The Jefferson Lab facility for light dark matter searches

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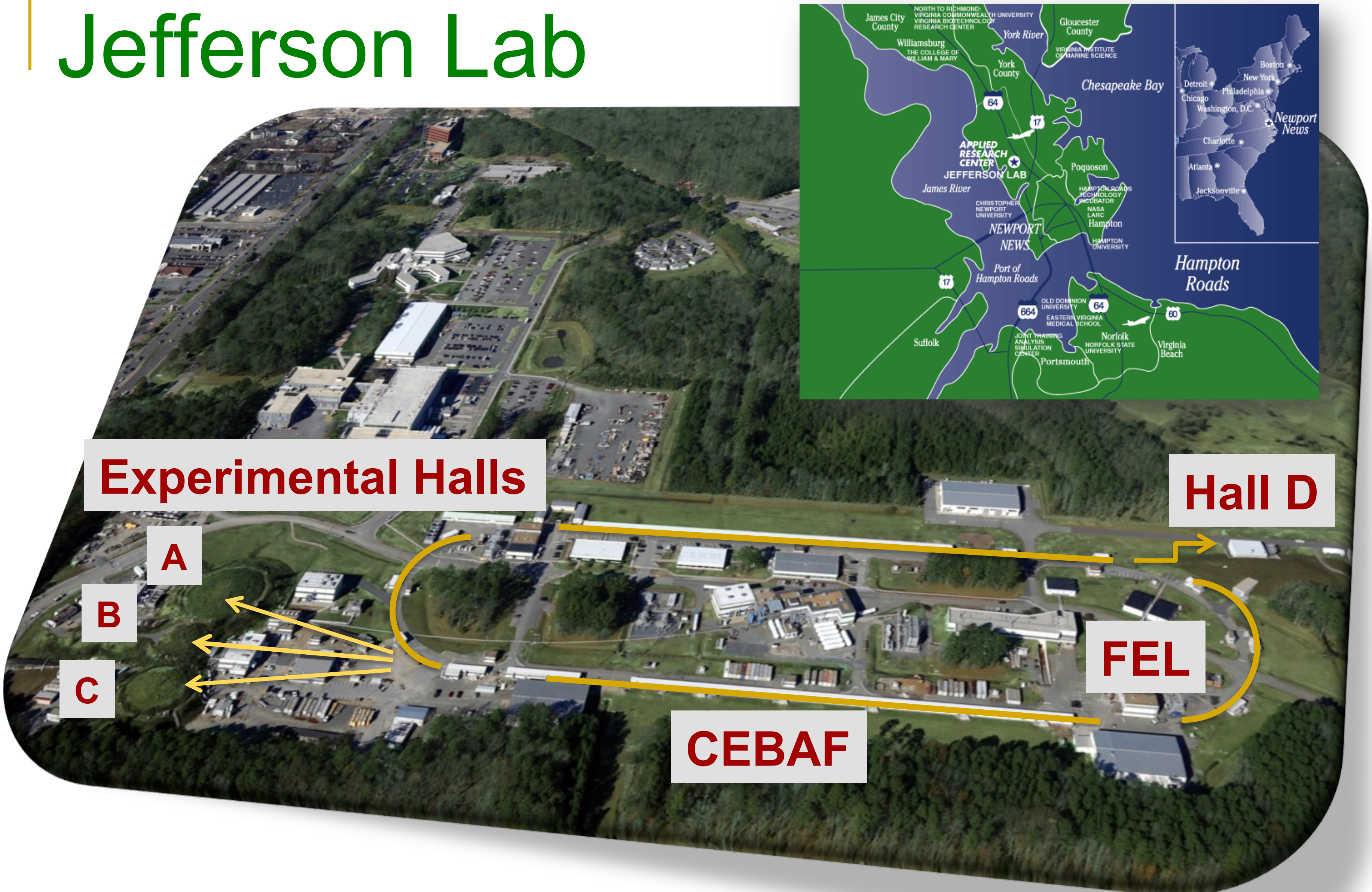
(JLAB)

Seminar INFN, 29 July, Genova, Italy

Outline

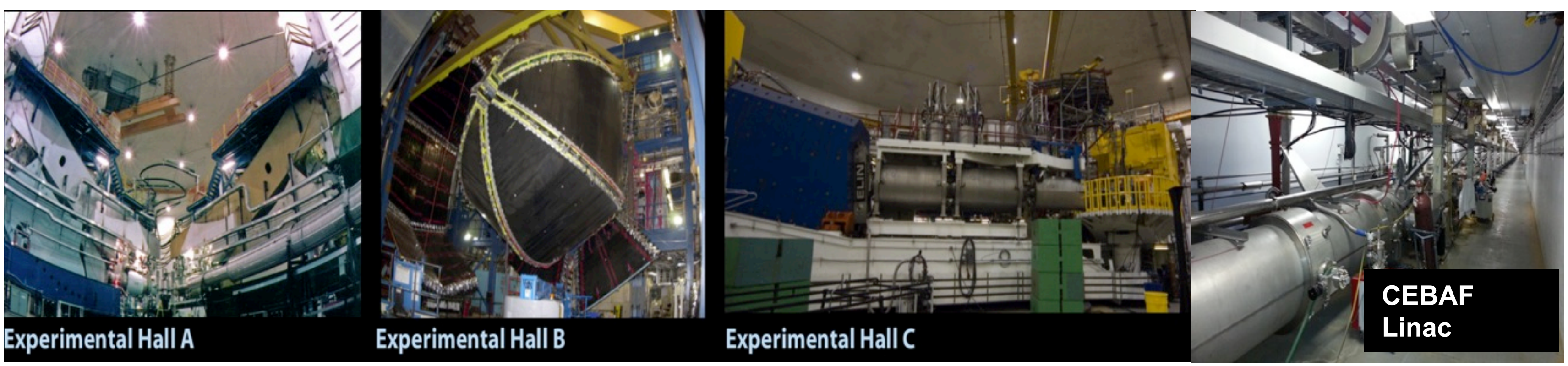
- Jefferson Lab, facilities and science
- CEBAF12 beam parameters
- Experiments using CEBAF
  - APEX in Hall-A
  - HPS in Hall-B
  - BDX
- Experimental halls and dumps
- ERL at FEL
  - DarkLight in FEL
- Summary

Jefferson Lab



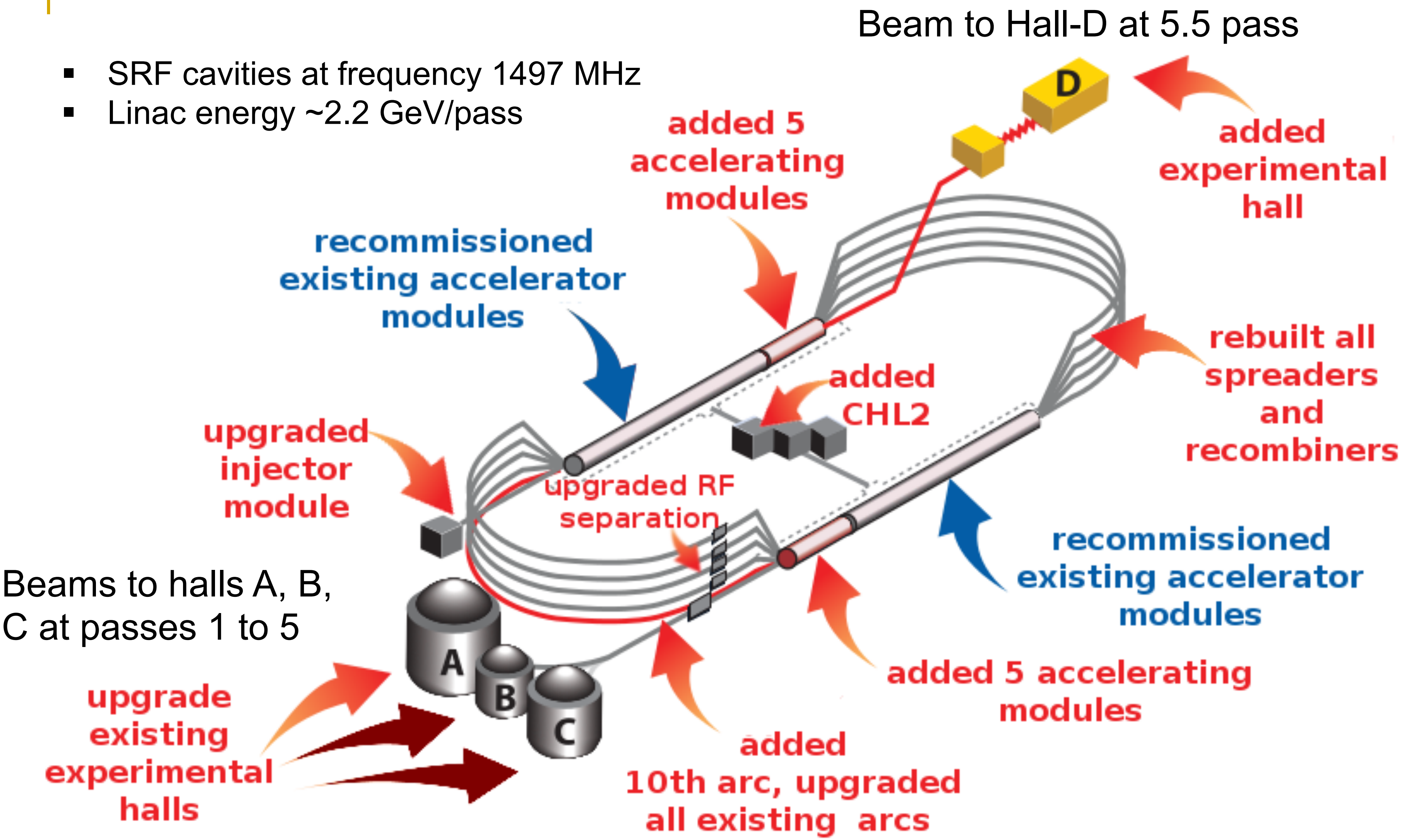
CEBAF Timeline

- 1985 CEBAF design changed to use SRF technology
  - First large scale (>40 cryomodules, >320 SRF cavities) implementation of SRF technology
- 1987 **4 GeV** CEBAF green site construction begins
- 1995 CEBAF achieves 4 GeV design energy
- 1996 CEBAF changes its name to Thomas Jefferson National Accelerator Facility (**Jefferson Lab**)
- 1997 All three halls (A, B & C) beam capable
- 2000 CEBAF reaches **6.07 GeV**
- 2012 CEBAF ceases 6 GeV operations
  - 17 years of experiments
  - 15 years of three hall operation
  - 178 completed experiments
  - 1380 Users (480 users from ~29 foreign countries)



CEBAF12

- SRF cavities at frequency 1497 MHz
- Linac energy ~2.2 GeV/pass



Expected beam parameters for physics

- Accelerator frequency 1497 MHz
- In CW mode, 499 MHz per hall at 1-4 passes (1 hall per pass). At 5th pass four hall operations at 249.5 MHz (750 MHz separation)
- Total beam power limit in the machine - 1MW
- 25-35 weeks of annual operations

Hall	E_{max} (GeV)	I_{max} (μA)	Emmitance (nm-rad)	Energy spread σ (%)	Spot size σ (μm)	Halo
A	11	85	$\varepsilon_x<10$	<0.05	$\sigma_x<400$	$< 10^{-4}$ ♮
			$\varepsilon_y<5$		$\sigma_y<200$	
B	11	1	$\varepsilon_x<10$	<0.1	$\sigma_x<400$	$< 2x10^{-4}$ ♮
			$\varepsilon_y<10$		$\sigma_y<400$	
C	11	85	$\varepsilon_x<10$	<0.05	$\sigma_x<500$	$< 2x10^{-4}$ ♮
			$\varepsilon_y<10$		$\sigma_y<500$	
D	12	5	$\varepsilon_x<50$	<0.5	$\sigma_x<1550$	$< 10^{-2}$ ♯
			$\varepsilon_y<10$		$\sigma_y<550$	

♮ Ratio of the integrated non-Gaussian tail to Gaussian core.
♯ Ratio of Halo background event rate to physics event rate.

Modes of running: CW and pulsed

- The nominal CEBAF running mode is CW
  - 499 MHz bunch repetition for passes 1 to 4
  - 249.5 MHz at 5^{th} pass
  - bunch charge ≤0.33 pC

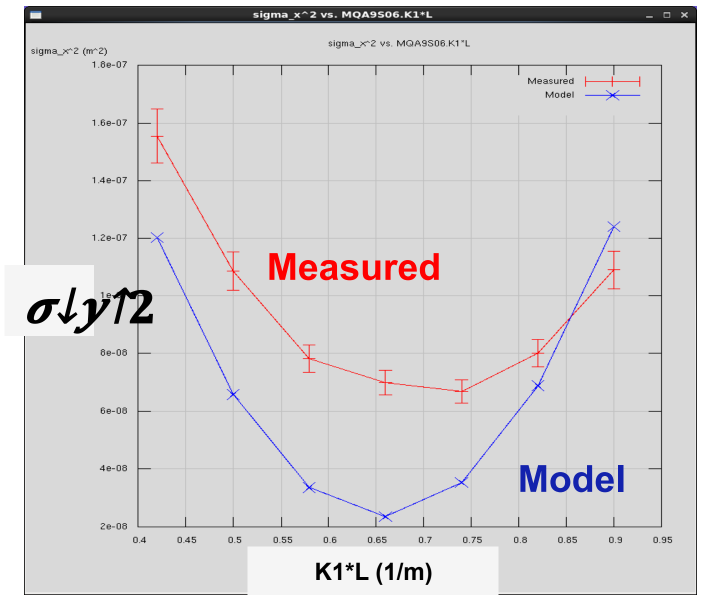
This mode is ideal for experiments that battle with beam related accidentals, not so good for experiments that have large non-beam related backgrounds (e.g. Beam dump experiments)

- Often, for beam tuning purposes "tune-mode" pulsed beam is used
  - 60Hz repetition rate, 250μs long pulse every 16.6msec, a short 4μs pulse about 10μs after the 250μs pulse
- There is an "expert-mode" that should in principal allow to run with $1/2^n$ of the nominal frequency. In the past 31.2 MHz bunch structure has been used.
- In all these modes CEBAF bunch charge is limited to 1.3pC, not ideal for experiments that can suffer from non-beam related backgrounds.
- The RF system is really design for CW beam and behaves poorly(energy jitter) with a tune-mode pulse structure
- Establishment beam transport with higher bunch charge will require sufficient planning and upgrades to the injector.

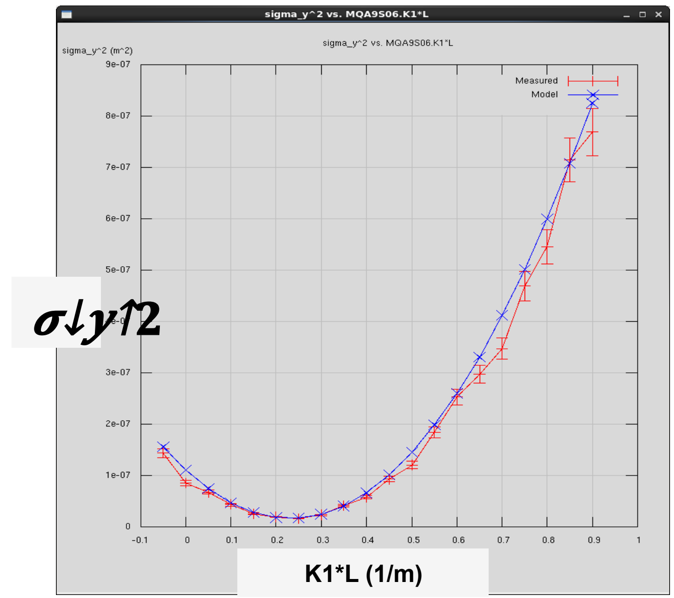
CEBAF setup

- Well mapped and understood magnet system
- Advanced optics tools, a new beam matching process

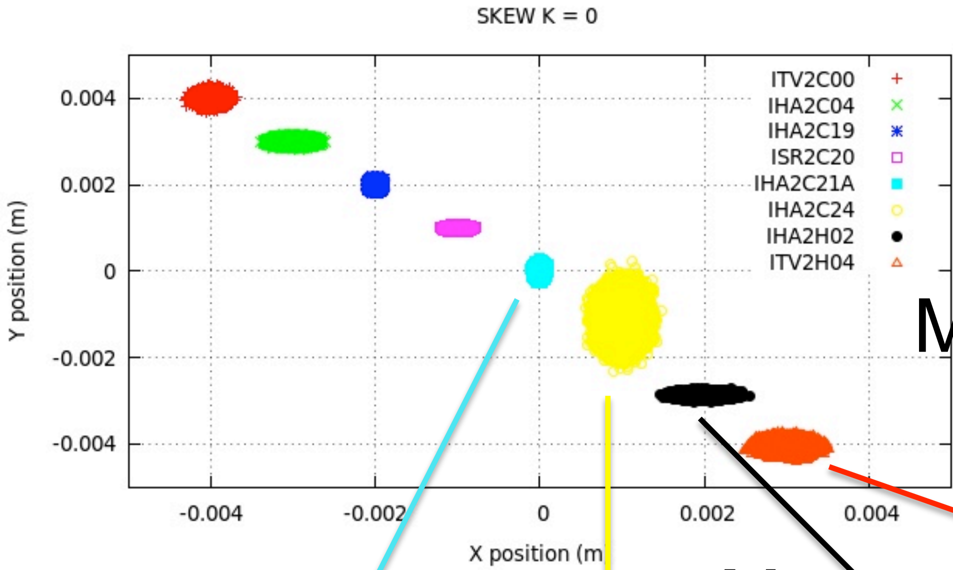
Quad Scan: Before match



Quad Scan: **After** match



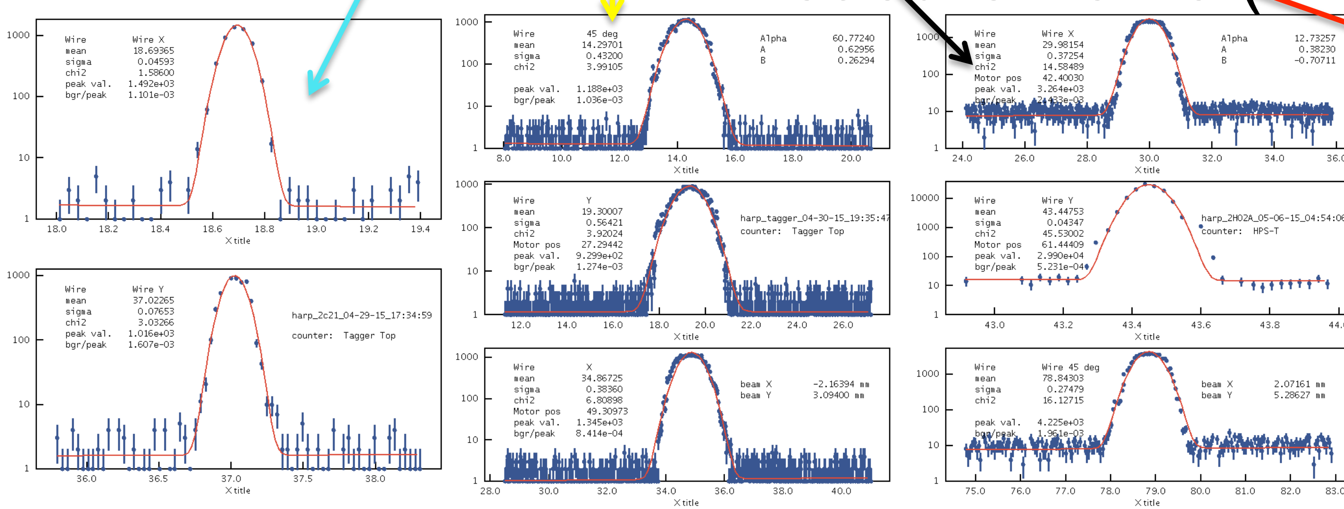
Beam formation: model and measurement

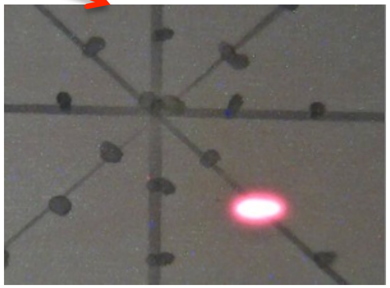


Model

Diagnostic	X_{RMS} (μm)	Y_{RMS} (μm)
ITV2C00	72	69
IHA2C04	90	39
IHA2C19	27	42
ISR2C20	48	20
IHA2C21A	41	82
IHA2C24	234	292
IHA2H02A	288	30
HPS-Target	289	24
ITV2H04	292	91

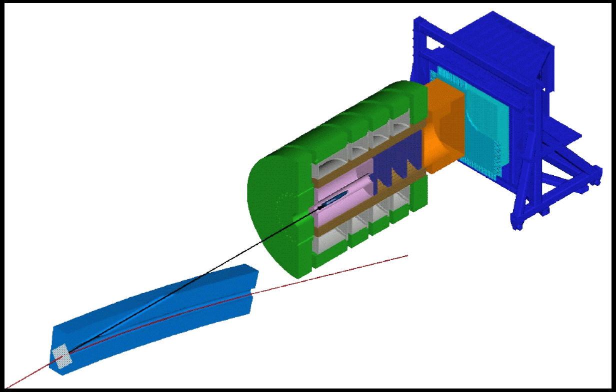
Measurements (HPS)





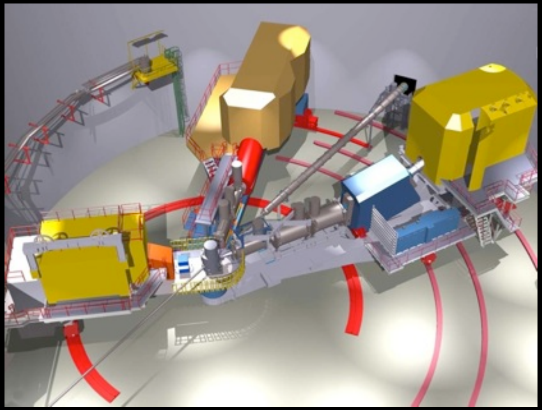
New Capabilities in Halls A, B, & C, and a New Hall D

D



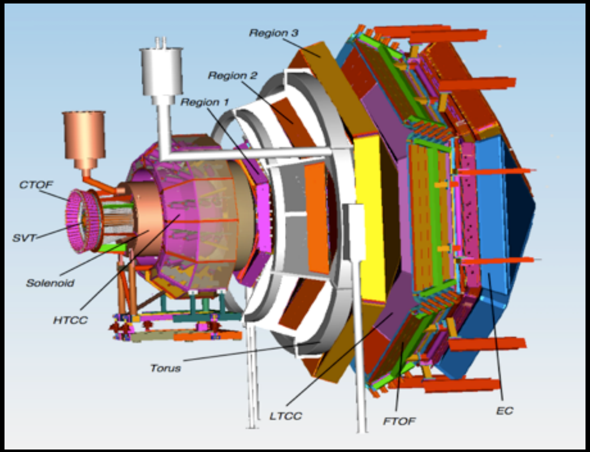
9 GeV tagged polarized photons and a 4π hermetic detector

C



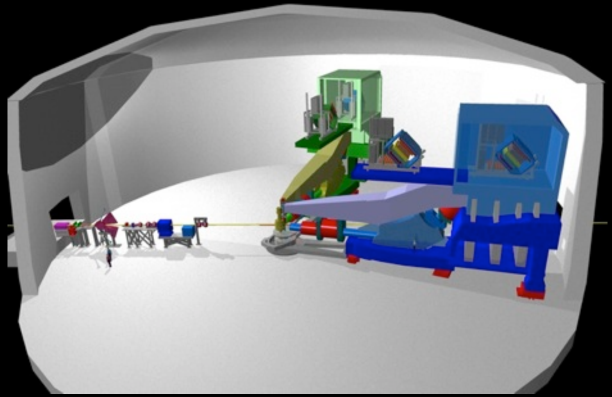
Super High Momentum Spectrometer (SHMS) at high luminosity and forward angles

B



CLAS12 high luminosity, large acceptance.

A



High Resolution Spectrometer (HRS) Pair, and specialized large installation experiments (Moller and SOLID)

JLAB12 science program

- User base ~1,300 scientists from the U.S. and abroad

Topic	Hall A	Hall B	Hall C	Hall D	Other	Total
The Hadron spectra as probes of QCD (GluEx and heavy baryon and meson spectroscopy)		1		3		4
The transverse structure of the hadrons (Elastic and transition Form Factors)	5	3	2	1		11
The longitudinal structure of the hadrons (Unpolarized and polarized parton distribution functions)	2	3	6			11
The 3D structure of the hadrons (Generalized Parton Distributions and Transverse Momentum Distributions)	5	9	7			21
Hadrons and cold nuclear matter (Medium modification of the nucleons, quark hadronization, N-N correlations, hypernuclear spectroscopy, few-body experiments)	6	3	7		1	17
Low-energy tests of the Standard Model and Fundamental Symmetries	3	1		1	1	6
Total Experiment	21	20	22	5	2	70
Total beam time	1346	1686	680	644	74	4430

The Standard Model

Almost all known particle physics phenomena are well described within the SM through its three basic interactions, but … it does not explain the complete picture

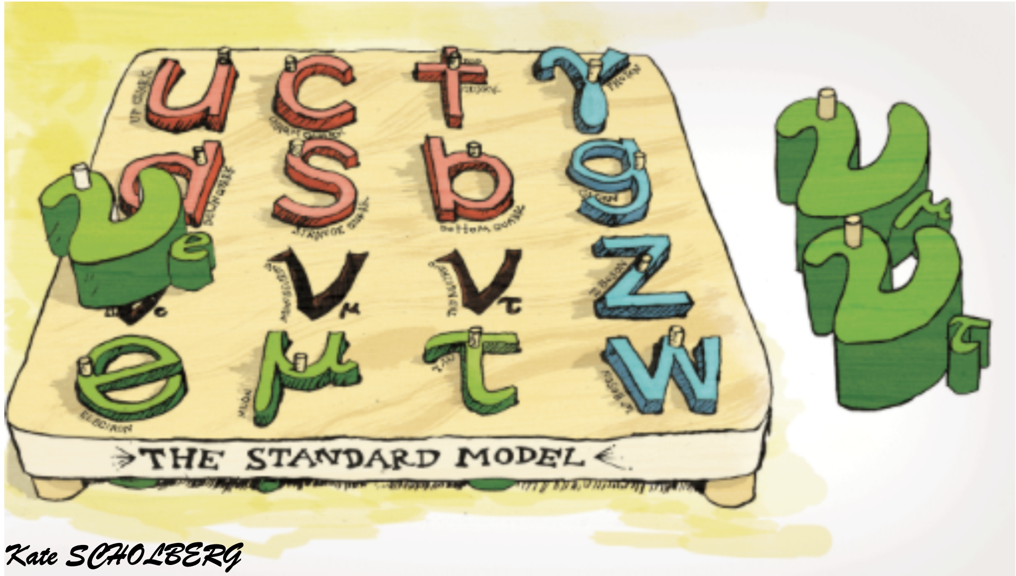
Standard Model

strong — g

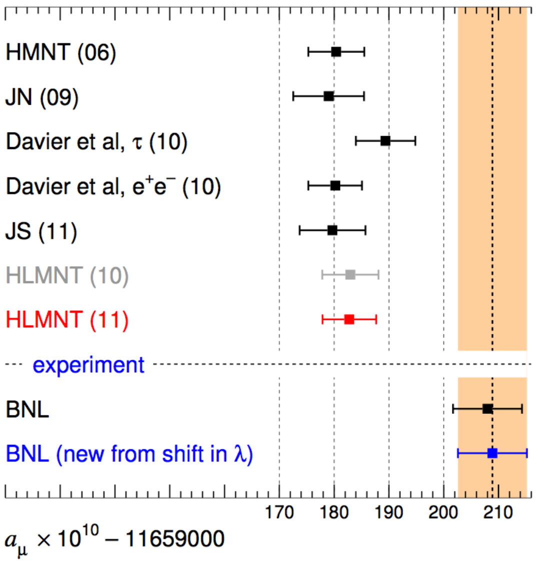
weak — $W^{\pm}, Z$

electromagnetic — γ

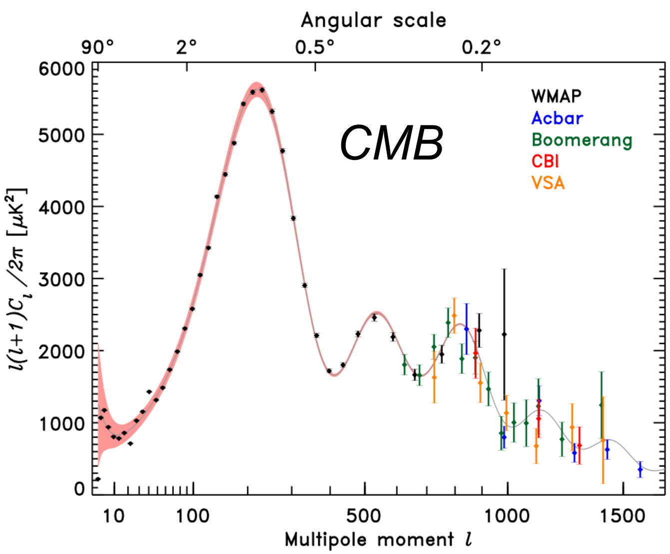
There are misfits

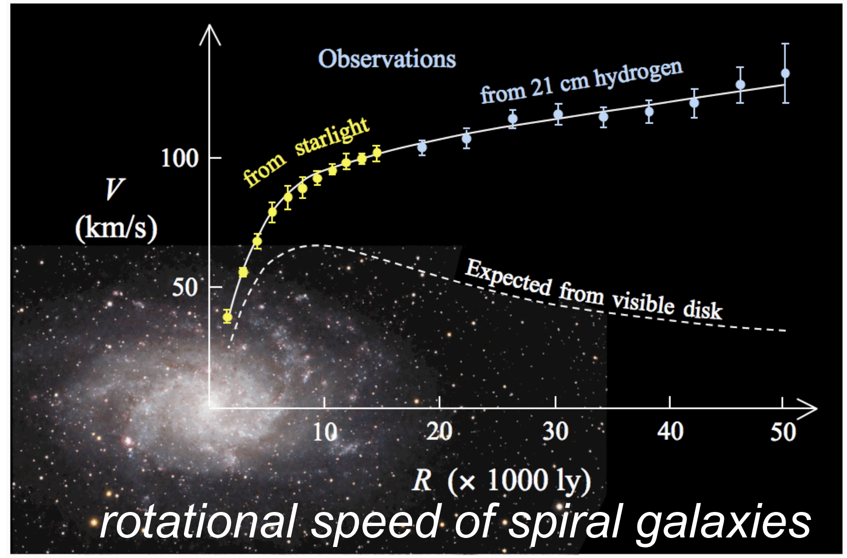


… and *Precision Anomalie*

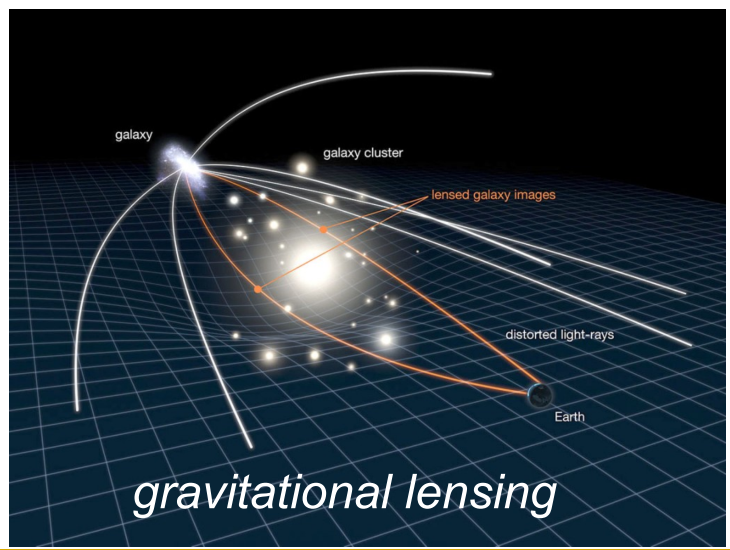


Cosmological observations



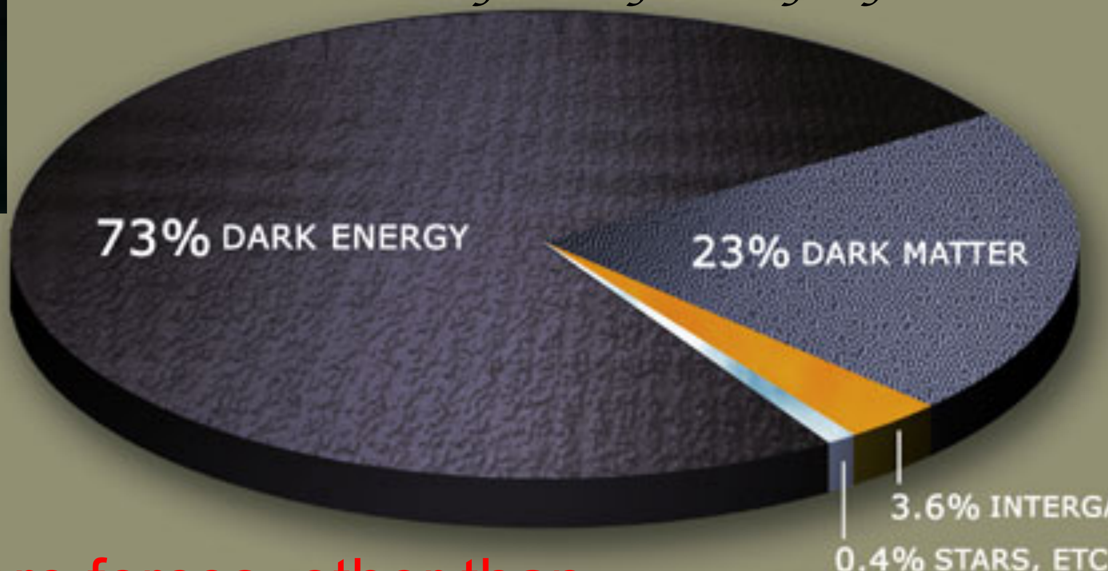


We know there is dark matter, but we do not know what it is -
extension of the SM
(axion, superpartner, ...)
or
completely new physics



Distribution of matter in Universe

We do not know what DM is –
extension of the SM(axion, superpartner, …)
or
completely new physics

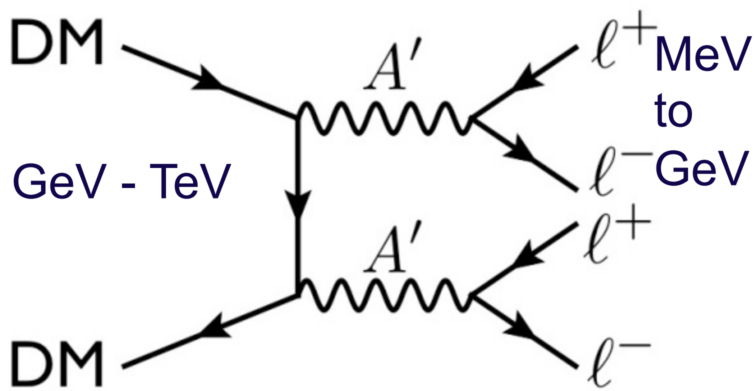


are there forces, other than gravity that connects baryonic matter to the hidden sector

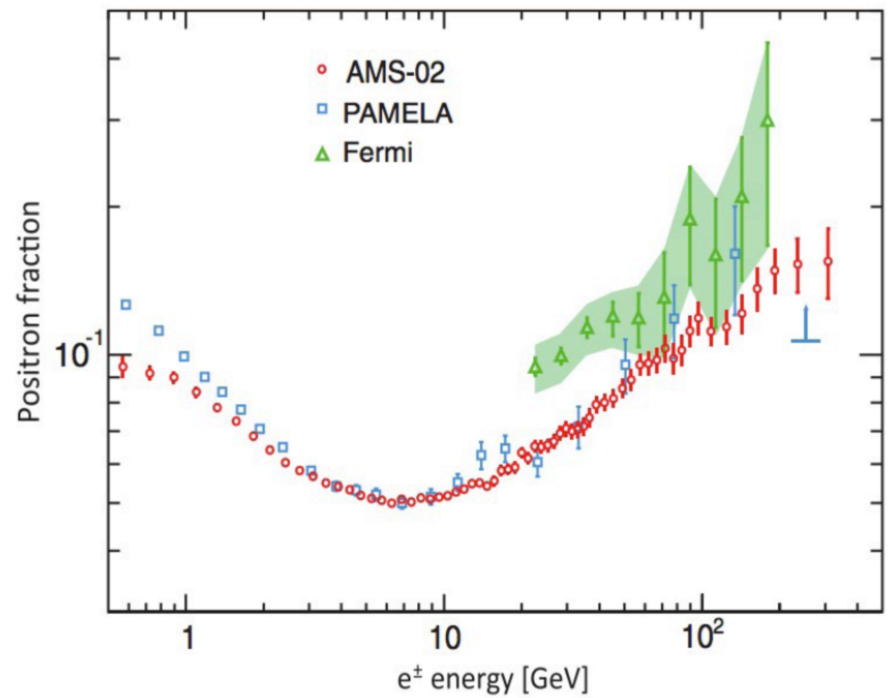
Heavy photons – window to Dark sector

This new gauge boson, a dark photon, A′, can be our way to reach to the dark sector. It is present in many extensions of the Standard Model below weak scale and is natural for string theories

Dark matter coupling to the A' can explain excess of positrons and electrons in cosmic rays via DM *annihilation or decay* into e^+e



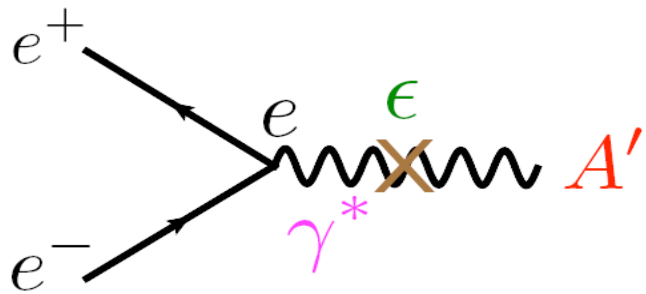
Arkani-Hamed, Finkbeiner, Slatyer, Weiner, Pospelov & Ritz



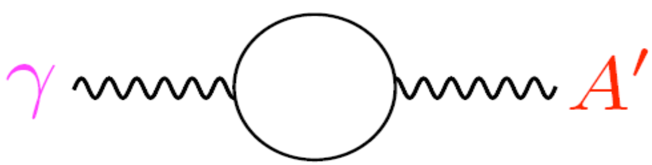
The Vector "Portal"

The simplest case, one heavy particle that is charged under EM charge and DM charge, and couples to the Standard Model photon through the kinetic mixing

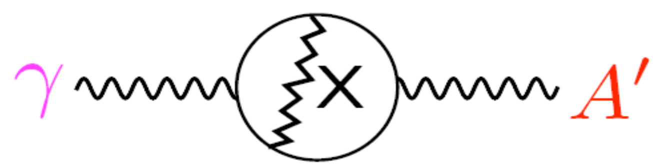
Holdom '86



$$\Delta\mathcal{L} = \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}$$



$$\epsilon \sim 10^{-4} - 10^{-2}$$

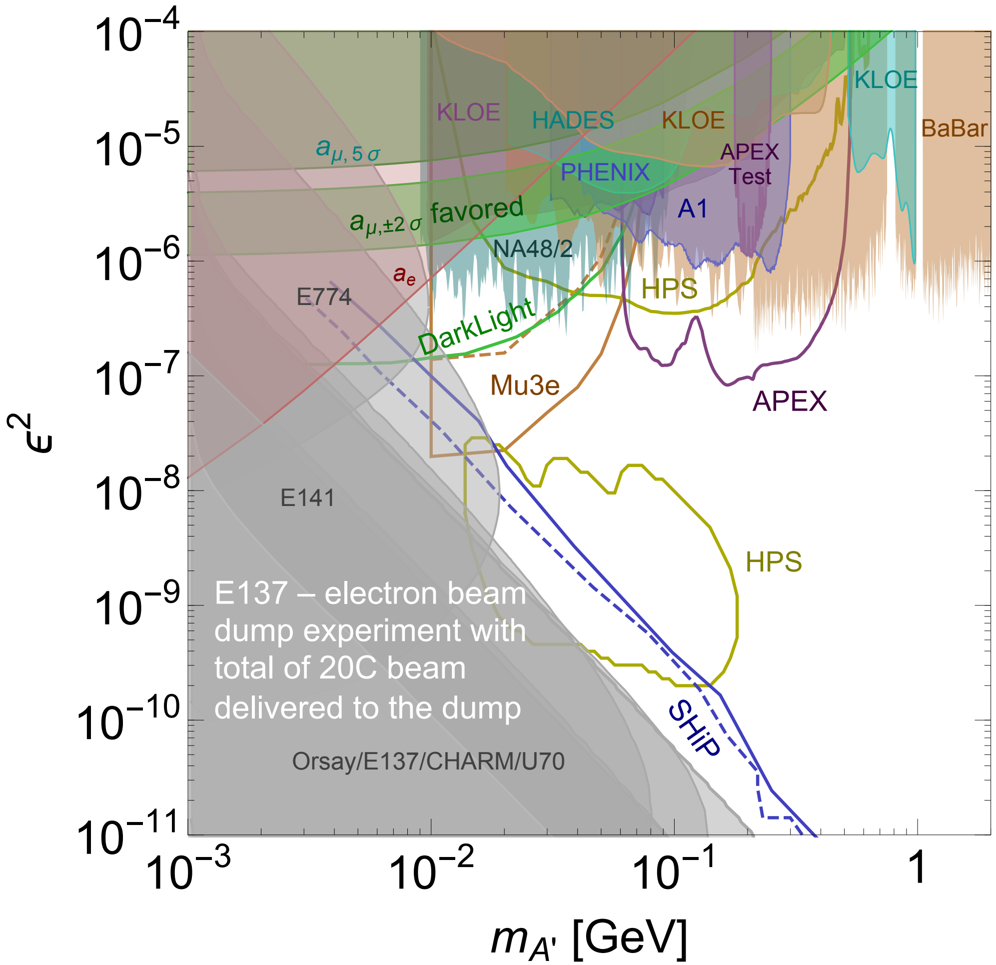


$$\epsilon \sim 10^{-5} - 10^{-3}$$

(if SM unifies in a GUT)

$$\varepsilon^2 = \frac{\alpha'}{\alpha}$$ α is the fine-structure constant

What JLAB can add to LDM searches



Existing constraints on heavy photons (A′) - 90% confidence level limits.

- High duty factor (> 250 MHz)
- Intense beams (CEBAF ~80 μA, ERL-FEL 1(10) mA)
- Small size beams (σ ~ 100 μm)
- Independent beam delivery for multiple users
- Expected to deliver in average 4C/day to a single high current hall beam dump during the normal operations

JLAB Experiments

Hall-B

Hall-A

APEX

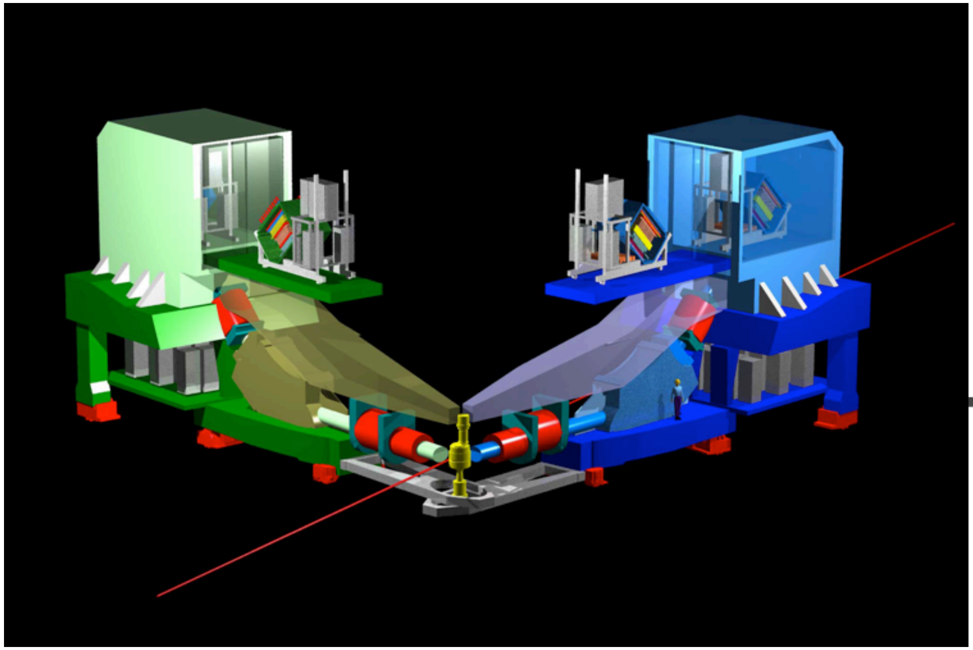
Behind high power beam dump (*LOI to PAC42*)

BDX @ JLAB

FEL

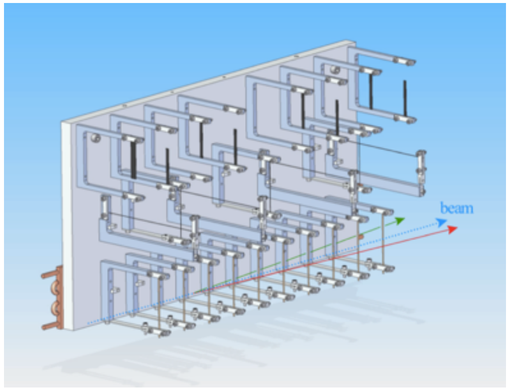
DARKLIGHT

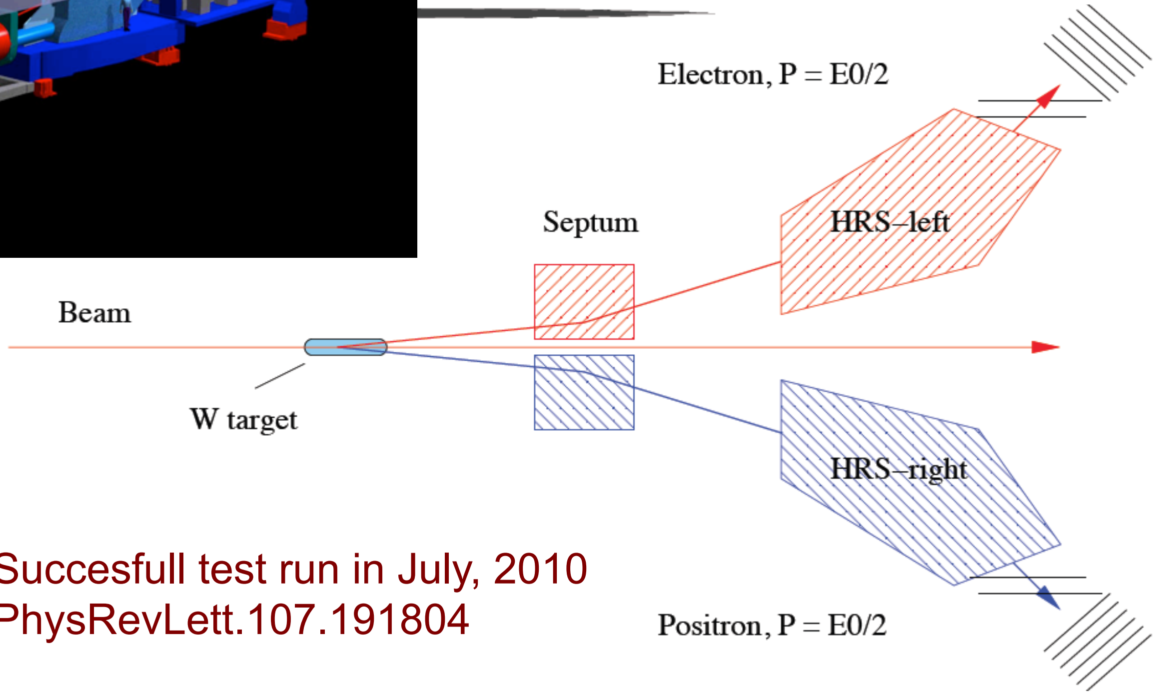
The A' Experiment in Hall-A (APEX)



Spectrometer-based search for 50-500 MeV A' decaying promptly to e^+e^- pairs in the electron scattering off of the tungsten target, beam current 150μA

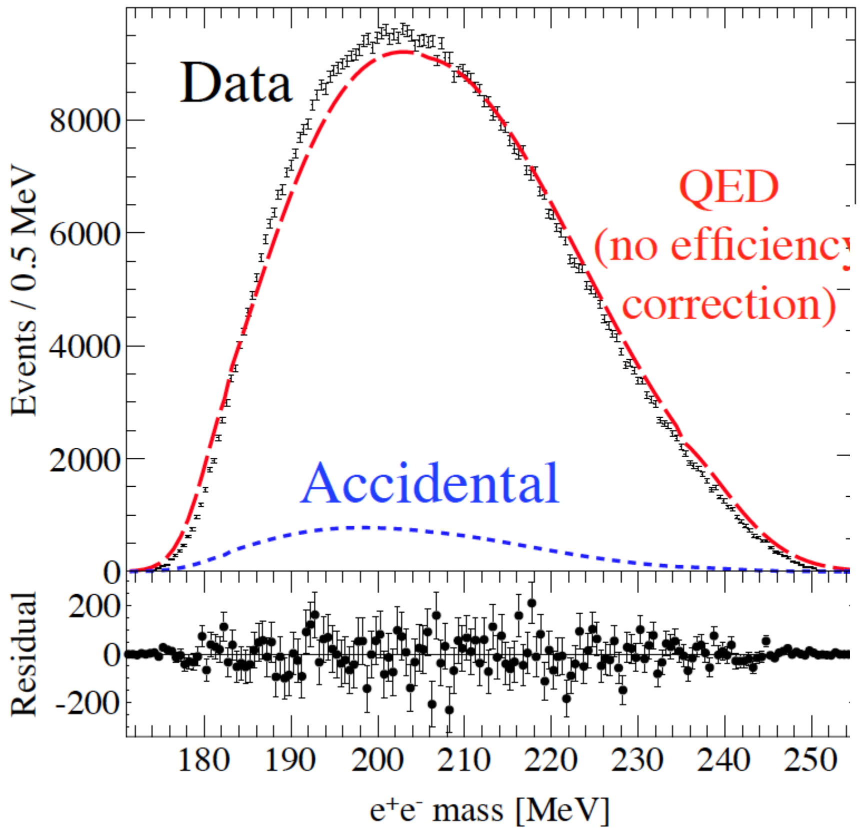
$$e^- W \rightarrow e^- e^+ X$$

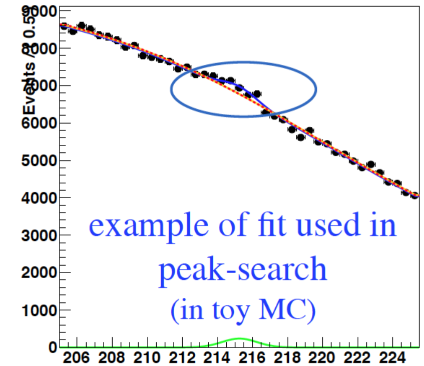


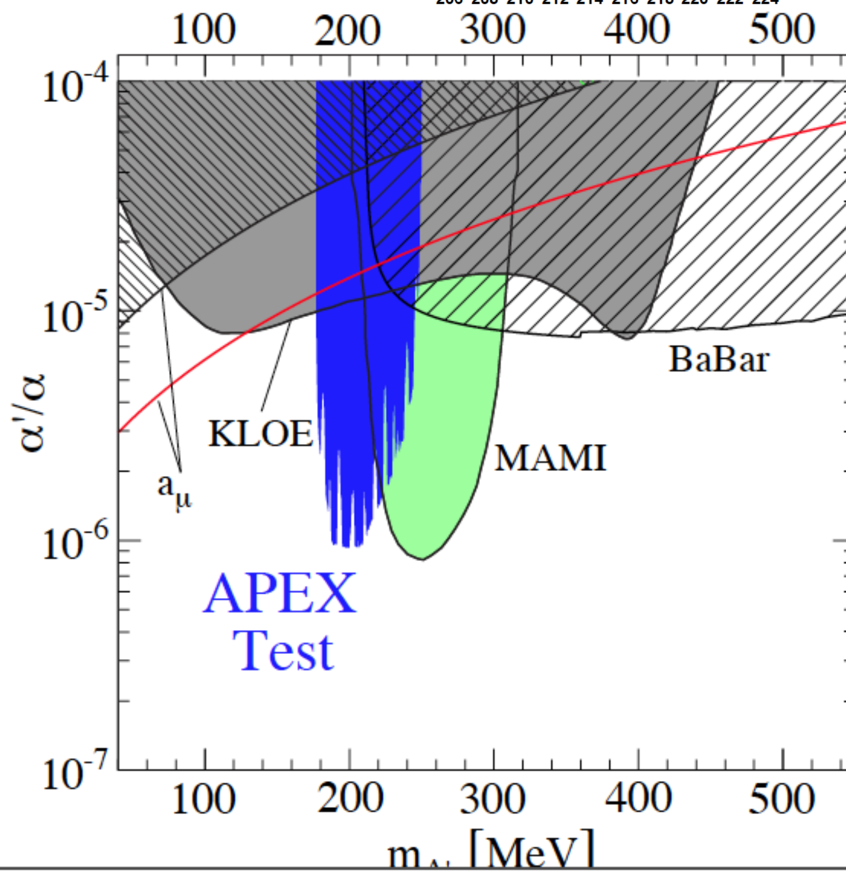


Succesfull test run in July, 2010
PhysRevLett.107.191804

APEX test run



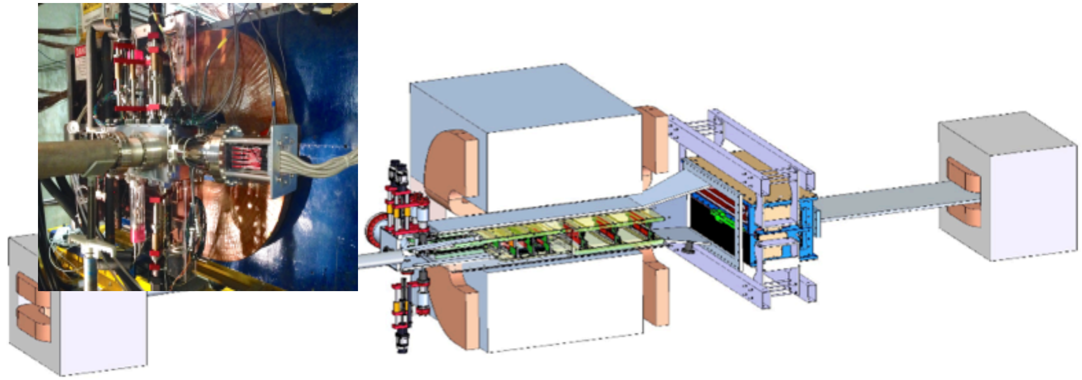




HPS in Hall-B

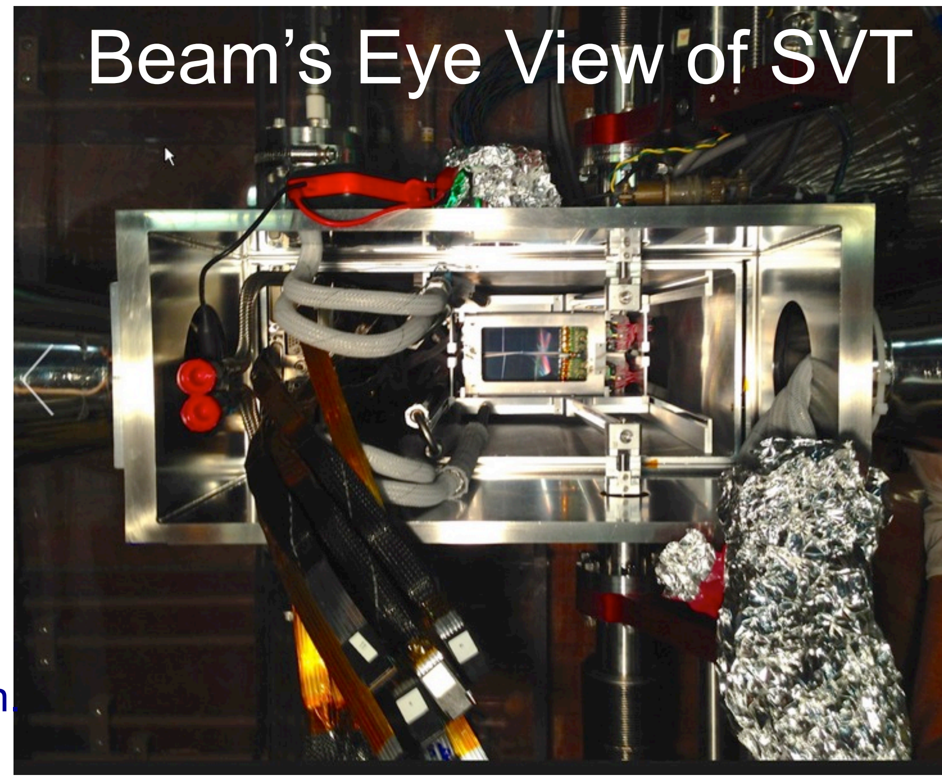
$$e^- W \rightarrow e^- e^+ X$$

Detection and identification of electrons at angles $\theta > 15$ mr



Detector package

- 3-magnet chicane, with the second dipole as the analyzing magnet
- detector package:
  - 6-layer Silicon Vertex Tracker (SVT) installed inside the analyzing magnet vacuum chamber,
  - Electromagnetic Calorimeter (ECal) installed downstream of the analyzing magnet

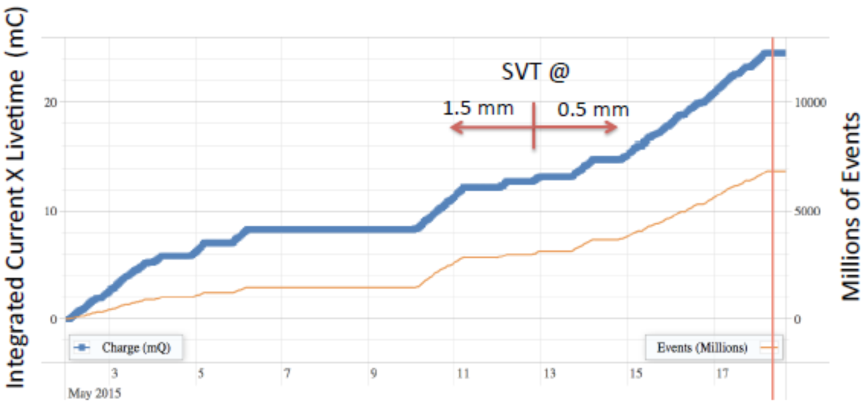


The challenge – operating Layer-1 Si-tracker at 500 μm from the high intensity beam!

Small size (σ_y~50 μm), very stable (~50 μm) beam is needed

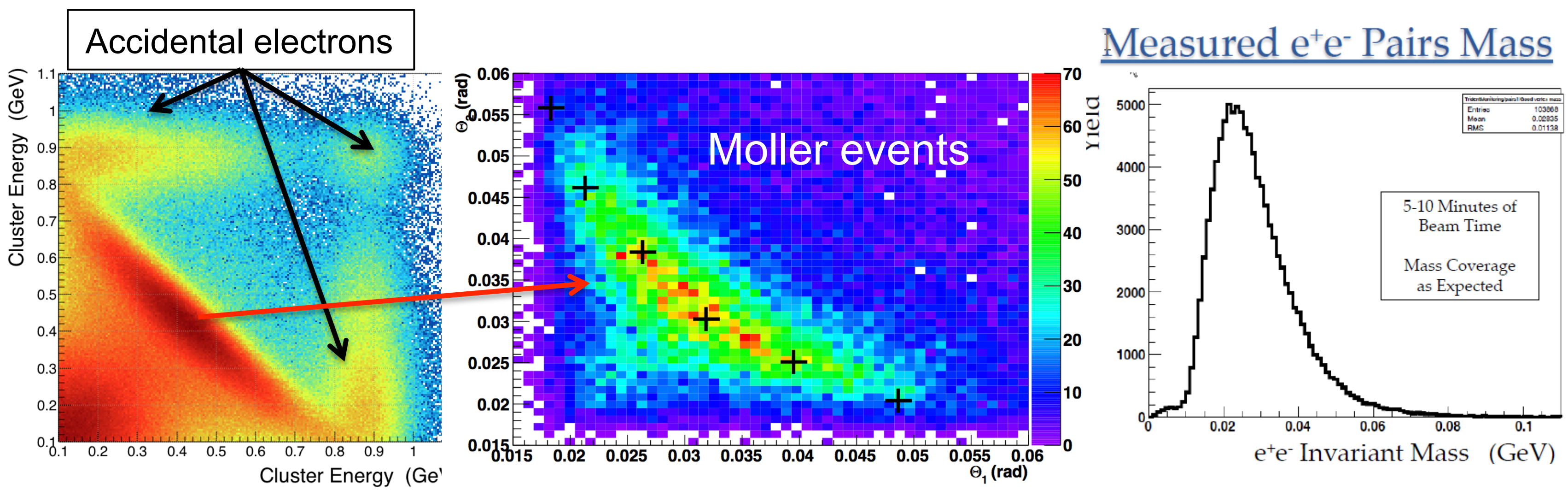
The operational goals have been achieved during the first engineering run.

HPS engineering run



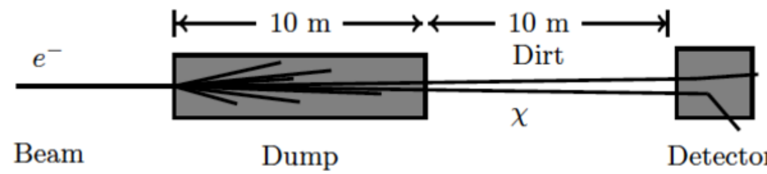
- 1-pass 1.05 GeV, 50 nA on 4 μm W target
- SVT at its nominal position (0.5 mm from the beam plane)
- Conditions & Performance as proposed
- Analysis & Calibration in Progress

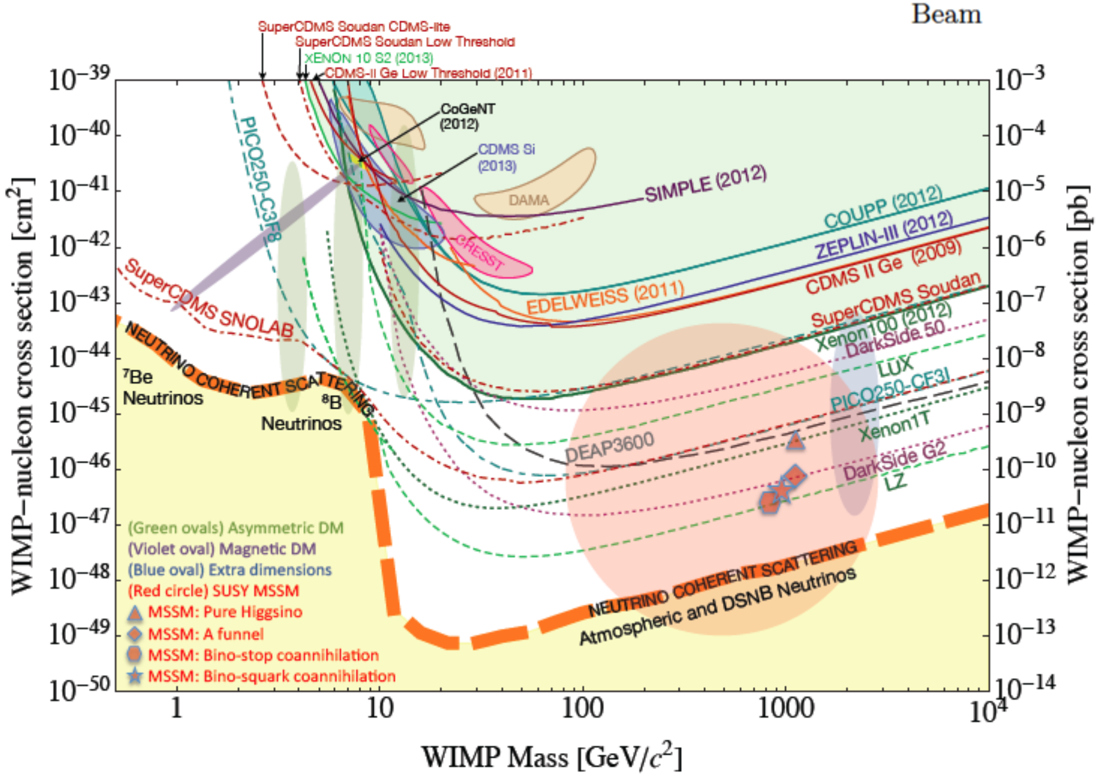
10 m,C 2 PAC-days of physics data at nominal settings

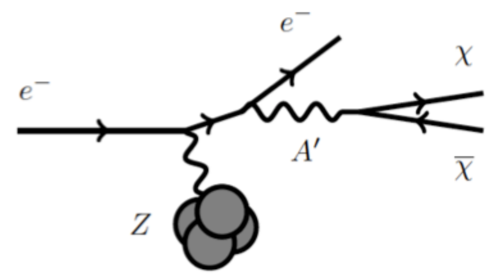


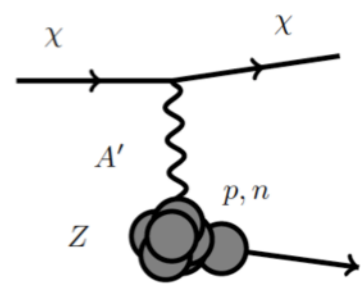
Beam Dump Experiment

- Letter-of-Intend to search for LDM in MeV-GeV mass range has been submitted to JLAB PAC 42 (2014)
- The collaboration was encouraged to proceed with a full proposal



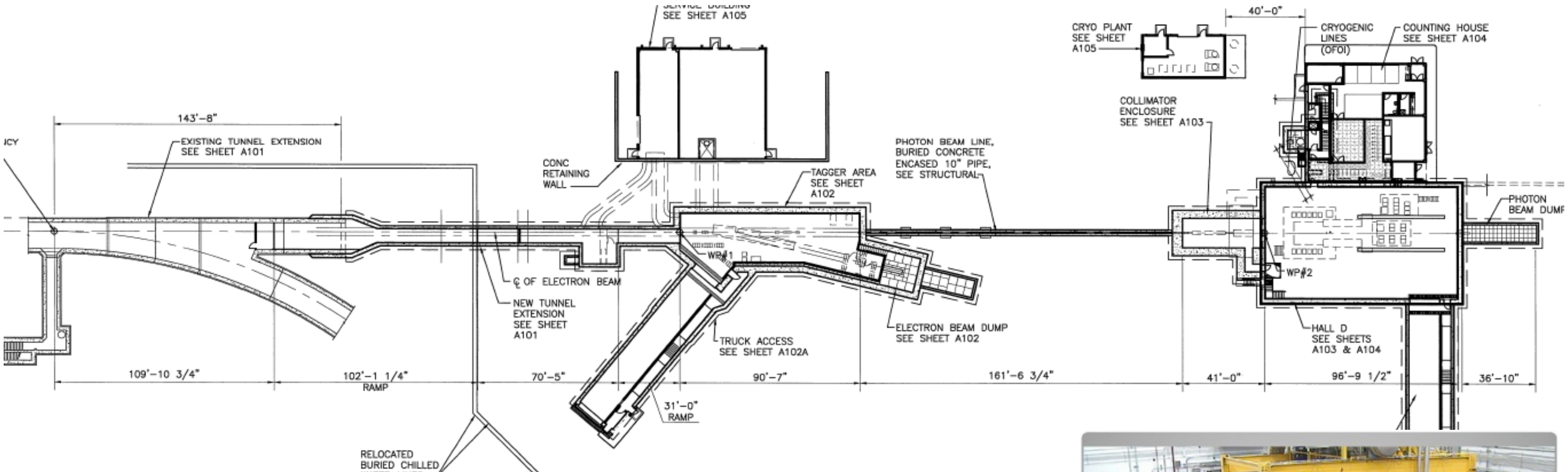


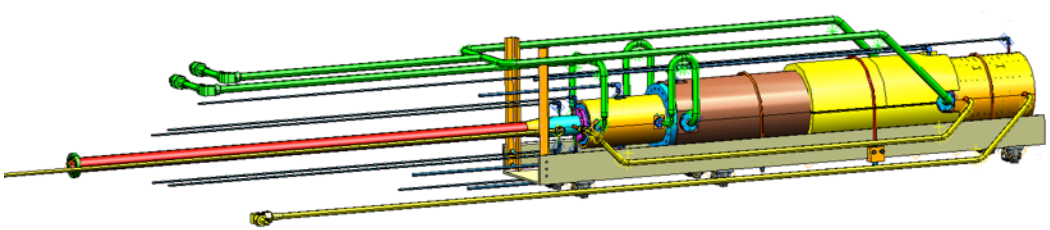




Hall-D beam dump

- E=12 GeV, moderate current ~200nA (may be increased up to 8 μA)
- Over-the-ground beam dump
- Easy access to the back of the BD enclosure
- Can operate without sending beam to Hall-D proper

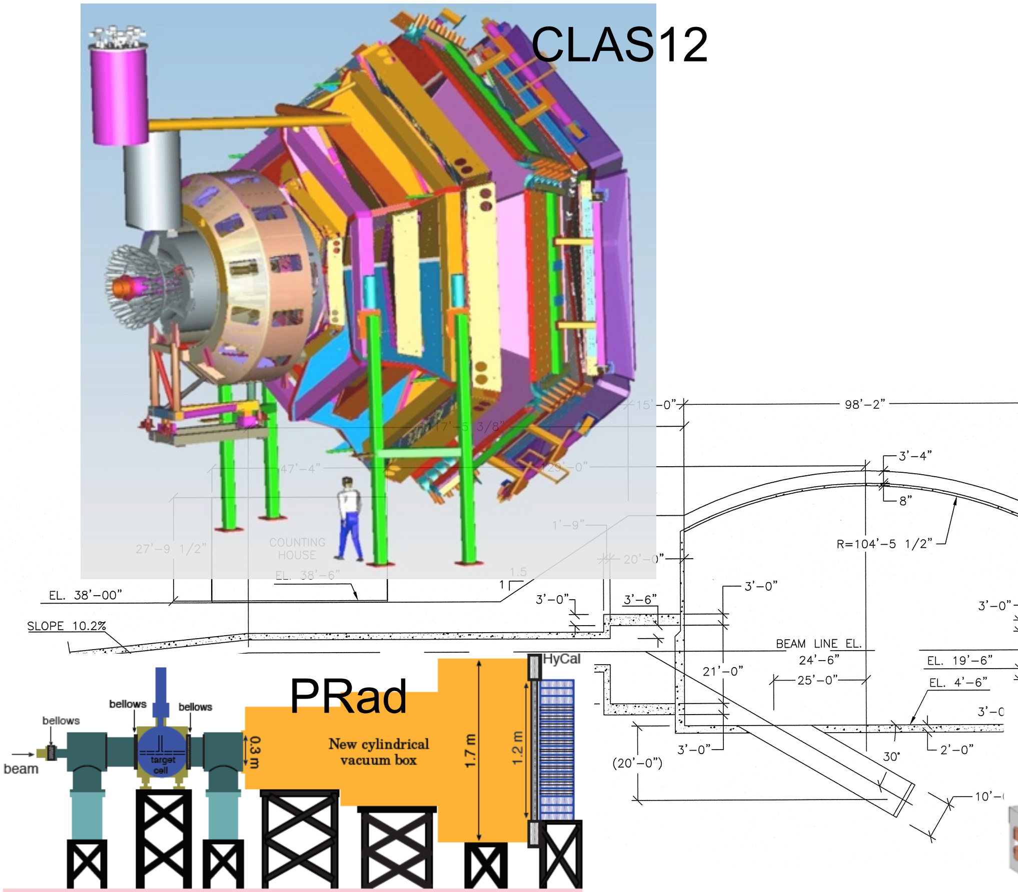


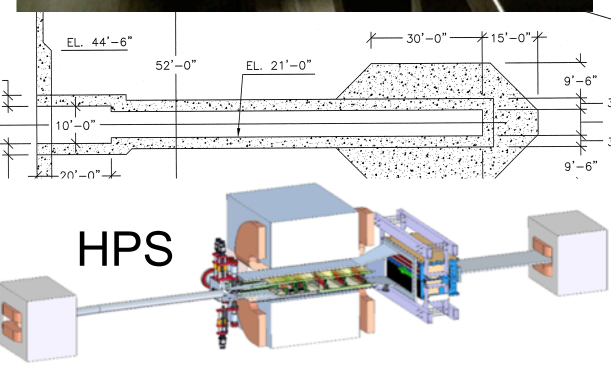


Hall D May 2014

Hall-B and its beam dump

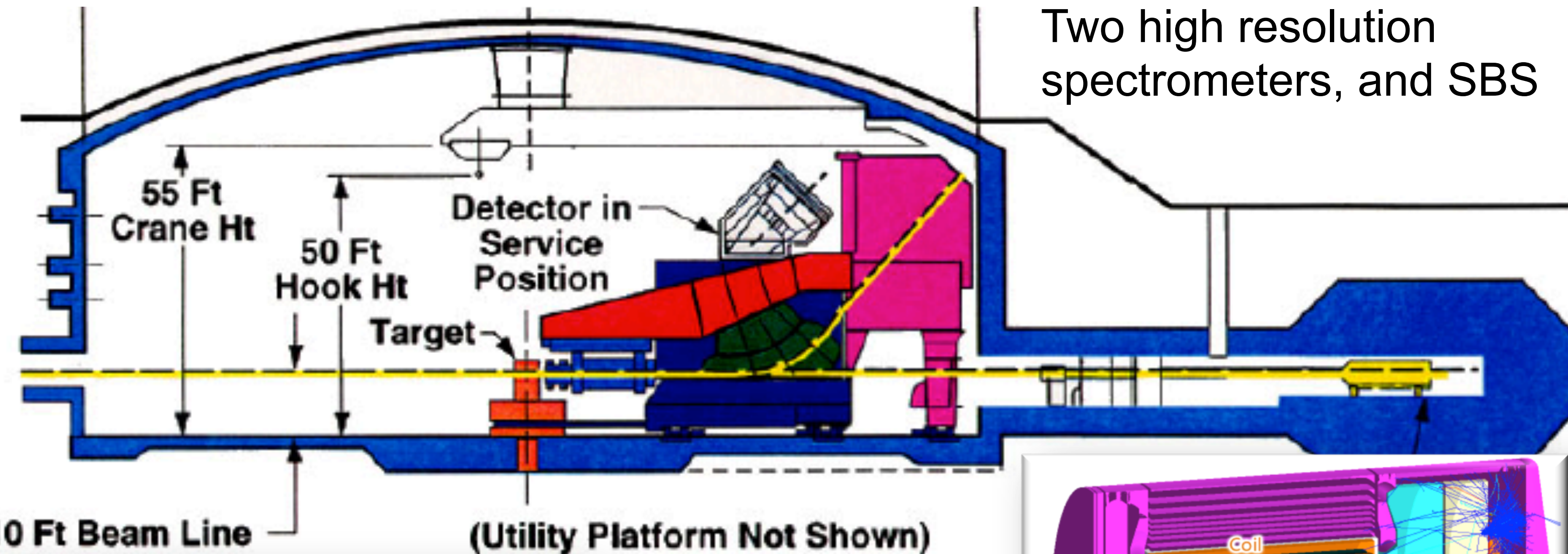
- Nominal running CW @ 50nA
- 5 kW beam dump
- More than 1500 hours of approved beam time



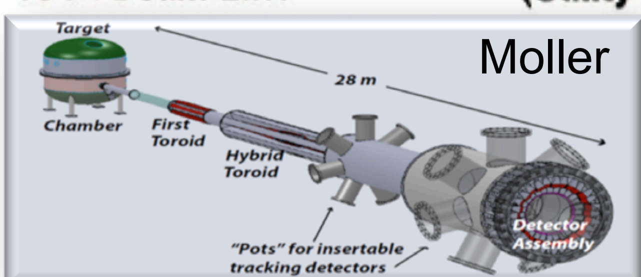


Hall-A

- Nominal running CW @ 50μA
- 900 kW beam dump
- More than 1300 hors of approved beam time



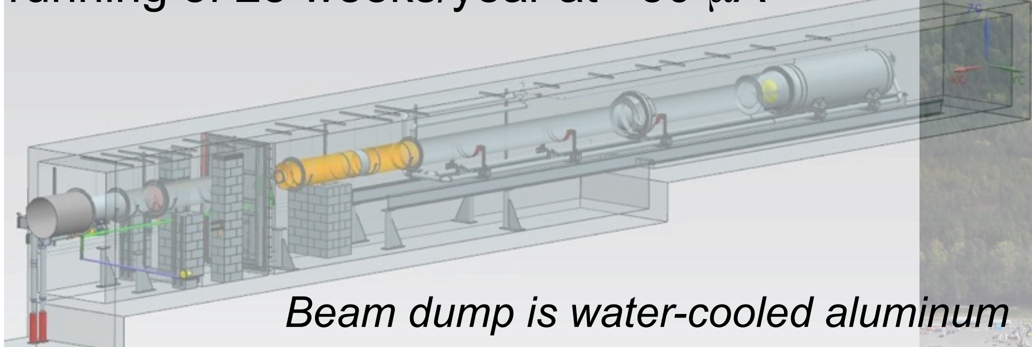
Two high resolution spectrometers, and SBS



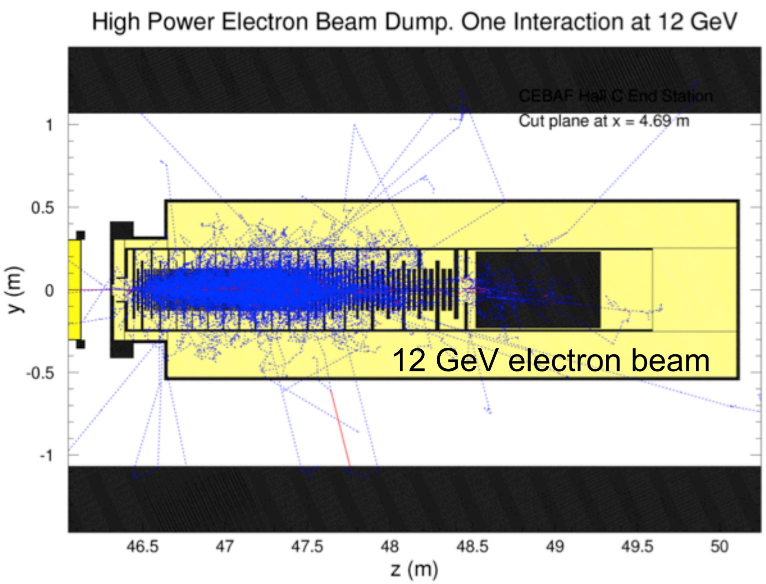
Future upgrades

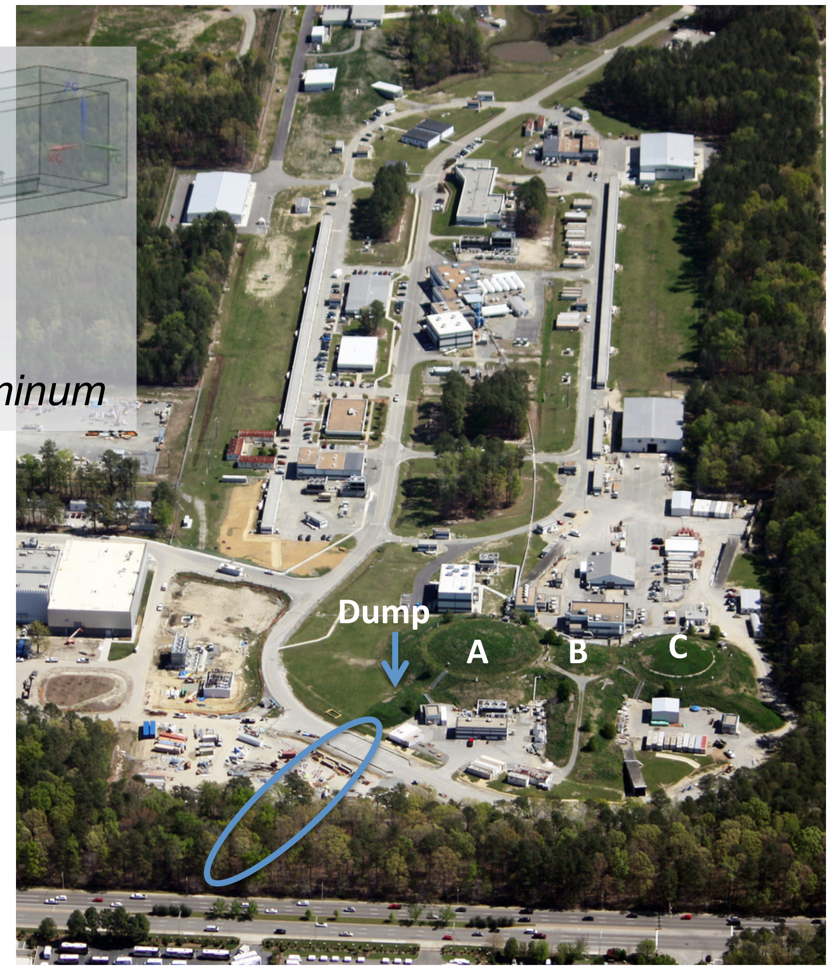
Hall-A beam dump

About 350 C/year of beam will be delivered to the Hall-A beam-dump with expected running of 25 weeks/year at ~50 μA



Beam dump is water-cooled aluminum

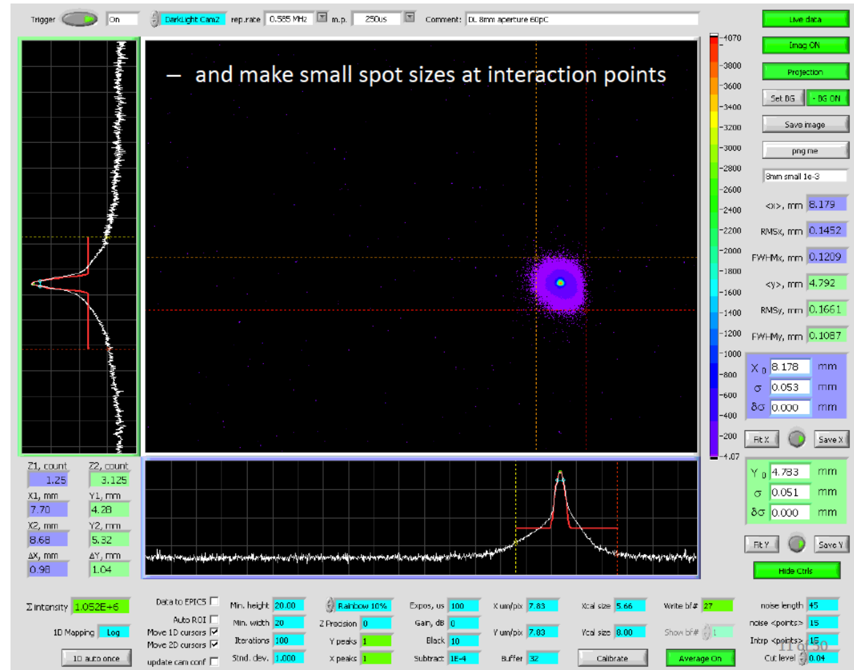




ERL at FEL

FEL beam characteristics

	Unit	External Target	Internal Target
E	MeV	80-300	80-165
P_{max}	kW	100	1650
I	mA	0.31-1.25	10
$\varepsilon_{transverse}$(norm)	mm-mrad	~1/~3	~3/~10
$\varepsilon_{longitudinal}$	keV-psec	~5/~15	~15/~50
Polarization	%	NA	NA
Annual Operating Weeks	week	?	?
f_{bunch}	MHz	750	750
Bunch Charge	pC	1.67-0.4	13.5
f_{bunch}	MHz	75	75
Bunch Charge	pC	16.7-4	135



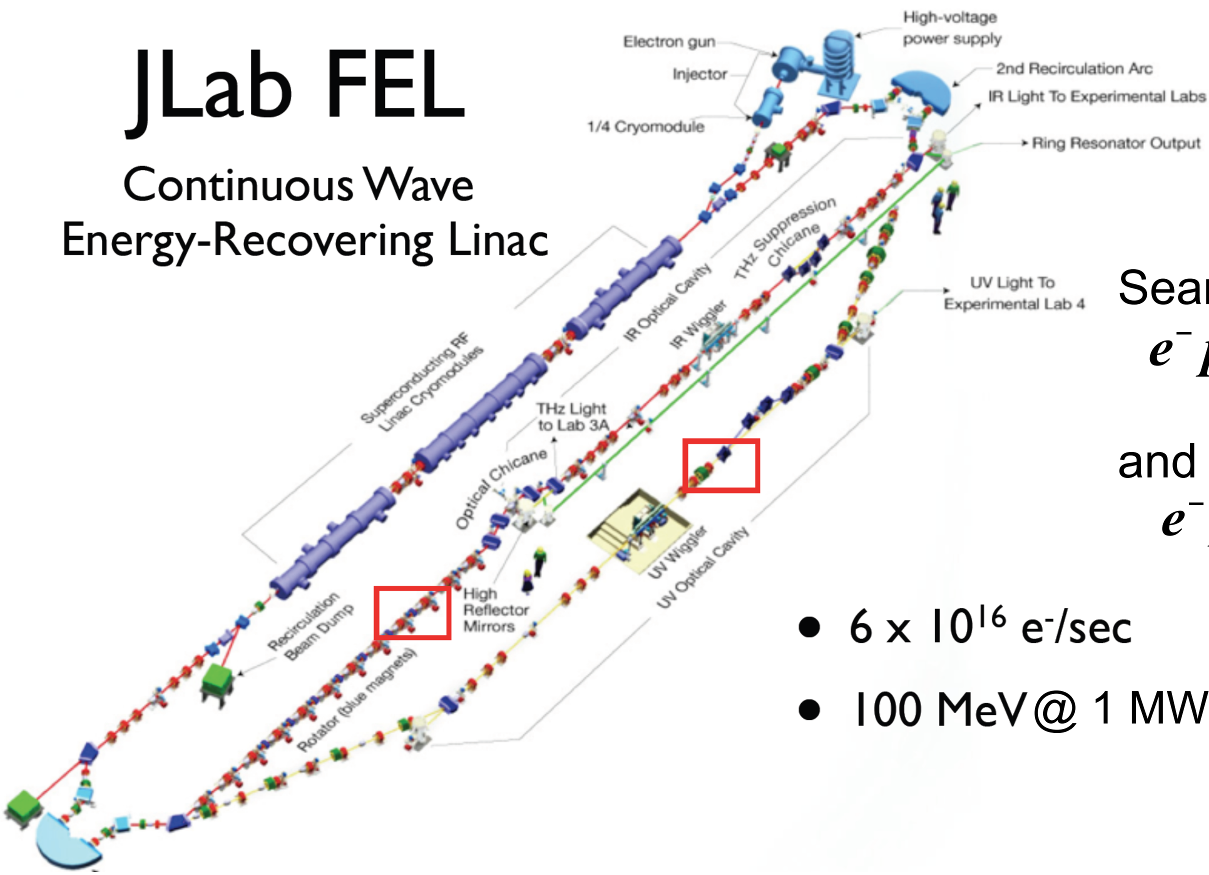
- Flexible control of full 6D phase space
- Broad range of beam parameters can be produced

DARKLIGHT

Electron scattering of hydrogen gas target

JLab FEL

Continuous Wave
Energy-Recovering Linac



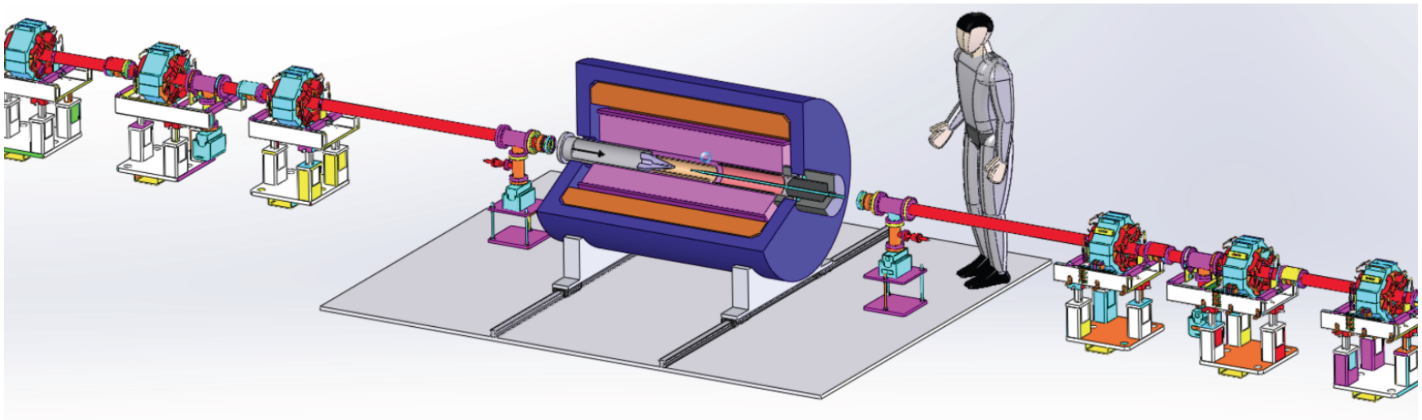
Search for A‘ in “visible“

$$e^- p \rightarrow e^- pA', \; A' \rightarrow e^+ e^-$$

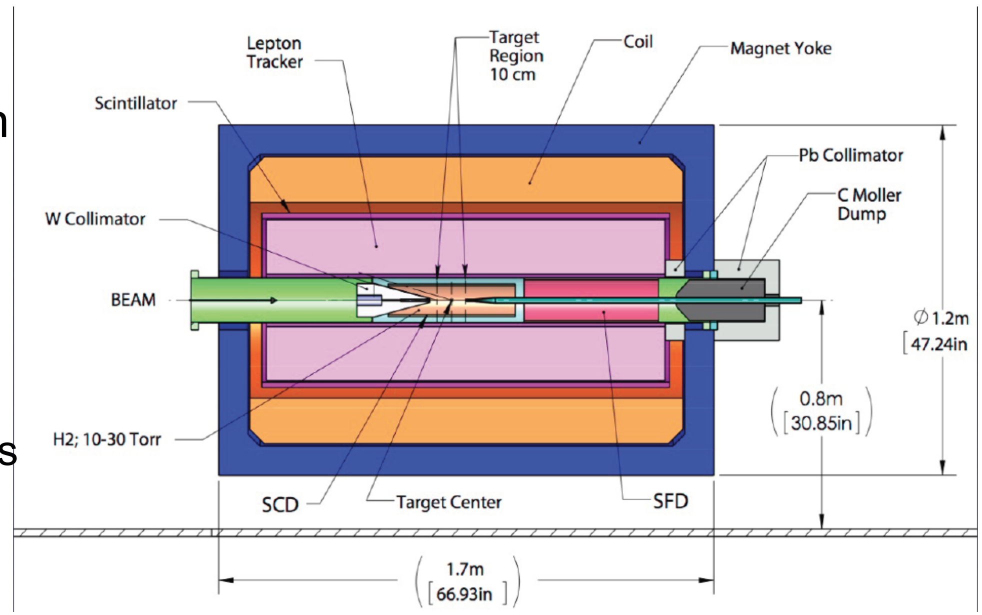
and “invisible“ decay modes

$$e^- p \rightarrow e^- pA', \; A' \rightarrow inv.$$

- 6×10^{16} e-/sec
- 100 MeV @ 1 MW



- Windowless target, aggressively pumped
- Gas thickness ~10^{19}cm^{-2} with 10mA beam yields~0.5 ab^{-1}/month
- Thin beryllium beam pipe
- Si detector for proton recoil
- TPC + 0.5 T magnet
  - High track density
  - ~250 μm hit res.
  - Magnet confines low-p_T backgrounds (e-p and Moller)
- Scintillators serves as veto for invisibles search

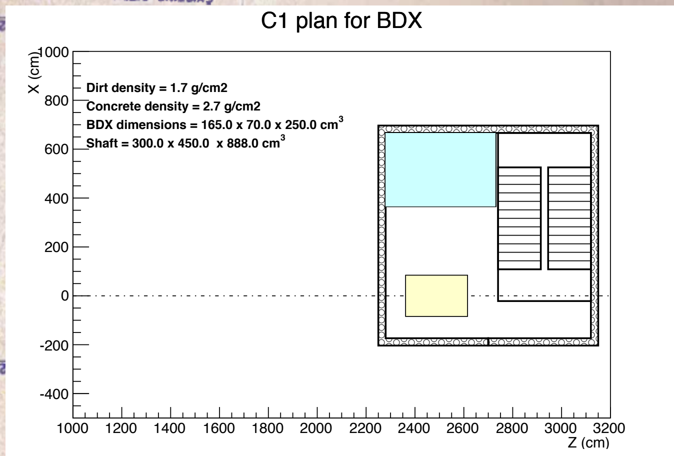


Summary

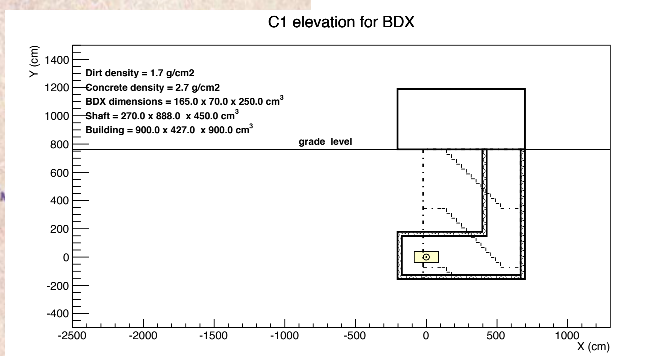
- Jefferson Lab is home for two electron machines based on superconducting RF technology: CEBAF and ERL-FEL
- Available high intensity, high precision beams with energies from 100 MeV to 12 GeV provide opportunities for high precision, high statistics experiments needed for LDM searches
- The first three experiments for Heavy Photon searches have been approved, two of them, APEX and HPS, have already seen beams
- JLAB experiments will cover large parameter space in mass and coupling, reaching the regions that are not covered in any of currently known experiments
- While high duty factor beams are not ideal for the beam dump experiments, with expected large amount of beam current (350 C/year) to be delivered to the high power beam dumps (Hall's A&C) makes this facility attractive place for electron beam dump experiments
- Design of such an experiment is started (BDX), proposal to JLAB PAC is expected to be submitted in 2016

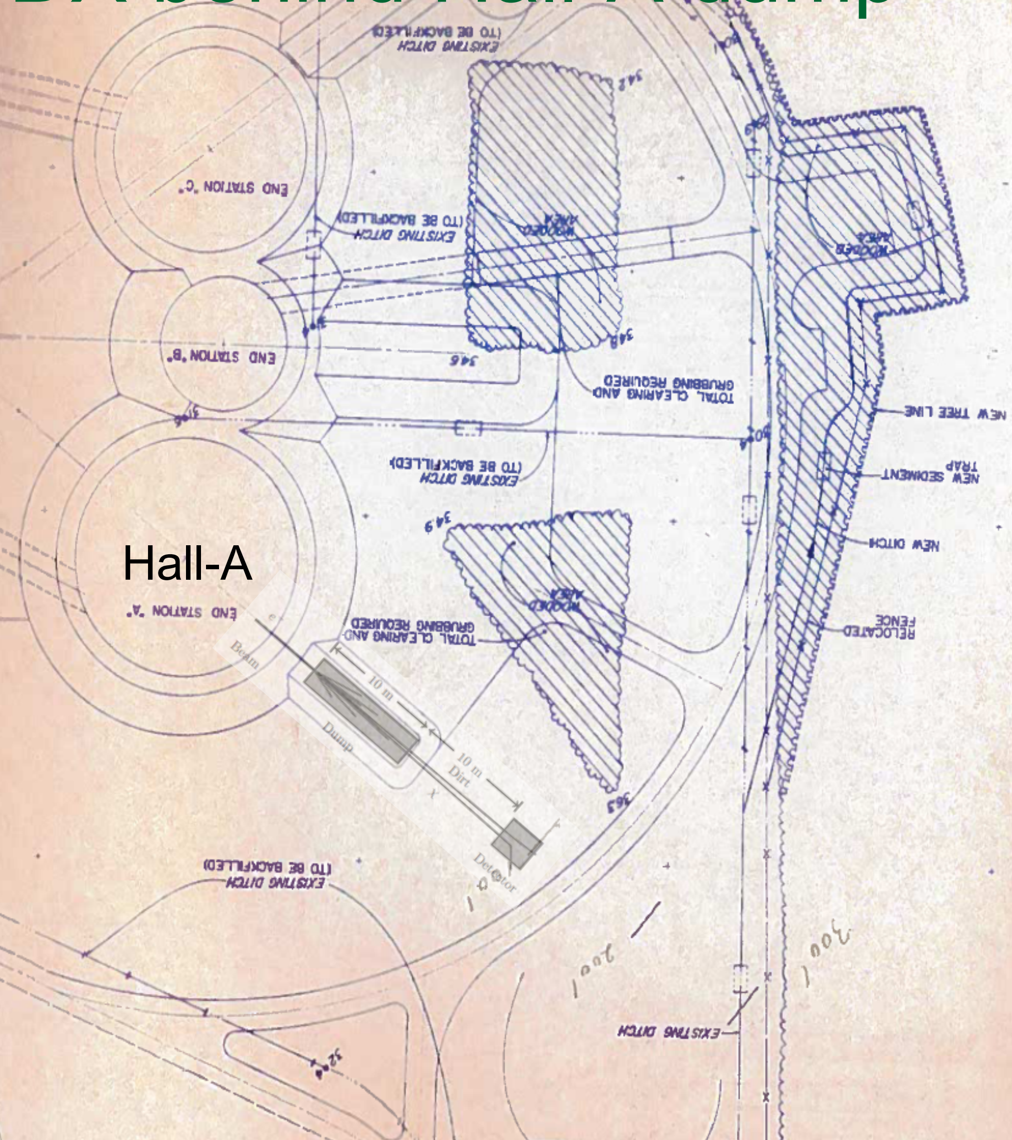
Acknowledgment: To Arne Freyberger for help in preparing the talk

Possible option for BDX behind Hall-A dump



Price tag ~$1M





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