Helicity difference in $\vec{\gamma}\vec{p} \rightarrow p\pi^+\pi^-$ production with CLAS spectrometer at the JLab

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on behalf of CLAS collaboration

Florida State University

NStar 2011
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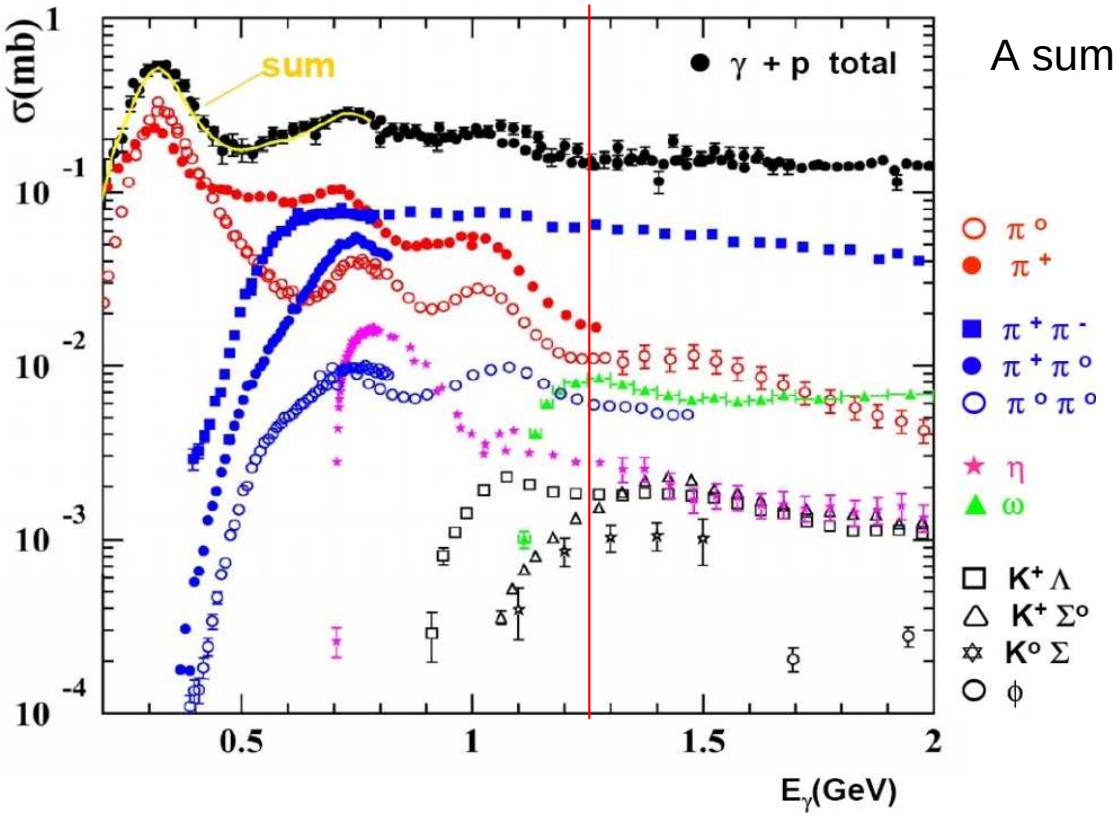
Supported by Department of Energy

Outline

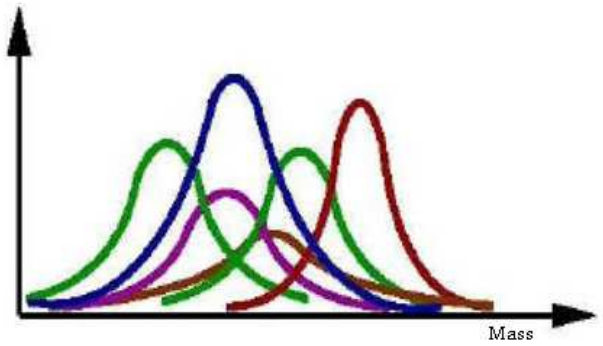
Outline

The motivation for the $\pi^+\pi^-$ photoproduction



A summary of photoproduction cross section

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



- The cross section of the $\pi^+\pi^-$ photoproduction dominates above W $\approx$ 1.8GeV
- The excited states are found as broadly overlapping resonances

  $\rightarrow$ The polarization observables can isolate single resonances from other interference terms

The differential cross section for $\gamma p \rightarrow p\pi^+\pi^-$

The differential cross section for $\gamma p \rightarrow p\pi^+\pi^-$

(without measuring the polarization of the recoiling nucleon)

$$\frac{d\sigma}{dx_i} = \sigma_0 \{ (1 + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}) + \delta_\odot (\mathbf{I}^\odot + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}^\odot) + \delta_l [\sin 2\beta (\mathbf{I}^s + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}^s) + \cos 2\beta (\mathbf{I}^c + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}^c)] \}$$

- σ_0: The unpolarized cross section
- β: The angle between the direction of polarization and the x-axis
- $\delta_{\odot,l}$: The degree of polarizaton of the photon beam $\Rightarrow \delta_\odot$, and δ_l
- $\vec{\Lambda}_i$: The polarization of the initial nucleon $\Rightarrow (\Lambda_x, \Lambda_y, \Lambda_z)$
- $\mathbf{I}^{\odot,s,c}$: The observable arising from use of polarized photons $\Rightarrow \mathbf{I}^\odot, \mathbf{I}^s, \mathbf{I}^c$
- $\vec{\mathbf{P}}$: The polarization observable $\Rightarrow (\mathbf{P_x}, \mathbf{P_y}, \mathbf{P_z})$ $(\mathbf{P}_x^\odot, \mathbf{P}_y^\odot, \mathbf{P}_z^\odot)$ $(\mathbf{P}_x^s, \mathbf{P}_y^s, \mathbf{P}_z^s)$ $(\mathbf{P_x^c}, \mathbf{P_y^c}, \mathbf{P_z^c})$

15 Observables

Polarization observables

The circularly-polarized beam $\rightarrow \delta_l = 0$

The longitudinally-polarized target $\rightarrow \Lambda_x = \Lambda_y = 0$

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

3 Observables

$\mathbf{I}^\odot$ only is published and small and sensitive

The linearly-polarized beam $\rightarrow \delta_\odot = 0$

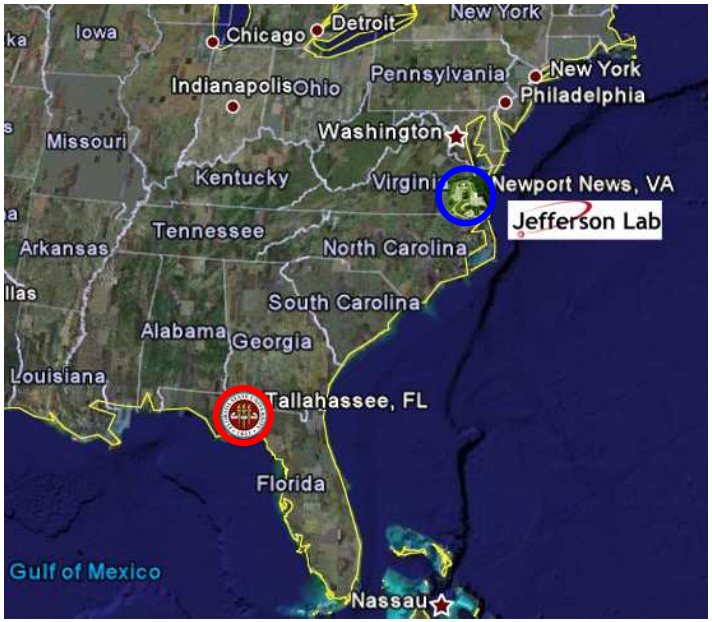
The longitudinally-polarized target $\rightarrow \Lambda_x = \Lambda_y = 0$

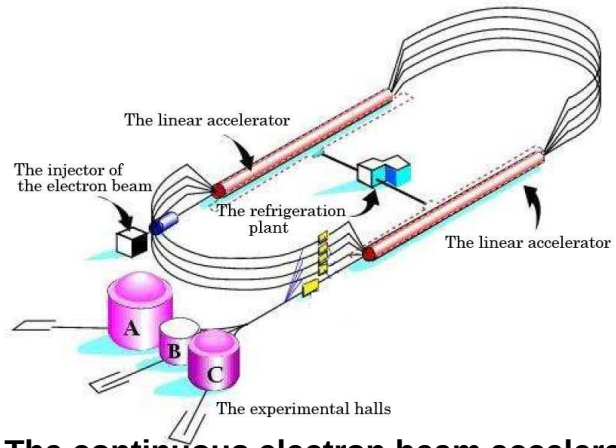
$$\frac{d\sigma}{dx_i} = \sigma_0 \{ (1 + \vec{\Lambda}_z \cdot \vec{\mathbf{P}}_z) + \delta_l [\sin 2\beta (\mathbf{I}^s + \vec{\Lambda}_z \cdot \vec{\mathbf{P}}_z^s) + \cos 2\beta (\mathbf{I}^c + \vec{\Lambda}_z \cdot \vec{\mathbf{P}}_z^c)] \}$$

5 Observables

Outline

Jefferson laboratory in Newport News, VA



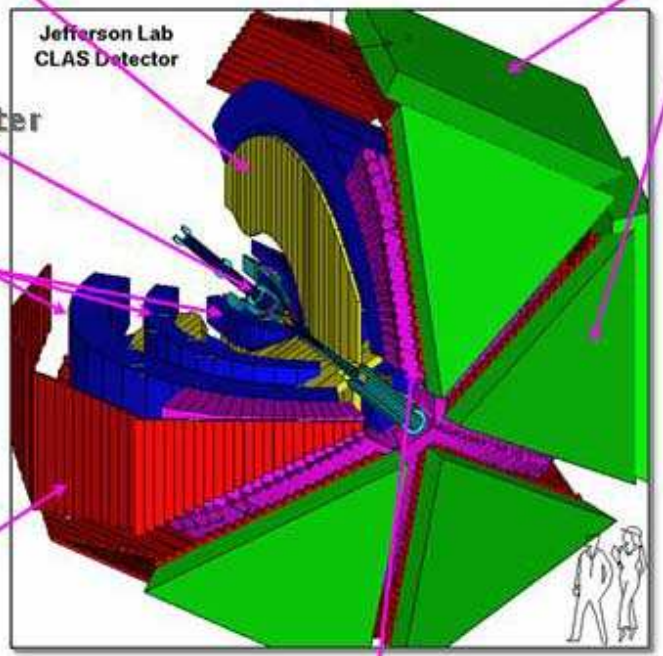


The continuous electron beam accelerator facility (CEBAF) can deliver a continuous electron beam up to 6 GeV.

CEBAF Large Acceptance Spectrometer (CLAS)

Torus magnet
6 superconducting coils

Electromagnetic calorimeters
Lead/scintillator, 1296 photomultipliers

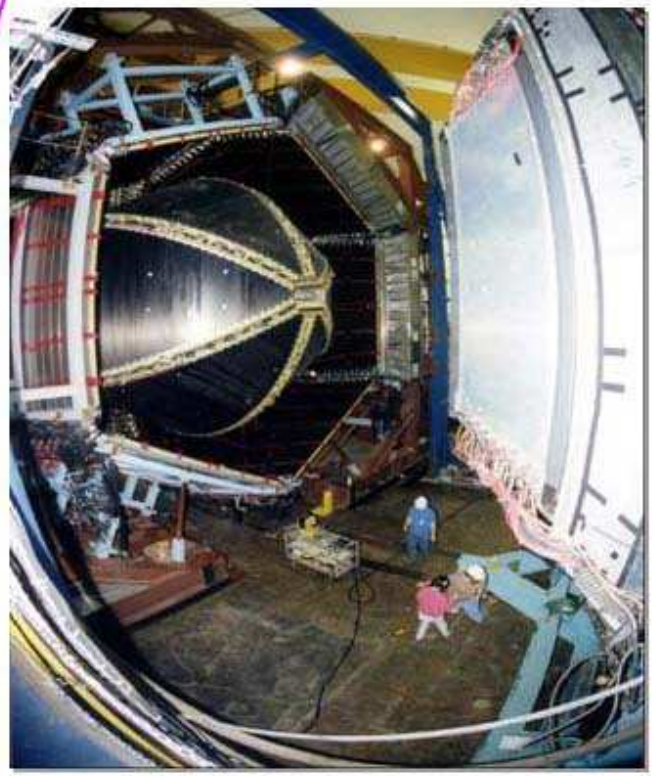


target + start counter

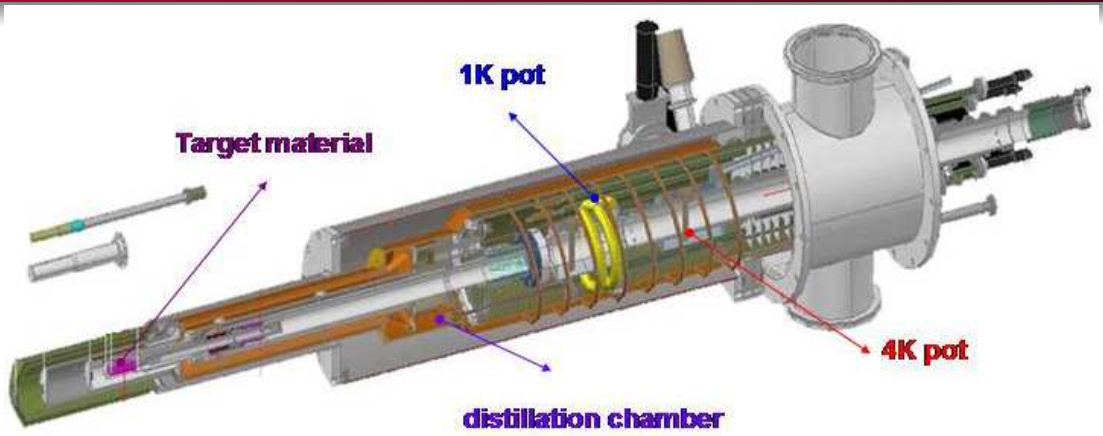
Drift chambers
argon/CO_2 gas, 35,000 cells

Time-of-flight counters
plastic scintillators, 684 photomultipliers

Gas Cherenkov counters



The FRozen-Spin Target (FROST)



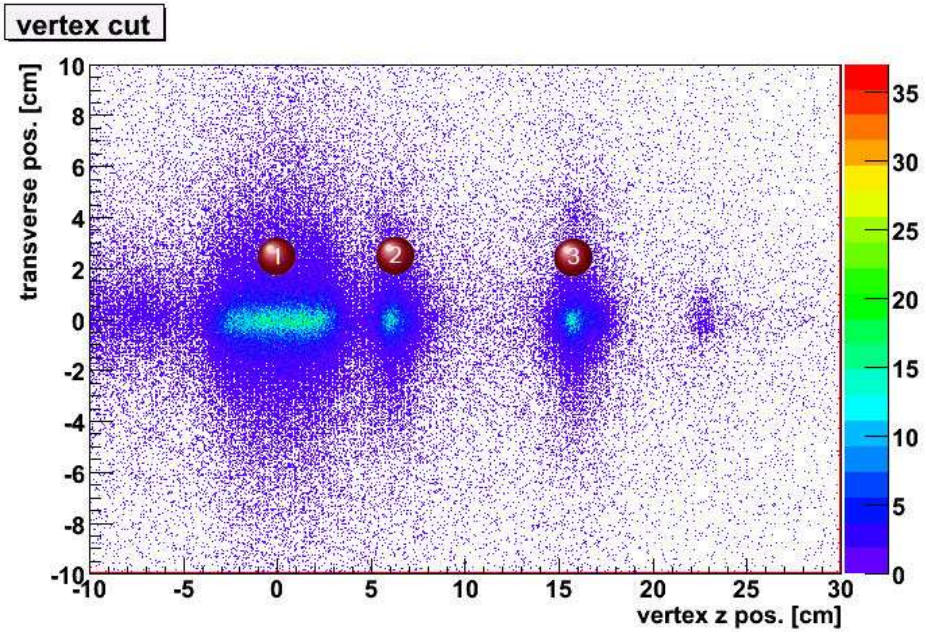
28 mK (w/o beam) and 30mK (w/ beam)

The magnets in the FROST experiment

(a) The longitudinal holding magnet. (About 0.5 T)

(b) The transversal holding magnet.
(March 2010 - August 2010)

(c) The polarizing magnet. (5 Tesla solenoid)



1. Polarized Butanol (C_4H_9OH) (L = 5.0 cm, ϕ = 1.5 cm) $\sim$ 5 g
2. Carbon (^{12}C) (L = 0.15 cm) (6 cm from CLAS center)
3. Polyethylene (CH_2) (L = 0.35 cm) (16 cm from CLAS center)

L: The length and ϕ: The diameter

The FROST-g9a run Data

The FROST run period: Nov. 3, 2007 - Feb. 12, 2008

Data set: 35 TBytes

Production data

Target:

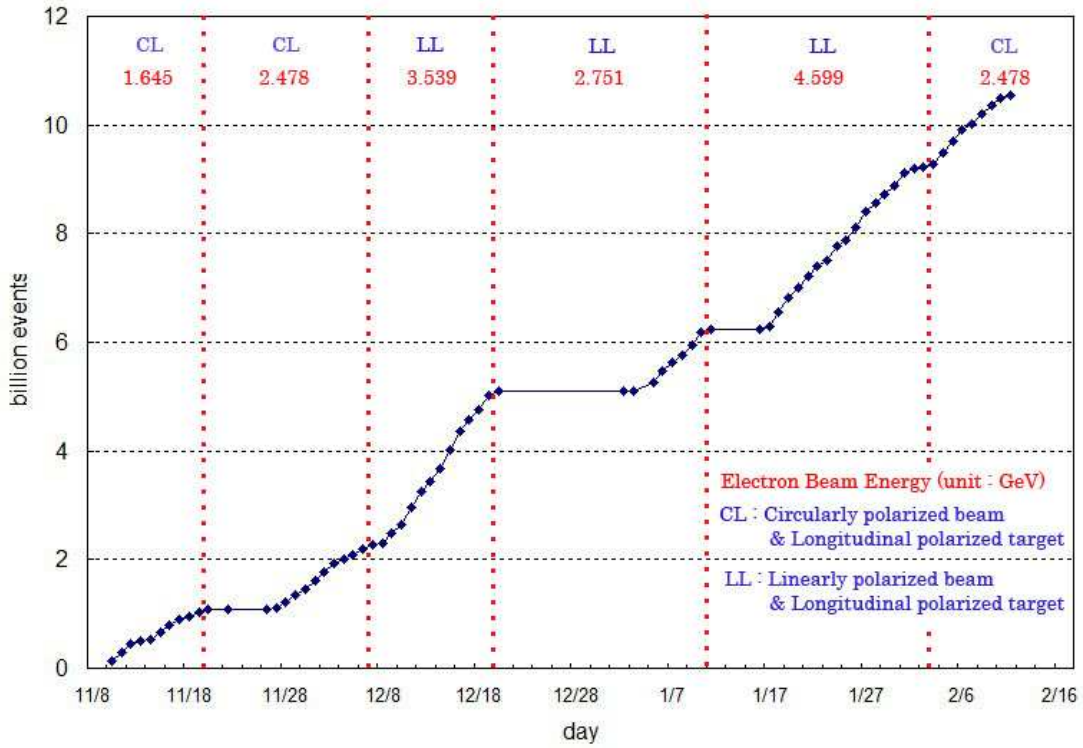
- Longitudinal polarized target
- Average target polarization
  $\sim$ 82 % (+Pol) and 85 % (-Pol)

Photon beam:

- Circularly and linearly polarized photon beam
  0.5 - 4.5 GeV
- Electron beam polarization $\sim$ 85 %

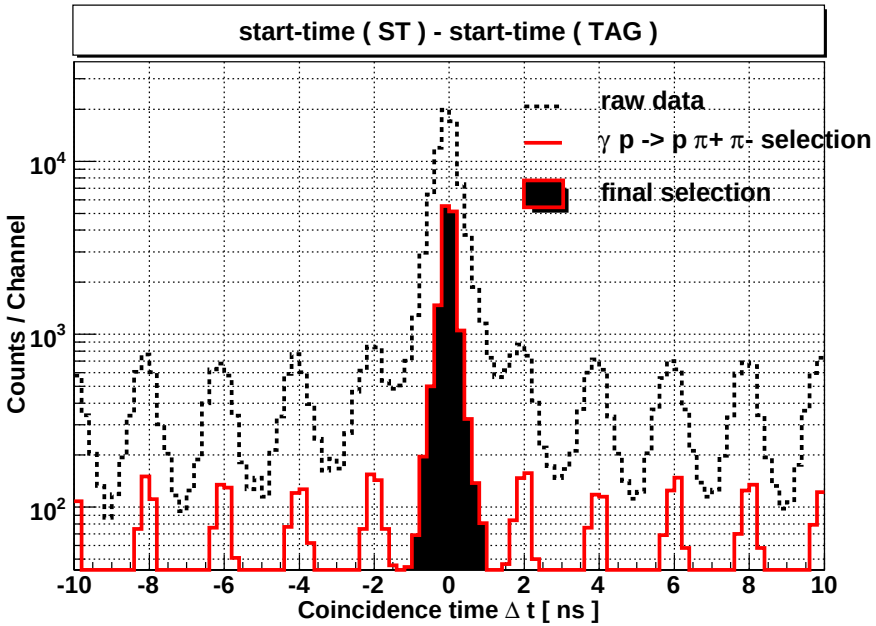
Trigger: - at least one charged particle in CLAS

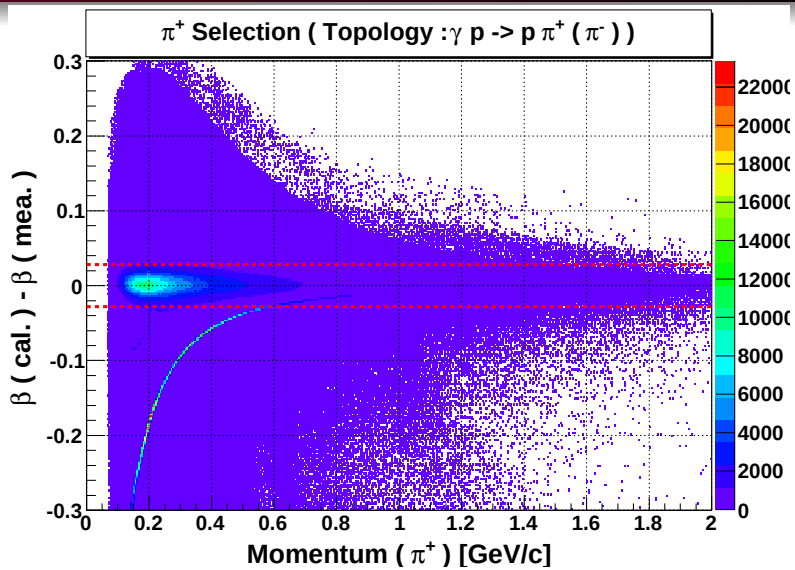
10.5 Billion events

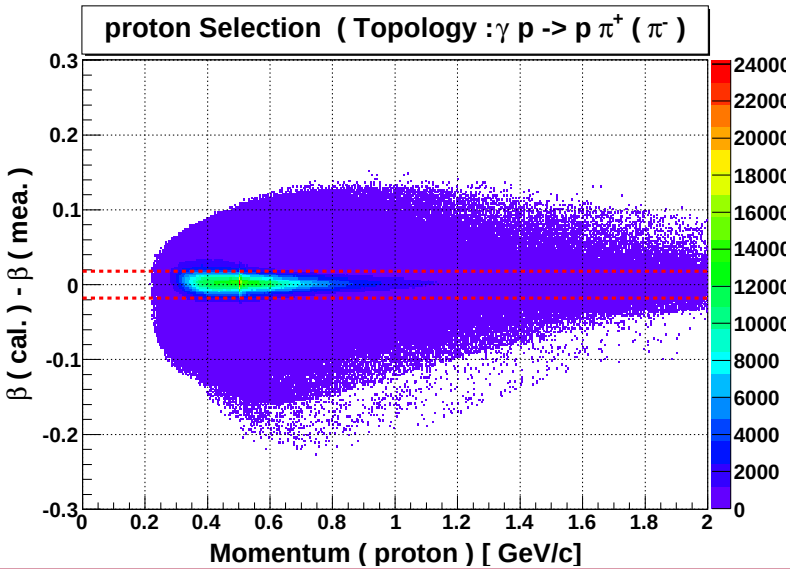


Outline

Particle identification ($\vec{\gamma}$, p, π^+, π^-)



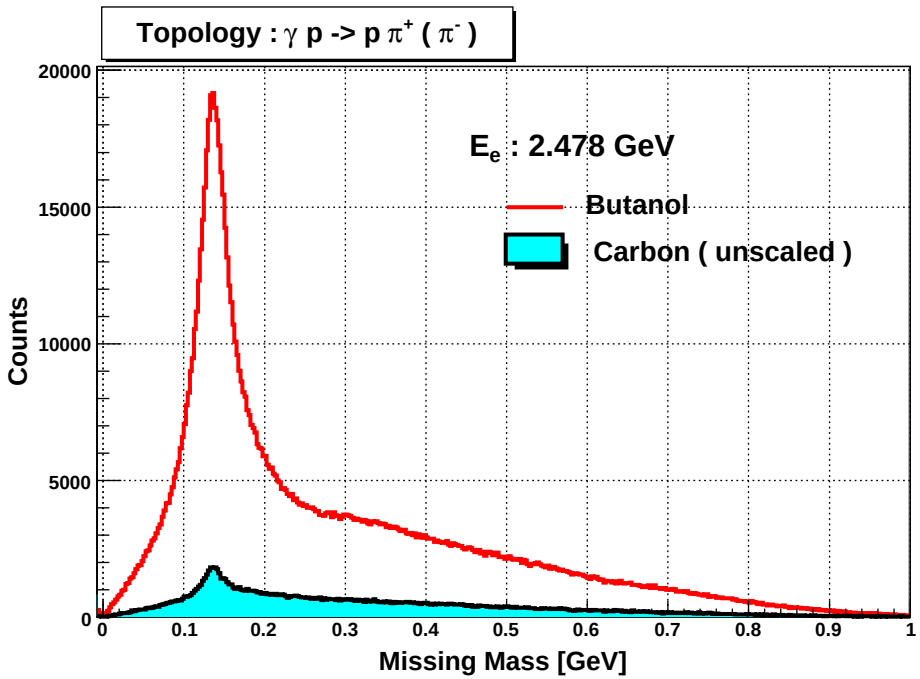


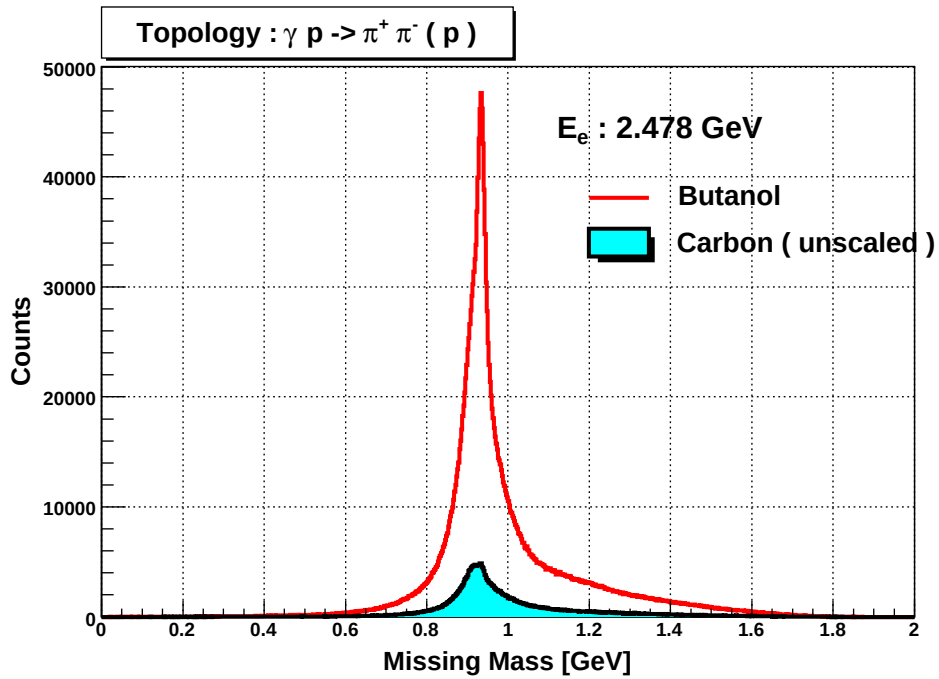


- Coincidence Time : $|\Delta t| < 1.2$ [ns]
- Particle identification
  - Proton : $|\Delta\beta| < 0.01882$
  - π^+ : $|\Delta\beta| < 0.0285$
  - π^- : $|\Delta\beta| < 0.0264$

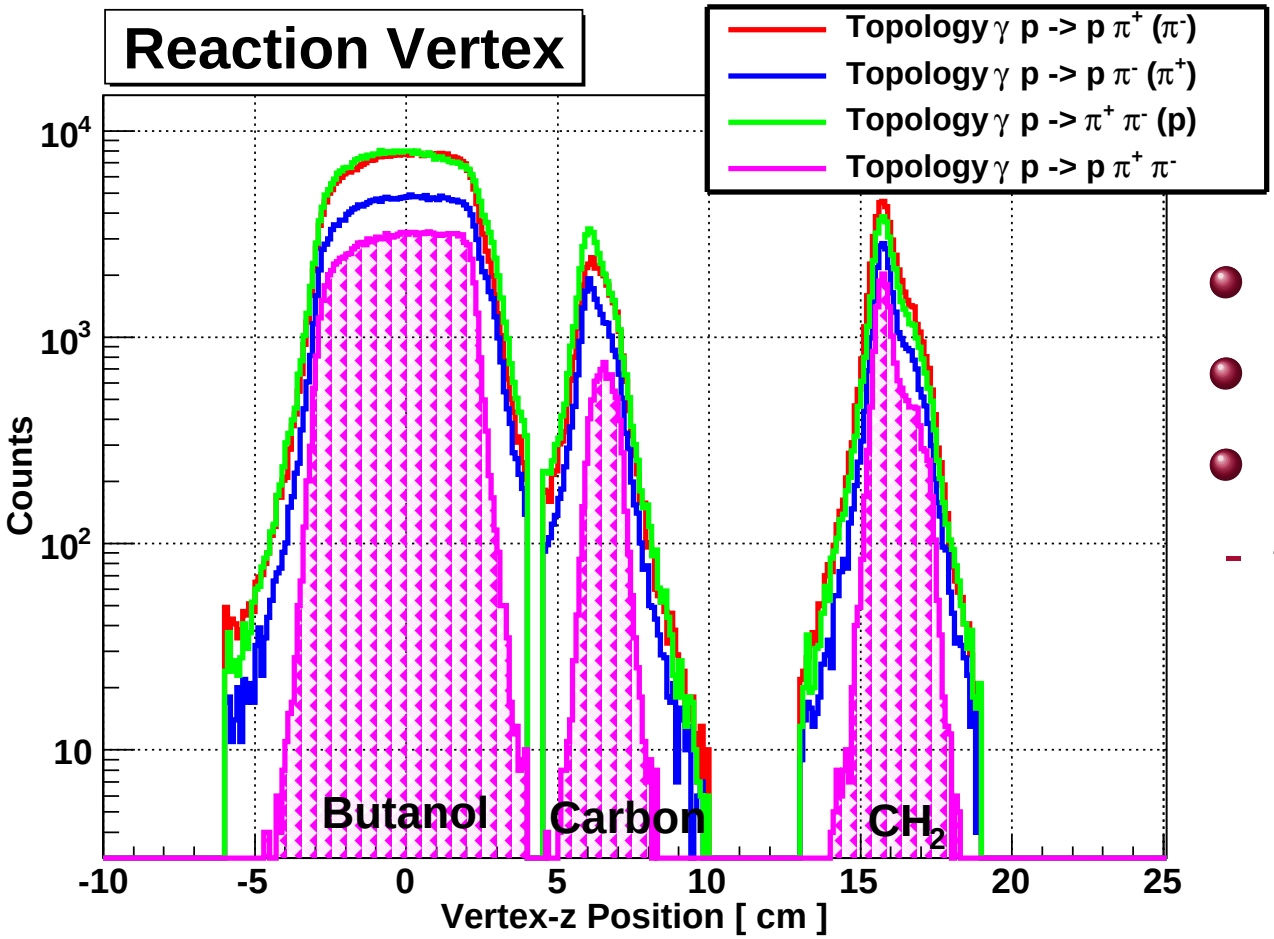
The four different topologies of $\gamma p \longrightarrow p\pi^+\pi^-$

- The topology : $\gamma p \longrightarrow p\pi^+(\pi^-)$
- The topology : $\gamma p \longrightarrow p\pi^-(\pi^+)$
- The topology : $\gamma p \longrightarrow \pi^+\pi^-(p)$
- The topology : $\gamma p \longrightarrow p\pi^+\pi^-$



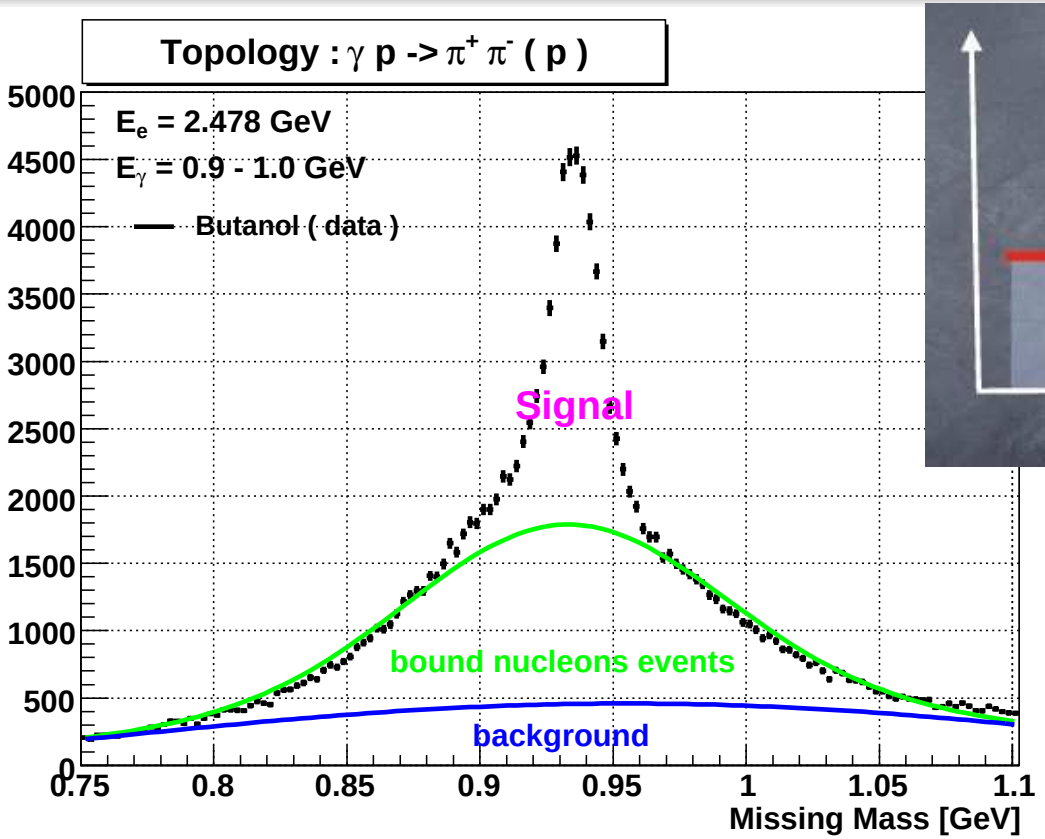


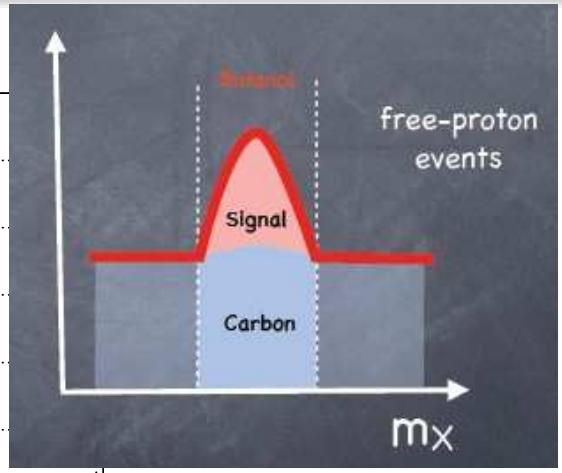
Three kinds of targets



- Butanol events from Z ∈ [-6,4] cm, r < 3 cm
- Carbon events from Z ∈ [4.5,10] cm, r < 3 cm
- CH_2 events from Z ∈ [13,19] cm, r < 3 cmm
- There is butanol background under carbon.

Dilution factor





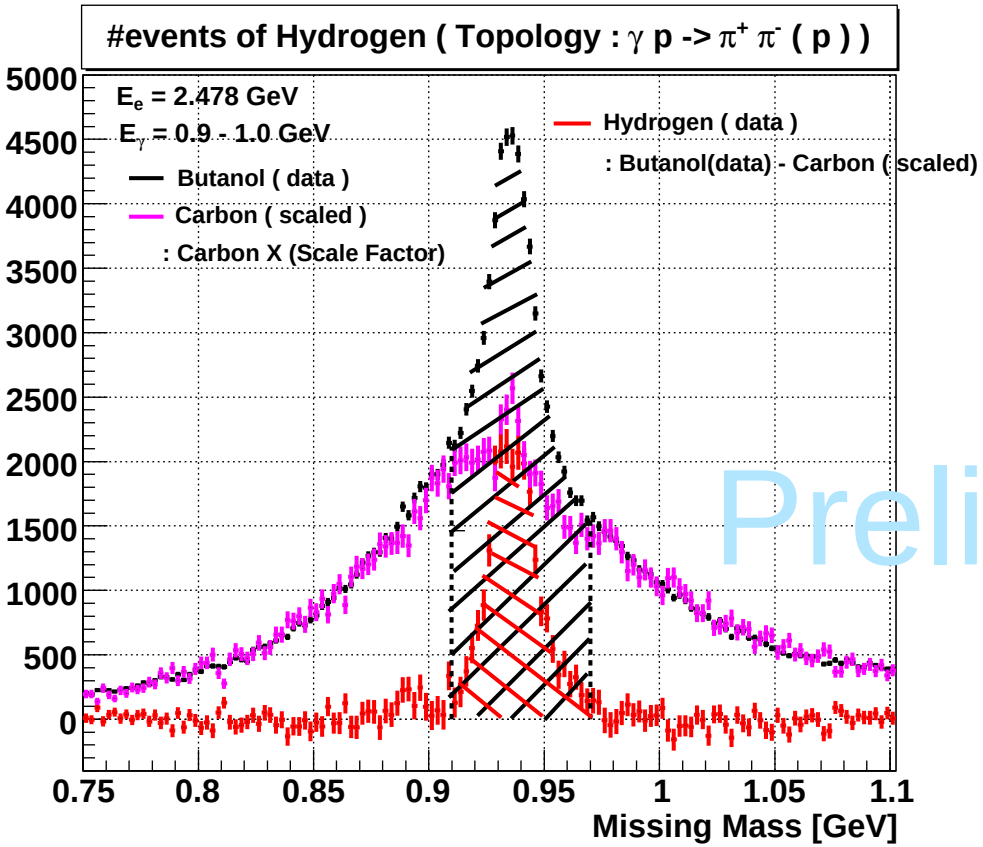
Butanol(C_4H_9OH)

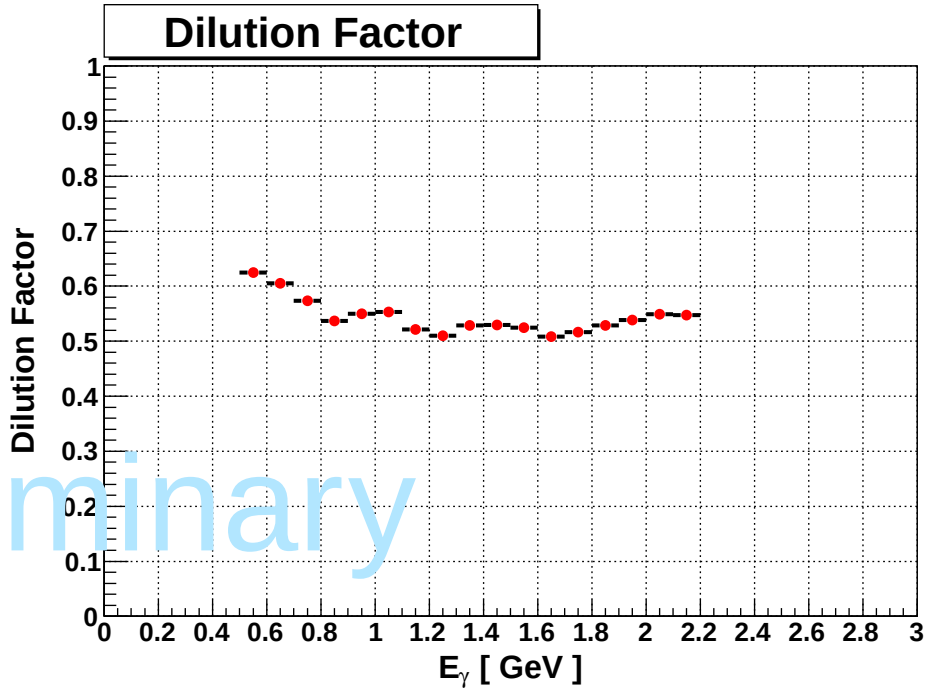
- Polarized Hydrogen
- Unpolarized Carbon
- Unpolarized Oxygen

$$\text{Dilution factor} = \frac{\sigma_H}{\sigma_{C_4H_9OH}} = \frac{N_{butanol} - N_{carbon} \cdot S}{N_{butanol}}$$

(S : Scale Factor-> Normalization factor btw butanol and carbon target)

Dilution factor





$$\text{Dilution factor} = \frac{(AREA)\ of\ \mathbf{N_{Hydrogen}}}{(AREA)\ of\ \mathbf{N_{Butanol}}}$$

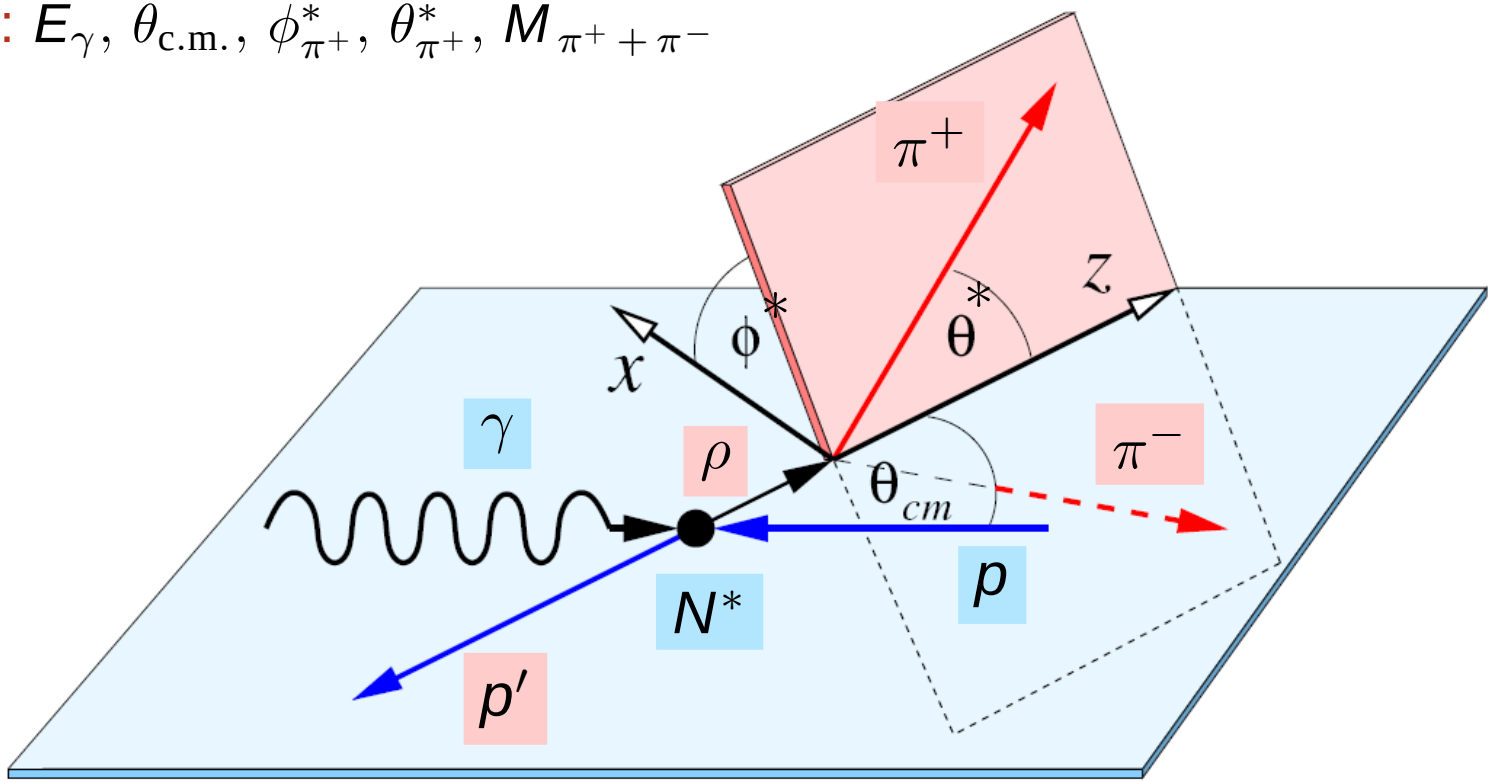
Outline

Photoproduction of $\pi^+\pi^-$ off the proton: Kinematics

The π^+ π^- in the final state require 5 independent variables!

$$\gamma p \rightarrow N^* \rightarrow p'\rho \rightarrow p'\pi^+\pi^-$$

ex: E_γ, $\theta_{\mathrm{c.m.}}$, $\phi^*_{\pi^+}$, $\theta^*_{\pi^+}$, $M_{\pi^+ + \pi^-}$



Polarization observable I^s

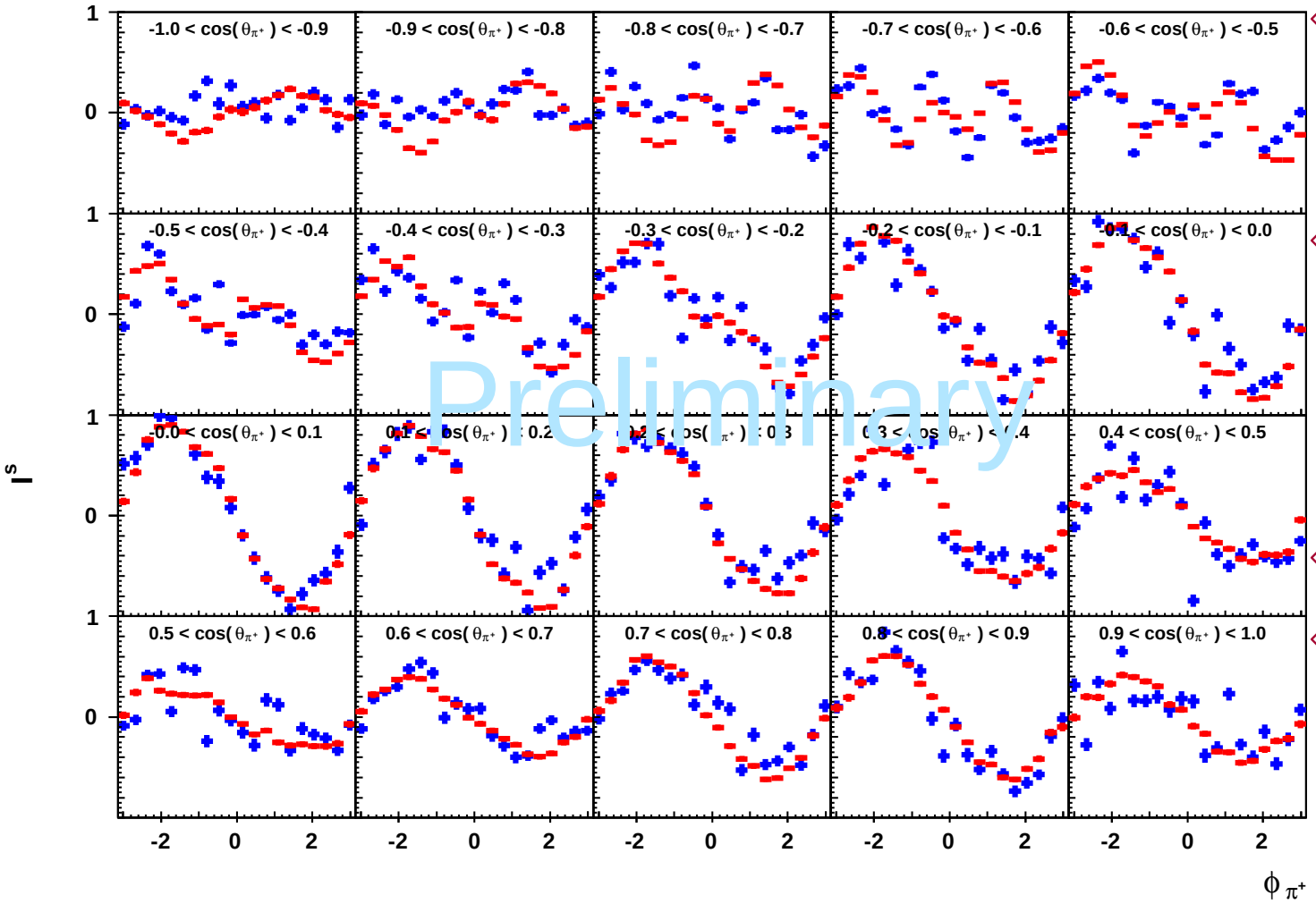
$$\frac{d\sigma(\Rightarrow)}{dx_i} + \frac{d\sigma(\Leftarrow)}{dx_i} =$$

$$= 2 \cdot \sigma_0 \{ 1 + \delta_l [\sin 2\beta (I^s) + \cos 2\beta (I^c)] \}$$

- σ_0: The unpolarized cross section
- β: The angle between the direction of polarization and the x-axis

Comparison of observable I^s with another data

E_γ : 1250 - 1300 MeV (comparison with g8b data)



- g9a (FROST)
  polarized beam
  polarized target
  (butanol)
- g8b
  polarized beam
  unpolarized target
  (liquid hydrogen)
  - previous presentation
- ϕ_{π^+} : the π^+ azimuthal angle
- θ_{π^+} : the π^+ polar angle

  (in the rest frame
  of the π^+ π^- system)

Polarization observable $P_z^{\odot}$

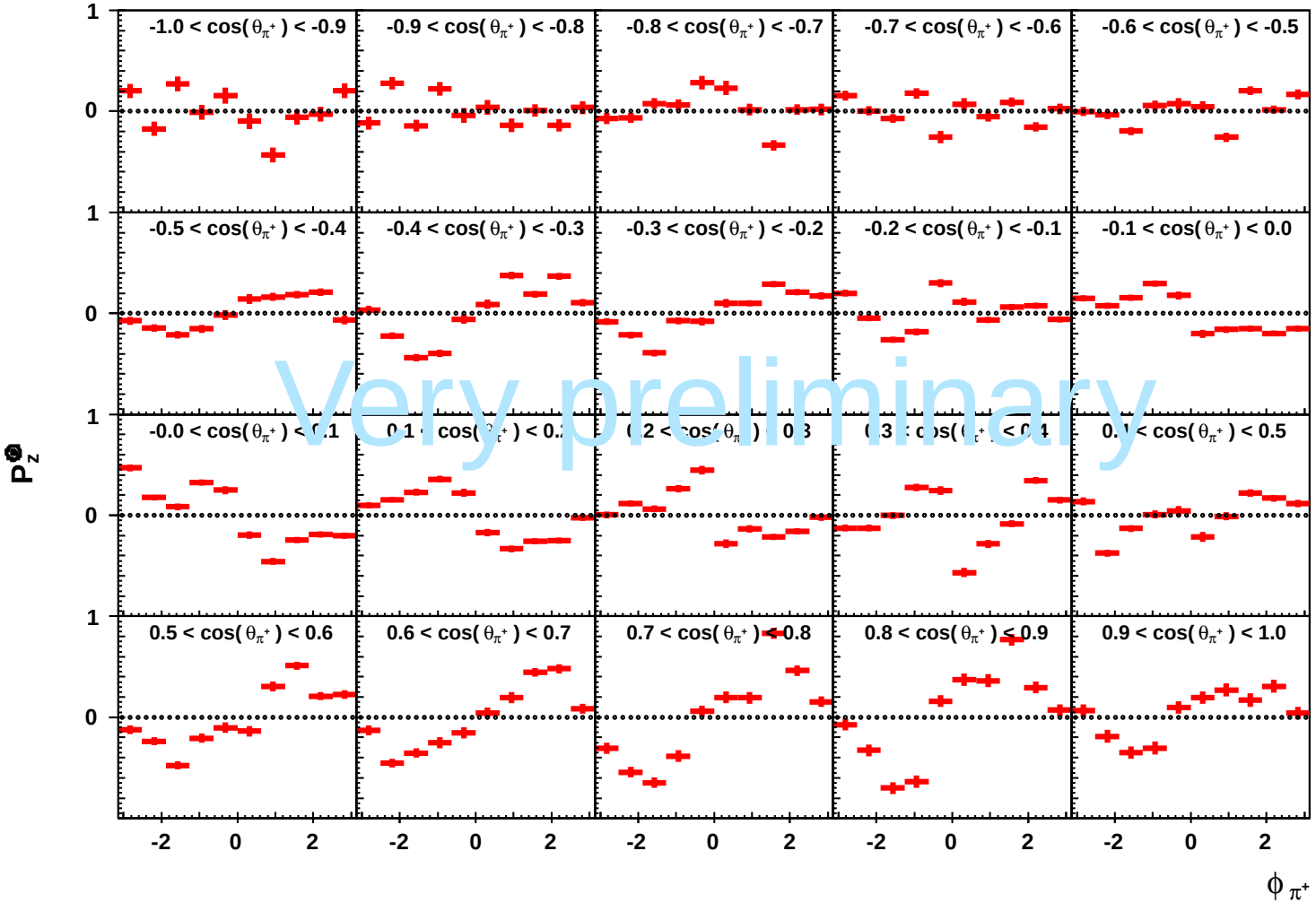
$$P_z^{\odot} = \frac{1}{f \cdot \delta_{\odot} \cdot \Lambda_z} \frac{\left(N(\rightarrow\Rightarrow)+N(\leftarrow\Leftarrow)\right) - \left(N(\rightarrow\Leftarrow)+N(\leftarrow\Rightarrow)\right)}{\left(N(\rightarrow\Rightarrow)+N(\leftarrow\Leftarrow)\right) + \left(N(\rightarrow\Leftarrow)+N(\leftarrow\Rightarrow)\right)}$$

- f - dilution factor ≈ 0.56 (10 %)
- $\delta_{\odot}$ - beam polarization
- Λ_z - target polarization ≈ 0.85 (5 %)
- $N(\rightarrow\Rightarrow)$ - the number of events
  with the circular beam polarization and longitudinal target polarization

$\rightarrow$ and $\leftarrow$: beam spin
$\Rightarrow$ and $\Leftarrow$: target spin

The asymmetry plot for $P_z^{\odot}$

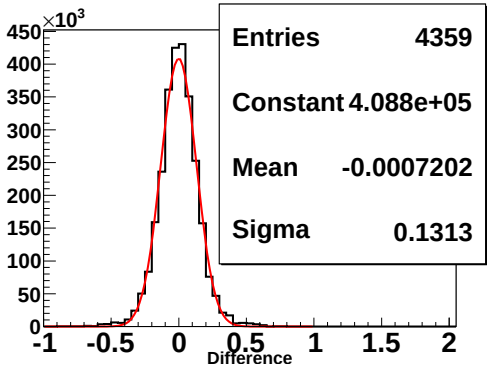
E_γ : 700 - 800 MeV



Data used

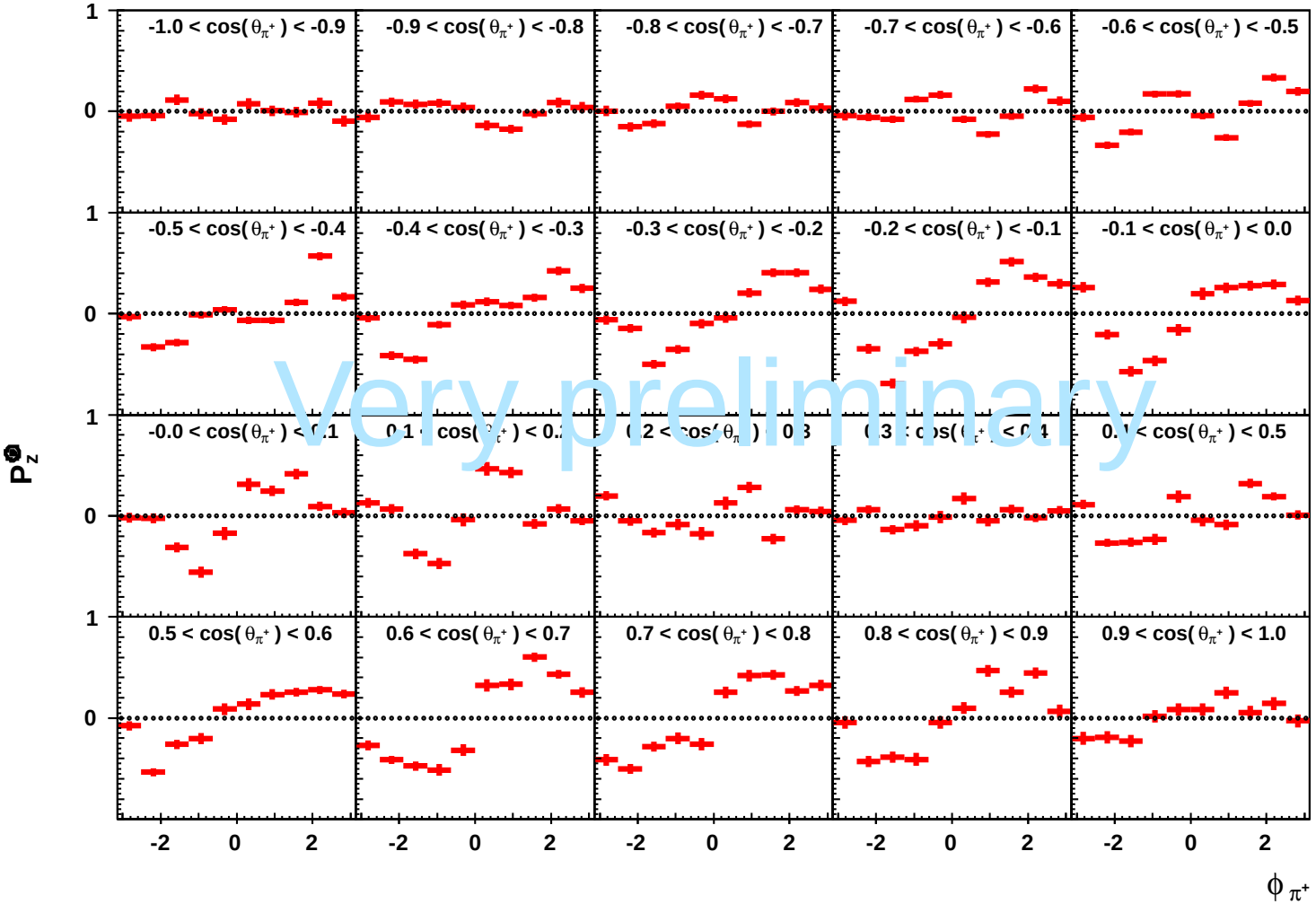
- E_e : 1.645 GeV
- E_e : 2.478 GeV
- Average

Difference
btw average and data



The asymmetry plot for $P_z^{\odot}$

E_γ : 1000 - 1100 MeV



Data used

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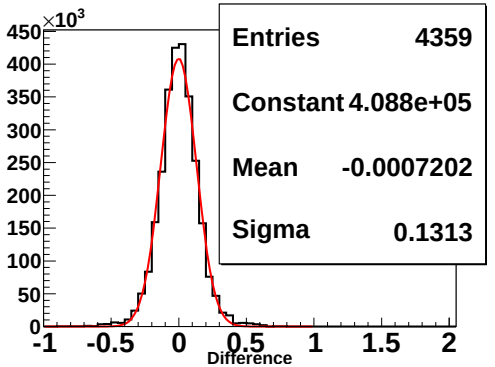
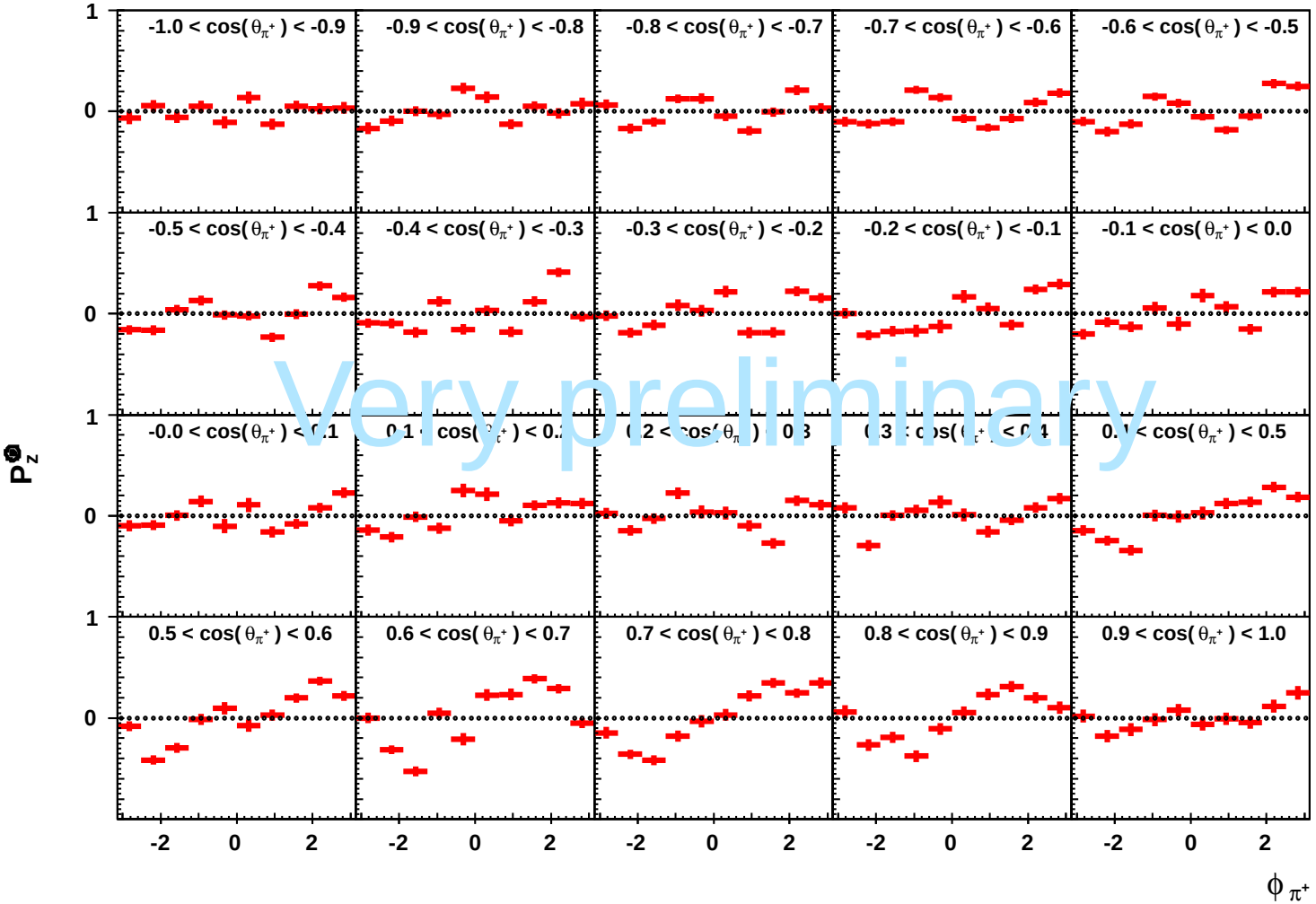
- E_e : 2.478 GeV
- Average

Difference
btw average and data



The asymmetry plot for $P_z^{\odot}$

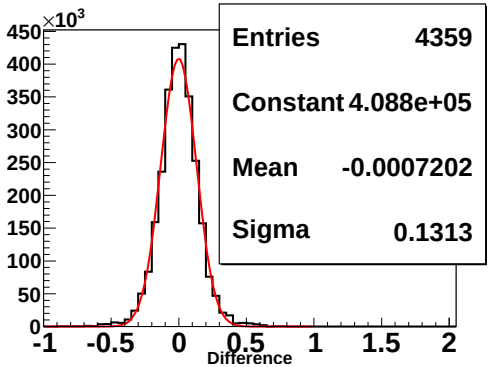
E_γ : 1200 - 1300 MeV



Data used

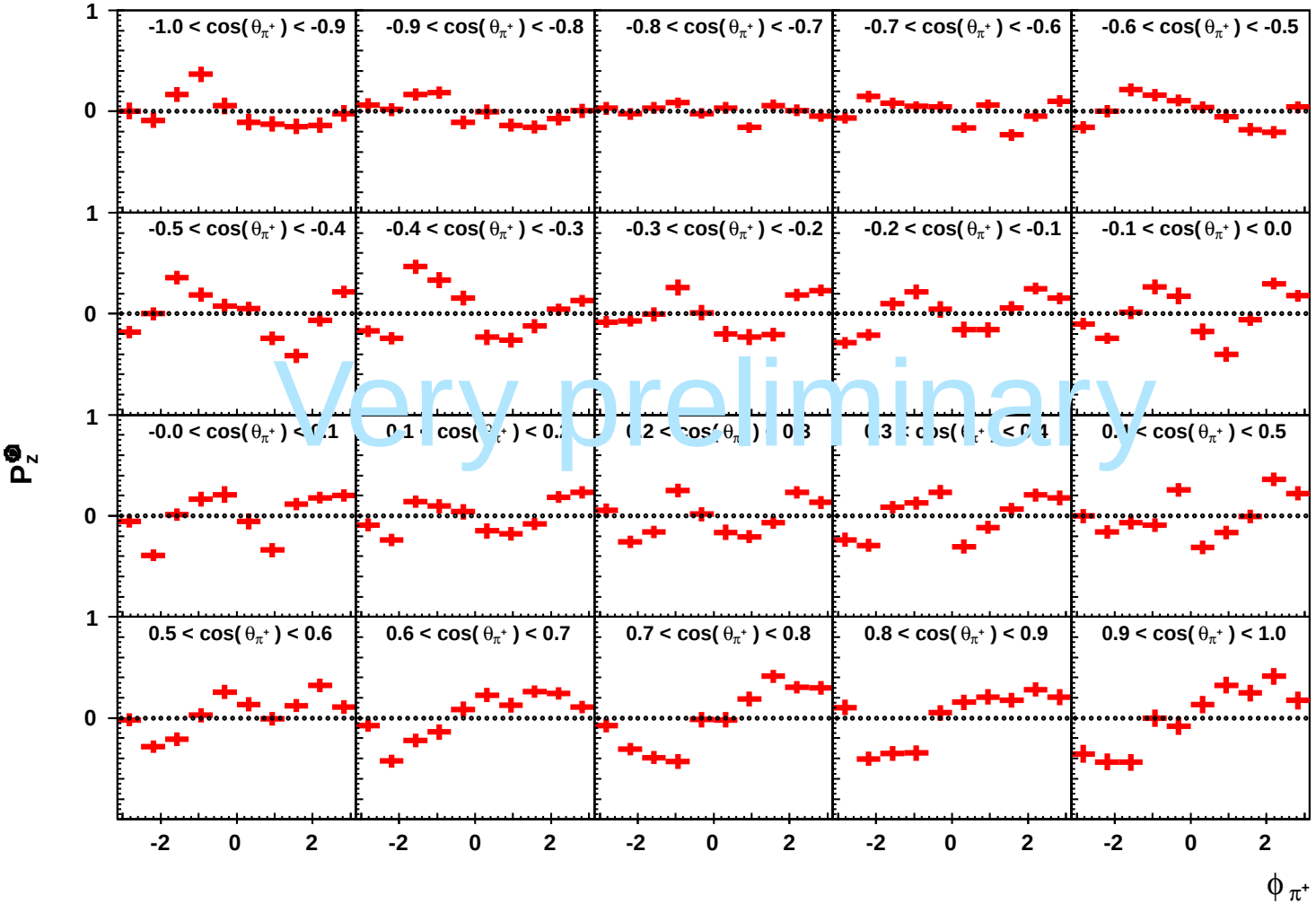
- E_e : 1.645 GeV
- E_e : 2.478 GeV
- Average

Difference
btw average and data



The asymmetry plot for $P_z^{\odot}$

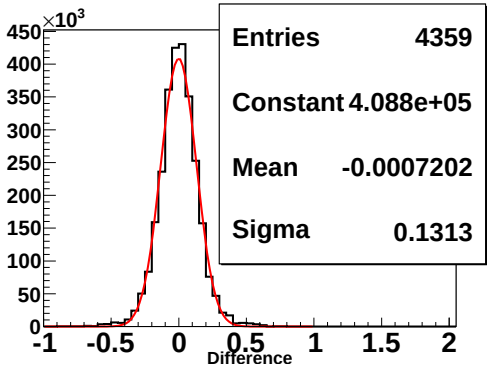
E_γ : 1500 - 1600 MeV



Data used

- E_e : 1.645 GeV
- E_e : 2.478 GeV
- Average

Difference
btw average and data



Polarization observable P_z

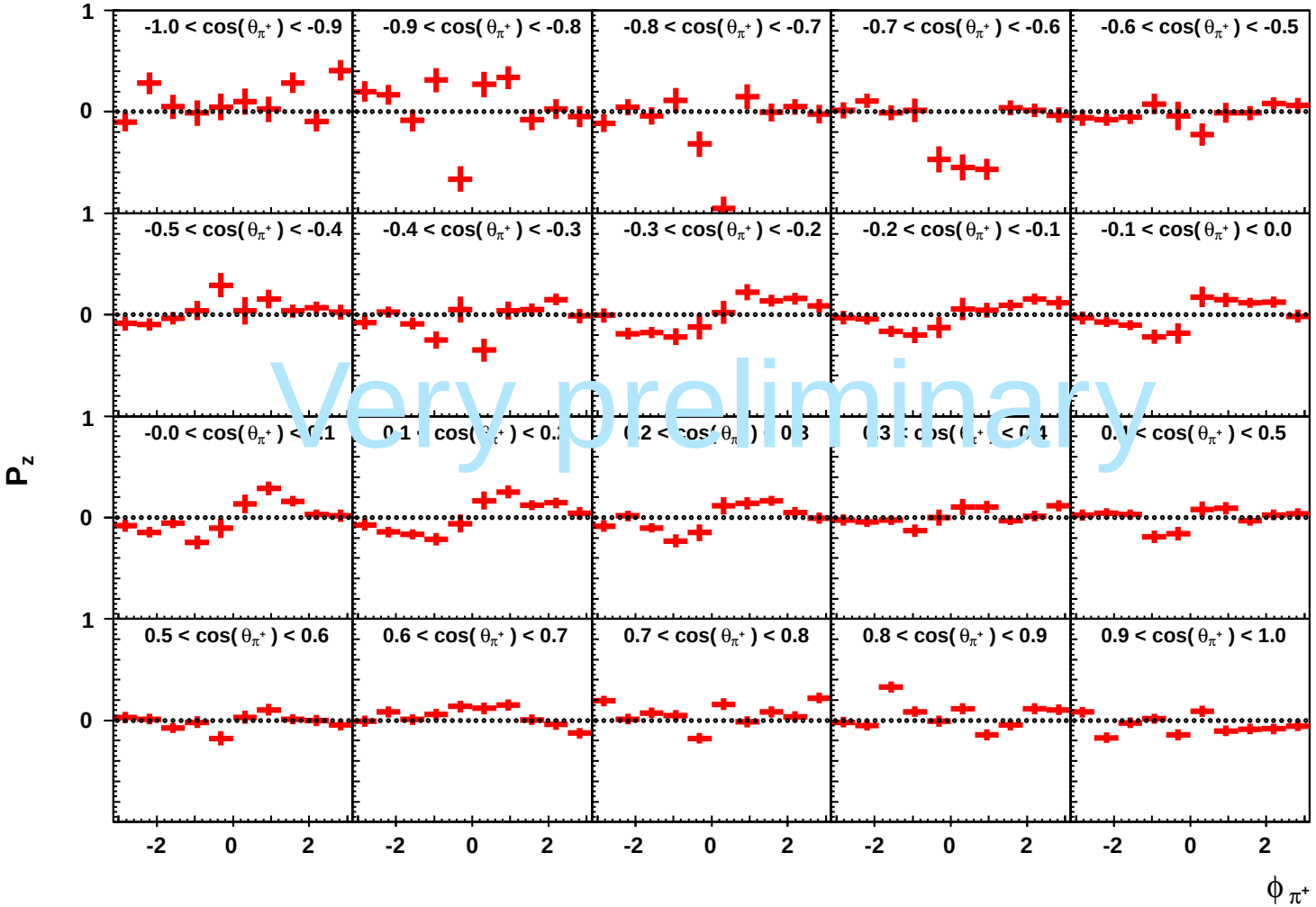
$$P_z = \frac{1}{f \cdot \Lambda_z} \frac{N(\Rightarrow) - N(\Leftarrow)}{N(\Rightarrow) + N(\Leftarrow)}$$

- f - dilution factor ≈ 0.56 (10 %)
- Λ_z - target polarization ≈ 0.85 (5 %)
- $N(\Rightarrow)$ - the number of events with the longitudinal target polarization

  $\Rightarrow$ and $\Leftarrow$:target spin

The asymmetry plot for P_z

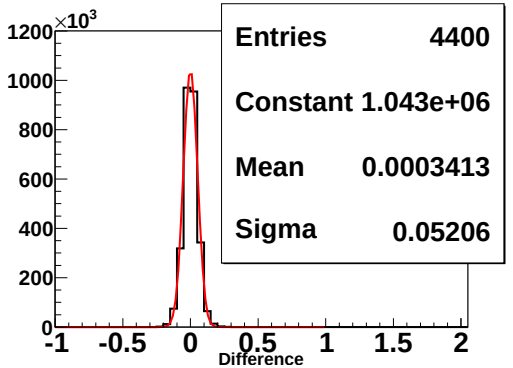
E_γ : 500 - 600 MeV



Data used

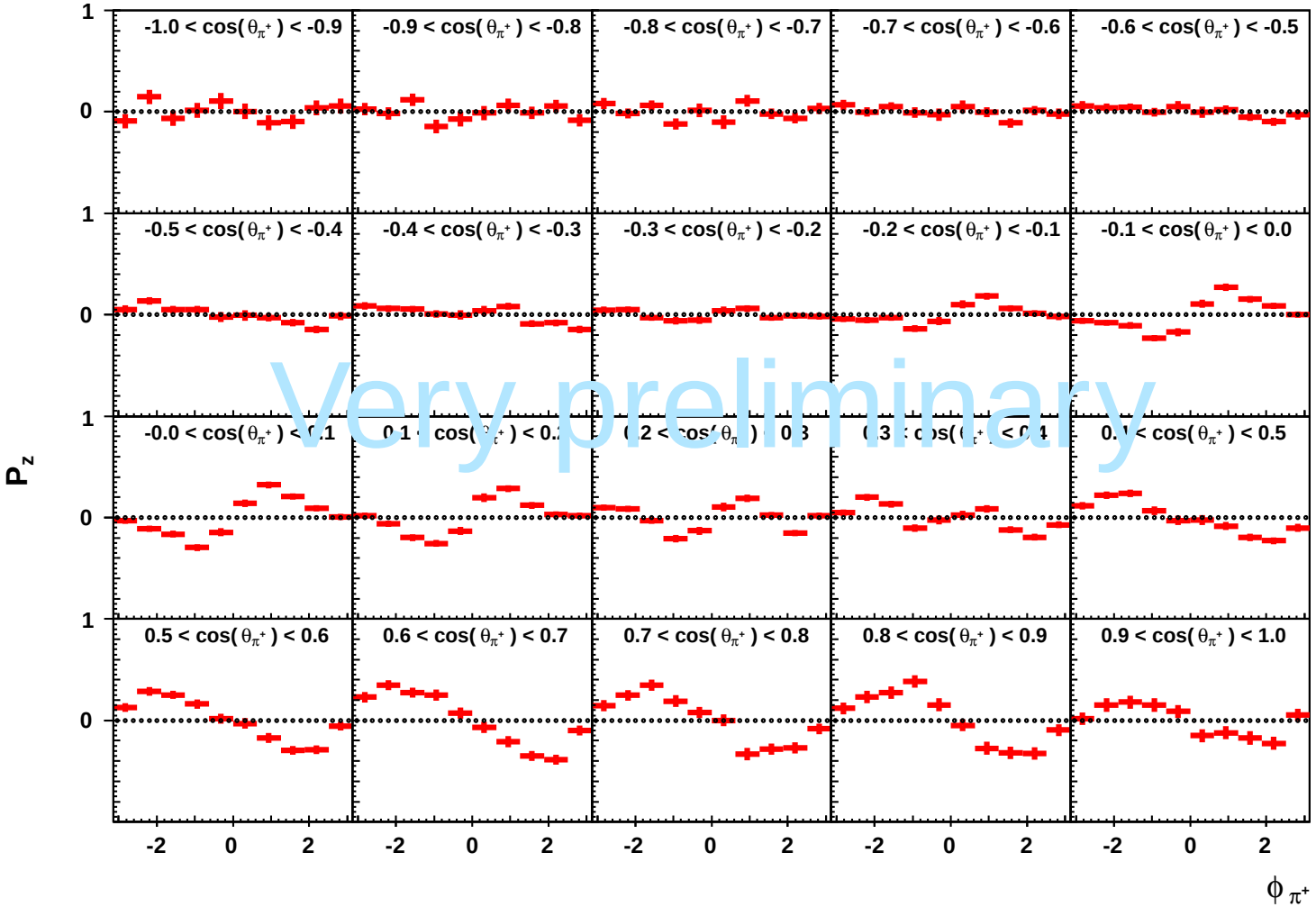
- E_e : 1.645 GeV
- E_e : 2.478 GeV
- Average

Difference
btw average and data



The asymmetry plot for P_z

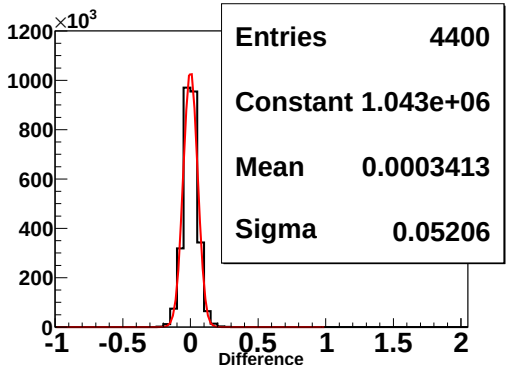
E_γ : 700 - 800 MeV



Data used

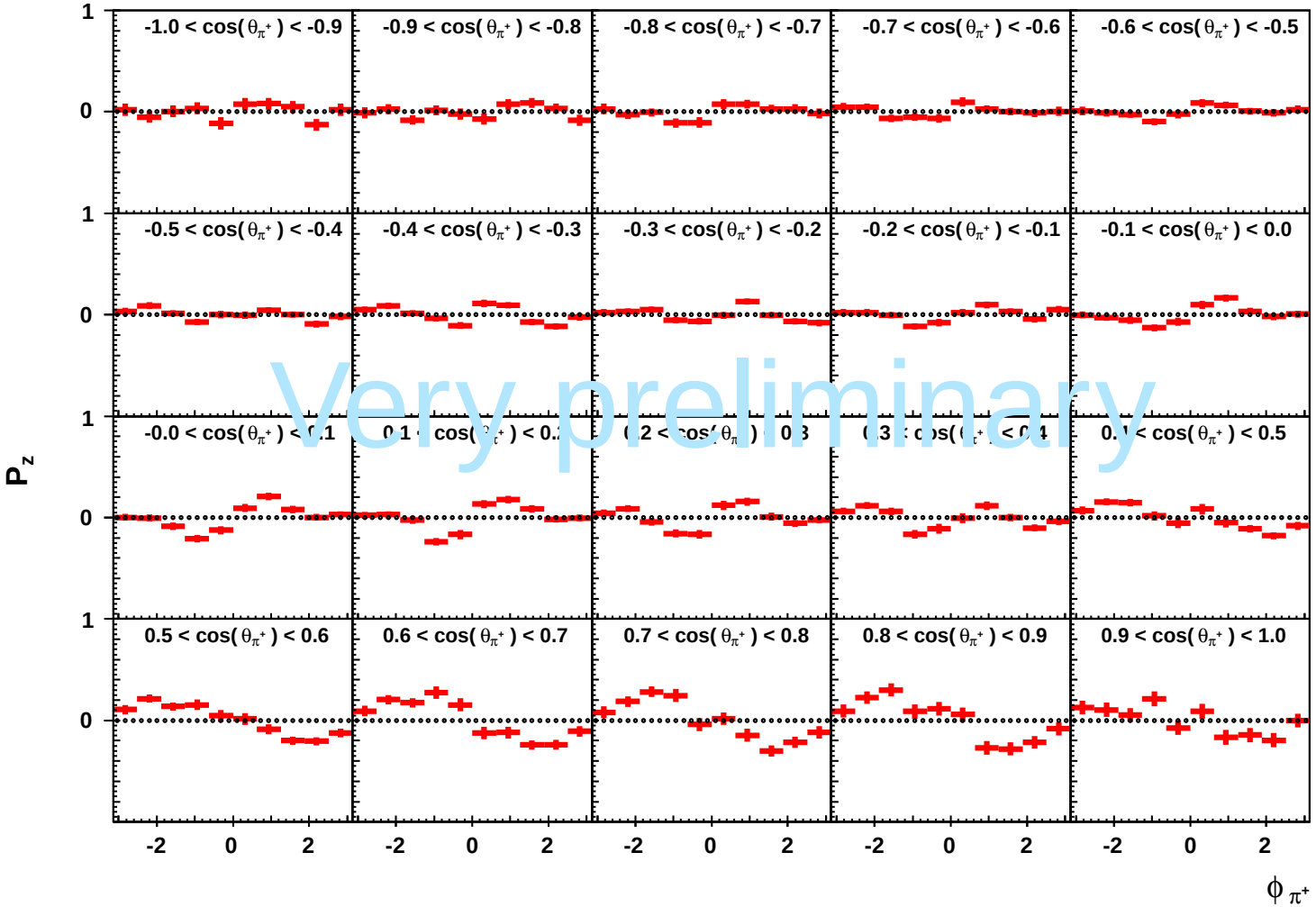
- E_e : 1.645 GeV
- E_e : 2.478 GeV
- Average

Difference
btw average and data



The asymmetry plot for P_z

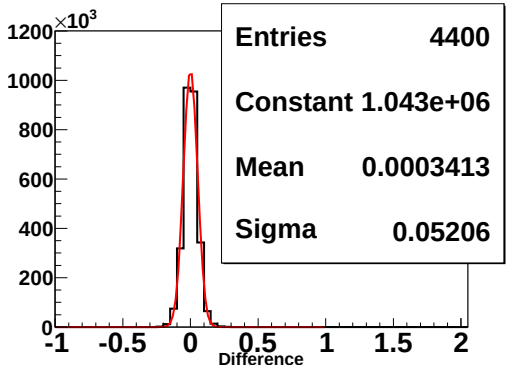
E_γ : 800 - 900 MeV



Data used

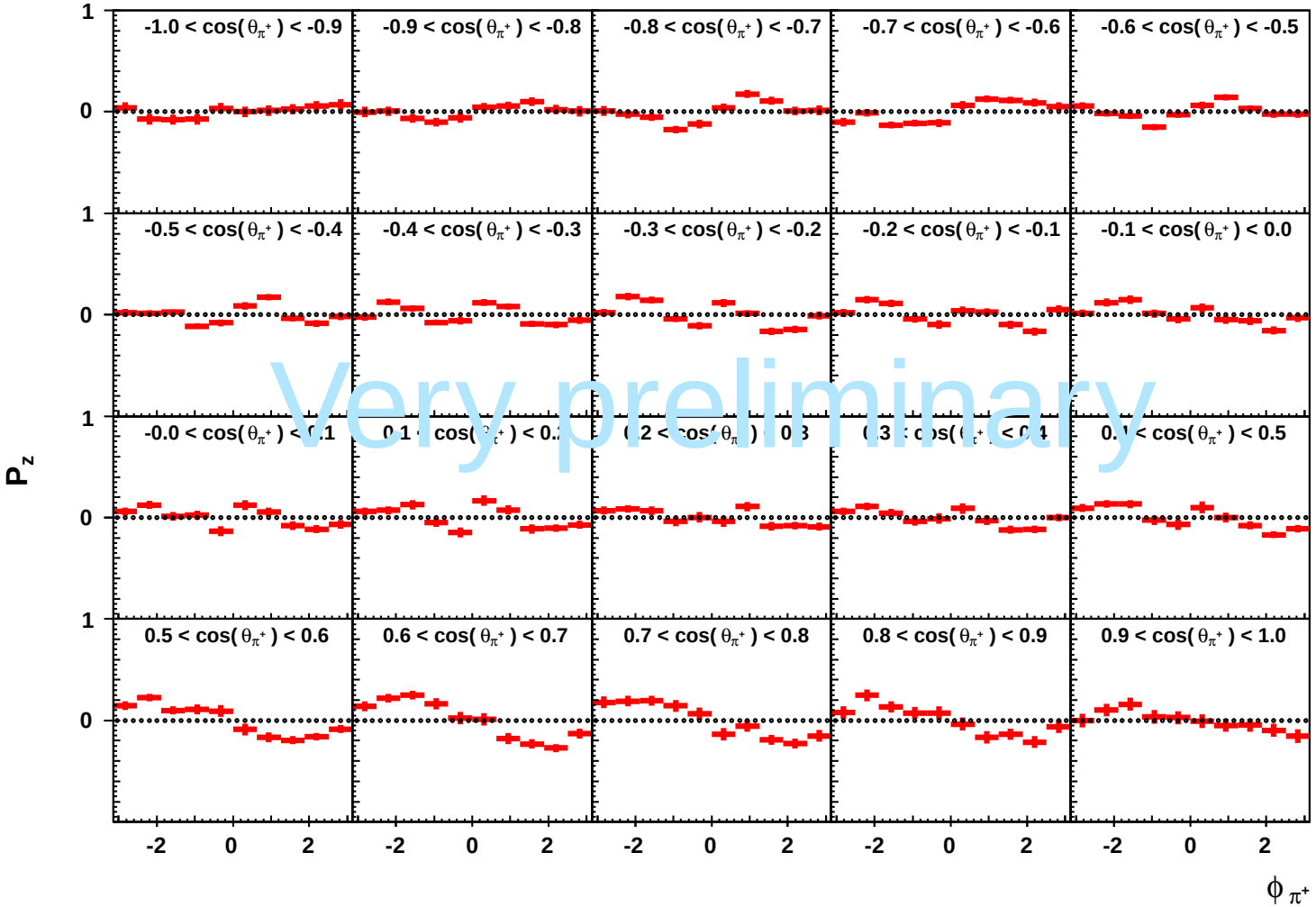
- E_e : 1.645 GeV
- E_e : 2.478 GeV
- Average

Difference
btw average and data



The asymmetry plot for P_z

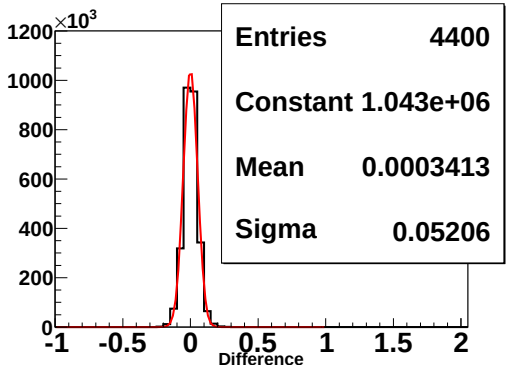
E_γ : 900 - 1000 MeV



Data used

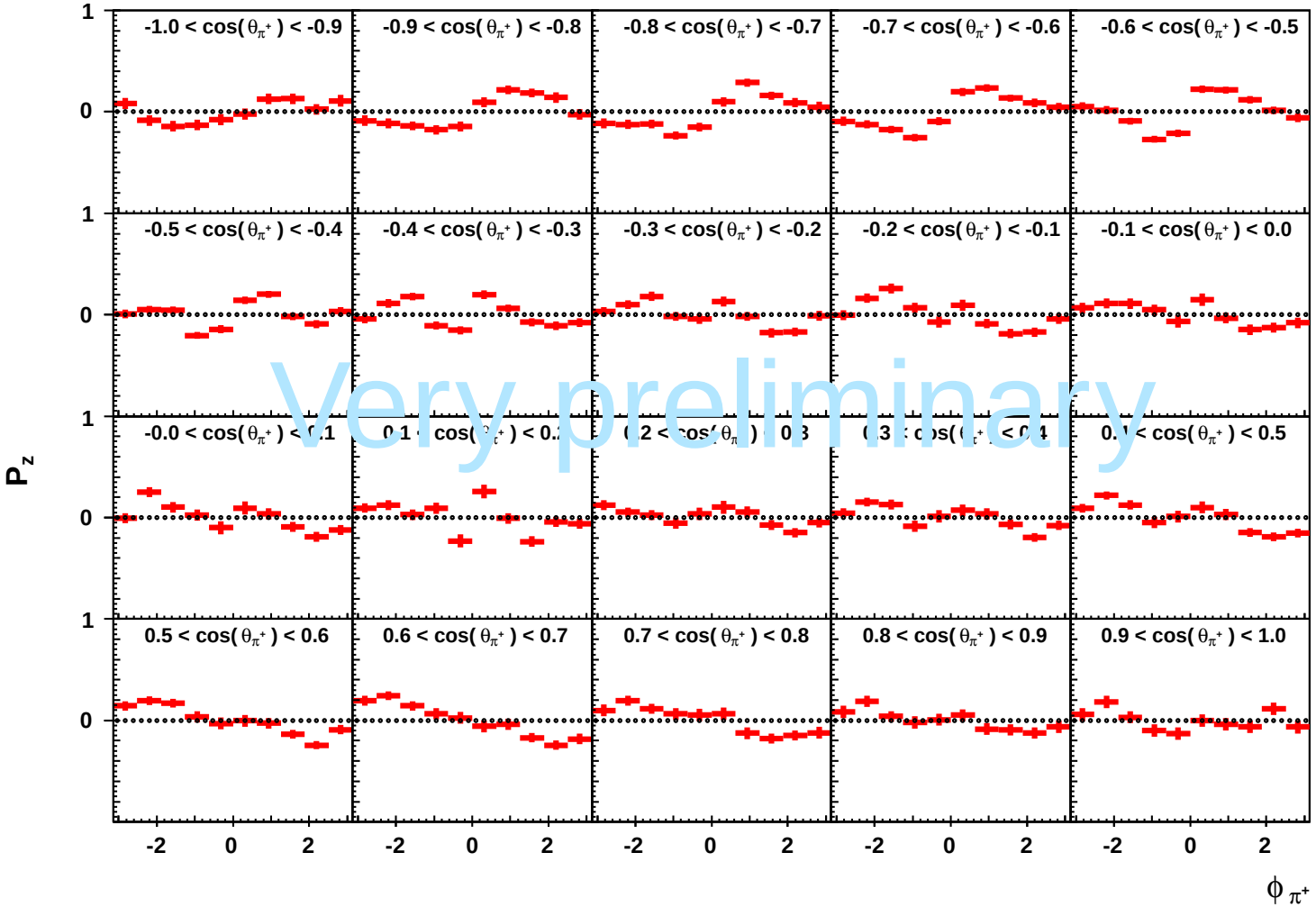
- E_e : 1.645 GeV
- E_e : 2.478 GeV
- Average

Difference
btw average and data



The asymmetry plot for P_z

E_γ : 1000 - 1100 MeV



Data used

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Difference
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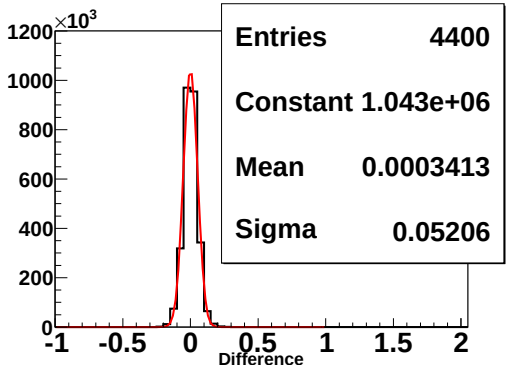
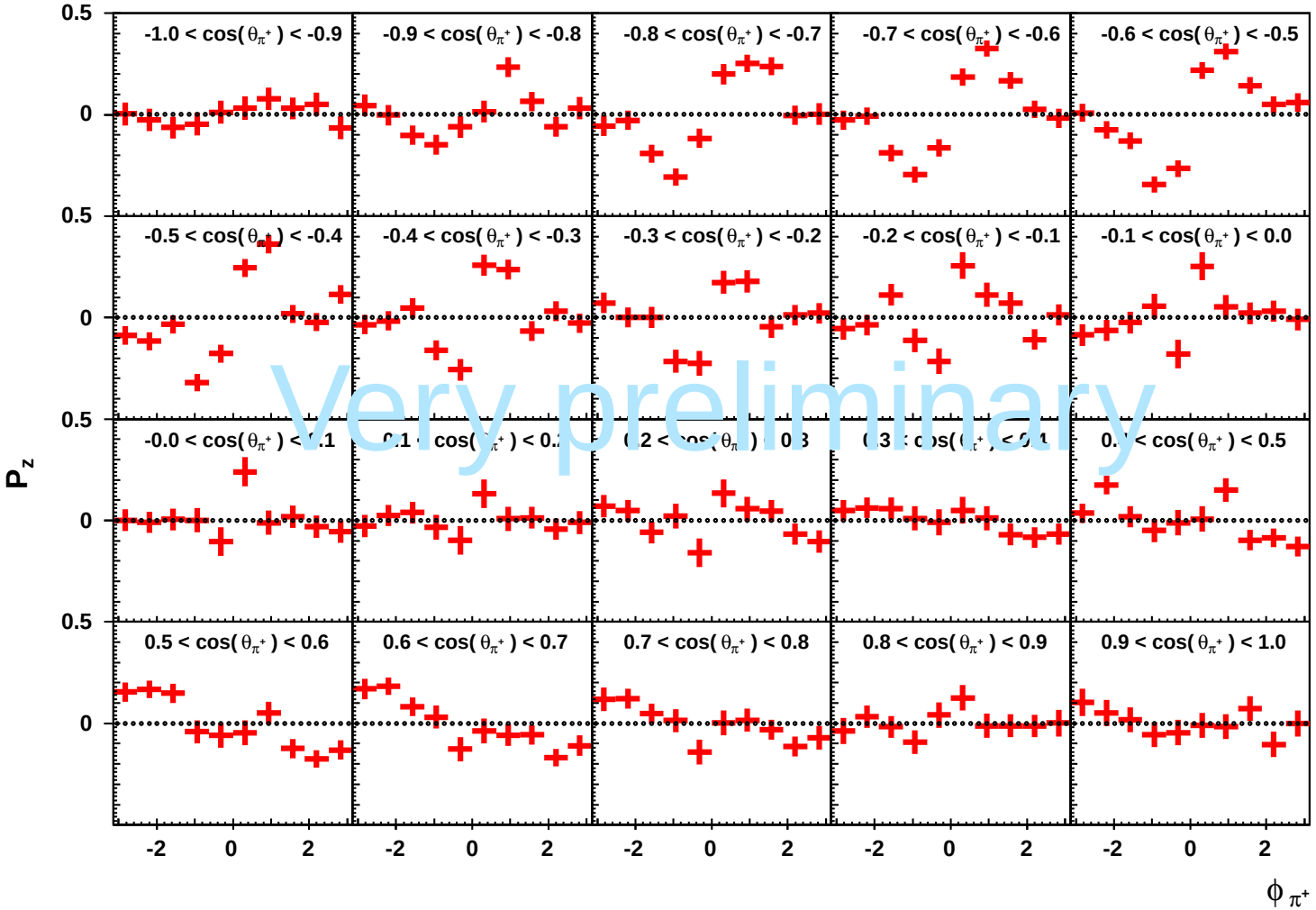


The asymmetry plot for P_z

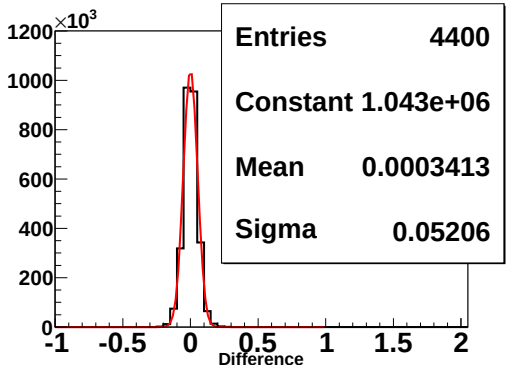
E_γ : 1100 - 1200 MeV



Data used

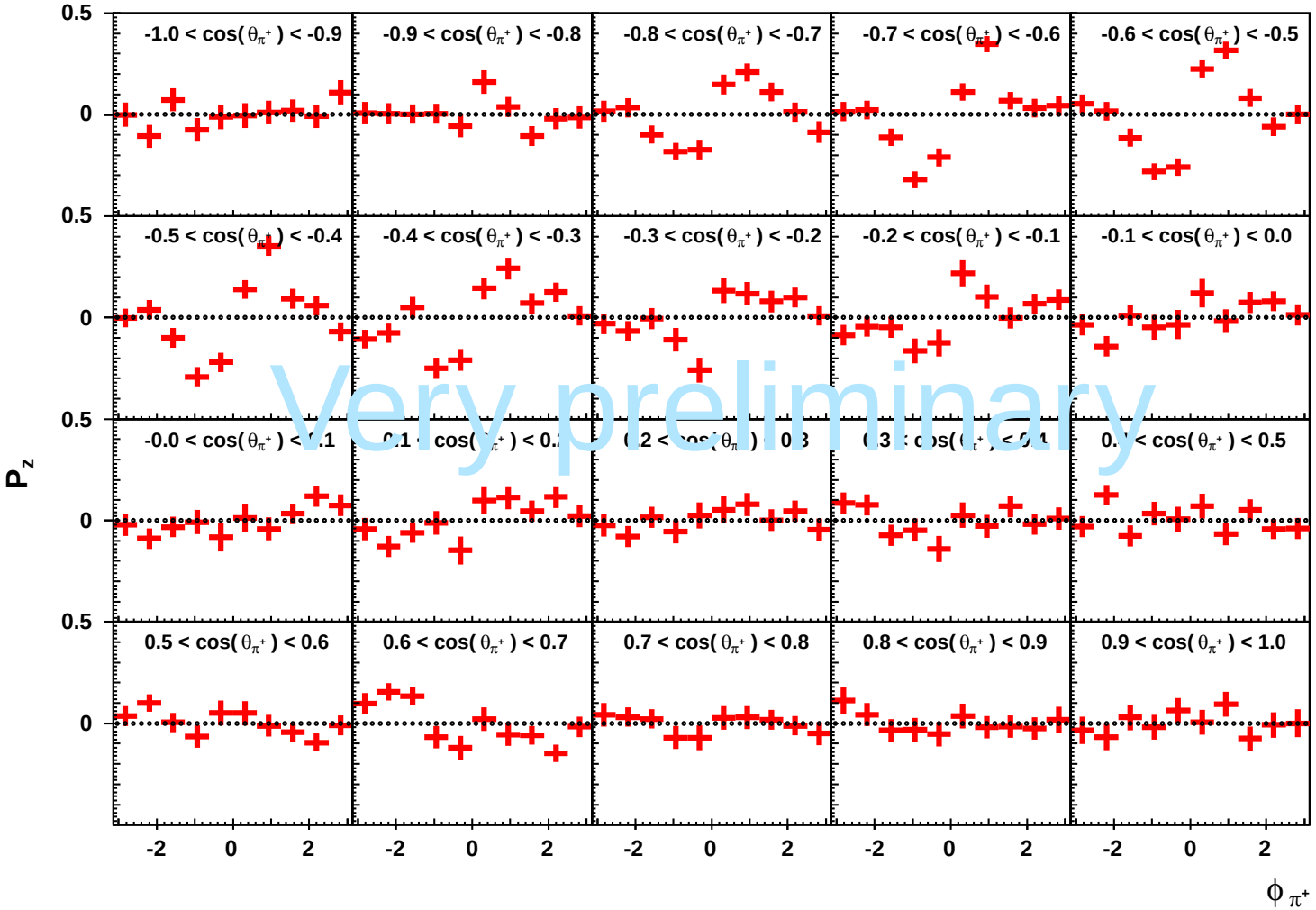
- E_e : 1.645 GeV
- E_e : 2.478 GeV
- Average

Difference
btw average and data



The asymmetry plot for P_z

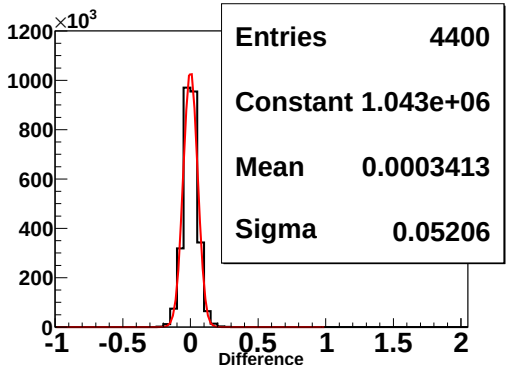
E_γ : 1200 - 1300 MeV



Data used

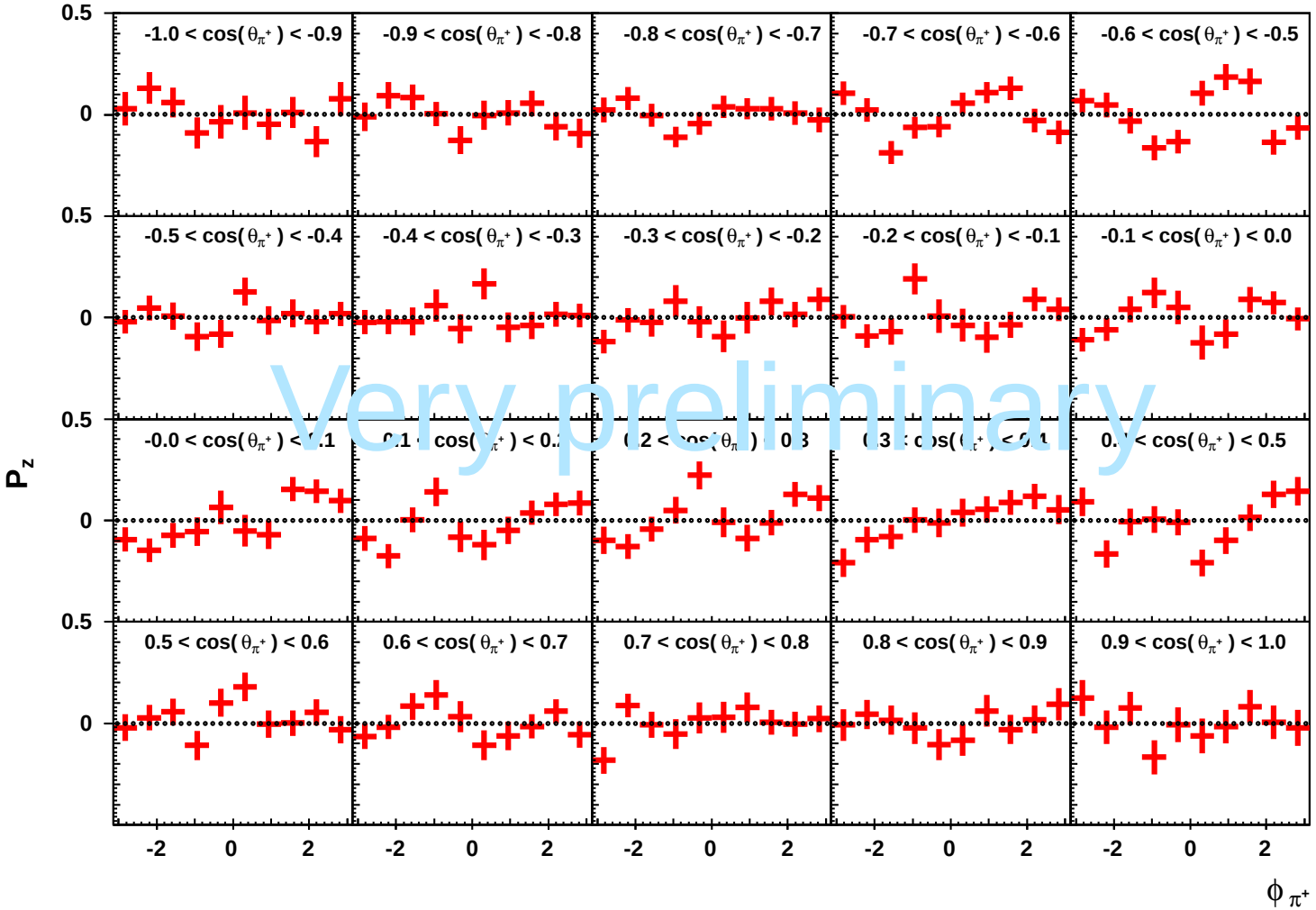
- E_e : 1.645 GeV
- E_e : 2.478 GeV
- Average

Difference
btw average and data



The asymmetry plot for P_z

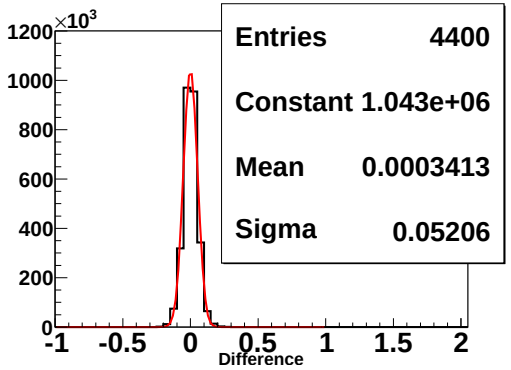
E_γ : 1500 - 1600 MeV



Data used

- E_e : 1.645 GeV
- E_e : 2.478 GeV
- Average

Difference
btw average and data



Summary

- Comparison of observable $\mathbf{I^s}$ with another data
- Preliminary results for $\mathbf{P_z}^{\odot}$ and $\mathbf{P_z}$ in $\pi^+ \pi^-$ photoproduction

In future,

- Results for $\mathbf{I}^{\odot}$ in $\pi^+ \pi^-$ photoproduction
- Comparison of observable $\mathbf{I}^{\odot}$ with the published data

Back up

One of the Goals of the N^* Program ...

Search for *missing* or yet unobserved resonances

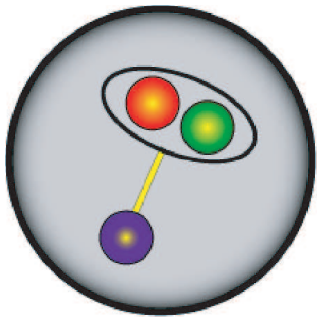
Quark models predict many more baryons than have been observed

	****	***	**	*
N Spectrum	11	3	6	2
Δ Spectrum	7	3	6	6

➜according to PDG
(Phys. Lett. B **667**, 1 (2008))
➜little known
(many open questions left)

Possible solutions:

1. Quark-diquark structure



one of the internal degrees of freedom is frozen

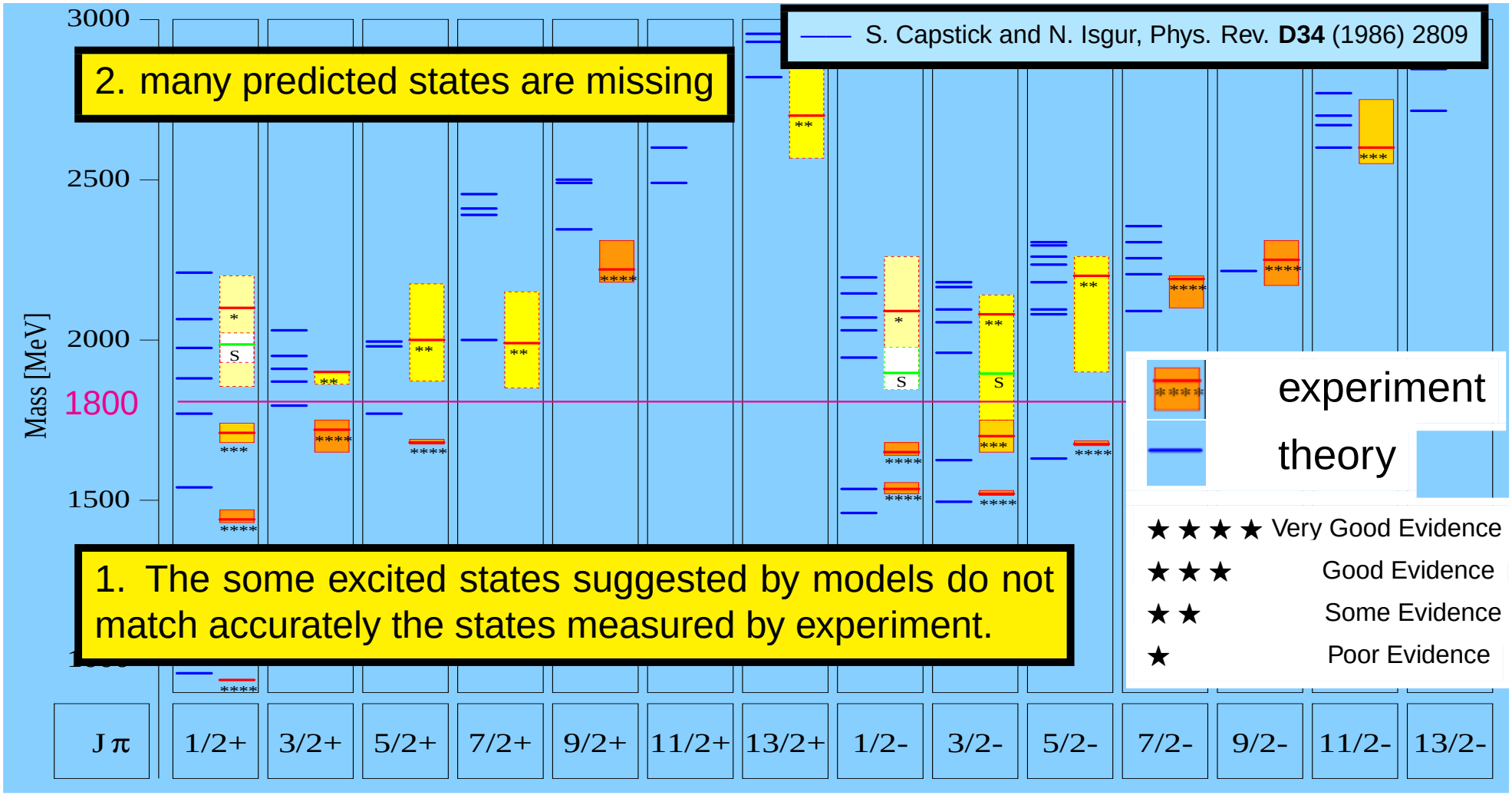
2. Have not been observed, yet

Nearly all existing data result from πN scattering experiments

➜ If the missing resonances did not couple to Nπ, they would not have been discovered!!

The excited states of the nucleon

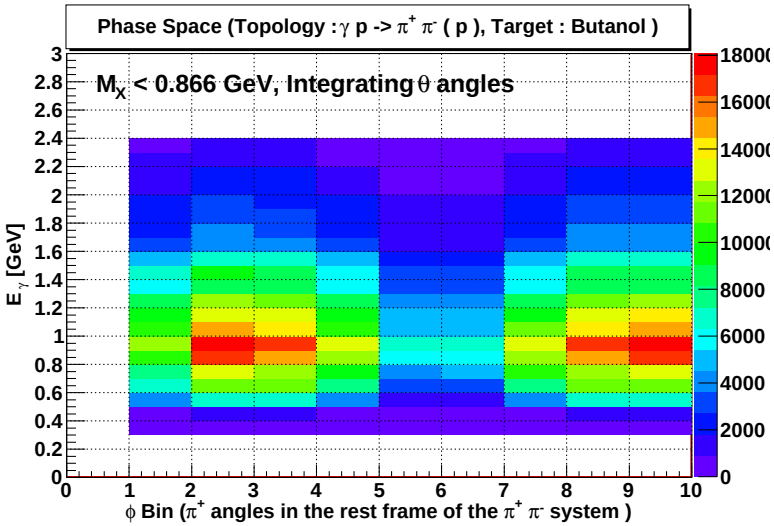
Constituent quark models: N^* resonances (Isospin $\frac{1}{2}$)

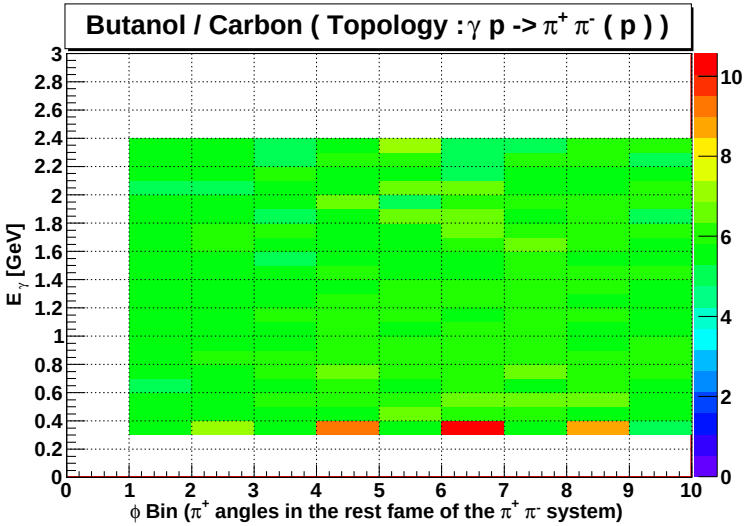


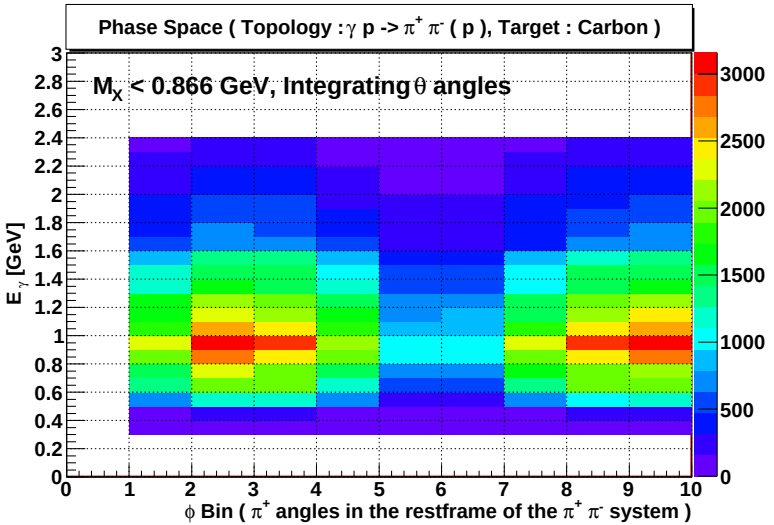
The Frozen-Spin Target - Summary of Results

	Expectation	Result
Base temperature:	50 mK	28 mK (w/o beam) 30 mK (w/ beam)
Cooling Power:	10 μW (Frozen) 20 mW (Polarizing)	800 μW @ 50mK 60mW @ 300 mK
Polarization:	80 %	+ 82 % - 85 %
1/e Relaxation Time:	500 hours	2700 hours (+ Pol.) 1600 hours (-Pol.)

Butanol/Carbon Normalization - Scale Factor



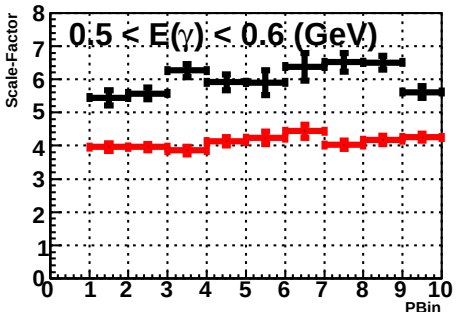


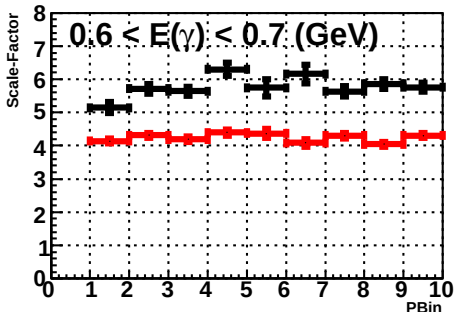


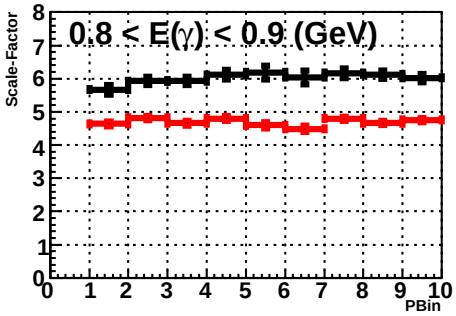
1. Selecting phase space with bound nucleon events in the butanol and carbon
2. Diving bound nucleon events from the butanol by the carbon.

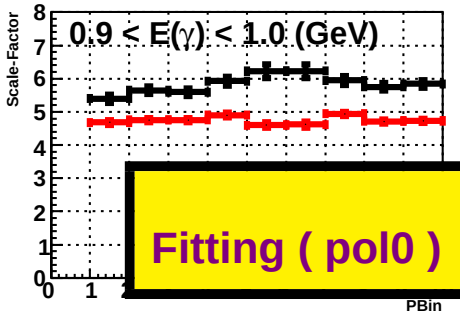
$$\text{Scale Factor} = \frac{phase\_space_{(Butanol)}}{phase\_space_{(Carbon)}}$$

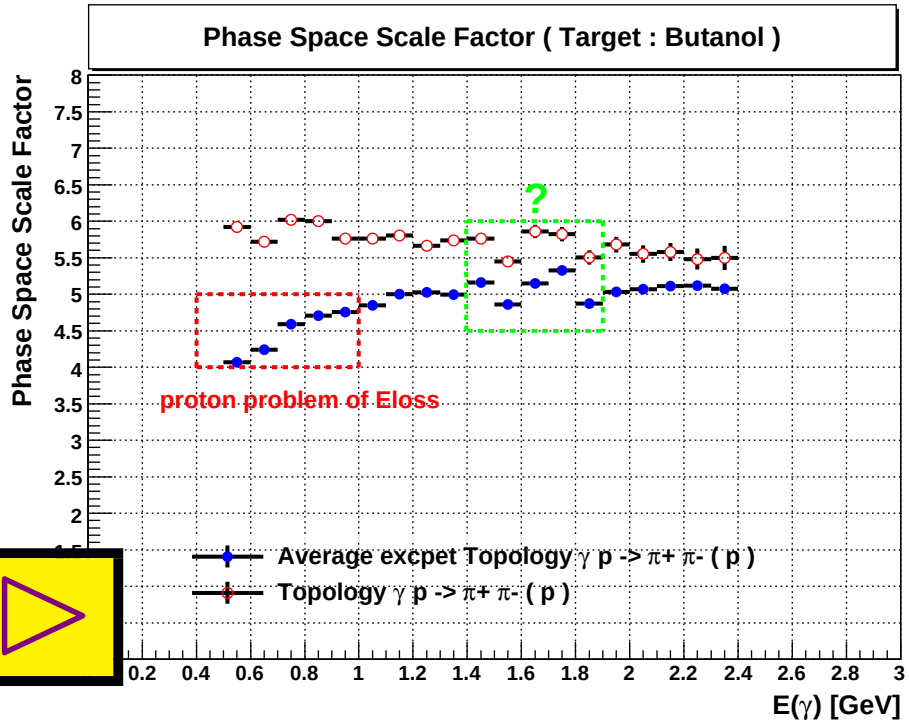
Butanol/Carbon Normalization - Scale Factor



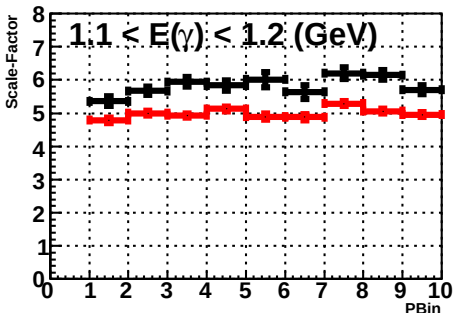


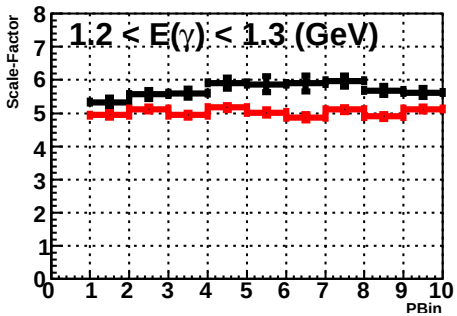


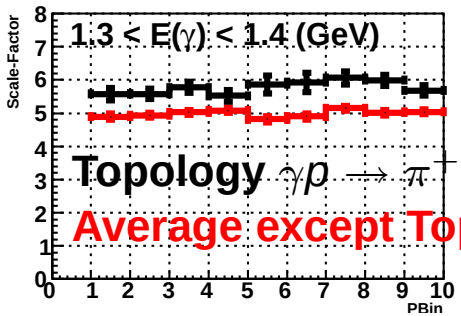




Fitting (pol0)







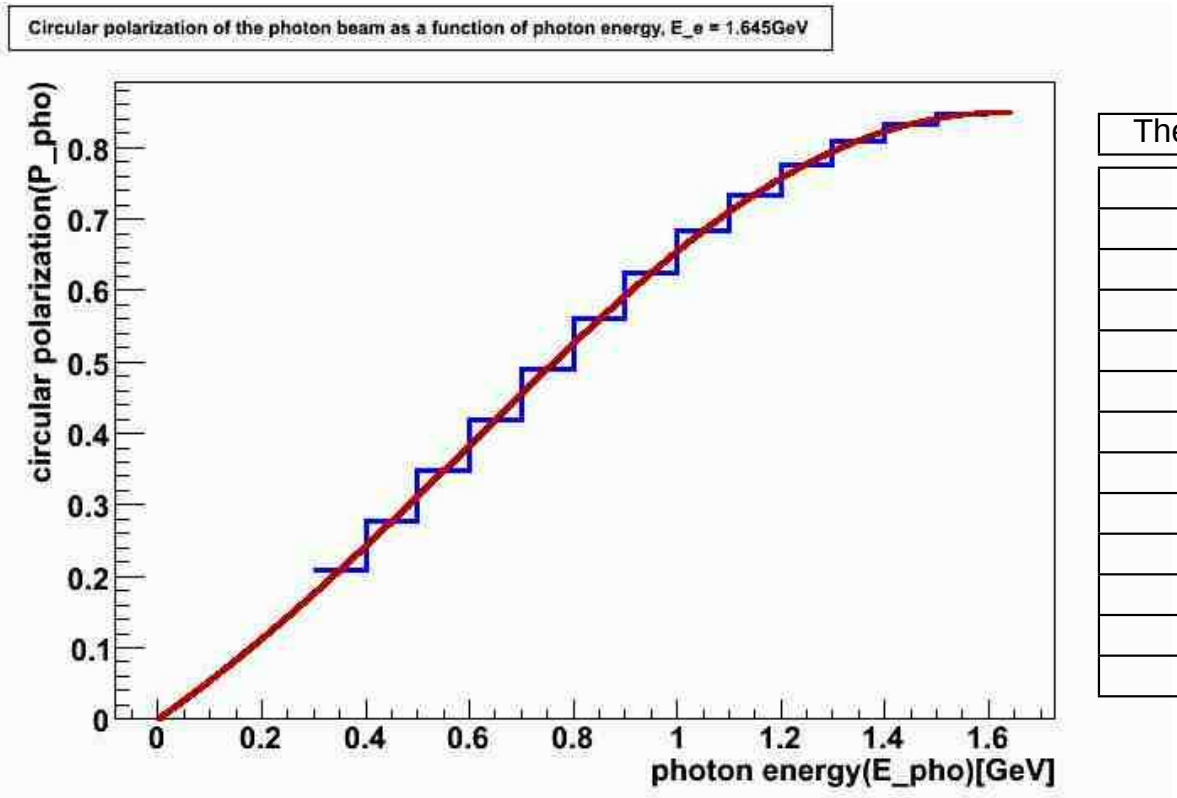
Topology $\gamma p \longrightarrow \pi^+\pi^-(p)$

Average except Topology $\gamma p \rightarrow \pi^+\pi^-(p)$

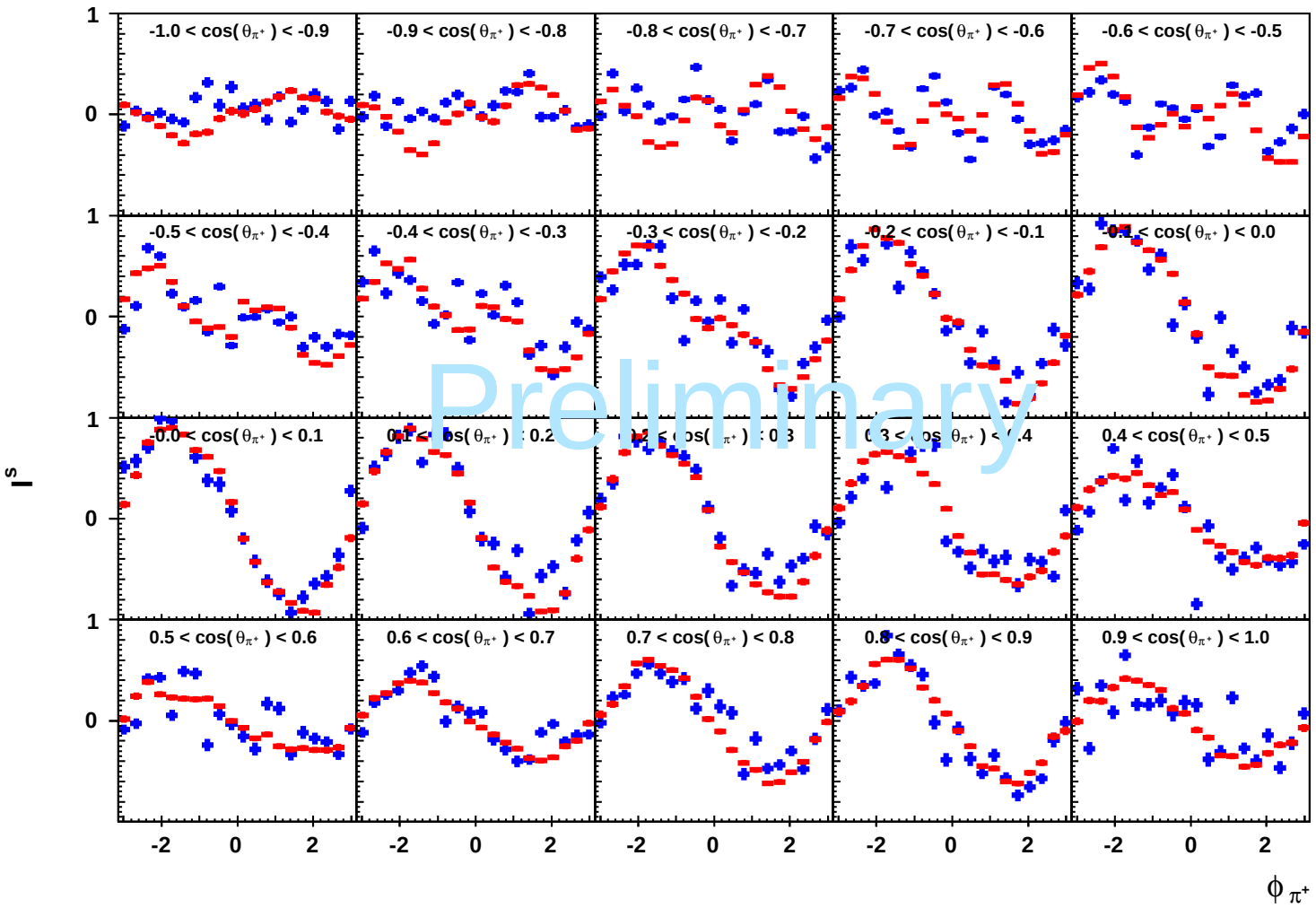
the beam and target polarization

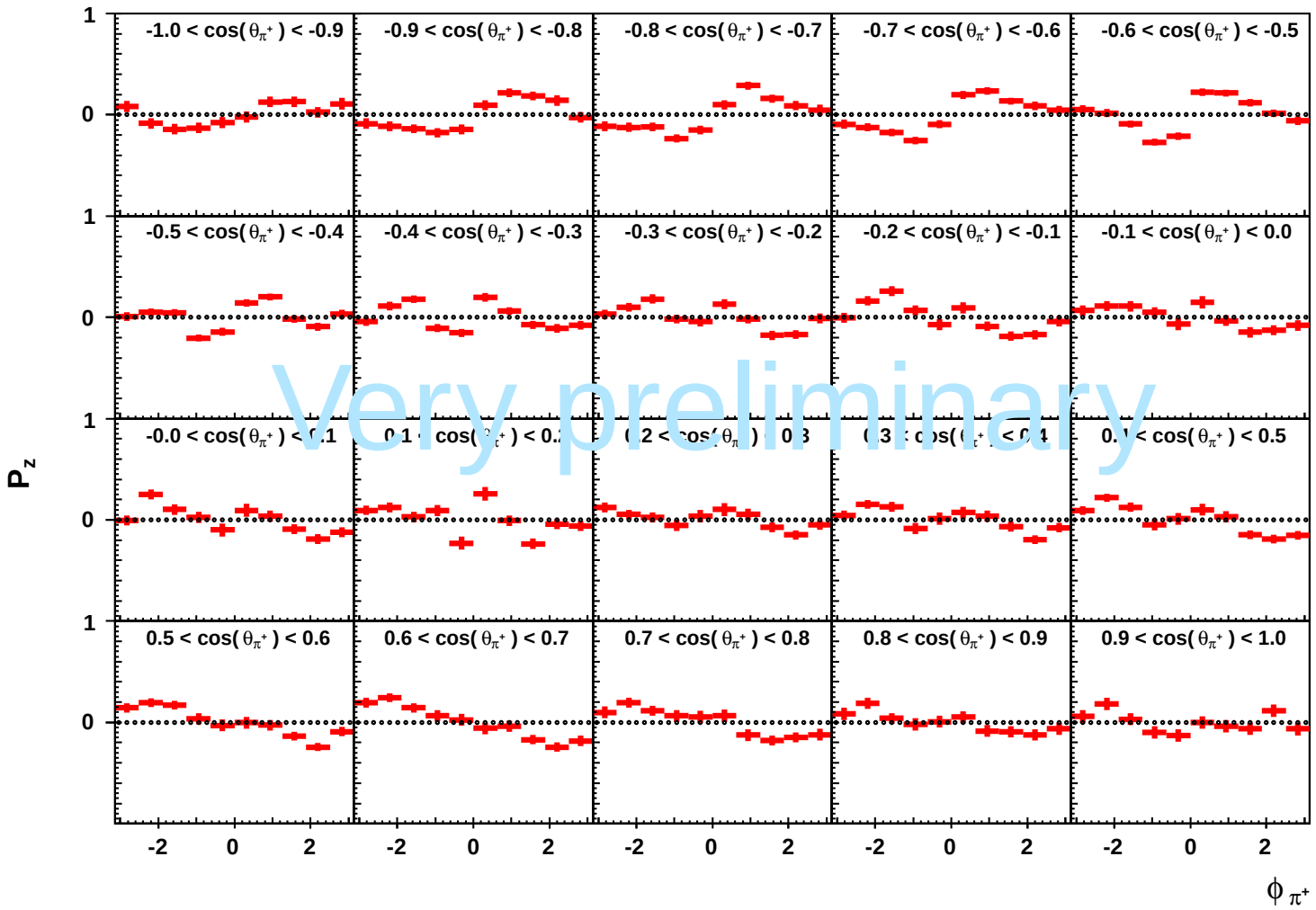
- Target polarization, $\Lambda_z \sim 0.85$
- Electron beam polarization, $P_e \sim 0.85$

$$P_\gamma = P_e \cdot \frac{(\frac{4}{E_e})E_\gamma - (\frac{4}{E_e})^2 E_\gamma^2}{4 - (\frac{4}{E_e})E_\gamma + 3(\frac{4}{E_e})^2 E_\gamma^2}$$



The photon energy [GeV]	The photon polarization
[0.3,0.4]	0.209
[0.4,0.5]	0.277
[0.5,0.6]	0.348
[0.6,0.7]	0.419
[0.7,0.8]	0.490
[0.8,0.9]	0.559
[0.9,1.0]	0.624
[1.0,1.1]	0.683
[1.1,1.2]	0.734
[1.2,1.3]	0.777
[1.3,1.4]	0.810
[1.4,1.5]	0.833
[1.5,1.6]	0.846


-1.0 < cos(θπ+) < -0.9
-0.9 < cos(θπ+) < -0.8
-0.8 < cos(θπ+) < -0.7
-0.7 < cos(θπ+) < -0.6
-0.6 < cos(θπ+) < -0.5
-0.5 < cos(θπ+) < -0.4
-0.4 < cos(θπ+) < -0.3
-0.3 < cos(θπ+) < -0.2
-0.2 < cos(θπ+) < -0.1
-0.1 < cos(θπ+) < 0.0
0.0 < cos(θπ+) < 0.1
0.4 < cos(θπ+) < 0.5
0.5 < cos(θπ+) < 0.6
0.6 < cos(θπ+) < 0.7
0.7 < cos(θπ+) < 0.8
0.8 < cos(θπ+) < 0.9
0.9 < cos(θπ+) < 1.0
Preliminary
I^s
φ π+


-1.0 < cos(θπ+) < -0.9
-0.9 < cos(θπ+) < -0.8
-0.8 < cos(θπ+) < -0.7
-0.7 < cos(θπ+) < -0.6
-0.6 < cos(θπ+) < -0.5
-0.5 < cos(θπ+) < -0.4
-0.4 < cos(θπ+) < -0.3
-0.3 < cos(θπ+) < -0.2
-0.2 < cos(θπ+) < -0.1
-0.1 < cos(θπ+) < 0.0
0.5 < cos(θπ+) < 0.6
0.6 < cos(θπ+) < 0.7
0.7 < cos(θπ+) < 0.8
0.8 < cos(θπ+) < 0.9
0.9 < cos(θπ+) < 1.0
Very preliminary
P z
ϕ π+