Searching for Dark Light

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DARKLIGHT

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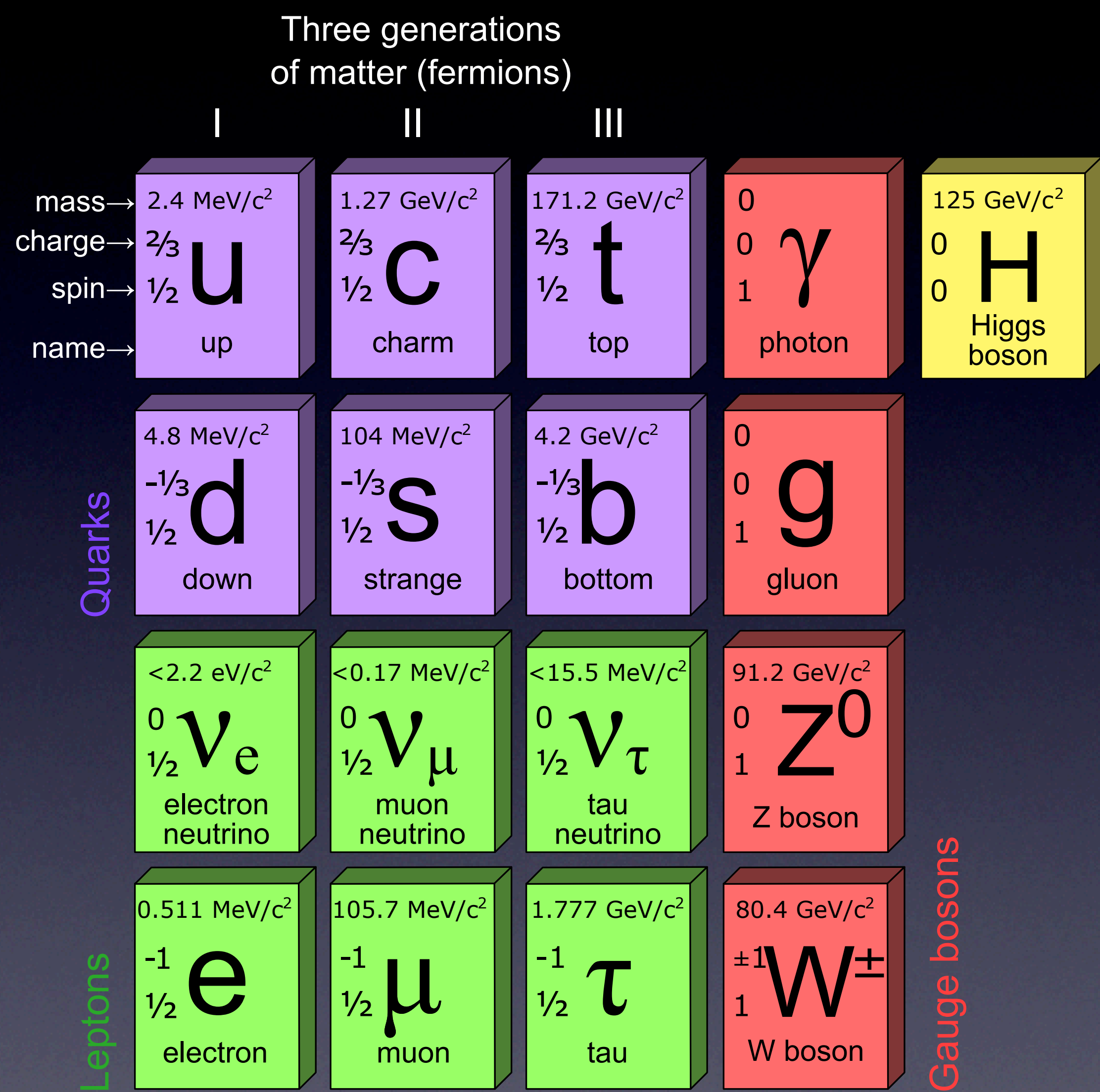
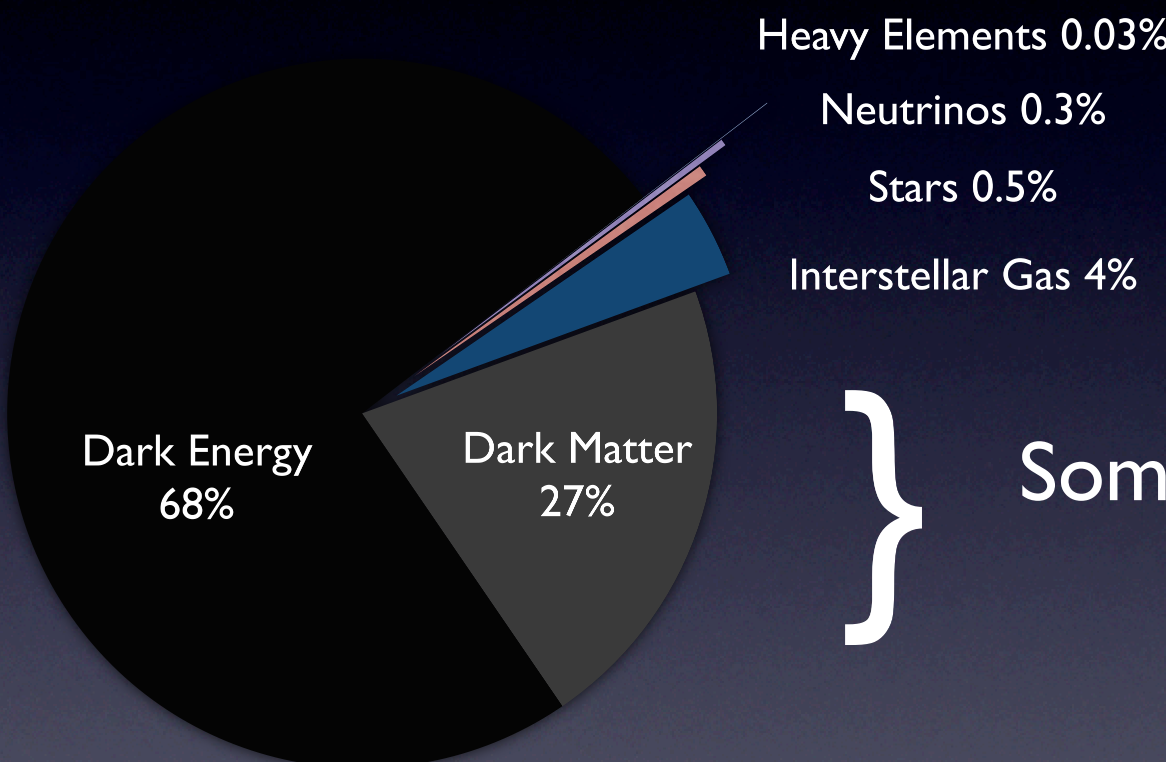
Outline

- Why we care about dark photons
- Where we look
- How we look
- DarkLight

Standard Model: Done!*



Dark Matter



The Standard Model
~5%

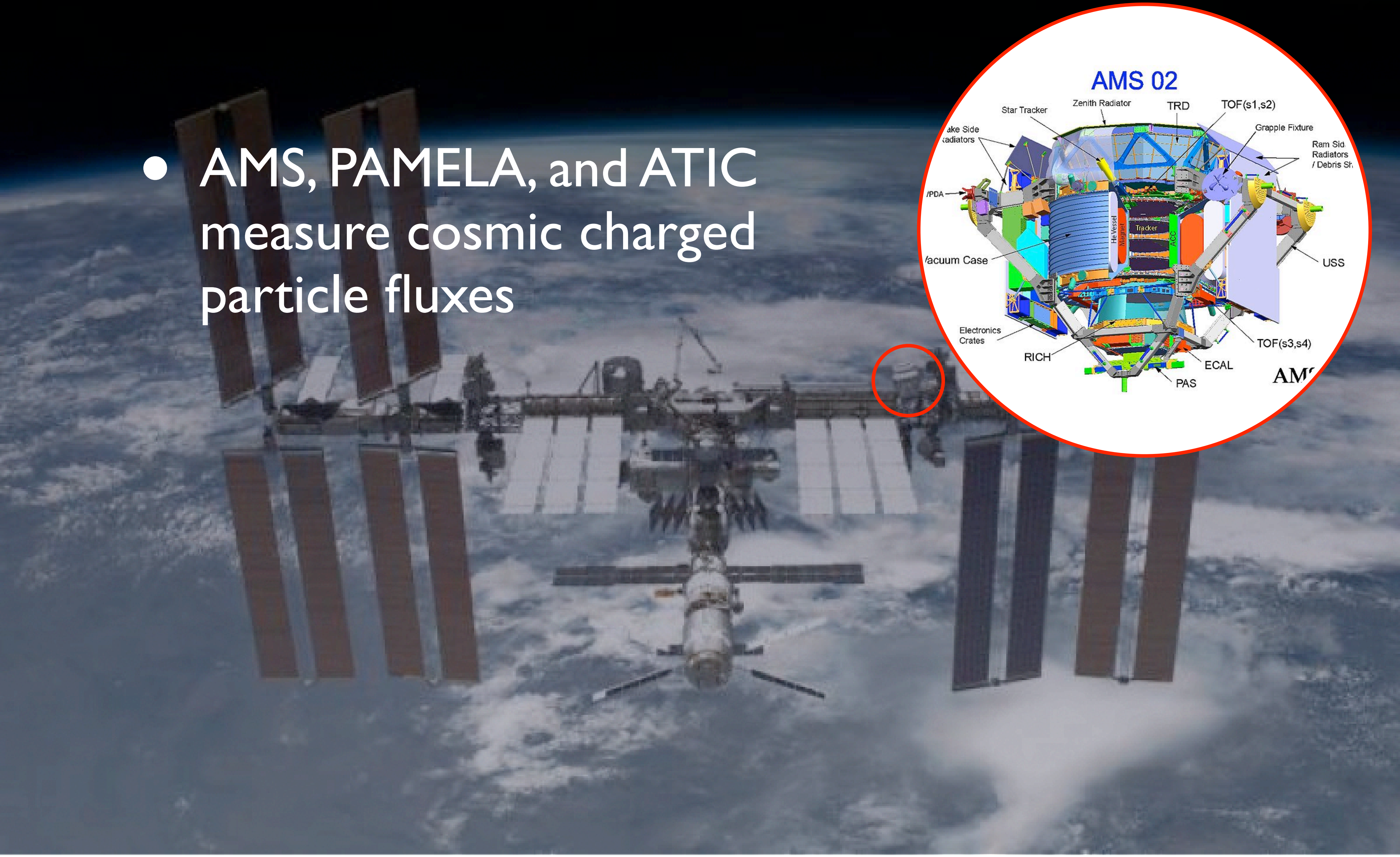
Something Else
95%

Dark Matter Interactions

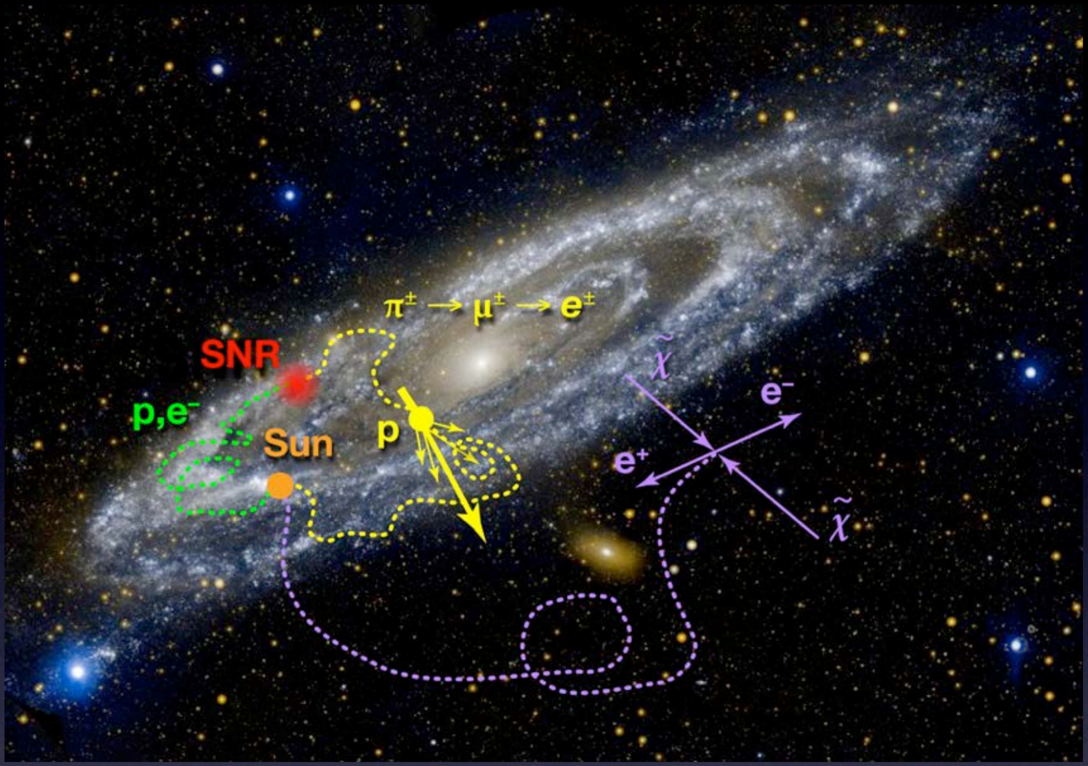
- Relic Abundance constrains mass/interaction strength ("WIMP Miracle", though that's a different discussion)
- We still expect some sort of decay or annihilation mechanism

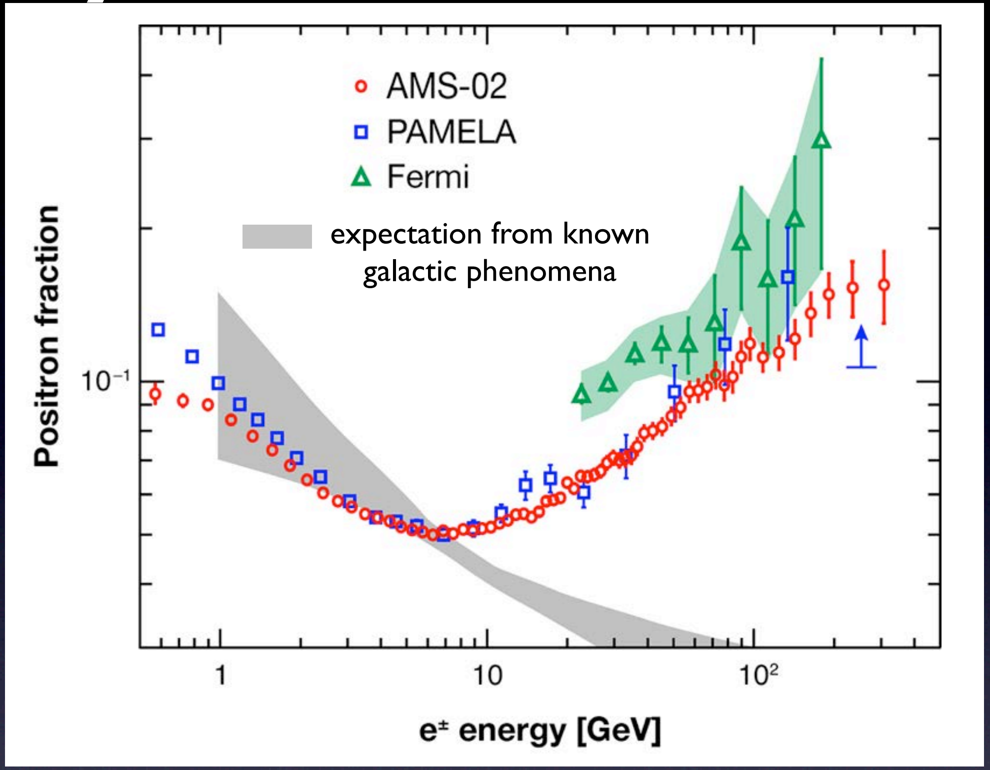
AMS, PAMELA, et al.

- AMS, PAMELA, and ATIC measure cosmic charged particle fluxes



Possible Decays to e^+e^-



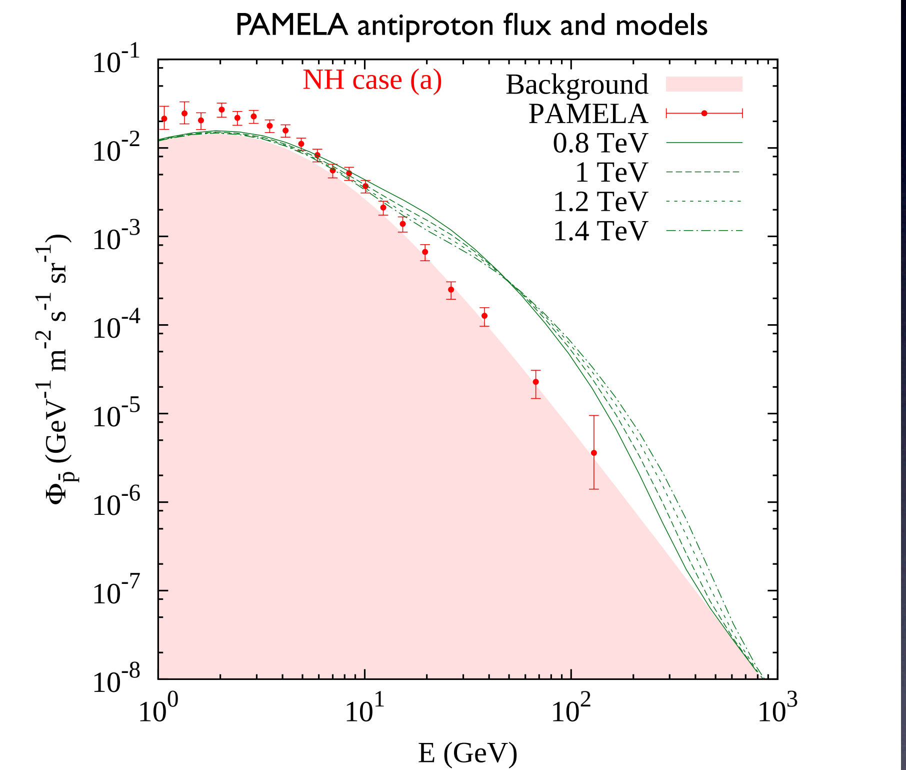


- Nearby cosmic accelerators or colliders?
- Dark matter decay or annihilation?

S. Coutu, Physics 6, 40 (2013)

...but not to hadrons?

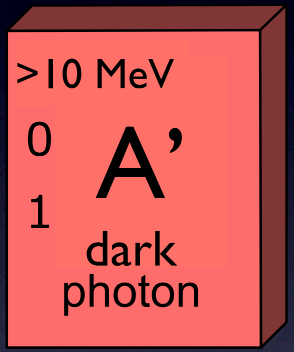
- No rise in antiproton flux
- M_{DM} < ~ GeV hard to reconcile with relic abundance*

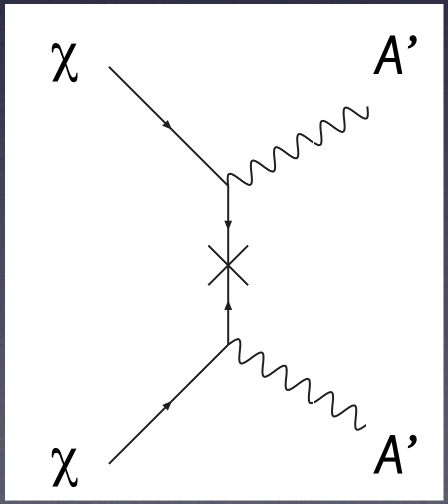


P. S. Bhupal Dev et al. arXiv:1307.6204

Light Dark Forces?

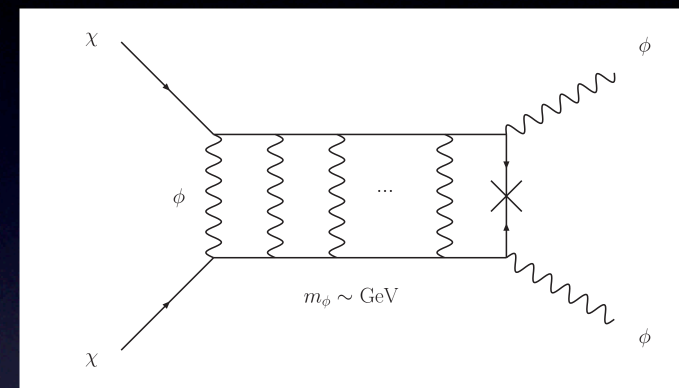
- These signals could be explained by a single new force-carrier that:
  - couples to the SM weakly
  - is unconstrained in its DM coupling
  - is too light to decay into hadronic final states itself (<~1 GeV)

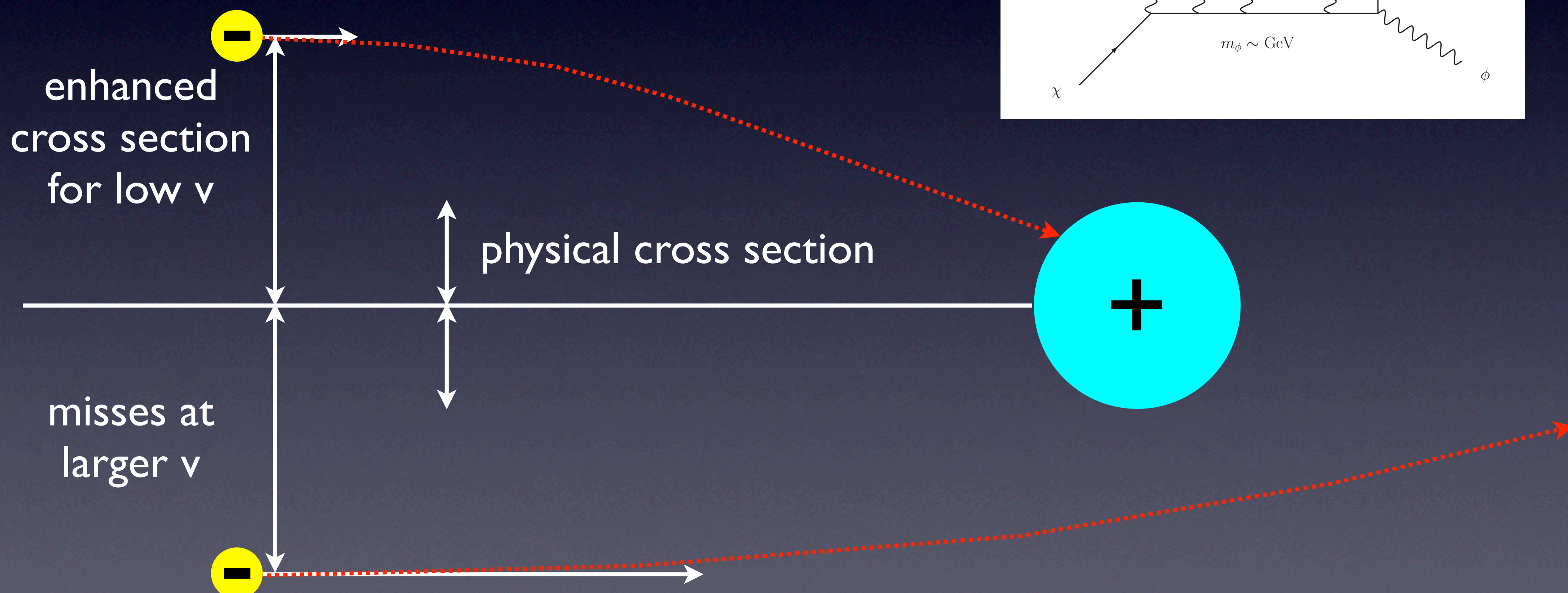




Sommerfeld Enhancement

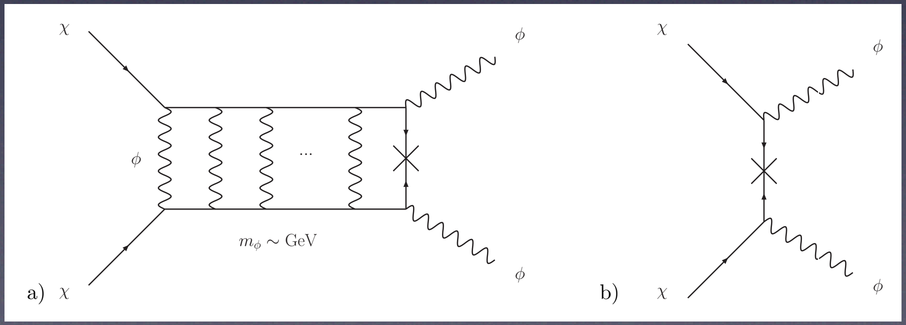
- In attractive potentials, the effective cross section has a velocity-dependent enhancement:



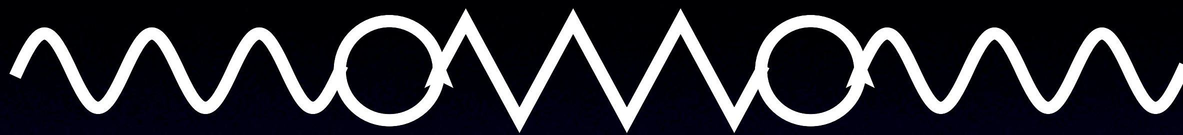


Sommerfeld Enhancement

- During freeze-out, the temperature is too high to see enhancement
- As the DM redshifts to lower temperature, the effect turns on
- Finite A' mass prevents the cross section from running away at extremely low temperature



Relation to Standard Model



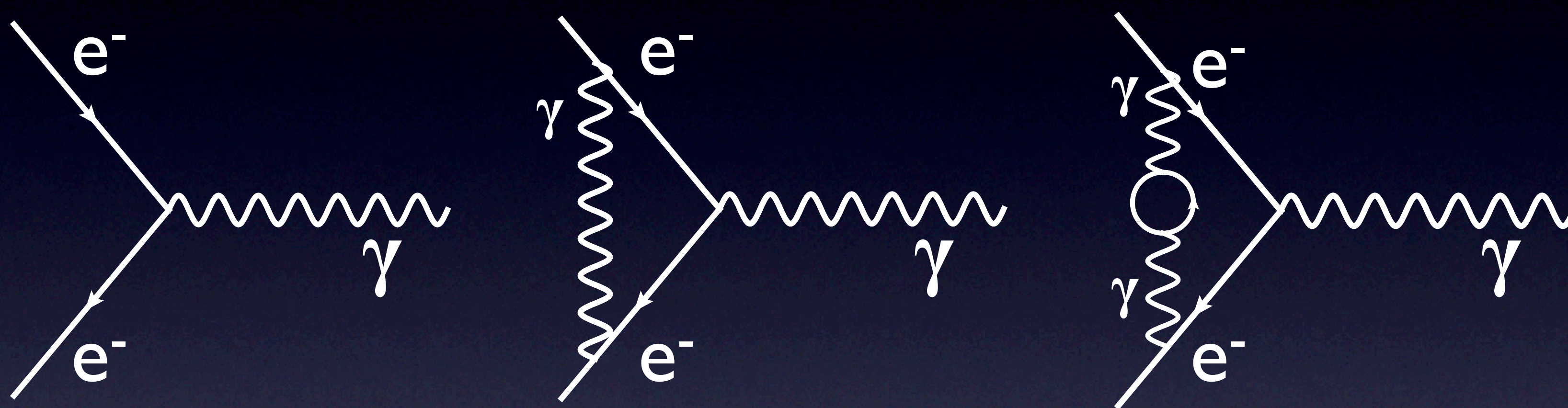
- Couples to standard model by kinetically mixing with the photon
- Shorter, DM-Agnostic motivation: No reason not to write

$$\frac{\epsilon}{2}F_{\mu\nu}F'^{\mu\nu}$$

- Effective coupling is $\alpha' = \epsilon^2\alpha$

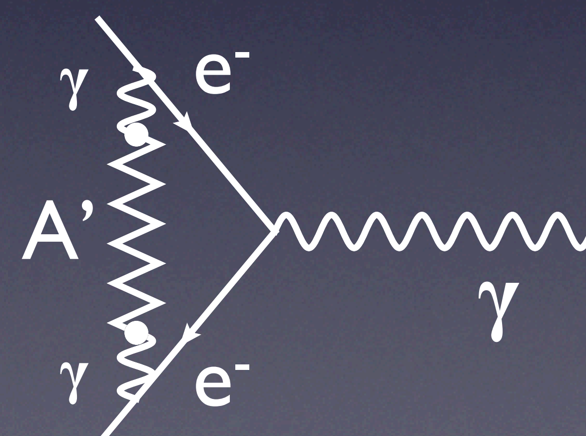
A’ in Magnetic Moments

- g-2 measurements are sensitive to the A’ through higher-order diagrams:



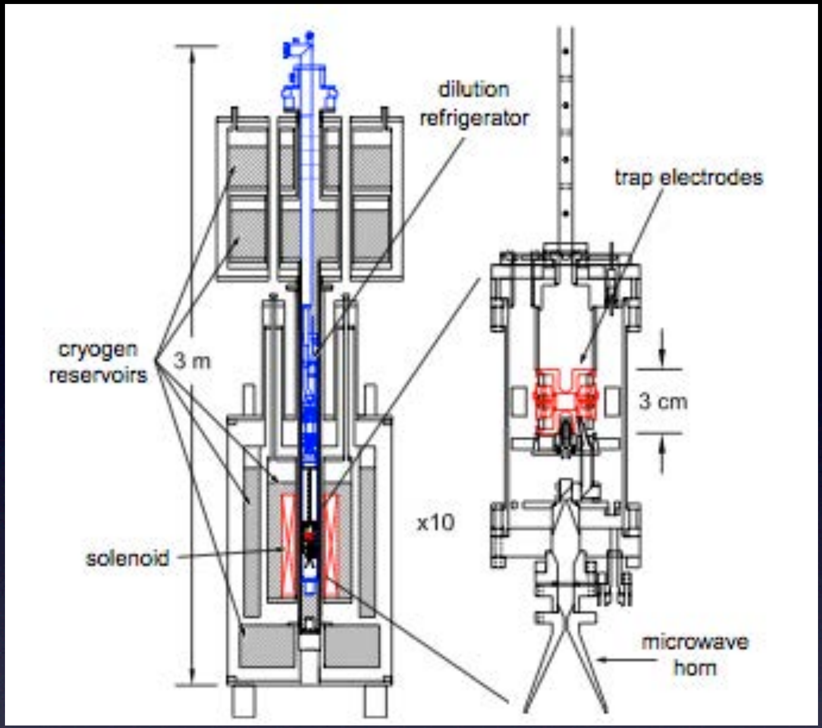
(g-2)= Dirac g=2 + QED terms + Hadronic terms

\+ new physics terms like:



Electron g-2

- Precision measurement of electron g-2 (combined with measurement of alpha via rubidium mass) is in excellent agreement with 10th-order calculations.

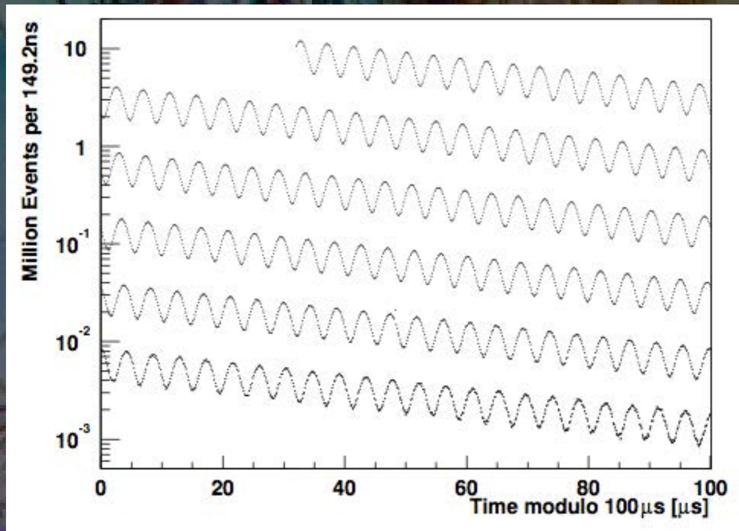


$$a_e(\mathrm{exp}) - a_e(\mathrm{SM}) = -(1.06 \pm 0.82) \times 10^{-12}$$

- Contribution from A' goes like $\mathrm{coupling} \times (\frac{m_e}{m_{A'}})^2$ so this rules out $m_{A'} \sim m_e$

Gabrielse, 2008; Aoyama 2012

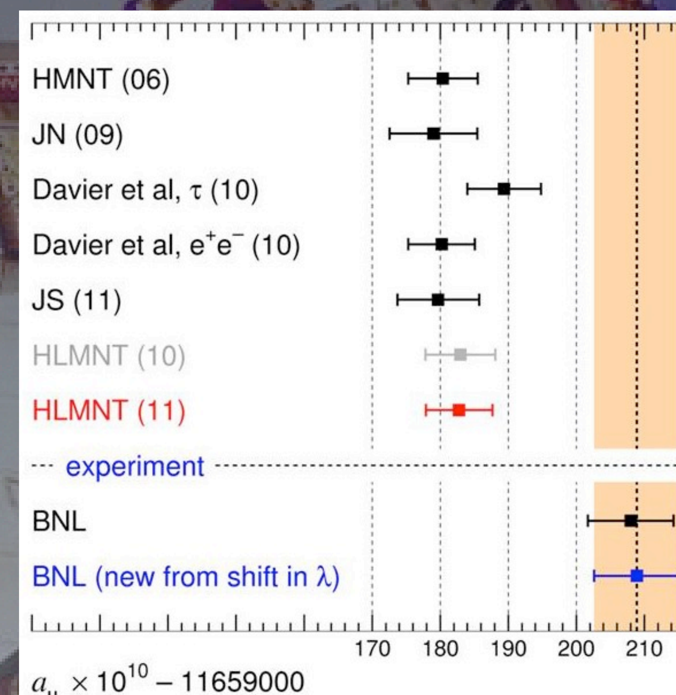
Repeating with Muons



Muons orbit (and precess) in the storage ring until they decay into e+2ν
The resulting electron is emitted in the direction of the muon's MDM

Oscillation frequency ~ g-2

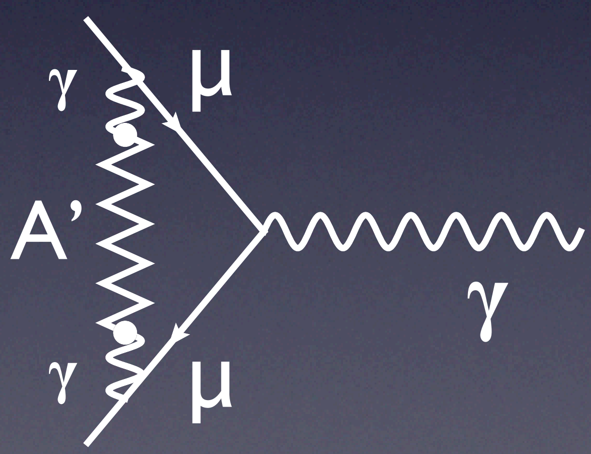
off by 2.7σ from SM prediction

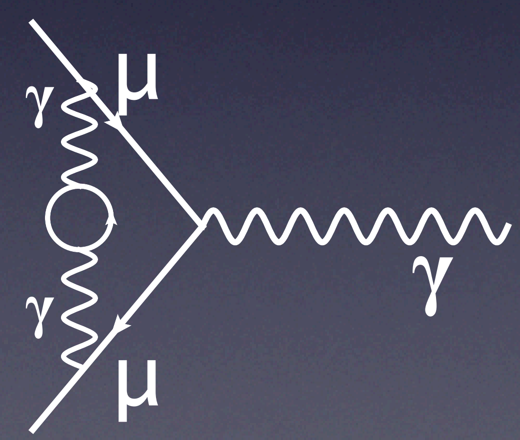


E821

Repeating with Muons

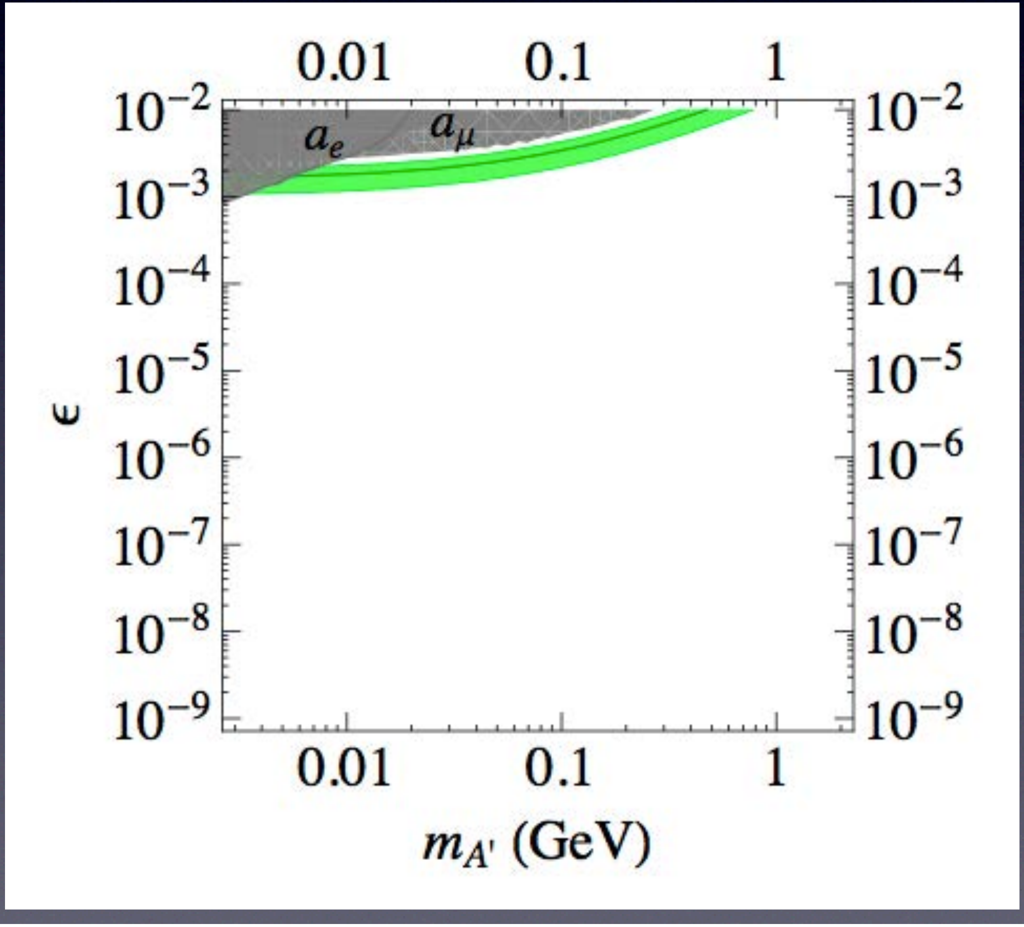
- The A' loop diagram could explain this -- in that sense, the g-2 discrepancy is a positive constraint on the A' mass and coupling!*
- *(but hadronic components are hard to calculate)





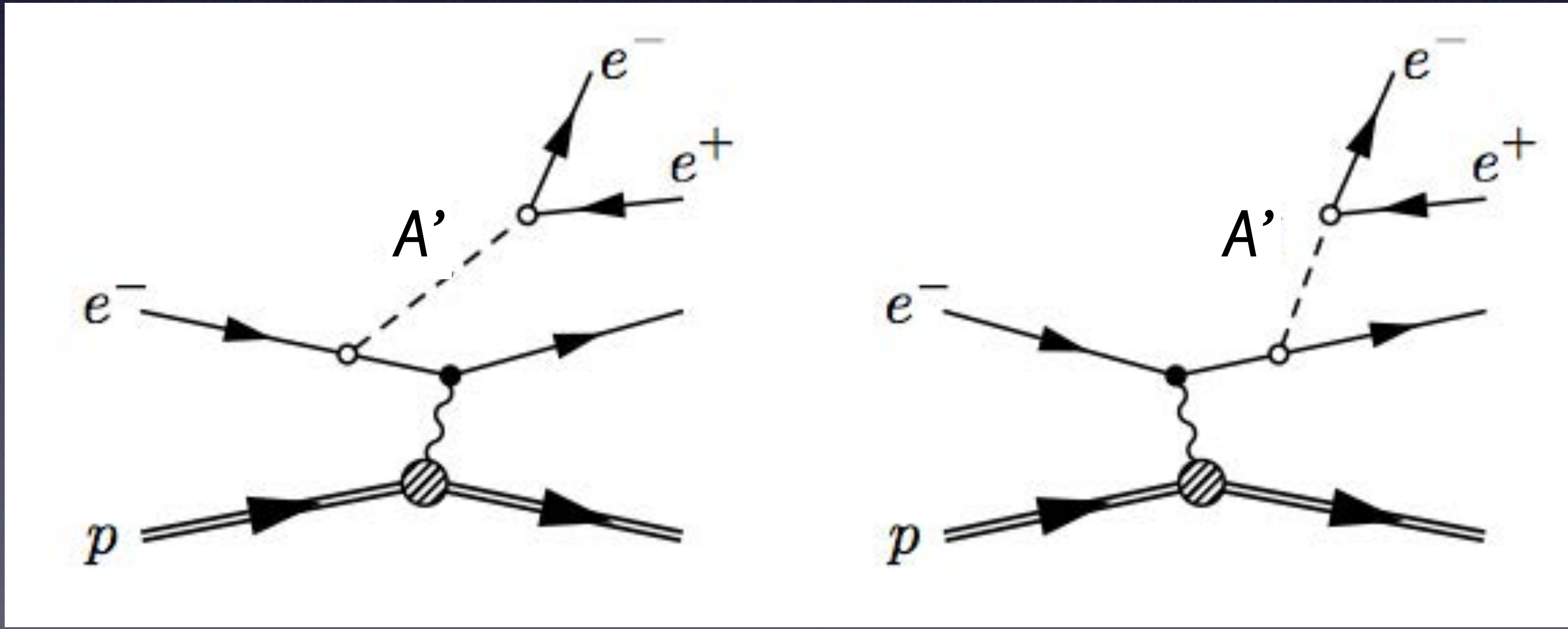
A’ Parameter Space

- Cosmic rays set the region of interest
- The g-2 measurements set an exclusion, and a sub-region of even higher interest:



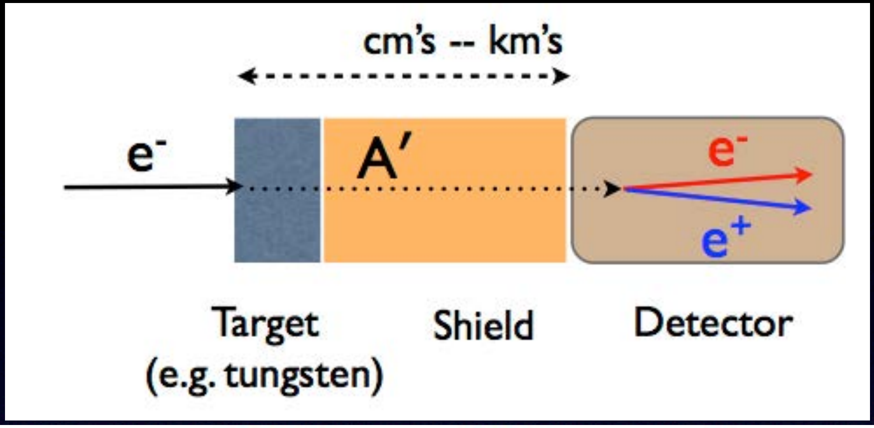
Producing the Dark Photon

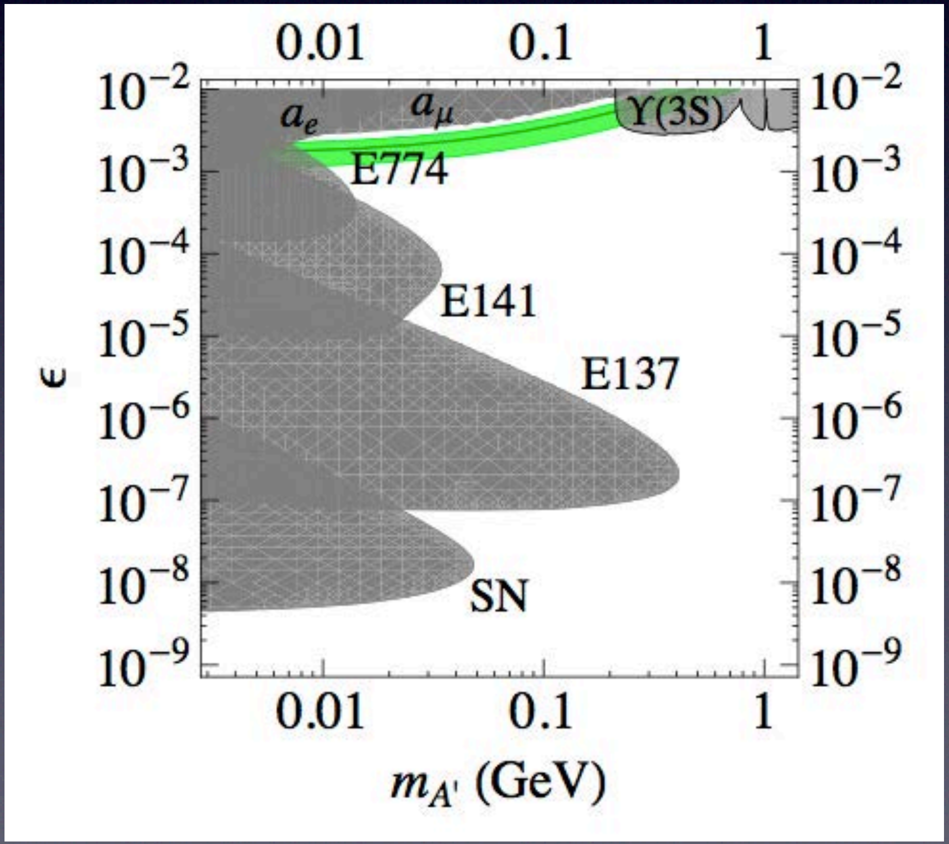
- Via kinetic mixing, we should be able to produce A' in any charged collision
- Mixing also means SM decays (e^+e^- or others, depending on mass)



Beam Dump Constraints

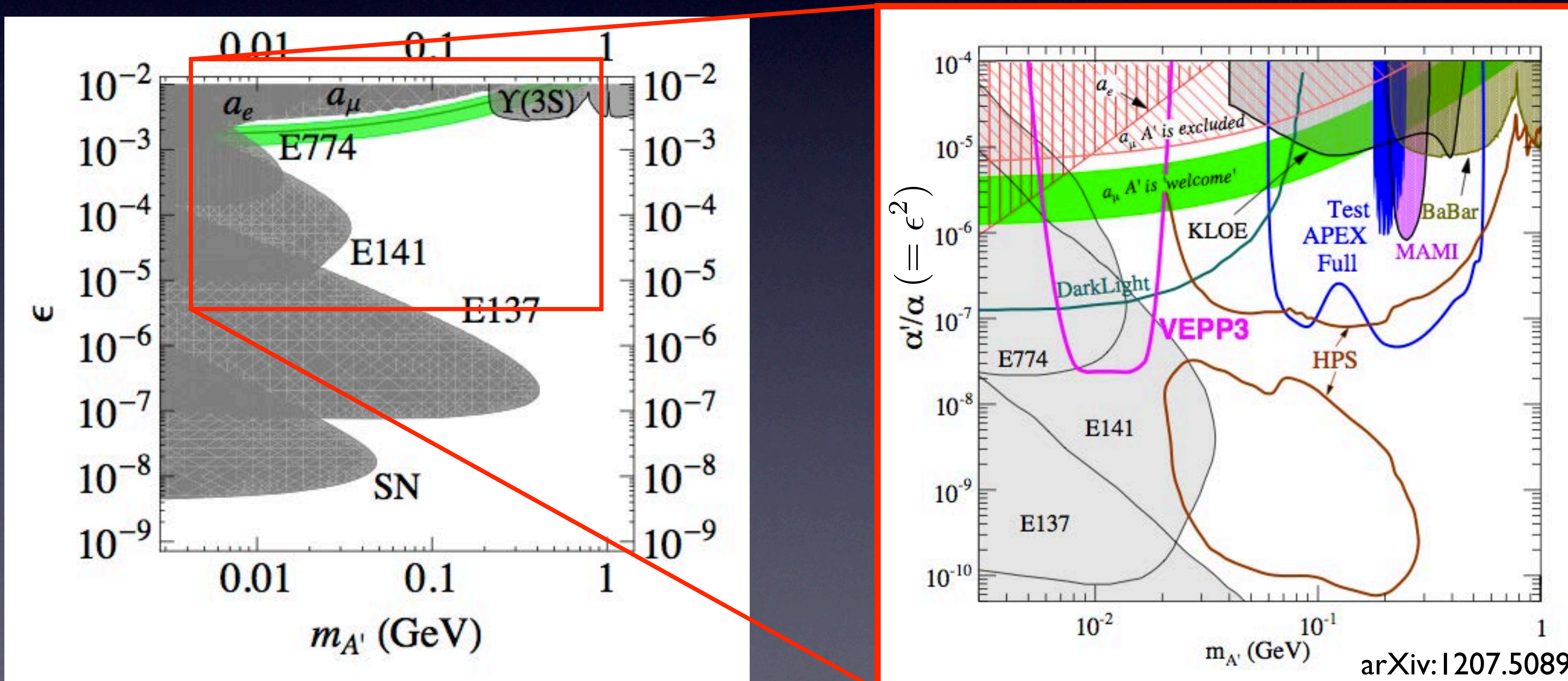
- Look for resonant peak in the inv. mass of e+e- pairs appearing after a thick shields.
- More shielding = less background but smaller coupling
- Supernova cooling also constrains





Hunting for Light Dark Light

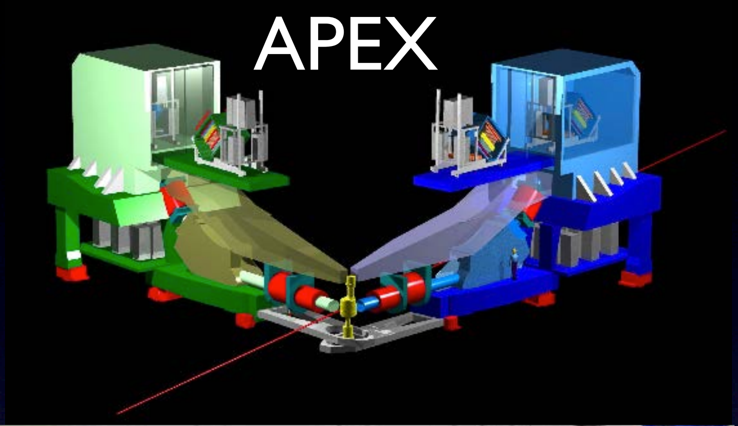
- Larger coupling = smaller lifetime
- Thin, fixed targets are viable:
  HPS, APEX, DarkLight; MAMI; VEPP-3

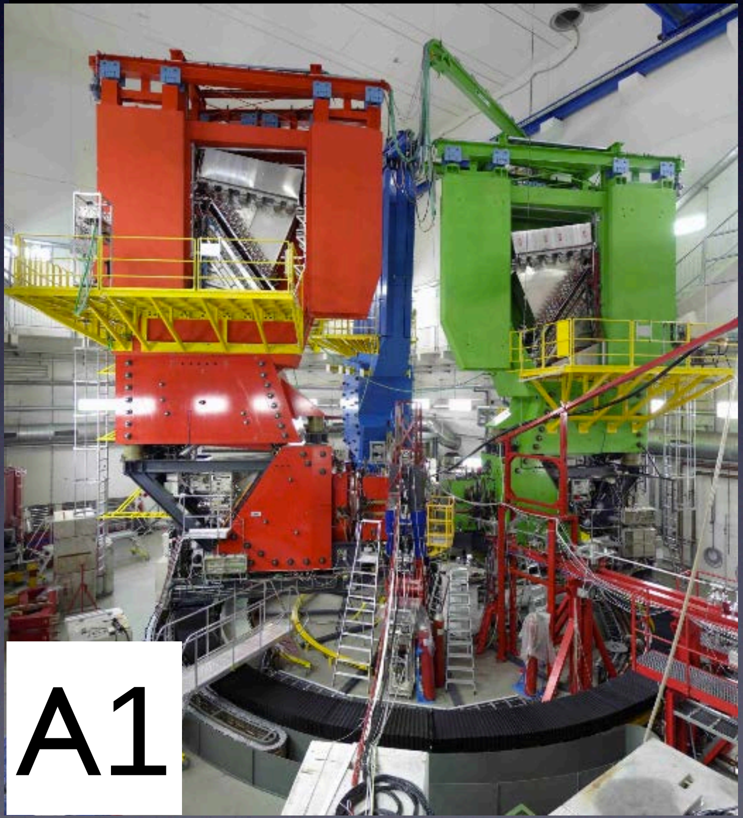


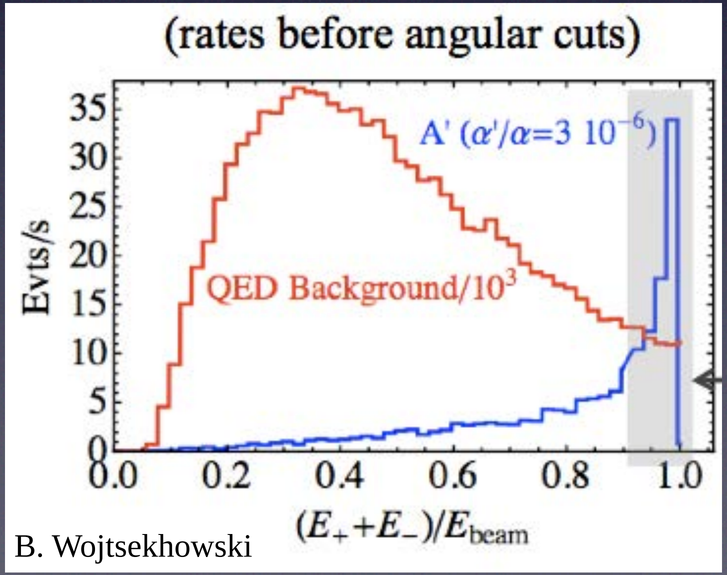
arXiv:1207.5089

APEX and A1

- Thin tantalum target
- Spectrometers for e^+e^- pairs
- Partial kinematic separation
- Preliminary runs completed for $m_{A'} \sim 250$ MeV

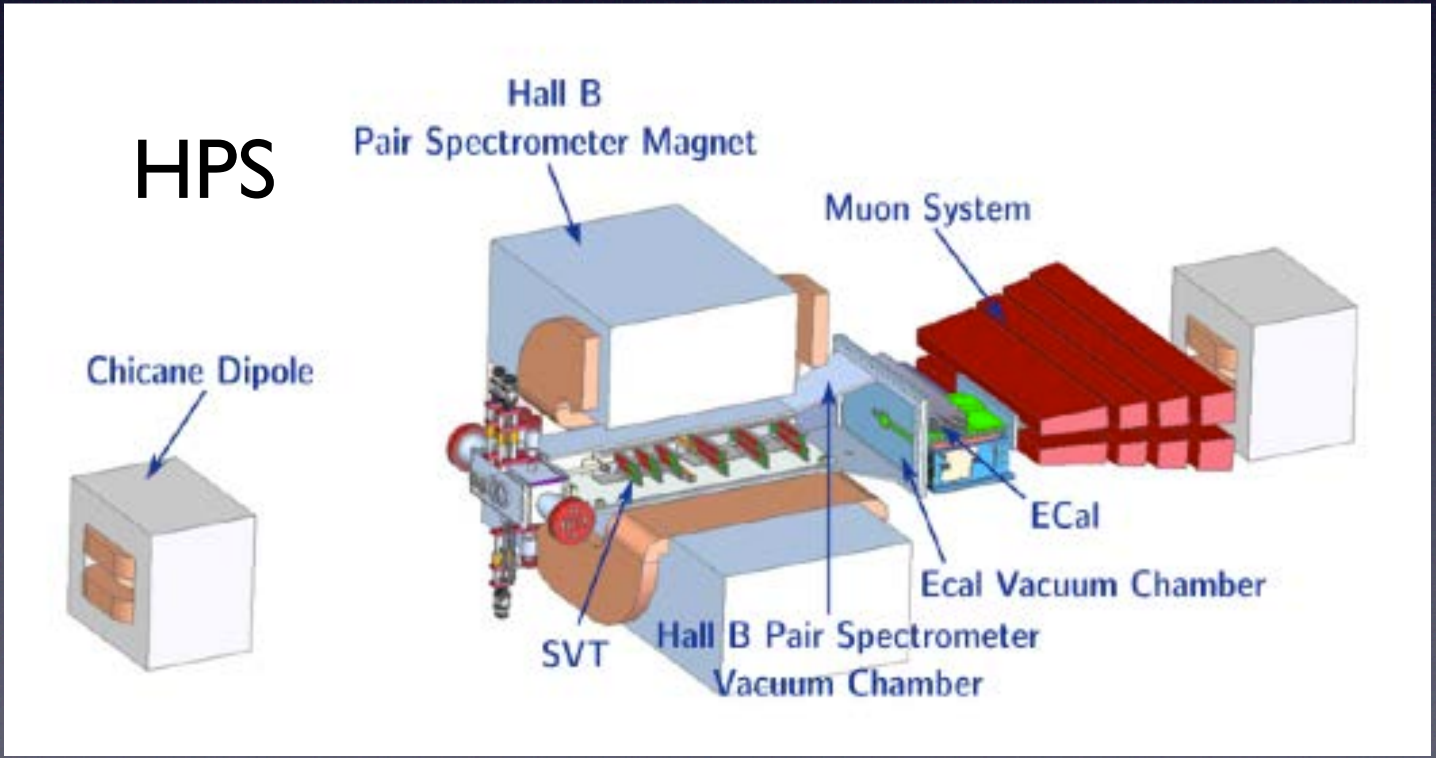






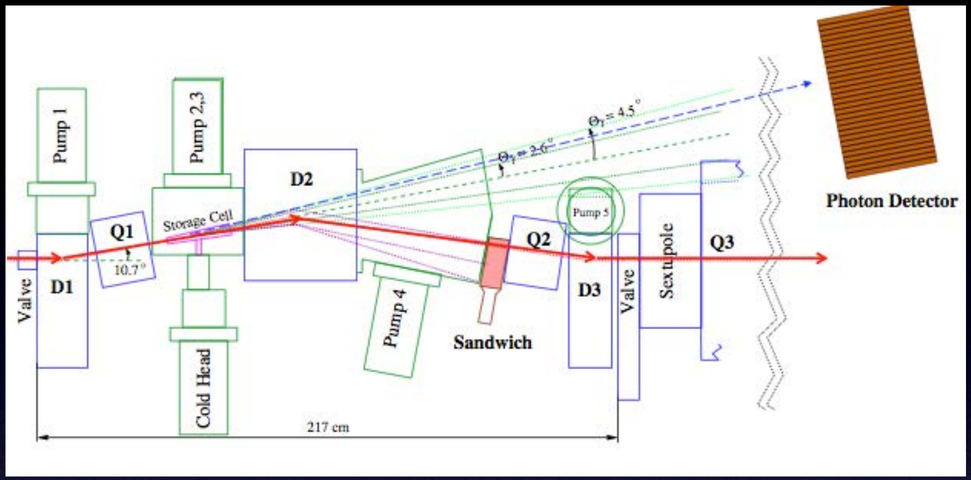
HPS

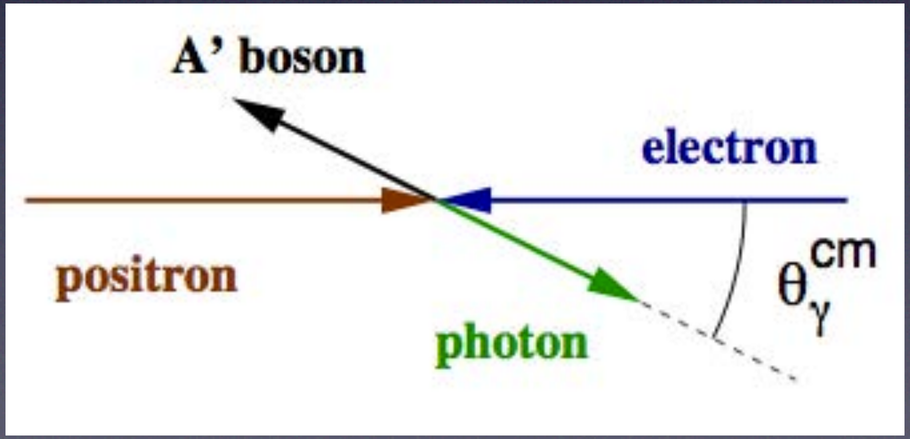
- Thin tungsten target
- e^+e^- and $\mu^+\mu$- pairs at small angles
- Invariant mass and displaced vertex search

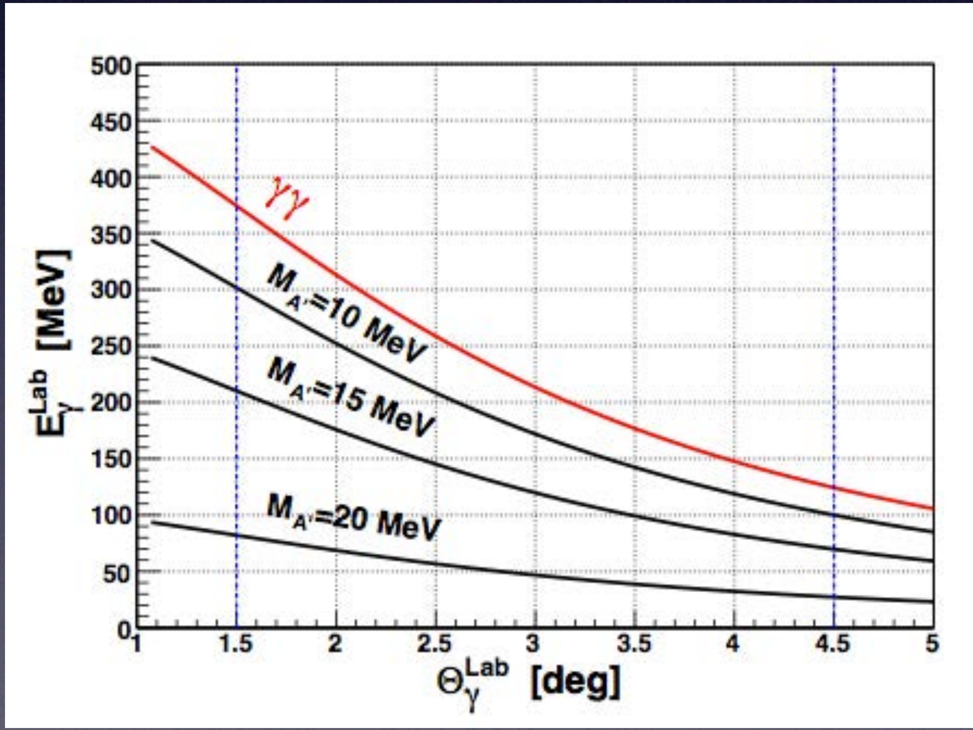


VEPP-3

- e^+e^- annihilation with e^+ beam
- A' event modifies energy of photon
- A' decay not needed







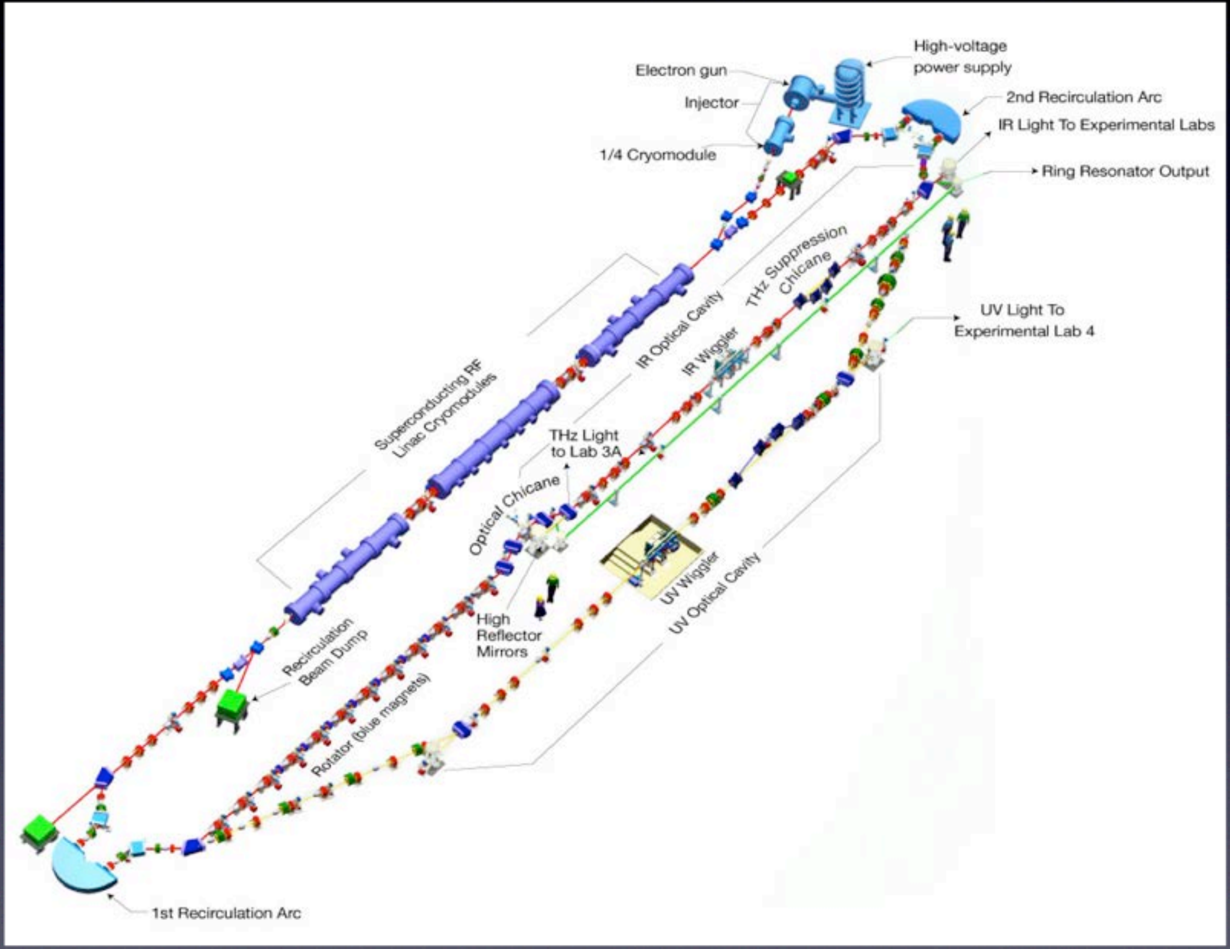
DarkLight Concept

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

- High intensity electron beam on dense gas target to overcome small coupling (~ab^{-1}/mo)
- At 100 MeV to rule out hadron production
- With solenoid and tracking for complete reconstruction of final state

Free Electron Laser (FEL)

- Free Electron Laser at JLab generates intense laser beams, from intense electron beams in its Energy Recovering Linac: 6×10^{16} e^-/s at 100 MeV 10 mA = 1 MW

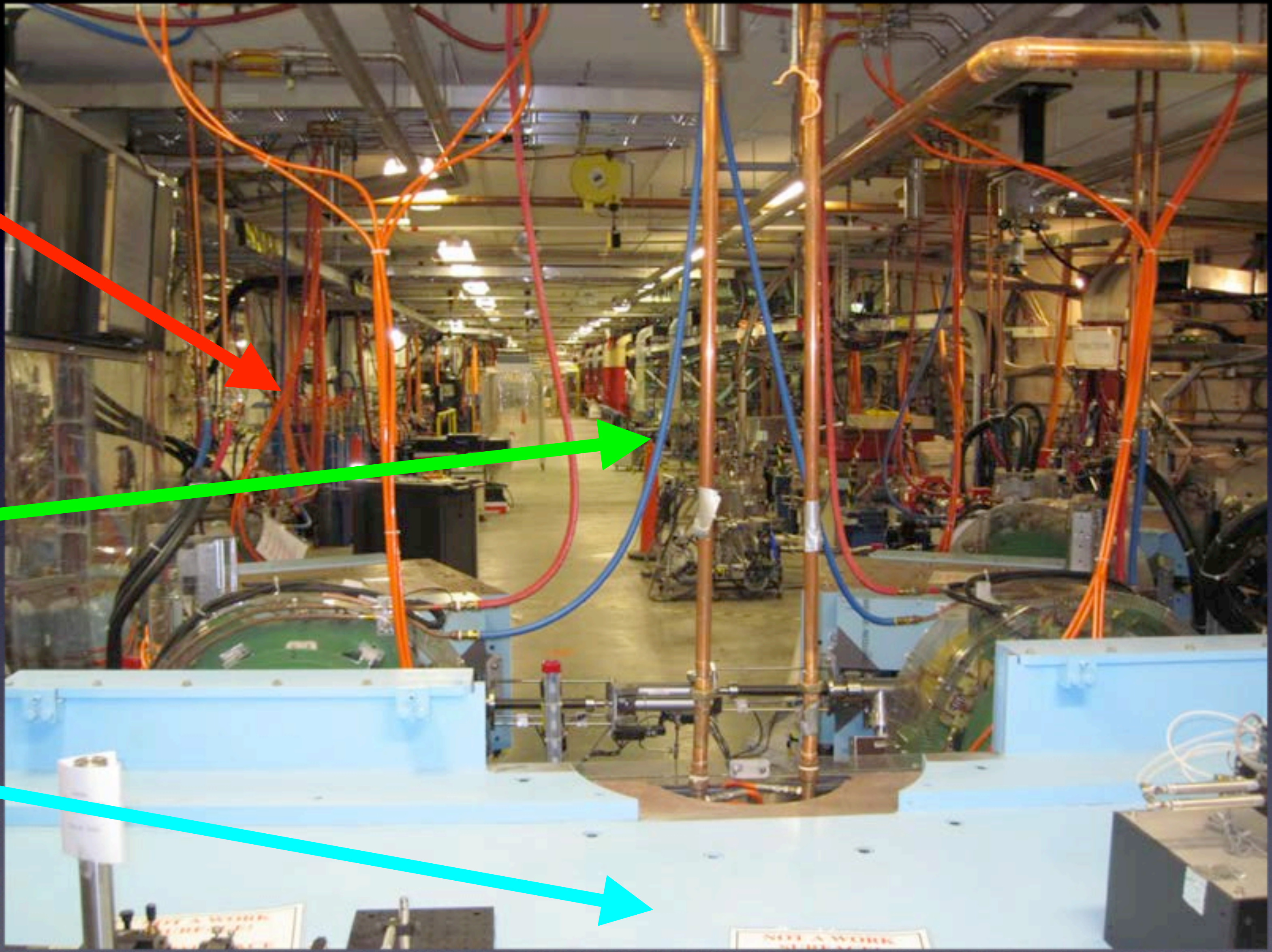


FEL Tour

Infrared FEL

RF Cavities

180° Dipole



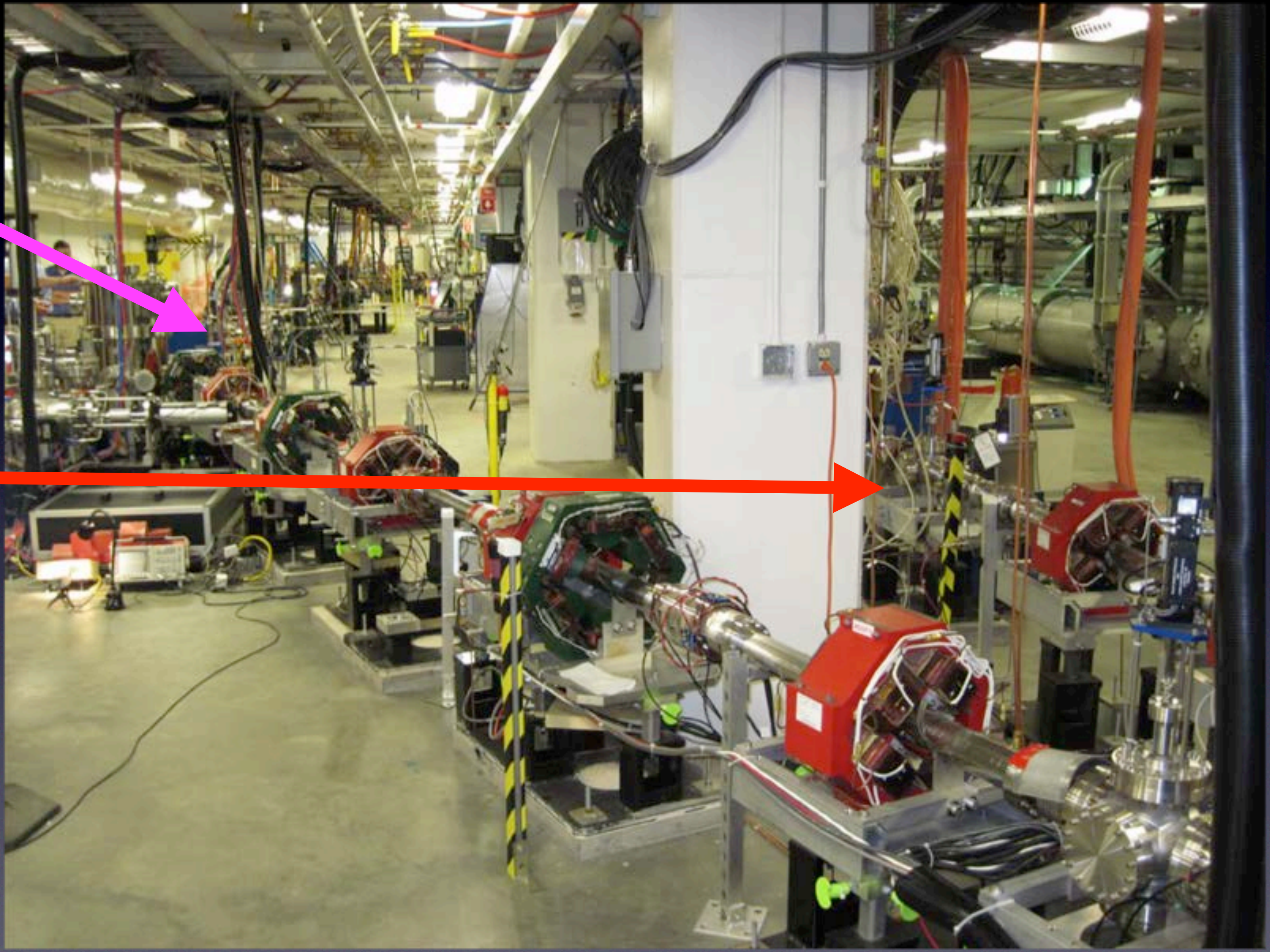
FEL Tour

The Energy
Recovering Linac

FEL Tour

Ultraviolet FEL
(produced from the 100 MeV electron beam)

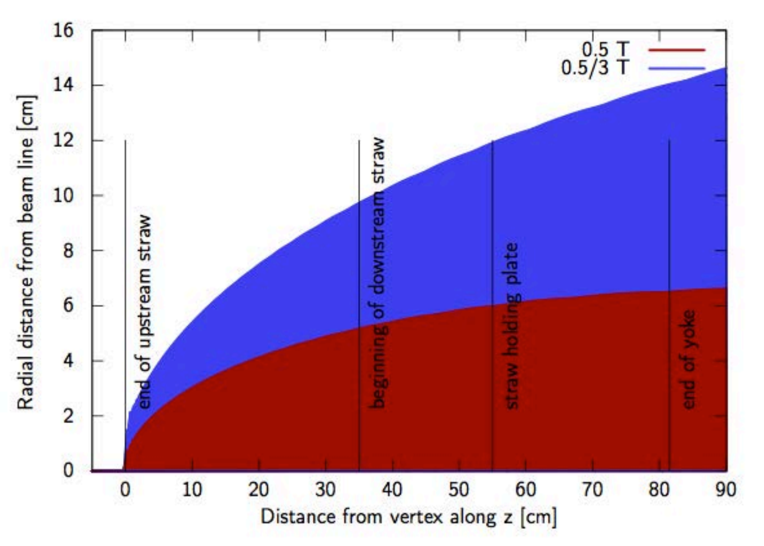
Infrared FEL



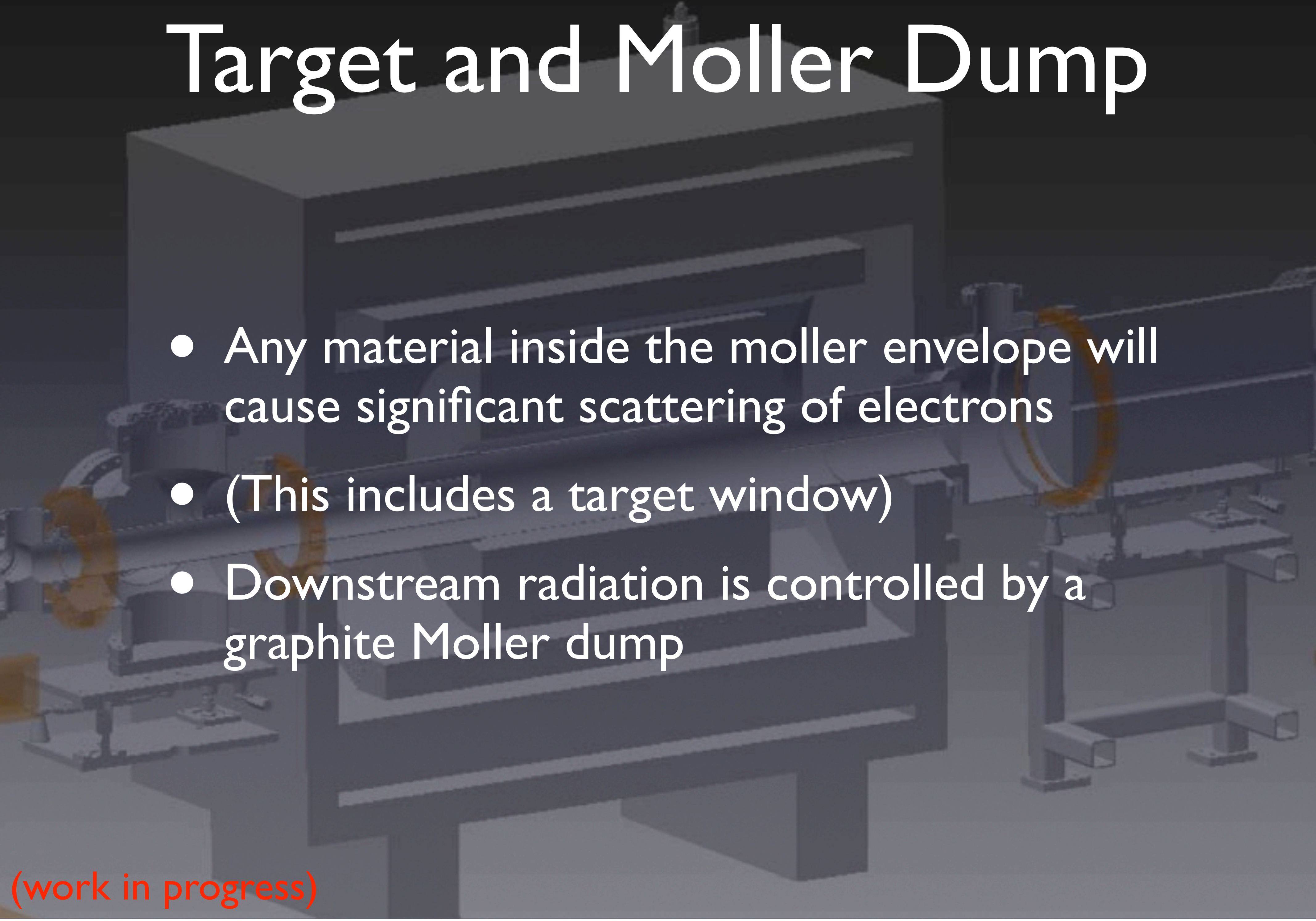
Handling 100 MeV Electrons

"You cannot collimate electrons, you can only make them angry"

- Electrons are likely to scatter off surfaces they encounter
- Moller scattering creates a cone of forward electrons that need to be avoided
- Even large-angle elastic scattering occurs at high rates



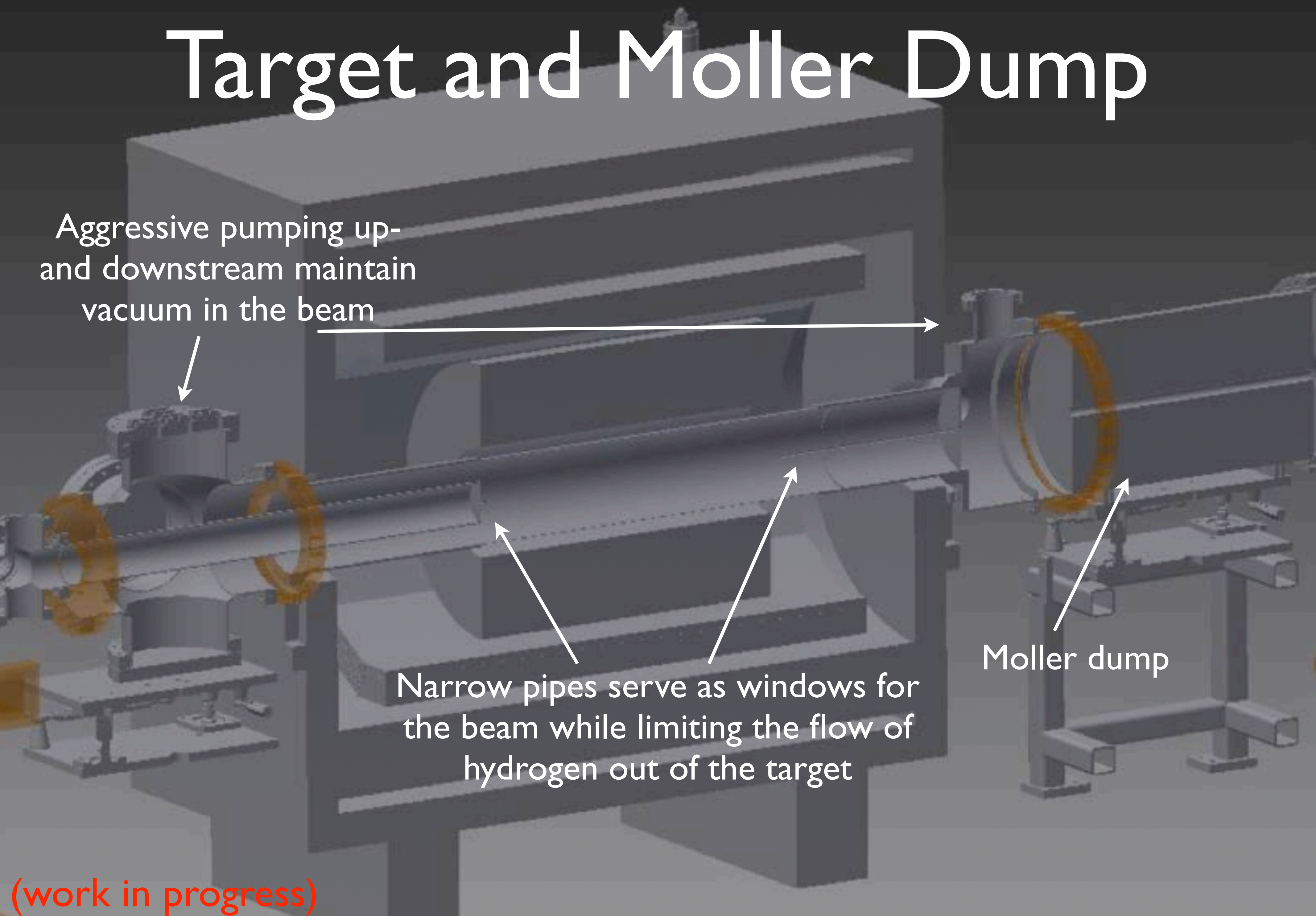
Target and Moller Dump



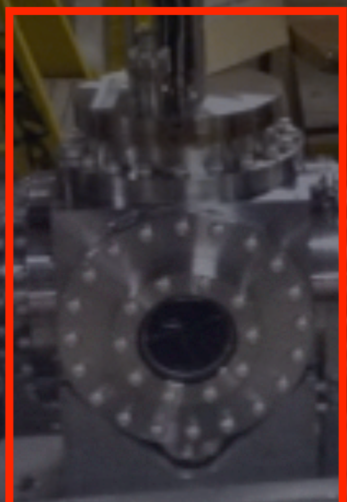
- Any material inside the moller envelope will cause significant scattering of electrons
- (This includes a target window)
- Downstream radiation is controlled by a graphite Moller dump

(work in progress)

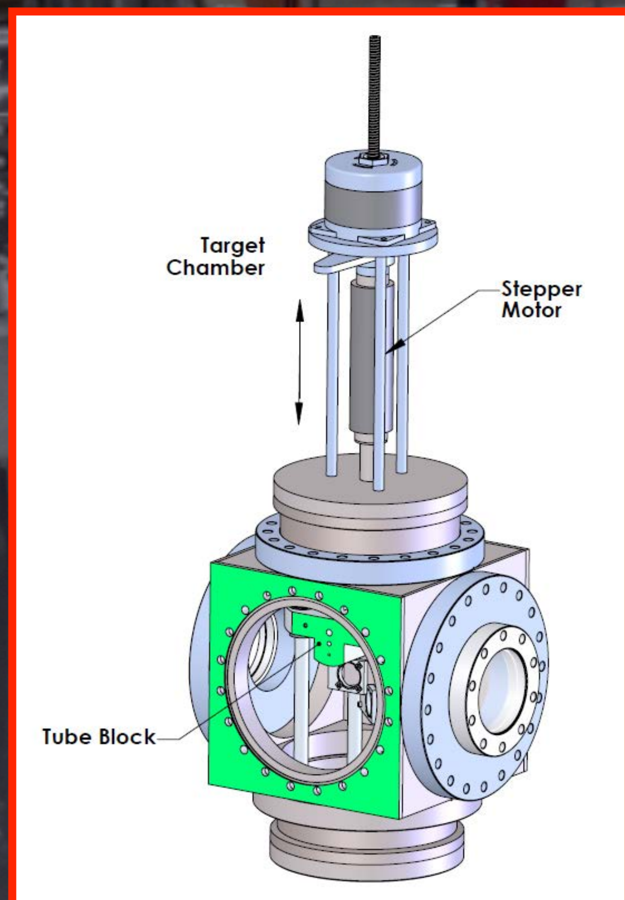
Target and Moller Dump

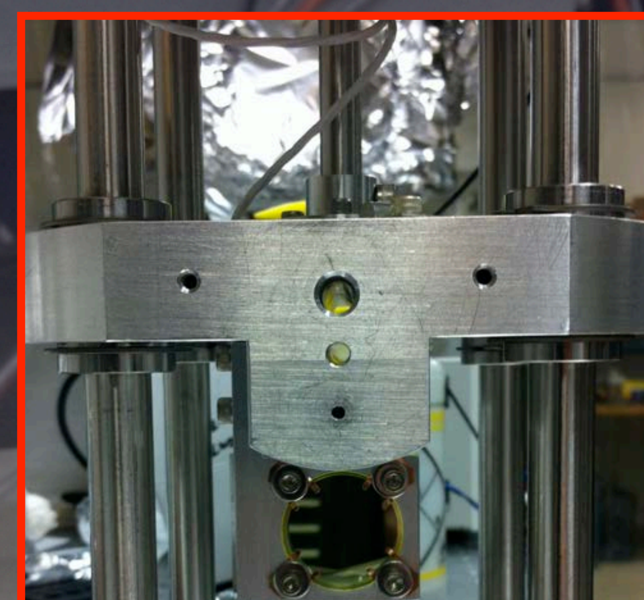


Beam Tests



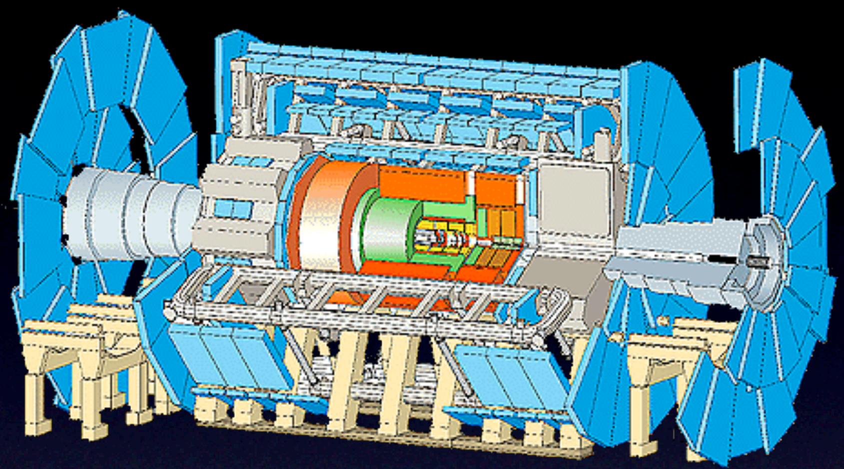
- Show beam can pass through 2mm aperture
- Characterize radiation backgrounds
- Verify trackers can operate in that environment



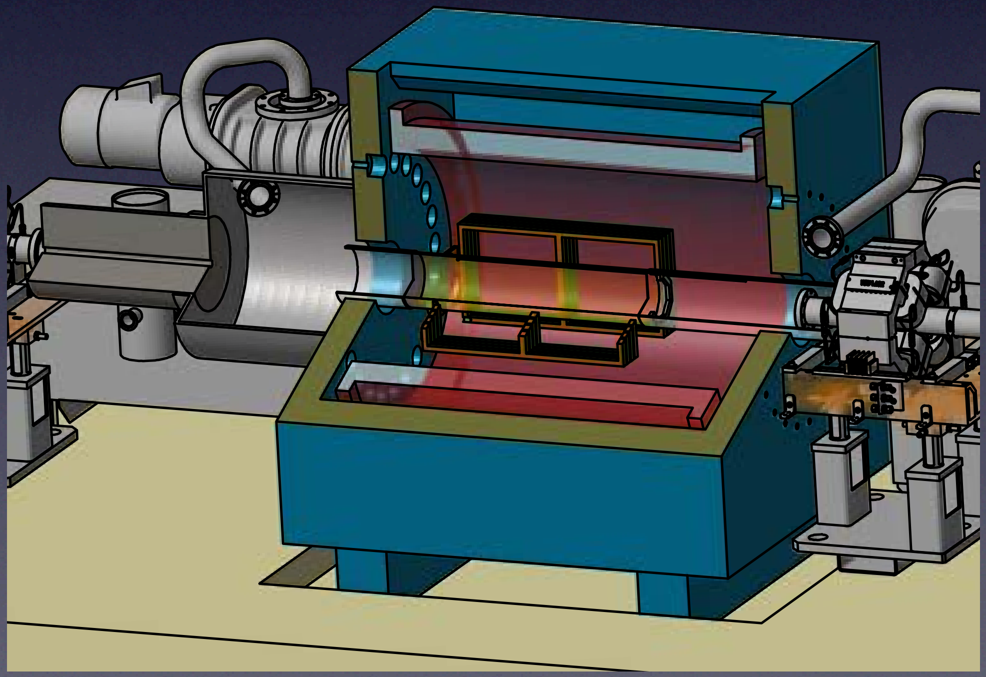


Comparing Design

ATLAS

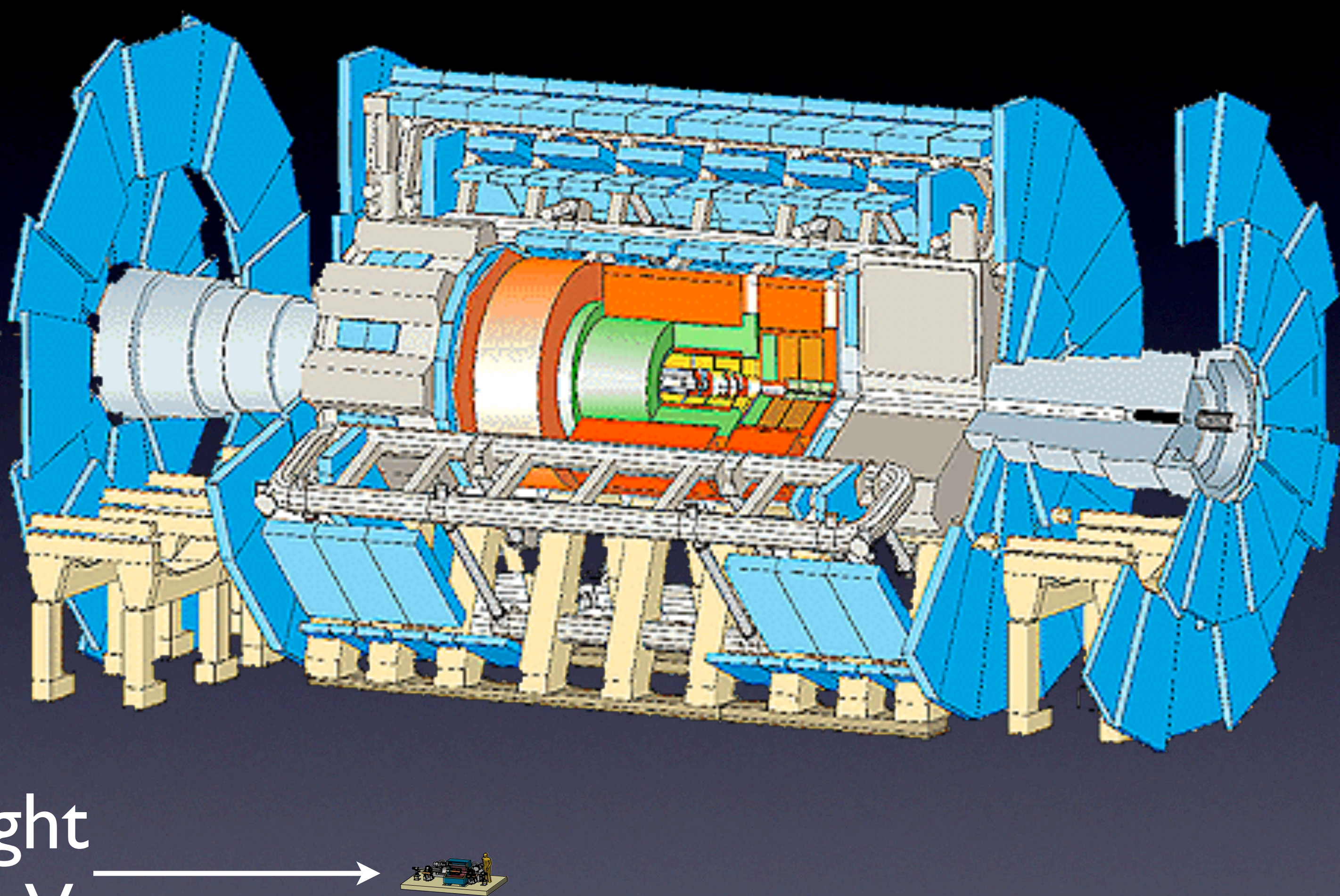


DarkLight



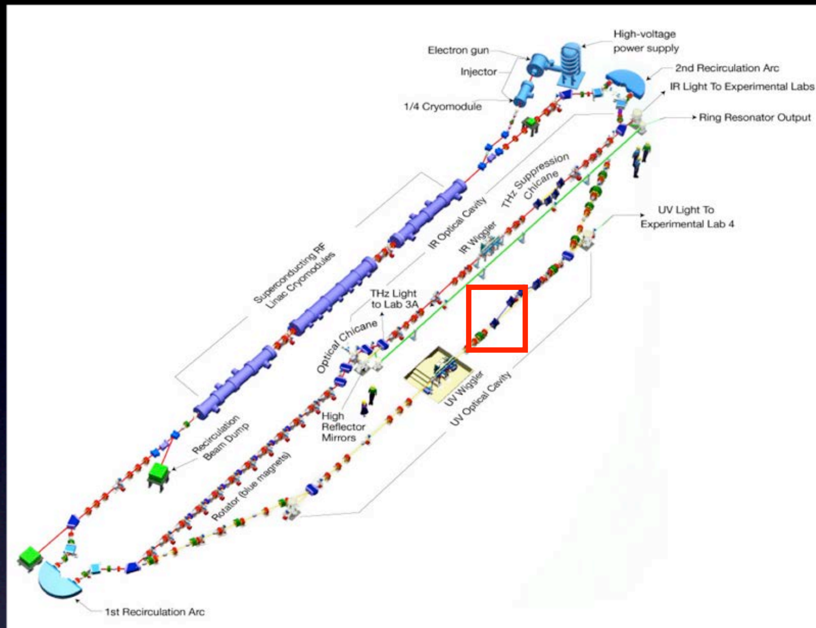
(work in progress)

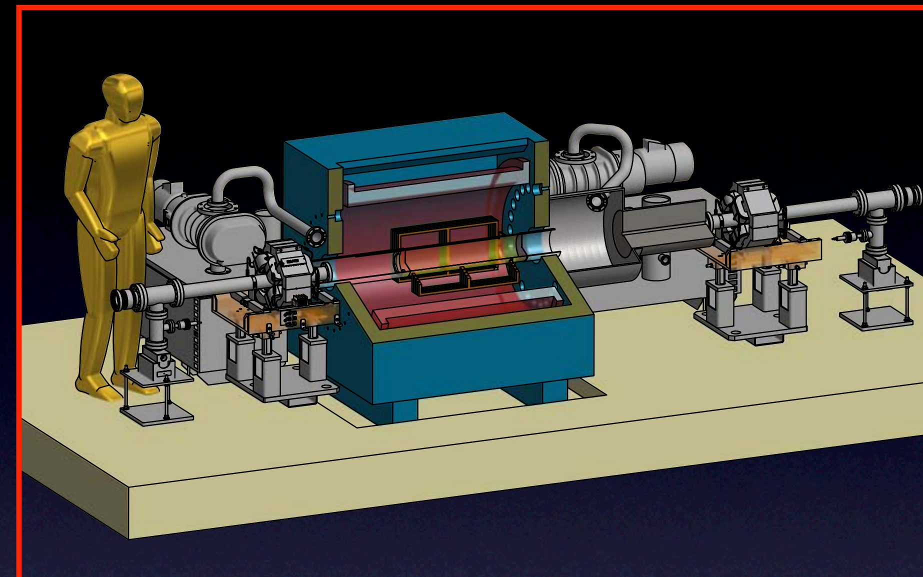
Comparing Design



(work in progress)

DarkLight Detector



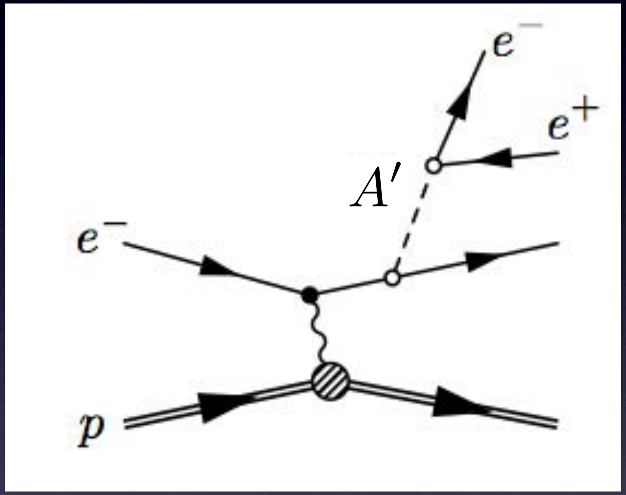


Complete reconstruction of the final state:

- Proton Detector to register recoil proton
- Lepton Tracker + Magnet to reconstruct momenta and sign of electrons
- Photon Calorimeter to measure photon (and hence missing) energy

(work in progress)

Basic Analysis

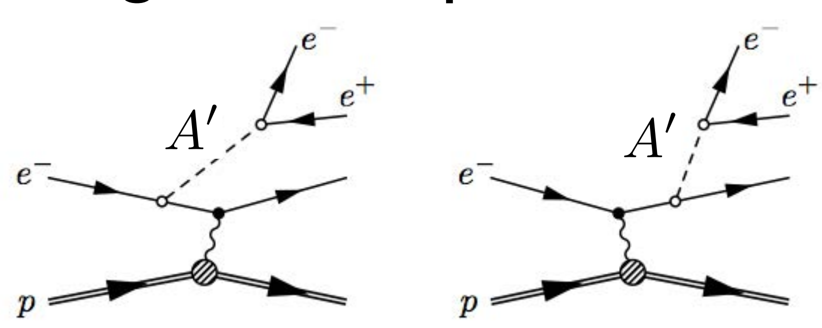


Look for collisions that send two electrons and one positron into the tracker

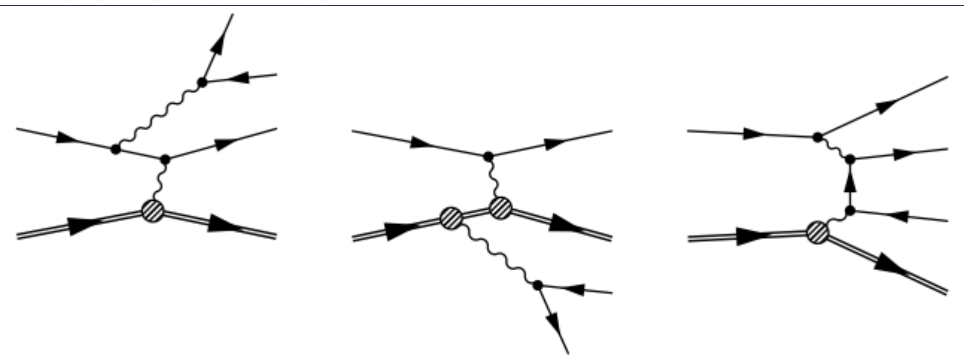
Calculate the mass of the electron-positron pairs

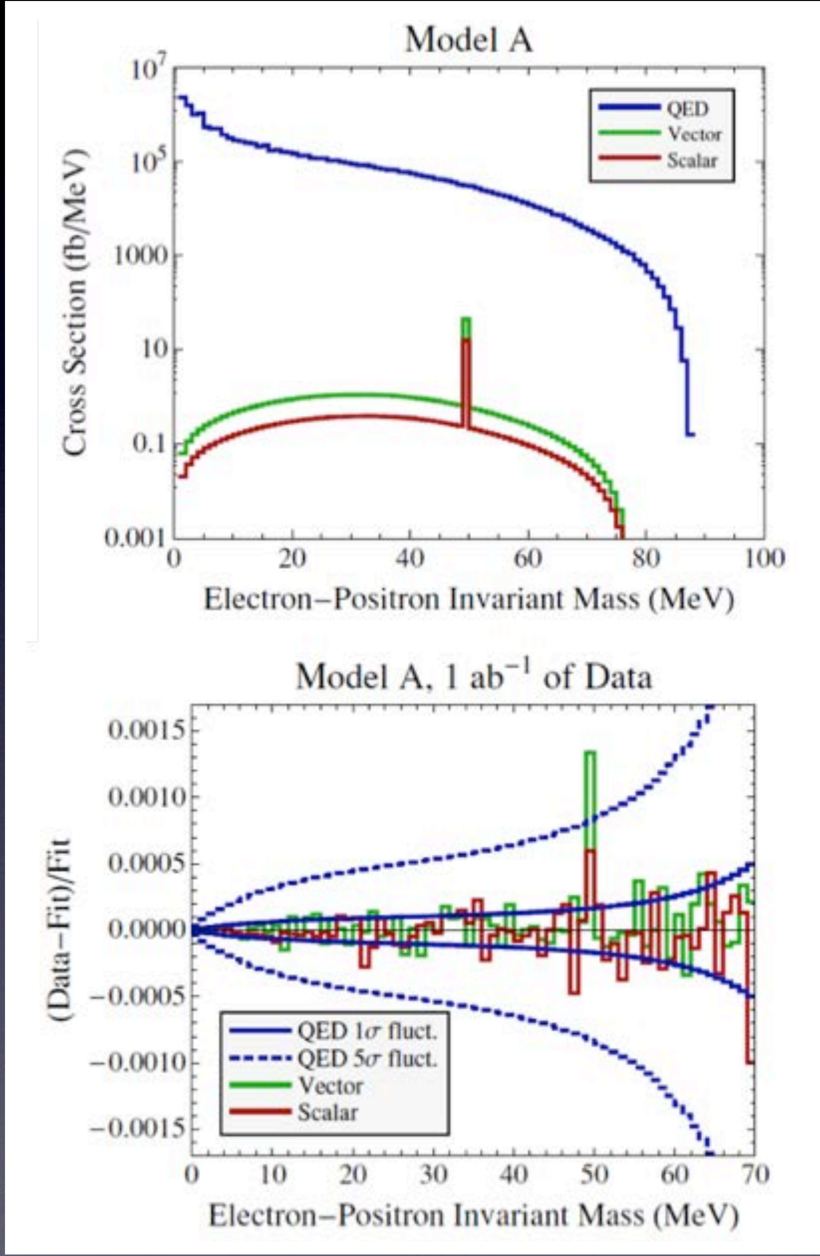
Simulated Signals

Signal $e^-e^-e^+$ processes



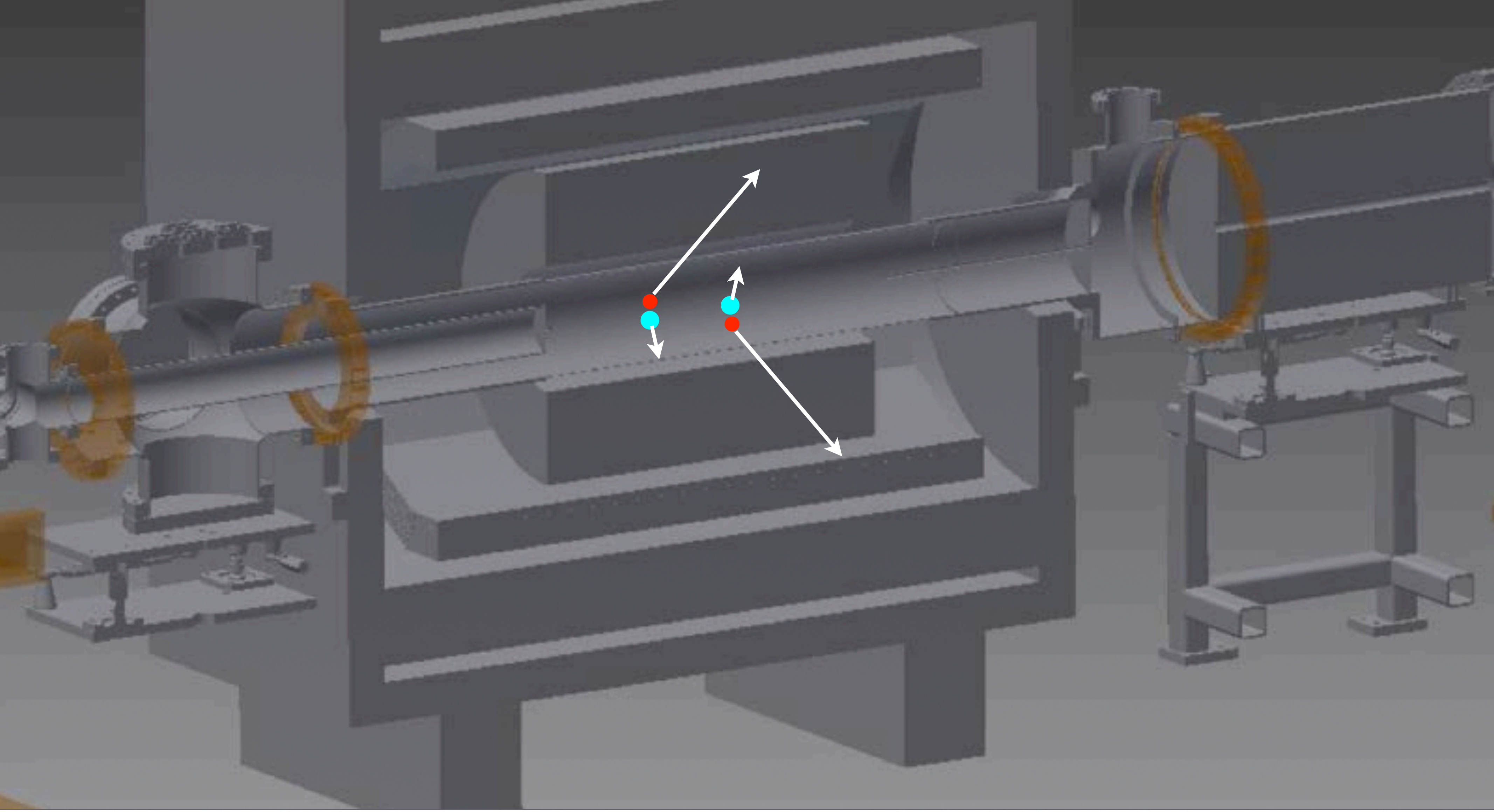
Background $e^-e^-e^+$ processes





Why Protons?

High rate of $ep \rightarrow ep$ x2 (and others)



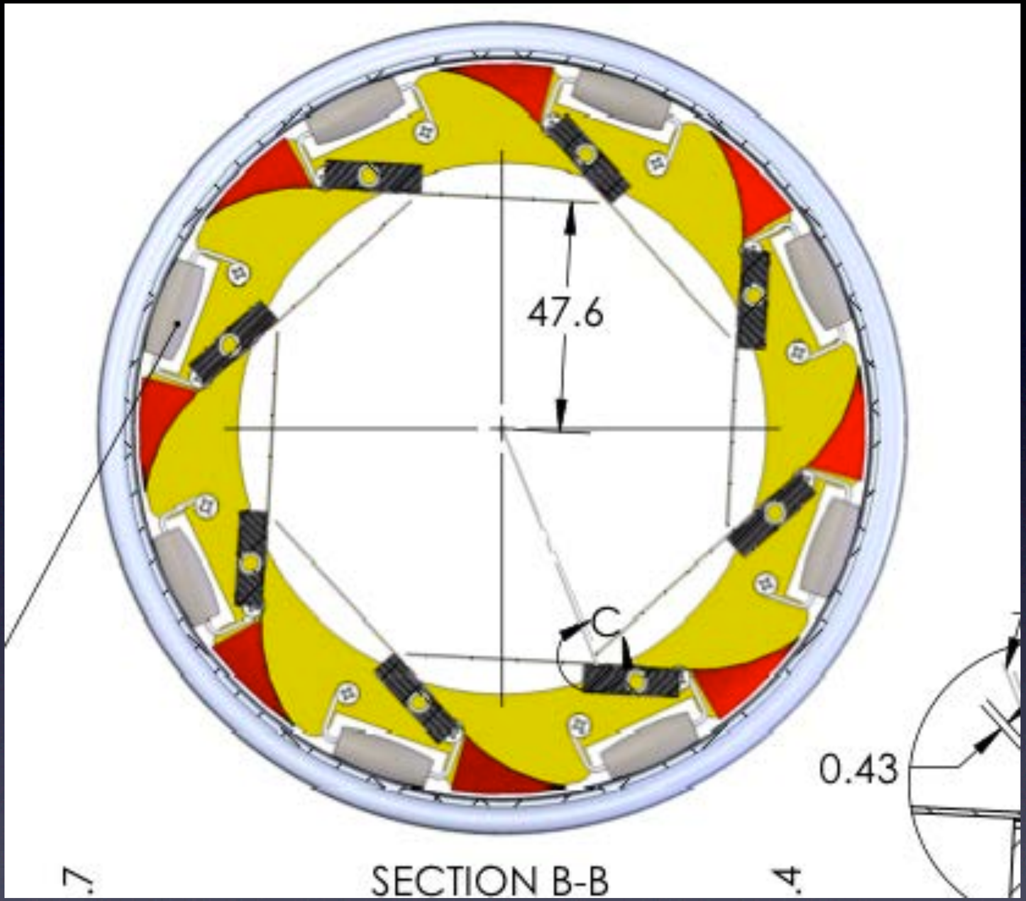
Proton Detector Design

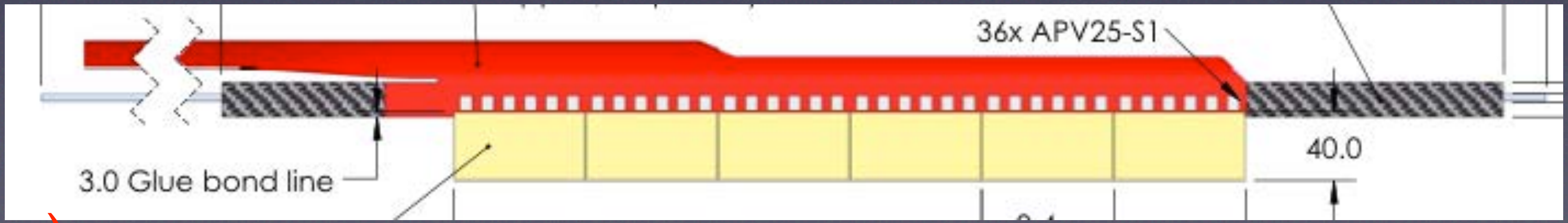
Overarching goal: Capture large fraction of recoil protons

- must be inside target chamber -- protons won't readily go through the wall
- want very low mass -- otherwise electrons will be scattered
- want high sensitivity -- protons will carry very little kinetic energy

Proton Detector Design

- Thin silicon active area
- Minimal dead material
- Provides overconstraint

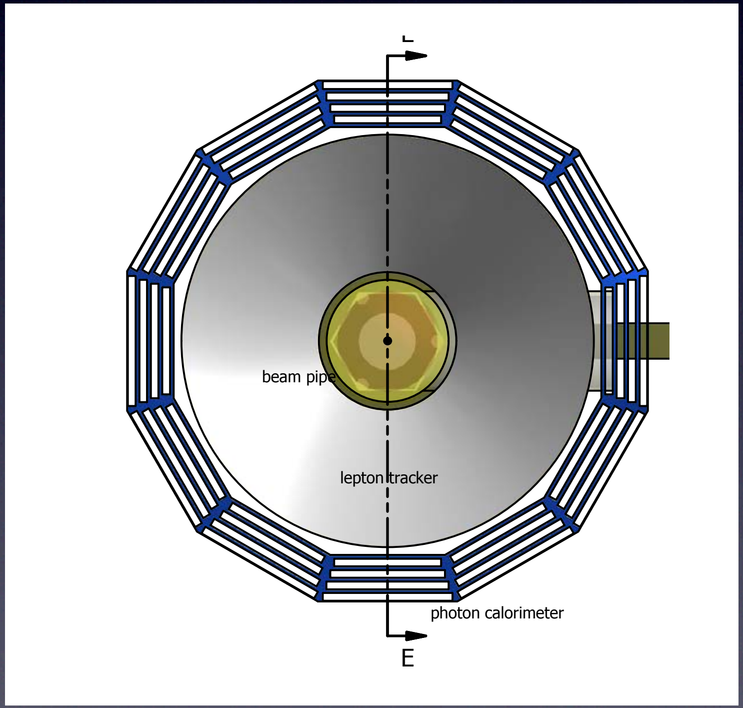


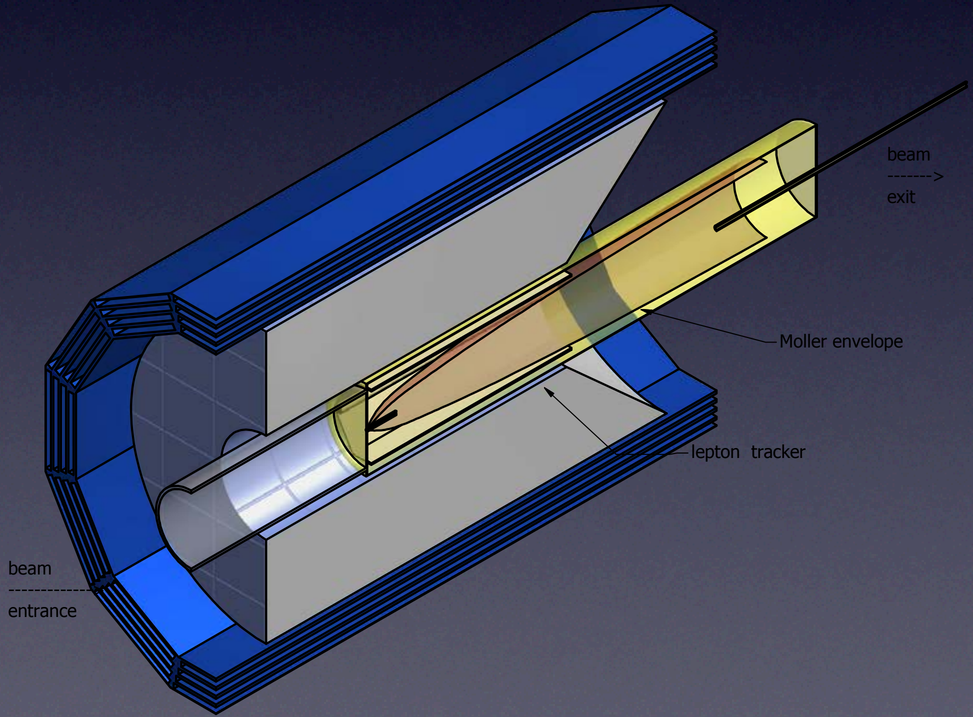


(work in progress)

Photon Detector Design

- Lead+scintillator sampling calorimeter
- Provides photon veto





(work in progress)

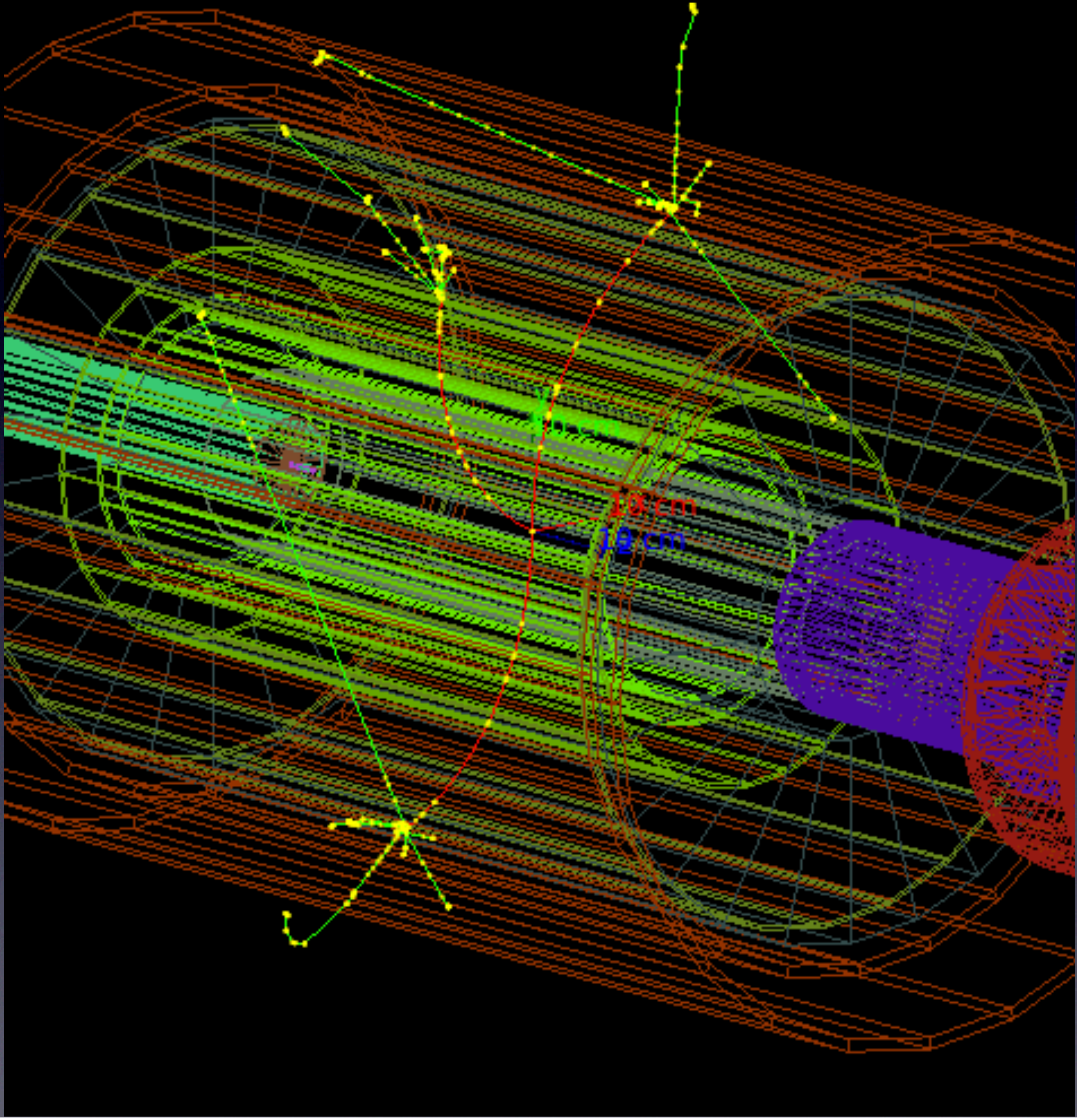
Lepton Tracker Design

Overarching goal: Optimize momentum resolution

- want large lever arm, but low pt must be reconstructed
- want very low mass -- multiple scattering will randomize tracks
- want very fast timing -- longer ghosting increases pile-up and complicates track-finding

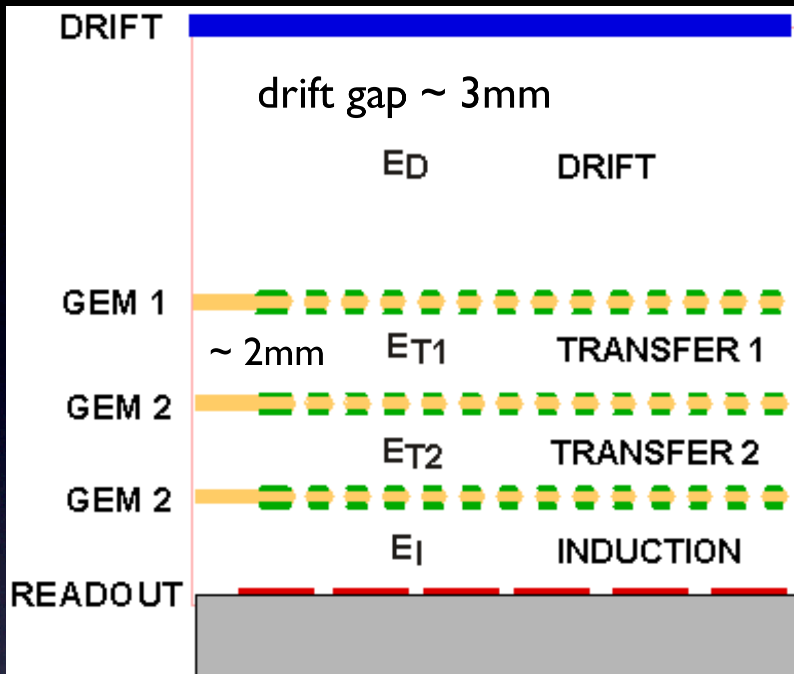
Lepton Tracker Design

- Four layers of lepton tracking (green)
- Strong curvature in 0.5 T solenoid



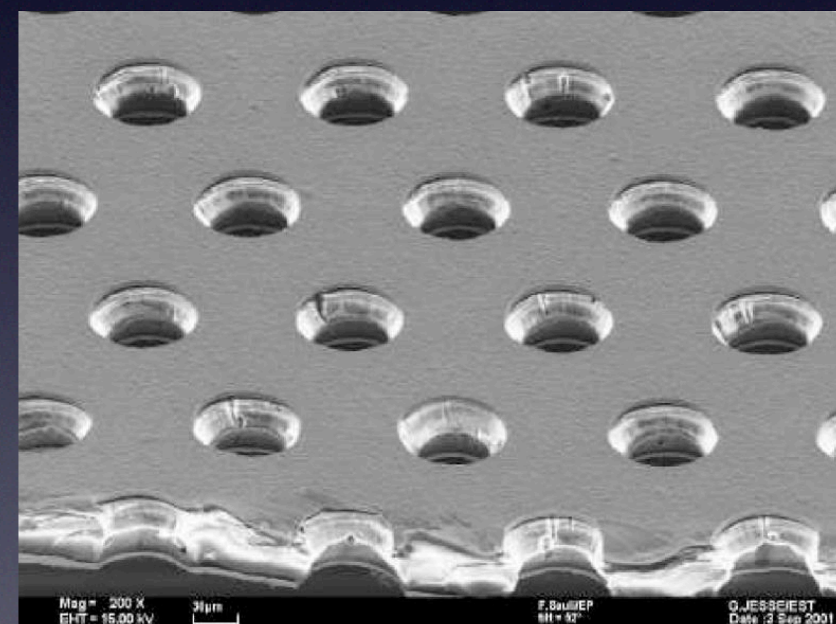
(work in progress)

Triple-GEM Design



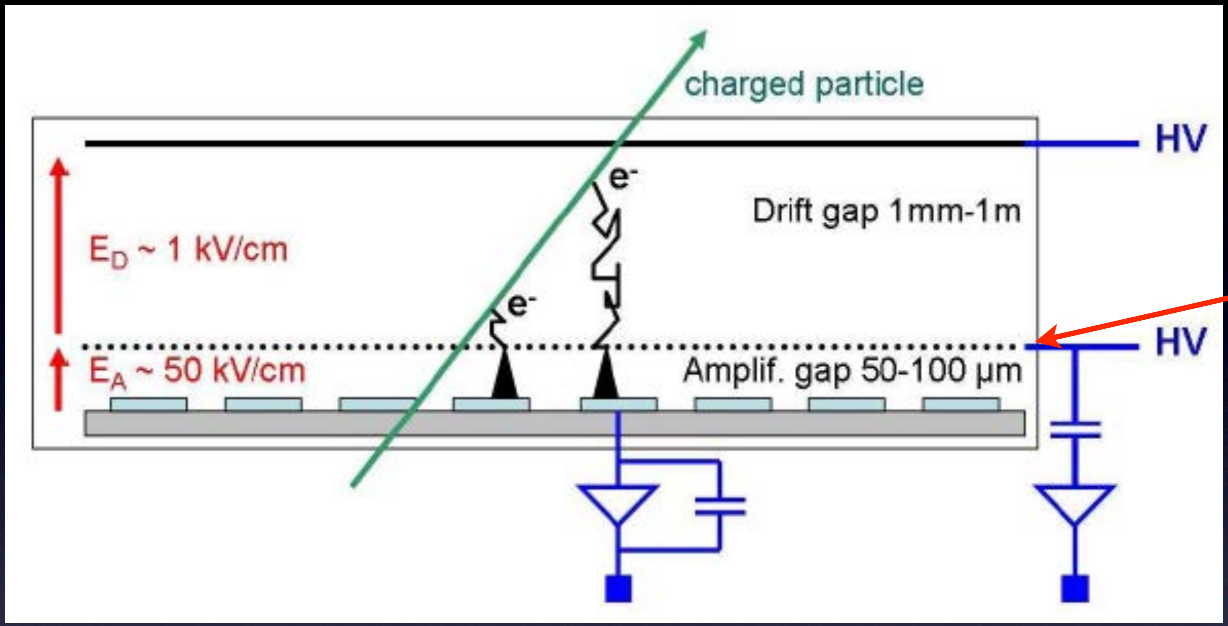
Three GEM foils form the amplification region for a single detector plane

Copper-clad Kapton:

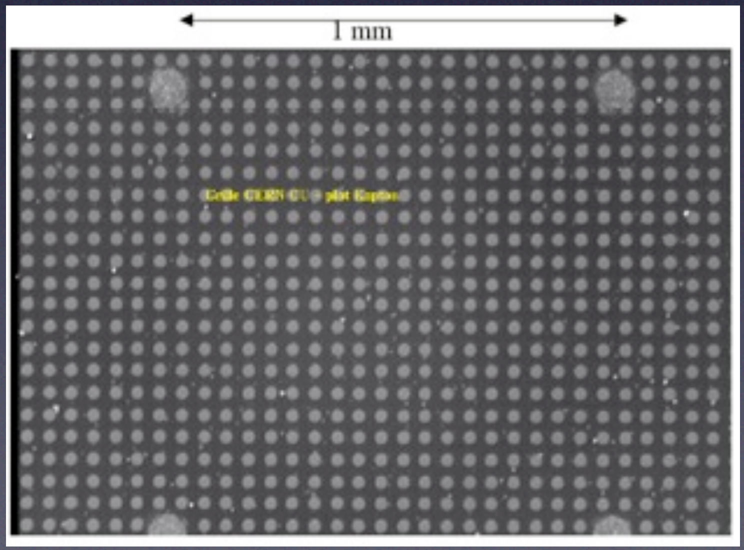


- well-tested technology
- relatively simple lithography, but many assembly steps

Micromegas Design



Conductive mesh is supported by micropattern Kapton posts

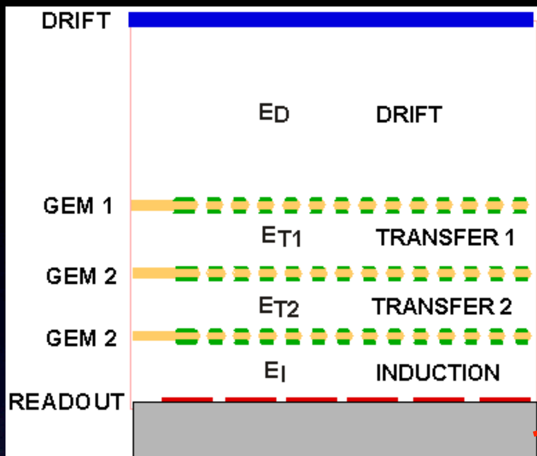


- more complex lithography, but simpler assembly
- resistive readout strips reduce sparking

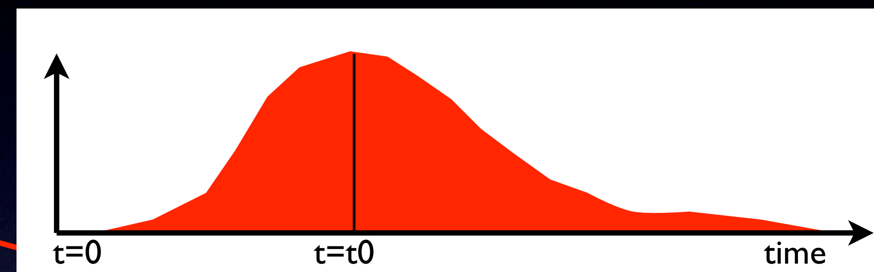
Micromegas Design

- Curved micromegas built for CLAS 12:

Trigger Design



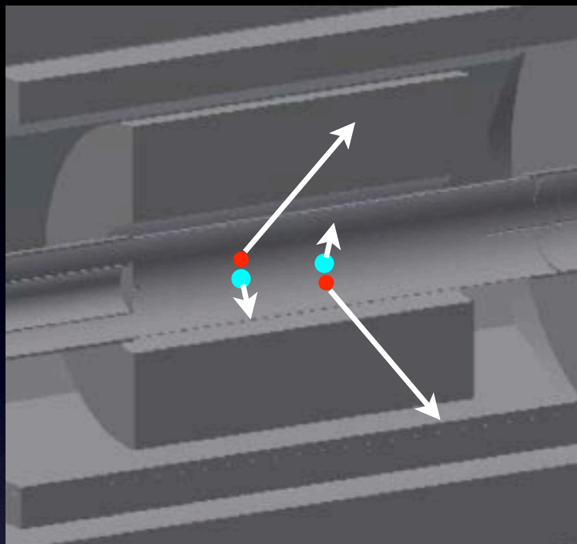
Signal Pulse



- for t0=50ns, expect ~5MHz of double-elastic events
- triggered readout with APVs hard above ~few kHz

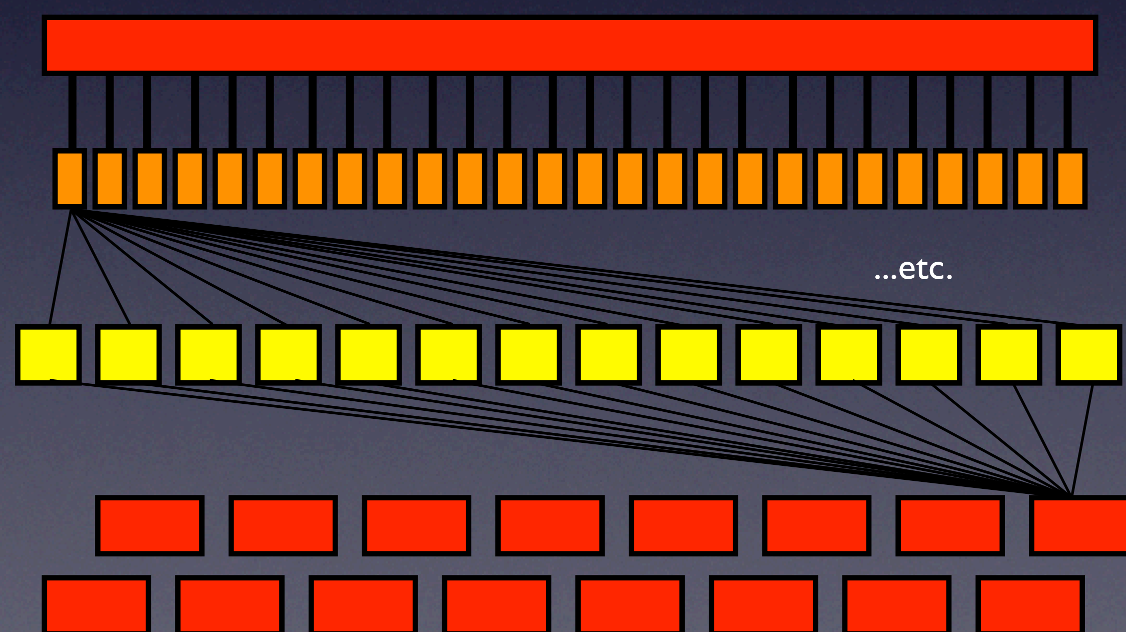
(work in progress)

Trigger Concept

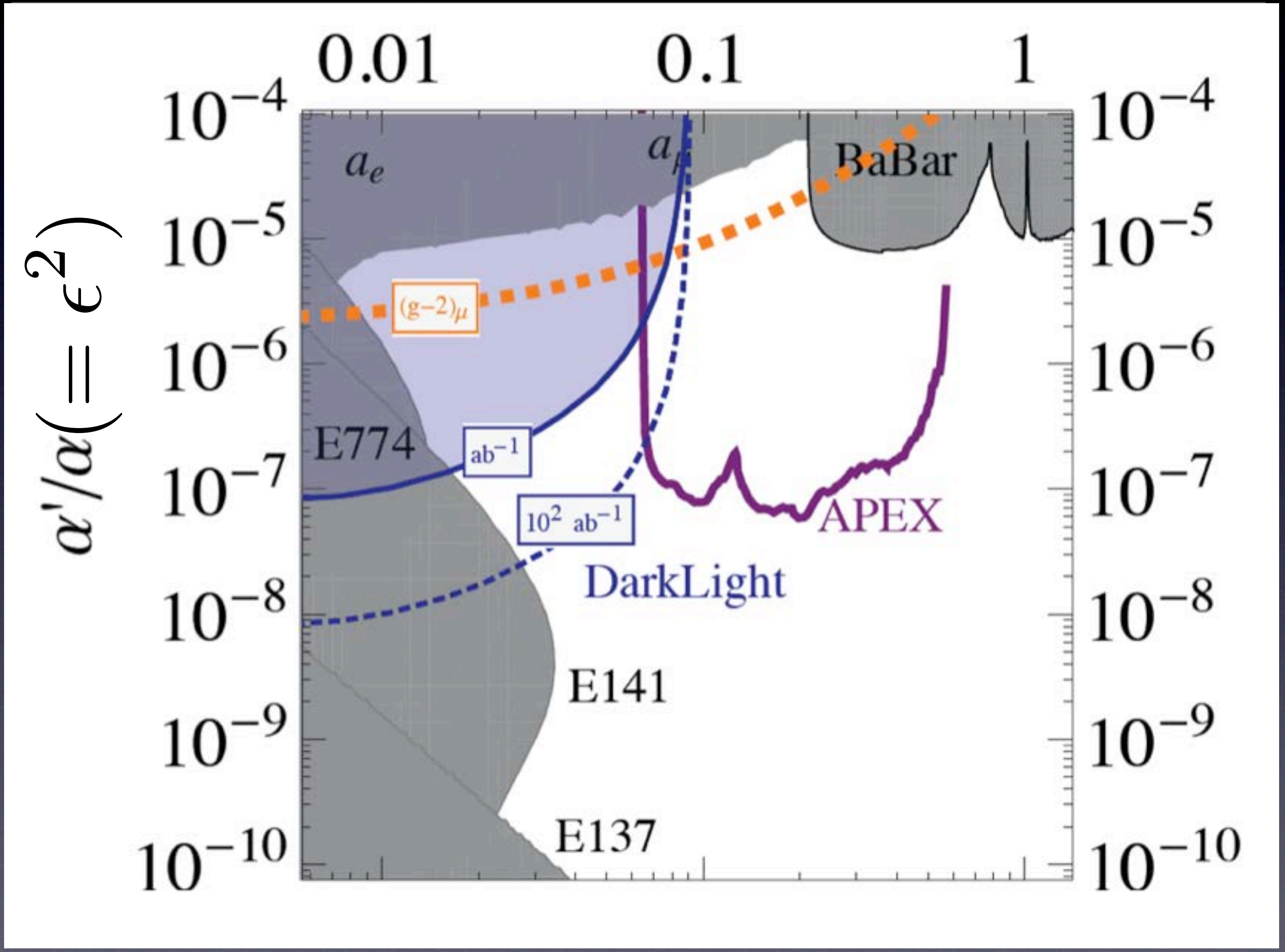


- Double-Elastic rate challenging for triggered readout
- Exploring streaming readout:

Detector Channels
read out to
Digital Signal Processors
that feed
Event Concentrators
that feed
CPU farm
that makes event selections
(work in progress)



Range



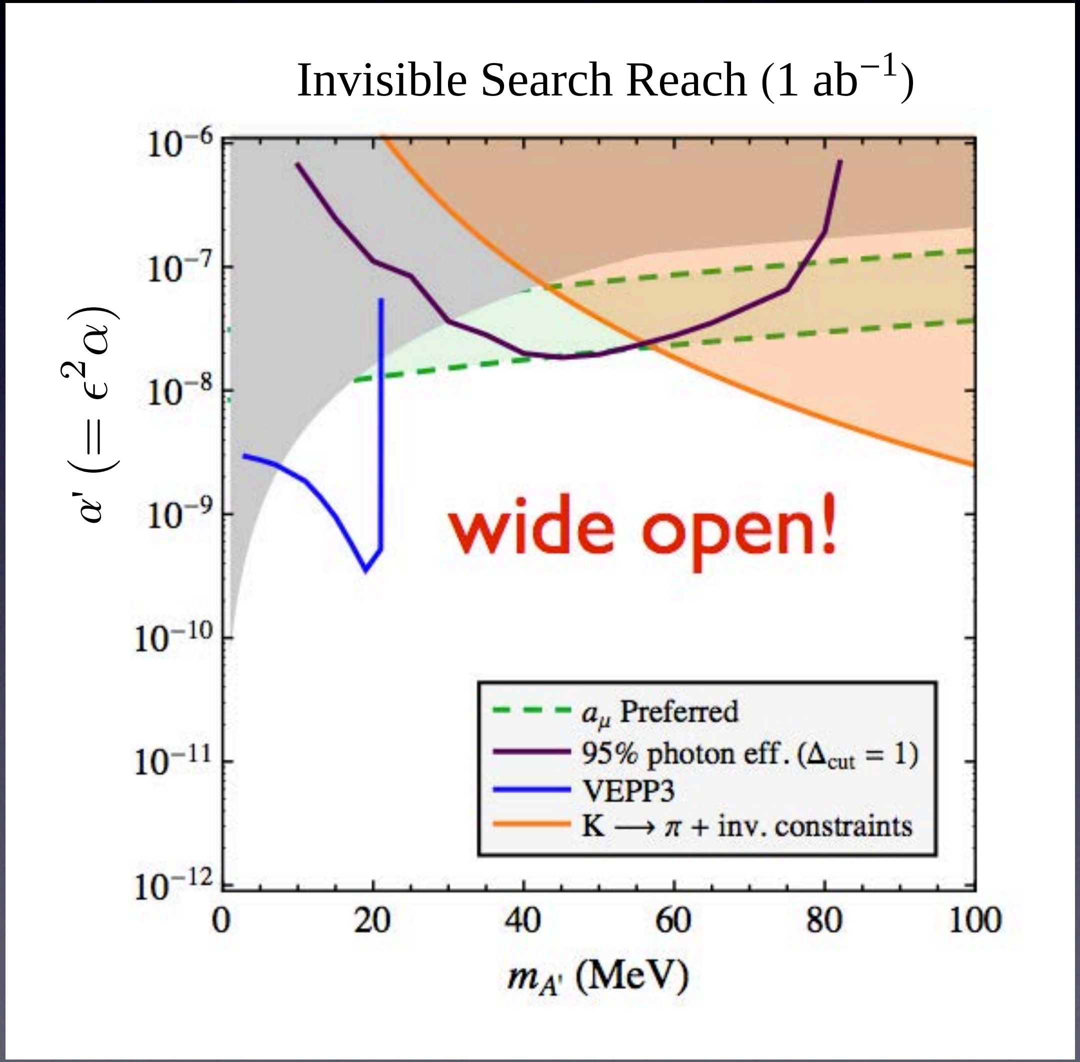
0.01
0.1
1
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
$\alpha'/\alpha(=\epsilon^2)$
a_e
a_μ
BaBar
$(g-2)_\mu$
E774
ab^{-1}
$10^2\ ab^{-1}$
APEX
DarkLight
E141
E137

Other Measurements

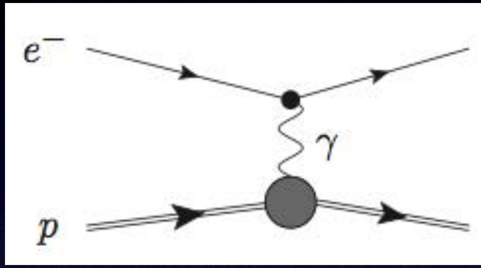
- Full Kinematic Reconstruction opens a variety other A' modes, as well as standard model measurements:
    - Invisible Resonances
    - Detached Vertices
    - Diphoton Resonances
    - Elastic ep Scattering

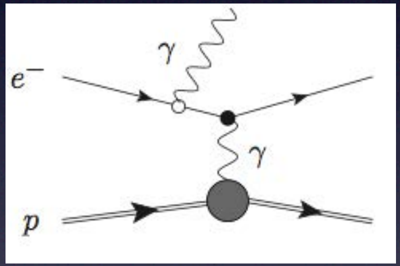
Invisibles

$$e^- p \to e^- p A', \qquad A' \to \text{inv.}$$

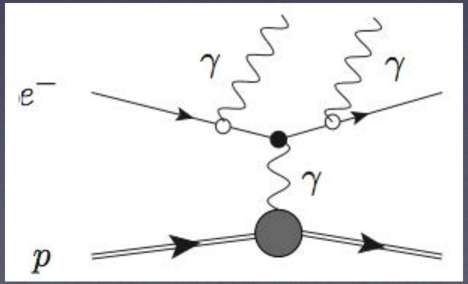


Need proton to cut

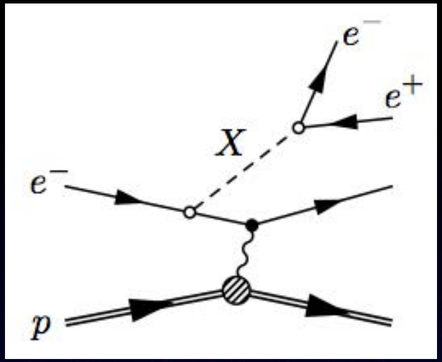




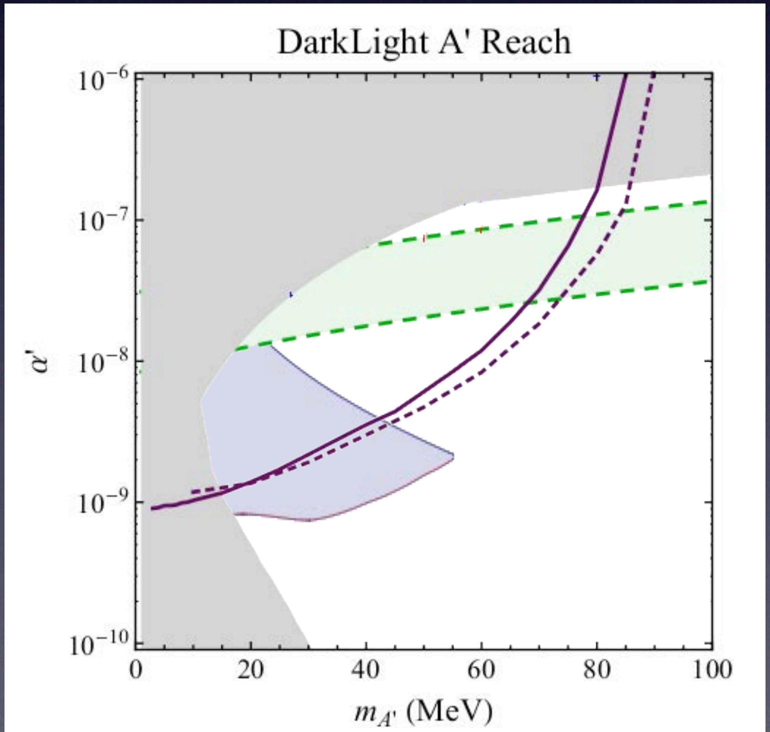
And photon veto for

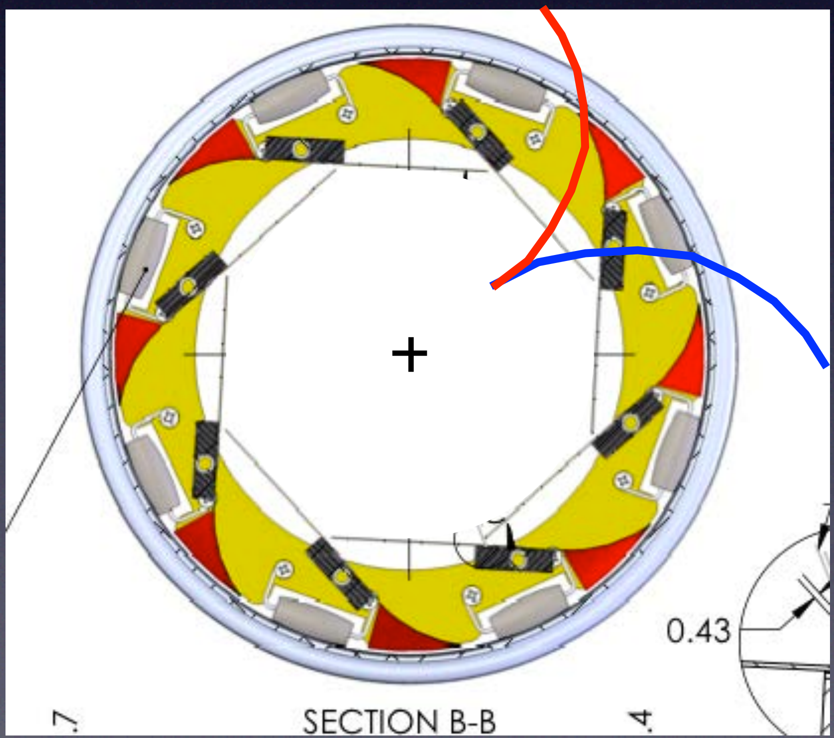


Detached Vertices



- Longer A' lifetimes seen in displaced e^+e^- vertices
- Lower limit from target size
- Upper limit comes from tracking

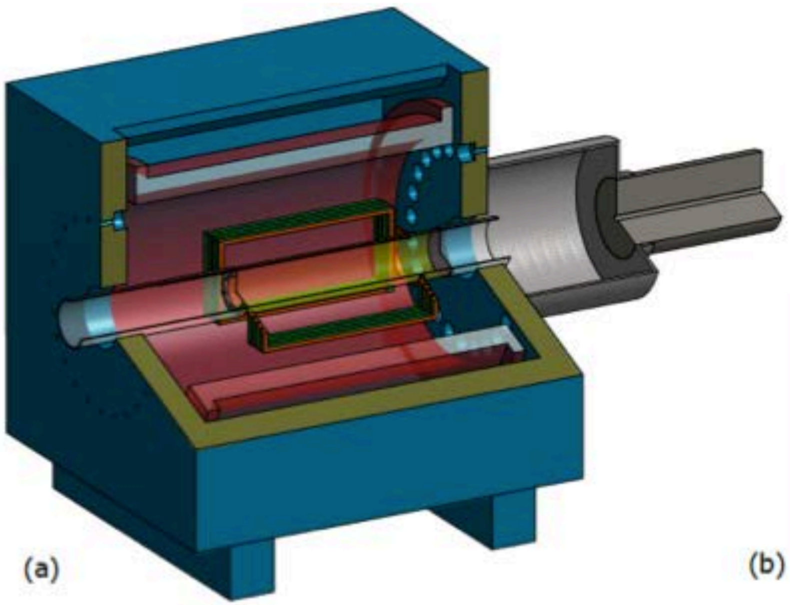


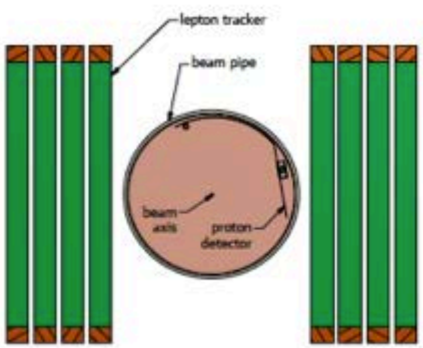


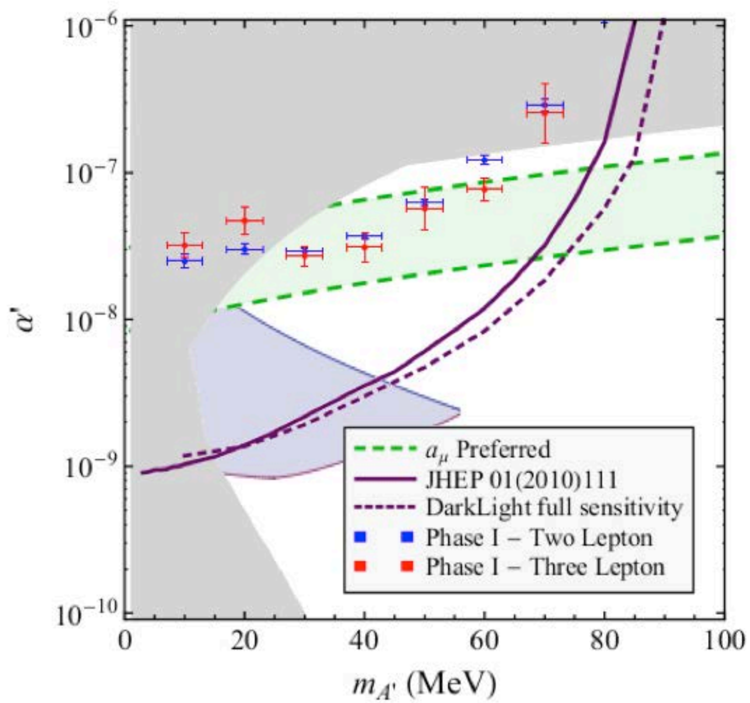
Phase 1

(Pending grant approval)

- Limited proton acceptance, partial lepton coverage
- Begins to probe g-2 band after a few days of running.

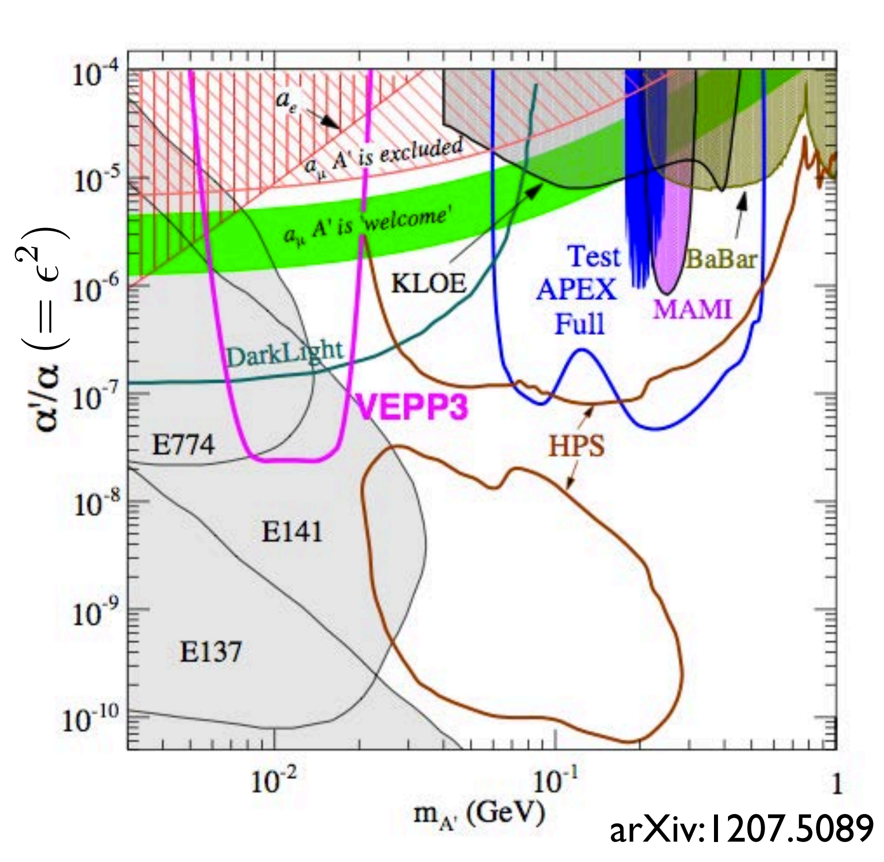






The Future

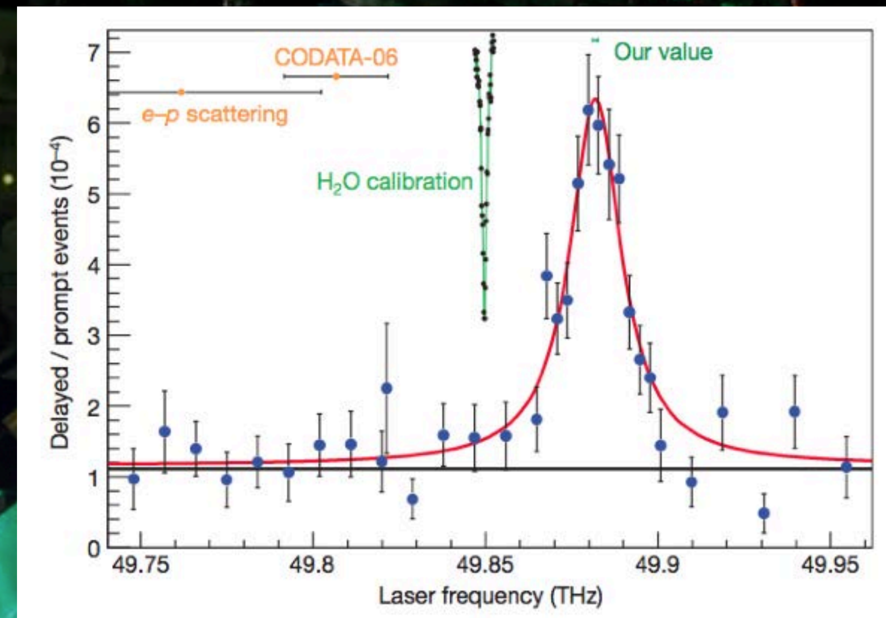
- DarkLight et al. are preparing to probe a very interesting region
- Full reconstruction opens important channels and cross-checks
- DarkLight will serve as a prototype for small, ultra-high luminosity experiments



arXiv:1207.5089

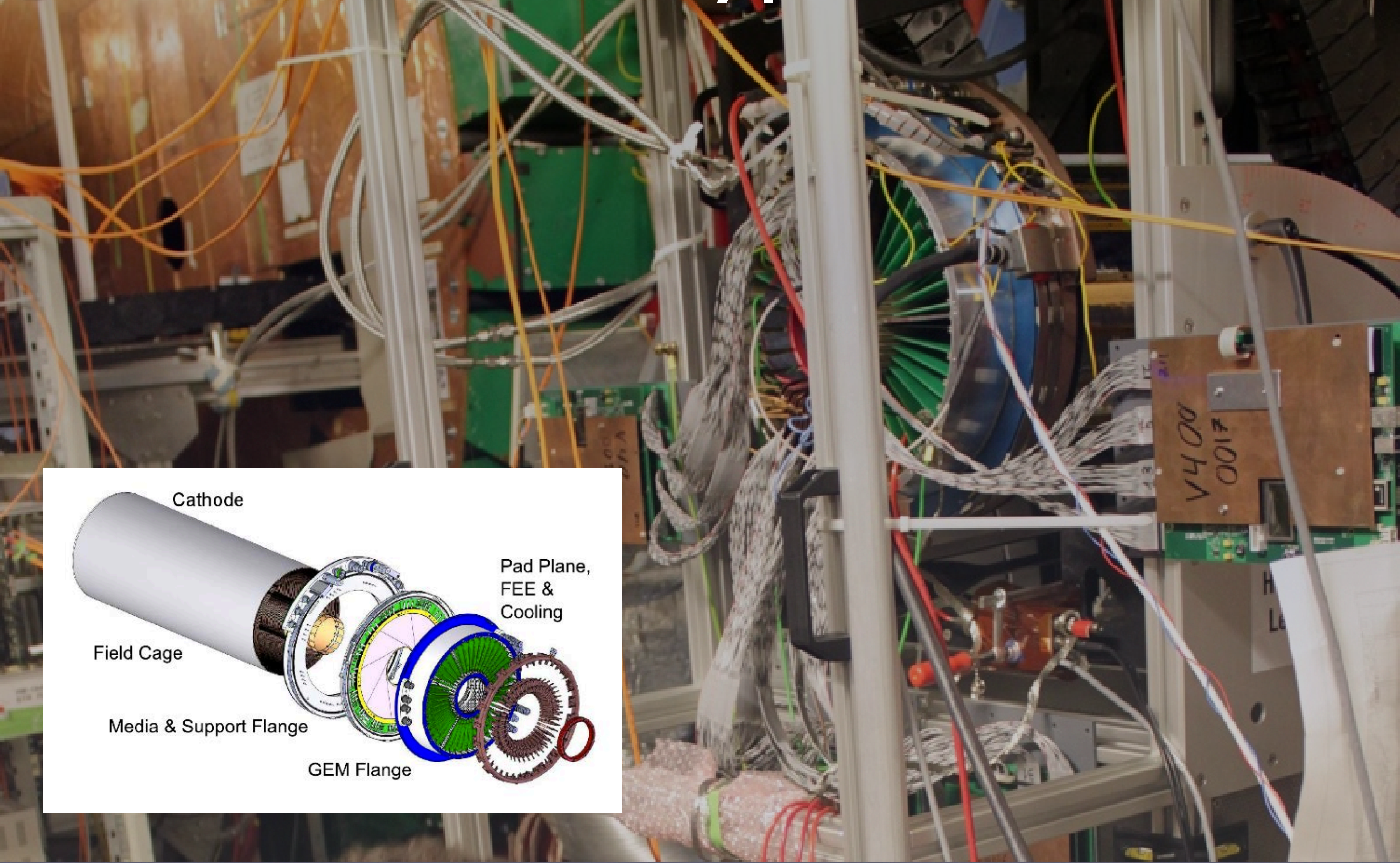
Thank you

Radius of the Proton

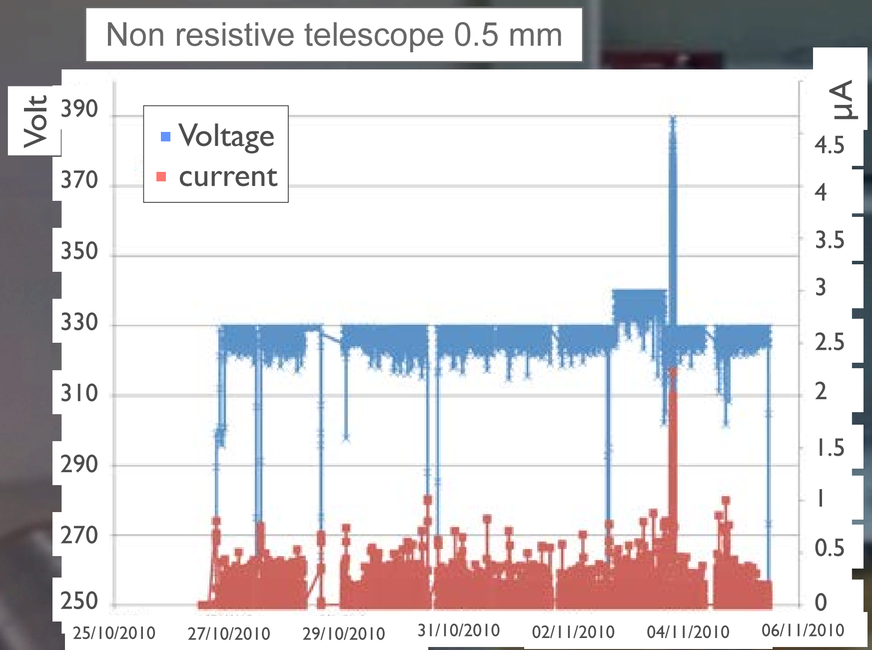


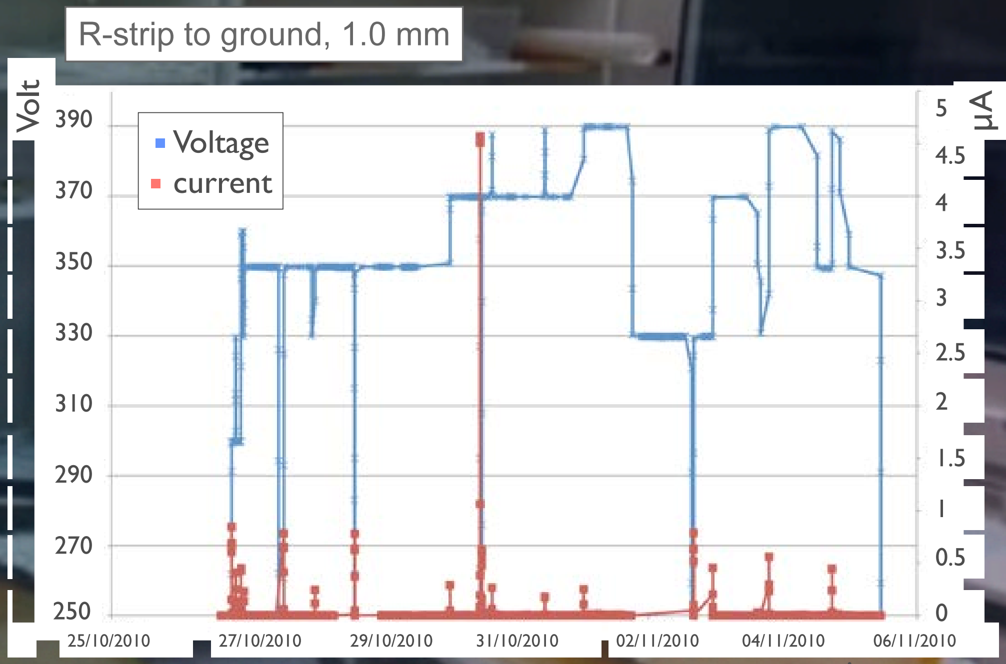
- Off by 7 sigma, but many possible explanations, and not compatible with the simple A' talked about here (though A' --> invisible still constrains)

PANDA Prototype GEM-TPC



uMegas design





The DarkLight Collaboration

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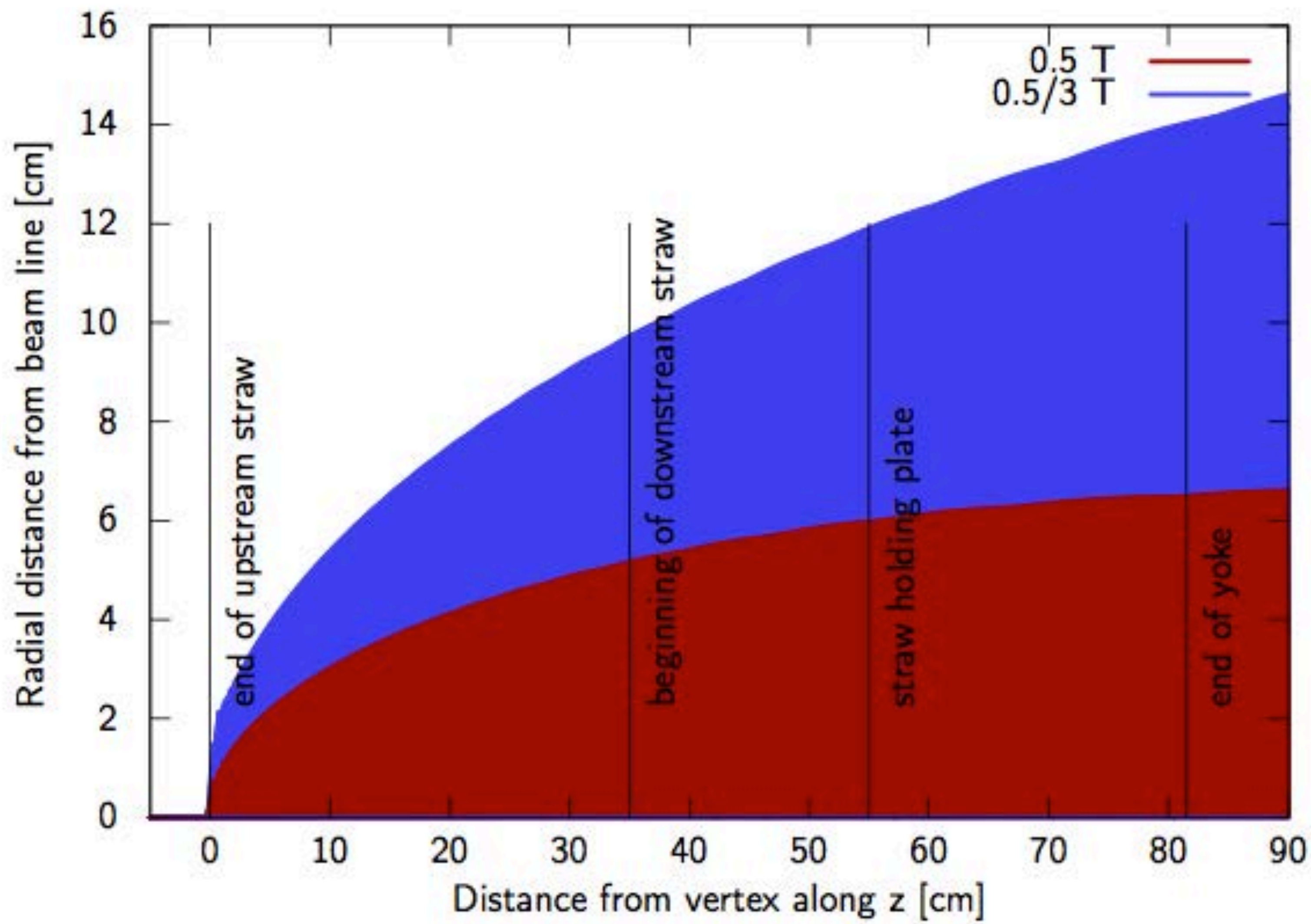
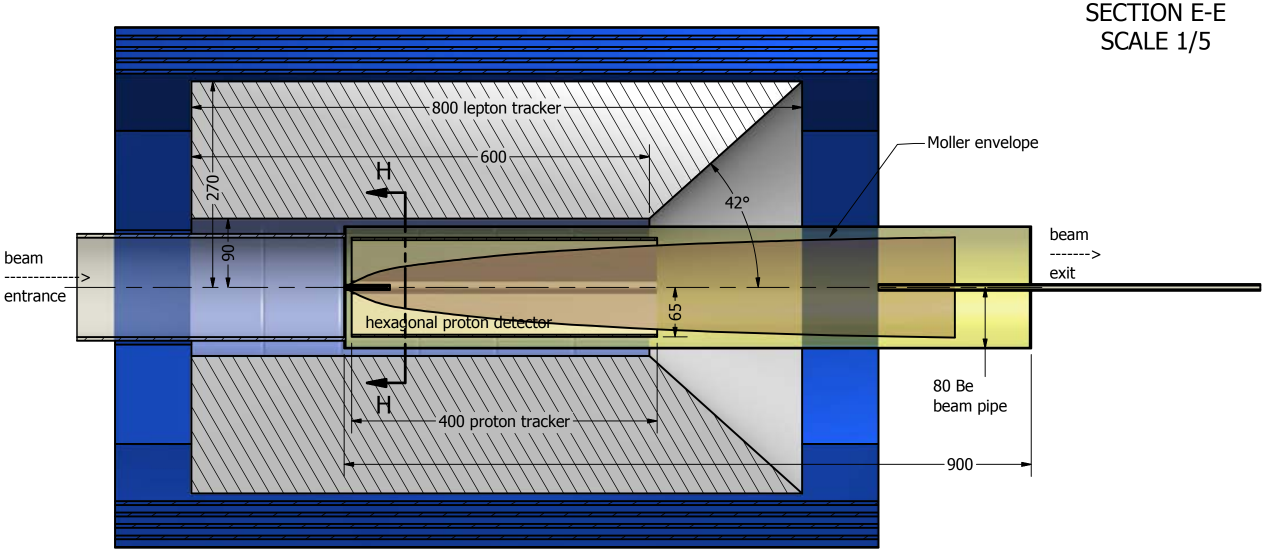
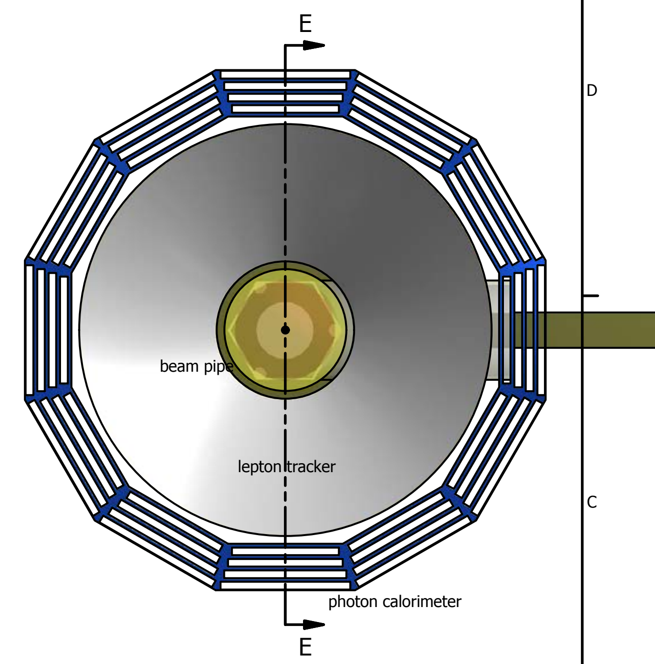
Moller Envelope

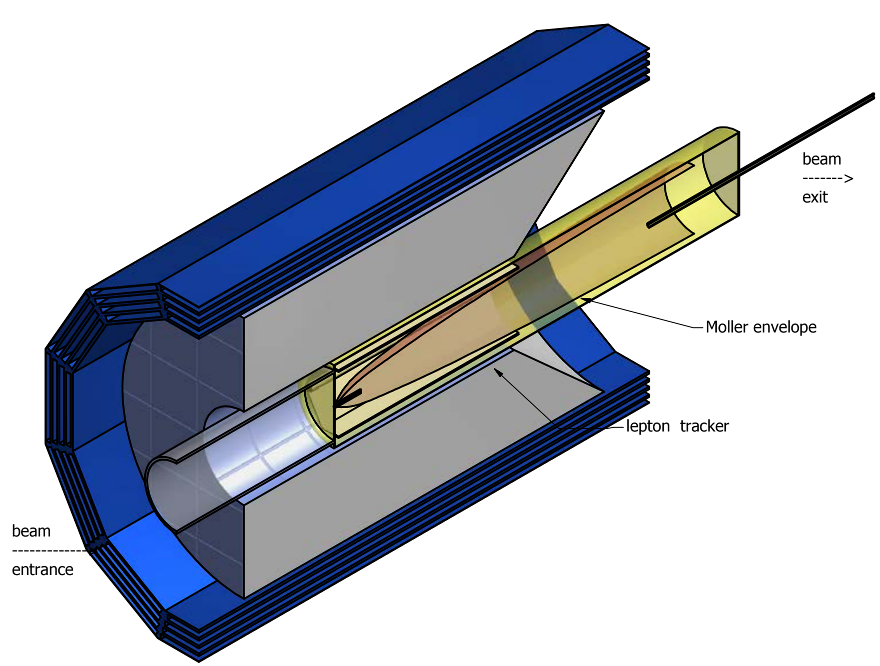


SECTION E-E
SCALE 1/5

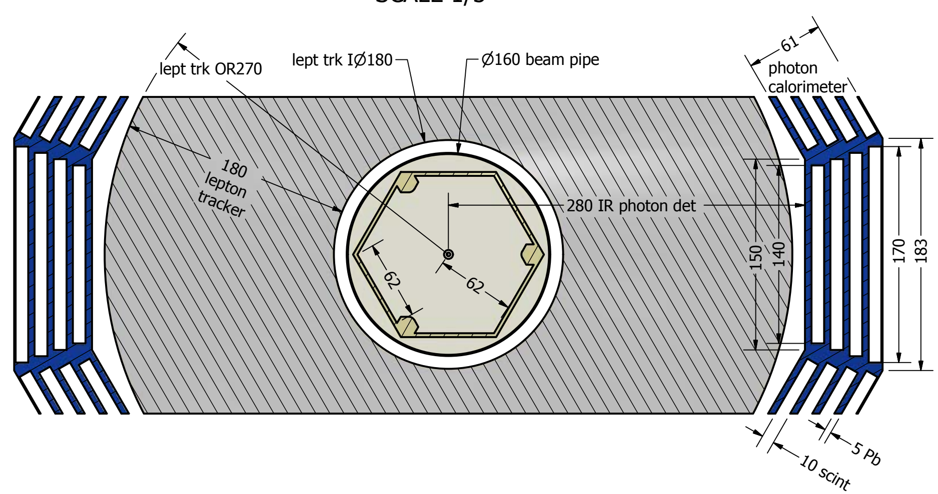


photon calorimeter made of 24 modules in azimuth



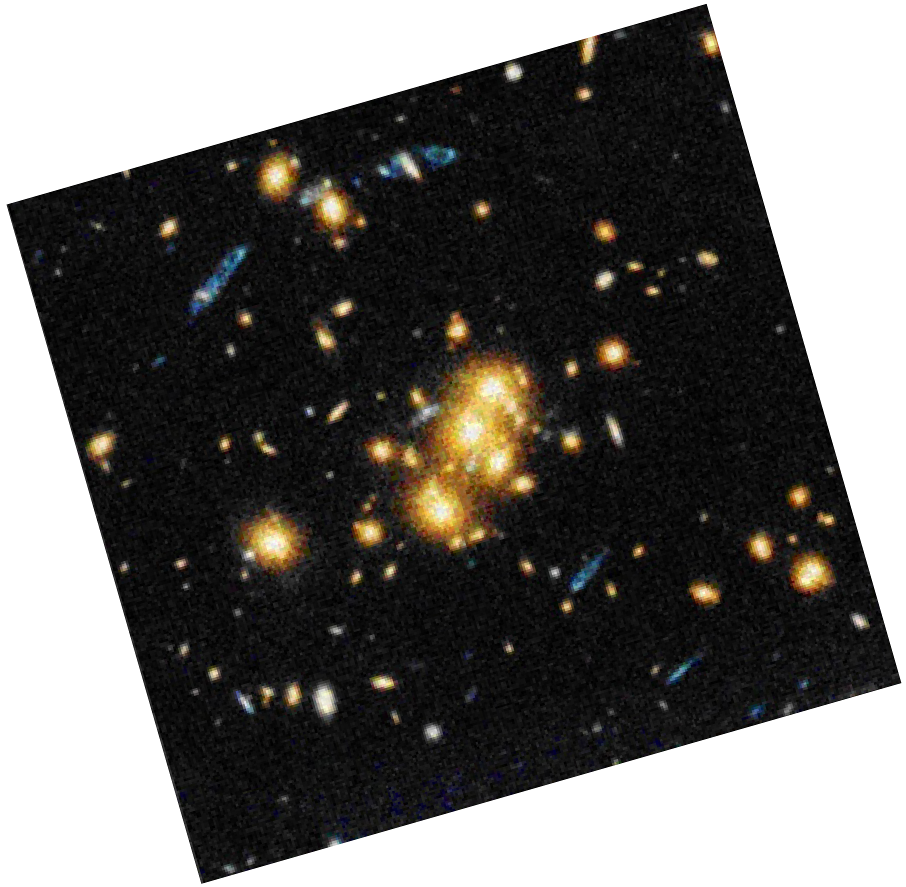


SECTION H-H
SCALE 1/3

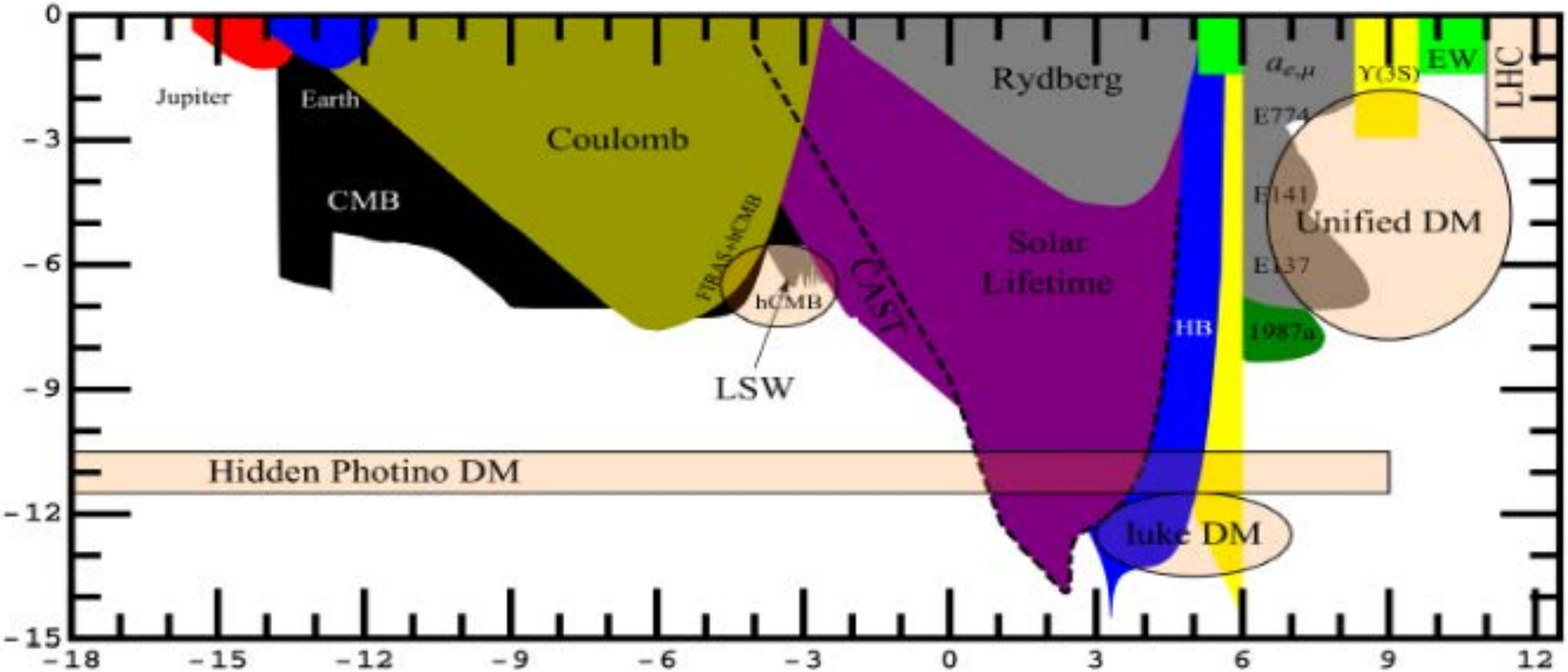


DRAWN Jan Balewski	10/14/2013	
CHECKED		TITLE Geometry ver 8.9 updated 2013-12-06
QA		
MFG		
APPROVED		SIZE C — DWG NO central region asmbly 2D — REV
		SCALE — SHEET 1 OF 1

Dark Matter Collisions



The Bigger Picture



from M.Titov