Charmonium(like) spectroscopy with Energy upgraded CLAS12

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University of Glasgow

Hadron Spectroscopy with a CEBAF Energy Upgrade
17th June 2022

Overview

Full simulations of charmonium-like meson production with the current CLAS12 detector system

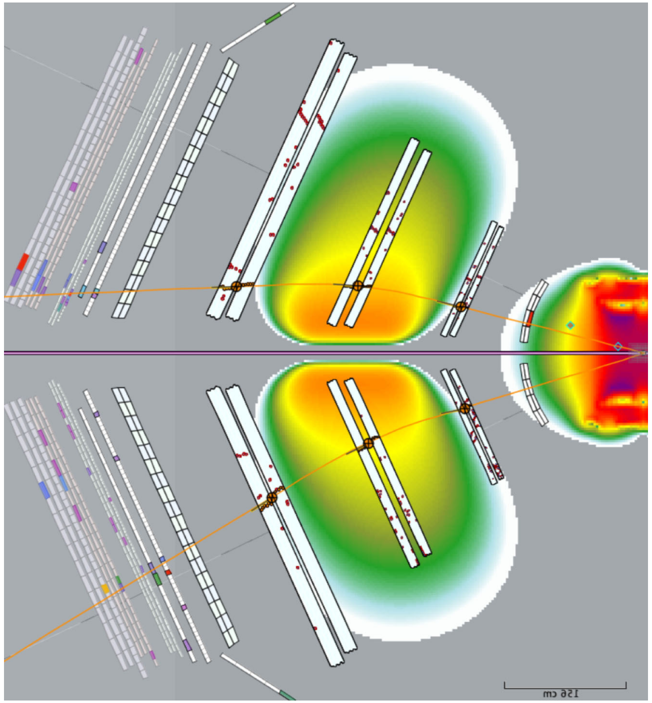
Consider both 17 and 22 GeV electron beams

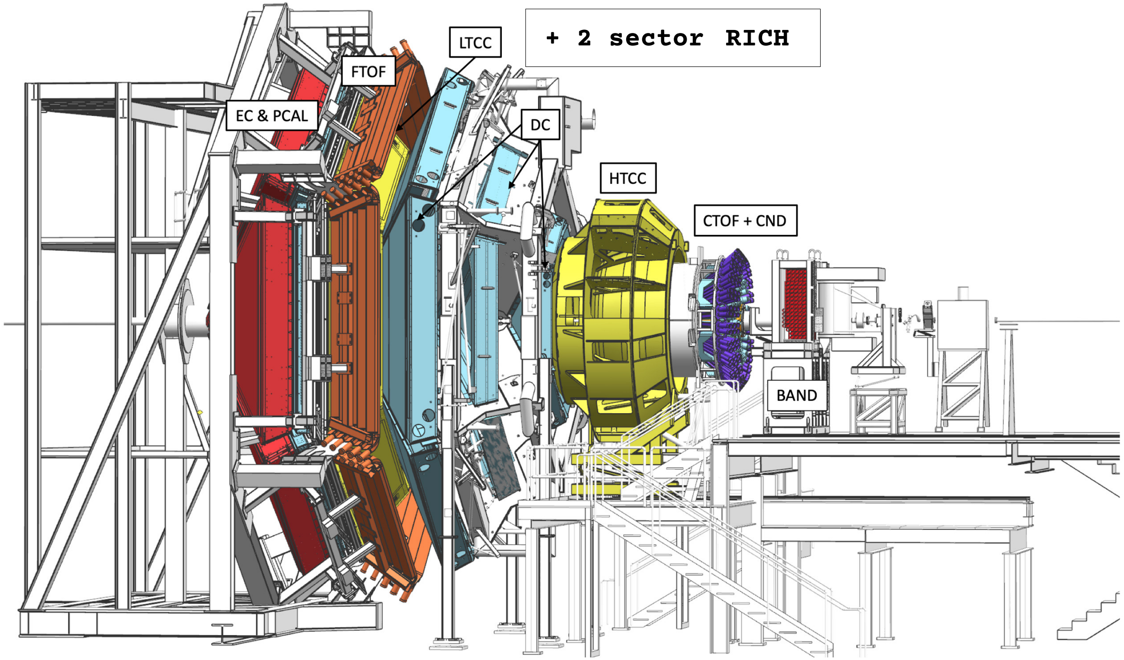
Follow up to JFUTURE workshop, here more focussed on CLAS12
https://indico.jlab.org/event/520/contributions/9515/attachments/7690/10733/SpectroscopyExperiment.pdf

Also D'Angelo, increasing CLAS12 luminosity
https://indico.jlab.org/event/520/contributions/9444/attachments/7687/10751/DAngelo_Jfuture_2022.pdf

And Burkert, energy upgraded CLAS12 detector
https://indico.jlab.org/event/520/contributions/9378/attachments/7704/10753/CLAS-CLAS12-CLAS24-talk.pdf

Hall B CLAS12 Detector





Excellent PID e−, K, p, π, n, γ

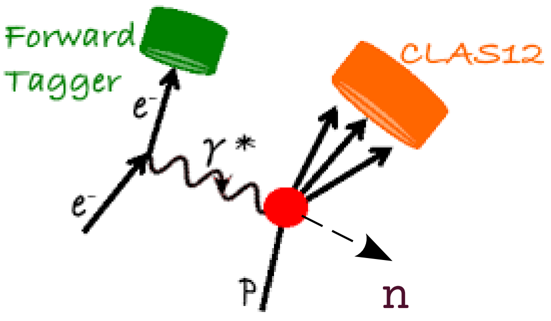
High luminosity electron scattering (10^{35} $cm^{-2}s^{-1}$) produces high flux of nearly real photons.

Can make measurements with missing particles

High resolution tracking spectrometer,
(1% momentum, 1 mrad angle)

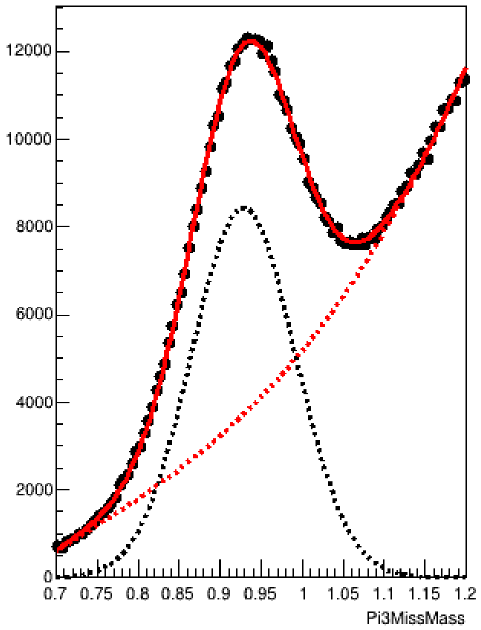
Can run simultaneously with other experiments

CLAS12 MesonEx: low Q2 electroproduction

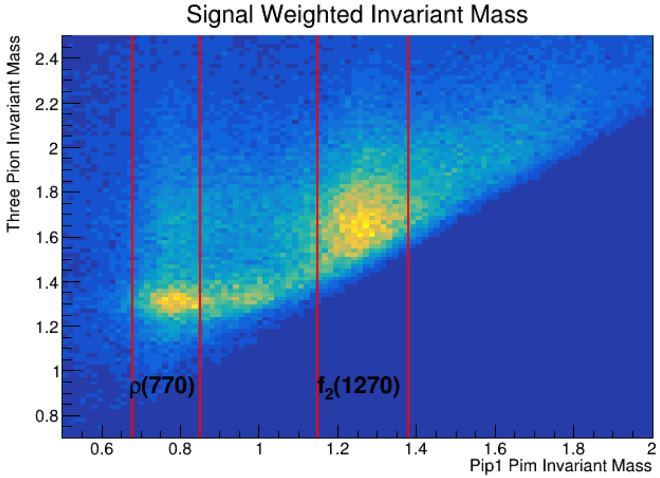


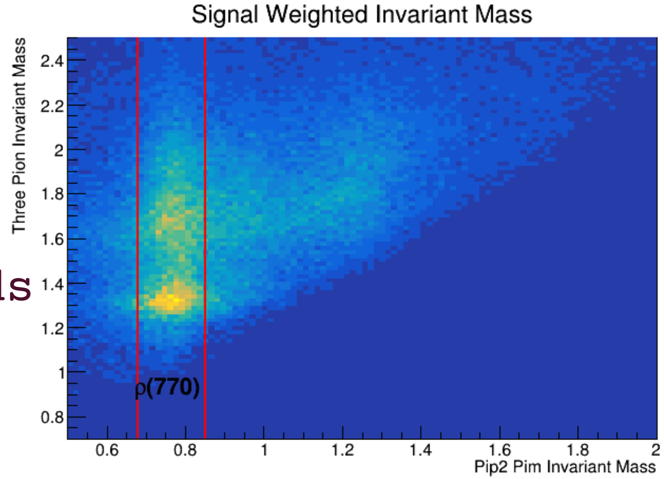
Forward tagger measures
Electron 2.5-4.5°
$Q^2 < 0.3\ (GeV/c)^2$

Example $\pi^+\pi^+\pi^-$ (n)

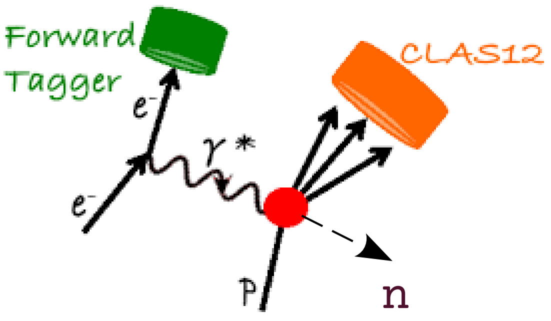


Reconstruct
Neutron mass to
Subtract backgrounds





CLAS12 MesonEx: low Q2 electroproduction



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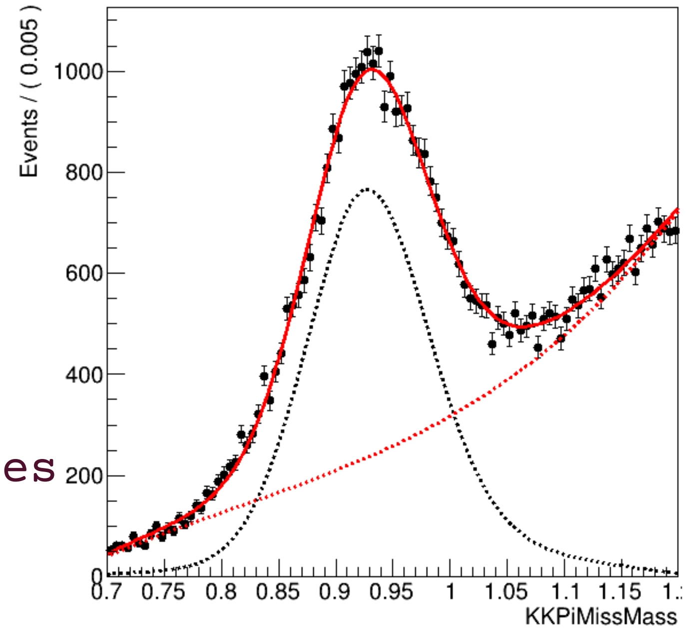
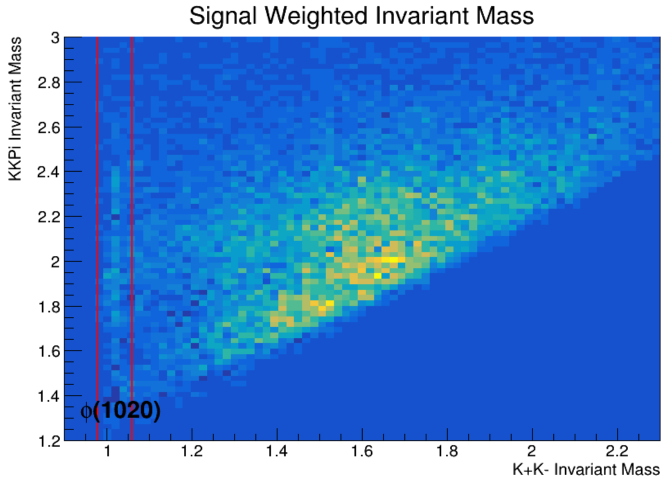
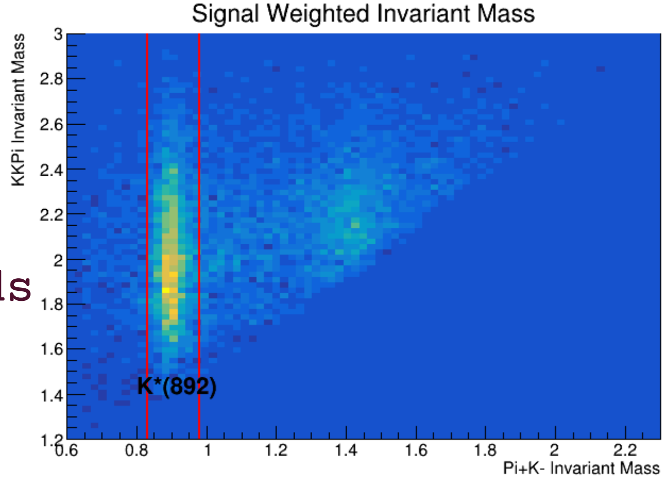
Example $\pi^+K^+K^-$ (n)



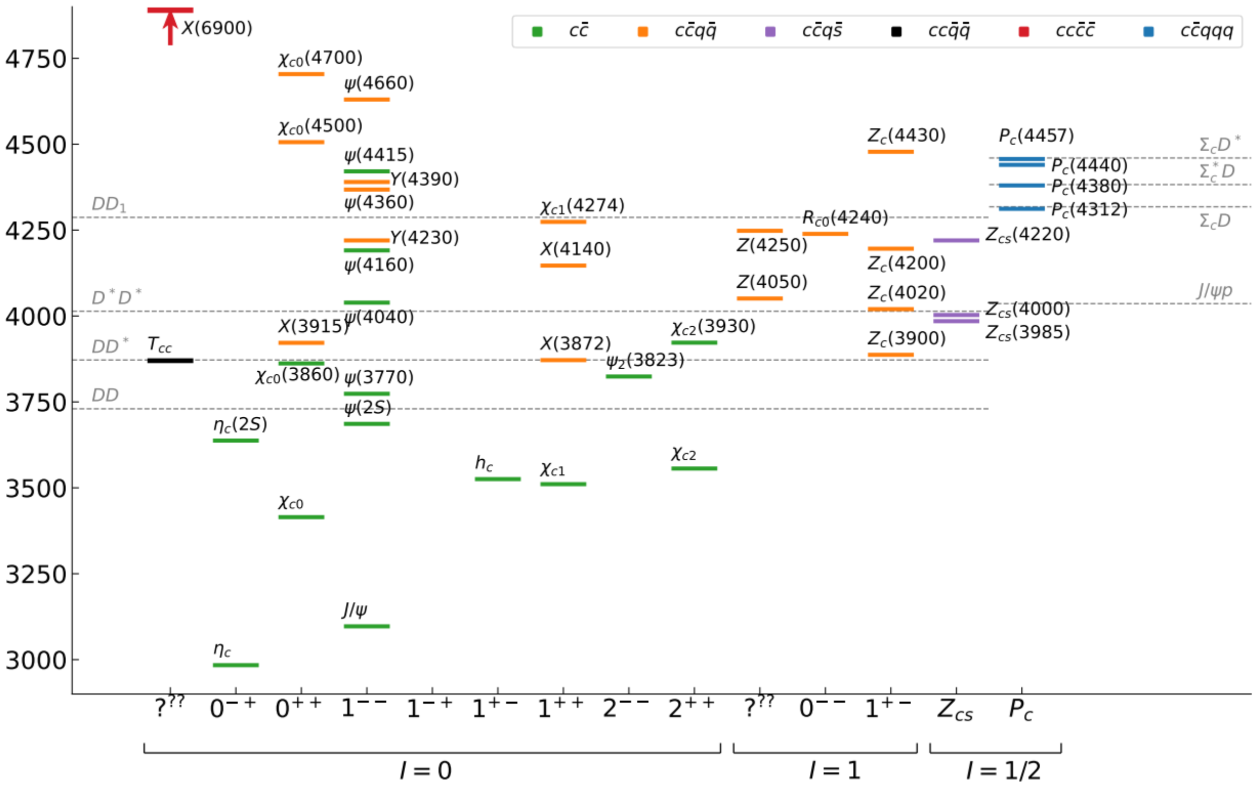
Reconstruct
Neutron mass to
Subtract backgrounds





Many candidates for new states!

JPAC https://arxiv.org/abs/2112.13436

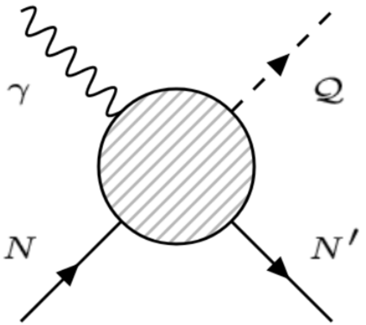


Photoproduction should be able to produce all true states
-validate current picture and search for more

Exclusive (Quasi-real)Photoproduction

jpacPhoto https://github.com/dwinney/jpacPhoto

Framework for amplitude analysis involving single meson production via quasi-elastic scattering of a real photon on a nucleon target. Focus on expandability and easy interfacing with Monte-Carlo tools and event generators.



Such processes are of interest at many experiments at JLab and the future EIC.

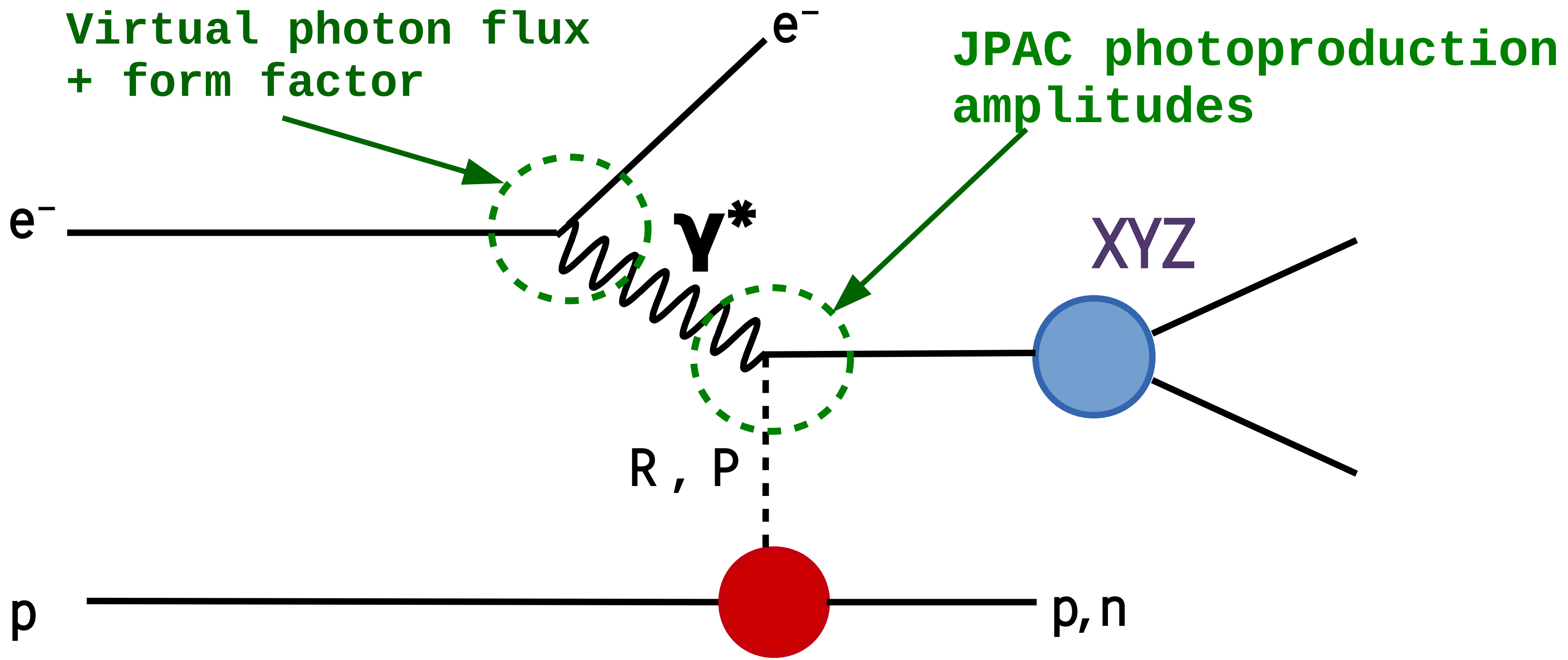
XYZ spectroscopy at electron-hadron facilities: Exclusive processes

M. Albaladejo, A. N. Hiller Blin, A. Pilloni, D. Winney, C. Fernández-Ramírez, V. Mathieu, and A. Szczepaniak
(Joint Physics Analysis Center)
Phys. Rev. D **102**, 114010 – Published 7 December 2020

- qualitative behaviour and order of magnitude estimates

Event Generator (Pictorial)

Factorise 2 photon vertices



$Z_c(3900)$ quasi-real photoprocution

17GeV 22GeV

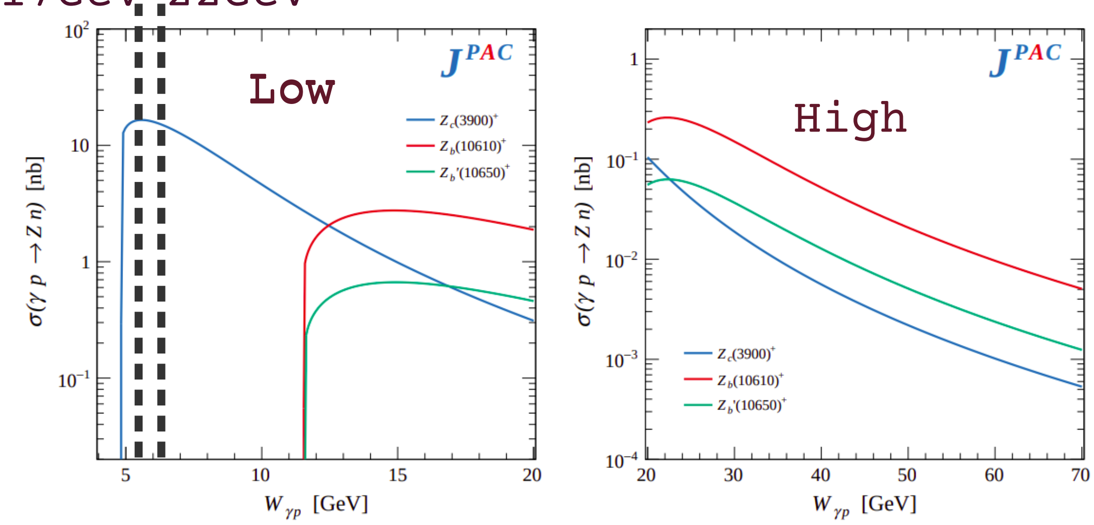
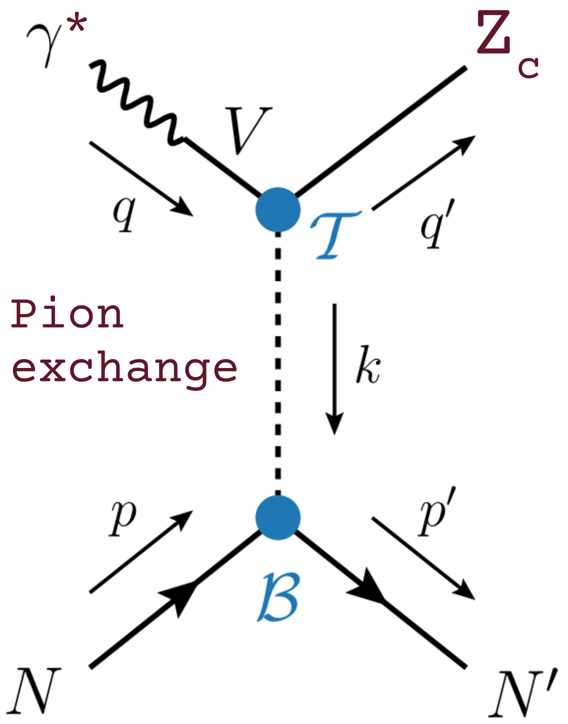


FIG. 2. Integrated cross sections for the three Z states considered. Left panel: predictions for fixed-spin exchange, which we expect to be valid up to approximately 10 GeV above each threshold. Right panel: predictions for Regge exchange, valid at high energies.

$Z_c \to J/\psi\ \pi+$

Branch R. 10%

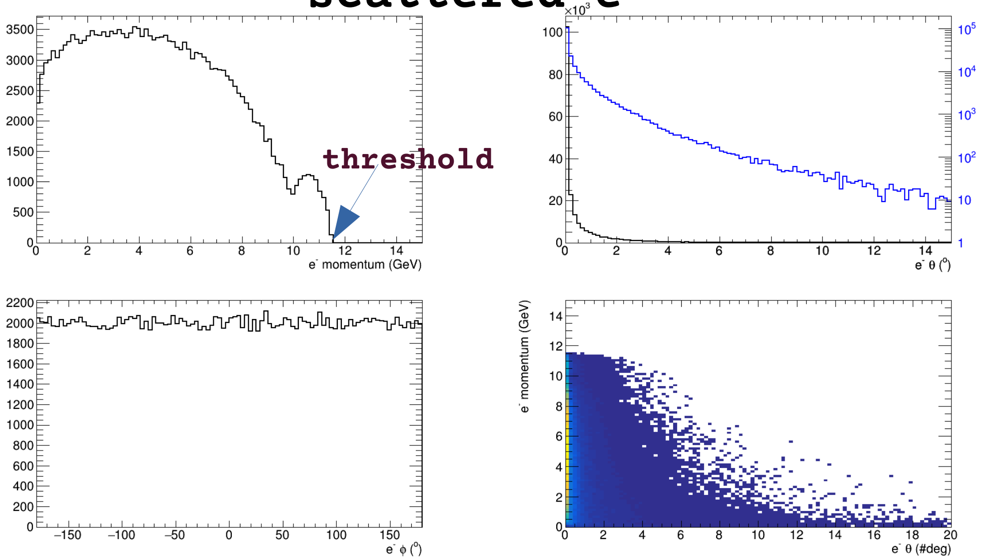


Only require low energy models

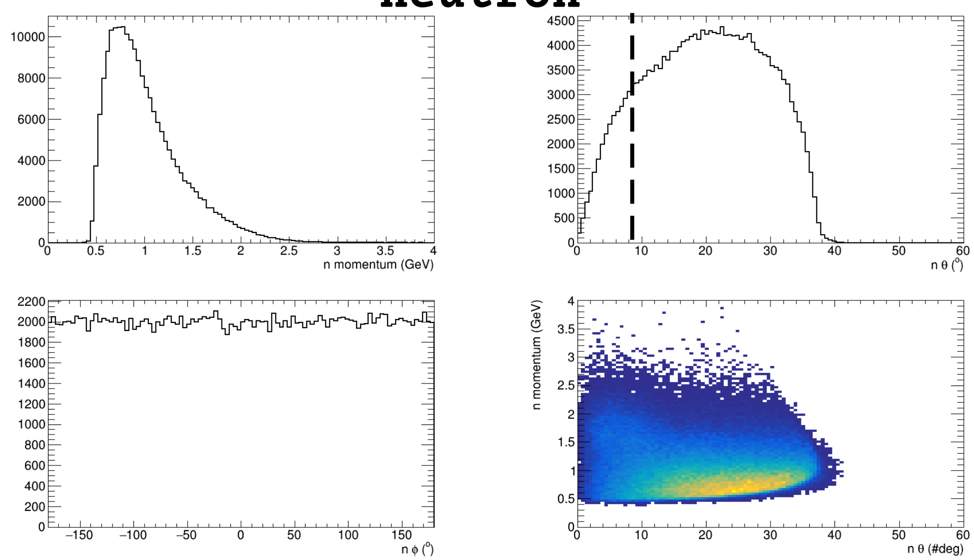
Assuming luminosity $10^{35}cm^{-2}s^{-1}$
and 50 days gives 210k (109k) events.
With 22 (17) GeV beam momentum

$Z_c(3900)$ Particle momentum @ 22GeV

scattered e-



neutron



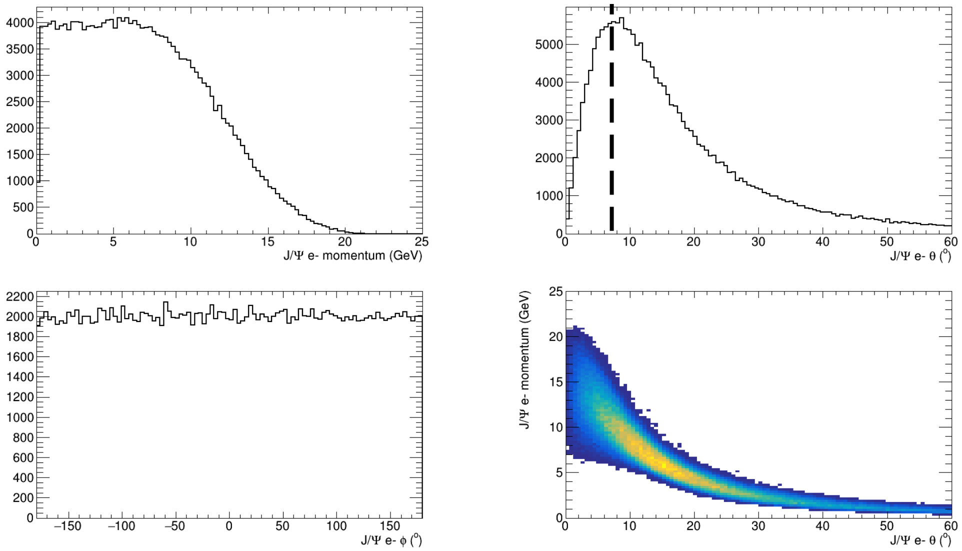
Most e- < 1deg.
And < 12 GeV

Neutron detection from 0.5 GeV

Outwith CLAS12 acceptance
For rest will assume new
zero-degree spectrometer : $\vartheta < 0.75°$ $\sigma^{P}=2\%$ $\sigma^{angle}=1\text{mrad}$

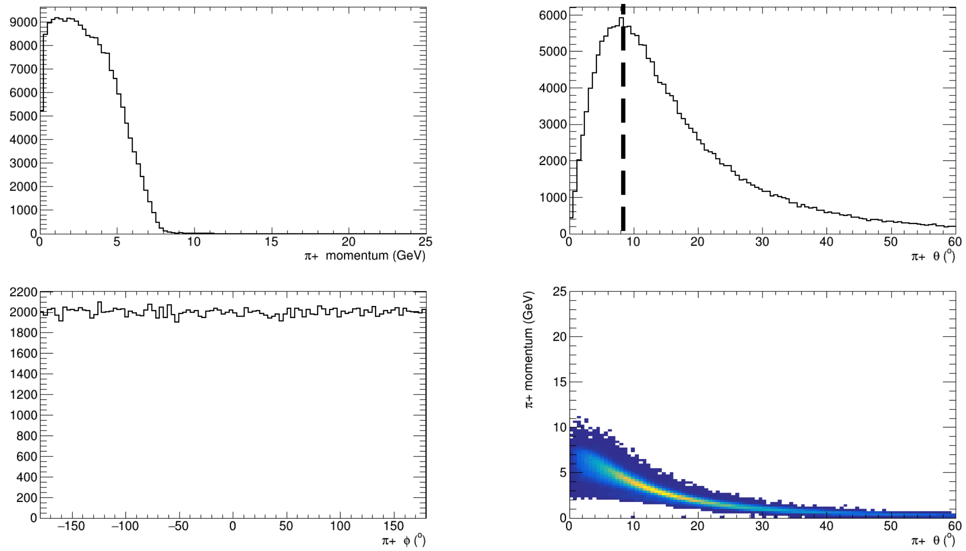
$Z_c(3900)$ Particle momentum @ 22 GeV

J/ψ e-



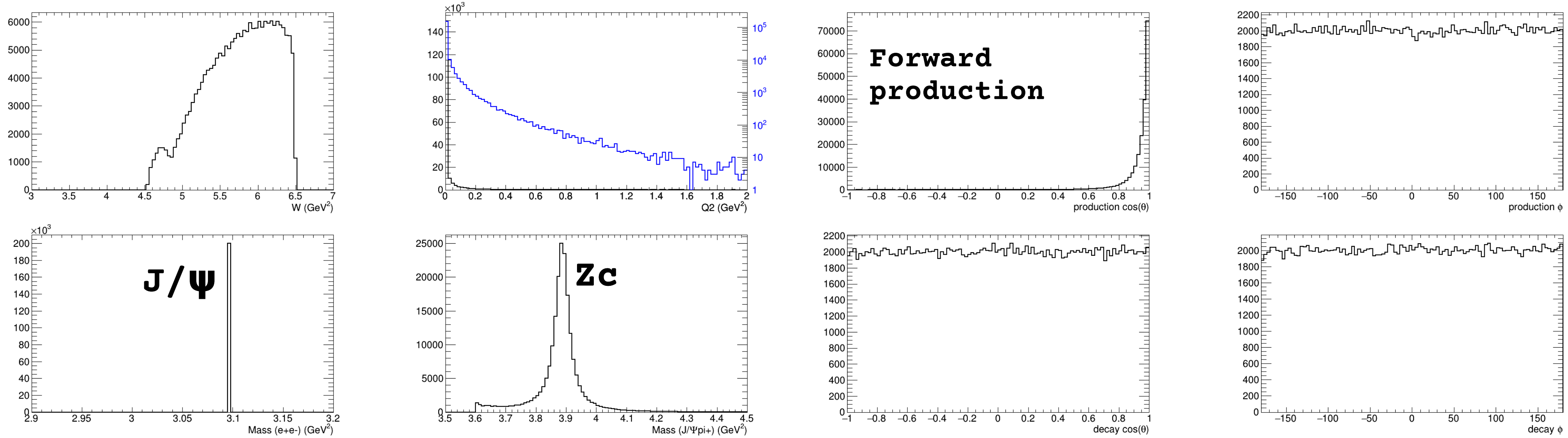
Leptons up to 20 GeV

π+



Decay pions have lower momentum
Similar angular range

Z_c(3900) Kinematics @ 22 GeV



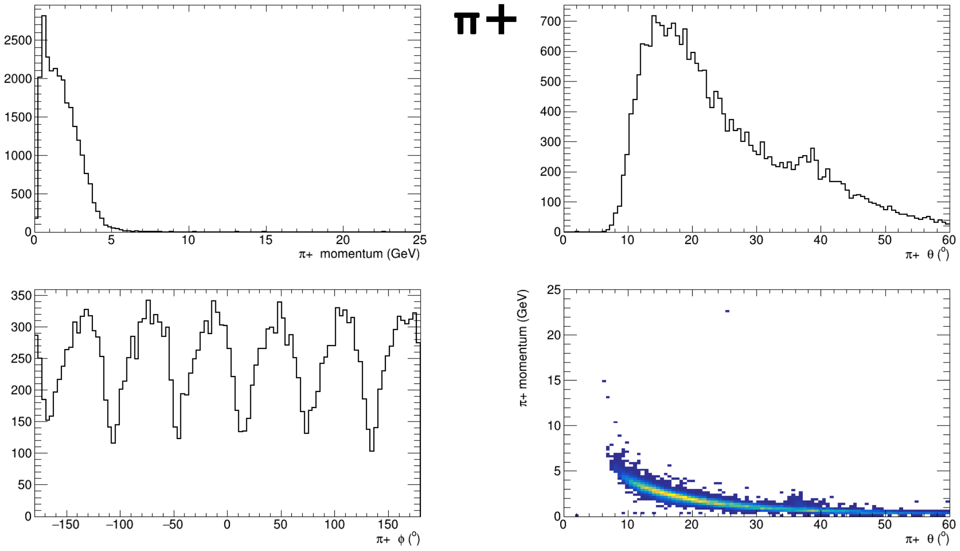
Full CLAS12 simulation at 22GeV

Use CLAS12 gemc simulation with Run Group A settings, outbending e-

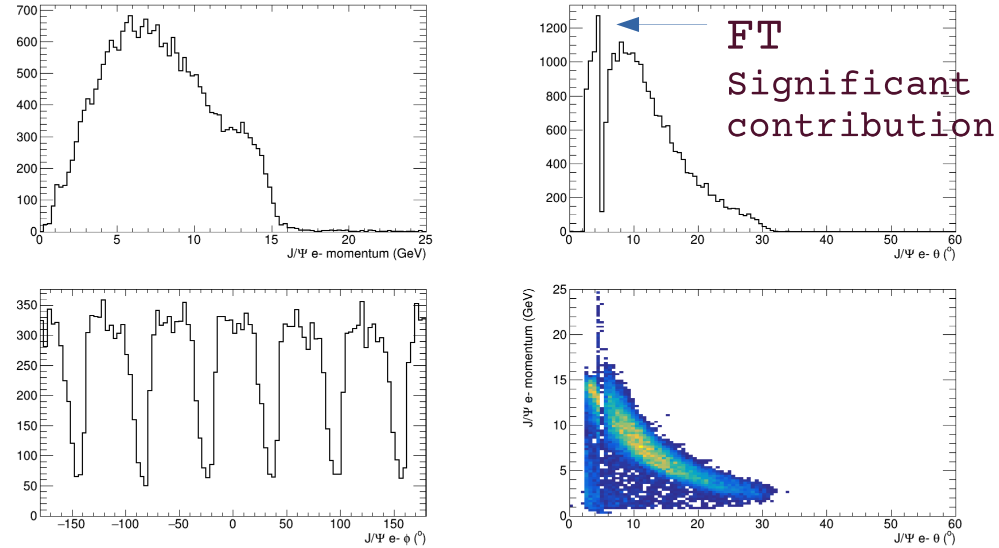
Assume scattered e- detected in “Zero degree spectrometer”

Do not detect the recoil neutron
-reconstruct from other particles

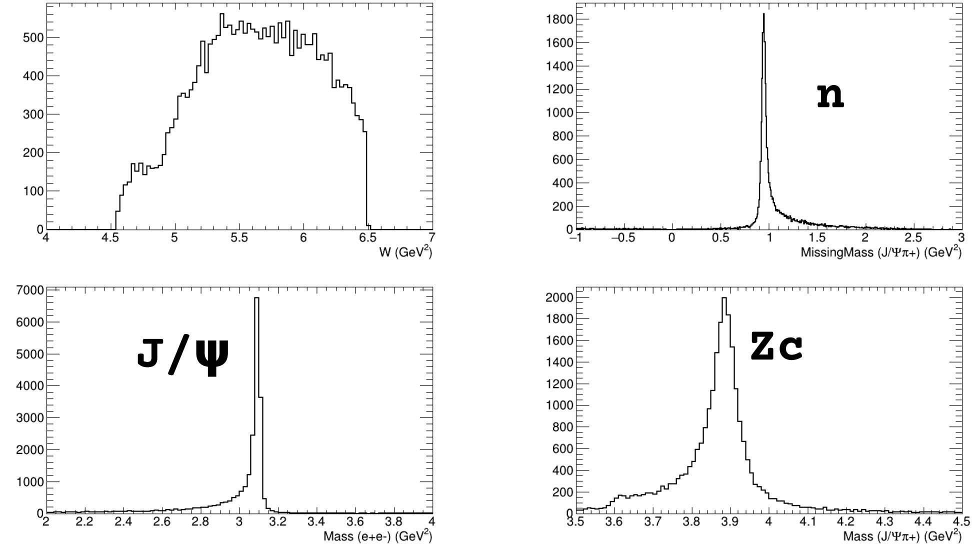
π+



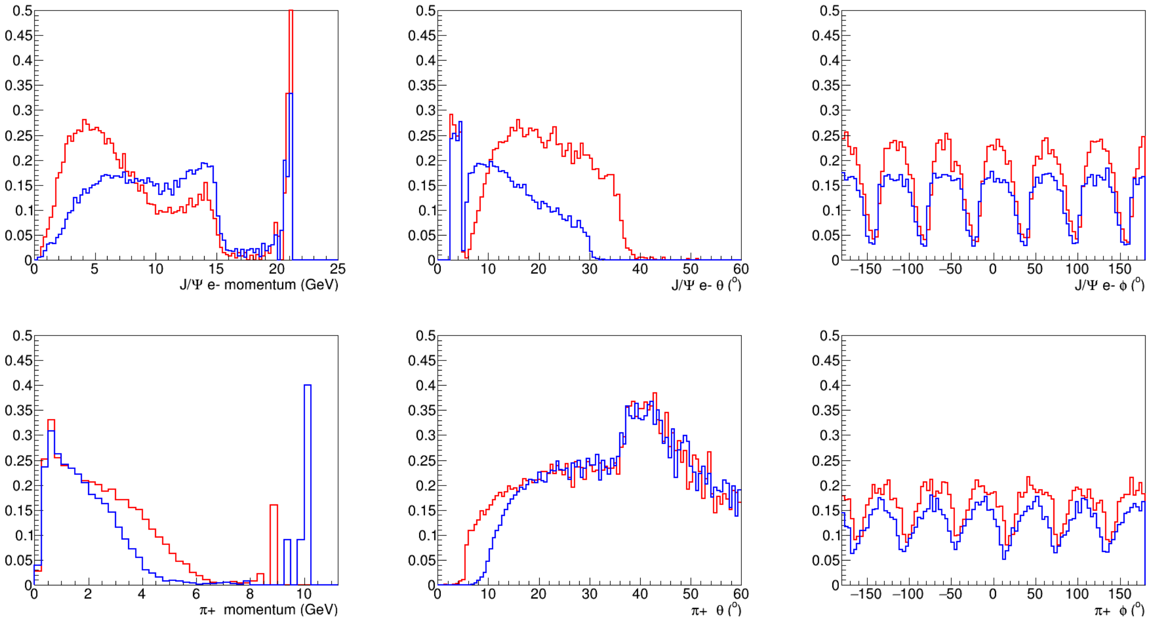
J/ψ e-

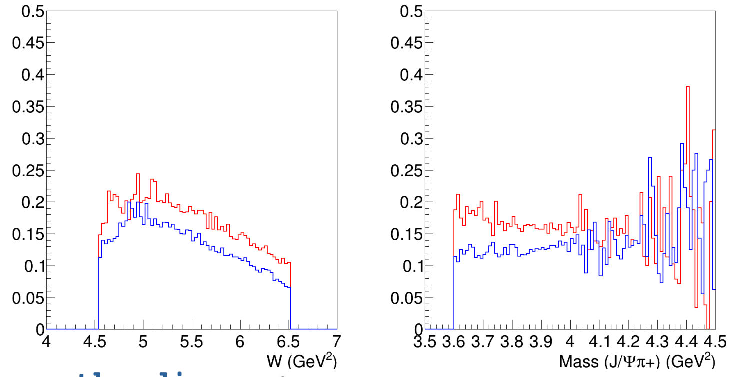


masses

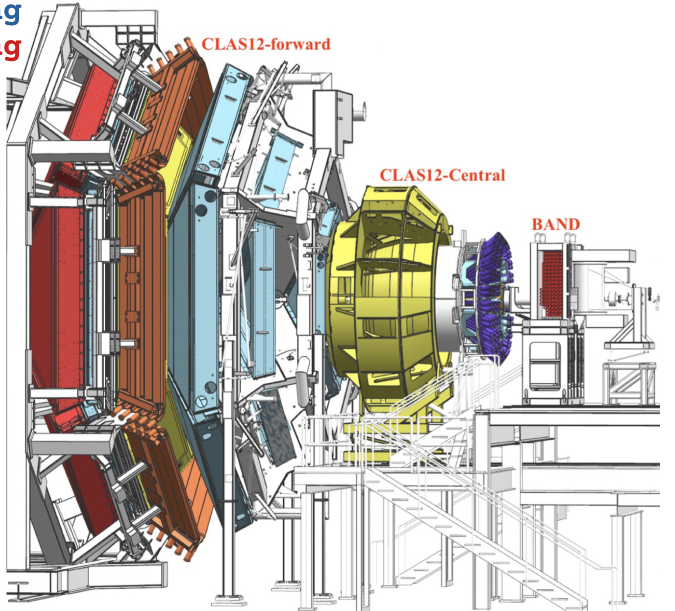


Acceptances @ 22GeV





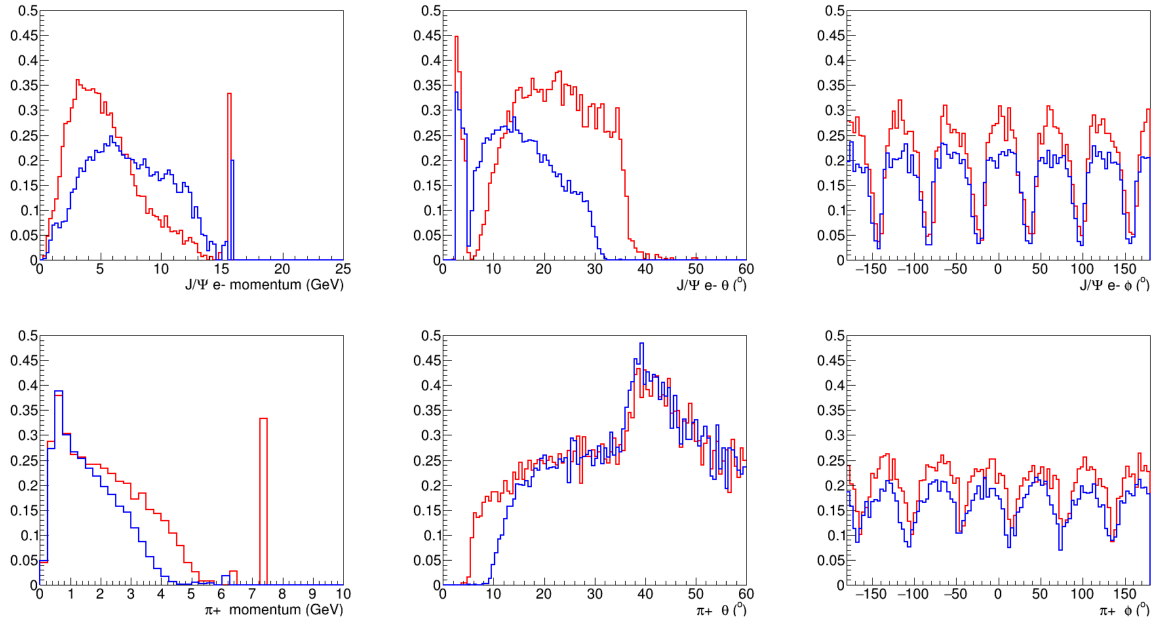
-ve outbending
+ve outbending

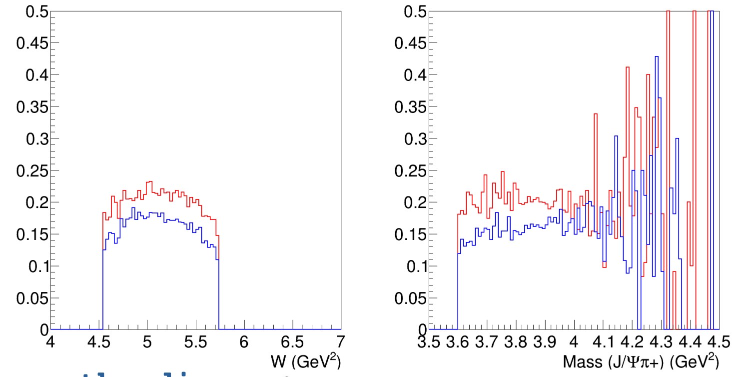


Results for combined detection of 2e−,e+,π+
Due to additional +ve particle, +ve outbending provides better acceptance, 14% compared to 11%

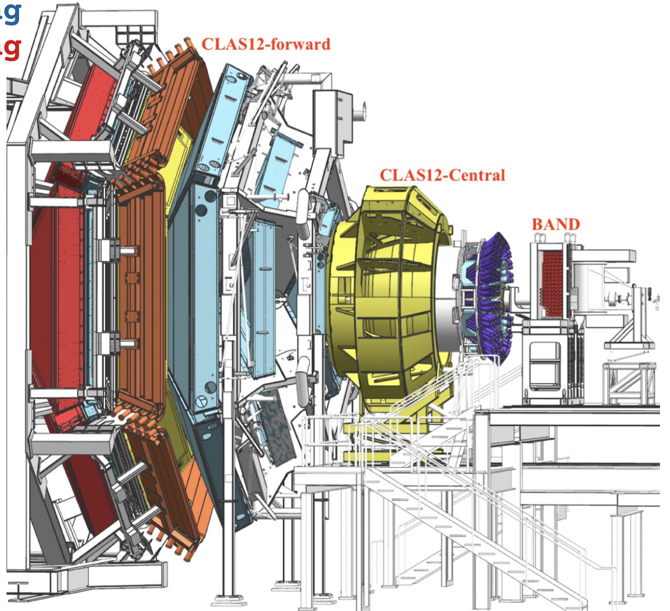
May improve acceptance further by reducing Toroidal field (at expense of resolution)

Acceptances @ 17GeV





-ve outbending
+ve outbending



Results for combined detection of 2e-,e+,π+
Due to additional +ve particle, +ve outbending provides better acceptance, 17% compared to 13%

Estimate 16k @ 17 Gev; 25k @ 22 GeV for 50 days

χ_{c1}(3872) quasi-real photoprocution

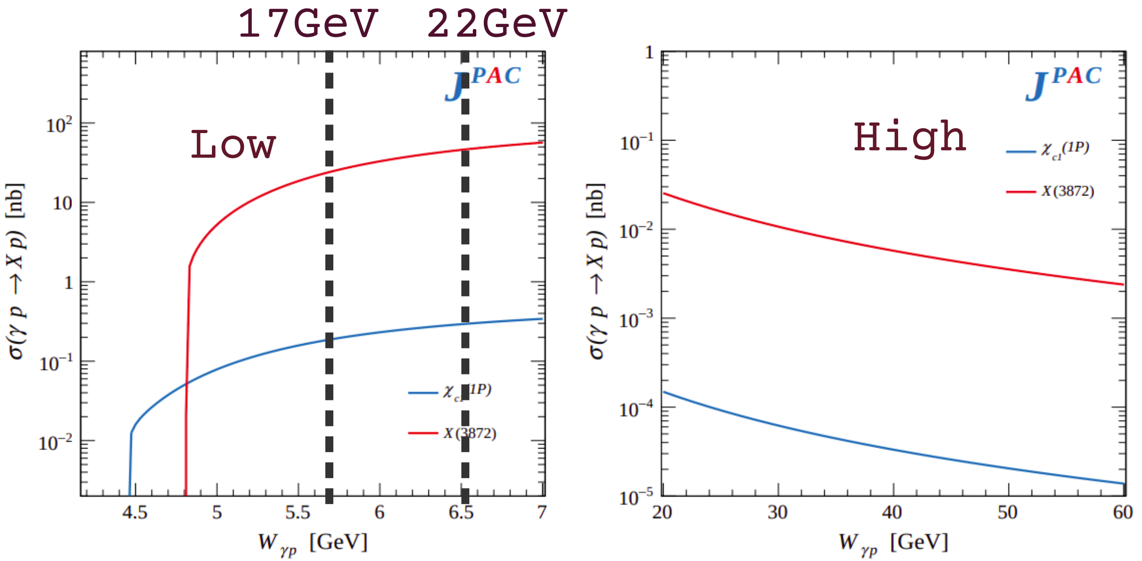
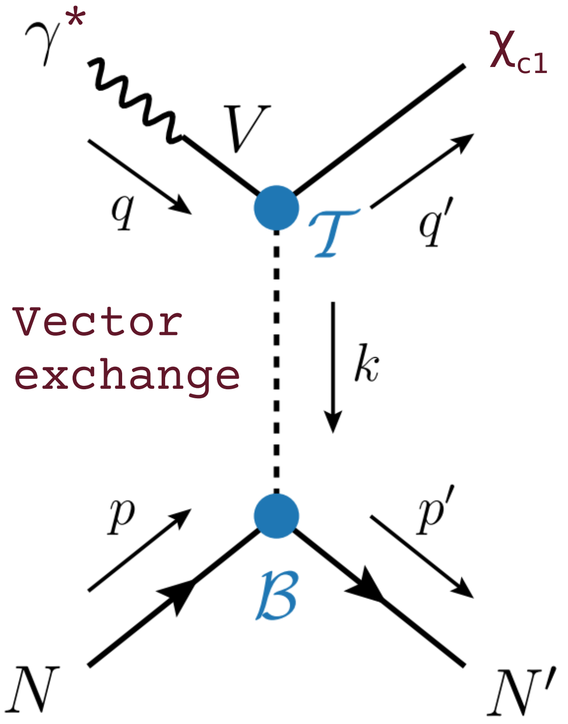


FIG. 3. Integrated cross sections for the axial $\chi_{c1}(1P)$ and $X(3872)$. Left panel: predictions for fixed-spin exchange, valid at low energies. Right panel: predictions for Regge exchange, valid at high energies.

$\chi_{c1} \to J/\psi\ \pi+\pi-$
Branch R. 5%



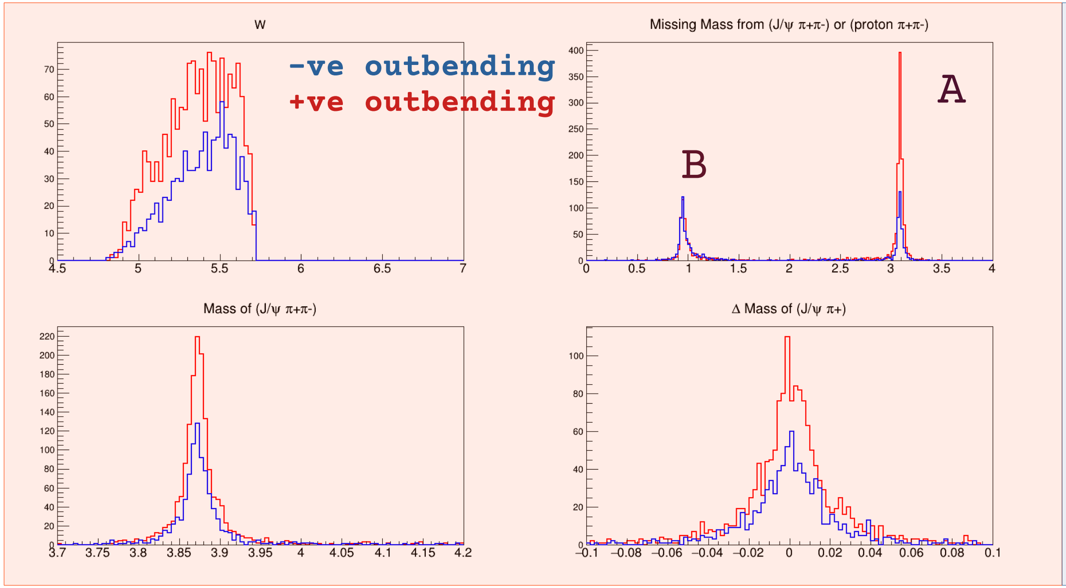
Only require low energy model

Assuming luminosity $10^{35}\text{cm}^{-2}\text{s}^{-1}$
and 50 days gives 190k (56k) events.
With 22 (17) GeV beam momentum

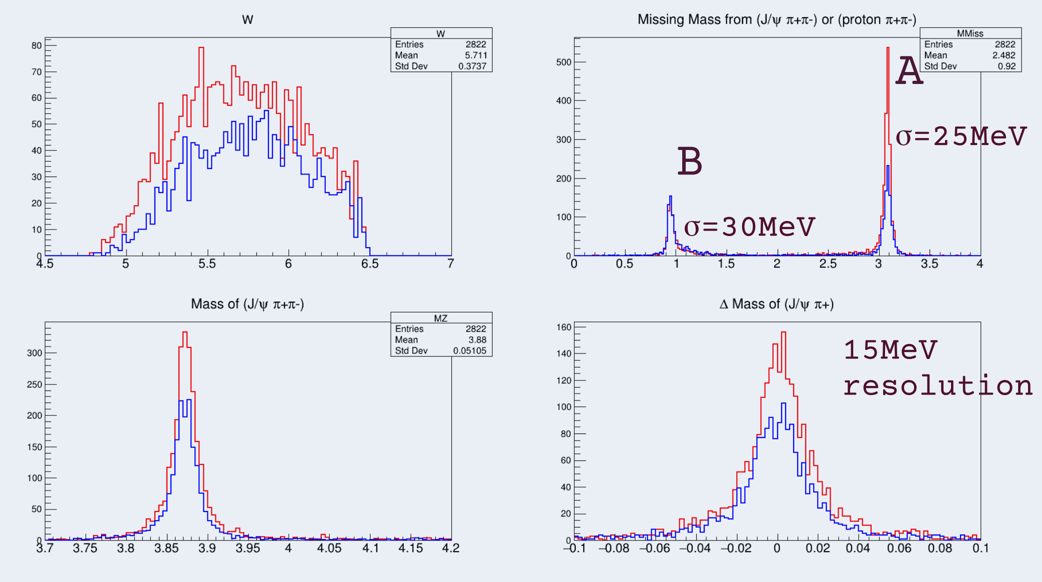
$\chi_{c1}(3872)$ Distributions

Consider two cases. (A) Do not detect Jpsi. (B) Do not detect proton

17 GeV



22 GeV

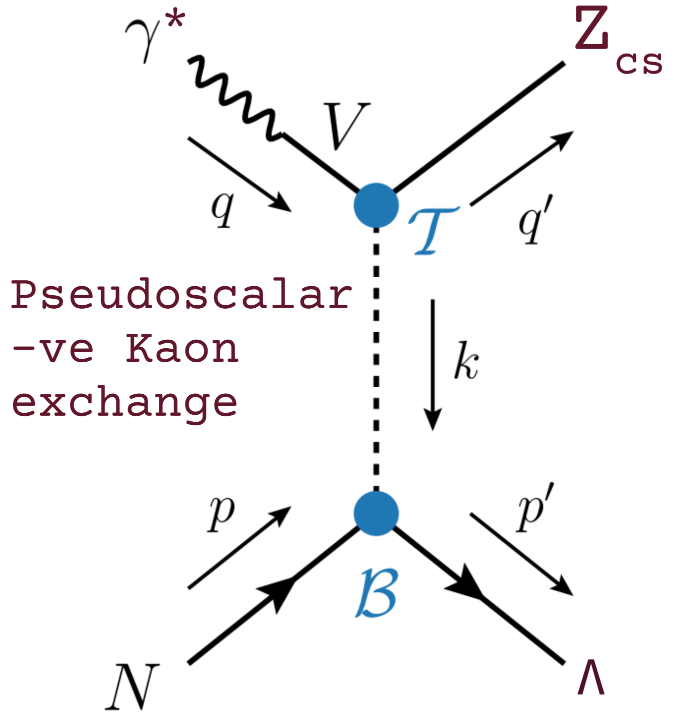


	+ve	-ve outbend
Expected yield	1600	900
Acceptance	3%	1.5%

	+ve	-ve outbend
Expected yield	2800	1900
Acceptance	1.5%	1.0%

Z_{cs}(4000) quasi-real photoproduction

Z_{cs} → J/ψ K+
Branch R. = 10%



Not "official" JPAC model
Adapted from jpacPhoto Z_c
with D. Winney

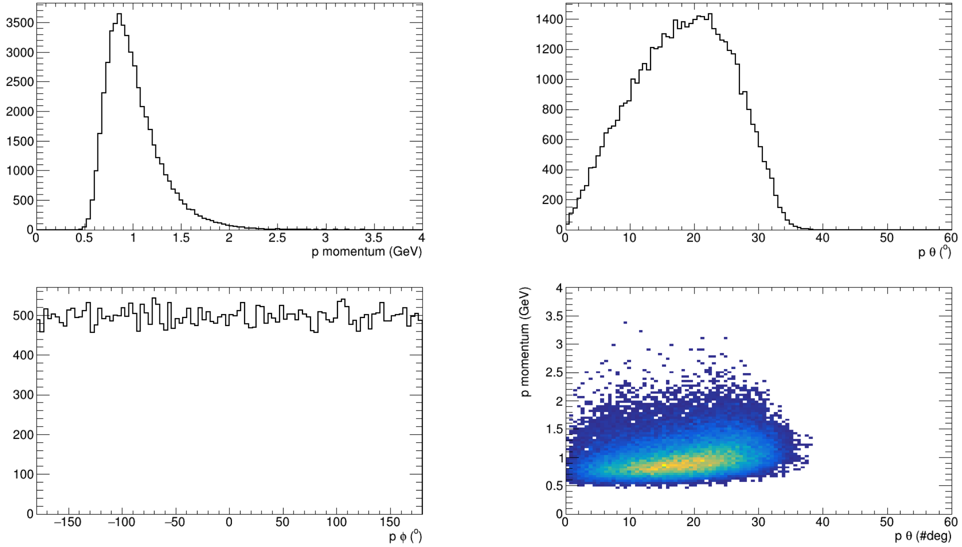
Assuming luminosity $10^{35}cm^{-2}s^{-1}$
and 50 days gives 33k (4.5k) events.
With 22 (17) GeV beam momentum

Λ→ pπ-

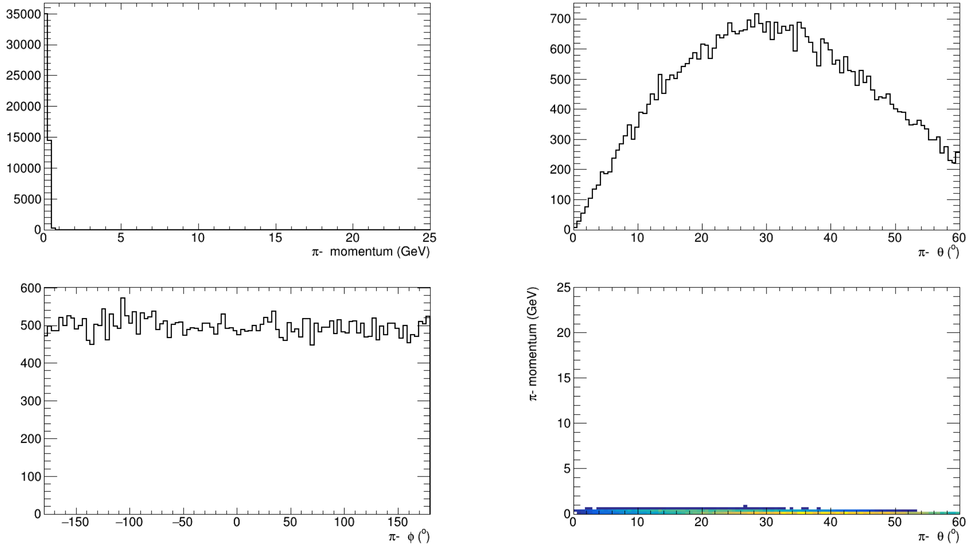
Not yet seen in J/ψ K+...

Z_{cs}(4000) Particle momentum

Λ proton



Λ π-



Protons 0.5-2 GeV

Λ Decay pions have very low Momentum ~0.2 GeV

Z_{cs} Simulation @ 22 GeV

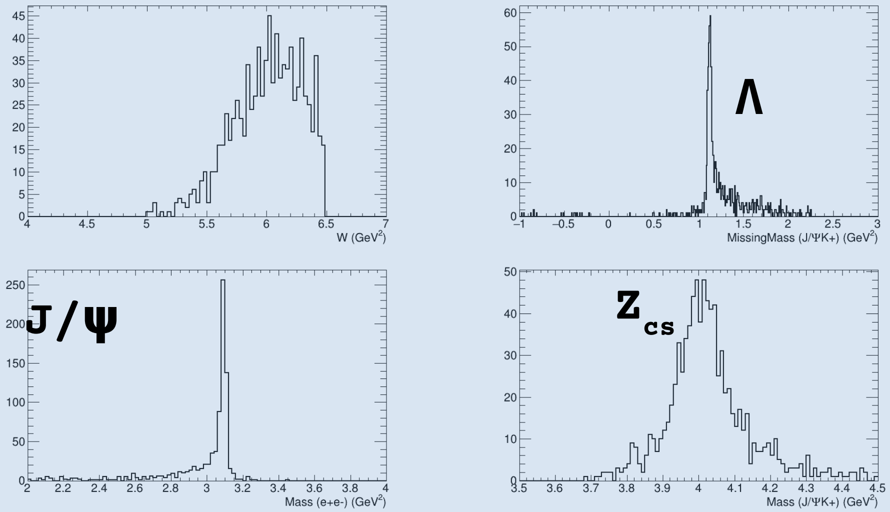
Total 33,000 events produced

Do not detect π-p, reconstruct Λ

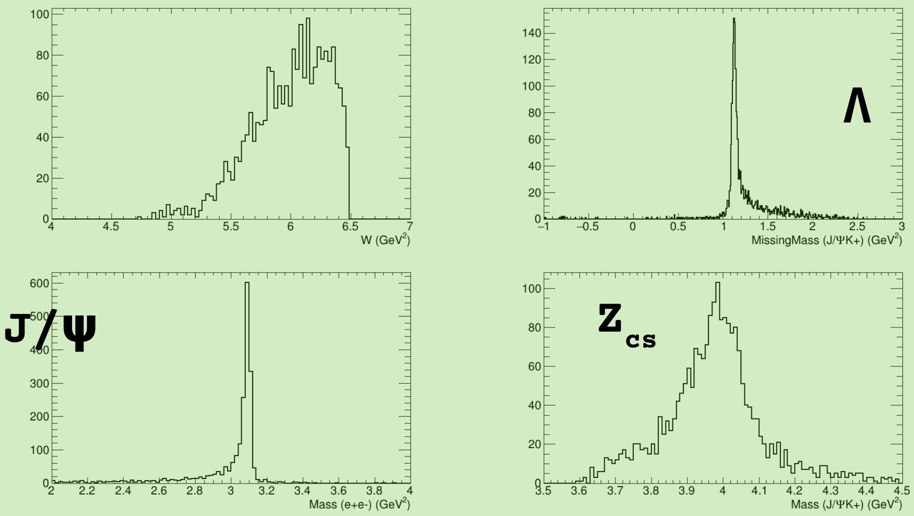
-ve outbend => 900 events, 3%

+ve outbend => 2000 events, 6%

-ve outbend



+ve outbend



Z_{cs} Simulation @ 17 GeV

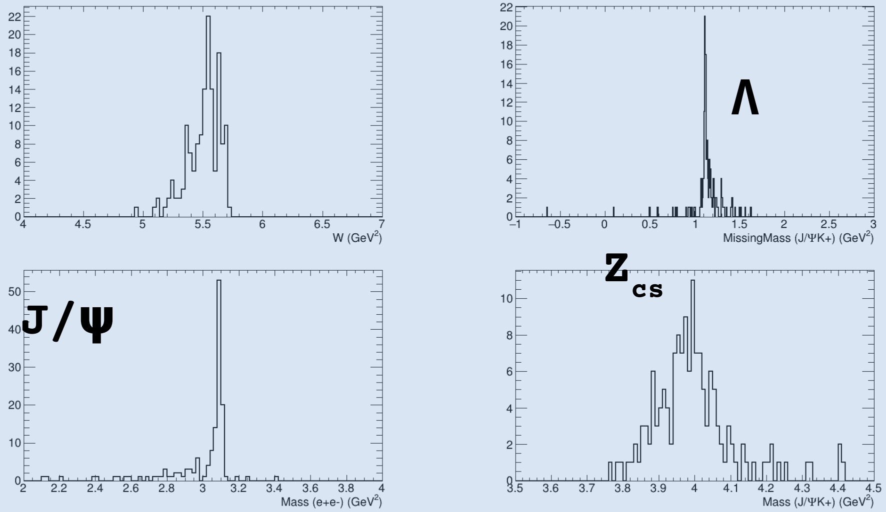
Total 4,500 events produced

Do not detect π-p, reconstruct Λ

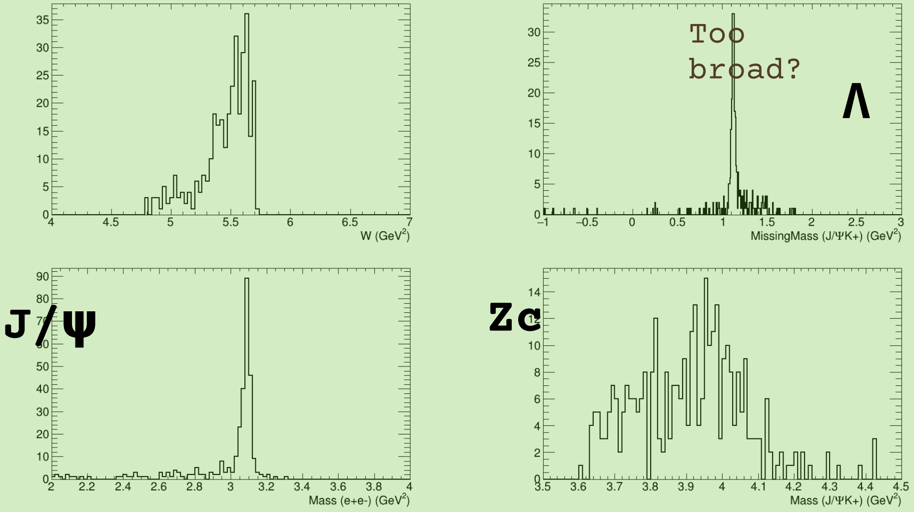
-ve outbend => 150 events, 3%

+ve outbend => 300 events, 6%

-ve outbend



+ve outbend



$D^0\Lambda_c$ quasi-real photoproduction

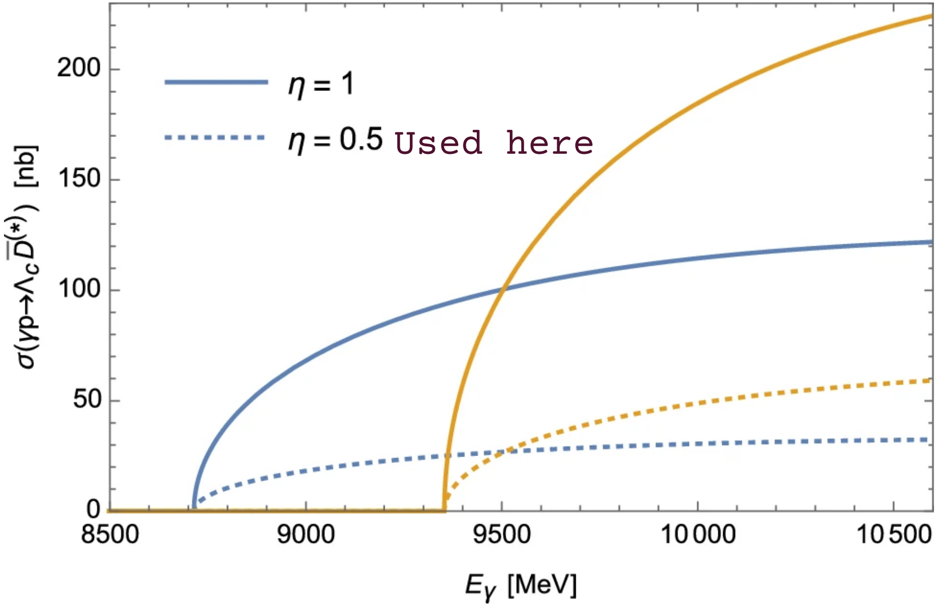
Deciphering the mechanism of near-threshold J/ψ photoproduction

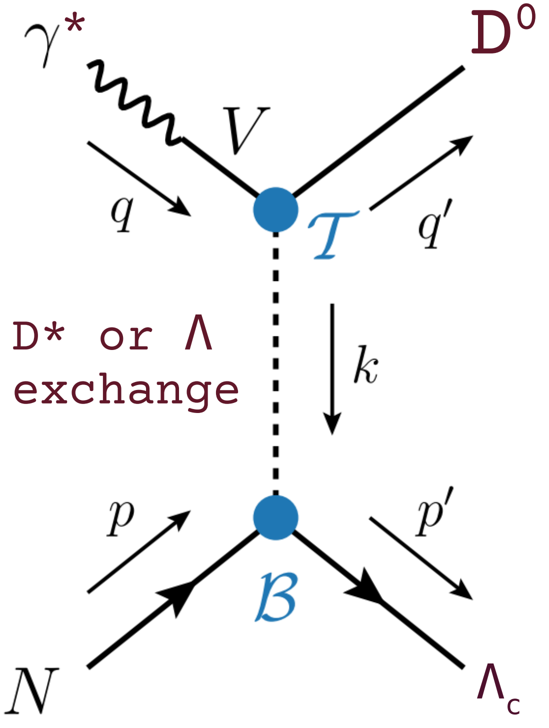
Meng-Lin Du, Vadim Baru, Feng-Kun Guo, Christoph Hanhart, Ulf-G. Meißner, Alexey Nefediev & Igor Strakovsky

The European Physical Journal C 80, Article number: 1053 (2020) | Cite this article

Using jpacPhoto implementation

$D^0 \rightarrow \pi^- K^+$





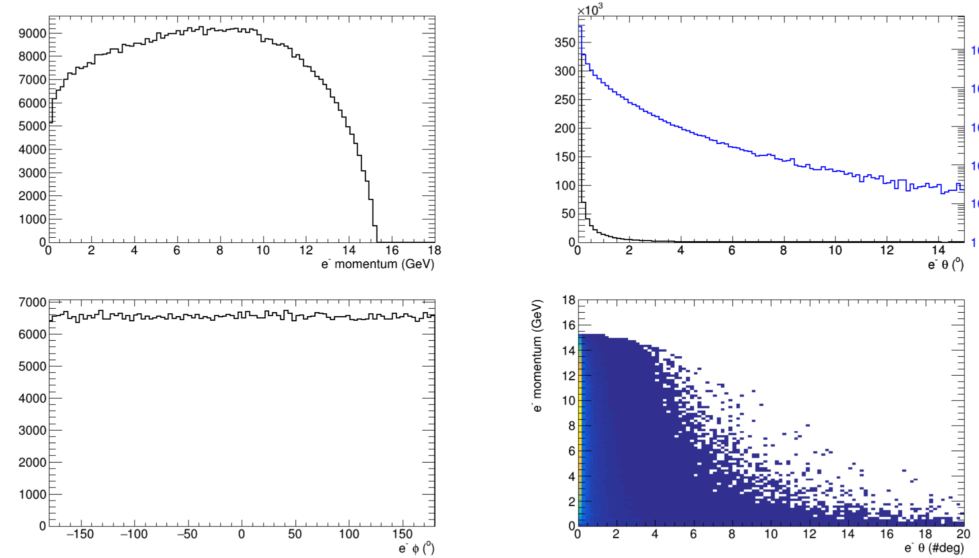
24 GeV!
Probably not
Valid for this
Range
=>
Number of events
Not reliable

$\Lambda_c \rightarrow p\pi^- K^+$

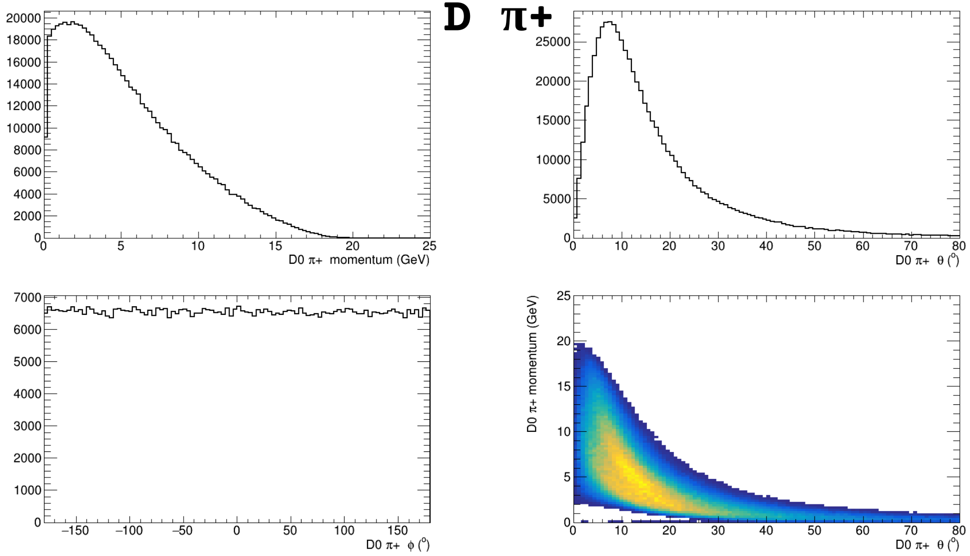
Assuming luminosity 10^{35}
And 50 days gives 450k events.
With 22 GeV beam momentum

Particle momentum

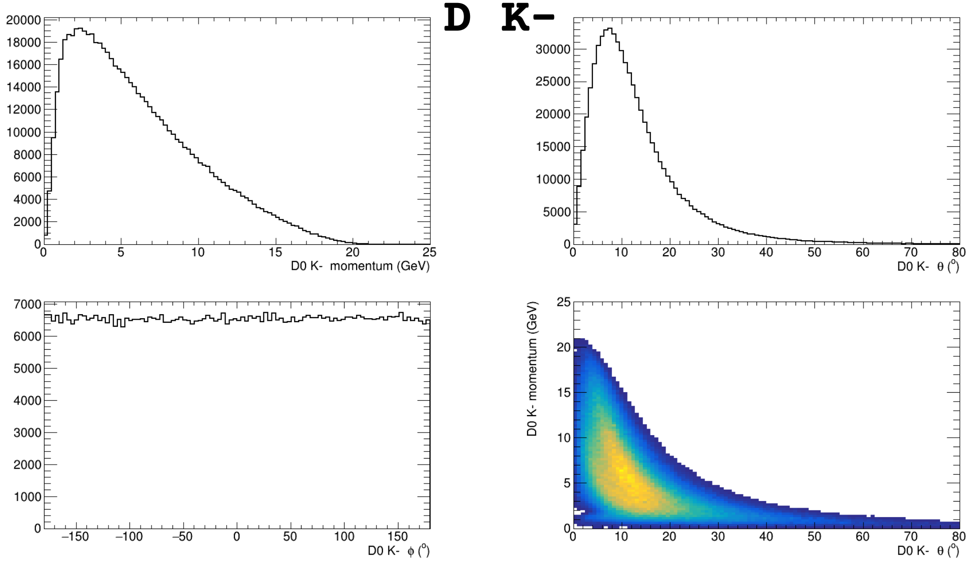
scattered e-



D π+



D K-

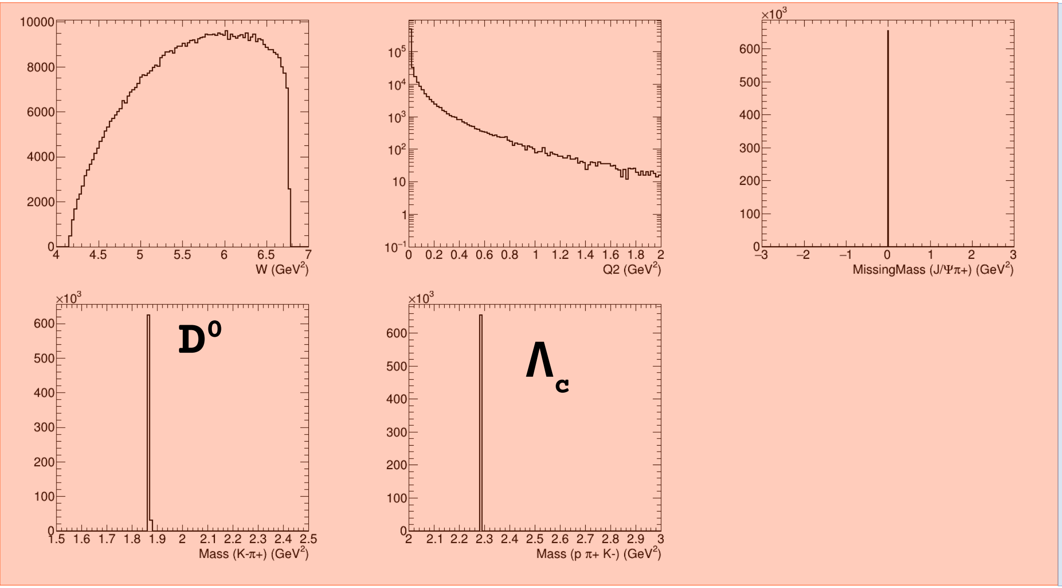


D^0 decay relatively detectable
Large momenta and angles

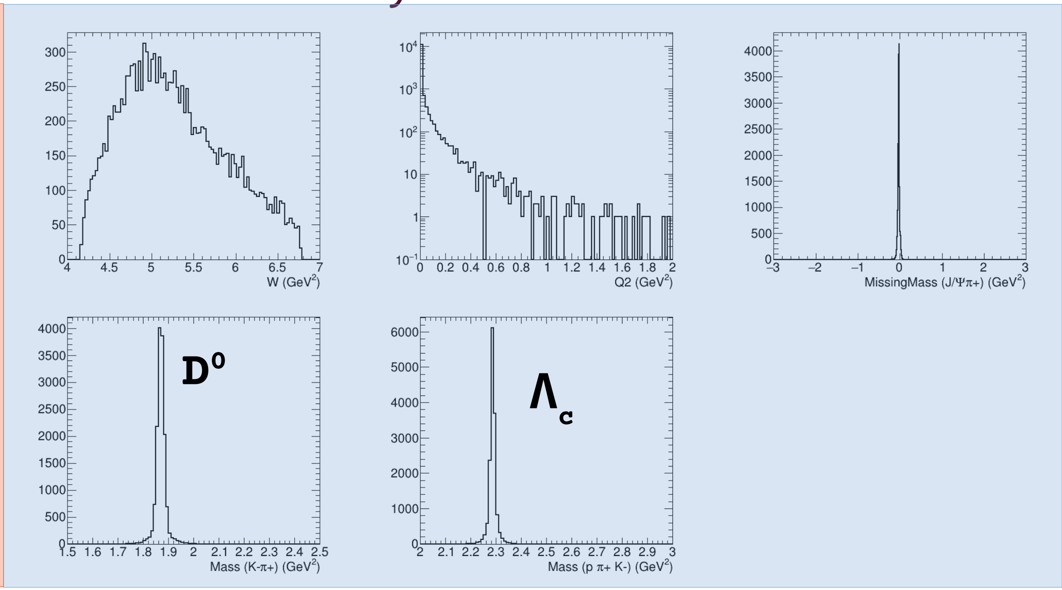
$D^0\Lambda_c$ Kinematics @ 22 GeV

Total 450,000 generated events
Detect all
Toy acceptance ~ 2%

Generated

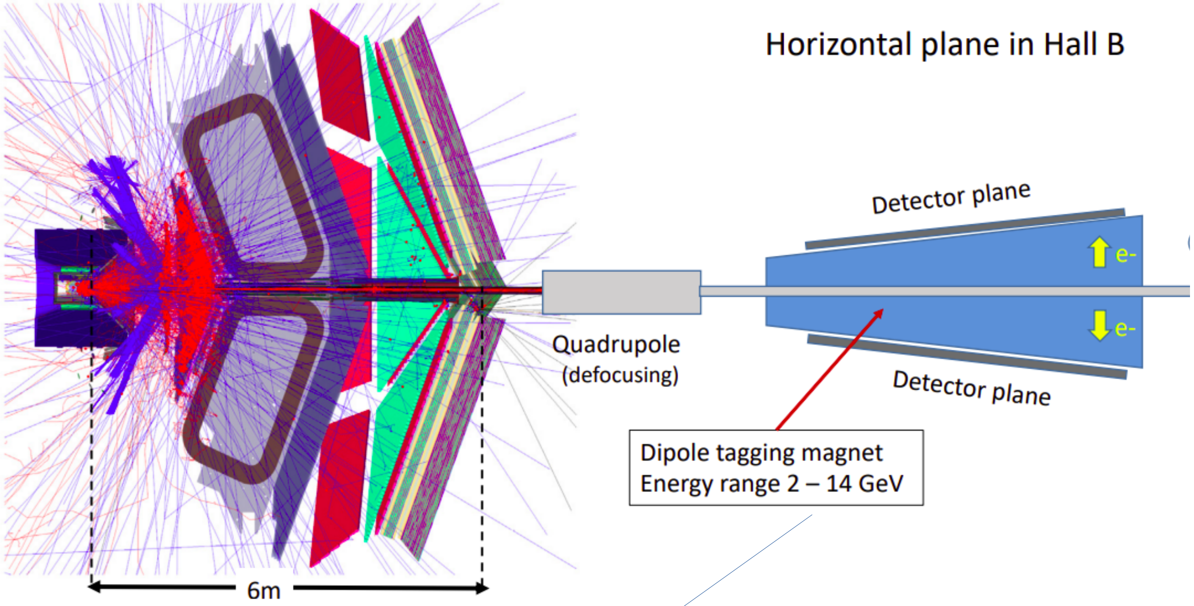


!!Toy simulation!!



Zero Degree Spectrometer

Courtesy: Burkert JFUTURE, Messina.



- Non-interacting electrons, Moller electrons, bremsstrahlung; electrons leave only accidental energy in CLAS12 detectors.
- Hadronically interacting electrons leave significant amount of energy and tracks in CLAS24, O(10GeV).
- The strategy would be to trigger on the event measured in CLAS24 detectors and tag those events with electrons measured in a 0-degree spectrometer.
- This should be studied in simulations to determine what magnitude in instantaneous luminosity can be achieved.
- Note that the Torus magnet open bore of ~ 4 cm accommodates ~0.5° scattering angle without interfering materials. * have assumed here can be increased to 0.75°

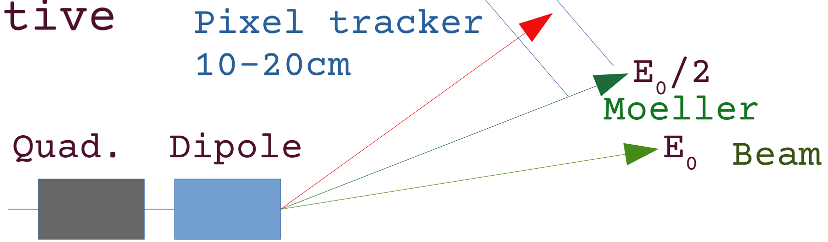
Spectroscopy 0-11GeV e' 22GeV
0-6GeV e' 17GeV

High rate
Pixel tracker
10-20cm

Alternative

High low energy threshold
Will reduce results shown
Here, particularly for 17GeV

CLAS12



Summary

Have shown initial investigation into spectroscopy with charm quarks at a possible energy upgraded Jlab and CLAS12, 17 or 22 GeV.

Event rates and kinematics overall look very promising

Partial upgrade to 17 GeV should allow measurement of some channels

Existing detector systems may already be suitable for such measurements

Some modifications and addition of new technologies should be be investigated for increasing rate capabilities

Supplementing the acceptance of CLAS12 detector could also improve efficiency significantly

Decays with D mesons need to be investigated further

X

22 GeV Cross section and rate estimates

σ is equivalent average photoproduction cross section from threshold to 22GeV

Number per day based On $10^{35} cm^{-2} s^{-1}$ lumi.

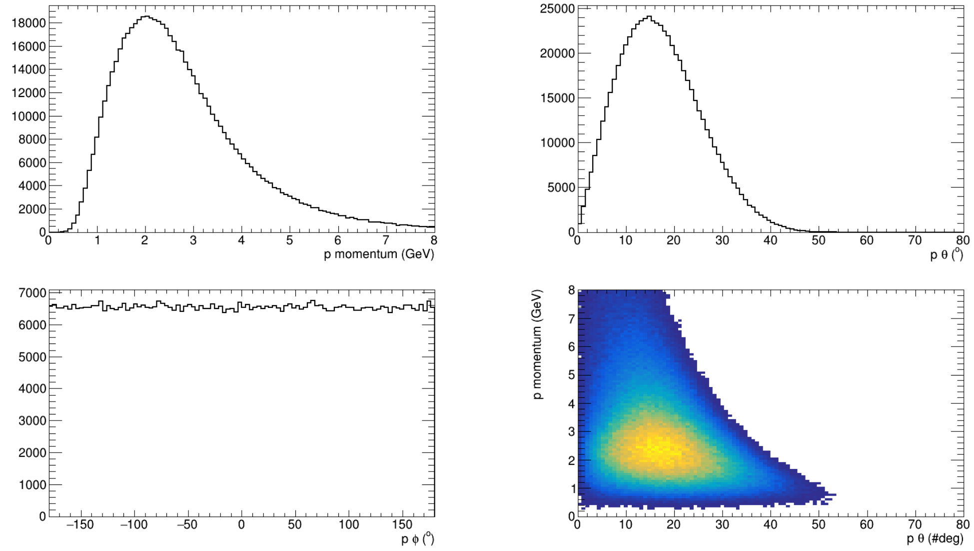
meson	σ (nb)	total branch ratio	#/day
J/ψ	1.9	6%	21000
X(3872)	12	0.3%	3800
Y(4260)	0.7	0.06%	33
Z_c(3900)	5.1	0.6%	4200
Z_{cs}(4000)	1	0.4%	440
$D^0\Lambda_c$	100	0.25%	42000

* estimates for production only.
No Detection considered

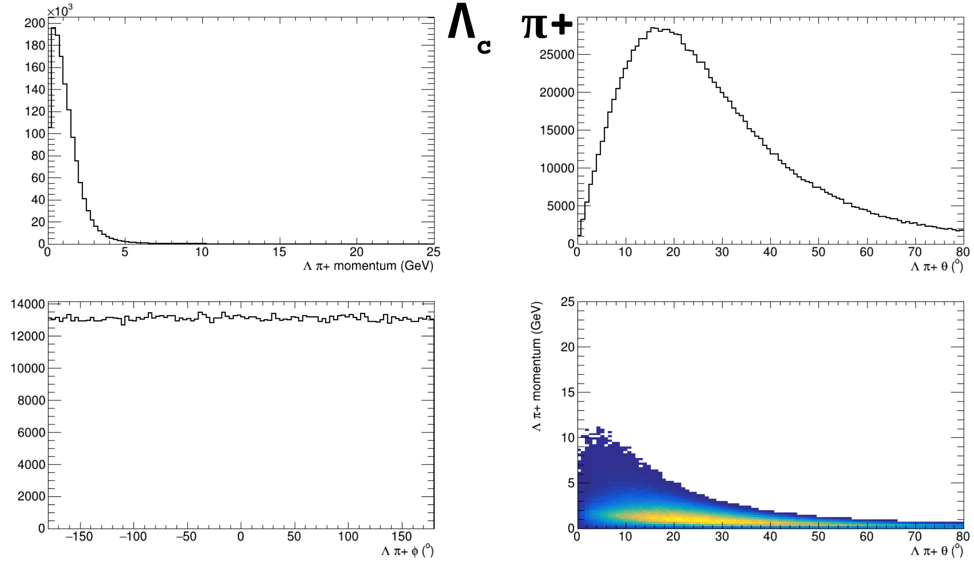
Branching ratios
$X \to J/\psi\pi\pi$ ~5%
$Y \to J/\psi\pi\pi$ ~1%
$Z_c \to J/\psi\pi$ ~10%
$Z_{cs} \to J/\psi K$ ~10%
$J/\psi \to e^+e^-$ ~6%
$D^0 \to K\pi$ ~4%
$\Lambda_c \to pK\pi$ ~6.3%
$\Lambda \to p\pi$ ~67%

Particle momentum

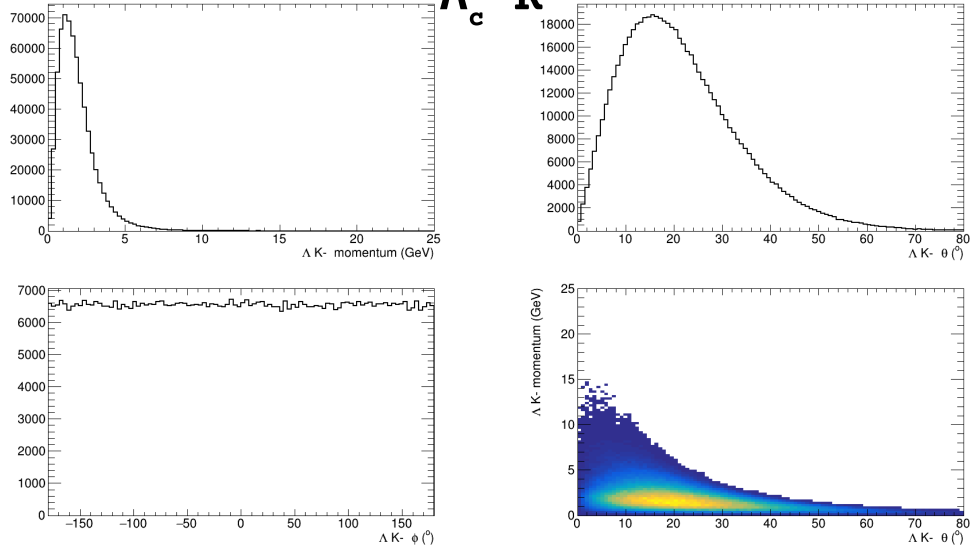
Λ_c proton



Λ_c π+



Λ_c K-

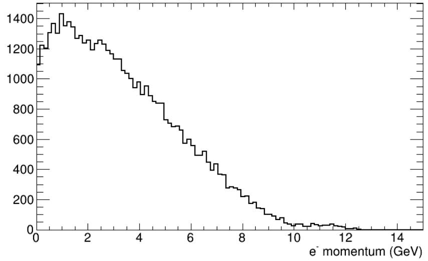


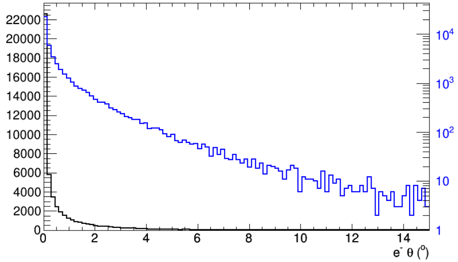
Λc proton very detectable

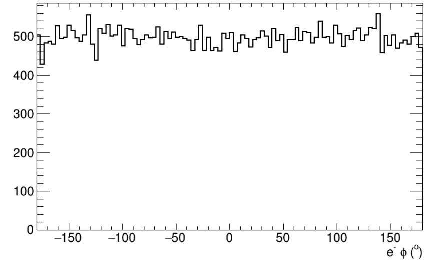
K,π reasonable (lower momentum)

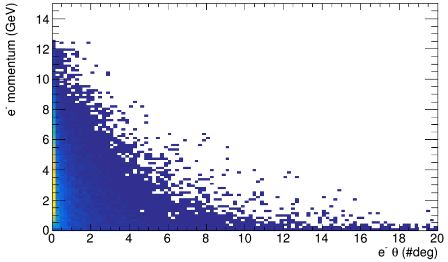
$Z_{cs}(4000)$ Particle momentum

scattered e-

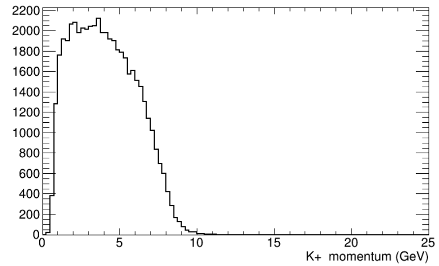


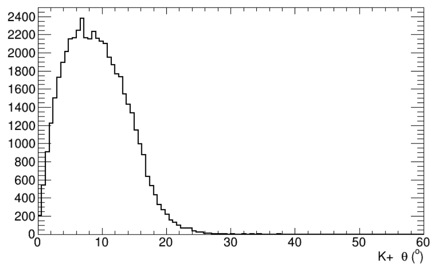


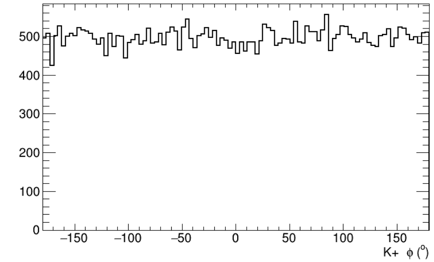


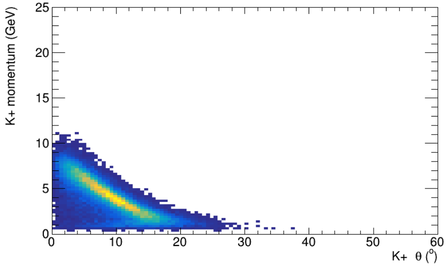


K+

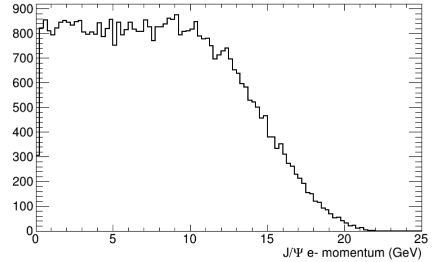


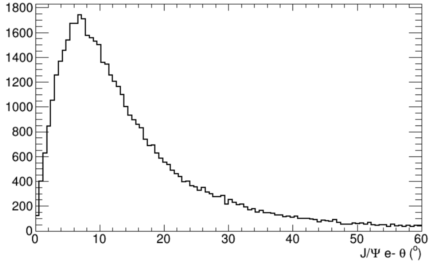


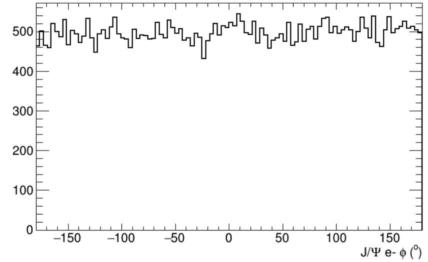


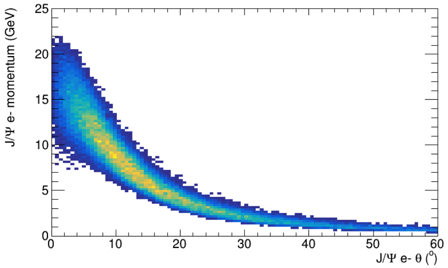


J/ψ e-









Event Generator (Formal)

$$\frac{d^4\sigma}{ds\,dQ^2\,d\phi\,dt} = \frac{d^2\sigma_{e,\gamma*e'}}{dsdQ^2}\frac{d^2\sigma_{\gamma*+p\to V+p}(s,Q^2)}{d\phi\,dt}$$

→ Integrate for event rate

$$Q^2 = 2\,E\,M\,x\,y$$

$$W^2 = M^2 + 2\,E\,M\,y - Q^2$$

$$\frac{d^2\sigma_{e,\gamma*e'}}{dsdQ^2} = \frac{\alpha}{2\pi}\cdot\frac{K.L}{E}\cdot\frac{1}{Q^2}\cdot\frac{1}{(s-M^2+Q^2)}$$

$$L = \frac{1+(1-y)^2}{y} - \frac{2m_e^2\,y}{Q^2}$$

$$\frac{d^2\sigma_{\gamma*+p}}{d\phi\,dt} = \frac{d\sigma^T(Q^2,s)}{d\phi\,dt} + (\epsilon+\delta)\frac{d\sigma^L(Q^2,s)}{d\phi\,dt}$$

$$K = \frac{W^2-M^2}{2\,M} = \nu(1-x) = Ey(1-x) = \nu - \frac{Q^2}{2\,M}$$

$$\frac{d^2\sigma^T(Q^2,s)}{d\phi\,dt} = \frac{d^2\sigma_{\gamma+p\to V+p}}{d\phi\,dt}F(Q^2)$$

$$\frac{d^2\sigma^L(Q^2,s)}{d\phi\,dt} = 0$$

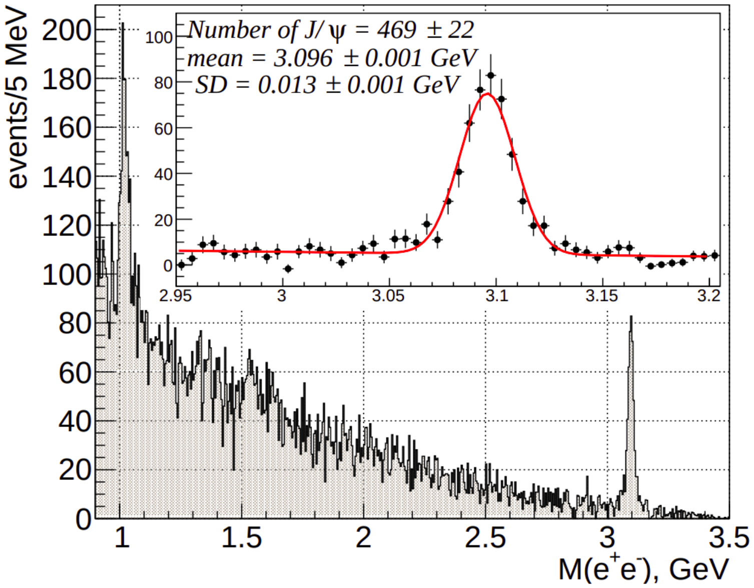
$$\frac{d^2\sigma_{\gamma+p\to V+p}}{d\phi\,dt} = \frac{1}{128\,\pi^2 s}\frac{1}{|\mathbf{p}_{\gamma*cm}|^2}|M(s,t)|^2$$

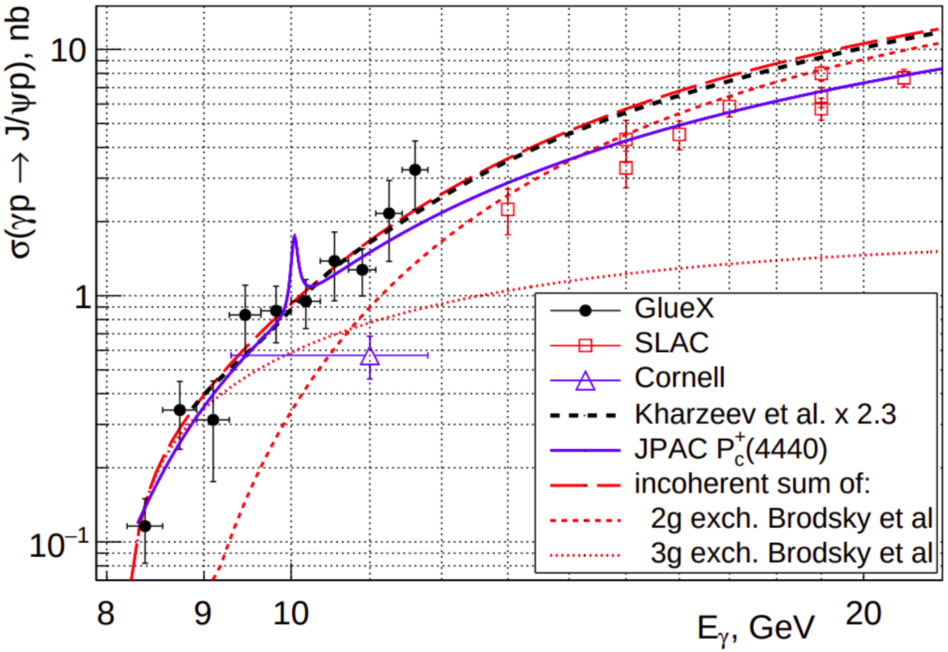
→ $|M(s,t)|^2$ JPAC Photoproduction Amplitudes

J/ψ photoproduction

First Measurement of Near-Threshold J/ψ Exclusive Photoproduction off the Proton

A. Ali *et al.* (GlueX Collaboration)
Phys. Rev. Lett. **123**, 072001 – Published 13 August 2019

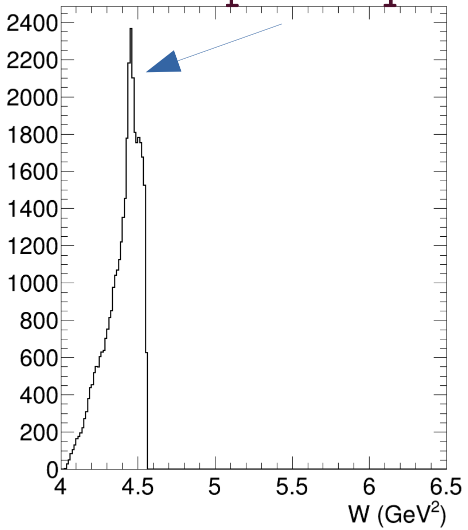


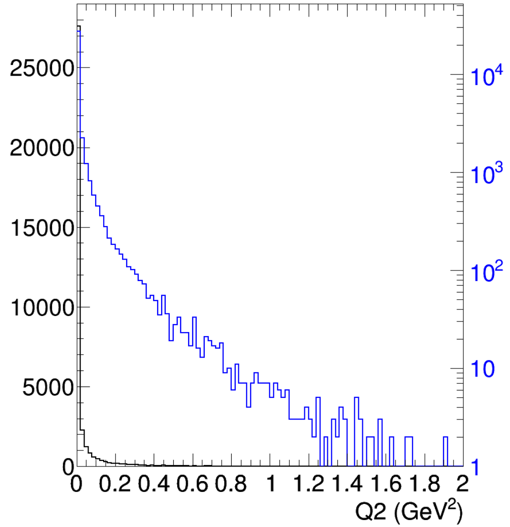


Note ~ 68 pb^{-1} of data

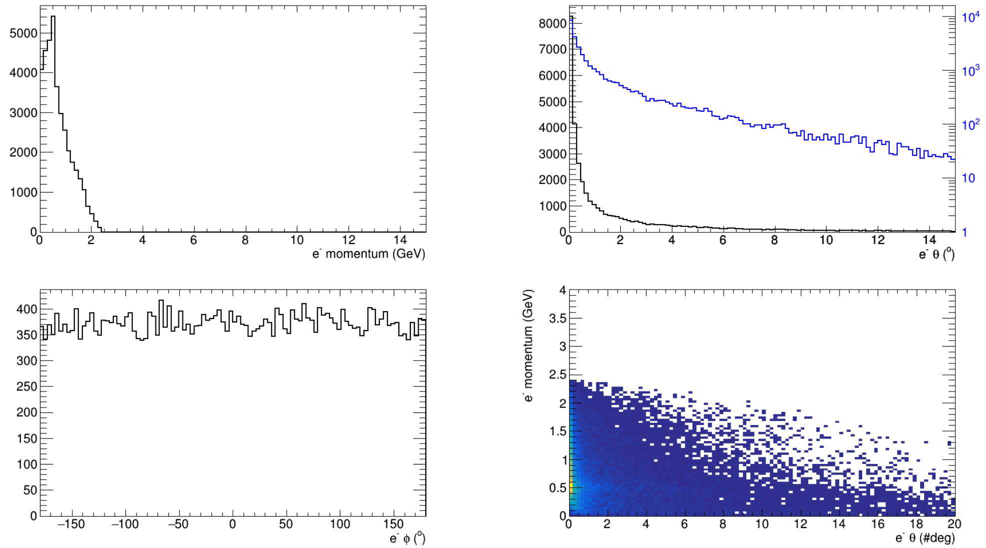
J/ψ (quasi-real)photoproduction @ 11GeV

pentaquark





scattered e-



Virtual photon flux
integrated from threshold

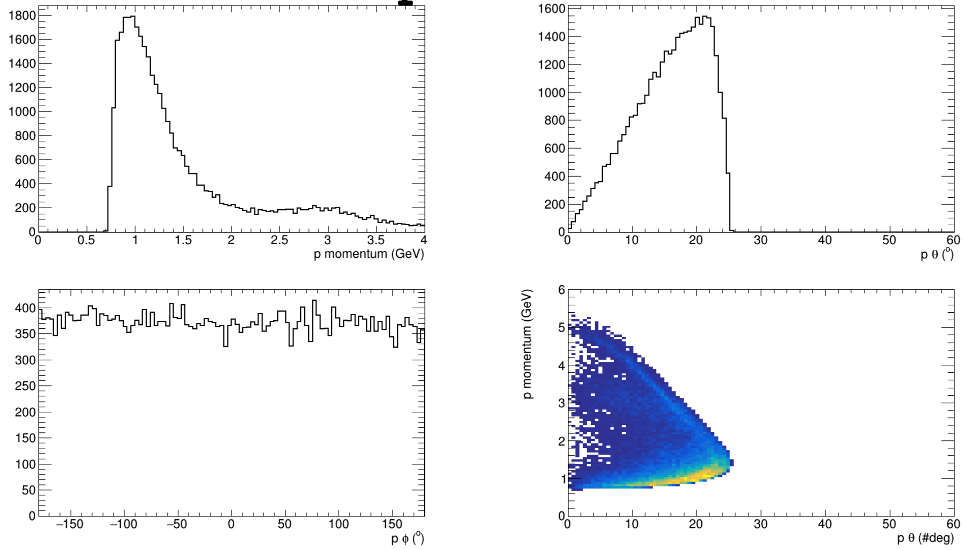
Note virtual photon luminosity :
10^{35} (cm^{-2}s^{-1}).50(days).0.004 = 1710 pb^{-1}
Scale GlueX: 1710/68 * 469 = 11,800 J/ψ
Consistent if GlueX acceptance ~0.3

e$^-$ momentum < 2 GeV
e$^-$ ϑ < 10°

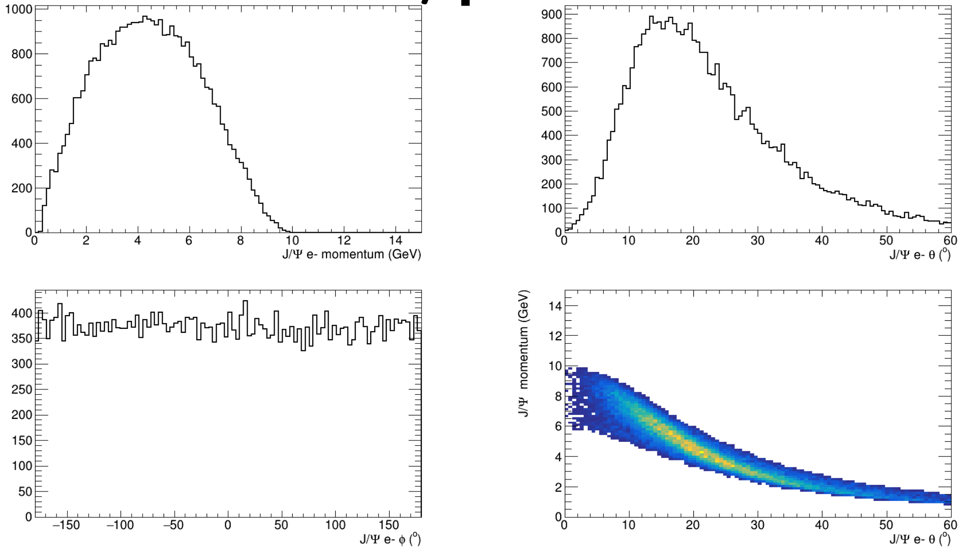
#events here 37,000

J/ψ (quasi-real)photoproduction @ 11GeV

proton



J/ψ e-

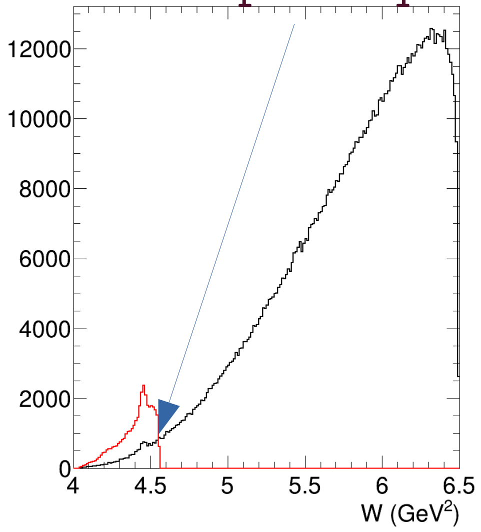


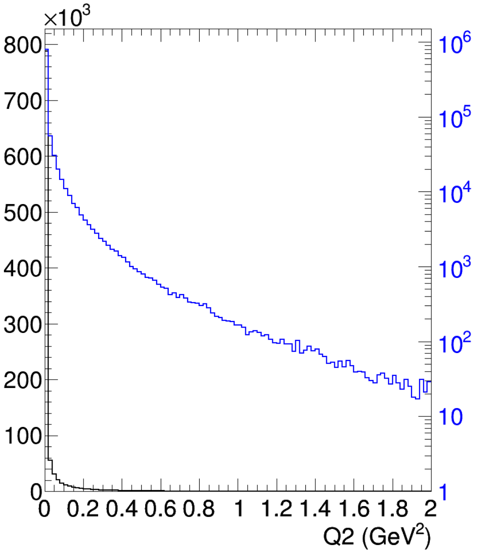
Proton momentum < 5 GeV
Proton ϑ < 26°

J/ψ e^- momentum < 10 GeV
J/ψ e^- ϑ < 60°

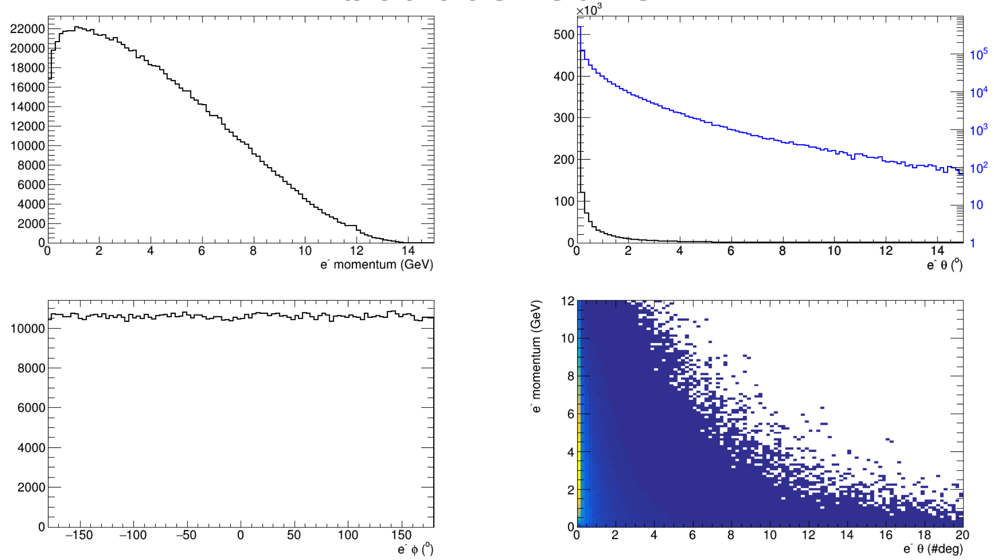
J/ψ (quasi-real)photoproduction @ 22GeV

pentaquark





scattered e-



Pentaquark narrow structure in W
Only produced over narrow E_γ range

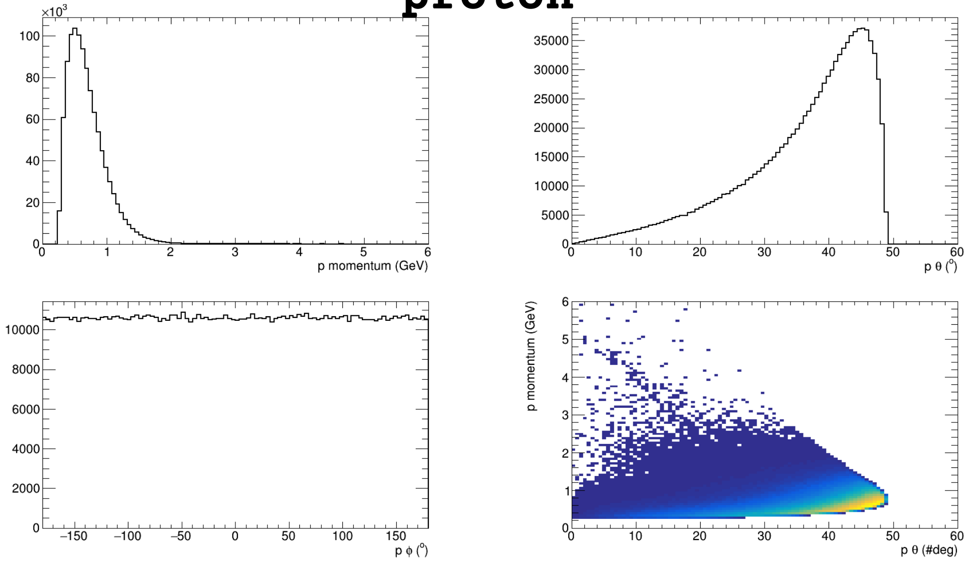
Lower beam energies is preferential
for pentaquark searches

e$^-$ momentum < 14 GeV
e$^-$ ϑ < 5°

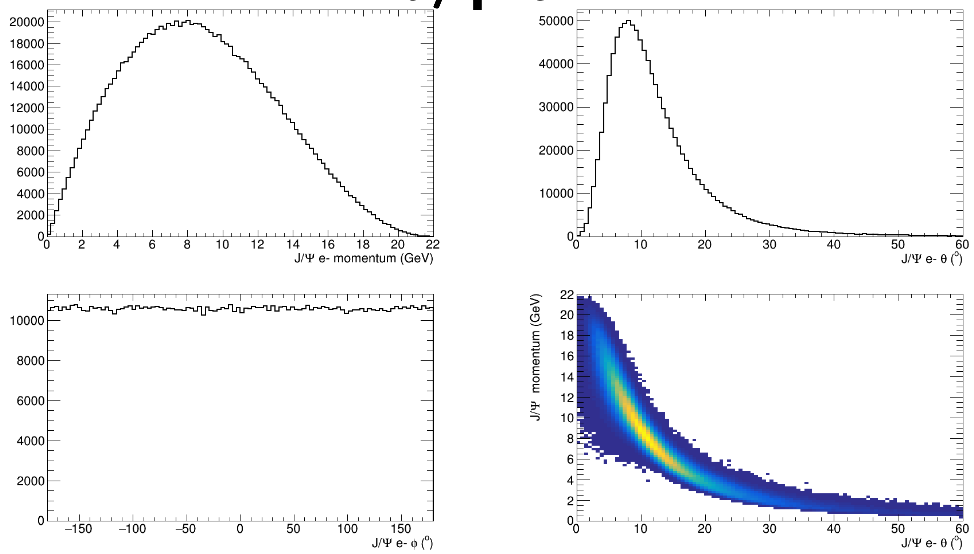
#events 1,060,000
85% with e$^-$ ϑ < 1°

J/ψ (quasi-real)photoproduction @ 22GeV

proton



J/ψ e-



Proton momentum < 5 GeV
Proton ϑ < 50°

J/ψ e^- momentum < 22 GeV
J/ψ e^- ϑ < 60°