Hadron Spectroscopy Working Group - I

Bluejeans link for off line attendes: https://bluejeans.com/245508558

Convener: Dr. Marco Battaglieri (INFN-GE)

Location: L102-104

08:40 **HSWG business** *20'*
Speaker: Dr. Marco Battaglieri (INFN-GE)

09:00 **JPAC update** *20'*
Speaker: Dr. Miguel Albaladejo (JLab)

09:20 **Kaon Photoproduction and the Lambda Weak Decay Parameter** *20'*
Speaker: David Ireland (University of Glasgow)
Material: **Slides**

09:40 **Measurement of polarization observables for Lambda hyperon** *20'*
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Hadron Spectroscopy Working Group - II

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12:20 **Discussion** *10'*

HSWG

CLAS Collaboration Meeting
JLab, Nov 15 2018

+ HS/Deep/Nuclear CLAS12 analyses joint session

Agenda

- ✳ CLAS6 data analysis + CLAS12calibration effort
- ✳ Status of ongoing analysis (update from previous collaboration meeting)
- ✳ Dedicated (joint) session for CLAS12

Talks

- ✳ Over all CLAS contributions, HSWG-related are 27% in 2018
- ✳ Election of HSWG representatives in the CSC
  - A.d'Angelo (currently CSC chair)
  - L.Guo
- ✳ Many thanks to Eugene and Stefan for serving in the CSC
- ✳ JSA-TFC $20k request for 2019

CLAS12-related Activities

- ✳ Bi-weekly HSWG meeting focused on Low-Q2 specific needs:
  - FT Calibration (in coordination with the CALCOM and FirstExperiment)
  - MesonExTrigger studies
  - pId task force
  - review the status of current analysis (similar to Fall '18 DNP preparation)
- ✳ Meeting on Tuesday at 11:00 (JLab-time) every other week
- ✳ All groups are encouraged to look at the data (low/high level) to check calibration, possible issues, …
- ✳ List of ongoing analysis on HSWG wiki page

For discussion

- ✳ Analysis framework
  - MesoneX framework (D.Glazier presentation)
  - alternatives?
- ✳ Analysis tools validation (in coordination with other WG)
  - simple in a shared analysis frame
  - or ?
- ✳ Analysis review optimization (strengthening the FEAR committee)
  - nominate two HSWG observers
  - nominate a reviewer for each analysis as link between with FEAR

Reaction	CLAS running period	Principal Investigator(s)	Graduate Student	Adviser(s)	Contact person(s)	Status
$\gamma^* p \to \pi^0 p$ and eta p	RG-A	Andrea Bianconi, Luca Venturelli			mailto:andrea.bianconi@unibs.it	
Q^2-dependent cross sections for $\gamma^* p \to \pi^+ \pi^- p$ at $Q^2 > 2$ GeV2	RG-A	Krishna Neupane		Ralf Gothe		Underway
$\gamma^* p \to \pi^+ \pi^- p$	RG-A	Adam Thornton		Derek Glazier		Underway
3pi	RG-A	Derek Glazier		Derek Glazier		No Signal Yet
rho beam asymmetry	RG-A	Michael Dugger		Michael Dugger		Underway
Survey of photoproduced cascade states	RG-A	Michael Dugger		Michael Dugger		No Signal Yet
survey of Cascade and Omega baryons	RG-A	Nicholas Zachariou		Nicholas Zachariou		Underway
Omega- cross section	RG-A	Will Phelps				Underway
Inclusive and elastic cross section studies	RG-A	Nikolay Markov			Nikolay Markov	Under way
Single pion electroproduction in the resonance region	RG-A	Nikolay Markov			Nikolay Markov	Under way
Single pion exclusive structure functions at Q2 > 5 GeV2	RG-A	Evgeny Isupov			Evgeny Isupov	Under way
$\gamma^* p \to \pi^+ \pi^- p$ cross sections at Q2 > 5 GeV2	RG-A	Evgeny Golovach			Evgeny Golovach	Under way
Exclusive Two K-short electroproduction cross sections	RG-A	Ken Hicks			Ken Hicks	Just started
N* structure: KY cross section, pol. transfer at Q2 > 1 GeV2	RG-A	Daniel S. Carman			Daniel S. Carman	Under way
Extraction of the nucleon resonance electroexcitation amplitude from $\gamma^* p \to \pi^+ \pi^- p$ electroproduciton off protons with the CLAS12.	RG-A	Viktor Mokeev			Viktor Mokeev	Under way
Evaluation of the resonant contribution into inclusive structure functions.	RG-A	Astrid Hiller Blin			Astrid Hiller Blin	Under way
eta.pi	RG-A	Carlos Salgado		Carlos Salgado		Did not start Yet (in January)
J/psi photoproduciton near threshold	RG-A	Stepan Stepanya	Joseph Newton	Nathan Baltzell, Rafayel Paremuzyan, Valery Kubarovsky		Analysis started
η' and ω decays					Susan Schadmand	Did not start yet

- CLAS12 data analysis
- List on HSWG wiki (https://www.jlab.org/Hall-B/secure/hadron/wiki/index.php/CLAS12_Analysis_projects)
- Keep it updated

WG Reviews status

Released

Polarization Observables in (Vector-)Meson Photoproduction (FROST)
PI: V.Crede
RC: K.Livingston (Chair), V.Mokeev
Status: started on , 1 round done

New since last meeting

WG Reviews status

In progress

Measurement of the G Double-Polarisation Observable in Positive Pion Photoproduction
PI: L.Zana
RC: S.Strauch (Chair), P.Cole, D.Sokhan
Status: 1 round of comments sent on August, waiting for the response

Vector-Meson Photoproduction decaying to Multitrack-Final States using CLAS-g12 Data
PI: Z.Akbar
RC: John Price (Chair), Susan Schadmand , Eugene Pasyuk
Status: started on Jan 1, progressing, the committee received the author's response, NEED TO GIVE FEEDBACK ASAP

WG Reviews status

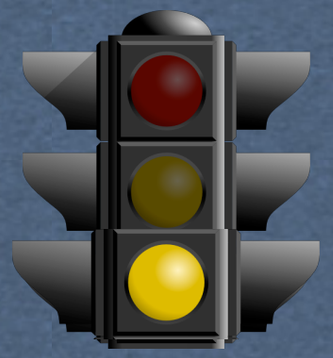
In progress

Exclusive pi- Electroproduction off the Neutron in Deuterium in the Resonance Region

PI: Y. Tian
RC: Nikolay Markov (Chair), Mikhail Bashkanov , Eugene Isupov
Status: 1st round in August, waiting for response from PI, response received, II round in preparation

Dalitz Plot Analysis of eta' to eta pi pi − from CLAS g12 Data Set

PI: S. Ghosh
RC: V. Crede (chair), A. Rizzo, E. Pasyuk
Status: Started in July'17; first round of comments on Sept 17: no response from the PI since then.
Scarce communication with the review committee. Is the analysis dead ?????



Polarization Observables T and F in the $\vec{p}(\vec{\gamma},\pi 0)p$ Reaction

PI: H. Jiang
RC: Barry Ritchie (Chair), Volker Crede , Bryan McKinnon
Status: the group is working on major issue, new Aanalysis Note expected by the end of the month

Photoproduction of the 3π mesons in the reaction $\gamma p \rightarrow \pi+\pi+\pi-n$ with CLAS detector at 6 GeV/c2

PI: P. Eugenio
RC: D. Glazier (chair), A. Filippi, M. Dugger
Status: 2nd round, response received, almost done

WG Reviews status

Pentaquark search in g10 by using the MMSA method

PI: Kenneth Hicks et al.
RC: Stepan Stepanyan (Chair), Lei Guo , Bryan McKinnon
Started Aug 2015
Status: NO progress

KLambda and KSigma from FROST

PI: N.Walforf et al.
RC: S.Strauch, M.Holtrop, P.Mattione,
Started May 2015
I round of comments in May 2015, waiting for a revised Status: stalled for a long while, now it seems to be resurrected, unfortunately NO, no news …
Should we give the analysis to another group?

Radiative decay of eta' to pi+ pi- gamma from g11 data set

PI:G. Mbianda Njencheu
RC: R. Schumacher,S.Schadmand,A.Celentano
Status: no response in many months ??????

Spin observables in eta meson photoproduction on the proton from FROST data

PI: R.Tucker (ArizonaU) et al.
RC: K.Livingston, J.Price, Xiangdong Wei
Sterted July 2016
Status: on-hold, still on-hold but authors are alive, paused for a while, still on-hold, …

Exclusive Photo-Production Measurement of K+Sigma*- off Quasi-Free Neutrons in Deuterium

PI: H.Lu (SCU) et al.
RC: N.Zachariou, M.Dugger, D.MacGregor
Started in 2012 (!)
Status: ?????????????

Actions

- ✳ Remove these analyses from the list of active analyses
- ✳ Share this information to the whole HSWG to see if ay resources could be allocated to continue (assuming full collaboration from the former PI!)

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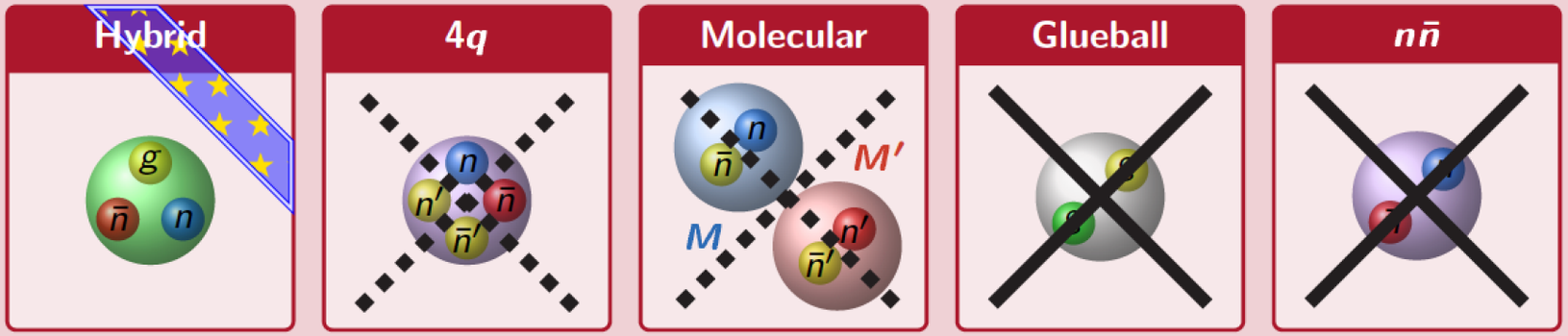
Miguel Albaladejo (Jefferson Lab – Theory Center)

November 15, 2018

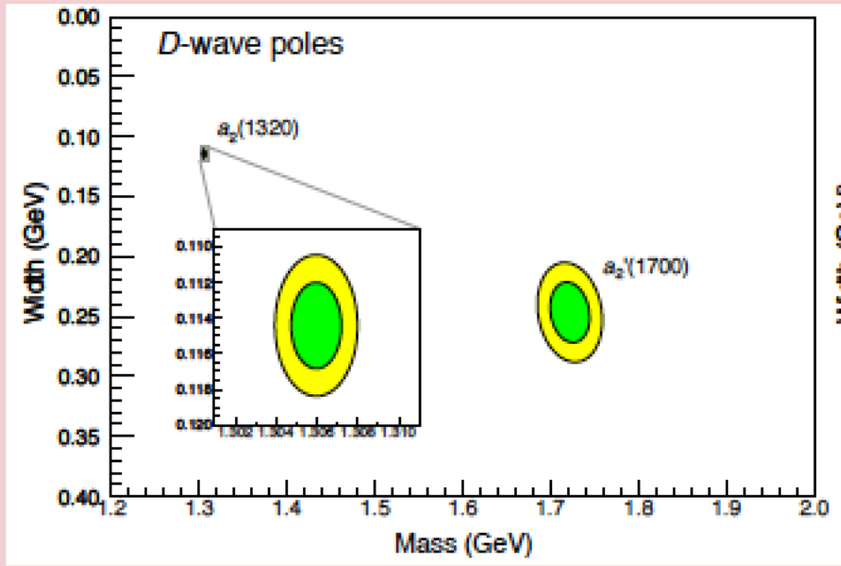
π_1: Introduction

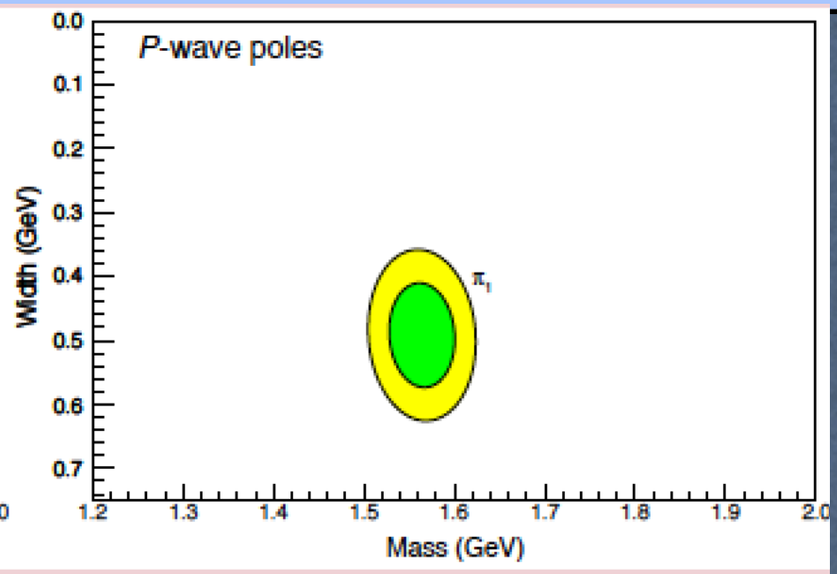


- $J^{PC} = 1^{-+}$ discards $q\bar{q}$
- $I = 1$ discards **glueball**.
- **Molecular** interpretation is very difficult.
- **Tetraquark? Hybrid?**
  - $\pi_1(1600)$ is consistent with the expected lightest hybrid ($1.7 - 1.9$ GeV).
  - $\pi_1(1400)$ *could* be interpreted as a tetraquark, but this brings more problems than solutions...

In this work...

We study COMPASS data ($\pi p \to \eta^{(\prime)} \pi p$) to shed some light into the π_1 puzzle

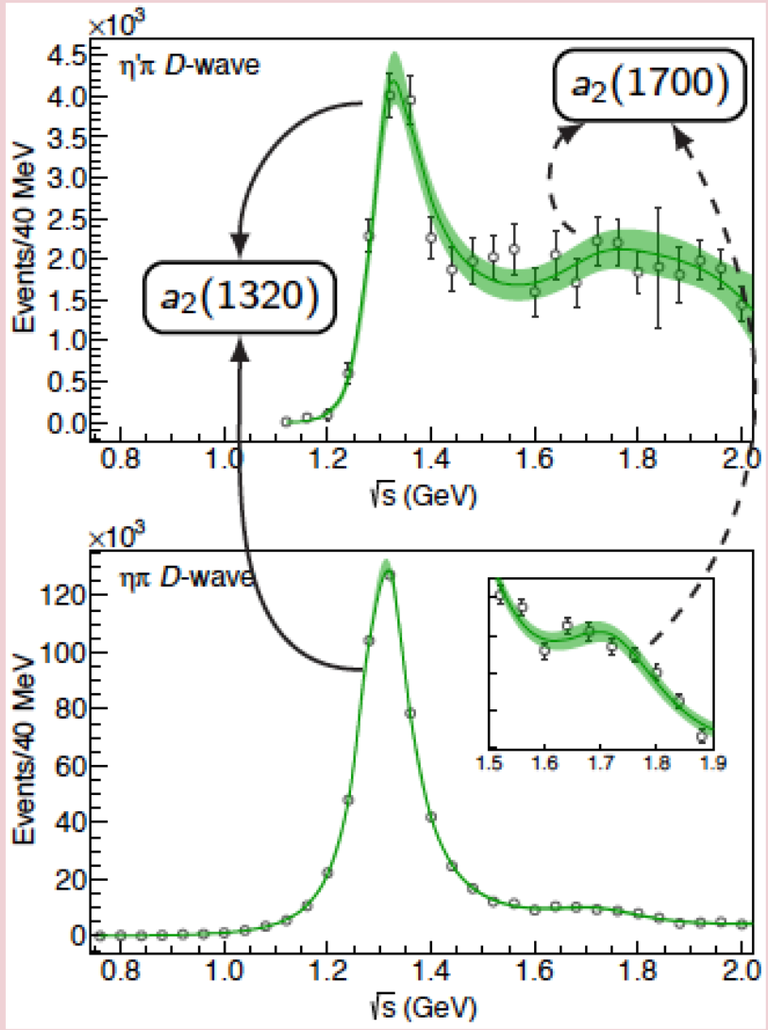


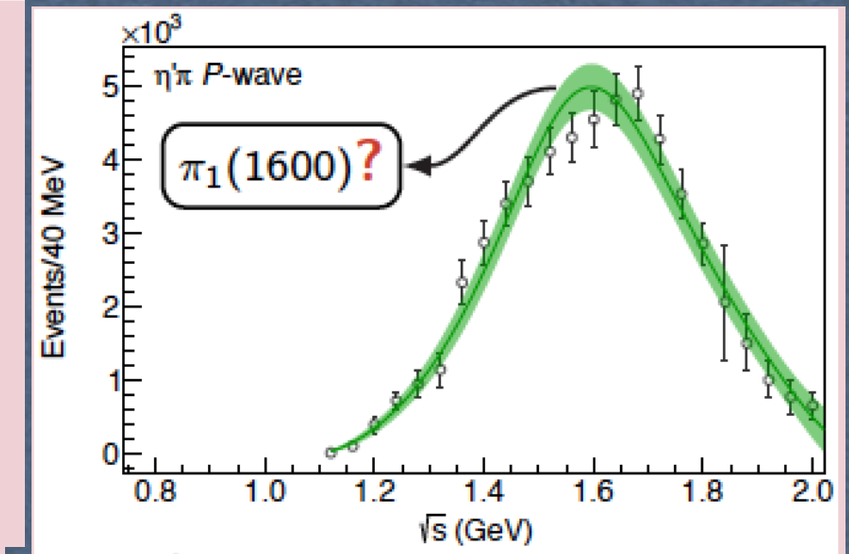


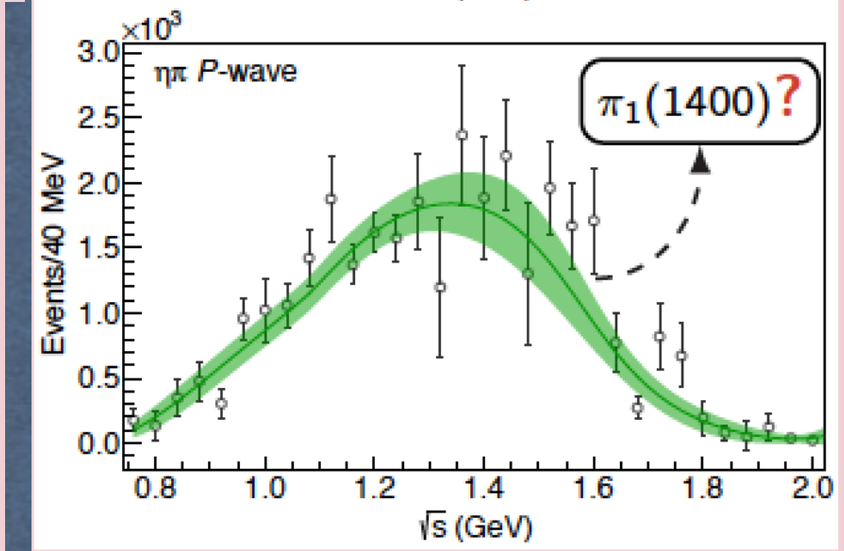
Pole	Mass (MeV)	Width (MeV)
$a_2(1320)$	1306.0(0.8)(1.3)	114.4(1.6)(0.0)
$a_2(1700)$	1722(15)(67)	247(17)(63)
π_1	1564(24)(86)	492(54)(102)

Conclusion

A single broad π_1 state ($\sim$ 1600 MeV) is able to reproduce both set ($\eta\pi$ and $\eta'\pi$) of data







Polarized moments: summary

MA, V. Mathieu *et al.* (JPAC), *in preparation*

- Introduce polarized intensities:

$$I(\Omega,\Phi) = I^0(\Omega) + \vec{P}_\gamma(\Phi)\cdot\vec{I}(\Omega)\ .$$

- Decompose $I^\alpha(\Omega)$ into moments $H^\alpha(LM)$,

$$I^\alpha(\Omega) = \sum_{L,M} \frac{2L+1}{4\pi} H^\alpha(LM) D^{L*}_{M0}(\Omega)\ ,$$

$$H^\alpha(LM) = \int \mathrm{d}\Omega\ I^\alpha(\Omega)\ D^L_{M0}(\Omega)\ .$$

- Expand $T_{\lambda;\lambda_1,\lambda_2}$ in $\eta\pi$ partial waves:

$$T_{\lambda;\lambda_1,\lambda_2}(\Omega) = \sum_{\ell,m} T^{\ell m}_{\lambda;\lambda_1,\lambda_2} Y^m_\ell(\Omega)\ ,$$

- SDME for arbitrary ℓ, ℓ':

$$(\rho_\alpha)^{\ell\ell'}_{mm'} = \sum_{\substack{\lambda,\lambda'\\ \lambda_1,\lambda_2}} T^{\ell m}_{\lambda;\lambda_1,\lambda_2} \frac{\sigma^\alpha_{\lambda\lambda'}}{2} T^{\ell' m'*}_{\lambda';\lambda_1,\lambda_2}$$

- Express $H^\alpha(LM)$ in terms of SDME:

$$H^\alpha(LM) = \sum_{\substack{\ell,\ell'\\ m,m'}} \left(\frac{2\ell'+1}{2\ell+1}\right) \langle \ell' 0, L0 |\ \ell 0\rangle \times \langle \ell' m', LM |\ \ell m\rangle\, (\rho_\alpha)^{\ell\ell'}_{mm'}$$

Beam asymmetry Σ:

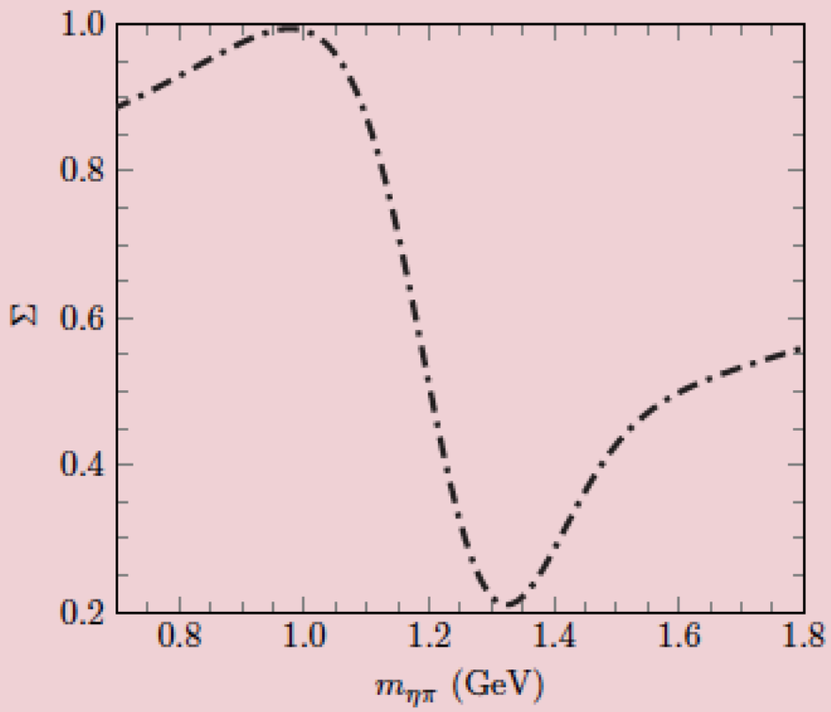
$$\int \mathrm{d}\Omega\ I(\Omega,\Phi) \equiv \sigma^0\left(1 + P_\gamma \Sigma \cos(2\Phi)\right)$$

Predictions with a simple model

MA, V

Simplifying assumptions:

- $\ell_{\max} = 2$ in $\eta\pi$ system ($L_{\max} = 4$ in $H(LM)$),
- $|\lambda - m| \leqslant 1$,
- Only positive naturality waves are included,
- Three resonances are included: $a_0(980)$, $\pi_1(1600)$, $a_2(1320)$.



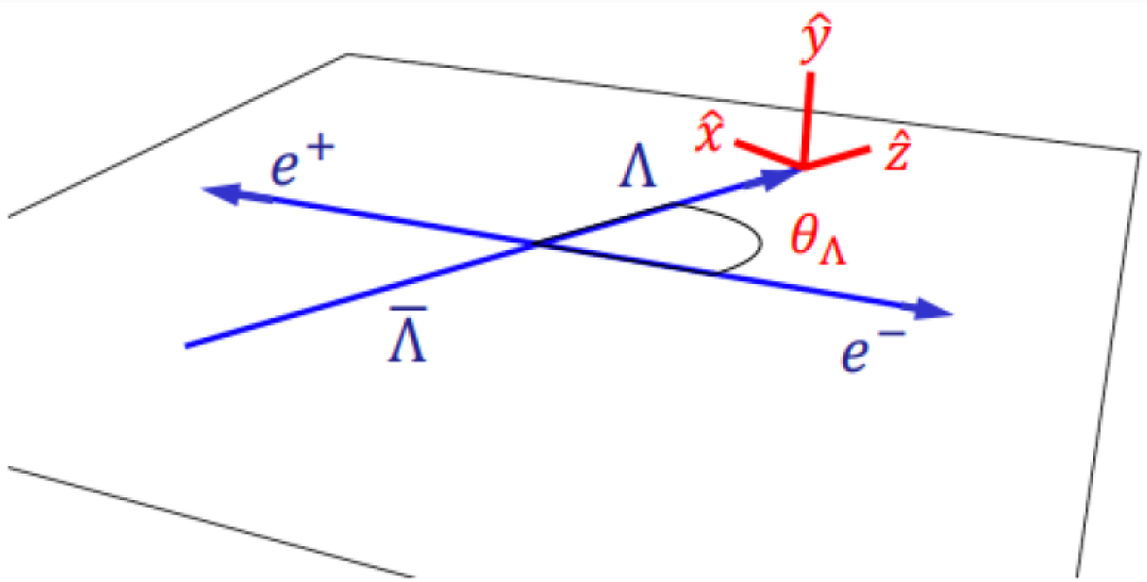
Kaon Photoproduction and the Λ Weak Decay Parameter

CLAS HSWG meeting

D.G. Ireland

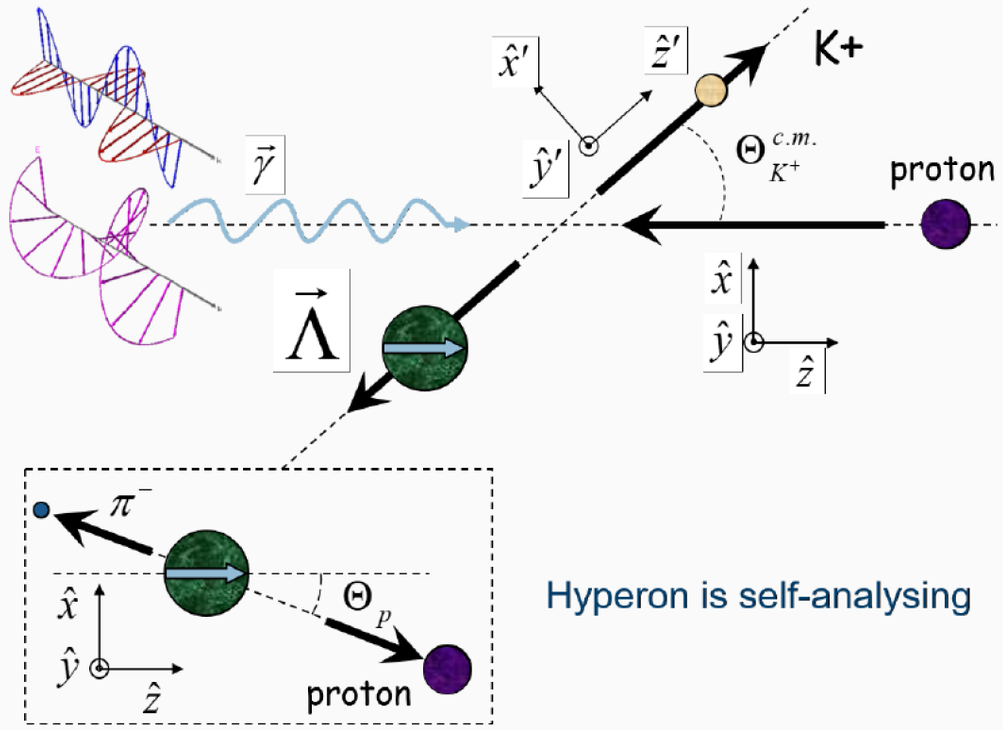
15 November, 2018

The Recent BESIII Result



$$\mathcal{W}(\boldsymbol{\xi};\alpha_\psi,\Delta\Phi,\alpha_-,\alpha_+) = 1+\alpha_\psi\cos^2\theta_\Lambda + \alpha_-\alpha_+\left[\sin^2\theta_\Lambda\left(n_{1,x}n_{2,x}-\alpha_\psi n_{1,y}n_{2,y}\right)+\left(\cos^2\theta_\Lambda+\alpha_\psi\right)n_{1,z}n_{2,z}\right] + \alpha_-\alpha_+\sqrt{1-\alpha_\psi{}^2}\cos(\Delta\Phi)\sin\theta_\Lambda\cos\theta_\Lambda\left(n_{1,x}n_{2,z}+n_{1,z}n_{2,x}\right) + \sqrt{1-\alpha_\psi{}^2}\sin(\Delta\Phi)\,\sin\theta_\Lambda\cos\theta_\Lambda\left(\alpha_-n_{1,y}+\alpha_+n_{2,y}\right),$$

Kaon Photoproduction - $K\Lambda$ example



Hyperon is self-analysing

Parameters	This work	Previous results
α_ψ	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027 [25]
$\Delta\Phi$	$(42.4 + 0.6 + 0.5)^\circ$	–
α_-	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013 [27]
α_+	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08 [27]
$\bar{\alpha}_0$	$-0.692 \pm 0.016 \pm 0.006$	–
A_{CP}	$-0.006 \pm 0.012 \pm 0.007$	0.006 ± 0.021 [27]
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$	–

Consequences for Observables from g8 and g1c?

Experimental Polarization Configurations:

LUY: Linear photon beam; unpolarized target; measured recoil

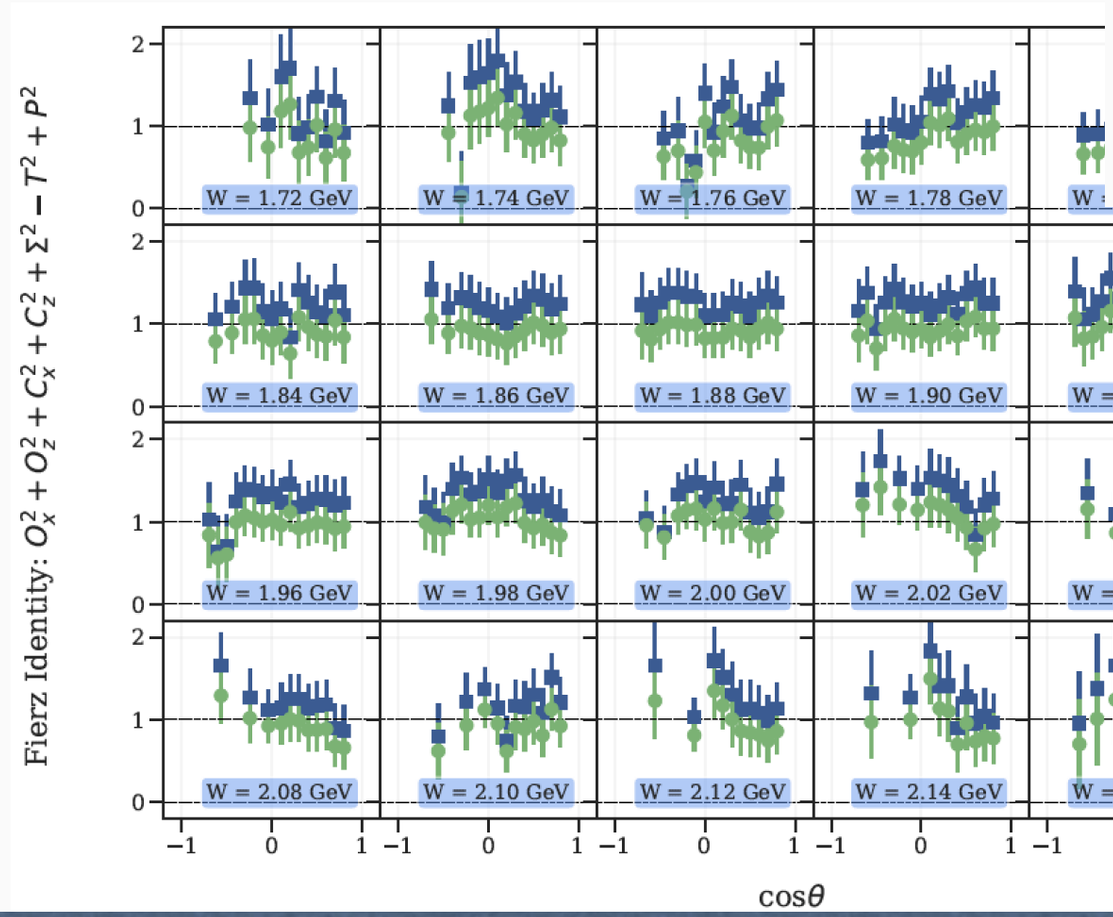
Intensity:

$$1 + \alpha_- \cos\theta_y \mathbf{P} - \{\mathbf{\Sigma} + \alpha_- \cos\theta_y \mathbf{T}\} P_L^\gamma \cos 2(\alpha - \phi) + \{\alpha_- \cos\theta_x \mathbf{O_x} + \alpha_- \cos\theta_z \mathbf{O_z}\} P_L^\gamma \sin 2(\alpha - \phi)$$

CUY: Circularly photon beam; unpolarized target; measured recoil

Intensity:

$$1 + \alpha_- \cos\theta_y \mathbf{P} + (\alpha_- \cos\theta_x \mathbf{C_x} + \alpha_- \cos\theta_z \mathbf{C_z}) P_C^\gamma$$



Fierz identity connecting two experiments:

$$\mathbf{O_x}^2 + \mathbf{O_z}^2 + \mathbf{C_x}^2 + \mathbf{C_z}^2 + \mathbf{\Sigma}^2 - \mathbf{T}^2 + \mathbf{P}^2 = 1$$

Using New Weak Decay Parameter for Jülich-Bonn Fits

Observable (# data points)	χ^2/n (JüBo2017) unscaled	scaled	χ^2/n (Refit) unscaled	scaled
$d\sigma/d\Omega$ (421)	2.65	2.65	1.11	0.96
Σ (314)	5.00	5.00	2.55	2.48
T (314)	1.96	3.00	1.75	1.29
P (410)	1.49	0.91	1.84	1.28
C_x (82)	1.99	1.56	2.15	1.30
C_z (85)	1.95	1.12	1.58	1.34
O_x (314)	1.63	2.00	1.44	1.18
O_z (314)	1.62	1.64	1.34	1.23
all (2254)	2.33	2.38	1.67	1.37

Source	Value
PDG	0.642 ± 0.013
BES III	$0.750 \pm 0.009 \pm 0.004$
CLAS	0.747 ± 0.006 (uniform)
	0.731 ± 0.014 (gaussian)

- New BES III result for α_- is 17% higher than PDG value
- Affects all recoil observables relying on Λ weak decay
- CLAS data corroborates BES result
- Previous physics interpretations are $\sim$ safe
- Preliminary calculation shows CLAS data can independently determine α_-
- More checks and cross-validation to do...

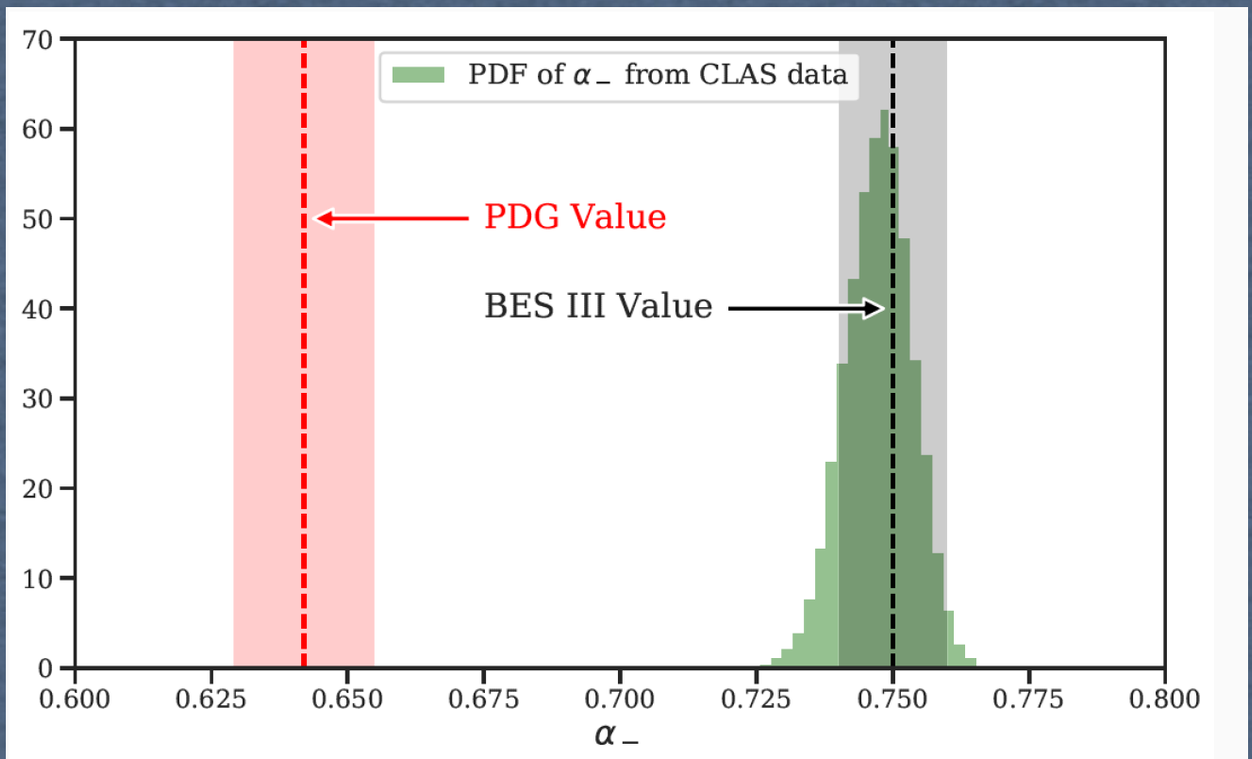
Measuring α_- from g8 and g1c data?

Define function

$$\mathcal{F}(a, l, c) = a^2 l^2 \left(\mathbf{O_x}^2 + \mathbf{O_z}^2 - \mathbf{T}^2\right) + a^2 c^2 \left(\mathbf{C_x}^2 + \mathbf{C_z}^2\right) + l^2 \mathbf{\Sigma}^2 + a^2 \mathbf{P}^2,$$

where a, l, c are the relative calibrations (i.e. systematics) for α_-, linear photon polarization and circular polarization, resp.

- Impose $\alpha_- \geq 0$
- Quoted systematic uncertainties in P_γ^L are 3-6% (use 5)
- Quoted systematic uncertainties in P_γ^C are 2% (use 2%)
- Which PDF to use? Gaussian $\mathcal{N}(1, \sigma)$? Uniform $\mathcal{U}(1-\sigma, 1+\sigma)$?



Measurement of polarization observables for Λ hyperon.

Shankar Adhikari

Missing Baryon Problem and $K^+\Lambda$ channel

From an experimental point-of-view;

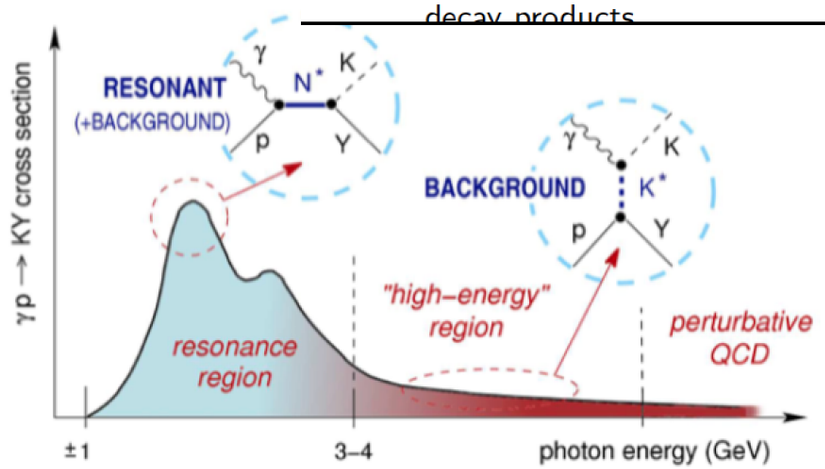
- Pion beams was the primary tool to study resonances. It is predicted that the high-mass resonances predominantly couple to γ beams.
- Not all resonances couple strongly to the $N\pi$ channel; coupled to other channels as well.
- Interference of states: Resonances are broad and overlapping, possible interference between N and Δ states.
- $\gamma p \to K^+\Lambda$ channel is important that;
  - only contribute to N^* with $I = 1/2$.
  - $\Lambda \to p\pi^-$, self-analyzing nature of Λ hyperon allow us to measure polarization observables from its decay products.

			Status as seen in									
Particle	J^P	overall	$N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$	ΛK	ΣK	$N\rho$	$N\omega$	$N\eta'$
N	$1/2^+$	****										
$N(1440)$	$1/2^+$	****	****	****	****	***						
$N(1520)$	$3/2^-$	****	****	****	****	**	****					
$N(1535)$	$1/2^-$	****	****	****	***	*	****					
$N(1650)$	$1/2^-$	****	****	****	***	*	****	*				
$N(1675)$	$5/2^-$	****	****	****	****	***	*	*	*			
$N(1680)$	$5/2^+$	****	****	****	****	***	*	*	*			
$N(1700)$	$3/2^-$	***	**	***	***	*	*			*		
$N(1710)$	$1/2^+$	****	****	****	*		***	**	*	*	*	
$N(1720)$	$3/2^+$	****	****	****	***	*	*	****	*	*	*	
$N(1860)$	$5/2^+$	**	*	**		*	*					
$N(1875)$	$3/2^-$	***	**	**	*	**	*	*	*	*	*	
$N(1880)$	$1/2^+$	***	**	*	**	*	*	**	**		**	
$N(1895)$	$1/2^-$	****	****	*	*	*	****	**	**	*	*	****
$N(1900)$	$3/2^+$	****	****	**	**	*	*	**	**		*	**
$N(1990)$	$7/2^+$	**	**	**			*	*	*			
$N(2000)$	$5/2^+$	**	**	*	**	*	*				*	
$N(2040)$	$3/2^+$	*		*								
$N(2060)$	$5/2^-$	***	***	**	*	*	*	*	*	*	*	
$N(2100)$	$1/2^+$	***	**	***	**	**	*	*		*	*	**
$N(2120)$	$3/2^-$	***	***	**	**	**		**	*		*	*
$N(2190)$	$7/2^-$	****	****	****	****	**	*	**	*	*	*	
$N(2220)$	$9/2^+$	****	**	****			*	*	*			
$N(2250)$	$9/2^-$	****	**	****			*	*	*			
$N(2300)$	$1/2^+$	**		**								
$N(2570)$	$5/2^-$	**		**								
$N(2600)$	$11/2^-$	***		***								
$N(2700)$	$13/2^+$	**		**								

**** Existence is certain.
*** Existence is very likely.
** Evidence of existence is fair.
* Evidence of existence is poor.

... polarization observables are sensitive to the interefence from different states and different processes.

- $\gamma p \to K^+\Lambda$; resonant and non-resonant process. Significant background from non-resonant processes which are entangled with resonant processes. Crucial to understand non-resonant process.
- C_x and C_z: E_γ up to 5.45 Gev or W up to 3.33 GeV (previously 2.5 GeV)
- P: W up to 3.33 GeV (previously 2.8 GeV)



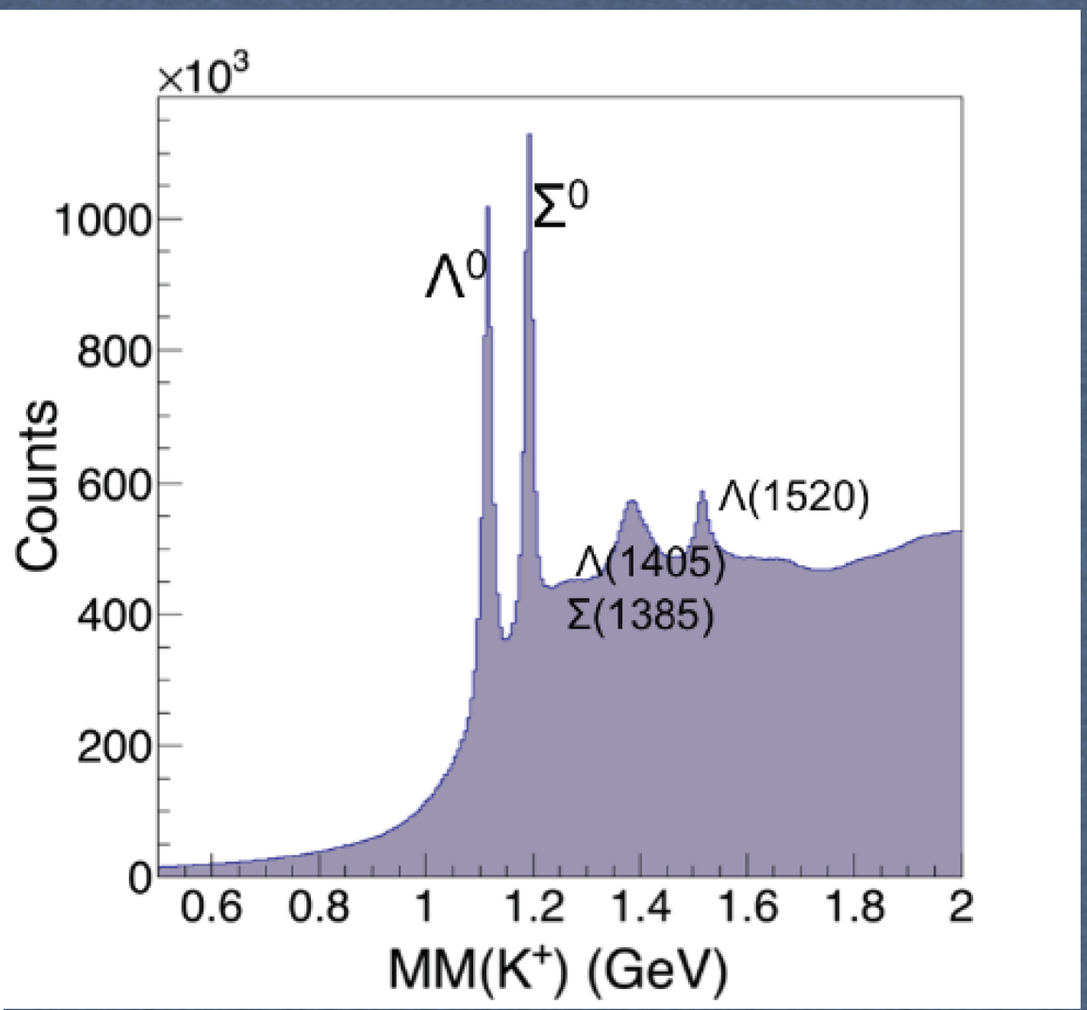
credit: T. Corthals

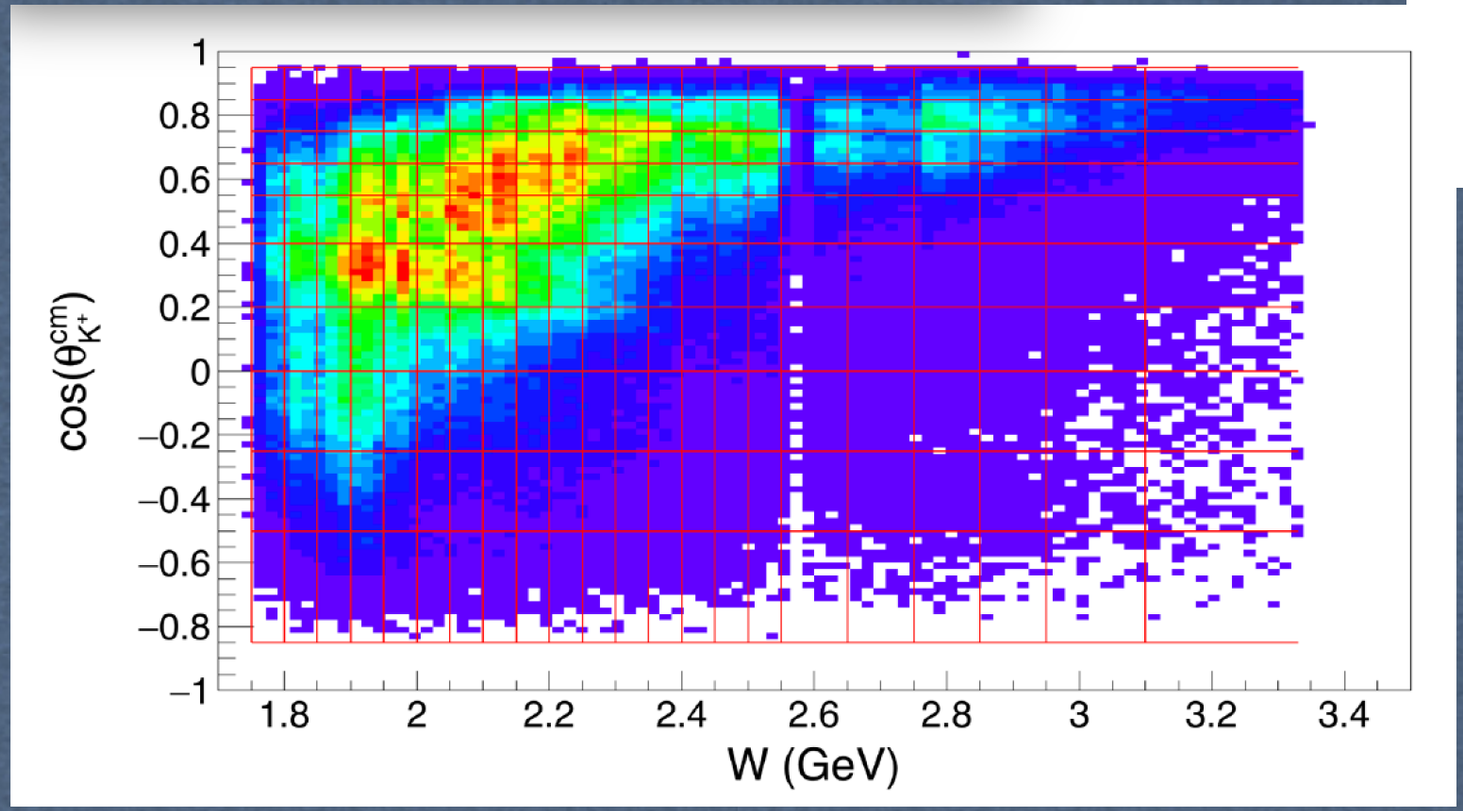
g12 Experiment using CLAS @ JLab

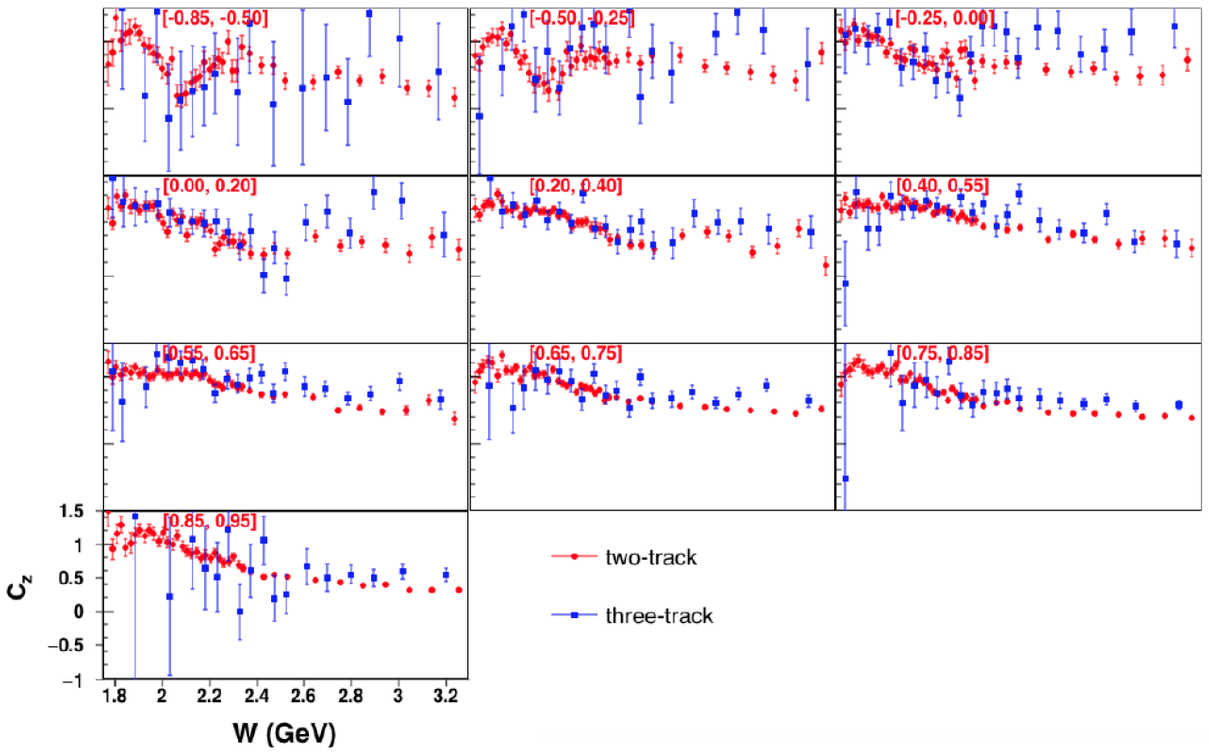
$\gamma p \to K^+\Lambda$, Λ decay mode

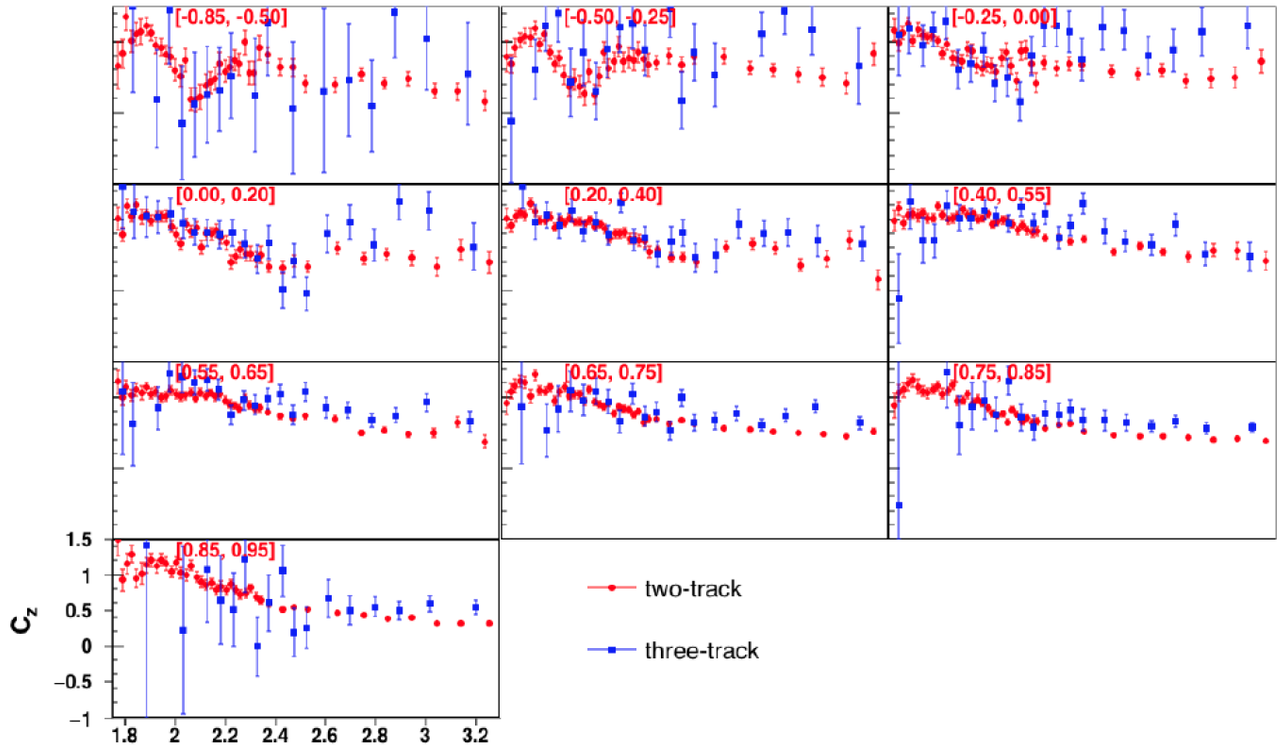
$p\pi^- \to 64\%$ $n\pi^\circ \to 36\%$.

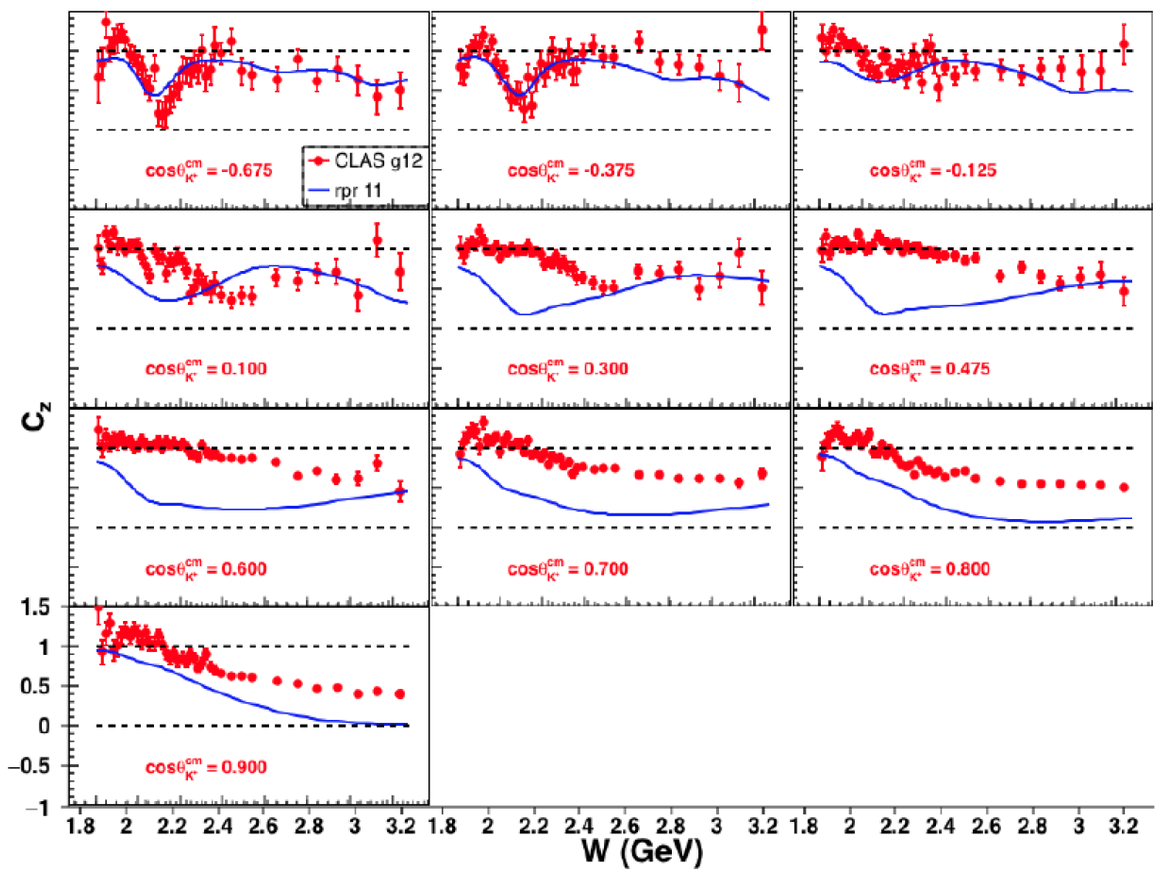
Final state K^+, proton, and π^- are required in data.











- Regge-Plus-Resonance Fit:
  – added t-channel contributions, exchange $K(494)$ and $K^*(892)$

RPR-2011 (PDG-2010)

- $S_{11}(1535)$ ★★★★
- $S_{11}(1650)$ ★★★★
- $D_{15}(1675)$ ★★★★
- $F_{15}(1680)$ ★★★★
- $D_{13}(1700)$ ★★★
- $P_{11}(1710)$ ★★★
- $P_{13}(1720)$ ★★★★
- $D_{13}(1875)$ *m*
- $P_{13}(1900)$ ★★
- $P_{11}(1900)$ *m*
- $F_{15}(2000)$ ★★★

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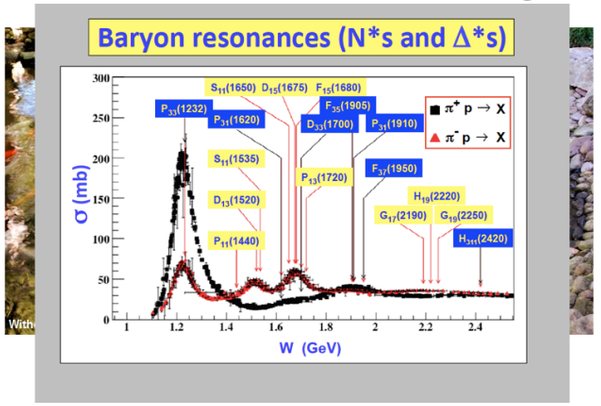
Beam Asymmetry for photoproduced ω mesons off bound protons in deuterons

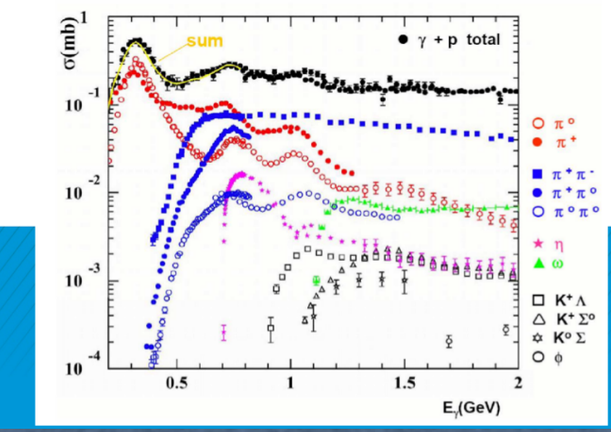
Olga Cortes Becerra

clas
CEBAF Large Acceptance Spectrometer

Motivation

Hadron spectroscopy





Bound nucleon

- There are some technicalities that have to be taken into account:
  - Fermi momentum smearing the distributions
  - Moving to the CoM frame has to take into account the Fermi momentum
  - All particles have to be detected
- How we treat the bound proton will give us a hint on how to treat bound neutron data (all neutron data)

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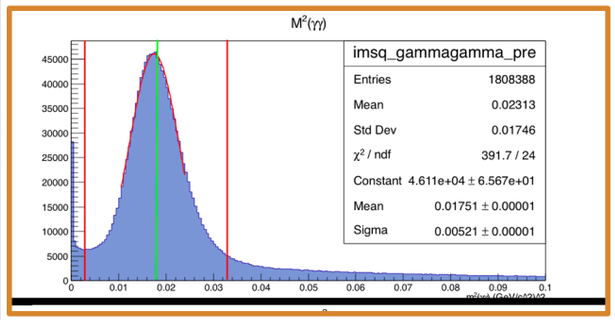
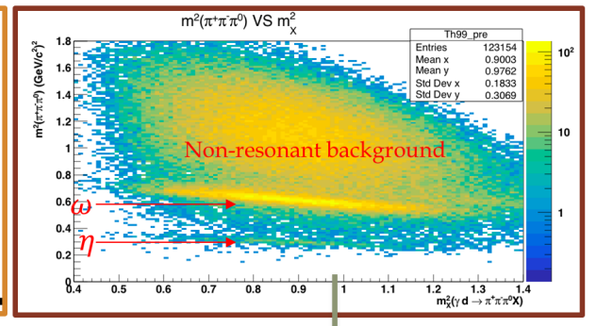
g13b:

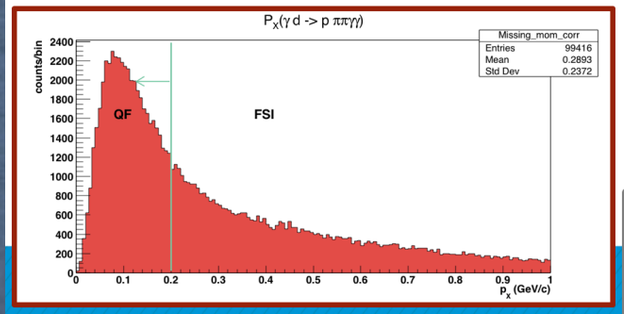
- Real photon. $E_\gamma = 1.1 - 2.3$ GeV
- Linearly polarized photons: Coherent Bremsstrahlung
- 40 cm deuterium target

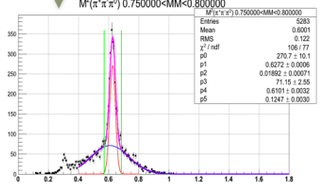
Data analysis: Event reconstruction

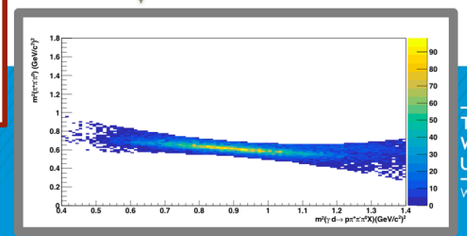
$$\gamma d \to \omega \; p(n)$$
$$\omega \to \pi^+\pi^- \pi^0$$
$$\pi^0 \to \gamma\gamma$$











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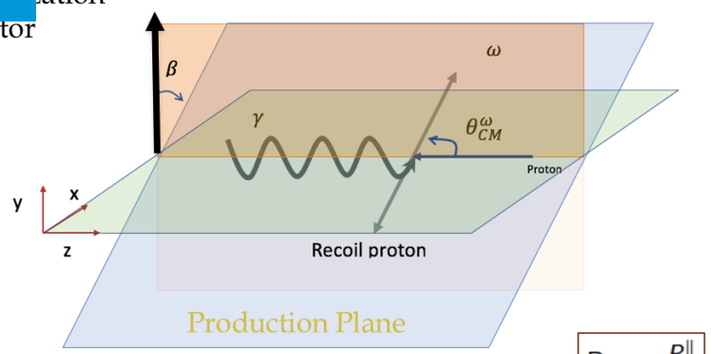
Beam Asymmetry

Vector ization



Perpendicular:

$$\varphi = \pi/2$$

$$\beta = \phi - \varphi$$

Parallel:

$$\varphi = 0$$

$$P_R = \frac{P^{\parallel}}{P^{\perp}}$$

$$\frac{(\frac{dN}{d\phi})^{\perp} - (\frac{dN}{d\phi})^{\parallel}}{(\frac{dN}{d\phi})^{\parallel} + (\frac{dN}{d\phi})^{\perp}} = \frac{1 - F_R + \frac{F_R P_R + 1}{P_R + 1} 2\bar{P}\Sigma \frac{\sin\Delta\phi}{\Delta\phi} \cos(2(\phi - \phi_0))}{1 + F_R + \frac{F_R P_R - 1}{P_R + 1} 2\bar{P}\Sigma \frac{\sin\Delta\phi}{\Delta\phi} \cos(2(\phi - \phi_0))} \quad (1)$$

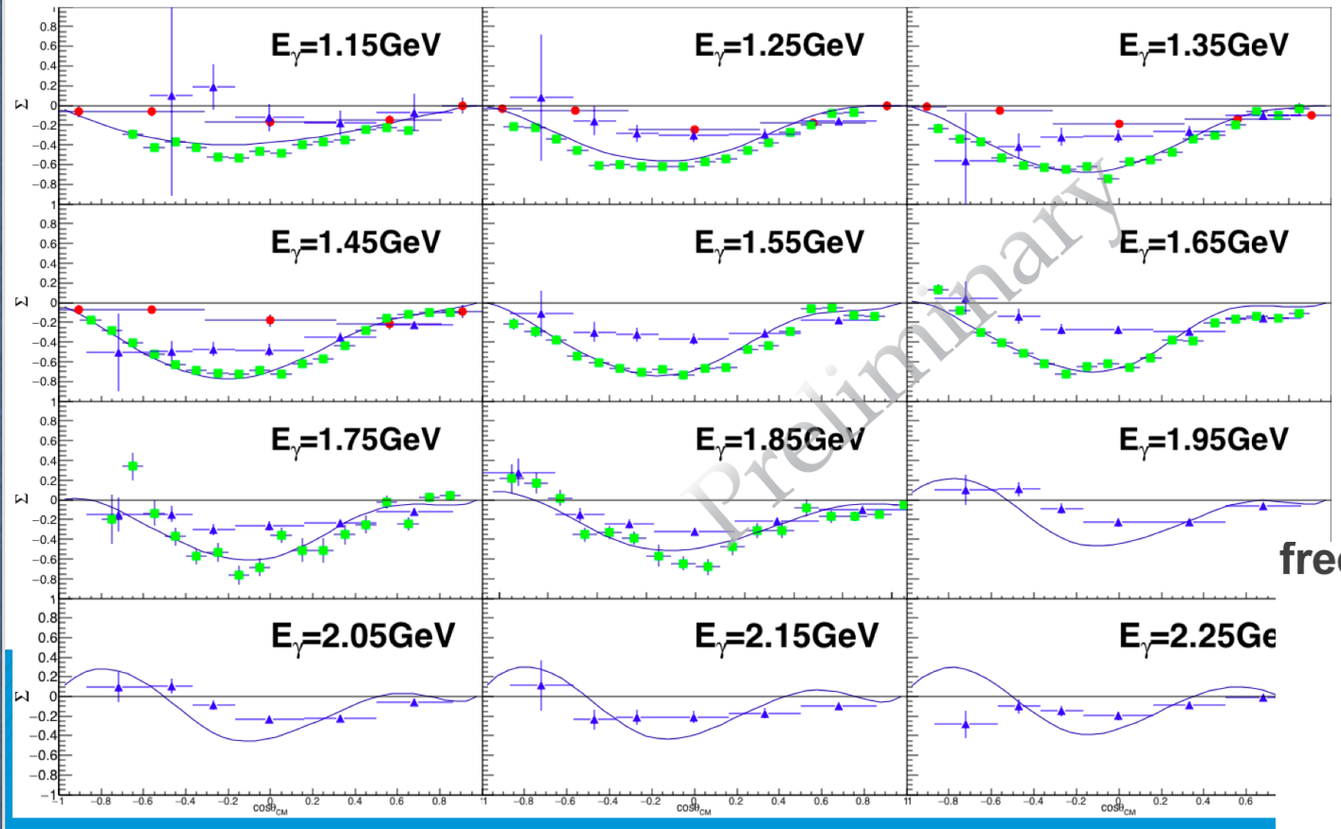
Background corrected

flux ratio $F_R = \frac{F^{\perp}}{F^{\parallel}}$

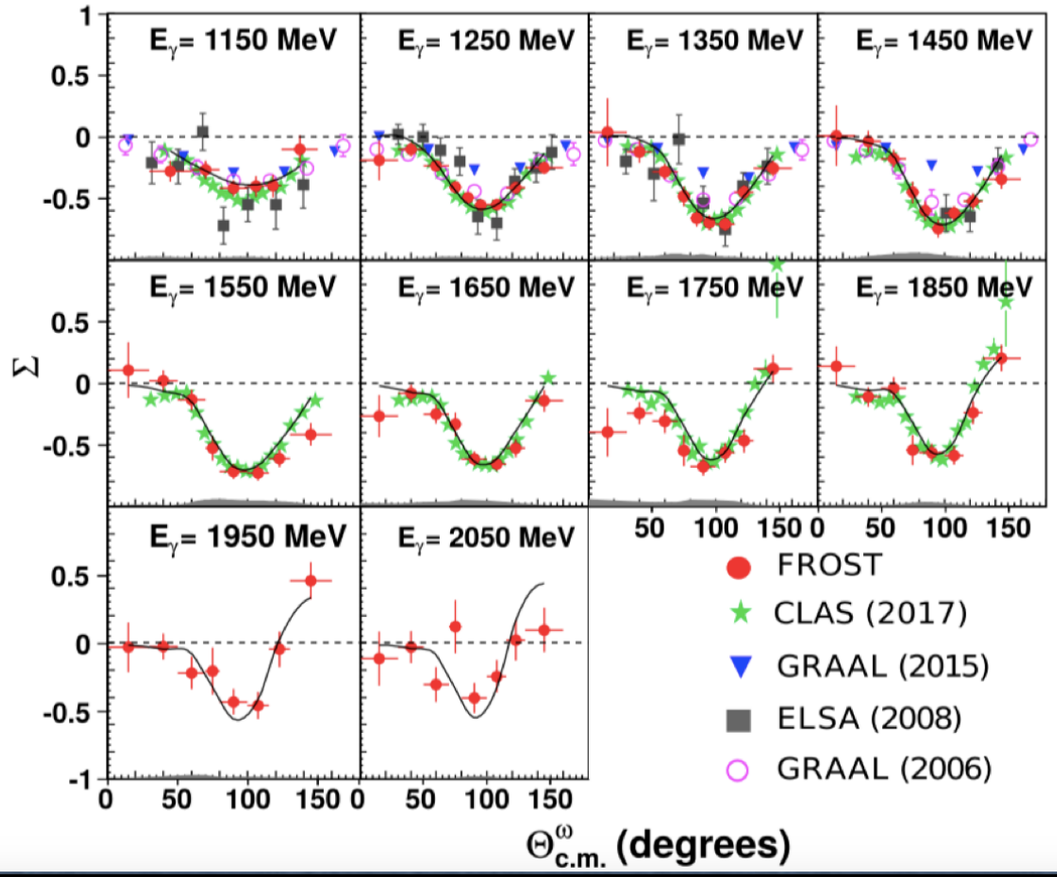
$\bar{P} = \frac{P^{\parallel} + P^{\perp}}{2}$

Preliminary Results

▲ This work ● quasi free GRAAL (Vegna et al. 2015) ■ Free proton CLAS (Collins et a..2017



free proton

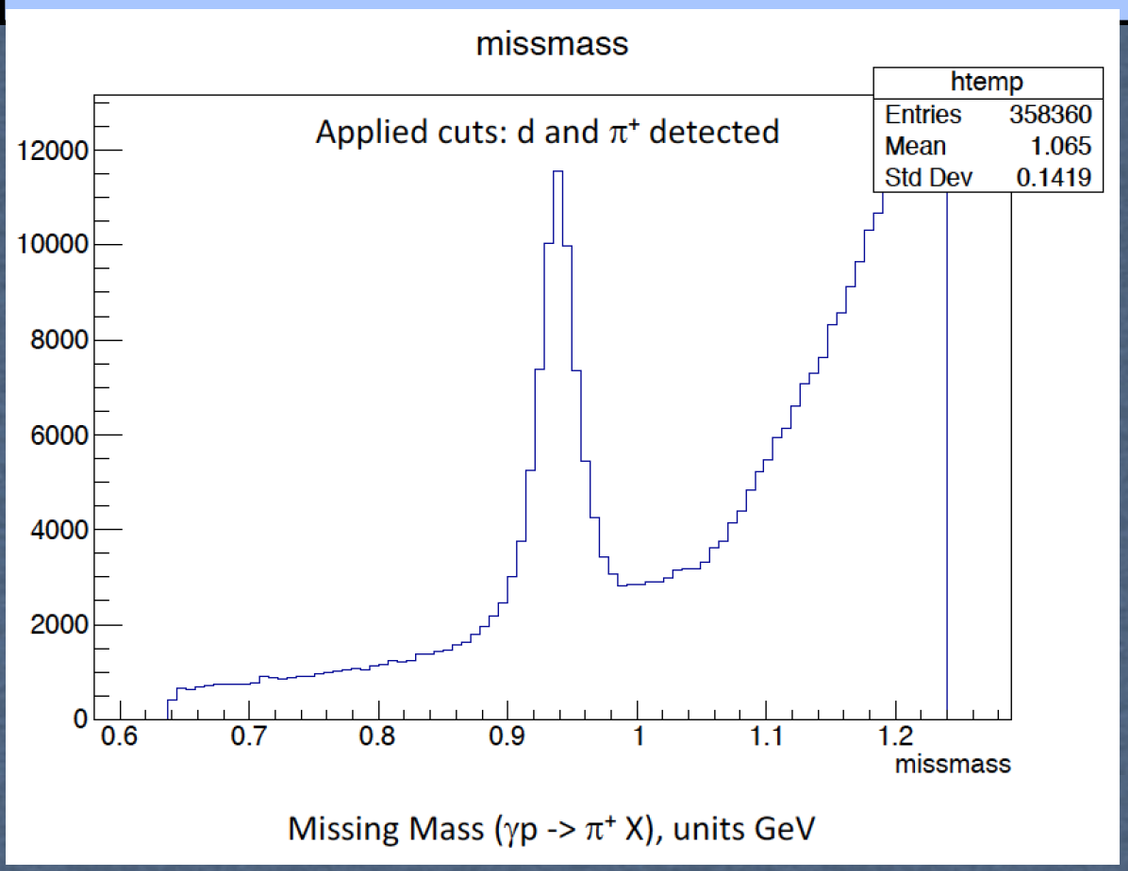


Hadronic reactions using g11
n p → d π^0

Nick Compton* and Ken Hicks (Ohio U)

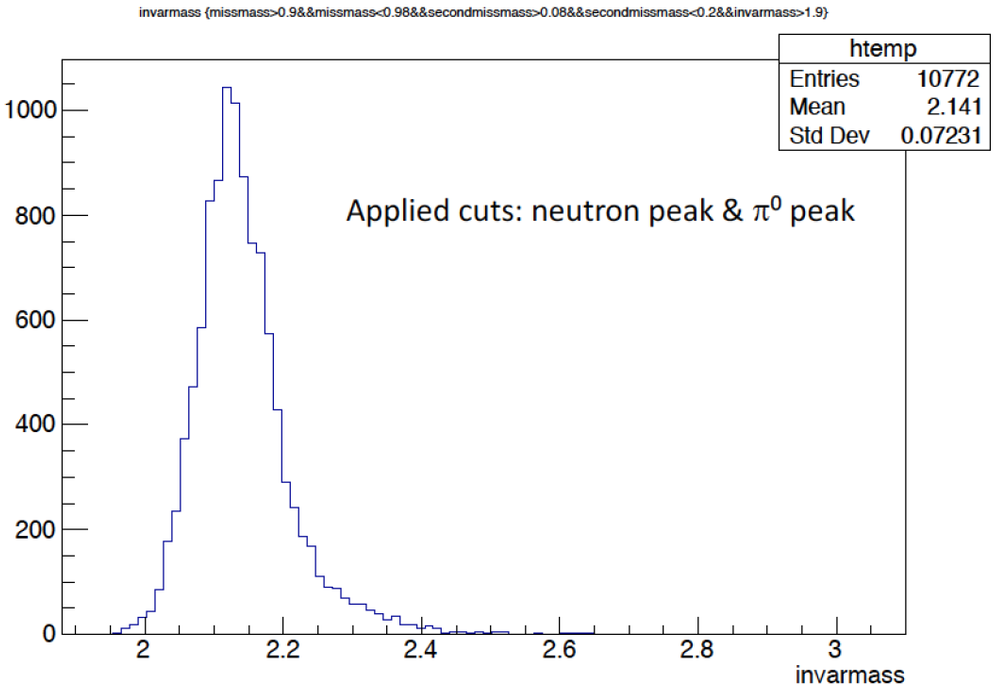
- Long LH2 target (40 cm) provides secondary scattering
  - Demonstrated for $\gamma p \rightarrow K^+\Lambda$ followed by $\Lambda N \rightarrow \Lambda N$ elastic scattering.
  - In principle, any hadronic reaction can be studied at CLAS
  - John Price: K_s rescattering possible (HYP2018 talk)
  - Two experiments have similar statistics: g11 and g12.
- Motivation for $np \rightarrow d\pi^0$ scattering:
  - Improve on previous cross sections (mostly via $pp \rightarrow d\pi^+$)
  - Look for possible polarization observables (depends on n-production)
  - Possible (?) to utilize this to measure n-polarization in $\gamma p \rightarrow \pi^+ n$.

- Data set: g11 (LH2 target, 40 cm length)
- Step 1: $\gamma p \rightarrow \pi^+(n)$
  - Detected: π^+.
  - Missing mass: M_n. Cut on the neutron peak.
- Step 2: $np \rightarrow d\pi^0$
  - Detected: d.
  - Missing mass: M_π. Cut on the π^0 peak.
  - Plot: E_{CM}-dependence. Expect a peak at about E_{CM} = 2150 MeV.

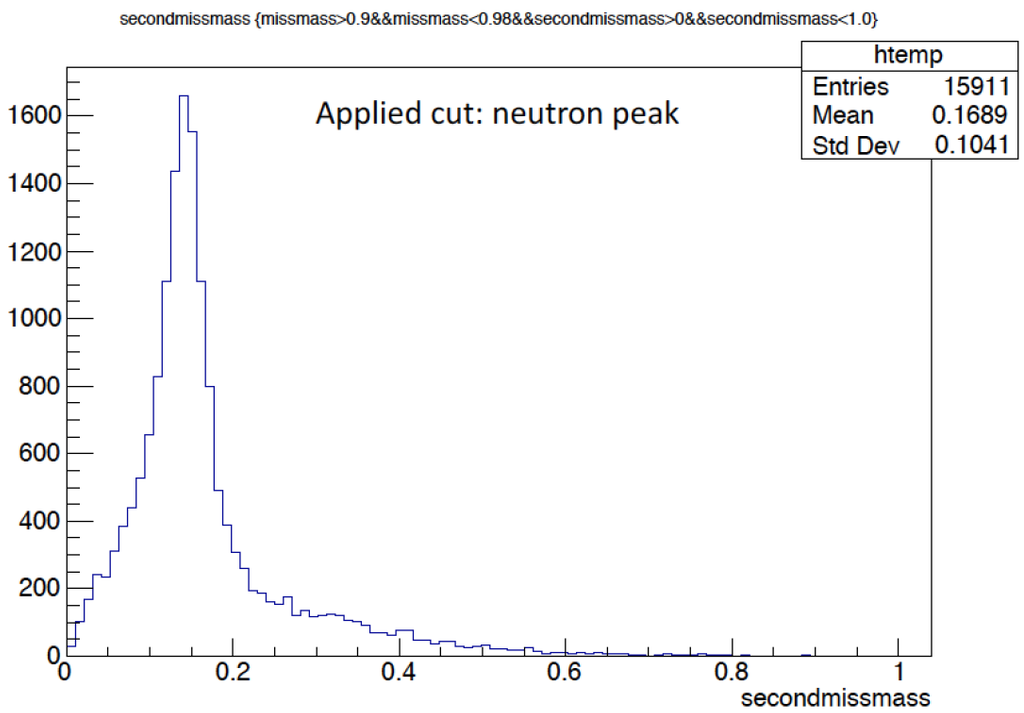


Missing Mass (γp -> π⁺ X), units GeV

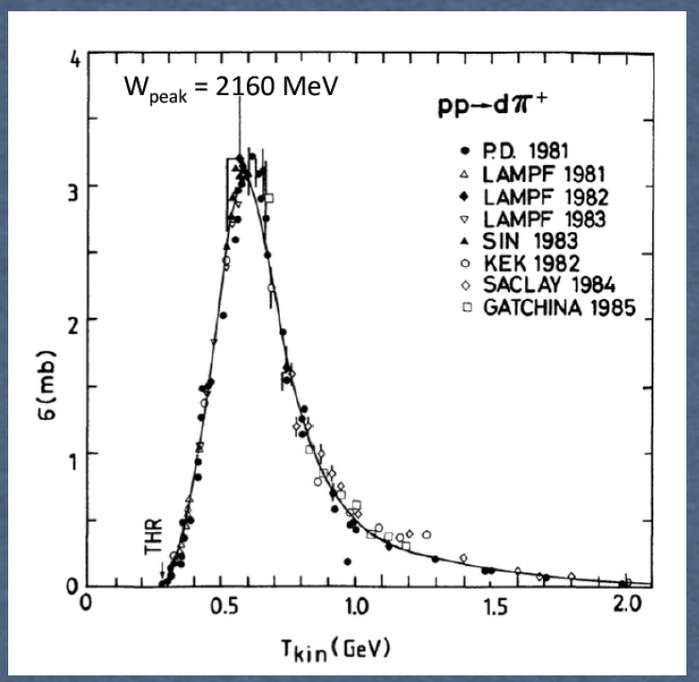
E_{CM} dependence



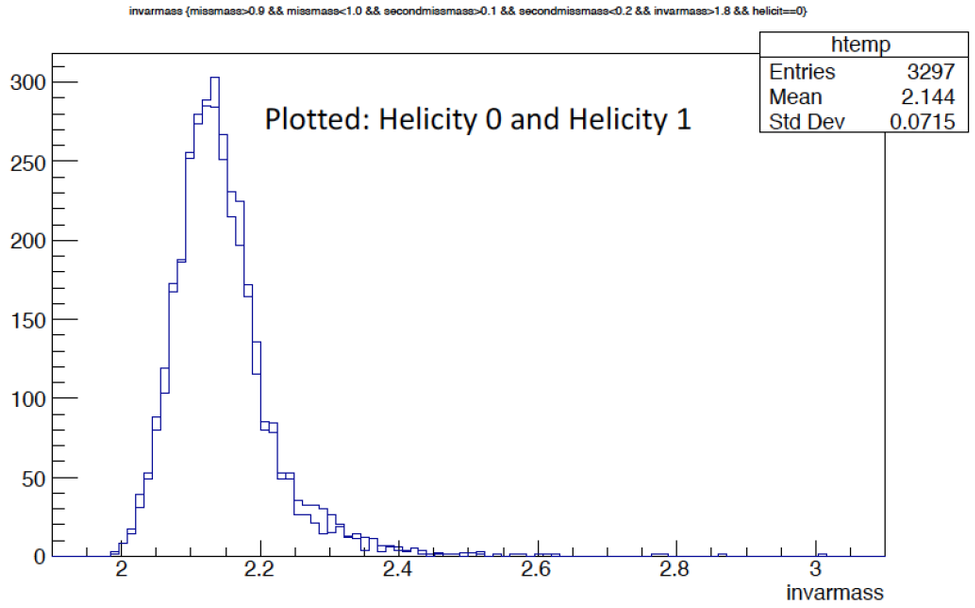
Invariant mass (np), units GeV



Missing Mass (np -> d X), units of GeV



Helicity dependence



Invariant Mass (np), units GeV

Summary

- G11 data has thousands of np -> $d\pi^0$ events.
  - Demonstration of hadronic scattering possibilities at CLAS
  - This is just the very beginning of the analysis—just a hint of what's to come.
  - Just one final state was looked at. Others, such as np -> np, are possible.
- G12 data has a similar number of events.
  - This could double the data set.
- Although no acceptance correction has been applied, the np data appear to show a clear peak at E_{CM} = 2130 MeV.
  - This matches well with previously published data from pp->$d\pi^+$.
  - No measureable polarization dependence so far.

Application of Machine Learning to π_0 photoproduction from CLAS/g9a

Chan Kim

The George Washington University

Igor Strakovsky and William Briscoe

CLAS g9a/FROST Experiment

- Polarization Observables → Helicty Amplitudes → Resonances (PWA)
- Polarizable: Incoming photons, target & recoiling nucleons

	UP_T and UP_R	UP_T and P_R	P_T and UP_R	P_T and P_R
UP_B	$\frac{d\sigma}{d\Omega}$	P	T	$T_{x'}, T_{z'}, L_{x'}, L_{z'}$
LP_B	$-\Sigma$	$O_{x'}, (-T), O_{z'}$	$H, (-P), -G$	
CP_B		$-C_{x'}, -C_{z'}$	$F, -E$	

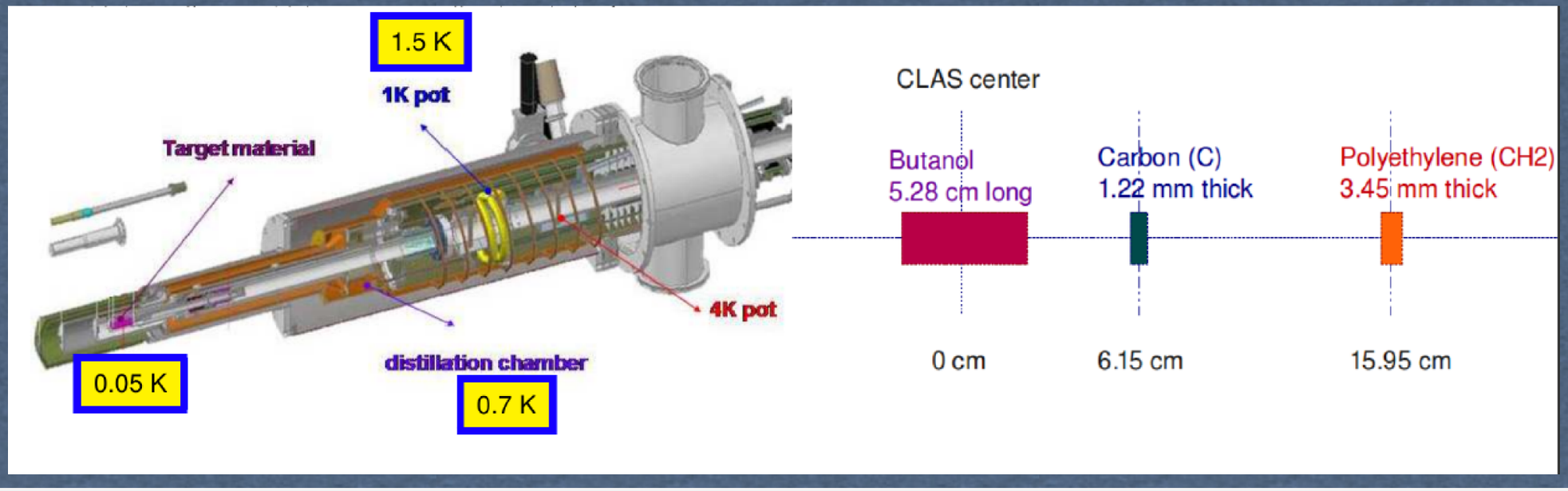
UP, P, LP, CP, B, T, R denote unpolarized, polarized, linearly polarized, circularly polarized, beam, target, and recoil, respectively.

- g9a/FROST - Circularly polarized photons with $E_\gamma \approx 0.4 - 2.4$ GeV and longitudinally polarized proton target:

Helicity Asymmetry E

- Double polarization observable E is the helicity asymmetry of the cross section:

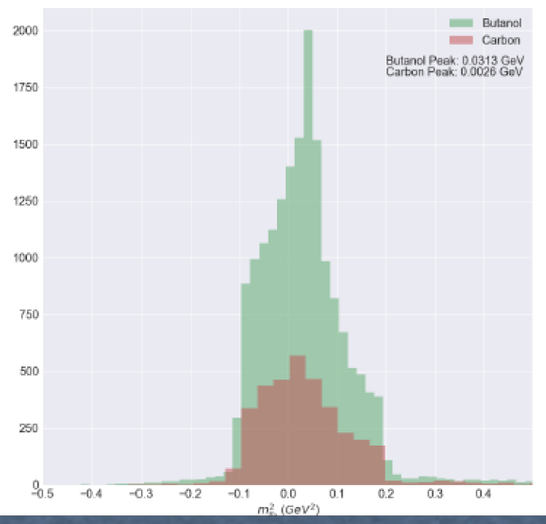
$$E = \frac{\sigma_{3/2} - \sigma_{1/2}}{\sigma_{3/2} + \sigma_{1/2}} \qquad \text{for } \frac{3}{2} \,\&\, \frac{1}{2} \text{ are total helicty states}$$

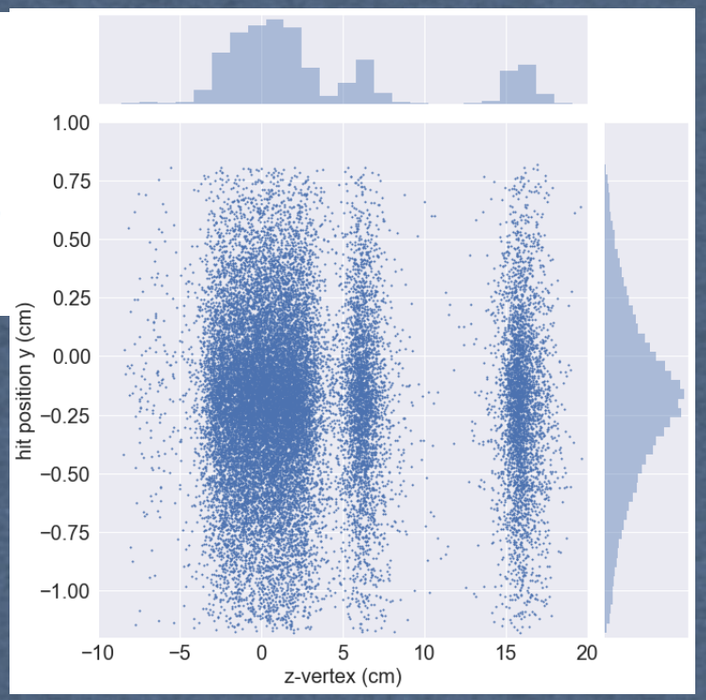


ML Objectives: Target Selection & Ice on Carbon

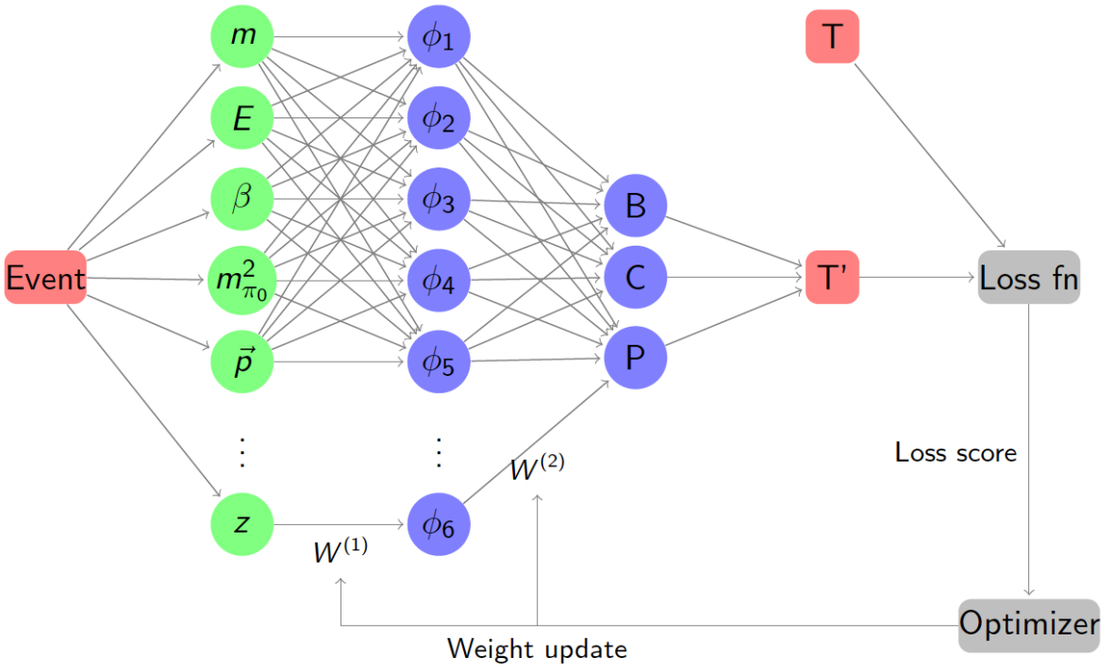
- Ice on Carbon
  - Carbon events (bound-nucleon) expected to have broader $m^2_{\pi_0}$ peak due to Fermi motion.
  - Sharp peak (free-nucleon) observed in the Carbon target region. Carbon events are scaled by $\sim$10.

- Target Selection
  - Events with z-vertex $\in$ [2, 5]cm, uncertain whether γ hit Butanol or Carbon

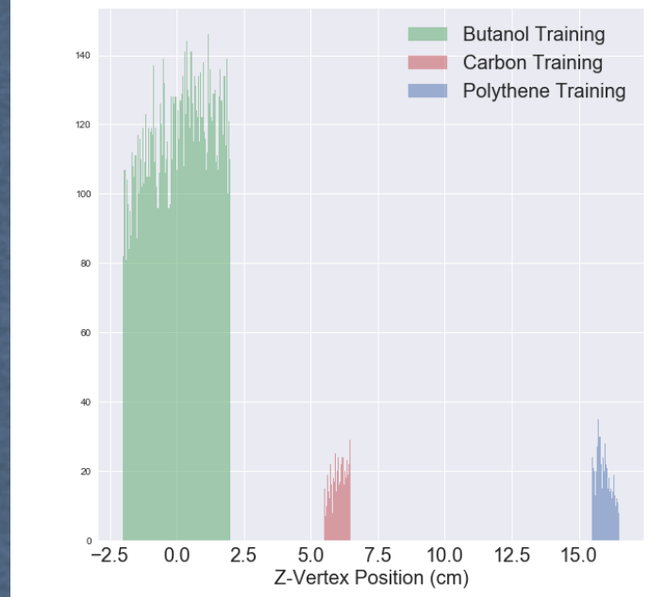




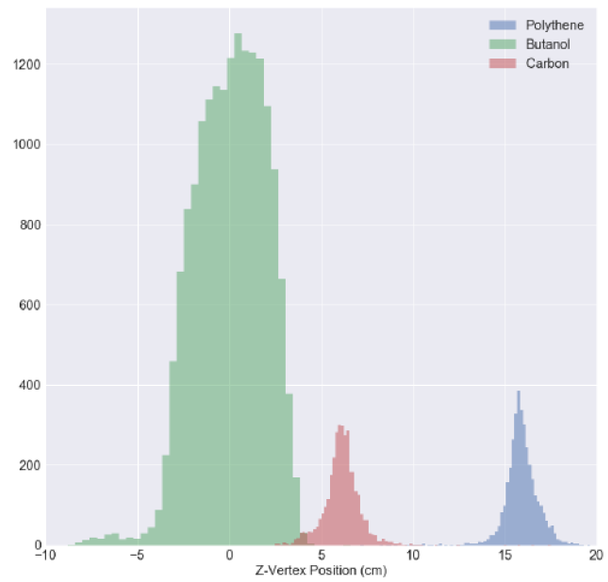
Neural Network Training Flowchart

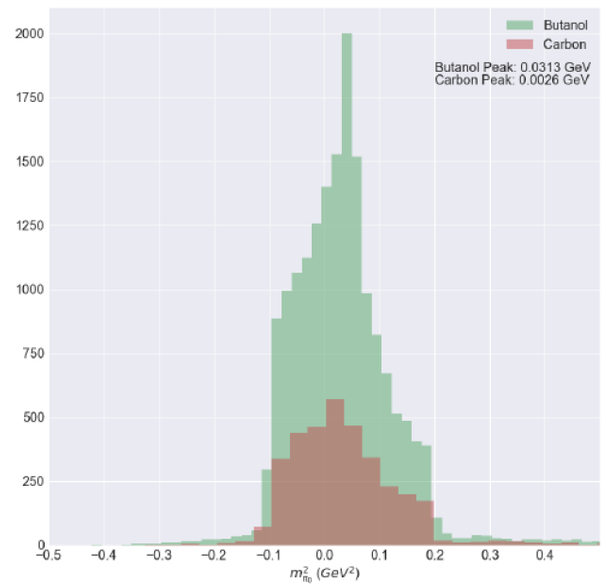


Training Data Selection



Result on Target Selection





- Classified Carbon events from Butanol in z-vertex $\in$ [2.5, 4.5]cm
- Some Carbon events in Polythene regions & Polythene events in Butanol region.
- Tail of Butanol events in Carbon region are missing. Under review [S. Fegan].