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Future Possibilities at Jefferson Lab (JLab)

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New Ideas in Dark Matter Workshop
March 23-25 2017

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Outline

- Jefferson Lab (JLab)
  - JLab Introduction
  - Continuous Electron Beam Accelerator Facility (CEBAF)
  - Low Energy Recirculator Facility (LERF)
  - Experimental End Stations (aka Halls)
- JLab Experimental Program
  - Overview
  - JLab Dark Matter Experiments
- Summary

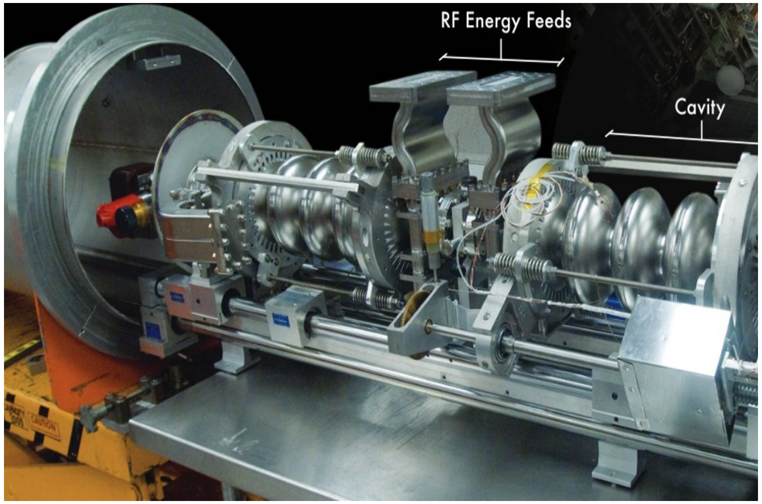
Jefferson Lab

Operated for the DOE Office of Science-Nuclear Physics

Jefferson Lab Research:
- Experimental, computational and theoretical nuclear physics
- Accelerator Science, SRF technologies and FEL
- Radiation detectors and medical imaging
- Cryogenic technology
- 1530 users from 236 institutions and 31 countries

CEBAF

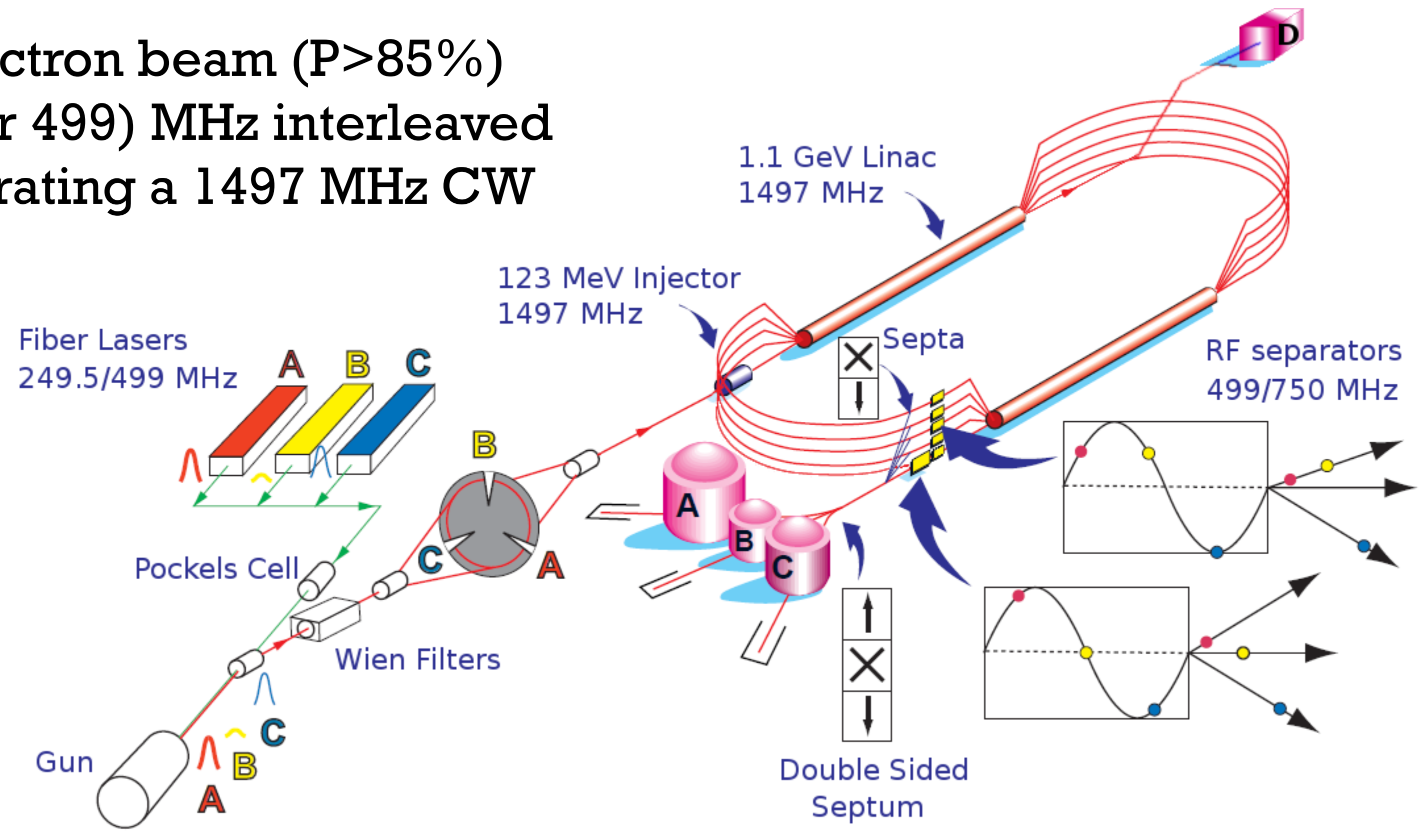
SRF



Cryogenics

12 GeV CEBAF Overview

- Polarized electron beam (P>85%)
- Four 249.5 (or 499) MHz interleaved beams, generating a 1497 MHz CW beam

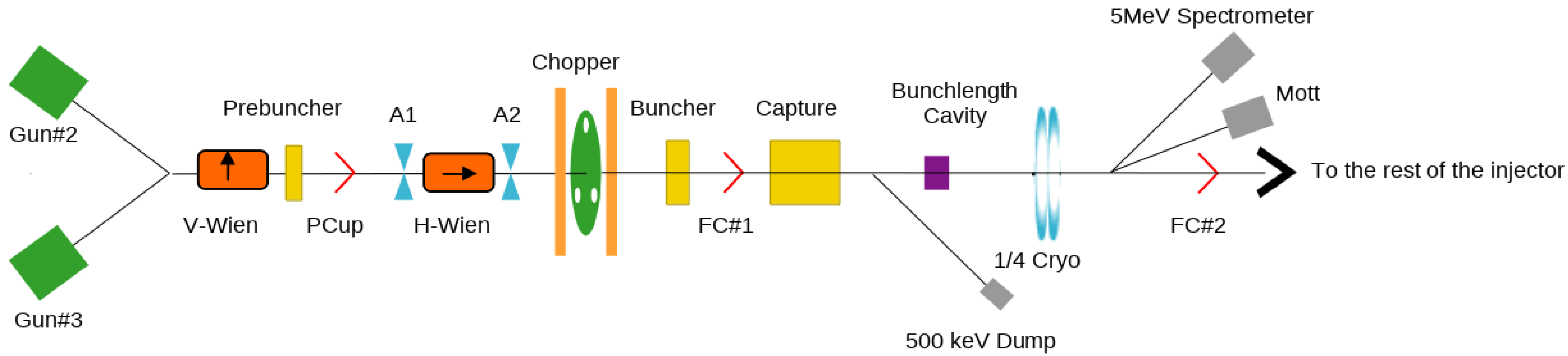


- CW SRF linacs
- Design energy 2.2 GeV/pass:
  - 5 passes, 11 GeV (Halls A,B & C)
  - 5.5 passes, 12 GeV (Hall-D)

- Flexible extraction options for ABC, 1st…5th pass
- Hall A & C 1 MW high power dumps

CEBAF Injector

Beam properties at the experimental target are determined by the beam properties in the injector.



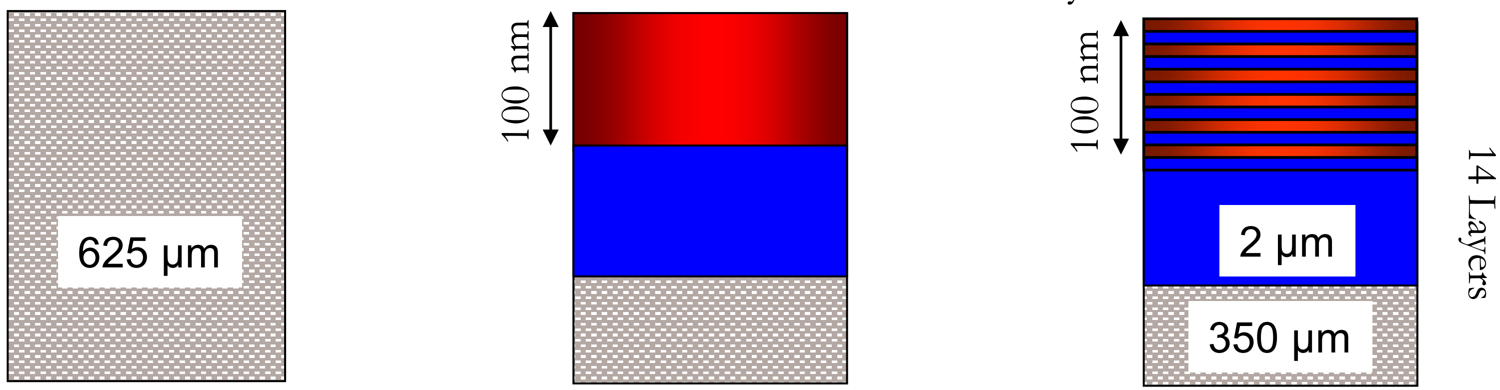
- Four lasers used to create 4 independent electron beams (249.5 or 499 MHz repetition rate).
- Strained GaAs cathode produces polarized beam with polarizations over 85%.
- Polarization is flipped (flip rate up to 1 kHz)
- Gun Voltage 130 kV (upgrade planned to 200 kV)
- Longitudinal Spin alignment at the hall achieved via Wien filters
- Large dynamic range in beam currents: nA's to Halls B&D, 100's μA to Halls A&C

CEBAF GaAs Photocathode Evolution

Bulk GaAs

Strained GaAs: GaAs on GaAsP

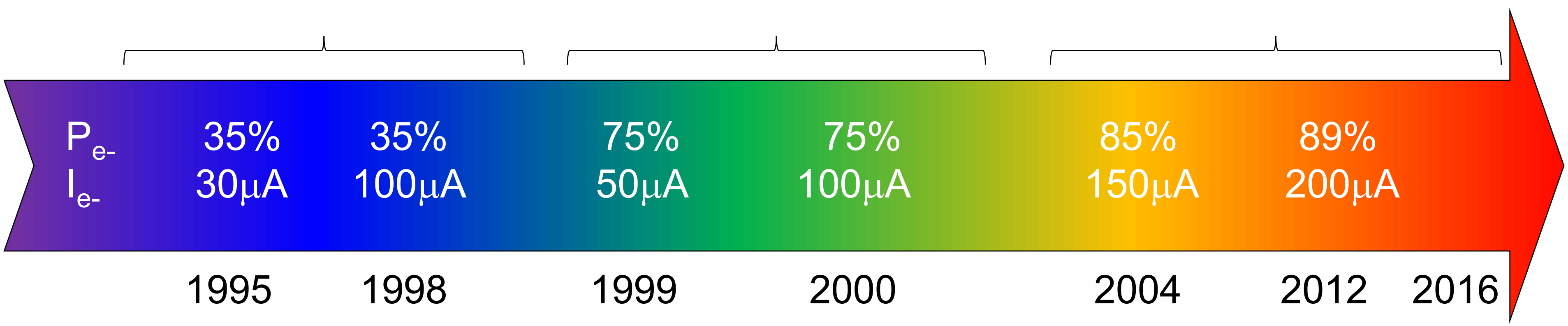
Superlattice GaAs: Layers of GaAs on GaAsP



QE ~ 5%, 30 mA/W
Pol ~ 35% @ 780 nm

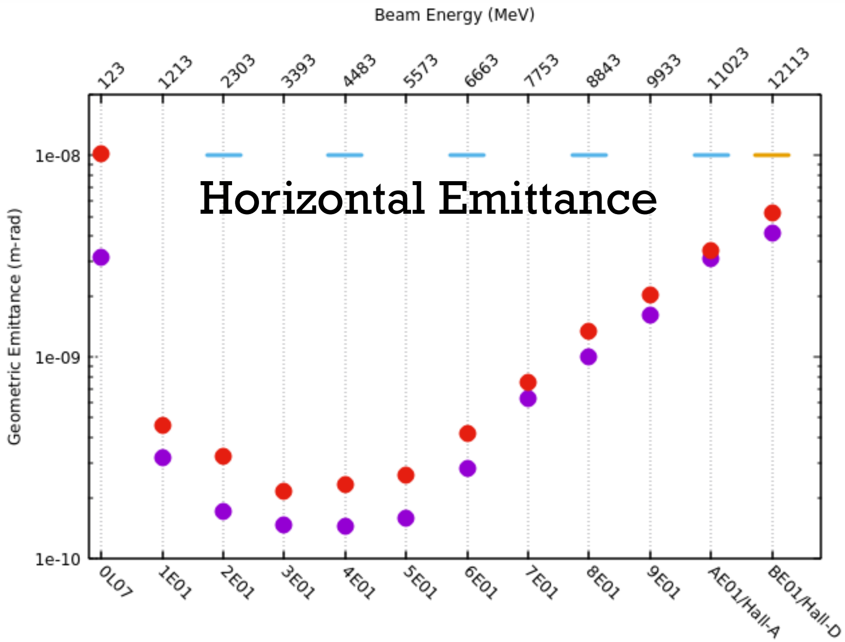
QE ~ 0.2%, 1 mA/W
Pol ~ 75% @ 850 nm

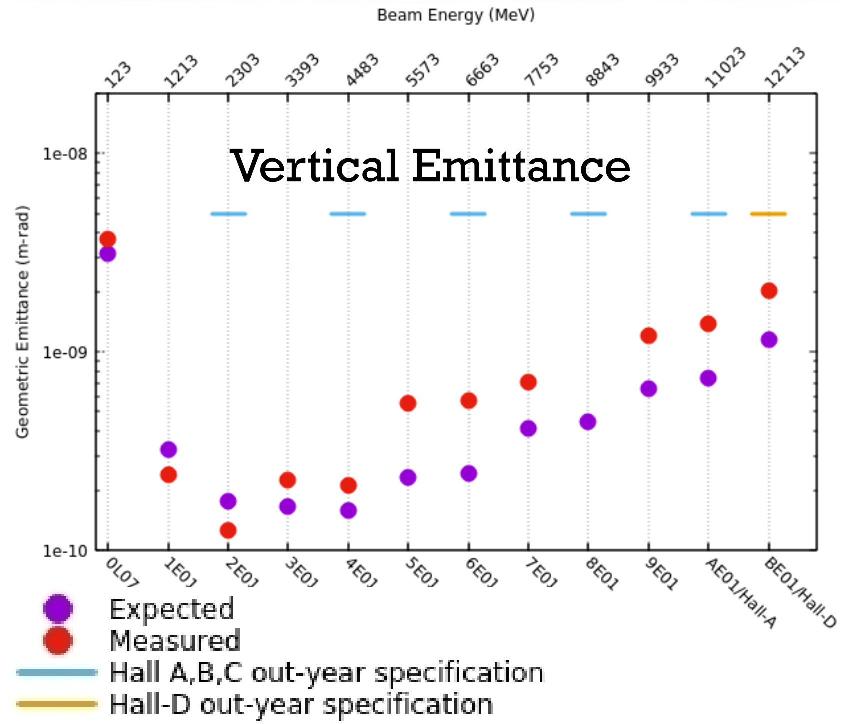
QE ~ 1%, 6 mA/W
Pol ~ 85% @ 780 nm

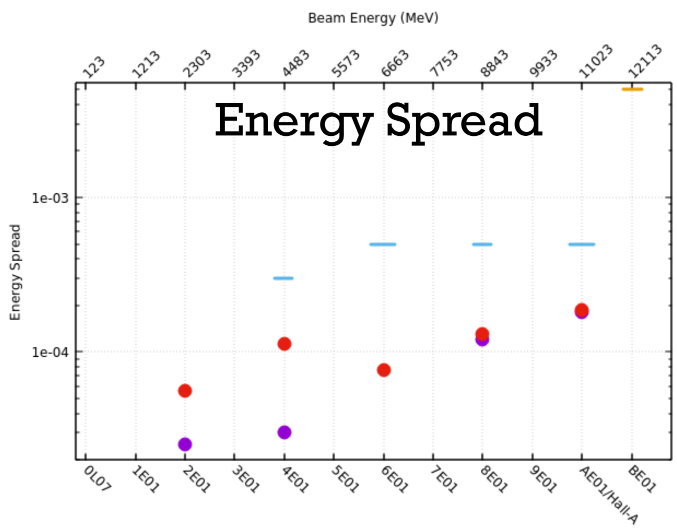


Spin Polarized Electron programs (particularly Parity Violation (PV) Users) have driven the need for improved performance over last 20+ years

Beam Parameters @ 12 GeV (2.2 GeV/pass)



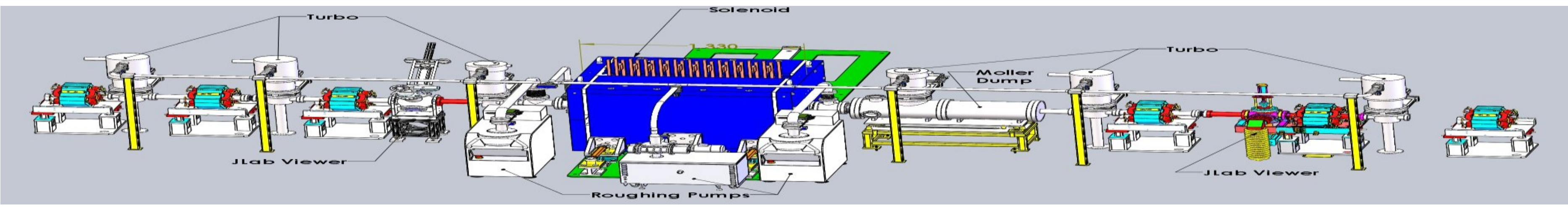


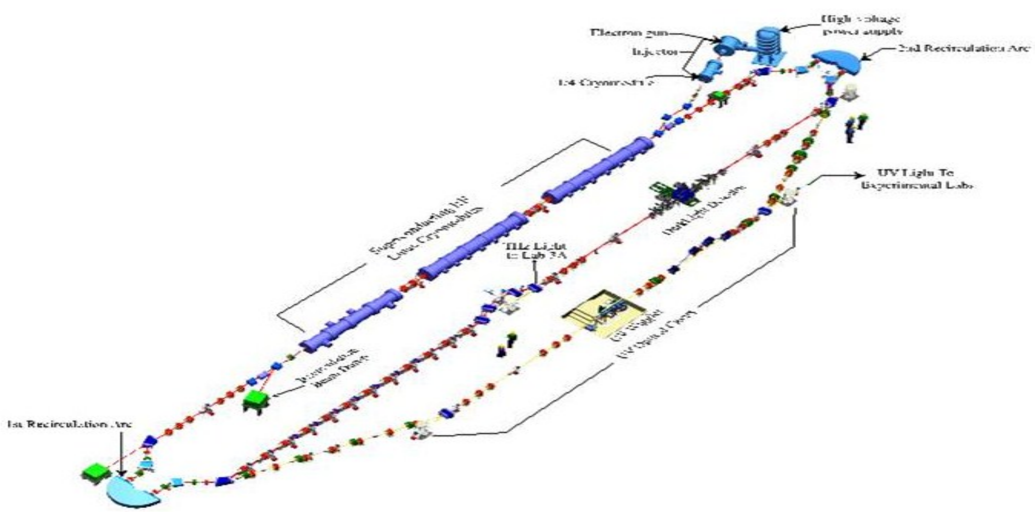


- **12 GeV CEBAF beam transport ready to support the physics program**
- Growth in emittance/energy spread due to synchrotron radiation.
- Accelerator modeling of growth in emittance/energy spread agrees well with expectations.

LERF (formerly FEL)

- Consists of an energy-recovery superconducting linear accelerator of ~170 MeV
- IR and UV wigglers exist to create laser light
- The accelerator is fully operational, but suffers from lack of funded operating hours
- Beam was successfully delivered to the DarkLight in August 2016



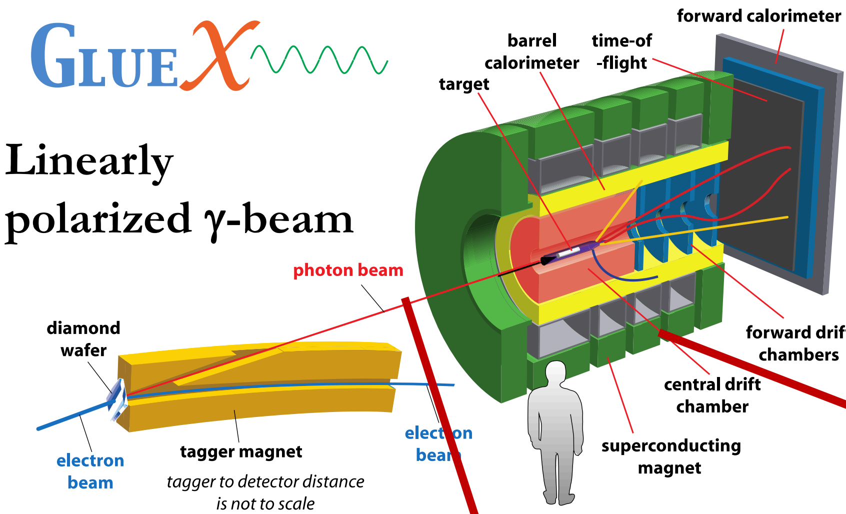


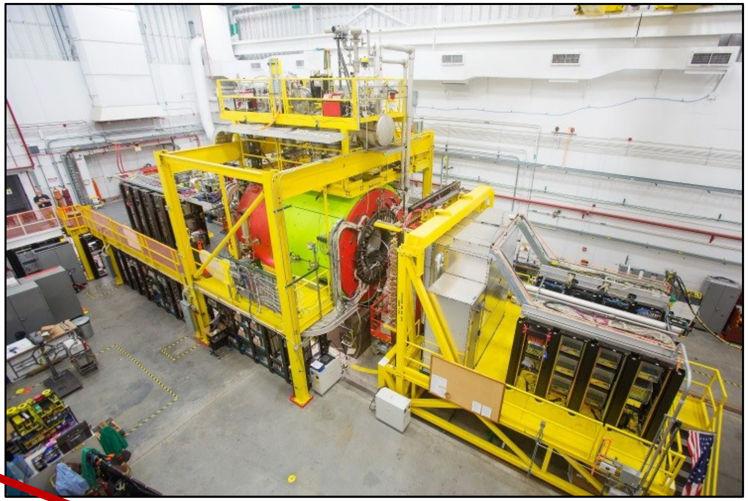
- LERF is fully operational
- Only superconducting energy recovery linac in the world
- LERF will operate for DarkLight experiment
- Still seeking other programs and stable operating funds

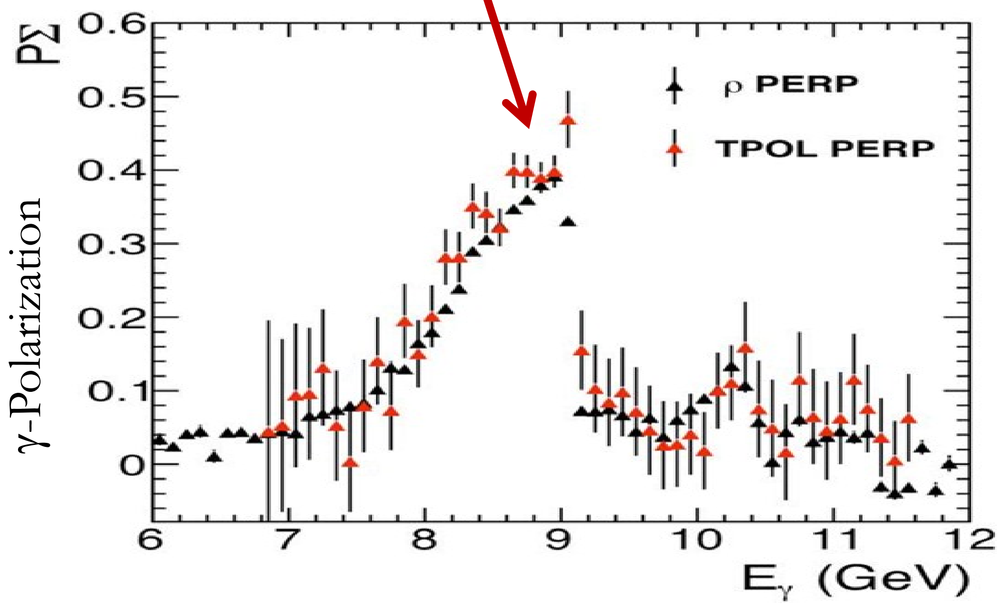
LERF and CEBAF Beam Parameters

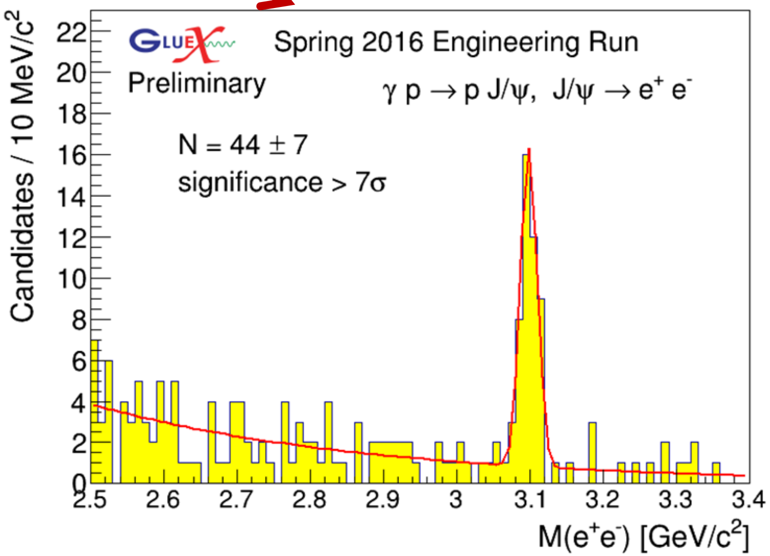
	LERF	CEBAF
Max. Energy	170 MeV	11 GeV (ABC)
		12 GeV (D)
Duty Factor	CW	CW
Max. Beam Power	>1 MW	1 MW
Bunch Charge (Min-Max)	**60-135 pC**	0.004 fC – 1.3 pC
Repetition Rate on Target	4.68 - 74.85 MHz	31.2 – 499 MHz
Nominal Hall Repetition Rate	74.85 MHz	**249.5** MHz
Number of Exp. Halls	1	**4**
Max. Number of Passes	1	5.5
Emittance (geometric) at full energy	**50** nm-rad(X)/**30** nm-rad(Y) @ 135 pC	**3 nm-rad(X)/1 nm-rad(Y)**
Energy Spread at full energy	0.02%	**0.018%**
Polarization	None	>85%

End Station D



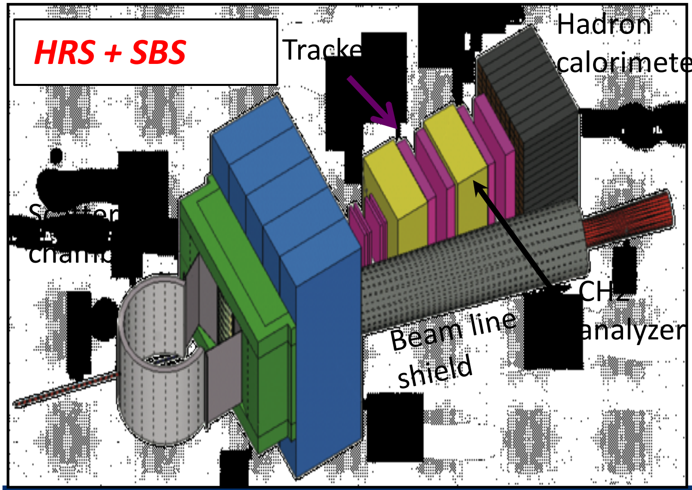




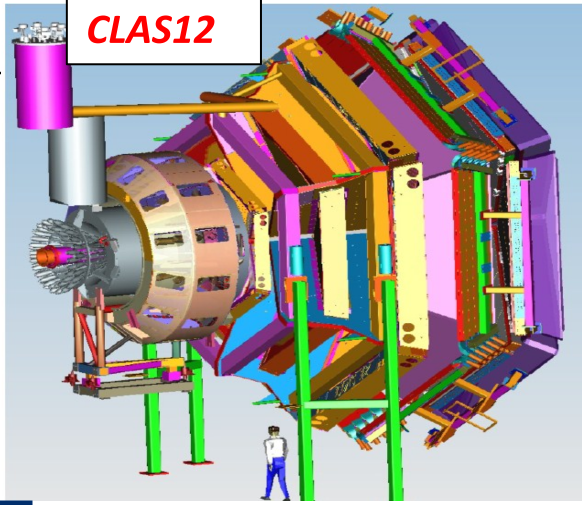


End Stations A, B & C

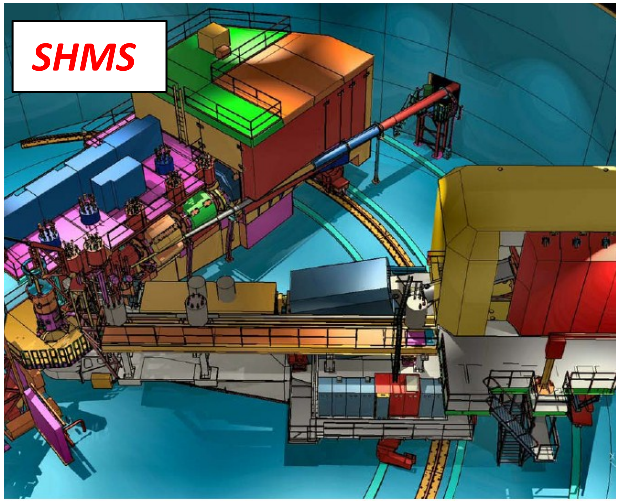
Hall A

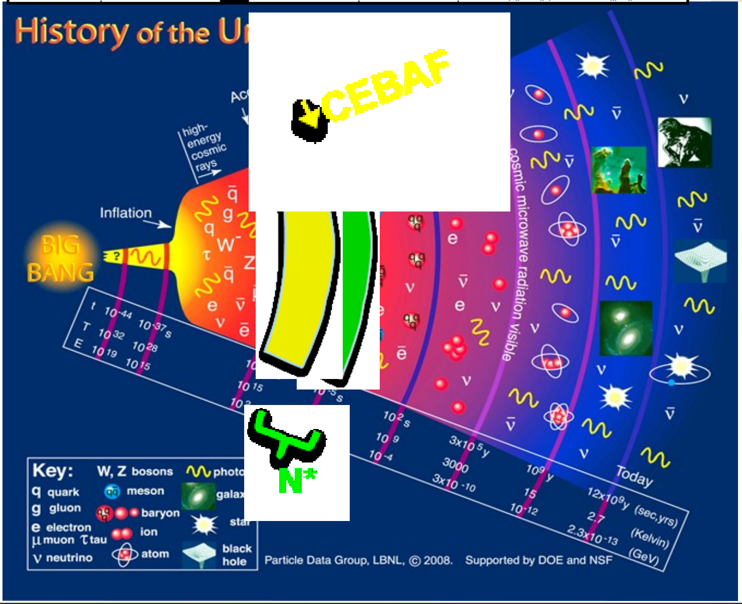


Hall B



Hall C



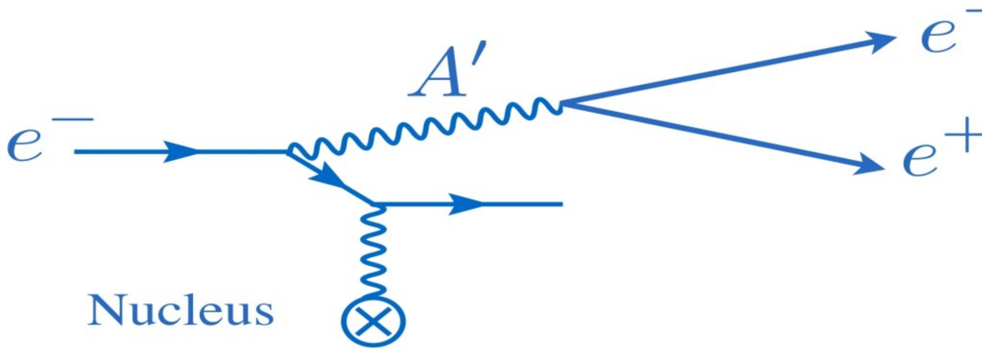


- Chiral symmetry broken, confinement occurs
  - **PDFs, TMDs, GPDs**
- How does QCD lead to confinement?
  - **Study confinement forces**
- Quarks attain masses dynamically
  - **Elastic and resonance form factors**
- Transition is driven by baryon excitations
  - **Search for missing baryons**

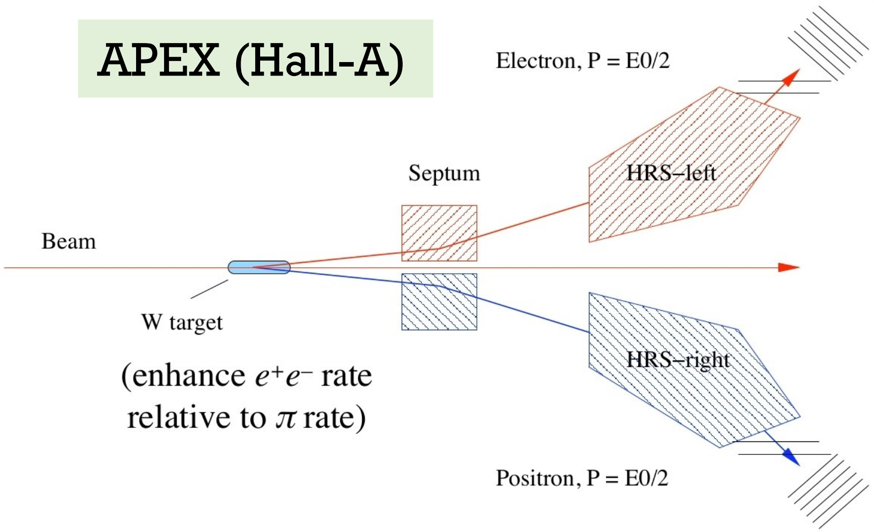
JLab Approved Experiments

- APEX (Hall A) HPS (Hall B) DarkLight (LERF)
- MOLLER (Hall A) BDX (Hall A Dump, parasitic not on plot)

Dark Matter @ JLab: $M_{XX'} > A'$

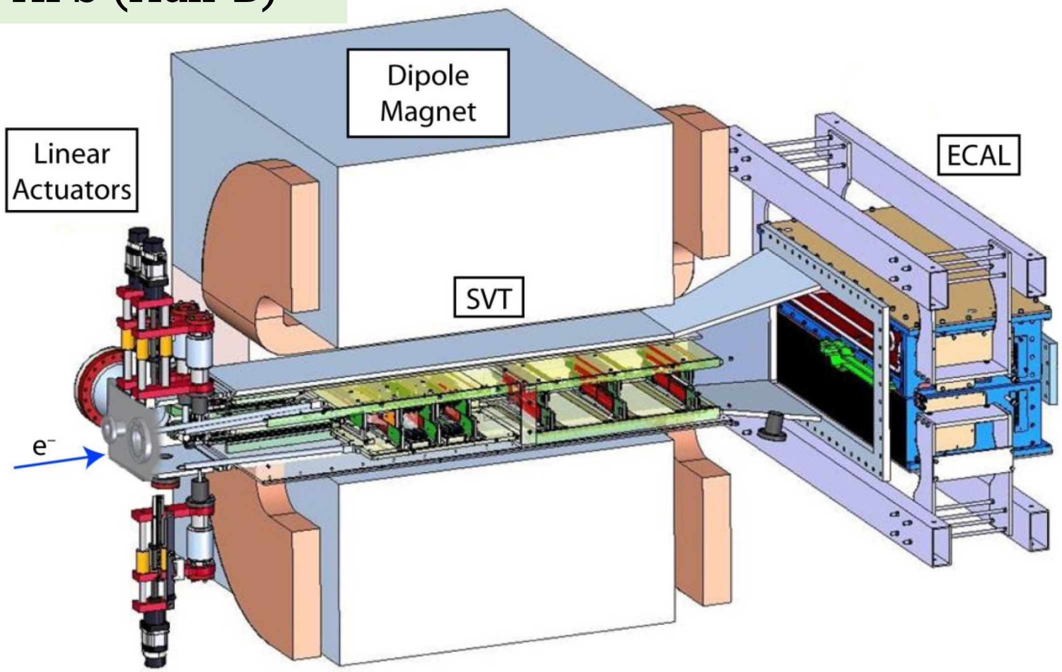


APEX (Hall-A)

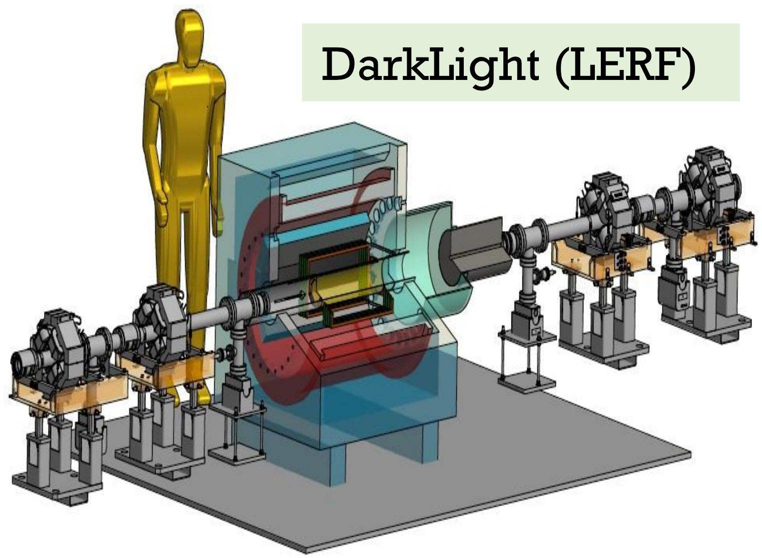


(enhance e^+e^- rate relative to π rate)

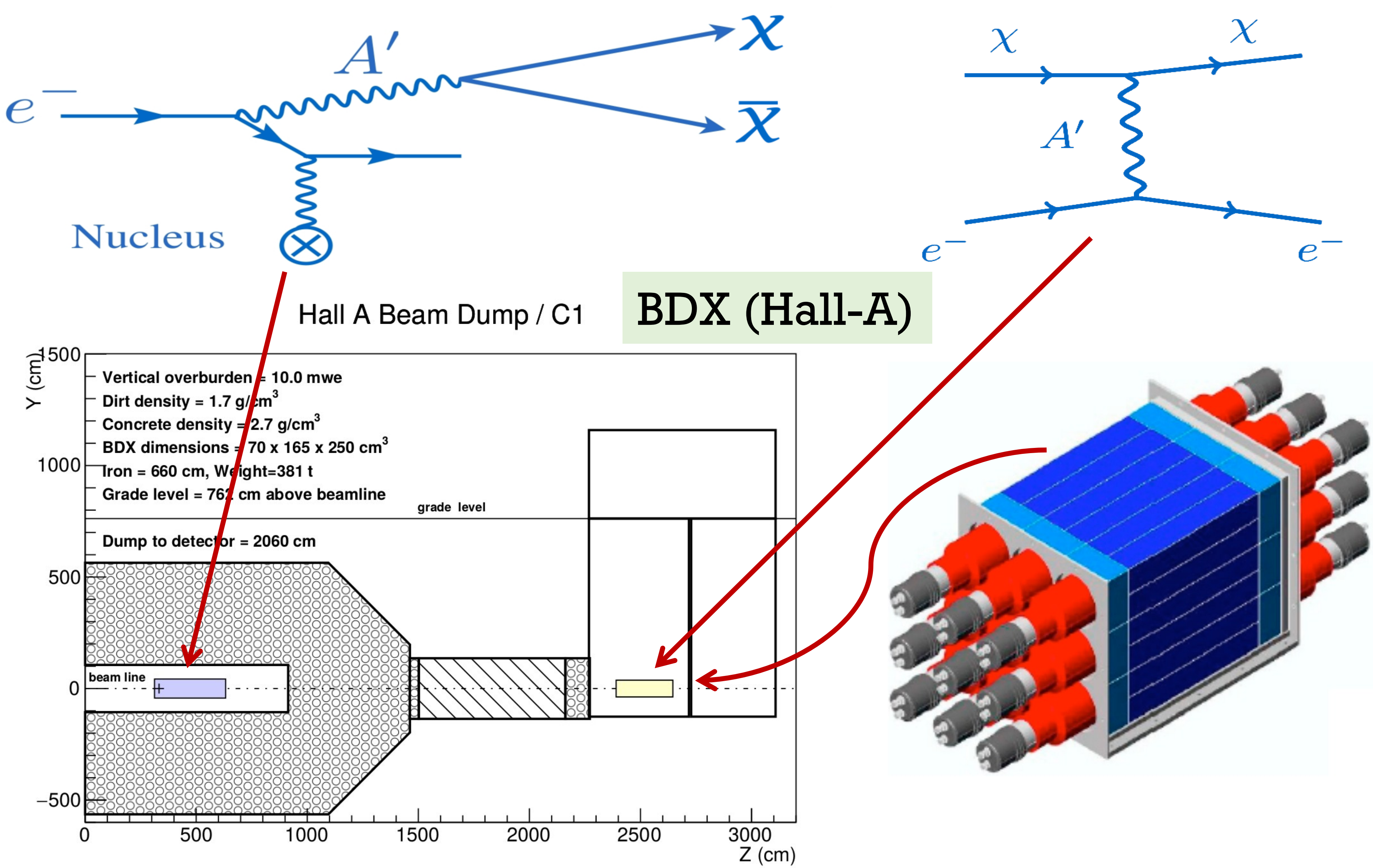
HPS (Hall-B)



DarkLight (LERF)

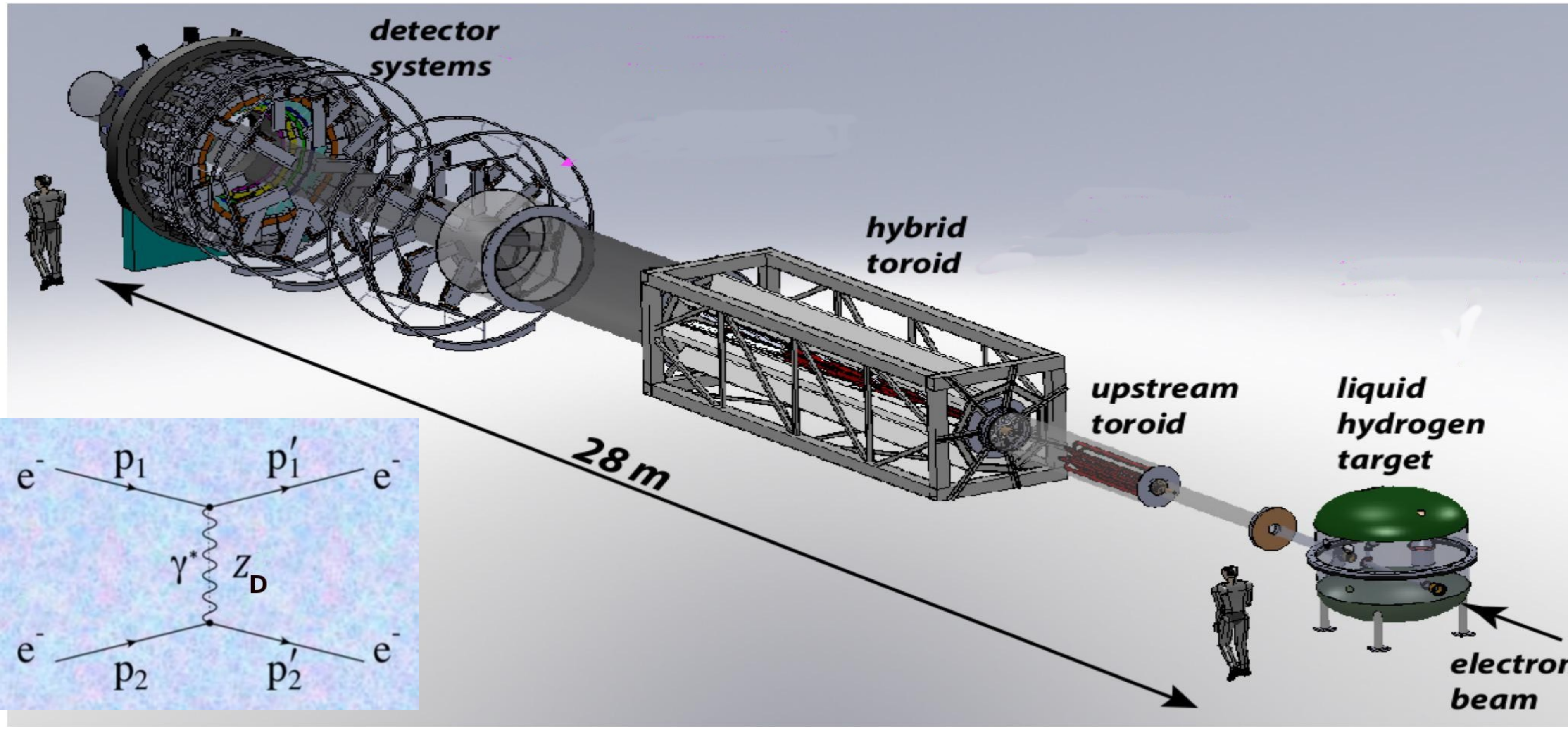


Dark Matter @ JLab: $M_{XX'} < A'$



Dark Matter @ JLab: $\sin^2\theta_W$

- Parity violated experiment with unprecedented precision
- Standard Model expectation: A_{PV} = 36 ppb (@ Q^2 = 0.0056 GeV/c^2)
  - $\delta\, A_{PV}$ = 0.74 ppb
- Agreement with SM places limits on dark Z interference.

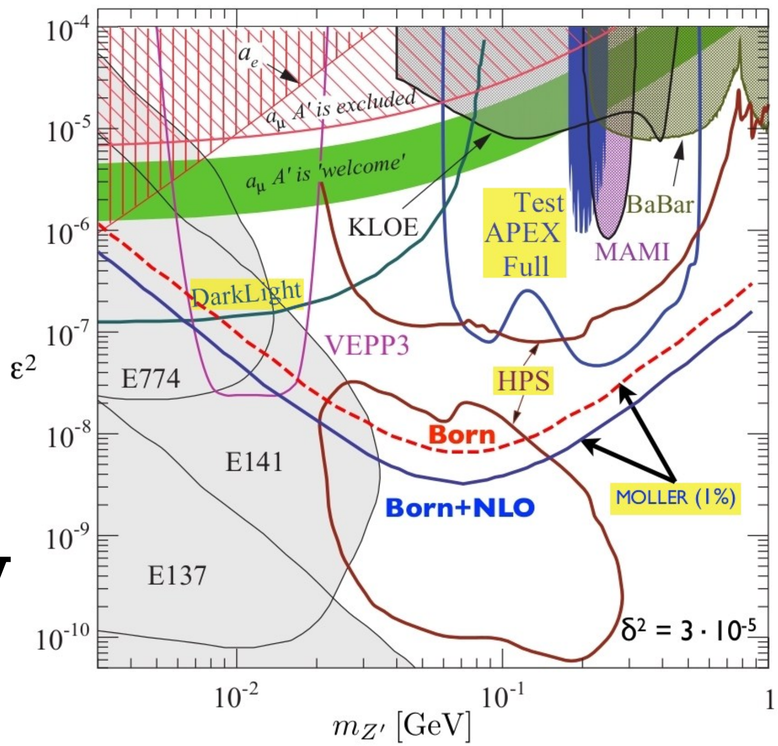


Summary

The JLab electron beam facilities, CEBAF and LERF, are actively being used to search for Dark Matter.

Enabling beam properties include:

- Low beam halo (HPS, DarkLight)
- Beam stability
- High beam polarization and parity quality
- CW beam
- Large dynamic range in bunch charge (beam current)
- Beam energies from 100 MeV up to 12 GeV



Aleksejevs et. al. (arXiv:1603.03006v1)

Backup

Parity Quality Beam (PQB) Parameters

Experiment	Energy (GeV)	Pol (%)	I (μA)	Target	A_{PV} Expected (ppb)	Charge Asym (ppb)	Position Diff (nm)	Angle Diff (nrad)	Size Diff ($\delta\sigma/\sigma$)
HAPPEx-I (Achieved)	3.3	38.8	100	^{1}H (15 cm)	15,050	200	12	3	
		68.8	40						
G0-Forward (Achieved)	3	73.7	40	^{1}H (20 cm)	3,000-40,000	300$\pm$300	7$\pm$4	3$\pm$1	
HAPPEx-II (Achieved)	3	87.1	55	^{1}H (20 cm)	1,580	400	2	0.2	
HAPPEx-III (Achieved)	3.484	89.4	100	^{1}H (25 cm)	23,800	200$\pm$10	3	0.5$\pm$0.1	
PREx-I (Achieved)	1.056	89.2	70	^{208}Pb (0.5 mm)	657$\pm$60	85$\pm$1	4	1	
QWeak-I (Achieved)	1.155	89	180	^{1}H (35 cm)	281$\pm$46	8$\pm$15	5$\pm$1	0.1$\pm$0.02	
QWeak (Analysis In Progress)	1.162	90	180	^{1}H (35 cm)	234$\pm$5	$<$100$\pm$10	$<$2$\pm$1	$<$30$\pm$3	$<10^{-4}$
PREx-II/CREx (To Be Scheduled, FY18+?)	1	90	70	^{208}Pb (0.5mm)	500$\pm$15	$<$100$\pm$10	$<$1$\pm$1	$<$0.3$\pm$0.1	$<10^{-4}$
MOLLER (To Be Scheduled, FY21+?)	11	90	85	^{1}H (150 cm)	35.6$\pm$0.74	$<$10$\pm$10	$<$0.5$\pm$0.5	$<$0.05$\pm$0.05	$<10^{-4}$

- PREx-II and its cousin, CREx, have requirements similar to QWeak-I. 12 GeV CEBAF can support these experiments without modification.

MOLLER PQB requirements more stringent than previous parity experiments. Upgraded CEBAF Injector is designed to make achieving these stringent requirements more *routine*.

Parity Quality Beam: Accelerator Perspective

$\overrightarrow{D}$ Number of detected events (normalized) for positive e helicity, $\overrightarrow{e}$

$\overleftarrow{D}$ Number of detected events (normalized) for negative e helicity, $\overleftarrow{e}$

$$A_{PV} = \frac{\overrightarrow{D} - \overleftarrow{D}}{\overrightarrow{D} + \overleftarrow{D}} \approx \frac{\text{Weak}}{\text{EM}}$$

This only holds if detector acceptance (or efficiency) is independent of electron spin orientation.

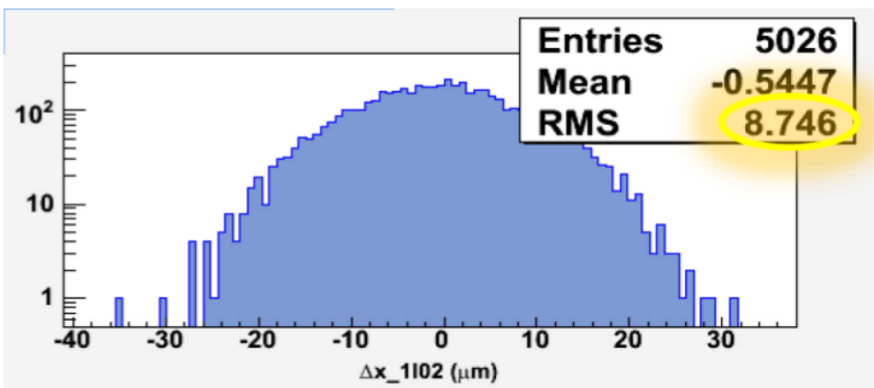
Parity Quality Beam refers to the position, angle, size and charge differences for the two helicity states averaged over the entire run.

$A_x = \overrightarrow{x} - \overleftarrow{x}$ Position difference at the target, typically in the nm range.

$A_{x'} = \overrightarrow{x}' - \overleftarrow{x}'$ Angle difference at the target, typically in the sub-nrad range.

$A_Q = \frac{\overrightarrow{Q} - \overleftarrow{Q}}{\overrightarrow{Q} + \overleftarrow{Q}}$ Charge asymmetry, $100 \rightarrow 10$ ppb

$A_{\sigma(x)} = \frac{\overrightarrow{\sigma_x} - \overleftarrow{\sigma_x}}{\overrightarrow{\sigma_x} + \overleftarrow{\sigma_x}}$ Beam size different at target: specification $< 10^{-4}$, how to measure?



Width of asymmetries folds contributions from:

1. **Beam stability**, $\overrightarrow{\text{helicity}}$ to $\overleftarrow{\text{helicity}}$
2. **Measurement resolution**, i.e. new BCM electronics for QWeak

The precision on determining the asymmetry centroid improves with smaller widths, enabling faster understanding of the impact of beam quality on the A_{PV} error.