Physics with CEBAF at 12 GeV and Future Opportunities

arXiv:2112.00060 *Progress in Particle and Nuclear Physics* (To be published)

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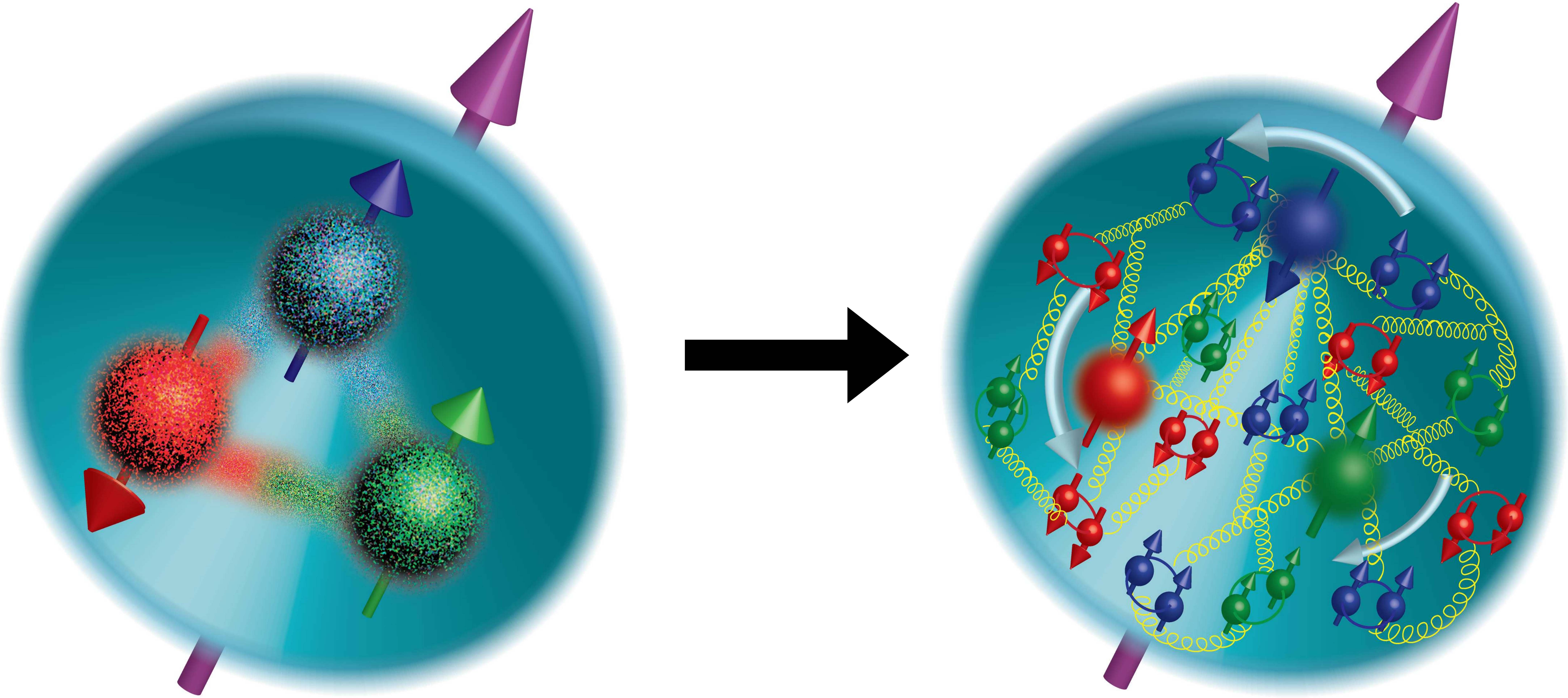
2022 JLUO Annual Meeting (15 June 2022)

Emergent Phenomena

Nuclear Femtography



Emergent Phenomena

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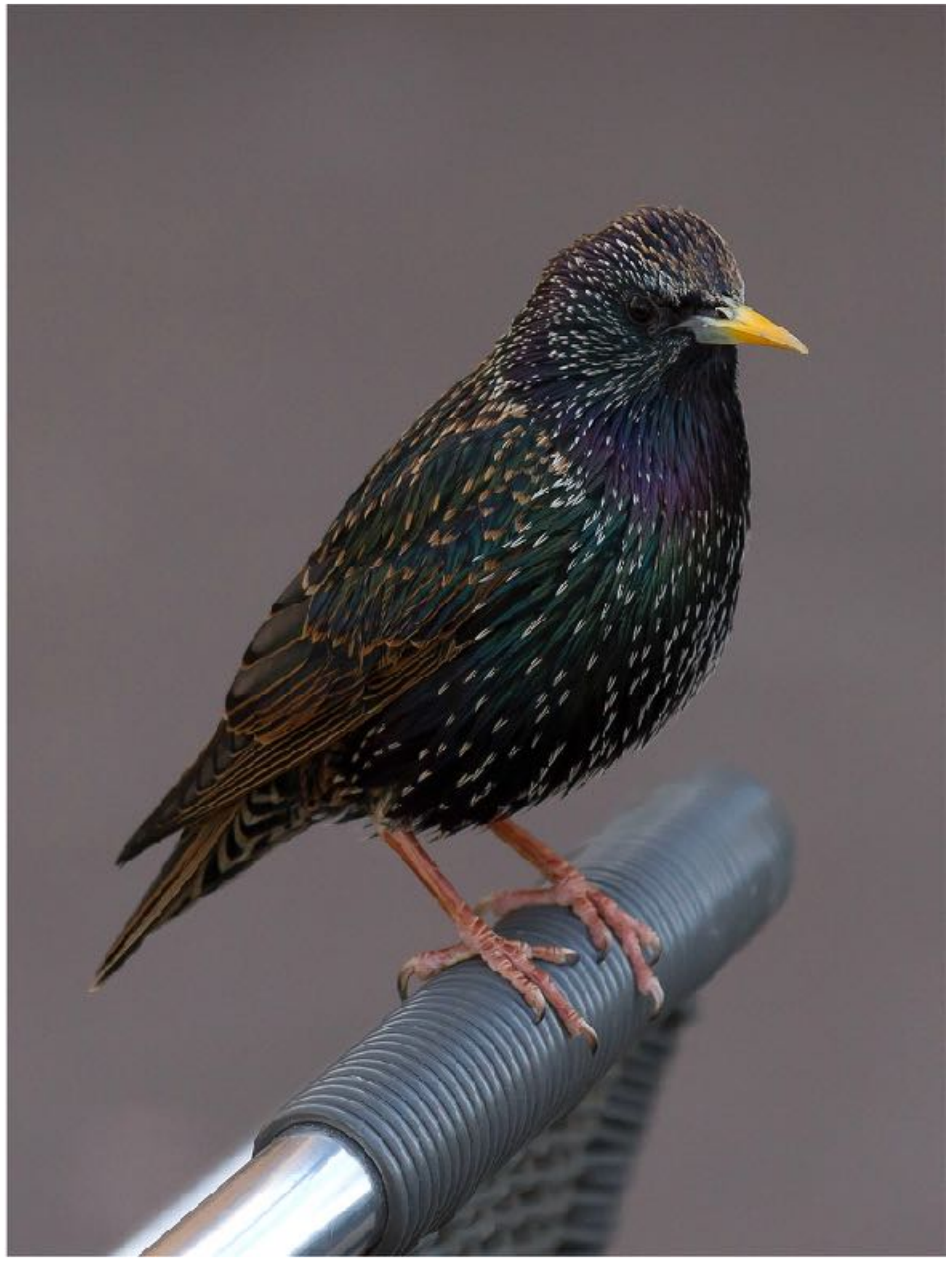

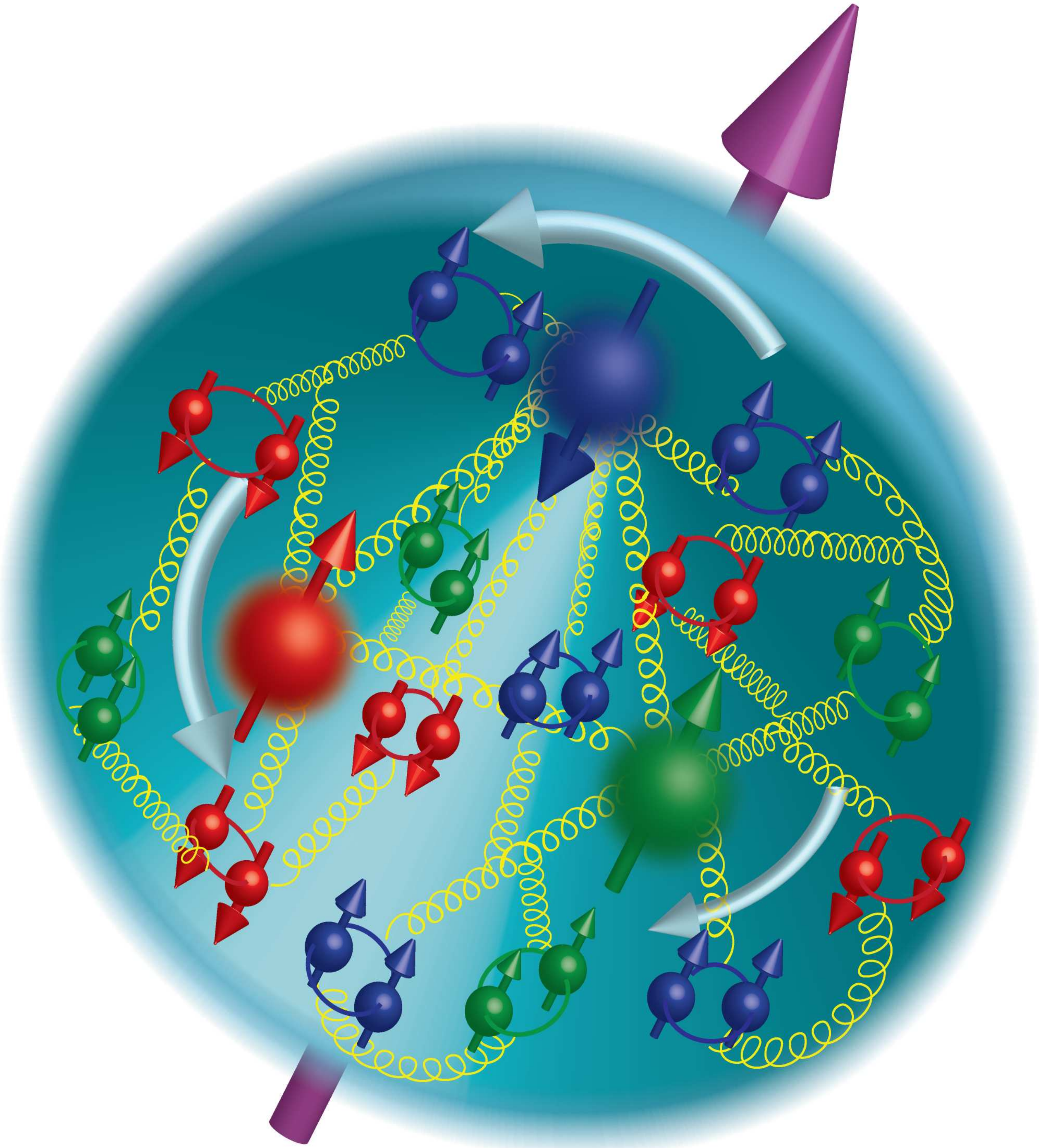

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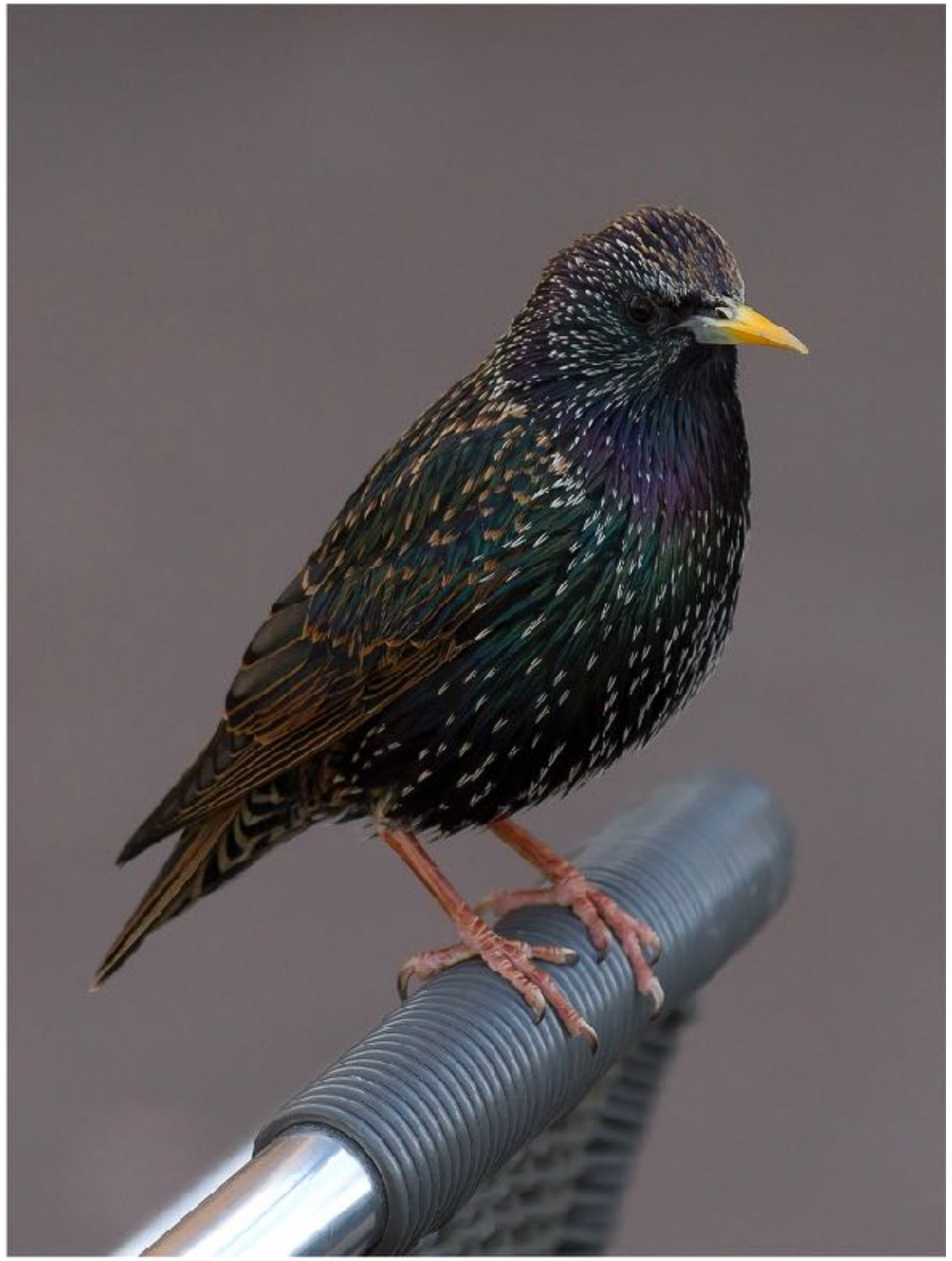
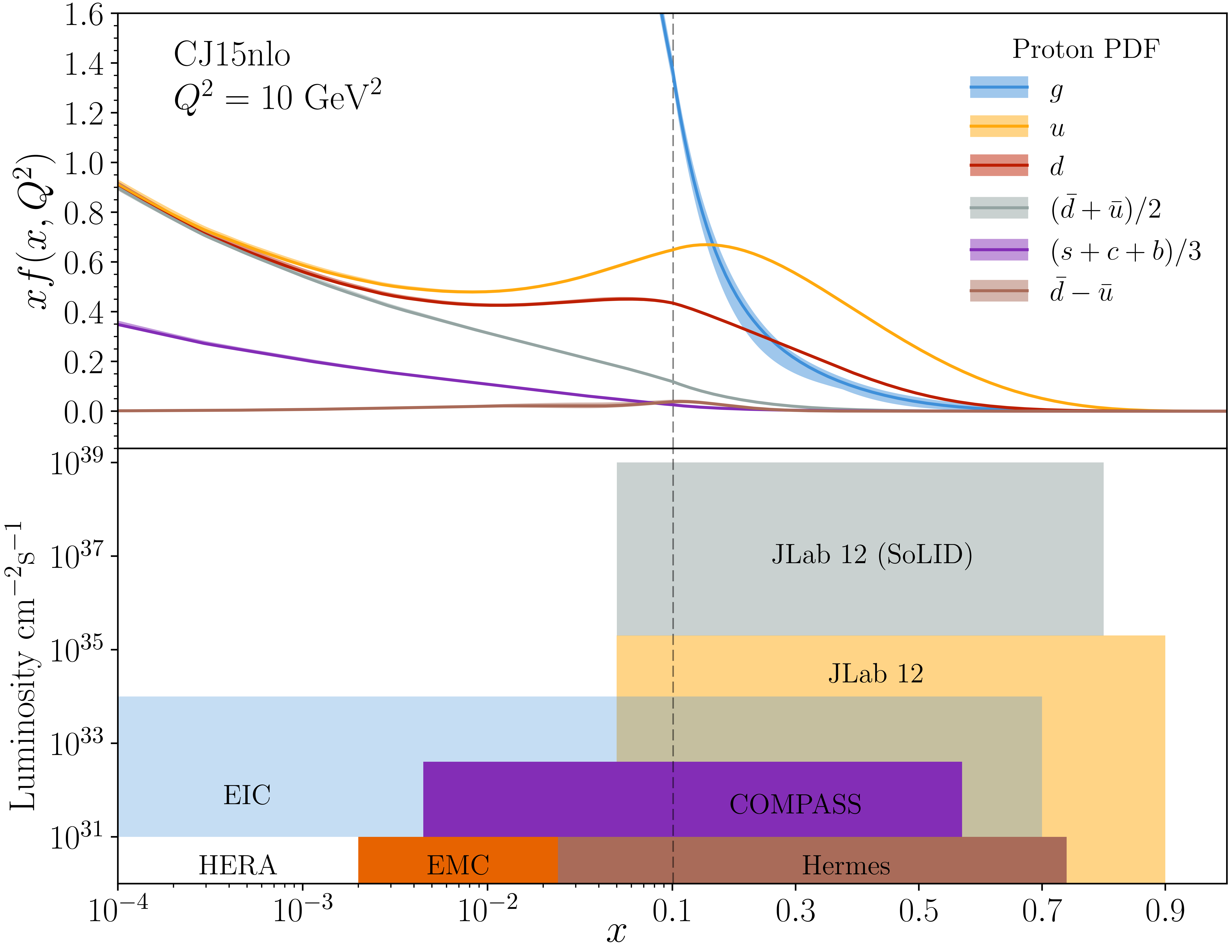


Kinematic Landscape for PDFs



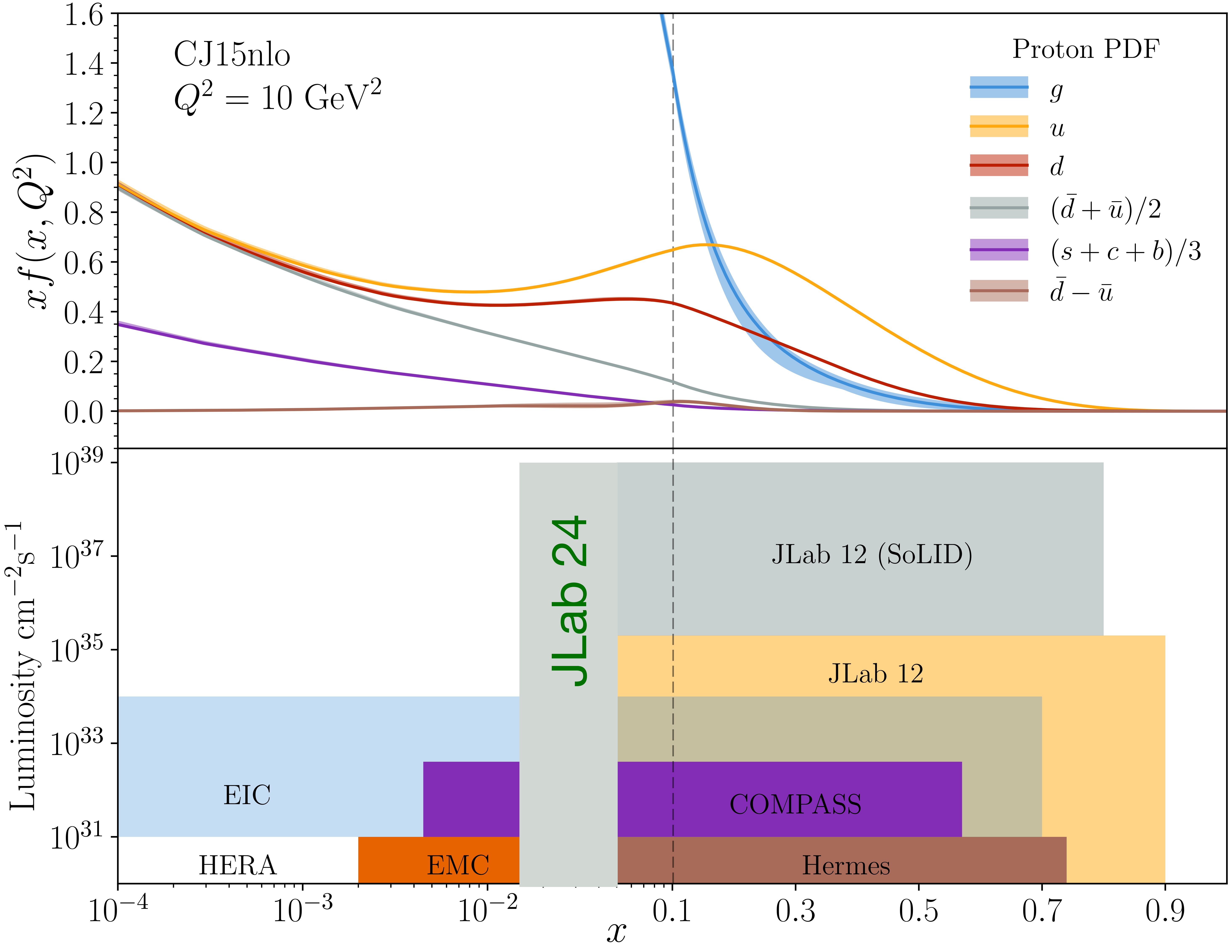
Parton Distribution Functions (PDFs) of quarks and gluons used to illustrate the reach of CEBAF/EIC.

EIC/CEBAF Complementarity:

- CEBAF focus is on valence quark region with high luminosity
- Solenoidal Large Intensity Device (SoLID) will enhance capabilities

Kinematic Landscape for PDFs

Nuclear Femtography



Parton Distribution Functions (PDFs) of quarks and gluons used to illustrate the reach of CEBAF/EIC.

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- CEBAF focus is on valence quark region with high luminosity
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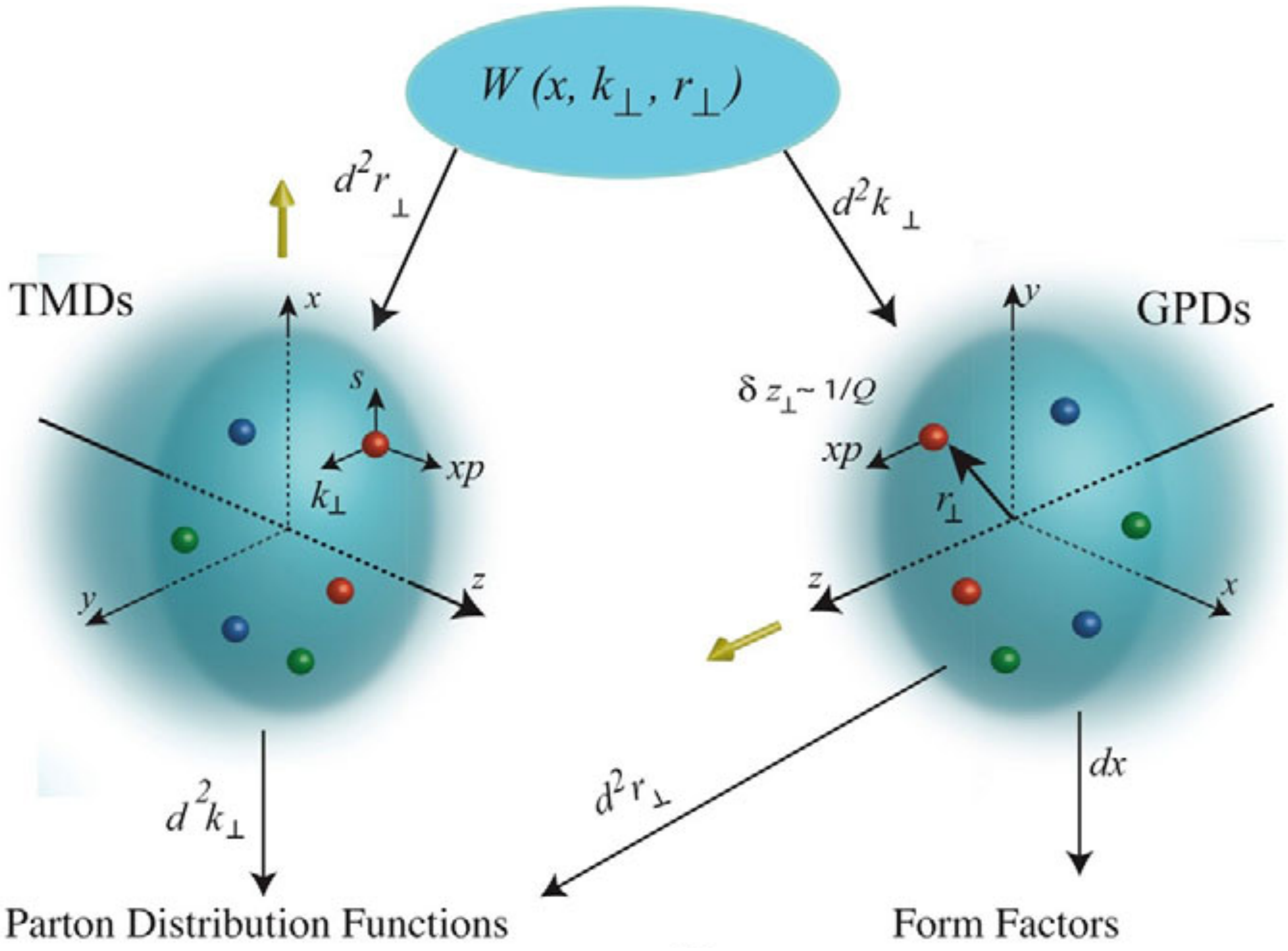
Higher CEBAF energies will allow an extension to lower x_{Bj}.

Wigner Distribution Function

Nuclear Femtography



The ultimate (and lofty!) goal is to extract $W(x, k_\perp, r_\perp)$ experimentally and compare to theory.

Program of experimentation:

- Ongoing measurements of PDFs and Form Factors
- A start on determining the Generalized Parton Distributions
- Planning for measurements of the Transverse Momentum Distribs

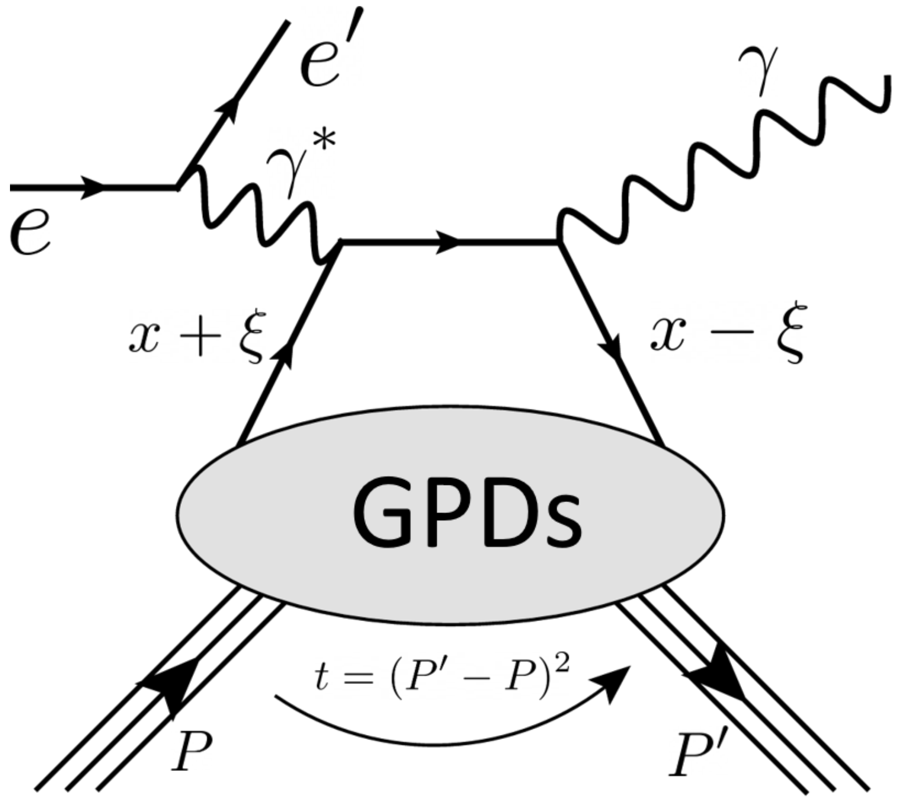
Phenomenology/Theory

- Lots of model-building
- Fundamental theory calculations are currently underway

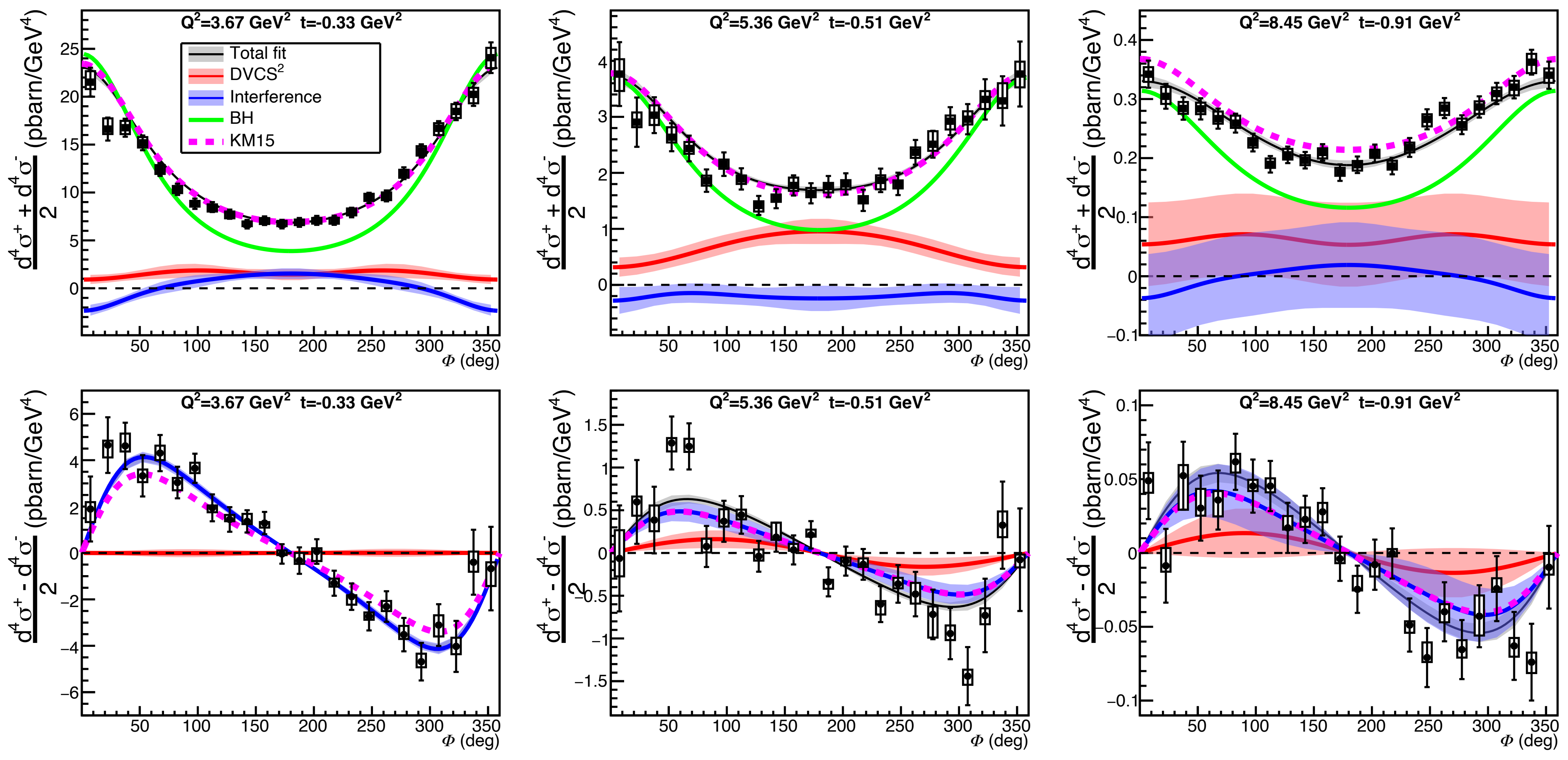
Deeply Virtual Compton Scattering

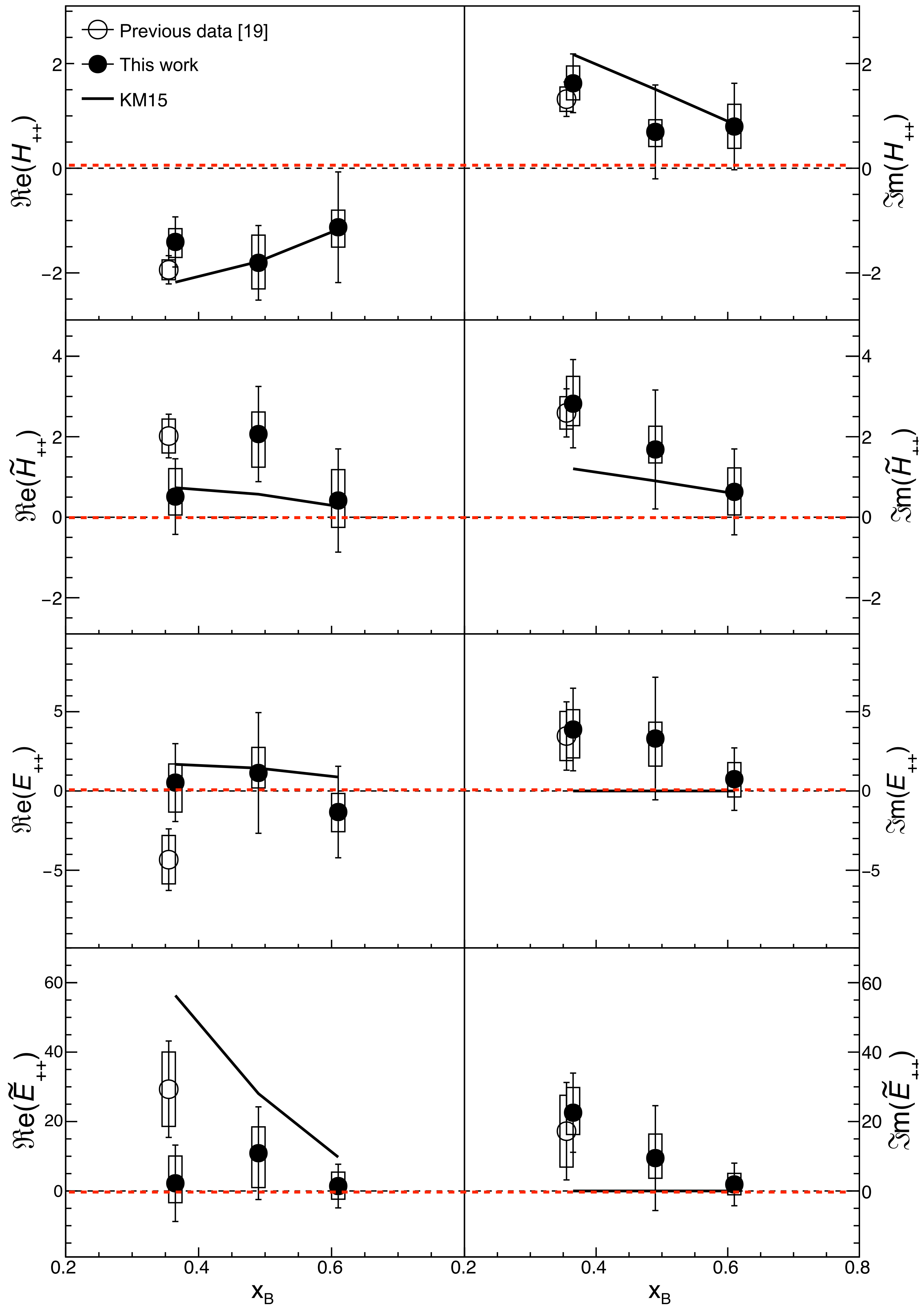
arXiv:2201.03714

Nuclear Femtography



+ Bethe-Heitler





Compton Form Factors (CFF) derived from asymmetries with polarized beam, compared to convolution integrals of GPDs.

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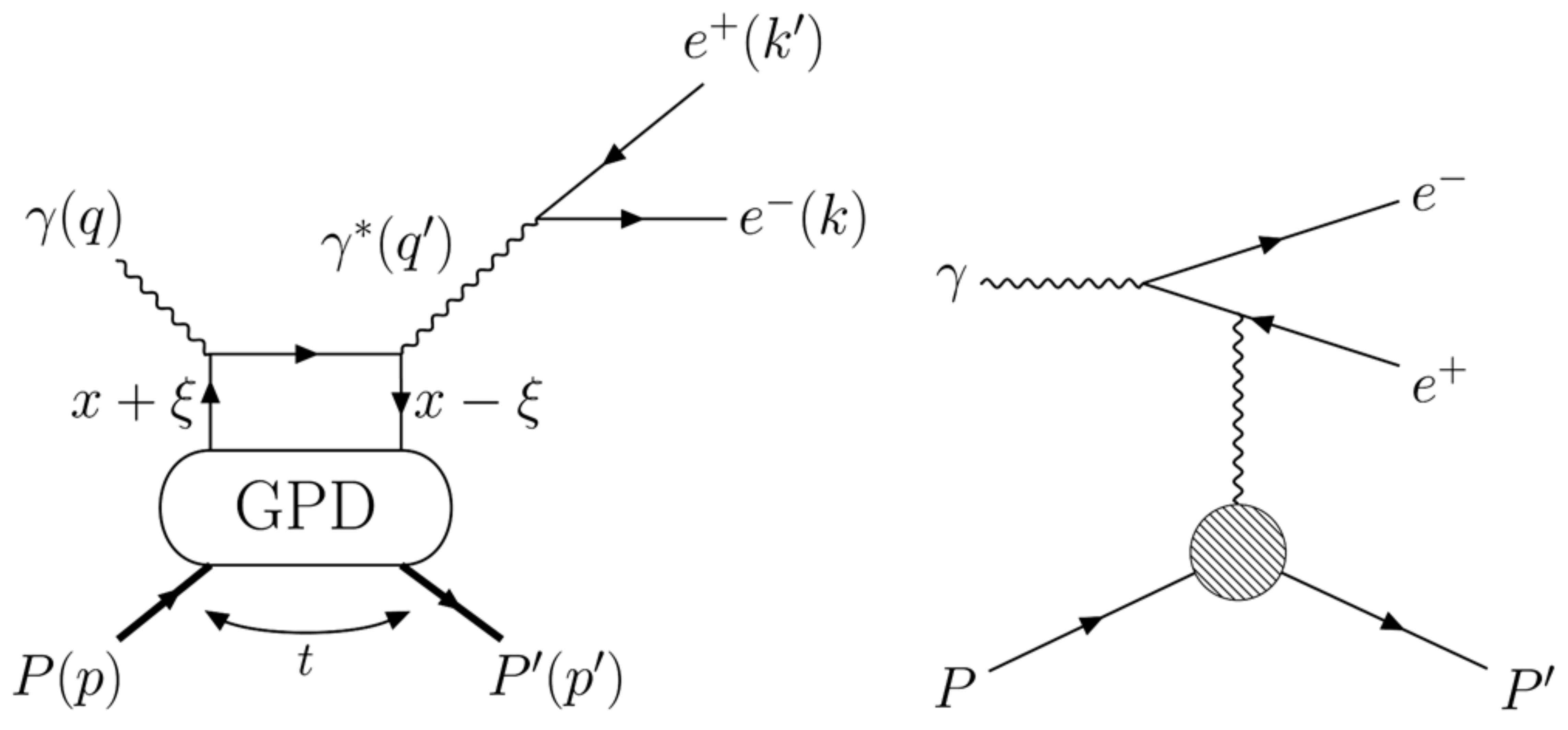
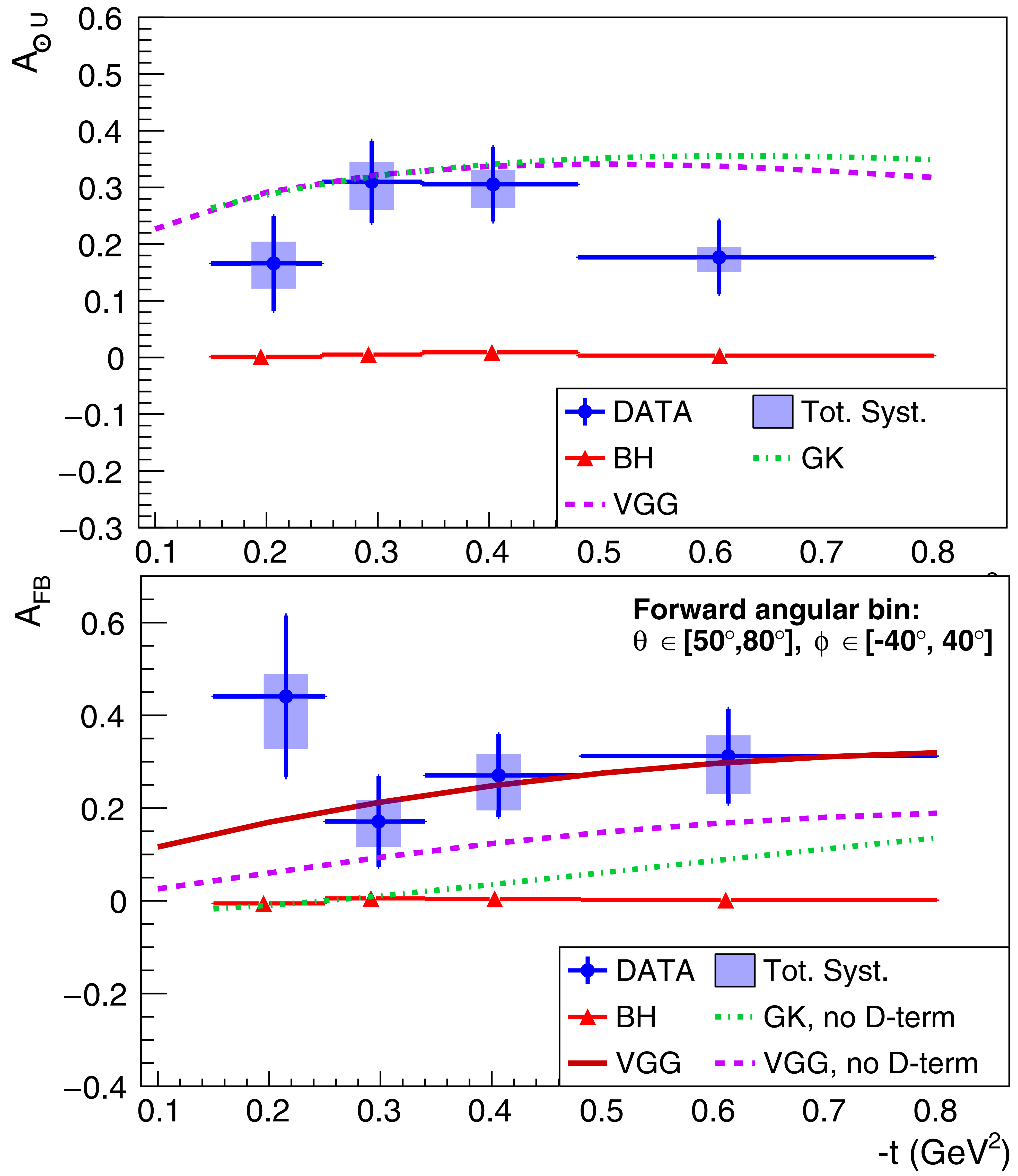
Timelike Compton Scattering

Nuclear Femtography

PRL 127(2021)262501
First Measurement of Timelike Compton Scattering (CLAS12)





Measured asymmetries arising from interference with Bethe-Heitler, compared to model calculations from Vanderhaeghen-Guichon-Guidal (VGG) model and Goloskokov-Kroll (GK).

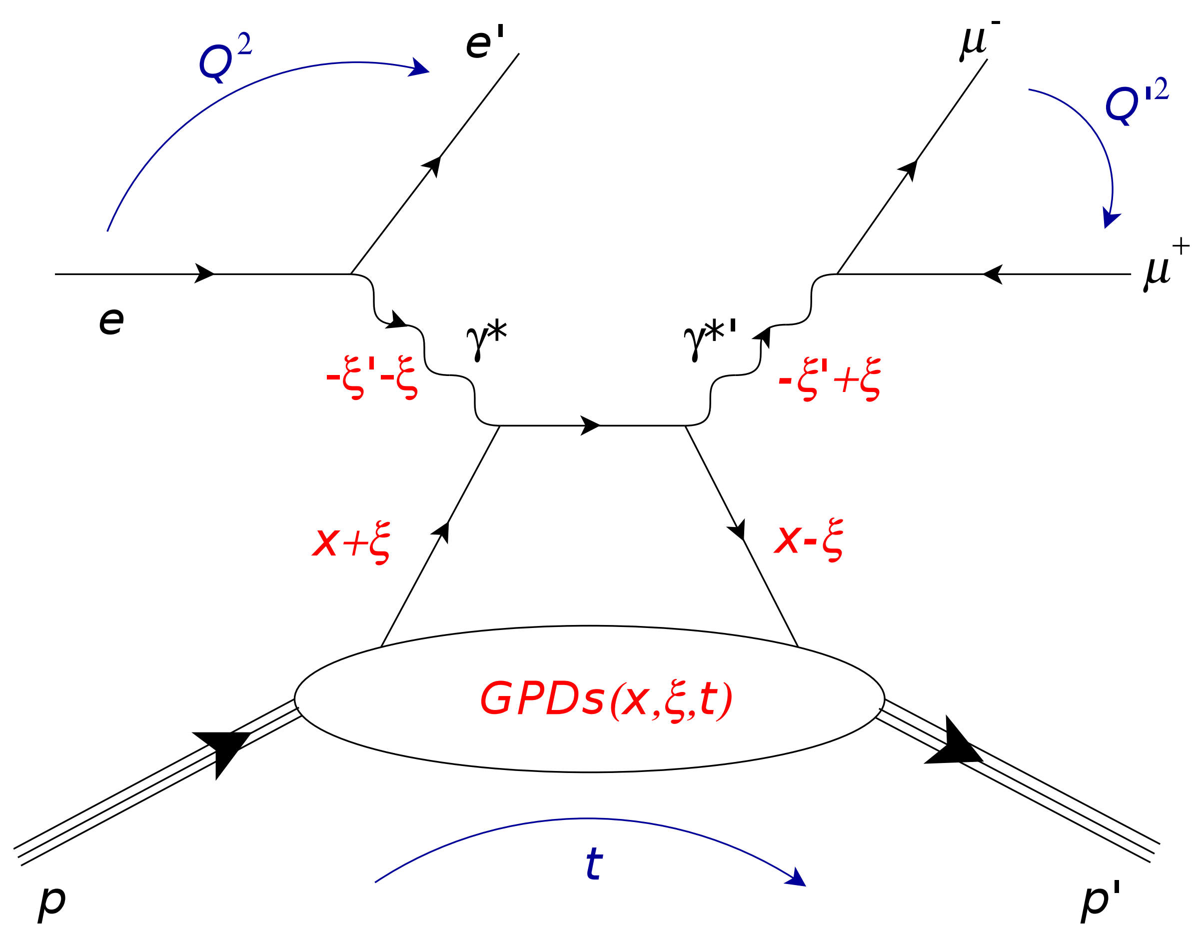
Double DVCS

$$\overrightarrow{e}^{\mp}p \rightarrow e^{\mp}p\mu^{+}\mu^{-}$$

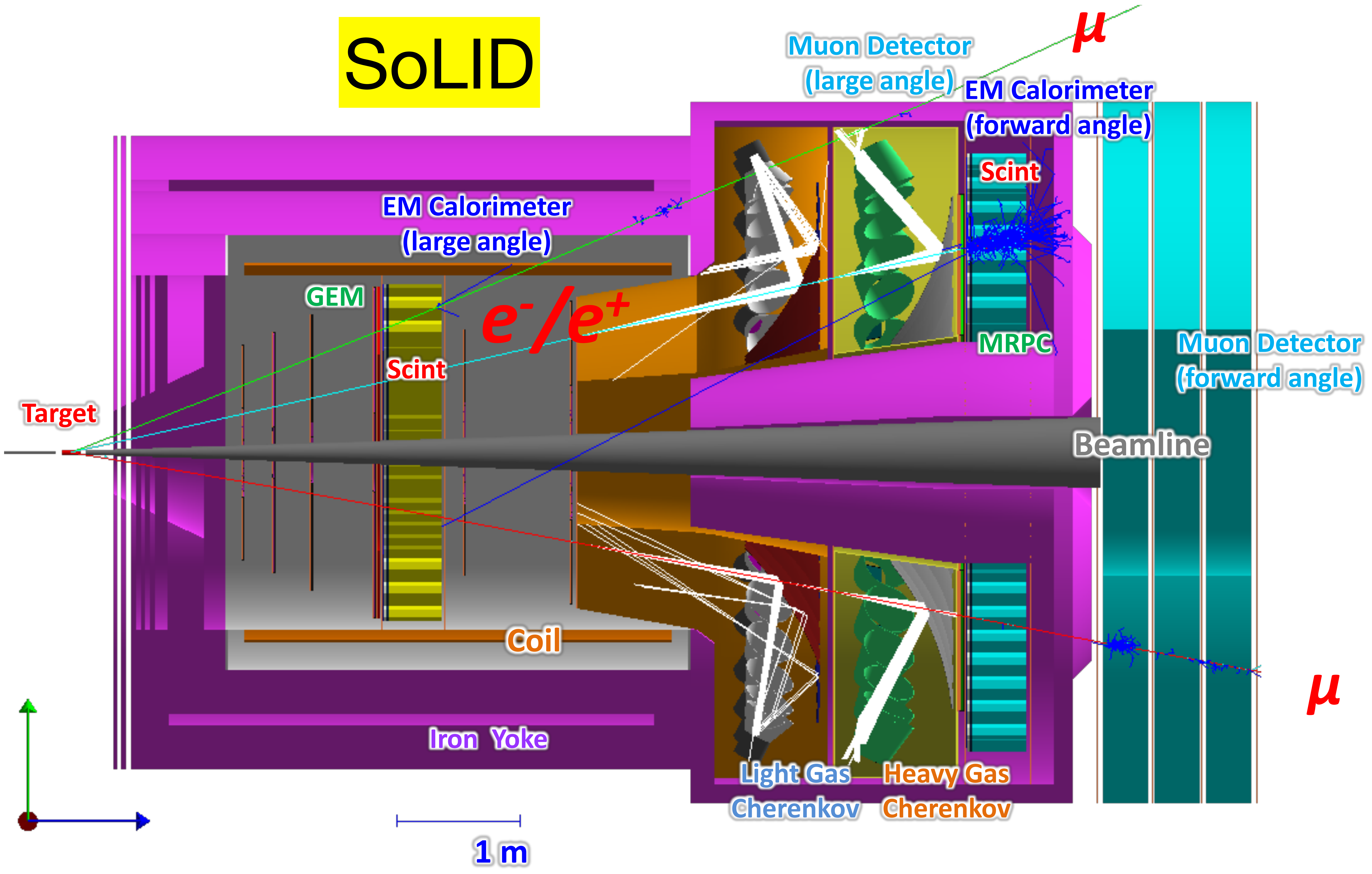
Nuclear Femtography

EPJA 57(2021)240

Note: Positron beams



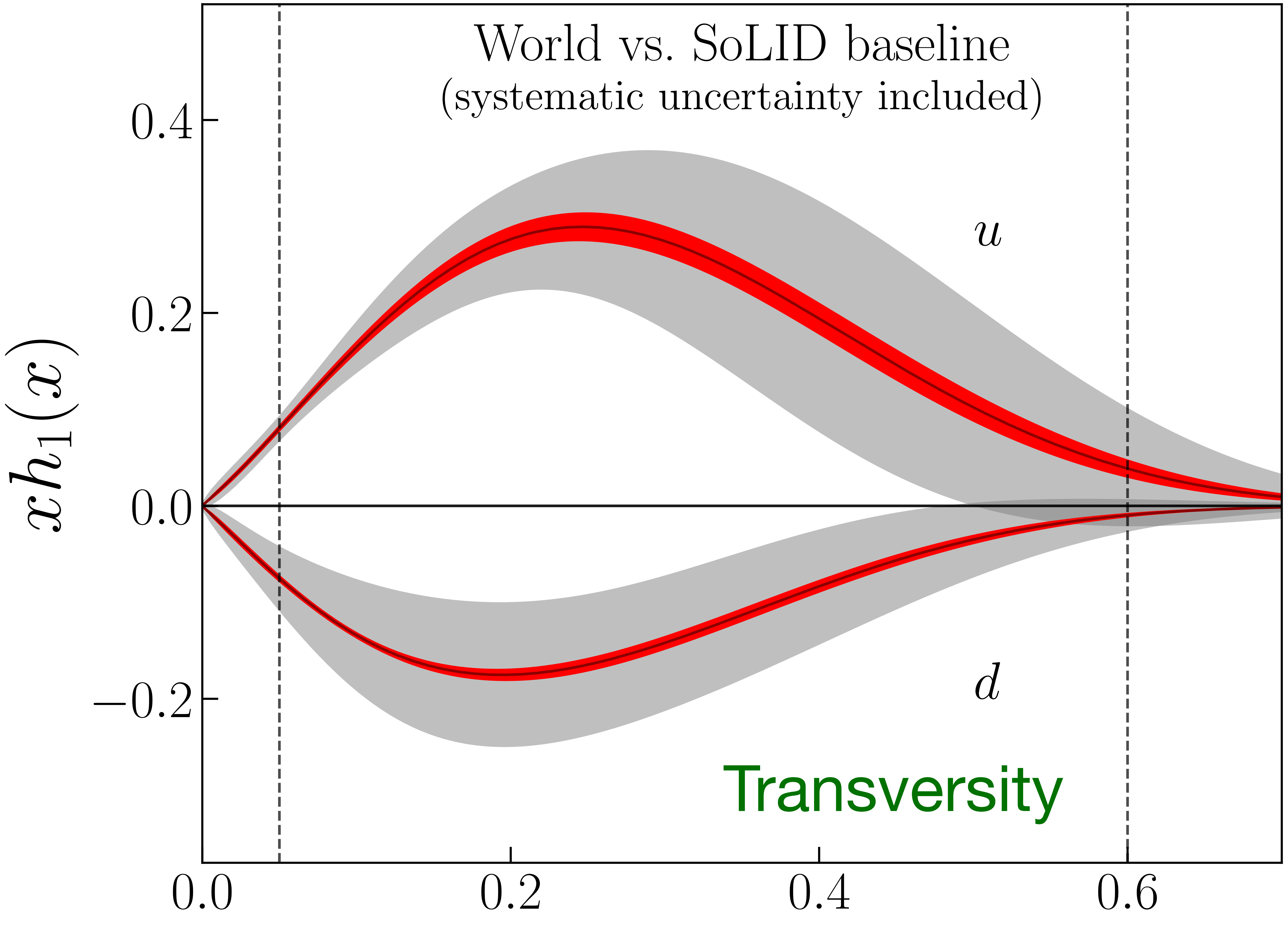
- Access GPDs away from x=±ξ
- Cross section ×100 smaller than for DVCS
- Requires large acceptance, high luminosity detector with superb muon detection
- Two Letters of Intent submitted to PAC (SoLID & CLAS12)

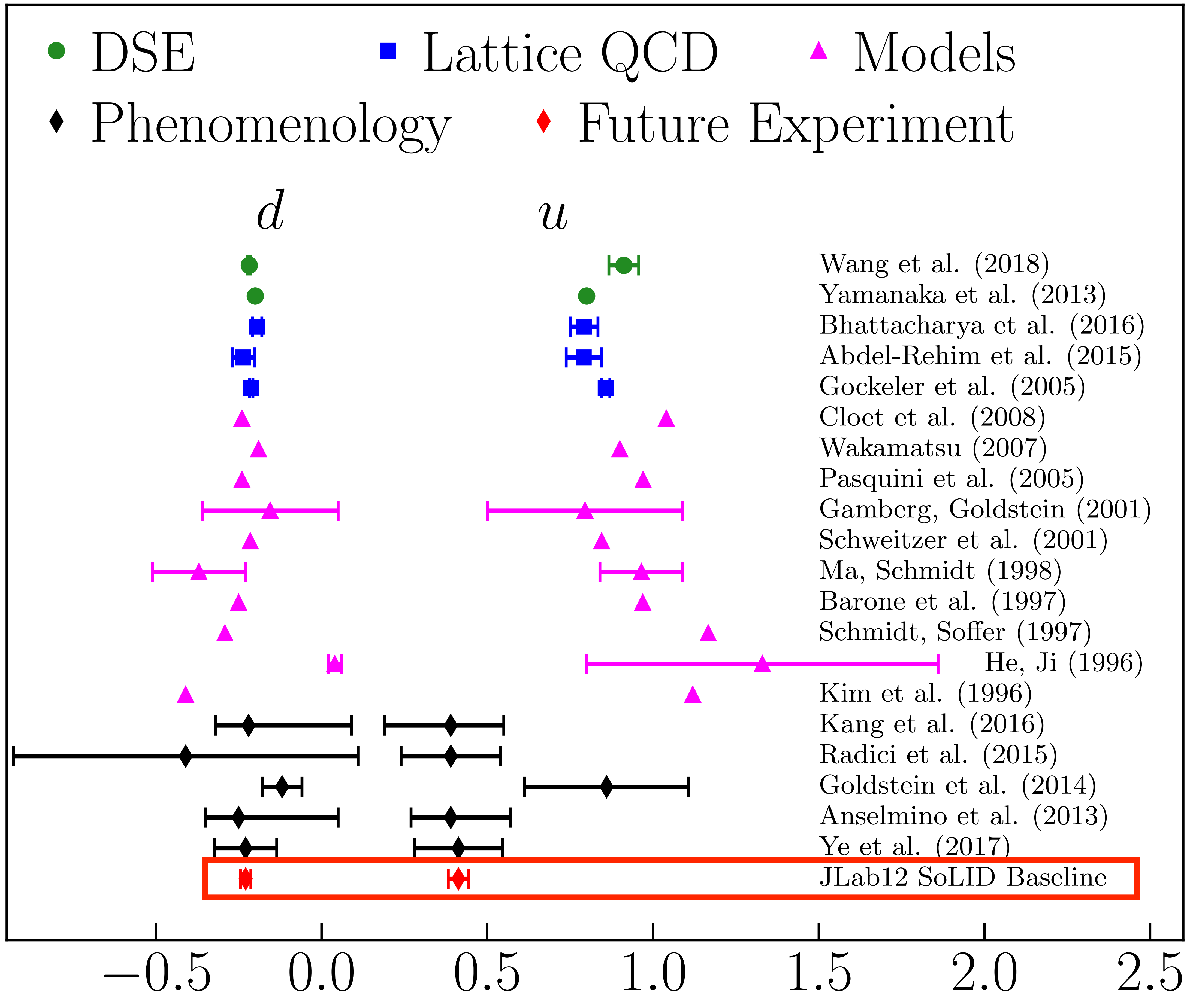


Transverse Momentum Dist

Nuclear Femtography

Semi Inclusive Deep Inelastic Scattering (SIDIS) at 12 GeV with SoLID





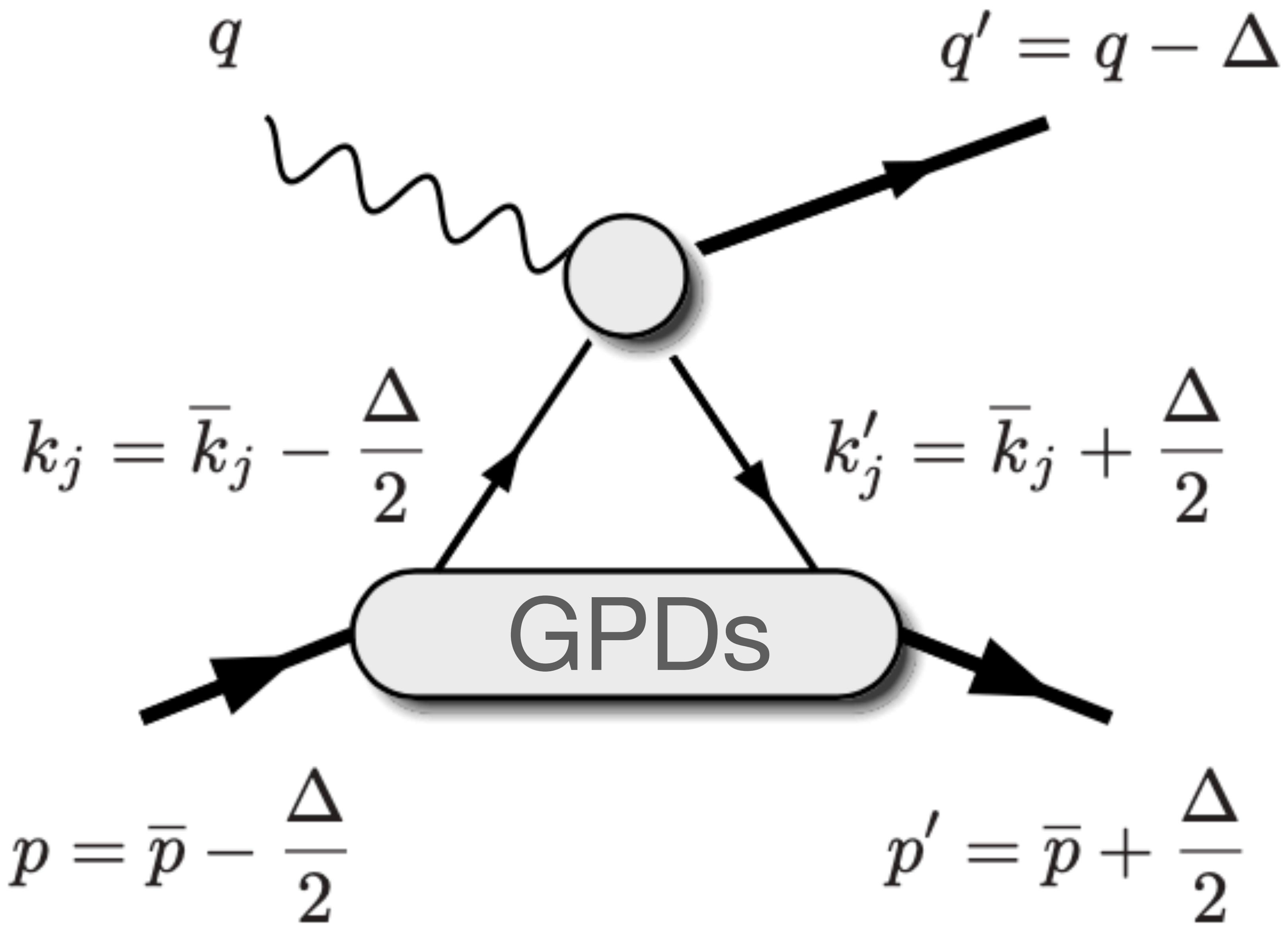
x ⟶ *Integrate* ⟶ g_T Tensor charge

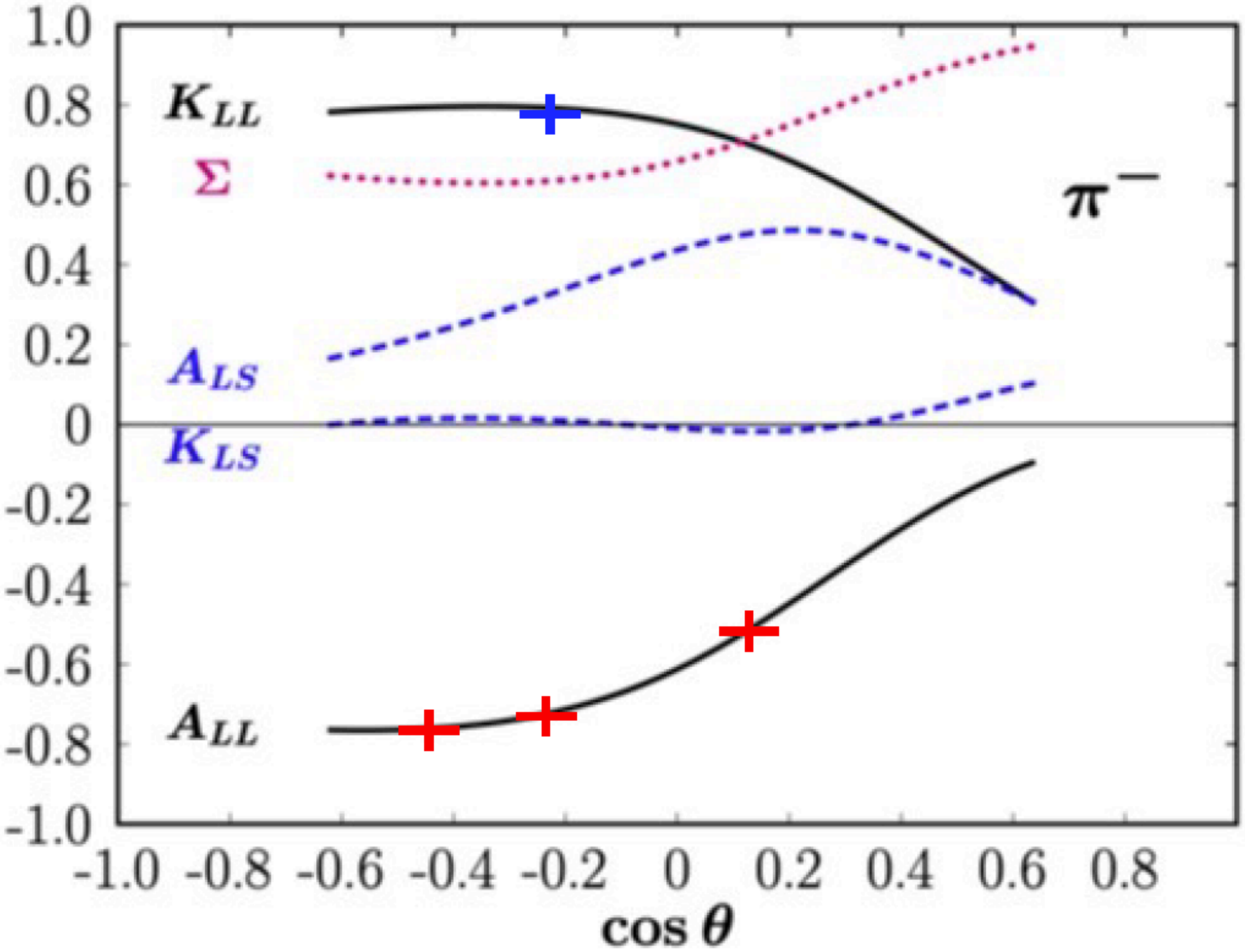
Exclusive Photoproduction

Nuclear Femtography

E12-20-008 and E12-21-005

$$\vec{\gamma}\,\vec{n} \rightarrow \pi^- p$$



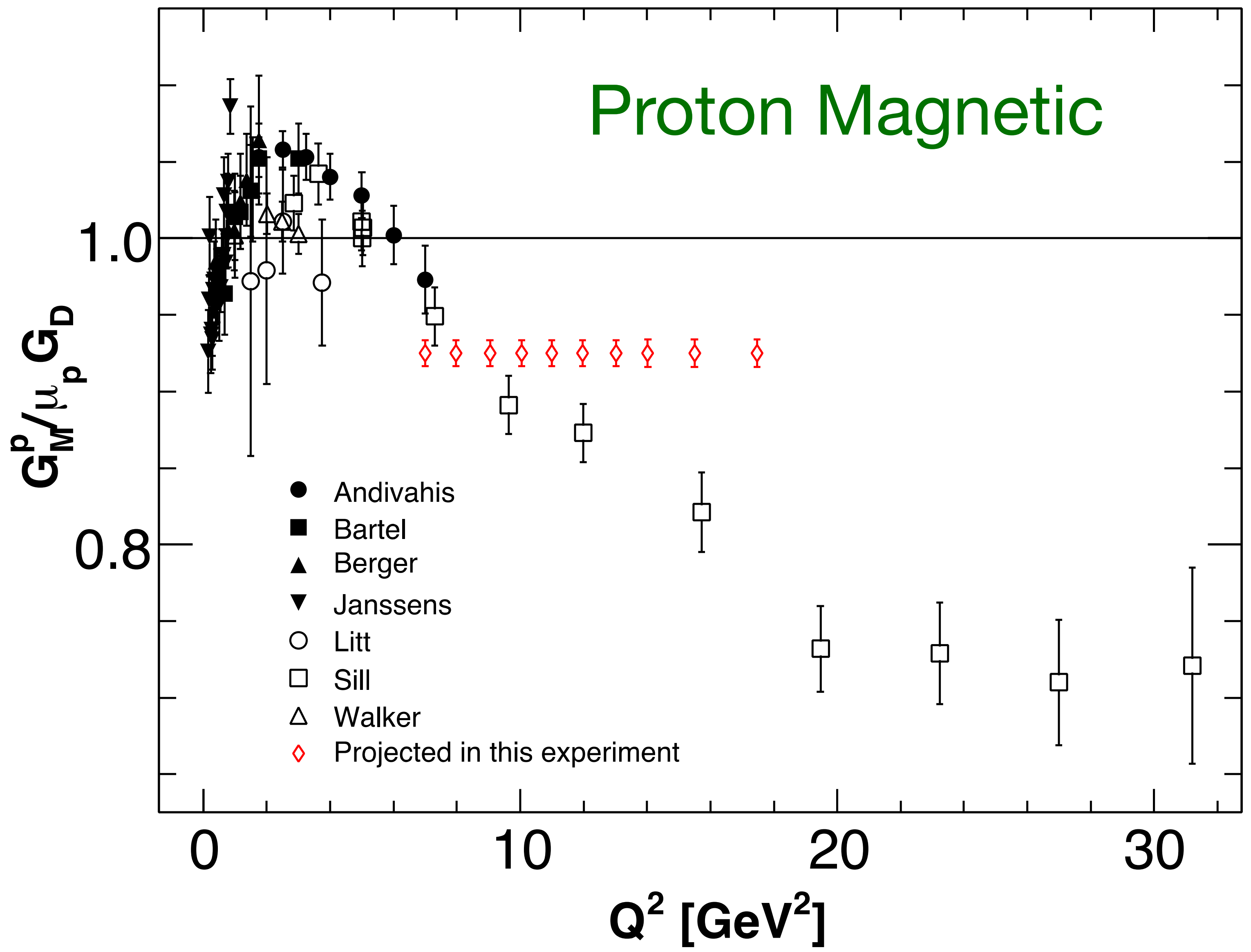


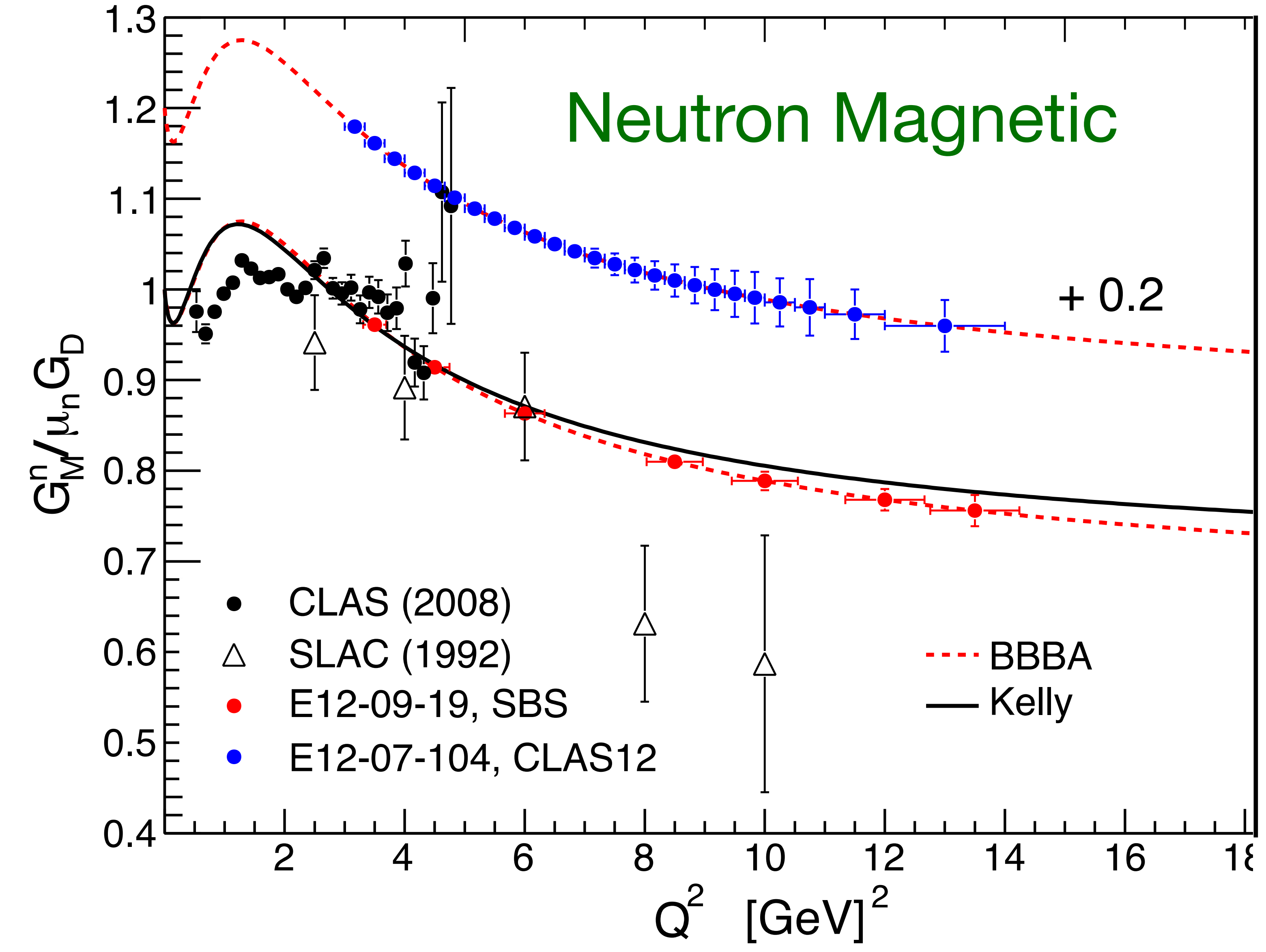
Precision $G_{M,E}$ at High Q^2

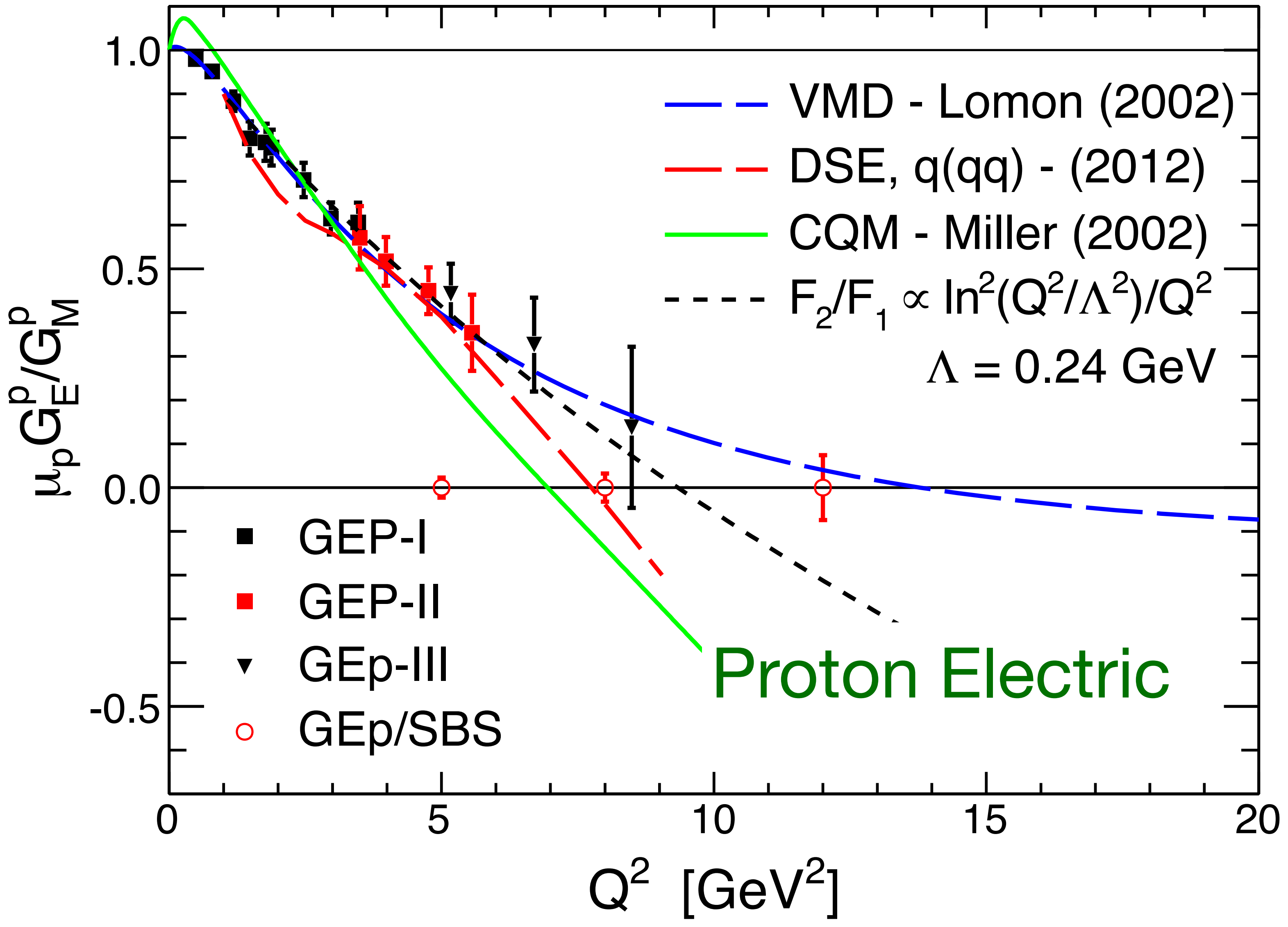
Nucleon Elastic Form Factors

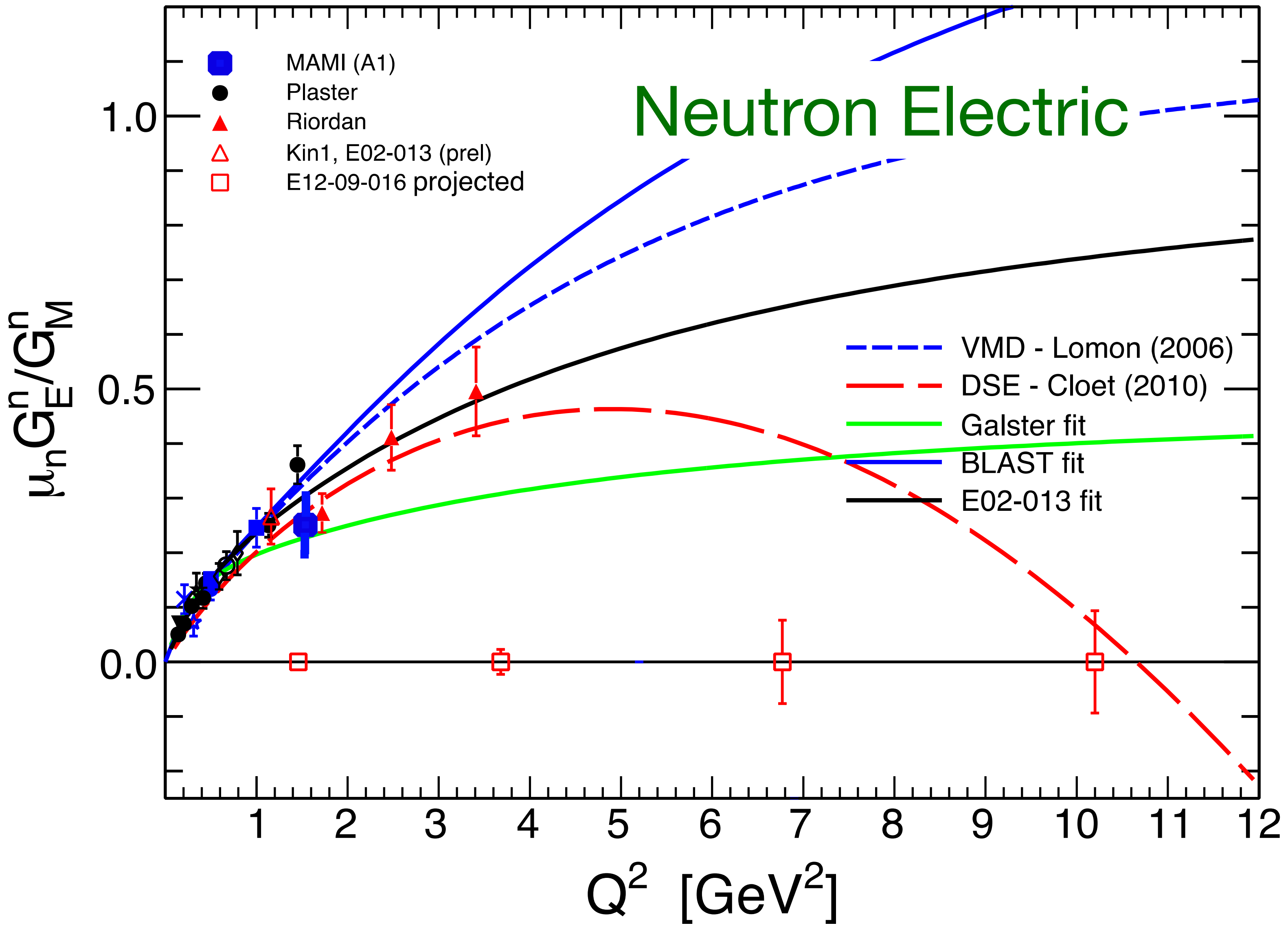
Several experiments in progress or planned in the near future, pushing the limits of Q^2 with highest possible precision.

Electric form factor measurements rely on polarization observables to extract the ratio of electric to magnetic.





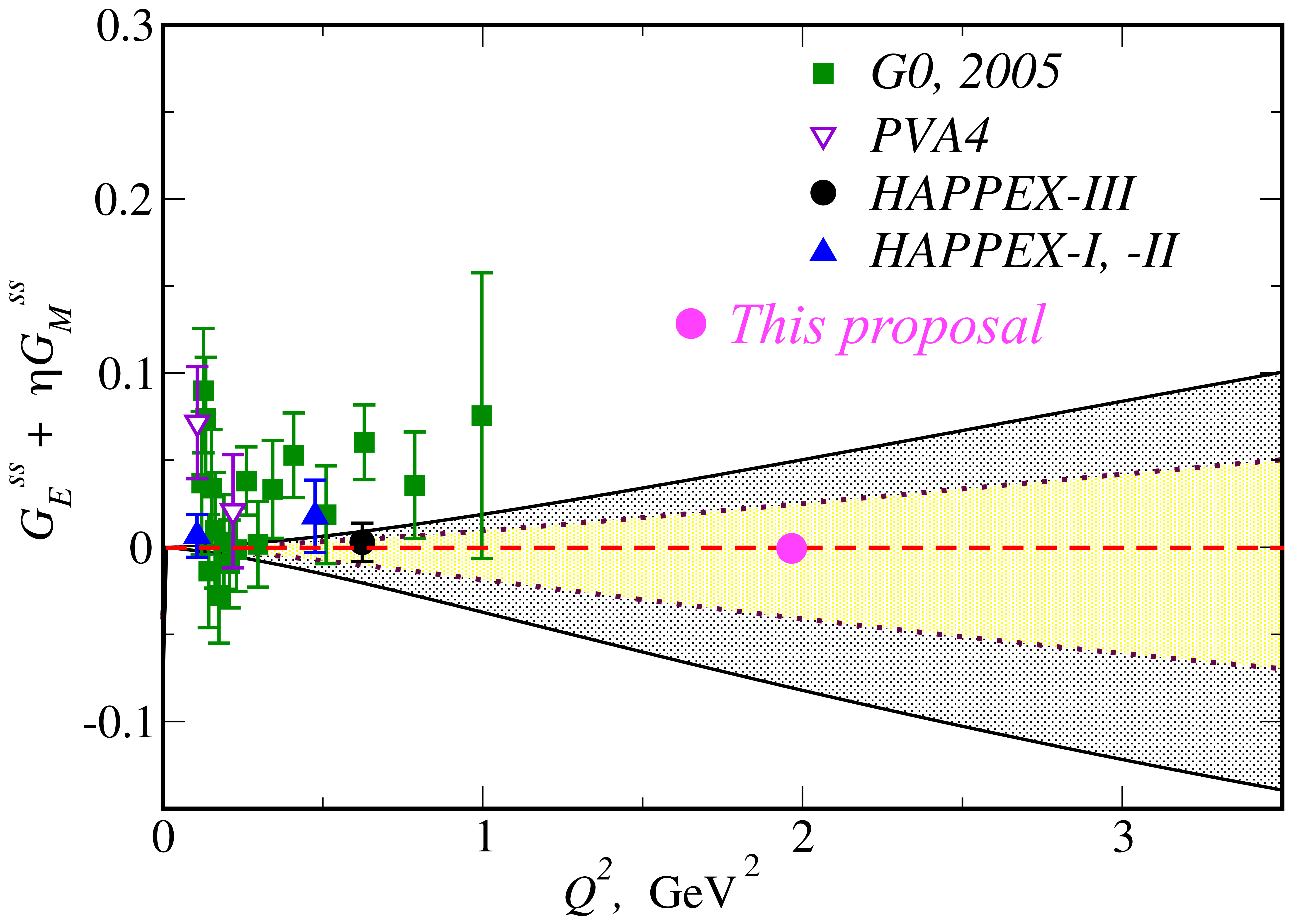


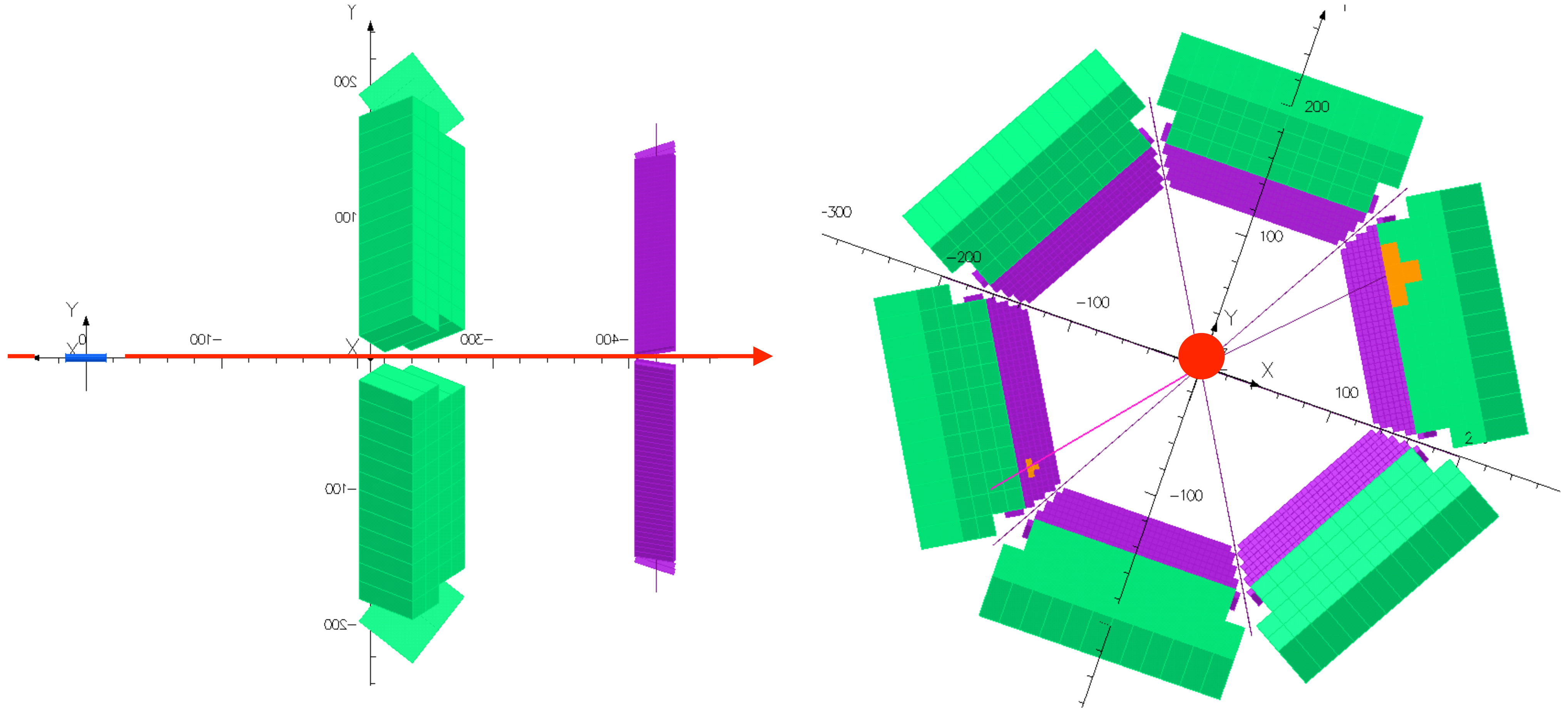


Search for a Strange $G_{M,E}$

Nucleon Elastic Form Factors

See "Jefferson Lab Hall C: Precision Physics at the Luminosity Frontier", The Hall C Futures Working Group





Parity violating elastic electron scattering from the proton using a coincidence counting approach.

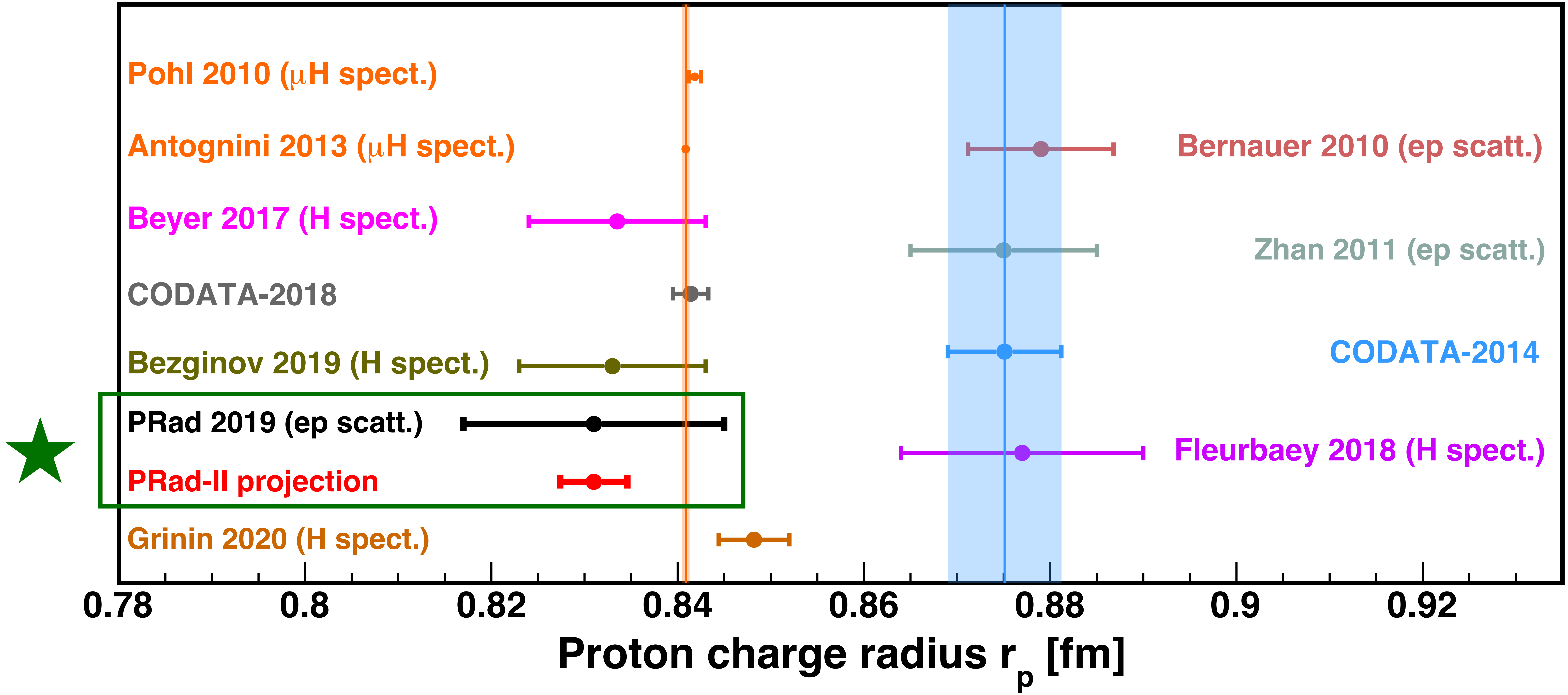
One issue is potential contributions from the proton axial vector form factor, but these seem to be under control.

Measurements go towards a flavor separation of elastic form factors.

The Proton Charge Radius

Low Energy Opportunities

See also Nature 575(2019)147 and arXiv:2009.10510

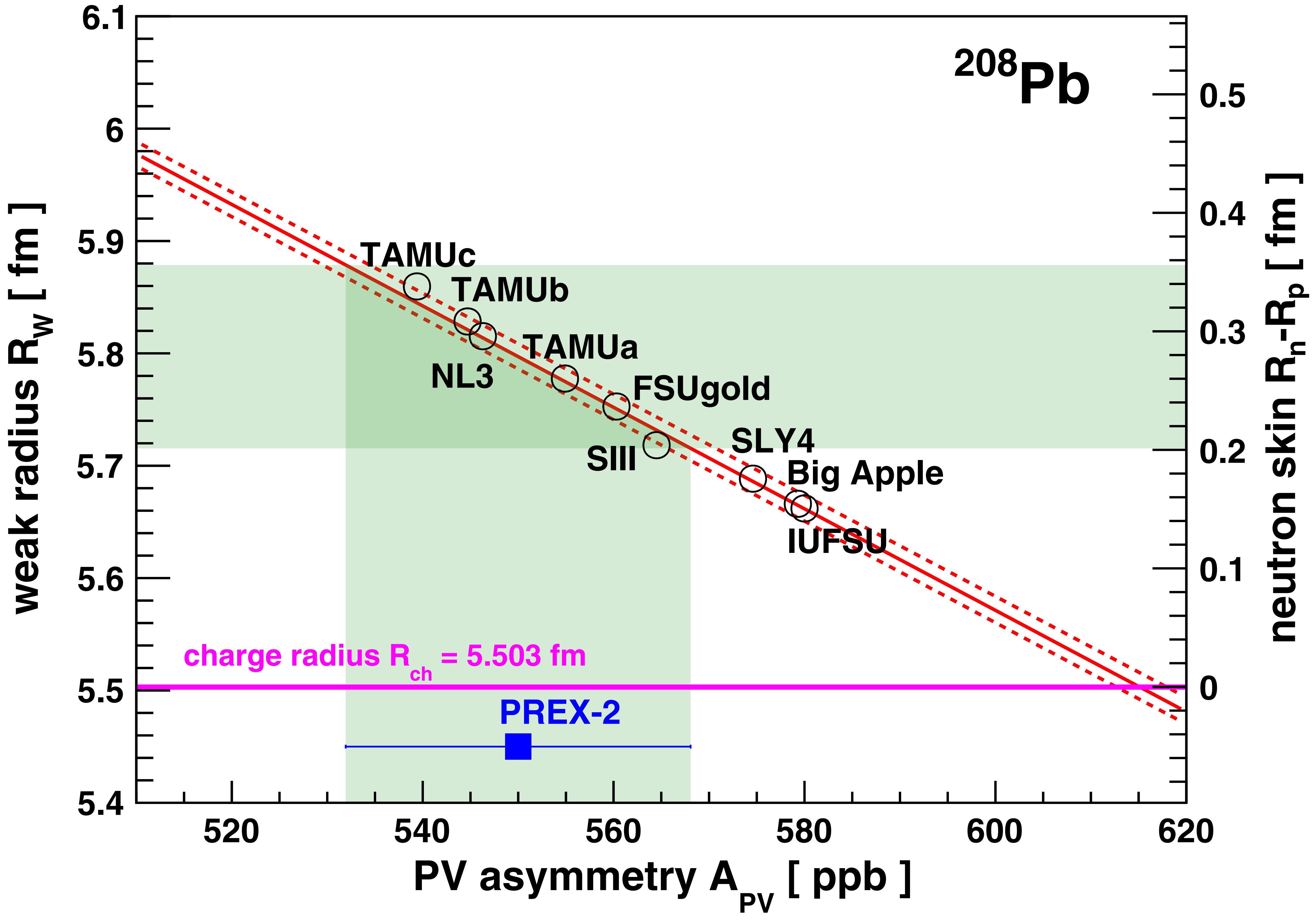


Neutron Skins

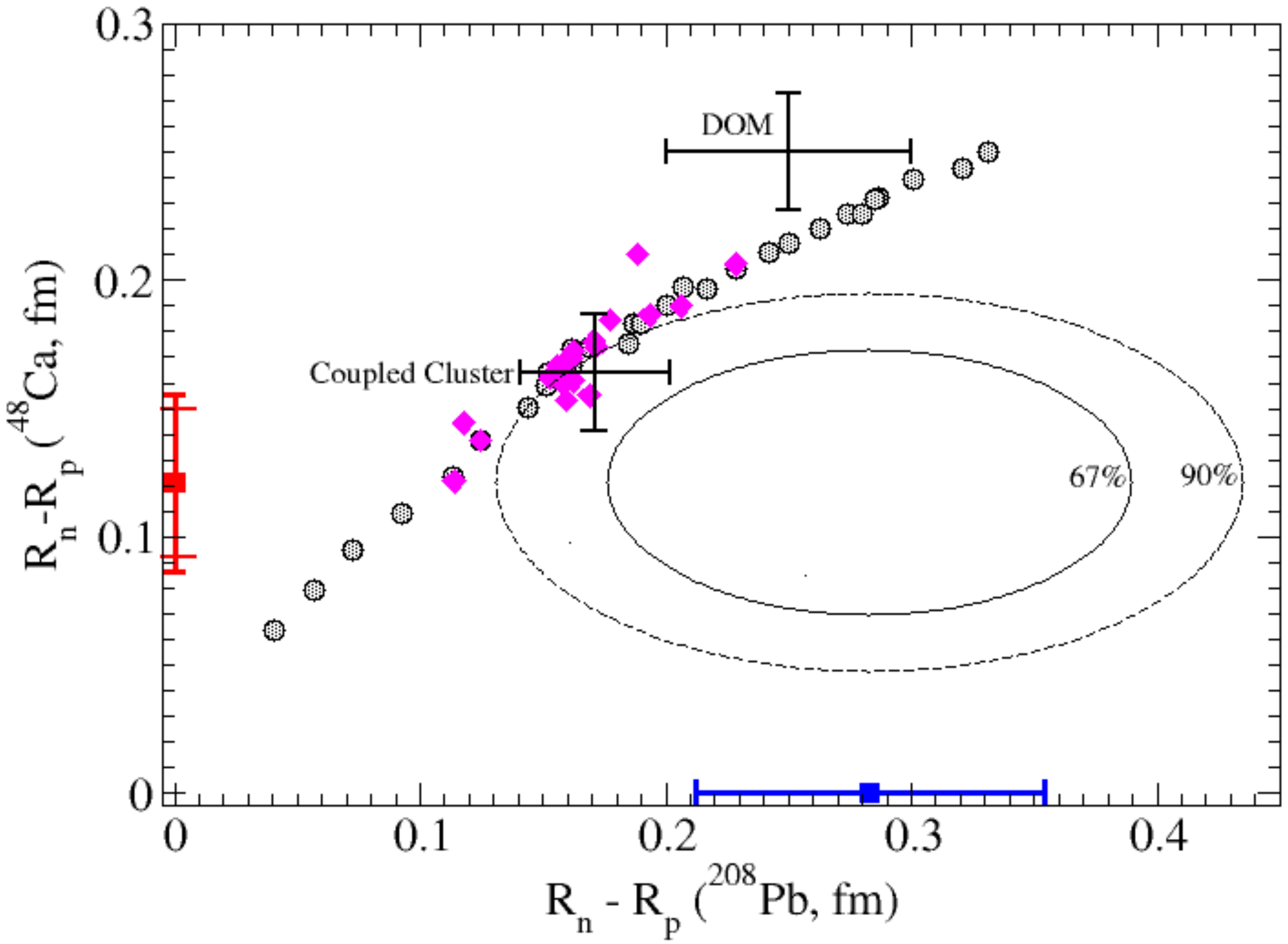
Low Energy Opportunities

PRL126(2021)172502 (PREX2) and arXiv:2205.11593 (CREX)

Extracting the skin in ^{208}Pb from PV Asymmetry



^{208}Pb skin thickness vs ^{48}Ca

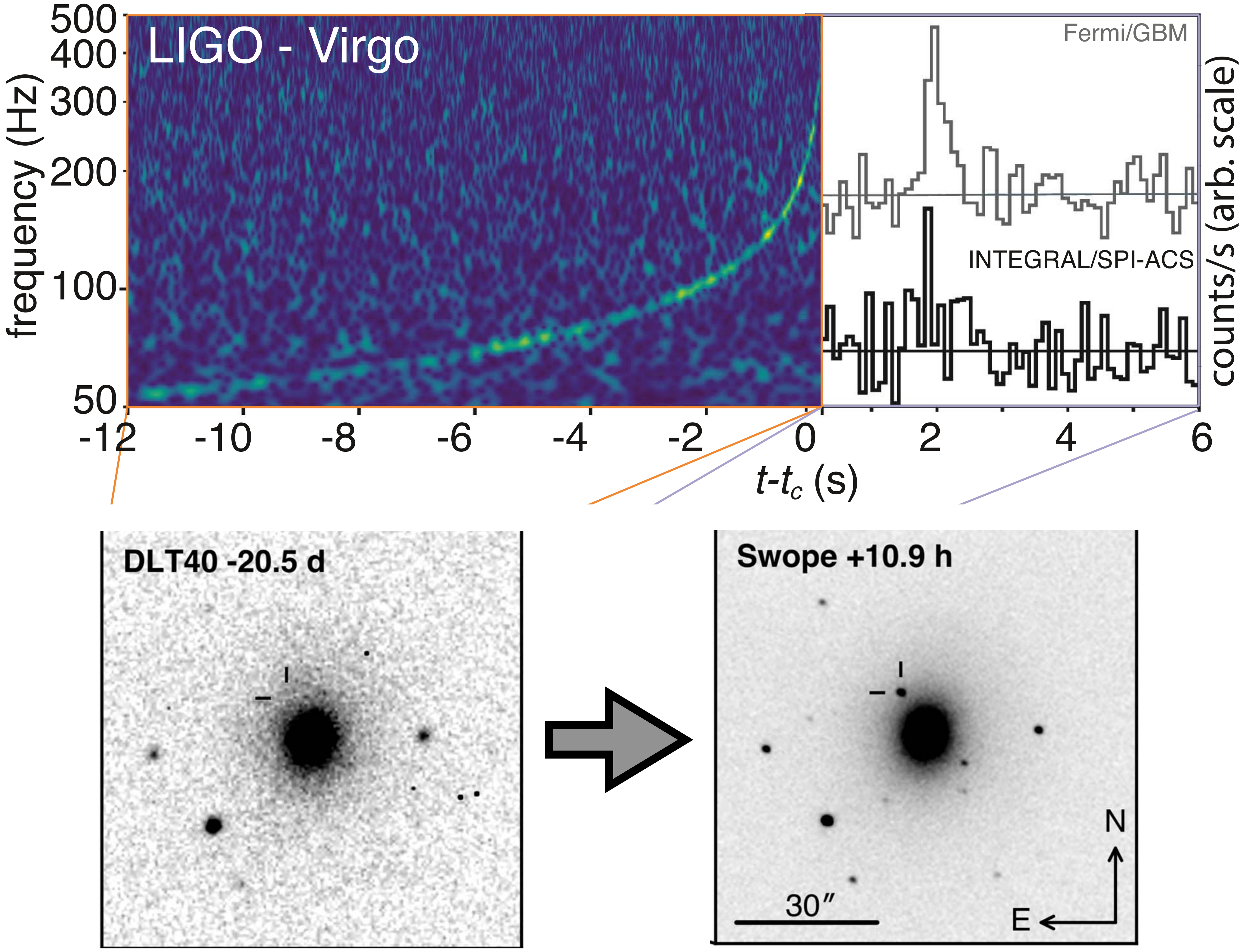


A narrow range of models are consistent with a "thick" skin in ^{208}Pb and a "thin" skin in ^{48}Ca.

Neutron Star Merger GW170817

Astrophysics!

ApJ 848(2017)L12



PRL 119(2017)161101

Primary mass m_1	1.36–$1.60\ M_\odot$
Secondary mass m_2	1.17–$1.36\ M_\odot$

Neutron Star Merger GW170817

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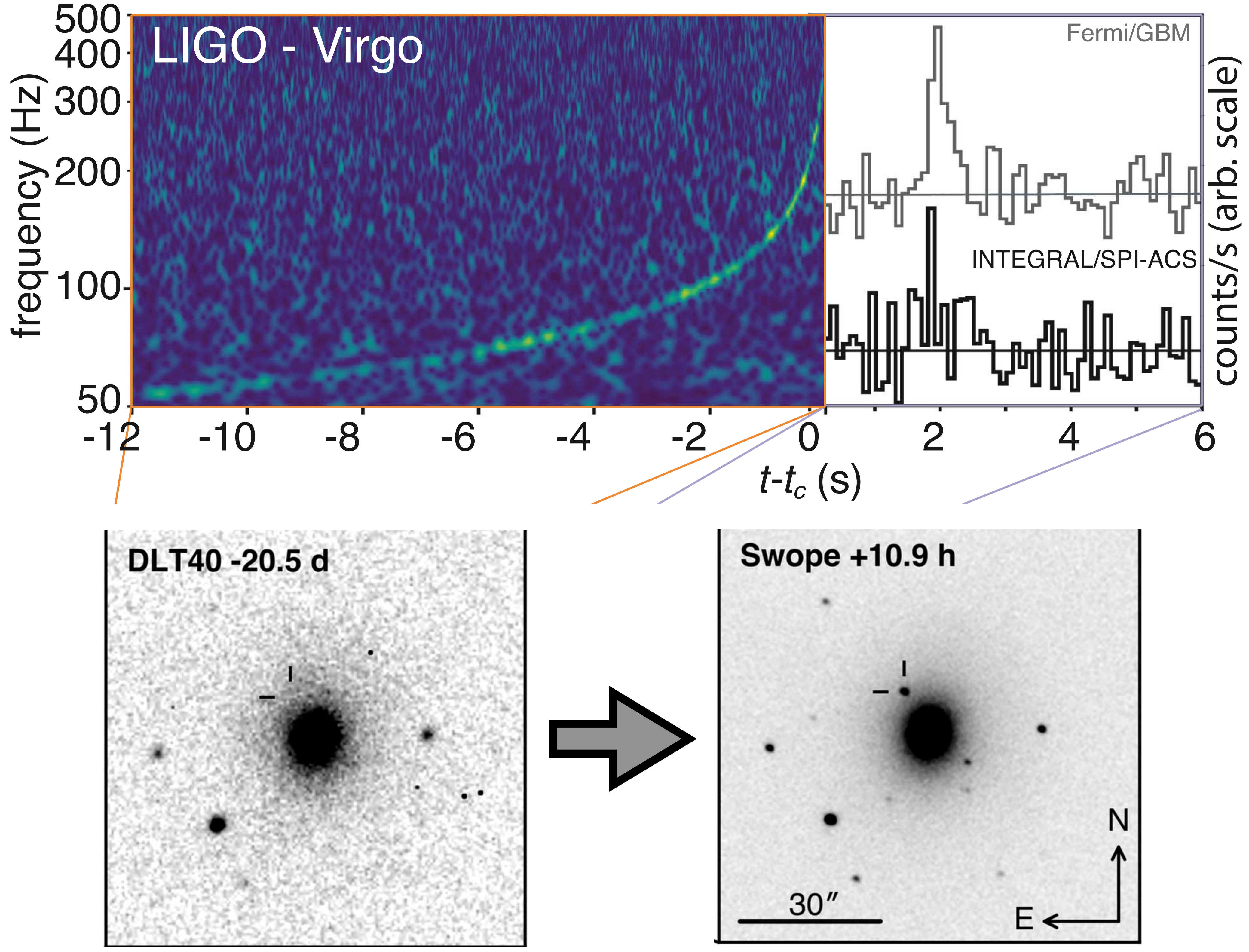
ApJ 848(2017)L12



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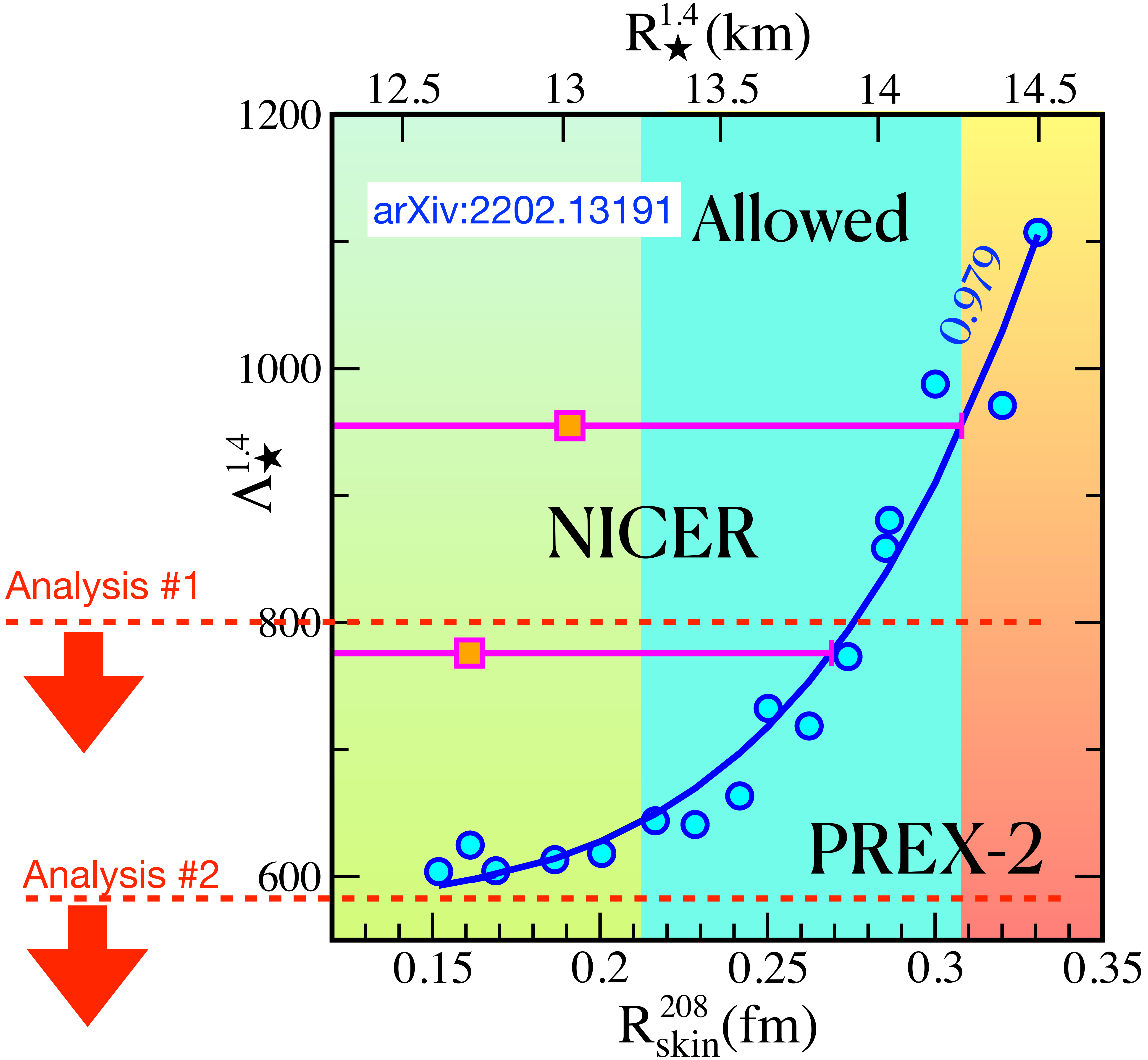
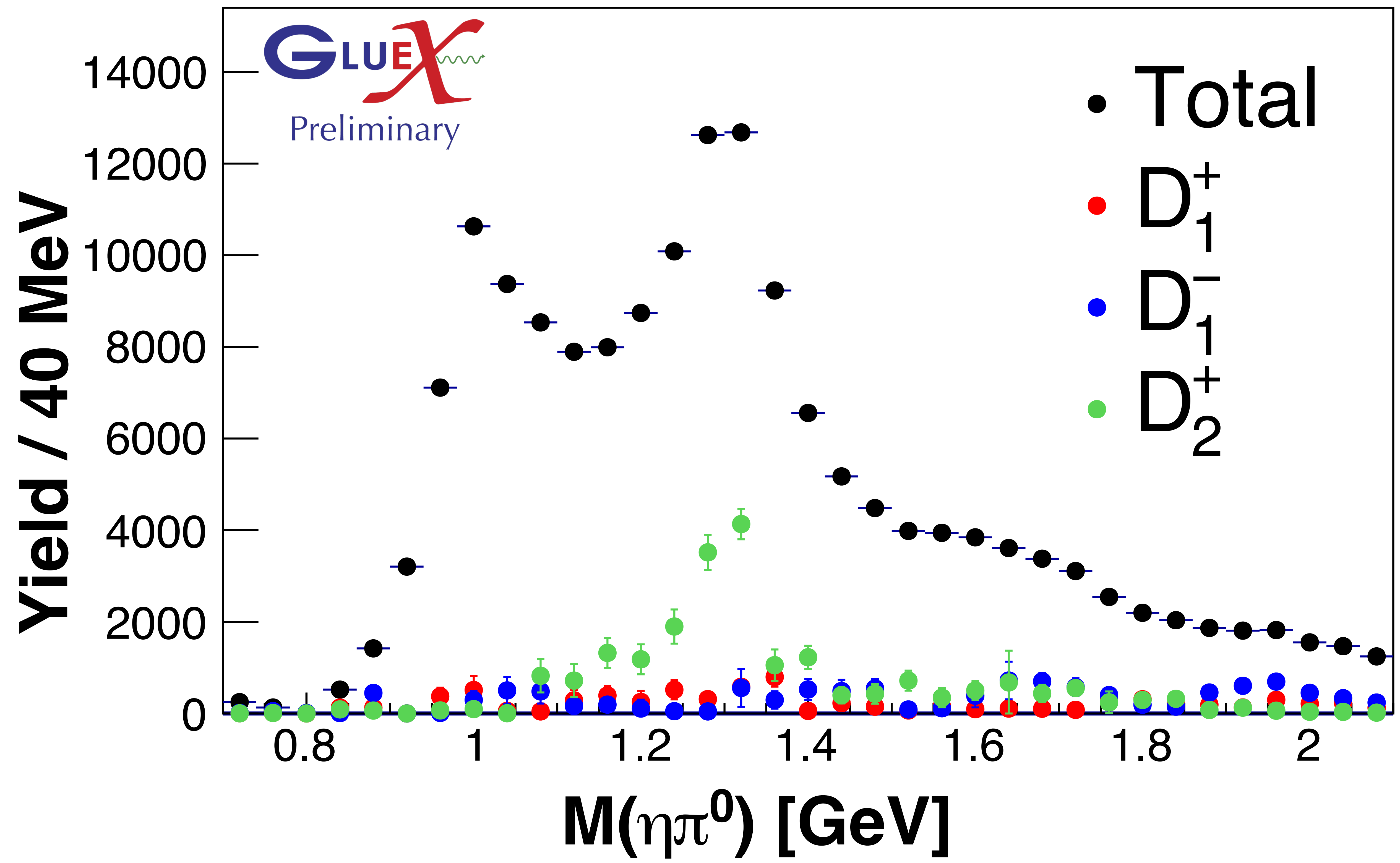
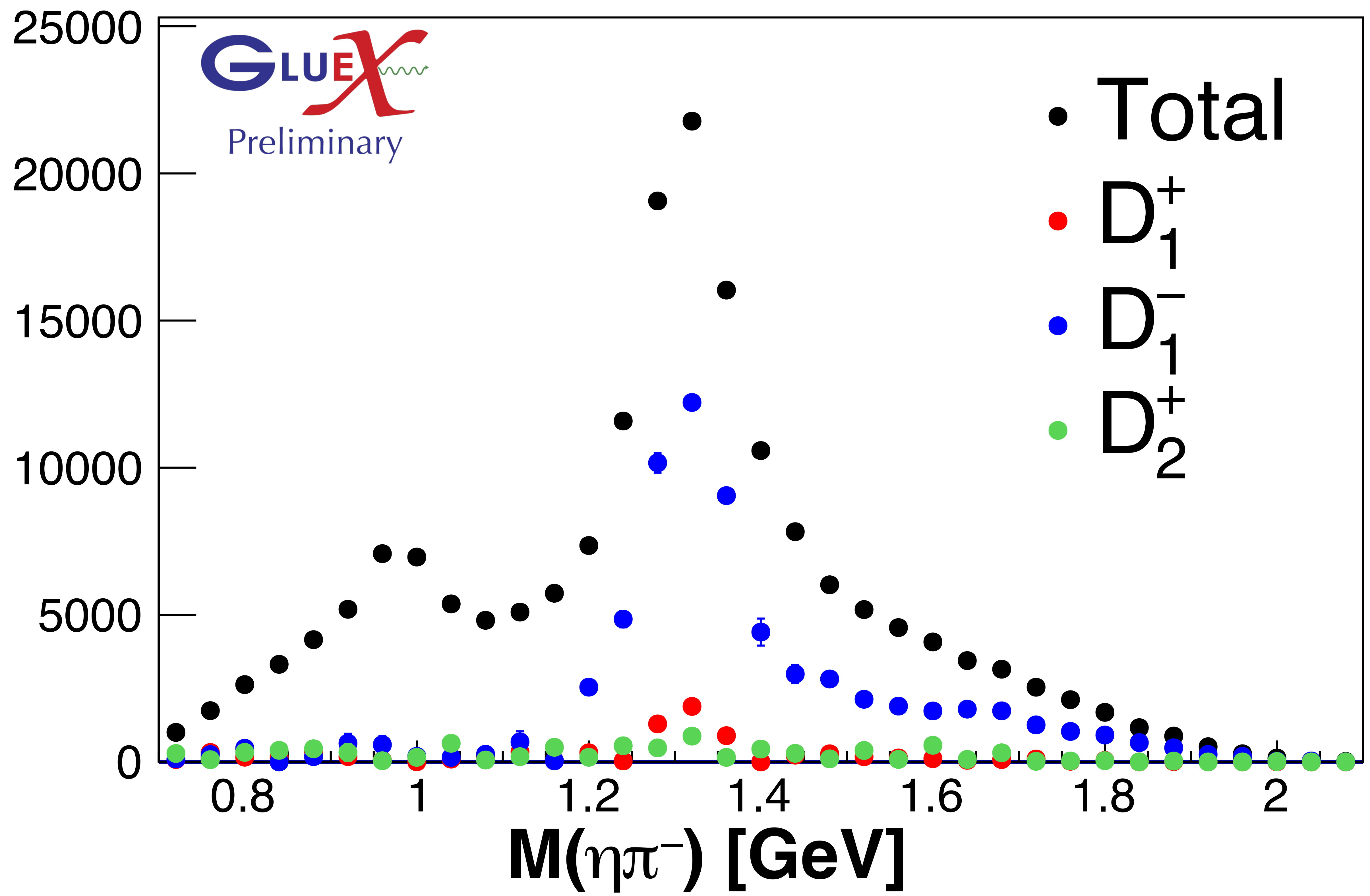


Exotic Meson Photoproduction

Hadron Spectroscopy

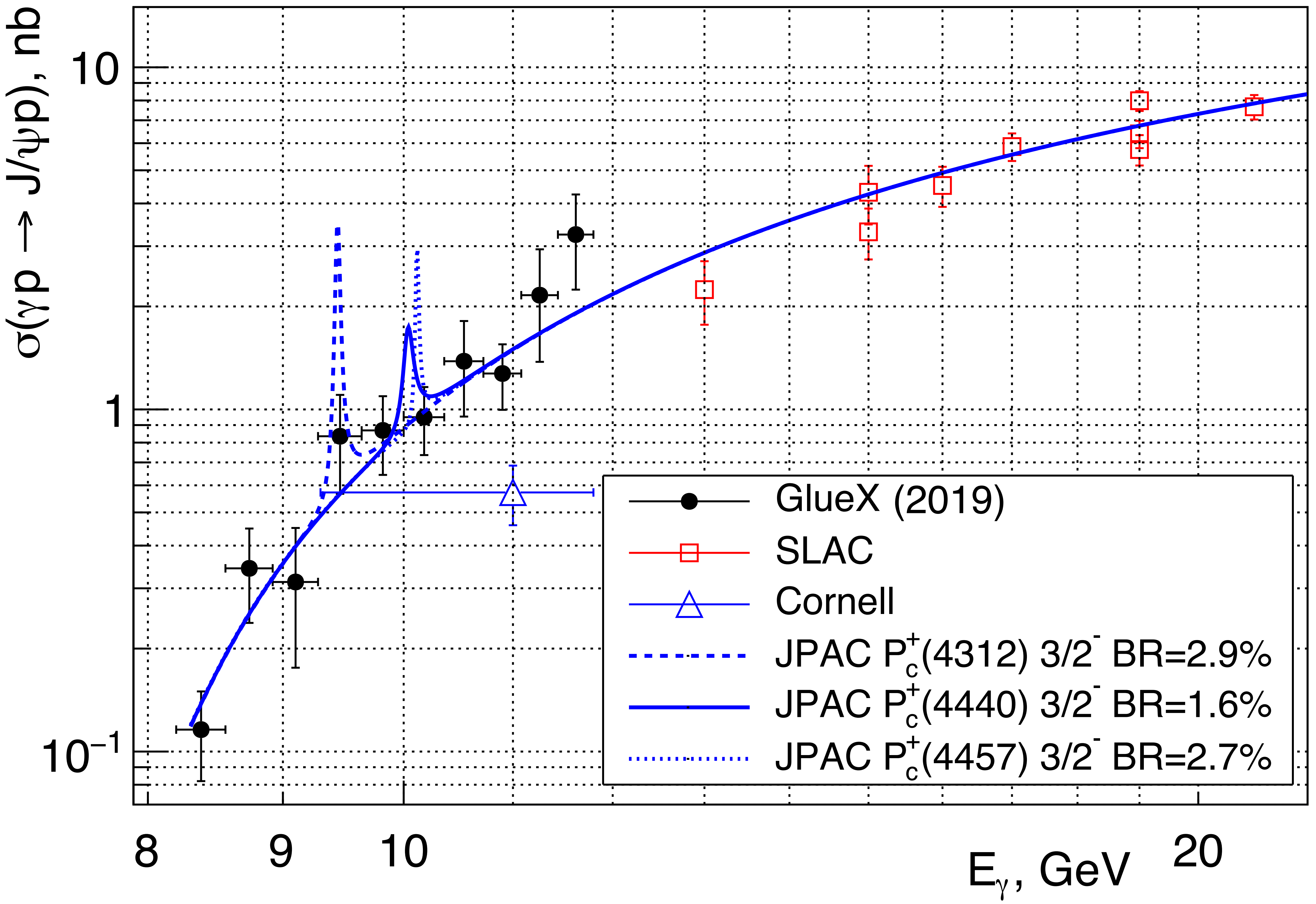
Primary goal for GlueX: Resonant (?) P-wave in $\vec{\gamma}\, p \to \eta\pi\, N$

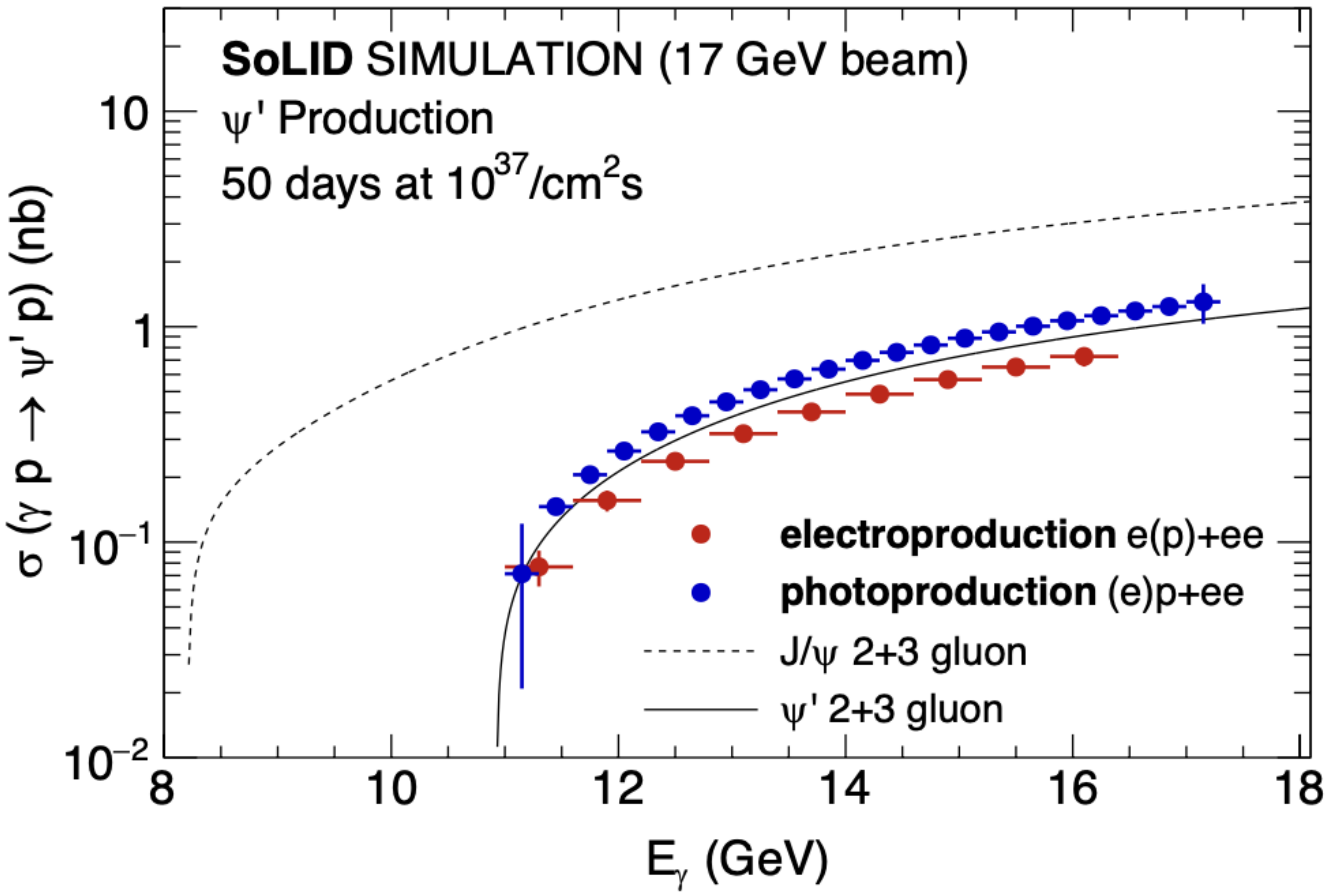




Excellent data quality, continuing analysis for unambiguous extraction of P-wave

Photoproduction of J/ψ



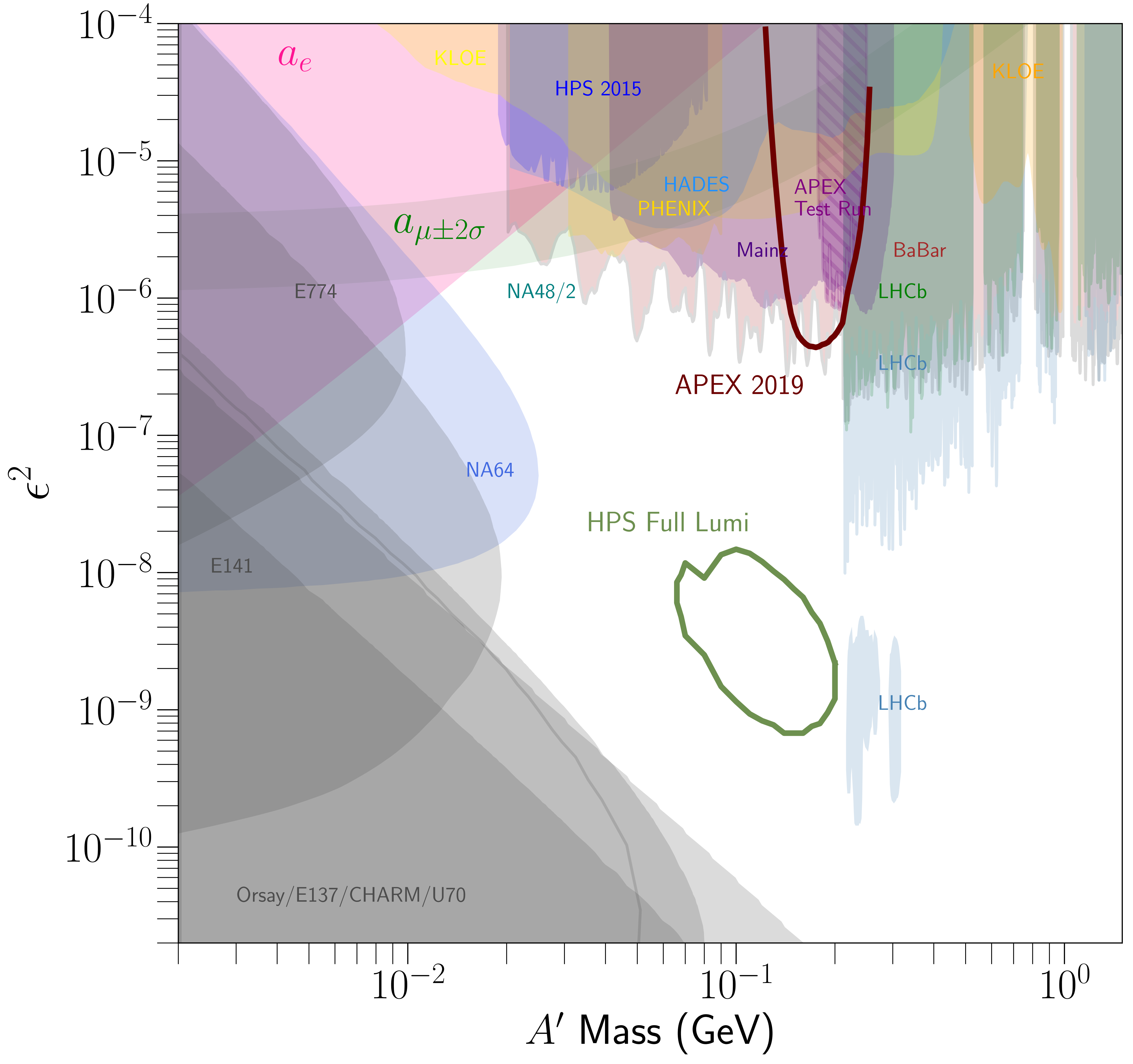


- Searching for evidence of photproduction of pentaquark state
- Connection to proton mass radius: Phys Rev D 104(2021)054015

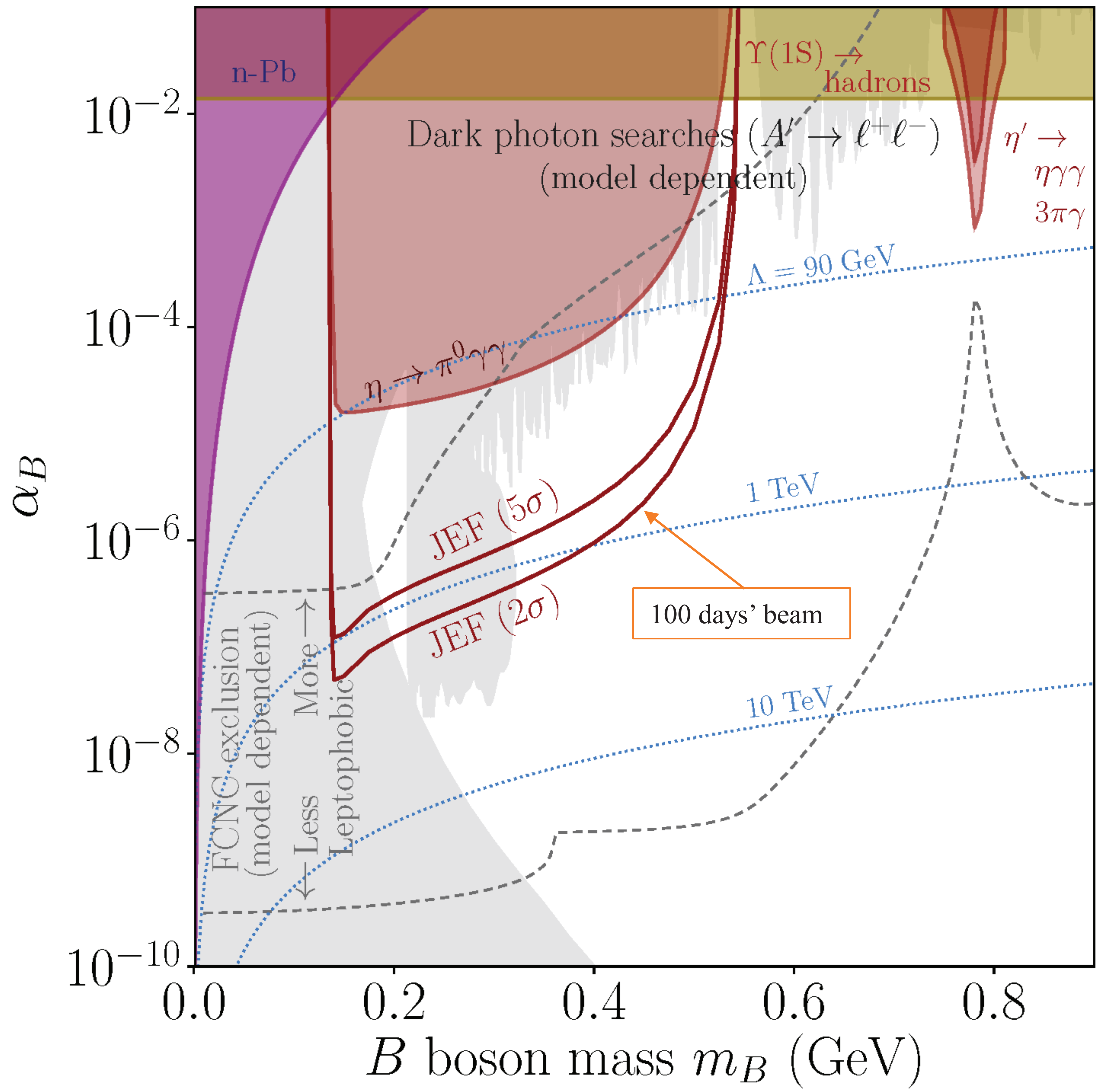
Search for New Particles

BSM Physics

Heavy photons: APEX and HPS



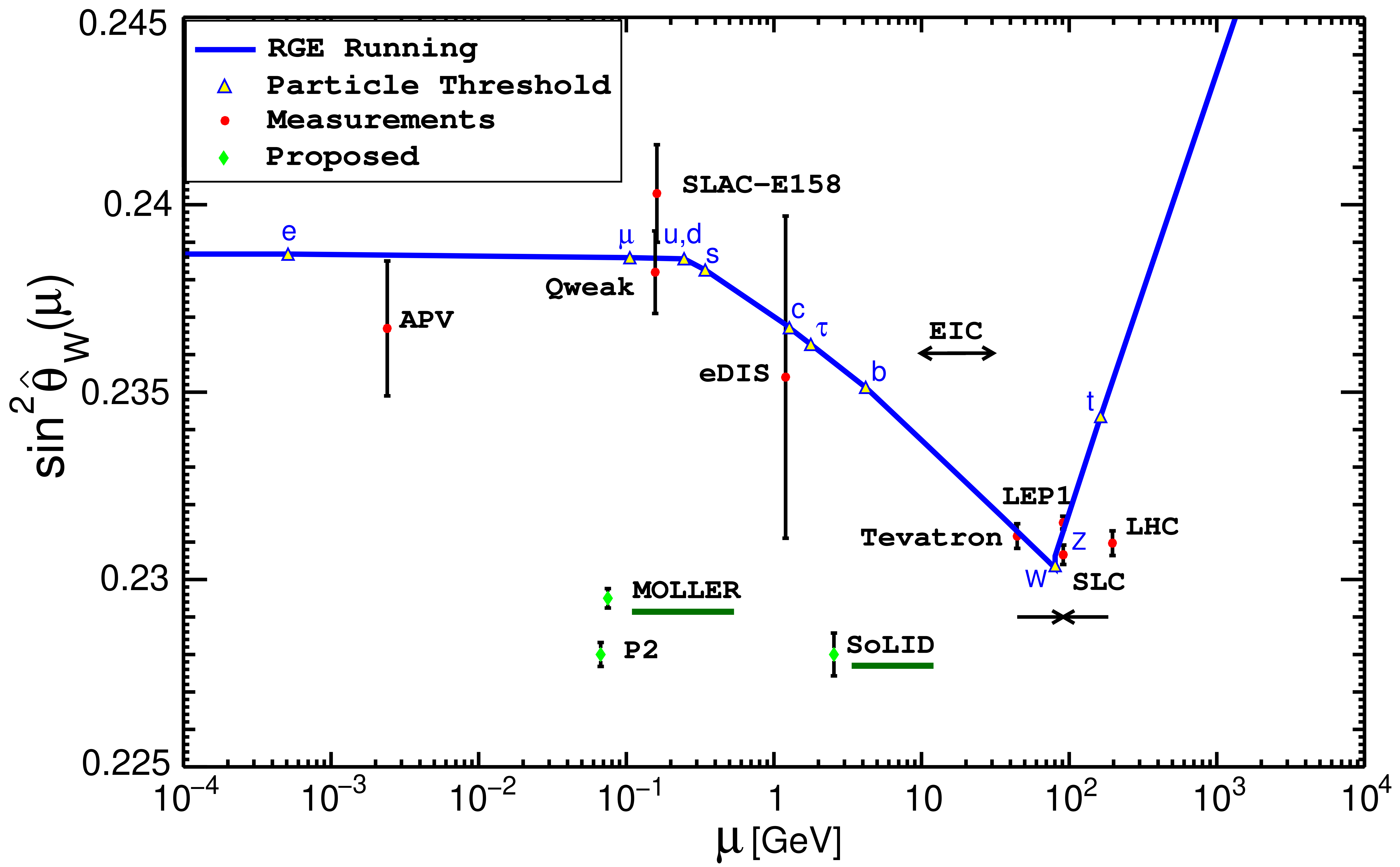
JLab Eta Factory



Note: Contours are projections

Precision Electroweak Physics

BSM Physics



Precise measurements of parity violation with polarized electrons.

MOLLER

$\vec{e}e \rightarrow ee$

SoLID

$\vec{e}q$ couplings using Deep Inelastic Scattering

An Exciting Future for CEBAF

Conclusion

The “12 GeV Era” continues to produce groundbreaking new measurements over a wide range of topics in fundamental Nuclear Physics. New facilities, including upgrades to CEBAF, show the promise of a long and productive future that will be complementary to eventual measurements from the Electron Ion Collider.

Talks follow this one on Positron Beams, the CEBAF Energy Upgrade, and the “J-FUTURE” workshop series.

Consider attending the High Energy Workshop Series 2022 organized by JLUO

- *Hadron Spectroscopy with a CEBAF Energy Upgrade*
- *The Next Generation of 3D Imaging*
- *Science at Mid-x: Anti-shadowing and the Role of the Sea*
- *J/ψ and Beyond*
- *Physics Beyond the Standard Model*