Hall B Status Report

We were busy taking data with > 50 % Efficiency!

- News from Hall-B Group
- Status of Hall-B Operations
- Target Updates
- Recent Publications & Press Room

Covering the time since Nov. 2023

Patrick Achenbach
Mar. 2o24

News from Hall-B Group

New Hires & Open Position in Hall-B Group

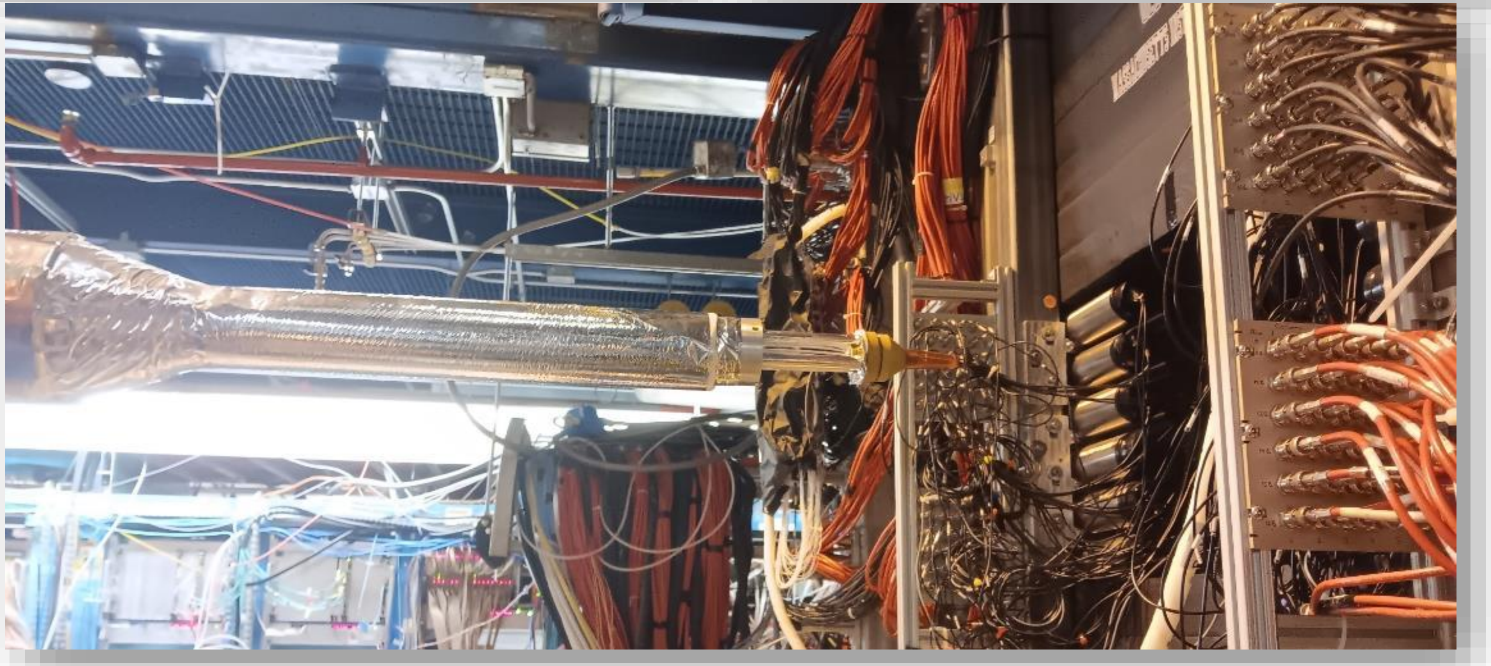
- Hall-B Postdoc **Richard Tyson** started in Nov 2023
  - J/ψ near threshold photoproduction of the proton and neutron (RG-A/B)
  - Development and deployment of an AI/ML level-3 trigger for CLAS12

- Hall-B Staff Scientist **Raffaella De Vita** started in Nov 2023
  - Development of offline CLAS12 software and common analysis tools
  - Scientific guidance and cooperation for CLAS12 experiments with higher-than-design luminosity

- 80%-LDRD, 20%-Hall-B Postdoc **Sara Liyanaarachchi** starts May 1, 2024
  (maiden name Sahara Jesmin Mohammed Prem Nazeer)
  - Developing a new high-rate micropattern gaseous detector for high-luminosity experiments
  - Sara has a PhD from Hampton University (supervisor Michael Kohl), > 8 years of experience in developing, handling, calibrating, and conducting QA for Gas Electron Multiplier (GEM) detectors
- 70%-SPF, 30%-Hall-B 2-year termed **Engineer II position** to be filled as soon as possible
  - Developing polarized material; design, construct, and commission cryogenic equipment
  - Interviews with candidates during this month

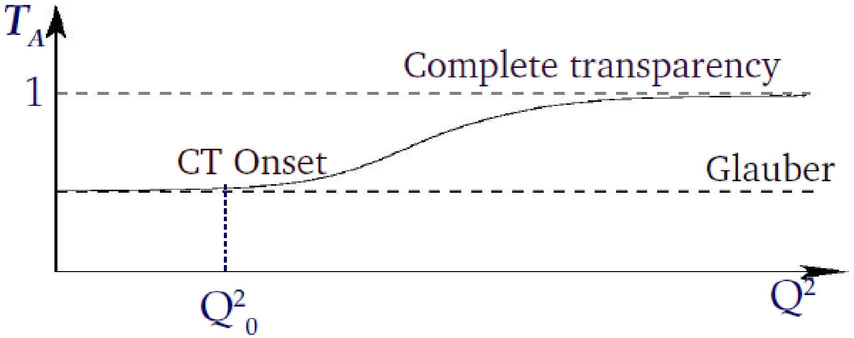
Status of Hall-B Operations

Cryo-Target Operation in Hall B



In operation since early Oct 2023

Run Group D

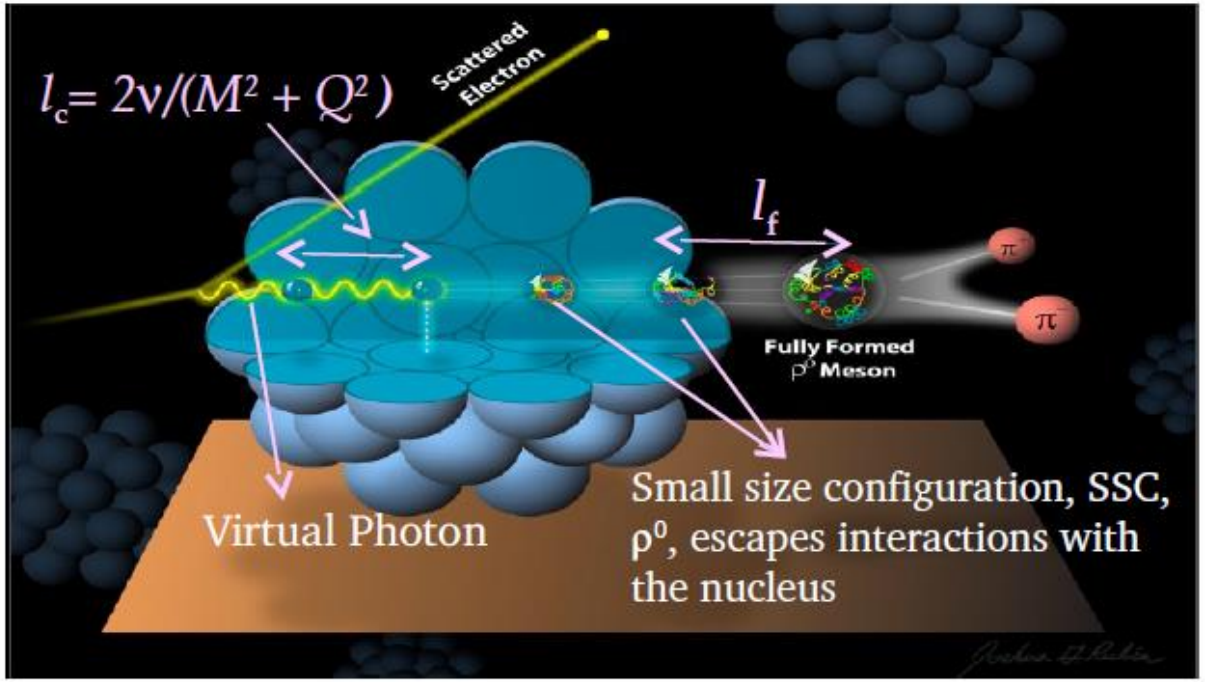


E12-06-106: Study of Color Transparency (CT) in Exclusive Vector Meson Electroproduction off Nuclei

Spokespeople: W. Armstrong[1], L. El Fassi[3], K. Hafidi[1], M. Holtrop[4], and B. Mustapha[1]

E12-06-106A (endorsed by *PAC-48*): Nuclear TMDs in CLAS12

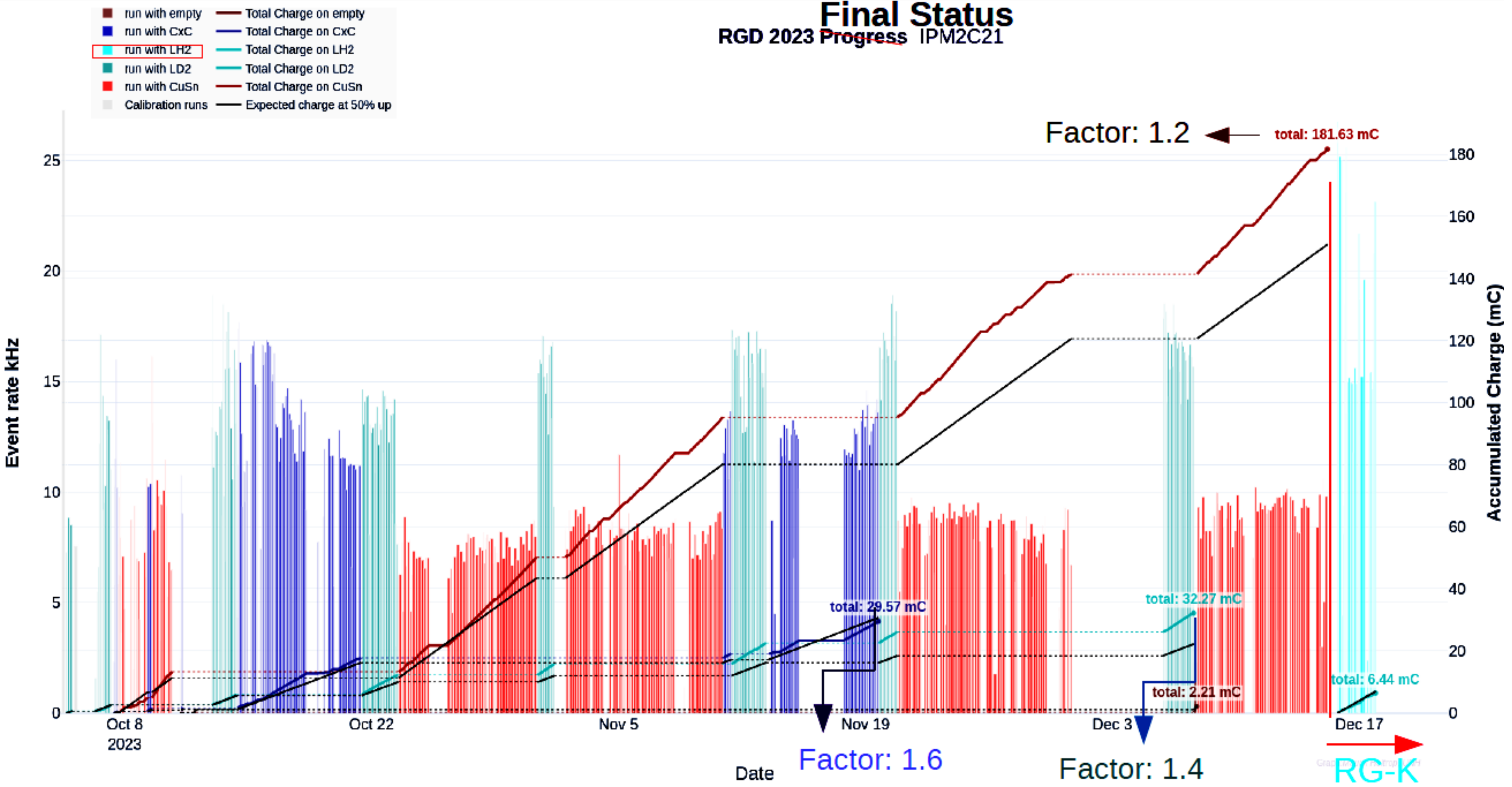
Spokespeople: R. Dupré[2], L. El Fassi[3], Zein-Eddine Meziani[1], and Holly Szumila-Vance[5]



- **10.5 GeV** polarized beam with CLAS12 (FT-OFF)
- Runs with **ℓD_2 and a nuclear target foil assembly**
- Study of **ρ^0-meson production** as a function of Q^2
- Extraction of **Color Transparency**
- **Nuclear TMDs** in CLAS12

Program is a continuation of CLAS 6-GeV

Run Group D Data-Taking Completion

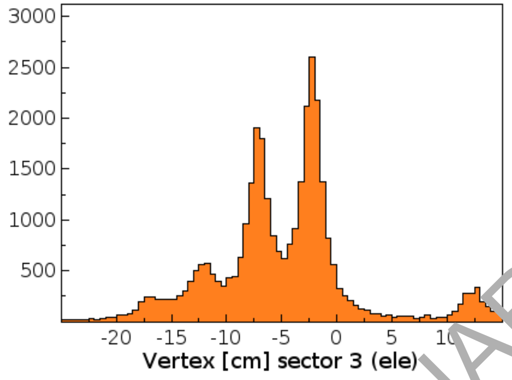


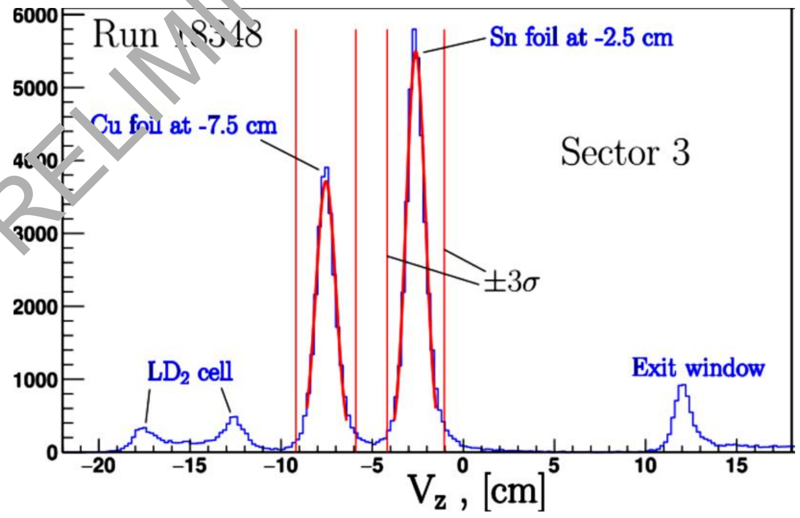
- RG-D was delayed by 10 days
- Ran from **early Oct to mid Dec = 75 calendar days (½ of extra time to compensate lower luminosity & ½ opportunistic)**
- **951 ABUs = 40 PAC days (40/75 > 50 % efficiency)**
- RG will not come back to Hall B
- Collected statistics on targets:
  - Cu x Sn foils: 182 mC
  - C x C foils: 30 mC
  - ℓD_2 cryo-target: 32 mC

- Three fast dumps of superconducting torus and solenoid magnets, **Faraday Cup failure**, 5 days of injector gun downtime, **Moller cone sagging**, several upsets of electronics/DAQ, etc.
- Acceptable beam current **limited by Central Tracking Detector**, requiring a longer-than-scheduled run
- After all, Run Group D collected **more production data than approved by PAC** (at Hall Leader’s discretion)

Run Group D Online Analysis

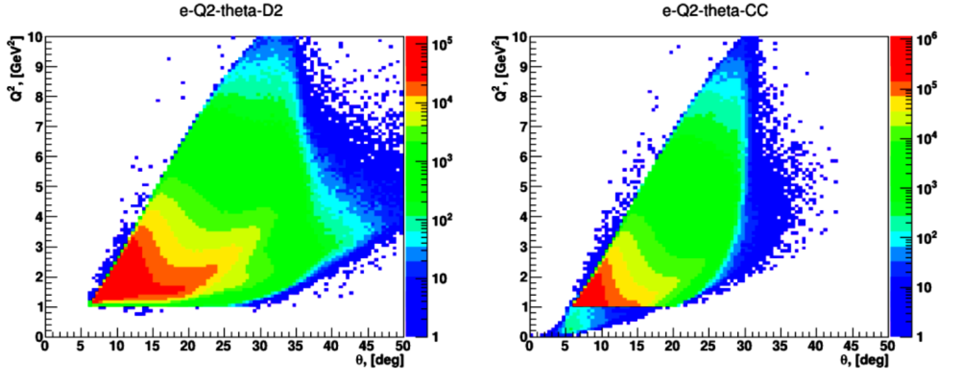
- First-ever use of **online reconstruction** in CLAS12
- Developed by Gagik Gavalian
- Very useful to **control targets** in *z*-vertex spectra



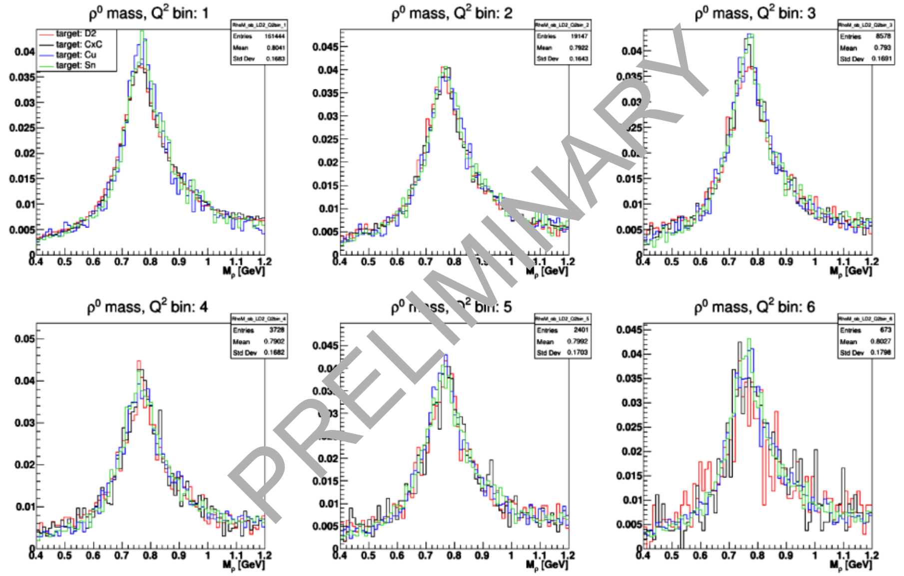


PRELIMINARY

- Covered **electron kinematics**



- **ρ-meson identification** in charged-two-π decays



PRELIMINARY

[Lamiaa El Fassi, Nov 2023]

Run Group K

HALL B
CURRENT
EXPERIMENT

This series of experiments focuses on understanding quark-gluon confinement through exploration of the structure of the ground and excited states of the nucleon.

E12-16-010
E12-16-010A
E12-16-010B
E12-16-010C

RUN GROUP K

E12-16-010:
A Search for Hybrid Baryons in Hall B with CLAS12
A. D’Angelo, V. Burkert, D.S. Carman, R. Gothe, V. Mokeev

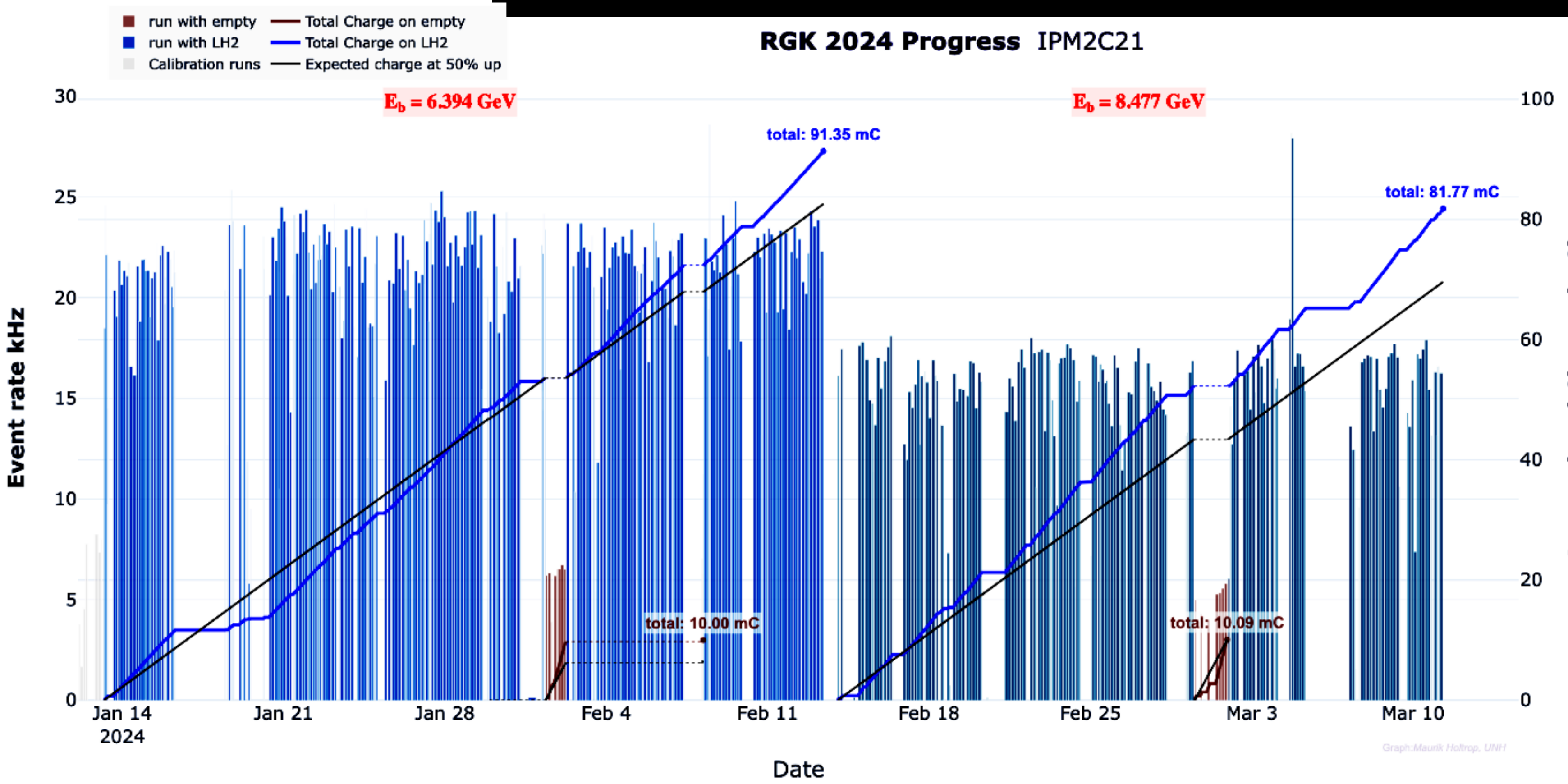
E12-16-010A:
Nucleon Resonance Structure Studies Via Exclusive KY Electroproduction at 6.6 GeV and 8.8 GeV
D.S. Carman, V. Mokeev, R. Gothe

E12-16-010B:
Deeply Virtual Compton Scattering with CLAS12 at 6.6 GeV and 8.8 GeV
L. Elouadrhiri, M. Defurne, F.X. Girod, F. Sabatie

E12-16-010C:
Separation of the σ_L and σ_T Contributions to the **Production of Hadrons** in Electroproduction
T. Hayward, H. Avakian

Program in part linked to RG-A, but at lower beam energy

Run Group K Data-Taking Completion

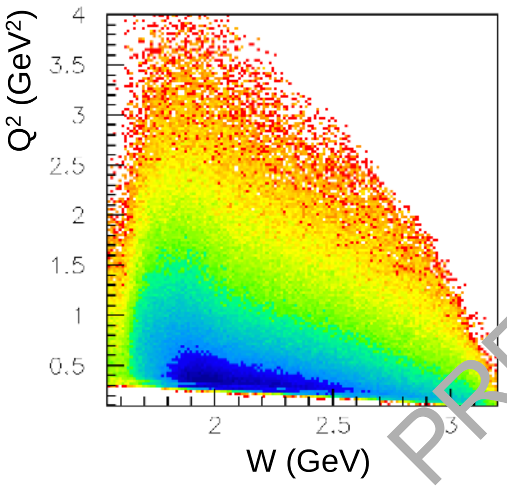


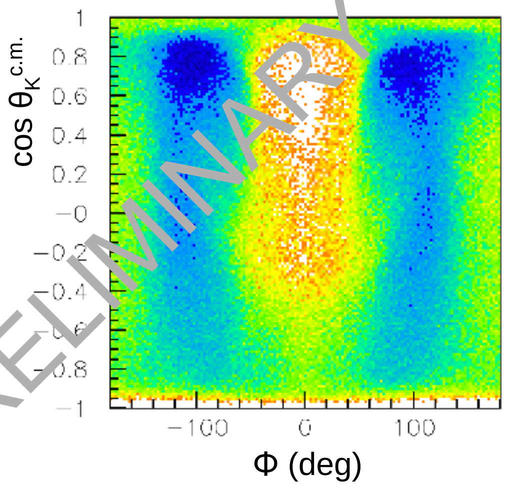
- RG-K **commissioned in Dec**
- Couldn’t start production before Win break due to Faraday Cup
- Ran **from mid Dec 2023 to yesterday = 60 calendar days**
- **887 ABUs = 37 PAC days**
- Collected statistics on ℓH_2:
  - 6.4 GeV: 91 mC
  - 8.5 GeV: 82 mC

- Issues with a **series of fast dumps** of superconducting torus and solenoid magnets
- Running at 6.4 GeV with **65 nA**, 13% less than design luminosity of CLAS12, i.e. $0.87\text{x}10^{35}$ cm^{-2}s^{-1}
- Running at 8.5 GeV with **75 nA** corresponding to **design luminosity of CLAS12**, i.e. $1\text{x}10^{35}$ cm^{-2}s^{-1}
- Run Group K has not only collected **large statistics of production data, but also many first-time empty target warm/cold alignment studies, trigger studies, DC HV and luminosity scans**

RG-K Online Analysis

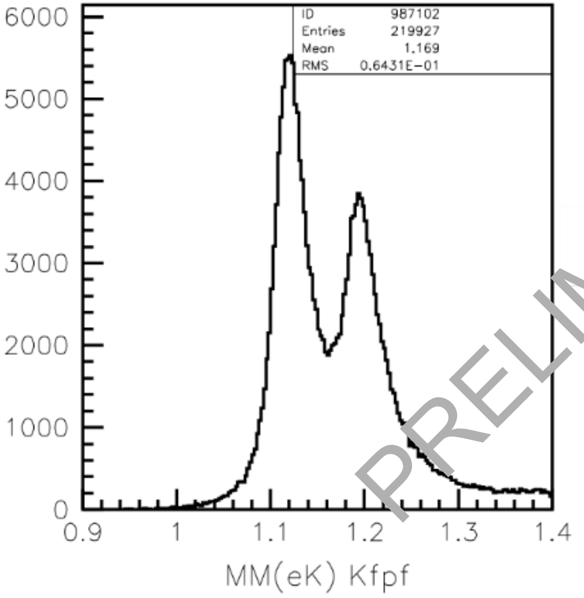
KY Analysis

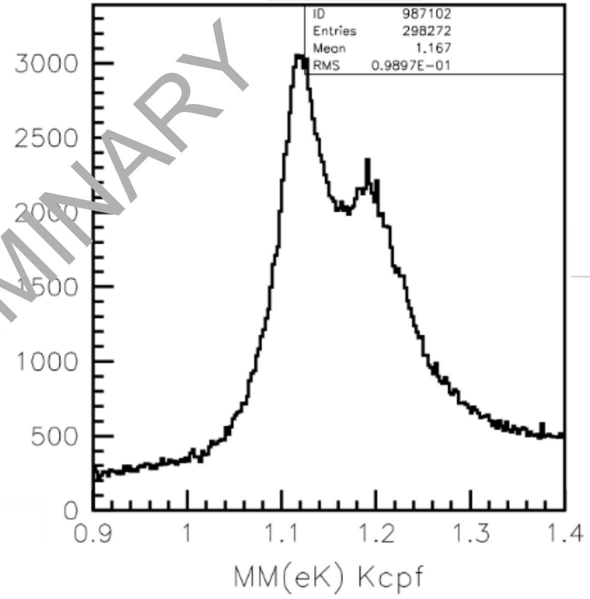




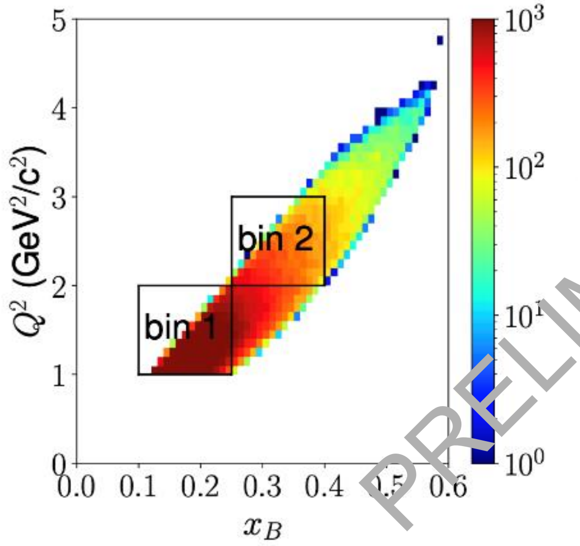
- 6.394 GeV
- 10 runs
- online calib/align

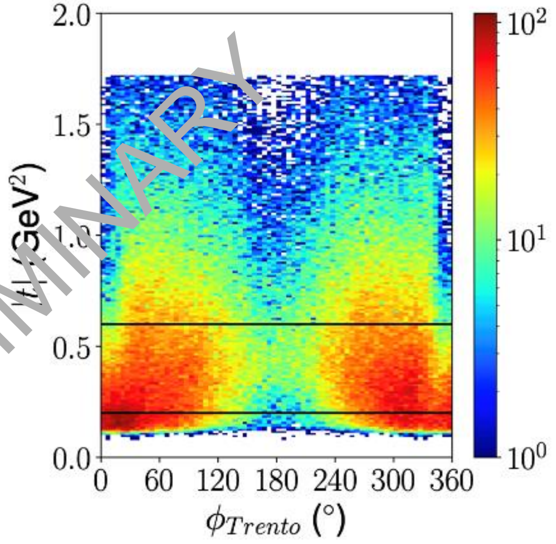
[Daniel Carman]





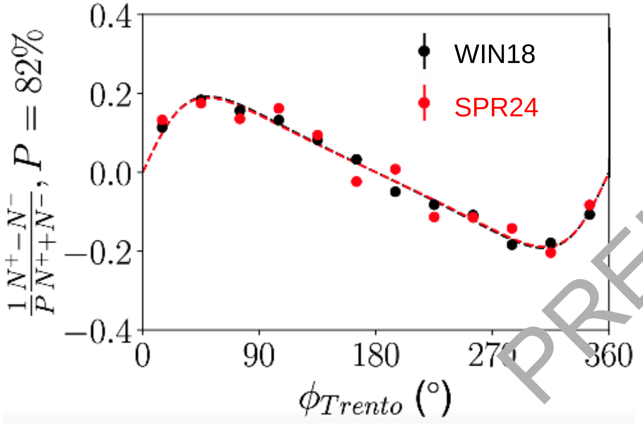
DVCS Analysis



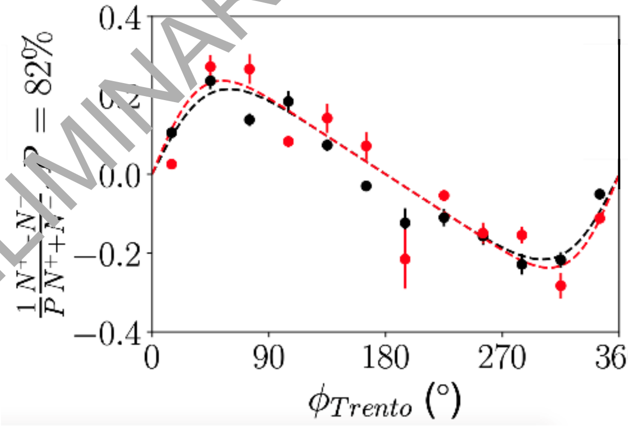


[Sangbaek Lee]

x_B [0.1:0.25], Q^2 [1:2] GeV², |t| [0.2:0.6] GeV²



x_B [0.25:0.4], Q^2 [2:3] GeV², |t| [0.2:0.6] GeV²



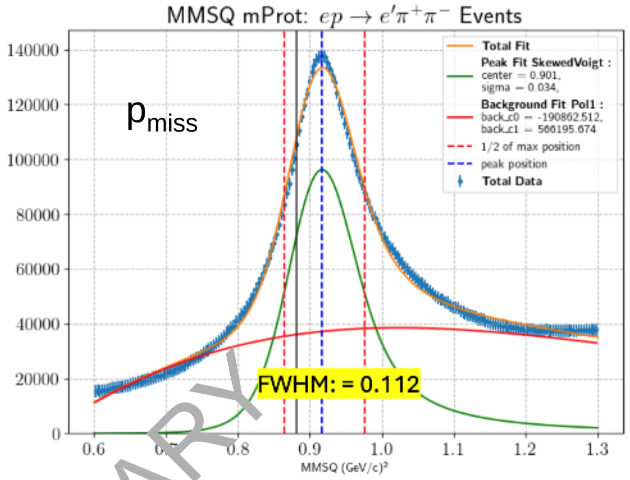
PRELIMINARY

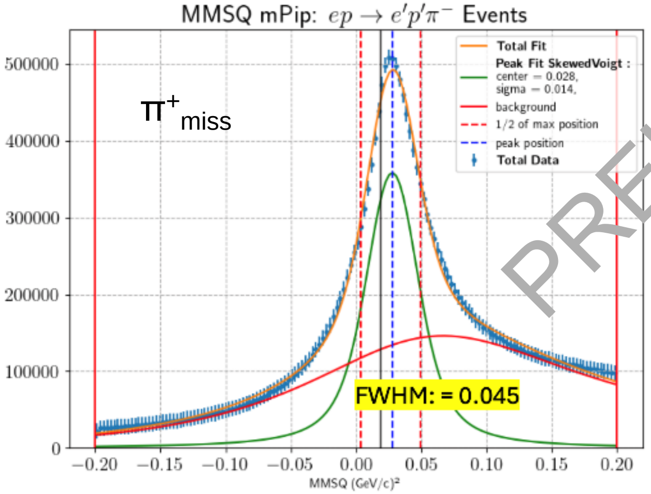
RG-K Online Analysis

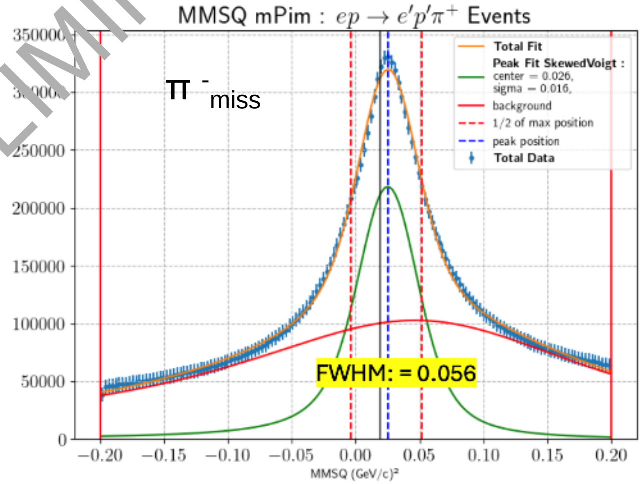
- 6.394 GeV
- 10 runs
- online calib/align

2π Analysis

[Krishna Neupane]

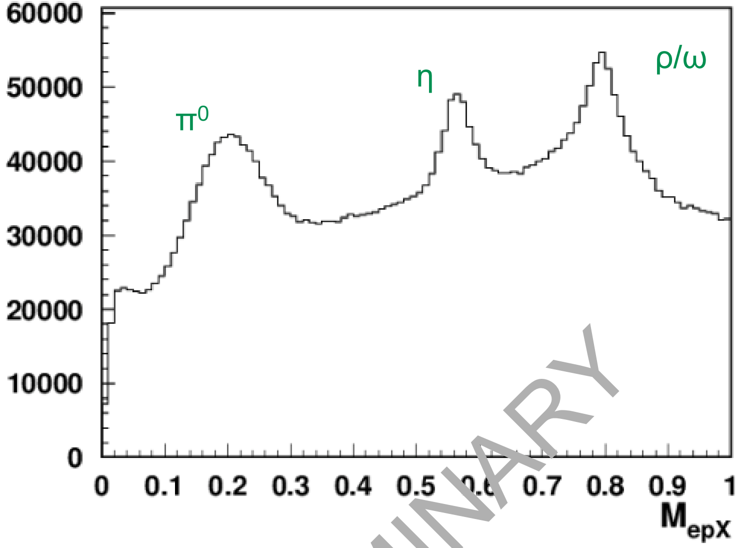


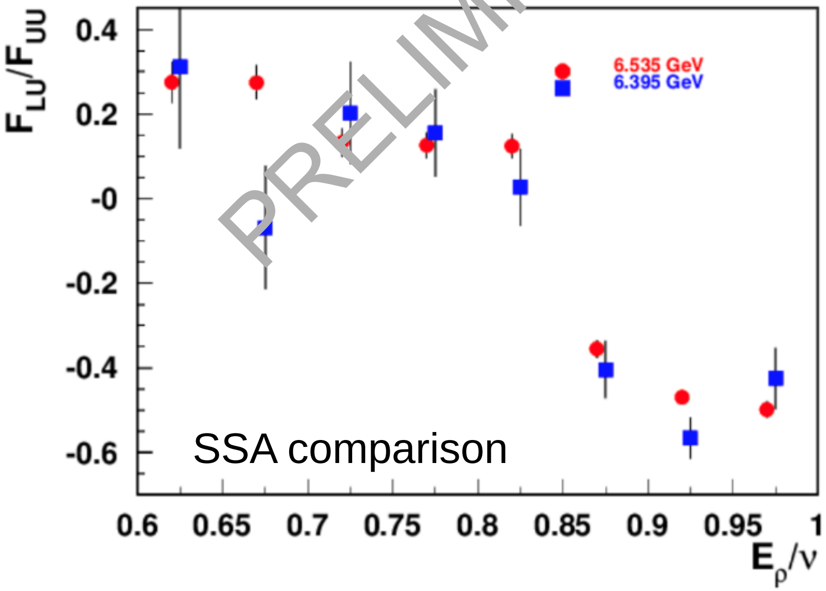




PRELIMINARY

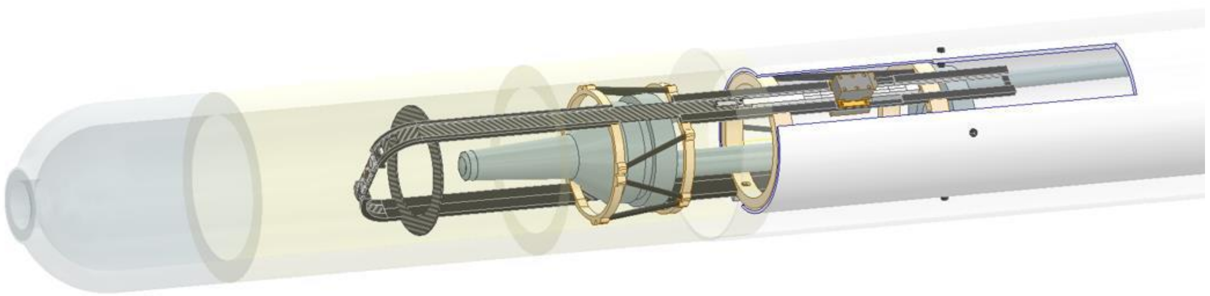
[Harut Avakian]

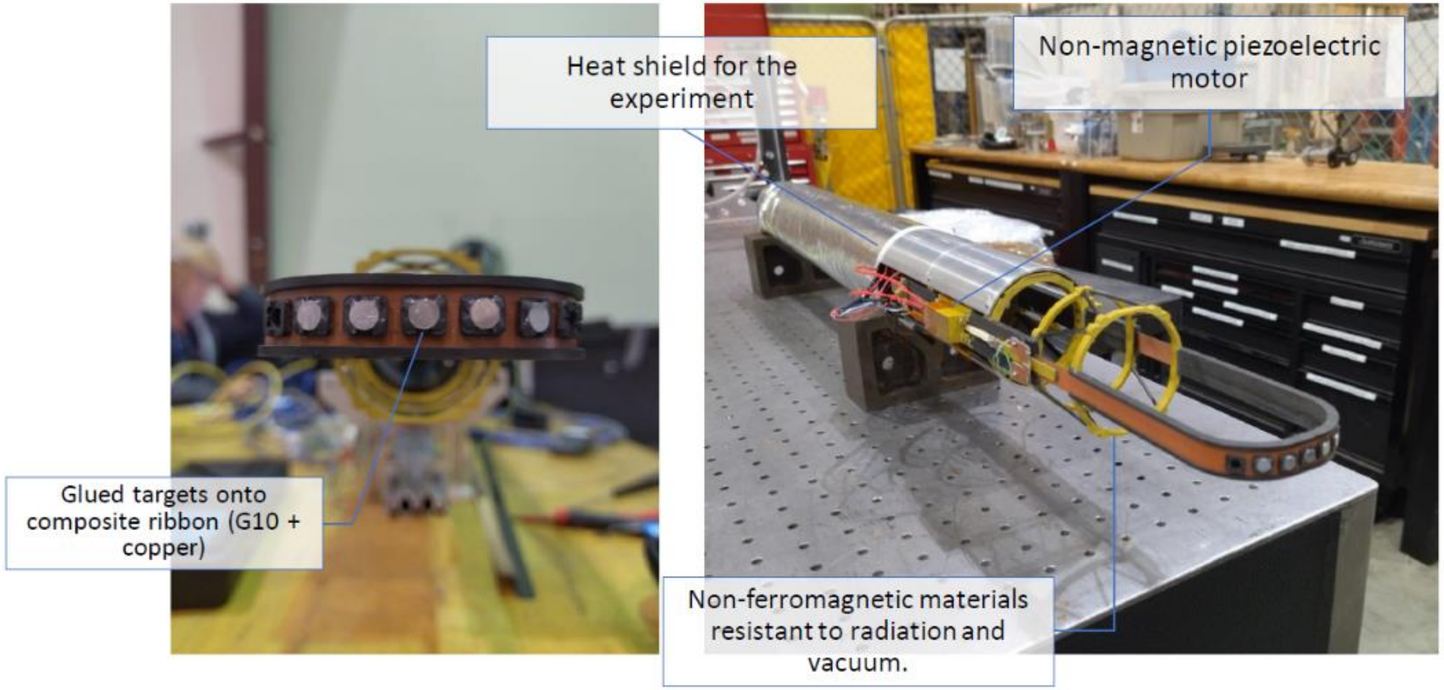




PRELIMINARY

Run Group E





Heat shield for the experiment

Non-magnetic piezoelectric motor

Glued targets onto composite ribbon (G10 + copper)

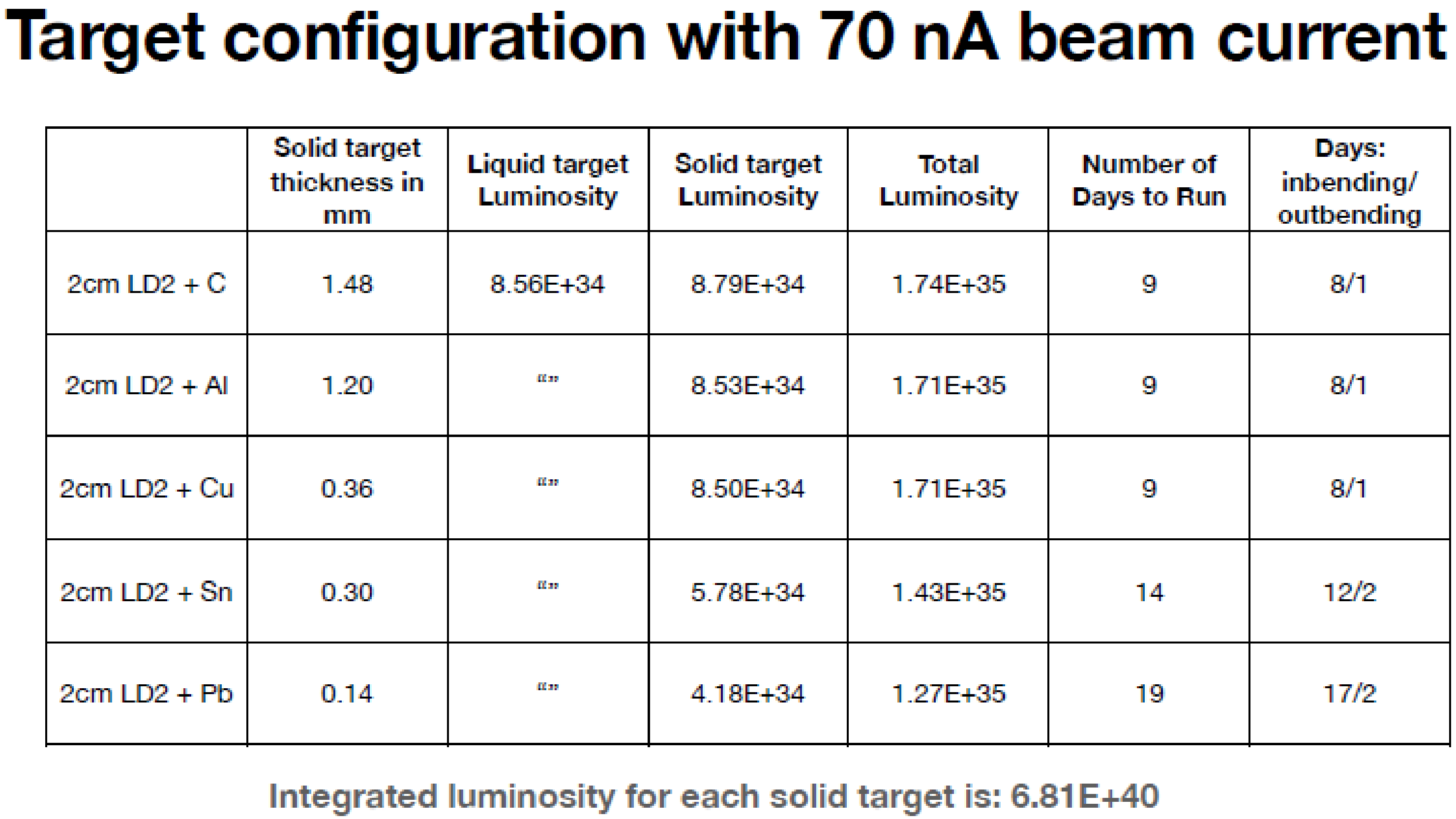
Non-ferromagnetic materials resistant to radiation and vacuum.

[Milan Ungerer, Nov 2023]

- Comprehensive study of impact of the **nuclear medium** on **quark hadronization**
- A multidimensional kinematical analysis of hadrons in DIS
- Carbon, aluminum, copper, tin, lead, and ℓD_2 **double targets**
- Target tests at JLab in Aug and Oct 2023

Change-over to RG-E this week

Run Group E Data-Taking



Target configuration with 70 nA beam current

	Solid target thickness in mm	Liquid target Luminosity	Solid target Luminosity	Total Luminosity	Number of Days to Run	Days: inbending/ outbending
2cm LD2 + C	1.48	8.56E+34	8.79E+34	1.74E+35	9	8/1
2cm LD2 + Al	1.20	“”	8.53E+34	1.71E+35	9	8/1
2cm LD2 + Cu	0.36	“”	8.50E+34	1.71E+35	9	8/1
2cm LD2 + Sn	0.30	“”	5.78E+34	1.43E+35	14	12/2
2cm LD2 + Pb	0.14	“”	4.18E+34	1.27E+35	19	17/2

Integrated luminosity for each solid target is: 6.81E+40

- RG-E **commissioning will take 4-8 days**
- Will run **from mid Mar 2024 to May 20 = 65 calendar days = 32.5 PAC days**
- Will possibly include some more streaming readout tests

[Haik Hakobyan, Mar 2024]

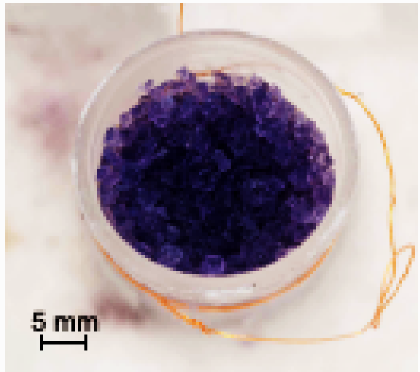
Target Updates From Chris Keith

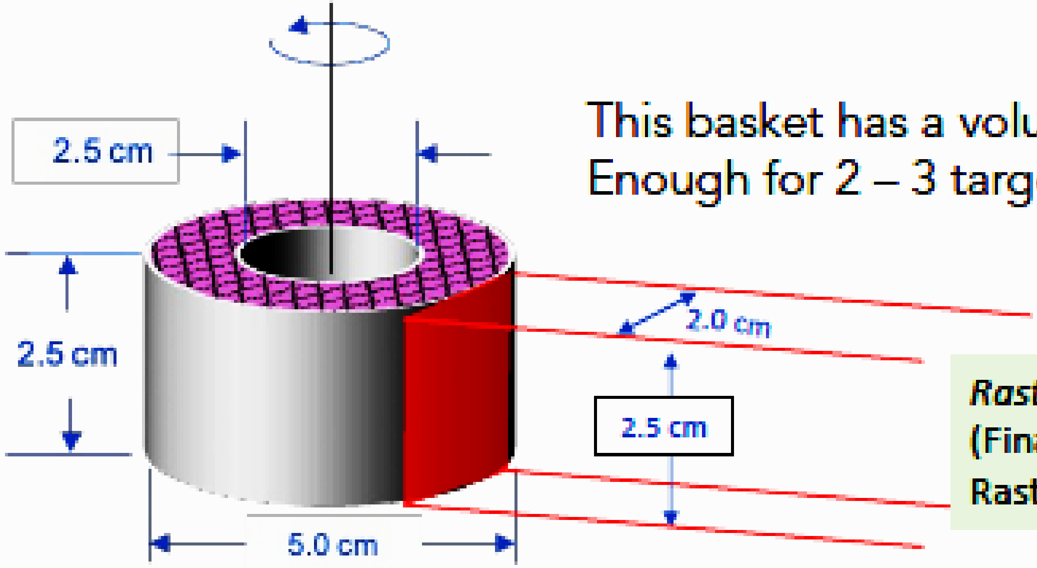
Irradiation of Polarized Target Materials

The irradiation will be done at the CEBAF injector (8– 10 MeV)

The typical dose on a sample for good polarization is ~ 10^{17} e-/cm^2

At 10 μA on a (2.5 x 5) cm^2 sample, this will take about 5 – 6 hr



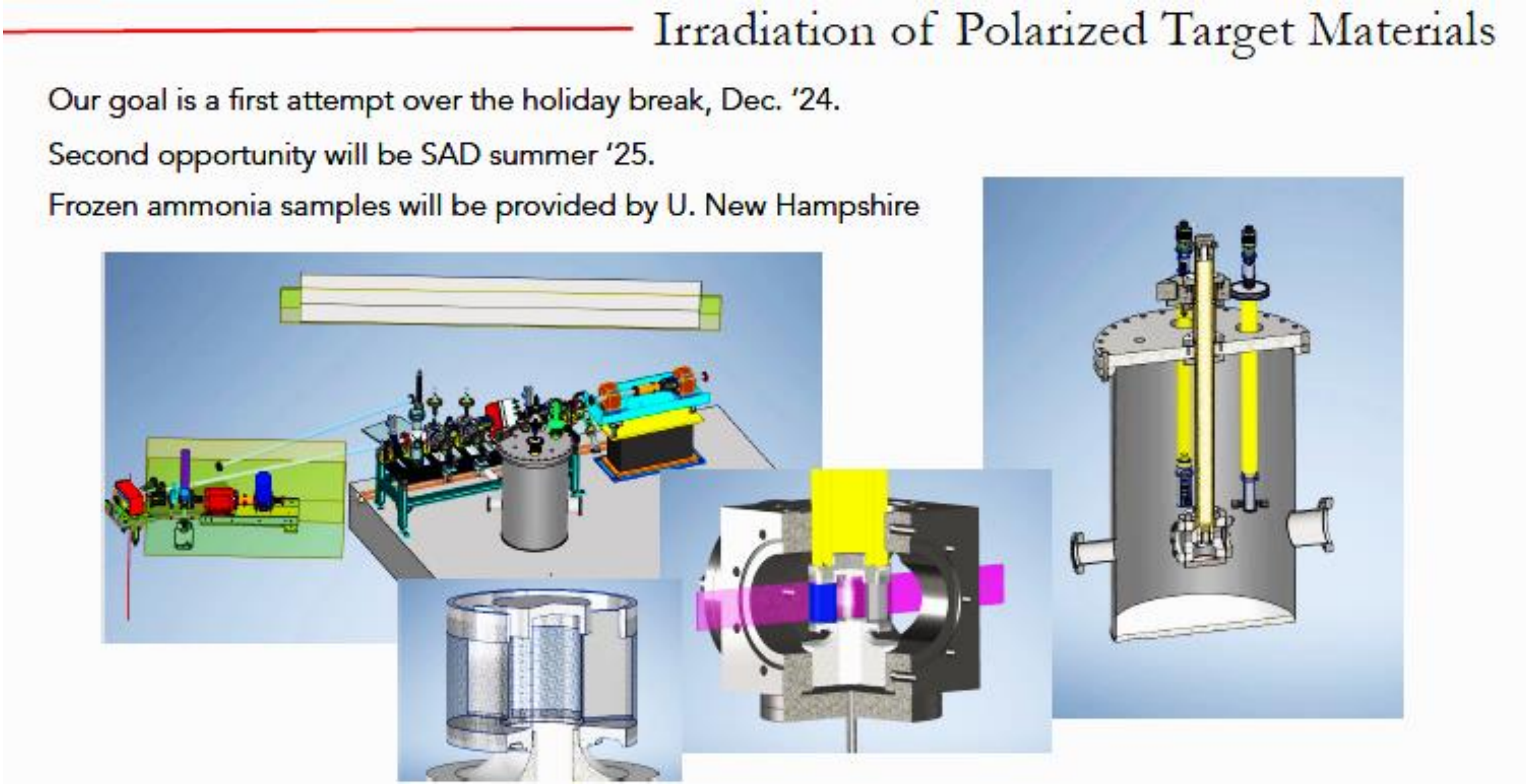


This basket has a volume of about 37 cc (22 g).
Enough for 2 – 3 target cells in Hall B or Hall C.

→ Up to 20 cells per experiment

Rastered beam, 2.5 x 2.0 cm^2
(Final number TBD)
Raster *speed* not important

Target Updates From Chris Keith



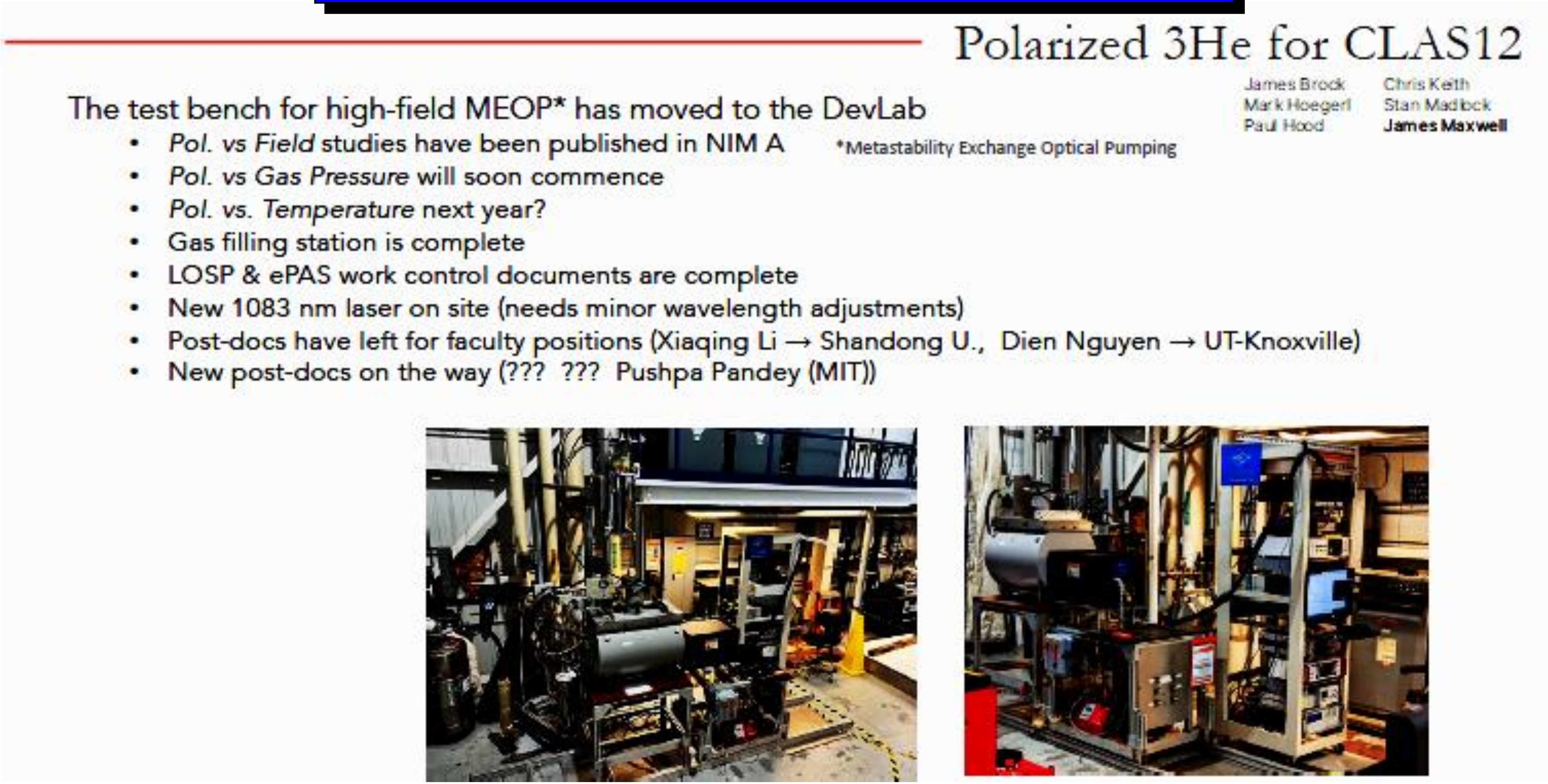
Irradiation of Polarized Target Materials

Our goal is a first attempt over the holiday break, Dec. '24.

Second opportunity will be SAD summer '25.

Frozen ammonia samples will be provided by U. New Hampshire

Target Updates from Chris Keith



Polarized 3He for CLAS12

James Brock
Mark Hoegerl
Paul Hood
Chris Keith
Stan Madlock
James Maxwell

The test bench for high-field MEOP* has moved to the DevLab

- *Pol. vs Field* studies have been published in NIM A
- *Pol. vs Gas Pressure* will soon commence
- *Pol. vs. Temperature* next year?
- Gas filling station is complete
- LOSP & ePAS work control documents are complete
- New 1083 nm laser on site (needs minor wavelength adjustments)
- Post-docs have left for faculty positions (Xiaqing Li → Shandong U., Dien Nguyen → UT-Knoxville)
- New post-docs on the way (??? ??? Pushpa Pandey (MIT))

*Metastability Exchange Optical Pumping

Physics Advisory Committee Meeting 2024

- **52nd JLab Program Advisory Committee Meeting (PAC52)** will be **July 8-12, 2024**
  Deadline for submission of proposals and updates is 9:00 am EDT on **May 1, 2024**
- **CLAS Collaboration proposals:**
  Updates required from Run Groups **A, B, C, G, H** as part of jeopardy process
- **CLAS internal review:** abstracts of new proposals for PAC52 must be sent to CLAS Chair and respective Physics Working Group Chair by **March 12, 2024**, full proposals to the review committee by **April 1, 2024**, that will provide their recommendations by **April 22, 2024**.
  For jeopardy reports to PAC52 the abstract is not expected and there is a later deadline of **April 8, 2024**.

Ensuring a Safe Work Environment in Hall B

- **After-Hours High-Hazard Work Policy**

Effective Sept. 15, 2023, JLab instituted a policy for **High-Hazard Work** performed in off-normal hours

- **Badges**

Recently, JLab instituted a policy requiring **DOE badges** to be displayed at all times when at the facility

- **Work Planning and Control Software ePAS**

“Effective Jan. 8, 2024, ePAS is used throughout the lab to identify the hazards and controls for **maintenance, diagnostics, repair, fabrication**, and non-construction installation activities”, but **not operation**. “Additionally, ePAS is used to identify the hazards and controls for spaces in which **R&D and production activities** occur.” Everyone that performs such work must do so under an ePAS Permit-To-Work. Hall-B Group learned a lot about how to **make the process better**. I have to note that ePAS also has **delayed operation** of the accelerator.

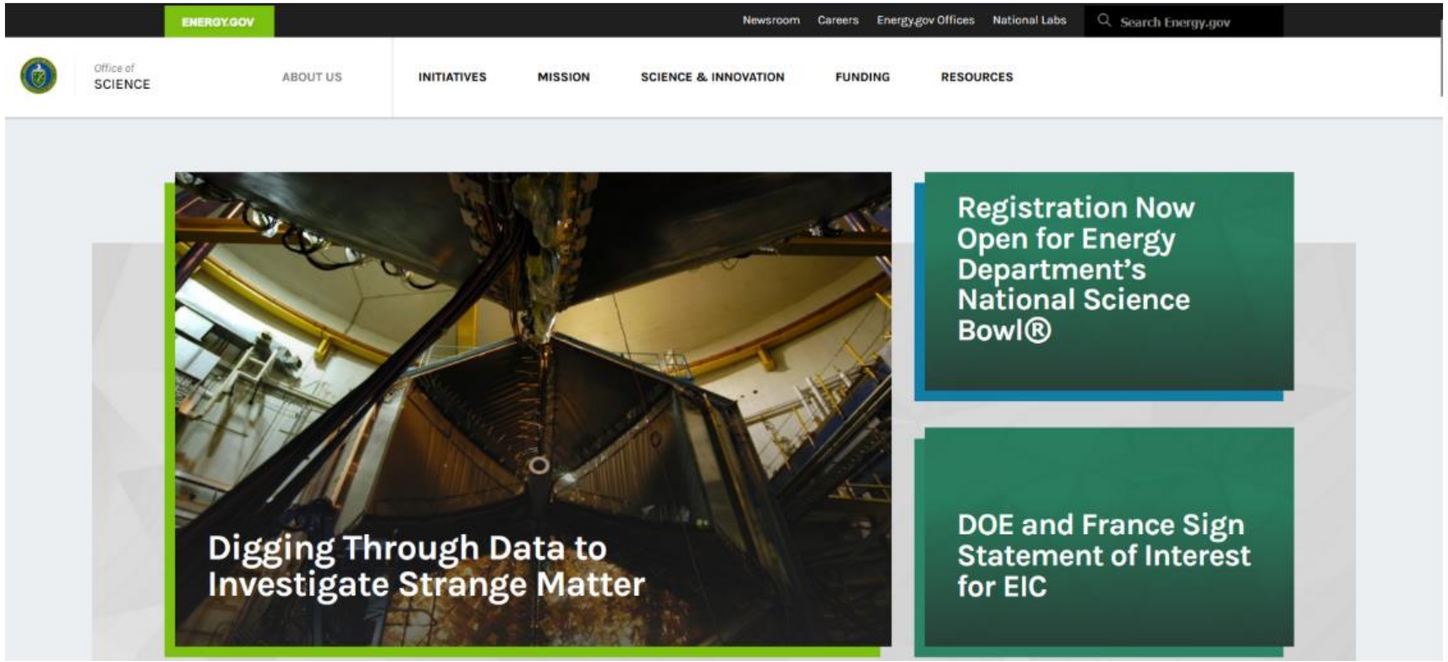
- **Training Requirements**

Most people will have to do **Basic Electrical Safety** training ESC001. Particularly, anybody who is going to touch cables. This is a virtual class followed by a quiz: https://misportal.jlab.org/training/skills/4825. It is not offered every week and it takes about an hour and a half. In addition, **Basic ePAS Training** ePAS000 can be taken by users, a web-based training: https://www.jlab.org/human_resources/training/webbasedtraining

Publications & Press Room Since Sep 2023

DOE Coverage of Earlier CLAS News Release

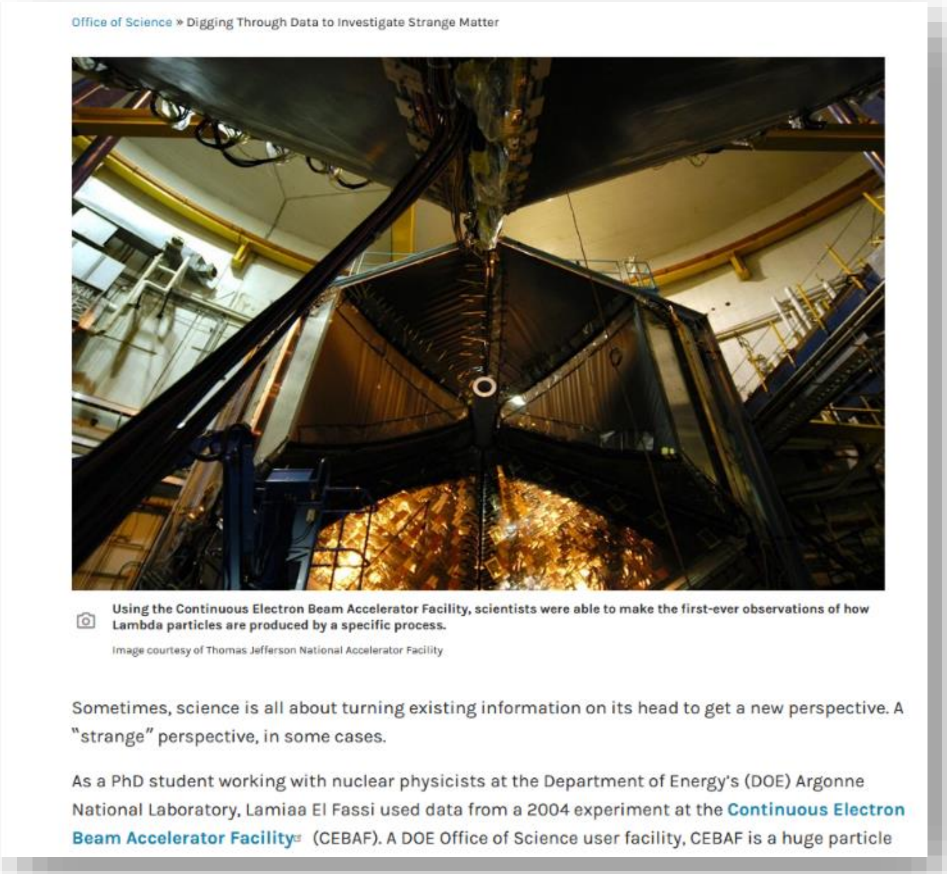
US Department of Energy Office of Science *Research News Update* 116, 4 December 2023 and appearance on the DOE office‘s landing page https://www.energy.gov/science/office-science:



Digging Through Data to Investigate Strange Matter

Registration Now Open for Energy Department’s National Science Bowl®

DOE and France Sign Statement of Interest for EIC



Using the Continuous Electron Beam Accelerator Facility, scientists were able to make the first-ever observations of how Lambda particles are produced by a specific process.

Image courtesy of Thomas Jefferson National Accelerator Facility

Sometimes, science is all about turning existing information on its head to get a new perspective. A “strange” perspective, in some cases.

As a PhD student working with nuclear physicists at the Department of Energy’s (DOE) Argonne National Laboratory, Lamiaa El Fassi used data from a 2004 experiment at the **Continuous Electron Beam Accelerator Facility** (CEBAF). A DOE Office of Science user facility, CEBAF is a huge particle

Science Communication Group at JLab is working with us to realize such features more often …

[Based on T. Chetry et al. (CLAS), Phys. Rev. Lett. 130, 142301 (4 Apr 2023)]

Research Outreach

Article in *The Innovation News Network* in response to latest N* spectroscopy & structure studies
https://www.innovationnewsnetwork.com/three-dimensional-pictures-quarks-inside-resonating-protons/39413/
appeared in the quarterly publication *The Innovation Platform* Issue 16 , 360–363 on 4 Dec 2023:

SCIENCE NEWS

e coils found to improve
ticle detectors

Science | 7th November 2023

Three-dimensional pictures of the quarks inside of resonating protons

Three-dimensional pictures of the quarks inside of resonating protons

Physicists at Jefferson Lab use resonating protons to gain insight into the Universe that existed just after the Big Bang

THE atomic nuclei of all elements in the Universe consist of protons and neutrons. From the pioneering measurements of Robert Hofstadter and his co-workers in the 1950s, it became evident that protons are not point-like particles. Protons have a finite size, on the order of one femtometre, which makes the size of the proton to be around 100,000 times smaller than that of the atom.

Electrons, on the other hand, are point-like particles that have the opposite charge of the proton. By directing high-energy beams of electrons onto protons by using a particle accelerator and by examining the directions in which the electrons were deflected, we can measure the inside of protons.

Taking pictures of the inside of protons

We can draw an analogy to spectroscopy from optics. Just as light reveals the structure of atoms, we can similarly infer the spatial structure of the objects under investigation from the diffraction pattern of the reflected electrons. By analogy, if we direct a laser through a pinhole, a pattern will be formed with a central bright spot surrounded by a series of concentric rings. Going outwards from the centre, the rings will become fainter. Examining this diffraction pattern provides telltale information on the size and shape of the pinhole. Electrons obey quantum mechanics and possess a wavelike nature. As their energy increases, the wavelength gets smaller. So, high-energy electrons of a billion electron volts (GeV), requiring powerful particle accelerators, will have wavelengths comparable to the size of the proton and will thereby provide spatial information on the inside of protons.

In fact, a proton's structure is quite complex, compelling scientists to abandon the notion that protons are elementary particles. Starting with Hofstadter's Nobel-prize-winning research, electron scattering experiments revealed that protons have a rich inner structure formed around three components, later named quarks, and possess distinct distributions. The discovery of unexpectedly large numbers of so-called deep inelastic scattering events gave direct proof that the quarks really exist inside of the proton. These quarks are bound so strongly that no quark can ever leave a proton. In the intervening years, many electron scattering measurements have been performed to provide one-dimensional pictures of the distribution of the quarks.

Resonating protons

Since the middle of the last century, physicists have employed accelerators to create beams impinging onto proton targets. They have found that protons may resonate just like striking a bell at its sweet spot. If the bell vibrates just right, there will be an ensuing tone. A proton is clearly not a bell, but it will vibrate when a particle strikes it at just the right energy or frequency. These characteristic tones of the proton are called resonances, and the quark model can explain their existence. A proton is a composite system of three quarks bound together by the strongest force known in nature, the strong force. The ground state is the lowest-energy state of the proton. When a proton is excited by a particle beam into a higher-energy state, its quarks rotate and vibrate against each other, exhibiting resonance characteristics. In 1952, Enrico Fermi saw the first resonance, the Δ, which is one-third times as massive as the proton and can be described as a magnetically excited state. Another very prominent resonating proton, called the Roper, is now understood as a radial excitation of the proton ground state. This is like the breathing mode frequency, wherein there is a variation in the distance of the quarks from each other, going in and out.

Advances in theory, electron accelerator, and detector technology over the past few decades have provided a novel way to describe proton structure in three dimensions, two in space and one in momentum, from electron scattering. This has further opened a new avenue of research and has led to three-dimensional pictures of the ground-state proton. Still, little is known about the three-dimensional structure of resonating protons. 3D imaging, also called nucleon photography, can potentially delineate the internal structure of protons completely. This is not unlike tomography in 3D imaging. These 3D images are captured by the distribution functions that encode the internal properties. Ultimately, the goal is to unambiguously extract and fully understand the distributions of quarks inside the proton. This requires high-precision measurements, good data sets, and powerful analytical tools.

Fig. 1: A schematic of the CLAS12 detector in Hall B at Jefferson Lab. The electron beam from CEBAF is entering from the left. The target is located at the centre. The CLAS12 detector covers almost all directions from the target with successive layers of particle detectors (labelled by the abbreviations delineating the different detectors) to track the particle paths or record the particle flight times. Two superconducting magnets, a solenoid in the centre and a torus in the forward direction, provide a strong field in which charged particles are deflected

New experiments and technologies at Jefferson Lab in the US

Currently, experiments are being conducted at the U.S. Department of Energy's Thomas Jefferson National Accelerator Facility (Jefferson Lab). From the world-class Continuous Electron Beam Accelerator Facility (CEBAF), high-energy electron beams are focused onto resonating protons surrounded by large detectors such as CLAS12 in Jefferson Lab's Experimental Hall B. CLAS stands for CEBAF large acceptance spectrometer, and the 12 represents the recent upgrade to Jefferson Lab from 6 GeV to 12 GeV beam energy. CEBAF is a DOE Office of Science user facility that supports the research of more than 1,800 nuclear physicists worldwide. The CLAS12 detector is a large-acceptance magnetic spectrometer based upon a superconducting torus magnet that provides a largely azimuthal field and a solenoid magnet with full azimuthal coverage. The complex instrument can operate at high luminosities. The higher the luminosity, the more likely an electron will strike the inside of protons. Since the proton is 100,000 times smaller than the atom, it takes many impinging electrons to contact the minute proton.

The capabilities of CLAS12 are being used in a broad programme to study the structure and interactions of fundamental particles. Resonating protons live for around a trillionth of a trillionth of a second, or about the time it takes for light to cross the distance of a proton. These resonances will typically relax into a ground state by emitting a quark-antiquark state – termed a meson. CLAS12 can track newly formed particles such as these mesons and the scattered electrons moving away from the target, allowing the reconstruction of resonating protons. It can also record the particle's flight times with a precision better than a tenth of a billionth of a second. Therefore, like an optical instrument but on a much larger scale, the spectrometer provides a view into the invisible realm inside of the proton. The CLAS12 detector's output is recorded 20,000 times per second. It is stored in hundreds and thousands of terabytes of data files for each experiment performed by the CLAS Collaboration, which involves about 200 physicists from almost 50 institutions worldwide.

It typically takes years to analyse the data and to extract observables that are sensitive to the proton structure. To access the deeply hidden world of distribution functions, the electrons from CEBAF impact the proton inside the hydrogen 'target' in the centre of the CLAS12 detector to excite the quarks further within and produce the proton resonances. These excitations are unbelievably short-lived, disappearing after ten to the power of – 24 seconds, one-millionth of one-billionth of one-billionth of a second. Still, they leave behind evidence of their fleeting existence. Multiple layers of advanced particle detector technologies are needed to identify the mesons produced in the collisions by measuring their properties, such as velocity, mass, and charge.

Modern Artificial Intelligence (AI) and machine learning methods are employed to support physicists, advance the development of software systems, improve experiments, and speed up the simulation and analysis processes. The CLAS Collaboration is at the forefront of scientific developments in its use of AI methods and tools, profoundly accelerating scientific knowledge acquisition, creating synergies across scientific areas, and improving international competitiveness. Modern physics research has already been transformed by AI techniques, and interfacing physics experiments with AI is expected to play an increasing role.

Three-dimensional pictures of the quarks inside of resonating protons

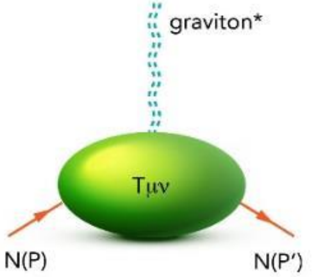
Science | 7th November 2023

© shutterstock/pixelparticle

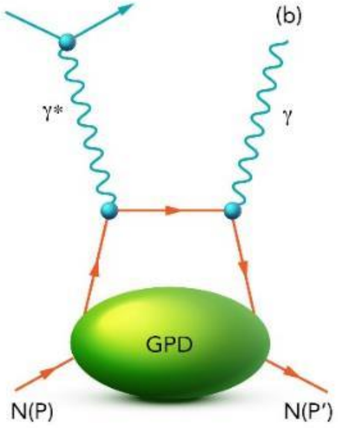
Physicists at Jefferson Lab use resonating protons to gain insight into the Universe that existed just after the Big Bang.

First Determination of Distribution of Forces in the Proton

$$\langle p_2|\hat{T}^q_{\mu\nu}|p_1\rangle = \bar{U}(p_2)\left[M_2^q(t)\,\frac{P_\mu P_\nu}{M} + J^q(t)\,\frac{\imath(P_\mu\sigma_{\nu\rho}+P_\nu\sigma_{\mu\rho})\Delta^\rho}{2M} + d_1^q(t)\,\frac{\Delta_\mu\Delta_\nu - g_{\mu\nu}\Delta^2}{5M}\right]U(p_1)$$



Graviton coupling to the proton

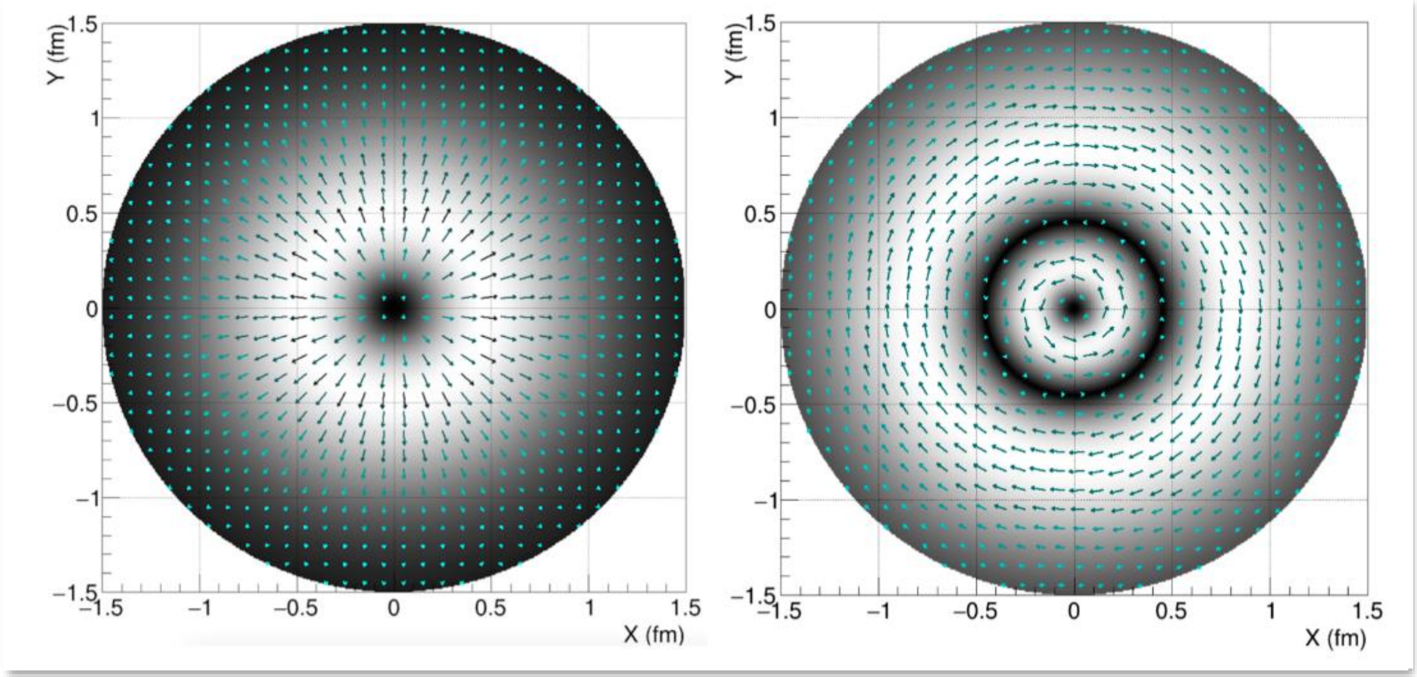


Deeply Virtual Compton Scattering

$$\int \mathrm{d}x\, x\,[\underline{H}(x,\xi,t) + \underline{E}(x,\xi,t)] \;=\; 2\underline{J(t)}$$

$$\int \mathrm{d}x\, x\underline{H}(x,\xi,t) \;=\; \underline{M_2}(t) + \frac{4}{5}\xi^2\underline{d_1}(t),$$

Distribution of forces as function of distance from proton center



Normal forces

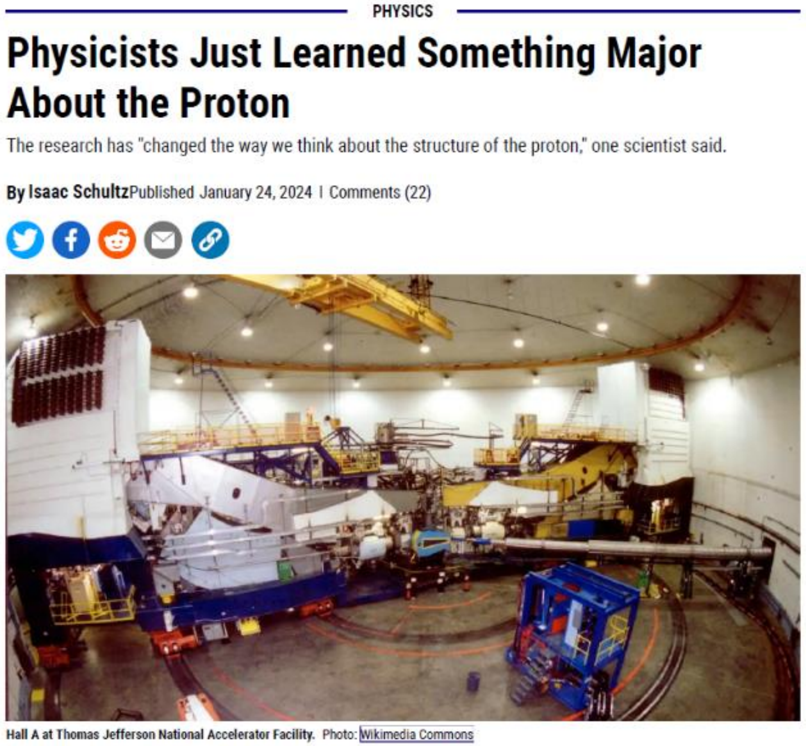
Tangential forces

[V. D. Burkert et al., Rev. Mod. Phys. 95, 041002 (22 Dec 2023)]

Coverage of News Release

News Release “*Gravity Helps Show Strong Force Strength in the Proton*“ on 23 Jan 2024 received wide coverage

https://gizmodo.com/proton-physics-strong-force-quarks-measurement-1851192840



PHYSICS

Physicists Just Learned Something Major About the Proton

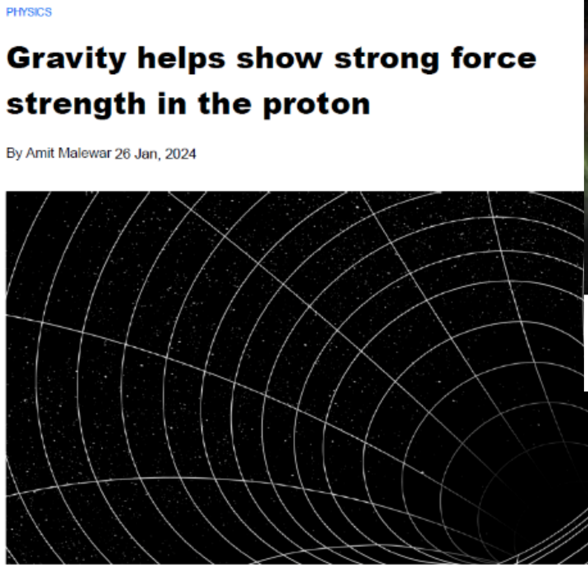
The research has "changed the way we think about the structure of the proton," one scientist said.

By **Isaac Schultz** Published January 24, 2024 | Comments (22)

Hall A at Thomas Jefferson National Accelerator Facility. Photo: Wikimedia Commons

New details about the properties of protons uncovered with gravity test

https://cosmosmagazine.com/science/physics/proton-strong-force-gravity/

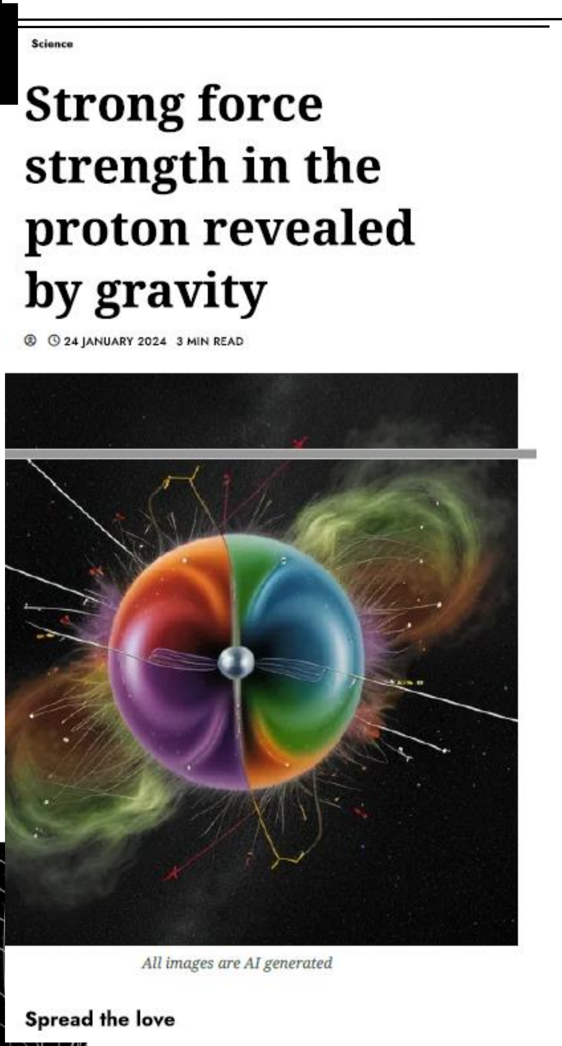


PHYSICS

Gravity helps show strong force strength in the proton

By Amit Malewar 26 Jan, 2024

https://www.techexplorist.com/gravity-helps-strong-force-strength-proton/80137/



Science

Strong force strength in the proton revealed by gravity

24 JANUARY 2024 3 MIN READ

All images are AI generated

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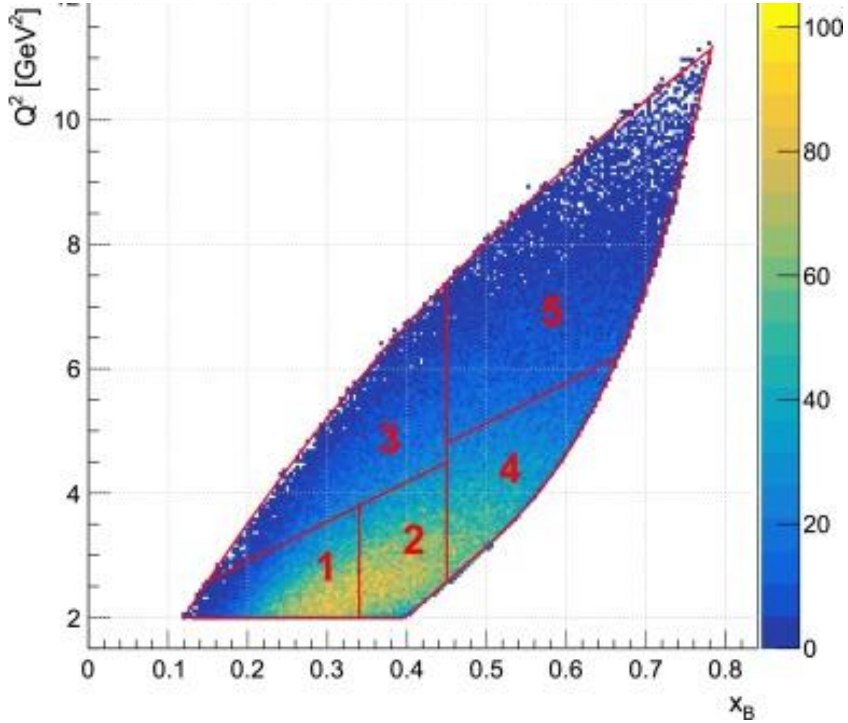
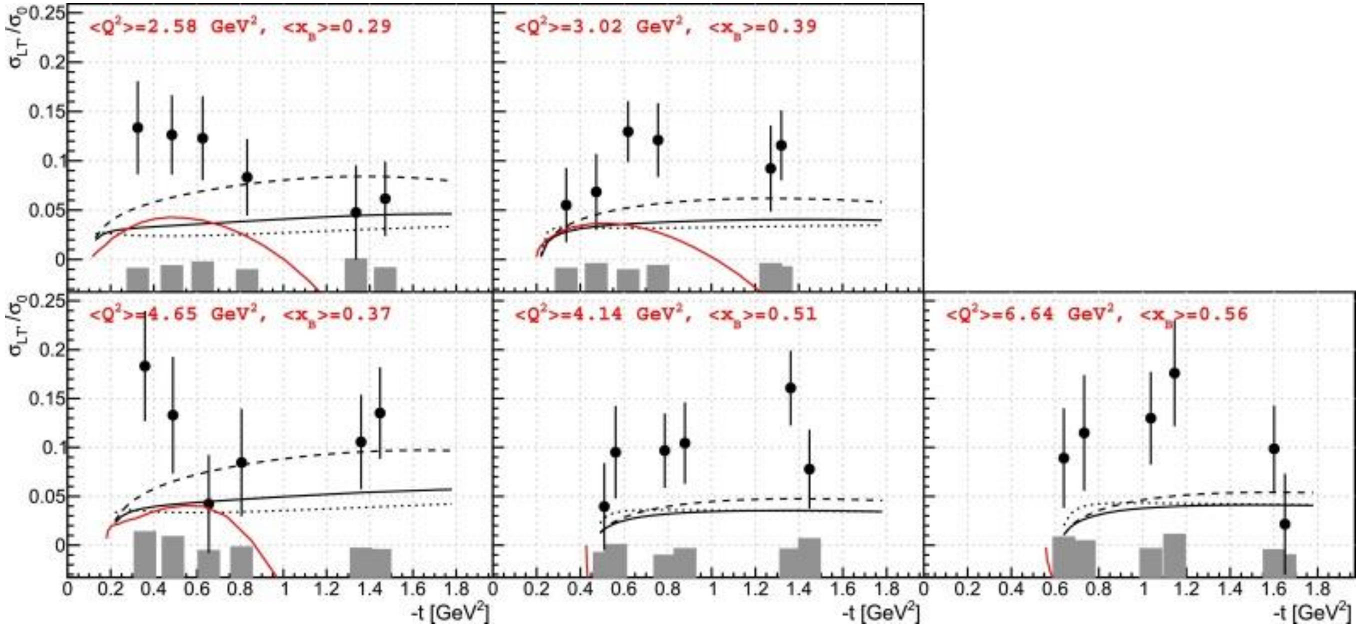
https://simplysciencenews.com/gravity-strong-force-proton-nuclear-physics/

Beam Spin Asymmetry Measurements of Deeply Virtual π^0 Production

$$BSA = \frac{\sqrt{2\epsilon(1-\epsilon)}\,\frac{\sigma_{LT'}}{\sigma_0}\sin\phi}{1+\sqrt{2\epsilon(1+\epsilon)}\,\frac{\sigma_{LT}}{\sigma_0}\cos\phi+\epsilon\frac{\sigma_{TT}}{\sigma_0}\cos 2\phi},$$



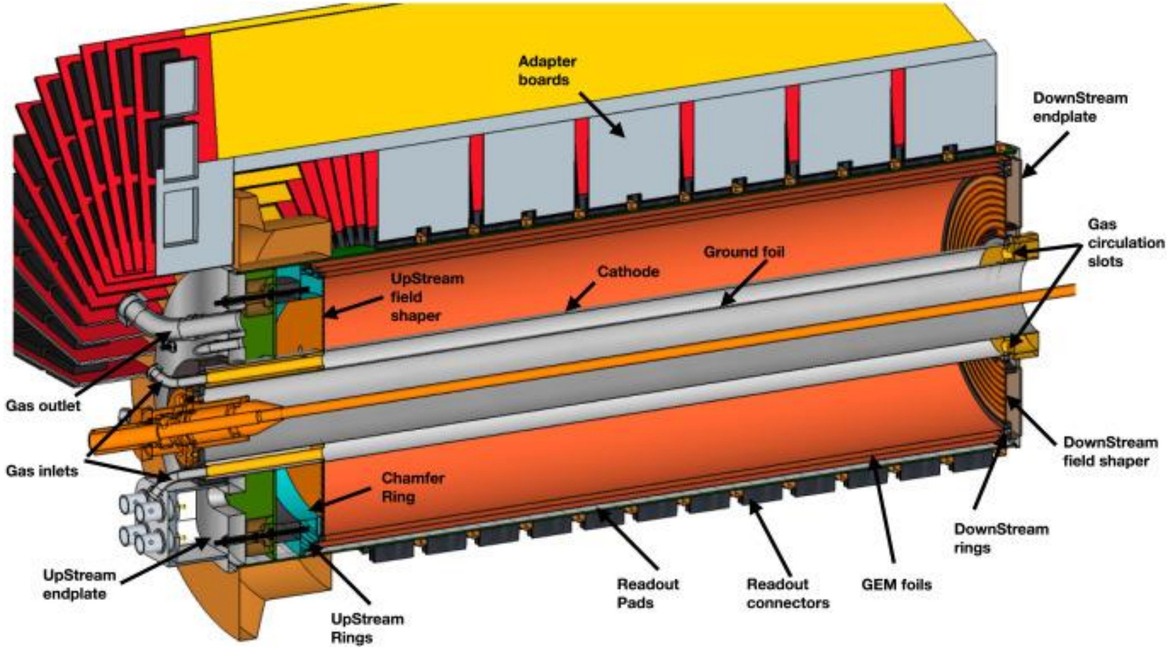


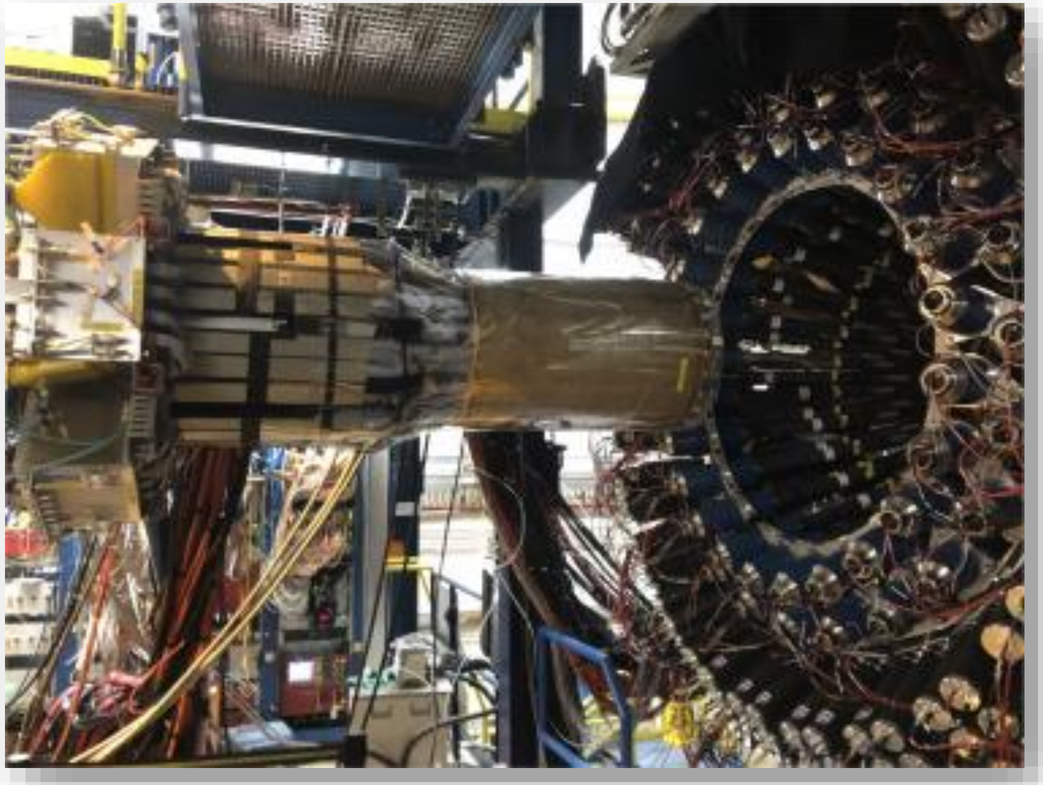
The black curves show the theoretical prediction from the GPD-based Goloskokov-Kroll model. The black dashed lines show the effect of the GPD multiplied by a factor of 0.5, and the black dotted lines show the effect of the GPD H_T multiplied by a factor 0.5

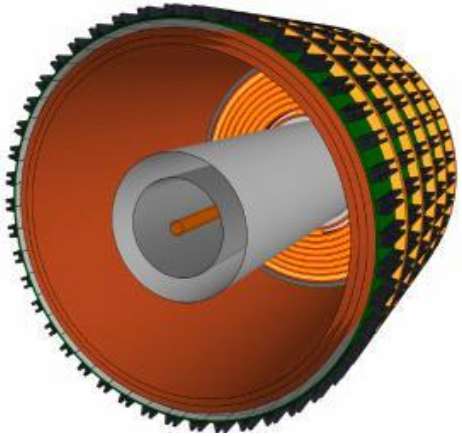
Sensitivity to the chiral-odd GPD, containing information on quark transverse spin densities in unpolarized and polarized nucleons

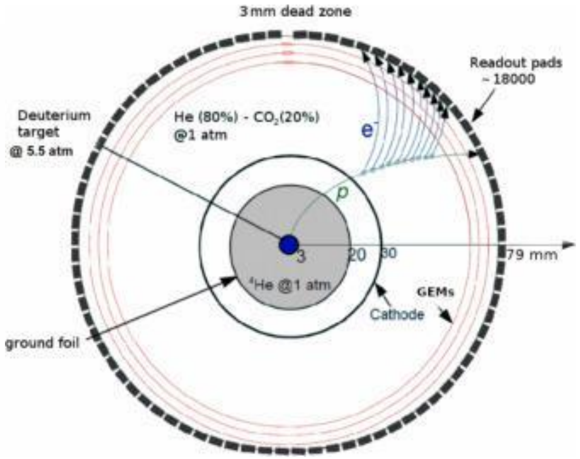
[A. Kim et al. (CLAS Collaboration), Phys. Lett. B 849, 138459 (Feb. 2024)]

Design, Construction, Performance of RTPC for BONuS12









[I. Albayrak et al., Nucl. Instrum. Meth. A 1062, 169190 (May 2024)]

Thank you!

Have a good time in Newport News while Spring is approaching!