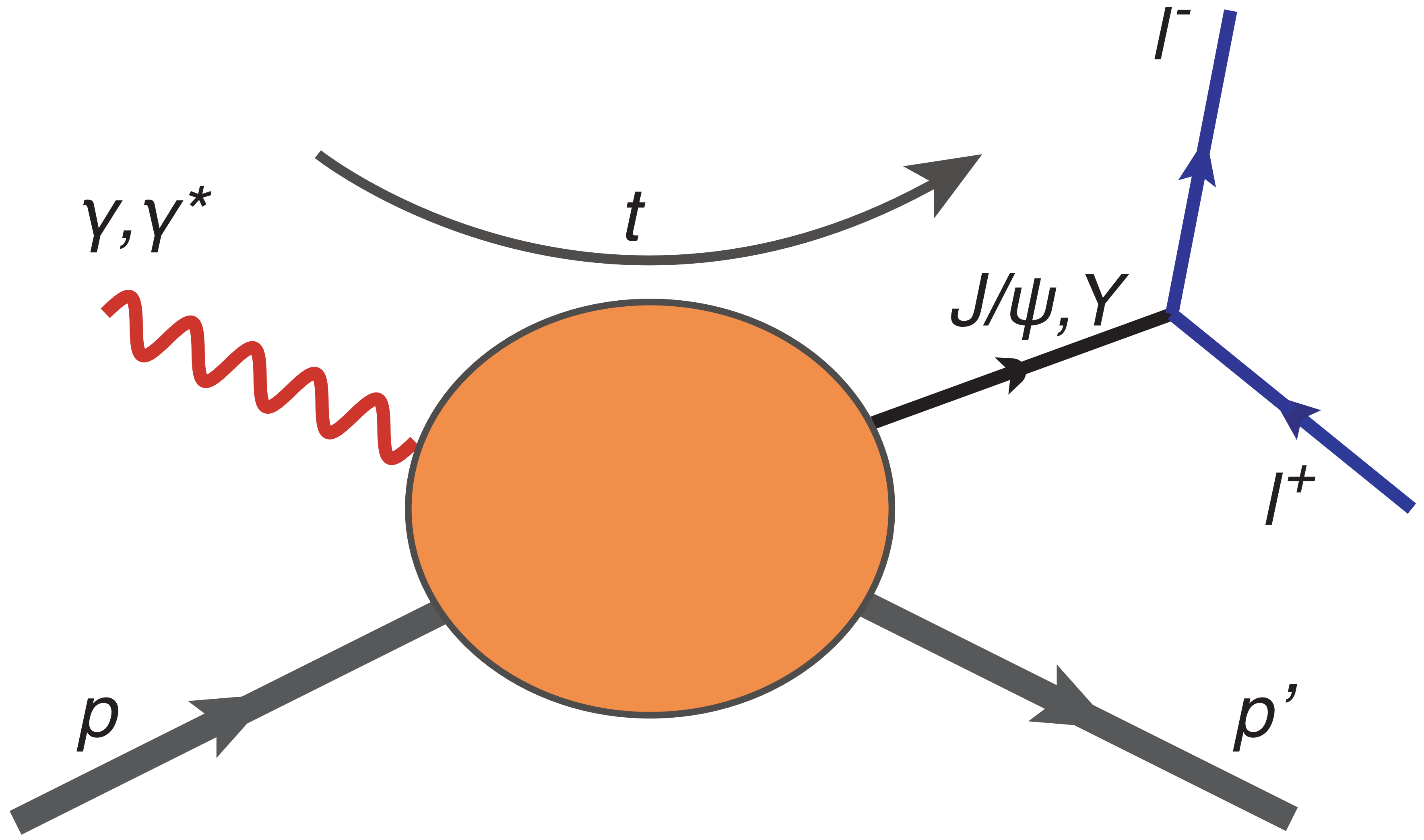
NEW RESULTS FROM HALL C
THE FUTURE SOLID PROGRAM AT JLAB

J/Ψ PRODUCTION AT THRESHOLD



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On behalf of the J/ψ-007 and SoLID-J/ψ collaborations.

U.S. DEPARTMENT OF ENERGY

Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.

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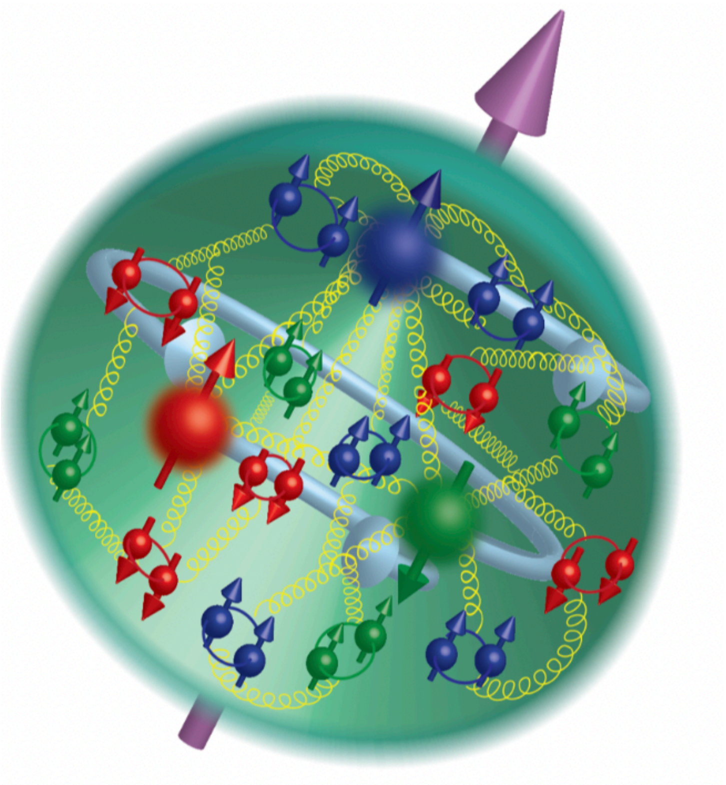
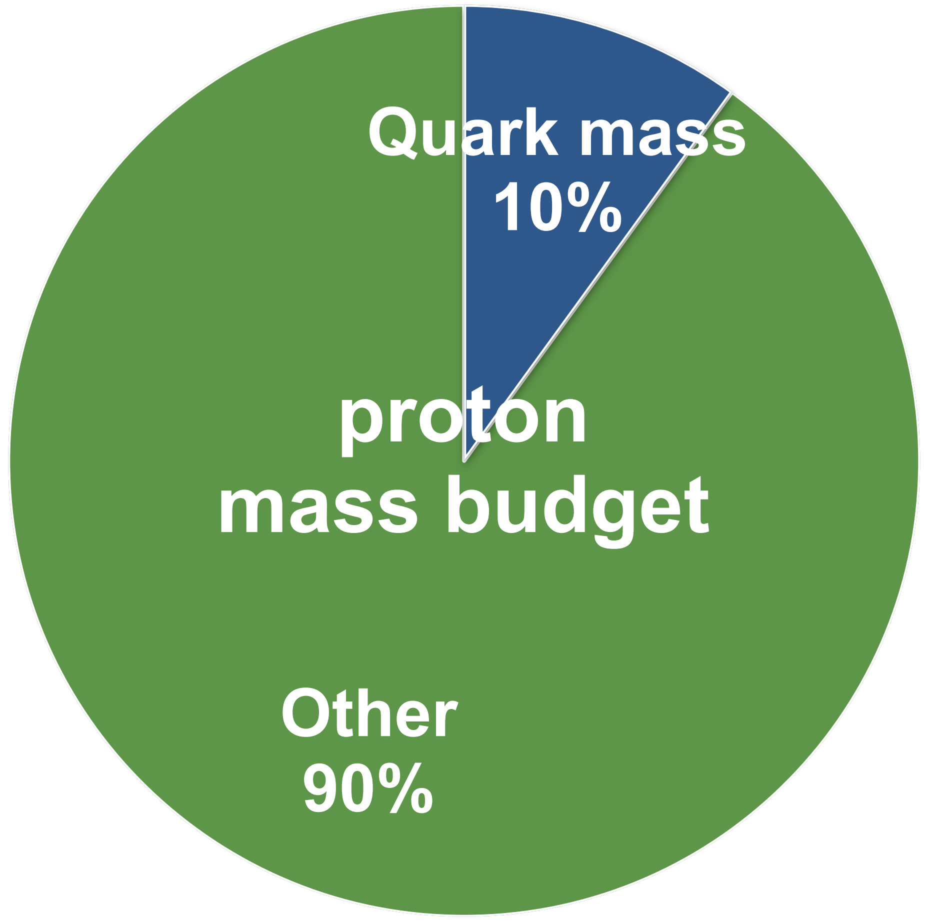
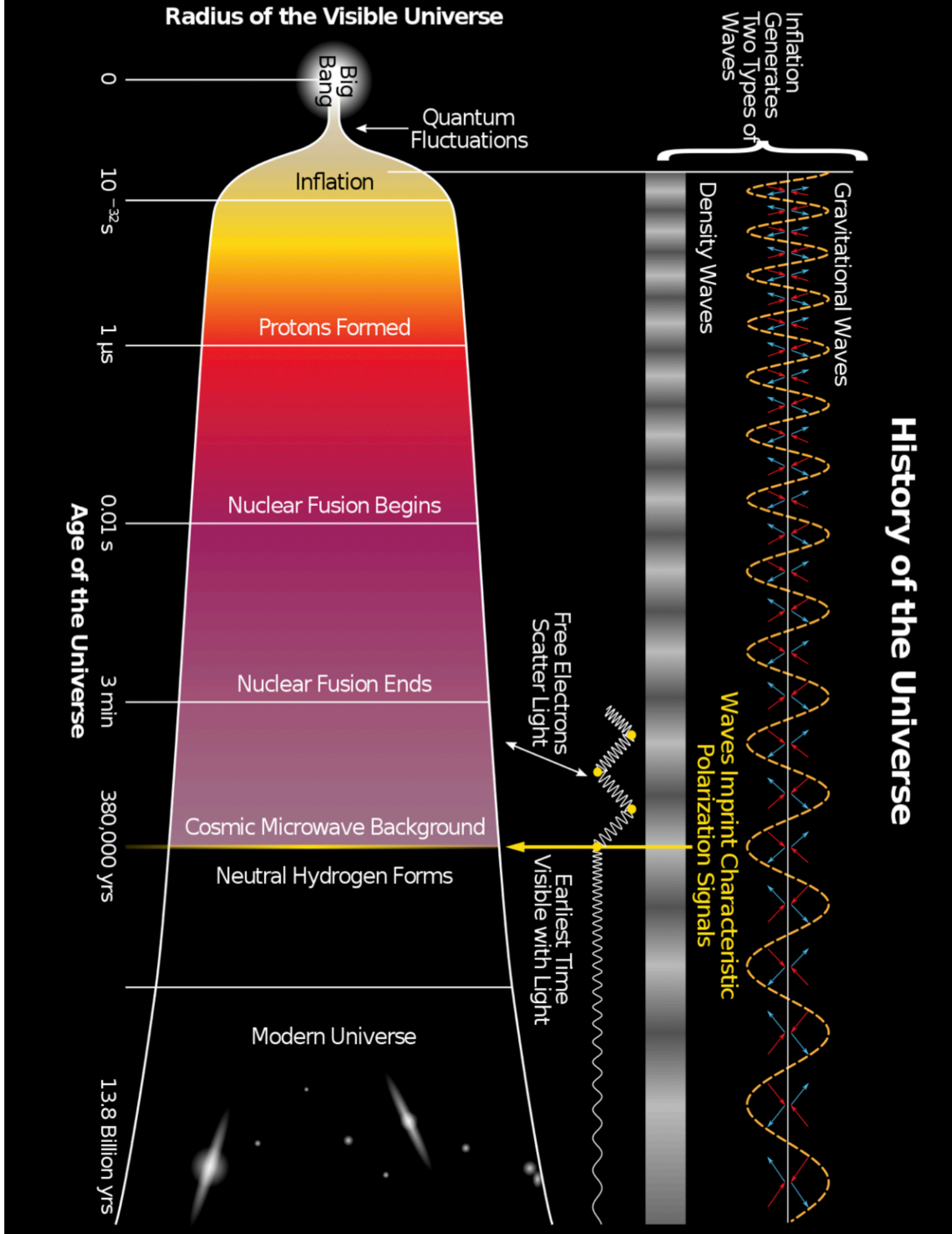
CIPANP
September 3, 2022

The emergence of nucleon mass
QCD IN THE STANDARD MODEL



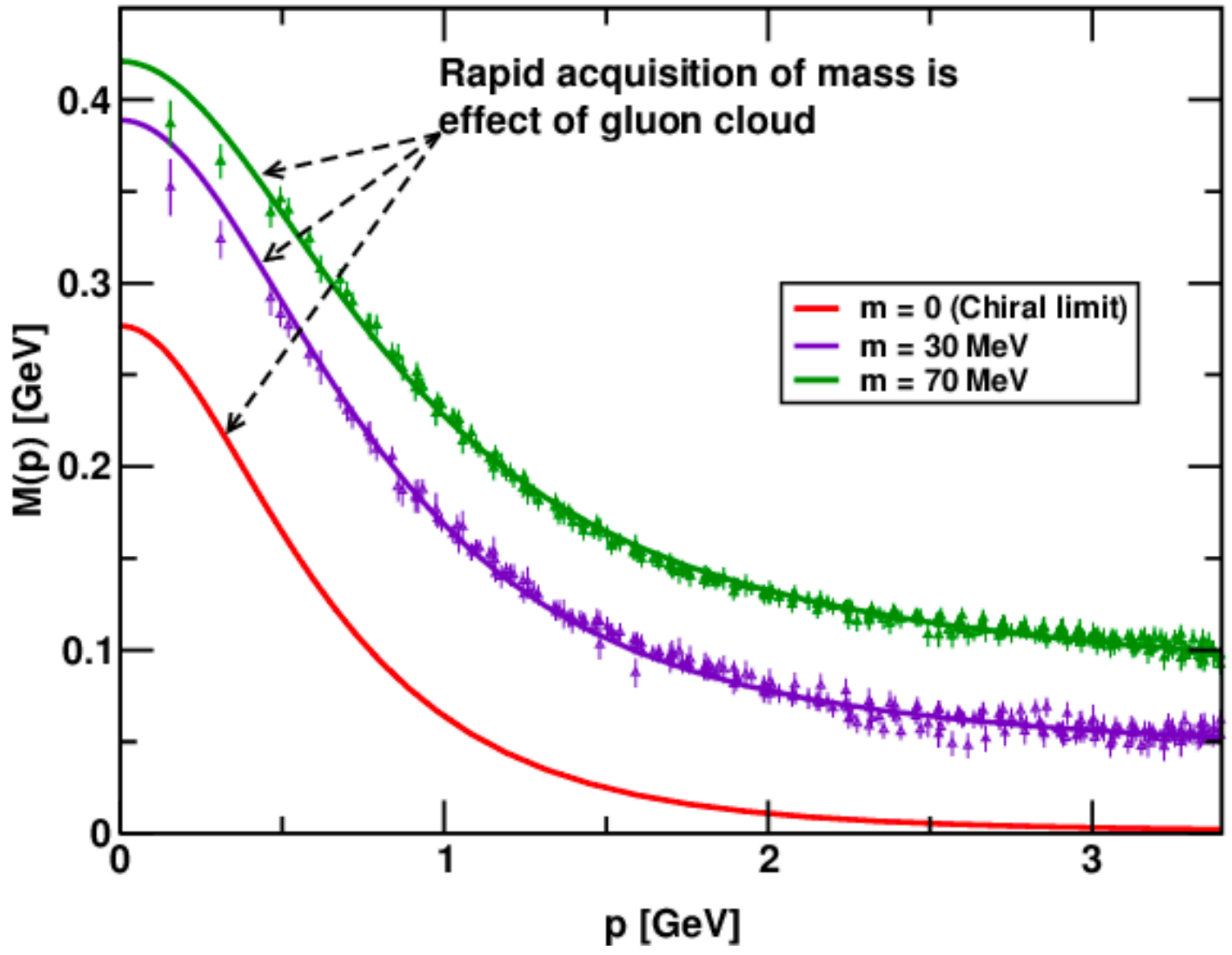


- Since the formation of protons and neutrons, most of the mass of the visible universe encapsulated in protons, neutrons, and nuclei.
- Surprising: nucleon mass much larger than sum of quark masses.
- *How does QCD give rise to the 1GeV proton?*
- *How is the proton mass distributed in its confinement size?*



NUCLEON MASS IS AN EMERGENT PHENOMENON

QCD responsible for the proton mass



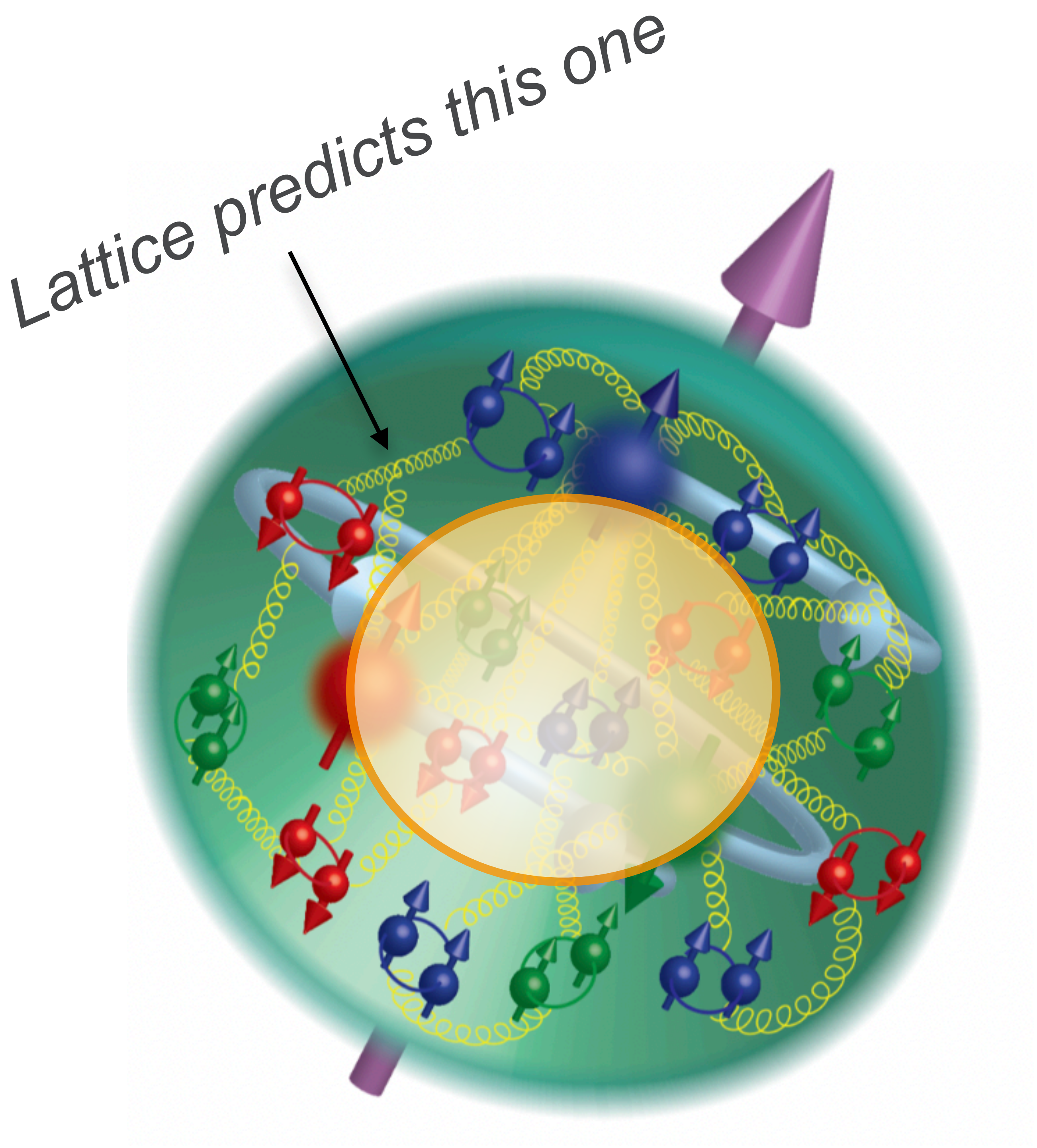
M. S. Bhagwat et al., Phys. Rev. C 68, 015203 (2003)
I. C. Cloet et al., Prog. Part. Nucl. Phys. 77, 1-69 (2014)

- In the proton rest frame, low momentum gluons attach to the current quarks (DCSB, demonstrated by many calculations and on the lattice)
- Each constituent quark accumulates ~300 MeV by "eating" these low momentum gluons.
- Even in when we assume quarks to be massless!
- **Mass from nothing? - No, mass from energy!**

Bottom line: The Higgs mechanism is largely irrelevant for most of "normal" visible matter!

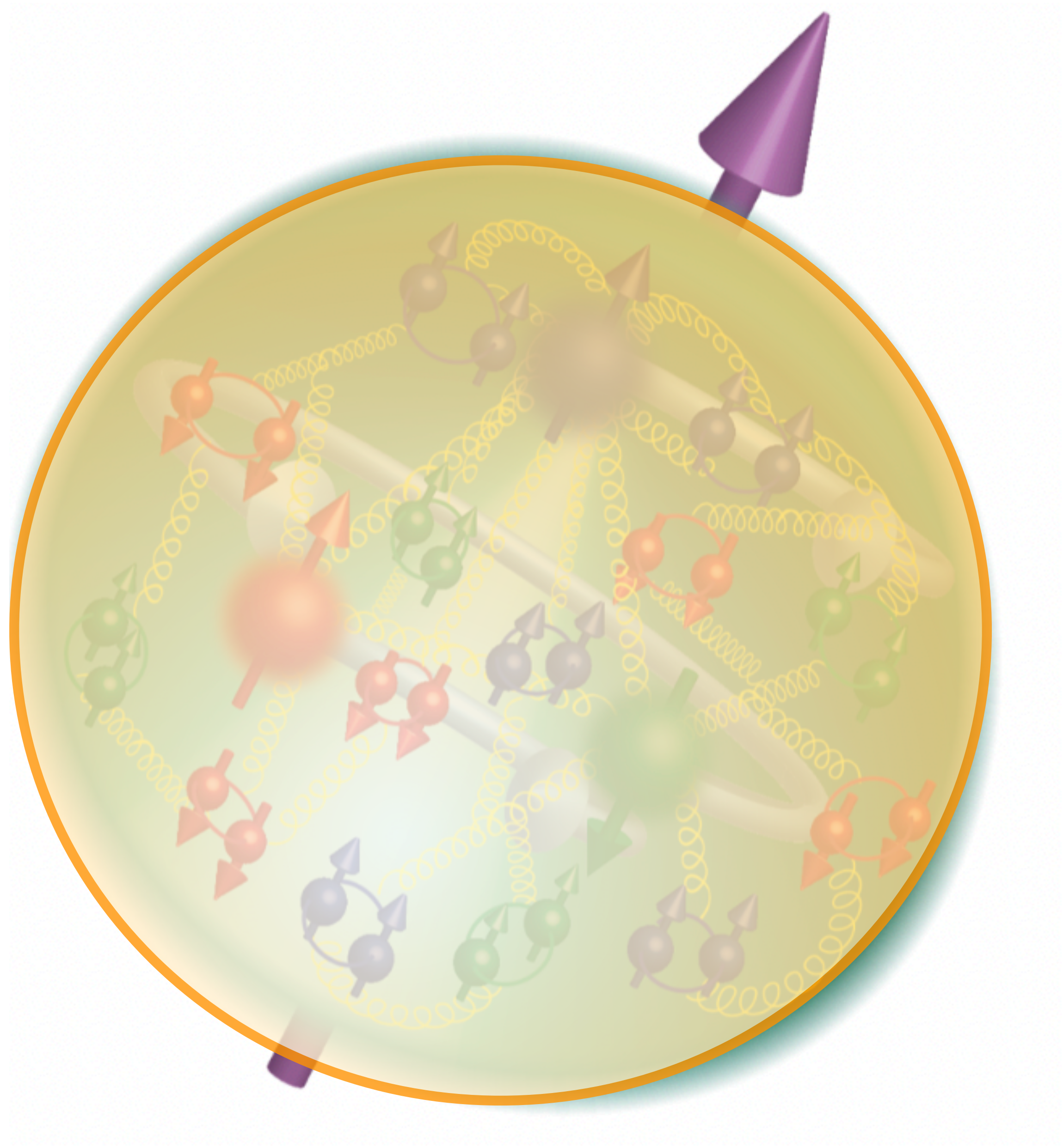
WHERE IS THE ENERGY INSIDE THE PROTON?

How does the mass radius compare to the charge radius?



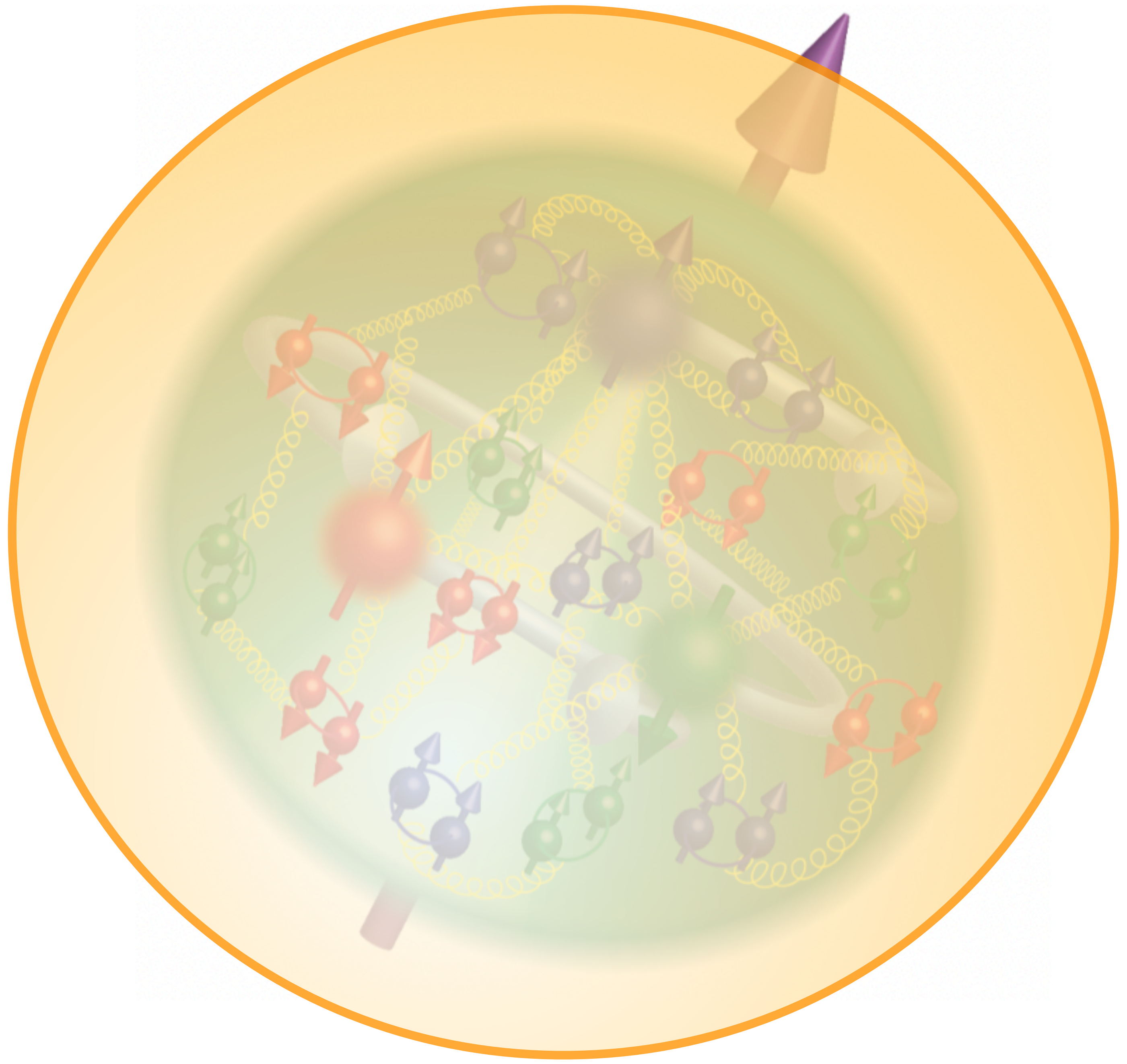
Dense energetic core?

Vs



Same as charge radius?

Vs



Energy halo beyond charge radius?

GRAVITATIONAL FORM FACTORS (GFFS)

Towards observables of the matter structure of the proton

GFFs are the form factors of the QCD energy-momentum tensor (EMT) for quarks and gluons

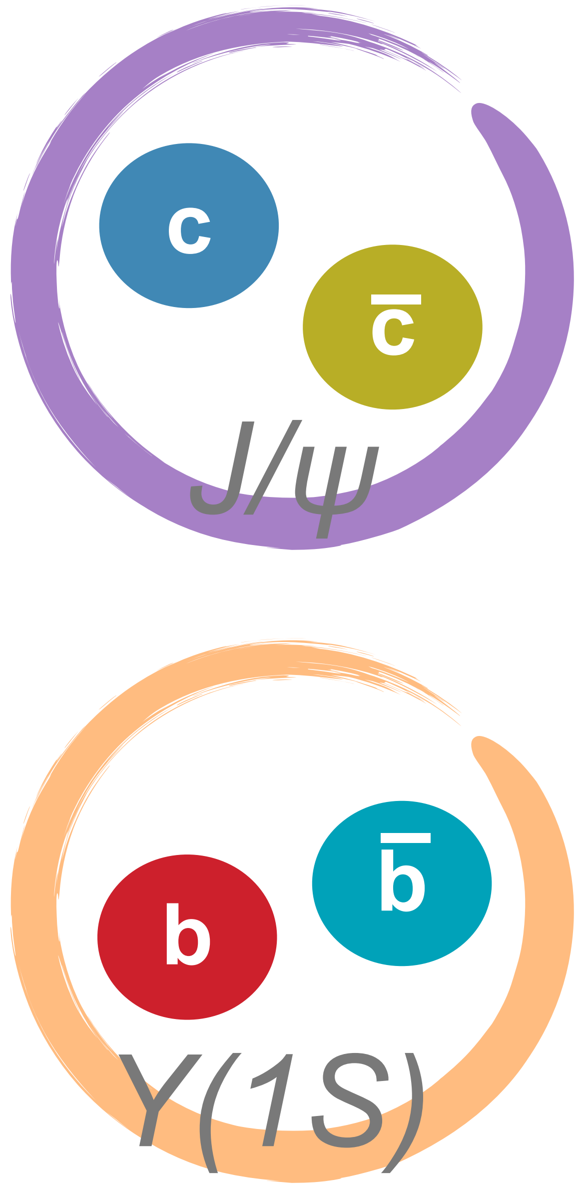
$$\langle N' \mid T^{\mu,\nu}_{q,g} \mid N \rangle = \bar{u}(N') \left(A_{g,q}(t) \gamma^{\{\mu} P^{\nu\}} + B_{g,q}(t) \frac{i P^{\{\mu} \sigma^{\nu\}\rho} \Delta_\rho}{2M} + C_{g,q}(t) \frac{\Delta^\mu \Delta^\nu - g^{\mu\nu} \Delta^2}{M} + \bar{C}_{g,q}(t) M g^{\mu\nu} \right) u(N)$$

EMT physics encoded in these GFFs:

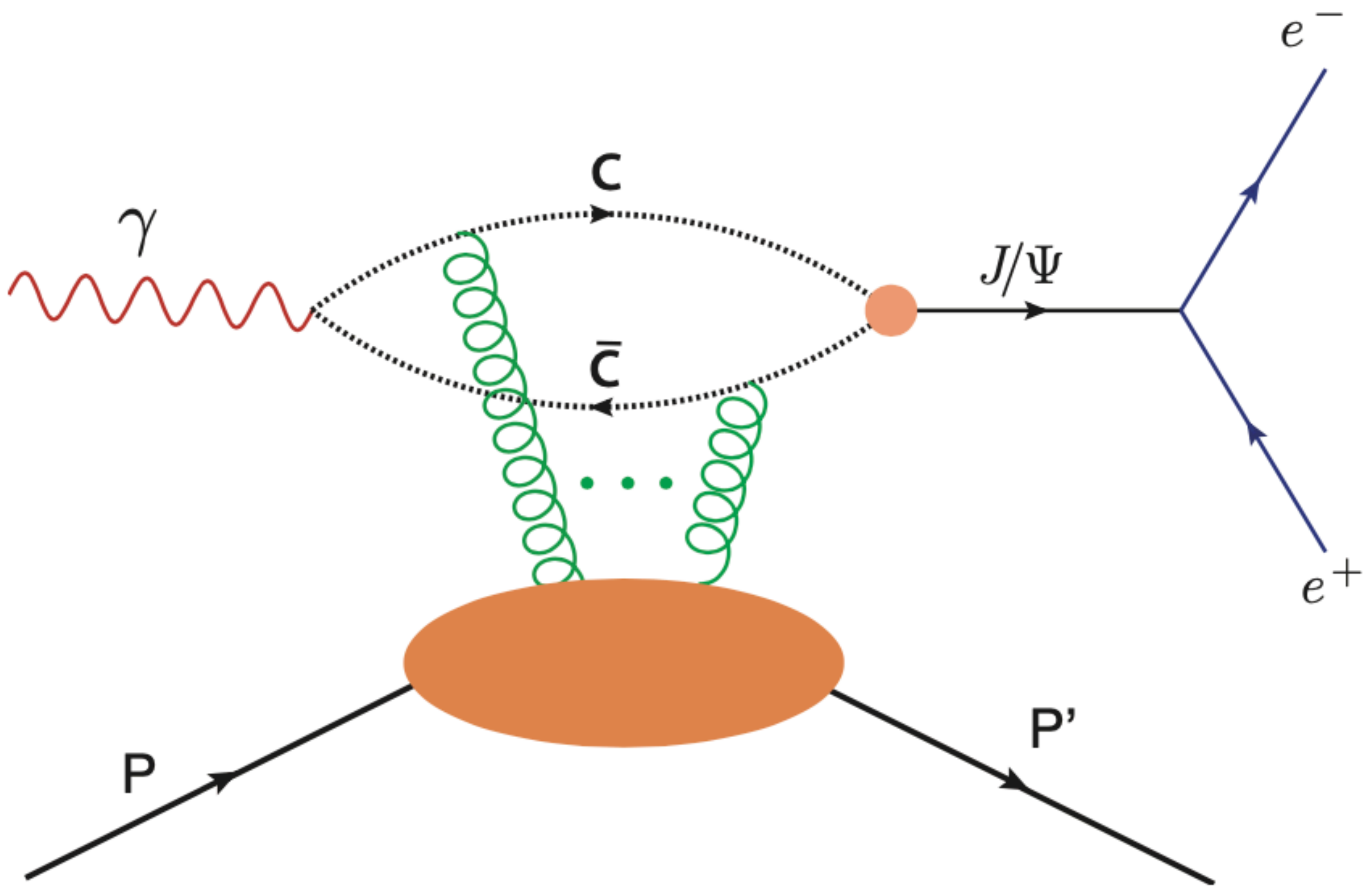
- $A_{g,q}(t)$: Related to quark and gluon momenta, $A_{g,q}(0) = \langle x_{q,g} \rangle$
- $J_{g,q}(t) = 1/2 \left(A_{g,q}(t) + B_{g,q}(t) \right)$: Related to angular momentum, $J_{\text{tot}}(0) = 1/2$
- $D_{g,q}(t) = 4C_{g,q}(t)$: Related to pressure and shear forces

PROBING THE GLUONS

Exclusive quarkonium production near the threshold

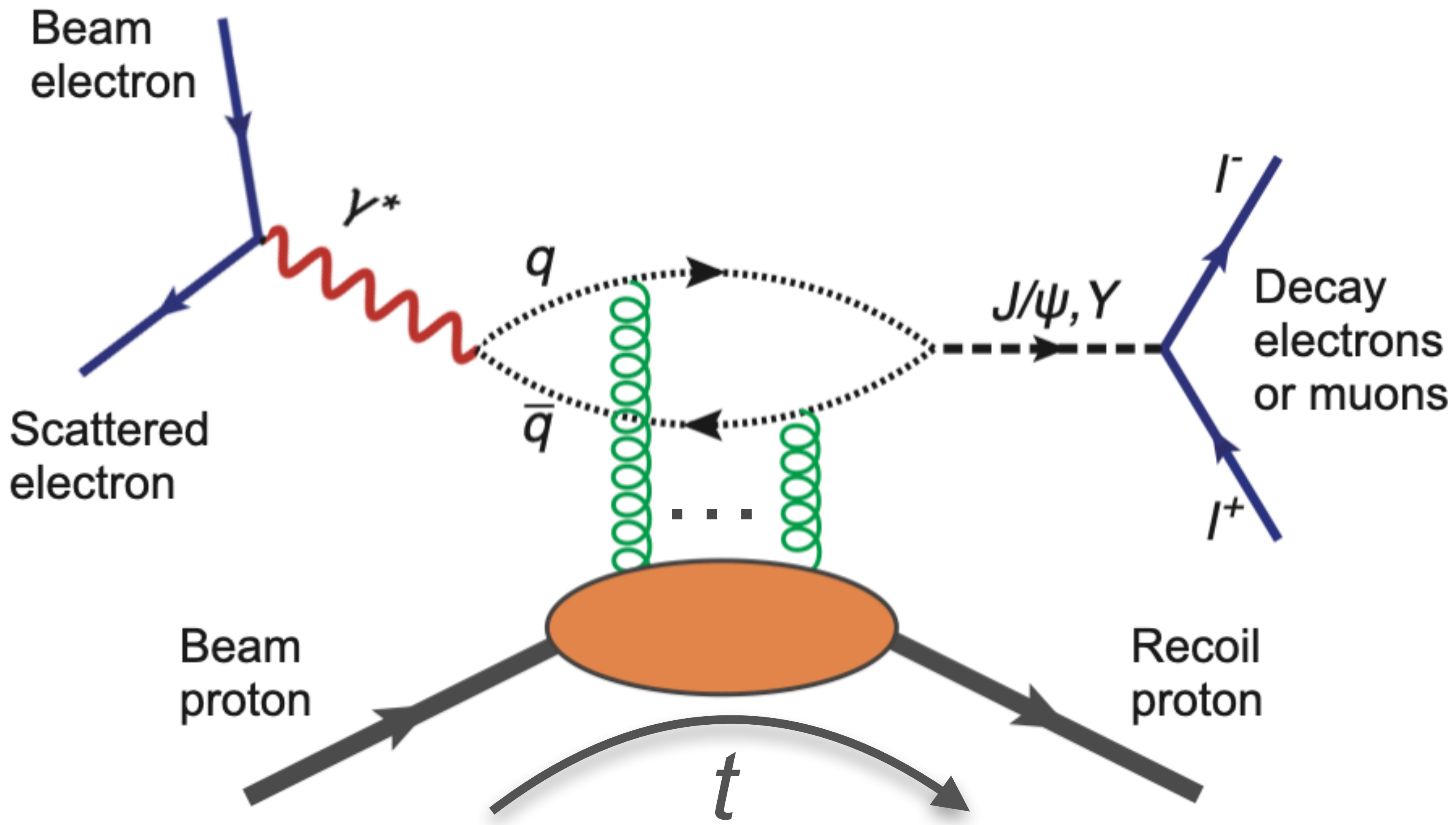


- Electromagnetic charge and spin of the proton well-studied through electron scattering
- Electromagnetic neutral gluons harder to access directly
  - Quarkonium uniquely sensitive to gluons: they do not couple to light quarks
  - Differential cross section of quarkonium near threshold promising channel to directly probe gluons
  - Sufficient data at different photon energies can constrain the GFF slopes and magnitudes in the forward limit (t=0)
  - **Access the matter distribution, mass radius, and potentially the trace anomaly of the EMT.**



EXCLUSIVE QUARKONIUM PRODUCTION

The basics



J/ψ threshold:

$W \approx 4.04\text{GeV}$

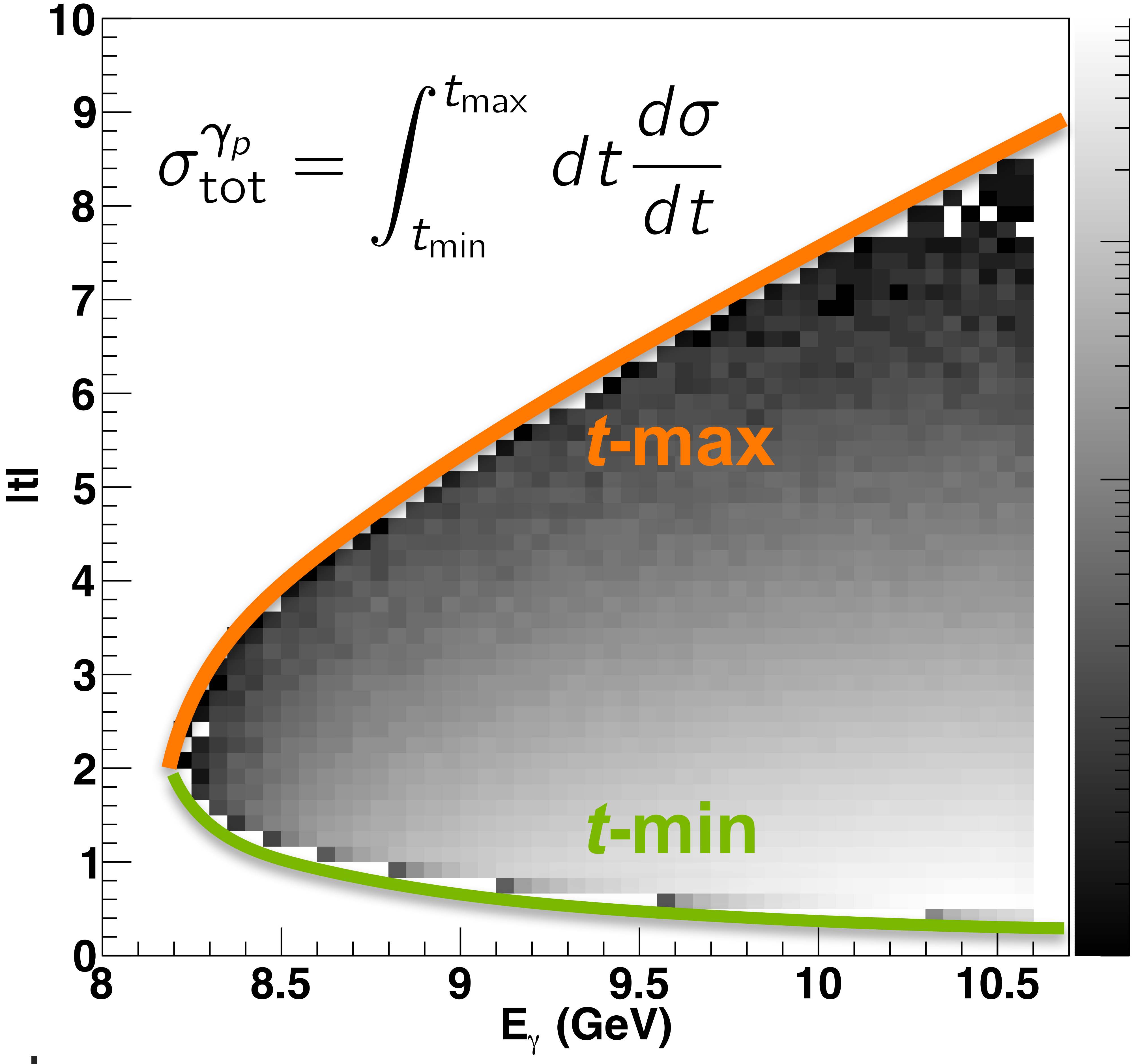
$E_\gamma^{\text{lab}} \approx 8.2\text{GeV}$

$t \approx -1.5\text{GeV}^2$

$\Upsilon(1S)$ threshold:

$W \approx 10.4\text{GeV}$

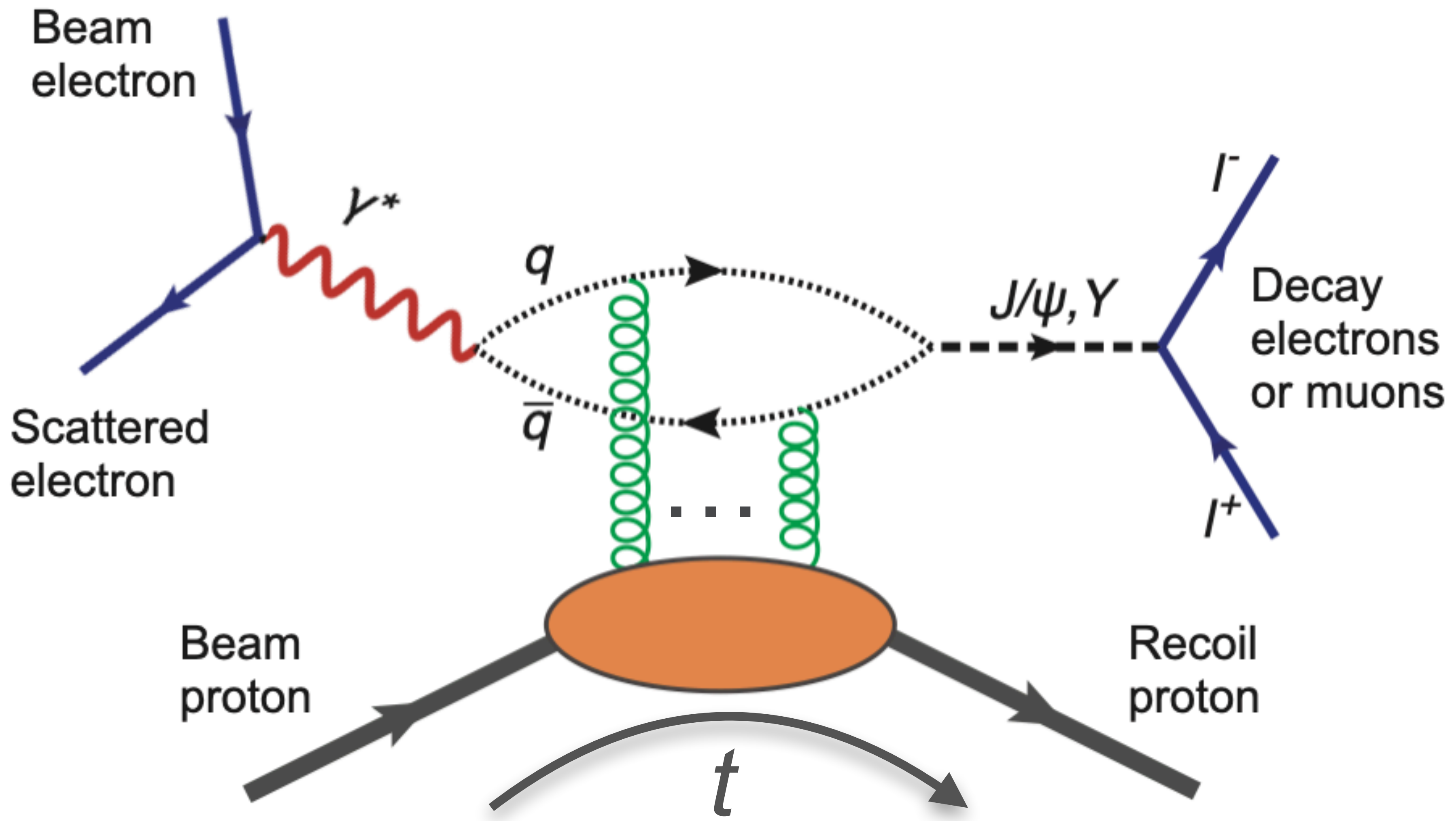
$t \approx -8.1\text{GeV}^2$

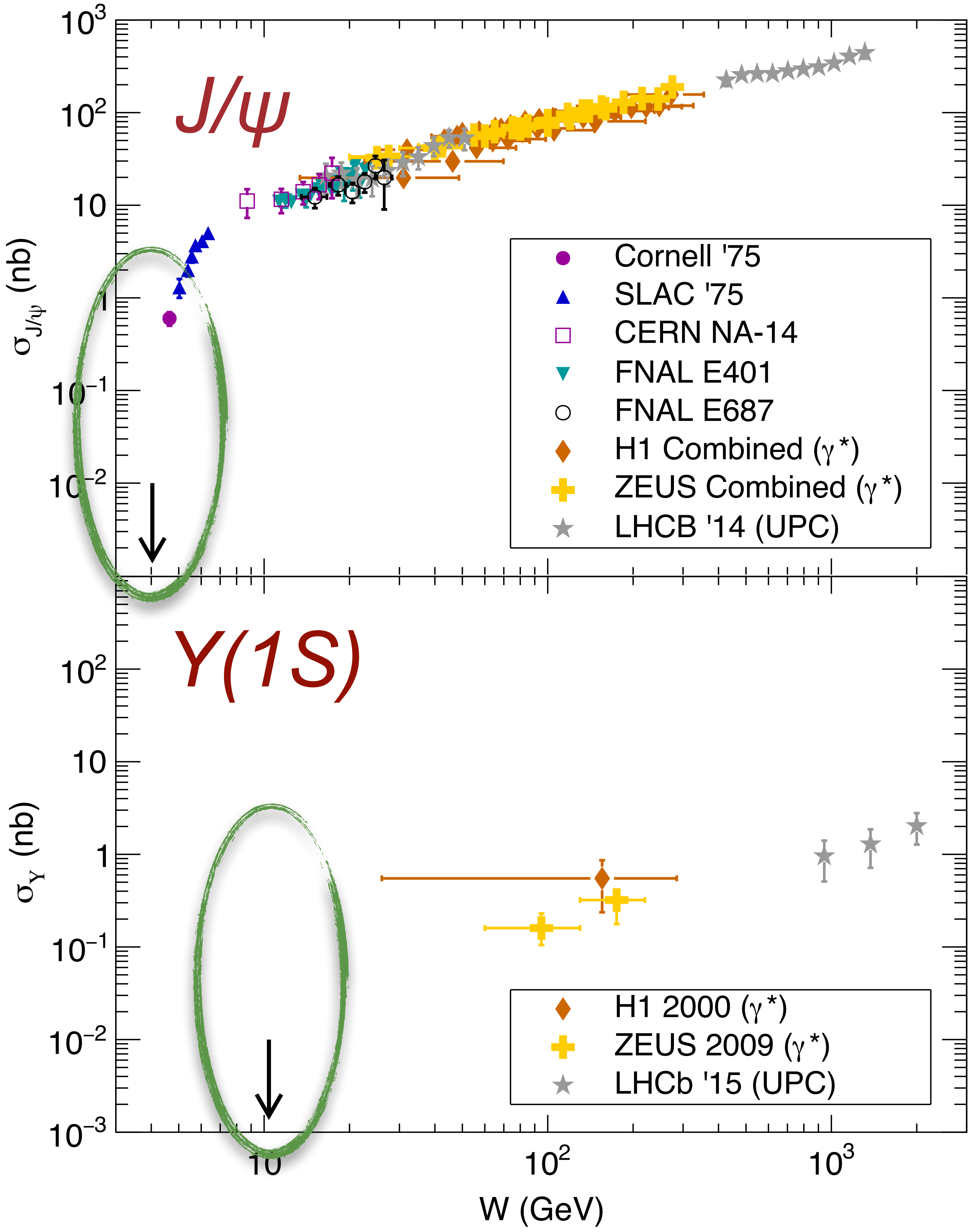


- Phase space limits defined by quarkonium direction
  - Forward (with photon): $t = t_{\min}$
  - Backward (with proton): $t = t_{\max}$
- Forward direction preferred: t-dependence ~exponential

EXCLUSIVE QUARKONIUM PRODUCTION

Before Jefferson Lab 12 GeV





- No near-threshold data available
- In case of Υ(1S): not much available overall
- **Almost no data near threshold before JLab 12 GeV**

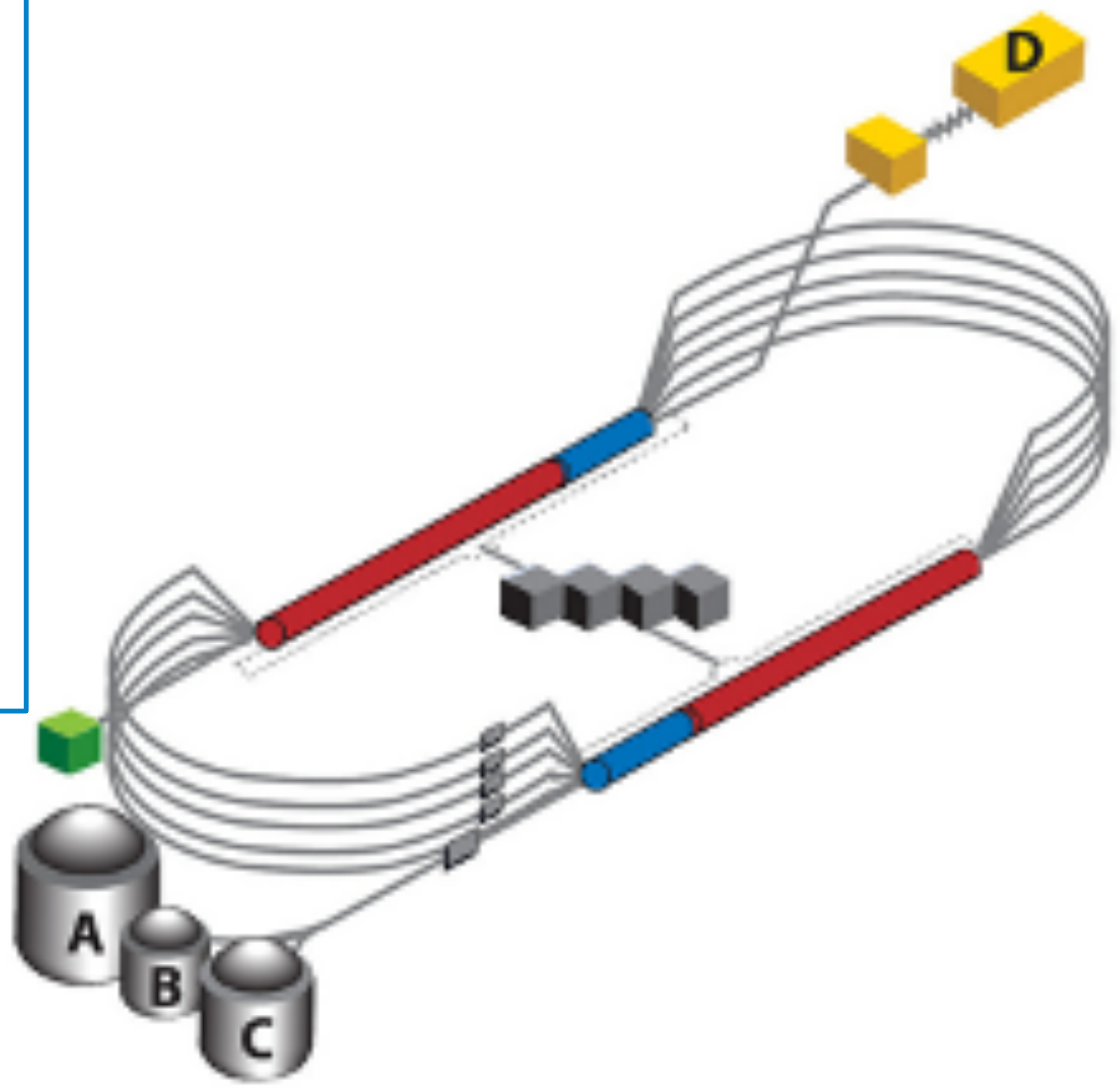
QUARKONIUM AT JEFFERSON LAB AND EIC

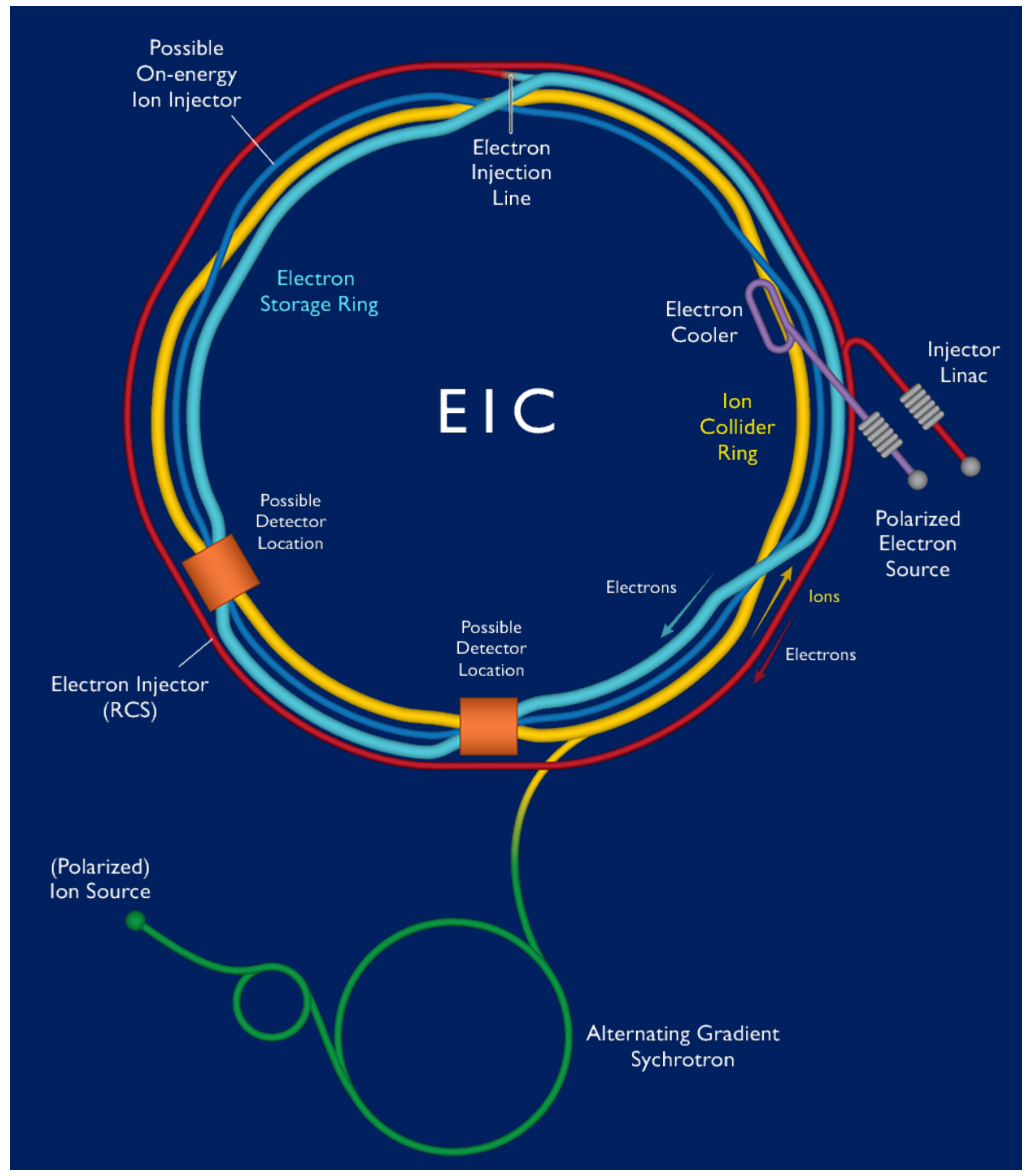
Jefferson Lab

CEBAF: very high luminosity (10^{35}-10^{39} $cm^{-2}s^{-1}$) continuous electron beam on fixed target

4 experimental halls:
- 11GeV in Hall A, B &C
- 12GeV in Hall D

Jefferson Lab is the ideal laboratory to measure J/ψ near threshold,
due to luminosity, resolution and energy reach





Electron-ion Collider

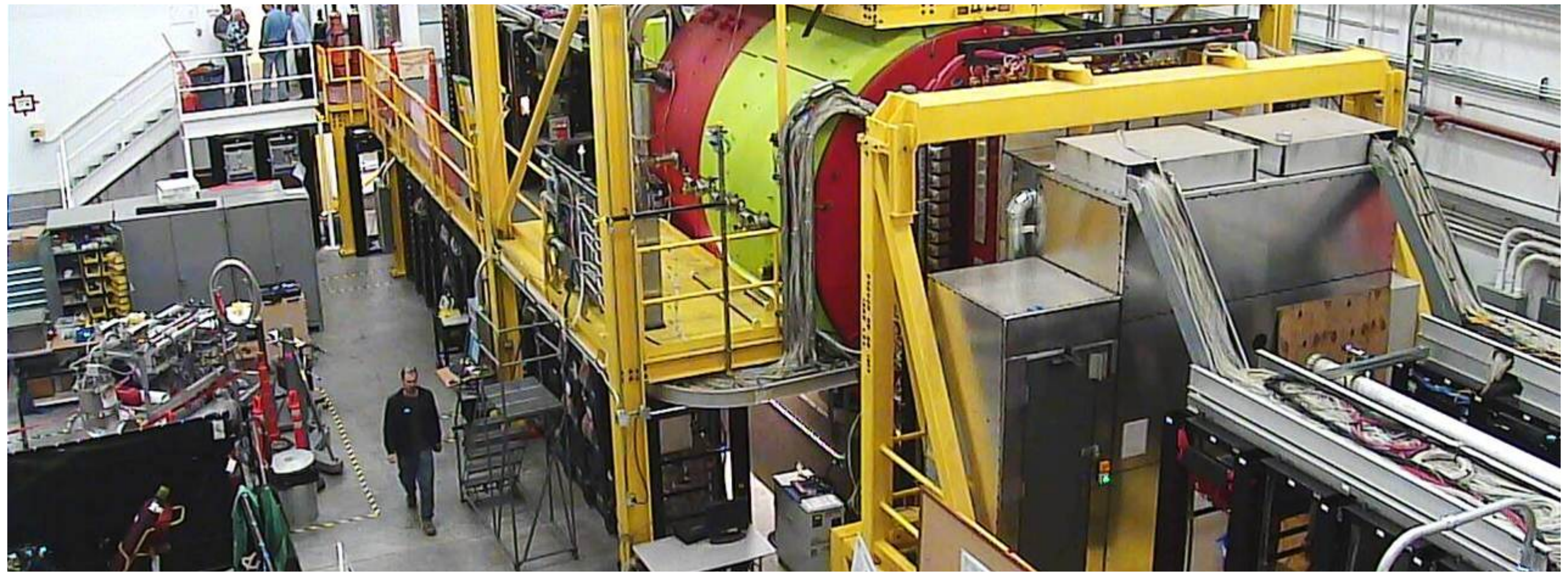
EIC: high luminosity (10^{33}-10^{34} $cm^{-2}s^{-1}$) polarized electron polarized ion collider

Variable CM energies: 29-140 GeV with 2 possible interactions regions

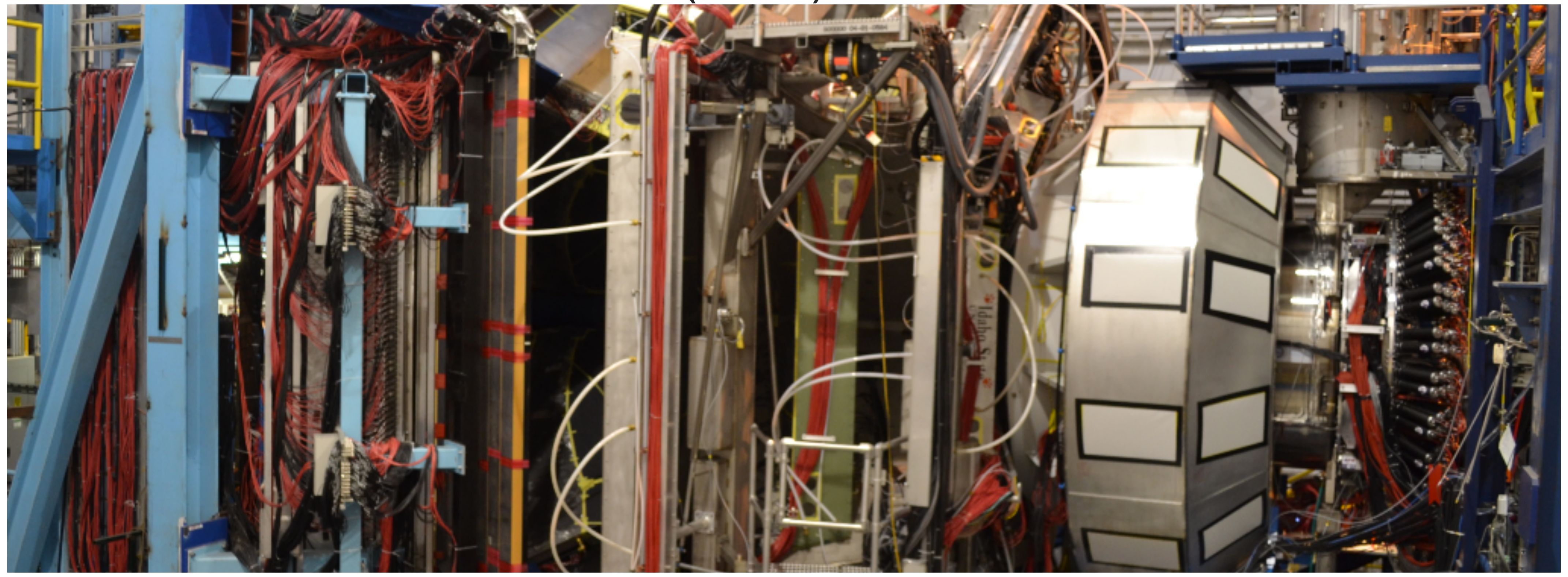
Reach to J/ψ threshold more difficult, sufficient energy and luminosity to study Y near threshold.

Complementary programs: Jefferson Lab is the ideal laboratory to measure J/ψ near threshold, and EIC has sufficient luminosity to measure Y near threshold

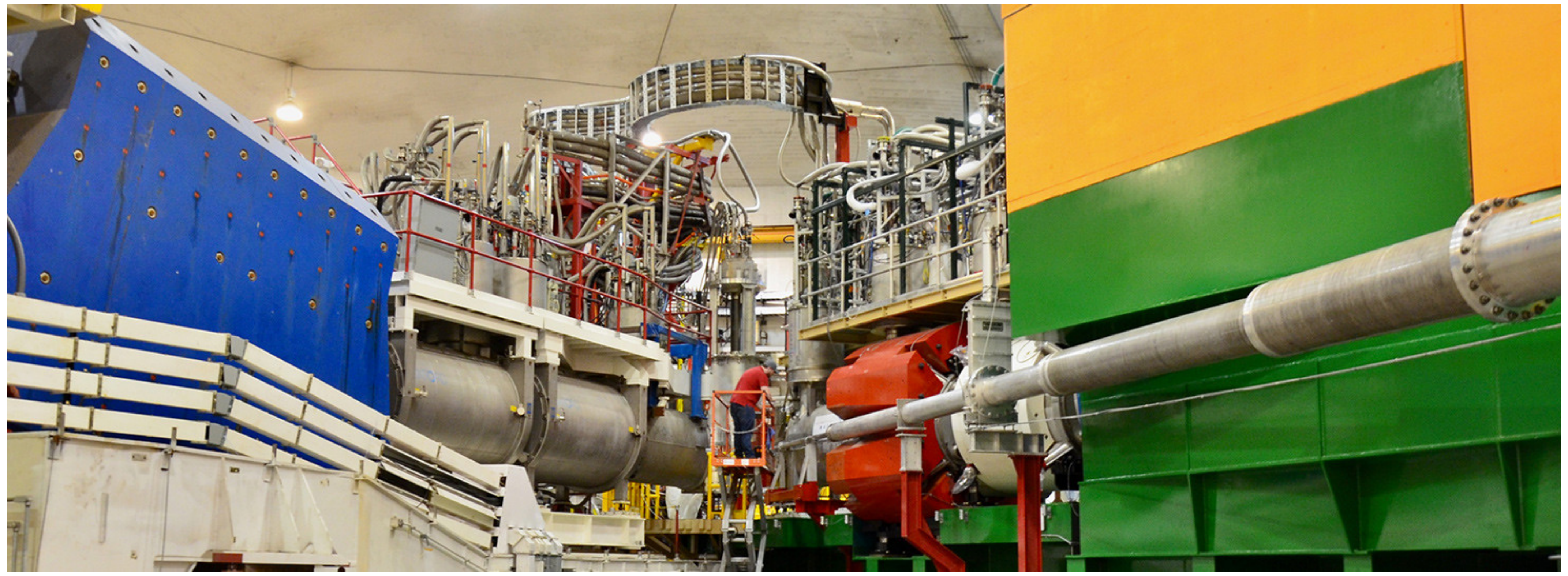
12 GEV J/Ψ EXPERIMENTS AT JEFFERSON LAB



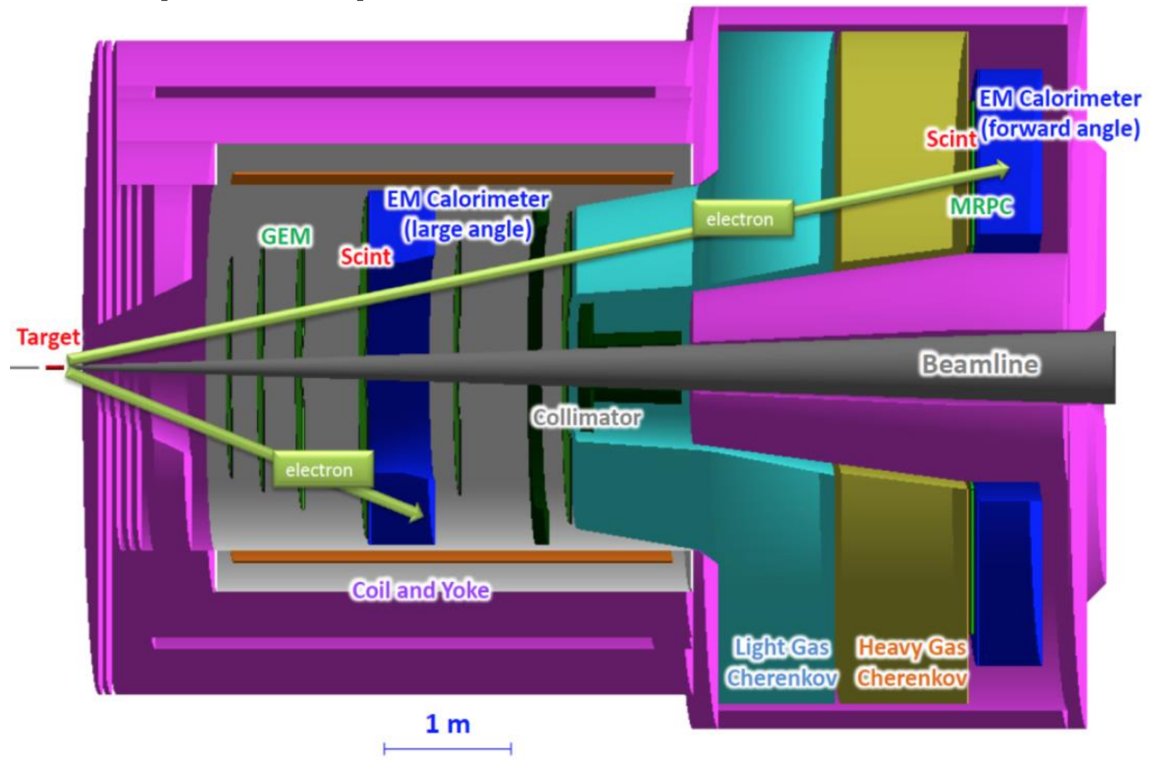
Hall D - GlueX observer the first J/ψ at JLab
A. Ali *et al.*, PRL 123, 072001 (2019)



Hall B - CLAS12 has experiments to measure TCS + J/ψ in photoproduction as part of Run Groups A (hydrogen) and B (deuterium): E12-12-001, E12-12-001A, E12-11-003B



Hall C has the **J/ψ-007** experiment (E12-16-007) to search for the LHCb hidden-charm pentaquark

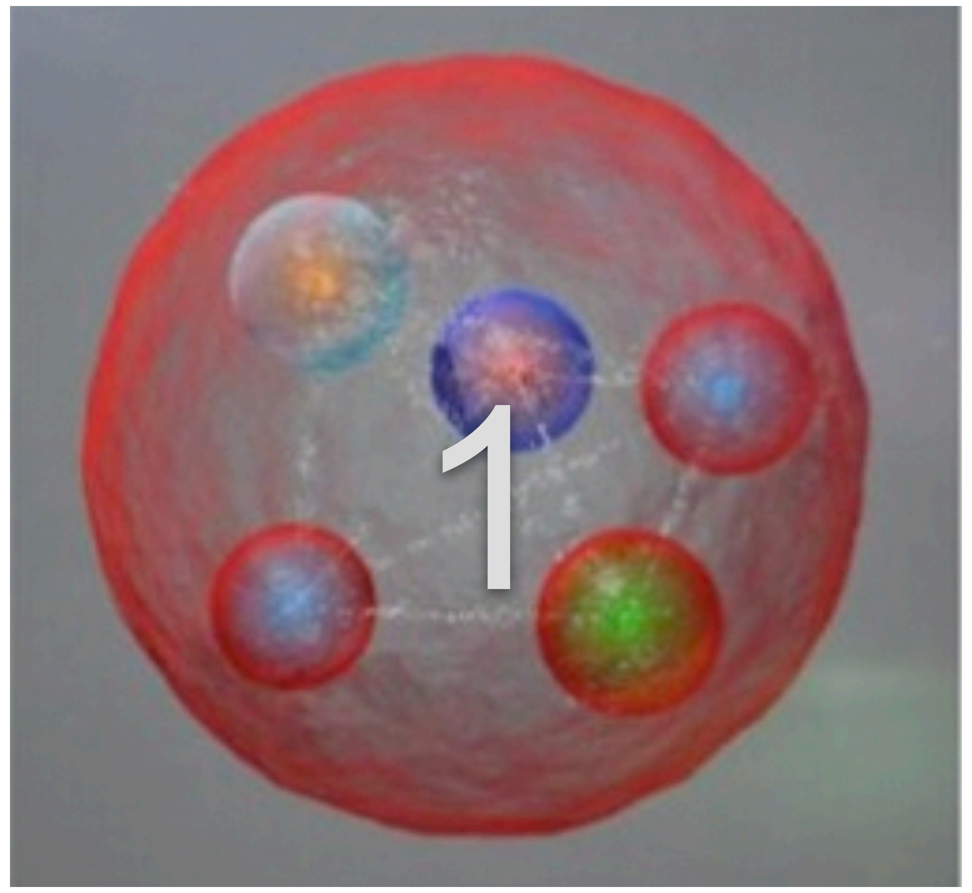


Hall A has experiment E12-12-006 at **SoLID** to measure J/ψ in electro- and photoproduction, and an LOI to measure double polarization using **SBS**

X-H Lui *et al.*, PLB 757, 231 (2016) and references therein
Q. Wang *et al.*, PRD 92-3 034022-7 (2015) and references therein

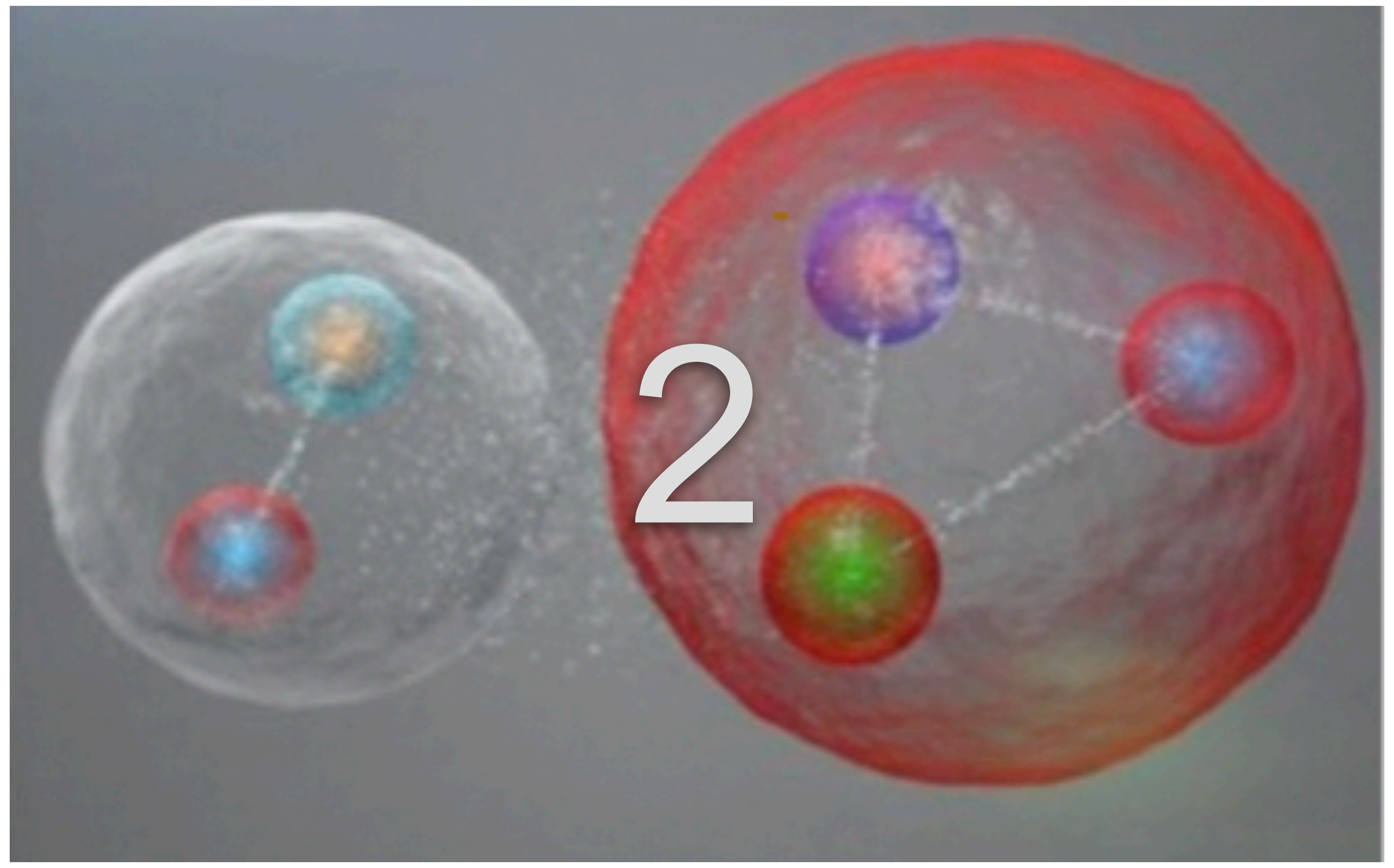
PENTAQUARKS IN PHOTOPRODUCTION?

Looking for pentaquarks at Jefferson Lab



What is the nature of the LHCb pentaquarks?

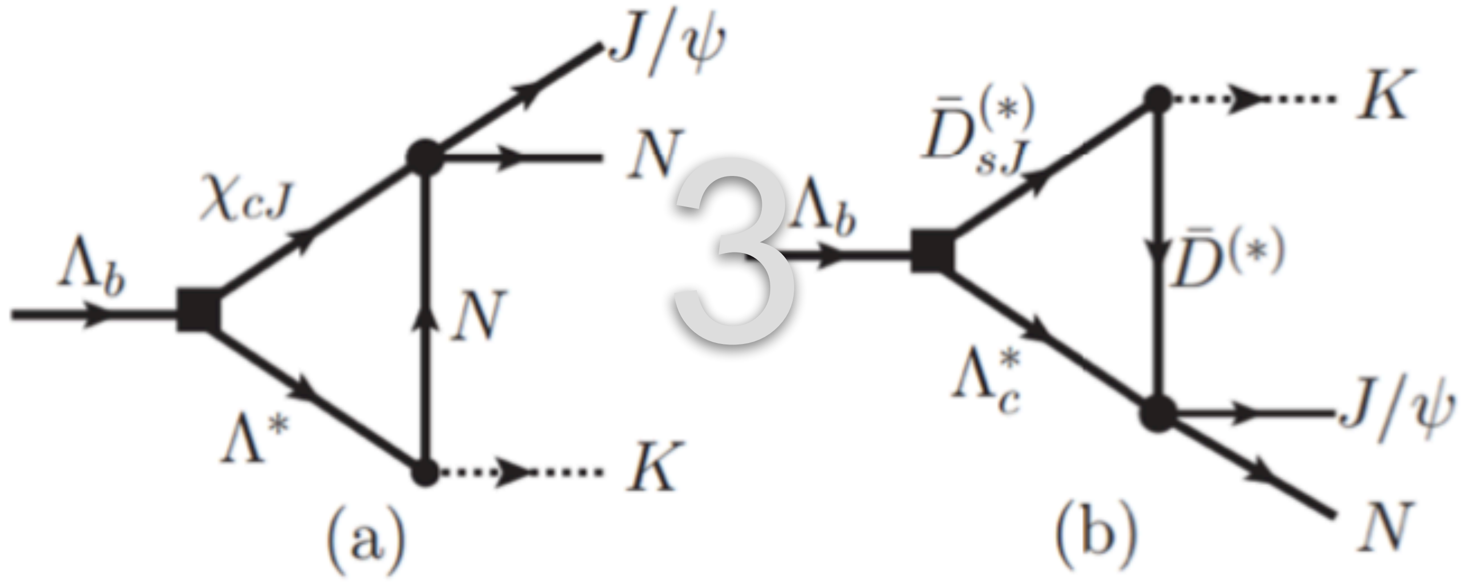
1. **"True" pentaquark state:** tightly bound 5-quark state
2. **"Molecular"** meson-baryon bound state
3. **Kinematic enhancement** through, eg., anomalous triangle singularities (ATS)



Photoproduction ideal channel to distinguish:

1. **"True" pentaquark:** strong s-channel resonance
2. **"Molecular"**: small s-channel resonance (less overlap with γp and J/ψp states)
3. **ATS** not a factor in photoproduction

Jefferson Lab the perfect place to search for P_c in photoproduction

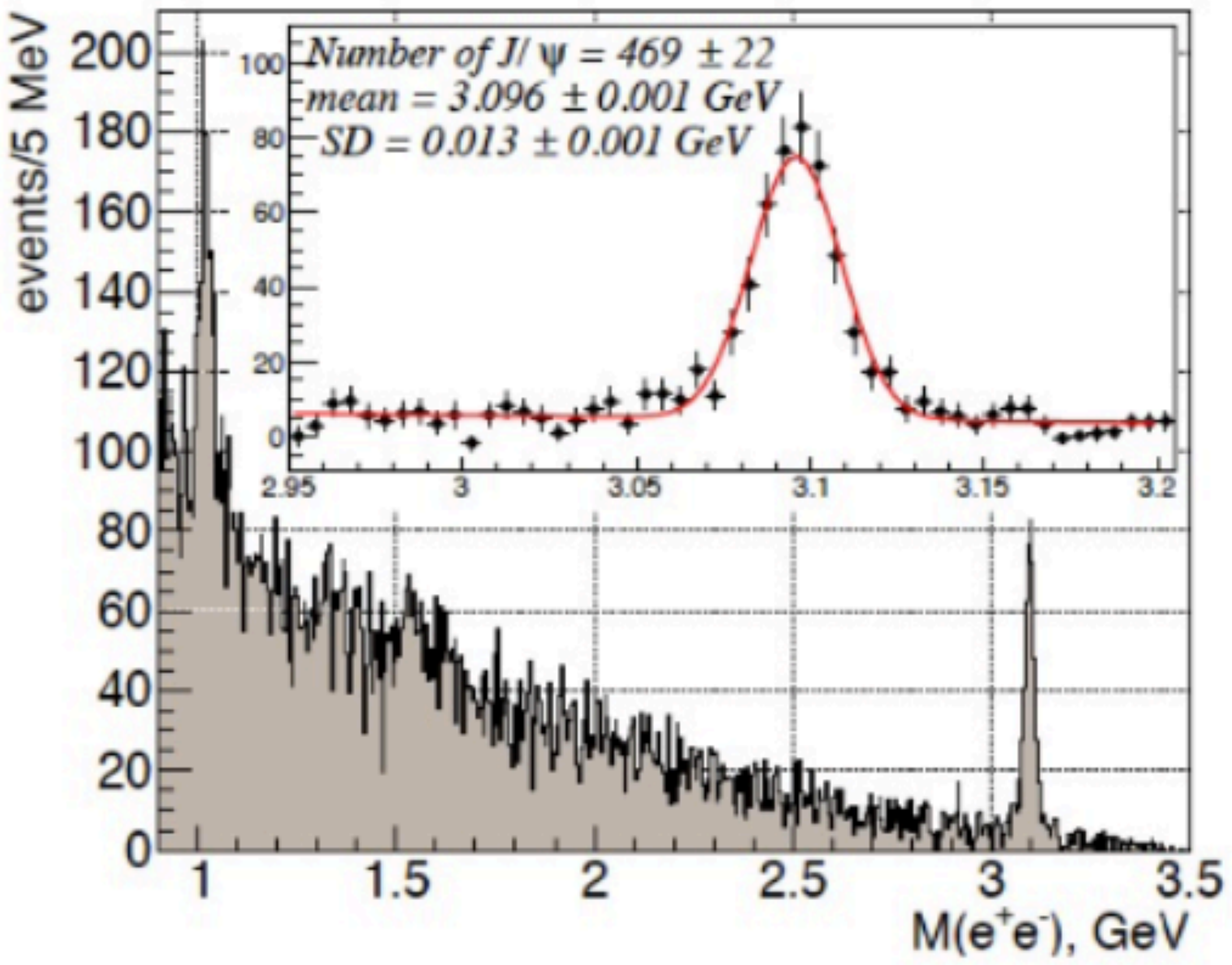


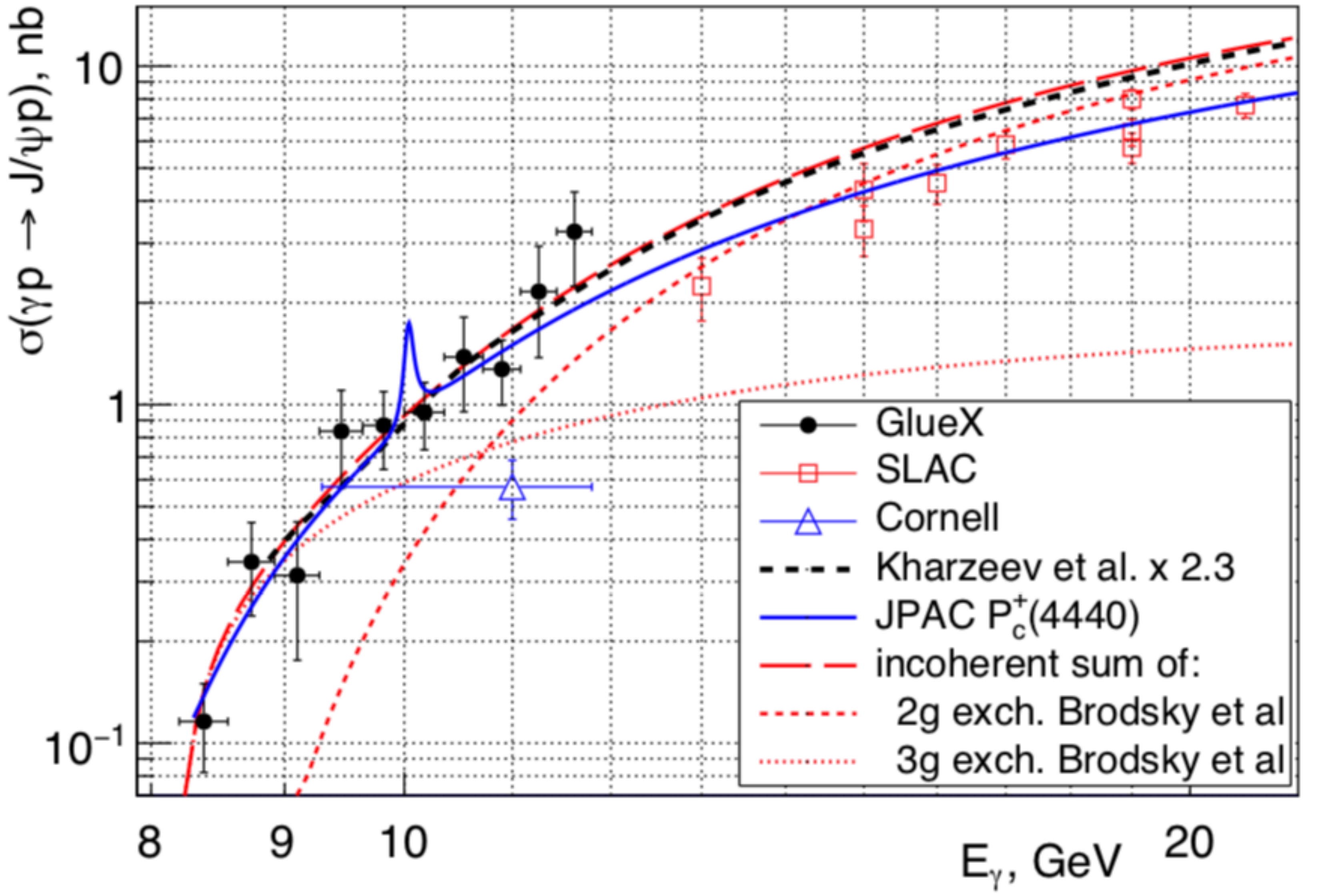
J/Ψ NEAR THRESHOLD IN HALL D

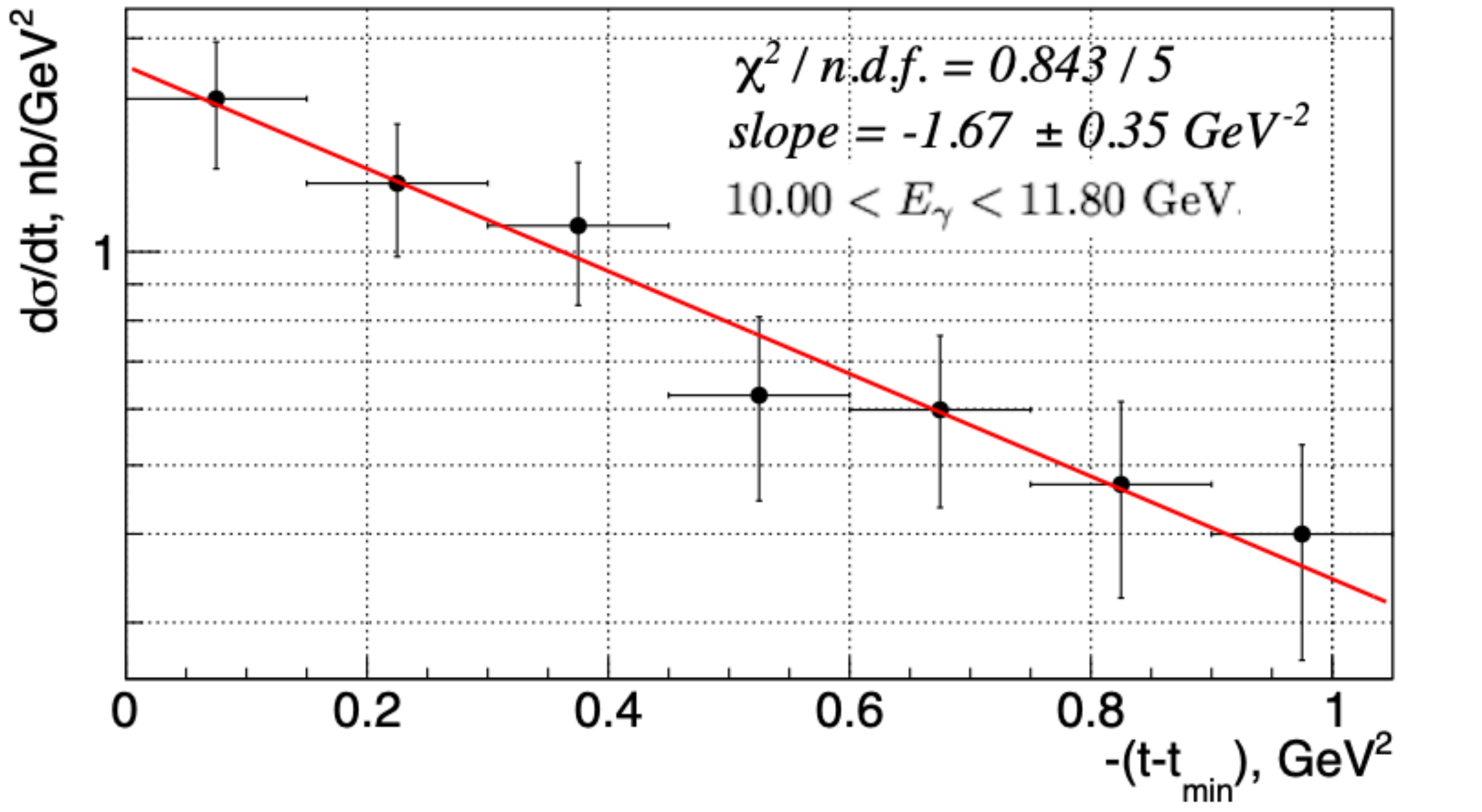
First J/ψ results from JLab, published in PRL 123, 072001 (2019)

- 1D cross section (~469 counts)
- Trends significantly higher than old measurements
- Single 1D t-profile spurred on many new theoretical calculations
- Did not see evidence for hidden-charm pentaquarks

$\gamma p \rightarrow p\, J/\psi \rightarrow p e^+ e^-$

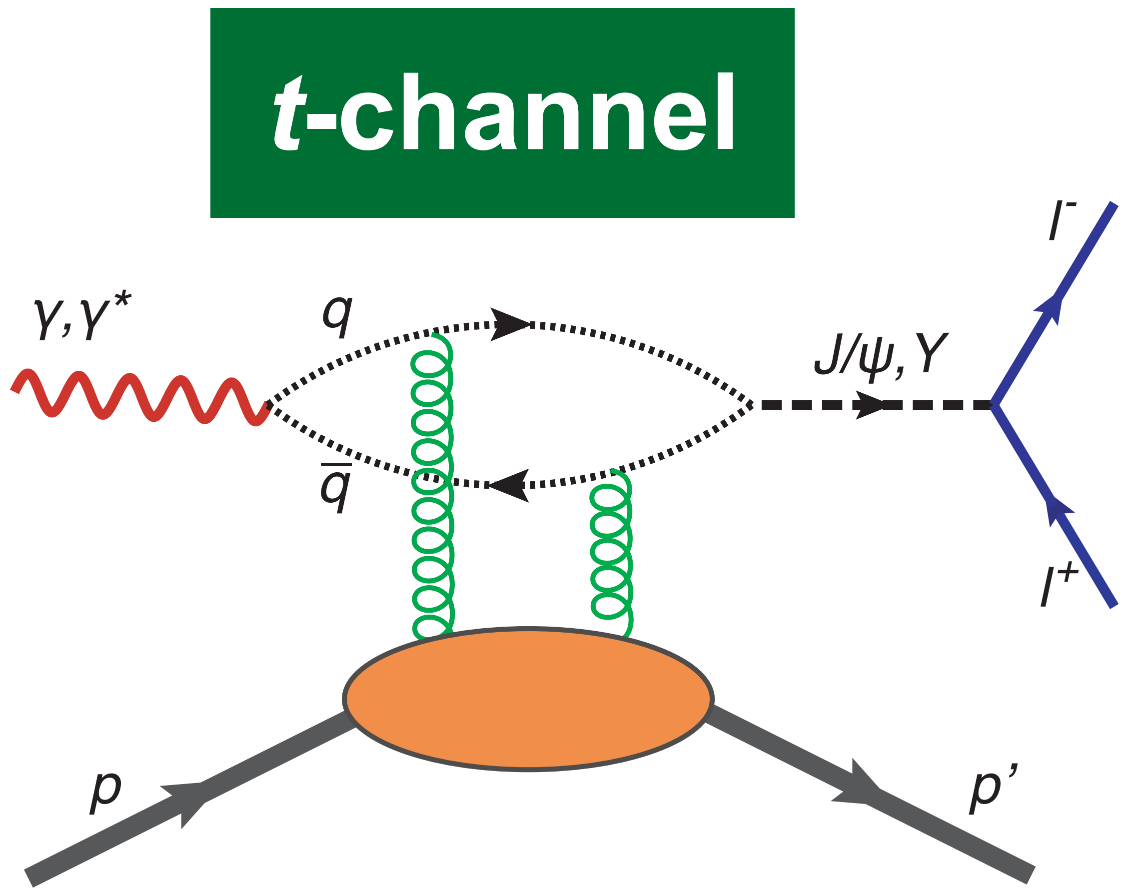


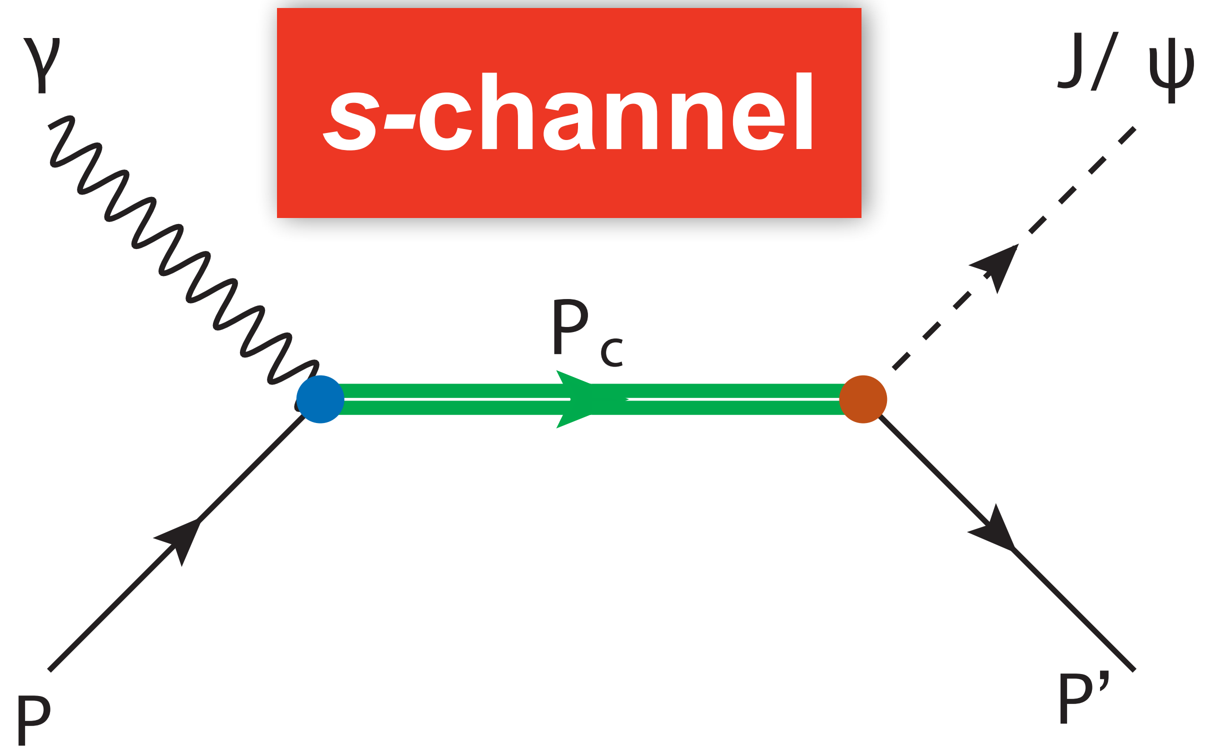


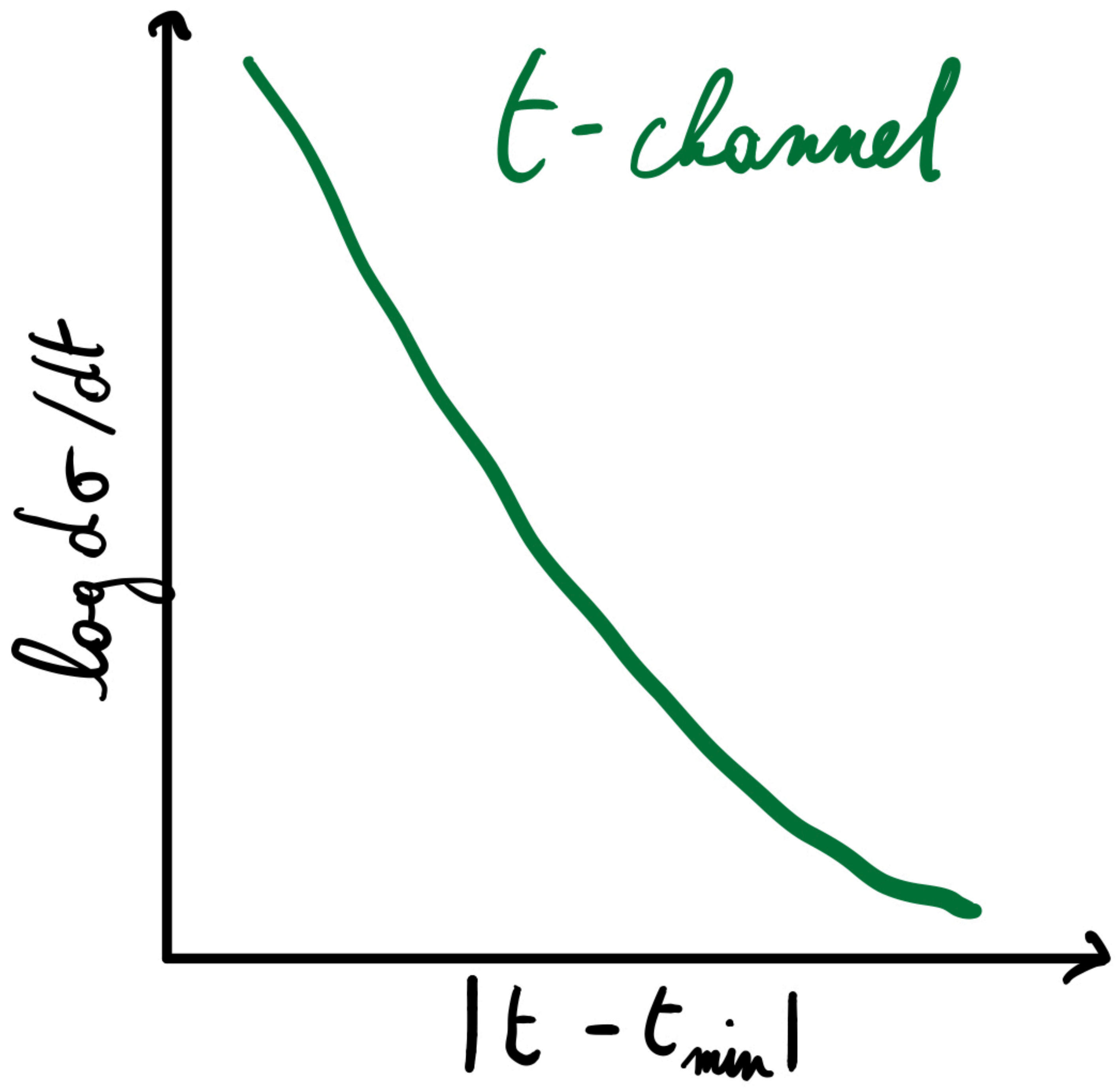


MAXIMIZING THE SENSITIVITY

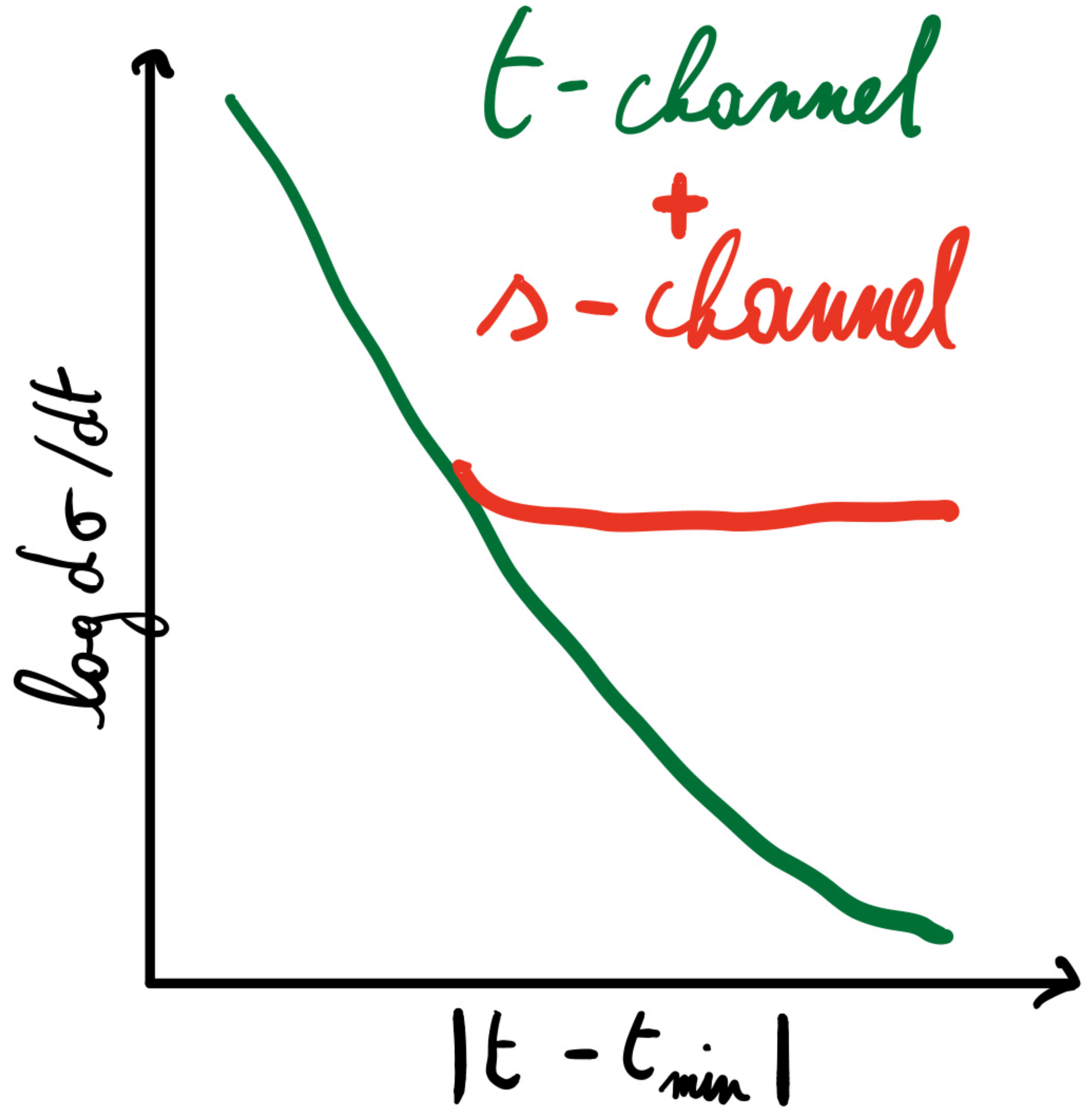
Maximum sensitivity for s-channel resonance at high *t*







t-channel production mostly forward (exponential-like *t*-dependence)



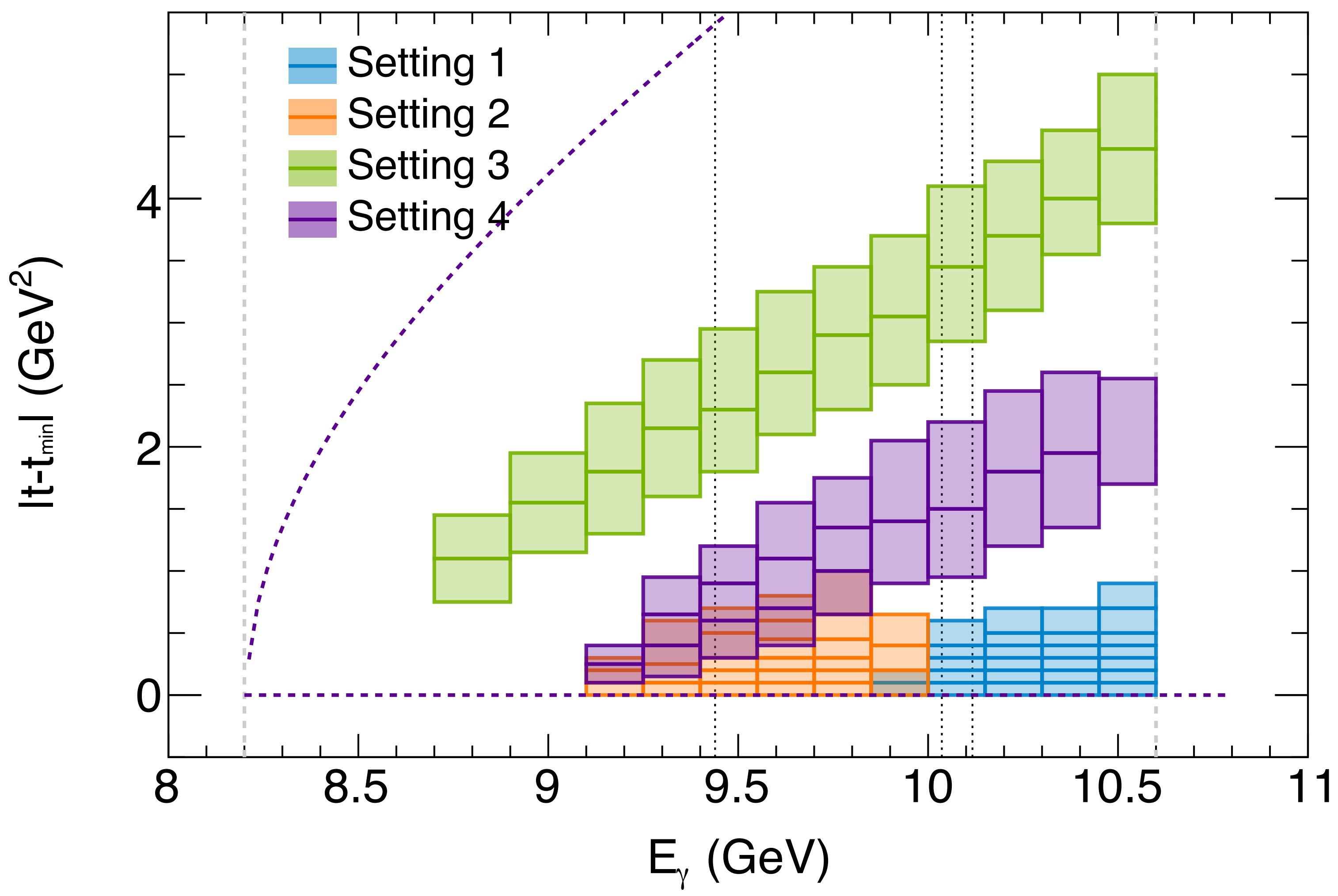
s-channel production more isotropic (flatter *t*-dependence)

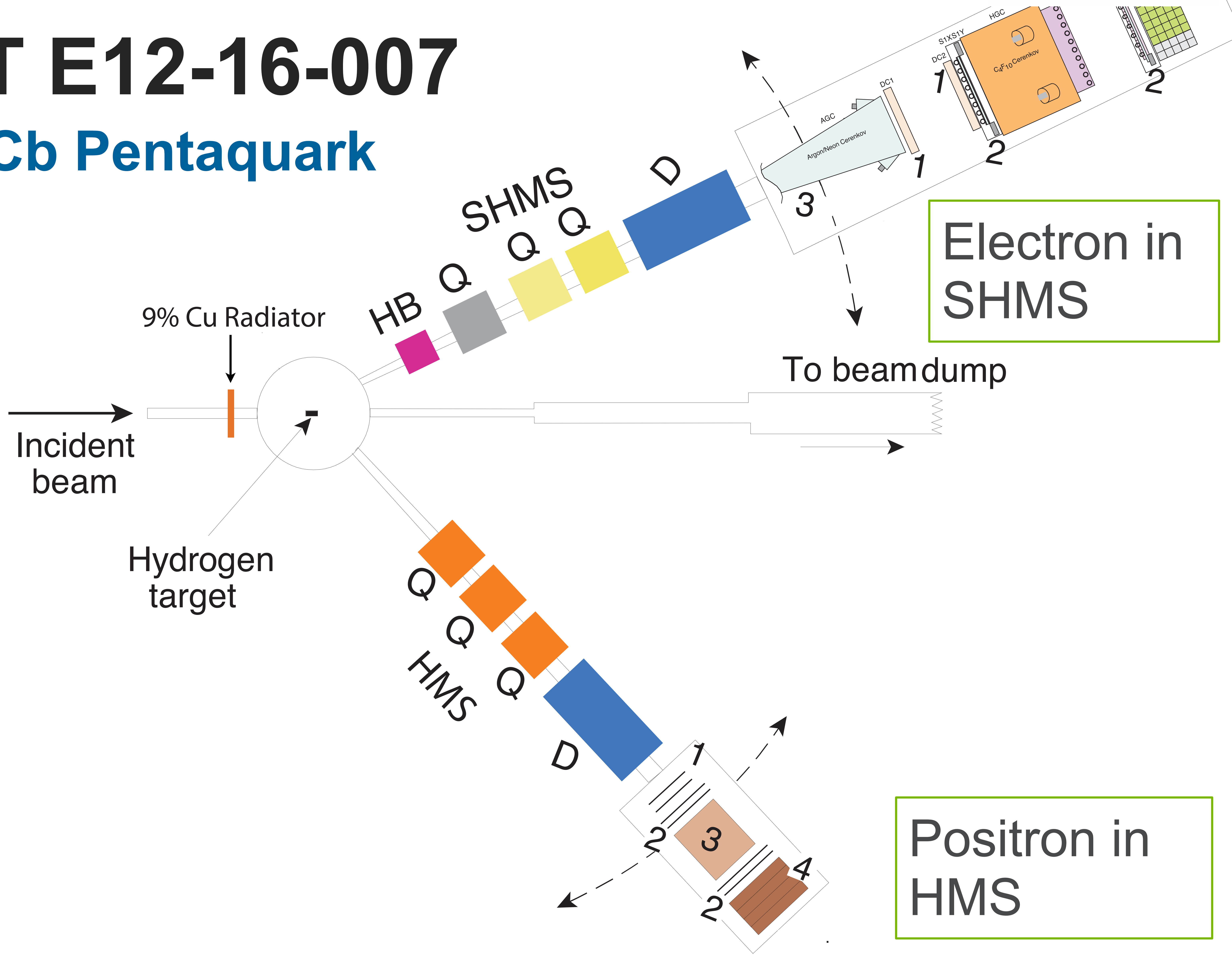
Z.-E. Meziani, S. Joosten *et al.*, arXiv:1609.00676 [hep-ex]
K. Hafidi, S. Joosten *et al.*, Few Body Syst. 58 (2017) no.4, 141

JLAB EXPERIMENT E12-16-007

J/ψ-007: Search for the LHCb Pentaquark

- Ran February 2019 for ~8 PAC days
- High intensity real photon beam (50μA electron beam on a 9% copper radiator)
- 10cm liquid hydrogen target
- Detect J/ψ decay leptons in coincidence
  - Bremsstrahlung photon energy fully constrained





Electron in SHMS

Positron in HMS

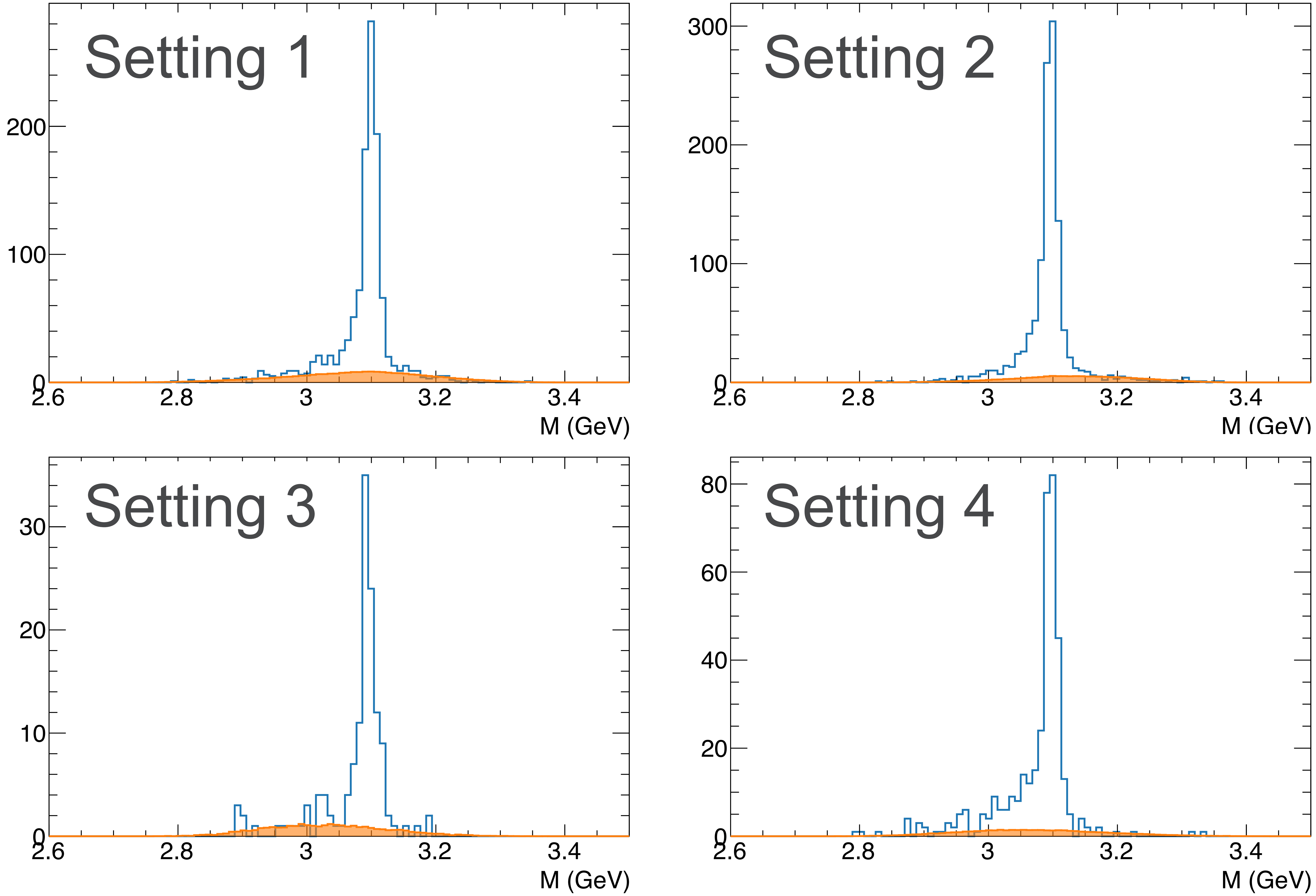
THE J/Ψ-007 COLLABORATION

…and many others!

B. Duran[3,1], Z.-E. Meziani[1,3], S. Joosten[1], M. K. Jones[2], S. Prasad[1], C. Peng[1], W. Armstrong[1], H. Atac[3], E. Chudakov[2], H. Bhatt[5], D. Bhetuwal[5], M. Boer[11], A. Camsonne[2], J.-P. Chen[2], M. Dalton[2], N. Deokar[3], M. Diefenthaler[2], J. Dunne[5], L. El Fassi[5], E. Fuchey[9], H. Gao[4], D. Gaskell[2], O. Hansen[2], F. Hauenstein[6], D. Higinbotham[2], S. Jia[3], A. Karki[5], C. Keppel[2], P. King[6], H.S. Ko[10], X. Li[4], R. Li[3], D. Mack[2], S. Malace[2], M. McCaughan[2], R. E. McClellan[8], R. Michaels[2], D. Meekins[2], L. Pentchev[2], E. Pooser[2], A. Puckett[9], R. Radloff[5], M. Rehfuss[3], P. E. Reimer[1], S. Riordan[1], B. Sawatzky[2], A. Smith[4], N. Sparveris[3], H. Szumila-Vance[2], S. Wood[2], J. Xie[1], Z. Ye[1], C. Yero[6], and Z. Zhao[4]**

CLEAR J/Ψ SIGNAL WITH MINIMAL BACKGROUND

settings	HMS	SHMS	target	charge [C]	goal
setting 1	19.1^o at +4.95GeV	17.0^o at -4.835GeV	LH2 with radiator	5.2	low-t and high energy
			dummy with radiator	0.6	target wall
			LH2, no radiator	0.1	electroproduction
setting 2	19.9^o at +4.6GeV	20.1^o at -4.3GeV	LH2 with radiator	8.2	low-t and low energy
			dummy with radiator	0.3	target wall
setting 3	16.4^o at +4.08GeV	30.0^o at -3.5GeV	LH2 with radiator	13.8	high-t
setting 4	16.5^o at +4.4GeV	24.5^o at -4.4GeV	LH2 with radiator	6.9	medium-t
			dummy with radiator	0.2	target wall



4% scale uncertainty on cross section

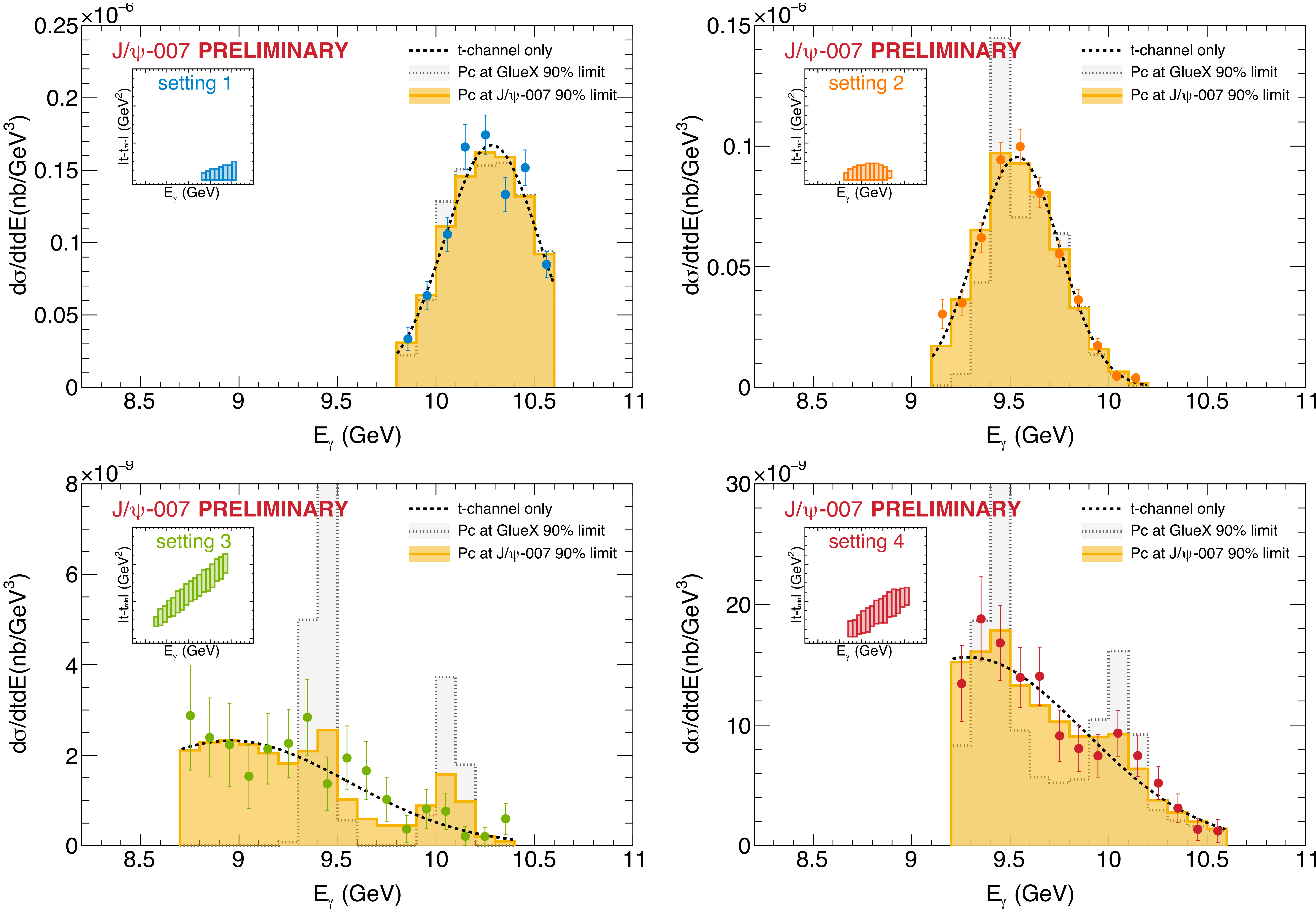
SCANNING THE SPECTRUM

Fit 1: bare Gaussian shape describes the cross section well

Fit 2: Signal + background at 2019 GlueX upper limit (90% confidence interval). The resonances lead to major tension with the data at high-t.

Fit 3: Same as 2, but with Pc at upper limit (90% confidence interval) from the preliminary J/ψ-007 results themselves

The data suggest a stringent upper limit on the resonant cross section (see next slide).



B. Duran, S. Joosten, Z.-E. Meziani, final results

4% scale uncertainty on cross section limit

RESULTS ON THE PENTAQUARK RESONANCES

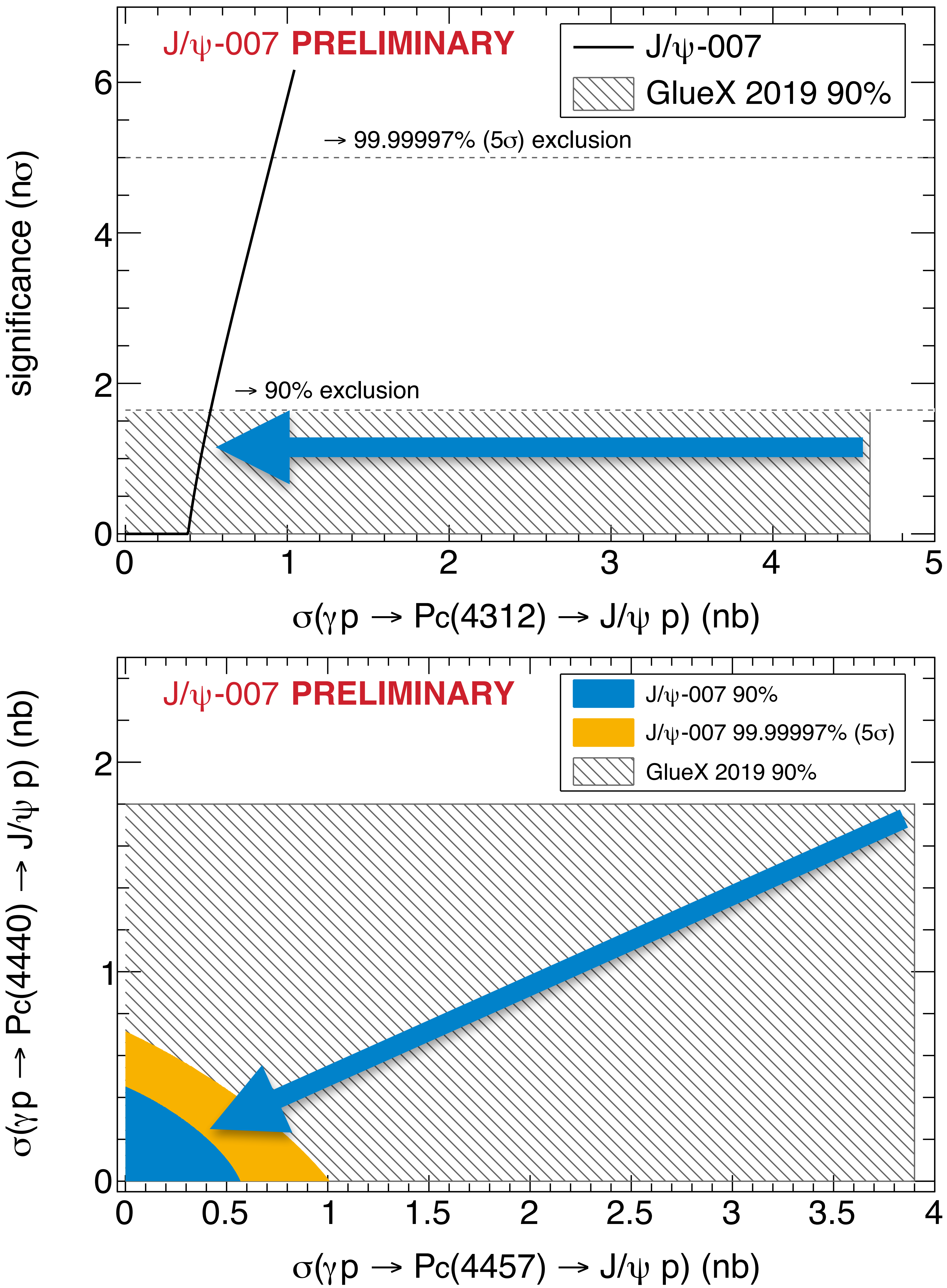
Cross-section at the resonance peak for model-independent upper limits

Upper limit for P_c cross section almost order of magnitude below GlueX limit.

Results seem inconsistent with reasonable assumptions for true 5-quark states.

Door is still open for molecular states, but will be very hard to measure in photoproduction due to small overlap with both γp initial state and J/ψp final state.

To learn more we need a large-acceptance high-intensity photoproduction experiment, and potentially access to polarization observables. **This can be achieved with the future SoLID-J/ψ experiment at Jefferson Lab**

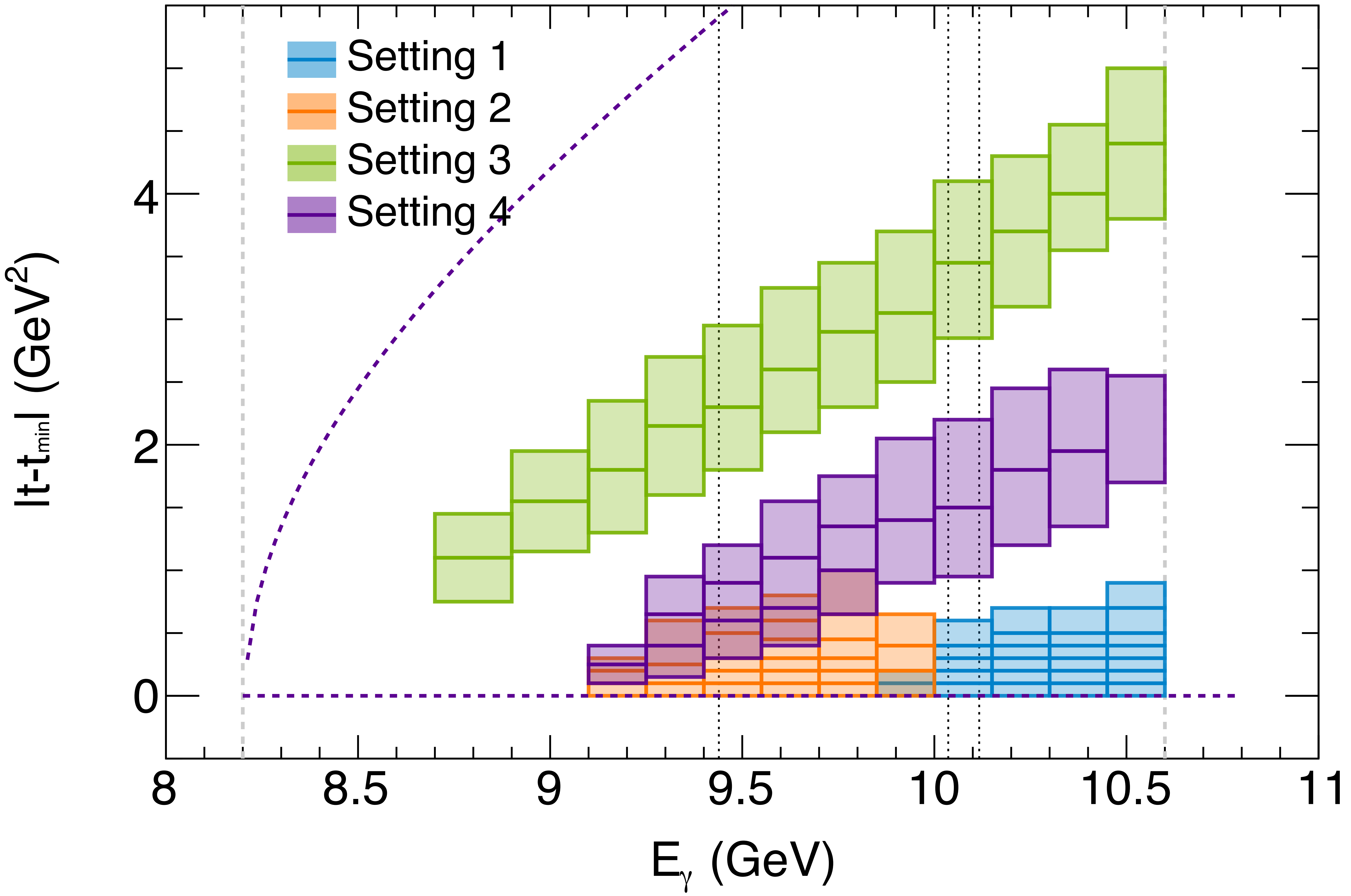


U.S. DEPARTMENT OF ENERGY
Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.

DIFFERENTIAL CROSS SECTION NEAR THRESHOLD

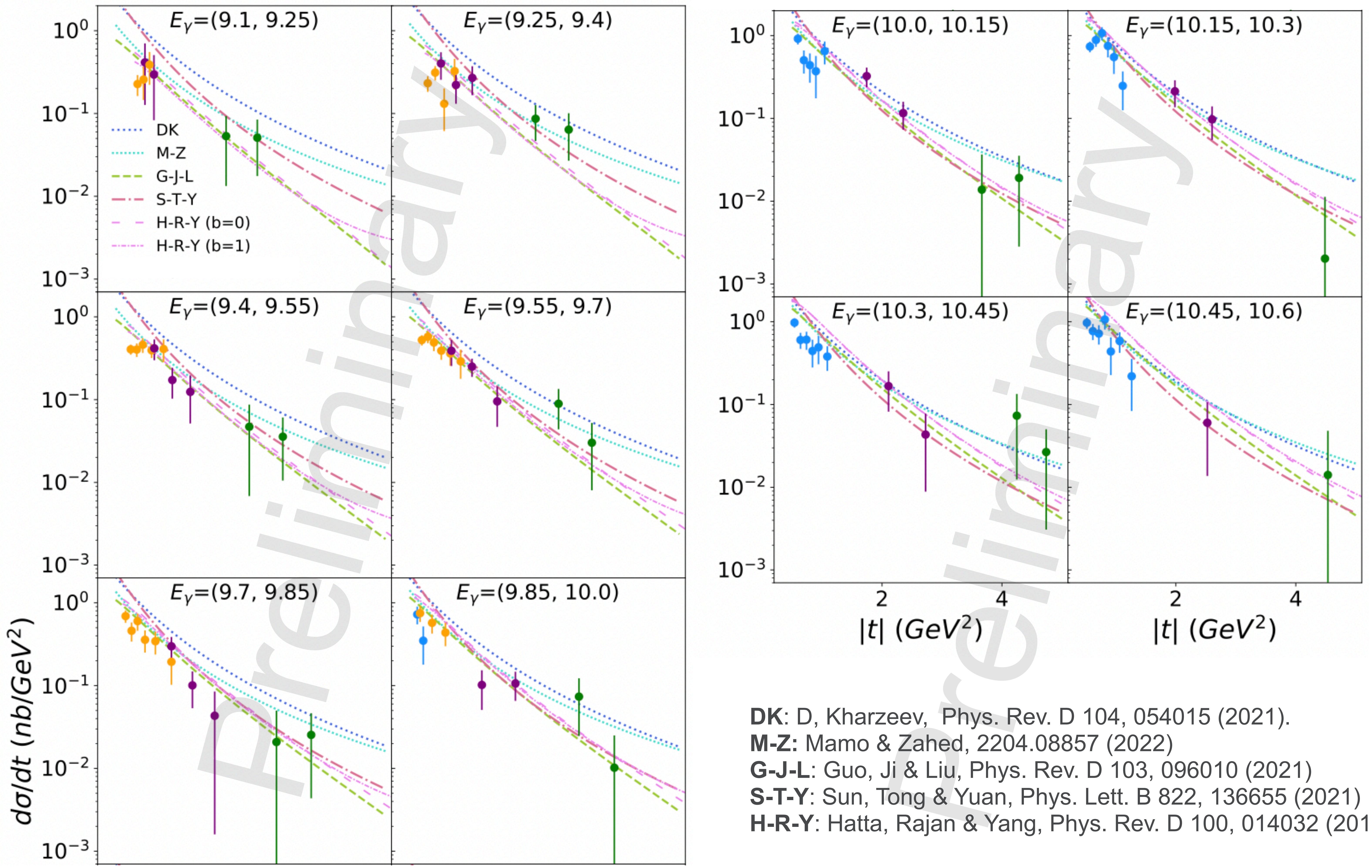
Unprecendented access to large-t region

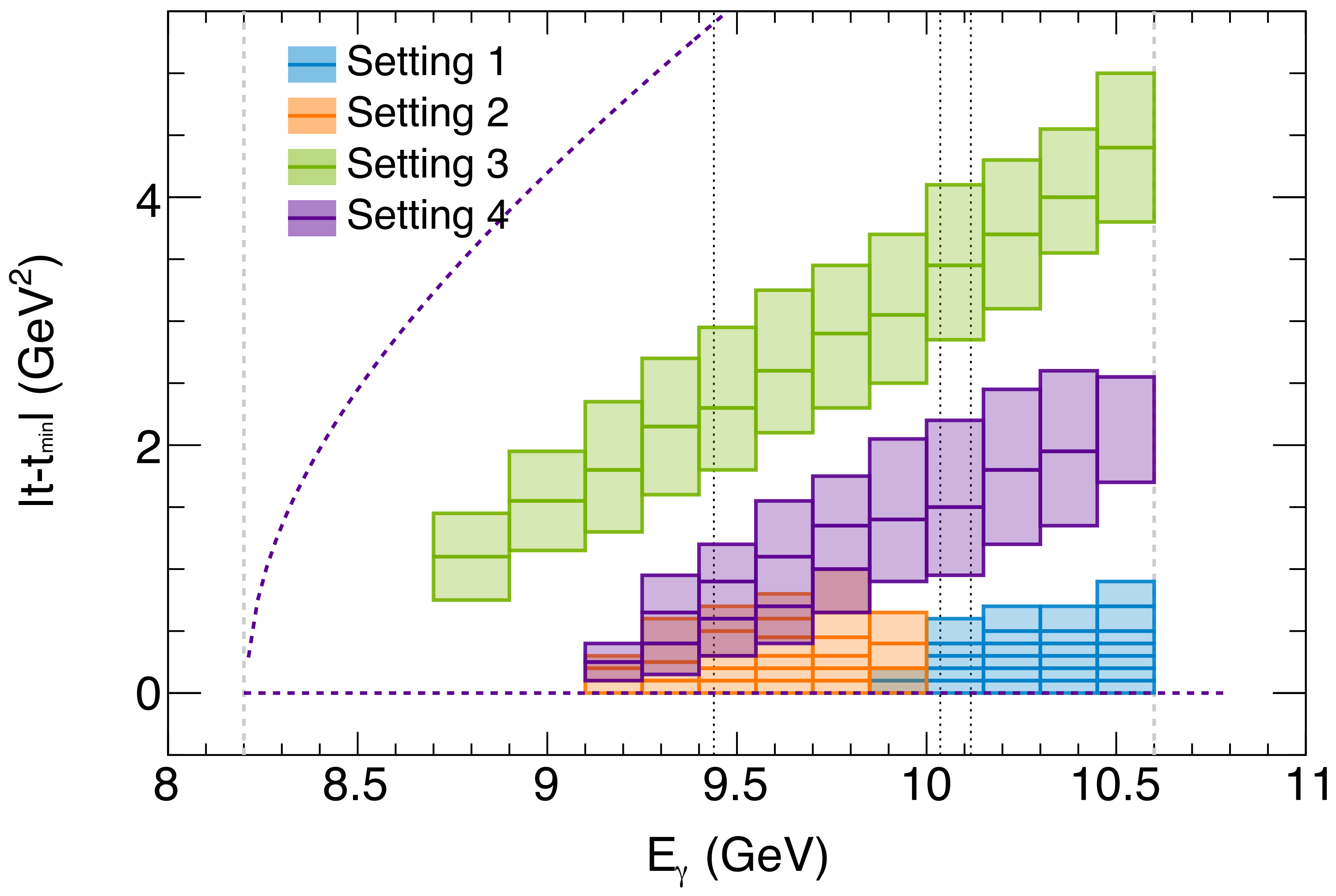
- Truly 2D measurement
- ~2000 counts in electron channel
- Additional 2000 counts in muon channel still under analysis



Results currently under peer-review

PRELIMINARY 2D J/Ψ CROSS SECTION RESULTS



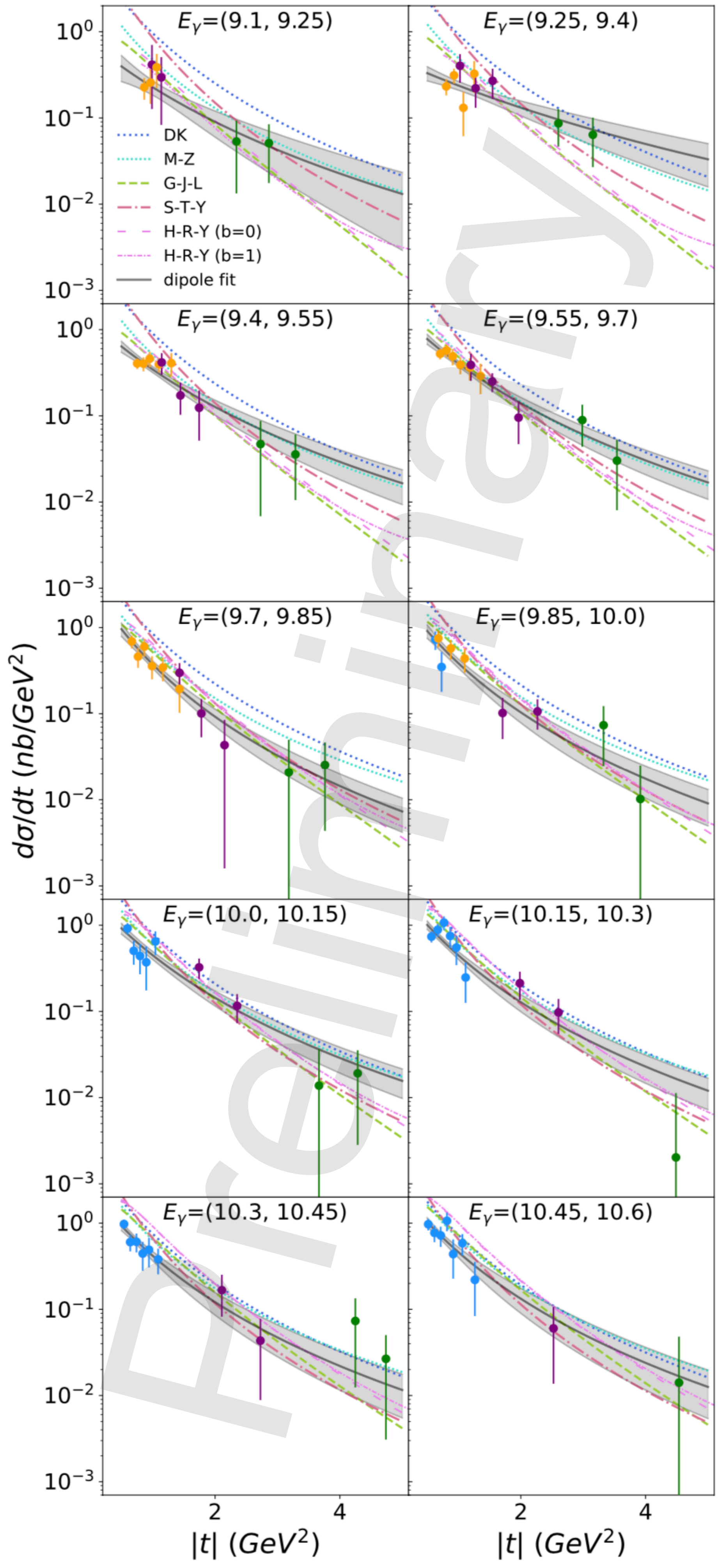


- Unfolded 2D cross section results compared to various model predictions informed by the 2019 1D GlueX results
- All models work reasonably well at higher energies but deviate at lower energies

DK: D, Kharzeev, Phys. Rev. D 104, 054015 (2021).
M-Z: Mamo & Zahed, 2204.08857 (2022)
G-J-L: Guo, Ji & Liu, Phys. Rev. D 103, 096010 (2021)
S-T-Y: Sun, Tong & Yuan, Phys. Lett. B 822, 136655 (2021)
H-R-Y: Hatta, Rajan & Yang, Phys. Rev. D 100, 014032 (2019)

EXTRACTING GFFS FROM THE 2D PROFILES

First ever extraction of gluonic GFFs from purely experimental data!

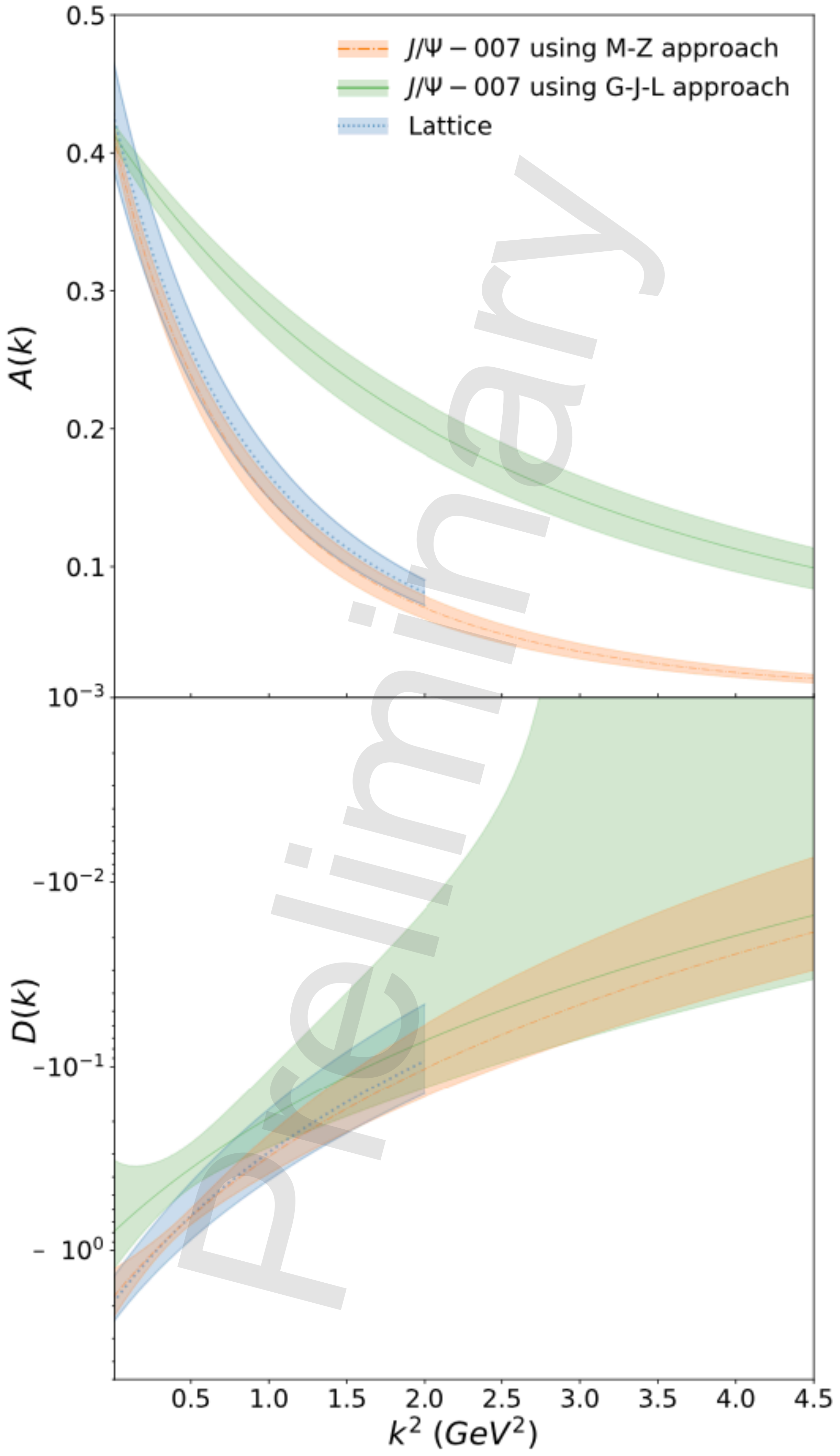


- **Model dependent extractions** using the available approaches in the literature
  - Holographic QCD approach: K. Mamo & I. Zahed, PRD 103, 094010 (2021) and 2204.08857 (2022)
  - GPD approach: Y. Guo, X. Ji, Y. Liu, PRD 103, 096010 (2021)
  - In both cases assume $B_g(t)$ contributes little (supported by lattice)
- Use tripole form for $A_g(t)$ and $C_g(t)$ (differences with dipole negligible)
- Use $A_g(0) = \langle x_g \rangle$ from the CT18 global fit, fit remaining 3 parameters $(m_A, C_g(0), m_C)$ to 2D cross section results.

Preprint: https://arxiv.org/abs/2207.05212

GLUONIC GFF RESULTS

Good agreement between Holographic QCD and Lattice results!



- Results from the 2D gluonic GFF fits
- Gluonic $A_g(t)$ and $D_g(t) = 4C_g(t)$ form factors
- χ^2/n.d.f. in both cases very close to 1
- M-Z (holographic QCD) approach fit to only experimental data gives results very close to the latest lattice results!
- GPD approach gives very different values, may indicate (expected) issues with the factorization assumption

M-Z: K. Mamo & I. Zahed, PRD 103, 094010 (2021) and 2204.08857 (2022)
G-J-L: Y. Guo, X. Ji, Y. Liu, PRD 103, 096010 (2021)
Lattice: D. Pefkou, D, Hackett, P. Shanahan, Phys. Rev. D 105, 054509 (2022).

M-Z: K. Mamo & I. Zahed, PRD 103, 094010 (2021) and 2204.08857 (2022)
G-J-L: Y. Guo, X. Ji, Y. Liu, PRD 103, 096010 (2021)
Lattice: D. Pefkou, D, Hackett, P. Shanahan, Phys. Rev. D 105, 054509 (2022).

WHAT ABOUT THE MASS AND SCALAR RADII?

Extracted from gluonic GFF results following M-Z and G-J-L

Theoretical approach GFF functional form	χ^2/n.d.f	m_A (GeV)	m_C (GeV)	$C_g(0)$	$\sqrt{\langle r_m^2\rangle_g}$ (fm)	$\sqrt{\langle r_s^2\rangle_g}$ (fm)
Holographic QCD Tripole-tripole	0.925	1.575±0.059	1.12±0.21	-0.45±0.132	0.755±0.035	1.069±0.056
GPD Tripole-tripole	0.924	2.71±0.19	1.28± 0.50	-0.20 ± 0.11	0.472±0.042	0.695±0.071
Lattice Tripole-tripole		1.641± 0.043	1.07± 0.12	-0.483± 0.133	0.7464±0.025	1.073±0.066

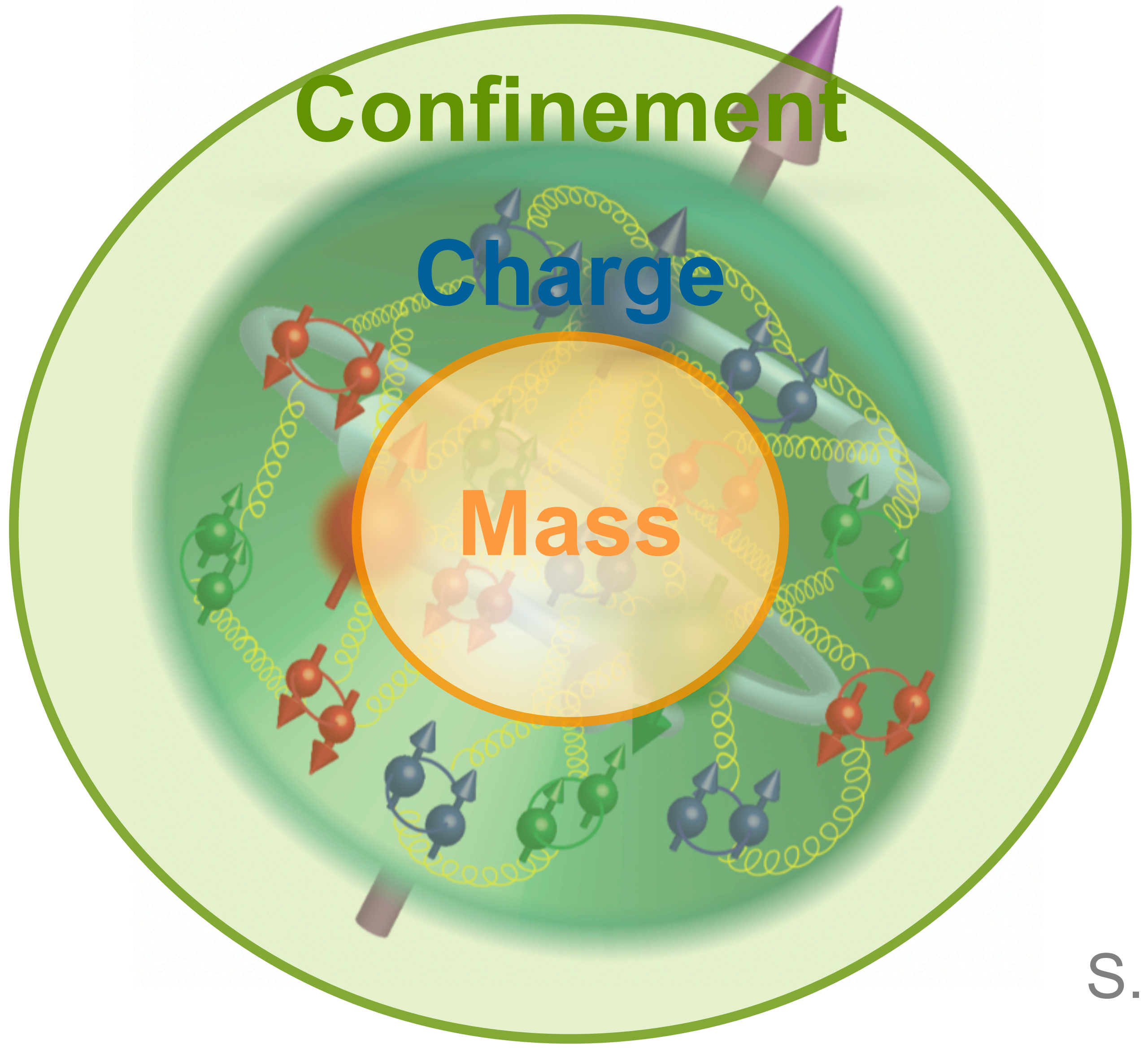
$$\langle r_m^2\rangle = \frac{6}{A_g(0)}\frac{dA_g(t)}{dt}\bigg|_{t=0} - \frac{6}{A_g(0)}\frac{C_g(0)}{M_N^2}$$

$$\langle r_s^2\rangle = \frac{6}{A_g(0)}\frac{dA_g(t)}{dt}\bigg|_{t=0} - \frac{18}{A_g(0)}\frac{C_g(0)}{M_N^2}$$

In all cases the extracted r_m is substantially smaller than the proton charge radius

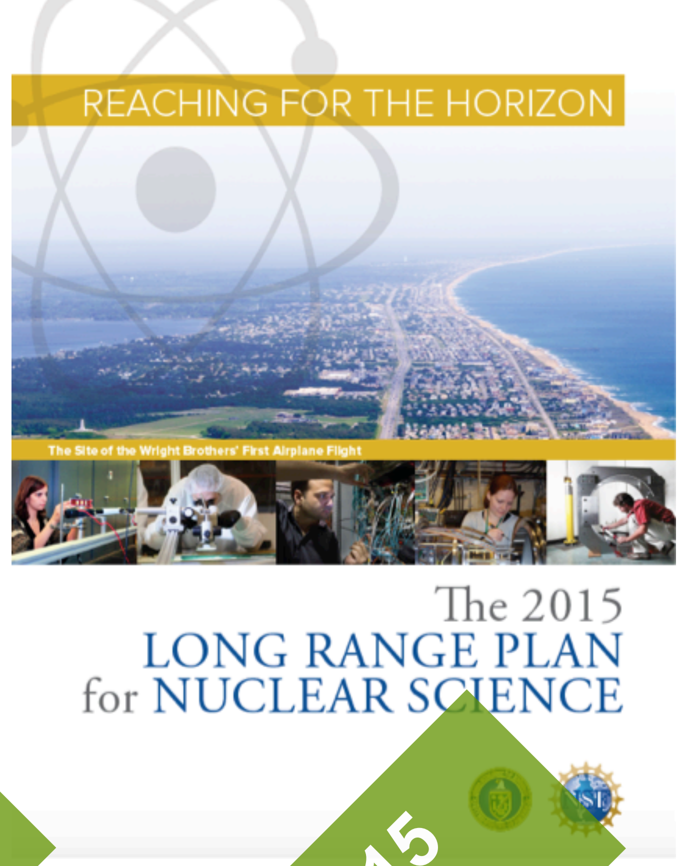
Both the holographic QCD fit to our data, and the latest Lattice calculations find a gluonic confining scalar potential radius of about 1 fermi

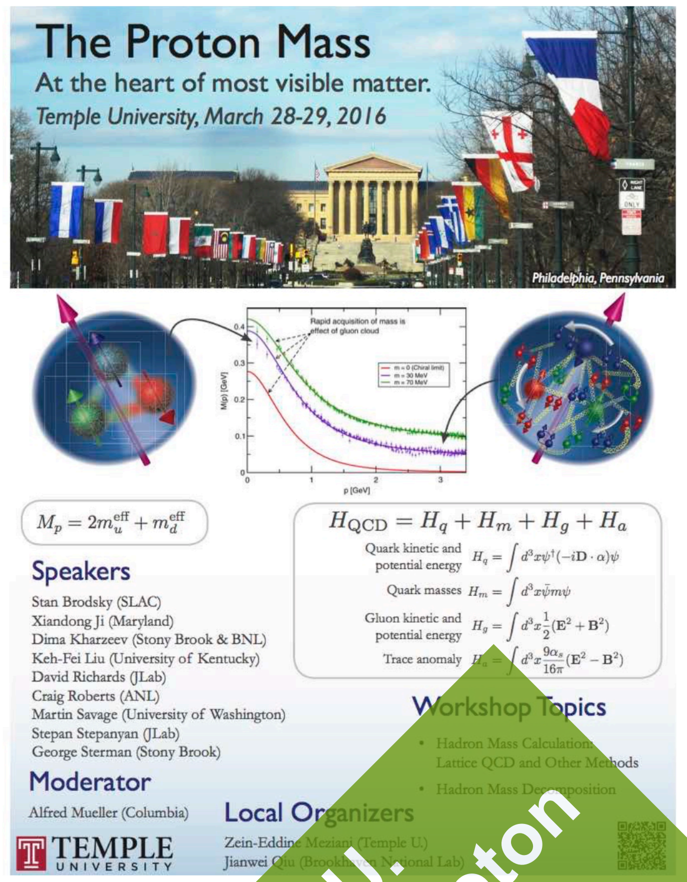
A picture of three zones

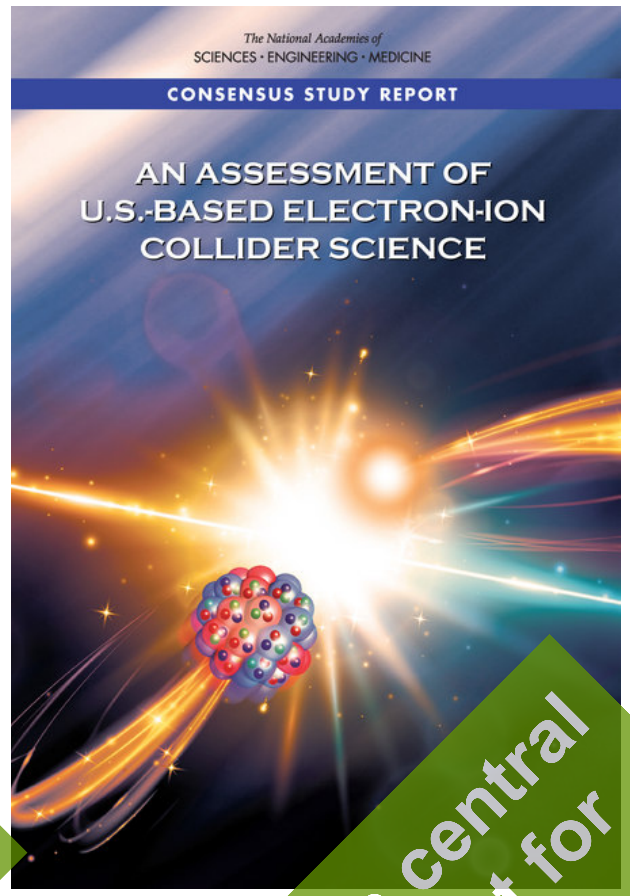


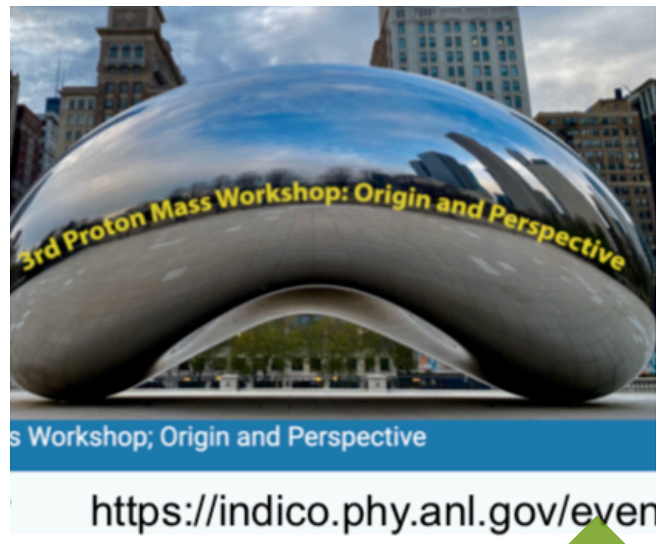
The proton mass: An important topic in contemporary hadronic physics!

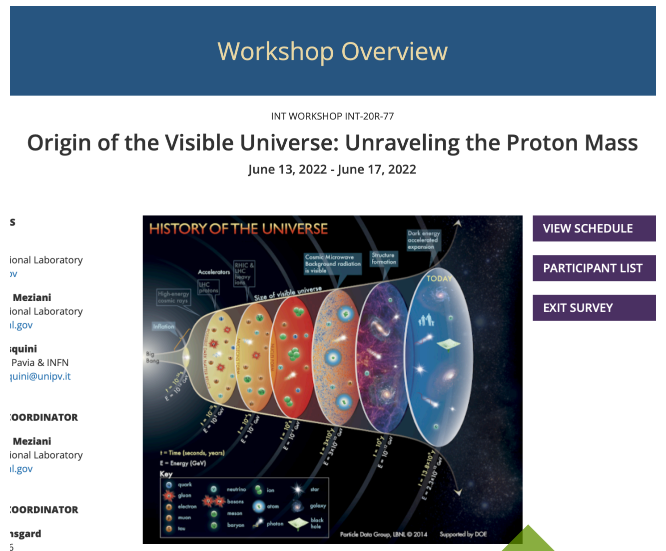
RAPIDLY EVOLVING





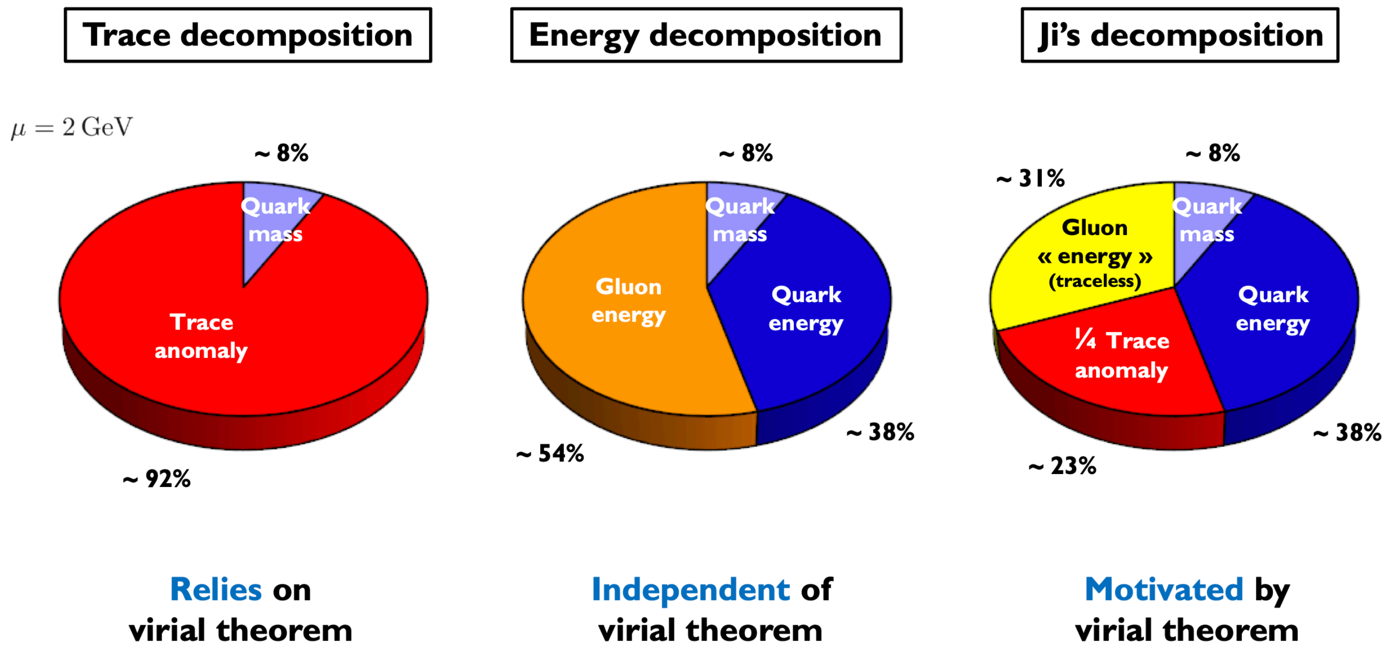




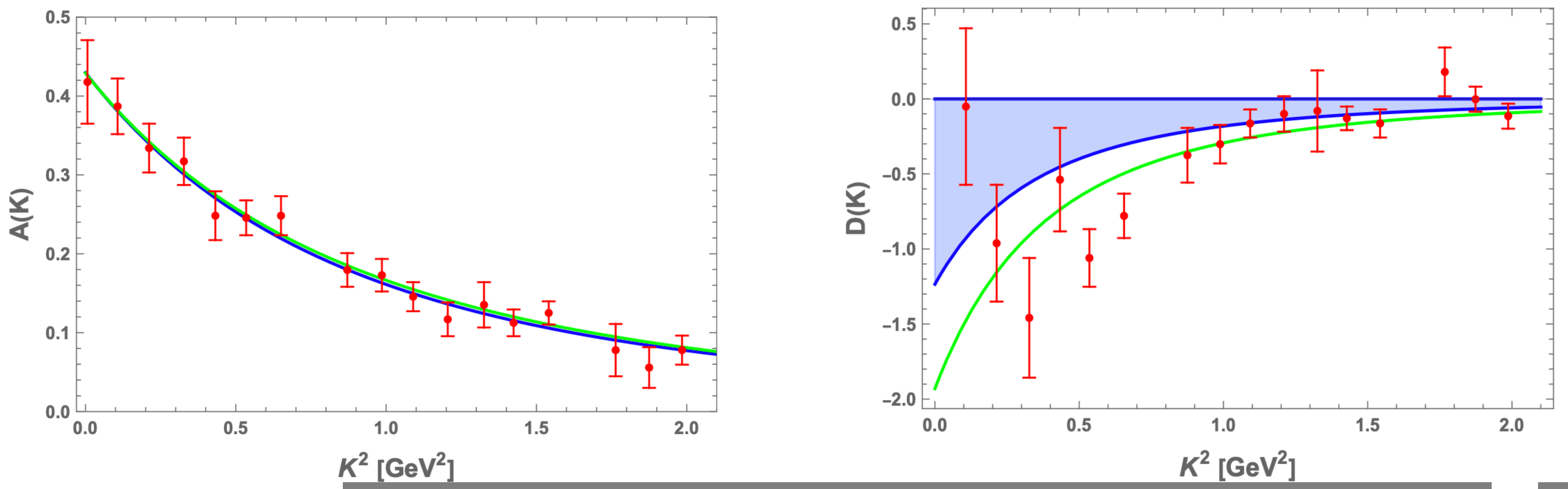


- 2012 Temple U. Workshop on heavy quarkonia
- Featured in the 2015 Long Range plan
- 2015 LHCb finds resonance in J/ψ-p channel consistent with pentaquarks
- 2016 Temple U. Workshop on the proton mass
- 2016 Proposal for Hall C Pentaquark search
- 2017 ECT* Workshop on the proton mass
- 2018 Proton mass central in NAS assessment for EIC
- 2019 First GlueX near-threshold J/ψ results
- 2021 Remote Workshop on the proton mass
- 2021 First Hall C results on the pentaquark search
- 2022 INT Workshop on the proton mass
- 2022 First 2D near-threshold J/ψ results from Hall C

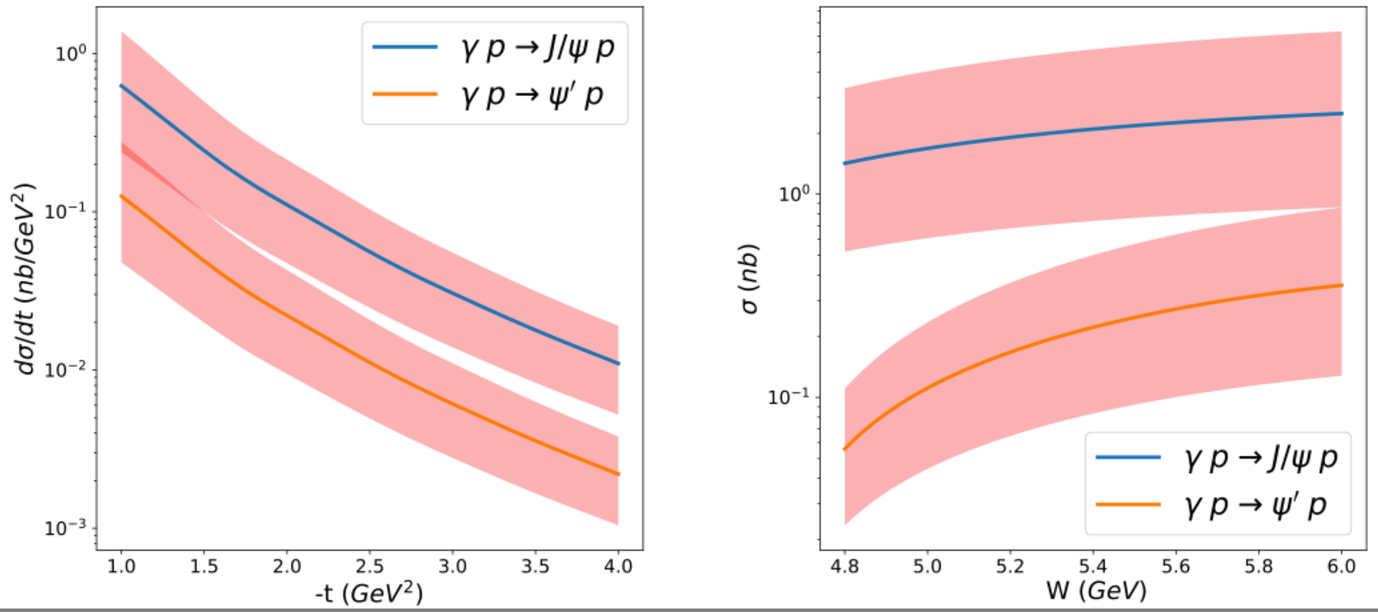
PROMINENT RECENT DEVELOPMENTS



Proton mass budget decompositions, C. Lorce (from 2022 INT workshop)

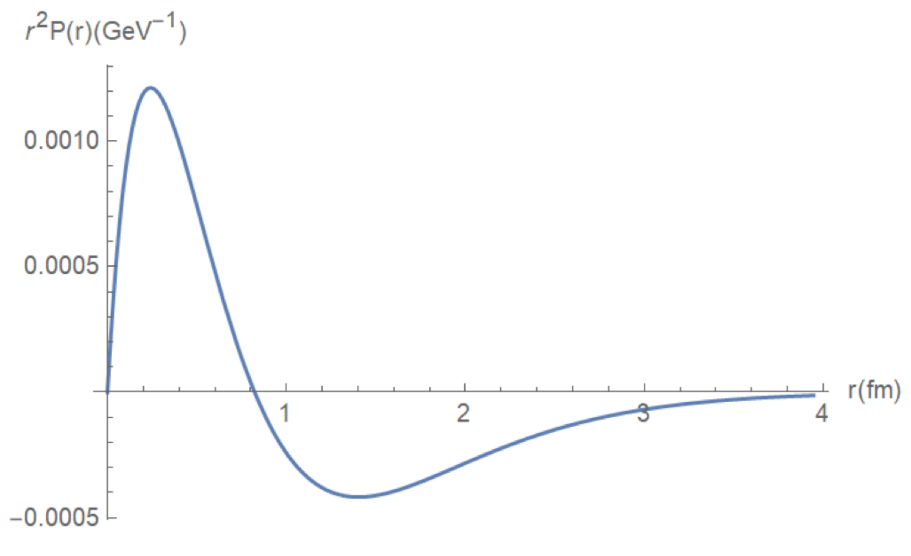


Proton gravitational form factors holographic QCD compared with Lattice, K. Mamo & I. Zahed (2022)

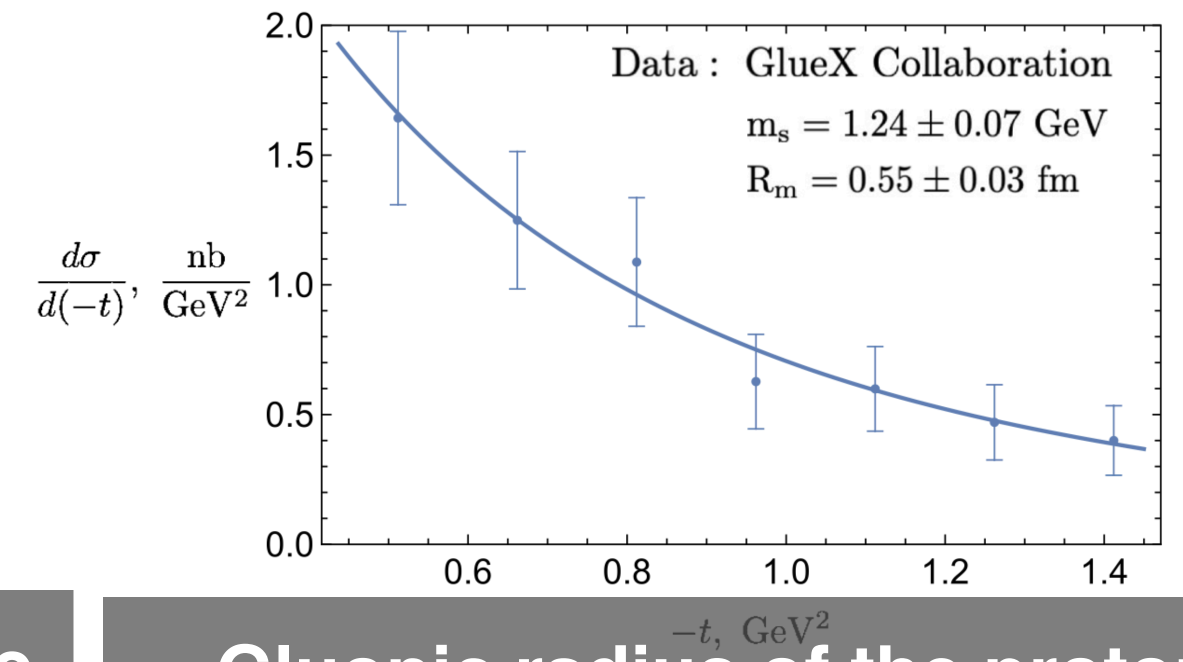


Near-threshold heavy quarkonium production at large momentum transfer, P. Sun, X-B. Tong, F. Yuan (PRD 2022)

- A hot topic: many theoretical developments, and pace of publications only speeding up!
- Many extractions depend on extrapolating to the forward limit (t=0), which introduces theoretical systematic uncertainties. Precise high-t as a function photon energy crucial.



Gluon contribution to pressure in GPD formalism, Y. Guo, X. Ji, Y. Liu, (PRD 2021)

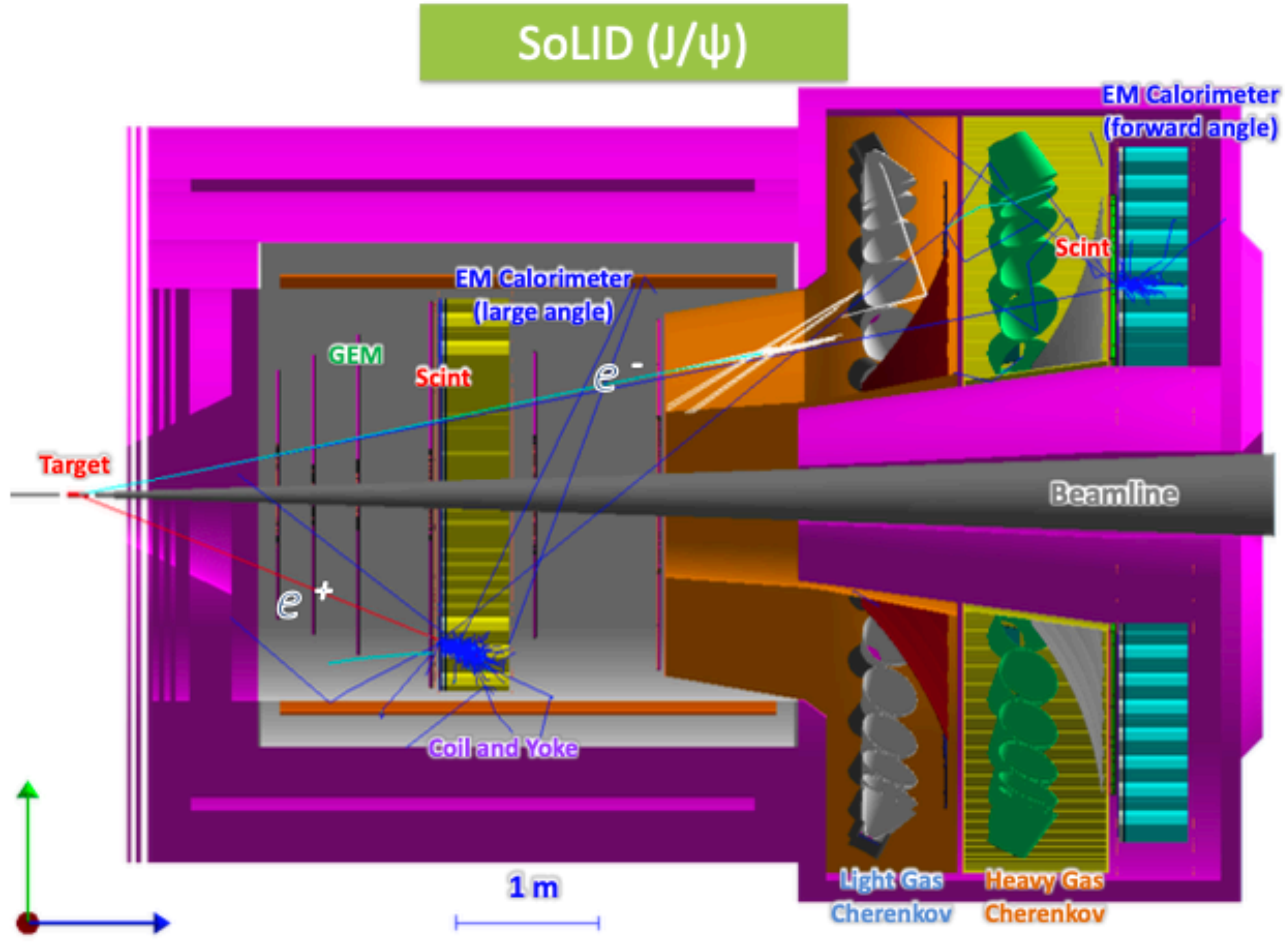


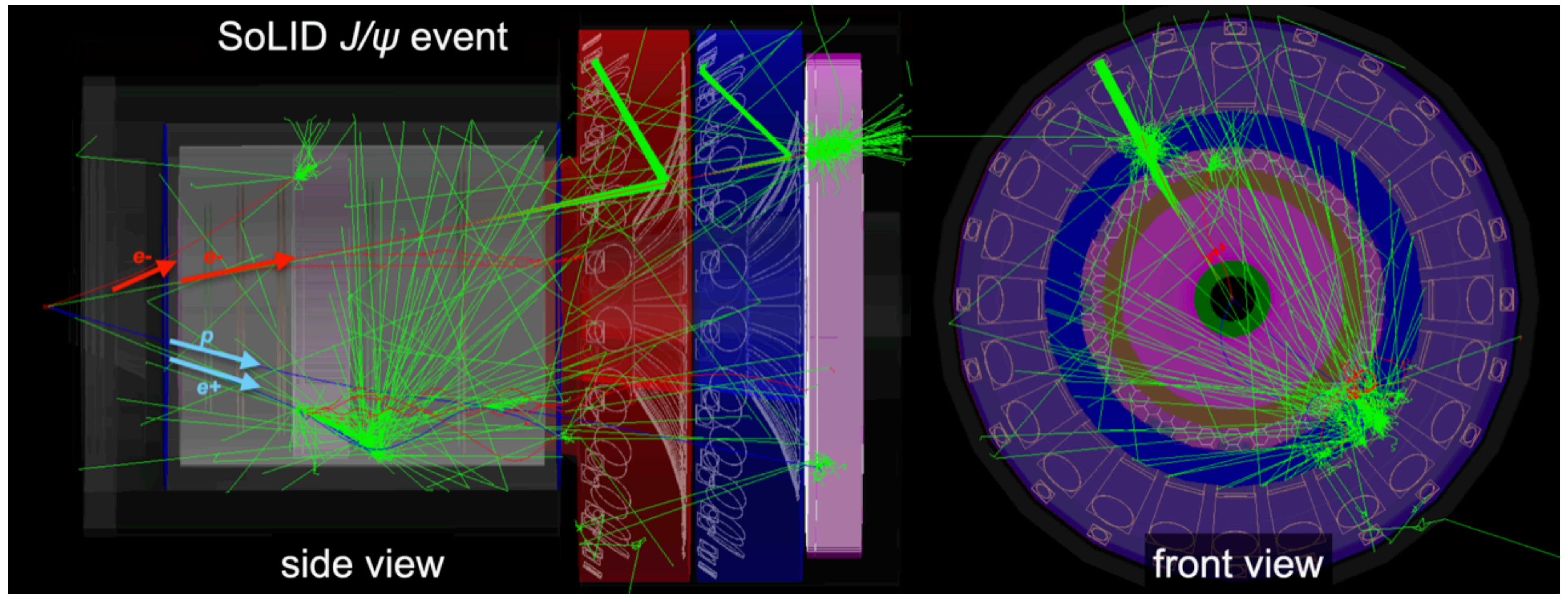
Gluonic radius of the proton based on 1D GlueX results, D. Kharzeev (PRD 2021)

THE SOLID-J/Ψ EXPERIMENT

Ultimate factory for near-threshold J/ψ

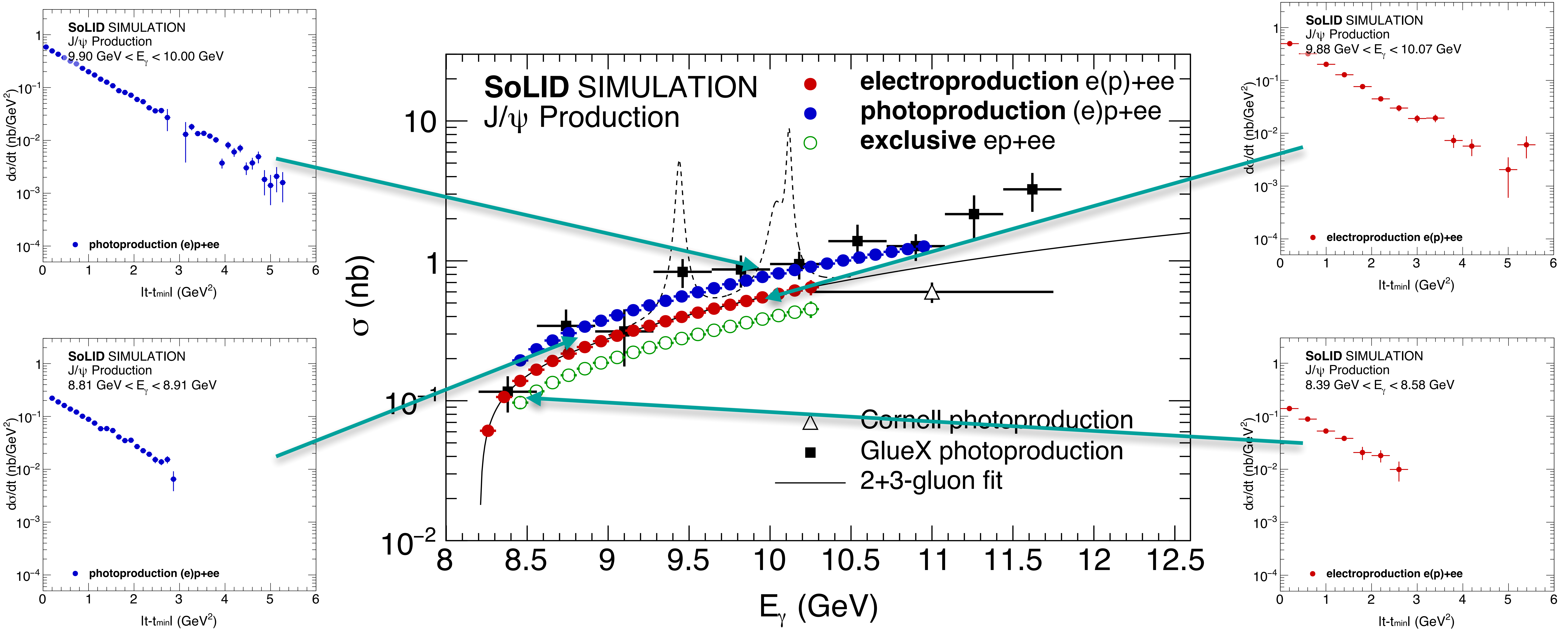
- General purpose large-acceptance spectrometer
- 50+10 days of 3μA beam on a 15cm long LH2 target ($10^{37}/cm^2/s$)
- **Ultra-high luminosity**: $43.2ab^{-1}$
- **Open 2-particle trigger,** covering J/ψ production in four channels: Electroproduction (e,e^-e^+), photoproduction (p,e^-e^+), inclusive (e^-e^+), exclusive (ep,e^-e^+)





SOLID-J/Ψ PROJECTIONS

Precision at high t crucial for extrapolations to the forward limit (exponential, dipole, triple, …)



J/Ψ EXPERIMENTS AT JLAB COMPARED

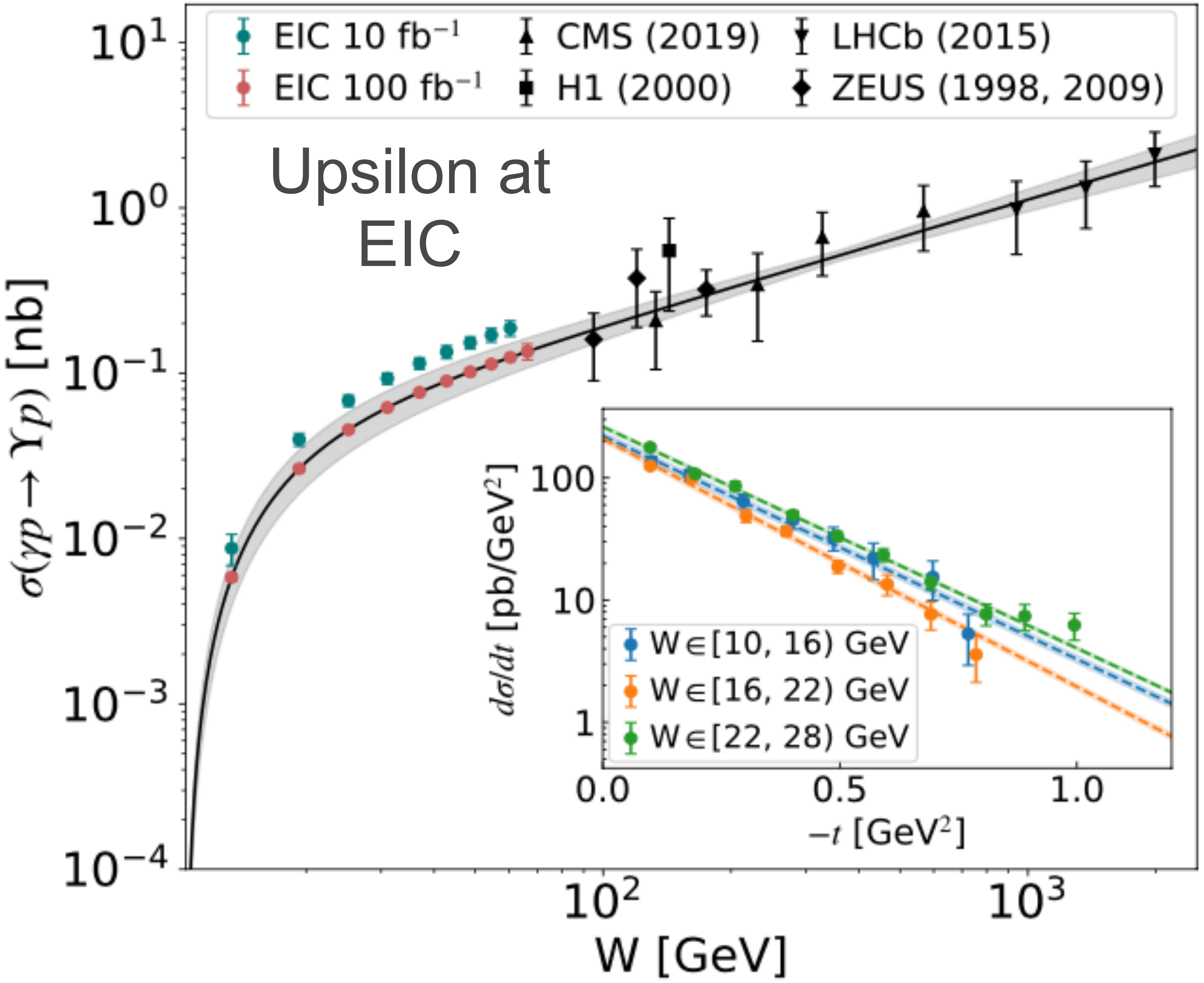
	GlueX HALL D	HMS+SHMS HALL C	CLAS 12 with upgrade[1] HALL B	SoLID HALL A
J/ψ counts (photo-prod.)	**469 published ~10k phase I + II**	**2k electron channel 2k muon channel**	**14k**	**804k**
J/ψ Rate (electro-prod.)	**N/A**	**N/A**	**1k**	**21k**
Features	Good reach to threshold. No high-t reach.	Can reach high-t only at higher energies. Low statistics.	No high-t reach. Electroproduction low statistics.	Enough luminosity to reach high t. High precision.
When?	Finished/Ongoing	Finished	Ongoing/Proposed	Future

[1]The CLAS12 projected count rates assume the proposed CLAS12 luminosity upgrade to $2x10^{35}/cm^2/s$

COMPLEMENTARITY WITH EIC

J/ψ at SoLID and Υ at EIC

- Υ(1S) at EIC trades statistical precision of J/ψ at SoLID for lower theoretical uncertainties, and extra channel to study universality.
- Large Q^2 reach at EIC an additional knob to study production

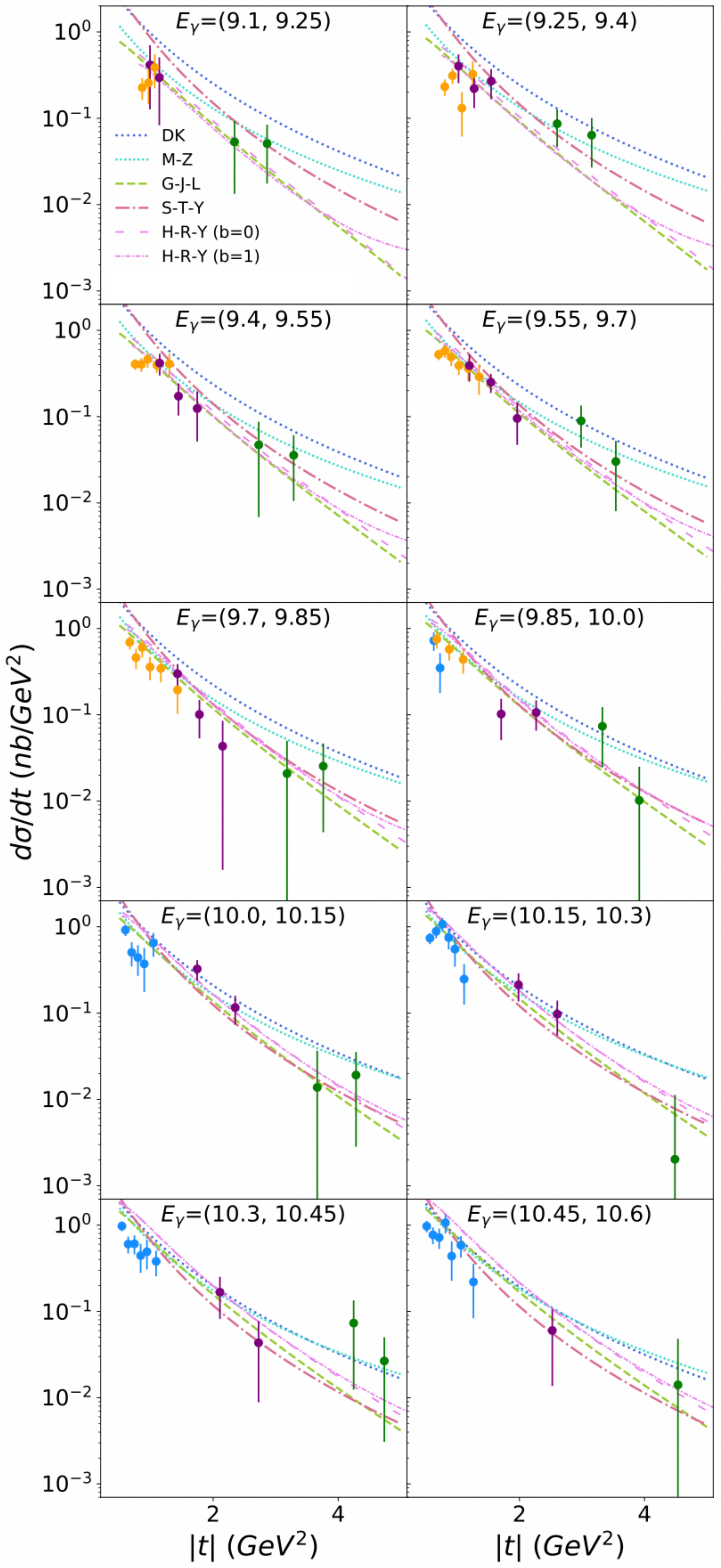


Preprint: https://arxiv.org/abs/2207.05212

CONCLUSION

007 J/ψ

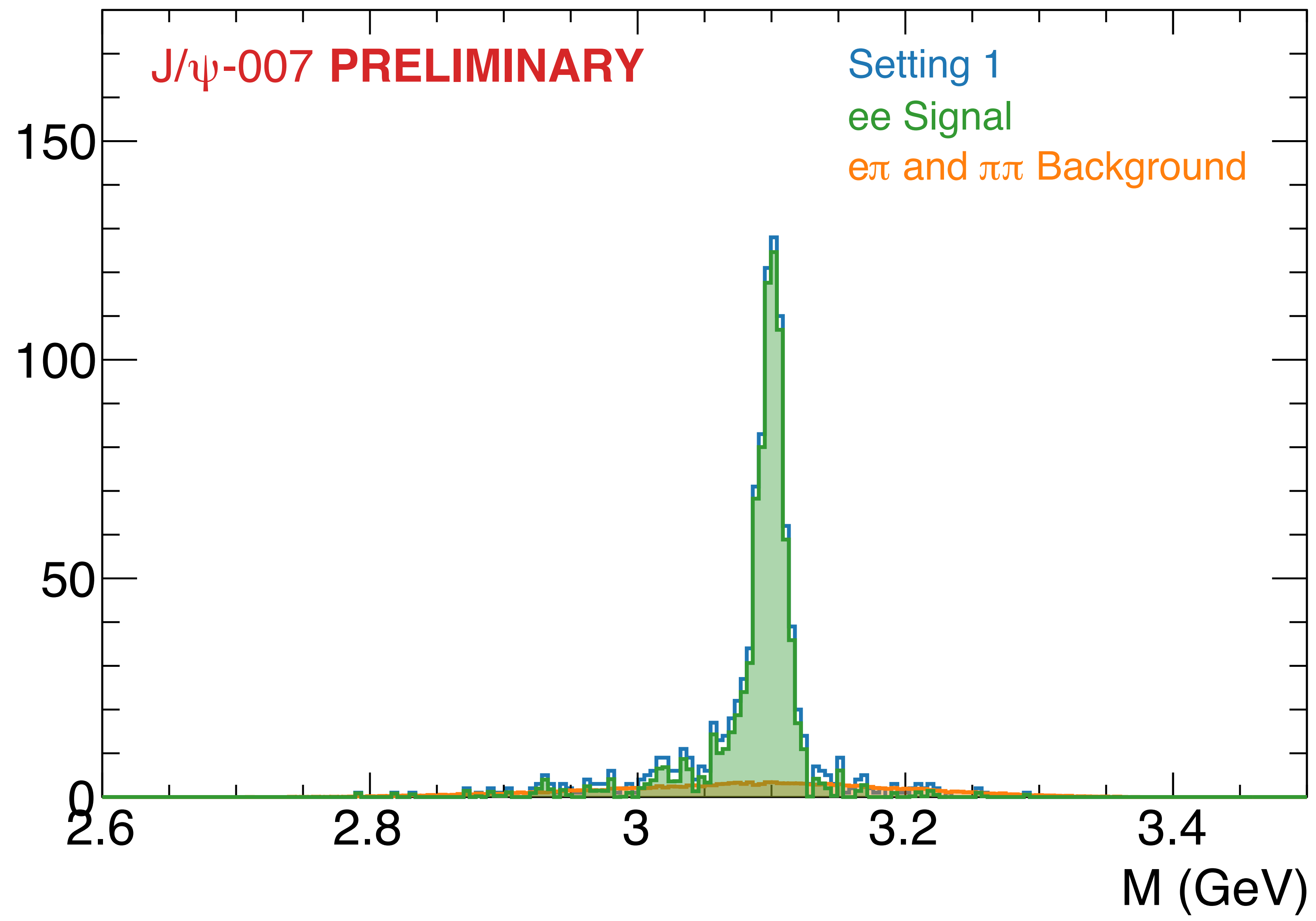
- The Hall C J/ψ-007 experiment has the first near-threshold 2D J/ψ cross section results in this area, currently under peer review.
  - Stringent exclusion limit for the LHCb charmed pentaquarks in photoproduction
  - New window on the gluonic GFFs in the proton
  - Does the proton have a dense energetic core?
- The matter structure of the proton and threshold quarkonium production are rapidly evolving topics that reach from Jefferson Lab to the EIC.

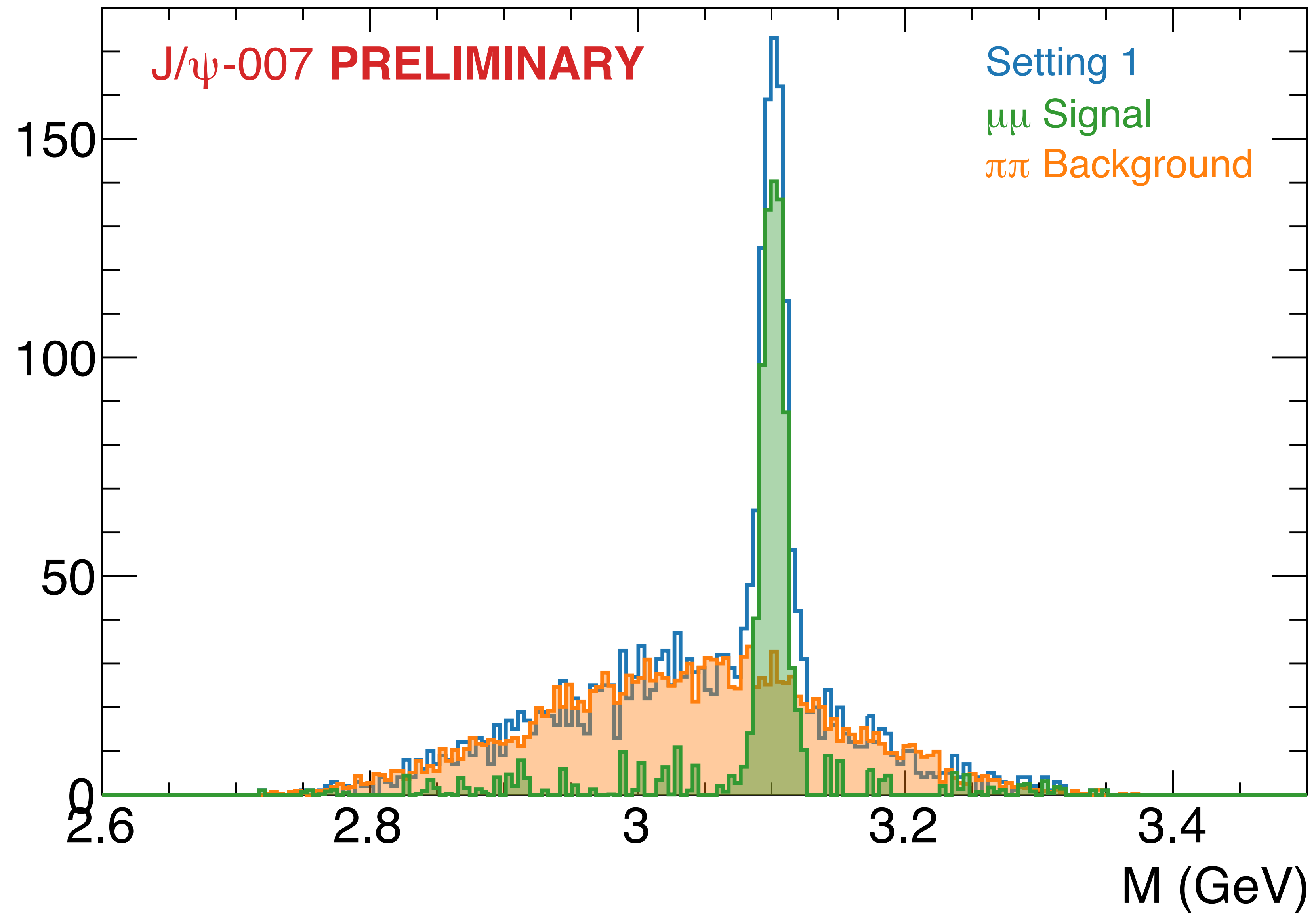


QUESTIONS?

ELECTRON AND MUON CHANNELS

007 J/ψ





- **Electron and muon channels independent measurements, same statistics but different systematics**
- **Electrons:**
  - Low background with Cherenkov and ECAL for PID
  - Undergo multiple scattering and more sensitive to radiative losses
  - Slightly worse resolution (10MeV)
- **Muons**
  - More background using only ECAL (require coincidence MIP in 4 layers in HMS and 2 layers in SHMS), but still reasonable
  - Background dominated by 2-pion events, can get shape from dataset
  - Less sensitive to multiple scattering and radiative losses
  - Better resolution (8MeV)
- **Invariant mass posititition *stable* between phases, well described by Monte Carlo!**

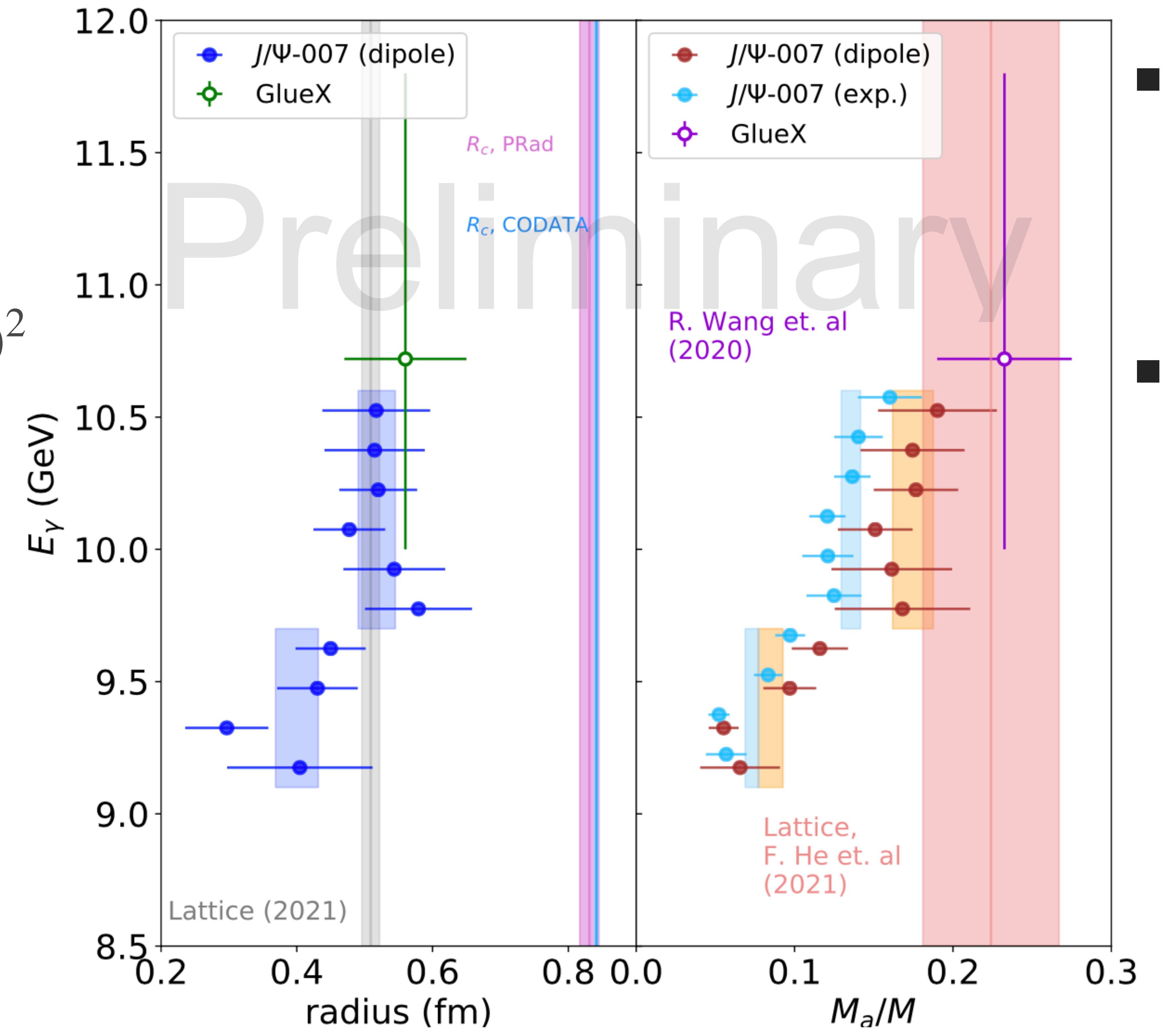
VARIOUS MODEL-DEPENDENT EXTRACTIONS

Radius (following DK), and Ma/M (following Ji), for each energy slice

D-K formalism for radius

$$\frac{d\sigma}{dt} = \frac{1}{64\pi s}\frac{1}{\left|p_{\gamma,\mathrm{cm}}\right|^2}(Q_e c_2)^2\left(\frac{16\pi^2 M^2}{b}\right)^2 G(t)^2$$

$$\langle r_m^2 \rangle = \frac{6}{M}\frac{dG}{dt}\bigg|_{t=0} = \frac{12}{m_s^2}$$



- Find flat region at higher energies, which seems to break below 9.7 GeV
- Good agreement with lattice in flat region ($9.7\,\mathrm{GeV} < E_\gamma < 10.6\,\mathrm{GeV}$)
  - $\sqrt{\langle r_m^2 \rangle} = 0.52 \pm 0.03\,\mathrm{fm}$
  - $M_a/M = 0.175 \pm 0.013$

DK: D, Kharzeev, Phys. Rev. D 104, 054015 (2021)
Charge radius: CODATA
Lattice radius: D. Pefkou, D, Hackett, P. Shanahan, Phys. Rev. D 105, (2022)

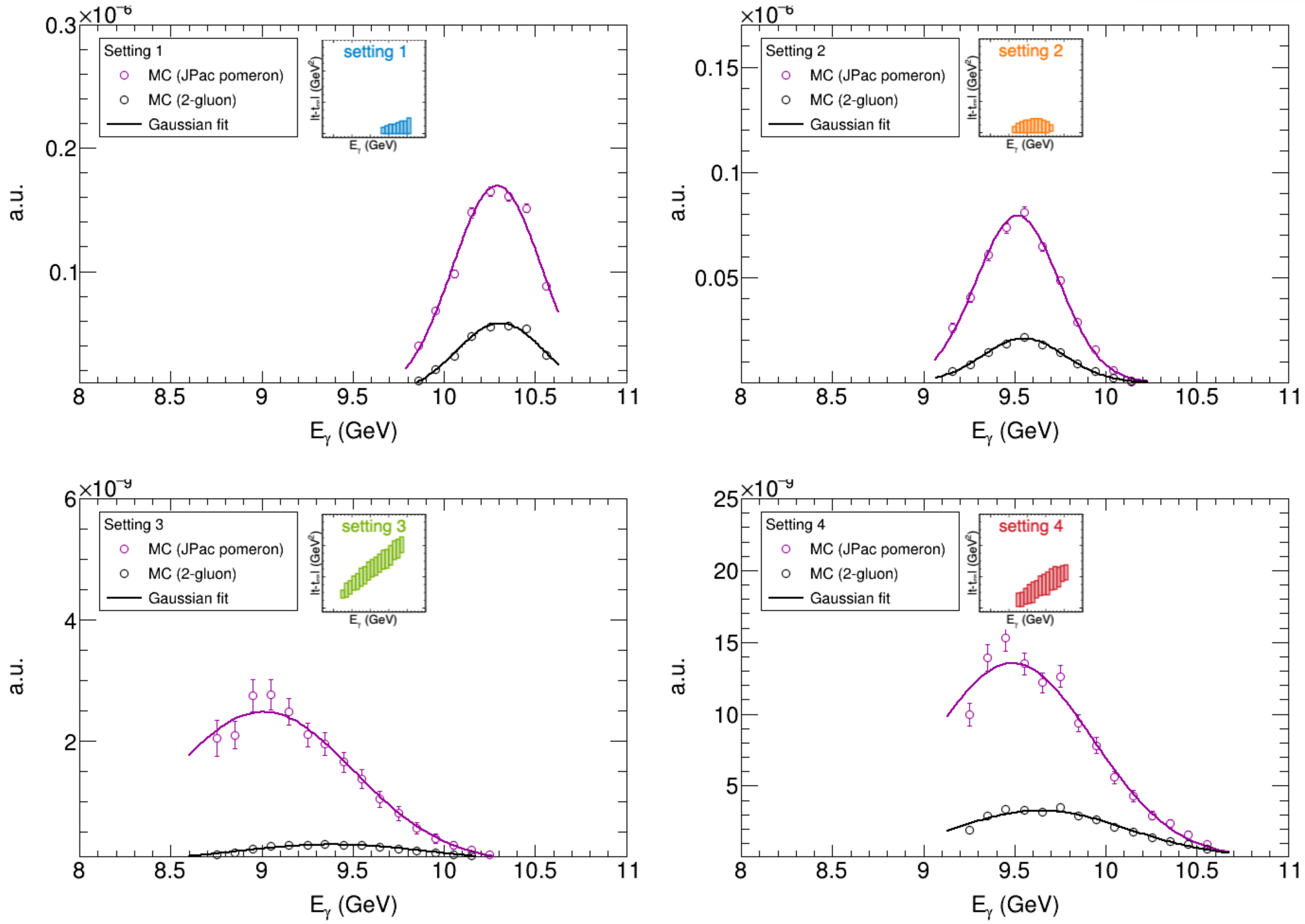
GlueX point: R. Wang, J. Evslin, X. Chen, Eur. Phys. J. C, 80, 507 (2020).
Approach: X. Ji, Phys. Rev. Lett. 74, 1071–1074 (1995), same procedure as the GlueX point
Lattice Ma: F. He, P. Sun,Y.-B. Yang, Phys. Rev. D 104, 074507 (2021)

WHAT DOES A PURE T-CHANNEL BACKGROUND LOOK LIKE?

Need model-independent fit shape to fit the t-channel background **inside the spectrometer acceptance**

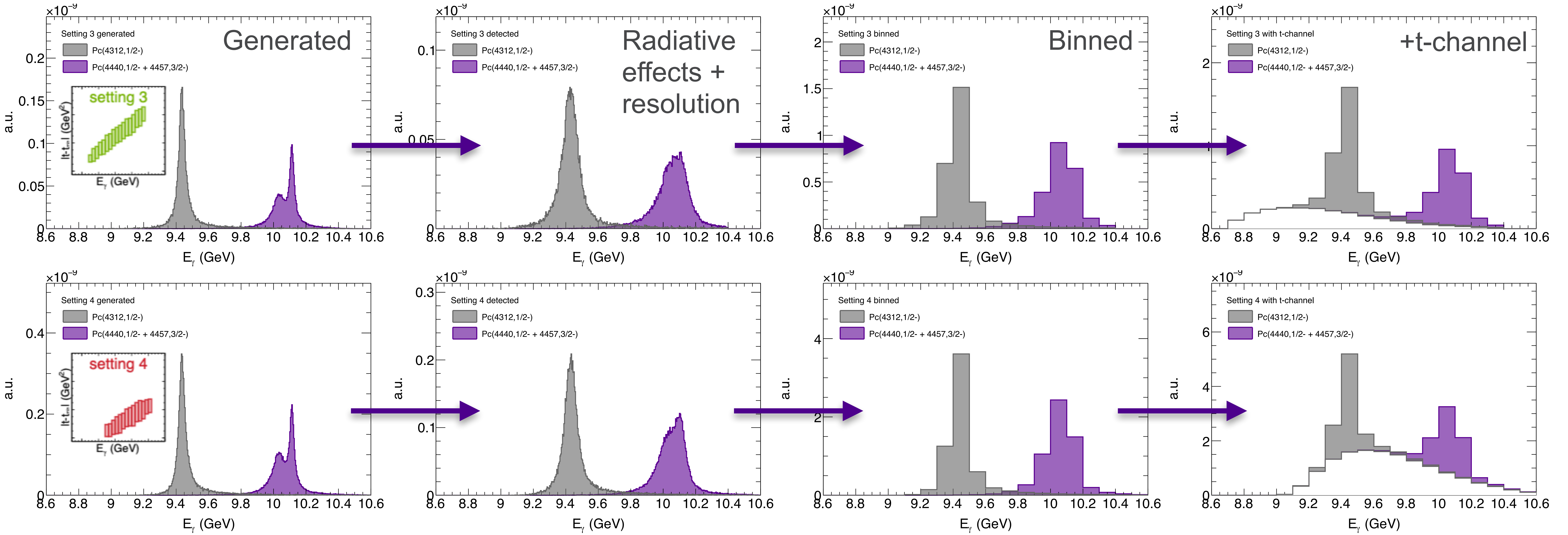
A **gaussian shape**, mostly driven by the spectrometer acceptance, does a good job describing both (very different!) Monte-Carlo models

For now used as independent shapes between the settings, could in principle gain more by levering the 2D t-profiles of the cross section



PENTAQUARK MODEL

Need to know pentaquark signatures in our experimental sample

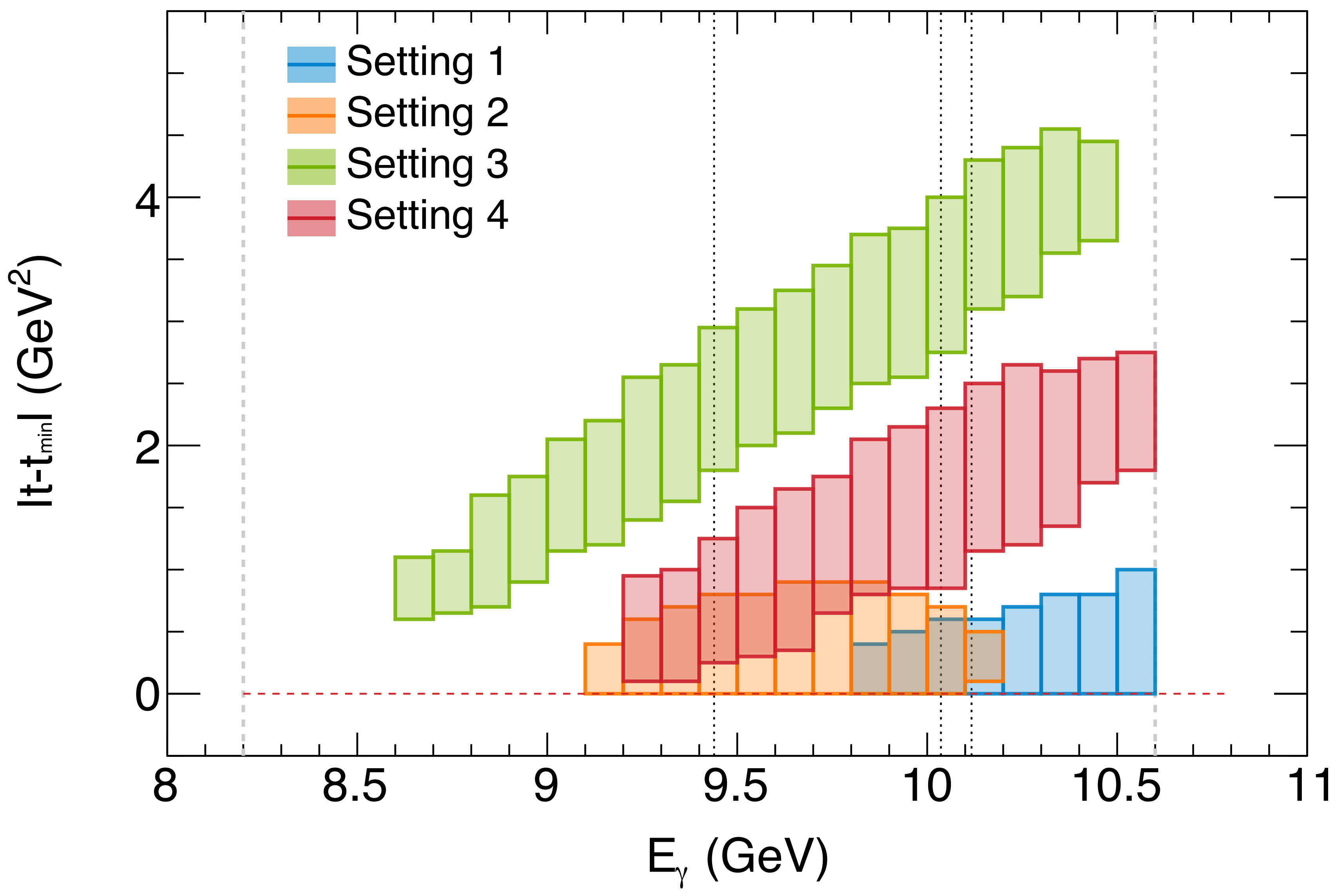


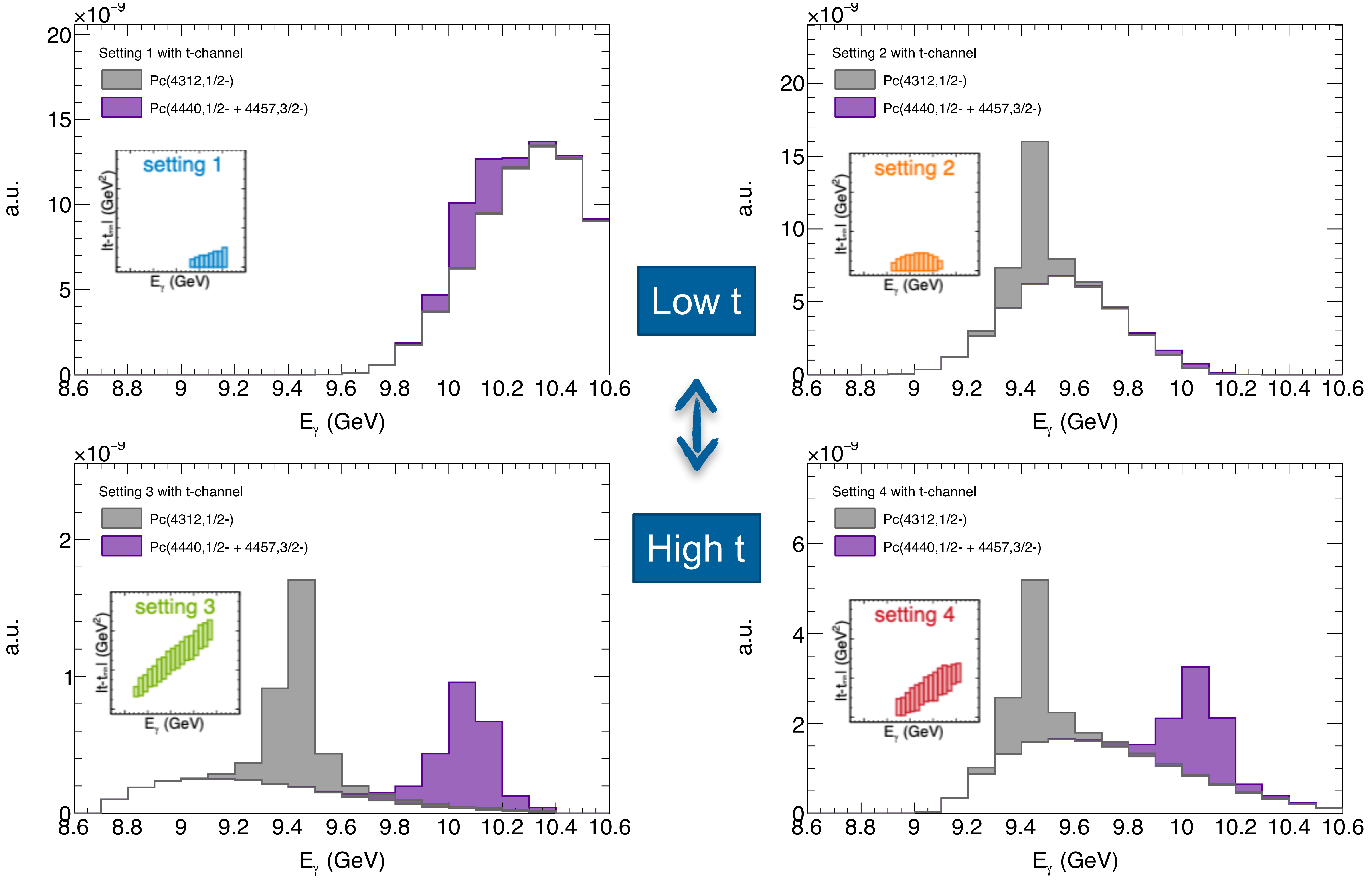
P_c resonances calculated at GlueX 90% upper limit from MC (JPacPhoto + Detector Simulation)

Difficult to separate higher-mass states due to radiative and detector smearing, and limited statistics (coarse binning)

HIGH-T SETTINGS CRUCIAL FOR SENSITIVITY

Improved sensitivity at high t for a given coupling





4% scale uncertainty on cross section

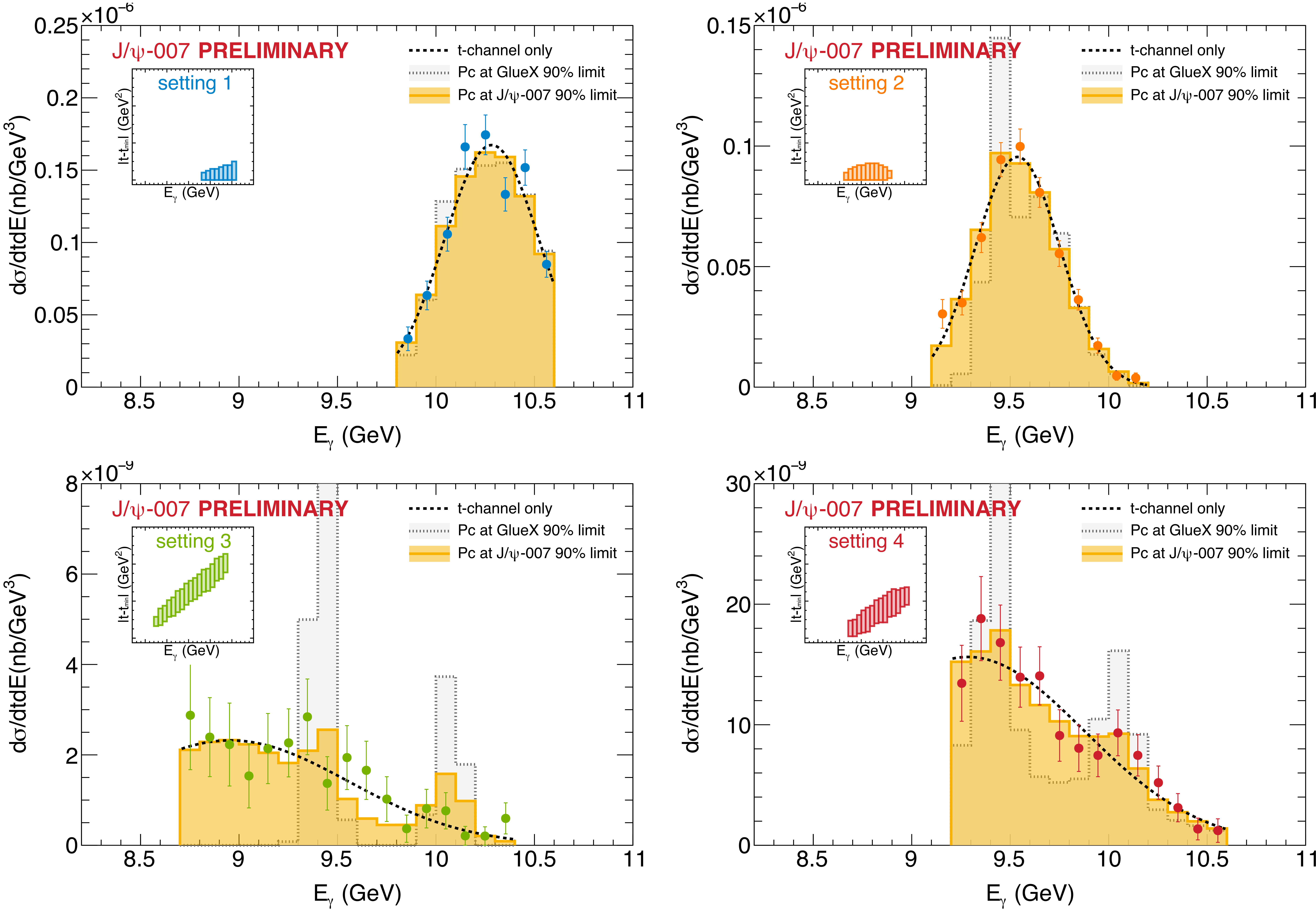
SIGNIFICANCE FIT

Fit 1: bare Gaussian shape describes the cross section well

Fit 2: Signal + background at GlueX upper limit (90% confidence interval). The resonances lead to major tension with the data at high-t.

Fit 3: Same as 2, but with Pc at upper limit (90% confidence interval) from the preliminary J/ψ-007 results themselves

The data suggest a stringent upper limit on the resonant cross section (see next slide).



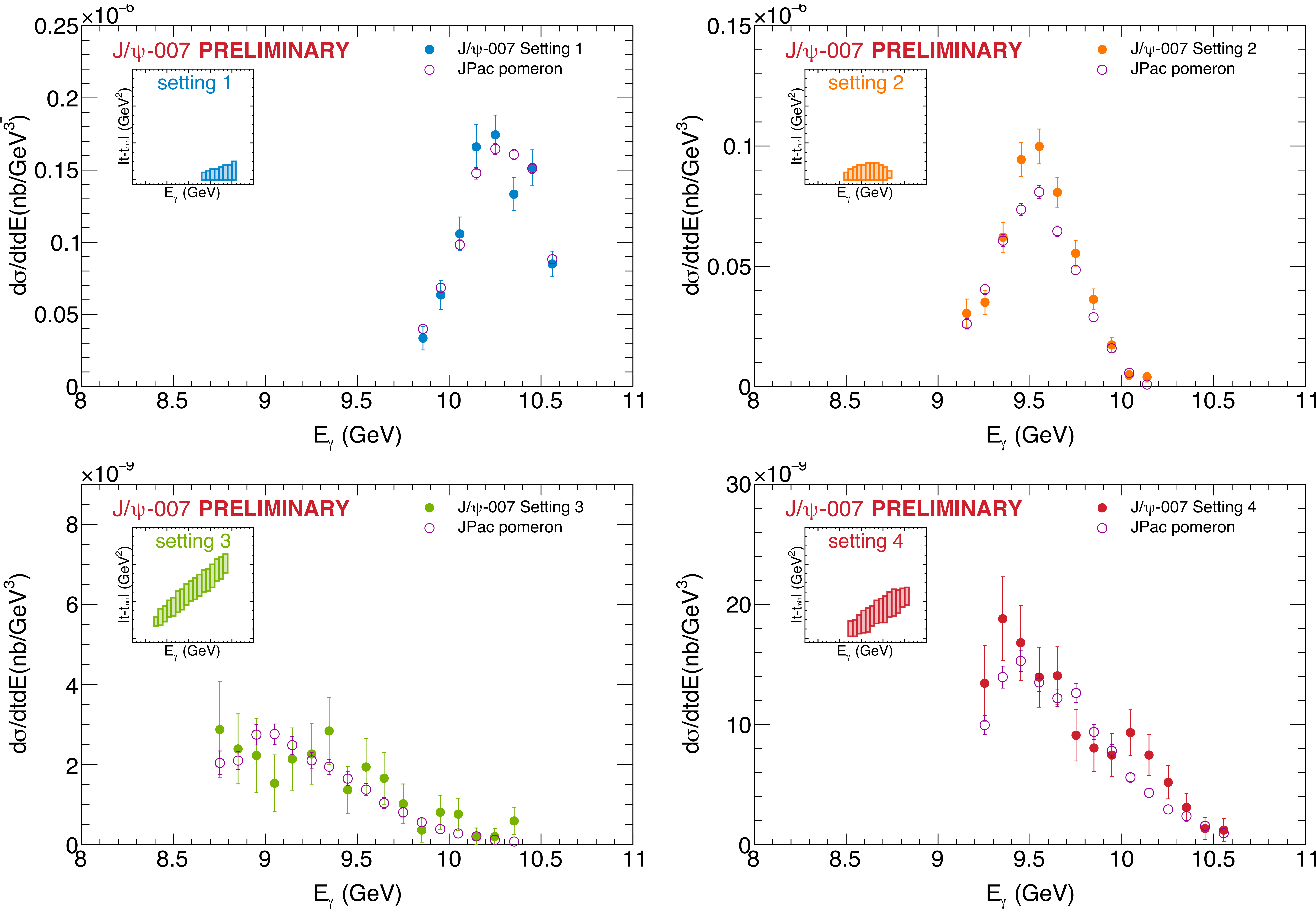
4% scale uncertainty on cross section

COMPARISON WITH T-CHANNEL MODEL CALCULATION

Measured 1D results show decent agreement with predictions from the JPac Pomeron model (constrained by old world data + GlueX 2019 results)

Largest deviations at lower energies

To get more sensitivity to details in the near-threshold cross section, we need the 2D cross section results (see next slide)



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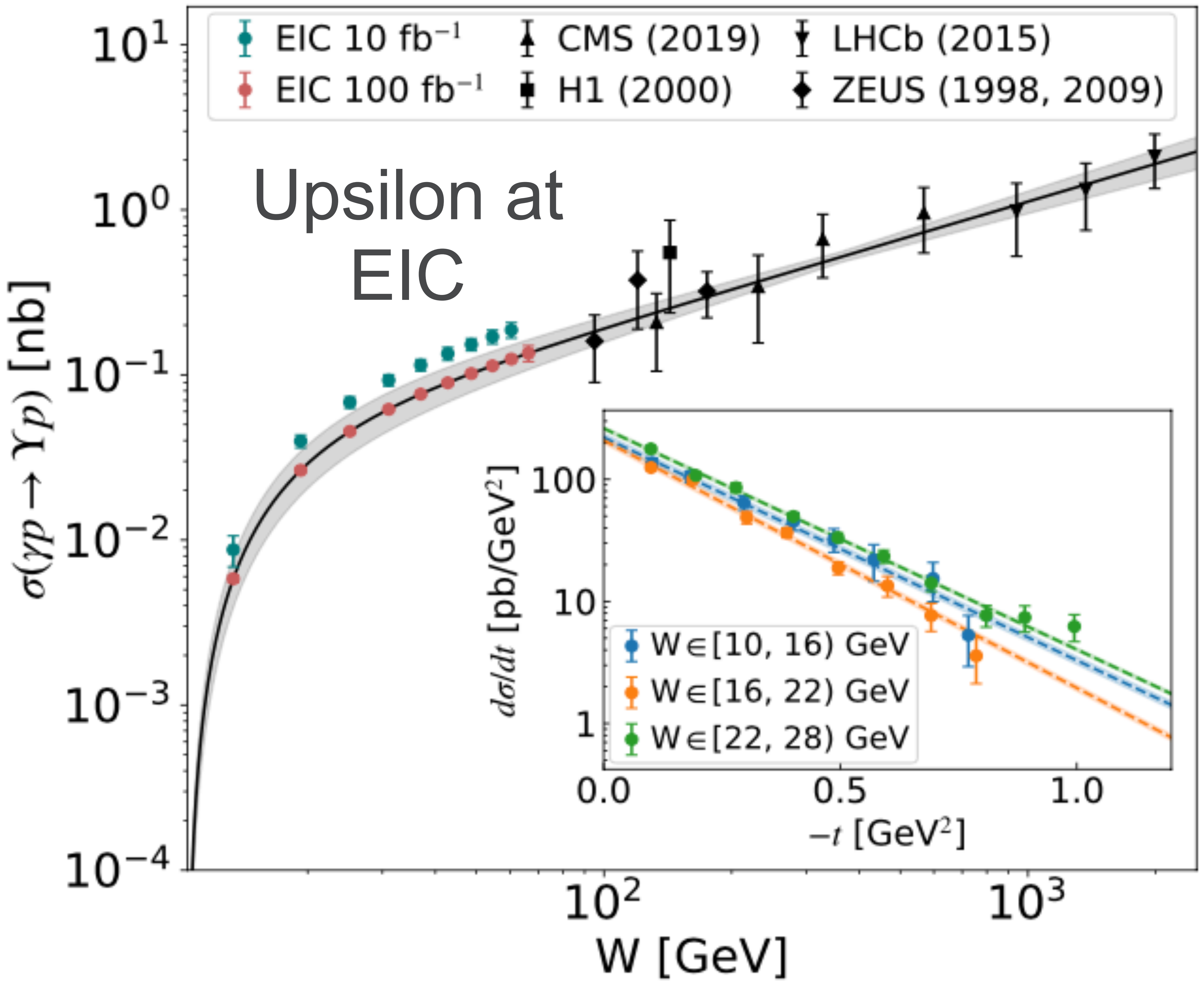
COMPLEMENTARITY WITH EIC (LONG)

J/ψ at SoLID and Υ at EIC

- In principle, EIC creates J/ψ at threshold, but events hard to reconstruct due to limited experimental resolution.
- Threshold production of higher-mass quarkonia (e.g. Υ(1S)) can be measured much more precisely.
- Υ(1S) at EIC trades statistical precision of J/ψ at SoLID for lower theoretical uncertainties, and extra channel to study universality.
- Large Q^2 reach at EIC an additional knob to study production (mostly at higher energies).



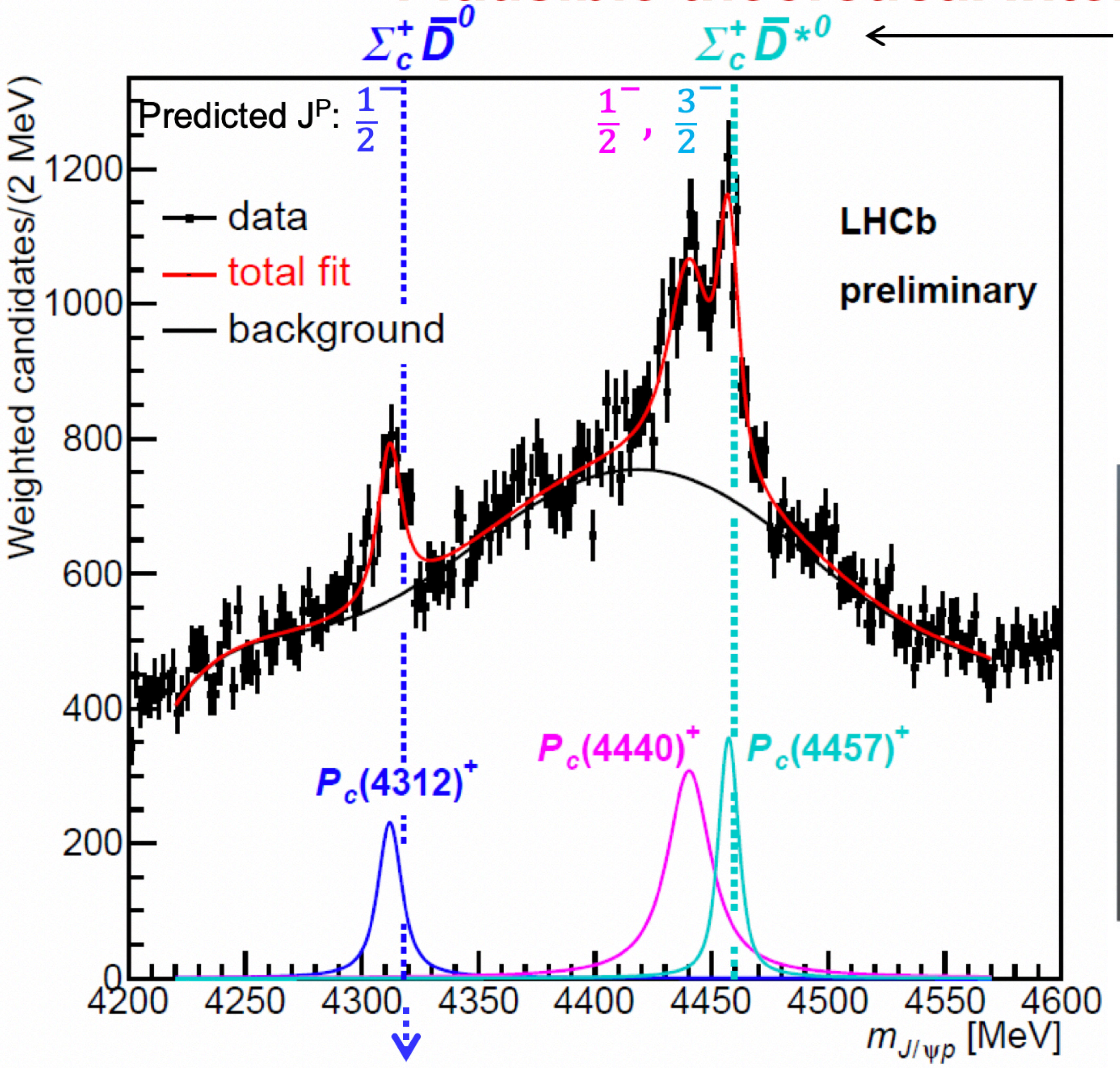
R. Aaij *et al.* (LHCb), Phys.Rev.Lett. 122 (2019) no.22, 222001

LHCb sees strong evidence for 3 resonant states

THE LHC-B CHARMED PENTAQUARKS

Moriond QCD, Tomasz Skwarnicki, Mar 26, 2019 — 14

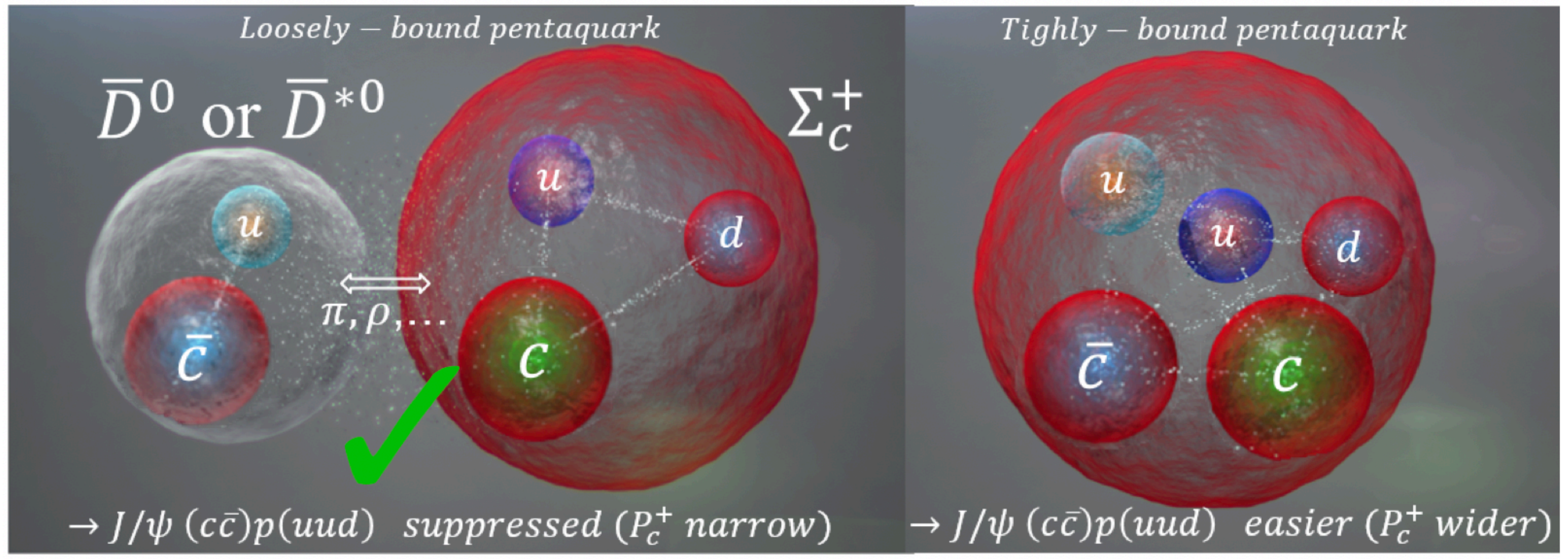
Plausible theoretical interpretation



The **only** thresholds below which molecular bound states are expected in this mass range

LHCb-PAPER-2019-014 in preparation

The near-threshold masses and the narrow widths of $P_c(4312)^+$, $P_c(4440)^+$ and $P_c(4457)^+$ favor "molecular" pentaquarks with meson-baryon substructure!



Existence of $\Sigma_c^+ \bar{D}^0$ molecule would imply importance of ρ-exchange

However, we need to measure J^{P}s to confirm molecular hypothesis, find isospin partners, …

Can diquark substructure separated by a potential barrier [Maiani, Polosa, Riquer, PL,B778, 247 (2018)] produce width suppression?
Are masses near thresholds just by coincidence?
This hypothesis is not ruled out

$P_c(4312)^+$, $P_c(4440)^+$ not near triangle diagram thresholds, $P_c(4457)^+$ is (see backup slides).