CLAS12 Options for LHCb Pentaquark and Hybrid Searches/Studies

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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)

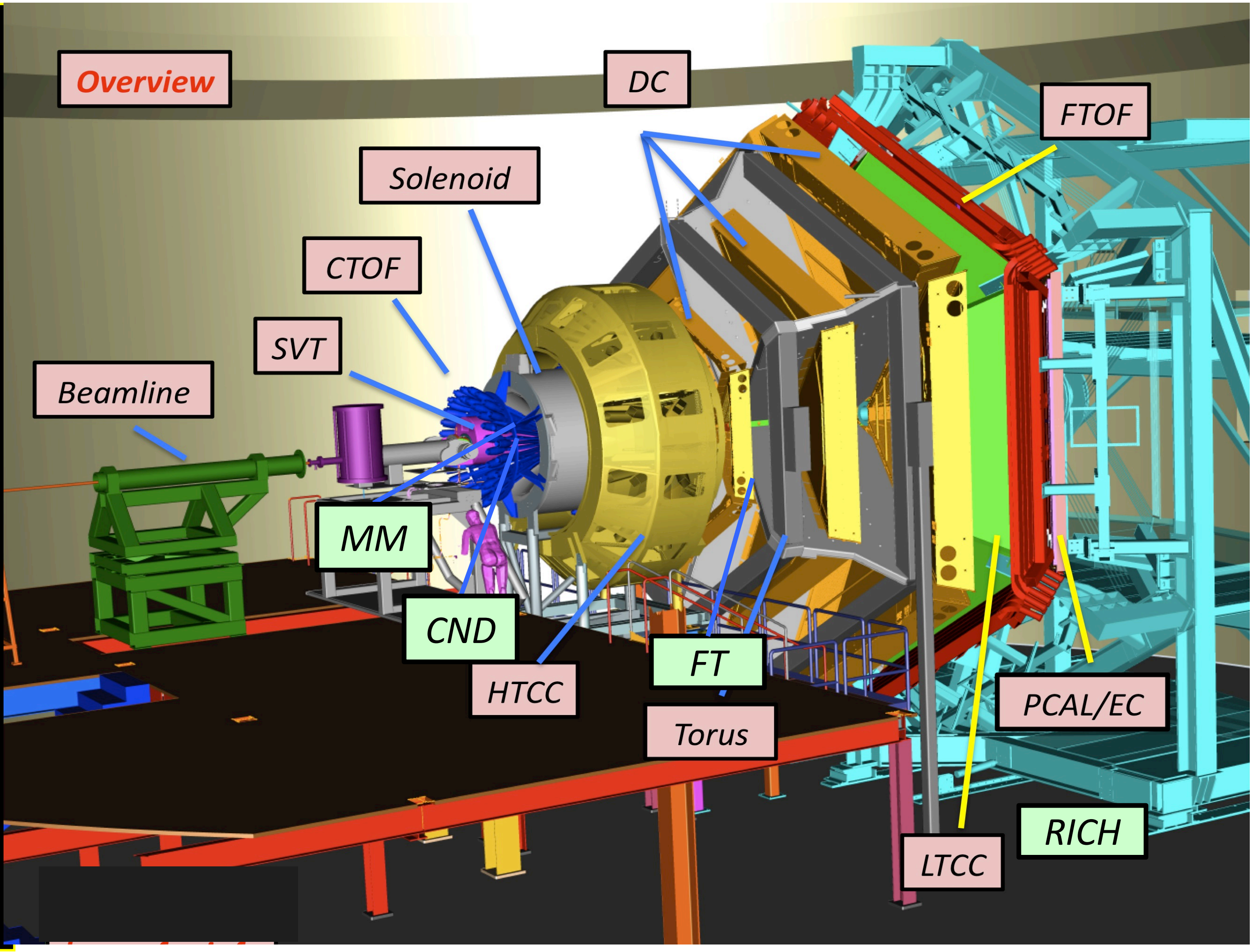
- SOLENOID magnet
- Silicon Vertex Tracker
- Central Time-of-Flight

Beamline

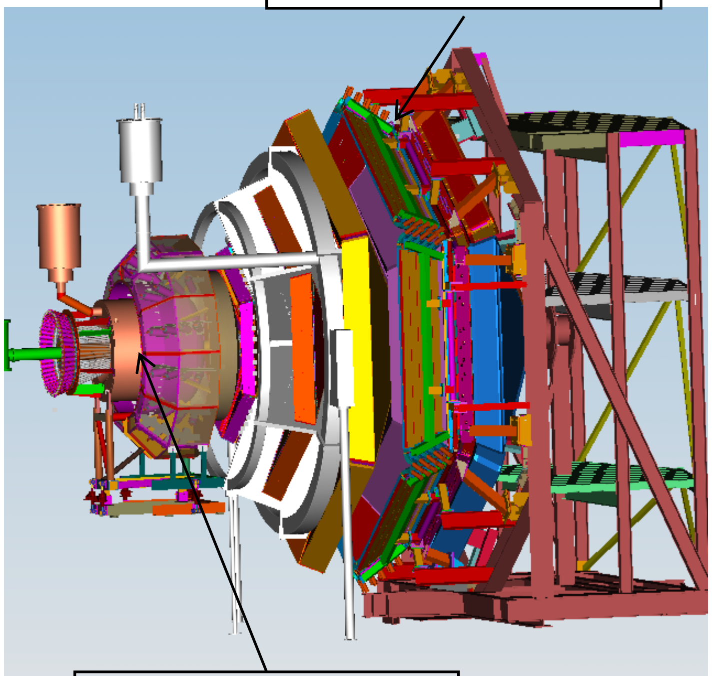
- Cryo Target
- Moller polarimeter
- Shielding
- Photon Tagger

Upgrade to the baseline

- Central Neutron Detector
- MicroMegas
- Forward Tagger
- RICH detector
- Polarized target



CLAS12 in Hall-B



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

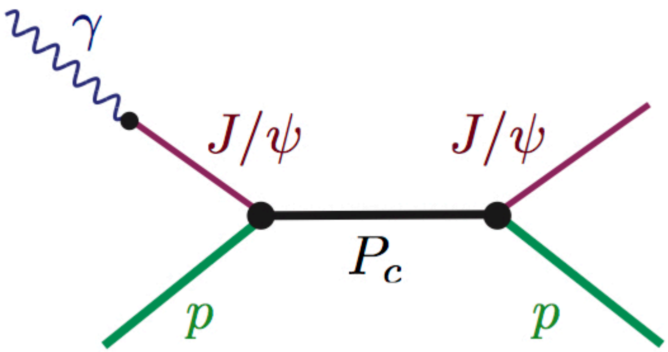
	FD	CD
Angular range		
Track	$5^0 - 40^0$	$35^0 - 125^0$
Photons	$2^0 - 40^0$	---
Resolution		
dp/p (%)	< 1 @ 5 GeV/c	< 5 @ 1.5 GeV/c
$d\theta$ (mr)	< 1	< 10 – 20
$\Delta\phi$ (mr)	< 3	< 5
Photon detection		
Energy (MeV)	>150	---
$\delta\theta$ (mr)	4 @ 1 GeV	---
Neutron detection	$N_{eff} < 0.7$	$N_{eff} < 0.3$
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	---

Photoproduction of Hidden-Charm Pentaquark in CLAS12

- 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

Pentaquark photo-production

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

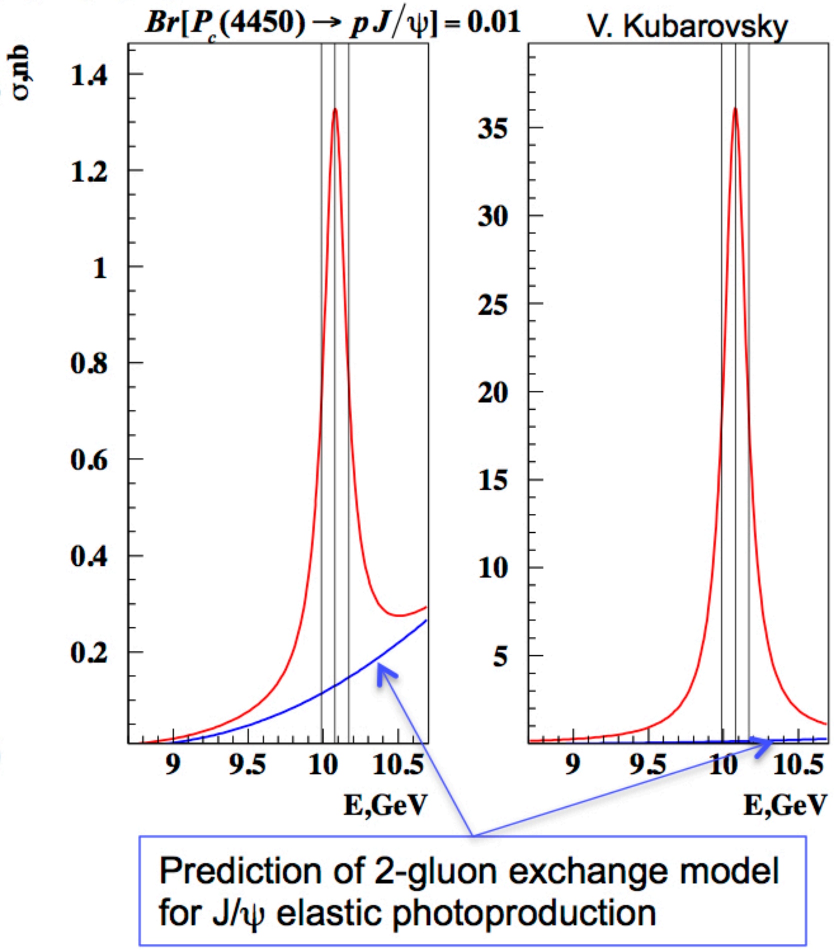


$$\sigma(W)| = \frac{2J+1}{4}\,\frac{4\pi}{k^2}\,\frac{\Gamma^2/4}{(W-M_c)^2+\Gamma^2/4}\,Br(P_c \to \gamma + p)\,Br(P_c \to J/\psi + p)$$

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

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

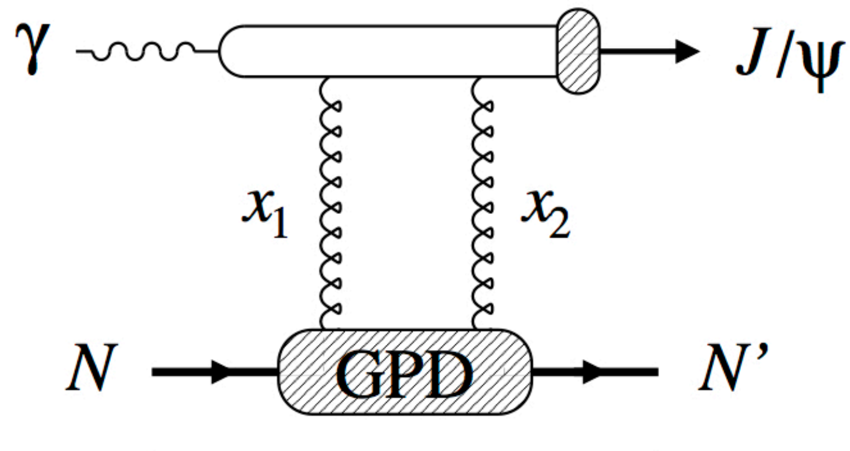
$$1.2 \times 10^{-29}\,\mathrm{cm}^2 < \frac{\sigma_{max}[\gamma + p \to P_c(4450) \to J/\psi + p]}{Br^2[P_c(4450) \to J/\psi + p]} < 36 \times 10^{-29}\,\mathrm{cm}^2$$

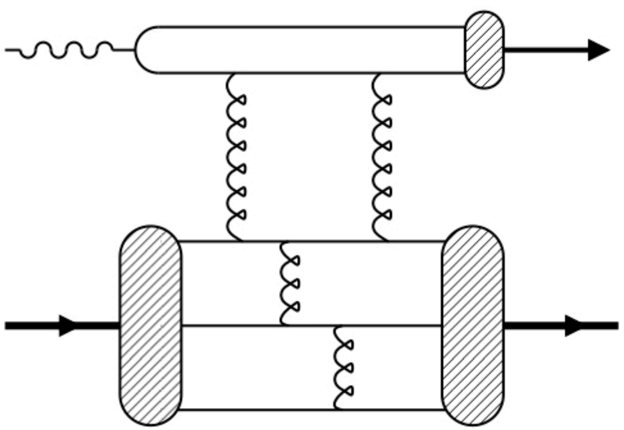


Q. Wang, X. H. Liu and Q. Zhao, arXiv:1508:00339.
V. Kubarovsky and M.B. Voloshin, arXiv:1508.00888.
M. Karliner and J.L. Rosner, arXiv:1508.01496.

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





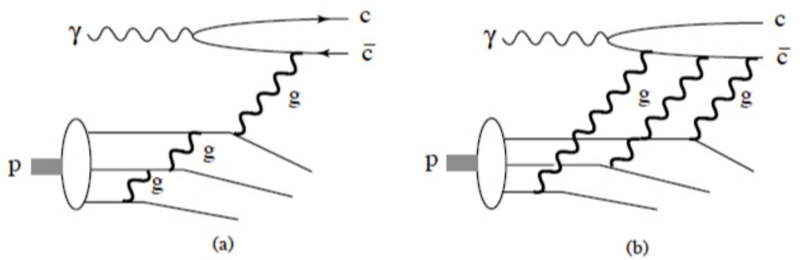
At high energies (HERA, FNAL) probes gluon GPDs. Wealth of data exists on electroproduction at W>10 GeV

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

There are no electroproduction measurements in this region

J/ψ production near threshold

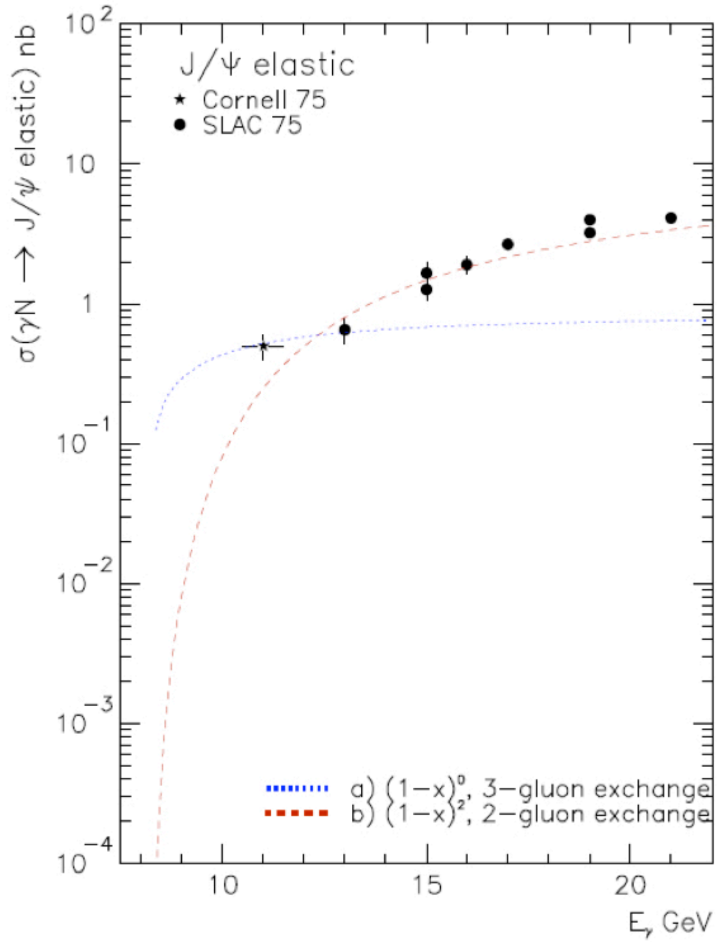
- The lowest published energy point is at E_γ=11 GeV
- Production mechanisms, 2-gluon and 3-gluon exchange, could be valid at the threshold region



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

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

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

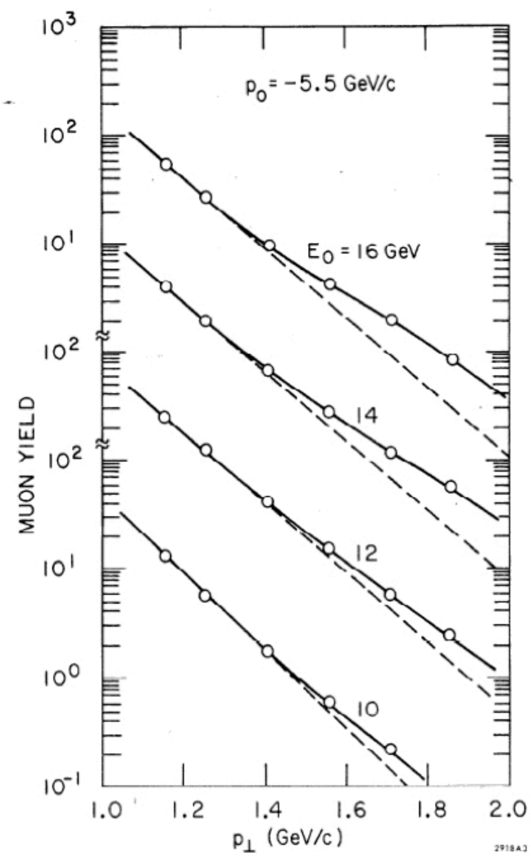


With CLAS12 and 11 GeV electron beam, the threshold region can be studied in great detail – E12-12-001

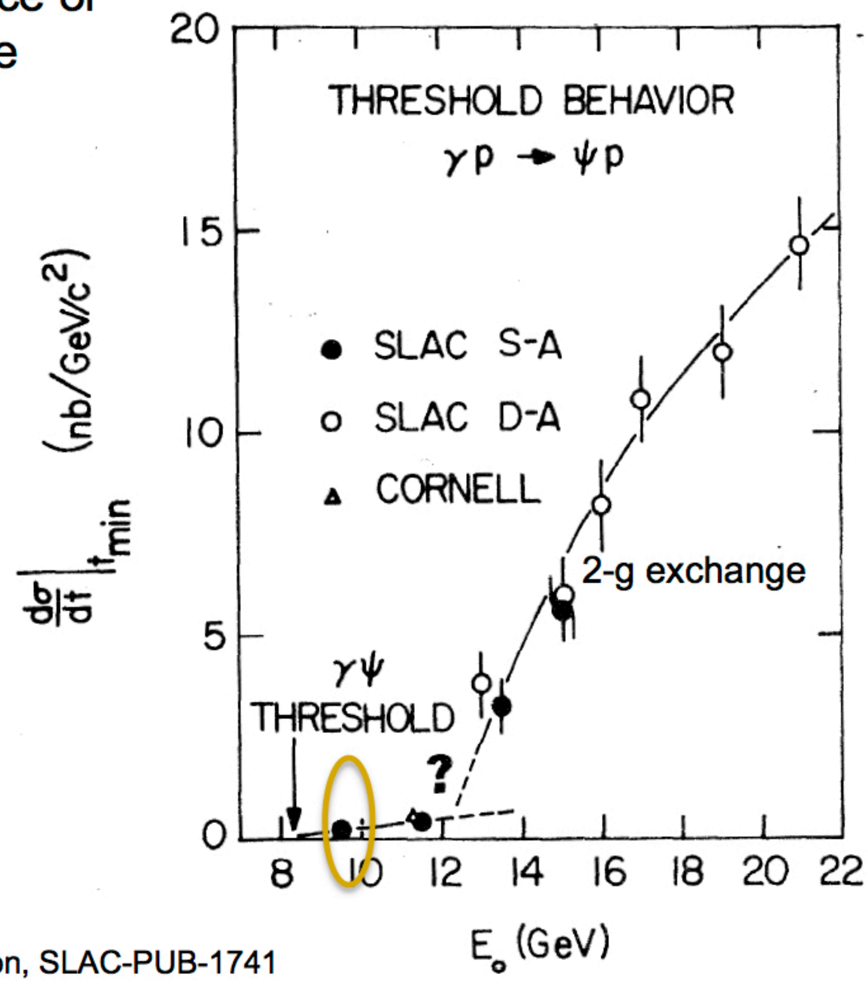
SLAC single arm measurements

Flattening of cross section near the threshold

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

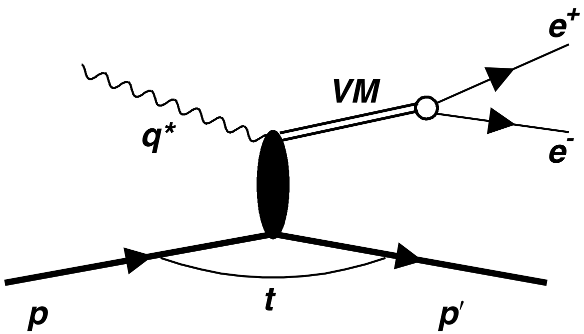


R.L. Anderson, SLAC-PUB-1741



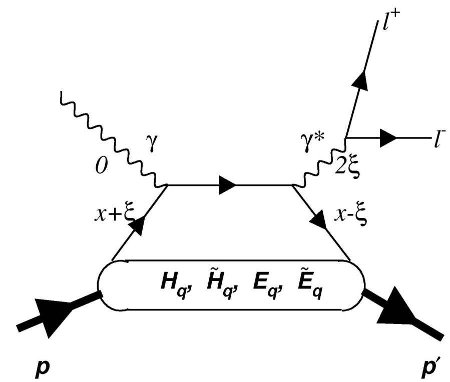
e^+e^- with CLAS12 – E12-12-001

Vector Meson Production

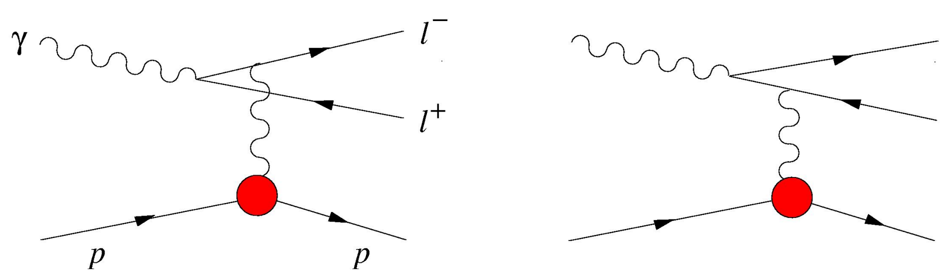


$$VM = \rho^0; \omega; \phi; J/\psi$$

Time-like Compton Scattering



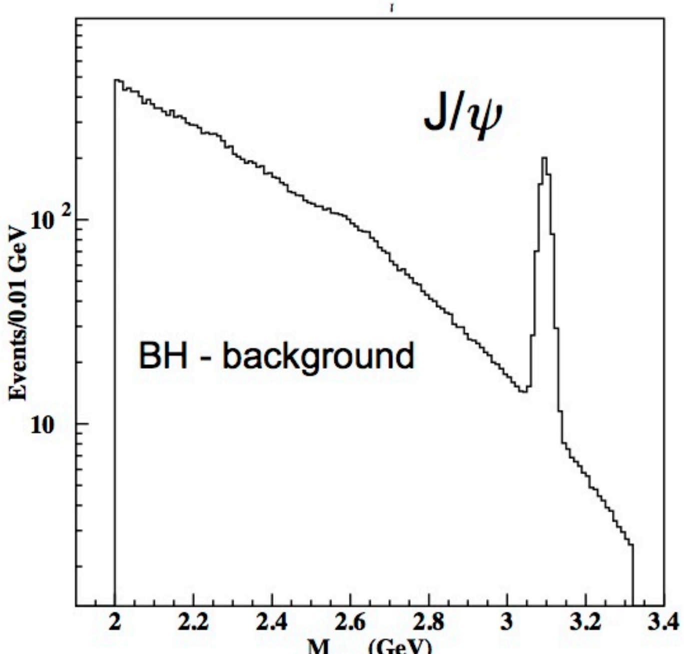
Bethe-Heitler Process

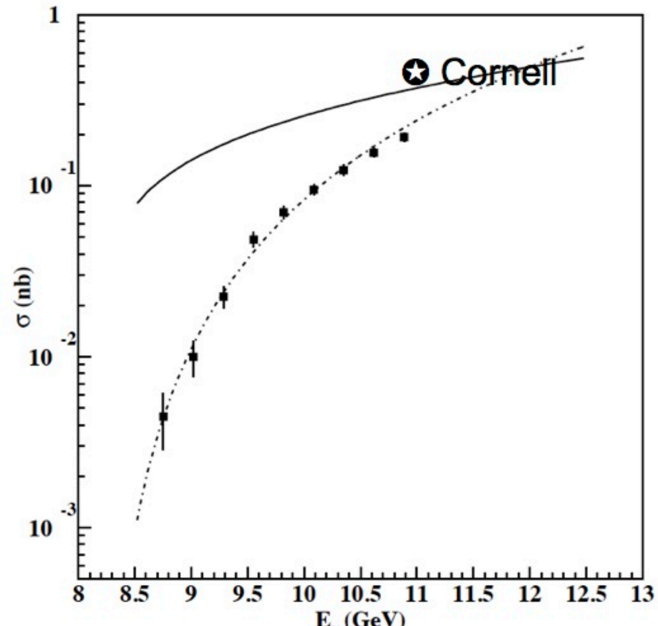


E12-12-001: TCS and J/ψ photoproduction

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

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

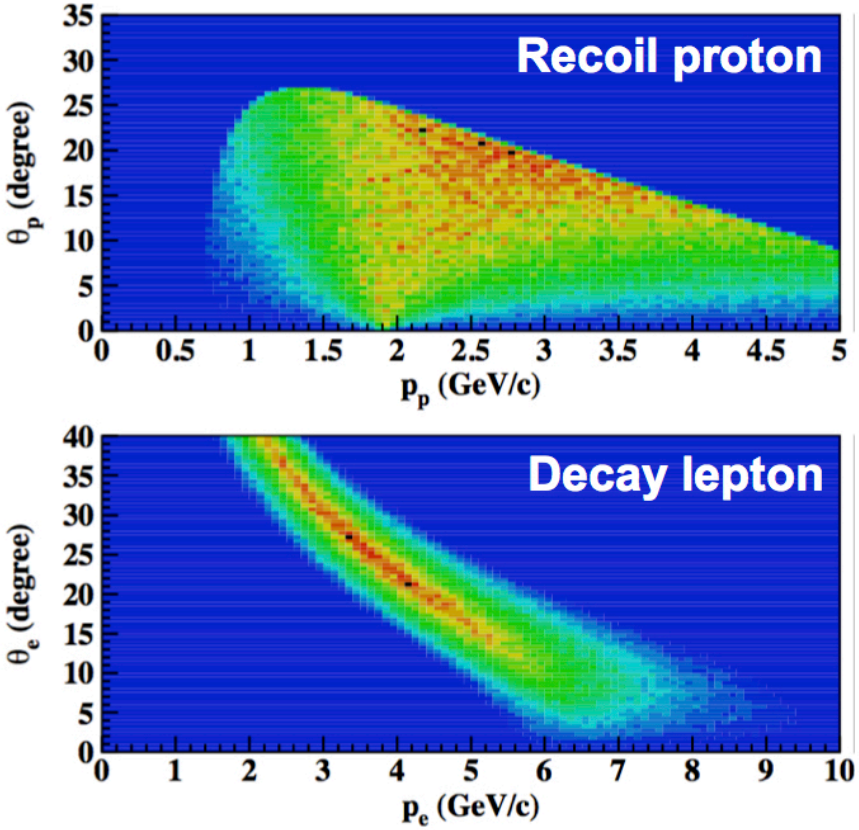




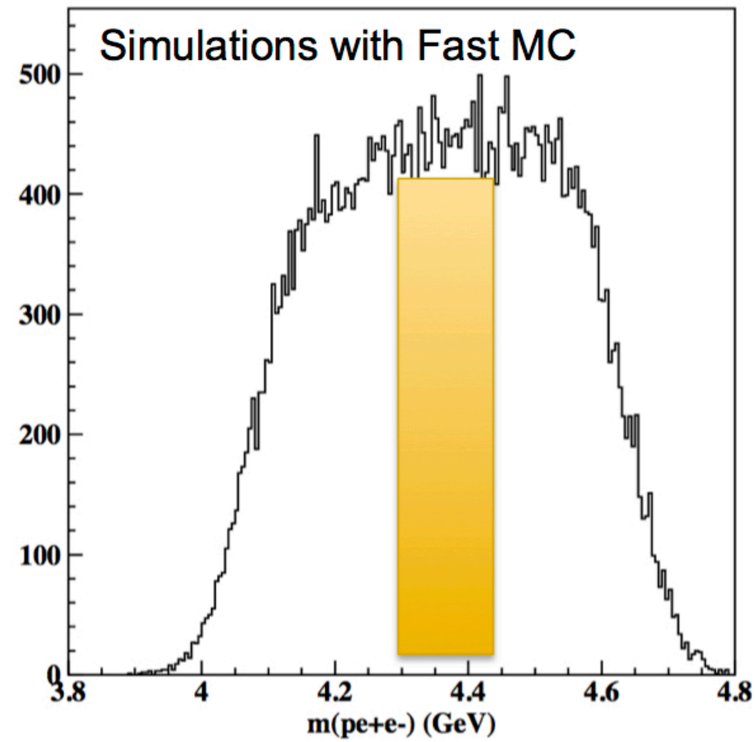
120 days of running at luminosity of 10^{35} cm^{-2} sec^{-1}

Kinematics for J/ψ photoproduction

Only CLAS12 FD is needed



With 11 GeV beam CLAS12 will cover LHCb pentaquark mass range



E12-12-001: J/ψ production rates

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

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

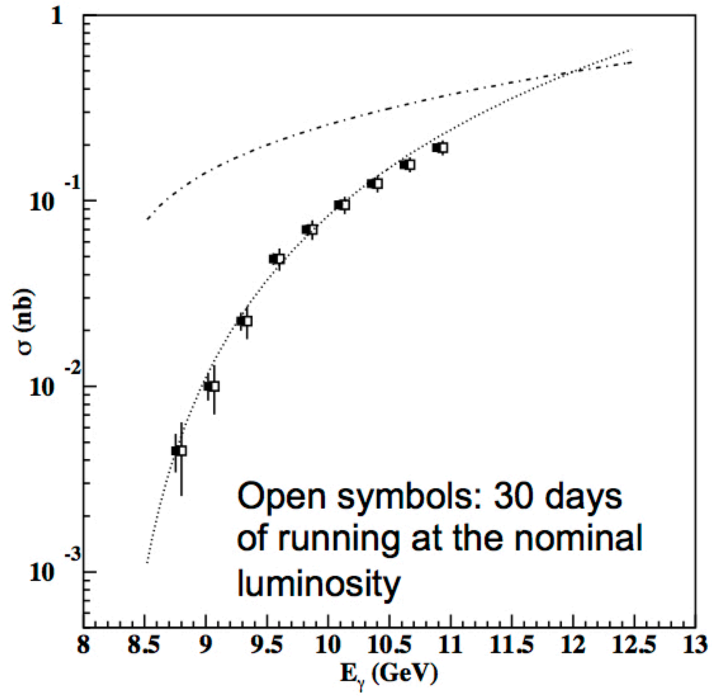
Virtual photon flux

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

Bremsstrahlung photon flux integrated over the target thickness

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

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



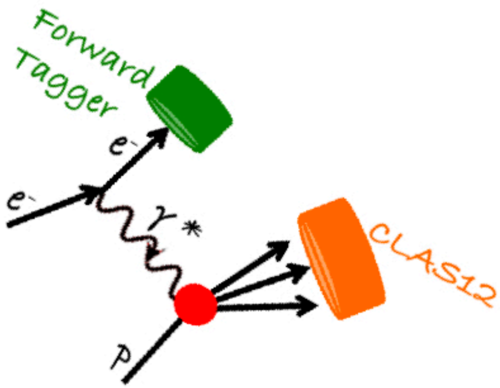
ε=0.1 – acceptance
Br=0.06

- 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

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:

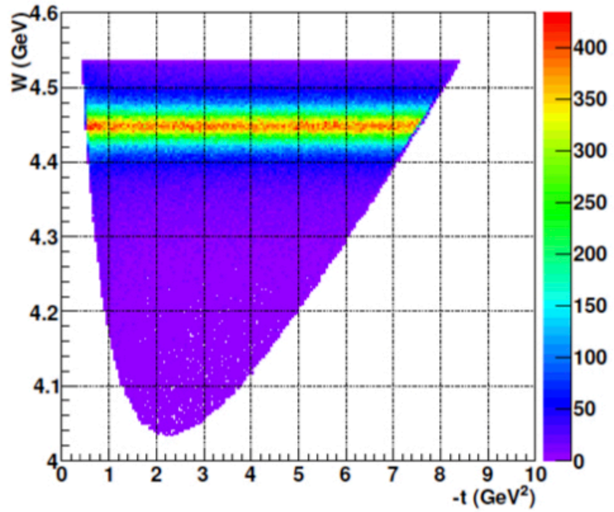
- Higher $\sqrt{s}$ resolution
- Initial state is known: measure p and/or J/ψ decays only to tag the reaction
- Lower rate

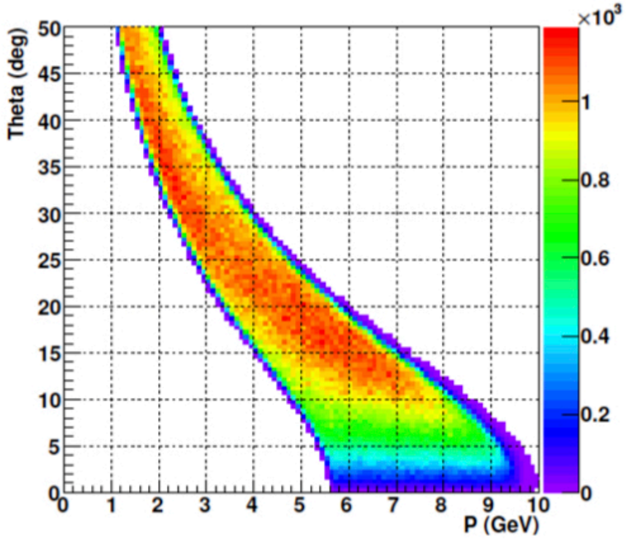
E12-11-005: kinematics

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





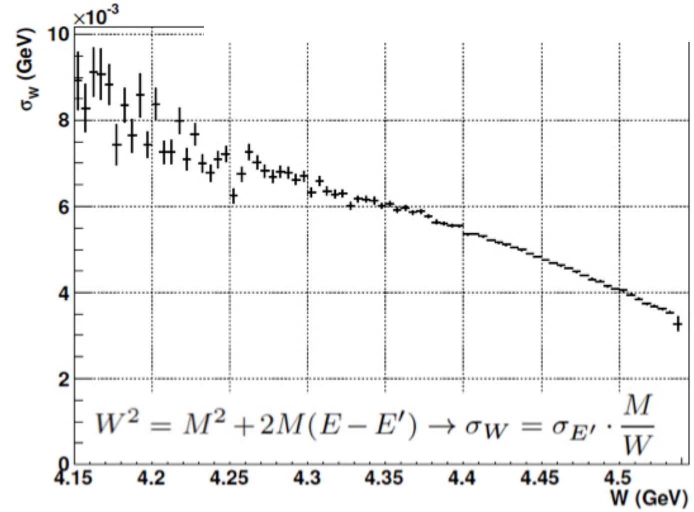
E12-11-005: acceptance, resolution, rates

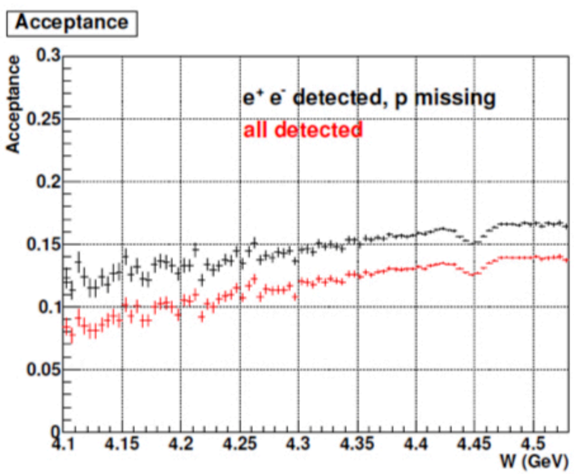
MC events projected on CLAS12 via FASTMC.
Assumptions:

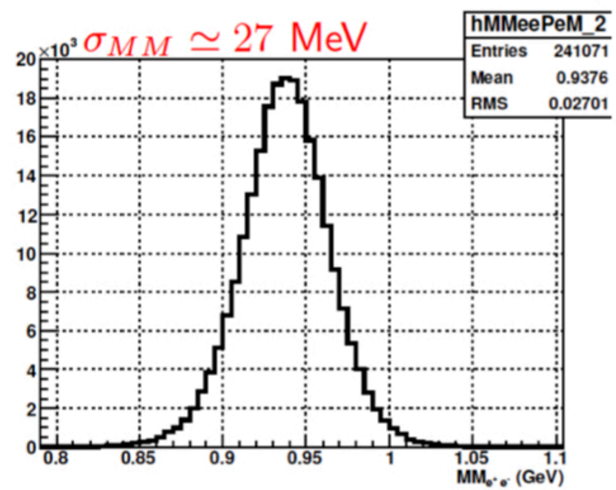
- CLAS12-CD acceptance for e^+/e^- is 0
- Only consider events with both e^+ and e^- from J/ψ in CLAS12-FD
- No combinatorial background included yet

Two reconstruction strategies:

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





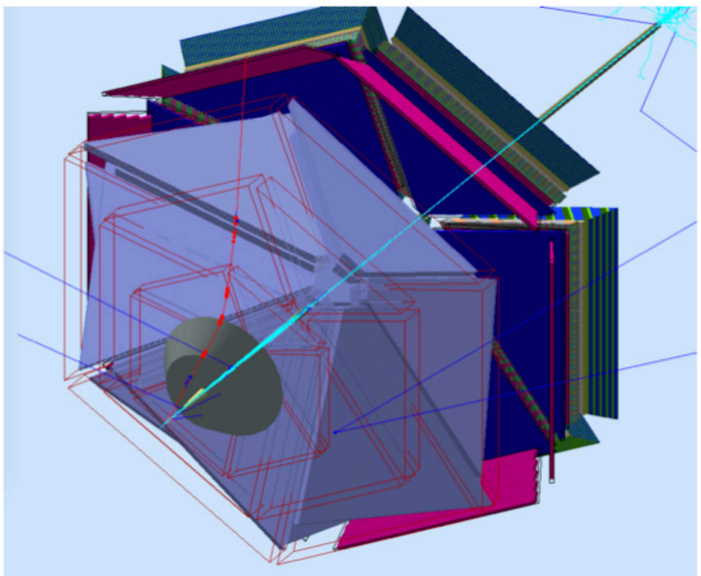


Expected rates – $1.5\text{x}10^3\ \sigma_\gamma$ event/day/μbarn

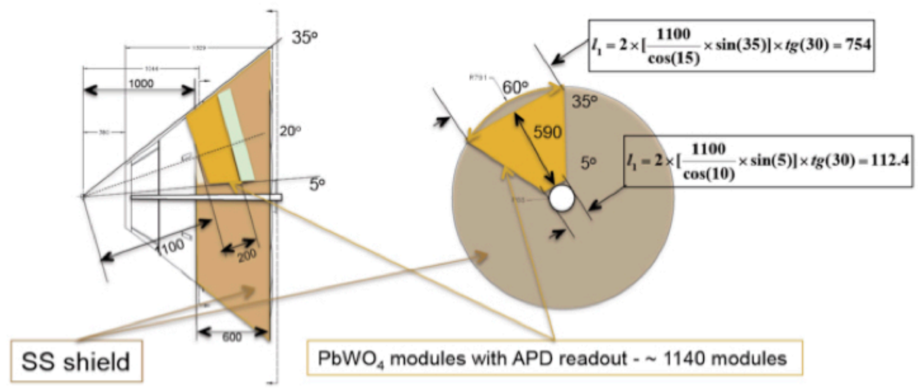
DDVCS and J/ψ electroproduction

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

Use heavily shielded CLAS12 forward detector for muons



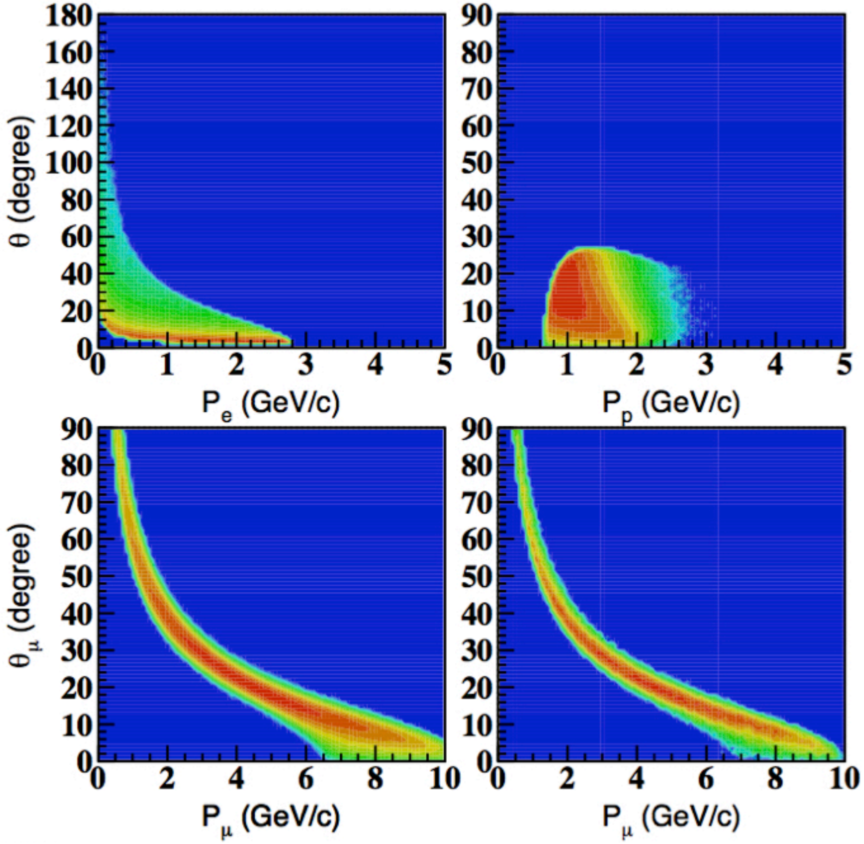
Use a compact electromagnetic calorimeter (part of the shield) for detection of scattered electrons

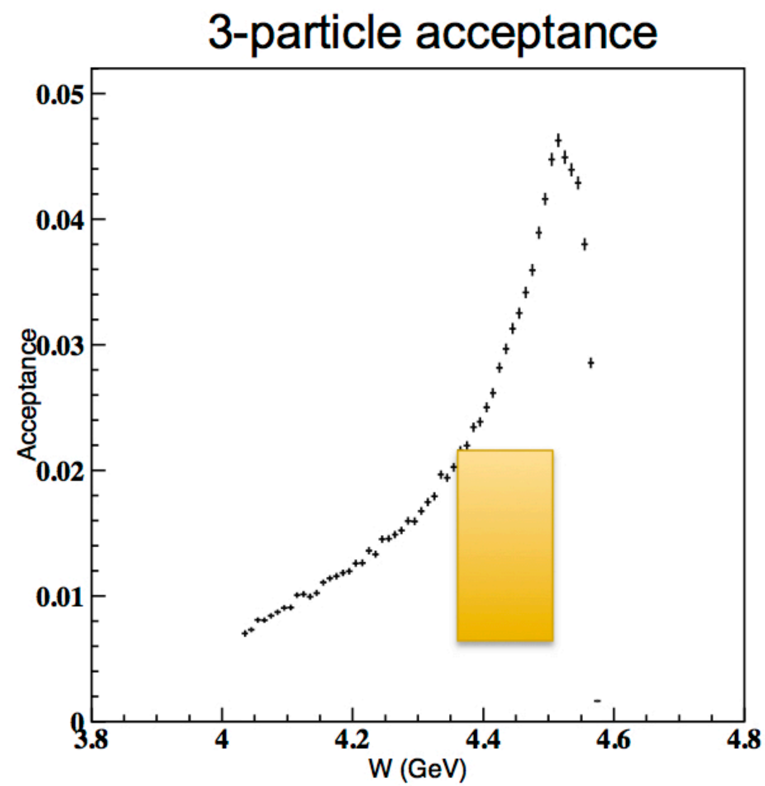


LOI never made to PAC43, but was fully ready.
Asking for 100 days of running at luminosity of 10^{37} cm^{-2} s^{-1}

Kinematics of J/ψ electroproduction

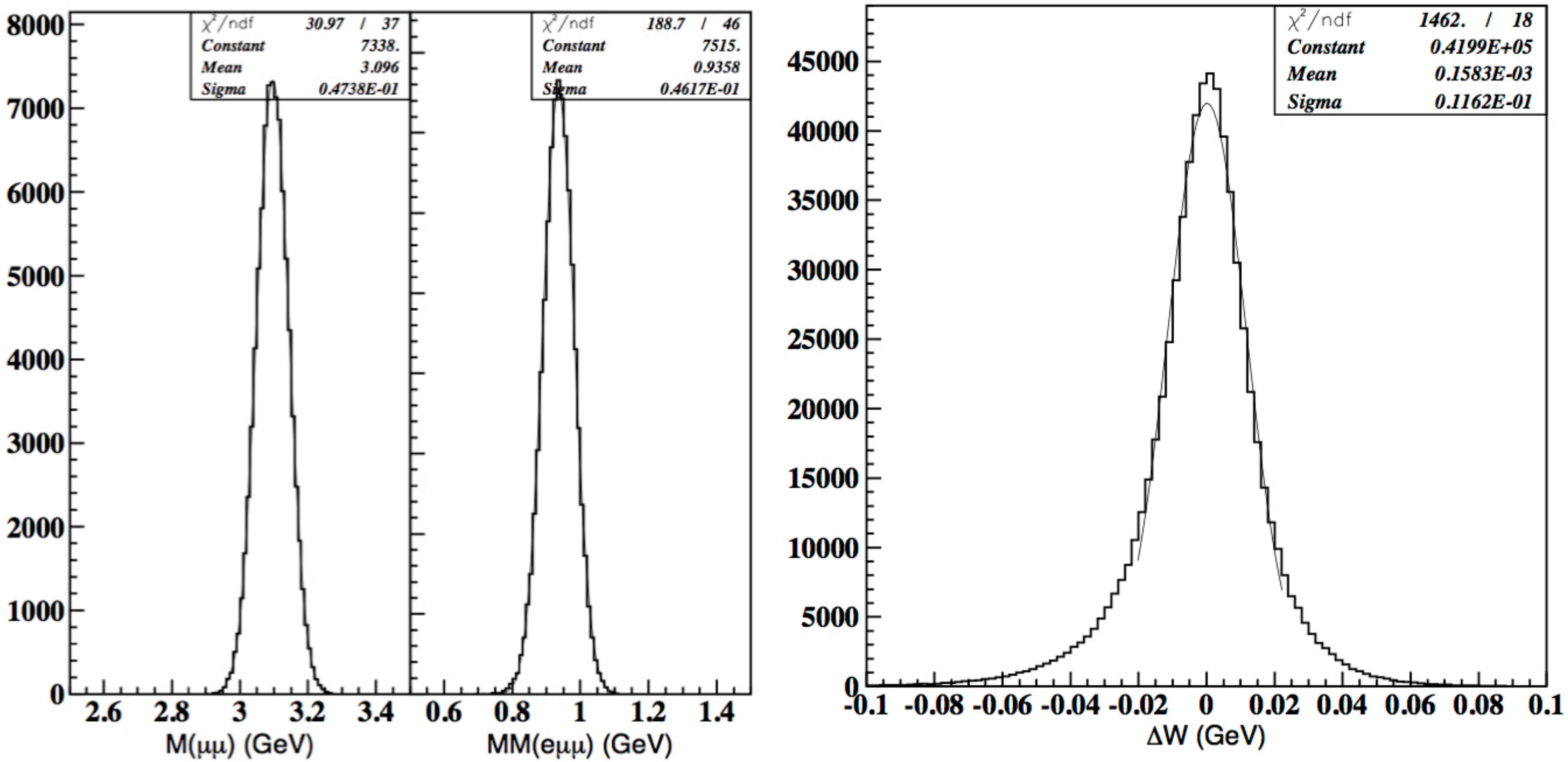
- Modified Fast MC to include the calorimeter and additional smearing for muons due to the multiple scattering in the shielding
- Event generator - $1/Q^4$ and exponential *t*-dependence, b_0=1.2 GeV^{-2}
- Recoil protons will not be detected





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/ψ*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

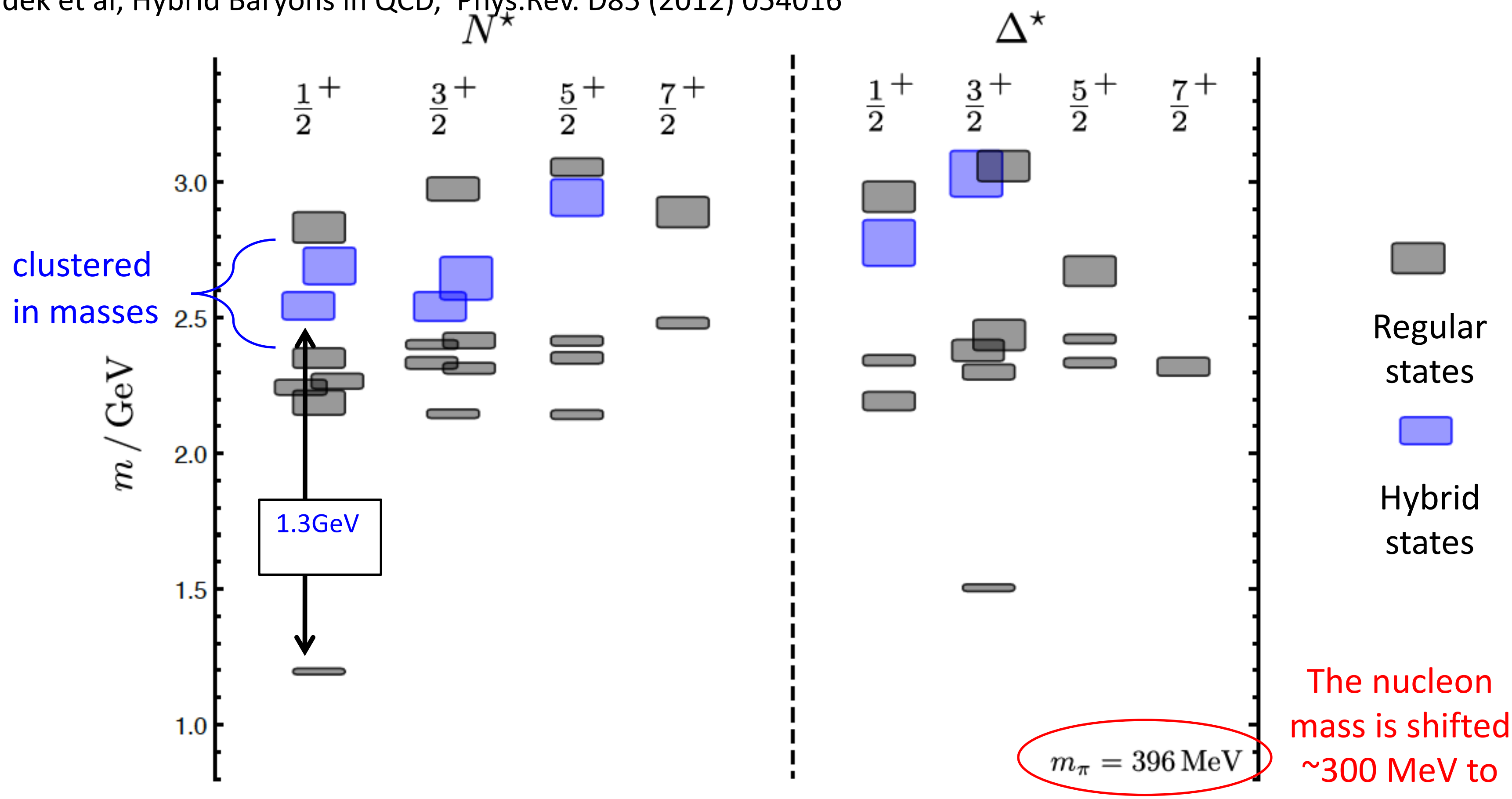
A Search for Hybrid Baryons with CLAS12

Hybrid Baryons in LQCD

QCD allows for the existence of Hybrid Baryons.

LQCD predicts several hybrid baryons states.

J. Dudek et al, Hybrid Baryons in QCD, Phys.Rev. D85 (2012) 054016

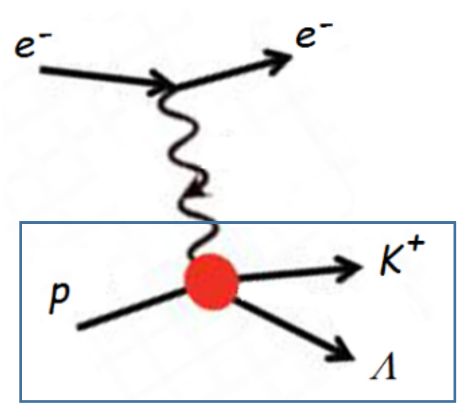


The nucleon mass is shifted ~300 MeV to higher masses

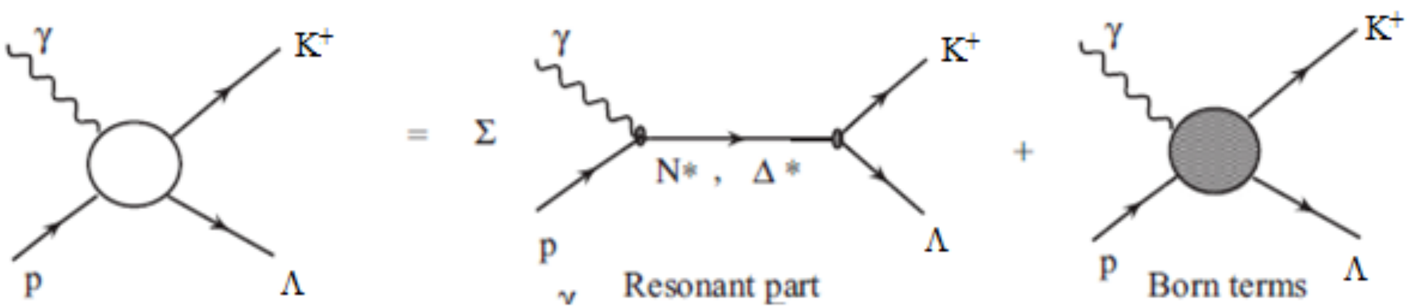
Differently from the case of hybrid mesons, hybrid baryons are predicted to have **same quantum numbers** of N* resonances

Separating Q^3G from Q^3 states: $A_{1/2,\,3/2}(Q^2)$ and $S_{1/2}(Q^2)$

Transverse helicity amplitude $A_{1/2}(Q^2)$, $A_{3/2}(Q^2)$ and longitudinal helicity amplitude $S_{1/2}(Q^2)$ allow to distinguish Q^3G from Q^3 states



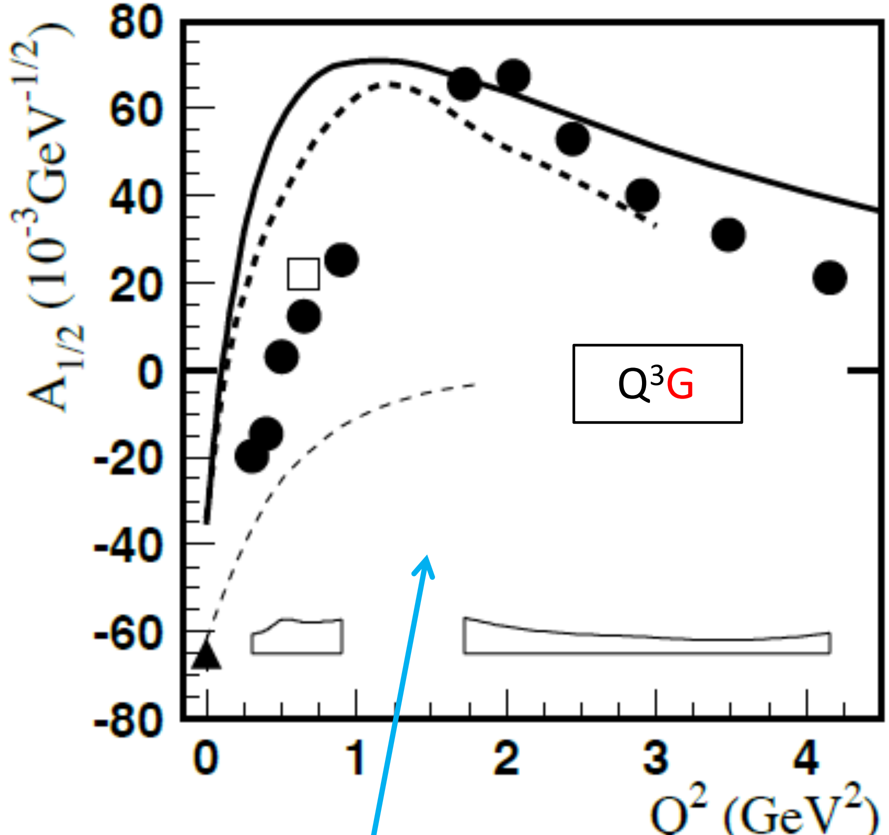
Electroexcitation via quasi-real photon exchange can be considered for practical purposes photo-production

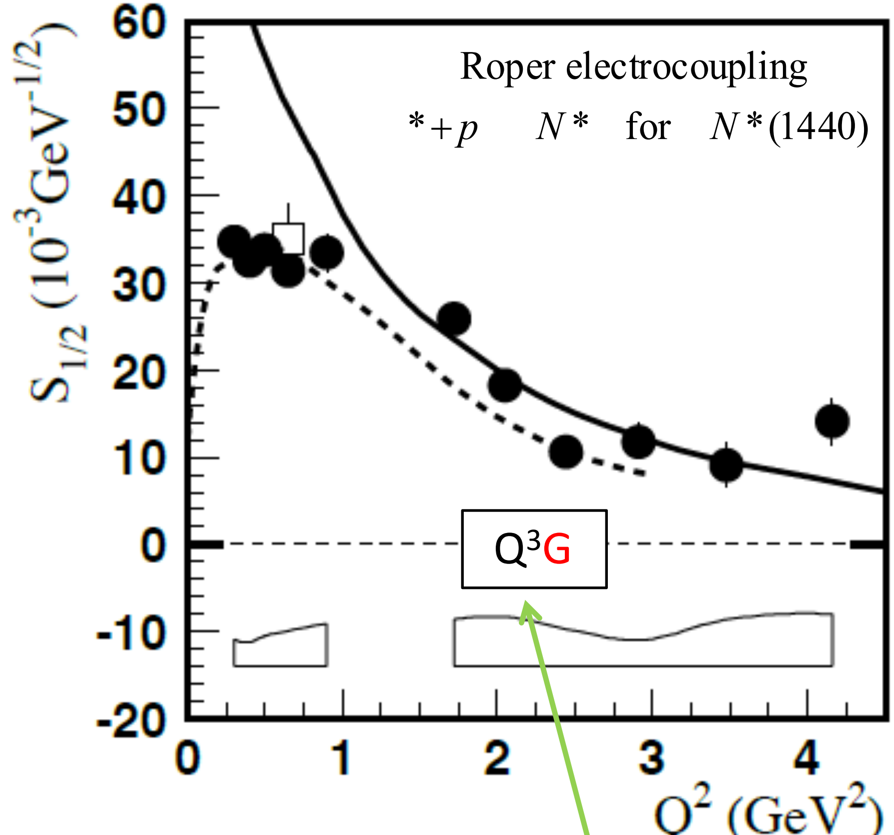


V. I. Mokeev, CLAS Collaboration, PHYSICAL REVIEW C 86, 035203 (2012)

Separating Q^3G from Q^3 states

Transverse helicity amplitude $A_{1/2}(Q^2)$ and longitudinal helicity amplitude $S_{1/2}(Q^2)$ allow to distinguish Q^3G from Q^3 states





A drop of the transverse helicity amplitudes $A_{1/2}(Q^2)$ faster than for ordinary three quark states, because of extra glue-component in valence structure

A suppressed longitudinal amplitude $S_{1/2}(Q^2)$ in comparison with transverse electro-excitation amplitude

I. G. Aznauryan et al., CLAS Collaboration, PHYSICAL REVIEW C 80, 055203 (2009)

Signature

Based on available knowledge, the ***signature*** for hybrid baryons may consist of ***:***

- Extra resonances with $J^p=1/2^+$ and $J^p=3/2^+$, with masses from 1.8 GeV to 2.5 GeV and decays to $N\pi\pi$ or KY final states

- A drop of the transverse helicity amplitudes $A_{1/2}(Q^2)$ and $A_{3/2}(Q^2)$ faster than for ordinary three quark states, because of extra glue-component in valence structure

- A suppressed longitudinal amplitude $S_{1/2}(Q^2)$ in comparison with transverse electro-excitation amplitude

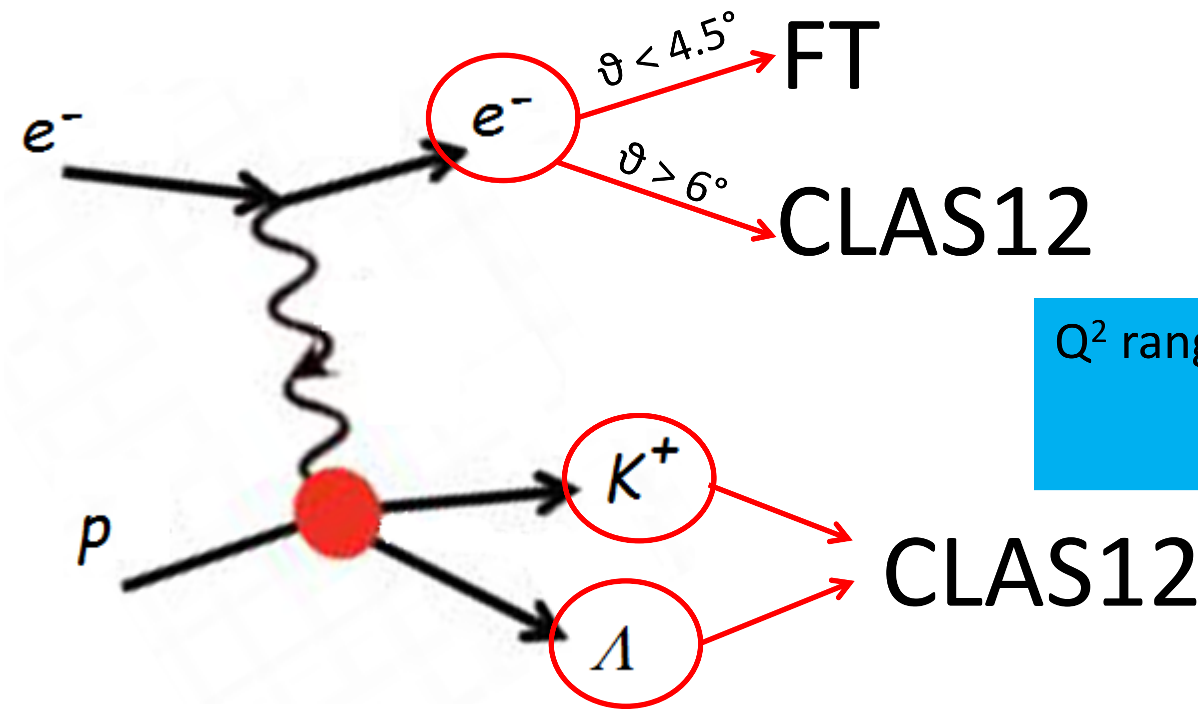
The proposal focuses on:

$$e\,p \longrightarrow e\,p\,\pi^+\pi^-$$

$$e\,p \longrightarrow e\,K^+\Lambda,\ e\,K^+\Sigma^0$$

Experiment

Scattered electrons will be detected in Forward Tagger for angles from 2.5° to 4.5°. FT allows to probe the **crucial Q^2 range** where hybrid baryons may be identified due to their fast dropping $A_{1/2}(Q^2)$ amplitude and the suppression of the scalar $S_{1/2}$ (Q^2) amplitude.



Q^2 range of interest: 0.05 - 2 GeV^2

Scattered electrons will be detected in the Forward Detector of CLAS12 for scattering angles greater than about 6°. Charged hadrons will be measured in the full range from 6° to 130°.

Quasi – Data Analysis

A hypothetical hybrid baryon contribution added at the amplitude level to the best presently available models: M_R = 2.2 GeV Γ_R=0.25 GeV $J^P = 1/2^+$ ($J^P = 3/2^+$)

The reaction cross section has been calculated with and without the baryon resonance contribution to determine:

1. Minimum beam time needed to obtain statistical uncertainty for cross sections comparable with CLAS photoproduction data.
   ⟶ 100 days of beam time (50 days at 6.6 GeV & 50 days at 8.8 GeV)

1. The Legendre moments of the unseparated and polarization interference components of the cross section.
   ⟶ Search for distinctive structures to the added resonance.

2. The statistical sensitivity to hybrid baryons electrocouplings.
   ⟶ Minimum electrocoupling values with 100 days of beam time.

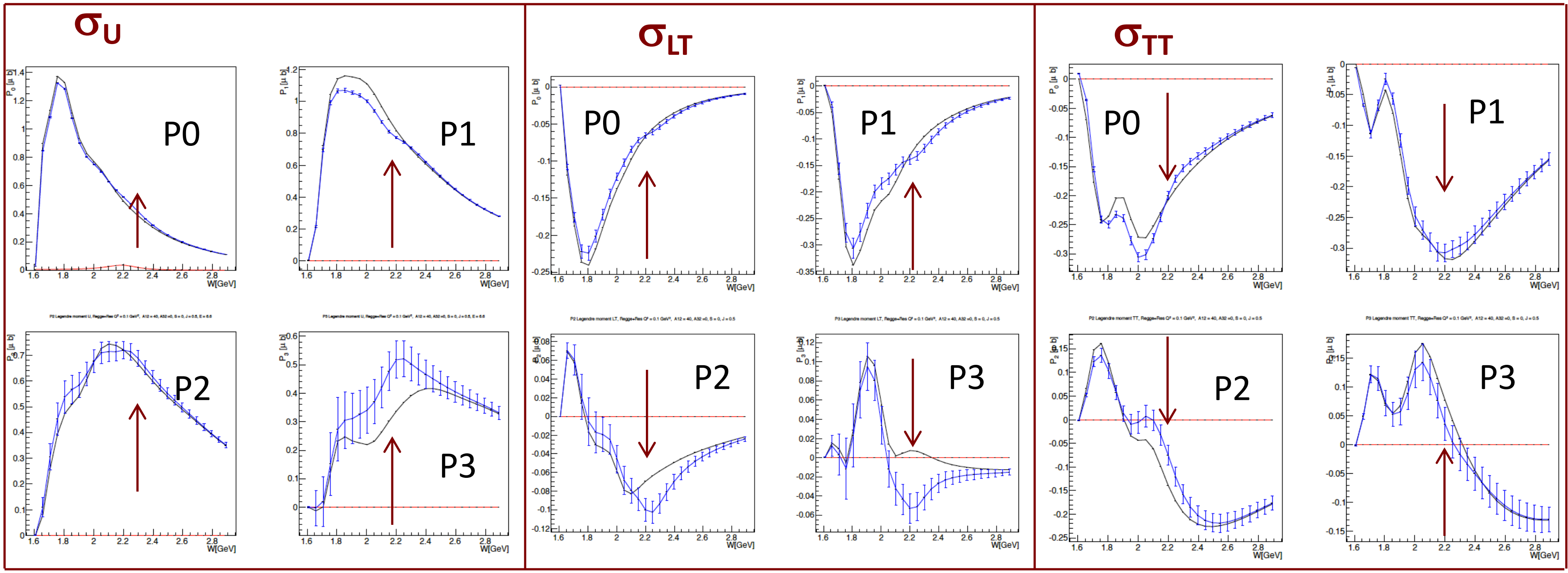
4. The capability of extracting the added resonance parameters from expected data. ⟶ Blind analysis of quasi-data.

Extraction of Legendre Moments

e p ⟶ e $K^+\Lambda$

First Legendre Moments

Black curves RPR 2011 model
Blue points RPR 2011 + Resonance



- J = ½ Regge + Res.
- $Q^2 = 1\ GeV^2$ $M_{res} = 2.2$ GeV $A_{1/2} = 0.04\ GeV^{-1/2}$ $S_{1/2} = 0$

Significant structures appear in most of the Legendre moments at the value of W = 2.2 GeV, corresponding to the mass of the added hybrid baryon

Summary

- A program to search for new states of baryonic matter: **hybrid baryons.**
- Complementing the international program to search for **hybrid mesons.**
- Identification of hybrid baryons will verify fundamental expectations of **strong QCD on the role of glue.**
- Search for these states in exclusive channels will cover the kinematical range $Q^2 > 0.05$ GeV^2, W< 3 GeV.
- Demonstrated for two major electroproduction channels **$p\pi^+\pi^-$** and **K^+Y** that, with **100 days** beam time with CLAS12, we have the statistical sensitivity to find new excited states and identify their nature.
- Amplitude analysis will be developed with the **theoretical support groups** to establish the existence and properties of new resonances in the 1.8 GeV < M < 3.0 GeV mass region.