Photoproduction of Hidden-Charm Pentaquark in CLAS12 - MesonEx

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CLAS HSWG Meeting

Introduction

LHCB hidden-charm pentaquark

LHCb recently announced[1] the discovery of two exotic structures in the J/ψ - p channel: P_c(4380) and P_c(4450), by measuring the decay $\Lambda_b^0 \to pJ/\psi K^-$.

They claimed that the minimum quark content is $c\bar{c}uud$.

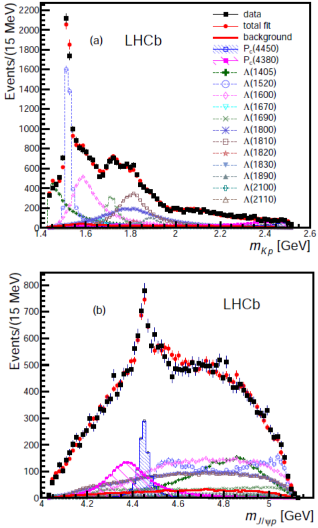
Widths:

- P_c(4450): $\Gamma = 39$ MeV
- P_c(4380): $\Gamma = 205$ MeV

Quantum numbers (PWA most probable solution)

- P_c(4450): $J_P = \frac{5}{2}^-$
- P_c(4380): $J_p = \frac{3}{2}^+$

Altough: *"Acceptable solutions are also found for additional cases with opposite parity"*



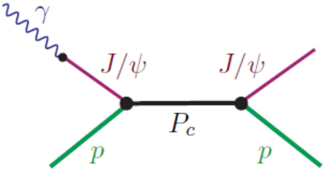
[1] Phys. Rev. Lett. **115**, 072001 (2015)

Hidden-charm pentaquark photo-production

Any p-J/ψ resonance would apper as an $s - channel$ resonance in the direct photo-production reaction:

$\gamma p \to pJ/\psi$. $M_R = \sqrt{s} = M^2 + 2E_\gamma M$

$M_R \simeq 4.4\text{GeV} \to E_\gamma \simeq 9.8\text{GeV}$



"Naive" cross-section estimate ingredients[2]:

- Breit-Wigner *elastic* cross-section
- Vector Meson Dominance

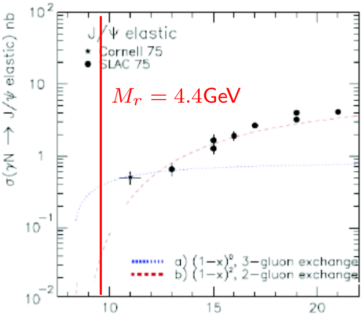
$$\sigma(W) = \frac{2J+1}{4}\frac{4\pi}{k_i \cdot k_f}\frac{B_{in}B_{out}\Gamma^2/4}{(W-M_R)^2+\Gamma^4/4}$$

Vector Meson Dominance:

$B_{in} = (e/f_V)^2 B_{out} \to B_{in} = B_{out} \cdot 7.37 \cdot 10^4$

(from $J/\psi \to e^+e^-$ decay)

$$\sigma_{max} \simeq \frac{2J+1}{4} B_{out}^2 \cdot 2.26\mu\text{barn}$$



[2] M. Karlineray and J.L. Rosnerbz, arXiv:1508.01496

Hidden-charm pentaquark tagged photo-production in CLAS12

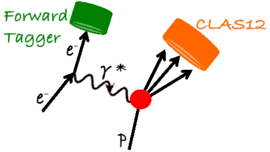
Actually, J/ψ tagged photo-production in CLAS12!

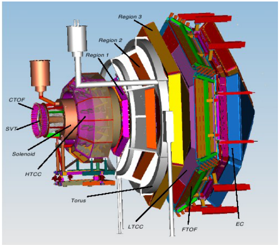
Strategy:

- 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





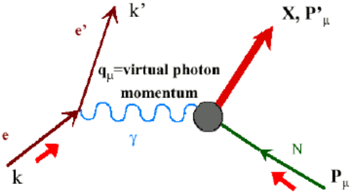
Low Q^2 electron-scattering: kinematics

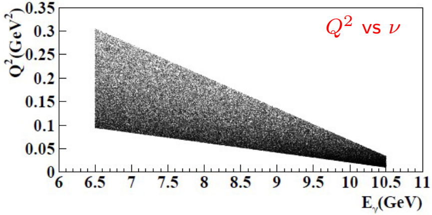
Kinematic variables:

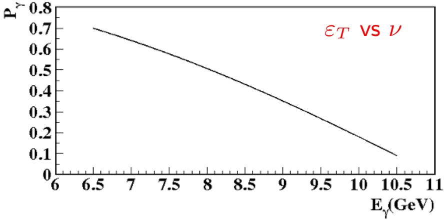
- $\nu = E - E'$
- $Q^2 = 4EE' \sin^2(\theta_e/2)$
- $W^2 = M^2 + 2M\nu - Q^2$

Virtual photon polarization:

- $\varepsilon_T = [1 + 2\frac{Q^2+\nu^2}{Q^2} \tan^2(\theta_e/2)]^{-1}$
- $\varepsilon_L = \frac{Q^2}{\nu^2}\varepsilon_T$







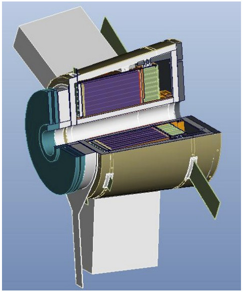
The Forward Tagger Facility

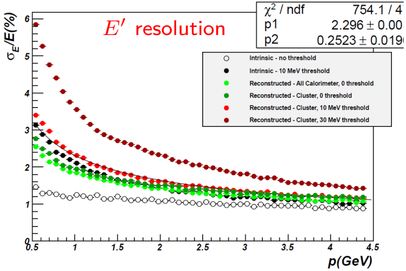
3 components:

- **Lead-tungstate calorimeter (FT-Cal):** measure the energy of scattered electrons with few % resolution.
- **Hodoscope (FT-Hodo):** distinguish photons from electrons.
- **Tracker (FT-Trck):** determine the electron scattering plane.

Nominal design parameters:

	Range
$E_{e'}$	0.5 - 4.5 GeV
$\theta_{e'}$	2.5^o - 4.5^o
$\phi_{e'}$	0° - 360°
E_γ	6.5 - 10.5 GeV
P_γ	70 - 10 %
Q^2	0.01 - 0.3 GeV^2 ($< Q^2 >$ 0.1 GeV^2)
W	3.6 - 4.5 GeV





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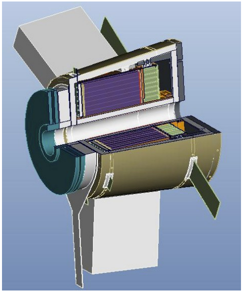
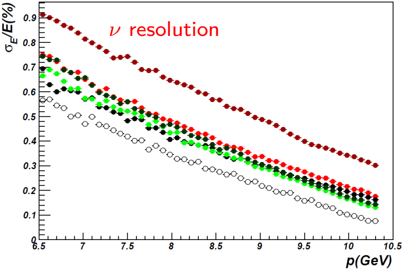


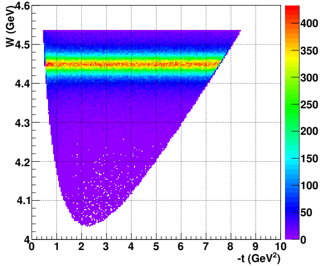


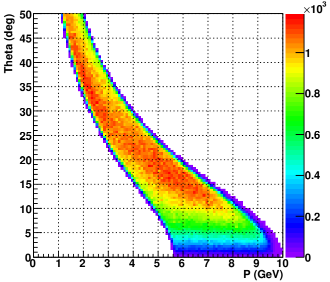
Detector acceptance evaluation: kinematics

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
   - $\sigma_{NR}(E_\gamma = 10$ 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





[3] Compatible with the range predicted in arXiv:0010.343, where a QCD-inspired calculation was performed.

Background model

- $t-$channel exchange of a Pomeron-like Regge Trajectory

$$M^{\lambda_\psi,\lambda_{p'}}_{\lambda_\gamma,\lambda_p} = \left(\frac{s}{s_0}\right)^{\alpha_P(t)} \beta_{\lambda_\gamma,\lambda_\psi}\beta_{\lambda_p,\lambda_{p'}} e^{-b|t|}$$

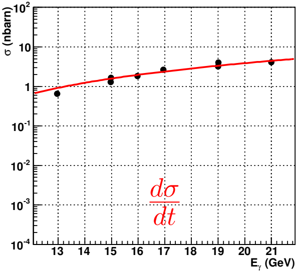
- Parity conservation:

$$\begin{aligned} \beta_{\lambda_\gamma,\lambda_\psi} &= \beta_{-\lambda_\gamma,-\lambda_\psi} \\ \beta_{\lambda_p,\lambda_{p'}} &= \beta_{-\lambda_p,-\lambda_{p'}} \end{aligned}$$

- Assumptions:
  - $s-$channel helicity conservation
  - No spin-flip at proton vertex
- Result:

$$\frac{d\sigma}{dt} = \frac{1}{64\pi s}\frac{1}{k_i^2}\beta_0^2\left(\frac{s}{s_0}\right)^{2\alpha_P(t)} e^{-2b|t|}$$

- α_P: Pomeron trajectory
- β: Regge coupling
- $e^{-b|t|}$: "effective" form factor



Signal model

- $s-channel$ resonance J^P production:

$M^{\lambda_\psi,\lambda_{p'}}_{\lambda_\gamma,\lambda_p}(s,t) = (2J+1)M^{\lambda_\psi,\lambda_{p'}}_{\lambda_\gamma,\lambda_p}(s)D^{J*}_{\lambda_\gamma-\lambda_p,\lambda_\psi-\lambda_{p'}}$

- Breit-Wigner approximation for $M^{\lambda_\psi,\lambda_{p'}}_{\lambda_\gamma,\lambda_p}(s)$:

$M^{\lambda_\psi,\lambda_{p'}}_{\lambda_\gamma,\lambda_p}(s) = -\frac{g_I^{\lambda_\gamma,\lambda_p} g_F^{\lambda_\psi,\lambda_{p'}}}{s-M^2+i\sqrt{s}\Gamma}$

- Parity conservation:

$$
\begin{aligned}
g_I^{\lambda_\gamma,\lambda_p} &= g_I^{-\lambda_\gamma,-\lambda_p} \\
g_F^{\lambda_\psi,\lambda_p'} &= g_F^{-\lambda_\psi,-\lambda_{p'}}
\end{aligned}
$$

- Assumptions:
  - Vector-meson dominance: $g_I^{\lambda_a,\lambda_b} = (e/f)g_F^{\lambda_a,\lambda_b}$ $(e/f = 2.7\cdot 10^{-4})$
  - Minimal $L-$value for the $X \to J\psi\ p$ decay
- Result:

$$\sigma(s) = \frac{8\pi}{3}\frac{s}{k_i k_f}(e/f)^2\frac{\Gamma^2 BR_F^2}{(s-M^2)^2+\Gamma^2 s}$$

$g_{I/F}^{\lambda_\gamma,\lambda_p}$: initial/final state coupling

$$
\begin{aligned}
g_F^{1,-} = g_F^{-1,+} &= \sqrt{3}g^{1,+} \\
g_F^{0,+} = g_F^{0,-} &= \sqrt{2}g^{1,+}
\end{aligned}
$$

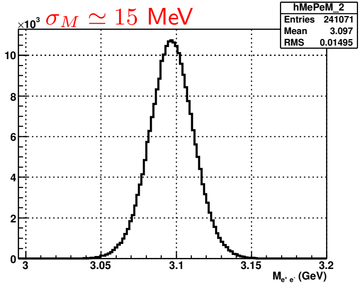
Detector acceptance evaluation: results

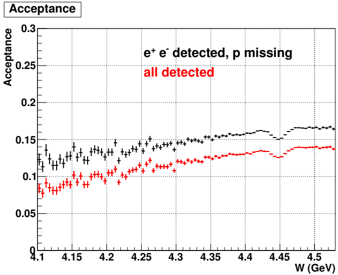
MC events projected on CLAS12 via FASTMC.
Assumptions:

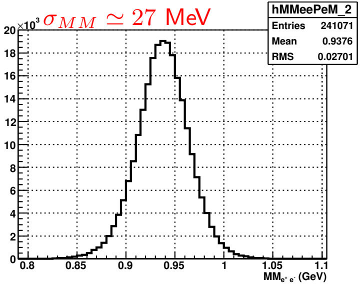
- CLAS12-CD acceptance for e^+/e^- is 0
- Only consider events with both e^+ and e^- from J/ψ in CLAS12-FD
- No combinatorial background included yet

Two reconstruction strategies:

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







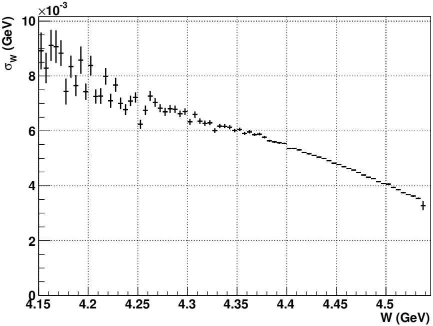
Invariant mass resolution

p-J/ψ invariant mass measured only trough the low-angle e^- detected in FT.

$$W^2 = M^2 + 2M(E - E') \rightarrow \sigma_W = \sigma_{E'} \cdot \frac{M}{W}$$

Close to the resonance region ($W = 4.4$ GeV):

- $E' \simeq 1$ GeV, $\sigma_{E'} \simeq 25$ MeV
- $\sigma_W \simeq 5$ MeV $\rightarrow$ x3 untagged



Compared to the untagged measurement, the detection of the low-angle electron in the Forward Tagger permits to map the p-J/ψ line shape with a higher resolution.

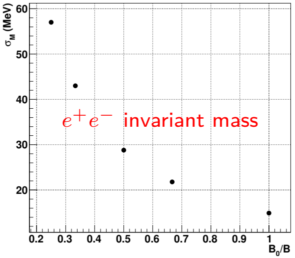
Magnetic field effects

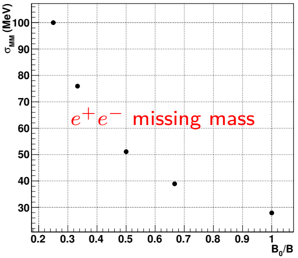
The effect of changing the intensity and polarity of the torus magnetic field was evaluated via FASTMC.

Results:

- e^+e^- invariant mass (i.e. J/ψ mass) and missing mass (i.e. proton mass) increase with decreasing the B field
- No effect on these observables by inverting the magnetic field
- Modest effect of the magnetic field intensity on the acceptance
- By inverting the field polarity (negatives outbending), the acceptance for the e^+e^-p topology drops to $\simeq 9\%$ at $W = 4.4$ GeV

The W resolution does not depend on the torus field configuration.





Rates

Low Q^2 limit → the unpolarized reaction cross-section is: $d\sigma(\Omega', E') = \sigma_\gamma(\nu) \cdot d\Gamma$

Virtual photon flux:

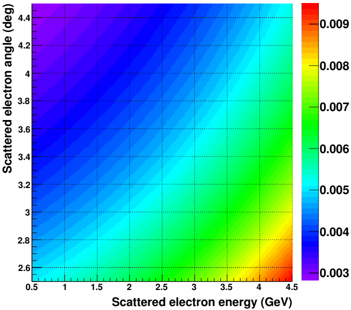
$$d\Gamma(\Omega', E') = \frac{\alpha}{4\pi^2} \frac{E'}{E_0} \frac{\nu}{Q^2} \left[\frac{(2E_0 - \nu)^2}{\nu^2} + 1 \right] d\Omega' \, dE'$$

Integration over FT acceptance ($2.5° \div 4.5°$):

$$d\Gamma(W) \simeq 1.1 \cdot \frac{\alpha}{4\pi} \frac{\nu}{E_0^2} \left[\frac{(2E_0 - \nu)^2}{\nu^2} + 1 \right] \frac{W}{M_p} dW$$

At $W = 4.4$ GeV, integrating over $\Delta W = 20$ MeV:

$$\Gamma = 1.23 \cdot 10^{-5} \rightarrow 1/10 \text{ x untagged}$$



Total number of events (case $P_c(4450)$, $\Gamma = 39$ MeV):

$$R_{gen} = \mathcal{L} \cdot \Gamma \cdot \sigma_0^\gamma \simeq 2 \cdot 10^5 \cdot \sigma_0^\gamma \text{ events / day / } \mu\text{barn}$$

$$R_{meas} = R_{gen} \cdot BR_{J/\psi \rightarrow e^+e^-} \cdot \varepsilon \simeq 1.5 \cdot 10^3 \cdot \sigma_0^\gamma \text{ events / day / } \mu\text{barn}$$

Conclusions

- The reaction $\gamma^* + p \rightarrow pJ/\psi$ can be measured with the CLAS12+Forward tagger detector, **tagging** the final state electron
- Preliminary results from MC simulations are encouraging:
    - $\sigma_W \simeq 5$ MeV @ 4.4 GeV, *independent from CLAS12 resolution*
    - $\varepsilon \simeq 15\%$ for the $e^+e^-(p)$ topology
- This measurement is **complementary** to the untagged one: higher resolution, lower requirements on CLAS12, but lower statistics
    - Untagged measurement: discovery potential
    - Tagged measurement: precise measurement of the p-J/ψ line-shape
- Further studies must be performed
    - Full MC simulation
    - Backgrounds evaluation