Extraction of polarization asymmetries in two pion photoproduction

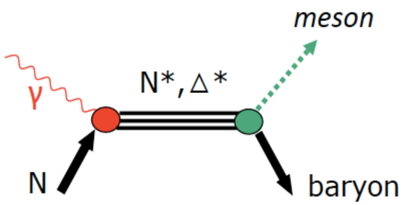
with circularly polarized beam and (maybe) longitudinally polarized target

Alessandra Filippi
INFN Torino, Italy

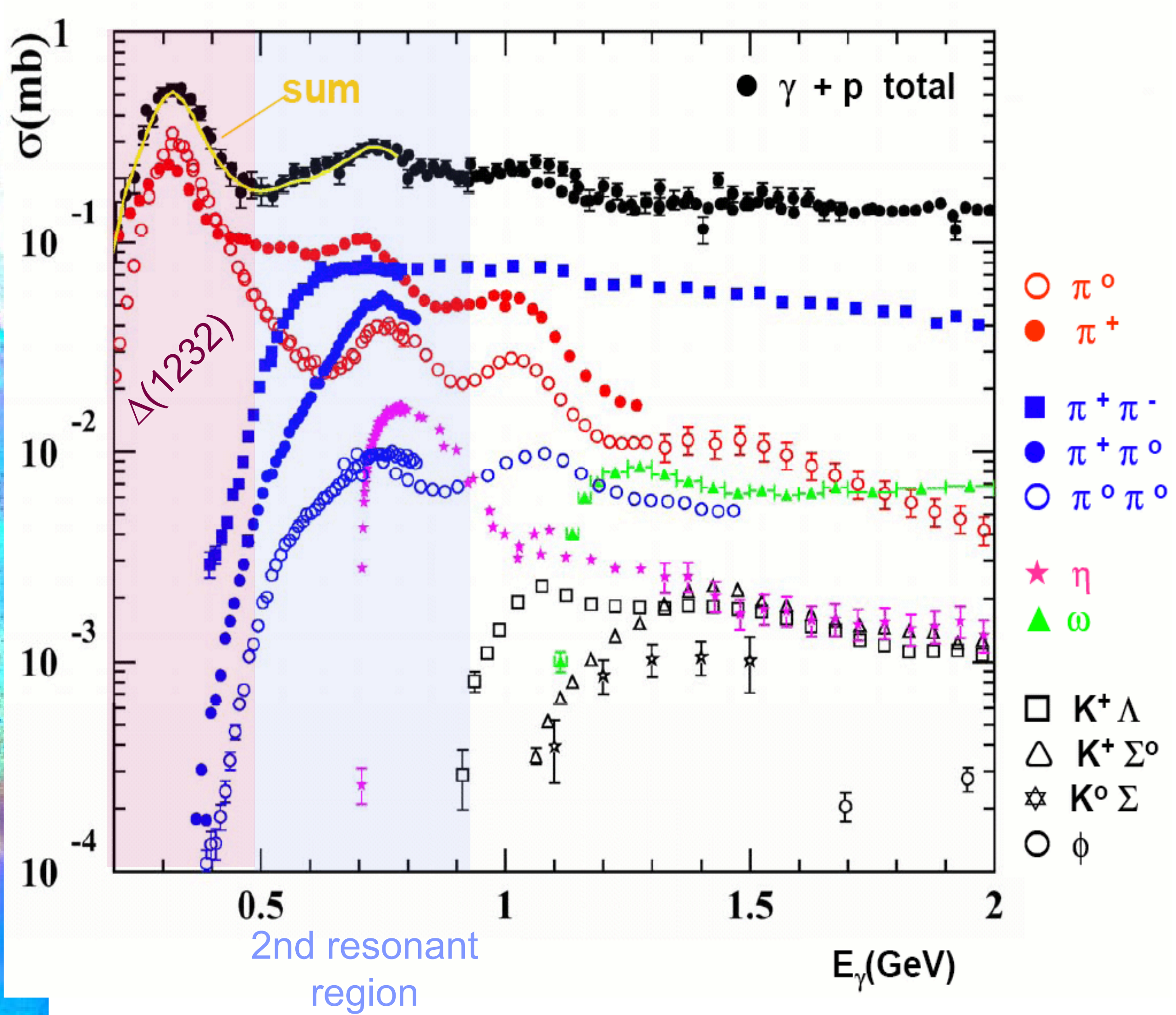
INFN
Istituto Nazionale di Fisica Nucleare

JPAC & JLAB12 Workshop
Genova, Feb. 18-20, 2026

N*/Δ* in photoproduction reactions



Photonuclear cross sections



- Photon induced reaction could favor the formation of missing resonances which might couple strongly to the γN vertex
- γ reactions not studied extensively in the past - lack of good enough (energy/intensity) photon beams
- Dominant contributions to the “second resonant region”: double-pion and η channels
  - Double-pion photoproduction: good tool to investigate this mass region

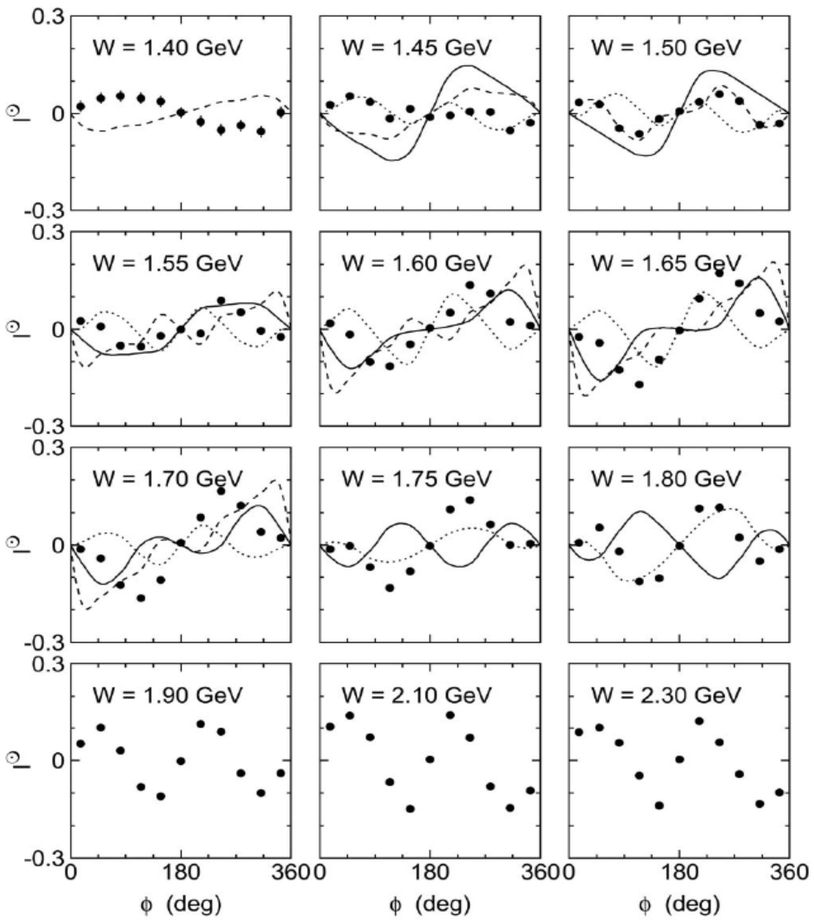
Photoproduction of $\pi^+\pi^-$ pairs from protons with circularly polarized beam

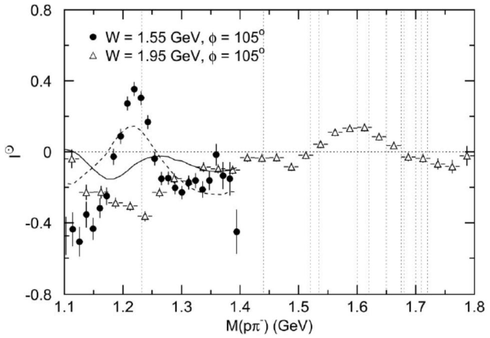
S. Strauch et al. (CLAS) PLR95 (2005), 162003

- CLAS data: 1.35 < W < 2.30 GeV
  - Missing resonances predicted to lie in the region W > 1.8 GeV
- Circularly polarized photon beam, no polarization specified for target and recoil proton
- First measurement of beam-helicity asymmetry distributions as a function of the helicity angle:

$$I^{\odot} = \frac{1}{P_\gamma}\frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

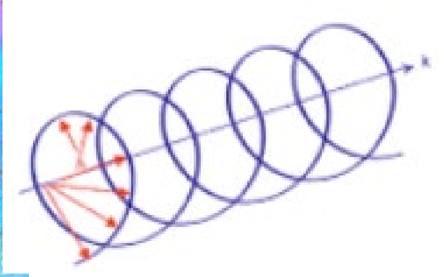
  - Odd trend in all W sub-ranges
  - Compared with models based on electroproduction of double-charged pions including a set of quasi-two body intermediate states (Mokeev et al.):
    - *πΔ, ρN, πN(1520), πN(1680)* + contributions from *Δ(1600), N(1700), N(1710), N(1720)*
    - The agreement is not satisfactory, calls for a more detailed description
    - The $I^{\odot}$ observable is critically sensitive to interferences



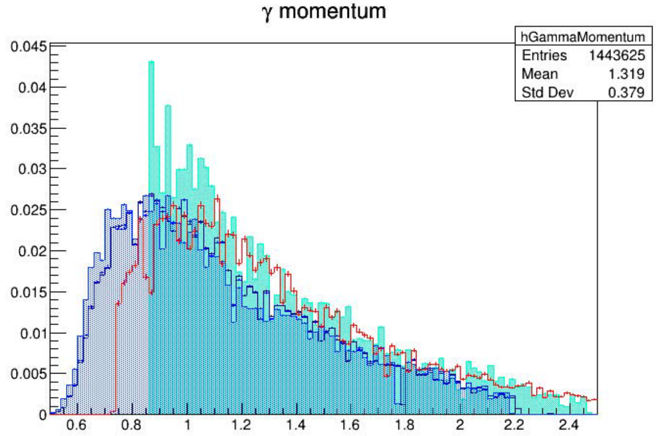


Experimental method – polarized beam and target

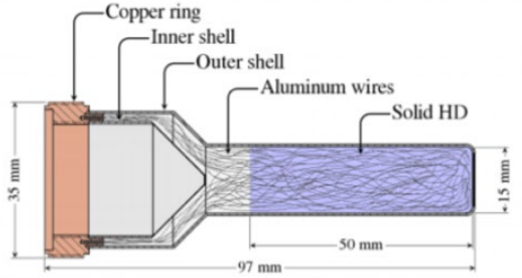
- CLAS-g14 data taking (2011-2012): *circularly polarized* photon beam with momentum up to 2.5 GeV/c interacting on a cryogenic HD *longitudinally* polarized target
  - **Beam:** circularly polarized photons by bremsstrahlung from a longitudinally polarized electron beam (>85%) through a gold foil radiator
    - Circular: ↑/↓ (960 Hz flip frequency)
    - Energy dependent γ polarization
  - **Target:** "brute-force + aging" polarization method (< 30%)
    - Longitudinal (along beam direction): ⇒/⇐
    - Fixed in different data-sets
    - Protons/neutrons

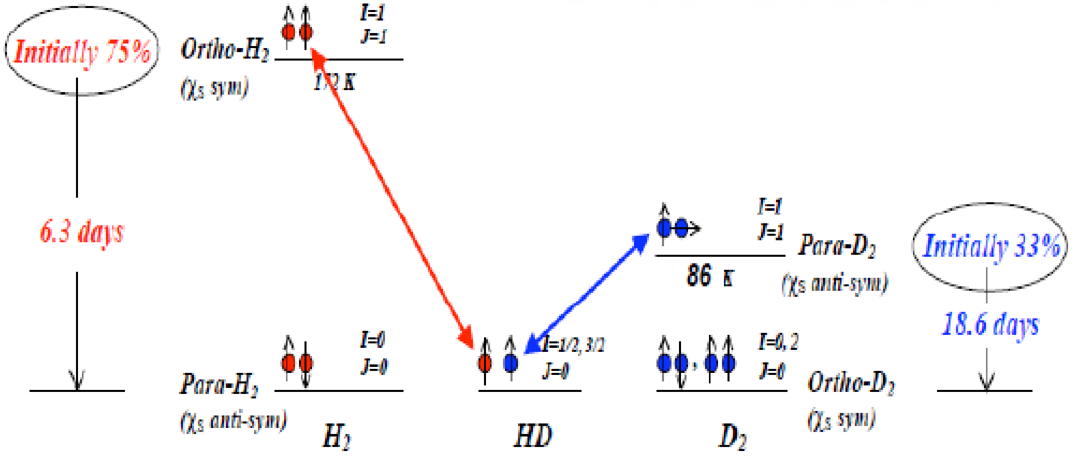


$$x = \frac{E_\gamma}{E_{beam}}$$

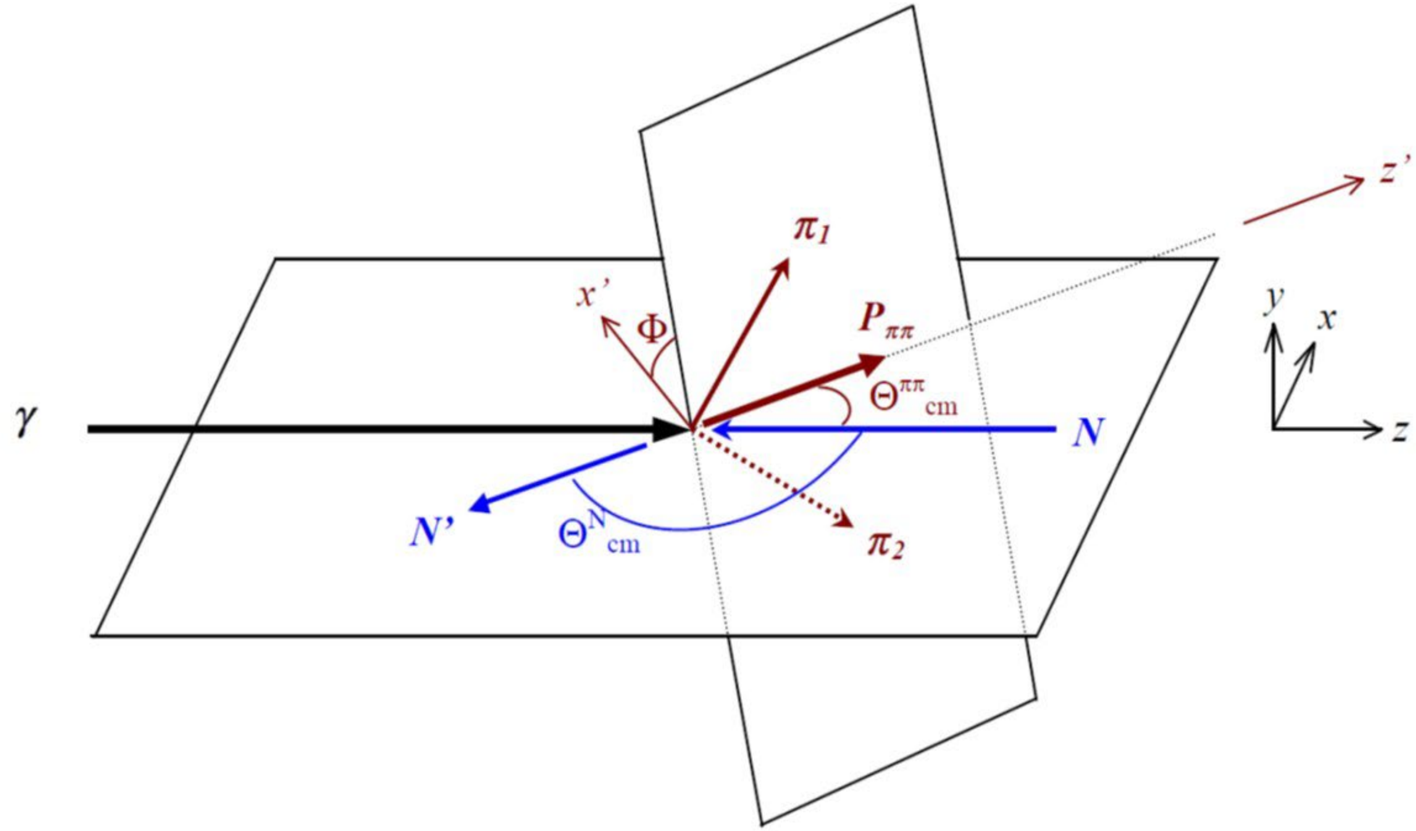


$$\delta_\odot = P_{el}\frac{4x - x^2}{4 - 4x + 3x^2}$$





Study of polarization observables in the $\vec{\gamma}\vec{N} \rightarrow \pi^+\pi^- N$ reaction



$$\frac{d\sigma}{dx_i} = \sigma_0\{(1 + \Lambda_z \cdot \mathbf{P_z}) + \delta_\odot(\mathbf{I}^\odot + \Lambda_z \cdot \mathbf{P}_z^\odot)\}$$

- Differential cross-section expressed as a function of polarization observables, weighted by the amount of beam $\delta_\odot$ and/or target Λ polarization
- The trend of the polarization observables depends on the resonance content in a given energy range
- Polarization observables are bilinear combinations of partial amplitudes (Roberts, Oed PRC71 (2005), 0552001): very sensitive to interference effects

Polarization observables extraction

Problem: extract from the number of collected events the ***$I^{\odot}$, P, $P^{\odot}$*** observables as a function of the Φ azimuthal angle in the helicity reference system, in W energy ranges

$$P_z = \frac{1}{\Lambda_z}\frac{[N(\rightarrow\Rightarrow)+N(\leftarrow\Rightarrow)]-[N(\rightarrow\Leftarrow)+N(\leftarrow\Leftarrow)]}{[N(\rightarrow\Rightarrow)+N(\leftarrow\Rightarrow)]+[N(\rightarrow\Leftarrow)+N(\leftarrow\Leftarrow)]}$$

$$I^{\odot} = \frac{1}{\delta_{\odot}}\frac{[N(\rightarrow\Rightarrow)+N(\rightarrow\Leftarrow)]-[N(\leftarrow\Rightarrow)+N(\leftarrow\Leftarrow)]}{[N(\rightarrow\Rightarrow)+N(\rightarrow\Leftarrow)]+[N(\leftarrow\Rightarrow)+N(\leftarrow\Leftarrow)]}$$

$$P_z^{\odot} = \frac{1}{\Lambda_z\delta_{\odot}}\frac{[N(\rightarrow\Rightarrow)+N(\leftarrow\Leftarrow)]-[N(\rightarrow\Leftarrow)+N(\leftarrow\Rightarrow)]}{[N(\rightarrow\Rightarrow)+N(\leftarrow\Leftarrow)]+[N(\rightarrow\Leftarrow)+N(\leftarrow\Rightarrow)]}$$

- Related to differential cross-section asymmetries
- Depending on the relative beam/target spin configurations
- Two data sets with opposite target ($\Rightarrow$/$\Leftarrow$) polarizations needed (with proper normalization)

Polarization asymmetries in φ_{hel} bins

$$\frac{d\sigma}{dx_i} = \sigma_0\{(1 + \Lambda_z \cdot \mathbf{P_z}) + \delta_\odot(\mathbf{I}^\odot + \Lambda_z \cdot \mathbf{P}_z^\odot)\}$$

- This equation (Roberts et al., PRC 718(2005), 055201) can be split in four depending on the orientation of beam helicity and target polarization (along z)
- Two data sets with opposite target polarization need to be used (but properly normalized)
- The system of equations can be solved analytically extracting, in every bin, $I^\odot$, P_z, $P^\odot_z$ and σ_0

$$N_{exp}^{\rightarrow\Rightarrow} = \left(\frac{d\sigma}{d\Omega}\right)_0 \mathrm{L}\,\varepsilon\left[1 + \Lambda_z P_z + \delta_\odot(I_\odot + \Lambda_z P_z^\odot)\right]$$

$$N_{exp}^{\leftarrow\Rightarrow} = \left(\frac{d\sigma}{d\Omega}\right)_0 \mathrm{L}\,\varepsilon\left[1 + \Lambda_z P_z - \delta_\odot(I_\odot + \Lambda_z P_z^\odot)\right]$$

$$N_{exp}^{\rightarrow\Leftarrow} = \left(\frac{d\sigma}{d\Omega}\right)_0 \mathrm{L}\,\varepsilon\left[1 - \Lambda_z P_z + \delta_\odot(I_\odot - \Lambda_z P_z^\odot)\right]$$

$$N_{exp}^{\leftarrow\Leftarrow} = \left(\frac{d\sigma}{d\Omega}\right)_0 \mathrm{L}\,\varepsilon\left[1 - \Lambda_z P_z - \delta_\odot(I_\odot - \Lambda_z P_z^\odot)\right]$$

$$I_\odot = \frac{\dfrac{N_1^{\rightarrow\Rightarrow} - N_1^{\leftarrow\Rightarrow}}{\delta_{\odot 1}} + \dfrac{\Lambda_{z1}}{\Lambda_{z2}} \cdot \dfrac{\mathrm{L}_{eff1}}{\mathrm{L}_{eff2}} \cdot \dfrac{N_2^{\rightarrow\Leftarrow} - N_2^{\leftarrow\Leftarrow}}{\delta_{\odot 2}}}{(N_1^{\rightarrow\Rightarrow} + N_1^{\leftarrow\Rightarrow}) + \dfrac{\Lambda_{z1}}{\Lambda_{z2}} \cdot \dfrac{\mathrm{L}_{eff1}}{\mathrm{L}_{eff2}}\,(N_2^{\rightarrow\Leftarrow} + N_2^{\leftarrow\Leftarrow})}$$

$$P_z^\odot = \frac{1}{\Lambda_{z2}} \cdot \frac{\dfrac{N_1^{\rightarrow\Rightarrow} - N_1^{\leftarrow\Rightarrow}}{\delta_{\odot 1}} - \dfrac{\mathrm{L}_{eff1}}{\mathrm{L}_{eff2}} \cdot \dfrac{N_2^{\rightarrow\Leftarrow} - N_2^{\leftarrow\Leftarrow}}{\delta_{\odot 2}}}{(N_1^{\rightarrow\Rightarrow} + N_1^{\leftarrow\Rightarrow}) + \dfrac{\Lambda_{z1}}{\Lambda_{z2}} \cdot \dfrac{\mathrm{L}_{eff1}}{\mathrm{L}_{eff2}}\,(N_2^{\rightarrow\Leftarrow} + N_2^{\leftarrow\Leftarrow})}$$

$$P_z = \frac{1}{\Lambda_{z2}} \cdot \frac{(N_1^{\rightarrow\Rightarrow} + N_1^{\leftarrow\Rightarrow}) - \dfrac{\mathrm{L}_{eff1}}{\mathrm{L}_{eff2}} \cdot (N_2^{\rightarrow\Leftarrow} + N_2^{\leftarrow\Leftarrow})}{(N_1^{\rightarrow\Rightarrow} + N_1^{\leftarrow\Rightarrow}) + \dfrac{\Lambda_{z1}}{\Lambda_{z2}} \cdot \dfrac{\mathrm{L}_{eff1}}{\mathrm{L}_{eff2}}\,(N_2^{\rightarrow\Leftarrow} + N_2^{\leftarrow\Leftarrow})}$$

g14 available data sets

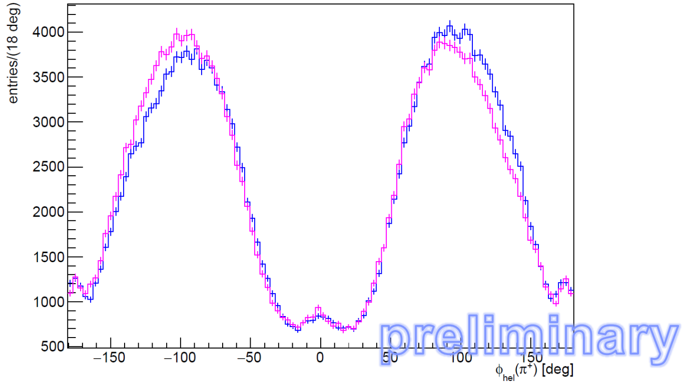
Data set	stats	Λ_D	Λ_H	<Λ>	e^- beam pol.	e^- beam energy	Torus pol	trigger
Silver1	830M	0.256	0.147	0.201	-0.82	2.28	--	1p
Silver2	1170M	0.230	-0.143	0.043	-0.76	2.28	--	1p
Silver3	250M	0.209	-0.003	0.103	-0.76	2.28	+	2p
Silver4	820M	-0.172	-0.008	-0.046	-0.76	2.28	+	2p
Silver5a	1750M	-0.155	-0.008	-0.082	+0.76	2.28	+	2p 1p pr8
Silver5b	3081M	-0.155	-0.008	-0.082	+0.89	2.23	+	2p 1p pr8
Silver6a	130M	-0.018	-0.025	-0.022	-0.89	2.23	+	2p
Silver6b	1200M	-0.018	-0.025	-0.022	-0.89	2.23	--	1p
Gold2a	440M	0.268	0.269	0.27	-0.88	2.54	+	2p 1p pr16
Gold2b	1660M	0.268	0.269	0.27	-0.83	2.54	+	2p 1p pr 16
Gold3	88M	0.158	0.183	0.27	-0.83	2.54	+	2p 1p pr 16

Experimental angular distributions

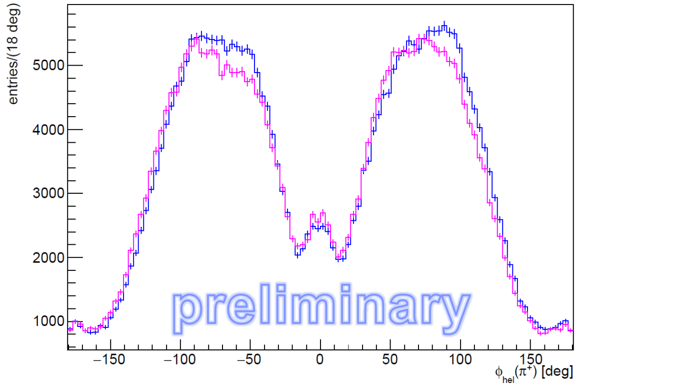
- Inputs: azimuthal angular distributions (φ_{hel})
- Bin by bin: number of events selected with
  - Given helicity (positive/negative in the same data set)
  - Given target polarization (in different data sets)
  - Selection in W energy ranges (~100 MeV wide window)
  - Counts to be properly normalized between different data sets
  - The sign of polarization depends on φ_{hel}

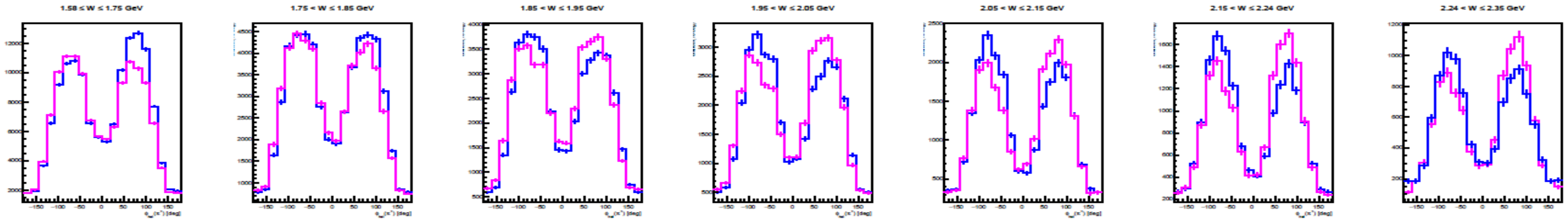
- Slight differences when selecting different combinations of helicities/target polarization: origin of the investigated asymmetries

Set w/ positive target polarization



Set w/ negative target polarization





Polarization observables extraction

- Recall: two data sets needed to extract the polarization observables
  - Each has its own normalization (i.e. luminosity)
  - Each data set was acquired with a given trigger (which might have different efficiency)
  - Each data set is characterized by a different acceptance
    - The L_{eff1}/L_{eff2} factor is crucial

$$I_{\odot} = \frac{\frac{N_1^{\rightarrow\Rightarrow} - N_1^{\leftarrow\Rightarrow}}{\delta_{\odot 1}} + \frac{\Lambda_{z1}}{\Lambda_{z2}} \cdot \frac{L_{eff1}}{L_{eff2}} \cdot \frac{N_2^{\rightarrow\Leftarrow} - N_2^{\leftarrow\Leftarrow}}{\delta_{\odot 2}}}{(N_1^{\rightarrow\Rightarrow} + N_1^{\leftarrow\Rightarrow}) + \frac{\Lambda_{z1}}{\Lambda_{z2}} \cdot \frac{L_{eff1}}{L_{eff2}} (N_2^{\rightarrow\Leftarrow} + N_2^{\leftarrow\Leftarrow})}$$

$$P_z^{\odot} = \frac{1}{\Lambda_{z2}} \cdot \frac{\frac{N_1^{\rightarrow\Rightarrow} - N_1^{\leftarrow\Rightarrow}}{\delta_{\odot 1}} - \frac{L_{eff1}}{L_{eff2}} \cdot \frac{N_2^{\rightarrow\Leftarrow} - N_2^{\leftarrow\Leftarrow}}{\delta_{\odot 2}}}{(N_1^{\rightarrow\Rightarrow} + N_1^{\leftarrow\Rightarrow}) + \frac{\Lambda_{z1}}{\Lambda_{z2}} \cdot \frac{L_{eff1}}{L_{eff2}} (N_2^{\rightarrow\Leftarrow} + N_2^{\leftarrow\Leftarrow})}$$

$$P_z = \frac{1}{\Lambda_{z2}} \cdot \frac{(N_1^{\rightarrow\Rightarrow} + N_1^{\leftarrow\Rightarrow}) - \frac{L_{eff1}}{L_{eff2}} \cdot (N_2^{\rightarrow\Leftarrow} + N_2^{\leftarrow\Leftarrow})}{(N_1^{\rightarrow\Rightarrow} + N_1^{\leftarrow\Rightarrow}) + \frac{\Lambda_{z1}}{\Lambda_{z2}} \cdot \frac{L_{eff1}}{L_{eff2}} (N_2^{\rightarrow\Leftarrow} + N_2^{\leftarrow\Leftarrow})}$$

- L_{eff1}/L_{eff2} is extracted from the data based on the assumption of the equality of $\left(\frac{d\sigma}{d\Omega}\right)_0$ in all data taking periods

Evaluation of luminosity & acceptance ratio

- **Assumptions:**
  1. In a given energy range the unpolarized cross section is the same for all data sets
  2. the acceptance for events with three charged tracks coming from the Kel-F IBC window is the same as if they were coming from HD

- **Method:**
  - If we compare, in the same W range, the cross sections γKel-F in $\pi^+ \pi^-$ p (with the exclusivity cuts applied, likely to be a γp reaction on a bound unpolarized proton of the Kel-F material), the following relationships follows ($\mathcal{L} = L_{eff} = L\epsilon$):

$$1 = \frac{\dfrac{N^{X}_{KelF} \cdot A}{\epsilon_x L_x \Delta x \, \rho \, N_{Av}}}{\dfrac{N^{s5}_{KelF} \cdot A}{\epsilon_{s5} L_{s5} \Delta x \, \rho \, N_{Av}}} = \frac{N^{X}_{KelF}}{\epsilon_x L_x} \frac{\epsilon_{s5} L_{s5}}{N^{s5}_{KelF}}$$

$$\frac{\epsilon_x}{\epsilon_{s5}} = \frac{N^{x}_{KelF}}{N^{s5}_{KelF}} \frac{L_{s5}}{L_x}$$

$$\frac{\mathcal{L}_x}{\mathcal{L}_{s5}} = \frac{N^{x}_{KelF}}{N^{s5}_{KelF}}$$

Overall (acceptance*luminosity) factors $\mathcal{L}_x/\mathcal{L}_{s5}$

- *This ratio is obtained directly from the ratio of counts in Kel-F*
- Weighted average ratios over all W ranges (and φ angles), or in every W range
- Based on the assumption that the acceptance for the selected tracks out of Kel-F is the same of those from HD (not really true)
- Smaller statistical error affecting this ratio
- Trigger efficiency automatically included since all events inKel-F HAVE passed the trigger condition

Data-set	Weighted average ϵ_x/ϵ_{s5}	Weighted average $\mathcal{L}_x/\mathcal{L}_{s5}$	
Silver1	0.42 ± 0.01	0.107 ± 0.003	2p trigger + inv. Tor. Pol.
Silver2	0.48 ± 0.01	0.189 ± 0.004	2p trigger + inv. Tor. Pol.
Silver3	1.34 ± 0.05	0.056 ± 0.002	
Silver4	1.62 ± 0.03	0.300 ± 0.005	2p trigger
Silver6a	0.92 ± 0.05	0.027 ± 0.002	
Silver6b	0.50 ± 0.01	0.209 ± 0.004	
Gold2a	0.90 ± 0.03	0.093 ± 0.003	
Gold2b	1.05 ± 0.01	0.325 ± 0.006	
Gold3	0.94 ± 0.07	0.016 ± 0.001	

ϵ_x/ϵ_5

$\mathcal{L}_x/\mathcal{L}_5$

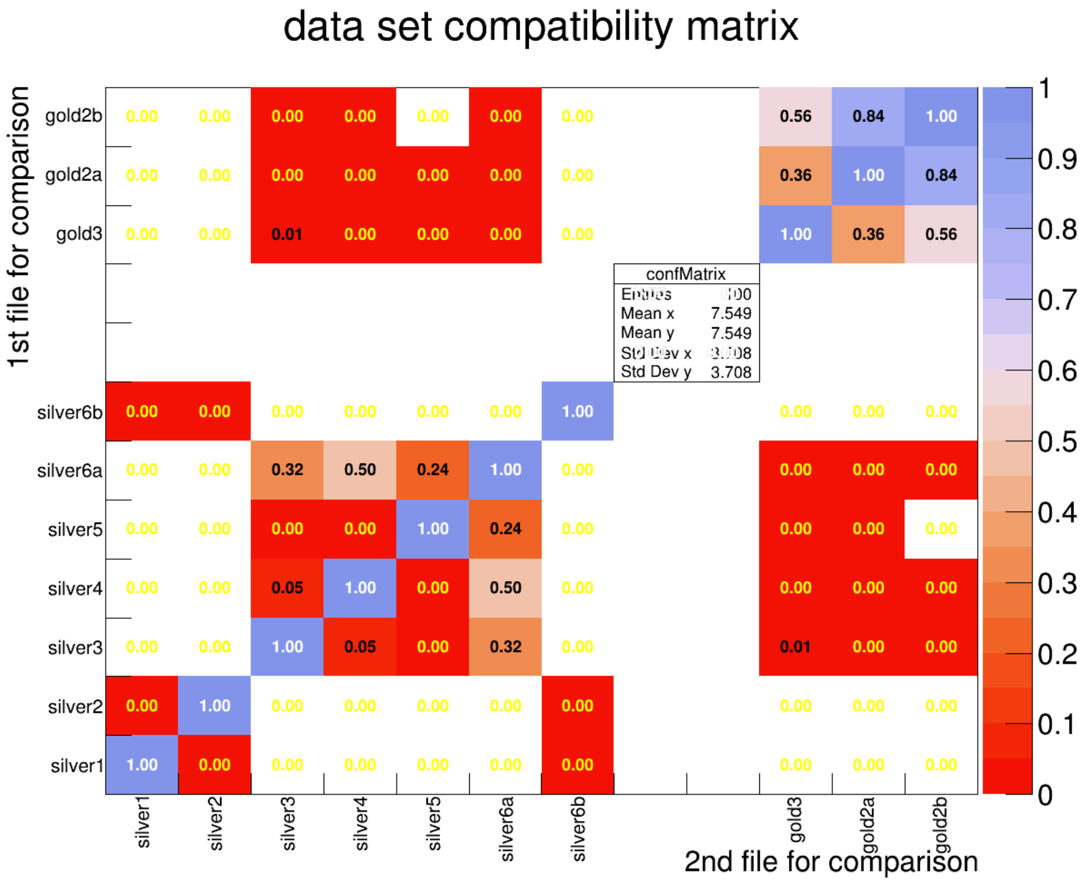
Dataset "labeling" issues

- 11 (or 10) data sets available characterized by different conditions:
  - maximum e^- beam energy and the degree of e^- beam polarization
  - target polarization extent
  - torus magnet polarization (determining the event acceptance)
  - trigger
- Only homogeneous/proper data samples can be combined to extract results

- Target polarization:
  - average value between H and D polarizations: correct?
  - Not sure they are known precisely and their evaluation is correct
  - The negative polarization is always very small
- Beam polarization sign
  - Helicity inversion
- Torus polarization sign
  - Different acceptance
  - Not a real problem, if the right polarization empty target data are subtracted

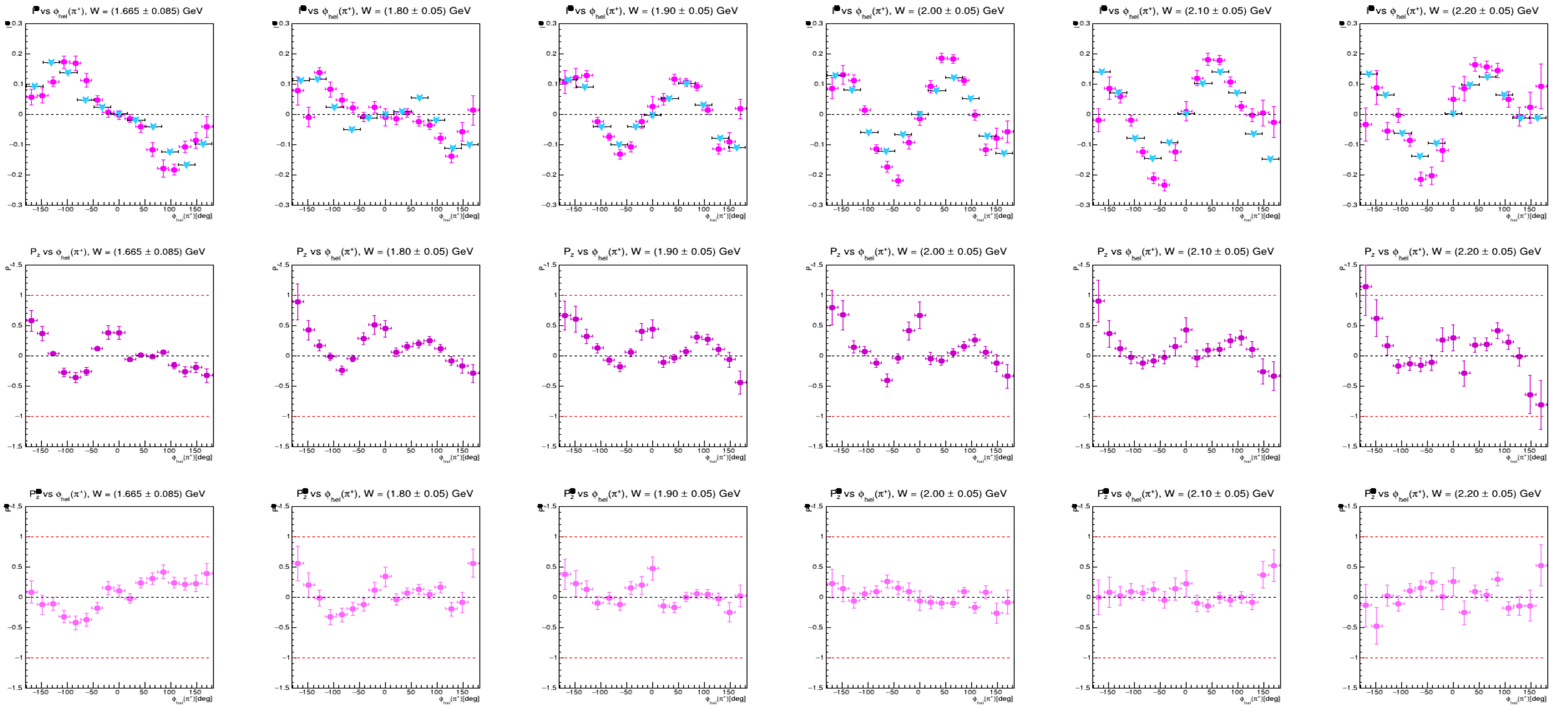
Some consistency studies on the datasets

- Let's assume nothing is known about the features of the data sets, except the helicity assignment of each event
- Compare angular distributions for N^+ and N^- in all energy bins with enough statistics (6)
- Take datasets in pairs:
  - Evaluate χ^2 on histograms (2 histos per set)
  - Cumulate χ^2 over energy bins
  - evaluate p-value given χ^2_{tot} and ndf_{tot}
  - Spot "friend" data-set (with histograms having similar features, or which need at most an helicity-flip)
    - **p>0.01 for consistent sets**
- Apply some ML technique to group data and eventually determine uncertain parameters?



- Gold: friends with each others
- Silver 1-2: mildly friends with each other and at most with silver6b (OK: reversed torus datasets)
- Silver 3-4-5 (same torus sign):
  - sympathy among themselves
  - Silver3 and silver4 more sympathetic
  - gold rejected only by silver5
- Silver6a: friend with all silver sets (nicer guy), better with silver4 (remember: silver6a has ~zero tgt polarization).

Polarization asymmetries
gold2b-silver5 “as-is” (no extra factor)



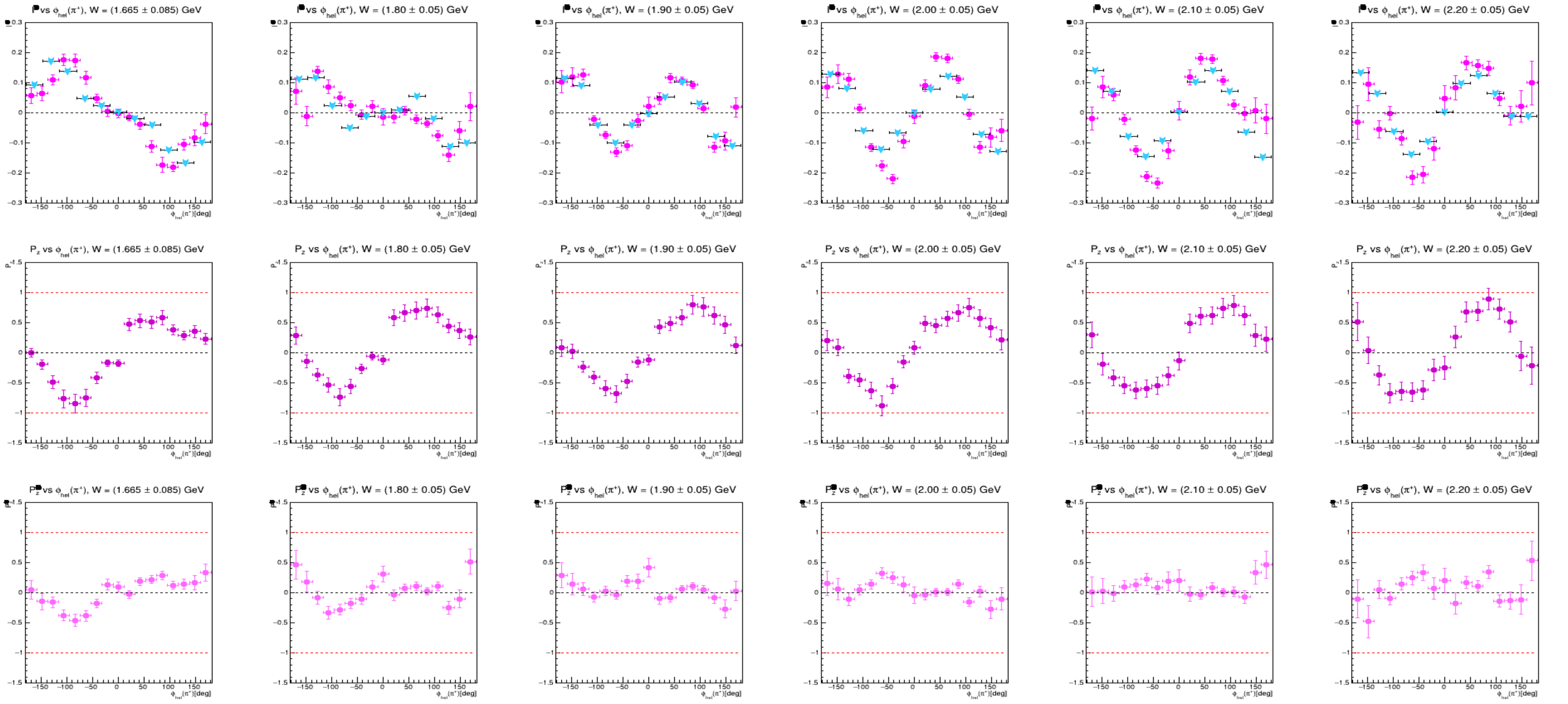
Extra factor?

- A multiplicative factor **0.85 = 1/1.212** is needed for $\mathcal{L}_1/\mathcal{L}_2$ to “reshape” the solutions and make the trend continuous
  - It might be possible this factor depends on the energy
  - The value 1.212 comes from an “optimization” on the shapes of the solutions

- How can this factor be explained?
  - Different energy range for gold2b and silver5
    - Common range chosen, but the relative population of the ranges might be different
  - Different trigger? (that’s why I call it “trigger efficiency”, at large – but the trigger effect should already be contained in the $\mathcal{L}_1/\mathcal{L}_2$ ratio)
  - Different target dimension and Al density of wires: already taken into account (overall multiplicative factor 1.424)

- Some more ideas/studies needed

Polarization asymmetries gold2b-silver5: with “extra factor”



Notes on polarization variables

$I^{\odot}$

$$I_{\odot} = \frac{\frac{N_1^{\rightarrow\Rightarrow} - N_1^{\leftarrow\Rightarrow}}{\delta_{\odot 1}} + \frac{\Lambda_{z1}}{\Lambda_{z2}} \cdot \frac{L_{eff1}}{L_{eff2}} \cdot \frac{N_2^{\rightarrow\Leftarrow} - N_2^{\leftarrow\Leftarrow}}{\delta_{\odot 2}}}{(N_1^{\rightarrow\Rightarrow} + N_1^{\leftarrow\Rightarrow}) + \frac{\Lambda_{z1}}{\Lambda_{z2}} \cdot \frac{L_{eff1}}{L_{eff2}} (N_2^{\rightarrow\Leftarrow} + N_2^{\leftarrow\Leftarrow})}$$

- $I^{\odot}$ is expected to be ***odd*** based on partial amplitude symmetry
  - It depends only on the ratio of target polarizations, and the dependence is very mild (if any)
- The trend is in reasonable agreement with the earlier observations by CLAS based on a different data-set (E* with unpolarized target)
- $I^{\odot}$ behavior as expected in all data ranges

P_z

$$P_z = \frac{1}{\Lambda_{z2}} \cdot \frac{(N_1^{\rightarrow\Rightarrow} + N_1^{\leftarrow\Rightarrow}) - \frac{L_{eff1}}{L_{eff2}} \cdot (N_2^{\rightarrow\Leftarrow} + N_2^{\leftarrow\Leftarrow})}{(N_1^{\rightarrow\Rightarrow} + N_1^{\leftarrow\Rightarrow}) + \frac{\Lambda_{z1}}{\Lambda_{z2}} \cdot \frac{L_{eff1}}{L_{eff2}} (N_2^{\rightarrow\Leftarrow} + N_2^{\leftarrow\Leftarrow})}$$

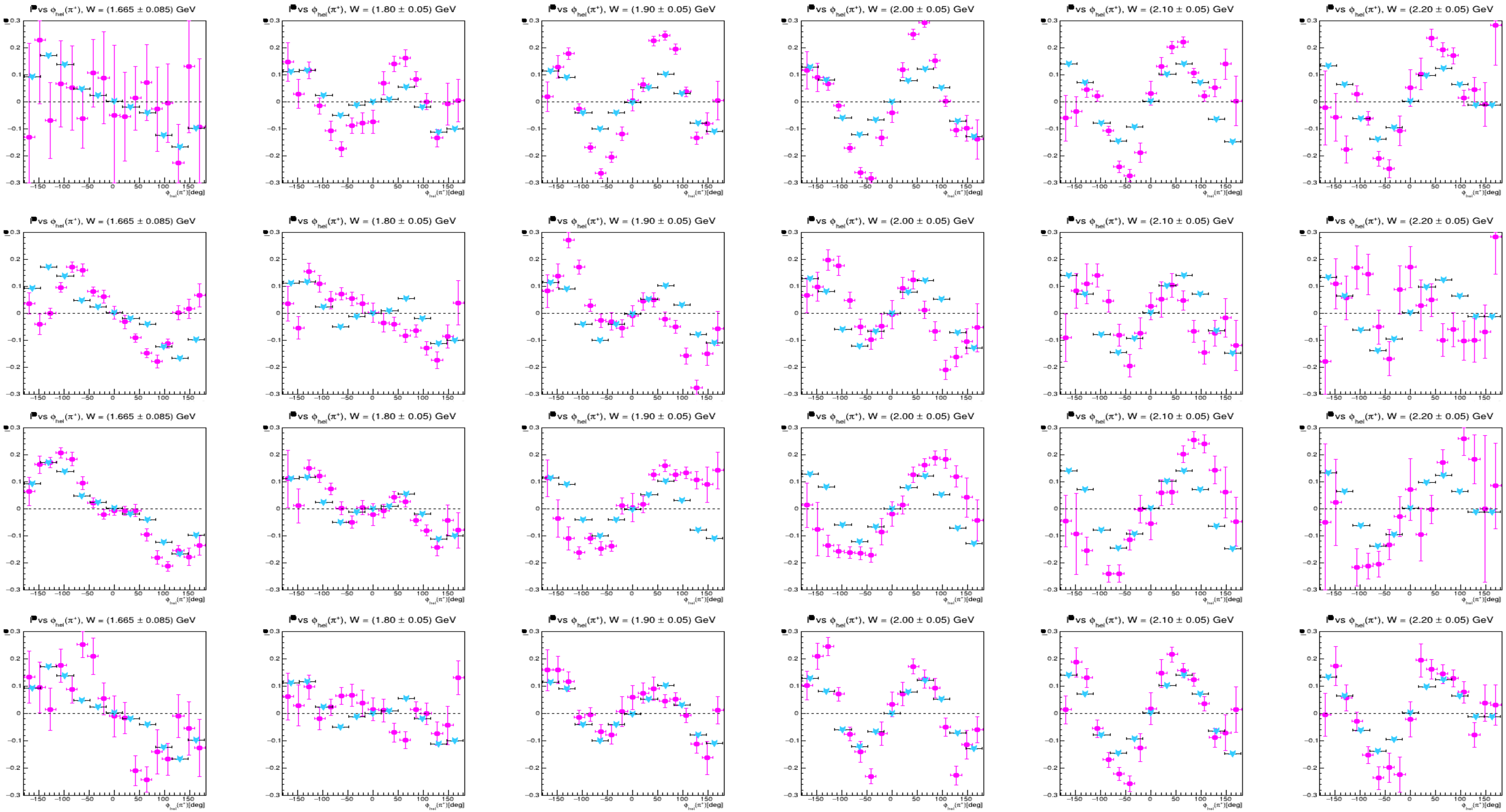
- P_z expected to be ***odd*** based on partial amplitudes symmetry
  - Vanishing at zero angle: coplanarity condition
  - When the helicity angle is oriented in the bottom hemisphere a sign flip occurs in Roberts' equations and, consequently, in the parity of the solutions (or: swap dataset order)
- Odd symmetry improves with W increase
  - The lack of left/right symmetry could be due to instrumental reasons (different acceptance, …)

$P_z^{\odot}$

$$P_z^{\odot} = \frac{1}{\Lambda_{z2}} \cdot \frac{\frac{N_1^{\rightarrow\Rightarrow} - N_1^{\leftarrow\Rightarrow}}{\delta_{\odot 1}} - \frac{L_{eff1}}{L_{eff2}} \cdot \frac{N_2^{\rightarrow\Leftarrow} - N_2^{\leftarrow\Leftarrow}}{\delta_{\odot 2}}}{(N_1^{\rightarrow\Rightarrow} + N_1^{\leftarrow\Rightarrow}) + \frac{\Lambda_{z1}}{\Lambda_{z2}} \cdot \frac{L_{eff1}}{L_{eff2}} (N_2^{\rightarrow\Leftarrow} + N_2^{\leftarrow\Leftarrow})}$$

- $P_z^{\odot}$ expected to be ***even*** based on partial amplitudes symmetry
- $P_z^{\odot}$ is compatible with zero (within errors)
  - Large statistical uncertainties obtained from the error propagation of the system solutions
  - small extent overall of target polarization (23% max.)

Selection in invariant mass ranges: $I^{\odot}$



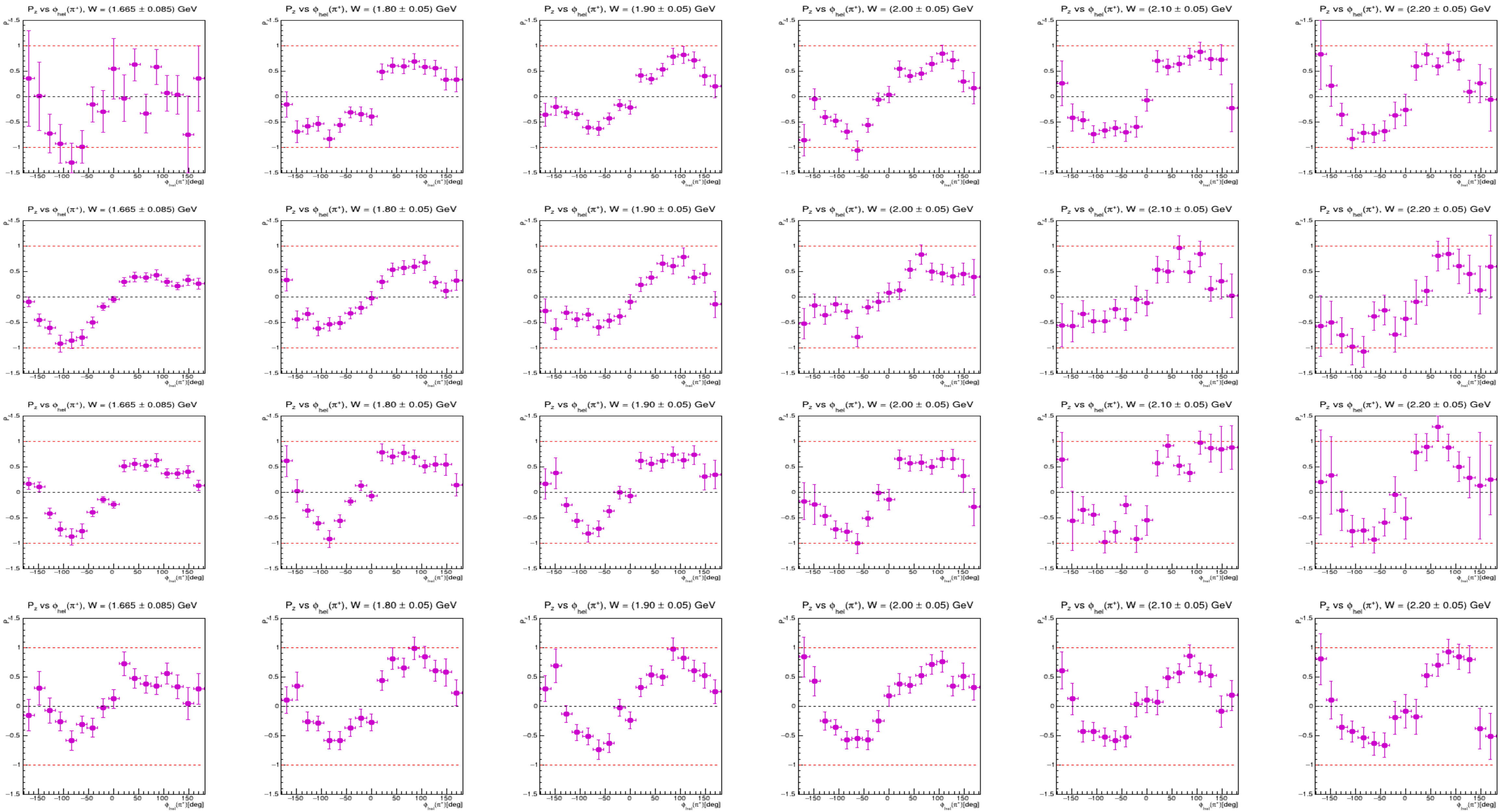
ρ^0

Δ^0

Δ^{++}

Non res.

Selection in invariant mass ranges: P_z



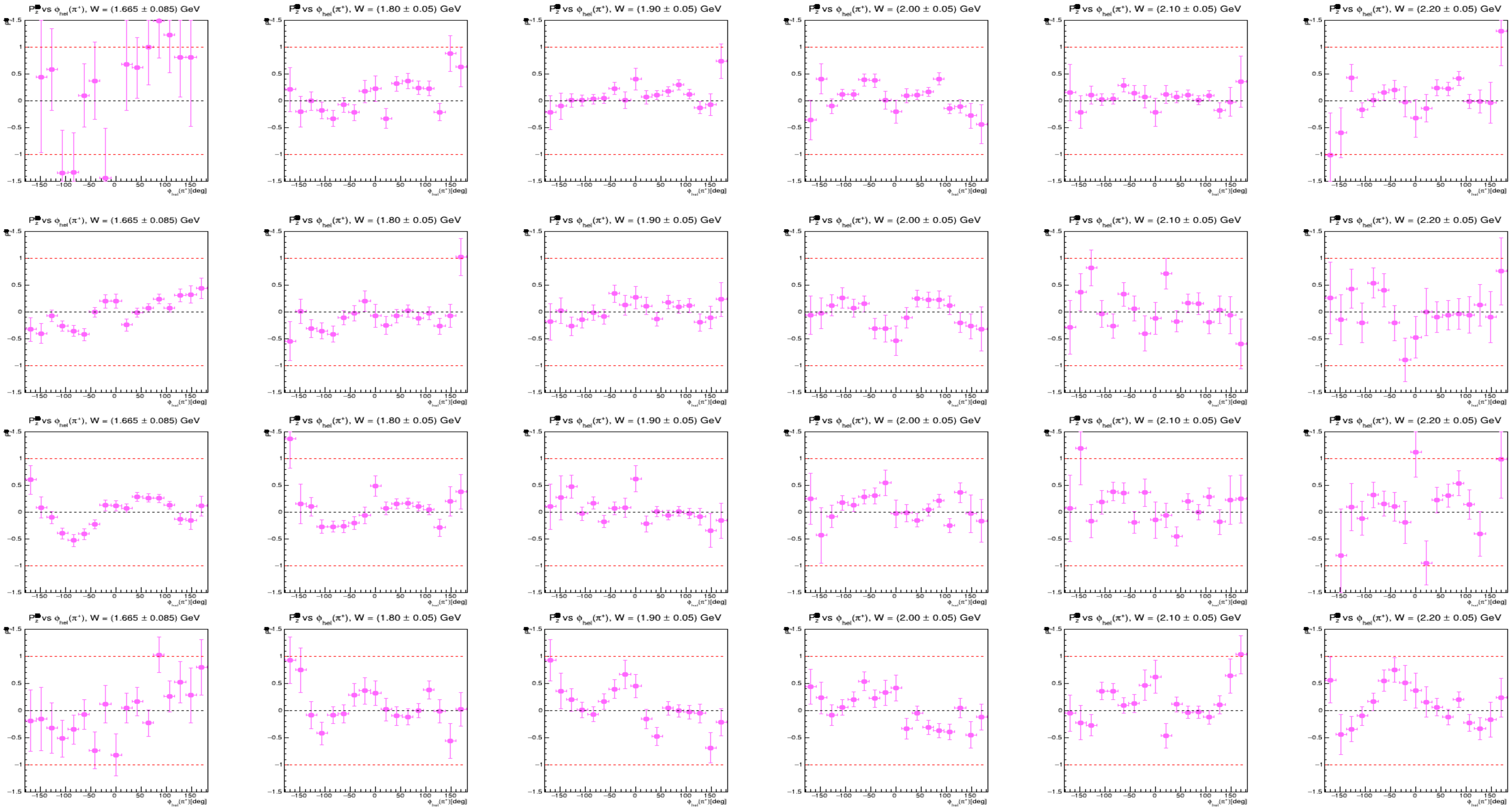
ρ^0

Δ^0

Δ^{++}

Non res.

Selection in invariant mass ranges: $P_z^{\odot}$



ρ^0

Δ^0

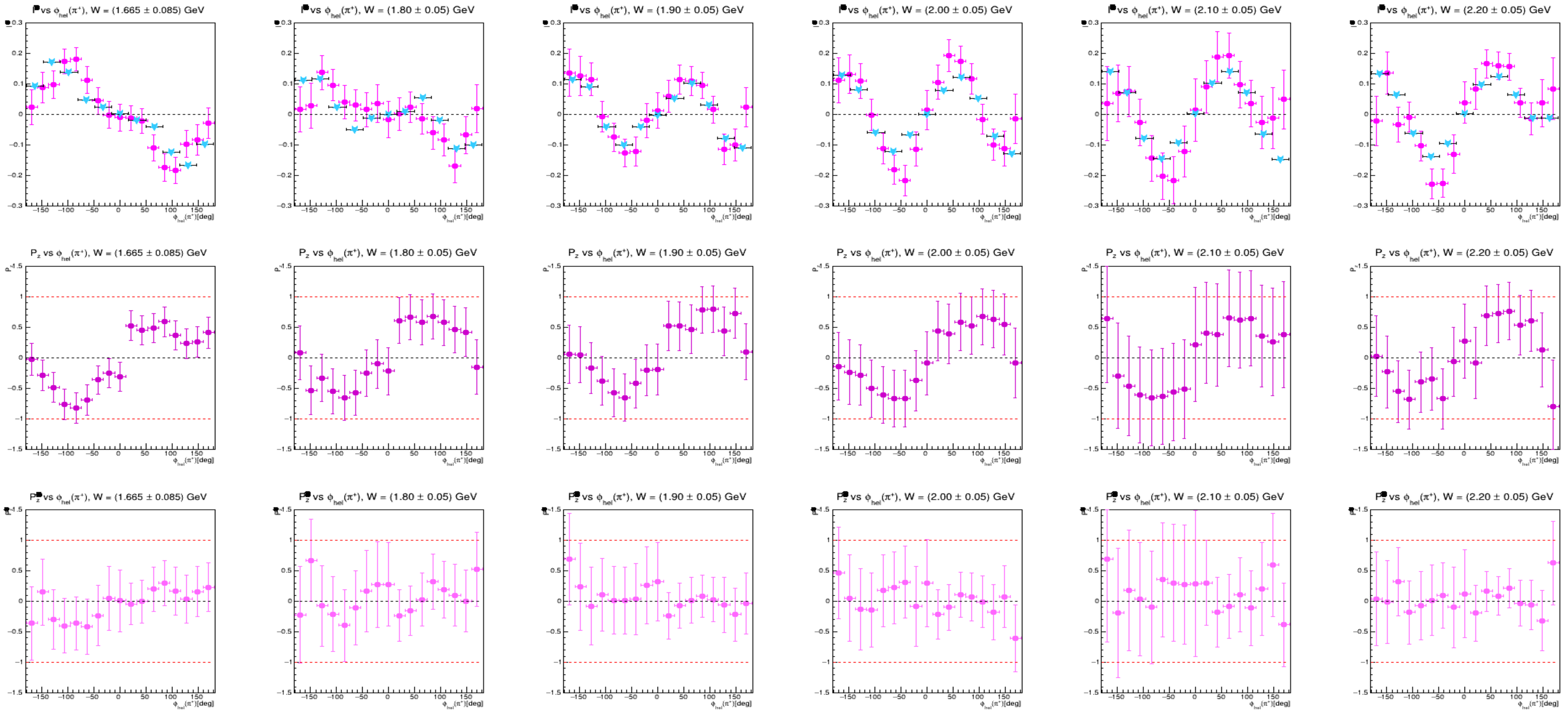
Δ^{++}

Non res.

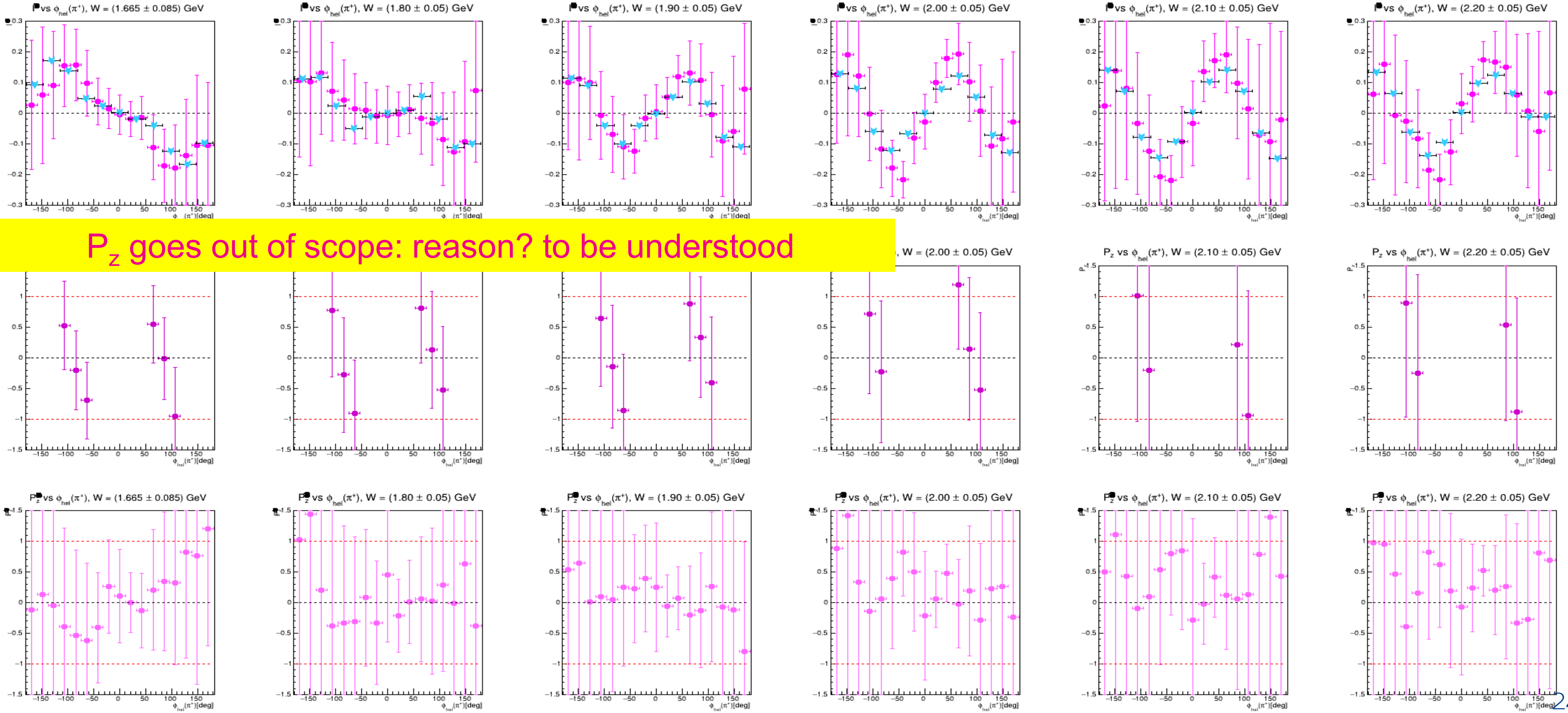
General observations

- There is not a large difference in $I^{\odot}$ when comparing resonant vs non-resonant regions
  - Max/min occur at different φ_{hel} values
- Same for P_z
  - Flatter for $\Delta^{0/++}$ production in forward angles
- Symmetries are preserved and independent on the reaction dynamics
- $P^{\odot}{}_z$ does not seem to have enough sensitivity (in general): almost always consistent with zero

Other datasets: gold2a/silver5 (440M)

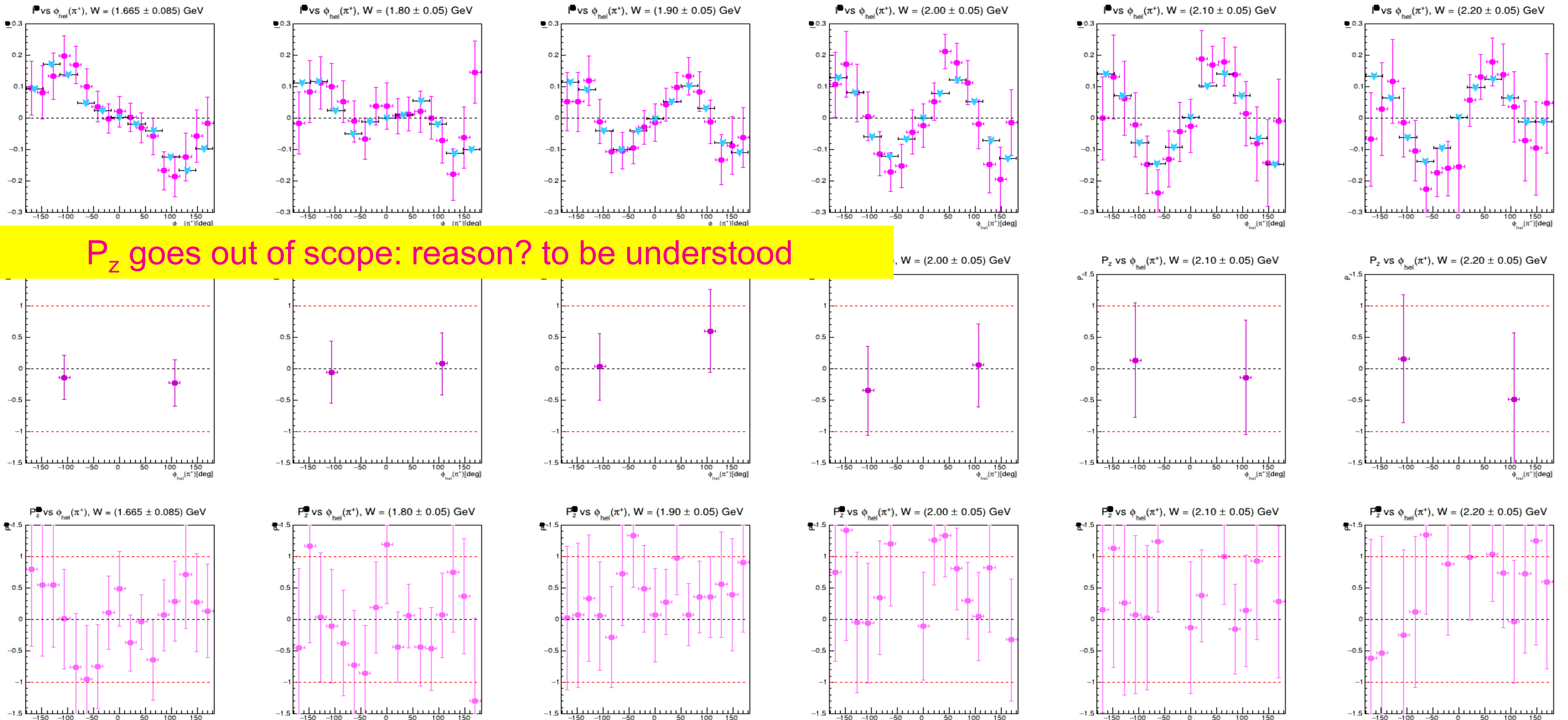


Other datasets: silver1/silver5 (830 Mevts, reversed torus pol.)



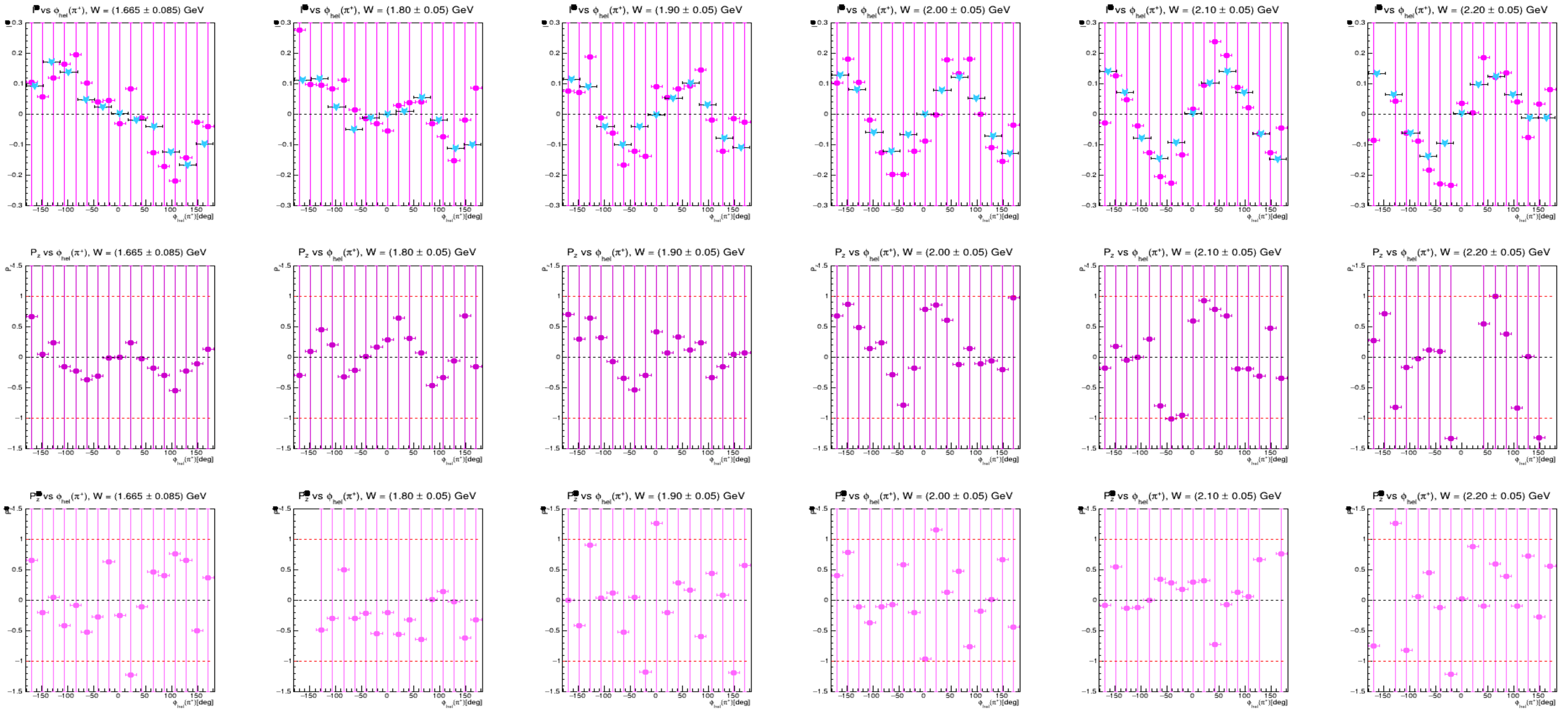
P_z goes out of scope: reason? to be understood

Other datasets: silver2/silver5 (1170 Mevts, reversed torus pol.)



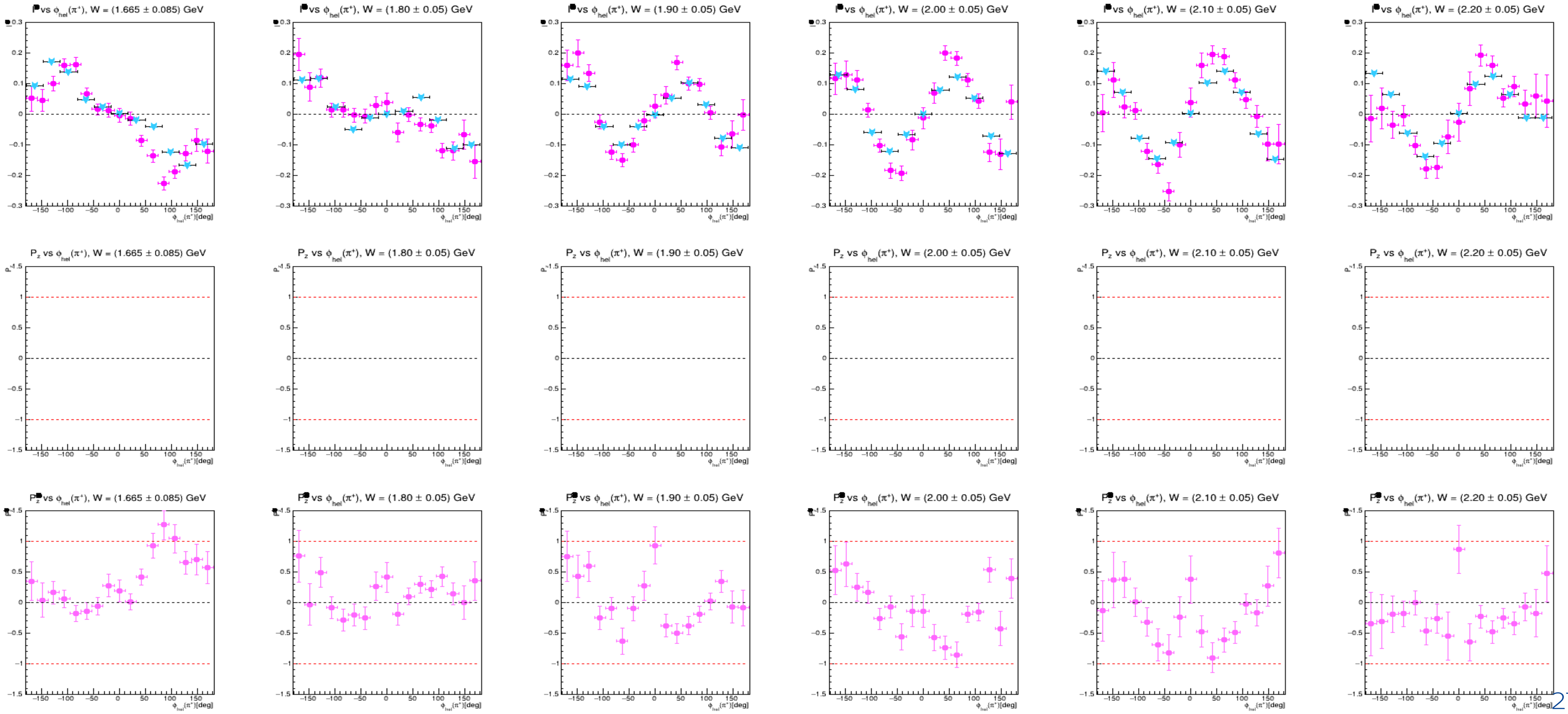
P_z goes out of scope: reason? to be understood

Other datasets: silver3/silver5 (250 Mevts) no correction factor



Other datasets: gold2b/silver4

P_z goes out of scope (factor ~3 larger)



Summary and outlook

- Some issues with datasets to be solved to explain inconsistencies
  - Extra multiplicative factor?
  - Why some solutions are out of scope?
  - Too large background included in the samples?
    - Is the background sensitive to beam/target polarization?

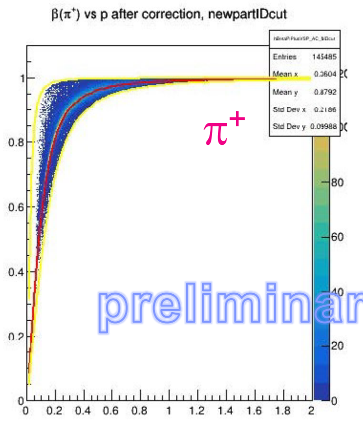
- Study of datasets homogeneity (grouping/labeling)
  - Use of statistical methods and ML techniques to understand inconsistent labeling and determine more reliable target polarizations and helicities

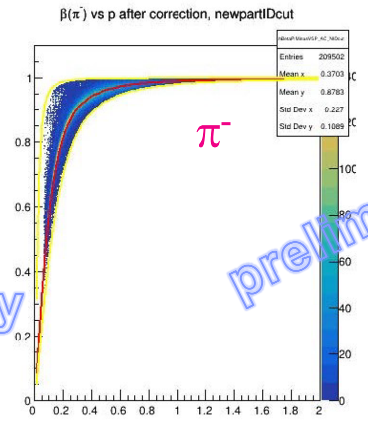
- Assemble all solutions with compatible dataset pairs for a final assessment

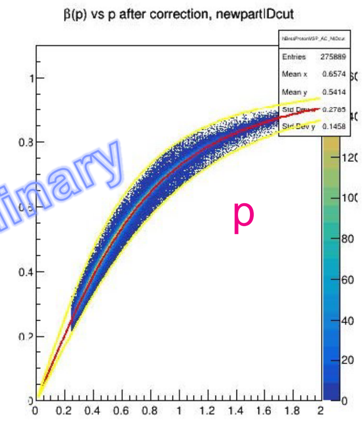
Backup slides

Data selection – exclusive $\vec{\gamma}\vec{p} \rightarrow \pi^+\pi^-p$ reaction

Description	Cut
Particle multiplicity	1 negative, 2 positives
Time coincidence	Time coincidence between: 1 proton, 1 π^+, 1 π^-
$2\pi p$ z-vertex in HD target	$-9.5 < z_{vertex} < -5.8$ cm
$2\pi p$ pId: β_{corr}	$p_{\pi^\pm}/\sqrt{p^2_{\pi^\pm m} + (m_\pi - 80\ [\mathrm{MeV}])^2} \leq \beta^{corr}_{\pi^\pm} \leq p_{\pi^\pm}/\sqrt{p^2_{\pi^\pm} + (m_\pi + 80\ [\mathrm{MeV}])^2}$ $p_p/\sqrt{p^2_p + (m_p - 200\ [\mathrm{MeV}])^2} \leq \beta^{corr}_p \leq p_p/\sqrt{p^2_p + (m_p + 200\ [\mathrm{MeV}])^2}$
$2\pi p$ pId: $\lvert\Delta\beta\rvert$	$\lvert\Delta(\beta_p)\rvert < 0.08$ $p_{\pi^\pm} \leq 500\ [\mathrm{MeV}/c]$: $\lvert\Delta(\beta_{\pi^\pm})\rvert < 0.08$ $p_{\pi^\pm} \geq 500\ [\mathrm{MeV}/c]$: $\lvert\Delta(\beta_{p})^\pm)\rvert < 0.2$
$2\pi p$ fiducial cuts	π^+ && π^- && p within fiducial volume
Missing mass for proton pId Total missing mass	$0.824 \leq \mathrm{m.m.}(\pi^+\pi^-) \leq 1.052\ [\mathrm{GeV}/c^2]$ $\mathrm{m.m.}(\pi^+\pi^-p) < 0\ [\mathrm{GeV}/c^2]$
Fermi momentum	$p_F < 100$ MeV/c
Coplanarity	$\lvert$coplanarity$\rvert < 10°$

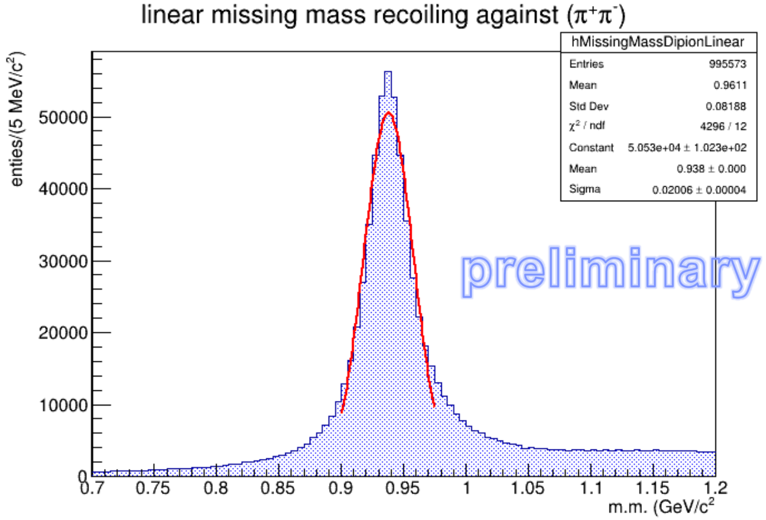




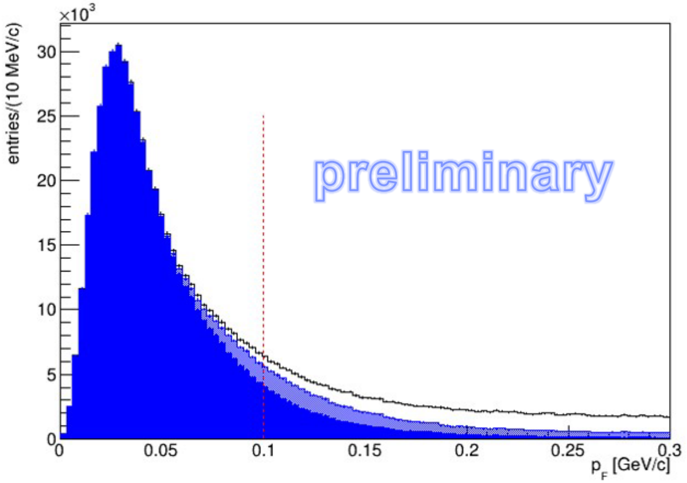


Particle ID for $\pi^+\pi^-$ and p based on TOF

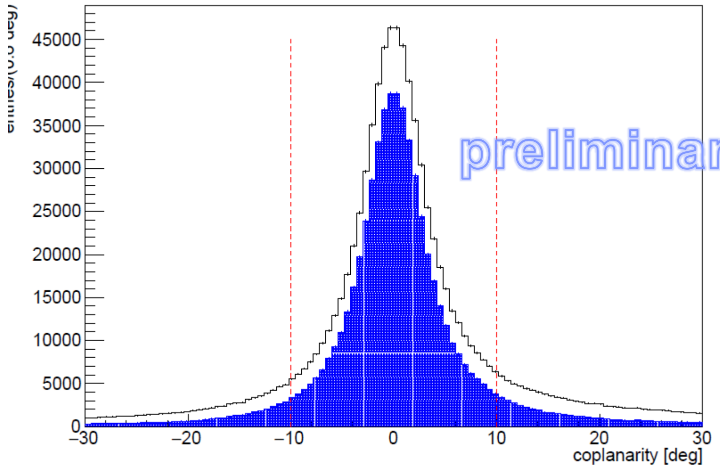
Further selection on ($\pi^+\pi^-$) missing mass to identify the proton



Total missing mass cut

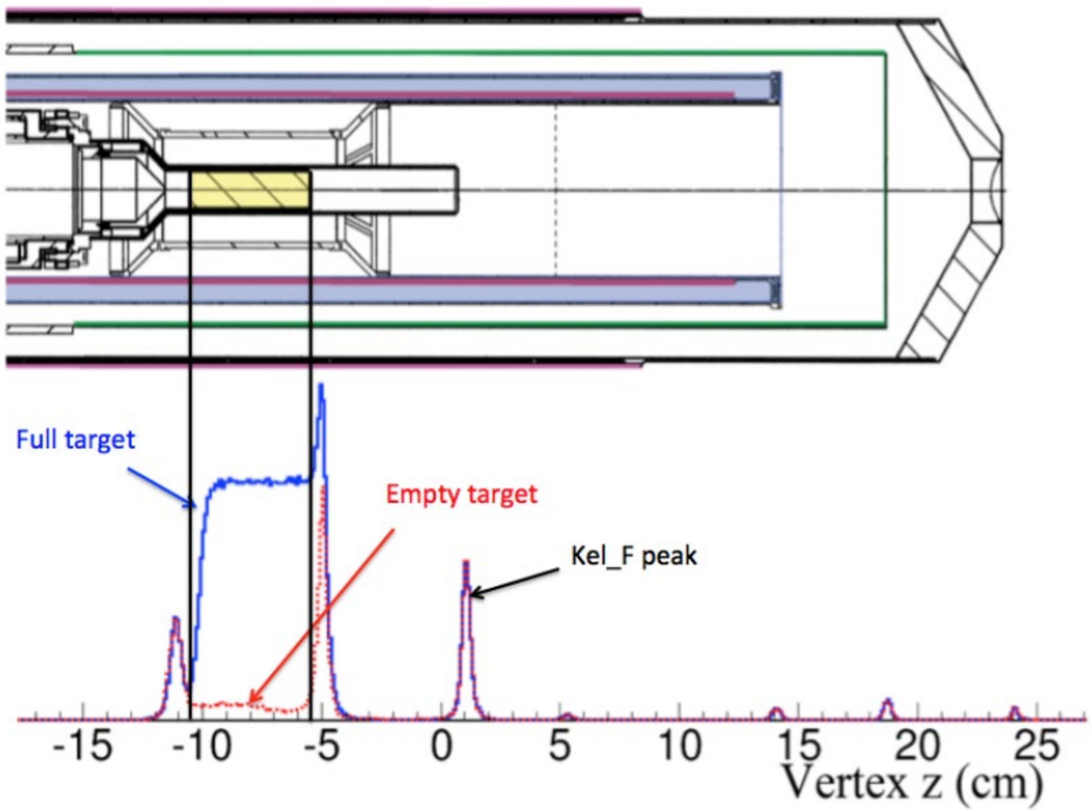


Missing momentum cut: reject reactions without spectator at rest



Coplanarity cut for pion pairs

Experimental data: empty target subtraction



- Selection of events from the HD target: fiducial cut in r and z
- The events selected in the fiducial volume of the target contain the contribution from the target walls (unpolarized)
  - Empty target subtraction needed
  - Relative normalization of different runs: height of Kel-F wall peak
  - Subtraction with empty-target runs
- Events in the Kel-F peak also used for relative luminosity normalizations between different data sets

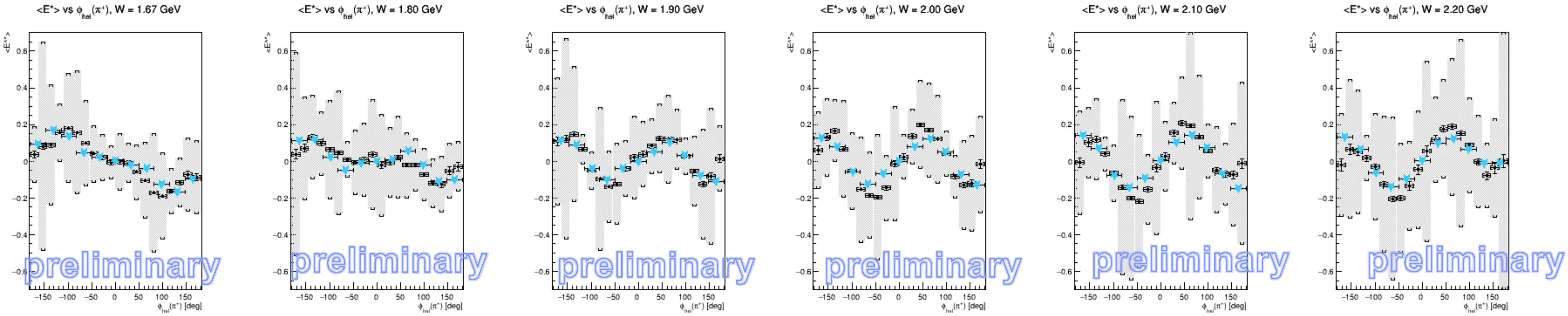
Evaluation of experimental beam-helicity asymmetries E*

- E* can be extracted from all available data samples (with similar experimental conditions)
- For each data set:

$$E^* = \frac{1}{\delta_\odot} \frac{N^+ - N^-}{N^+ + N^-}$$

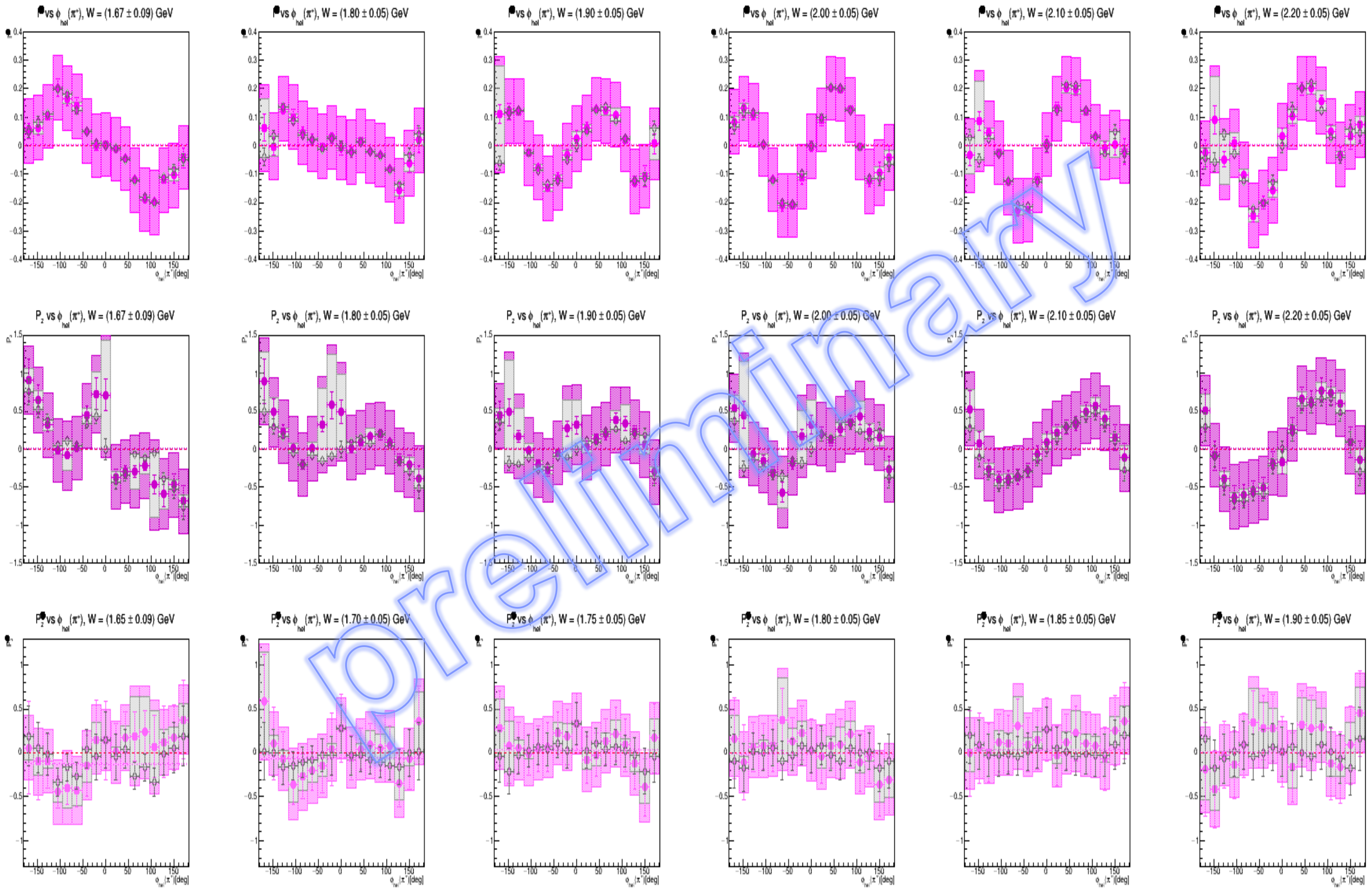
- The E* values agree with previous measurements with polarized beam only (blue points)
- Systematic errors (grey bars) from the spread of values obtained with different data sets

Blue points from S. Strauch et al., CLAS Coll., PRL**95** (2005), 162003



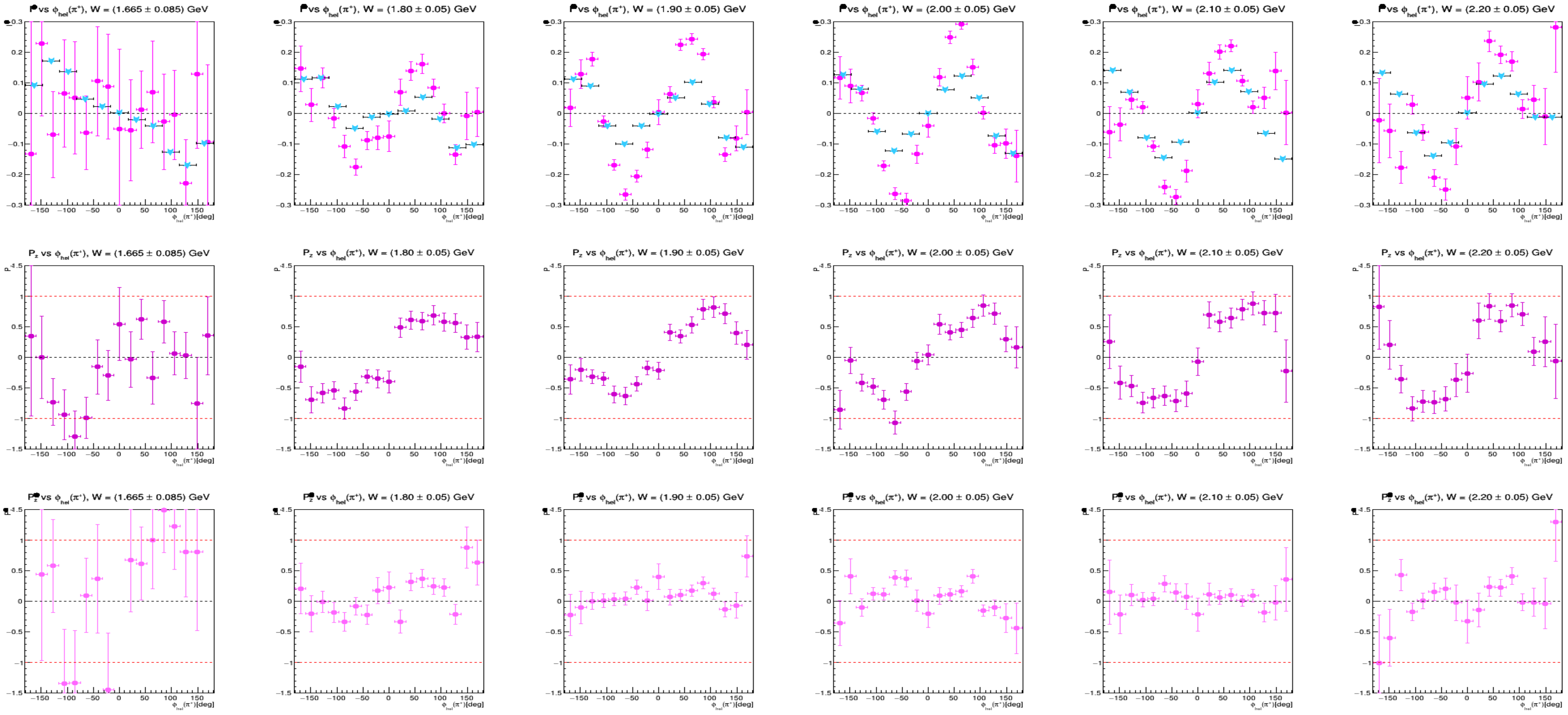
Evaluation of systematic uncertainties (in progress)

- Several sources of systematic uncertainty may affect the result
- Multiplicative factors or bin-by-bin dependence

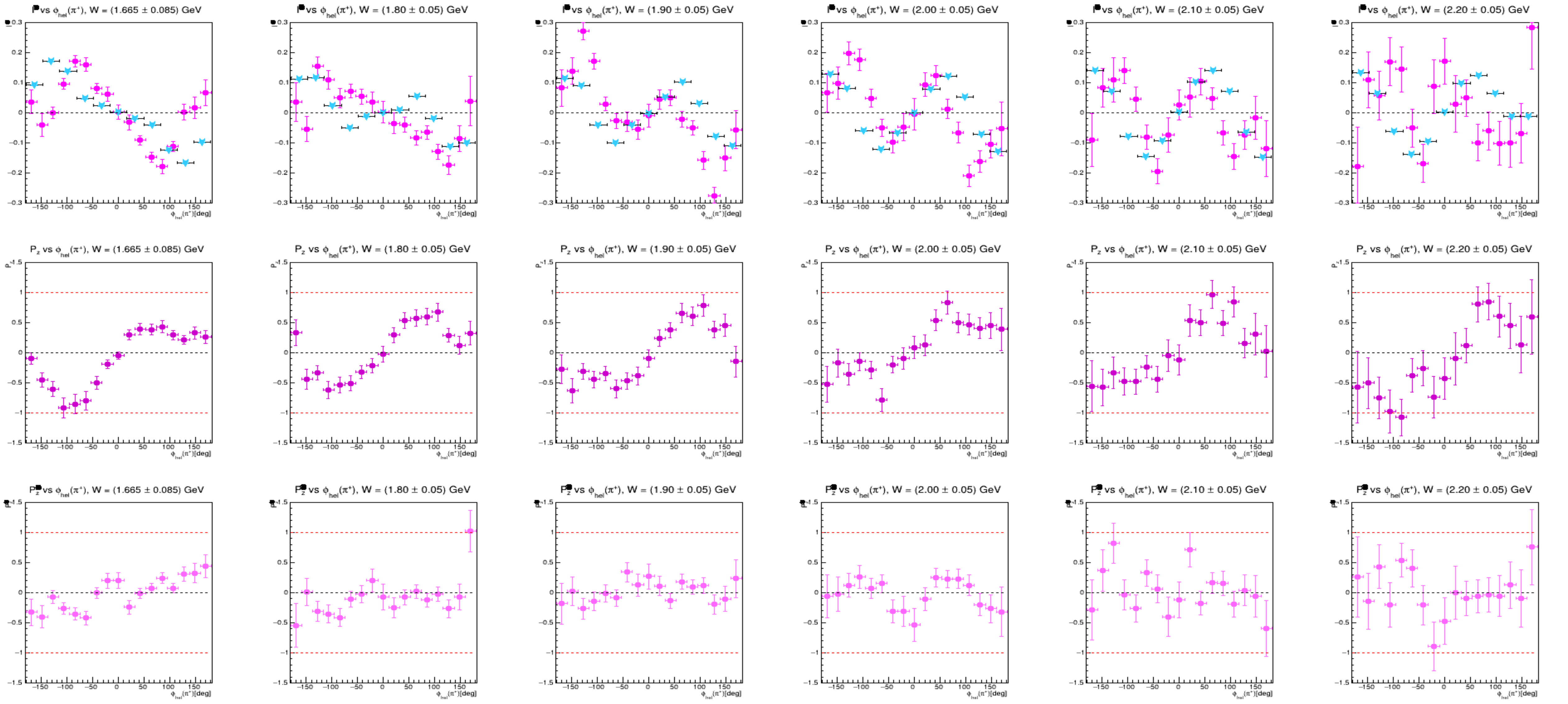


- **Beam**
  - Beam polarization, beam charge asymmetry
  - Photon normalizations
  - Photon related selections: multiple photons, accidentals, …
- **Target (polarization)**
- **Trigger**
- **Analysis selection criteria**
  - PID
  - Reaction topology and kinematics
  - Acceptance regions, angular cuts, …

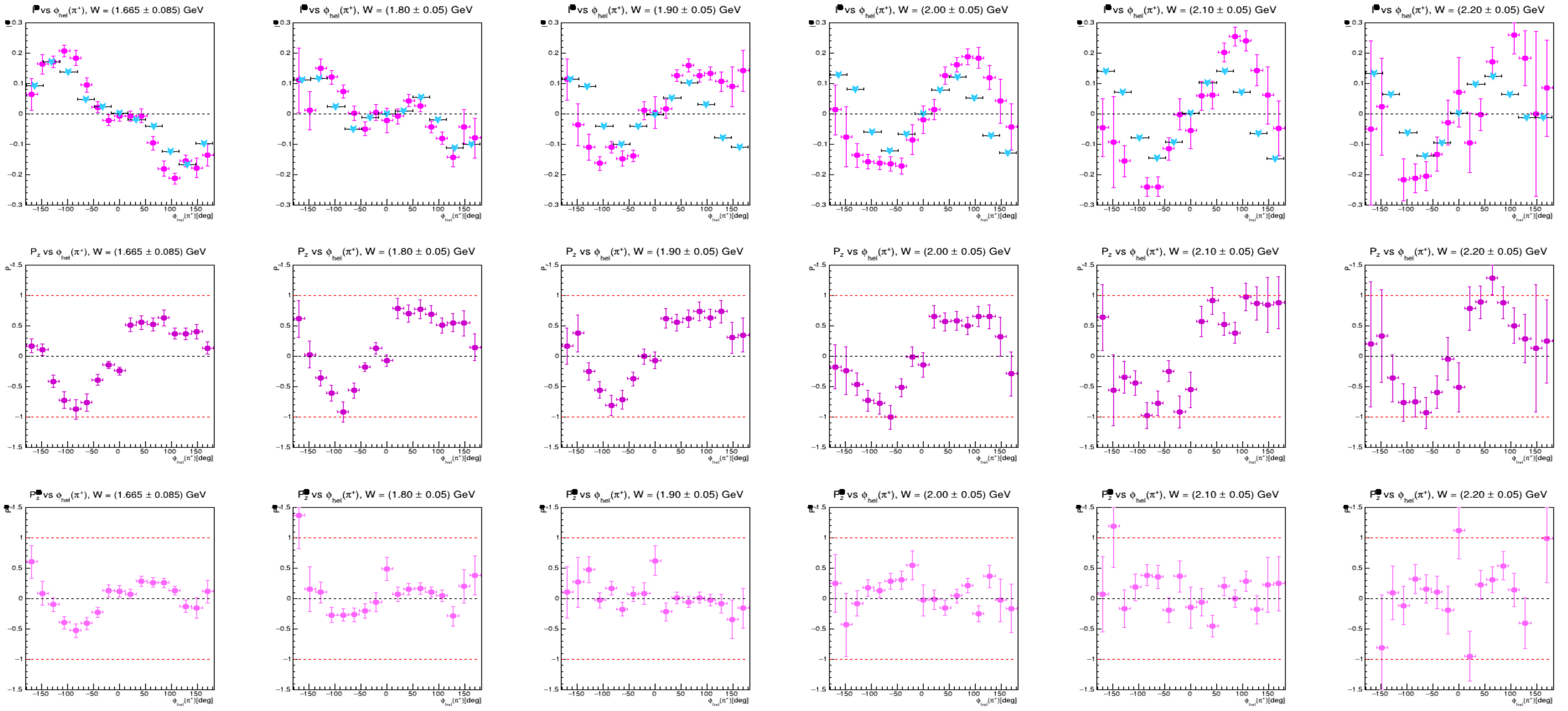
Selection in invariant mass ranges: ρ^0 region



Selection in invariant mass ranges: Δ^0 region



Selection in invariant mass ranges: Δ^{++} region



Selection in invariant mass ranges:
no-resonance regions