Beam Asymmetry Measurements from g8b for $\gamma p \rightarrow p \pi^+ \pi^-$: An Update

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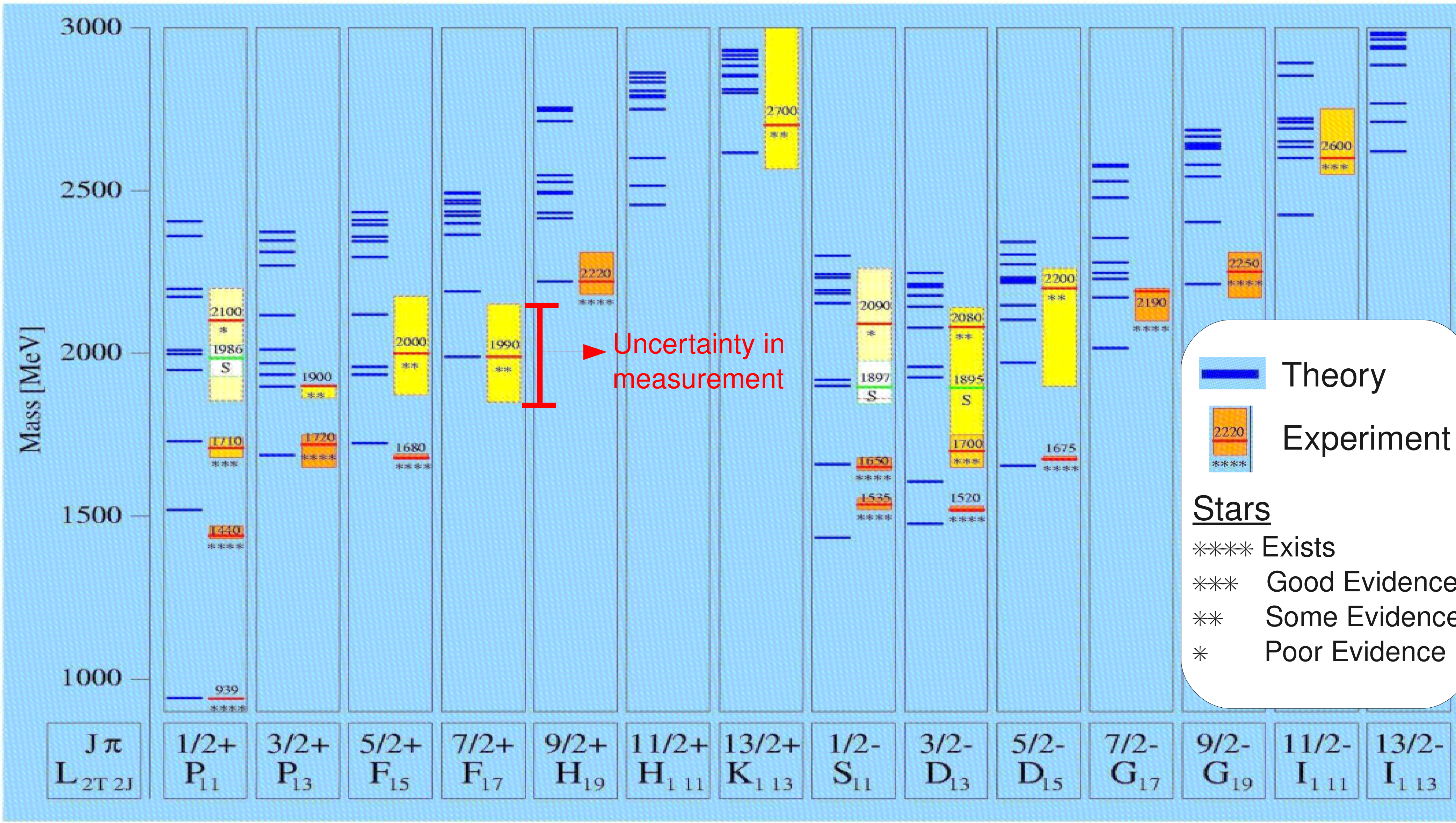
For the CLAS Collaboration: 20Nov09

Outline

- Motivation
- Kinematic Fitter
- Momentum Corrections
- Tagger Sag (Photon Energy Corrections)
- Preliminary Results
- Q-Values (Background Subtraction)

Constituent Quark Model

N* Resonances (Isospin = ½ states)



Constituent Quark Model

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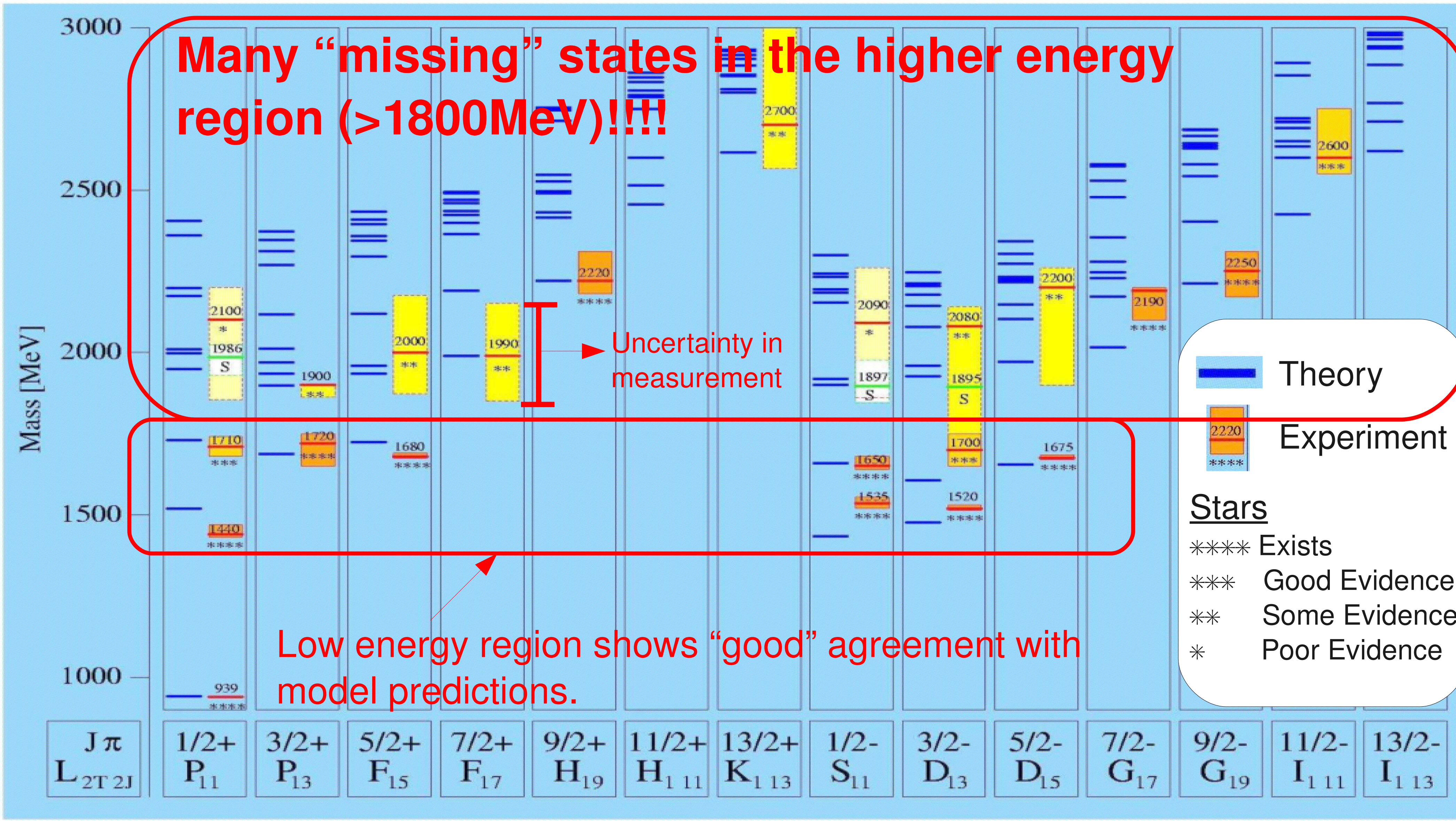
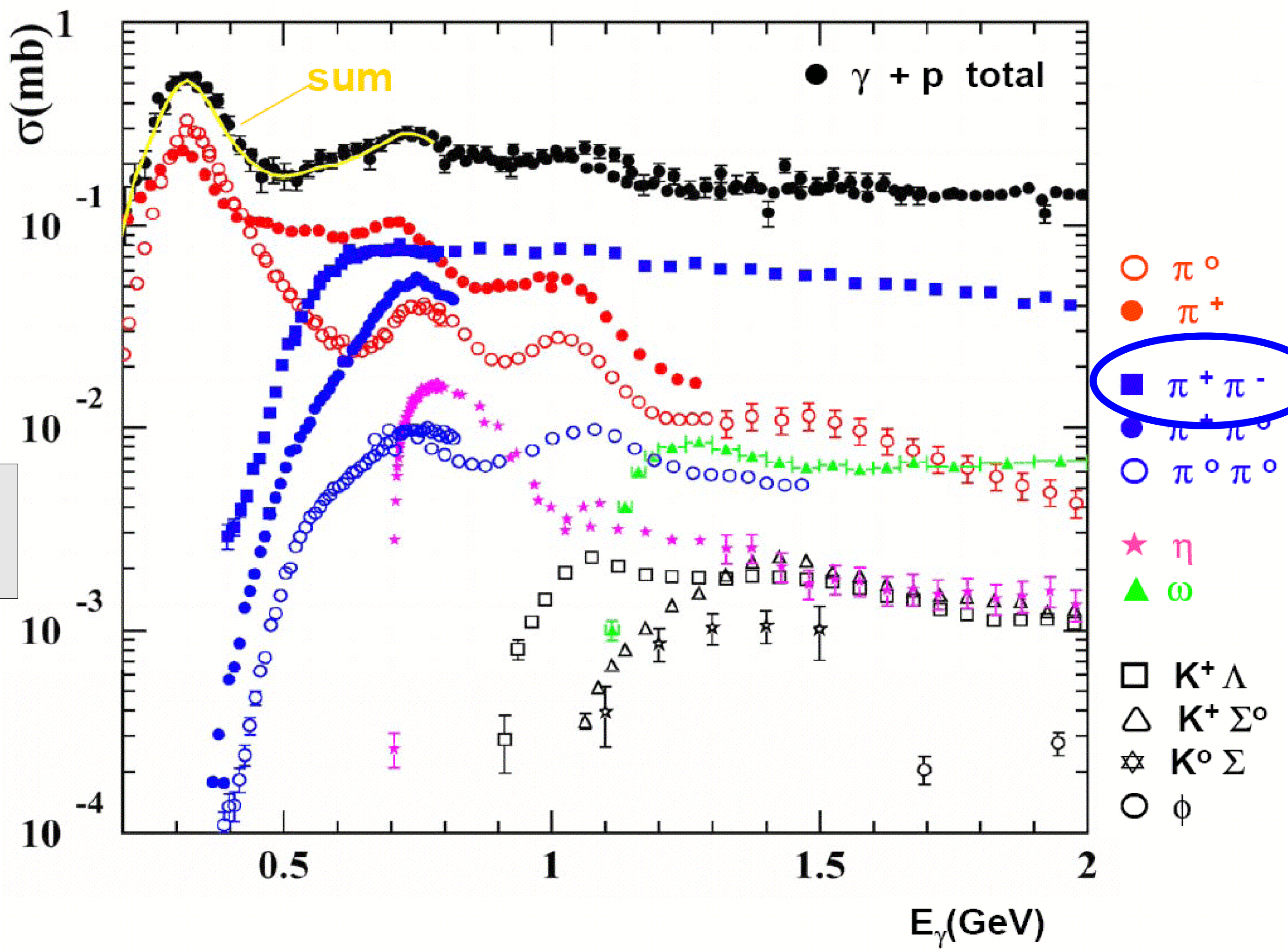


γ+p Cross Section

Experimental Cross Sections



- $\pi^{+}\pi^{-}$ cross section is large but devoid of structure. → resonances are broad and overlapping.
- Cannot go "peak hunting".
- Constraints provided by polarization are needed to disentangle and isolate resonance contributions.

Final State Equation

- To isolate resonance contributions we aim to measure polarization observables.
- The final state equation for two mesons in the final state has a total of 15 observables.

$$I = I_0 \{ (1 + \Lambda_i \bullet \mathbf{P}) + \delta_\odot (\mathbf{I}^\odot + \Lambda_i \bullet \mathbf{P}^\odot) + \delta_l [\sin 2\beta (\mathbf{I}^s + \Lambda_i \bullet \mathbf{P}^s) + \cos 2\beta (\mathbf{I}^c + \Lambda_i \bullet \mathbf{P}^c)] \}$$

I_0 = unpolarized reaction rate
Λ_i = degree of polarization of target
$\delta_{\odot, l}$ = degree of polarization of photon beam
$\mathbf{P}$ = observables arising from target polarization
$\mathbf{I}^{\odot, s, c}$ = observables arising from use of polarized photons
β = orientation of polarization w.r.t. a final state particle

- Through the use of experimental conditions/setup, we can reduce the number of observables making a measurement possible.

Final State Equation : g8b

- Used linearly polarized photons incident on an unpolarized LH_2 target.

$$I = I_0 \{(1 + \Lambda_i \bullet \mathbf{P}) + \delta_\odot(\mathbf{I}^\odot + \Lambda_i \bullet \mathbf{P}^\odot) + \delta_l [\sin 2\beta(\mathbf{I}^s + \Lambda_i \bullet \mathbf{P}^s) + \cos 2\beta(\mathbf{I}^c + \Lambda_i \bullet \mathbf{P}^c)]\}$$

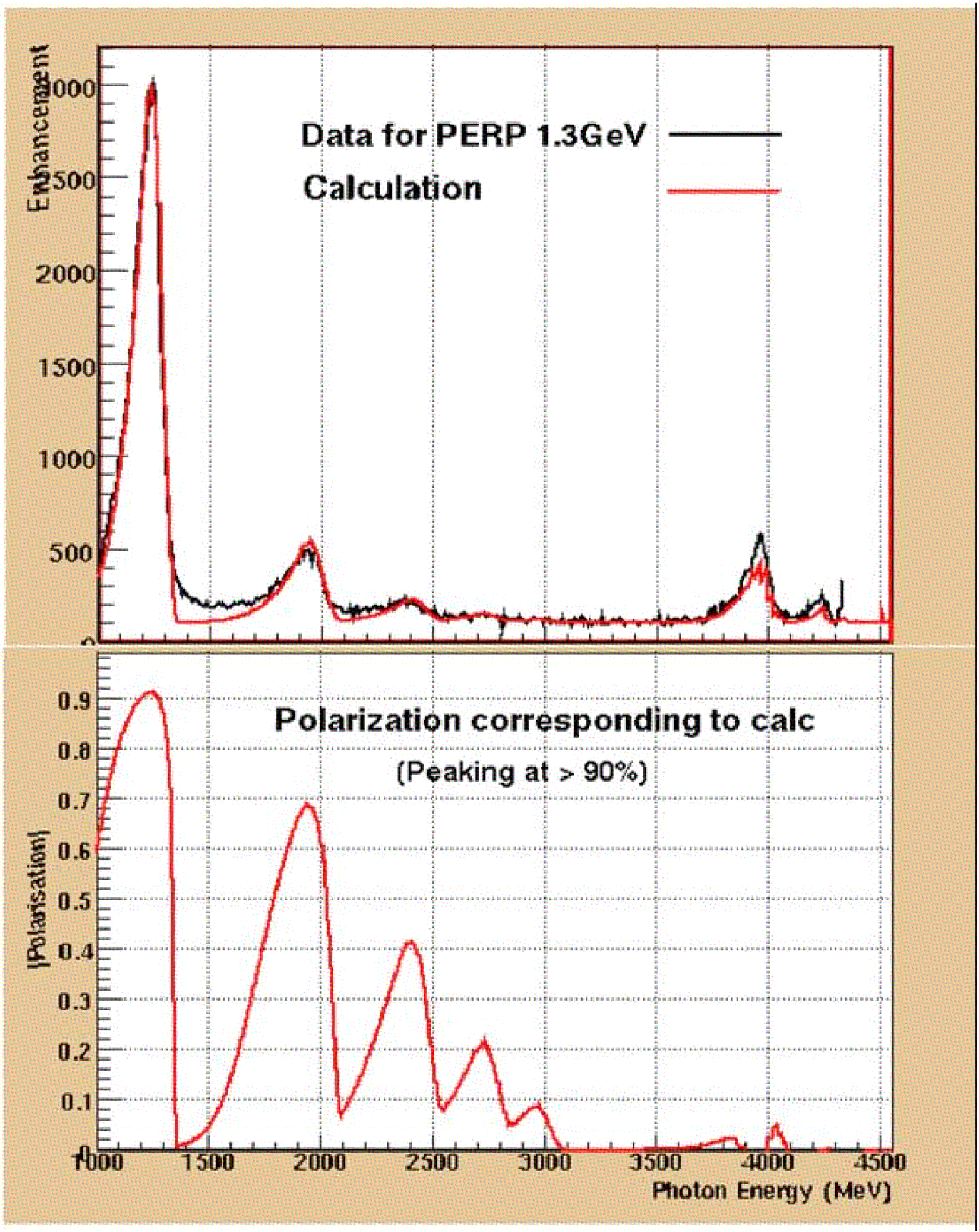
$$\Downarrow$$

$$I = I_0 \{1 + \delta_l [\mathbf{I}^s \sin 2\beta + \mathbf{I}^c \cos 2\beta]\}$$

- I^c (also known as Σ in the single-meson equation)
- I^s
- Measuring both for $\gamma p \rightarrow p\,\pi^+\pi^-$

g8b : A reminder

- The g8b experiment ran from July 20 to Sep 1st 2005
- Used linearly polarized and tagged photons incident on unpolarized LH_2.
- Obtained a degree of linear polarization of over 90%
- Polarized photon were produced at 5 different coherent edge energies : 1.3, 1.5, 1.7, 1.9, 2.1 GeV.



g8b : A reminder

THE CATHOLIC UNIVERSITY of AMERICA

UNIVERSITY of GLASGOW

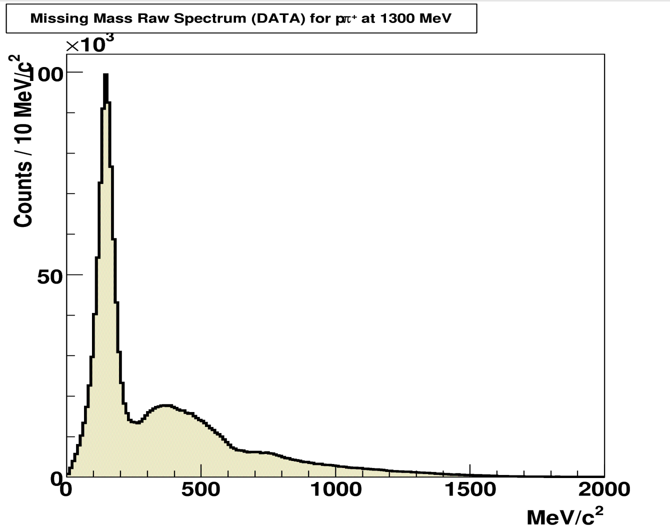
ARIZONA STATE UNIVERSITY

IDAHO STATE UNIVERSITY

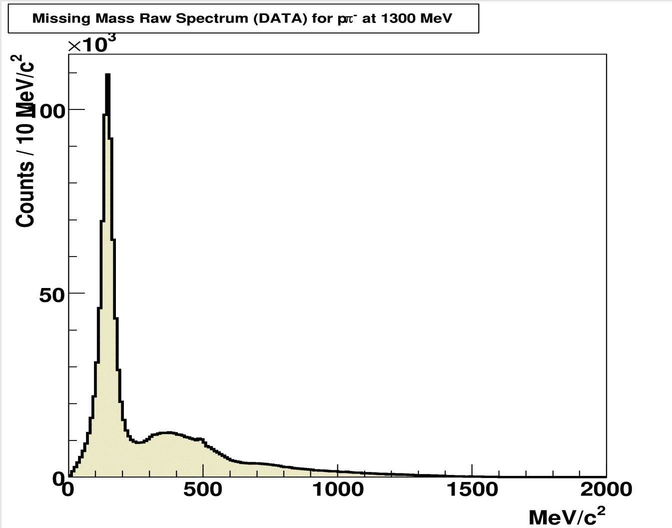
Jefferson Lab

The g8b Data Set

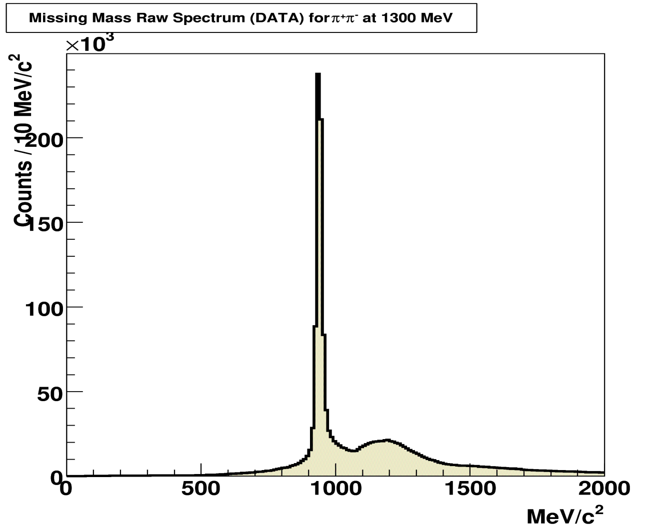
- $\gamma p \rightarrow p\, \pi^{+}\pi^{-}$ from the g8b data set
- Kinematically fitting four topologies:



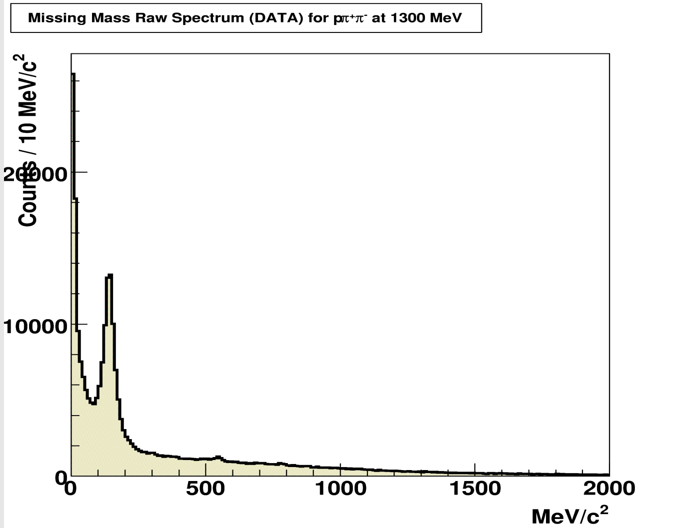
$p\, \pi^{+} (\pi^{-})$



$p\, \pi^{-}(\pi^{+})$



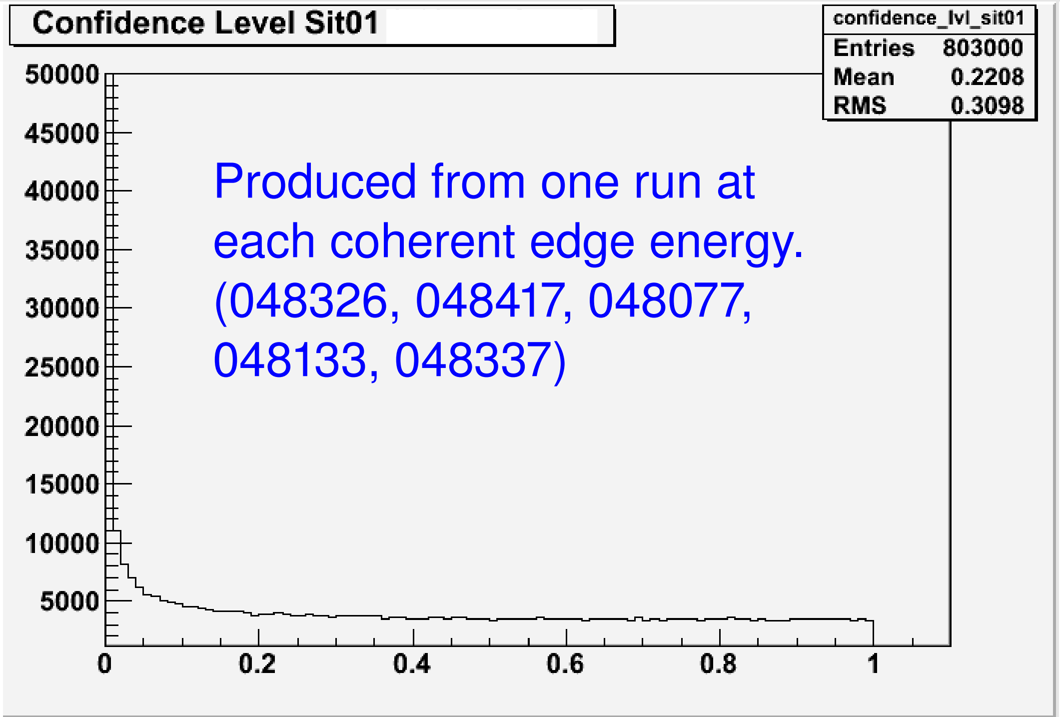
$\pi^{+} \pi^{-}$ (p)

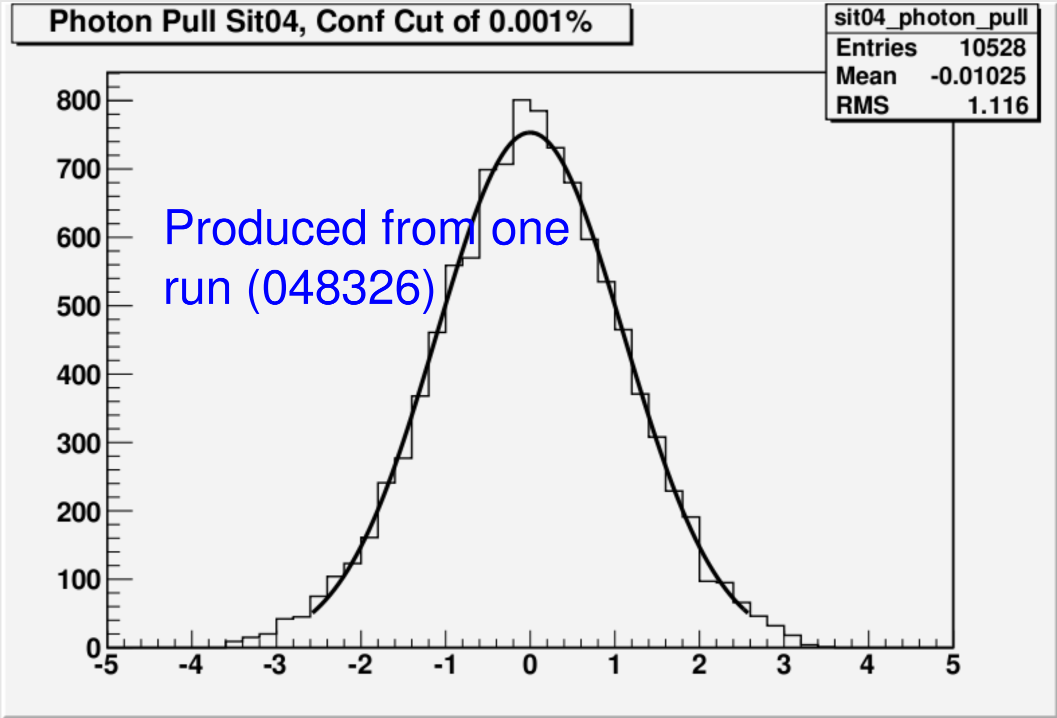


$p\, \pi^{+} \pi^{-}(\,)$

Kinematic Fitting of g8b Data

- Uses energy/momentum conservation and missing mass to vary final state measurements within the error of the measurements.
- Tracking measurements (from the TBER bank) are used to build the covariance matrix*.
- Quality of a fit → pull distributions and confidence level.
- "Pure" parameters of the covariance matrix have pull distributions.
- Systematics affect pull means, covariance matrix errors affect pull widths and slope of confidence level plots.





Kinematic Fitting of g8b Data

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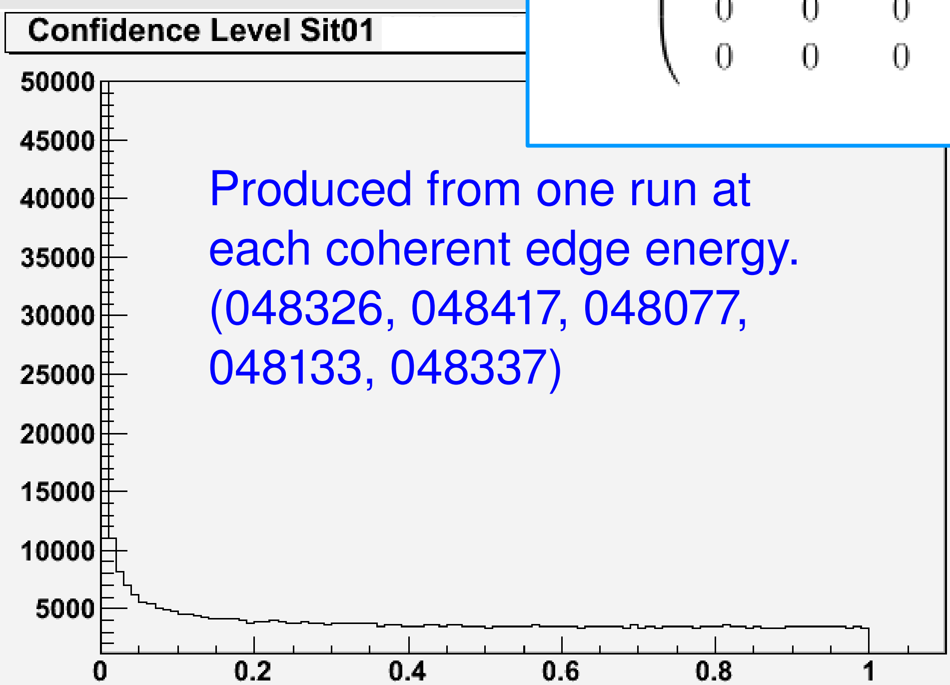
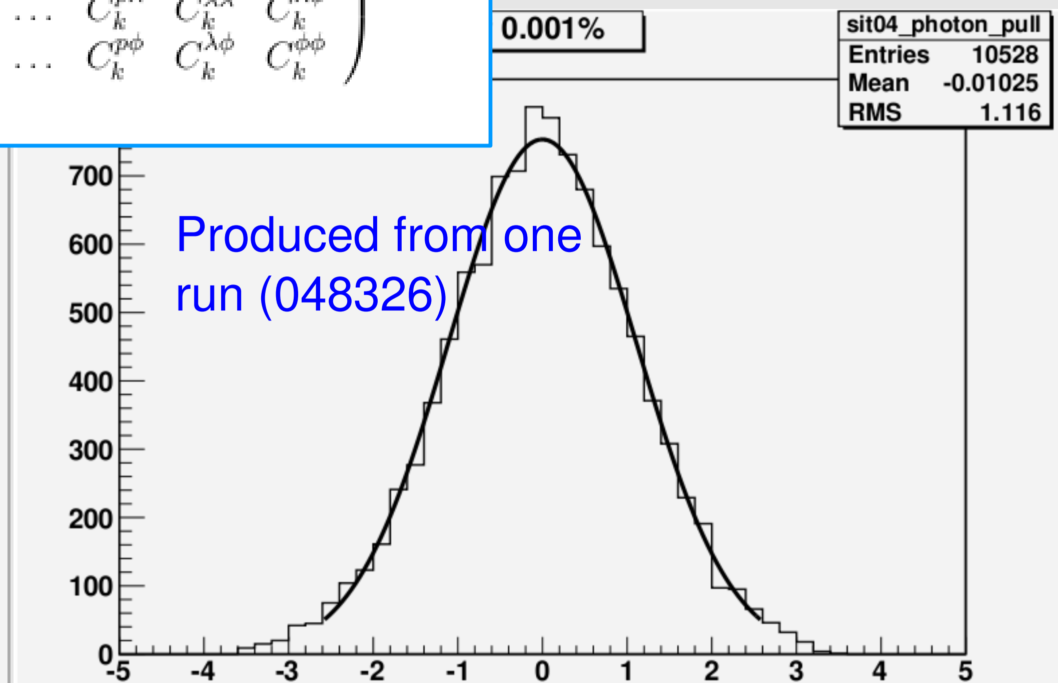
- Systematics affe ... ull widths and slope of confidence lev

$$C = \begin{pmatrix} \sigma^2_{E_\gamma} & 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ 0 & C_1^{pp} & C_1^{p\lambda} & C_1^{p\phi} & \dots & 0 & 0 & 0 \\ 0 & C_1^{p\lambda} & C_1^{\lambda\lambda} & C_1^{\lambda\phi} & \dots & 0 & 0 & 0 \\ 0 & C_1^{p\phi} & C_1^{\lambda\phi} & C_1^{\phi\phi} & \dots & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & \dots & C_k^{pp} & C_k^{p\lambda} & C_k^{p\phi} \\ 0 & 0 & 0 & 0 & \dots & C_k^{p\lambda} & C_k^{\lambda\lambda} & C_k^{\lambda\phi} \\ 0 & 0 & 0 & 0 & \dots & C_k^{p\phi} & C_k^{\lambda\phi} & C_k^{\phi\phi} \end{pmatrix}$$





Kinematic Fitting of g8b Data

- Uses energy/momentum conservation and missing mass to vary final state measurements within the error of the measurements.
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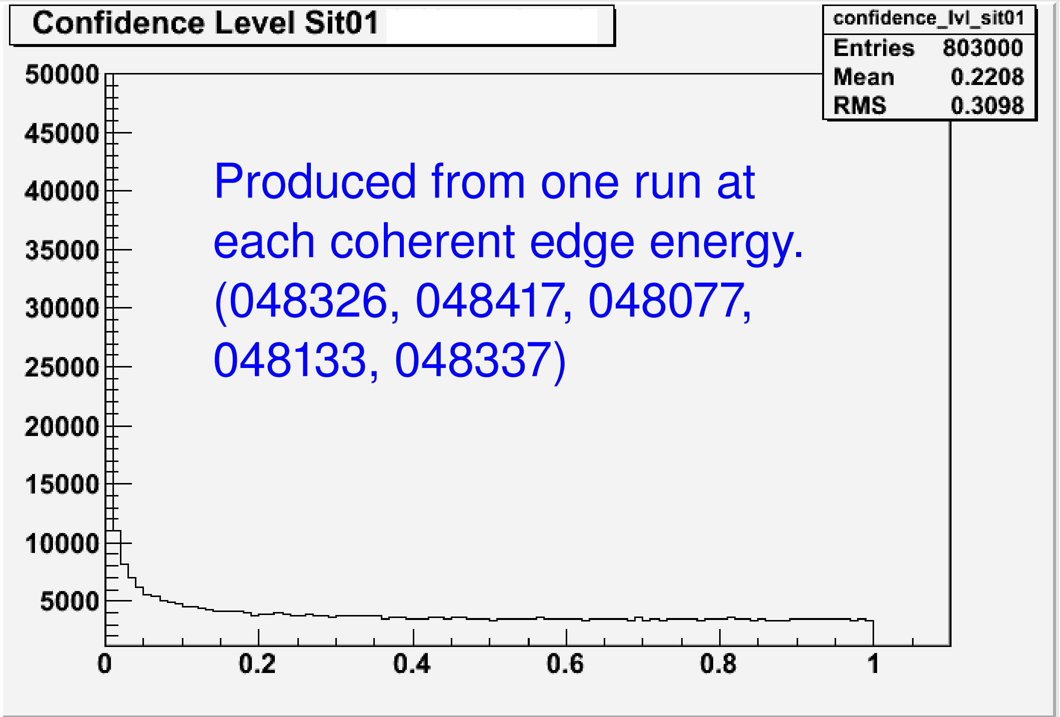
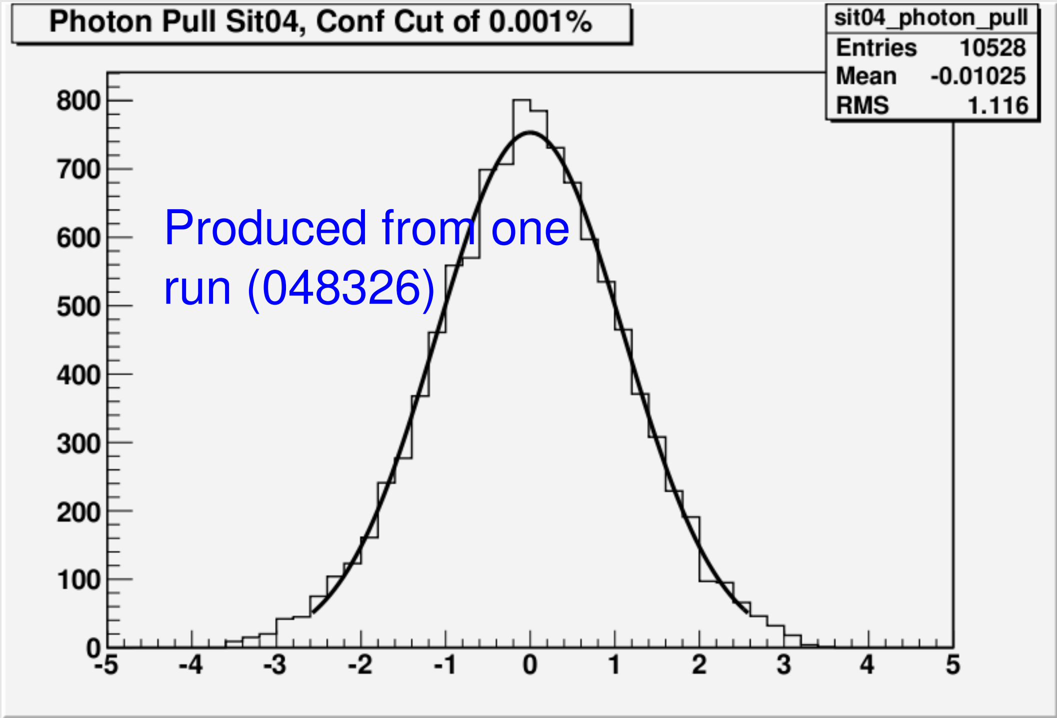


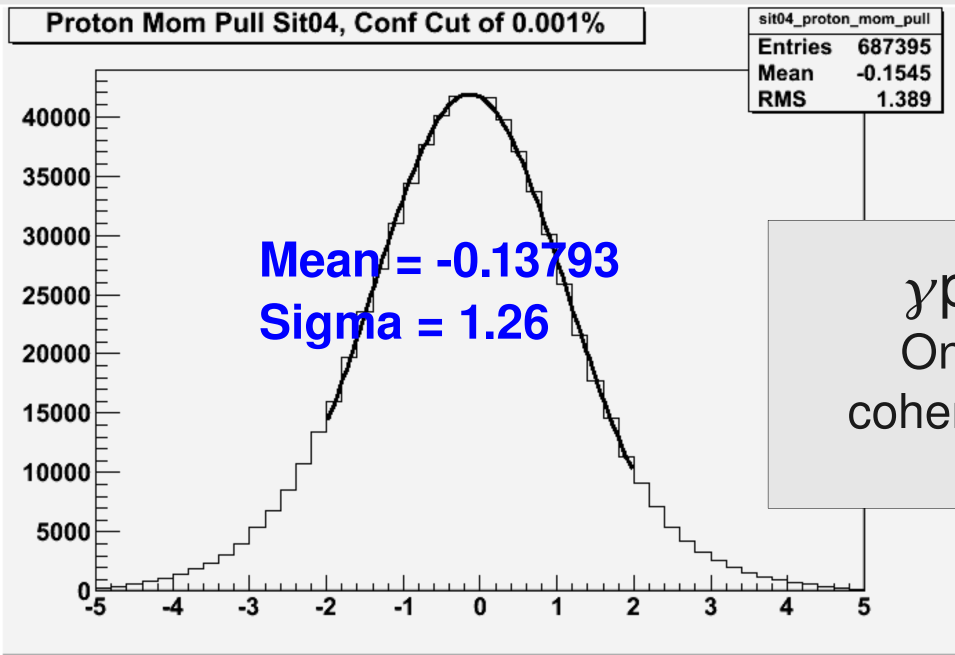


Correcting the g8b data set

- Momentum corrections were determined using the pulls generated from fitting to a p $\pi^+ \pi^-$() final state.
- The errors applied to the covariance matrix were determined by starting with the g11a errors. Errors were altered to obtain pull widths of one.
- A study into the sag of the tagger E-counters produced an energy dependent photon correction.
- Momentum corrections were refined after the application of the photon corrections.
- Covariance matrix errors were also refined/finalized.

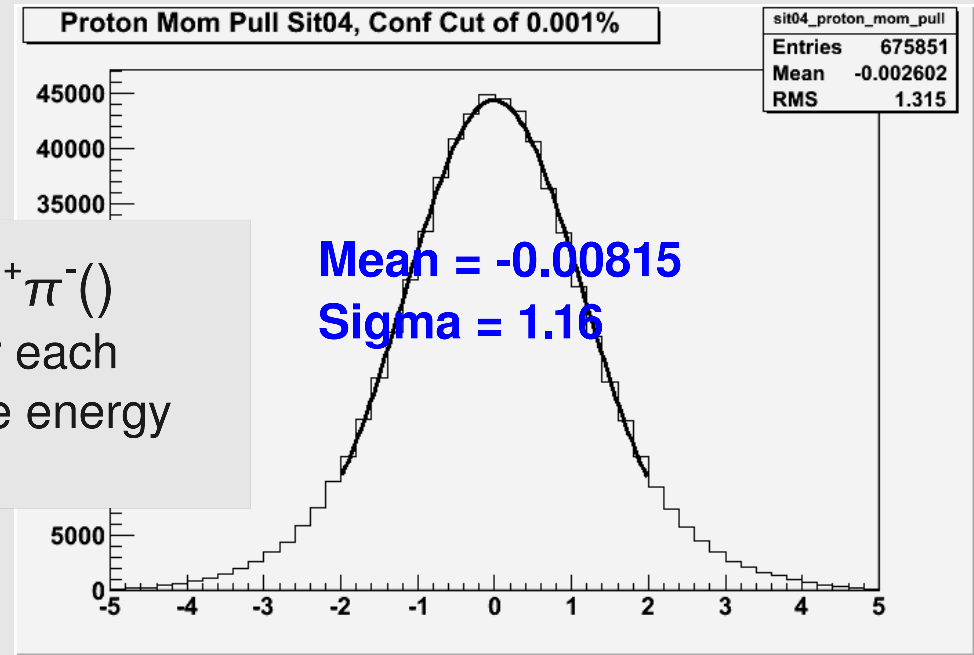
Momentum Corrections

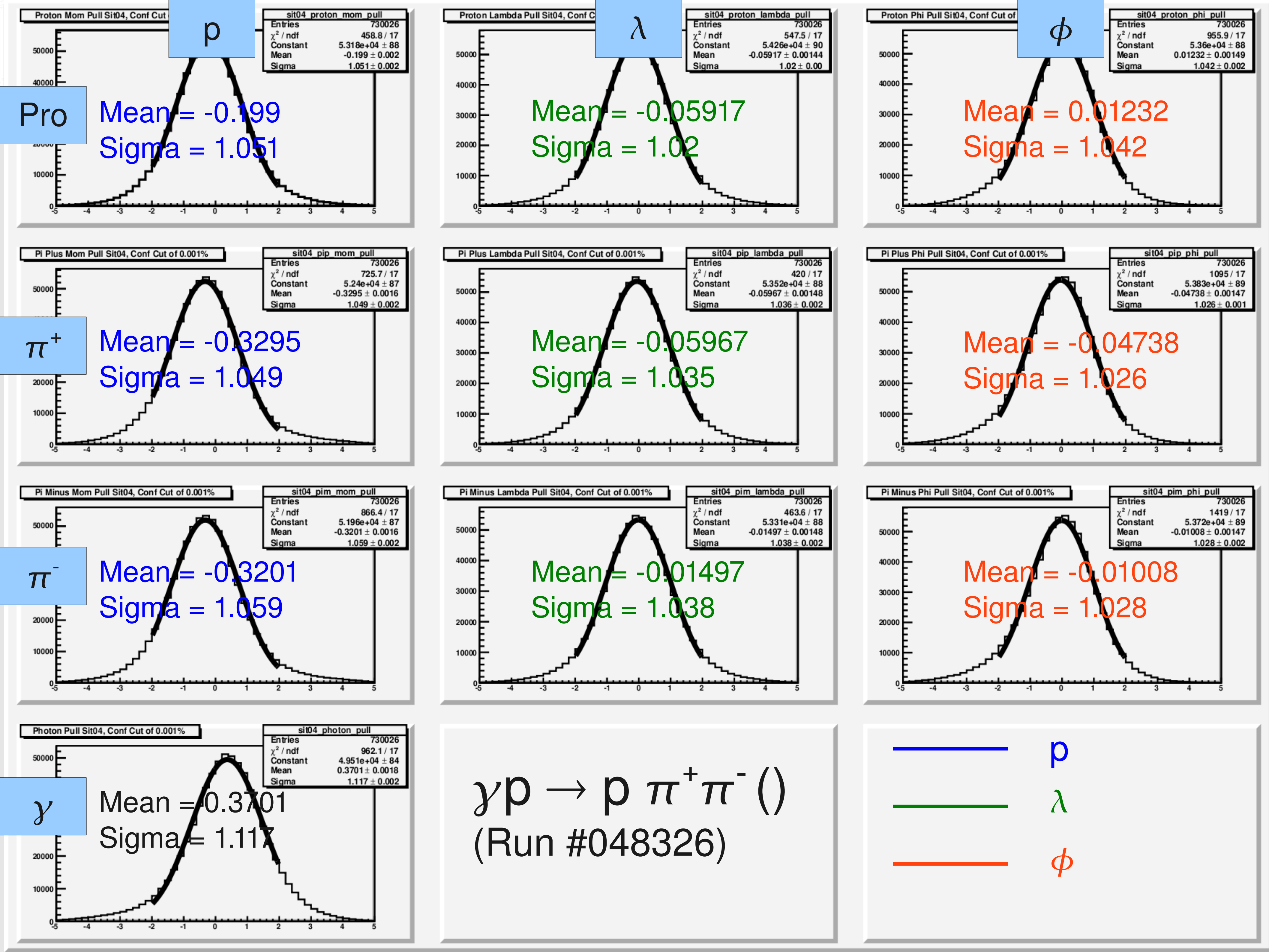
- Kinematic fitter is highly sensitive to changes in momentum → good tool for determining momentum corrections.
- Momentum pulls binned in: 7 bins in θ (lab), 18 bins in ϕ (lab), 6 bins in momentum (0.2-1.7 GeV).
- Corrections range from a few percent to ~10%.



$\gamma p \rightarrow p\ \pi^{+}\pi^{-}()$

One run for each coherent edge energy

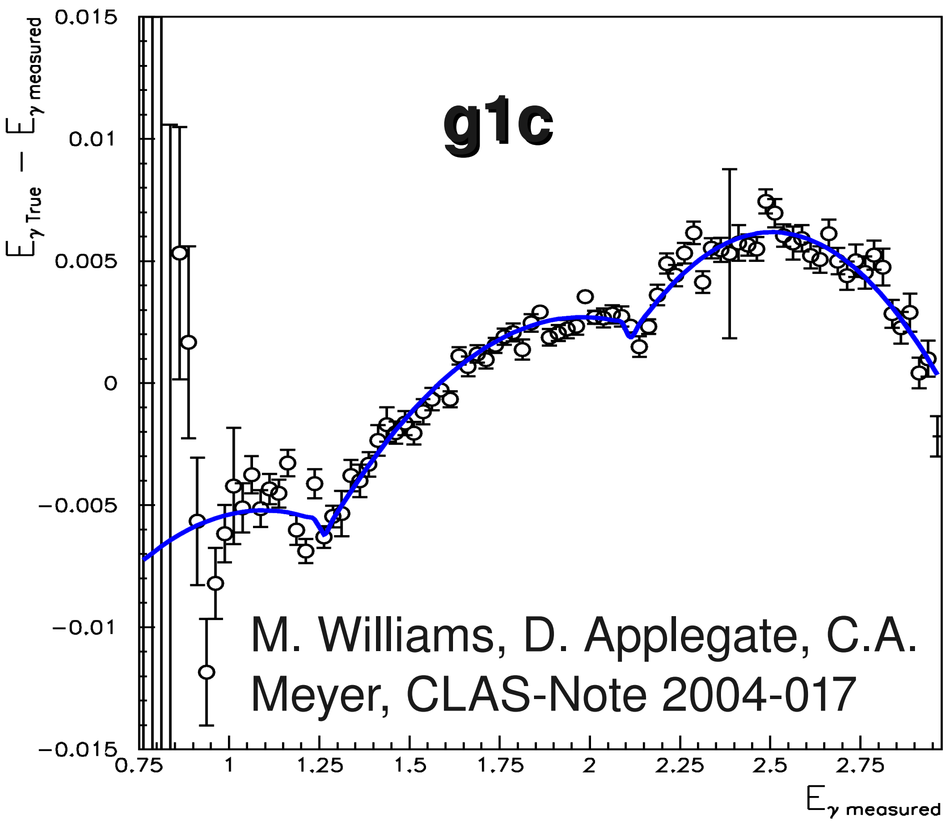


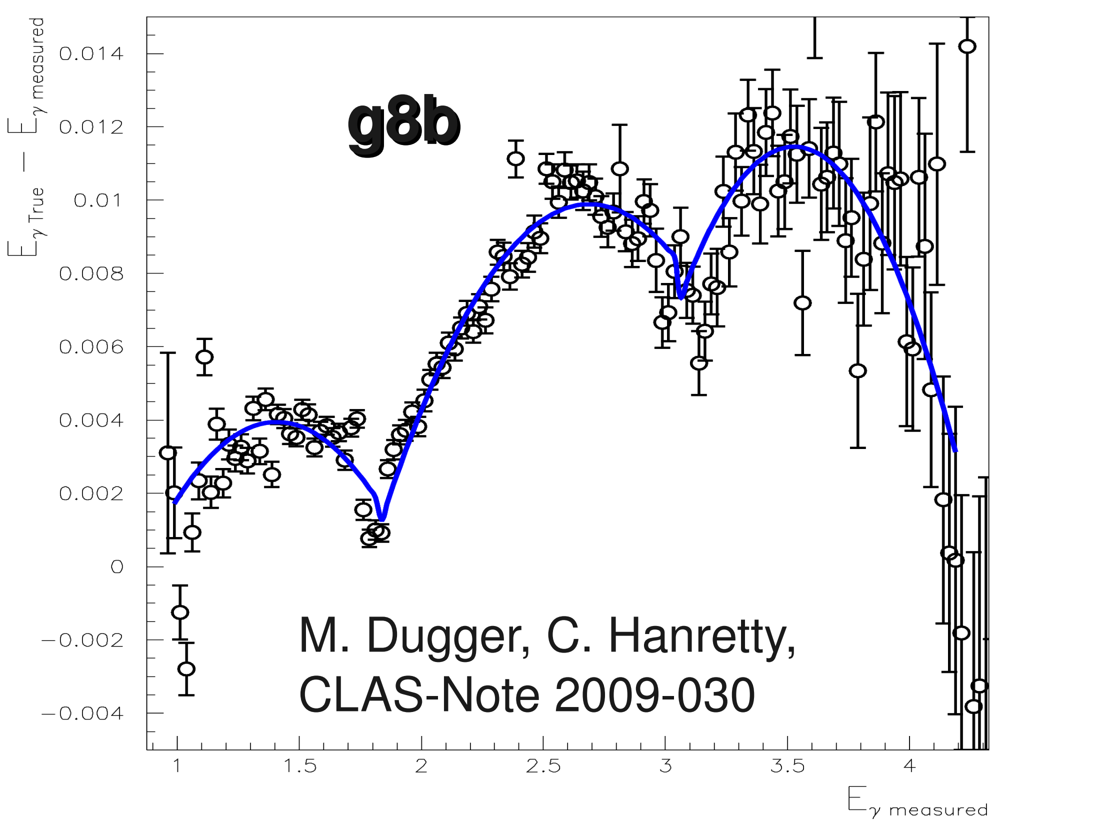


p
λ
ϕ
Pro
π+
π-
γ
Proton Mom Pull Sit04, Conf Cut
sit04_proton_mom_pull
Entries 730026
χ² / ndf 458.8 / 17
Constant 5.318e+04 ± 88
Mean -0.199 ± 0.002
Sigma 1.051 ± 0.002
Mean = -0.199
Sigma = 1.051
Proton Lambda Pull Sit04, Conf C
sit04_proton_lambda_pull
Entries 730026
χ² / ndf 547.5 / 17
Constant 5.426e+04 ± 90
Mean -0.05917 ± 0.00144
Sigma 1.02 ± 0.00
Mean = -0.05917
Sigma = 1.02
Proton Phi Pull Sit04, Conf Cut of
sit04_proton_phi_pull
Entries 730026
χ² / ndf 955.9 / 17
Constant 5.36e+04 ± 88
Mean 0.01232 ± 0.00149
Sigma 1.042 ± 0.002
Mean = 0.01232
Sigma = 1.042
Pi Plus Mom Pull Sit04, Conf Cut of 0.001%
sit04_pip_mom_pull
Entries 730026
χ² / ndf 725.7 / 17
Constant 5.24e+04 ± 87
Mean -0.3295 ± 0.0016
Sigma 1.049 ± 0.002
Mean = -0.3295
Sigma = 1.049
Pi Plus Lambda Pull Sit04, Conf Cut of 0.001%
sit04_pip_lambda_pull
Entries 730026
χ² / ndf 420 / 17
Constant 5.352e+04 ± 88
Mean -0.05967 ± 0.00148
Sigma 1.036 ± 0.002
Mean = -0.05967
Sigma = 1.035
Pi Plus Phi Pull Sit04, Conf Cut of 0.001%
sit04_pip_phi_pull
Entries 730026
χ² / ndf 1095 / 17
Constant 5.383e+04 ± 89
Mean -0.04738 ± 0.00147
Sigma 1.026 ± 0.001
Mean = -0.04738
Sigma = 1.026
Pi Minus Mom Pull Sit04, Conf Cut of 0.001%
sit04_pim_mom_pull
Entries 730026
χ² / ndf 866.4 / 17
Constant 5.196e+04 ± 87
Mean -0.3201 ± 0.0016
Sigma 1.059 ± 0.002
Mean = -0.3201
Sigma = 1.059
Pi Minus Lambda Pull Sit04, Conf Cut of 0.001%
sit04_pim_lambda_pull
Entries 730026
χ² / ndf 463.6 / 17
Constant 5.331e+04 ± 88
Mean -0.01497 ± 0.00148
Sigma 1.038 ± 0.002
Mean = -0.01497
Sigma = 1.038
Pi Minus Phi Pull Sit04, Conf Cut of 0.001%
sit04_pim_phi_pull
Entries 730026
χ² / ndf 1419 / 17
Constant 5.372e+04 ± 89
Mean -0.01008 ± 0.00147
Sigma 1.028 ± 0.002
Mean = -0.01008
Sigma = 1.028
Photon Pull Sit04, Conf Cut of 0.001%
sit04_photon_pull
Entries 730026
χ² / ndf 962.1 / 17
Constant 4.951e+04 ± 84
Mean 0.3701 ± 0.0018
Sigma 1.117 ± 0.002
Mean = 0.3701
Sigma = 1.117
γp → p π+π- ()
(Run #048326)
p
λ
ϕ

Tagger Sag

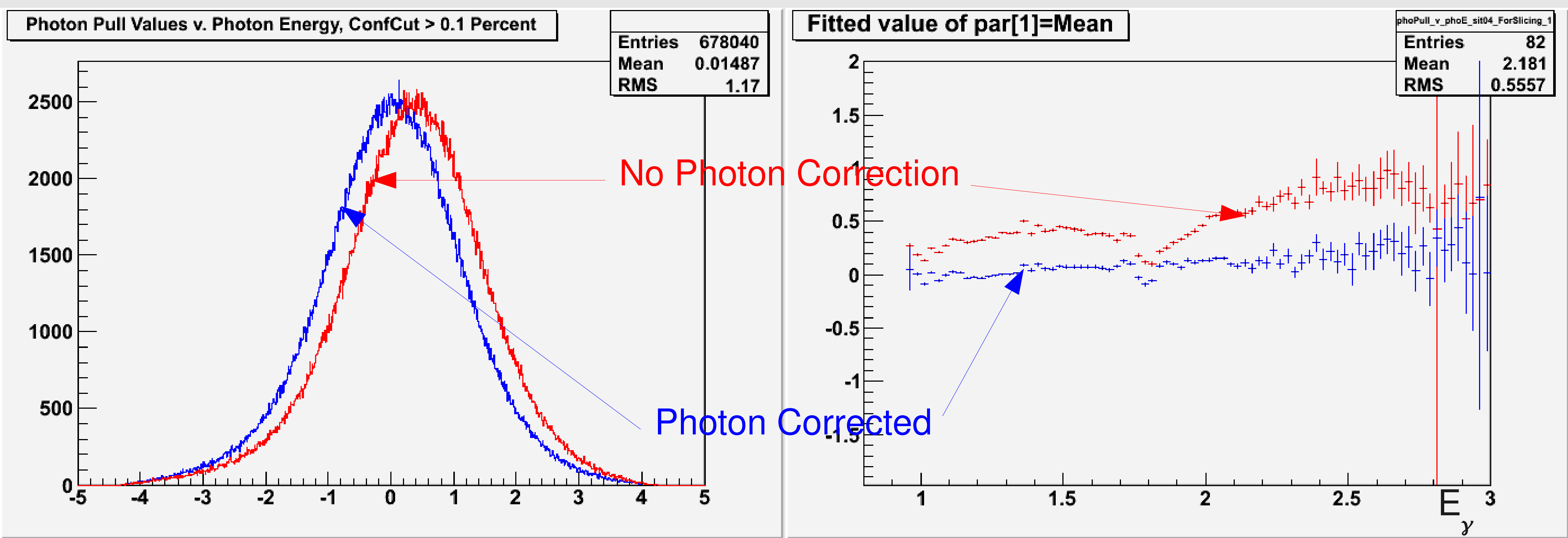
- Results from a physical “sagging” of the E-counter scintillator bars.
- Has been seen in several runs.

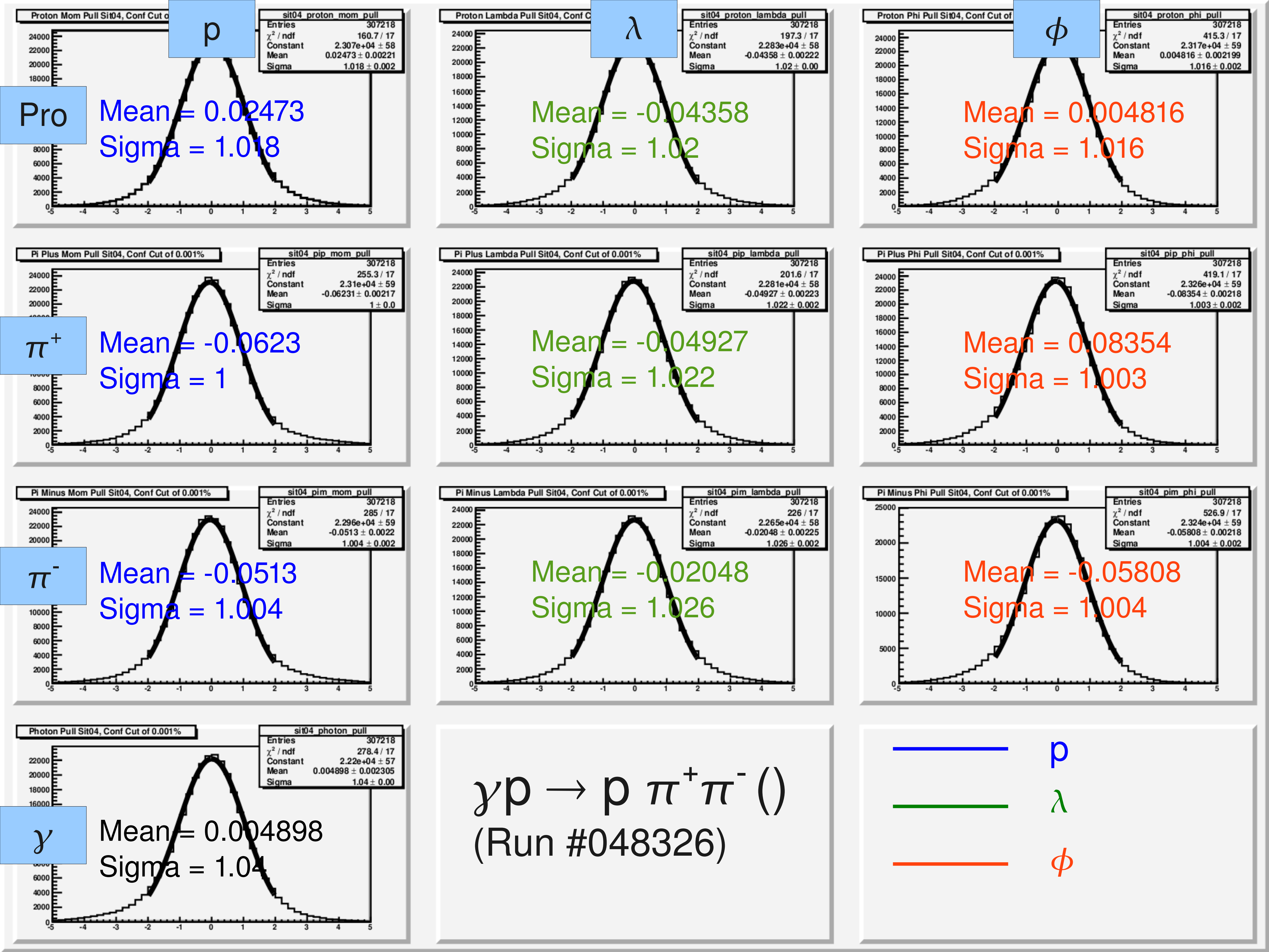




Tagger Sag

- Results from a physical “sagging” of the E-counter scintillator bars.
- Has been seen in several runs.
- Requires and energy-dependent photon energy correction.



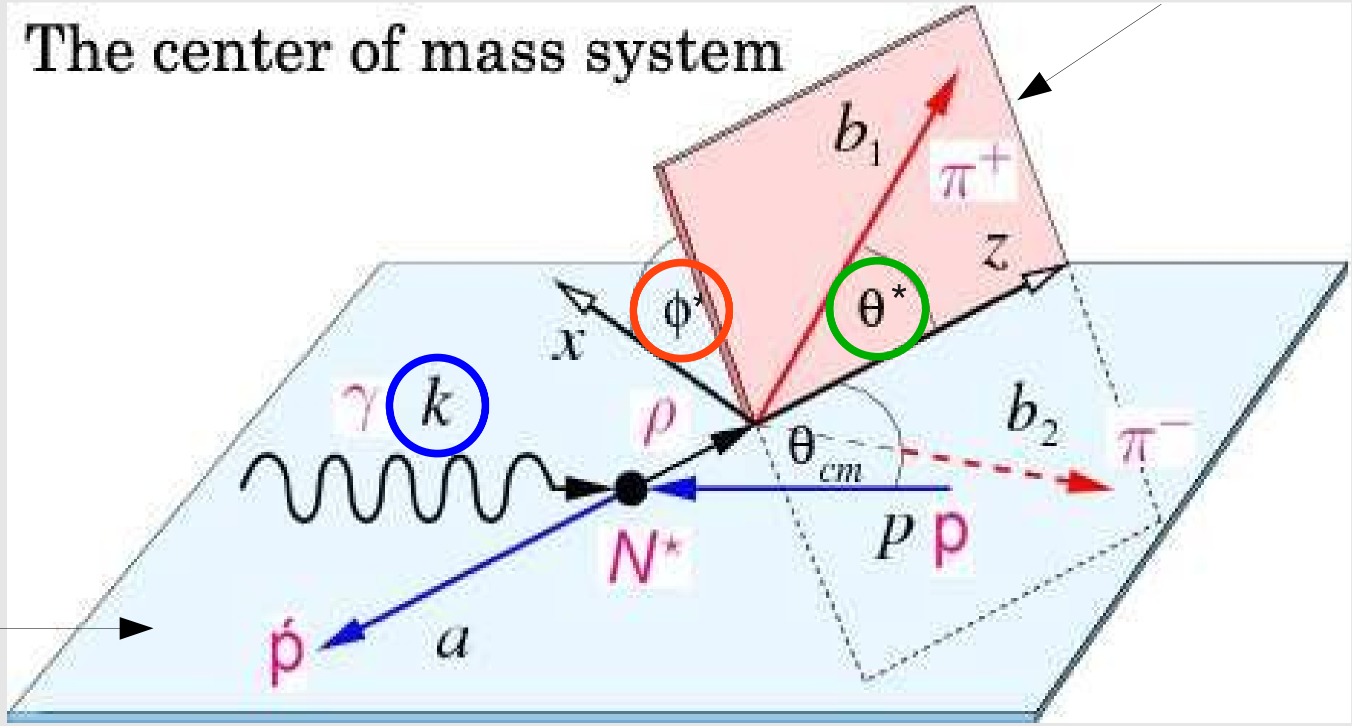


p
λ
φ
Pro
π+
π-
γ
Proton Mom Pull Sit04, Conf Cut o
sit04_proton_mom_pull
Entries 307218
χ² / ndf 160.7 / 17
Constant 2.307e+04 ± 58
Mean 0.02473 ± 0.00221
Sigma 1.018 ± 0.002
Mean = 0.02473
Sigma = 1.018
Proton Lambda Pull Sit04, Conf C
sit04_proton_lambda_pull
Entries 307218
χ² / ndf 197.3 / 17
Constant 2.283e+04 ± 58
Mean -0.04358 ± 0.00222
Sigma 1.02 ± 0.00
Mean = -0.04358
Sigma = 1.02
Proton Phi Pull Sit04, Conf Cut of
sit04_proton_phi_pull
Entries 307218
χ² / ndf 415.3 / 17
Constant 2.317e+04 ± 59
Mean 0.004816 ± 0.002199
Sigma 1.016 ± 0.002
Mean = 0.004816
Sigma = 1.016
Pi Plus Mom Pull Sit04, Conf Cut of 0.001%
sit04_pip_mom_pull
Entries 307218
χ² / ndf 255.3 / 17
Constant 2.31e+04 ± 59
Mean -0.06231 ± 0.00217
Sigma 1 ± 0.0
Mean = -0.0623
Sigma = 1
Pi Plus Lambda Pull Sit04, Conf Cut of 0.001%
sit04_pip_lambda_pull
Entries 307218
χ² / ndf 201.6 / 17
Constant 2.281e+04 ± 58
Mean -0.04927 ± 0.00223
Sigma 1.022 ± 0.002
Mean = -0.04927
Sigma = 1.022
Pi Plus Phi Pull Sit04, Conf Cut of 0.001%
sit04_pip_phi_pull
Entries 307218
χ² / ndf 419.1 / 17
Constant 2.326e+04 ± 59
Mean -0.08354 ± 0.00218
Sigma 1.003 ± 0.002
Mean = 0.08354
Sigma = 1.003
Pi Minus Mom Pull Sit04, Conf Cut of 0.001%
sit04_pim_mom_pull
Entries 307218
χ² / ndf 285 / 17
Constant 2.296e+04 ± 59
Mean -0.0513 ± 0.0022
Sigma 1.004 ± 0.002
Mean = -0.0513
Sigma = 1.004
Pi Minus Lambda Pull Sit04, Conf Cut of 0.001%
sit04_pim_lambda_pull
Entries 307218
χ² / ndf 226 / 17
Constant 2.265e+04 ± 58
Mean -0.02048 ± 0.00225
Sigma 1.026 ± 0.002
Mean = -0.02048
Sigma = 1.026
Pi Minus Phi Pull Sit04, Conf Cut of 0.001%
sit04_pim_phi_pull
Entries 307218
χ² / ndf 526.9 / 17
Constant 2.324e+04 ± 59
Mean -0.05808 ± 0.00218
Sigma 1.004 ± 0.002
Mean = -0.05808
Sigma = 1.004
Photon Pull Sit04, Conf Cut of 0.001%
sit04_photon_pull
Entries 307218
χ² / ndf 278.4 / 17
Constant 2.22e+04 ± 57
Mean 0.004898 ± 0.002305
Sigma 1.04 ± 0.00
Mean = 0.004898
Sigma = 1.04
γp → p π+π- ()
(Run #048326)
p
λ
φ

CM Coordinate System for $\gamma p \rightarrow p\ \pi^+\pi^-$

- Analysis of the $\gamma p \rightarrow p\ \pi^+\pi^-$ channel requires the employ of 5 independent variables, for example : $\cos\theta_{cm}$, m, k, ϕ^*, θ^*
- $\gamma p \rightarrow N^* \rightarrow N\rho \rightarrow p\ \pi^+\pi^-$

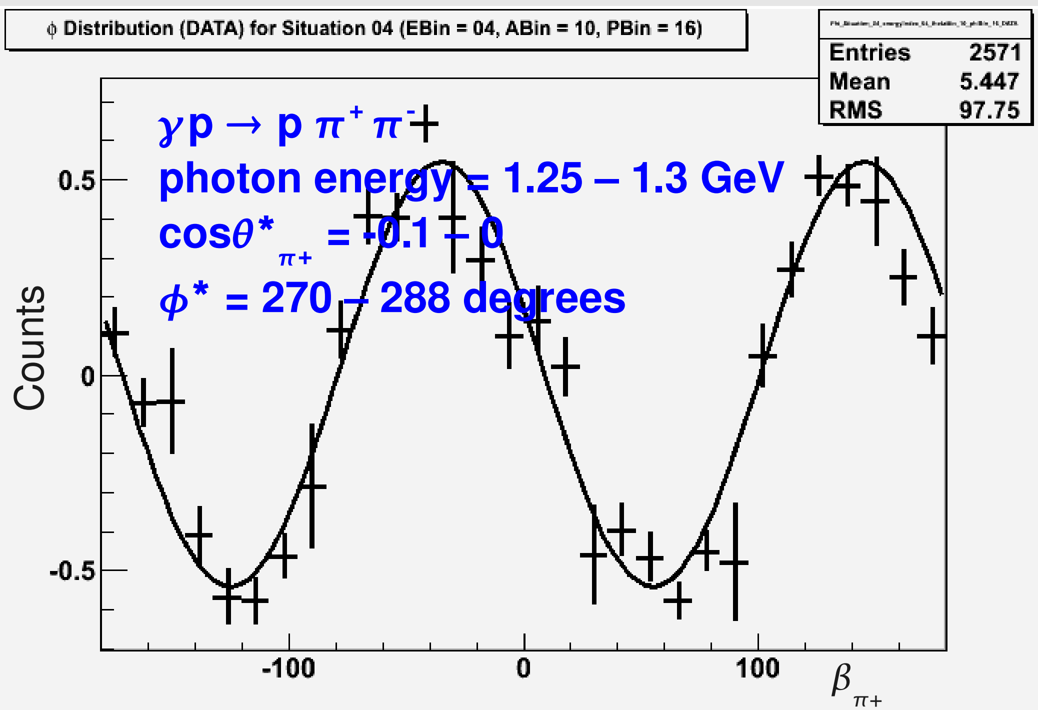
Event plane formed by 2 final state particles

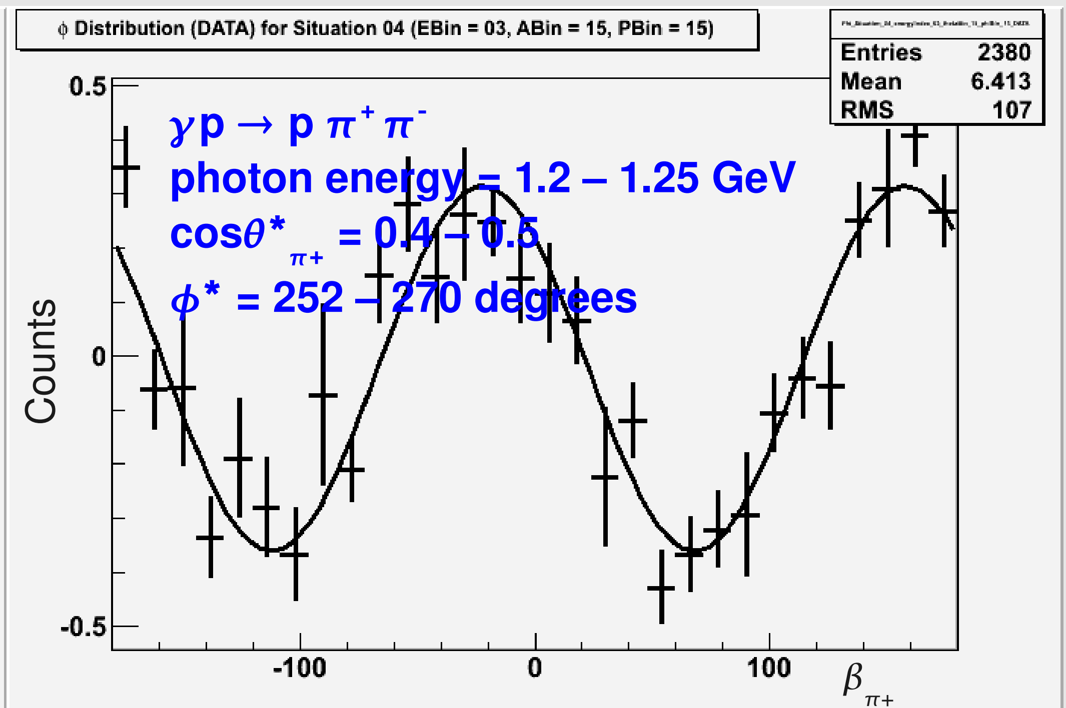


Production plane

Preliminary Results: Phi Distributions

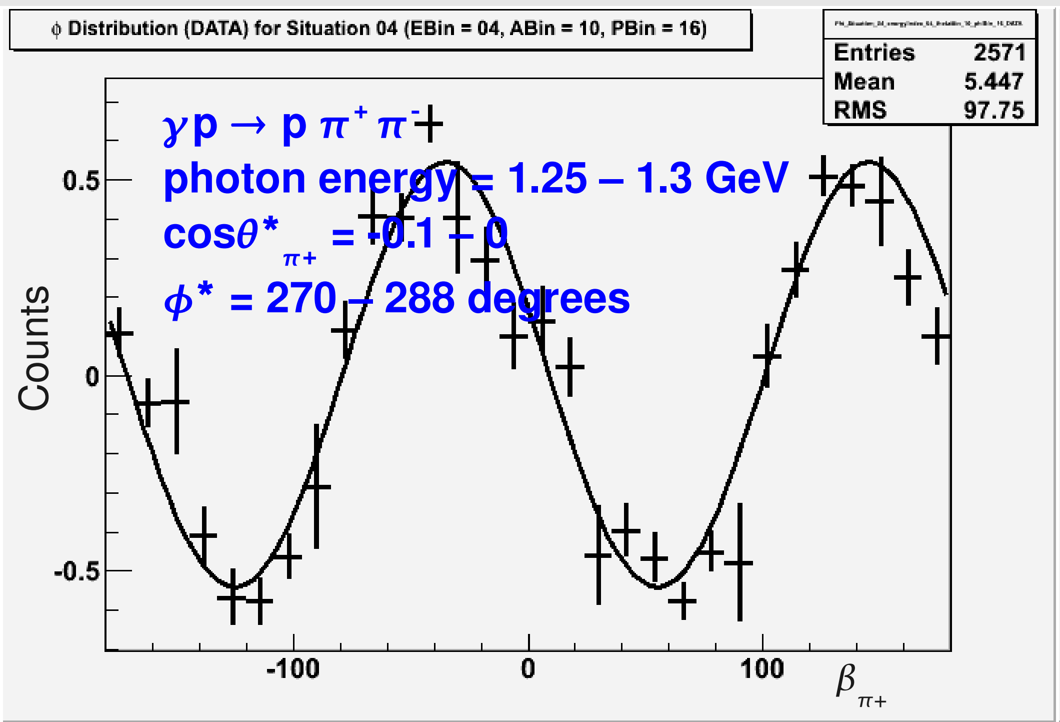
- To remove systematics while maintaining statistics, the phi distributions for PARA are normalized to the PERP phi distributions.
- Fit to : $$\frac{PARA - PERP}{PARA + PERP} = \frac{I_{PARA} - I_{PERP}}{I_{PARA} + I_{PERP}}$$

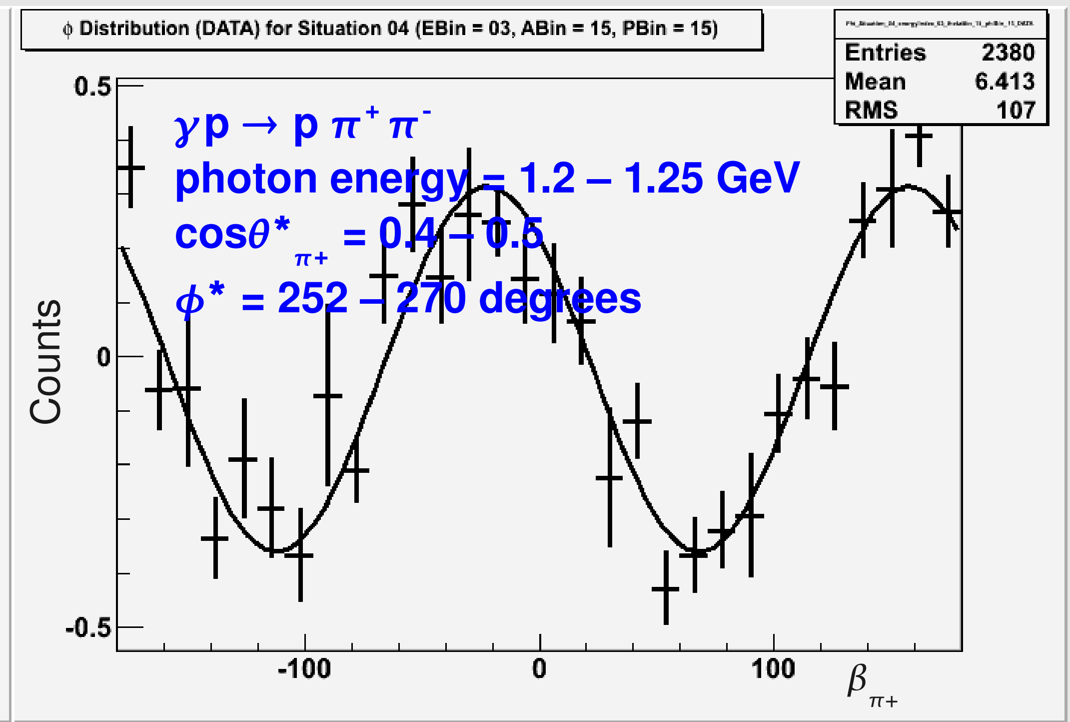




Preliminary Results: Phi Distributions

- To remove systematics while maintaining statistics, the phi distributions for PARA are normalized to the PERP phi distributions.
- Fit to : $\dfrac{[(\delta_l^{para}+\delta_l^{perp})I^s\sin(2\beta)+(\delta_l^{para}+\delta_l^{perp})I^c\cos(2\beta)]}{2+(\delta_l^{para}-\delta_l^{perp})I^s\sin(2\beta)+(\delta_l^{para}-\delta_l^{perp})I^c\cos(2\beta)}$ $\quad \beta=\phi_{lab}+\phi_{polarization}$



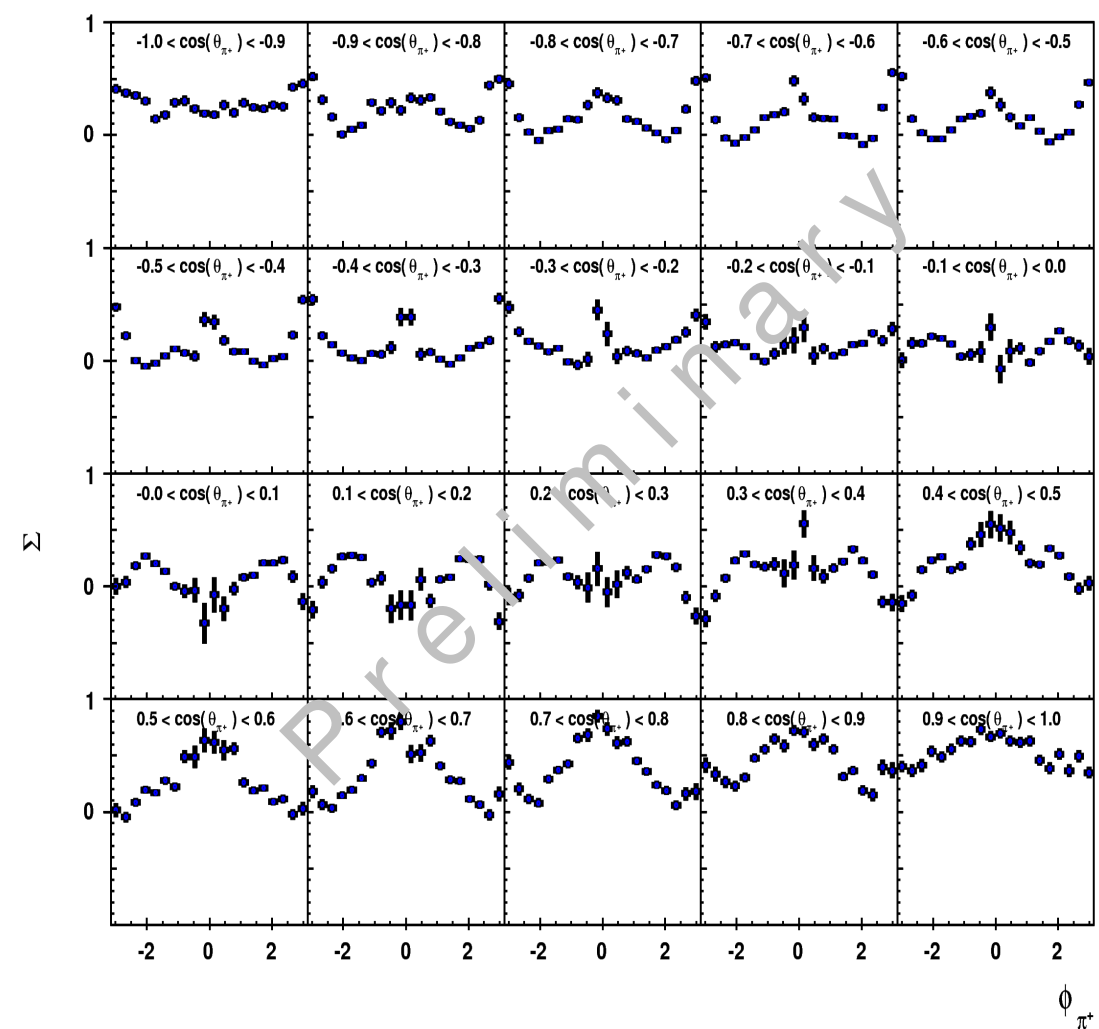


Preliminary Results : I^c

$$\frac{[(\delta_l^{para}+\delta_l^{perp})I^s\sin(2\beta)+(\delta_l^{para}+\delta_l^{perp})I^c\cos(2\beta)]}{2+(\delta_l^{para}-\delta_l^{perp})I^s\sin(2\beta)+(\delta_l^{para}-\delta_l^{perp})I^c\cos(2\beta)}$$

- Photon energy of 1100 – 1150 MeV
- Each square is an bin in $\cos\theta^*$ of the π^+.
- Y-axis is the value of the observable.
- X-axis is the ϕ of the π^+.
- We see a non-zero value for I^c (Σ).
- I^c is symmetric around the origin.

$\gamma p \rightarrow p\, \pi^+\pi^-$ ()

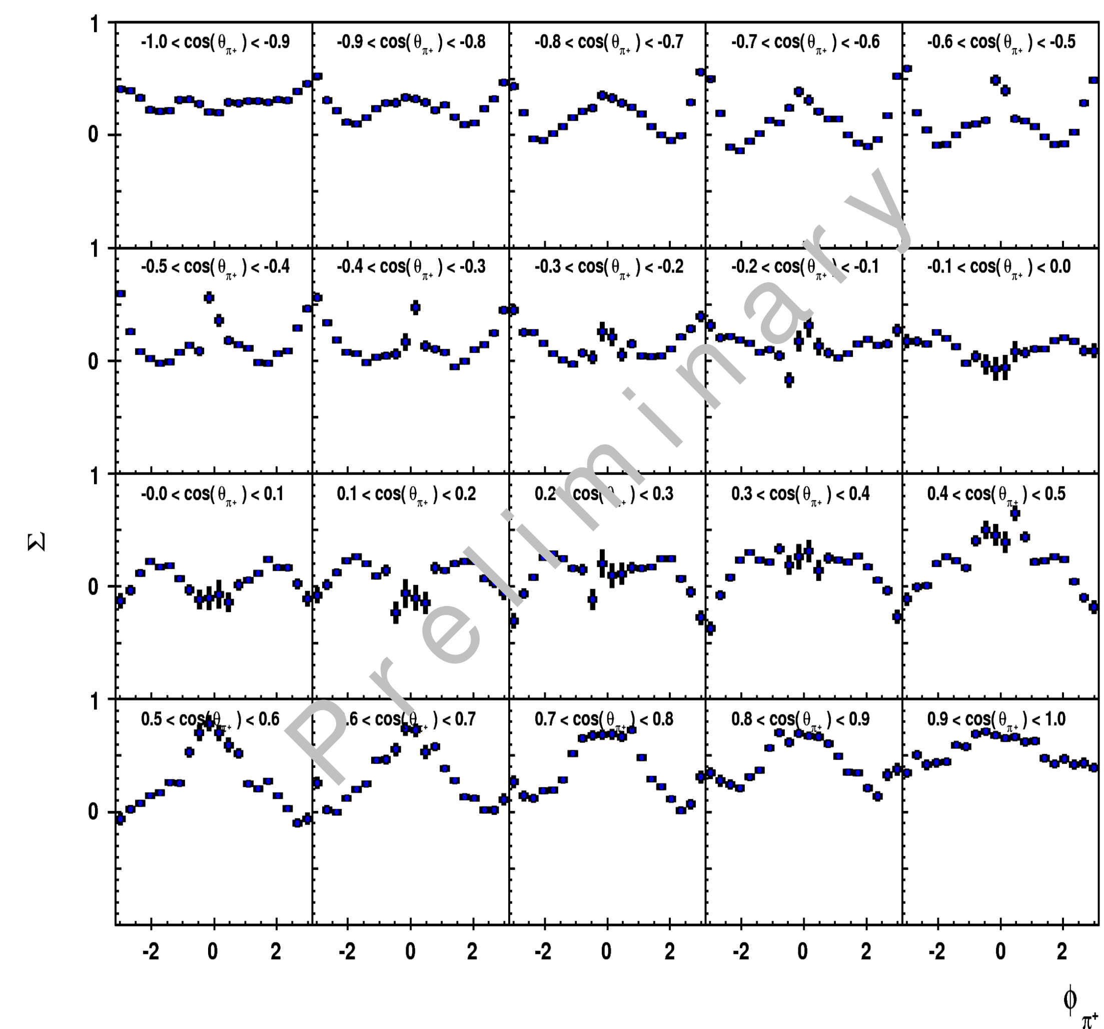


Preliminary Results : I^c

$$\frac{[(\delta_l^{para}+\delta_l^{perp})I^s\sin(2\beta)+(\delta_l^{para}+\delta_l^{perp})I^c\cos(2\beta)]}{2+(\delta_l^{para}-\delta_l^{perp})I^s\sin(2\beta)+(\delta_l^{para}-\delta_l^{perp})I^c\cos(2\beta)}$$

- Photon energy of 1150 – 1200 MeV
- Each square is an bin in $\cos\theta^*$ of the π^+.
- Y-axis is the value of the observable.
- X-axis is the ϕ of the π^+.
- We see a non-zero value for I^c (Σ).
- I^c is symmetric around the origin.

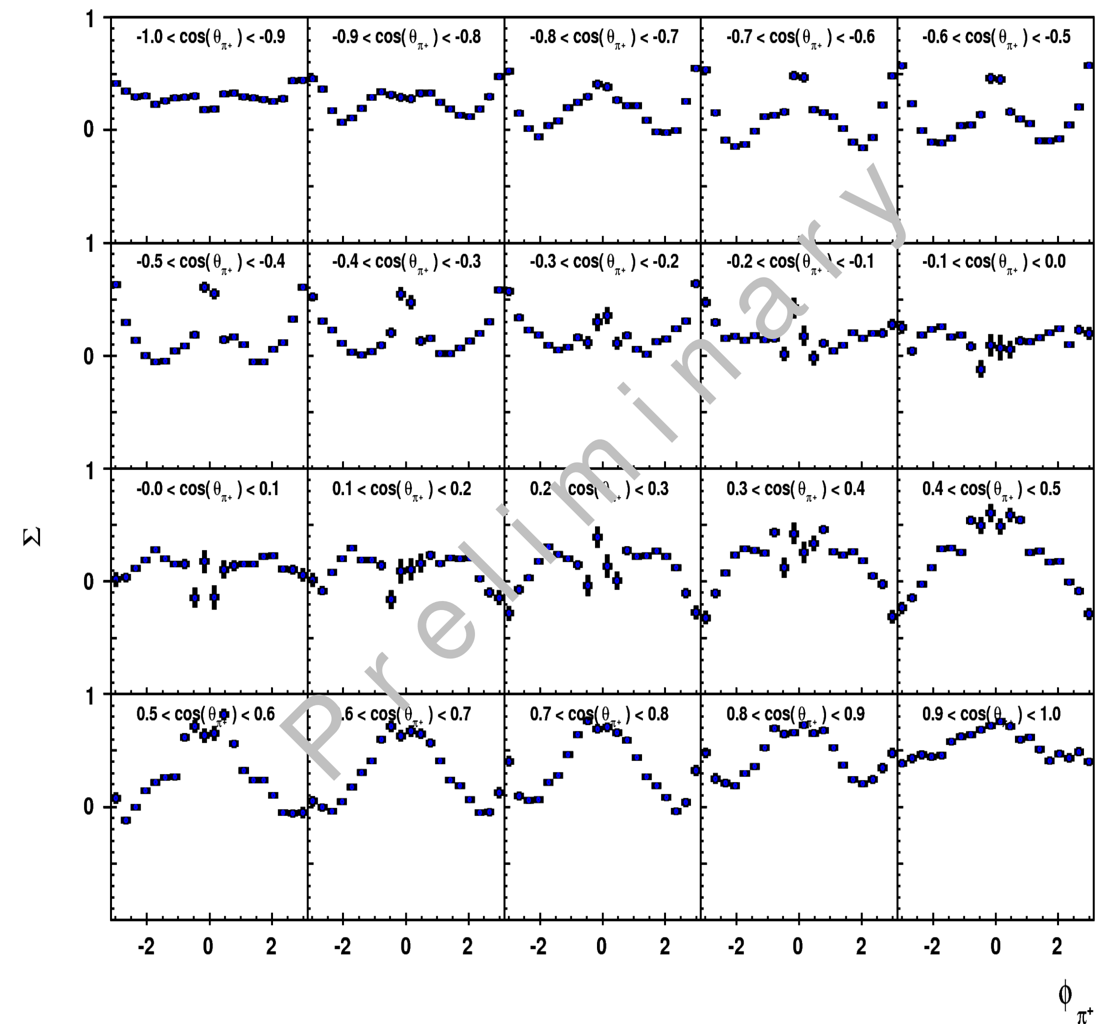
$\gamma p \rightarrow p\,\pi^+\pi^-$ ()



Preliminary Results : I^c

$$\frac{[(\delta_l^{para}+\delta_l^{perp})I^s\sin(2\beta)+(\delta_l^{para}+\delta_l^{perp})I^c\cos(2\beta)]}{2+(\delta_l^{para}-\delta_l^{perp})I^s\sin(2\beta)+(\delta_l^{para}-\delta_l^{perp})I^c\cos(2\beta)}$$

$\gamma p \rightarrow p \pi^+\pi^-$ ()



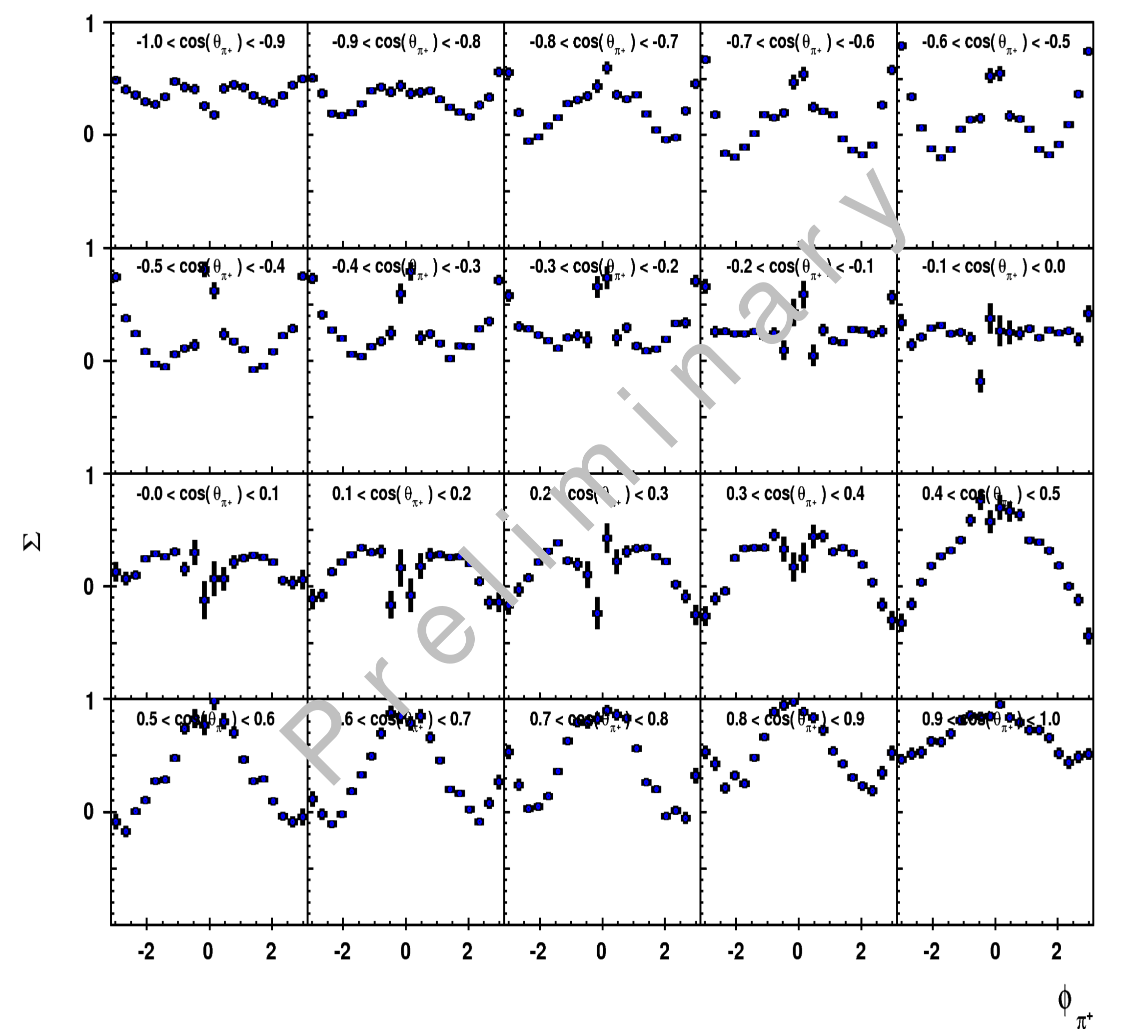
- Photon energy of 1200 – 1250 MeV
- Each square is an bin in cosθ* of the π^+.
- Y-axis is the value of the observable.
- X-axis is the ϕ of the π^+.
- We see a non-zero value for I^c (Σ).
- I^c is symmetric around the origin.

Preliminary Results : I^c

$$\frac{[(\delta_l^{para}+\delta_l^{perp})I^s\sin(2\beta)+(\delta_l^{para}+\delta_l^{perp})I^c\cos(2\beta)]}{2+(\delta_l^{para}-\delta_l^{perp})I^s\sin(2\beta)+(\delta_l^{para}-\delta_l^{perp})I^c\cos(2\beta)}$$

$\gamma p \rightarrow p\,\pi^+\pi^-$ ()

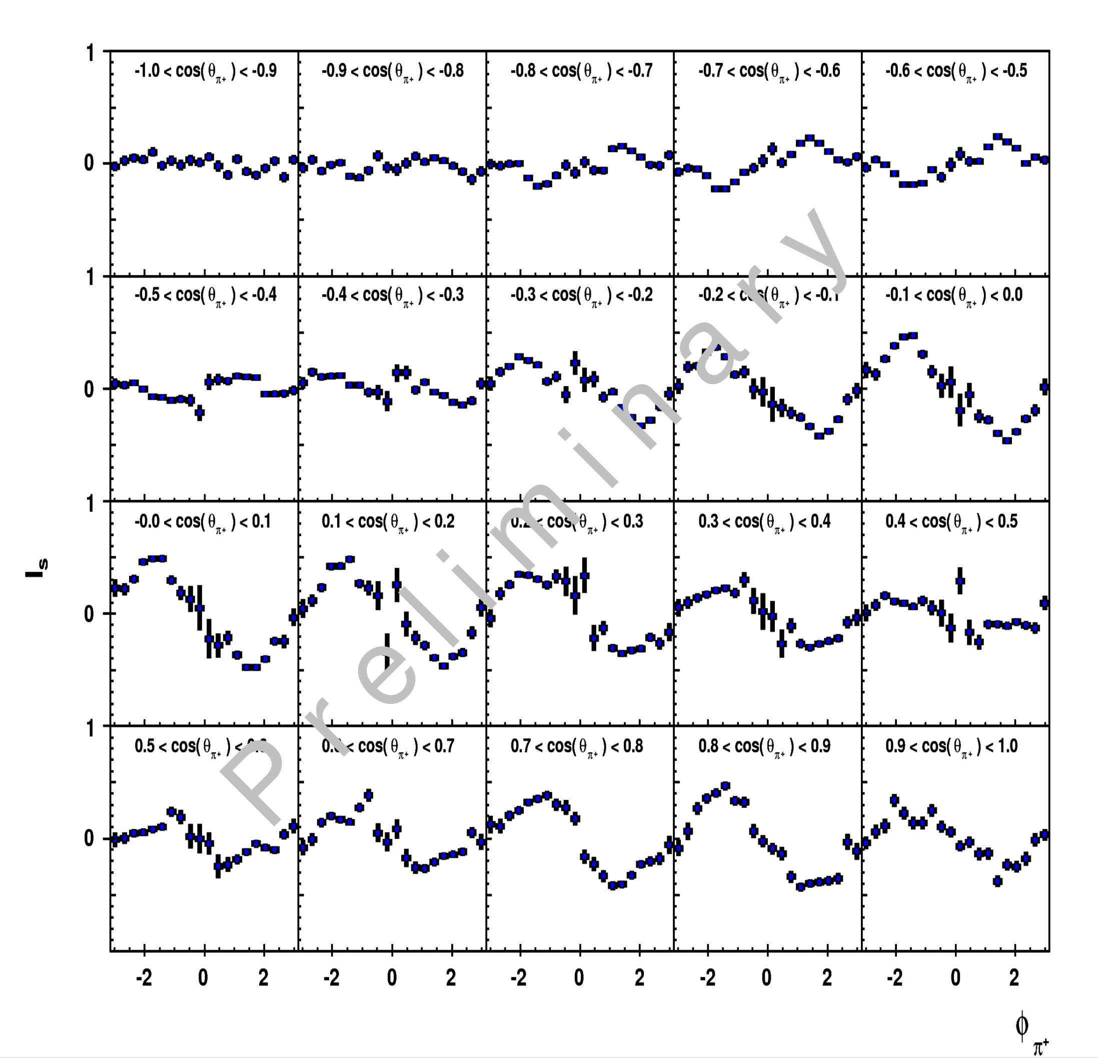
- Photon energy of 1250 – 1300 MeV
- Each square is an bin in $\cos\theta^*$ of the π^+.
- Y-axis is the value of the observable.
- X-axis is the ϕ of the π^+.
- We see a non-zero value for I^c (Σ).
- I^c is symmetric around the origin.



Preliminary Results : I^s

$$\frac{[(\delta_l^{para}+\delta_l^{perp})I^s\sin(2\beta)+(\delta_l^{para}+\delta_l^{perp})I^c\cos(2\beta)]}{2+(\delta_l^{para}-\delta_l^{perp})I^s\sin(2\beta)+(\delta_l^{para}-\delta_l^{perp})I^c\cos(2\beta)}$$

$\gamma p \rightarrow p\,\pi^+\pi^-$ ()

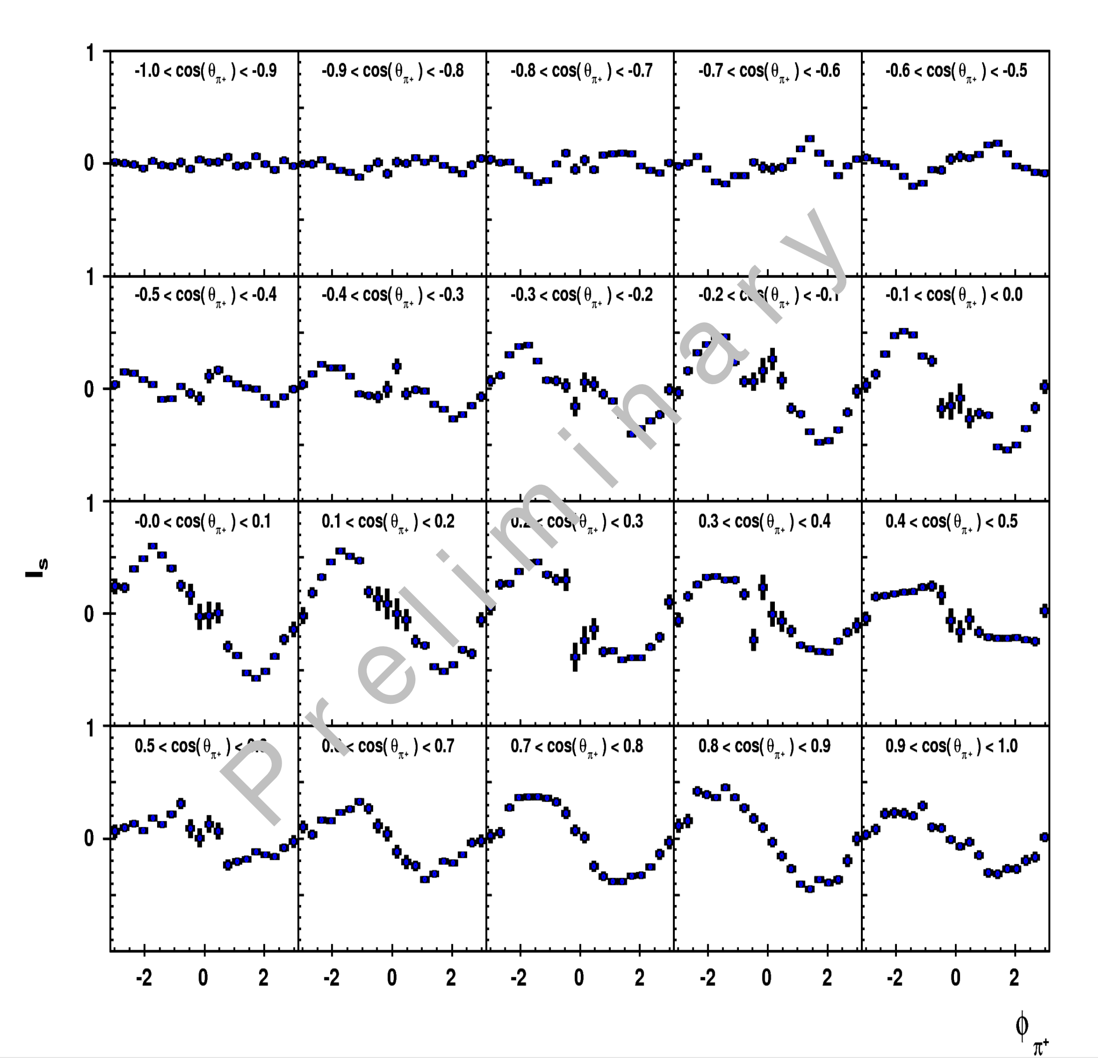


- Photon energy of 1100 – 1150 MeV
- Each square is an bin in $\cos\theta^*$ of the π^+.
- Y-axis is the value of the observable.
- X-axis is the ϕ of the π^+.
- I^s is antisymmetric around the origin.

Preliminary Results : I^s

$$\frac{[(\delta_l^{para}+\delta_l^{perp})I^s\sin(2\beta)+(\delta_l^{para}+\delta_l^{perp})I^c\cos(2\beta)]}{2+(\delta_l^{para}-\delta_l^{perp})I^s\sin(2\beta)+(\delta_l^{para}-\delta_l^{perp})I^c\cos(2\beta)}$$

$\gamma p \rightarrow p\,\pi^+\pi^-$ ()

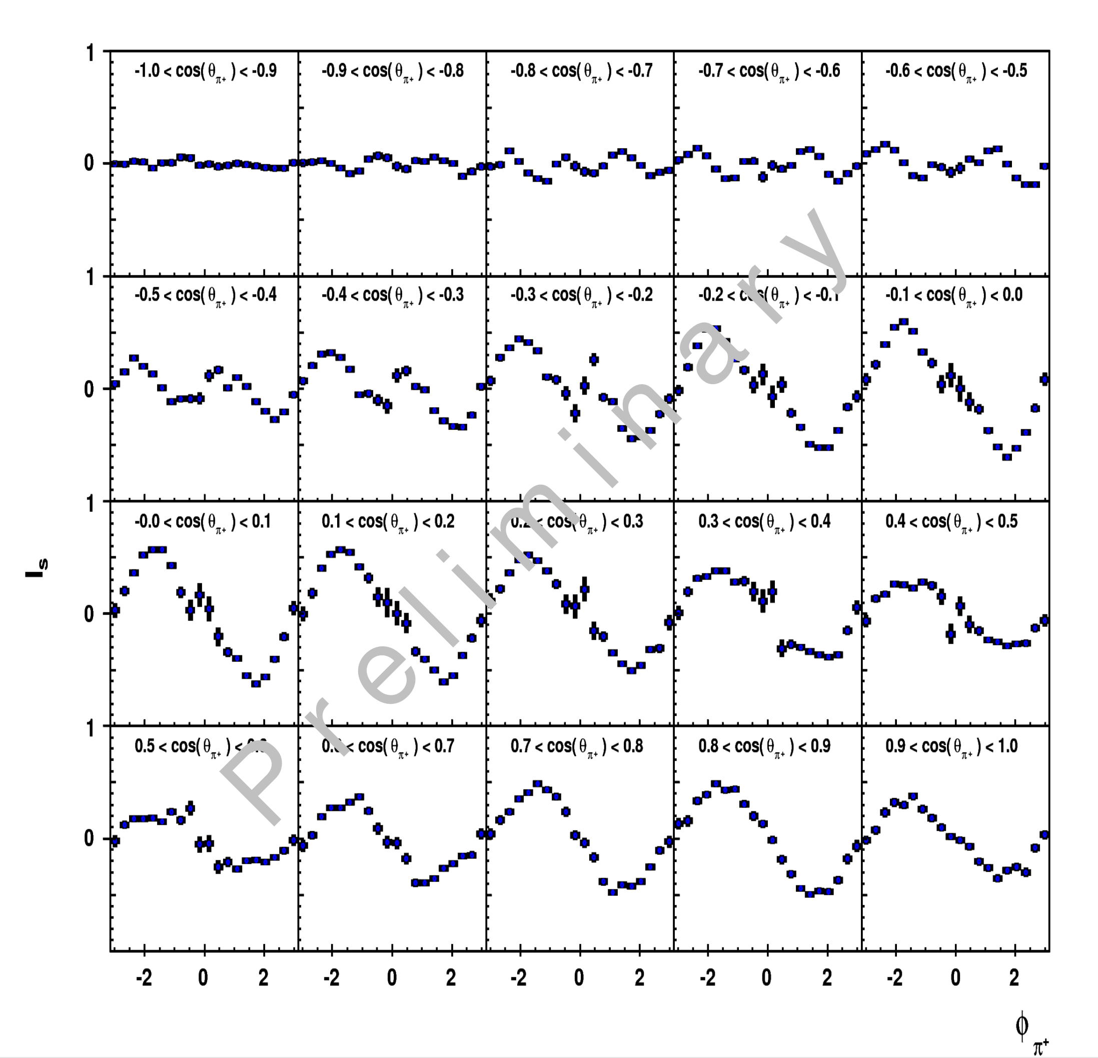


- Photon energy of 1150 – 1200 MeV
- Each square is an bin in cosθ* of the π^+.
- Y-axis is the value of the observable.
- X-axis is the ϕ of the π^+.
- I^s is antisymmetric around the origin.

Preliminary Results : I^s

$$\frac{[(\delta_l^{para}+\delta_l^{perp})\,I^s\sin(2\beta)+(\delta_l^{para}+\delta_l^{perp})\,I^c\cos(2\beta)]}{2+(\delta_l^{para}-\delta_l^{perp})\,I^s\sin(2\beta)+(\delta_l^{para}-\delta_l^{perp})\,I^c\cos(2\beta)}$$

$\gamma p \rightarrow p\,\pi^+\pi^-$ ()

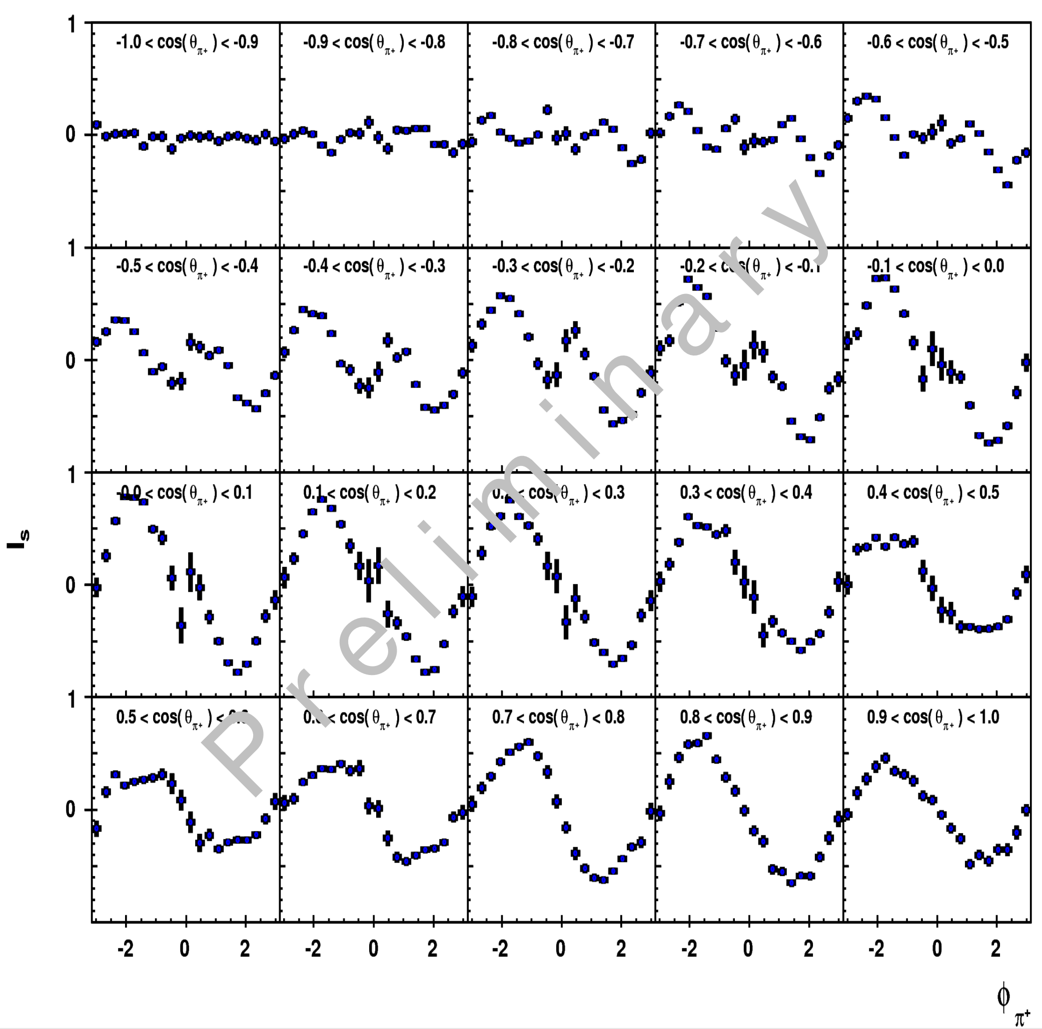


- Photon energy of 1200 – 1250 MeV
- Each square is an bin in $\cos\theta^*$ of the π^+.
- Y-axis is the value of the observable.
- X-axis is the ϕ of the π^+.
- I^s is antisymmetric around the origin.

Preliminary Results : I^s

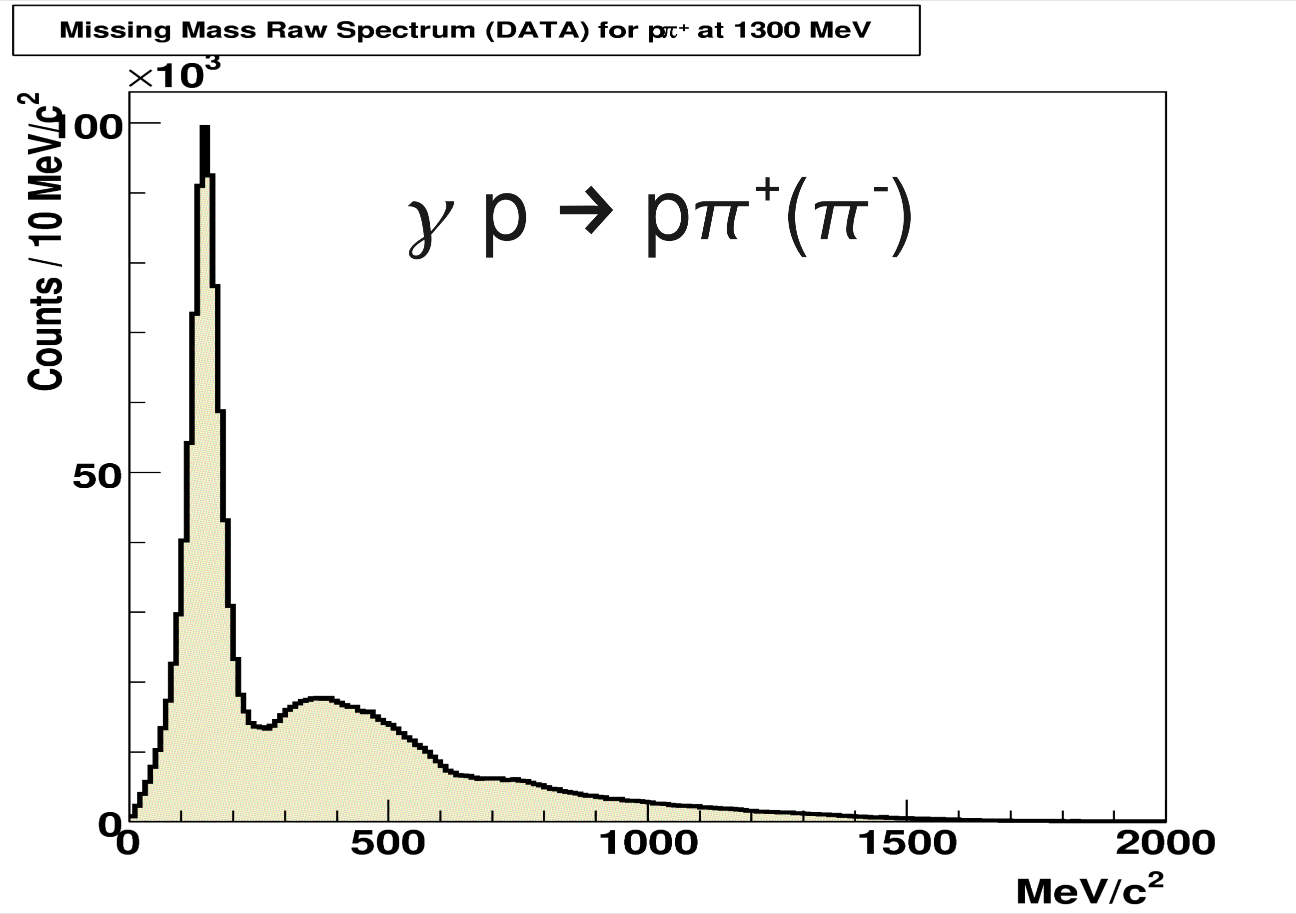
$$\frac{[(\delta_l^{para}+\delta_l^{perp})I^s\sin(2\beta)+(\delta_l^{para}+\delta_l^{perp})I^c\cos(2\beta)]}{2+(\delta_l^{para}-\delta_l^{perp})I^s\sin(2\beta)+(\delta_l^{para}-\delta_l^{perp})I^c\cos(2\beta)}$$

$\gamma p \rightarrow p\,\pi^+\pi^-$ ()



- Photon energy of 1250 – 1300 MeV
- Each square is an bin in cosθ* of the π^+.
- Y-axis is the value of the observable.
- X-axis is the ϕ of the π^+.
- I^s is antisymmetric around the origin.

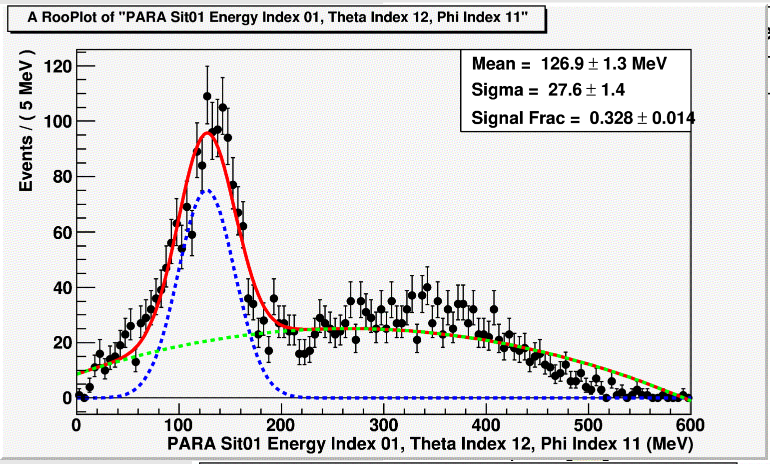
Background

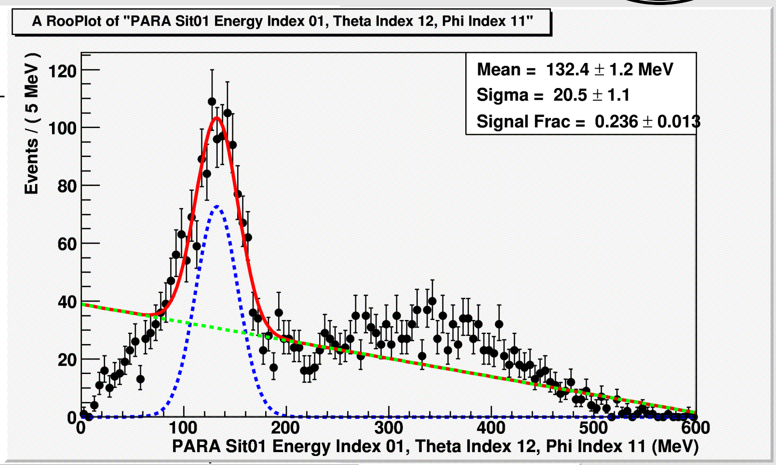

Missing Mass Raw Spectrum (DATA) for pπ+ at 1300 MeV
×10^3
Counts / 10 MeV/c^2
100
50
0
0
500
1000
1500
2000
MeV/c^2
$\gamma p \rightarrow p\pi^+(\pi^-)$

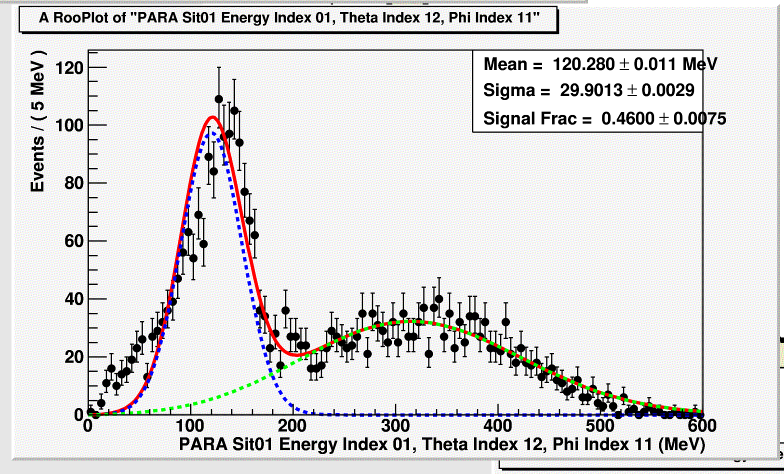
Background

ectrum (DATA) for pπ⁺ at 1300 MeV

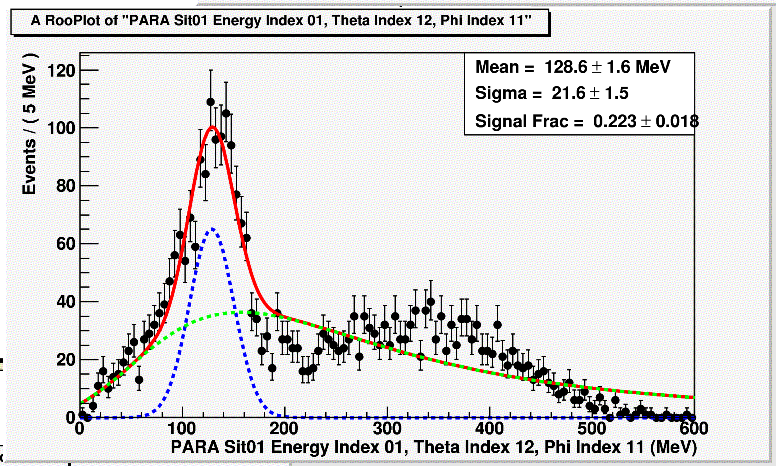
$\gamma\, p \rightarrow p\pi^{+}(\pi^{-})$

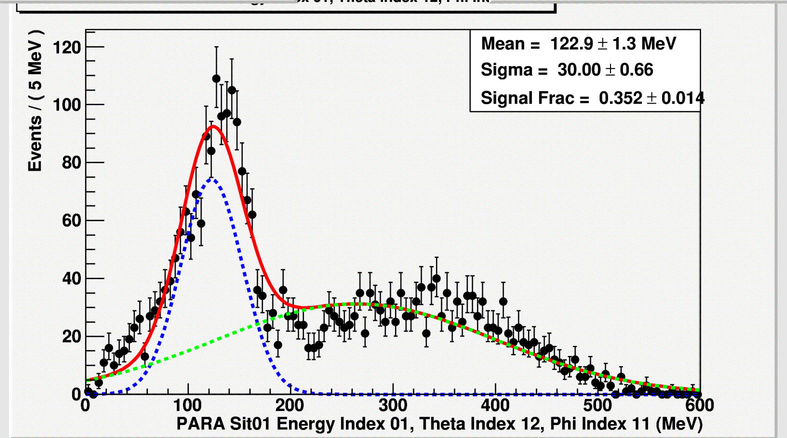






1000





Q-Values

- Traditional (side-band) background subtraction requires binning in the kinematic variables and is therefore limited by statistics.
- This method is statistics-independent and uses unbinned fits.
- Q is the “probability” that an event is from signal, (1-Q) is the chance its background.
- Can be used “universally” weight an event in any distribution.
- The good : Event-based background determination, statistic-independent, “universal” application.
- The bad : Very time consuming and computationally intensive.
- For further information see: M. Williams, M. Bellis, C. A. Meyer, CLAS-Note: 2007-013

Q-Values : The procedure

- Find/Get 4-vecs, angles, photon energy for first event (this is the “seed” event).
- Out of all of the kinematic variables, pick a “reference coordinate”.
- Loop through all other events finding/getting the 4-vecs, angles, photon energy.
- Find the 100 events that are closest to the seed event in terms of the non-reference kinematic variables.
- Using these 100 events, perform a fit to the reference coordinate using a signal and background function. Not a fit to a histo and therefore unbinned.
- Extract Q value for seed event by finding the number of events in signal peak at the value of the reference coordinate of the seed event in the fit. $Q = s/(s+b)$; s=events
- “Q” is the chance that the seed event is a signal event, “(1-Q)” is the chance that the seed event is from background.
- Rinse and repeat for all events.

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- Us… a sig… ned.
- Ex… pe… . Q
- “Q… ance that the seed event is from background.
- Rinse and repeat for all events.

$$d_{ij}^2 = \sum_{k=1}^{n} \left[\frac{\xi_k^i - \xi_k^j}{r_k} \right]^2$$

n = number of kinematic variables
i = seed event
j = the next event (in loop over events)
r = range of kinematic variable

Q-Values : The procedure

- Find/Get 4-vecs, angles, photon energy for first event (this is the “seed” event).
- Out of all of the kinematic variables, pick a “reference coordinate”.
- Loop through all other events finding/getting the 4-vecs, angles, photon energy.
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- Using these 100 events, perform a fit to the reference coordinate using a signal and background function. Not a fit to a histo and therefore unbinned.
- Extract Q value for seed event by finding the number of events in signal peak at the value of the reference coordinate of the seed event in the fit. $Q = s/(s+b)$; s=events in the signal; b=events in background.
- “Q” is the chance that the seed event is a signal event, “(1-Q)” is the chance that the seed event is from background.
- Rinse and repeat for all events.

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- Find the … e non-referenc

$$Q = \frac{s}{s+b}$$

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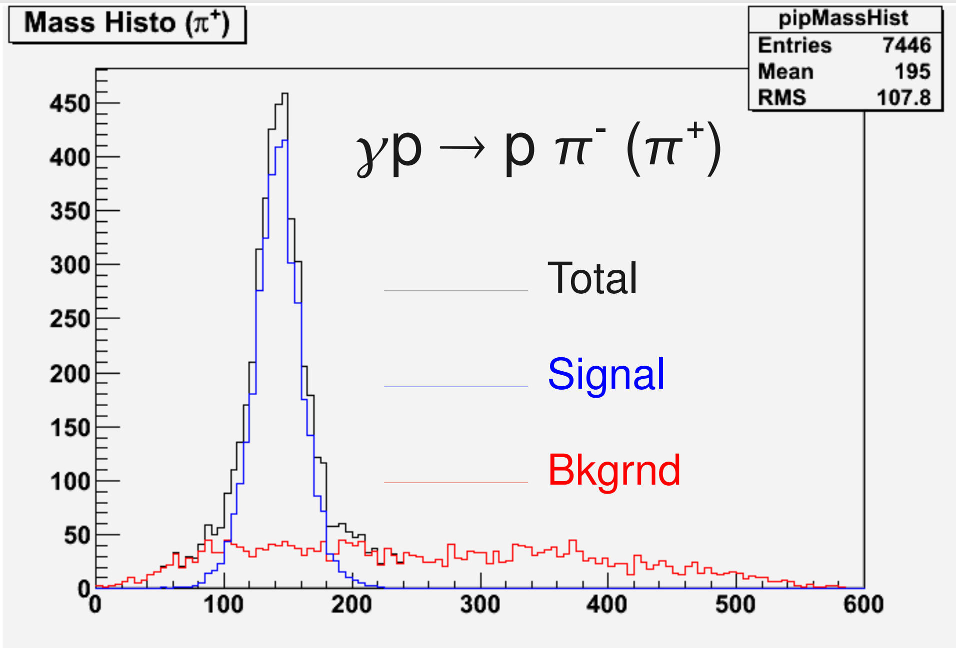
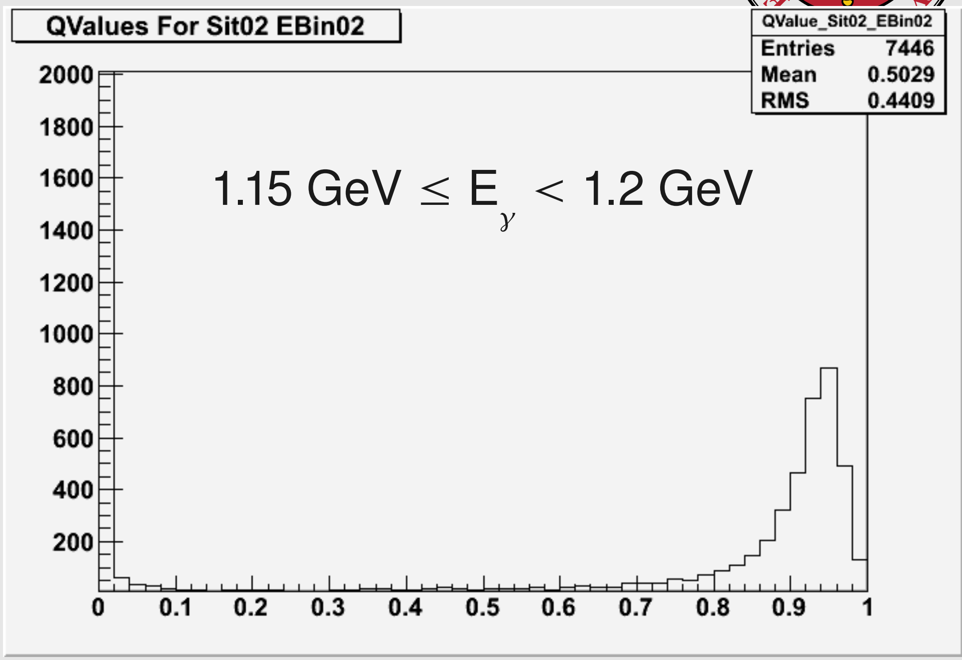
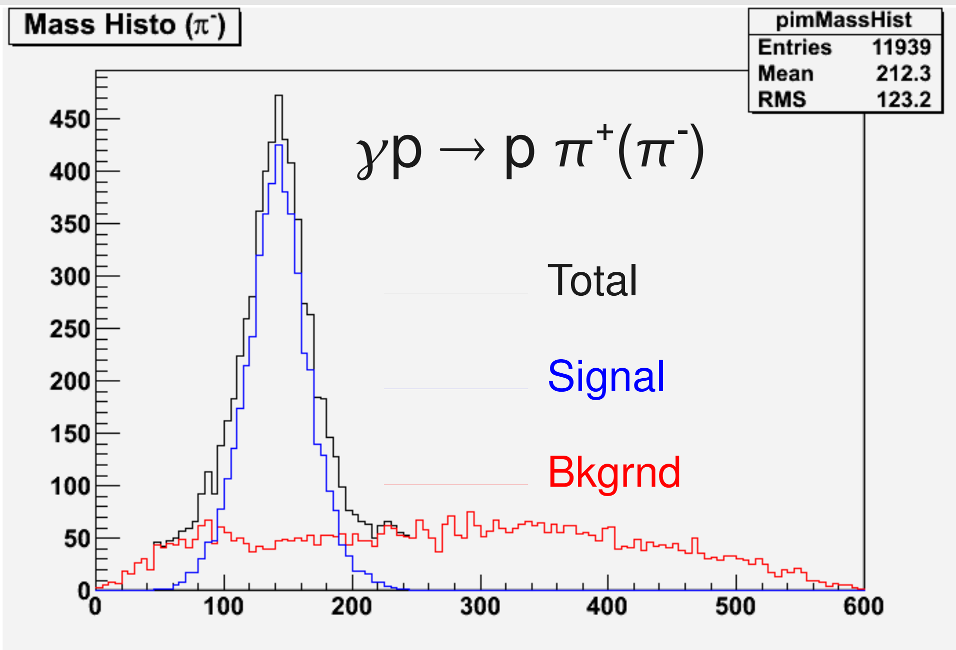
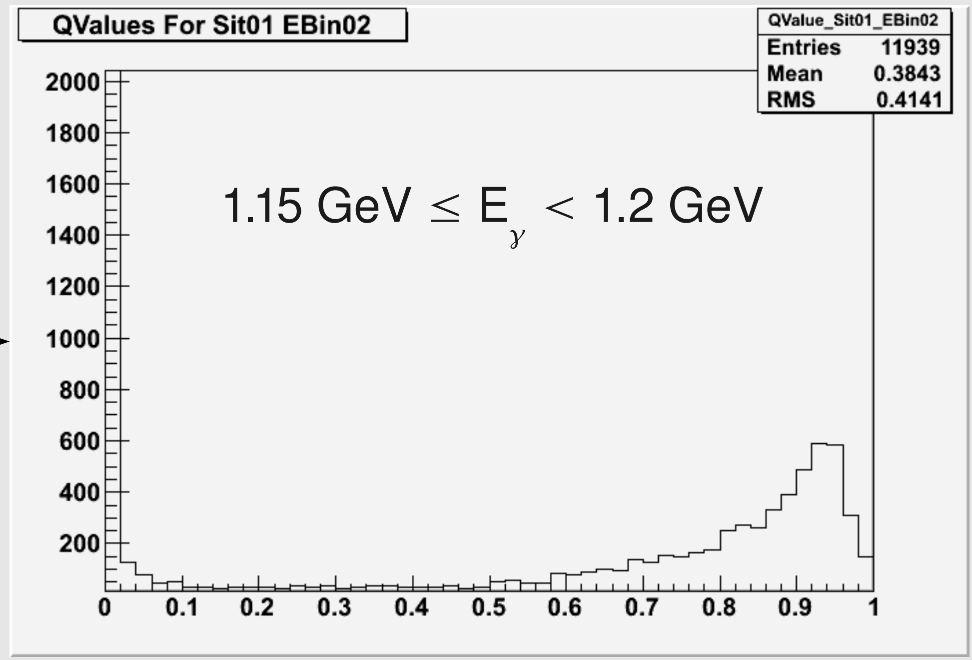
Q-Values









......Application of this procedure to the g8b data set not yet finalized

Still to do:

- Get and implement new degree-of-polarization tables from Ken Livingston.
- Re-run data to produce new asymmetry plots and measurements.
- Finalize Q-Value determinations for background subtraction.
- Apply these Q-Values to beam asymmetry measurements.

END