CLAS12 Options for LHCb Pentaquark Searches

Bryan McKinnon
University of Glasgow
For CLAS Collaboration

Exotic Hadron Spectroscopy Workshop Edinburgh 11 - 13 December 2017

CLAS12 Plans for LHCb Pentaquark Searches

Bryan McKinnon
University of Glasgow
For CLAS Collaboration

Exotic Hadron Spectroscopy Workshop Edinburgh 11 - 13 December 2017

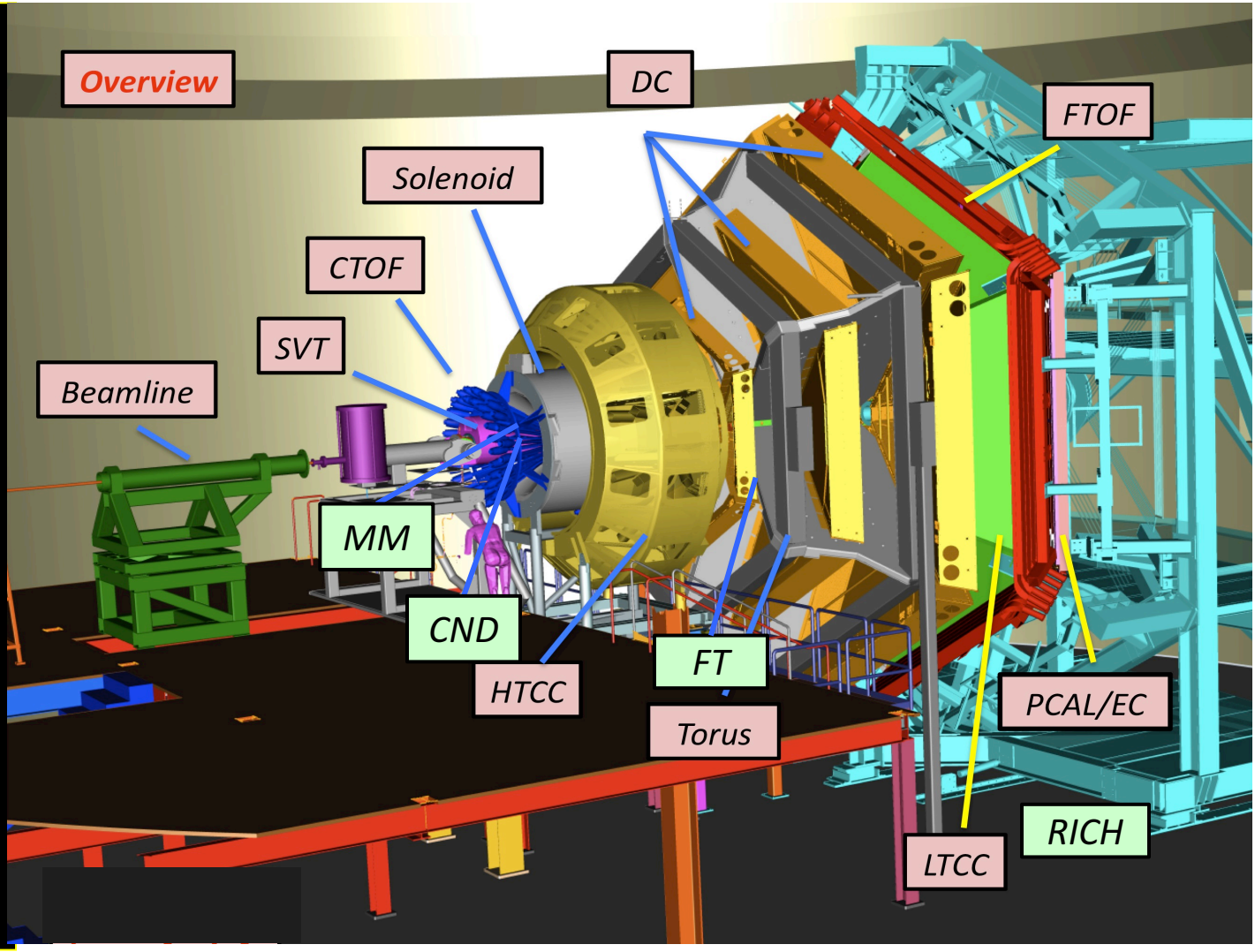
CLAS12 in Hall-B

Forward Detector (FD)
- TORUS magnet
- HT Cherenkov Counter
- Drift chamber system
- LT Cherenkov Counter
- Forward TOF System
- Pre-shower calorimeter
- E.M. calorimeter

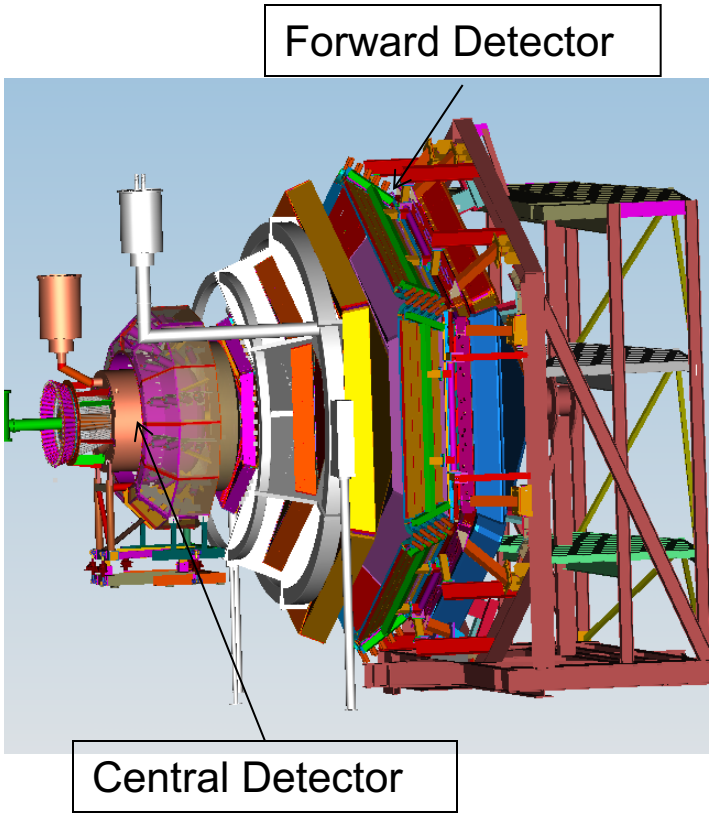
Central Detector (CD)
- SOLENOID magnet
- Silicon Vertex Tracker
- Central Time-of-Flight

Beamline
- Cryo Target
- Moller polarimeter
- Shielding
- Photon Tagger

Upgrade to the baseline
- Central Neutron Detector
- MicroMegas
- Forward Tagger
- RICH detector
- Polarized target



CLAS12 in Hall-B



$$L = 10^{35} cm^{-2} s^{-1}$$

	FD	CD
Angular range		
Track	$5^0 - 40^0$	$35^0 - 125^0$
Photons	$2^0 - 40^0$	---
Resolution		
dp/p (%)	< 1 @ 5 GeV/c	< 5 @ 1.5 GeV/c
$d\theta$ (mr)	< 1	< 10 – 20
$\Delta\phi$ (mr)	< 3	< 5
Photon detection		
Energy (MeV)	>150	---
$\delta\theta$ (mr)	4 @ 1 GeV	---
Neutron detection	N_{eff}< 0.7	N_{eff}< 0.3
Particle ID		
e/π	Full range	---
π/p	< 5 GeV/c	< 1.25 GeV/c
π/K	< 2.6 GeV/c	< 0.65 GeV/c
K/p	< 4 GeV/c	< 1.0 GeV/c
$\pi(\eta)\rightarrow\gamma\gamma$	Full range	---

Accepted by PAC45

Near threshold J/ψ photoproduction and study of LHCb pentaquarks with CLAS12

M. Battaglieri*, G. Bracco, A. Celentano*, R. De Vita*,
L. Marsicano, P. Musico, M. Osipenko, M. Ripani, M. Taiuti
INFN, Sezione di Genova, 16146 Genova, Italy

N. Baltzell, S. Boyarinov, V. Burkert, G. Gavalian, Y. Furletova, V. Kubarovsky*, V. Mokeev, M. Mestayer, K. Park, E. Pasyuk, S. Stepanyan*†
Thomas Jefferson National Accelerator Facility, Newport News, VA 23606

R. Paremuzyan
University of New Hampshire, Durham, New Hampshire 03824-3568

C. Hyde, J. Newton, L. Weinstein
Old Dominion University, Norfolk, VA 23529

P. Nadel-Turonski
Stony Brook University, Stony Brook, NY 11794

D. Glazier, D. G. Ireland, D. MacGregor, B. McKinnon, B. Seitz, D. Sokhan
University of Glasgow, Glasgow G12 8QQ, United Kingdom

L. Guo
Florida International University, Miami, FL 33199

W. Armstrong, K. Hafidi, M. Hattawy
Argonne National Laboratory, Argonne, Illinois 60439

Accepted by PAC45

Near threshold J/ψ photoproduction and study of LHCb pentaquarks with CLAS12

M. Battaglieri*, G. Bracco, A. Celentano*, R. De Vita*,
L. Marsicano, P. Musico, M. Osipenko, M. Ripani, M. Taiuti
INFN, Sezione di Genova, 16146 Genova, Italy

N. Baltzell, S. Boyarinov, V. Burkert, G. Gavalian, Y. Furletova, V. Kubarovsky*, V. Mokeev, M. Mestayer, K. Park, E. Pasyuk, S. Stepanyan*†
Thomas Jefferson National Accelerator Facility, Newport News, VA 23606

Extends measurements by including J/$\psi \rightarrow \mu+\mu$- decay mode

Will study pentaquarks with hidden charm using tagged and untagged photoproduction with CLAS12

P. Nadel-Turonski
Stony Brook University, Stony Brook, NY 11794

D. Glazier, D. G. Ireland, D. MacGregor, B. McKinnon, B. Seitz, D. Sokhan
University of Glasgow, Glasgow G12 8QQ, United Kingdom

L. Guo
Florida International University, Miami, FL 33199

W. Armstrong, K. Hafidi, M. Hattawy
Argonne National Laboratory, Argonne, Illinois 60439

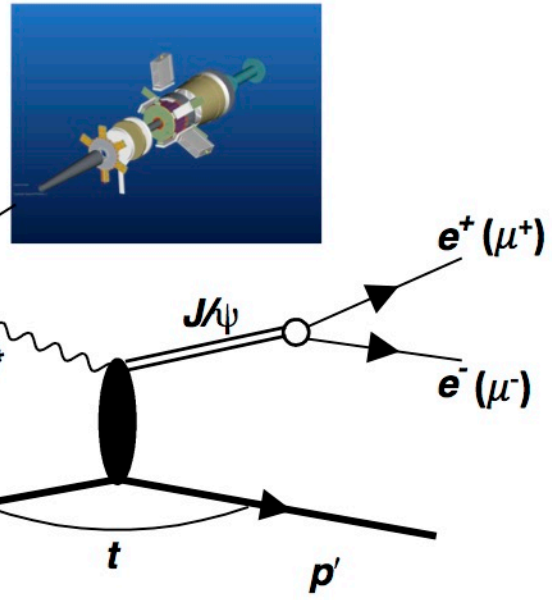
Outline

- The highlights of new proposal
- LHCb pentaquarks
- J/ψ photoproduction kinematics, acceptance and resolution
- Statistics and expected results
- Summary

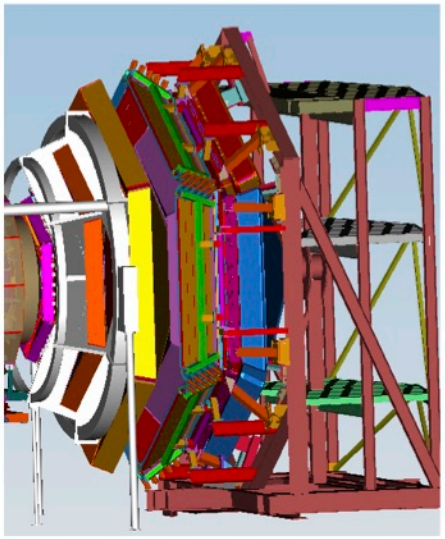
Photoproduction with CLAS12

- Untagged photoproduction – E12-12-001 CLAS12 analysis: $ep \rightarrow (e')p'l^+l^-;\ l = e, \mu$
  - Recoil proton and decay leptons will be detected
  - kinematics of the scattered electron will be reconstructed in the missing momentum analysis
- Tagged photoproduction – E12-12-005 CLAS12 MesonX:
  - scattered electron will be detected in the CLAS12 FT, Q^2<0.02 GeV^2
  - Multiple combination of hadronic final state (the recoil proton and the J/ψ decay leptons) will be detected in CLAS12 FD

CLAS12 Forward Tagger



CLAS12 Forward Detector



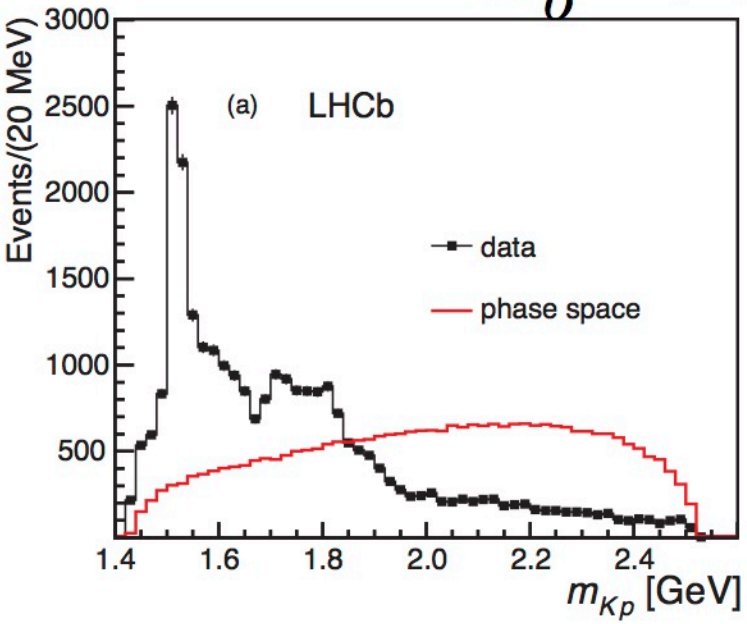
Claim of two pentaquark states

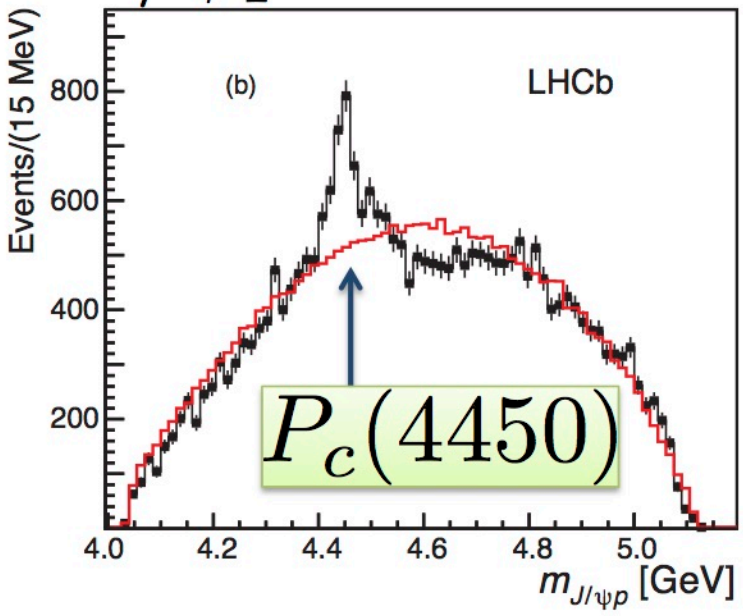
$P_c(4380)$ and $P_c(4450)$ in $J/\psi p$ decay mode

$\Gamma(4380)$=205 MeV $\Gamma(4450)$=40 MeV

with 9 and 12 standard deviations, respectively.

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

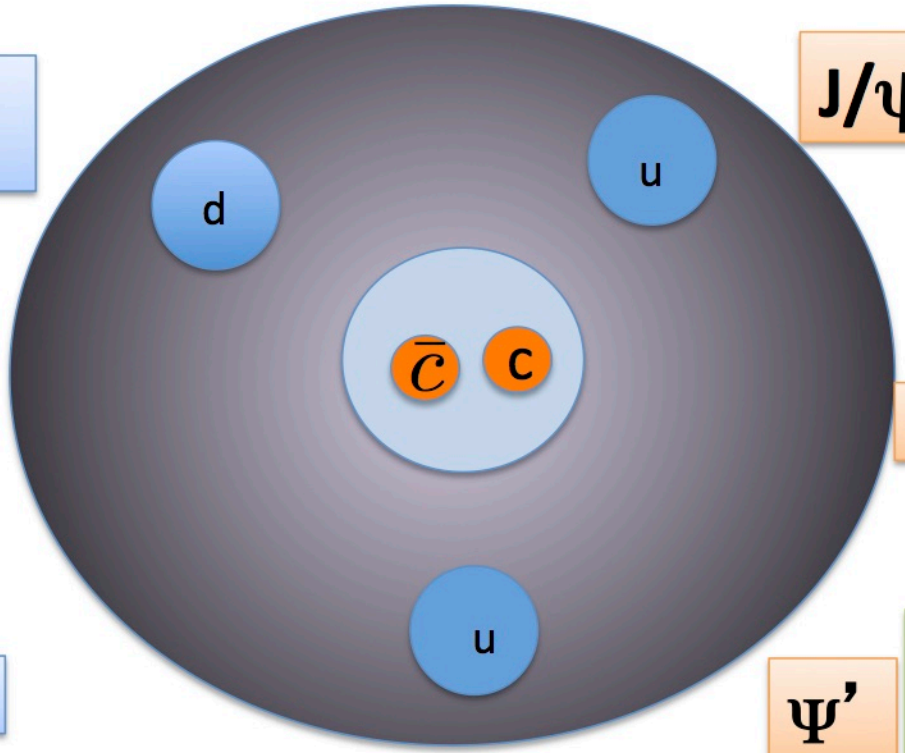




The fit includes **146** parameters. It was reduced in so called restricted model down to 64 keeping only low orbital Λ^* excitation in the Λ_b^o decay.

Baryocharmonium

Exited state
as N(1440), N(1520)



Proton

J/ψ

V. K. and M.B. Voloshin,
Phys.Rev. D 92, 3, 031502 (2015)

χ_1

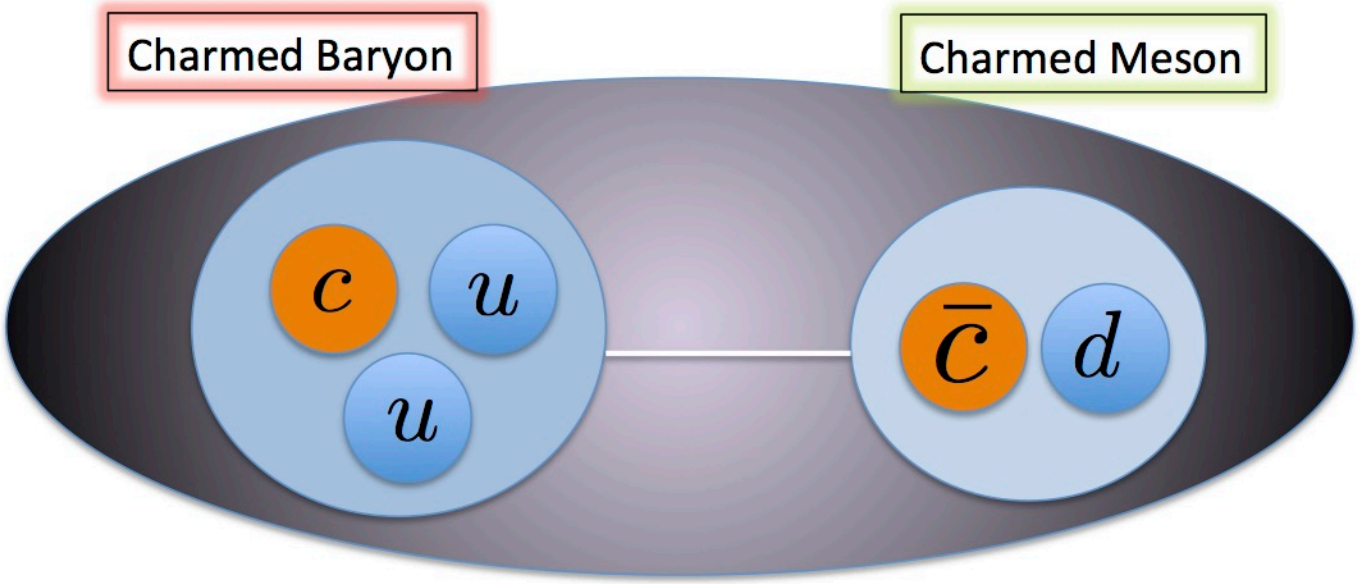
U.-G. Meisner
and J. A. Oller,
arXiv:1507.07478

Ψ'

M. I. Eides, V.Petrov,M.Polyakov
PRD 93, 054039 (2016)
arXiv:1709.09523 (2017)

Pentaquark in this scenario looks like atomic system with a small nucleus whose role plays the heavy quarkonium state and light quarks that play the role of the atomic electrons. The predicted **(27 Sep. 2017)** in 1709.09523 (Sept 2017) $\Gamma(P_5 \to J/\psi + p) = 11$ MeV.

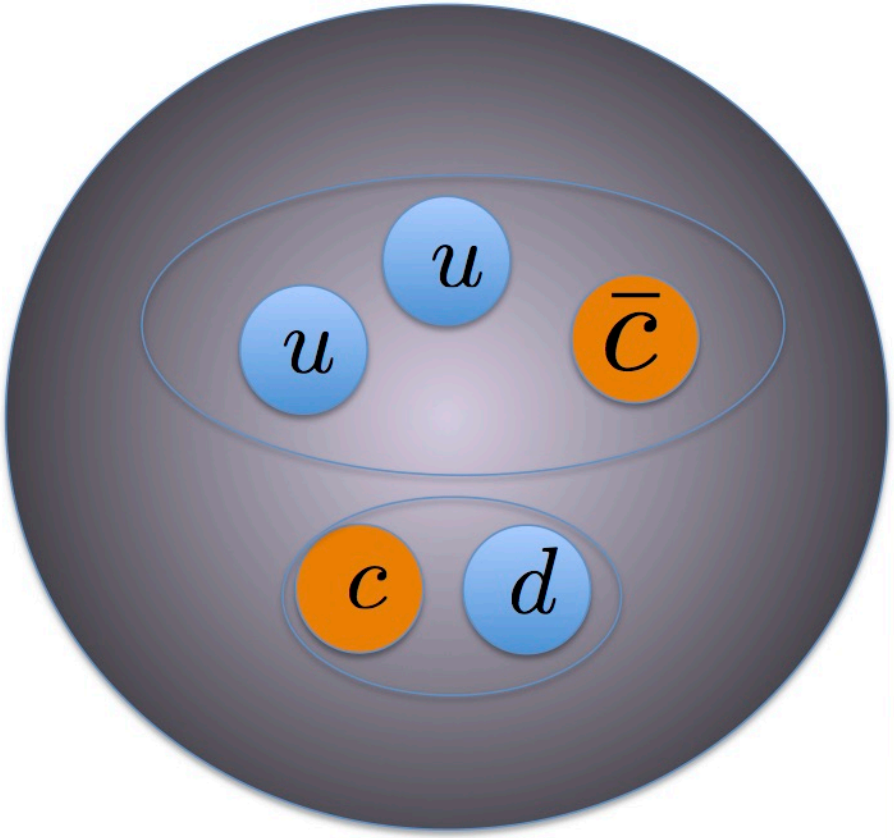
Hadronic molecule



These molecules made from a charmed baryon and charmed meson with week coupling. Such pentaquarks will decay predominantly to the charmed baryon and charmed meson.

- M. Karliner and J. L. Rosner, arXiv: 1506.06386
- L. Roca, J. Nieves, and E. Oset, arXiv: 1507.04249
- R. Chen, X. Liu, X.-Q. Li, and S.-L. Zhu, arXiv: 1507.03704
- H-X. Chen, W. Chen, X. Liu, T.G. Steele, and S-L. Zhu, arXiv: 1507.0317
- J. He, arXiv: 1507.05200

Bag with color objects



Pentaquarks made of tightly correlated **diquarks or colored baryon-like and meson-like constituents**.

- L. Maiani et al. Phys. Lett. B 749, 289 (2015)
- V. V. Anisovichet al., arXiv: 1507.07652
- A. Mironov and A. Morozov, JETP Lett. 102, no. 5, 271 (2015)
- R. F. Lebed, Phys. Lett. B 749, 454 (2015)

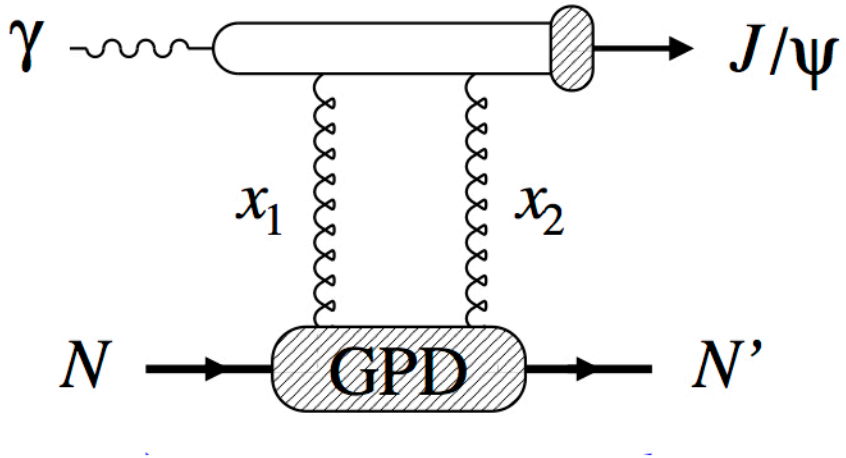
Hidden-Charm Pentaquark Models

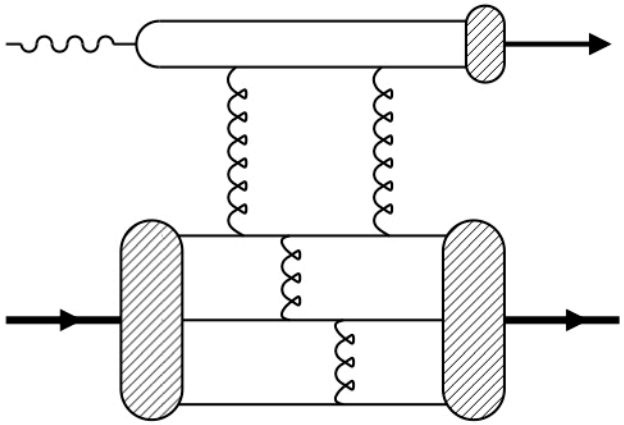
- It has been also suggested that at least one of the peaks is not a resonance at all, but rather a **kinematical singularity** due to rescattering in the decay $\Lambda_b \to J/\psi\, p\, K^-$.

- F. K. Guo, U. G. Meißner, W. Wang and Z. Yang, Phys. Rev. D 92, no. 7, 071502 (2015).
- X. H. Liu, Q. Wang and Q. Zhao, Phys. Lett. B 757, 231 (2016).
- M. Mikhasenko, arXiv:1507.06552 [hep-ph].

Why J/ψ production?

- There are no $c\bar{c}$ in nucleons, production of J/ψ goes via gluon exchange
- Small size $Q\bar{Q}$ state due to large mass of *c*-quark
- Unique probe of the gluon field of the target





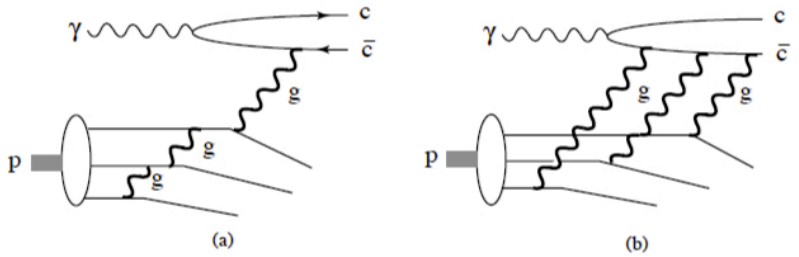
At high energies (HERA, FNAL) probes gluon GPDs. Wealth of data exists on electroproduction at W>10 GeV

Near threshold (large momentum transferred) probes gluonic form factor.

There are no electroproduction measurements in this region

J/ψ production near threshold

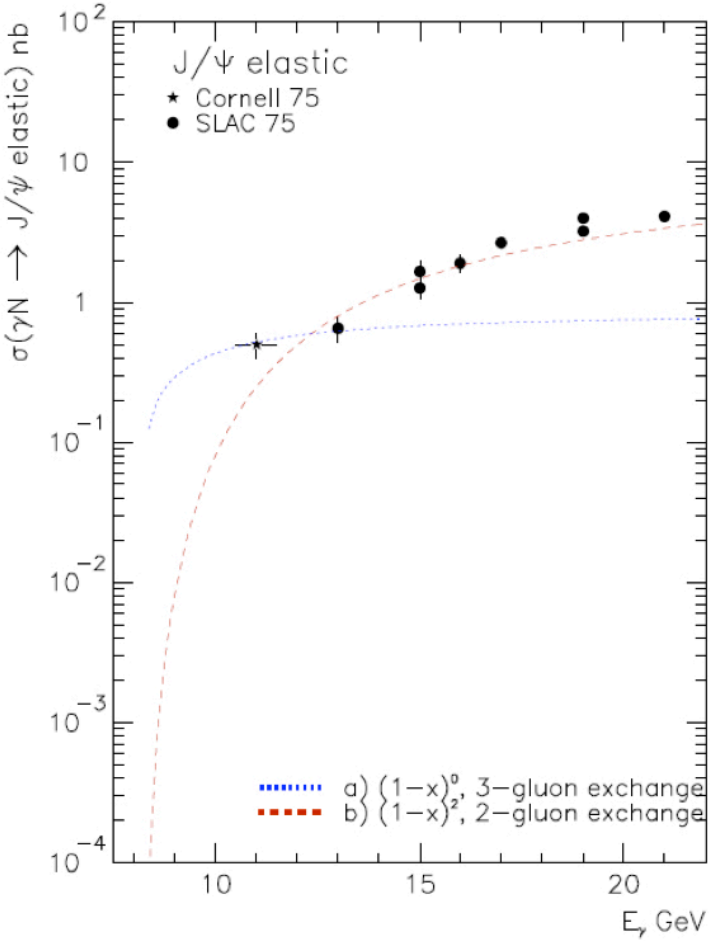
- The lowest published energy point is at E_γ=11 GeV
- Production mechanisms, 2-gluon and 3-gluon exchange, could be valid at the threshold region



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

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

S.J. Brodsky, E. Chudakov, P. Hoyer, and J-M. Laget, Phys.Lett B498, 23-28 (2001)

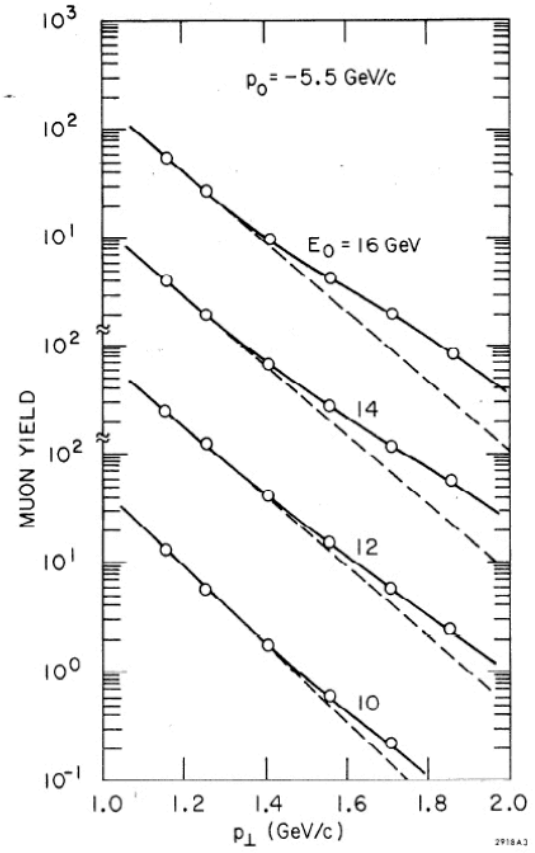


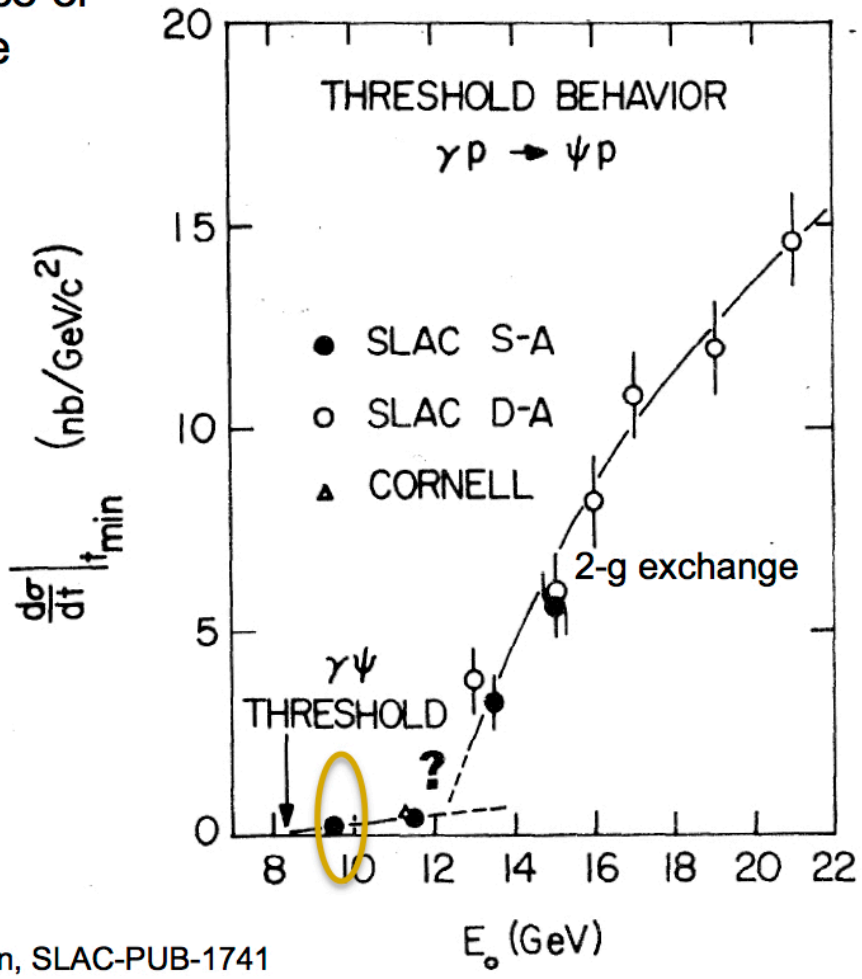
With CLAS12 and 11 GeV electron beam, the threshold region can be studied in great detail – E12-12-001

SLAC single arm measurements

Flattening of cross section near the threshold

Can enhancement be due to a resonance or another mechanism – 3-gluon exchange

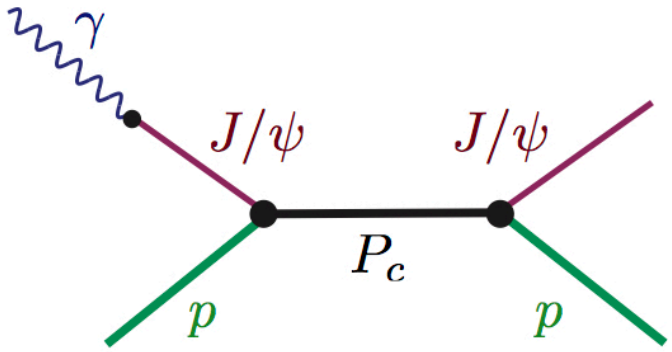




R.L. Anderson, SLAC-PUB-1741

Pentaquark photo-production

- The production of pentaquarks proceeds as an s-channel resonance
- VDM can be used to relate initial and final states

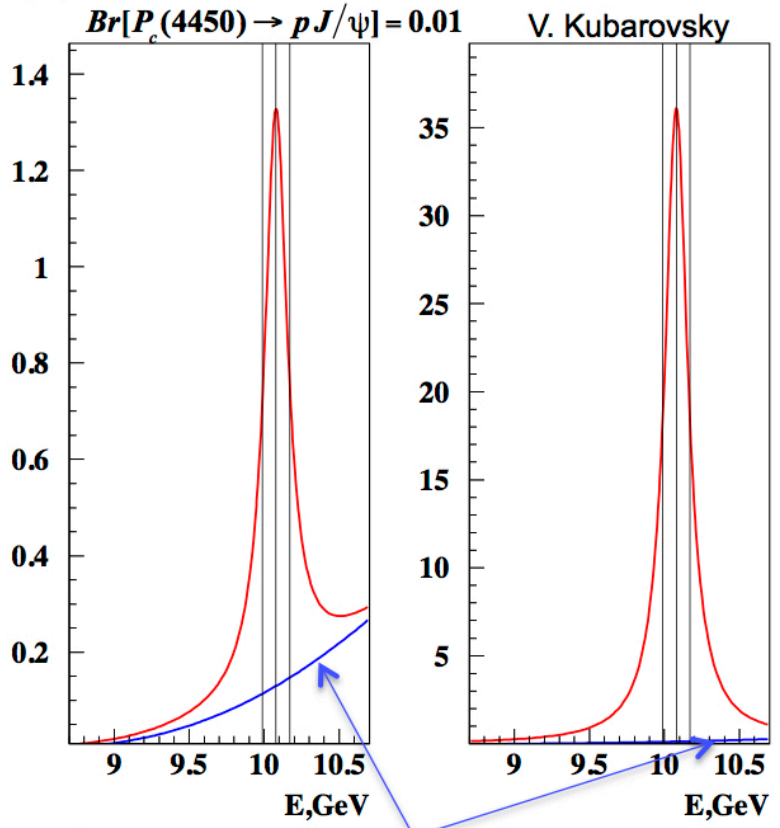


$$\sigma(W)| = \frac{2J+1}{4}\frac{4\pi}{k^2}\frac{\Gamma^2/4}{(W-M_c)^2+\Gamma^2/4} Br(P_c \to \gamma + p)\, Br(P_c \to J/\psi + p)$$

$$\Gamma(P_c \to \gamma + p) = \frac{3\Gamma_{ee}(J/\psi)}{\alpha\, M(J/\psi)} \sum_L f_L \left(\frac{k}{p}\right)^{2L+1} \Gamma_L(P_c \to J/\psi + p)$$

$$1.5 \times 10^{-30}\,\mathrm{cm}^2 < \frac{\sigma_{max}[\gamma + p \to P_c(4380) \to J/\psi + p]}{Br^2[P_c(4380) \to J/\psi + p]} < 47 \times 10^{-30}\,\mathrm{cm}^2$$

$$1.2 \times 10^{-29}\,\mathrm{cm}^2 < \frac{\sigma_{max}[\gamma + p \to P_c(4450) \to J/\psi + p]}{Br^2[P_c(4450) \to J/\psi + p]} < 36 \times 10^{-29}\,\mathrm{cm}^2$$

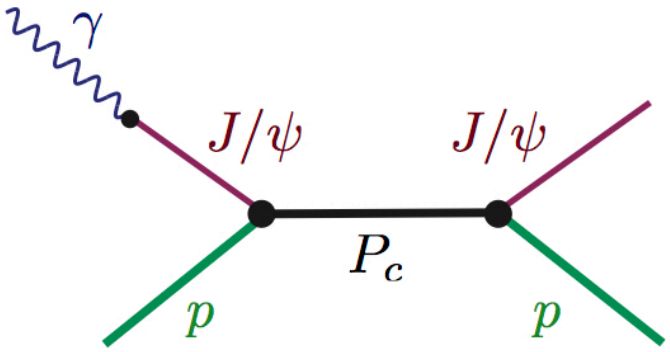


Prediction of 2-gluon exchange model for J/ψ elastic photoproduction

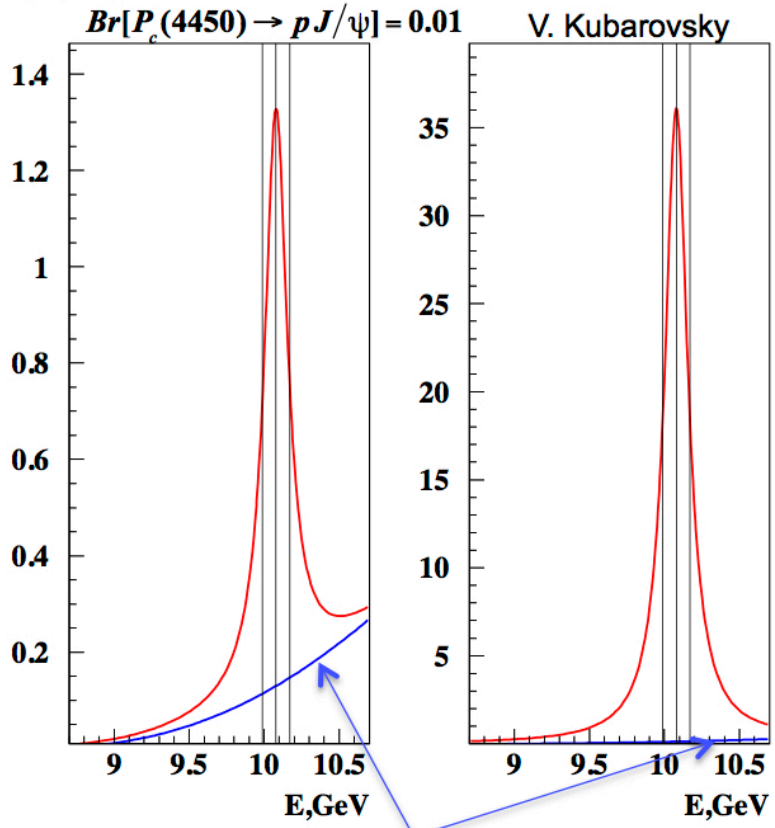
Q. Wang, X. H. Liu and Q. Zhao, arXiv:1508:00339.
V. Kubarovsky and M.B. Voloshin, arXiv:1508.00888.
M. Karliner and J.L. Rosner, arXiv:1508.01496.

Pentaquark photo-production

- The production of pentaquarks proceeds as an s-channel resonance
- VDM can be used to relate initial and final states



BR(PC->J/ψ+p)=1% is very conservative (yet still produces a very good S/B ratio). CLAS12 can confirm and study the pentaquark properties or raise a question about the existence of the LHCb pentaquark



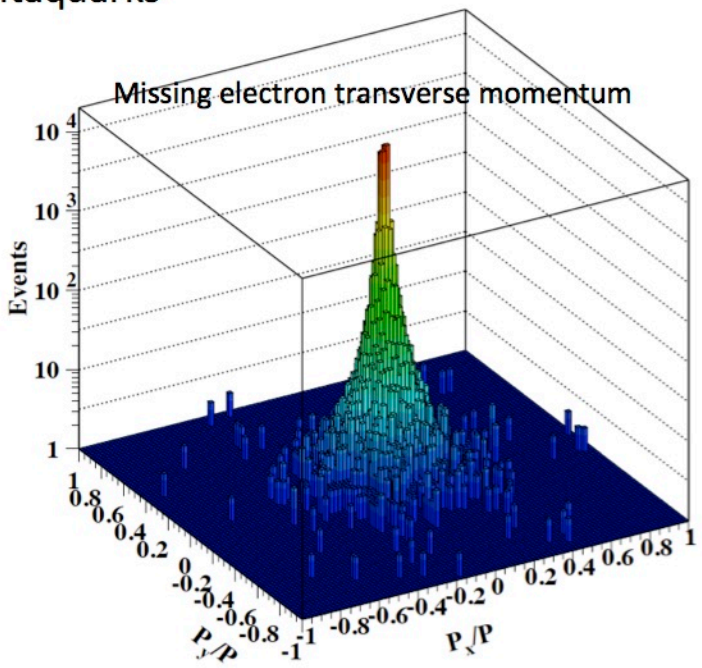
Prediction of 2-gluon exchange model for J/ψ elastic photoproduction

Q. Wang, X. H. Liu and Q. Zhao, arXiv:1508:00339.
V. Kubarovsky and M.B. Voloshin, arXiv:1508.00888.
M. Karliner and J.L. Rosner, arXiv:1508.01496.

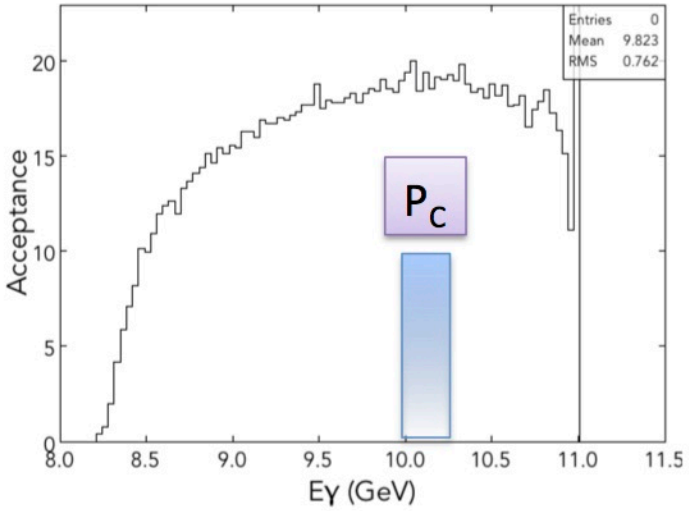
CLAS12 performance – untagged photoproduction

$$ep \rightarrow (e')p'l^+l^-;\ l = e, \mu$$

- Recoil proton and decay leptons are detected
- Kinematics of the scattered electron will be reconstructed in the missing momentum analysis - requires missing transvers momentum to be ~0
- Acceptance covers the mass range of charmed pentaquarks



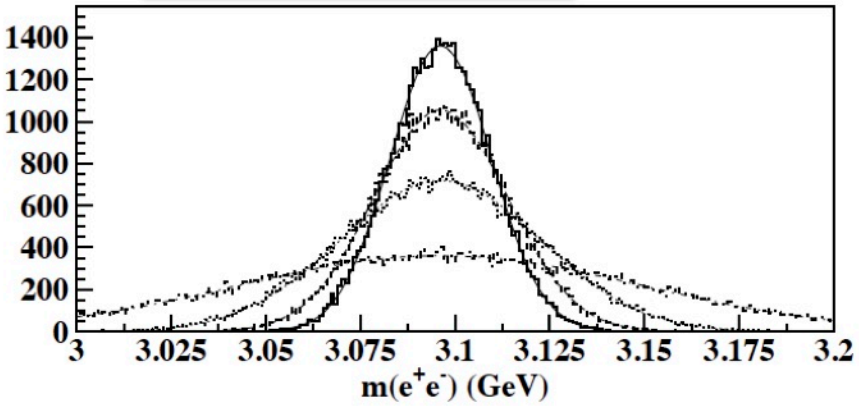
Acceptance vs E_γ

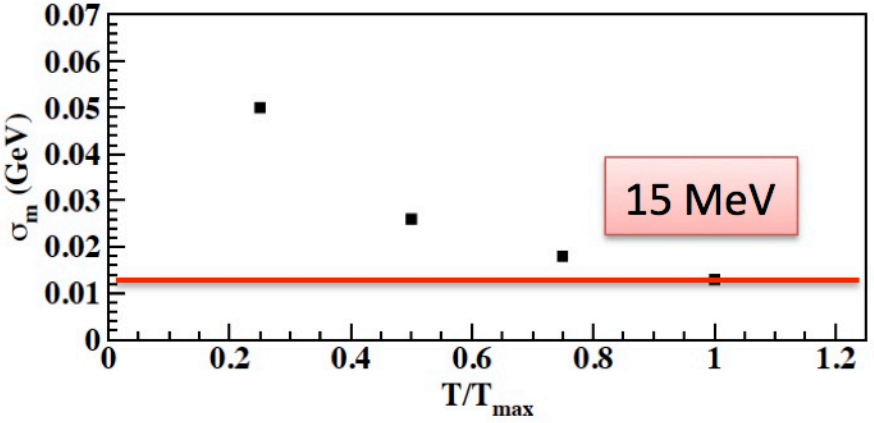


Mass resolutions

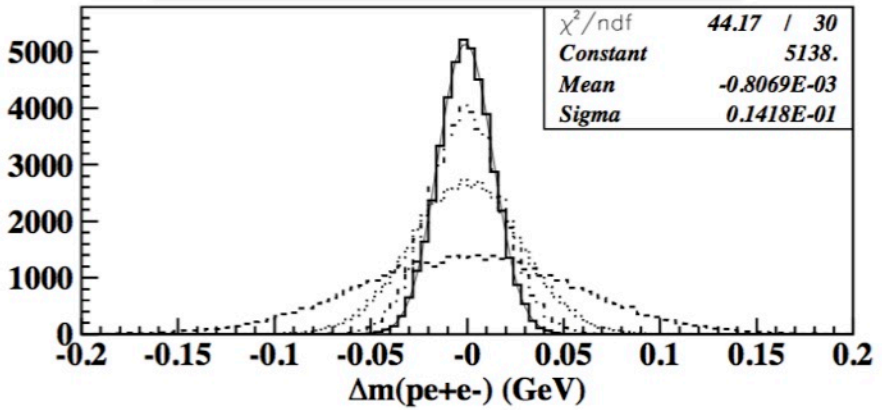
- J/ψ will be identified in the lepton pair invariant mass analysis
- Charmed pentaquarks, $P_c(4380)$ and $P_c(4450)$, will be identified in the invariant mass of $M(p'l^+l^-);\ l = e, \mu$

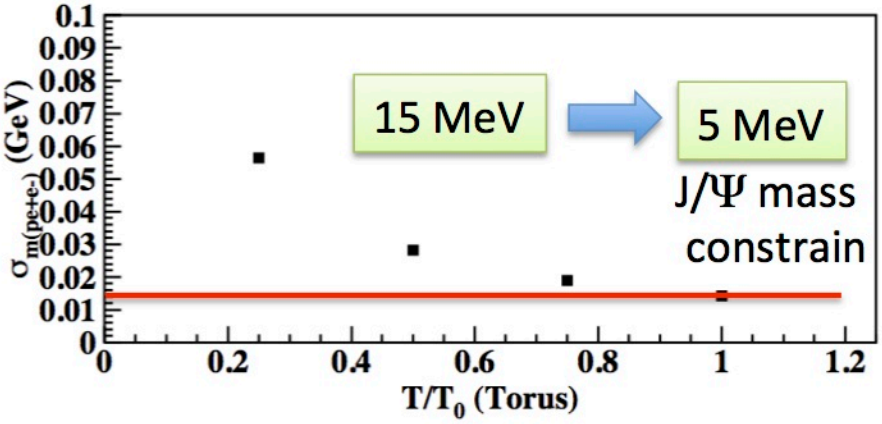
J/ψ mass resolution





Pentaquark mass resolution





CLAS12 performance – tagged photoproduction

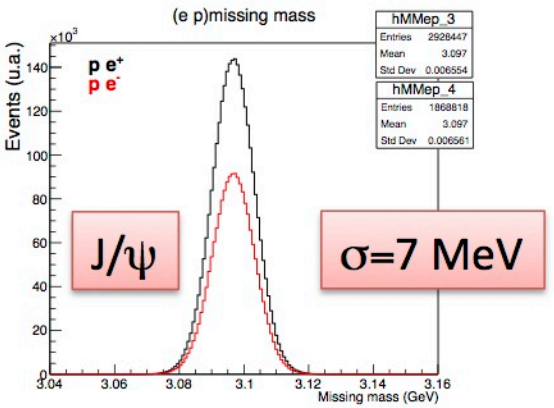
- About x10 lower photon flux, but …
- Multiple final states to measure J/ψ photoproduction
- Excellent mass resolutions:
  - J/ψ as sharp peak either in the invariant mass of decay leptons (ΔM~15 MeV) or in the electron-proton missing mass (ΔM~7 MeV)
  - Pentaquarks will be reconstructed in the missing mass analysis of the scattered electron (W-distribution) (ΔM~5 MeV)

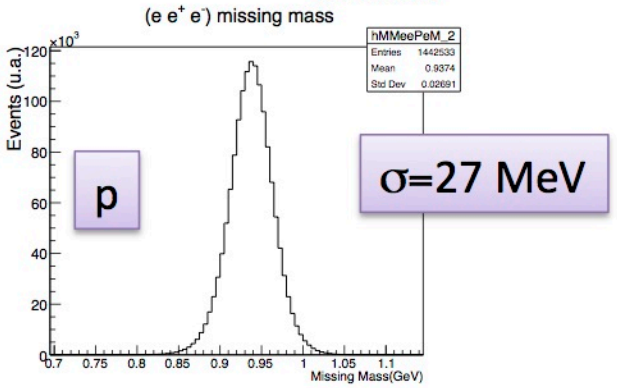
$$ep \rightarrow e'p'l^{+(-)},\ l^{-(+)};\ l = e, \mu$$

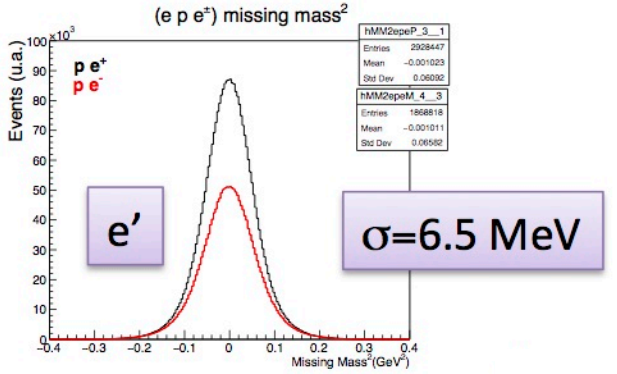
Detection efficiency ~28%

$$ep \rightarrow e'l^{+}l^{-}(p');\ l = e, \mu$$

Detection efficiency ~18%

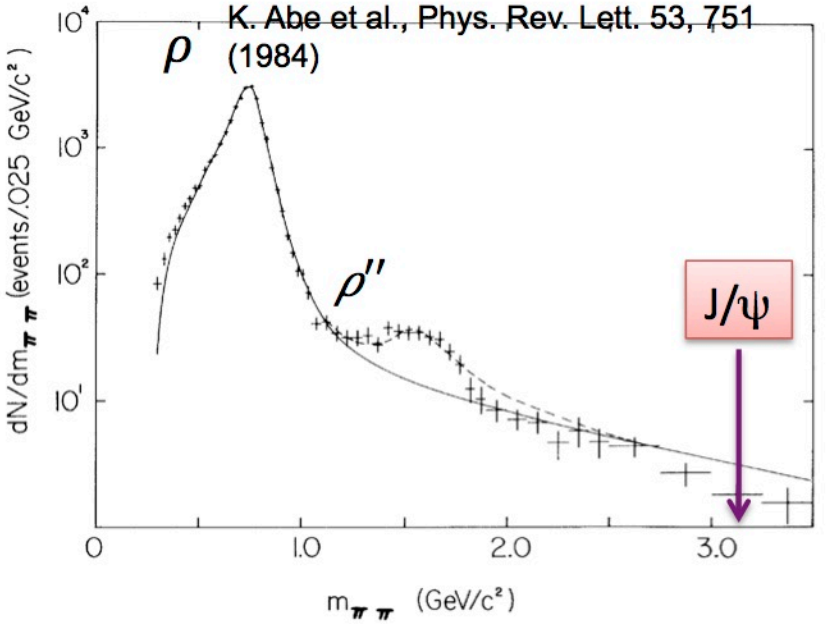


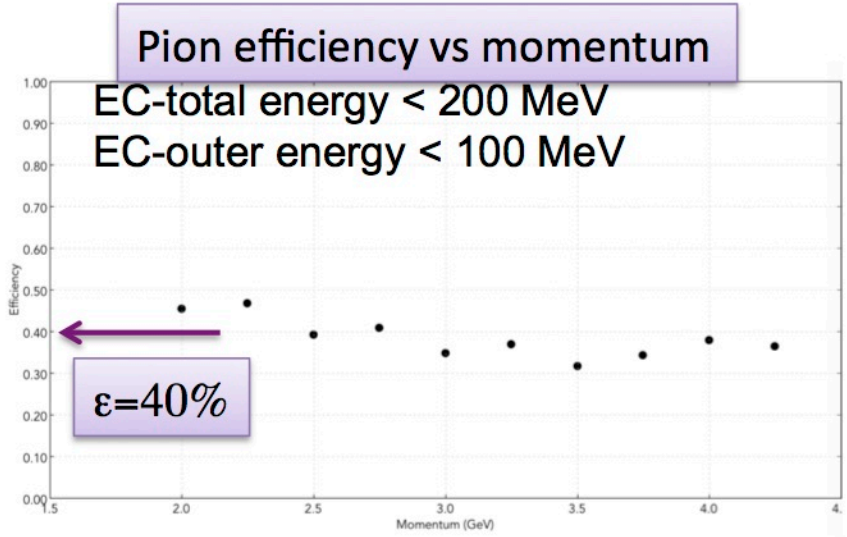




Muon final state

- The main background to muon final state is from $\gamma p \rightarrow p'\pi^+\pi^-$
- In our energy rage $\sigma_{tot}\pi\pi \approx 15\mu b$
- The fraction of pion pairs with $M_{\pi\pi} > 3$ GeV $< 2\ 10^{-4}$
- The effective cross section for pion pair photoproduction in the region of J/ψ is expected to be < 5 nb
- Charged pion detection efficiency with MIP signature is $\lesssim 0.4$, pion pair suppression factor ~6
- The rate of pion pairs with the invariant mass > 3 GeV is the same order as J/ψ production





CLAS12 statistics (events/day)

including e^+e^- and $\mu^+\mu^-$ J/ψ decay modes

$$BR(P_c \to J/\psi p) = 1\%$$

$$L = 10^{35} cm^{-2} s^{-1}$$

	$P_c(4380)$		$P_c(4450)$	
	Minimum	Maximum	Minimum	Maximum
Untagged mode	48	500	70	220
Tagged mode	20	600	28	880
Total	68	1100	98	1100

98 events/day for narrow $P_c(4450)$ pentaquark state at nominal CLAS12 luminosity

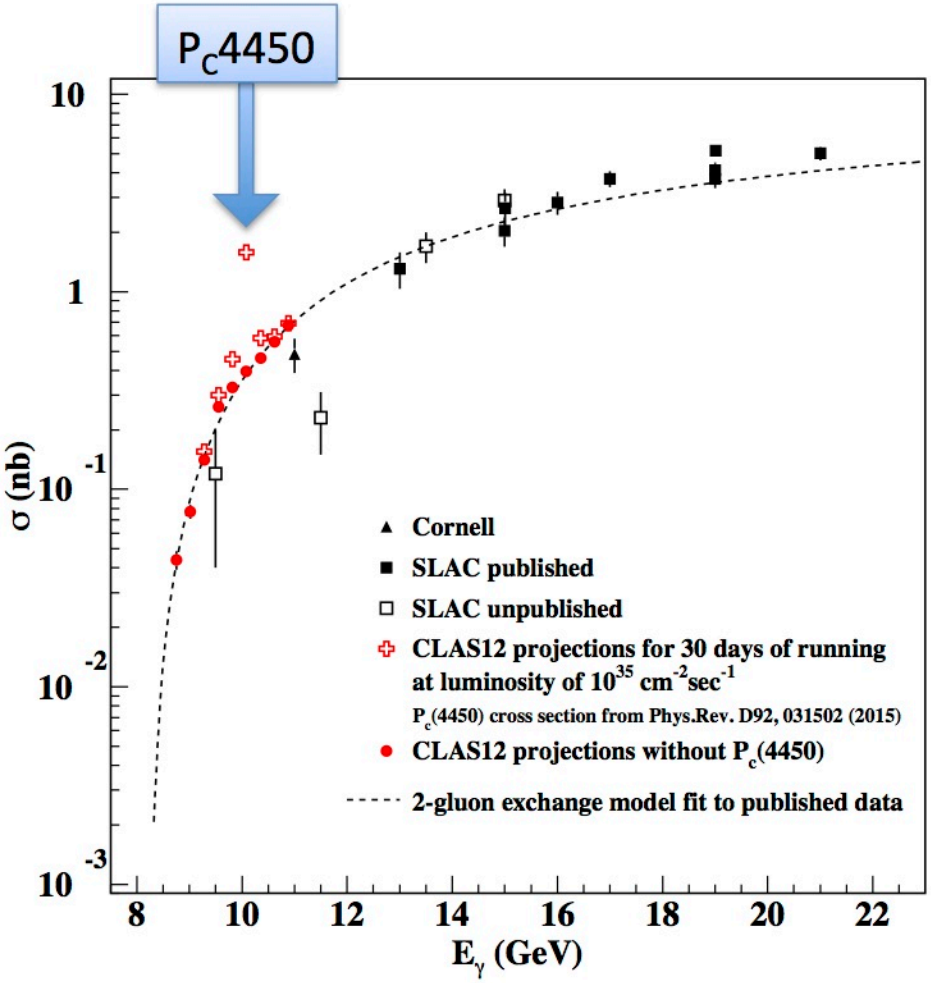
- Theoretical uncertainty is connected with the unknown partial wave decomposition of the pentaquark decay
- Maximum cross section (higher allowed partial wave only)
- Minimum cross section (lower allowed partial wave only)

CLAS12 expected results

- From the two gluon exchange prediction for cross section, we expect total of 45 J/ψ detected per day in the whole energy range
- Expected total number of P_C4450 pentaquarks 98 per day

Compared to -

- The Hall-C E12-16-007 with the same cross section formalism will detect 70 pentaquarks per day
- The Hall-A experiment E12-12-006 with future SoLID detector expects ~42 J/ψ per day
- With current luminosity Hall-D Gluex experiments expects 5-10 J/ψ per day



$J/\psi\, N$ photoproduction off deuterium as a test for exotic baryons

Marek Karliner[a†] **and Jonathan L. Rosner**[b‡]

[a] *School of Physics and Astronomy*
Raymond and Beverly Sackler Faculty of Exact Sciences
Tel Aviv University, Tel Aviv 69978, Israel

[b] *Enrico Fermi Institute and Department of Physics*
University of Chicago, 5620 S. Ellis Avenue, Chicago, IL 60637, USA

ABSTRACT

We extend a previous study of photoproduction of exotic baryon resonances to the reaction $\gamma + d \to J/\psi + n + p$, which permits simultaneous investigation of the reactions $\gamma + p \to P_c^+ \to J/\psi\ p$ (n spectator) and $\gamma + n \to P_c^0 \to J/\psi\ n$ (p spectator). Here P_c^+ is an exotic baryon with quark content $c\bar{c}uud$, and P_c^0 is its hypothetical isospin partner with quark content $c\bar{c}ddu$. We find: (1) The cross section for $J/\psi\, n$ photoproduction should be equal to that for $J/\psi\, p$ photoproduction if these processes are dominated by the photon coupling to a $c\bar{c}$ pair. In that case the two processes are equal by isospin reflection. (2) If a P_c^+ candidate is a genuine $c\bar{c}uud$ resonance, its isospin partner $P_c^0 = c\bar{c}ddu$ should have the same mass (again by isospin reflection). (3) In the absence of Fermi motion, the cross section for photoproduction of P_c off a deuteron should be nearly the sum of two equal cross sections: $\sigma(\gamma p \to P_c^+)$ (spectator n) and $\sigma(\gamma n \to P_c^0)$ (spectator p). (4) The effects of Fermi motion are significant. They include smearing, form-factor suppression and offshellness. The upshot is that the resonance is significantly wider and the peak cross section off a deuteron is expected to be considerably less than twice that in γp.

PACS codes: 12.39.Hg, 12.39.Jh, 14.20.Pt, 14.40.Rt

Two candidates for baryon resonances composed of four quarks and an antiquark have been reported by the LHCb Collaboration [1], challenging the conventional picture of baryons as exclusively three-quark states. The new states are a broad one with mass $4380 \pm 8 \pm 29$ MeV, width $205 \pm 18 \pm 86$ MeV, and statistical significance 9σ, and a narrower one with mass $4449.8 \pm 1.7 \pm 2.5$ MeV, width $39 \pm 5 \pm 19$ MeV, and statistical significance 12σ. They are seen decaying into $J/\psi\, p$, suggesting that their quark content is

[†] marek@proton.tau.ac.il
[‡] rosner@hep.uchicago.edu

$J/\psi\, N$ photoproduction off deuterium as a test for exotic baryons

Marek Karliner[a†] **and Jonathan L. Rosner**[b‡]

[a] *School of Physics and Astronomy*
Raymond and Beverly Sackler Faculty of Exact Sciences
Tel Aviv University, Tel Aviv 69978, Israel

[b] *Enrico Fermi Institute and Department of Physics*
University of Chicago, 5620 S. Ellis Avenue, Chicago, IL 60637, USA

Included in J/ψ from Deuteron LOI to recent PAC

Proposal development timeline depending upon future CLAS12 findings

This is a direct result from a conversation with Marek at this workshop last year.

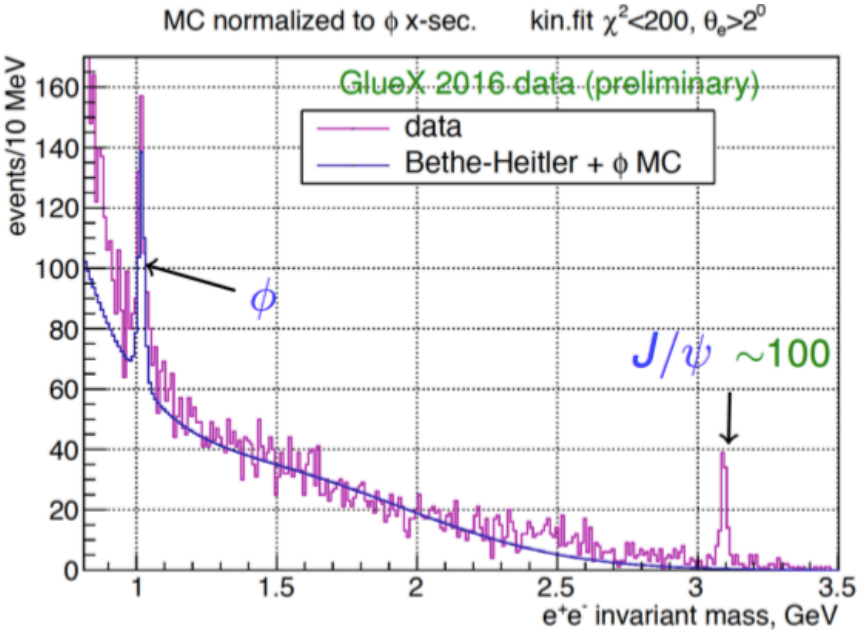
$\sigma(\gamma n \to P_c^o)$ (spectator p). (4) The effects of Fermi motion are significant. They include smearing, form-factor suppression and offshellness. The upshot is that the resonance is significantly wider and the peak cross section off a deuteron is expected to be considerably less than twice that in γp.

PACS codes: 12.39.Hg, 12.39.Jh, 14.20.Pt, 14.40.Rt

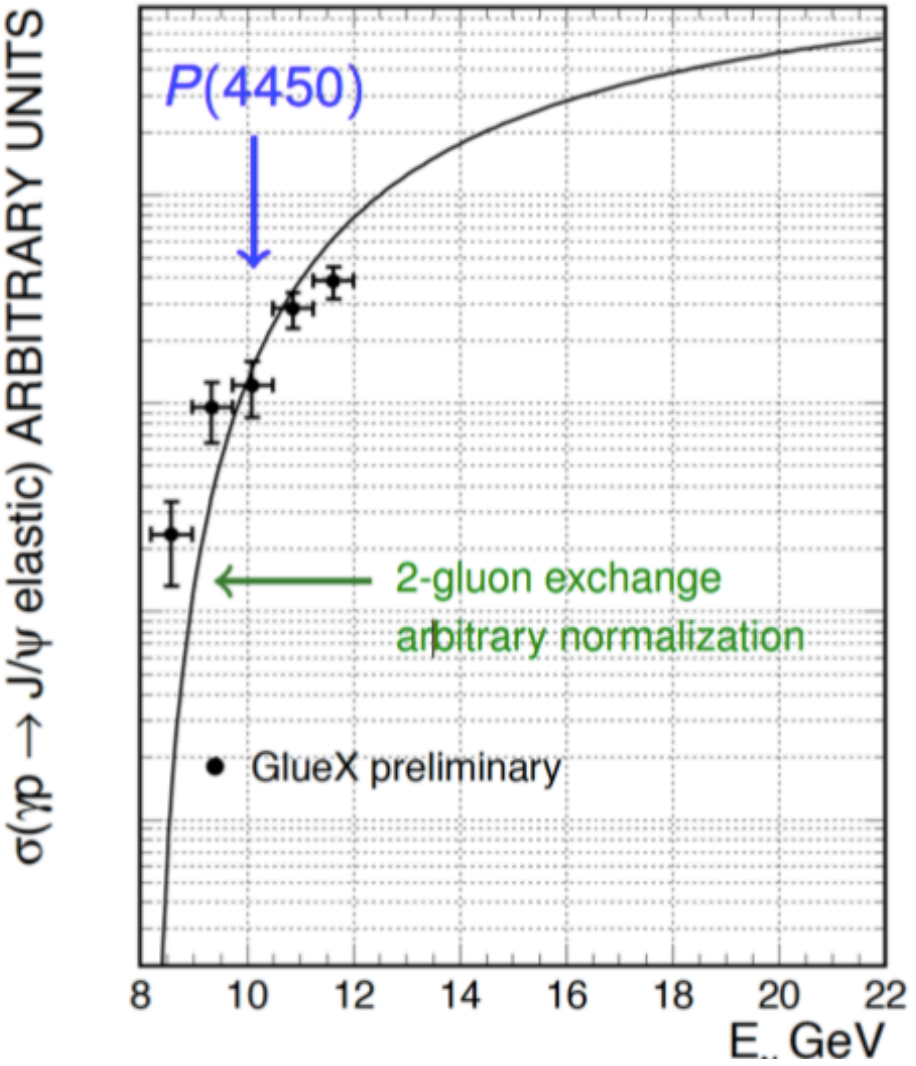
Two candidates for baryon resonances composed of four quarks and an antiquark have been reported by the LHCb Collaboration [1], challenging the conventional picture of baryons as exclusively three-quark states. The new states are a broad one with mass $4380 \pm 8 \pm 29$ MeV, width $205 \pm 18 \pm 86$ MeV, and statistical significance 9σ, and a narrower one with mass $4449.8 \pm 1.7 \pm 2.5$ MeV, width $39 \pm 5 \pm 19$ MeV, and statistical significance 12σ. They are seen decaying into $J/\psi\, p$, suggesting that their quark content is

[†] marek@proton.tau.ac.il
[‡] rosner@hep.uchicago.edu

Hall-D GlueX Status



All 2016 data: exclusive events pe+e, the e+e- PID using the electromagnetic calorimeters BCAL and FCAL. Kinematic fit with the beam energy from the tagger



Summary

Resolving between the models and clarifying the nature of the discovered hidden-charm pentaquarks requires further experimental studies

Beside the study of gluonic form factors of the proton and testing the models for J/ψ photoproduction mechanism near threshold, CLAS12 has a unique opportunity to detect pentaquarks. The 2 states would be observed as s-channel resonances and properties studied via PWA

Peak XSecs may also allow for searches of similar states such as $P_c \rightarrow J/\psi p\pi$ and $J/\psi p\pi\pi$. Prominent if baryocharmonium and would disfavour molecular models (expect charmed baryon and meson)

Any observation of P_c peaks in γp XSec would confirm the resonance nature and rule out any singularities/cusps

Possible searches for P_c isospin partner $P_c \rightarrow J/\psi n$