Near Threshold Electroproduction of J/ψ at 11 GeV

Z.-E. Meziani

on behalf of the spokespeople

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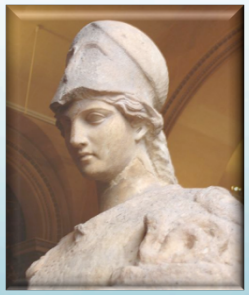
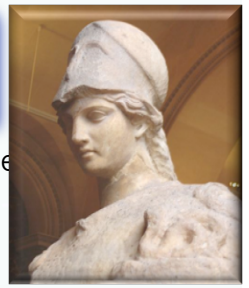
for

the ATHENNA Collaboration



ATHENNA Collaboration



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Outline

- Physics Motivation
- Proposed Measurement
- Experimental Setup
- Backgrounds and Projected Results
- Beam Request

Physics Motivation

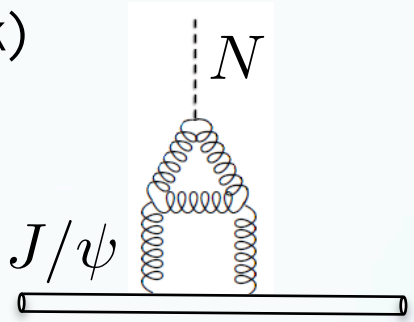
- This proposal is about exploring and understanding some aspects of the strong regime of QCD
- Probes strong gluonic interaction between two color neutral objects J/Ψ and the nucleon
- Uses J/Ψ to probe color fields *in* the nucleon (minimal quark exchange)
- Tests the production mechanism of J/Ψ in a nucleon
- Probes the conformal anomaly of low energy interaction $J/\Psi - N$

A unique opportunity by exploring the threshold region and taking advantage of the high luminosity of CEBAF and the new energy reach namely 11 GeV

Statements from experts in the field!

"Low-energy J/psi-N interaction is a probe of the scalar gluon form factor of the nucleon. This quantity is of fundamental importance since it is related to conformal anomaly of QCD and to the origin of the nucleon's mass".

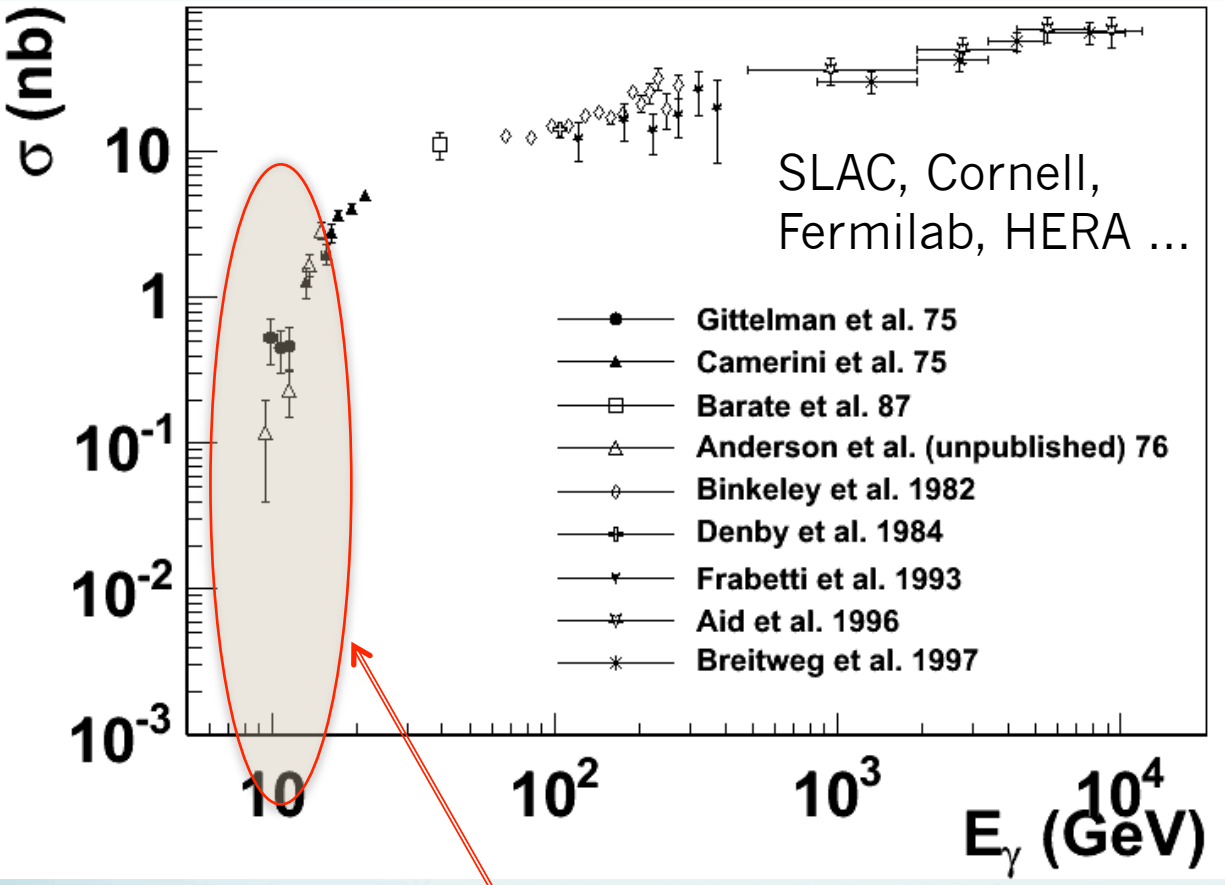
Dima Kharzeev (Stony Brook)



"I am very enthusiastic about the physics of J/psi production at JLab" refer to: http://www-public.slac.stanford.edu/sciDoc/docMeta.aspx?slacPubNumber=SLAC-PUB-14985

Stan Brodsky (SLAC, Stanford)

Experimental status $\gamma(\gamma^*) + N \rightarrow N + J/\Psi$

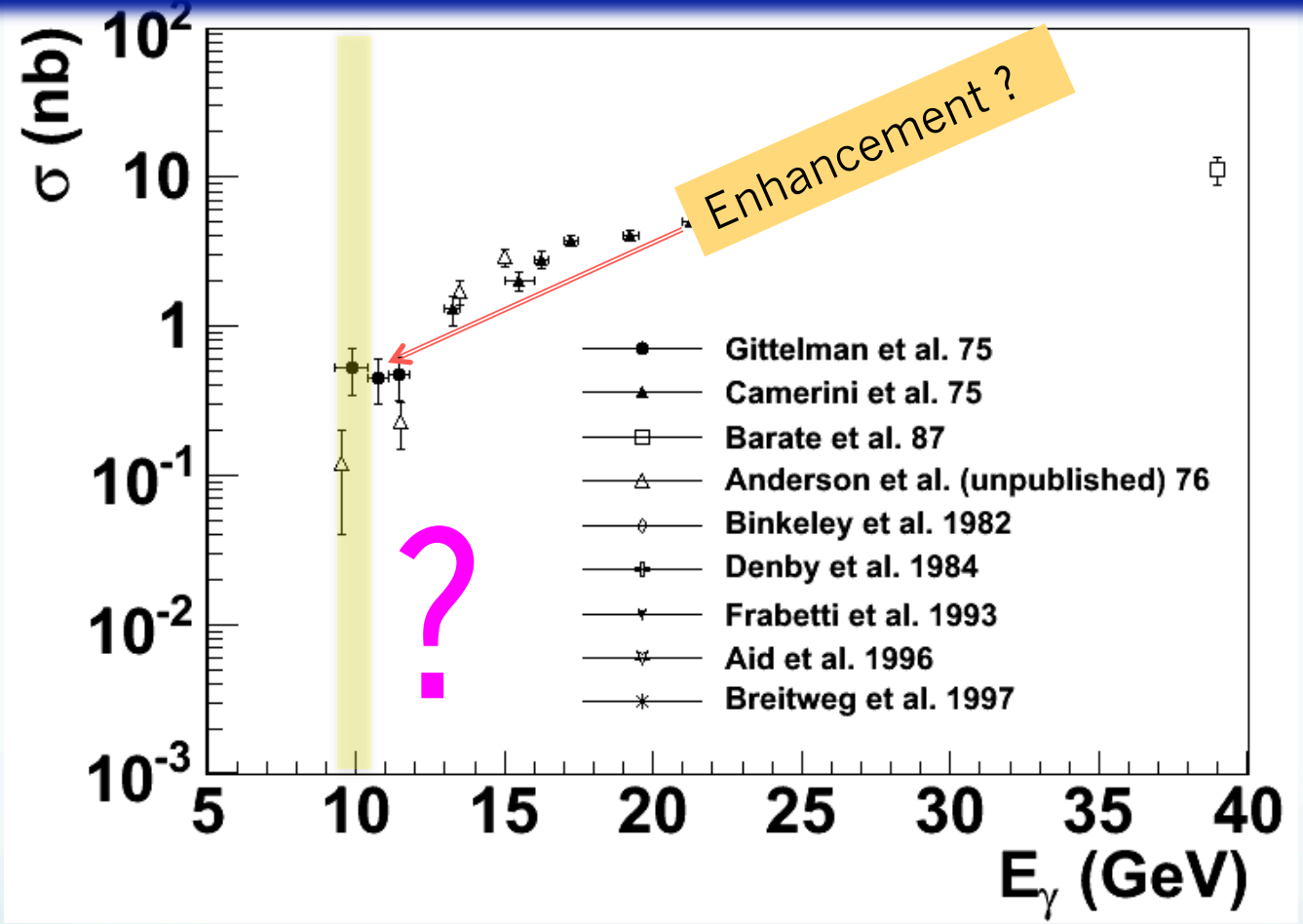


More data exist with inelastic scattering on nuclei, such as A-dependence.

Not included are the most recent results from HERA H1/ZEUS at large momentum transfers and diffractive production with electroproduction

The physics focus is this threshold region

Near Threshold $\gamma + N \longrightarrow N + J/\Psi$

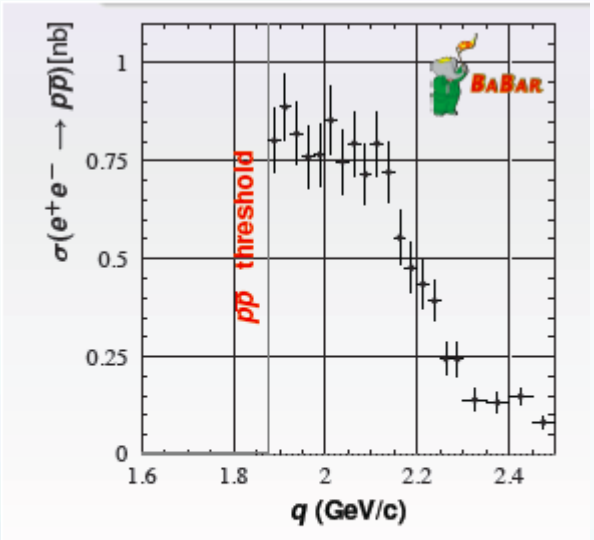


Intense experimental effort (SLAC, Cornell …) shortly after the discovery of J/ψ

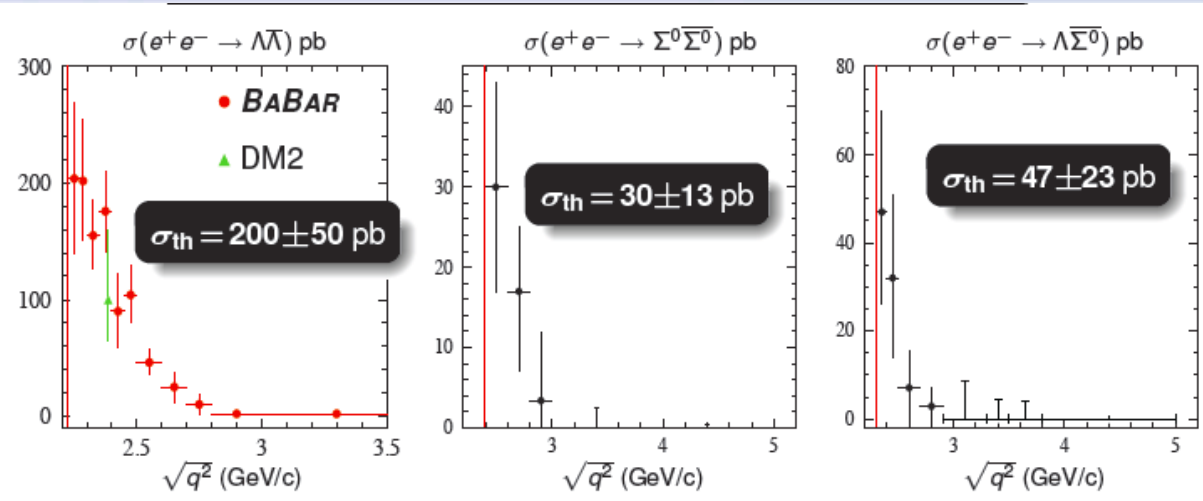
But near threshold not much since (**36 years till now**)

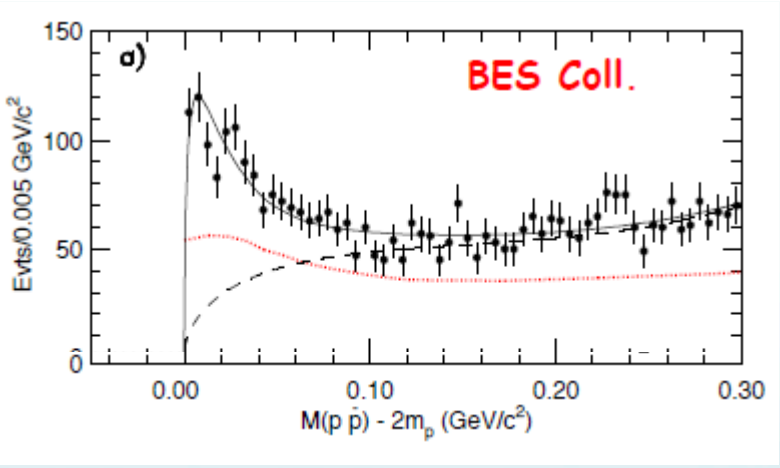
Threshold Enhancement is not rare!

$$e^+e^- \to p\bar{p}$$



At threshold
$\sigma(e^+e^- \to p\bar{p}) = 0.80 \pm 0.05$ nb





$$J/\psi \to \gamma p\bar{p}$$

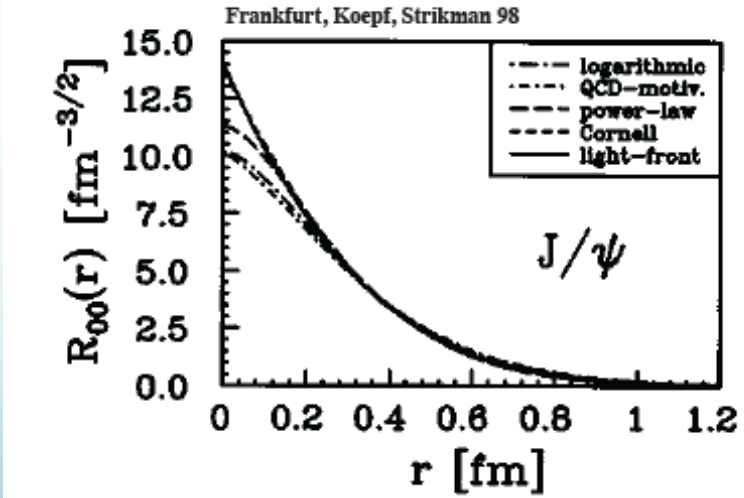
Summary of NPCFiQCD Workshop
http://quarks.temple.edu/~npcfiqcd

J/ψ as probe of the strong color fields in the nucleon!

$$J/\psi(1S): I^G\left(J^{PC}\right) = 0^-\left(1^{--}\right) \qquad M_{J/\psi} \approx 3.097 GeV$$

- **J/ψ is a charm-anti-charm system**
  - Little (if not zero) common valence quark between J/ψ and nucleon
  - Quark exchange interactions are strongly suppressed

- **Charm quark is heavy** $\gg \Lambda_{QCD}$
  - Typical size of J/ψ is 0.2-0.3 fm



Interaction between J/ψ-N

- New scale provided by the charm quark mass and size of the J/ψ
  - OPE, Phenomenology, Lattice QCD …
- High Energy region: Pomeron picture …
- Medium/Low Energy: 2-gluon exchange
- Very low energy: QCD color Van der Waals force
  - Prediction of J/ψ-Nuclei bound state
    - Brodsky et al. ….
- Experimentally no free J/ψ are available
  - Challenging to produce close to threshold!
  - **Photo/electro-production of J/ψ at JLab is an opportunity**

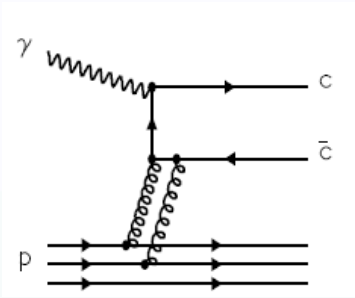
Reaction Mechanism ?

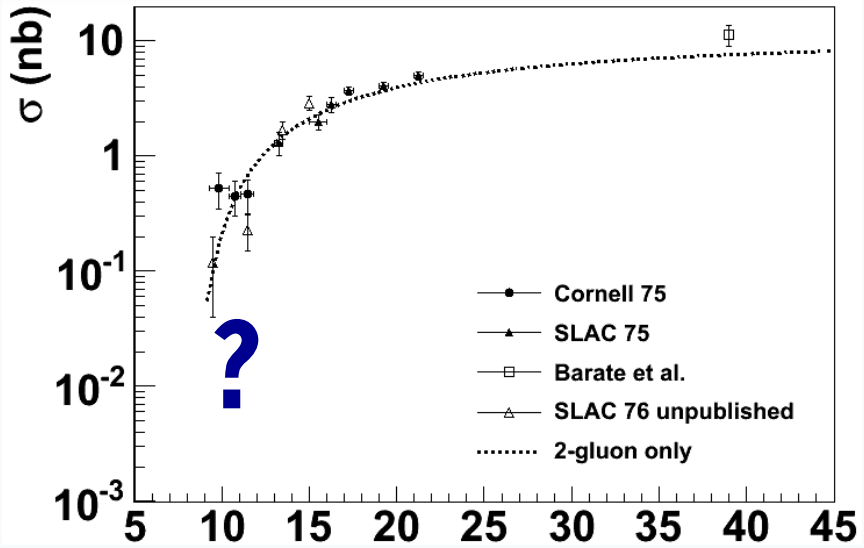
Models-I: Hard scattering mechanism (Brodsky, Chudakov, Hoyer, Laget 2001)

$$2-g:(1-x)^2 F(t)$$

$$F(t) \propto \exp(1.13t)$$

$$x = \frac{2M_p M_{J/\psi} + M_{J/\psi}^2}{2E_\gamma M_p}$$



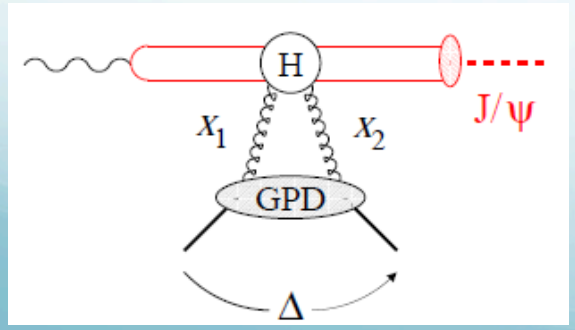


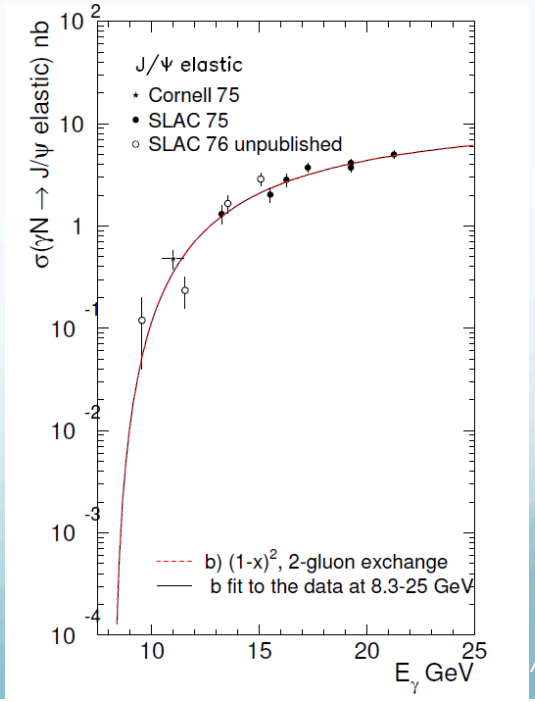
Models -II: Partonic soft mechanism

(Frankfurt and Strikman, PRD 66, 031502 [2002])

2-gluon Form Factor

$$F.F. \propto (1 - t/1.0\ \mathrm{GeV}^2)^{-4}$$





Reaction Mechanism

Models (I): Hard scattering
(Brodsky, Chudakov, Hoyer, Laget 2001)

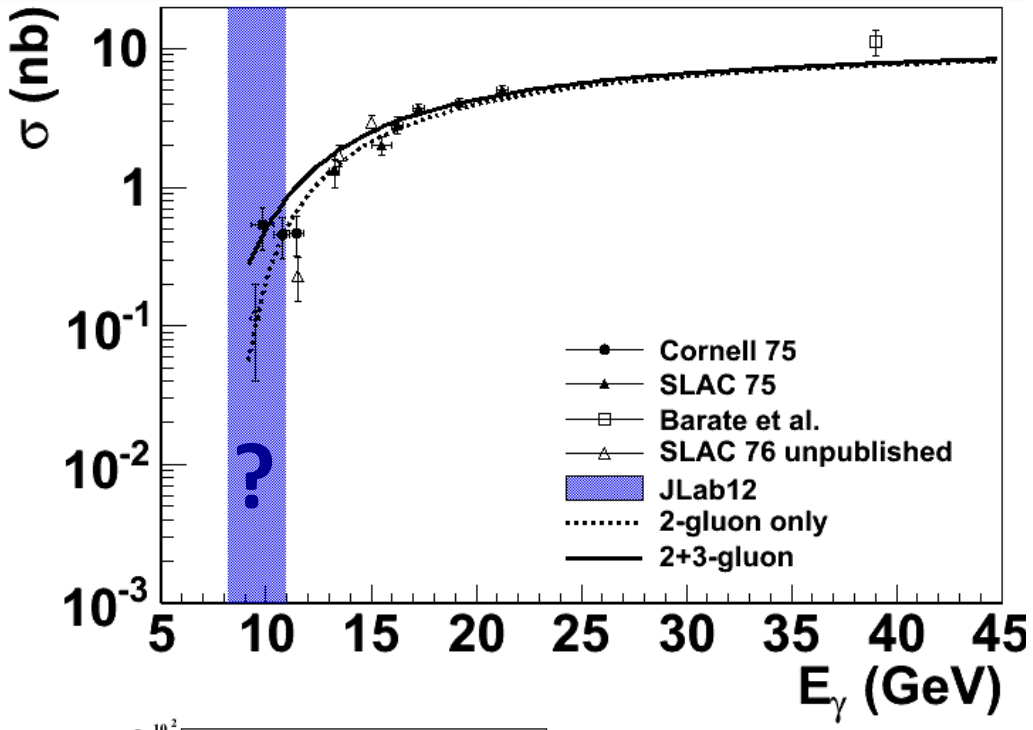
Add in 3-gluon scattering

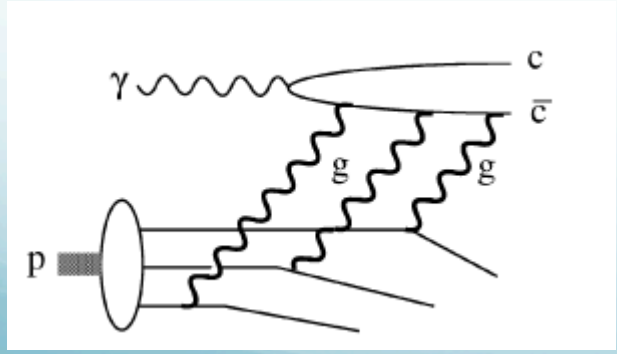
$$2-g:(1-x)^2F(t)$$

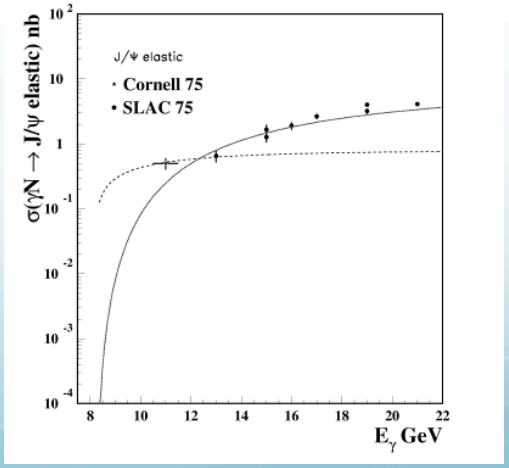
$$3-g:(1-x)^0F(t)$$

$$F(t)\propto \exp(1.13t)$$

$$x=\frac{2M_pM_{J/\psi}+M_{J/\psi}^2}{2E_\gamma M_p}$$

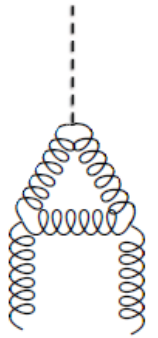






Conformal (Trace) Anomaly

$$G^{\alpha\beta\gamma}G^{\gamma}_{\alpha\beta}$$



- **Trace of energy momentum tensor**
- **"Beta" function** energy evolution of strong interaction coupling constant

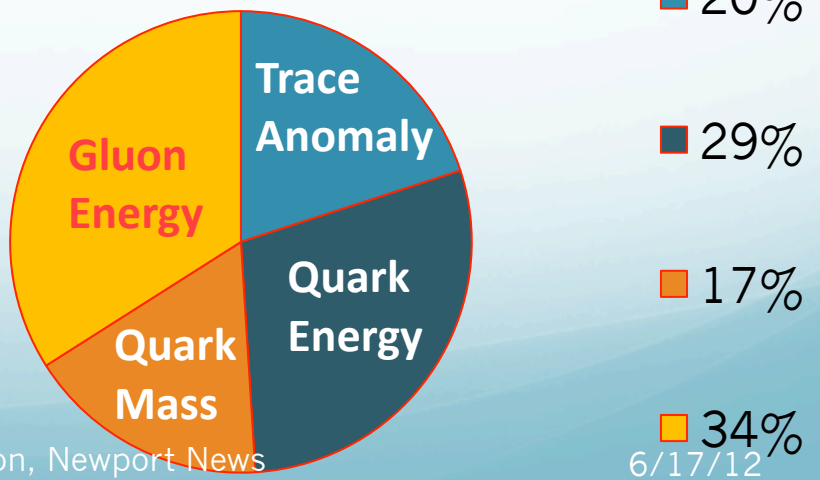
$$< N | \frac{\beta(g)}{2g} G^{\alpha\beta\gamma}G^{\gamma}_{\alpha\beta} + \sum_{u,d,s,} m_q \bar{q}q | N >= M_N$$

⊙Decomposition of Proton mass [X. Ji PRL 74 1071 (1995)]

CM frame

$\overline{MS}@1GeV^2$

Proton Mass Budget



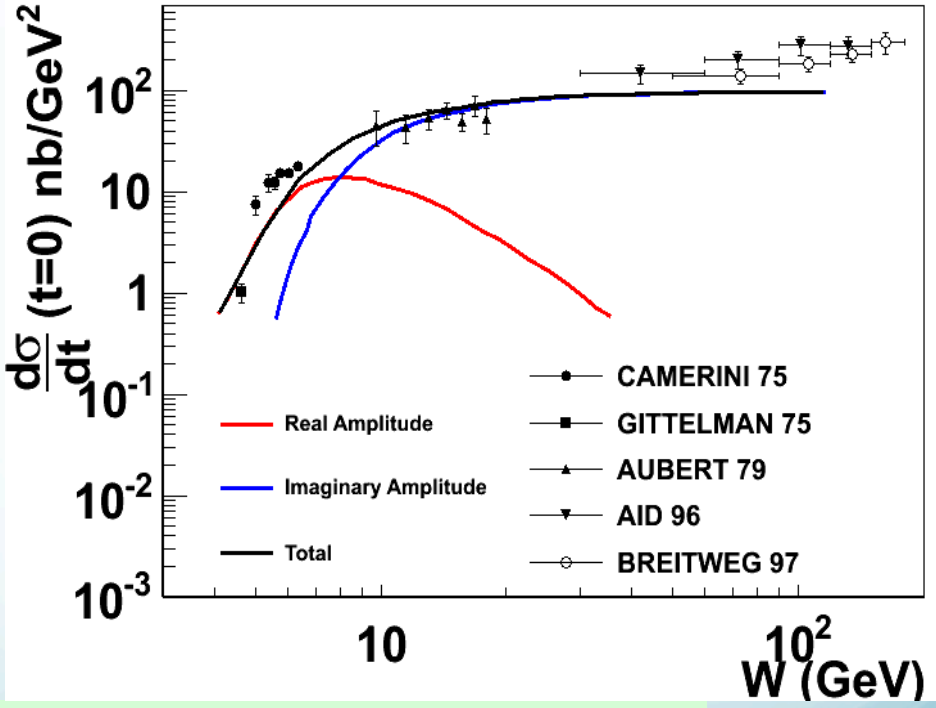
Another view: Reaction mechanism with FSI?

D. Kharzeev. Quarkonium interactions in QCD, 1995
D. Kharzeev, H. Satz, A. Syamtomov, and G. Zinovjev, Eur.Phys.J., C9:459–462, 1999

$$\frac{d\sigma_{\gamma N\to\psi N}}{dt}(s,t=0)=\frac{3\Gamma(\psi\to e^+e^-)}{\alpha m_\psi}\left(\frac{k_{\psi N}}{k_{\gamma N}}\right)^2\frac{d\sigma_{\psi N\to\psi N}}{dt}(s,t=0)$$

$$\frac{d\sigma_{\psi N\to\psi N}}{dt}(s,t=0)=\frac{1}{64\pi}\frac{1}{m_\psi^2(\lambda^2-m_N^2)}|\mathcal{M}_{\psi N}(s,t=0)|^2$$

- **Imaginary part** is related to the total cross section through optical theorem
- **Real part contains the conformal (trace) anomaly**
  - ➥ Dominate the near threshold region



A measurement near threshold could shed light on the conformal anomaly

We propose to

- **Measure the *t* dependence and energy dependence of *J/ψ* cross sections near threshold.**
  - Probe the nucleon strong fields in a non-perturbative region
  - Search for a possible enhancement of the cross section close to threshold
  - Shed some light on the conformal/trace anomaly

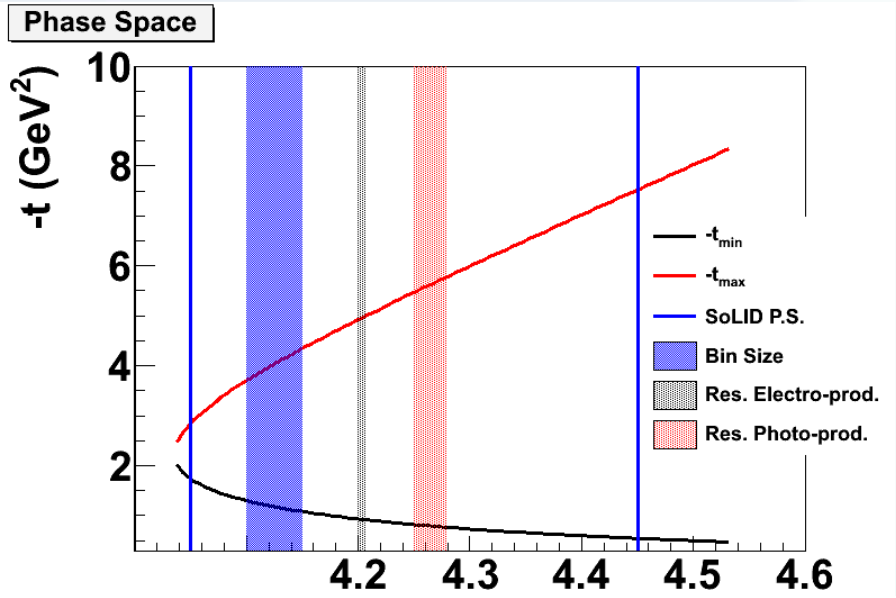
Establish a baseline for *J/ψ* production in the JLab energy range!

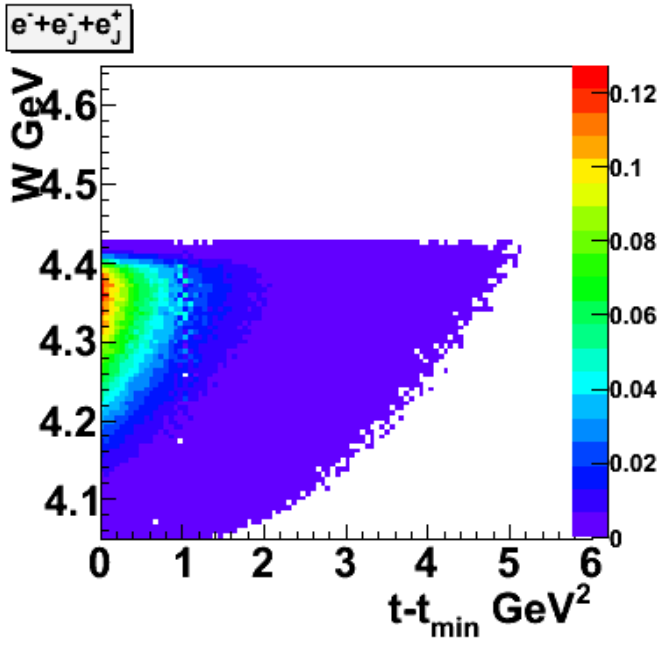
- **Bonuses:**
  - Decay angular distribution of J/ψ
  - Interference with Bethe-Heitler term (real vs. imaginary)
- **Future Plans:**
  - Search for J/ψ-Nuclei bound state
  - J/ψ medium modification

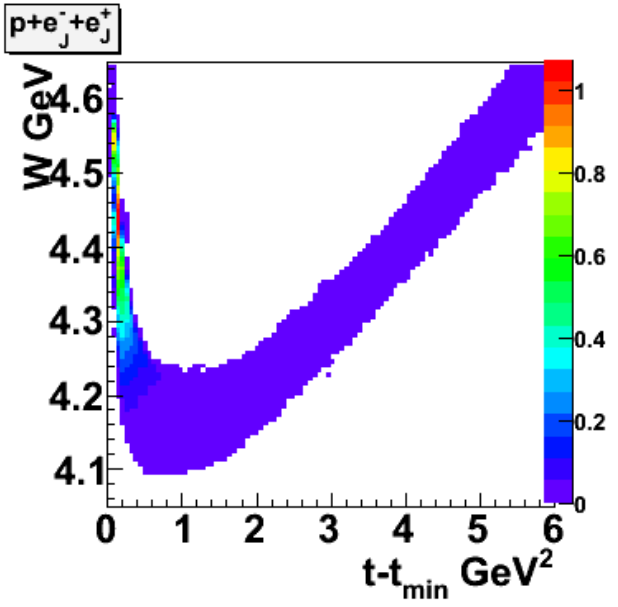
Electroproduction vs Photoproduction

- Better resolution near threshold
  - use of a tagged photon beam
- Larger coverage in *t*
- Lower radiation budget
- Less background (full exclusivity)
- Near threshold

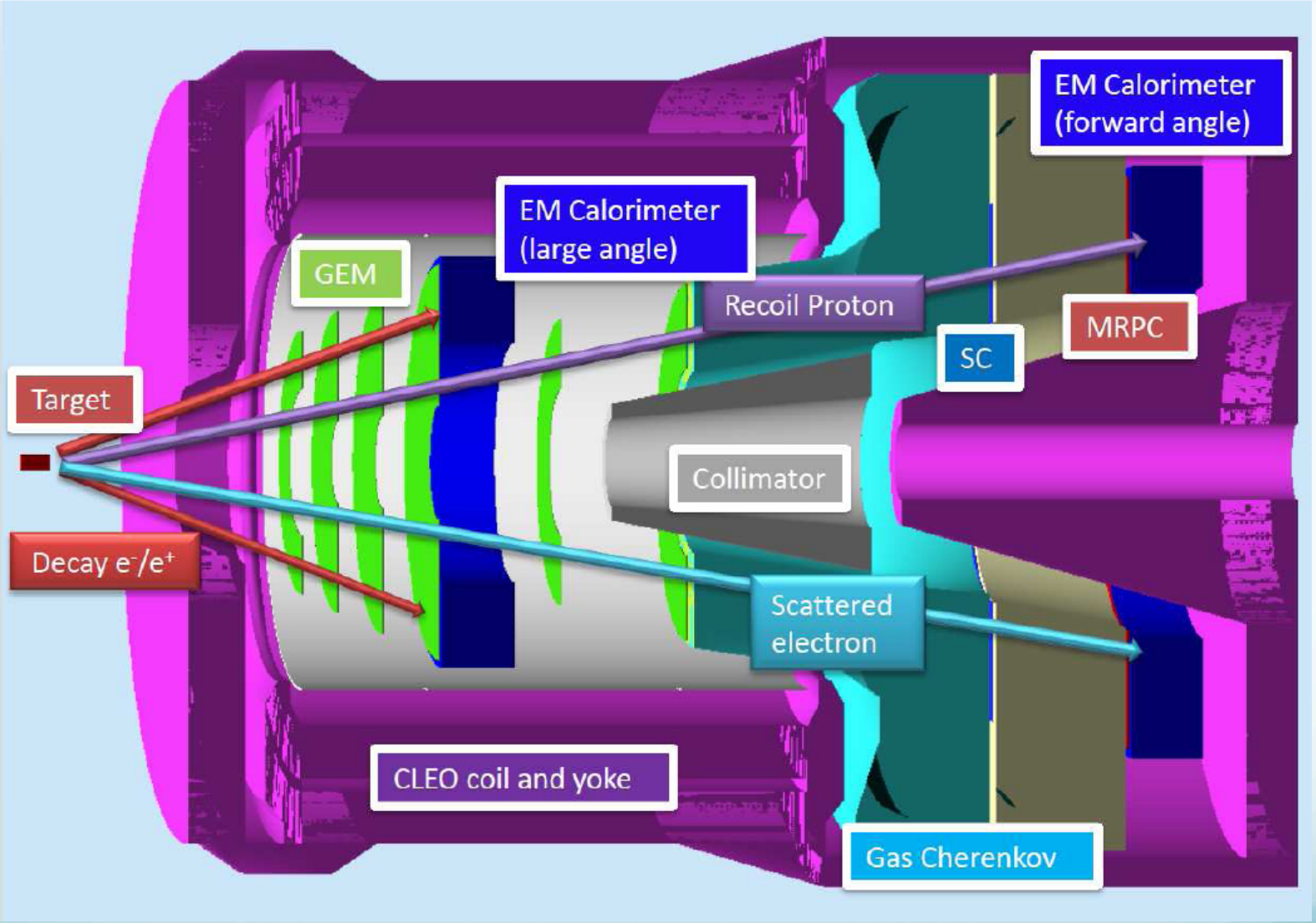
$$W^2 = 2\nu \cdot M_p + M_p^2 - Q^2$$
$$= 2E_\gamma^{eff} \cdot M_p + M_p^2$$







SoLID - J/Ψ Setup



- **Symmetric acceptance** for e^+ and e^-

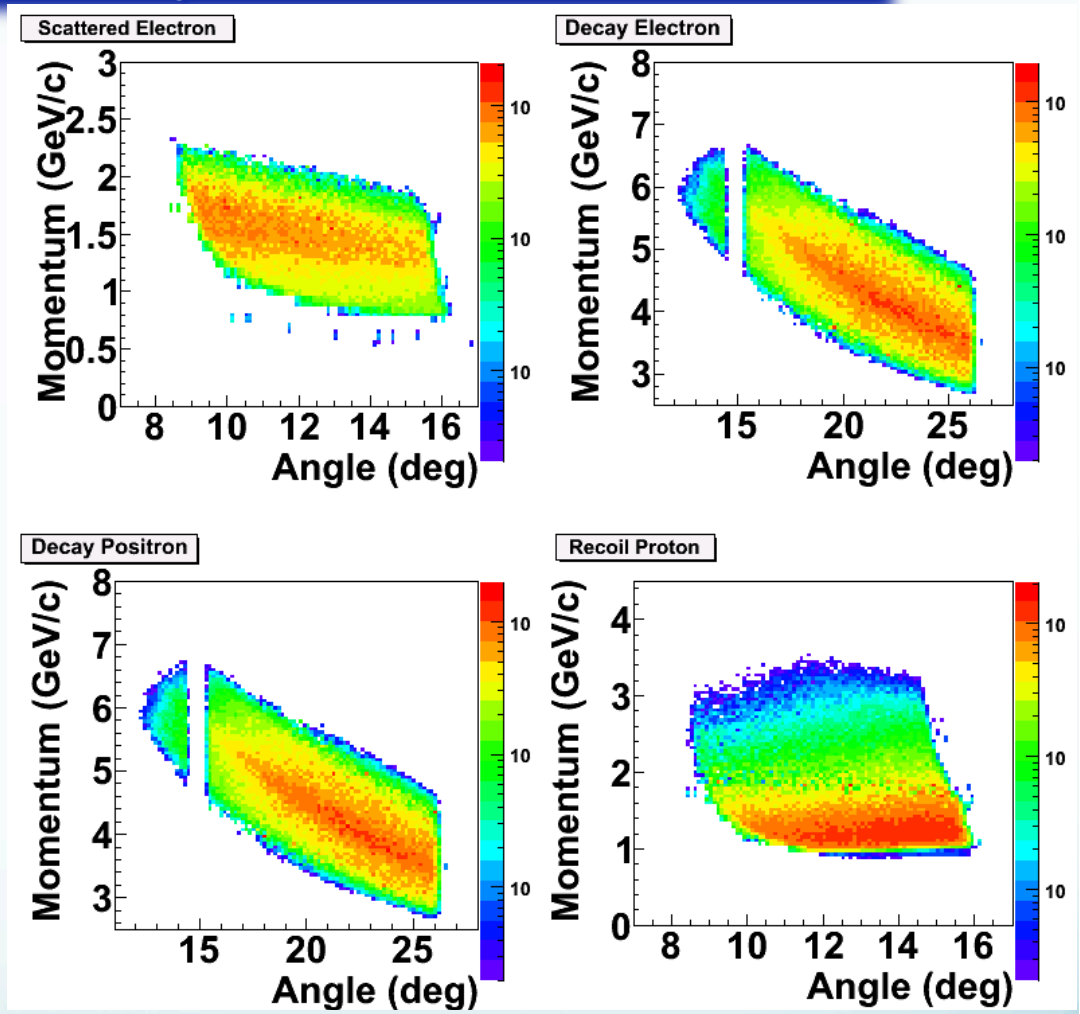
Experimental Overview

- 50 days of 3 μA beam on a 15 cm long LH_2 target at $1 \times 10^{37} \mathrm{cm}^{-2}\mathrm{s}^{-1}$
  - 10 more days include calibration/background run
- SoLID design overall compatible with SIDIS with some changes
  - +10 cm of the radius of the first three GEM planes
  - Move large angle detector upstream by 12 cm
  - Opening angle at 26 degrees achieved by moving the front yoke forward
- Main Trigger: Triple coincidence of $e^-e^-e^+$
  - Additional trigger double coincidence (e^+e^-)

$$e^- + p \longrightarrow e^- + p + J/\Psi(e^- + e^+)$$

PID and Acceptance

- Scattered electron:
  - Gas Č + Calorimeter @ forward angle
- Decay electron/Positron:
  - Calorimeter only at large angle
  - Gas Č + Calorimeter at forward angle
- Recoil proton:
  - 100 ps TOF: 2 ns separation between p/K @ 2 GeV/c
  - ~ 8m flight path



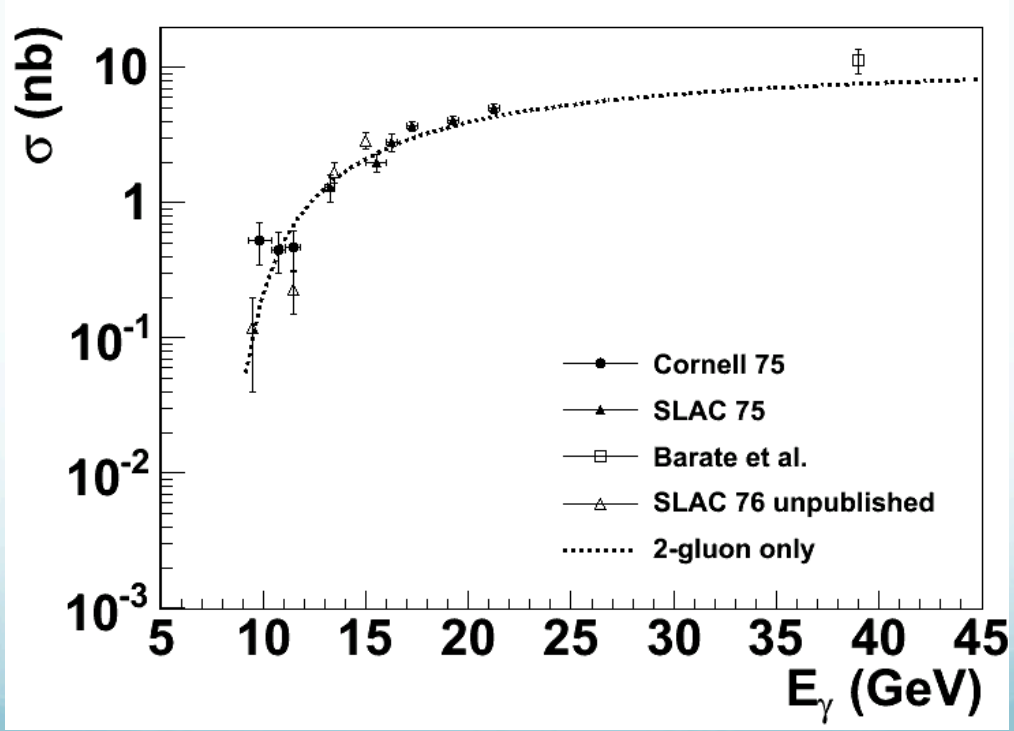
Main trigger rate is below **1 kHz** with 50 ns coincidence window. Comparing to **~50 kHz** design trigger rate for SIDIS.

Rates Estimates

- Used equivalent photon approximation

$$\frac{d^5\sigma}{d\Omega_e dP_e d\Omega_P} = \Gamma \frac{J}{2\pi} \frac{d\sigma}{dt}$$

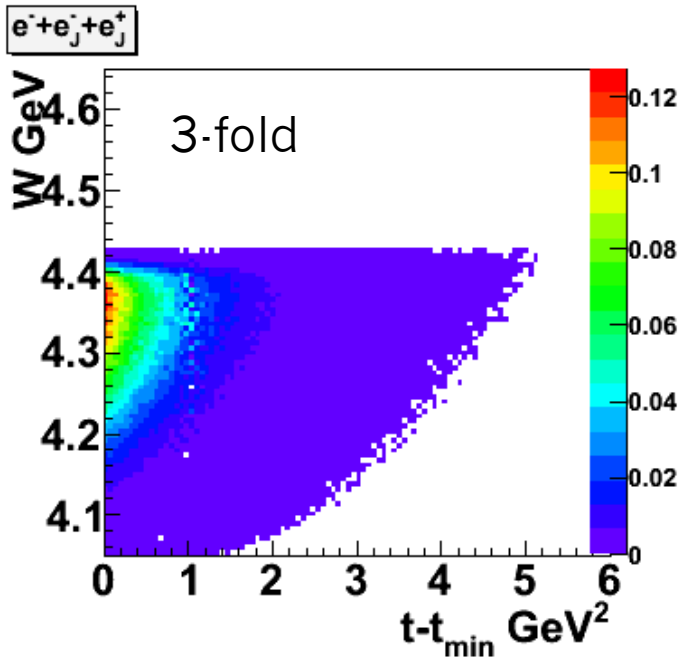
- Γ is the virtual photon flux and J is the Jacobian
- Cross section is based on fits to data at high W within the 2-gluon exchange model

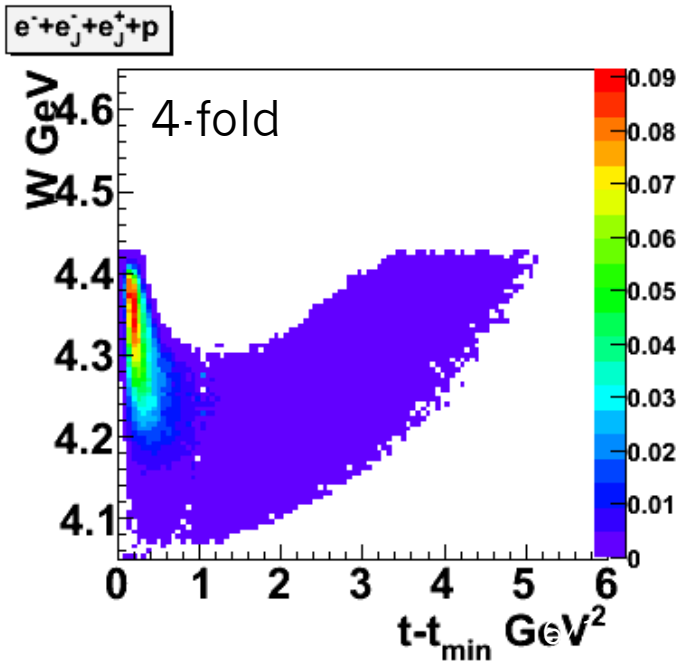


Event Counts @ $1x10^{37}$ in 50 days

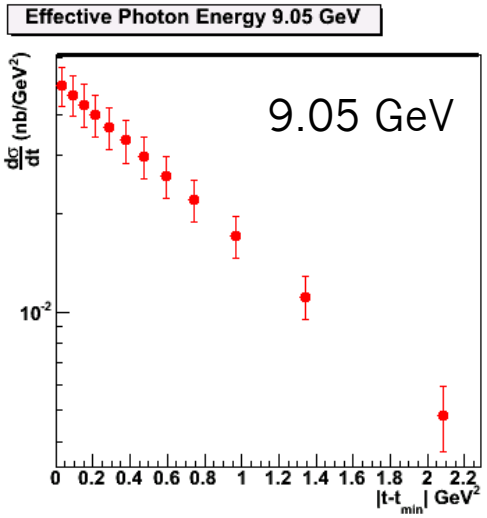
- 4-fold coincidence:
  - 2g-only: **0.68 k** events
  - 2g + 3g: **2.9 k** events
- 3-fold no proton:
  - 2g-only: **2.1 k** events
  - 2g + 3g: **8.08 k** events

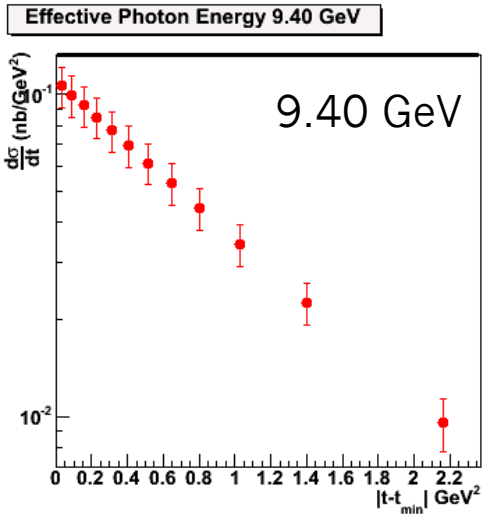
	Time (Hour)	Time (Day)
LH2 at 11 GeV	**1200**	**50**
Dedicated Al dummy run	**72**	**3**
Optics and detector check out	**72**	**3**
Special low luminosity	**96**	**4**
Total	**1440**	**60**

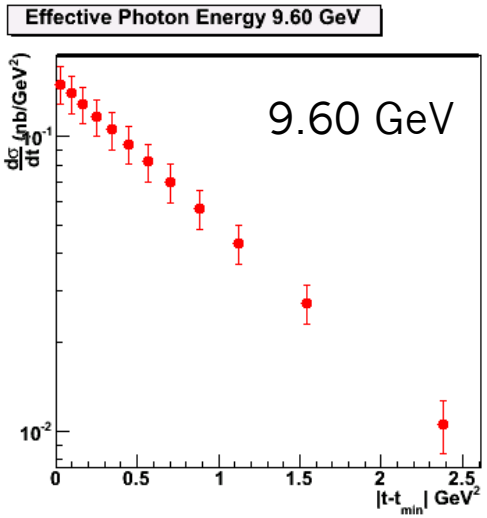


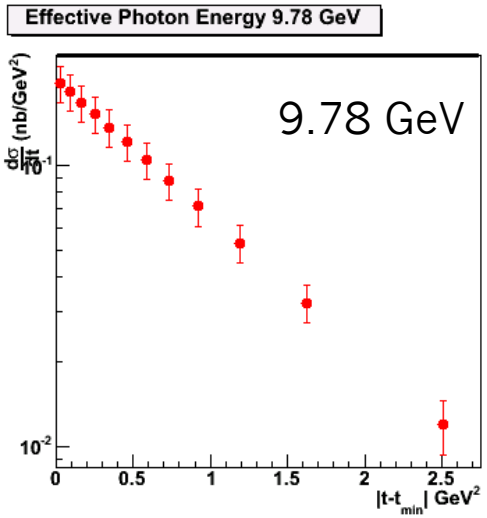


Projections of $d\sigma/dt$ with 2-g model

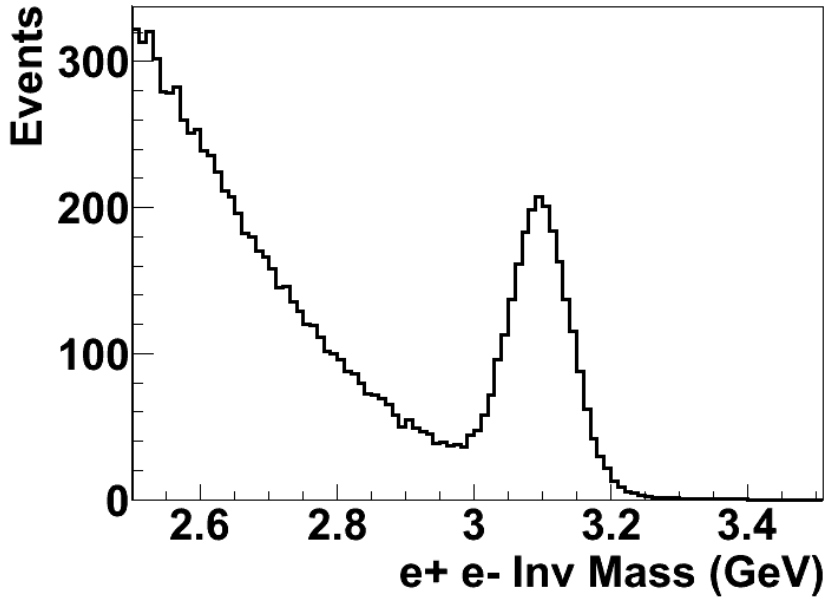






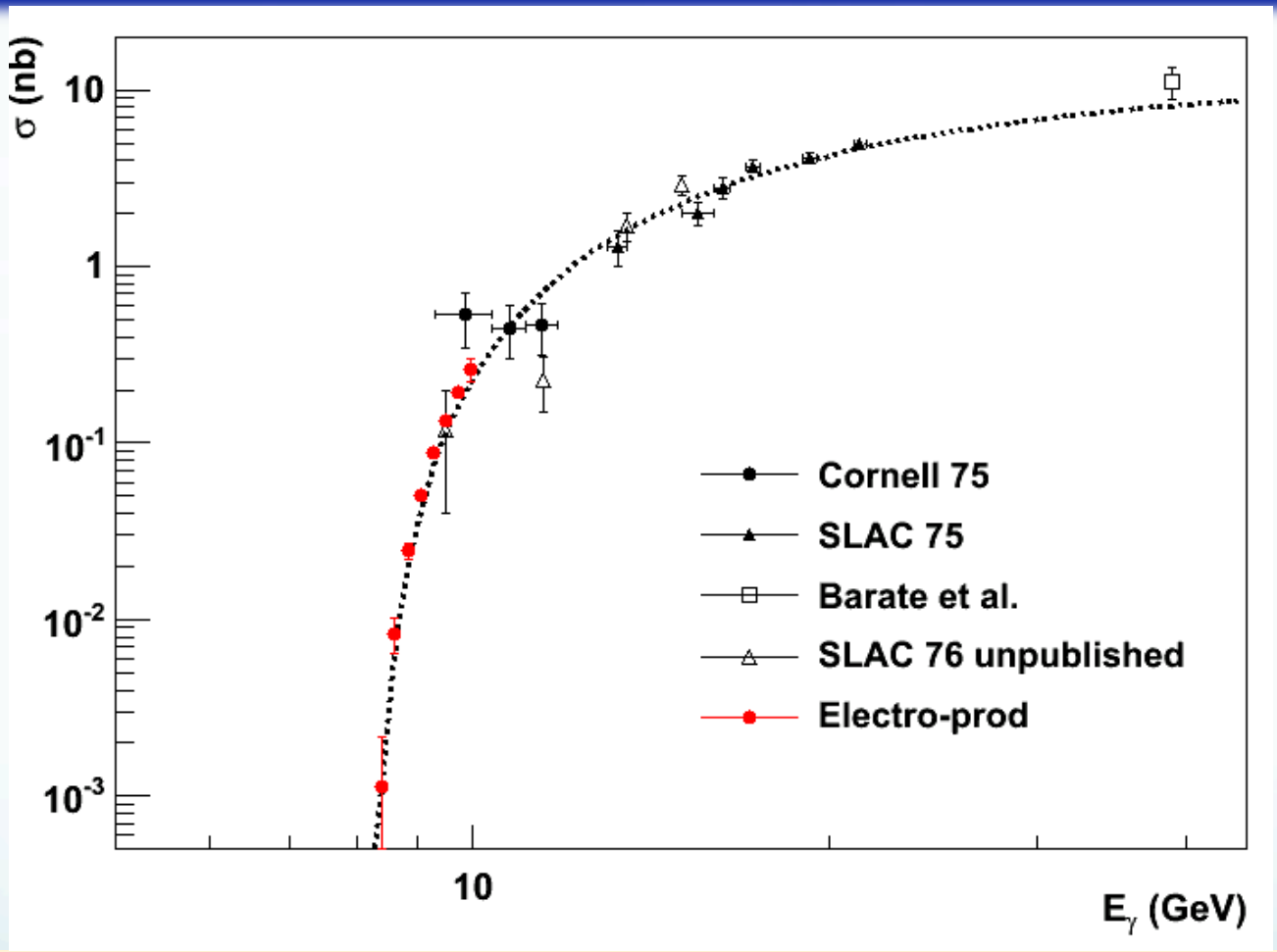


- Data will be first binned in *t* at different *W* (or effective photon energy) to study the t-dependence of the differential cross section



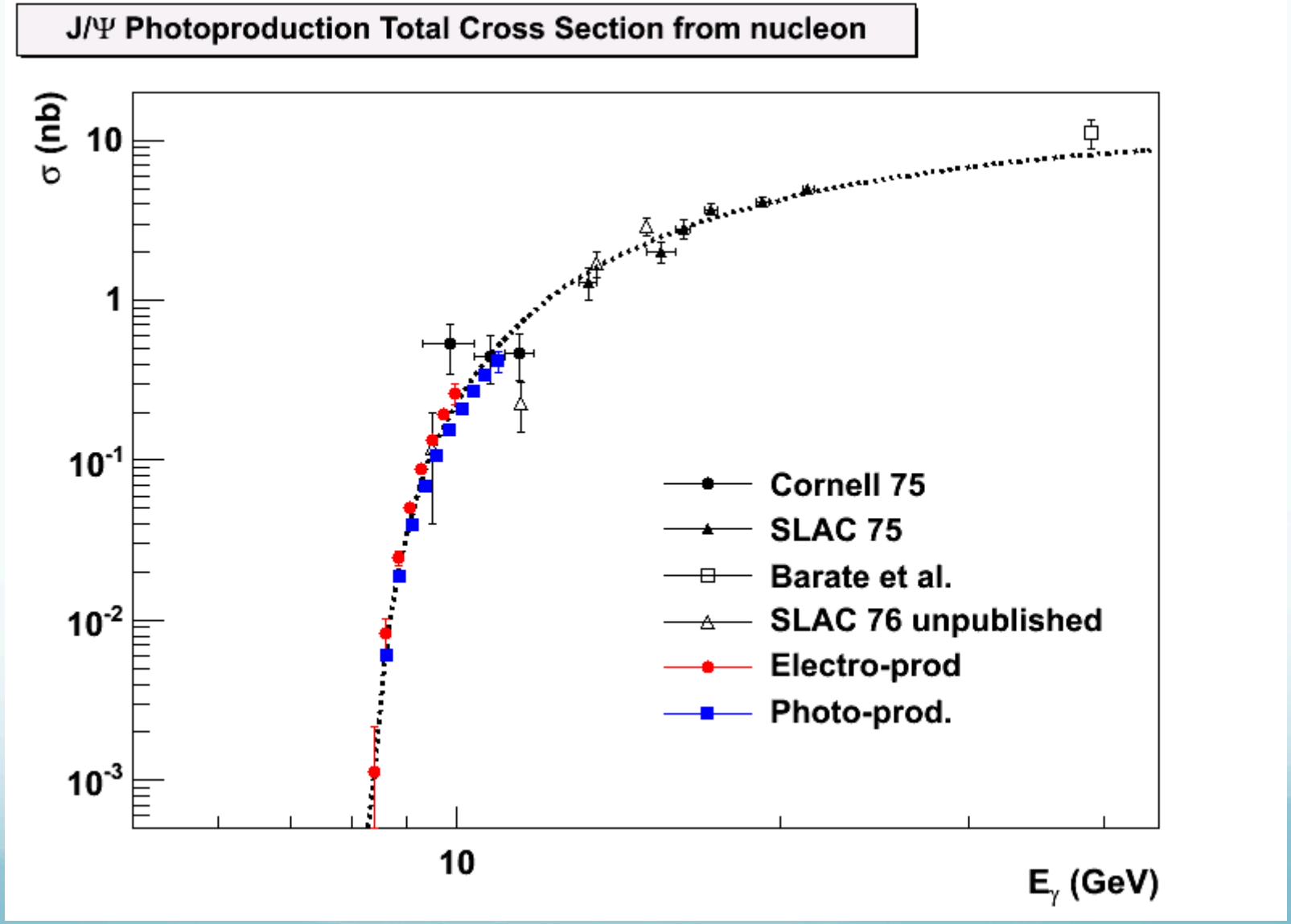
$$E_\gamma^{eff} = \frac{W^2 - M_p^2}{2M_p}$$

Projection of Total Cross Section



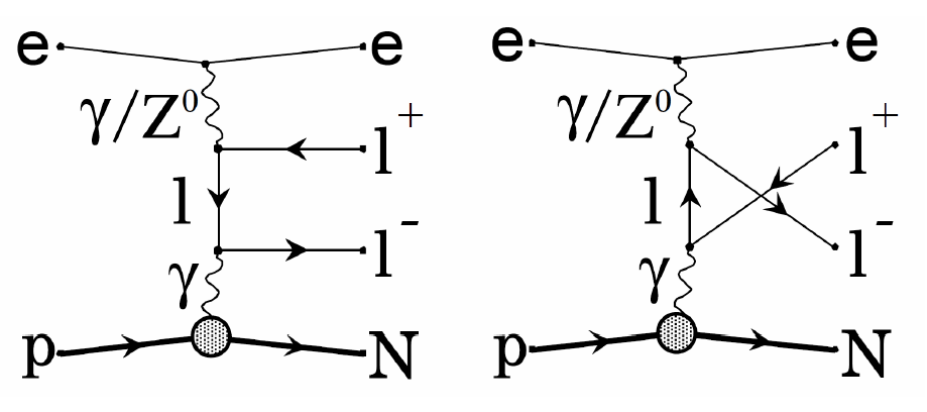
With < 0.01 GeV energy resolution in W and 8 energy bins in W to study the threshold behavior of cross section.

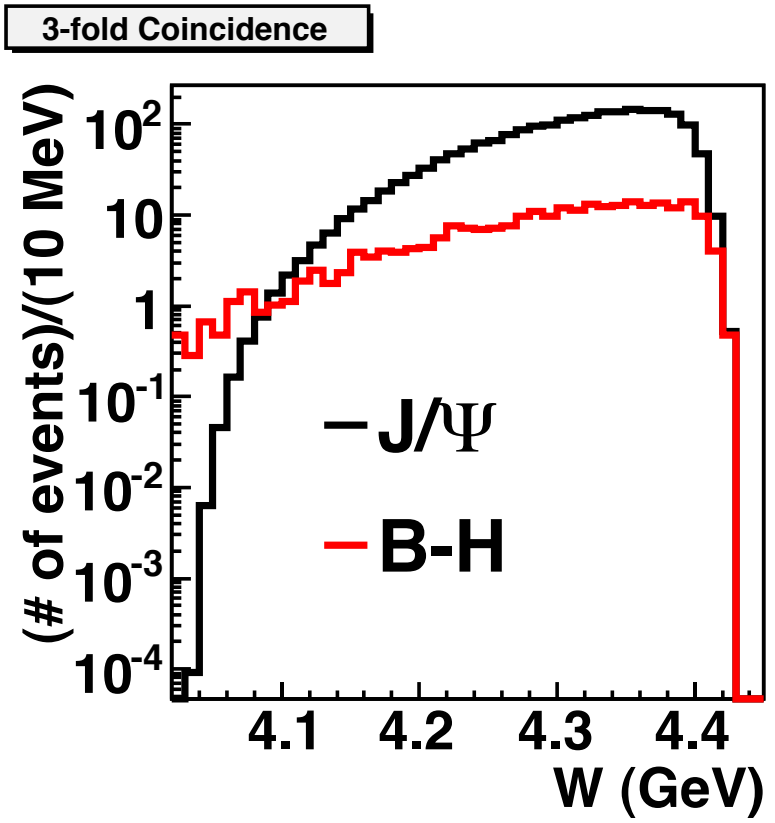
Bonus: photoproduction



Physics Background

- Due to large mass of J/ψ and near-threshold kinematics, little physics background
  - The main background is Bethe-Heitler term



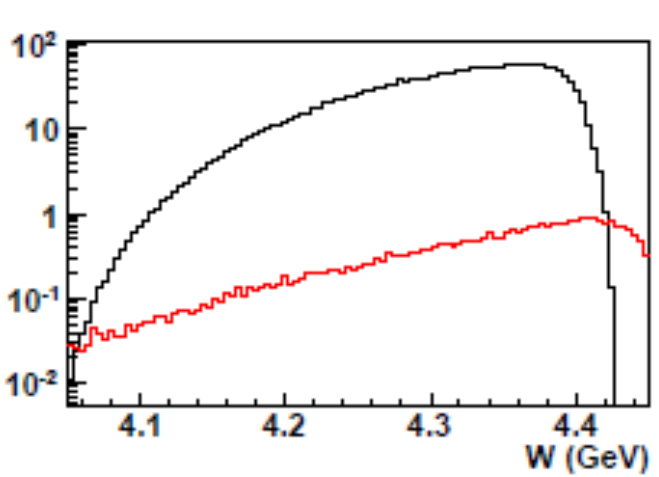


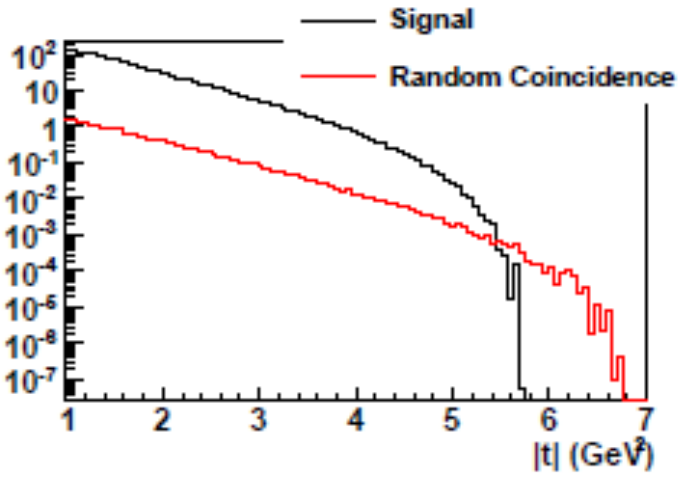
- B-H process calculated with GRAPE-Dilepton program. Compared with 2-gluon model assuming no threshold enhancement.

The t-dependence background level is acceptable.

Random Coincidence Background

- Studied with Pythia and can be subtracted.
  - Largest contribution coming from J/ψ photoproduction in random coincidence with a scattered electron.
  - With the same 2-gluon model, we calculated the random coincidence rate after all cuts and a 6 ns window.





Do not expect a problem either from physics (B-H) or random coincidence background!

Cross Section Validation

$$e + p \rightarrow e' + V(e^- + e^+) + p$$

	Bethe-Heitler	ω	ρ	ϕ	η
Cross Section	**0.1 ub**	**1ub**	**1ub**	**50 nb**	**10 ub**
Decay Channel and BR	**e^+e^-** **1.0**	**e^+e^-** **$7.30\ 10^{-5}$**	**e^+e^-** **$4.71\ 10^{-5}$**	**e^+e^-** **$2.97\ 10^{-4}$**	**$\gamma\gamma$** **0.39**
Compared to J/ψ	**>10**	**x2**	**x1**	**x0.5**	**Large**
SoLID capability	**good**	**good**	**good**	**good**	**good**

- e+p elastic channel: (2.2 and 4.4 GeV beam)
  SoLID Optics Calibration Channel for electrons
- SIDIS charged pion (also DIS)
  SIDIS program, comparing with Hall C measurements

Systematic Budget

- Acceptance Effect: 10% for triple coincidence
- Detector and Trigger Efficiency <2%
- Target Luminosity: <2%
- Contribution from Al wall <1%
  - Dummy run + target vertex Cut
- Background Contamination ~0.5%
  - B-H background + Random Coincidence (measured directly)

Goal: 10-15% cross section measurements

Beam request

- We request 50 days of beam on target to measure the electroproduction and bonus photoproduction of J/Psi at threshold
- We request 10 days for Al dummy run, Optics and special low luminosity run
- In total we request

  50 + 10 days

	Time (Hour)	Time (Day)
LH2 at 11 GeV	**1200**	**50**
Dedicated Al dummy run	**72**	**3**
Optics and detector check out	**72**	**3**
Special low luminosity	**96**	**4**
Total	**1440**	**60**