A Search For Dark Forces At The Jefferson Lab Free Electron Laser

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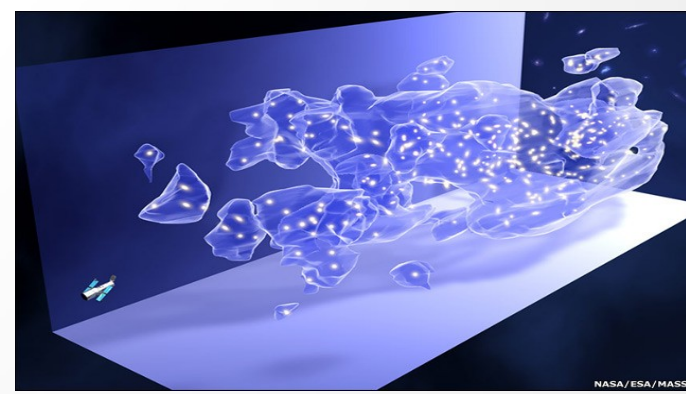
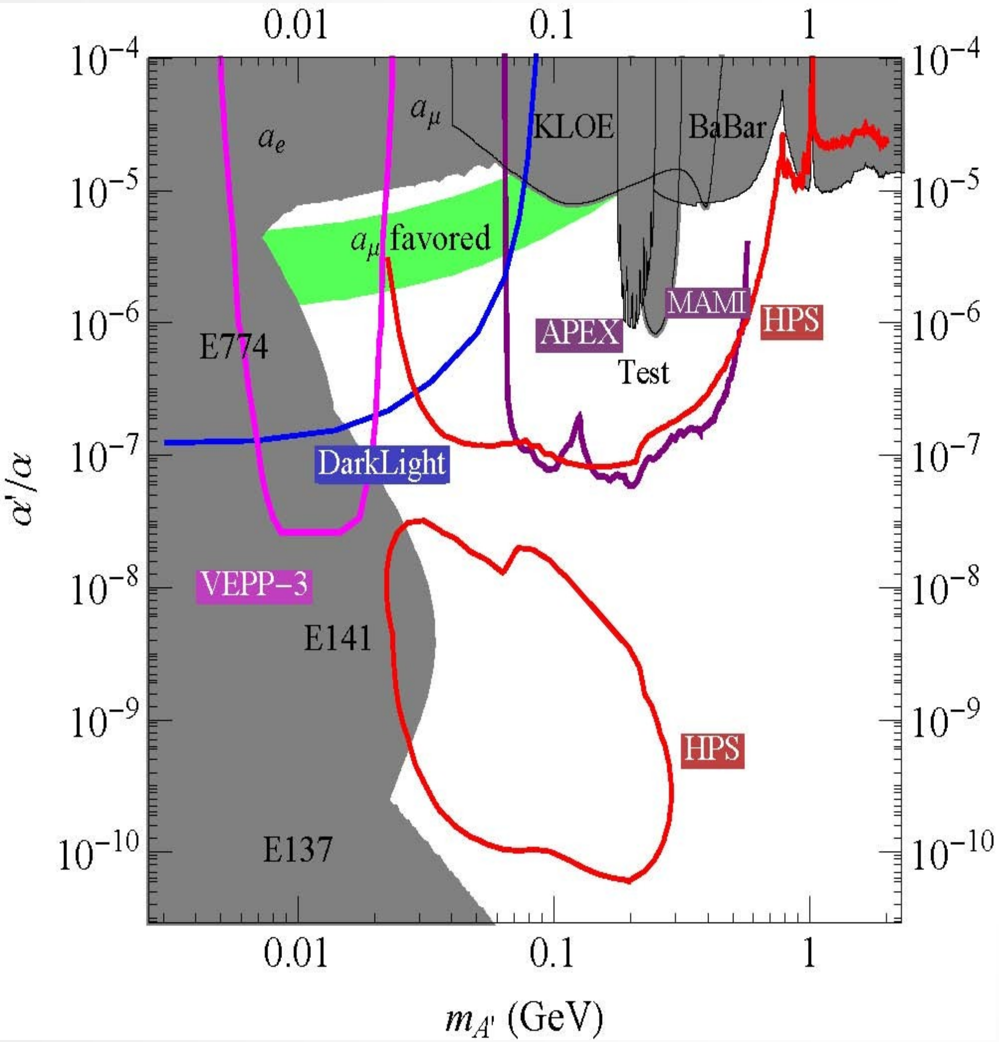
Hampton University

UVA Nuclear Physics Seminar
26 February 2013

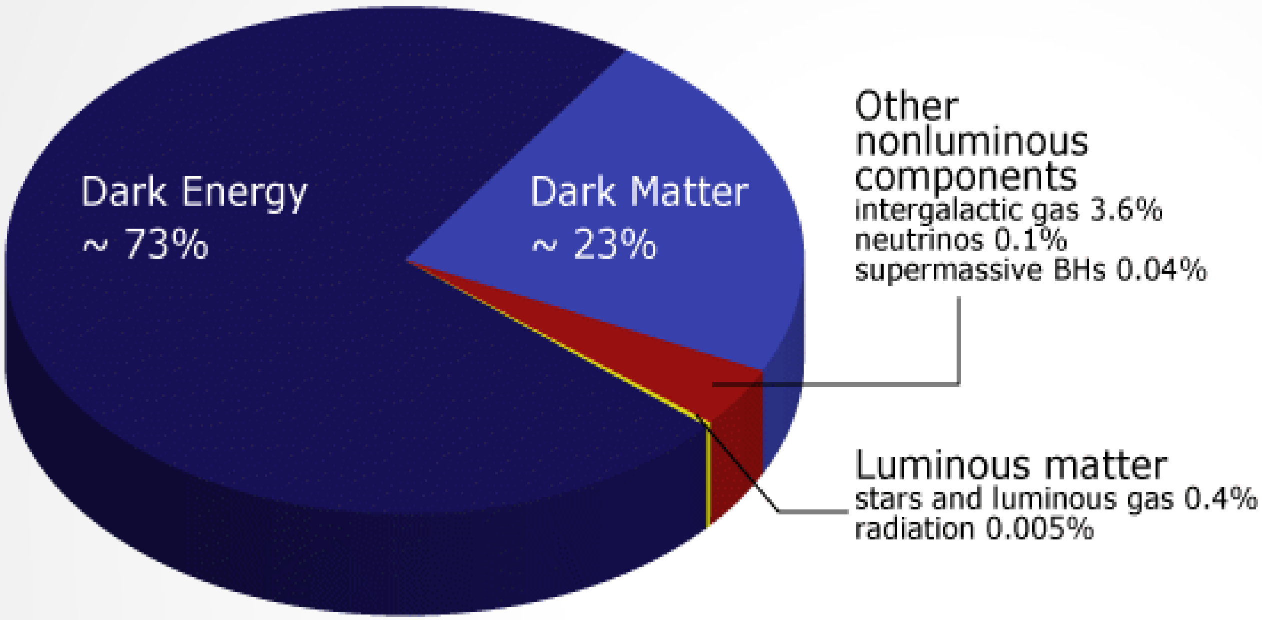


Outline



- Background/Motivation
- DarkLight Experiment
- JLab PAC Proposals
- Beam Test Run & Background Rad. Measurements
- Timeline
- Summary

Much Ado About (Almost) Nothing



Dark a. [OE. dark, derk, deork, AS. Dearc, deorc; cf. Gael. & Ir. dorch, dorcha, dark, black, dusky.]
1. Destitute, or partially destitute, of light; not receiving, reflecting, or radiating light; wholly or partially black, or of some deep shade of color; not light-colored; as, a dark room; a dark day; dark cloth; dark paint; a dark complexion.
[1913 Webster]
2. Matter, not (observed) interacting with "ordinary" matter, other than gravitationally.

The ordinary matter we observe is a trace part of the Universe.

**Another way of picturing this:*
Universe ~ Cup of Coffee
Dark Energy ~ Coffee
Dark Matter ~ Creamer
Observable Matter ~ Sweetener

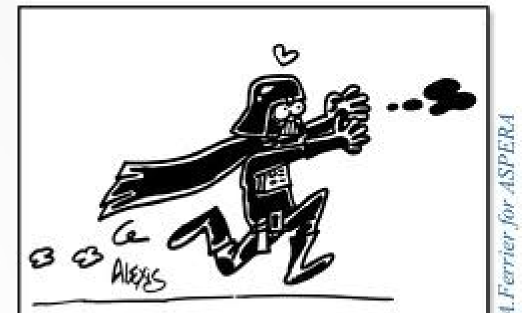
Searching For Dark Matter

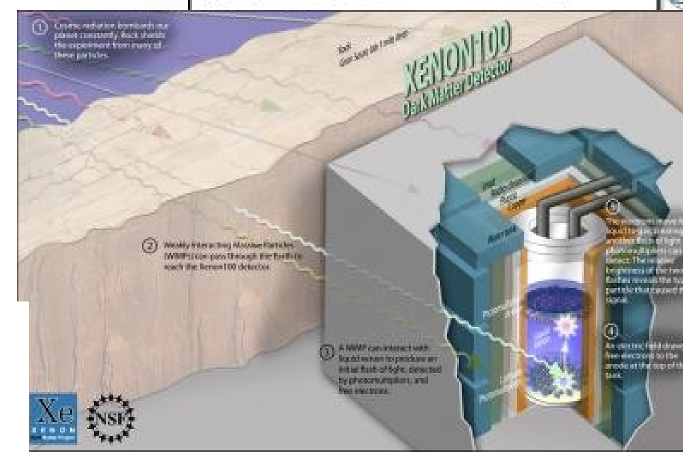
- **Direct**

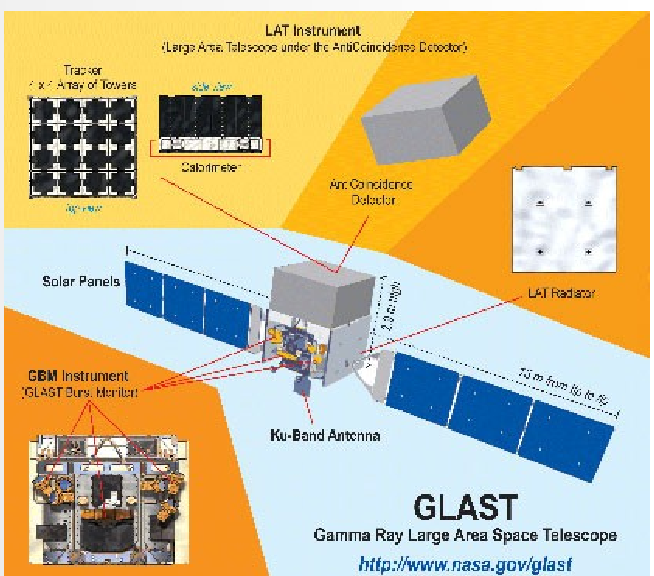
Deep underground;
- Cryogenic (temperature), Noble Gas (scintillation)
- CDMS, XENON, DMTPC, ...

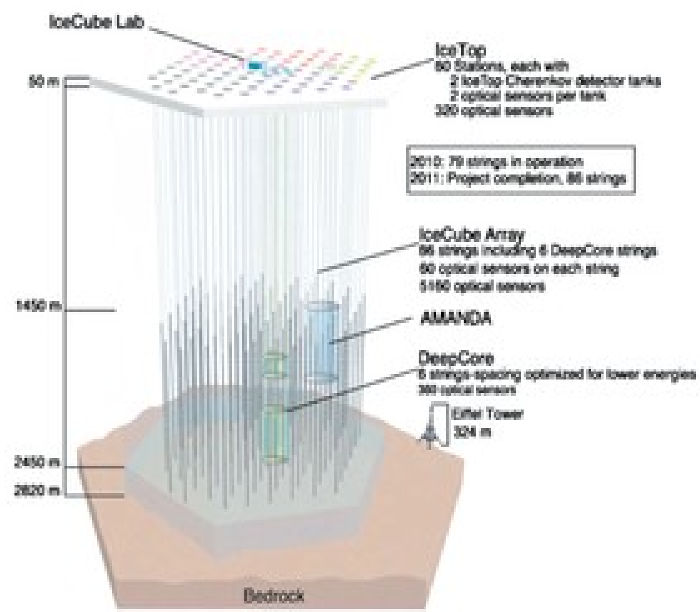
- **Indirect**

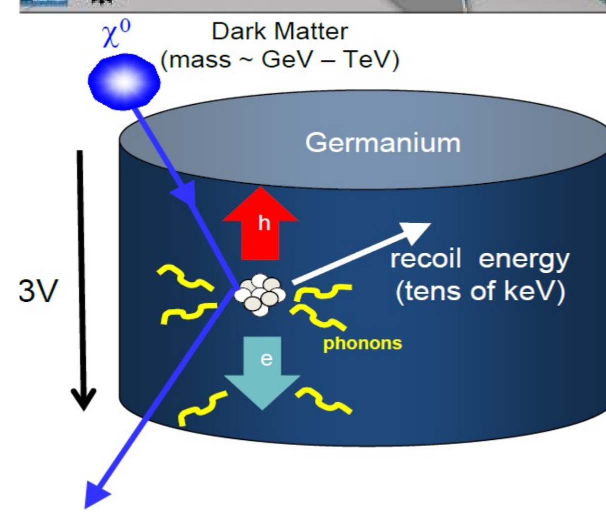
Annihilation signatures;
- γ, particle/anti-particle, neutrinos, ...
- IceCube, FERMI, ...





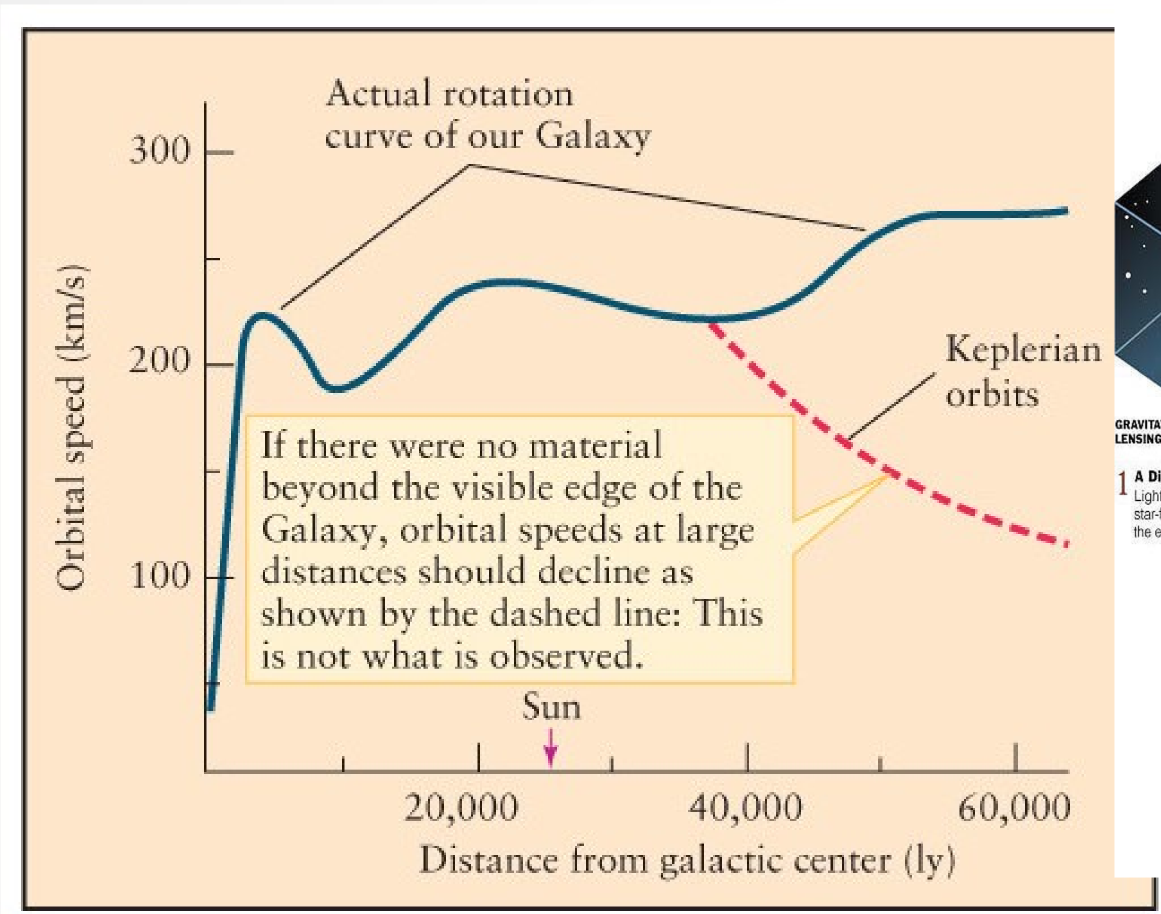


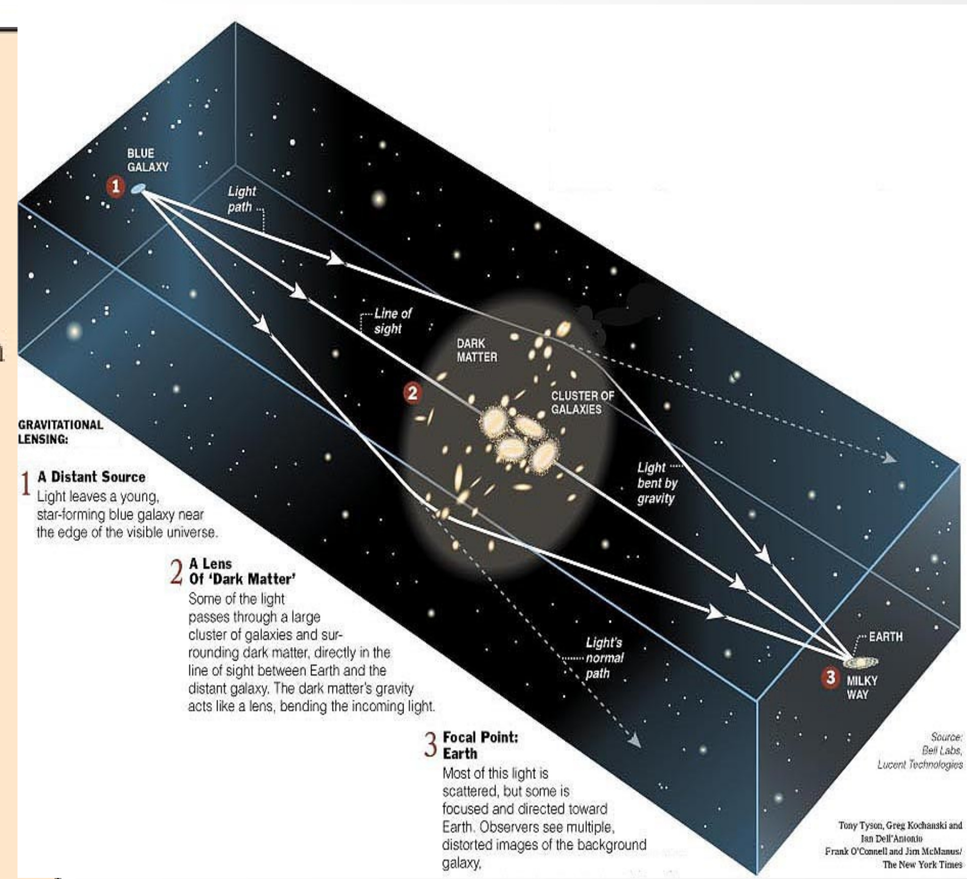




Indicators for Dark Matter

Astrophysics





Galaxies: Rotation, Gravitational Lensing

Indicators for Dark Matter

Feldman, Liu, Nath
arXiv:0810.5762v3

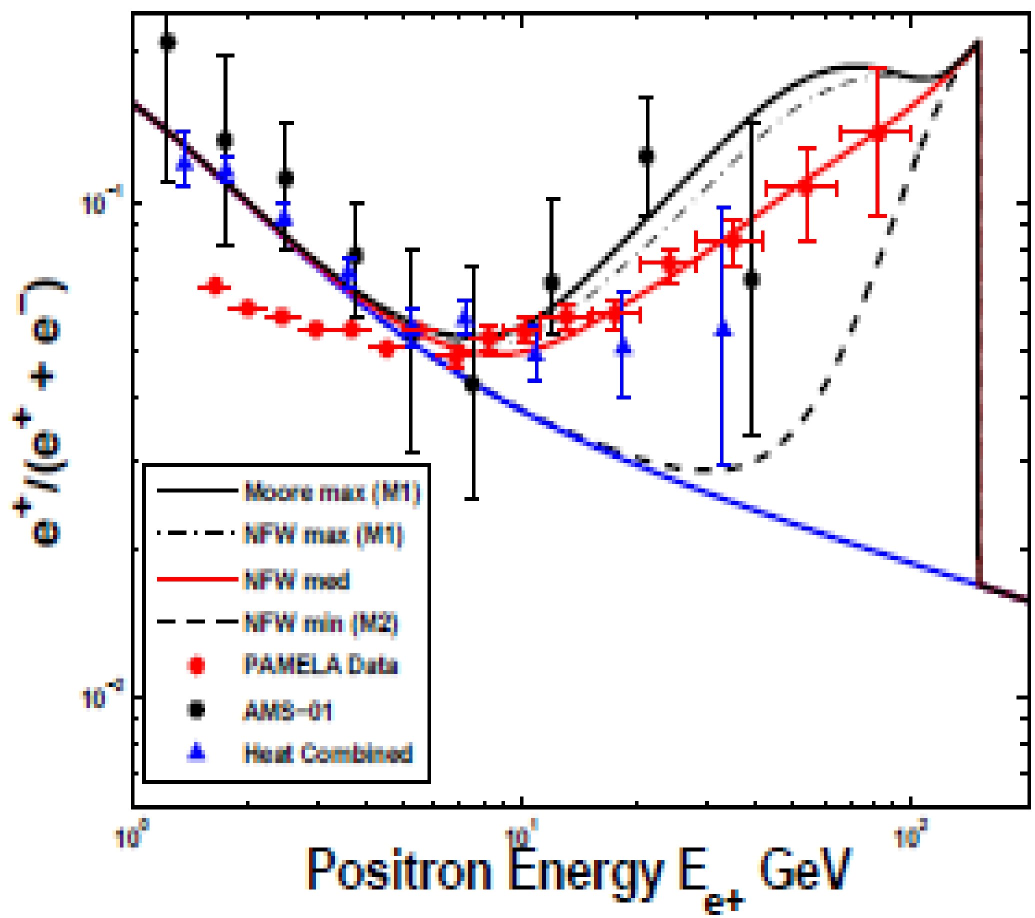
Nuclear/Particle Physics

PAMELA Results:
e^+ excess
(not for p^-, though)

Sizable cross-section

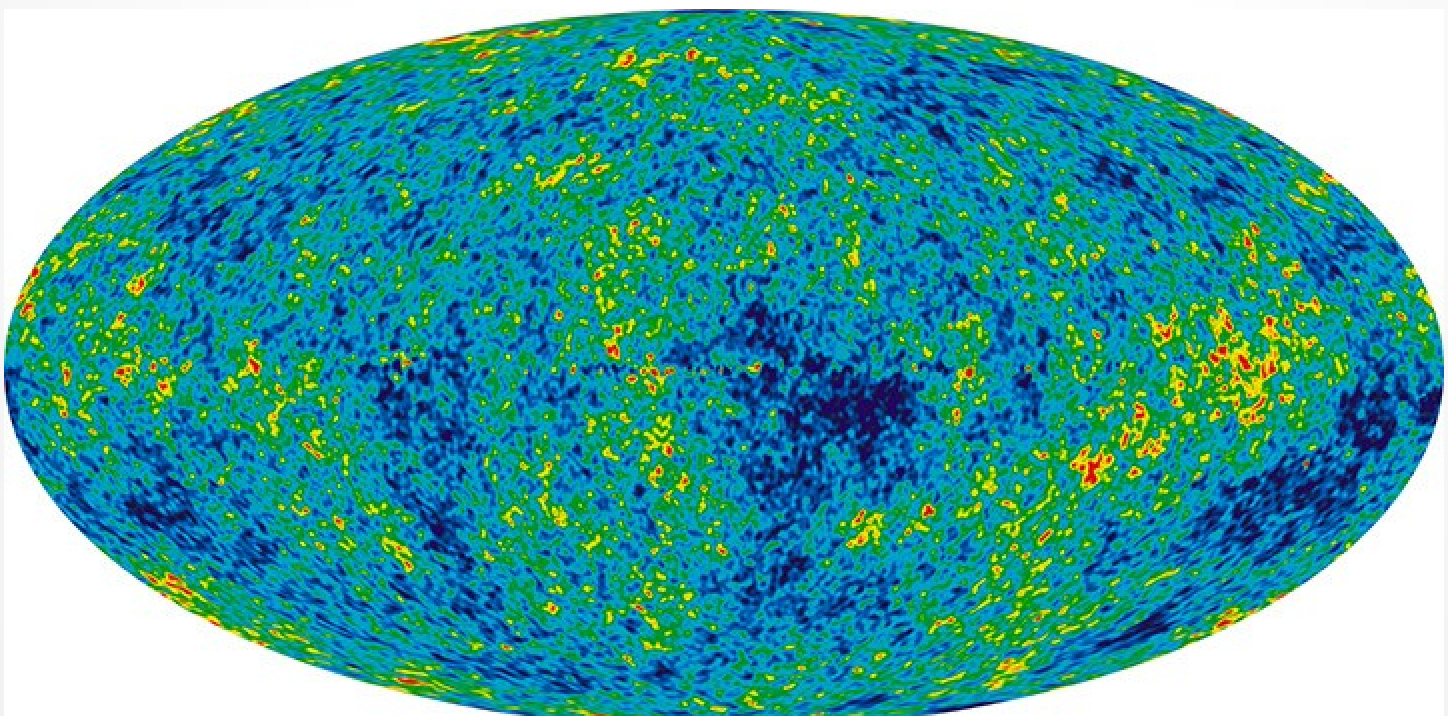
Similar result from ATIC

***Leads to an interesting idea**



WIMP “Miracle”

Currently observed dark matter density is consistent with massive particle production in Big Bang theory with WIMPS of 100 GeV mass and weak interaction cross-section (~1 pb).



Interesting Idea

A Theory of Dark Matter

Nima Arkani-Hamed,[1] Douglas P. Finkbeiner,[2] Tracy R. Slatyer,[3] and Neal Weiner[4]

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[2]*Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138, USA*

[3]*Physics Department, Harvard University, Cambridge, MA 02138, USA*

[4]*Center for Cosmology and Particle Physics, Department of Physics, New York University, New York, NY 10003, USA*

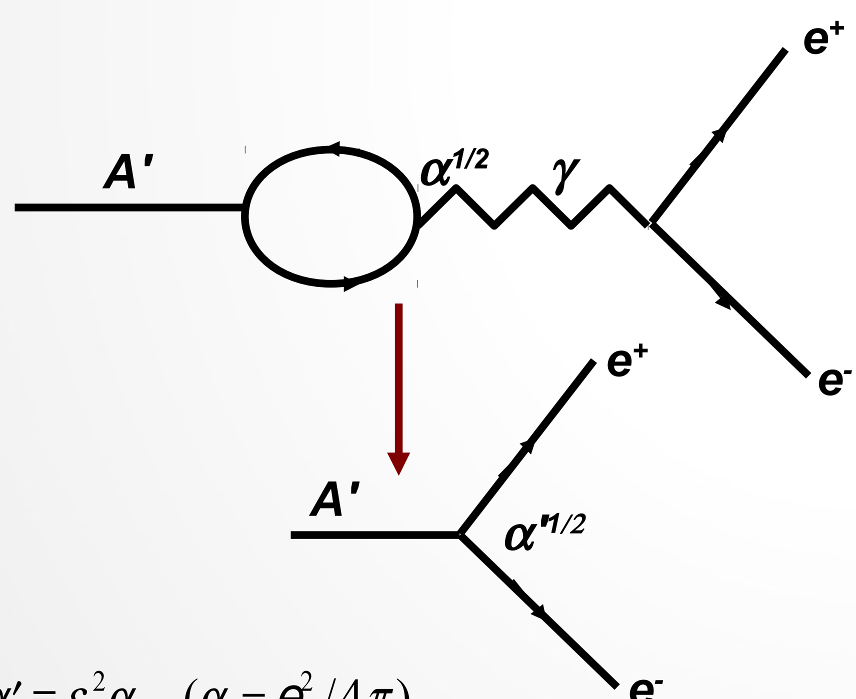
(Dated: January 20, 2009)

arXiv:0810.0173v3

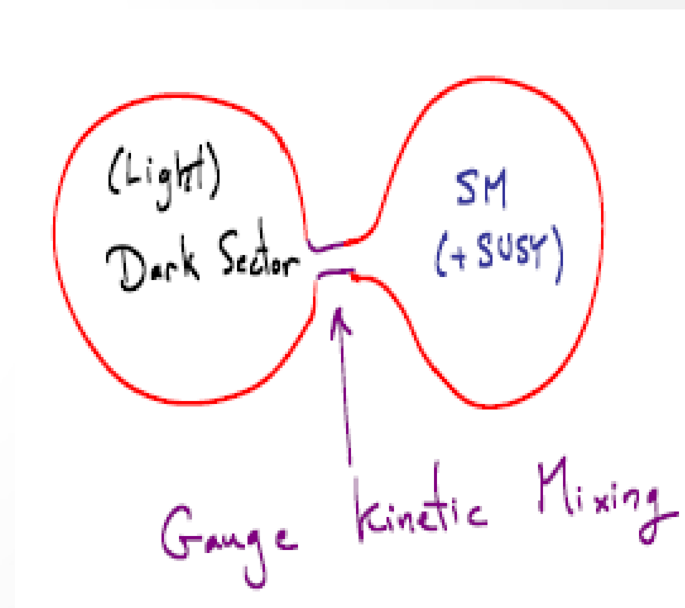
*The idea for a dark sector was proposed in 1986
(B. Holdom Phys. Lett. B 166, 196-198; 1986)
But remained largely unexplored.

Interesting Idea: Gist/Pith

- **PAMELA data → WIMP Mass M_χ ~ 500-800 GeV (reinforced by WMAP "Haze")**
- **Upper limits on hadronic channels from p^- limits**
- **These can imply possibility of hidden/"dark" force, $\lambda_{Compton} \sim m_{A'}^{-1} \sim 1\ \mathrm{GeV}^{-1}$**
- **Predict carrier to be gauge boson *A′*, in mass range 10-100 MeV, coupling like a photon via kinetic mixing**



$$\alpha' \equiv \varepsilon^2 \alpha\,,\ \ (\alpha = e^2/4\pi)$$



Arkani-Hamed

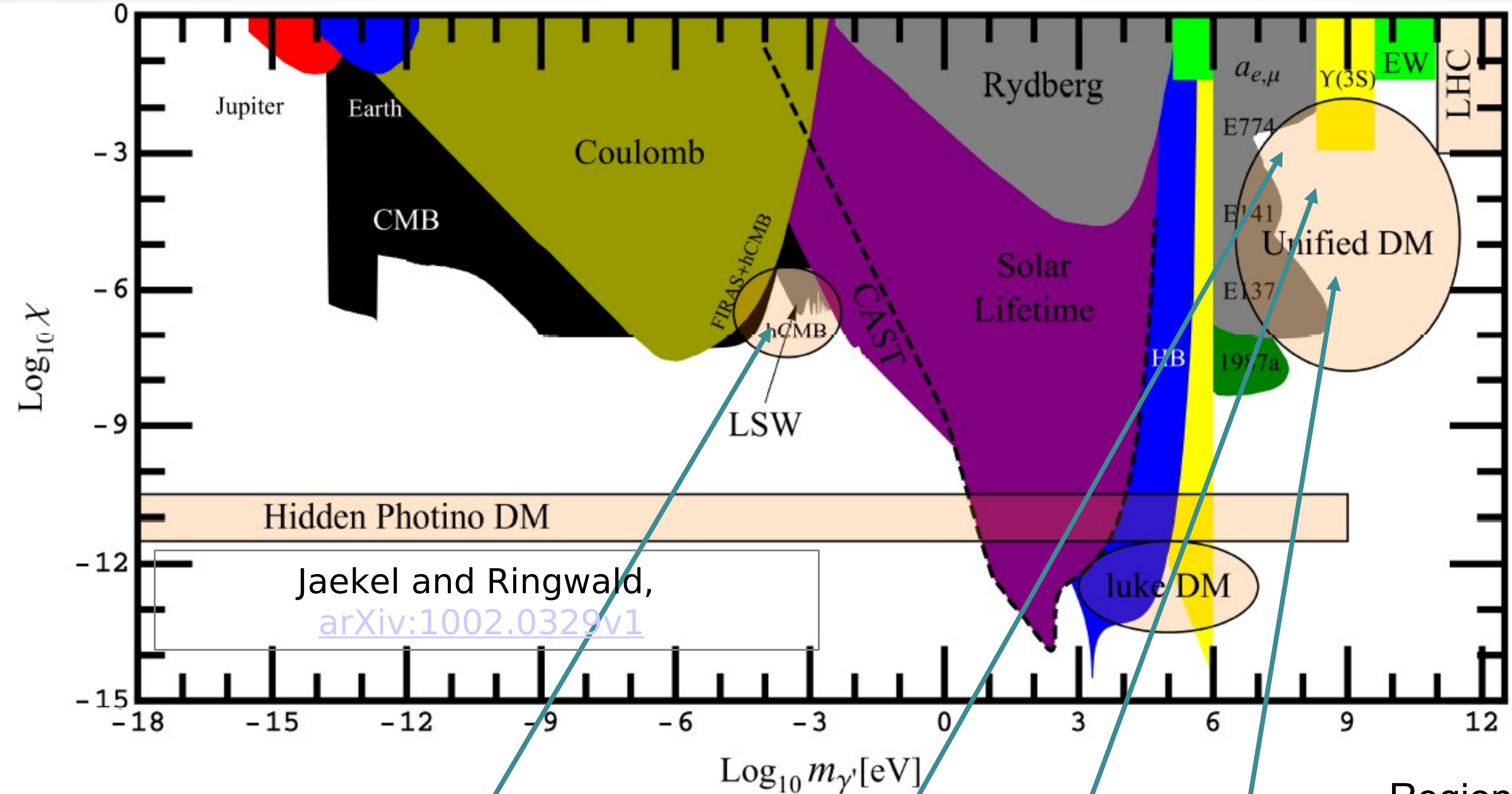
Interesting Idea: Testing

Beyond Observation: *Provides a 3rd, independent study.
- **Hadron Colliders; High Energy, Low Luminosity**
- **e+e- Colliders; Higher/Lower Energy, Lower/Higher Luminosity (arXiv:0903.3941v2)**
- **Fixed Target; Low Energy, High Luminosity (arXiv:0906.0580v1)**

http://www.nature.com/news/physicists-hunt-for-dark-forces-1.10386

Previously Explored Dark Matter Regions

χ *(kinetic mixing) vs.* $m\gamma'$ *(mass of Dark Matter mediator)*



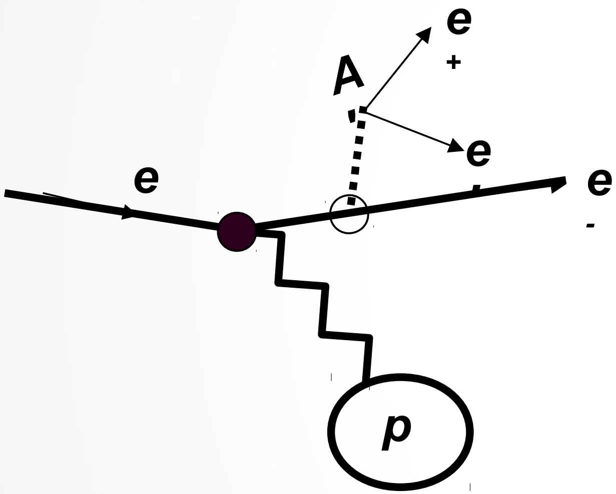
JLAB BSM Experiments: **LIPSS** DARKLIGHT **APEX** **HPS**

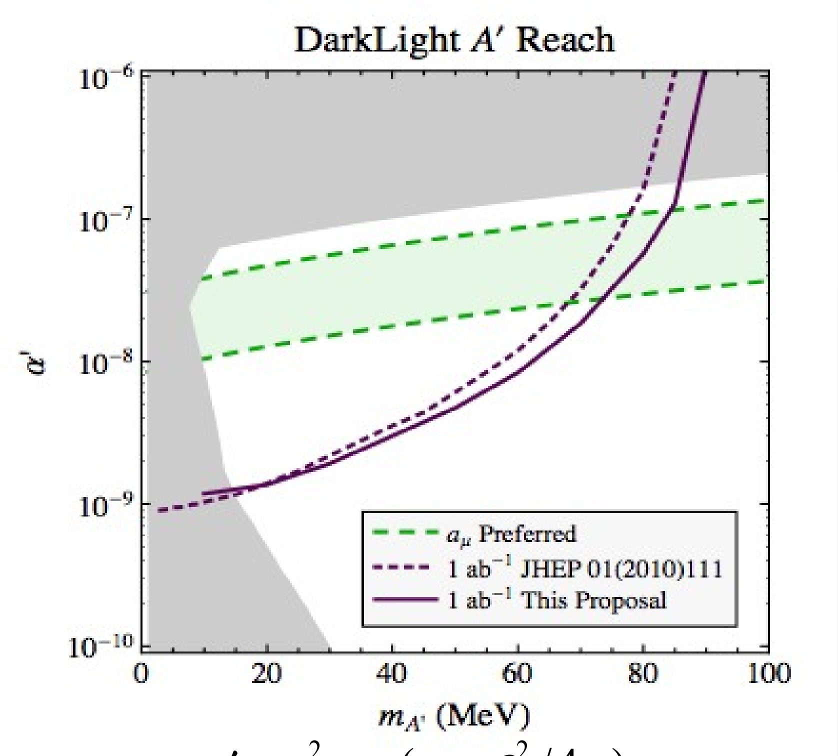
Regions not yet explored, but reachable

DarkLight: Goal

Detecting **A** **R**esonance **K**inematically with e**L**ectrons **I**ncident on a **G**aseous **H**ydrogen **T**arget

A Search for new light bosons using the Jefferson Lab FEL facility.





Goal: Explore e^+-e^- invariant mass spectrum using the process $e^- + p \rightarrow e^- + p + e^- + e^+$

High Intensity, Low Energy Electron Beam

Using JLab's FEL on Thick Hydrogen Gas Target

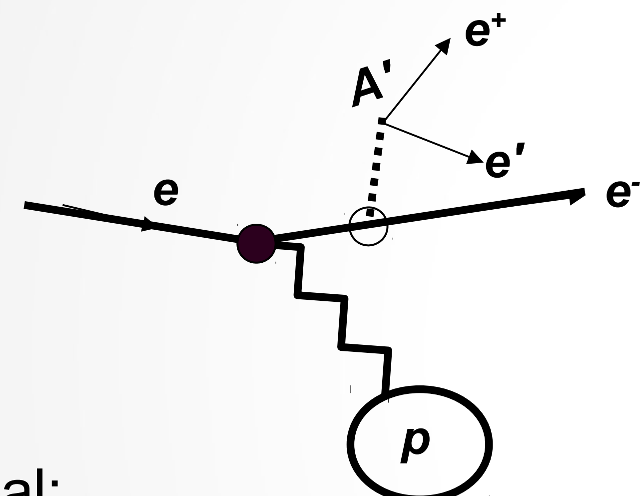
==> Luminosity: 1 ab^{-1}/month
(Formal request ~60 days)

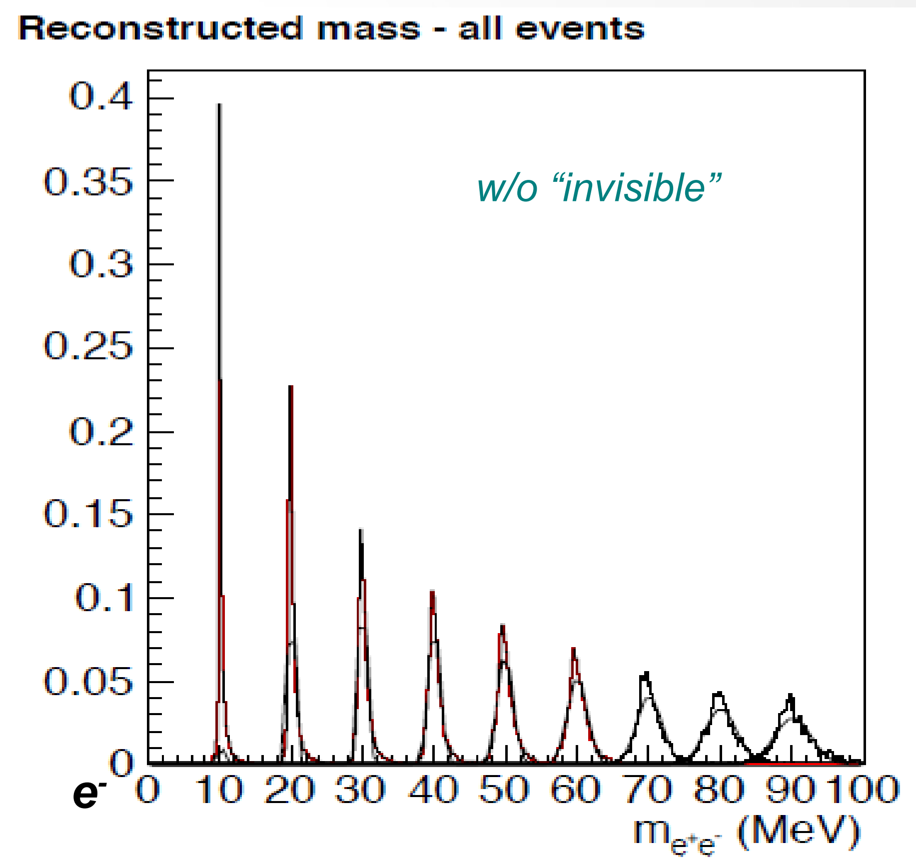
$$\alpha' \equiv \varepsilon^2 \alpha\,,\ \ (\alpha = e^2/4\pi)$$

"Dark Force Detection in Low Energy e-p Collisions"
[Freytsis, Ovanesyan, Thalar: arXiv:0909.2862 (JHEP 1001;111)]

DarkLight: Physics Processes

For $\alpha' \sim 10^{-8}$ the expected signal is 10^{-4} of the irreducible QED background:





Signal:
epγ/epA', ep/epA' ("invisible")

Backgrounds:
ep/ep, ep/epγ, ep/ep$\gamma\gamma$, epγ/epγ

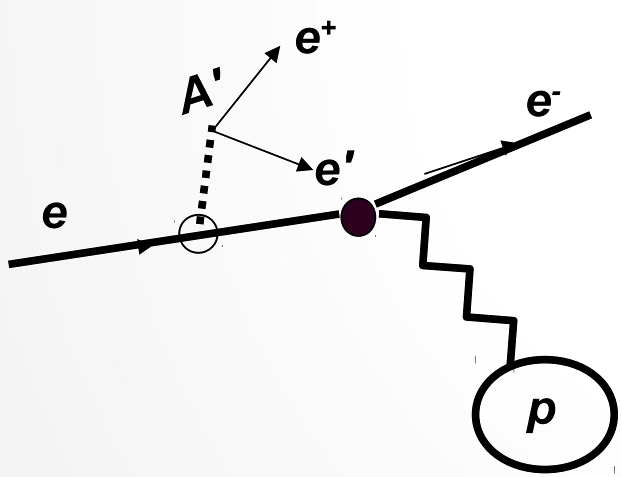
The experiment is basically a measurement of the QED background with 0.1ppm precision. *The detection of all 4 final states is essential.*

DarkLight: "Invisible"

- *ep → epA' ("invisible")* observe only final state electron and proton

- Backgrounds' kinematics different enough that they can be controlled

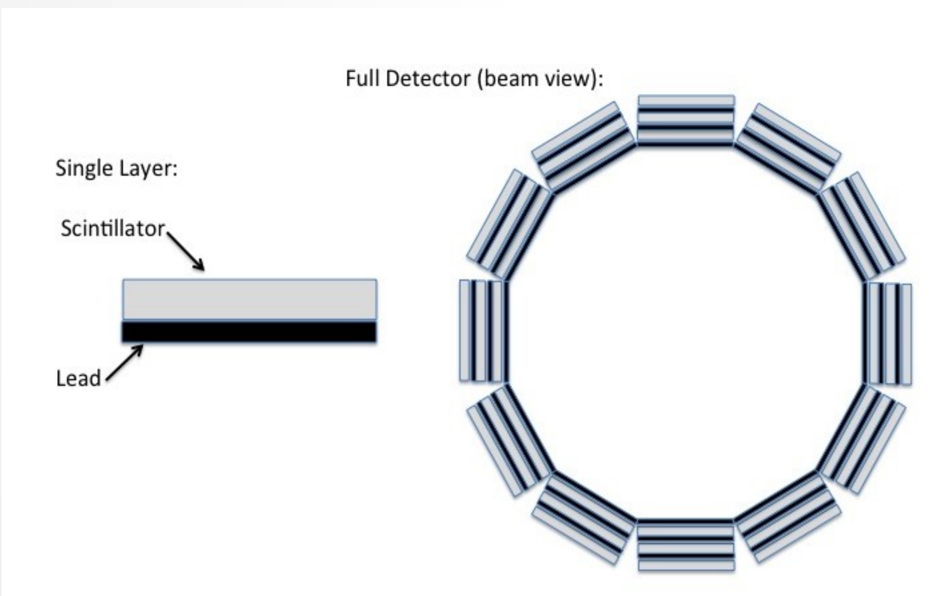
- Requires photon tagging; scintillator

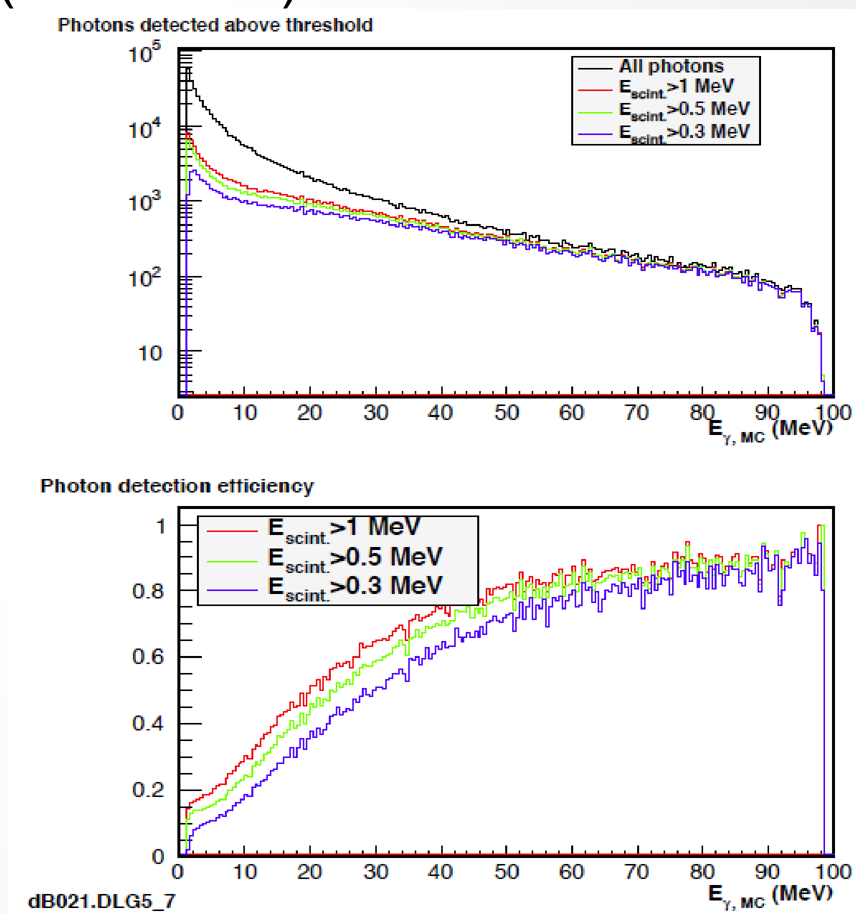


Kahn, Thaler arXiv:1209.0777

DarkLight: "Invisible"

Detector:
- Cylindrical Array
  60 cm (diam) x 150 cm (length)
- Composed of 10 segments (10 cm wide)
- Segment = Pb (0.5 cm thick) + scintillator (1 cm thick) x 3+
- 3 layers => 90% efficiency.

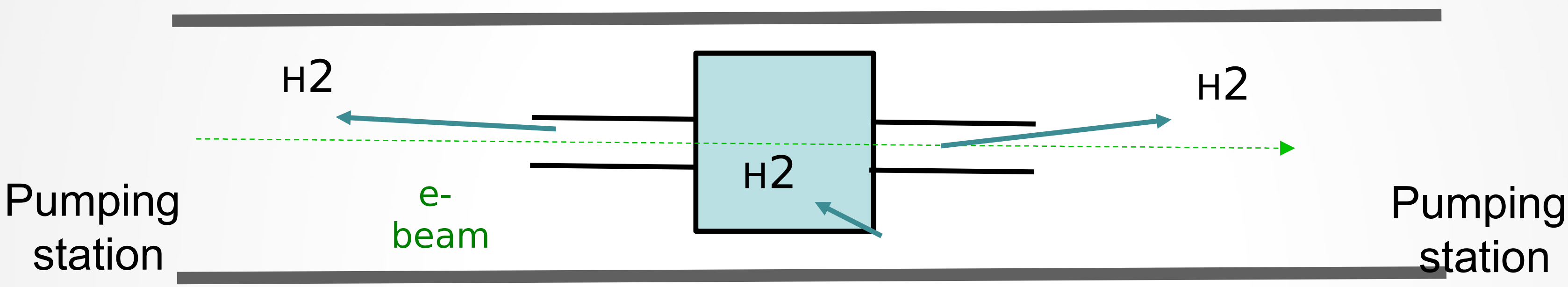




Jlab PAC Proposals

1. PAC 37: DarkLight Collaboration, PAC 37, November 30, 2010.

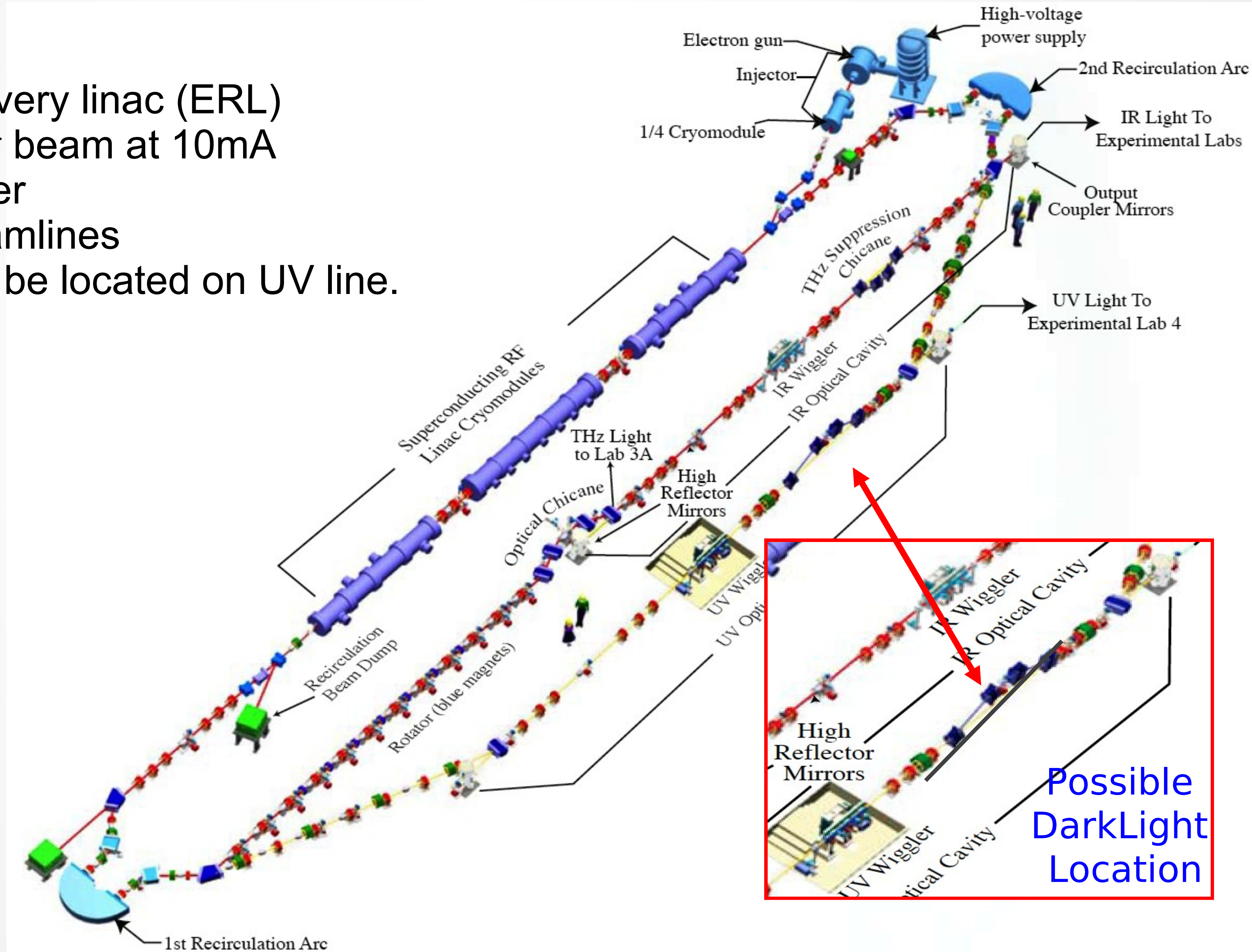
Early concept: electron beam scattering off H2 in a windowless chamber.



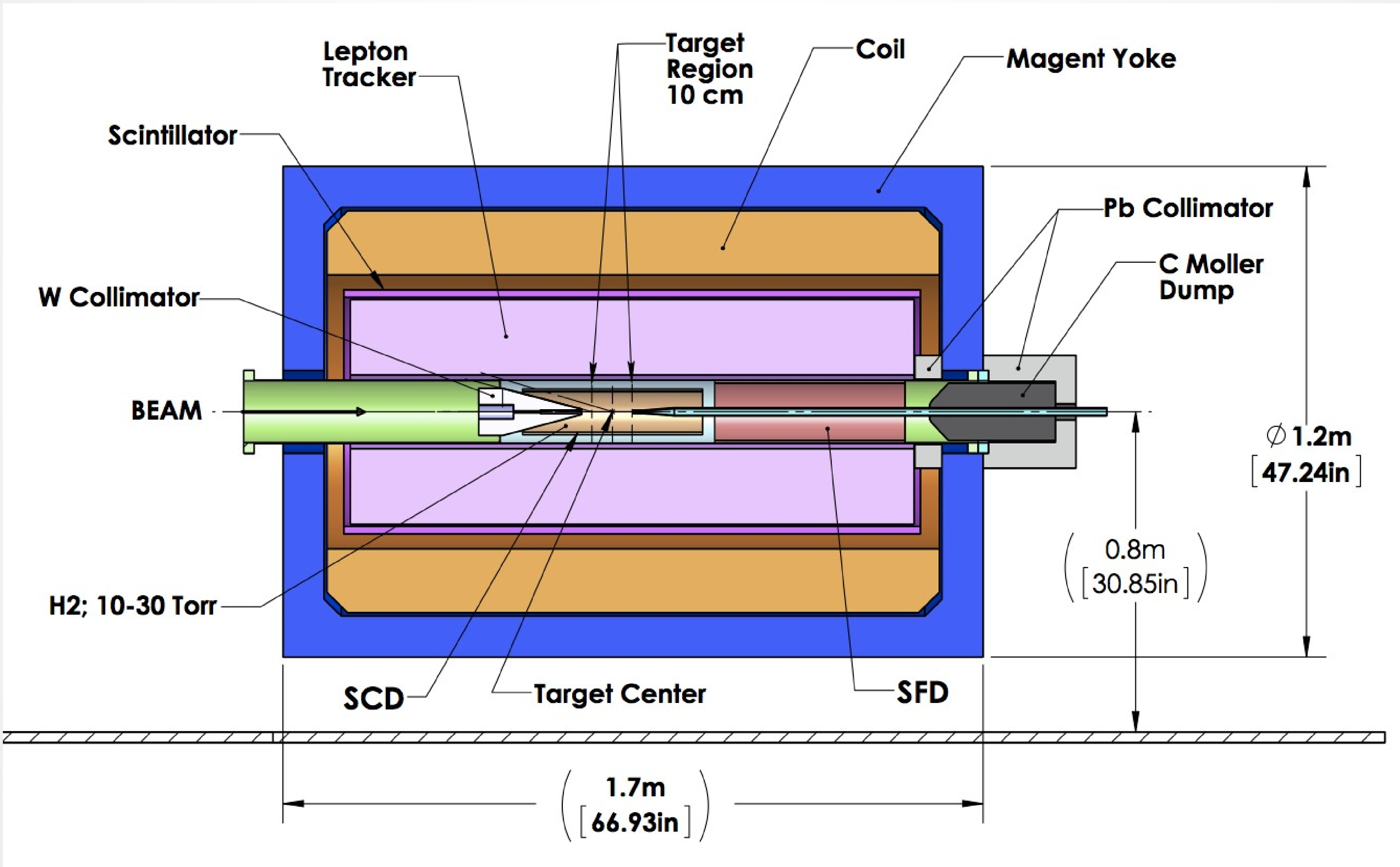
2. PAC 39: DarkLight Collaboration, PAC 39, May 4, 2012.
   - Can DarkLight identify and shield against ambient FEL Vault background radiation.?
   - Can the FEL beam be threaded through the proposed H2 target?
   - Can beam halo be managed?
   - Are there any RF heating/effects on the target entrance/exit?

DarkLight: At FEL

- Energy recovery linac (ERL)
  - 100 MeV e^- beam at 10mA
  - 1 MW power
- IR & UV Beamlines
- DarkLight to be located on UV line.



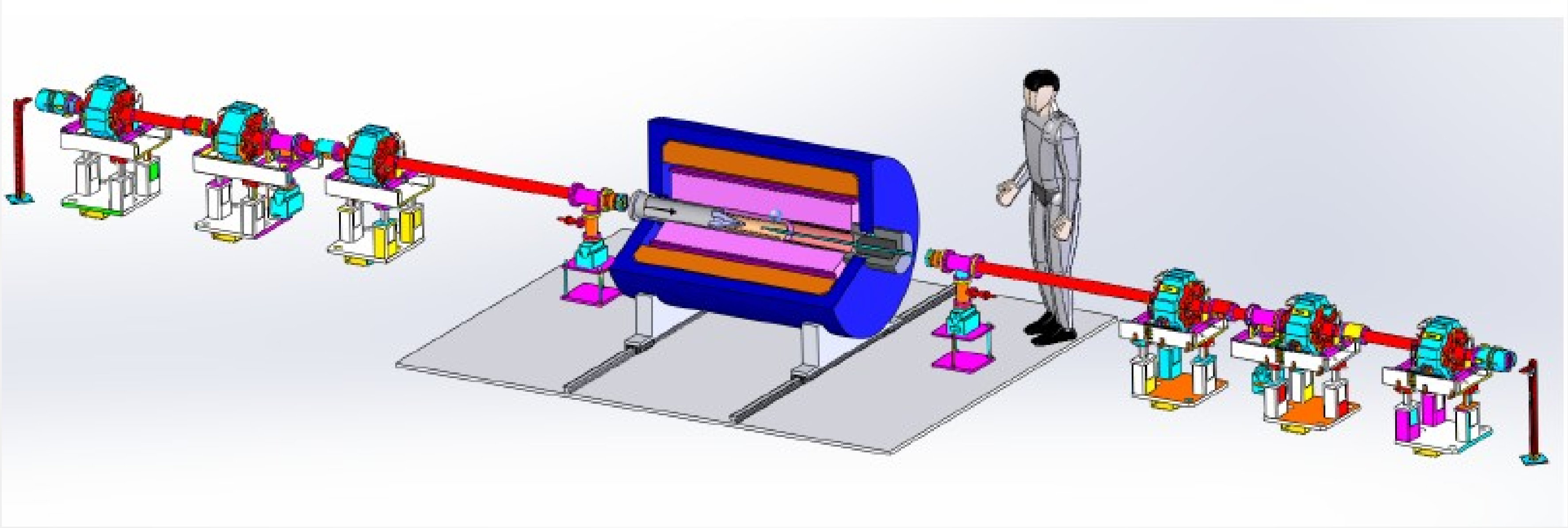
DarkLight: Schematic



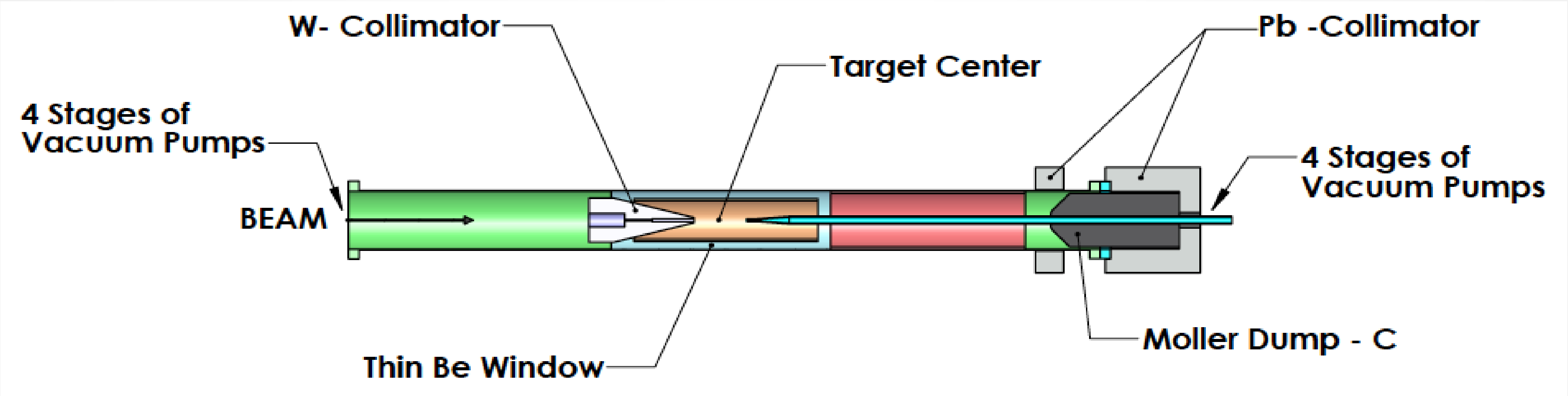
DarkLight: Components

DarkLight has 4 primary components:

- Target – Differentially pumped hydrogen gas target $10^{19}/cm^2$, 10 cm long.
- Silicon proton detector - ~3.5 cm from beam, single layer of silicon micro-strip detector. Measure energy and angle of recoil proton.
- Lepton tracker – 10-25 cm radius TPC, based on PANDA design.
- Magnet – Solenoid provides 0.5 T B-field to focus Moller e^- and measure lepton momentum and direction.



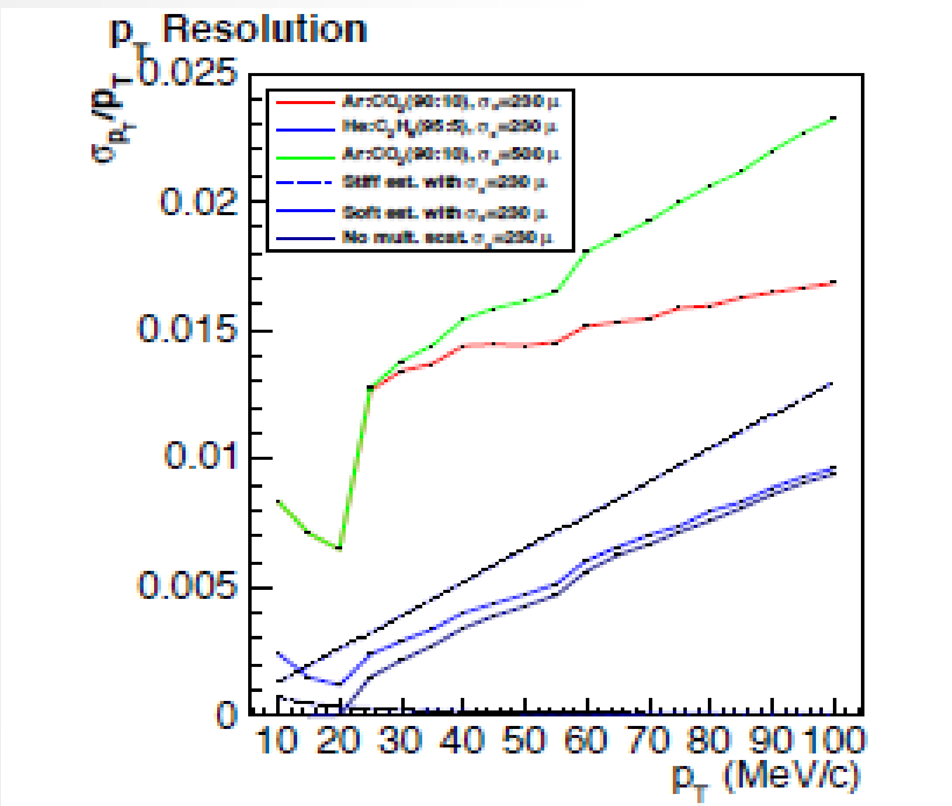
DarkLight: Target

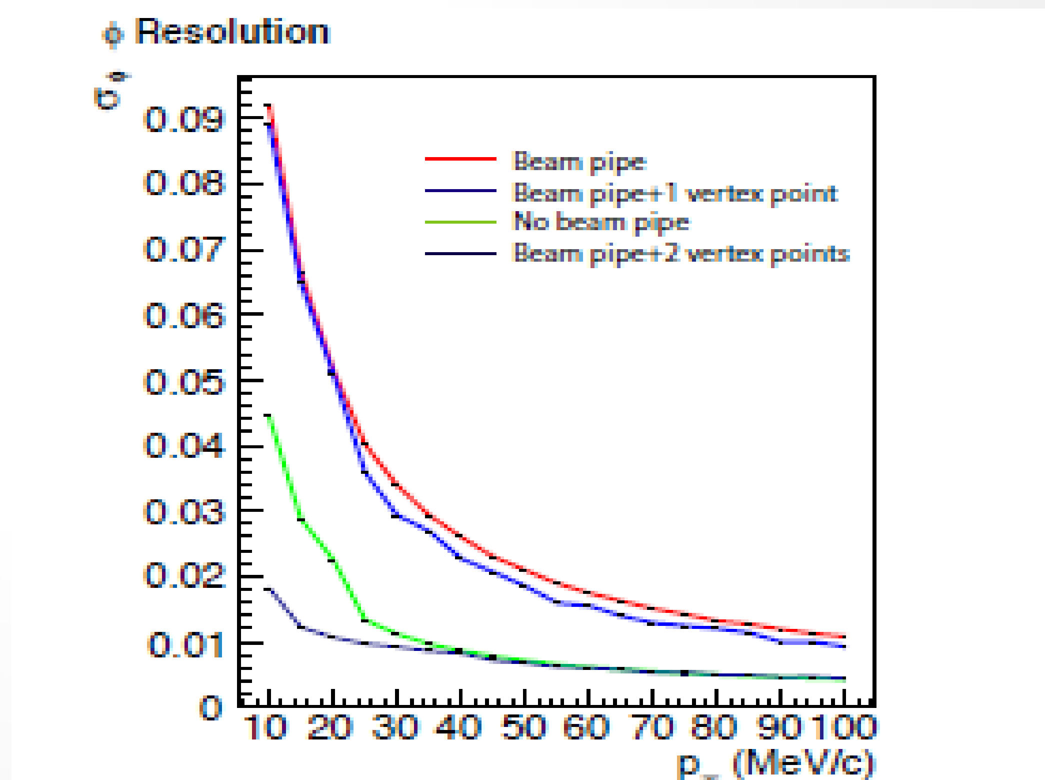


- Hydrogen target realized by flowing gas through narrow apertures
- Aperture diameter: 2 mm
- Aperture length: 50 mm
- Thickness: 10^{19} Hydrogen atoms cm^{-2}
- Flow rate: 24 Torr-liter s^{-1}
- Viscous subsonic flow regime
- Multiple stages of differential pumping required
- Plasma windows under consideration

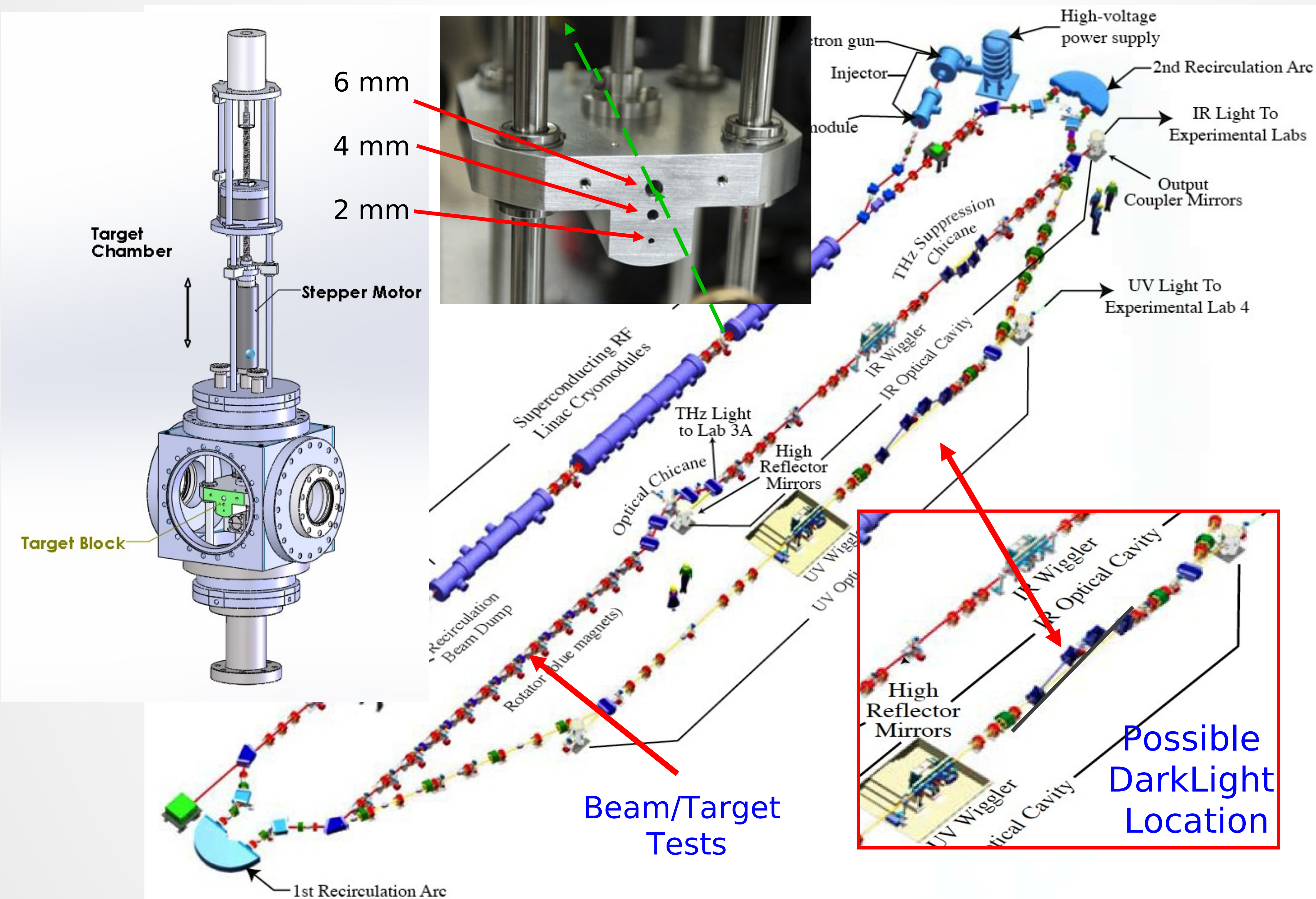
DarkLight: Lepton Tracker

- Similar to PANDA TPC or STAR Forward Tracker.
- Gas Ar(Ne)/CO_2 (90/10)
- ~10^4 channels
- Triple GEM; gain ~10
- Drift length 725 mm
- Inner/Outer diameter 105/300 mm

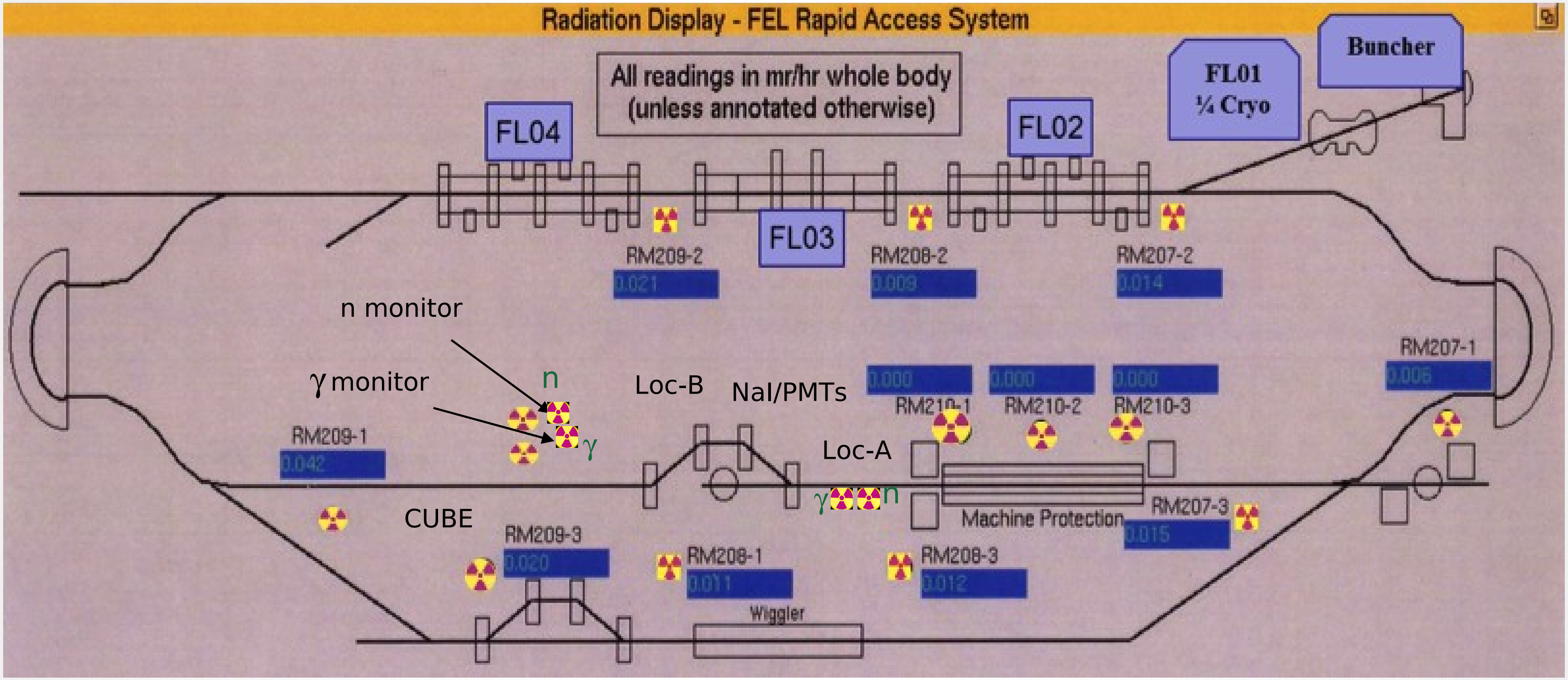




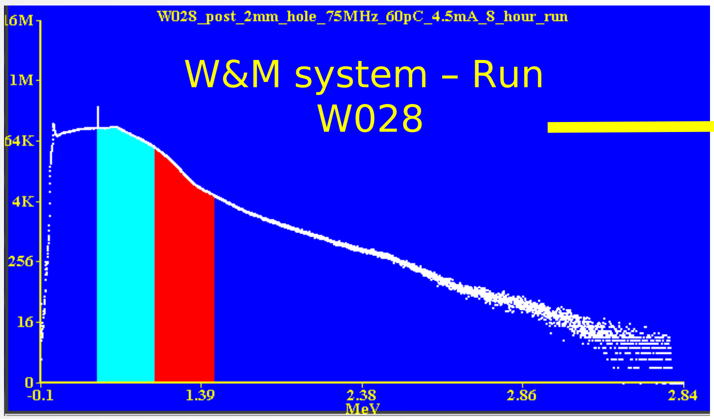
DarkLight: Beam Tests

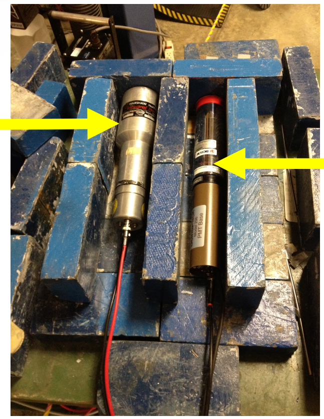


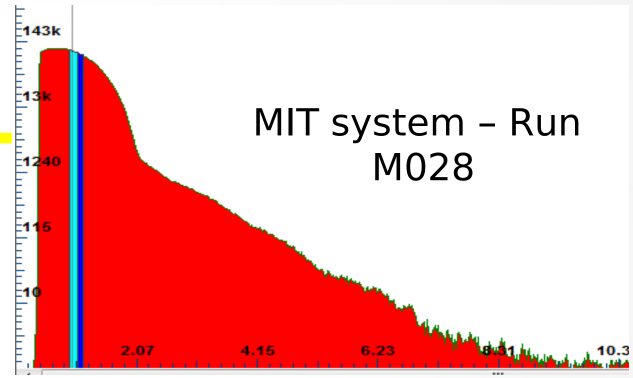
FEL Rapid Access System

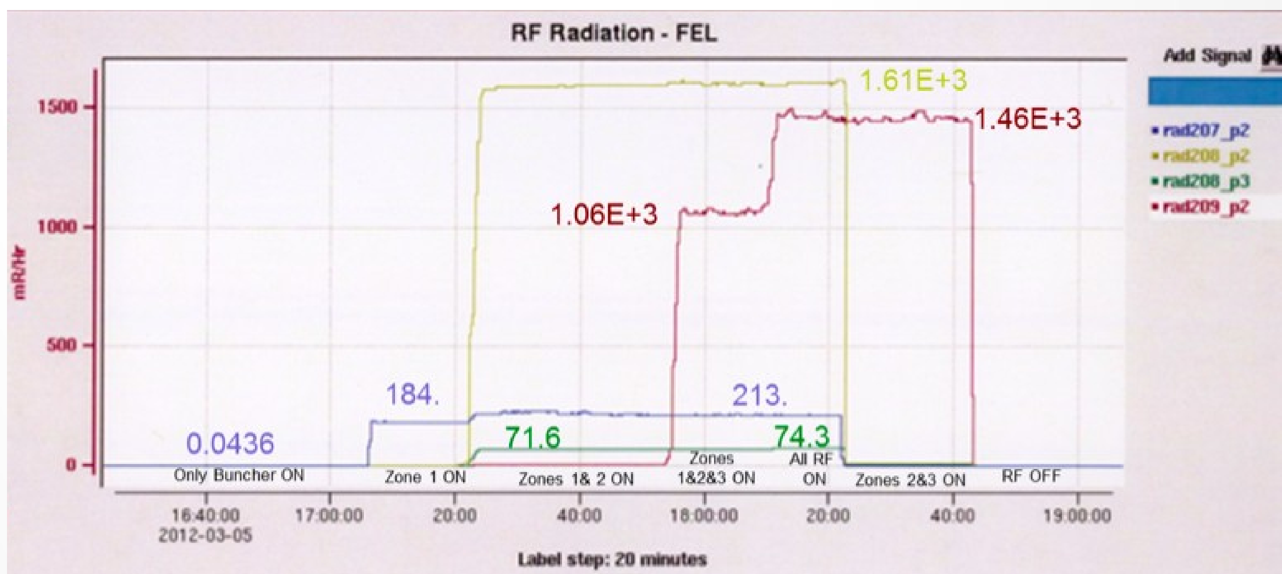


FEL Vault Background Radiation

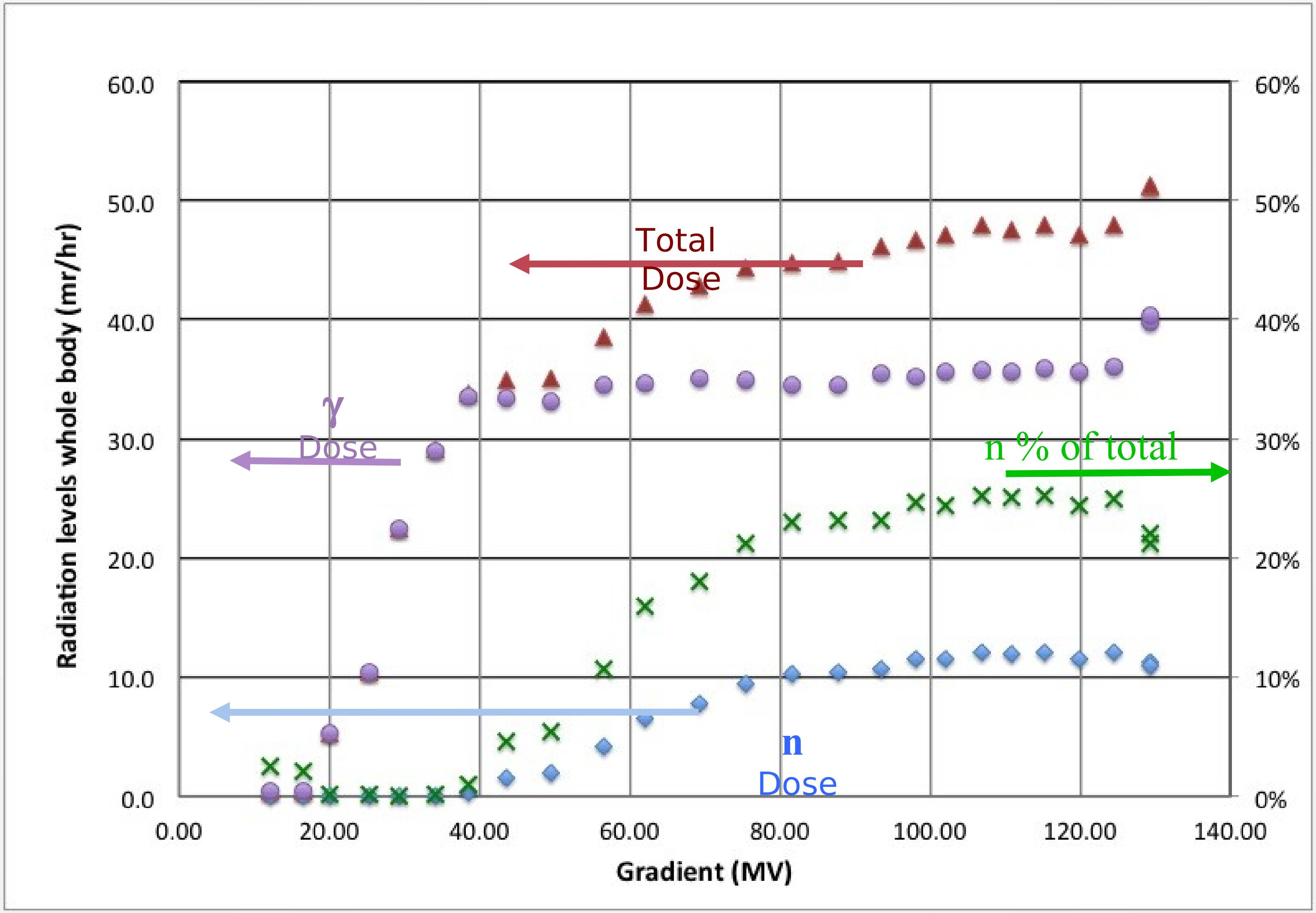




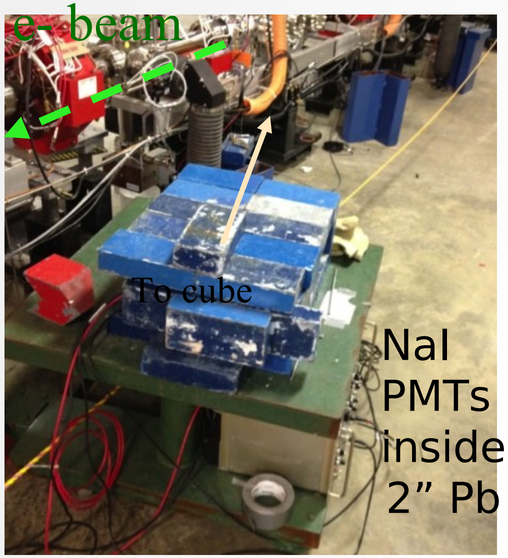


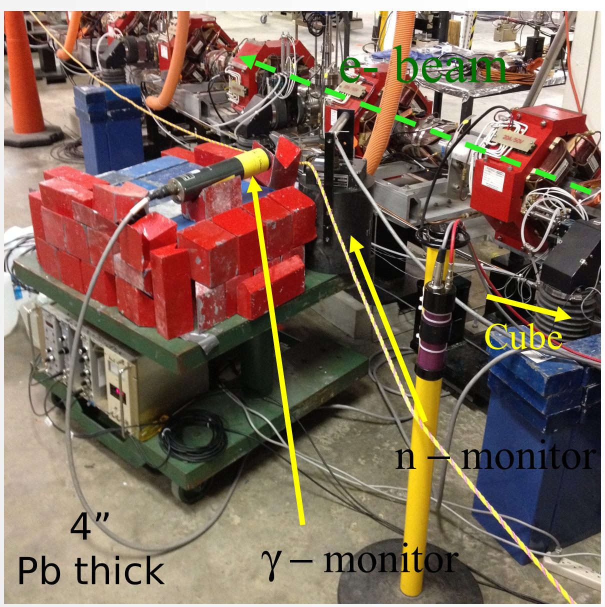


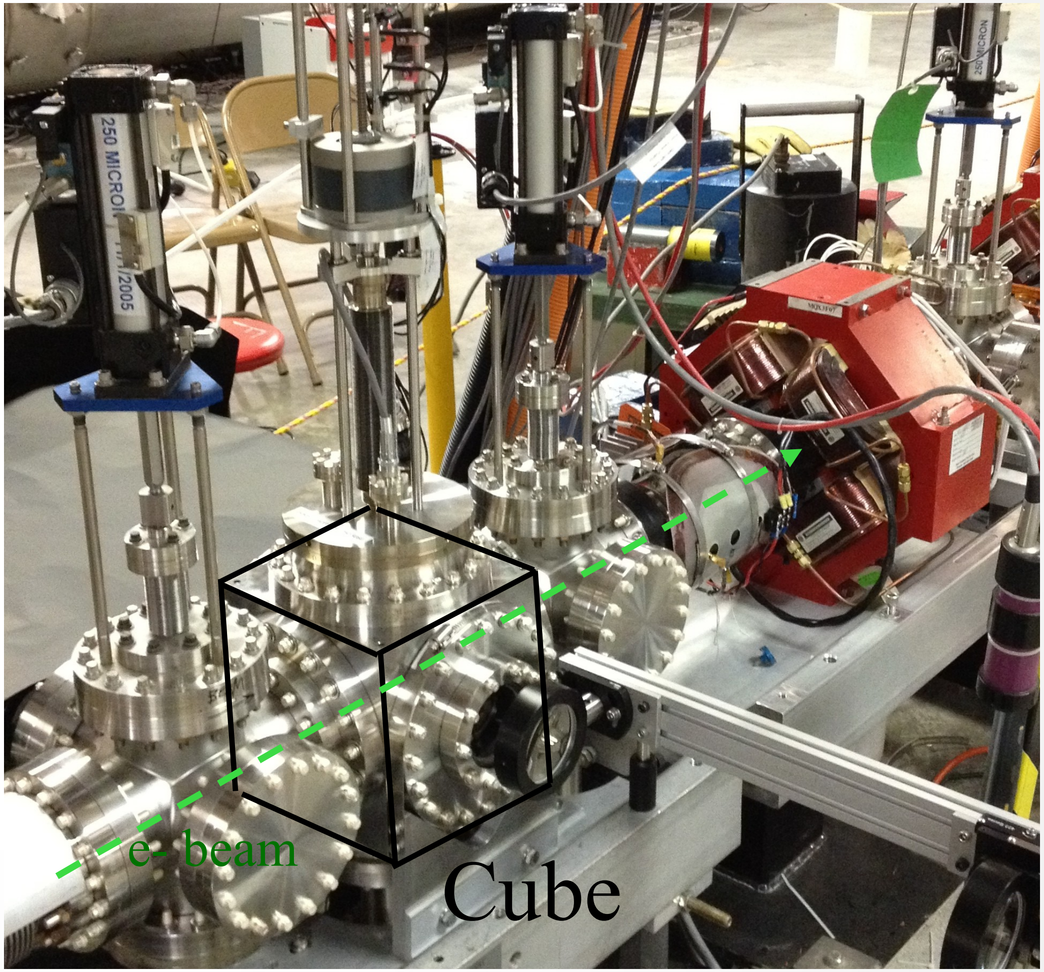
FEL Vault Radiation Levels vs. Total RF Gradient



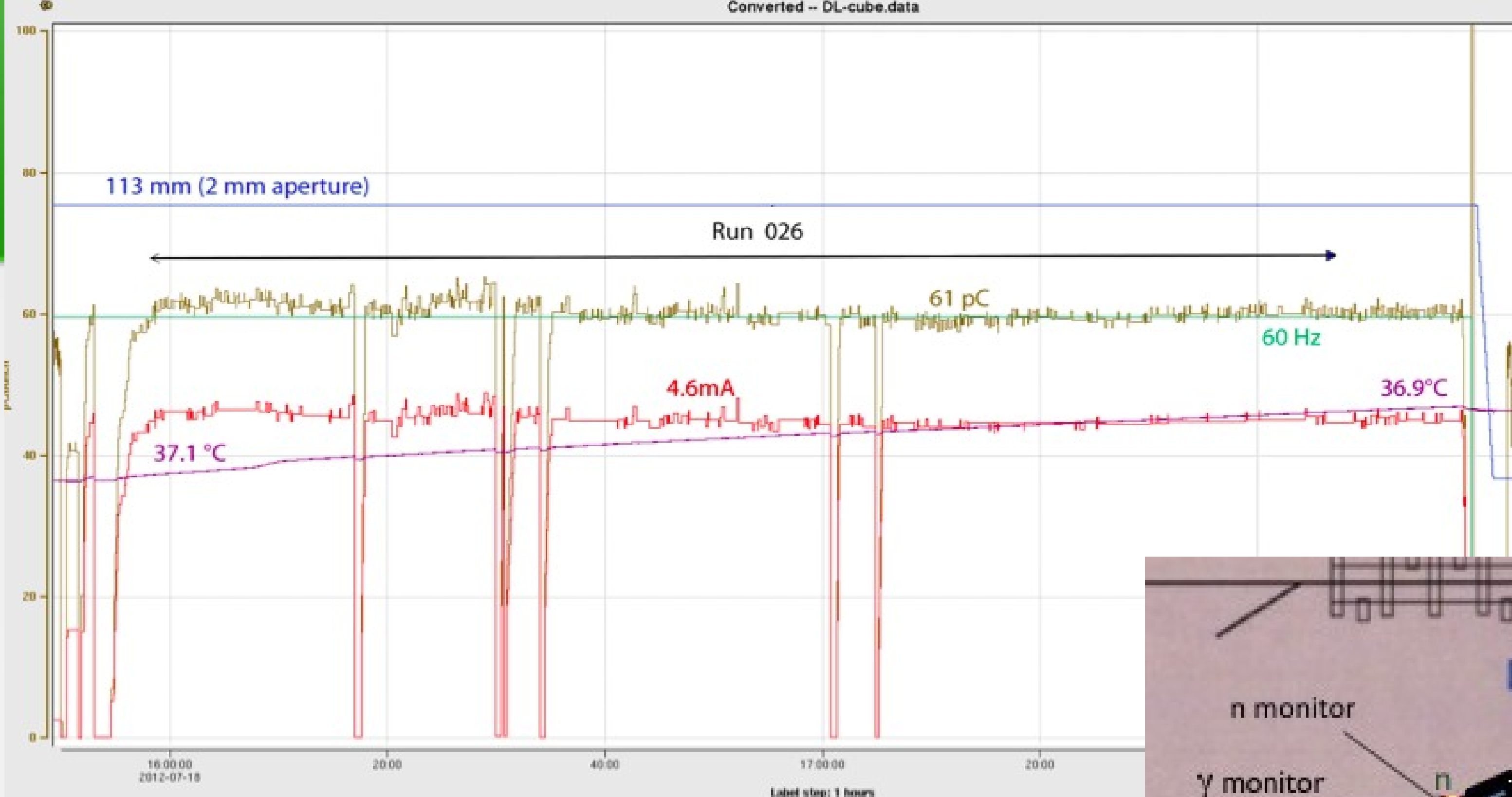
FEL Beam-Target Tests & Radiation Measurements

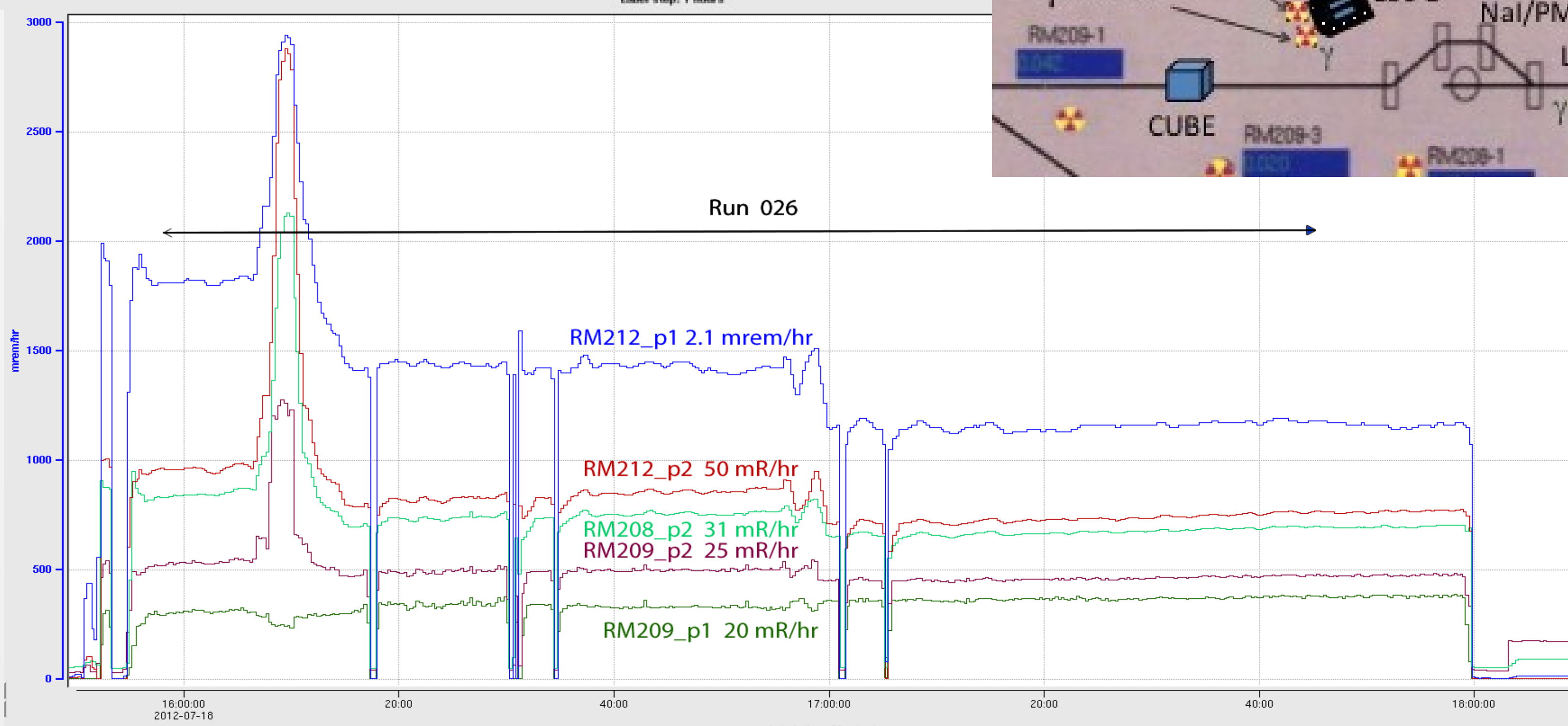


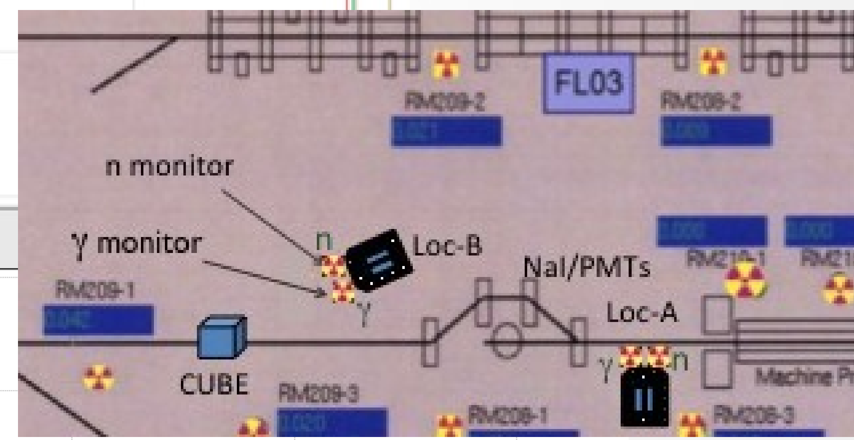




DL Run 26 Location B







Beam Tests Results

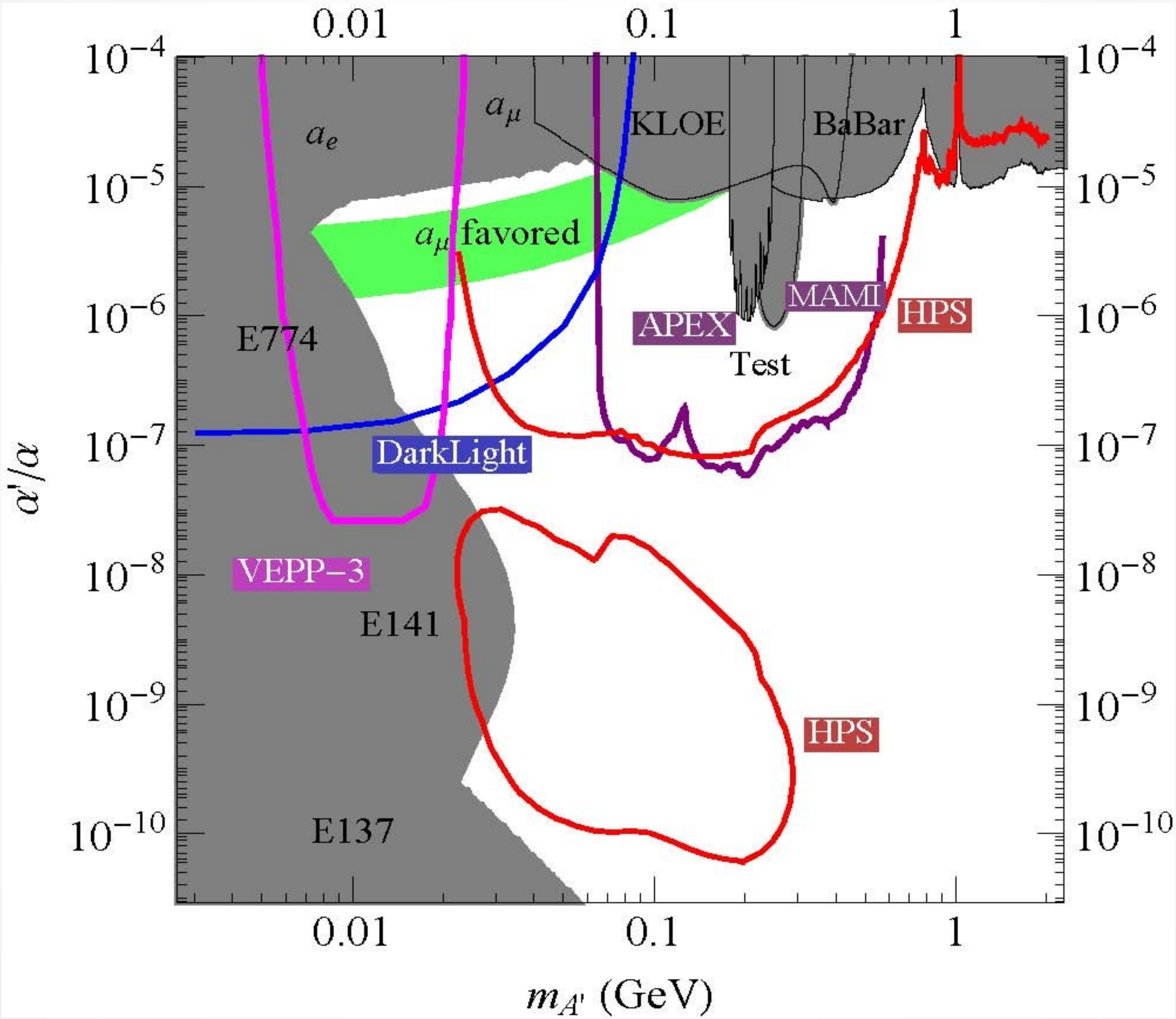
A test e^- beam 100 MeV, 4.5 mA (450 kW power) was successfully transmitted through a 2mm hole, 12.7 cm long, with max loss of 7 ppm for 7 hours. This showed that

- e^- beam bunch CAN be threaded through a 12.7 cm long, 2 mm hole.
- Halo CAN be minimized.
- The FEL has the stability required for a successful DarkLight experiment.
- Radiation in the vault is manageable.

Possible Timeline

Year Focus	2012	2013	2014	2015	2016
FEL beam & Radiation limits					
Finalize Design Secure funding					
Technical Review Start Construction					
Detector Commissioning					
DarkLight data taking begins					

Projected Results



Collaboration

Spokespersons: Peter Fisher and Richard Milner

J. Balewski, J. Bernauer, W. Bertozzi, J. Bessuille, B. Buck, R. Cowan, K. Dow, C. Epstein, P. Fisher [2], S. Gilad, E. Ihloff, Y. Kahn, A. Kelleher, J. Kelsey, R. Milner, C. Moran, L. Ou, R. Russell, B. Schmookler, J. Thaler, C. Tschalaer, C. Vidal, A. Winnebeck
Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, MA 02139, USA and the Bates Research and Engineering Center, Middleton MA 01949
S. Benson, C. Gould, G. Biallas, J. Boyce, J. Coleman, D. Douglas, R. Ent, P. Evtushenko, H. C. Fenker, J. Gubeli, F. Hannon, J. Huang, K. Jordan, R. Legg, M. Marchlik, W. Moore, G. Neil, M. Shinn, C. Tennant, R. Walker, G. Williams, S. Zhang *Jefferson Lab, 12000 Jefferson Avenue, Newport News, VA 23606*
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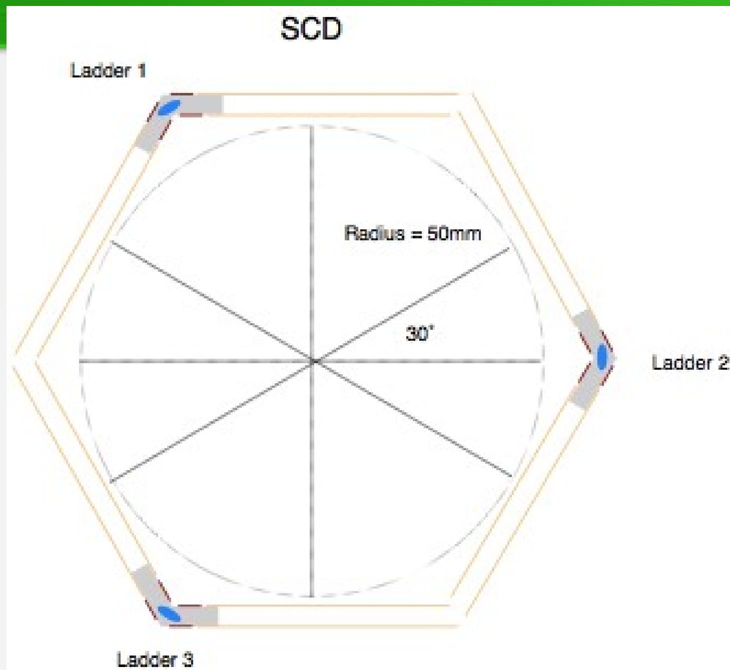
Summary and Conlusion

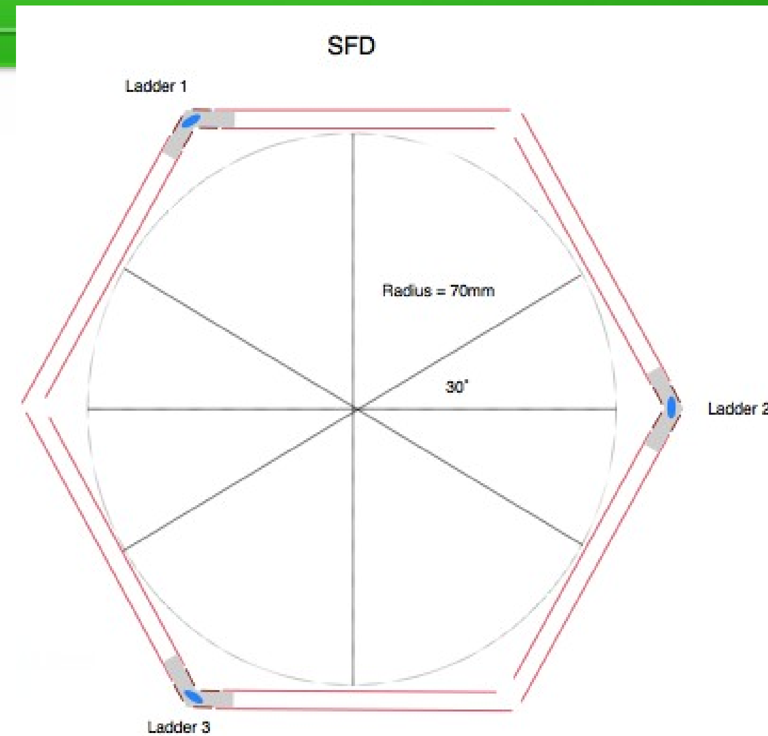
- **Fairly recent theoretical developments suggest interaction between dark matter and SM via gauge boson.**
- **Lepton scattering, fixed-target provides yet another method for studying dark matter.**
- **DarkLight intends to use the FEL beam (~1 mA, 100 MeV) incident on a H2 gas target. Collect 1/ab in ~ 60 days of beam time.**
- **High acceptance detector inside a 0.5T solenoid: Si-strip recoil detector, TPC for lepton tracking.**
- **Satisfied condition for PAC to recommend approval.**

Support Slides

DarkLight: Central & Forward Detectors



- Radius: 50mm
- Φ-coverage: 360°
- θ-coverage: 17° - 163°
- Number of ladders: 3
- Ladder length: 430mm
- Sensor dimensions: 56.5mm X 60.0mm / 52.5mm X 60.0mm
- Sensor thickness: 300μm
- Total number of sensors: 84
- Power dissipation: 0.3W per chip / 50W per ladder
- Radiation tolerance of sensors: 1MRad
- Radiation tolerance of readout chip: >>1MRad



• Radius: 70mm
• Φ-coverage: 360°
• θ-coverage: 6.1° - 19°
• Number of ladders: 3
• Ladder length: 458mm
• Sensor dimensions: 78.5mm X 64.0mm / 72.5mm X 64.0mm • Number of sensors: 28 per ladder
• Sensor thickness: 300μm
• Total number of sensors: 84
• Power dissipation: 0.3W per chip / 50W per ladder
• Radiation tolerance of sensors: 1MRad
• Radiation tolerance of readout chip: >>1MRad

DarkLight Specs

$M_{A'}$ 1 MeV (< 1% Rad. Length)

Incident electron energy 100 MeV

Scattered lepton angle 25-165 deg

Scattered lepton energy 10-100 MeV

Recoil proton angle 6-163 deg

Recoil proton energy 1-6 MeV

Position: 250 μm

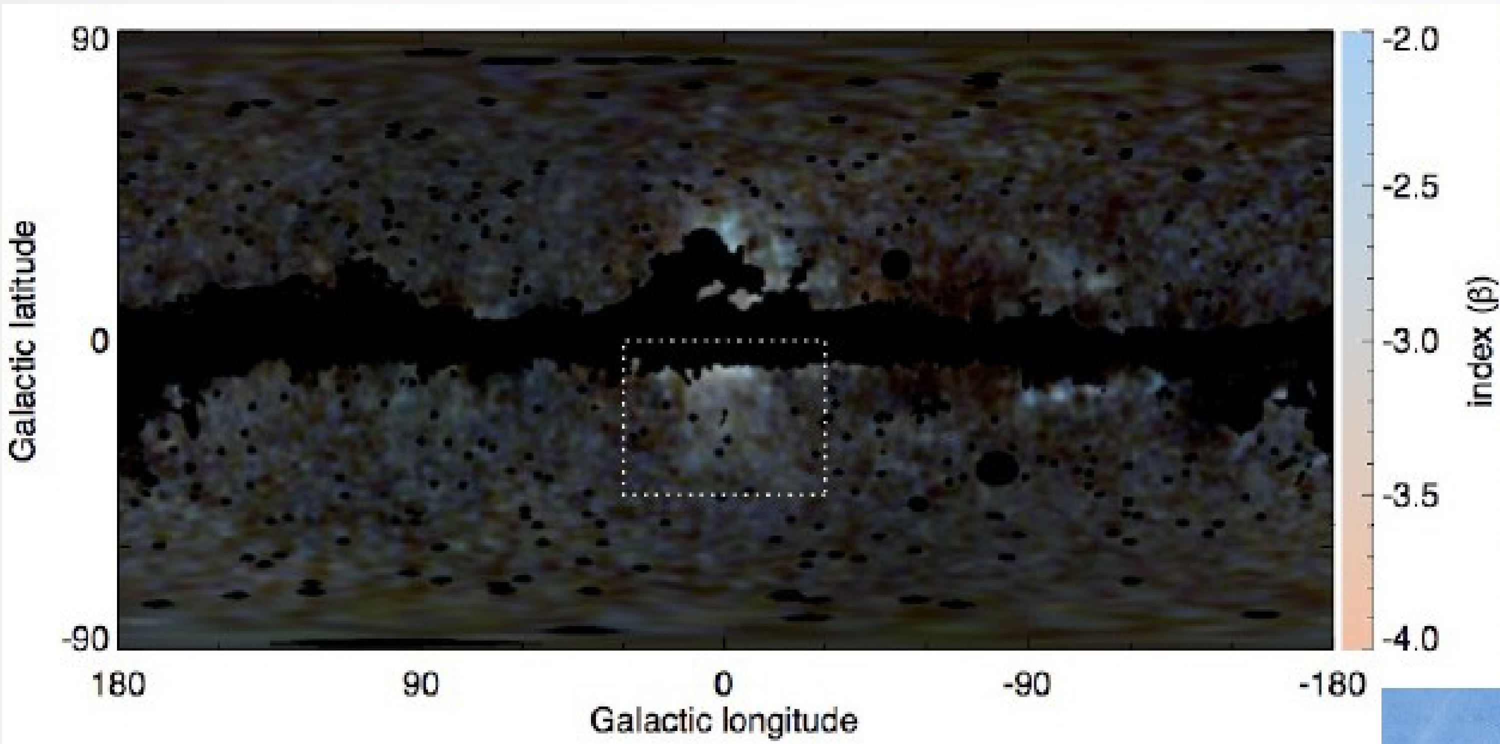
Elastic rate within acceptance 10 MHz

Trigger Rate ~ kHz

Jlab FEL Capabilities

	Near Term Capability, Dec. 2013	Full Capability	Internal Target (Near Term)
	external target	external target	internal target
E (MeV)	80-320	80-610	80-165
P_{max} (kW)	100	300	1650
I (mA)	0.31-1.25	0.5-3.75	10
f_{bunch} (MHz)	750 / 75	750 / 75	750 / 75
Q_{bunch} (pC)	1.67-0.4 / 16.7-4	5-0.67 / 50-6.7	13.5 / 135
$\varepsilon_{transverse}$ (mm-mrad)	~1 / ~3	~2 / ~5	~3 / ~10
$\varepsilon_{longitudinal}$ (keV-psec)	~5 / ~15	~10 / ~25	~15 / ~50
Polarization	No	Up to 600 μA	No
	750 MHz drive laser; single F100	12 GeV RF drive; three F100s	12 GeV RF drive; three F100s

WMAP "Haze"



Dobler & Finkbeiner 2008;
New source of 10+ GeV e^+e^- in galactic center

Electrons spiraling in
B-fields create microwaves