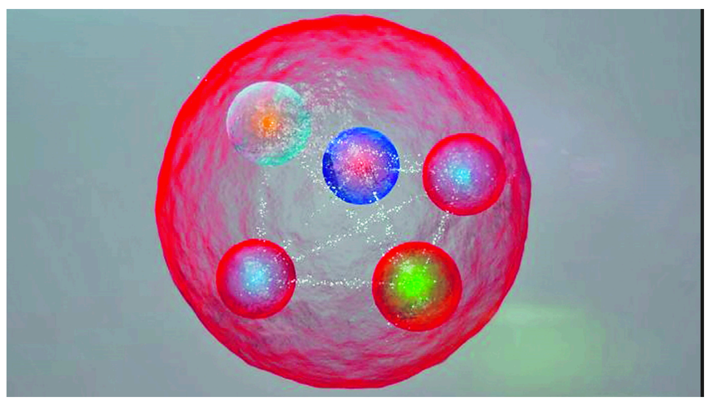
Jefferson Lab
Thomas Jefferson National Accelerator Facility

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

Valery Kubarovsky

Jefferson Lab



CLAS Collaboration Meeting
October 4, 2017

U.S. DEPARTMENT OF ENERGY
Office of Science

Outline

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

Accepted by PAC45

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

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Submitted to PAC45

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

Spokespersons:

- Jefferson Lab Valery Kubarovsky Stepan Stepanyan
- INFN Marco Battaglieri, Andrea Celentano, Raffaella De Vita

The proposal was signed by **124** scientists from **32** Institutions

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Approved J/Ψ Photoproduction Experiments at Jlab

- PR12-12-001: Hall-B, untagged technique
- PR12-12-006: Hall-A
- PR12-16-007: Hall-C (Search for the LHCb pentaquarks)

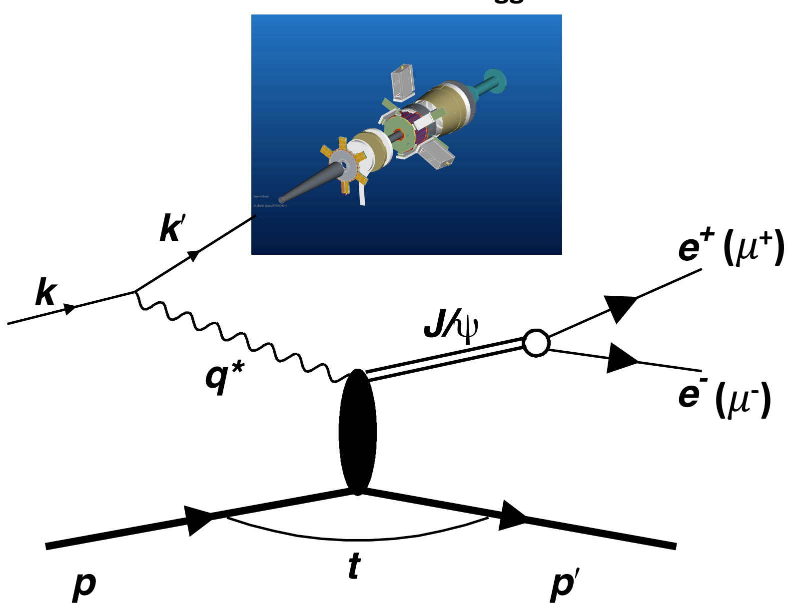
New proposal – JLAB PAC45

- Extends measurements of approved CLAS12 experiment E12-12-001 by including $J/\psi \rightarrow \mu^+\mu^-$ decay mode
- Will study pentaquarks with hidden charm using tagged (E12-12-005, MesonX) and untagged (E12-12-001) photoproduction with CLAS12

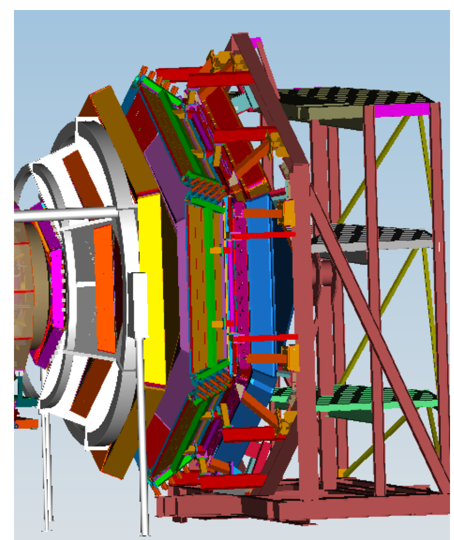
Photoproduction with CLAS12

- Untagged photoproduction – E12-12-001 CLAS12 analysis: $ep \to (e')p'l^+l^-;\ l = e, \mu$
  - 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



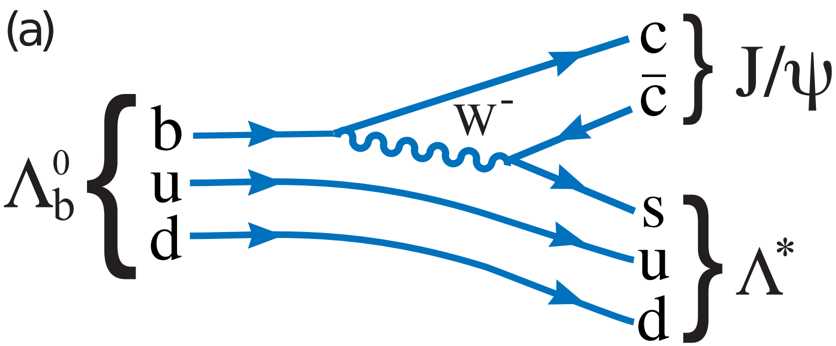
CLAS12 Forward Detector



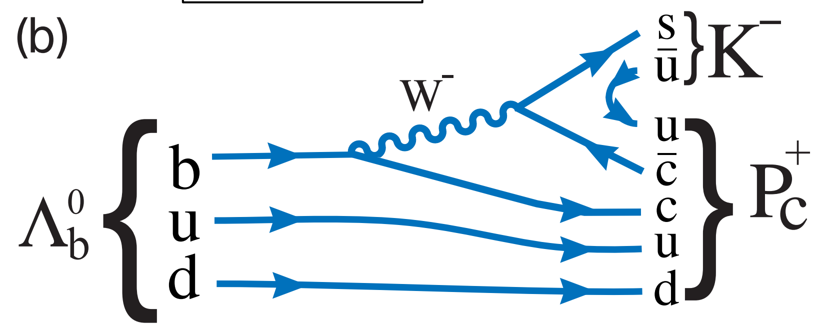
LHCb:
Background and Signal

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

$\boxed{\Lambda^0_b \to J/\psi\Lambda^*}$



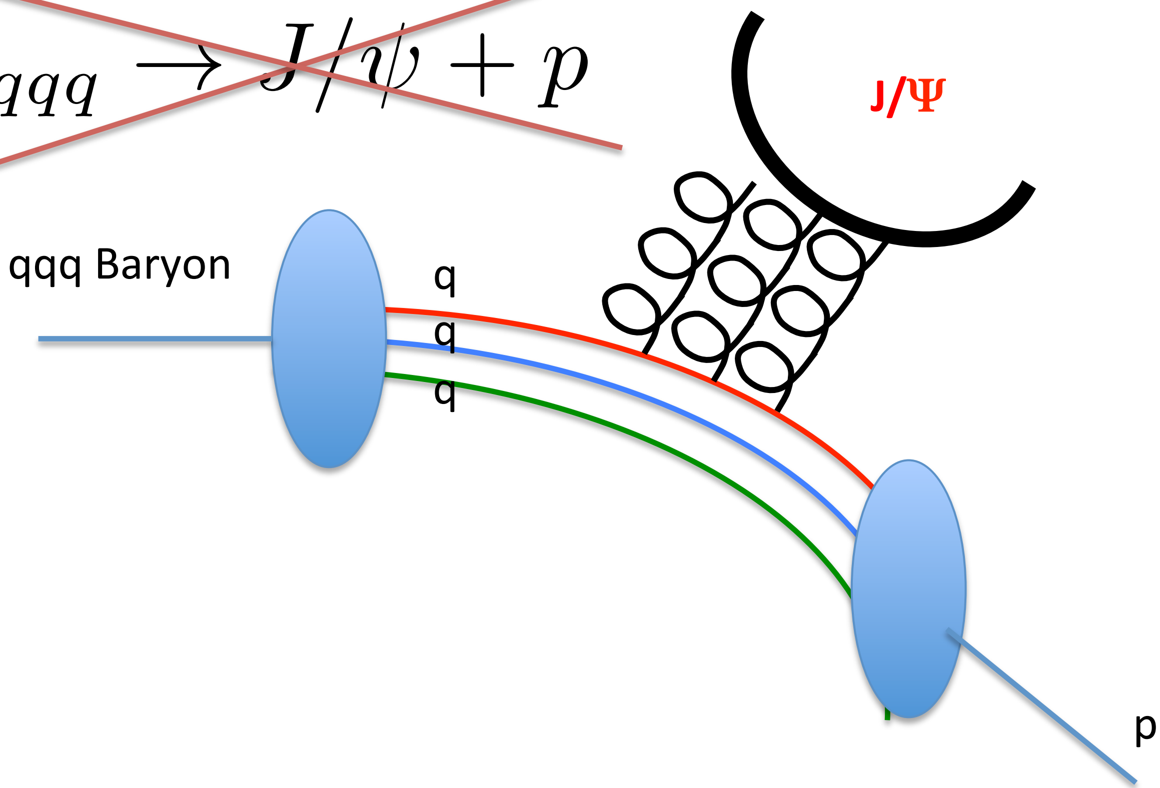
$\boxed{\Lambda^0_b \to P_c K^-}$



- LHCb accidentelly found a signal in the J/ψp invariant mass spectrum
- PRL LHCb paper: In practice baryons decaying strongly into J/ψ p must have a minimal quark content of **$c\bar{c}uud$**, and thus are charmonium-pentaquarks.
- It is the consequence of the Okuba–Zweig–Iizuka rule.

Okubo Zweig Iizuka (OZI) rule

$$\cancel{B_{qqq} \to J/\psi + p}$$



The decay of ordinary baryons to J/Ψ+p is highly suppressed by OZI rule

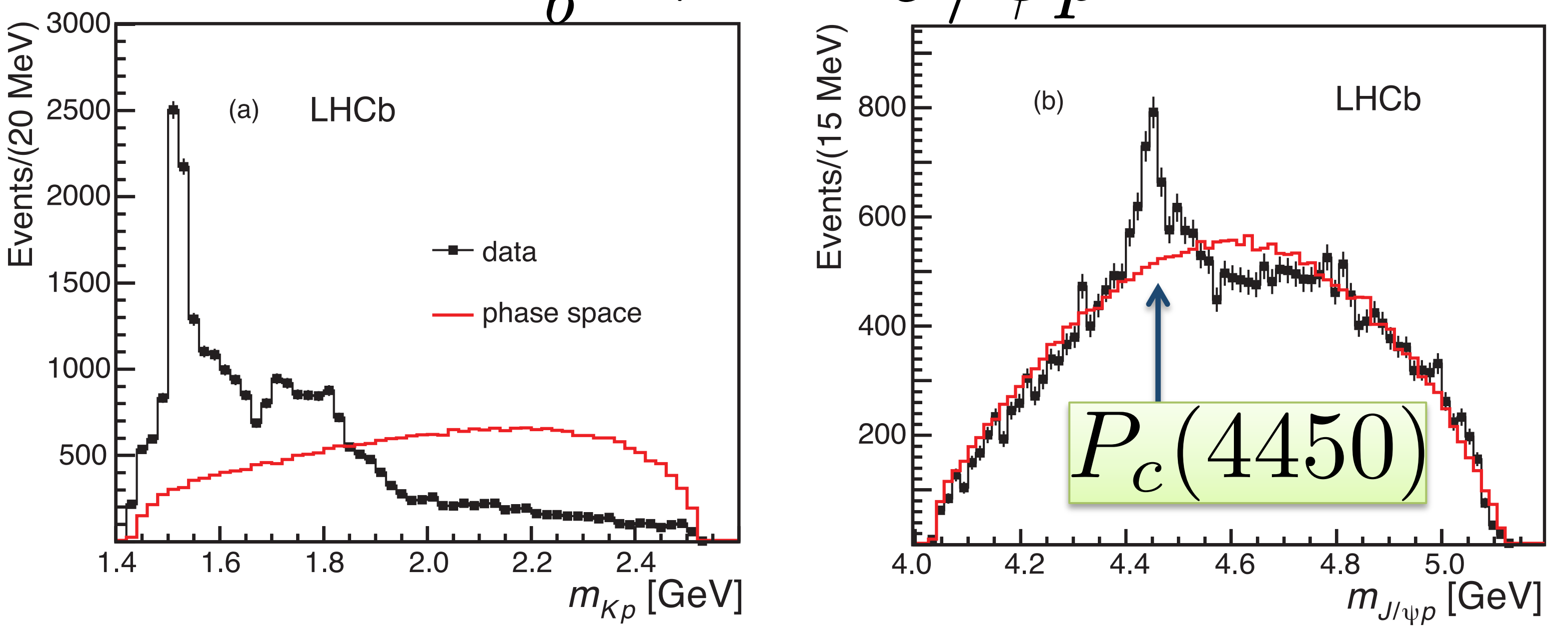
Claim of two pentaquark states

$P_c(4380)$ 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.

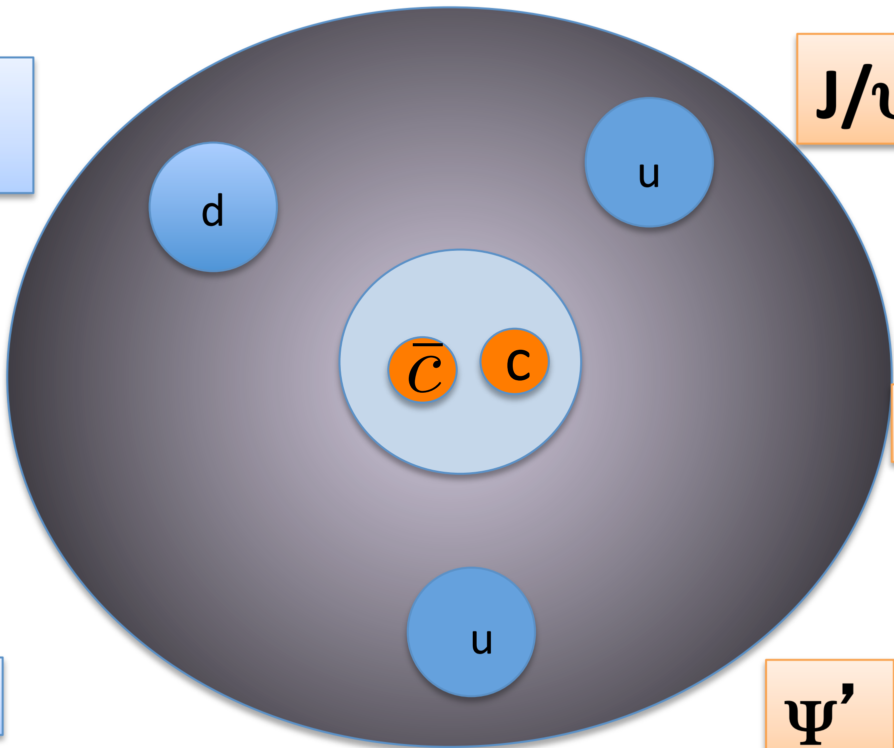
$$\Lambda_b^0 \to K^- J/\psi p$$



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

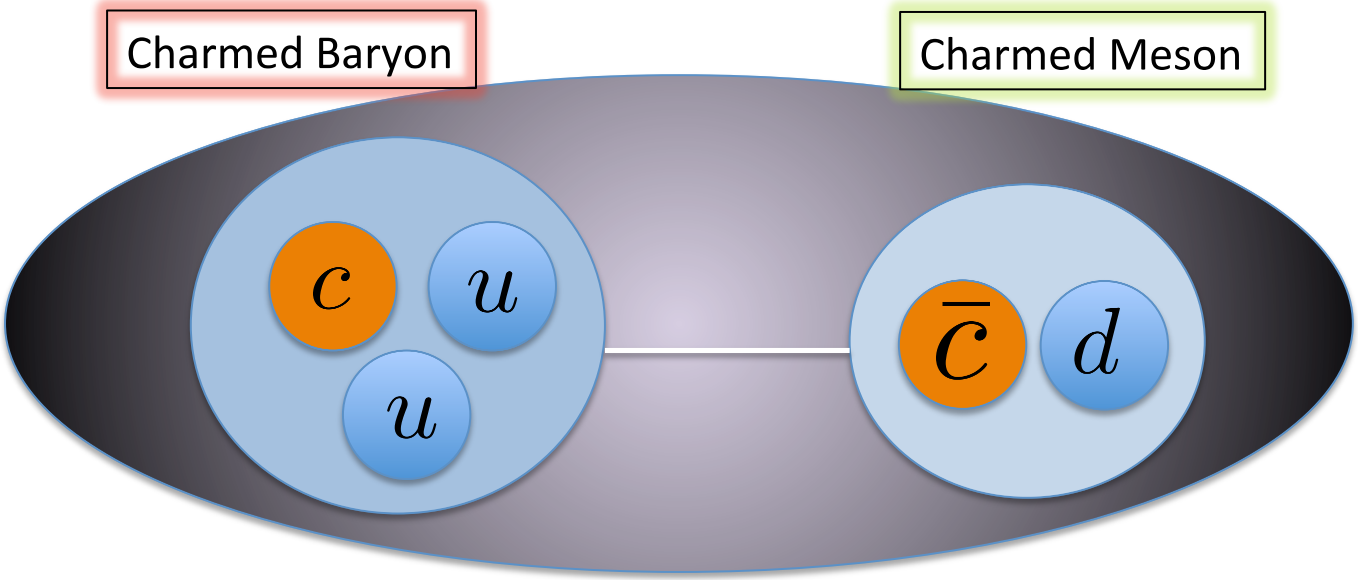
U.-G. Meisner
and J. A. Oller,
arXiv:1507.07478

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) $\Gamma(P_5\text{->}J/\psi\text{+}p)$=11 MeV.

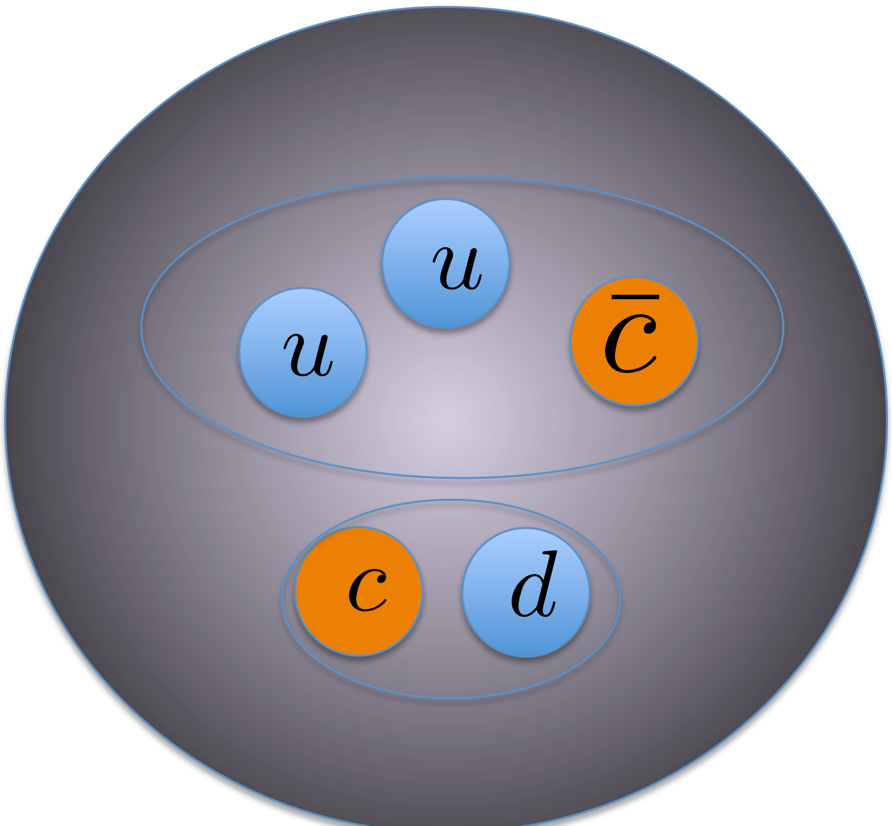
Hadronic molecule



- 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

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.

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)

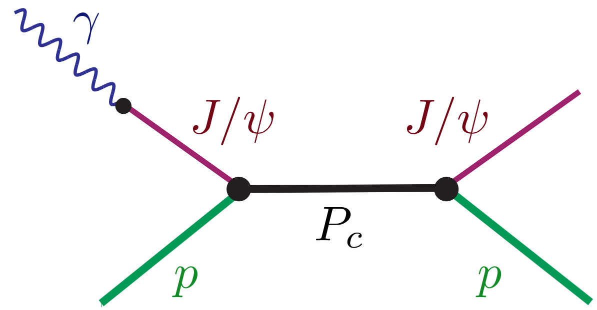
Hidden-Charm Pentaquark Models

- 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 Λ_b ->J/ψ 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].

Pentaquark photoproduction

- It was shown that the vector dominance model works for the s-channel photoproduction of hidden-charm pentaquark.



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

$$\boxed{\sigma \sim Br^2(P_c \to J/\psi p)}$$

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

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

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

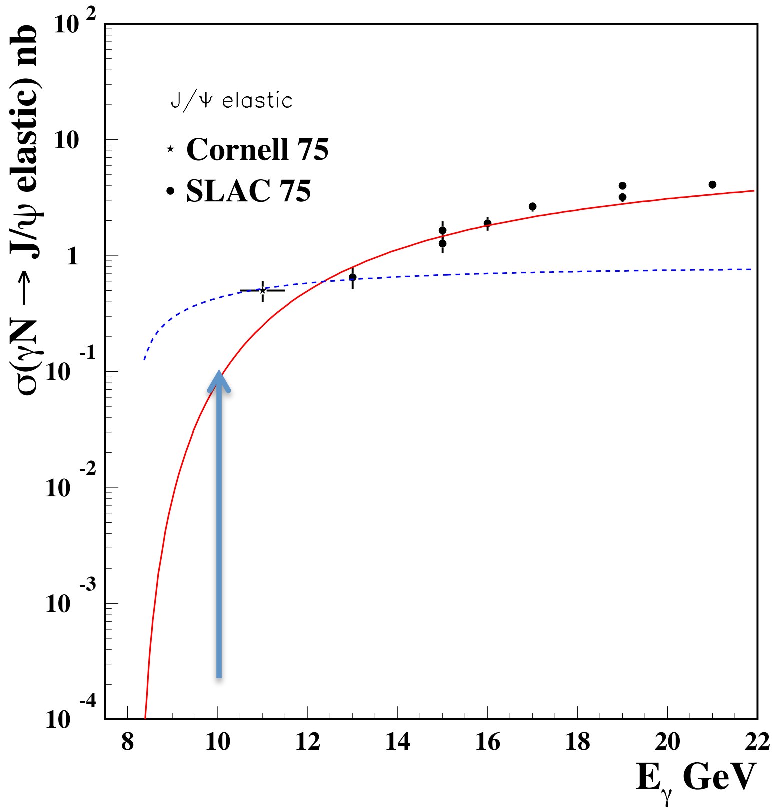
$$\boxed{\sigma(W) \sim \frac{\Gamma^2/4 \cdot Br^2(P_c \to J/\psi + p)}{(W-M_c)^2 + \Gamma^2/4}}$$

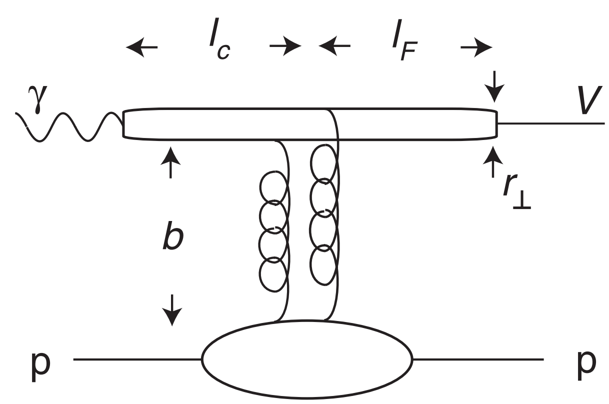
- Theoretical uncertainty is connected with the unknown partial wave decomposition of the pentaquark decay
- Maximum cross section (higher allowed partial wave only)
- Minimum cross section (lower allowed partial wave only)

V.K. and M. B. Voloshin, Phys.Rev. D92 (2015) 3, 031502, arXiv:1508.00888.

hep-ph/0010343, Brodsky et al (2000)

- J/ψ photoproduction cross section is around **0.1 nb** in the region of expected pentaquarks



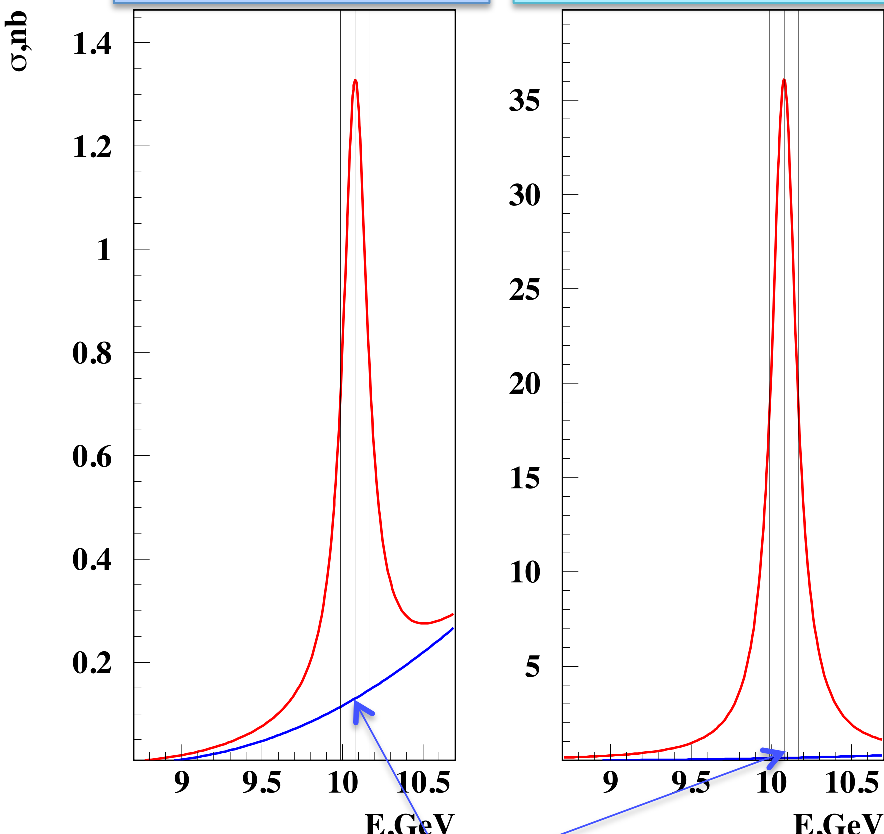


P_C1450 Photoproduction cross section

Lower allowed partial wave only

Higher allowed partial wave only

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



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

$$\sigma(W) \sim \frac{\Gamma^2/4 \cdot Br^2(P_c \to J/\psi + p)}{(W - M_c)^2 + \Gamma^2/4}$$

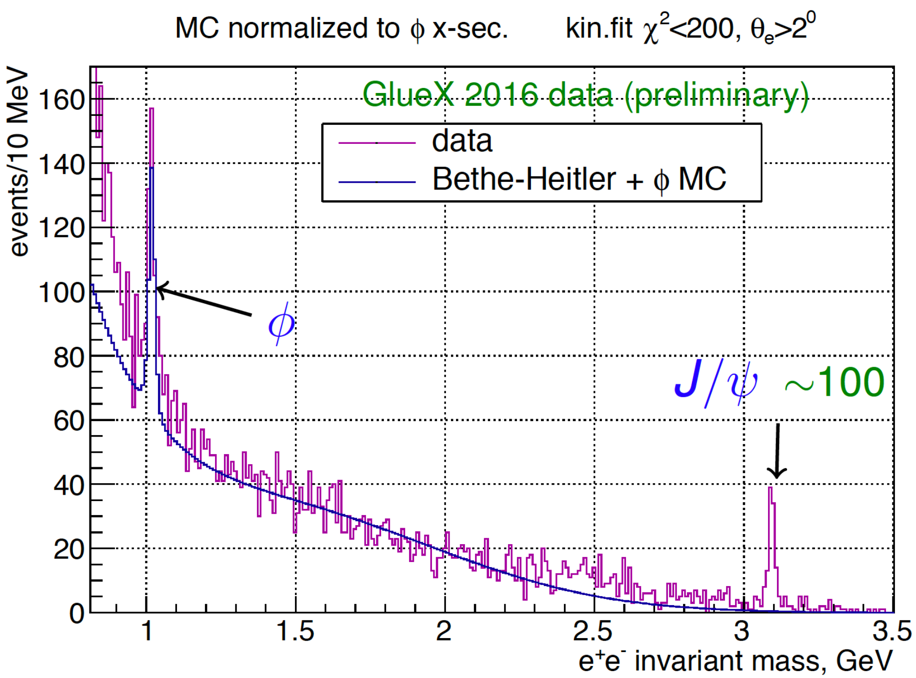
The S/B ratio is **extremely good** even for such small BR=1%

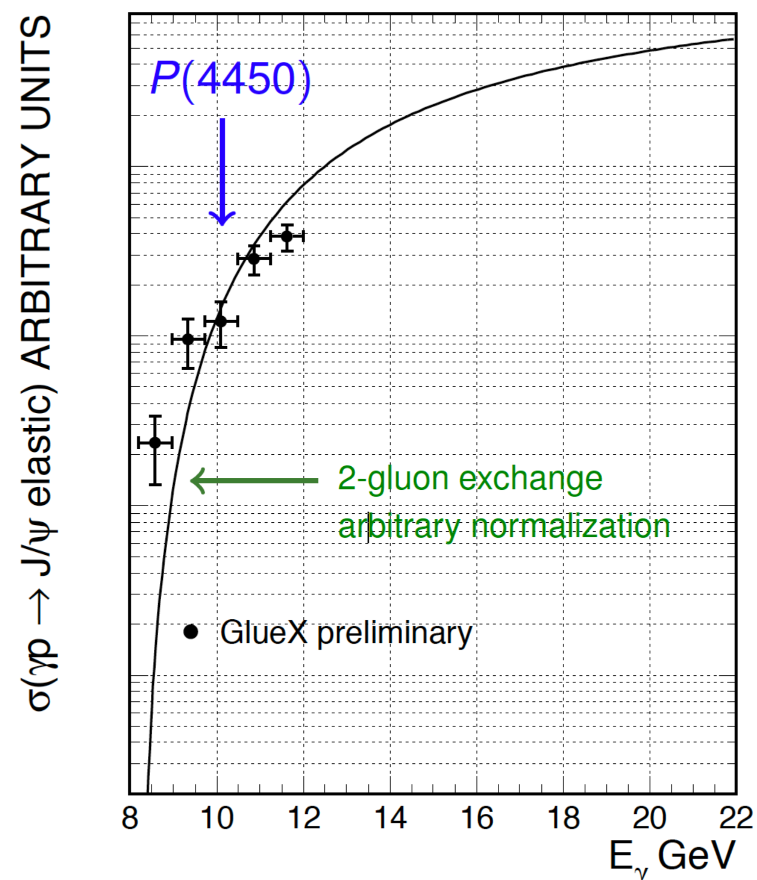
BR(P_C->J/ψ+p)=1% is very conservative. CLAS12 can confirm and study the pentaquark properties or rise a question about the existence of the LHCb pentaquark.

V.K. and M. Voloshin, arXiv 1609.00050 (2016)

Hall-D Gluex results

- 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
- Planned measurements, after adding the 2017 Spring data will limit the pentaquark yield (the mass resolution 6 MeV/c^2)



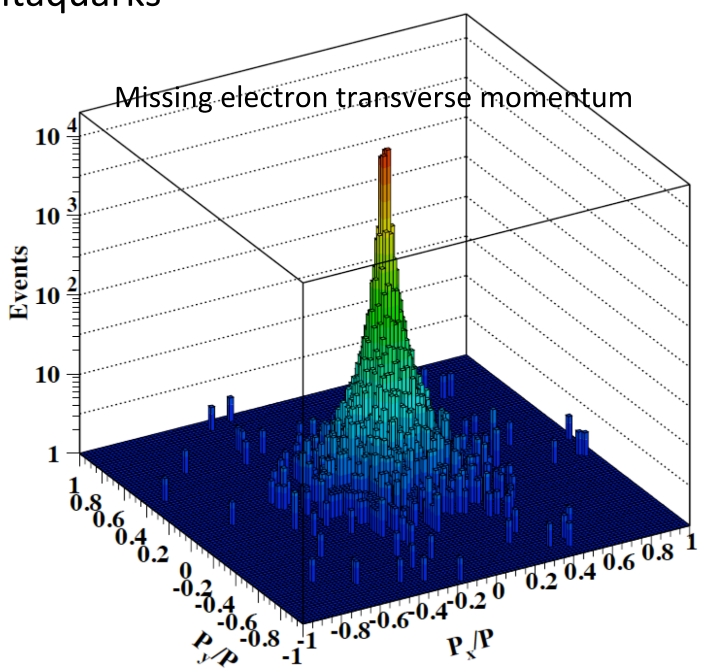


Note how clean the J/ψ signal is

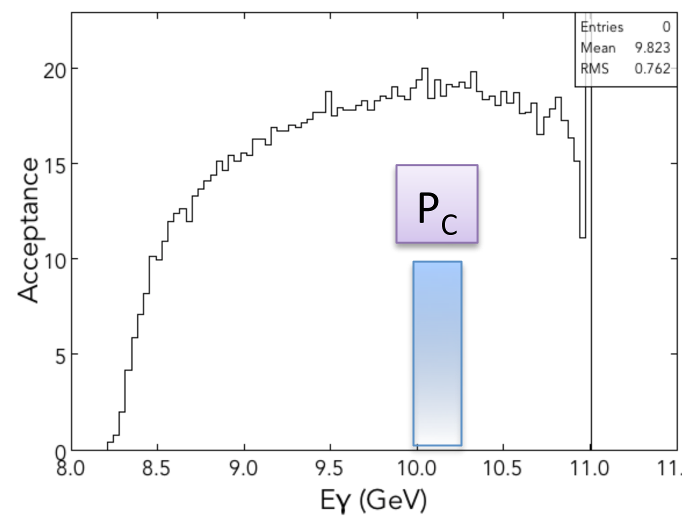
CLAS12 performance – untagged photoproduction

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

- 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

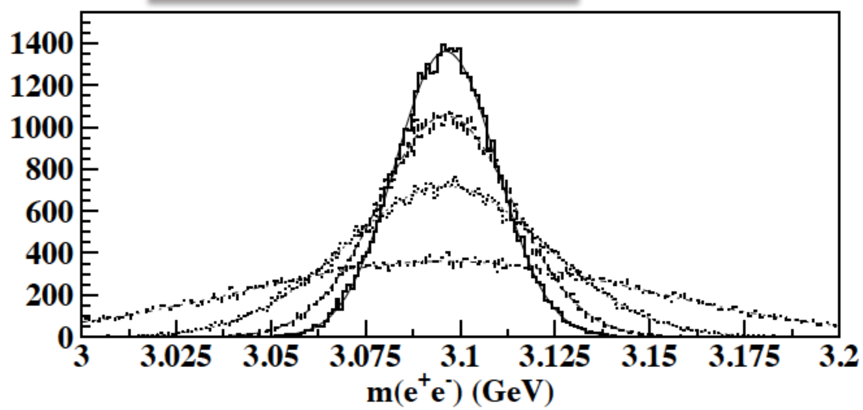


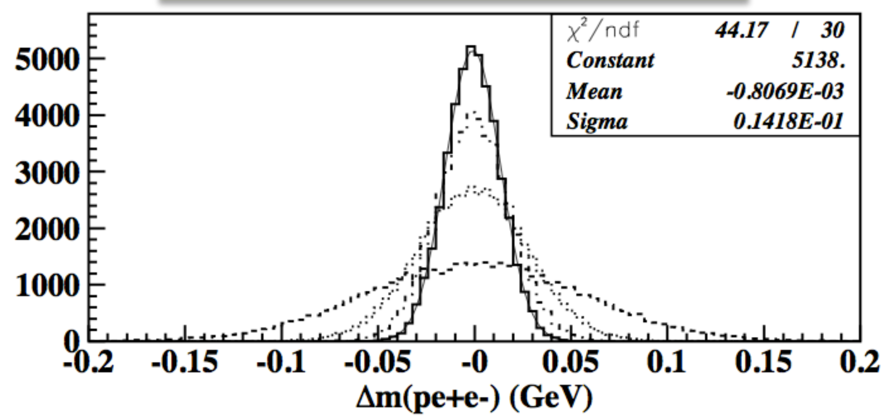
Mass resolutions

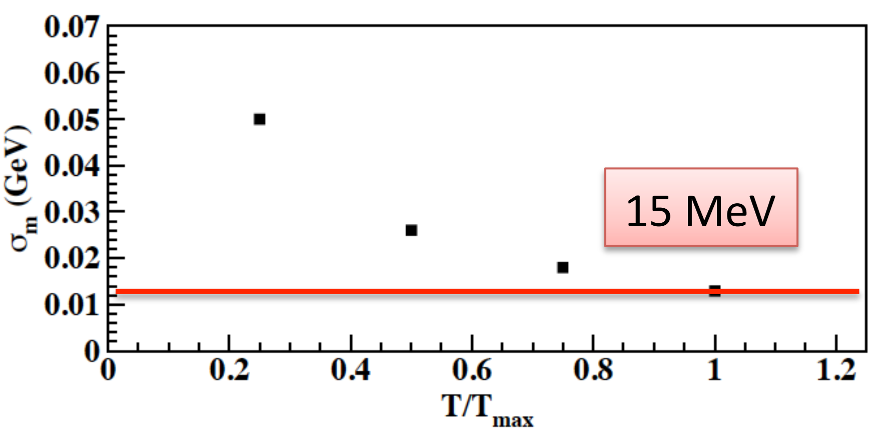
- J/ψ will be identified in the lepton pair invariant mass analysis
- Charmed pentaquarks, $P_c(4380)$ and $P_c(4450)$, will be identified in the invariant mass of $\boxed{M(p'l^+l^-);\ l = e, \mu}$

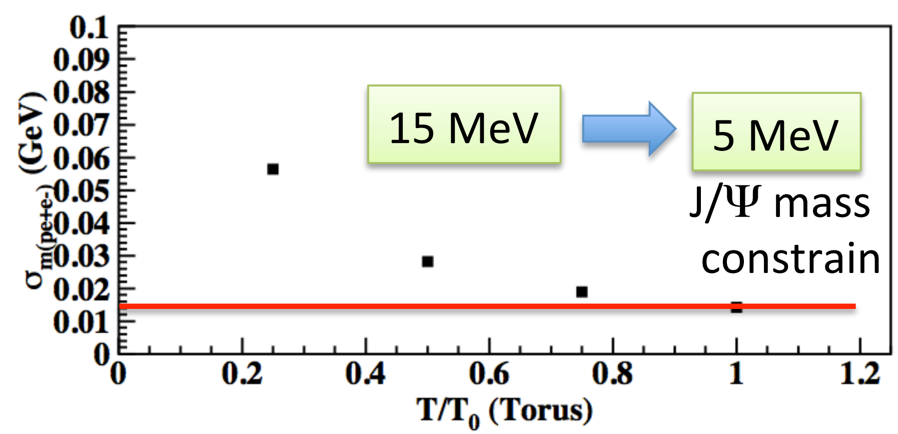
J/ψ mass resolution

Pentaquark mass resolution









CLAS12 performance – tagged photoproduction

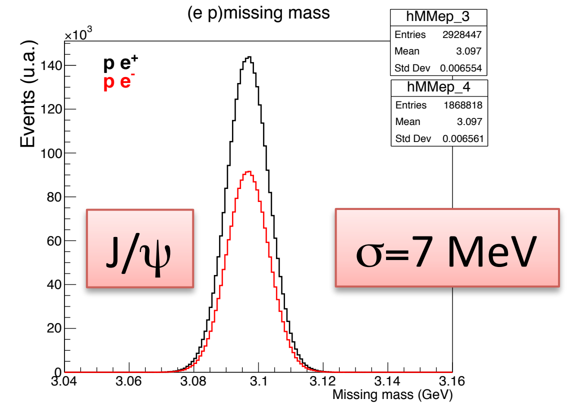
- About x10 lower photon flux, but …
- Multiple final states to measure J/ψ photoproduction
- Excellent mass resolutions:
  - J/ψ as sharp peak either in the invariant mass of decay leptons ($\Delta M \sim 15$ MeV) or in the electron-proton missing mass ($\Delta M \sim 7$ MeV)
  - Pentaquarks will be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

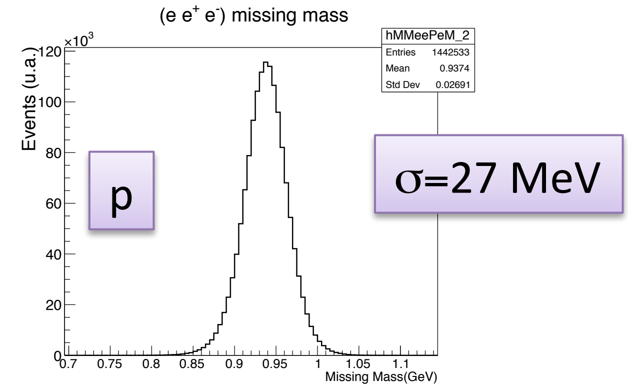
$$ep \rightarrow e'p'l^{+(-)},\ l^{-(+)};\ l = e, \mu$$

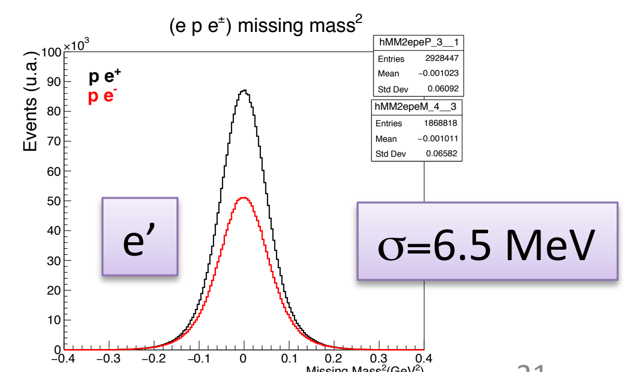
Detection efficiency ~28%

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

Detection efficiency ~18%

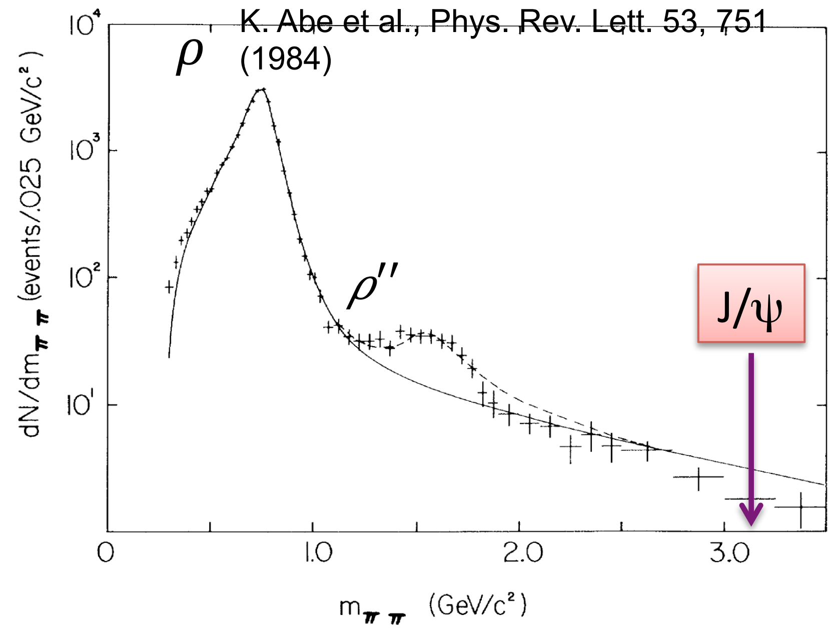


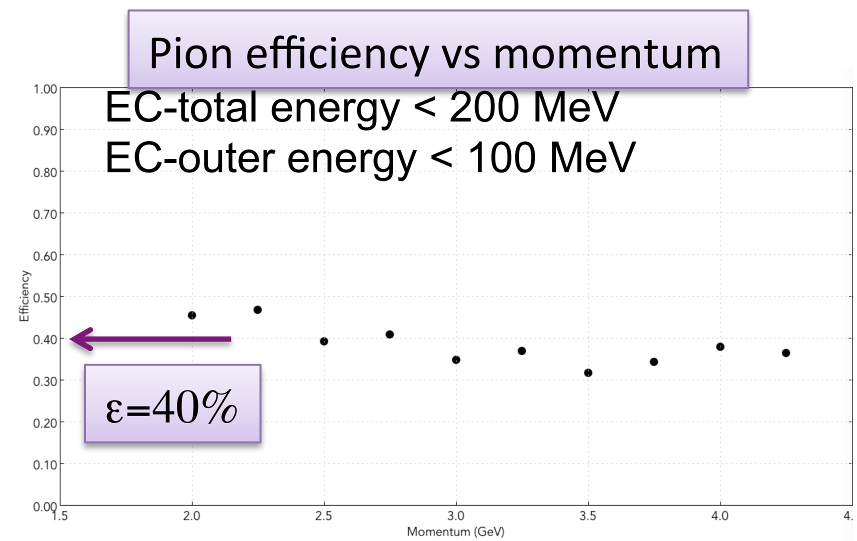




Muon final state

- 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





J/ψ Triggers

- The final states that will have an electron or a positron in CLAS12 FD will be a subset of events recorded using the CLAS12 standard electron trigger
- For final states with muons
  - two charged particles detected in CLAS12 FD with 0.3 – 3 GeV electron cluster in the FT
  - three charged particles in CLAS12 FD

Trigger #	Final state	Trigger setting	Expected trigger rate
1	$e'p'\mu^{\pm}$	Cluster in FT $\otimes$ 2-charged tracks in CLAS12 FD	4 kHz
2	$p'\mu^{+}\mu^{-}$	3-charged tracks in CLAS12 FD	2.5 kHz
3	$e'p'e^{\pm}$ $(e')e^{+}e^{-}$ $p'e^{+}e^{-}$	CLAS12 electron trigger	2 kHz
4	$e'p'l^{+}l^{-}$	MesonX trigger[a]	2.8 kHz

- Trigger4 is a subset of trigger 1
- Total trigger rate is about 8.5 kHz
- MIP in EC will decrease trigger1 by a factor of 2 and trigger2 by a factor of 4

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

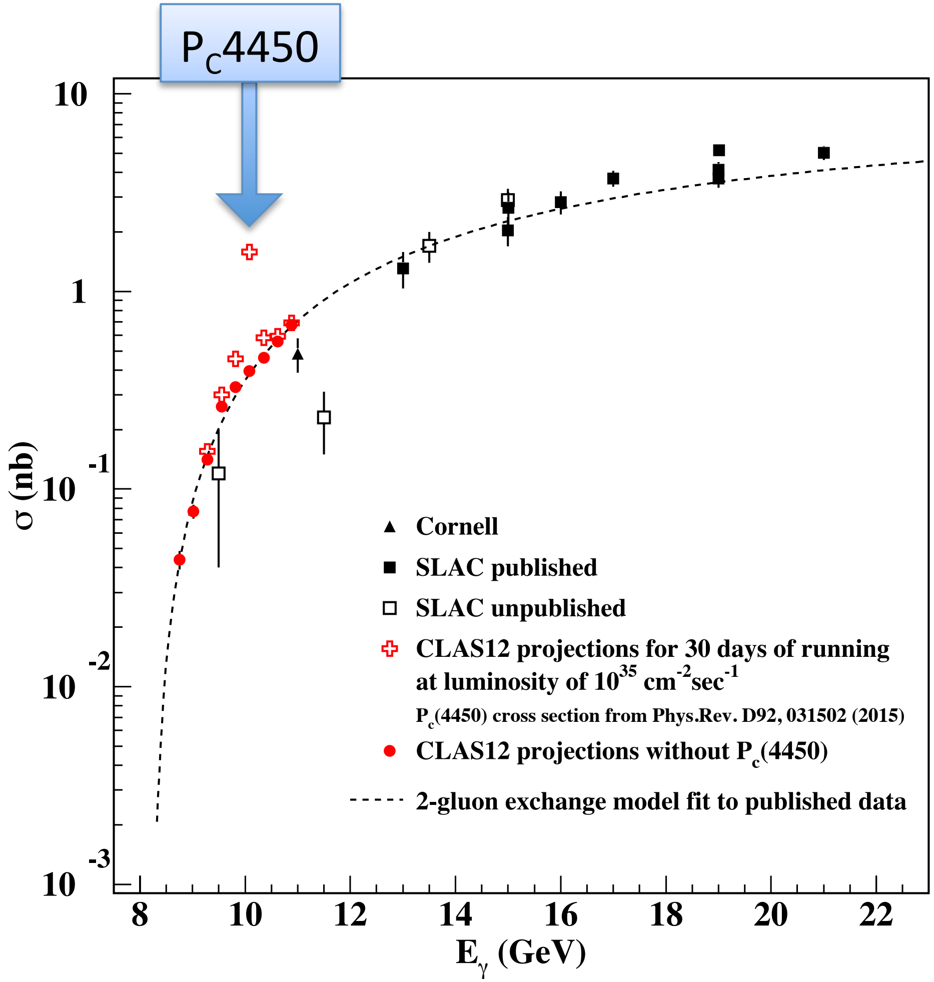
- Theoretical uncertainty is connected with the unknown partial wave decomposition of the pentaquark decay
- Maximum cross section (higher allowed partial wave only)
- Minimum cross section (lower allowed partial wave only)

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 rage
- 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



Conclusion

- Resolving between the models and clarifying the nature of the discovered hidden-charm pentaquarks requires further experimental studies.
- CLAS12 has a unique opportunity to detect pentaquarks. It will definitely help with the resolving between different models.
- Naturally, **any** observation of the P_c peaks in the γp cross section would strongly disfavor the interpretation in terms of 'accidental' singularities in the Λ_b decays.
- First preliminary data from the Hall-D Gluex experiment has been already presented.
- A new proposal extends measurements of approved CLAS12 experiment E12-12-001 by including $J/\psi \to \mu^+\mu^-$ decay mode and will study pentaquarks with hidden charm using tagged (E12-12-005, MesonX) and untagged (E12-12-001) photoproduction.