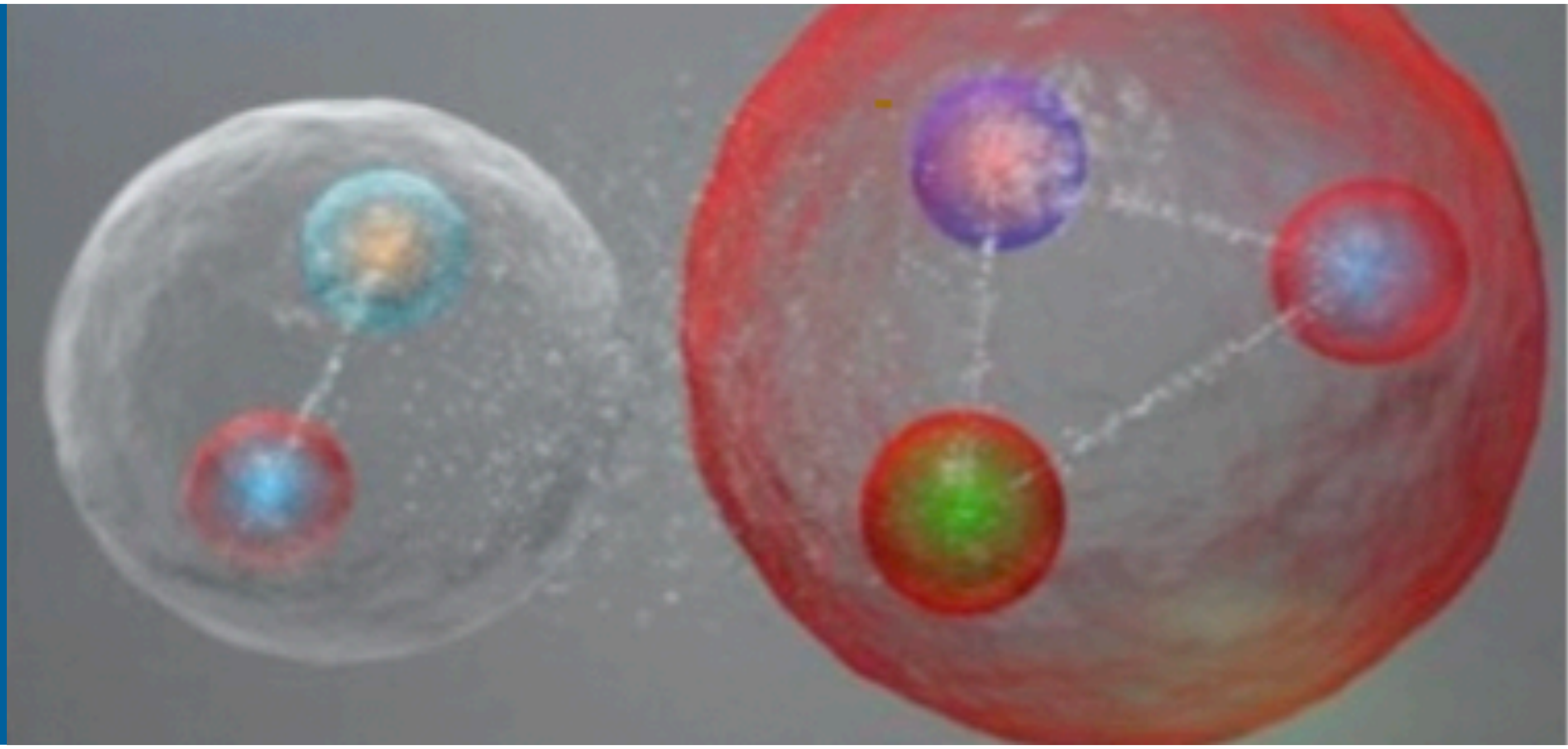
FROM THE PROTON MASS TO PENTAQUARKS

NEW RESULTS ON THRESHOLD J/Ψ PRODUCTION FROM HALL C



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NEW RESULTS ON BEHALF OF
THE HALL C J/Ψ-007 COLLABORATION

This work is supported by the U.S. Department of
Energy, Office of Science, Office of Nuclear Physics,
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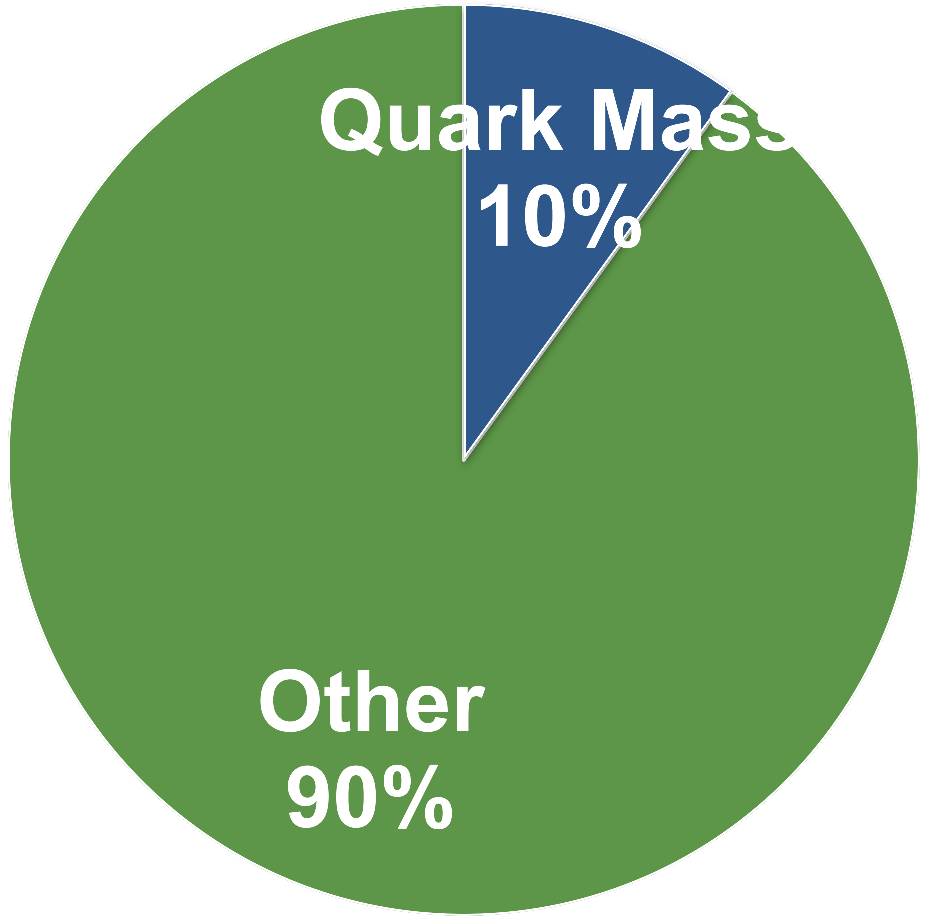
Virginia Tech
July 20, 2022

WHY IS THE PROTON SO HEAVY?

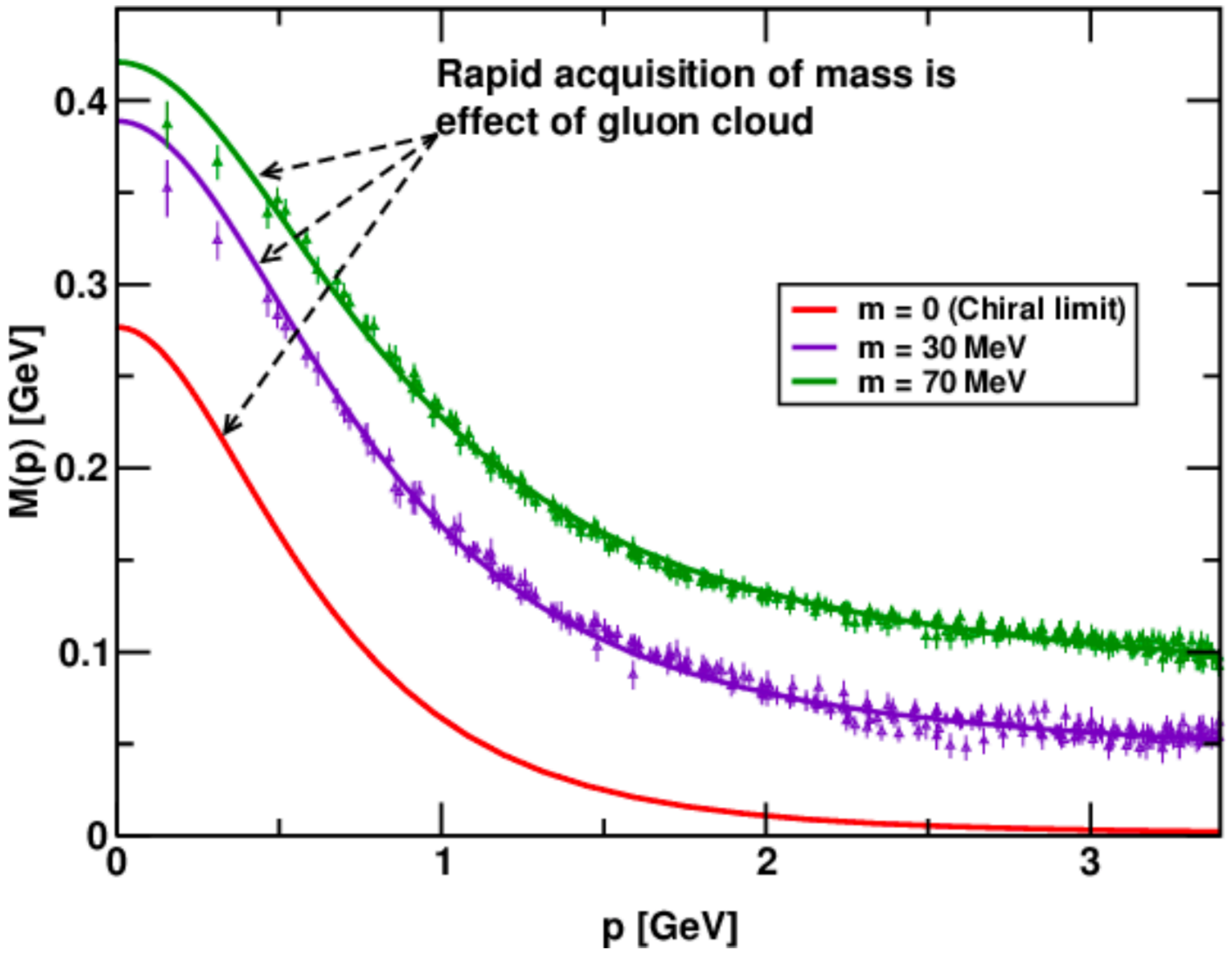
Nucleon mass is an emergent phenomenon

- The proton mass is much larger than the mass sum of its constituents
- Calculations have shown that even in the massless limit, the proton mass would be almost unchanged
- This implies interactions with the Standard Model Higgs field are largely irrelevant for "normal" matter



How do massless gluons provide for the large proton mass?

How is the proton mass distributed inside its confinement size?



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

X. Ji, PRL 74, 1071 (1995) & PRD 52, 271 (1995)

PROTON MASS: REST-FRAME DECOMPOSITION

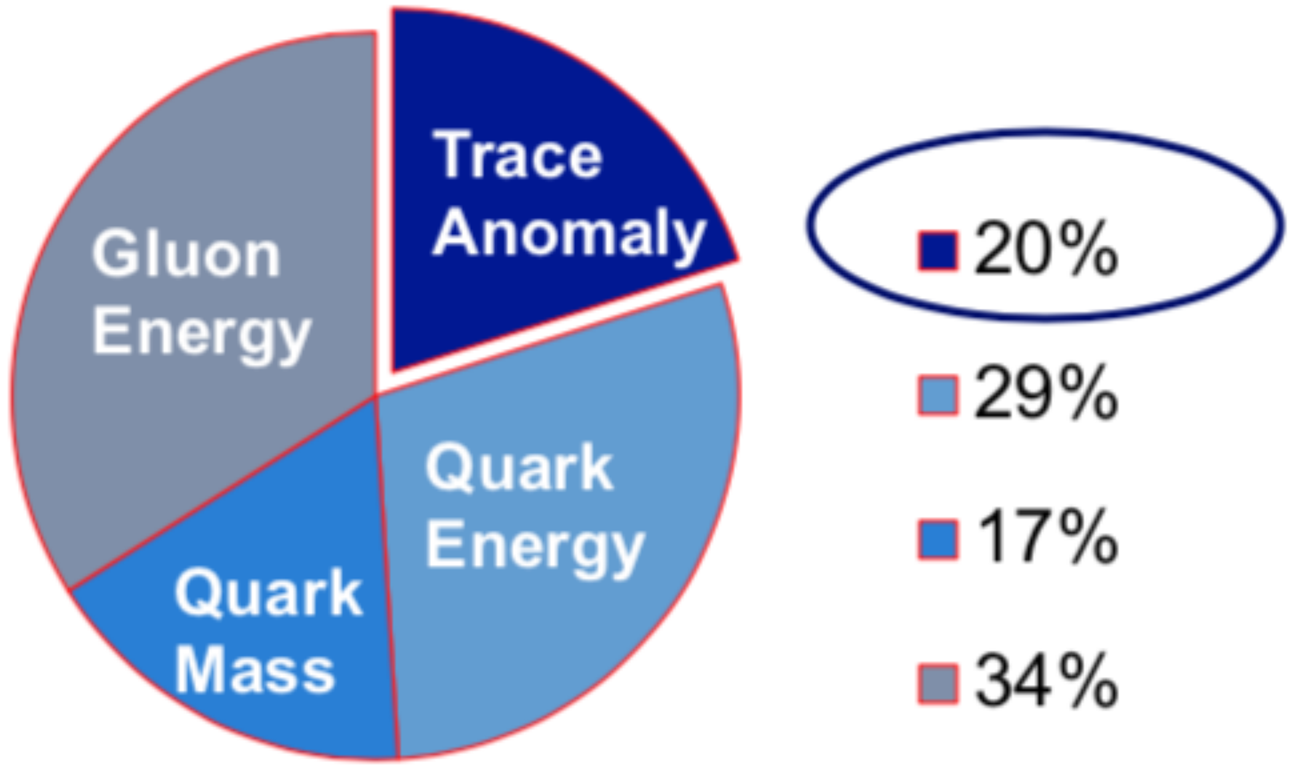
Disentangling the proton mass in its rest frame

- Proton mass is the matrix element of the QCD Hamiltonian in the proton rest frame

$$H_{\mathrm{QCD}} = \int d^3x T^{00}(0,\vec{x})$$
$$= \underbrace{H_q} + \underbrace{H_m} + \underbrace{H_g} + \underbrace{H_a}$$

At leading order:

$$\underbrace{M_q} = \frac{3}{4}\left(a - \frac{b}{1+\gamma_m}\right)M$$
$$\underbrace{M_m} = \frac{4+\gamma_m}{4(1+\gamma_m)}bM$$
$$\underbrace{M_g} = \frac{3}{4}(1-a)M$$
$$\underbrace{M_a} = \frac{1}{4}(1-b)M$$



a(μ) related to PDFs, well constrained

b(μ) related trace anomaly, unconstrained

GRAVITATIONAL FORM FACTORS (GFFS)

The matter structure of the proton

GFFs are the form factors of the EMT for quarks and gluons

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

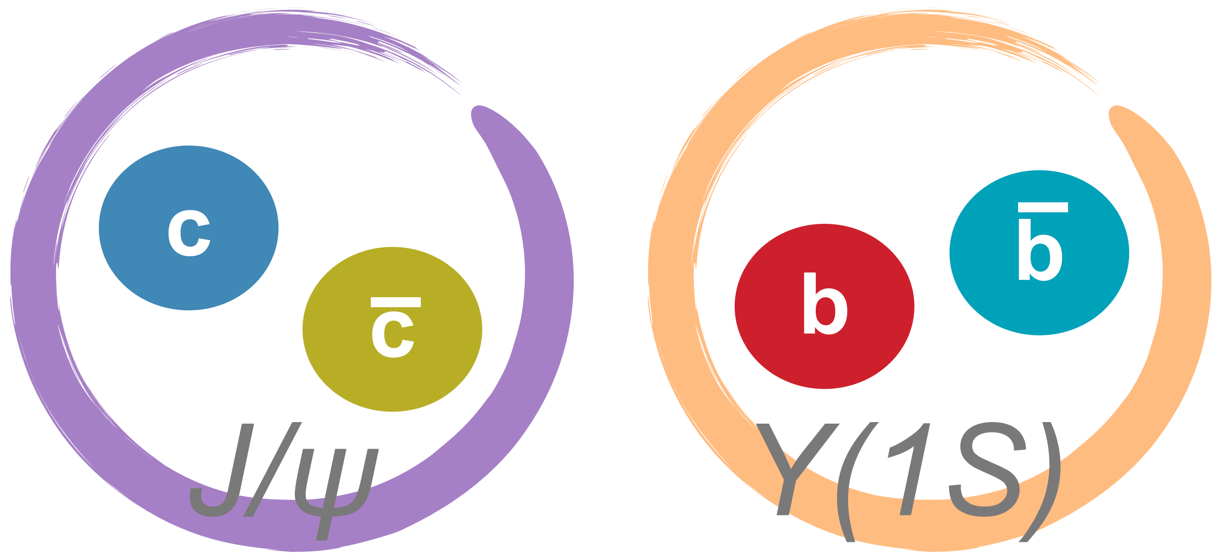
Physics encoded in these GFFs:

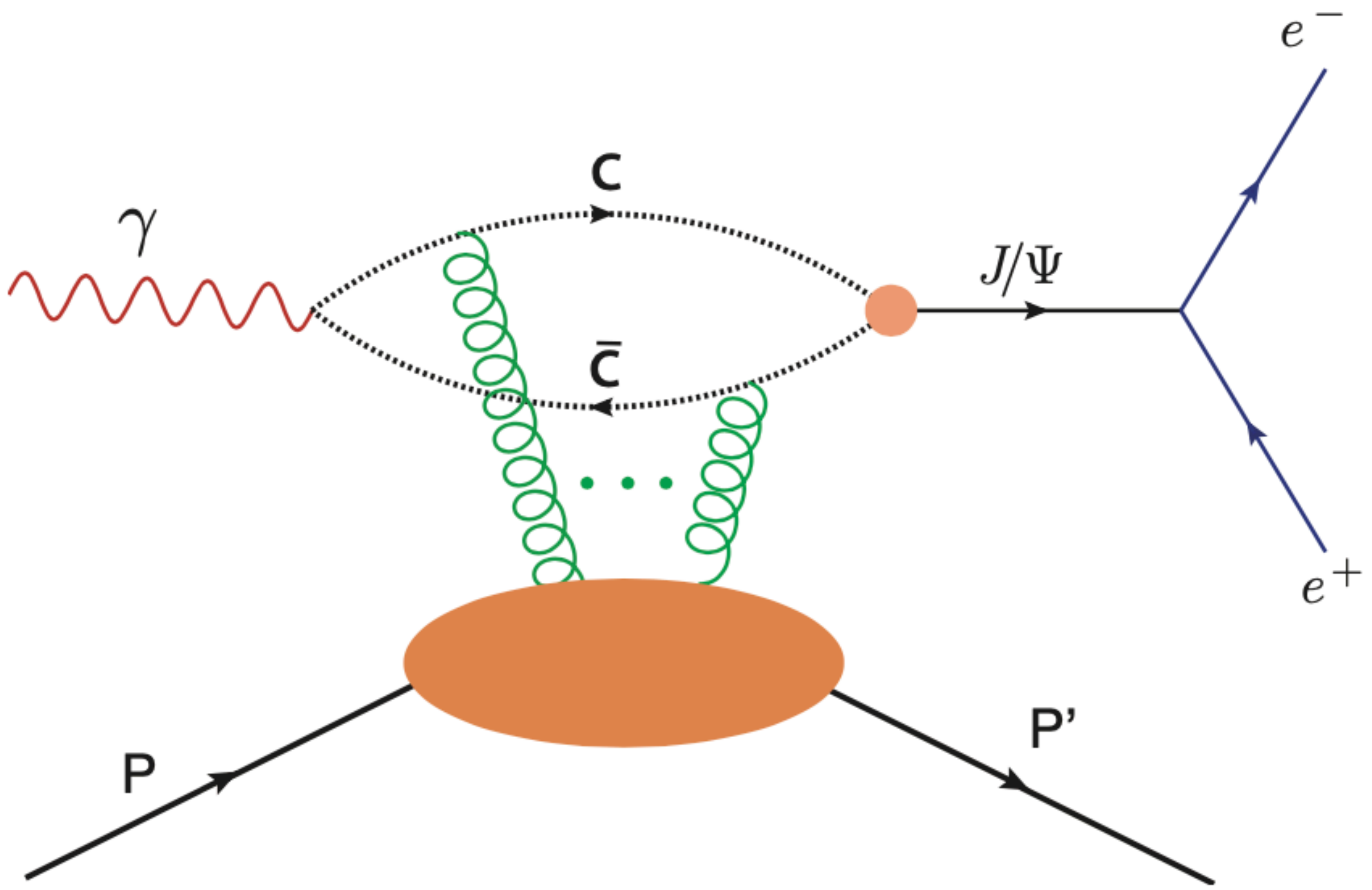
- $A_{g,q}(t)$: Related to quark and gluon momenta, $A_{g,q}(0) = \langle x_{q,g}\rangle$
- $J_{g,q}(t) = 1/2\left(A_{g,q}(t) + B_{g,q}(t)\right)$: Related to angular momentum, $J_{\text{tot}}(0) = 1/2$
- $D_{g,q}(t) = 4C_{g,q}(t)$: Related to pressure and shear forces

WHY QUARKONIUM PRODUCTION NEAR THRESHOLD

Gluons are hard to probe

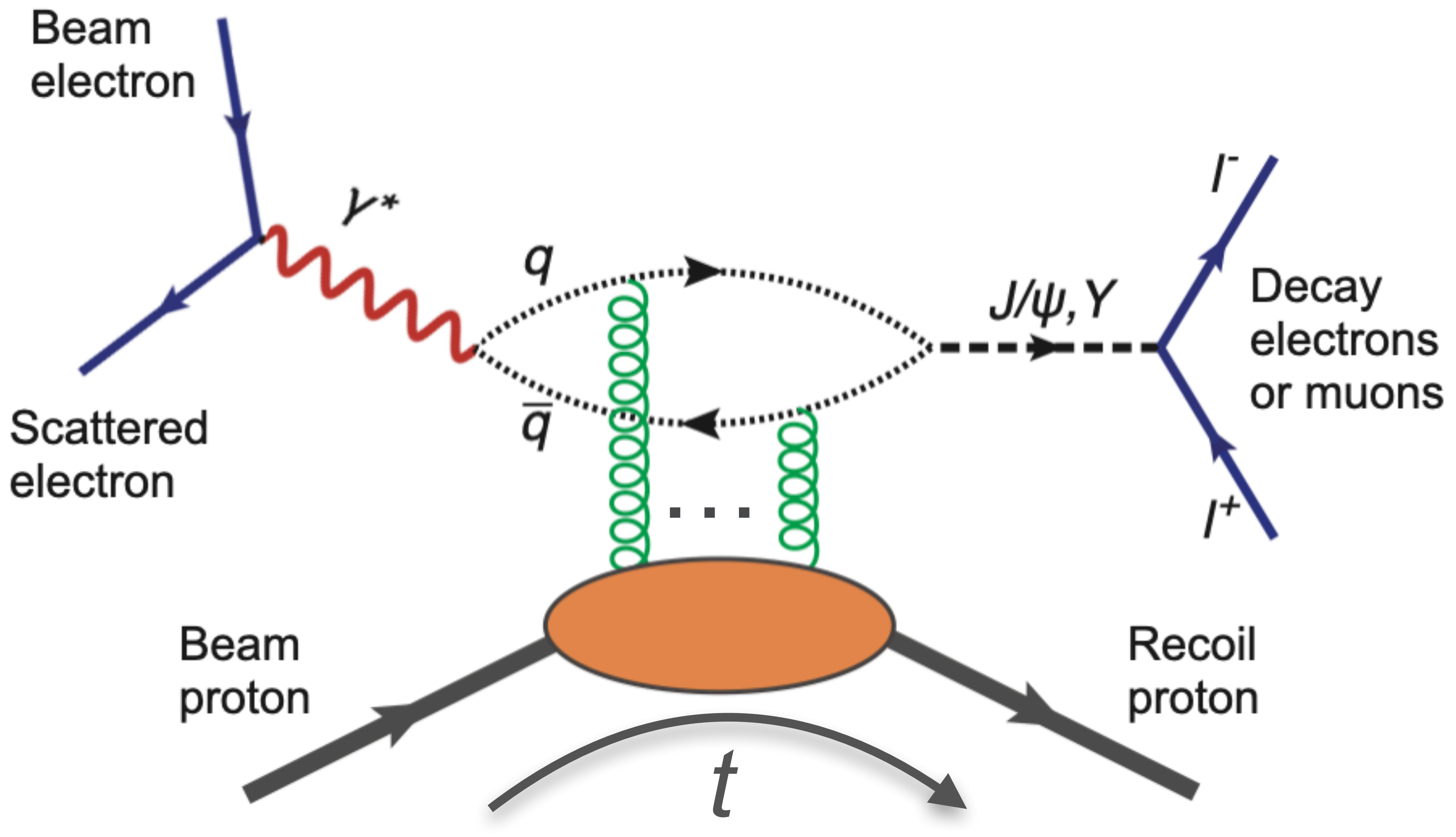
- Electromagnetic charge and spin of the proton well-studied through electron scattering
- Gluons are harder to directly access, as they do not carry electromagnetic charge
  - Description of mass still in infancy, as most energy (and hence mass) carried by the gluons
  - J/ψ and Y(1S) only couple to gluons, not 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:

$W \approx 4.04\text{GeV}$

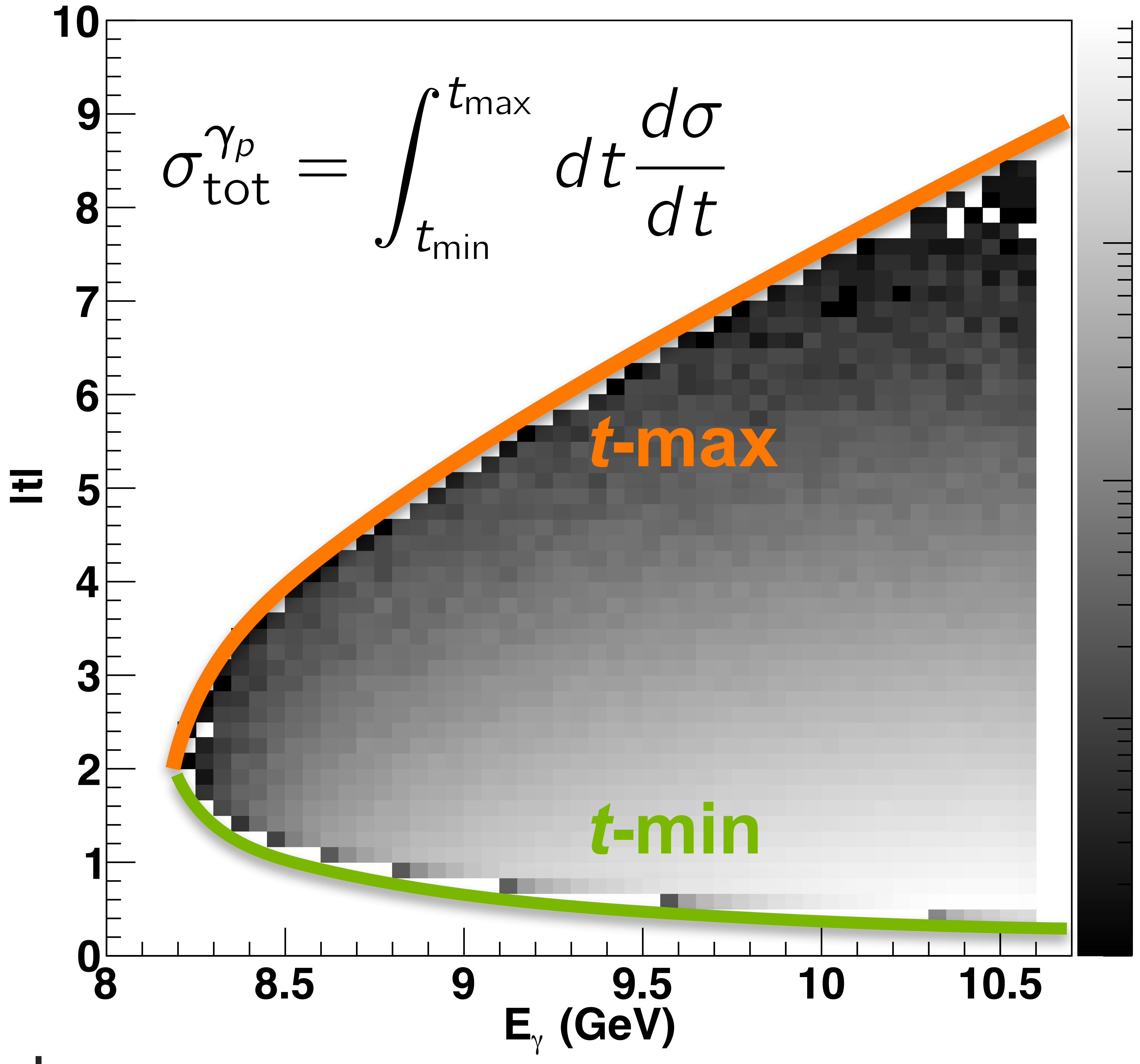
$E_\gamma^{\text{lab}} \approx 8.2\text{GeV}$

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

$Y(1S)$ threshold:

$W \approx 10.4\text{GeV}$

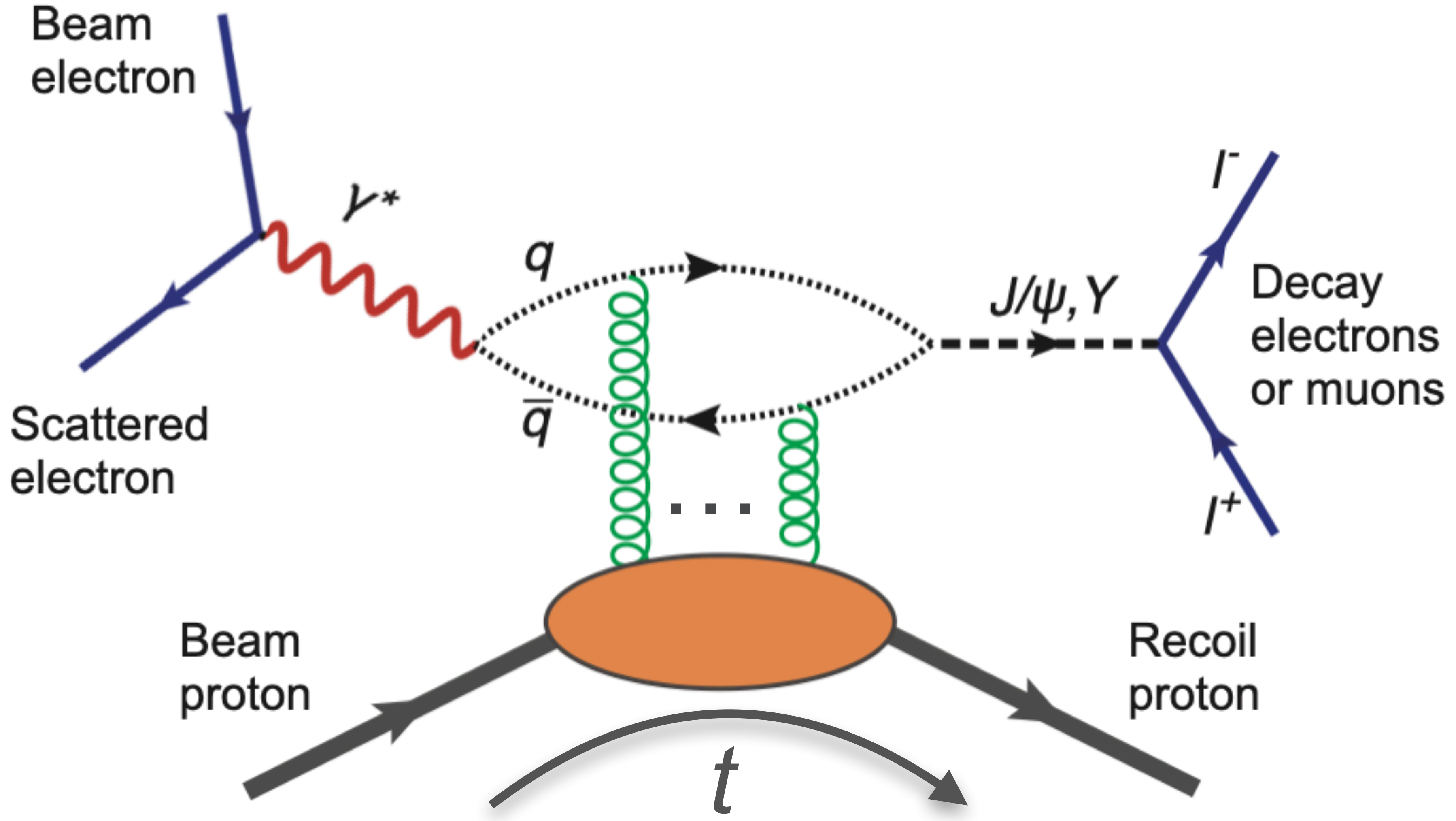
$t \approx -8.1\text{GeV}^2$

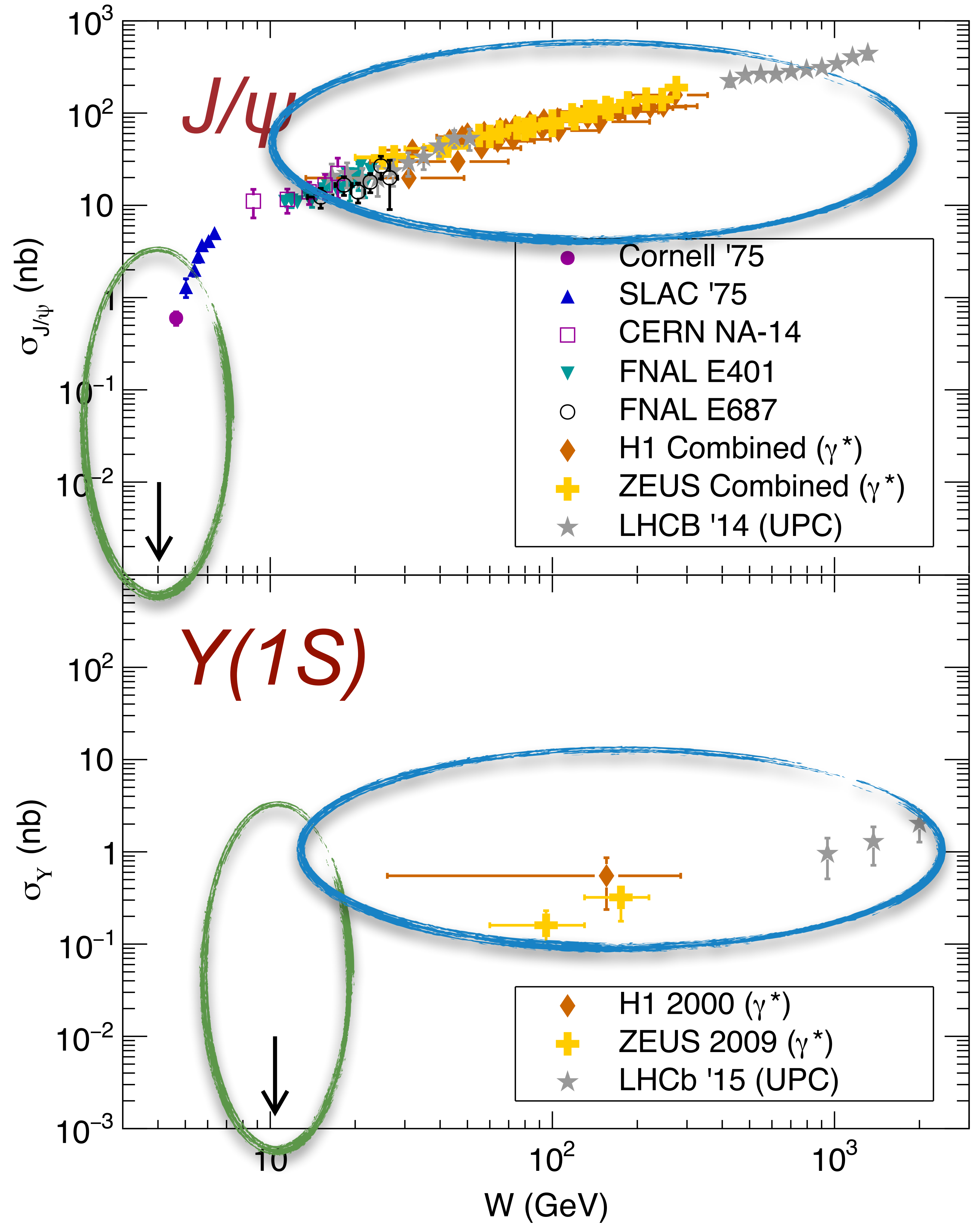


- Phase space limits defined by quarkonium direction
  - Forward (with photon): $t = t_{\text{min}}$
  - Backward (with proton): $t = t_{\text{max}}$
- Forward direction preferred: t-dependence ~exponential

EXCLUSIVE QUARKONIUM PRODUCTION

Before Jefferson Lab 12 GeV





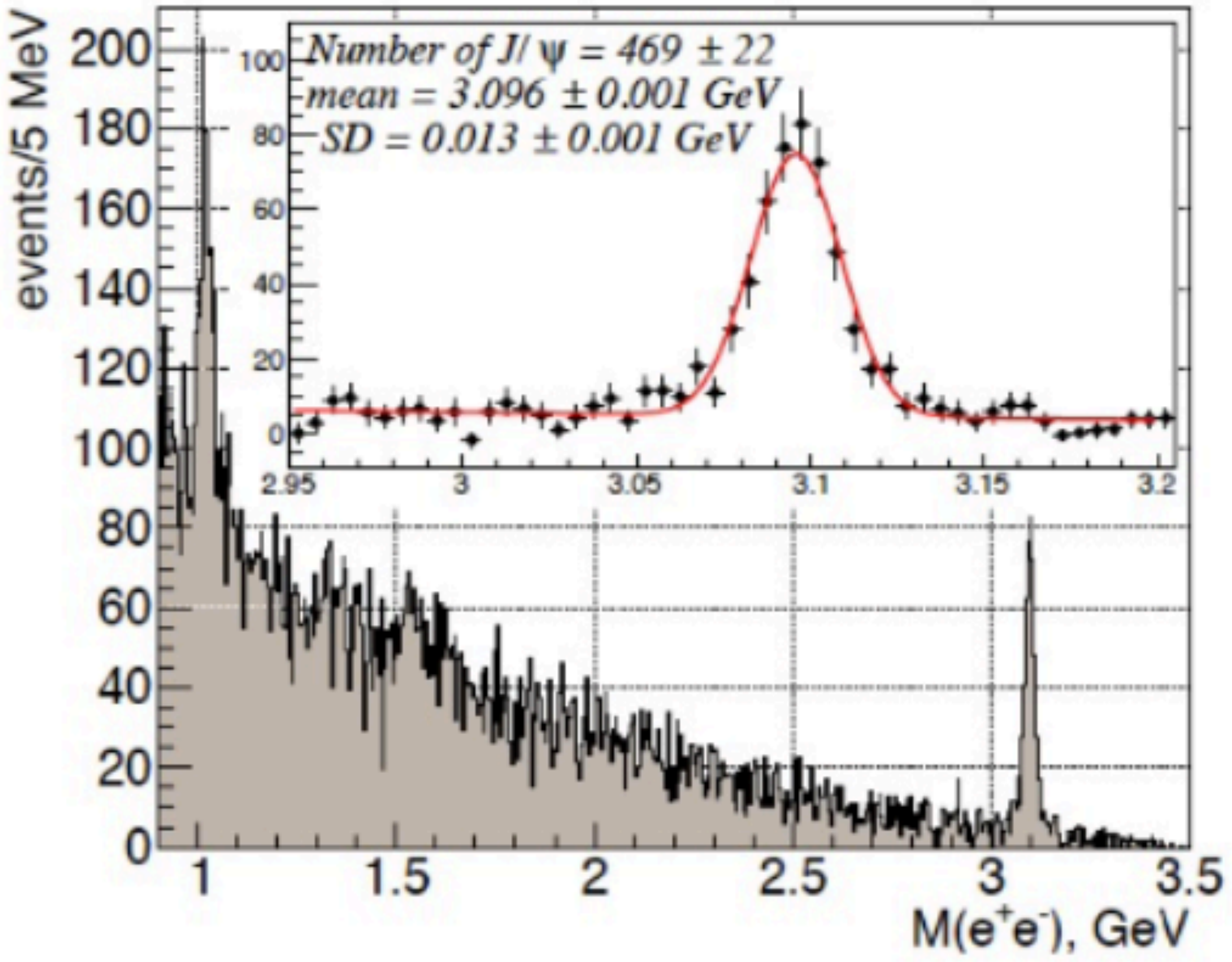
- J/ψ well constrained for high energies in photoproduction
- Υ(1S): not much available
- No significant electroproduction data available
- **Almost no data near threshold before JLab 12 GeV**

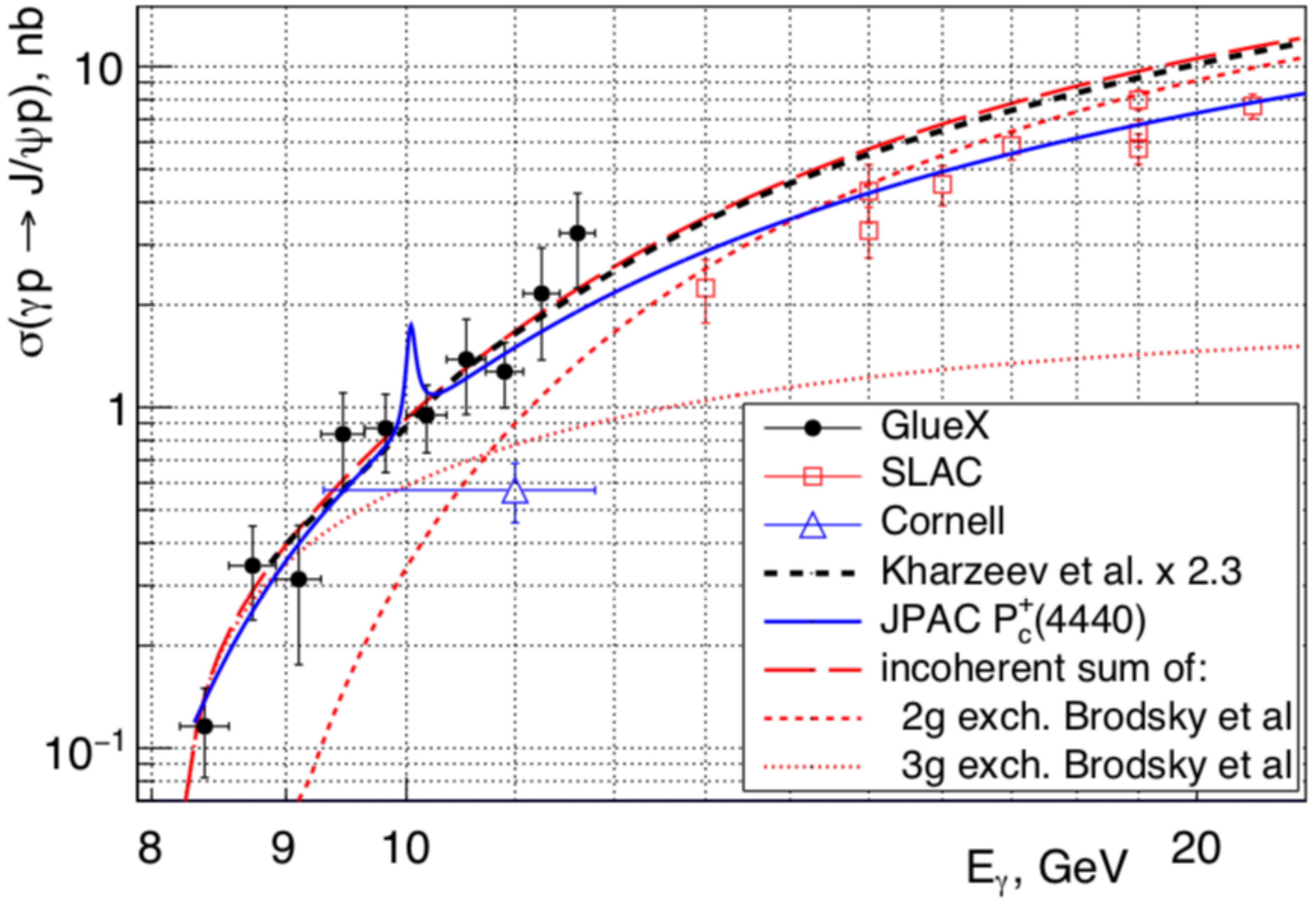
J/Ψ NEAR THRESHOLD IN HALL D

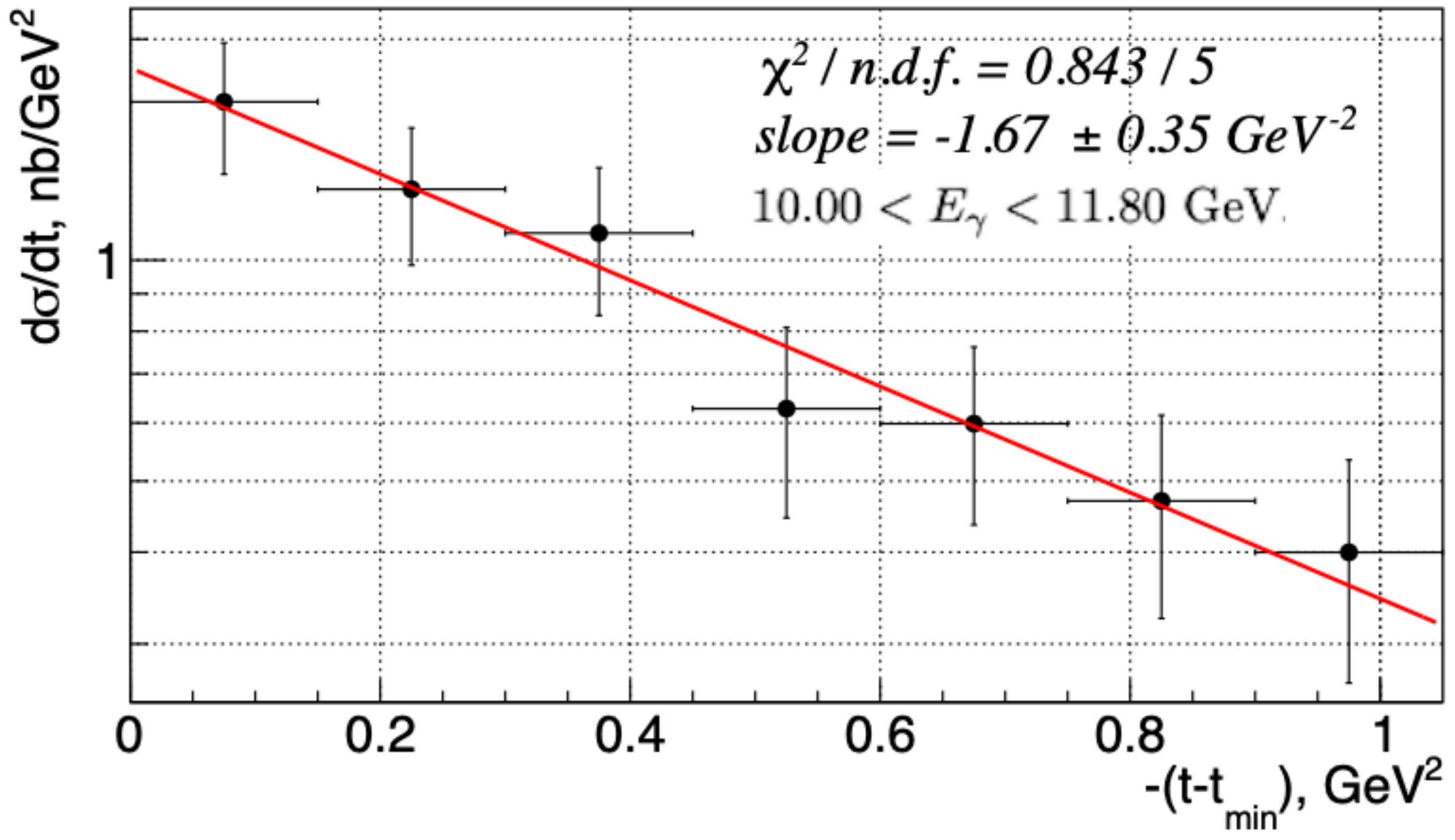
First J/ψ results from JLab, published in PRL 123, 072001 (2019)

- 1D cross section (~469 counts)
- Trends significantly higher than old measurements
- Also released a single 1D t-profile
- Did not see evidence for hidden-charm pentaquarks
- Preliminary new results with 4x more statistics (see Lubomir's talk)

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

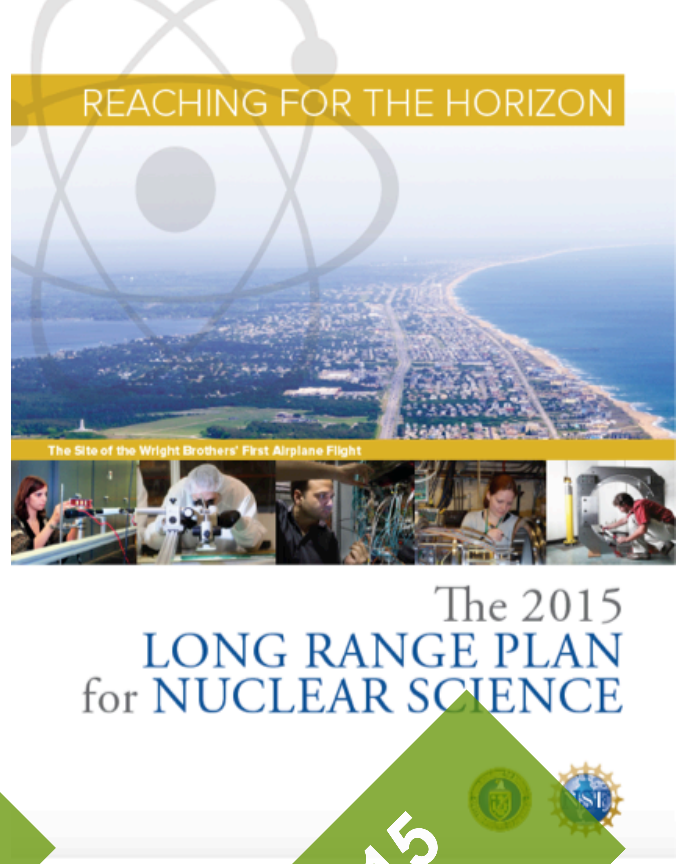






The proton mass: An important topic in contemporary hadronic physics!

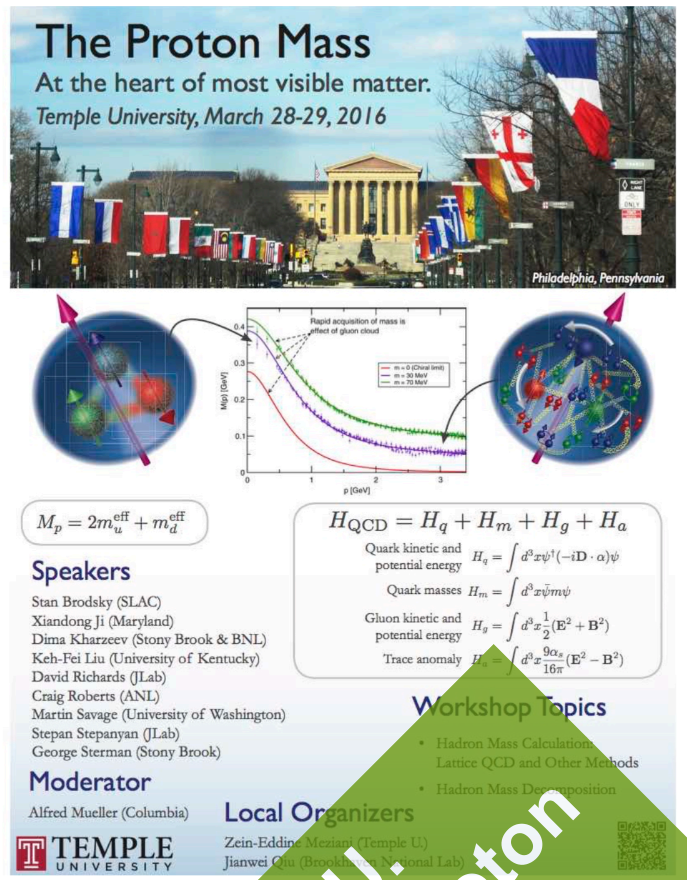
RAPIDLY EVOLVING



REACHING FOR THE HORIZON

The Site of the Wright Brothers' First Airplane Flight

The 2015
LONG RANGE PLAN
for NUCLEAR SCIENCE



The Proton Mass
At the heart of most visible matter.
Temple University, March 28-29, 2016

Philadelphia, Pennsylvania

$$M_p = 2m_u^{\text{eff}} + m_d^{\text{eff}}$$

$$H_{\text{QCD}} = H_q + H_m + H_g + H_a$$

Quark kinetic and potential energy $H_q = \int d^3x\, \psi^\dagger(-i\mathbf{D}\cdot\alpha)\psi$

Quark masses $H_m = \int d^3x\, \bar{\psi} m \psi$

Gluon kinetic and potential energy $H_g = \int d^3x\, \frac{1}{2}(\mathbf{E}^2 + \mathbf{B}^2)$

Trace anomaly $H_a = \int d^3x\, \frac{9\alpha_s}{16\pi}(\mathbf{E}^2 - \mathbf{B}^2)$

Speakers

Stan Brodsky (SLAC)
Xiandong Ji (Maryland)
Dima Kharzeev (Stony Brook & BNL)
Keh-Fei Liu (University of Kentucky)
David Richards (JLab)
Craig Roberts (ANL)
Martin Savage (University of Washington)
Stepan Stepanyan (JLab)
George Sterman (Stony Brook)

Moderator

Alfred Mueller (Columbia)

Workshop Topics

- Hadron Mass Calculation: Lattice QCD and Other Methods
- Hadron Mass Decomposition

Local Organizers

Zein-Eddine Meziani (Temple U.)
Jianwei Qiu (Brookhaven National Lab)

TEMPLE UNIVERSITY

ECT*
EUROPEAN CENTRE FOR THEORETICAL STUDIES IN NUCLEAR PHYSICS AND RELATED AREAS
TRENTO, ITALY
Institutional Member of the European Expert Committee NUPECC

TEMPLE UNIVERSITY
INFN Istituto Nazionale di Fisica Nucleare

Castello di Trento ("Trint"), watercolor 19.8 x 27.7, painted by A. Dürer on his way back from Venice (1495). British Museum, London

The Proton Mass: At the Heart of Most Visible Matter

Trento, April 3 - 7, 2017

Main Topics
Hadron mass decomposition in terms of constituents:
Uniqueness of the decomposition, Quark mass, and quark and gluon energy contribution, Anomaly contribution, ...
Hadron mass calculations:
Lattice QCD (total & individual mass components), Approximated analytical methods, Phenomenological model approaches, ...
Experimental access to hadron mass components:
Exclusive heavy quarkonium production at threshold, nuclear gluonometry through polarized nuclear structure function, …

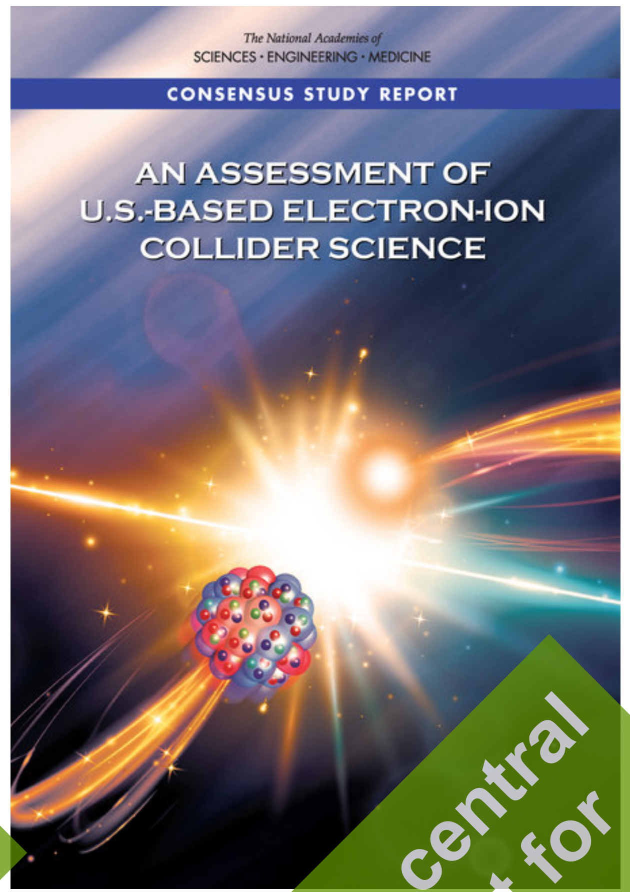
Confirmed speakers and participants
Alexandrou Constantia (*Cyprus University*), Brodsky Stan (*SLAC*), Burkardt Matthias (*New Mexico State University*), Chen Jian-Ping (*Jefferson Lab*), Chudakov Eugene (*Jefferson Lab*), Cloët Ian (*Argonne National Lab*), de Teramond Guy (*University Costa Rica*), Deshpande Abhay (*Stony Brook University*), Eichmann Gernot (*Giessen University*), Hafidi Kawtar (*Argonne National Lab*), Hoelbling Christian (*University of Wuppertal*), Lin Huey-Wen (*Michigan State University*), Liu Keh-Fei (*University of Kentucky*), Lorcé Cédric (*École Polytechnique, Palaiseau*), Mulders Piet (*Vrije University of Amsterdam*), Papavassiliou Joannis (*Valencia University*), Pascalutsa Vladimir (*Johannes Gutenberg University of Mainz*), Richards David (*Jefferson Lab*), Roberts Craig (*Argonne National Lab*), Slifer Karl (*University of New Hampshire*), Mauro Anselmino (*University of Torino & INFN*), Bob Jaffe (*Massachusetts Institute of Technology*), Dima Kharzeev (*Stony Brook University*), Xiangdong Ji (*University of Maryland*).

Organizers
Zein-Eddine Meziani (*Temple University*)
Barbara Pasquini (*University of Pavia*)
Jianwei Qiu (*Jefferson Lab*)
Marc Vanderhaeghen (*Universität Mainz*)

Director of the ECT*: Professor Jochen Wambach (ECT*)

The ECT* is sponsored by the "Fondazione Bruno Kessler" in collaboration with the "Assessorato alla Cultura" (Provincia Autonoma di Trento), funding agencies of EU Member and Associated States and has the support of the Department of Physics of the University of Trento.

For local organization please contact: Gianmaria Ziglio - ECT* Secretariat - Villa Tambosi - Strada delle Tabarelle 286 - 38123 Villazzano (Trento) - Italy
Tel.:(+39-0461) 314721 Fax:(+39-0461) 314750, E-mail: **ect@ectstar.eu** or visit **http://www.ectstar.eu**



The National Academies of SCIENCES · ENGINEERING · MEDICINE

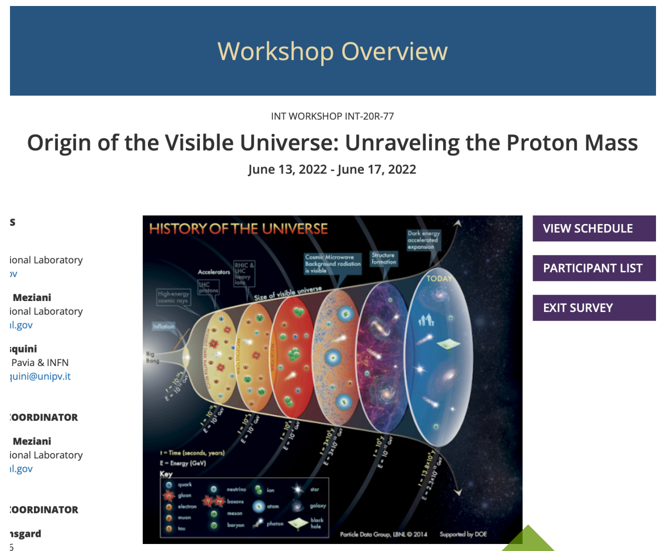
CONSENSUS STUDY REPORT

AN ASSESSMENT OF U.S.-BASED ELECTRON-ION COLLIDER SCIENCE

3rd Proton Mass Workshop: Origin and Perspective

s Workshop; Origin and Perspective

https://indico.phy.anl.gov/even



Workshop Overview

INT WORKSHOP INT-20R-77

Origin of the Visible Universe: Unraveling the Proton Mass

June 13, 2022 - June 17, 2022

2012 Temple U. Workshop on heavy quarkonia

2015 LHCb finds resonance in J/ψ-p channel consistent with pentaquarks

Featured in the 2015 Long Range plan

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

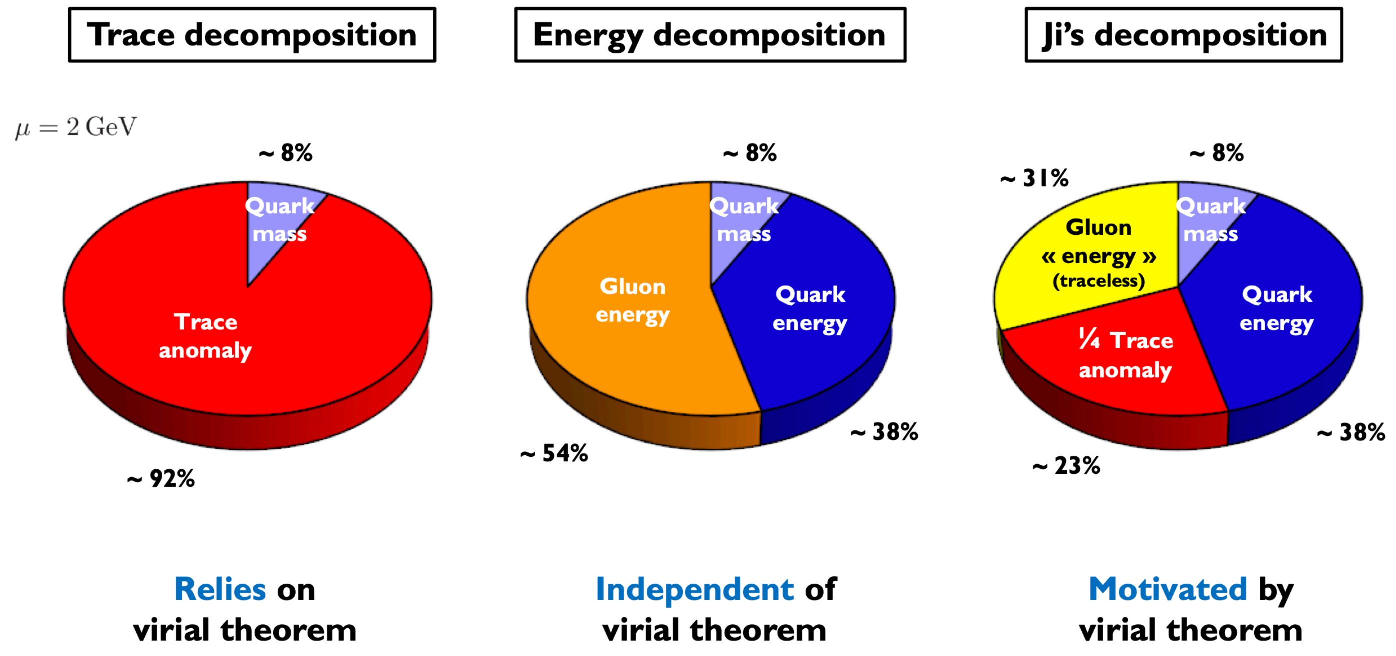
2021 Remote Workshop on the proton mass

2021 First Hall C results on the pentaquark search

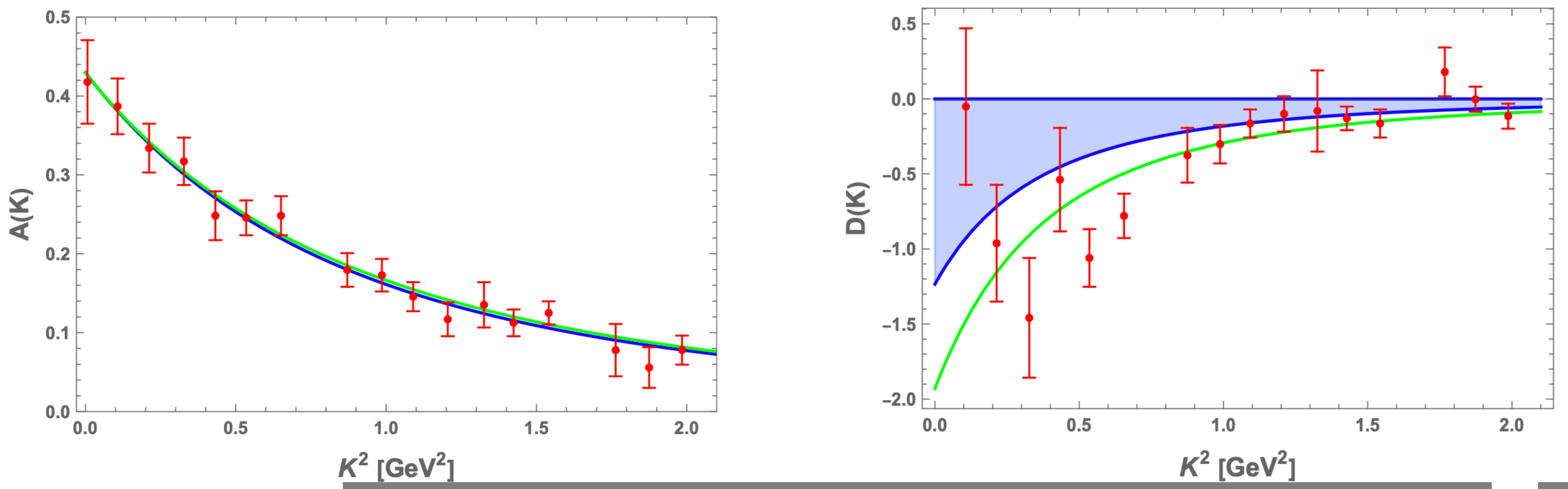
2022 INT Workshop on the proton mass

2022 First 2D near-threshold J/ψ results from Hall C

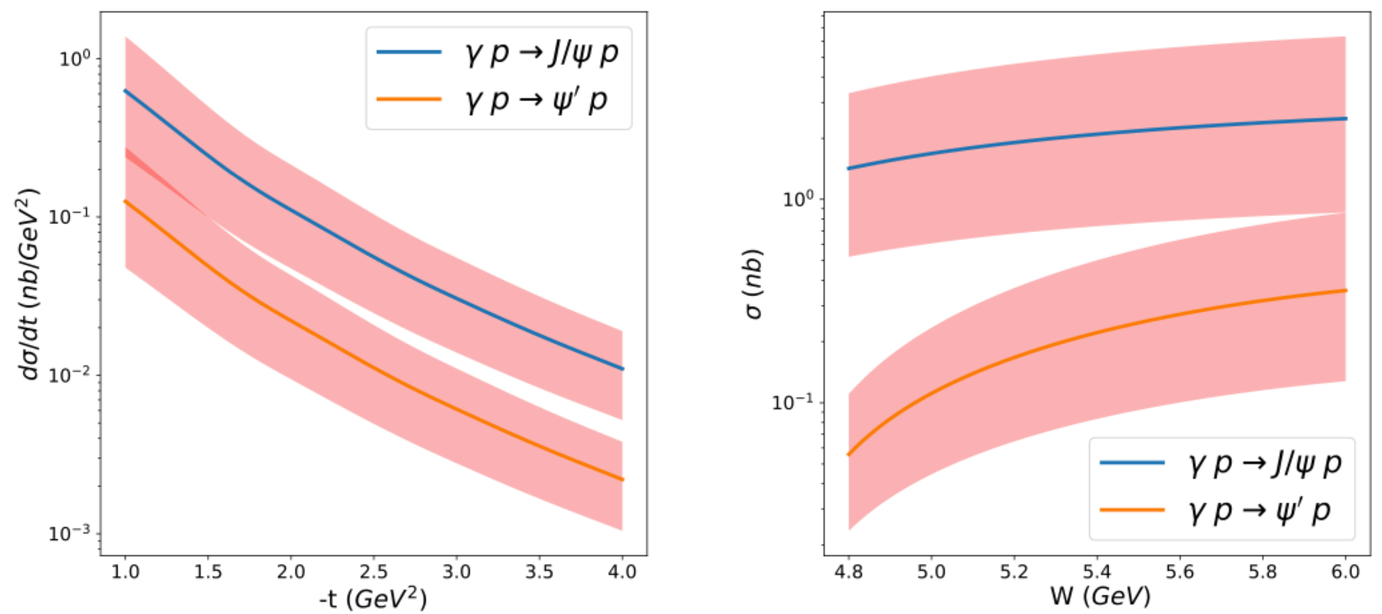
PROMINENT RECENT DEVELOPMENTS



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

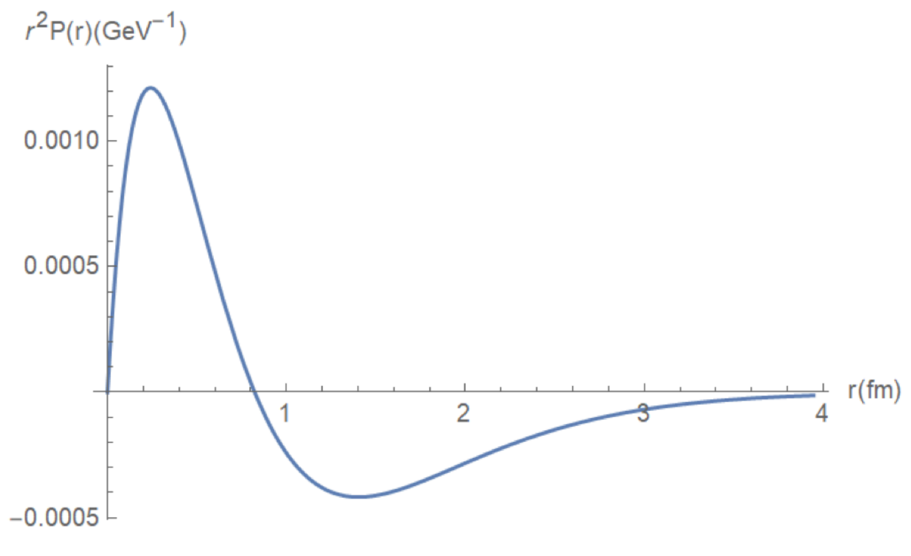


Proton gravitational form factors holographic QCD compared with Lattice, K. Mamo & I. Zahed (2022)

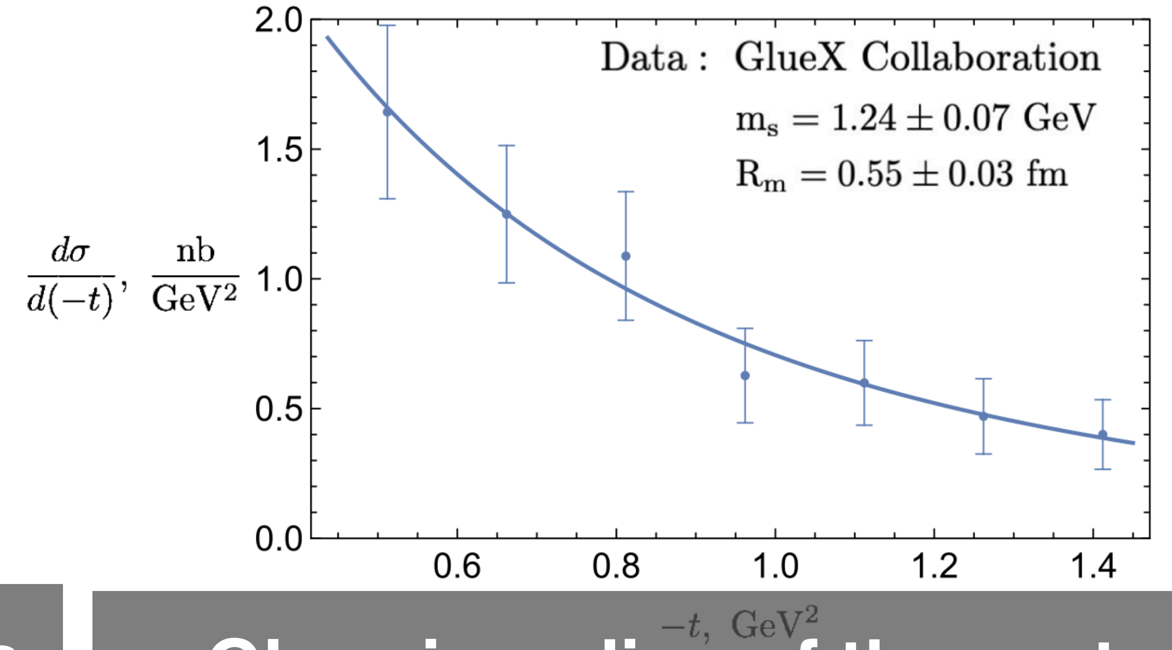


Near-threshold heavy quarkonium production at large momentum transfer, P. Sun, X-B. Tong, F. Yuan (PRD 2022)

- 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)



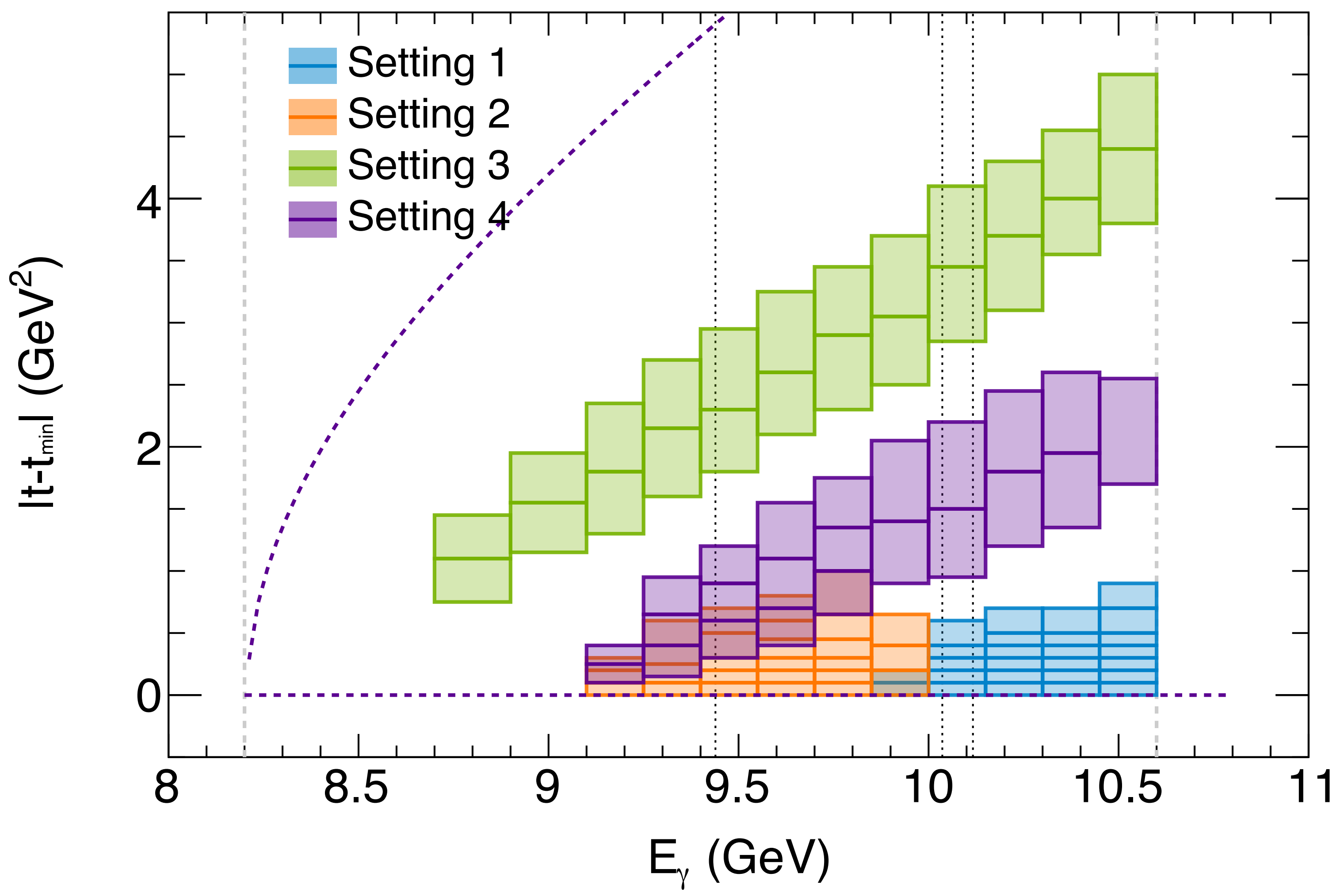
Gluonic radius of the proton based on 1D GlueX results, D. Kharzeev (PRD 2021)

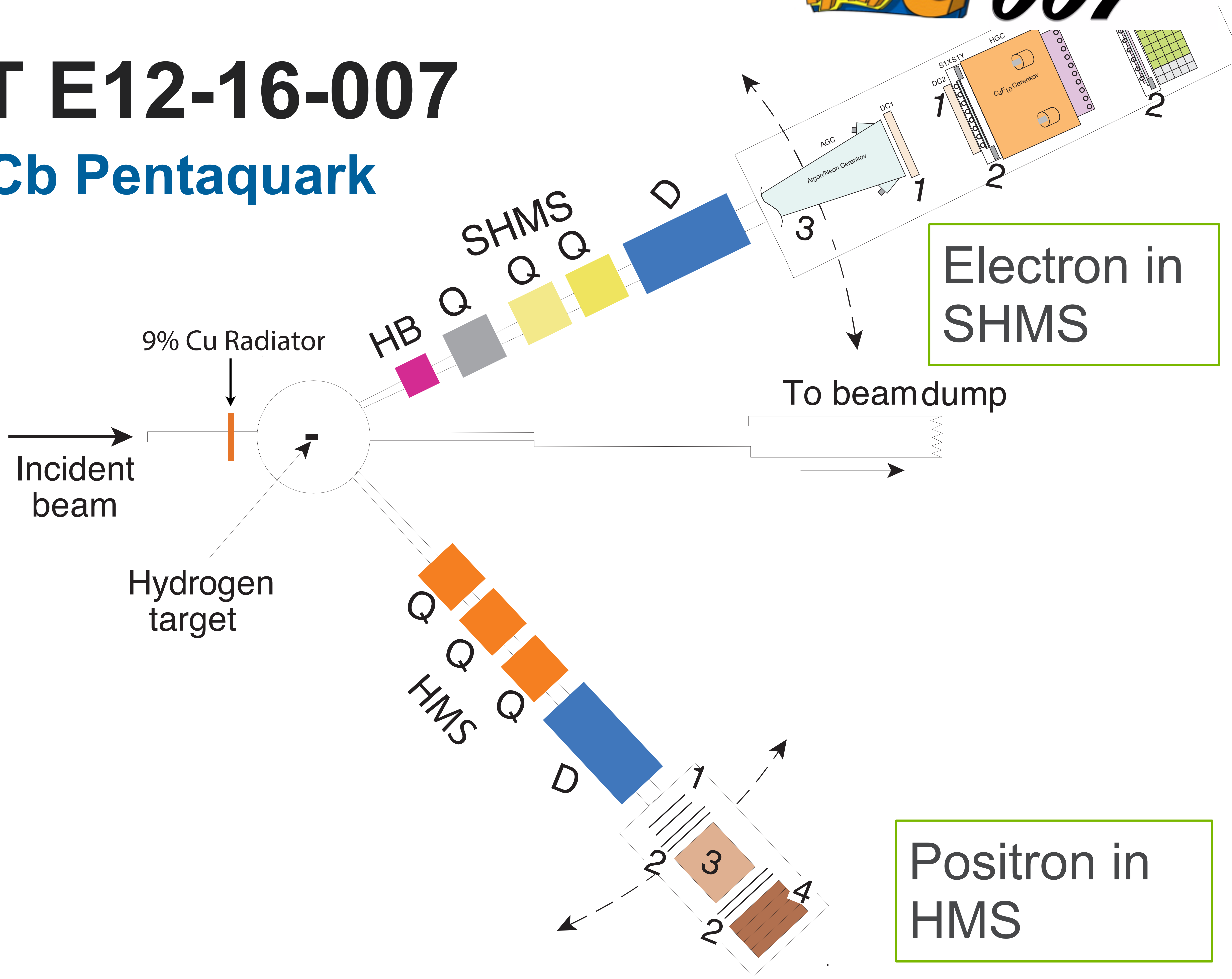
Z.-E. Meziani, S. Joosten *et al.*, arXiv:1609.00676 [hep-ex]
K. Hafidi, S. Joosten *et al.*, Few Body Syst. 58 (2017) no.4, 141

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



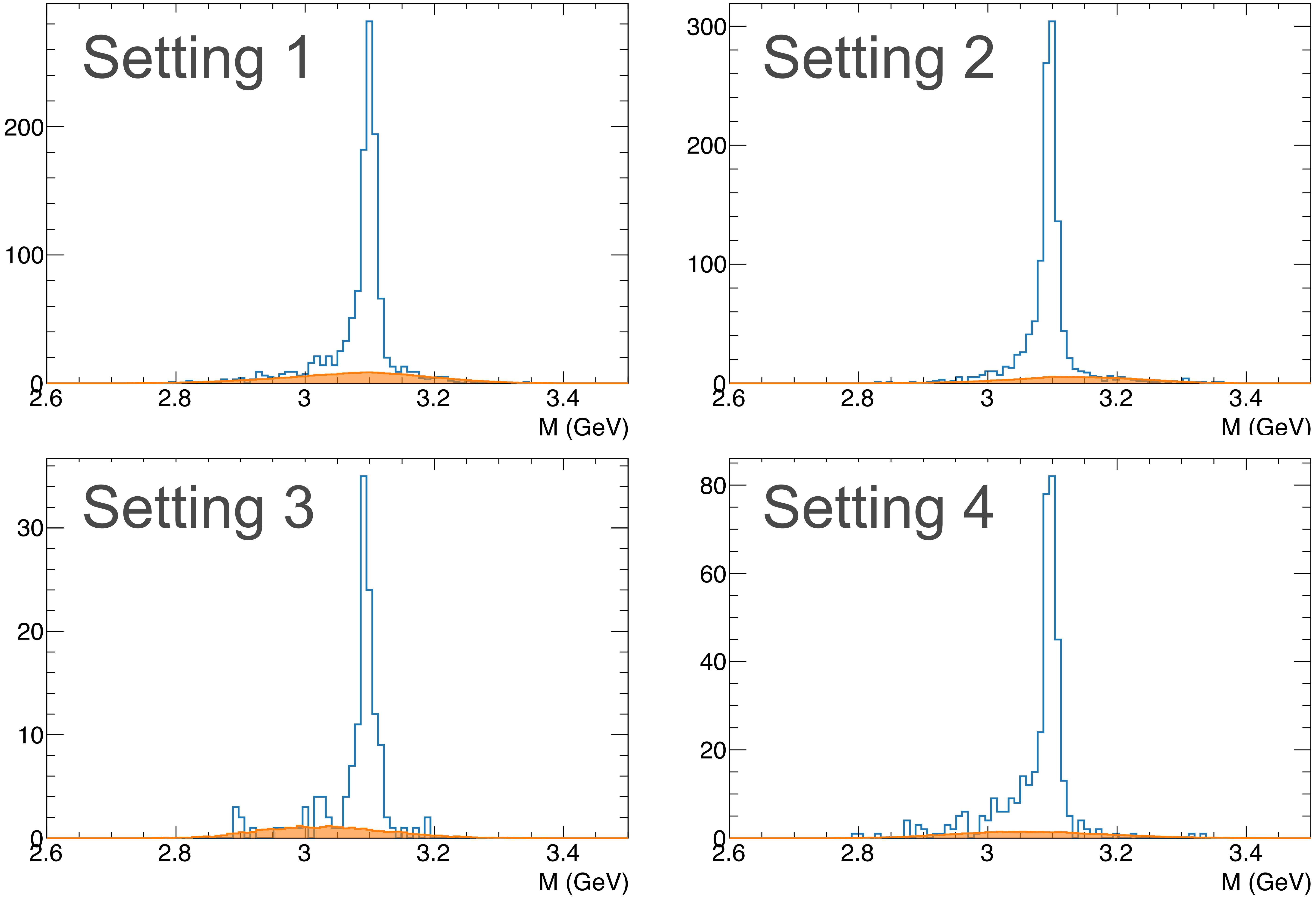


Electron in SHMS

Positron in HMS

CLEAR J/Ψ SIGNAL WITH MINIMAL BACKGROUND

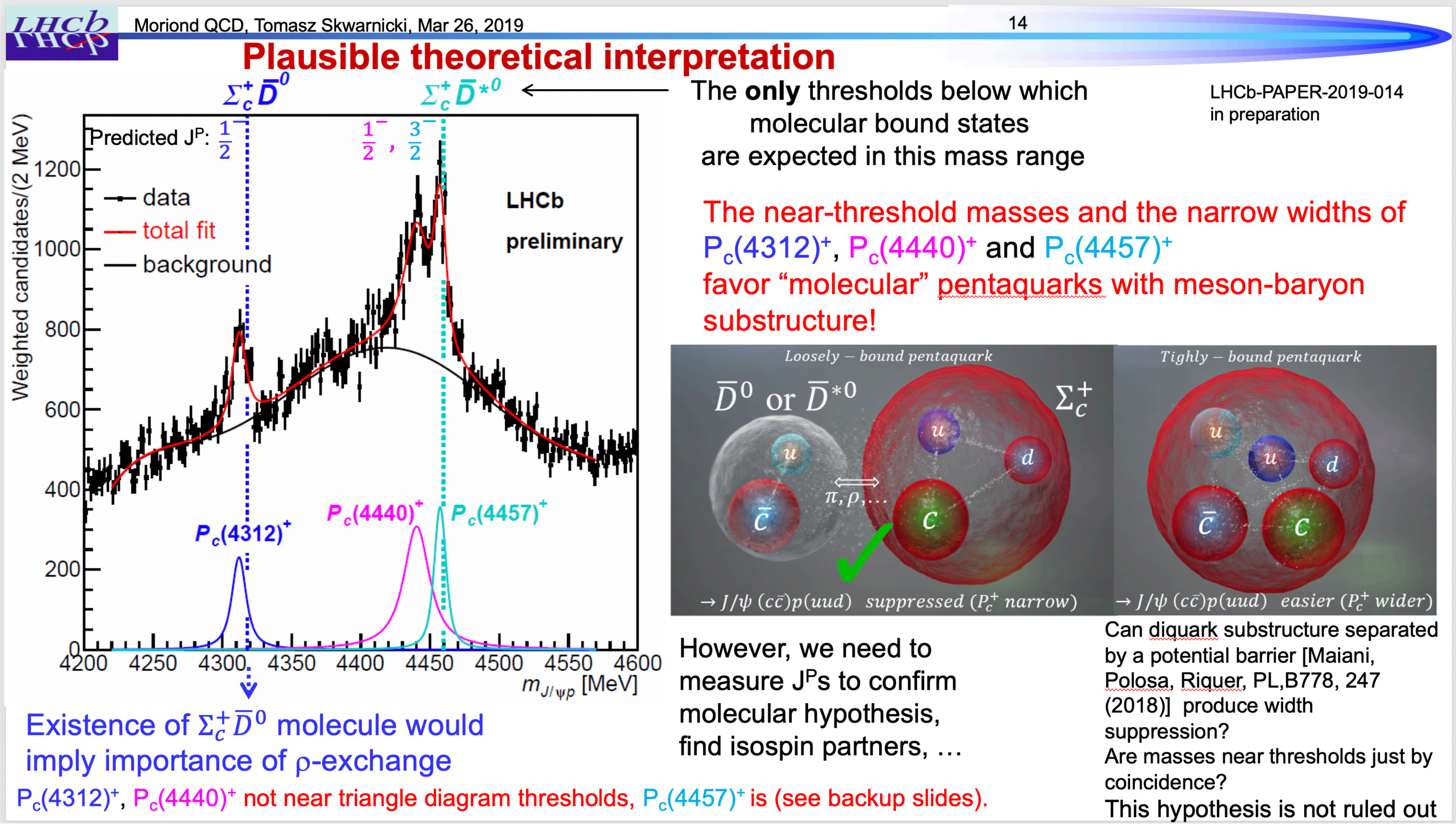
settings	HMS	SHMS	target	charge [C]	goal
setting 1	19.1° at +4.95GeV	17.0° at -4.835GeV	LH2 with radiator	5.2	low-t and high energy
			dummy with radiator	0.6	target wall
			LH2, no radiator	0.1	electroproduction
setting 2	19.9° at +4.6GeV	20.1° at -4.3GeV	LH2 with radiator	8.2	low-t and low energy
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



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

$\Sigma_c^+\bar{D}^0$ $\Sigma_c^+\bar{D}^{*0}$ ← 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^Ps 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).

4% scale uncertainty on cross section

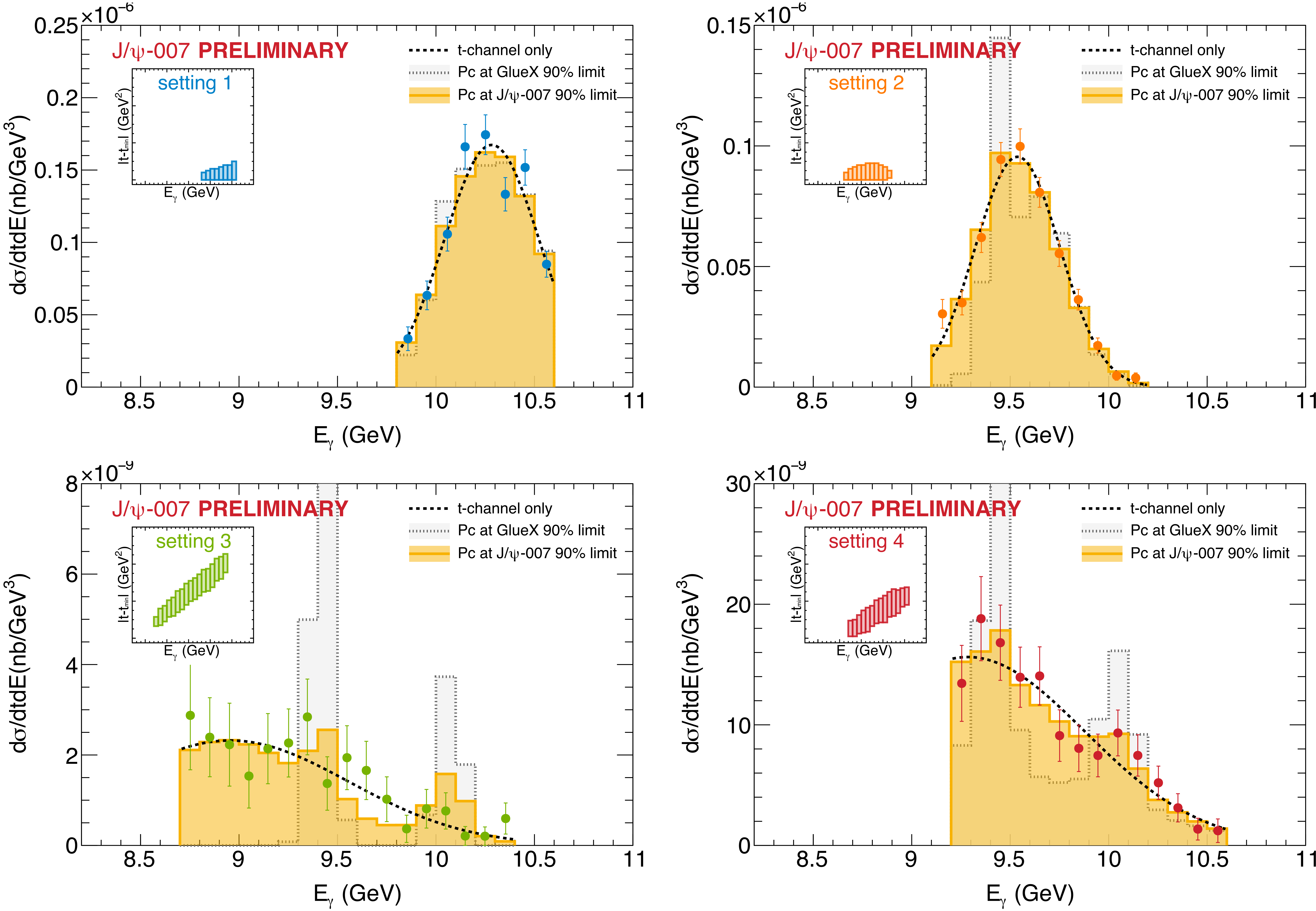
SCANNING THE SPECTRUM

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

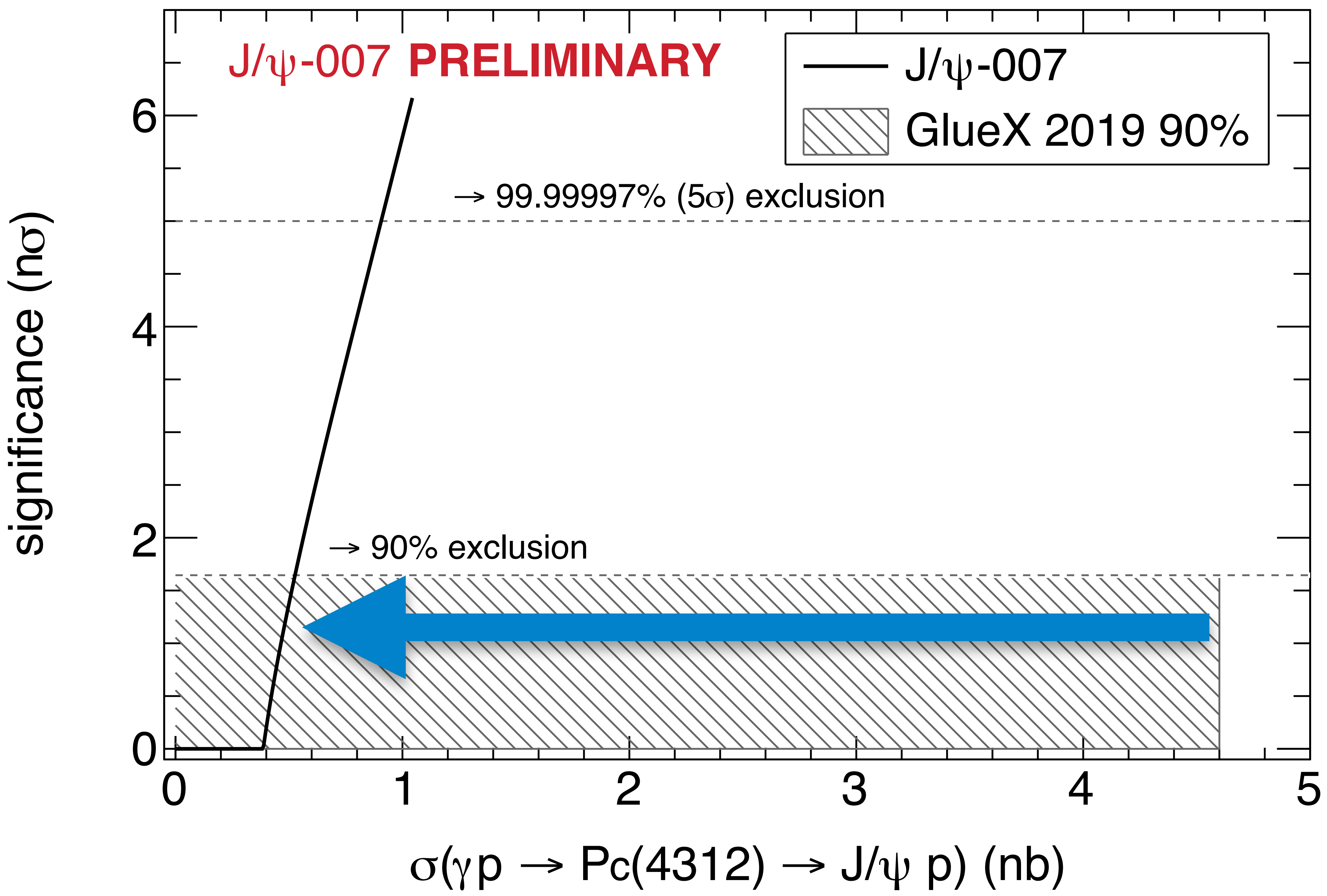
Cross-section at the resonance peak for model-independent upper limits

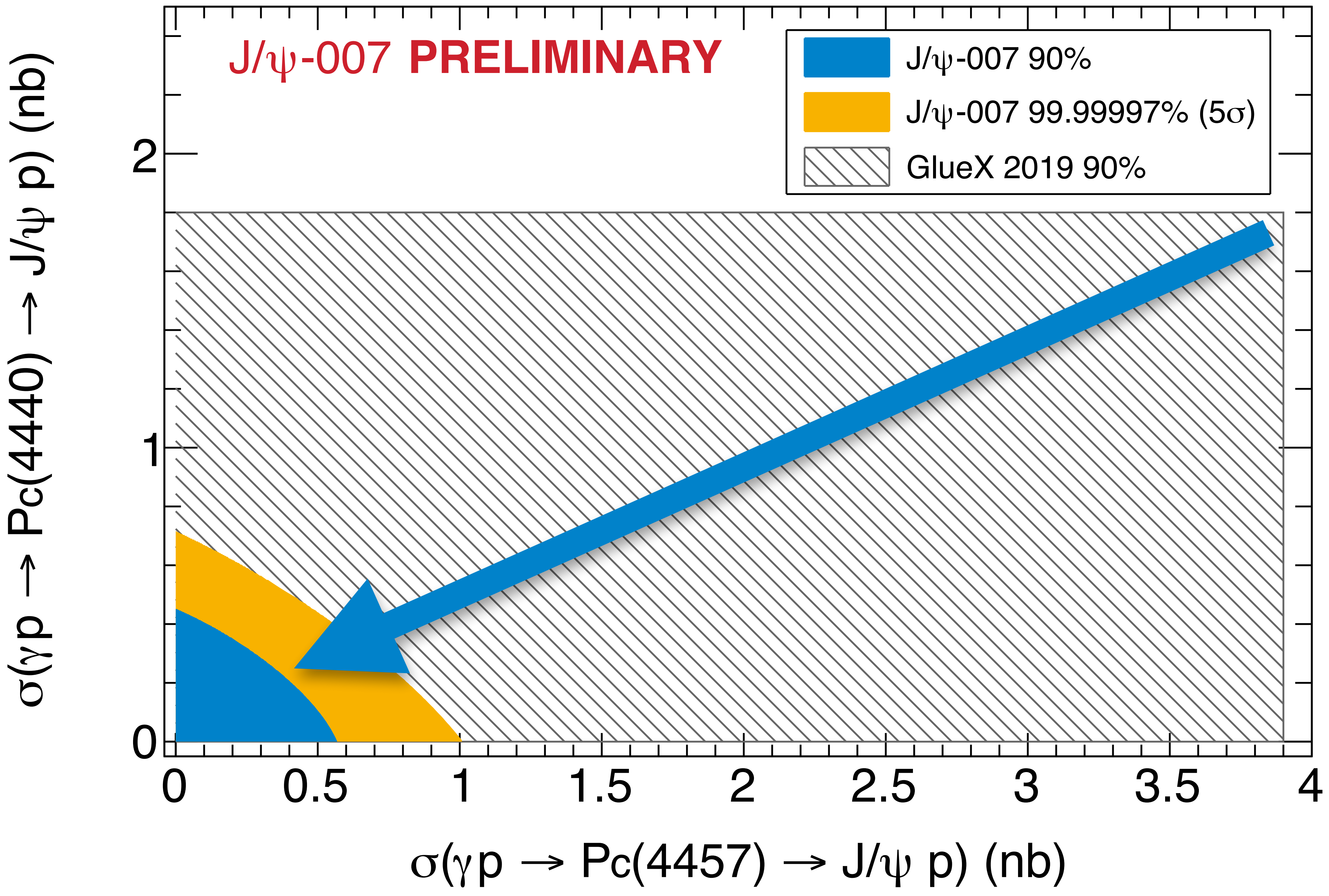
Upper limit for P_c cross section almost order of magnitude below GlueX limit.

Results are 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**

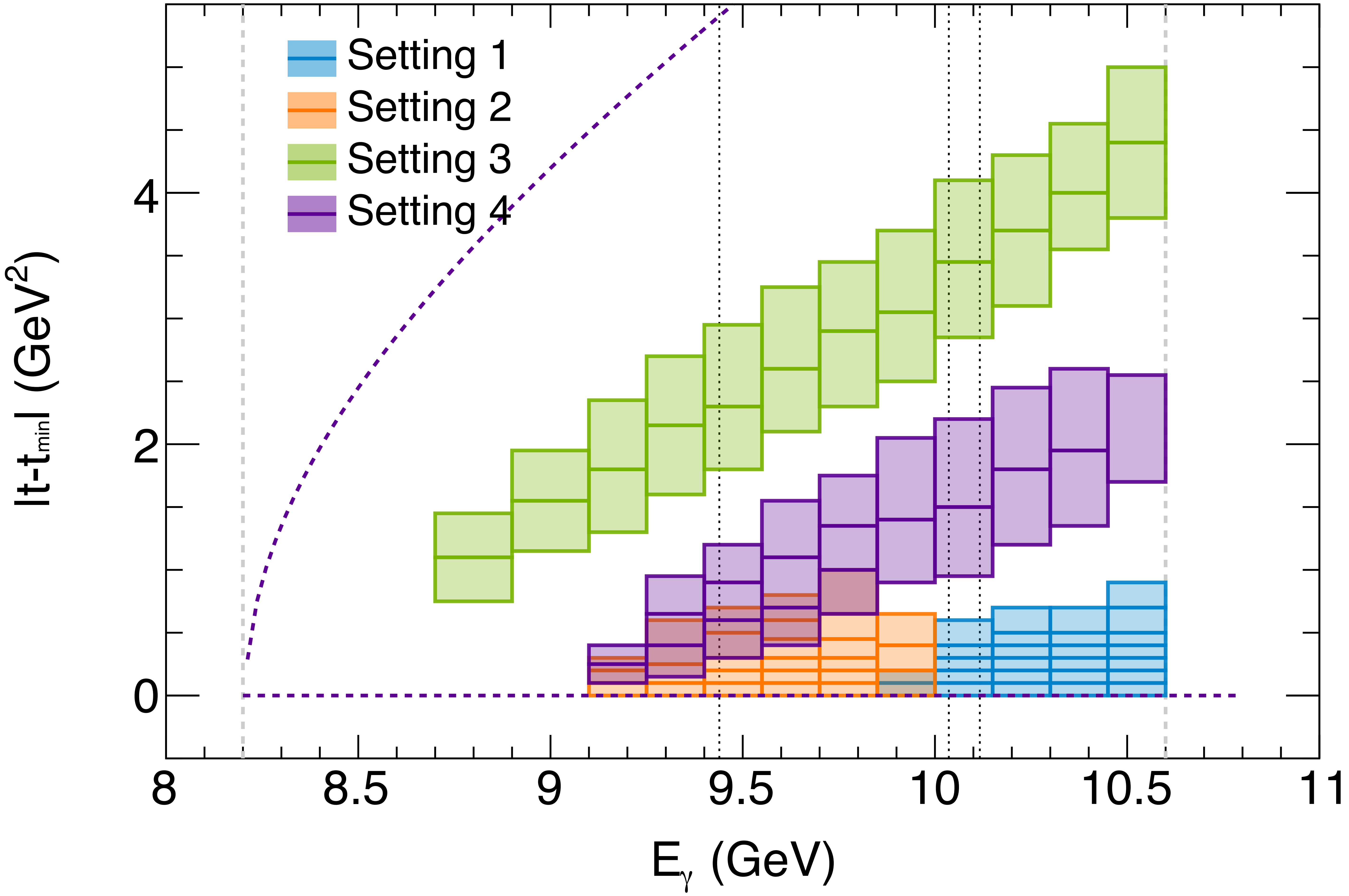




PHASE SPACE COVERAGE

Unprecendented access to large-t region

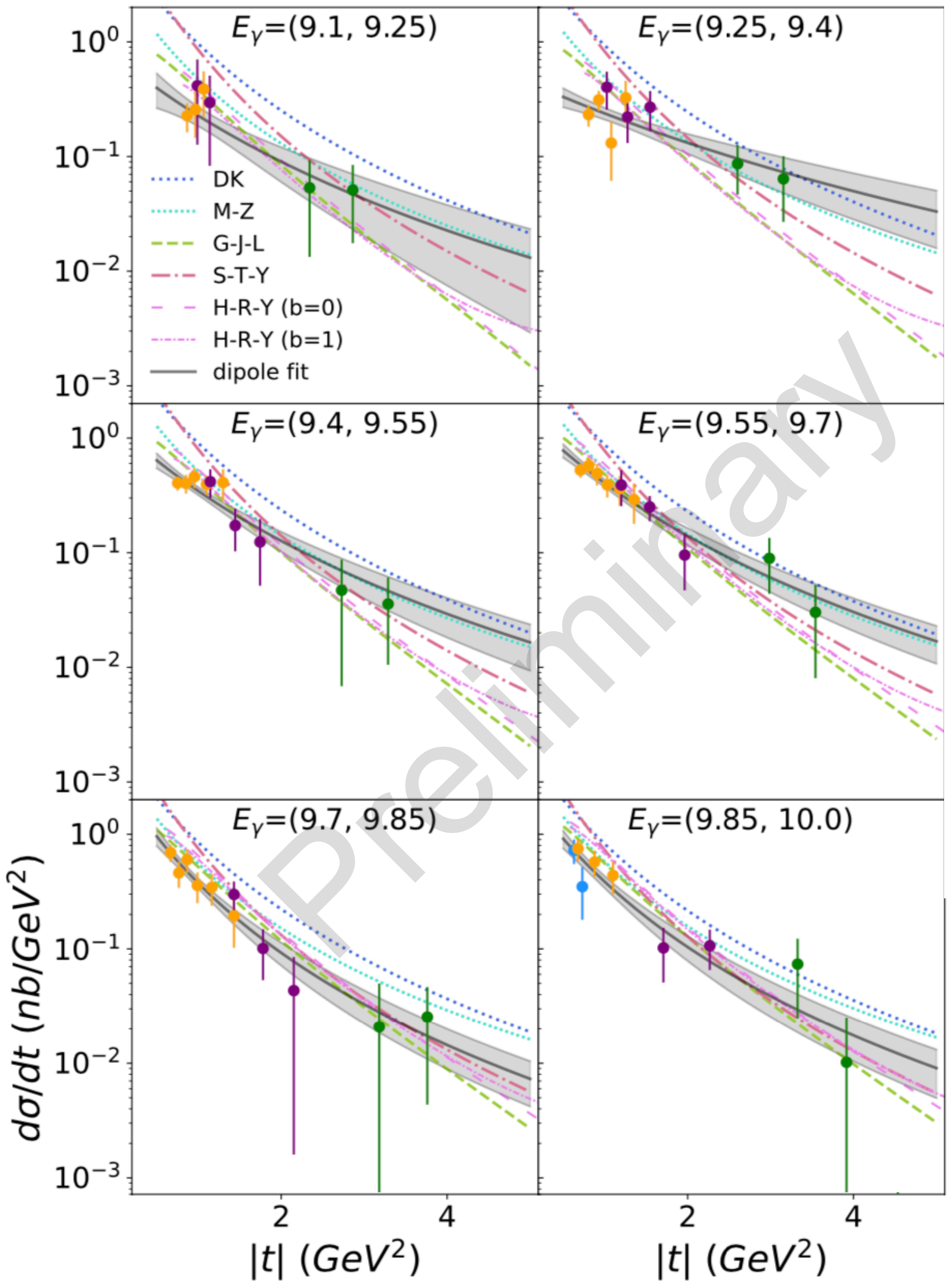
- Truly 2D measurement
- ~2000 counts in electron channel
- Additional 2000 counts in muon channel still under analysis

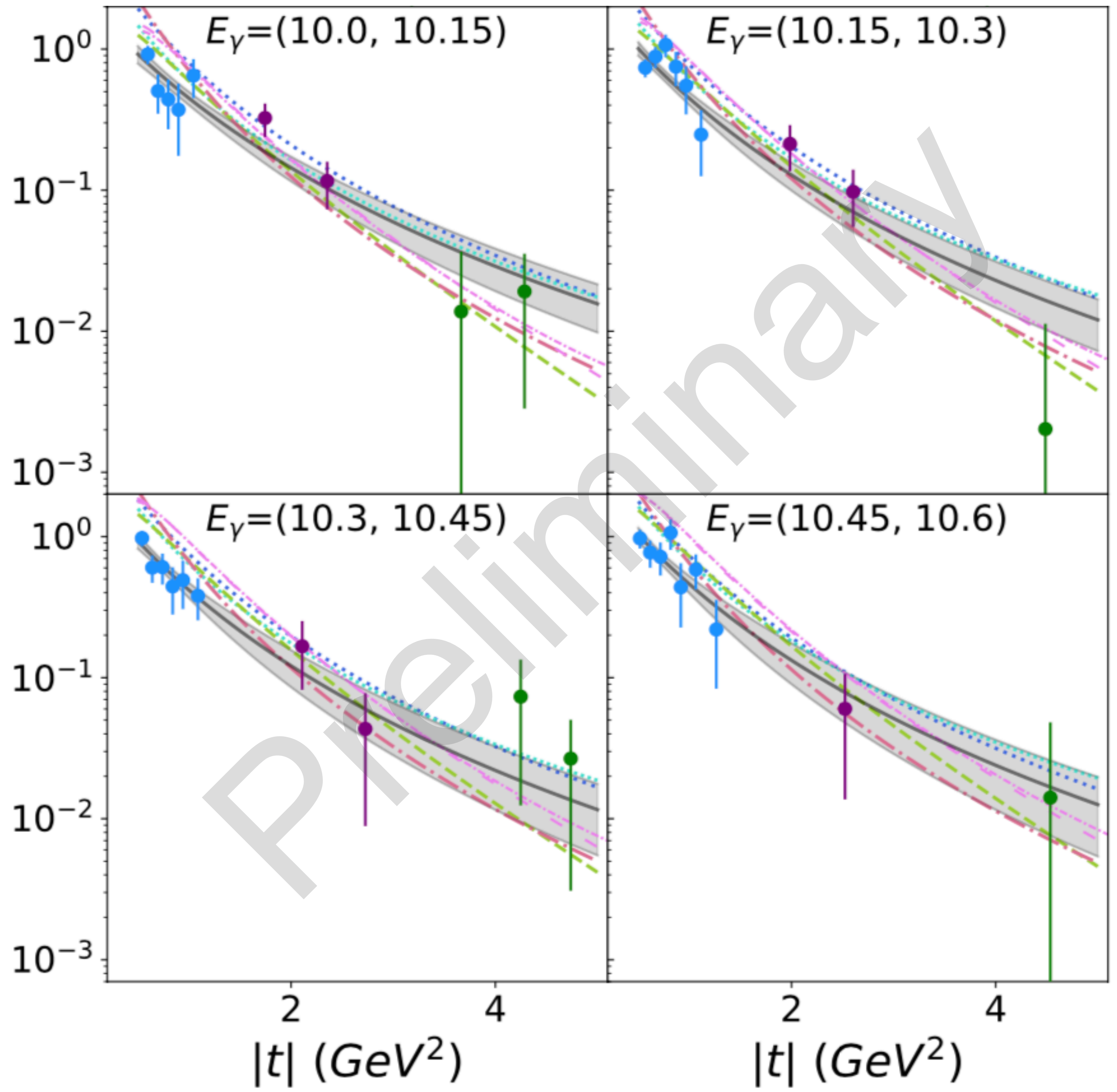


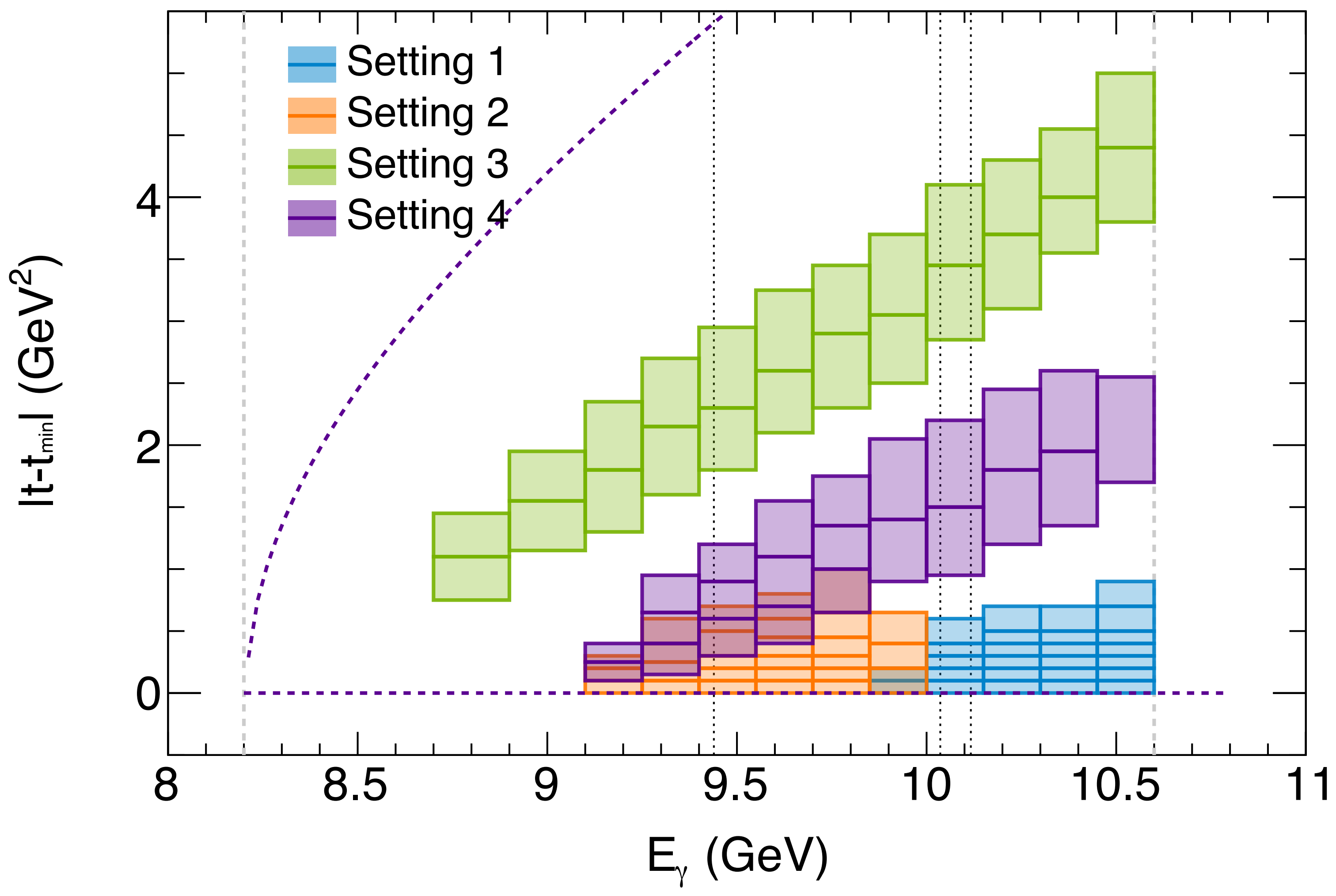
Preprint: https://arxiv.org/abs/2207.05212

Results currently under peer-review

PRELIMINARY 2D J/Ψ CROSS SECTION RESULTS







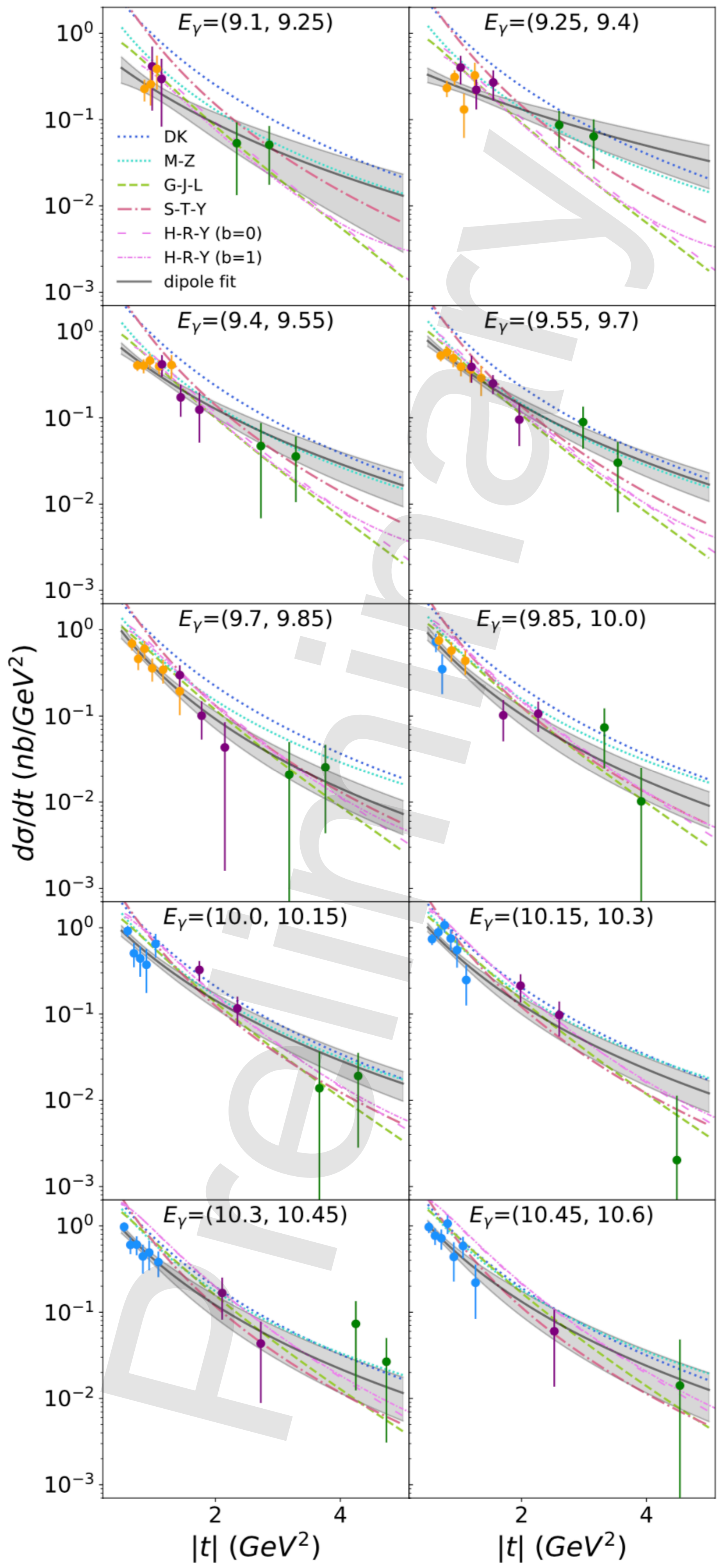
DK: D, Kharzeev, Phys. Rev. D 104, 054015 (2021).
M-Z: Mamo & Zahed, 2204.08857 (2022)
G-J-L: Guo, Ji & Liu, Phys. Rev. D 103, 096010 (2021)
S-T-Y: Sun, Tong & Yuan, Phys. Lett. B 822, 136655 (2021)
H-R-Y: Hatta, Rajan & Yang, Phys. Rev. D 100, 014032 (2019)
Dipole fit: Independent dipole fit to each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

- 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

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

EXTRACTING GFFS FROM THE 2D PROFILES

First ever extraction of gluonic GFFs from purely experimental data!

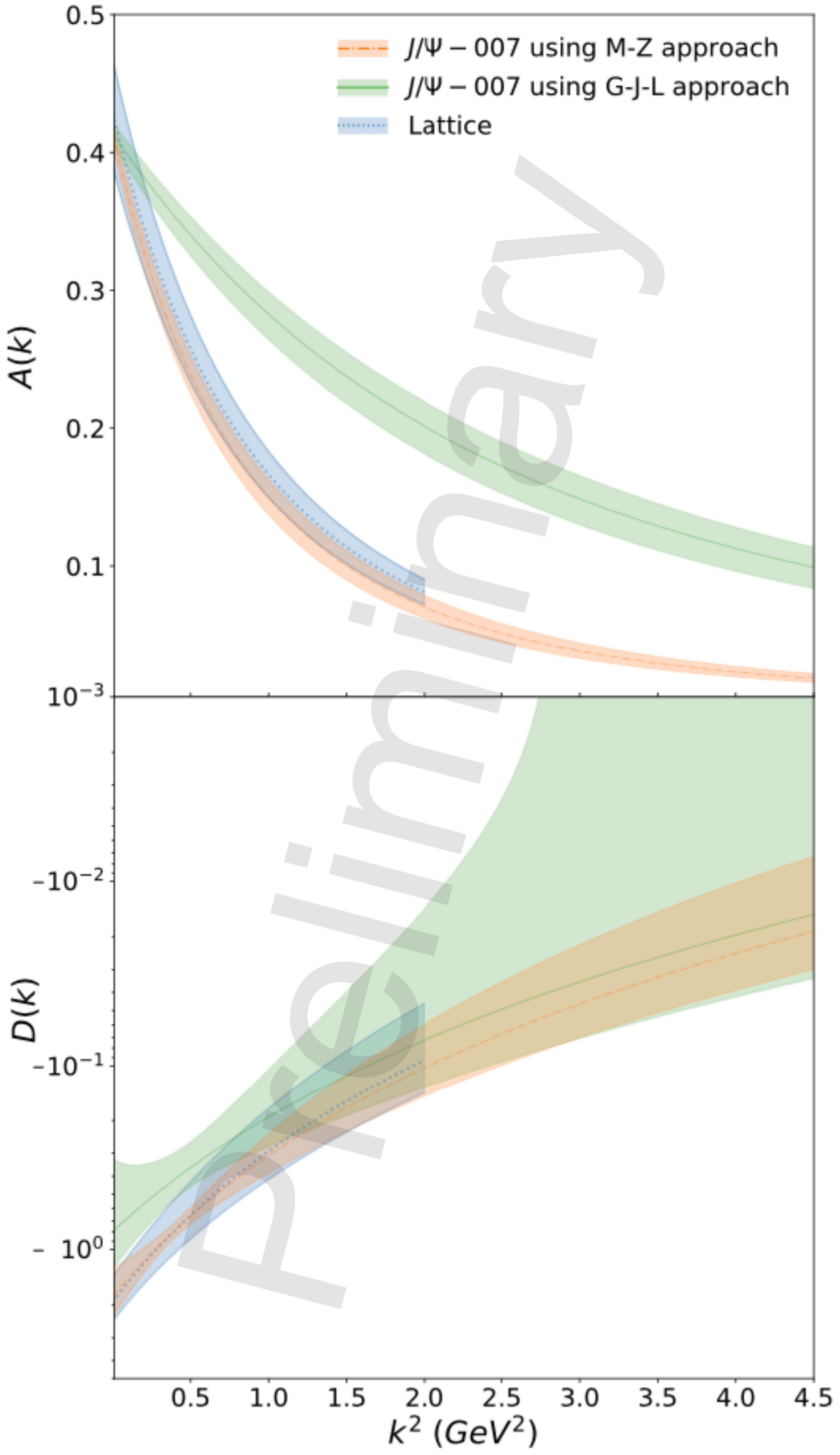


- **Model dependent extractions** using the available approaches in the literature
  - Holographic QCD approach: K. Mamo & I. Zahed, PRD 103, 094010 (2021) and 2204.08857 (2022)
  - GPD+VMD approach: Y. Guo, X. Ji, Y. Liu, PRD 103, 096010 (2021)
  - In both cases assume $B_g(t)$ contributes little (supported 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!
- In both cases the extracted mass radius is substantially smaller than the proton charge radius, hinting at a picture where the proton has a dense, energetic core surrounded by a larger quark region.

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).

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

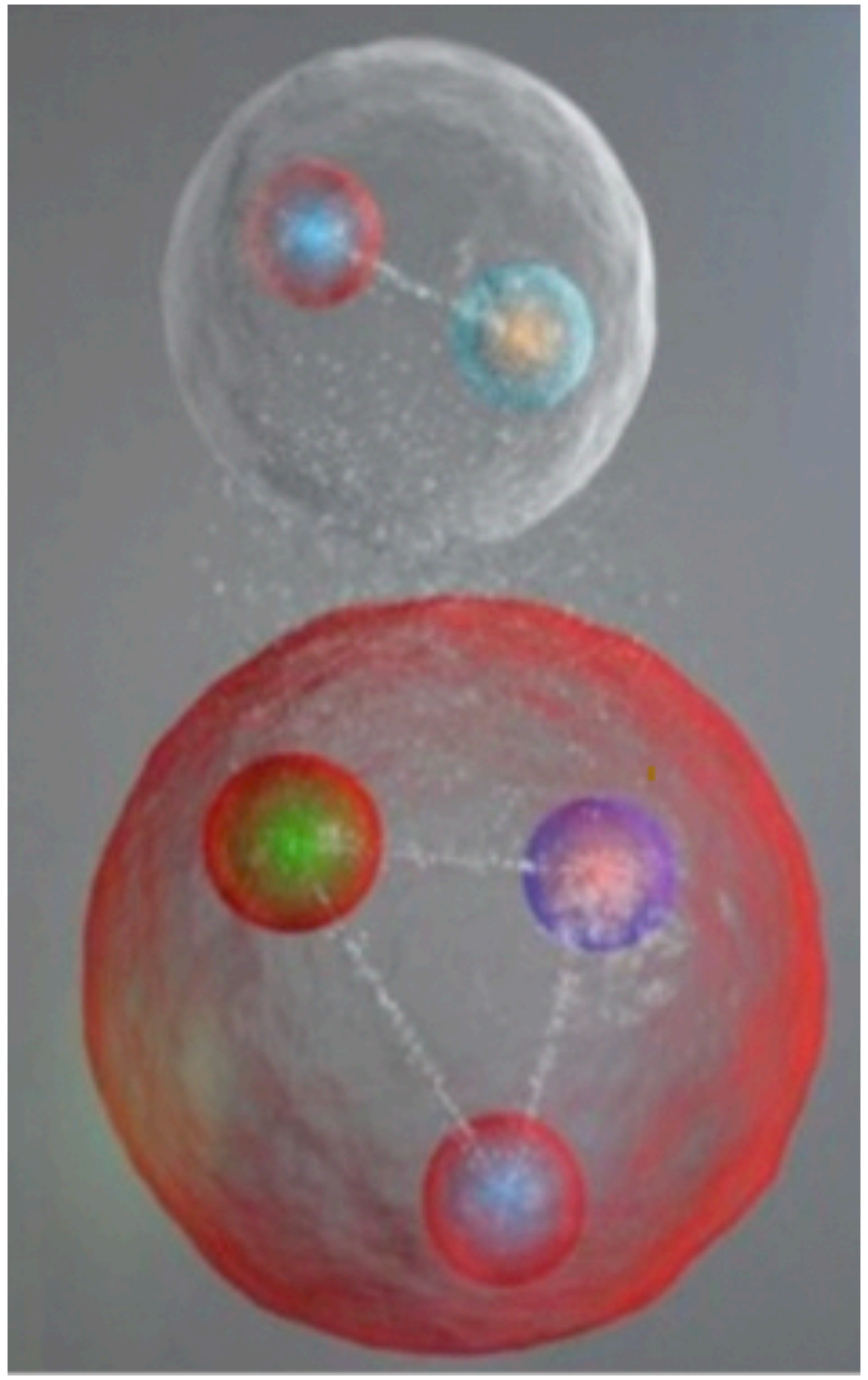
J/Ψ EXPERIMENTS AT JLAB COMPARED

	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 $2\text{x}10^{35}/\text{cm}^2/\text{s}$

CONCLUSION

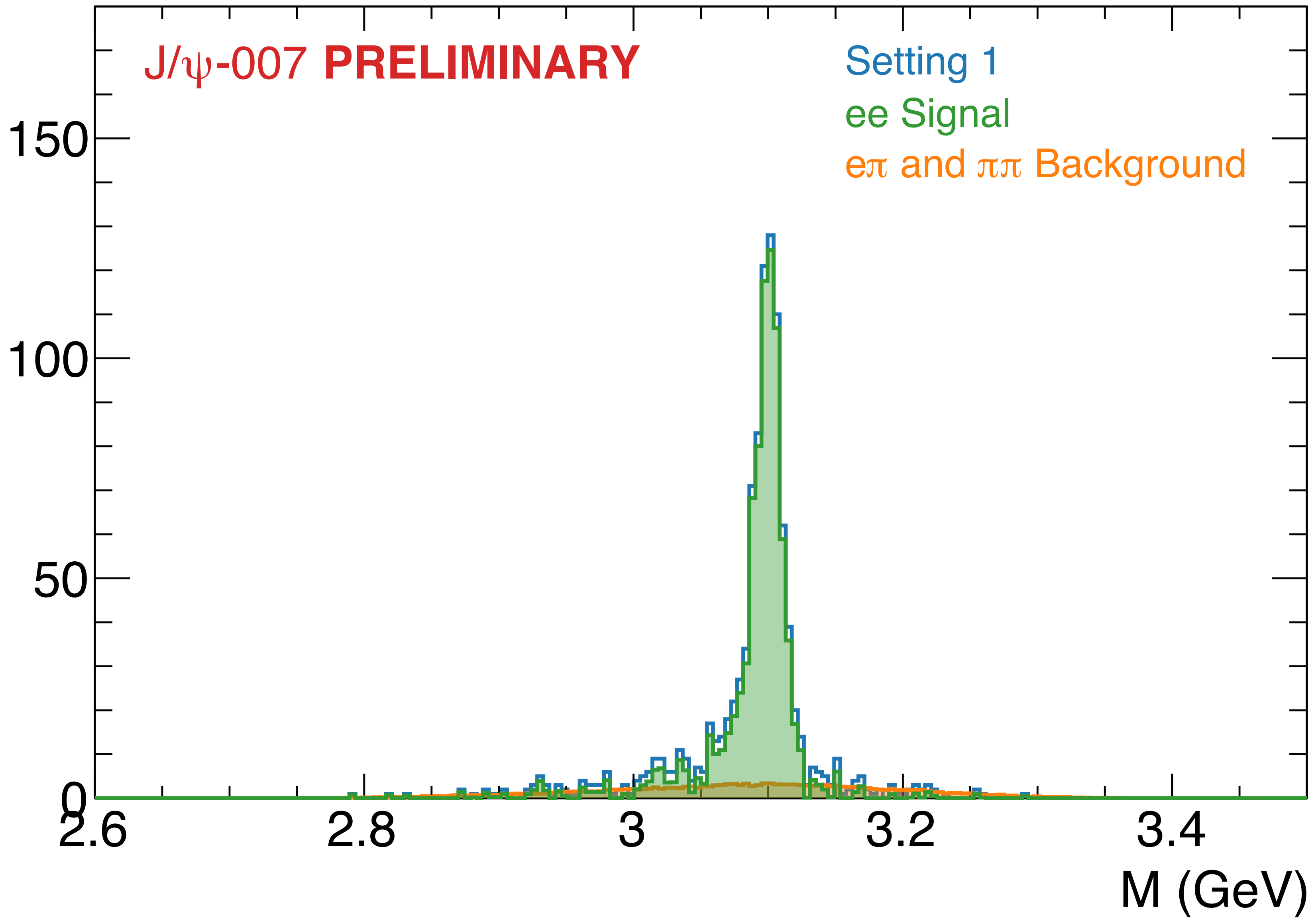
- The Hall C J/ψ-007 experiment has the first near-threshold 2D J/ψ cross section results in this area, currently under peer review.
  - Stringent exclusion limit for the LHCb charmed pentaquarks in photoproduction
  - New window on the gluonic GFFs in the proton
  - Does the proton have a dense energetic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

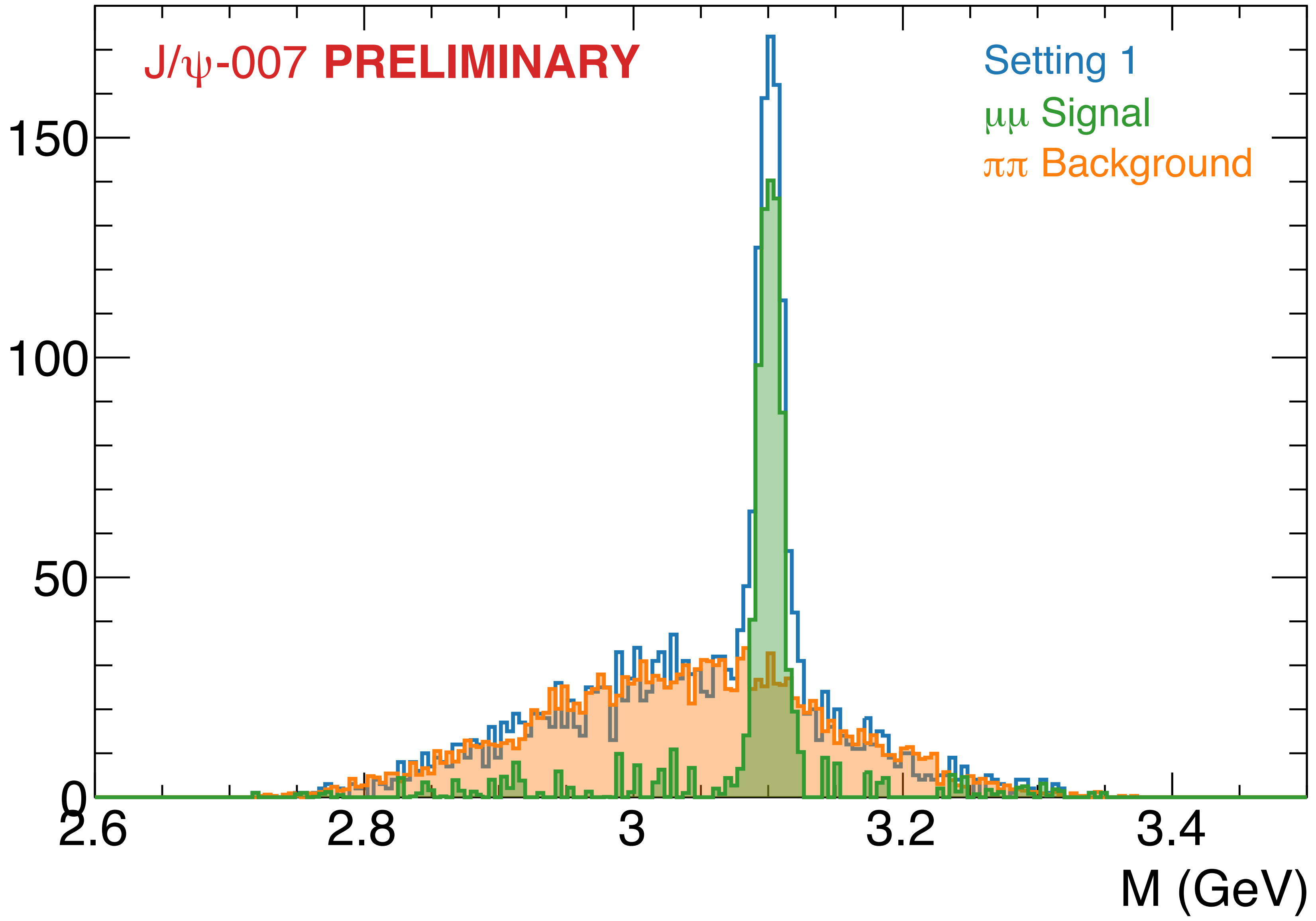


QUESTIONS?

ELECTRON AND MUON CHANNELS

007$^{J/\psi}$





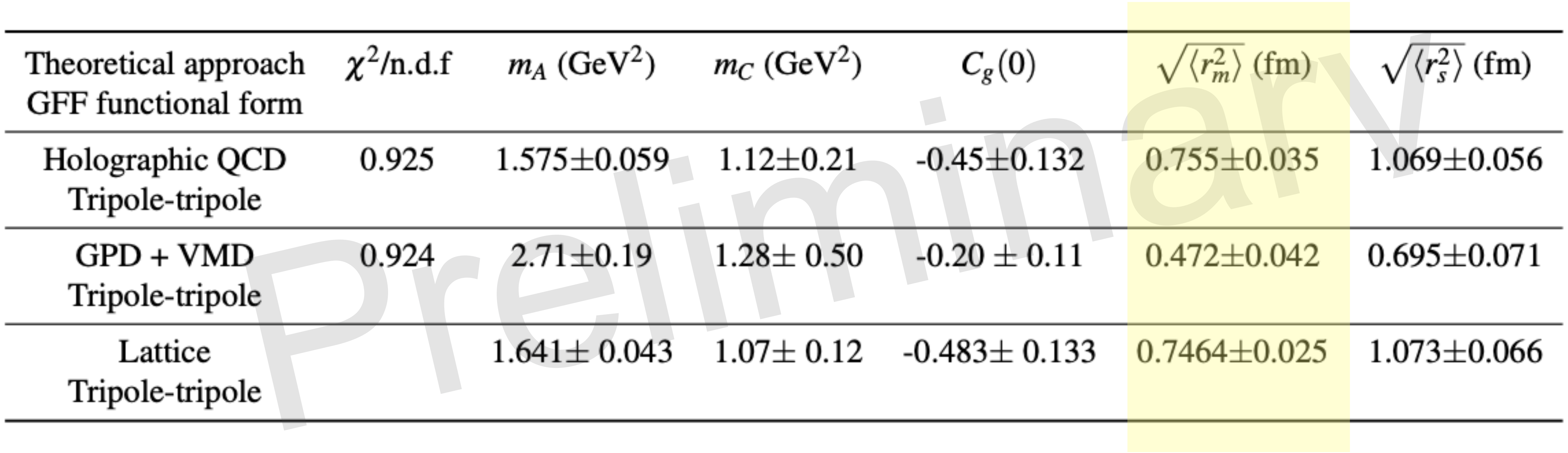
- **Electron and muon channels independent measurements, same statistics but different systematics**
- **Electrons:**
  - Low background with Cherenkov and ECAL for PID
  - Undergo multiple scattering and more sensitive to radiative losses
  - Slightly worse resolution (10MeV)
- **Muons**
  - More background 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 positition *stable* between phases, well described by Monte Carlo!**

MASS AND SCALAR RADII

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

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

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



Theoretical approach GFF functional form	χ^2/n.d.f	m_A (GeV^2)	m_C (GeV^2)	$C_g(0)$	$\sqrt{\langle r_m^2 \rangle}$ (fm)	$\sqrt{\langle r_s^2 \rangle}$ (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 + VMD 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

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

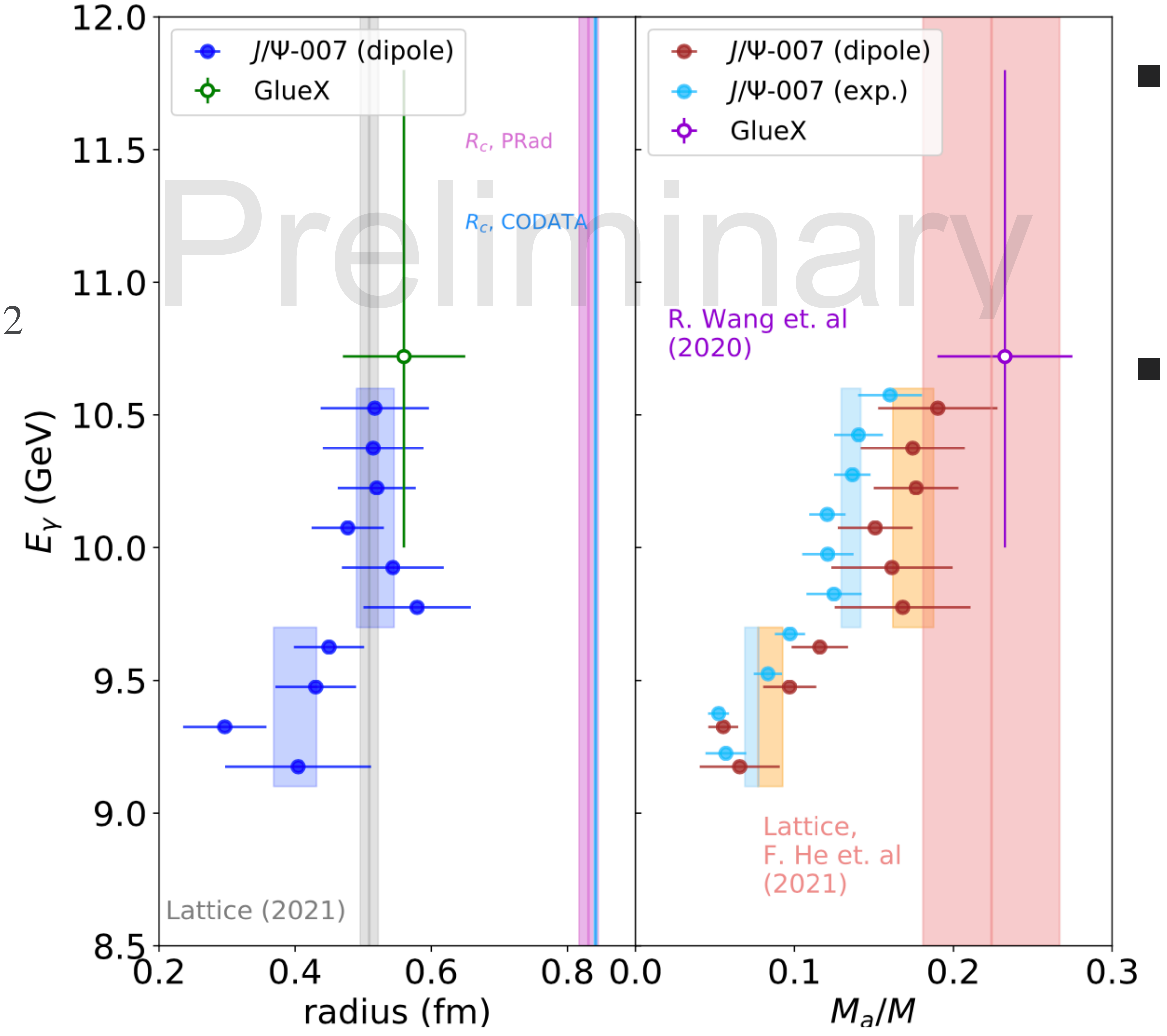
VARIOUS MODEL-DEPENDENT EXTRACTIONS

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

D-K formalism for radius

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

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



- 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)

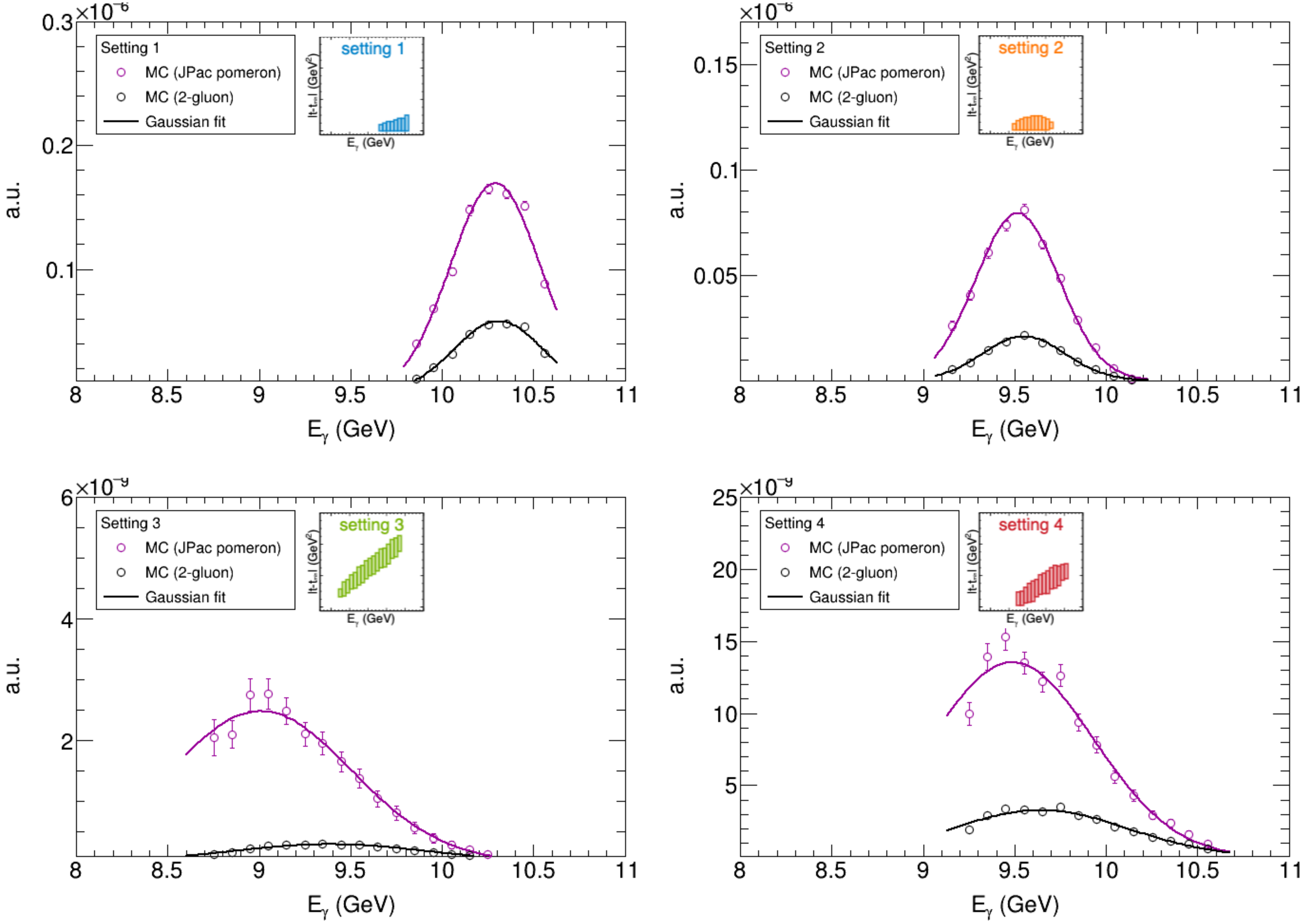
GlueX point: R. Wang, J. Evslin, X. Chen, Eur. Phys. J. C, 80, 507 (2020).
Approach: X. Ji, Phys. Rev. Lett. 74, 1071–1074 (1995), same procedure as the GlueX point
Lattice Ma: F. He, P. Sun,Y.-B. Yang, Phys. Rev. D 104, 074507 (2021)

WHAT DOES A PURE T-CHANNEL BACKGROUND LOOK LIKE?

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

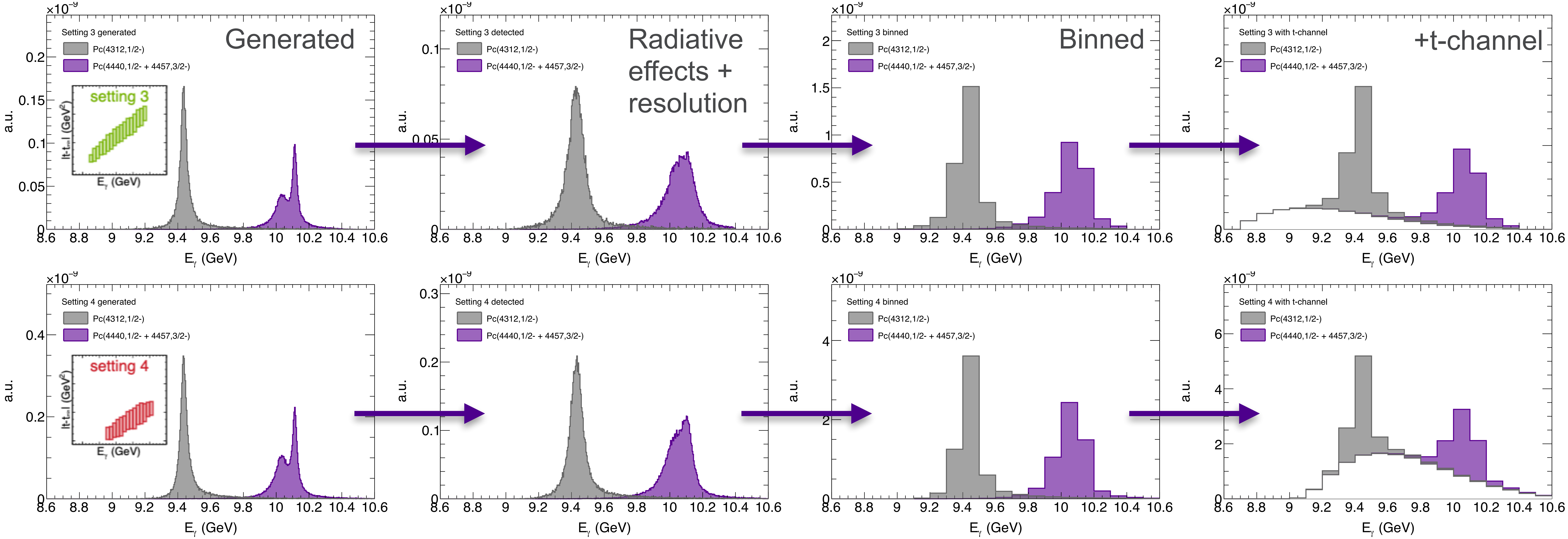
A **gaussian shape**, mostly driven by the spectrometer acceptance, does a good job describing both (very different!) Monte-Carlo models

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

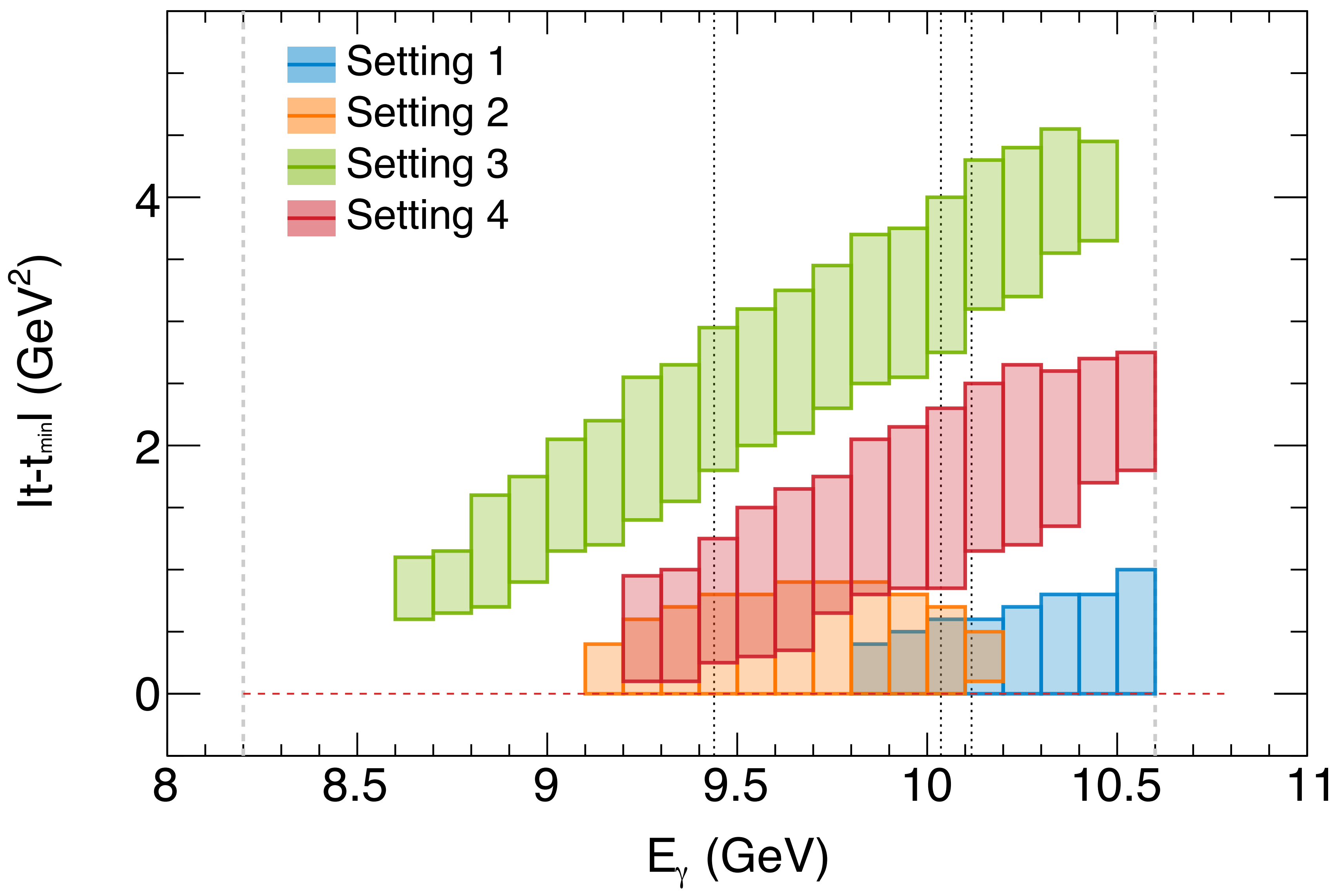


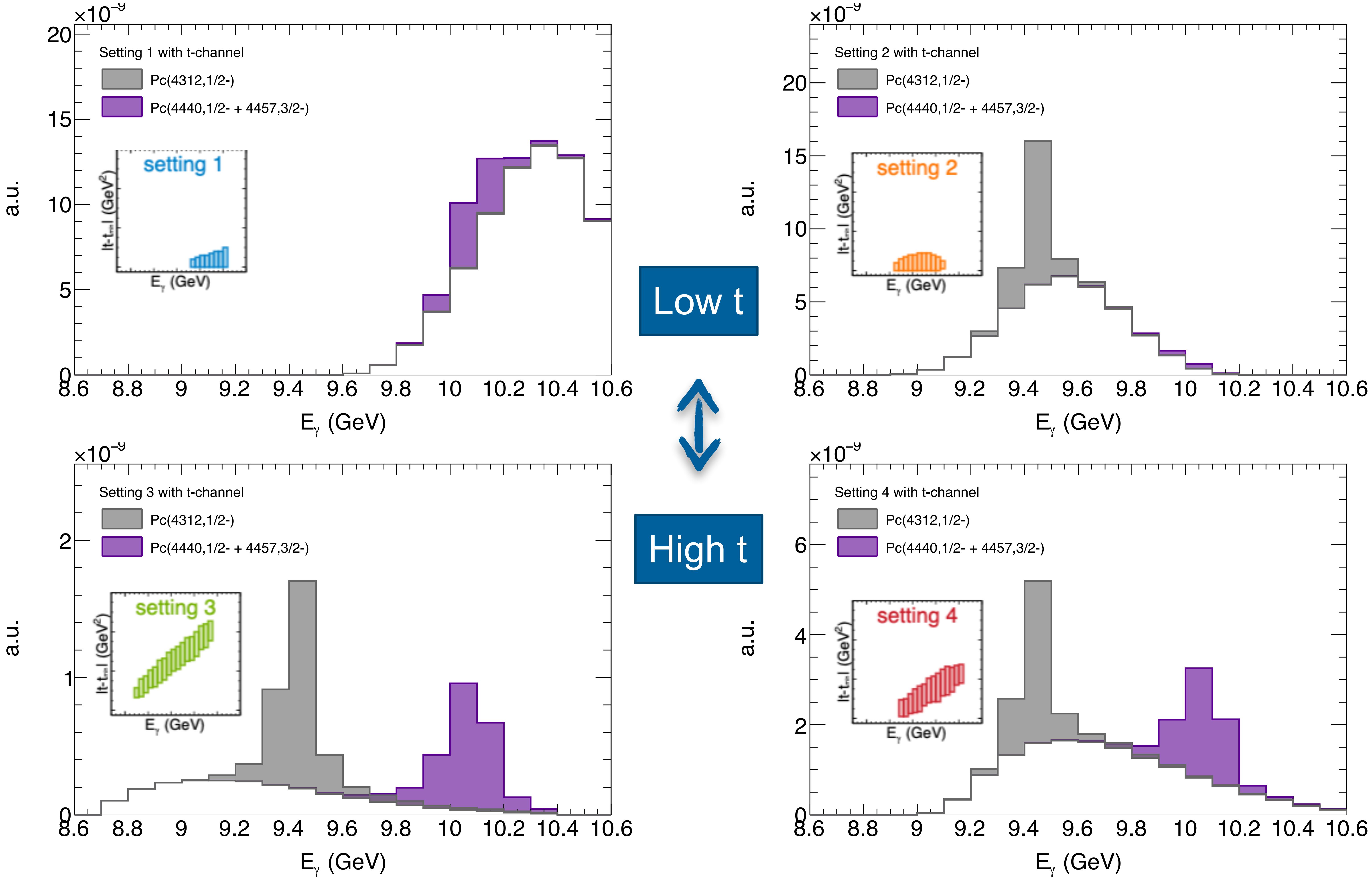
Pc resonances calculated at GlueX 90% upper limit from MC (JPacPhoto + Detector Simulation)

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





Low t

High t

4% scale uncertainty on cross section

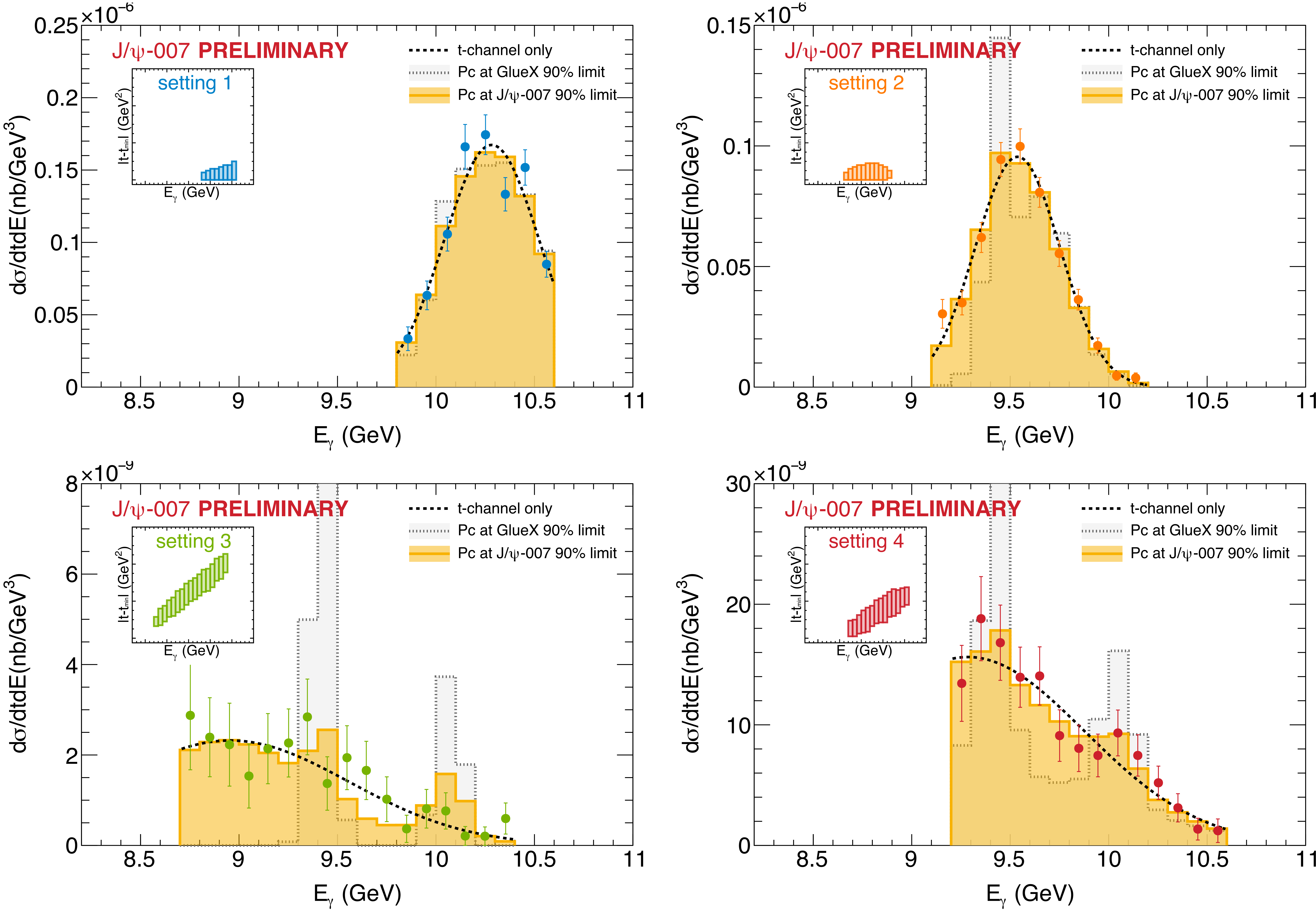
SIGNIFICANCE FIT

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)