This work is supported by DOE grant DE-FG02-94ER4084

Heavy Quarkonium Production: From JLab to an EIC

Sylvester Joosten

sylvester.joosten@temple.edu

Overview:

1. Near-threshold J/ψ production
2. A Search for the LHCb Pentaquarks in Hall C
3. 12 GeV J/ψ Experiments at JLab
4. Heavy Quarkonium at an EIC

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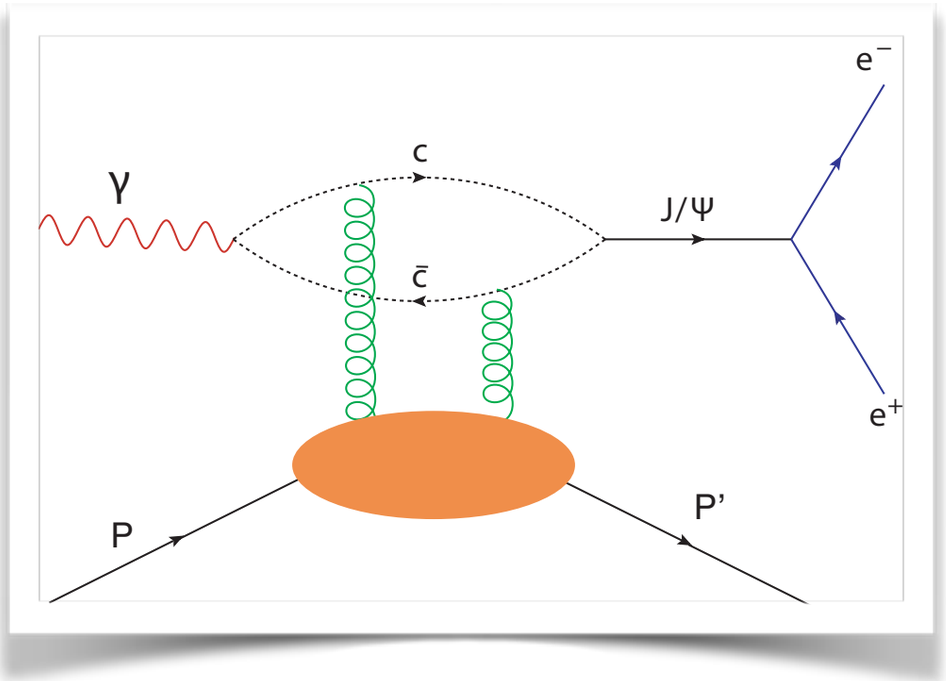
INT, August 30, 2017

Heavy Quarkonium as a Probe

- **Near Threshold:**
  - ☆ Study **color Van der Waals force**, possible charmonium-nucleon/nucleus bound states
  - ☆ Access **trace anomaly** of the QCD energy-momentum tensor, study the **origin of mass**
  - ☆ Disentangle real from imaginary part of the amplitude through the interference with Bethe-Heitler
  - ☆ ***J/ψ* program at Jefferson Lab**

- **High Energies (far from threshold)**
  - ☆ Dominated by 2-gluon exchange
  - ☆ Access the **gluon GPD at an EIC**



Near-threshold J/ψ production

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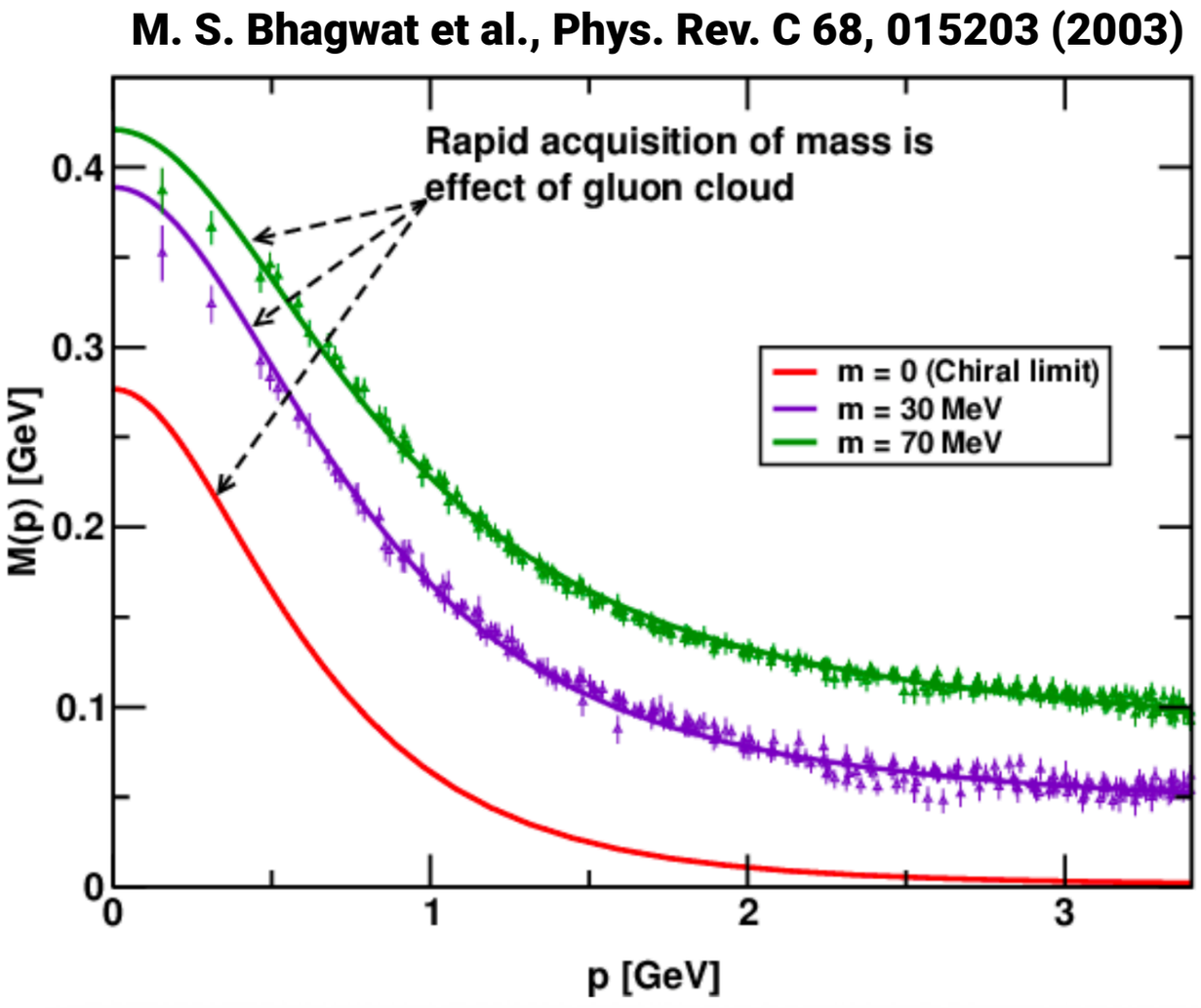
The **Proton Mass** is an **Emergent Phenomenon**



Event in the chiral limit, the **gluon field accumulates ~300 MeV/constituent quark**. The Higgs mechanism is largely irrelevant in normal matter!

$$M^2 \propto \langle p|T^\alpha_\alpha|p\rangle$$

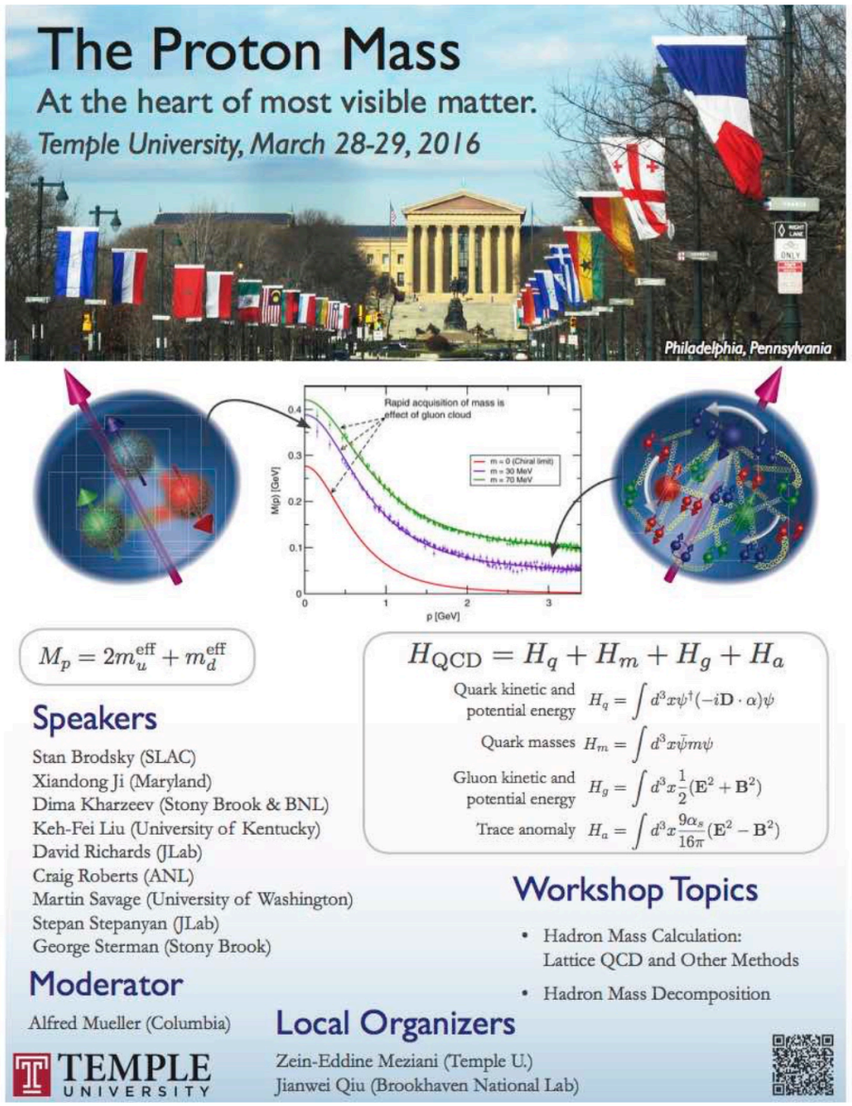
- Proton **mass** related to **trace of QCD energy-momentum tensor**
- Has two distinct components:
  - Quark mass term
  - Conformal (trace) anomaly

- Trace anomaly related to real part of heavy quarkonium-nucleon scattering amplitude
- Dominant contribution near threshold!

The Origin of Mass is a Hot Topic!

"... The vast majority of the nucleon's mass is due to quantum fluctuations of quark- antiquark pairs, the gluons, and the energy associated with quarks moving around at close to the speed of light. ..."

(The 2015 Long Range Plan for Nuclear Science)



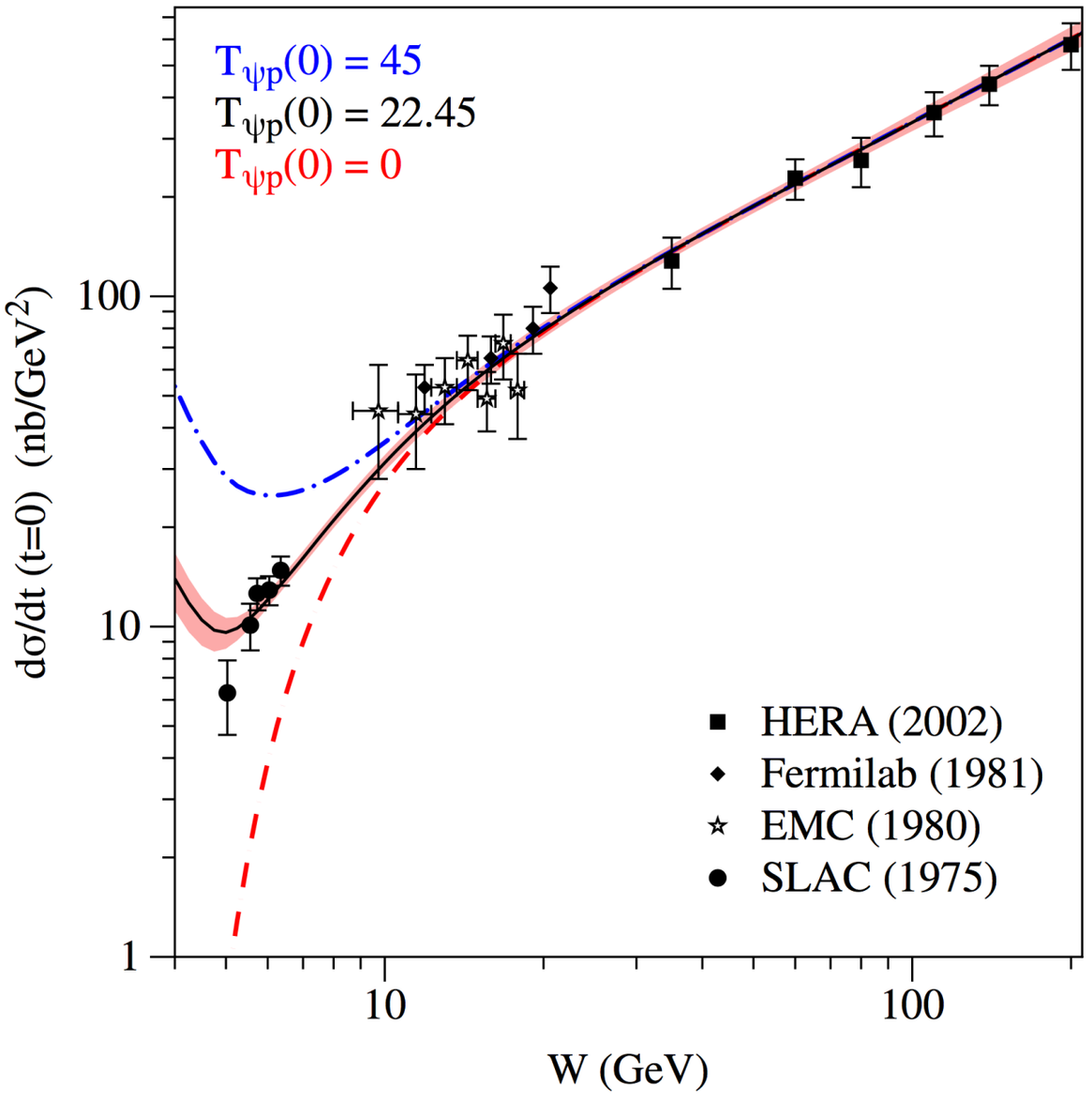
JLab will play a leading role:

Access Trace anomaly through elastic J/ψ production near threshold

Do J/ψ and protons **attract each other**?

- Color neutral objects: "***QCD Van der Waals force***"
- Characterized by *s*-wave scattering length $a_{\psi p}$
- Current estimates ranging from 0.05-0.30 fm, corresponding to $B_{\psi p} < 20$ MeV
- LQCD: $B_{\psi p} < 40$ MeV
- At threshold: $\sigma^{\rm tot}_{\psi p} \equiv 4\pi a^2_{\psi p}$
- Fit to existing data: $a_{\psi p} = 0.05$ fm ($B_{\psi p} = 3$ MeV)

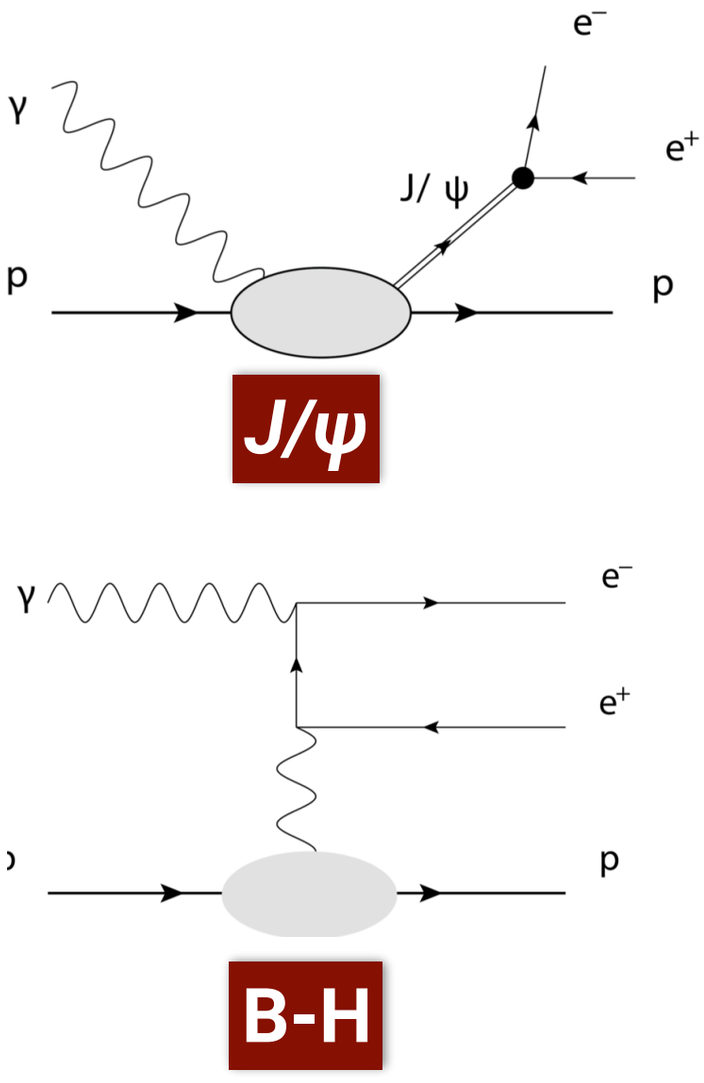
O. Gryniuk and M. Vanderhaeghen, Phys. Rev. D 94, 074001 (2016)



- Photo-production near threshold constrained with dispersion relations
- **Threshold data needed to really constrain $B_{\psi p}$**

Alternative way to extract the **scattering length $a_{\psi p}$**

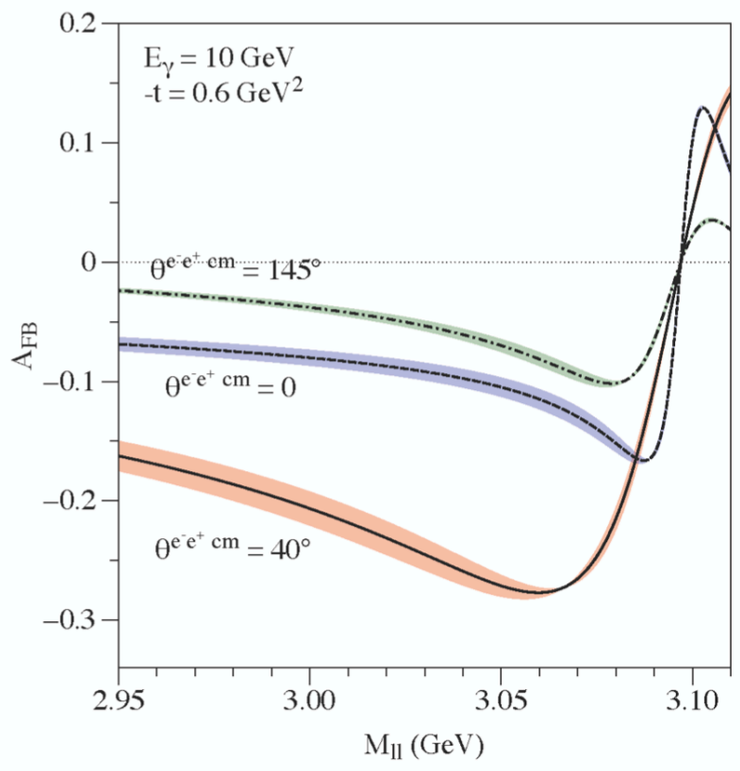
- ☆ **Interference** between elastic ***J/ψ* production** near threshold and **Bethe-Heitler**
- ☆ **Forward-backward asymmetry** near the *J/ψ* invariant mass peak
- ☆ Sensitive to real part of the scattering amplitude, and therefore $a_{\psi p}$ and $B_{\psi p}$

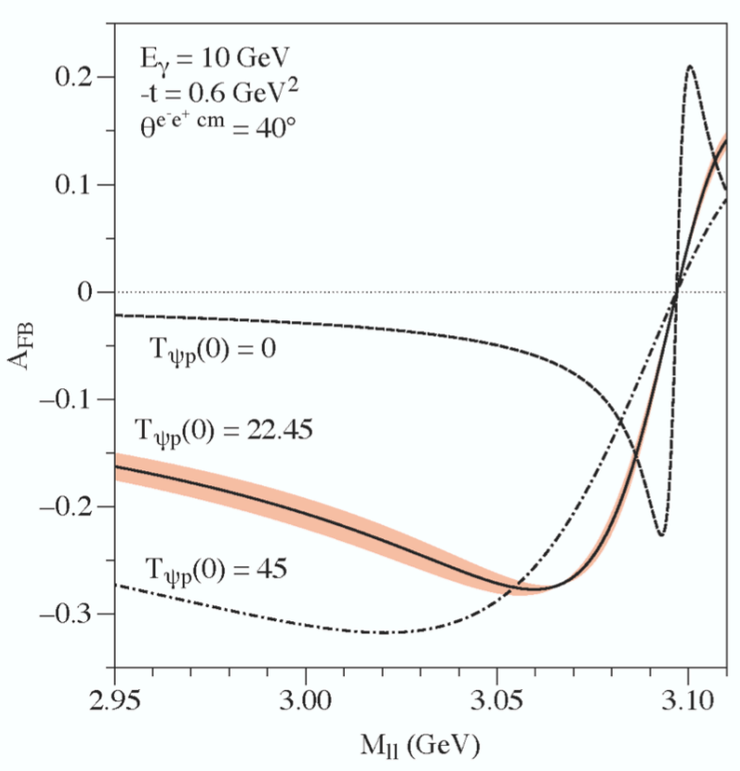


interference term

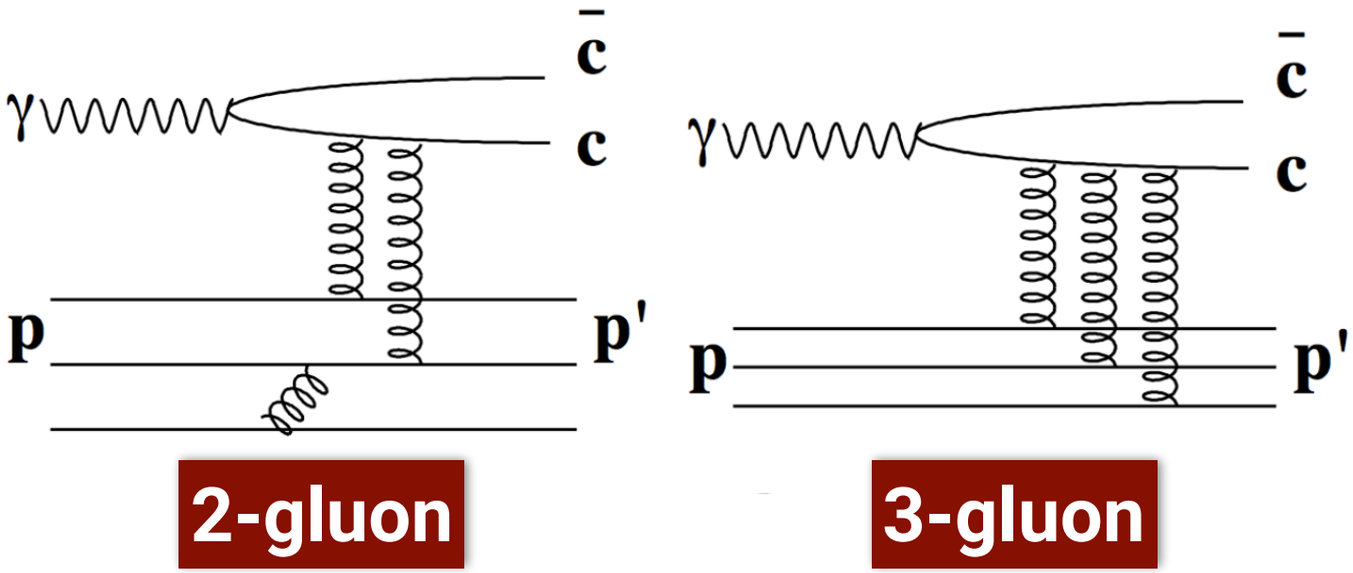
$$A_{\rm FB} \equiv \frac{\frac{d\sigma}{d\Omega}(\theta_{cm}) - \frac{d\sigma}{d\Omega}(\theta_{cm}-\pi)}{\frac{d\sigma}{d\Omega}(\theta_{cm}) + \frac{d\sigma}{d\Omega}(\theta_{cm}-\pi)} = \frac{\sum_s 2\,\mathrm{Re} T_\psi\, T_{BH}}{\sum_s |T_\psi|^2 + \sum_s |T_{BH}|^2}$$

$\theta_{\rm cm}$ — scattering angle in a lepton pair CM frame





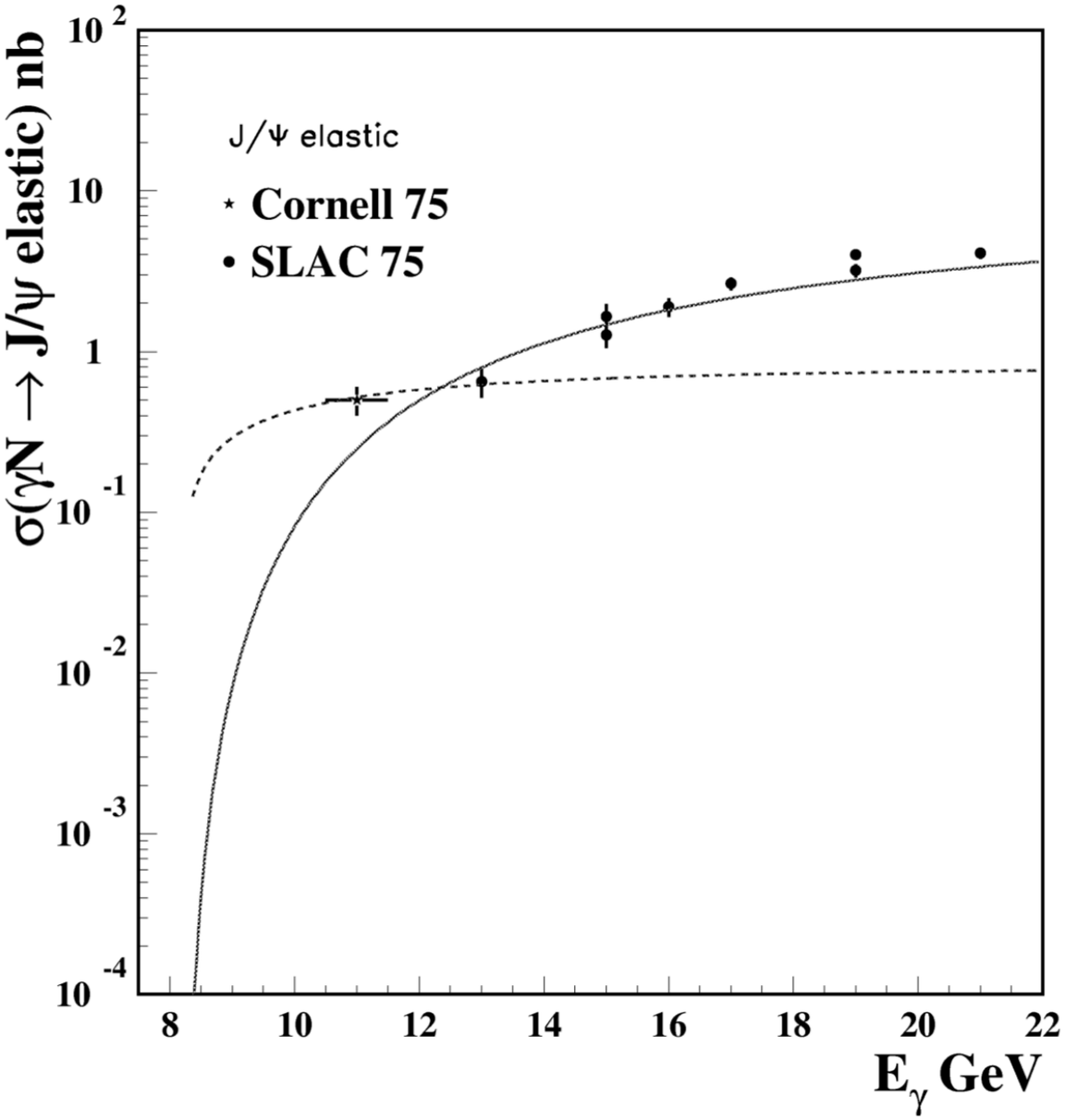
What do we (not) know about *J/ψ photo-production?*



2-gluon **3-gluon**

- ☆ ***J/ψ* threshold region crucially important.**
- ☆ **BUT… almost no data available!**
- ☆ Need new data to study production mechanism near threshold:
  - ☆ Do we need a 3-gluon model instead of a 2-gluon model?
  - ☆ Are there any resonances or bounds states hiding near threshold?
  - ☆ Is there any sub-threshold production?

S.J. Brodsky, *et al.*, Phys.Lett. B498, 23-28 (2001

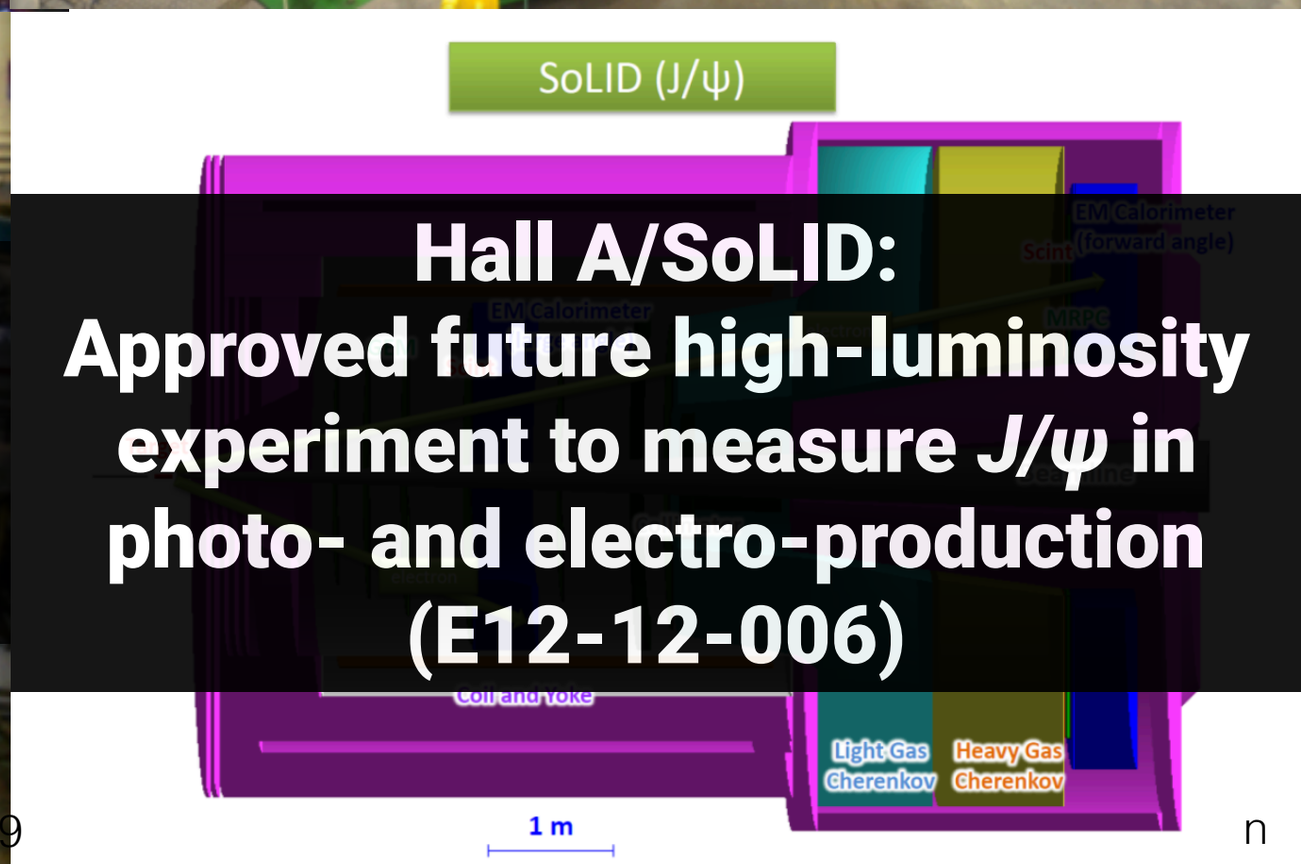


12 GeV *J/ψ* experiments at JLab

Hall D/GlueX:
First *J/ψ* at JLab!

Hall C/SHMS+HMS:
Approved experiment to search for the LHCb pentaquark
(E12-16-007)

Hall B/CLAS12:
Approved experiment to measure TCS + *J/ψ* in photo-production
(E12-12-001)



Hall A/SoLID:
Approved future high-luminosity experiment to measure *J/ψ* in photo- and electro-production
(E12-12-006)

A Search for the LHCb Pentaquarks in Hall C

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The LHCb charmed "pentaquark" P_c is a **hot topic**

- **Since the CERN press release from July 14, 2015…**

INSPIRE HEP

HEP :: HEPNAMES :: INSTITUTIONS :: CONFERENCES :: JOBS :: EXPERIMENTS :: JOURNALS :: HE

Information | References (55) | Citations (441) | Fi

441 citations in 2 years!

Observation of $J/\psi p$ Resonances Consistent with Pentaquark States in $\Lambda_b^0 \to J/\psi K^- p$ Decays - LHCb Collaboration (Aaij, Roel *et*
(2015) 072001 arXiv:1507.03414 [hep-ex] CERN-PH-EP-2015-153, LHCB-PAPER-2015-029

Cited by: 441 records

(185) **The hidden-charm pentaquark and tetraquark states** - Chen, Hua-Xing *et al.* Phys.Rept. 639 (2016) 1-121 arXiv:1601.02092 [hep-ph]
(139) **Averages of b-hadron, c-hadron, and τ-lepton properties as of summer 2016** - Amhis, Y. *et al.* arXiv:1612.07233 [hep-ex] FERMILAB-PUB-16-611-ND
(120) **How to reveal the exotic nature of the $P_c(4450)$** - Guo, Feng-Kun *et al.* Phys.Rev. D92 (2015) no.7, 071502 arXiv:1507.04950 [hep-ph]
(109) **Evidence for a $B_s^0\pi^\pm$ state** - D0 Collaboration (Abazov, V.M. *et al.*) Phys.Rev.Lett. 117 (2016) no.2, 022003 arXiv:1602.07588 [hep-ex] FERMILAB-PUB-16-038-E
(104) **LHCb pentaquark as a $\bar{D}^*\Sigma_c - \bar{D}^*\Sigma_c^*$ molecular state** - Roca, L. *et al.* Phys.Rev. D92 (2015) no.9, 094003 arXiv:1507.04249 [hep-ph]

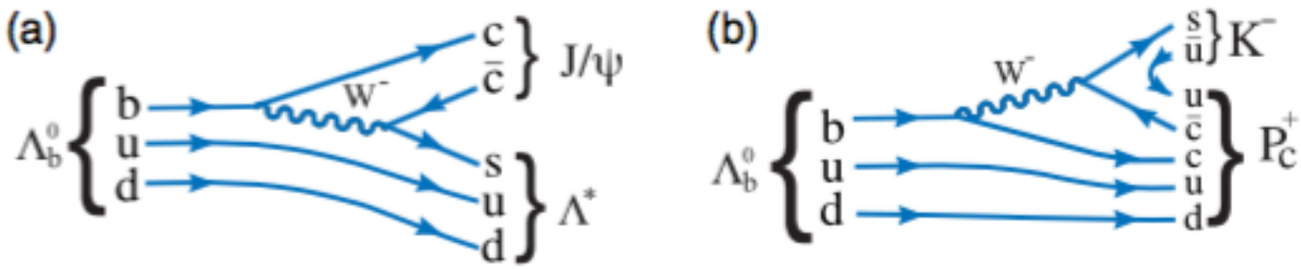
more

Discovery inspired large number of theoretical work, touching our community and beyond

Discovery of the LHCb charmed "pentaquark" P_c

$$\Lambda_b \to K^- p J/\Psi$$

Aaij, R, et. al (LHCb) PRL 115-7 (2015)



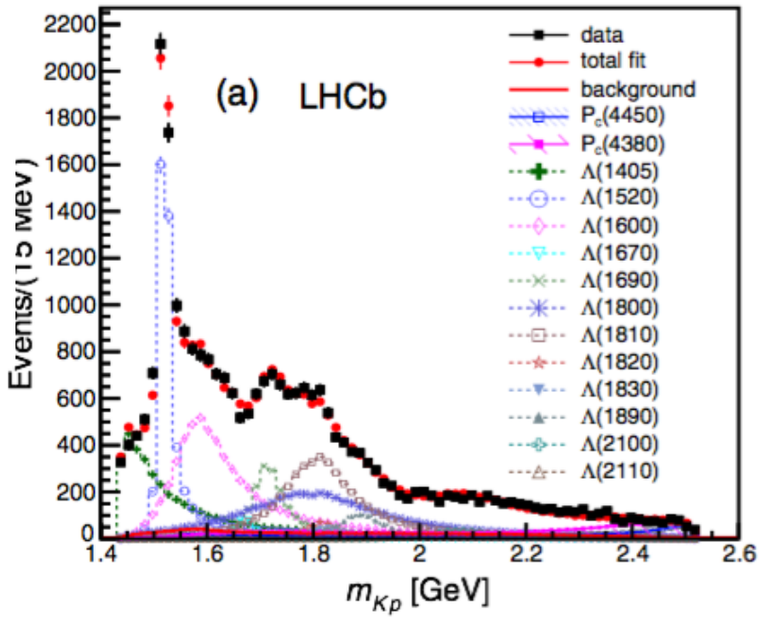
$$\Lambda_b \to \Lambda^* J/\Psi \to (K^- p) J/\Psi$$

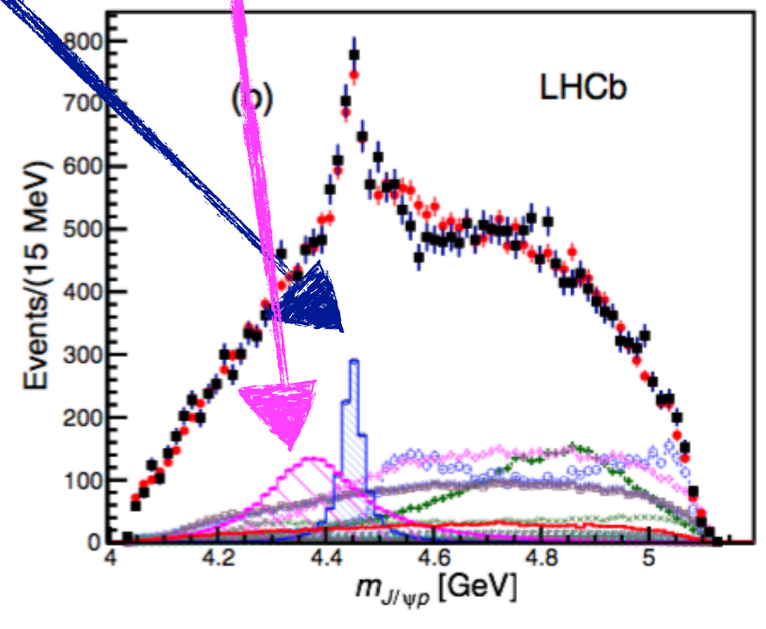
$$\Lambda_b \to K^- P_c \to K^- (p J/\Psi)$$

- **2 P_c states** needed to describe results
  - ☆ **narrow**: $P_c(4450)$
  - ☆ **wide**: $P_c(4380)$
- spin/parity either:
  - ☆ **5/2+, 3/2- (most likely!)**
  - ☆ 5/2-, 3/2+
  - ☆ 3/2-, 5/2+

narrow: $P_c(4450)$ (12 σ)

wide: $P_c(4390)$ (9σ)





charmed “pentaquark” in **photo-production**

- Common explanations:
  - ☆ **LHCb**: 2 new **charmed “pentaquark”** (P_c) states
  - ☆ **alternative: kinematic enhancements** through anomalous triangle singularity **(ATS)**

Lui X-H, *et al.*, PLB 757 (2016), p231 (and references therein)

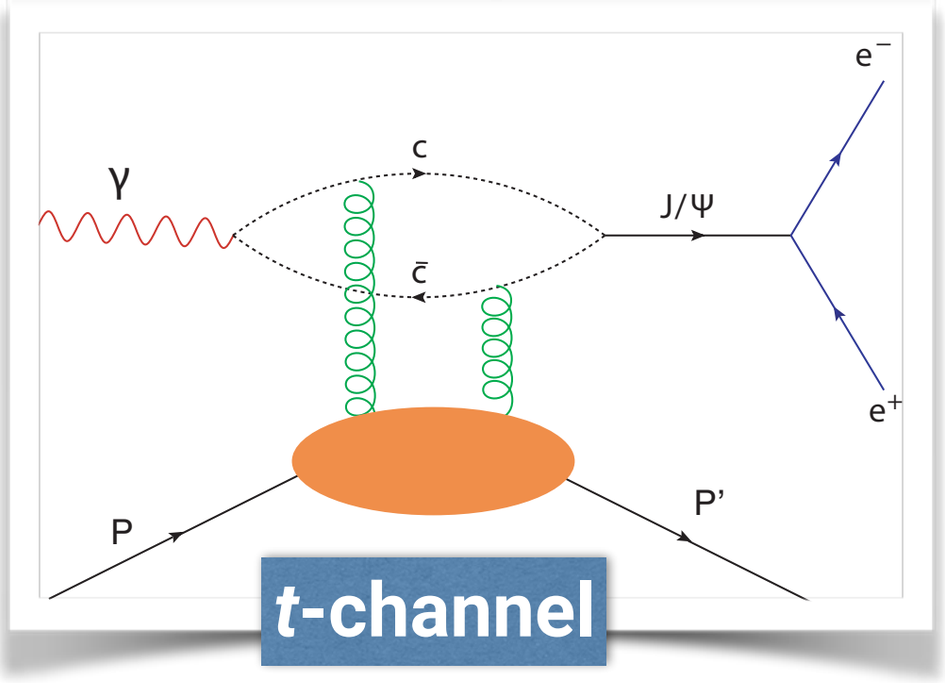
- **Photo-production** ideal tool to **distinguish** between both explanations
  - ☆ if P_c real states, **also created in photo-production**
  - ☆ kinematic enhancement through **ATS not possible in photo-production**

Wang Q., *et al.*, PRD 92-3 (2015) 034022-7 (and references therein)

- $P_c(4450)$ translates to **narrow peak around E_γ = 10 GeV**

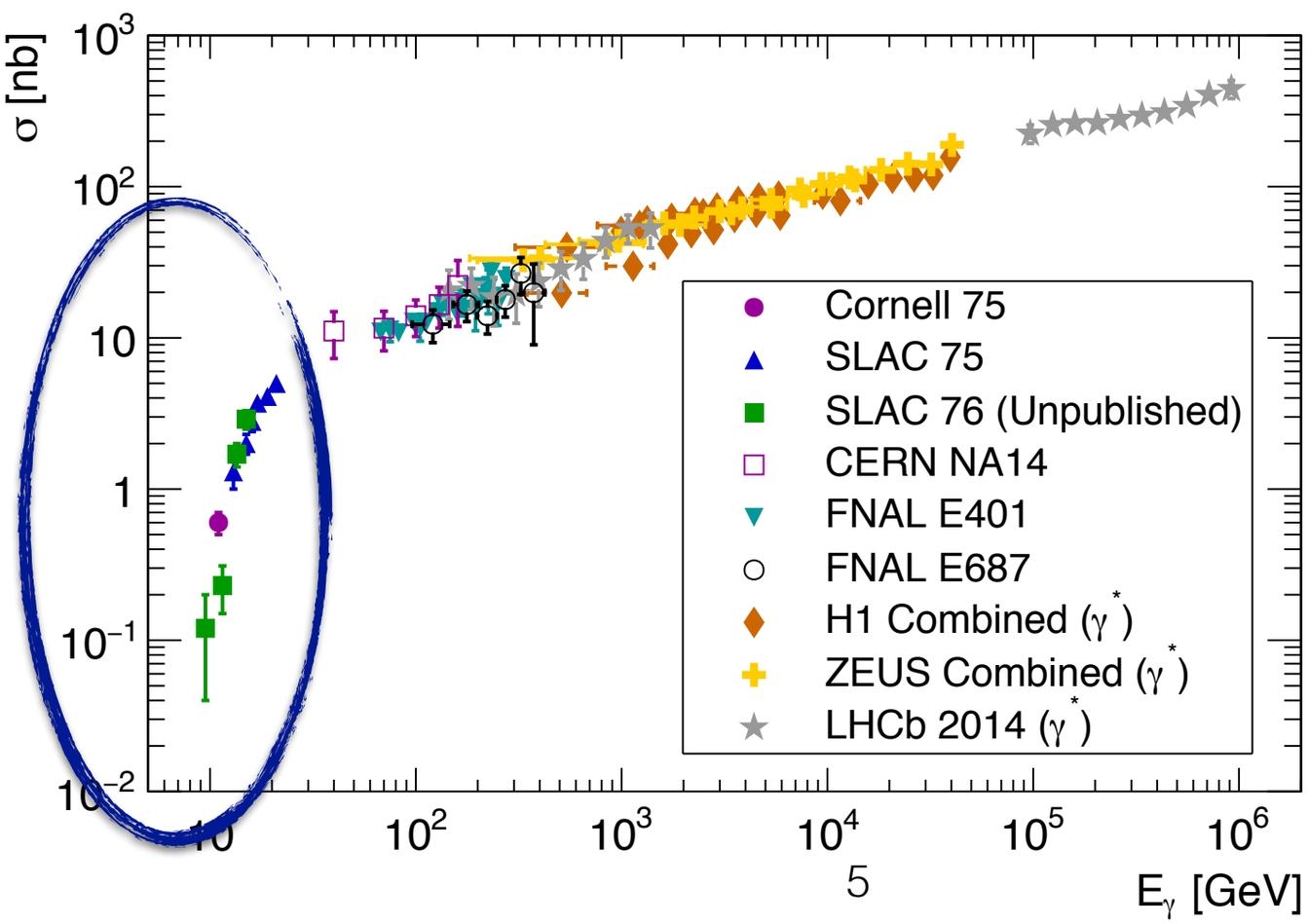
JLab is the ideal laboratory for the measurement, due to luminosity, resolution and energy reach at threshold!

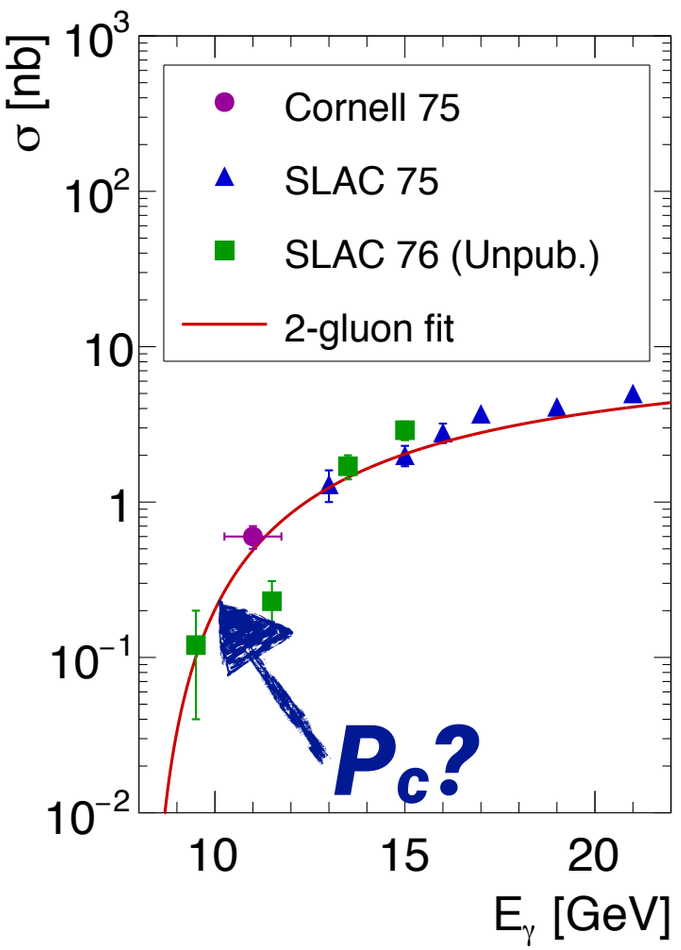
J/ψ photo-production: **what do we know?**



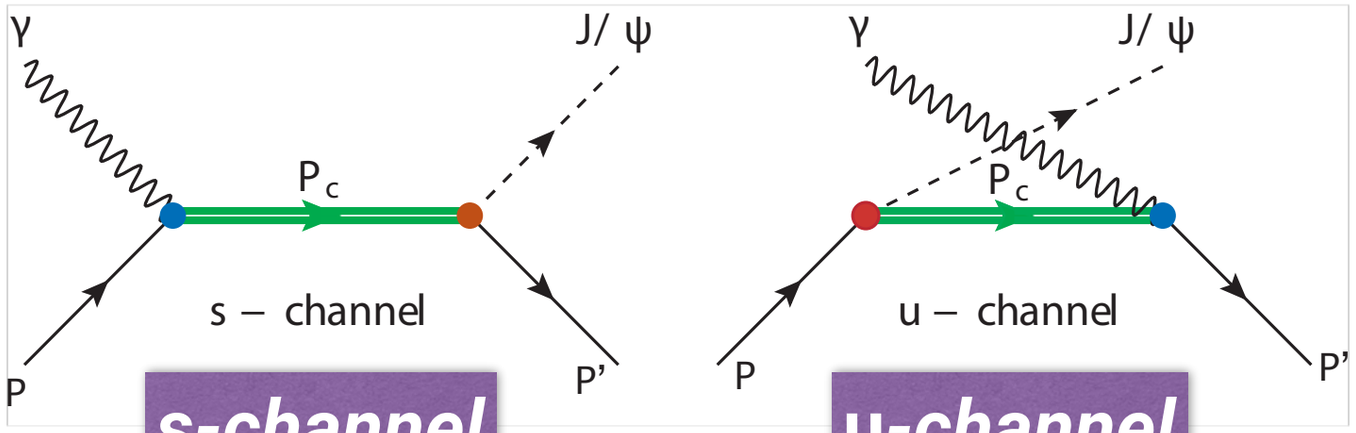
Brodsky S J, *et al.*, PLB 498-1 (2001), p23

- 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!



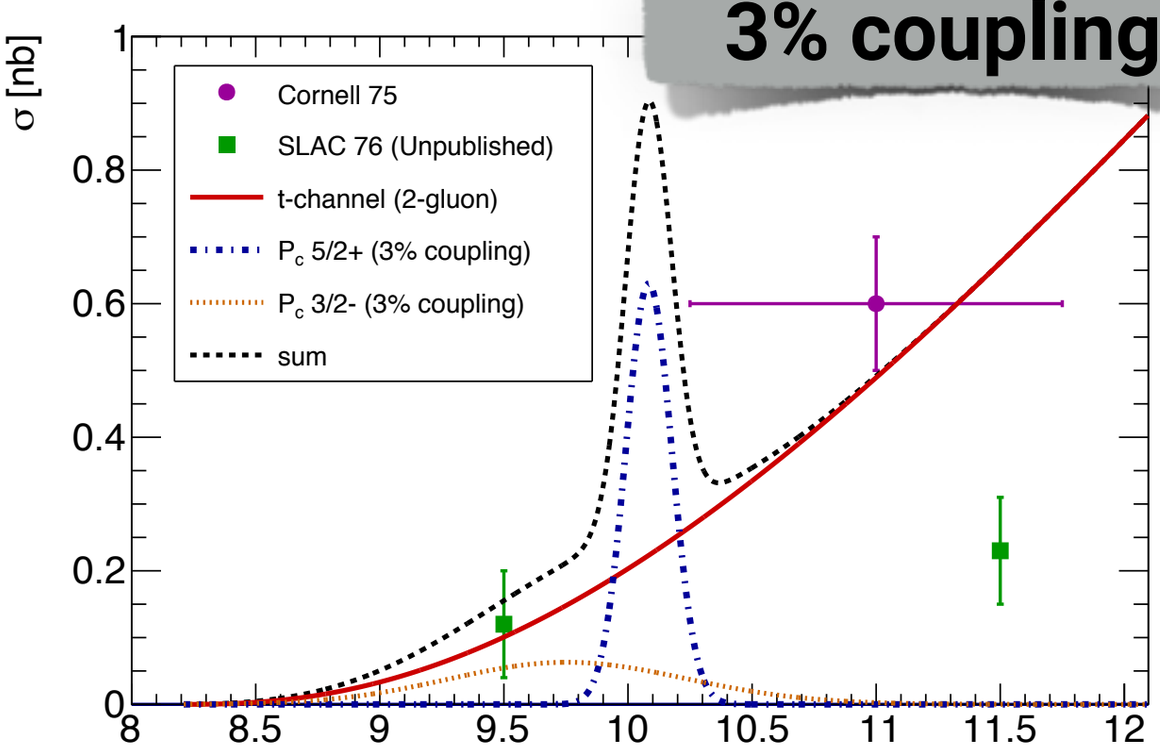


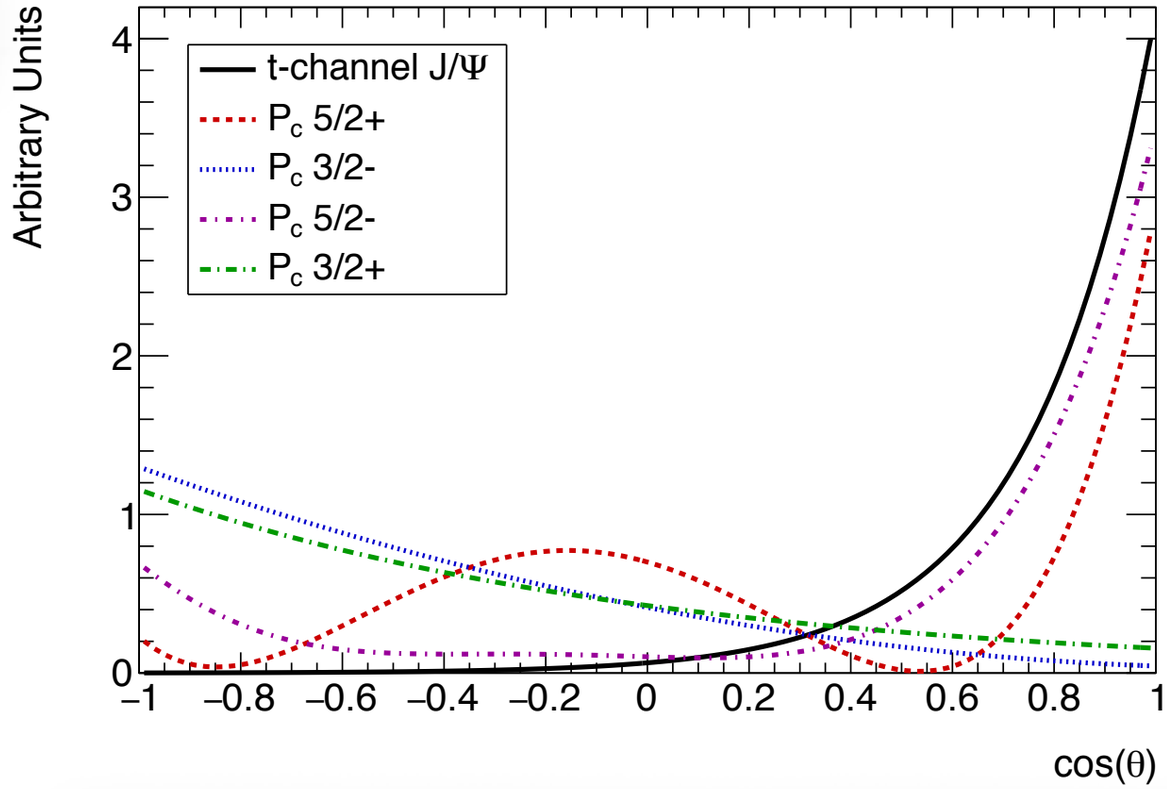
Resonant *J/ψ* production through P_c decay



- Cross section depends on **coupling to (*J/ψ*, *p*) channel**
- ***J/ψ* angular distribution** depends on P_c **spin/parity**

3% coupling



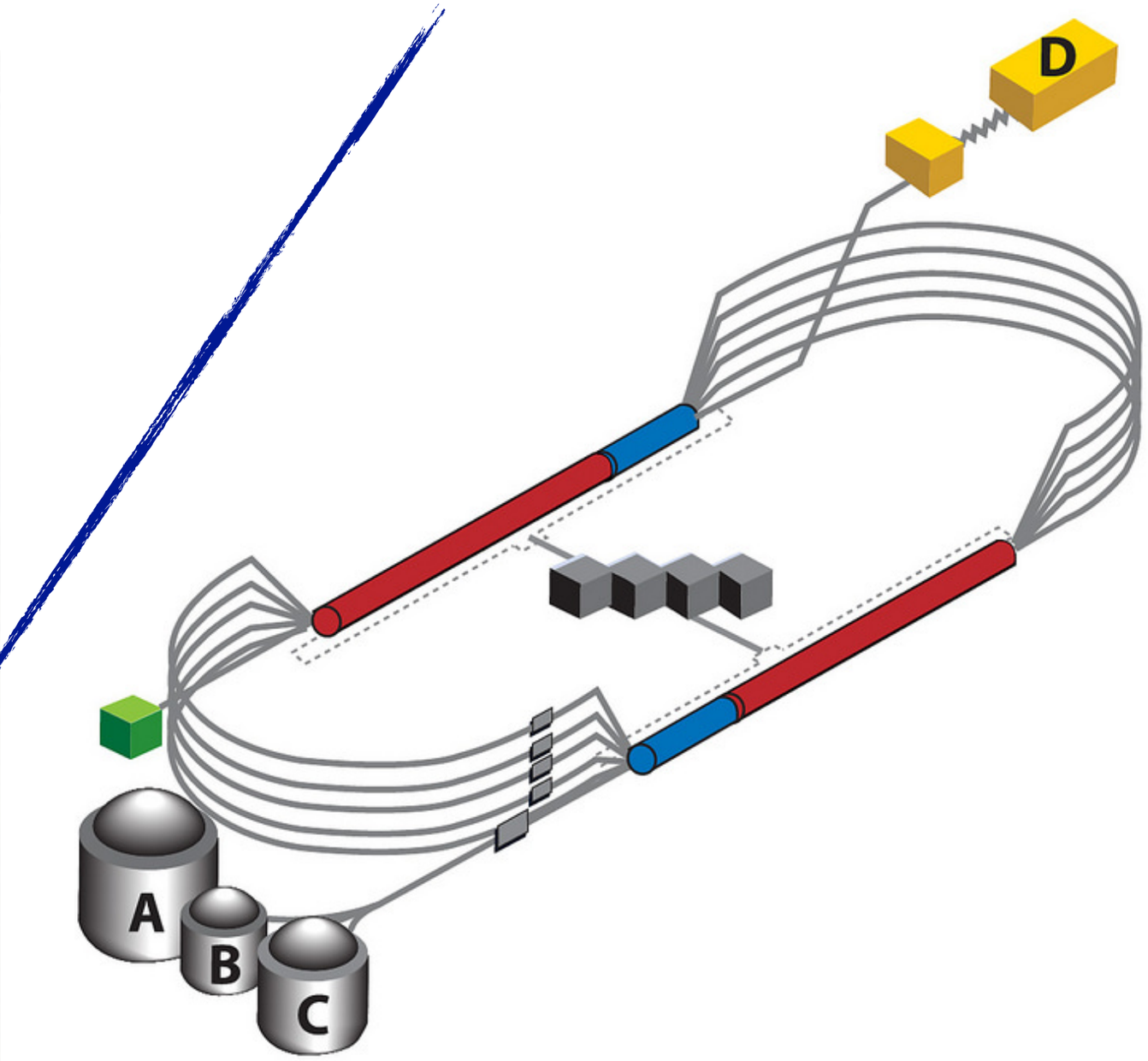


$$\frac{d\sigma}{d\cos\theta_{J/\psi}}(\gamma p \to P_c \to J/\psi p)$$

Leverage cos(*θ*) dependence to maximize S/B at low coupling!

Wang Q., *et al.*, PRD 92-3 (2015) 034022-7

Experiment E12-16-007 in **Hall C** at JLab

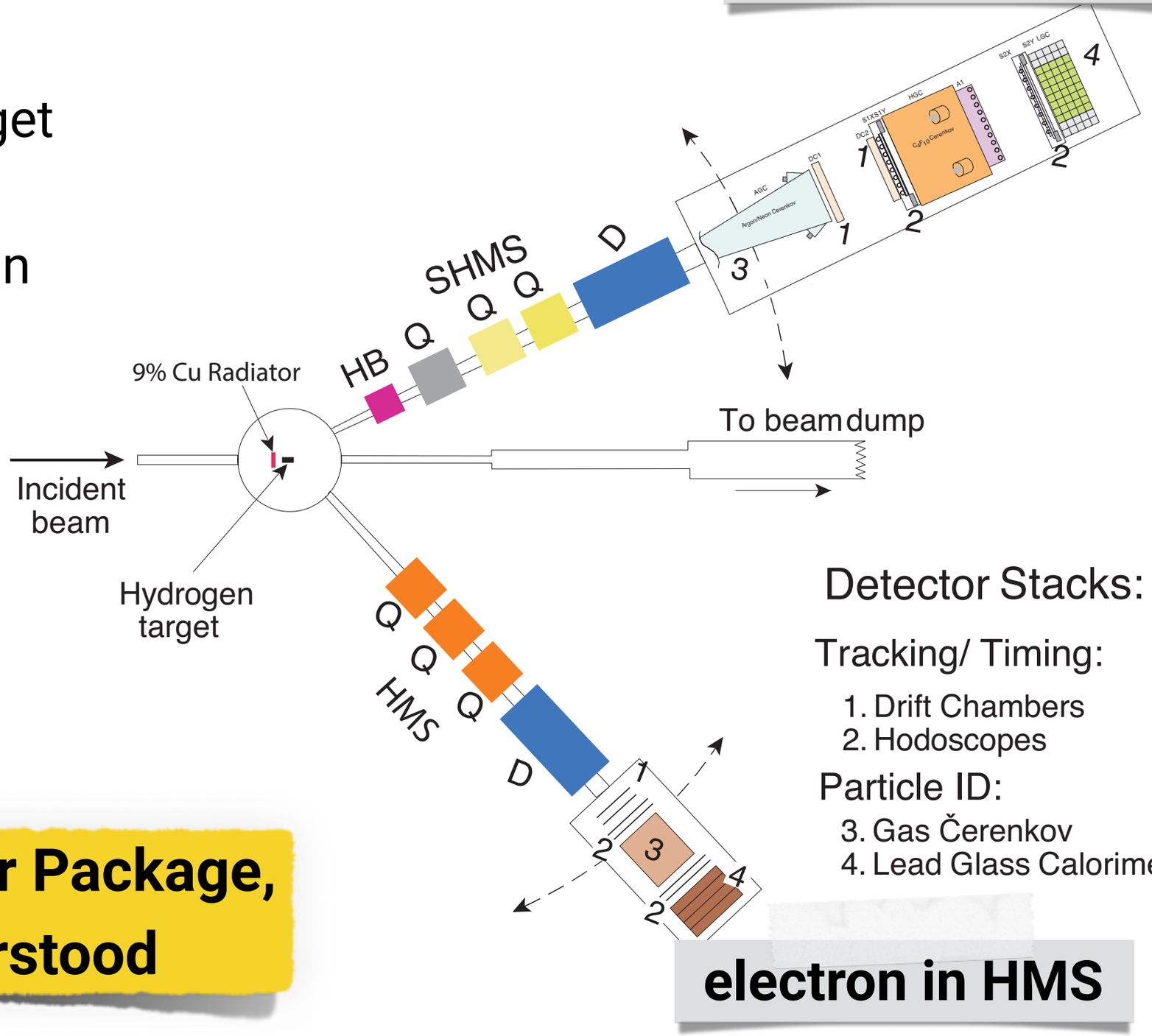


Approved by PAC44
Rated A/“high impact”

Experiment E12-16-007 in **Hall C** at JLab

- 50μA electron beam at 11 GeV
- 9% copper radiator
- 15cm liquid hydrogen target
- **total 10% RL**
- Detect J/ψ decay leptons in coincidence
  - Bremsstrahlung photon energy fully constrained

positron in SHMS



Detector Stacks:

Tracking/ Timing:

1. Drift Chambers
2. Hodoscopes

Particle ID:

3. Gas Čerenkov
4. Lead Glass Calorimeter

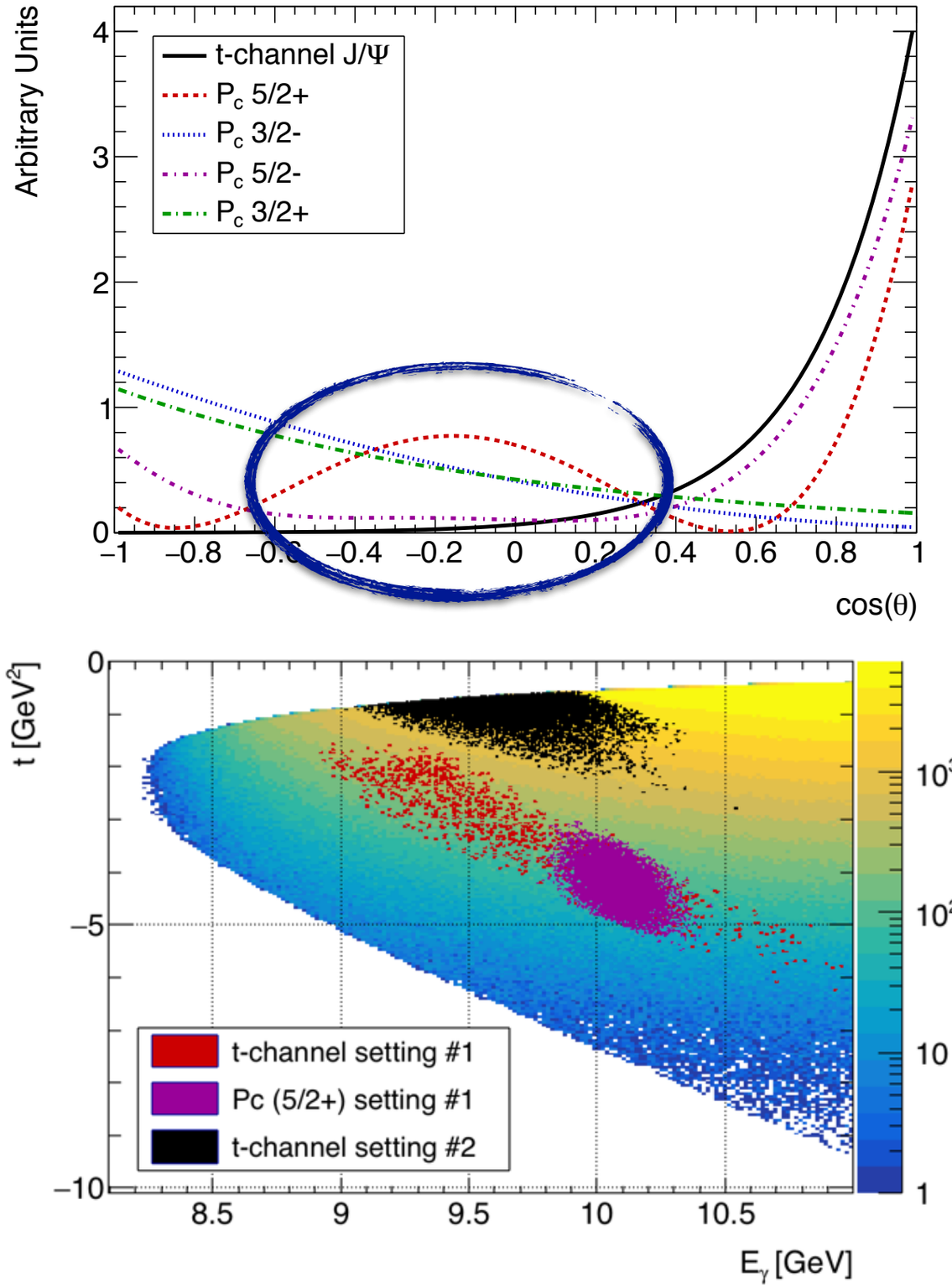
electron in HMS

Standard Hall C Detector Package, Radiator Well Understood

Maximizing the sensitivity

- Use **HMS** and **SHMS** to maximize P_c signal over *t*-channel background
- **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

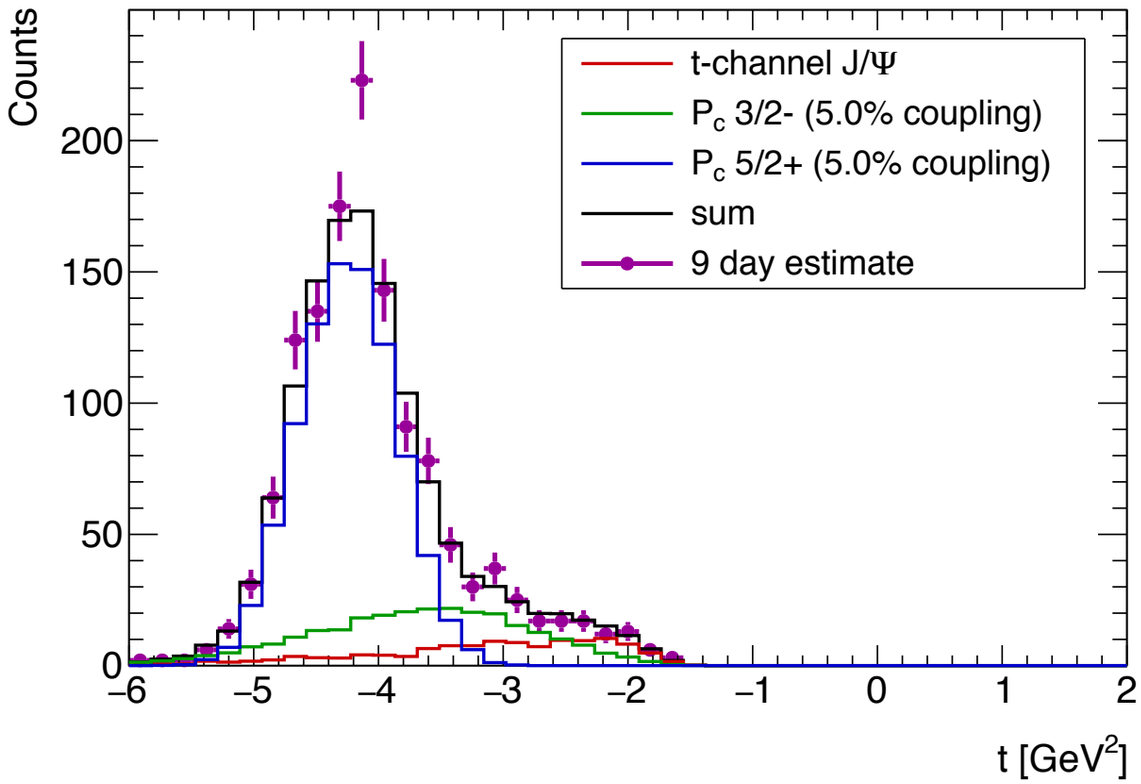
Bottom line:
can run SOON and FAST

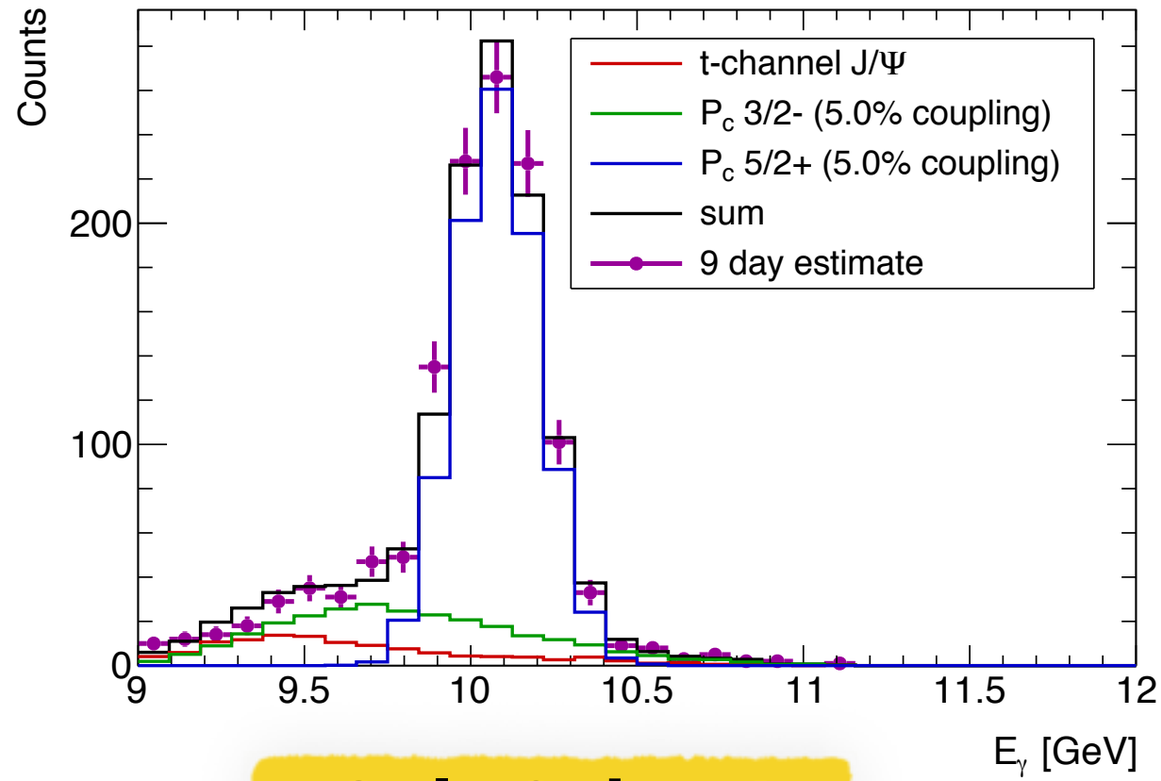


Projected results for **“SIGNAL” Setting**

- **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





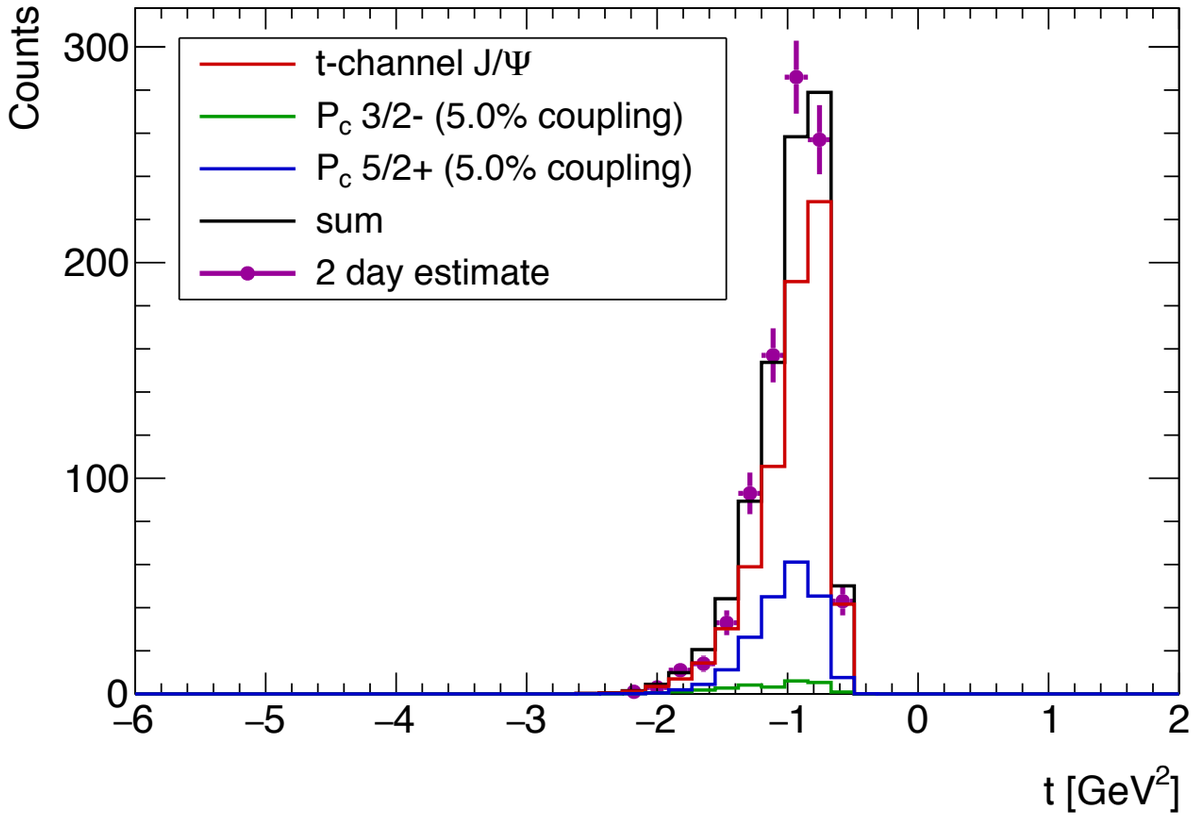
Only 9 days!

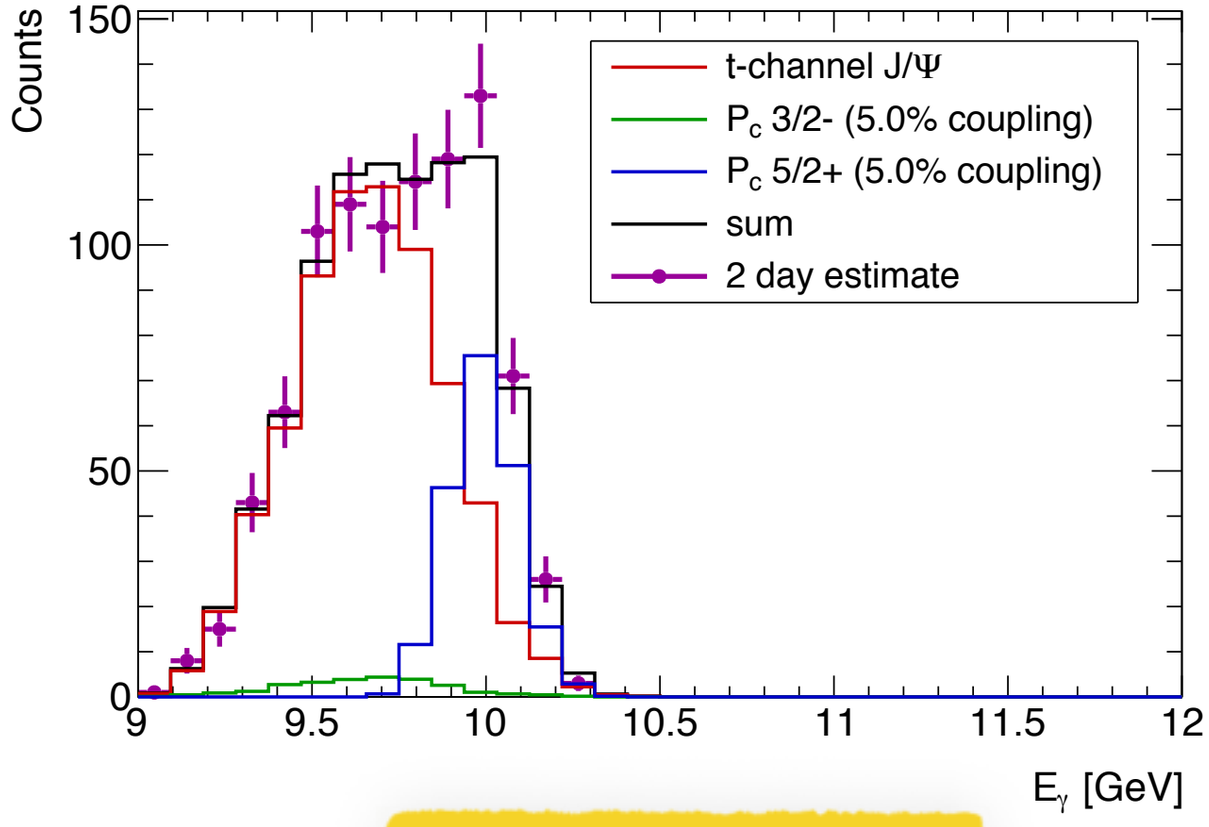
Significance > 20σ!

Projected results for **“BACKGROUND” Setting**

- 2 days of beam time at 50μA
- able to separate 5/2+ from ***t*-channel at low E_γ**
- will provide **first-hand information about *t*-channel production near threshold**
- assuming 5% coupling (value favored by existing photo-production data)

_t_-channel: 682 events
5/2+: 204 events
3/2-: 26 events

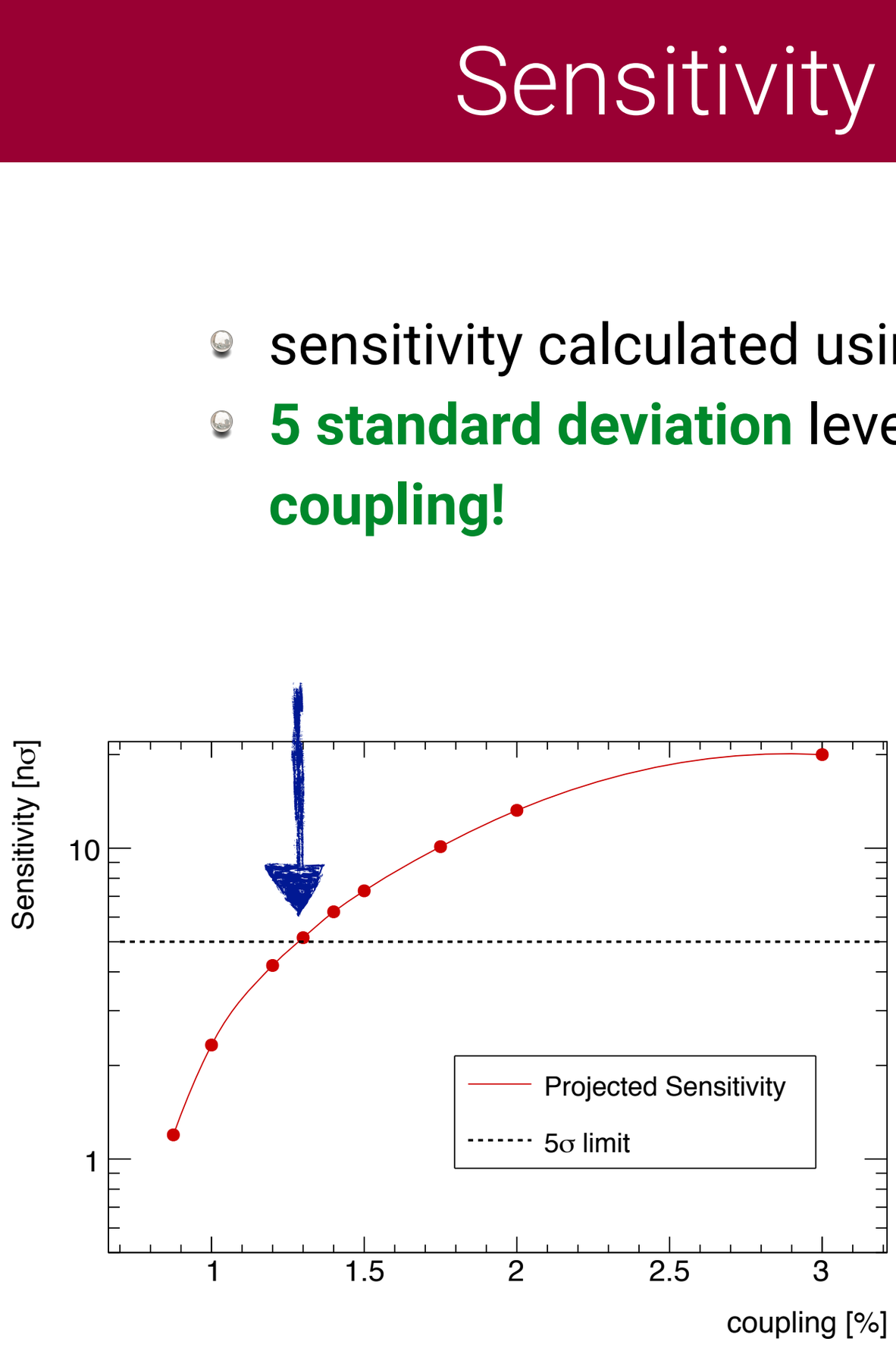


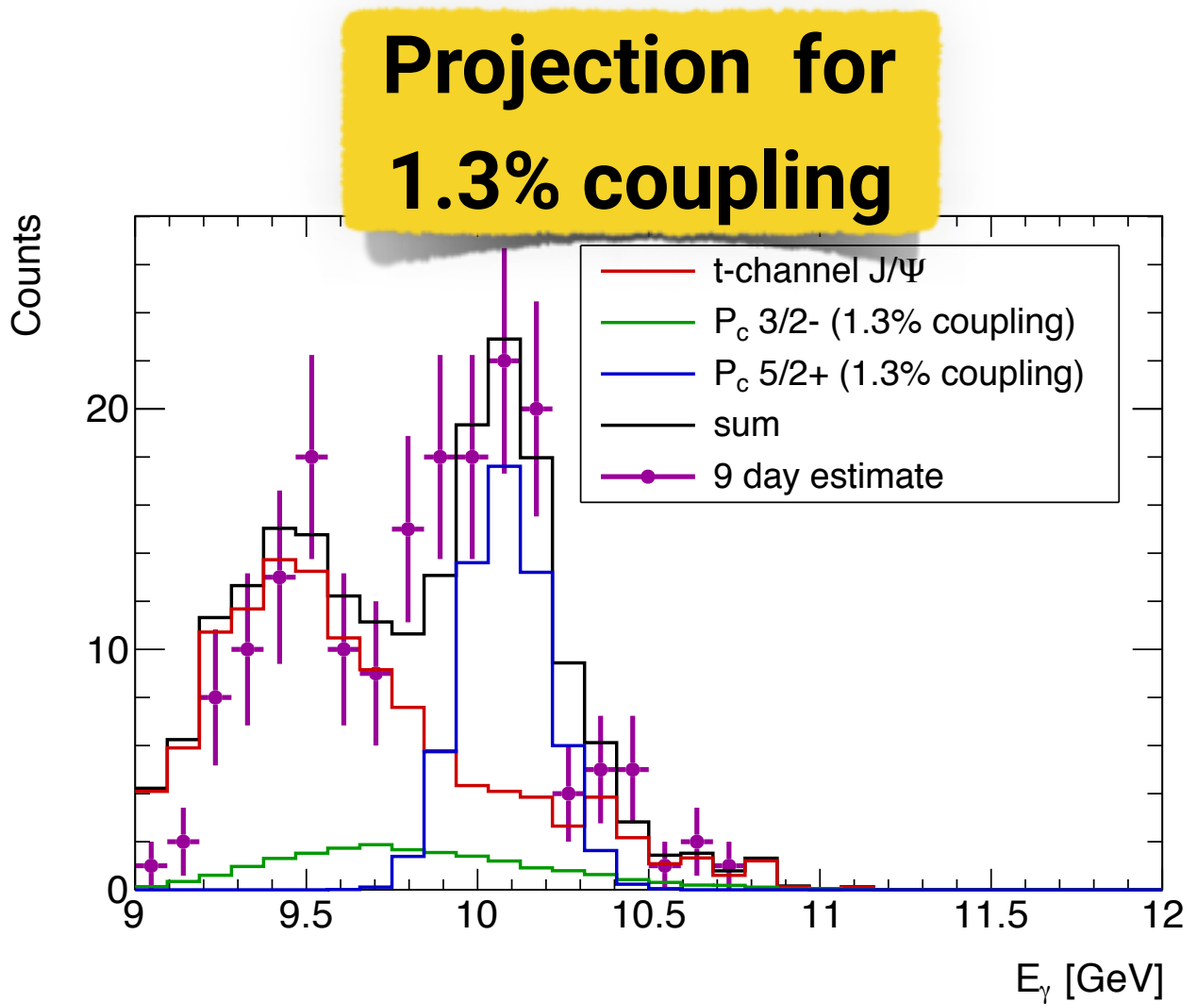


Only 2 days!

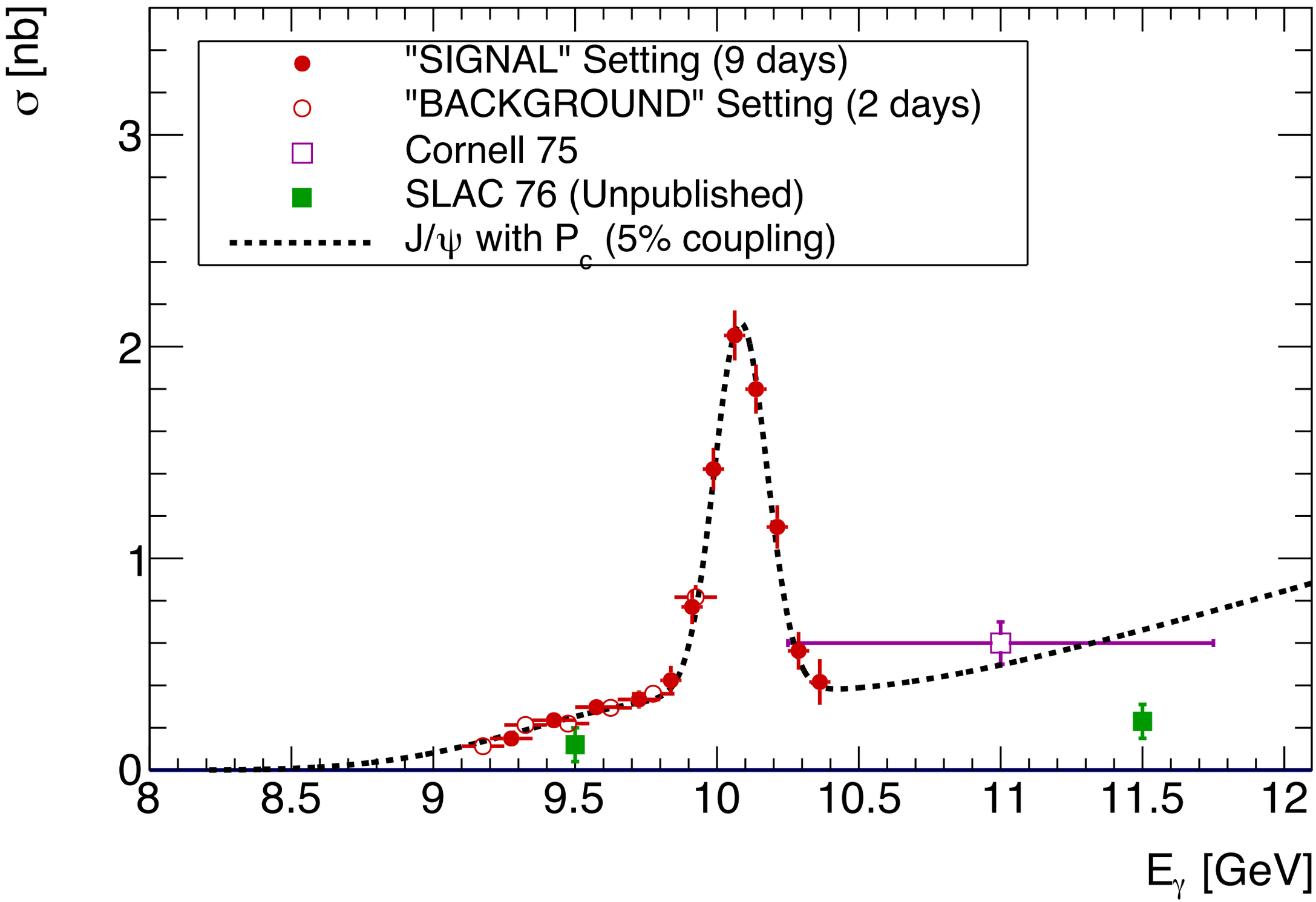
Sensitivity for **Discovery**

- sensitivity calculated using a Δ-log-likelihood formalism
- **5 standard deviation** level of sensitivity **starting from 1.3% coupling!**





Impact on the world data for J/ψ production



E12-16-007 Summary

- **High impact** result will
  - **either confirm** P_c resonance, **or strongly exclude** its existence
- **Strong sensitivity** to the coupling down to 1.3%
- Will provide **knowledge about J/ψ production (absolute cross section!) near threshold**
  - Helps future experimental endeavors at CLAS12 and SoLID
- Only need **11 days**
- **Straightforward** experiment, able to **run early** with a **standard Hall C package**

12 GeV J/ψ experiments at JLab

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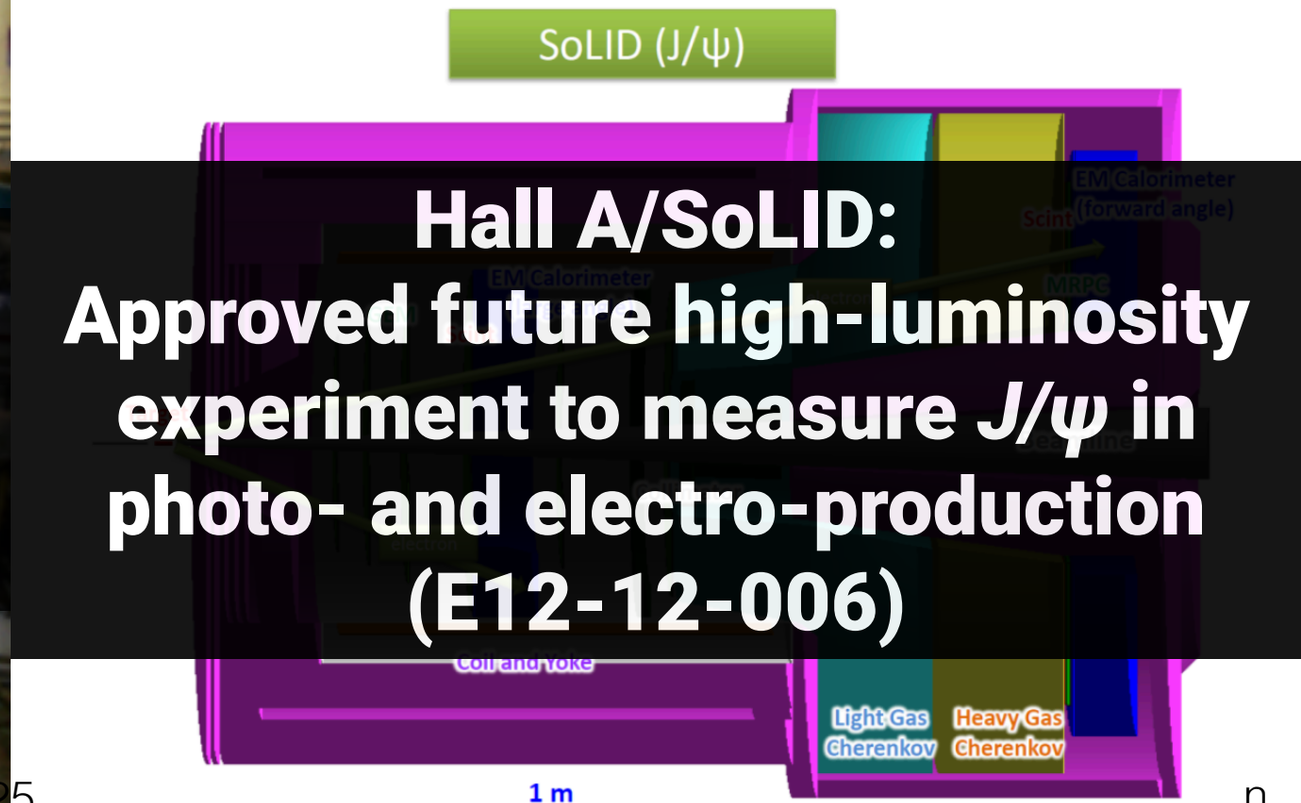
12 GeV *J/ψ* experiments at JLab

Hall D/GlueX:
First *J/ψ* at JLab!

Hall C/SHMS+HMS:
Approved experiment to search for the LHCb pentaquark (E12-16-007)

Hall B/CLAS12:
Approved experiment to measure TCS + *J/ψ* in photo-production (E12-12-001)

Hall A/SoLID:
Approved future high-luminosity experiment to measure *J/ψ* in photo- and electro-production (E12-12-006)



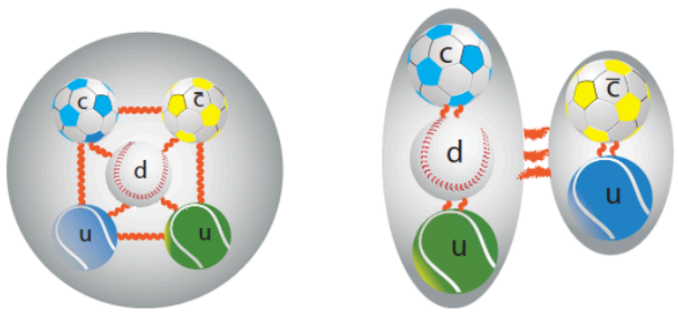
Hall B/CLAS12 **Experiment E12-12-001**

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

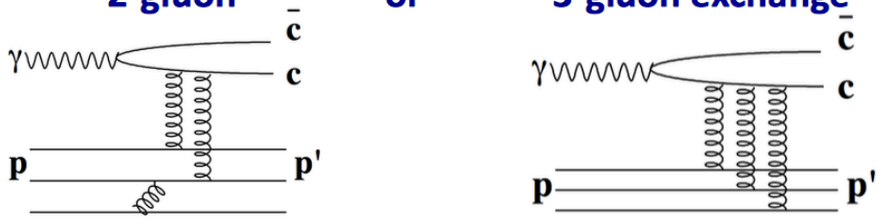
$$P_c \Rightarrow J/\psi\, p$$

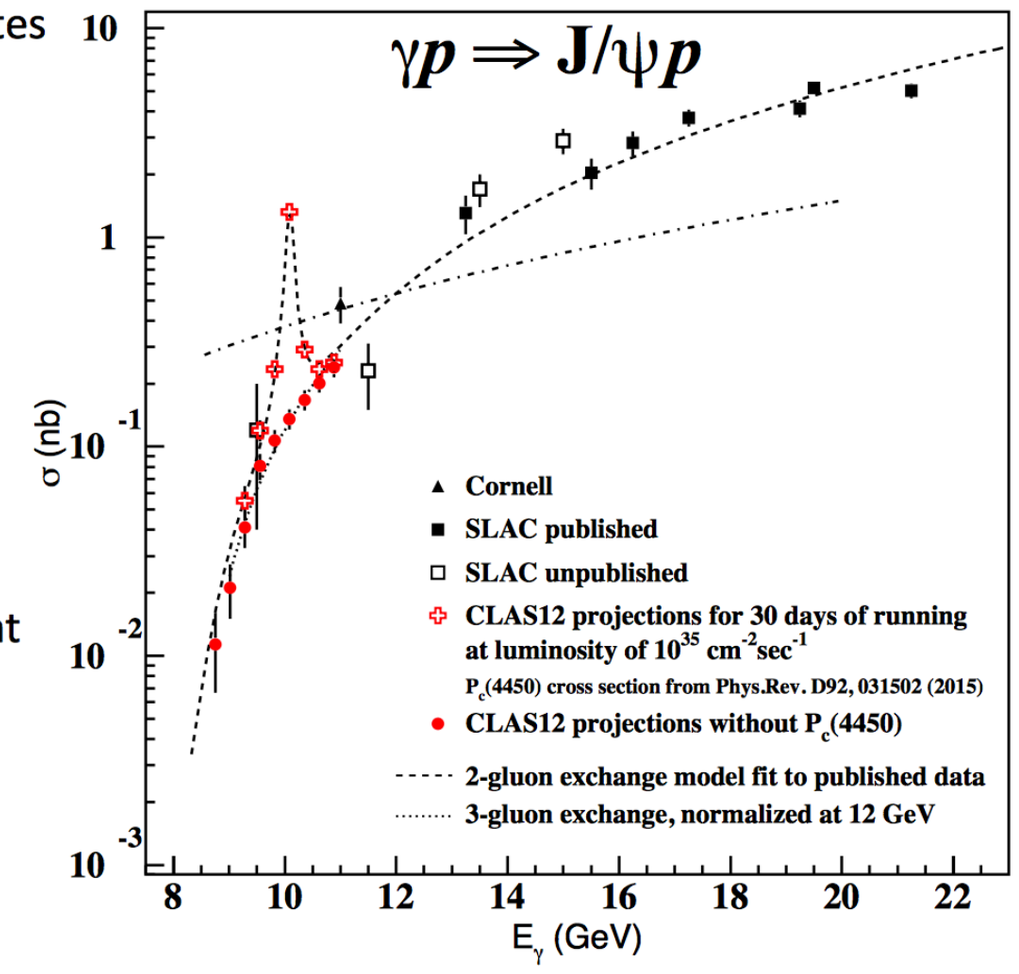
5-quark bound state **or** **Hadronic molecule**



What is the mechanism of charmonium production at the threshold

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



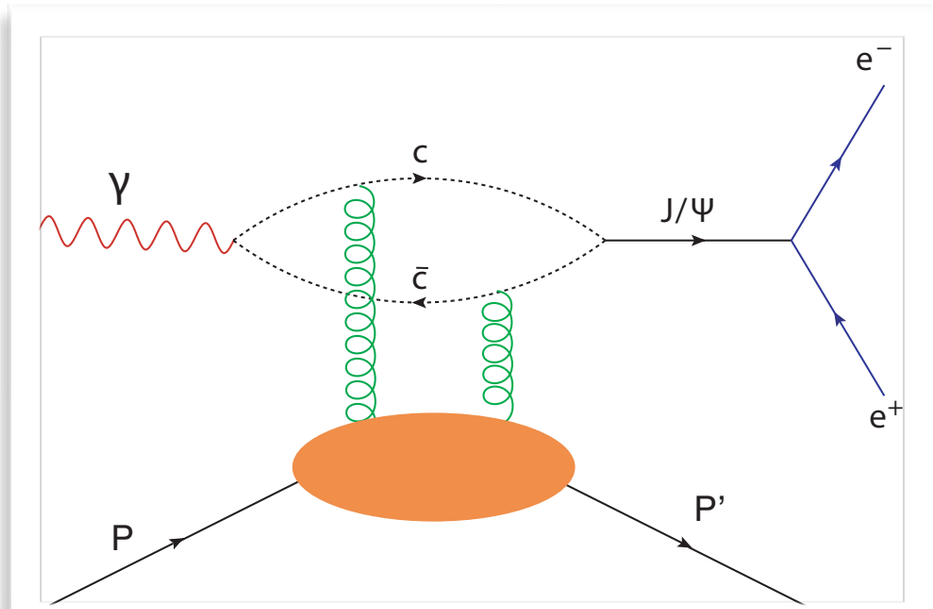


Experiment E12-12-001 measures J/ψ production on the proton near threshold – will verify existence of the ***charmed pentaquarks*** and will study ***the gluon field of the nucleon***

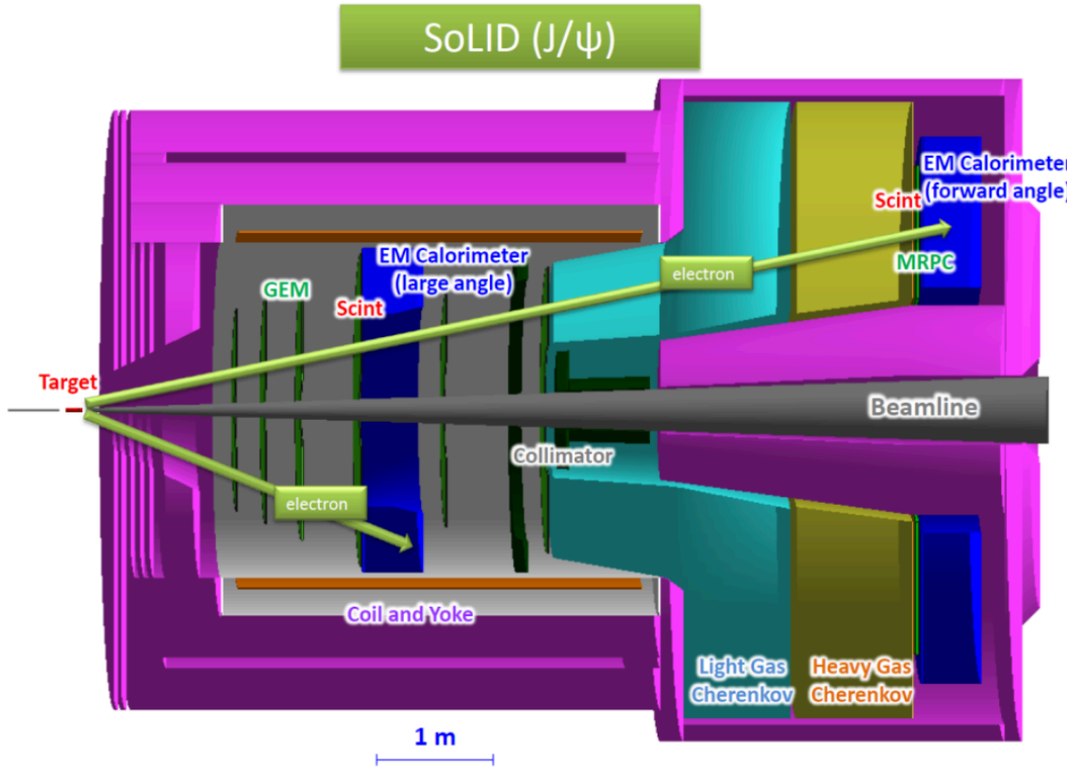
OFFICE OF SCIENCE JSA JLAB experiment E12-12-001 Jefferson Lab Thomas Jefferson National Accelerator Facility clas CEBAF Large Acceptance Spectrometer

J/ψ experiment E12-12-006 at SoLID

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



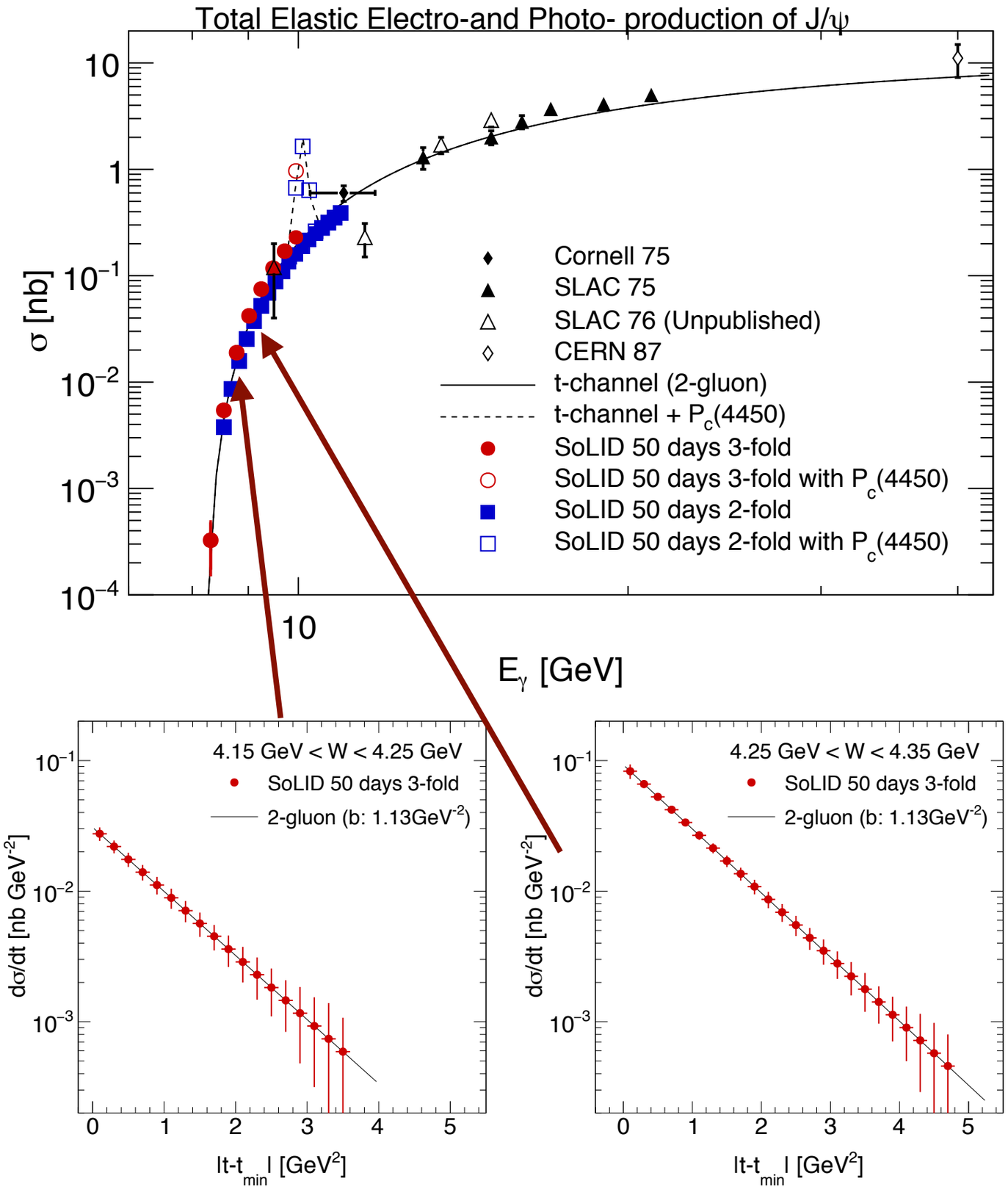
- Threshold *J/ψ* production, probing strong color field in the nucleon, QCD trace anomaly (important for proton mass budget)
  - **Ultra-high luminosity** (43.2 ab^-1)
  - Will allow for **high-resolution multidimensional access** to the *J/ψ* production cross section
  - Precision measurement of the charm-pentaquarks, if they exist



J/ψ experiment E12-12-006 at SoLID

- **Photo-production**
  - **2-fold** coincidence + **recoil** proton
  - *t*-channel *J/ψ* rate: **1627 per day**
  - *Pc*(4450) rate: **927 per day**
    - ☆ (5% coupling)

- **Electro-production**
  - **3-fold** coincidence (3 leptons)
  - *t*-channel *J/ψ* rate: **86 per day**
  - *Pc*(4450) rate: **36 per day**
    - ☆ (5% coupling)



12 GeV *J/ψ* experiments at JLab

	GlueX HALL D	HMS+SHMS HALL C	CLAS 12 HALL B	SoLID HALL A
***J/ψ* Rate (photo-prod.)**	**5-10/day**	#1: 13/day #2: **341/day**	**45/day**	**1627/day**
***J/ψ* Rate (electro-prod.)**				**86/day**
Experiment		E12-16-007	E12-12-001	E12-12-006
PAC		9+2 days **high-impact**	130 days	50 days
When?	Now	Soon!	Few years	5-10 years

Time

Heavy Quarkonium at an EIC

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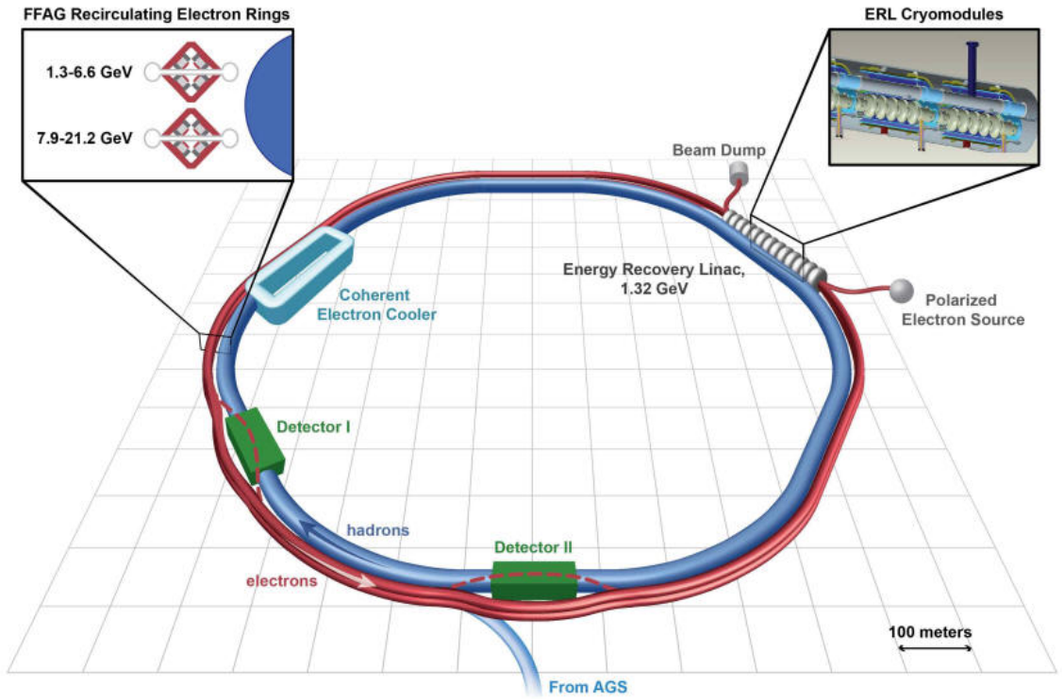
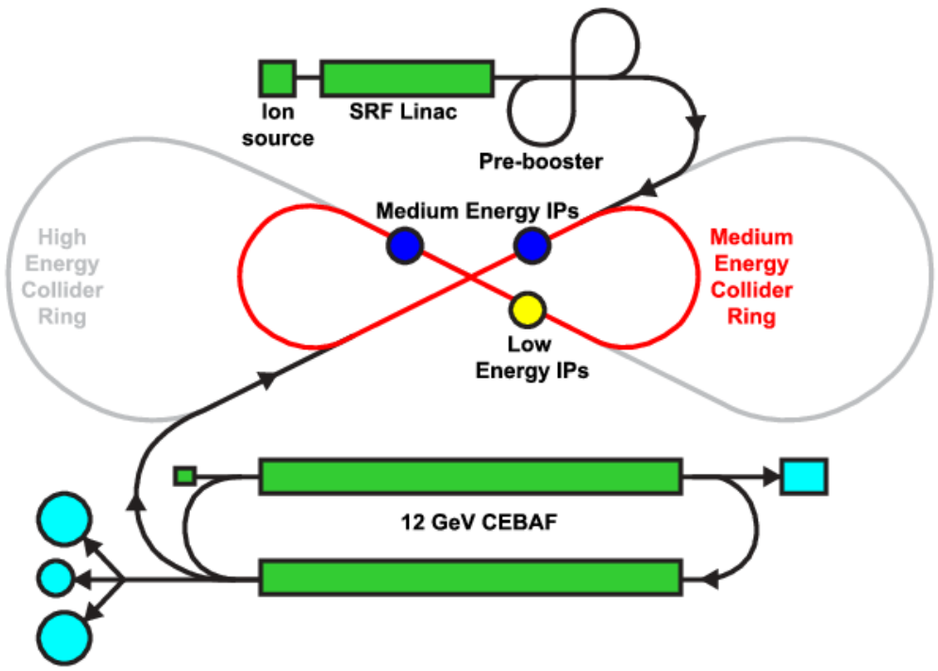
US Based EIC: The Machines

eRHIC (BNL)



JLEIC (JLab)



- First polarized electron-proton/ion collider in the world
- First electron-nucleus collider in the world
- Both make use of existing infrastructure

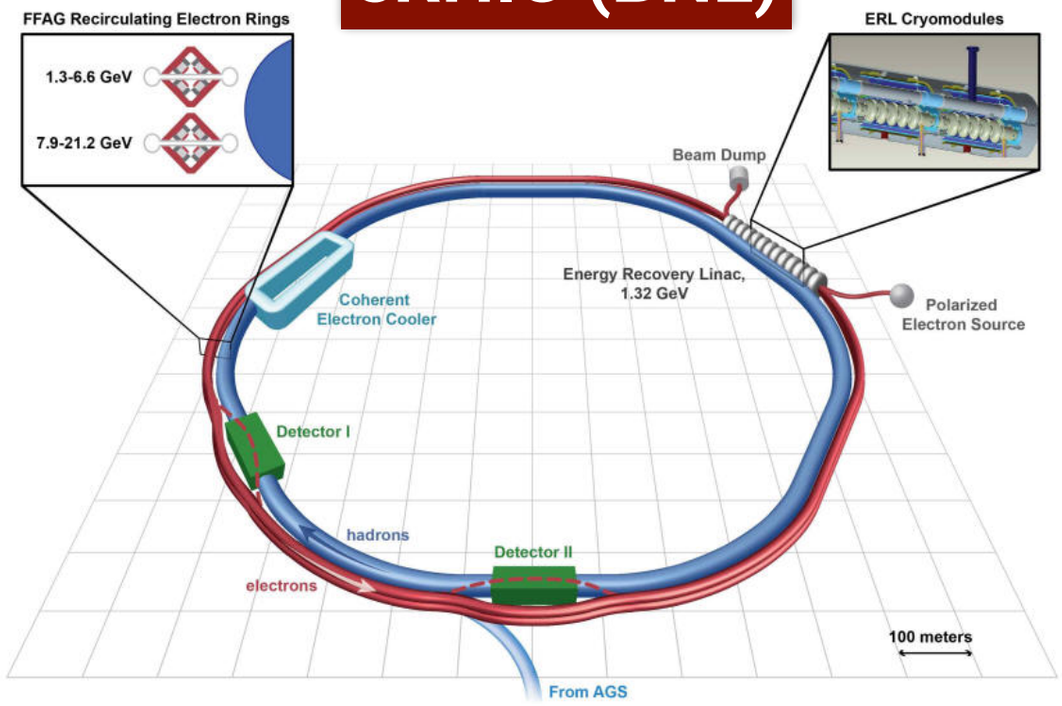
Quarkonia at an EIC **complimentary to JLab**

- J/ψ production at high W tool for gluon imaging not possible at JLab12
- Access to Q^2 dependence close to J/ψ threshold

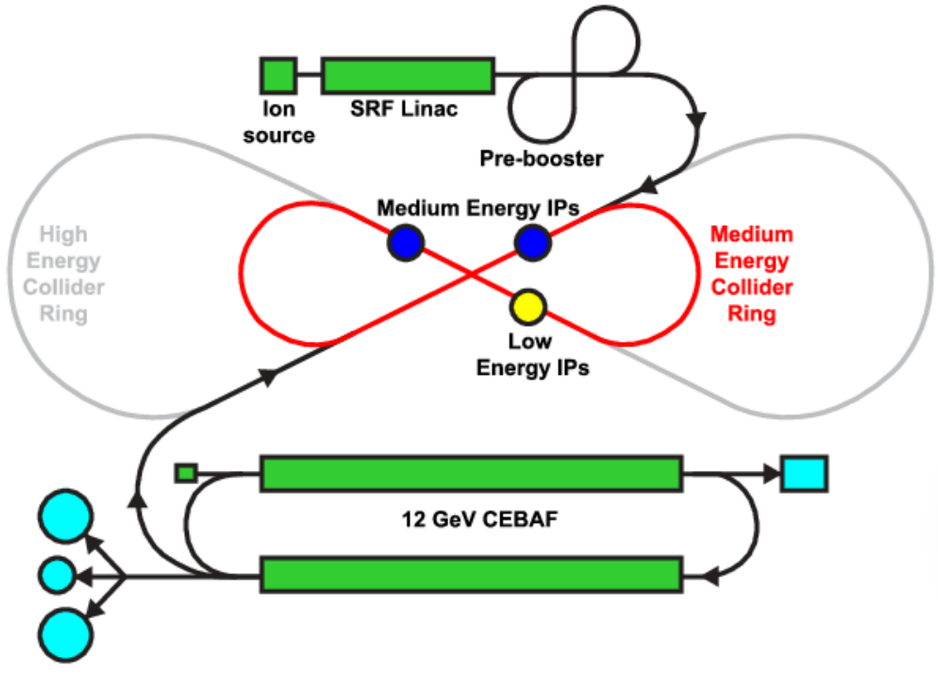
- Υ production possible at threshold and high W
- Important cross check for universality due to smaller higher-order corrections
  - For gluon GPDs extracted with J/ψ at the EIC
  - For J/ψ threshold physics at JLab12
- Is there a “bottom pentaquark?”

Accelerator and detector parameters

eRHIC (BNL)



JLEIC (JLab)

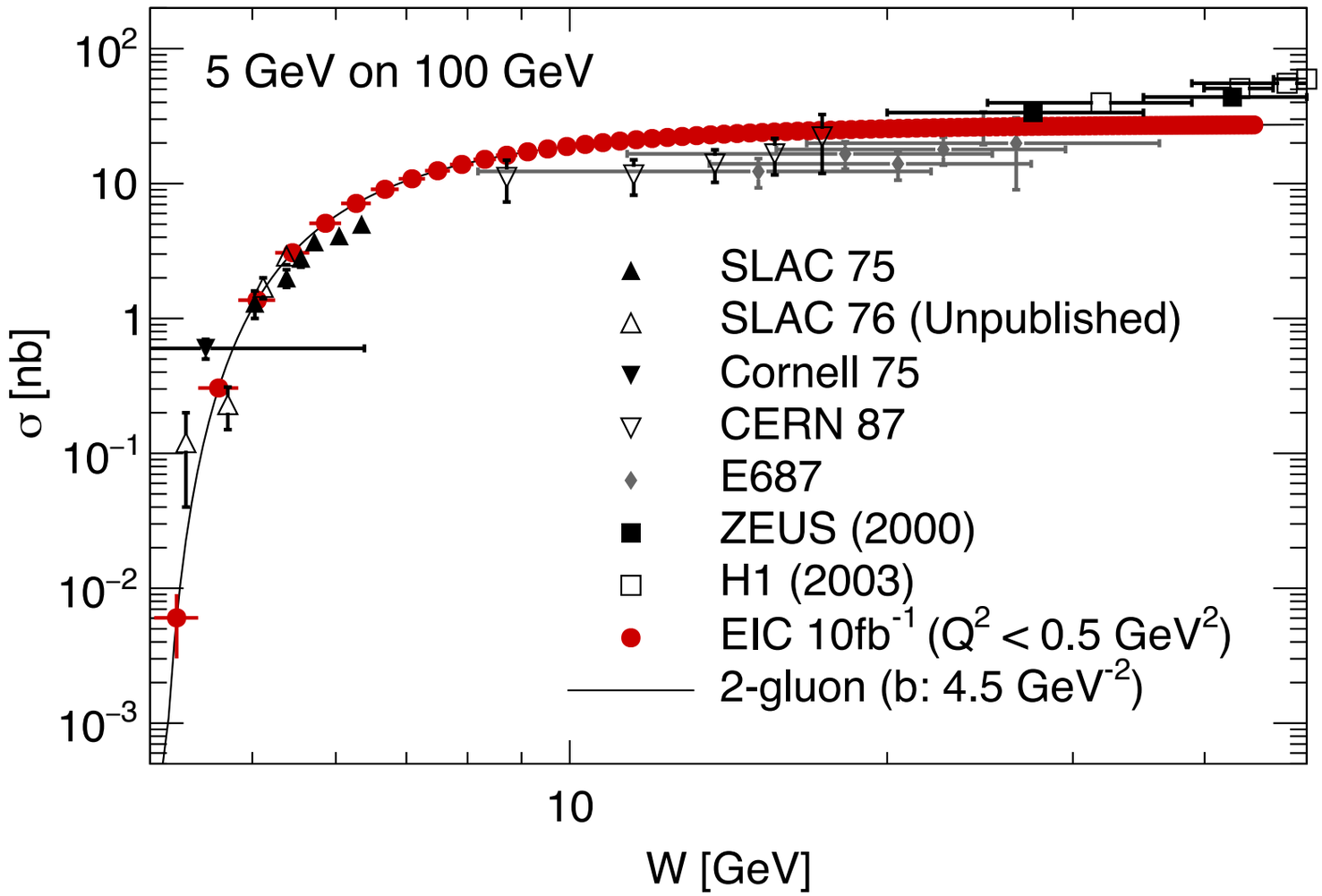


- Nominal parameters relevant to DVMP:
  - (Consistent with accelerator/ detector specs from white-paper)
  - **5 GeV electron beam on 100 GeV proton beam** in range of both designs
  - **Luminosity: 10-100 fb^{-1}**
  - **Acceptance**:
    - **Leptons**: pseudo-rapidity $|\eta| < 5$
    - **Recoil proton:** scattering angle $\theta > 2$ mrad
  - Resolution:
    - Angular < 0.5 mrad
    - Momentum < 1%

Only looking at electron-positron channels!

J/ψ photo-production cross section

- **Quasi-real production** at an EIC
- Simulation based on a 2-gluon fit to the world data
- **Fully exclusive** reaction
- Can go **close to threshold**
  - *W*-range limited by the electron acceptance



Spatial **Imaging of gluon density** with J/ψ

$$\rho(|\vec{b}_T|, x_V) = \int \frac{d^2\vec{\Delta}_T}{(2\pi)^2} e^{i\vec{\Delta}_T\vec{b}_T} |\langle H_g \rangle|(t = -\vec{\Delta}_T^2)$$

Fourier transform

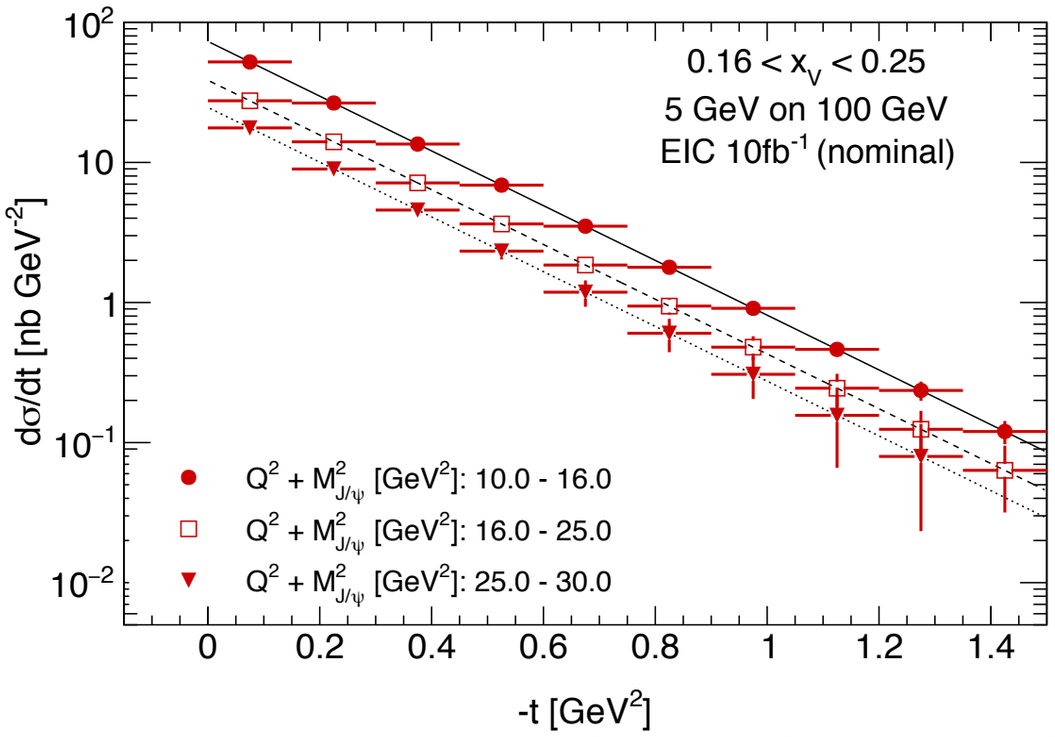
Hard scale: $Q^2 + M^2_{J/\psi}$

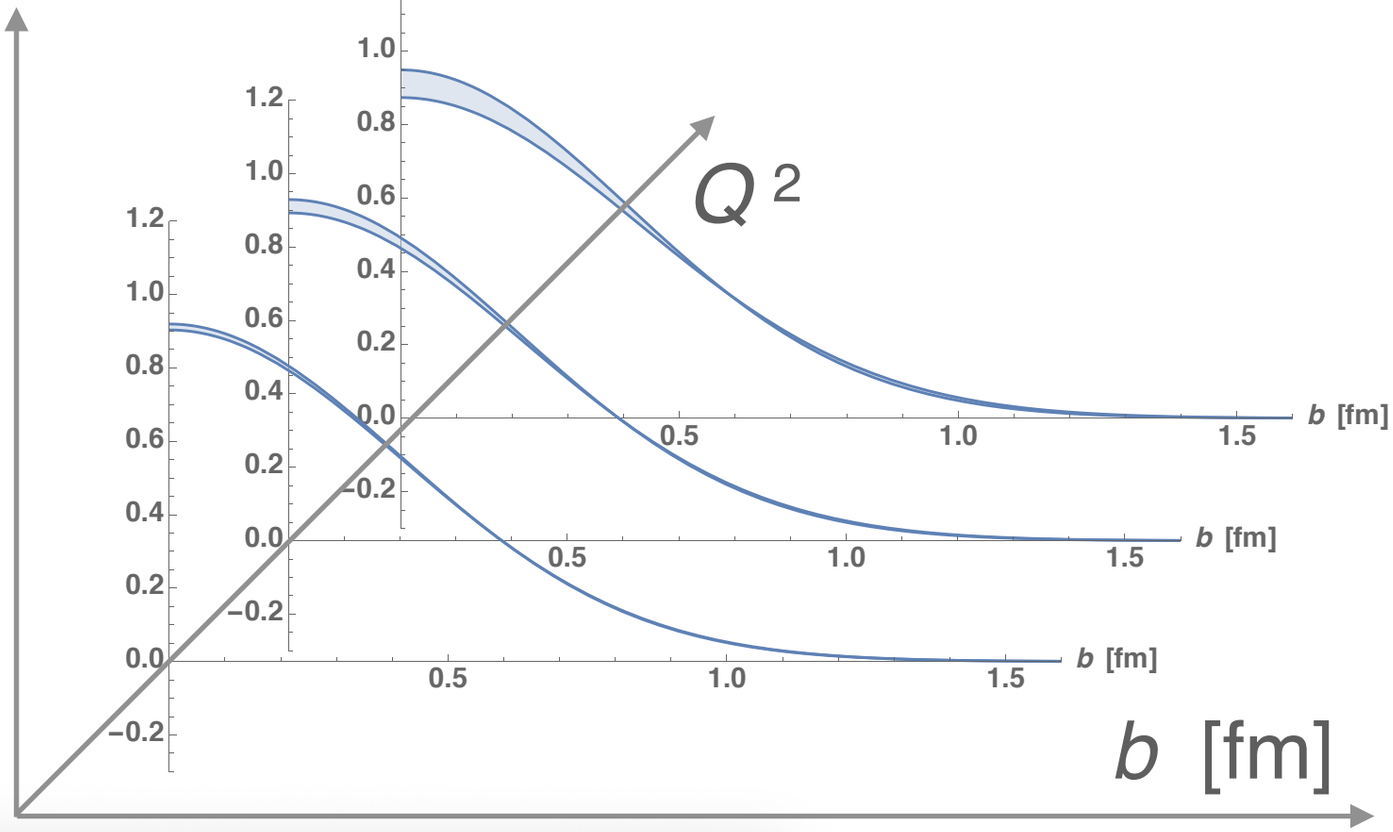
Modified Bjorken-x: $x_V = \dfrac{Q^2 + M^2_{J/\psi}}{2p \cdot q}$

Normalized average gluon density:

$\rho(b, x_V)$ [fm^{-2}] $0.16 < x_V < 0.25$

3D *t*-spectrum





Only possible at an EIC:
from the valence region deep into the sea!

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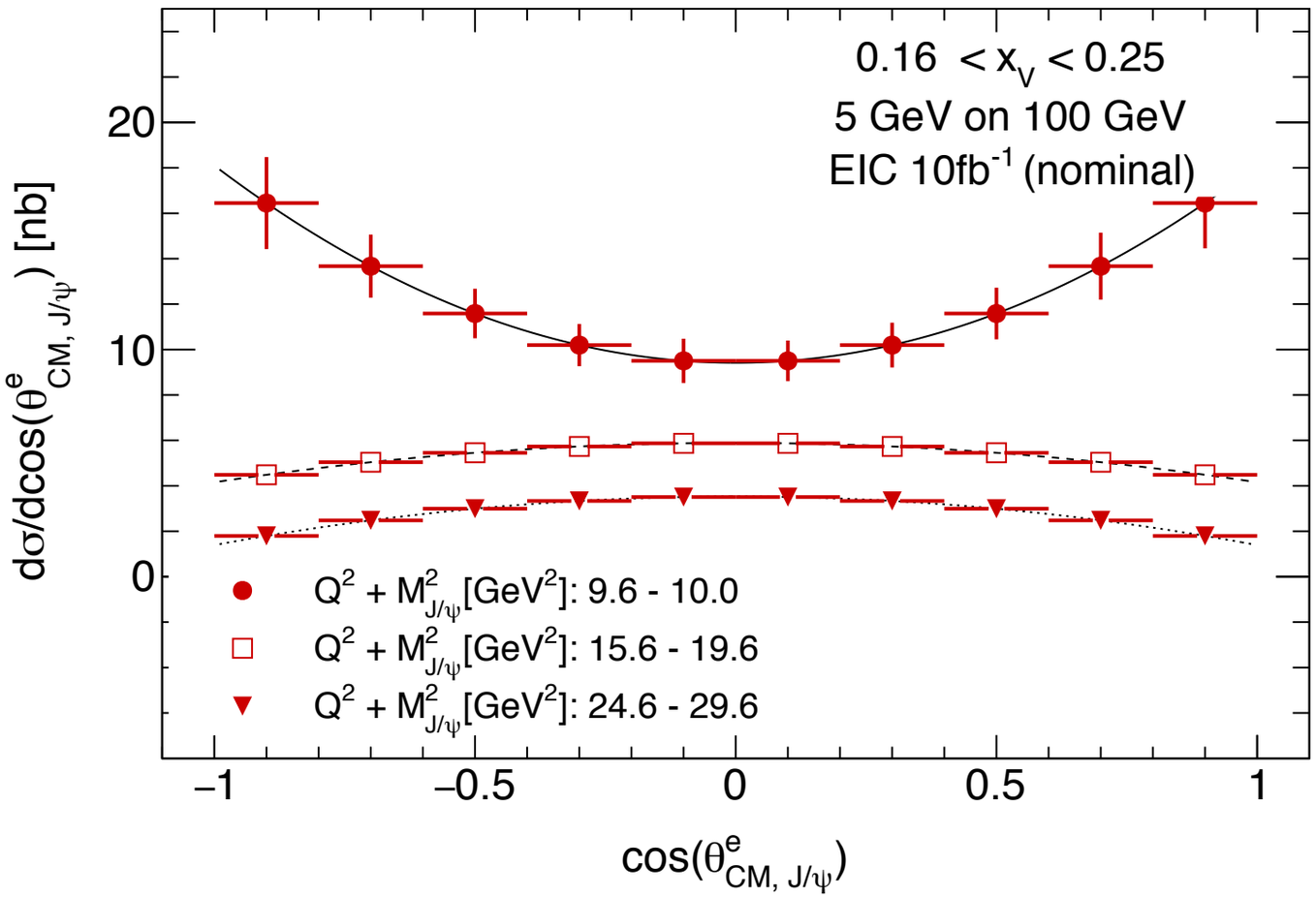
L-T separation and the Q^2 dependence of R

$$\mathcal{W}(\cos\theta_{\mathrm{CM}}) = \frac{3}{8}\left(1 + r_{00}^{04} + (1 - 3r_{00}^{04})\cos^2\theta_{\mathrm{CM}}\right) \qquad R = \frac{1}{\epsilon}\frac{r_{00}^{04}}{1 - r_{00}^{04}}$$

Angular distribution of the decay pair



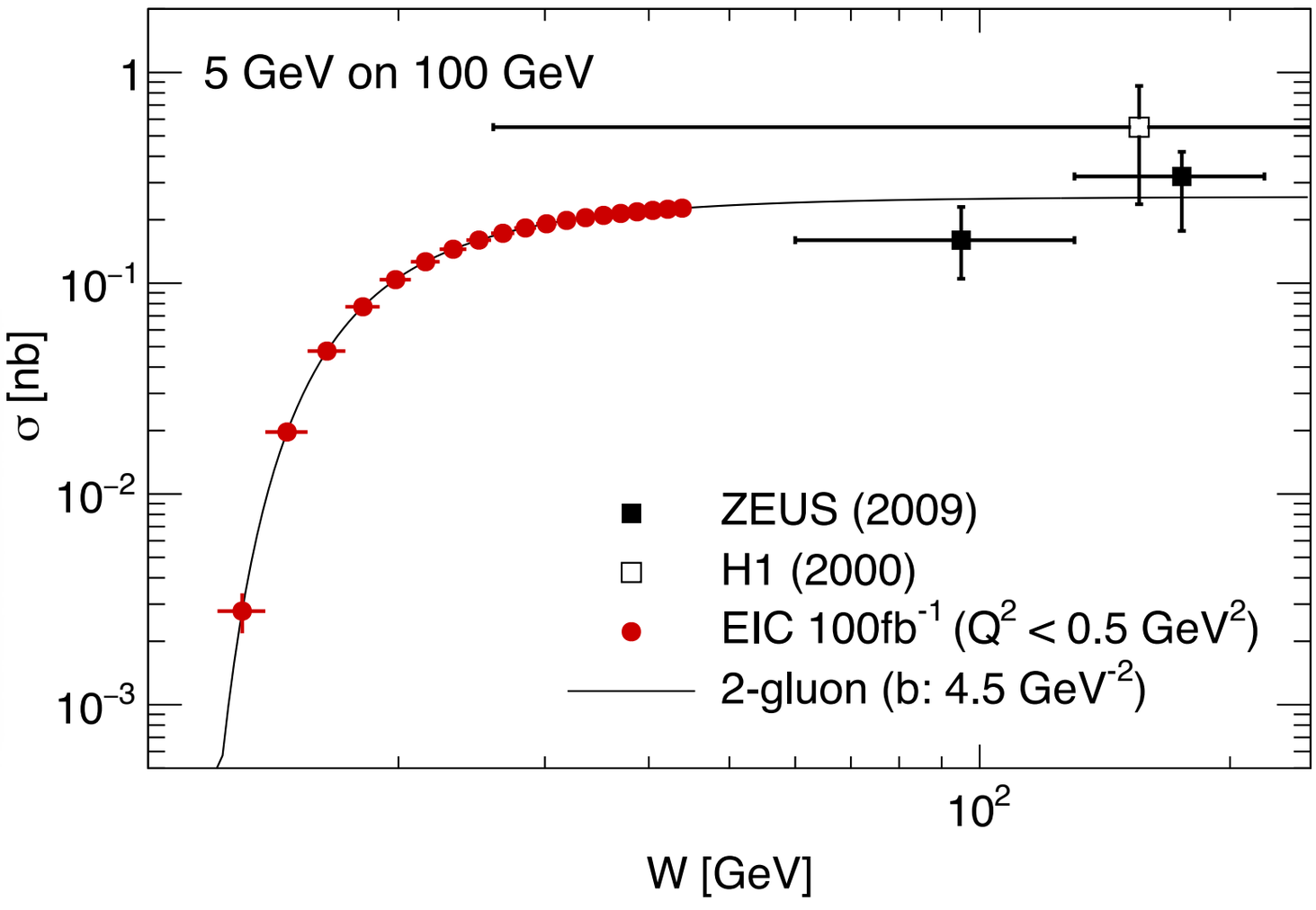
- Can extract R in 3D or even 4D
- Test s-channel helicity conservation (SCHC)
- Precise measurement of the Q^2 dependence of R

Y photo-production cross section

- **Quasi-real production** at an EIC
- Simulation based on a 2-gluon fit to the (sparse) world data
- **Fully exclusive** reaction
- Can go **to near-threshold region**

Y cross section ~100x lower than *J/ψ*.

Reasonable precision with 10x more luminosity



Spatial **Imaging of gluon density** with *Y*

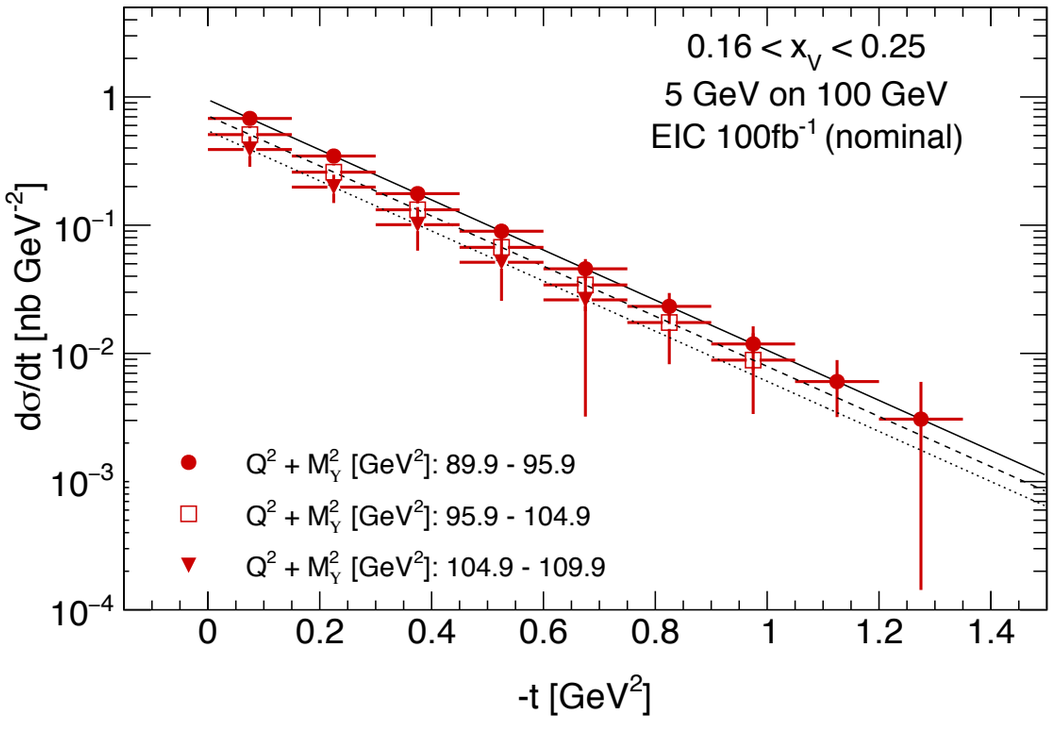
$$\rho(|\vec{b}_T|, x_V) = \int \frac{d^2\vec{\Delta}_T}{(2\pi)^2} e^{i\vec{\Delta}_T\vec{b}_T} |\langle H_g \rangle|(t = -\vec{\Delta}_T^2)$$

Fourier transform

Hard scale: $Q^2 + M_\Upsilon^2$

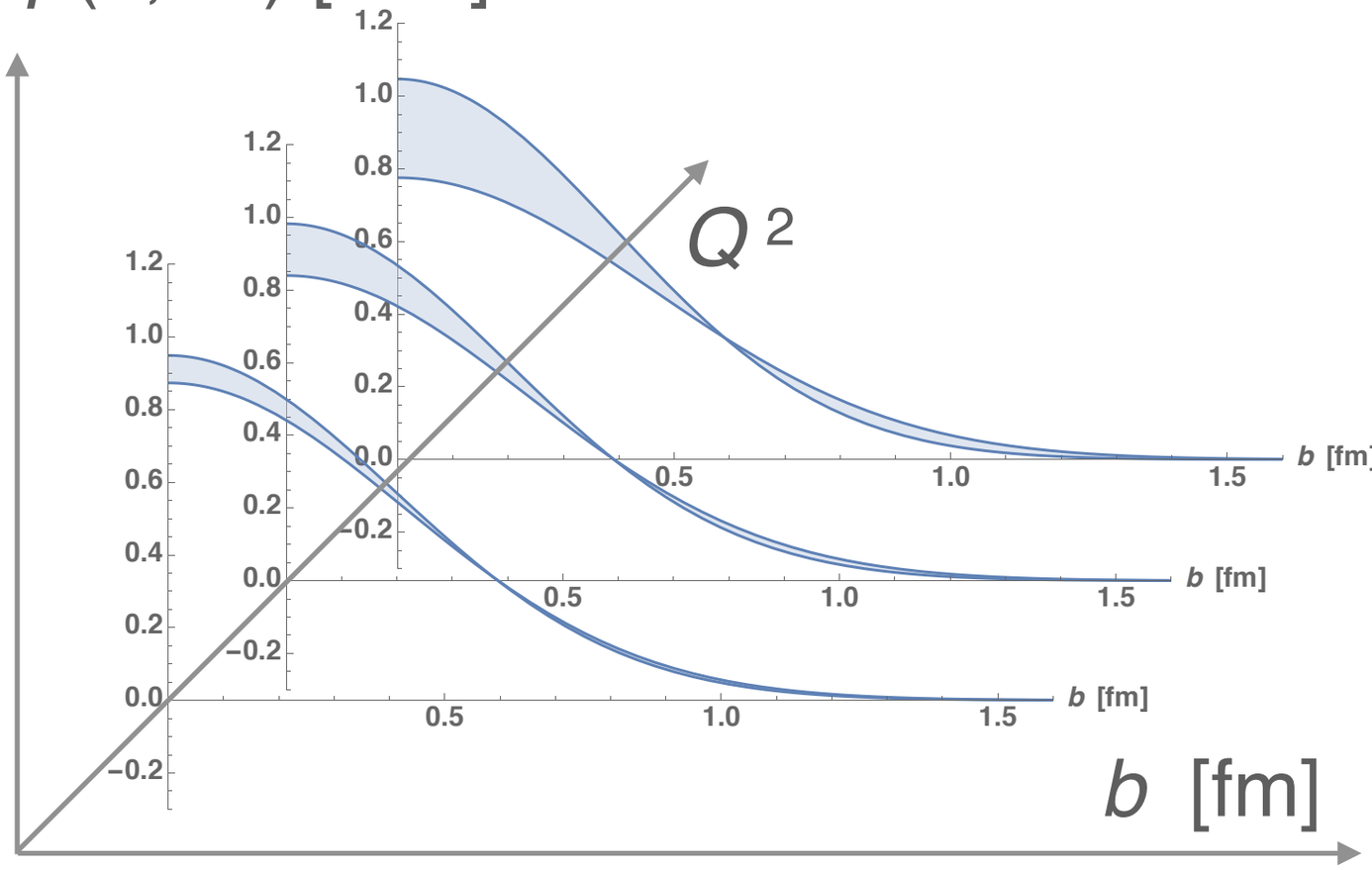
Modified Bjorken-x: $x_V = \dfrac{Q^2 + M_\Upsilon^2}{2p \cdot q}$

3D *t*-spectrum



Normalized average gluon density:

$\rho(b, x_V)$ [fm^{-2}] $0.16 < x_V < 0.25$



***Y* a viable tool to check Universality!**

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Conclusion

- **Heavy Quarkonium** production an important tool to study the **gluons fields** in the nucleon
- **Threshold production** of heavy quarkonium can shed light on the **trace anomaly and proton mass**
- Possible to study charm (and bottom?) pentaquarks
- At **high *W***: possible to access **gluon GPDs**
- Can **test universality by comparing *Υ* to *J/ψ*** results
- **JLab12 and the EIC** are (will be) perfectly positioned to **significantly contribute to these topics**

This work is supported by DOE grant DE-FG02-94ER4084

BACKUP SLIDES

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$$\frac{d\sigma}{dQ^2 dy dt} = \Gamma_T (1 + \epsilon R) D \frac{d\sigma_\gamma}{dt}$$

$$R = \left(\frac{AM_V^2 + Q^2}{AM_V^2} \right)^{n_1} - 1$$

$$D = \left(\frac{M_V^2}{M_V^2 + Q^2} \right)^{n_2}$$

$$\frac{d\sigma_\gamma}{dt}$$

- Martynov, et. al., “Photoproduction of Vector Mesons in the Soft Dipole Pomeron Model.” PRD 67 (7), 2003. doi:10.1103/PhysRevD.67.074023
- R. Fiore et al., "Exclusive Jpsi electroproduction in a dual model.” PRD80:116001, 2009"
- A. Airapetian et al, "Exclusive Leptoproduction of rho0 Mesons on Hydrogen at Intermediate W Values", EPJ C 17 (2000) 389-398
- Adams et al., "Diffractive production of ρ0 mesons in muon–proton interactions 470 GeV", ZPC74 (1997) 237-261.
- M Tytgat, "Diffractive production of ρ0 and ω vector mesons at HERMES” DESY-Thesis 2001-018 (2001)
- P. Liebing, “Can the Gluon Polarization be Extracted From HERMES Data”, DESY-Thesis (2004)
- Brodsky, S J, E Chudakov, P Hoyer, and J M Laget. 2001. “Photoproduction of Charm Near Threshold.” Physics Letters B 498 (1-2): 23–28. doi:10.1016/S0370-2693(00)01373-3.

Angular dependence of the decay lepton pair in the J/psi Helicity frame

$$\mathcal{W}(\cos\theta_{\mathrm{CM}}) = \frac{3}{8}\left(1 + r_{00}^{04} + (1 - 3r_{00}^{04})\cos^2\theta_{\mathrm{CM}}\right)$$

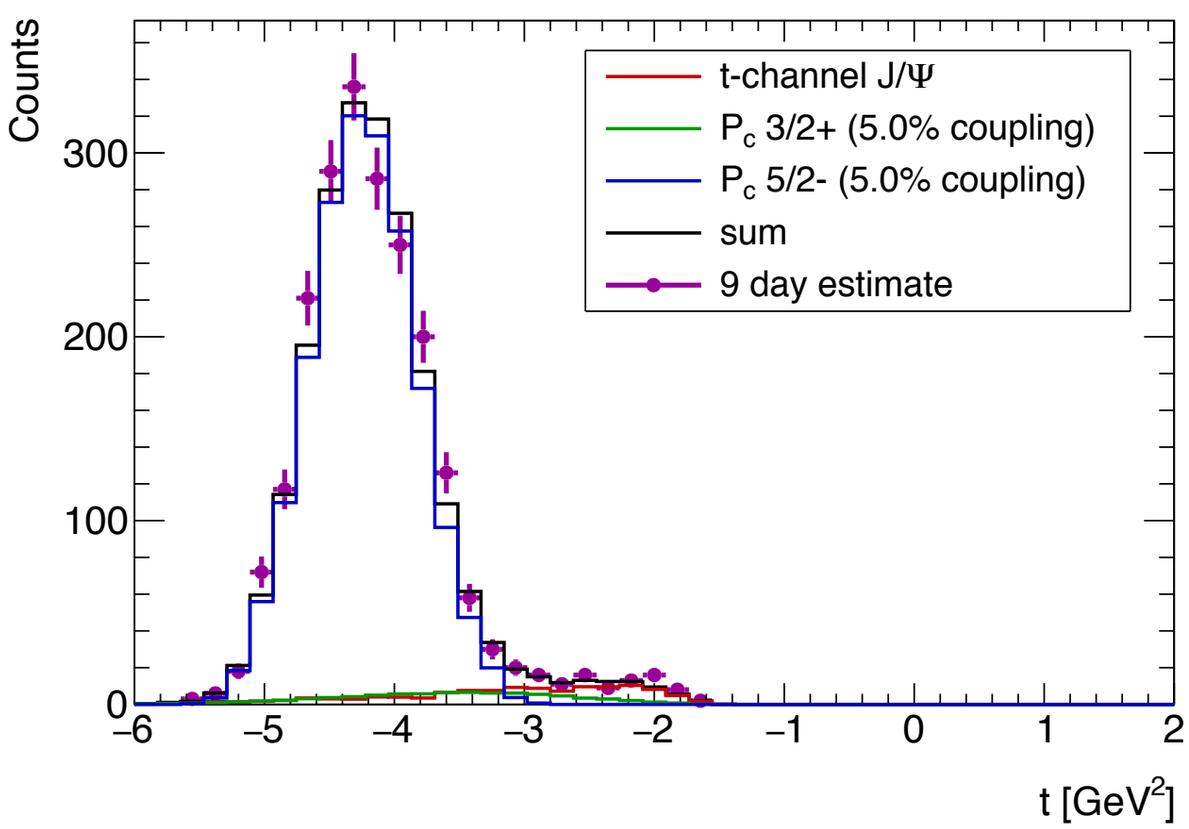
- **FORMULA FOR TWO FERMION DECAY**
- J. Breitweg et al. (ZEUS), Exclusive electro-production of rho0 and J/psi mesons at HERA, EPJ-C 6-4 (1999)
- Chekanov et al. (ZEUS), Exclusive photo production of J/psi mesons at HERA (2002)
- K. Schilling et. Al, Nucl.Phys. B 61, 381 (1973)

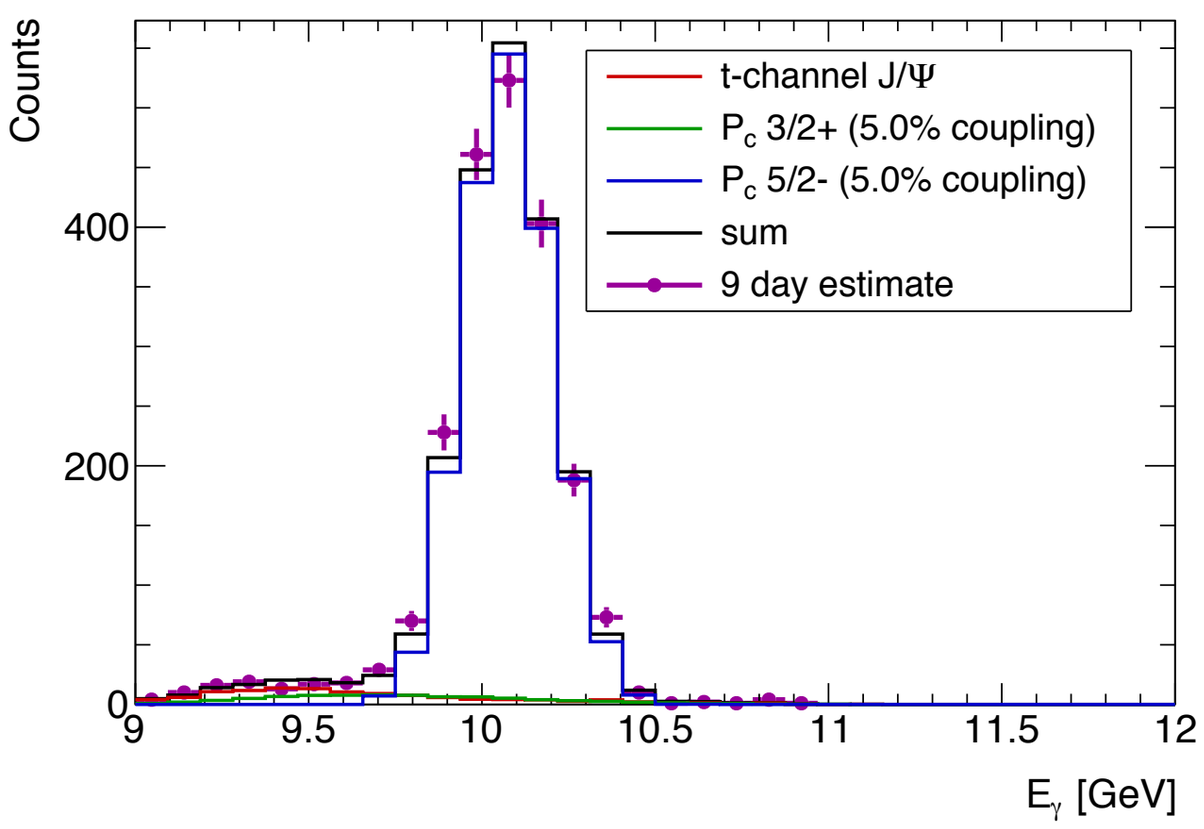
$$R = \frac{1}{\epsilon}\frac{r_{00}^{04}}{1 - r_{00}^{04}}$$

- **Extract r04 from the measured angular distribution**
- **Directly related to R!**

Alternate P_c Assumption (Setting "SIGNAL")

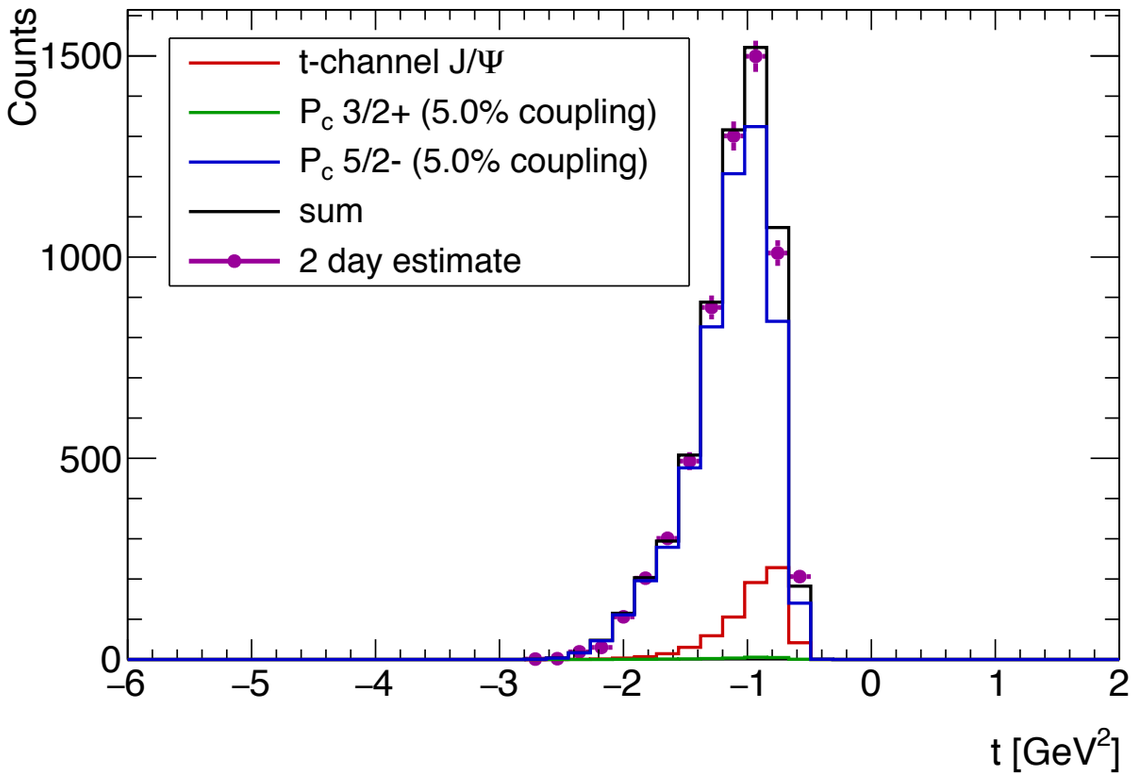
- **Alternate (5/2-, 3/2+) P_c assumption**
- assuming 5% coupling for the (5/2-, 3/2+) P_c assumption
- 9 days of beam time at 50μA
- 5/2- peak **dominates the spectrum** (even larger than the 5/2+ peak!)

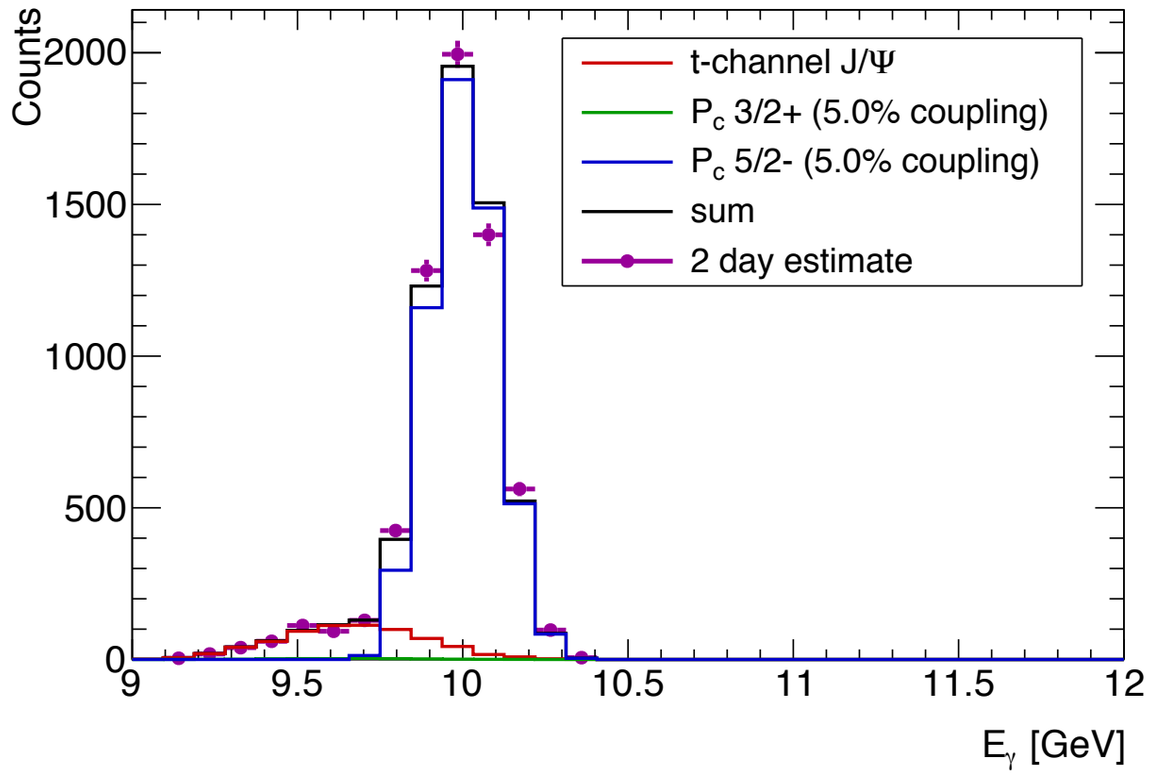




Alternate P_c Assumption ("BACKGROUND" Setting)

- **Alternate (5/2-, 3/2+) P_c assumption**
- 2 days of beam time at 50μA
- able to **separate** 5/2- from ***t*-channel at low E_γ**
- will provide **first-hand information about *t*-channel production near threshold**
- assuming 5% coupling for the (5/2-, 3/2+) P_c assumption

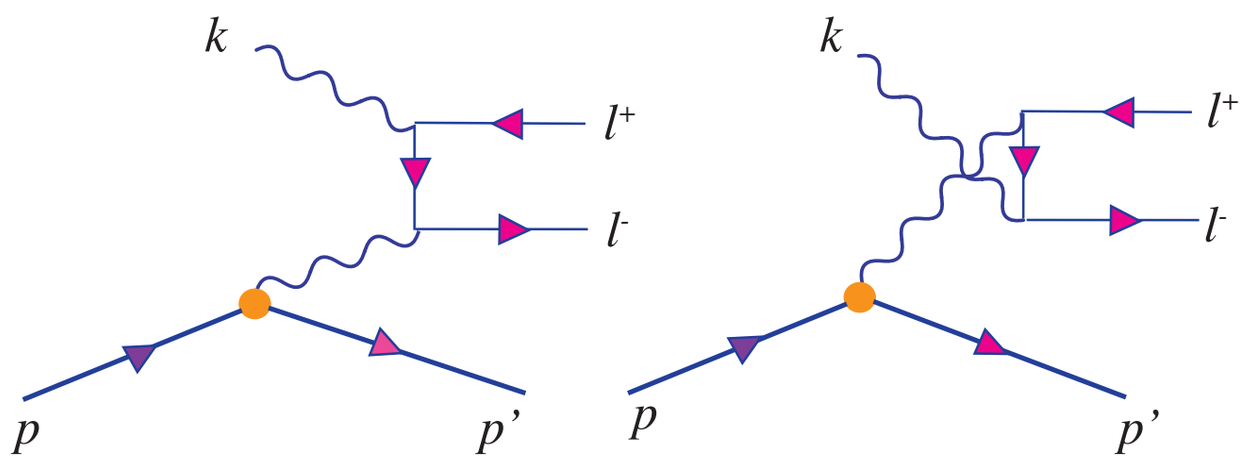




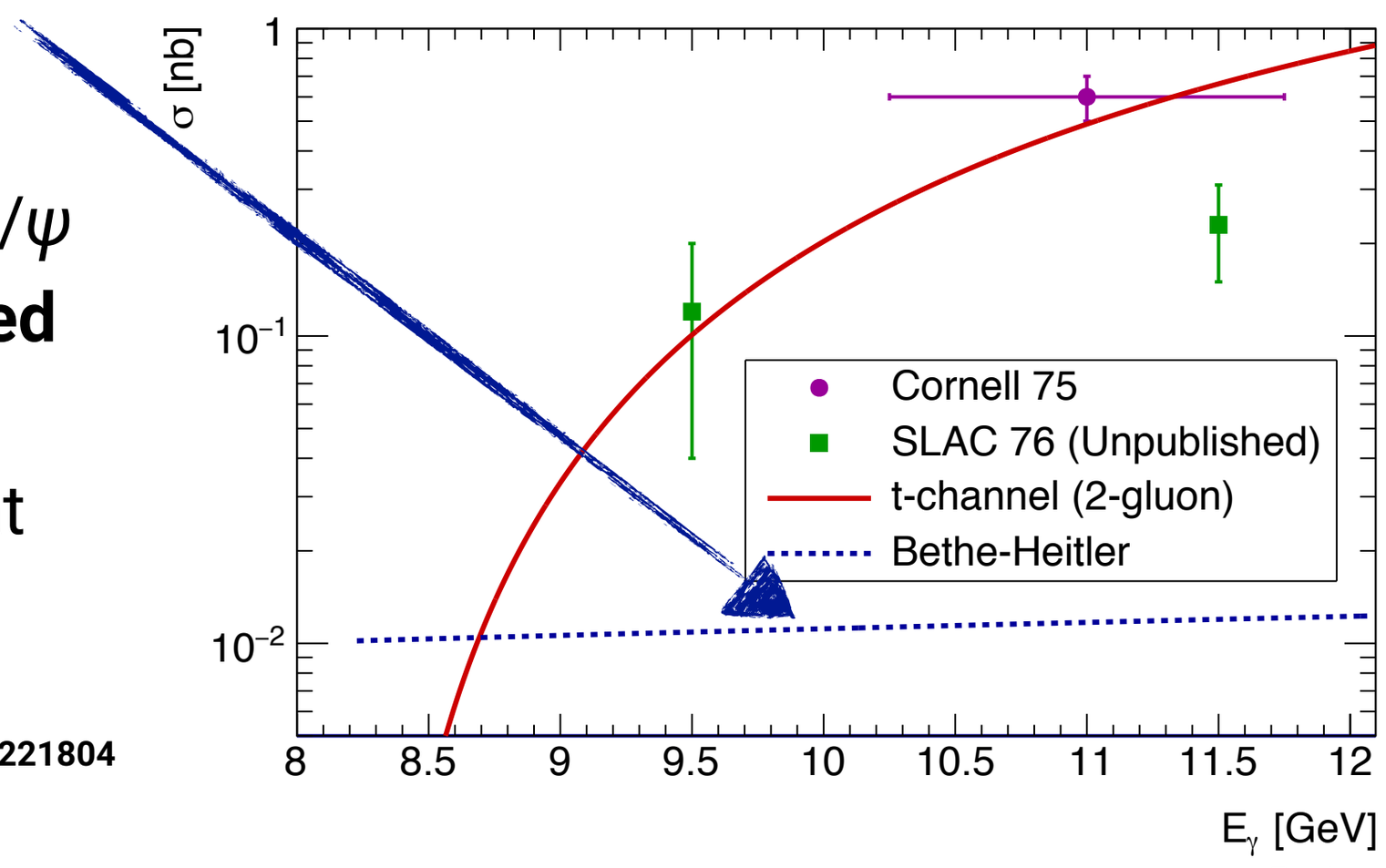
Background: **Bethe-Heitler pair production**

$$\gamma p \to e^+ e^- p$$

Not an issue!



- Estimated using calculations from Pauk and Vanderhaeghen
- Constant background < 10% of the *t*-channel J/ψ
- Can be **exactly calculated** and controlled for
- Interference negligible at the $P_c(4450)$ peak



Pauk V and Vanderhaeghen M, PRL 115(22) (2015) 221804

Background: **inelastic *t*-channel** (*γp -> J/ψpπ*)

- Threshold at 9 GeV
- Reconstructed photon energy $\underline{E}_{rc}$ is ~1 GeV too low
- **less than 30% of the elastic *t*-channel** background
- Contaminates the **8 GeV < $\underline{E}_{rc}$ < 9.7 GeV** range for a photon end-point energy of 10.7 GeV
  - **not an issue for the $P_c(4450)$ ($\underline{E}_{rc}$ > 9.7GeV)!**

not an issue for the P_c!

Photon Energy Reconstruction

- Can **unambiguously** reconstruct the initial photon energy from the reconstructed J/ψ momentum and energy
- Assumptions:
  - photon beam along the *z*-axis
  - proton target at rest
  - 2 final state particles: a proton and a *J/ψ*

$$E_\gamma = \frac{M_J^2 - 2E_J M_P}{2(E_J - M_p - P_J \cos\theta)}$$

Properties of the Hall C Spectrometers

	P	$\Delta P/P$	$\sigma P/P$	θ^{in}	$\Delta\theta^{\text{in}}$	$\Delta\theta^{\text{out}}$	$\Delta\Omega$	$\sigma\theta^{\text{in}}$	$\sigma\theta^{\text{out}}$
	GeV/c	%	%		mrad	mrad	msr	mrad	mrad
HMS	0.4-7.4	-10 +10	0.1	10.5°-90°	$\pm$24	$\pm$70	8	0.8	1.0
SHMS	2.5-11.	-15 +25	0.1	5.5°-25°	$\pm$20	$\pm$50	4	1.0	1.0

Run Plan for E12-16-007

- **Total Beam Time Request:**
  - 11 days (264h), 10.7 GeV (or 11 GeV), 50μA, Hall C
- **Run Plan:**
  1. ***t*-channel "BACKGROUND": 40 hours**
  2. **radiator out: 8 hours (longer if needed)**
  3. **main "SIGNAL" measurement: 216 hours**

11 days,
standard equipment!