Jefferson Lab
Thomas Jefferson National Accelerator Facility

University of New Hampshire

clas
CEBAF Large Acceptance Spectrometer

J/ψ photoproduction near threshold at CLAS12

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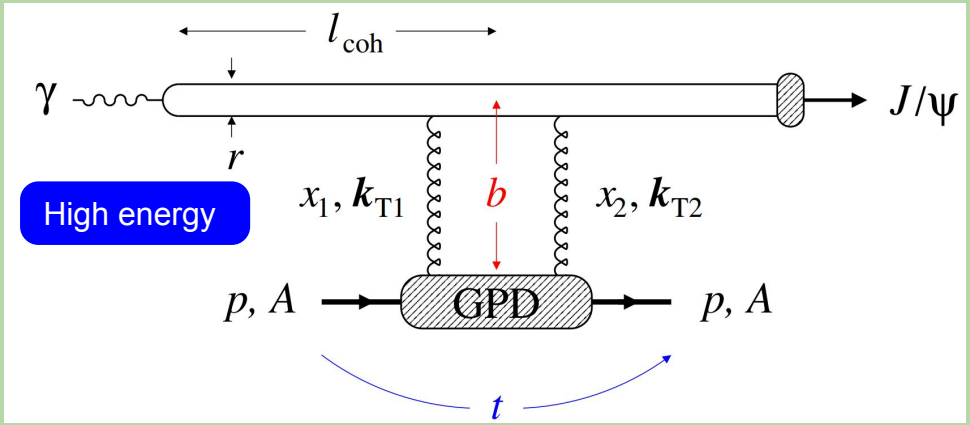
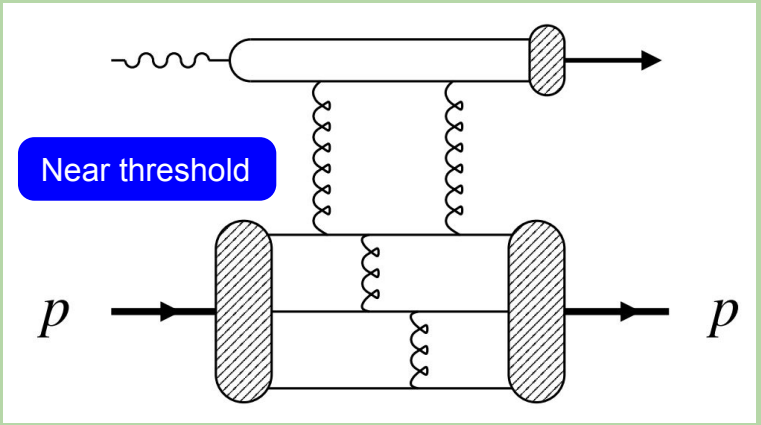
Next-generation GPD studies with exclusive meson production at EIC
June 4-6 2018, CFNS Stony Brook

J/ψ photoproduction

Quark content of J/ψ: $c\bar{c}$

There are no $c\bar{c}$ pairs in the nucleon, so the production goes through gluon exchange

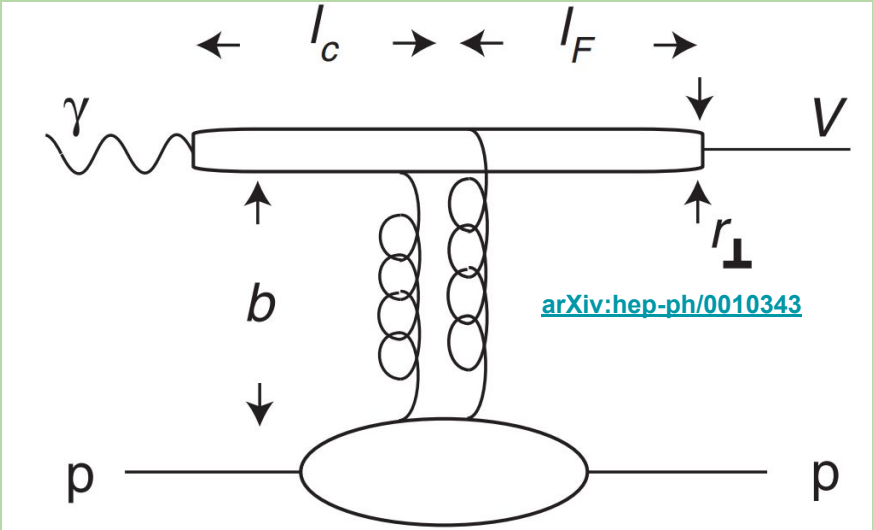




Two gluon exchange mechanism,
Small *t*
Probes gluonic GPDs
Confirmed in HERA experiments
H1 arXiv:hep-ex/0510016, Zeus arXiv:hep-ex/0404008

It is expected the production mechanism to be changed.
$|t_{min}| = 2.23 GeV^2$ @ threshold
All three quarks share the large momentum transfer

VDM picture of J/ψ photoproduction



arXiv:hep-ph/0010343

$$\frac{d\sigma_{\gamma N\to VN}}{dt} = \mathcal{K}\frac{3\Gamma(V\to e^-e^+)}{\alpha m_V}\frac{d\sigma_{VN\to VN}}{dt}$$

$$m_c \approx 1.5\ GeV \quad r_\perp \approx \frac{1}{m_c} = 0.13\ fm$$

Close to production threshold $E_\gamma \approx$ 10 GeV

$$l_c = \frac{2E_\gamma}{4m_c^2} \approx 0.4\ fm \quad b \approx \frac{1}{\sqrt{-t}} \approx 0.2\ fm$$

$$l_F \approx \frac{2E_{J/}}{2m_c(m_{\psi'} - m_{J/\psi})} \approx 1-2\ fm$$

Photoproduction near threshold creates favorable conditions for studying J/ψ elastic scattering

Cross-section near threshold

$$\frac{d\sigma}{dt} = N_{2g}\nu\frac{(1-x)^2}{R^2\mathcal{M}^2}F_{2g}^2(t)(s-m_p^2)^2$$

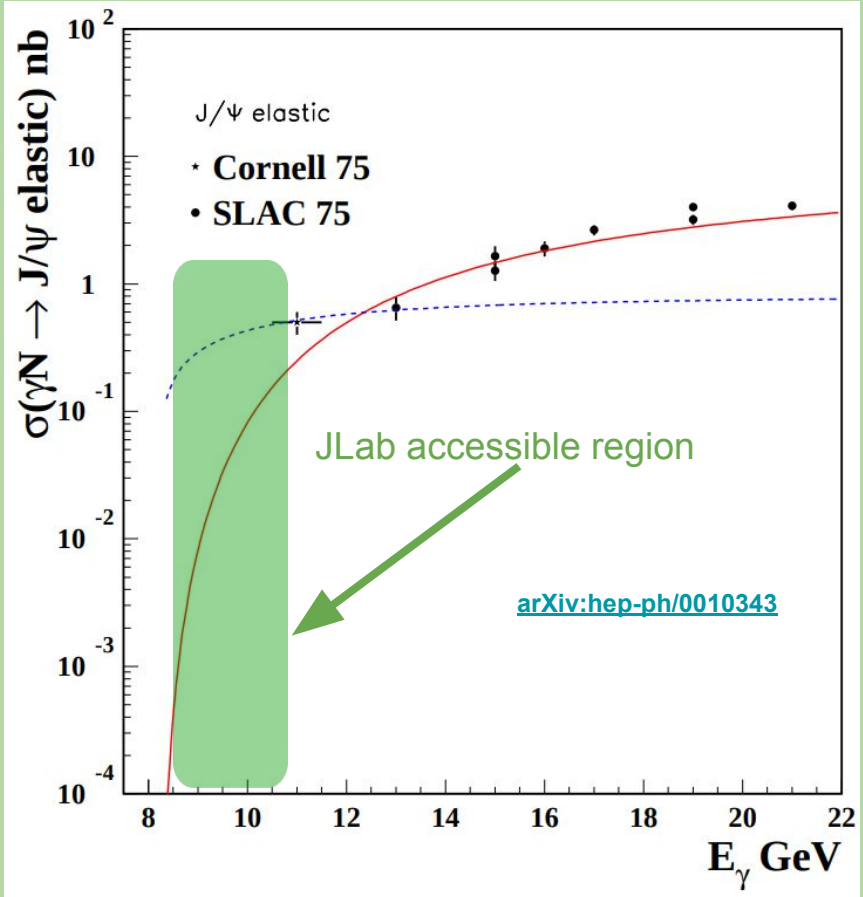
$$\frac{d\sigma}{dt} = N_{3g}\nu\frac{(1-x)^0}{R^4\mathcal{M}^4}F_{3g}^2(t)(s-m_p^2)^2$$

x is defined as $x = \frac{2M_pM_{J/\psi}+M_{J/\psi}^2}{(s-M_m)^2}$

There is no published data below E_γ < 11 GeV

Precision measurements are needed in this region

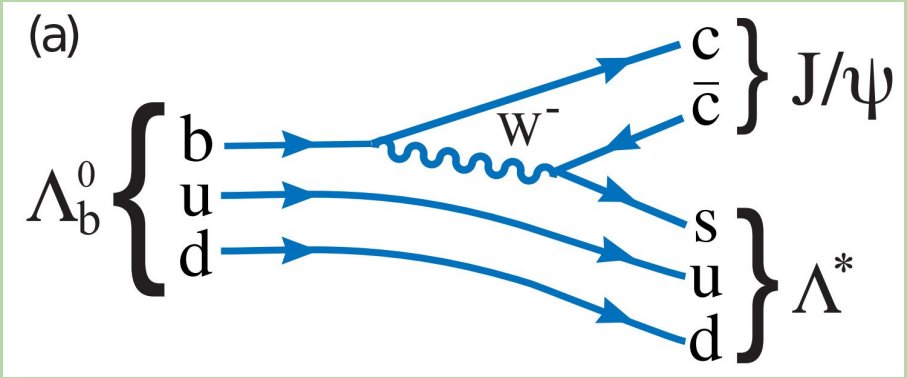
JLab is in a good position to explore the near threshold region

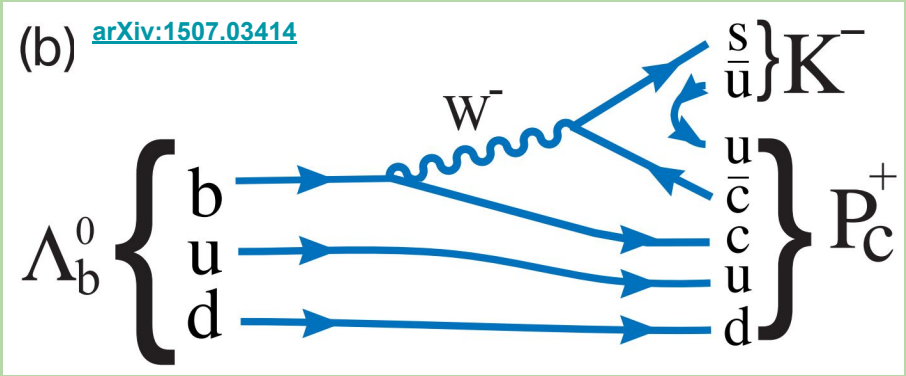


Possibility to detect LHCb pentaquarks w/ CLAS12

LHCb: observation of two resonance states referred as charmonium pentaquarks

$$\Lambda_b^0 \to J/\psi K^- p$$

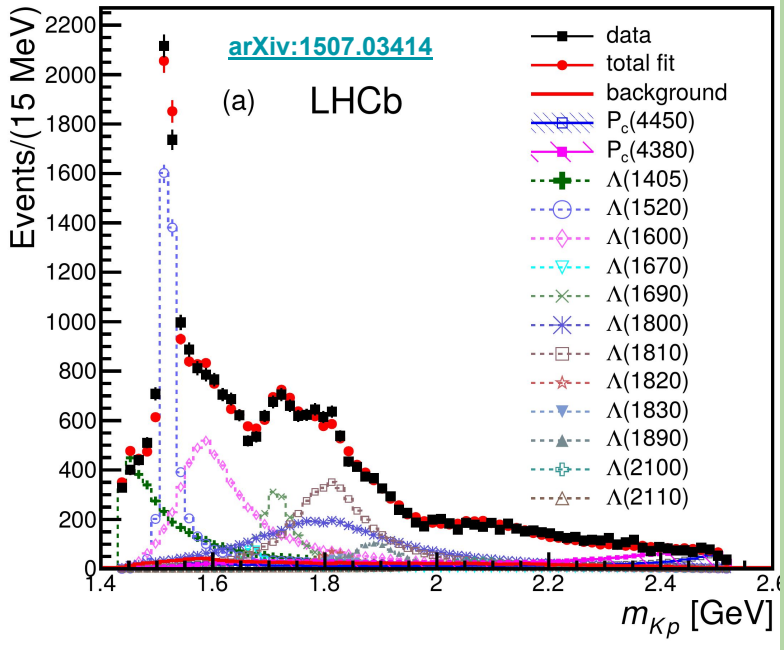


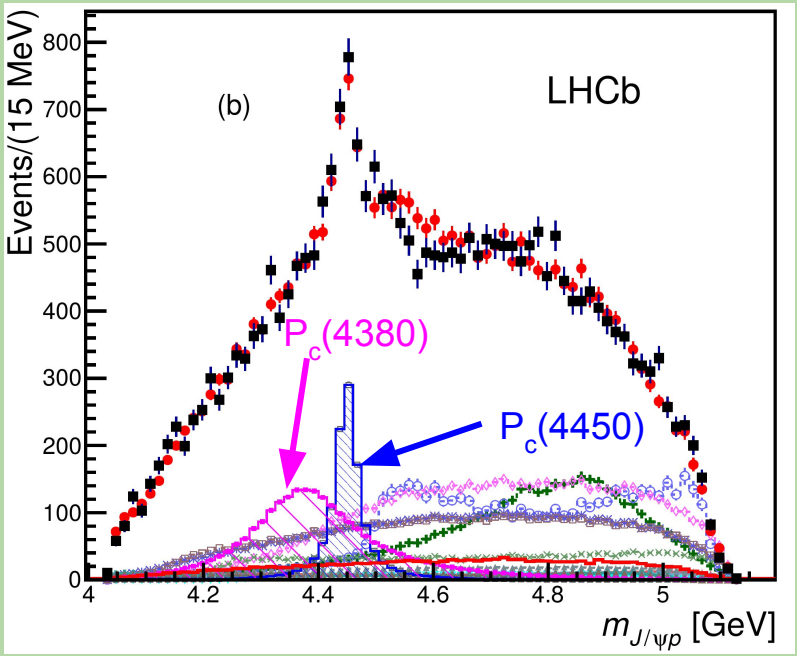


Amplitude analysis of $J/\psi K^- p$ final state with inclusion of all know $\Lambda^* \to K^- p$ decays was not able to describe the data.

Data was described by inclusion of two "$c\bar{c}uud$" exotic states.

Possibility to detect LHCb pentaquarks w/ CLAS12





Resonances have 9σ ($P_c(4380)$) and 12σ ($P_c(4450)$) significance

$P_c(4380)$
M = 4380±8±29 MeV
Γ = 205±18±86 MeV

$P_c(4450)$
M = 4449.5±1.7±2.5 MeV
Γ = 49±5±19 MeV

Possibility to detect LHCb pentaquarks w/ CLAS12

It has triggered multiple papers arguing the nature of these two structures

Hadronic molecule: charmed baryon with anti-charmed meson $\Sigma_c D^*$
arXiv:1507.03704

Colored three quark and quark-antiquark (Non-molecule)
arXiv:1507.04694

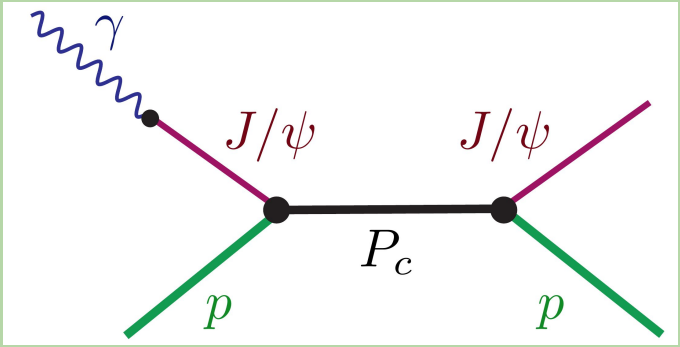
No resonance at all, just a kinematic effect (threshold effect, triangle singularity)
arXiv:1507.06552, arXiv:1507.04950

Clearly, independent measurements are needed with different production mode

It was suggested to search for P_c states in the J/ψ photoproduction on the proton
arXiv:1508.00339, arXiv:1508.01496, arXiv:1508.00888

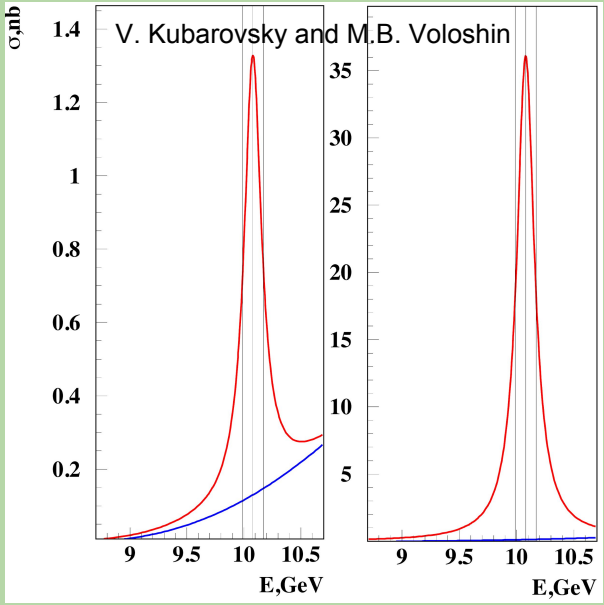
s channel resonance in the $\gamma+p \rightarrow P_c \rightarrow J/\psi+p$ reaction

Possibility to detect LHCb pentaquarks w/ CLAS12



σ(γ+p→Pc→J/ψ+p)

$$\sigma(W) = \frac{2J+1}{4}\frac{\Gamma^2/4}{(W-M_{P_c}^2)+\Gamma^2/4}\mathcal{BR}(P_c \to \gamma P)\mathcal{BR}(P_c \to J/\psi P)$$



$$1.5\mu bn < \frac{\sigma_{max}(\gamma + p \to P_c(4380) \to J/\psi\, p)}{\mathcal{BR}^2[P_c(4380) \to J/\psi\, p]} < 47\mu bn$$

$$12\mu bn < \frac{\sigma_{max}(\gamma + p \to P_c(4450) \to J/\psi\, p)}{\mathcal{BR}^2[P_c(4450) \to J/\psi\, p]} < 360\mu bn$$

Min and max limits come from theoretical Uncertainty of partial waves

CLAS12 (along with other JLab experiments) are in the good position to probe this channel

Assuming BR(P_c(4450)J/ψ+p) = 1%

CLAS12 experiments on J/ψ

E12-12-001: Timelike Compton Scattering and J/ψ photoproduction on the proton in e^-e^+ pair production with CLAS12 at 11 GeV. *Has been approved in 2012, and granted 120 PAC days*

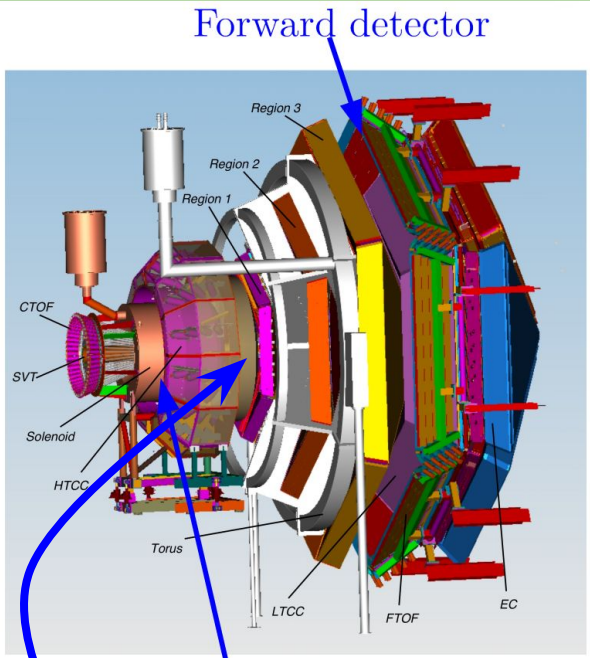
The LHCb pentaquark paper triggered a new proposal

E12-12-001A: Near threshold J/ψ photoproduction and study of LHCb pentaquarks with CLAS12.

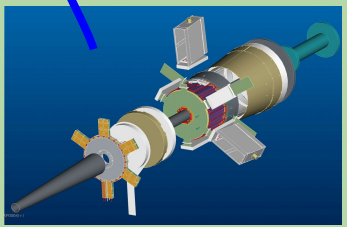
- Includes J/$\psi \to \mu^-\mu^+$ decay mode
  CLAS12 has no muon detector however, using ECal we will achieve ≈×6 suppression of π-π+ pairs.

- Study charmed pentaquarks $P_c(4380)$ and $P_c(4450)$

CLAS12 design parameters



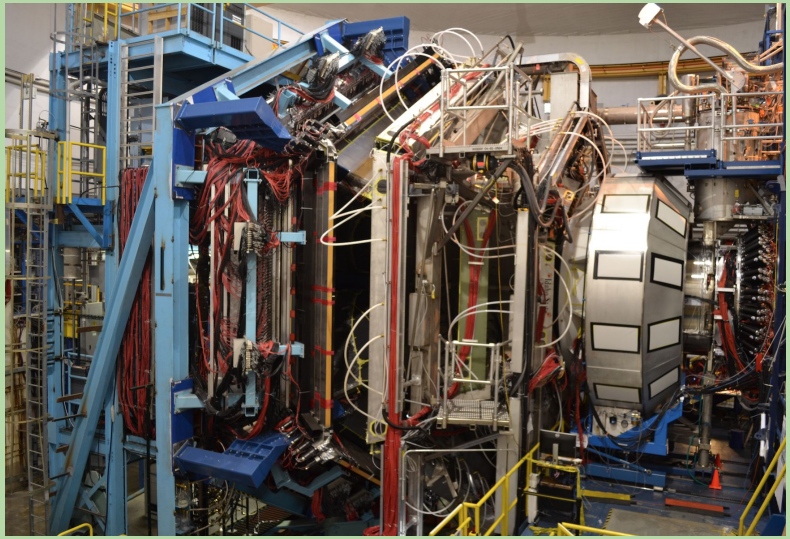
Parameters	Forward Detector	Central Detector
Charged tracks:		
polar angular range (θ)	5° to 35°	35° to 125°
resolution:		
polar angle ($\delta\theta$)	$<$ 1 mr	$<$ 10 mr to 20 mr
azimuthal angle ($\delta\phi$)	$<$ 4 mr	$<$ 5 mr
momentum (δp/p)	$<$ 1% at 5 GeV/c	$<$ 5% at 1.5 GeV/c
Neutral particles:		
angular range (θ)	5° to 40°	40° to 125° (neutrons)
angular resolution ($\delta\theta$)	$<$ 4 mr	$<$ 10 mr
Energy resolution	$< 0.1/\sqrt{(E)}$	$<$ 5%
PID:		
e/π	full momentum range	NA
π/p	full momentum range	$<$ 1.25 GeV/c
K/π	$<$ 3 GeV/c	$<$ 0.65 GeV/c
K/p	$<$ 4 GeV/c	$<$ 1 GeV/c



Forward tagger
non-baseline equipment

Expected Performance	**VALUE**
Horizontal angular coverage	2.5° to 4.5°
EM shower energy range	E_{max}–E_{min}= (0.5 – 8.0) GeV
Energy resolution	$\sigma_E/E \le 2\%/\sqrt{E(GeV)} \oplus 1\%$
Angular resolution	$\sigma_\vartheta/\vartheta \le 1.5$ %, $\sigma_\varphi \le 2°$
Time resolution	≤300 ps

CLAS12



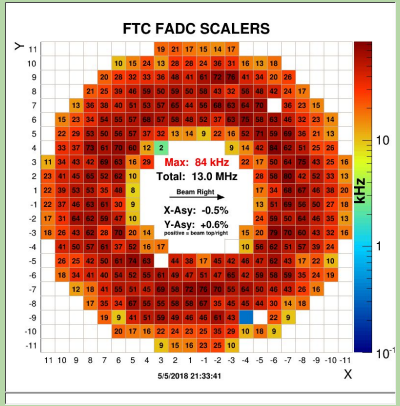
Commissioning: Dec 2017, Jan 2018

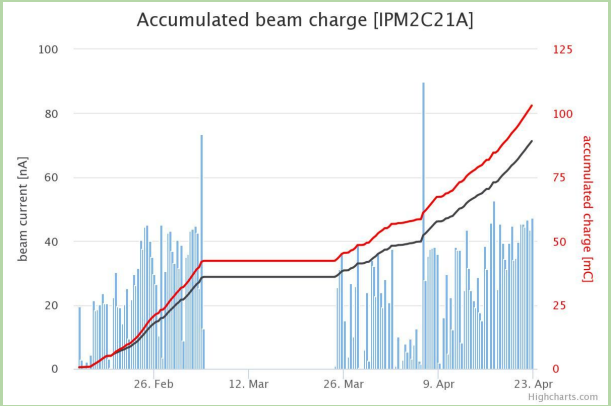
Torus and solenoid achieved full designed currents

All baseline and non-baseline detectors operational

Three main triggers + >30 prescaled diagnostic triggers. Main trigs: e-, MesonX and J/ψ (muon trigger)

Beam polarization: ≈ 85%





- Beam energy: 10.6 GeV
- 50 nA current.
- 79 mC (e- neg.pol.) + 22 mC (e+ pos.pol.)
- Accumulated charge corresponds to ≈ 10% RGA expected full luminosity.

CLAS12

Commissioning: Dec 2017, Jan 2018

Torus and solenoid achieved full field

operational

ostic

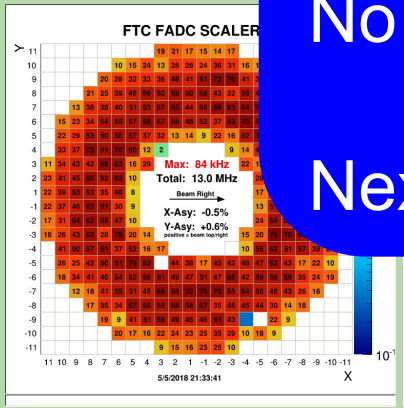
muon

Calibrations are in progress

Full cooking will start in mid. July

No CLAS12 data will be shown today

Next Run: Aug 22 to Nov 15, 2018



e+ pos.pol.)

- Accumulated charge corresponds to ≈ 10% RGA expected full luminosity.

Untagged photoproduction

Events with $Q^2 \sim 0$ will be selected as a candidate for quasi-real photoproduction events

In the electroproduction of lepton pairs there are two electrons in the final state

From pair production

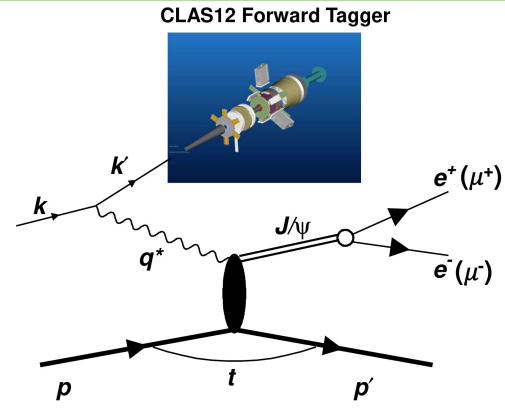
$$ep \rightarrow e^- e^+ p e^-$$

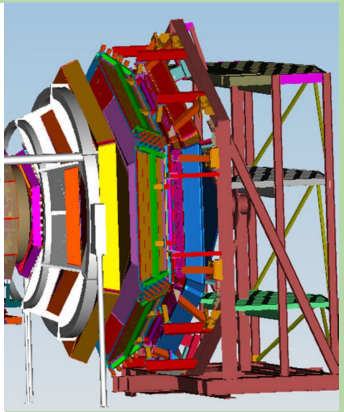
Beam electron

The final state to be analyzed

$$ep \rightarrow e^- e^+ p X$$

Tagged photoproduction





-Beam electron is detected in the Forward tagger

-Different combinations of $l^- l^+ p$ will be detected in CLAS12 forward detector

- Low rate, however detecting only p and/or J/ψ products will allow tag the reaction.

Untagged photoproduction

Events with $Q^2 \sim 0$ will be selected as a candidate for quasi-real photoproduction events

From pair production

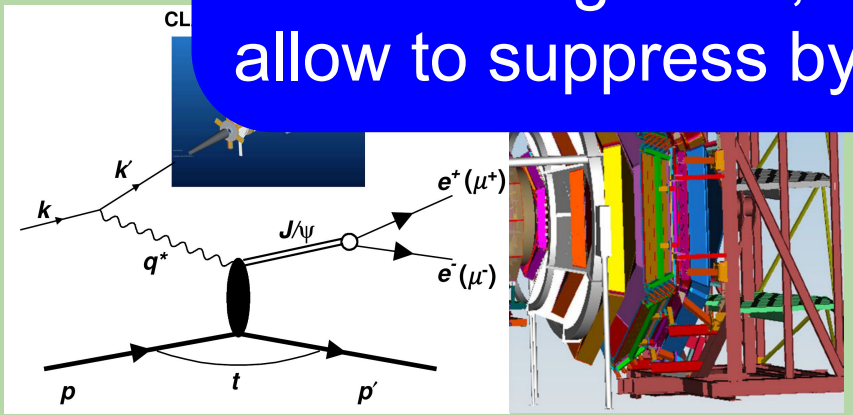
In the electroproduction of lepton pairs there a

The fi

lectron

ward

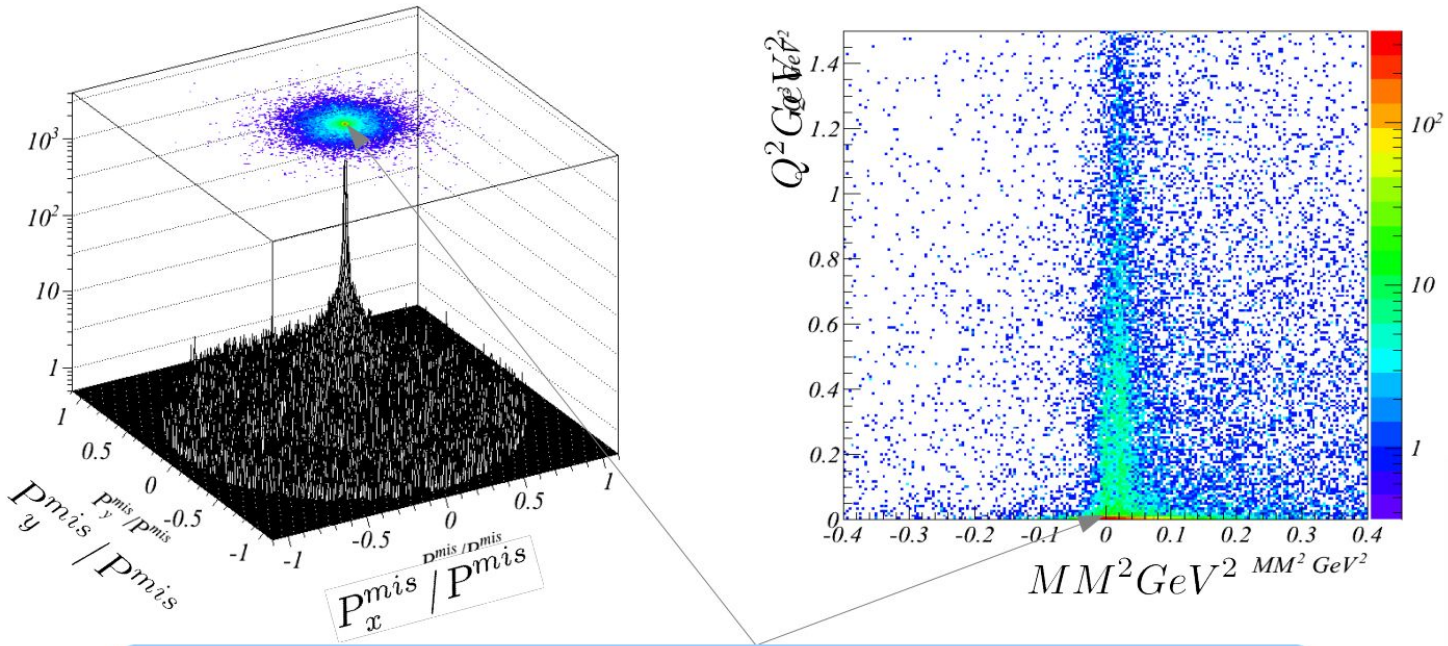
NOTE: while CLAS12 has no muon detector, for J/ψ analysis, EC will be used to select μ^- μ^+ pairs, since $\pi^-\pi^+$ pairs will contribute only to the background, moreover PCal/EC will allow to suppress by ≈×6



Different combinations of l^-l^+p will be detected in CLAS12 forward detector

CLAS E1-6 data: selection of quasi-real photoproduction events

The final state to be analyzed $ep \rightarrow e^- e^+ pX$



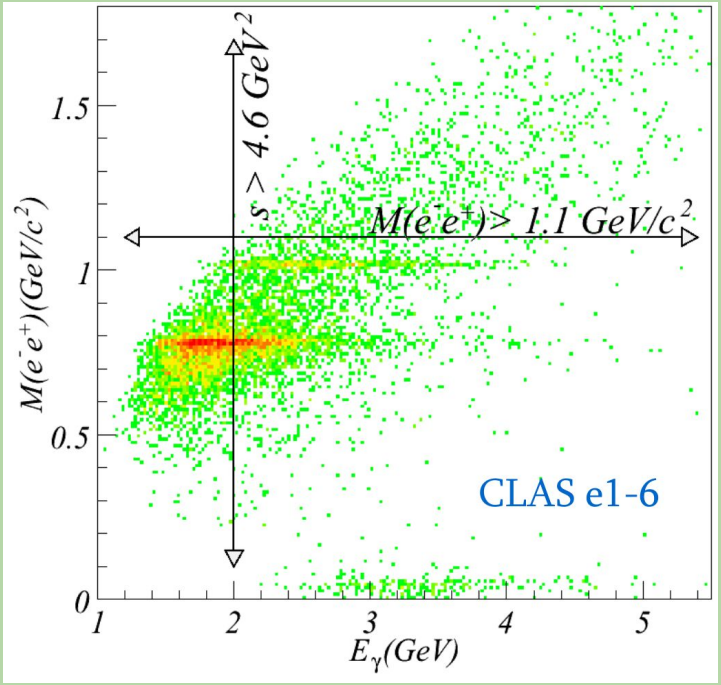
X is identified as a beam electron scattered at 0 degree

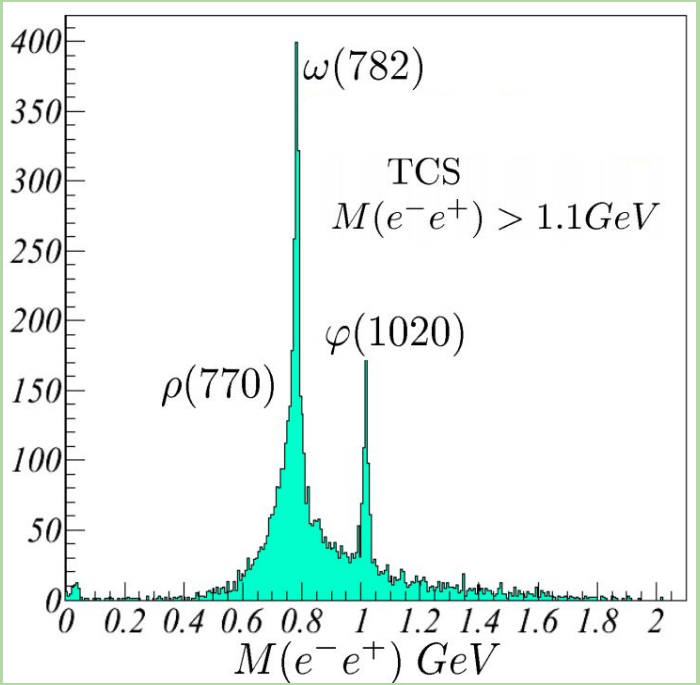
$Q^2 < 0.01 GeV^2 \quad |M_x|^2 < 0.1 GeV^2$

Invariant mass distribution from CLAS e1-6 data

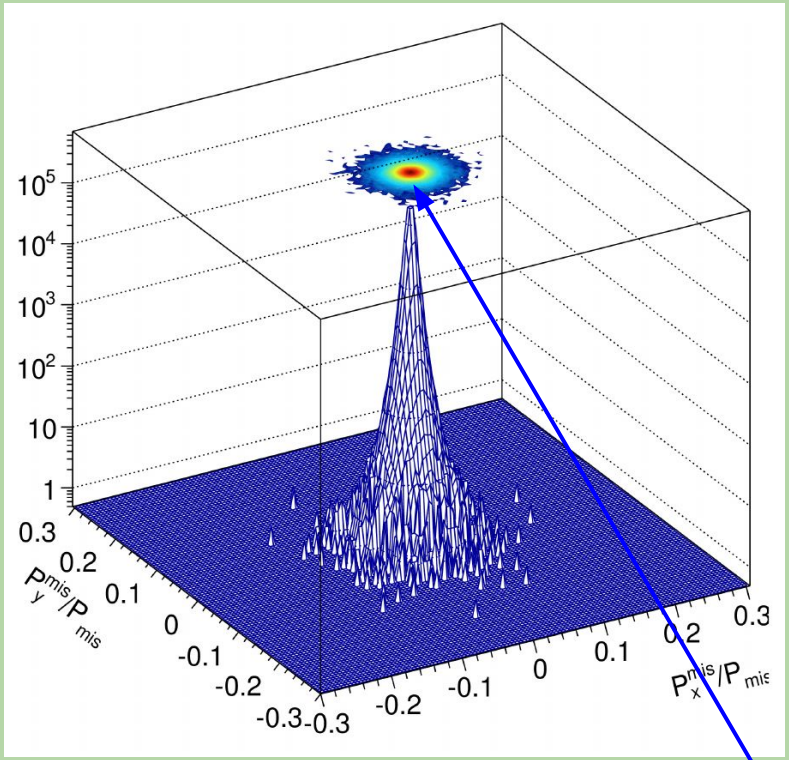
ω and ϕ peaks are clearly visible

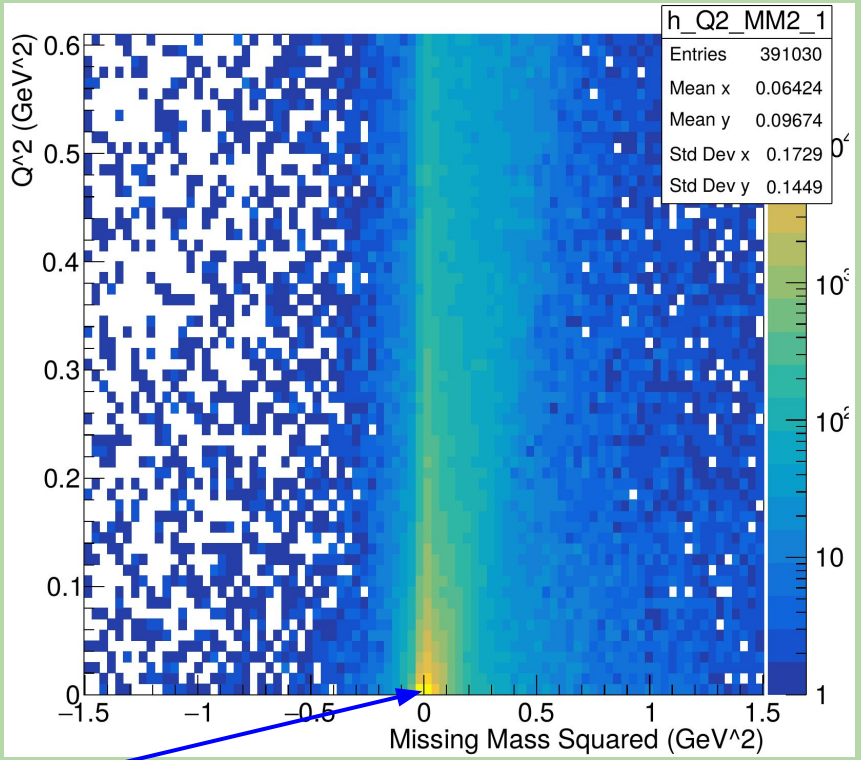
M > 1.1 GeV was selected for TCS analysis





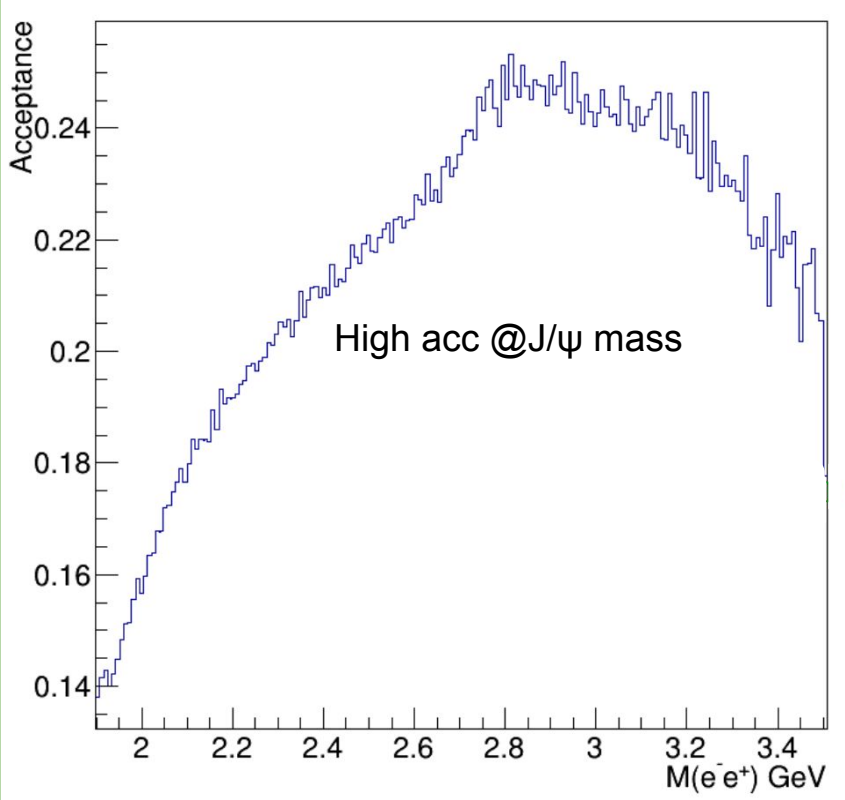
Simulations: untagged photoproduction

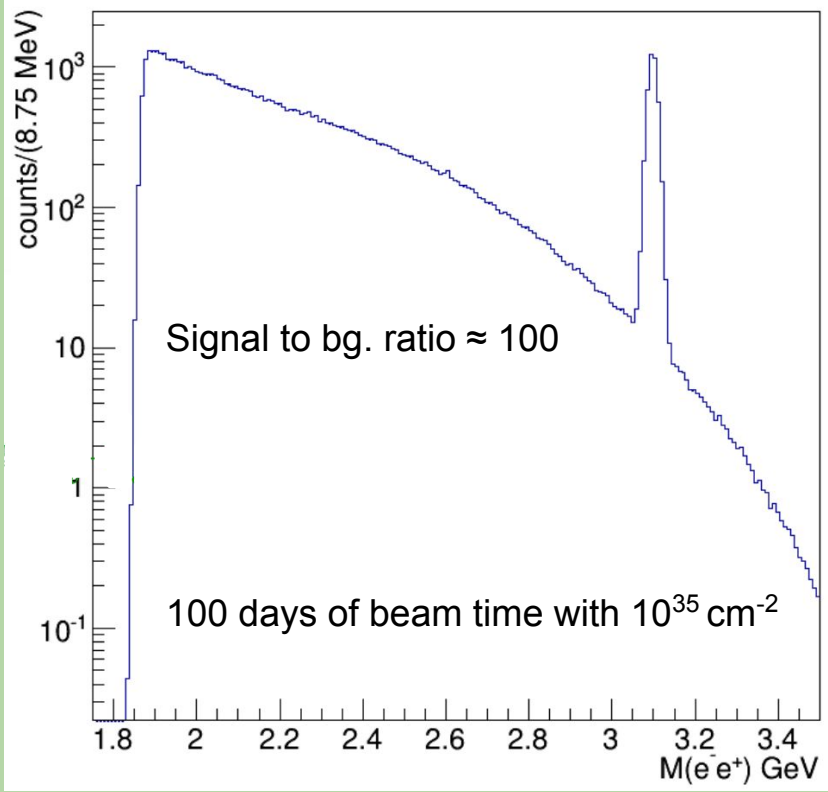




Quasi-real photoproduction events

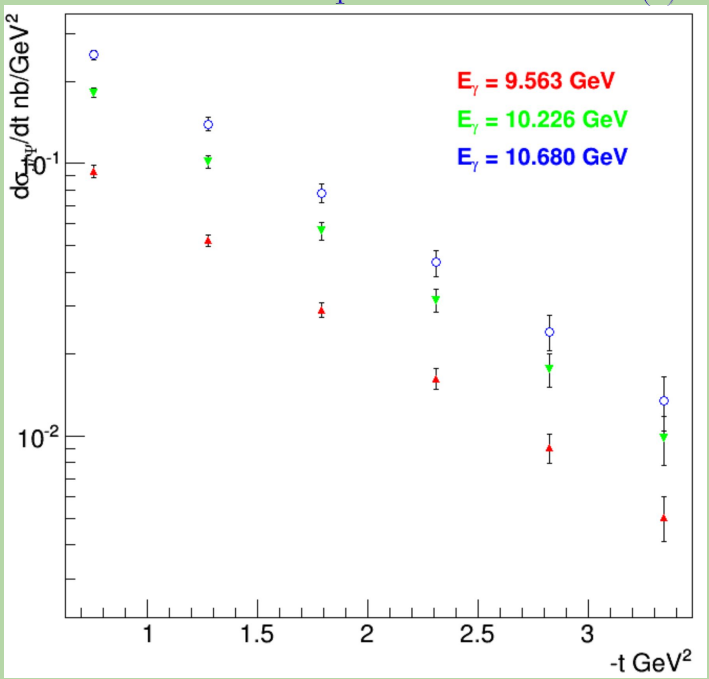
Acceptance and expected M(e-e+) distribution

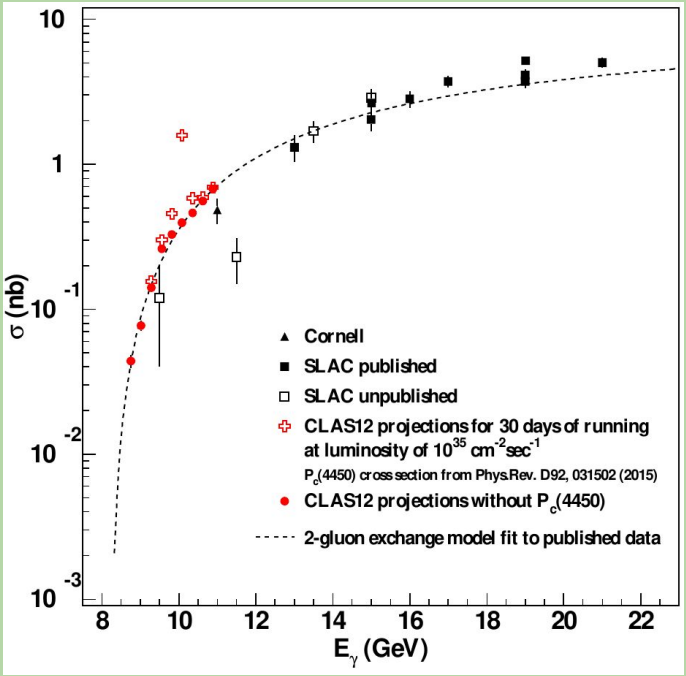




CLAS12 expected results

Proton Form Factor is parametrized as $F(t) = e^{-1.13t}$





About 45 J/ψ per day according to 2 gluon exchange mechanism

Expected number of charmed pentaquarks 98 per day

Summary

12 GeV JLab upgrade crosses the J/ψ production threshold

Measurements of t and W dependence of J/ψ production cross section will be important input to different proposed J/ψ production mechanism near the threshold.

Has potential to detect and study P_c pentaquark(s)

CLAS12 commissioned successfully in Dec,2017 - Jan 2018, and all detector components met design requirements.

1st CLAS12 RG-A run recently completed. Preliminary results are expected soon

Next part of RG-A will start Aug 2018

Backup Slides

Triggers

Menu

CLAS12 VTP Trigger

05/05/2018 10:13:42

Beam Current (nA)

53.7 2C21

51.1 FCup

Electron Alarms

1-6: NO_ALARM 1-6 Tolerance: 0.40

Totals (Hz)

2462528 13685

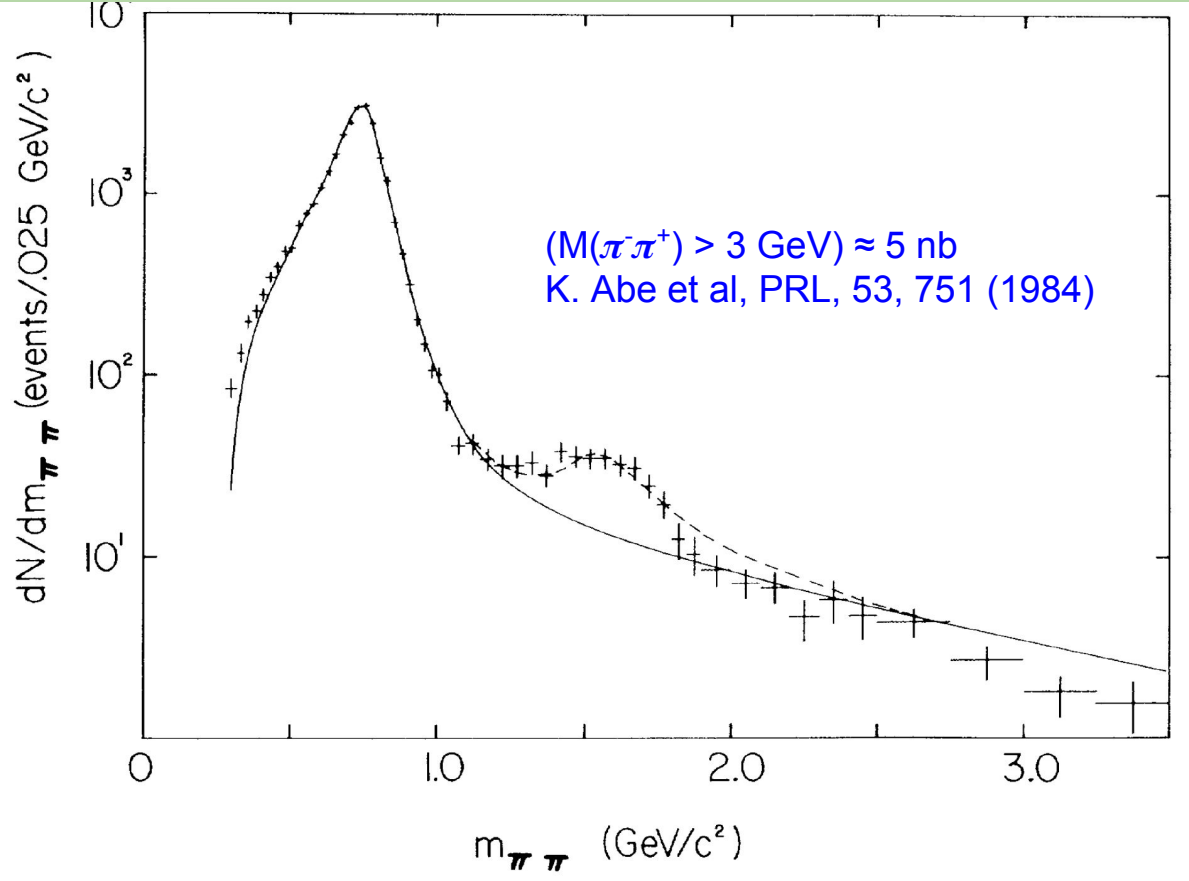
Livetime

TS 94.3 %

Pulser 92.9 %

Bit	Description	Raw (Hz)	Prescaled (Hz)	Fraction (%)	Prescale	In Totals
0	Electron - OR of 1-6	6271	6271	46.4	0	
1	Sector 1	905	905		0	
2	Sector 2	860	860		0	
3	Sector 3	1148	1148		0	
4	Sector 4	1295	1295		0	
5	Sector 5	1170	1170		0	
6	Sector 6	935	935		0	
7	Elctron OR no DC >300MeV	7540	228	1.7	6	
8	PCALxECAL>10MeV	318527	155	1.2	12	
13	DCxFTOFxPCUxPCAL S1	57009	3	0.0	15	
14	DCxFTOFxPCUxPCAL S2	65115	4	0.0	15	
15	DCxFTOFxPCUxPCAL S3	64594	4	0.0	15	
16	DCxFTOFxPCUxPCAL S4	68297	4	0.0	15	
17	DCxFTOFxPCUxPCAL S5	67585	4	0.0	15	
18	DCxFTOFxPCUxPCAL S6	63610	4	0.0	15	
19	FTOFxPCALxECAL 1-4	839	839	6.2	0	
20	FTOFxPCALxECAL 2-5	842	842	6.2	0	
21	FTOFxPCALxECAL 3-6	837	837	6.2	0	
24	FTxHDxFTOFxPCALxCTOF	14076	427	3.2	6	
25	FTxHDx(FTOFxPCAL)^2	3645	3645	27.0	0	
26	FT 2 clusters>500MeV	7045	213	1.6	6	
27	FT > 100 MeV	1652002	101	0.7	15	
31	Pulser	100	100	0.7	0	

Pion pair production cross section



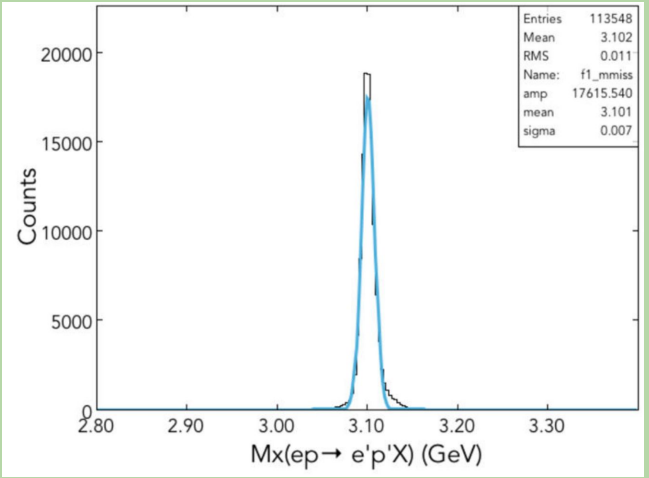
Simulations: Tagged photoproduction

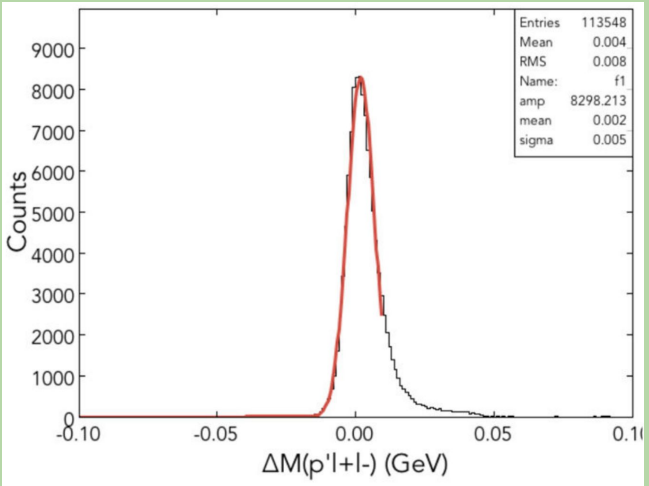
Photon flux is ×10 smaller

Very good mass resolution

Better W resolution

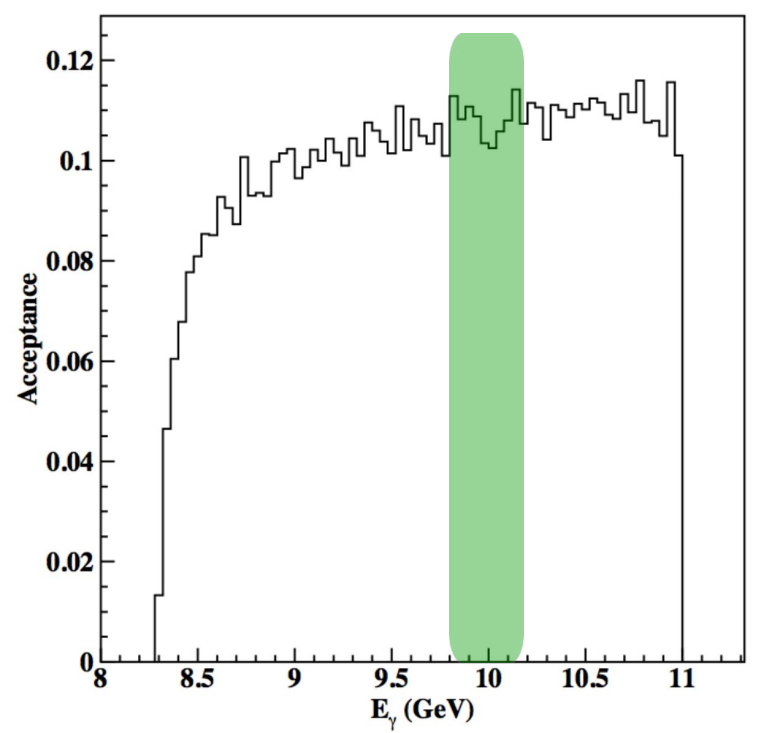
Better acceptance, Detecting p, and/or J/ψ products (e,μ pairs) will allow tag the reaction.



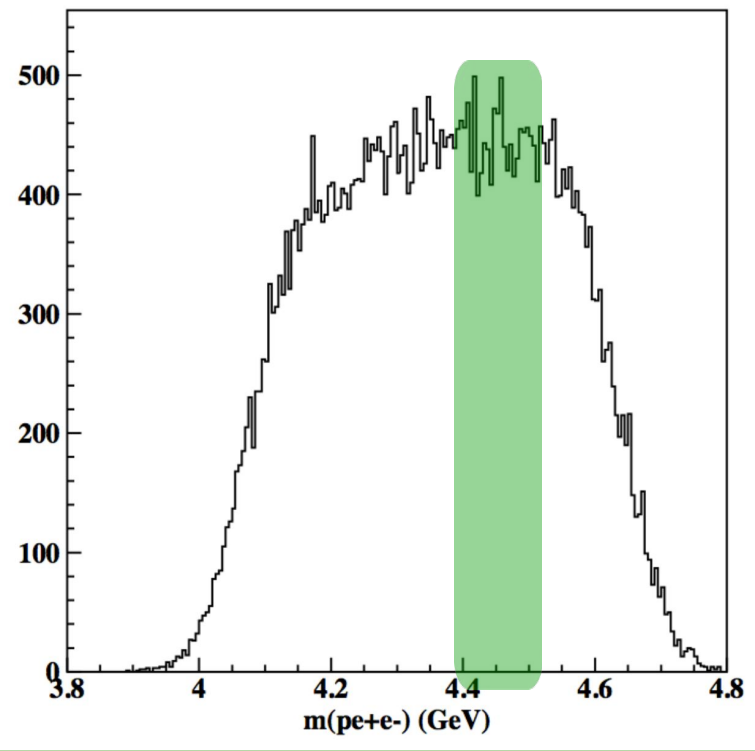


Kinematic coverage

Acceptance $ep \rightarrow J/\psi(\rightarrow e^- e^+)p(e')$



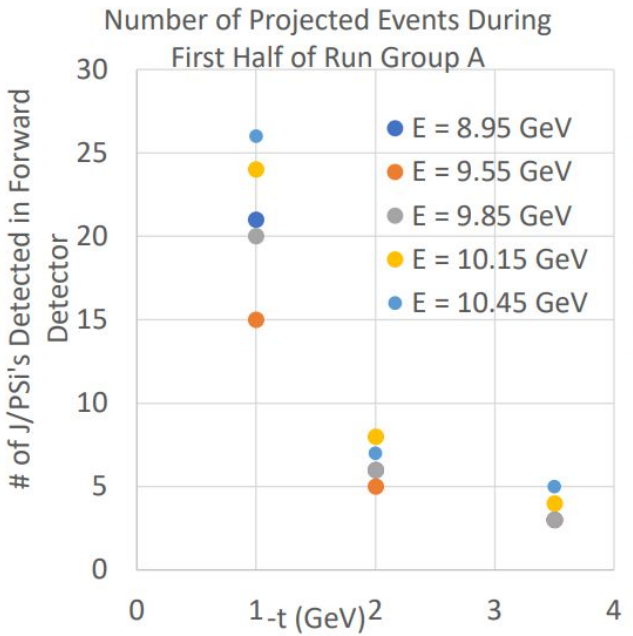
Invariant mass of $e^- e^+ p$ system



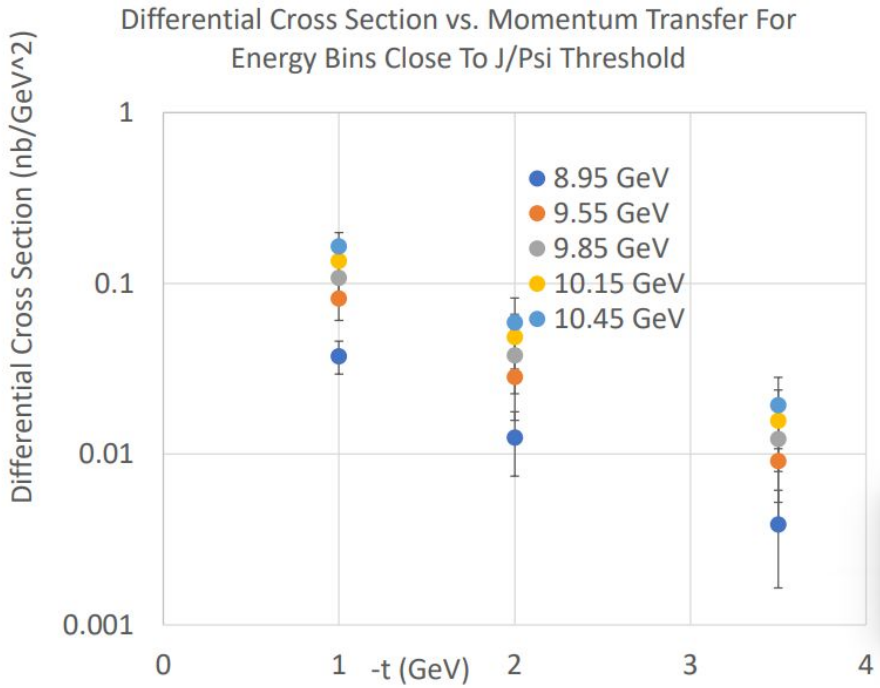
P_c pentaquarks are well inside the acceptance region

Slide from J. Newton

Projections for J/ψ from RG-A Spring 2018 Run



***Bin sizes for photon energy…**
8.5 < E < 9.4
9.4 < E < 9.7
9.7 < E < 10.0
10.0 < E < 10.3
10.3 < E < 10.6
***Bin sizes for -t…**
0.5 < -t < 1.5
1.5 < -t < 2.5
2.5 < -t < 4.5



***A total of 184 J/Psi events for the time period corresponding to the first half of Run Group A are projected based off acceptances from simulation and tracking efficiency from data**

Acceptance with tagged photoproduction