The Long Term Future of Jefferson Lab

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Positron Working Group Workshop
March 7,8 2023
University of Virginia

Starting point: Highlights from February DOE Budget Meeting

- 12 GeV scientific era is going strong
  - More than 30 weeks operation in FY22 and FY23 (planned), enabled by supportive Operations budget
  - High-profile results emerging from 12 GeV program (and still from 6 GeV program)
  - Progressing on CPP with CM refurbishments, C75 CM construction and spares purchases
- Successful partnership with BNL in management, design, construction of EIC Project
  - Developed and defended cost/schedule basis for JLab scope integrated into EIC project plan
- Successful MOLLER Project CD-3a OPA review, on-track; SoLID ready to move ahead
- Exploring exciting scientific opportunities enabled by cost-effective and technically innovative CEBAF upgrade concept
- Multi-Lab Partnerships: SNS PPU (nearing completion) and LCLS-II HE are delivering good project performance
- Very good management of COVID impacts
- Significant developments in DEI culture and safety performance and culture
- Initial steps toward diversifying Jefferson Lab's scientific mission
- Recruiting is at a high pace; a number of great additions to Jefferson Lab, even as we lose expertise to attrition

12 GeV Experiments by PAC Days *(status Feb 15, 2023)*

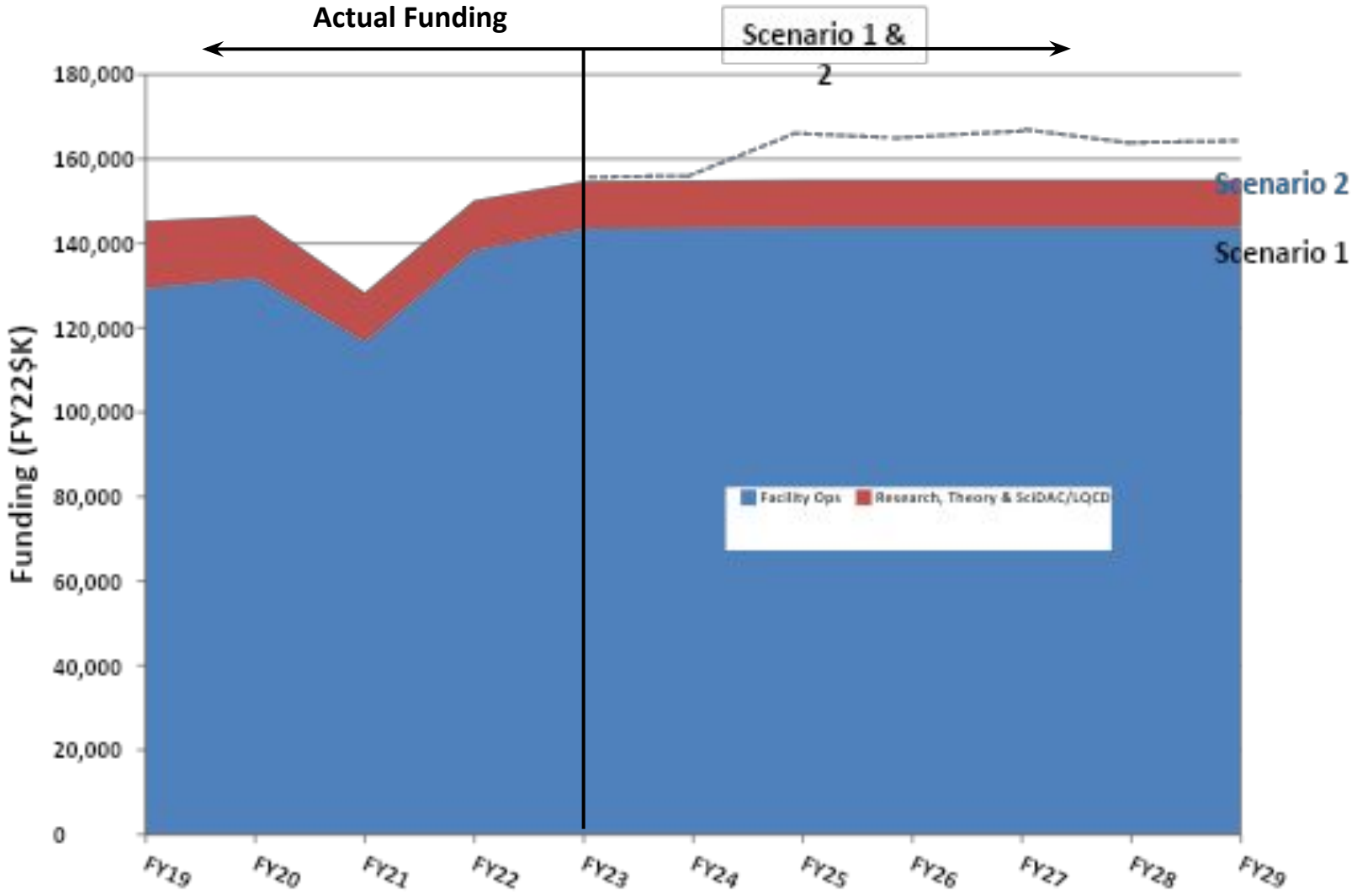
Topic	Hall A	Hall B	Hall C	Hall D	Other	Total
Hadron spectra as probes of QCD	0	3	1	4	0	**8**
Transverse structure of the hadrons	7	4	1	1	0	**13**
Longitudinal structure of the hadrons	1	3	12	1	0	**17**
3D structure of the hadrons	7	9	8	0	0	**24**
Hadrons and cold nuclear matter	9	6	8	1	1	**25**
Low-energy tests of the Standard Model and Fundamental Symmetries	3	2	0	1	2	**8**
Total	**27**	**27**	**30**	**8**	**3**	**95**
Total Completed	**11**	**11**	**8**	**3**	**0**	**33**
Experiments Removed by Jeopardy	**4**	**4**	**3**	**0**	**0**	**11**
Total Experiments Remaining	**12**	**12**	**19**	**5**	**3**	**51**

355 PAC days completed since last February

56 Hall A (SBS target installation), 87 Hall B (power supply failure), 106 Hall C, 106 Hall D

32 weeks = 112 PAC days

Lab Funding Scenarios



Lab Funding (FY22$K)
(without MOLLER, EIC, Generic Detector R&D)

If realized, translates to optimal running….

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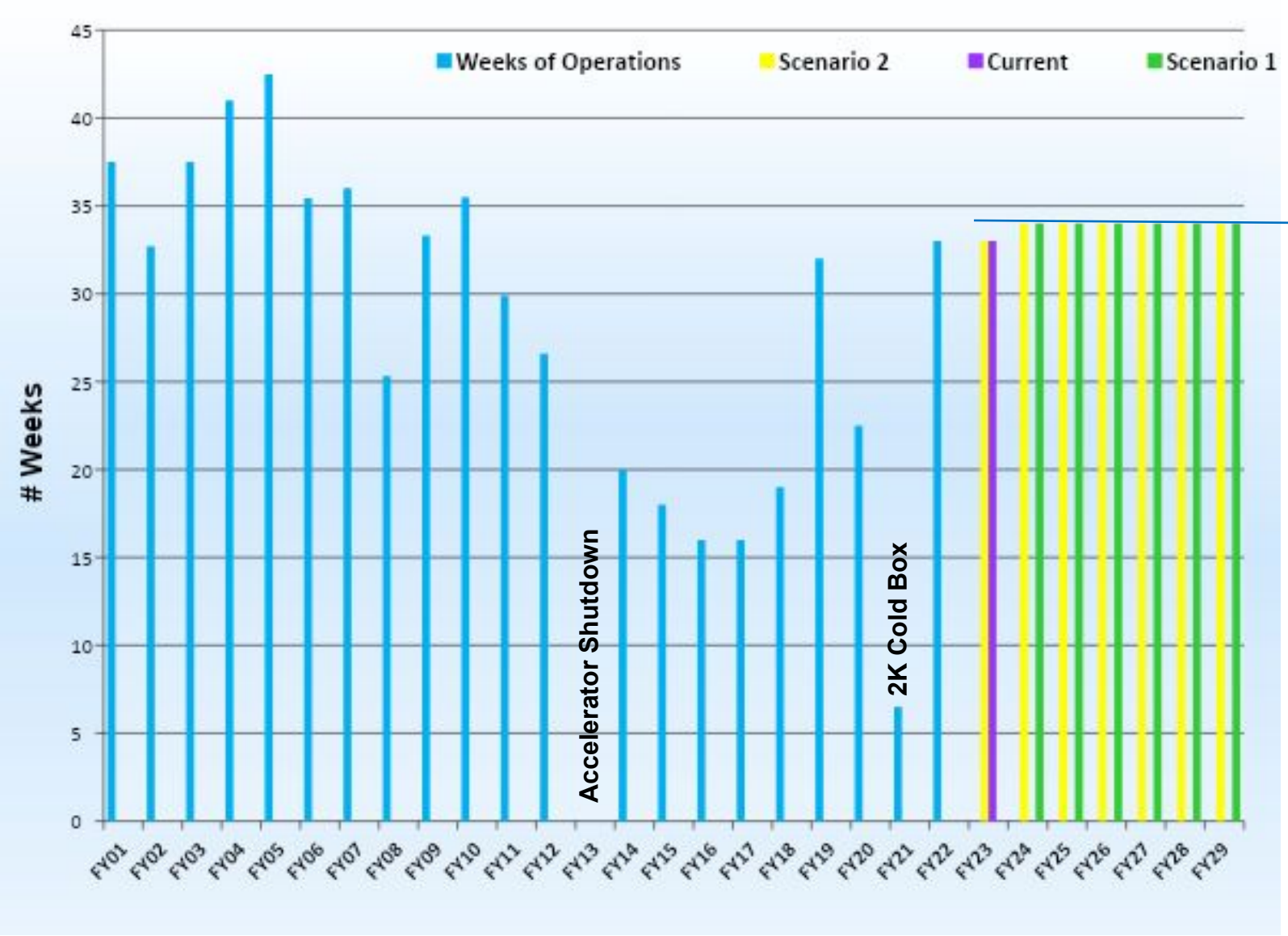
CEBAF Weeks of Operations



Scenarios 1 & 2: Execution of 86% of approved Program*

*** Without SoLID or conditionally approved experiments**

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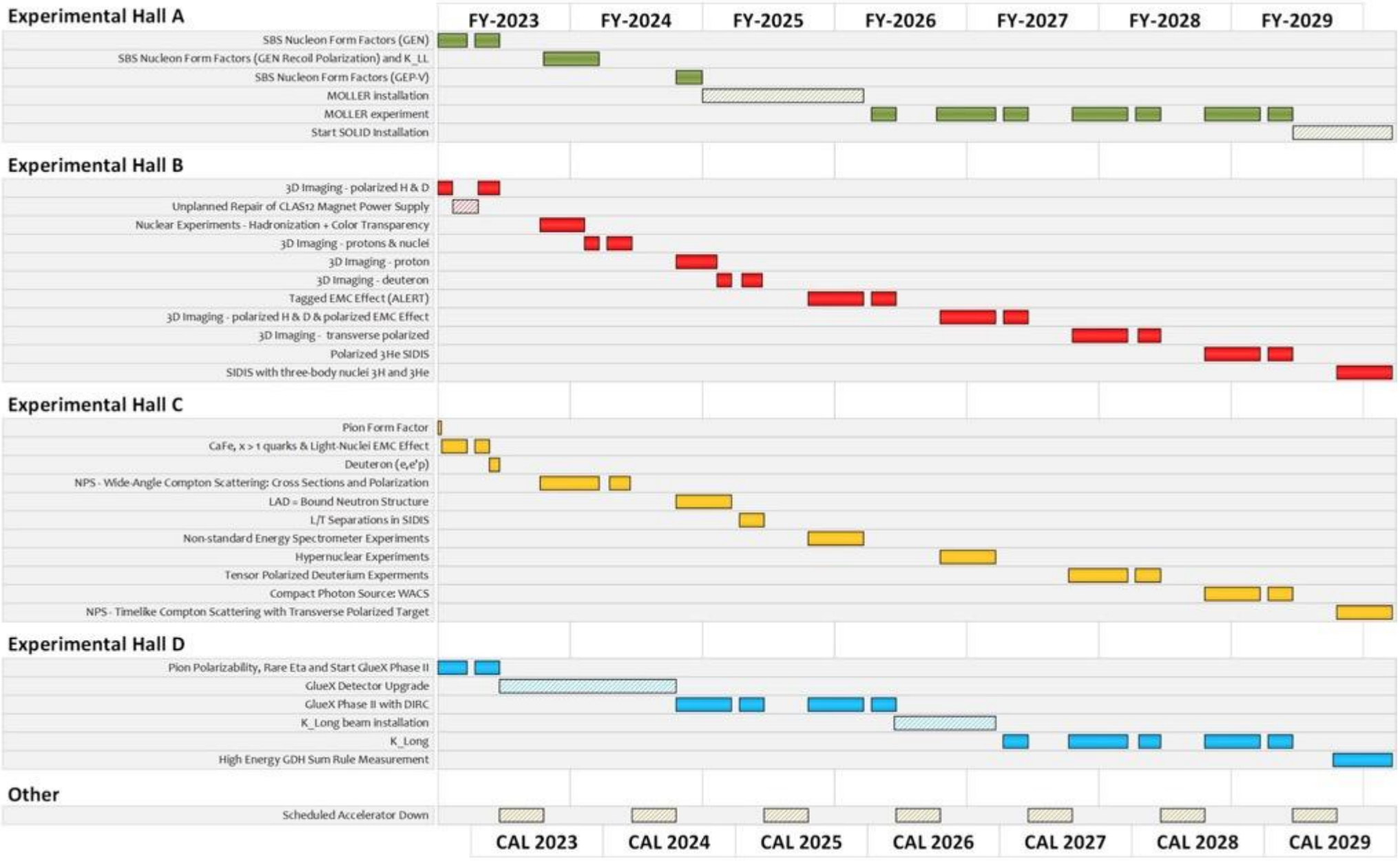
JLab – Long Term Schedule (in preparation…)



- Low luminosity experiments scheduled in Hall C for compatibility with MOLLER
- SoLID installation could start ~mid-FY29
- 86% complete in FY29 without SoLID, 70% complete with SoLID

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Probing the Standard Model to 27 TeV

Elastic scattering of longitudinally polarized electrons on unpolarized electrons

$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \qquad \vec{e} + e \rightarrow e' + e'$$

Parity violating asymmetry:

A_{PV} ~ 33×10^{-9} or 33 ppb (parts per billion)

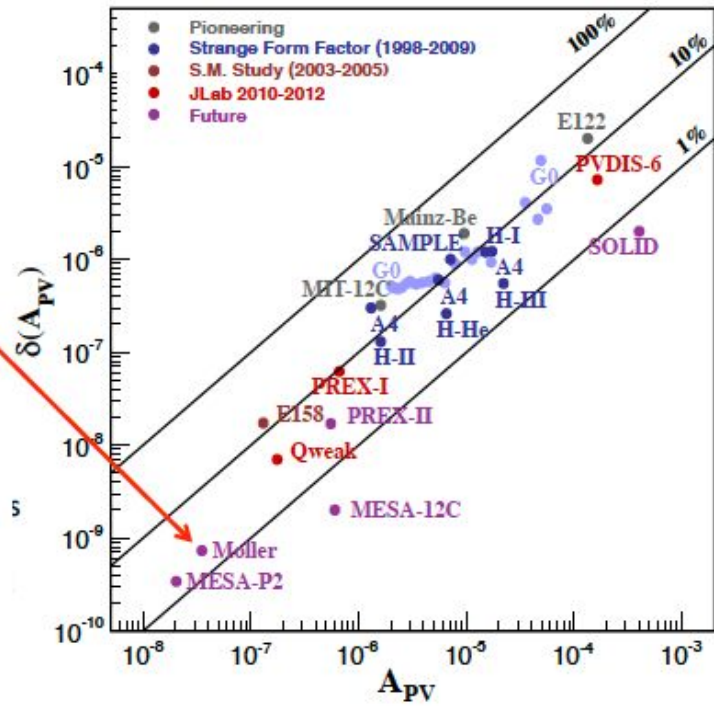
δA_{PV} ~ ± 0.8 ppb (2.4% precision)

→ next generation in size and precision of asymmetry for parity-violating electron scattering experiments

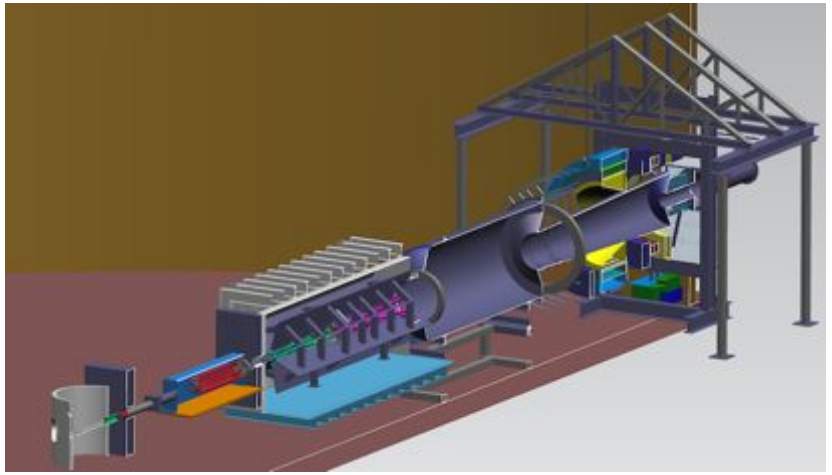
proportional to the electron's weak charge Q^e_W
- precisely predicted in Standard Model

At tree level $Q^e_W = -\left(1 - 4\sin^2\theta_W\right)$

2.4% precision on Q^e_W 0.1% on $\sin^2\theta_W$



Slide from Mark Pitt



MOLLER will probe energy regions for Beyond Standard Model Physics to ~27 TeV in this Q-weak sector

LHC energies: 13 TeV

OPA review, January 2023: "Proceed to CD-3A after updating cost estimates, risks, and the contingency analysis (for the CD-3A scope)."

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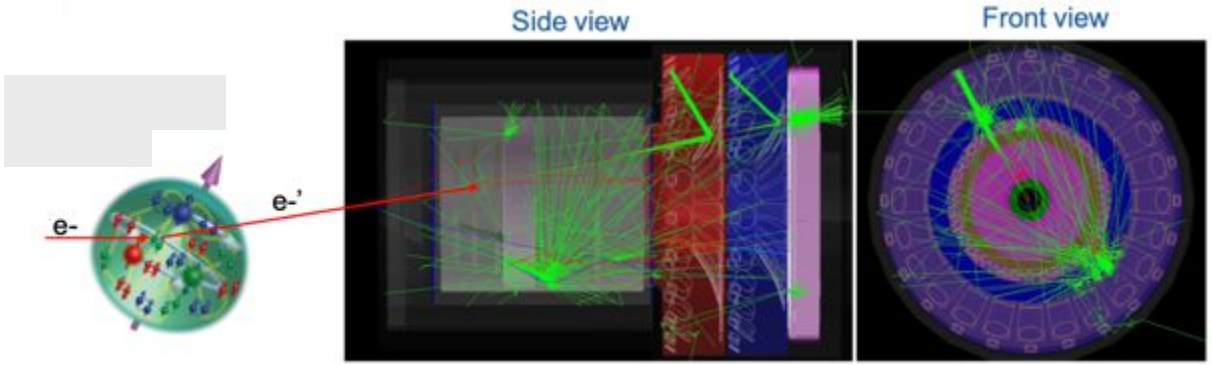
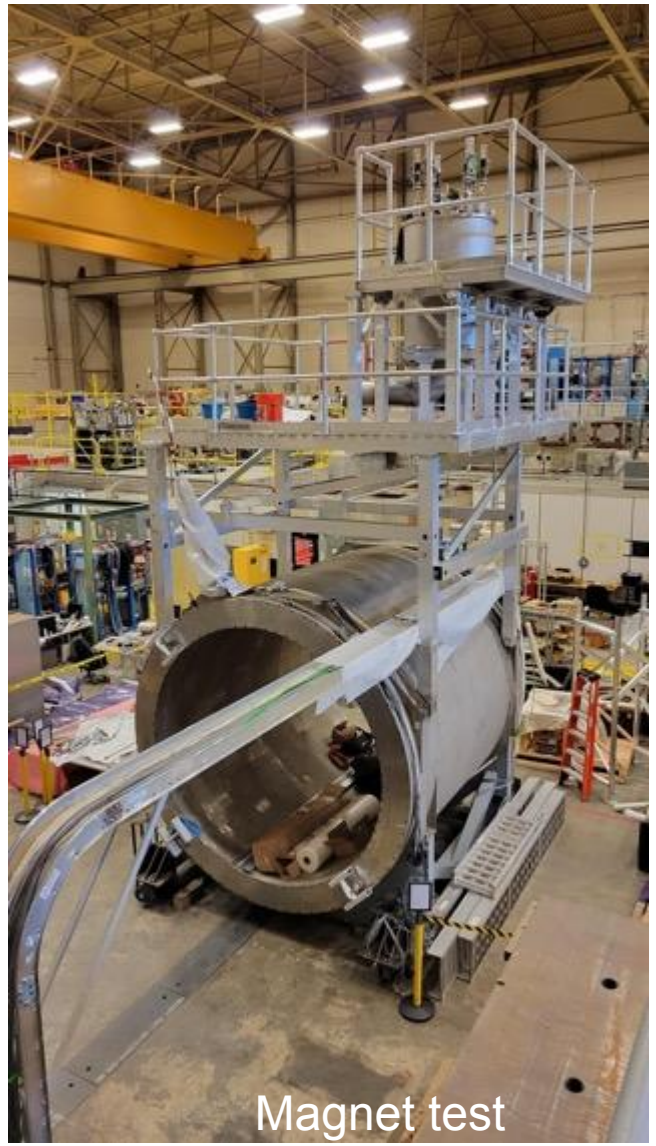
SoLID fully enables CEBAF 12 GeV at the Intensity Frontier

- Nucleon spin, proton mass, BSM experiments require precision measurements of small cross sections and asymmetries, combined with multiple particle detection
- High luminosity 10^{37}-10^{39} $cm^{-2}s^{-1}$ **and** large acceptance working in tandem
- Science reach
  - Precision 3D momentum imaging in the valence quark region
  - Exploring the origin of the proton mass and gluonic force in the non-perturbative regime
  - Beyond Standard Model searches complementary to Moller



Awaiting Science Review Report



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EIC R&D (Project and generic) highlights with strong JLab synergy

- Generic EIC Detector R&D ($2M) funded and R&D starting
- MPGD-based R&D:
  - Development of cylindrical mRWELL prototypes with capacitive-sharing readout and small drift space
  - Small 10 x 10 cm2, working towards 30 x 30 cm2.
  - Synergy with Hall B luminosity upgrade (x 2-3 increase)
  - Beam test in Hall D
  - Spatial resolution of ~60 μm (s) achieved, operating at 98% efficiency
  - Synergy with medical imaging: e.g., development of GEM-based proton computed tomography device and hadron therapy beam QA device (with recent beam test at HUPTI).
- Proceeding with prototypes of ESR 591 MHz single cell and 197 MHz crab cavity
  - Prototype RF designs complete and reviewed
  - Fabrication plans reviewed, materials ordered
  - Dies and tooling in fabrication
  - First article cryomodule designs started
  - Successful test of 5-mode harmonic kicker in UITF
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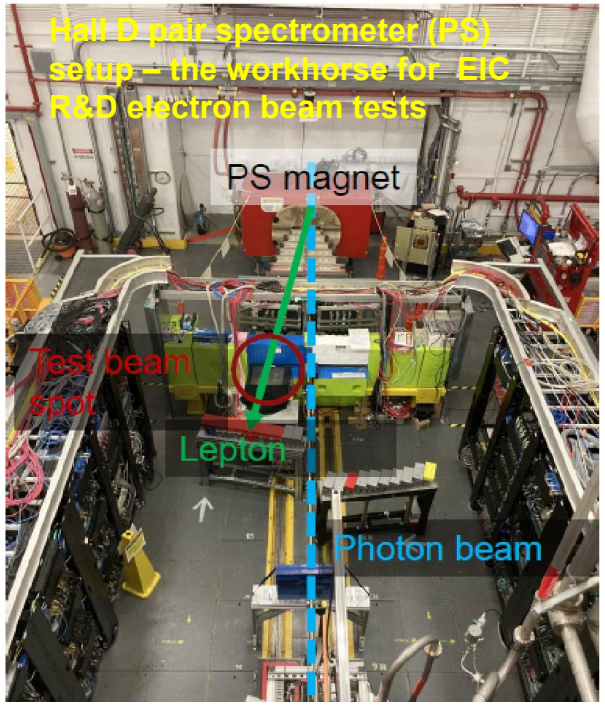
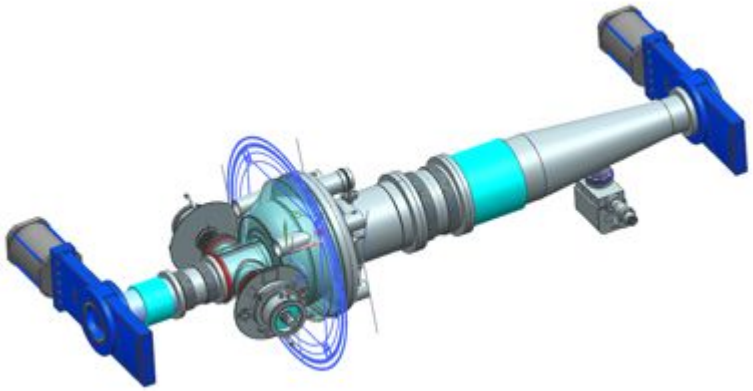
- SHC ERL studies underway





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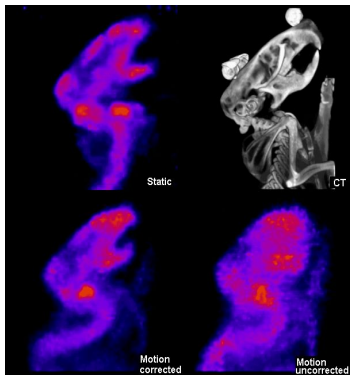
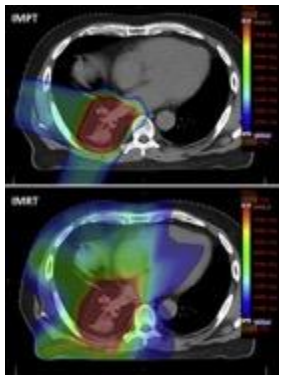
Detector R&D (NP Applications) – New Initiatives

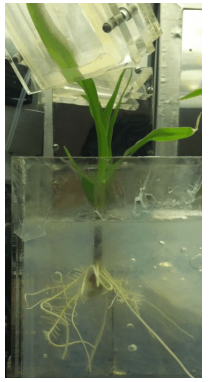
US-based MicroPattern Gaseous Detector Center - A Community User Facility

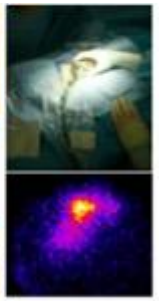
- Large number of US institutions engaged in MPGD activities
  - Limited inter-disciplinary interaction between the institutions
- The community needs a dedicated US-based MPGD User Facility with a:
  - Production workshop like to the SiDet Facility for at FNAL
  - Detector R&D Lab like the RD51 / GDD Lab at CERN
- US-MPGD center will be greatly beneficial for EIC detector development
- Jefferson Lab is an excellent place for an MPGD center in the US
  - At the forefront in the deployment of large MPGDs in NP experiments
  - In-house MPGD expertise and beam test capabilities for MPGD tests

BRIC | Biomedical Research & Innovation Center









Leverage nuclear science capabilities for biomedical applications

Launch event this month with Dr. Berhe at Jefferson Lab!

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Accelerator Highlights – CEBAF near future

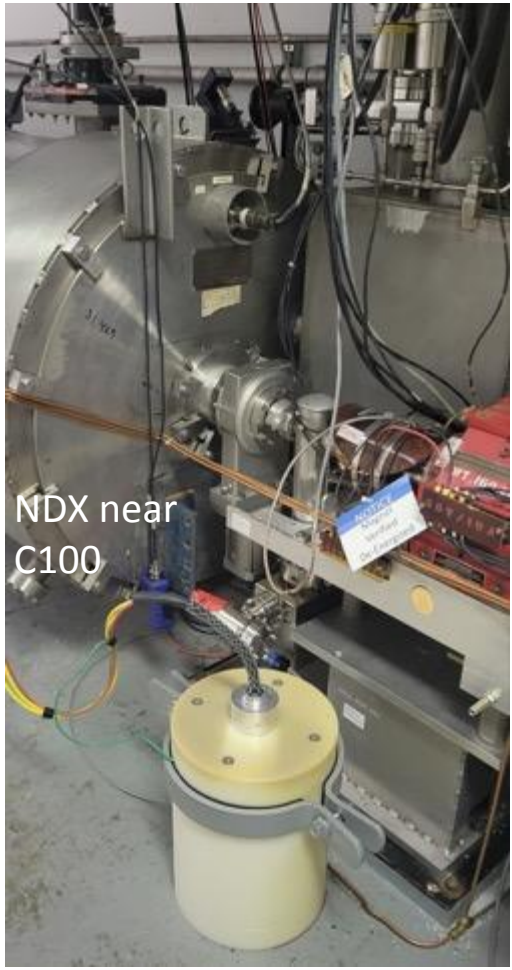
- Injector upgrade
  - CEBAF beamline rebuilt with 200 keV magnets, upgraded Wien filters and improved vacuum quality
  - SRF Booster (10MeV, 2&7 cell) commissioned at UITF 2021/22 and will be installed in CEBAF during FY23 SAD
  - The upgrade reduces helicity correlated asymmetries for the Parity Quality Beam program


Booster in UITF

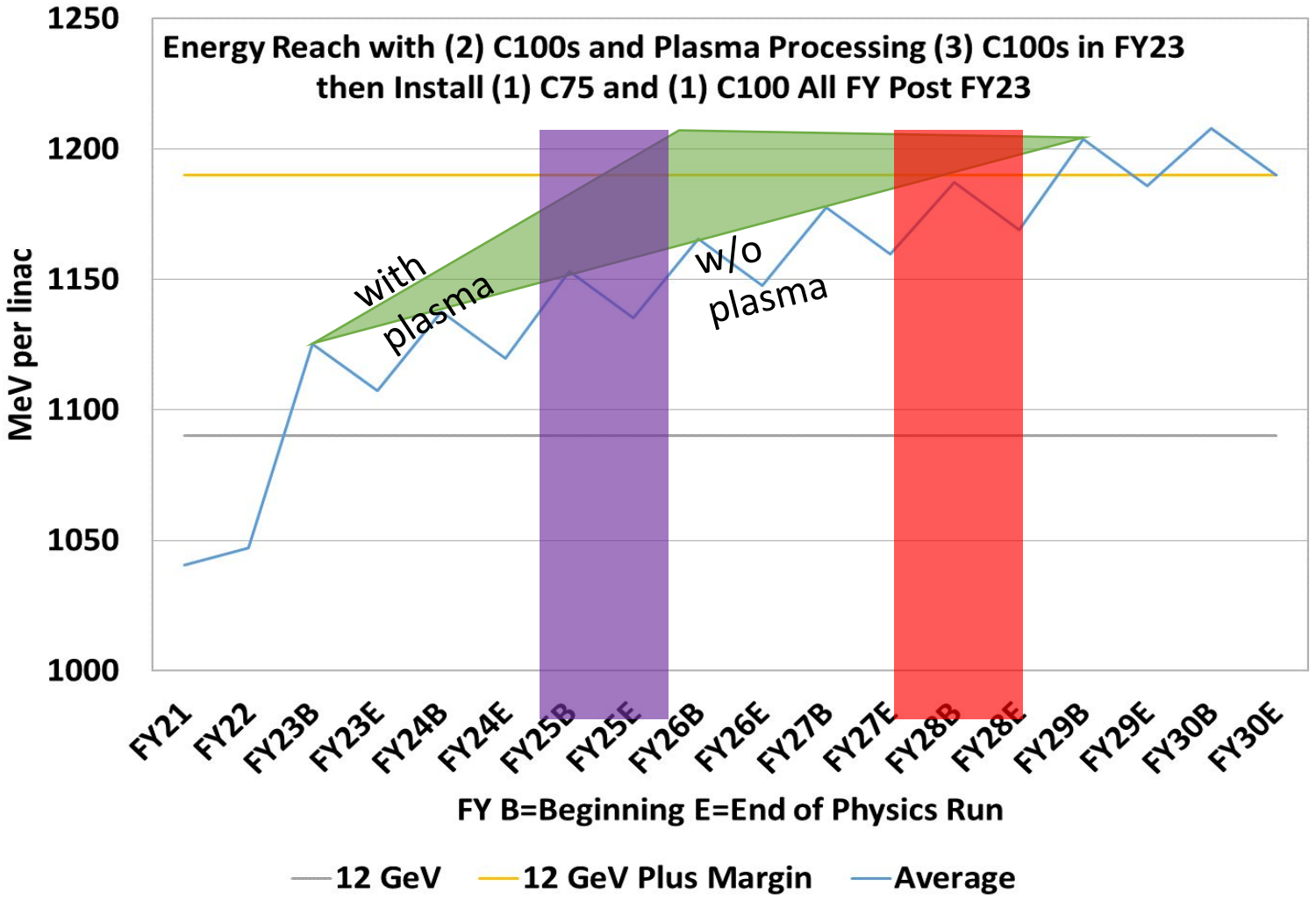

Plasma discharge in different cells

- Plasma processing
  - Developed for C100 cryomodules
  - Performed 40 cavity process cycles to establish procedures
  - Application to C100-05R in June '22 showed an overall 12 MV gain
  - Will plasma-process 3 CMs in CEBAF tunnel during FY23 SAD
  - Developing the process for C20/C50/C75
  - Incorporation into CPP provides a faster path toward 12 GeV

- Developing AI/ML for use in CEBAF Control Room
  - Broad program across Field Emission Management, SRF Fault Identification/Prediction, Heat Load/Trip Rate Management and Beam Transport Error Mitigation
  - Continuing use of NDX neutron detectors for gradient optimization and reduction of radiation levels


NDX near C100

Energy Reach with and w/o plasma processing



- Assume 2CM per year (one new C75)
- Then w/o plasma can get 12GeV with 100MeV margin around beginning of FY28

- If plasma-process 3CM/year, and it will give 30MeV increase (=15MeV/linac increase), climb up in energy accelerates (green triangle)
- With plasma, optimistically can get to 12GeV with 100 MeV margin in the middle of FY25

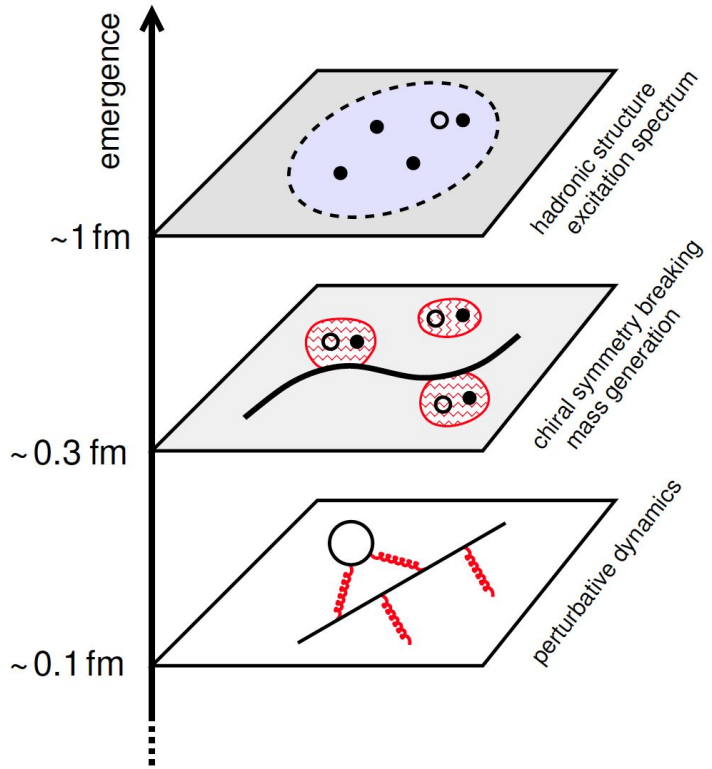
- Large uncertainly in predictions, need results of this SAD plasma treatment and data from C20/C75/C50 plasma development to give more accurate estimate

Computational Capability for 12 GeV Transitioning EIC Era

- Strong track record of accomplishments supporting the 12 GeV program and moving towards “self driving” EIC detectors.
  - SciComp Systems:
    - Deploying xrootd; deployed SciTokens
    - EIC resource delivery
    - ePIC adopts JLab software framework
  - AI/ML:
    - Experimental Control—online calibration of the GlueX Central Drift Chamber
    - Hydra AI/ML monitoring in use in all four halls
  - Streaming Readout (SRO):
    - Streaming software chain deployed for GlueX and EIC
    - Synergistic with ASCR funded activities and LDRDs
- Goals:
  - Production real-time applications for 12 GeV program
  - Support for ePIC S&C conceptual design report
  - FY29: Proof of concepts for EIC self-driving detectors with full SRO, real-time calibration, and data/theory/simulation comparisons.
- EIC Joint Institute for Computing and Software established
  - Provides coordination and execution of host lab responsibilities in computing

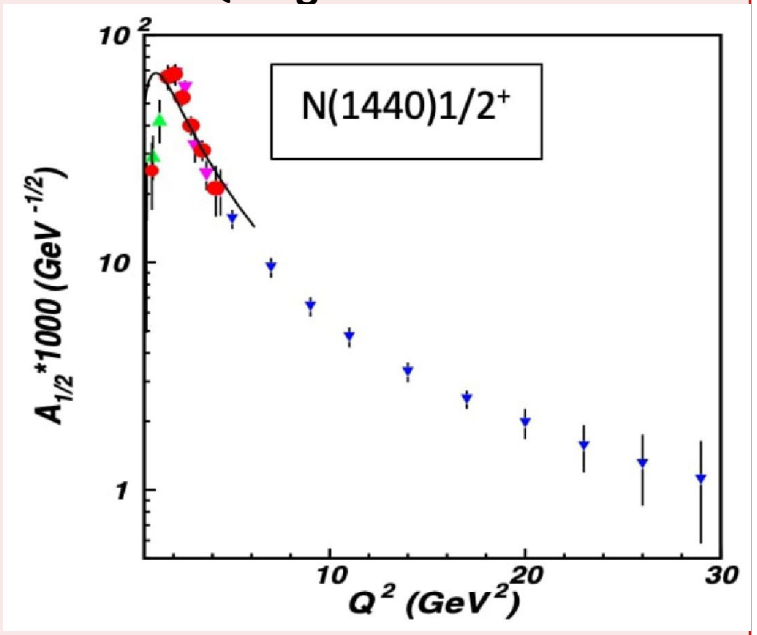
A CEBAF Energy Upgrade – the Big Picture

- How do hadrons emerge from fundamental QCD principles?
- Study of the quark-gluon dynamics which determines the structure of hadrons and hadron-hadron interactions
  - Spectroscopy
  - Excited hadronic states
  - Hadron structure
  - TMDs, GPDs
  - Hadronization
- What an upgrade brings:
  - Builds upon a world-leading program of investigation in the valence region (x>~0.1)
  - Validation of theory (we rely on QCD inspired models in this regime)
  - Deeper access to and understanding of the structure of strongly-interacting quark gluon systems
  - Opens new opportunities for studies of the charm sector



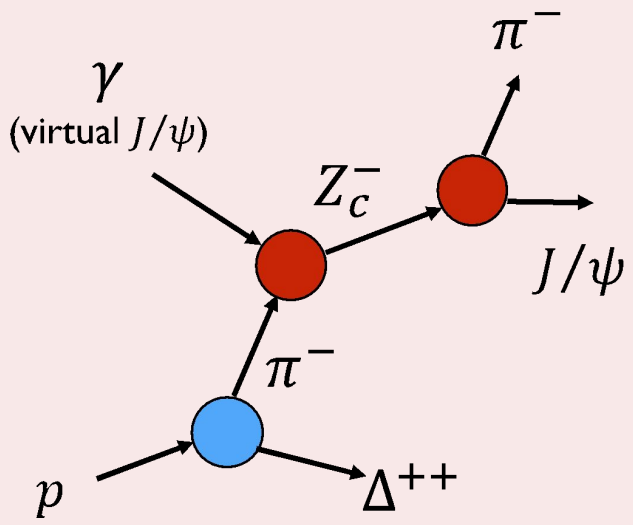
Scientific vignettes for the 22 GeV upgrade

How does QCD generate hadrons?



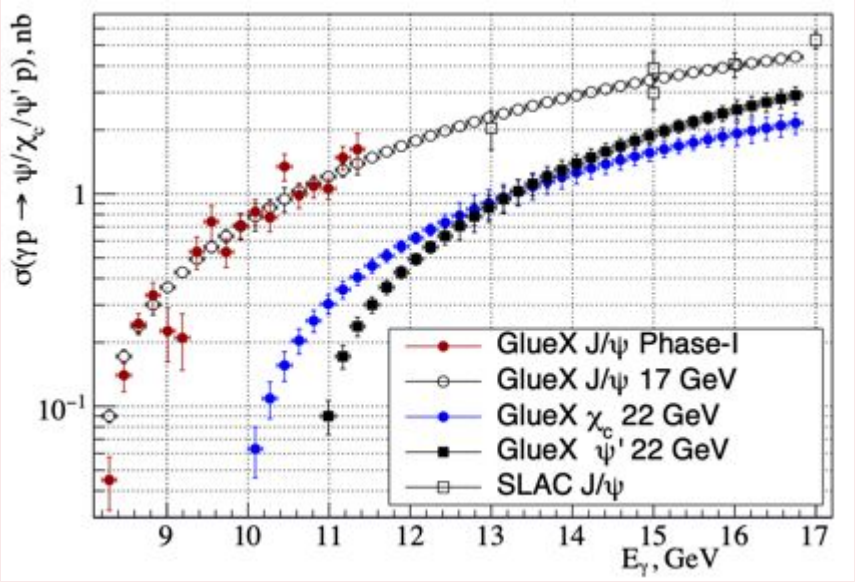
- Q^2 evolution of the $\gamma_v pN^*$ electrocouplings could offer an insight into hadron mass generation and the emergence of the N* structure from QCD
- Simulations indicate JLab22 is the only foreseeable facility to extend these measurements up to 30 GeV^2 and down to α_s/π=0.15 where non-and perturbative QCD coexist.

Are there pure exotic states?



Direct (photon) probe of the $Z_c \to J/\psi\pi$ coupling without rescattering effects provides unique complementary data to constrain interpretation of e^+e^- data.

Can we harness threshold charmonium production to probe proton/gluon properties?



Exclusive charmonium production near threshold probes gluon/mass properties of proton (mass radius, gravitational form factors, D-term, anomalous contribution to proton mass), however

- assuming factorization
- assuming two-gluon exchange

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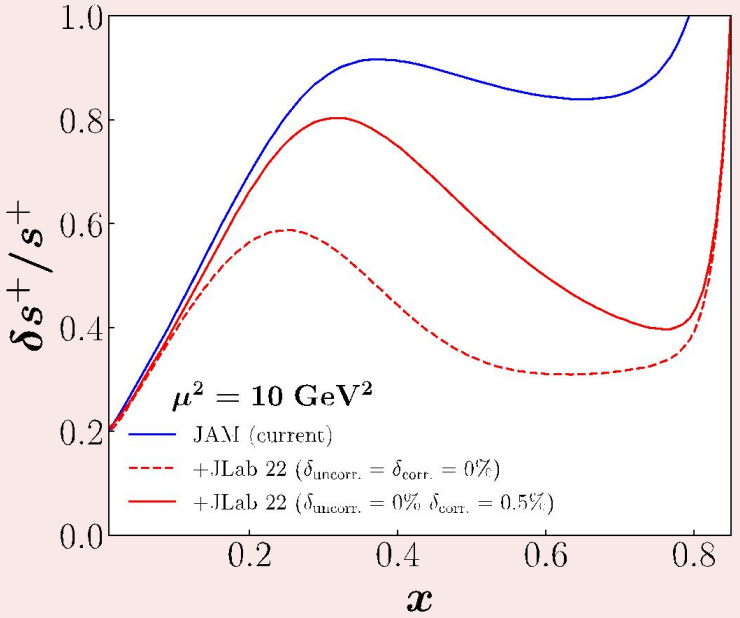
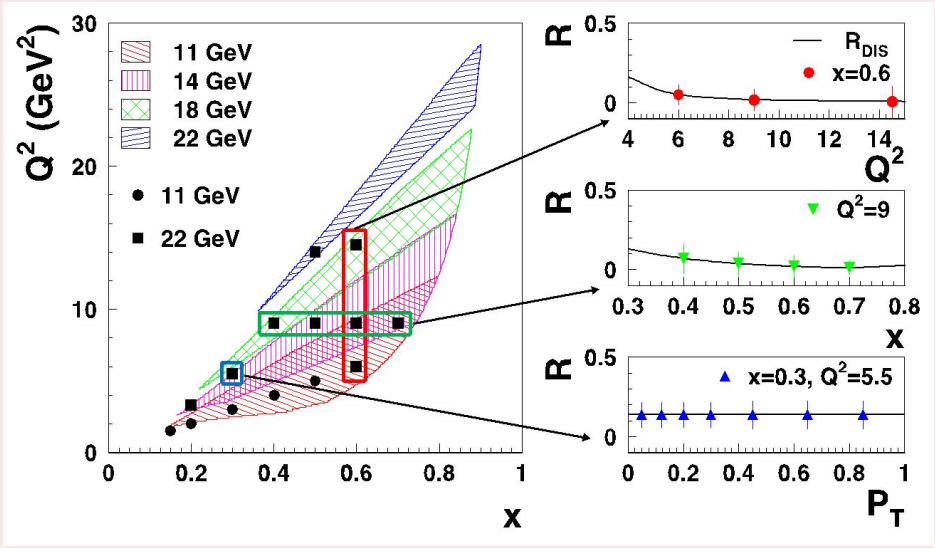
Scientific vignettes for the 22 GeV upgrade

Partonic structure and spin



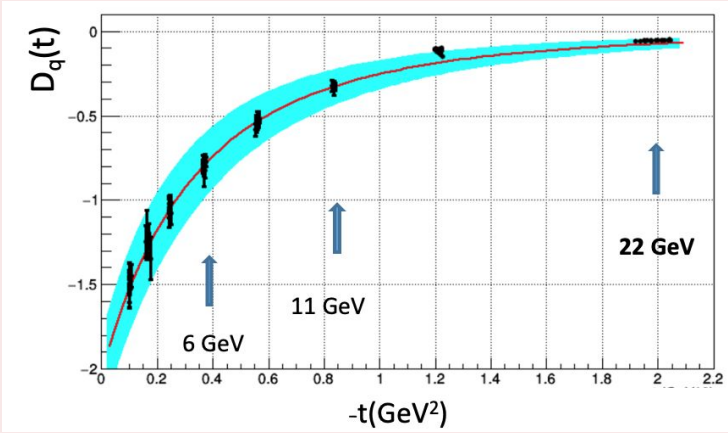
- Impact of JLab 22 GeV DIS PV data with the SoLID detector on nucleon's s+ = s + s̄ PDF.
- The nucleon strange sector is largely unexplored, with an up to 80% uncertainty in the s+ = s + s̄ PDF. Parity violating Deep Inelastic Scattering (PVDIS) of electrons offers a unique opportunity to provide data for global PDF extractions.

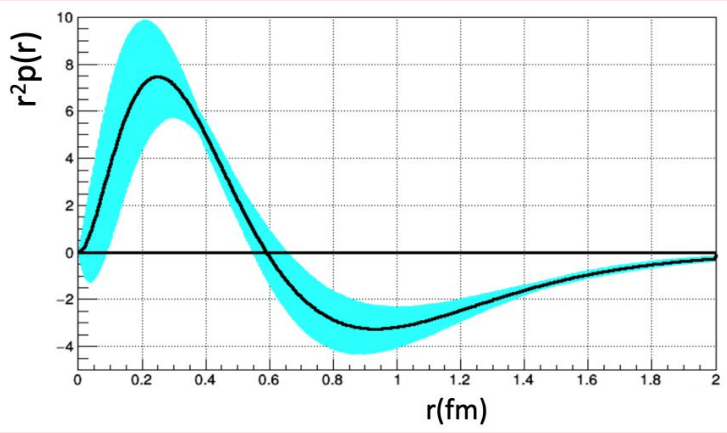


Enhanced 3D imaging

A combined 11 and 22 GeV SIDIS program will increase our ability to measure a variety of SIDIS SFs acrossan enhanced, multidimensional phase

DVCS provides access to gravitational form factors





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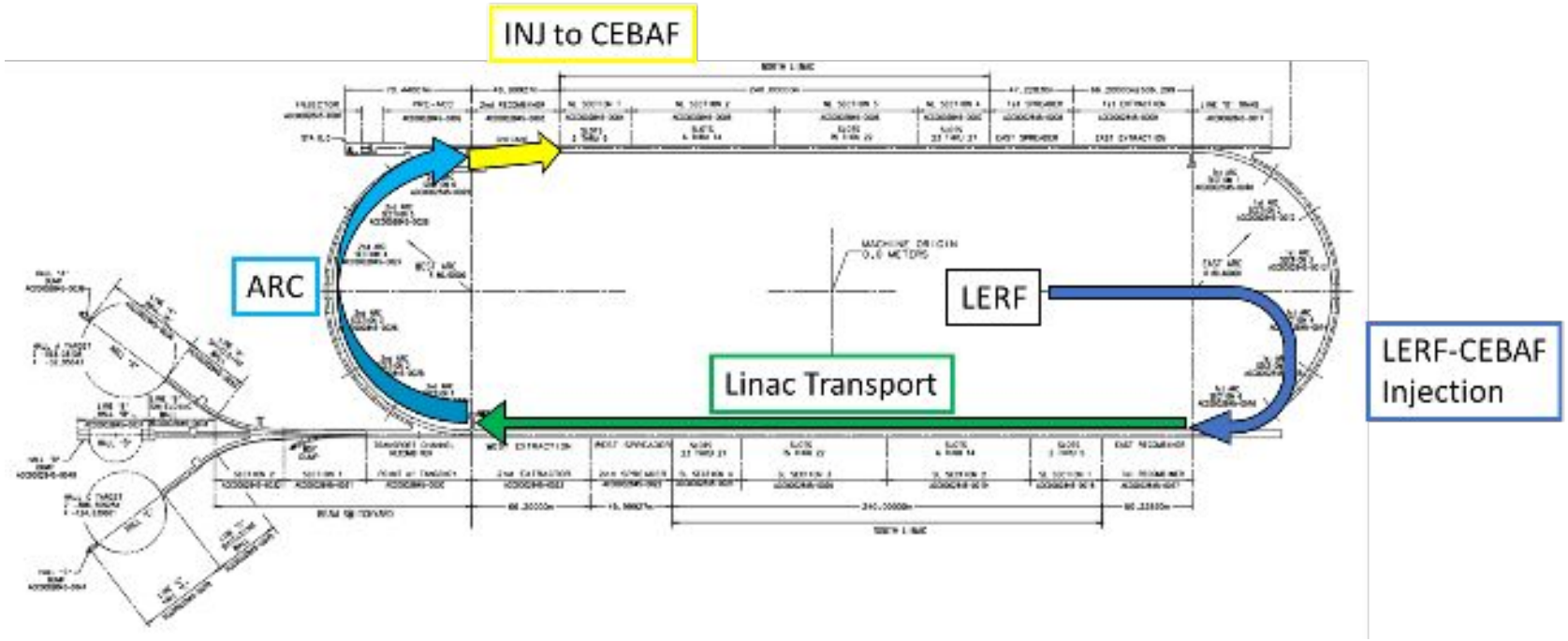
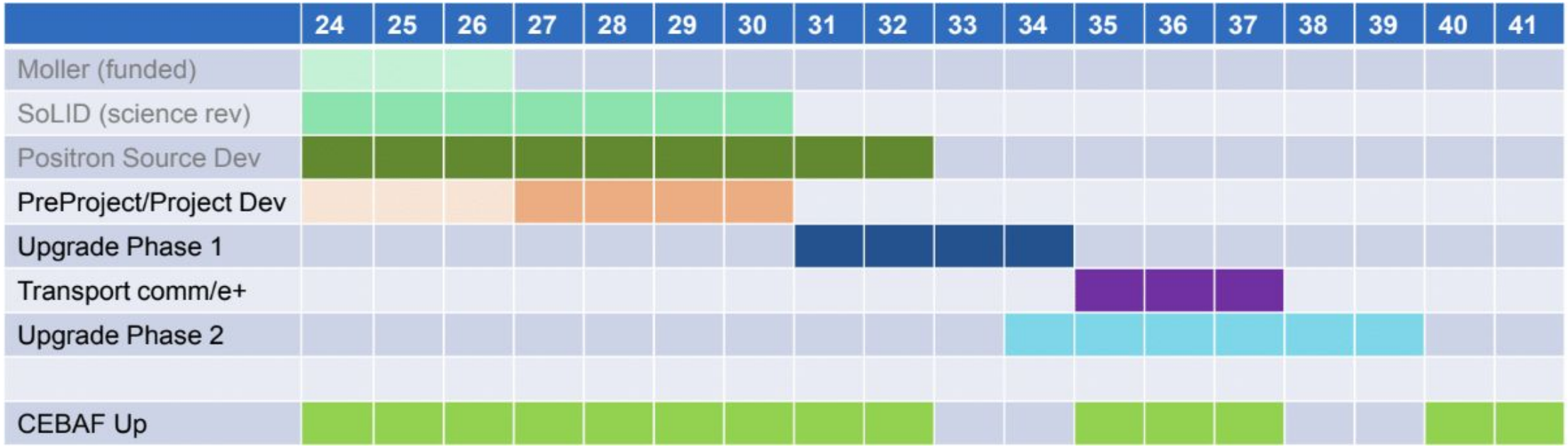
Feasible, cost effective, innovative path from positrons to 22 GeV

- Capitalizing on recent science insights and US-led accelerator science and technology innovations, develop a staged program at the luminosity frontier:
- Positrons (e+) in the LERF (former FEL) with transport to CEBAF
- Injection energy upgrade for 650 MeV Electron (e-) in LERF
- Replace arcs on each side with new FFA permanent magnet arcs to upgrade to 22 GeV



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



- 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)

JLab into the future

- QCD manifests fascinating complexity (‘more is different’)
  - Large research facilities like CEBAF are required to understand the implications of QCD in experiments
  - CEBAF has a long program ahead that is complementary to the envisioned EIC program (science case)
- CEBAF will remain the prime facility for fixed target electron scattering at the luminosity frontier
  - A groundbreaking experimental program has been developed stretching well into the 2030s
  - MOLLER is fully funded, and SoLID enables CEBAF to reach its full intensity capability
- We are developing an exciting technical path toward e+ @ 12 GeV and e- @ 22 GeV
  - Accelerator R&D in FY25, FY26, and FY27

Perspective

- The Lab is in a strong position moving forward
- Supportive funding for CEBAF Operations
- Our priorities are clear:
  - Ensuring that the 12 GeV program is successful in all facets
  - Moving EIC forward
  - Diversifying Jefferson Lab's scientific mission
  - Laying the groundwork for an exciting role for CEBAF in the EIC era – positrons and 22 GeV
  - Increasing our impact in accelerator S&T

Thank you!