Update on E12-20-011

Measurement of the high-energy contribution to the Gerasimov-Drell-Hearn sum

(REGGE, Real Gamma GDH Experiment)

Spokespersons: M-M. Dalton (JLab), A.D. (JLab), J. Stevens (W&M) and S. Širca (Univ. Ljubljana)

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Proposed in 2020 (PAC 48) to run in Hall D.

Proposal reviewed and endorsed by the GlueX collaboration.

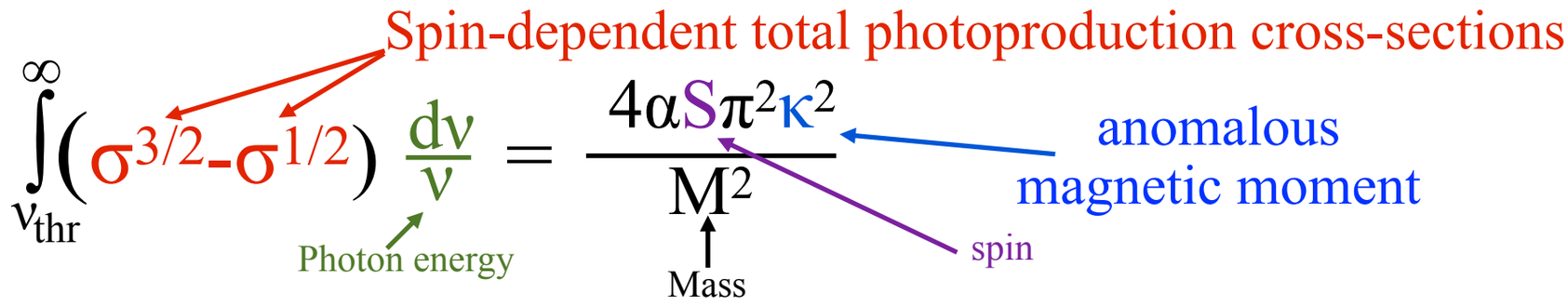
Theory Report for PAC 48: "this an important measurement with impact on nuclear and particle physics."

TAC for PAC 48 reports that while the experiment requires new equipment "no real showstopper has been identified."

PAC 48: experiment approved (A^-) for 33 days: "The PAC recognizes the strong science case for this proposal, and recommends running with the full beam time requested in the proposal."

The Gerasimov-Drell-Hearn sum rule

First principle* prediction.
Links spin-dependent photoproduction cross-sections to target anomalous magnetic moment:



Integral convergence (conditional for GDH's validity): mainly determined by large ν behavior of $\sigma^{3/2}-\sigma^{1/2}$

⇒ for nucleon target: studies QCD/nucleon structure.

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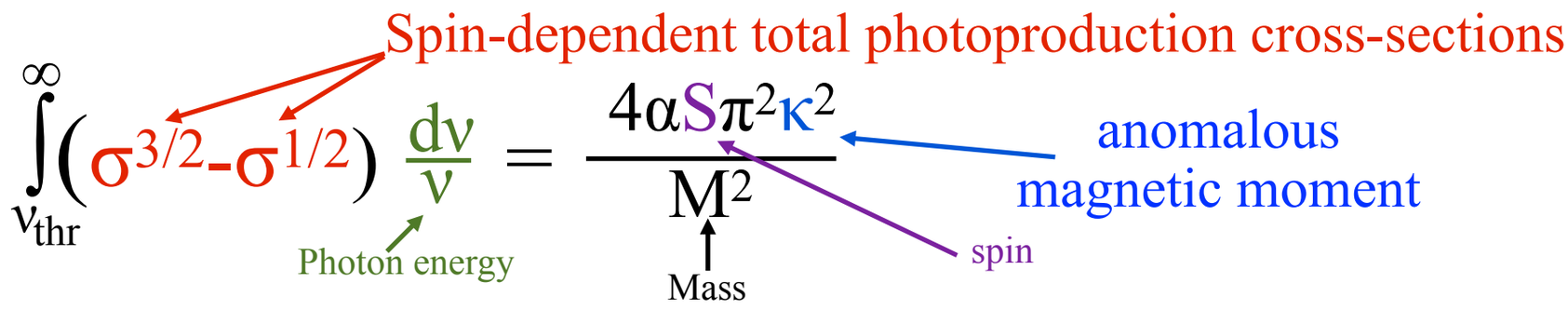

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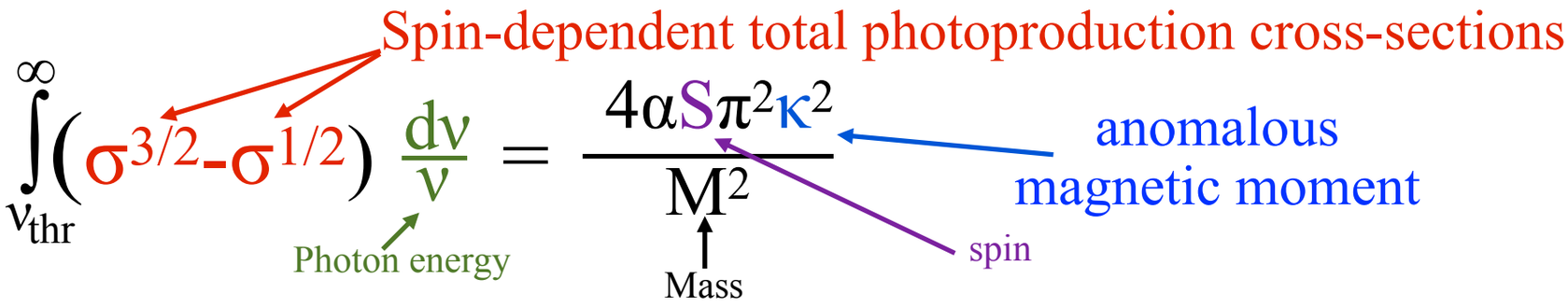

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Apparent failure possible due to finite upper integration limit ($\nu_{max} \neq \infty$) if unknown physics/dynamics above ν_{max} (e.g., quark substructure).

⇒ Sum rule: constrain high-energy phenomenology with lower energy measurement.

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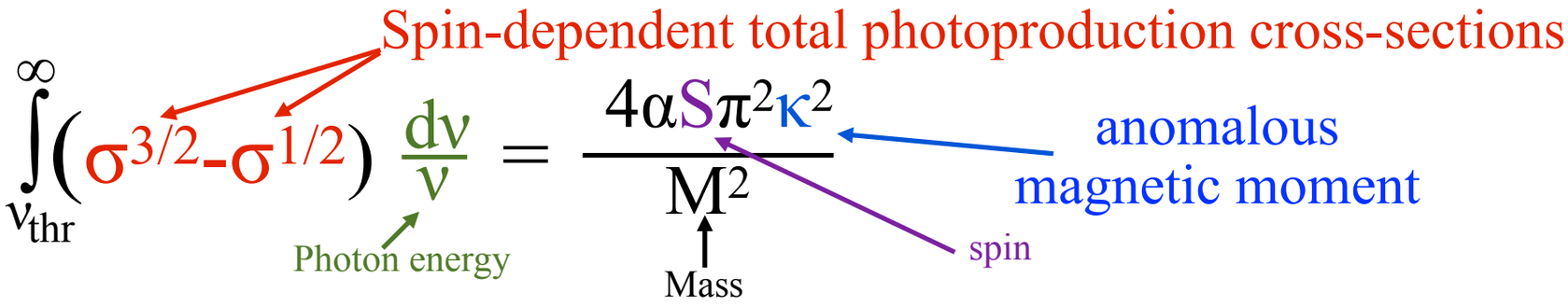

$\sigma^{3/2}-\sigma^{1/2}$ interesting on its own: $\vec{\gamma}$-$\vec{N}$ interaction unknown at large ν. Should follow Regge theory but photo- and electro-production data conflict with Regge expectation.

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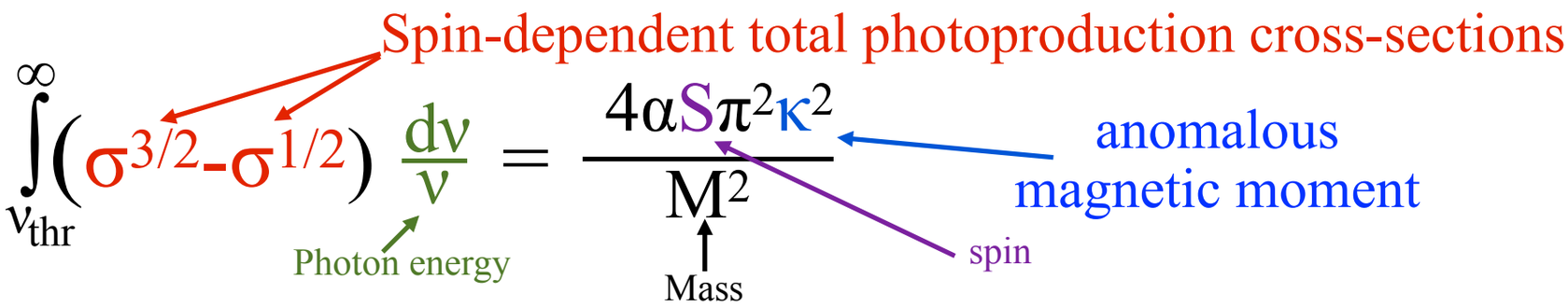

Large ν behavior critical, yet there are no data:

- Proton: $\nu < 3$ GeV.
- Neutron: $\nu < 2$ GeV.

Unique opportunity to gather such data in Hall D: tagger + large solid angle detector + high γ flux.

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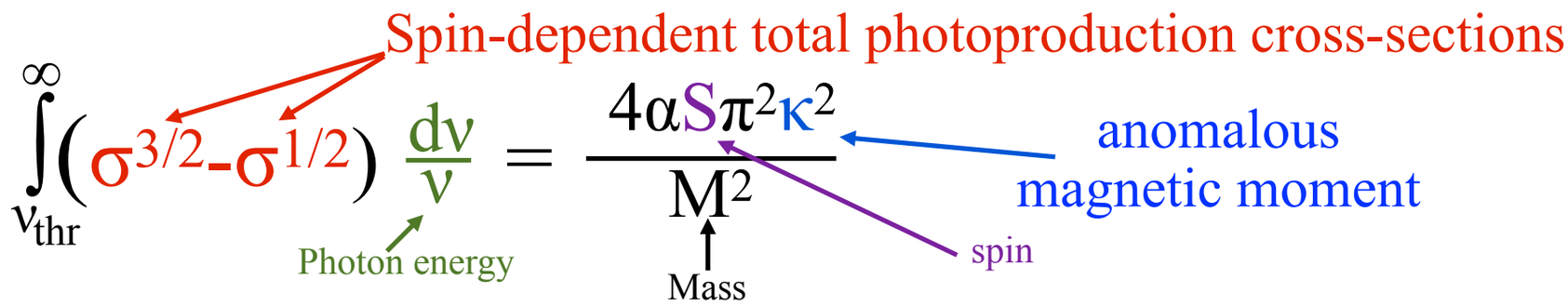

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Simple experiment and analysis: relative measurement (main goal: ν-dependence. Yield measurement sufficient. No backgrounds).

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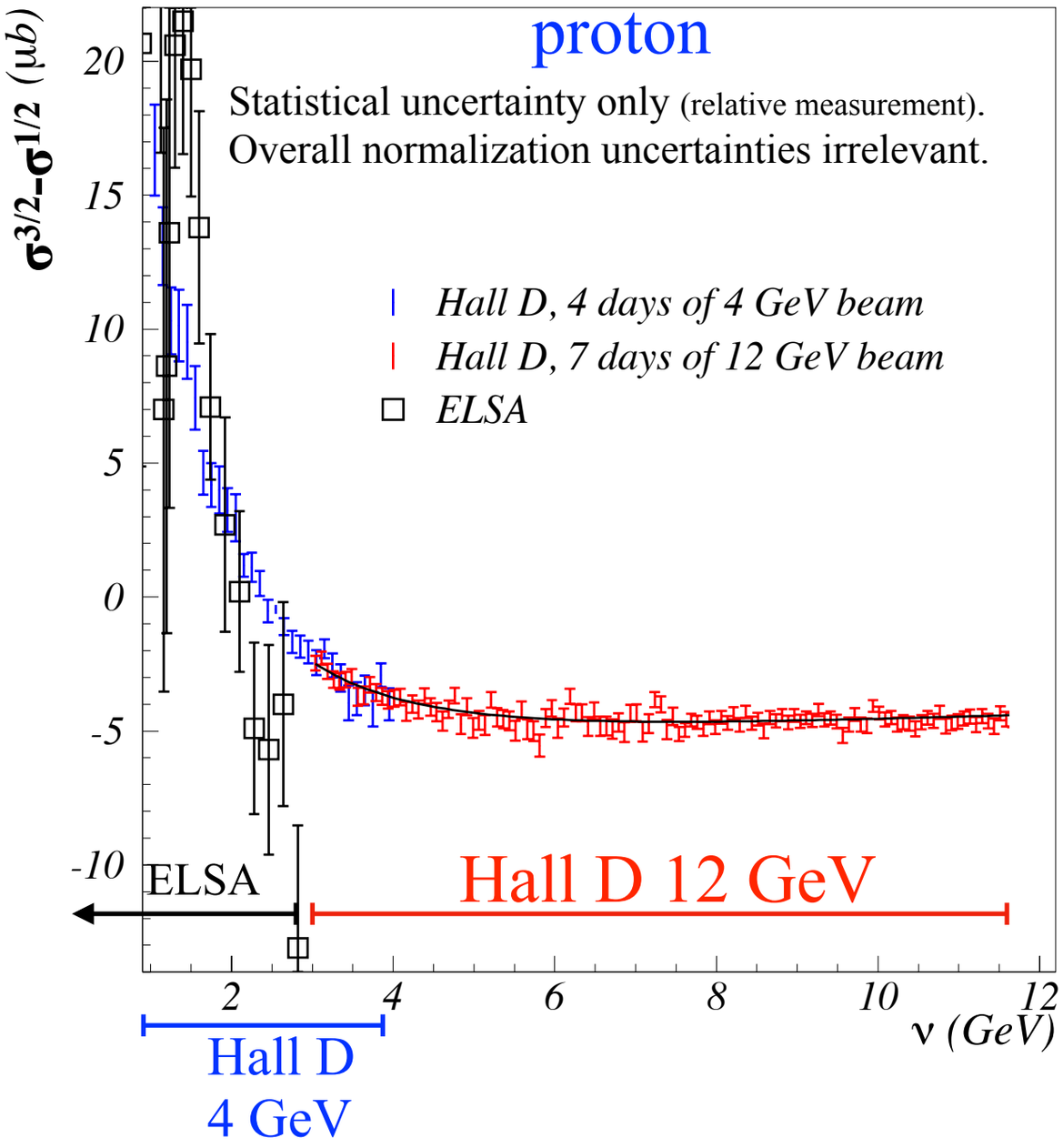
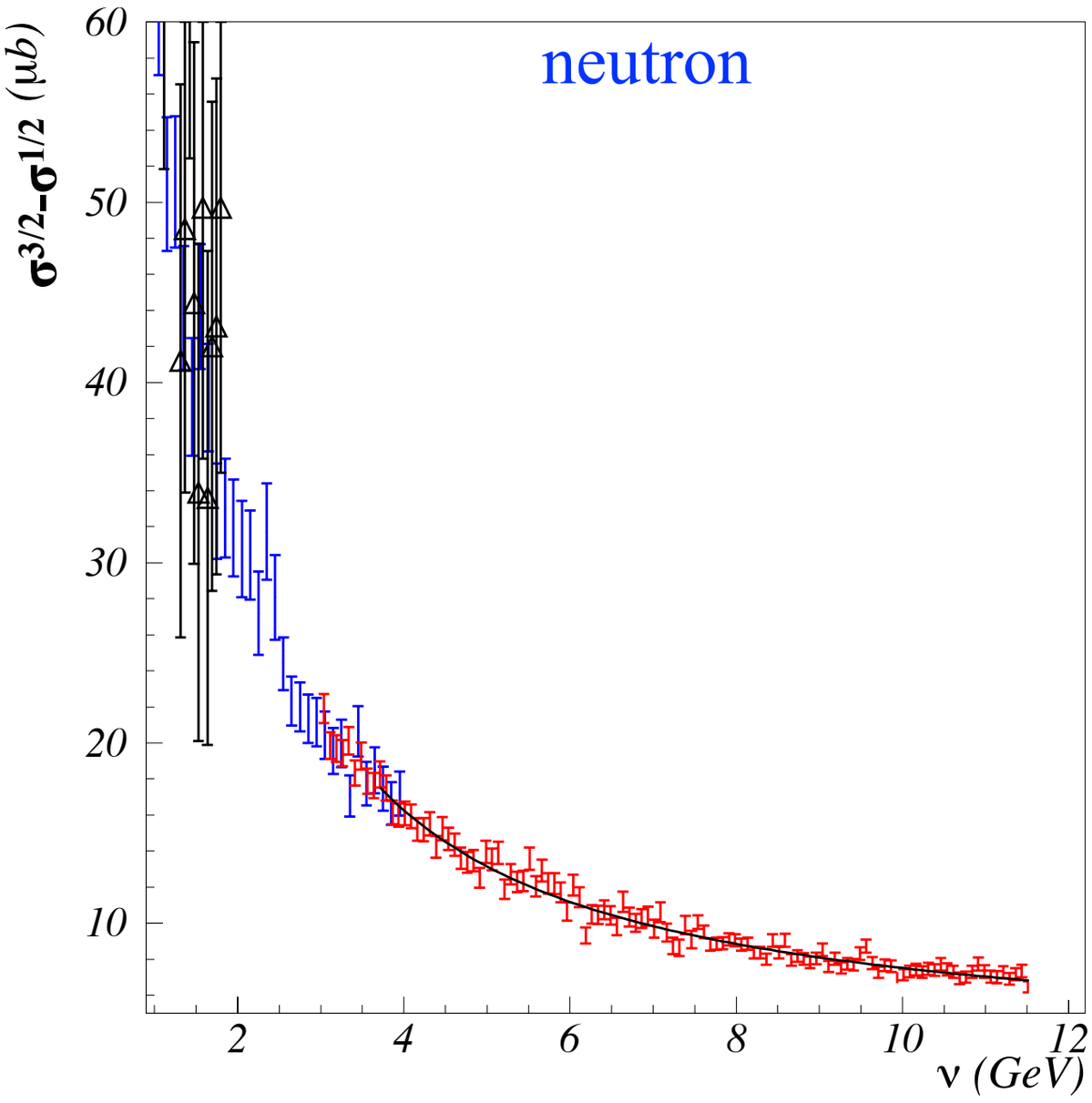
Expectations for REGGE

Simulated data





- Precision: greatly improve over world data.
- Much extended energy reach: extend ν coverage by factor 4 for proton and 7 for neutron/deuteron
- low energy run: overlap with world data + bridge gap for neutron data.

Motivations (2020 proposal)

Knowledge of large ν behavior is critical, yet, no data there:

- Proton: ν < 3 GeV.
- Neutron: ν < 2 GeV.

- Large-ν uncertainty dominates proton GDH test. No test on neutron yet.

- Regardless of the sum rule considerations, it is an important domain to explore:
  - First Regge theory test in polarized case: need to go beyond the resonance bumps.
  - Extract spin-dependent Compton amplitude f_2. Test of Chiral Perturbation Theory.
  - Non-zero polarized deuteron signal not seen yet at large ν or in the diffractive domain.
  - Discrepancy between Regge expectation and DIS and low-ν data.
  - Q^2=0 baseline for EIC diffractive studies.
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New results for $\nu \lesssim 2$ GeV from Hall A & CLAS data (proton, neutron, deuteron, ^{3}He and p-n.)*:

- $0.03 \leq Q^2 \leq 1$ GeV^2. $Q^2 \to 0$ extrapolation provides $\nu < 2$ GeV.
- With Regge model for $\nu \gtrsim 2$ GeV, $Q^2 \to 0$ data yields:

Target	JLab ($Q^2 \to 0$)	GDH-SR	Agreement
Proton	$203.1 \pm 10.7\,\mu$b	$204.9(0)\,\mu$b	$0.2\,\sigma$
Neutron	$275.9 \pm 33.1\,\mu$b	$232.5(0)\,\mu$b	$1.3\,\sigma$
Deuteron (w/o q-el.)	$438.8 \pm 14.5\,\mu$b	$400.6(6.6)\,\mu$b	$1.8\,\sigma$
Isovector nucl.	$81.3 \pm 16.0\,\mu$b	$27.6\,\mu$b	$3.3\,\sigma$

Isovector sector: Δ cancels ⇒ large high-ν contribution

⇒ 3.3σ: likely from inaccurate estimate of the unmeasured high-ν part.

*
K. P. Adhikari et al. PRL 120 6 062501 (2018)
V. Sulkosky et al. PLB 805 135328 (2020)
X. Zheng et al., Nature Phys. 17 6 736 (2021)
A. Deur et al. PLB 825, 136878 (2022)
A. Deur et al., PRC 111 3, 035202 (2025)

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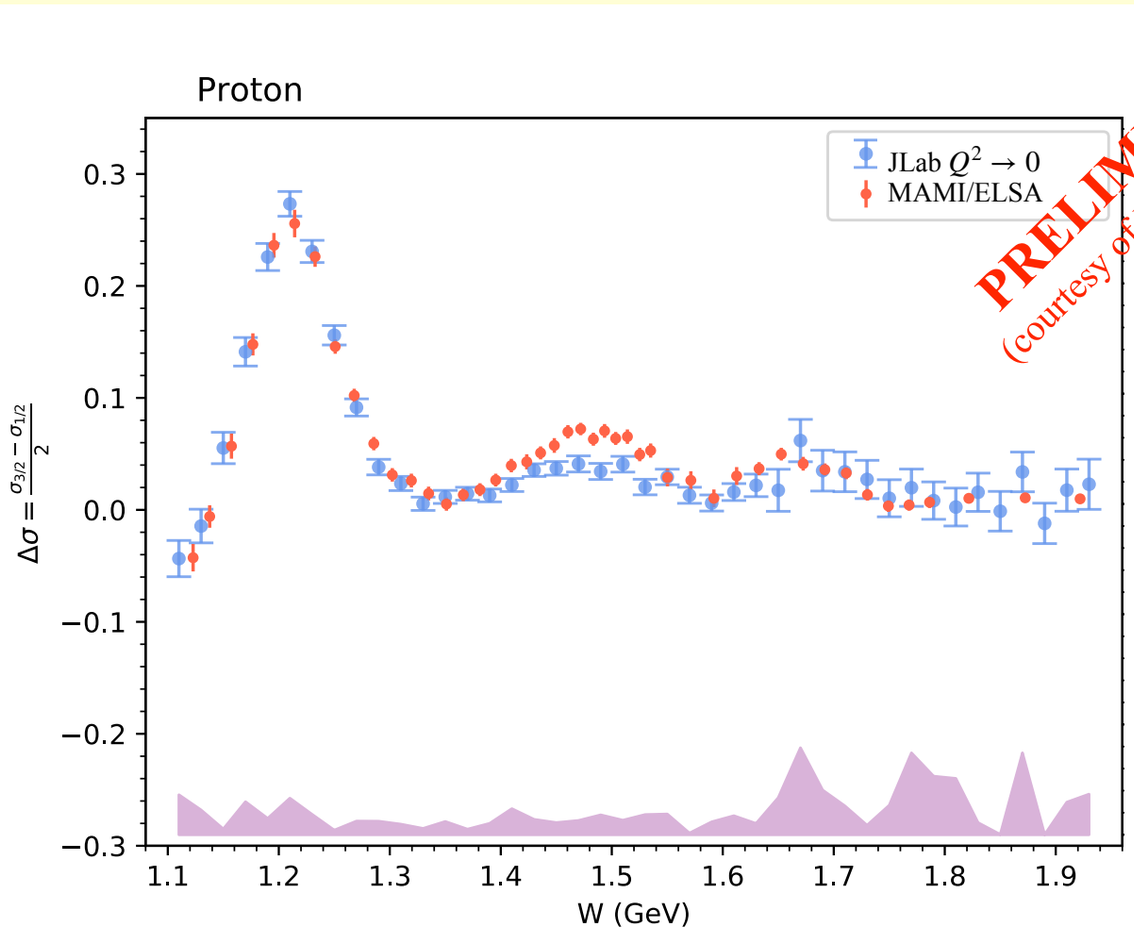
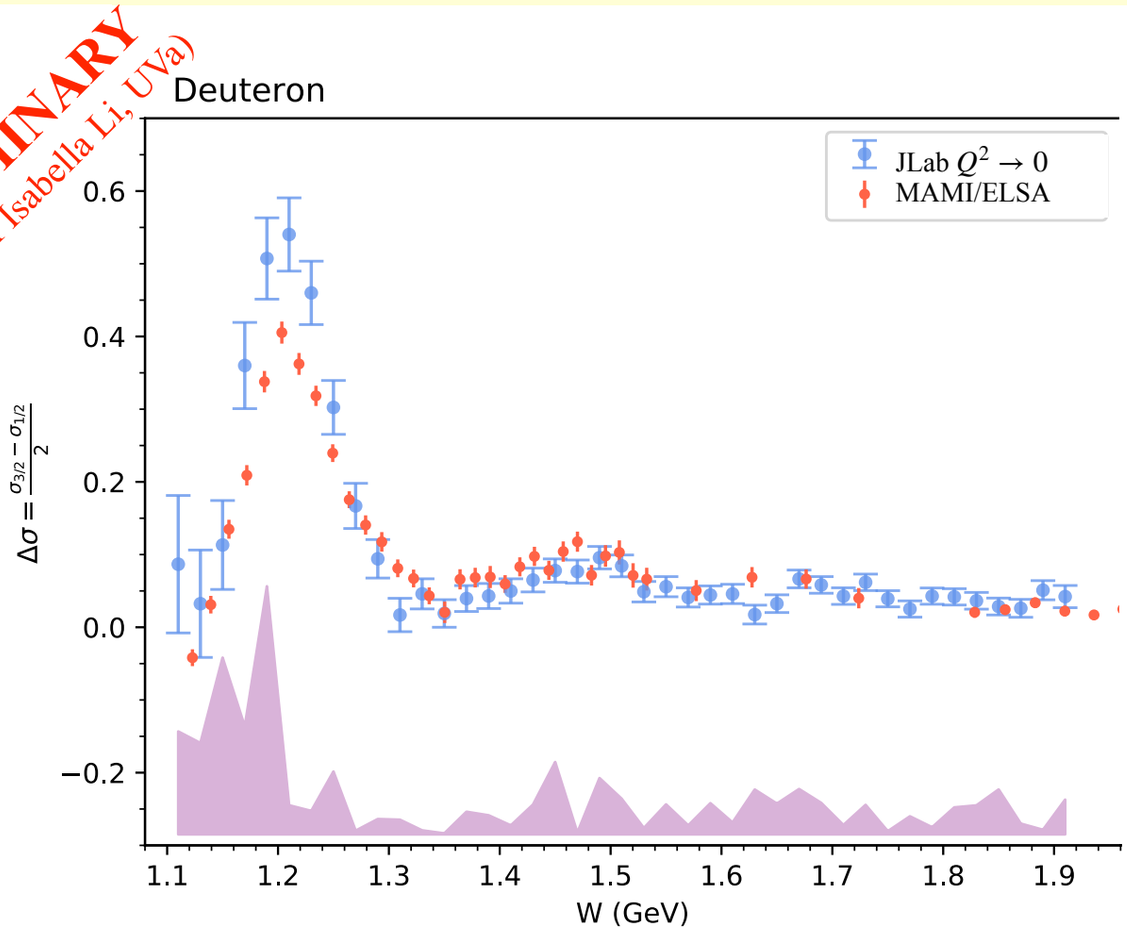


PRELIMINARY (courtesy of Isabella Li, UVa)



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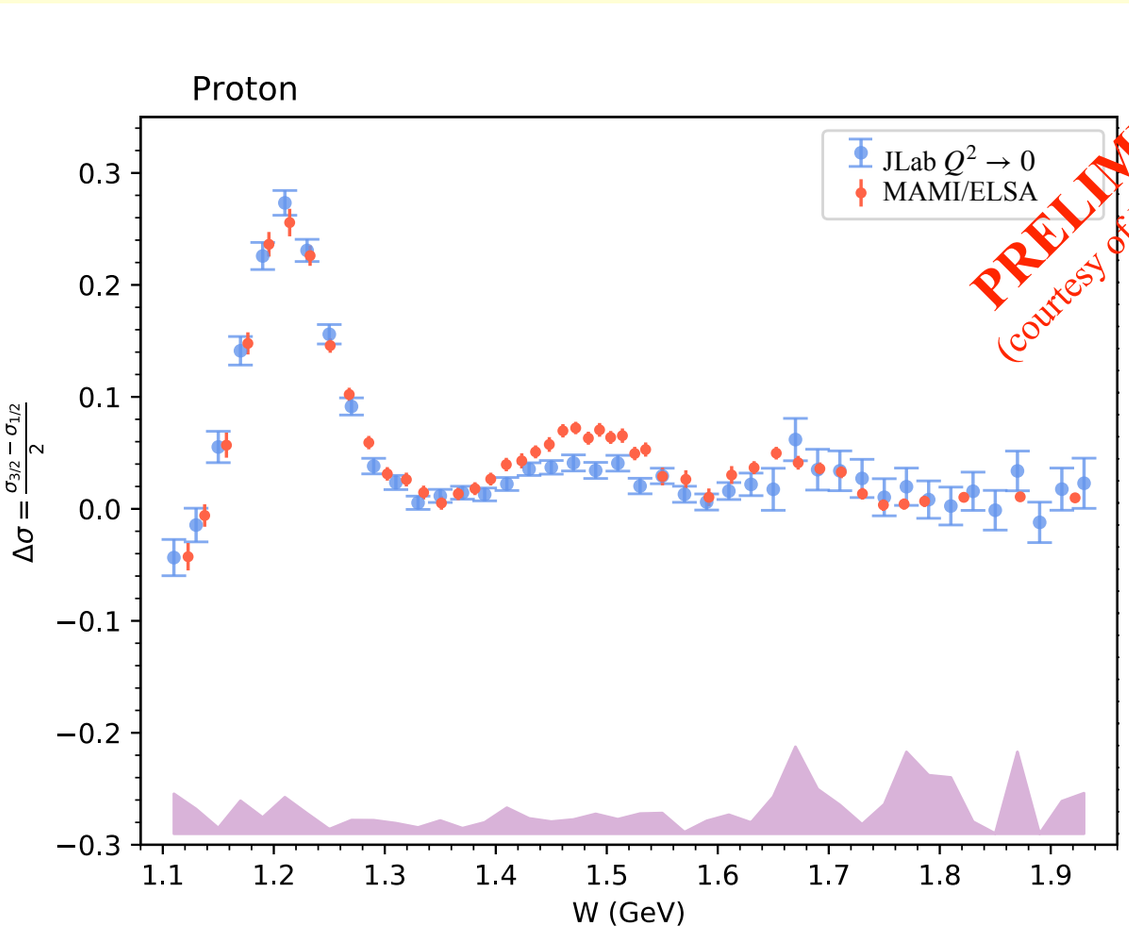

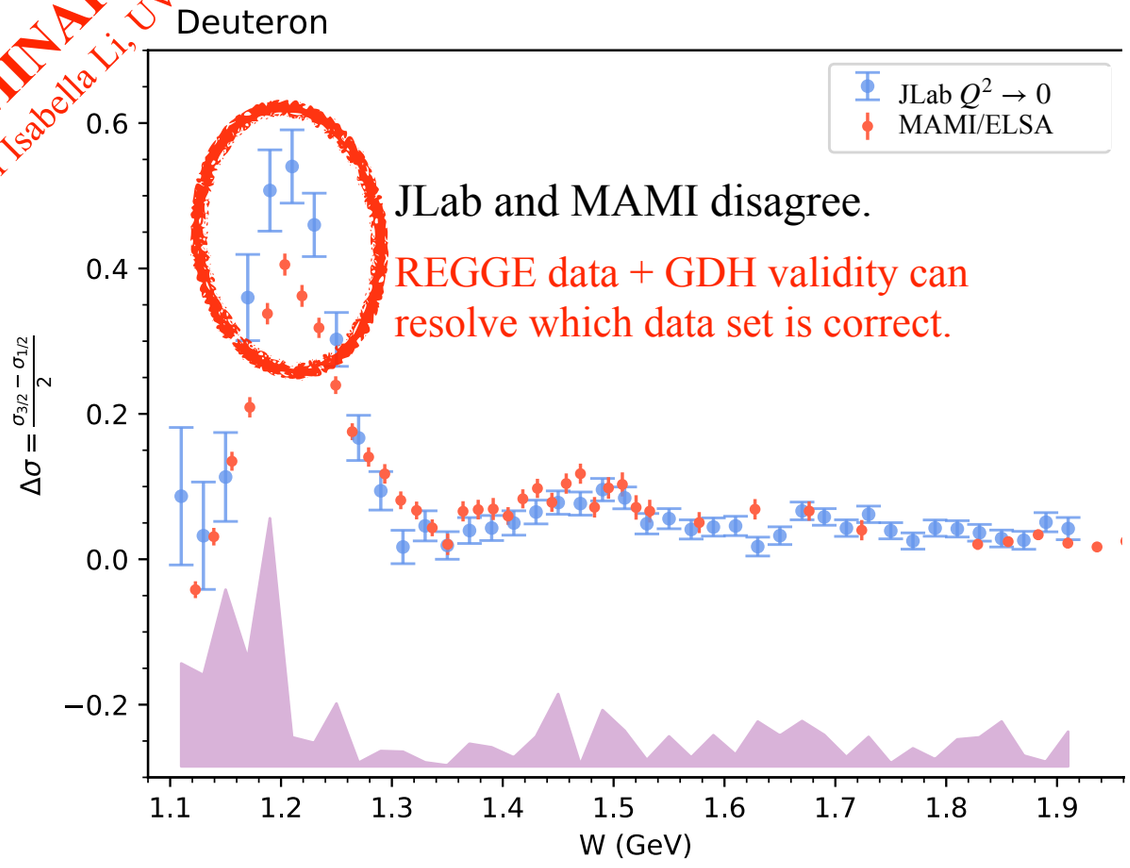

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This is not an issue for REGGE for the following reasons.

- Polarization drift from variations at the source can be monitored by other halls or by accelerator (Mott polarimetry). Also, such drifts over the relatively short timescale of REGGE have been very small.
- The Polarization change from beam energy drift modifying spin precession into Hall D: we precisely and continuously monitor beam energy with two independent devices*.

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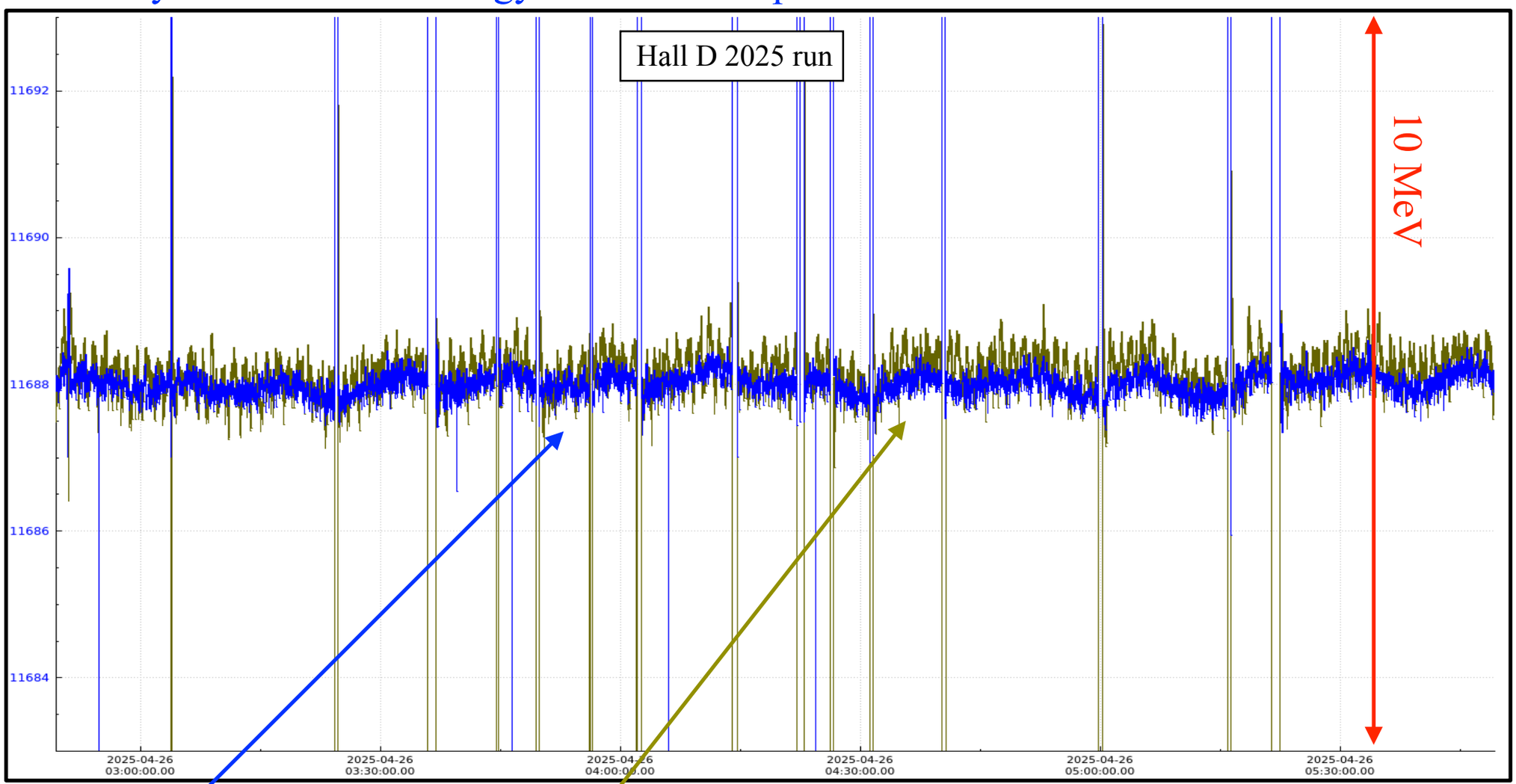

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The experiment will strongly benefit from running at an energy < 6 GeV […] *A potential problem at low energies is the calibration of the magnets in the Hall D beam extraction line.* […] *Such running of Hall D has not been tested yet.*

- 2026: low energy program. PR12-25-005 proposed to run at that time. (If not, test runs can be conducted). Will solve any possible issues before REGGE's run.

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Hall D and JLab's Target Group have formed a collaboration with the University of Tennessee-Knoxville (research group of Nadia Fomin).

- JLab's Target Group: conceptual target design. Construction and testing.
- Univ. Tenn.-Kn.: final design, engineering and personnel training.

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    - PAC 48:
      - REGGE (approve 33 days, A^-)
    - PAC 51:
      - LOI-12-23-004: *A measurement of double polarization photoproduction on various nuclei.*
    - PAC 52:
      - LOI-12-24-001: *Hadron spectroscopy with a polarized target at GlueX in Hall D - From the strange to the charm sector*
    - PAC 53:
      - PR12-25-005: *High precision measurement of ϕ-nucleon cross section and tensor asymmetry with a tensor polarized deuteron target*

    2024: Workshop on physics with polarized target in Hall D (white paper: arXiv:2407.06429.)

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Ex.: the JLab $^3\overrightarrow{\text{He}}$ polarized target program:

- Target built for E94-010.
- All other $^3\overrightarrow{\text{He}}$ experiments* were proposed *after* the target was built (1997).
- The JLab $^3\overrightarrow{\text{He}}$ target enabled an extremely successful program. As of now:
  - 17 approved experiments** in addition to E94-010;
  - 40 peer-reviewed articles, totaling about 3000 citations.

*With exception of E95-001, which was approved (B rated) as an addition to E94-010's run.

** E95-001, E97-110, E97-103, E99-117, E01-012, E02-013, E06-010, E06-014, E08-005, E12-06-110, E12-06-121, E12-09-014, E12-09-018, E12-10-006, E12-11-007, E12-11-108.

Summary

- The original motivations of REGGE remain, as only JLab can make such study.

- REGGE:
  - Endorsed and supported by the GlueX collaboration.
  - High scientific rating (PAC48);
  - Short and low-demand running time;
  - Uses mature, low-risk technologies (including the target);
  - Moderate equipment costs ($600k when REGGE was proposed, ~$1M in 2025);
  - Robust (relative quantity, no backgrounds) and easy (⇒ fast) analysis with guaranteed scientific impact;
  - Open new possibilities in Hall D.

- Recent GDH data at $Q^2 \to 0$ from JLab ($\nu \lesssim 2$ GeV):
  - Complement REGGE coverage.
  - Tensions (isovector, neutron and deuteron GDH; MAMI vs JLab) underline the need for high-ν data.

- Electron beam helicity recording now available in Hall D.

- Polarized target: collaboration with external polarized target experts has been formed.

- We looked into extending the Hall D polarized target program (Proposal/LOI submitted to PACs).

- We hope that the jeopardy of REGGE can be the occasion to prioritize more the building of the target.

$$\int_{\nu_{thr}}^{\infty}(\sigma^{3/2}-\sigma^{1/2})\,\frac{d\nu}{\nu}=\frac{2\alpha\pi^2\kappa^2}{M^2}$$

Thank you

REGGE one-slide summary

$$\int_{\nu_{thr}}^{\infty}(\sigma^{3/2}-\sigma^{1/2})\,\frac{d\nu}{\nu}=\frac{2\alpha\pi^2\kappa^2}{M^2}$$

- First measurement of the high-ν behavior of GDH integrand $(\sigma^{3/2}-\sigma^{1/2})/\nu$
- Hall D + FROST-D target (H and D) + polarized electron beam on Diamond radiator not required.
- Hall D is uniquely suited for such measurement.
- High-ν is where a failing of the sum rule would be revealed.
- Analysis first step: map yield difference $N^{3/2} - N^{1/2}$ for proton and neutron. This will elucidate the convergence of GDH integrals.
  - Point-to-point correlated errors cancel.
  - Unpolarized background cancel.
- 21-days 12 GeV measurement provides α_{f1} and α_{a1} at 2% level (present uncertainties: 50%)
- 12-days at 4 GeV bridge gap between 12 GeV and low energy data. Data overlap: much improved precision + cross-check of experiments.
- Solve discrepancy between DIS data and Regge theory prediction.
- Provide first non-zero data on $\sigma^{3/2}-\sigma^{1/2}$ at high-ν for the deuteron.
- Analysis second step (regardless of the convergence and sum rule validity):
  - Verify proton GDH sum rule within 6%. Verification of neutron GDH sum rule.
  - Allow extraction of complex Compton amplitude f_2 and new test of Chiral Perturbation Theory.
  - Improve knowledge of atomic hyperfine splitting.
  - Polarized diffractive scattering phenomenology essentially unknown. $Q^2=0$ baseline for g_1 for EIC.

  $\Longrightarrow$ study of the transition between DIS and diffractive regimes.
- Once Hall D has a polarized target, a rich program opens. Sensible to initiate it with simplest experiment and a robust observable.

Motivations 2025 update

C. Keppel's charge#1: Is there any new information that would affect the scientific importance or impact of the Experiment since it was originally proposed?

Knowledge of large ν behavior is critical, yet, no data there:

- Proton: ν < 3 GeV.
- Neutron: ν < 2 GeV.
- Large-ν uncertainty dominates proton GDH test. No test on neutron yet.

Still no available data: JLab is the only facility where such data can be acquired.

New $\nu \lesssim 2$ GeV data at low Q^2:
⇒ **Accrued need for the REGGE data.**

- Reliable Regge fit: need to go beyond the resonance bumps.
  - Check Regge theory for the first time in the polarized case,
  - Reliable basis for ν→∞ extrapolation.

No changes. The facts remain

- Hall D's 3-12 GeV range: extend ν coverage by factor 4 for proton and 7 for neutron/deuteron.
  - Sensitive domain for sum rule violation; smooth cross-section allows Regge-based fit.
  - Regardless of the sum rule considerations, it is an important domain to explore:
    - Extract spin-dependent Compton amplitude f_2. Test of Chiral Perturbation Theory.
    - Non-zero polarized deuteron signal not seen yet at large ν or in the diffractive domain.
    - Discrepancy between Regge expectation and DIS and low-ν data.
    - Q^2=0 baseline for EIC diffractive measurements. Study transition between DIS and diffractive regimes.
    - Constraint on hydrogen hyperfine splitting.

Collaboration

C. Keppel's charge#3: What is the status of the collaboration in terms of institutes, committed staff and prospective students?

Collaborations:

- Endorsement and continued support of the GlueX collaboration.
- Target: collaboration with the University of Tennessee-Knoxville (weekly meetings).

Staff:

- All Hall D Staff part of GlueX collaboration. Also, M. Dalton and A.D. among REGGE's spokespersons.
- JLab Target Group: Started conceptual design. Waiting for Management's green light for further commitment.

Students:

- Ph.D. students:
  - Experimental run & analysis: too early to recruit students (4 years of target construction). Expectations: students provided by the GlueX collaboration and by Univ. Ljubljana.
  - Target construction: waiting on funding (Univ. Tenn. Kn.).