CLAS12 options for LHCb pentaquark searches/studies

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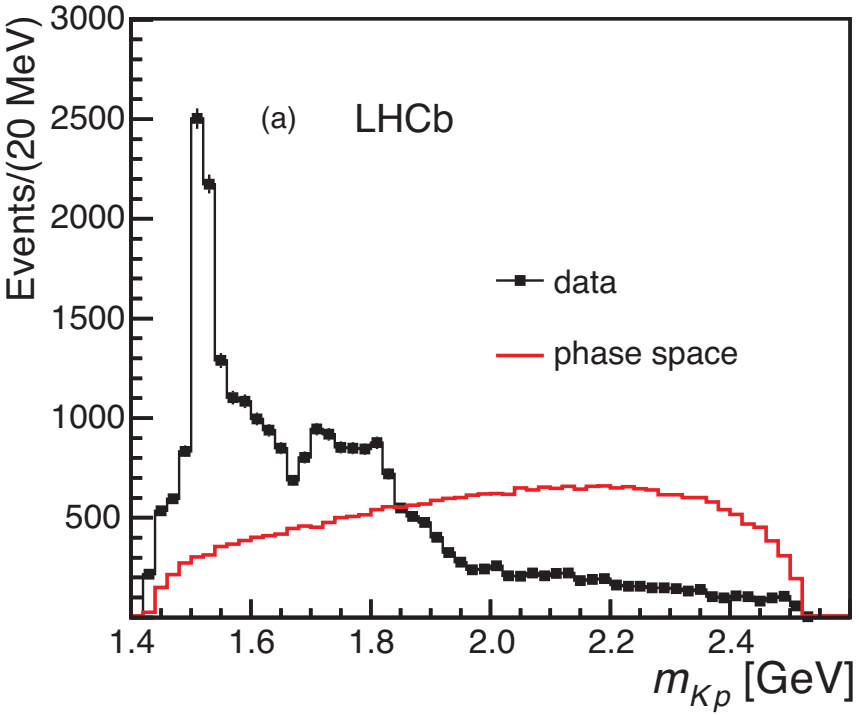
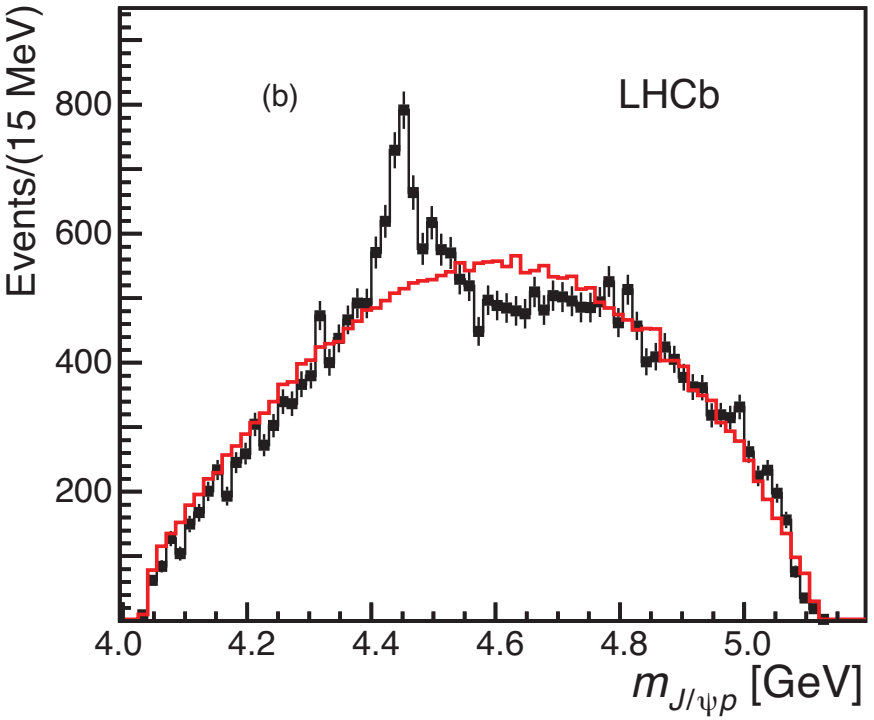
CLAS Collaboration meeting
JLAB, October 21-23, 2015

- LHCb pentaquarks in Λ_b^0 decay
- Photoproduction of pentaquarks
- J/ψ photoproduction near threshold
- CLAS12 options
  - E12-12-001
  - E12-11-005
  - Electroproduction of $\mu^+\mu^-$
- Summary

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

- The data sample corresponds to an integrated luminosity of 3 fb^{-1} acquired with the LHCb detector from 7 (1 fb^{-1}) and 8 TeV (2 fb^{-1}) pp collisions
- Events are triggered by a J/ψ to $\mu^+\mu^-$ decay, with P_T>500 MEV

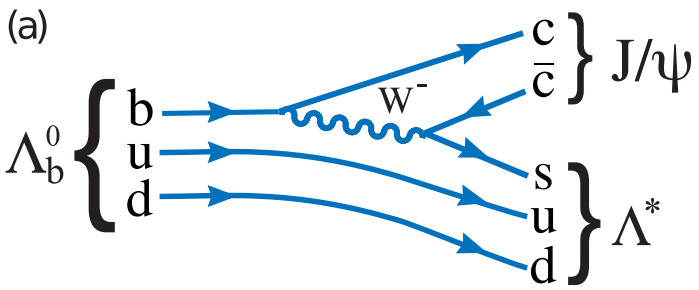


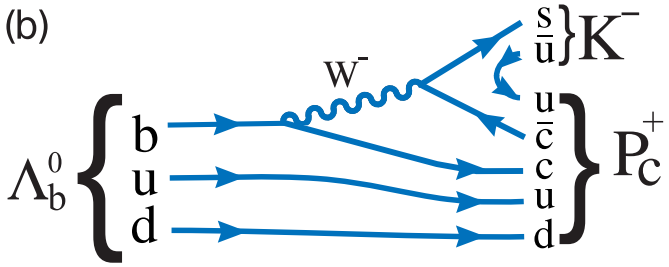


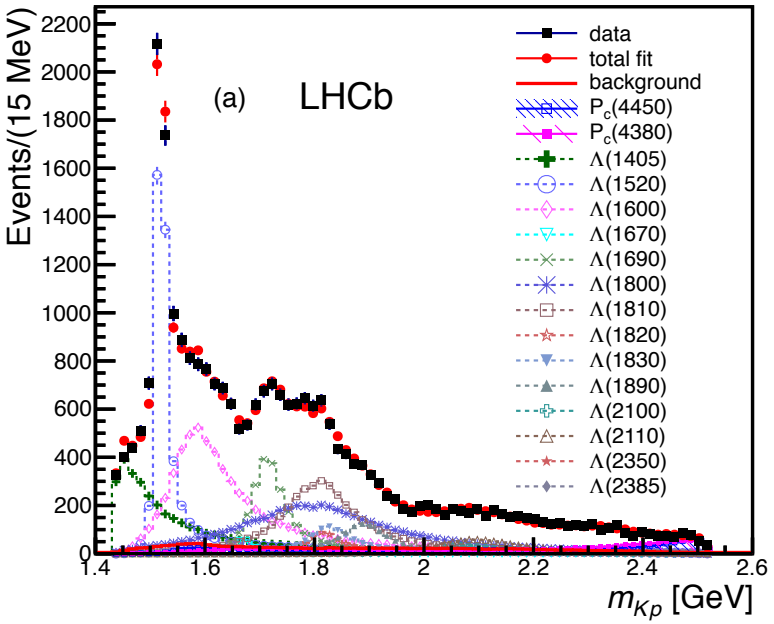
R. Aaij et al. [LHCb Collaboration], arXiv:1507.03414 [hep-ex].

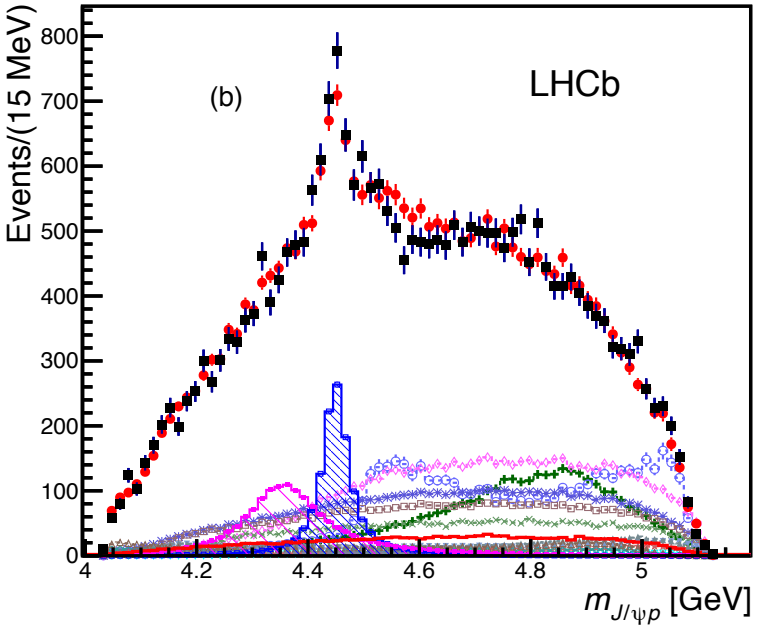
Fitted resonances in pK^- and pJ/ψ

- Fit to the data with a model that contains 14 Λ^* states listed by PDG did not give a satisfactory description of the data
- A 2 new states that decay to pJ/ψ were needed to describe the data







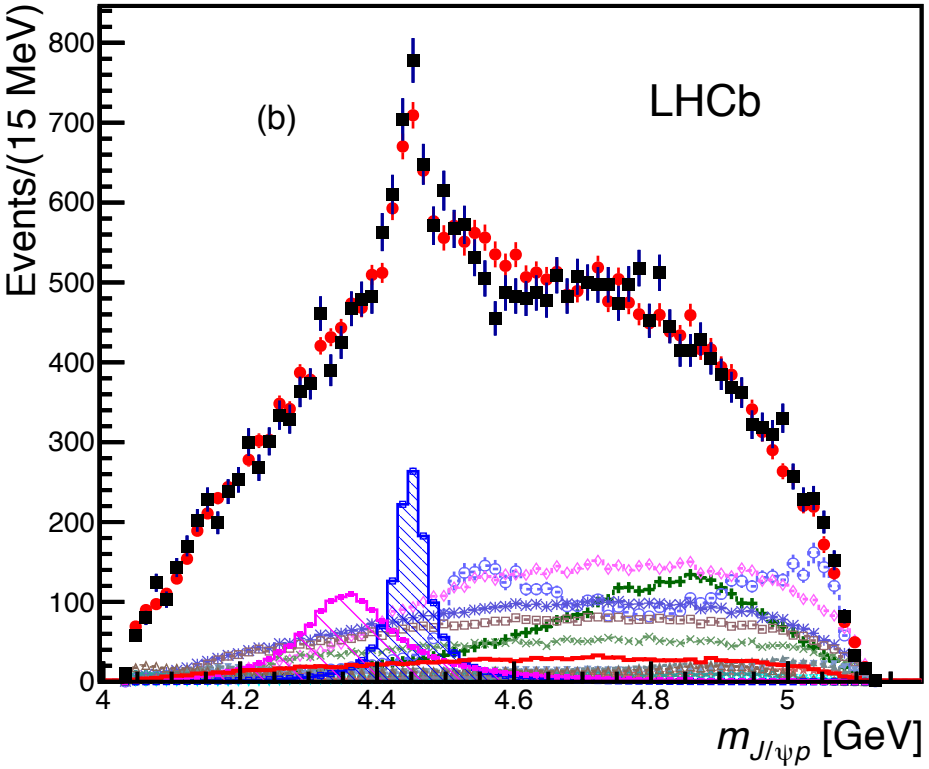


New states in pJ/ψ final state

- Amplitude analysis has been performed with two interfering modes of Λ_b^0 decay:

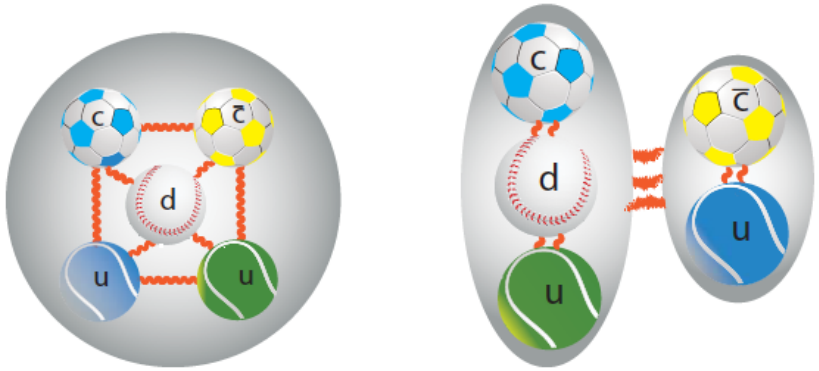
$$\Lambda_b^0 \to \Lambda^* J/\psi \qquad \Lambda_b^0 \to K^- P_c^+$$

- Two exotic states, must be $c\bar{c}uud$ 5-quark states, have been extracted
- The significance of each of these resonances is more than 9σ.
- The masses, widths, and spin-parity assignments of P_c^+
  - M_-=4380±8±29 MeV, Γ_-=205±18±86 MeV, J^P=3/2$^-$
  - M_+=4449.8±1.7±2.5 MeV, Γ_+=39±5±19 MeV, J^P= 5/2$^+$.



R. Aaij et al. [LHCb Collaboration], arXiv:1507.03414 [hep-ex].

Interpretation of new states



Charmed Baryon and anti-charmed meson 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
- U.-G. Meiner and J. A. Oller,, arXiv:1507.07478. For P(4550) $\chi_{c1}p$
- A. Mironov and A. Morozov, arXiv:1507.04694. Is NOT a molecule

$$\bar{D}^{*}\Sigma_{c} - \bar{D}^{*}\Sigma_{c}^{*}$$

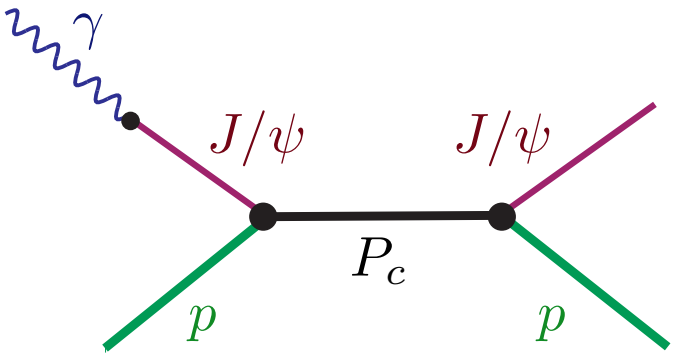
A resonance state or reflection:

- F.-K. Guo, U.-G. Meiner, W. Wang, and Z. Yang, arXiv:1507.04950; Dominant decay to $\chi_{c1}p$ if real
- M. Mikhasenko, arXiv:1507.06552. Possible reflection in the complicated decay chain

Need independent verification with a different production mechanism

Pentaquark photo-production

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

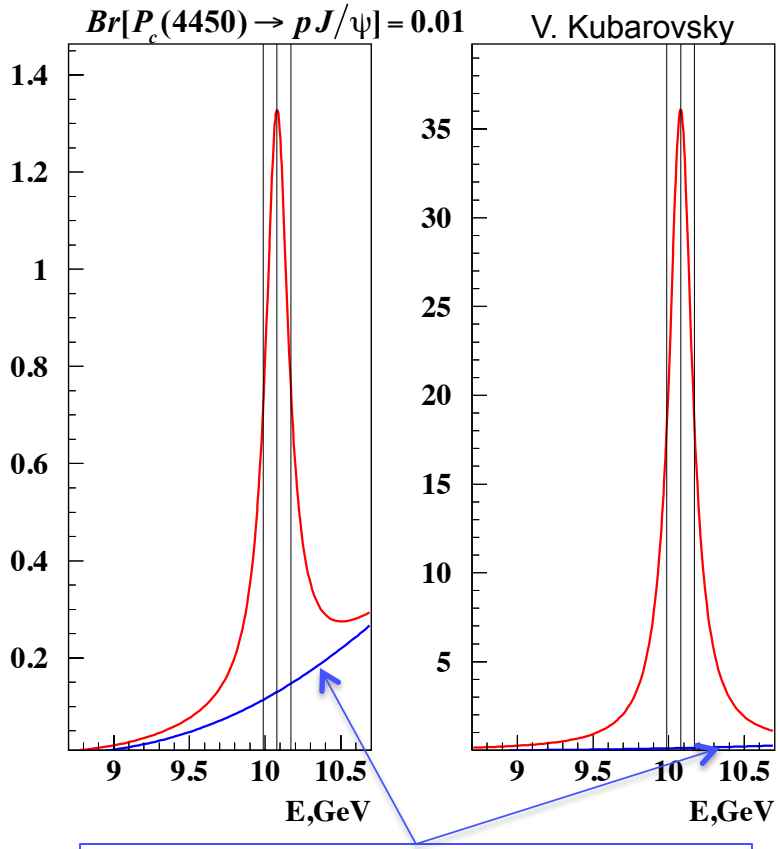


$$\sigma(W)| = \frac{2J+1}{4}\frac{4\pi}{k^2}\frac{\Gamma^2/4}{(W-M_c)^2+\Gamma^2/4}\,Br(P_c\to\gamma+p)\,Br(P_c\to J/\psi+p)$$

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

$$1.5\times10^{-30}\,\mathrm{cm}^2 < \frac{\sigma_{max}[\gamma+p\to P_c(4380)\to J/\psi+p]}{Br^2[P_c(4380)\to J/\psi+p]} < 47\times10^{-30}\,\mathrm{cm}^2$$

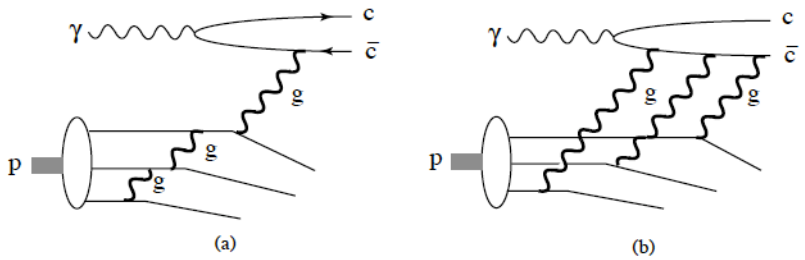
$$1.2\times10^{-29}\,\mathrm{cm}^2 < \frac{\sigma_{max}[\gamma+p\to P_c(4450)\to J/\psi+p]}{Br^2[P_c(4450)\to J/\psi+p]} < 36\times10^{-29}\,\mathrm{cm}^2$$



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.

J/ψ production near threshold

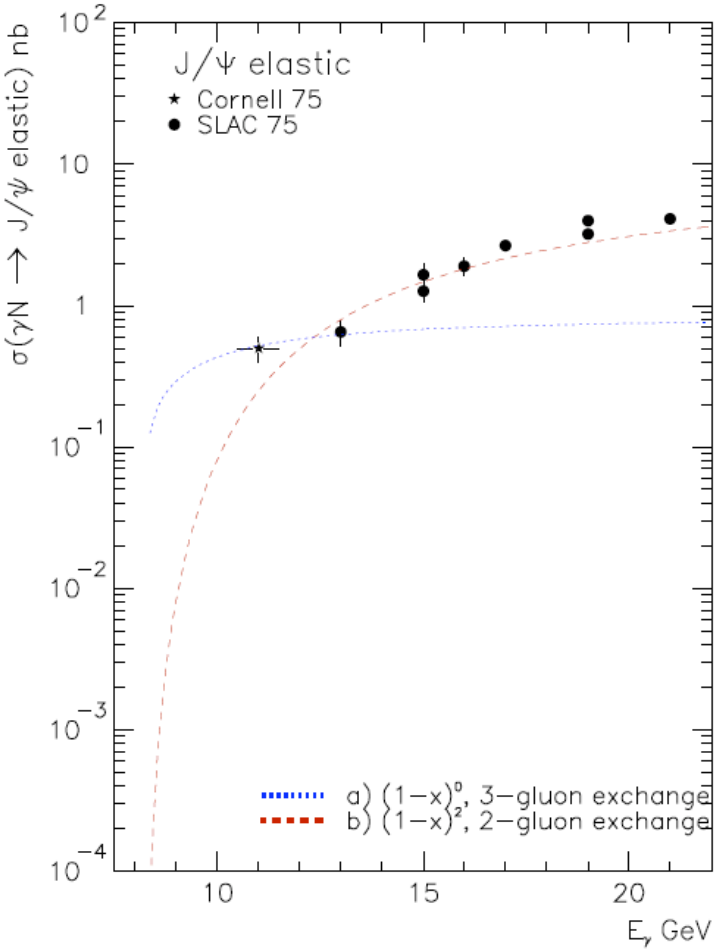
- The lowest published energy point is at E_γ=11 GeV
- Production mechanisms, 2-gluon and 3-gluon exchange, could be valid at the threshold region



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

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

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

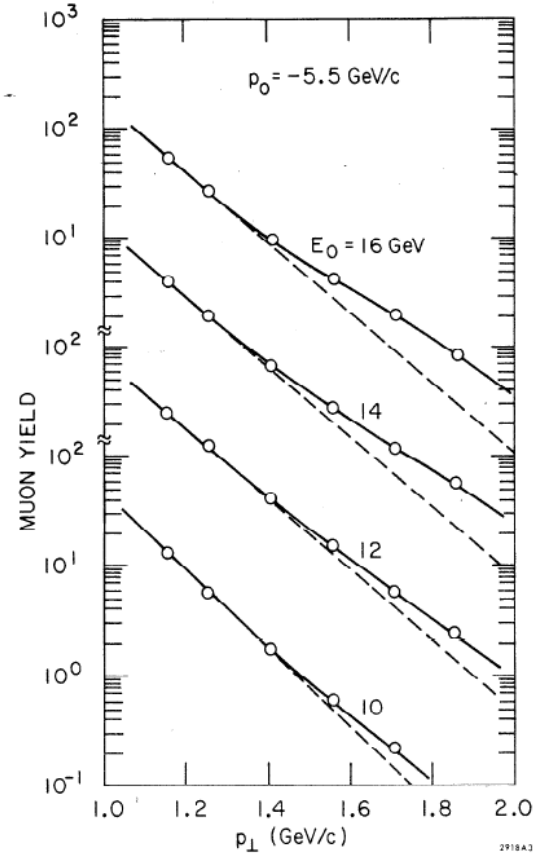


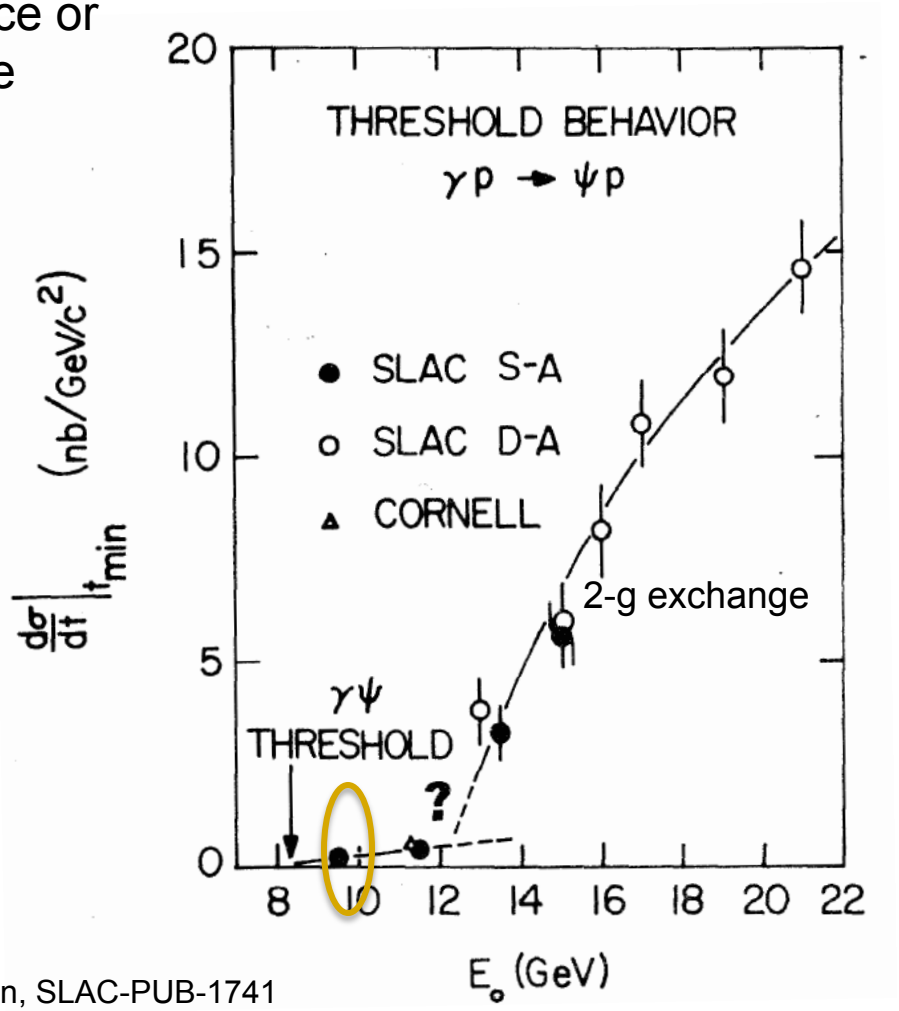
With CLAS12 and 11 GeV electron beam, the threshold region can be studied in great detail – E12-12-001

SLAC single arm measurements

Flattening of cross section near the threshold

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



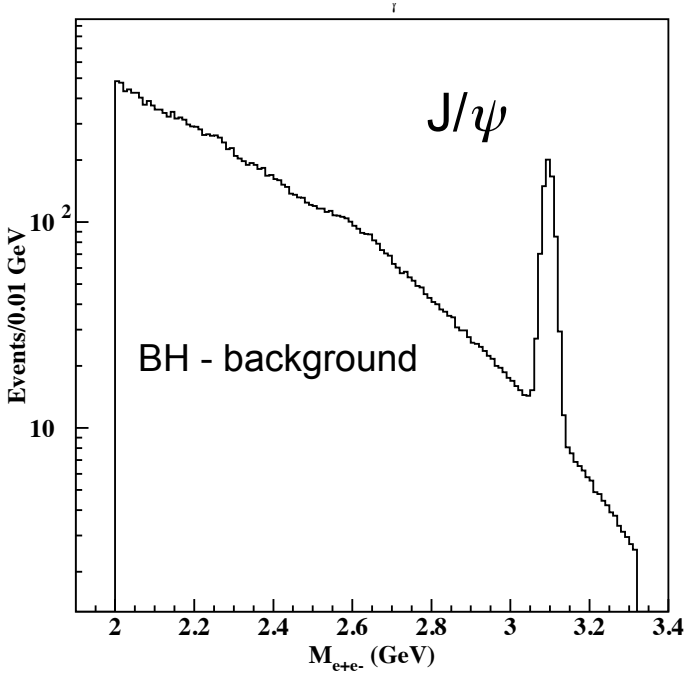


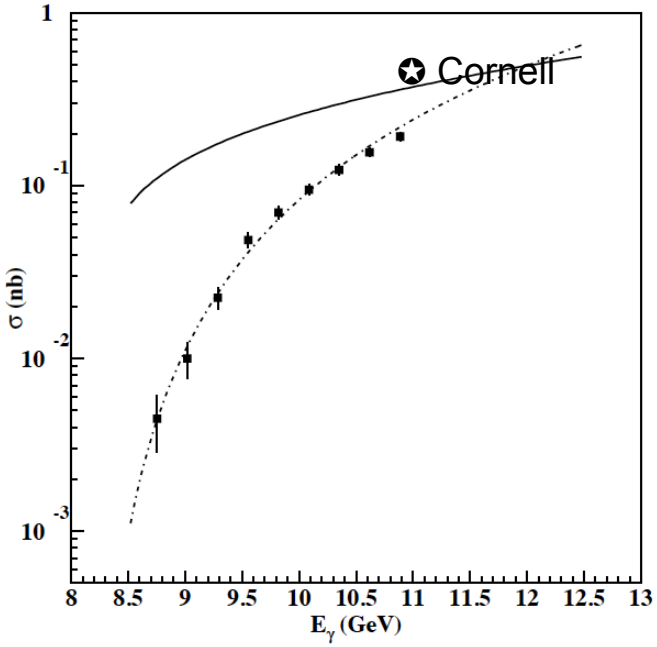
R.L. Anderson, SLAC-PUB-1741

E12-12-001: TCS and J/ψ photoproduction

- Quasi-real (untagged) photoproduction of lepton pairs
- Only recoil proton and decay leptons are detected, scattered electron is identified in the missing momentum analysis

$$ep \rightarrow p'e^+e^-(e') \quad (Q^2 \approx 0)$$

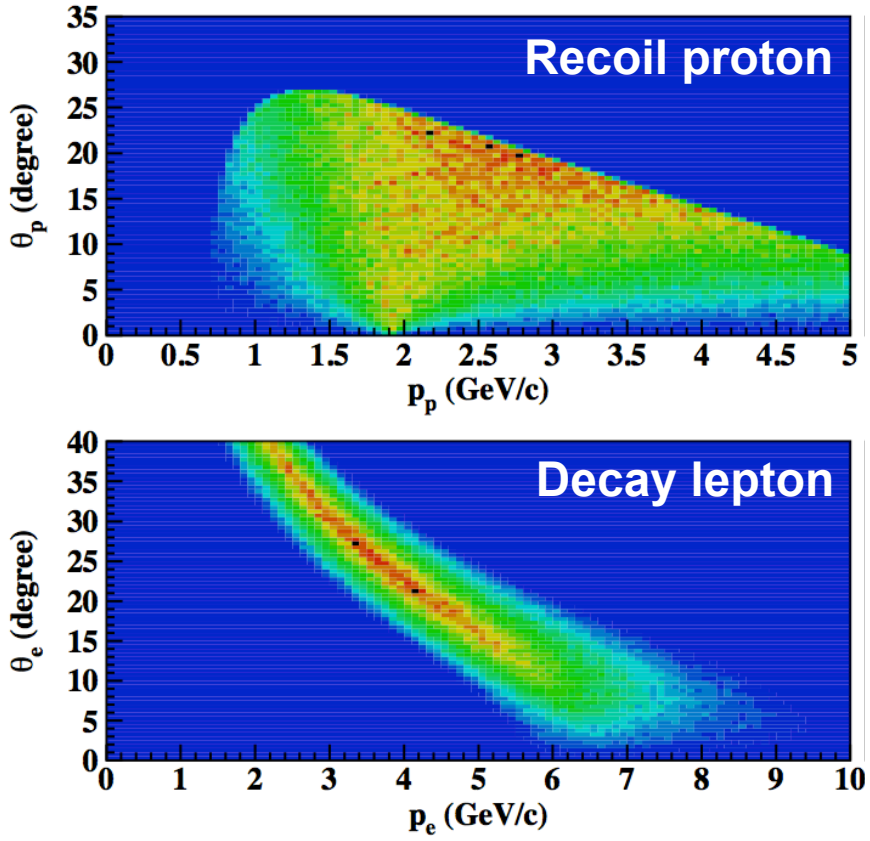




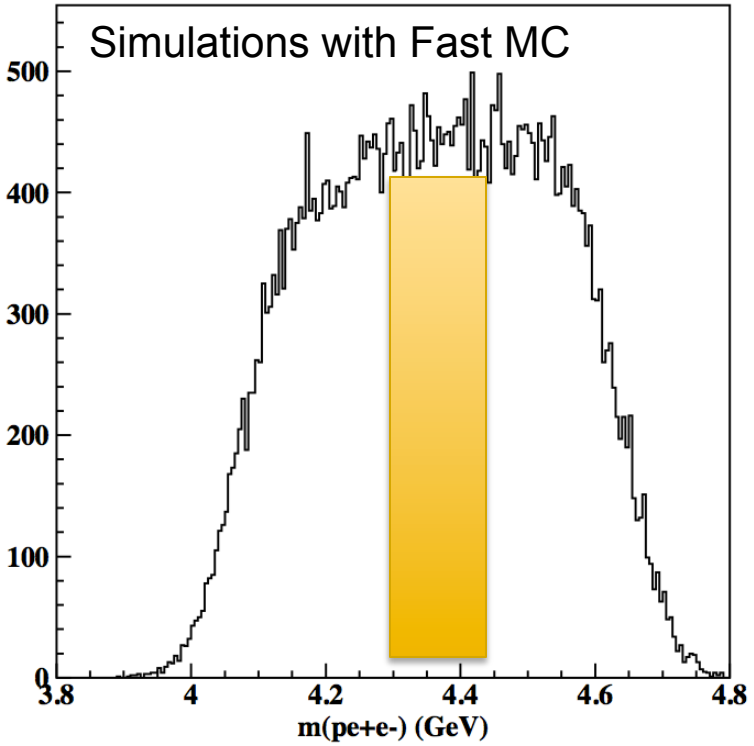
120 days of running at luminosity of 10^{35} cm^{-2} sec^{-1}

Kinematics for J/ψ photoproduction

Only CLAS12 FD is needed

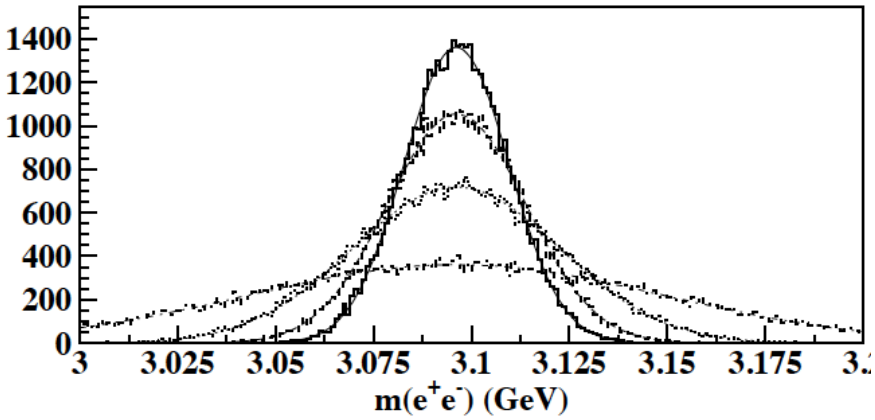


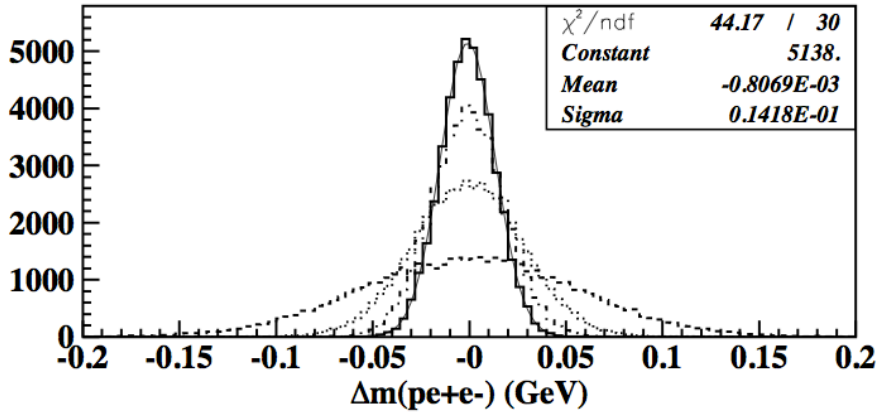
With 11 GeV beam CLAS12 will cover LHCb pentaquark mass range

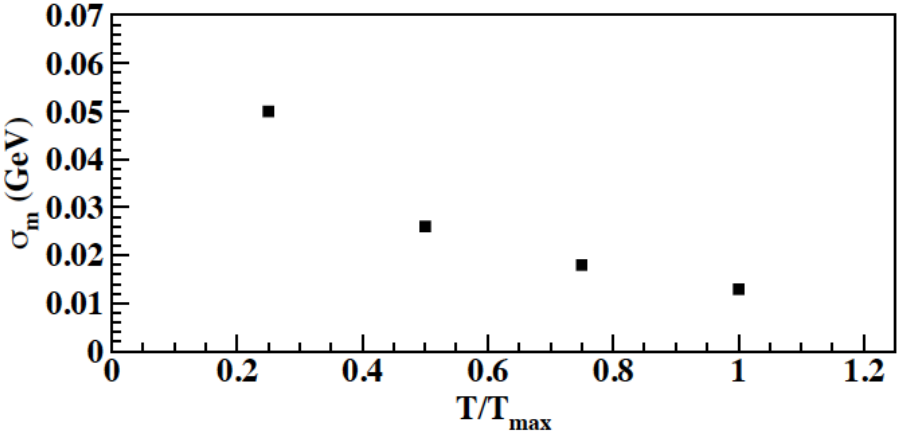


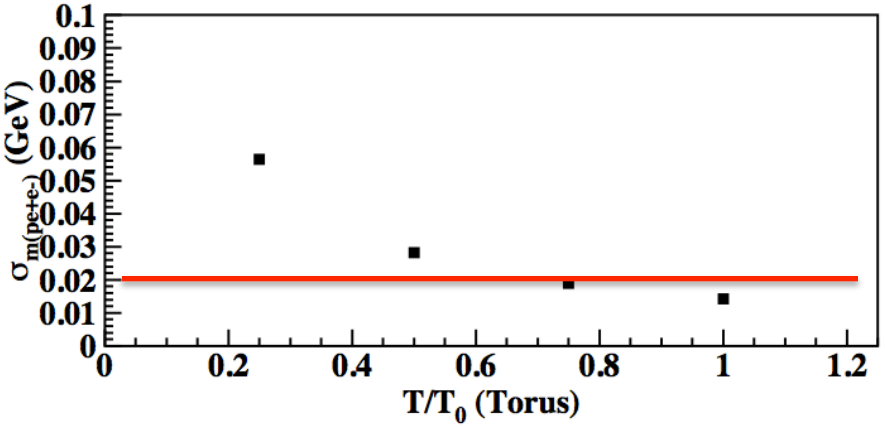
Mass resolutions with untagged photoproduction

Studies with Fast MC – field setting should be ≥75% to have at least 2σ of the invariant mass resolution within Γ_+









E12-12-001: J/ψ production rates

$$ep \rightarrow p' J/\psi(e') \quad (Q^2 \approx 0)$$

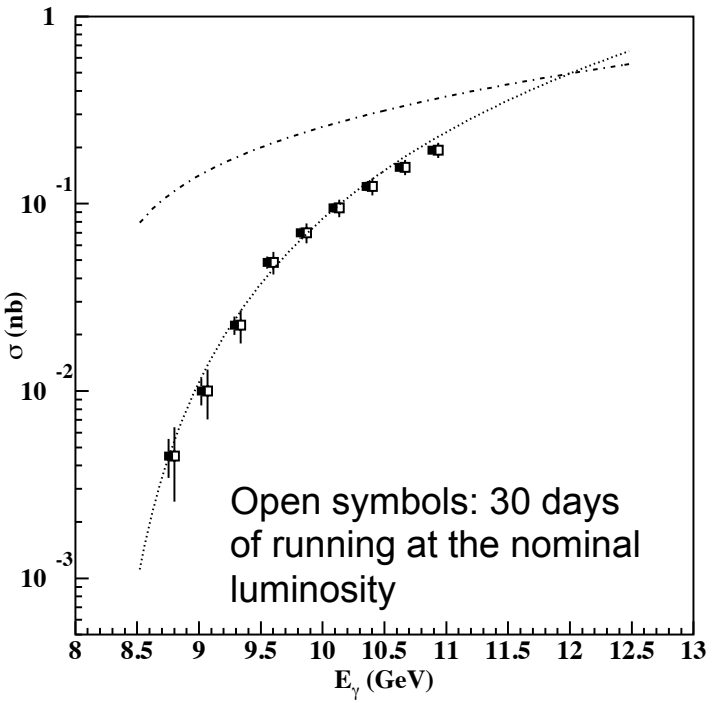
$$\sigma_e = N_\gamma(E_\gamma)\sigma_\gamma; \quad N_\gamma(E_\gamma) = \Gamma(E_\gamma) + n_\gamma$$

Virtual photon flux

$$\Gamma(E_\gamma) = \frac{1}{E_b}\frac{\alpha}{\pi \cdot x} \cdot \left((1 - x + \frac{x^2}{2}) \cdot log(\frac{Q^2_{max}}{Q^2_{min}}) - (1 - x) \right)$$

Bremsstrahlung photon flux integrated over the target thickness

$$n_\gamma(E_\gamma) = \frac{l}{2X_0}\frac{1}{E_\gamma}\left(\frac{4}{3} - \frac{4E_\gamma}{3E_b} + \frac{E_\gamma^2}{E_b^2}\right)$$



$$n = \sigma \cdot L \cdot BR(J/\psi \rightarrow e^+e^-) \cdot \epsilon = \sigma \cdot L \cdot 0.06 \cdot 0.1$$

ε=0.1 – acceptance
Br=0.06

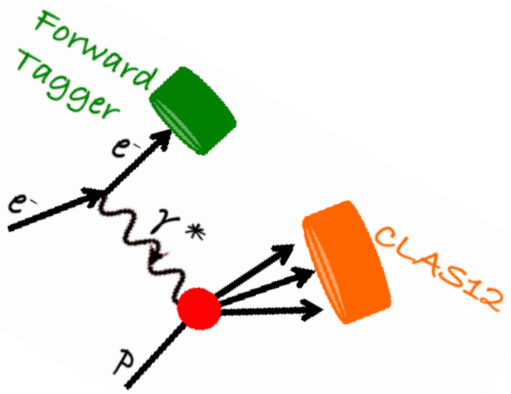
- Expected rate in the 20 MeV energy beam at 10 GeV is 1/day/0.1 nbarn)
- For pentaquarks estimated rate is 10 to 500/day

E12-11-005: tagged J/ψ photoproduction

From A. Celentano's talk

Strategy:

- 11 GeV e^- beam impinging on LH_2 target
- Proton and / or J/ψ decay products measured in CLAS12
- Low-angle scattered e^- measured in the Forward Tagger



Advantages-disadvantages compared to untagged photo-production:

- Higher $\sqrt{s}$ resolution
- Initial state is known: measure p and/or J/ψ decays only to tag the reaction
- Lower rate

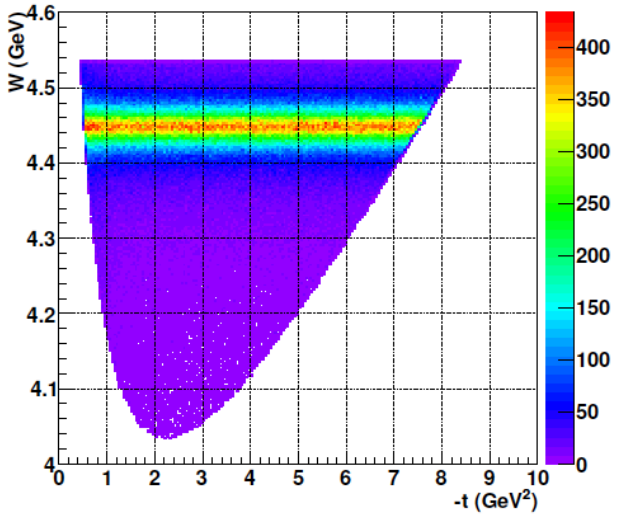
E12-11-005: kinematics

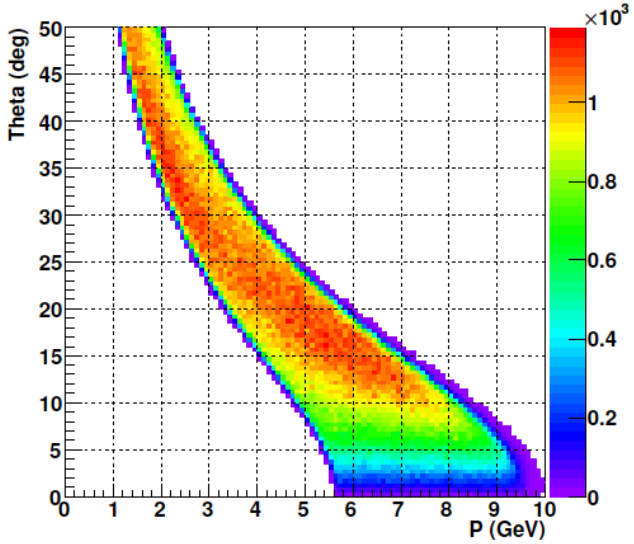
From A. Celentano's talk

MC events generated trough an ad-hoc model, that includes:

1. Non-resonant the $t-$channel exchange of a Pomeron trajectory.
   - Parameters tuned to reproduce existing data at $E_\gamma > 13$ GeV
   - $\sigma_{NR}(E_\gamma = 10 \text{ GeV}) = 0.2$ nbar[3]
2. Resonant $s-$channel production, $\gamma^* p \to X \to J/\psi\, p$
   - Focus on the narrower P_c state
   - $J^P = (3/2)^-$, altough this has limited impact on results
   - Single free parameter: $\sigma_R = (BR)^2 \cdot 1.3\,\mu$barn

Events are generated with final state e^- within FT acceptance.
Only considering the decay $J/\psi \to e^+e^-$ (BR$\simeq 0.06$): CLAS12 not optimized for μ identification





E12-11-005: acceptance, resolution, rates

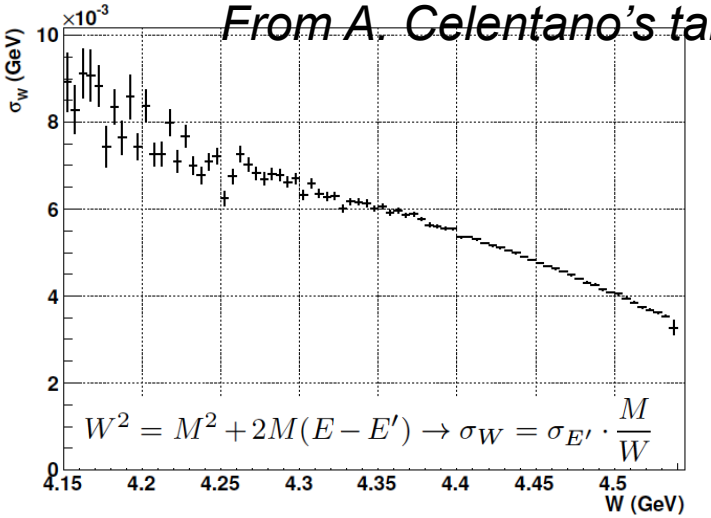
MC events projected on CLAS12 via FASTMC.
Assumptions:

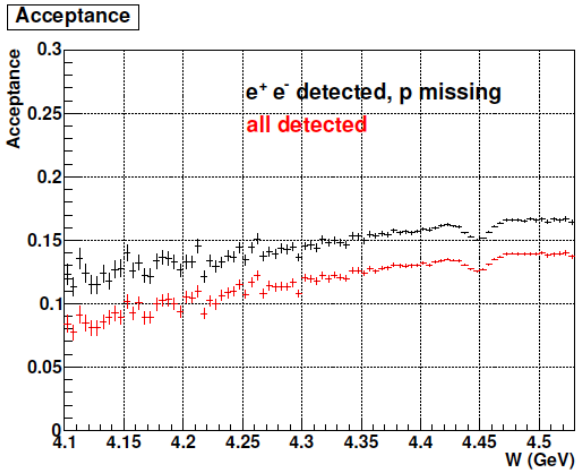
- CLAS12-CD acceptance for e^+/e^- is 0
- Only consider events with both e^+ and e^- from J/ψ in CLAS12-FD
- No combinatorial background included yet

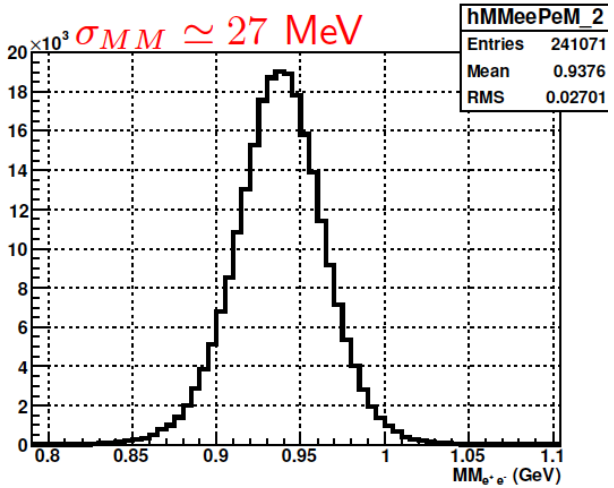
Two reconstruction strategies:

- All final state particles measured
- Only e^+ and e^- measured, p missing

From A. Celentano's talk





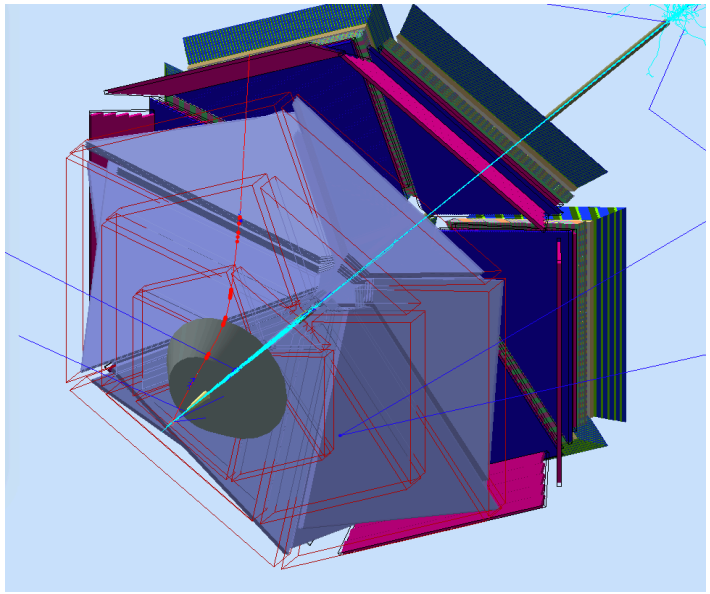


Expected rates – 1.5x10^3 σ_γ event/day/μbarn

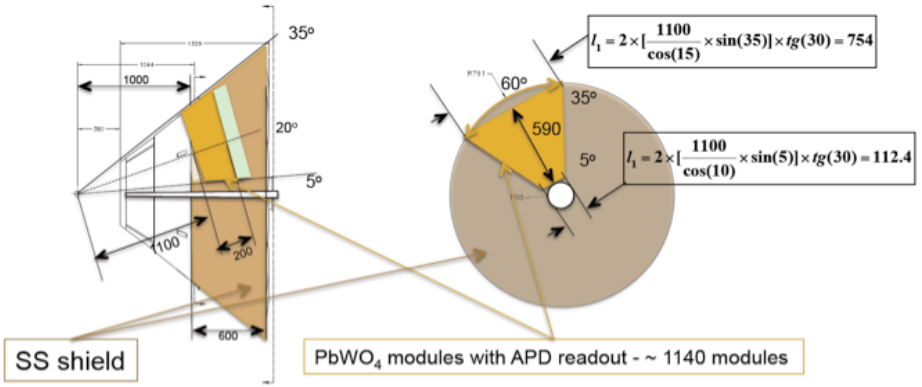
DDVCS and J/ψ electroproduction

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

Use heavily shielded CLAS12 forward detector for muons



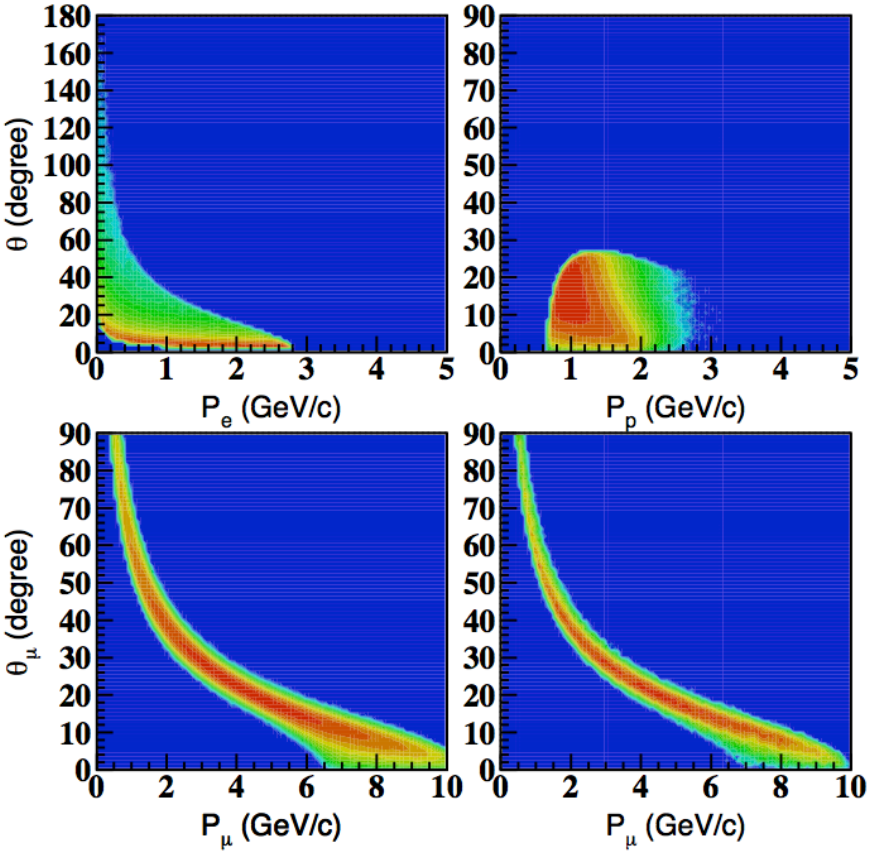
Use a compact electromagnetic calorimeter (part of the shield) for detection of scattered electrons

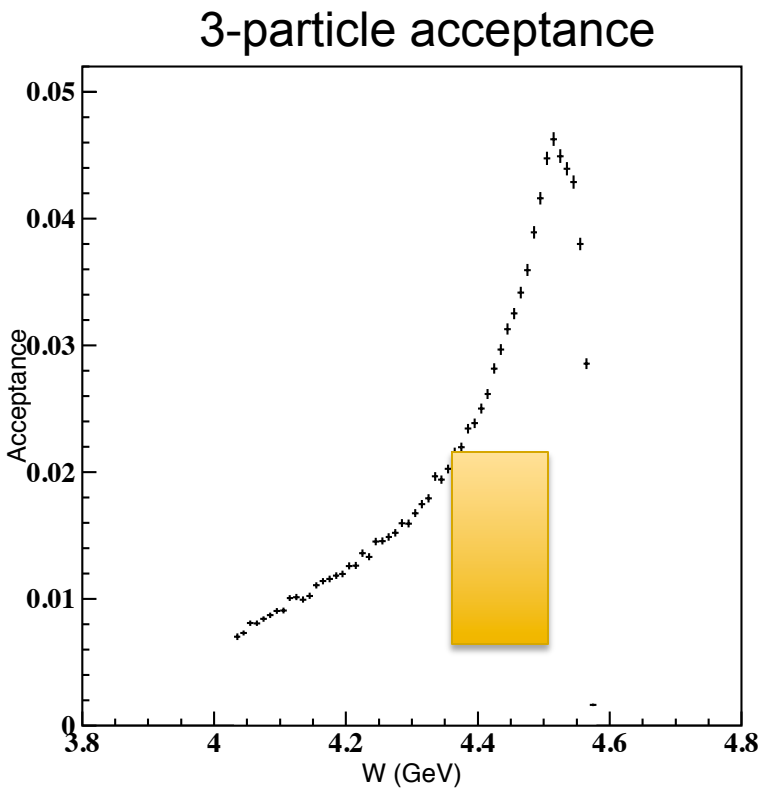


LOI never made to PAC43, but was fully ready.
Asking for 100 days of running at luminosity of 10^{37} cm^{-2} s^{-1}

Kinematics of J/ψ electroproduction

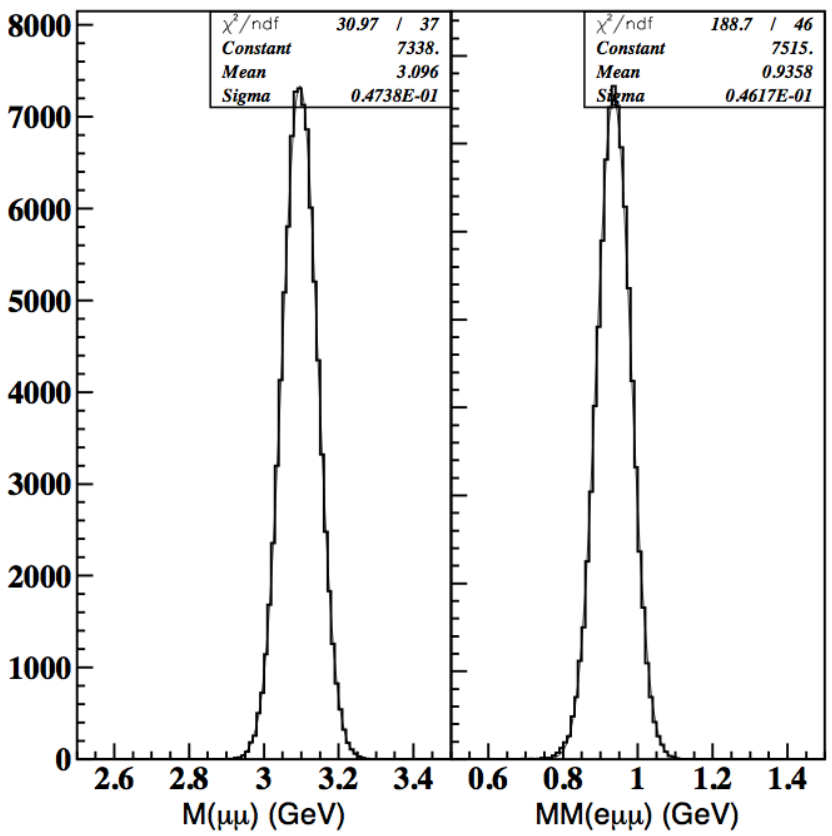
- Modified Fast MC to include the calorimeter and additional smearing for muons due to the multiple scattering in the shielding
- Event generator - $1/Q^4$ and exponential *t*-dependence, b_0=1.2 GeV^{-2}
- Recoil protons will not be detected

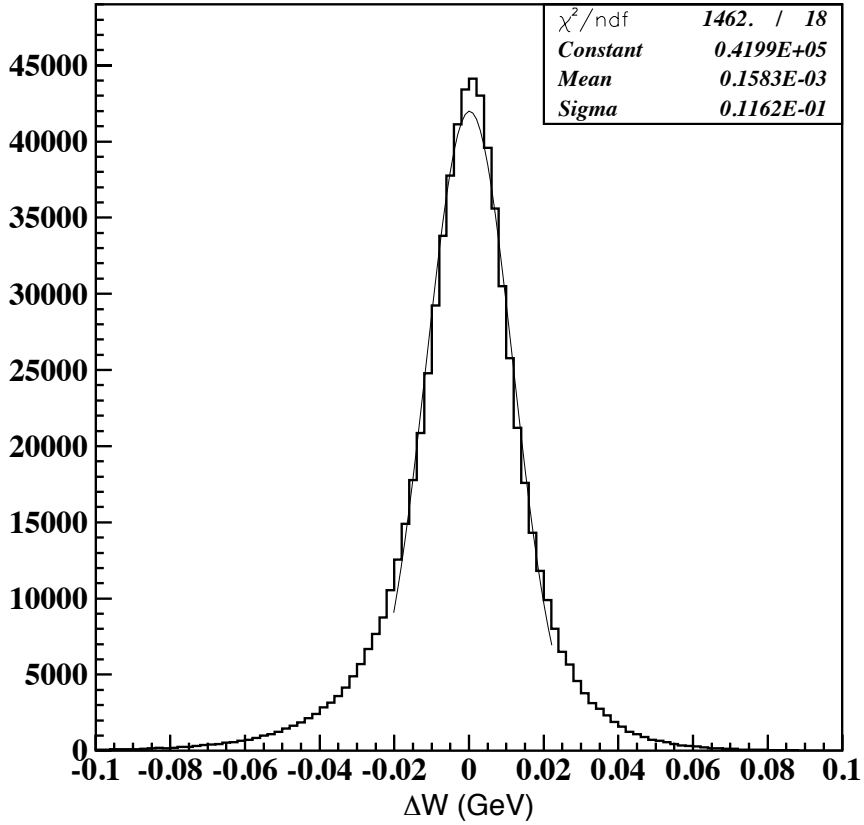




Mass resolutions in electroproduction

- J/ψ will be identified in the invariant mass of $\mu^+\mu^-$
- Proton will be identified in the missing mass of e'$\mu^+\mu^-$
- Pentaquarks will be searched in the missing mass of e'





J/ψ electroproduction rates

Electroproduction cross section can be presented as a sum of cross sections for transversely (T), and longitudinally (L) polarized photons

$$\frac{d\sigma_{eN\to eM^0N}}{dQ^2dWdt} = \Gamma_W \cdot (\frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt})$$

where

the virtual photon flux

$$\Gamma_W = \frac{\alpha}{4\pi}\cdot\frac{W^2-m^2}{m^2E^2}\cdot\frac{W}{Q^2}\cdot\frac{1}{1-\epsilon}$$

VDM relation for transversely polarized (T)

$$\sigma_T = \left(\frac{m^2_{J/\Psi}}{m^2_{J/\Psi}+Q^2}\right)^2\cdot\sigma_{\gamma N\to M^0N}$$

the virtual photon polarization

$$\epsilon = \left(1+2\frac{Q^2+q^{02}}{4EE'-Q^2}\right)^{-1}$$

and longitudinally polarized (L) photon cross sections

$$\sigma_L = \left(\frac{m^2_{J/\Psi}}{m^2_{J/\Psi}+Q^2}\right)^2\cdot\frac{Q^2}{m^2_{J/\Psi}}\cdot(1-x)^2\cdot\xi(Q^2,\nu)\cdot\sigma_{\gamma N\to M^0p}$$

With 100 times of the CLAS12 nominal luminosity, for the 2-gluon exchange model expecting 1/day in 40 MeV bin of W at 4.4 GeV

Summary

- The LHCb announcement of the discovery of charmed pentaquark states in the pJ/ψ decay mode, $P_c(4380)$ and $P_c(4450)$, generated a considerable excitement in the field.
- A lots of publications, but no consensus on what these states are. New measurements are needed to confirm or refute the resonance nature of the observed states
- With 11 GeV electron beam CLAS12 in Hall-B will be able to study mass range of these resonances with the $J/\psi p$ final state in both photoproduction and electroproduction reactions – there are approved experiments!
- Already in the setting of the E12-12-001 we should be able to see these states with ~30 days of beam
- There are ways to improve the reach of these experiments by
  - increasing luminosity, separate run (no particle detection below 10^o)
  - identifying J/ψ in both lepton pair (e^+e^-) and ($\mu^+\mu^-$) decay modes
  - identifying J/ψ in the missing mass of ep->e'pX, challenging to trigger
- All these options must be studied