Spin Observables and Spin Density Matrix Elements for $\gamma p \rightarrow \rho^0 p$

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QNP, Valparaiso, Mar 15

ToC

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- Why $\gamma p \rightarrow \pi^+\pi^-$ channel specifically?
- Preceeding analyses dominated by single pion channels and 1.7GeV two pion channel becomes dominant.

Theory

$$\mathscr{F} \equiv \langle \boldsymbol{q}\lambda_V\lambda_2 \mid T \mid \boldsymbol{k}\lambda\lambda_1\rangle \tag{1}$$

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-

- The vector meson amplitude can be expressed in helicity space by the following matrix:

$$\mathscr{F} = \begin{bmatrix} H_{21} & H_{11} & H_{3-1} & -H_{4-1} \\ H_{41} & H_{31} & -H_{1-1} & H_{2-1} \\ H_{20} & H_{10} & -H_{30} & H_{40} \\ H_{40} & H_{30} & H_{10} & -H_{20} \\ H_{2-1} & H_{1-1} & H_{31} & -H_{41} \\ H_{4-1} & H_{3-1} & -H_{11} & H_{21} \end{bmatrix} \tag{3}$$

Generally spin observables,Ω can be expressed as:

$$\Omega = \frac{Tr[\mathscr{F}(A_\gamma A_N)\mathscr{F}^\dagger(B_V B_{N'}]}{Tr[\mathscr{F}\mathscr{F}^\dagger]} \tag{4}$$

Where the trace is over the helicity quantum numbers.

$$\Sigma = \frac{Tr[\mathscr{F}\sigma_x^y \mathscr{F}^\dagger]}{Tr[\mathscr{F}\mathscr{F}^\dagger]} \tag{5}$$

Usually seen expressed as an asymmetry.

$$\Sigma = \frac{\sigma^{\parallel} - \sigma^{\perp}}{\sigma^{\parallel} + \sigma^{\perp}} \tag{6}$$

So much for the beam asymmetry.

SDMEs

The helicity state is dependent on the spin-helicity relationship and we need the SDM for the decaying vector meson which is associated with the SDM of the photon:

$$\rho(V) = T\rho(\gamma)T^{\dagger} \tag{7}$$

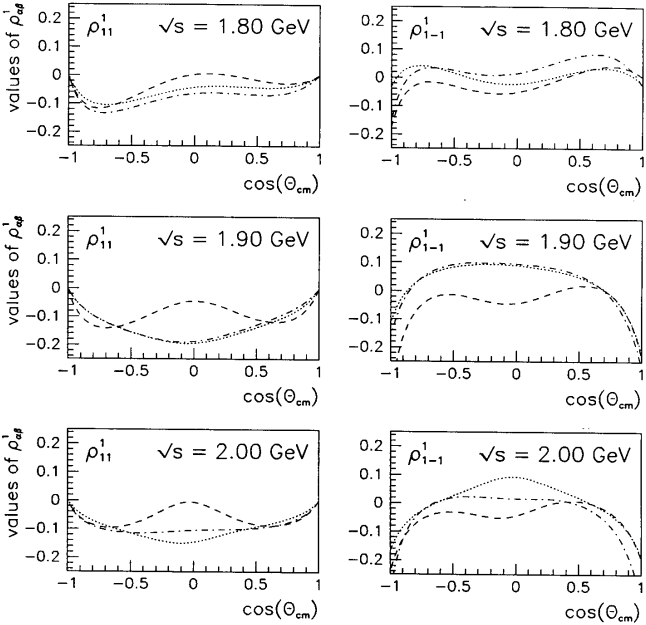
$$\rho(\gamma) = \frac{1}{2}\boldsymbol{I} + \boldsymbol{P}_{\gamma} \cdot \boldsymbol{\sigma} \tag{8}$$

Using the above relations and the helicity-amplitude formalism we can show the dependence of the polarisation vector $\boldsymbol{P}_{\gamma}$ of the density matrix $\rho(V)$:

$$\rho(V) = \rho^{o} + \sum_{i=1}^{3} P_{\gamma}^{\alpha}\rho^{\alpha} \tag{9}$$

Where P_{γ}^{α} are the components of the polarisation vector, $\boldsymbol{P}_{\gamma}$, and the ρ^{α} are hermitian matrices.

SDMEs Resonance Dependency



Anderson et al, 1973

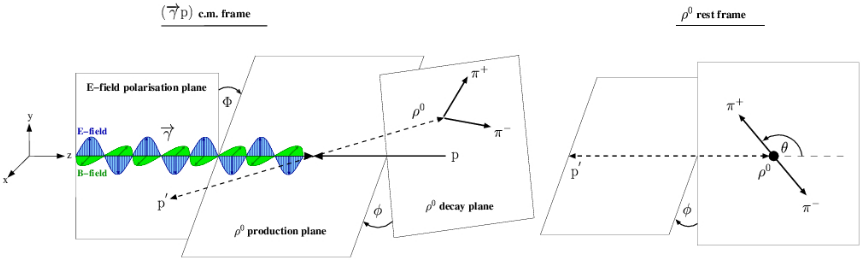
Angular Decay Distribution

The density matrix is related to the decay angular distribution:

$$W(\cos\theta, \phi) = M\rho(V)M^{\dagger} \tag{10}$$

M is the decay amplitude and θ and ϕ are the polar and azimuthal angles of the detected π^+ in the helicity frame. And so we get the following for ρ^0-meson decay distribution:

$$W(\cos\theta, \phi, \rho) = W^0(\cos\theta, \phi, \rho) - P_\gamma \cos 2\Phi W^1(\cos\theta, \phi, \rho) - P_\gamma \sin 2\Phi W^2(\cos\theta, \phi, \rho) \tag{11}$$



$$
\begin{aligned}
W^0(\cos\theta,\phi,\rho) &= \frac{3}{4\pi}(\frac{1}{2}(1-\rho^0_{00}) + \frac{1}{2}(3\rho^0_{00}-1)\cos^2\theta - \sqrt{2}Re\rho^0_{10}\sin 2\theta\cos\phi \\
&\quad - \rho^0_{1-1}\sin^2\theta\cos 2\phi \\
W^1(\cos\theta,\phi,\rho) &= \frac{3}{4\pi}(\rho^1_{11}\sin^2\phi + \rho^1_{00}\cos^2\theta - \sqrt{2}\rho^1_{10}\sin 2\theta\cos\phi - \rho^1_{1-1}\sin^2\theta\cos 2\phi) \\
W^2(\cos\theta,\phi,\rho) &= \frac{3}{4\pi}(\sqrt{2}Im\rho^2_{10}\sin 2\theta\sin\phi + Im\rho^2_{1-1}\sin^2\theta\sin 2\phi)
\end{aligned}
$$

To simplify our task we integrate over two of the angles to leave us with a single angle function. We are left with the five following equations:

$$W(\cos\theta) = \frac{3}{4}[1 - \rho^0_{00} + (\rho^0_{00} - 1)\cos^2\theta] \tag{12}$$

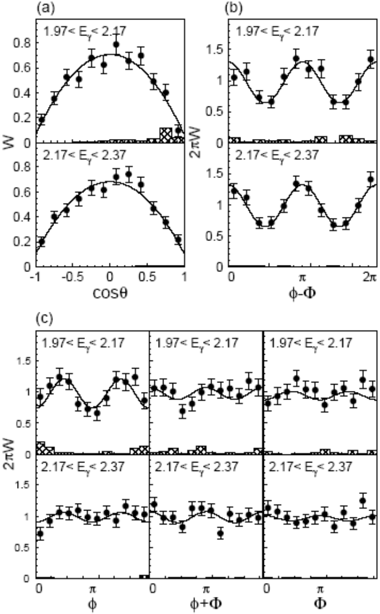
$$W(\phi) = \frac{1}{2\pi}[1 - 2Re\rho^0_{1-1}\cos 2\phi] \tag{13}$$

$$W(\phi - \Phi) = \frac{1}{2\pi}[1 + P_\gamma(\rho^1_{1-1} - Im\rho^2_{1-1})\cos 2(\phi - \Phi)] \tag{14}$$

$$W(\phi + \Phi) = \frac{1}{2\pi}[1 + P_\gamma(\rho^1_{1-1} + Im\rho^2_{1-1})\cos 2(\phi + \Phi)] \tag{15}$$

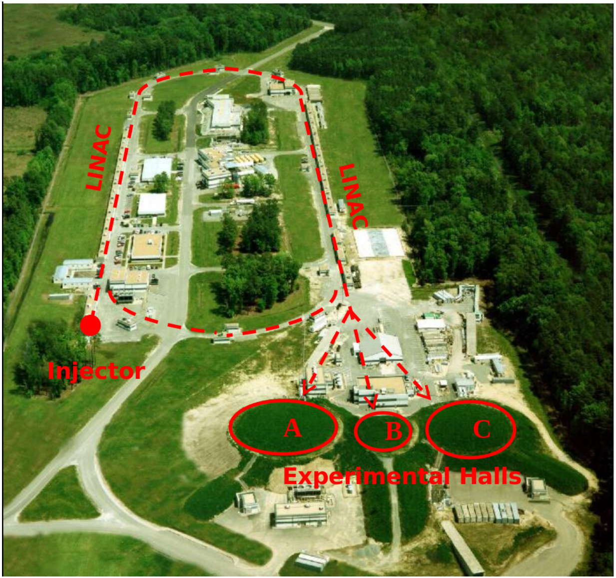
$$W(\Phi) = \frac{1}{2\pi}[1 - P_\gamma(2\rho^1_{11} + \rho^1_{00})\cos 2\Phi] \tag{16}$$

And what these distributions look like.



Distributions for photoproduced ϕ. T. Mibe et al, 2005 from Salamanca-Bernal thesis.

Jefferson Lab and CEBAF

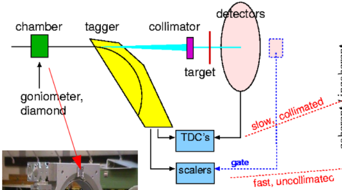


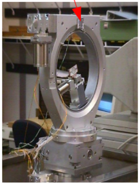
Continuous
Electron
Beam
Accelerator
Facility

- → E: 0.75 –6 GeV
- → I_{max}: 200 μA
- → RF: 1499 MHz
- → Duty Cycle: 100%
- → (E)/E: 2.5x10^{-5}
- → Polarization: 80%
- → Simultaneous distribution to 3 experimental Halls

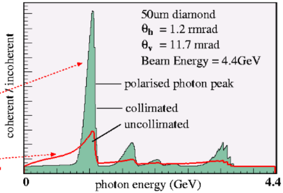
Photon Tagging Facility

tagged photon facility

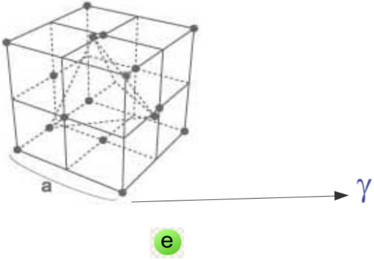


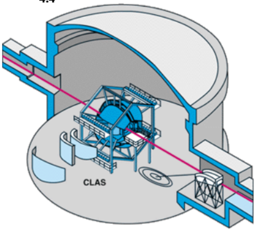


simulated coherent brem. spectrum



- Beam energies of 1.3, 1.5, 1.7 1.9, 2.1 GeV.
- Polarization ~70-80%

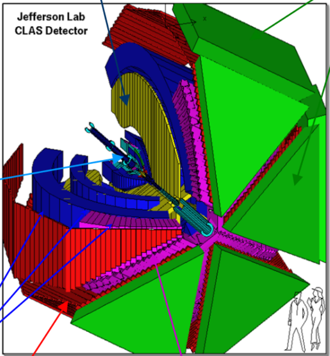




CEBAF Large Acceptance Detector

Torus Magnet
6 Superconductive Coils

Electromagnetic Calorimeter
lead/plastic scintillator, 1296 PMTs

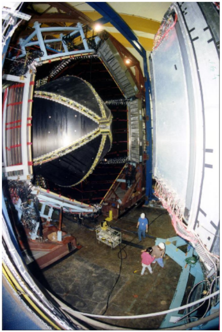


Target +
γ start
counter e
mini-torus

Drift Chamber
35,000 cells

Time of Flight
Plastic Scintillator, 684 PMTs

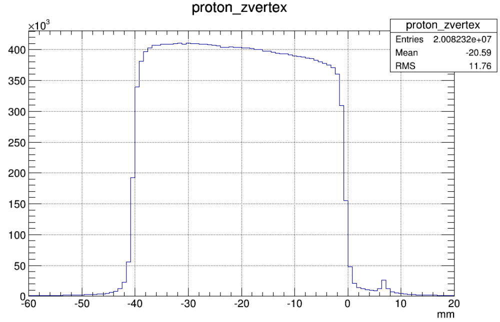
Cherenkov Counter
e/π separation, 256 PMTs

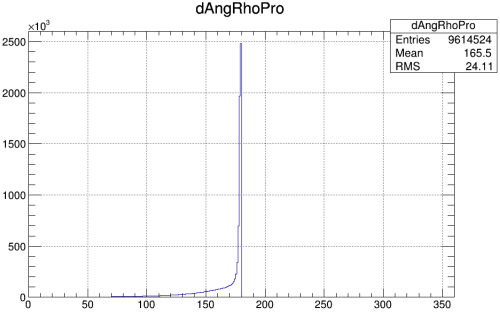


Particle Identification Stage

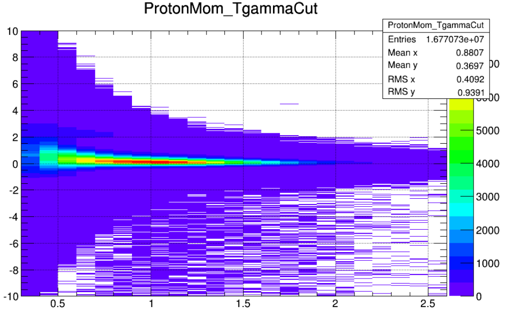
- First stage is to identify charged particles and remove all events with less than two charged particles.
- This means we can have more than one topology: e.g. $\pi^+ p$
- Fudicial cuts around the regions near the torus coils.
- Momentum and energy loss corrections.
- Then apply cuts such as missing mass cuts.

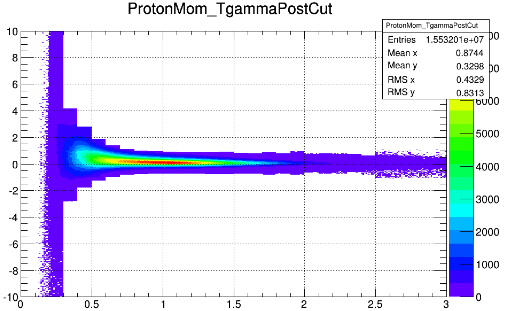
Z Vertex and Production Angle Cuts



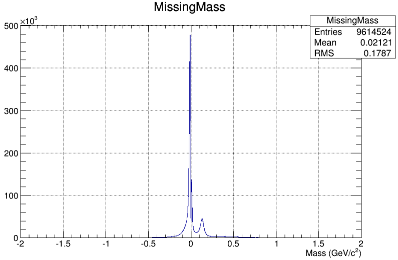


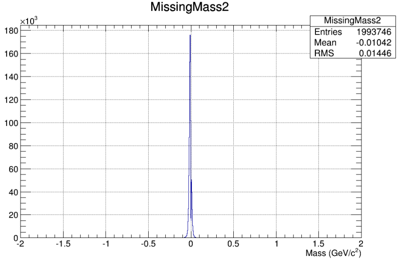
Timing Cuts: Momentum Dependent



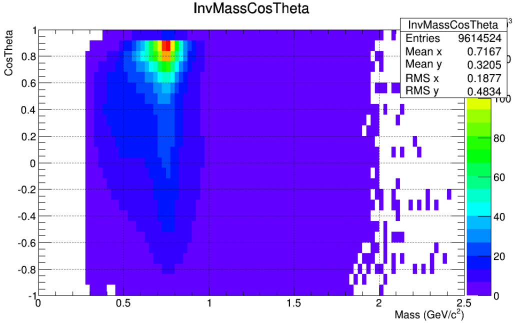


Missing mass for exclusive topology



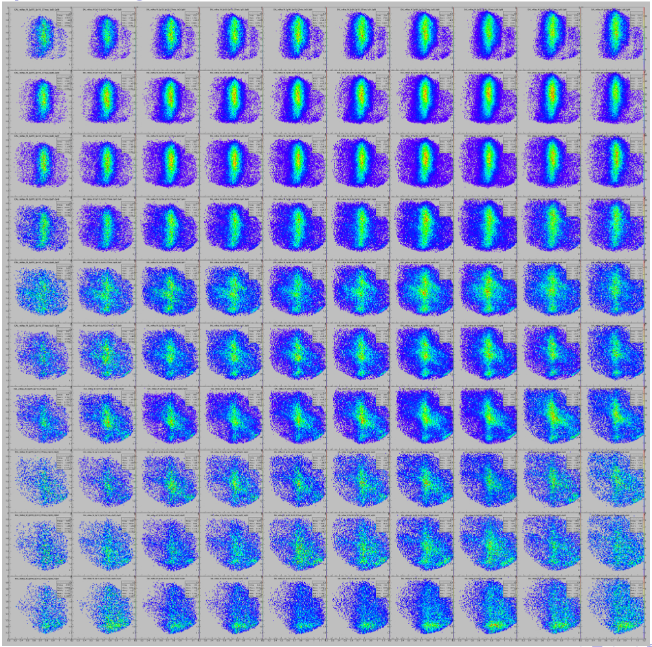


Then we split the events into kinematic bins: W and cos θ.



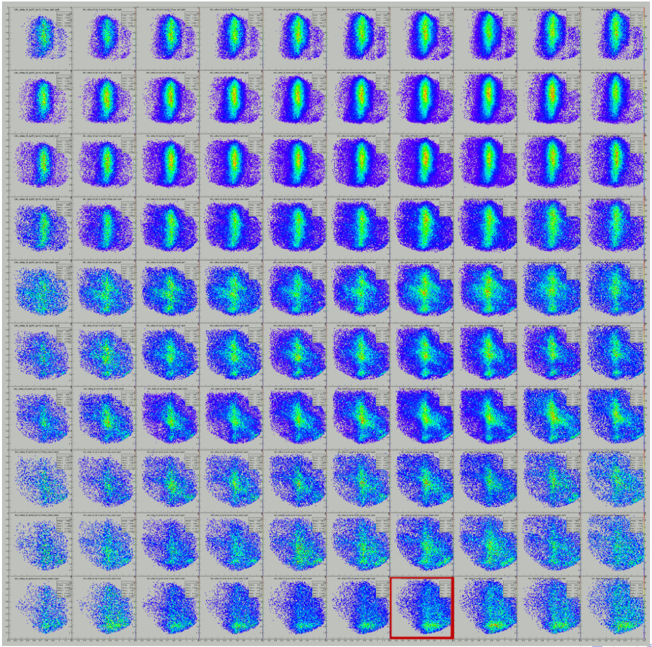
Cut on 3σ.

Separating Other Contributions



- Can try and separate other contributions to the final state.
- E.g. Δ^{++} is produced with π^{-}.
- Also N(1440), N(1520), Δ^{0} etc.
- Reconstruct it the same as with the two pions for the ρ^{0}.
- Separate using Dalitz plots. Not necessarily viable for every kinematic bin.

Other contributions



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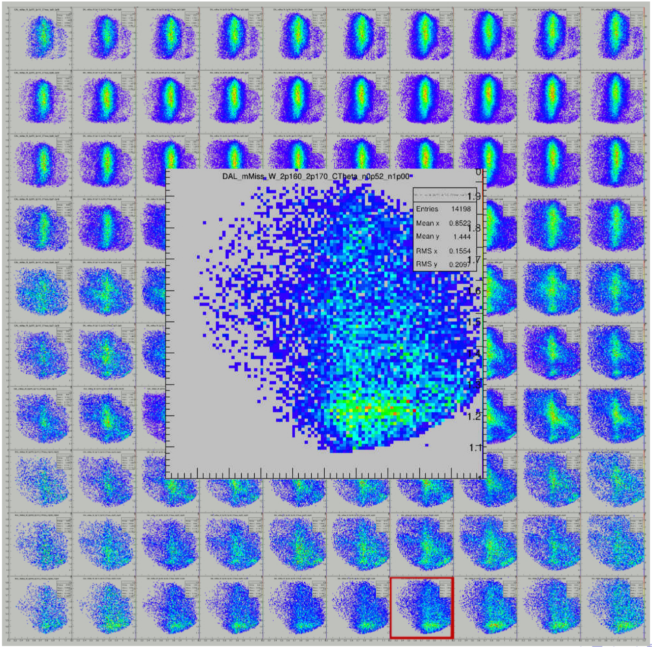

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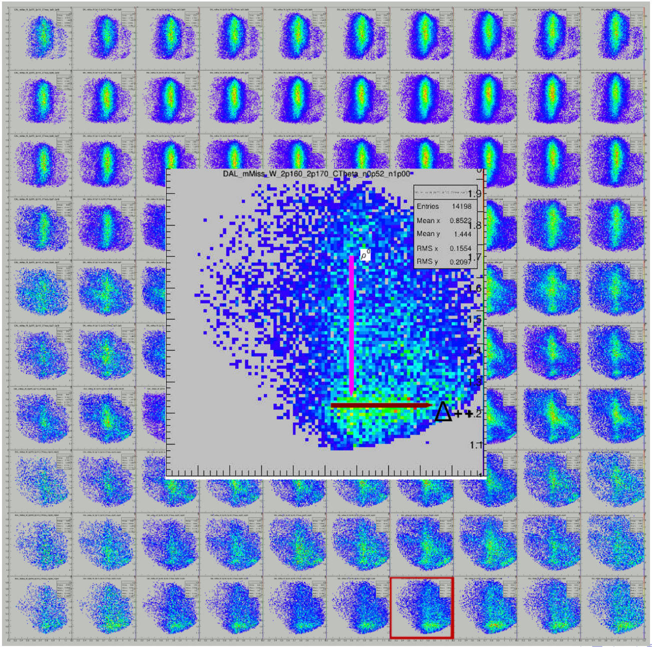

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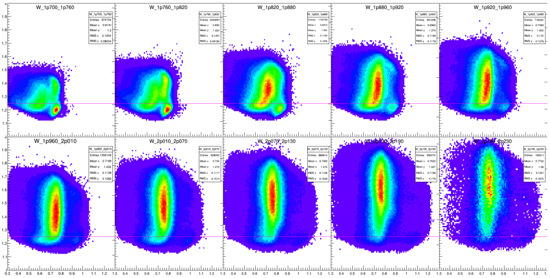
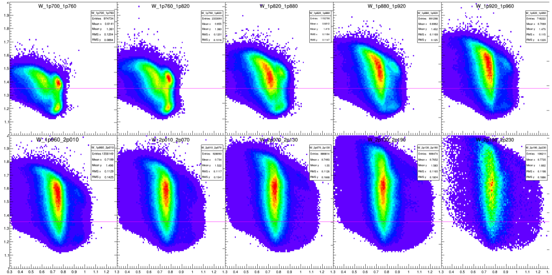
Delta dalitz plots for different W ranges

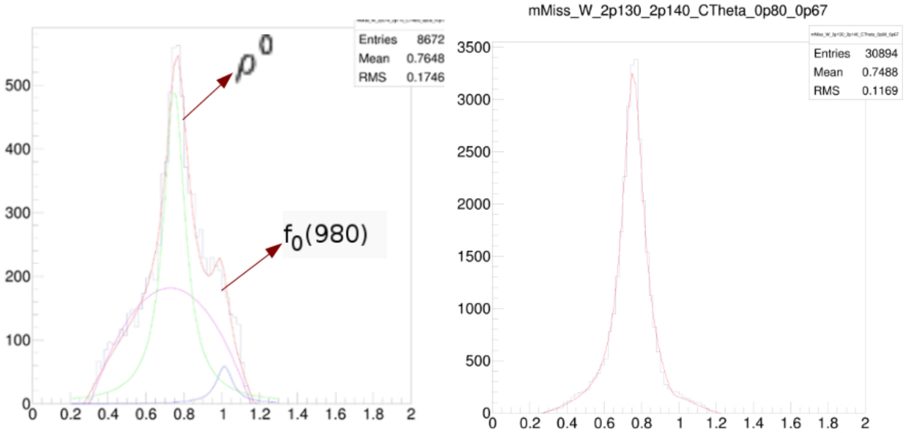
DELTA++



DELTA0

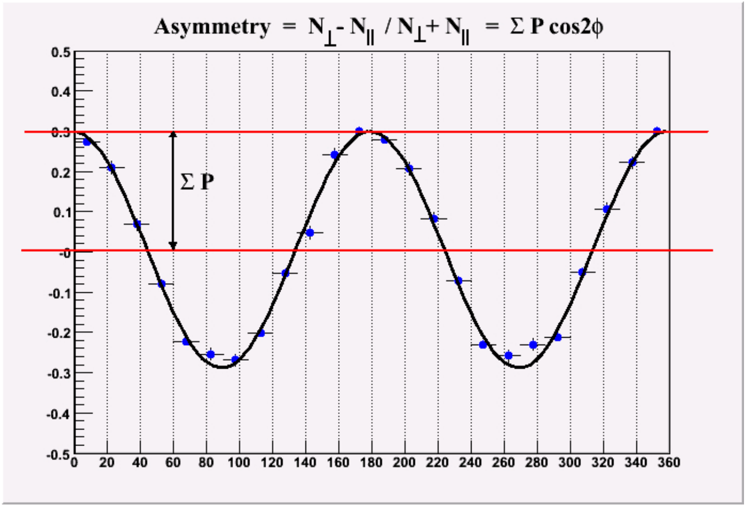


ρ^0 Signal Extraction

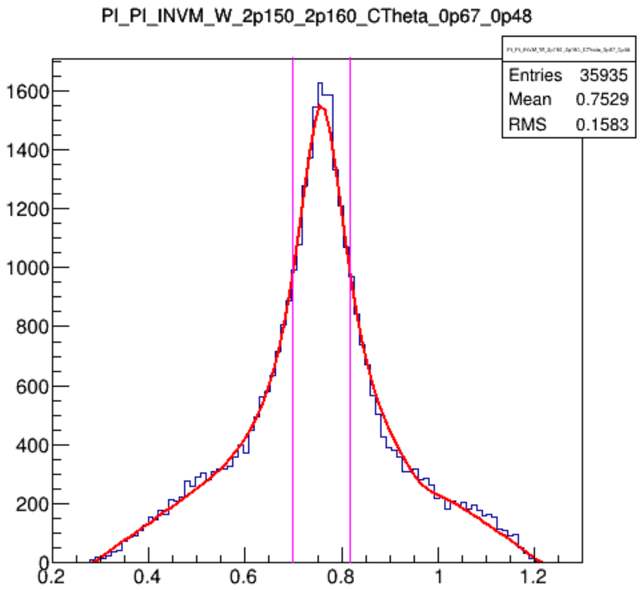


Currently using a binned fit to analysis $\pi\pi$ contributions: not useful beyond highlighting the complexity of neighbouring contributions.

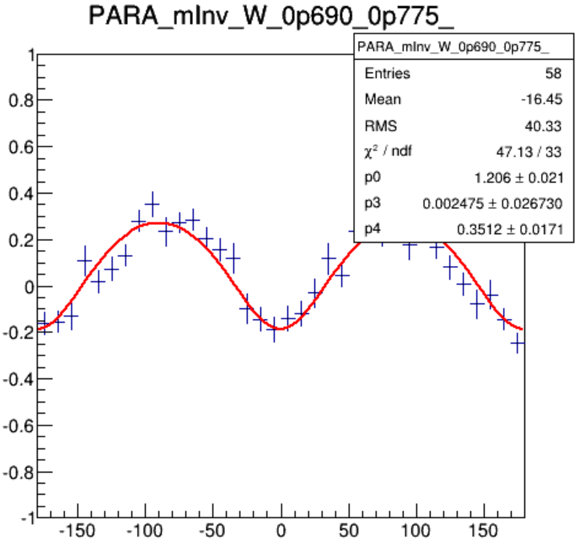
Asymmetry Extraction



- Systematics of detector acceptance cancel out.
- Only need to know $\boldsymbol{P}_{lin}$.



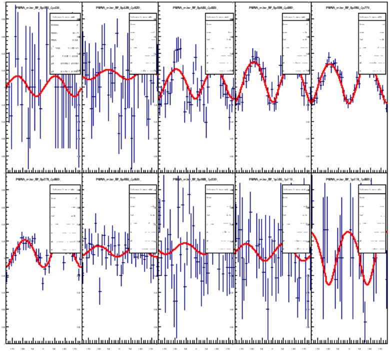
PI_PI_INVM_W_2p150_2p160_CTheta_0p67_0p48
Entries 35935
Mean 0.7529
RMS 0.1583
1600
1400
1200
1000
800
600
400
200
0
0.2
0.4
0.6
0.8
1
1.2

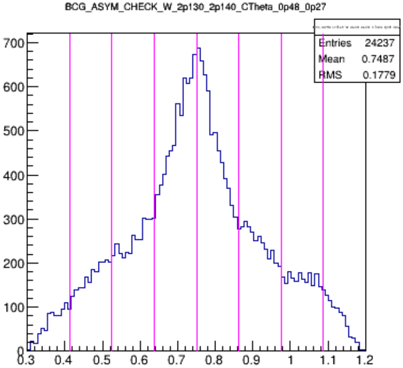


- Yield not equal for PARA and PERP.
- Photon polarization not equal.
- Small offset left as free parameter.

$$\frac{\sigma_\perp - \sigma_\parallel}{\sigma_\perp + \sigma_\parallel} = \frac{(\frac{N_\perp}{N_\parallel} - 1) - (\frac{N_\perp}{N_\parallel} P_\perp + P_\parallel)\,\Sigma \cos(2(\phi - \phi_0))}{(\frac{N_\perp}{N_\parallel} + 1) - (\frac{N_\perp}{N_\parallel} P_\perp - P_\parallel)\,\Sigma \cos(2(\phi - \phi_0))}$$

Simple Dilution Factor





Checking what is considered background doesn't have a contribution to the asymmetry.

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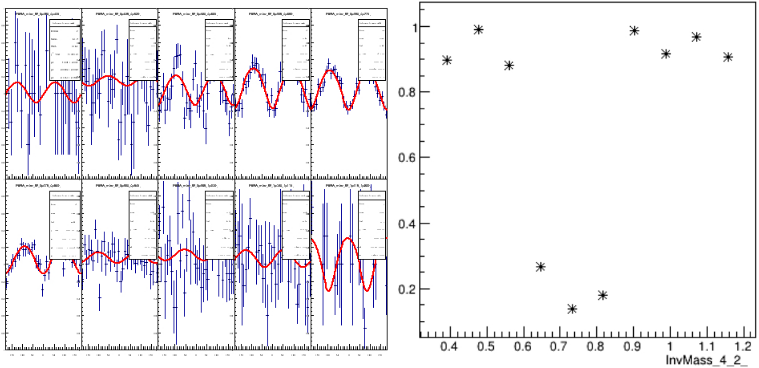
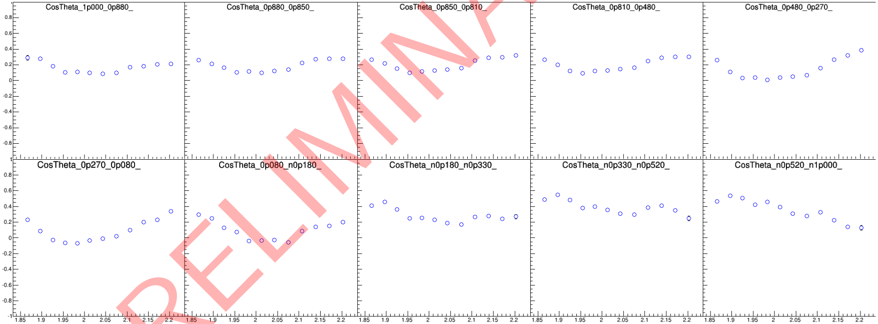
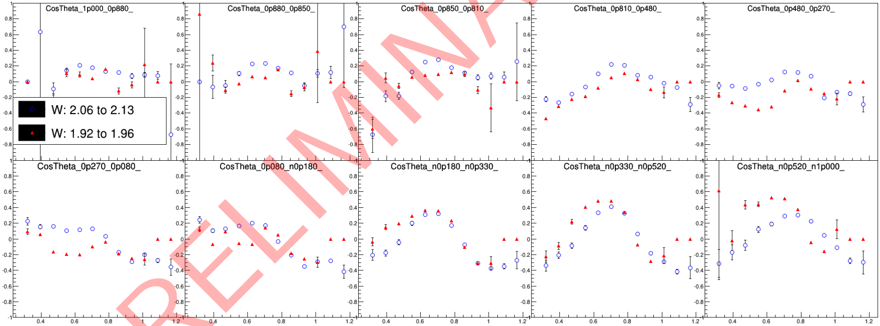


Checking what is considered background doesn't have a contribution to the asymmetry.

Extracted Σ: different $\cos\theta$ regions against W in the ρ^0 region.



Extracted Σ: different W regions against invariant mass of $\pi^+\pi^-$



Summary

- Beam asymmetry in the region of ρ^0 meson has been extracted.
- Still analysing effects of other contributions to the asymmetry measurements in order to ascertain a dilution factor.
- Simulation for aiding this analysis and also for detector acceptance is now fully working.
- Will initially deduce the availabe SDMEs for $\gamma p \rightarrow \pi^+ pi - p$.
- This is in lieu of a full PWA need to separate the many processes, which will be aided by the extracted SDMEs and Σ.