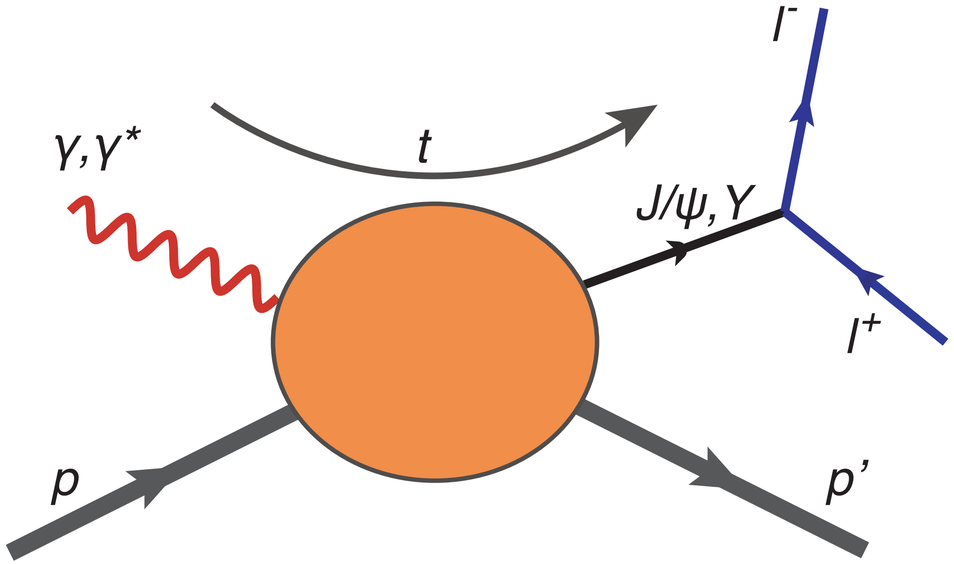
PROBING THE GLUONIC STRUCTURE OF THE NUCLEON AND THE DYNAMIC ORIGIN OF ITS MASS

Argonne NATIONAL LABORATORY

EXCLUSIVE UPSILON PRODUCTION AT EICC



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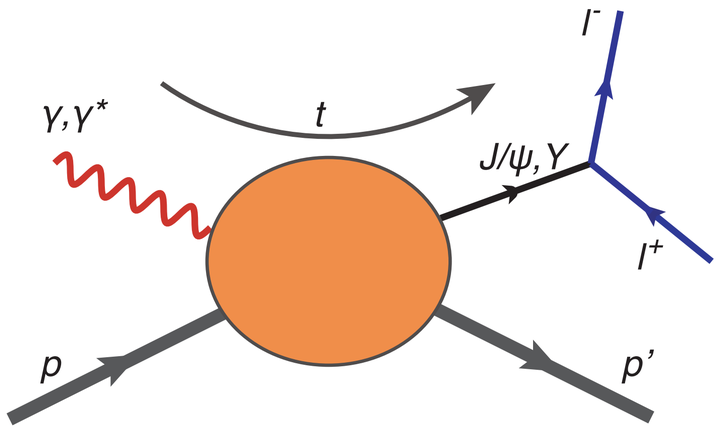
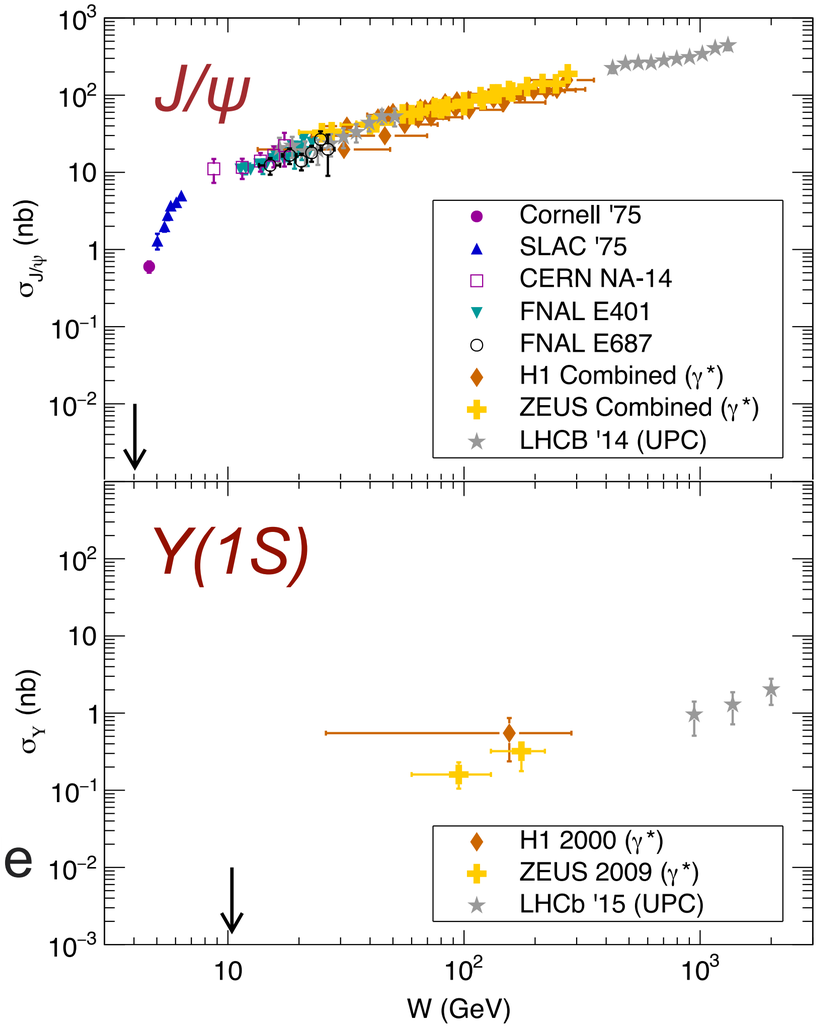
11th Workshop on Hadron Physics in China and Opportunities Worldwide

QUARKONIUM PHOTO-PRODUCTION

What do we know?



- *J/ψ* well constrained for high energies
- *Υ(1S)*: not much available
- No electro-production data available
- **Almost no data near threshold**



Near Threshold:

- **Origin of proton mass,** trace anomaly of the QCD EMT
- **Gluonic Van der Waals force**, possible quarkonium-nucleon/ nucleus bound states
- **Mechanism** for quarkonium production itself

J/ψ at JLab
Υ(1s) at EIC

See K. Hafidi, S. Joosten *et al.*, Few Body Syst. 58 (2017) no.4, 141 and references therein

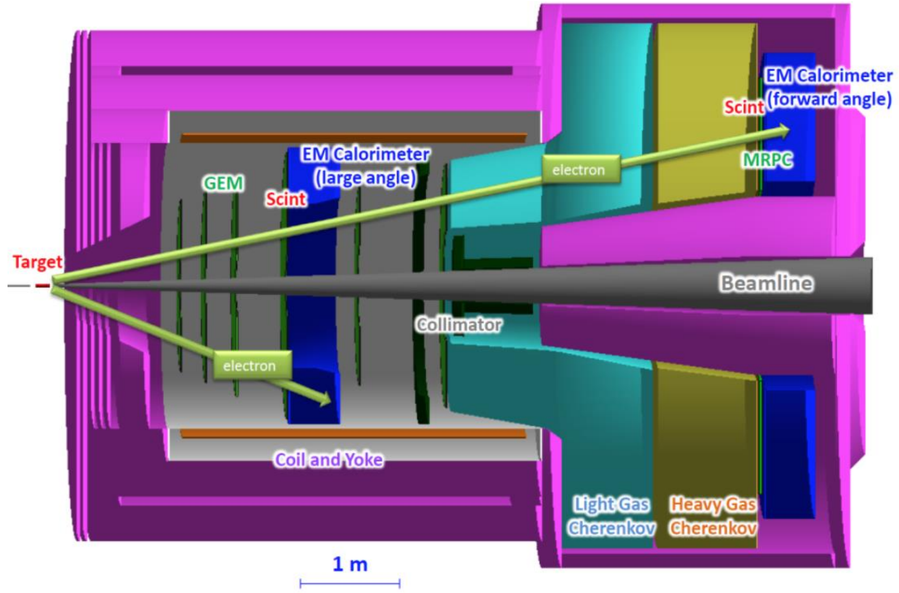
ATHENNA Collaboration

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

J/Ψ EXPERIMENT E12-12-006 AT SOLID

The ultimate experiment to study *J/ψ* at threshold.

- 3*μ*A electron beam at 11 GeV for 50 days
- 15 cm liquid hydrogen target
- **Ultra-high luminosity: 43.2 ab^{-1}**
- General purpose large acceptance spectrometer
- Symmetric acceptance for electrons and positrons
- Channels:
  - Electro-production
  - Quasi-real production
  - Photo-production through bremsstrahlung in target cell



- **Electro-production**
  - Measure scattered electron and decay leptons
  - t-channel J/ψ rate: ~90/day
  - Clean signal (less background)
  - Closer to threshold

- **Photo-production**
  - Measure decay leptons and recoil proton
  - t-channel J/ψ rate: >1600 per day
  - Ultra-high rate

See K. Hafidi, S. Joosten *et al.*, Few Body Syst. 58 (2017) no.4, 141 and references therein

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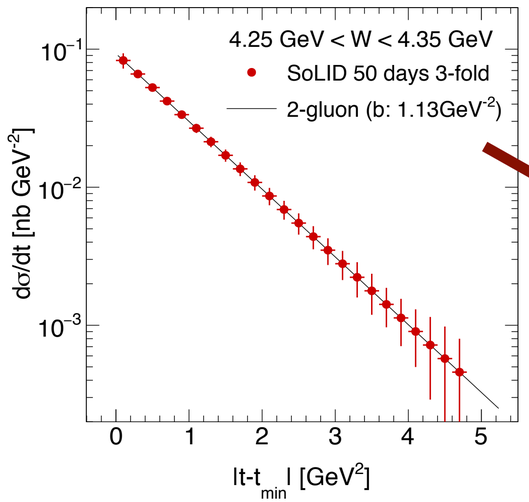
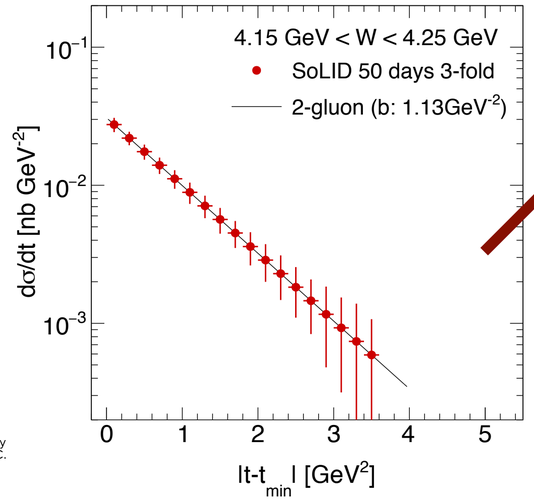
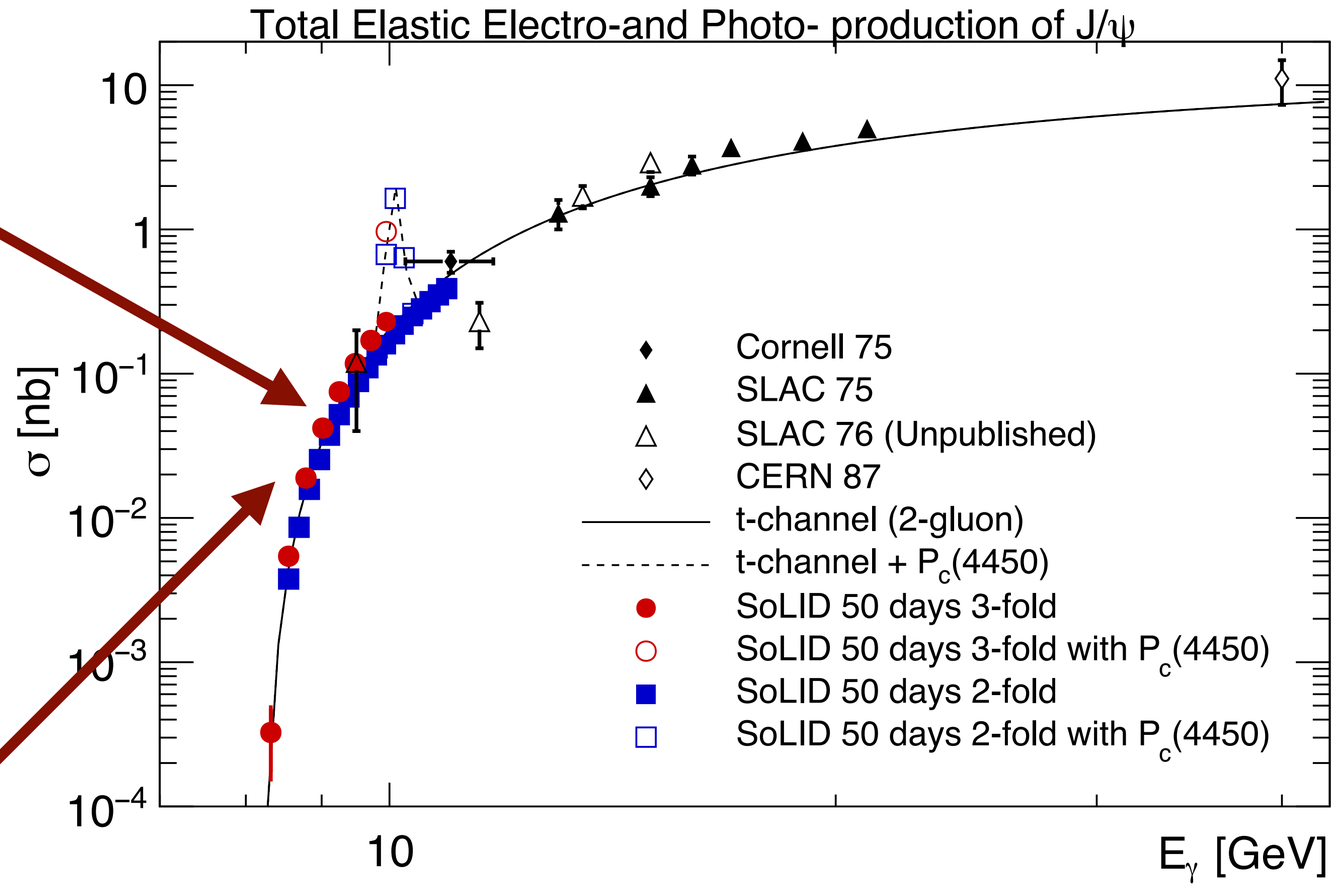






Sensitivity below 10^{-3} nb!

J/Ψ EXPERIMENTS IN JLAB IN A NUTSHELL

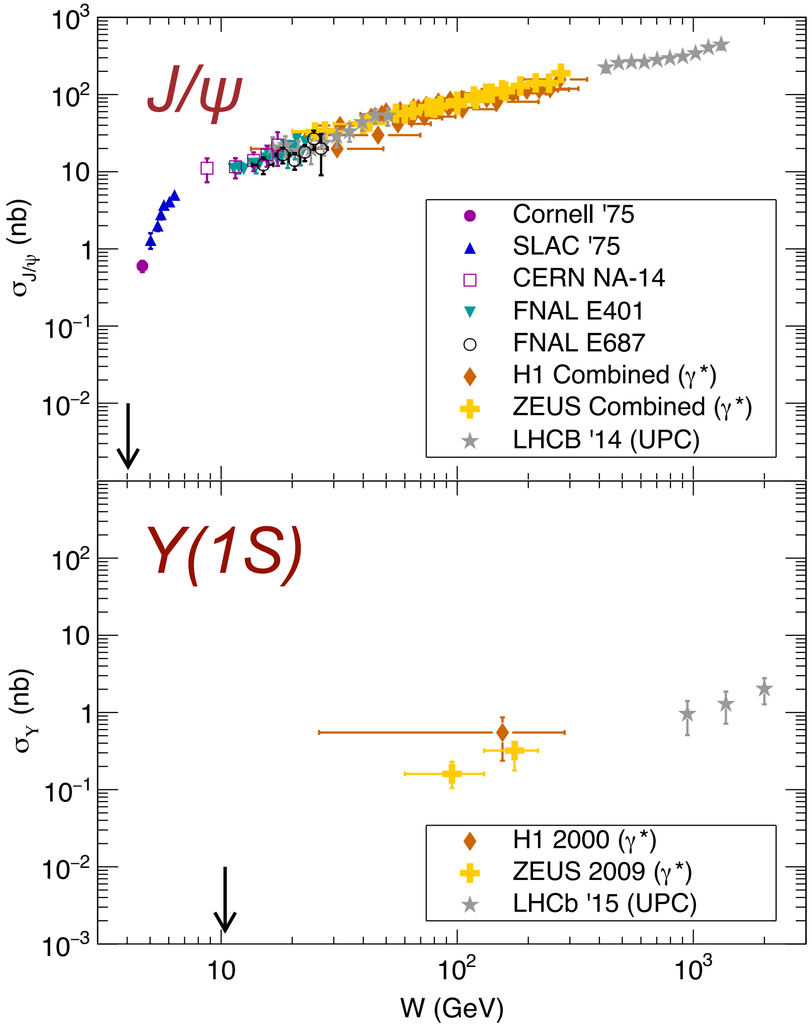
Exciting times for *J/ψ* near threshold!

	GlueX HALL D	HMS+SHMS HALL C	CLAS 12 HALL B	SoLID HALL A
J/ψ counts (photo-prod.)	~400	~2100 (4200 with muons)	45/day	1627/day
J/ψ Rate (electro-prod.)				86/day
Experiment		E12-16-007	E12-12-001	E12-12-006
PAC days		9+2	130	50
When?	Finished	Finished	Ongoing	~10 years?

Y(1S): THE OPTIMAL GLUONIC PROBE

…but a challenging measurement

- *Y(1S)* is a heavier (smaller) probe than *J/ψ*
  - *Y(1S)* production near threshold crucial to **universality**
- Cross section very small (2 orders of magnitude smaller than *J/ψ)*
- Measurement can be done at EIC

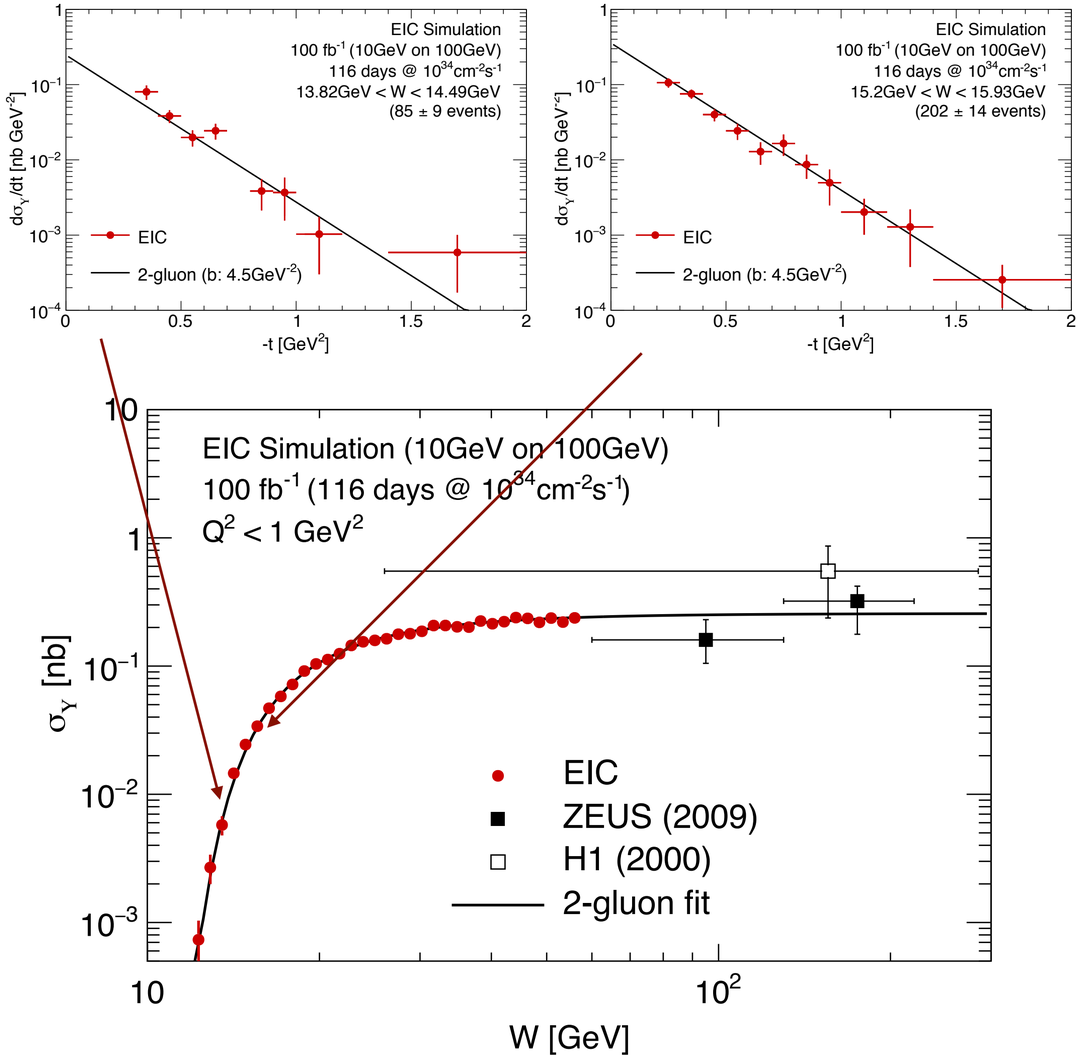


Y(1S) PHOTO-PRODUCTION AT EIC

…Threshold measurement possible!

- **Quasi-real production** at an US EIC
- Both electron and muon channel
- **Fully exclusive** reaction
- Can go **to near-threshold region**

- ***Y(1s)*** production possible at threshold!
  - Provides measure for **universality,** complimentary to threshold *J/ψ* program at JLab12
  - Are there a “beautiful” pentaquarks?
- Sensitivity down to ~10^{-3} nb!



HOW ABOUT EICC?

Can we do *Y(1S)* physics with a lower energy machine?

- At first glance, nominal 3.5GeV on 20GeV seems perfect for *Y(1S)* near threshold.
- However *Y(1S)* yield proportion to virtual photon flux, which goes as *1/y*
  - *(y is the fractional energy of the incoming electron transferred to the virtual photon in the target rest frame)*
- At lower energies (closer to the *Y(1S)* threshold), we need larger *y* to reach a given value of *W*, compared to higher energies.
- **This leads to a lower relative *Y(1S)* yield**

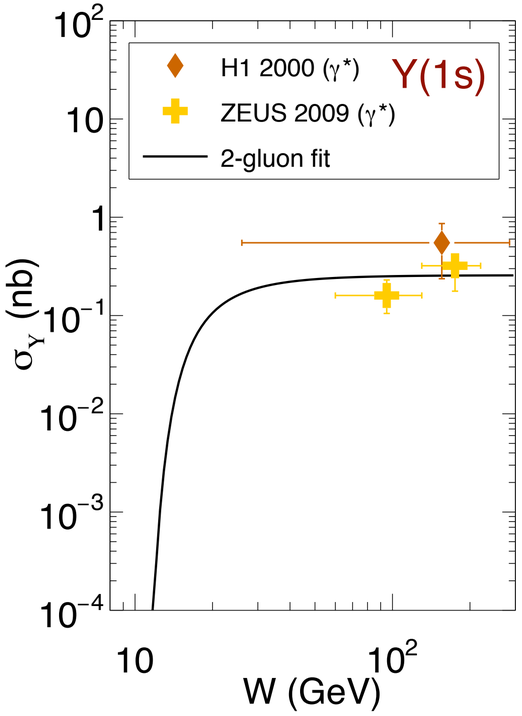
$$\sqrt{s} \approx 17.75$$

$$y = \frac{P.q}{P.k}$$

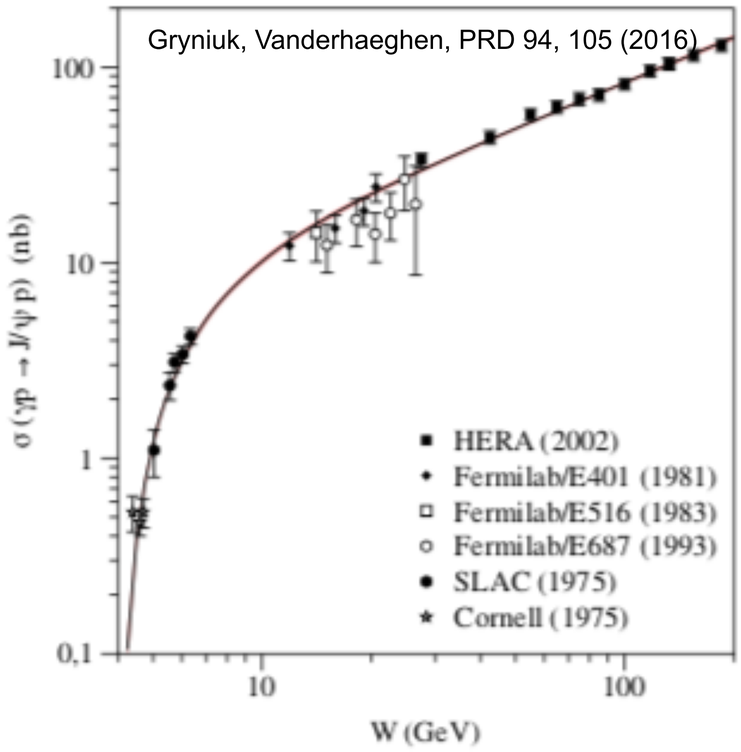
MODELLING THE CROSS SECTION

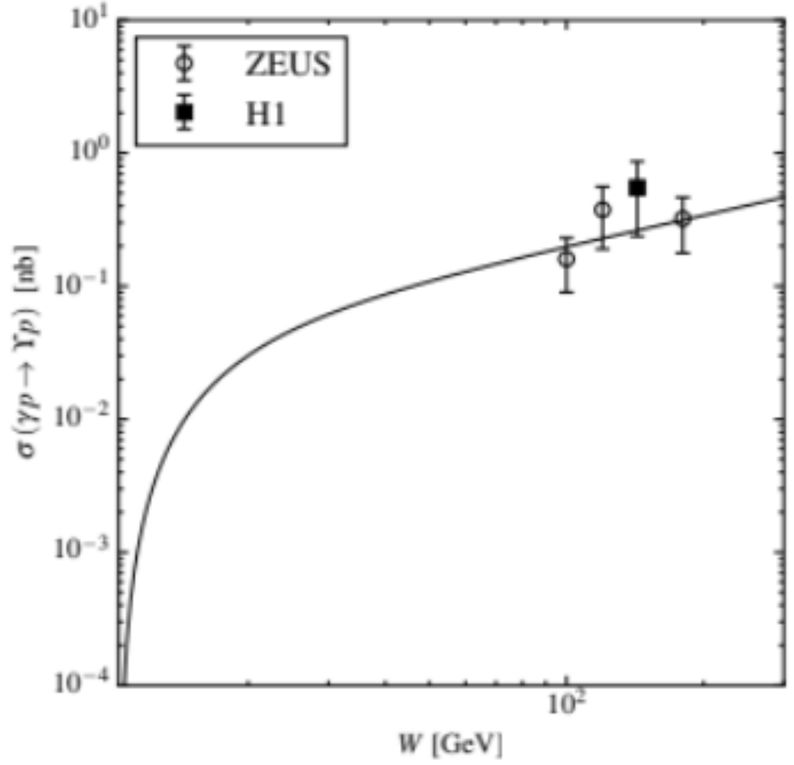
Need realistic model near threshold

Naive: 2-gluon
Fast drop-off near threshold



More realistic: dispersive framework
Includes binding effects near thresholds (favors ~3MeV)

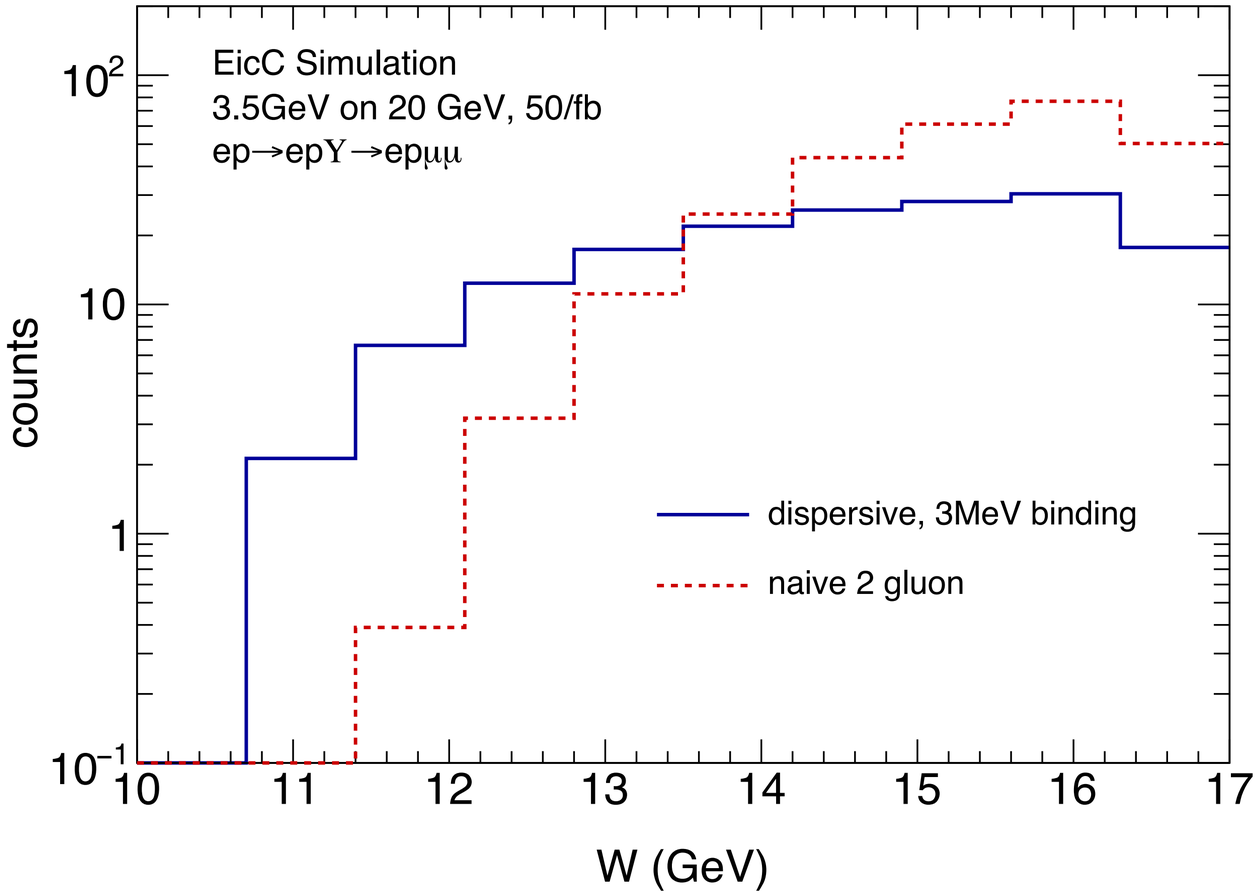




HOW ABOUT EICC?

Dispersive model results promising

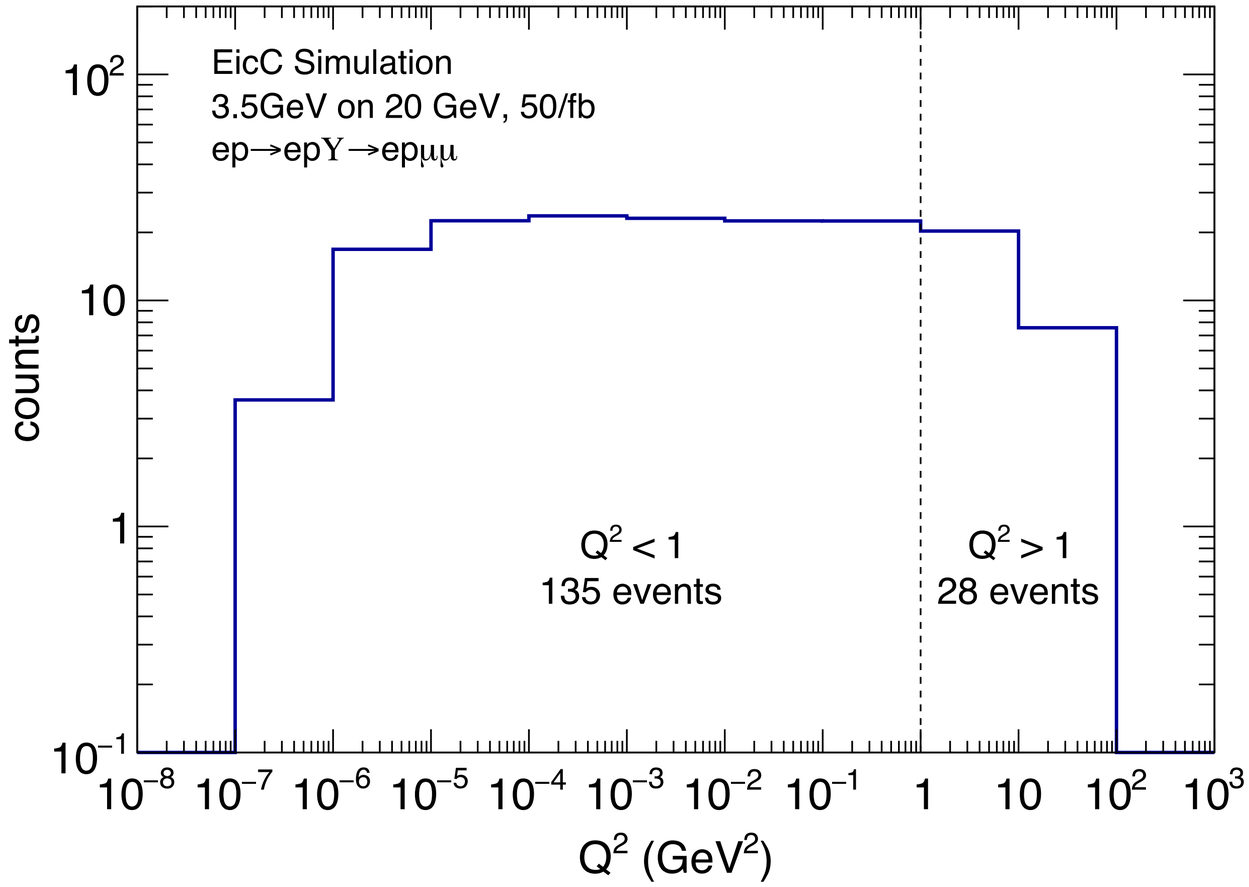
- Prohibitive to go to threshold without binding (2-gluon)
- More realistic dispersive framework predicts non-negligible rate down to threshold region
- But… this is all of Q^2



HOW ABOUT EICC?

Can we do electro-production?

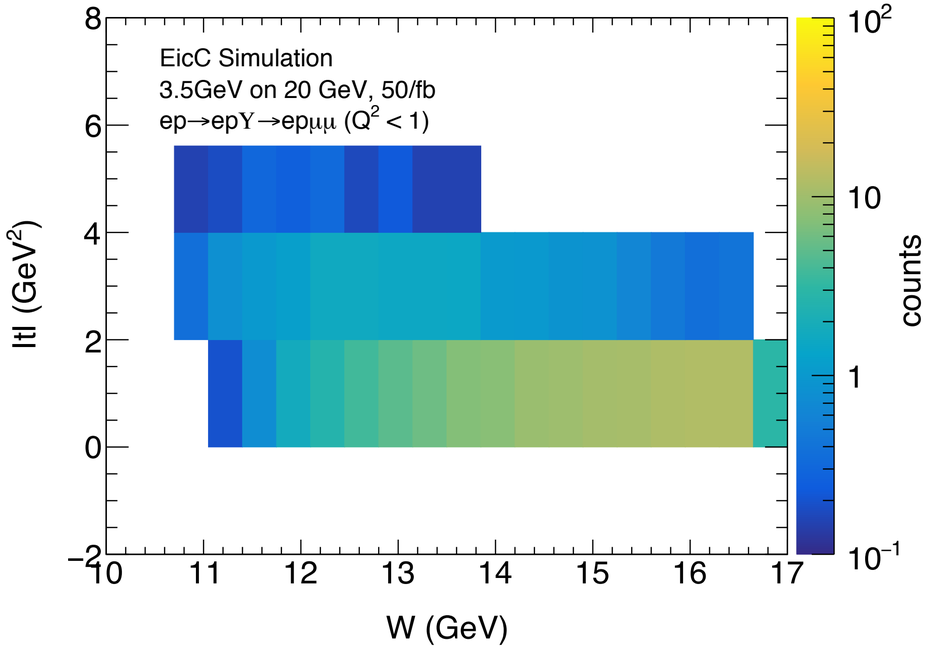
- Not really… quasireal—production dominant, but that is fine for most threshold physics!

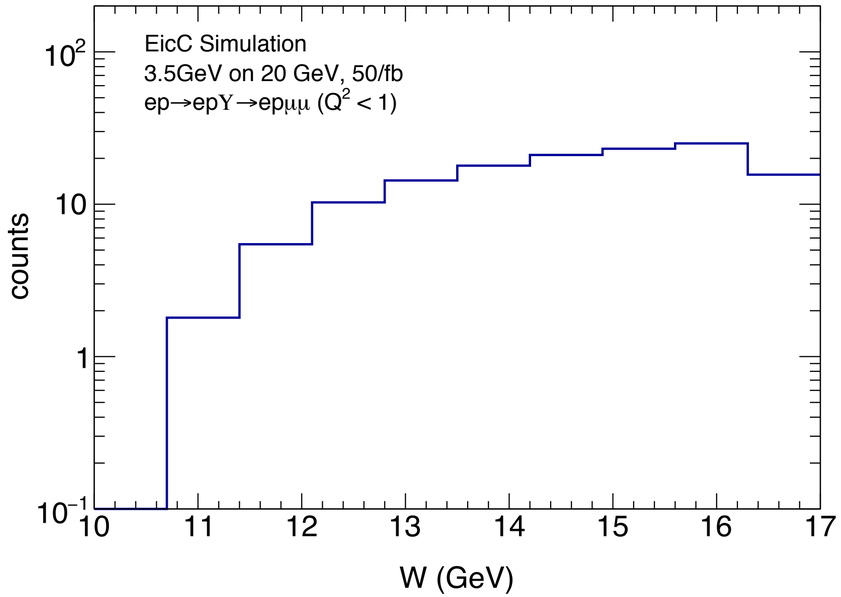


PROJECTIONS

Phase space for quasi-real production

- Exploratory measurement possible
- Low statistics …unless stronger binding effects near threshold
- Sensitivity in threshold region allows to search for beautiful pentaquark.





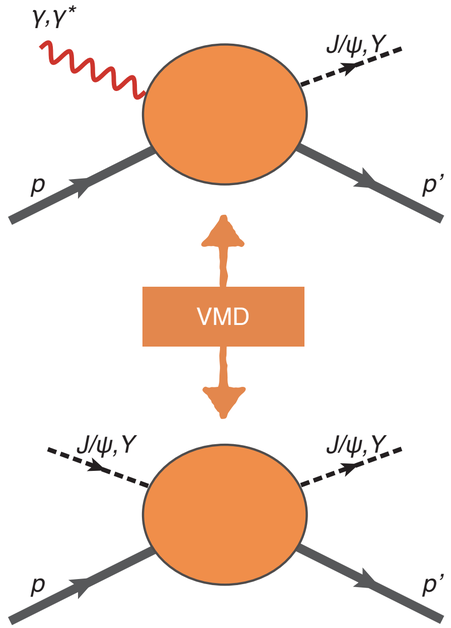
BACKUP

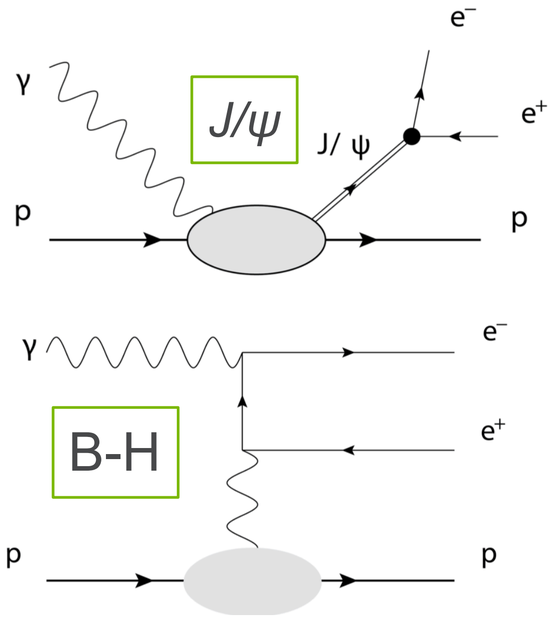
Three possible avenues for…

MEASURING THE TRACE ANOMALY

1. Cross section at threshold
Assuming VMD, measure t-dependence at threshold. Note: factorization not yet rigorously proven

D. Kharzeev *et al.,* PLB 289 595-599 (1996), EPJ-C 9 459-462 (1999)



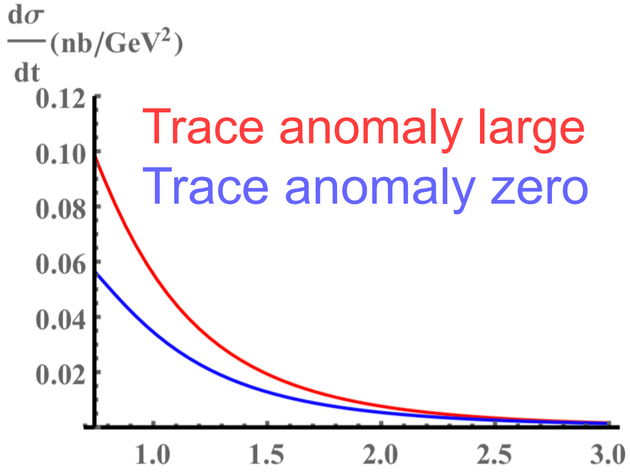


2. Interference with Bethe-Heitler
Interference between for *J/ψ* production and Bethe-Heitler near (but not at) threshold. Needs very high statistics. Possible at SoLID.

Gryniuk, Vanderhaeghen, PRD 94, 105 (2016)

3. Holographic approach:
Non-perturbative approach using AdS/CFT gauge-string duality. New development. Predicts sensitivity for *J/ψ* production near threshold.

Y. Hatta *et al.*, PRD 98 no. 7, 074003 (2018)



Gryniuk, Vanderhaeghen, PRD 94, 105 (2016)
S. R. Beane *et al.*, PRD 91, 114503 (2015)

BINDING ENERGY OF THE *J/Ψ* - NUCLEON POTENTIAL

The nature of the gluonic Van der Waals force

- Force between color neutral *J/ψ* and nucleon purely gluonic
- Binding energy $B_{\psi p}$ can be derived from s-wave scattering length $a_{\psi p}$ at threshold
  - $T_{\psi p} = 8\pi(M + M_\psi)a_{\psi p}$
  - Experimental access through *J/ψ* photo-production at threshold
  - Note: *link with trace anomaly*!
- Current estimates between 0.05-0.30fm (3-20MeV)
- Lattice QCD (at large pion mass): $B_{\psi p} < 40$ MeV

Need high-precision photo-production data near threshold