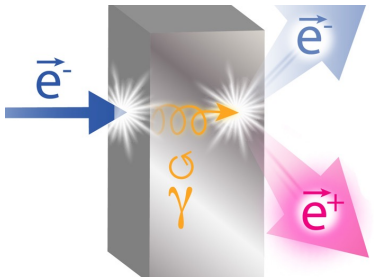
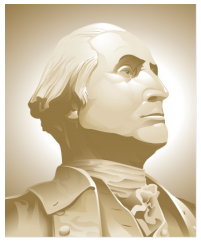
Physics with a Positron Beam at Jefferson Lab

Axel Schmidt

25th International Spin Symposium

September 25, 2023

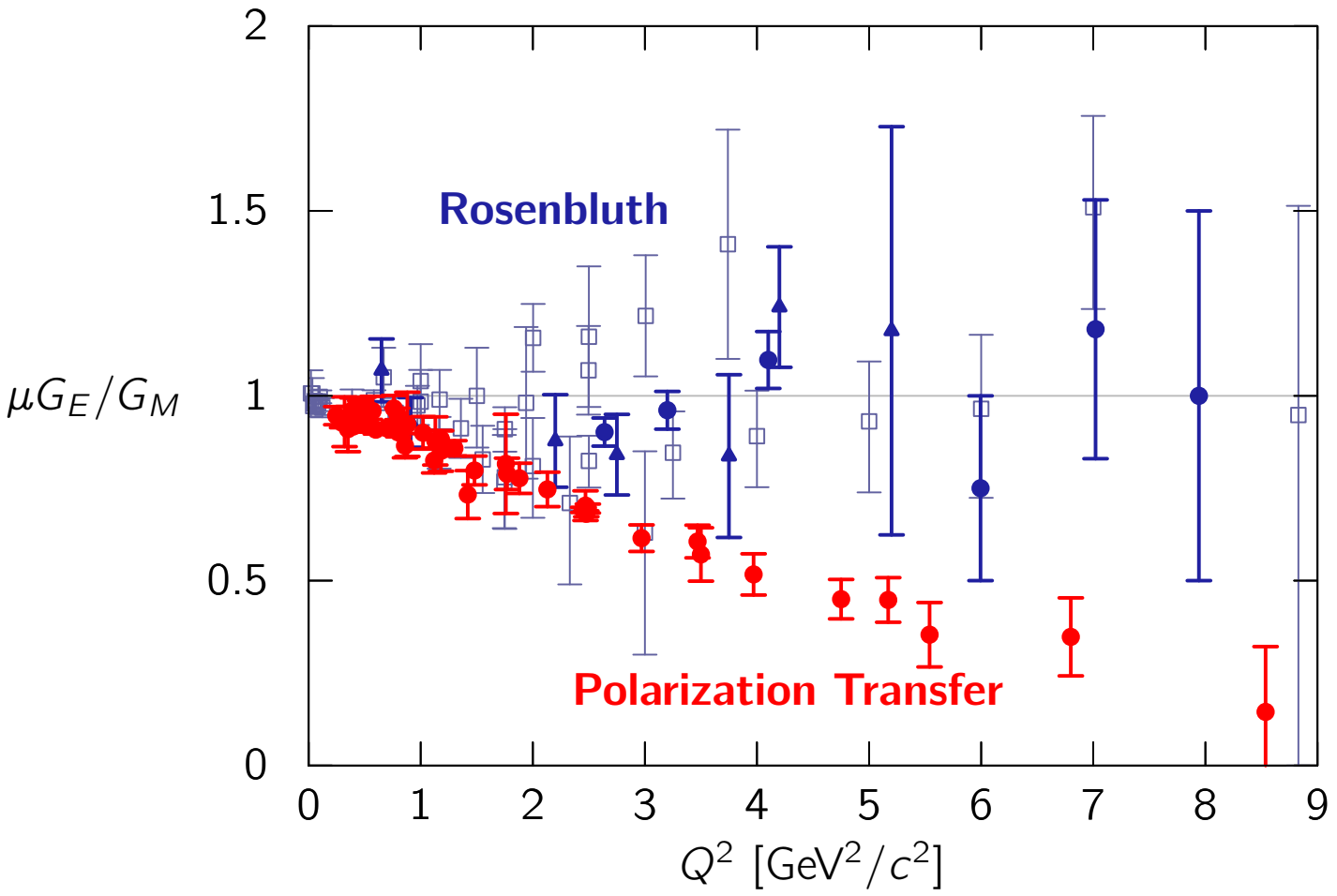




THE GEORGE WASHINGTON UNIVERSITY

WASHINGTON, DC

“Spin” reveals a discrepancy in the proton’s form factors.



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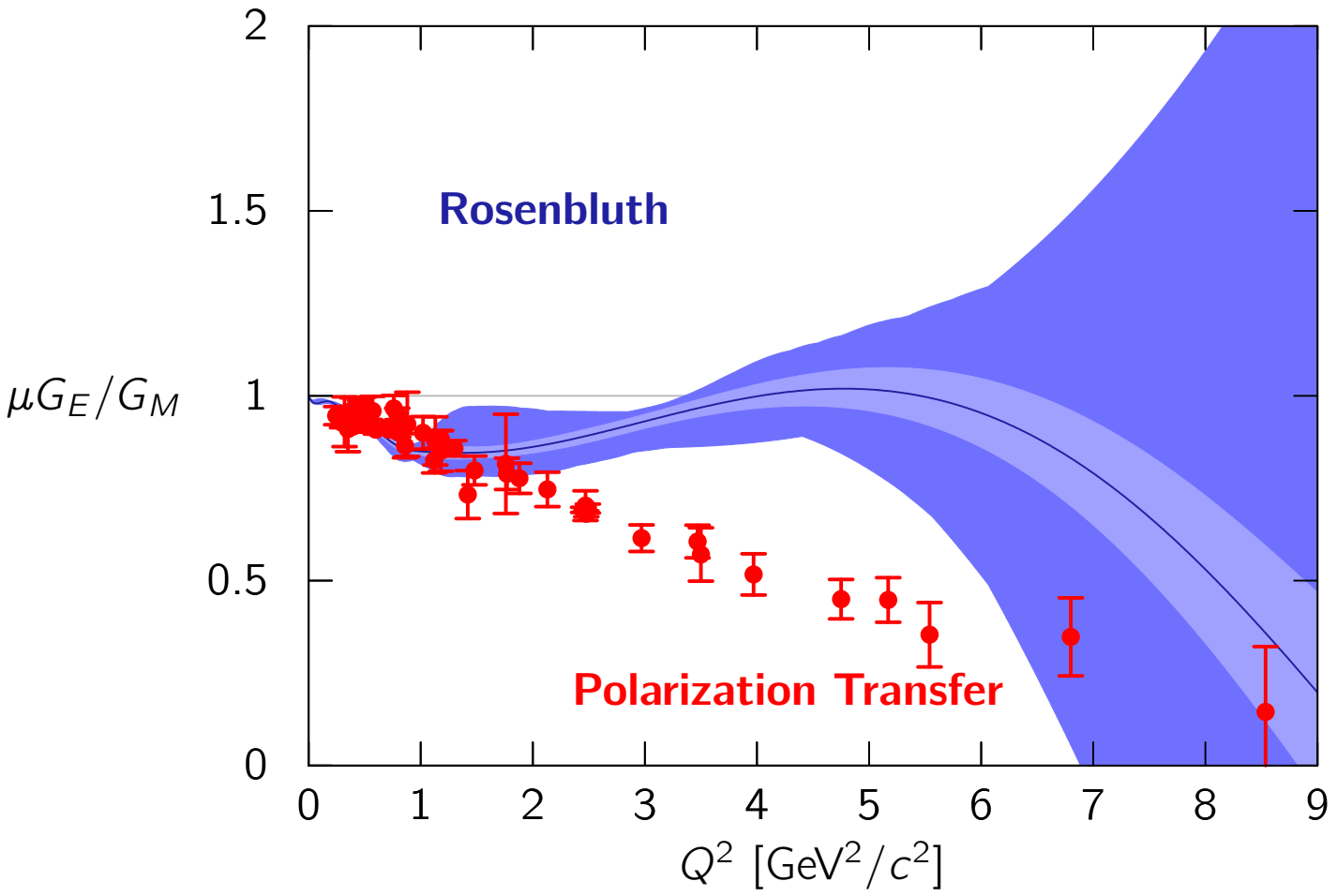
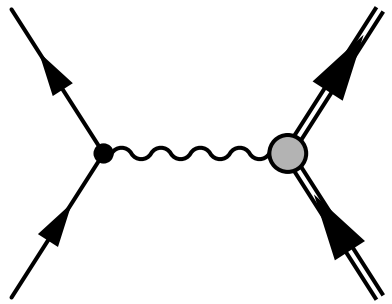
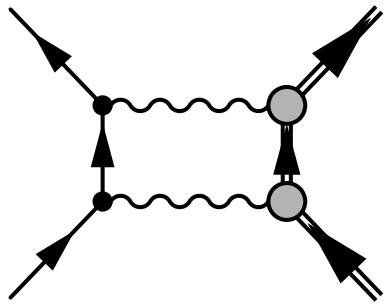


Positrons can reveal interference terms.

$\mathcal{M} \sim$  +  ...

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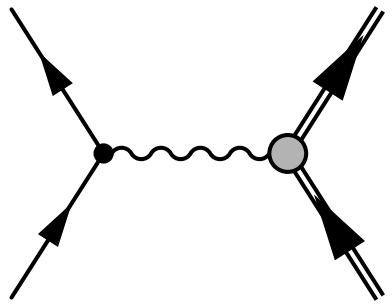
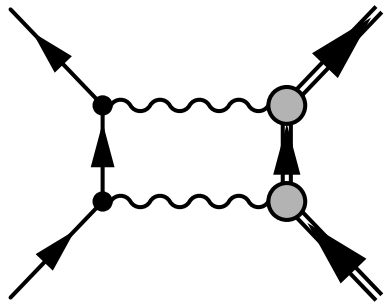
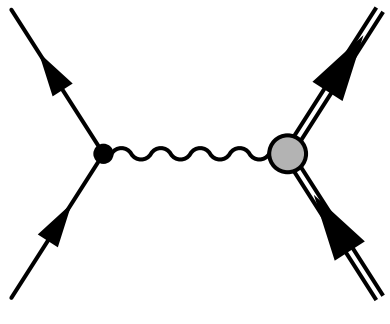
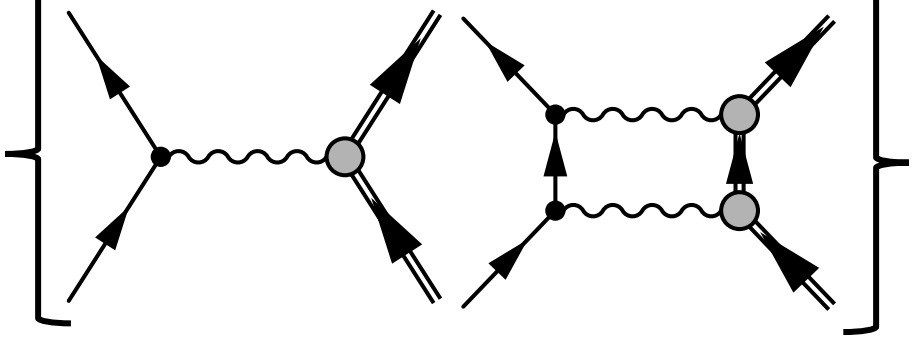
$\mathcal{M} \sim$  $+$  …

$\sigma \sim |\mathcal{M}|^2 \sim \left|\right.$  $\left.\right|^2 \pm 2Re\{$  $\}$ …

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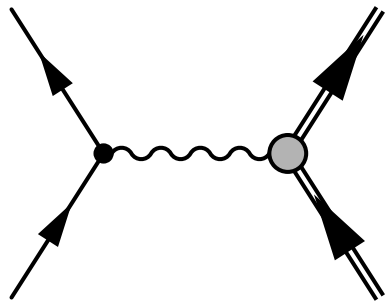
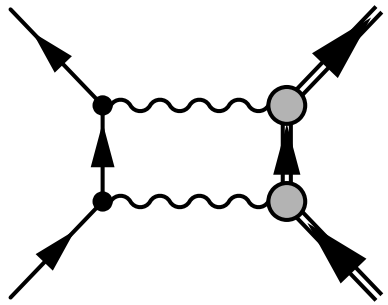
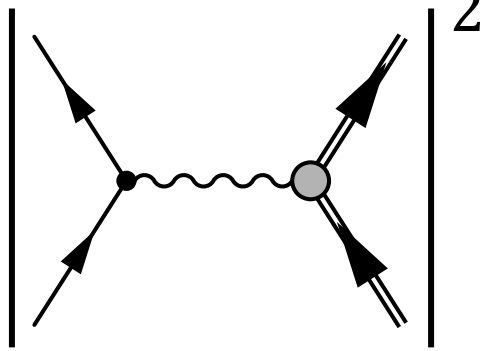
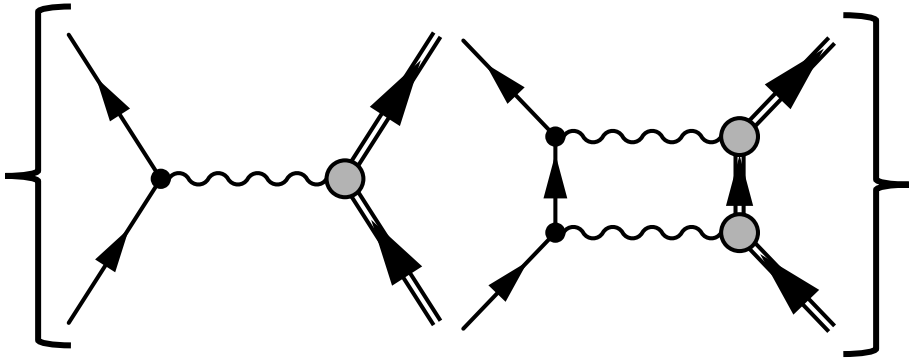
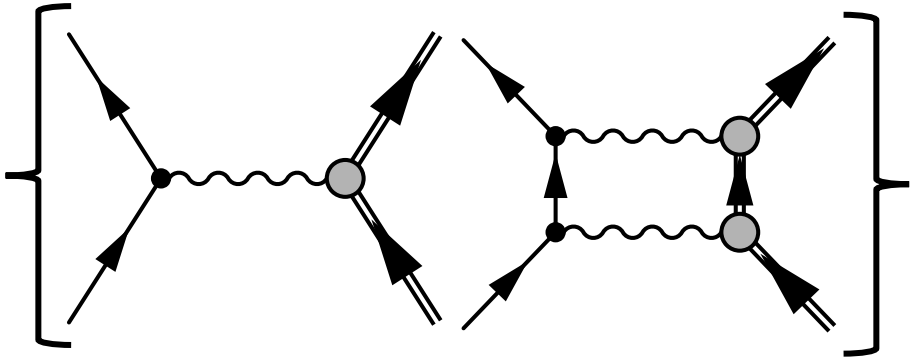
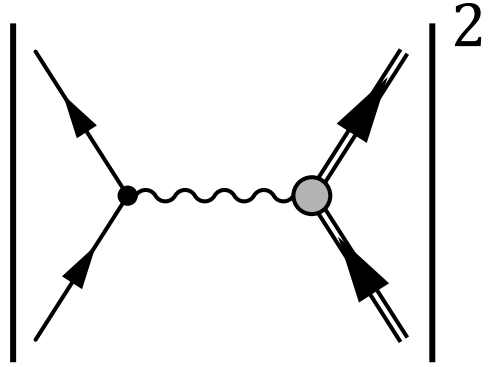
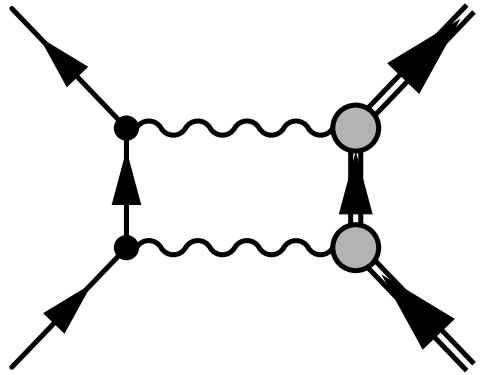
$\mathcal{M} \sim$  $+$  ...

$\sigma \sim |\mathcal{M}|^2 \sim$  $\pm 2Re$  ...

$\frac{\sigma_{e^+}}{\sigma_{e^-}} \sim 4\,Re$  / 

Positrons can provide information that just electrons cannot.

- Interference Physics
  - Two-photon exchange
  - DVCS / Bethe-Heitler
  - Coulomb effects



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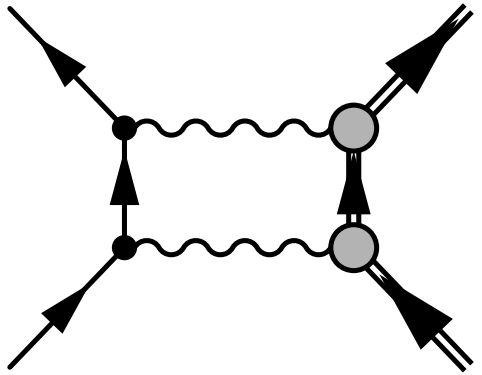
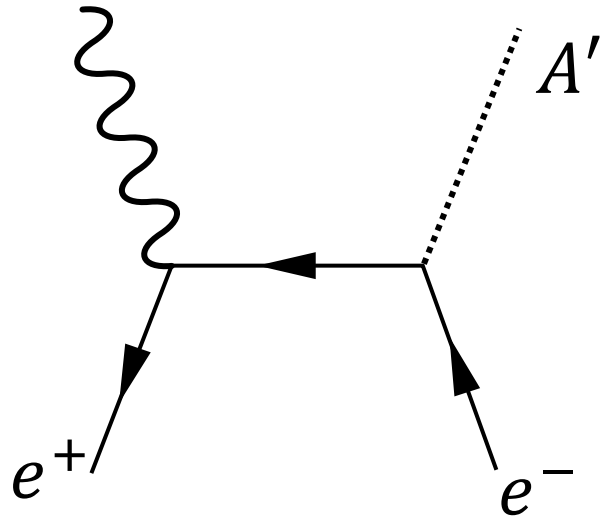
  - DVCS / Bethe-Heitler
  - Coulomb effects

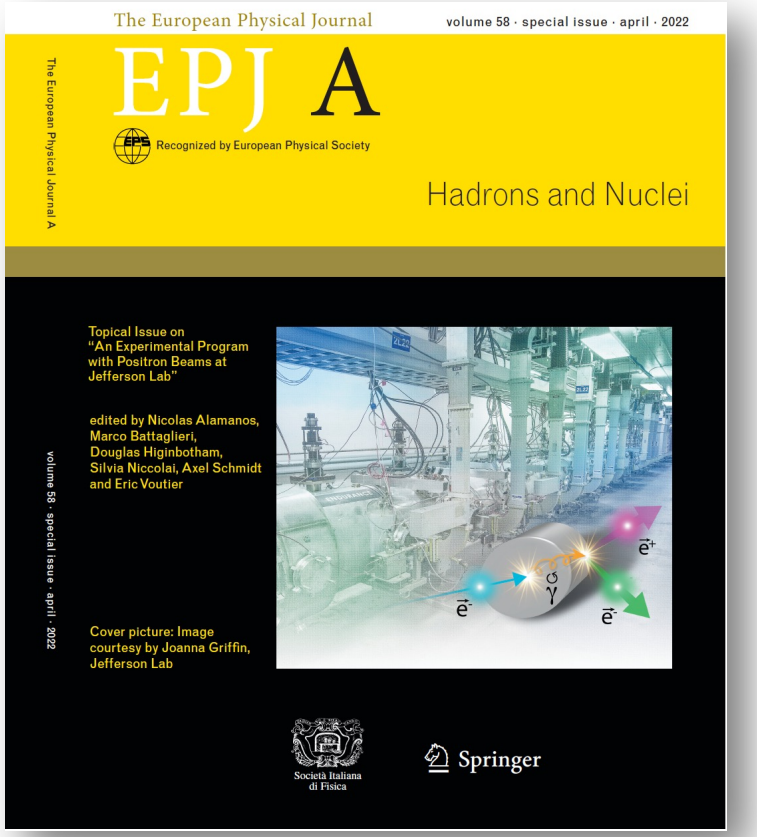
- Charged-current Physics
  - Dark photon searches
  - Axial-form factors
  - Strangeness





Jefferson Lab Positron Working Group

EPJ A Topical Issue: [An Experimental Program with Positron Beams at Jefferson Lab]



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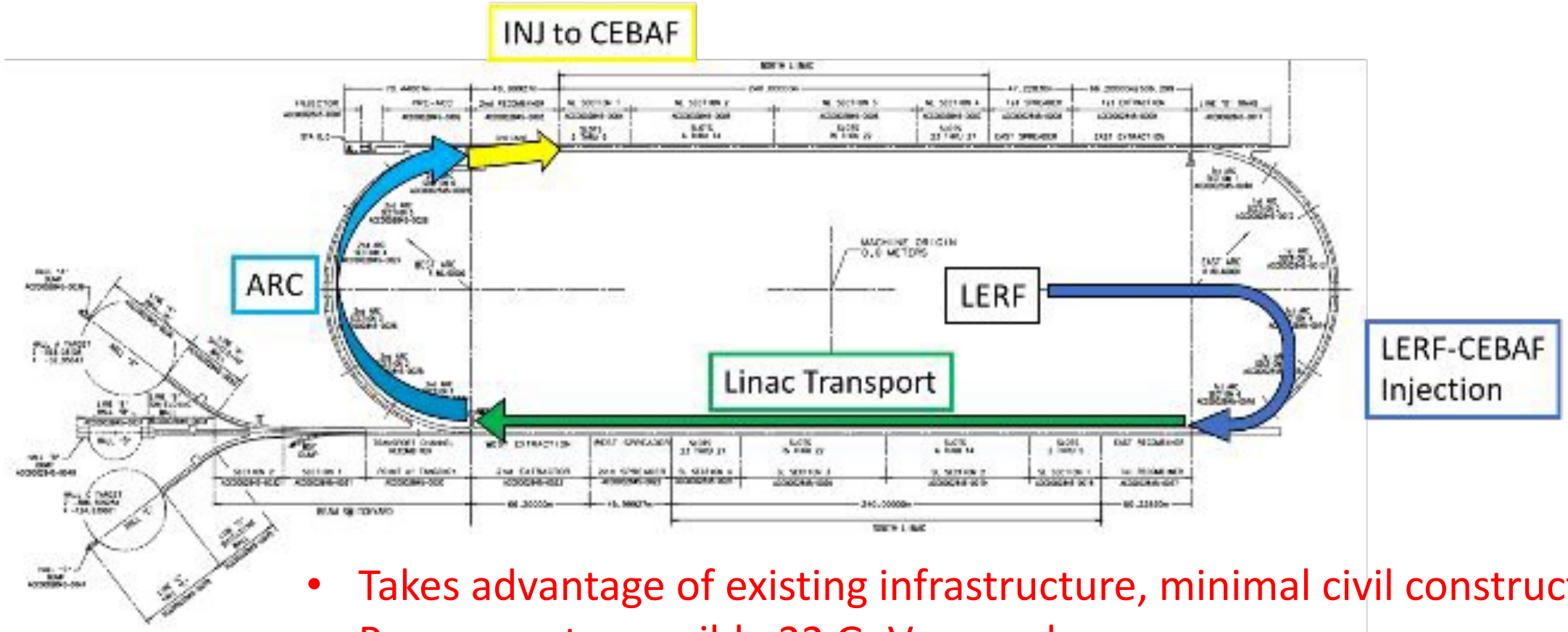
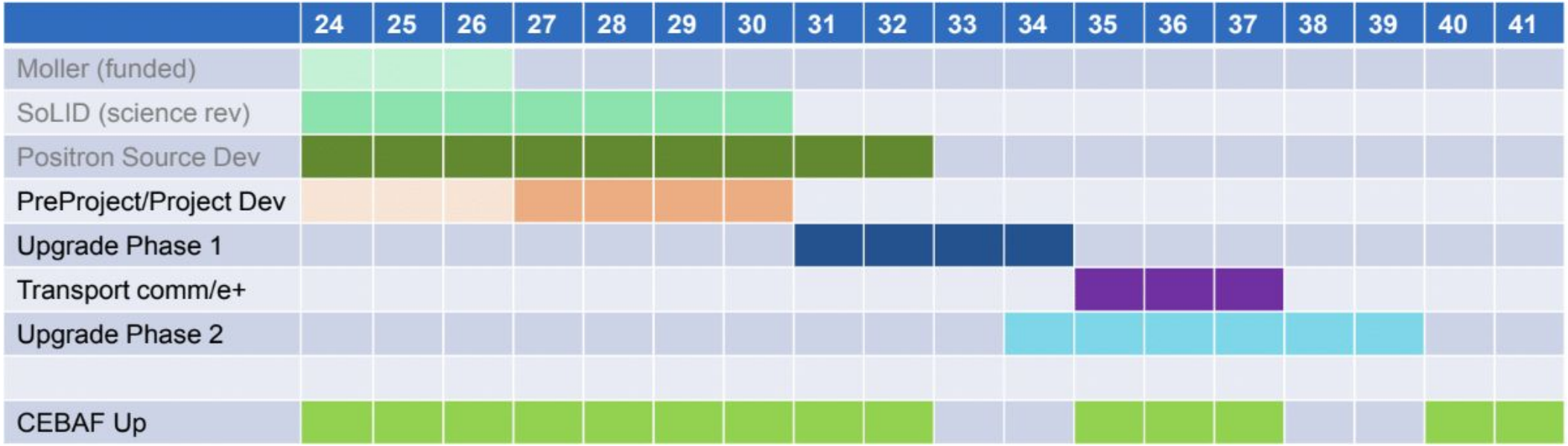
Steering positrons to the halls



- Takes advantage of existing infrastructure, minimal civil construction.
- Pre-cursor to possible 22 GeV upgrade

Timeline



- FY23 $$
- Phase 1: tie LERF to CEBAF & injector for e+ $101M ($78M – $152M)
- Phase 2: High Energy Upgrade (includes FFAs) $244M ($188M – $366M)
- Total cost (Class 4 estimate) $345M ($265M – $517M)
- Pre-R&D (FY25 – FY27) $3.0M/year (+$0.5M/year in LDRD)

Jefferson Lab

Source: Thia Keppel, March 2023

Positron Experiments/Concepts at JLab

Multi-photon exchange

PR12+23-003: Coulomb Effects in DIS
PR12+23-008: Two-photon Exchange at CLAS12
PR12+23-012: Two-photon Exchange in Hall C
LOI12+23-008: Two-photon Exchange in Pol. Trans.
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White paper: Electroweak couplings at SOLID
Two-photon in elastic eA
Imaginary part of TPE amplitude

Virtual Compton Scatt.

PR12+23-002: DVCS asymmetries at CLAS12
PR12+23-006: DVCS cross section in Hall C
LOI12+23-001: Generalized Polarizabilities
White papers: DVCS on neutrons, He-4
DDVCS at SOLID

Dark Photon Searches

PR12+23-005: Annihilation Search
LOI12+23-005: Bhabha Search

Charged-Current

LOI12+23-002: Axial Form Factor
White paper: Strangeness via Charm Tag

Other BSM

White paper: charged-lepton flavor violation search

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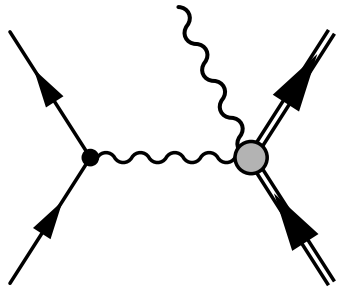
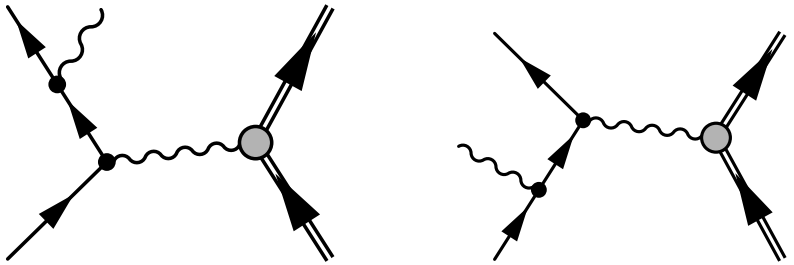
Positrons for Deeply Virtual Compton Scattering



DVCS: Probe GPDs



Bethe-Heitler Process

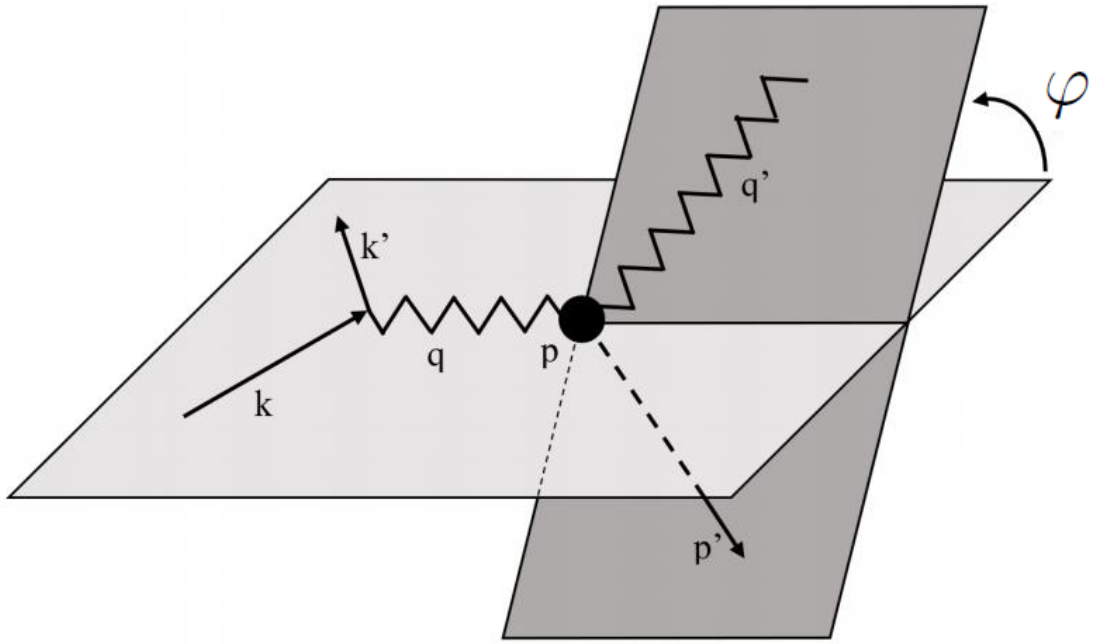
$$\sigma \sim \left| \quad \right|^2 + \left| \quad \right|^2 \pm 2Re \{ \quad \}$$

Bi-linear combination of GPDs

QED: Known to ≈1%

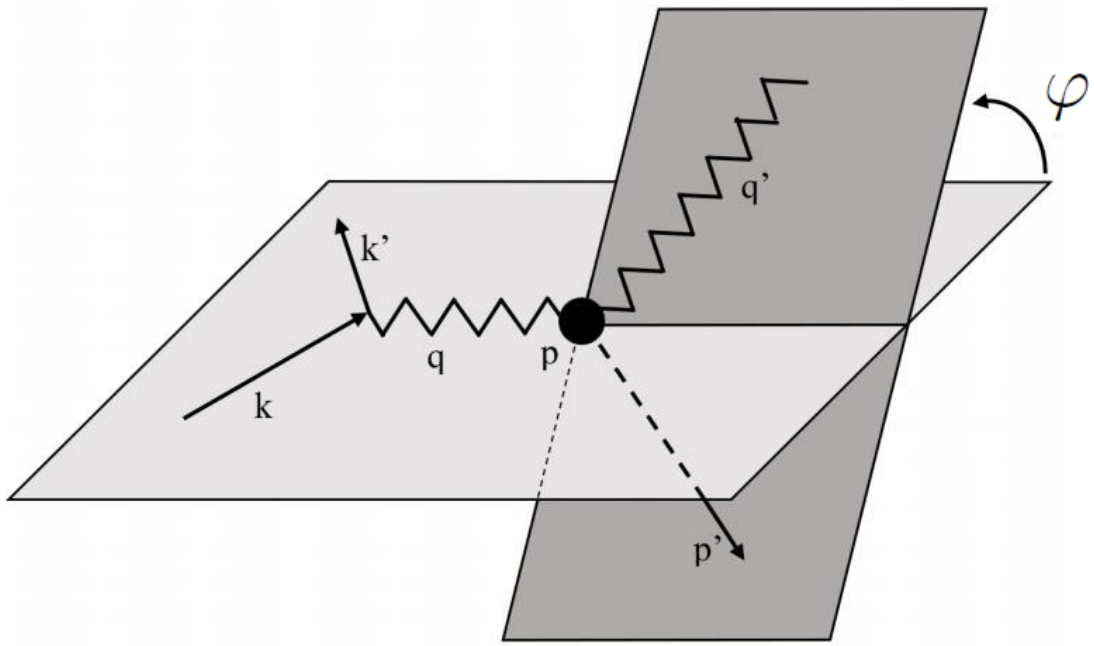
Linear Combination of GPDs
Beam charge-dependent

Kinematics of DVCS



φ-dependence contains 5 observables:
$\sim 1, \cos\varphi\,, \sin\varphi\,, \cos 2\varphi\,, \sin 2\varphi$

Kinematics of DVCS



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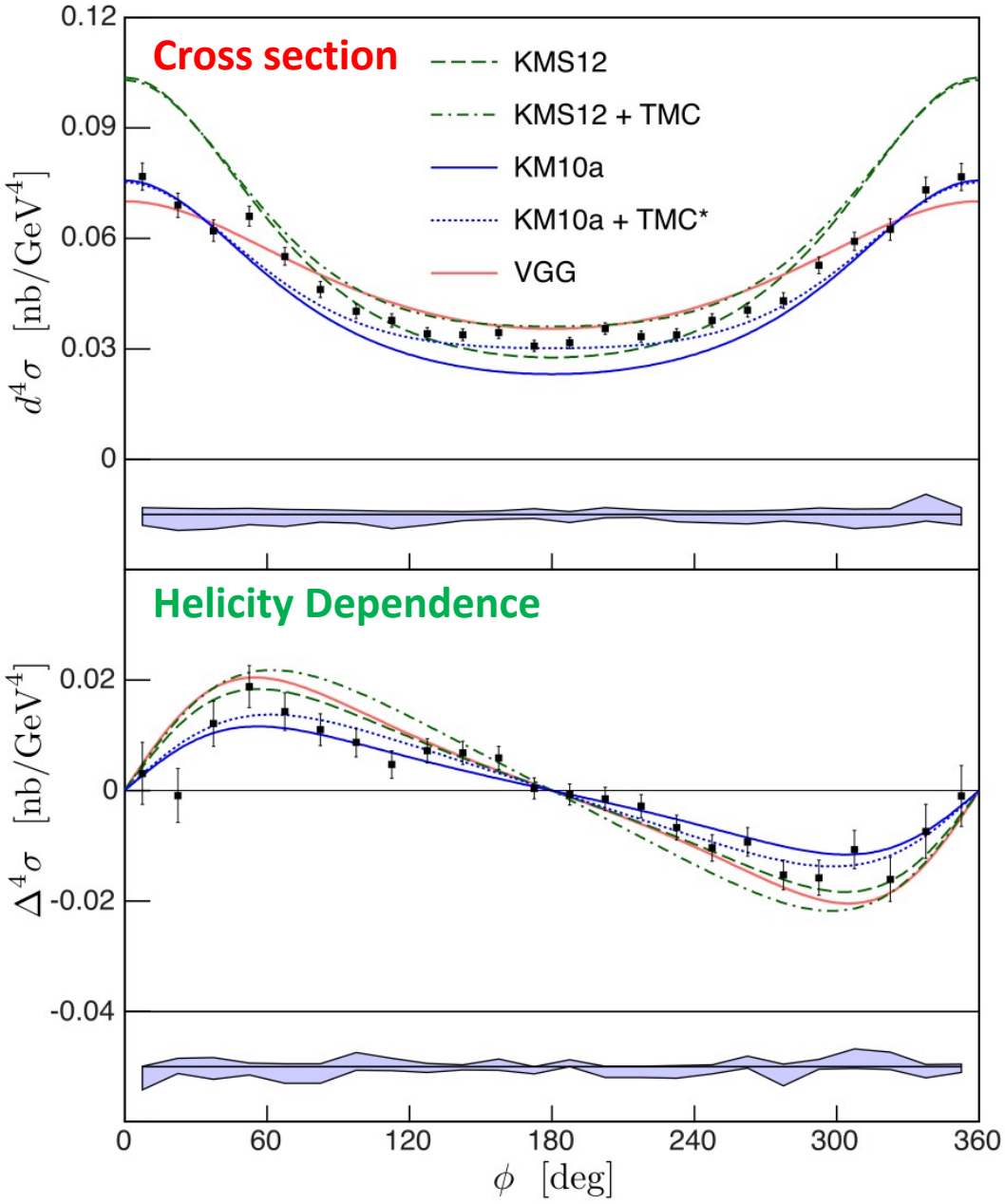


M. Duferne et al., PRC 92, 055202 (2015)

Proposed DVCS Experiments

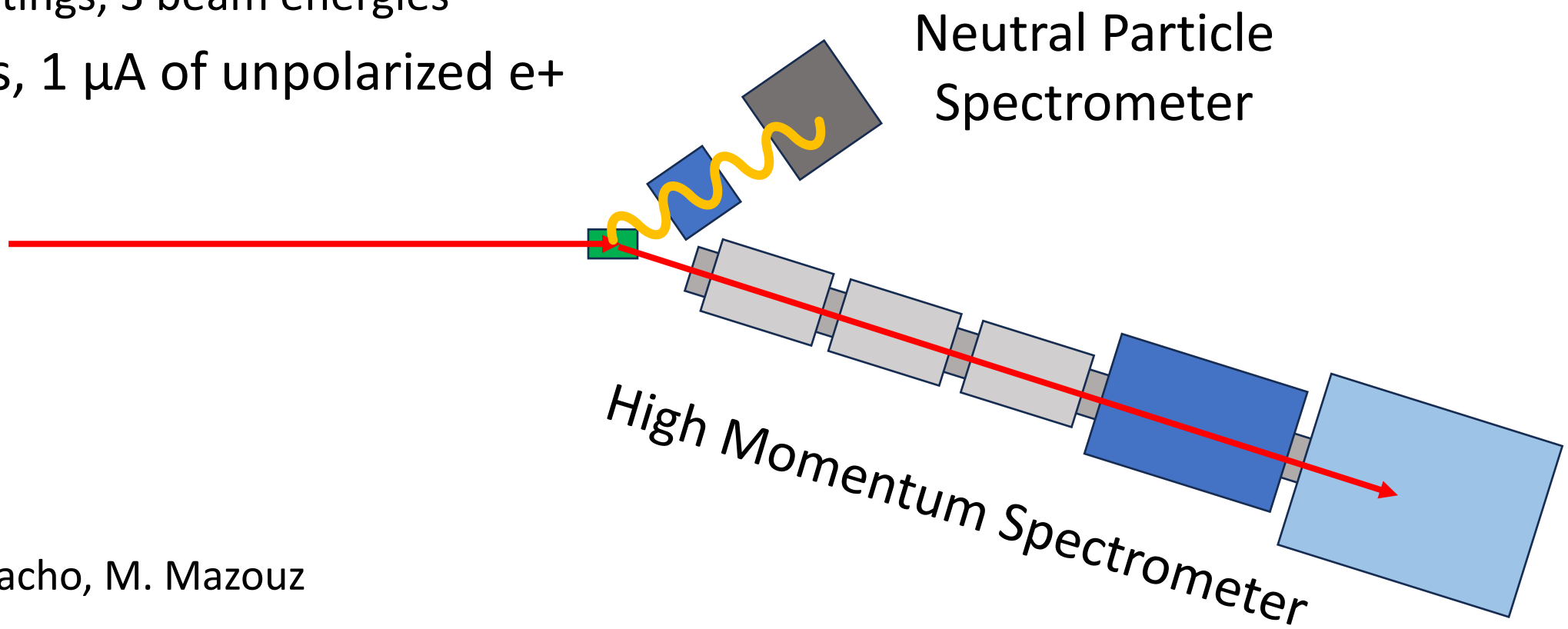
- Precision Measurements in Select Kinematics (Hall C)
  - PR12+23-006
  - High Momentum Spectrometer (HMS) + Neutral Particle Spec. (NPS)

- Survey Measurements over a Wide Phase Space (Hall B)
  - PR12+23-002
  - CLAS12

E12+23-006 in Hall C

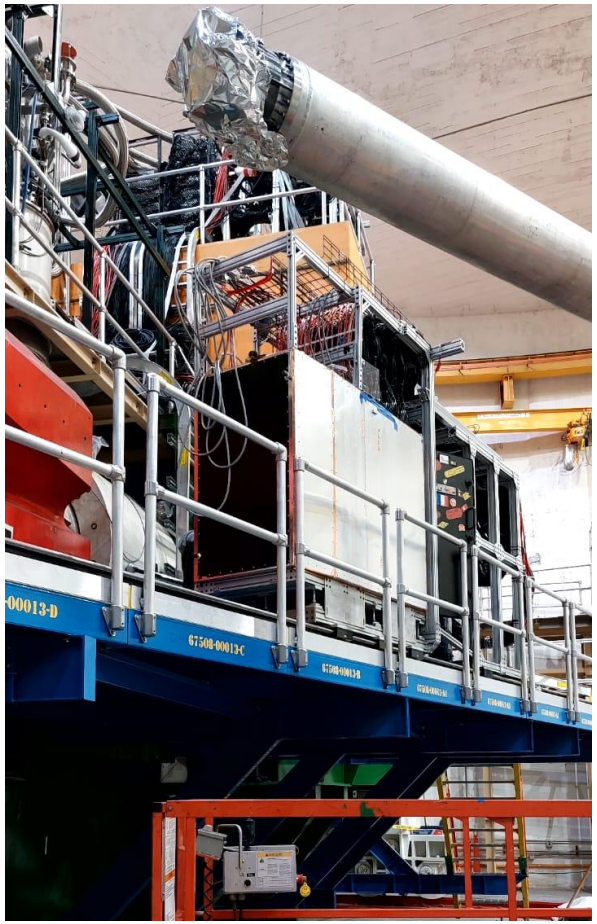
Goal: high-precision cross sections overlapping electron data

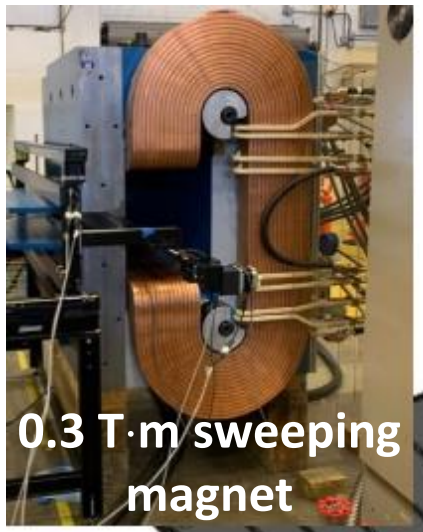
- Same kinematics as E12-13-010
  - 17 settings, 3 beam energies
- 135 days, 1 μA of unpolarized e+



Spokespeople:
C. Munoz-Camacho, M. Mazouz

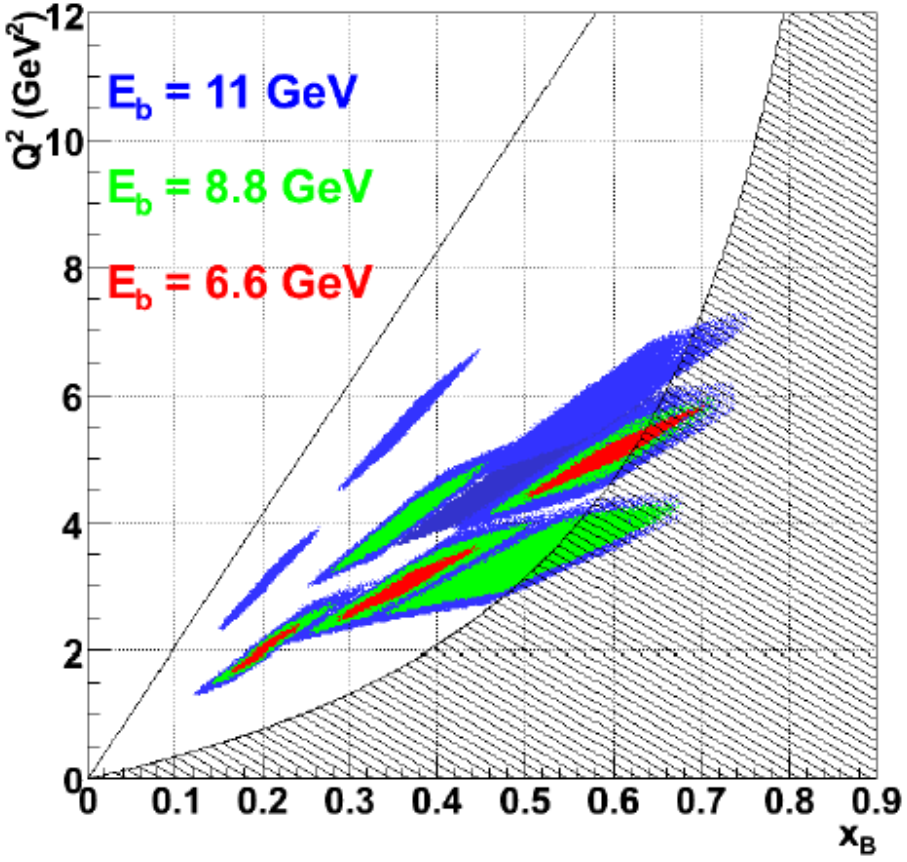
Neutral Particle Spectrometer

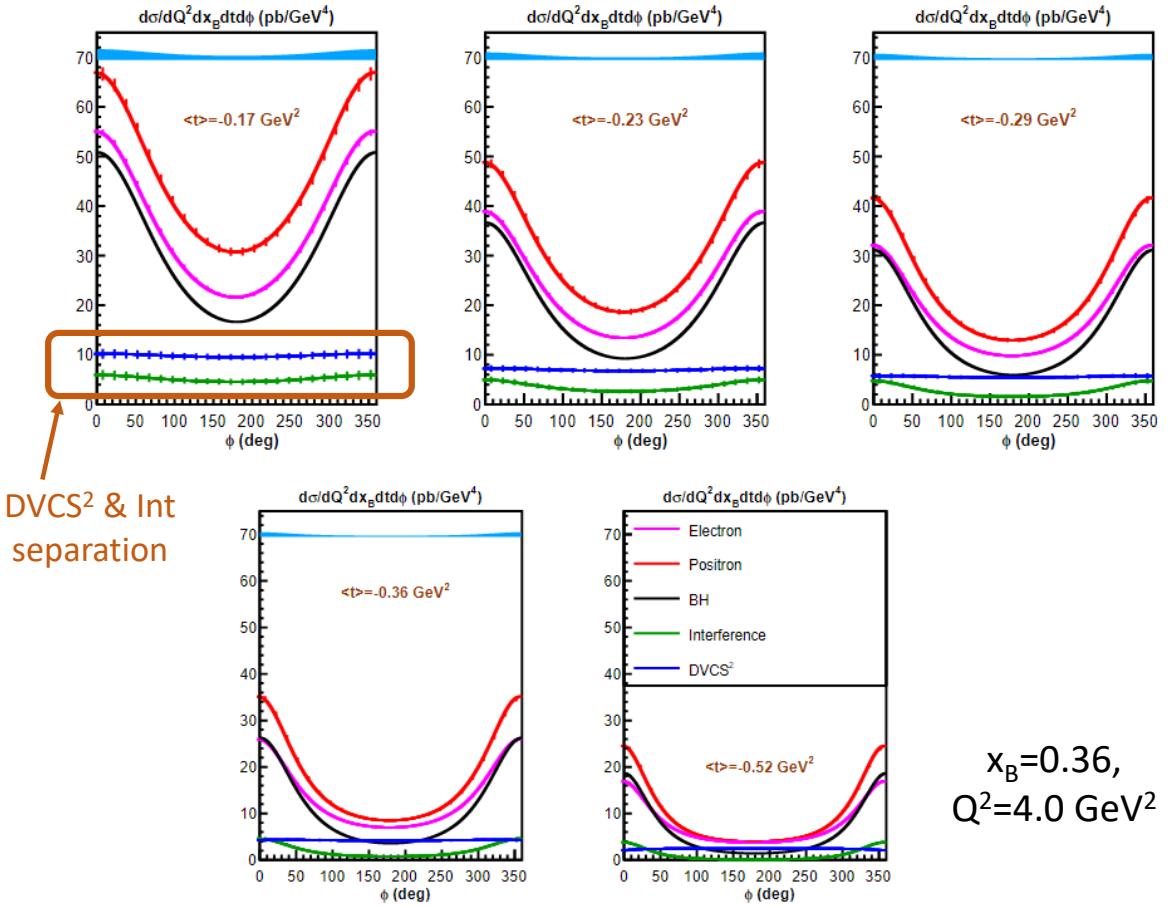




Sits on SHMS carriage

E12+23-006: Coverage and Reach





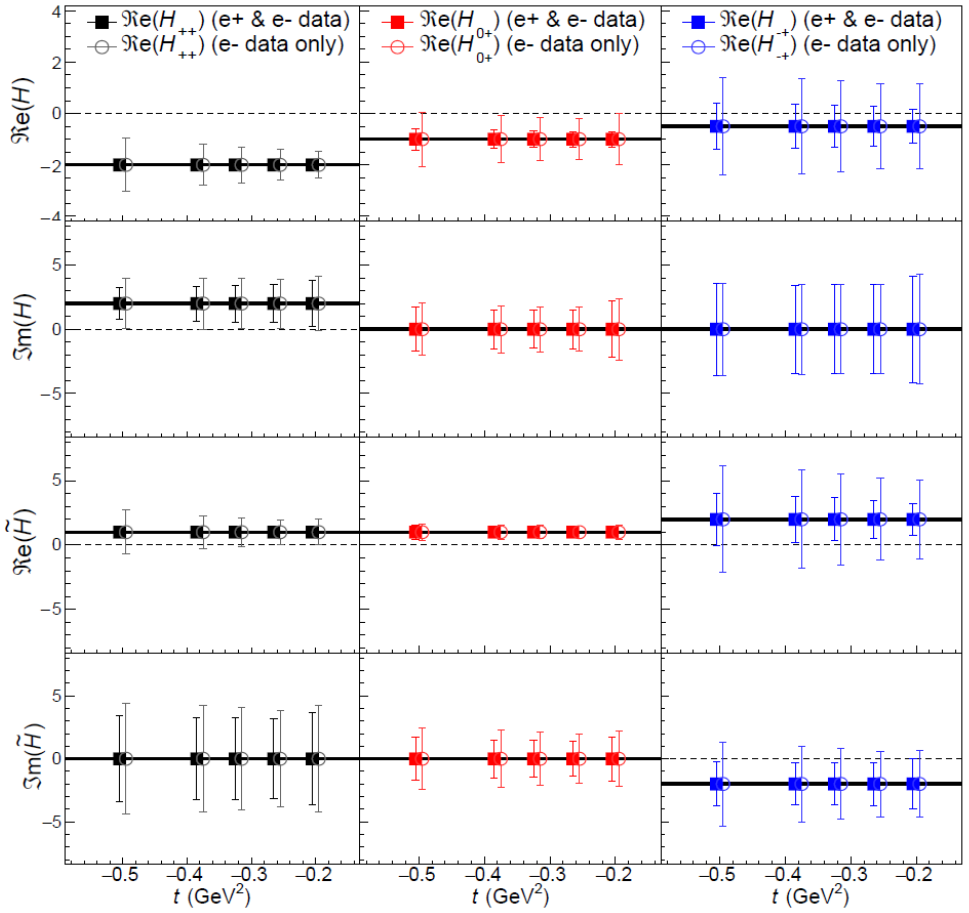
DVCS² & Int separation

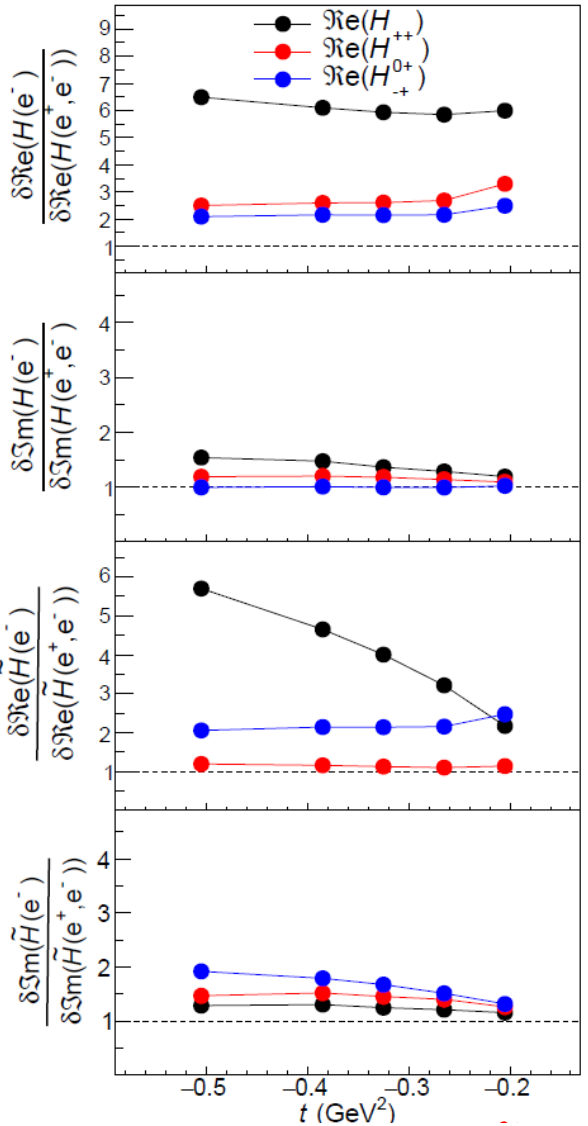
Systematic uncertainty

x_B=0.36,
Q^2=4.0 GeV²

Systematic Estimates: 2% point-to-point, 3.5% scale

Hall C positron measurement will greatly improve CFF extraction.

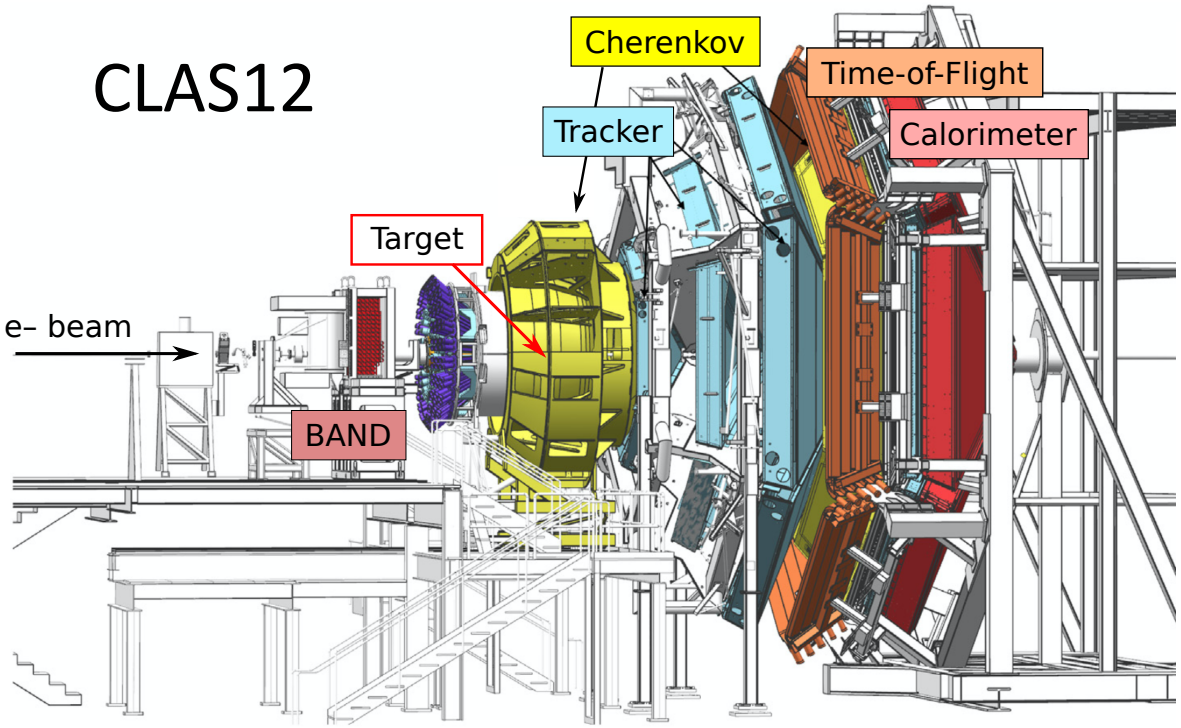


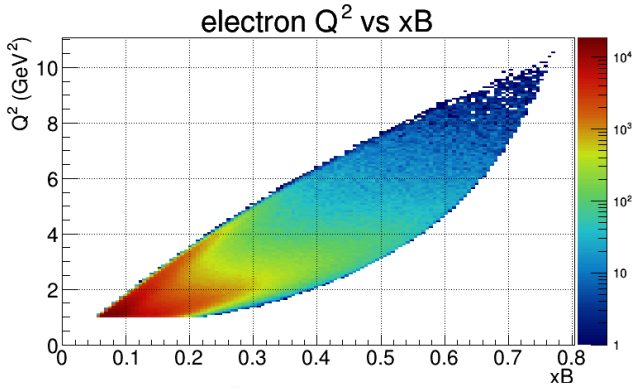


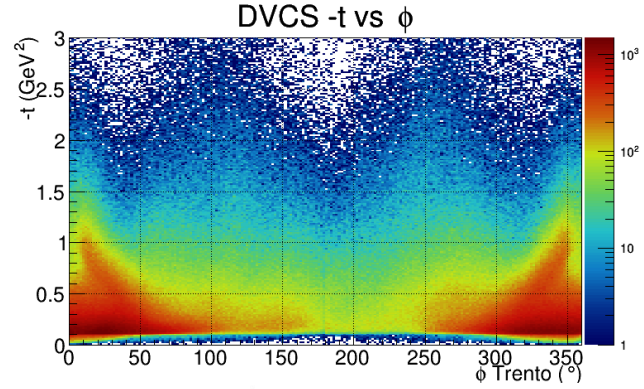
E12+23-002 in Hall B

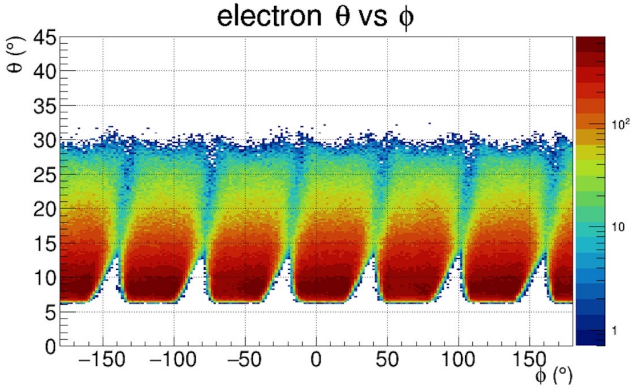
- Goal: determination of helicity and charge asymmetries over a wide phase space.

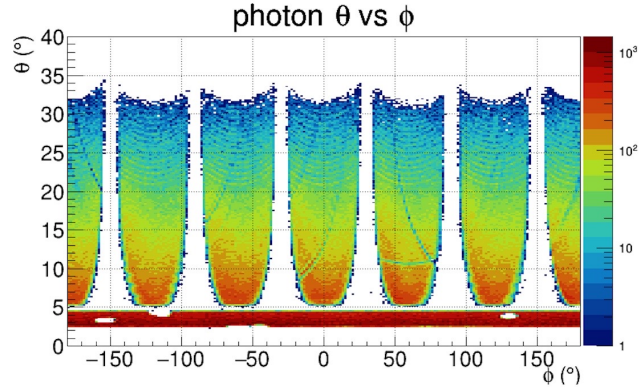
CLAS12







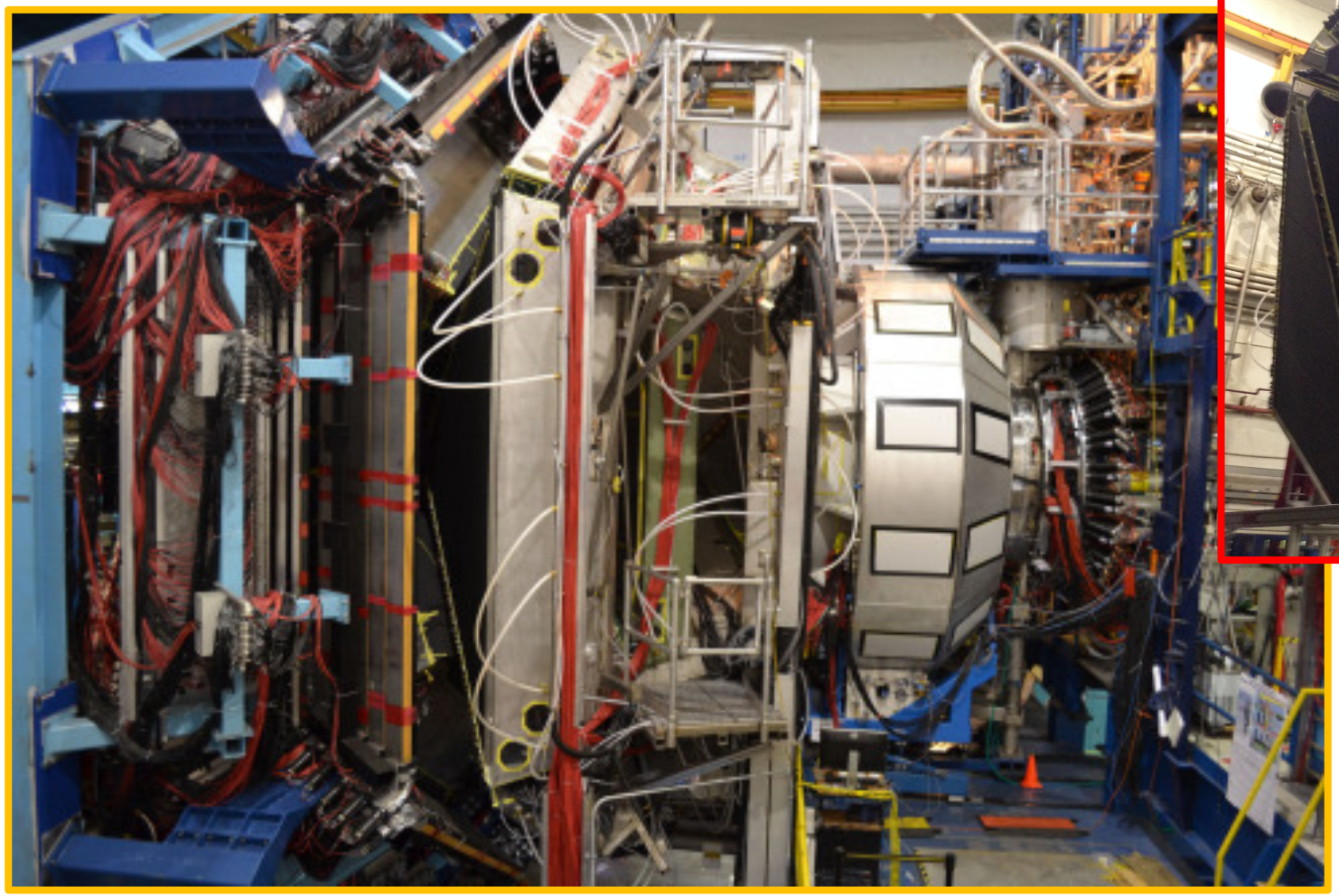


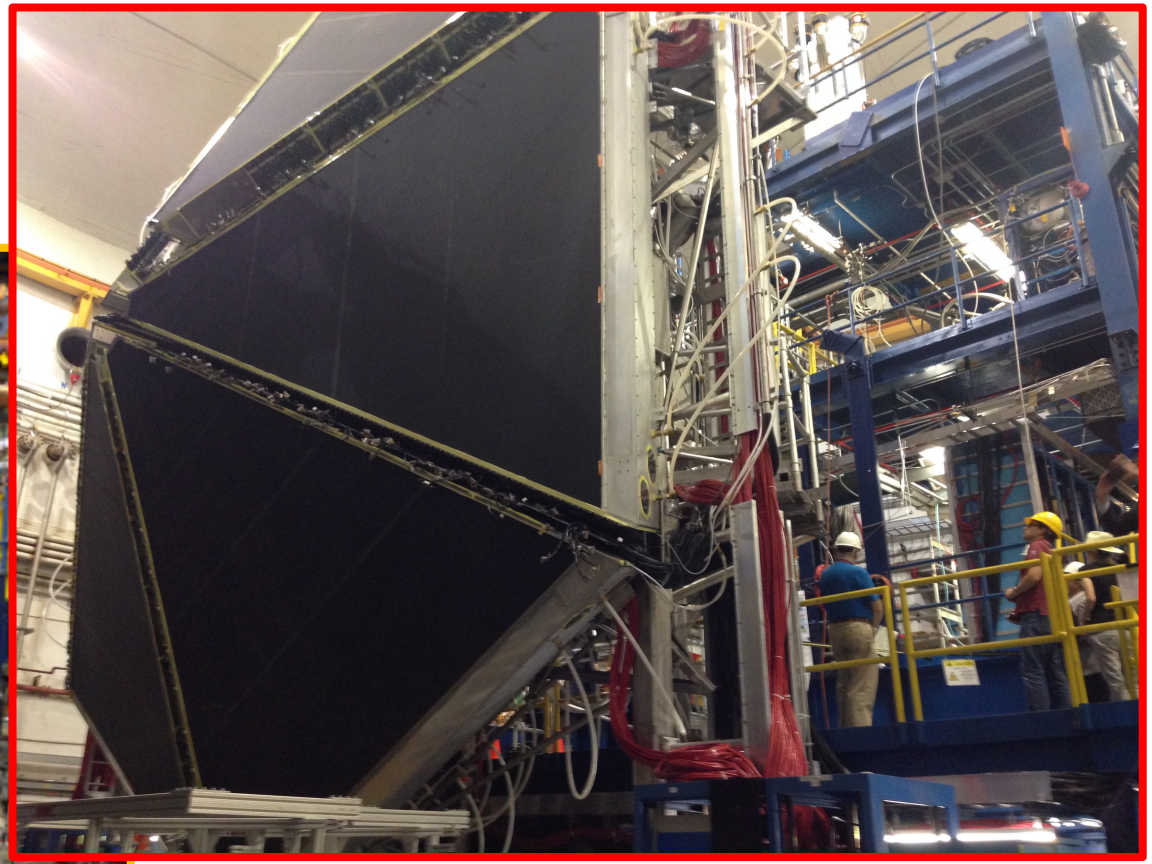


Spokespeople:

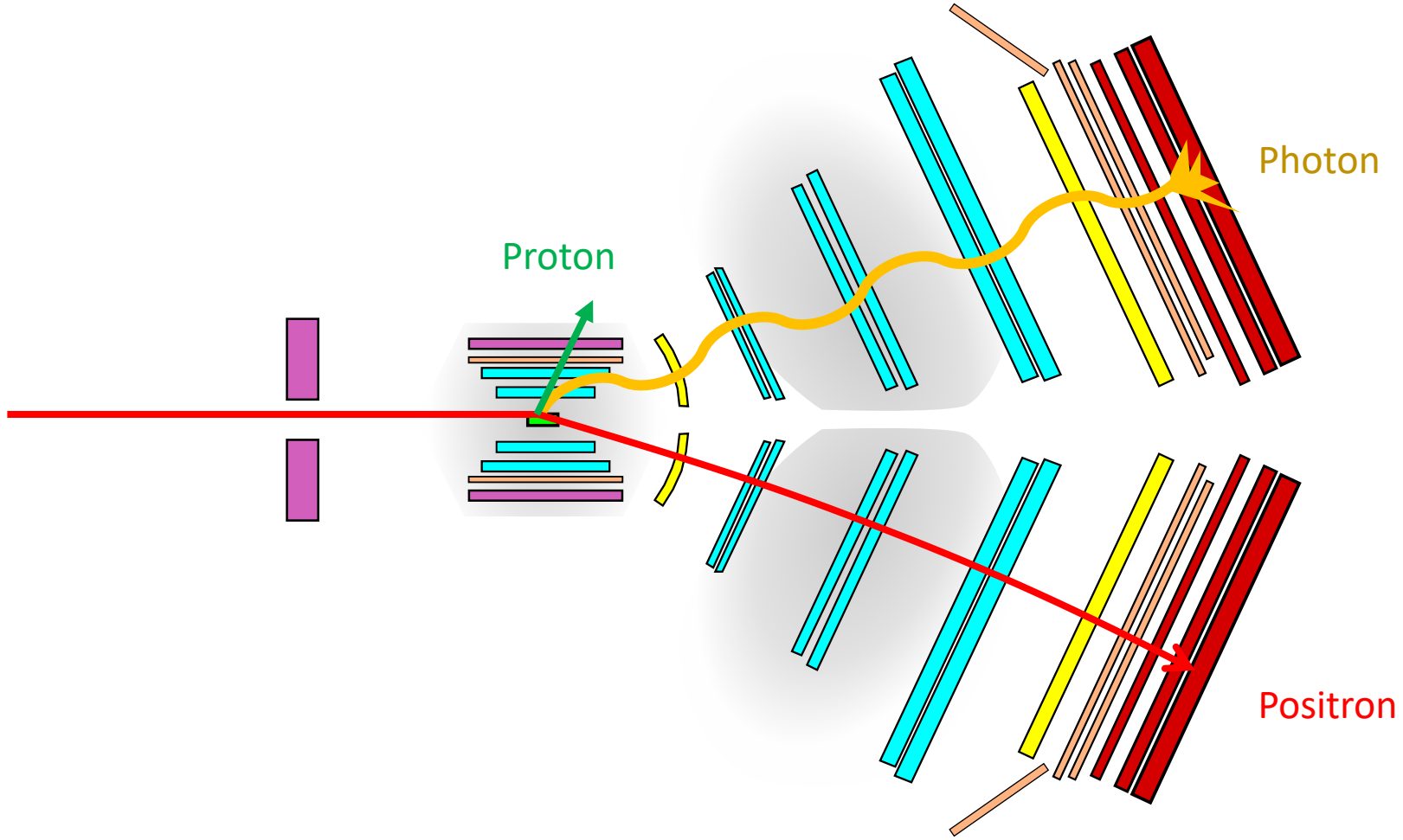
E. Voutier, V. Burkert, S. Niccolai, R. Paremuzyan

CLAS12 – Hall B





Magnetic field reversals are critical for suppressing systematics.



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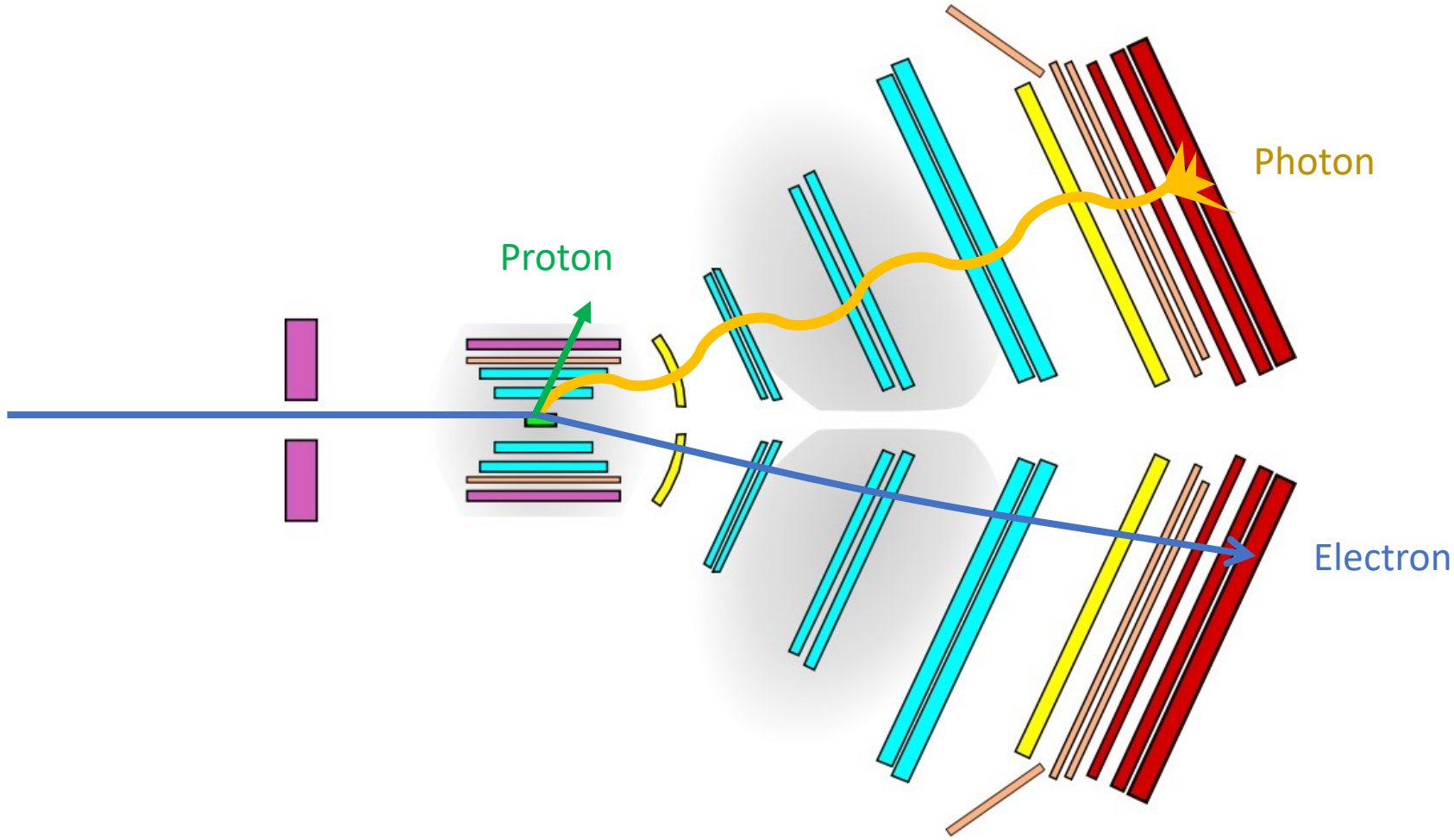


Charge and helicity asymmetries

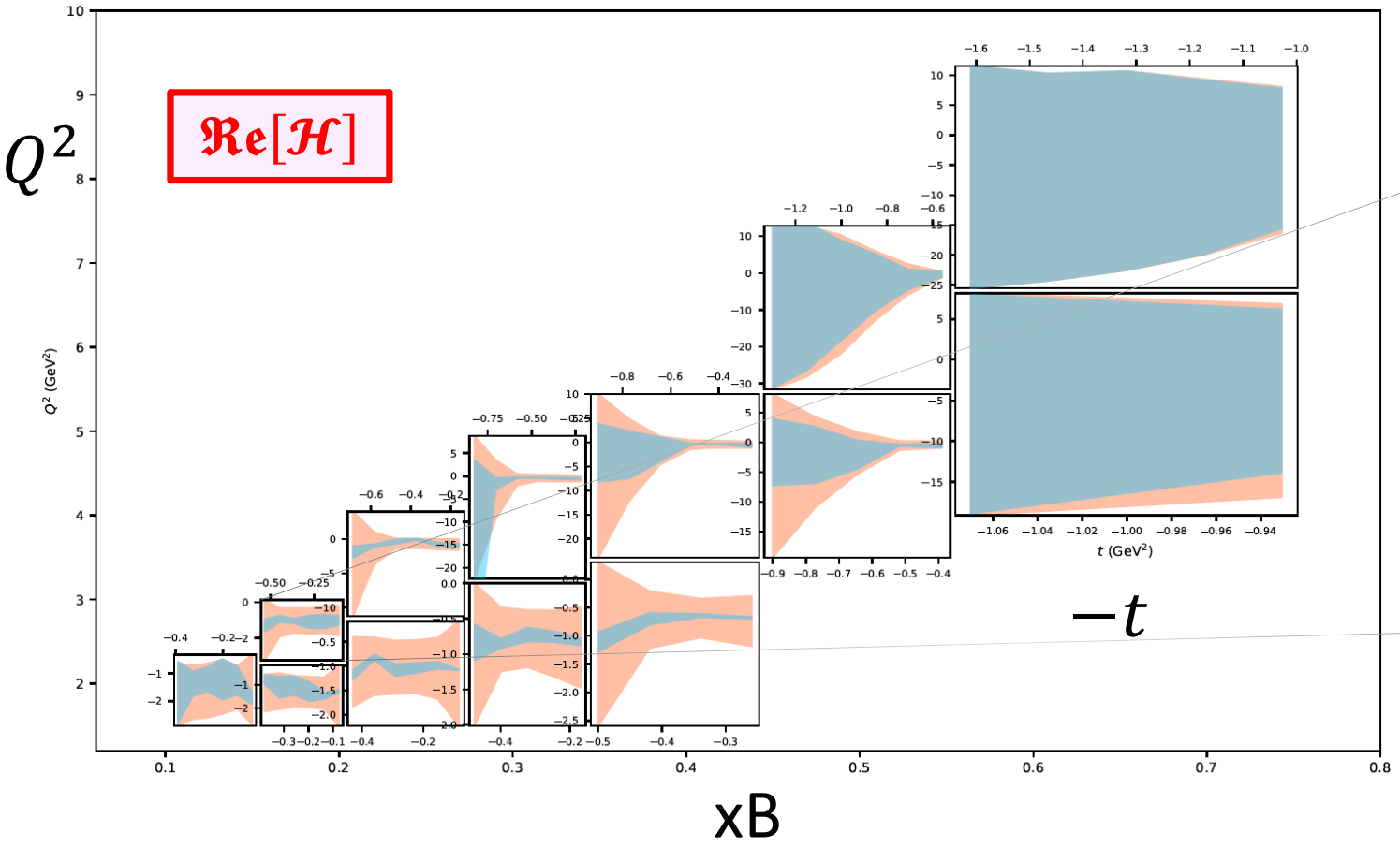
Four combinations for $\sigma_{Helicity}^{Beam\ charge}$ $\sigma_+^+, \sigma_-^+, \sigma_+^-, \sigma_-^-$

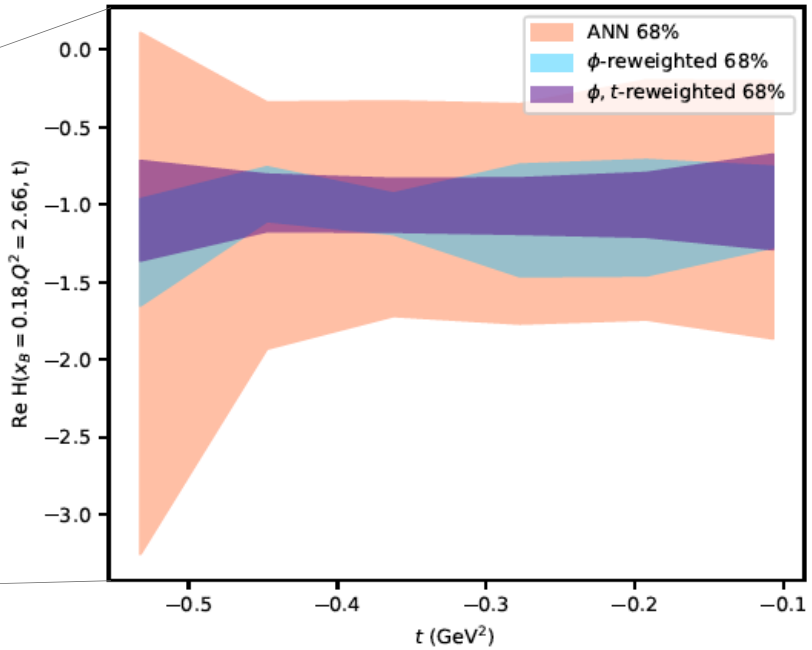
Unpolarized BCA $A_{UU}^{C} = \frac{(\sigma_+^+ + \sigma_-^+) - (\sigma_+^- + \sigma_-^-)}{(\sigma_+^+ + \sigma_-^+) + (\sigma_+^- + \sigma_-^-)}$

Avg. Helicity Asymmetry $A_{LU}^{0} = \frac{(\sigma_+^+ - \sigma_-^+) + (\sigma_+^- - \sigma_-^-)}{(\sigma_+^+ + \sigma_-^+) + (\sigma_+^- + \sigma_-^-)}$

Polarized BCA $A_{LU}^{C} = \frac{(\sigma_+^+ - \sigma_-^+) - (\sigma_+^- - \sigma_-^-)}{(\sigma_+^+ + \sigma_-^+) + (\sigma_+^- + \sigma_-^-)}$

Significant improvements in constraints on GPDs





H. Dutrieux, V. Bertone, H. Moutarde, P. Sznajder, EPJ A 57:250 (2021)

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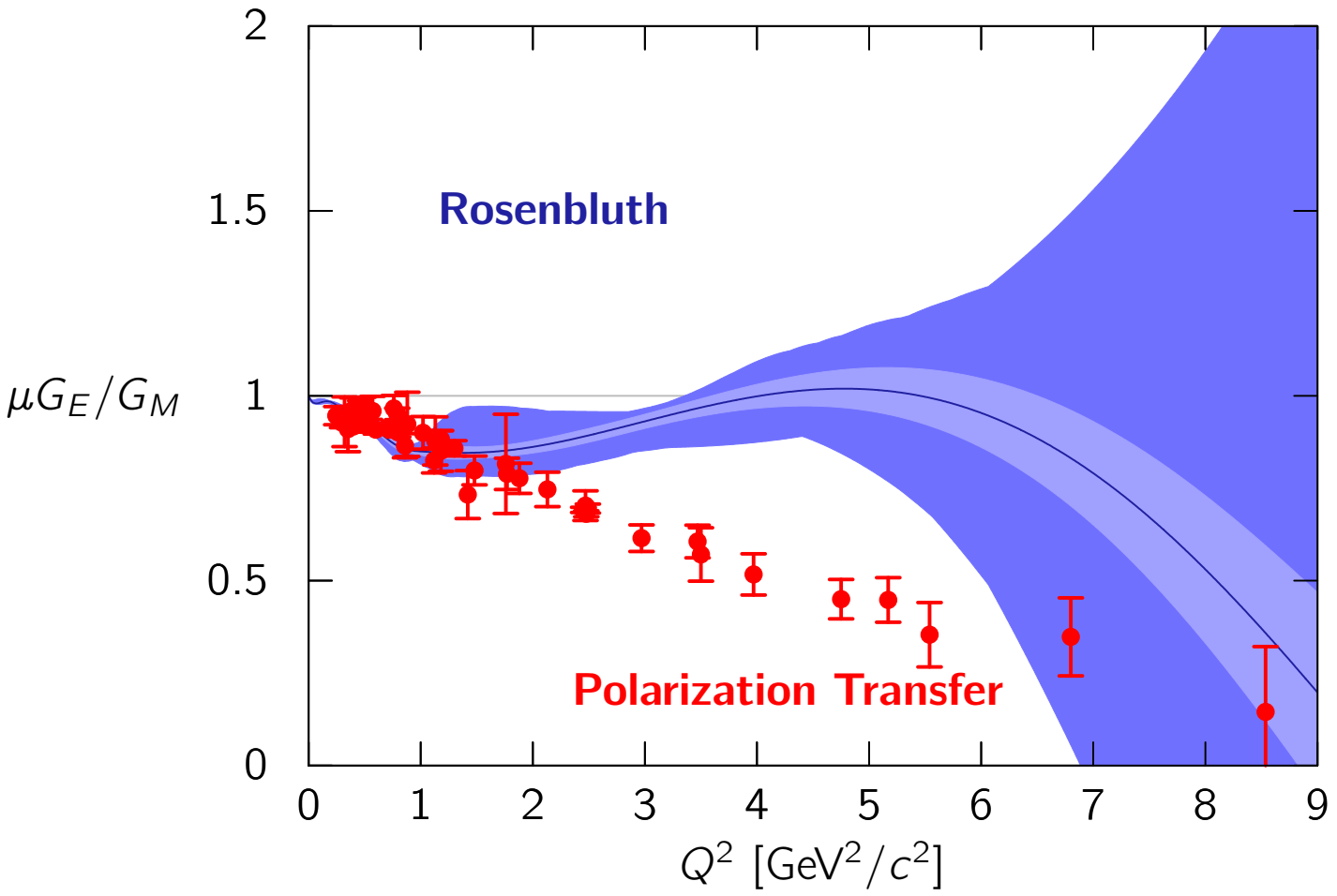
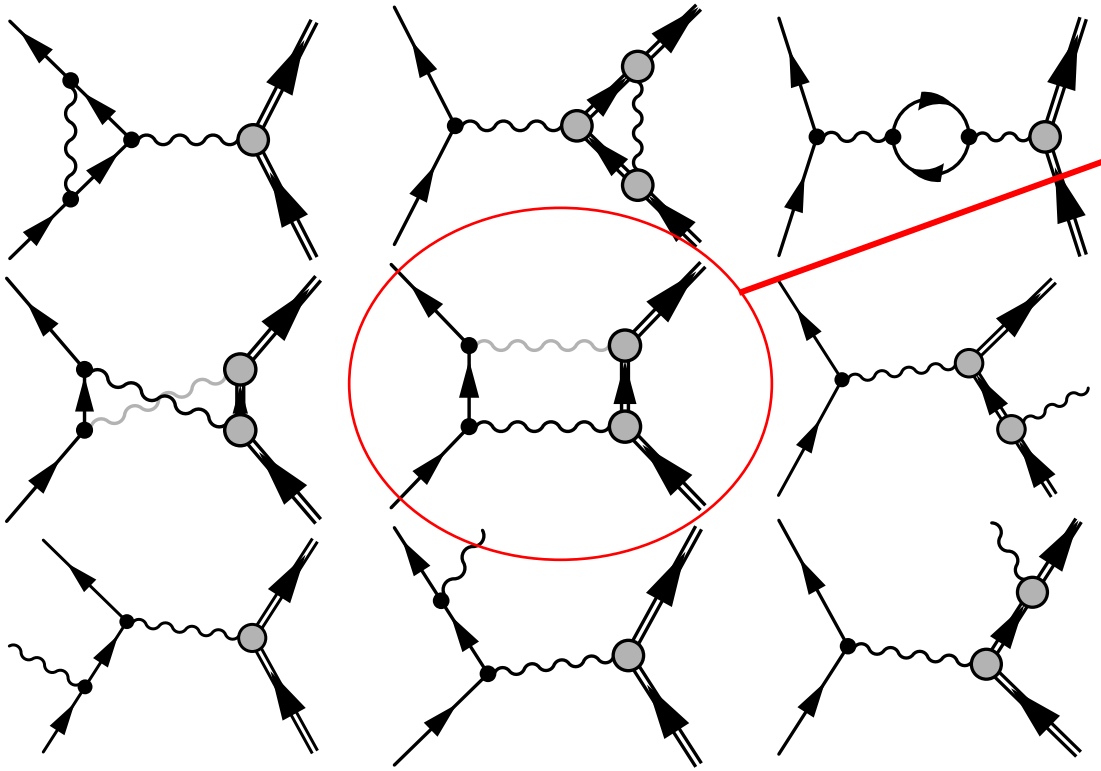
White paper: charged-lepton flavor violation search

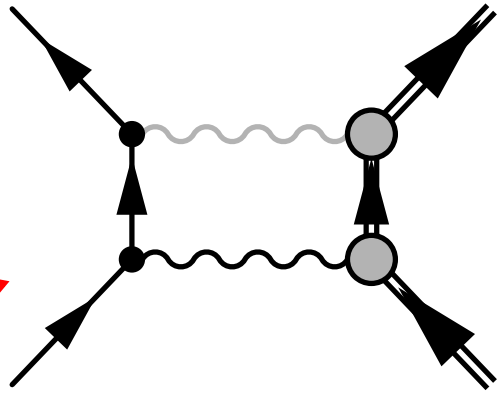
For decades, proton form factors were observed to “scale.”



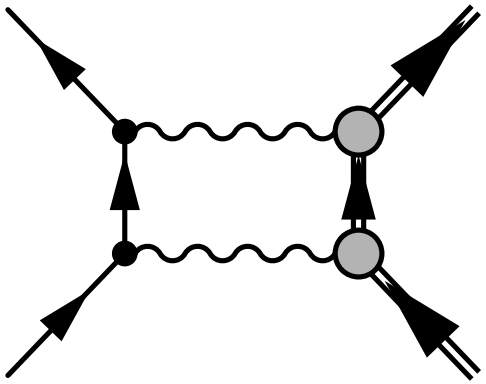
The one missing radiative correction is Hard Two-Photon Exchange

The Standard Set



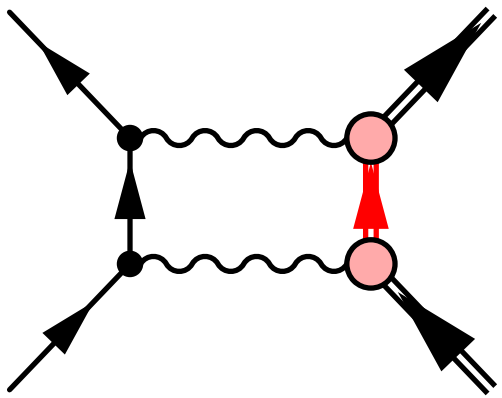


Included: soft TPE



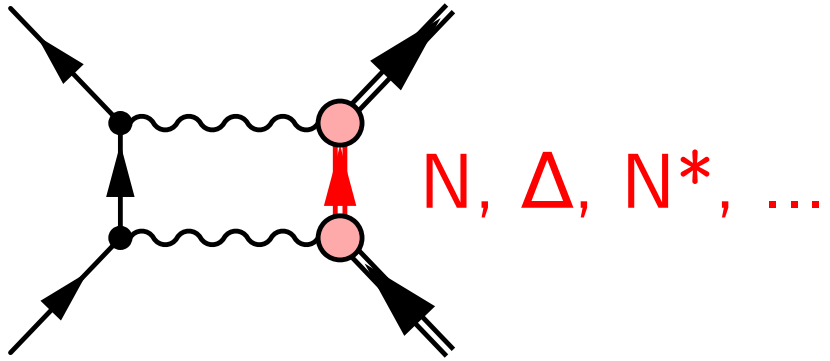
Missing: hard TPE

Hard TPE cannot be calculated without model dependency.



Hard TPE cannot be calculated without model dependency.

- Hadronic Approaches
  - Treat propagator as a sum of on-shell states.
  - e.g. Ahmed et al., PRC 2020, Blunden PRC 2017



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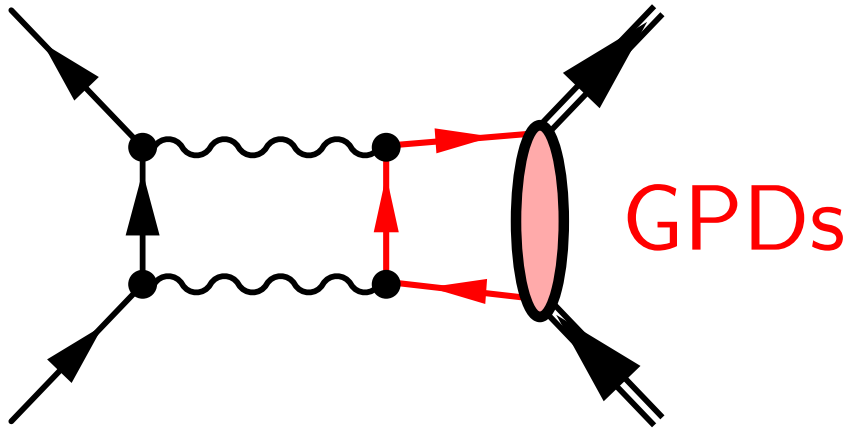

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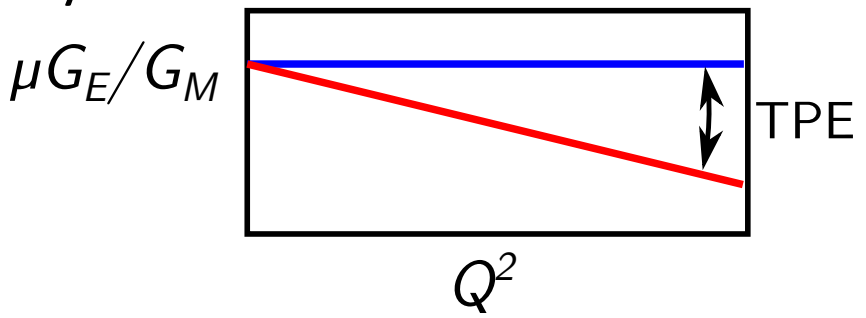
  - How much TPE is needed to resolve the FF discrepancy
  - e.g. Bernauer et al., PRC 2014, Schmidt JPG 2020



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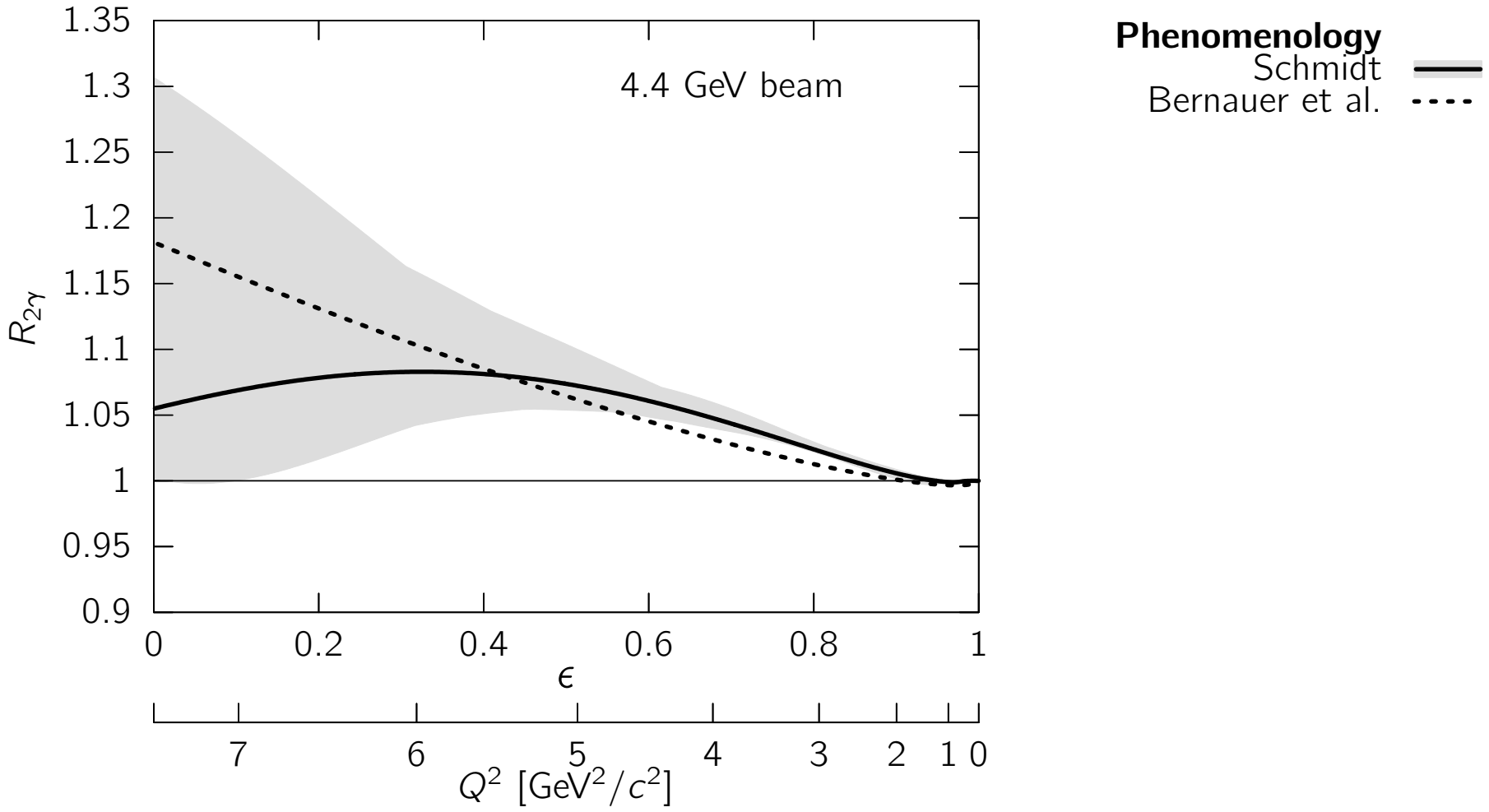
- Phenomenology
  - How much TPE is needed to resolve the FF discrepancy
  - e.g. Bernauer et al., PRC 2014, Schmidt JPG 2020
- Dissenting opinions
  - e.g. Kuraev PRC 2008

Predictions for $R_{2\gamma} \equiv \sigma_{e^+p}/\sigma_{e^-p}$



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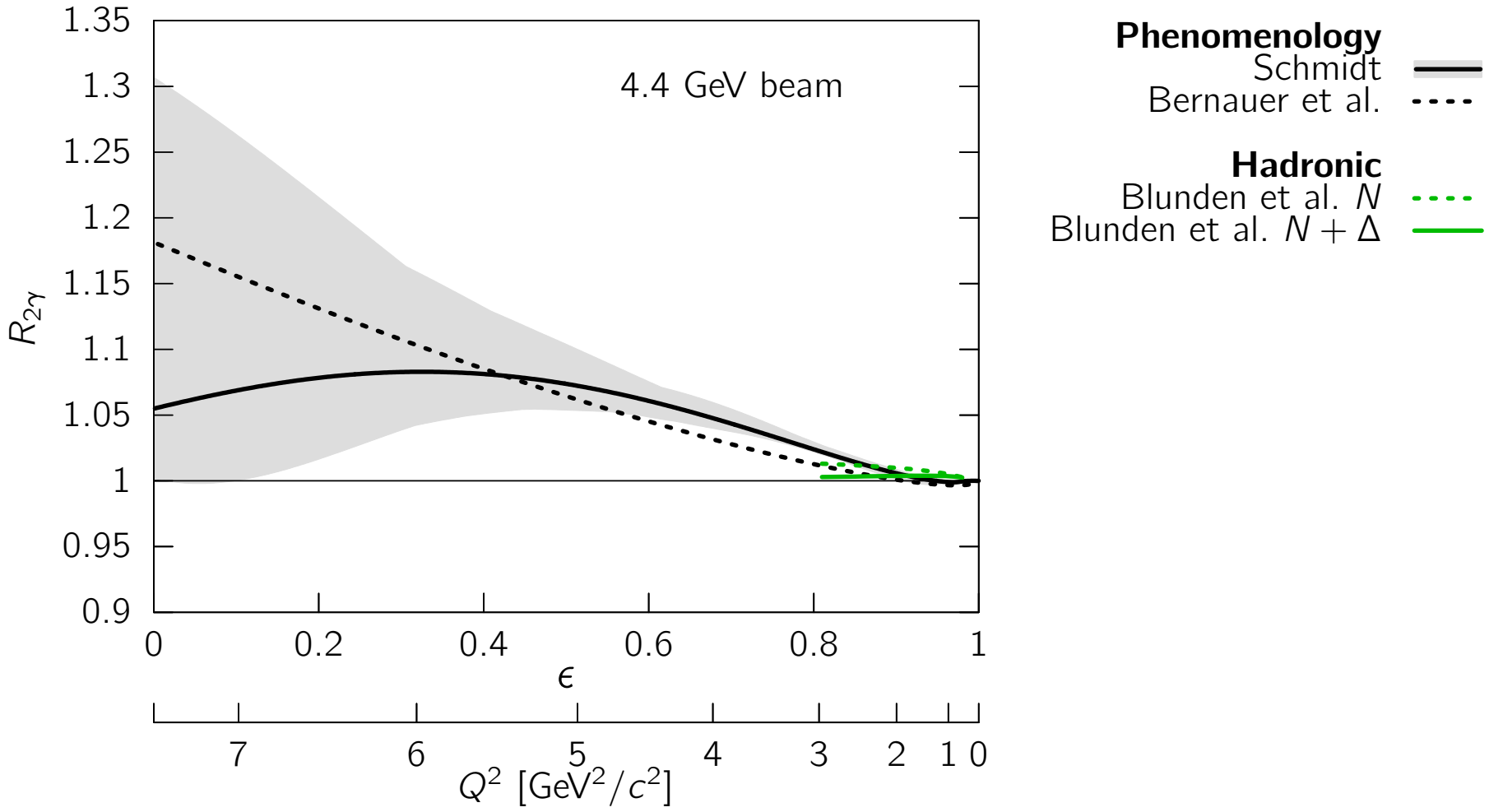

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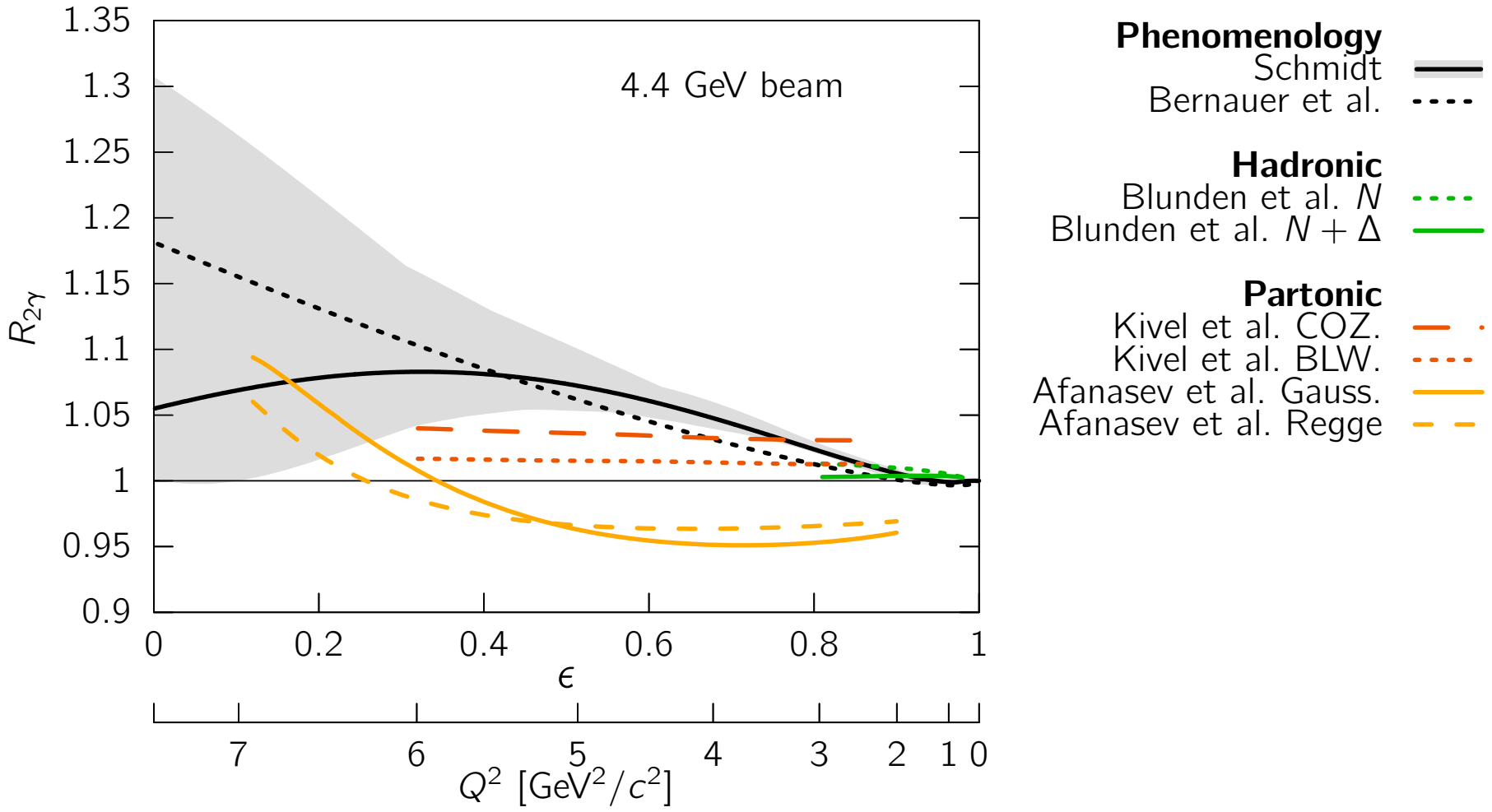

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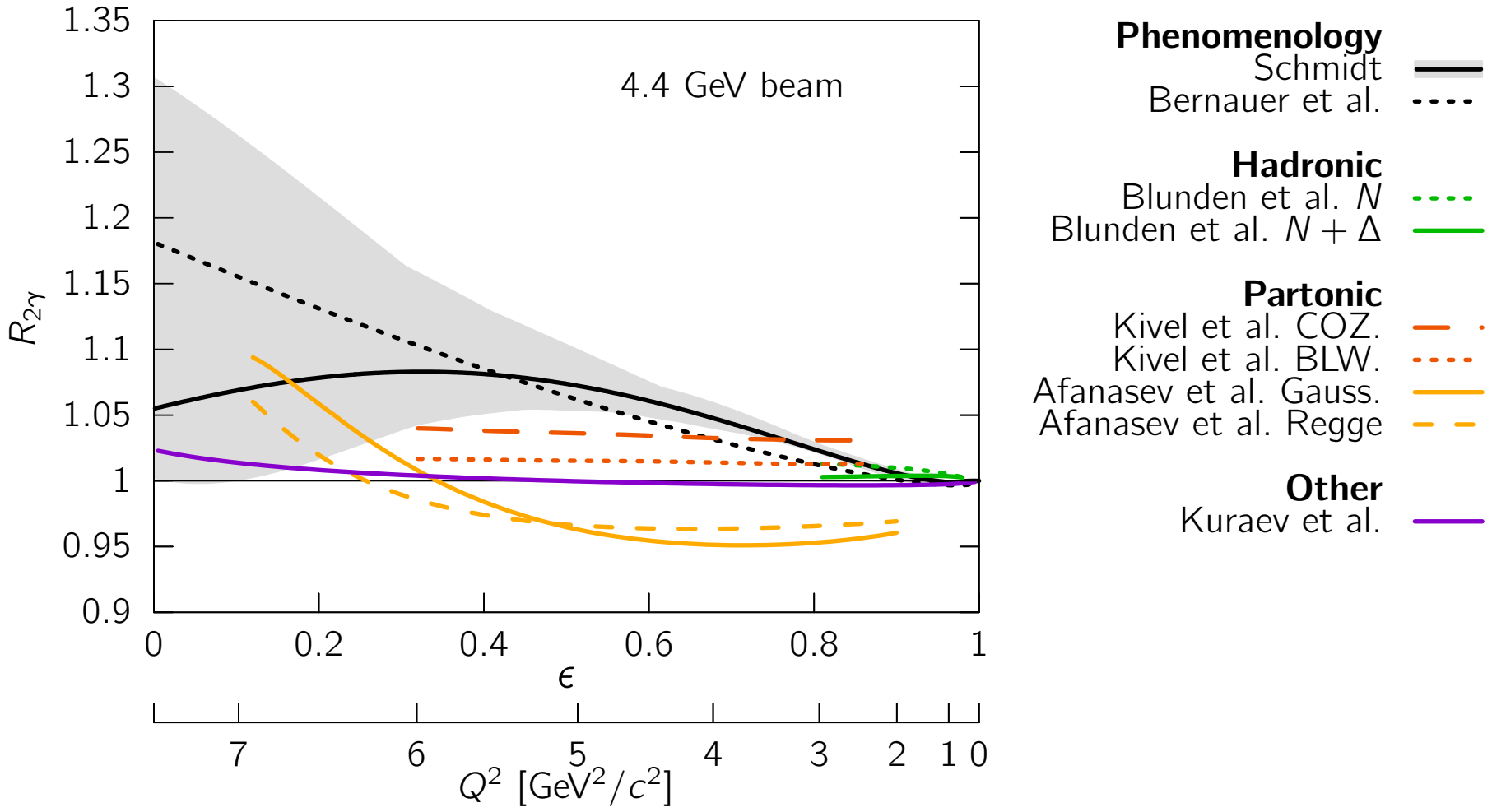
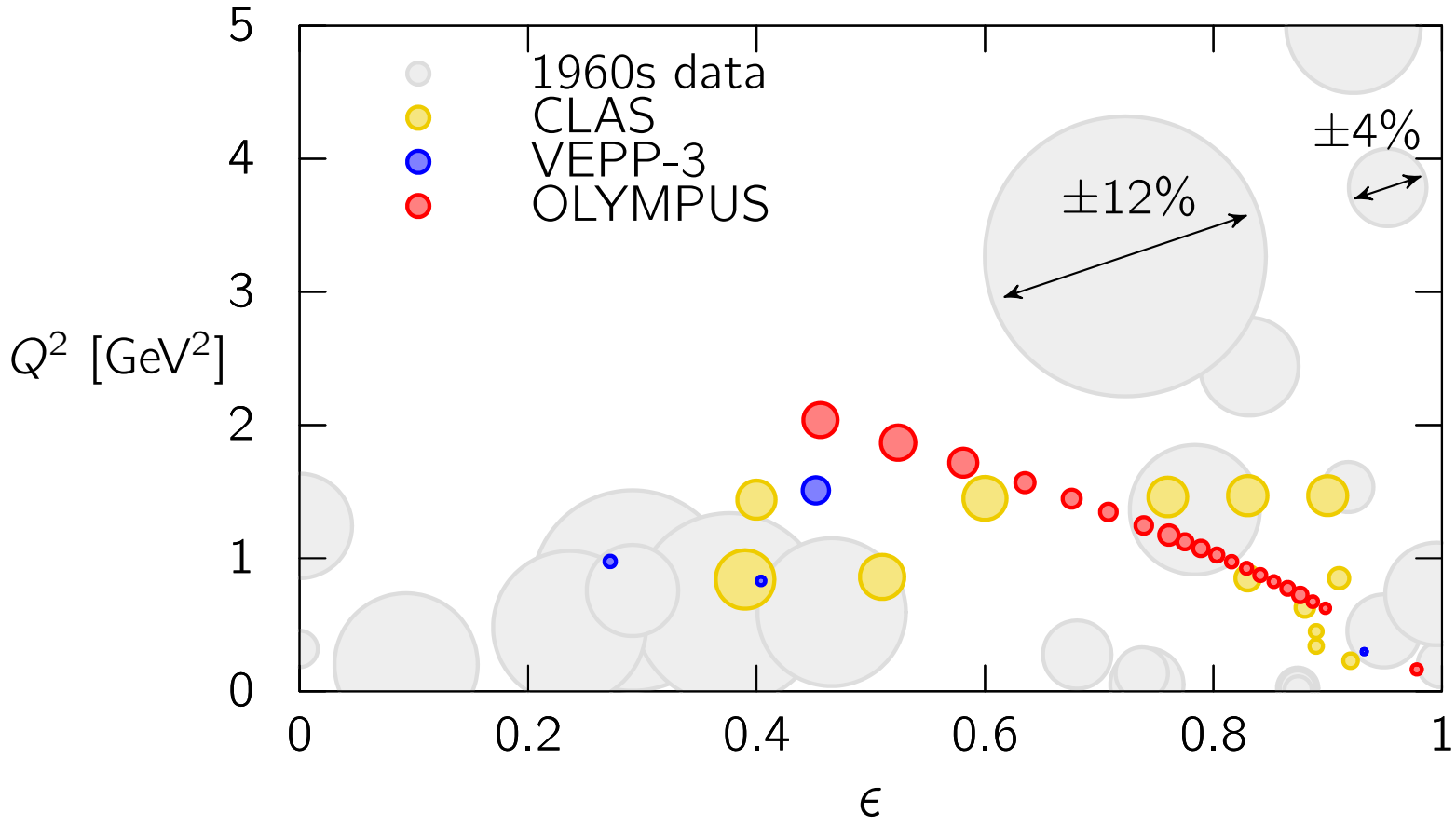
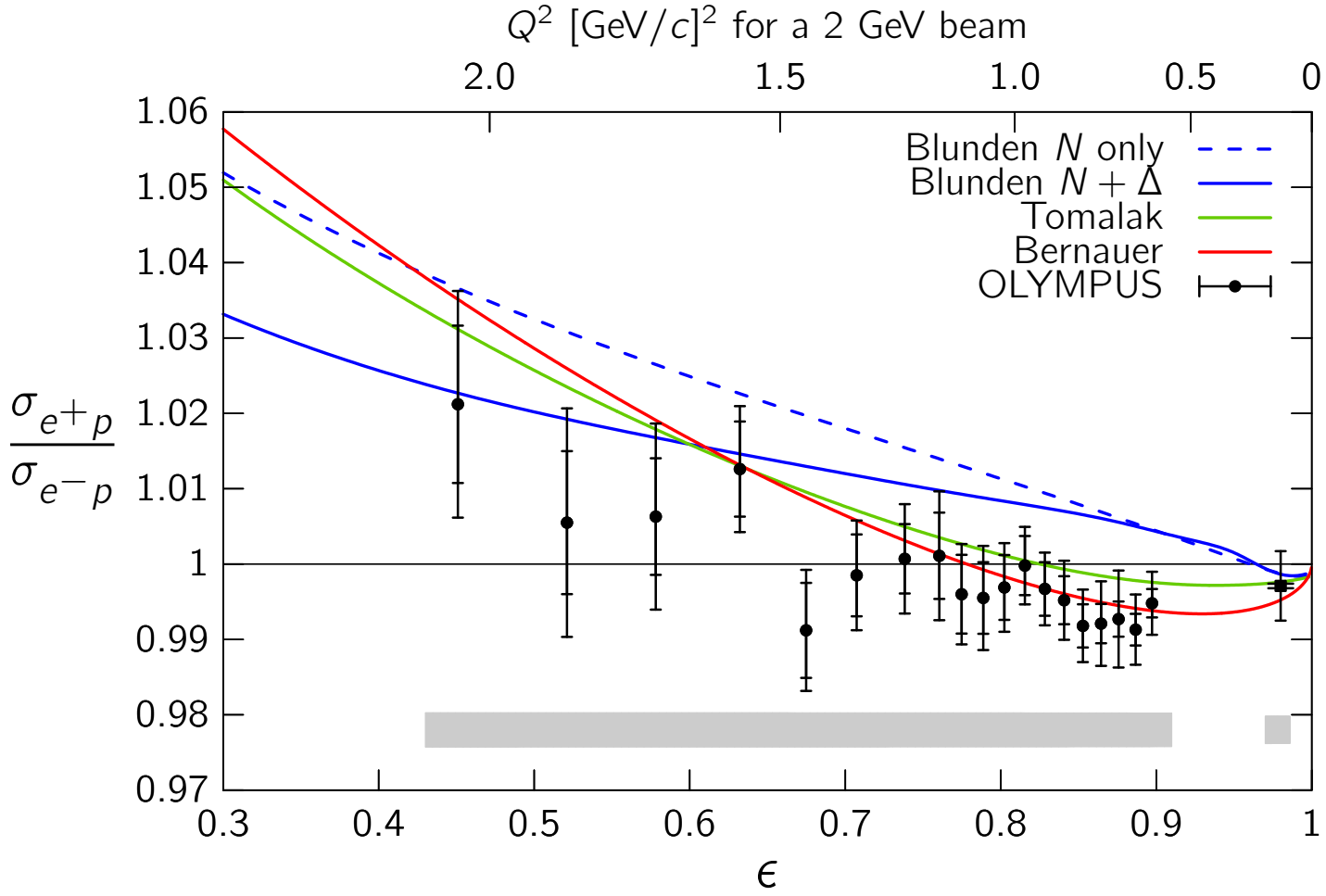


Existing data on $R_{2\gamma}$

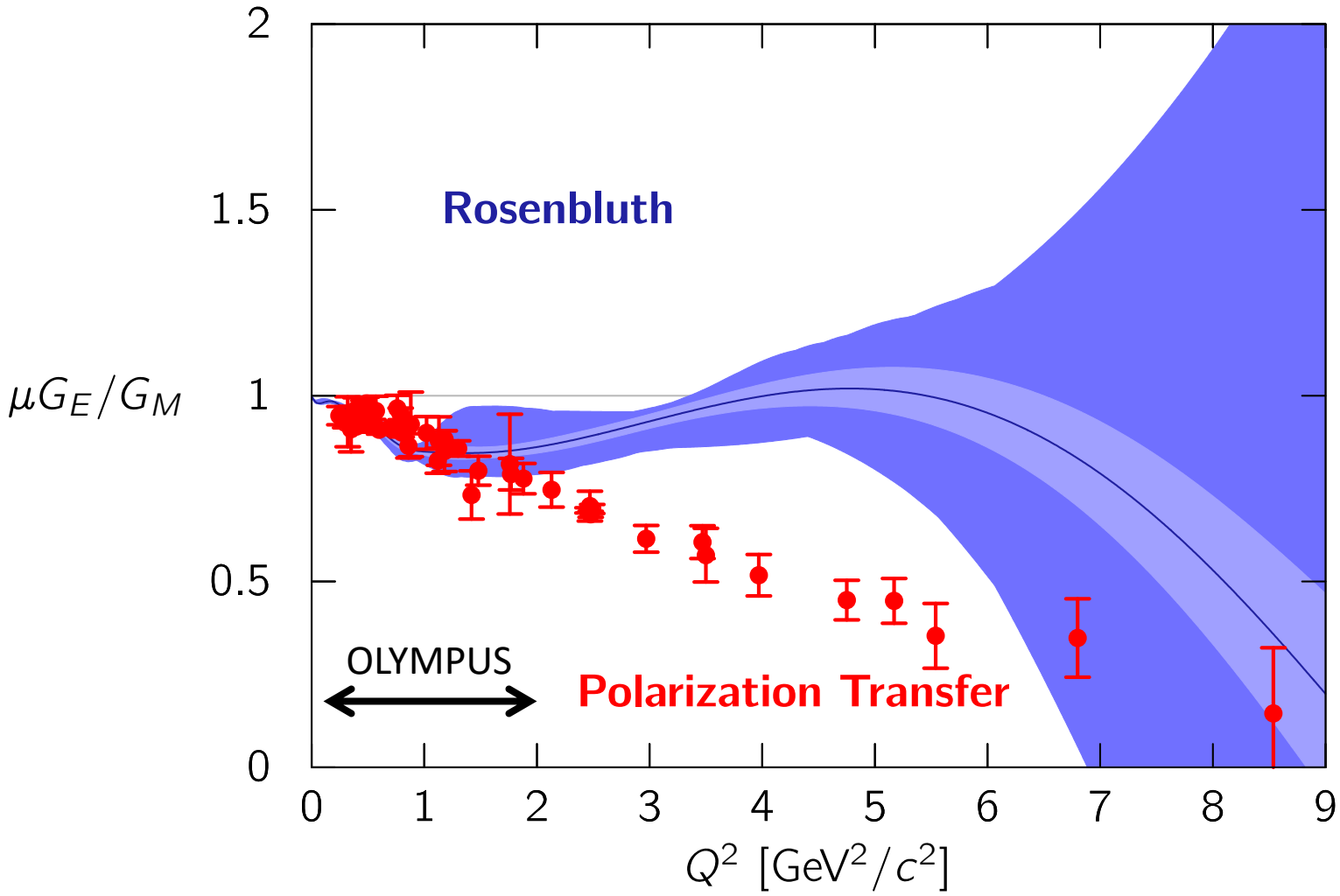


OLYMPUS measured a small TPE effect.



Henderson et al., PRL 2017

Recent experiments lacked the kinematic reach.



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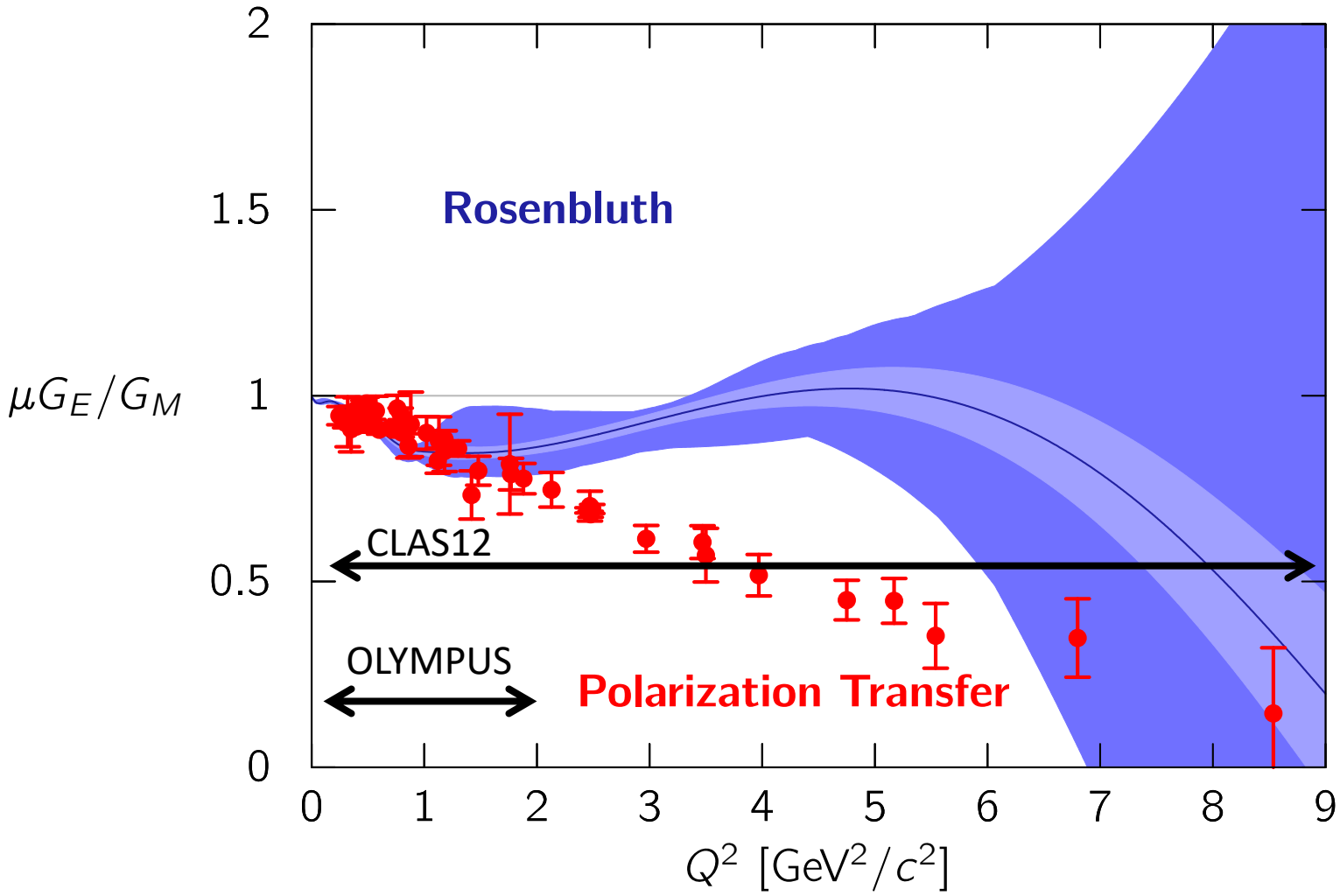
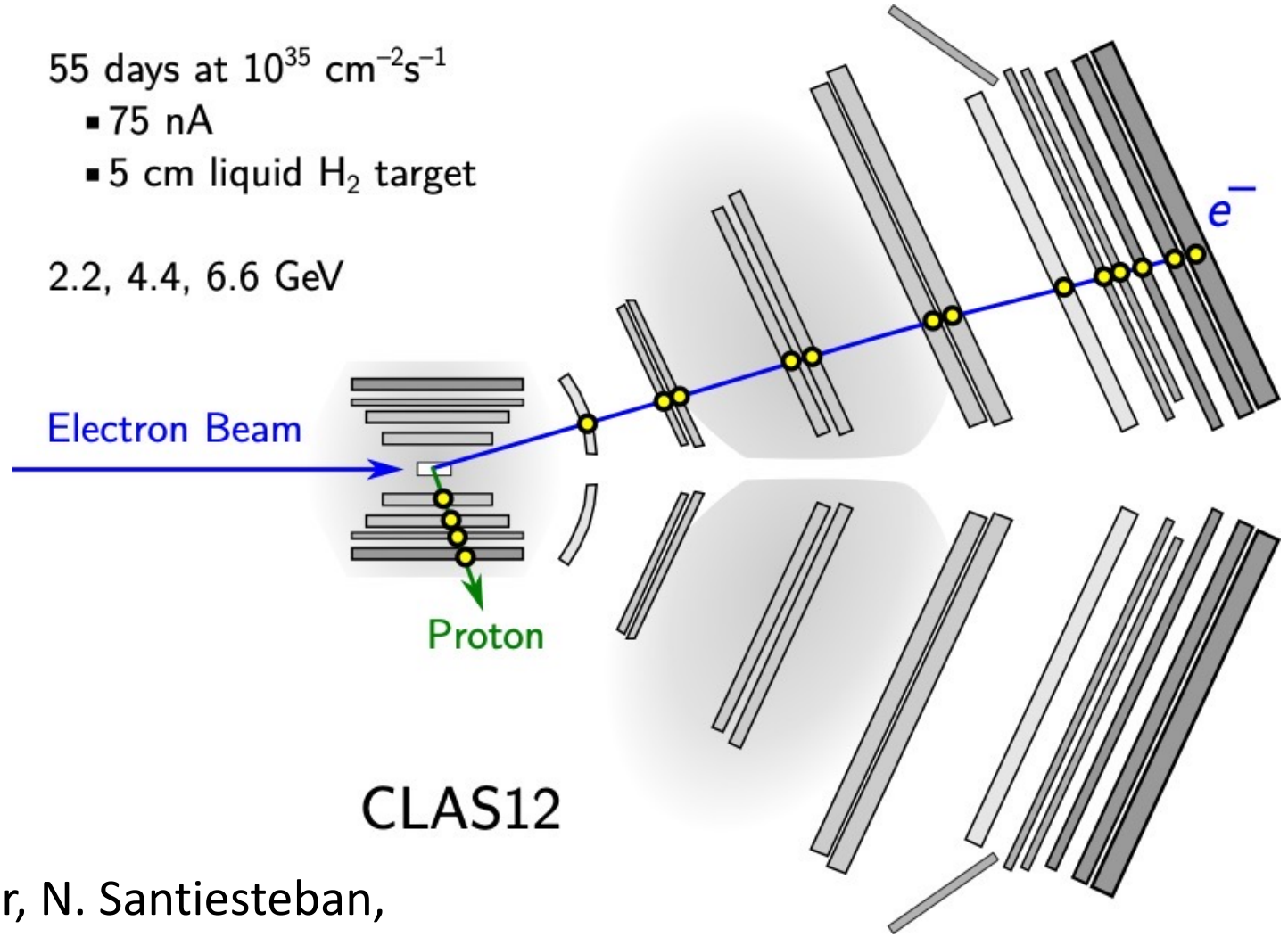


CLAS12 can do a way better job than OLYMPUS

Performance	OLYMPUS	CLAS12
Azimuthal Acceptance	$\pi/4$	2π
Luminosity	$2 \cdot 10^{33}$	10^{35}
Beam Energy	2 GeV	6.6 GeV

Our proposed experiment



Spokespeople:
A. Schmidt, J. Bernauer, N. Santiesteban,
T. Kutz, I. Korover, E. Cline, V. Burkert

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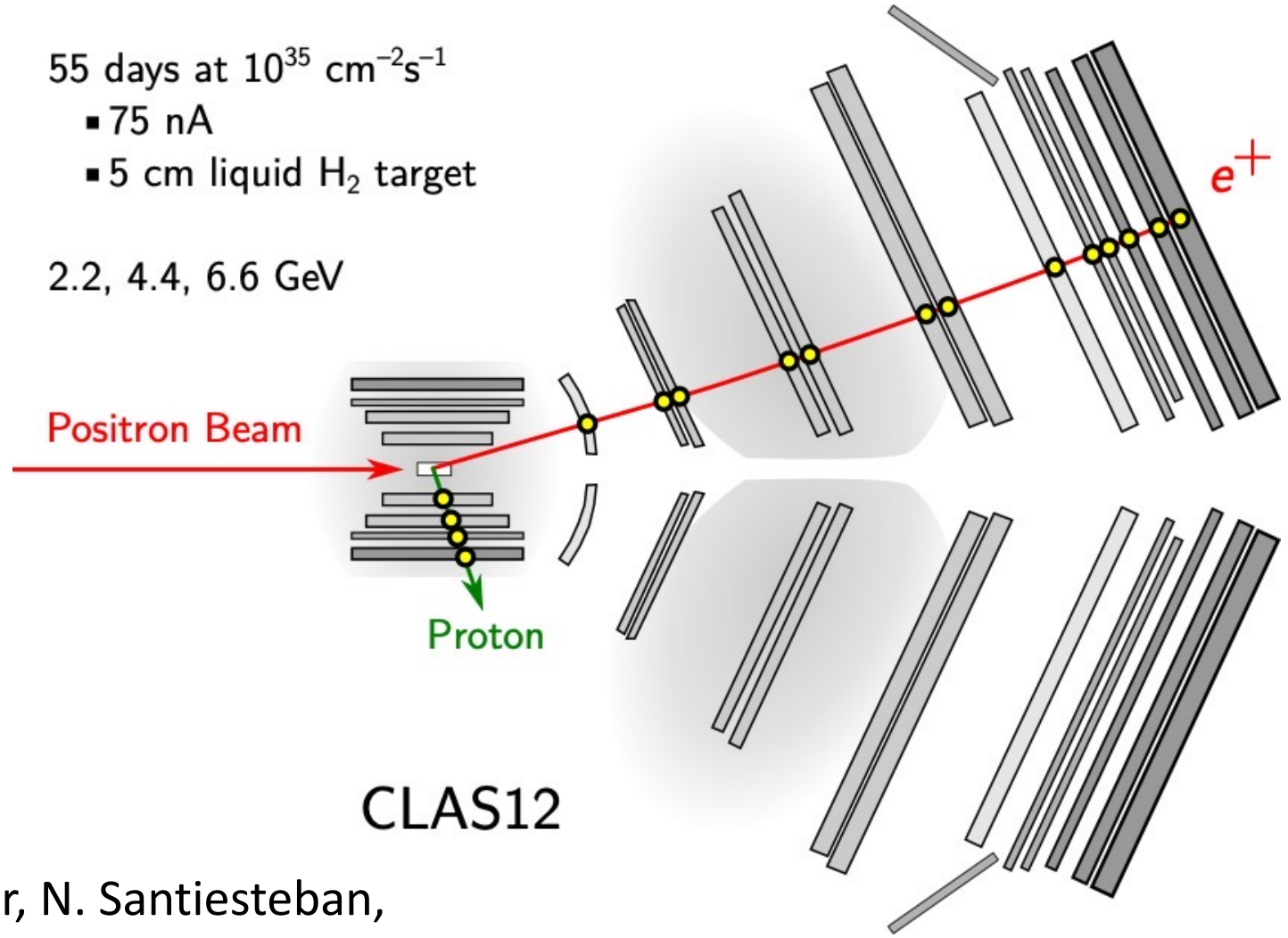

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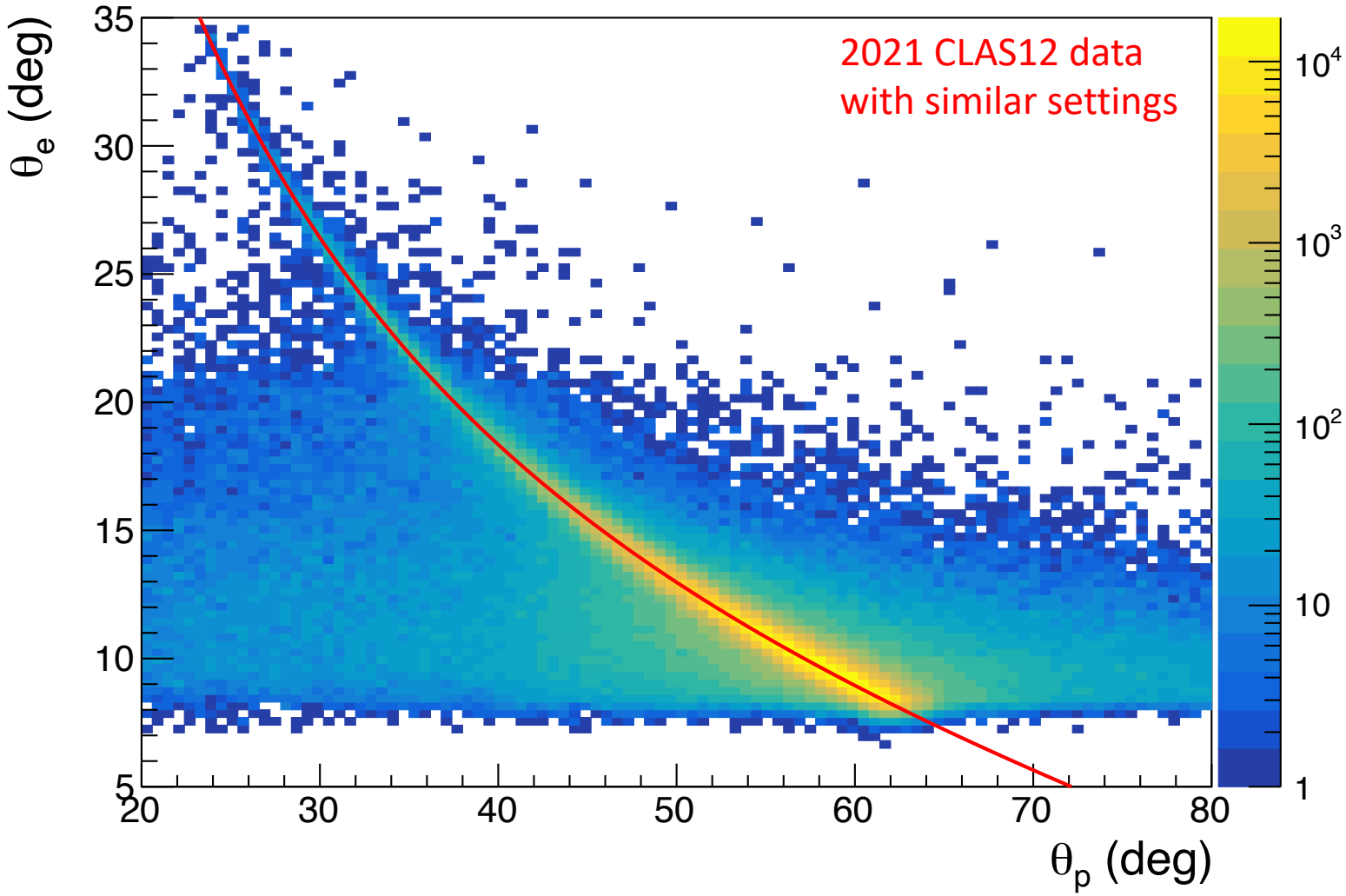
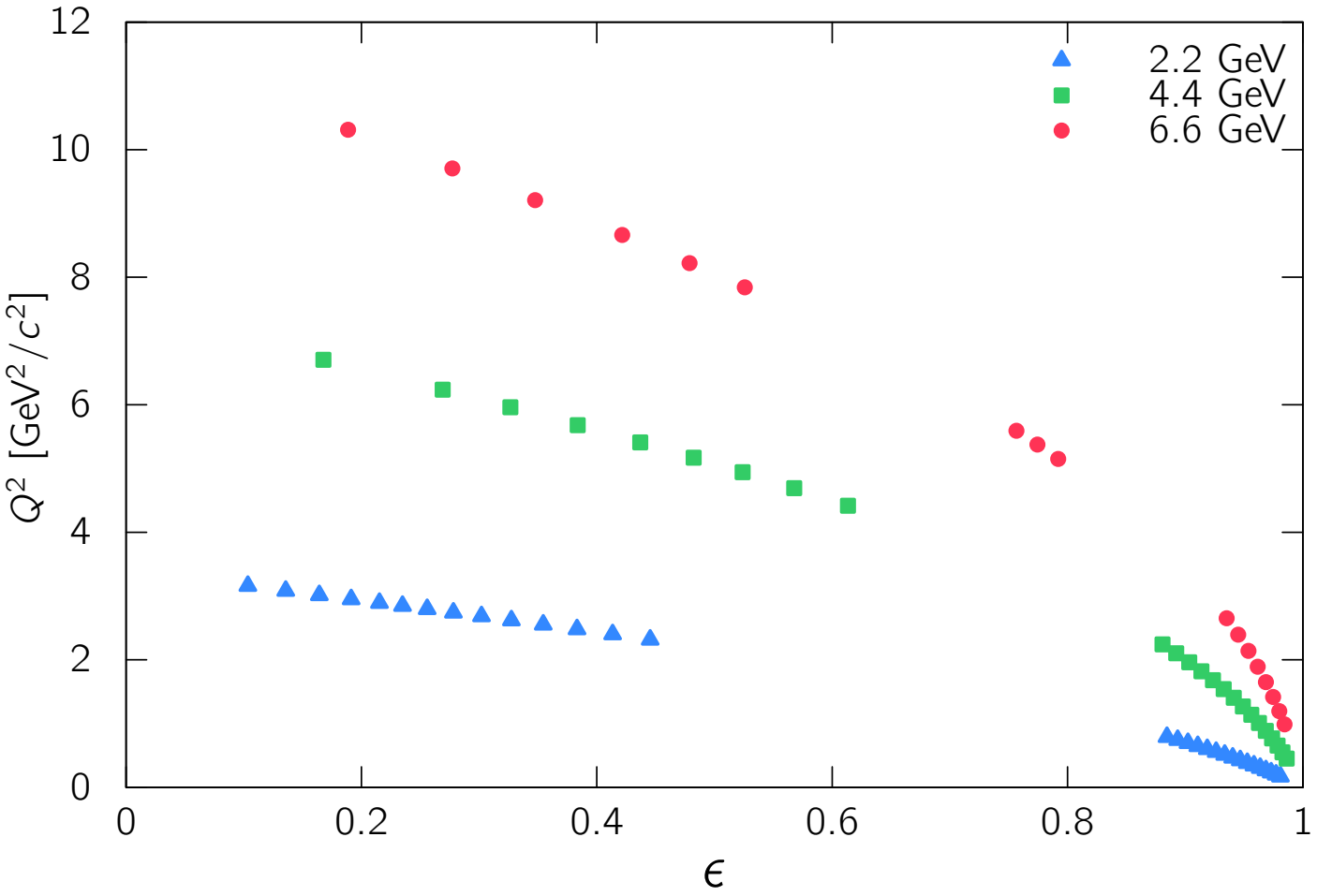
Elastic scattering is easy to identify.



CLAS12 covers a huge amount of new phase space.



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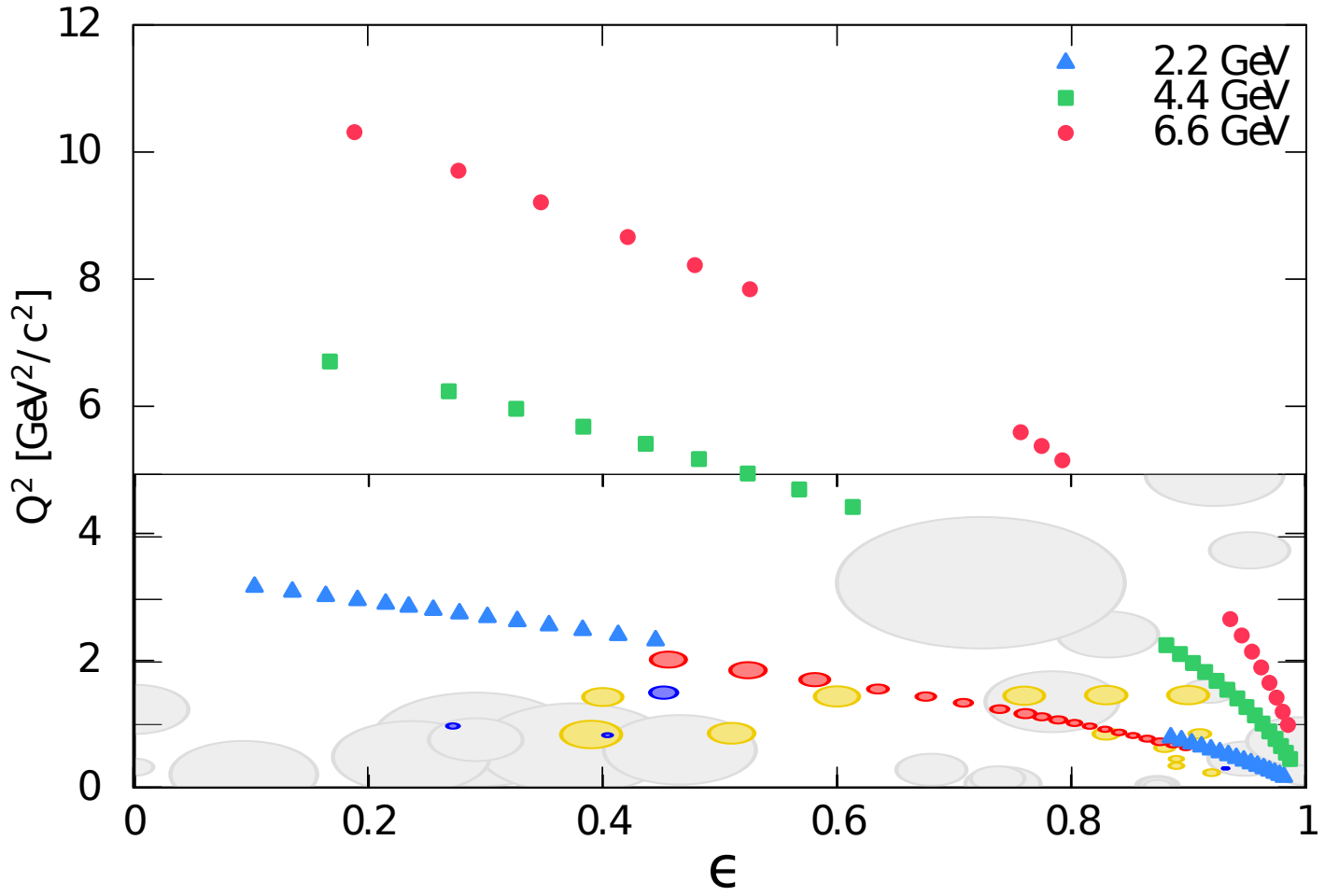
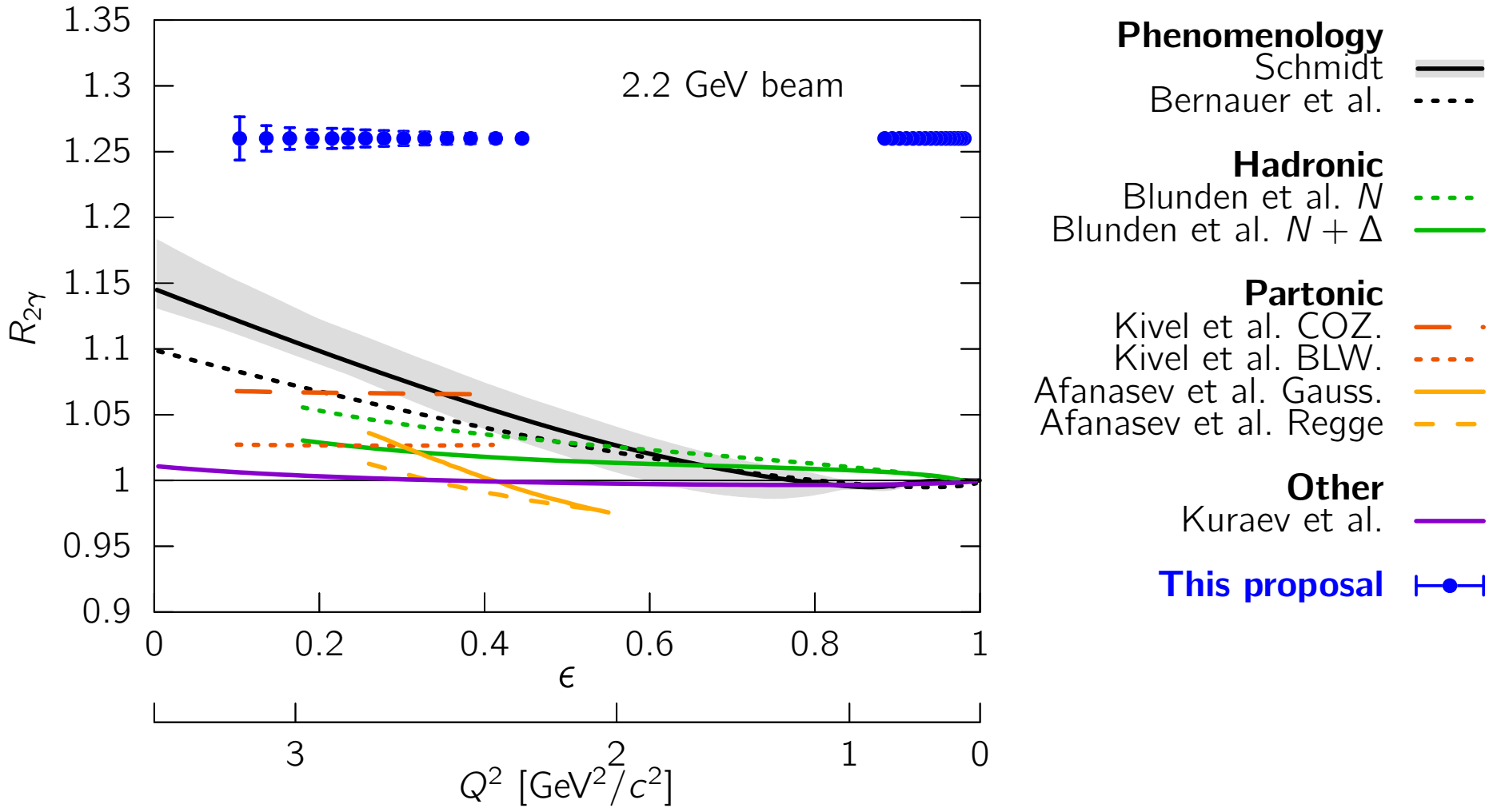


Projected stat. uncertainties



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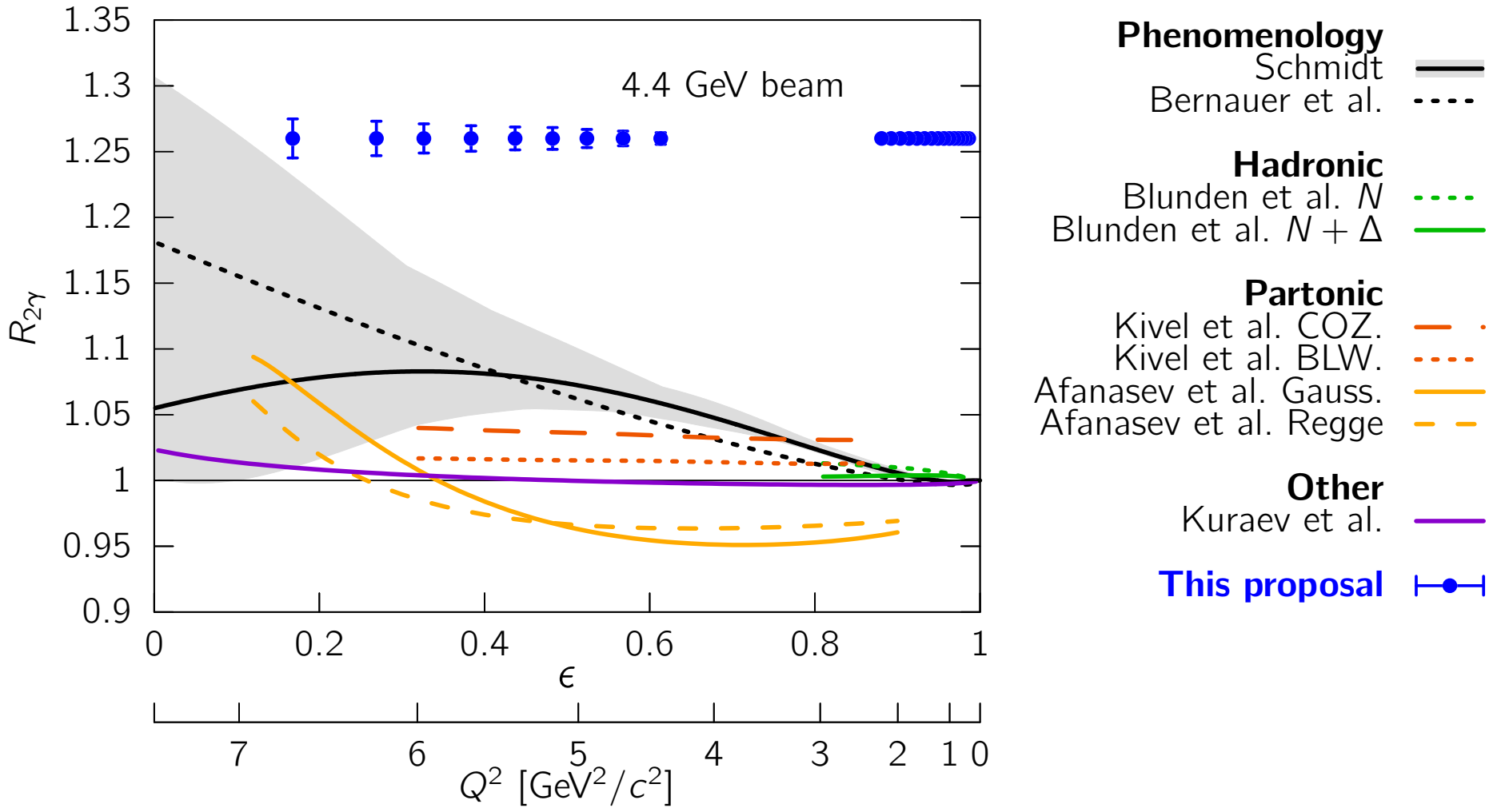

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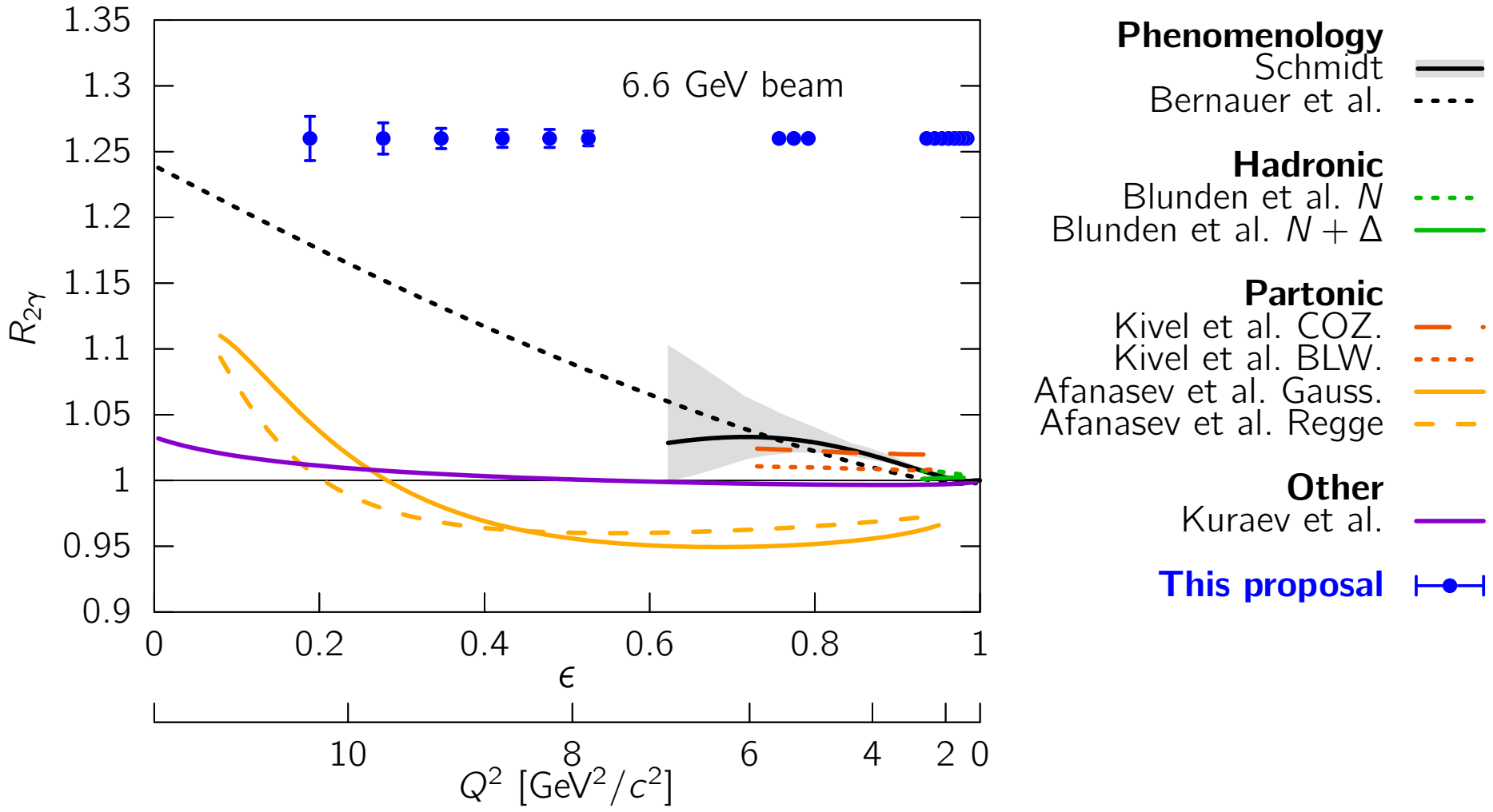
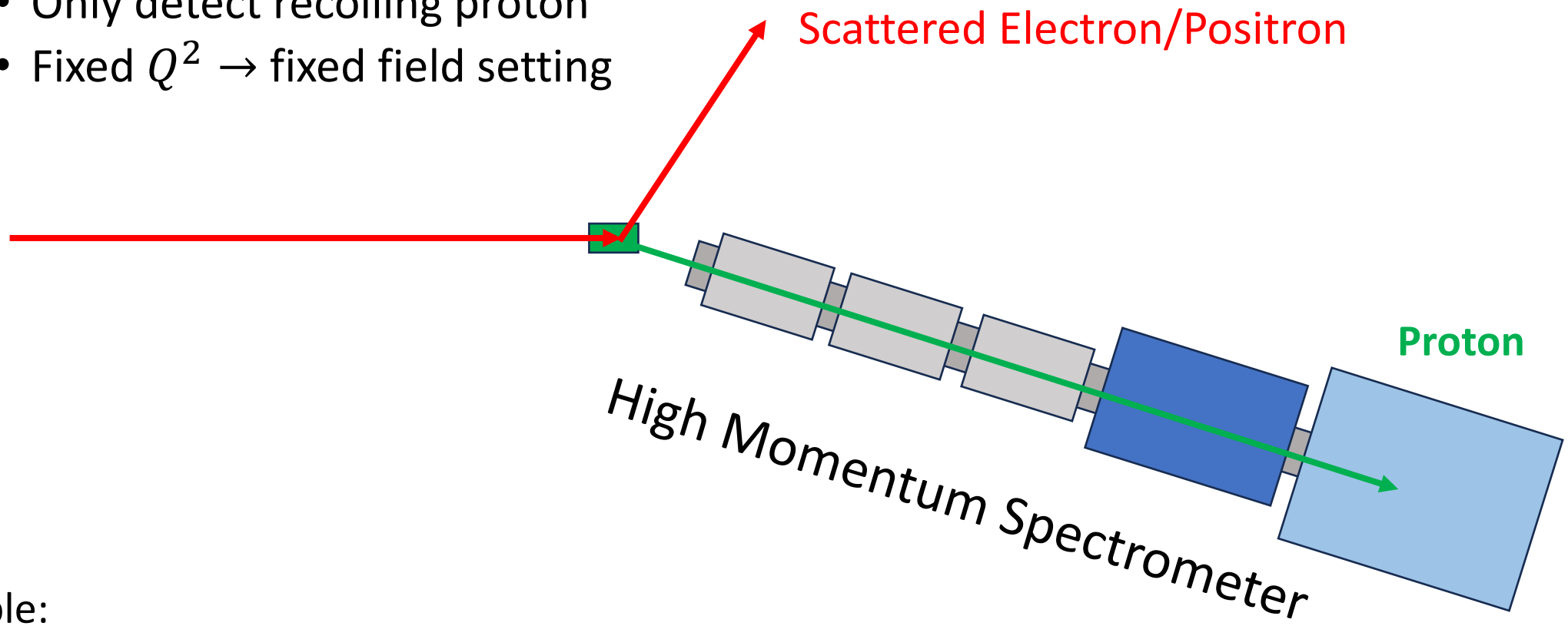


E12+23-012: Complimentary Approach

- Super-Rosenbluth Technique
  - Only detect recoiling proton
  - Fixed $Q^2 \rightarrow$ fixed field setting



Spokespeople:
M. Nycz, J. Arrington, N. Santiesteban, M. Yurov

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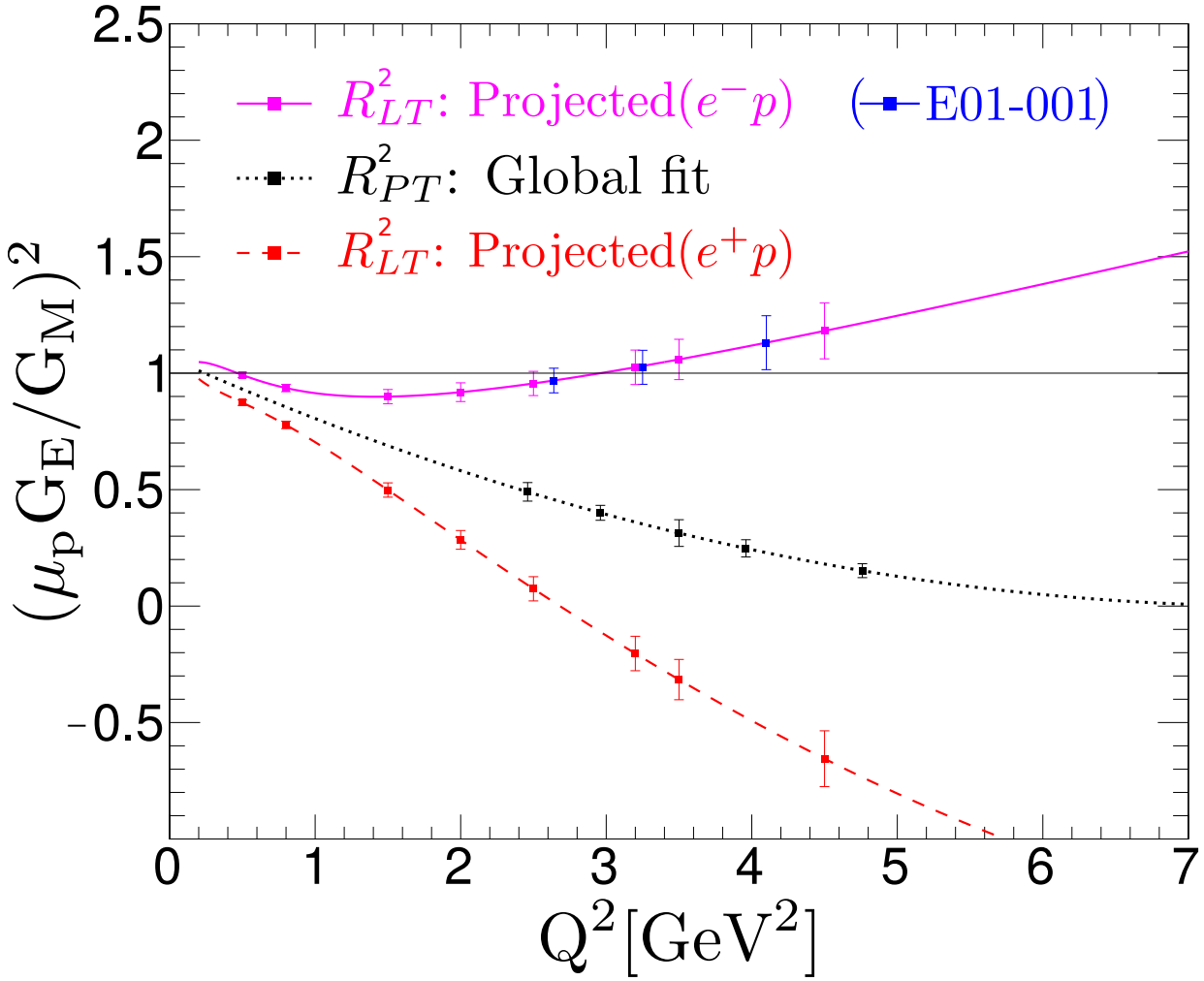

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Positron Experiments/Concepts at JLab

Multi-photon exchange

PR12+23-003: Coulomb Effects in DIS
PR12+23-008: Two-photon Exchange at CLAS12
PR12+23-012: Two-photon Exchange in Hall C
LOI12+23-008: Two-photon Exchange in Pol. Trans.
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White paper: Electroweak couplings at SOLID
Two-photon in elastic eA
Imaginary part of TPE amplitude

Virtual Compton Scatt.

PR12+23-002: DVCS asymmetries at CLAS12
PR12+23-006: DVCS cross section in Hall C
LOI12+23-001: Generalized Polarizabilities
White papers: DVCS on neutrons, He-4
DDVCS at SOLID

Dark Photon Searches

PR12+23-005: Annihilation Search
LOI12+23-005: Bhabha Search

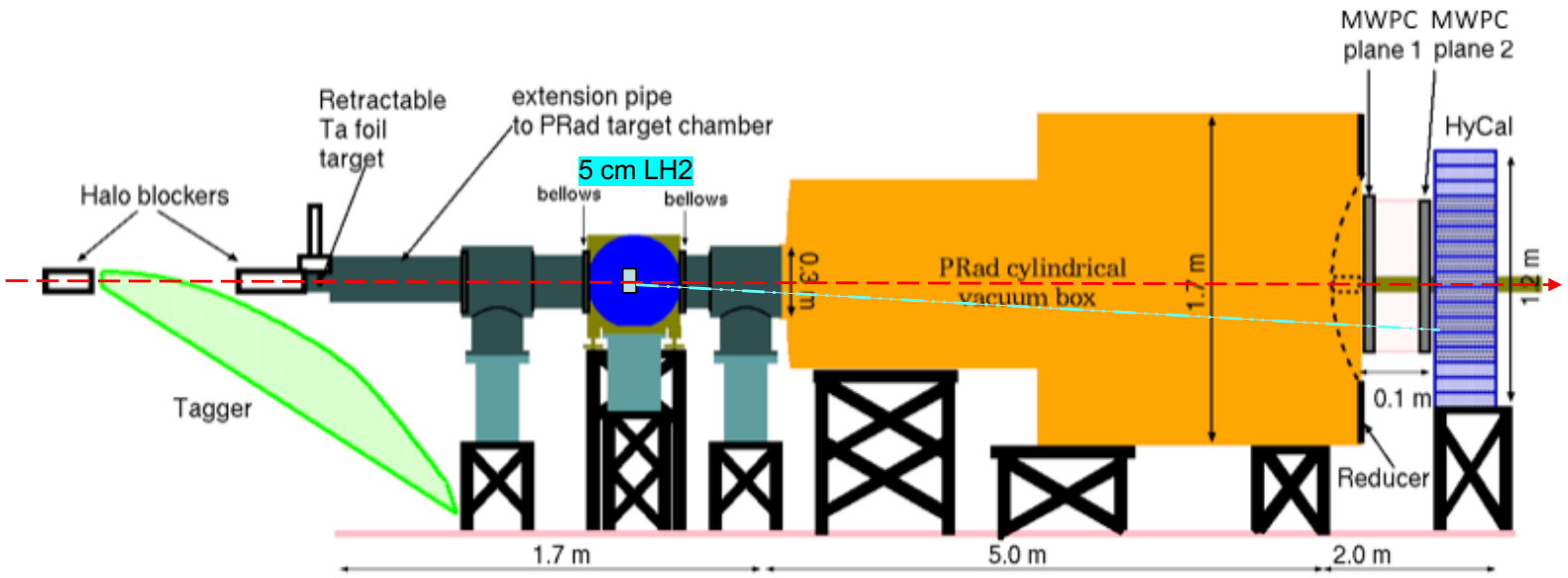
Charged-Current

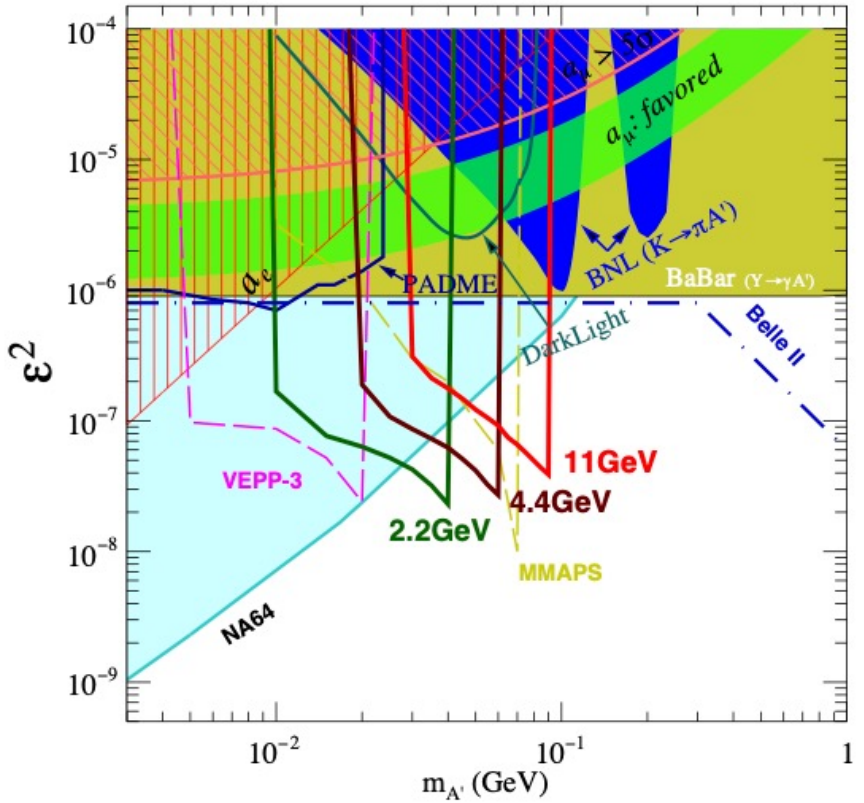
LOI12+23-002: Axial Form Factor
White paper: Strangeness via Charm Tag

Other BSM

White paper: charged-lepton flavor violation search

PR12+23-005: Dark Matter Search





- PRAD set-up to search for $e^+e^- \to \gamma(A')$

Spokespersons:
A. Gasparian, N. Liyanage, B. Raydo, B. Wojtsekhowski

Positron Experiments/Concepts at JLab

Multi-photon exchange

PR12+23-003: Coulomb Effects in DIS
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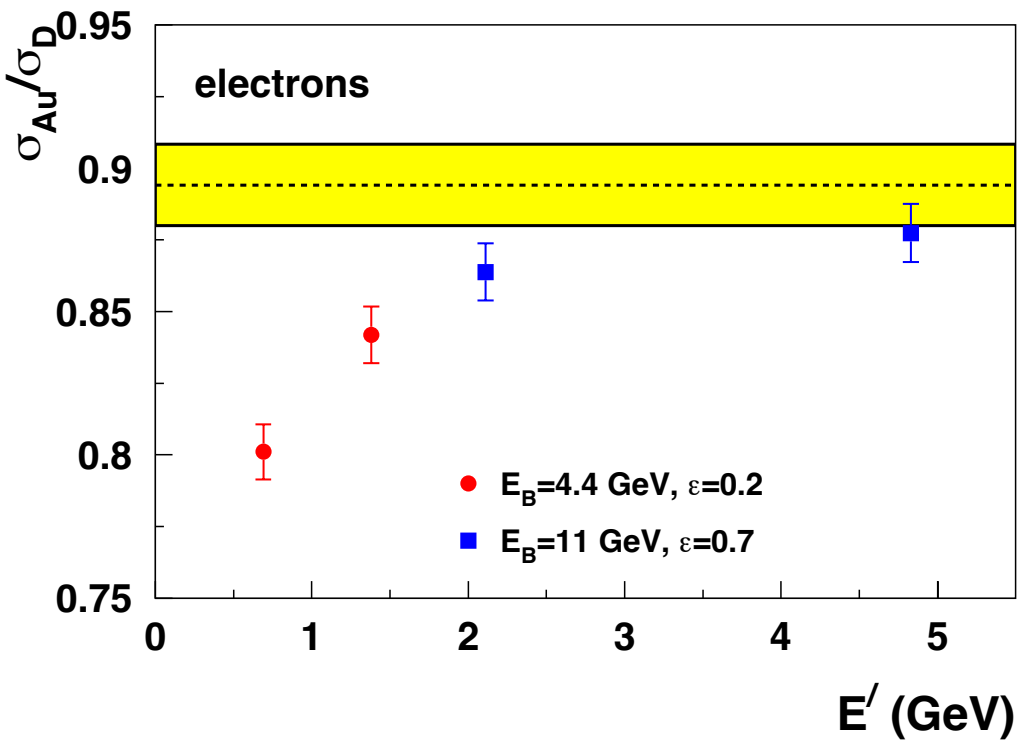
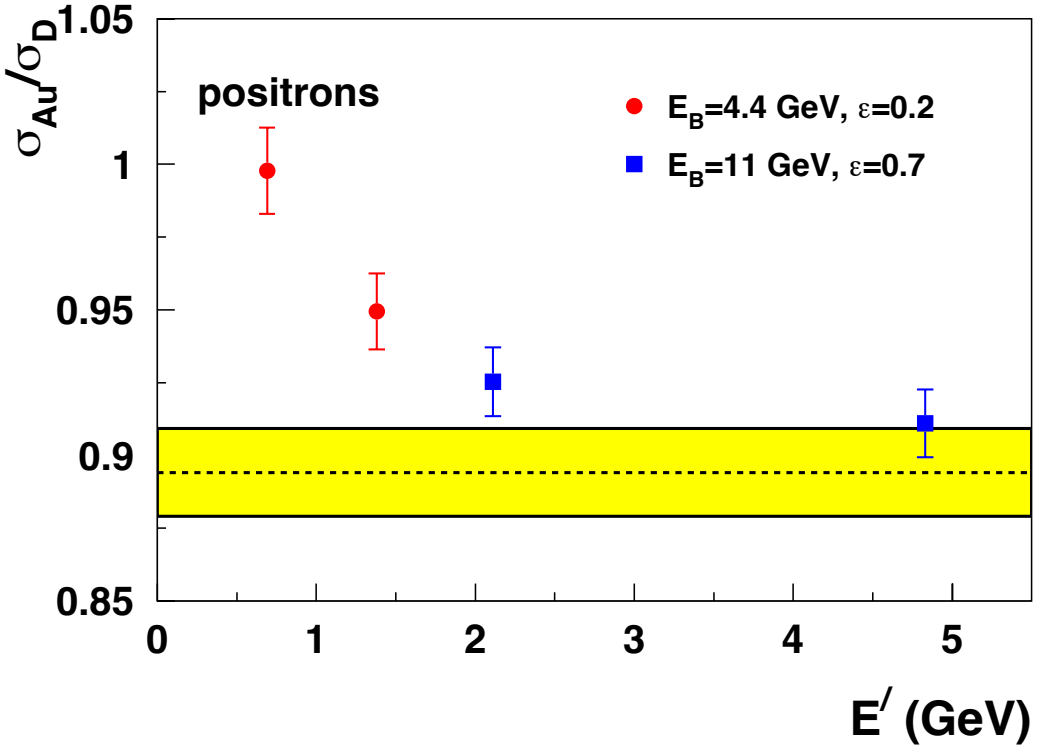
Other BSM

White paper: charged-lepton flavor violation search

E12+23-003: Coulomb Effects in DIS

9-day measurement of DIS on Au, d for positrons and electrons

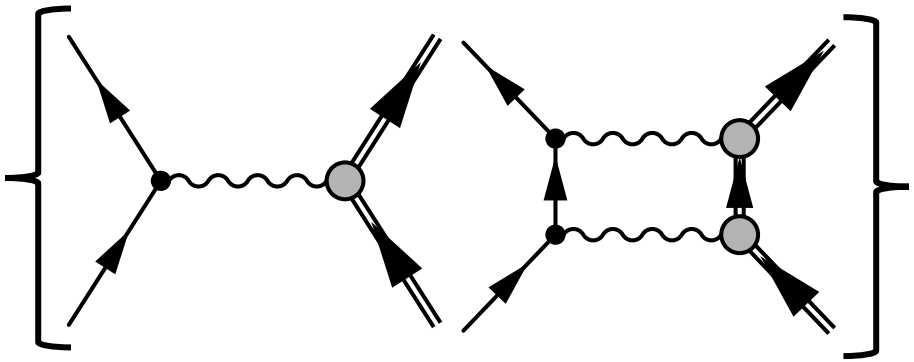


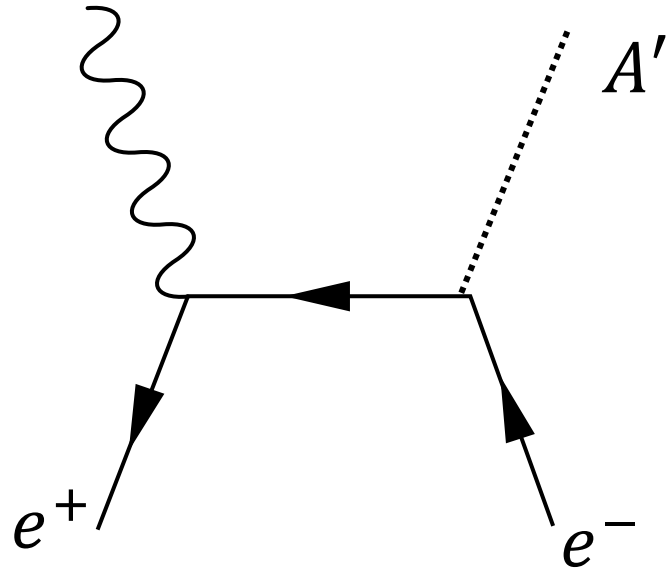


Spokespersons:
Bill Henry, Dave Gaskell, Nadia Fomin

To Recap:

- Positrons are useful for a wide range of
  - Interference physics
  - Charge-current physics

$\pm 2Re$ 



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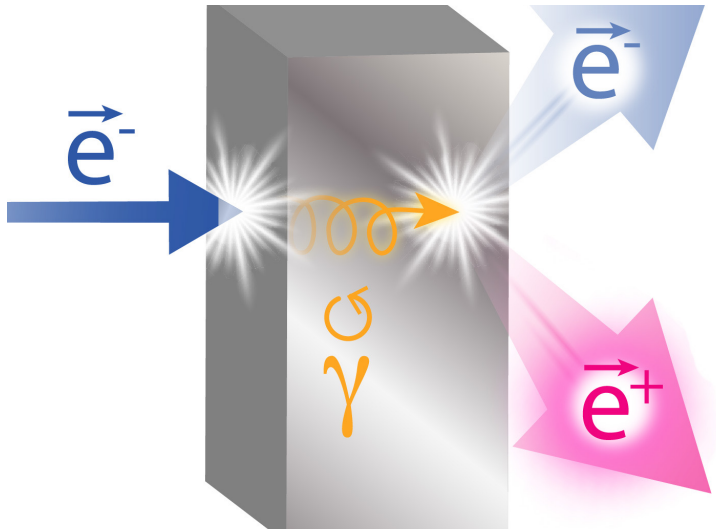
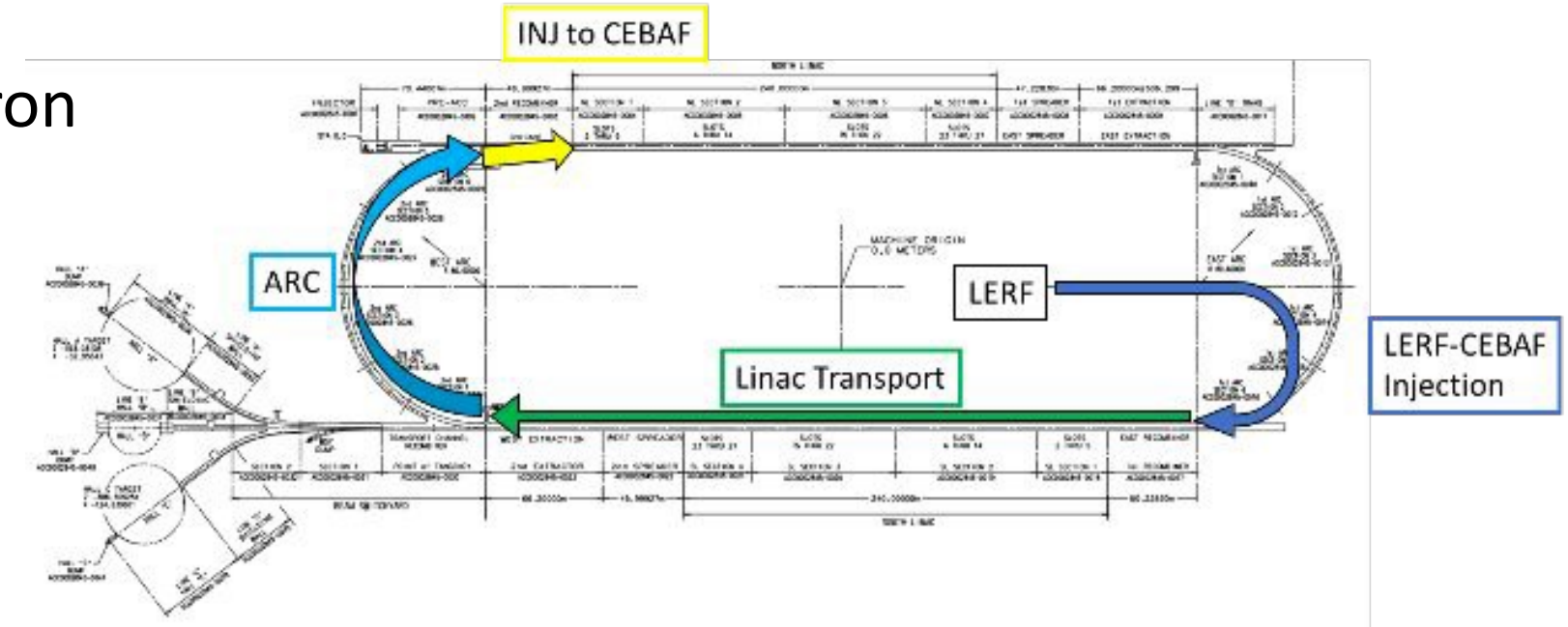


- JLab is planning positron upgrade



To Recap:

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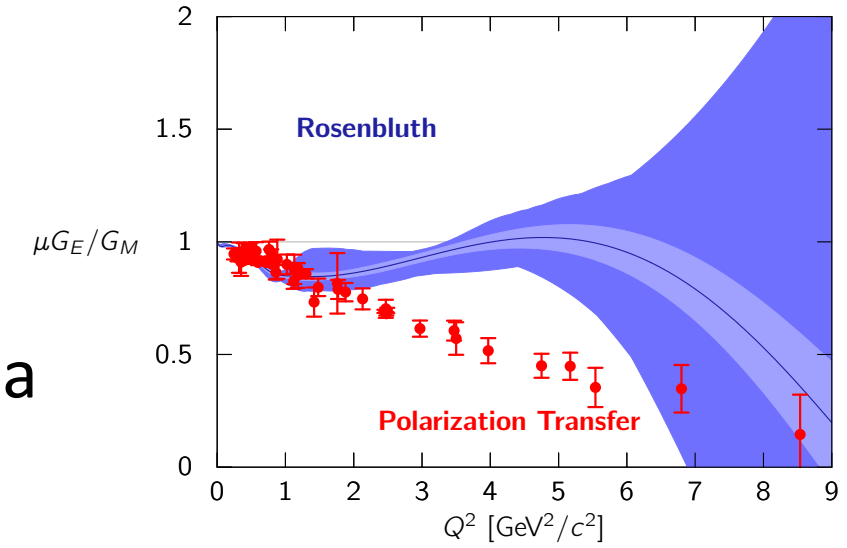
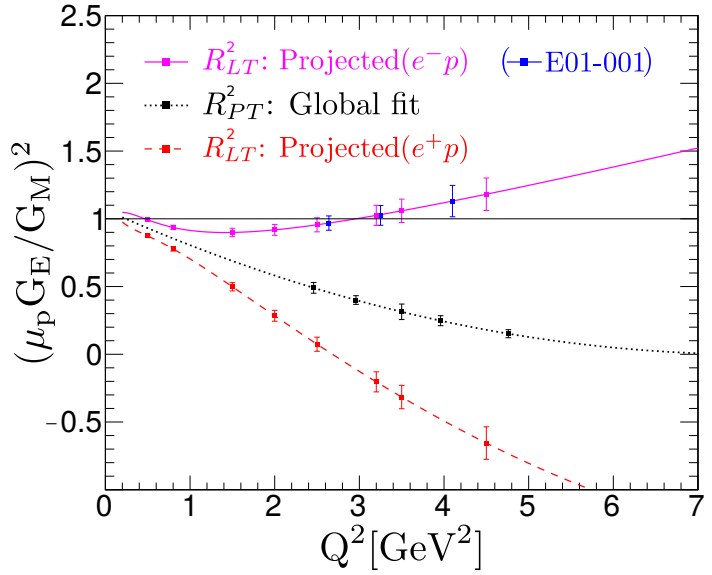
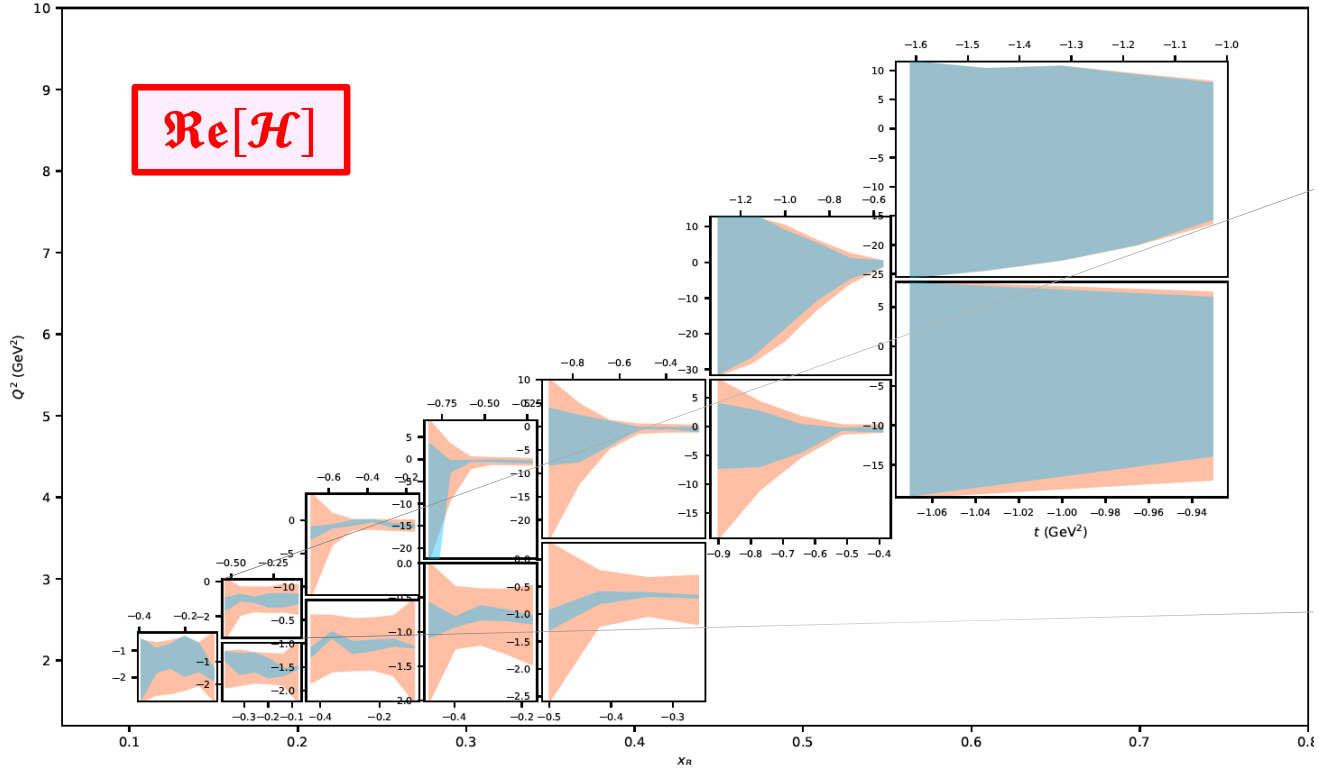
  - Interference physics
  - Charge-current physics
- JLab is planning positron upgrade
- 5 newly approved proposals at this years' PAC.

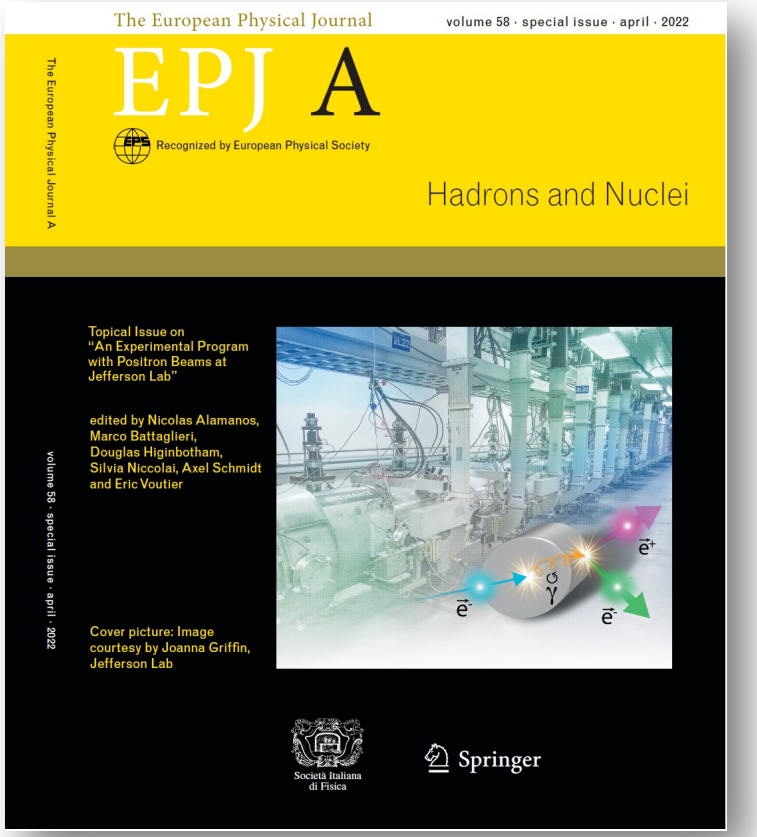






Jefferson Lab Positron Working Group

EPJ A Topical Issue: [An Experimental Program with Positron Beams at Jefferson Lab]



Join our mailing list

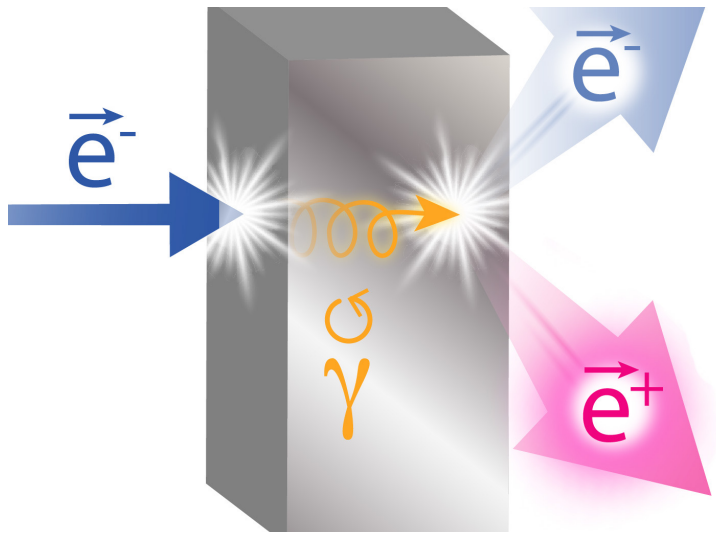
pwg-request@jlab.org

BACK-UP

Positron experiments at PAC51

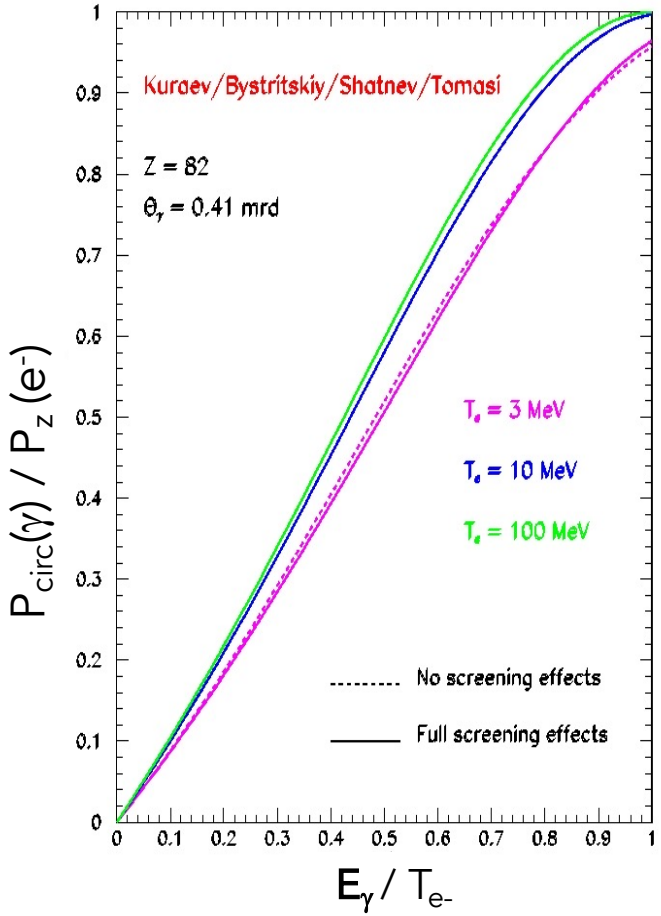
	NUMBER	CONTACT PERSON	TITLE	HALL	DAYS REQ'D	DAYS AWARDED	SCIENTIFIC RATING	PAC DECISION	TOPIC
	PR12-23-001	Nikos Sparveris	Measurement of the Generalized Polarizabilities of the Proton in Virtual Compton Scattering	C	62	62	A-	Approved	2
DVCS	PR12+23-002	Eric Voutier	Beam Charge Asymmetries for Deeply Virtual Compton Scattering on the Proton at CLAS12	B	100	100	A-	C1	4
Coulomb	PR12+23-003	Dave Gaskell	Measurement of Deep Inelastic Scattering from Nuclei with Electron and Positron Beams to Constrain the Impact of Coulomb Corrections in DIS	C	9.3	9.3	A-	C1	5
	PR12-23-004	Bogdan Wojtsekhowski	A Search for a Nonzero Strange Form Factor of the Proton at 2.5 (GeV/c)^2	C	45	45	A-	Approved	2
Dark Matter	PR12+23-005	Bogdan Wojtsekhowski	A Dark Photon Search with a JLab positron beam	B	60			Deferred	6
DVCS	PR12+23-006	Carlos Munoz Camacho	Deeply Virtual Compton Scattering using a positron beam in Hall C	C	137	137	A-	C1	4
	PR12-23-007	David Ruth	A Measurement of the Proton g2 Structure Function at Intermediate Q2	C	33			Deferred	2
TPE	PR12+23-008	Axel Schmidt	A Direct Measurement of Hard Two-Photon Exchange with Electrons and Positrons at CLAS12	B	55	55	A	C1	2
	PR12-23-009	Or Hen	Nuclear Charm Production and Short-Range Correlations in Hall D	D	100			C2	5
	PR12-23-010	Holly Szumila- Vance	Color Transparency in Maximal Rescattering Kinematics	C	95	40	B+	Approved	5
	PR12-23-011	Dipangkar Dutta	Precision Deuteron Charge Radius Measurement with Elastic Electron-Deuteron Scattering	B	40			Deferred	3
TPE	PR12+23-012	Michael Nycz	A measurement of two-photon exchange in unpolarized elastic positron–proton and electron–proton scattering	C	56	56	A-	C1	2

Polarized Electrons for Polarized Positrons

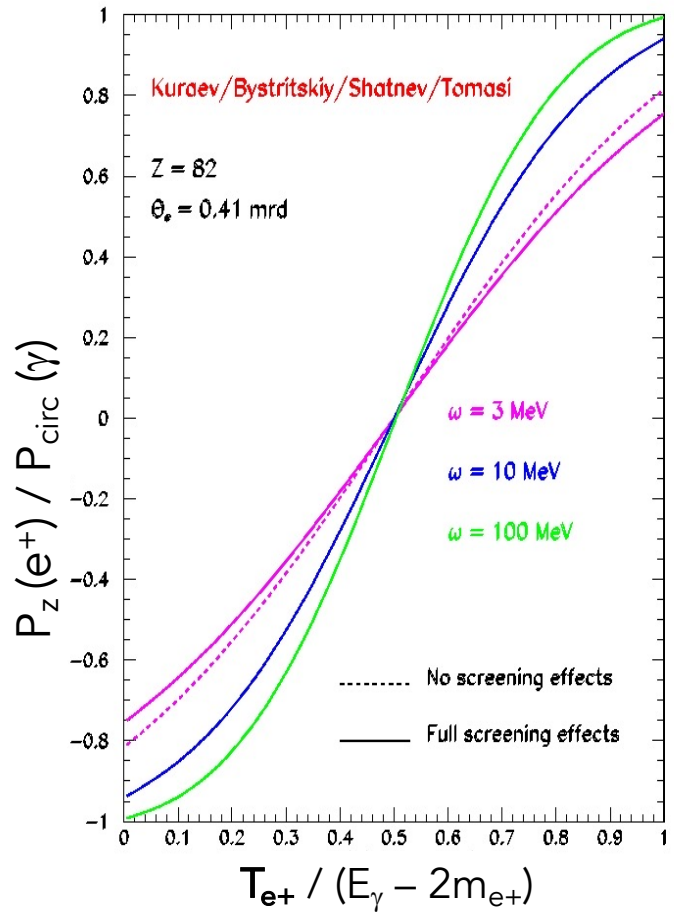


Polarized electrons will tend to pair-produce polarized positrons.

Polarized Bremsstrahlung



Polarized Pair Creation



E.A. Kuraev, Y.M. Bystritskiy, M. Shatnev, E.Tomasi-Gustafsson, PRC 81 (2010) 055208

Polarized Electrons for Polarized Positrons

CEBAF Positron Source Concept

- Pair production from 120 MeV e^- beam
- Capture positrons from 20–60 MeV
- Inject into CEBAF at 123 MeV