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Polarization observables in double pion photo-production with circularly polarized photons off transversely polarized protons(g9b-FROST)

CLAS Collaboration Meeting

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October 20-23, 2015

Jefferson Lab

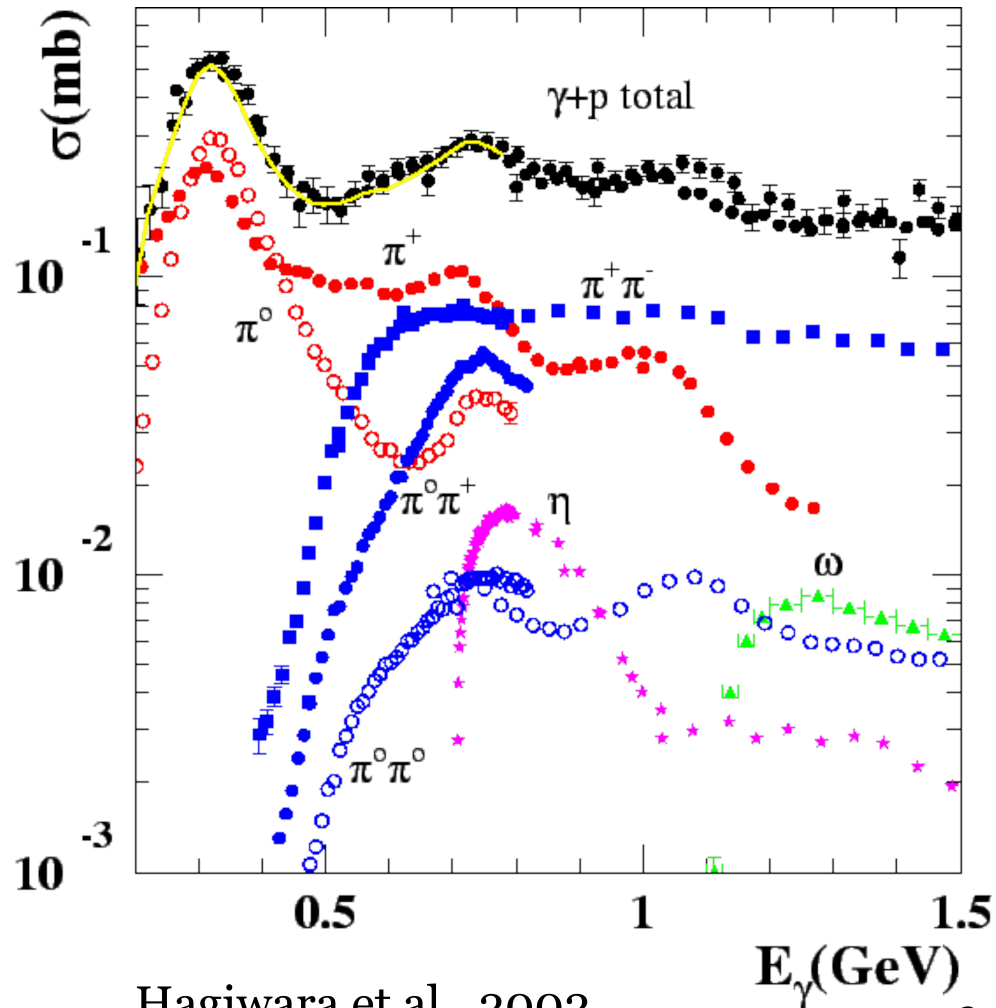
clas

Outline

- g9b (FROST) Experiment
- Analysis
- Preliminary Results
- Outlook

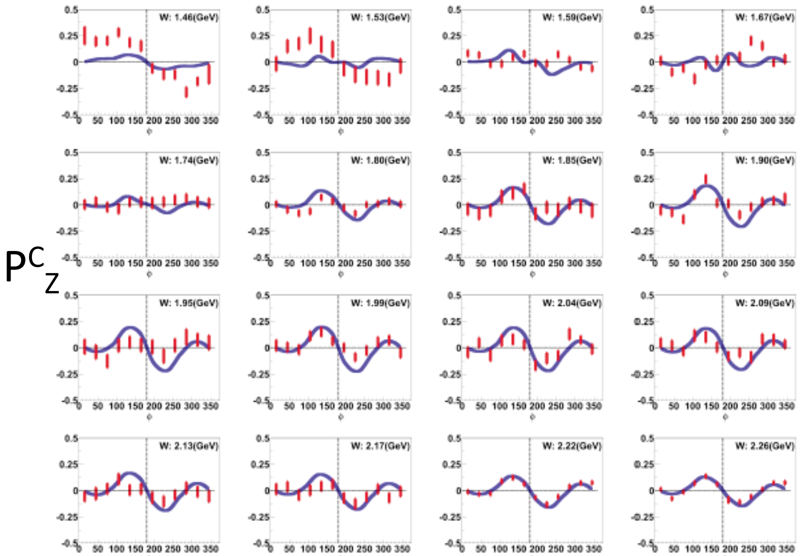
Why $\gamma p \rightarrow p\pi^{+}\pi^{-}$?

- Biggest contribution to the photo-production cross section at higher energies
- Brings additional information to what single pion photo-production could provide

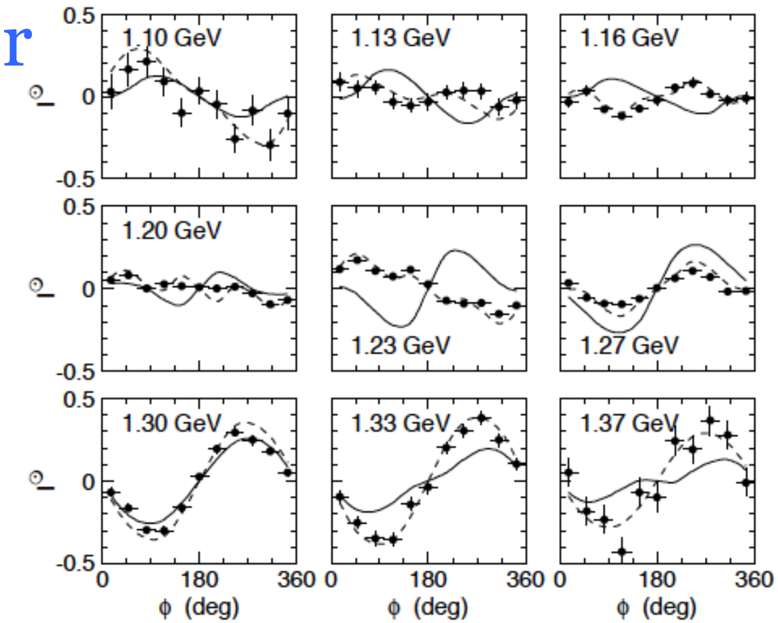


Hagiwara et al., 2002

Previous and Current Studies for Double Pion Photo-production



[Yuqing Mao, USC]



[Strauch, 2005]

JLab Projects (USC and FSU)

Beam

Target	unpolarized	circular	linear	
unpolarized	I_0	$I^{\odot}$	I^s, I^c	g1c
longitudinal	P_z	$P^{\odot}_z$	P^c_z, P^s_z	g8
transversal	P_x, P_y	$P^{\odot}_x$, $P^{\odot}_y$	P^c_x, P^c_y, P^s_x, P^s_y	g9

Polarization Observables

$$I_0 = |\mathcal{M}_1^-|^2 + |\mathcal{M}_1^+|^2 + |\mathcal{M}_2^-|^2 + |\mathcal{M}_2^+|^2 + |\mathcal{M}_3^-|^2 + |\mathcal{M}_3^+|^2 + |\mathcal{M}_4^-|^2 + |\mathcal{M}_4^+|^2$$

$$I_0 P_x = 2\Re(\mathcal{M}_1^- \mathcal{M}_3^{-*} + \mathcal{M}_1^+ \mathcal{M}_3^{+*} + \mathcal{M}_2^- \mathcal{M}_4^{-*} + \mathcal{M}_2^+ \mathcal{M}_4^{+*})$$

$$I_0 P_y = -2\Im(\mathcal{M}_1^- \mathcal{M}_3^{-*} + \mathcal{M}_1^+ \mathcal{M}_3^{+*} + \mathcal{M}_2^- \mathcal{M}_4^{-*} + \mathcal{M}_2^+ \mathcal{M}_4^{+*})$$

$$I_0 I^{\odot} = -|\mathcal{M}_1^-|^2 + |\mathcal{M}_1^+|^2 - |\mathcal{M}_2^-|^2 + |\mathcal{M}_2^+|^2 - |\mathcal{M}_3^-|^2 + |\mathcal{M}_3^+|^2 - |\mathcal{M}_4^-|^2 + |\mathcal{M}_4^+|^2$$

$$I_0 P_x^{\odot} = 2\Re(-\mathcal{M}_1^- \mathcal{M}_3^{-*} + \mathcal{M}_1^+ \mathcal{M}_3^{+*} - \mathcal{M}_2^- \mathcal{M}_4^{-*} + \mathcal{M}_2^+ \mathcal{M}_4^{+*})$$

$$I_0 P_y^{\odot} = 2\Im(\mathcal{M}_1^- \mathcal{M}_3^{-*} - \mathcal{M}_1^+ \mathcal{M}_3^{+*} + \mathcal{M}_2^- \mathcal{M}_4^{-*} - \mathcal{M}_2^+ \mathcal{M}_4^{+*})$$

[W. Roberts and T. Oed, 2005]

Reaction rate for $\vec{\gamma}\vec{p} \to p\pi^+\pi^-$ with circularly polarized photons off transversely polarized protons is written:

$$\rho_f I = I_0[(1 + \vec{\Lambda}_i \cdot \vec{P}_i) + \delta_{\odot}(I^{\odot} + \vec{\Lambda}_i \cdot \vec{P}_i^{\odot})]$$ i = x, y

ρ_f - spin density matrix of the recoiling nucleon

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g9b(FROST) experiment

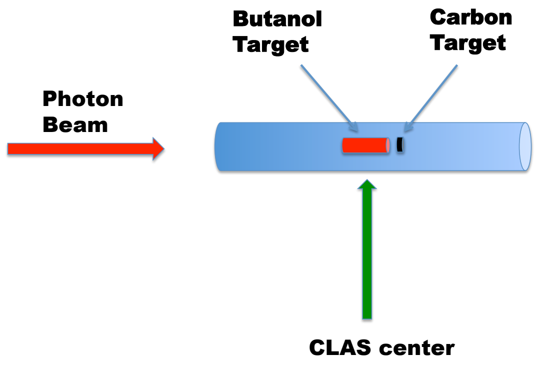
Electron beam: - longitudinally polarized; $\bar{P}_e = 87\%$

- beam energy: 3081.73 MeV

Photon beam: - circularly polarized

Targets:

- FROzen Spin Target (FROST) = transversely polarized butanol (C_4H_9OH) L=5 cm, d=1.5 cm
- Carbon target – L = 0.15 cm



CLAS Detector

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g9b circularly polarized data

Run range	Events	Beam energy	Target polarization
62207 - 62289	723.1 M	3081.73 MeV	83% - 80% positive
62298 - 62372	894.9 M	3081.73 MeV	86% - 80% negative
62374 - 62464	1129.7 M	3081.73 MeV	79% - 75% positive
62504 - 62604	1307.1 M	3081.73 MeV	81% - 76% negative
62609 - 62704	972.6 M	3081.73 MeV	85% - 79% positive

The target polarization was flipped to allow a cancellation of the CLAS acceptance in the asymmetry calculations.

Reaction Selection

$$\gamma p \to p\pi^+\pi^-$$

Final State Composition: 2 positive charges and 1 negative charge

Topology 1: $\vec{\gamma}\vec{p} \to p\pi^+\pi^-(X)$ nothing missing

Topology 2: $\vec{\gamma}\vec{p} \to \pi^+\pi^-(X)$ p missing

Topology 3: $\vec{\gamma}\vec{p} \to p\pi^+(X)$ π^- missing

Topology 4: $\vec{\gamma}\vec{p} \to p\pi^-(X)$ π^+ missing

Background Determination

Butanol Target (C_4H_9OH) - 10 free protons and 64 bound nucleons

Carbon Target - 12 bound nucleons(no free protons)

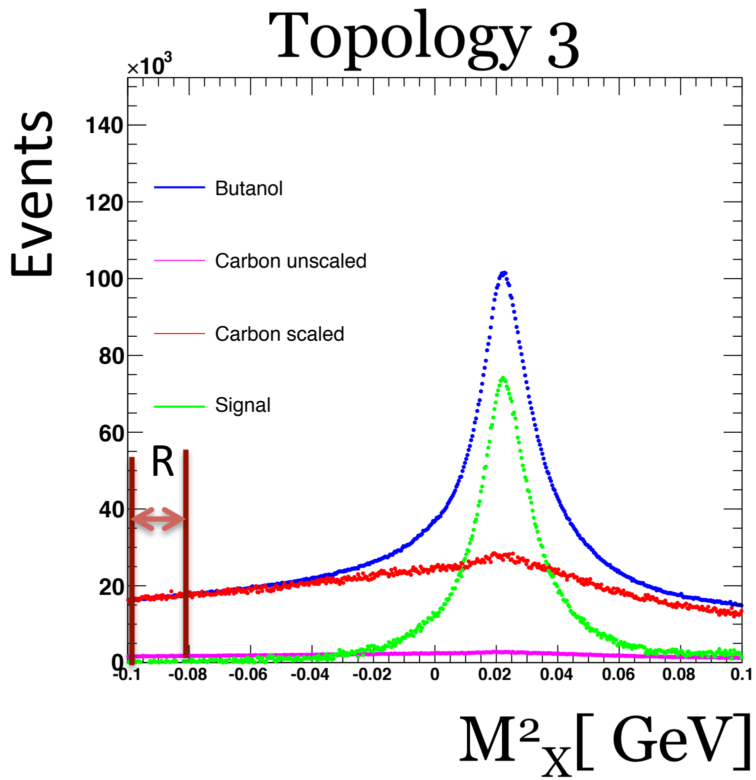
The missing mass technique is used to reconstruct the missing particle:

$$\vec{\gamma}\vec{p} \to p\pi^+\pi^-(X)$$

$$M_X = \sqrt{(E_\gamma + m_p - E_p - E_{\pi^+} - E_{\pi^-})^2 - |\vec{p}_\gamma - \vec{p}_p - \vec{p}_{\pi^+} - \vec{p}_{\pi^-}|^2}$$

Two background subtraction methods

1) Integrated Method



Scale factor =
Number of butanol events in R range divided by the number of carbon events in R range

Scale factor = 10.18

Signal = Butanol – Scale factor x Unscaled carbon

2) Event-based background subtraction

Q-factor = an event-based quality factor equal to the probability for one given event to come from a signal distribution

$$Q = \frac{Signal}{Signal + Background}$$

Step 1 – Pre-bin data in the center-of-mass energy W.

Step 2 - Calculate the distance measure between one event *a* and any other random event *b* from our data set

$$D^2_{a,b} = \sum_{i=1}^{5} \left(\frac{\Gamma_i^a - \Gamma_i^b}{\Delta_i} \right)^2 \qquad \Gamma_i = \Phi^*, \cos\Theta_{CM}, \cos\Theta^*, m_{\pi^+\pi^-}, m_{p\pi^+}$$

Step 3 - For each event *a* (called seed event), we select 5,000 kinematically nearest neighbors, which will be butanol, respectively carbon events

2) Event-based background subtraction (continuation)

Step 4 – Fit carbon and butanol distributions using χ^2-minimization technique and extract the parameters needed to determine Q value

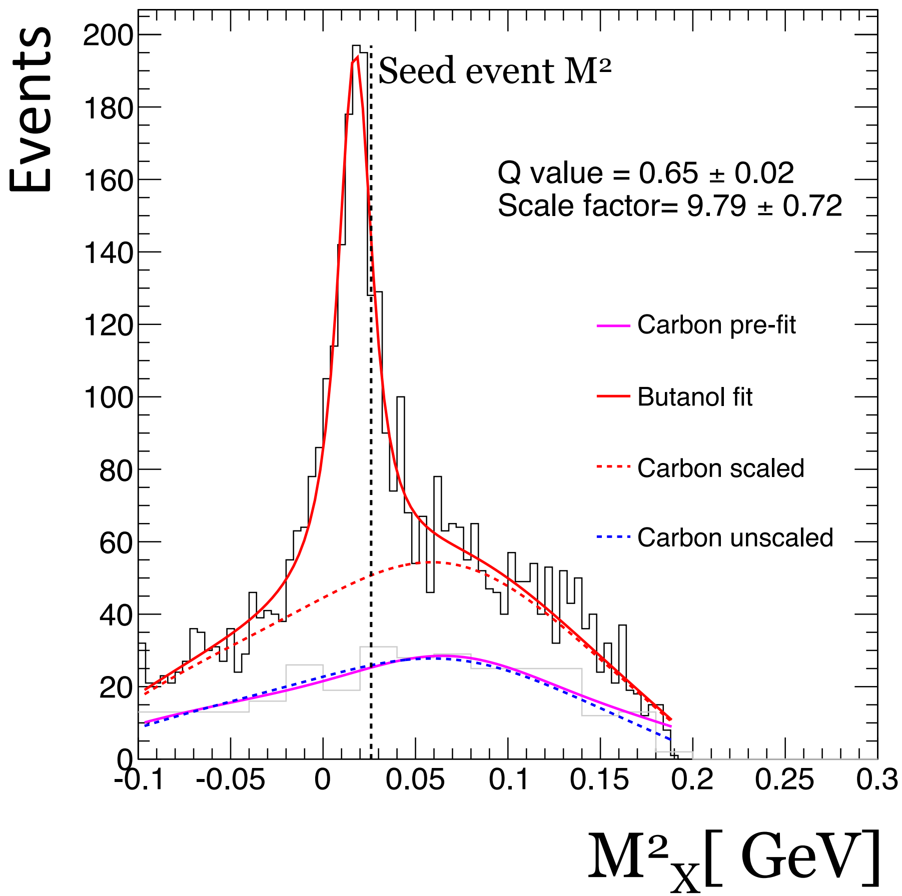
Carbon function = Gaussian + 2nd order Polynomial

Butanol function = Voigt(peak) + Scale Factor x (Gaussian + 2nd order Polynomial)

Step 5 – After the fit is completed, the resulted fit parameters will be used calculate the Q value, by evaluating the butanol and carbon functions at the seed event position.

2) Event-based background subtraction (continuation)

Example: 5,000 nearest neighbors distribution for topology 3



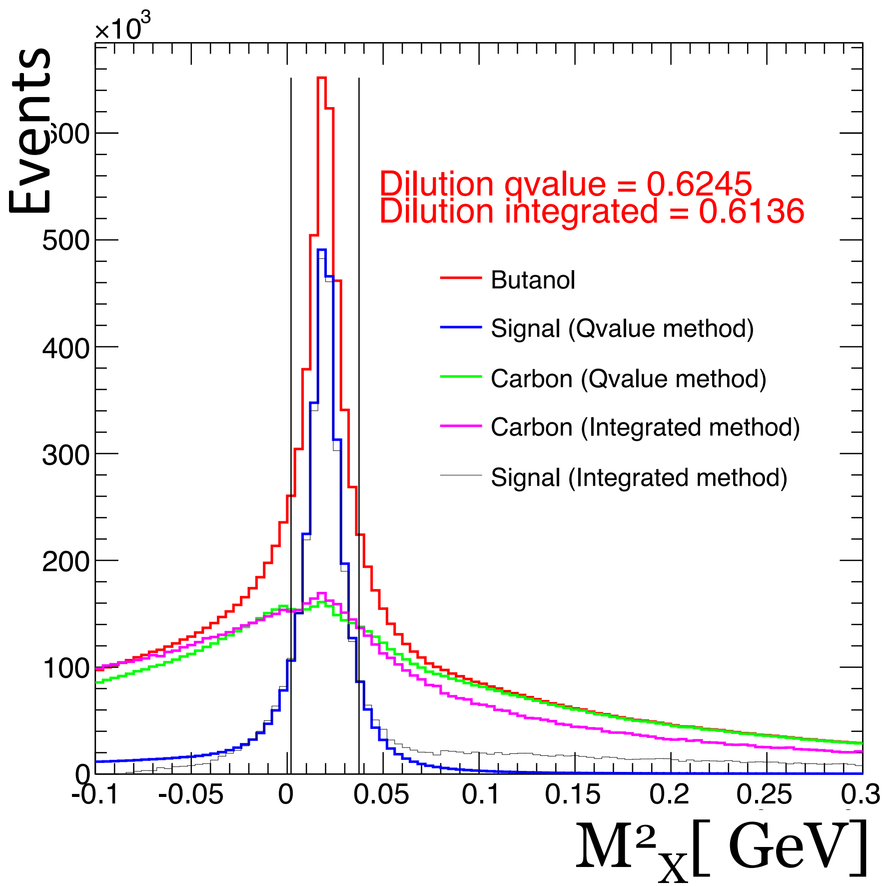
$$Q = \frac{Signal}{Signal + Background}$$

Q value is determined:

$$Q = \frac{145 - 51}{145} = 0.65$$

Two methods of background subtraction comparison

Topology 3: $\vec{\gamma}\vec{p} \rightarrow p\pi^{+}(X)$

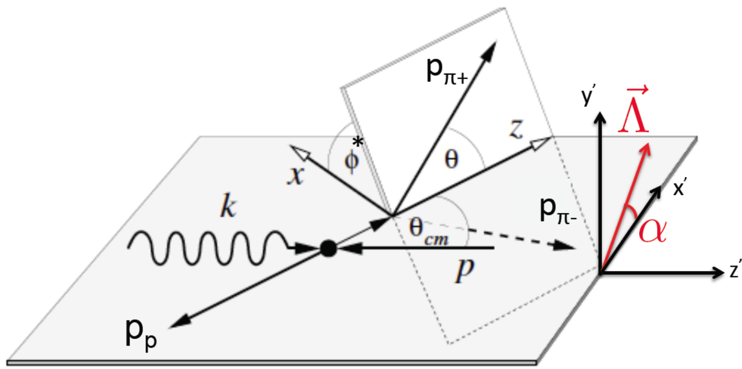


$$d = \frac{\text{free} - \text{proton events}}{\text{butanol events}}$$

Data is integrated over all kinematic variables!

There is a good match between the two methods within 2-sigma range of the signal !

Observables extraction: Moment Method



The acceptance of the detector for the two polarization directions:

$$A(\alpha) = a_0 + a_1 \cdot \cos\alpha + b_1 \cdot \sin\alpha + a_2 \cdot \cos 2\alpha + b_2 \cdot \sin 2\alpha$$

$$A(\alpha+\pi) = a_0 - a_1 \cdot \cos\alpha - b_1 \cdot \sin\alpha + a_2 \cdot \cos 2\alpha + b_2 \cdot \sin 2\alpha$$

The total yield for the reaction of this analysis is:

$$Y = \frac{1}{2\pi}\int_0^{2\pi} Y_{unpol} A(\alpha)(1+\bar{\Lambda}P_x\cos\alpha+\bar{\Lambda}P_y\sin\alpha+\delta_{\odot}(I^{\odot}+\bar{\Lambda}P_x^{\odot}\cos\alpha+\bar{\Lambda}P_y^{\odot}\sin\alpha))d\alpha$$

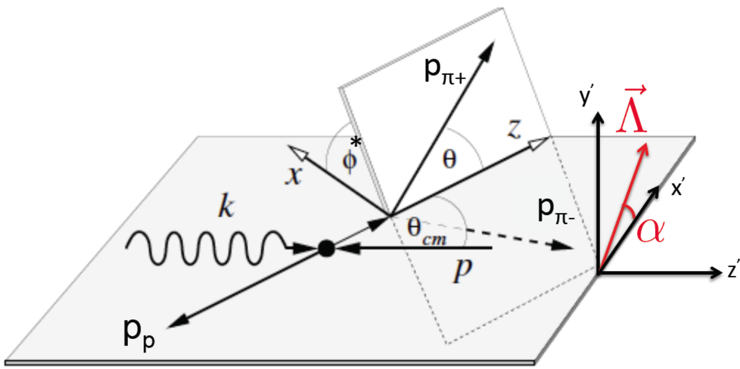
Different moments related to the two target polarization directions(0°,180°) and two helicity states(+,-) of the photon beam are used to write the expressions for the polarization observables: $I^{\odot}, P_x, P_y, P_x^{\odot}, P_y^{\odot}$

For example, the beam-helicity asymmetry is given by:

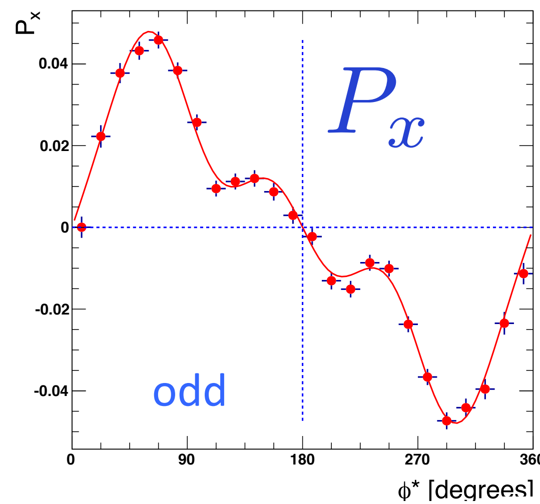
$$I^{\odot} = \frac{\bar{\Lambda}^{180}(Y^{+0} - Y^{-0}) + \bar{\Lambda}^{0}(Y^{+180} - Y^{-180})}{\delta_{\odot}(\bar{\Lambda}^{180}Y^{0} + \bar{\Lambda}^{0}Y^{180})}$$

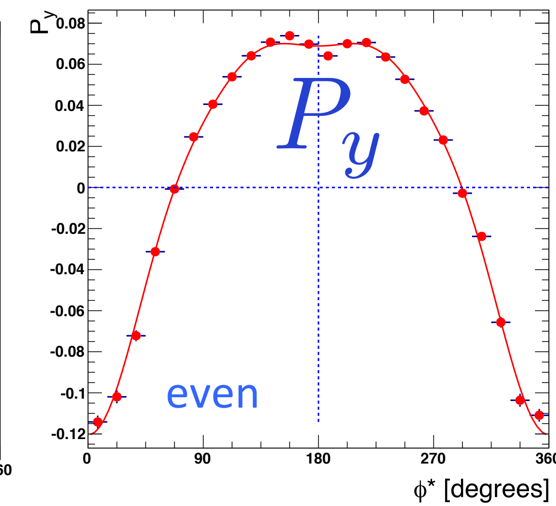
All the final expressions correct for the acceptance effects and for the fact that the target polarization is slightly different for different run groups.

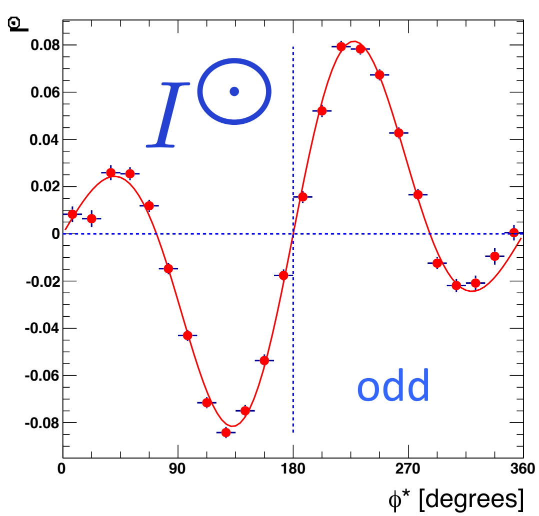
Polarization Observables

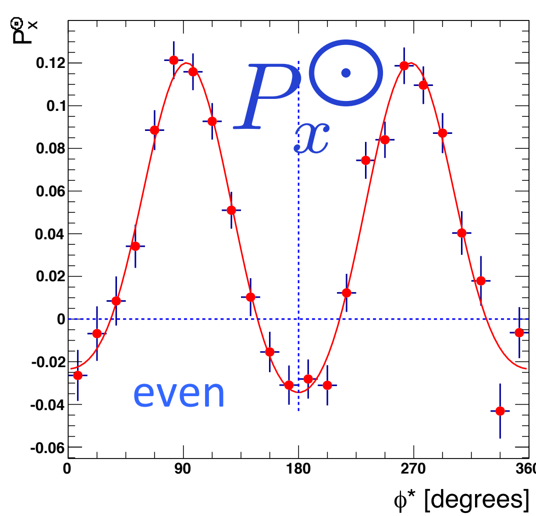


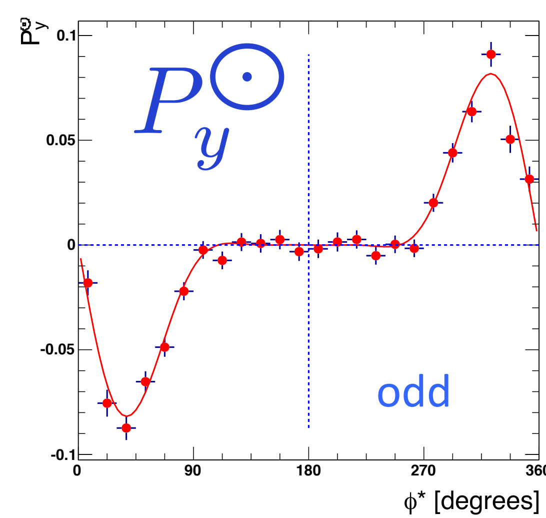
The results are obtained after integrating over all energies and all variables.











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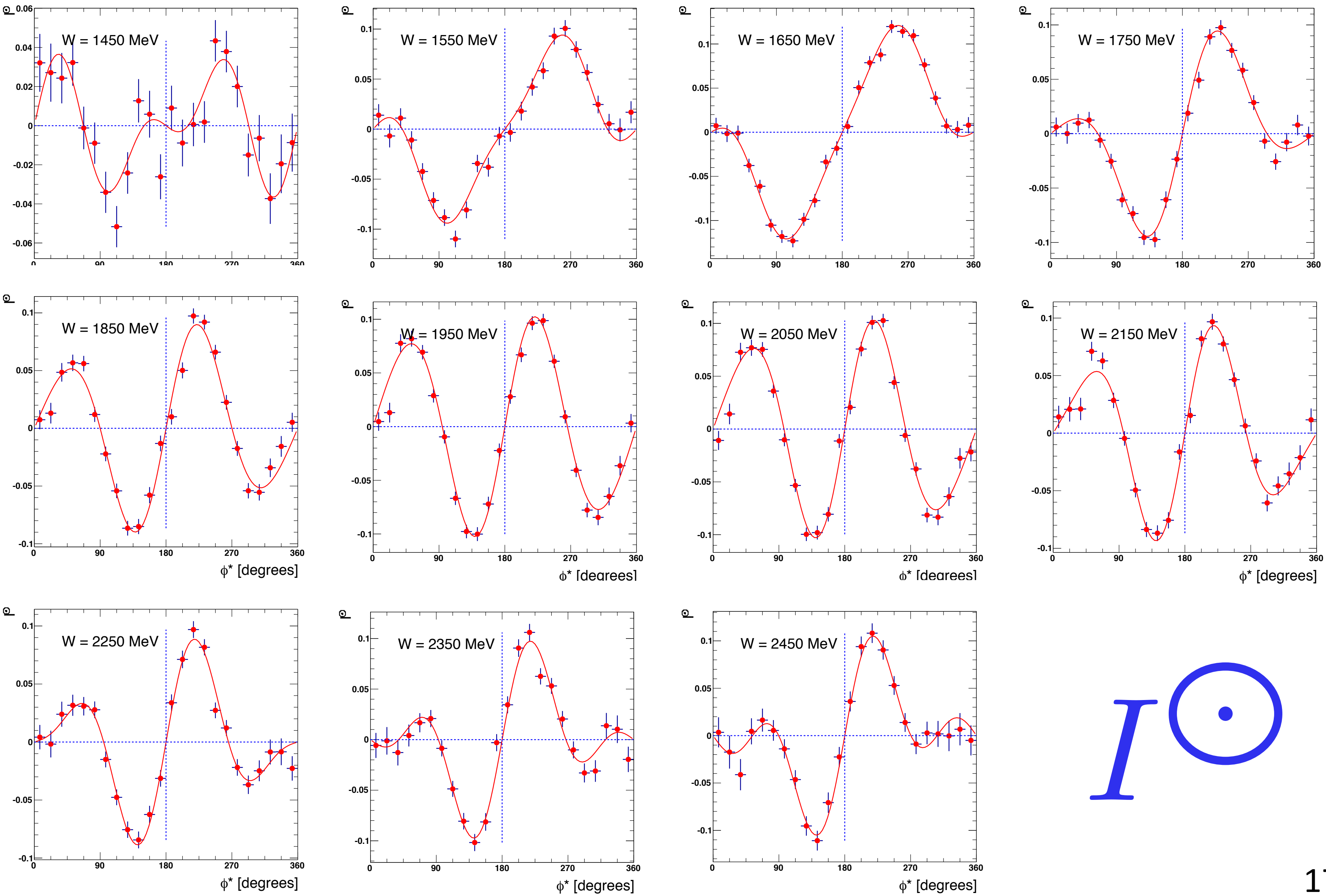
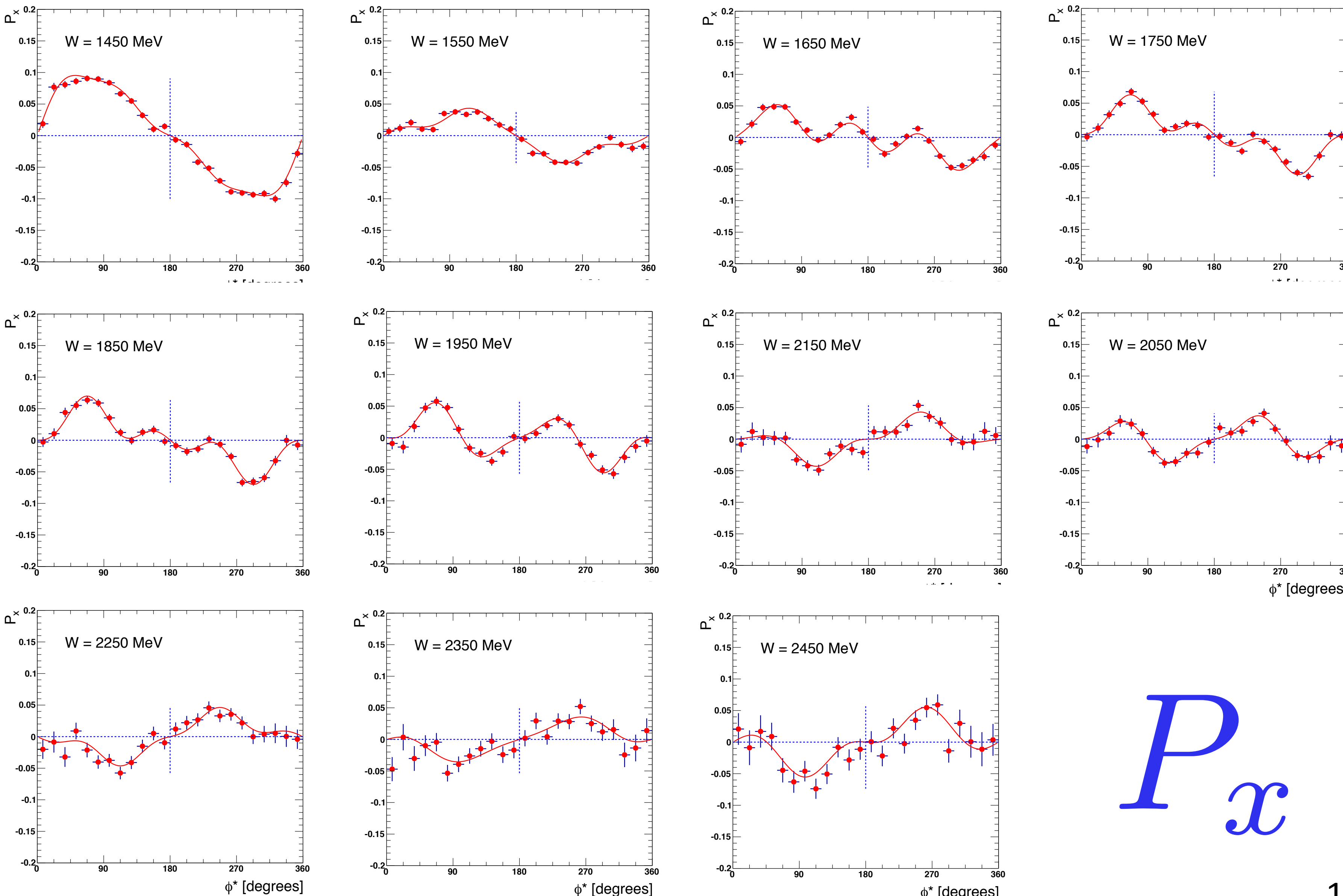


$I^{\odot}$


W = 1450 MeV
W = 1550 MeV
W = 1650 MeV
W = 1750 MeV
W = 1850 MeV
W = 1950 MeV
W = 2150 MeV
W = 2050 MeV
W = 2250 MeV
W = 2350 MeV
W = 2450 MeV
P_x
ϕ* [degrees]
0
90
180
270
360
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2

P_x

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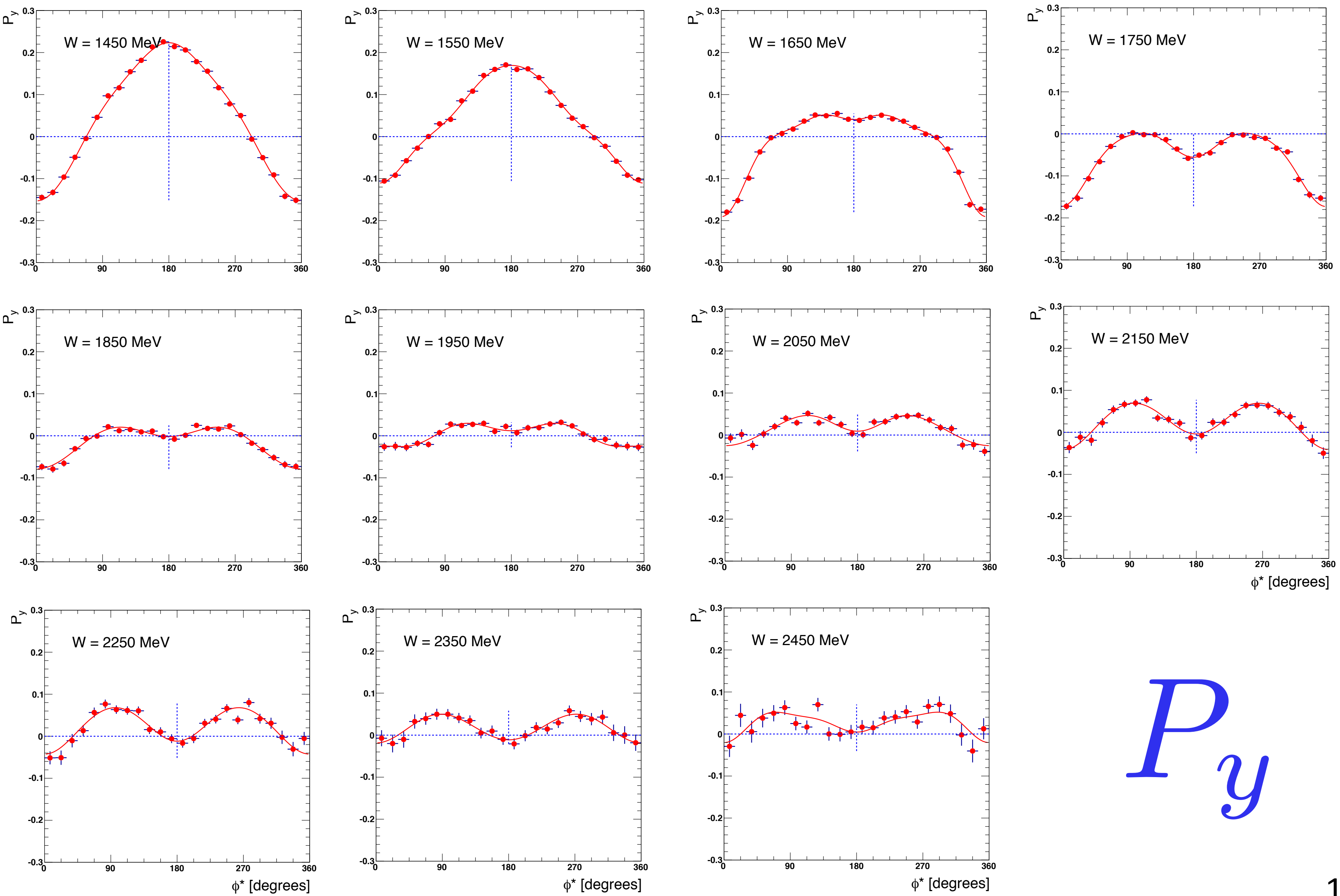

$$P_y$$

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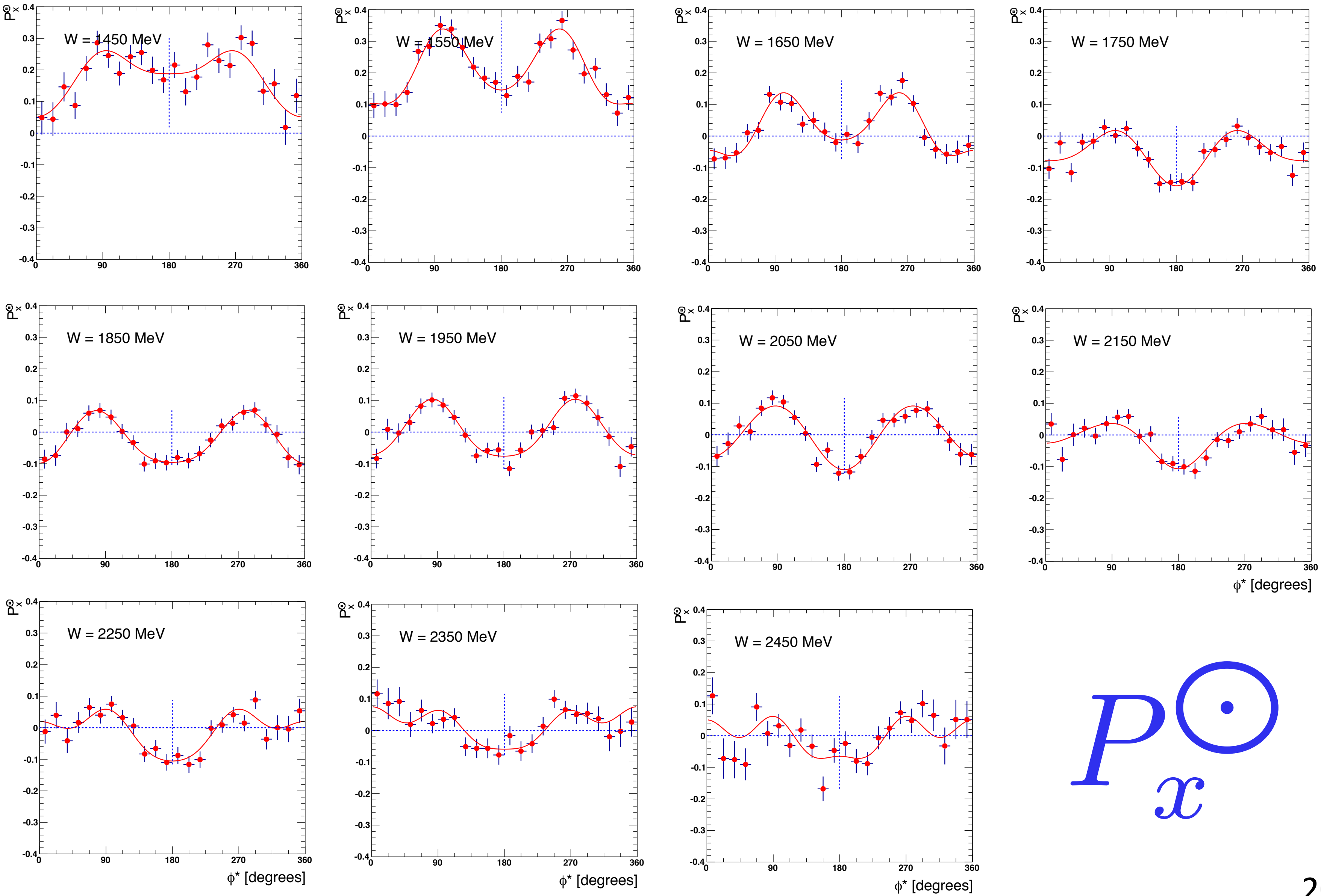

$$P_x^{\odot}$$

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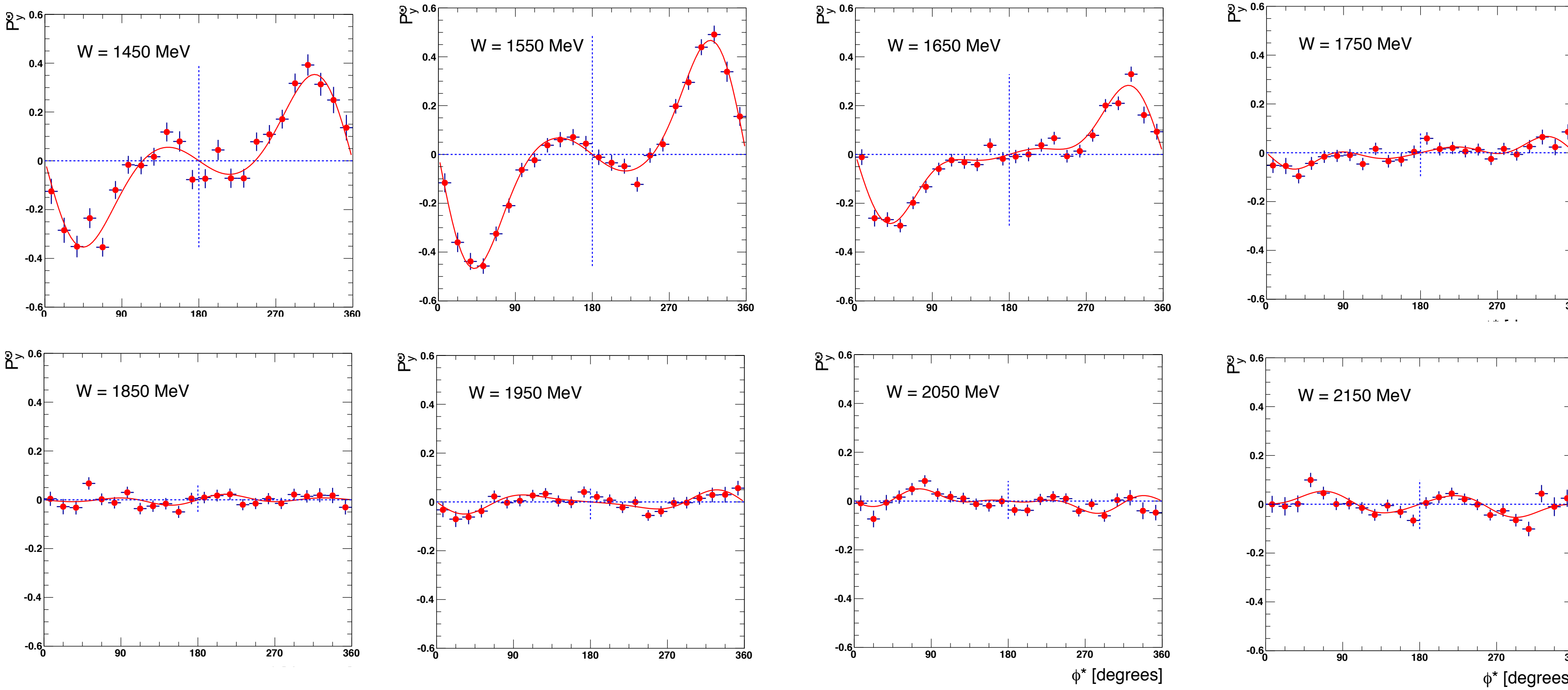

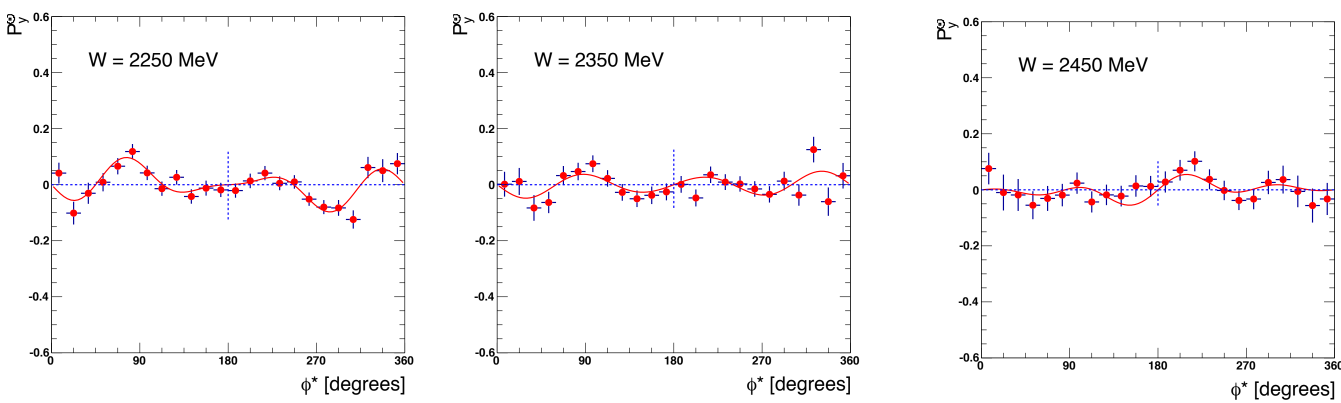

$P_y^{\odot}$

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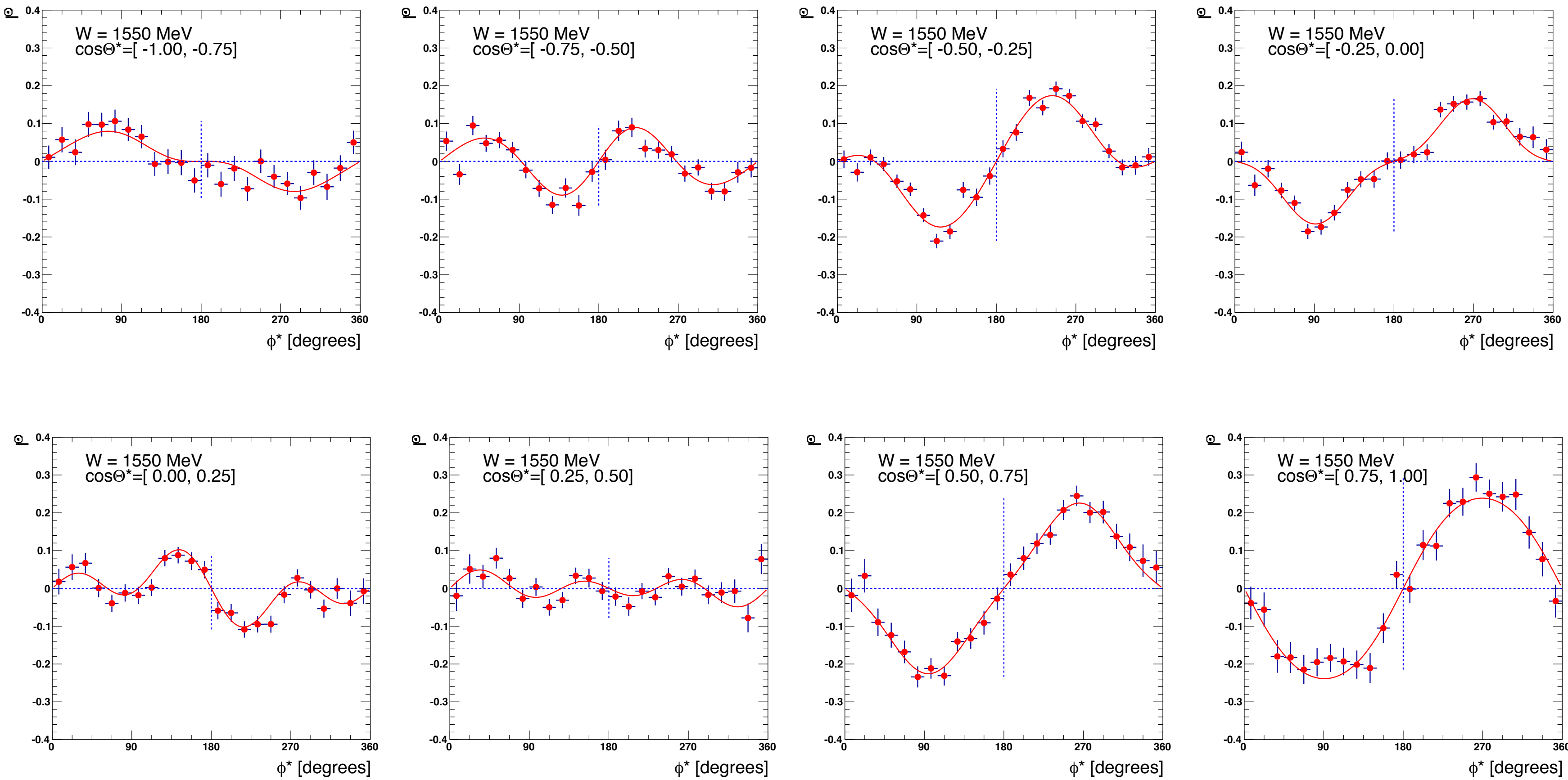
$I^{\odot}$ W=1550 MeV cosθ*=[-1,1]



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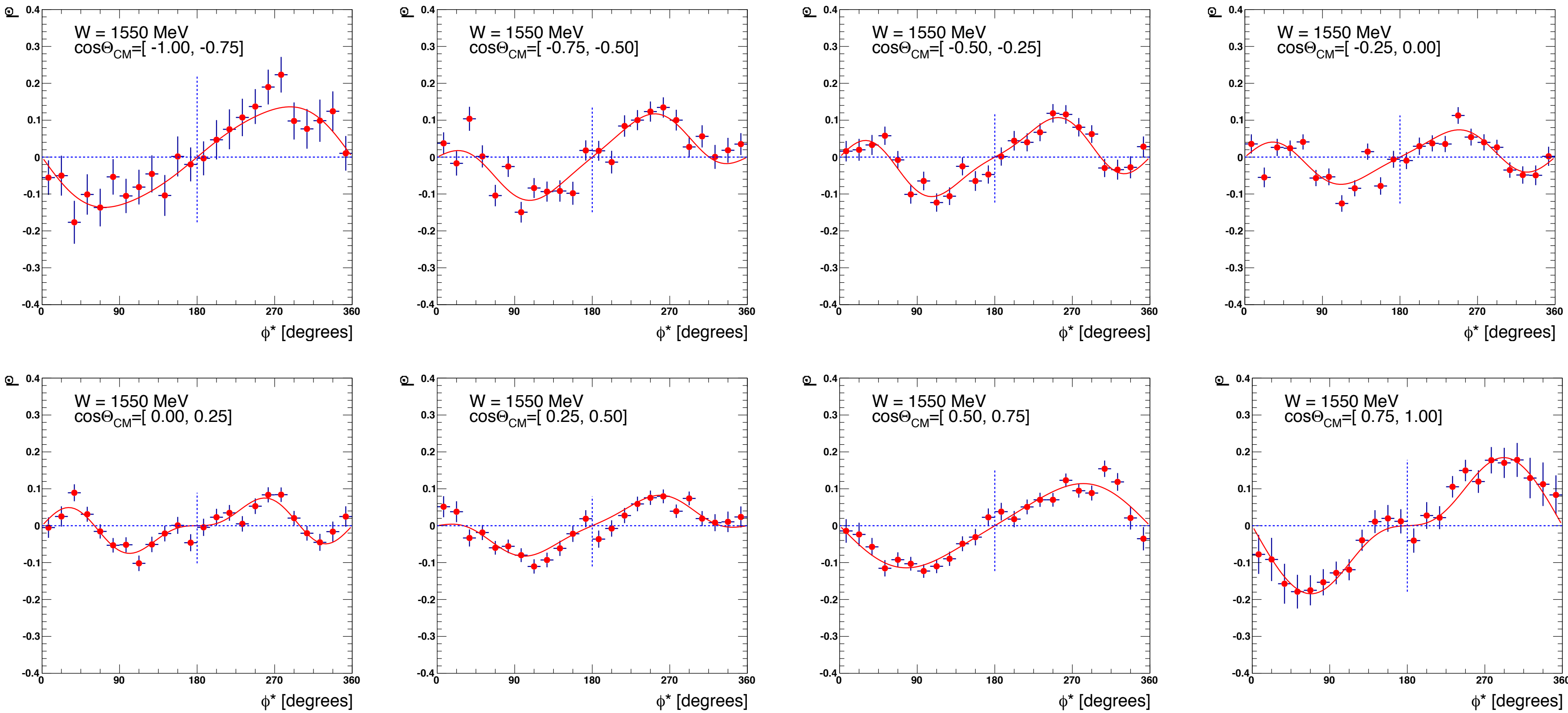
$I^{\odot}$ W=1550 MeV $\cos\theta_{CM}$=[-1,1]



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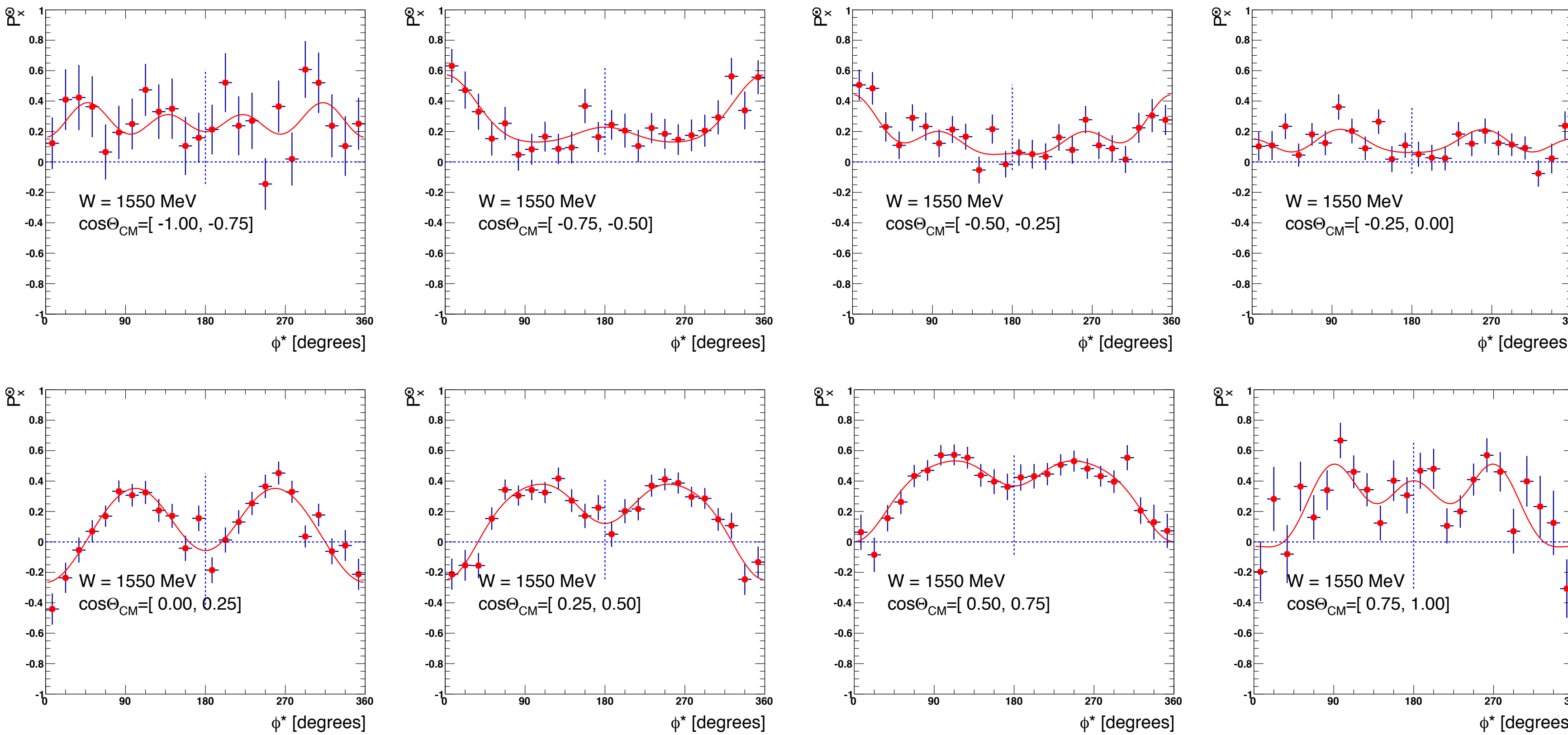
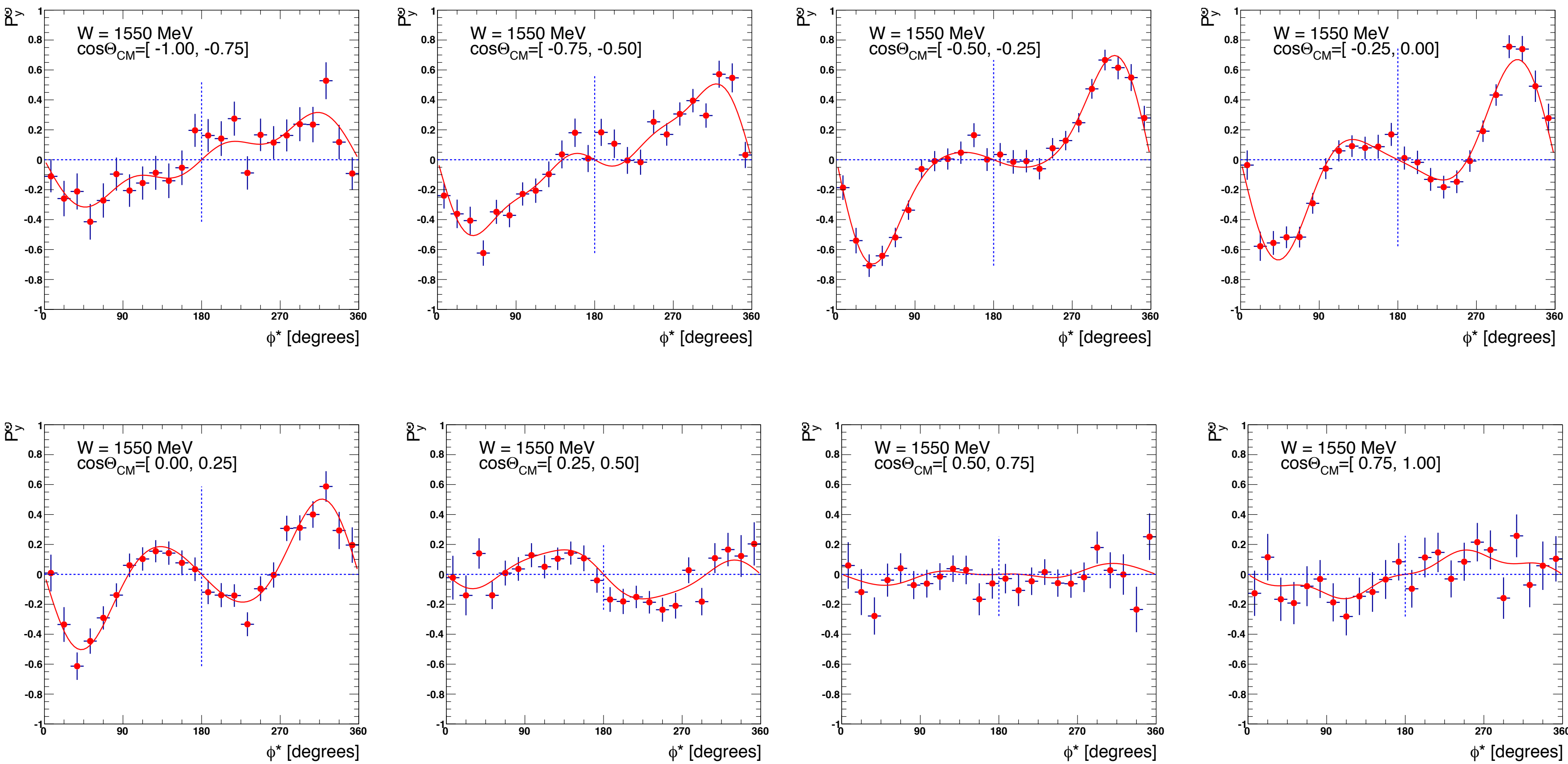
$P_x^{\odot}$ W=1550 MeV $\cos\theta_{CM}$=[-1,1]



$P_y^{\odot}$ W=1550 MeV cosθ*=[-1,1]



Outlook

- overview of the methods used to analyze $\vec{\gamma}\vec{p} \rightarrow p\pi^{+}\pi^{-}$ with circularly polarized photon beam off transversely polarized protons and to extract the polarization observables: $I^{\odot}, P_x, P_y, P_x^{\odot}, P_y^{\odot}$

- preliminary results were shown

- next step: binning data in different ways and compare with the models, getting the systematic uncertainties

EXTRA SLIDES

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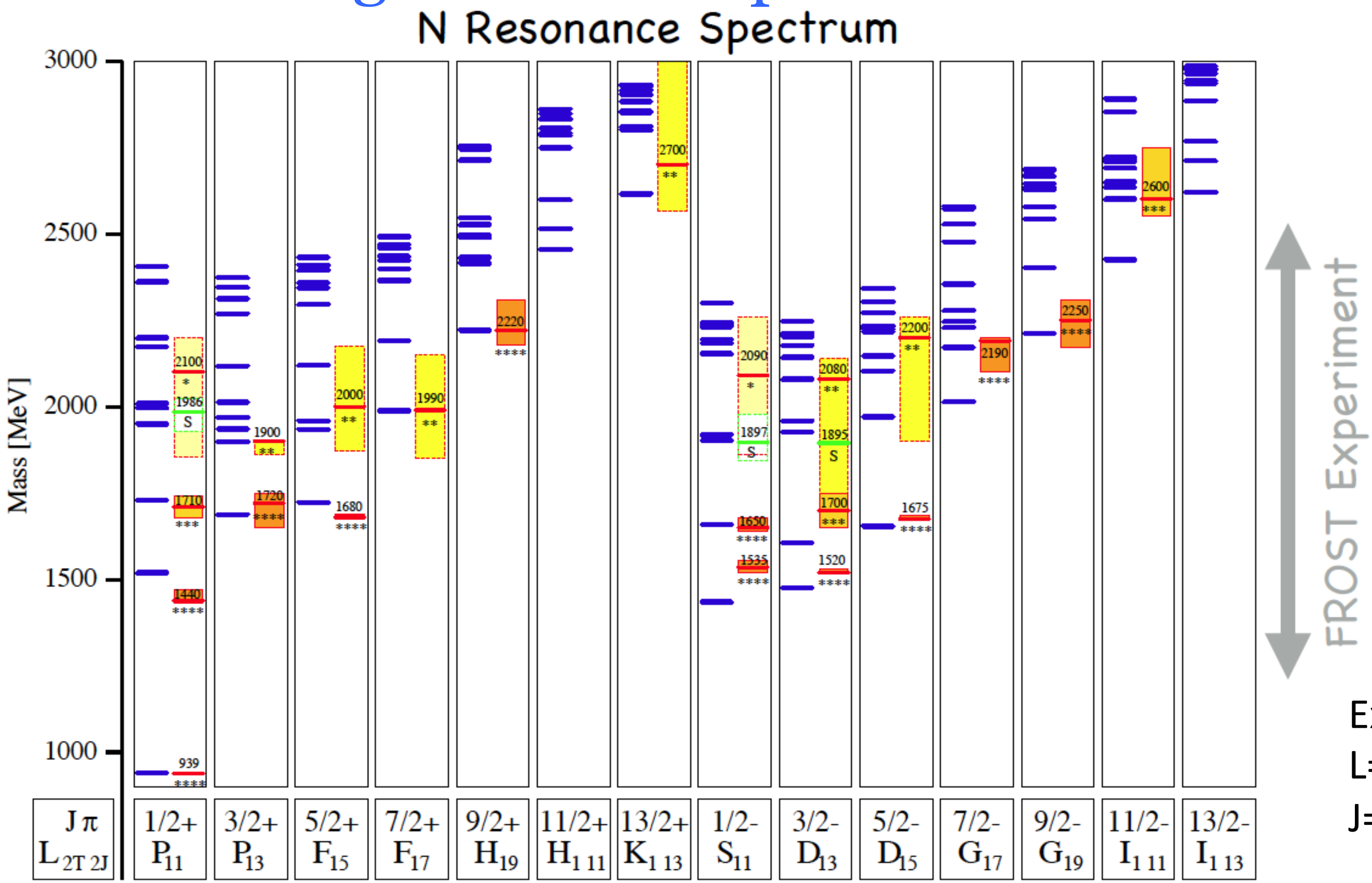
“Missing resonance” problem



Example: P_{11}
L= 1, T= 1/2,
J= 1/2, π= +1

L – orbital angular momentum of nucleon-pion pair
T – isospin, J – total angular momentum,

[U. Löring, B.C. Metsch, and H.R. Petry, Eur. Phys. J. A10 395 (2001)]

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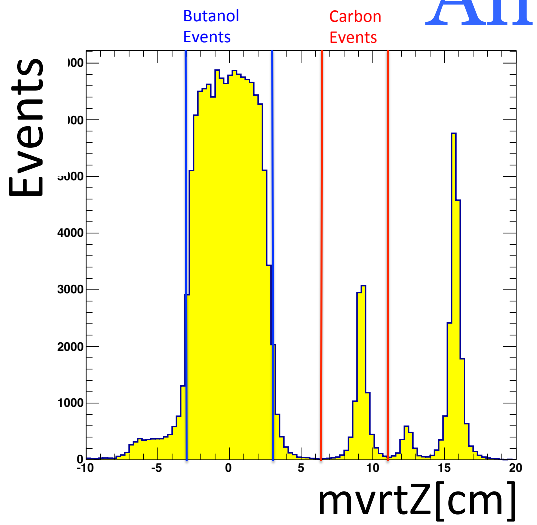
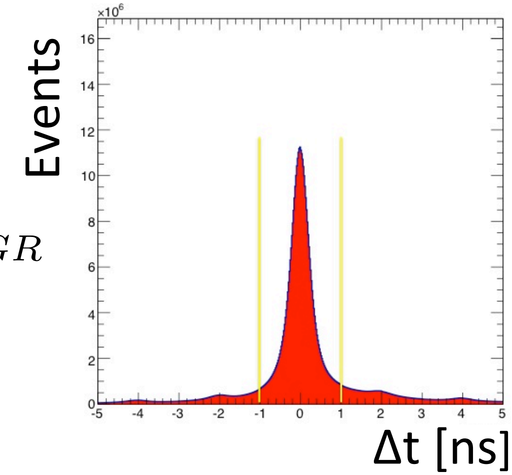
Analysis: Event Pre-selection



Photon selection

$$\Delta t = t_{CLAS} - t_{TAGR}$$

$$|\Delta t| < 1 \text{ ns}$$

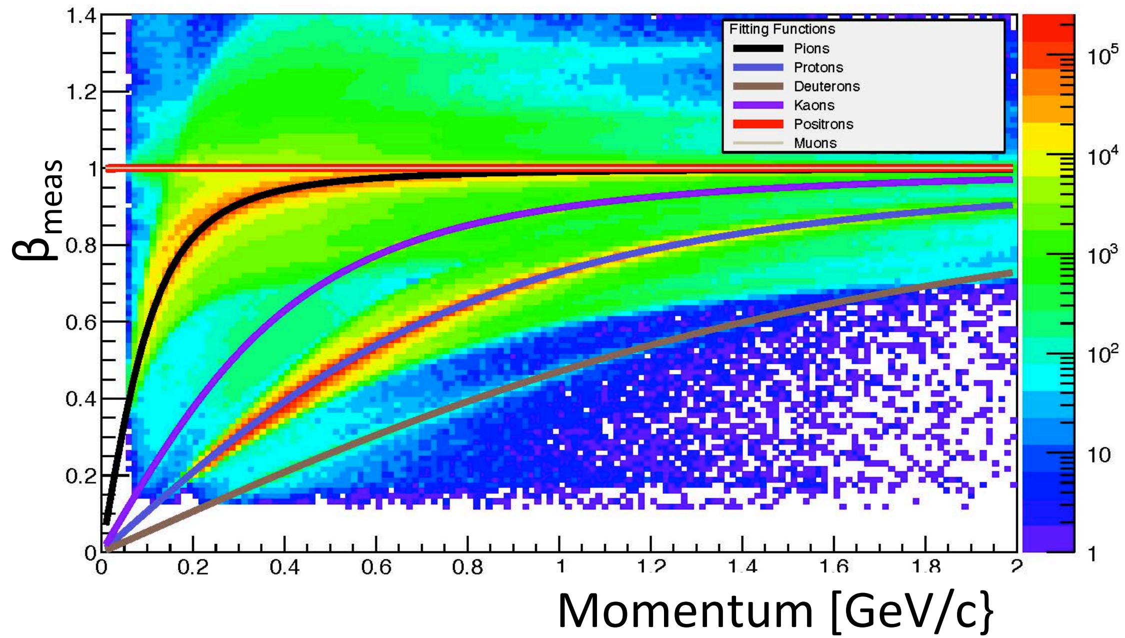


Butanol events: -3 cm < mvrtZ < +3cm

Carbon events: +6cm < mvrtZ <+11cm

$$\beta_{calc} = \frac{p}{\sqrt{p^2 + m^2}}$$

$$\Delta\beta = \beta_{meas} - \beta_{calc}$$



The moments for the two target polarization directions(0°,180°) are:

$$Y^0, Y^{180}, Y^0_{\sin\alpha}, Y^{180}_{\sin\alpha}, Y^0_{\cos\alpha}, Y^{180}_{\cos\alpha}, Y^0_{\sin 2\alpha}, Y^{180}_{\sin 2\alpha}, Y^0_{\cos 2\alpha}, Y^{180}_{\cos 2\alpha}$$

After adding and subtracting different combinations of these yields we get:

$$P_x = 2\frac{[(Y^0\bar{\Lambda}^{180} + Y^{180}\bar{\Lambda}^0) - (Y^0_{\cos 2\alpha}\bar{\Lambda}^{180} + Y^{180}_{\cos 2\alpha}\bar{\Lambda}^0)](Y^0_{\cos\alpha} + Y^{180}_{\cos\alpha}) -}{(Y^0\bar{\Lambda}^{180} + Y^{180}\bar{\Lambda}^0)^2 - (Y^0_{\cos 2\alpha}\Lambda^{180} + Y^{180}_{\cos 2\alpha}\Lambda^0)^2 - (Y^0_{\sin 2\alpha}\bar{\Lambda}^{180} + Y^{180}_{\sin 2\alpha}\bar{\Lambda}^0)^2}$$

$$\frac{-(Y^0_{\sin 2\alpha}\bar{\Lambda}^{180} + Y^{180}_{\sin 2\alpha}\bar{\Lambda}^0)(Y^0_{\sin\alpha} + Y^{180}_{\sin\alpha})}{(Y^0\bar{\Lambda}^{180} + Y^{180}\bar{\Lambda}^0)^2 - (Y^0_{\cos 2\alpha}\Lambda^{180} + Y^{180}_{\cos 2\alpha}\Lambda^0)^2 - (Y^0_{\sin 2\alpha}\bar{\Lambda}^{180} + Y^{180}_{\sin 2\alpha}\bar{\Lambda}^0)^2}$$

$$P_y = 2\frac{[(Y^0\bar{\Lambda}^{180} + Y^{180}\bar{\Lambda}^0) + (Y^0_{\cos 2\alpha}\bar{\Lambda}^{180} + Y^{180}_{\cos 2\alpha}\bar{\Lambda}^0)](Y^0_{\sin\alpha} + Y^{180}_{\sin\alpha}) -}{(Y^0\bar{\Lambda}^{180} + Y^{180}\bar{\Lambda}^0)^2 - (Y^0_{\cos 2\alpha}\Lambda^{180} + Y^{180}_{\cos 2\alpha}\Lambda^0)^2 - (Y^0_{\sin 2\alpha}\bar{\Lambda}^{180} + Y^{180}_{\sin 2\alpha}\bar{\Lambda}^0)^2}$$

$$\frac{-(Y^0_{\sin 2\alpha}\bar{\Lambda}^{180} + Y^{180}_{\sin 2\alpha}\bar{\Lambda}^0)(Y^0_{\cos\alpha} + Y^{180}_{\cos\alpha})}{(Y^0\bar{\Lambda}^{180} + Y^{180}\bar{\Lambda}^0)^2 - (Y^0_{\cos 2\alpha}\Lambda^{180} + Y^{180}_{\cos 2\alpha}\Lambda^0)^2 - (Y^0_{\sin 2\alpha}\bar{\Lambda}^{180} + Y^{180}_{\sin 2\alpha}\bar{\Lambda}^0)^2}$$

$$P_x^{\odot} = 2\frac{(\bar{\Lambda}^{180}Y^0_{\sin 2\alpha} + \bar{\Lambda}^0 Y^{180}_{\sin 2\alpha})(Y^{+0}_{\sin\alpha} - Y^{-0}_{\sin\alpha} + Y^{+180}_{\sin\alpha} - Y^{-180}_{\sin\alpha}) -}{\delta_{\odot}[(\bar{\Lambda}^{180}Y^0_{\sin 2\alpha} + \bar{\Lambda}^0 Y^0_{\sin 2\alpha})^2 - (Y^0\bar{\Lambda}^{180} + Y^{180}\bar{\Lambda}^0)^2 + (Y^0_{\cos 2\alpha}\bar{\Lambda}^{180} + Y^{180}_{\cos 2\alpha}\bar{\Lambda}^0)^2]}$$

$$\frac{-[(Y^0\bar{\Lambda}^{180} + Y^{180}\bar{\Lambda}^0) - (Y^0_{\cos 2\alpha}\bar{\Lambda}^{180} + Y^{180}_{\cos 2\alpha}\bar{\Lambda}^0)](Y^{+0}_{\cos\alpha} - Y^{-0}_{\cos\alpha} + Y^{+180}_{\cos\alpha} - Y^{-180}_{\cos\alpha})}{\delta_{\odot}[(\bar{\Lambda}^{180}Y^0_{\sin 2\alpha} + \bar{\Lambda}^0 Y^{180}_{\sin 2\alpha})^2 - (Y^0\bar{\Lambda}^{180} + Y^{180}\bar{\Lambda}^0)^2 + (Y^0_{\cos 2\alpha}\bar{\Lambda}^{180} + Y^{180}_{\cos 2\alpha}\bar{\Lambda}^0)^2]}$$

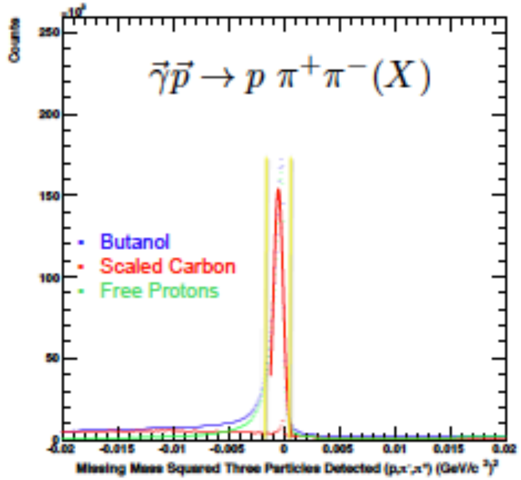
$$P_y^{\odot} = 2\frac{[(Y^0\bar{\Lambda}^{180} + Y^{180}\bar{\Lambda}^0) - (Y^0_{\cos 2\alpha}\bar{\Lambda}^{180} + Y^{180}_{\cos 2\alpha}\bar{\Lambda}^0)](Y^{+0}_{\sin\alpha} - Y^{-0}_{\sin\alpha} + Y^{+180}_{\sin\alpha} - Y^{-180}_{\sin\alpha}) -}{\delta_{\odot}[(Y^0\bar{\Lambda}^{180} + Y^{180}\bar{\Lambda}^0)^2 - (\bar{\Lambda}^{180}Y^0_{\sin 2\alpha} + \bar{\Lambda}^0 Y^0_{\sin 2\alpha})^2 - (Y^0_{\cos 2\alpha}\bar{\Lambda}^{180} + Y^{180}_{\cos 2\alpha}\bar{\Lambda}^0)^2]}$$

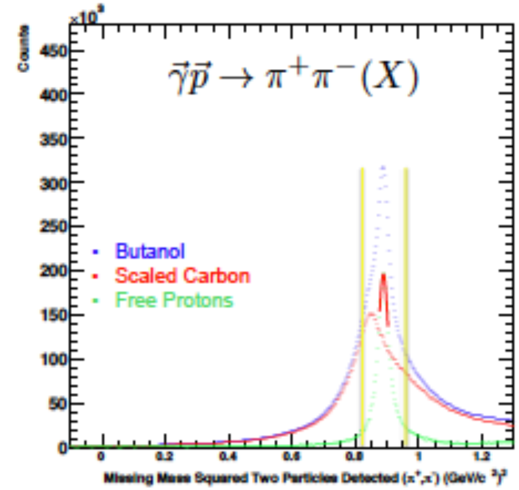
$$\frac{-(\bar{\Lambda}^{180}Y^0_{\sin 2\alpha} + \bar{\Lambda}^0 Y^{180}_{\sin 2\alpha})(Y^{+0}_{\cos\alpha} - Y^{-0}_{\cos\alpha} + Y^{+180}_{\cos\alpha} - Y^{-180}_{\cos\alpha})}{\delta_{\odot}[(Y^0\bar{\Lambda}^{180} + Y^{180}\bar{\Lambda}^0)^2 - (\bar{\Lambda}^{180}Y^0_{\sin 2\alpha} + \bar{\Lambda}^0 Y^{180}_{\sin 2\alpha})^2 - (Y^0_{\cos 2\alpha}\bar{\Lambda}^{180} + Y^{180}_{\cos 2\alpha}\bar{\Lambda}^0)^2]}$$

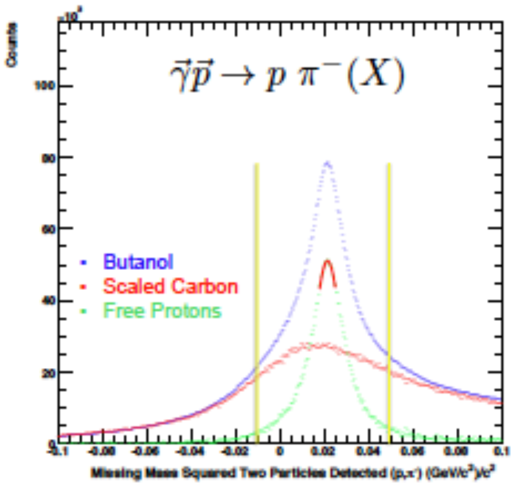
Run range	Date range	Events	Beam energy	Beam current	Live time	Helicity freq.	H.W.P	Phi_FG	Target pol.
62207 - 62289	3/19 - 3/23	723.1 M	3081.73 MeV	11.9 nA	0.82	240 Hz (octets)	1	90	83% - 80% (+ +)
62298 - 62372	3/24 - 3/30	894.9 M	3081.73 MeV	13.4 nA	0.83	240 Hz (octets)	1	90	86% - 80% (- +)
62374 - 62464	3/30 - 4/05	1129.7 M	3081.73 MeV	13.4 nA	0.78	240 Hz (octets) or 30 Hz (pairs, quartets)[1]	0	90	79% - 75% (+ +)
62504 - 62604	4/07 - 4/13	1307.1 M	3081.73 MeV	13.6 nA	0.83	240 Hz (octets)	0	90	81% - 76% (+ -)
62609 - 62704	4/13 - 4/19	972.6 M	3081.73 MeV	13.5 nA	0.83	240 Hz (octets) or 30 Hz (quartets)[2]	0 or 1[3]	90	85% - 79% (- -)

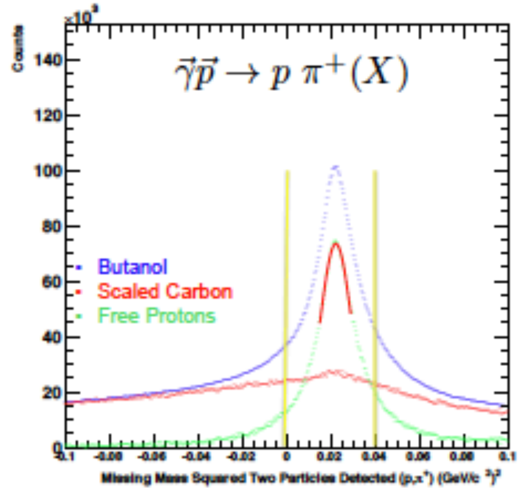
Target polarization: (NMR_sign Holding_magnet_sign) e.g. (+ +) and (- -) means pos.sign; (+ -) and (- +) means neg.sign

Missing Mass Squared Distributions









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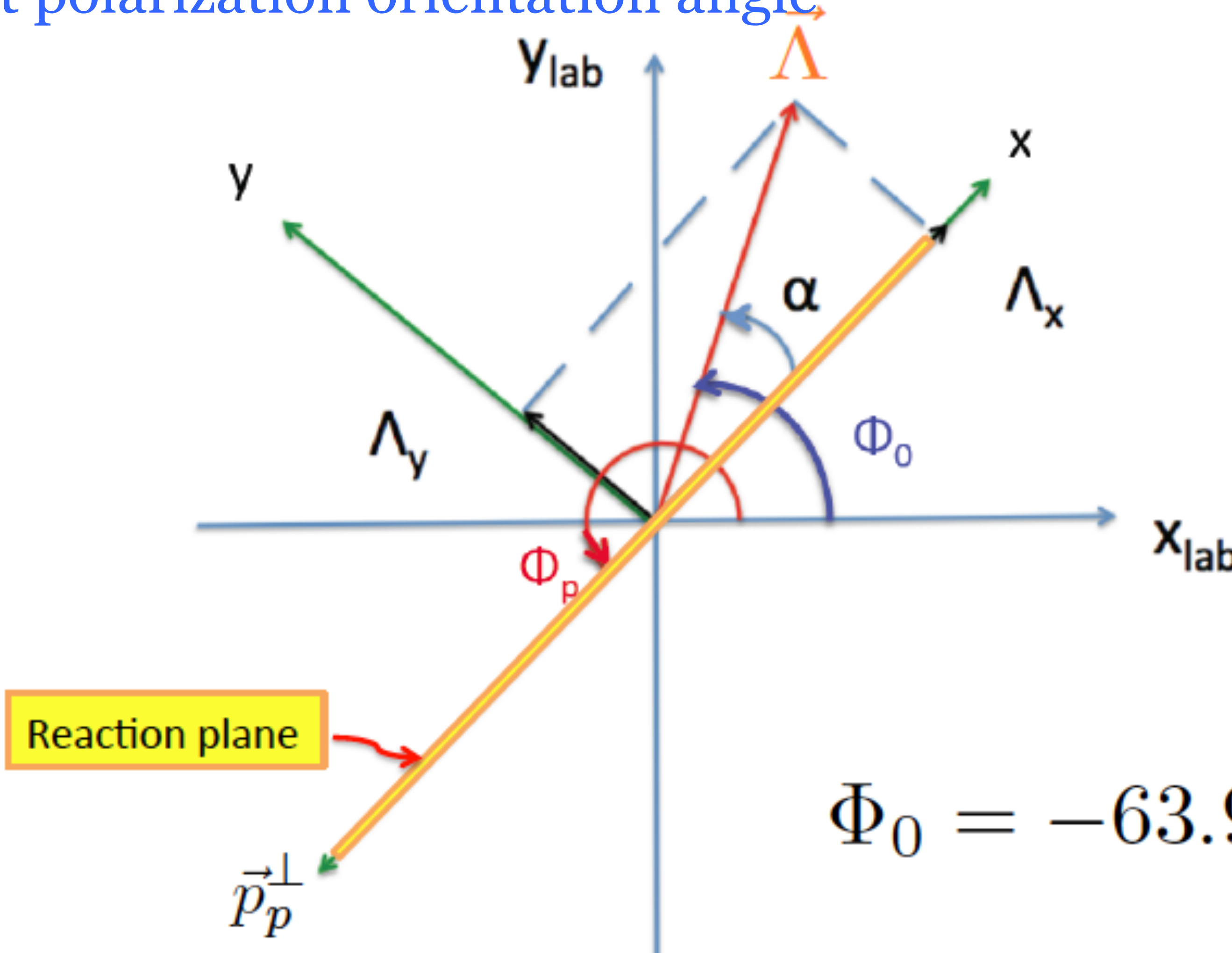
Observables odd/even behavior fit check

$$F_{even} = a_0 + a_1 \cos(\Phi^*) + a_2 \cos(2\Phi^*) + a_3 \cos(3\Phi^*) + a_4 \cos(4\Phi^*$$

$$F_{odd} = b_1 \sin(\Phi^*) + b_2 \sin(2\Phi^*) + b_3 \sin(3\Phi^*) + b_4 \sin(4\Phi^*$$

Target polarization orientation angle



$$\Phi_0 = -63.9°, 116.1°$$

$$\alpha = 180° - \Phi_p^{lab} + \Phi_0$$