Hall B Status Report

- News from the Hall B Group
- Hall B Setup Changes
- Status of RG-C Data Taking
- Status of Alignments & Calibrations
- Developments and Upgrades
- Updated Run Group Schedule
- Collaborations & Cooperations
- Backup: Recent Analyses and Papers



[V.D. Burkert, L. Elouadrhiri, et al., Nuclear Inst. and Methods in Physics Research, A 959 (2020) 163419]

Patrick Achenbach March 2023

Hall B Group News

- Joseph Newton left from his postdoc position
- Linda Ceraul retired after working with Hall B for decades; Thanks a lot for her long-standing support of our activities!
- New administrative support and travel coordinator is Jessica Adams Email: jadams@jlab.org Point of contact for users Help in organizing meetings on site
- Current job openings: 1 Staff Scientist, 1 Postdoc, 1 Senior Designer
- Follow-up job opening: Staff Scientist

Hall B Setup: Polarized Target, Møller Shield, RICH Detectors

Longitudinally polarized cryo-target inside solenoid \rightarrow James: <u>Performances of the longitudinally</u> <u>polarized target for CLAS12</u>













Forward Tagger Replaced with ...

... new large Møller shield









Additional 2nd RICH:

2-sector coverage with 50,048 channels





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Solenoid Power Supply Failure





Hall B was down for 80 days during current RG-C run \rightarrow Approved physics program could not get completed before SAD 2023

Repair completed (01/30/23)

Run Group D Preparations at JLab

Development of unpolarized cryo target





Refurbishment of non-maintained Saclay target



 \rightarrow Xiangdong: <u>Status of the Hall-B targets for CLAS12</u> <u>experiments</u>



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Run Group C Data Taking 2022



run with empty — Total Charge on empty Physics: NH₃ & ND₃ run with C Total Charge on C Calibration (dilution factor, run with NH3+ — Total Charge on NH3 background subtraction, alignment): run with NH3-Total Charge on ND3 C, CH₂, CD₂, empty, zero-field run with ND3+ Expected Charge run with ND3-Calibration runs

Run Group C Data Taking 2023



RGC 23 FTon Progress

- Back in business since end of January reaching 96% of total scheduled data
- Online trigger-bit polarization reconstruction follows relative NMR reading closely
- Highest degree of polarization in ND₃ ever observed by the target experts

→ Noémie: RG-C end of run and first look at physics



Status:

- Detector Alignment, Calibration, Reconstruction
- Calibration work proceeding efficiently with good interactions across the groups
 - RG-B (LD2 @ 11 GeV): pass-2 review held on Oct. 28 for Spr19
 - <u>RG-A (LH2 @ 11 GeV)</u>: pass-2 review upcoming soon for Spr19
 - <u>RG-K (LH2 @ 6.5/7.5 GeV)</u>: subsystem calibration for pass2 now getting underway
 - <u>RG-M (e4n @ 2/4/6 GeV)</u>: pass-1 review expected
 - <u>RG-C (long polarized target @ 11 GeV)</u>: alignments and subsystem calibration for pass-1
- pass-2 cooking submissions delayed waiting for official pass-2 reconstruction software

[Daniel Carman, Feb. 2023]

- \rightarrow Nathan: <u>Reconstruction: what comes after pass2</u>
- \rightarrow Veronique: <u>CVT tracking</u>, status and plans

Comparison of Oct and Mar Calibration Timelines



Improvements to pass-2 code (among other things) for AI-assisted de-noising of hits in the DC, cluster separation in the calorimeter, hit losses in CND, CPU efficiency, displaced vertex finder (?), RICH reconstruction, new banks & flags, ...

Preliminary Run Group Scheduling in Hall B

Preliminary	Hall B	Run	Groups	and	Schedule	
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				2023-2026				Scheduled	Remaining PAC
START DATE	END DATE	Calendar Days	Remaining PAC Days	Setup/Exp.	Target	Beam Energy	Run Group	cal. days =	days after ena date
2022-06-14	2022-11-11	143	120		long. polarized NH3/ND3	11	RG-C	71,5	49
2022-11-12	2022-12-19	37		downtime					
2022-12-20	2023-01-12	23				Winter break			
2023-01-21	2023-01-29	8		downtime					
2023-01-30	2023-03-19	48	49		long. polarized NH3/ND3	11	RG-C	24	25
2023-03-20	2023-07-20	122		setup change	target change	SAD 2023			
2023-07-21	2023-09-17	58	30		liq. D2 & nucl. (JLab)	11	RG-D	29	1
2023-09-18	2023-09-22	4			target change				
2023-09-23	2023-12-17	85	88		liq. H2	6,6	RG-K	42,5	45,5
2023-12-18	2024-01-10	23			target change	Winter break			
2024-01-15	2024-03-17	62	60		liq. D2 & nucl. (Chile)	11	RG-E	31	29
2024-03-18	2024-07-18	122		setup change	target change	SAD 2024			
2024-07-29	2024-11-12	106	55	ALERT	high pressure gas	11	RG-L	53	2
2024-11-12	2024-11-16	4			target change				
2024-11-20	2024-12-15	25	46		liq. H2	8,8	RG-K	13	33
2024-12-16	2025-01-12	27				Winter break			
2025-01-13	2025-03-17	63	33		liq. H2	8,8	RG-K	32	2
2025-03-18	2025-07-23	127		setup change	target change	SAD 2025			

- SAD 2023: With more gradient (overhead) but same energy should mean a stable machine
- Mid-2025 is a time non-standard beam energy experiments

- 2023 SAD for installation of cryo-target and solids
- **RG-D**: Jul to Sept 2023, ~30 PAC days to **compete**
- RG-K: Sept to Dec 2023, to reach ~50% PAC days
- RG-E: Jan to Mar 2024, to reach ~ 50% PAC days
- 2024 SAD for installation of ALERT
- **RG-L**: Jul to Nov 2024, ~55 PAC days to **complete**
- **RG-K**: Nov to Mar 2025, ~45 PAC days to **complete**
- 2025 SAD for setup/target change

Remaining PAC days for run groups

- RG-A: >70 PAC days
- RG-B: +/- 40 PAC days
- RG-C: +/- 25 PAC days
- RG-E: 30 PAC days
- RG-M: 10 PAC days

Not scheduled

- Non-CLAS12 experiments: PRad-II, π⁰TFF, X17
- CLAS12 experiments: Polarized He-3, H-3 and He-
- s 3, transv. polarized H/D, long. polarized LiH/LiD

Update on Long-Term Schedule

Notional CEBAF & upgrade schedule (FY24 – FY42)

- · Accelerator/engineering team have worked up an early schedule and cost estimate
 - Schedule assumptions based on a notional timing of when funds might be available (near EIC ramp down based on EIC V3 profile)
 - For completeness, Moller and SoLID (part of 12 GeV program) are shown; early positron source development also shown



- JLab plan to run the 12 GeV electron beam until 2032
 JLab plan to run the 22 GeV electron beam from 2040
- \rightarrow Yves: <u>The CEBAF Positron Beam upgrade</u>
- \rightarrow Alex: <u>Status of CEBAF upgrades</u>
- \rightarrow David: <u>Status of Jefferson Lab</u>
- \rightarrow Patrizia: <u>Physics Perspectives for an energy upgrade at</u> <u>Jefferson Lab</u>



12 GeV Ce⁺BAF : present high level goals

[Thia Keppel & Joe Grames, Positron Workshop, Mar. 2023]

- 9 more years for present CLAS12 Run Groups
- included about 1 year running of non-CLAS expts.
- CLAS positron program for 2035 37
- \rightarrow Axel: <u>Proposal for TPE with positron beam</u>
- 50 nA max. current for polarized beam fits well

Beam Dump (Phase 1) Upgrade









- No need for beam blocker anymore due to new safety evaluation
- Faraday cup will get moved down towards the end of the tunnel
- Work to be accomplished in current scheduled accelerator down
- Phase 2 upgrade requires entirely new high-power dump

AI/ML for improved track reconstruction



- Neural networks developed for CLAS12
 forward drift chamber tracking led to 15% –
 35% increase in physics outcome depending on experiment
- Other developments include
- Displaced vertex for finder for hyperon identification by Veronique
- Improved DC tracking by Tongtong

AI/ML level-3 trigger running on GPUs



[Richard Tyson, Gagik Gavalian et al. 2023]

- Includes implementation of secondary event transfer system
- Can significantly reduce amount of recorded data

Evaluation of Subsystem Performance for x2 Design Luminosity

- Series of Task Force Meetings
- RG-A with average luminosity of 0.7×L and η = 0.8 for a single track
 → in pass-1, analysis with two particles in the final state will get only ~40% of the expected statistics
- Renewed evaluation of beamline, forward tagger (FTCal, FTHodo), PMT devices (HTCC, LTCC, RICH, FTOF, ecal, CND,CTOF), forward detector tracking, central detector tracking, DAQ/trigger

- From the summary by Stepan:
- Most of the CLAS12 subsystems will perform at luminosities $L \approx 2 \times 10^{35} cm^{-2} sec^{-1}$ with efficiencies and resolutions we have now.
- The main concern is CVT: BMT lifetime and the low efficiency of CVT tracking (will be ≈ 50%). The efficiency issue may be possible to mitigate with the inclusion of MLA into CVT tracking.
- There are requests from various detectors for more dedicated performance studies at high luminosities to iron out some details. We will coordinate with run groups D and K, Nathan and Stepan PDLs. (FT has to wait, these runs are with FTOff).
- There are three items on critical path for the upgrade in 2-3 years time frame:
 - μRWELL detector development (R&D and prototyping started);
 - FEE development for MM and µRWELL detectors based on SAMPA and VMM3 chips.
 - □ The BMT problem no spares and low chance of replacing degraded tiles.

Luminosity Upgrade with Additional Tracker

• μ RWELL development for luminosity upgrade to $L = 2 \times 10^{35} \text{ cm}^{-2} \text{ sec}^{-1}$



- µRWELL with capacitive sharing readout provides
 2D points in front of drift chambers
- Work on prototype at UVa, CERN, and JLab during the last months
- Time frame of 2 to 3 years for completion
- \rightarrow Rafayel: Luminosity upgrade for CLAS12

- Simulation studies with background merging and µRWELL + DC + AI result in improved inefficiency of better than 0.1 % per nA, better than upgrade design goal
- CLAS12 readiness for higher luminosities is key for future success









Hardware Developments & Plans

 First beam test of a large-area µRWELL during the last days



 Some data were taken, to be continued ...

- Implementation of a tracking algorithm with AI/ML
 → Gagik: Usage of Machine Learning in CLAS12
- Cylindrical µRWELL Detector for high luminosities with CLAS12: DOE Early Career Award application "Low-mass, fasttiming micro-pattern gaseous detector for CLAS12 at ultra-high luminosities" prepared by Florian



 DOE Innovative Fusion Technology and Collaborative Fusion Energy Research "Spin Polarized Nuclei for Injection into DIII" application by Xiangdong

Micro Patterned Gaseous Detectors Lab(s)



Equipping ARC lab for Micro Patterned Gaseous Detector (MPGD) development. Ability to deliver ArCO₂ and N₂ to two different MPGD test beds. (Kondo Gnanvo, Eric Christy, Brian Kross, Seungjoon Lee) Expanding MPGD work into lab F117 of CEBAF Center F-wing. Will install 6' x 8' and 8 x 12 cleanrooms (Brian Kross, Eric Christy, Kondo Gnanvo)





- Declared need for MPGDs R&D facility in the US for the Nuclear Physics community
- MPGD facility could be modeled on Gaseous Detector Development laboratory at CERN



[Drew Weisenberger, Leadership Meeting, Mar. 2023]

- JLab is expanding its R&D activities in MPGDs
- CLAS luminosity upgrade will benefit strongly

Upgrade of HyCal Calorimeter

- Combination of PbWO₄ and Pb-glass detectors (118 x 118 cm²) PbWO₄ crystals → high resolution Pb glass → low budget
- Two upgrade needs identified:
- All 1152 PbWO₄ + 576 Pb glass detectors need new readout
 → inner part upgrade with FADC250v3 by JLab
- − Light yield of Pb glass is too low for future high-resolution measurements in Hall $B \rightarrow \text{new PbWO}_4$ crystals needed
- Application for MRI Consortium: "Track 2 Development of an enhanced magnetic-spectrometer-free apparatus for ultraprecise forward angle electron scattering experiments " by Ashot Gasparian and collaborators



X (cm)

Cooperation with Theoreticians to Explore Emergence of Hadron Mass

- Extension of results on electrocouplings of N* states in from pN, ppN, KY, K*Y, KY* exclusive channels to access quark momenta where ~50 % of dressed quark mass is generated in order to resolve the problem on Emergence of Hadron Mass
- Long-stay visitor Adnan Bashir to explore N* transition amplitudes with Continuum Schwinger Method
- "Nucleon Resonance Electroexcitation Amplitudes and Emergent Hadron Mass" in "Particles 6, 416–439 (2023)
- Common Workshop at DNP-JPS Joint Meeting: Exploring excited nucleons with meson, electron, and photon beams





Cooperation with COMPASS

- Task Force Meeting in which Harut discussed the need for stronger cooperation across the labs
- \rightarrow Jan: <u>AMBER: a new QCD facility at CERN</u>
- From Harut's summary:

Extending JLab measurements to a wider range in x,Q² and P_T with energy upgrade, will be crucial in studies of QCD dynamics, including studies of evolution properties and transverse momentum dependences of PDFs.

Coordination of efforts at JLab and COMPASS will help both, also in pushing for analysis frameworks for making extractions and projections with controlled systematics

Cooperation with J-PARC

- Japan is one of the key players sharing the same objectives in understanding hadron physics, hadron structure, hadron interaction, and hadron mass
- The role of international projects in hadron physics at J-PARC is increasing
- CLAS Collaboration should seek connection to leading groups



Creating a Platform to Strengthen Collaboration

Currently, J-PARC Hadron Facility Extension Project is largest upgrade project

ab-initio calculation

- Proposal for "International Leading Research" has been submitted in 2023
 - Formation of baryons with multiple strange quarks
 - A-p interactions
 - Emergence of hadron mass



excited states

Summary in Black & White

- Run Group C successfully conducted first polarized target experiment with CLAS12, ... but not completed
- Tracking/reconstruction upgrades, mostly AI assisted, improve performance, ... but still no pass-2 cooking
- Detector und beam dump upgrades are progressing,
 ... but µRWELL operation is on a long and winding road
- Several publications submitted and analyses in review,
 but still no absolute cross sections published



Thanks for the invitation to the center of intellectual Enlightenment, ...but sometimes it feels like Paris in the rain

Data Analysis Results in Publication



[Silvia Niccolai, Sept. 2022]

Mar 2023 Patrick Achenbach

Timothy B. Hayward (UCONN) Harut Avakian (JLab)

Open Access

Observation of Correlations between Spin and Transverse Momenta in Back-to-Back Dihadron Production at CLAS12

H. Avakian et al. (CLAS Collaboration) Phys. Rev. Lett. **130**, 022501 – Published 11 January 2023

- First back-to-back analysis of proton-π+ RGA data
- Sizable nonzero asymmetries
 → first ever observation of a signal sensitive to TMD fracture functions
- PRL published last month
- Follow-up analysis involving RGA and RGB in order to study flavor dependence of fracture functions and both positive and negative pions in order to control systematics and test universality
- Analysis note ~90% completed, finalizing two remaining systematic uncertainties and working on cross check







Hard Exclusive π^+ Electro-Production off Protons

A multidimensional study of the structure function ratio $\sigma_{LT'}/\sigma_0$ from hard exclusive π^+ electro-production off protons in the GPD regime

S. Diehl^{ah,f}, A. Kim^f, K. Joo^f, P. Achenbach^{an}, Z. Akbar^{au,l},



blue: GK GPD model magenta: Laget Regge model

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Hard Exclusive $\pi^{-}\Delta^{++}$ Electro-Production BSA off Protons

First measurement of hard exclusive $\pi^- \Delta^{++}$ electroproduction beam-spin asymmetries off the proton



- Access to transition GPDs
- 3D structure of resonances
- Collaboration review started this week
- Paper expected to be submitted to PRL in March

Multidimensional Study of SIDIS Single π^- and π^0 BSA

A multidimensional study of SIDIS $\pi^$ and π^0 beam spin asymmetry over a wide range of kinematics in the valence quark regime.





- Second round of the analyis review ongoing since January
- Extension of published π^+ SIDIS
- Flavor decomposition of TMDs



Mar 2023 Patrick Achenbach Inclusive (e,e'X) Cross Section

V. Klimenko, UConn

- First results on inclusive (e,e'X) cross sections at 4.0 GeV² < Q² < 10 GeV²
- Large coverage in W and Q²
- New opportunities for insight into PDF in resonance region and for exploration of quark-hadron



Analysis note and draft of paper submission by first half 2023

- Black preliminary cross sections
- Red CLAS data, Phys. Rev. D67, 092001 (2003)

SIDIS kinematics for A electroproduction with CLAS6

First Measurement of Λ Electroproduction off Nuclei in the Current and Target Fragmentation Regions

T. Chetry,³ L. El Fassi,^{3,*} W. K. Brooks,^{5,4,6,7} R. Dupré,² A. El Alaoui,⁵ K. Hafidi,¹ K. P. Adhikari,³ and M. L. Kabir³



- Probing QCD Dynamics
- Study of transverse momentum broadening and multiplicity ratio
- Paper submitted to PRL, under review

DVCS Beam-Spin Asymmetries

First CLAS12 measurement of DVCS beam-spin asymmetries in the extended valence region

G. Christiaens,^{1,2} M. Defurne,^{1,*} D. Sokhan,^{1,2} P. Achenbach,³ Z. Akbar,⁴ M.J. Amaryan,⁵ H. Atac,⁶ C.



- Greatly extend the Q² and Bjorken-x phase space
- Submitted to PRL

Heavy Photon Search 2016 Run

Searching for Prompt and Long-Lived Dark Photons in Electro-Produced e⁺e⁻ Pairs with the Heavy Photon Search Experiment at JLab

P. H. Adrian,¹ N. A. Baltzell,² M. Battaglieri,³ M. Bondí,⁴ S. Boyarinov,² C. Bravo,¹,^{*} S. Bueltmann,⁵ P. Butti,¹



- Including bump hunt and displaced vertex analysis
- Submitted to PRD

Beam Spin Asymmetry for Deeply Virtual Kaon Production

A multidimensional study of charged kaon SIDIS beam spin asymmetry over a wide range of kinematics

Áron Kripkó¹, Stefan Diehl^{1,2}, Utsav Shrestha²

- First round of the analysis review finished in November
- Finalizing the response to the first round
- Second round of the analyis review expected

Beam Spin Asymmetry for Deeply Virtual π 0 Production

Andrey Kim (UConn)



Paper is under the CLAS ad-hoc review (round 1)



FIG. 1. Hard exclusive electroproduction of a pion on the proton in very forward kinematics $(-t/Q^2 \ll 1)$, described by GPDs [22, 23].

Deeply Virtual Neutral Pion Cross Section

Robert Johnston (MIT)

Deeply Virtual π^{o} Production (DV π^{o} P)

 $egin{array}{c} {e} + {p}
ightarrow \ {e'} + {p'} + {\pi^{
m o}}
ightarrow \end{array}$

- $e' + p' + \gamma_1 + \gamma_2$
- Process is sensitive to chiral-odd GPDs, distinct from DVCS

- CLAS12 data significantly extends kinematic reach compared to previous measurements and with higher statistics
- Currently calculating correction factors and systematic uncertainties to arrive at quantitative conclusions



Beam Spin Asymmetry for Exclusive Vector Meson p0 Electroproduction

Nicholaus Trotta (UConn), Kyungseon Joo (UConn), Andrey Kim (UConn)

- ep -> ep⁰(p): ρ^0 decays into $\pi^+\pi^-$, protons are identified by missing mass, pions only in Forward Detector
- Exclusive vector meson ρ^0 channel is sensitive to GPDs H, E at leading twist and H_T and $\overline{E_T}$ at next leading twist



Mar 2023

Cross section for J/ψ photoproduction

Pierre Chatagnon (Jefferson Lab) & Richard Tyson (Glasgow)

 J/ψ Total Cross Section vs E_v

 E_{v} [GeV]

9.50 9.75 10.00 10.25 10.50

 LD_2 Target (n_{bound} , $J/\psi \rightarrow e^+e$

LD₂ Target (pound, l/w→e⁺e

 IH_{-} Target (p. $IIW \rightarrow U^{+}U^{-}$

8.75 9.00 9.25

Analysis status

- Event selection and particle identification
- Additional use of AI to identify leptons above 4 GeV
- Irreducible backgrounds (from photon conversion and pion decays) are subtracted using same-charge lepton events
- Overall normalization factors obtained from Bethe-Heitler events
- Cross-section extracted for proton (both electron-positron and di-muon channel), bound neutrons and bound protons





Path forward

- Ongoing studies to better understand the overall normalization, especially understand the particle detection efficiencies in both data and Monte-Carlo
- Upcoming pass 2 data will provide greatly improved tracking efficiency, providing significantly more statistics
- Systematic uncertainties remain to be studied



Figure 2: Invariant mass spectrum of the lepton pair after irreducible background subtraction, compared the normalized yields from Monte-Carlo simulation



Beam Spin Asymmetries for $\pi^{\pm}\pi^{0}$ Dihadron Production

Beam spin asymmetries of dihadron SIDIS allow for **targeted** extraction of the twist-3 PDF e(x) and twist-2 DiFF G_1^{\perp}

 $ep \rightarrow e' \pi^{\pm} \pi^0 X$ channel supplements published $\pi^+ \pi^-$ results

Main Challenge: $\pi^0 \rightarrow \gamma \gamma$ has large combinatorial background

- Requires sideband (or sWeighting) procedure for projecting out background asymmetries
- Strict event cuts, <u>increasing purity</u> yet <u>decreasing statistics</u>
 Solution: Train a GBTs model to classify SIDIS photons from bkg.

Inputs: Train on 3 feature types:

- Event-wide information
- Photon intrinsic (E,θ,...)
- Intrinsic to photon's Nearest Neighbors (N-N)

Outputs: 0<p<1 prediction score for each photon

 New N-N approach rejects photons created by secondary interactions



Gregory Matousek (Duke University)

Patrick Achenbach



Studies of Proton Fracture Functions in $ep \rightarrow epX$

Fatiha Benmokhtar and Students, Harut Avakian and Timothy Hayward



Neutral Pion Multiplicity in SIDIS

Number of neutral pions generated in the five-dimensional SIDIS phase space (x, Q², z, p_T^2 , ϕ_h) divided by the DIS phase space (x, Q²).

- Related to the $D^{0}(z)$ fragmentation function describing the probability of quarks fragmentating into neutral pions, and further serve as a test on the isospin symmetry between $D^{0}(z)$ and the charged pion fragmentation functions.
- Extraction of cosine moments from ϕ_h dependence and studying the acceptances utilizing bin-by-bin and multidimensional unfolding methods.
- Preliminary results will be presented at upcoming April APS meeting.



Fig. 1. Semi-inclusive pion electroproduction diagram



Marshall B. C. Scott (ANL)

Example Multiplicities for one x-Q² Bin

x-Q² Bin 1 : M_H(z)



Measurements of the $Cos\phi_h$ and $Cos2\phi_h$ Moments of the Unpolarized SIDIS π + Cross-section at CLAS12

- Working towards the extraction of the $cos(\phi_h)$ and $cos(2\phi_h)$ moments of unpolarized SIDIS cross-section for charged pions using RG-A data
- The collected statistics enable a high-precision study of these azimuthal moments which probe the Boer-Mulders function and Cahn effect
- The high statistics data will, for the first time, enable a multidimensional analysis of both moments over a large kinematic range of Q², x_B, z, and P_T.



