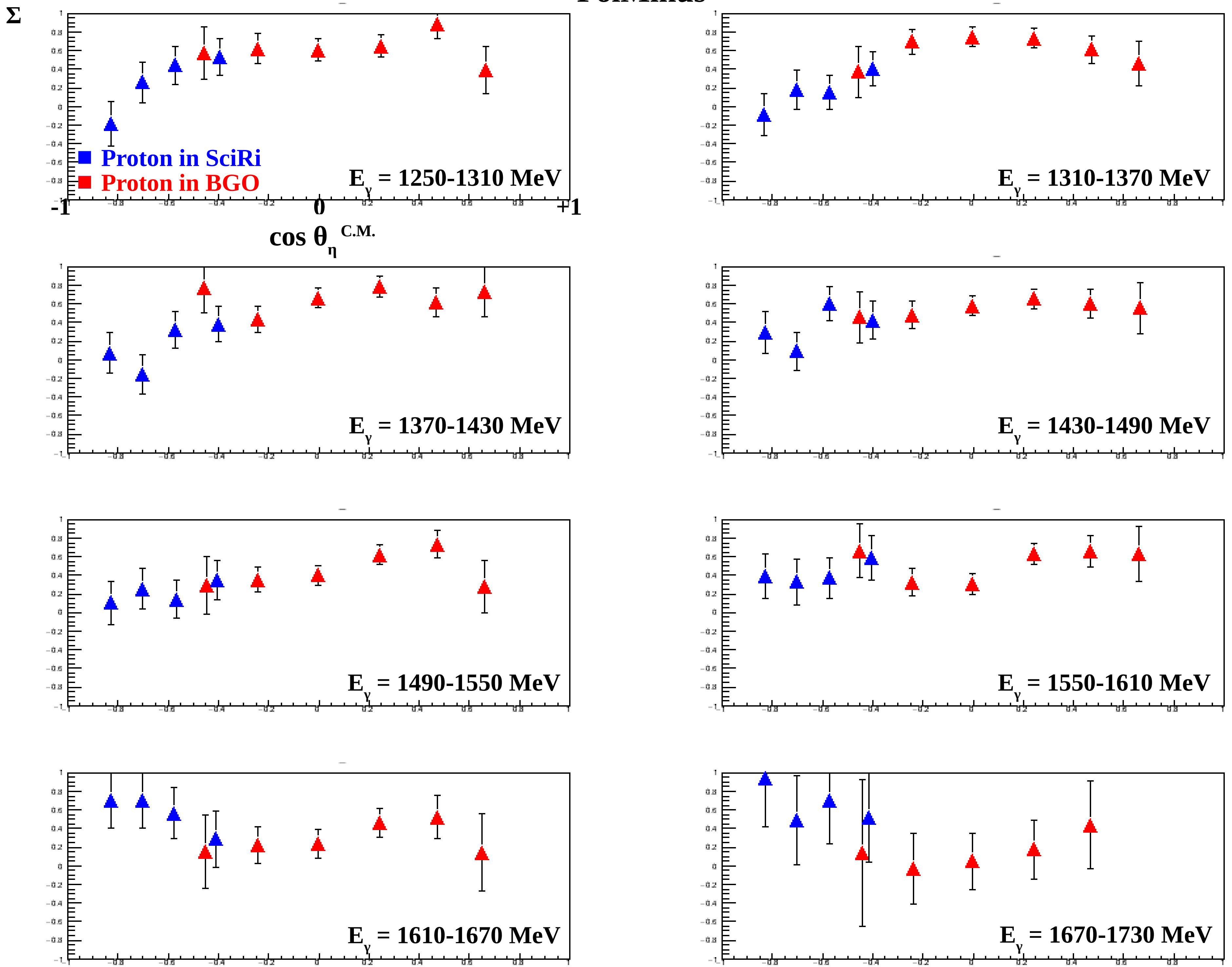
Proton in BGO/Bar

Proton in SciRi

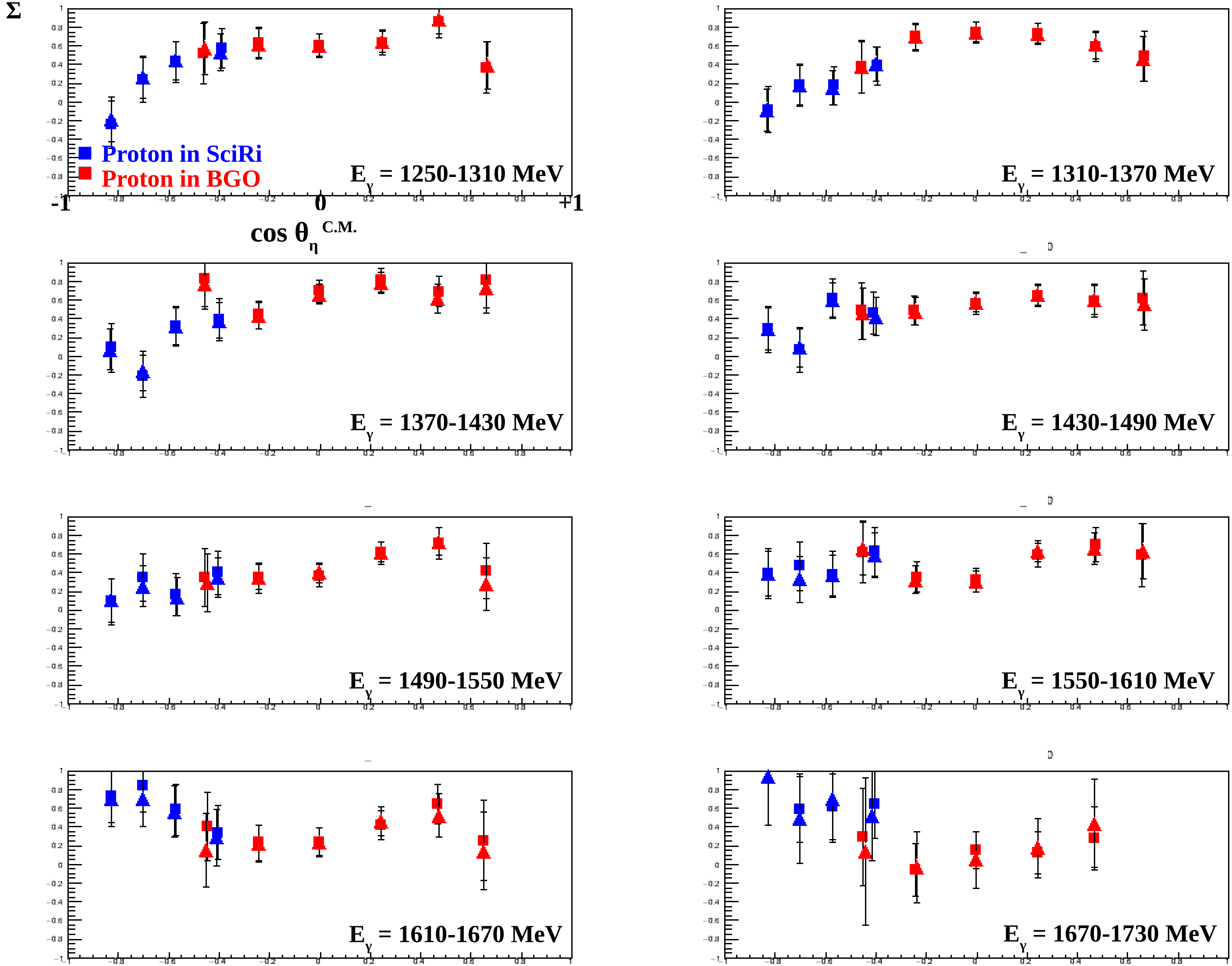


PolPlus
Σ
Proton in SciRi
Proton in BGO
-1
0
+1
cos θη C.M.
Eγ = 1250-1310 MeV
Eγ = 1310-1370 MeV
Eγ = 1370-1430 MeV
Eγ = 1430-1490 MeV
Eγ = 1490-1550 MeV
Eγ = 1550-1610 MeV
Eγ = 1610-1670 MeV
Eγ = 1670-1730 MeV

PolMinus

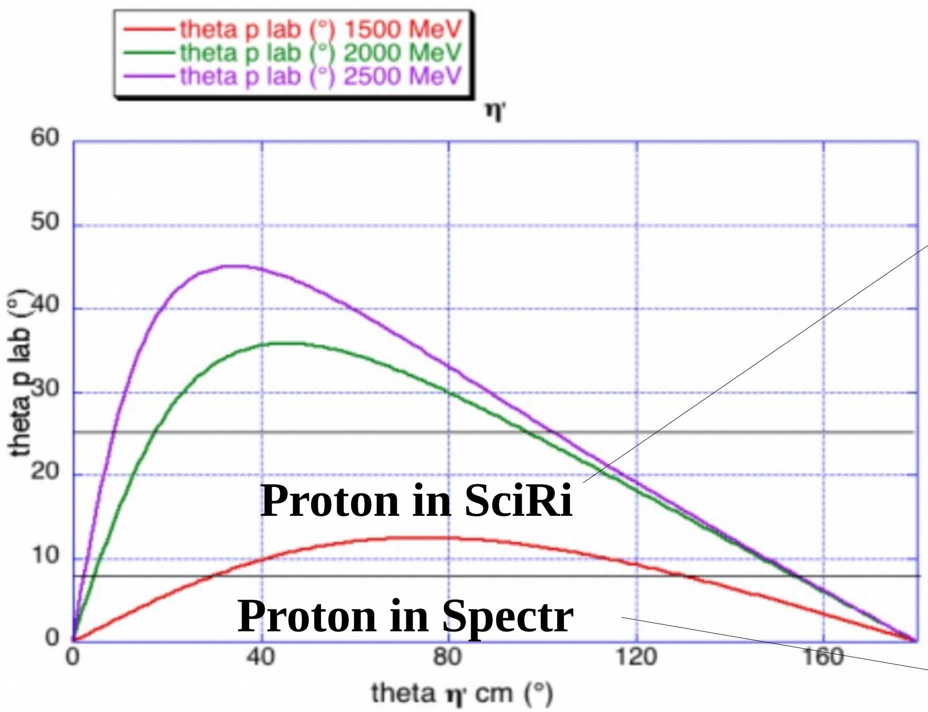

Σ
Proton in SciRi
Proton in BGO
E$_\gamma$ = 1250-1310 MeV
-1
0
+1
cos θ$_\eta$ C.M.
E$_\gamma$ = 1310-1370 MeV
E$_\gamma$ = 1370-1430 MeV
E$_\gamma$ = 1430-1490 MeV
E$_\gamma$ = 1490-1550 MeV
E$_\gamma$ = 1550-1610 MeV
E$_\gamma$ = 1610-1670 MeV
E$_\gamma$ = 1670-1730 MeV

PolPlus/PolMinus

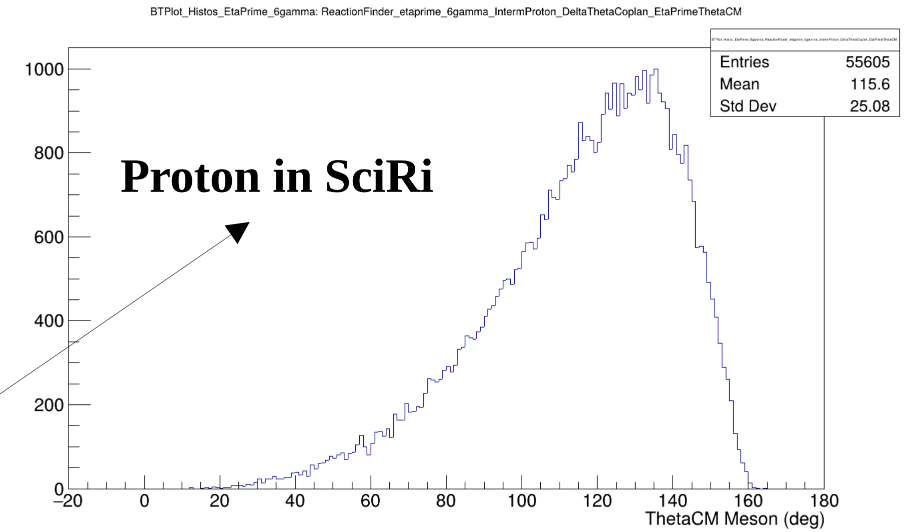


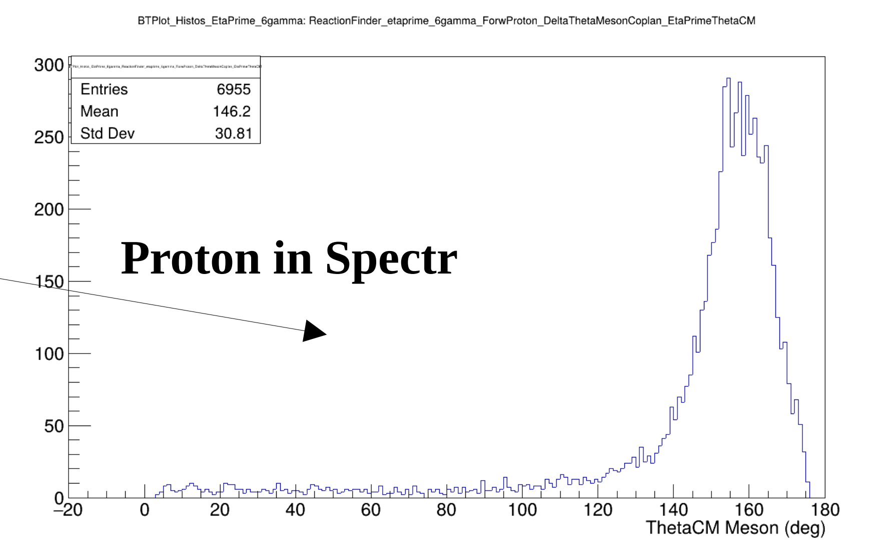
η' ANALYSIS

η' KINEMATICS



DATA





BEAM ASYMMETRY Σ FOR:

$$\gamma\, p \rightarrow \eta'\, p$$

- Analysis of 3 data taking periods
(OctNov2015, AprMay2017, NovDec2018)

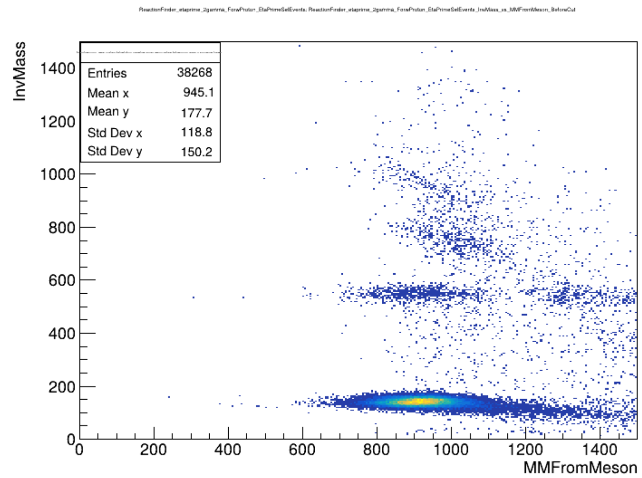
- Analysis of:
Proton in Spectr → 3 decay channels

$\eta' \rightarrow 2\gamma$ $\quad$ $\eta' \rightarrow \pi^0\pi^0\eta \rightarrow 6\gamma$ $\quad$ $\eta' \rightarrow \pi^+\pi^-\eta$

Proton in SciRi → 2 decay channels

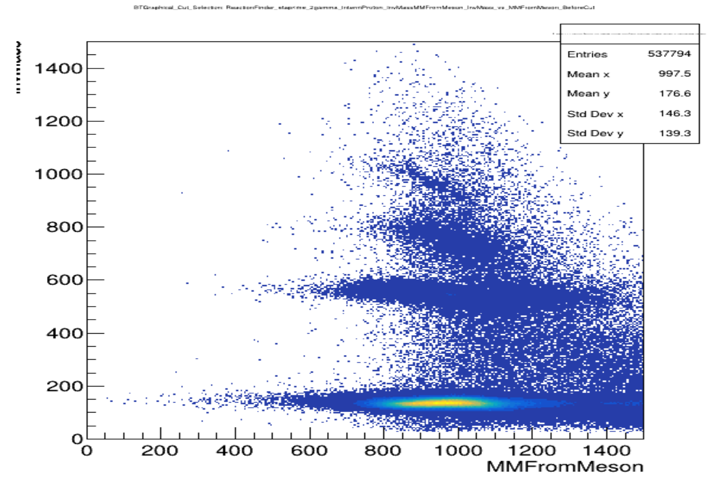
$\eta' \rightarrow 2\gamma$ $\quad$ $\eta' \rightarrow \pi^0\pi^0\eta \rightarrow 6\gamma$

Results are promising BUT not yet final



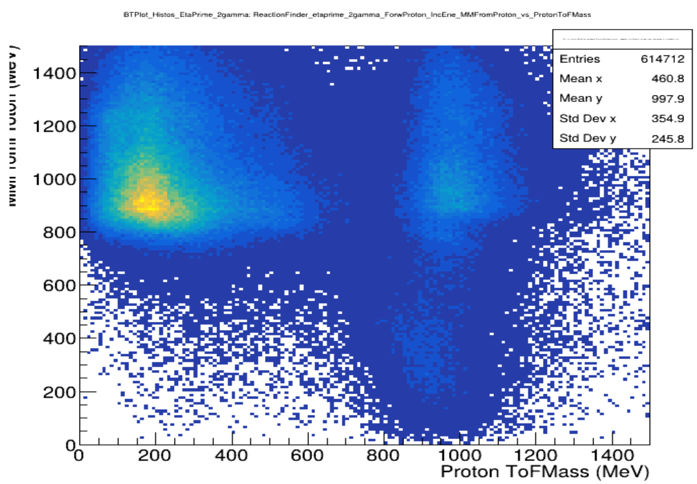
η' → 2γ – Proton in Spectr

2γ InvMass vs MMFromMeson



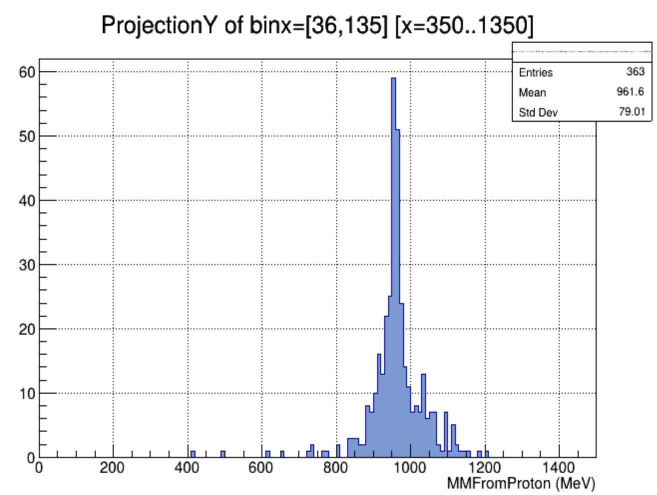
η' → 2γ – Proton in SciRi

2γ InvMass vs MMFromMeson



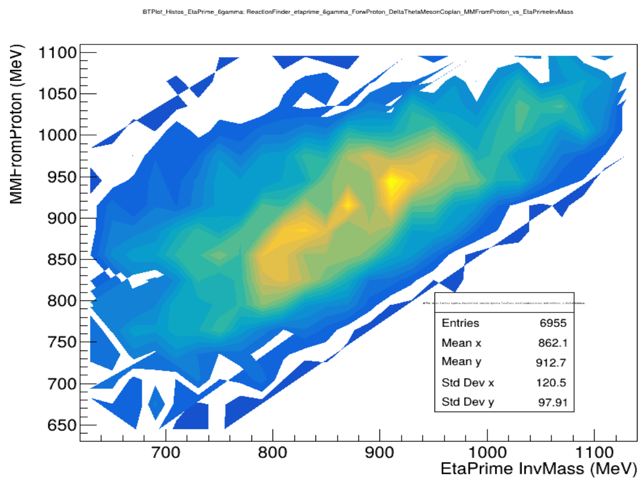
η' → 2γ – Proton in Spectr

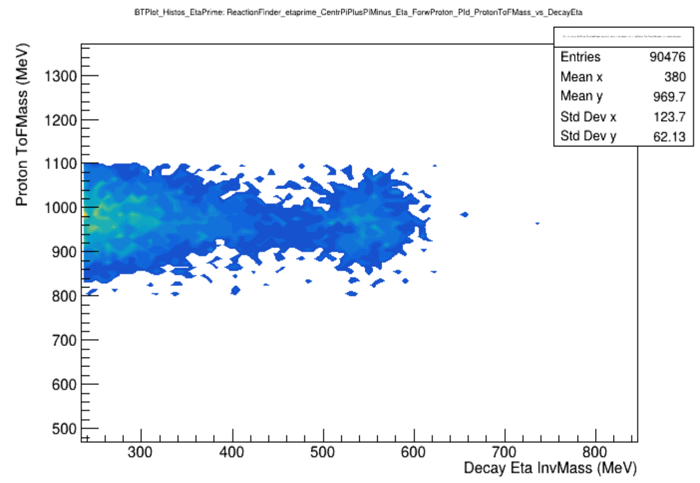
MMFromProton vs ToFMass



η' → 2γ – Proton in Spectr

MMFromProton After Cuts



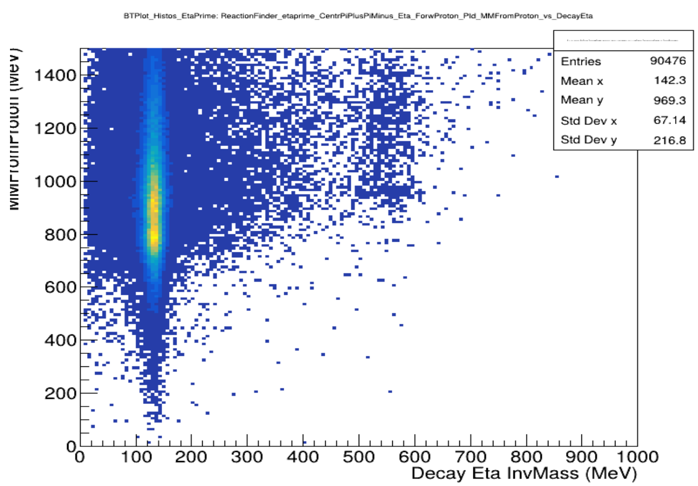


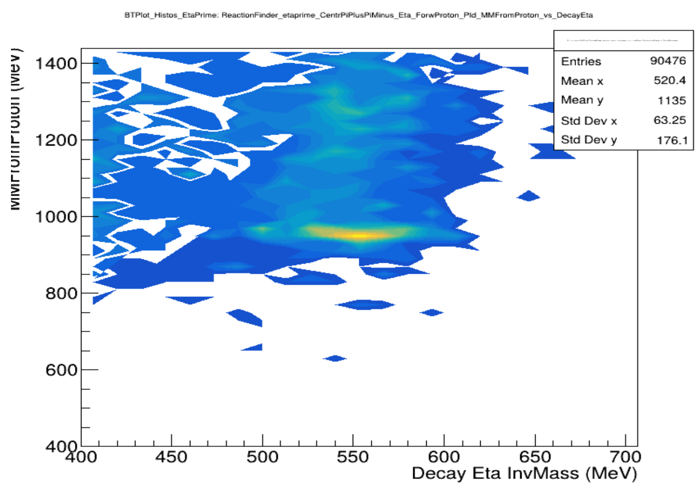
η' → 6γ – Proton in Spectr

MMFromProton vs 6γ InvMass

η' → $\pi^+\pi^-\eta$ – Proton in Spectr

ToFMass vs η DecayInvMass





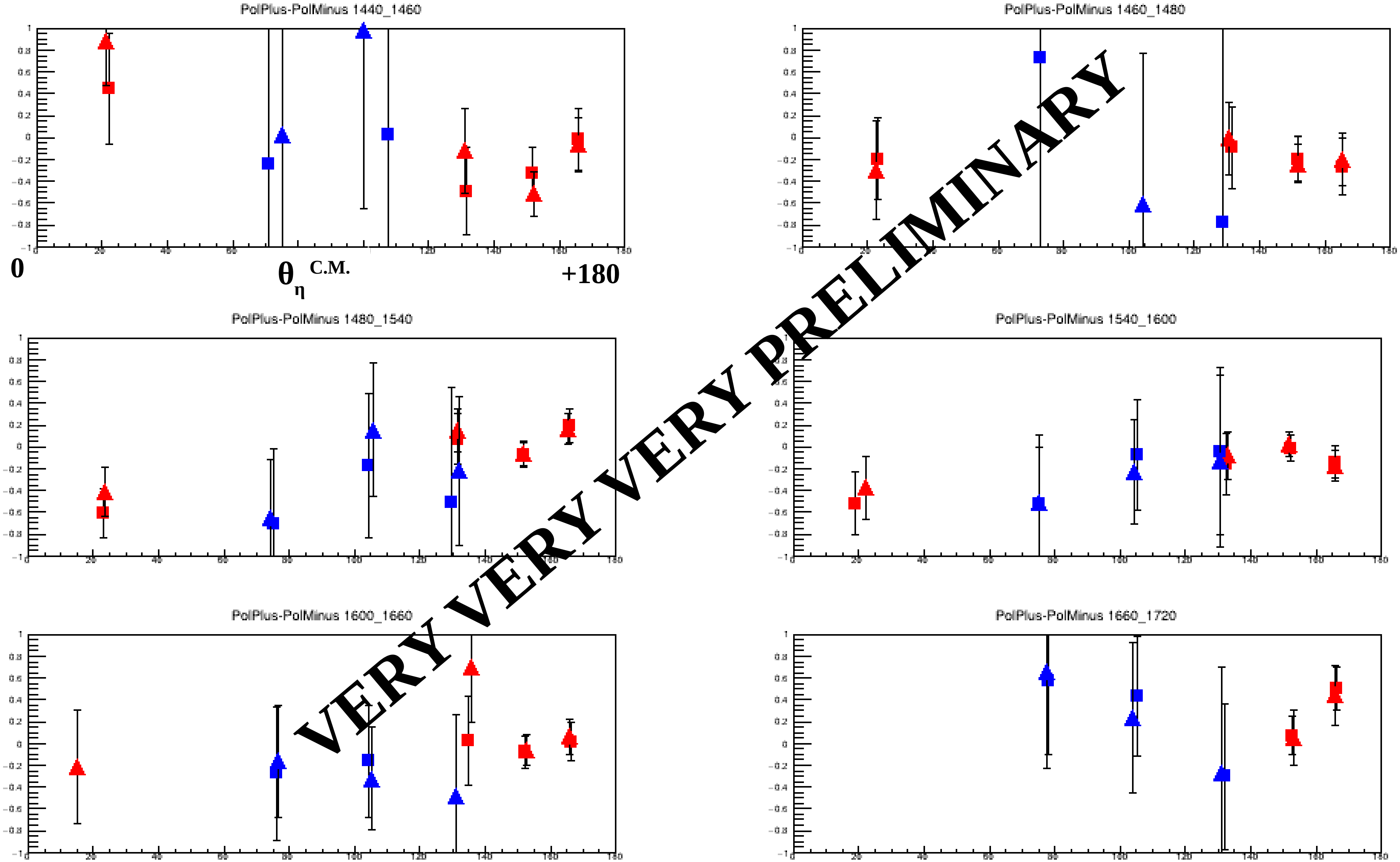
η' → $\pi^+\pi^-\eta$ – Proton in Spectr

MMFromProton vs η DecayInvMass

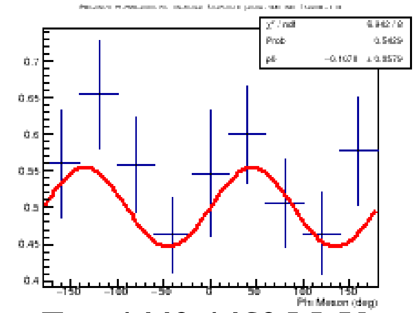
η' → $\pi^+\pi^-\eta$ – Proton in Spectr

MMFromProton vs η DecayInvMass

PolPlus/PolMinus

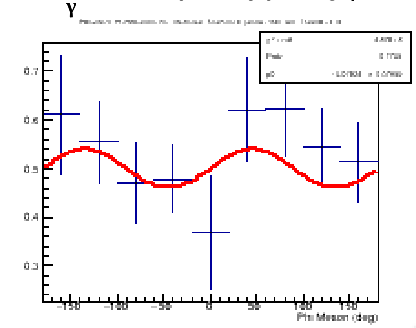


Proton in Spectr
First Bin in ThetaCM



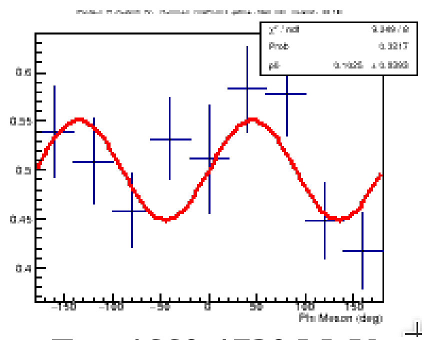
E_γ = 1440-1460 MeV

Proton in Spectr
First Bin in ThetaCM

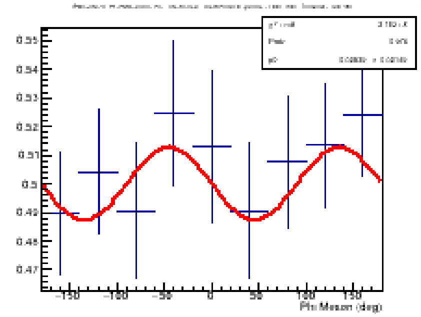


E_γ = 1460-1480 MeV

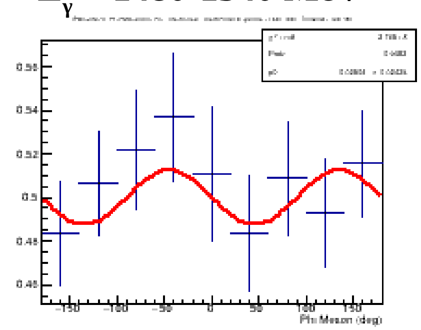
Proton in Spectr
Last Bin in ThetaCM



E_γ = 1660-1720 MeV

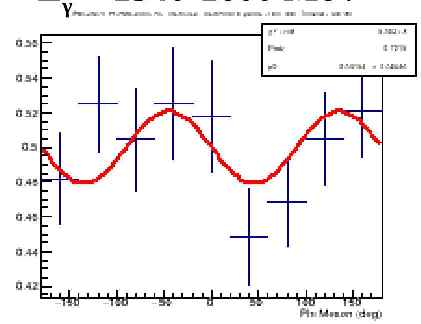


E_γ = 1480-1540 MeV

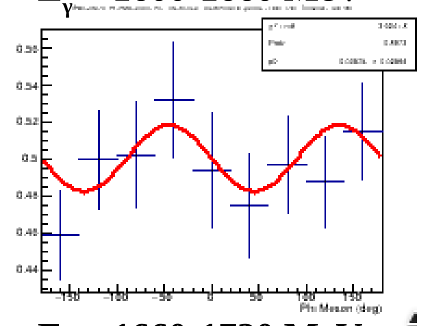


E_γ = 1540-1600 MeV

Proton in SciRi
First Bin in ThetaCM



E_γ = 1600-1660 MeV



E_γ = 1660-1720 MeV

TO DO LIST

- We analysed only 3 data taking periods on H2 (OctNov2015, AprMay2017, NovDec2018)

  We need to implement a reliable procedure for the extraction of the pol. degree of new periods (not trivial because pol. changes also during a d.t. period)

- In η analysis we checked that asymmetry results obtained with a Proton in BGO/Bar or in SciRi are compatible

  We can sum up the statistics BEFORE the extraction of the asymmetry in bins with same ThetaCM

  This can be applied in the η' analysis to the statistics of Protons in Spectr and in SciRi in order to increase the statistics

- In η analysis we showed that the procedure of kinematical reconstruction applied to $\eta \rightarrow \pi^+ \pi^- \pi^0$ is valid and allows the correct identification of this decay channel when Proton is in SciRi

  We can apply this procedure in the analysis of $\eta' \rightarrow \pi^+ \pi^- \eta$ with Proton in SciRi in order to increase the statistics

THANK YOU!

$\gamma\, p \rightarrow \eta\, p \rightarrow \pi^+ \pi^- \pi^0 + p$
with: 2 γ in BGO (π^0) + 1 proton in Centr/Interm Det
$\pi^+ \pi^-$ in BGO

We miss the energies of pions (and also proton when it is in Centr or Interm Det)

We apply momentum conservation along the three directions and we get a system of three equations:

$$0 = p_P \sin\theta_P \cos\varphi_P + E_{\gamma1}\sin\theta_{\gamma1}\cos\varphi_{\gamma1} + E_{\gamma2}\sin\theta_{\gamma2}\cos\varphi_{\gamma2} + p_{\pi1}\sin\theta_{\pi1}\cos\varphi_{\pi1} + p_{\pi2}\sin\theta_{\pi2}\cos\varphi_{\pi2}$$

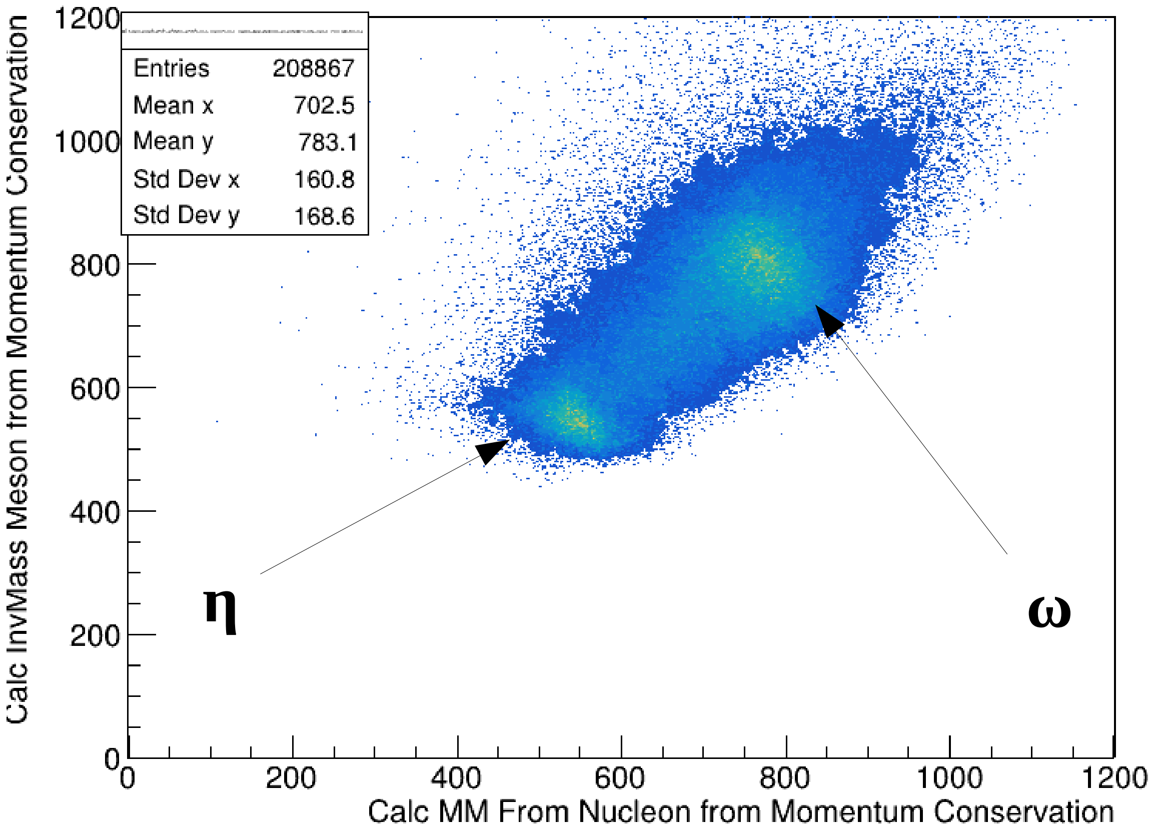
$$0 = p_P \sin\theta_P \sin\varphi_P + E_{\gamma1}\sin\theta_{\gamma1}\sin\varphi_{\gamma1} + E_{\gamma2}\sin\theta_{\gamma2}\sin\varphi_{\gamma2} + p_{\pi1}\sin\theta_{\pi1}\sin\varphi_{\pi1} + p_{\pi2}\sin\theta_{\pi2}\sin\varphi_{\pi2}$$

$$E_\gamma = p_P \cos\theta_P + E_{\gamma1}\cos\theta_{\gamma1} + E_{\gamma2}\cos\theta_{\gamma2} + p_{\pi1}\cos\theta_{\pi1} + p_{\pi2}\cos\theta_{\pi2}$$

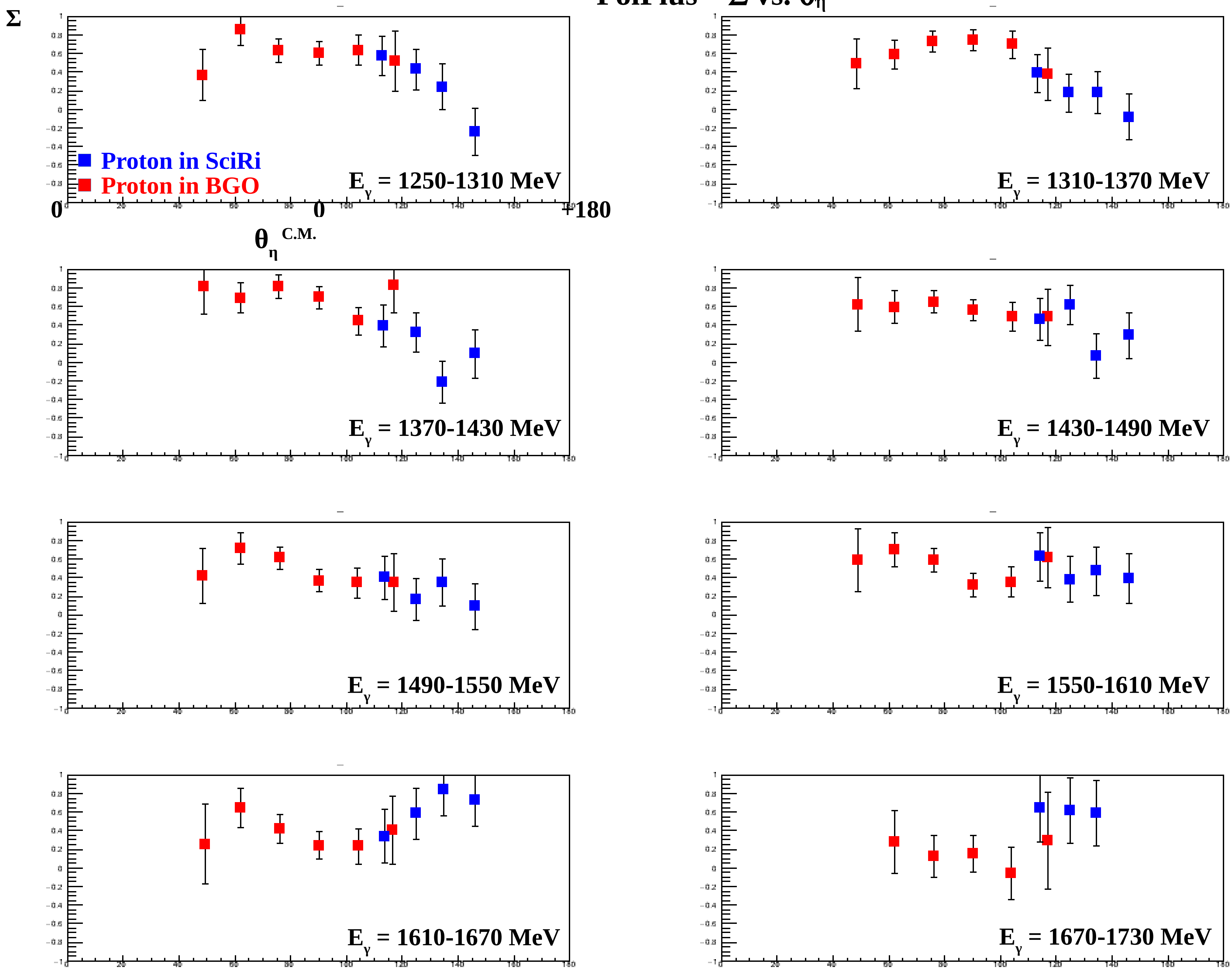
Where:
- **proton and charged pions angles** ($\theta_{P,}\, \varphi_P$) ($\theta_{\pi1}\, \varphi_{\pi1}$) ($\theta_{\pi1}\, \varphi_{\pi1}$) are measured
- **photons energies and angles** ($\theta_{\gamma2}\varphi_{\gamma2}$) ($\theta_{\gamma2}\varphi_{\gamma2}$) are measured
- **proton and charged pions momenta are unknown**
- **NO HYPOTHESIS has been done on the nature of the meson decaying into $\pi^+\pi^-\pi^0$**

These means that we can build two independent variables:

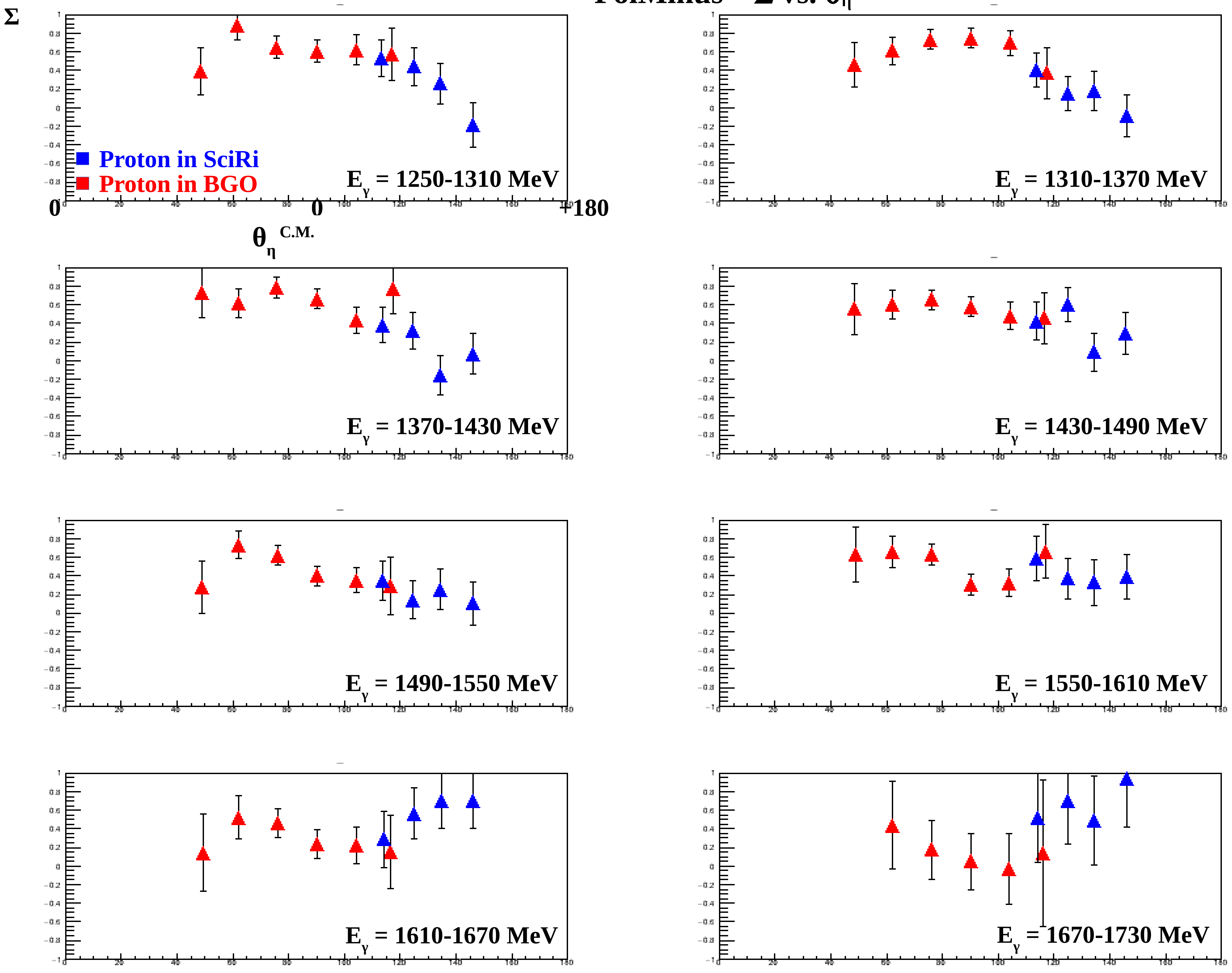
- **Calculated Invariant Mass of ($\pi^0\ \pi^+\ \pi^-$)** **which involves:**
  - **Reconstructed $\pi^+\ \pi^-$ momenta**
  - **Detected π^0**
- **Calculated Missing Mass from Proton ($\gamma p \rightarrow p\ X$)** **which involves:**
  - **Reconstructed proton momentum**
  - **Incident Beam Energy**



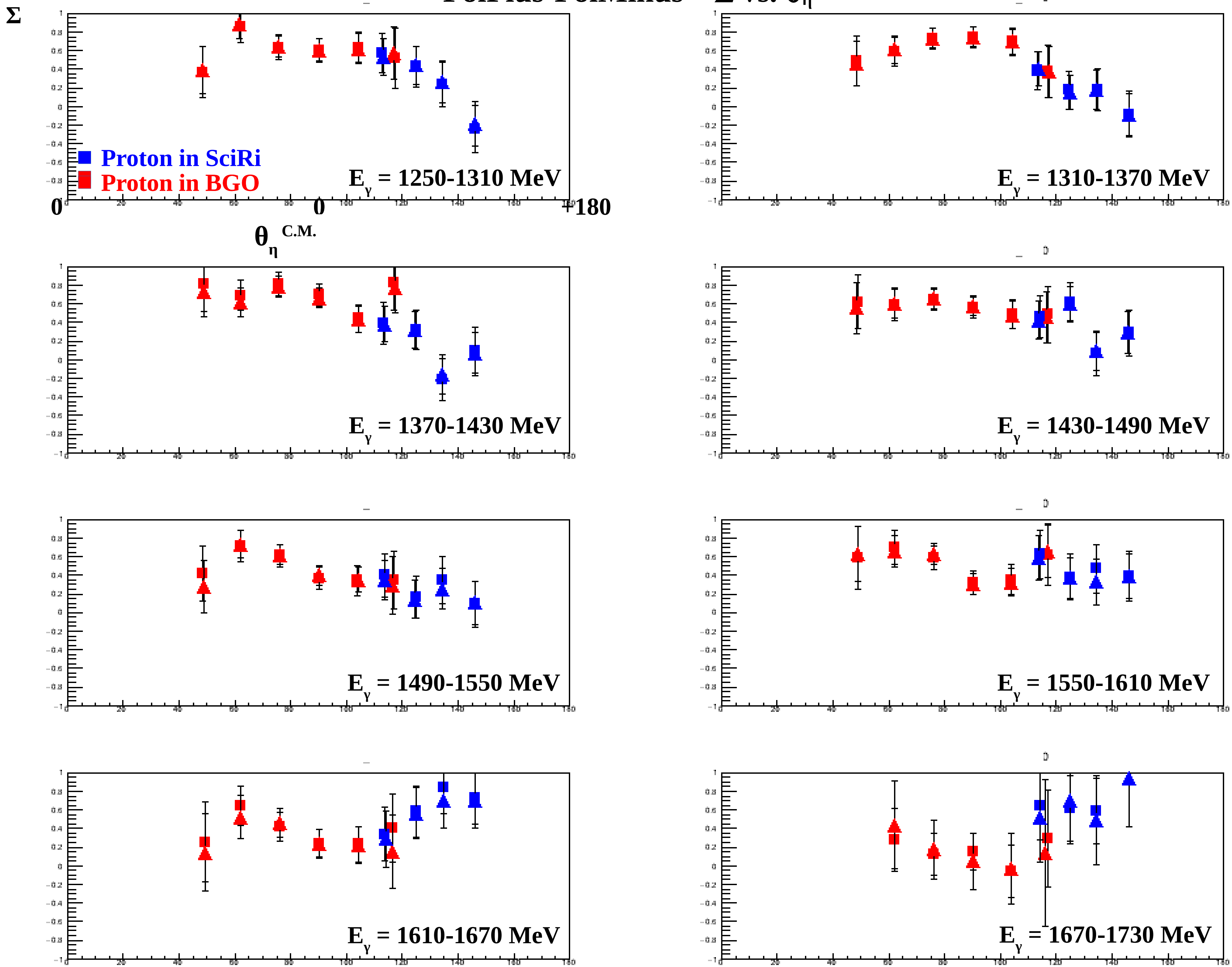
PolPlus – Σ vs. θ_η^{CM}



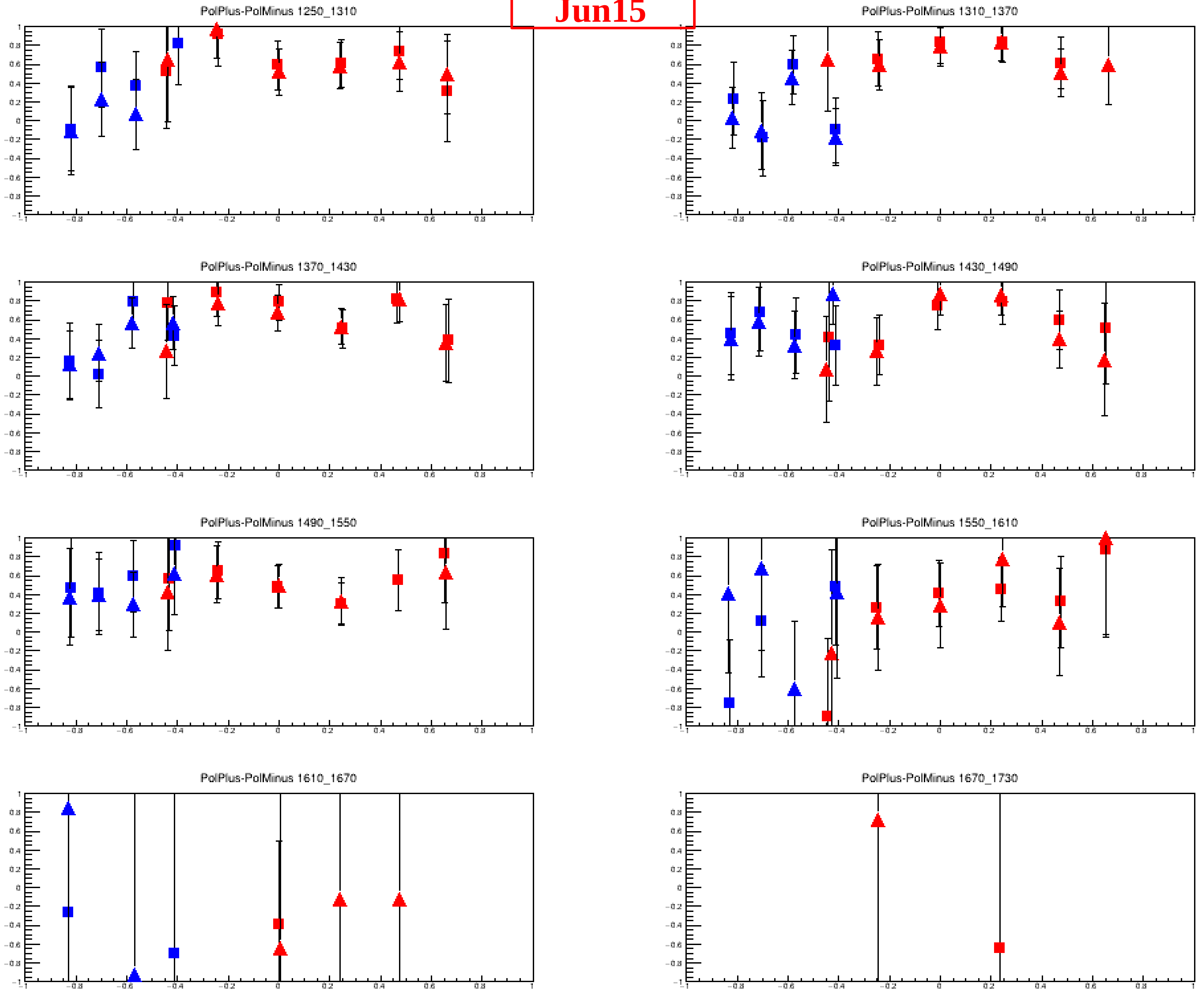
PolMinus – Σ vs. θ_η^{CM}



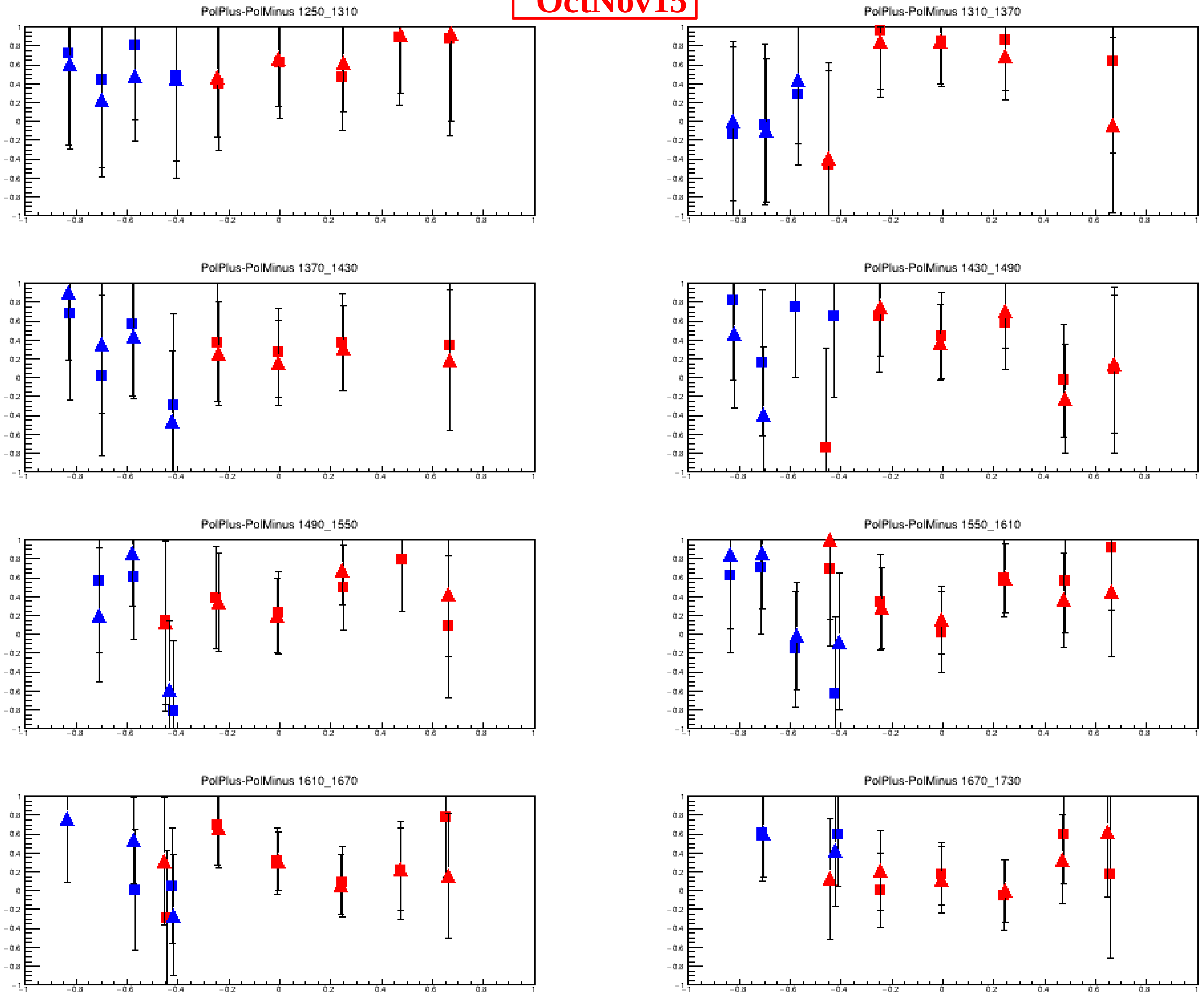
PolPlus-PolMinus – Σ vs. θ_η^{CM}



Jun15


PolPlus-PolMinus 1250_1310
PolPlus-PolMinus 1310_1370
PolPlus-PolMinus 1370_1430
PolPlus-PolMinus 1430_1490
PolPlus-PolMinus 1490_1550
PolPlus-PolMinus 1550_1610
PolPlus-PolMinus 1610_1670
PolPlus-PolMinus 1670_1730

OctNov15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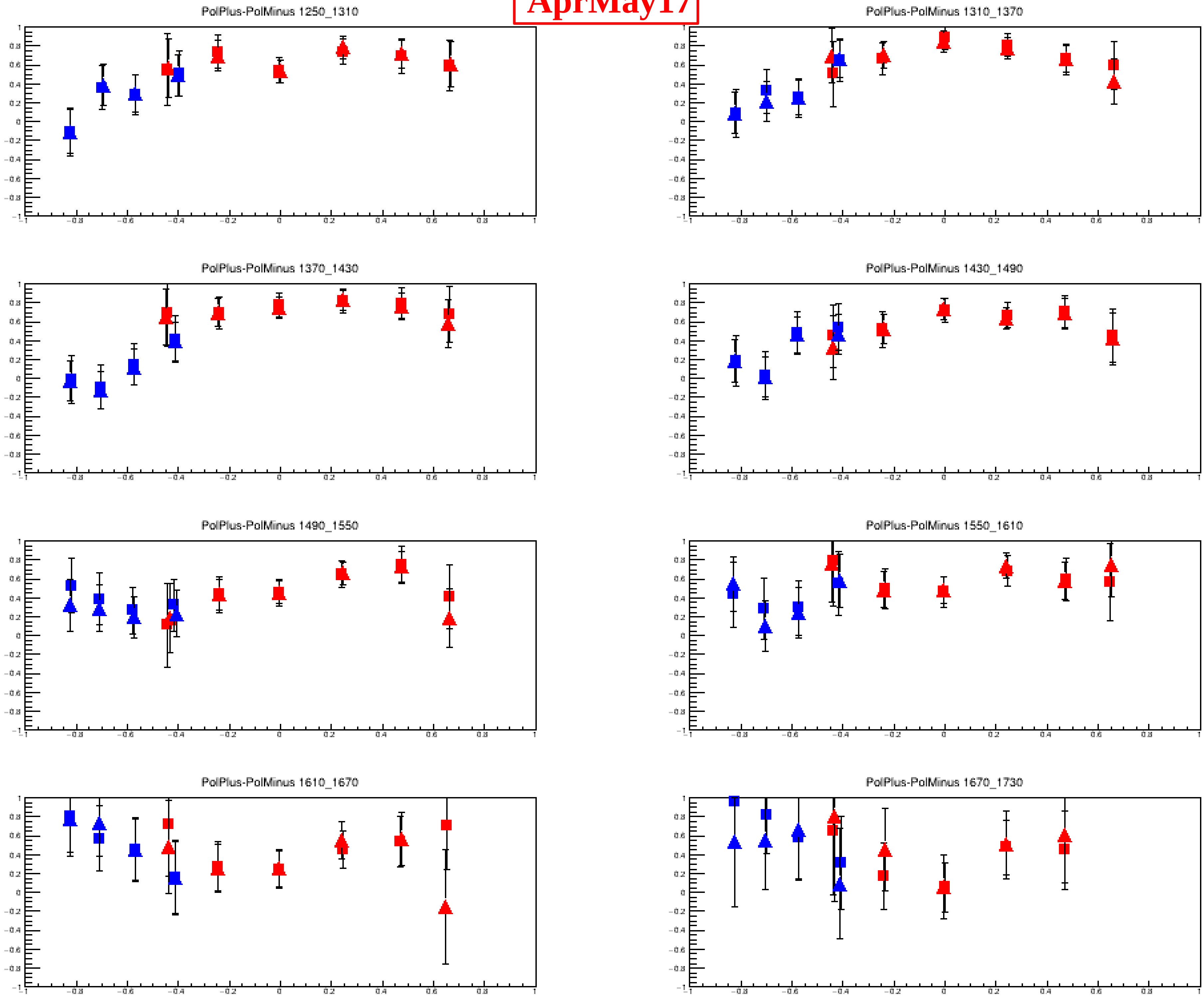
PolPlus-PolMinus 1550_1610
PolPlus-PolMinus 1610_1670
PolPlus-PolMinus 1670_1730

AprMay17


PolPlus-PolMinus 1250_1310
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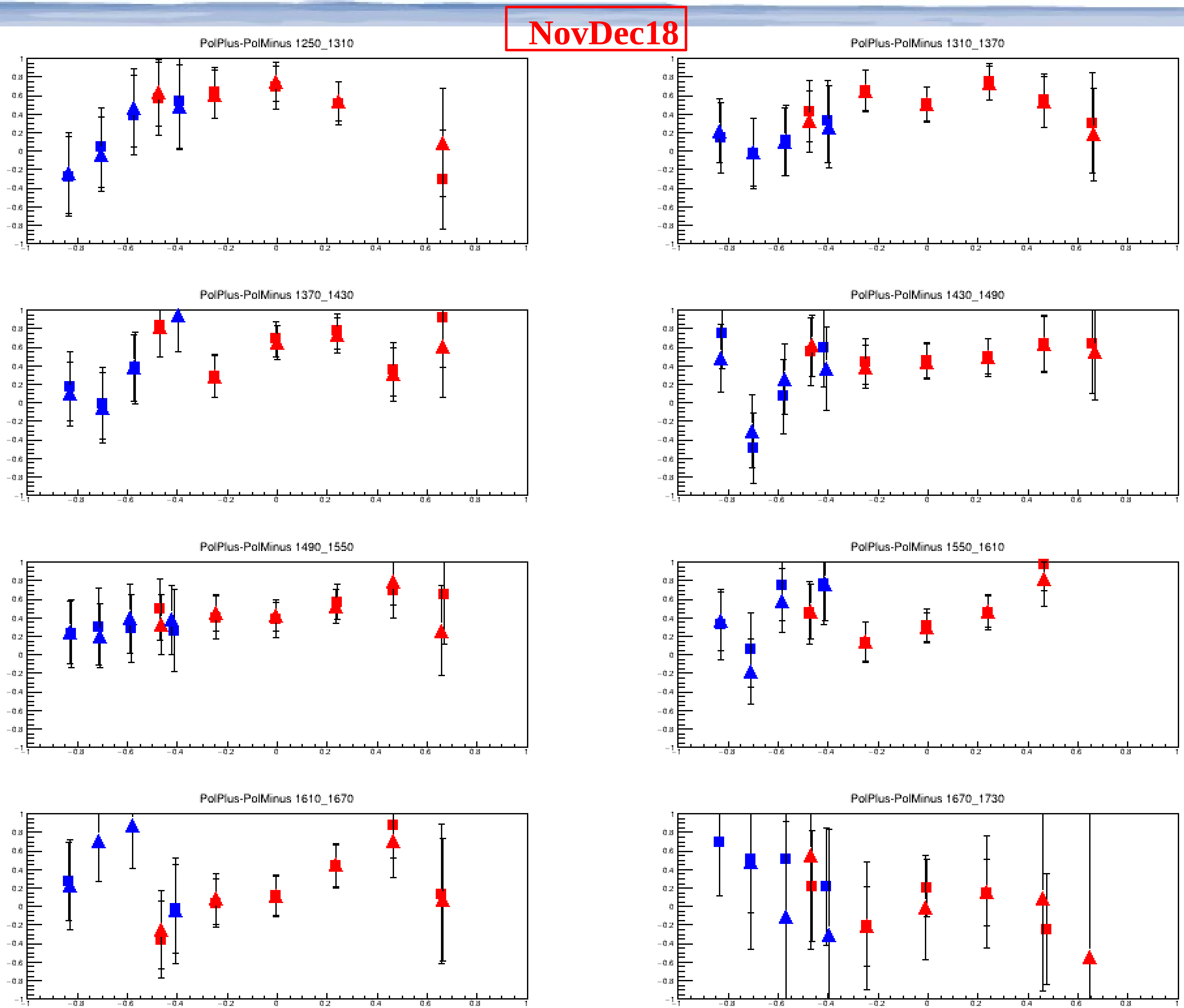
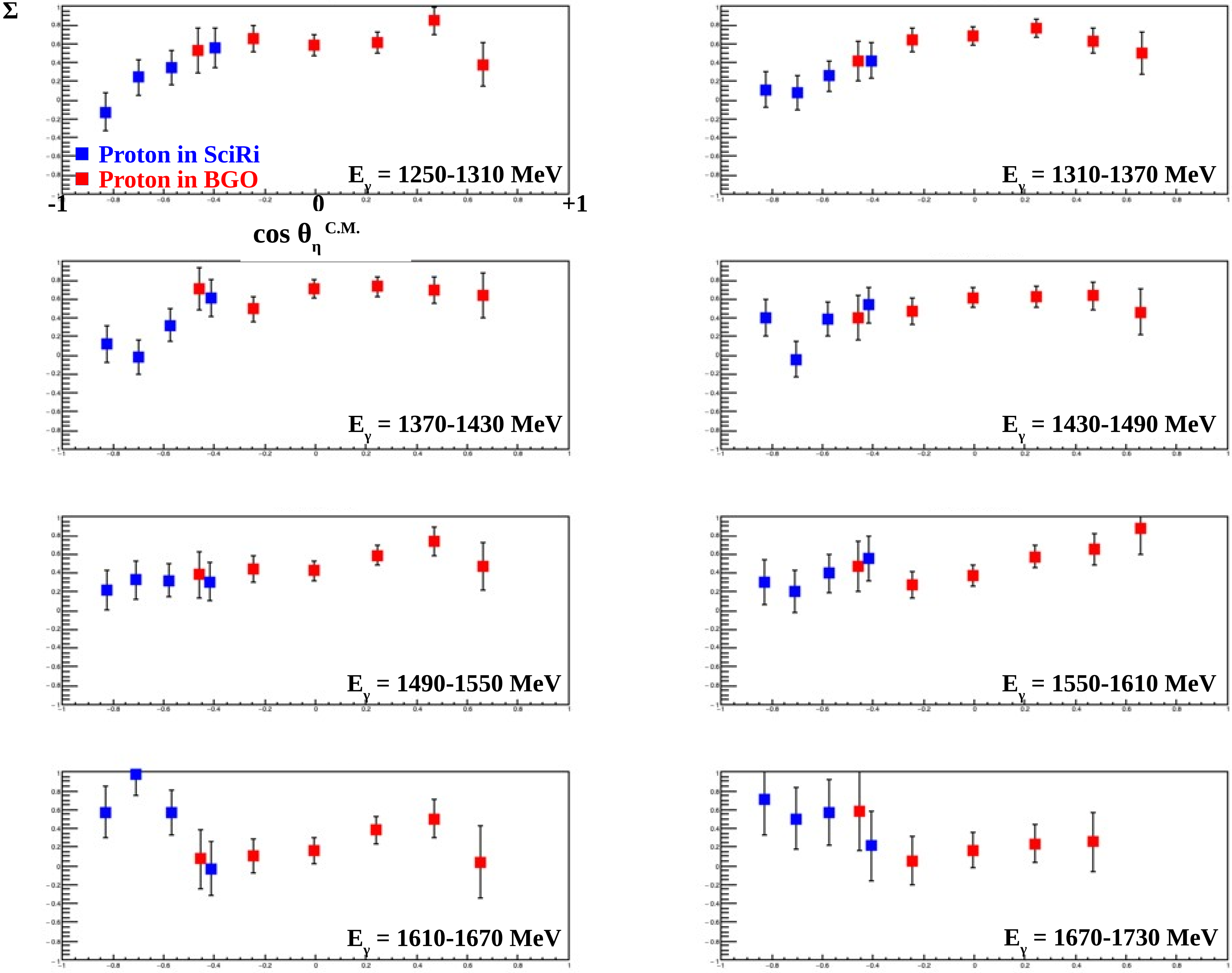
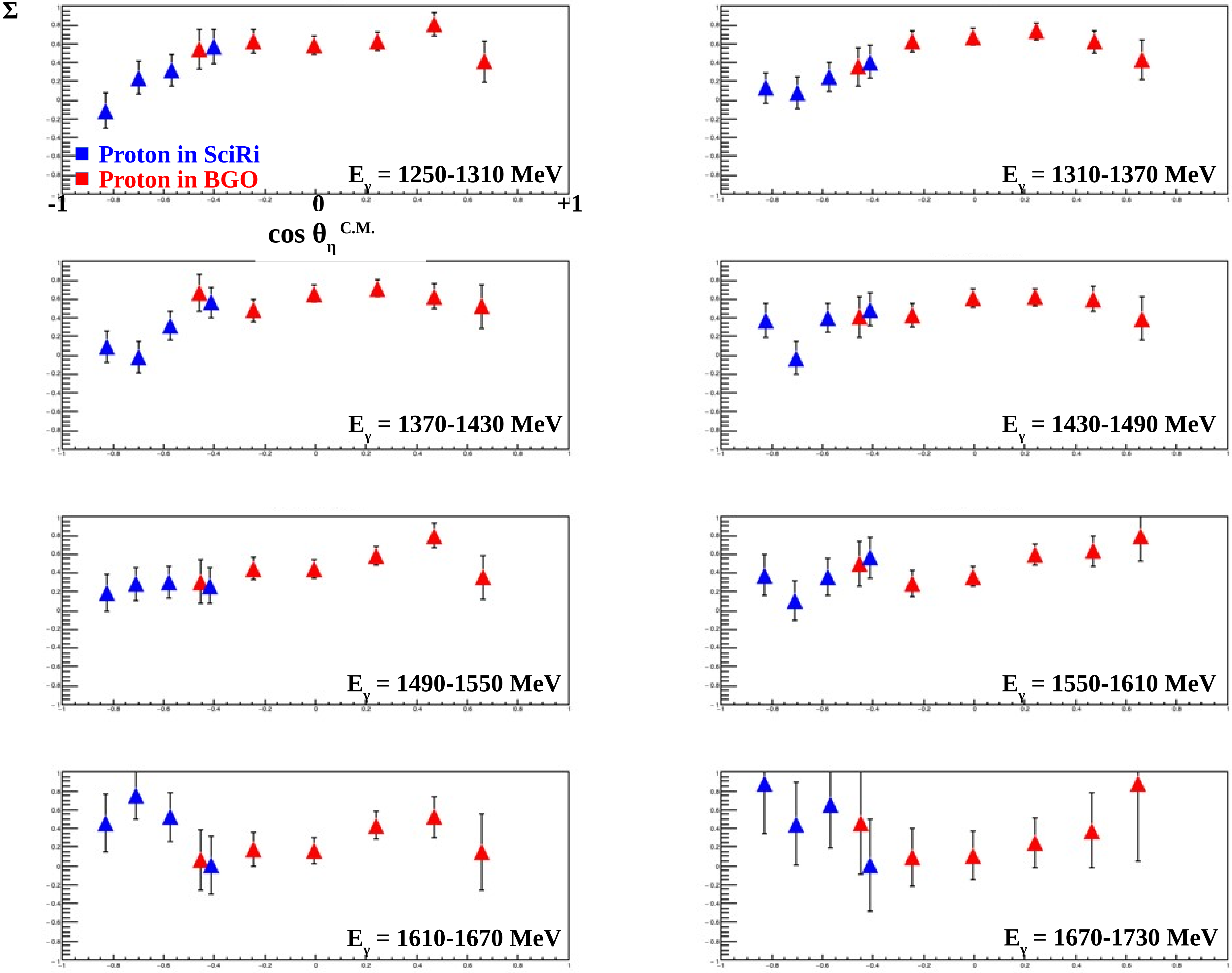
PolPlus-PolMinus 1550_1610
PolPlus-PolMinus 1610_1670
PolPlus-PolMinus 1670_1730


NovDec18
PolPlus-PolMinus 1250_1310
PolPlus-PolMinus 1310_1370
PolPlus-PolMinus 1370_1430
PolPlus-PolMinus 1430_1490
PolPlus-PolMinus 1490_1550
PolPlus-PolMinus 1550_1610
PolPlus-PolMinus 1610_1670
PolPlus-PolMinus 1670_1730

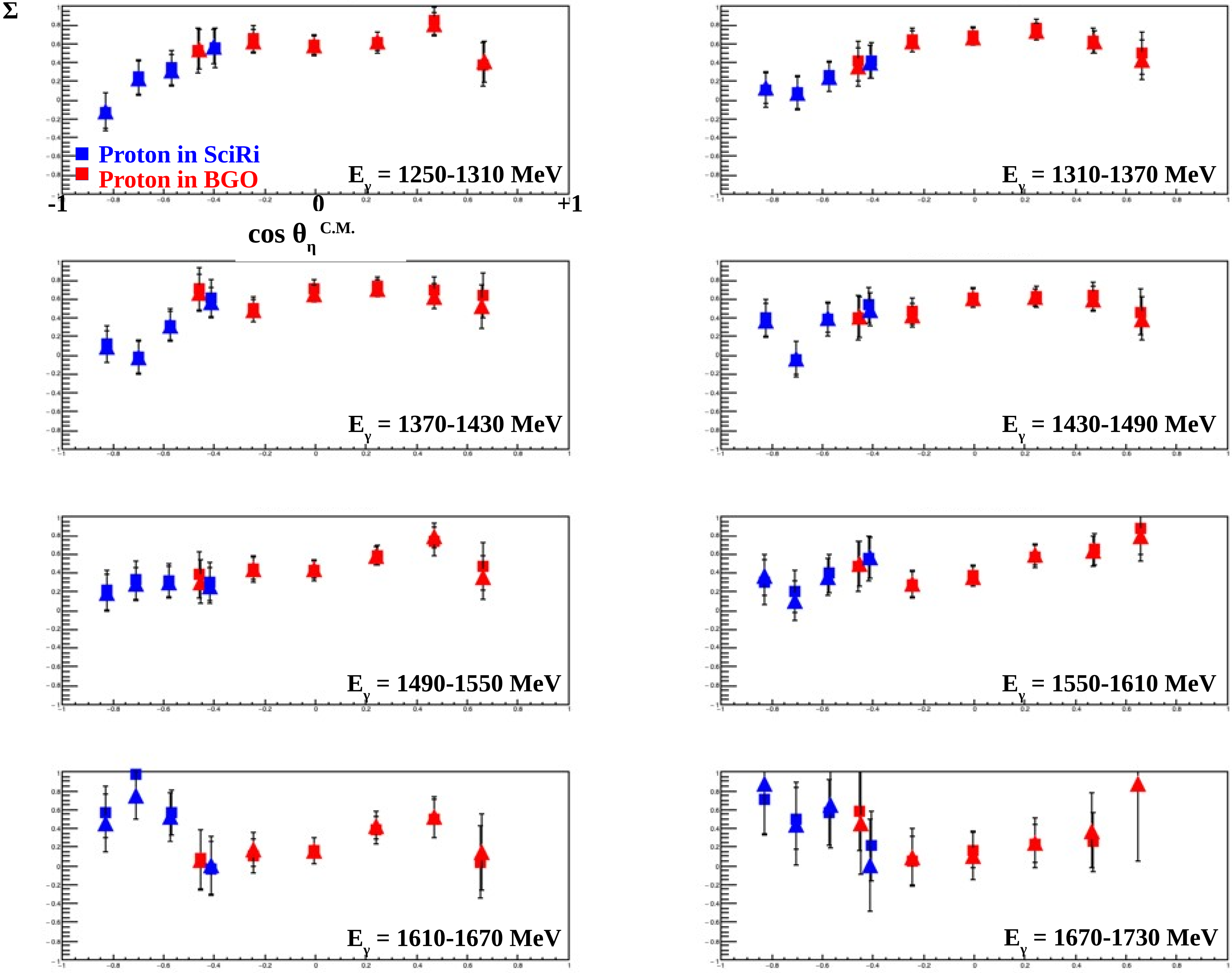
PolPlus – Old Cuts



PolMinus – Old Cuts



PolPlus/PolMinus – Old Cuts



1) **PREVIOUSLY USED TECHNIQUE**

We first sum up the *Pol+* number of events of the two periods and then normalize to the sum of the fluxes of the two periods:

$$\frac{N_{Pol+}^{P1}+N_{Pol+}^{P2}}{F_{Pol+}^{P1}+F_{Pol+}^{P2}} \qquad (9)$$

The behaviour of the average of normalized and unpolarized number of events on the number of periods N_{PER} (N_{PER}=2 in this case) is in general:

$$\langle N_{UNP,norm}\rangle=\frac{1}{N_{PER}}\sum 2\,\varepsilon^{Pi}(\varphi) \qquad (10)$$

The behaviour of (9) (with some mathematical passages) becomes:

$$\frac{N_{Pol+}^{P1}+N_{Pol+}^{P2}}{F_{Pol+}^{P1}+F_{Pol+}^{P2}}\propto\frac{\varepsilon^{P1}(\varphi)\,F_{Pol+}^{P1}\left(1+P_{Pol+}^{P1}\Sigma\cos(2\varphi)\right)+\varepsilon^{P2}(\varphi)^{P2}F_{Pol+}^{P2}\left(1+P_{Pol+}^{P2}\Sigma\cos(2\varphi)\right)}{F_{Pol+}^{P1}+F_{Pol+}^{P2}}$$

ONLY IF the detection/reconstruction efficiency of the two periods is the same:

$$\varepsilon^{Pi}(\varphi)=\varepsilon(\varphi) \qquad \forall\, Pi \qquad i=1,\ldots,N_{PER}$$

the behaviour of (9) becomes:

$$\frac{N^{P1}_{Pol+}+N^{P2}_{Pol+}}{F^{P1}_{Pol+}+F^{P2}_{Pol+}}=\varepsilon(\varphi)\left[1+\langle P_{Pol+}\rangle\Sigma\cos(2\varphi)\right] \qquad (9)$$

where:

$$\langle P_{Pol+}\rangle=\frac{P^{P1}_{Pol+}F^{P1}_{Pol+}+P^{P2}_{Pol+}F^{P2}_{Pol+}}{F^{P1}_{Pol+}+F^{P2}_{Pol+}} \qquad (11)$$

And the efficiency can be simplified in the ratio (9)/(10):

$$\frac{\dfrac{N^{P1}_{Pol+}+N^{P2}_{Pol+}}{F^{P1}_{Pol+}+F^{P2}_{Pol+}}}{\langle N_{UNP,norm}\rangle}=\frac{\cancel{\varepsilon(\varphi)}\left[1+\langle P_{Pol+}\rangle\Sigma\cos(2\varphi)\right]}{2\cancel{\varepsilon(\varphi)}}=\frac{1}{2}\left(1+\langle P_{Pol+}\rangle\Sigma\cdot\cos(2\varphi)\right) \qquad (12)$$

This is no more possible if the efficiencies are not the same. For instance for two periods the ratio (9)/(10) becomes:

$$\frac{\dfrac{\dfrac{N^{P1}_{Pol+}+N^{P2}_{Pol+}}{F^{P1}_{Pol+}+F^{P2}_{Pol+}}}{\langle N_{UNP,norm}\rangle}}{} = \frac{\dfrac{\left[\varepsilon^{P1}(\varphi)F^{P1}_{Pol+}+\varepsilon^{P2}(\varphi)F^{P2}_{Pol+}\right]}{F^{P1}_{Pol+}+F^{P2}_{Pol+}}\left[1+\langle P_{Pol+}\rangle\Sigma\cos(2\varphi)\right]}{\frac{1}{2}\left(2\varepsilon^{P1}(\varphi)+2\varepsilon^{P2}(\varphi)\right)} \qquad (13)$$

→ With this technique **it is not possible** to extract the asymmetries from two or more data taking periods **unless the efficiencies are the same**.