Proton Mass Workshop: Experimental Summary

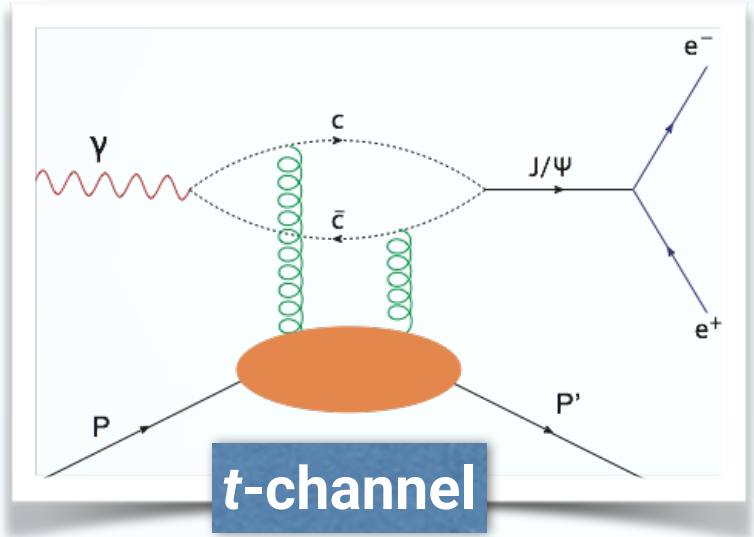
Z.-E. Meziani

Temple University

Dominant Theme
Accessing the Trace Anomaly through production of heavy quarkonia at threshold

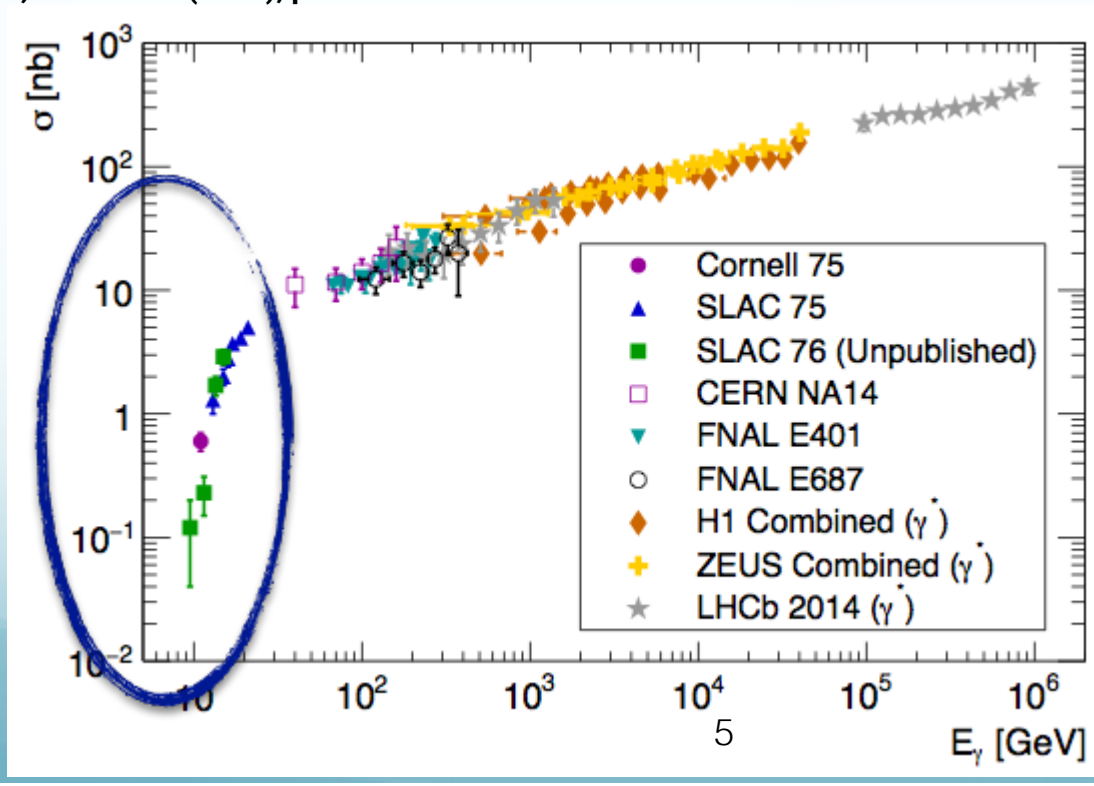
- Charmonium production at threshold as a probe of non-perturbative gluonic physics—Color Van-der Waal force, Trace Anomaly?
  - J/Psi production at threshold at JLab12 ,
    - Hall D (GlueX) [Eugene Chudakov]
    - Hall B (CLAS12), Hall A (SoLID) [Jian-Ping Chen]
    - Hall C LHCb pentaquark search [Sylvester Joosten]
    - Accessing the real part of the Amplitude [Oleksii Gryniuk]
  - J/Psi and Upsilon production at EIC
    - Simulation (work in progress[Nils Feege/A. Deshpande]
- Spin Structure functions of a spin 1 system: the deuteron
    - Approved measurement in Hall C at JLab, b_1, T_{20}[Karl Slifer]

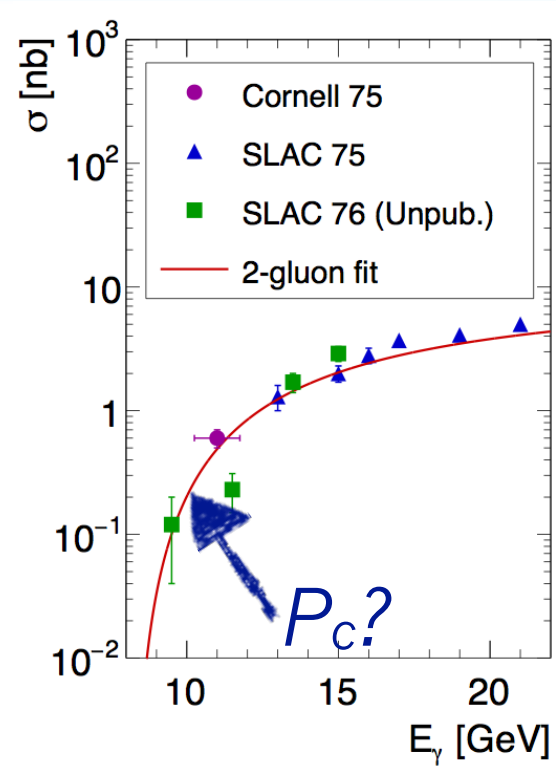
J/ψ photo-production: **what do we know?**



Brodsky S J, *et al.*, PLB 498-1 (2001), p23

- Cross section well constrained above 100 GeV
- **Almost no data near-threshold**
- Resolution of the existing measurements too low
- 2 of the 3 lowest points unpublished!





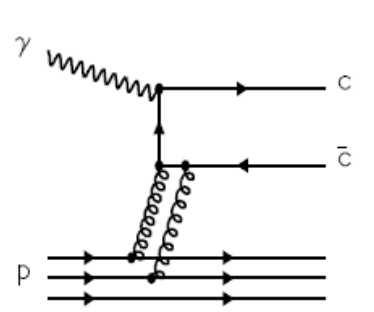
Reaction Mechanism ?

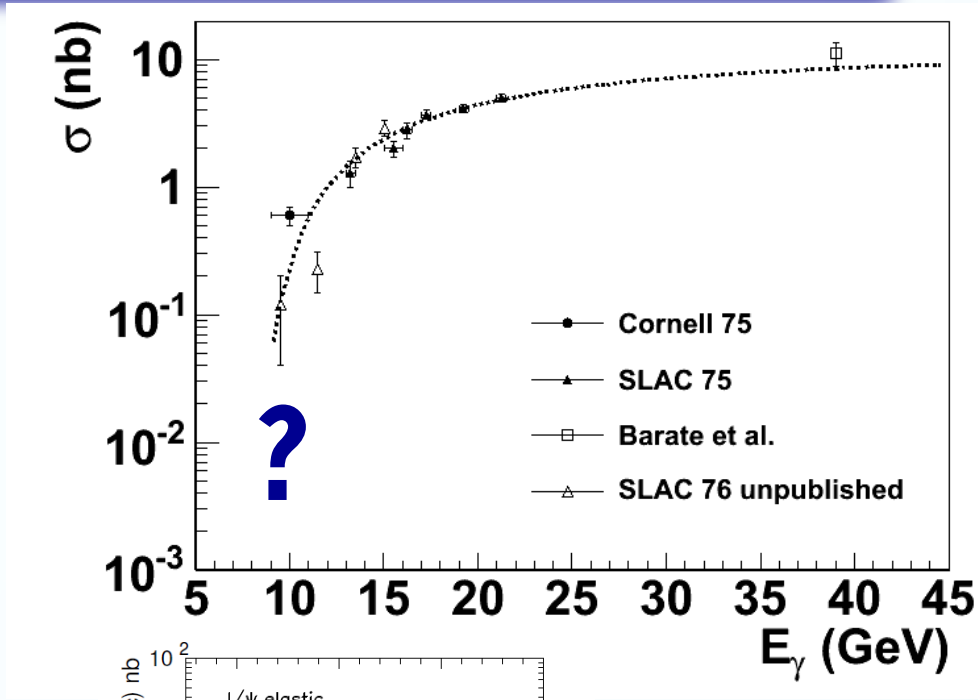
Models-I: Hard scattering mechanism (Brodsky, Chudakov, Hoyer, Laget 2001)

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

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

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

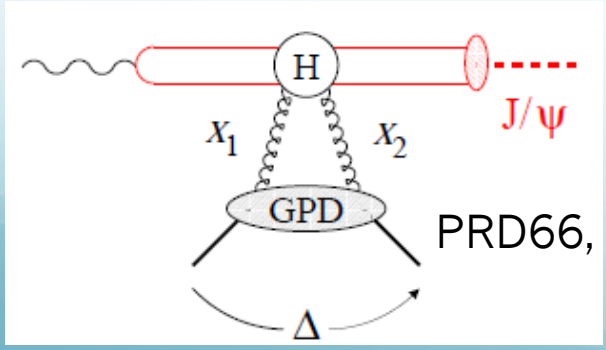




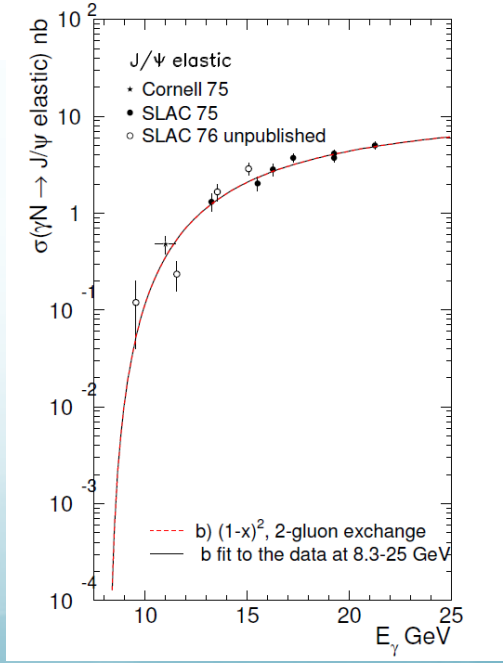
Models -II: Partonic soft mechanism (Frankfurt and Strikman 2002)

2-gluon Form Factor

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



PRD66, 031502 (2002)



J/Psi photoproduction measurement in Hall D

Hall D/GlueX Spectrometer and DAQ

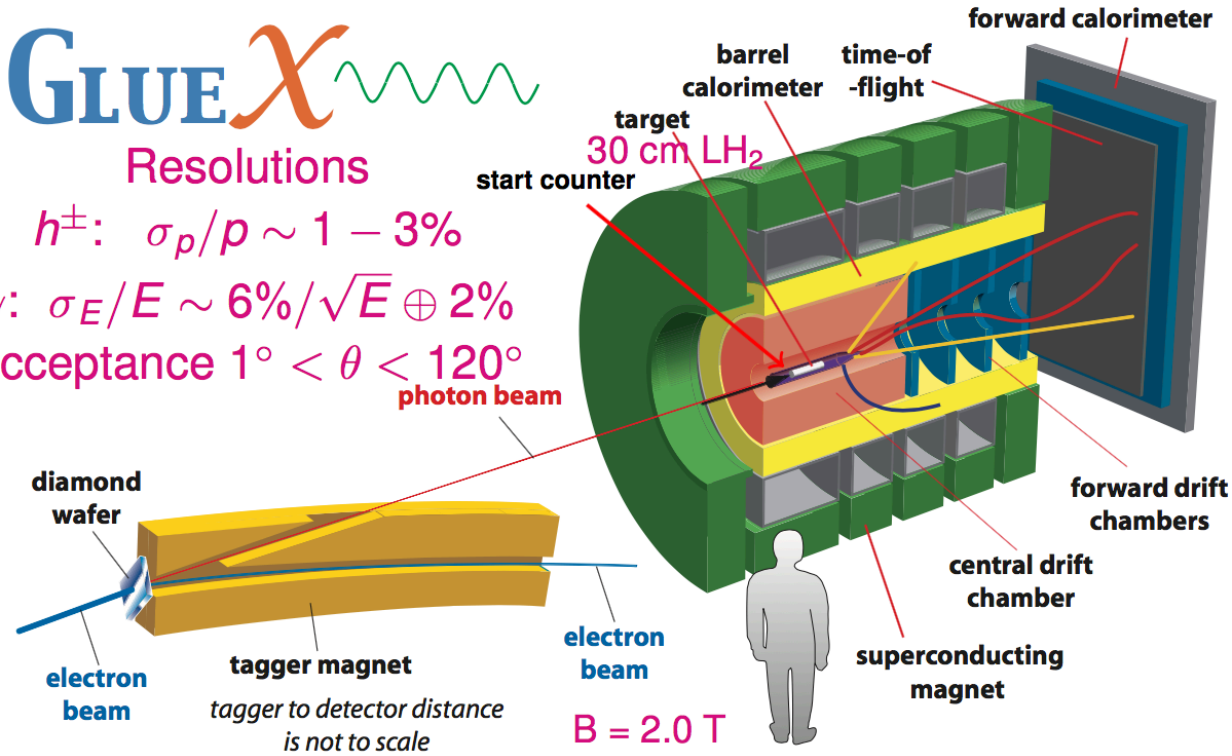
GlueX

Resolutions

$h^{\pm}$: $\sigma_p/p \sim 1-3\%$

γ: $\sigma_E/E \sim 6\%/\sqrt{E} \oplus 2\%$

Acceptance $1^\circ < \theta < 120^\circ$



Detectors

- CDC, FDC
- BCAL, FCAL
- TOF, ST

Plans to add

- 2018 L3
- 2019 DIRC

Photoproduction γp 15 kHz for a 100 MHz beam

Beam 10 MHz/GeV: inclusive trigger 20 kHz $\Rightarrow$ DAQ $\Rightarrow$ tape

Beam 50 MHz/GeV: inclusive trigger 100 kHz $\Rightarrow$ DAQ $\Rightarrow$ L3 farm $\Rightarrow$ tape

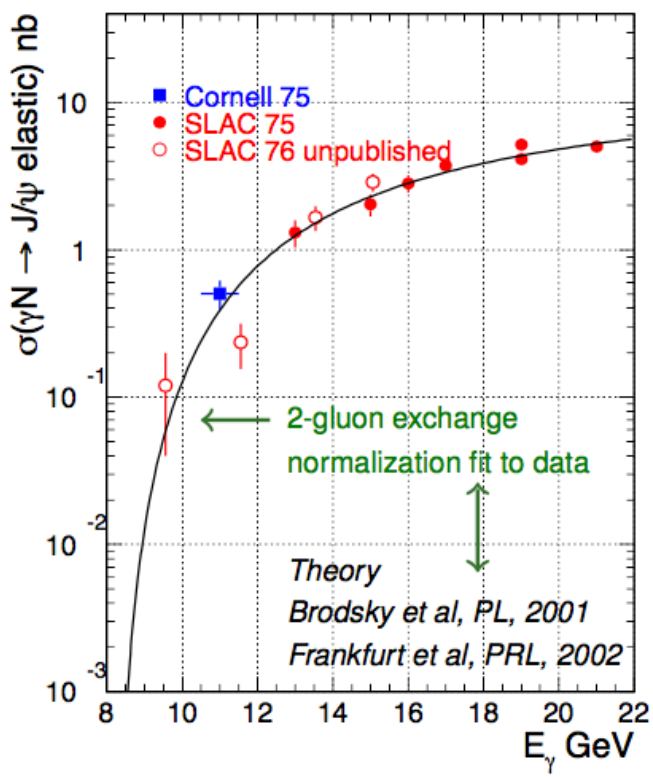
E.Chudakov ECT*, Trento, April 2017 Early results from *GlueX* 11 / 24 Jefferson Lab

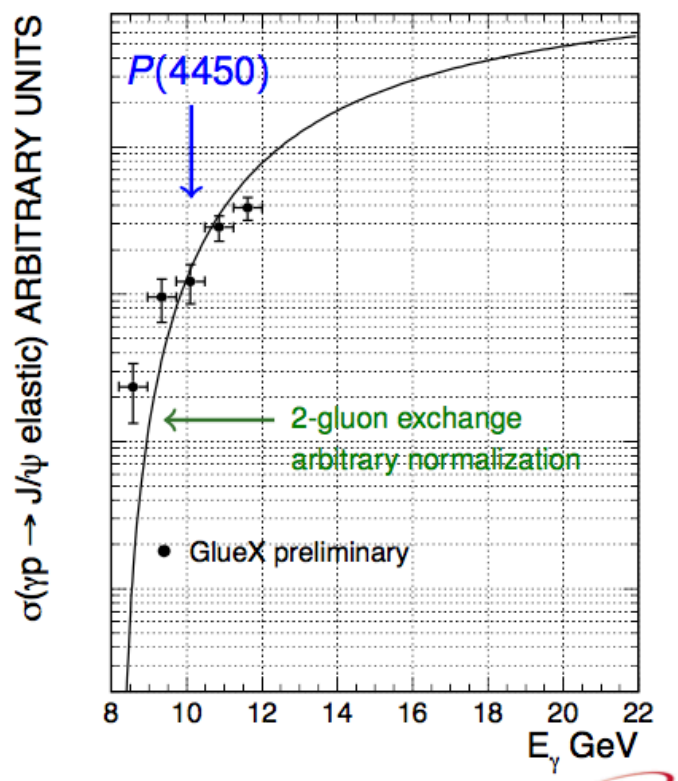
Preliminary Hall D results on J/Psi at threshold

Photoproduction of J/ψ close to threshold

Planned measurements, after adding the 2017 Spring data:

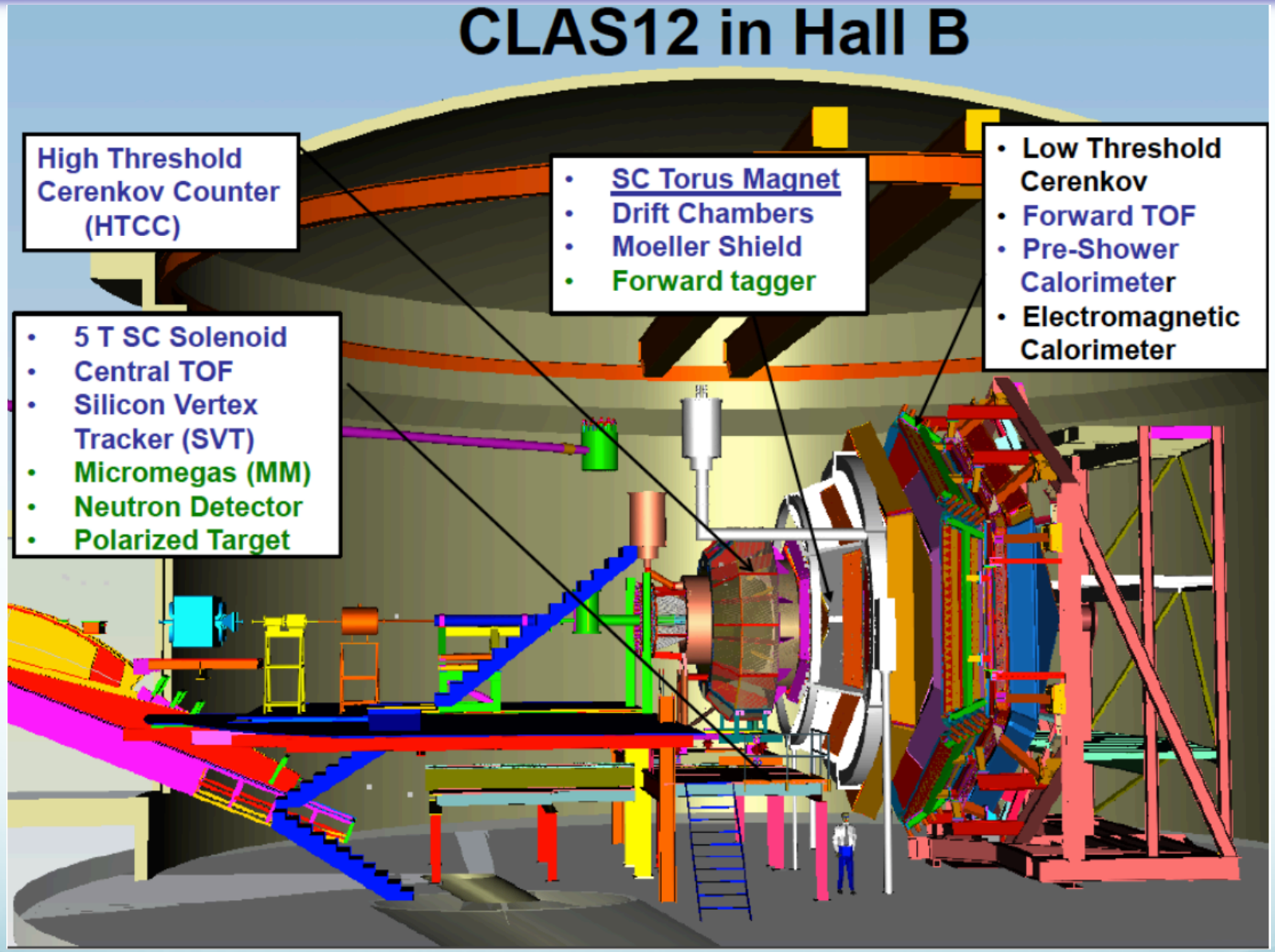
- $\sigma(E)$ - sensitive to gluons at high x
- t-slope
- Limits on the pentaquark yield (the mass resolution ~6 MeV/c^2)





E.Chudakov ECT*, Trento, April 2017 Early results from *GlueX* 20 / 24 Jefferson Lab

CLAS12 –TCS and J/Psi experiment



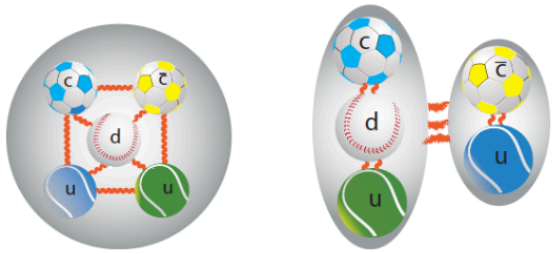
CLAS12 J/Psi Proposed measurement

Search for *hidden charmed pentaquarks* and study of *gluonic structure* of the nucleon

What is the exact nature of *charmed pentaquark* states discovered by LHCb collaboration at CERN

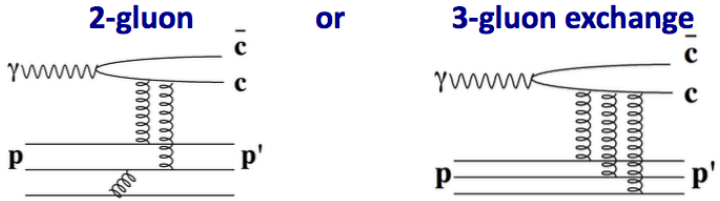
$$P_c \Rightarrow J/\psi\, p$$

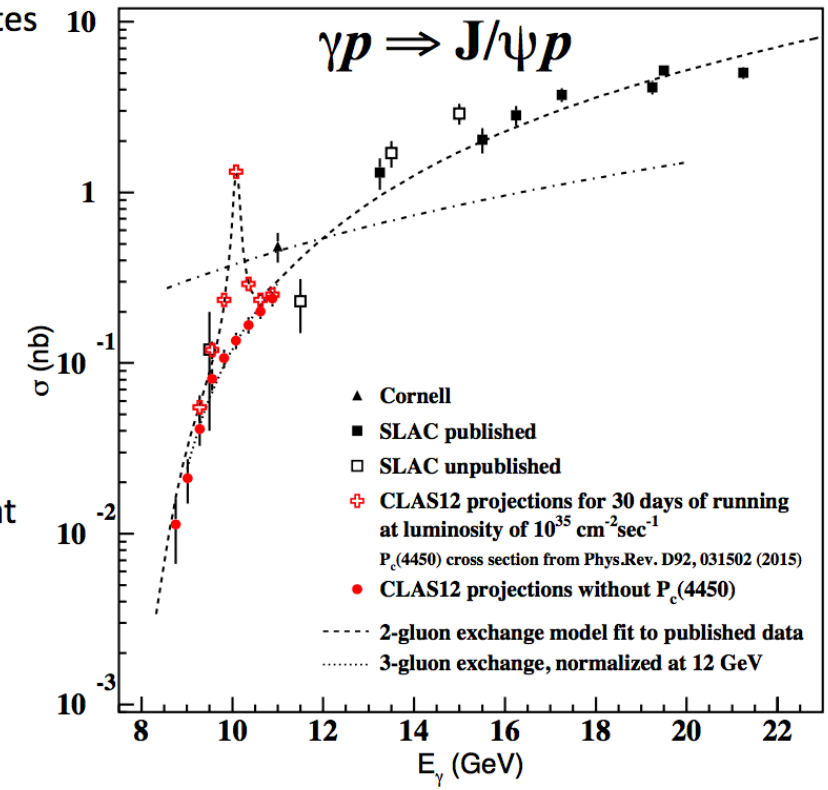
5-quark bound state or **Hadronic molecule**



What is the mechanism of charmonium production at the threshold

2-gluon or **3-gluon exchange**





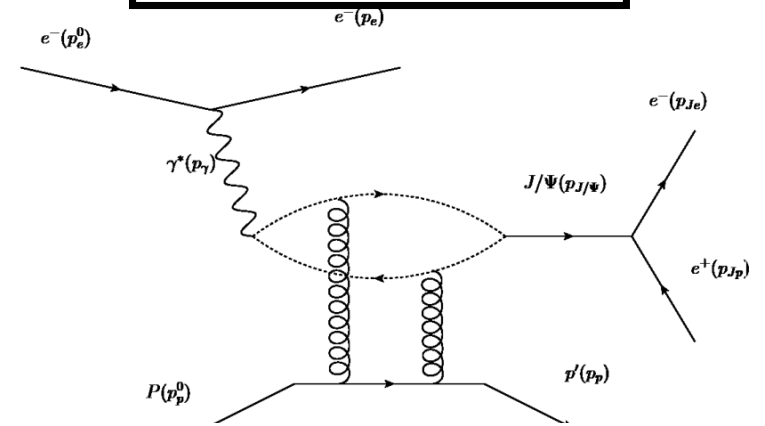
Experiment E12-12-001 measures J/ψ production on the proton near threshold – will verify existence of the ***charmed pentaquarks*** and will study ***the gluon field of the nucleon***

JLAB experiment E12-12-001

J/ψ @ SoLID

$$\gamma^* + N \rightarrow N + J/\psi$$

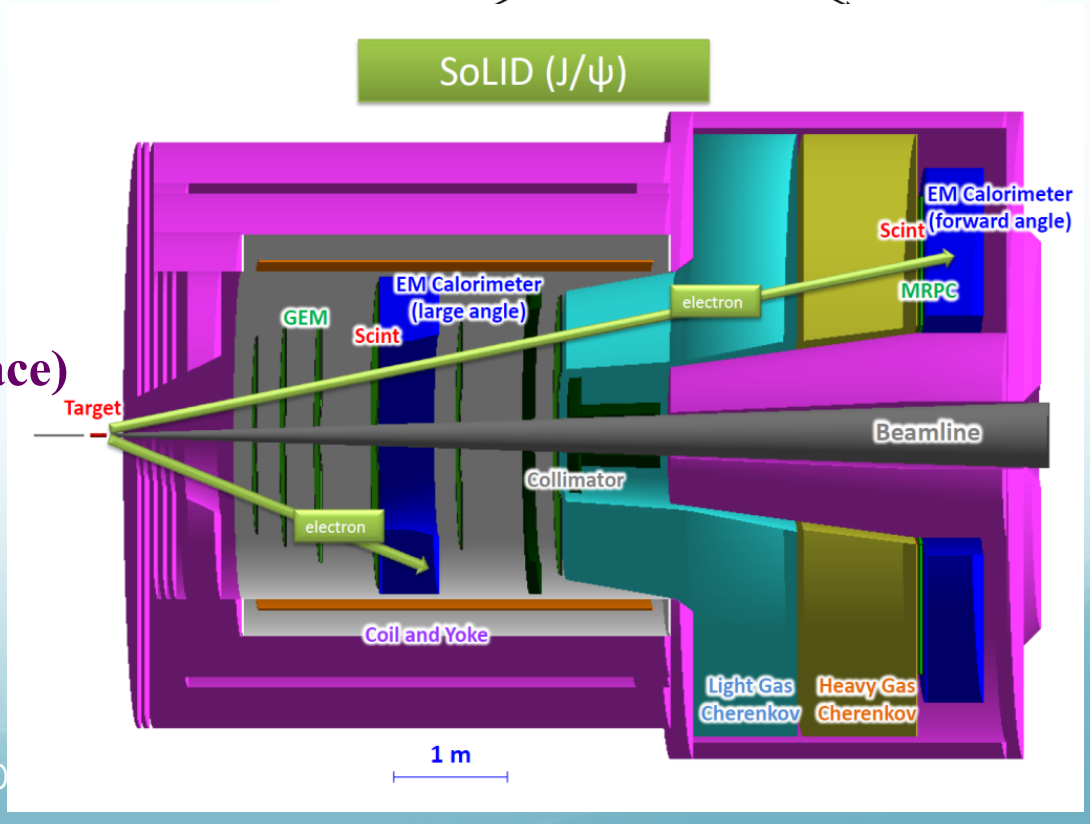
Threshold J/Ψ production, probing strong color field in the nucleon, QCD trace anomaly (important to proton mass budget)



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

Imaginary part: related to the total cross section through optical theorem

Real part: contains the conformal (trace) anomaly



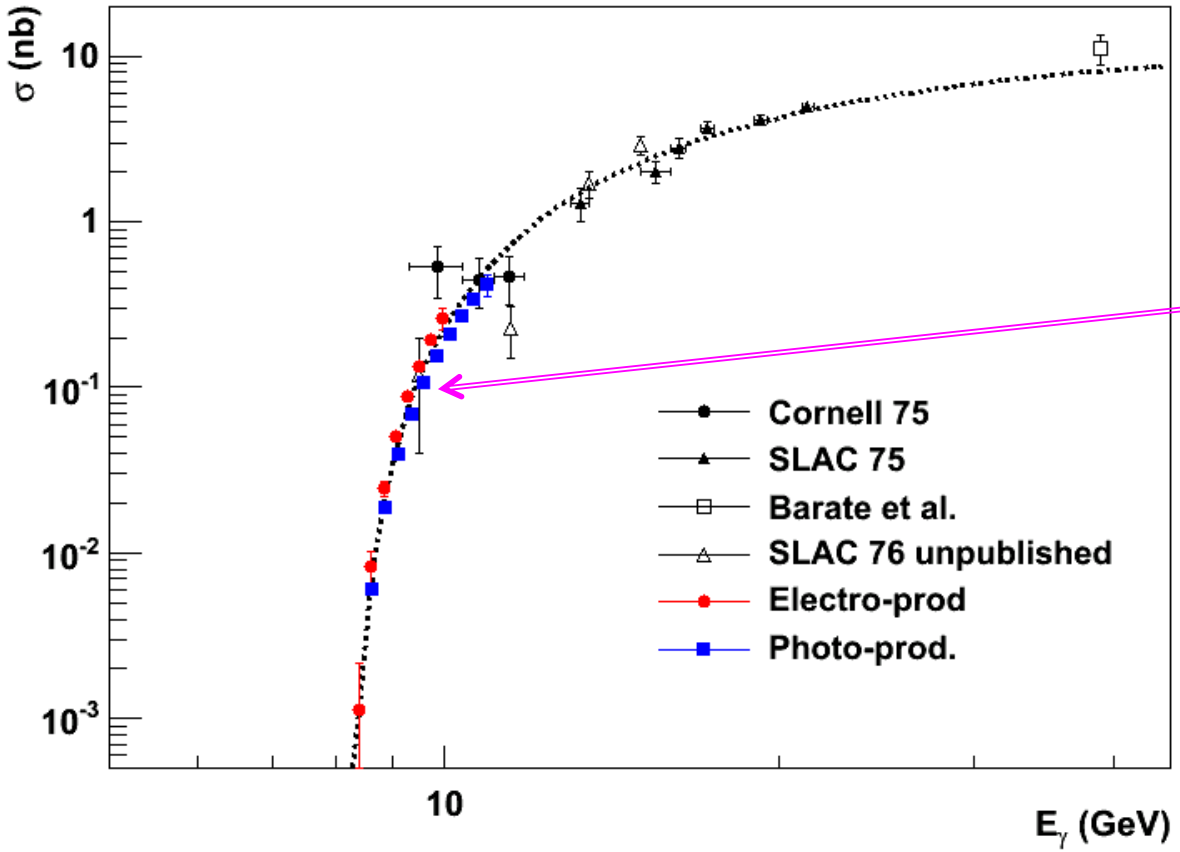
PR12-12-06: Near Threshold J/Ψ Electroproduction

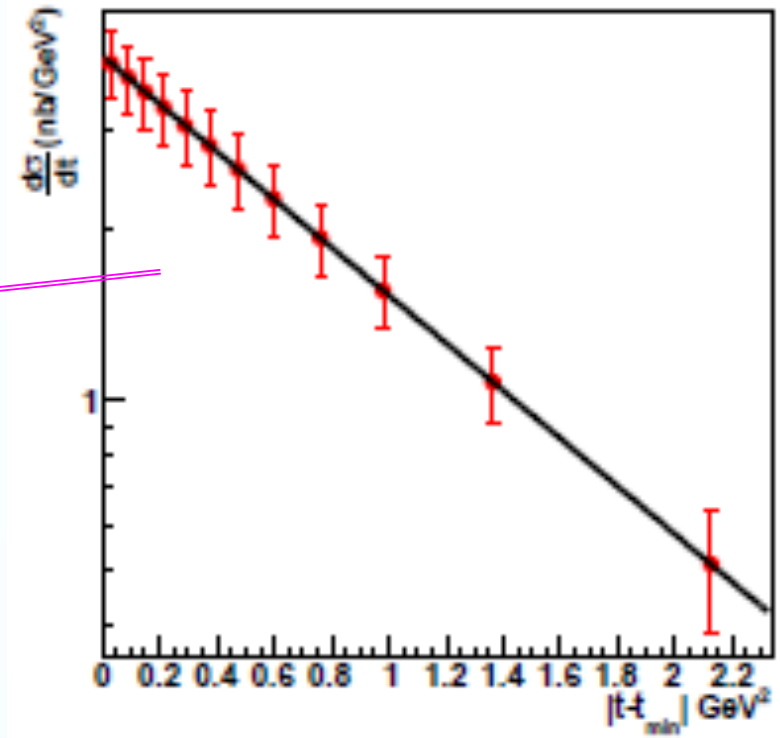
- **Measure the *t* dependence and energy dependence of *J/ψ* cross sections near threshold**
  - Probe the nucleon strong fields in a non-perturbative region
  - Search for a possible enhancement of the cross section close to threshold
  - Shed some light on the conformal/trace anomaly

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

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

Projection of Differential and Total Cross Section





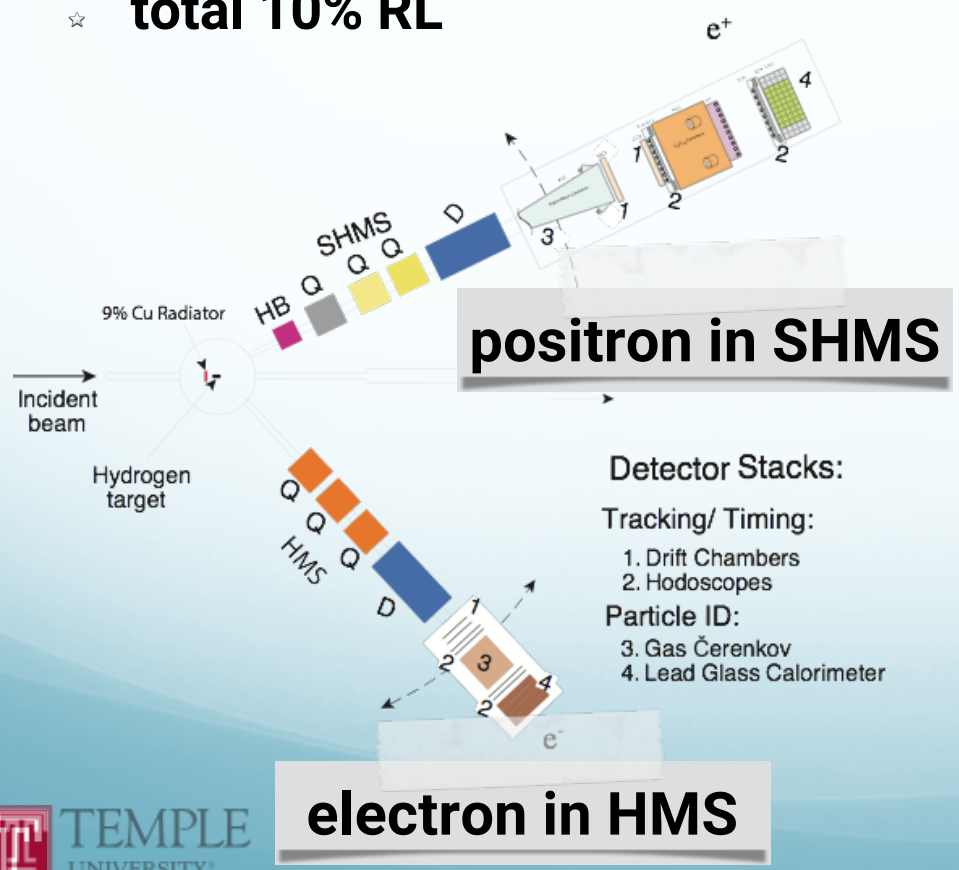
Luminosity 1.2*10^{37}/cm^2/s, 11GeV 3uA e- on 15cm LH2 50 Days

No competition in statistics

Study the threshold behavior of cross section with high precision **could shed light on the conformal anomaly**

Proposed Experiment in **Hall C**

- Setup similar to E-05-101(WACS)
  - 50μA electron beam at 10.7 GeV (or 11 GeV)
  - 9% copper radiator
  - 15cm liquid hydrogen target
  - **total 10% RL**



- **Run with 2 settings:**
  - **"SIGNAL" Setting** (9 days): minimizes accidentals and **maximizes signal/background**:
    - HMS: 34º, 3.25 GeV electrons
    - SHMS: 13º, 4.5 GeV positrons
  - **"BACKGROUND" Setting:** (2 days): precise determination of the ***t*-channel background**
    - HMS: 20º, 4.75 GeV electrons
    - SHMS: 20º, 4.25 GeV positrons

Standard Detector Package, Radiator Well Understood

Bottom line: can run SOON and FAST

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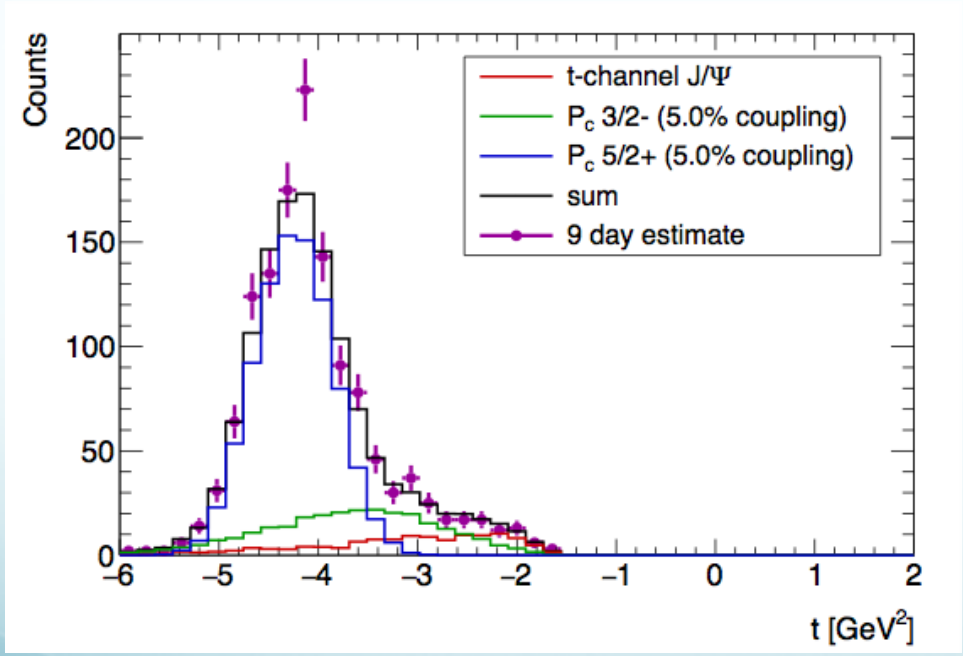
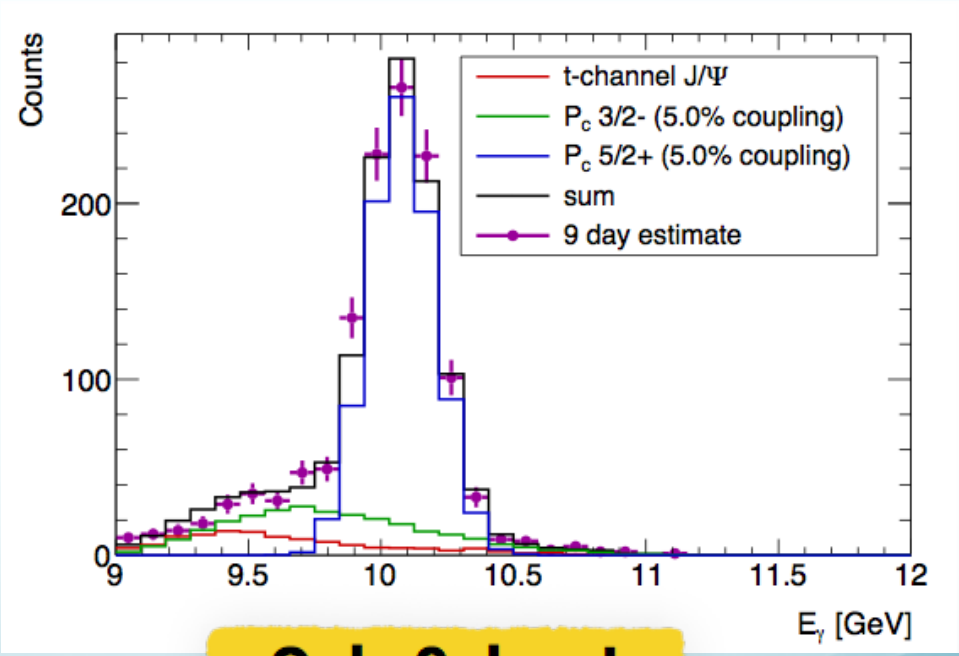
Projected results for **"SIGNAL" Setting**

- **assuming 5% coupling** (value favored by existing photo-production data) Wang Q., *et al.*, PRD 92-3 (2015) 034022-7
- 9 days of beam time at 50μA
- 5/2+ peak **dominates the spectrum**

***t*-channel: 120 events**
5/2+: 881 events
3/2-: 266 events

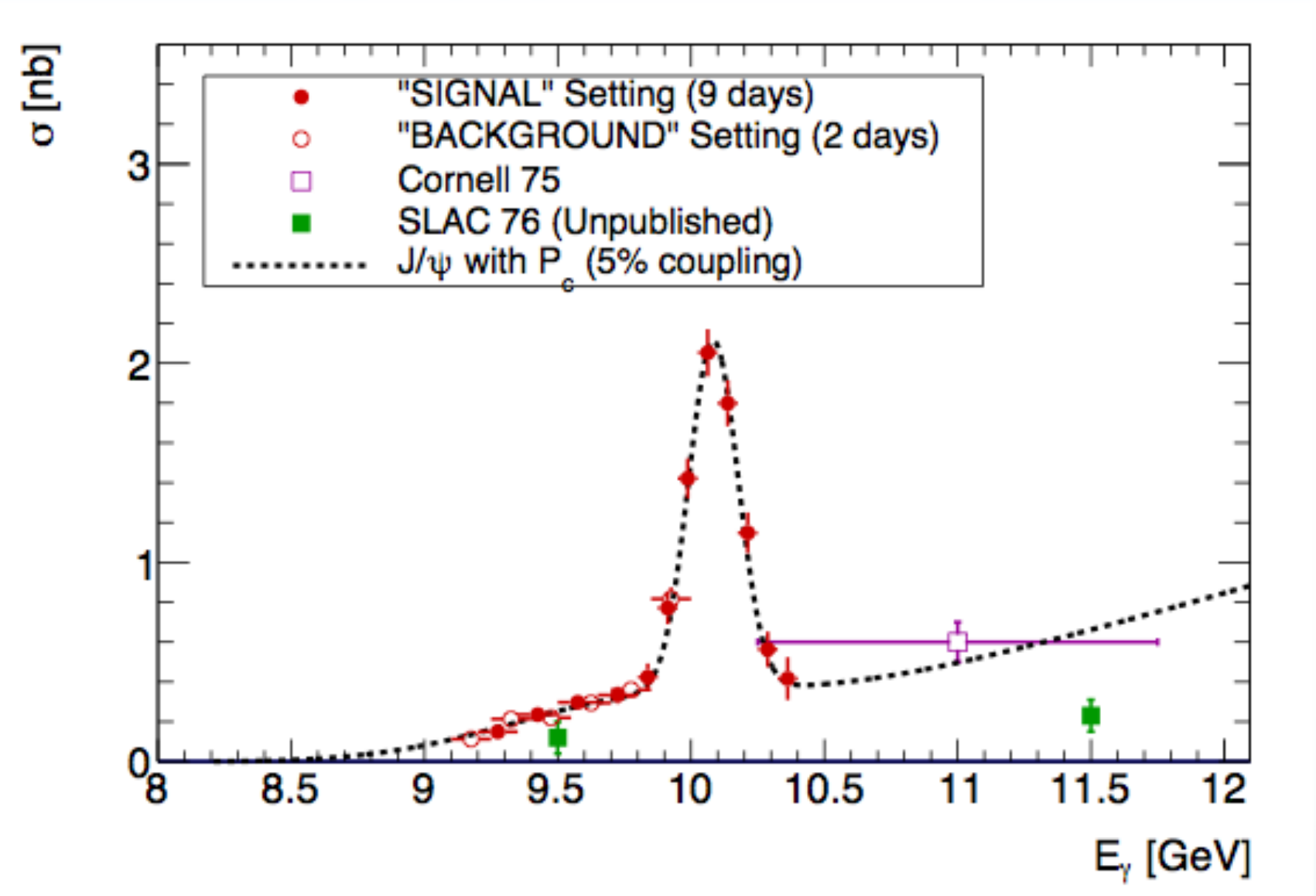




Only 9 days!

Significance > 20σ!

LHCb pentaquark search



Approved ***J/ψ* experiments** at JLab

- GlueX (**Hall D**, *γp*)
  - Luminosity: **low**
    - <100 **MHz** photon rate
  - Acceptance: **very high**
    - First access to 2D *J/ψ* cross section
    - Harder to separate P_c from *t*-channel background
  - Timeline: **ongoing!**

- E12-12-001 (**CLAS12**, HallB, *ep*)
  - Luminosity: **medium**
    - luminosity: 2 x $\mathbf{10^{35}}$ s^{-1} cm^{-2}
  - Acceptance: **high**
    - Access 2D *J/ψ* cross section
    - Harder to separate P_c from *t*-channel background
  - Timeline: **~few years**

- E12-16-007 (**Hall C**, *γp*)
  - luminosity: **very high**
    - 8000 **GHz** photon rate
    - equiv. *ep*-luminosity: $\mathbf{10^{39}}$ s^{-1} cm^{-2}
  - Acceptance: **limited**
    - Optimized for **maximal P_c sensitivity**
    - cannot do 2D *J/ψ* cross section
  - Timeline: **soon (high-impact!)**

- E12-12-006 (**SoLID**, Hall A, *ep*)
  - Luminosity: **high**
    - luminosity: 2 x $\mathbf{10^{38}}$ s^{-1} cm^{-2}
  - Acceptance: **high**
    - Precision 2D *J/ψ* cross section
    - Good sensitivity for Pc resonance due to very high statistics
  - Timeline: **~5-10 years**

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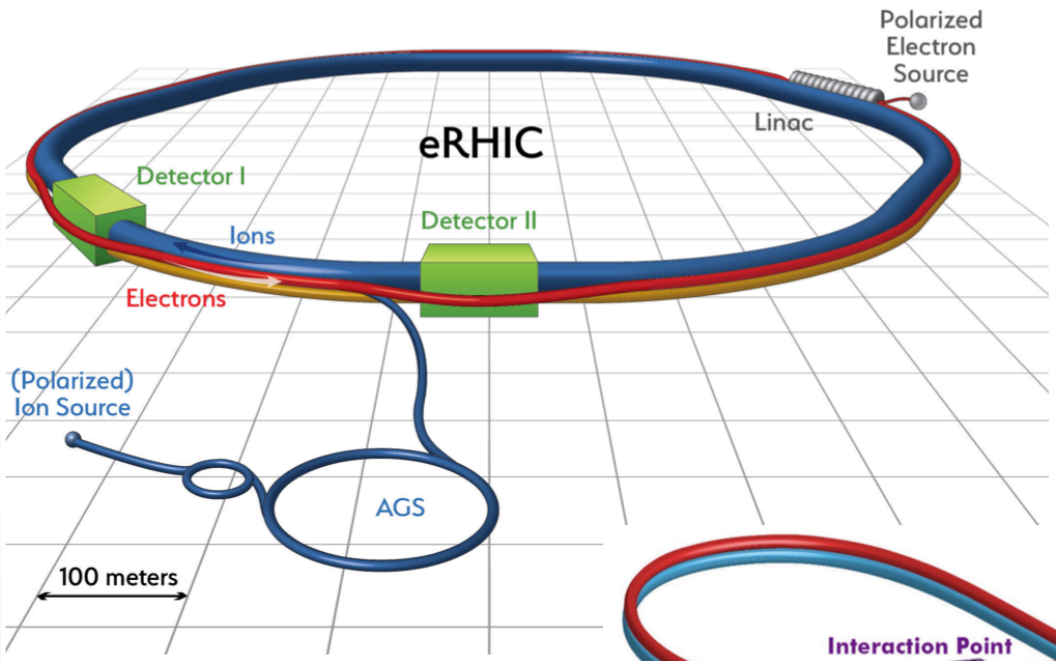
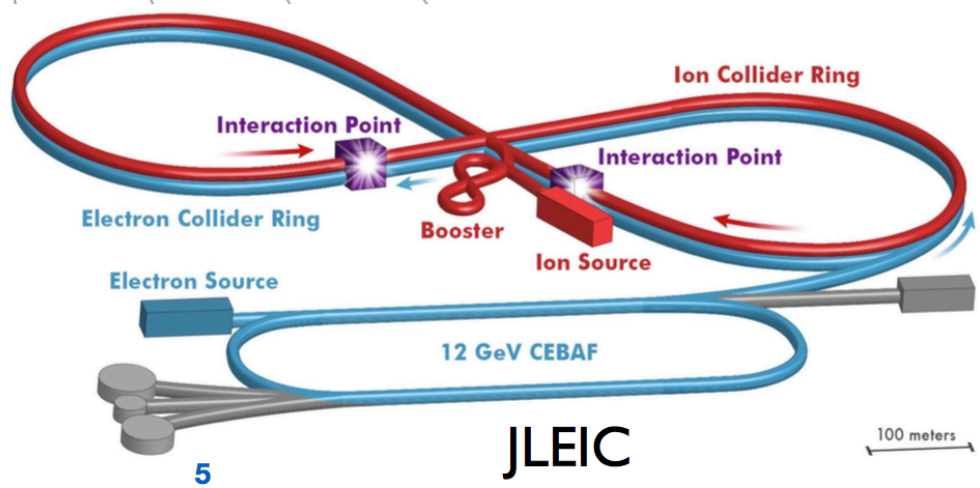
J/Psi and Upsilon at an EIC

Abhay Deshpande and Nils Feege

The Electron Ion Collider

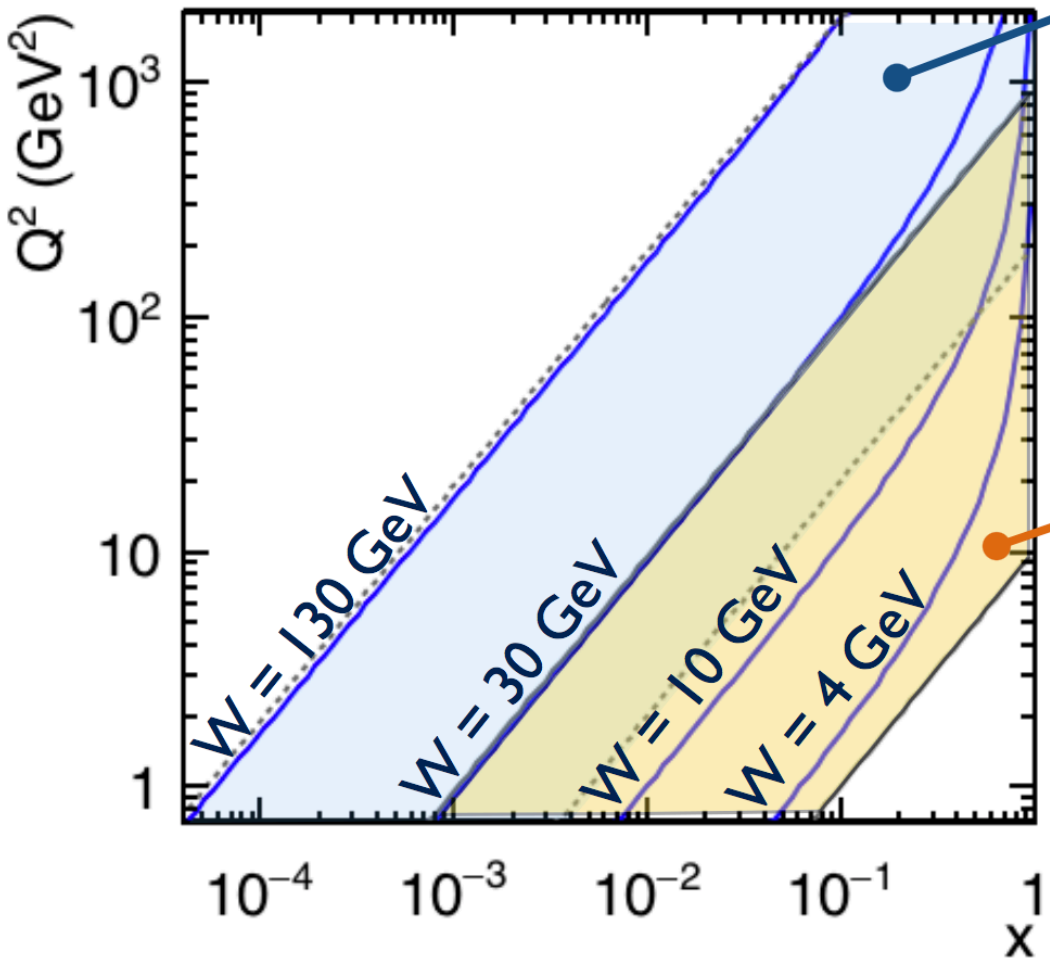


Ee (GeV)	Ep (GeV)	√s (GeV)
5	50	31.6
10	100	63.2
20	250	141



J/Psi and Upsilon at an EIC

What can an EIC contribute?



$\sqrt{s}$ = 141 GeV
0.01 < y < 0.95

$\sqrt{s}$ = 31.6 GeV
0.01 < y < 0.95

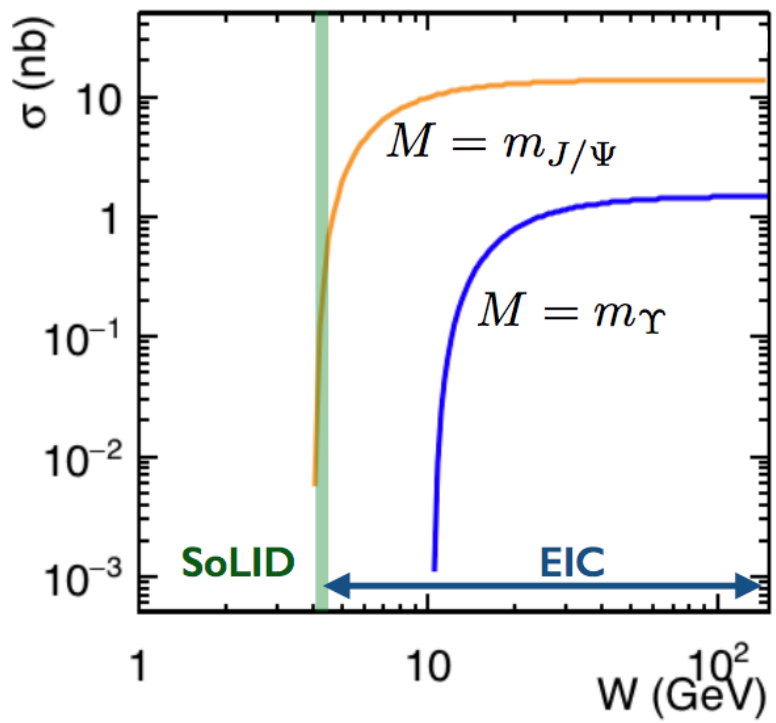
DIS kinematics-
range accessible by EIC

6

J/Psi and Upsilon at an EIC

Using SoLID event generator for EIC is work in progress:

- ➡ SoLID acceptance looks mostly good (need to understand remaining discrepancies).
- ➡ Need correct event weights (cross section).
- ➡ Need to implement boost of final state particles for EIC.



Measuring Upsilon (and J/Psi) production near threshold at the EIC seems like an exciting opportunity- kinematics coverage looks promising!

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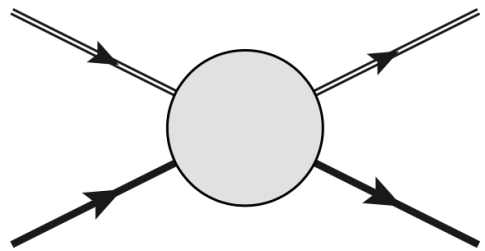


Accessing the **real part** of the forward **elastic J/ψ - p and ϕ - p** scatterings amplitudes close to threshold

Oleksii Gryniuk, Marc Vanderhaeghen

JGU, Mainz, Germany

Forward J/ψ - p scattering

Vector meson dominance (VMD) assumption:

K. Redlich, H. Satz and G. M. Zinovjev, Eur. Phys. J. C **17**, 461 (2000)

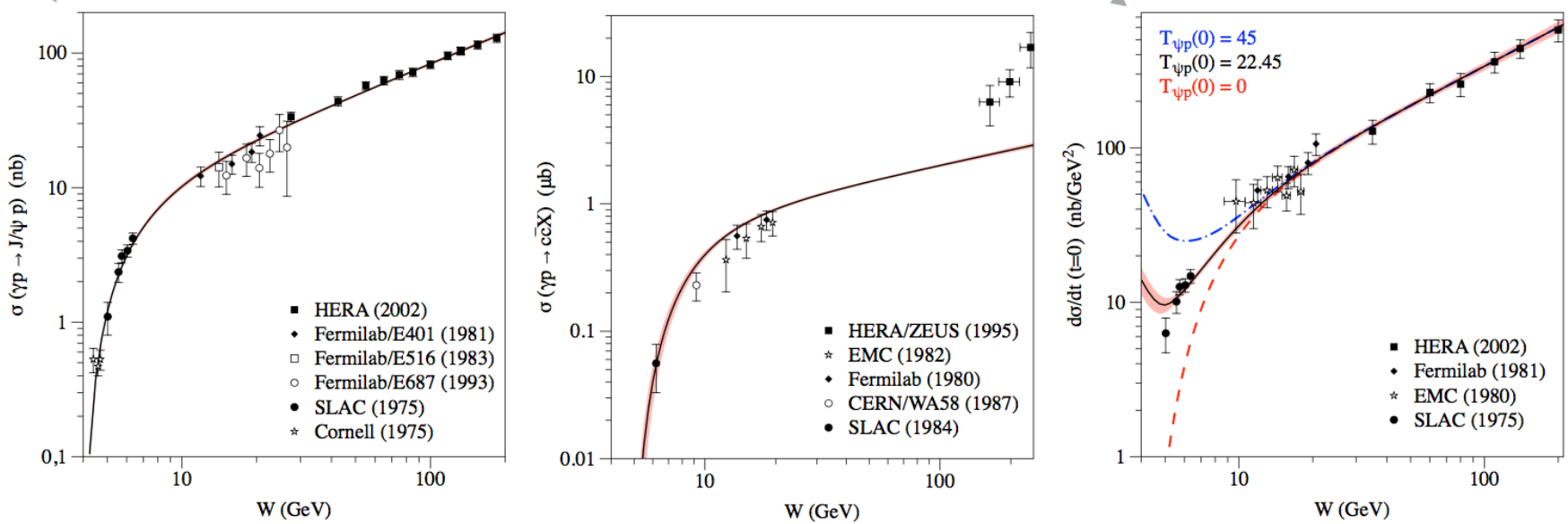
V. D. Barger and R. J. N. Phillips, Phys. Lett. B **58**, 433 (1975)

$$\sigma^{el}_{\psi p} = \left(\frac{M_\psi}{e f_\psi}\right)^2 \left(\frac{q_{\gamma p}}{q_{\psi p}}\right)^2 \boxed{\sigma(\gamma p \to \psi p)}$$

$$\sigma^{inel}_{\psi p} = \left(\frac{M_\psi}{e f_\psi}\right)^2 \left(\frac{q_{\gamma p}}{q_{\psi p}}\right)^2 \boxed{\sigma(\gamma p \to c\bar{c}X)}$$

forward differential cross section:

$$\boxed{\left.\frac{d\sigma}{dt}\right|_{t=0}(\gamma p \to \psi p)} = \left(\frac{e f_\psi}{M_\psi}\right)^2 \left(\frac{q_{\psi p}}{q_{\gamma p}}\right)^2 \left.\frac{d\sigma}{dt}\right|_{t=0}(\psi p \to \psi p)$$



OG, M. Vanderhaeghen, **PRD 94, 074001 (2016)**

simultaneously fitting ⇨ $T(0) = 22.5 \pm 2.5$ ⇨ $a_{\psi p} \sim 0.05$ fm $\quad B_\psi \sim 3$ MeV

Scattering length estimates

QCD sum rules:

A. Hayashigaki, **Prog.Theor.Phys. 101**, 923 (1999) → $a_{\psi p} \approx 0.1$ fm

based on J/ψ chromo-electric polarisability:

A. B. Kaidalov and P. E. Volkovitsky, **Phys. Rev. Lett. 69**, 3155 (1992) → $a_{\psi p} = 0.05$ fm

A. Sibirtsev and M. B. Voloshin, **Phys. Rev. D 71**, 076005 (2005) → $a_{\psi p} = 0.37$ fm

our estimate → $a_{\psi p} \approx 0.05$ fm

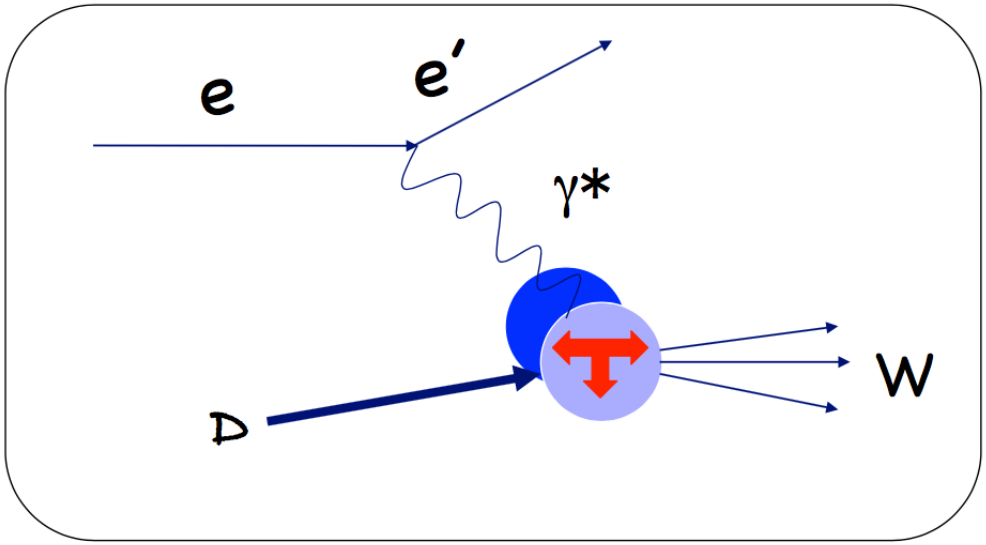
Karl Slifer

New Experiments with Tensor Polarized Targets

The Proton Mass:
At the heart of most visible matter

Trento, Italy
4/4/2017

Tensor Structure Functions



Construct the most general Tensor W consistent with Lorentz and gauge invariance

Frankfurt & Strikman (1983)

Hoodbhoy, Jaffe, Manohar (1989)

$$
\begin{aligned}
W_{\mu\nu} \;=\; & -F_1 g_{\mu\nu} + F_2 \frac{P_\mu P\nu}{\nu} \\
& + i\frac{g_1}{\nu}\epsilon_{\mu\nu\lambda\sigma} q^\lambda s^\sigma + i\frac{g_2}{\nu^2}\epsilon_{\mu\nu\lambda\sigma} q^\lambda (p\cdot q s^\sigma - s\cdot q p^\sigma) \\
& - b_1 r_{\mu\nu} + \frac{1}{6} b_2 (s_{\mu\nu} + t_{\mu\nu} + u_{\mu\nu}) \\
& + \frac{1}{2} b_3 (s_{\mu\nu} - u_{\mu\nu}) + \frac{1}{2} b_4 (s_{\mu\nu} - t_{\mu\nu})
\end{aligned}
$$

Tensor Polarization

Caution : There is an alternate similar formulation by Edelmann, Piller, Weise

b_1 Structure Function

$$b_1(x) = \frac{q^0(x) - q^1(x)}{2}$$

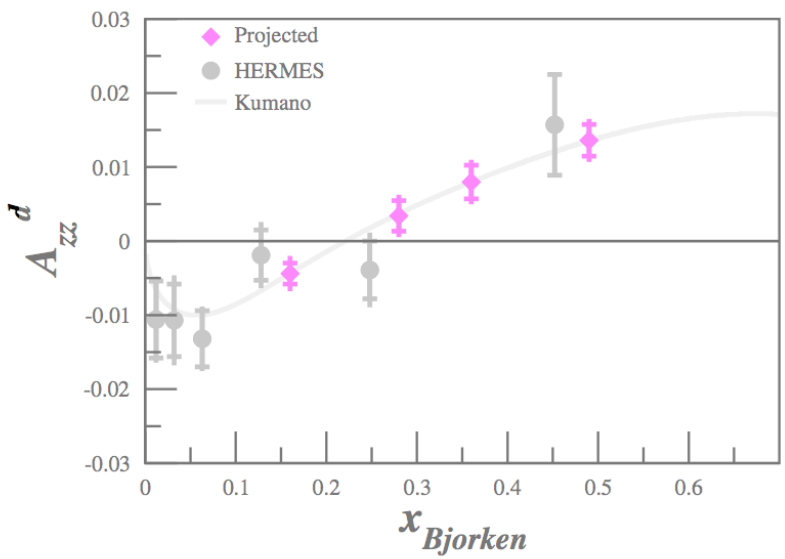
measured in DIS (so probing quarks), but depends solely on the deuteron spin state

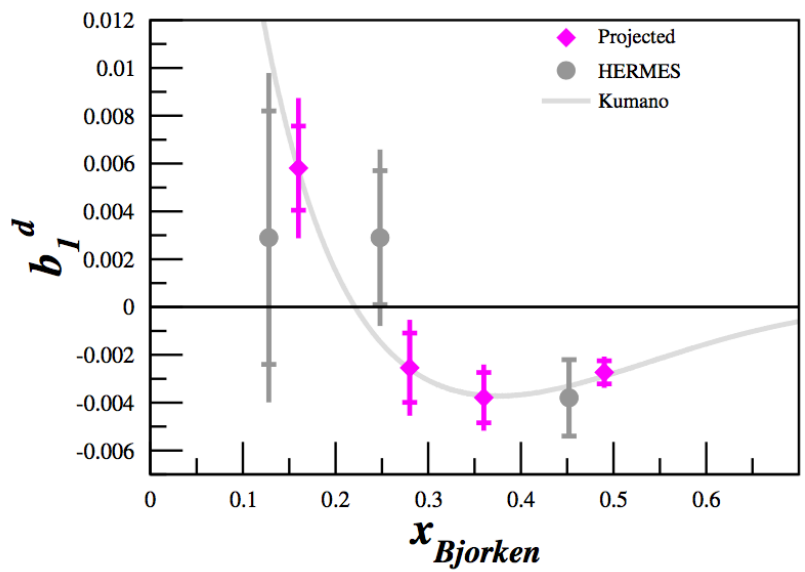
Investigate nuclear effects at the level of partons!

q^0 : Probability to scatter from a quark (any flavor) carrying momentum fraction x while the *Deuteron* is in state m=0

q^1 : Probability to scatter from a quark (any flavor) carrying momentum fraction x while the *Deuteron* is in state |m| = 1

Projected Results for P_{zz} = 35%





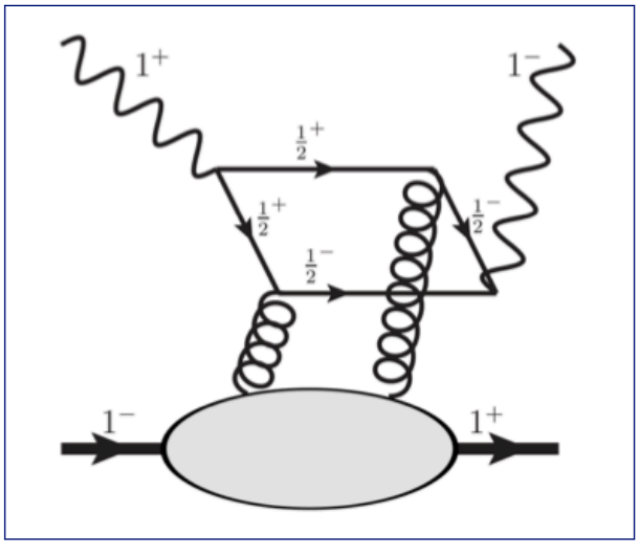
30 Days in Jlab Hall C

verification of zero crossing
essential for satisfaction of CK Sum

LOI-12-16-006

James Maxwell (contact)

"Nuclear Gluonometry"



Look for novel gluonic components in nuclei that are not present in nucleons

Non-zero value would be a clear signature of exotic gluon states in the nucleus

Deep inelastic scattering experiment:
- Unpolarized electrons
- Polarized $^{14}NH_3$ Target
- Target spin aligned transverse to beam

$\Delta(x,Q^2)$ double helicity flip structure function

Encouraged for full submission by PAC44

Conclusion

- Threshold electro-photo-production of heavy quarkonia at Jlab and EIC might provide critical data for the determination of the trace anomaly.
- A path to identify a quantitative connection between the measurement of the threshold cross section (differential and total) and the matrix element of $\langle p|F^2|p\rangle$ needs to be established
- Polarization observables need to be explored to help extract the real part of the amplitude of production. And perhaps more information connected to the Energy Momentum Tensor
- A bright future awaits?.....