Spectroscopy in the JFUTURE

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29/03/2022

Overview

Main focus here initial look at meson production at >20GeV

Use event-generator and toy simulations
- low Q2 electroproduction

Mostly consider 3 experimental aspects we wish to maximise :
- Luminosity
- Acceptance
- Resolution

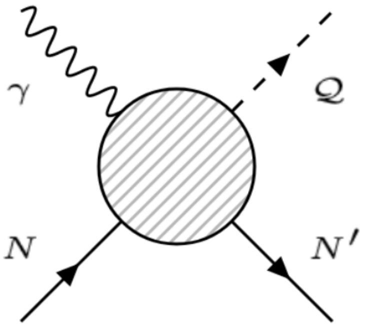
See also CLAS12 presentations from D'Angelo and Burkert

Other aspects also important
- PID
- Vertex reconstruction
- Background rejection
- Detector rates

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.

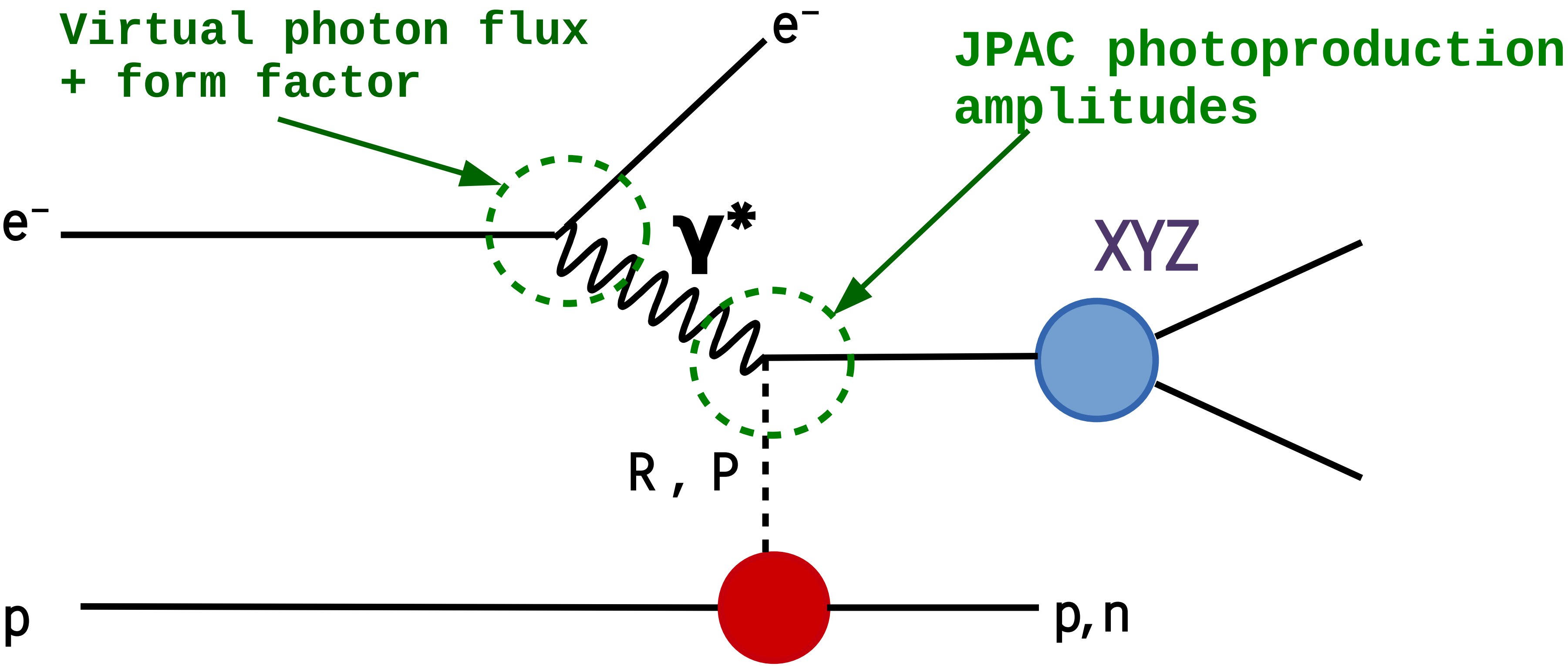
XYZ spectroscopy at electron-hadron facilities: Exclusive processes

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



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

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

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

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

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

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

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

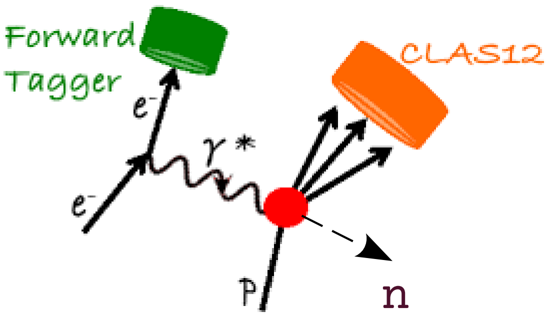
$$\frac{d^2\sigma^T(Q^2,s)}{d\phi\,dt} = \frac{d^2\sigma_{\gamma+p\to V+p}}{d\phi\,dt}F(Q^2)$$

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

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

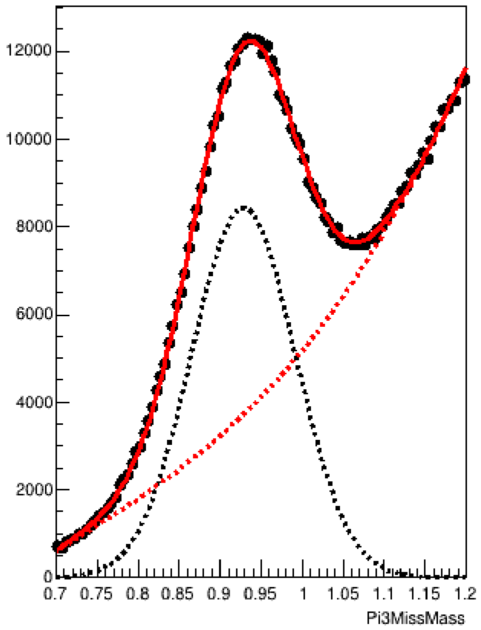
→ $|M(s,t)|^2$ JPAC Photoproduction Amplitudes

CLAS12 MesonEx: low Q2 electroproduction

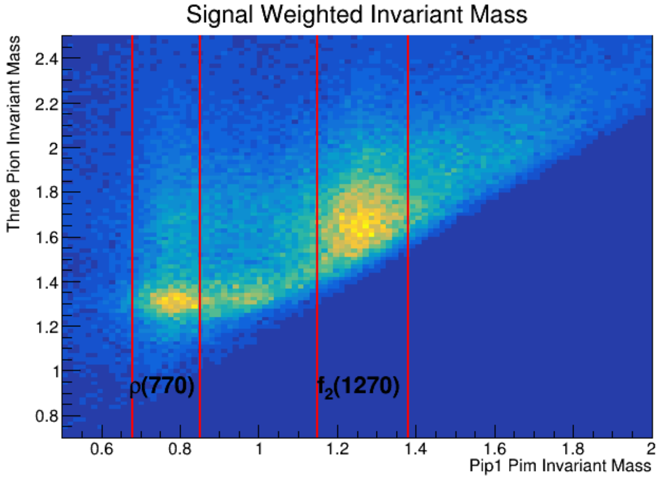


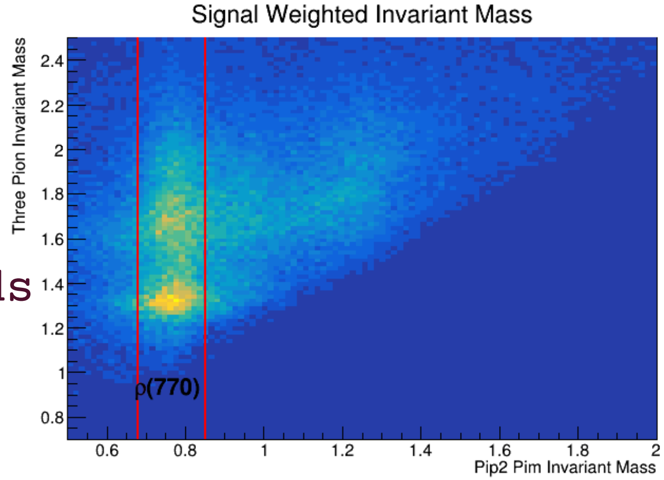
Forward tagger measures
Electron 2.5-4.5°
Q^2<0.3 (GeV/c)^2

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



Reconstruct
Neutron mass to
Subtract backgrounds

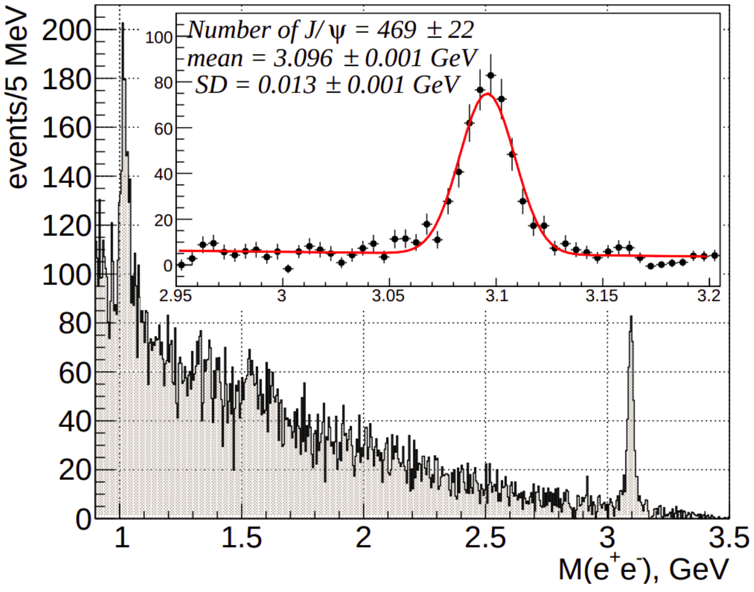


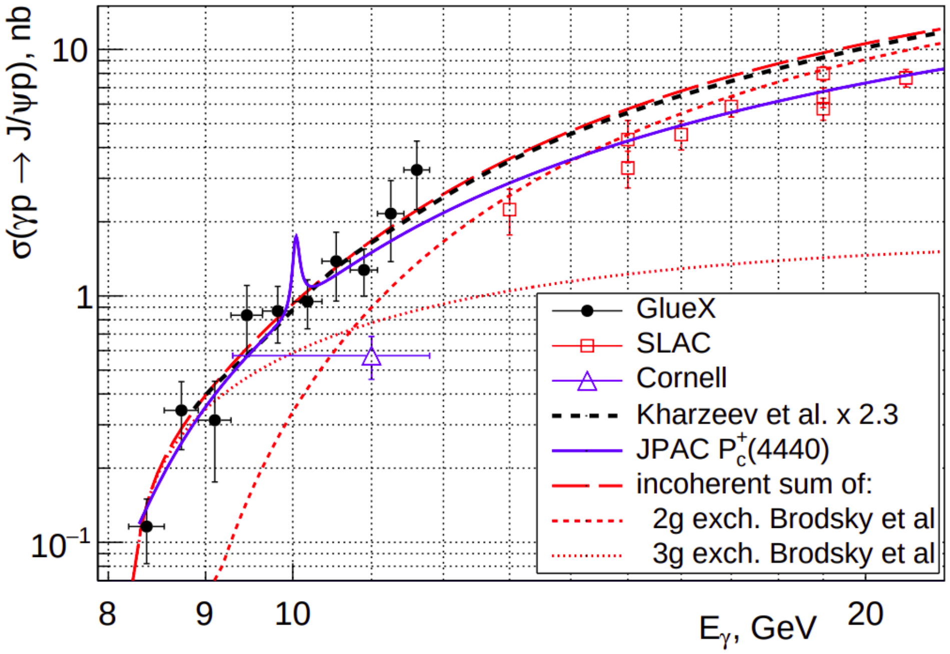


J/ψ photoproduction

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

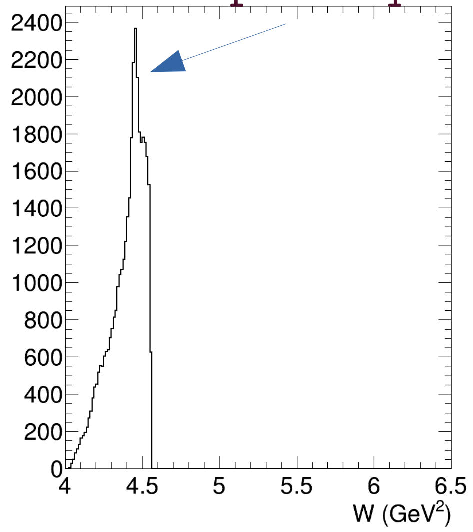


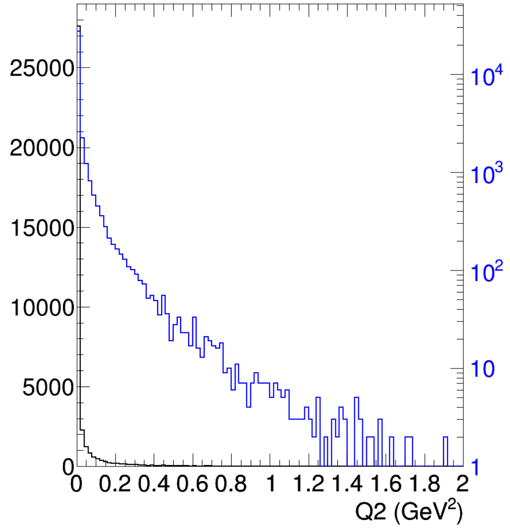


Note ~ 68 pb^{-1} of data

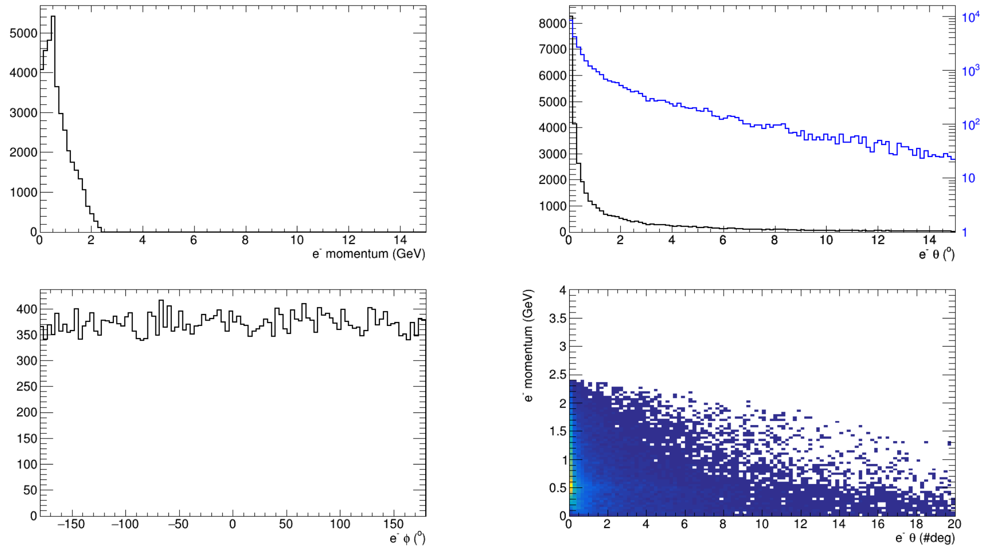
J/ψ (quasi-real)photoproduction @ 11GeV

pentaquark





scattered e-



Virtual photon flux
integrated from threshold

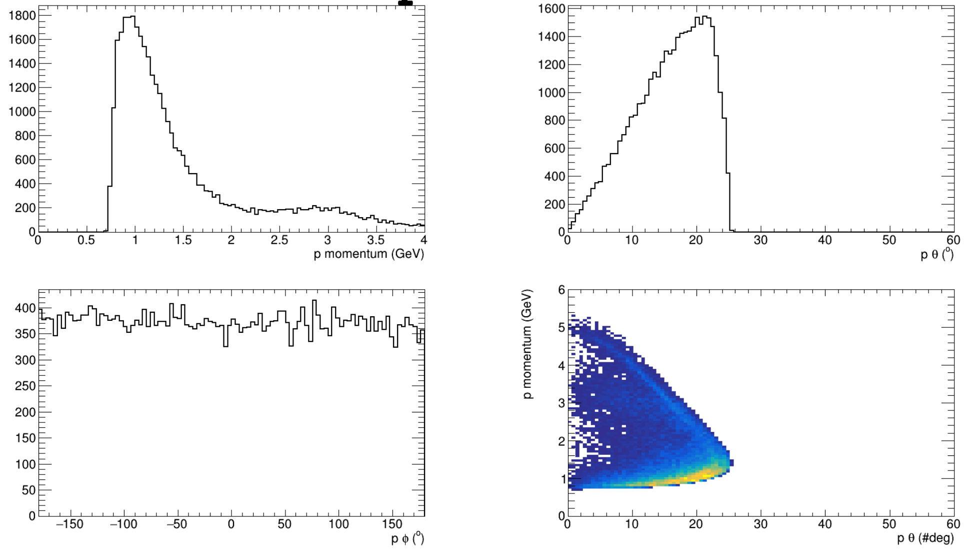
e$^-$ momentum < 2 GeV
e$^-$ ϑ < 10°

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

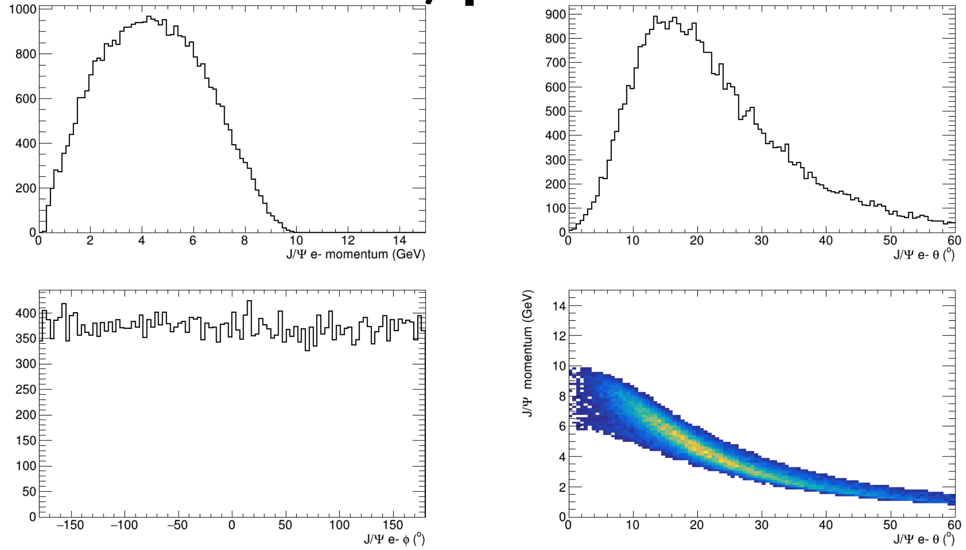
#events here 37,000

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

proton



J/ψ e-

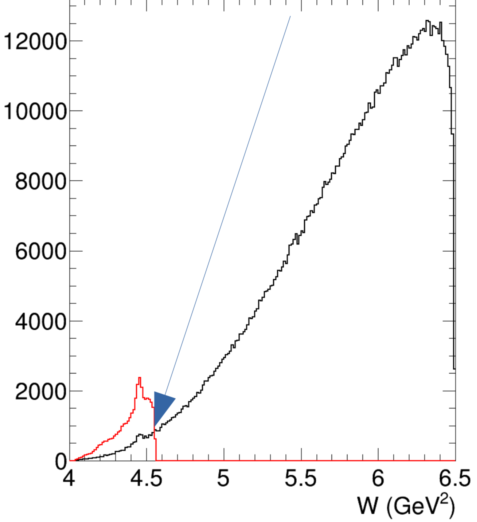


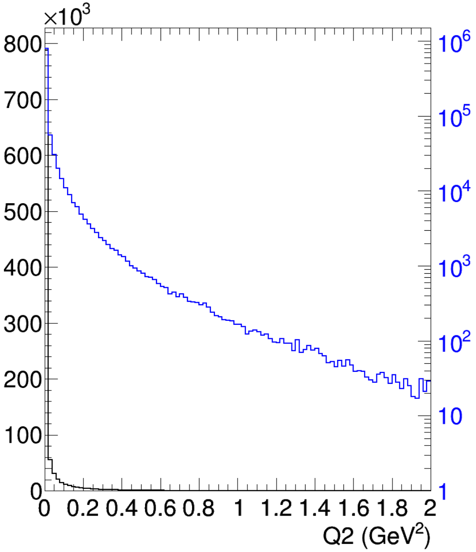
Proton momentum < 5 GeV
Proton ϑ < 26°

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

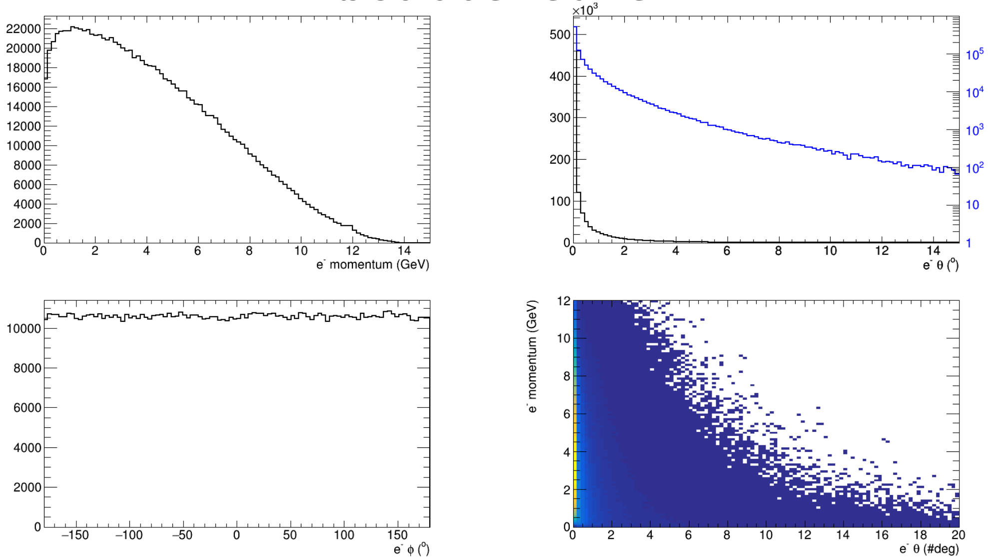
J/ψ (quasi-real)photoproduction @ 22GeV

pentaquark





scattered e-



Pentaquark narrow structure in W
Only produced over narrow E_γ range

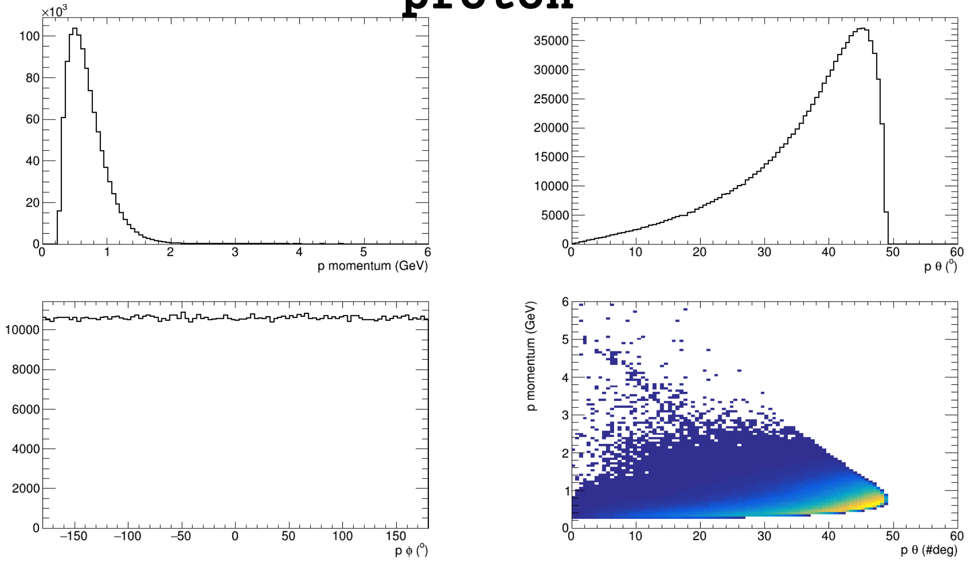
Lower beam energies is preferential for pentaquark searches

e^- momentum < 14 GeV
e^- ϑ < 5°

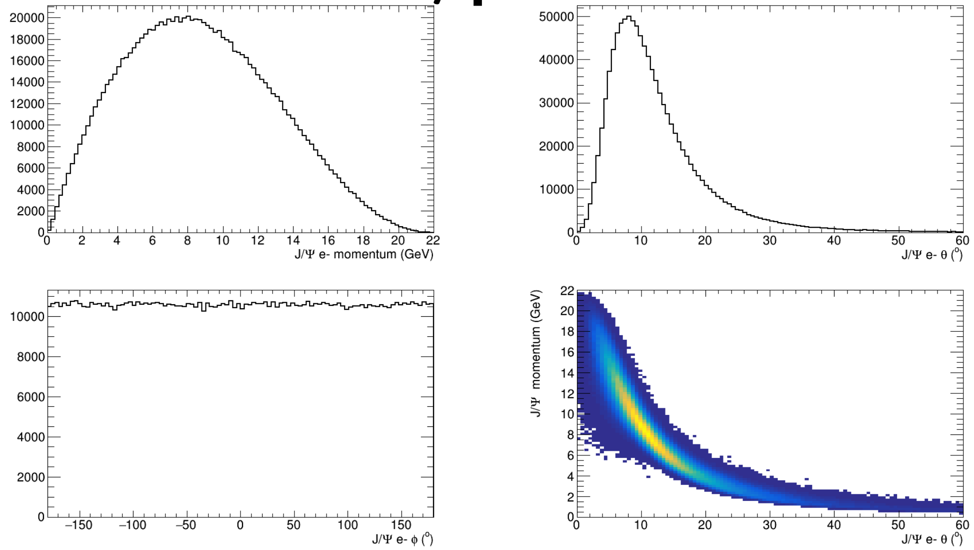
#events 1,060,000
85% with e^- ϑ < 1°

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°

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

SoLID detector in Hall A

https://www.jlab.org/exp_prog/proposals/12/PR12-12-006.pdf

The SoLID acceptance was mimicked by the following: i) recoil proton, $P_p > 1$ GeV and $8 < \theta_p < 15$ degs, ii) scattered electron, $1 < P_e < 2.5$ GeV and $8 < \theta_e < 15$ degs, iii) electron from the J/Ψ decay, $P_{J/\Psi e} > 2.5$ GeV and $8 < \theta_{J/\Psi e} < 25$ degs, and iv) positron from the J/Ψ decay, $P_{J/\Psi p} > 2.5$ GeV and $8 < \theta_{J/\Psi p} < 25$ degs. The rate calculated from

Nominal acceptance 4-fold 0.03% ; 3-fold 0.07% *0.85 efficiency

	2-gluon only	(2+3)-gluon
4 fold	0.7k	2.9k
3 fold	2.1k	8.1k

3 fold no e-

This model with approximate acceptances

0.9k

2.2k

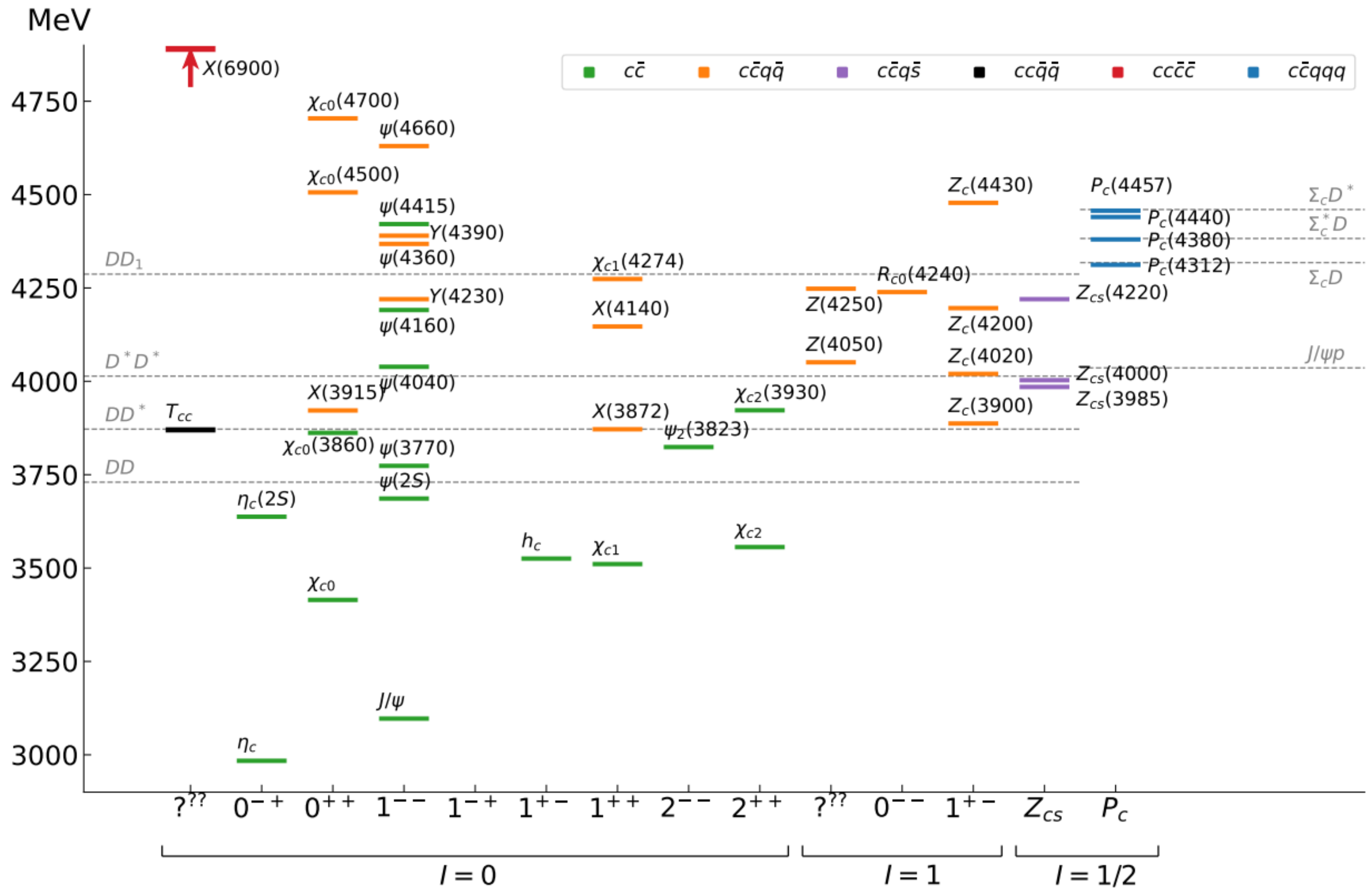
67k

Design specialised for 11 GeV proton kinematics

→ Well suited for pentaquark search

(i.e. at 22GeV acceptance lower)

Exotics review



See presentation Spectroscopy Theory

Z_c(3900) quasi-real photoprocution

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

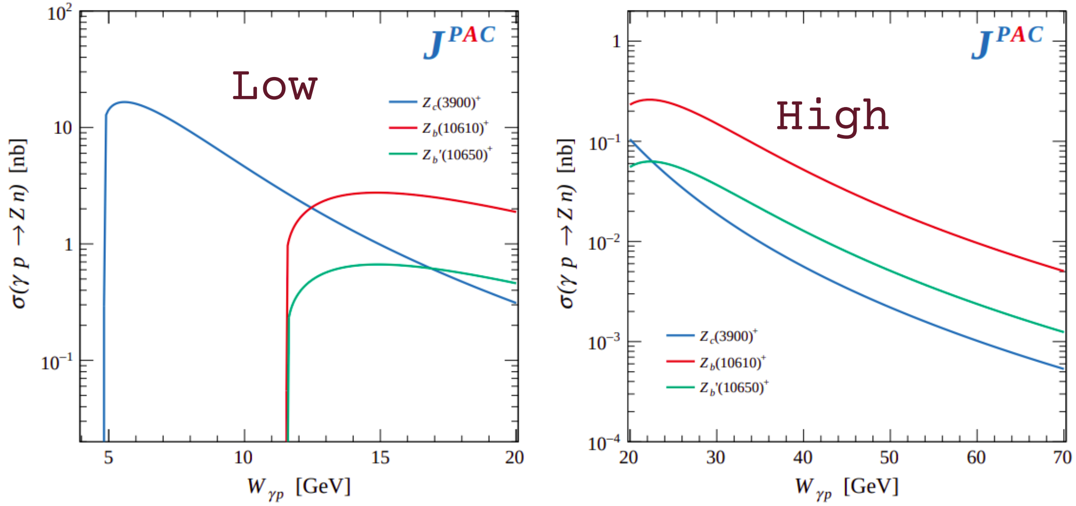
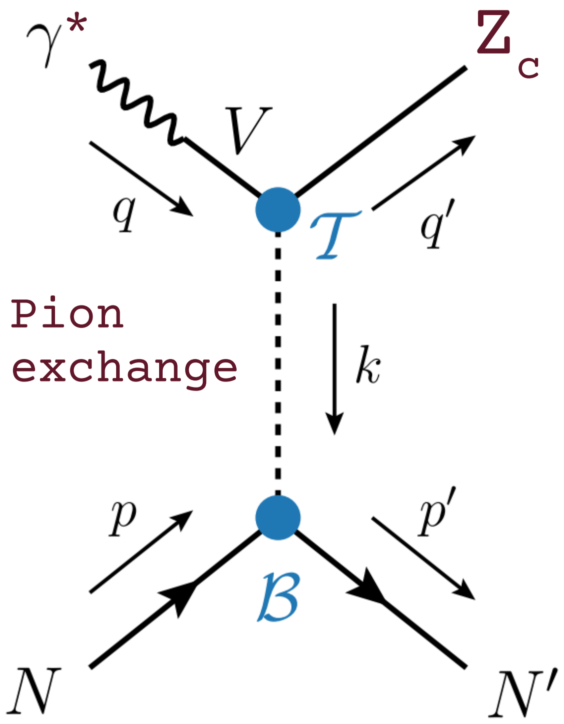


FIG. 2. Integrated cross sections for the three Z states considered. Left panel: predictions for fixed-spin exchange, which we expect to be valid up to approximately 10 GeV above each threshold. Right panel: predictions for Regge exchange, valid at high energies.

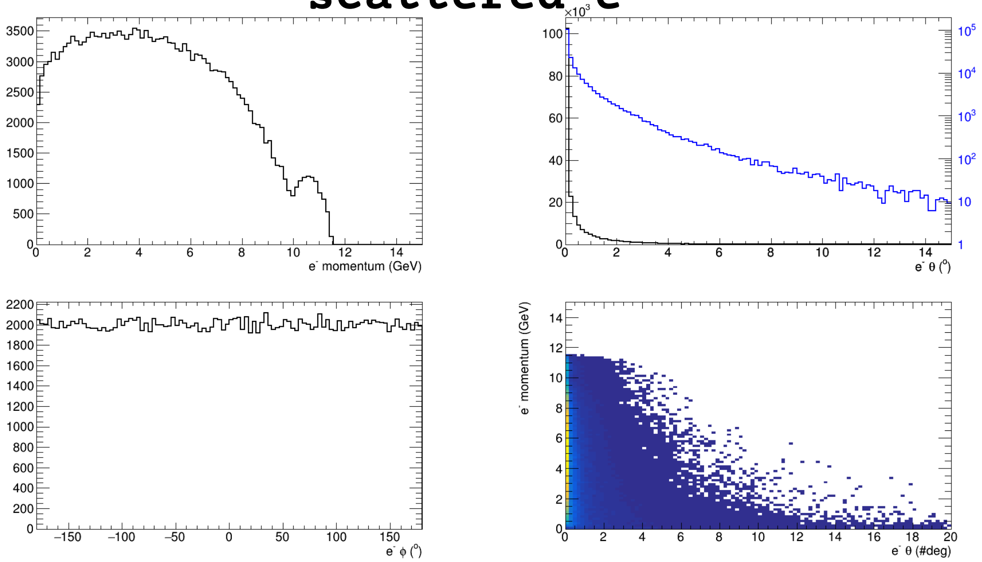


Interpolate between low and high models

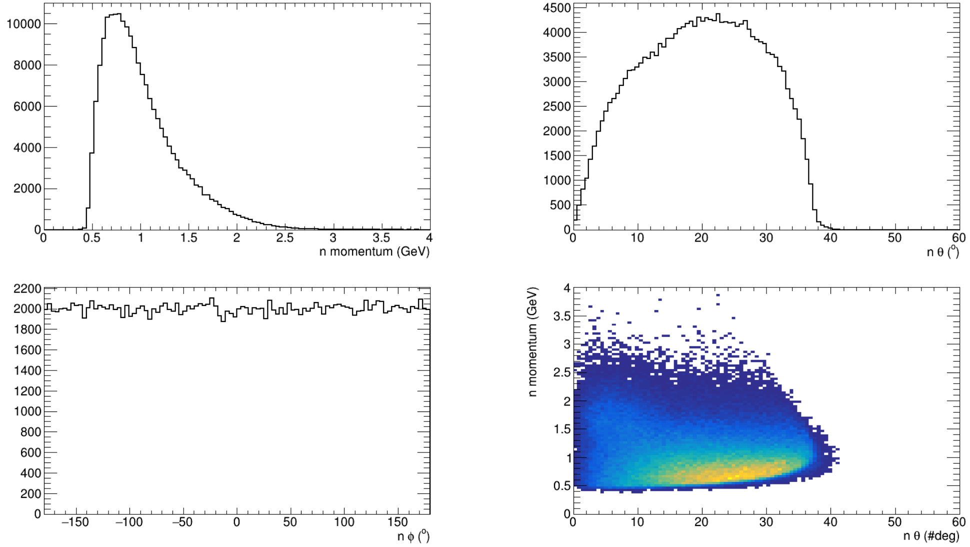
Assuming luminosity 10^{35}
and 50 days gives 210k events.
With 22 GeV beam momentum

$Z_c(3900)$ Particle momentum @ 22GeV

scattered e-



neutron

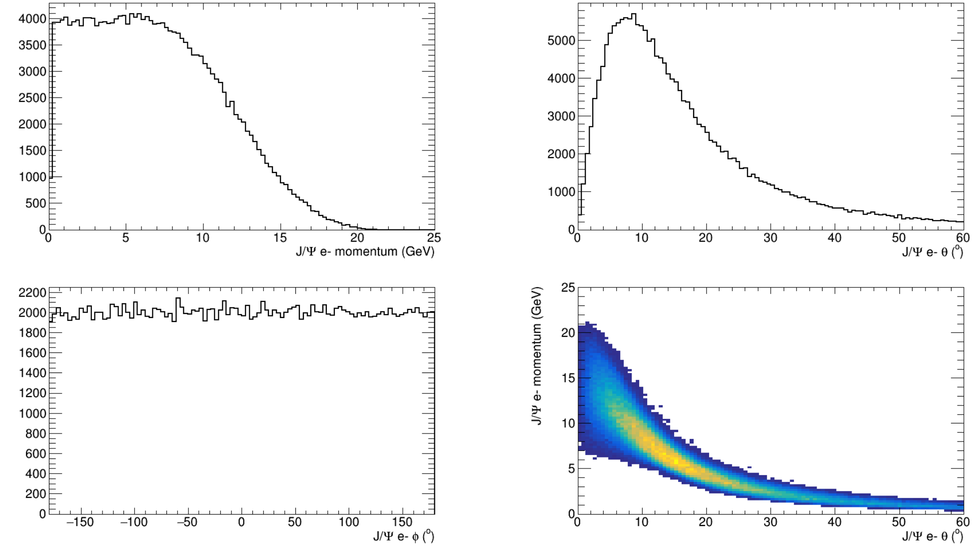


Most e- < 1deg.
And < 12 GeV

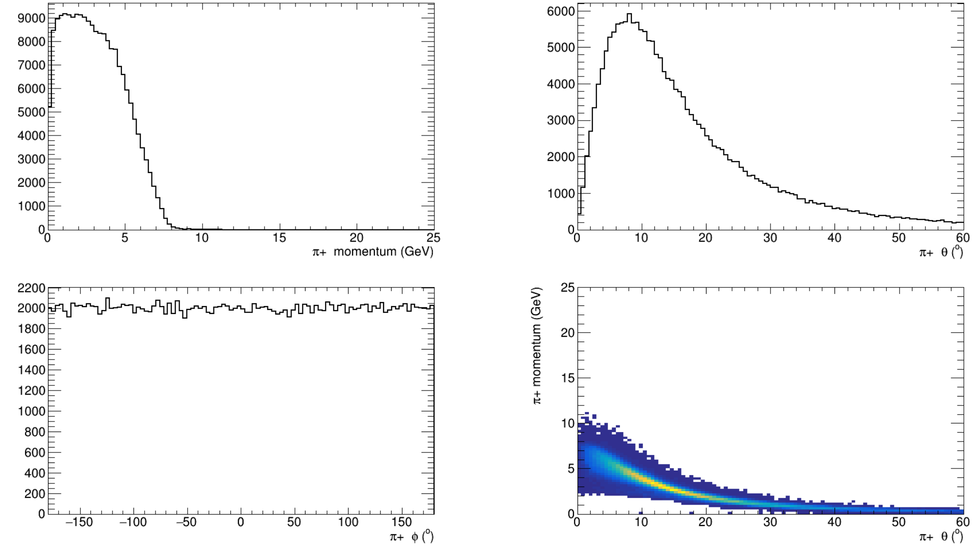
Neutron detection from 0.5 GeV

$Z_c(3900)$ Particle momentum @22 GeV

J/ψ e-



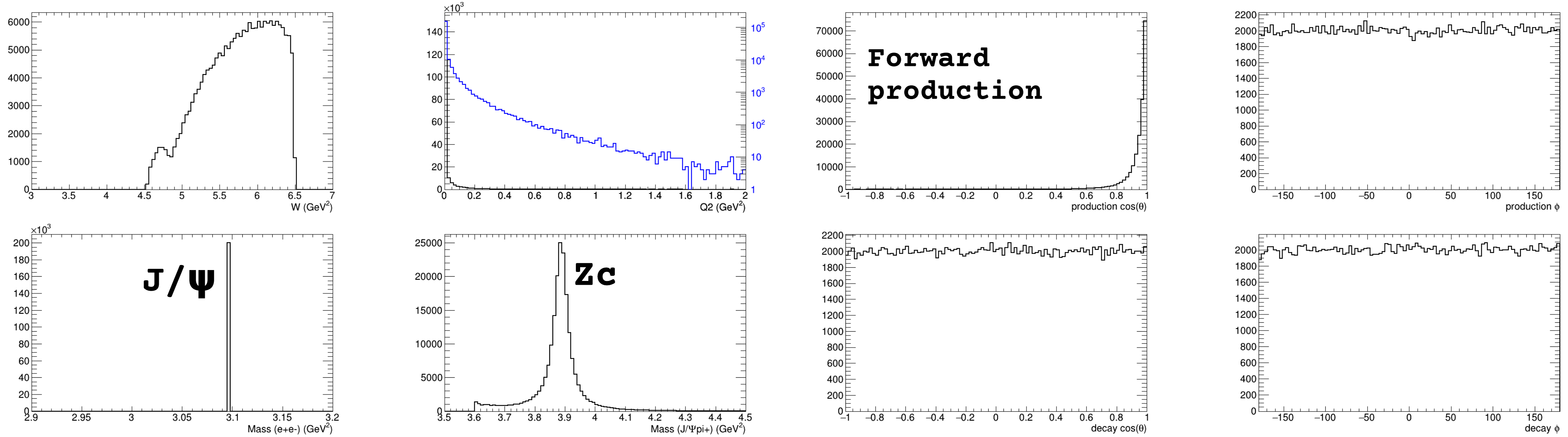
π+



Leptons up to 20 GeV

Decay pions have lower momentum
Similar angular range

$Z_c(3900)$ Kinematics



Toy Detectors

High Luminosity, Resolution
Low Acceptance detector

, P > 0.3 GeV
, ϑ > 9° ; 70% detection
For ϑ < 35°
, σ_p = 1%
, σ_ϑ = 1 mrad
, σ_ϕ = 1/sin(ϑ) mrad
For ϑ > 35°
, σ_p = 5%
, σ_ϑ = 1 mrad
, σ_ϕ = 10/sin(ϑ) mrad

For scattered e-
, σ_p = 2%

High Acceptance
Low Luminosity detector

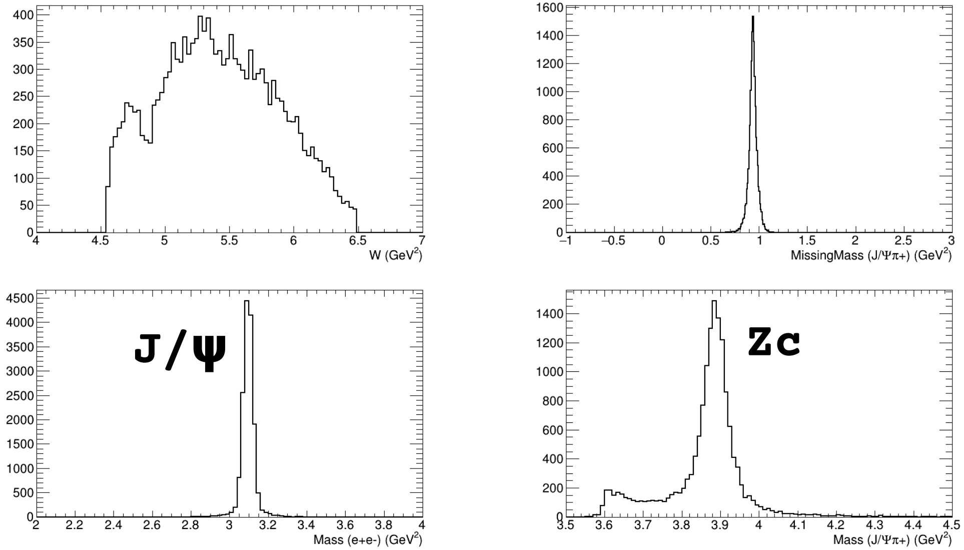
, P > 0.2 GeV
, ϑ > 2° (or 5°)*
, σ_p = 3%
, σ_ϑ = 0.5 rad
, σ_ϕ = 0.2/sin(ϑ)

Any resemblance to currently existing detectors is not entirely coincidental, but are extremely approximate

** Remember High Luminosity => could be order magnitude higher rates
Higher resolution => less backgrounds

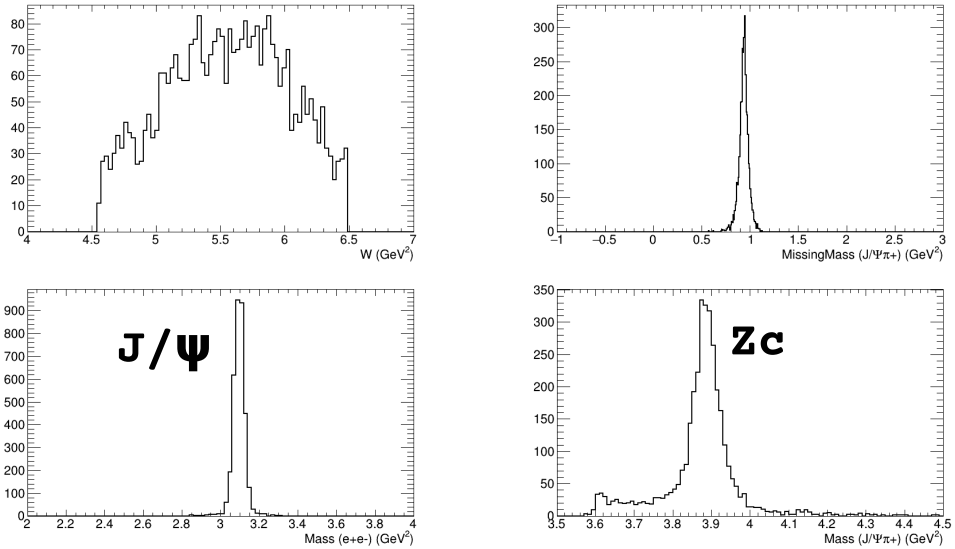
$Z_c(3900)$ High Luminosity

untagged



~15,000 events
7.5%

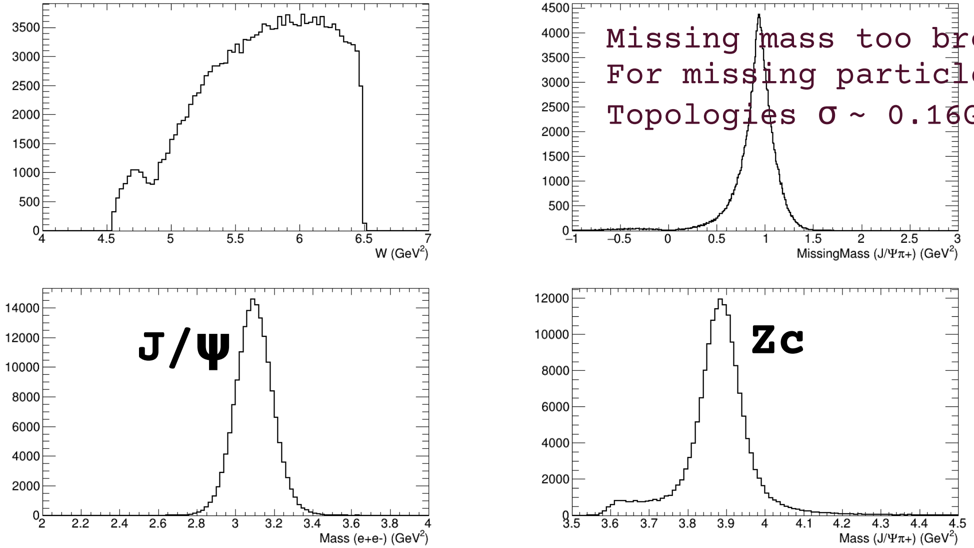
e^-'tagged >0.5°



~3,000 tagged events
1.5%
Missing particle can be reconstructed

Zc High Acceptance

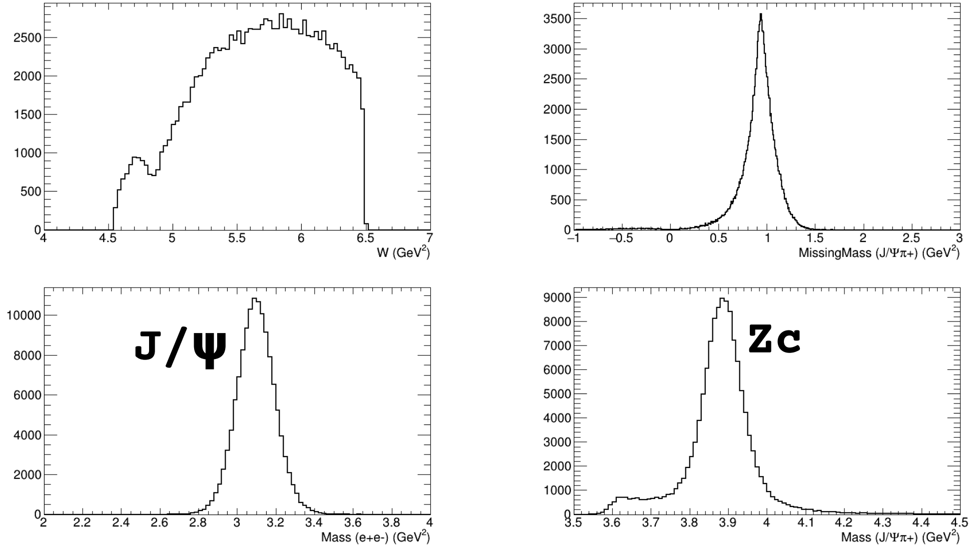
With >2° forward detection



Missing mass too broad
For missing particle
Topologies σ ~ 0.16GeV

~ 180,000 events
90%

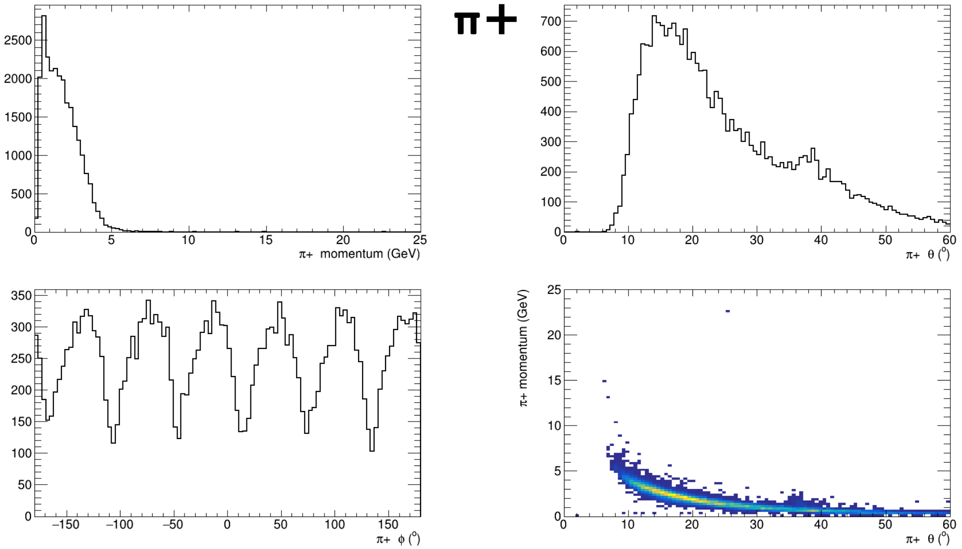
With >5° forward detection



~ 130,000 events
65%

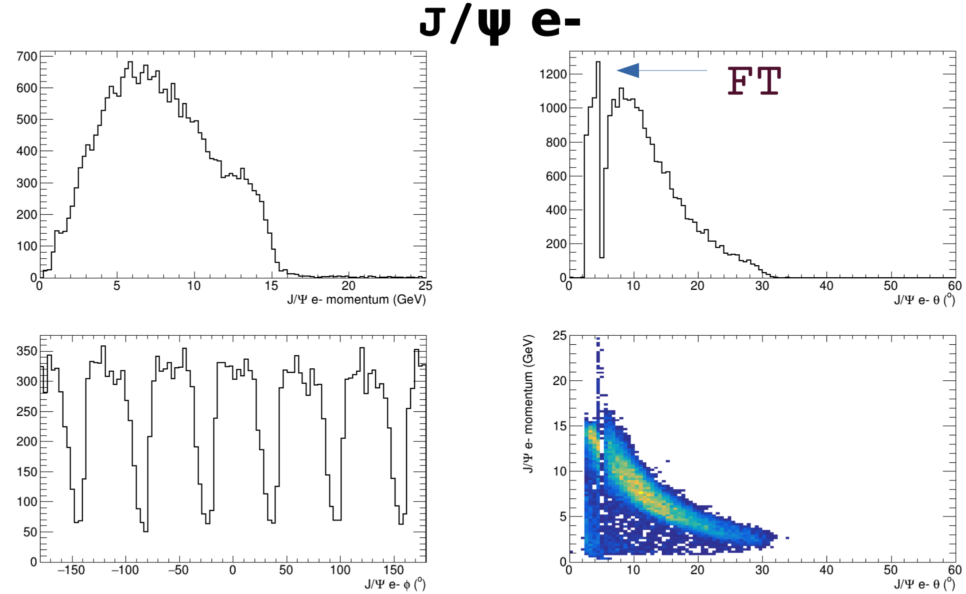
Z_c^0 would be better here
(detect proton and π^0)

Full CLAS12 simulation and reconstruction

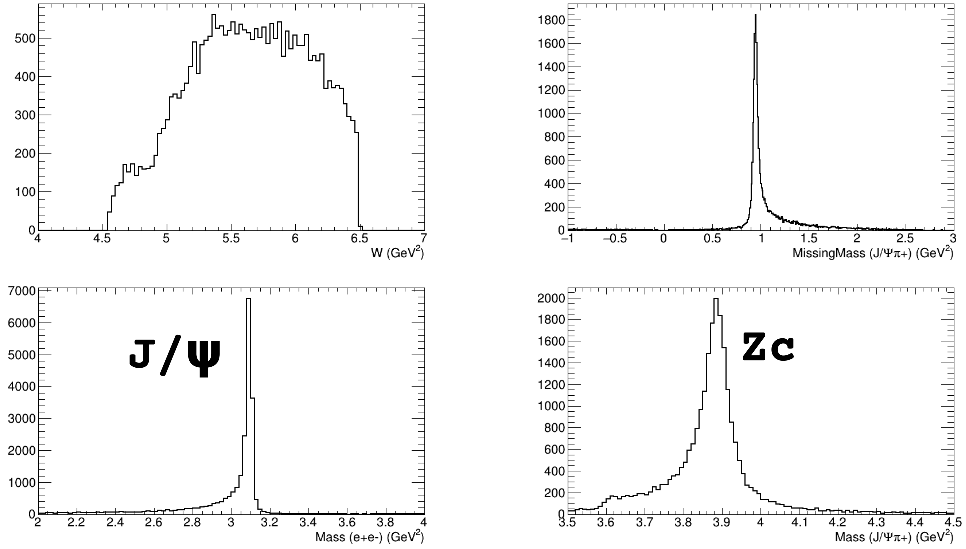


Use CLAS12 gemc simulation with Run Group A settings, outbending e-

Assume scattered e- detected with Toy detector resolutions



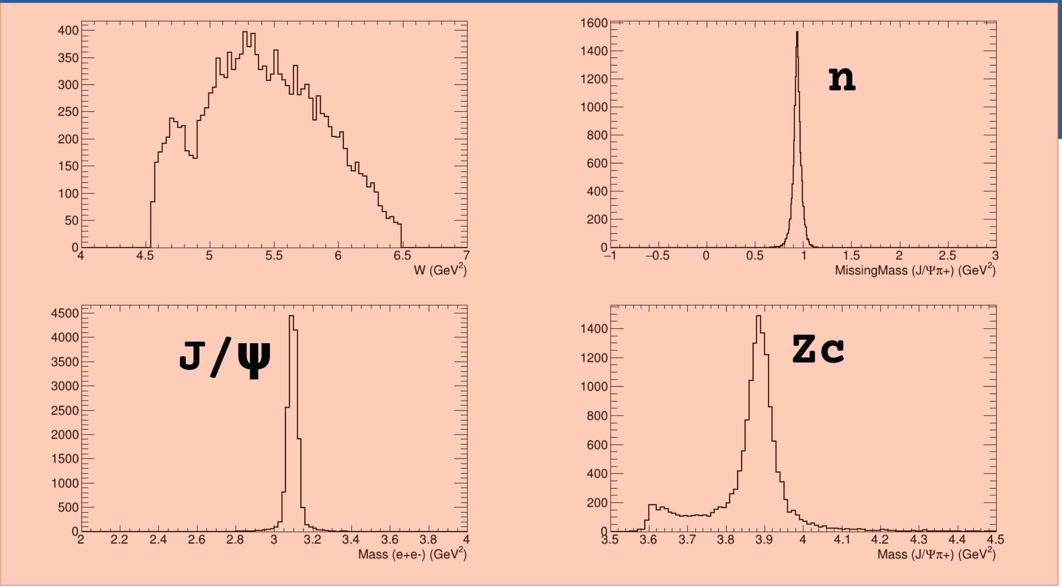
masses

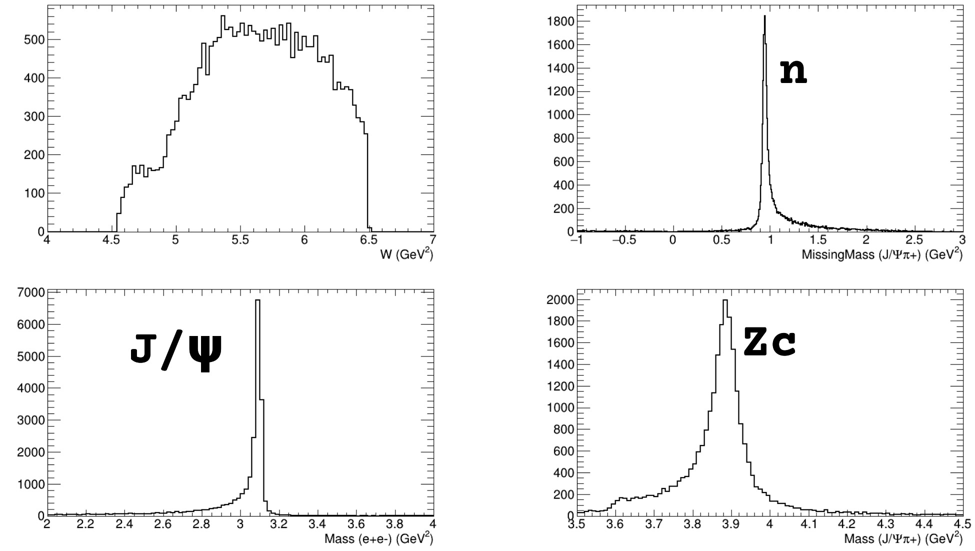


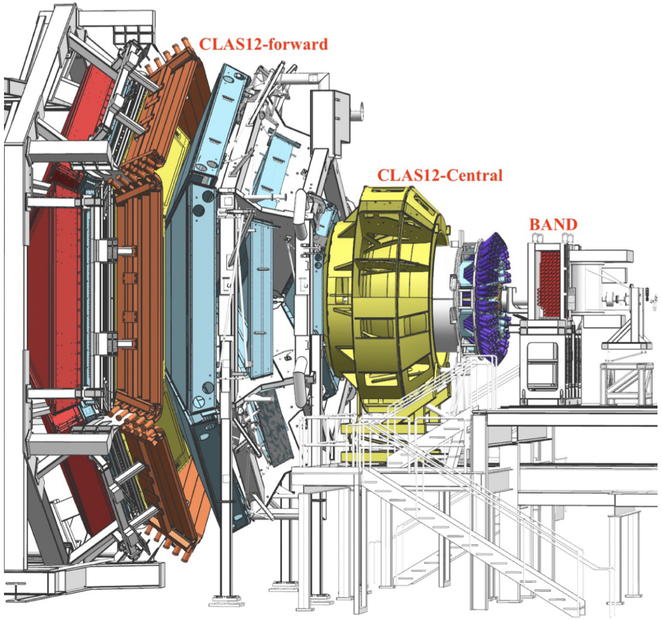
Full CLAS12 Compared to Toy

Acceptance > in Full (12%)
than toy(7%)

Resolution better in Full,
But with radiative tails





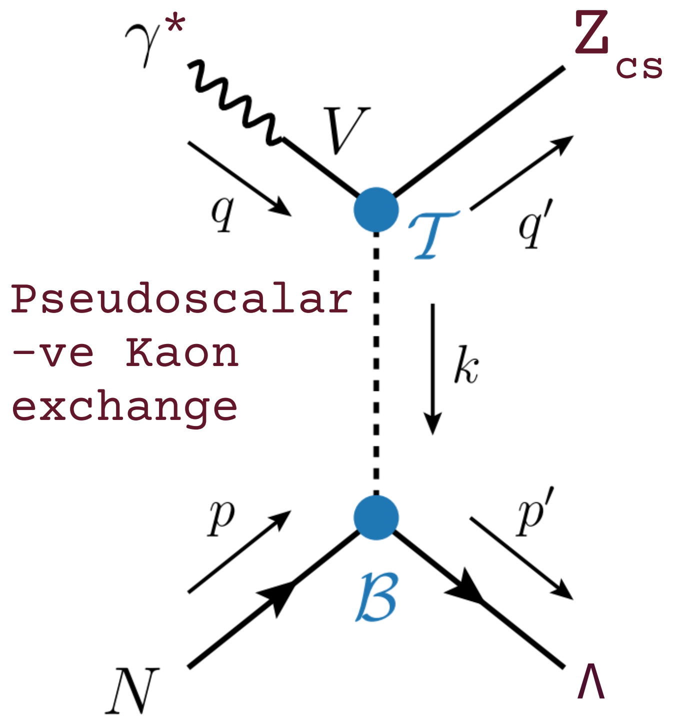


Z_{cs}(4000) quasi-real photoproduction

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 events.
With 24 GeV beam momentum

$Z_{cs} \rightarrow J/\psi\ K+$

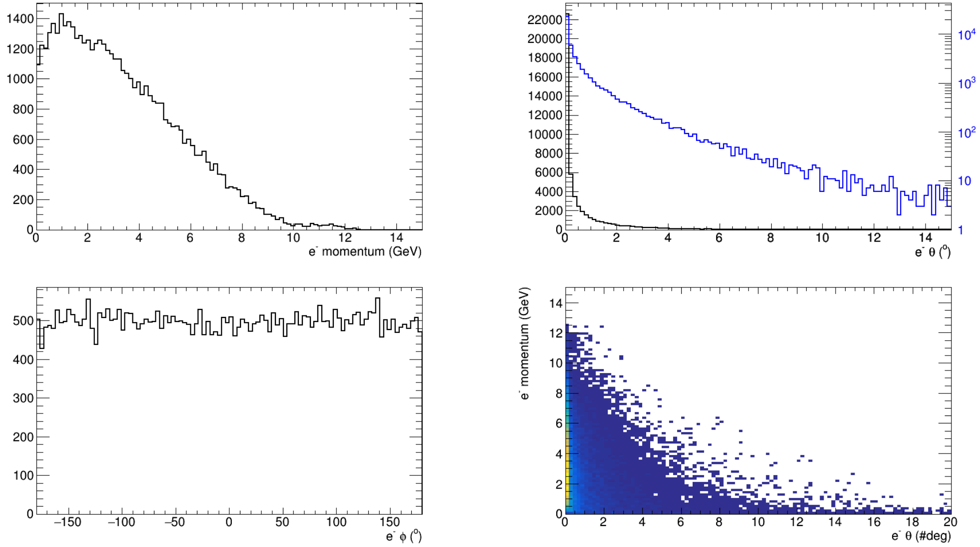


$\Lambda \rightarrow p\pi-$

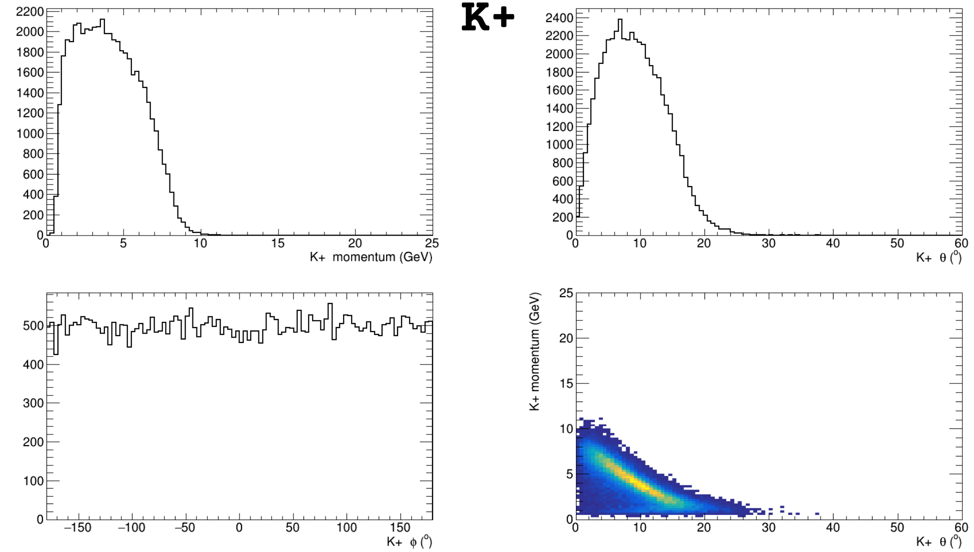
Not yet seen in J/ψ K+...

$Z_{cs}(4000)$ Particle momentum

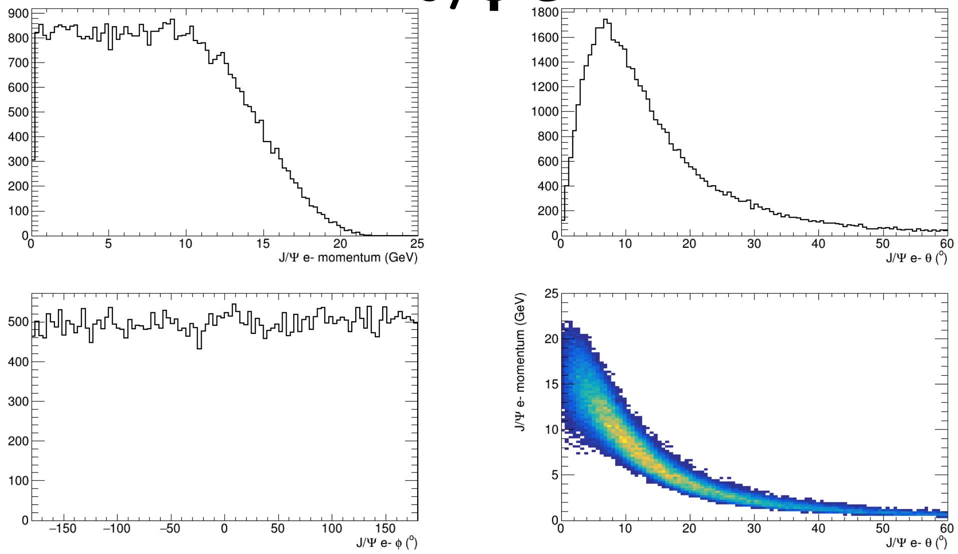
scattered e-



K+

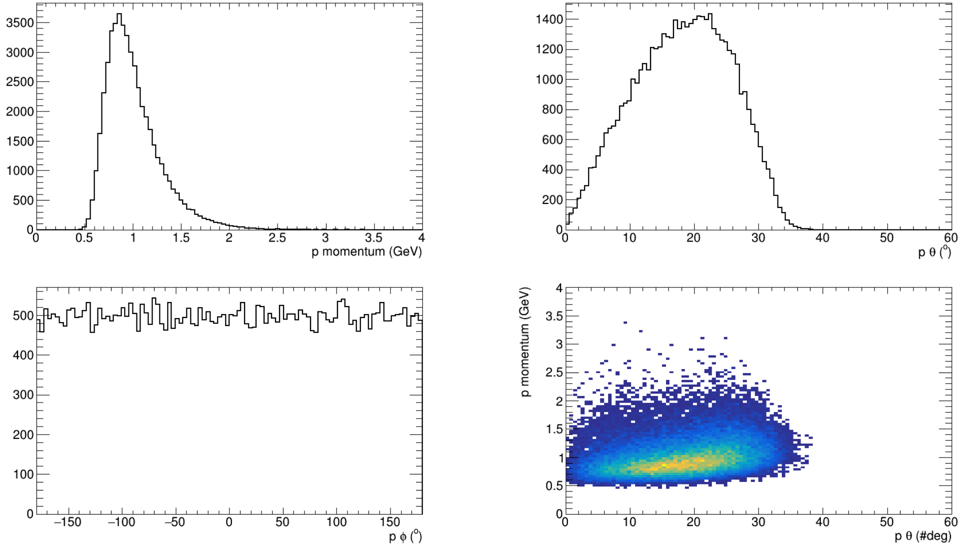


J/ψ e-

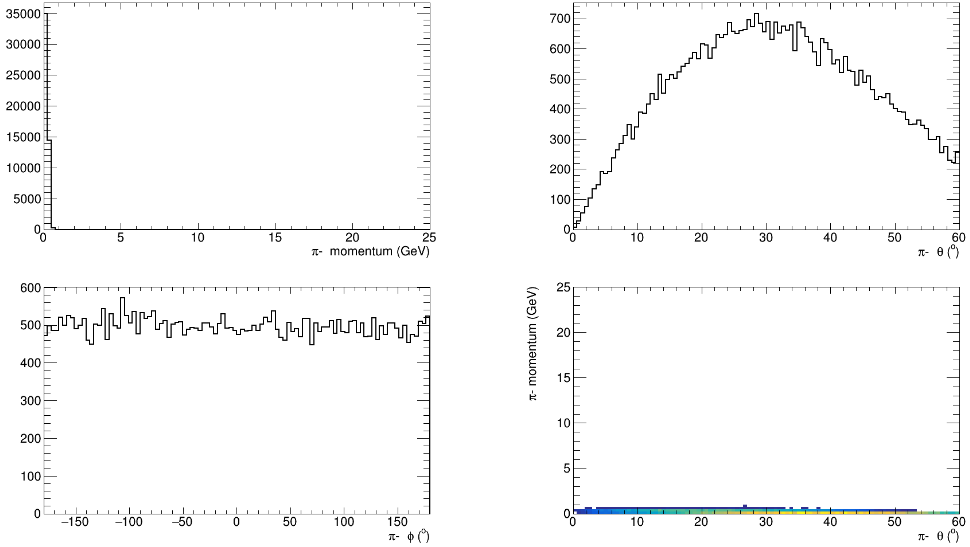


$Z_{cs}(4000)$ Particle momentum

Λ proton



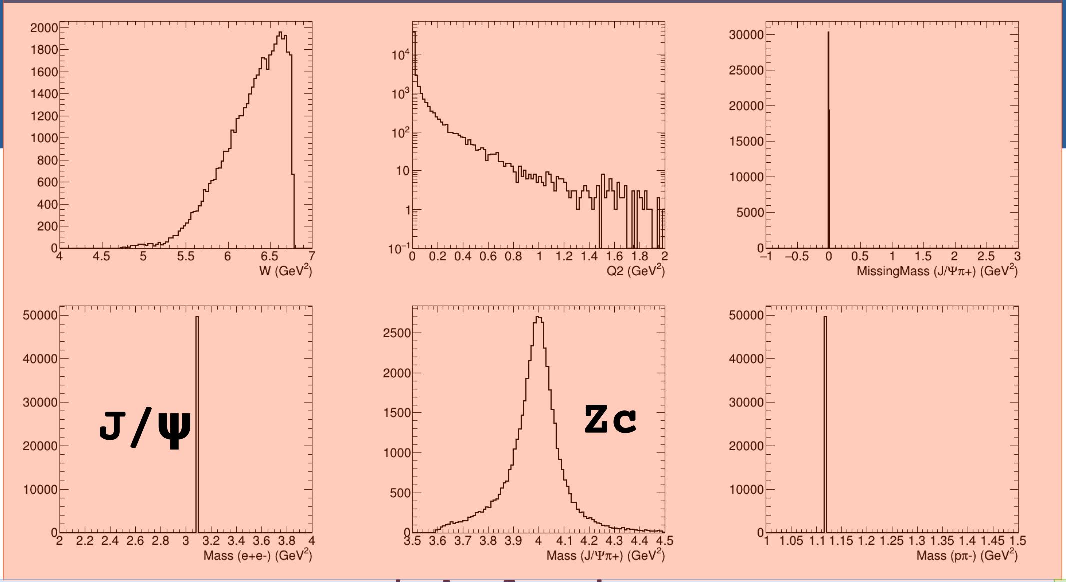
Λ π-



Protons 1-2 GeV

Λ Decay pions have very low Momentum ~0.2 GeV

Z_{cs} Kinematics



Total 33,000 events

Do not detect π-

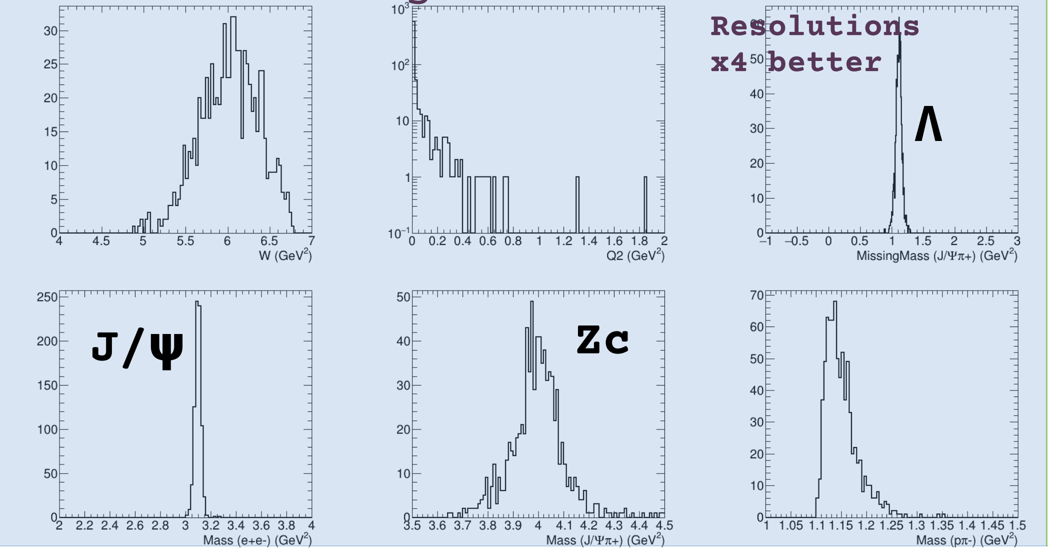
High lumi accept = 2% @ all e-'

High accept accept = 88% @ >2°

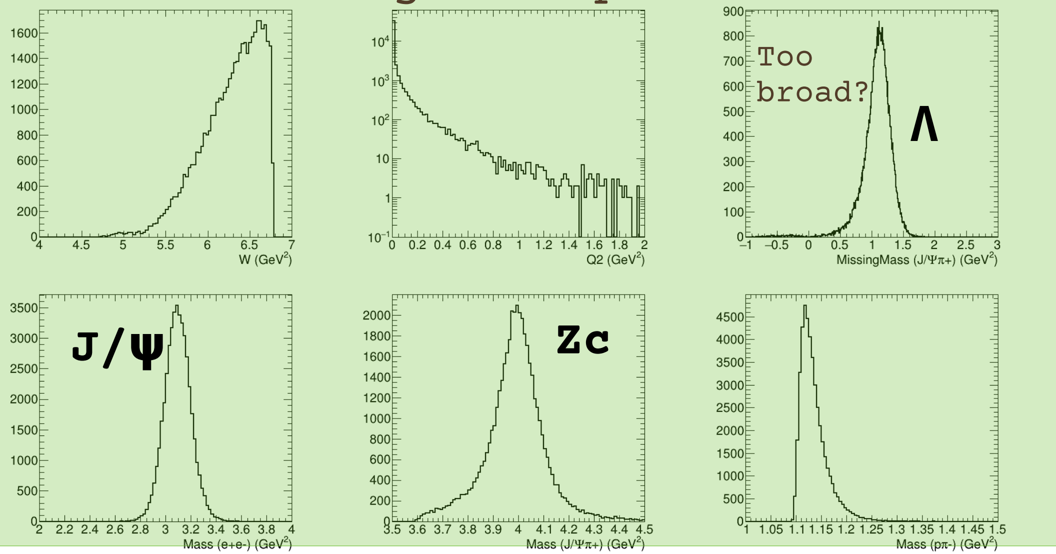
High accept accept = 50% @ >5°

More sensitive to
Forward detection

High lumi



High accept

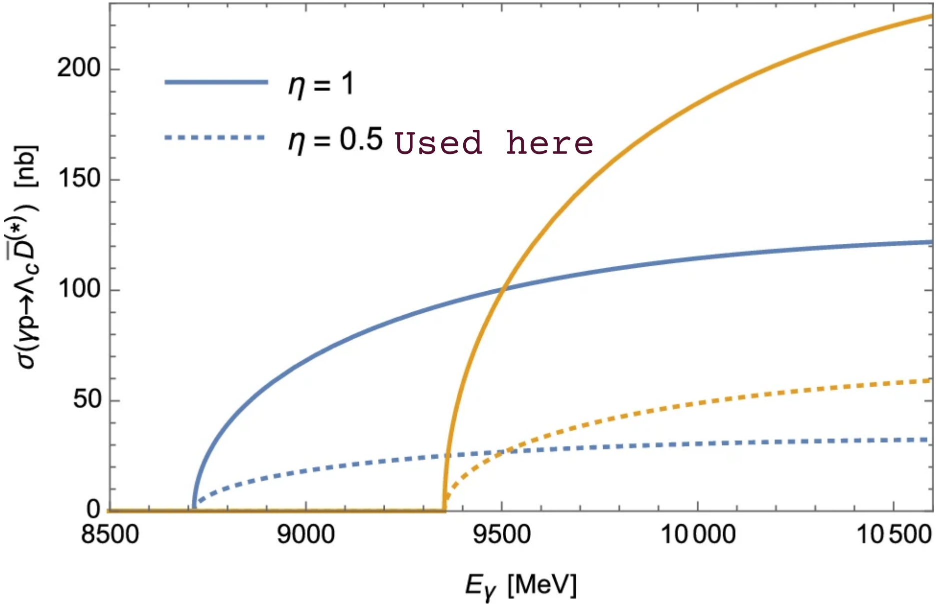


$D^0\Lambda_c$ quasi-real photoproduction

Deciphering the mechanism of near-threshold J/ψ photoproduction

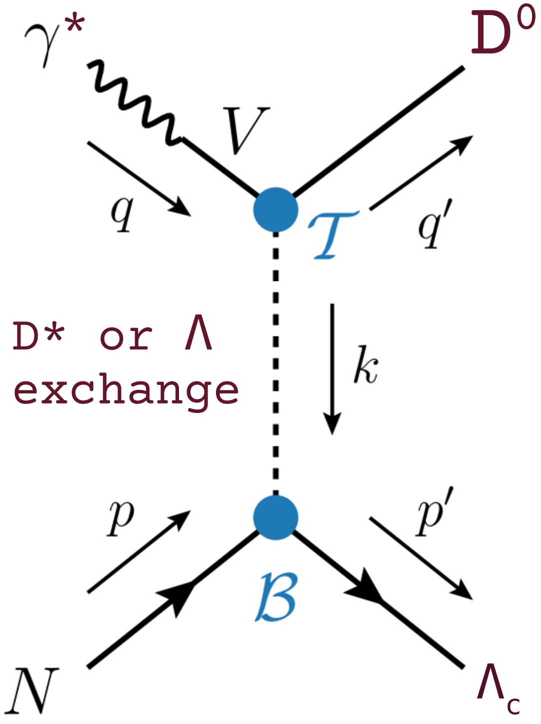
Meng-Lin Du, Vadim Baru, Feng-Kun Guo, Christoph Hanhart, Ulf-G. Meißner, Alexey Nefediev & Igor Strakovsky

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



Using jpacPhoto implementation

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



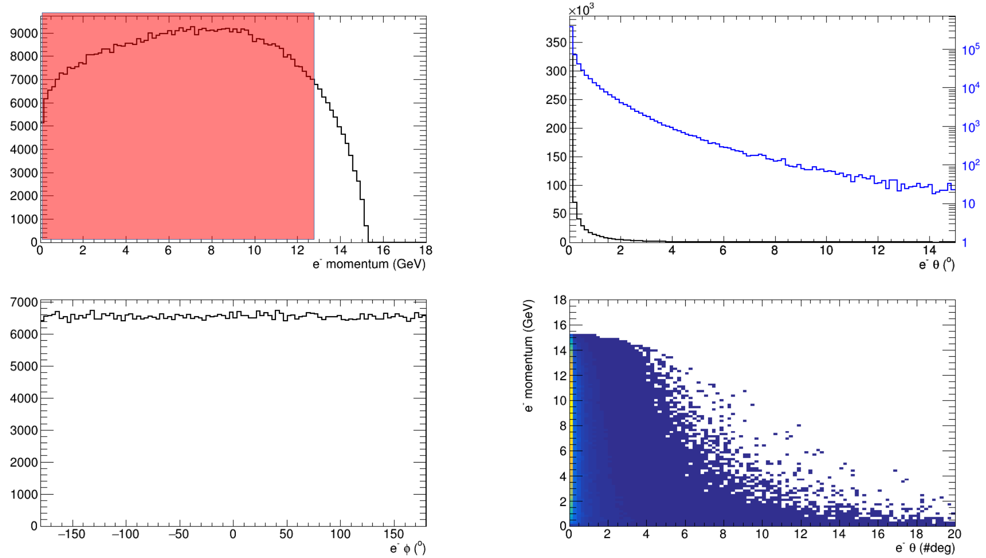
24 GeV!
Probably not
Valid for this
Range
=>
Number of events
Not reliable

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

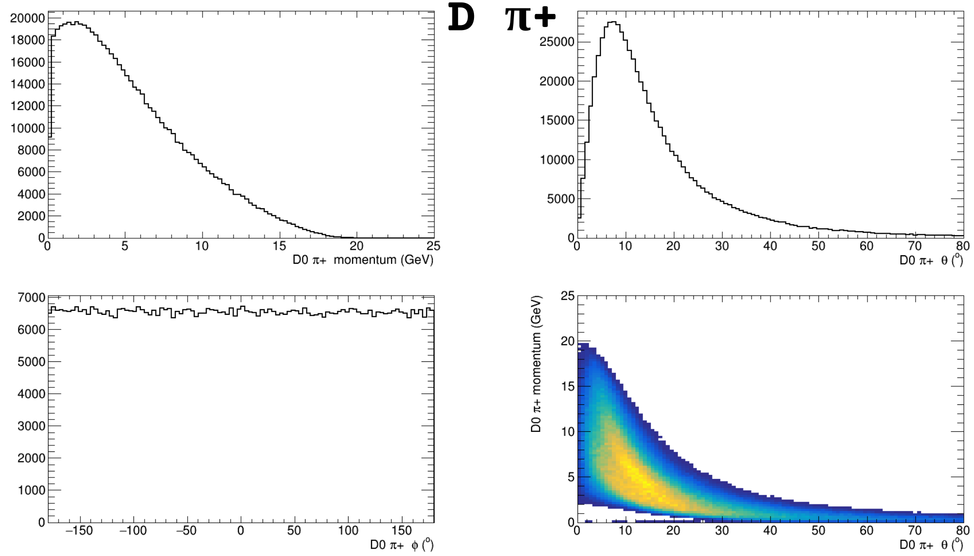
Assuming luminosity 10^{35}
And 50 days gives 450k events.
With 22 GeV beam momentum

Particle momentum

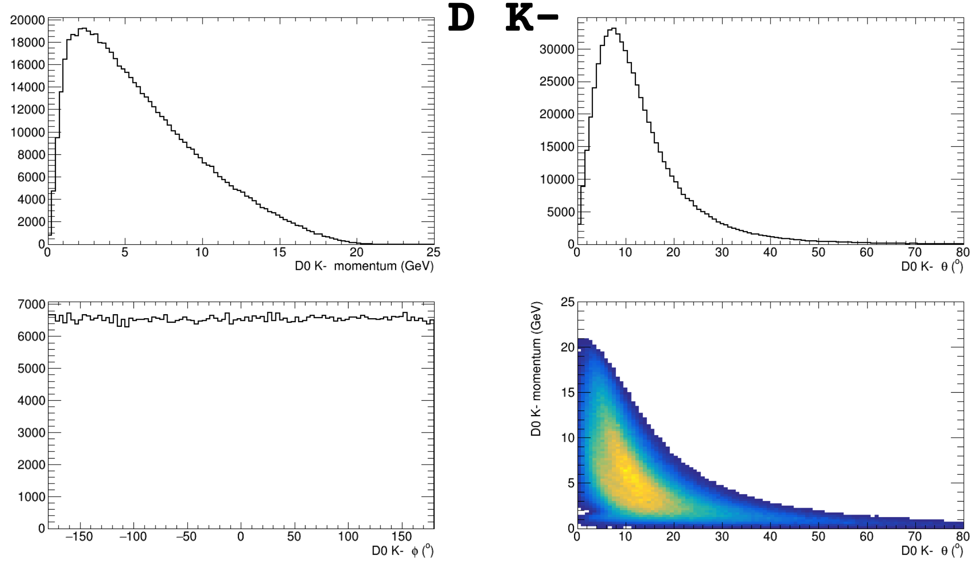
scattered e-



D π+



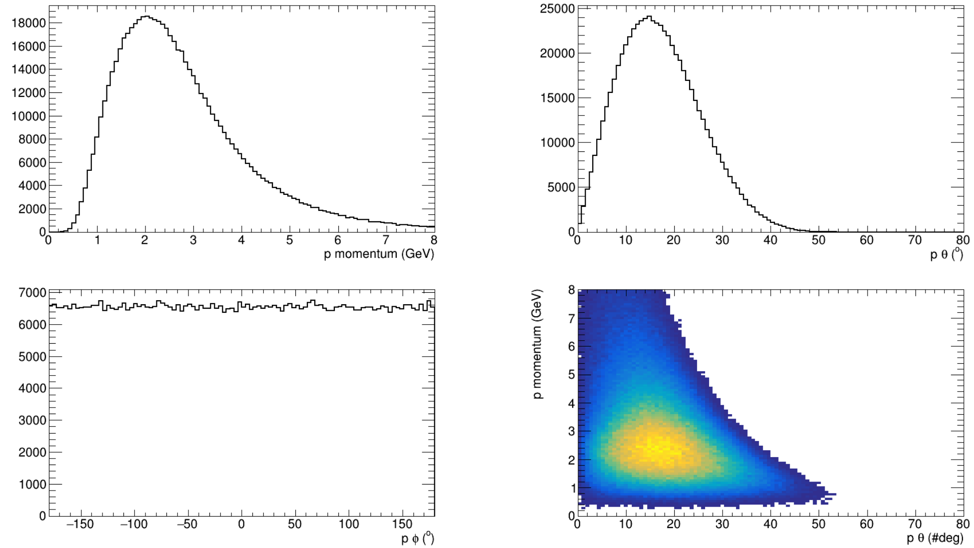
D K-



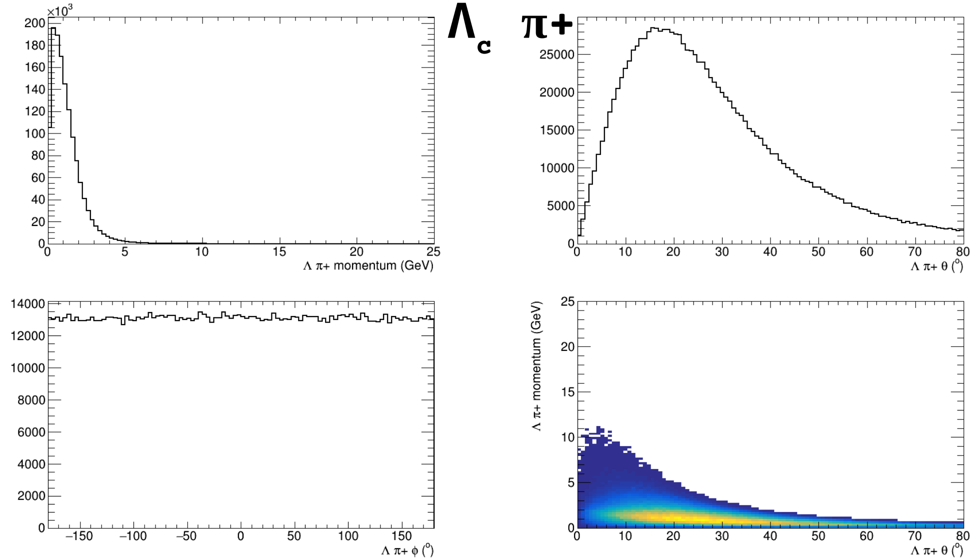
D^0 decay relatively detectable
Large momenta and angles

Particle momentum

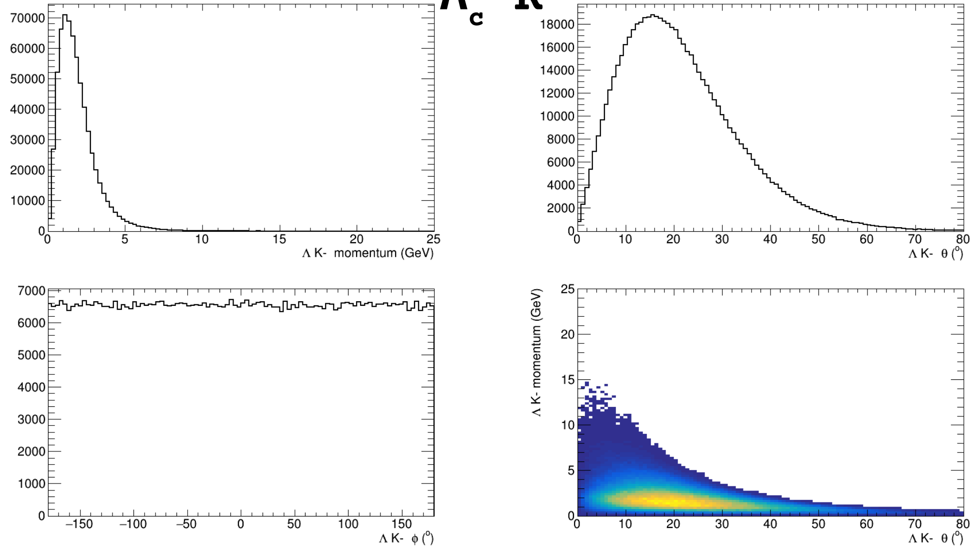
Λ_c proton



Λ_c π+



Λ_c K-

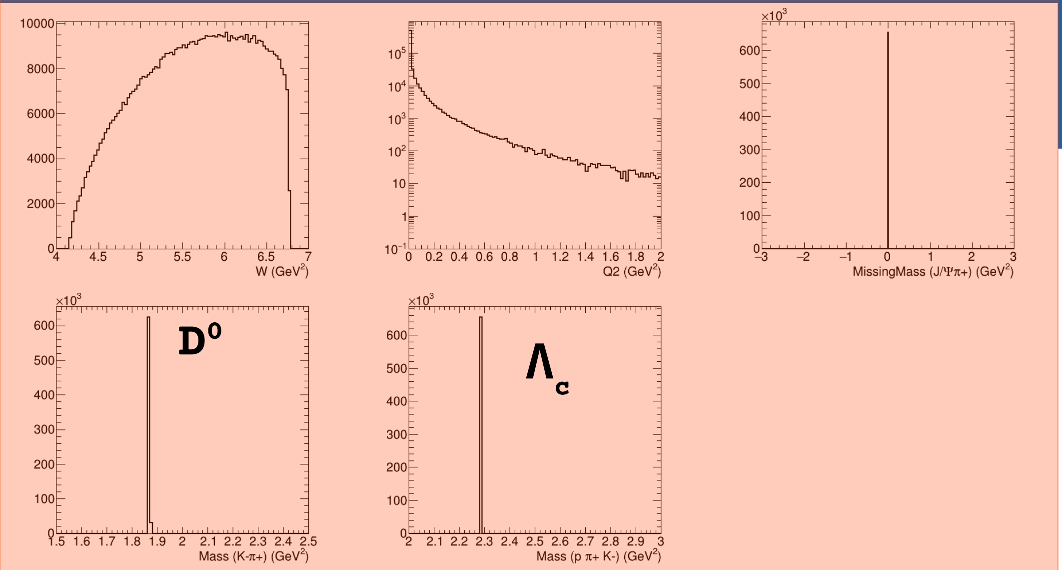


Λc proton very detectable

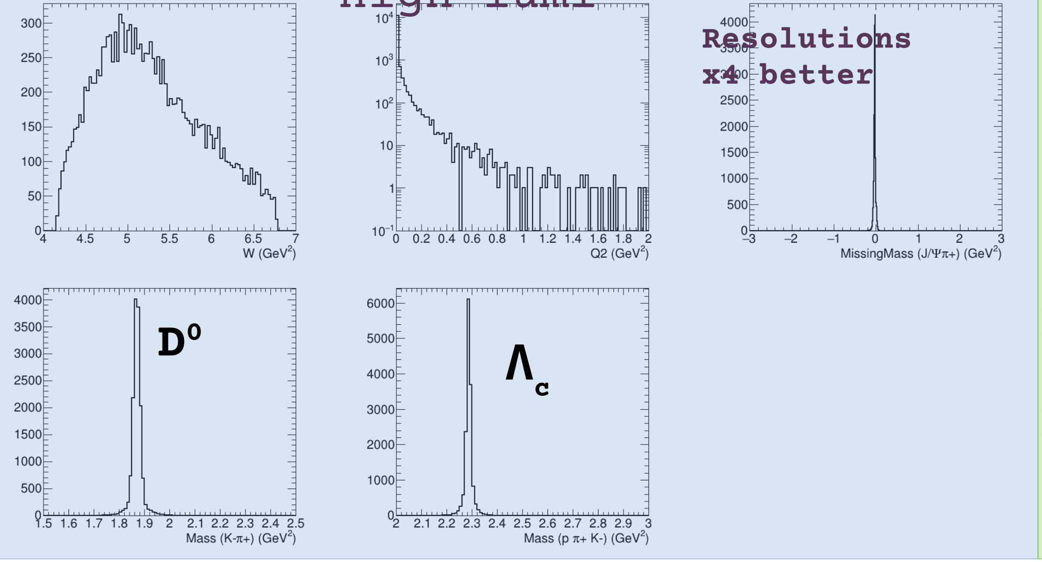
K,π reasonable (lower momentum)

$D^0\Lambda_c$ Kinematics

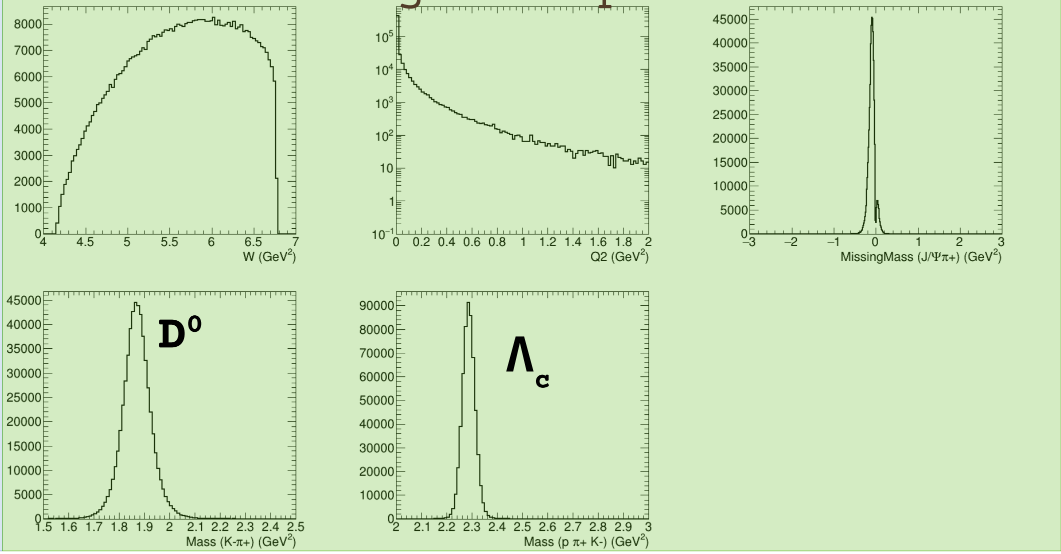
Total 450,000 events
Detect all
High lumi accept = 2% @ all e−'
High accept accept = 87% @ >2°
= 57% @ >5°



High lumi



High accept



Possible Luminosities e.g. Z_c

Photoproduction (extrapolate from GlueX)

Gluex early running Jpsi publication ~ 5 weeks → $70pb^{-1}$

Higher rate (~x2) => $140pb^{-1}$ in 5 weeks, or 210pb-1 in 50days

Integral bremsstrahlung 10.5-22@22 / 8.5-12 @12 ~ 2.1

Hence Zc luminosity ~ $440pb^{-1}$ in "50 days"

$$N_\gamma = \frac{d}{X_0}\left[\frac{4}{3}\ln\left(\frac{k_{\max}}{k_{\min}}\right) - \frac{4(k_{\max}-k_{\min})}{3E} + \frac{k_{\max}^2 - k_{\min}^2}{2E^2}\right].$$

Low Q^2 electroproduction (calculate from model)

10^{35} $(cm^{-2}s^{-1})$.50(days).0.013 ~ $5900pb^{-1}$ in "50 days"

Tagging scattered electron >0.5°

10^{35} $(cm^{-2}s^{-1})$.50(days).0.006 ~ $2500pb^{-1}$ in "50 days"

Tagging scattered electron >1°

10^{35} $(cm^{-2}s^{-1})$.50(days).0.005 ~ $2100pb^{-1}$ in "50 days"

Tagging scattered electron >2°

10^{35} $(cm^{-2}s^{-1})$.50(days).0.003 ~ $1300pb^{-1}$ in "50 days"

Virtual photon flux factor

****$5900pb^{-1}$ was used for previous slides, Must scale accordingly!**

Zero Degree Spectrometer

Can we tag electrons with very low scattering angles
and very high flux?

→ e.g. downstream Dipole magnet with calorimeter and/or tracking

→ measure electron momentum, ϑ and Φ
→ Φ important as gives scattering plane => linear polarisation

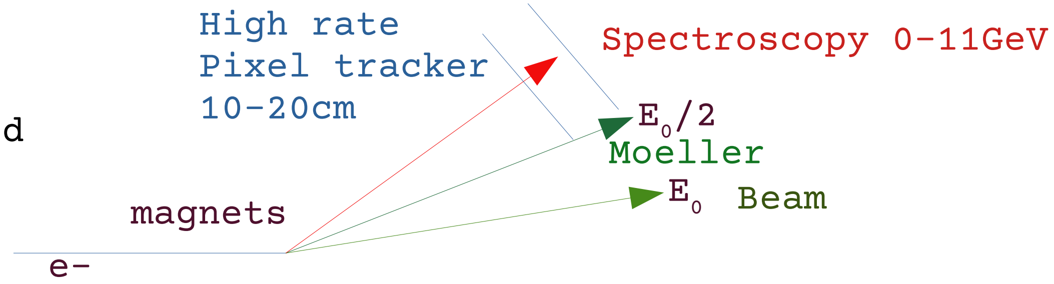
Scattering angle needs to be outwith beam divergence
need to separate from Moeller and Bremsstrahlung backgrounds

Only need to detect e- below half beam energy (approximately)

Similar to EIC low Q2 tagger projects
e.g. Glasgow investigating Timepix pixel detectors

Could something like
This work ?
Could be issues with field
Uniformity etc.

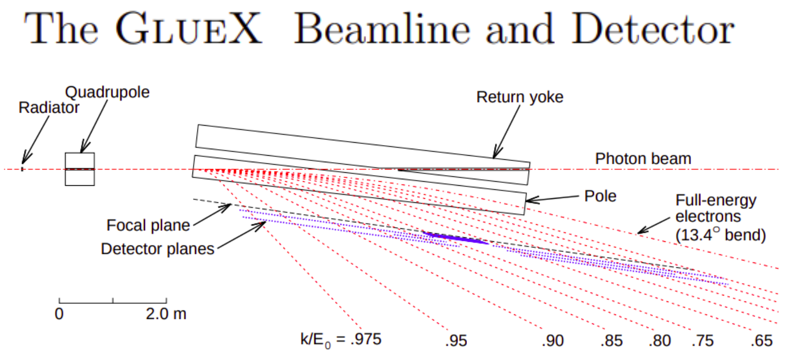
CLAS12



See also Volker Burkert presentation

Hall D photon tagger

https://www.sciencedirect.com/science/article/pii/S0168900220312043?via%3Dihub



Photons 25-97% of E_{beam} @12GeV

=> 3-11.6 GeV for E_γ

=> 0.36-9 GeV for E_{e-}

=> 15-23.6 GeV for E_γ @24GeV

Increase field 1.5→1.75T

=>13.5-23.6 GeV for E_γ @24GeV

Using Hall D tagger at 24 GeV would require significant modifications to beamline and beamdump, if possible at all.

However the magnet as stands would cover very interesting region for charmonium like spectroscopy E_γ > 13 GeV

Limiting factor may be rates on small angle hadron detectors and tagger focal plane detectors ? I do not know

- -but do not need angle coverage to 1°…
- -perhaps can use more modern high rate detector components

Cross section and channel 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.

Branching ratios
X→ J/ψππ ~5%
Y→ J/ψππ ~1%
Z_c→ J/ψπ ~10%
Z_{cs}→ J/ψK ~10%
J/ψ→ e+e- ~6%
D^0→Kπ ~4%
Λ_c → pKπ ~6.3%
Λ → pπ ~67%

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

Summary

Have shown initial investigation into spectroscopy with charm quarks at a possible energy upgraded Jlab

Event rates and kinematics overall look very promising

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

Combination of charm spectroscopy and new technologies make this a very exciting opportunity to pursue.

X