The DARKLIGHT Approach

- motivation
- apparatus
- method
- milestones

INTENSE ELECTRON BEAMS WORKSHOP
CORNELL UNIVERSITY, JUNE 17-19, 2015

Jan Balewski

MIT LNS Laboratory for Nuclear Science

Postulated new dark gauge forces

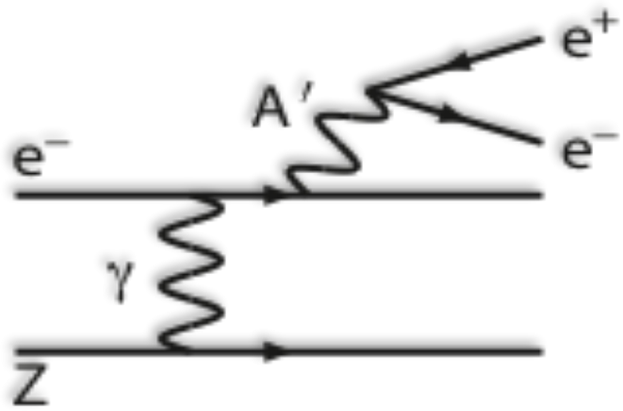
- New dark Abelian forces can couple to the SM hypercharge through the kinetic mixing operator
- ≈ MeV to GeV scale mass for the gauge boson
- can be produced in collisions with charged particles and can decay to electrons or muons
- Production cross-section

$$\sigma_{A'} \sim 100\ \mathrm{pb}\left(\epsilon/10^{-4}\right)^2 \left(100\,\mathrm{MeV}/m_{A'}\right)^2$$

- Decay length

$$\gamma c\tau \sim 1\ \mathrm{mm}\left(\gamma/10\right)\left(10^{-4}/\epsilon\right)^2 \left(100\,\mathrm{MeV}/m_{A'}\right)$$

- $\alpha' = \epsilon^2 \alpha_{\mathrm{EM}}$
- Look for evidence of A' in the presence of QED radiation



A′→e+e- exclusion plot

^{8}Be experiment
1504.01527 April 2015

NA48 / 2 π° decay
1504.00607 April 2015

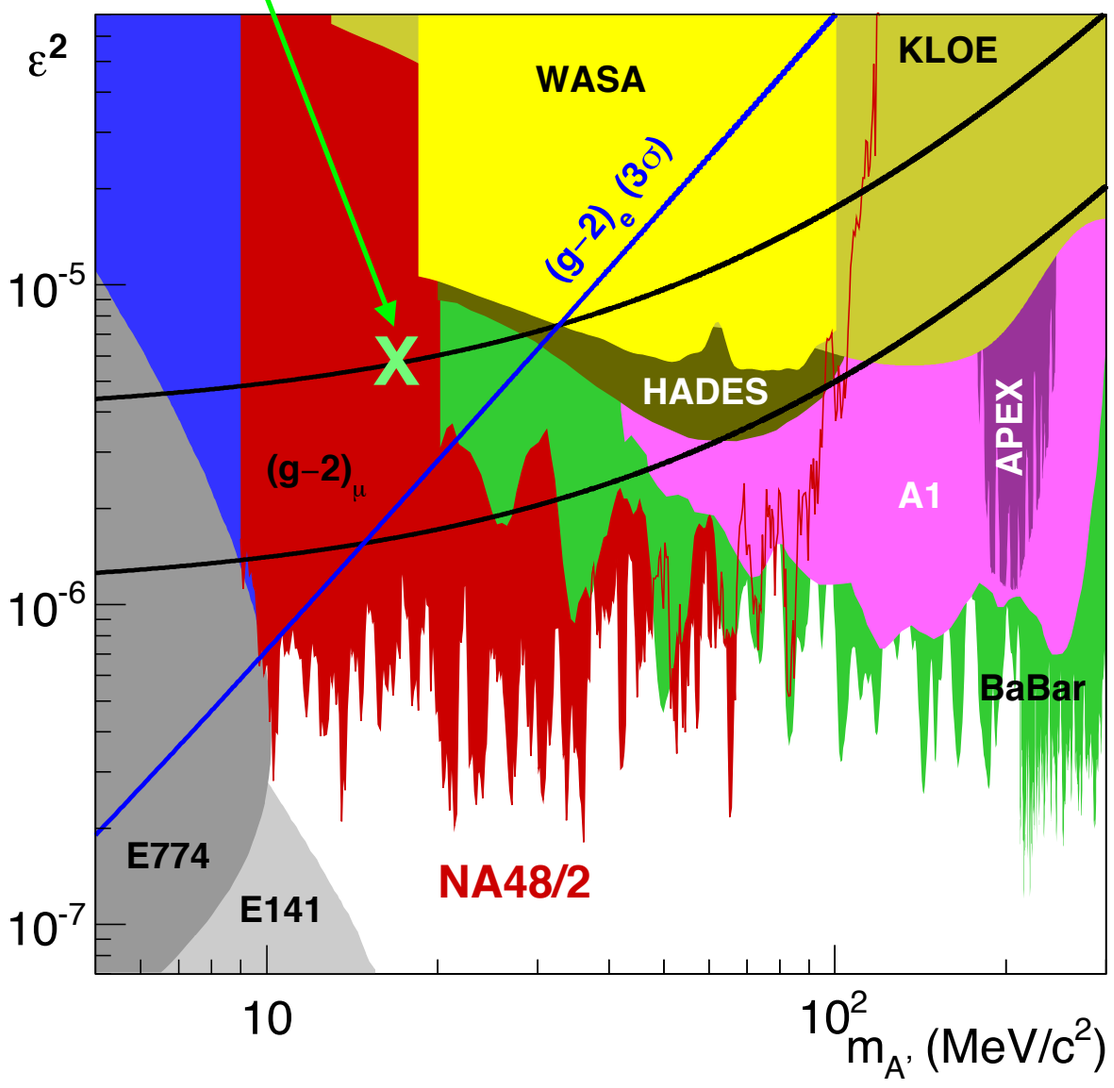
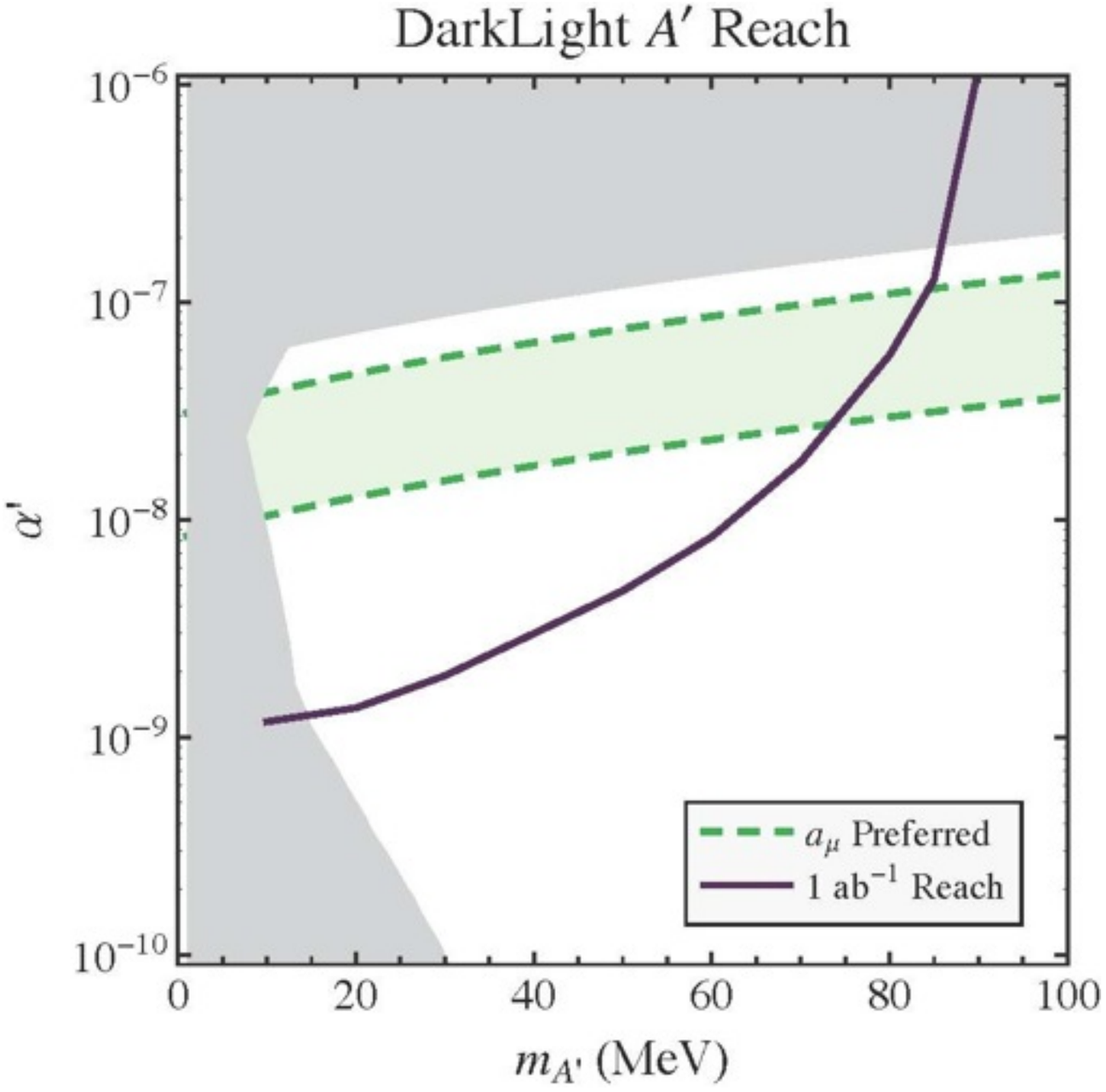


Figure 4: Obtained upper limits at 90% CL on the mixing parameter ε^2 versus the DP mass $m_{A'}$, compared to other published exclusion limits from meson decay, beam dump and e^+e^- collider experiments [16–22]. Also shown is the band where the inconsistency of theoretical and experimental values of muon $(g-2)$ reduces to less than 2 standard deviations, as well as the region excluded by the electron $(g-2)$ measurement [2, 23, 24].

Sensitivity A'→e+e-



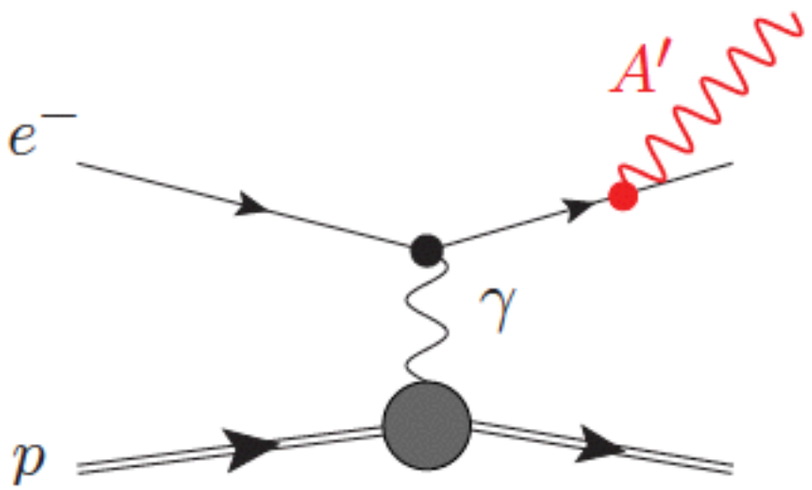
- Precision test of QED radiative processes in electron-proton elastic scattering as $Q^2 \rightarrow 0$
- Completely calculable
- Complete reconstruction of final-state
- 5σ discovery limit
- 1 ab^{-1} attained in several months of data taking with 10 mA at 100 MeV on 10^{19} cm^{-2} target
- Green region is present muon (g-2) result explained by a dark force

Freytsis, Ovanesyan, and Thaler
JHEP **1001**, (2011) 111

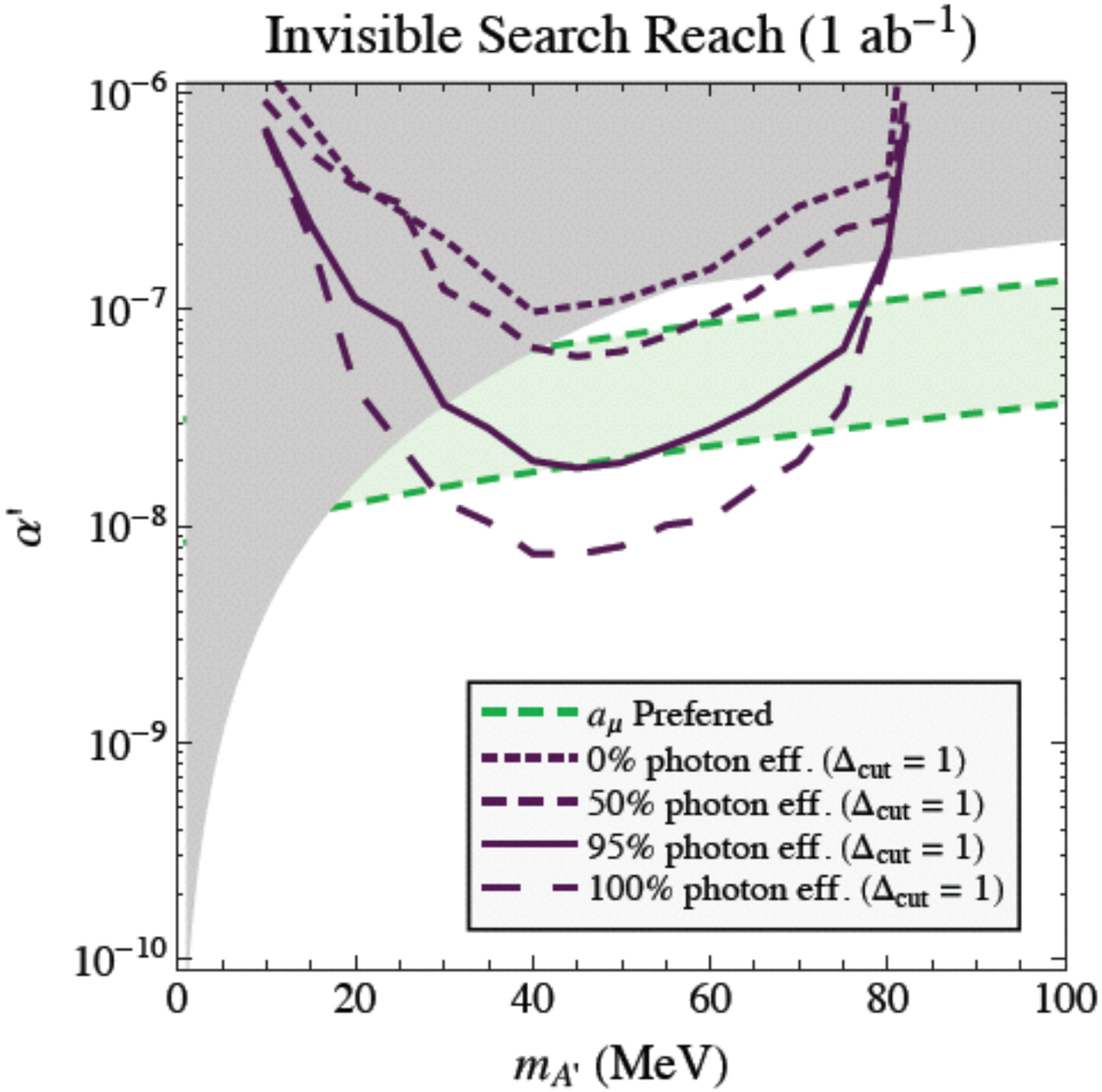
Sensitivity A'→invisible

Bremsstrahlung:

$$e^- p \to e^- p A'$$



Yonatan Kahn
with Jesse Thaler
Phys. Rev. D86:115012



DARKLIGHT Collaboration

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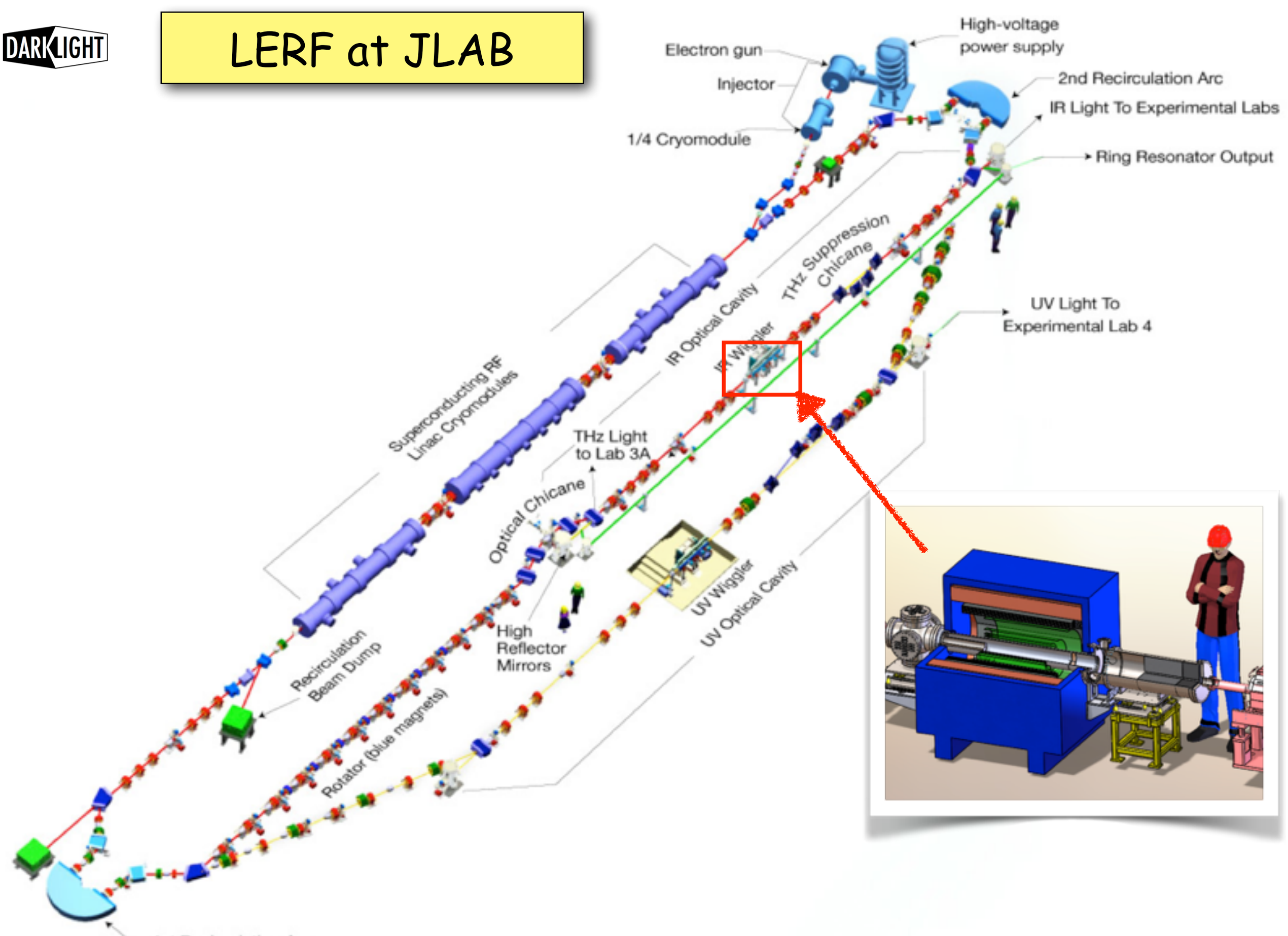
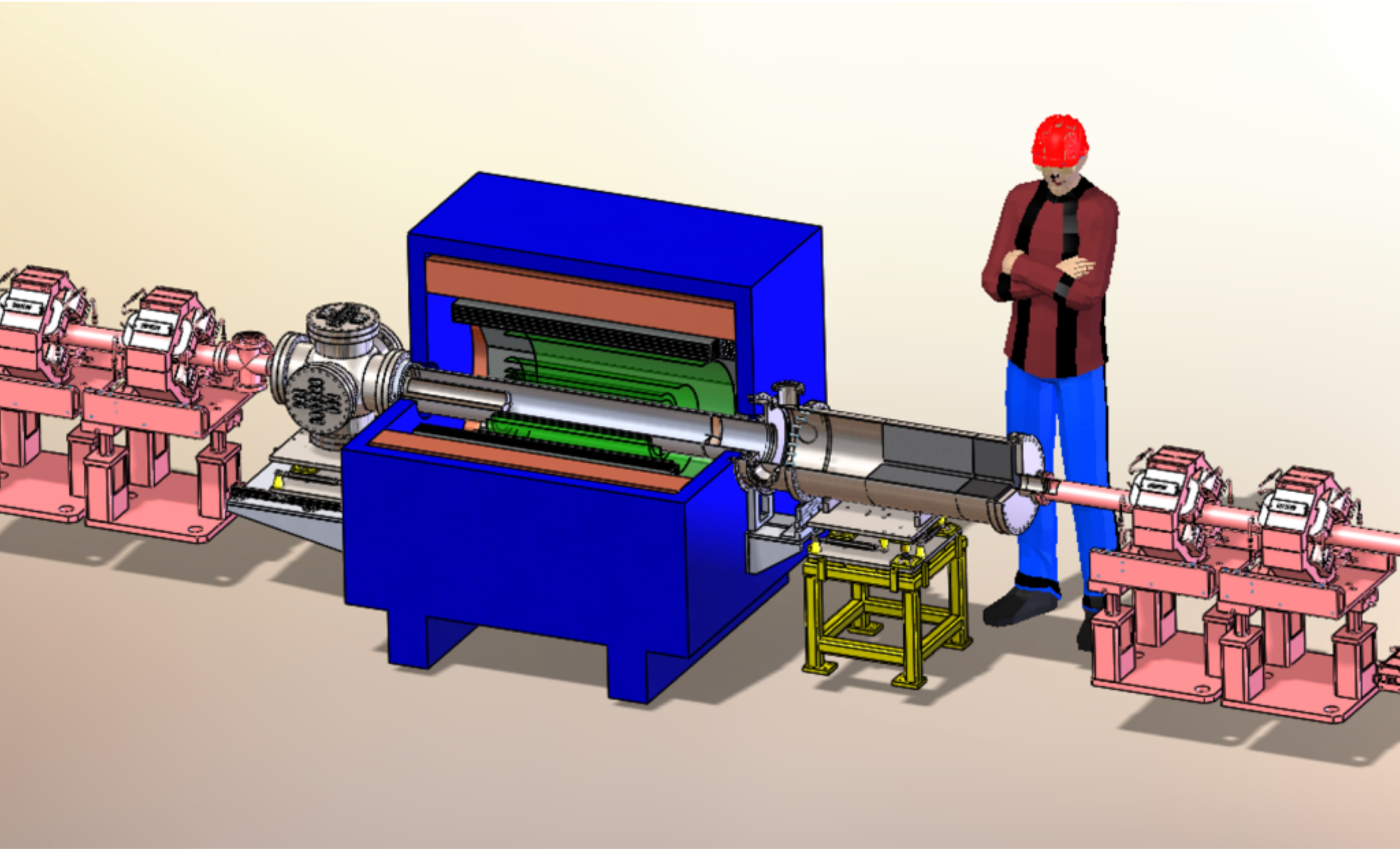
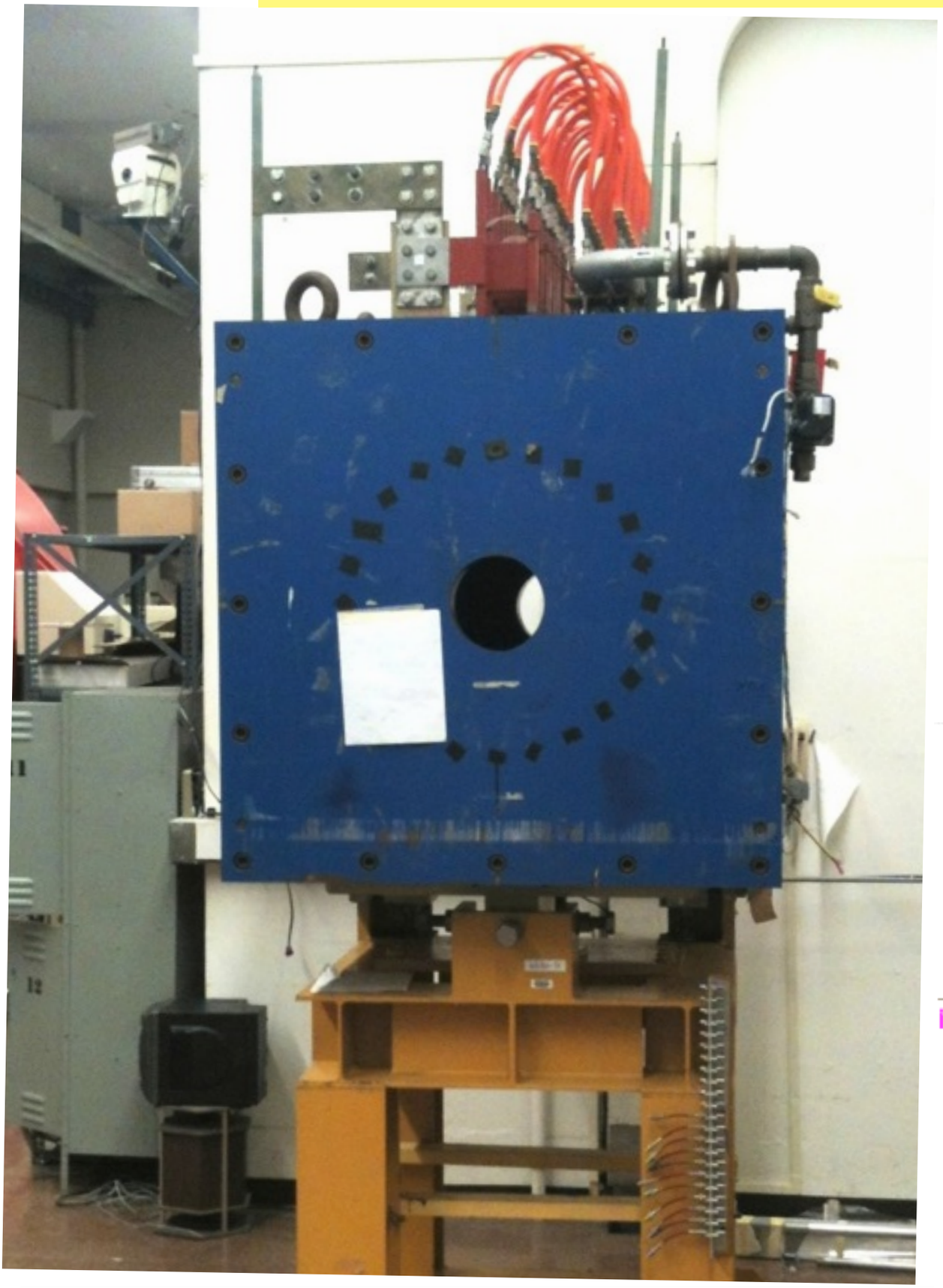
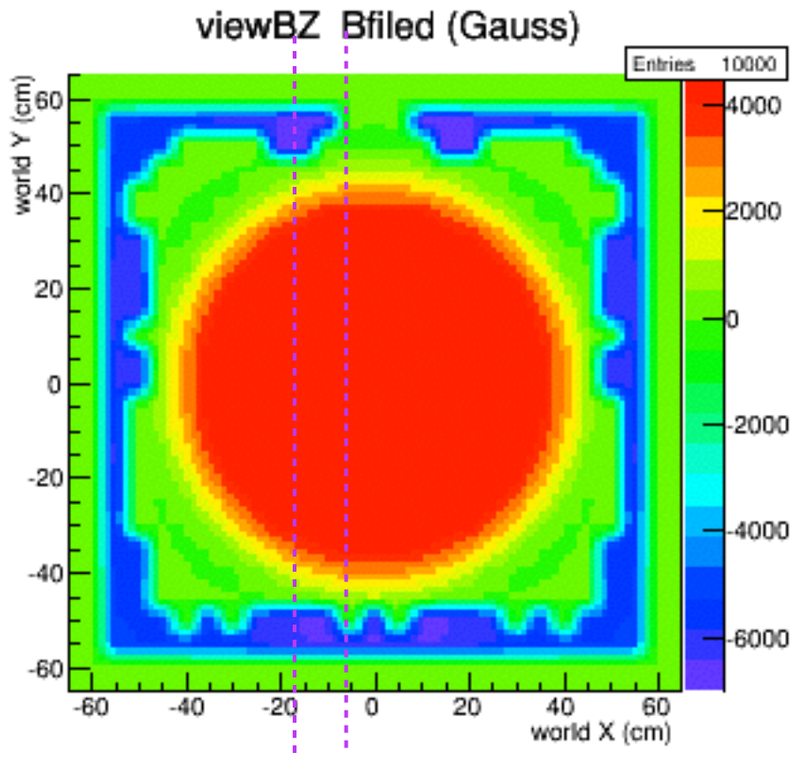

Electron gun
Injector
1/4 Cryomodule
High-voltage
power supply
2nd Recirculation Arc
IR Light To Experimental Labs
Ring Resonator Output
THz Suppression
Chicane
IR Optical Cavity
IR Wiggler
UV Light To
Experimental Lab 4
Superconducting RF
Linac Cryomodules
THz Light
to Lab 3A
Optical Chicane
High
Reflector
Mirrors
UV Wiggler
UV Optical Cavity
Recirculation
Beam Dump
Rotator (blue magnets)

Experimental layout



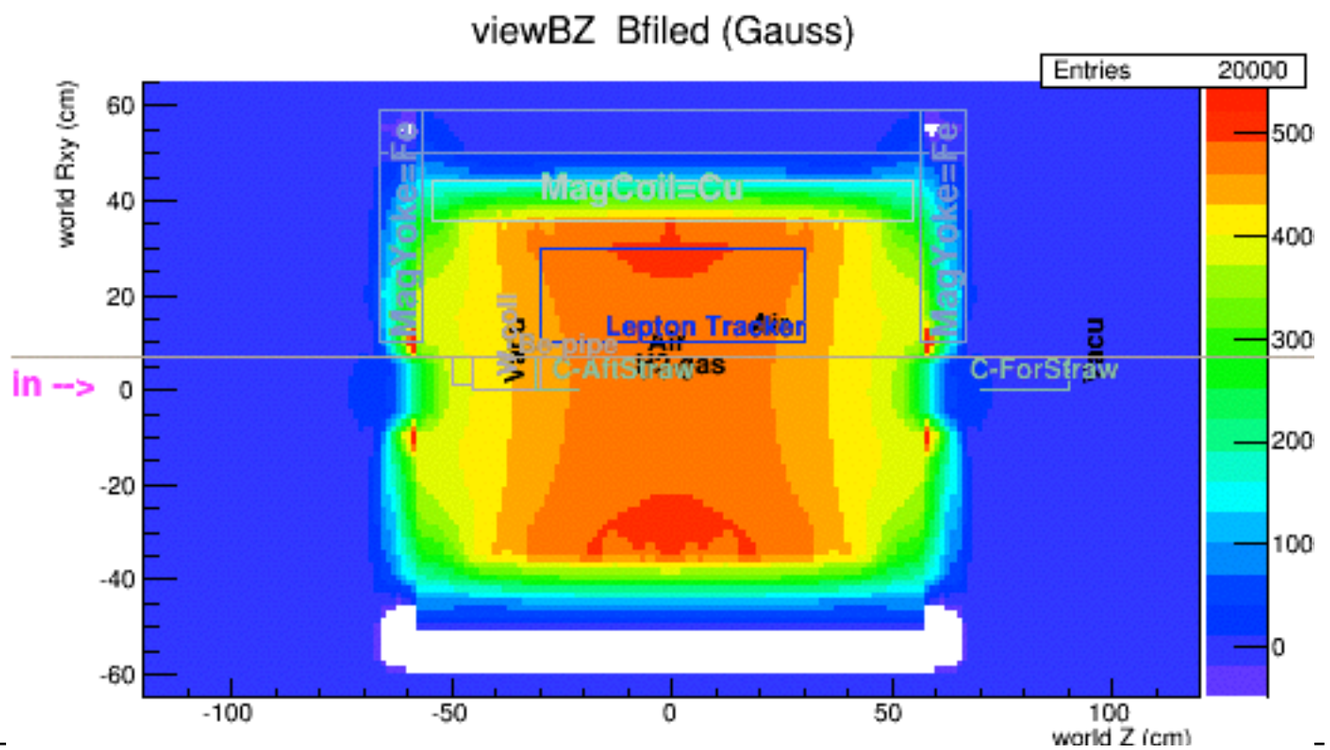
Existing solenoidal 0.5T magnet from E906 at BNL



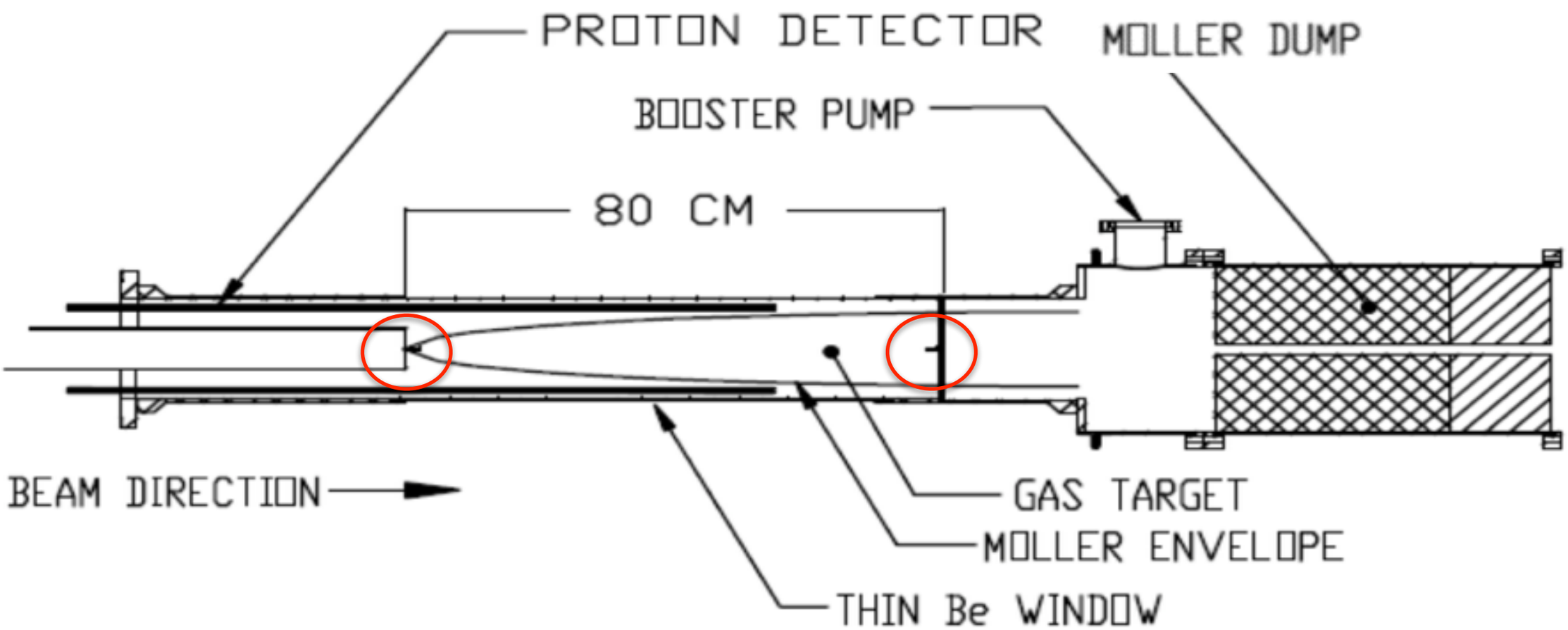


OPERA field map at Z= -35 cm

plane at Y-Z, slice at X=-5cm

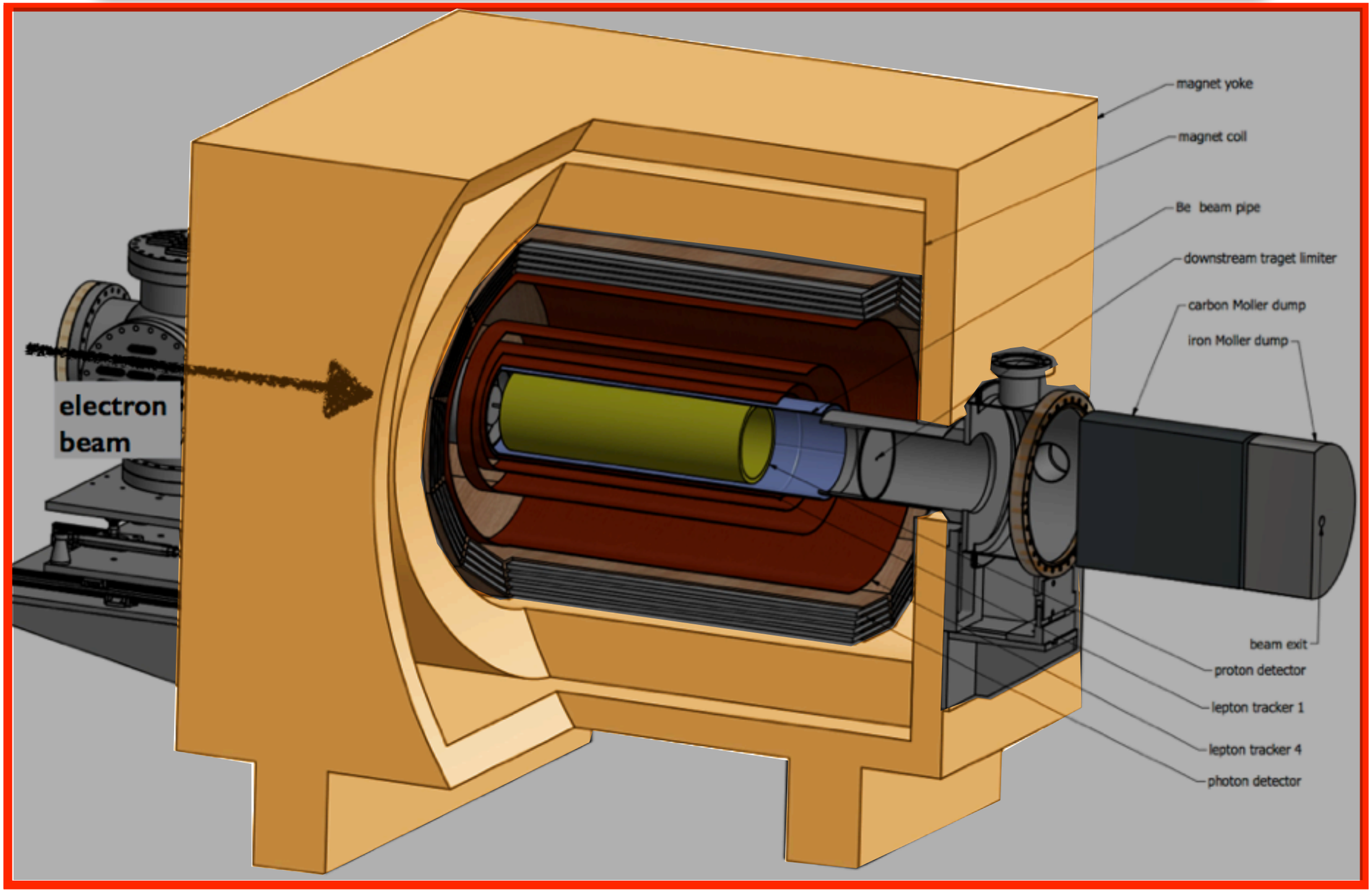


Extended gas target



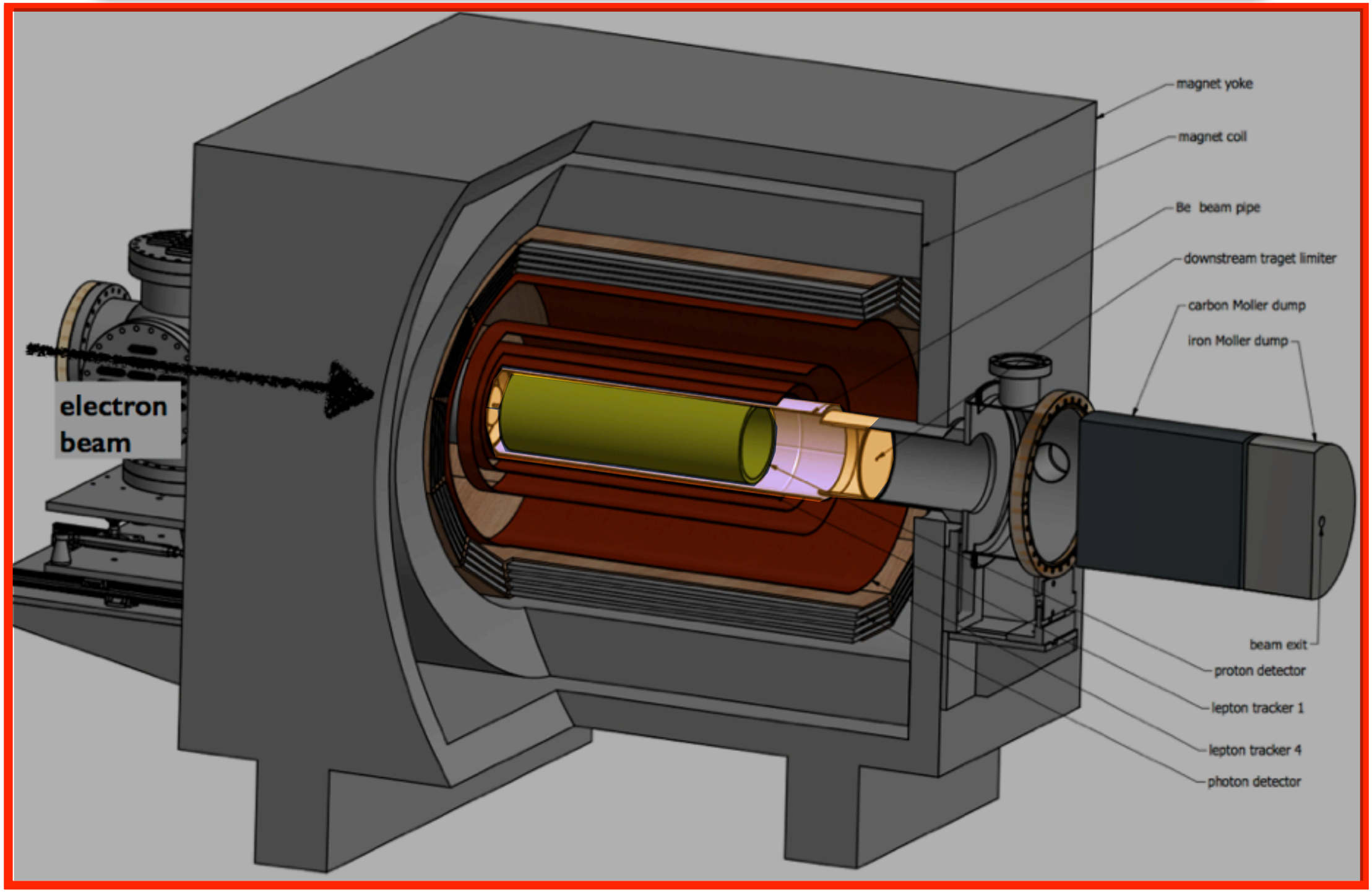
- Hydrogen target realized by flowing gas through narrow apertures, diameter : 2mm
- Design thickness: 10^{19} hydrogen atoms/cm^2
- Flow rate: 24 Torr-liter/s
- Viscous subsonic low regime
- Multiple stages of differential pumping required
- Phase-I will realize full thickness with limited acceptance

Conceptual view of DarkLight phase-2



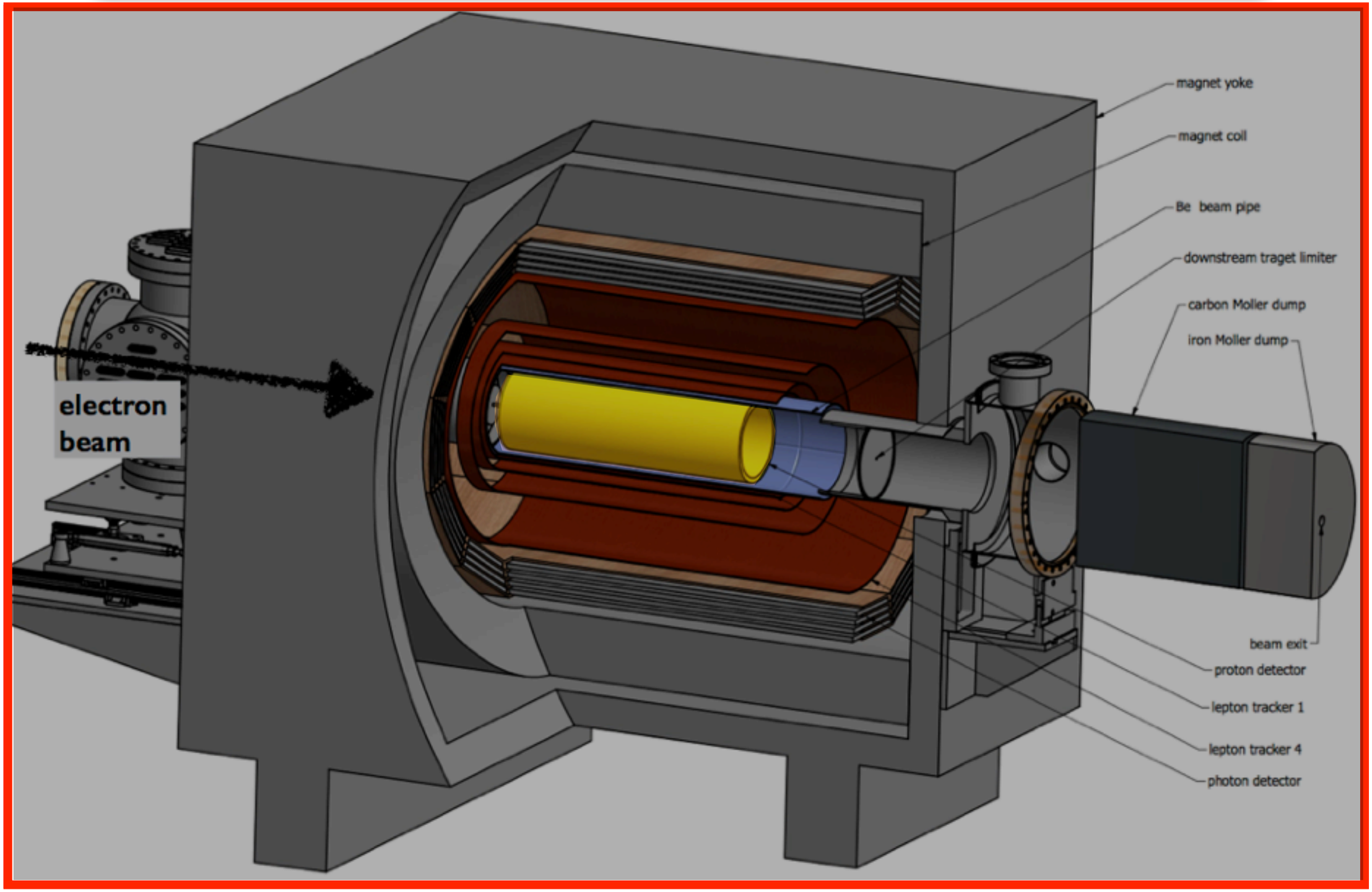
- 0.5T magnet

Conceptual view of DarkLight phase-2



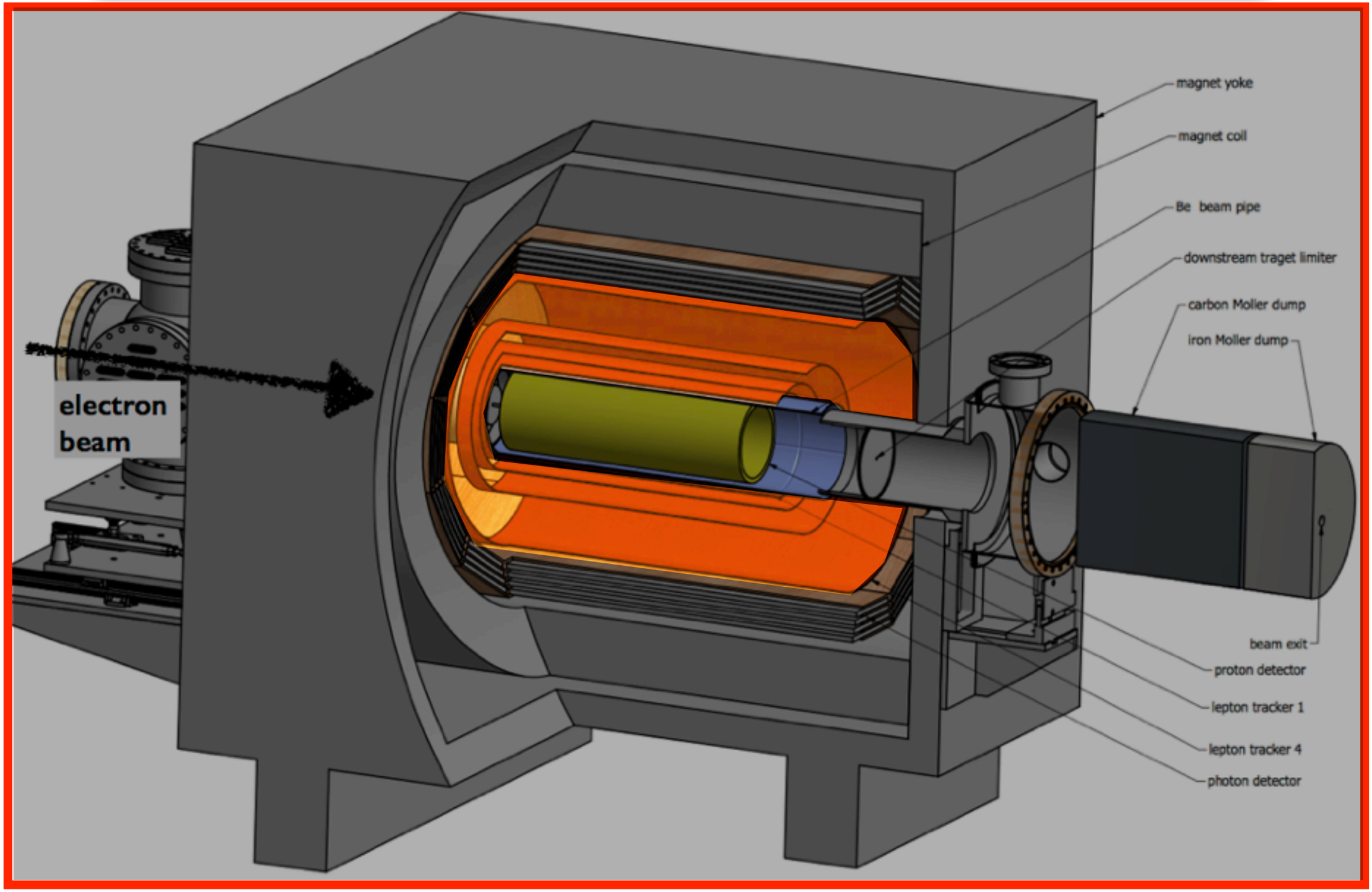
- 0.5T magnet
- windowless gas target

Conceptual view of DarkLight phase-2



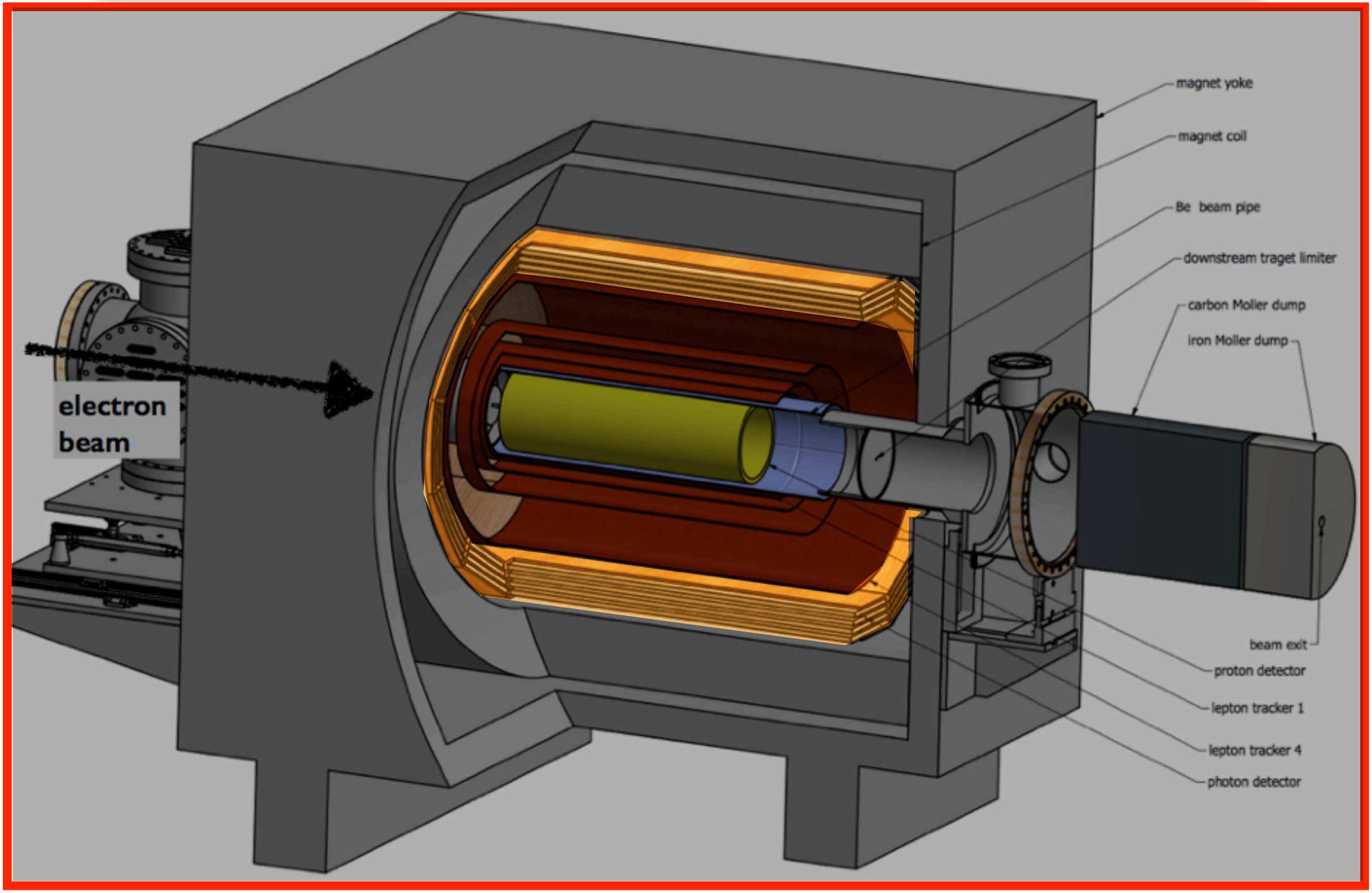
- 0.5T magnet
- windowless gas target
- proton detector

Conceptual view of DarkLight phase-2



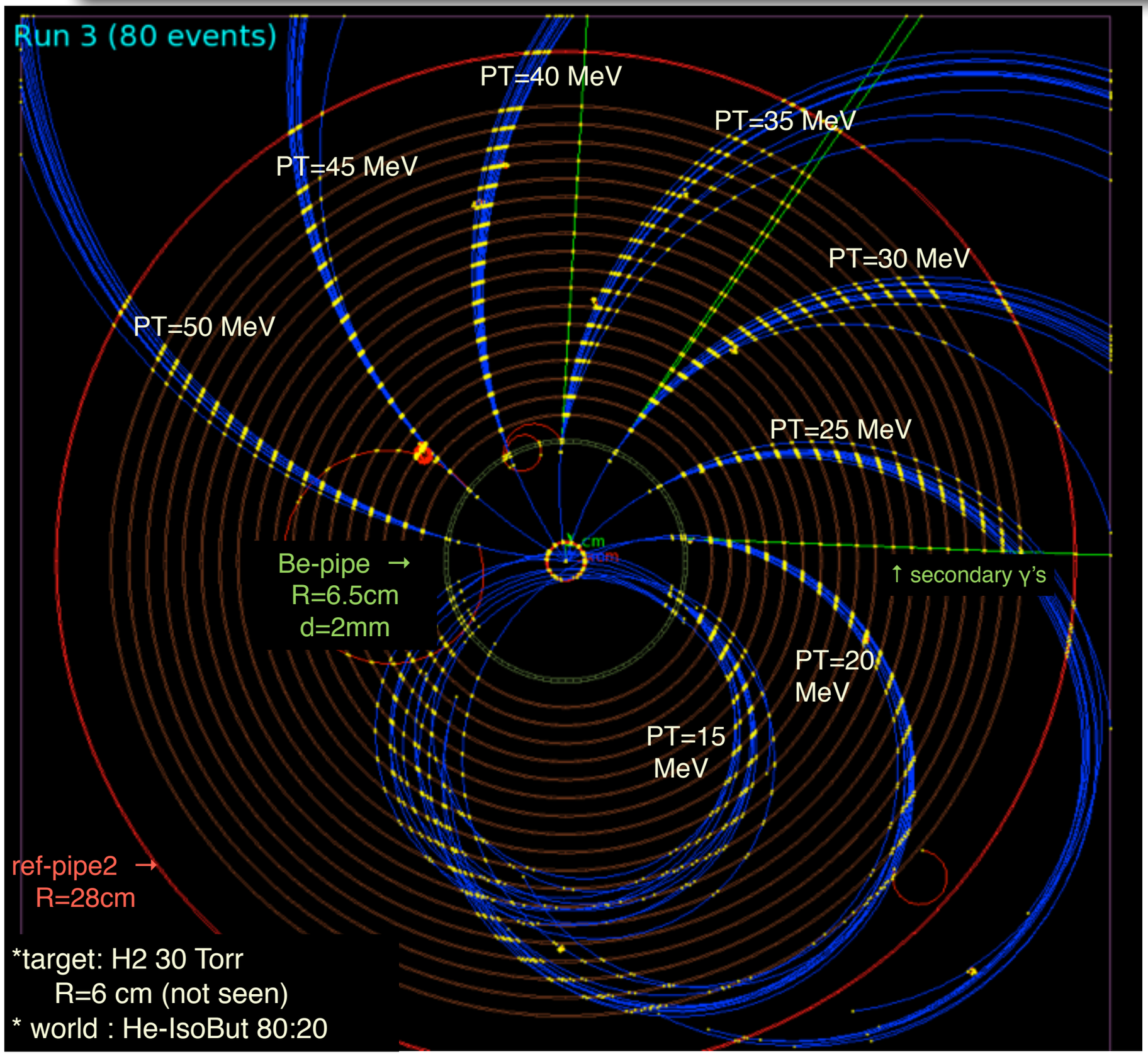
- 0.5T magnet
- windowless gas target
- proton detector
- lepton tracker

Conceptual view of DarkLight phase-2

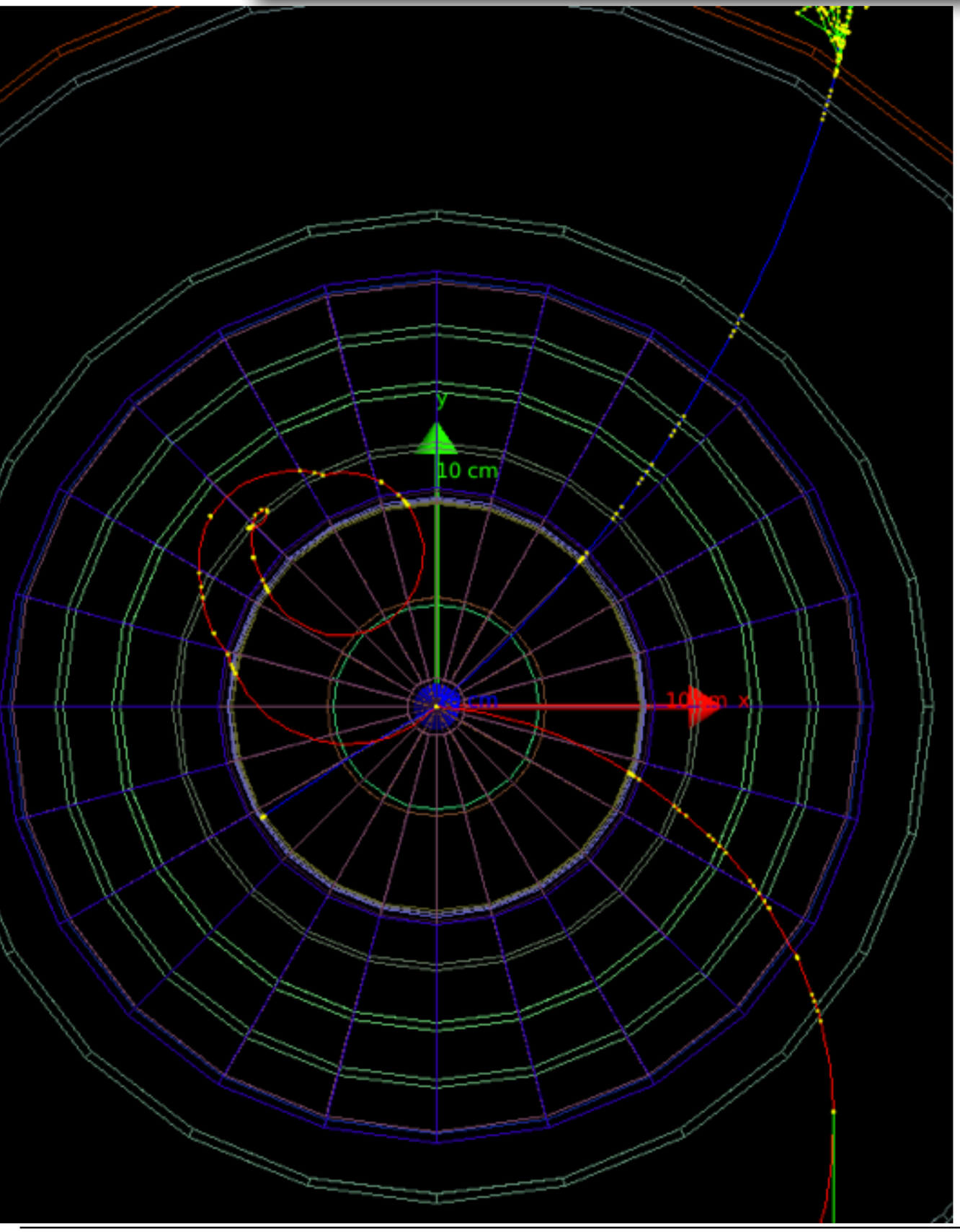


- 0.5T magnet
- windowless gas target
- proton detector
- lepton tracker
- photon calorimeter

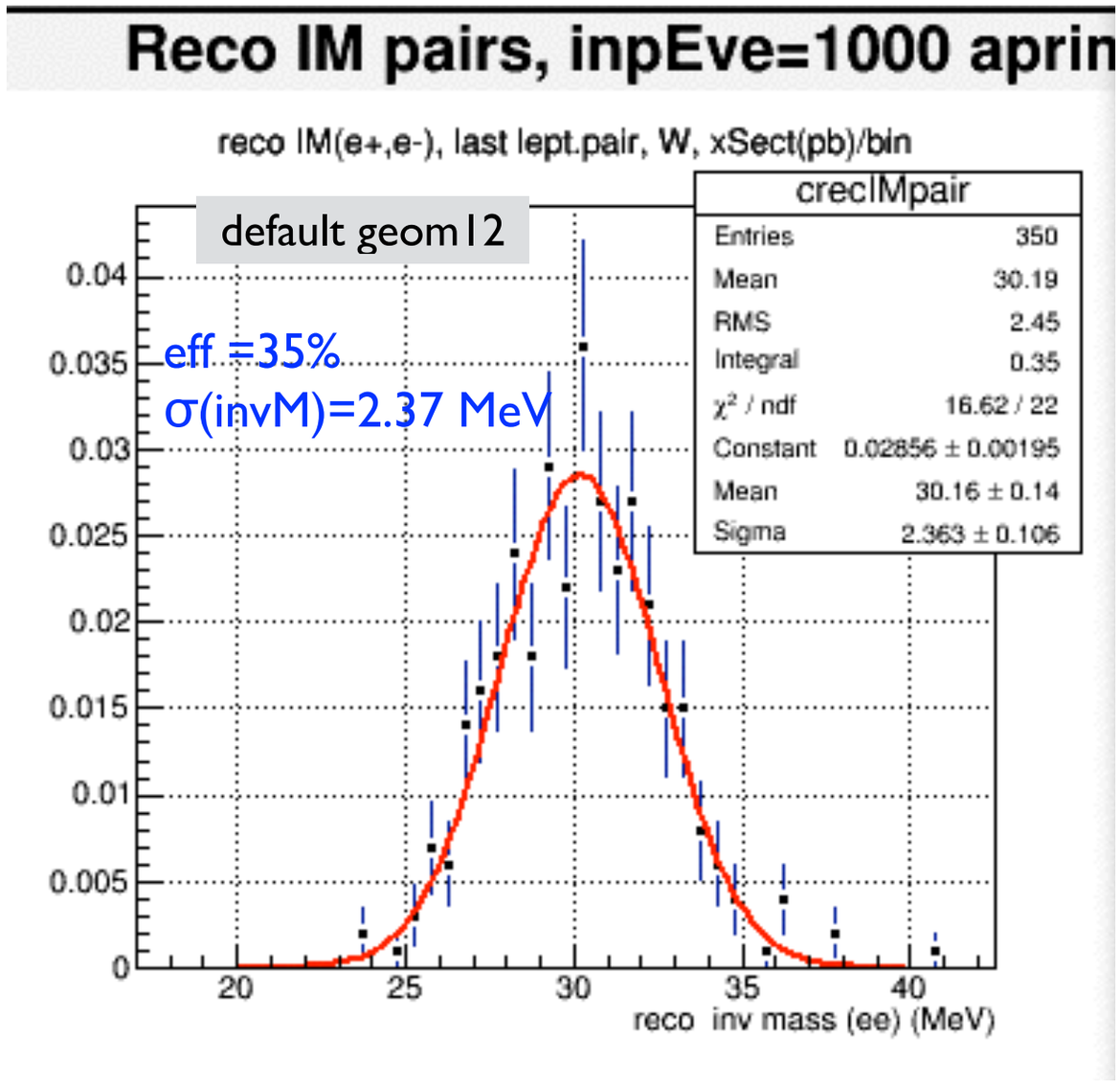
Lepton Momentum spread due to Be pipe



Reconstructed invariant mass of A'



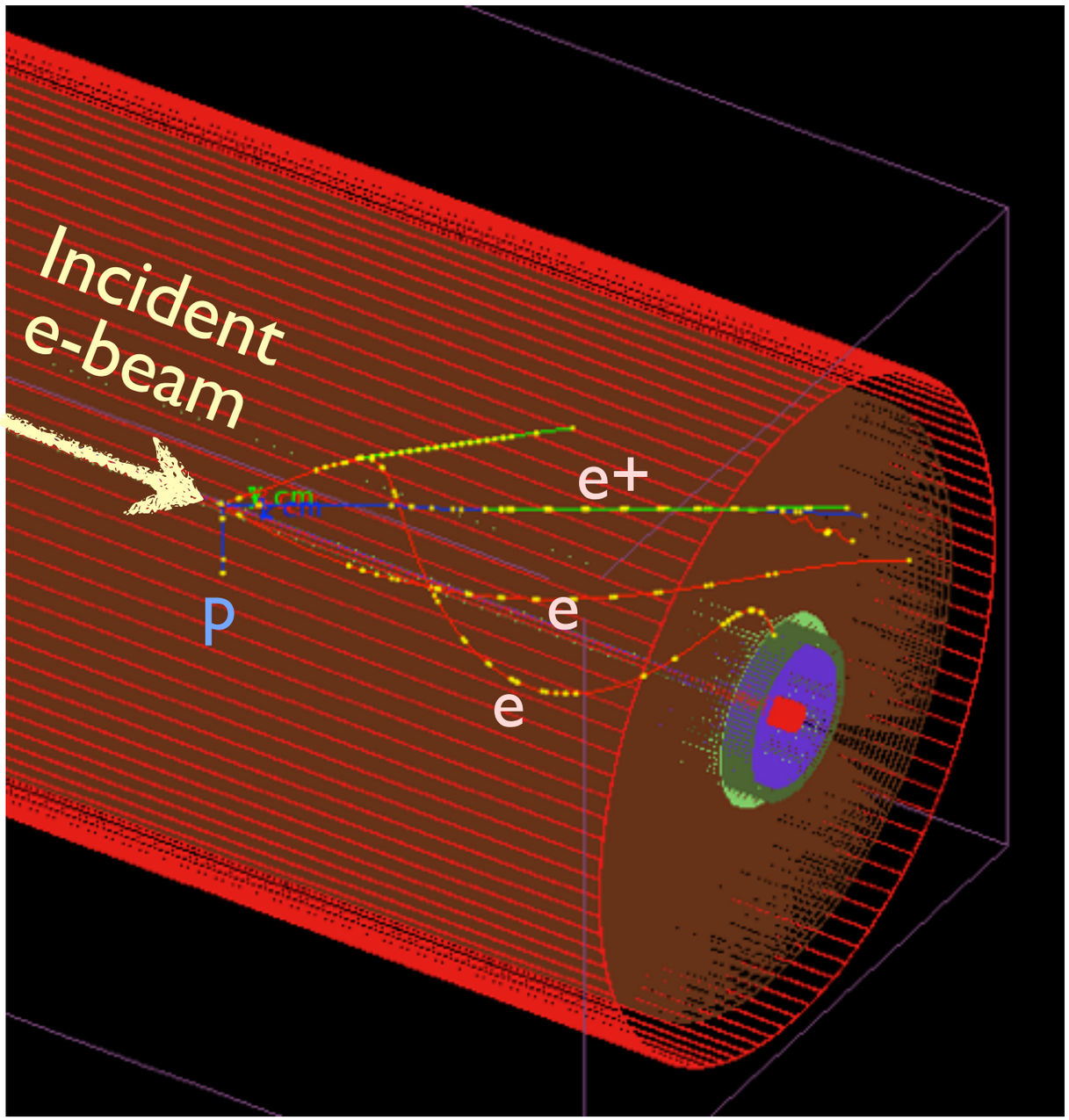
A' -> e+ e- events, PT=60 MeV, PZ=0, M(A)=30 MeV, vert=000, sigSim=0.1 mm

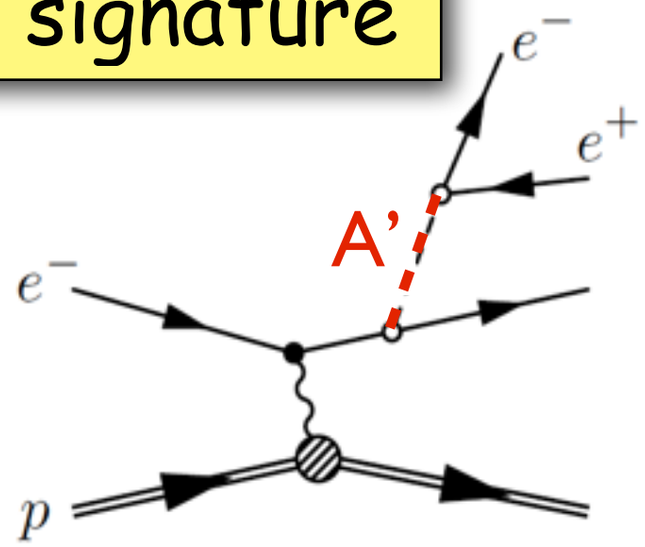


Principle of detecting of dark matter signature

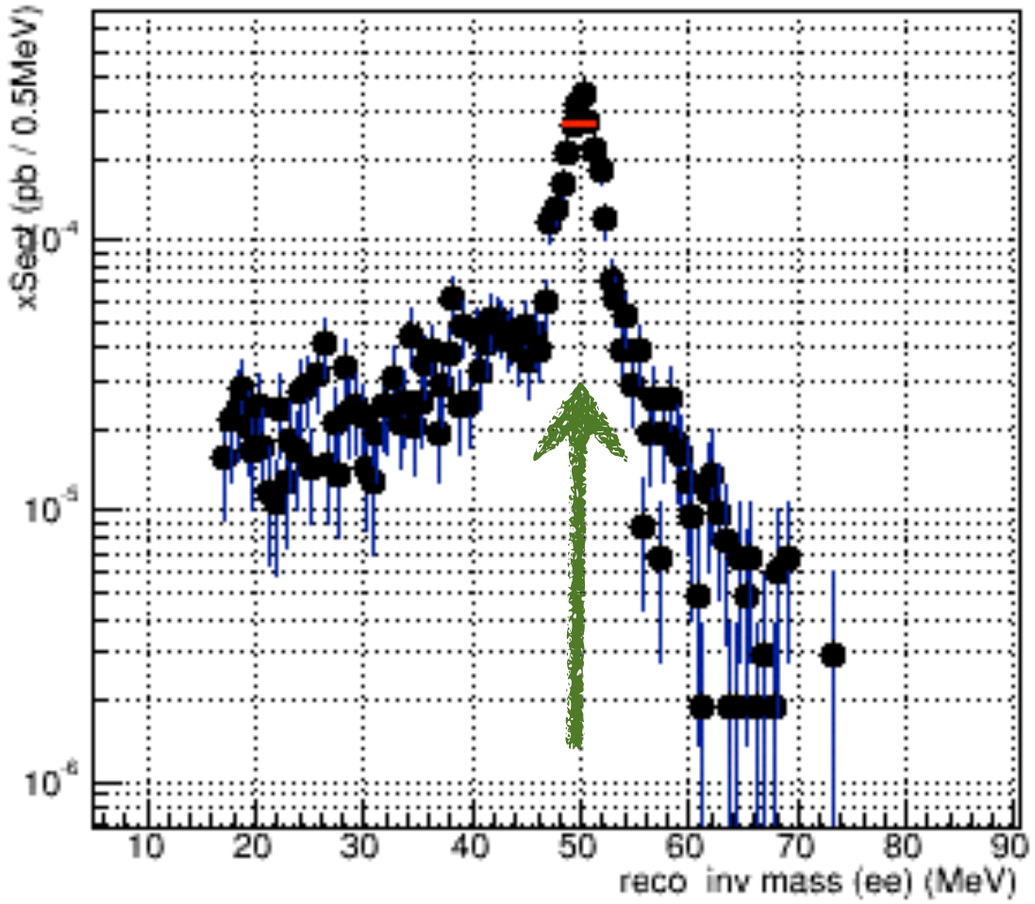
Ee=100 MeV

e p → e- p A'(30 MeV) →e+ e-

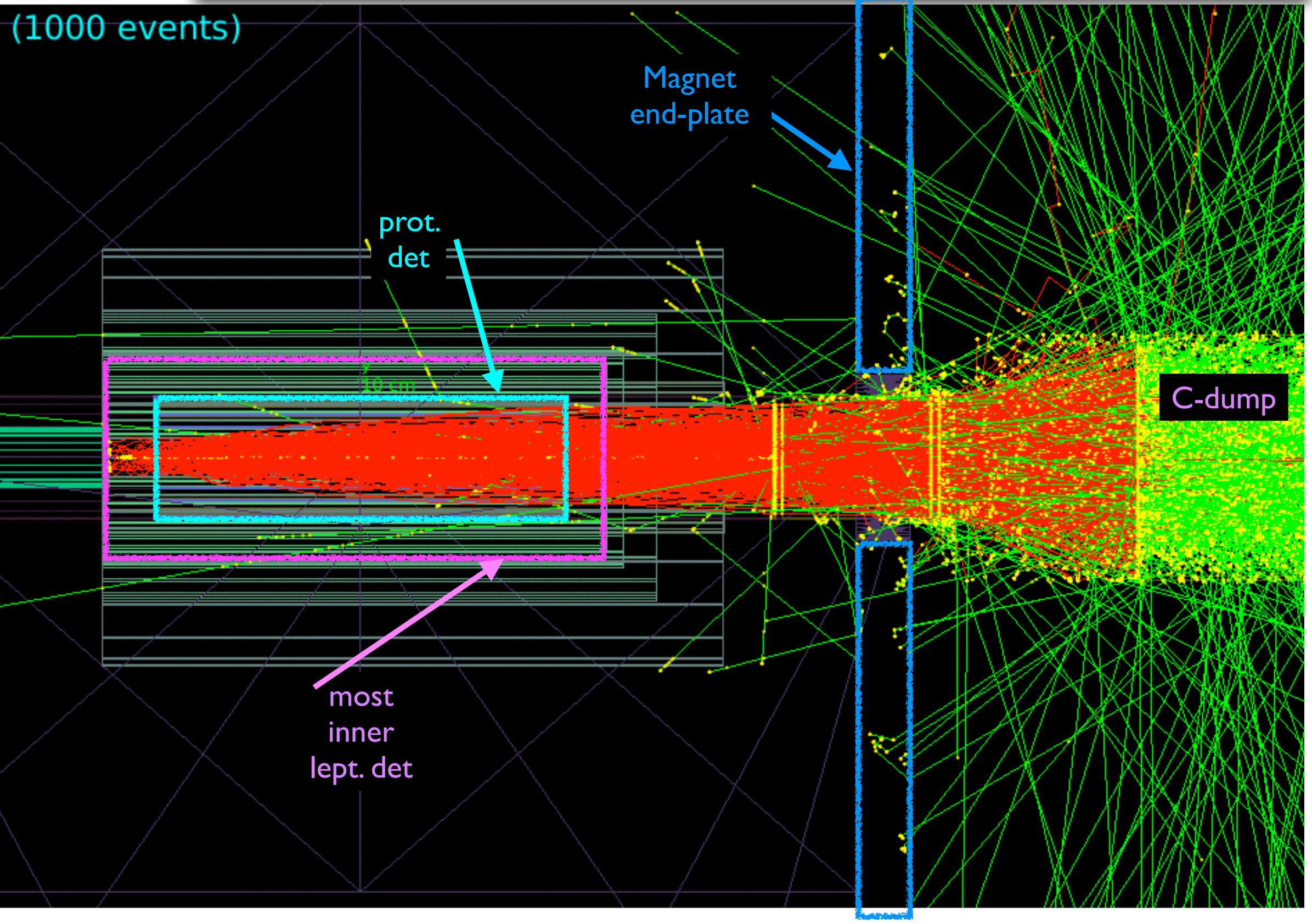




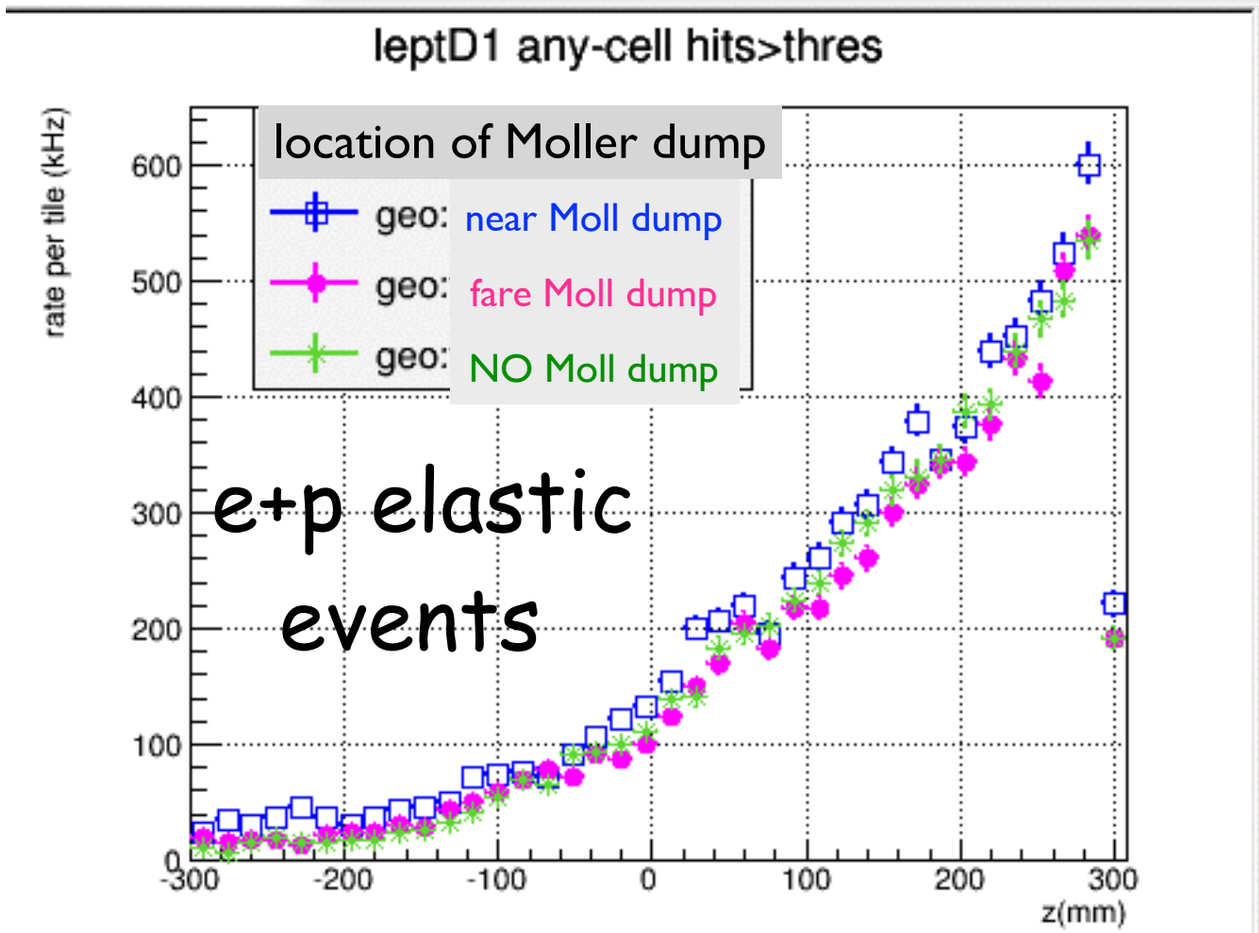
reconstructed **A' signal**
assumed mass of A'=50 MeV

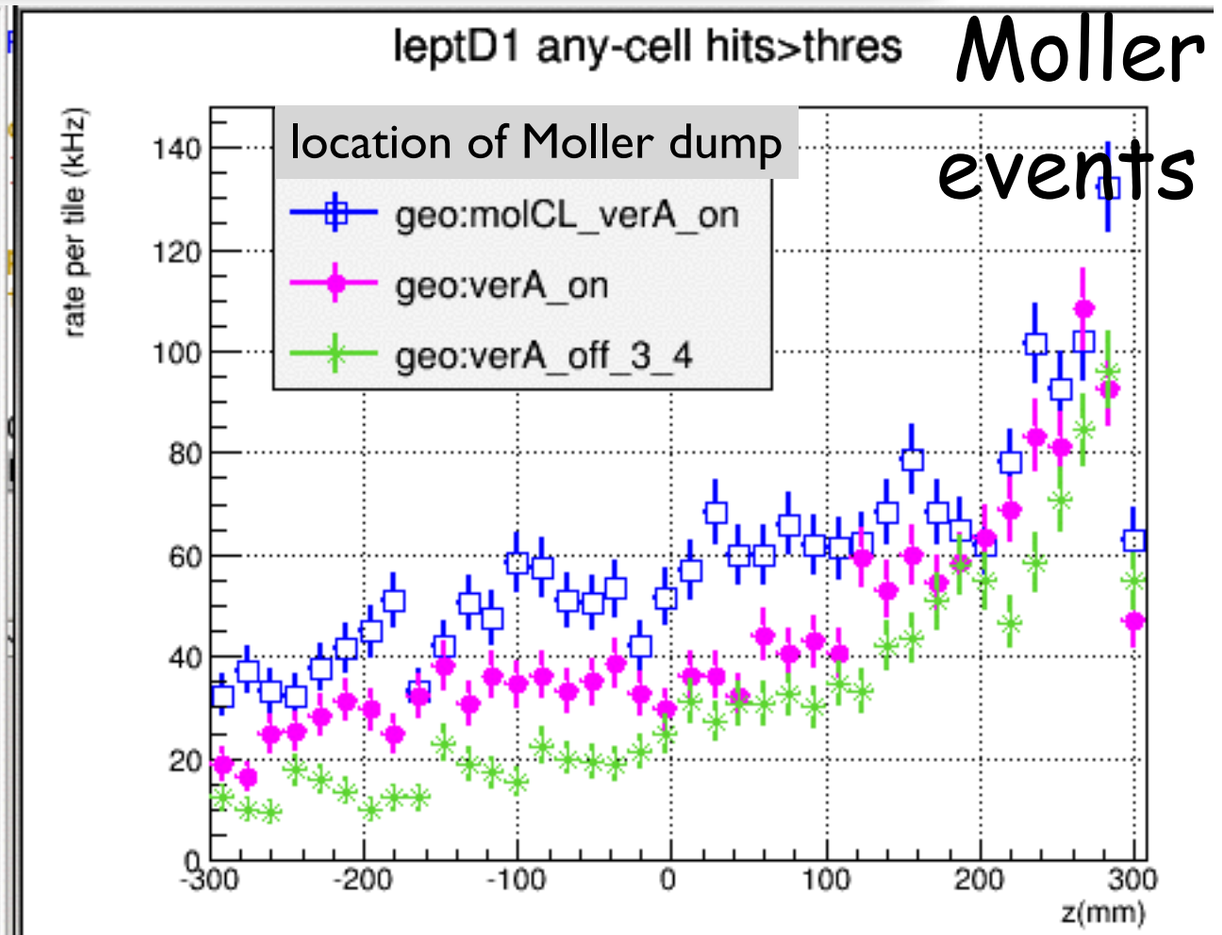


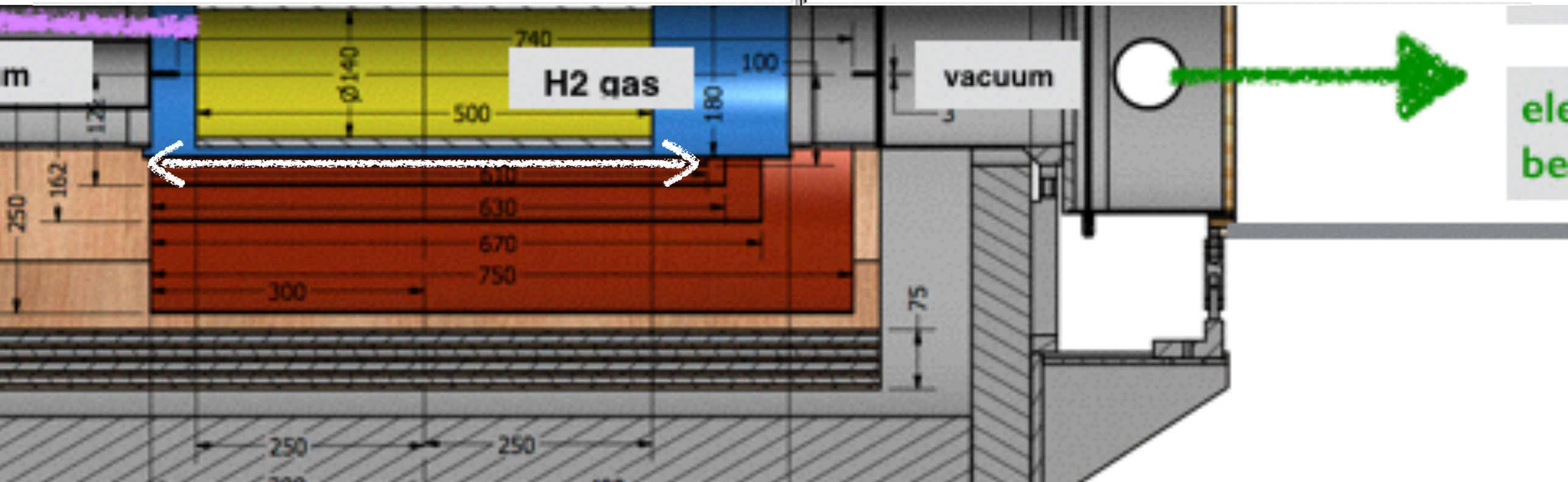
Geant4 simulation of back scattering of Mollers



Estimated background rate in Lepton Tracker

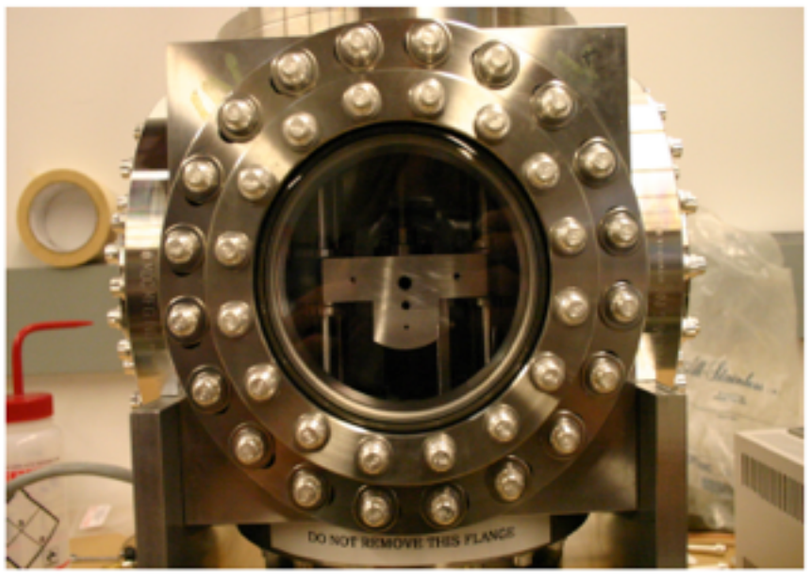




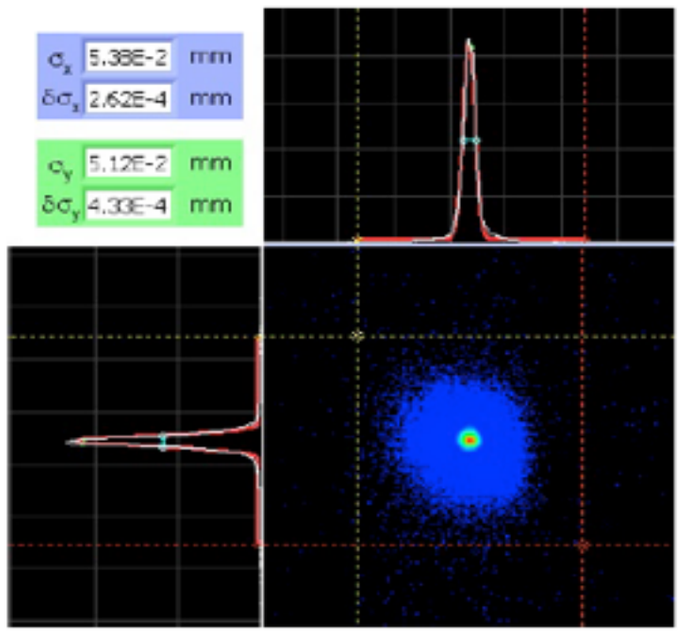


Successful DARKLIGHT beam test

July 2012

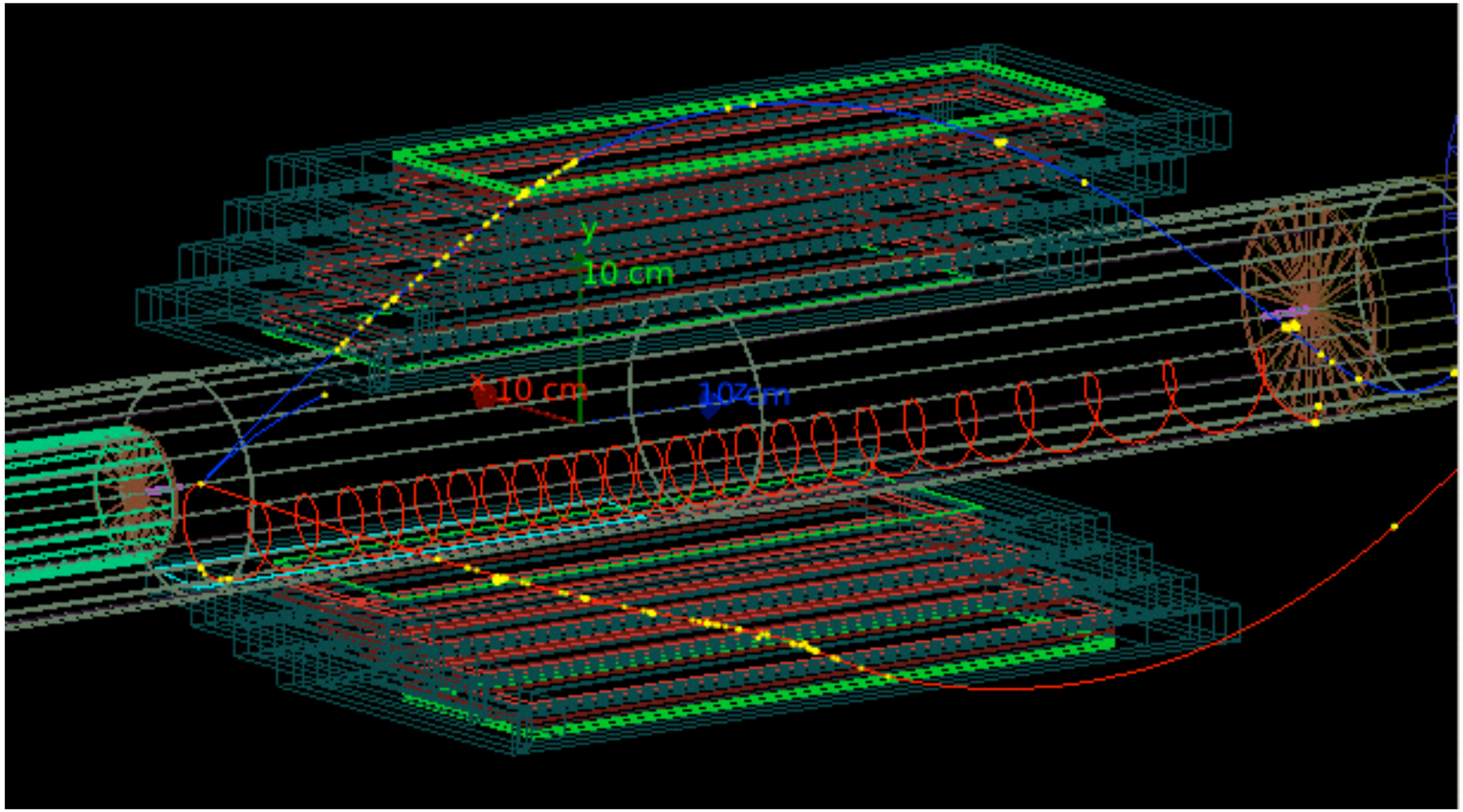


Target system designed and constructed at MIT-Bates R&E Center



- A test beam of 4.3 mA, 100 MeV (430 kWatt of e-beam power) was successfully transmitted through a 2 mm hole, 127 mm long, with a maximum loss of about 3 ppm for seven hours.
- Halo can be minimized and radiation in vault is manageable.
- The ERL has the stability required for DarkLight.
- Three papers written on test: *Phys. Rev. Lett*. **111**, 164801 (2013)
  Nucl. Instr. Meth. **A729**, 233 (2013)
  Nucl. Instr. Meth. **A729**, 69 (2013)

Limited acceptance experiment: Phase 1c

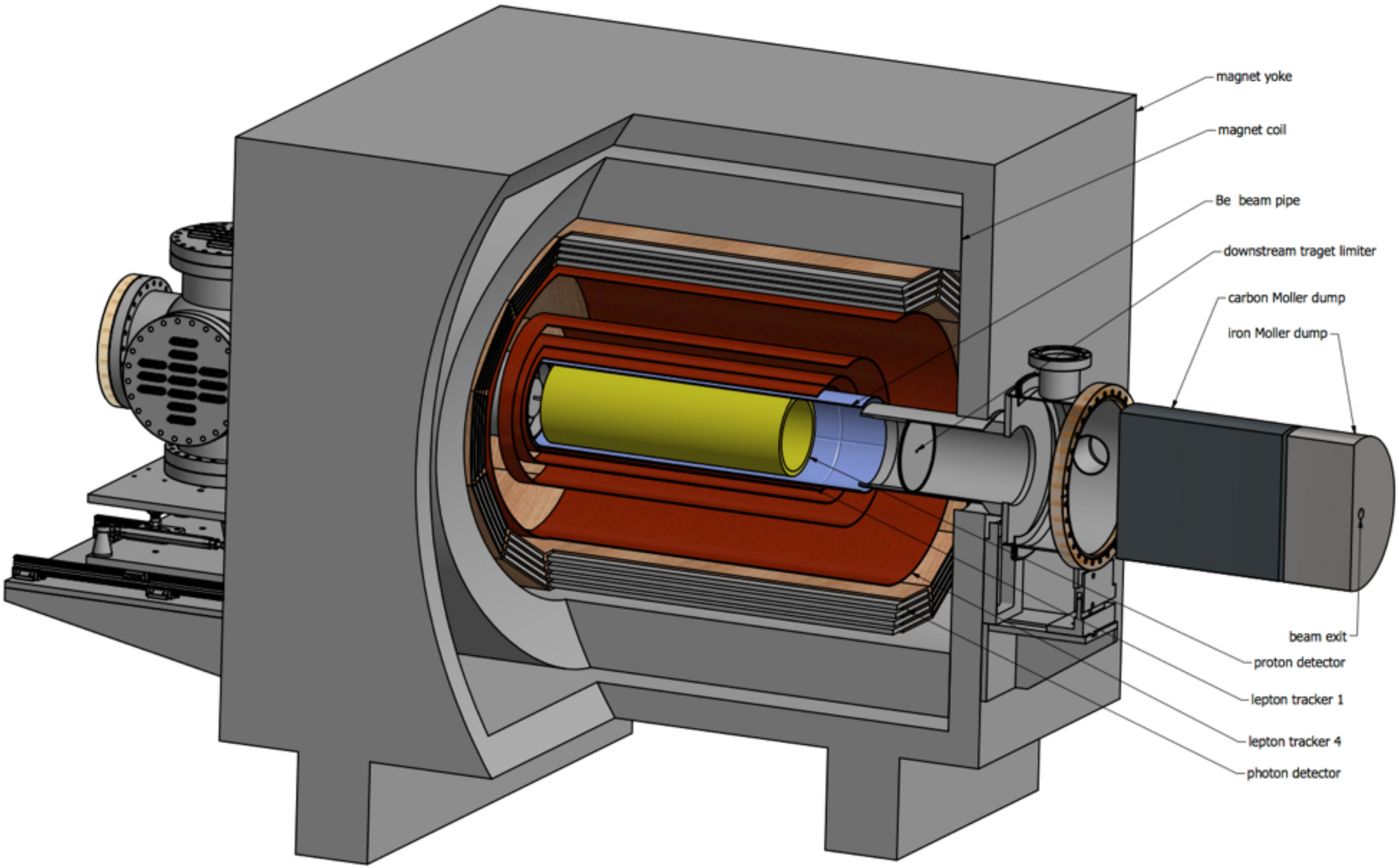


Summary

- The search for new physics beyond the Standard Model must take place at all energy scales
- There are indication for a dark photon in the mass range below 1 GeV. Despite intensive searching no signature of A' found so far
- **DarkLight** is designed to search for dark photon with **increased sensitivity of 5σ** in the mass range 10 to 100 MeV/c by bringing **new experimental techniques**
- **DarkLight** is technically **transformational**: beam, target, detector, and readout
- An MRI proposal to carry out phase-I was founded by the NFS in July 2014. Data taking could begin in 2016
- The full DarkLight experiment design will be finalized in the next 3-4 months, full proposal submission anticipated in the fall of 2015

backups

Conceptual view of DarkLight phase-2



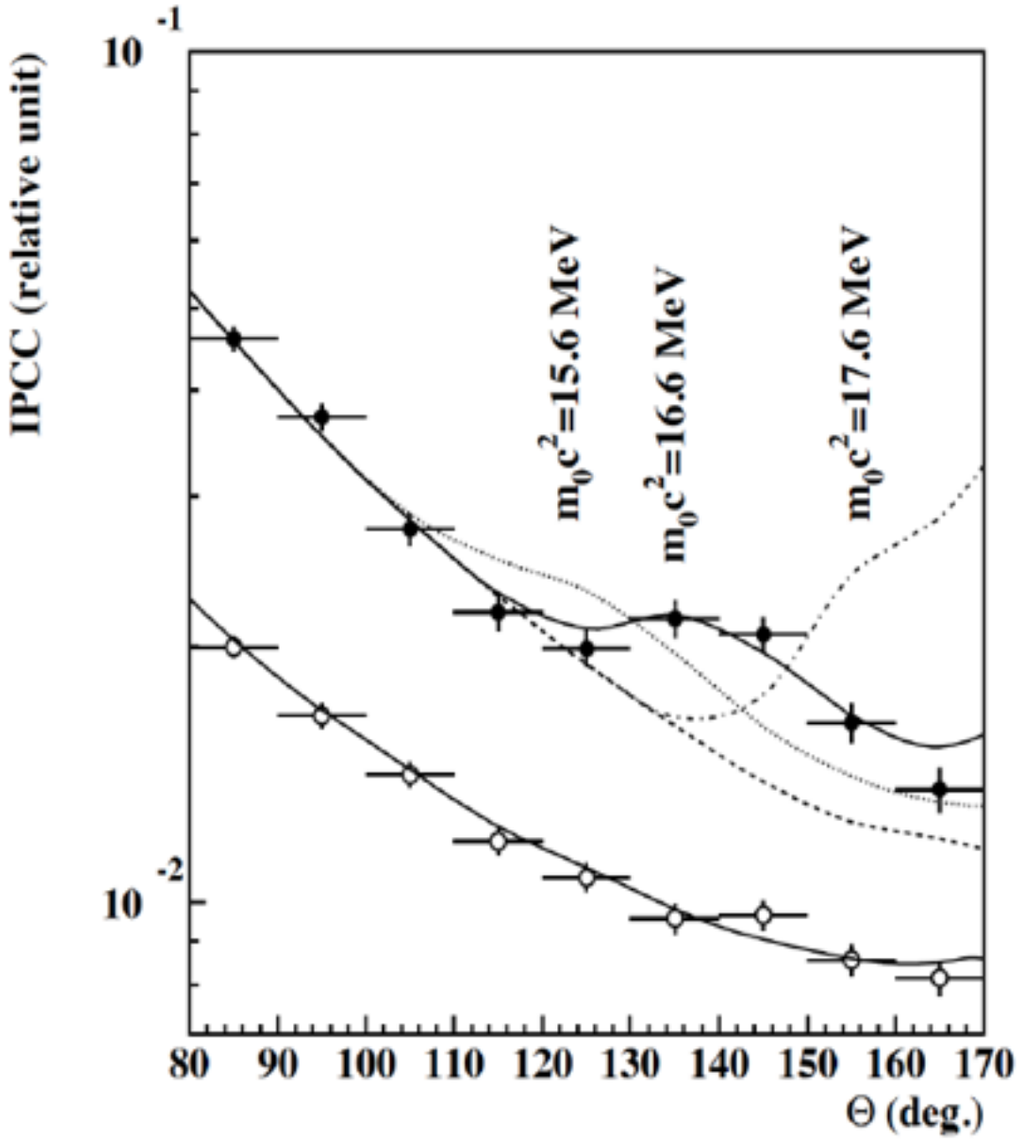
DARKLIGHT Schedule

- DarkLight proposal approved at JLab PAC 39 in June 2012 with "A" scientific rating for 90 days, conditional upon a successful test being completed
- Test successfully completed in July 2012
- Full scientific approval granted in May 2013
- Phase-I experiment funded by NSF MRI July 2014
- Detailed simulations in progress to finalize the design: lepton tracker, trigger and readout
- The OLYMPUS target was shipped back to MIT in summer 2013 and development of the DarkLight target is proceeding.
- The existing 0.5 T solenoid is now at MIT-Bates.
- Anticipate shipping target and solenoid to JLab in fall 2015.
- Anticipate that DarkLight will start to take data early in 2016.

observed anomaly …

Observation of Anomalous Internal Pair Creation in ^{8}Be: A Possible Signature of a Light, Neutral Boson

1504.01527 April 2015

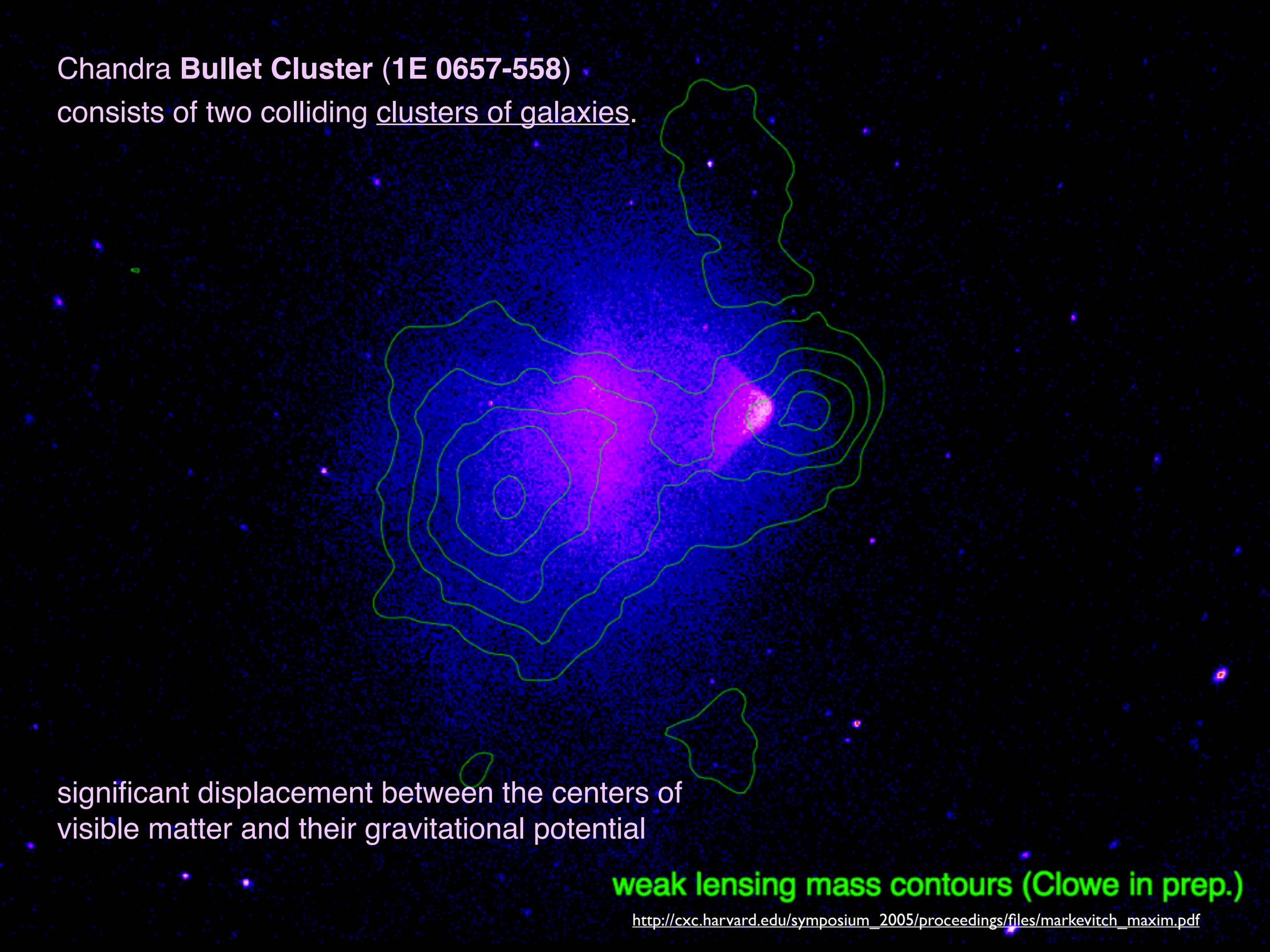


- Use the ^{7}Li(p,γ)^{8}Be reaction at E_p = 0.441 and 1.03 MeV to populate the 17.6 and 18.15 MeV resonances in ^{8}Be
- Measured the e+e- angular correlation in internal pair creation for the M1 transitions depopulating the 17.6 and 18.15 MeV states
- Observed anomolous internal pair creation in the 18.15 MeV transition
- Ascribe it as due to a boson of mass
  16.7 ± 0.35 (stat.) ± 0.5 (syst.) MeV
- Estimate A'/γ branching ratio of order 5.8×10^{-6}

Ongoing A' searches

- KLOE-2@DAϕNE(ϕ➔ϕA' followed by A'➔e+e-)
- HADES@GSI (p+p, p+^{93}Nb, p+^{40}Ar, ^{84}K+^{35}Cl production: π^0,η, Δ decay followed by A'➔e+e-)
- BaBar@SLAC (e+e-➔Υ➔γA' with A'➔μμ)
- WASA@COSY (π^0 decay)
- PHENIX@RHIC (π^0 decay)
- NA48@CERN (π^0 decay)
- APEX@JLab (e on ^{181}Ta)
- A1@MAMI (e on ^{181}Ta)
- ATLAS and CMS @LHC
- HPS@JLab (e on ^{184}W)
- SeaQuest @ FNAL
- DarkLight @ JLab ERL
- milliQ @ SLAC: invisible search

Chandra **Bullet Cluster** (**1E 0657-558**)
consists of two colliding clusters of galaxies.



significant displacement between the centers of
visible matter and their gravitational potential

weak lensing mass contours (Clowe in prep.)

http://cxc.harvard.edu/symposium_2005/proceedings/files/markevitch_maxim.pdf