Dark Sector Searches at Jefferson Lab

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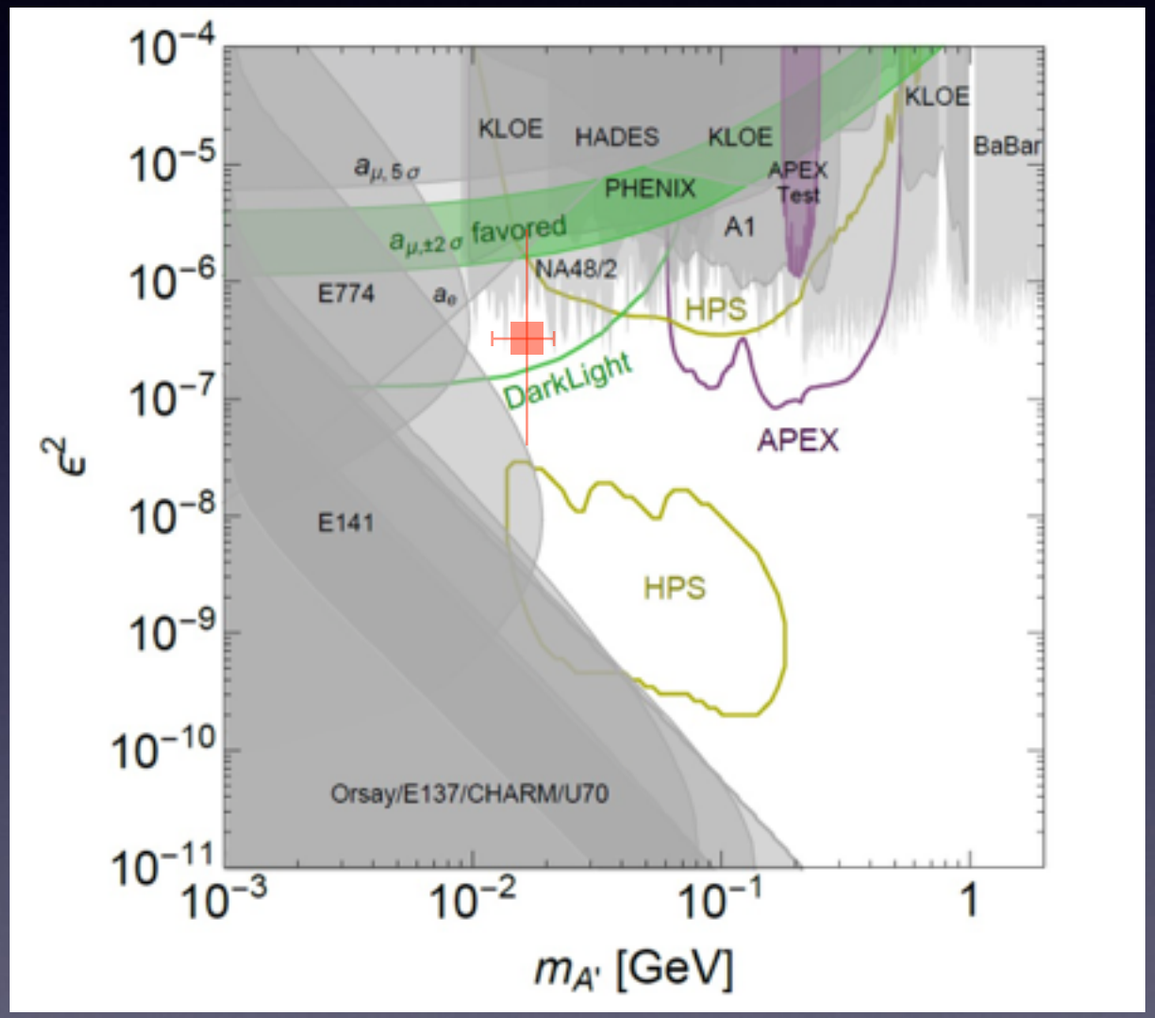
7th Workshop of the APS Topical Group on
Hadronic Physics, Washington D.C.
February 3, 2017

Massachusetts
Institute of
Technology

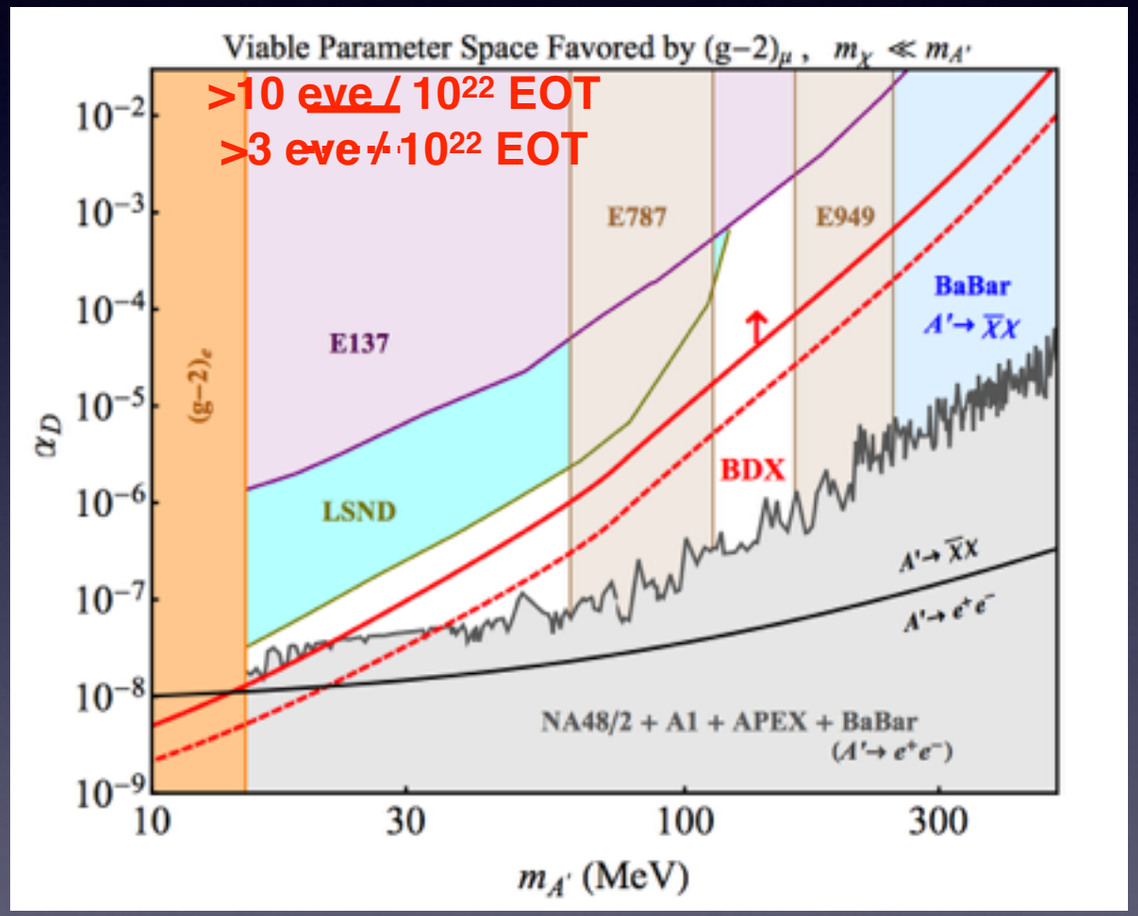
A' Searches at JLab



- effective dark charge: εq
- tension for g-2 + ^{8}Be ==> $\varepsilon_e \neq \varepsilon_d \neq \varepsilon_u$...? Or a_e wrong?†
- Hadronic couplings: HADES, PHENIX, NA48/2
- Leptonic couplings: KLOE, BaBar, A1, **HPS, DarkLight, APEX, BDX***

† John Ralston's talk

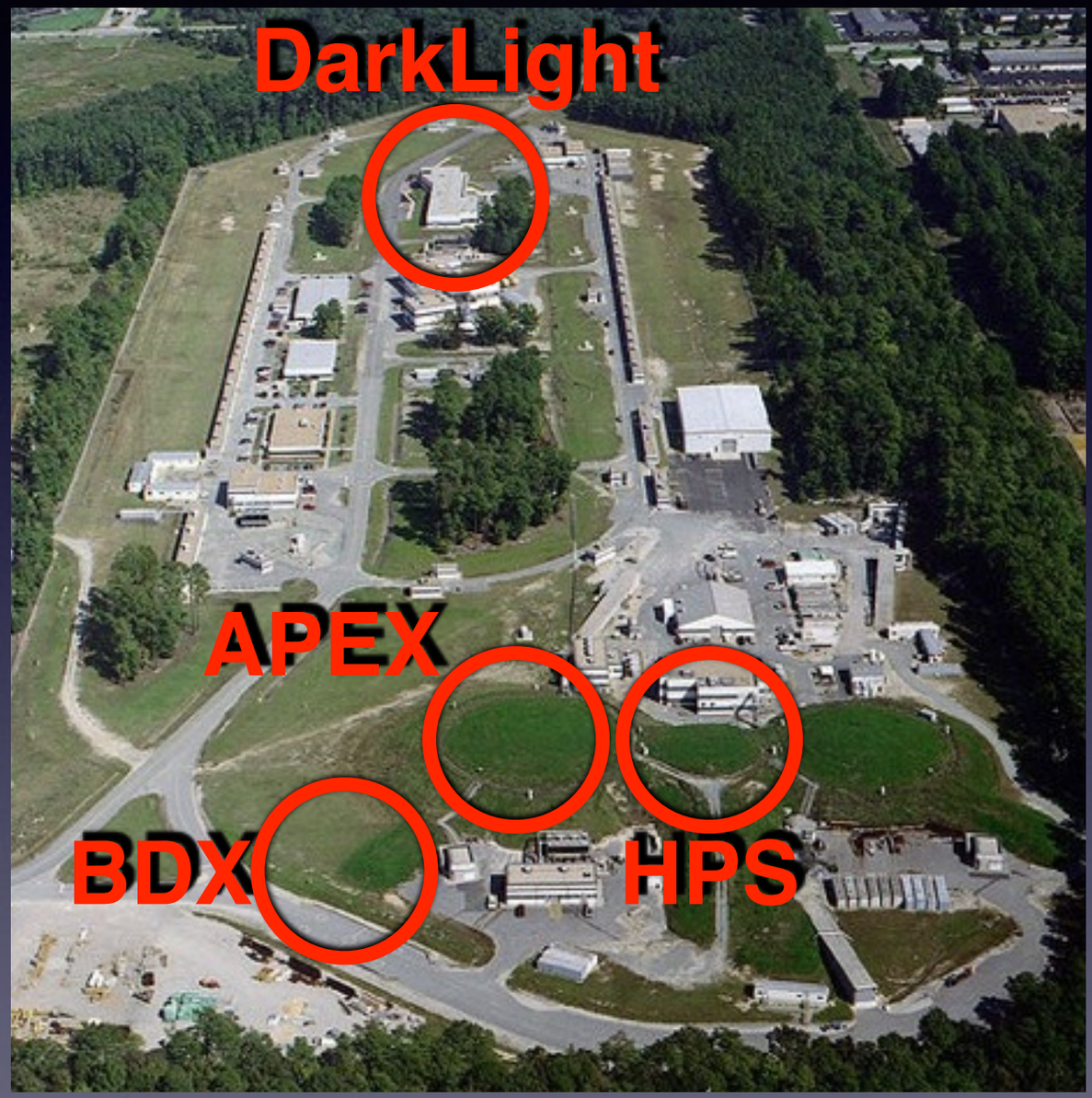
* LDM Search (BDX)



- Probes $m_{A'}$ through LDM interactions with detector
- Difficult to plot model independent limits
- Shown: slice with $\varepsilon(m_{A'})$ fixed at lower bound of $(g\text{-}2)_\mu$ 2σ band

Experiments at Jefferson Lab

	Target	Range	Probe
BDX	beam dump	model dependent. Sensitive to $M_{A'}$, M_X, α_D...	X-e or X-N scattering
DarkLight	H_2 gas	$10<\mathbf{M_A}<100$MeV	e^+e^- pairs, full final state
APEX	W, Ta foils	$65<\mathbf{M_A}<600$MeV	e^+e^- pairs
HPS	W foil	$0.02<\mathbf{M_A}<1$GeV	e^+e^- pairs, displaced vertex



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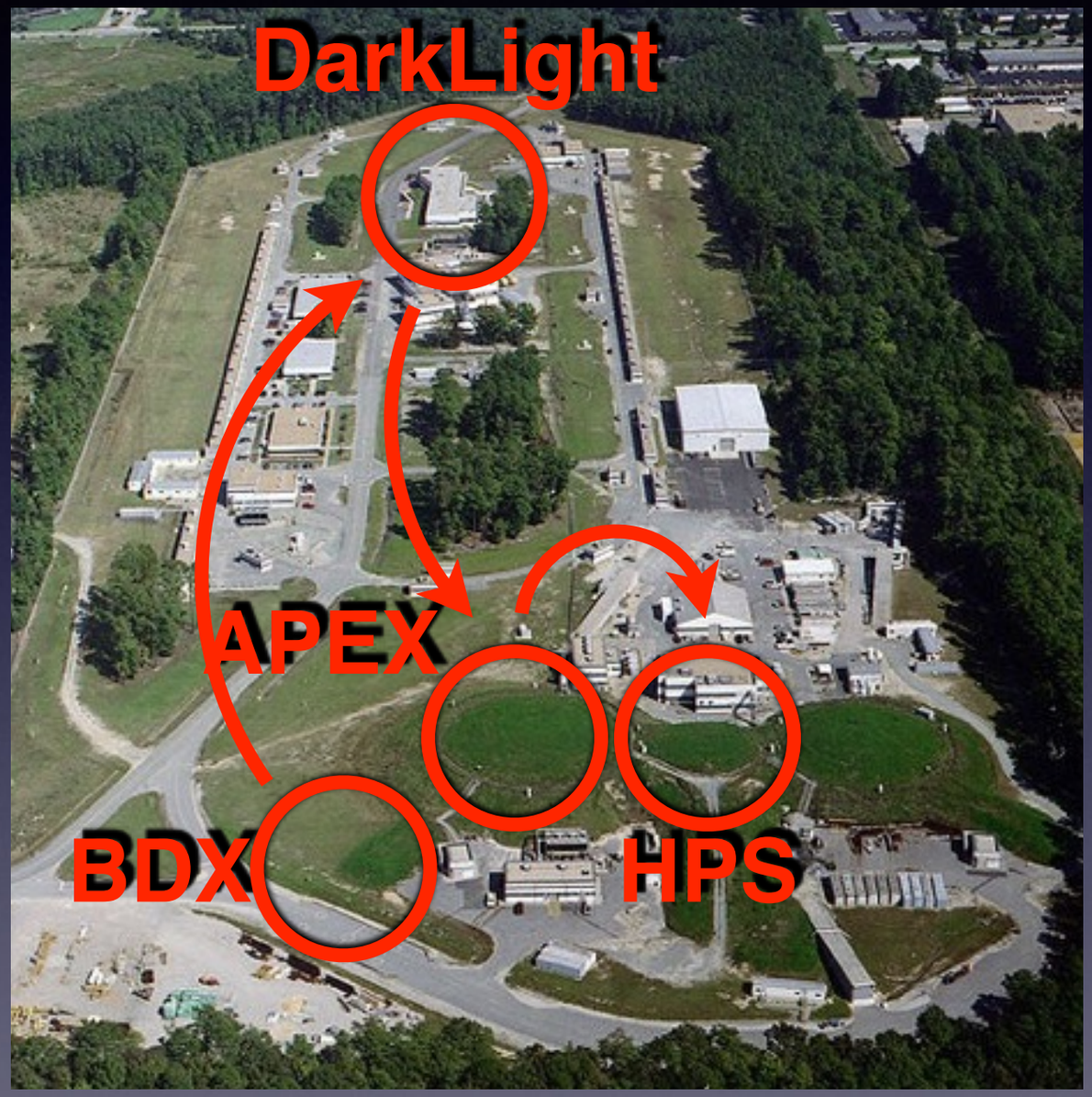
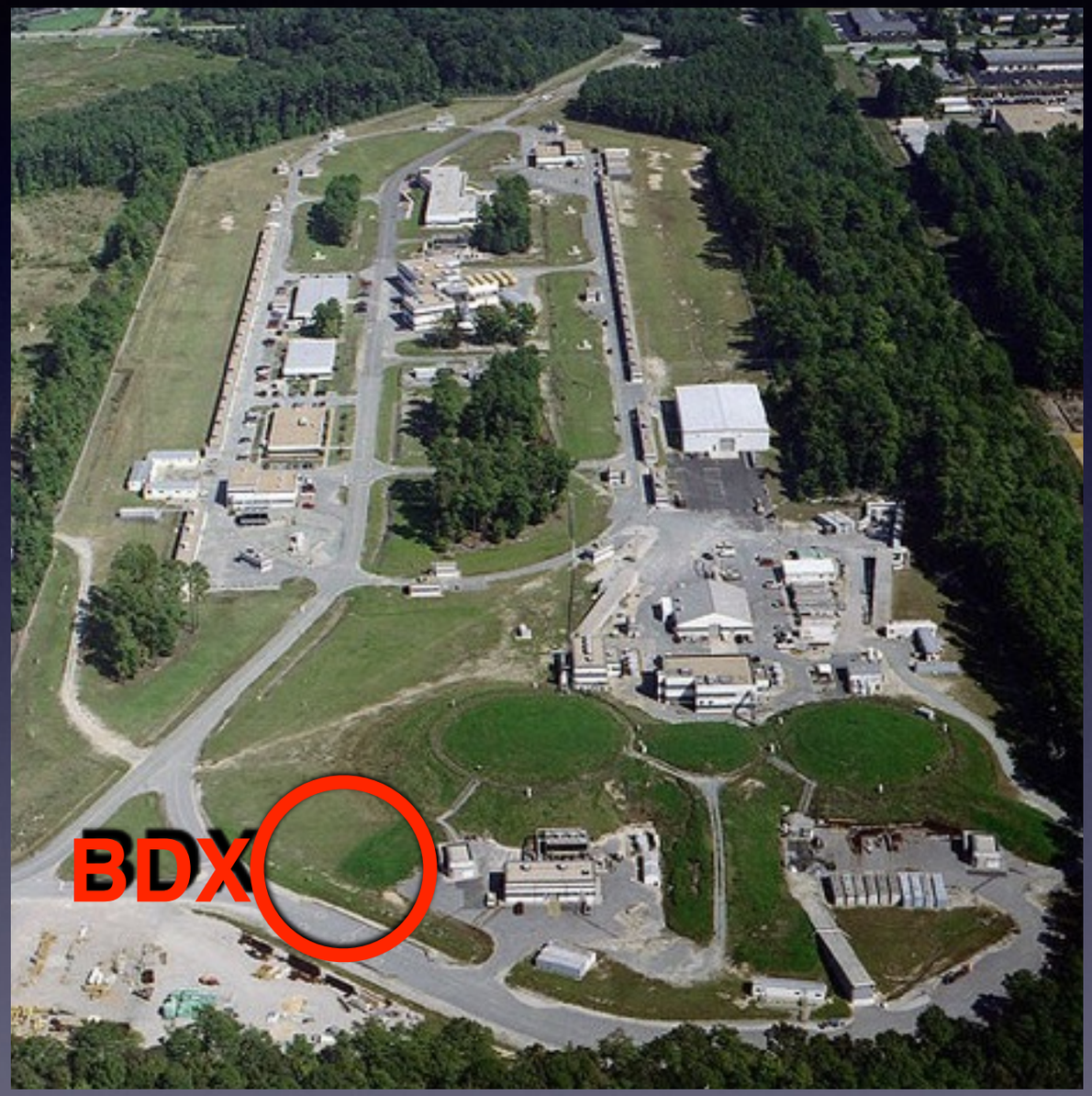


BDX at Jefferson Lab

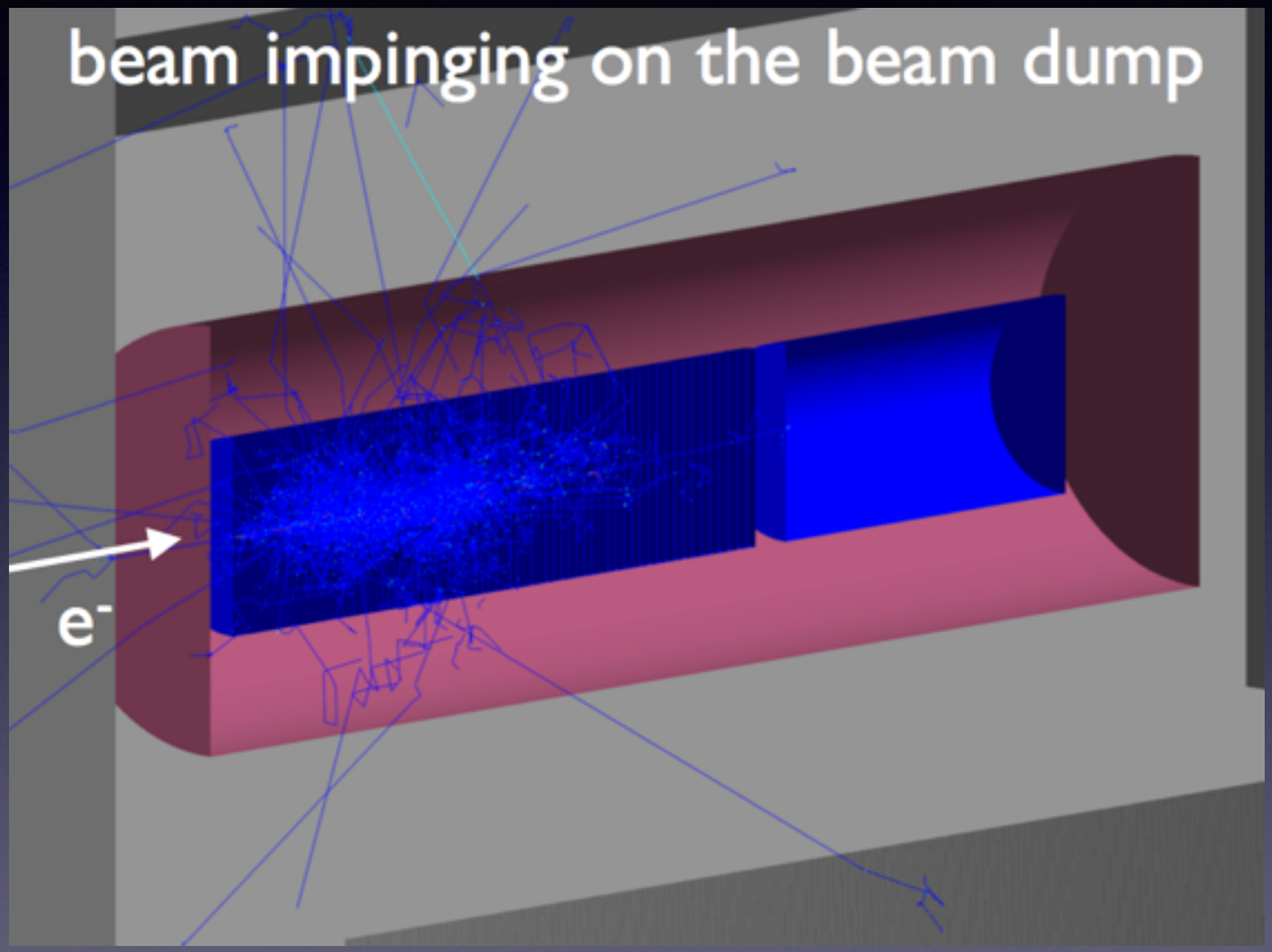
"Beam Dump eXperiment"

- Generate LDM in beam dump
- Detect LDM through X-e scattering, possibly access X-N scattering
- GeV recoil easy to detect
- Parasitically operates with **Hall A** experiment



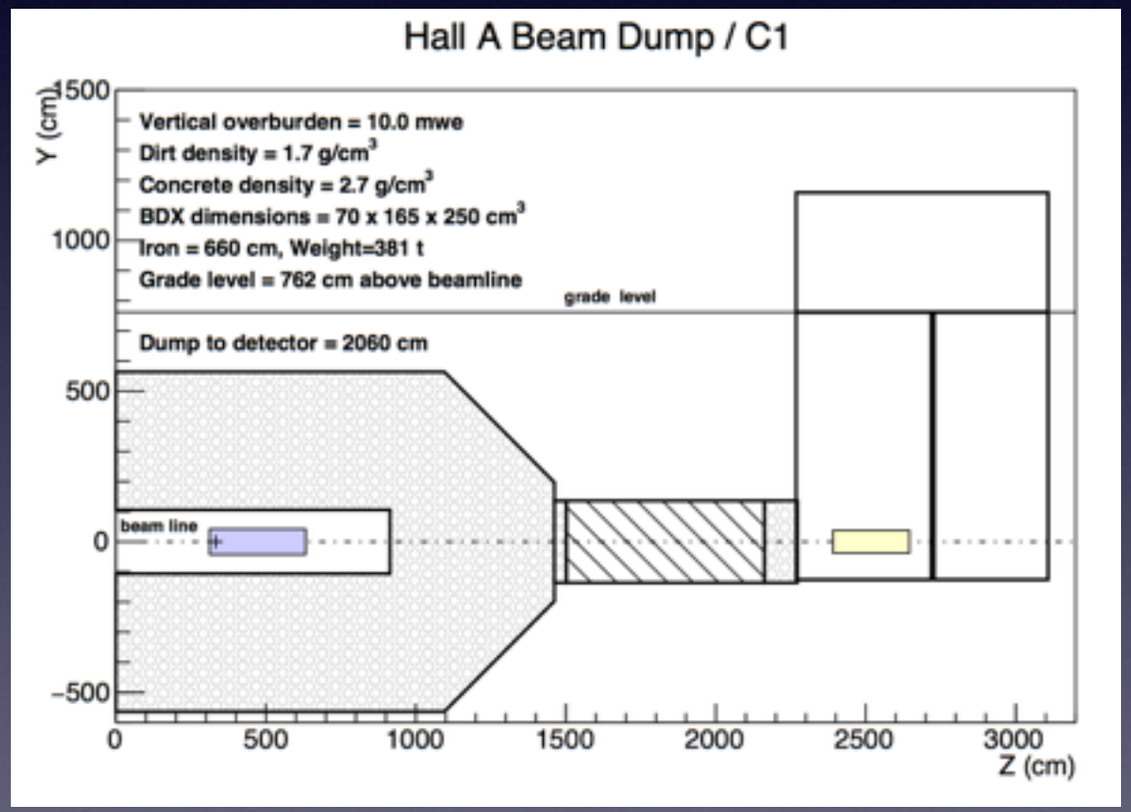
Beam Dump and Onward

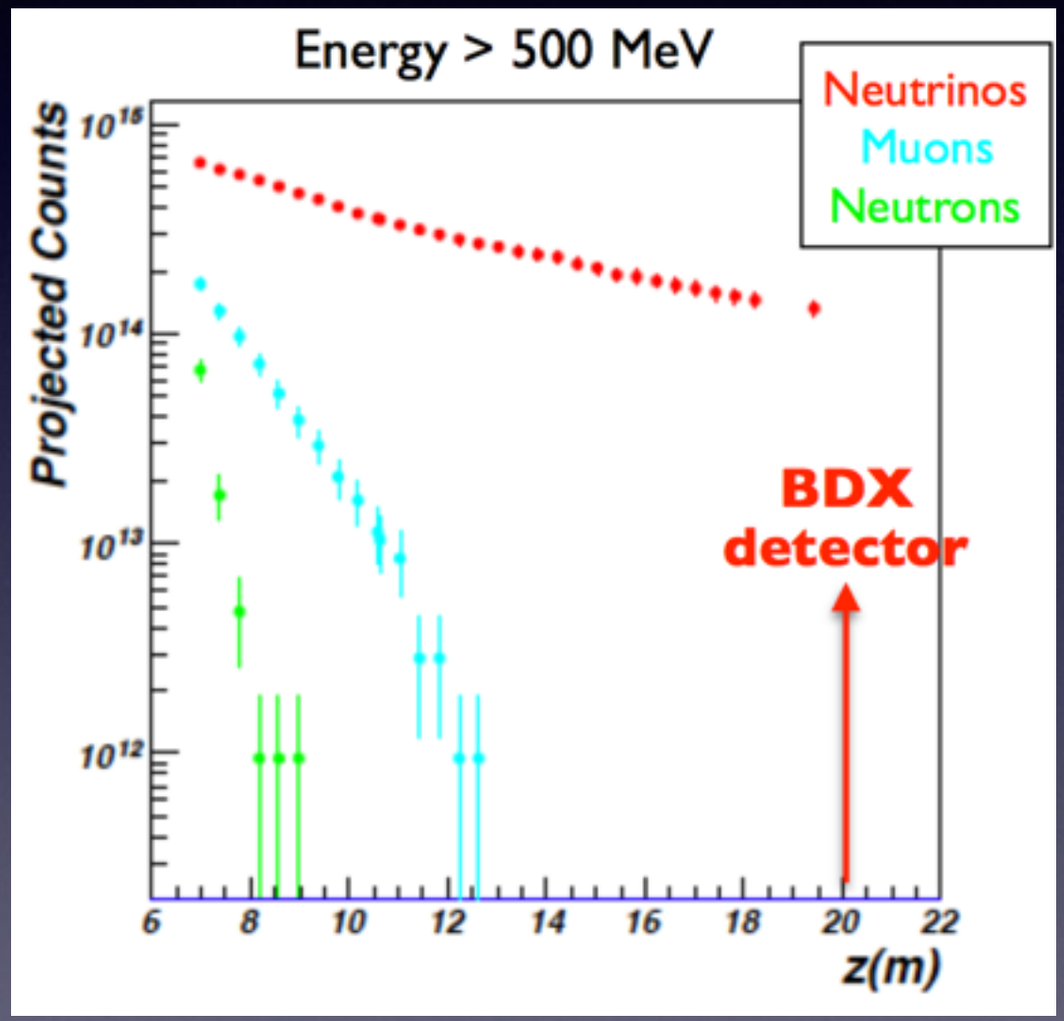
- 11 GeV e^- showers in dump
- LDM produced via eN->eNA'->eNXX
- Primary background from neutrons, muon pair production
- (also produces neutrinos)



Shielding

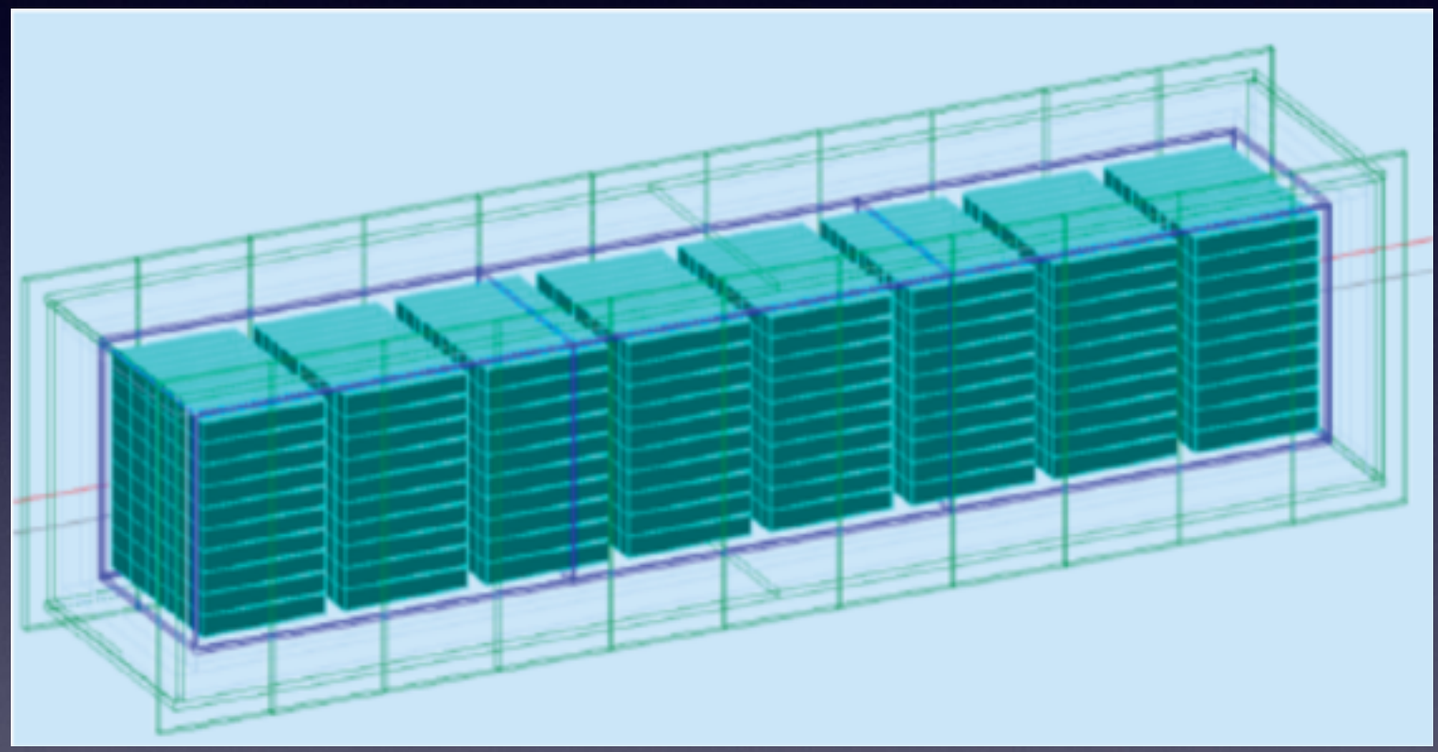
- Iron shielding ranges out μ
- Concrete shields n





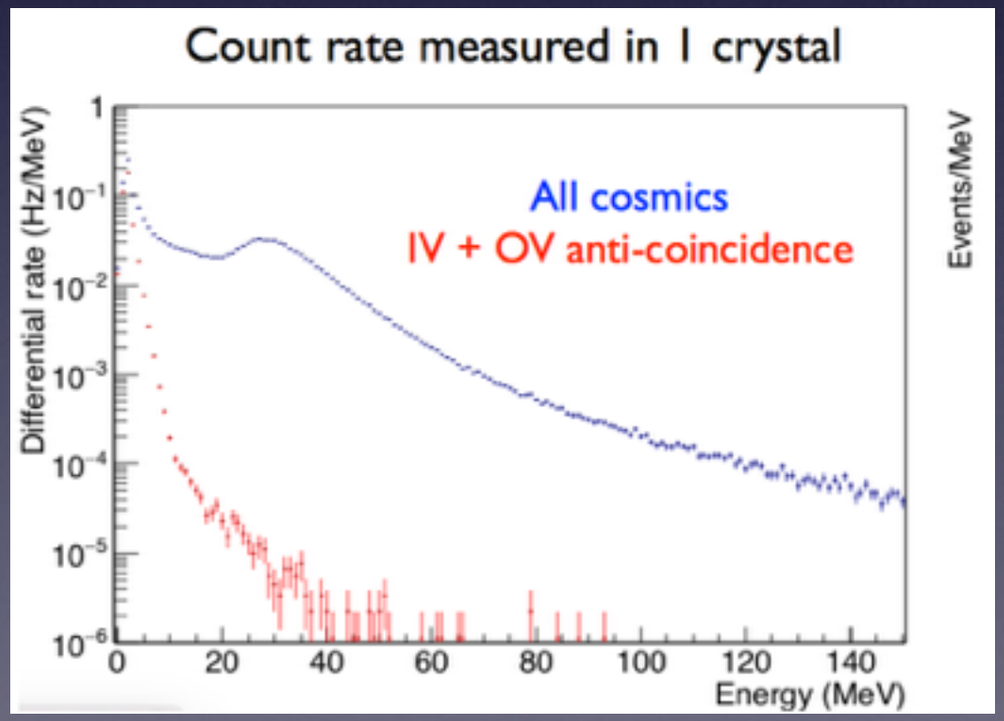
BDX Detector

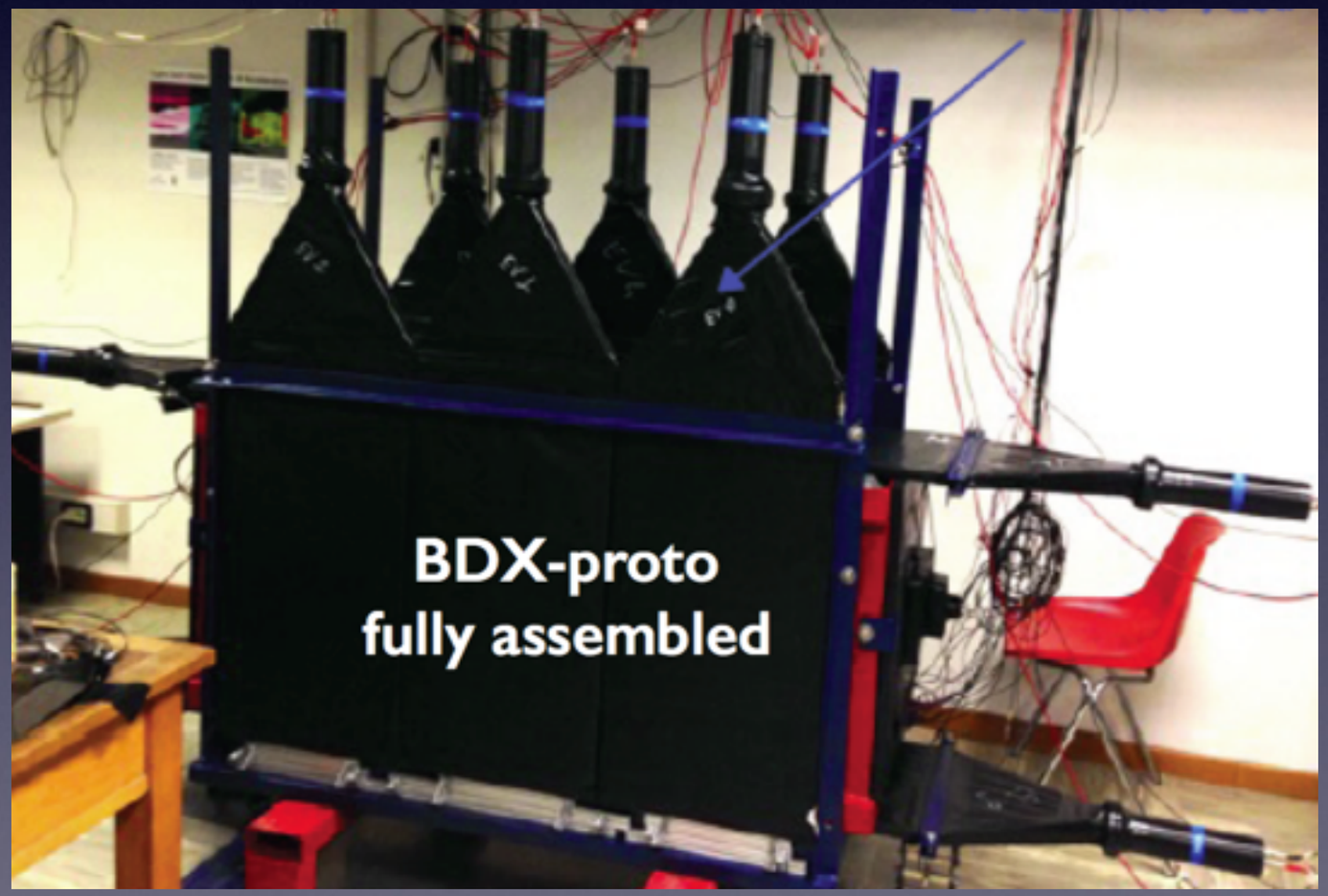
- ~1m^3 of CsI(Tl) crystals from BaBar endcap EM calorimeter ~1k channels
- Veto sandwich of Sci-Pb-Sci registers cosmic muons/showers
- Significant beam-off time to characterize cosmic neutrons



BDX Prototype

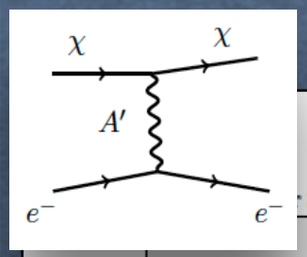
- Operating at INFN
- 3x3 BaBar crystals with SiPM
- 2-layer veto



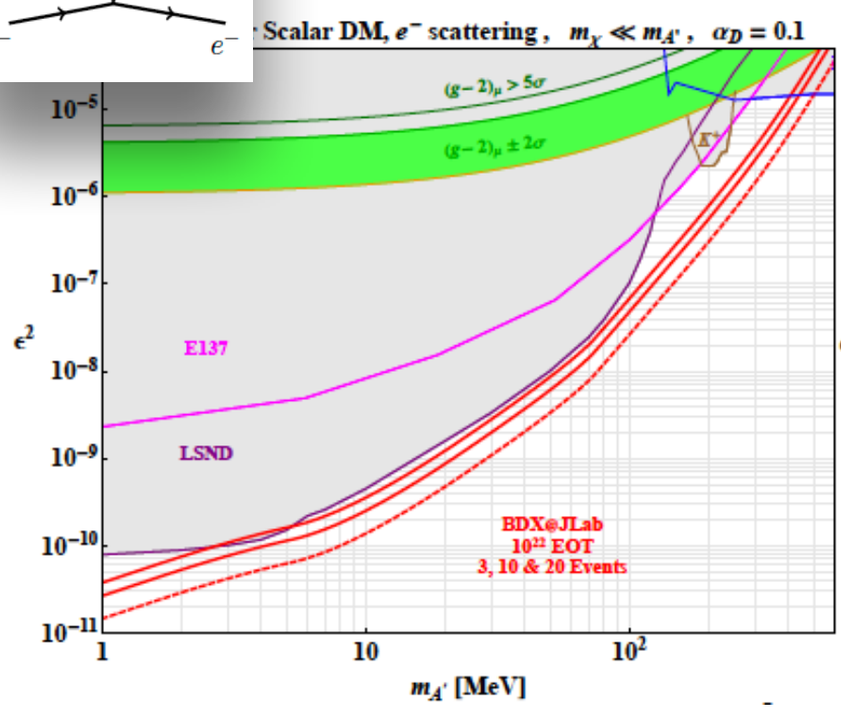


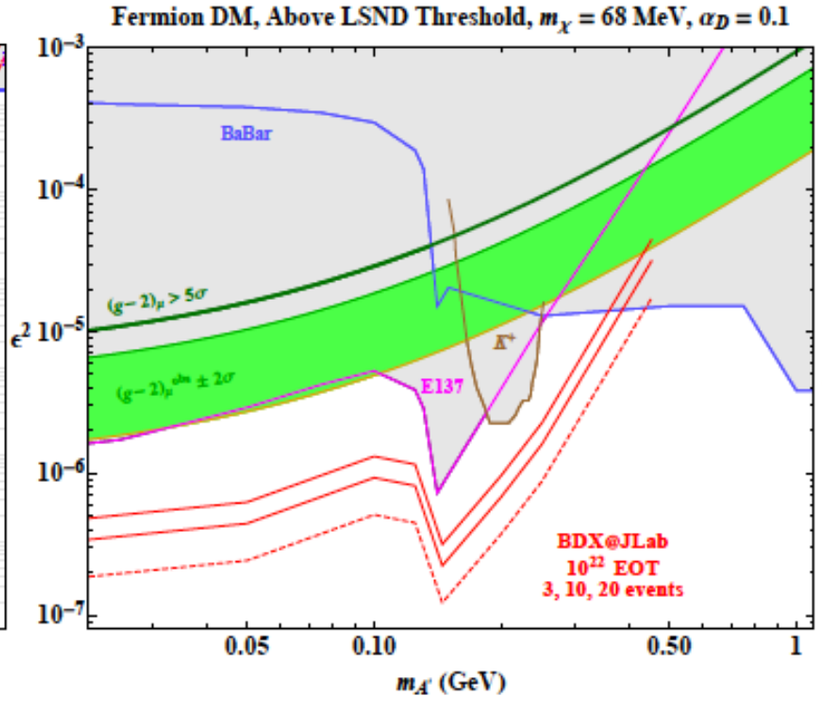
10^{22} EOT = 285 days of running:

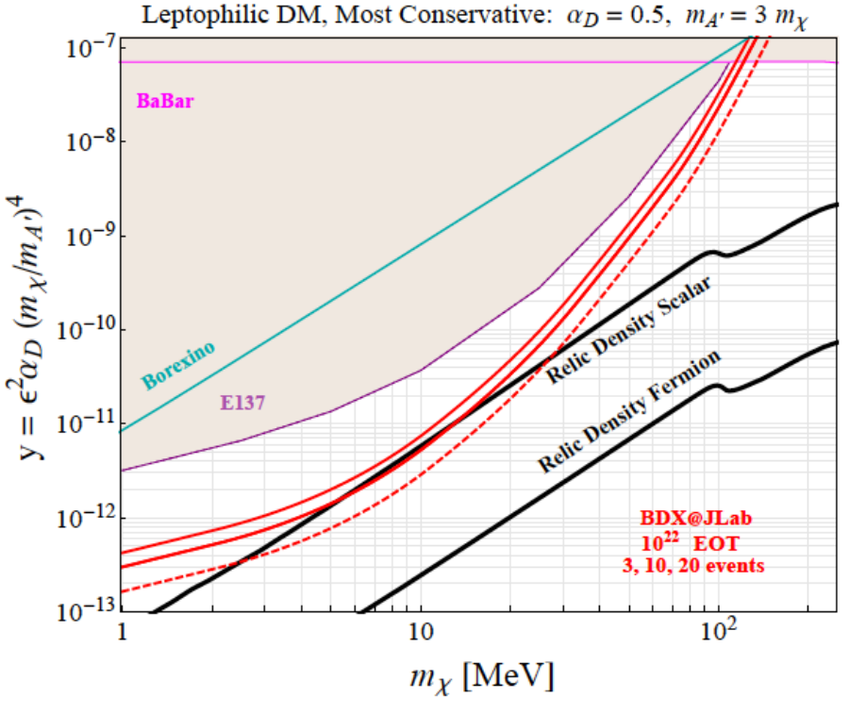
BDX expected reach



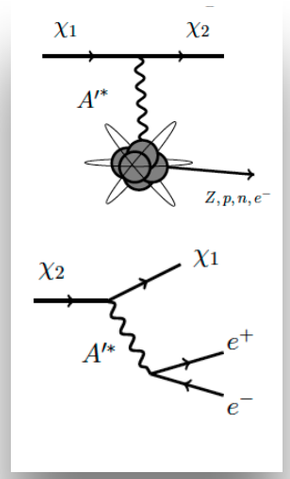
Elastic X-e⁻ scattering - BDX reach

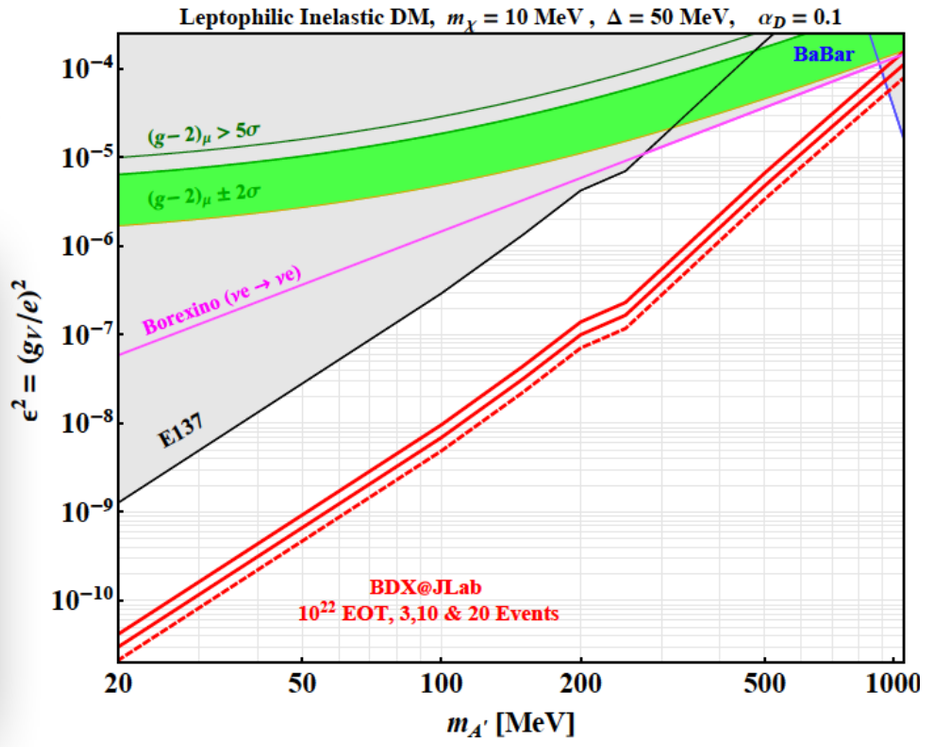




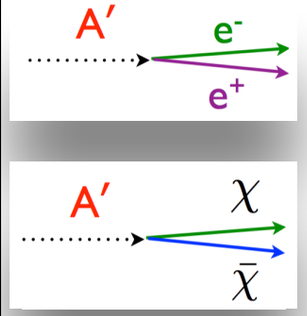


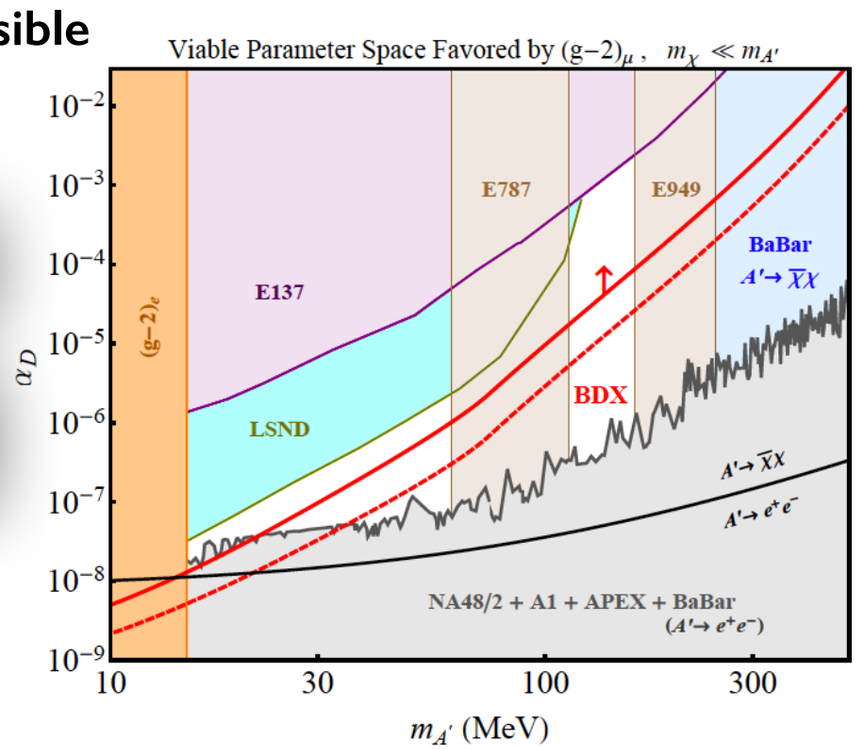
Inelastic X-N scattering





Visible + Invisible decay





BDX Status

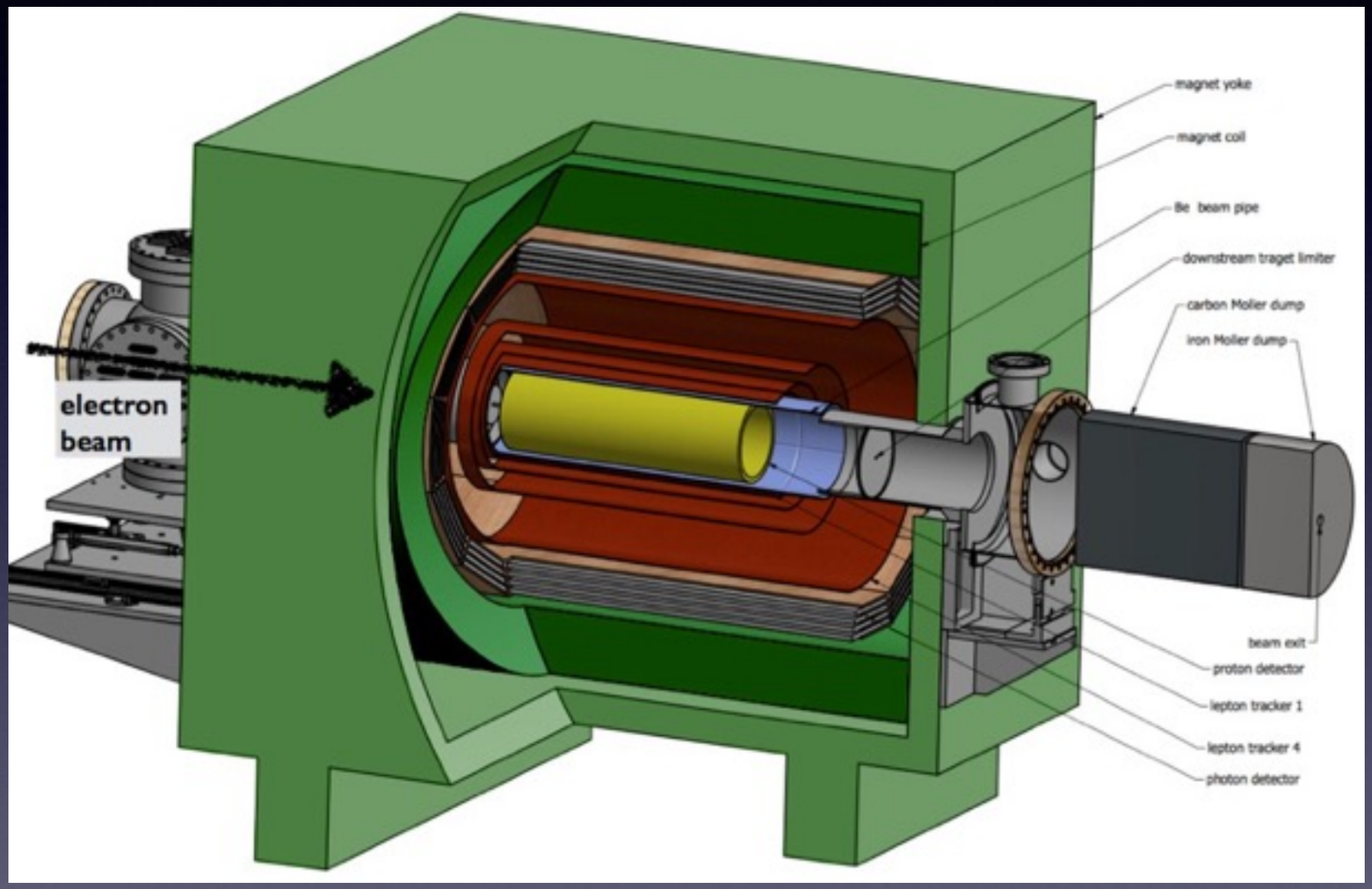
- Conditionally approved by JLab PAC (C2)
- Simulating muon backgrounds and planning to measure these in the near future
- Operating prototype at INFN
- Benchmark 10^{22} EOT (285 days)
- Hoping to run parasitically with MOLLER / PVDIS

DarkLight at Jefferson Lab

"Detecting A Resonance Kinematically with eLectrons Incident on a Gaseous Hydrogen Target"

- ISR/FSR A' production off e^- in ep scattering
- **LERF** (5mA, 100MeV) beam on ~5 Torr gas target to overcome small coupling (~ab^{-1}/mo)
- Detection of all final state particles to suppress backgrounds

DarkLight Concept



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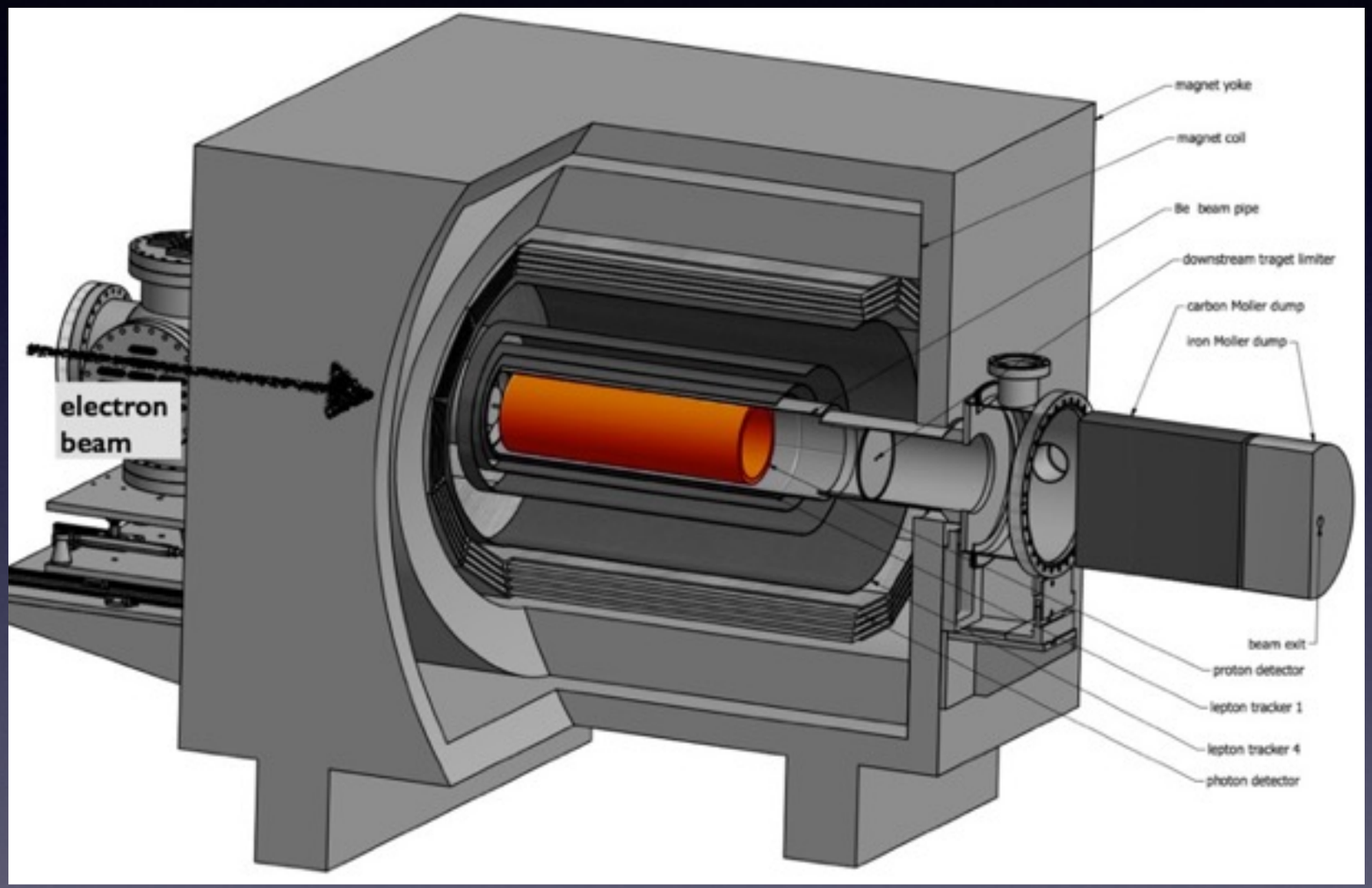
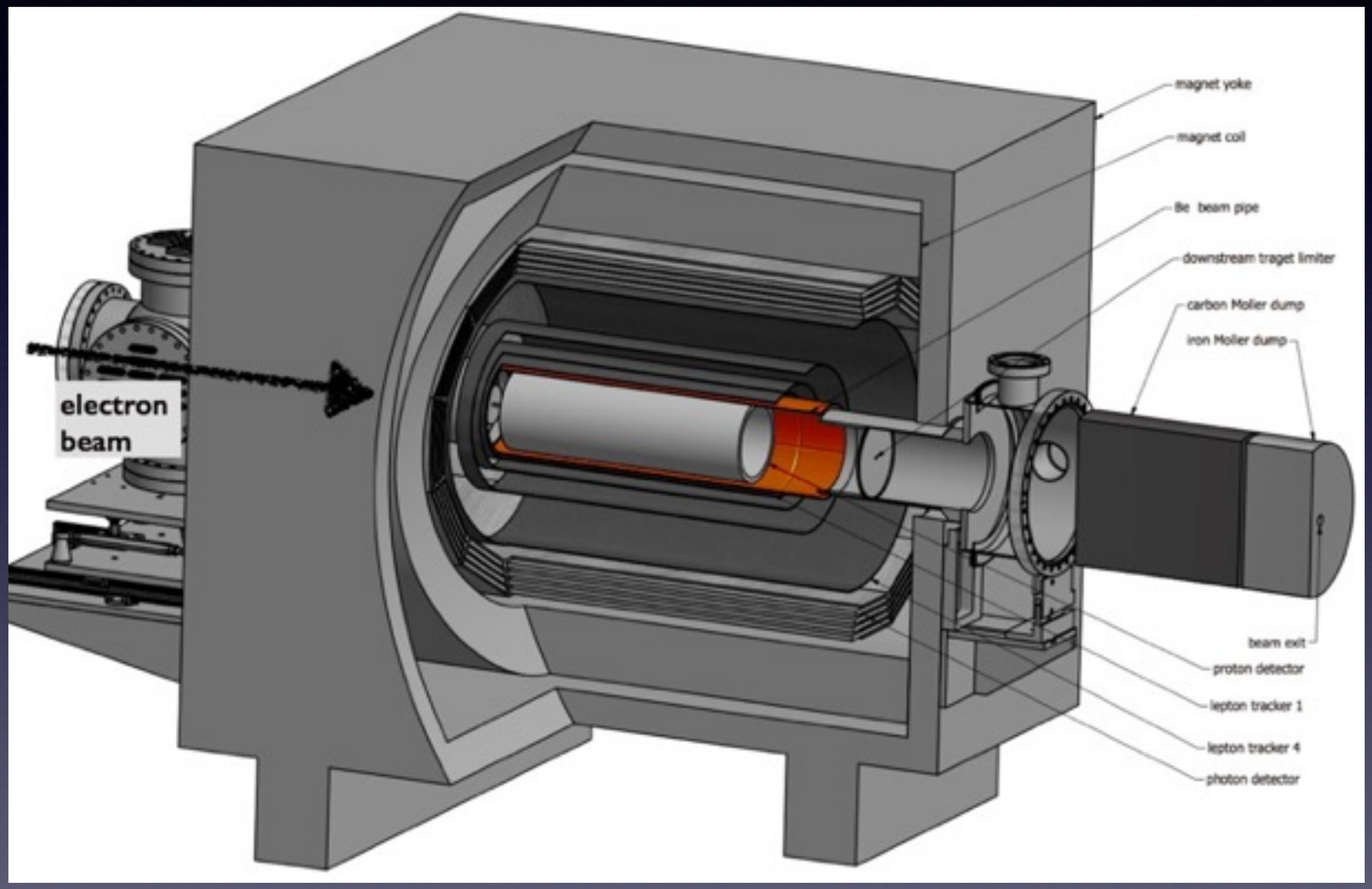


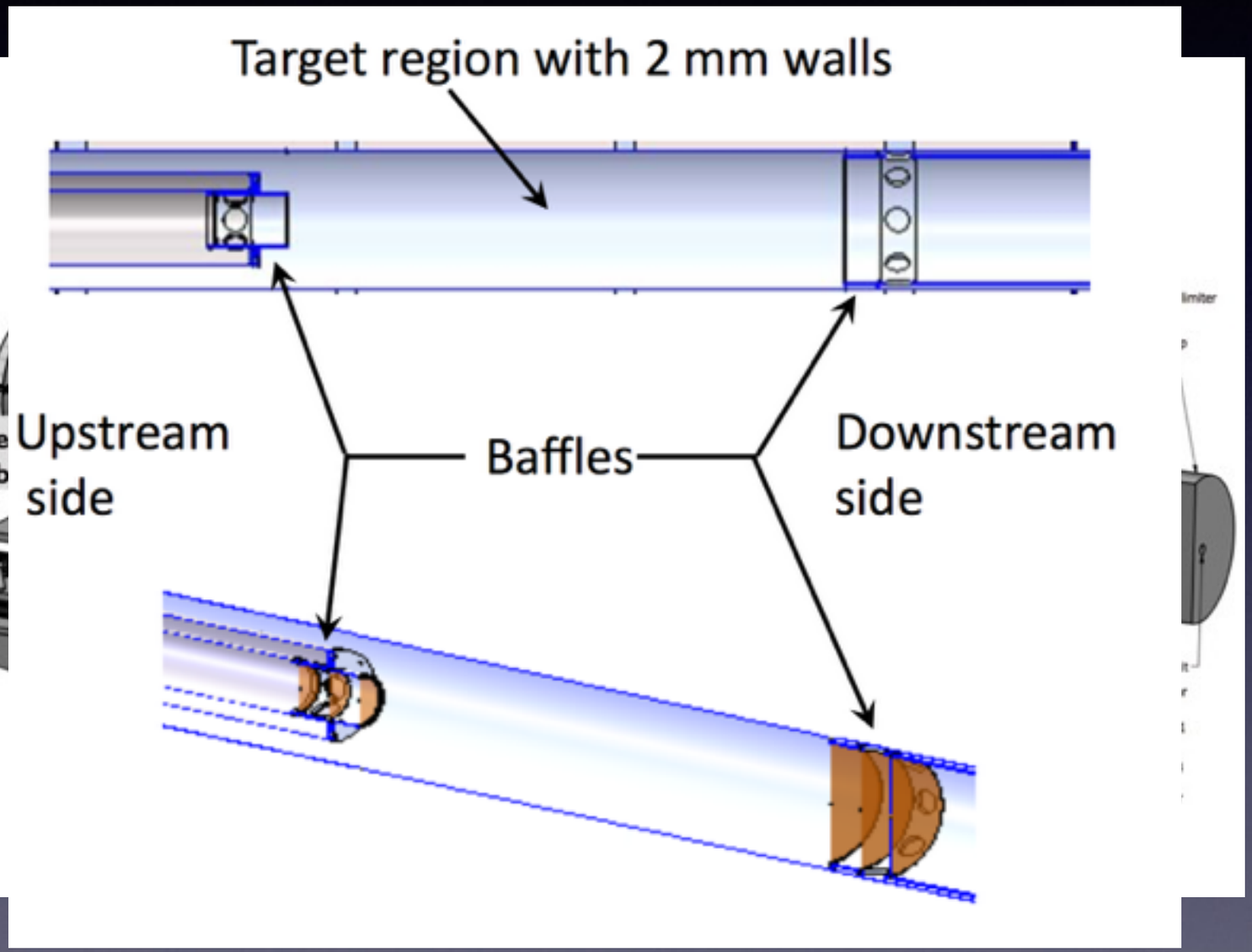
- Si detector inside target to detect proton

DarkLight Concept



- Si detector inside target to detect proton
- Thin-walled, windowless target cell to minimize $e^{\pm}$ disruption and background

DarkLight Concept



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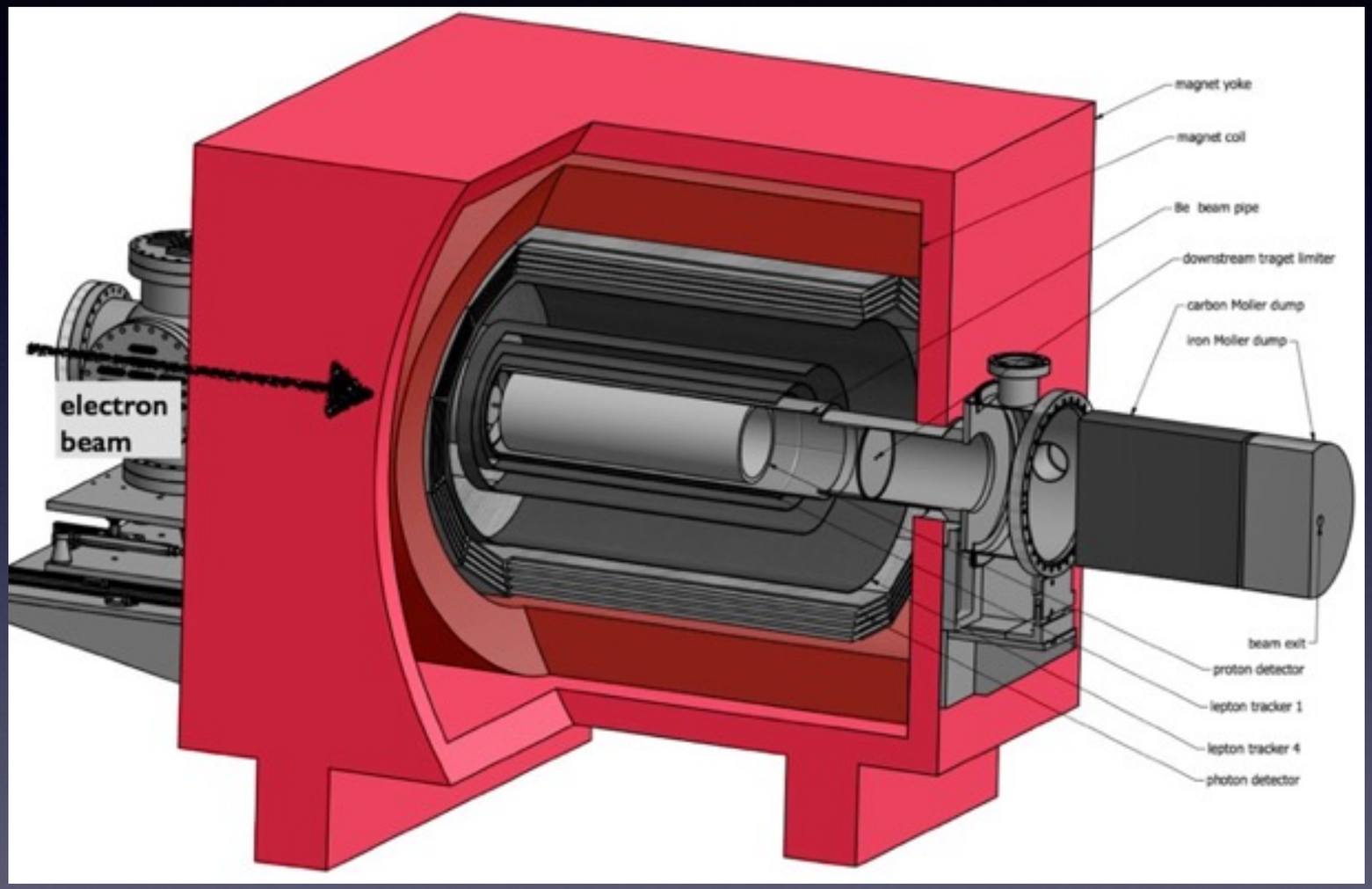
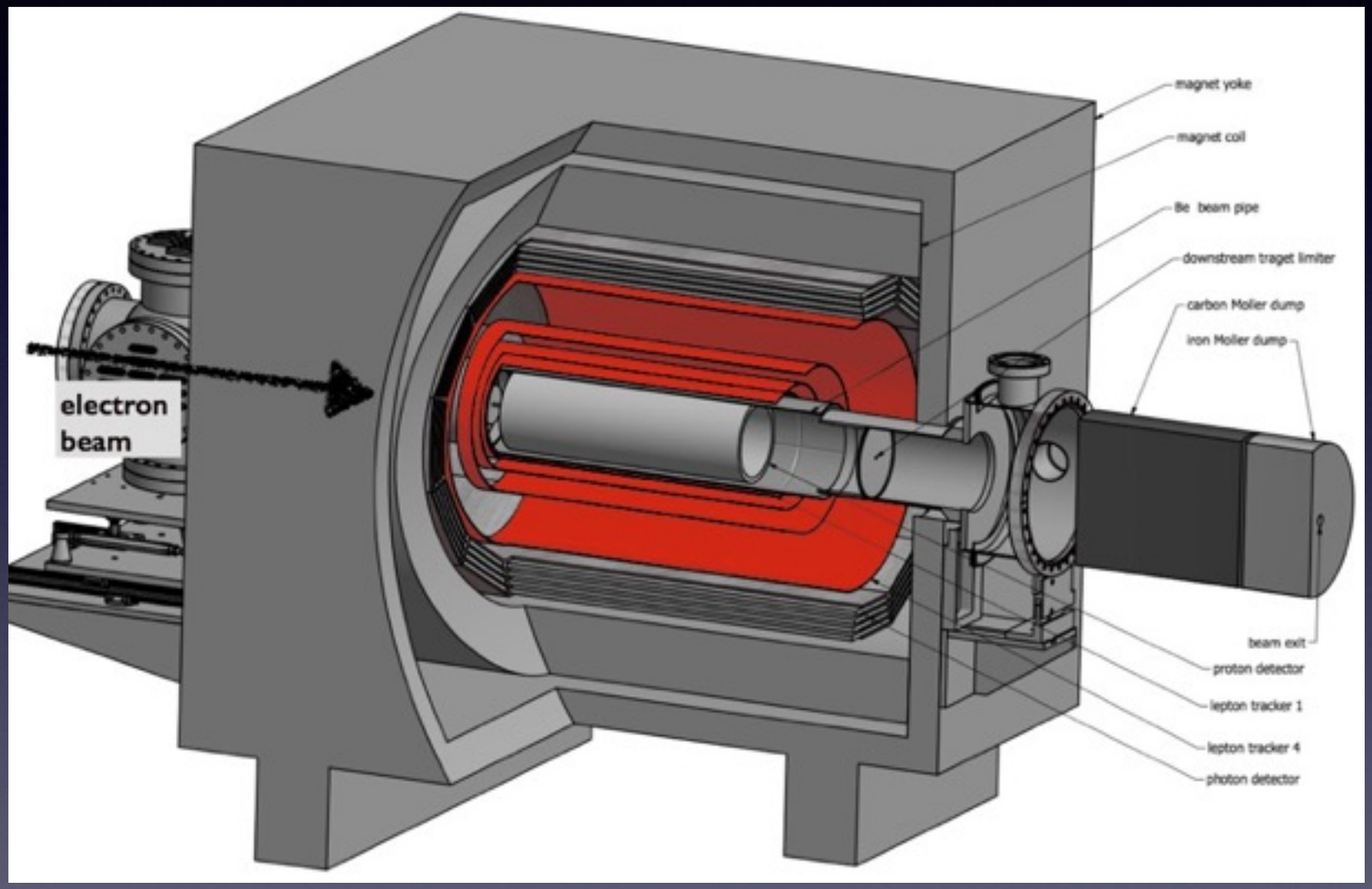


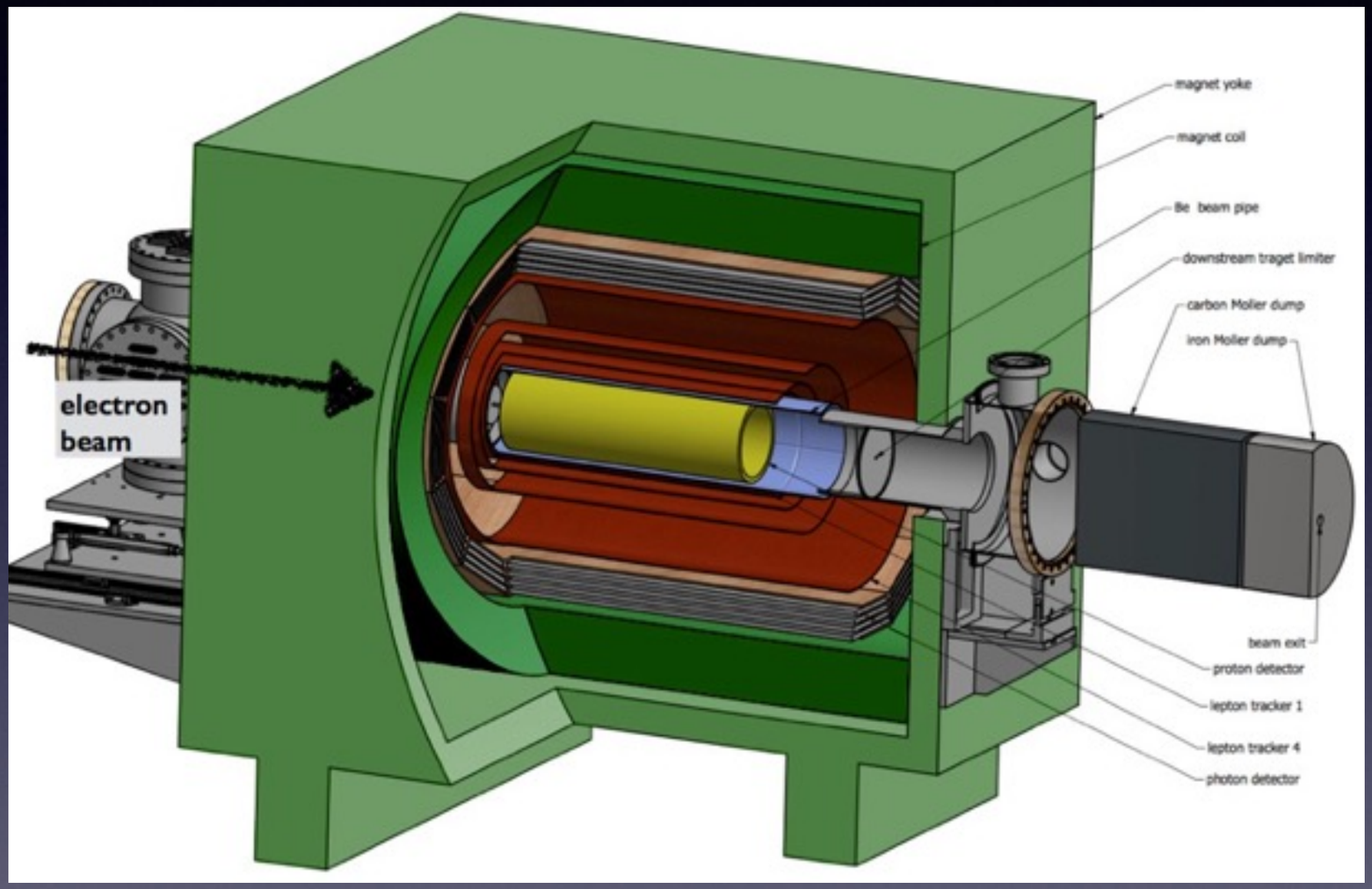
- Si detector inside target to detect proton
- Thin-walled, windowless target cell to minimize $e^{\pm}$ disruption and background
- Solenoidal magnet for Møllers and momentum

DarkLight Concept



- Si detector inside target to detect proton
- Thin-walled, windowless target cell to minimize $e^{\pm}$ disruption and background
- Solenoidal magnet for Møllers and momentum
- Cylindrical detectors for e± tracking

DarkLight Concept

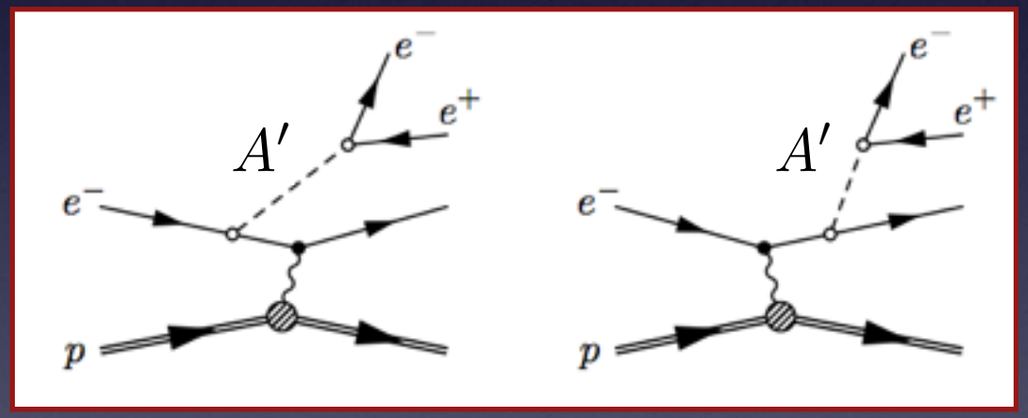


- Si detector inside target to detect proton
- Thin-walled, windowless target cell to minimize $e^{\pm}$ disruption and background
- Solenoidal magnet for Møllers and momentum
- Cylindrical detectors for e± tracking
- Streaming readout to accommodate high SM rate

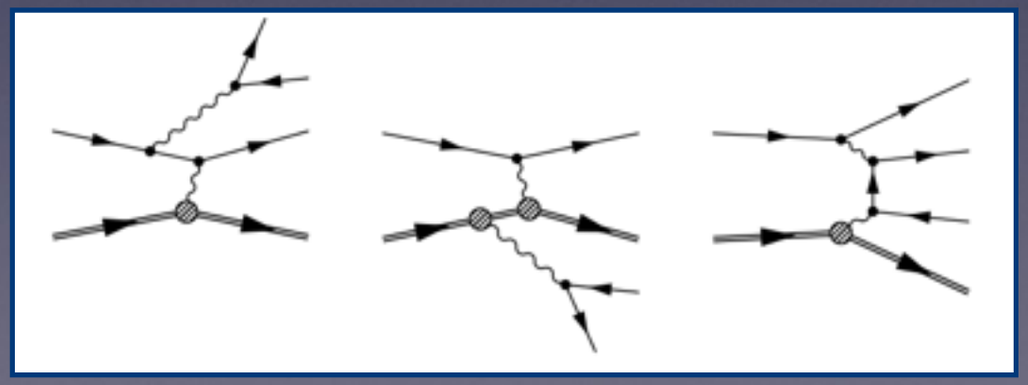
DarkLight Concept

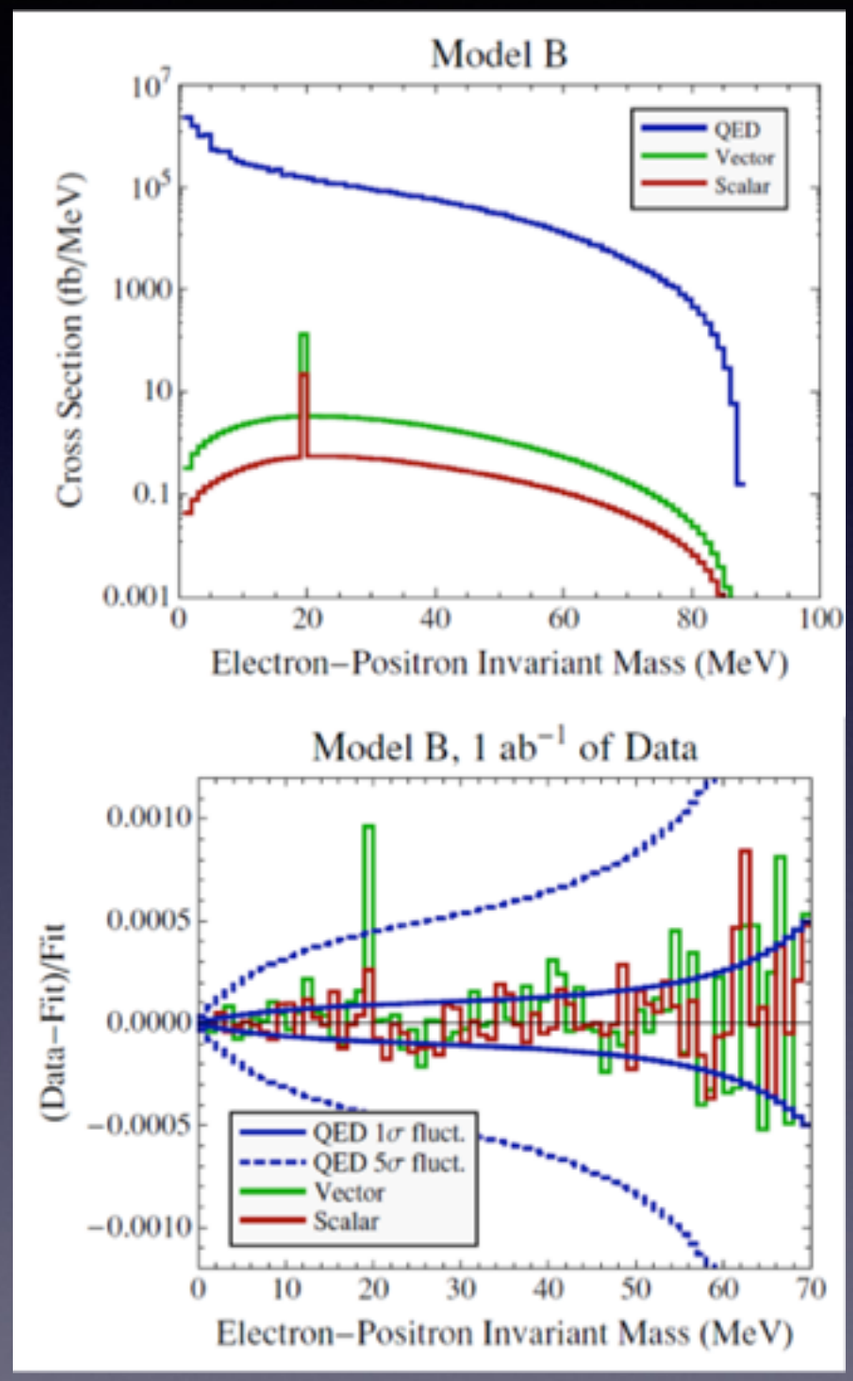
- Detect all final state particles (Access to visible and invisible decay modes)
- Search for e^+e^- resonance or missing mass

A' Signal



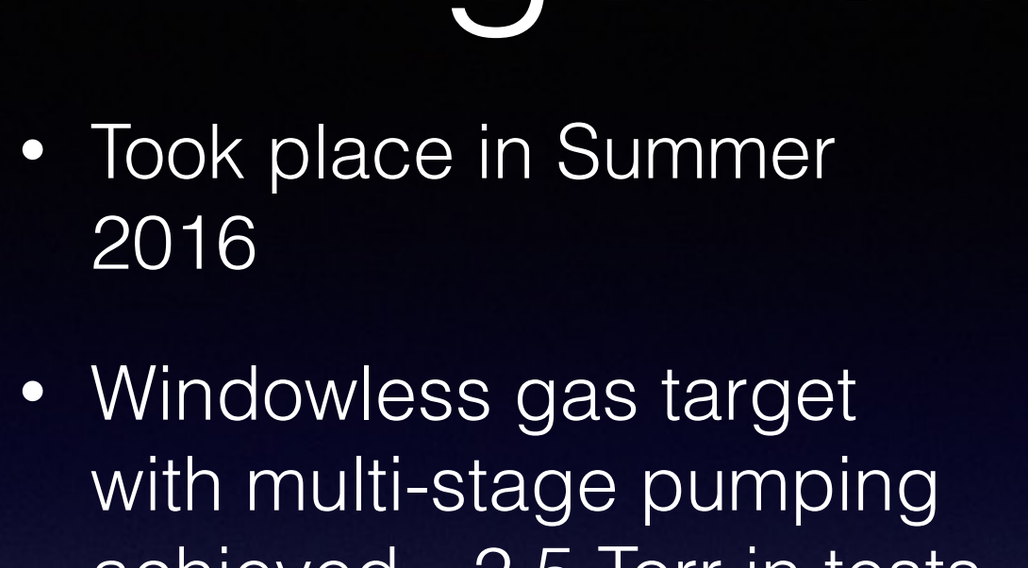
QED Background

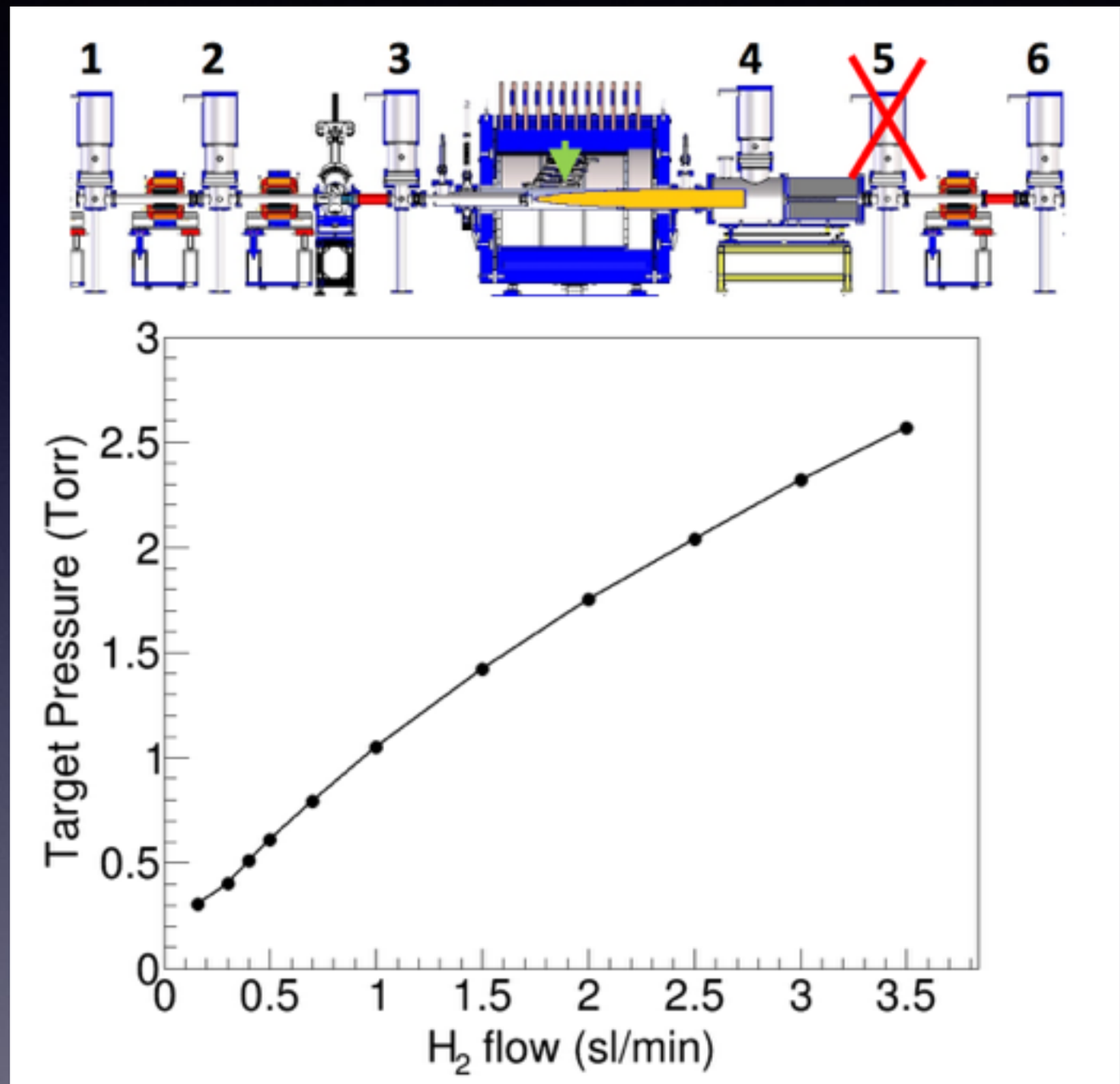




Target Commissioning

- Took place in Summer 2016
- Windowless gas target with multi-stage pumping achieved ~2.5 Torr in tests
- Prototype detector telescope operated parasitically





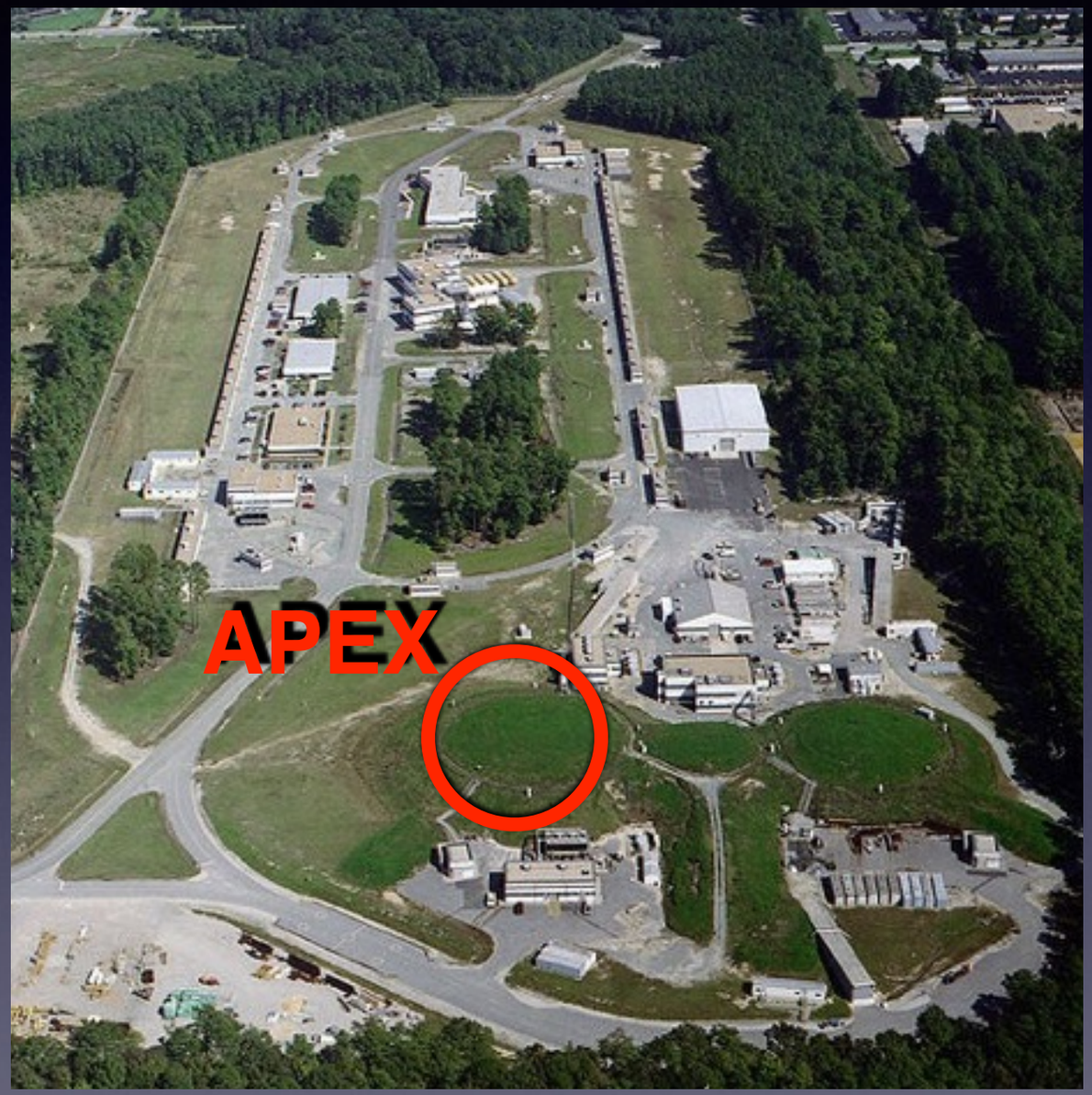
DarkLight Status

- Funded (DOE, NSF MRI award):
  1A: Operated LERF with Solenoid + Target, Summer 2016
  1B: Measure radiative Møller rates (spectrometer ready in 2017)
  1C: Proof-of-principle with partial coverage detector in solenoid
- Analyzing detector performance/rates from 1A
- Upgrading gas system/target

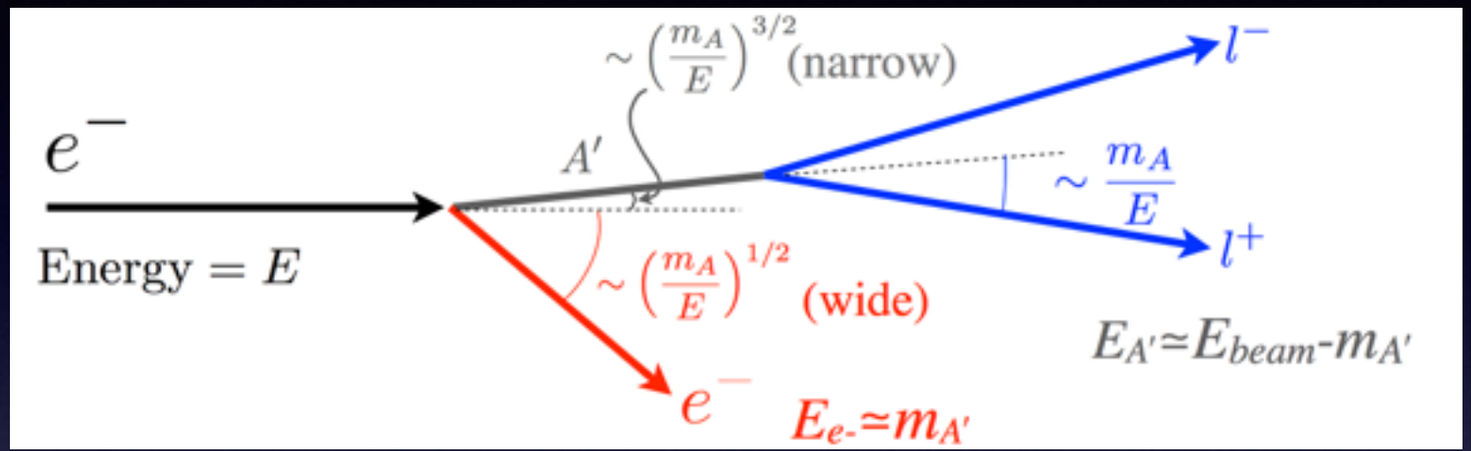
APEX at Jefferson Lab

"A Prime EXperiment"

- ISR A' production off e^- in electron-nucleus scattering
- Complex, multi-foil, high-Z targets
- Exploit boosted/most probably kinematics in A' decay
- **Hall A** High Resolution Spectrometers reconstruct narrow peak.

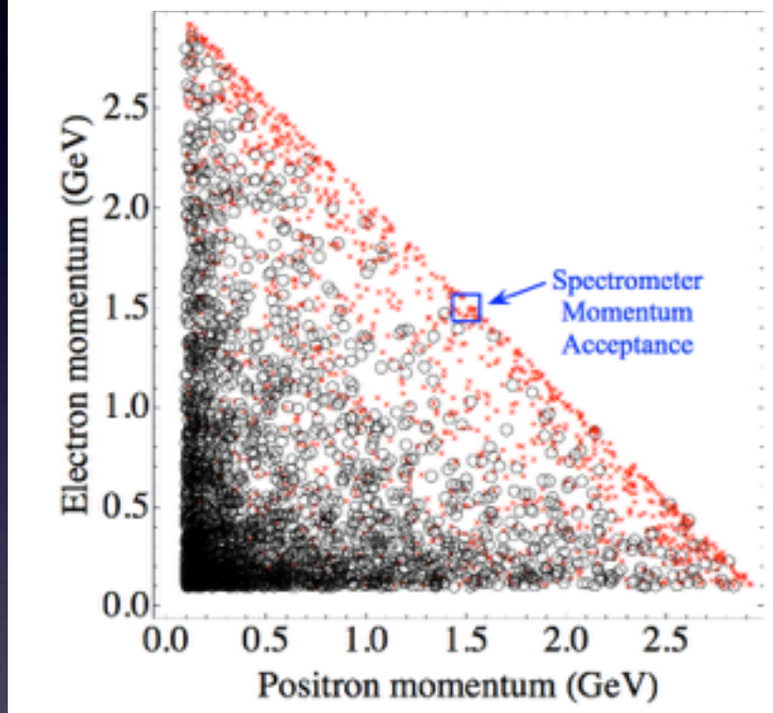


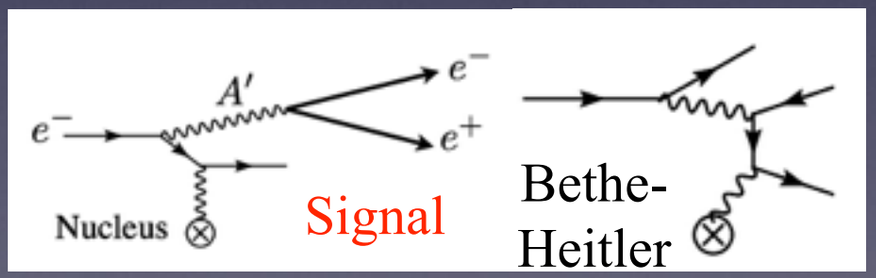
APEX Kinematics



- A' carries large fraction of beam energy
- Dominant BH background suppressed via acceptance. (QED analog of A' production remains)

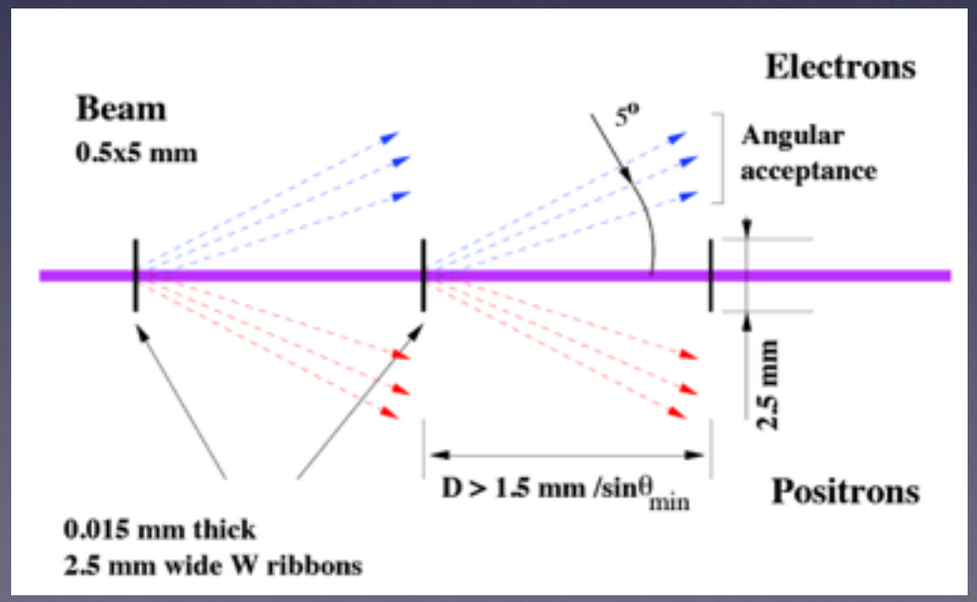
Bethe-Heitler vs. Signal Kinematics

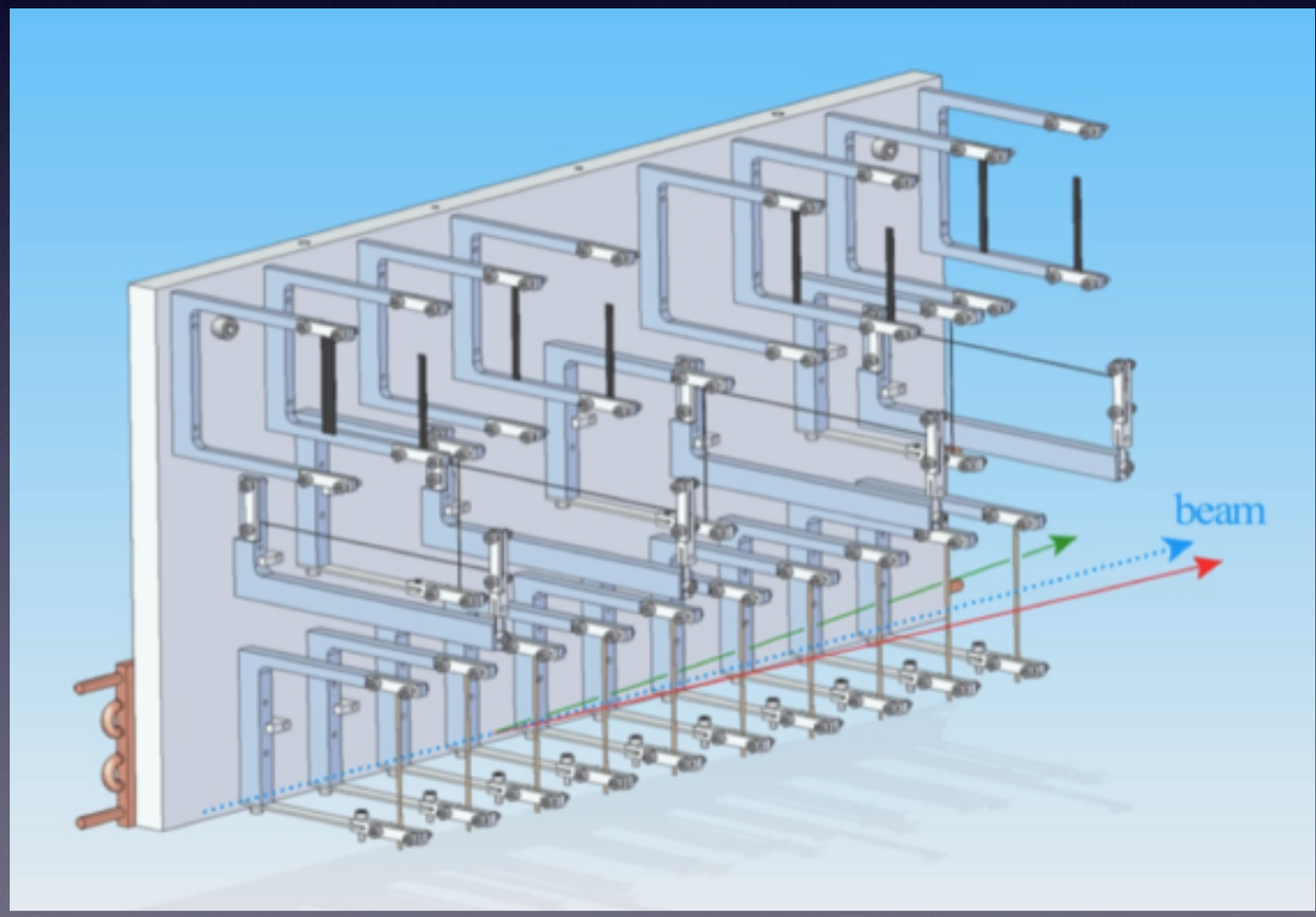




Target Design

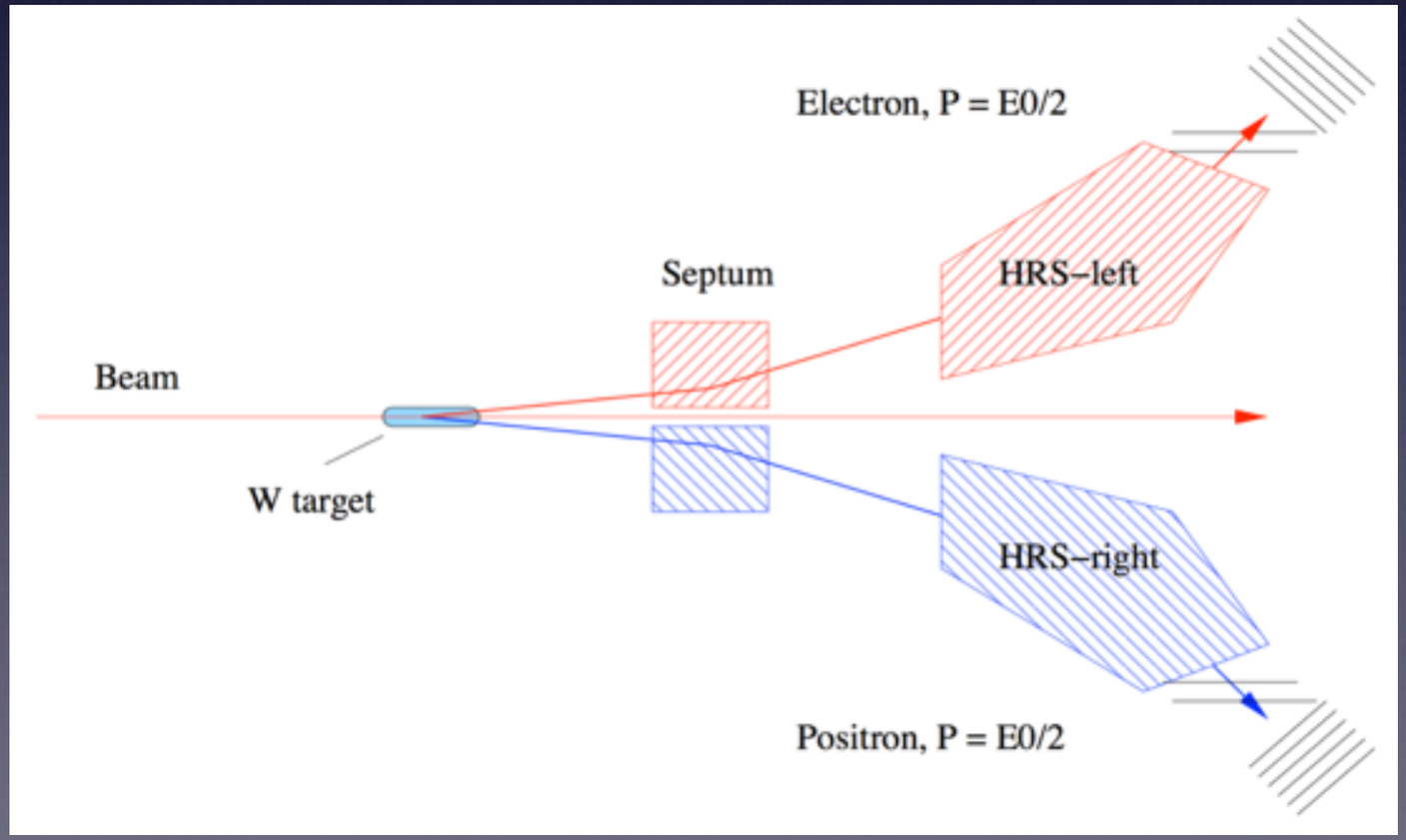
- Multiple scattering in target is significant background
- Thin, spaced elements so small angle clears next foil.

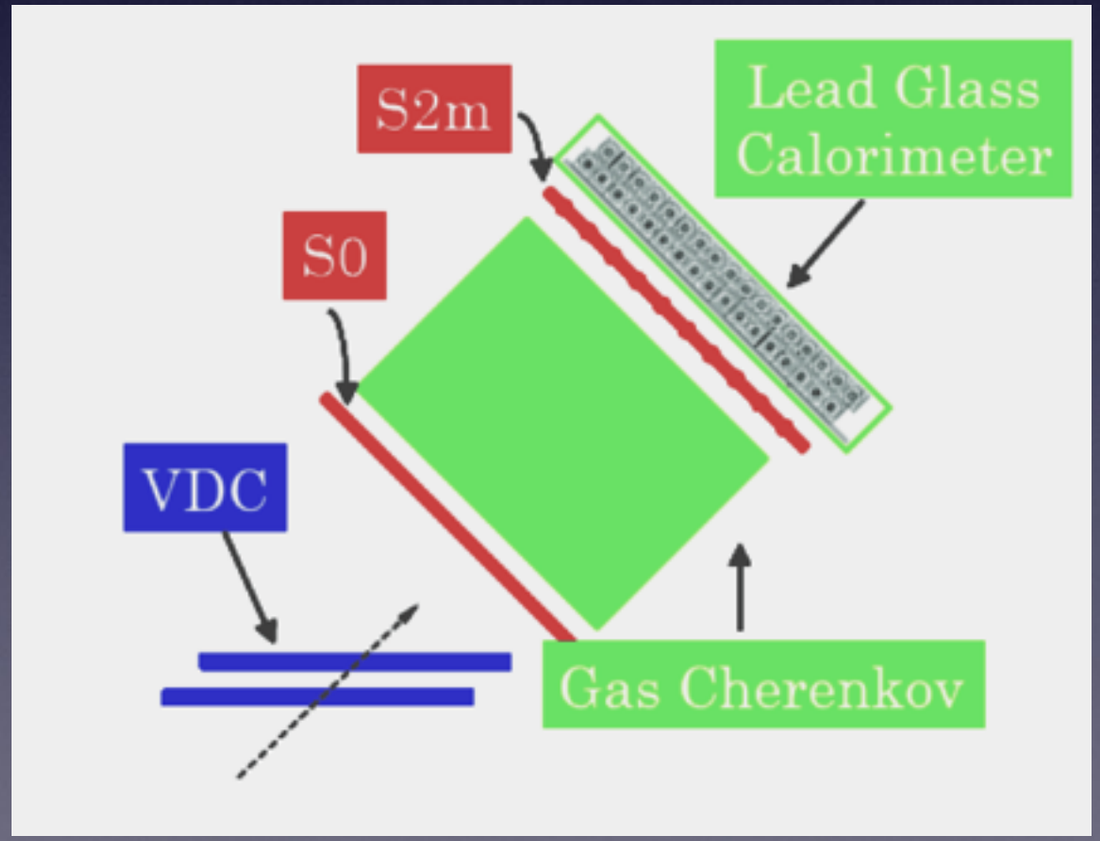




APEX Design

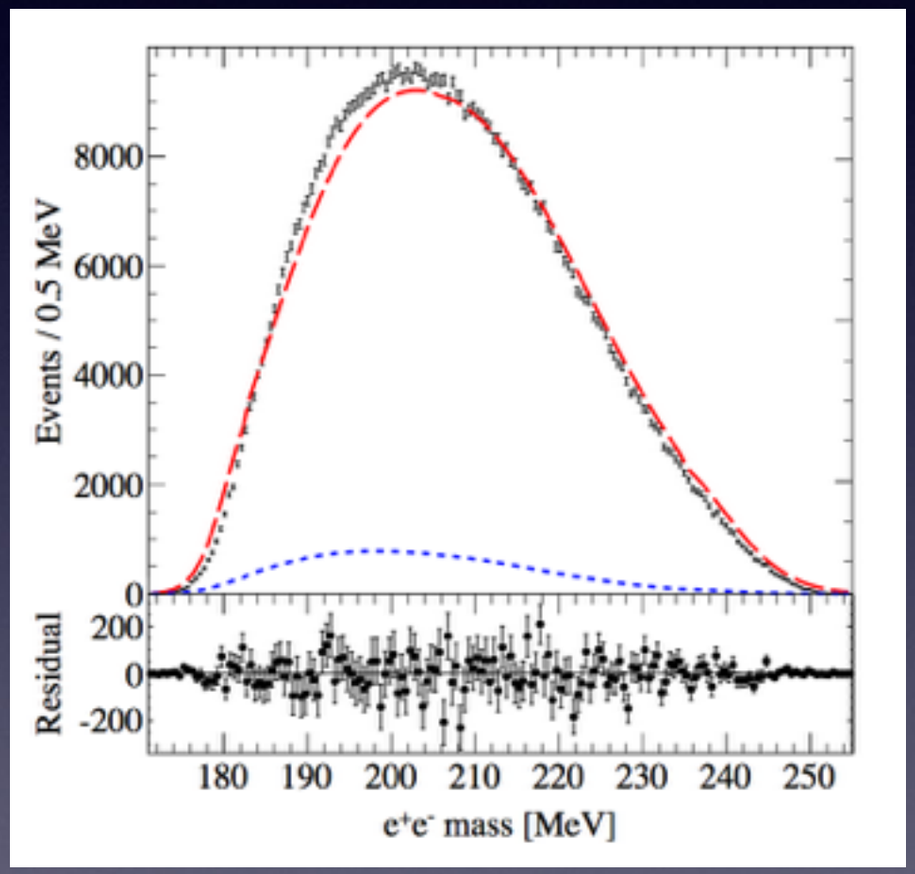
- Septum magnet opens e+e- decay into HRS reach
- Vertical Drift Chambers for tracking
- Gas Cherenkov for pion rejection (in trigger)

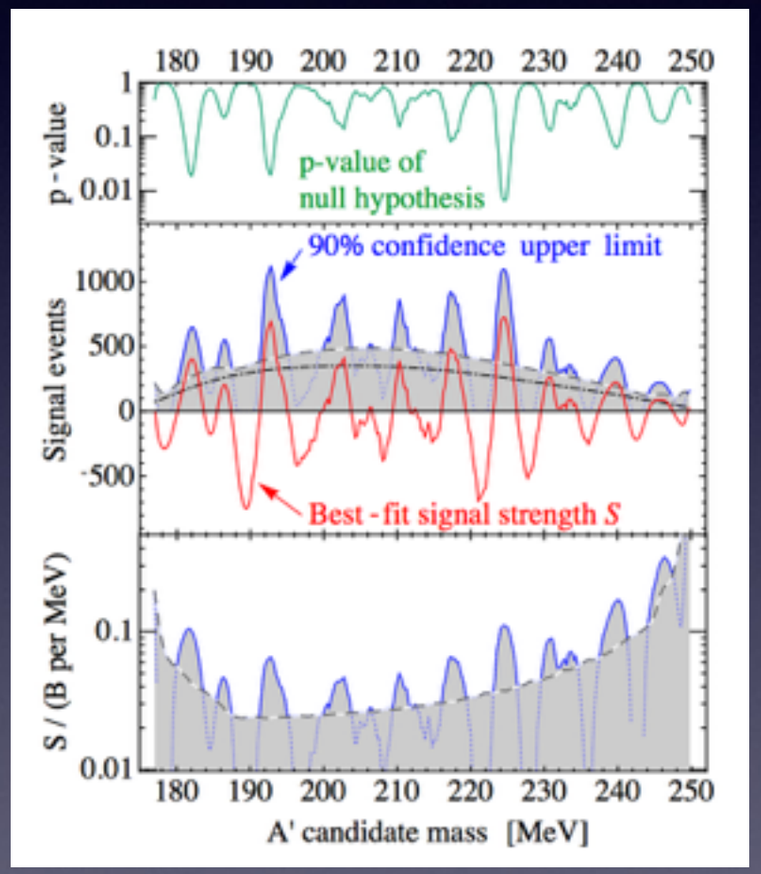


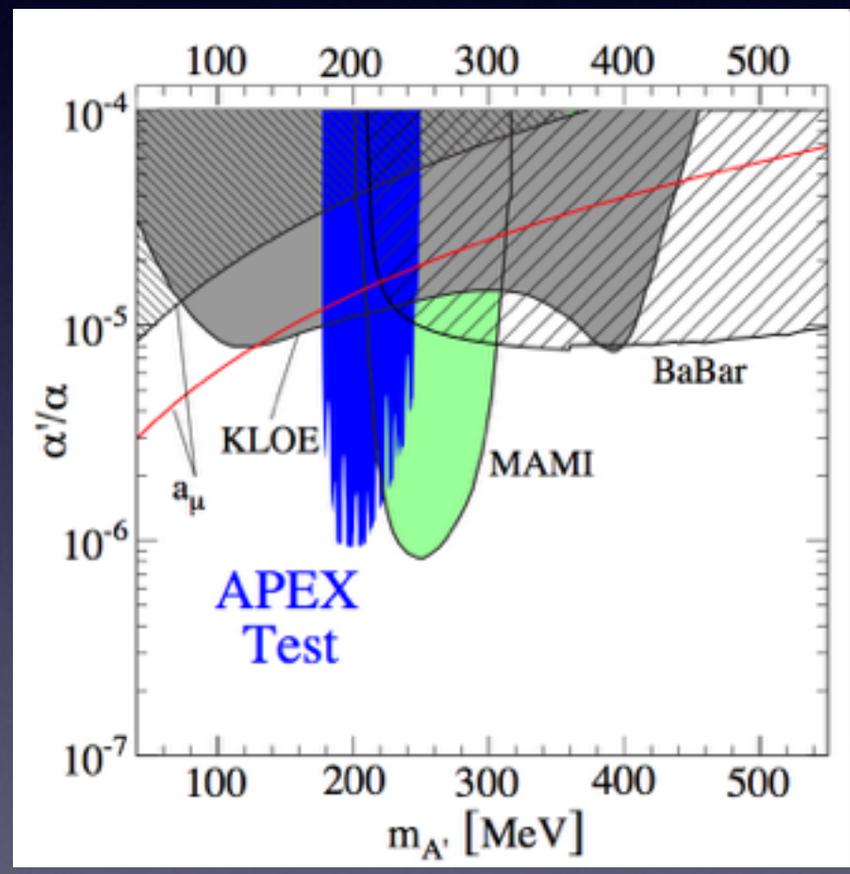


2010 Test Run

- Gaussian peak (width controlled by mass resolution studies) on 7th order polynomial







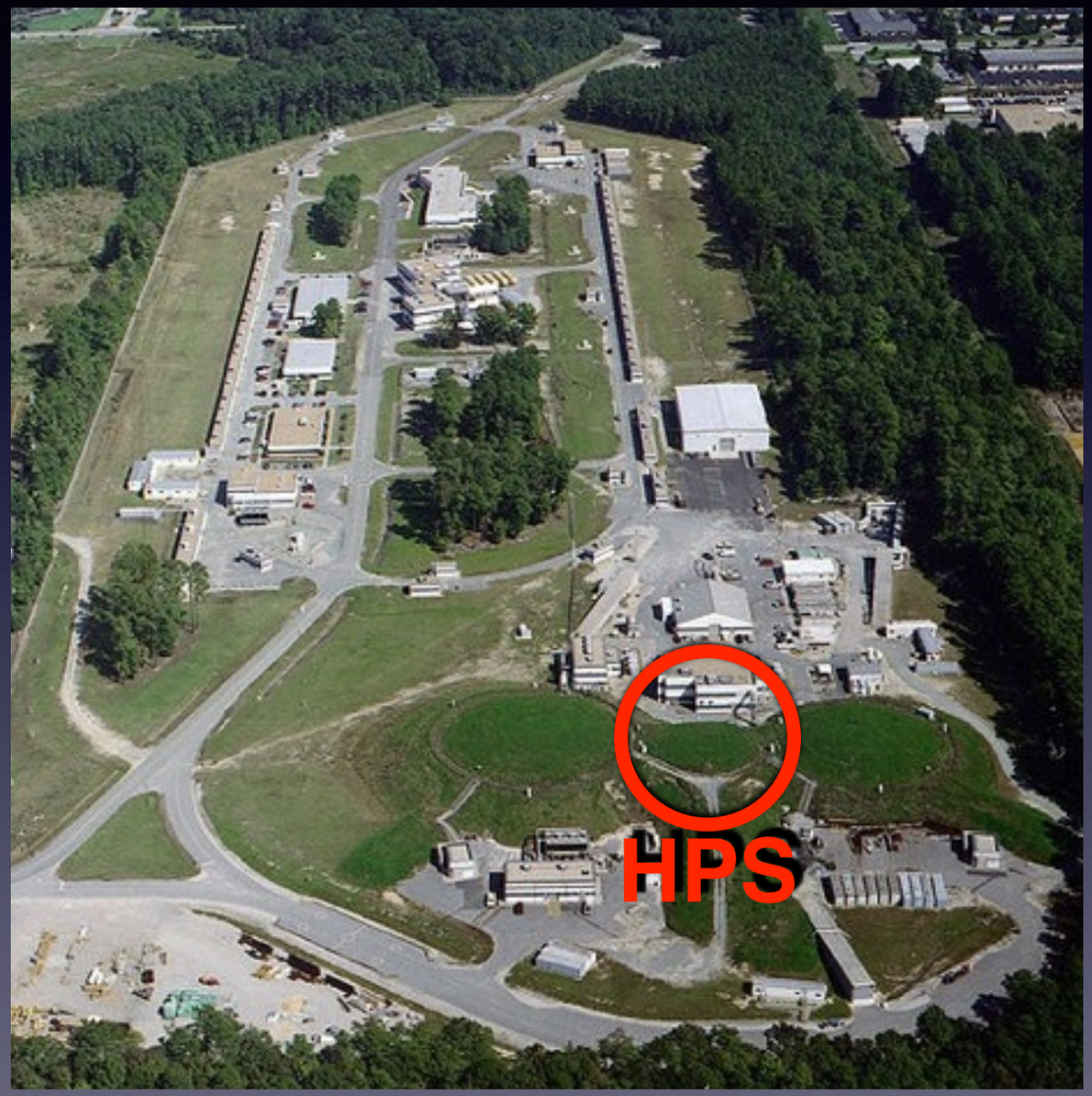
APEX Status

- Electronics upgrade to HRS can handle 5MHz in VDC
- SciFi hodoscope calibration of e^+ optics 0.5 ==> 0.1mrad
- Study of W target thermal cycling in progress
- Septum magnet testing in progress
- Vacuum system delivery to Hall A ~ February
- Most systems ready, testing this year
- Could run fall 2018, pending approval

HPS at Jefferson Lab

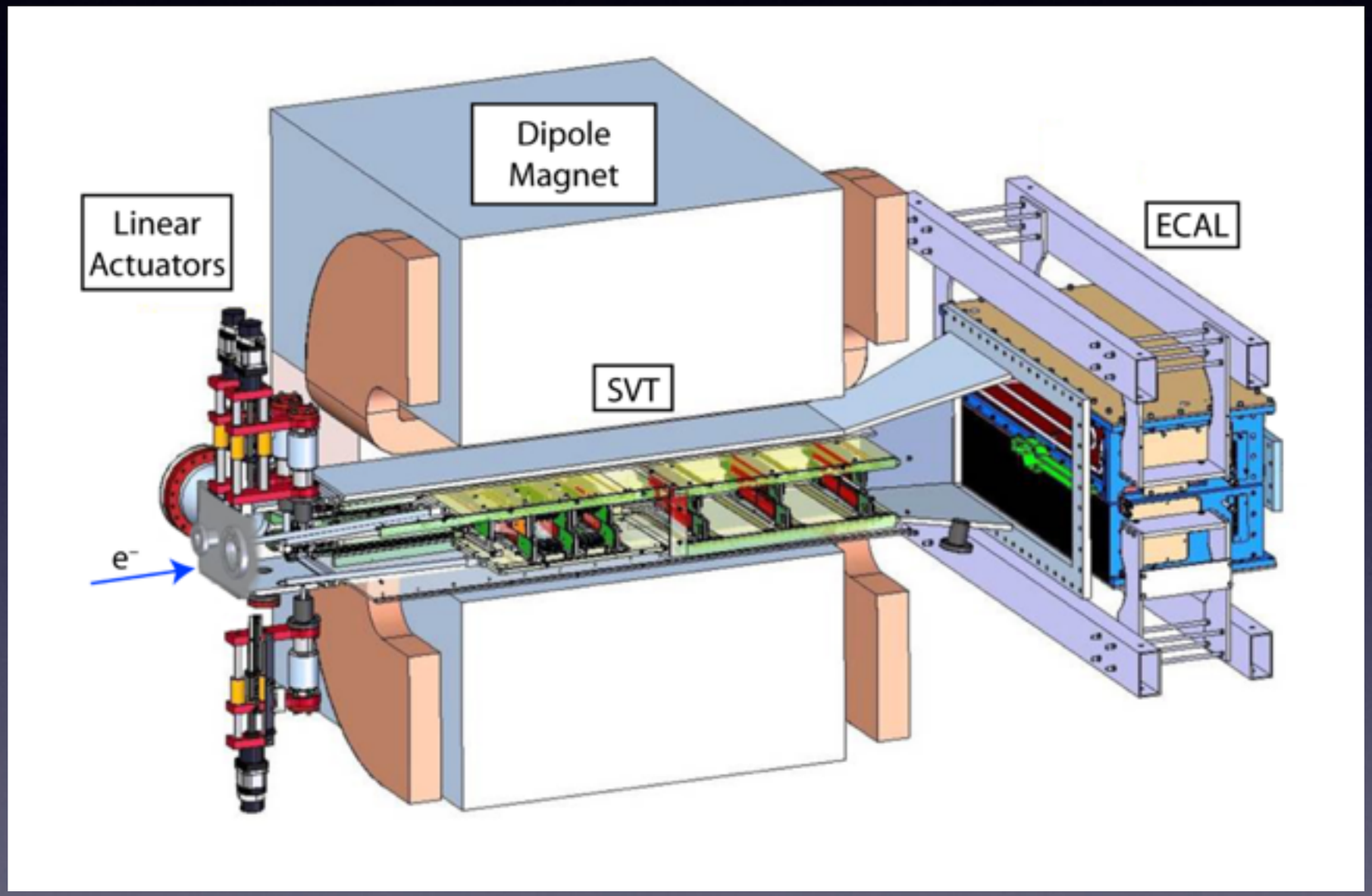
"Heavy Photon Search"

- ISR in W foil produces boosted A' which decays to lepton pair
- Precision tracking near target/ beam for angular resolution and displaced vertex
- Multiple beam energy settings to expand $m_{A'}$ reach



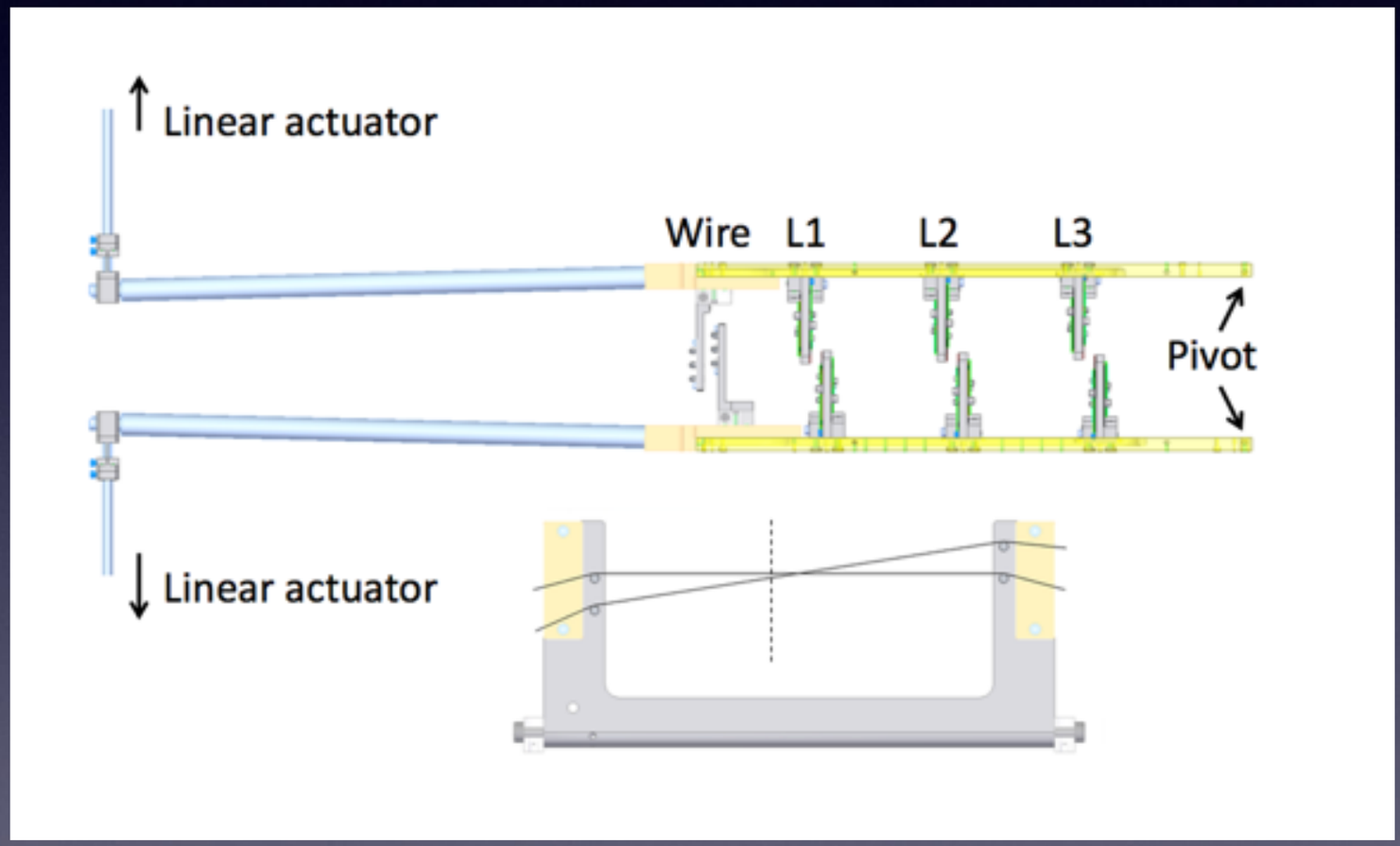
HPS Design

- Dipole for momentum, e^+e^- separation
- Si Vertex Tracker at 1.5mm ==> 0.5mm from beam (<5mm vertex, <8% mom.)
- ECAL opening for sheet of flame (4% ene.)



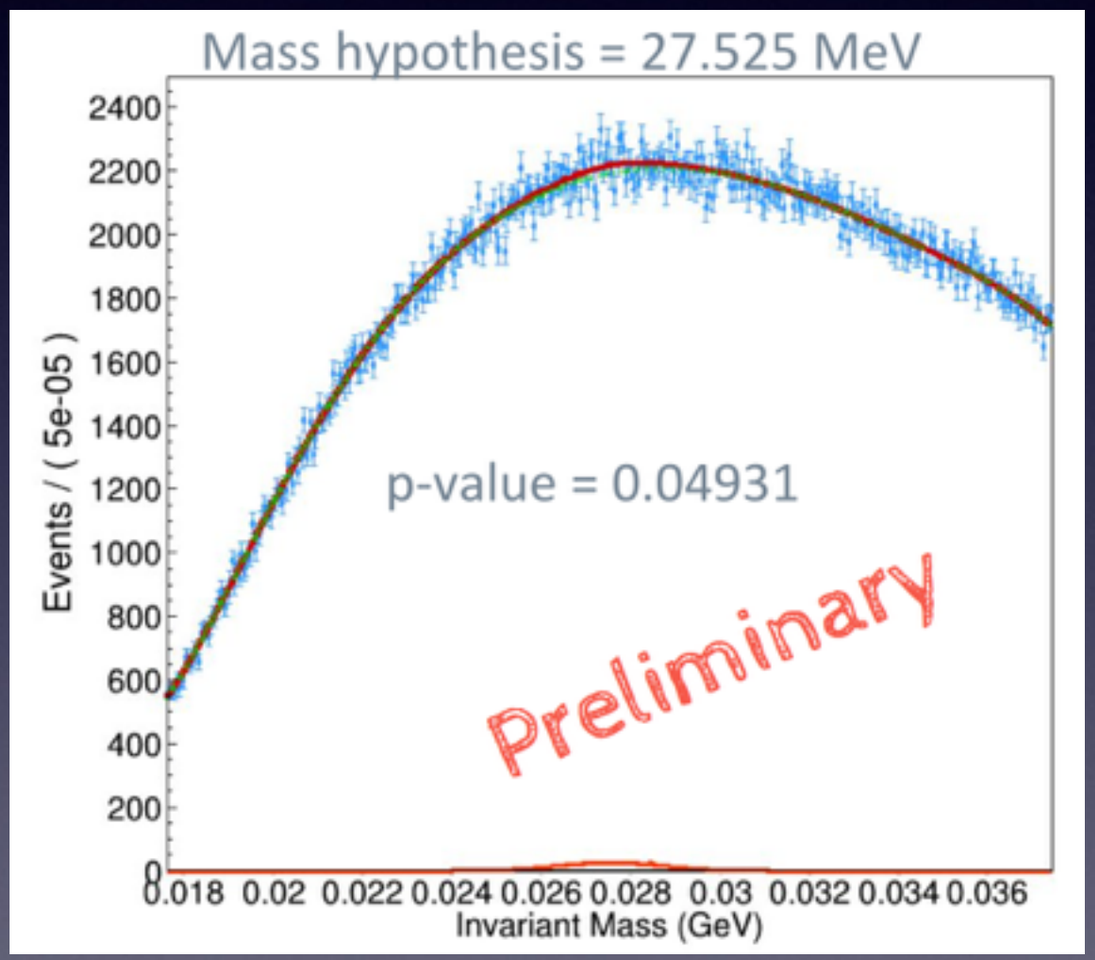
Beam Position Control

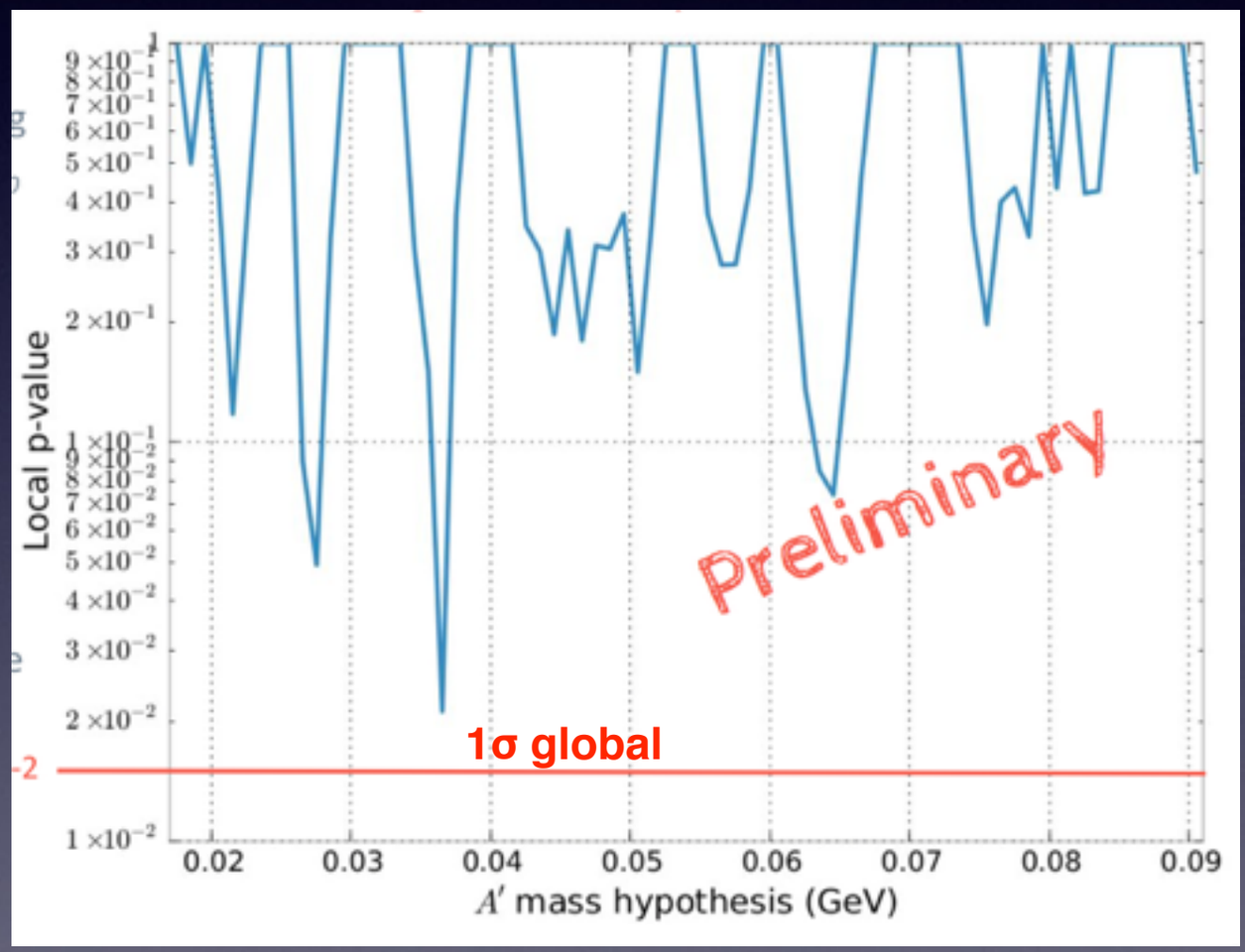
- Low frequency active feedback in steering
- High frequency motion small
- Fast Shut Down in case of large excursion ~1 per 16hrs
- Other trips ~ 10 per hr



Preliminary Result

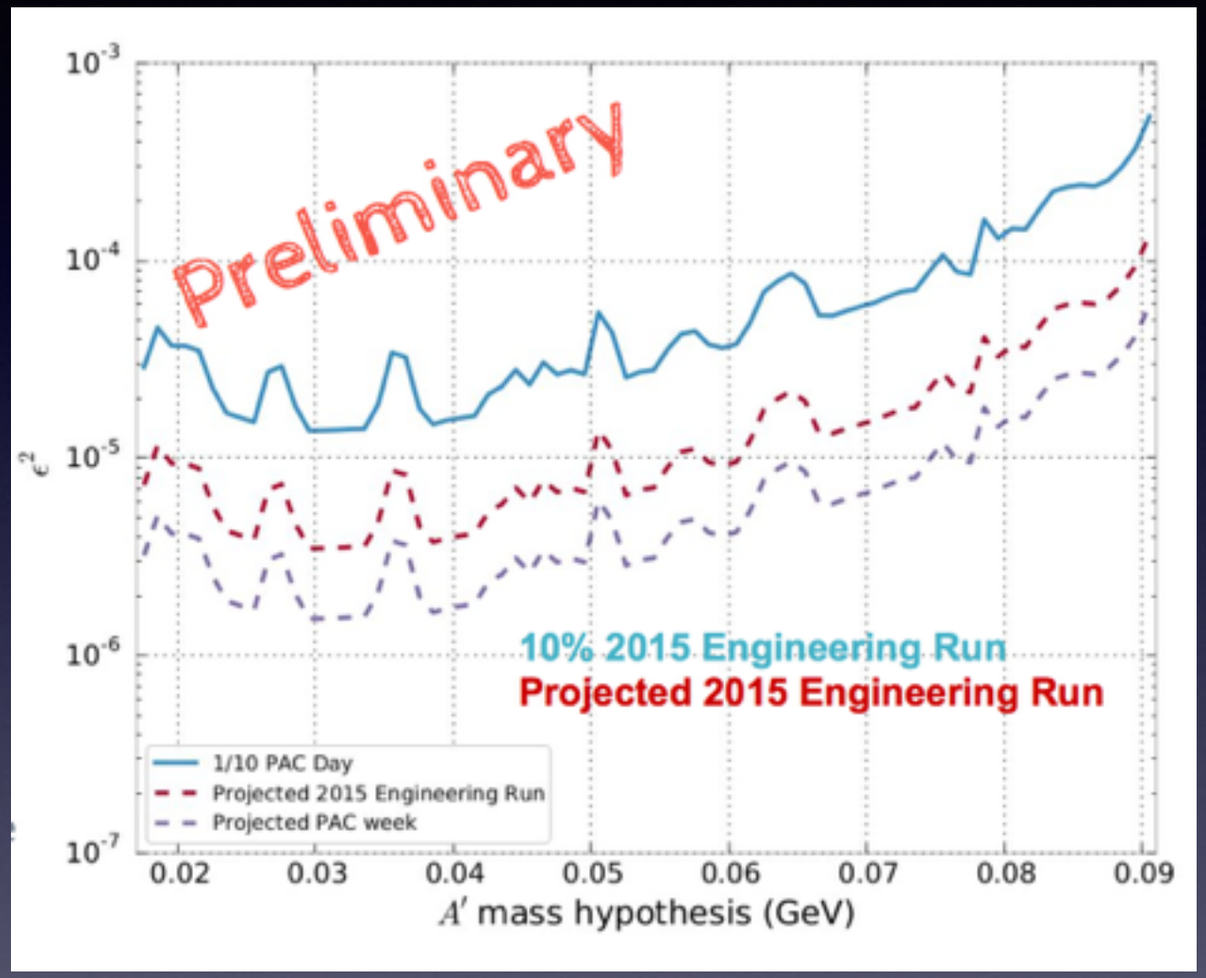
- Gaussian peak (width controlled by Møller resolution studies) on 7th order polynomial





Preliminary Result

Parameter	Proposal value	Measured value
Beam current	50 nA	50 nA
SVT occupancy	<1%	1%
DAQ/trigg. rate	18 kHz	19 kHz
Pair mass res. @ 33 MeV/c^2	1.4 MeV	1.4 MeV
Pair vertex res. @ 40 MeV/c^2	4.4 mm	4.6 mm



- Lots more detail of this recent analysis: "Searching for a Resonance with HPS" Omar Moreno APS talk

HPS Status

- Detector performance in 2015-2016 very close to projections
- 6.7 beam days taken, bump hunt and vertex searches:
  - 1.1 GeV (1.7 days) analysis nearing completion (early 2017)
    17-90MeV search, 10% unblinded
  - 2.3 GeV (5 days) calibration underway
- 165 days left: 2018- run?

Status Summary

- Variety of searches coming online in coming years:

	Target	Range	Probe	
BDX	beam dump	model dependent. Sensitive to $M_{A'}$, M_X, α_D...	X-e or X-N scattering	Testing prototype. Prepping for μ rate measurements in situ.
DarkLight	H_2 gas	$10<\mathbf{M_A}<100$MeV	e^+e^- pairs, full final state	2016 target commissioning run. Prepping for 1B.
APEX	W, Ta foils	$65<\mathbf{M_A}<600$MeV	e^+e^- pairs	Studying target heating. Prepping for possible 2018 run.
HPS	W foil	$0.02<\mathbf{M_A}<1$GeV	e^+e^- pairs, displaced vertex	Analyzing 2016 data (2017 release). Ready to run in 2018.