Di-muon electroproduction with CLAS12

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CLAS collaboration meeting, June 16 - 18, 2016

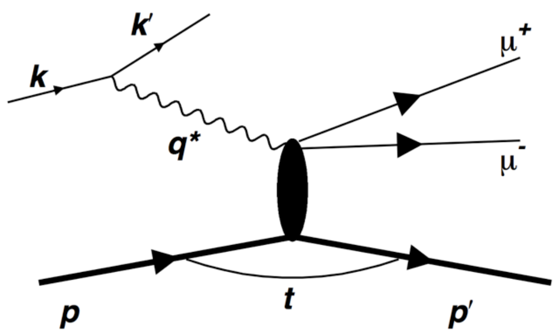
- Physics motivation for LOI:
  - Double DVCS
  - J/ψ-electroproduction
- Detector configuration
  - Background simulations
  - GEM tracker
  - $PbWO_4$ calorimeter
  - Triggering and final state identification
- Expected results
- Summary

New LOI for di-muon electroproduction

- Includes two experiments:
  - study of Generalized Parton Distributions using the Double Deeply Virtual Compton Scattering (DDVCS) process
  - study the nucleon gluonic structure in J/ψ production near threshold region

The Reaction:

$$ep \rightarrow e'p'\gamma^*(J/\psi) \rightarrow e'\mu^+\mu^-(p')$$



in a wide kinematical range in: x_B, Q^2, $M_{\mu\mu}$, t

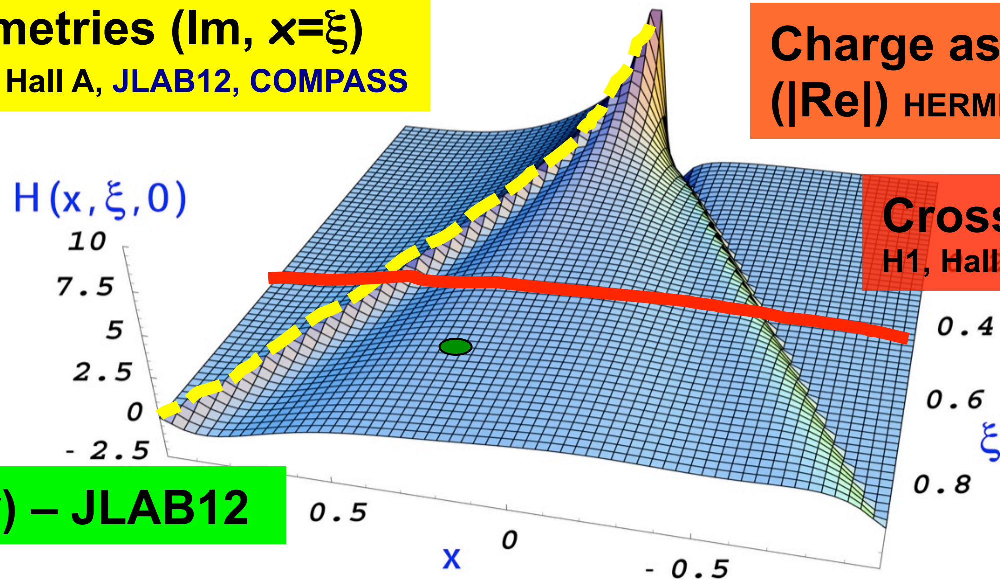
Detecting time-like photon or a vector meson through their di-muon decay eliminates ambiguity and anti-symmetrization issues for DDVCS, and reduces combinatorial background under the J/ψ peak in the lepton pair invariant mass distribution

Accessing GPDs experimentally

Spin asymmetries (Im, $x=\xi$)
HERMES, CLAS, Hall A, JLAB12, COMPASS

Charge asymmetry and TCS (|Re|) **HERMES, COMPASS. JLAB12**

Cross sections (|Re|^2)
H1, Hall A, JLAB12, COMPASS



DDVCS ($x \neq \xi$) – JLAB12

GPDs at $x \neq \xi$ point with DDVCS

By measuring imaginary part of the DDVCS amplitude, e.g the beam spin asymmetry (BSA), one has access, i.e. in a concise notation:

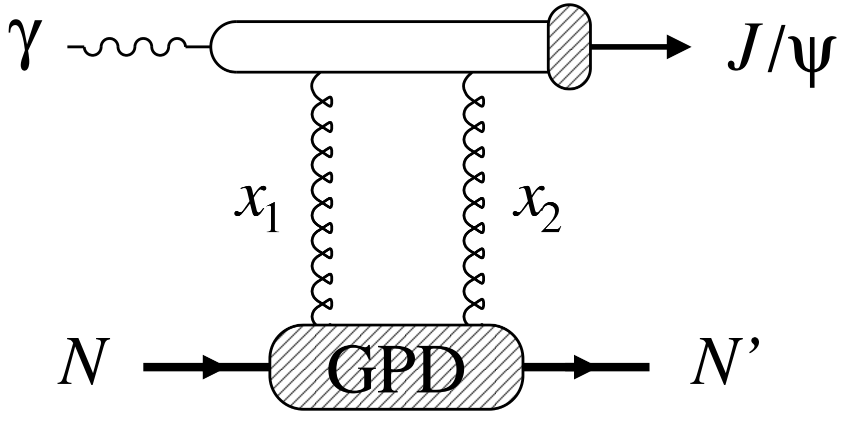
$$H\left(2\xi' - \xi, \xi, t\right) + H\left(\xi - 2\xi', \xi, t\right)$$

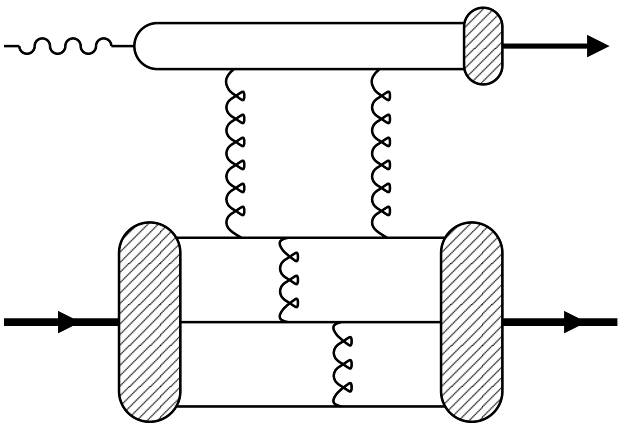
$$\xi' \approx \frac{x_B}{2 - x_B}; \quad \xi = \xi' \frac{Q^2 + Q'^2}{Q^2}$$

- This allows the mapping of GPDs along each of the three axis (x, ξ and t) independently
- An important restriction is that only the region $0 < 2\xi' - \xi < \xi$ can be accessed
- Prediction of the "handbag" formalism is the sign change of BSA in transitioning from "space-like dominated" to "time-like dominated" regime

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





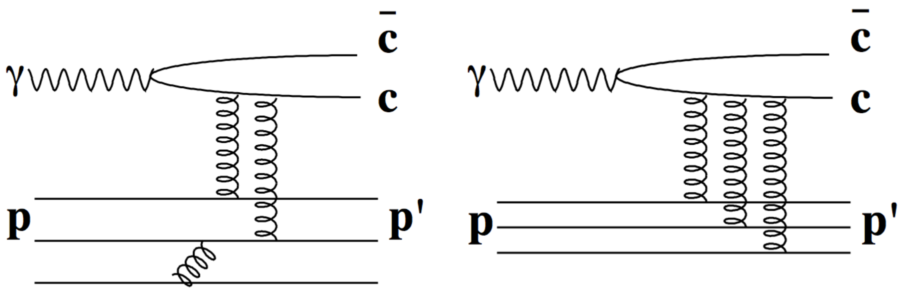
At high energies (HERA, FNAL) probes gluon GPDs. Wealth of data exists on electroproduction at W>10 GeV

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

There are no electroproduction measurements in this region

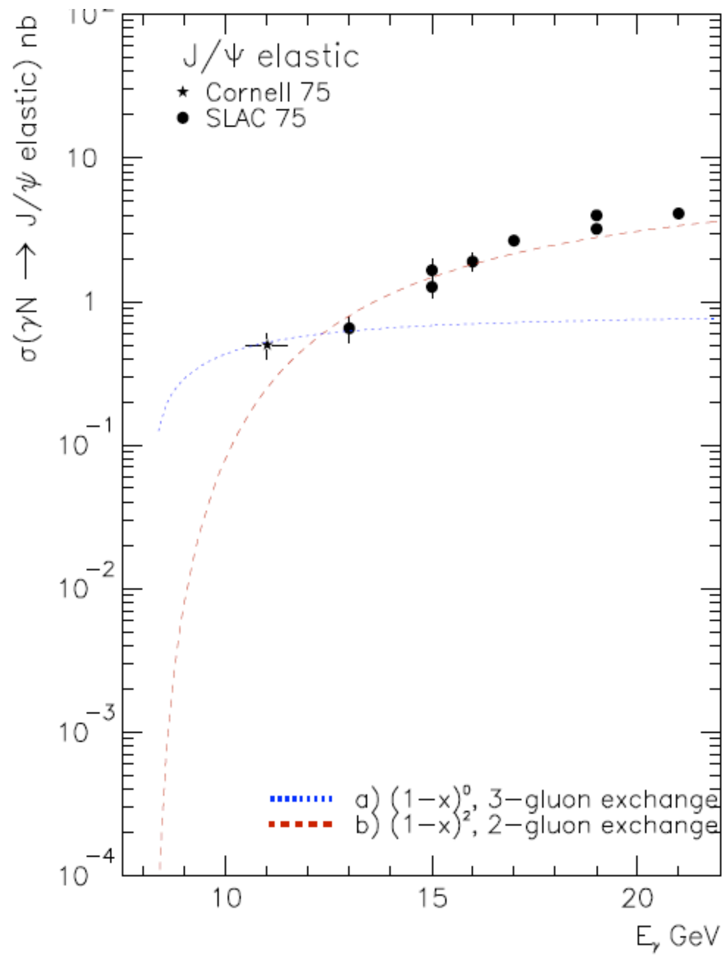
J/ψ photoproduction near threshold

- The lowest published energy point is at E_γ=11 GeV
- Production mechanisms, 2-gluon or 3-gluon exchange
- Need precision data to sort this out



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

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

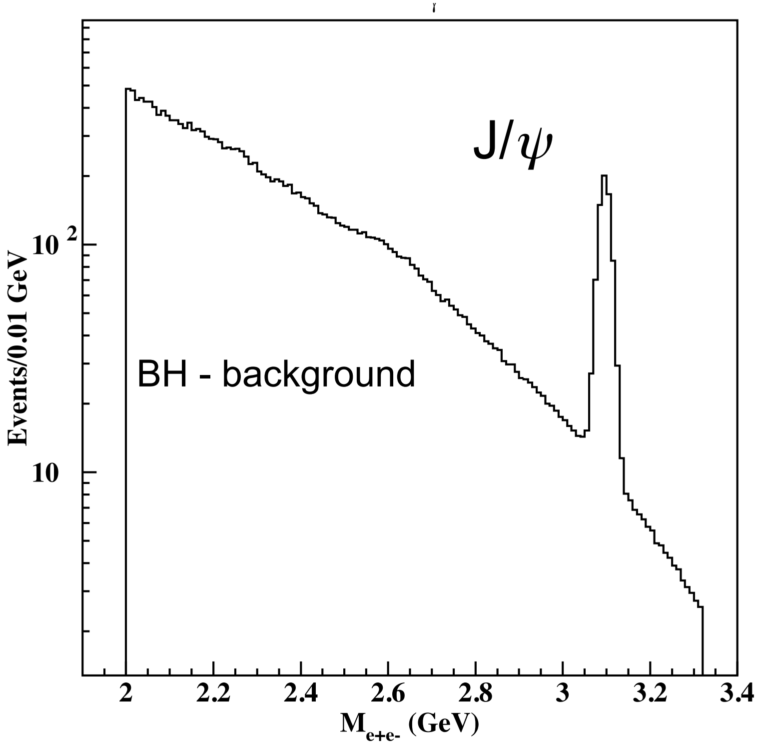


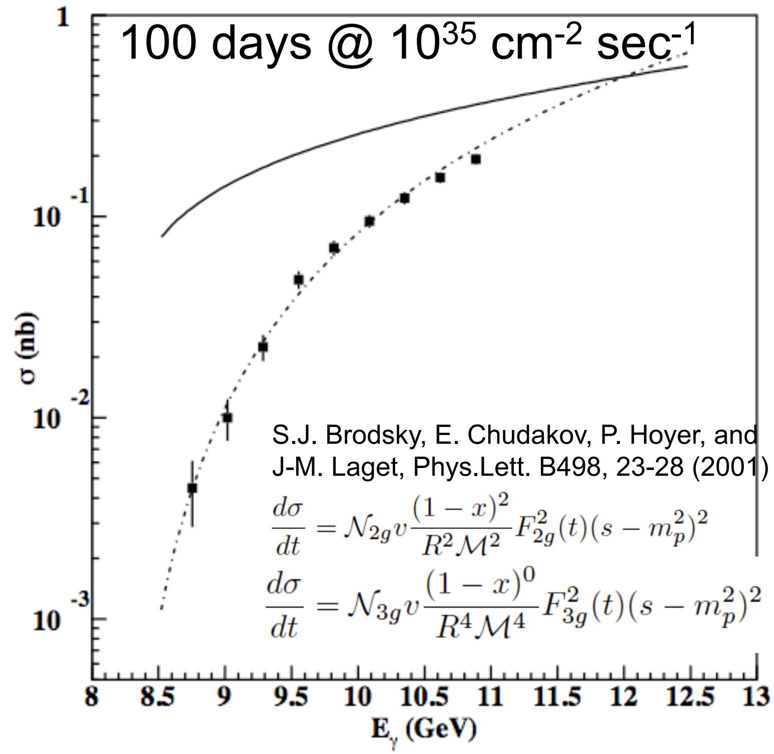
S.J. Brodsky, E. Chudakov, P. Hoyer, and J-M. Laget, Phys.Lett. B498, 23-28 (2001)

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

- Quasi-real (untagged) photoproduction of lepton pairs
- Only recoil proton and J/ψ decay leptons are detected
- Scattered electron kinematics from the missing momentum analysis

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

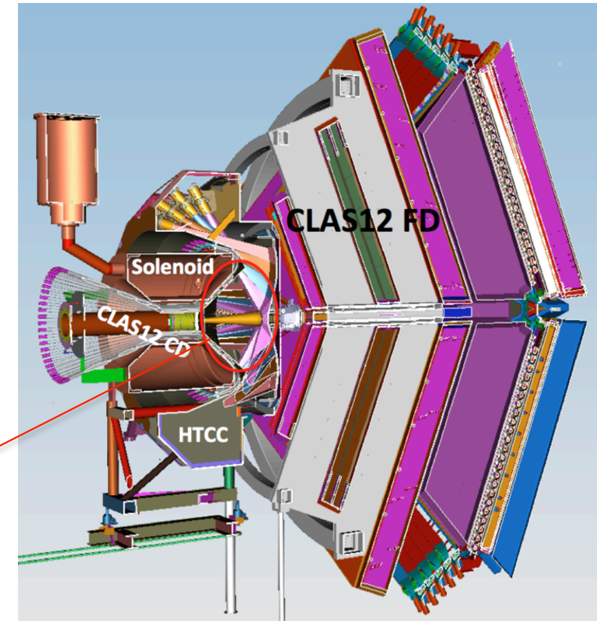


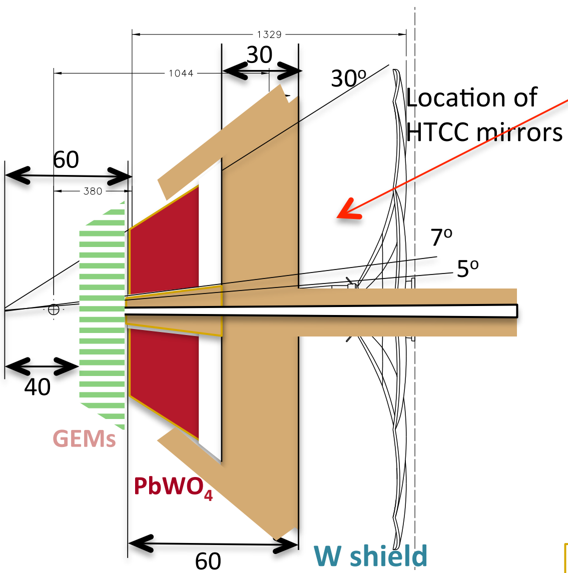


CLAS12 modifications for

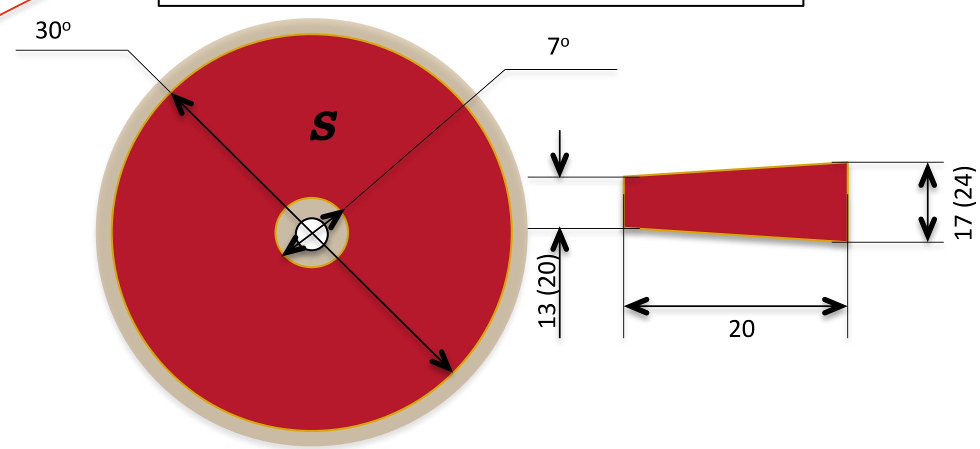
$$ep \rightarrow e'p'\mu^+\mu^- \;\; @ \;\; 10^{37}\, cm^{-2}\, s^{-1}$$

- Remove HTCC and install in the region of active volume of HTCC
  - a new Moller cone that extends up to 7°
  - a new $PbWO_4$ calorimeter that covers 7° to 30° polar angular range with 2π azimuthal coverage.
- Behind the calorimeter, a 30 cm thick tungsten shield covers the whole acceptance of the CLAS12 FD
- GEM tracker in front of the calorimeter for vertexing





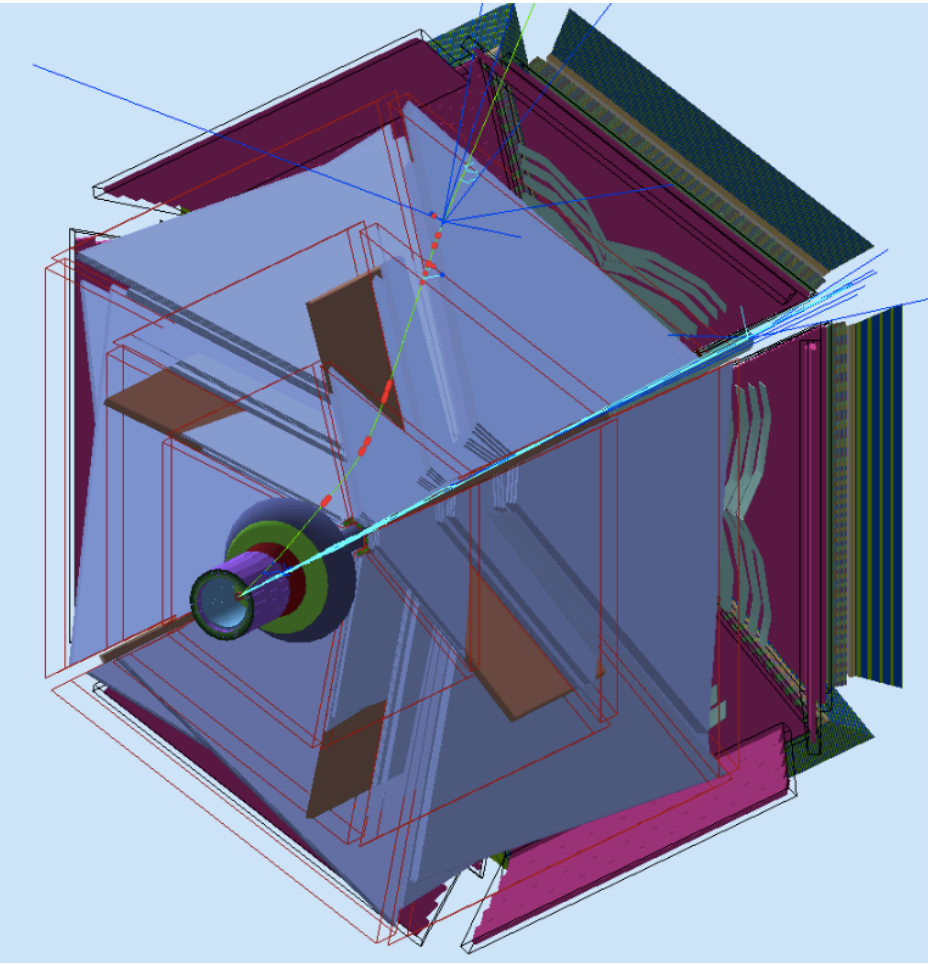
$$S = \pi l^2 [(tg^2(30^o) - tg^2(7^o)] = 3600\, cm^2;\; l = 60\, cm$$



$PbWO_4$ modules with APD readout - ~ 1200 modules

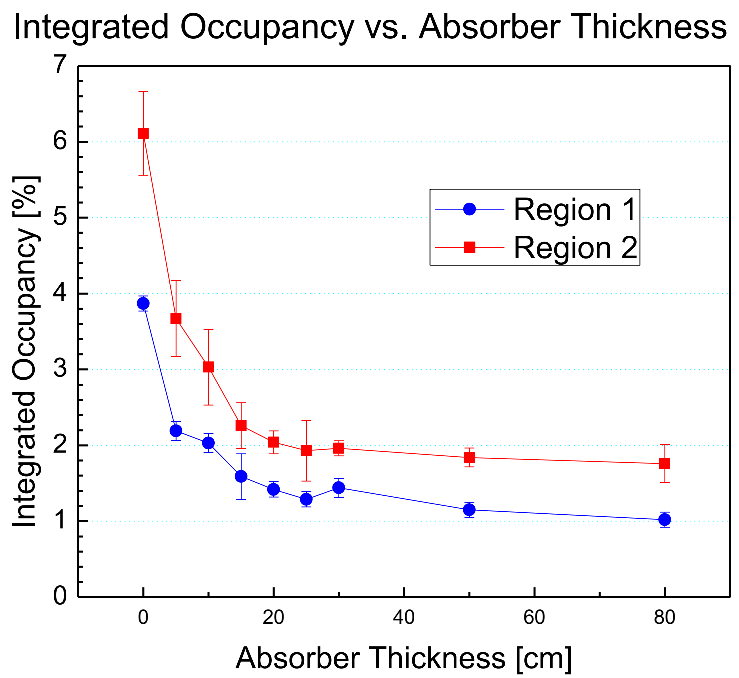
CLAS12 FD new configuration

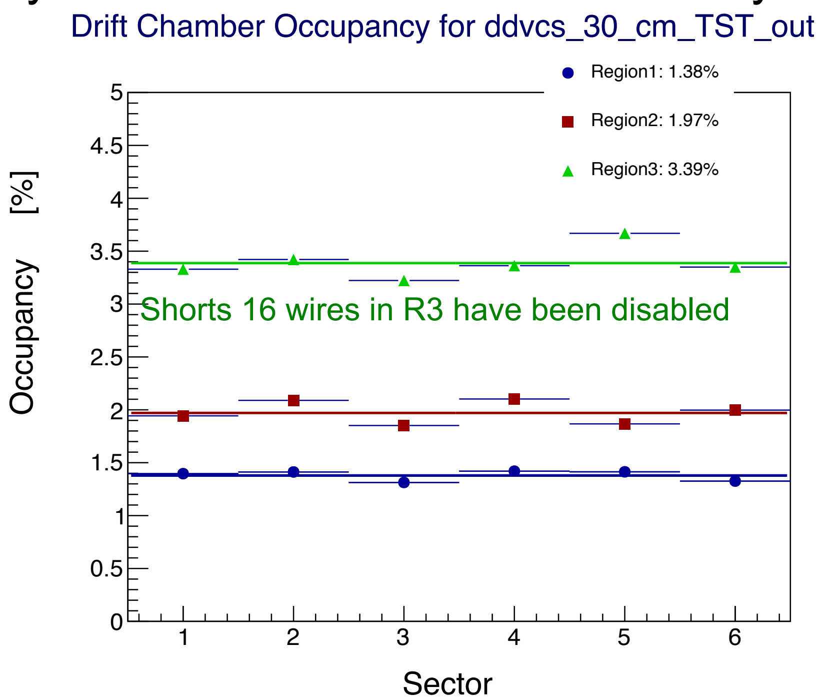
- In this configuration the forward drift chambers are fully protected from electromagnetic and hadronic background
- Calorimeter/shield configuration will play a role of the absorber for the muon detector, i.e. the CLAS12 FD
- The scattered electrons will be detected in the calorimeter
- GEM based tracking detectors will aid reconstruction of vertex parameters (angles and positions) of charged particles.



Simulation of background rates

- CLAS12 simulation software, GEMC
- Studies were done at 10^{35} $cm^{-2}sec^{-1}$ luminosity using a 5 cm long LH_2 target
- Generated events in the time window of 252 ns, grouped in bunches of 4 ns
- The rates provided below are scaled by x100 for 10^{37} $cm^{-2}sec^{-1}$ luminosity .

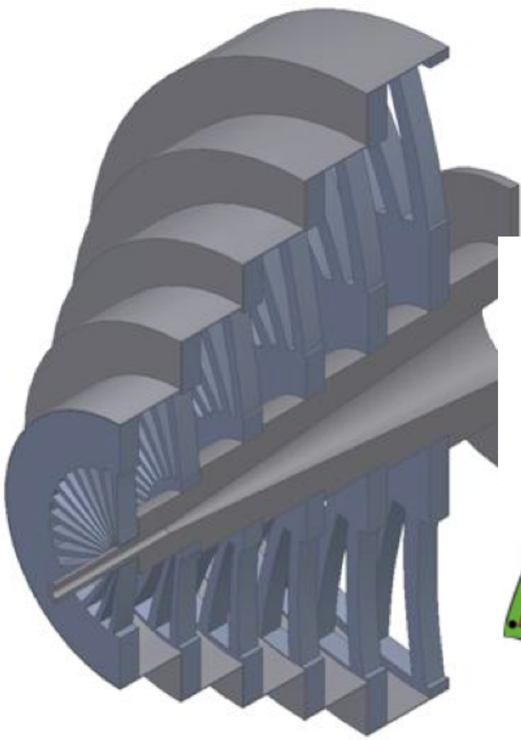




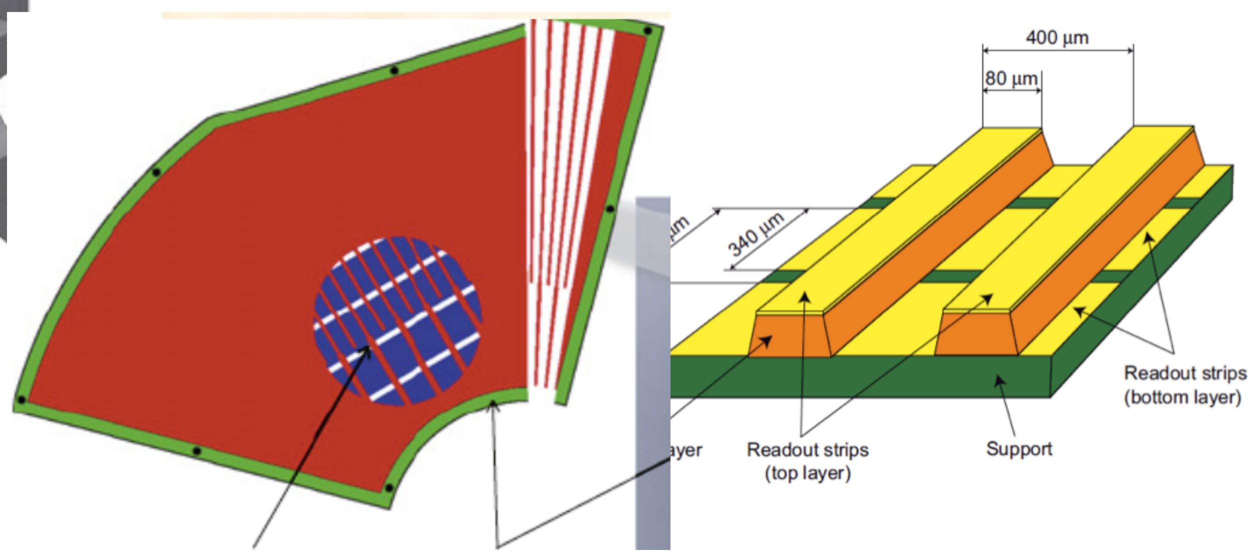
The final thickness of the absorber, 30 cm, was chosen based on considerations of π/μ separation, muon energy loss, and the muon momentum resolution

GEM tracker

- GEM based tracking detectors have been used in several JLAB experiments, e.g. Hall-B Bonus, eg6 ^{4}He, and Proton Charge Radius experiments
- High rate GEM trackers that can handle up to 1 MHz/cm^2 rates are currently being fabricated for Hall-A SBS spectrometer, and are prototyped for the proposed SoLid device.

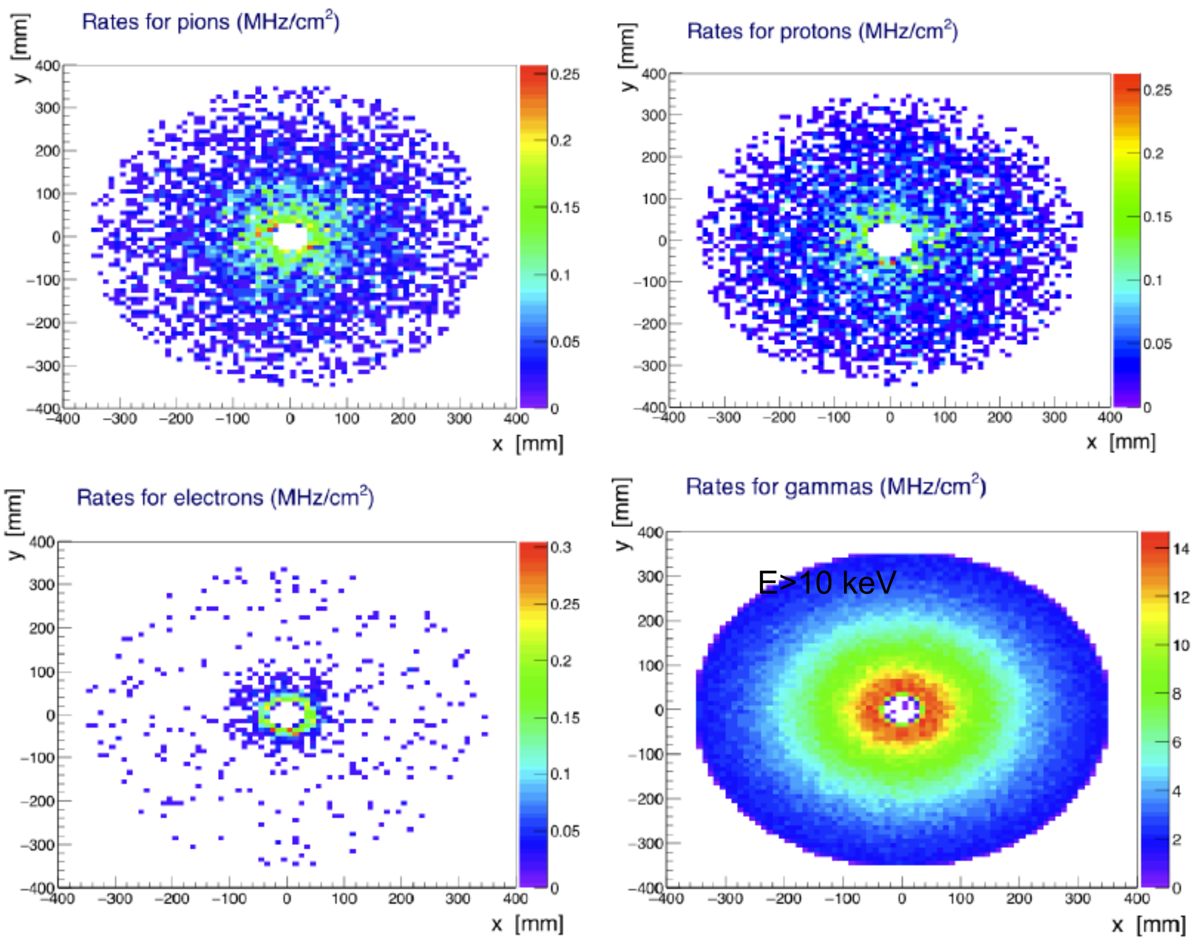


- "disk" design, five tracking detectors, first detector at 40 cm from the target
- polar angular coverage 5^o to 35^o. Each disc will be divided azimuthaly into six trapezoidal sections
- 2D readout strips, with radial and ϕ-readout strips to dene polar and azimuthal angles
- the area of the readout for the strip at 5^o 0.18 cm^2 (4.5 cm x 0.04cm)



Rates in GEM tracker

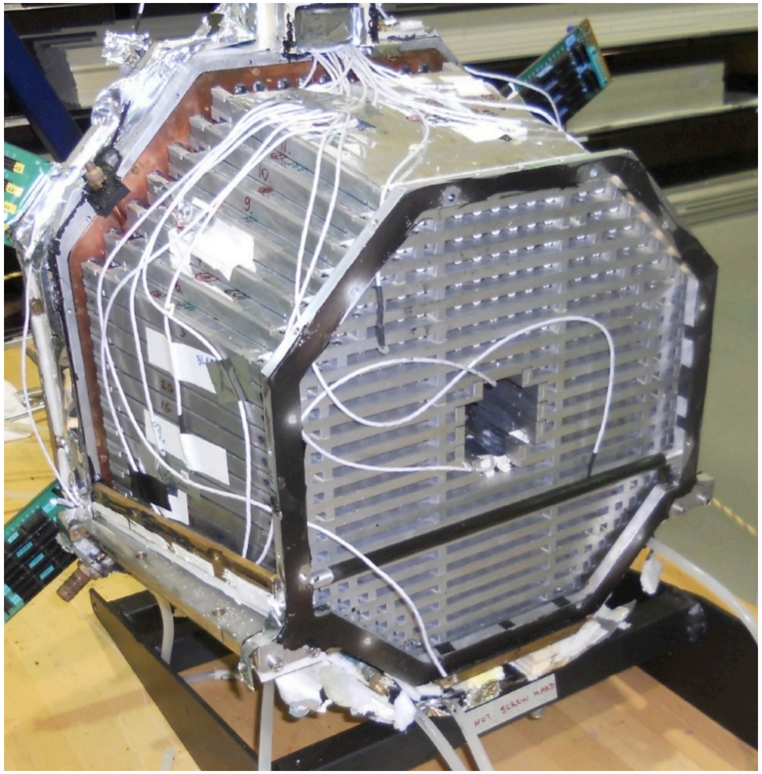
Scoring plane at 40cm, minimum angle 4.8° – rates in MHz/cm^2



- From studies performed for SBS and SoLid, only 0.5% of photons with E>10 keV will leave signal in GEM
- Highest rates in the GEM from photons is 70 kHz/cm^2
- Total rates ~600 kHz/cm^2 or ~100 kHz/strip for the "hottest" strip

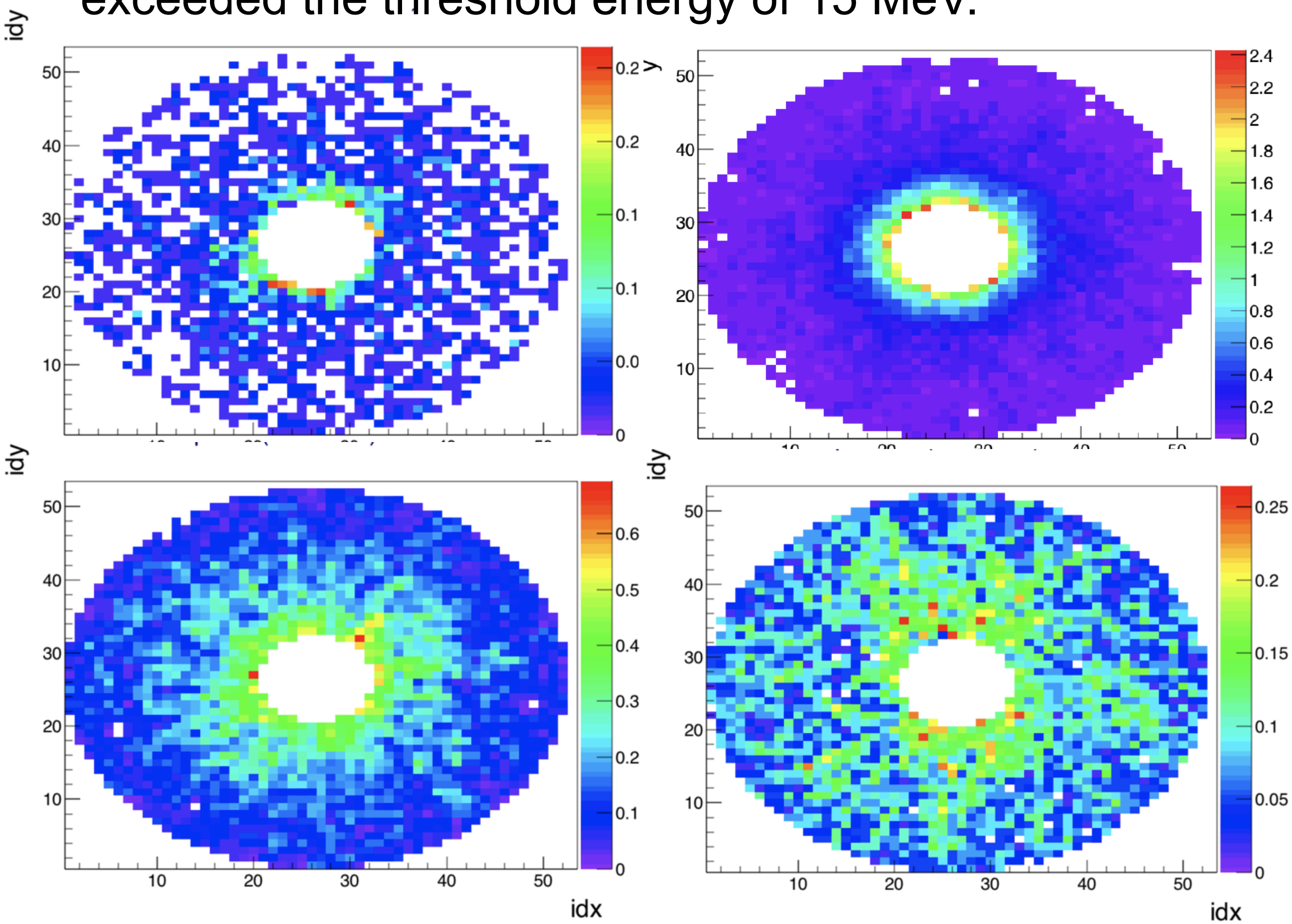
$PbWO_4$ Calorimeter for electron detection

- Similar to Inner Calorimeter, total of ~1200 modules, mounted at 60 cm from the target
- Angular coverage from 7^o to 30^o
- Small size modules, 1.3x1.3 cm^2, in the inner part, 7^o to 12^o. 2x2 cm^2 modules in the outer part
- Readout with APDs, similar to IC, HPS ECal, and FTCal
- HPS Ecal modules run successfully at rates of ~1.5 MHz and performed very well: $\sigma/E \approx 4\%/\sqrt{E}$ and $\sigma_t \leq 0.5$ ns



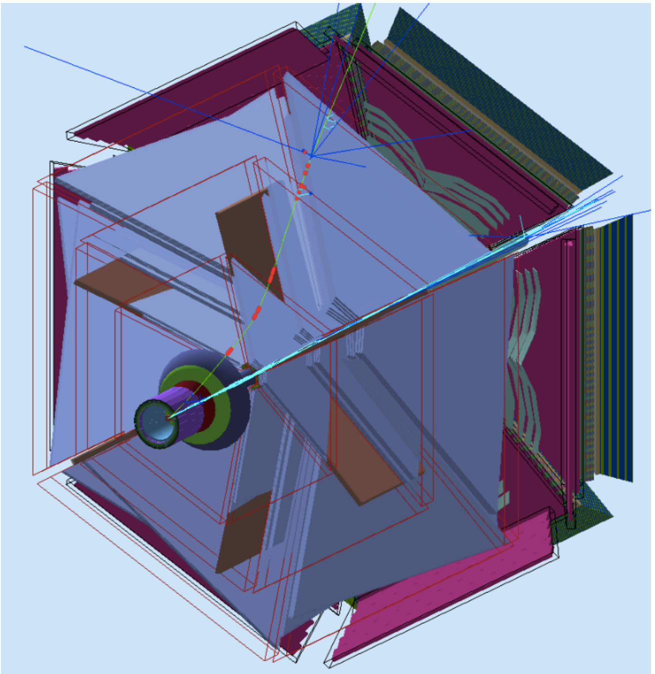
Rates $PbWO_4$ Calorimeter

- the whole volume was divided into 1.3x1.3x20 cm3 rectangles (modules)
- Hit in the module was counted if the energy deposition in the PbWO4 crystal exceeded the threshold energy of 15 MeV.



- The highest rates are from photons, 2 MHz max
- Total rates in the innermost modules ~3 MHz

Muon detection and trigger rates



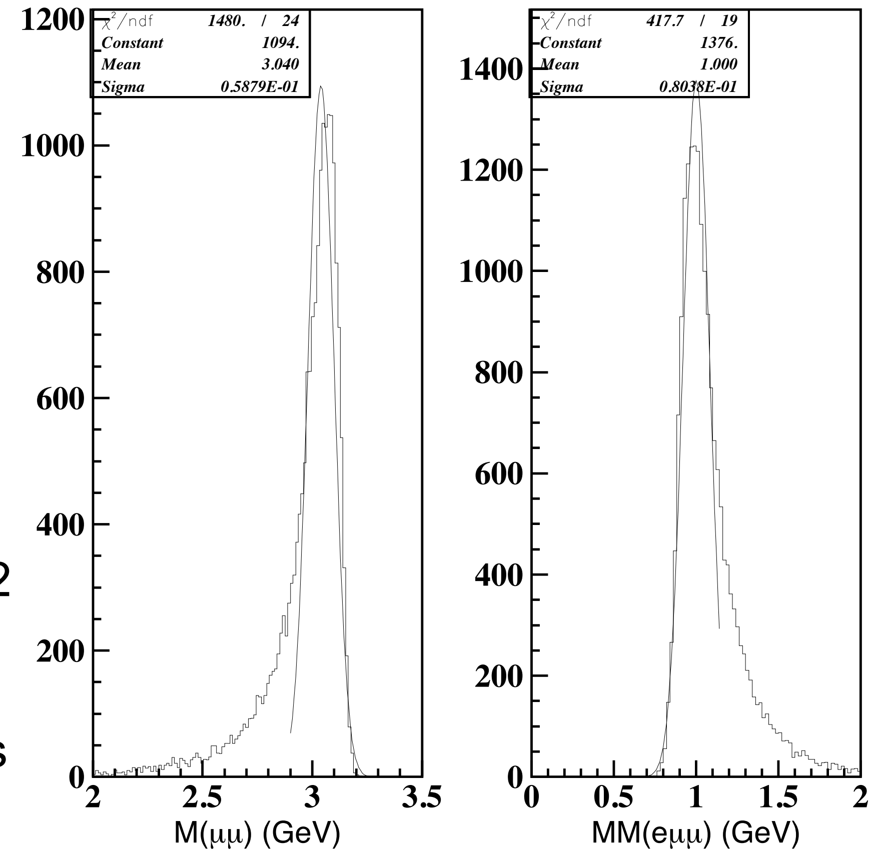
- Muons will punch through the calorimeter and W-shield and will be detected in CLAS12 FD.
- Muon ID – track in DC with matched MIP energy cluster in PCAL/EC.
- Based on GEANT4 (GEMC) simulations background rates from charged tracks (mostly from pions penetrating the shield) in CLAS12 FDC will be 150 kHz and 190 kHz for positively and negatively charged tracks, respectively
- MIP energy cut in PCAL/EC reduces these rates to 75/95 kHz (from those only 40% are from the target – 30/38 kHz respectively)
- With 50 ns trigger time coincidence window, the rate of two oppositely charged MIP particles in CLAS12 FD will be 360 HZ – well within CLAS12 DAQ specs (the true muon pair rate is ~1 Hz, mostly from BH)
- Experiment can run with two charged particle trigger CLAS12 FD

Event ID and background rates

- The ($e\mu^+\mu^-$) final state will be identified as two oppositely charged MIP in CLAS12 FD paired with "electron" like hit in the $PbWO_4$ calorimeter.
- Clusters with energy > 0.4 GeV that have negatively charged GEM track pointing to it will be selected as electron candidates
- The rate of non-electrons with that signature (π^-s) is 150 kHz (840 kHz) in the region of interest in W and Q^2 (total)
- The true (inclusive) electron rates for E'>0.5 GeV is ~650 kHz in the acceptance region, so the total rate of clusters with more than 0.4 GeV energy in the calorimeter will be 800 kHz
- Requiring two tracks in FD from the same beam bucket and from the target reduces two MIP coincidence rate to 5 Hz, only 50% of which have M>1 GeV.
- The true mion pair rate is 0.6 Hz making total pair rate from the same beam bunch in FD ~3. Hz
- Accidental rate of ($e\mu\mu$) will be ~0.01 Hz, with MM cut for recoil proton ID will reduce this rate 0.004 Hz
- The expected rate for BH/DDVCS events in the kinematics of the experiment is 0.02 Hz

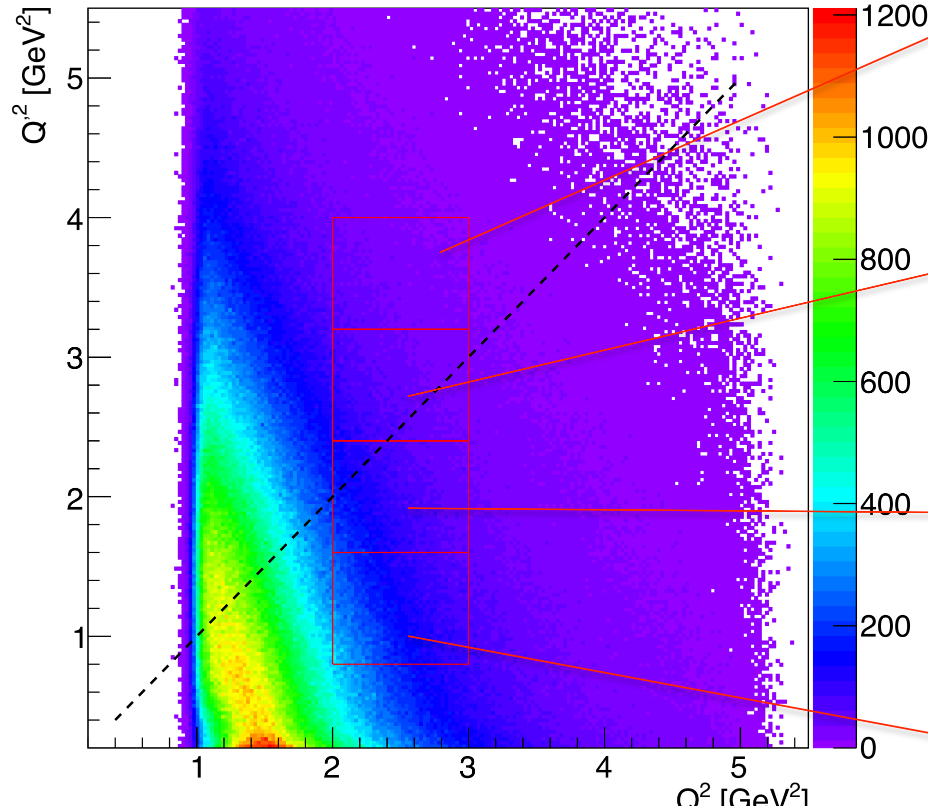
Detector response simulation

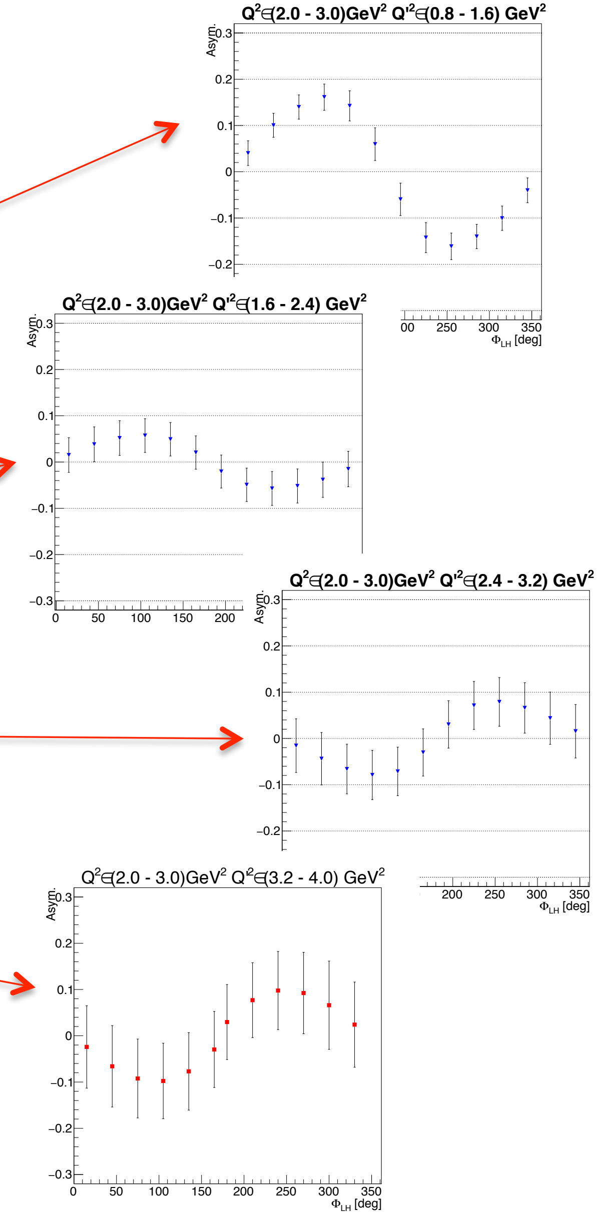
- Modified version of the CLAS12 Fast MC was used to simulate acceptances and resolutions
- For electron detection a new detector was introduced in fast MC with polar angular coverage of 7^o to 30^o and 2π azimuthal coverage. Detection energy threshold was set to p > 0.5 GeV/c, energy resolution of $\sigma/E=3.7\%/\sqrt{E}$ and angular resolutions of $\sigma_{\theta(\phi)}$ = 2 mrad
- Since muons will be detected in CLAS12 FD after passing through 20 cm long PbWO4 modules and a 30 cm thick tungsten absorber, momentum of muons before CLAS12 acceptance and smearing functions was recalculated to take into account energy loss



DDVCS beam spin asymmetry

Sign change with change of kinematics – from Space-like to Time-like dominance region

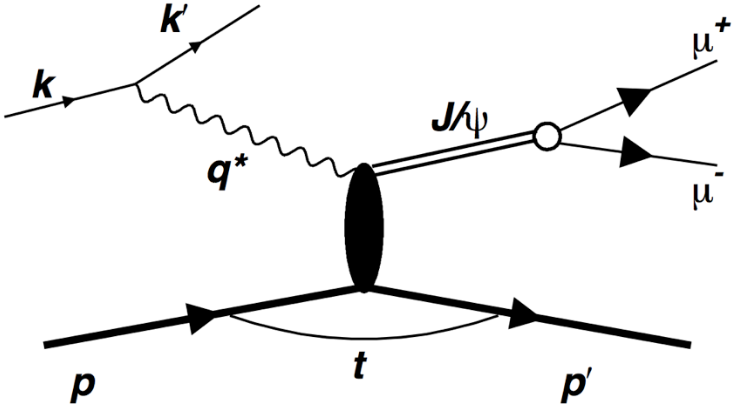


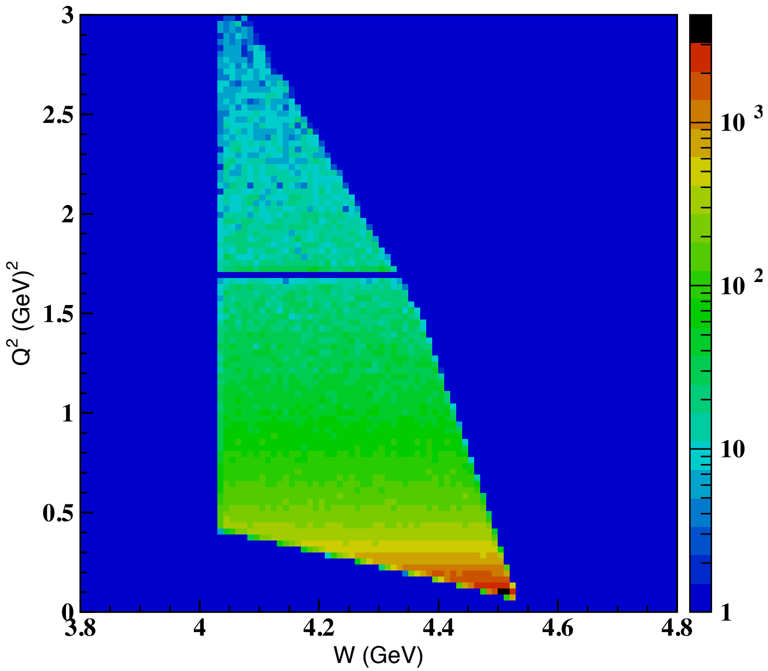


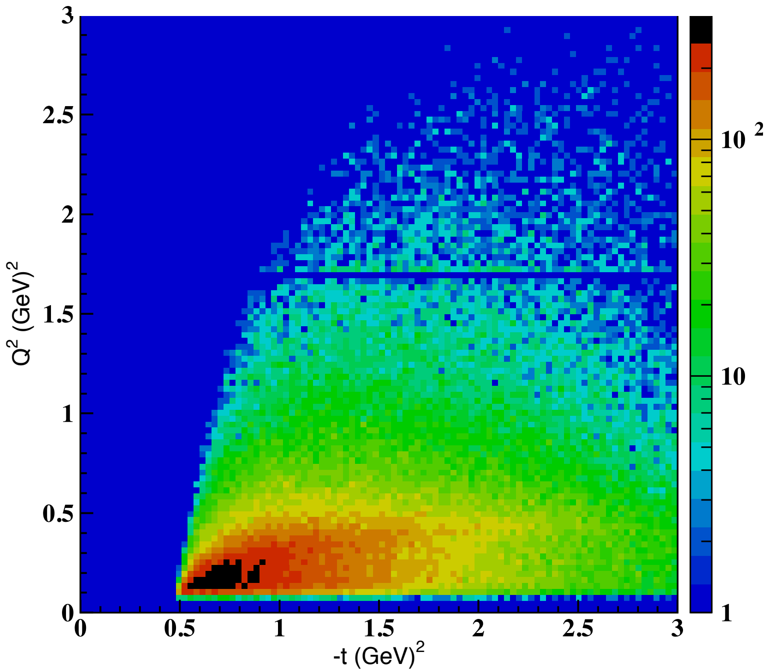
- The VGG code was used for DDVCS BSA
- GRAPE-dilepton event generator was used to estimate rates

J/ψ electroproduction

- First measurements in the threshold region
- Study W- and t-dependences at different Q^2 (0.2 GeV^2, 0.5 GeV^2, and 1.5 GeV^2)
- Study decay muon angular distributions to extract $R=\sigma_L/\sigma_T$

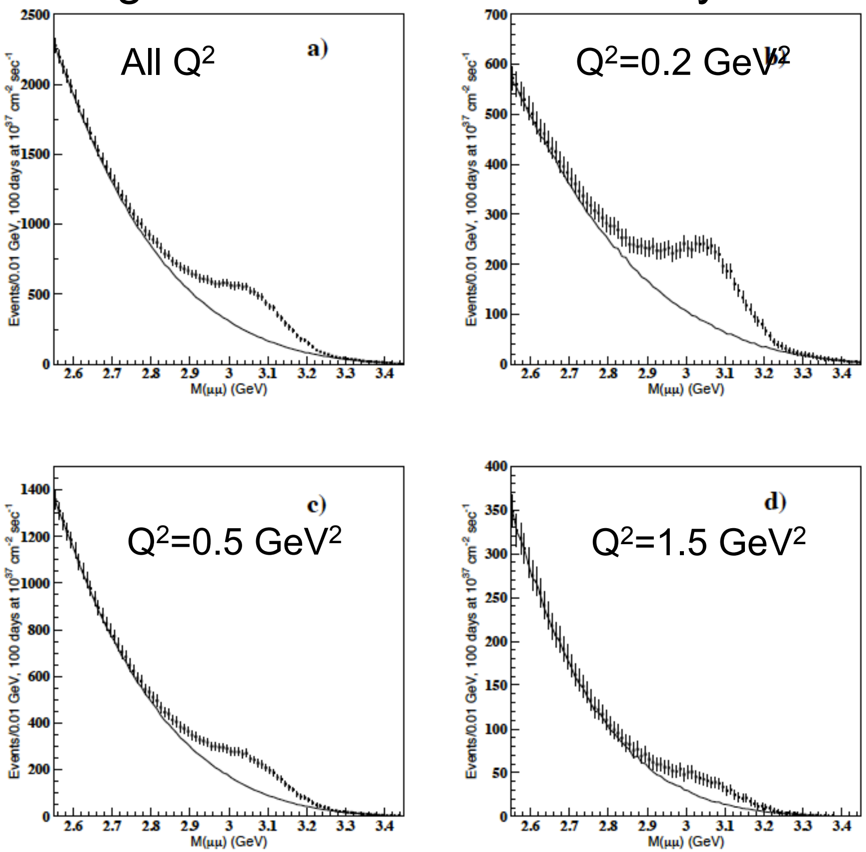


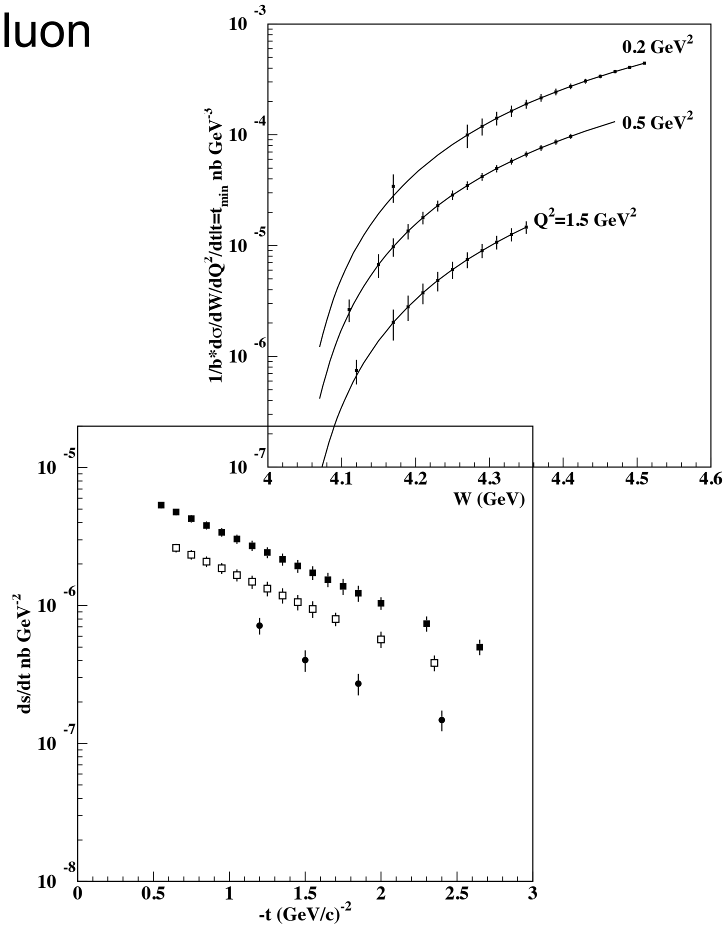




Expected results on J/ψ electroproduction

- Vector Dominance Model (VDM) is used to relate electroproduction cross section to the photoproduction.
- For the photoproduction cross section the 2-gluon exchange model from S.J. Brodsky et al.





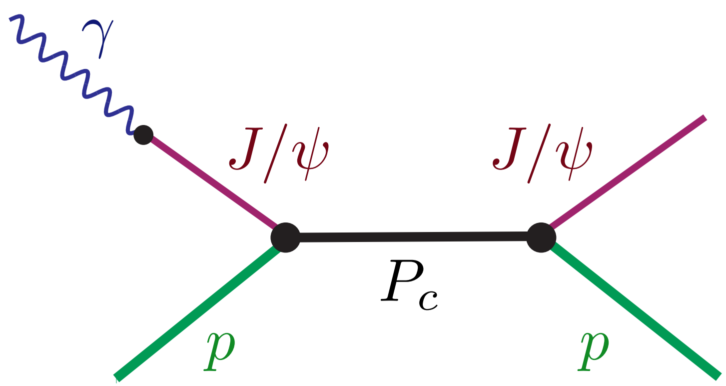
LHCb pentaquarks

V. Kubarovsky

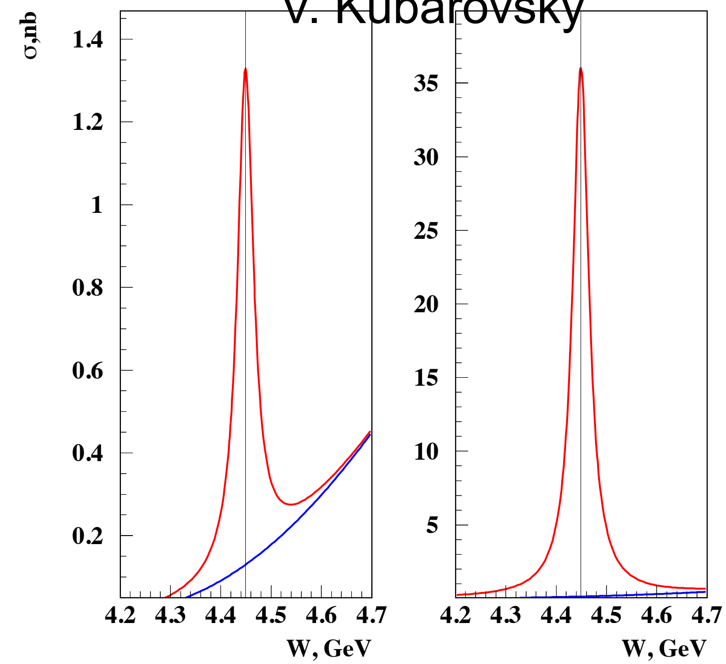
Since the states were observed in the decay mode J/ψ p, it is natural to expect that these states can be produced in photoproduction process

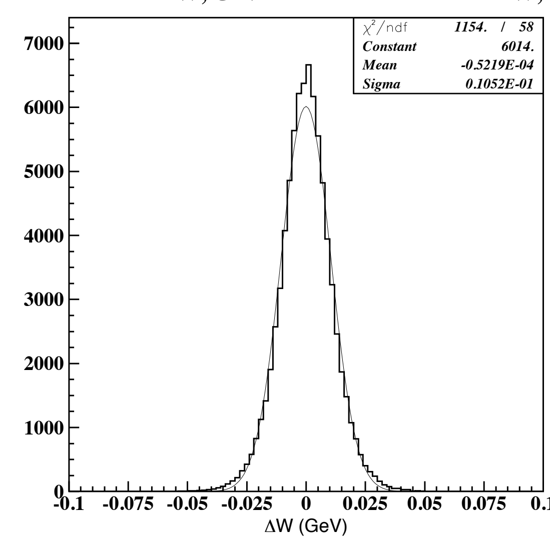
$\gamma^* + p \rightarrow P_c \rightarrow J/\psi\ p$

where they will appear as s-channel resonances at photon energy around 10 GeV



	$\sigma(W = M_c)$ Minimum - Maximum	Number of events per day Minimum - Maximum
$P_c(4380)$	0.15 - 4.7 nb	150 - 4700
$P_c(4450)$	1.2 - 36 nb	230 - 7000

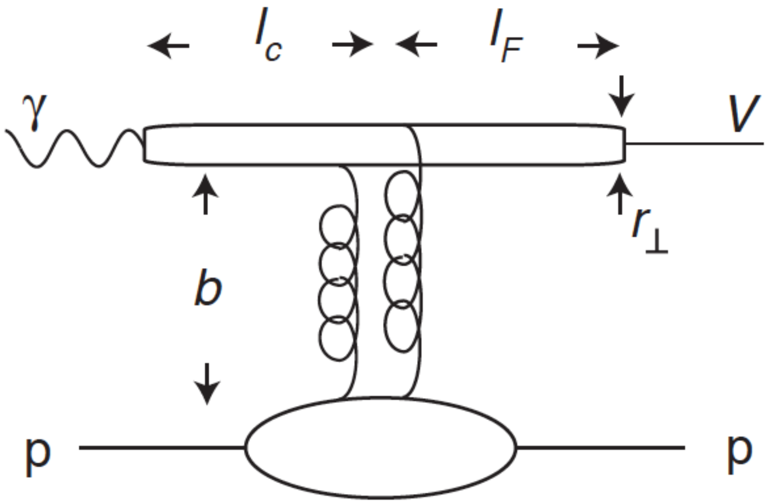




Summary

- There is a rich experiential program for studying nucleon and nuclear structure within GPD formalism on CLAS12 using DVCS, DVMP, and TCS
- While these measurements will generate wealth of data on GPDs, information still will be limited to certain kinematic constraints
- The Double DVCS measurement will extend kinematic region of GPD determination into a new dimension
- Studying DDVCS requires high luminosity and muon detection
- Proposed modifications to CLAS12 aims to serve two purposes (a) allow to run at orders of magnitude higher luminosity, and (b) to convert the CLAS12 FD into a muon detector
- The same experiment is well suited to study J/ψ electroproduciton in uncharted, near threshold region to probe gluonic form factors of the nucleon
- This modified setup will be an excellent place for very high rate inclusive J/ψ production and opens up a new avenue for studies of J/ψ production on nuclei in order to investigate $J/\psi\ N$ interaction.
- These studies can also include other vector mesons, e.g. $\phi(1020)$
- To conduct measurements, 100 days at $L=10^{37}$ cm^{-2} sec^{-1} will be needed

VDM picture of the production



$$m_c \approx 1.5\ GeV;$$

$$r_\perp \sim \frac{1}{m_c} = 0.13\ fm$$

Close to the threshold, $E_\gamma \approx$ 10 GeV

$$l_c = \frac{2E_\gamma}{4m_c^2} \approx 0.4\ fm;\ \ l_F \approx \frac{2E_{J/\psi}}{2m_c\left(m_{\psi'} - m_{J/\psi}\right)} \sim 1-2\ fm;\ \ b \sim \frac{1}{\sqrt{-t}} \sim 0.2\ fm$$

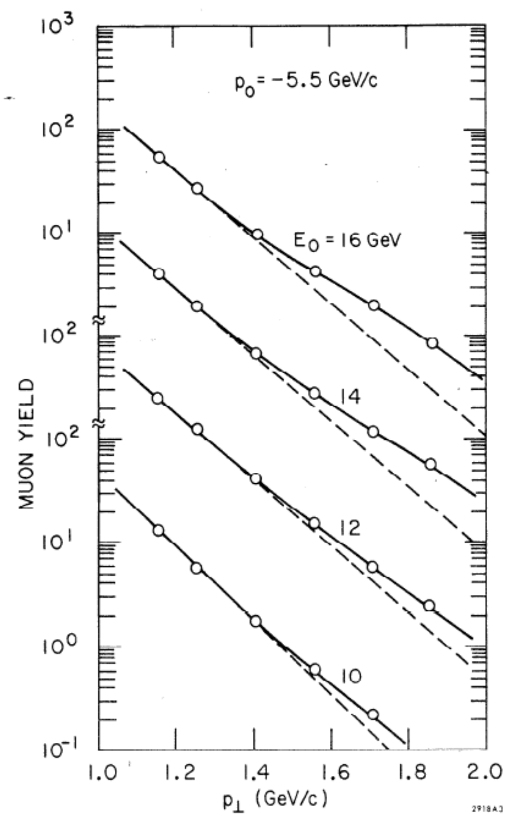
Favorable kinematics for studies of J/ψN scattering

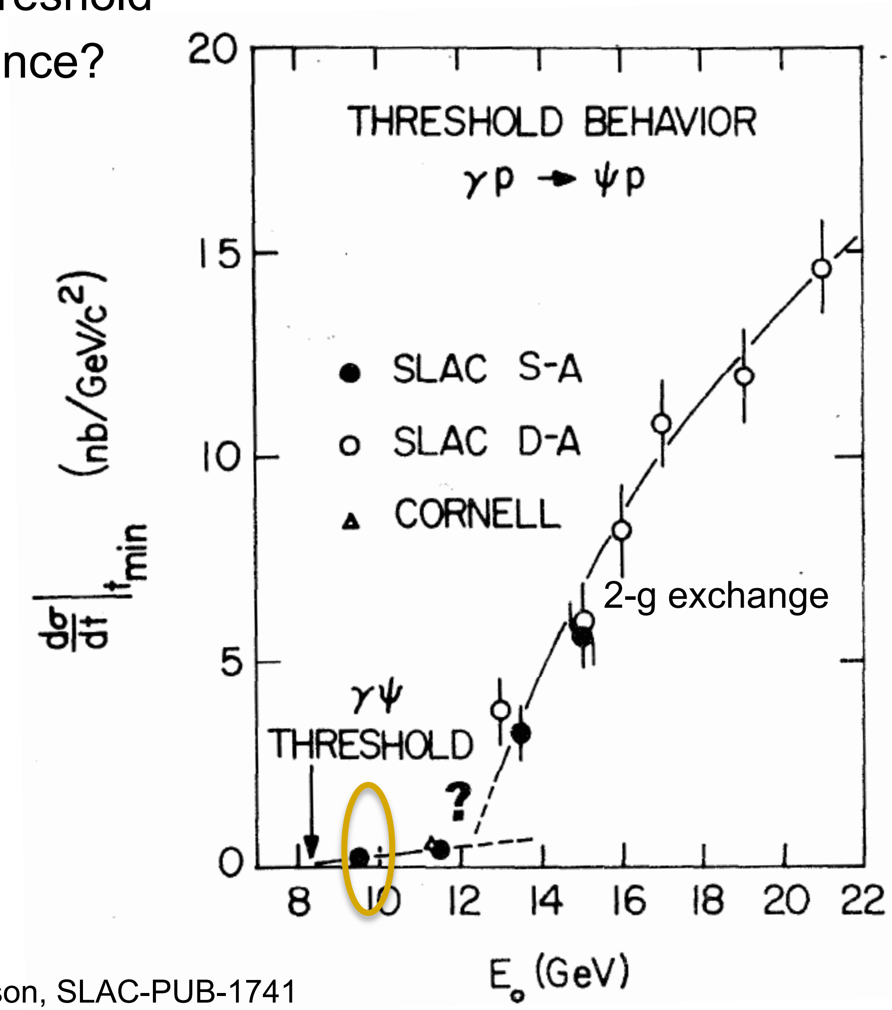
SLAC single arm measurements

Flattening of cross section near the threshold

Can enhancement be due to a resonance?

S. Brodsky, SLAC-PUB-14985





R.L. Anderson, SLAC-PUB-1741