Measurement of polarization observables in $\pi^0\pi^0$ photoproduction off the proton with the CBELSA/TAPS experiment

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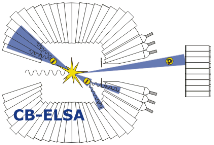
for the CBELSA/TAPS collaboration

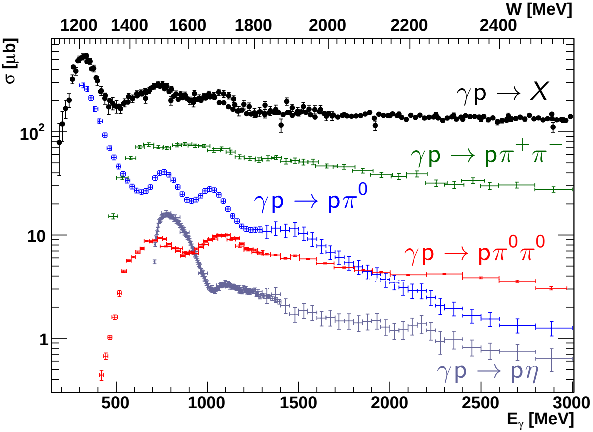


Helmholtz-Institut für Strahlen- und Kernphysik

University of Bonn

May 26, 2015

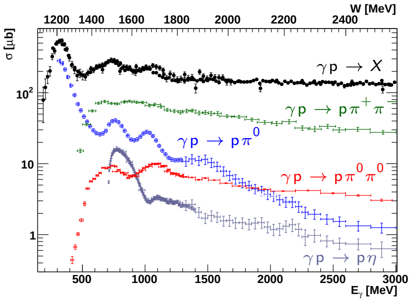
Photoproduction cross sections

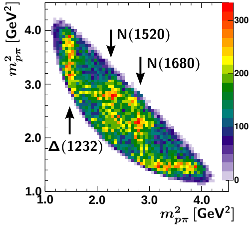


total: PDG, $p\pi^+\pi^-$: ABBHHM
$p\pi^0$, $p\pi^0\pi^0$: CBELSA/TAPS, $p\eta$: CBELSA/TAPS, MAMI

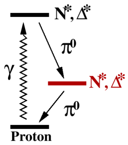
- AIM:
  Good understanding of the baryon excitation spectrum
- importance of multi-meson final states increases with E_γ

▶ The reaction $\gamma p \rightarrow p\pi^0\pi^0$





E_γ = 2.0 GeV — 2.1 GeV



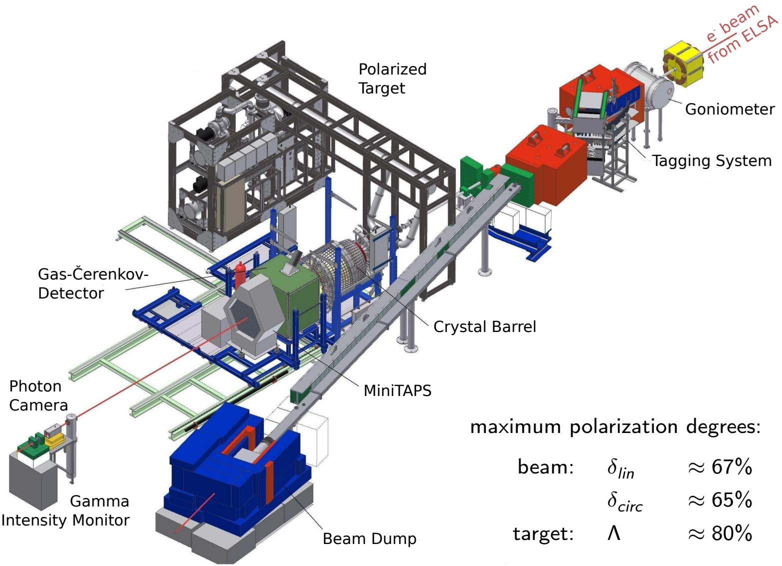
- Compared to $\gamma p \rightarrow p\pi^+\pi^-$: less background amplitudes in $p\pi^0\pi^0$
  - no diffractive $\rho(770)$ production
  - no direct $\Delta^{++}\pi^-$ production
  - fewer Born-terms, t-channel exchanges

→ higher sensitivity on baryon resonances

- exhibits sequential decays

⇒ **resolve PWA ambiguities: polarization observables needed!**

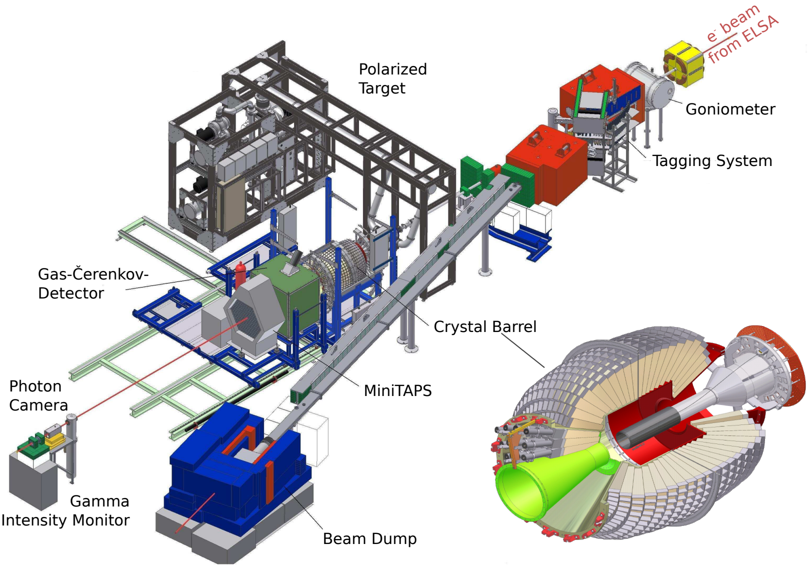
▶ The Crystal Barrel Experiment @ ELSA



maximum polarization degrees:

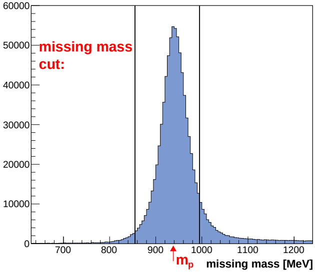
beam:	δ_{lin}	$\approx 67\%$
	δ_{circ}	$\approx 65\%$
target:	Λ	$\approx 80\%$

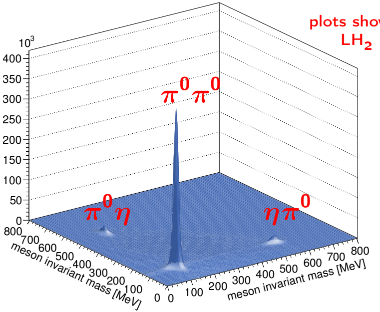
▶ The Crystal Barrel Experiment @ ELSA



▶ Event selection $\gamma p \to p\pi^0\pi^0$

- detector signature:
  4 neutral hits $\longrightarrow$ reconstructed γ_i
  1 charged hit $\longrightarrow$ direction of p
- angular cuts:
  $\varphi(p, \sum \gamma_i)$, $\vartheta^{CMS}(p, \sum_i \gamma_i)$
- missing mass cut: $\gamma p \to 4\gamma X$





plots showing
LH_2 data

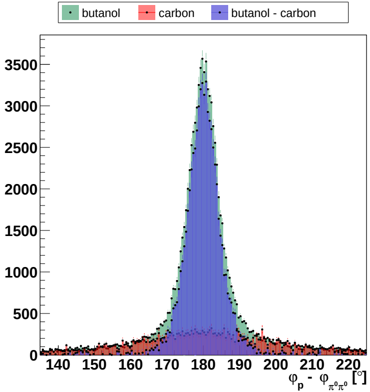
+ kinematic fit:
  - eliminate combinatorial background
  - cut on confidence level: $CL > 0.1$
  - anti cut on $p\pi^0\eta$ final state

▶ Dilution factor f

- target material: $\mathrm{C_4H_9OH} \rightarrow$ target contains bound, unpolarizable protons
- dilution factor: $f = \dfrac{N_{\text{free}}}{N_{\text{total}}}$
- cuts favor free protons:

$\longrightarrow$ experimental determination via dedicated carbon runs

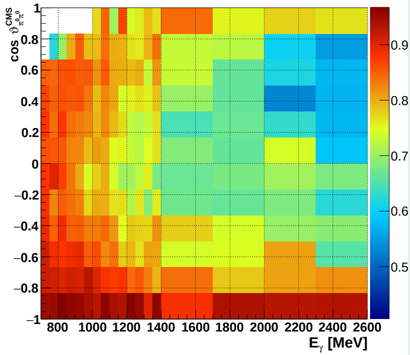
Carbon-subtraction Method:



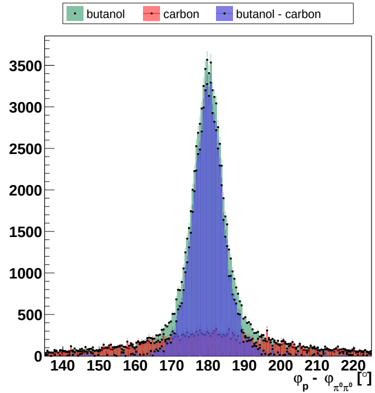
$$f = \frac{N_{\text{butanol}} - c \cdot N_{\text{carbon}}}{N_{\text{butanol}}}$$

▶ Dilution factor f

$f(E_\gamma, cos\,\vartheta^{CMS}_{\pi^0\pi^0})$



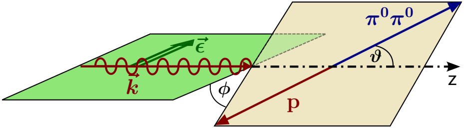
Carbon-subtraction Method:



$$f = \frac{N_{\text{butanol}} - c \cdot N_{\text{carbon}}}{N_{\text{butanol}}}$$

Polarization observables in the 2-body approach

reaction $\gamma p \to p(\pi^0\pi^0)$



- back-to-back in production plane:
  1. recoil particle
  2. quasi-particle q

$\Rightarrow$ 2-body kinematics

Pol. obs. of single meson photoproduction
$\mathcal{O} = \mathcal{O}(E_\gamma, \vartheta)$

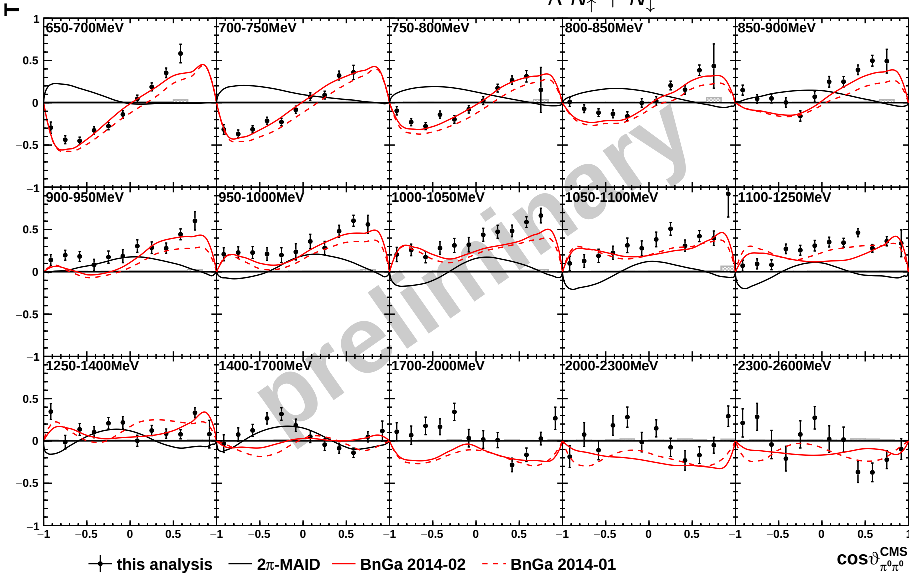
Photon pol.		Target Pol. Axis x	y	z
unpolarized	σ		T	
linear	$-\Sigma$	$-H$	$-P$	G
circular		F		$-E$

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega} \cdot \Big[1 - \delta_\ell\, \Sigma \cos(2\phi) + \Lambda_x \cdot \left(-\delta_\ell\, H \sin(2\phi) + \delta^{\odot}\, F\right) + \Lambda_y \cdot \left(-\delta_\ell\, P \cos(2\phi) + T\right) - \Lambda_z \cdot \left(-\delta_\ell\, G \sin(2\phi) + \delta^{\odot}\, E\right)\Big]$$

I. S. Barker, A. Donnachie, J. K. Storrow, Nucl. Phys. B95, 347 (1975)

▶ Target asymmetry T

$$\frac{1}{\Lambda}\frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow} = T\sin(\beta-\varphi)$$



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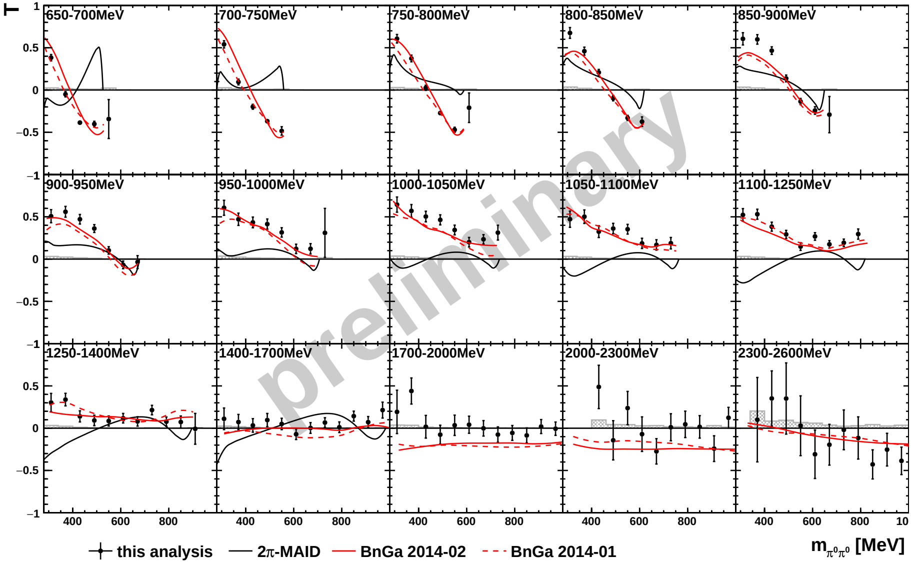
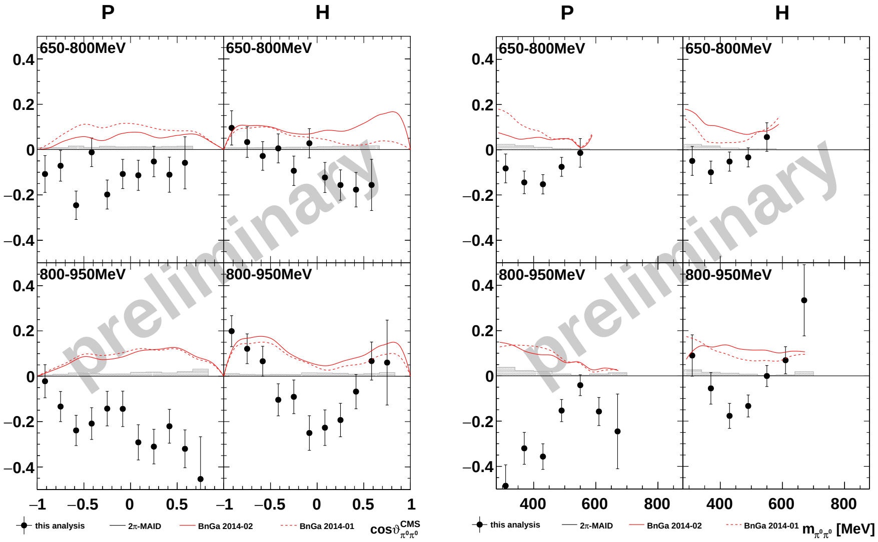
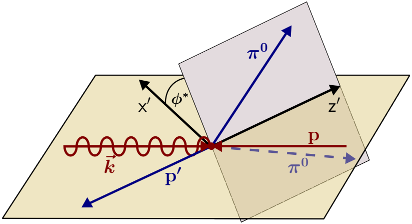


▶ Beam-Target asymmetries *P* and *H*



▶ 3-body kinematics



- production plane:
  γ and recoil particle
- decay plane:
  remaining two particles

$\Rightarrow$ 5-dimensional problem

$$\mathcal{O} = \mathcal{O}(E_\gamma, \vartheta, m_{\text{decay}}, \varphi^*, \vartheta^*)$$

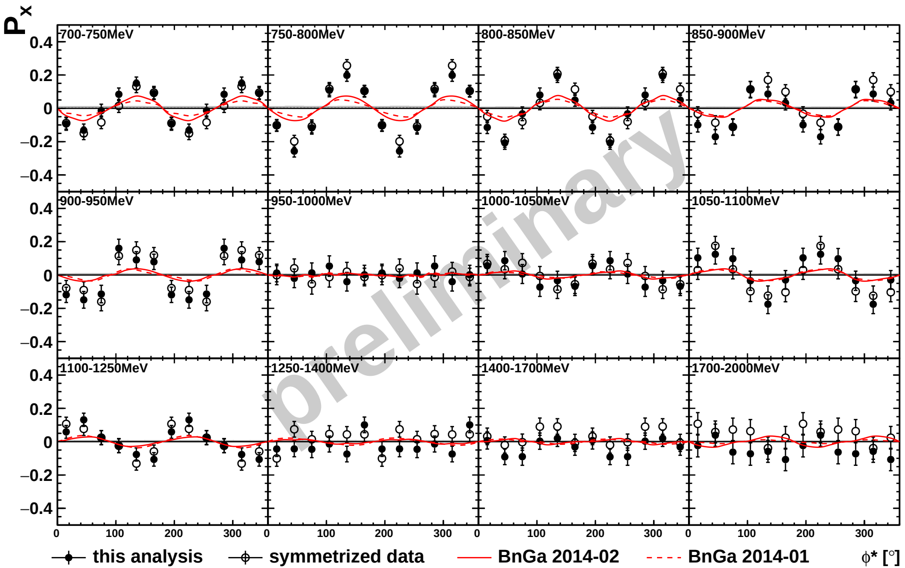
Photon Pol.		Target Pol. Axis x	y	z
unpolarized	σ	P_x	P_y	P_z
linear $\sin(2\phi)$	I^s	P_x^s	P_y^s	P_z^s
linear $\cos(2\phi)$	I^c	P_x^c	P_y^c	P_z^c
circular	$I^\odot$	$P_x^\odot$	$P_y^\odot$	$P_z^\odot$

W. Roberts, T. Oed, Phys. Rev. C 71 (2005)

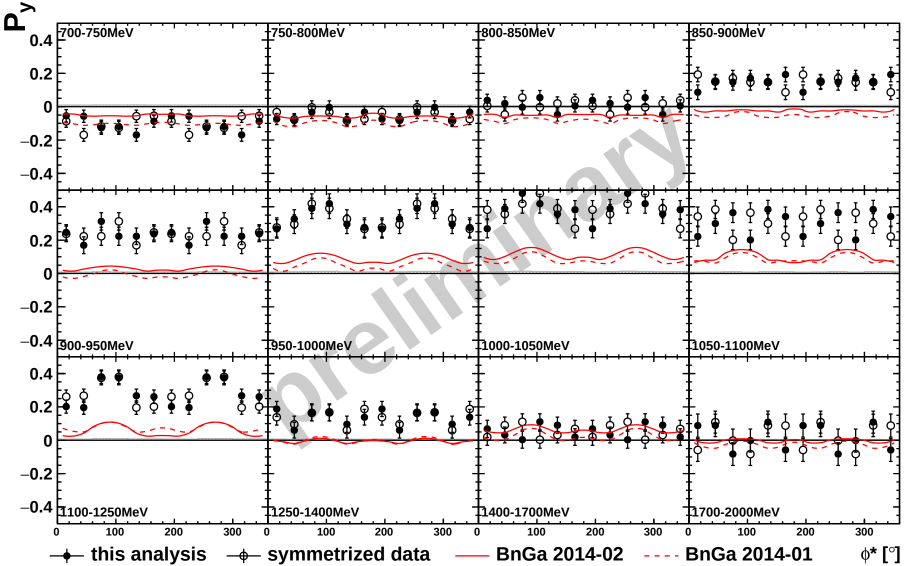
symmetry properties:

- $\mathcal{O}$ odd/even in $\phi^\star$:
  $P_x(2\pi - \phi^*) = -P_x(\phi^*)$
  $P_y(2\pi - \phi^*) = +P_y(\phi^*)$
- if identical particles in decay plane:
  $\mathcal{O}(\phi^*) = \mathcal{O}(\phi^* + \pi)$

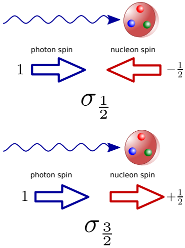
▶ 3-body polarization observables P_X and P_Y



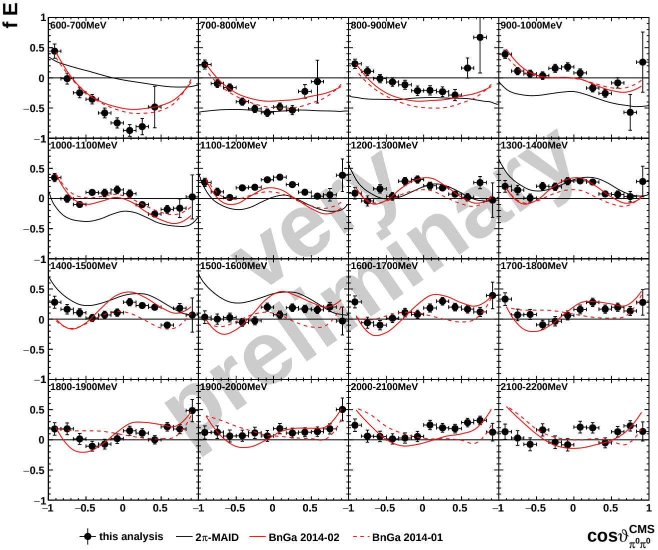
▶ 3-body polarization observables P_X and P_Y



▶ First glimpse on *E*



$$E = \frac{N_{\frac{1}{2}} - N_{\frac{3}{2}}}{N_{\frac{1}{2}} + N_{\frac{3}{2}}}$$



Summary

- Understanding the nucleon excitation spectrum: Polarization observables needed
- Crystal Barrel experiment ideally suited to measure neutral multi-meson final states

polarization data shown for $p\gamma \rightarrow p\pi^0\pi^0$:

- 2-body approach: T, P, H, E
- 3-body approach: P_X, P_Y

. . . more to come!

$\longrightarrow$ new, crucial information for PWA

supported by:
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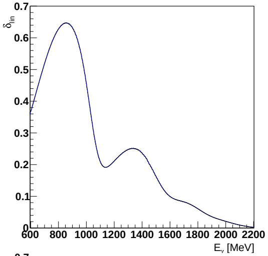
THANK YOU FOR YOUR ATTENTION!

Backup slides

▶ Double Polarization Experiment

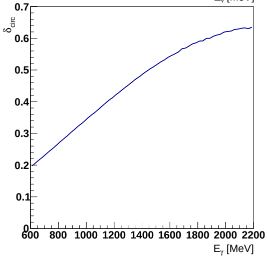
- linear beam polarization:

  coherent bremsstrahlung with 3.2 GeV unpolarized electrons



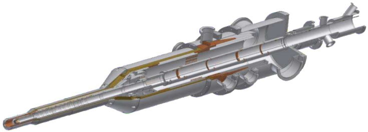
- circular beam polarization:

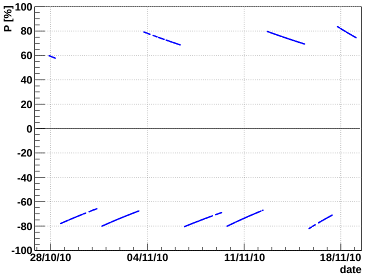
  helicity transfer from 2.4 GeV polarized electrons



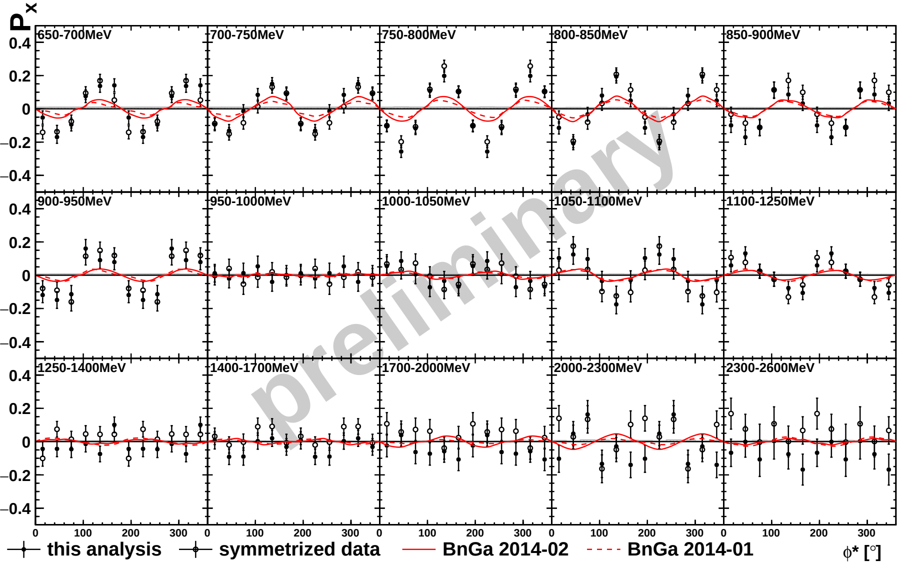
- Frozen-Spin-Target

  target material: C_4H_9OH

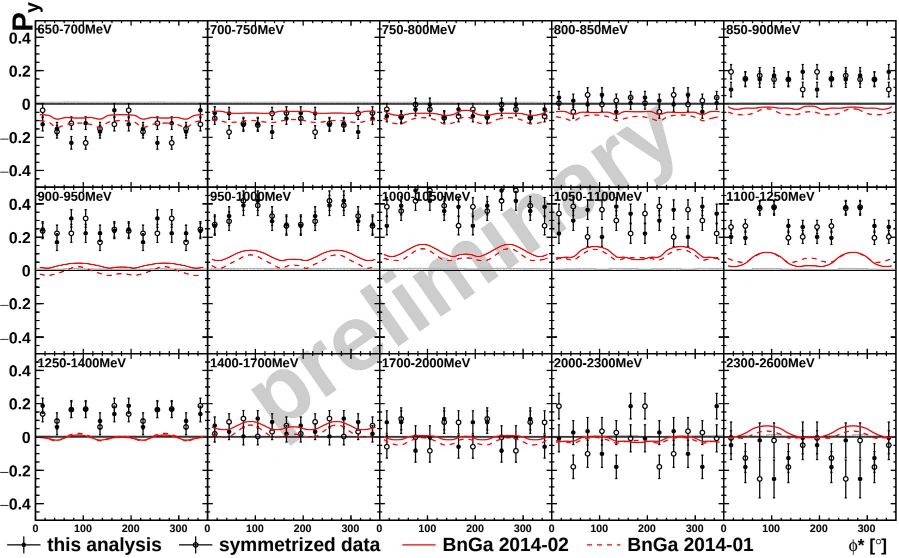




▶ P_X and P_Y in $p\gamma \to p(\pi^0\pi^0)$



▶ P_X and P_Y in $p\gamma \rightarrow p(\pi^0\pi^0)$



▶ P_X and P_Y in $p\gamma \to (p\pi^0)\pi^0$