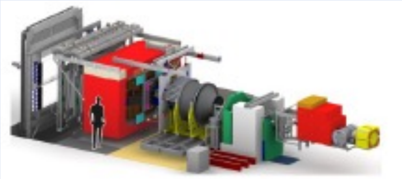

Σ beam asymmetry for η photoproduction off the proton at BGOOD

Alessia Fantini

on behalf of the BGOOD collaboration

Project supported by the EU Horizon 2020 research & innovation programme, grant agreement 824093

Exotic Multi-Quark States and Baryon Spectroscopy Workshop

June 25th –27th 2024 University of Bonn

TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

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STRONG 2020

ELSA

Outline:

- Brief introduction to Physics Motivations for meson photoproduction measurements
- Short description of BGOOD apparatus
- Analysis and η photoproduction events selection
- Beam Asymmetry Σ extraction method
- Σ measurement Results & comparison with Existing Data
- Summary & Conclusions

Why meson photoproduction ?

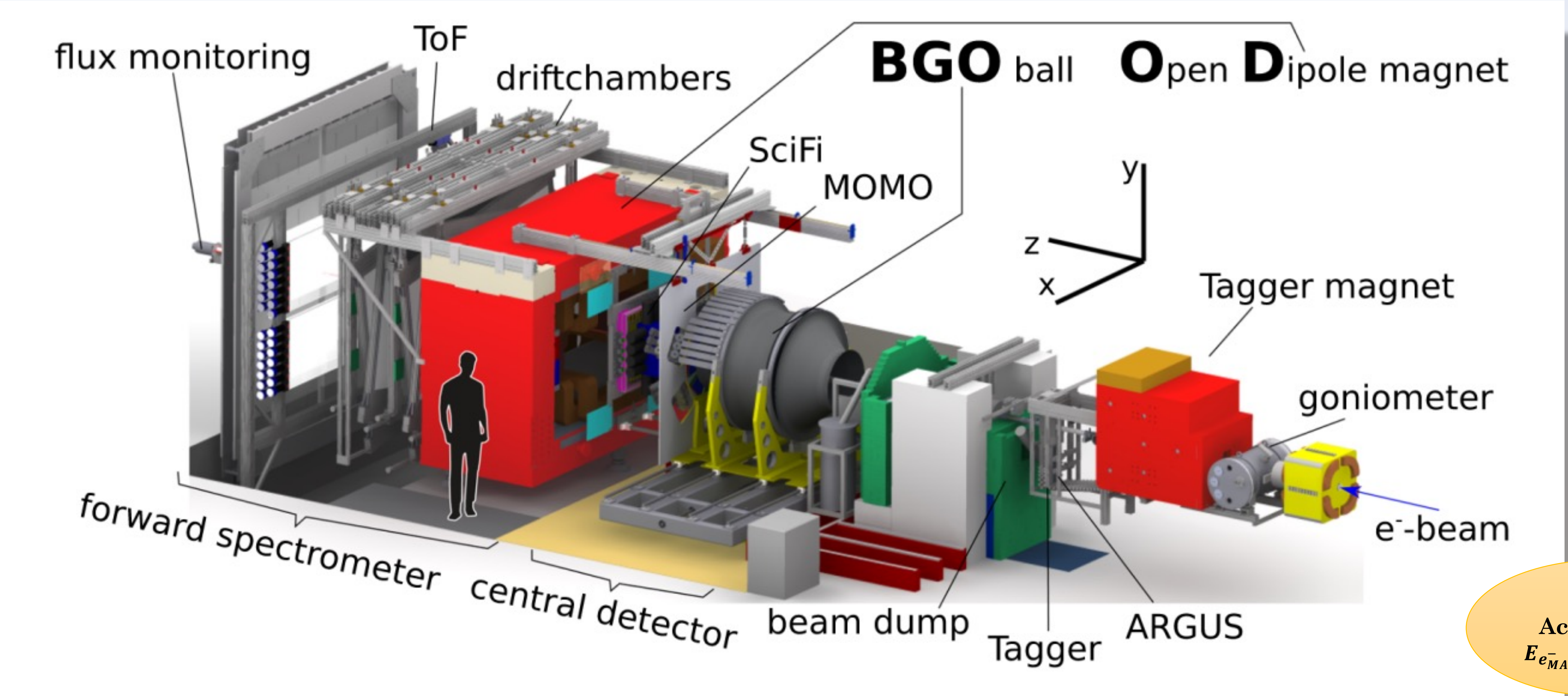
- The understanding of the dynamics underlying the bound state of the nucleon and its excited spectrum still remain a crucial task since in this energy range QCD cannot be treated in perturbative mode.
- Many models, based on different *degrees of freedom* descriptions, have been developed in order to describe the spectrum of excitation states and their features
- Meson photoproduction studies represent a strong tool for probing nucleon resonances:
  - ✓ Access to resonance states coupled to photons which only weakly coupling to the πN processes (Missing Resonances problem)
  - ✓ Access to Polarization Observables => Separation of overlapping resonances and characterization in terms of Spin and Parity, Constrains for unambiguous PWA

- Low e.m cross section => ✓ Overcome thanks to technological developments
- Non resonance contribution => ✓ Disentagled with polarization observables

η photoproduction isoscalar meson (I=0) => Isospin Filter => only N*(I=1/2)resonances as intermediate states

BGOOD Detector:

BGO calorimeter (central region) & Forward Spectrometer combination

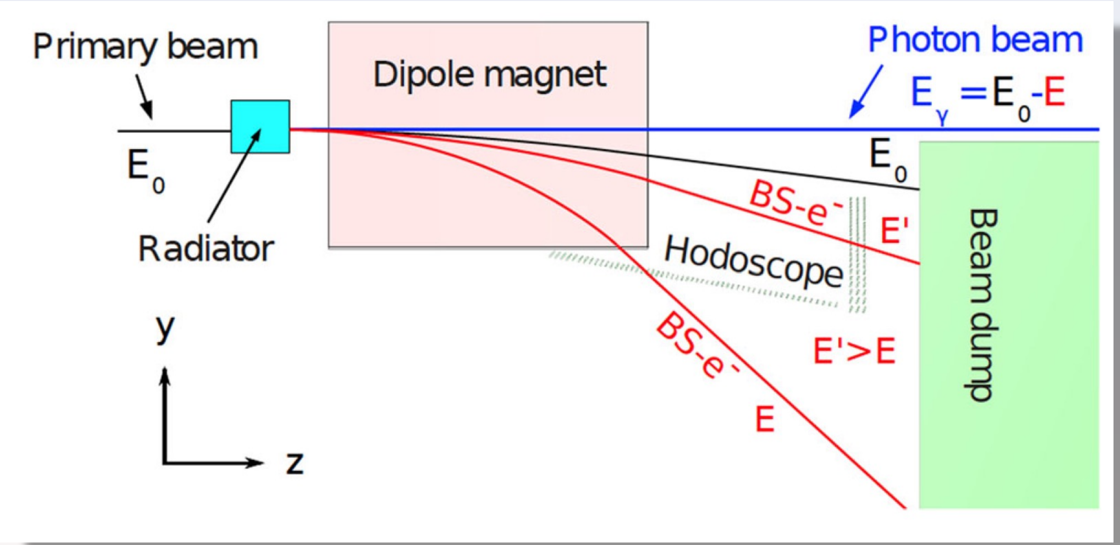


ELSA
Accelerator
$E_{e^-_{MAX}} = 3.2\ GeV$

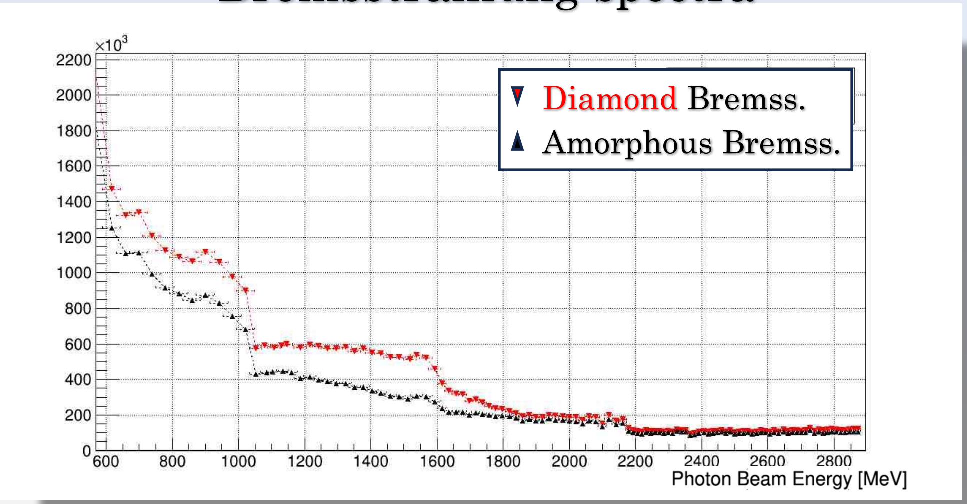
BGOOD Tagged and Polarized Bremsstrahlung Photon Beam

Tagging Detector

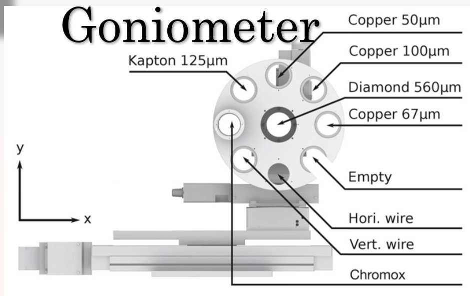
E_γ measured through the detection of the corresponding electrons in the tagging system.

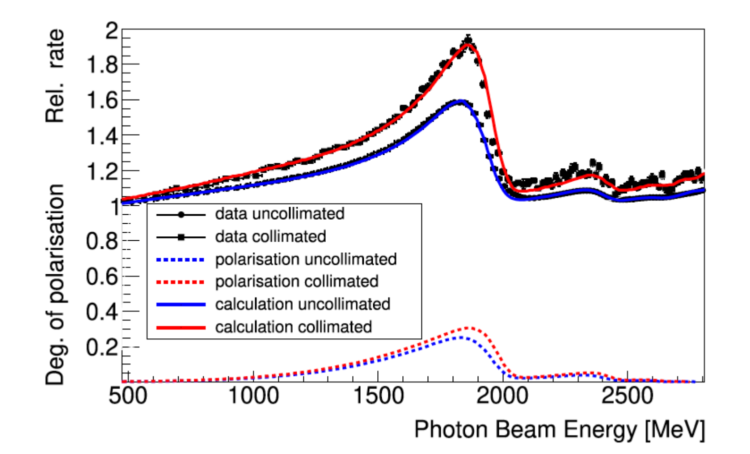


Bremsstrahlung spectra



Normalized Diamond Spectra and Polarization





linearly polarised photon beams generated by coherent bremsstrahlung using a diamond crystal radiator.

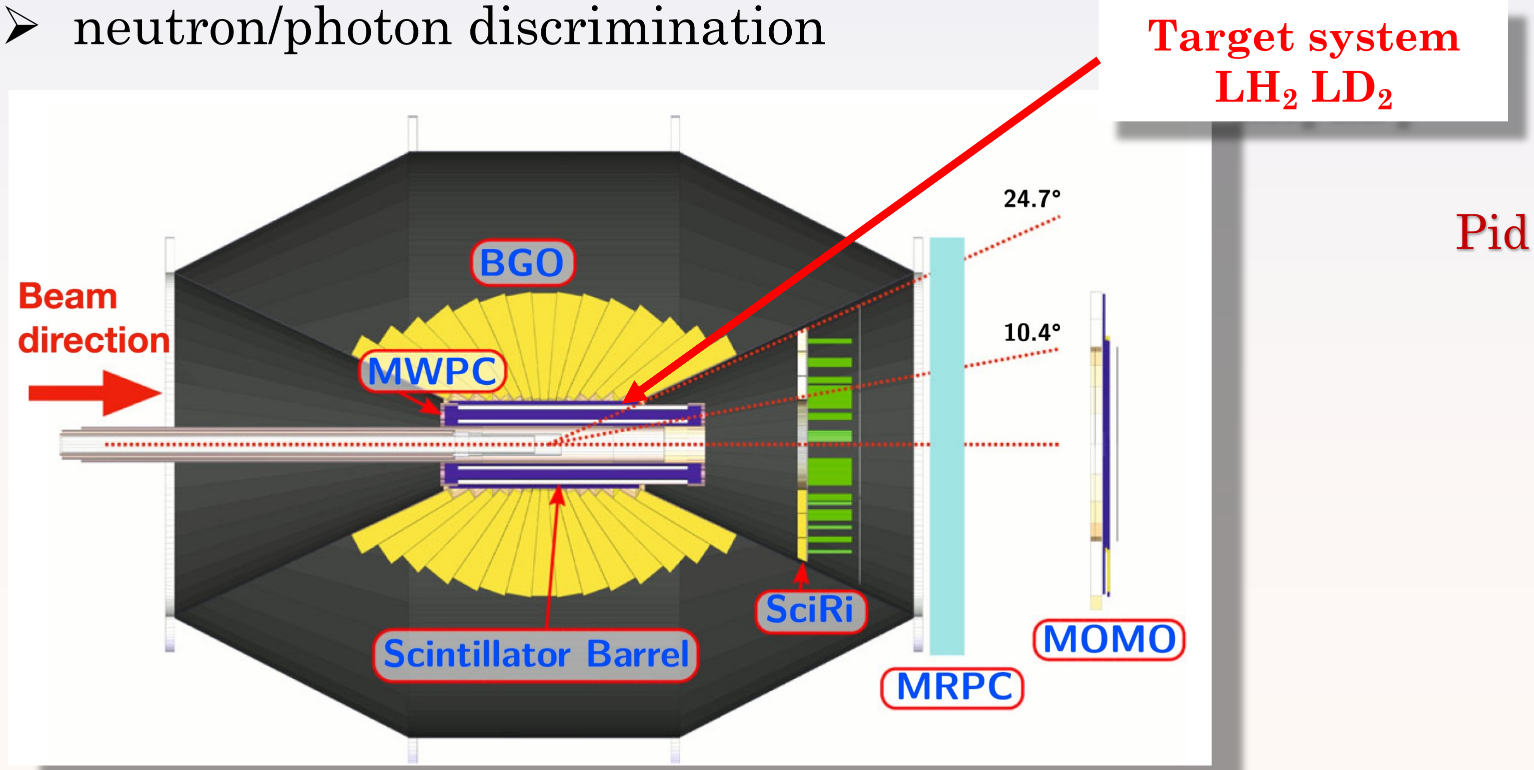
Cu Radiator → Incoherent Bremsstrahlung

Diamond Radiator → Coherent Bremss → Linearly Polarized γ beam

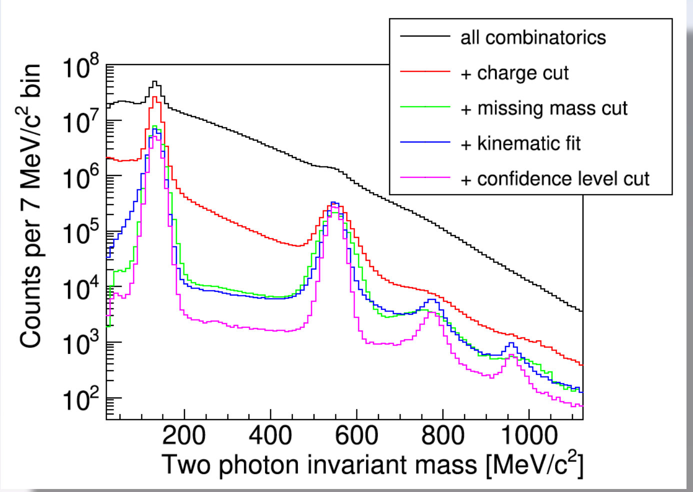
BGOOD Central Detectors:

large solid angle calorimeter:

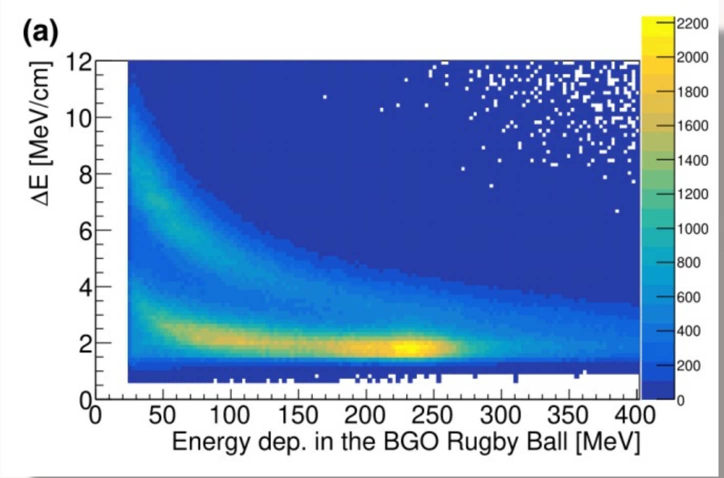
- excellent energy resolution for photons
- good detection efficiency for neutrons
- charged particle tracking and identification
- neutron/photon discrimination



Photons in BGO Rugby Ball

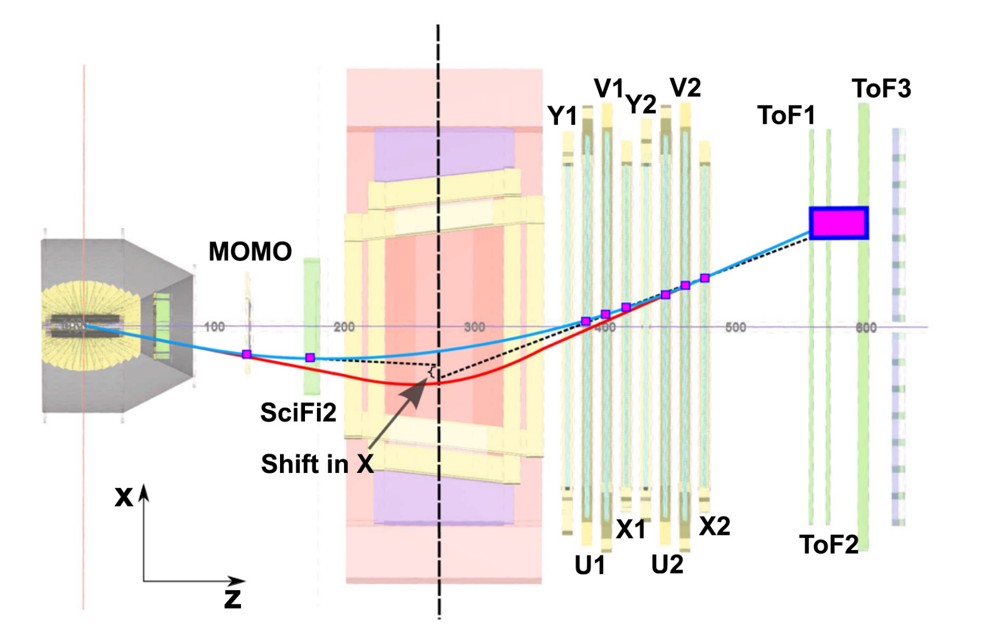


Pid BGORugbyBall-Plastic Scint. Barrel

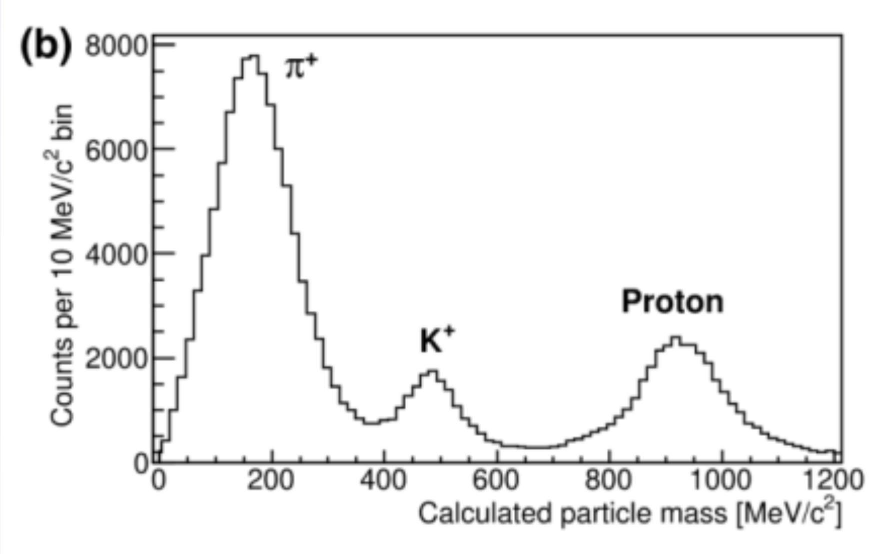


BGOOD Forward Spectrometer

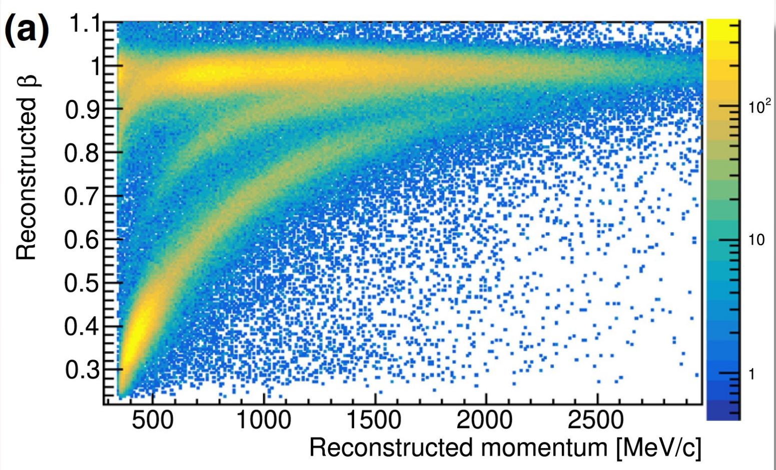
High momentum resolution forward tracking



Mass from ToF Walls



β vs Momentum in Forw Spectrometer



- Charged particles tracking in front of the magnet by means of two scintillating fibre detectors
- Behind the magnet, particle trajectories are determined through eight double layers of drift chambers

Particle identification through velocity measurements with the ToF Walls

Σ Beam Asymmetry of η photoproduction on the proton

$$\vec{\gamma} + p \rightarrow \eta + p$$

Energy Range: $E_\gamma = 1.2 \div 1.7\ GeV$

Analyzed simultaneously all main η decay channels:

$$\eta \rightarrow 2\gamma$$

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

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

for

4 data taking periods

- With different Polarization degrees
- With different detection and reconstruction efficiencies

$\vec{\gamma} + p \rightarrow \eta + p$ *Events Selection:*

1) $\eta \rightarrow 2\gamma$

2 γ detected in the BGO + 1 proton in whole apparatus

2) $\eta \rightarrow 3\pi^0$

6 γ detected in the BGO + 1 proton in whole apparatus

3) $\eta \rightarrow \pi^+ + \pi^- + \pi^0$

2 γ detected in BGO + 1 proton $+\pi^+ + \pi^-$ in whole apparatus

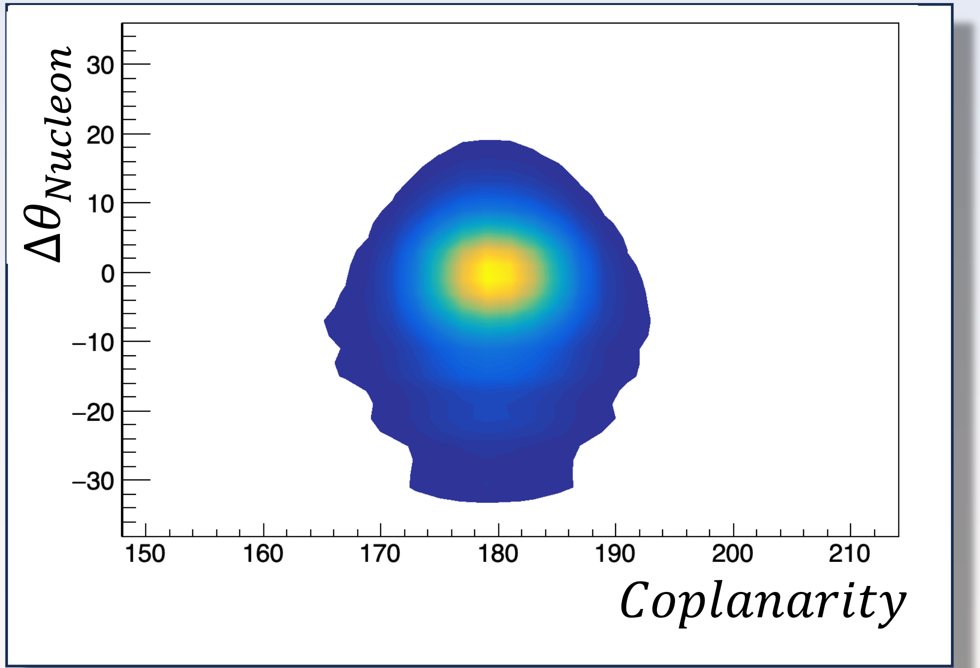
for this last case:

$|\boldsymbol{p_p}|$ $|\boldsymbol{p_{\pi^+}}|$ $|\boldsymbol{p_{\pi^-}}|$ **reconstructed** from momentum conservation between Initial and Final State Particles with NO hypothesis on the decaying meson

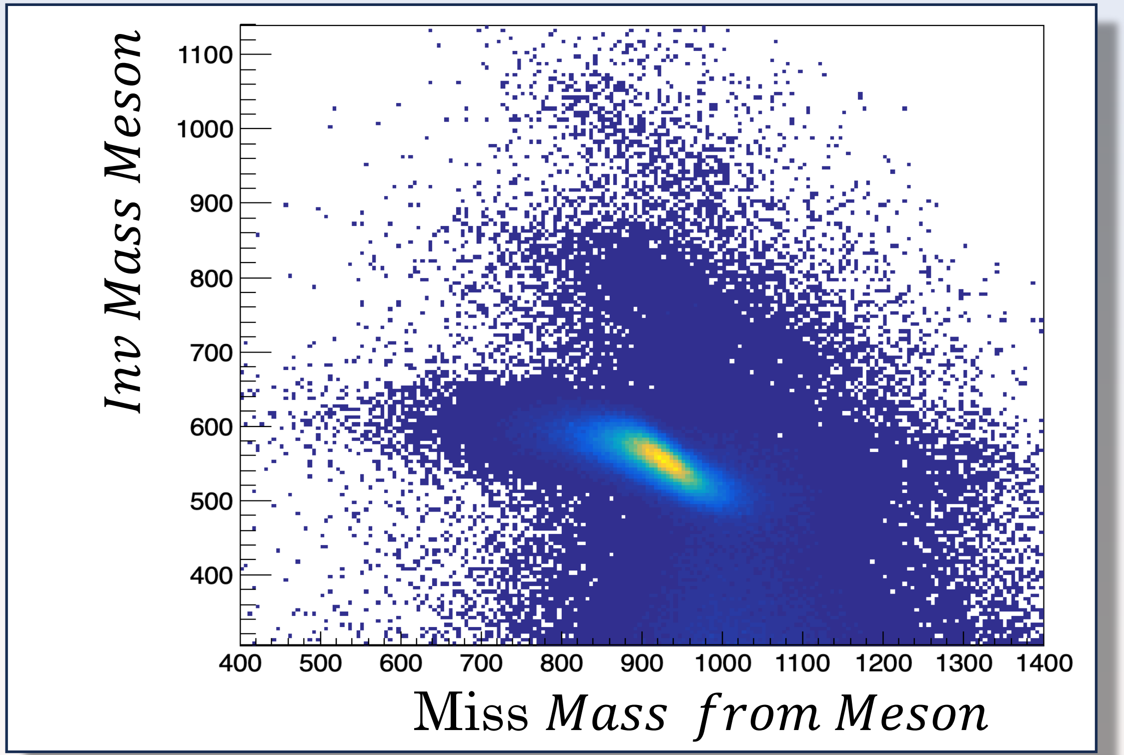
Measured quantities: => *Beam Energy* E_γ
p *and* $\pi^\pm$ *angles* (θ_P, φ_P) $(\theta_{\pi^+}, \varphi_{\pi^+})$ $(\theta_{\pi^-}, \varphi_{\pi^-})$
$2\,\gamma's$ *energies and angles* $(E_{\gamma_1}, \theta_{\gamma_1}, \varphi_{\gamma_1})$ $(E_{\gamma_2}, \theta_{\gamma_2}, \varphi_{\gamma_2})$

$1)\ \vec{\gamma} + p \rightarrow \eta + p\ \rightarrow 2\gamma + p$ $2)\ \vec{\gamma} + p \rightarrow \eta + p\ \rightarrow 6\gamma + p$

$\theta^{calc}_{missP} - \theta^{meas}_{P}$ % $Coplanarity$



Meson $InvMass$ % $MissMass\ from\ Meson$

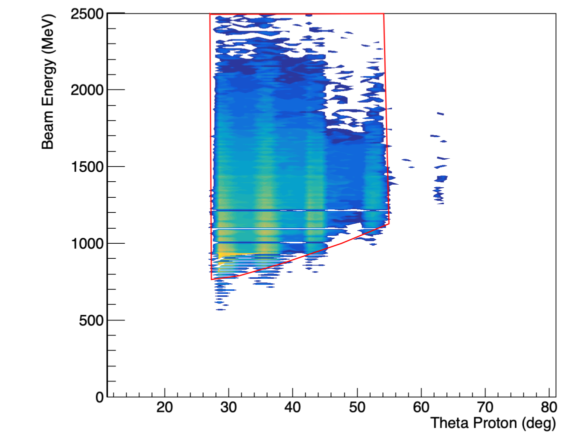


2-body reaction completely defined by the meson reconstructed from the 2 γ's or 6 γ 's in BGO and the proton detected in whole apparatus.

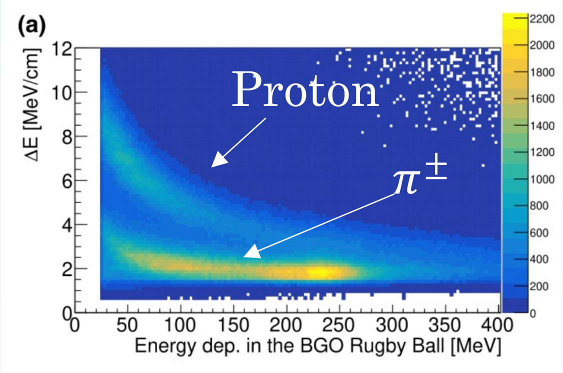
Redundancy of Measured variables => Clean Event Selection by means of 2D Graphical Cuts

3) $\vec{\gamma} + p \rightarrow \eta + p \rightarrow \pi^{+} + \pi^{-} + \pi^{0} + p$

Preselection

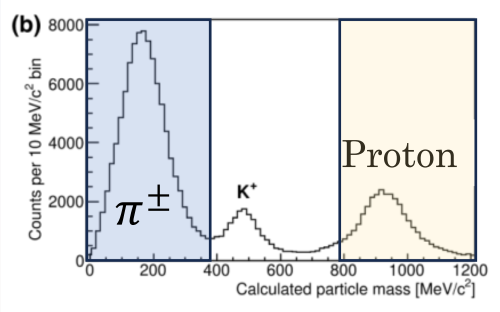


E_{γ} % $\theta_{P_{LAB}}$

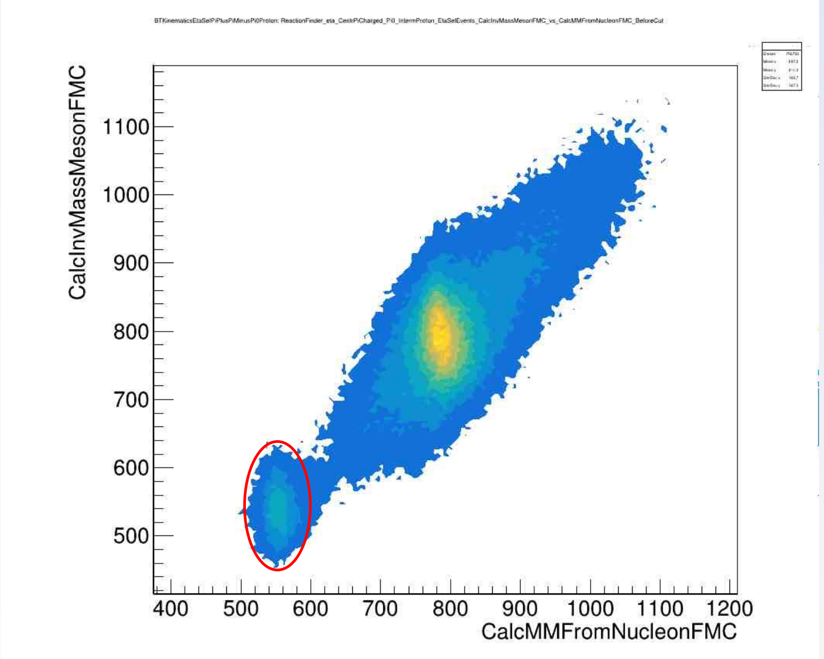


$\Delta E\%E$

PID



Mass from ToF



Preselection => Kinematical cut on E_{γ} % $\theta_{P_{LAB}}$

Cut on 2γ's InvMass $\Rightarrow$ π^{0} *selection*

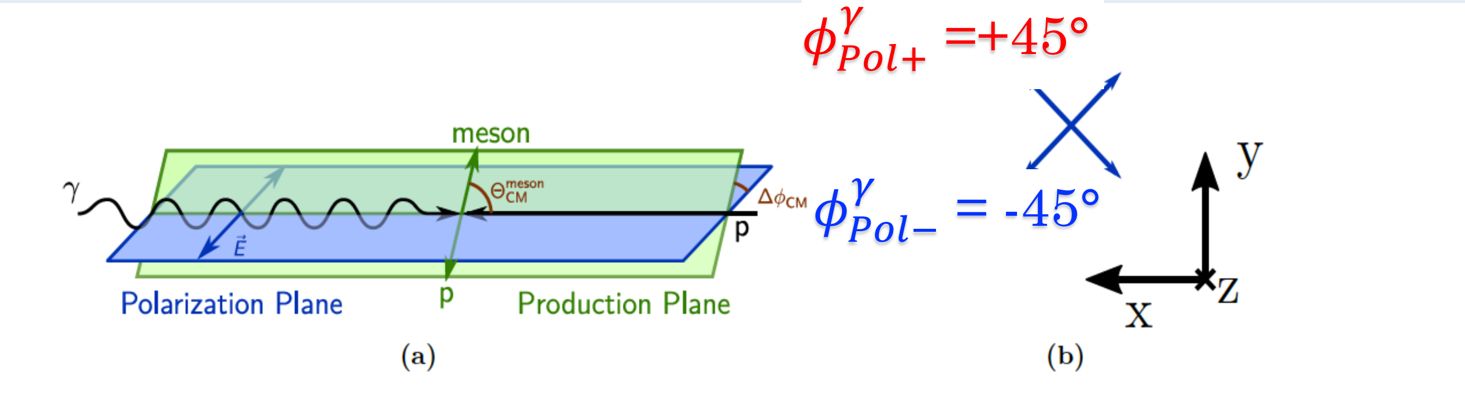
PID Proton - $\pi^{\pm}$ => $\Delta E\%E$ in BGO-Barrel detectors

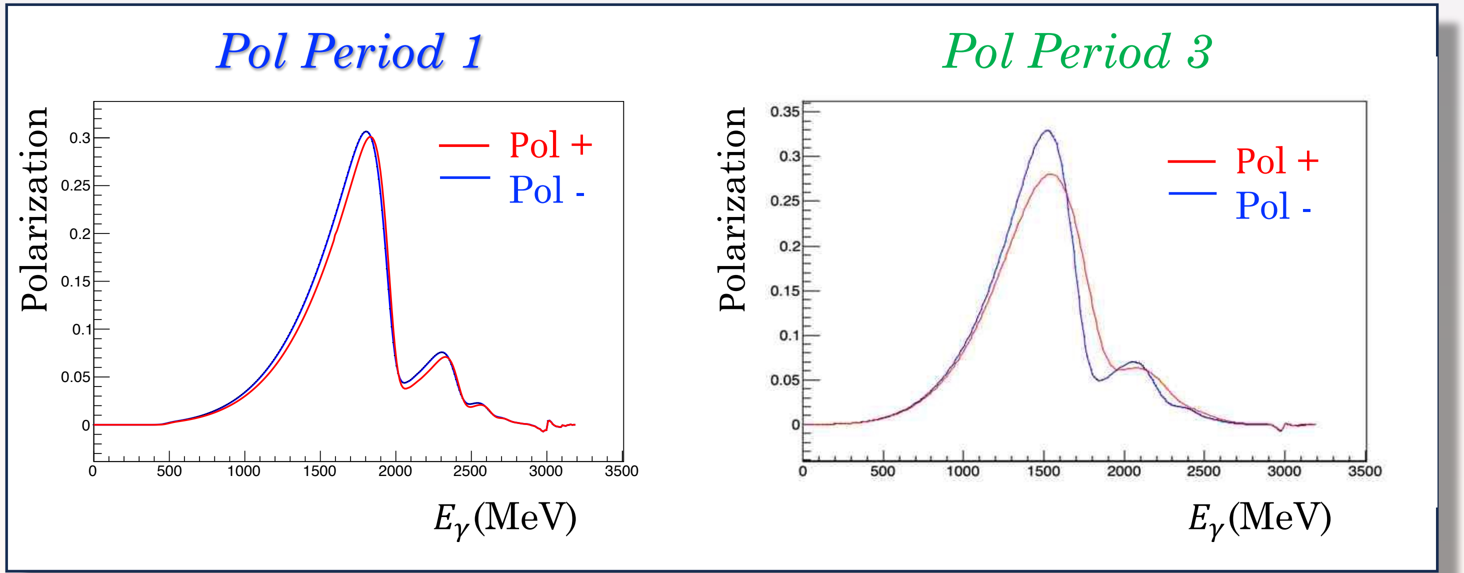
Mass from ToF in the Spectrometer

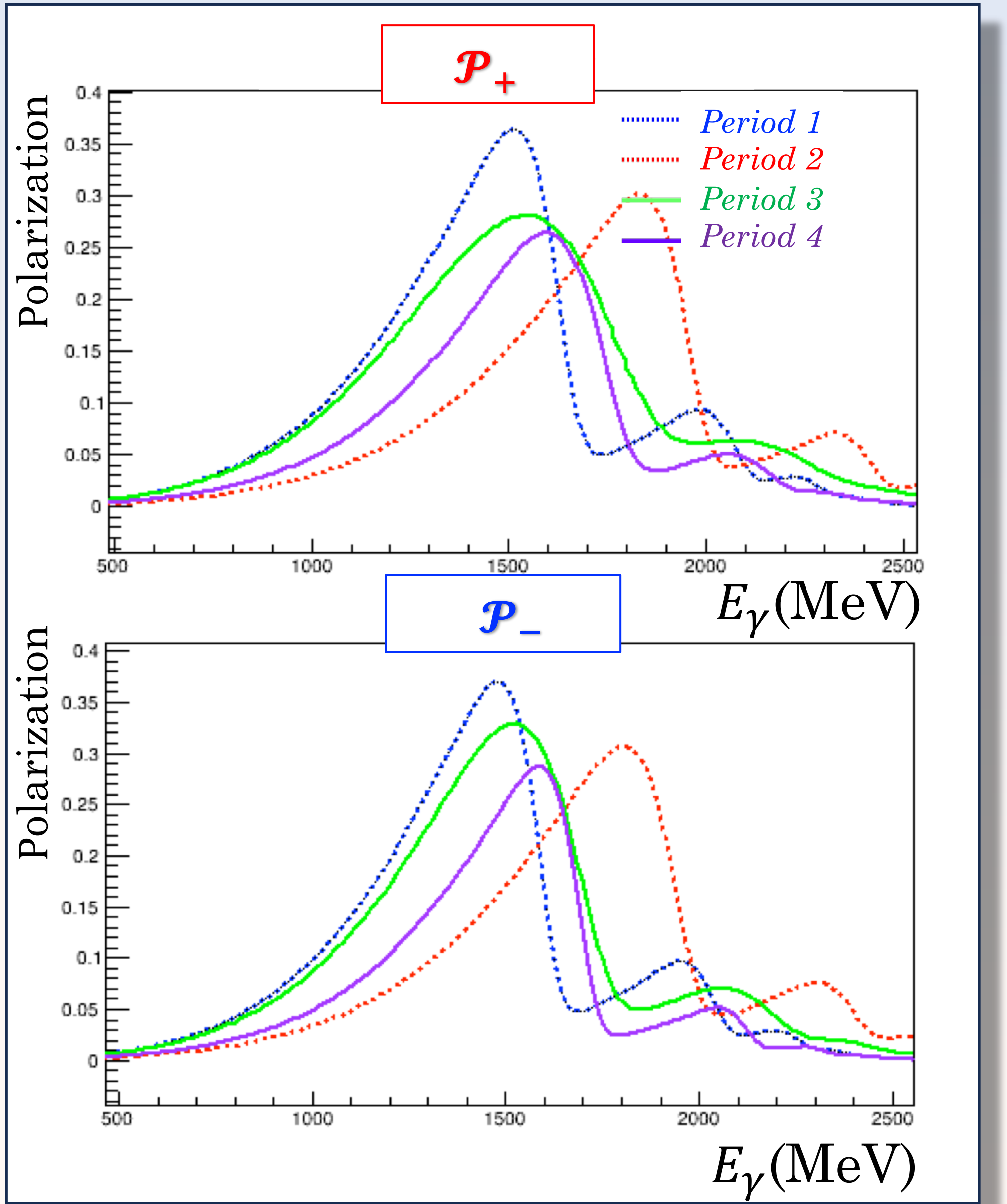
Events selection => 2D-Graph. Cut on Calc Meson Inv Mass % Calc Missing Mass from Proton

Four Data taking periods with different polarized E_γ spectra

During each data period two different polarization planes







«*Standard*» *method* for Σ beam asymmetry extraction:

In case of One Data Taking period P with polarization $\mathcal{P}_{+}^{P} = \mathcal{P}_{-}^{P} = \mathcal{P}^{P}$

- For fixed $(E_\gamma, \theta_\eta^{cm})$ bins the number of polarized events normalized to the flux is modulated in **sin $(2\varphi_\eta)$

$$\frac{N_{\pm}^{P}}{F_{\pm}^{P}} = \left(\frac{d\sigma}{d\Omega}\right)_{UNP} \varepsilon^{P}(\varphi) N_{SC}(1 \mp \mathcal{P}^{P}\, \Sigma \cdot \sin(2\varphi_\eta))$$

$$^{**}\cos 2(\phi_{pol} - \varphi_\eta^{cm}) \xrightarrow{\phi_{pol}=\pm 45^\circ} \mp \sin(2\varphi_\eta^{cm}) = \mp \sin(2\varphi_\eta)$$

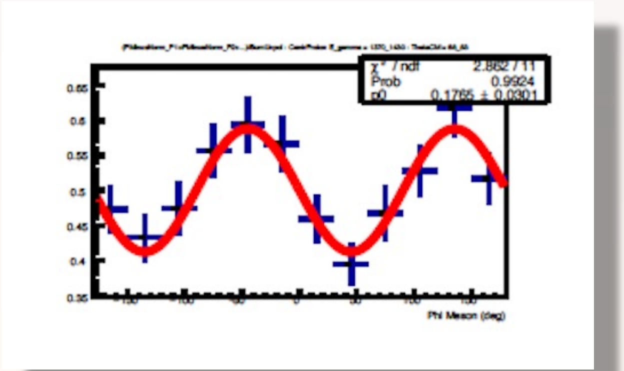
Since the detectio and recostruction efficiency $\varepsilon^{P}(\varphi)$ can be assumed to be the same for the two polarization states

$$N_{UNP,norm}^{P} = \frac{N_{+}^{P}}{F_{+}^{P}} + \frac{N_{-}^{P}}{F_{-}^{P}} \quad \propto \varepsilon^{P}(\varphi) \cdot (1 - \mathcal{P}^{P}\Sigma \cdot \sin(2\varphi_\eta) + 1 + \mathcal{P}^{P}\,\Sigma \cdot \sin(2\varphi_\eta)) \Rightarrow$$

$$N_{UNP,norm}^{P} \propto 2\varepsilon^{P}(\varphi_\eta)$$

- For each $(E_\gamma, \theta_\eta^{cm})$ => The term $\mathcal{P}^{P}\Sigma$ can be extracted from an azimuthal fit of the ratio

$$\frac{\frac{N_{+}^{P}}{F_{+}^{P}}}{N_{UNP,norm}^{P}} = \frac{\frac{N_{+}^{P}}{F_{+}^{P}}}{\frac{N_{+}^{P}}{F_{+}^{P}} + \frac{N_{-}^{P}}{F_{-}^{P}}} = \frac{1}{2}(1 \mp \mathcal{P}^{P}\Sigma \sin(2\varphi_\eta))$$



«Standard» method for Σ beam asymmetry extraction (continued):

In case of a single period of data taking, but with $\mathcal{P}_{+}^{P} \neq \mathcal{P}_{-}^{P}$

In the ratio:

$$\frac{\frac{N_{\pm}^{P}}{F_{\pm}^{P}}}{N_{UNP,norm}^{P}} = \frac{1}{2}\left(1 \mp \mathcal{P}_{\pm}^{P}\Sigma\, sin(2\varphi_{\eta})\right)$$

it is necessary to redefine the expression of the unpolarized term $N_{UNP,norm}$ because the form $N_{UNP,norm}^{P} = \frac{N_{+}^{P}}{F_{+}^{P}} + \frac{N_{-}^{P}}{F_{-}^{P}}$ has a dependence on *sin(2φ)*.

$N_{UNP,norm}^{P}$ has to be defined as

$$N_{UNP,norm}^{P} = \frac{2}{\mathcal{P}_{+}^{P}+\mathcal{P}_{-}^{P}}\left(\mathcal{P}_{-}^{P}\frac{N_{+}^{P}}{F_{+}^{P}}+\mathcal{P}_{+}^{P}\frac{N_{-}^{P}}{F_{-}^{P}}\right) \quad \Rightarrow \quad N_{UNP,norm}^{P} \propto 2\varepsilon^{P}(\varphi_{\eta})$$

It is simple to show that this quantity depends on φ_{η} only via the efficiency $\varepsilon^{P}(\varphi_{\eta})$

Σ beam asymmetry extraction method considering several data taking periods

Different Polarization spectra for the two polarization states and several periods

For each $(E_\gamma, \theta_\eta^{cm})$ **bin *we start* from** the ratio:

$$1)\quad \frac{\sum_i N_{+,norm}^{Pi}}{\sum_i N_{UNP,norm}^{Pi}} = \frac{1}{2}\left(1 - \mathcal{P}_{+}^{*}\Sigma\, sin(2\varphi)\right)$$

Where:

- $P_i \Rightarrow$ i-th data taking period (i=1,2,3,4)
- $N_{\pm,norm}^{Pi} = \frac{N_{\pm}^{Pi}}{F_{\pm}^{Pi}} \Rightarrow$ yeld of polarized events, normalized to flux for the period P_i
- $N_{UNP,norm}^{P_i}(E_\gamma, \theta_\eta^{cm}, \varphi) = \frac{2}{\mathcal{P}_{+}^{P_i} + \mathcal{P}_{-}^{P_i}}\left(\mathcal{P}_{-}^{P_i}\frac{N_{+}^{Pi}}{F_{+}^{Pi}} + \mathcal{P}_{+}^{P_i}\frac{N_{-}^{Pi}}{F_{-}^{Pi}}\right) \Rightarrow N_{UNP,norm}^{P_i}(E_\gamma, \theta_\eta^{cm}, \varphi) \propto \varepsilon^{P_i}(\varphi)$
- $\mathcal{P}_{+}^{*} = \frac{\sum_i\left(\varepsilon^{Pi}\mathcal{P}_{+}^{Pi}\right)}{\sum_i \varepsilon^{Pi}} \Rightarrow$ sum of polarizations weighted on the efficiencies of the respective periods
- NB !!!!!! $\mathcal{P}_{+}^{*} = \mathcal{P}_{+}^{*}(\varphi)$ => the fit on the ratio 1) is not possible

Σ beam asymmetry extraction method considering several data periods (cont.)

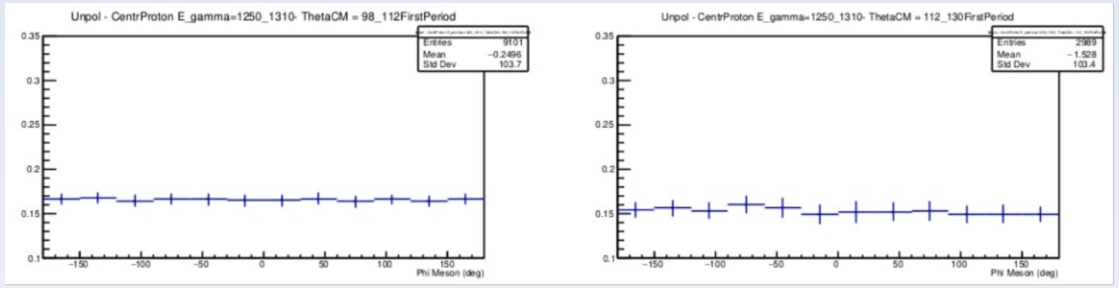
Since $N^{P_i}_{UNP,norm} \propto \varepsilon^{P_i}(\varphi)$:

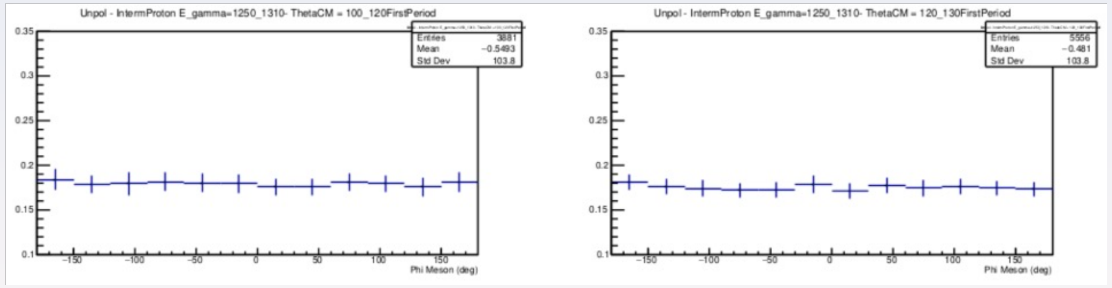
the quantity $\mathcal{P}^*_+$ can be extracted directly from data replacing the efficiency $\boldsymbol{\varepsilon^{Pi}}$ by $N^{P_i}_{UNP,norm}$

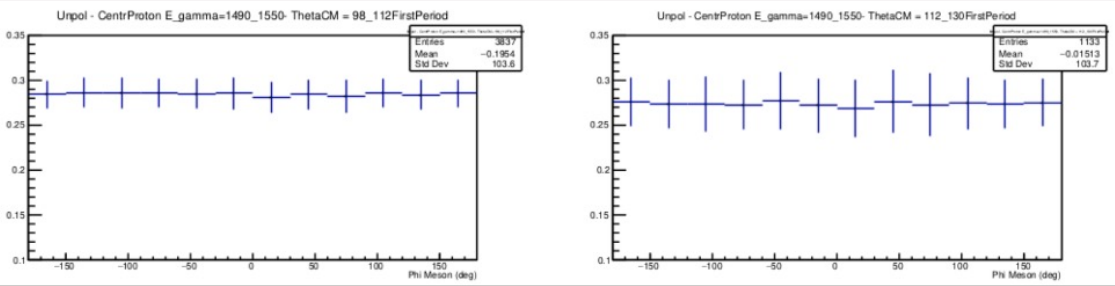
$$\mathcal{P}^*_+ = \frac{\sum_i \left(\varepsilon^{Pi} \mathcal{P}^{P_i}_+\right)}{\sum_i \varepsilon^{Pi}} = \frac{\sum_i \left(N^{P_i}_{UNP,norm} \mathcal{P}^{P_i}_+\right)}{\sum_i N^{P_i}_{UNP,norm}}$$

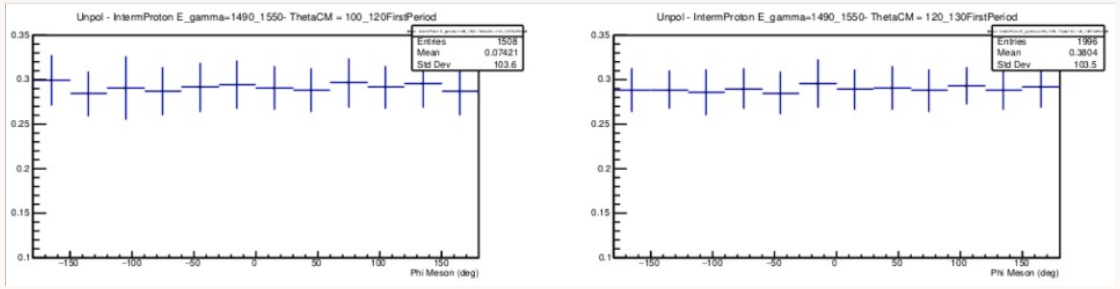
We still have the problem that $\mathcal{P}^*_+$ depends on φ, but it is possible to show that the behavior of $\mathcal{P}^*_+(\varphi)$ is quite flat as function of the azimuthal angle φ for each $(E_\gamma, \theta^{cm}_\eta)$

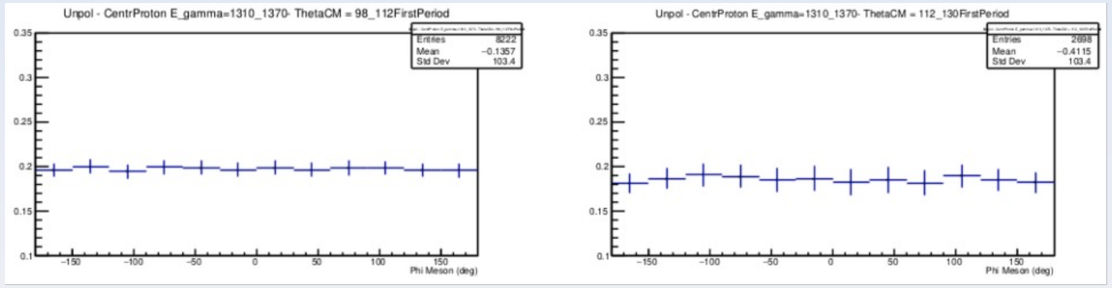
$\mathcal{P}^*_+ = \mathcal{P}^*_+(\boldsymbol{\varphi})$

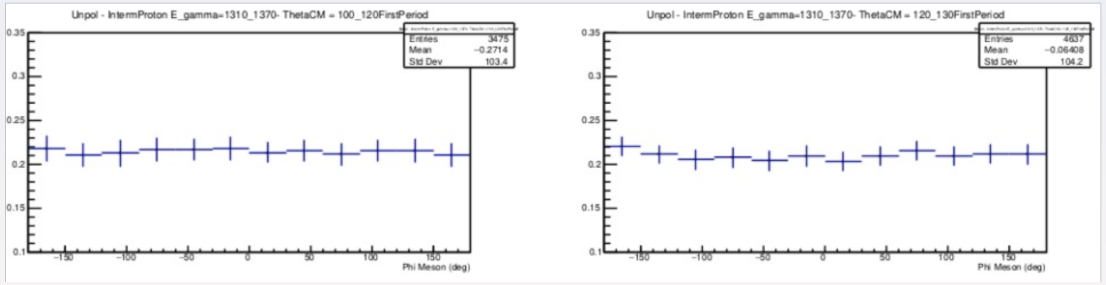


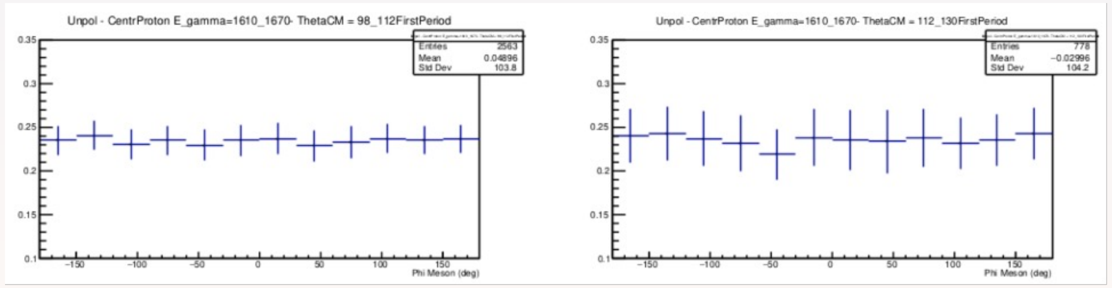


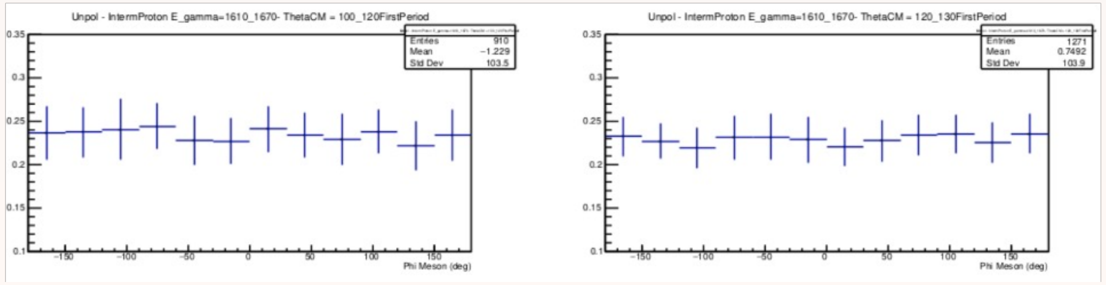












Σ beam asymmetry extraction method considering several data periods (cont.)

Since $N^{P_i}_{UNP,norm} \propto \varepsilon^{P_i}(\varphi)$:

the quantity $\mathcal{P}^*_+$ can be extracted directly from data replacing the efficiency $\boldsymbol{\varepsilon^{Pi}}$ by $N^{P_i}_{UNP,norm}$

$$\mathcal{P}^*_+ = \frac{\sum_i \left(\varepsilon^{Pi}\mathcal{P}^{P_i}_+\right)}{\sum_i \varepsilon^{Pi}} = \frac{\sum_i \left(N^{P_i}_{UNP,norm}\mathcal{P}^{P_i}_+\right)}{\sum_i N^{P_i}_{UNP,norm}}$$

We still have the problem that $\mathcal{P}^*_+$ depends on φ, but it is possible to show that the behavior of $\mathcal{P}^*_+(\varphi)$ is quite flat as function of the azimuthal angle φ for each $(E_\gamma, \theta^{cm}_\eta)$

It is possible to make the average of $\mathcal{P}^*_+$ all over the φ bins.

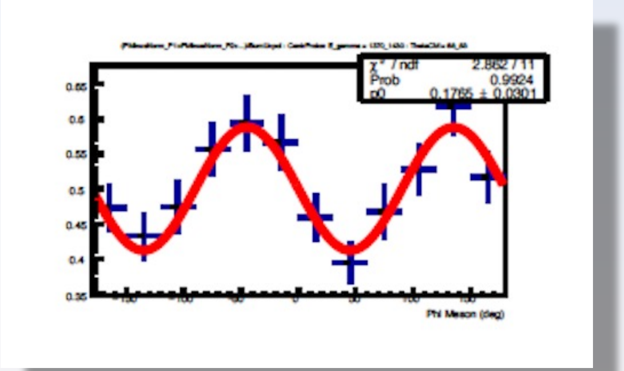
$$\overline{\mathcal{P}^*_+} = \frac{\sum_\varphi \mathcal{P}^*_+(\varphi)}{N_{\varphi\,\mathrm{bins}}}$$

Σ beam asymmetry extraction method considering several data periods (Cont.)

For each $(E_\gamma, \theta_\eta^{cm})$ bin we can then obtain *the* Σ beam asymmetry by:

1) extracting $\overline{\mathcal{P}_\pm^*}\Sigma$ from the azimuthal fit of the ratio:

$$\frac{\sum_i N_{\pm,norm}^{Pi}}{\sum_i N_{UNP,norm}^{Pi}} = \frac{1}{2}\left(1 \mp \overline{\mathcal{P}_\pm^*}\Sigma \sin(2\varphi)\right)$$



2) Dividing the value $\overline{\mathcal{P}_\pm^*}\Sigma$ by $\overline{\mathcal{P}_\pm^*}$

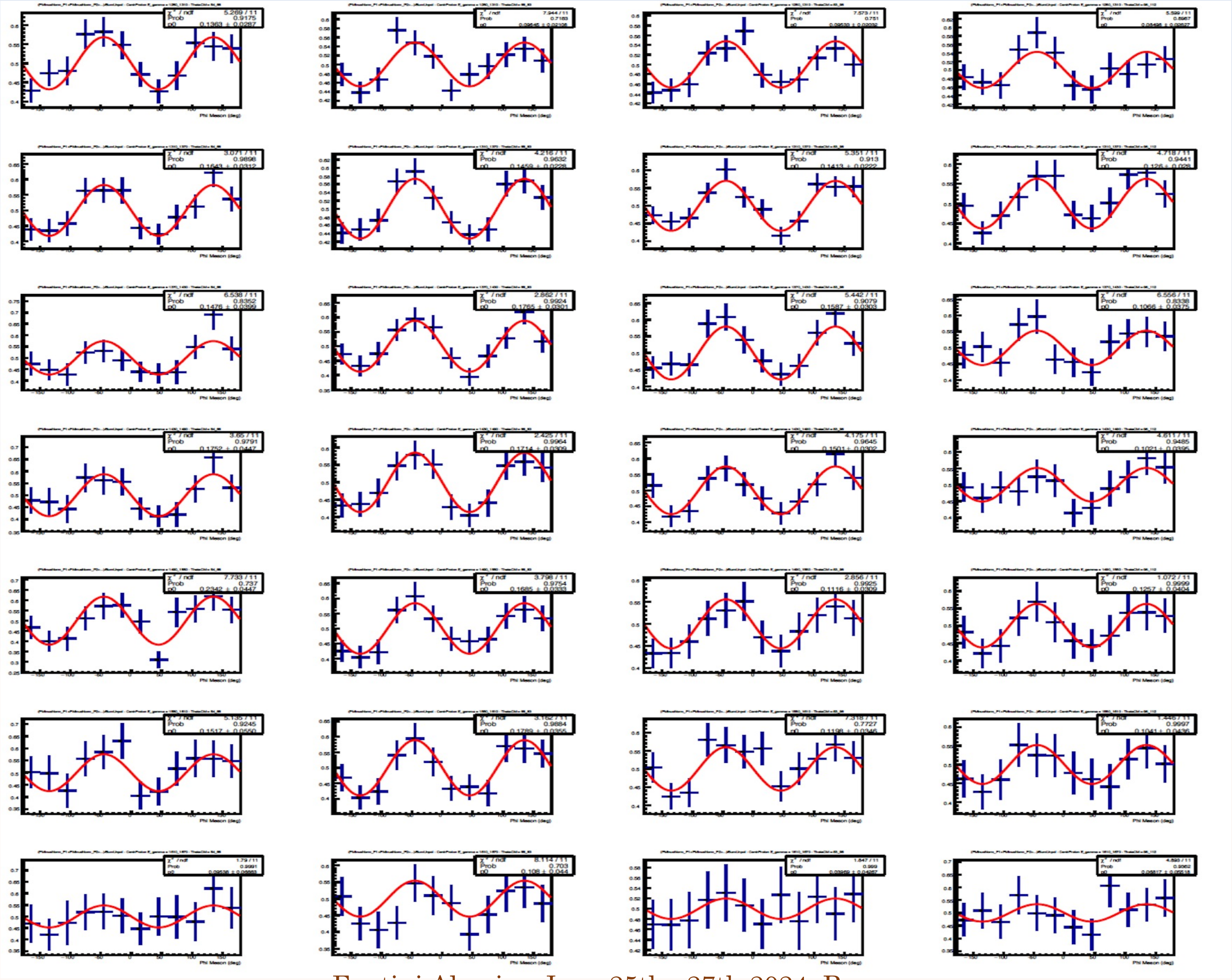
$$\Sigma = \frac{\overline{\mathcal{P}_\pm^*}\Sigma}{\overline{\mathcal{P}_\pm^*}}$$

NB: Since we analyze several η decay channels: $\eta \to 2\gamma$, $\eta \to 3\pi^0 \to 6\gamma$, $\eta \to \pi^+ + \pi^- + \pi^0$

$\boldsymbol{\varepsilon}^{\boldsymbol{Pi}}(\varphi)$ is the "global efficiency" ⇒ i.e the sum of the efficiencies of each channel

$$\boldsymbol{\varepsilon}^{\boldsymbol{Pi}}(\varphi) = \varepsilon^{Pi,C1}(\varphi) + \varepsilon^{Pi,C2}(\varphi) + \varepsilon^{Pi,C3}(\varphi)$$

Azimuthal Fit of ratio $\sum_i N^{Pi}_{+,norm} / \sum_i N^{P_i}_{UNP,norm}$



Σ Beam Asymmetry Results (Preliminary)

8 E_γ bins (60 MeV)

11 θ_η^{cm} bins

$\eta \rightarrow 2\gamma$

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

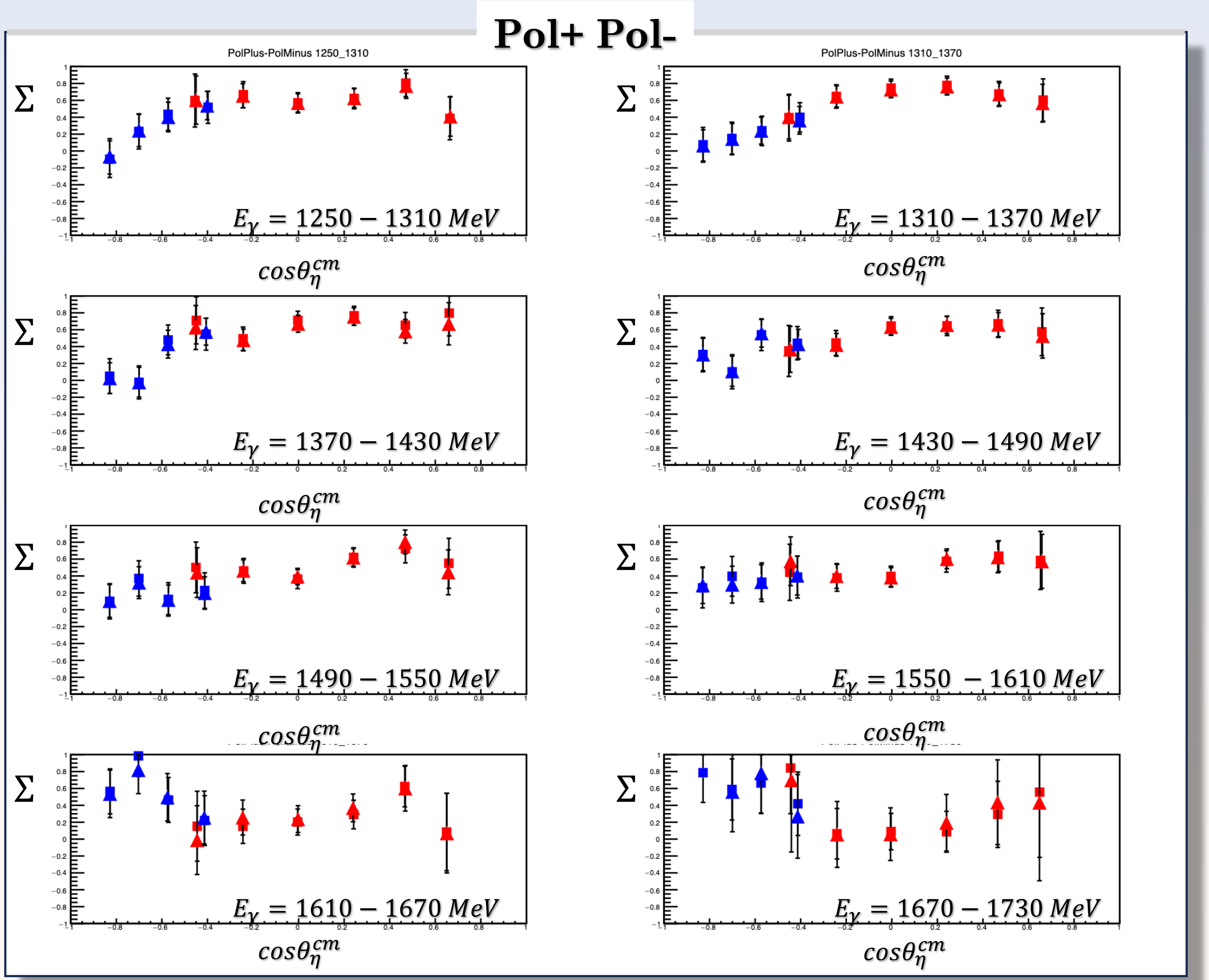
$\eta \rightarrow \pi^+ \pi^- \pi^0$

4 ANALYZED PERIODS

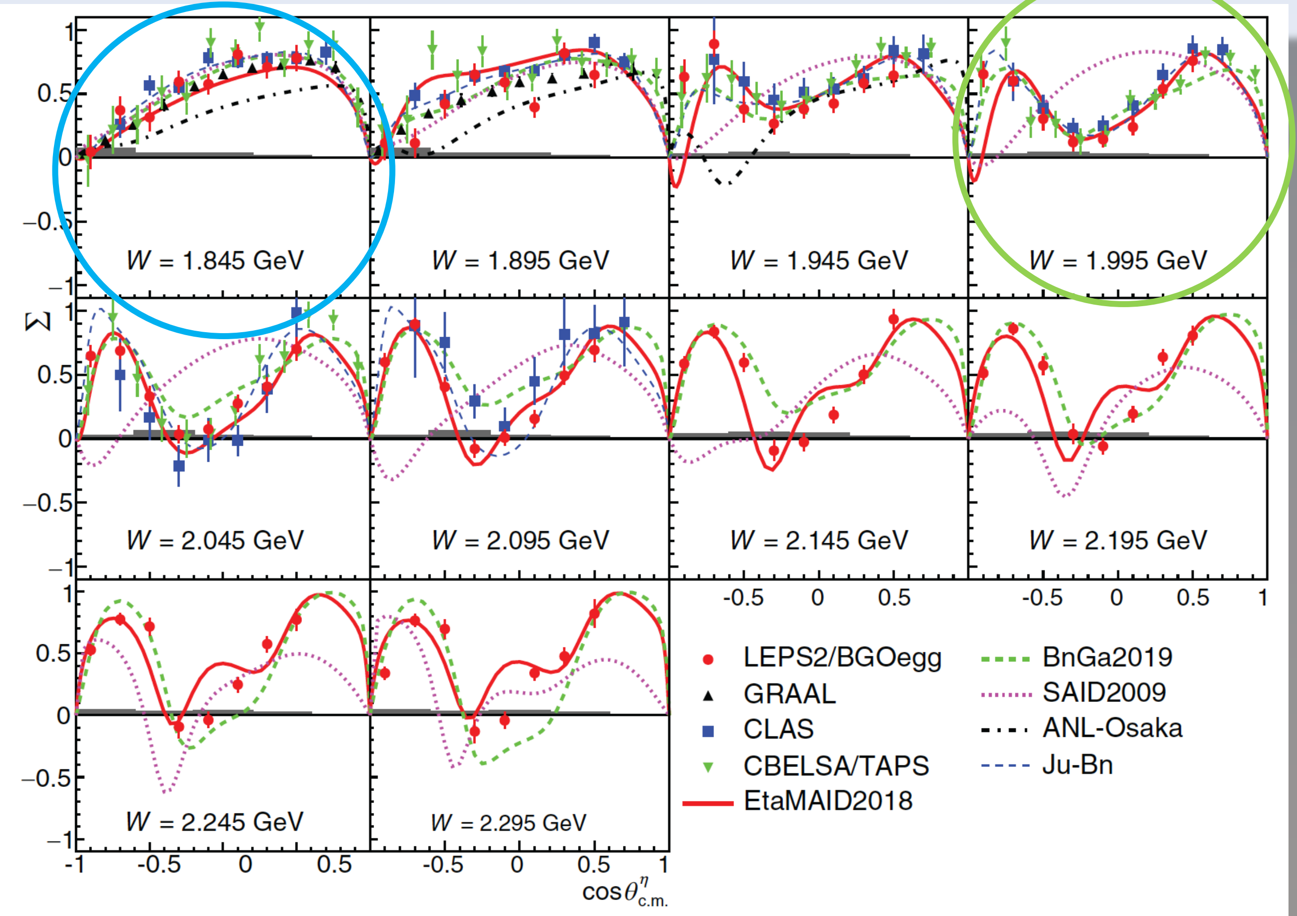
# selected events:Period1:	**31747**
# selected events:Period2:	**54598**
# selected events:Period3:	**144879**
# selected events:Period4:	**90579**
Total # selected events	**321803**

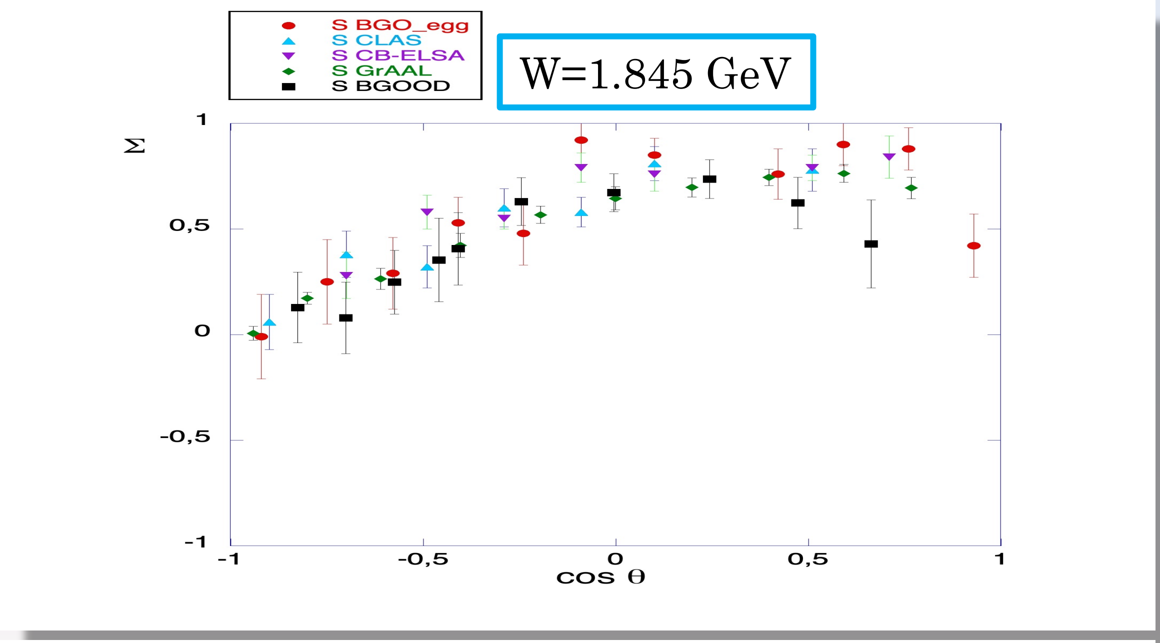
Pol- ▲ Proton in Intermediate Reg. ▲ Proton in BGO

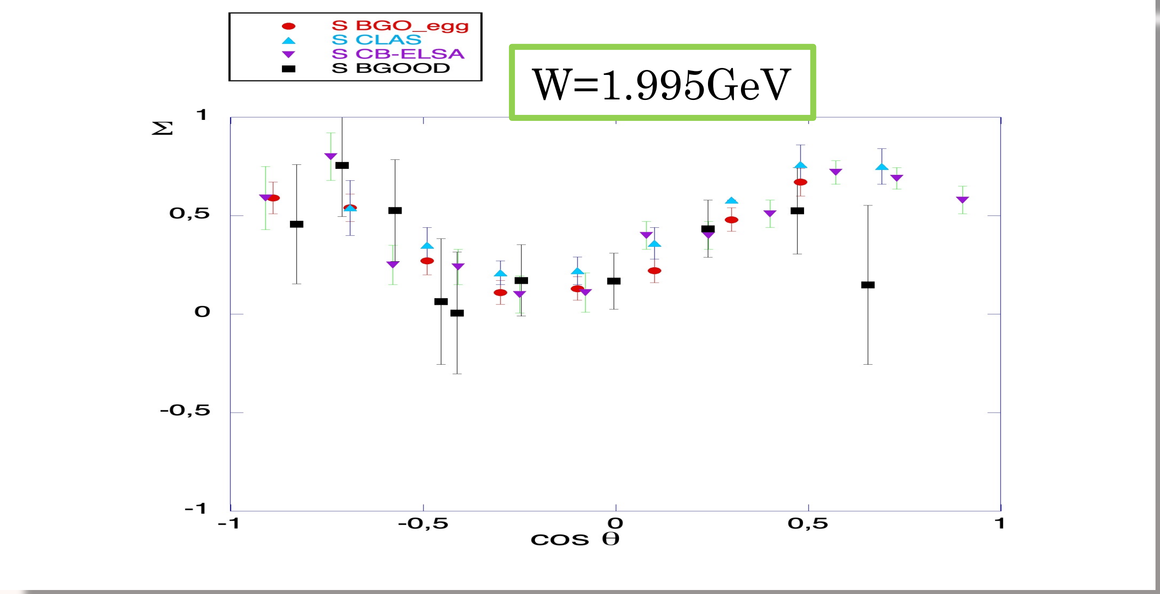
Pol+ ■ Proton in Intermediate Reg. ■ Proton in BGO



Comparison with data from GRAAL-CLAS-CBELSA-LEP2







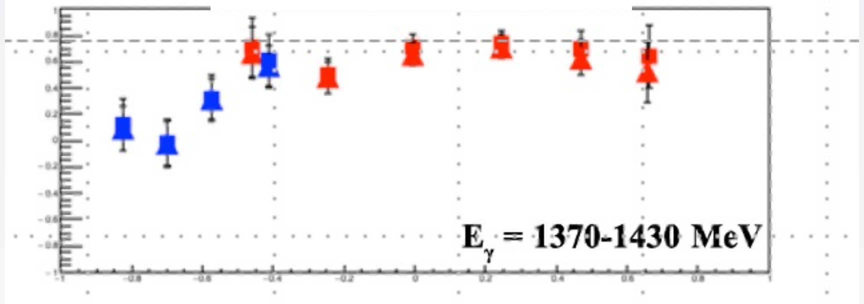
PHYSICAL REVIEW C 106, 035201 (2022)

T. Hashimoto et al. (LEPS2/BGOegg Collaboration)

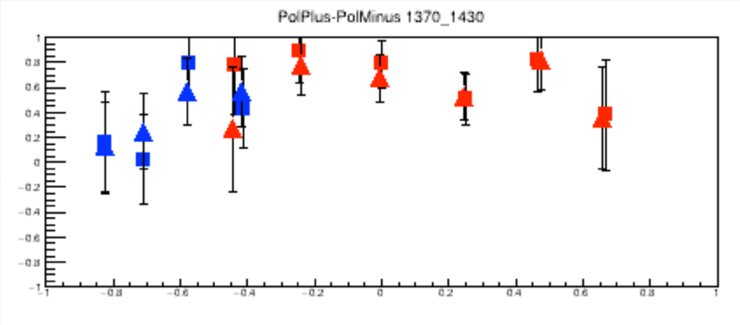
Comparison between Σ extracted analizing 4 periods together or individually

$E_\gamma = 1370 \div 1430\ MeV$

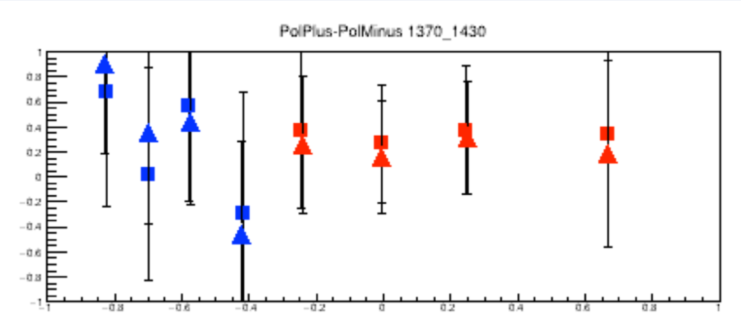
All the 4 periods



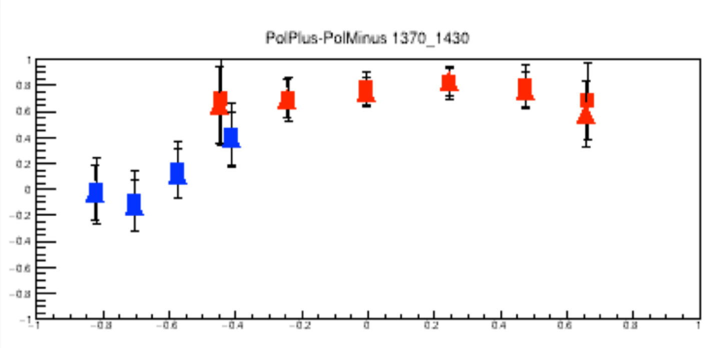
Period 1



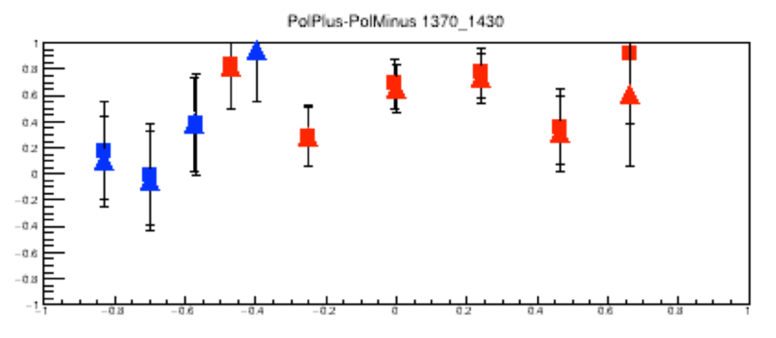
Period 2



Period 3



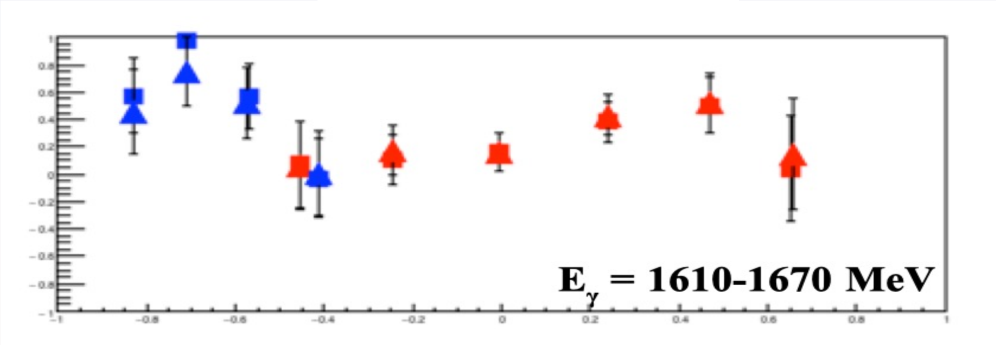
Period 4



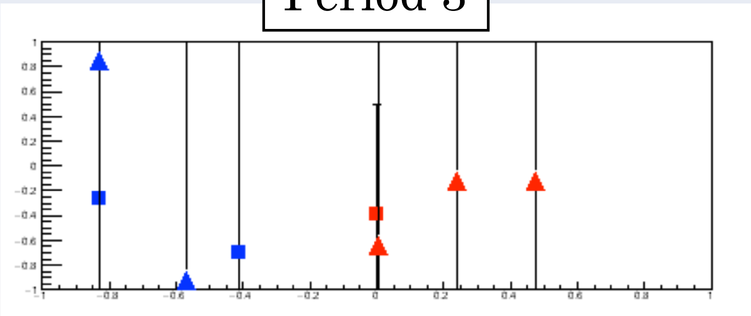
Comparison between Σ extracted analizing 4 periods all together or individually

$E_\gamma = 1610 \div 1670\ MeV$

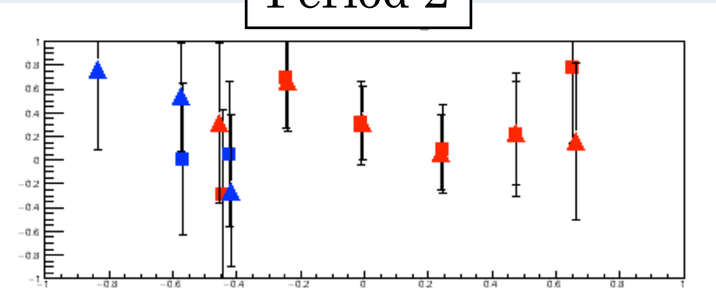
All the 4 periods



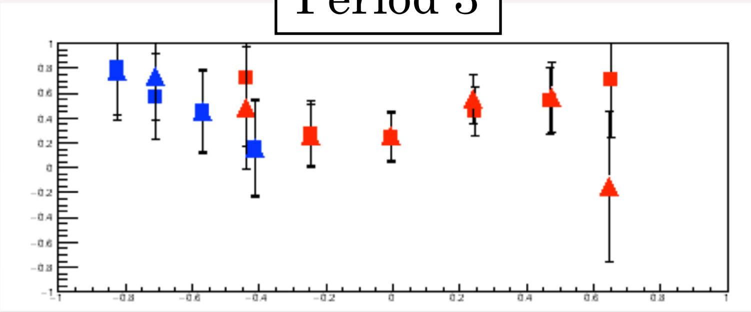
Period 3



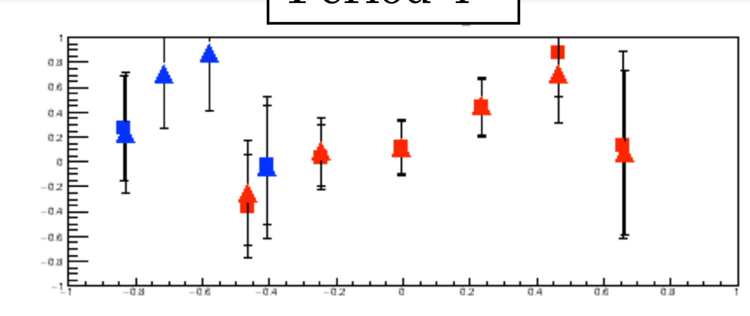
Period 2



Period 3



Period 4



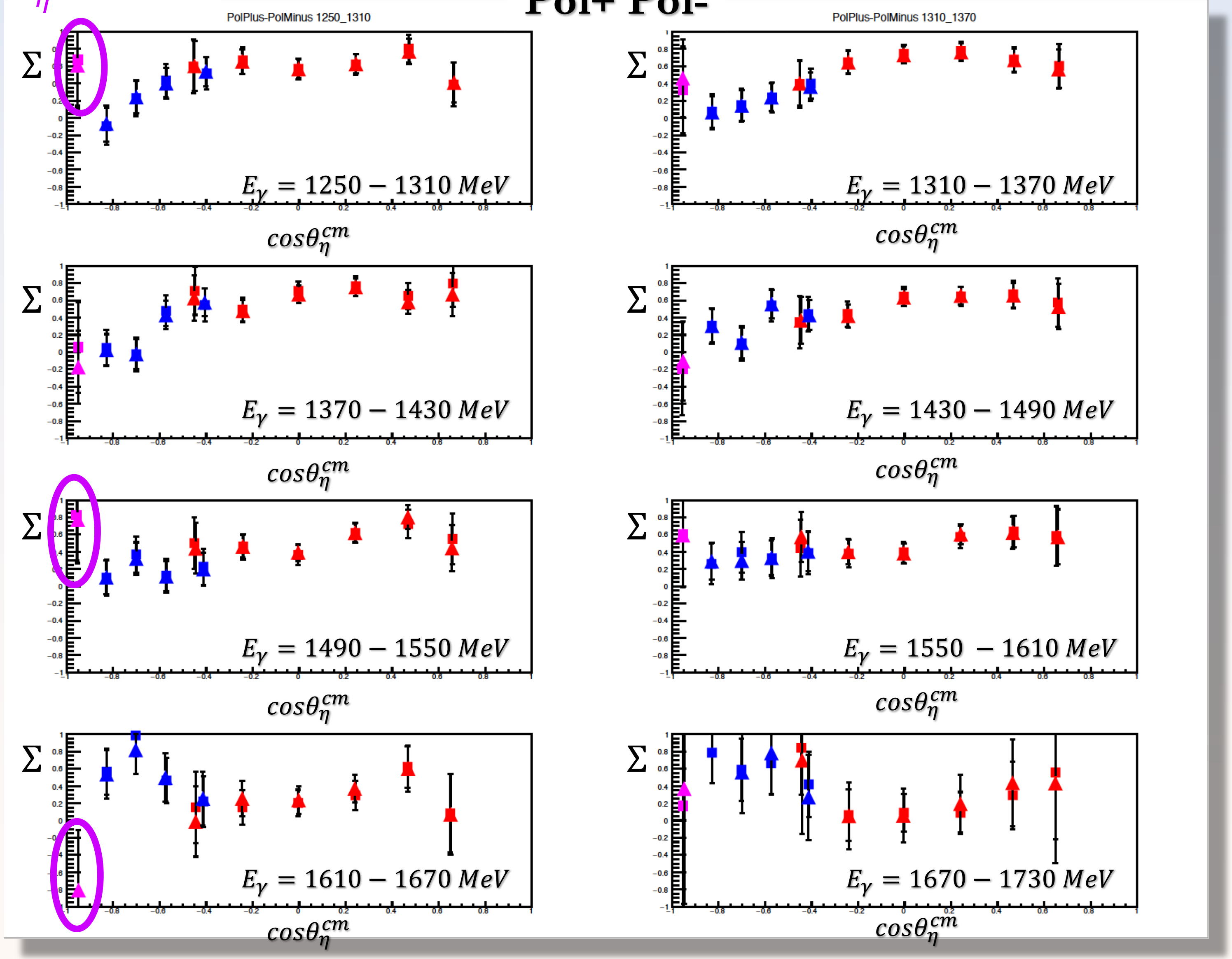
Σ Beam Asymmetry Results (VERY Preliminary)

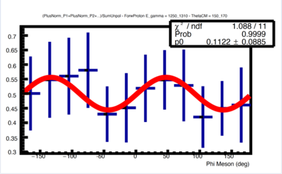
▲ Proton in Forward region

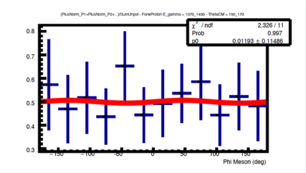
■ Proton in Forward region

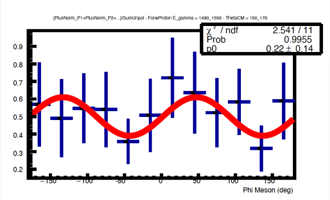
$\overline{\theta_\eta^{cm}} \approx 160°$

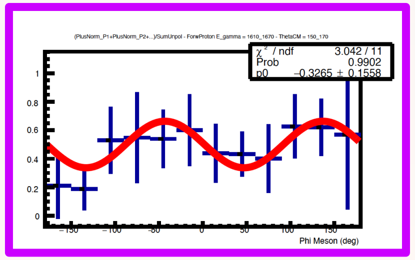
Pol+ Pol-

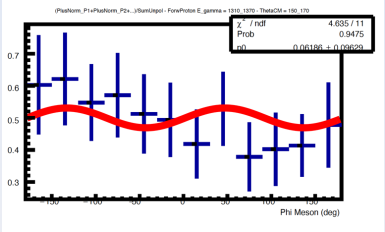


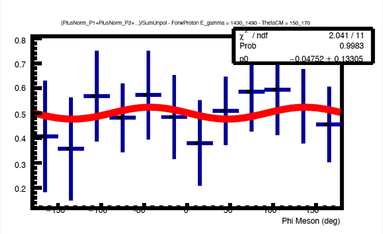


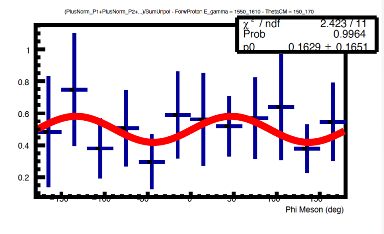












Summary & Conclusions

We extracted the Beam Asymmetry Σ for η photoproduction on the proton, with an technique which allows to analyze simultaneously data:

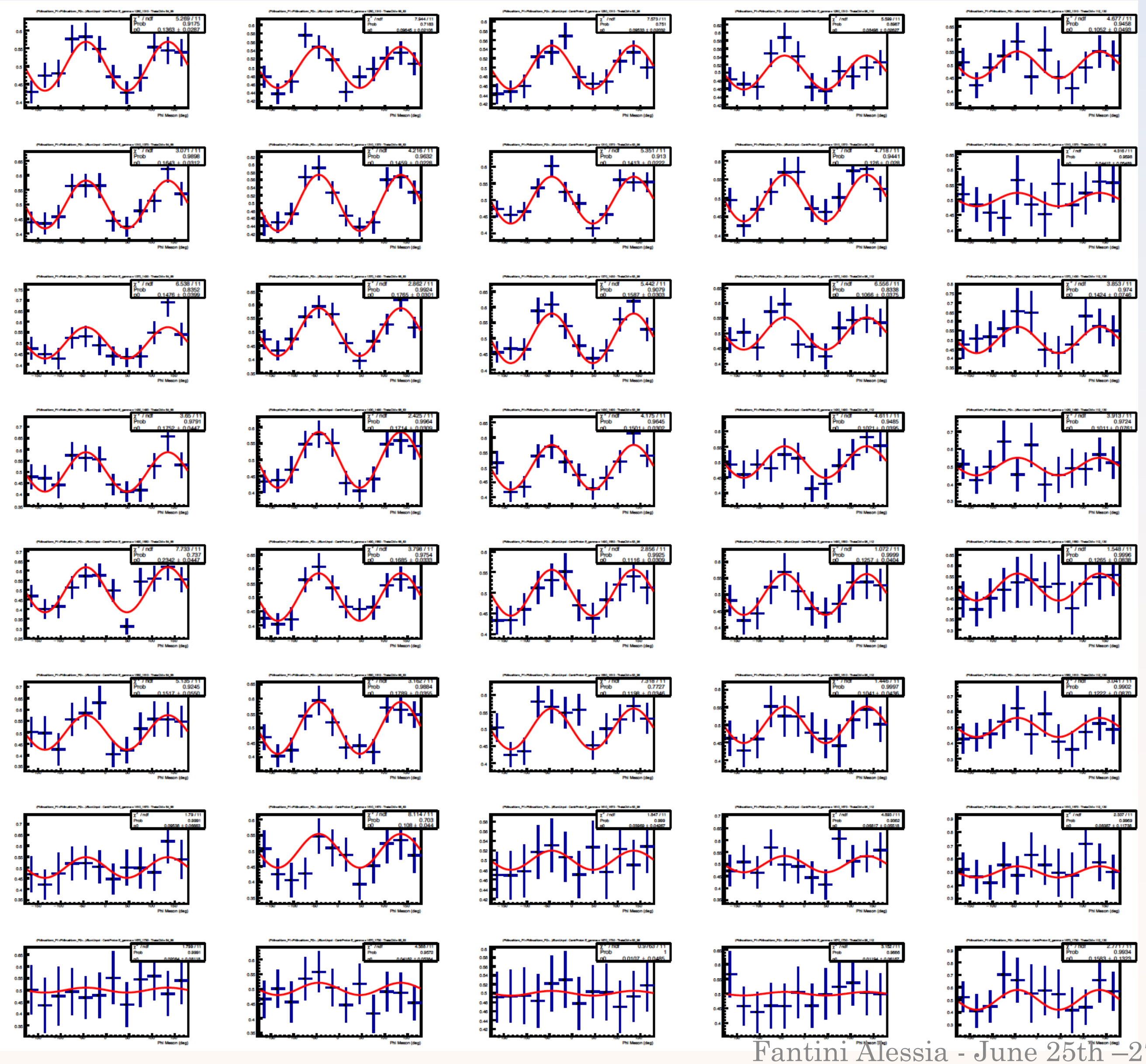
- With Different polarization Degrees
- With Different Detection and Reconstruction Efficiencies
- From Different Eta decay channels

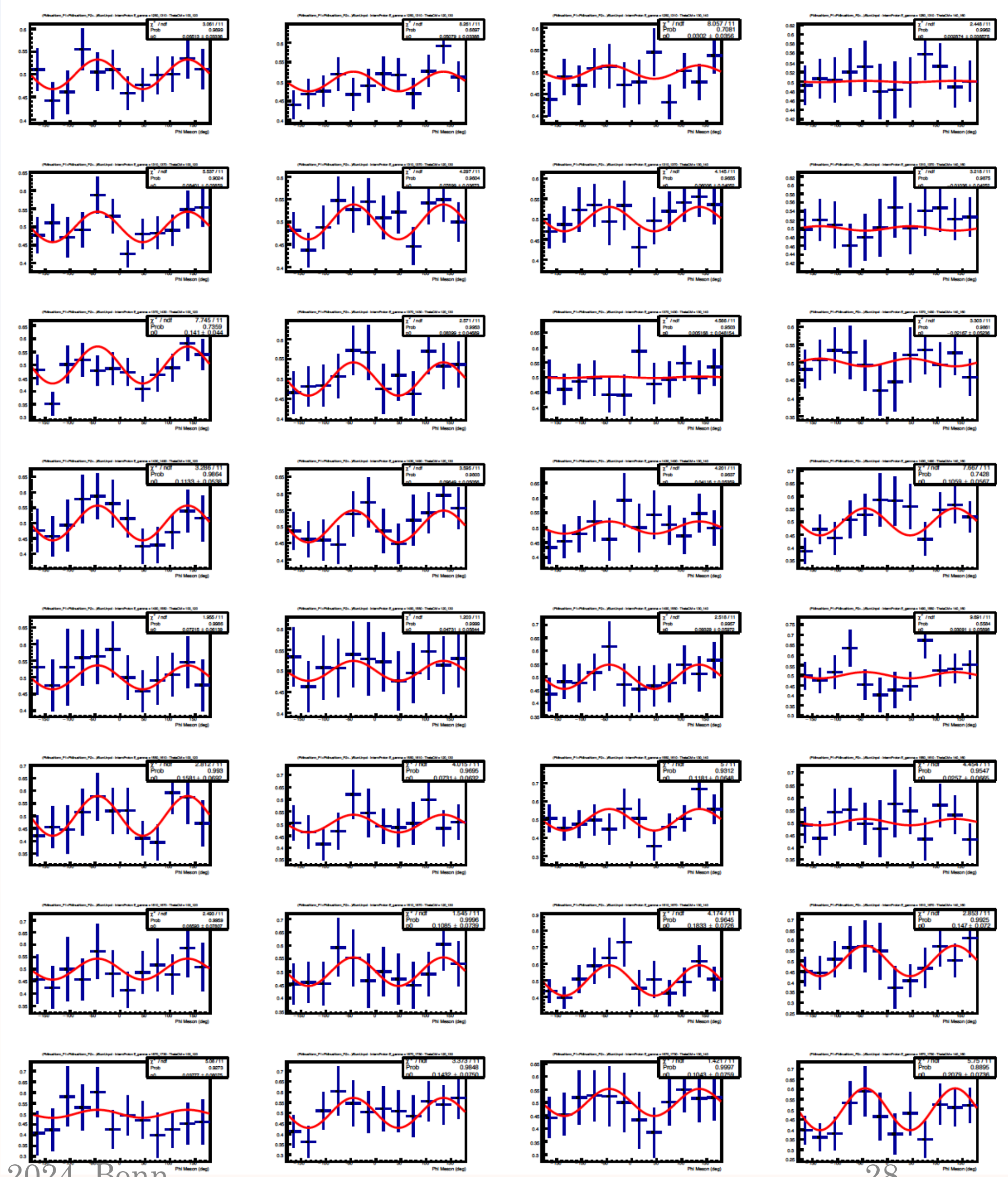
- This technique permits to considerably improve the statistics and opens the possibility for us to analyze η photoproduction on neutron and η' phoproduction on proton.

- The work is in progress => systematic errors estimation & checks with simulation, other two periods have to be analyzed for η photoproduction on the proton and data taking is still in progress

- Backup

Σ beam asymmetry extraction method considering different data periods





$\vec{\gamma} + p \rightarrow \eta + p \;\rightarrow \pi^{+} + \pi^{-} + \pi^{0} + p$

2 γ in BGO (π^0) + 1 proton in Centr/Interm Det $\pi^+ \pi^-$ everywhere (most in BGOBarrel)

We miss the energies of pions and proton => apply momentum conservation along the three directions and we get a system of three equations:

$$0 = \begin{cases} 0 = p_P \, sin\theta_P cos\varphi_P + E_{\gamma_1} \, sin\theta_{\gamma_1} cos\varphi\_\gamma_1 + E_{\gamma_2} \, sin\theta_{\gamma_2} cos\varphi_{\gamma_2} + p_{\pi}^{+} \, sin\theta_{\pi^+} \, cos\varphi_{\pi^+} + p_{\pi^-} \, sin\theta_{\pi^-} cos\varphi_{\pi^-} \\ 0 = p_P \, sin\theta_P sin\varphi_P + E_{\gamma_1} \, sin\theta_{\gamma_1} sin\varphi_{\gamma_1} + E_{\gamma_2} \, sin\theta_{\gamma_2} sin\varphi_{\gamma_2} + p_{\pi}^{+} \, sin\theta_{\pi^+} \, si\varphi_{\pi^+} + p_{\pi^-} \, sin\theta_{\pi^-} sin\varphi_{\pi^-} \\ E_\gamma = p_P \, cos\theta_P + E_{\gamma_1} \, cos\theta_{\gamma_1} + E_{\gamma_2} \, cos\theta_{\gamma_2} + p_{\pi^+} \, cos\theta_{\pi^+} + p_{\pi^-} \, cos\varphi_{\pi^-} \end{cases}$$

Where:

- Measured quantities:

proton and charged pions angles (θP, φP) (θπ1 φπ1) (θπ1 φπ1)

photons energies and angles (θγ2φγ2) (θγ2φγ2)

- Unknown quantities:

proton and charged pions momenta (pP , pπ1 , pπ2)

- NO HYPOTHESIS on the nature of the meson decaying into π+π-π0