Dark Matter/Forces & Axions Session Review

Gordan Krnjaic

Intense Electron Beam Workshop
Cornell University, June 19, 2015

The Galactic Centre Excess: Review, Interpretation and Future Directions

Nick Rodd - MIT

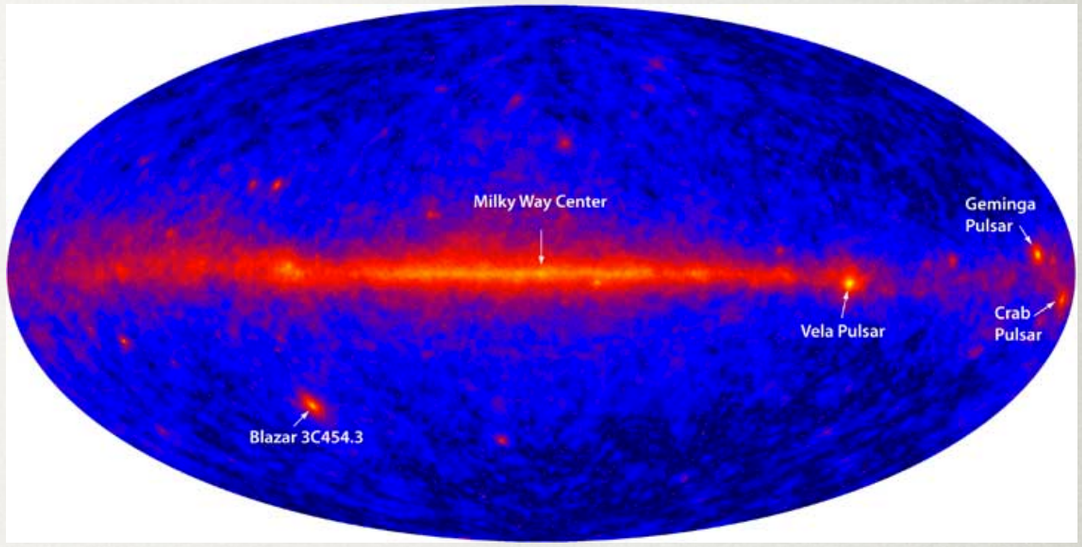
Intense Electron Beams Workshop
06/18/15

Image Courtesy of NASA Goddard/A. Mellinger (Central Michigan Univ.) and T. Linden (Univ. of Chicago)

GCE Review: Fermi Satellite

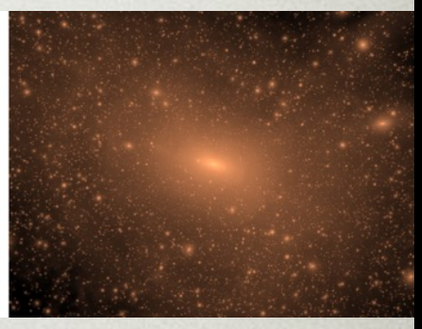
- Fermi Large Area Telescope (LAT)
  - Wide field of view - covers the entire sky in 2 orbits
  - Energy range: 20 MeV - 300 GeV
  - Data publicly available

The Gamma-Ray Sky



- Where should we look for signs of DM annihilation? Recall photon flux from DM annihilation:

$$\Phi(E_\gamma, l, b) = \frac{\langle \sigma v \rangle}{8\pi m_\chi^2} \frac{dN_\gamma}{dE_\gamma} J(l, b)$$



Particle physics: what the DM is

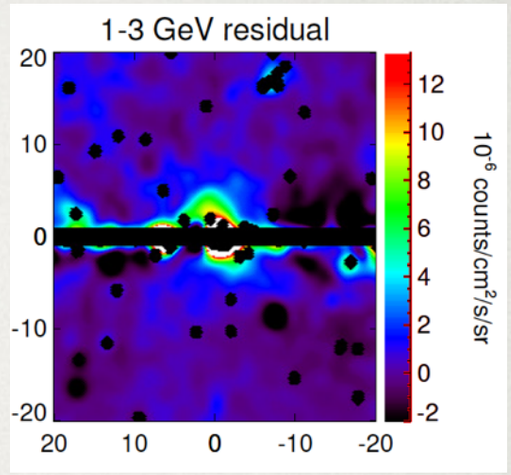
Astrophysics: how the DM is distributed

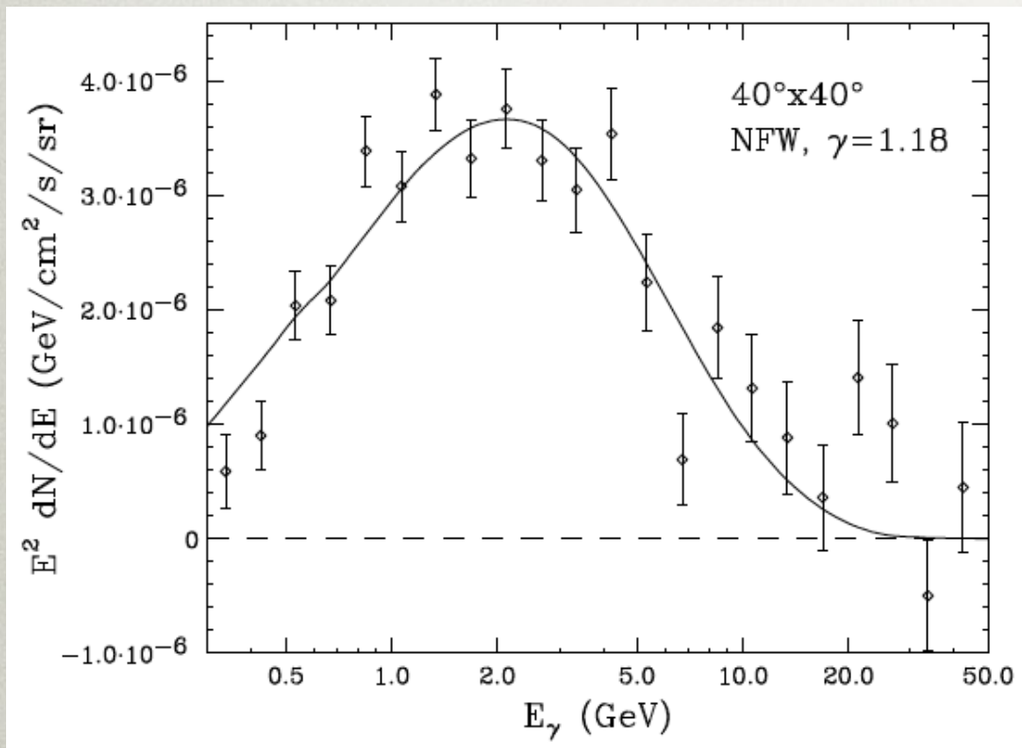
- Galactic centre has the largest value of J on the sky - good place to look
- Find an excess over the expected background: **Galactic Centre Excess**

GCE Review: Spectral Properties

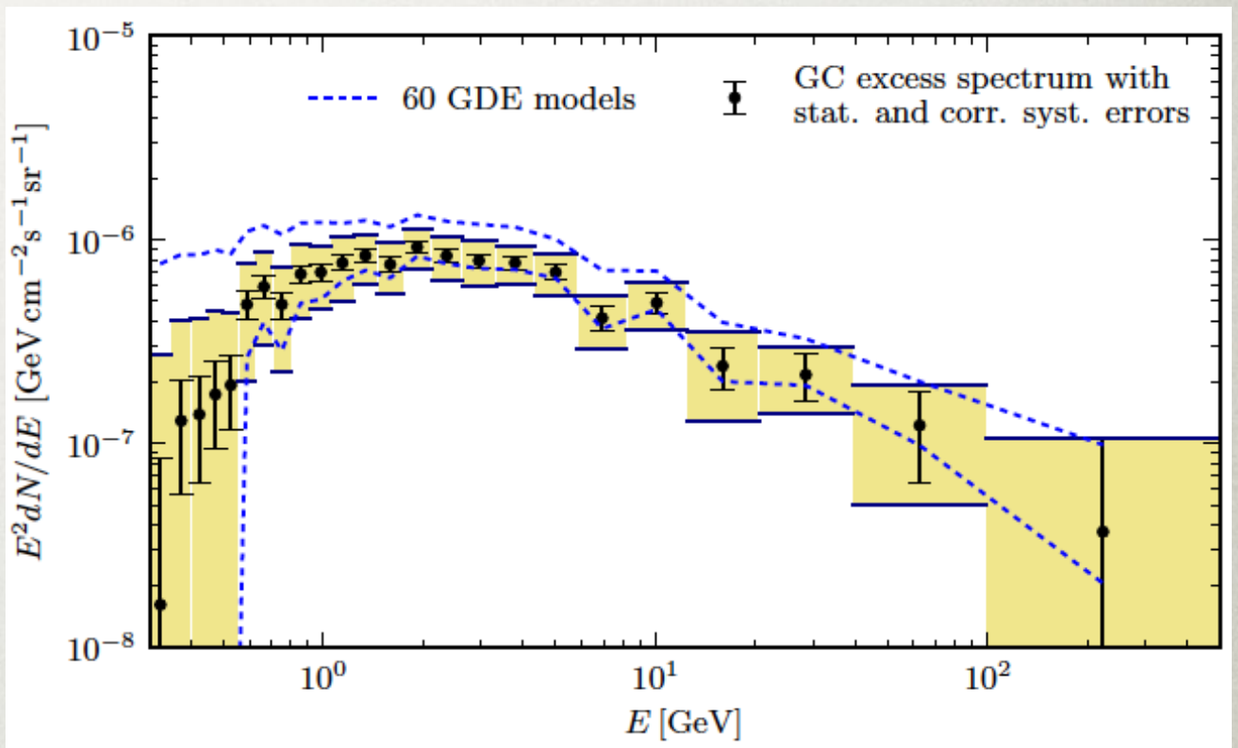
Spectrum is the emission correlated with a generalized NFW squared profile integrated along the line of sight, as determined by a template fit

$$\rho(r,\gamma) = \rho_0 \frac{(r/r_s)^{-\gamma}}{(1+r/r_s)^{3-\gamma}}$$





Result from Daylan, NLR et al - overlaid is spectrum of 43.0 GeV DM annihilating into b-quarks with $\sigma v = 2.25 \times 10^{-26}$ cm^3/s



Result from CCW - includes systematics

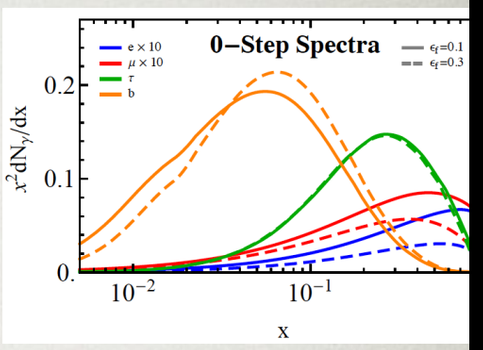
NB: NFW templates normalized differently

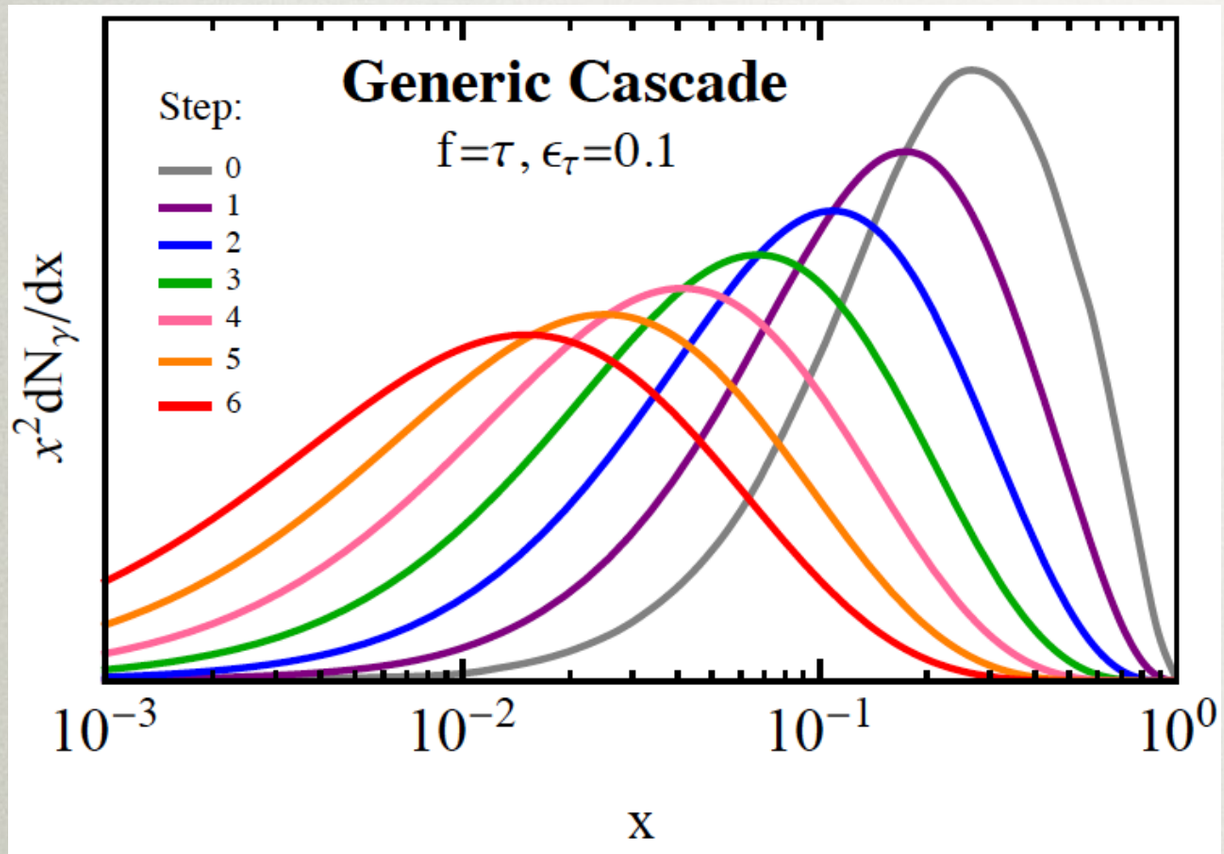
Cascade Spectra

Add a step in the dark sector

$$\underbrace{\chi\chi \to}\ \phi_1\phi_1\ \underbrace{\to 2 f \bar{f}}$$

$$\epsilon_1 = m_1/m_\chi \qquad \epsilon_f = 2m_f/m_1$$





Generically cascade spectra:

- are described by just f, ε_f and the number of steps in the large hierarchies regime
- are peaked at lower x, allowing higher mass DM to fit the GCE
- are broader, opening the way for final states with sharper direct spectra
- can ease tension with direct detection and collider bounds (see e.g. 1405.0272 or 1404.6528)
- can provide an approximation to more complex dark sectors that might involve hadronization

Conclusions

- The Galactic Centre Excess is an interesting potential DM signal - still a long way from a conclusive answer though
- Cascade spectra are much simpler than one might expect:
  - Spectrum determined by three parameters: n, ε_f and f
  - The preferred m_χ-$\langle\sigma v\rangle$ for GCE is determined by the power into photons and the width of the spectrum
- Cascades in the dark sector increases the viable mass and cross section parameter space for the GCE
- Exactly how much depends on whether we attribute high energy data points to the excess
- Initial results of looking at the high energy tail of the GCE suggest the excess extends to at least 10 GeV and maybe higher, but these results are still preliminary

The Heavy Photon Search Experiment at Jefferson Lab

Takashi Maruyama, SLAC
For the HPS Collaboration

Intense Electron Beams Workshop
Cornell University, June 17-19, 2015

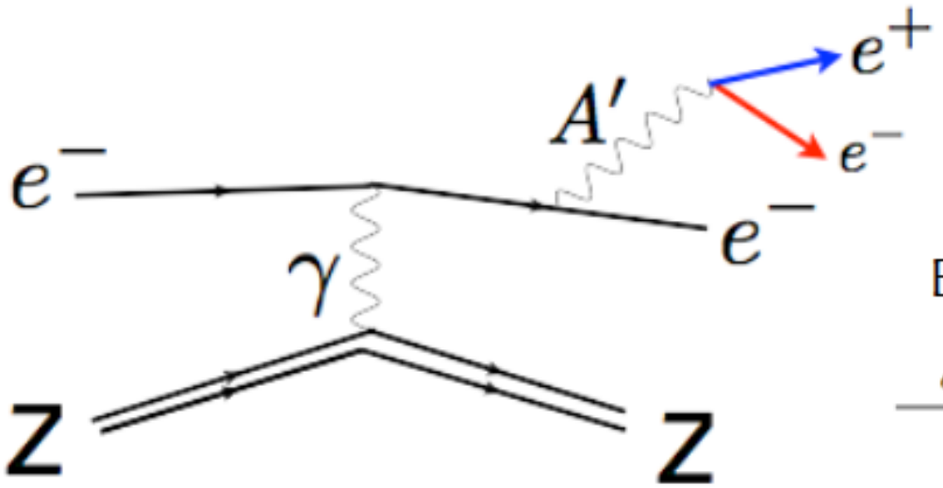
U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Fixed Target Searches

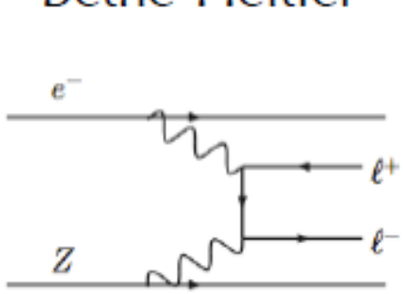
SLAC

Look for radiated A' decay to e^+e^-, ($\mu^+\mu^-$)

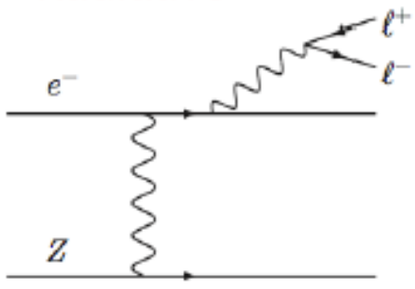


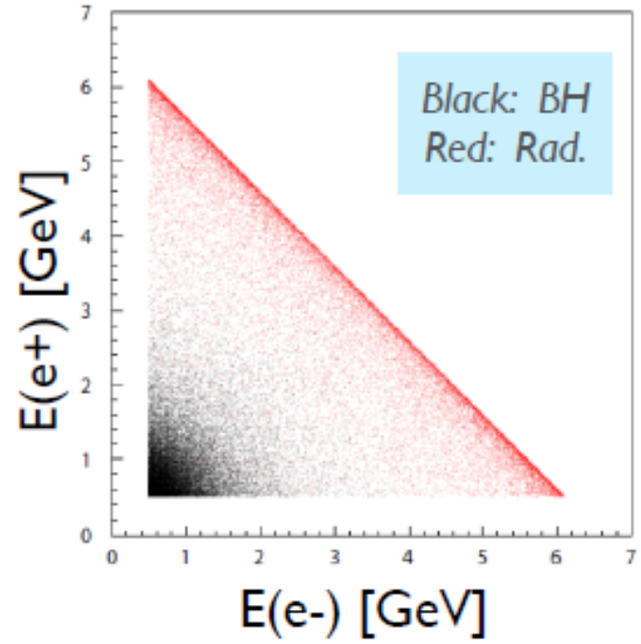
$\sigma_{B\text{-}H}$ very large » $\sigma_{Rad.}$
But kinematically distinct → Use clever trigger to separate.

Bethe-Heitler



Radiative





Bump Hunt:
Look for signal over background.

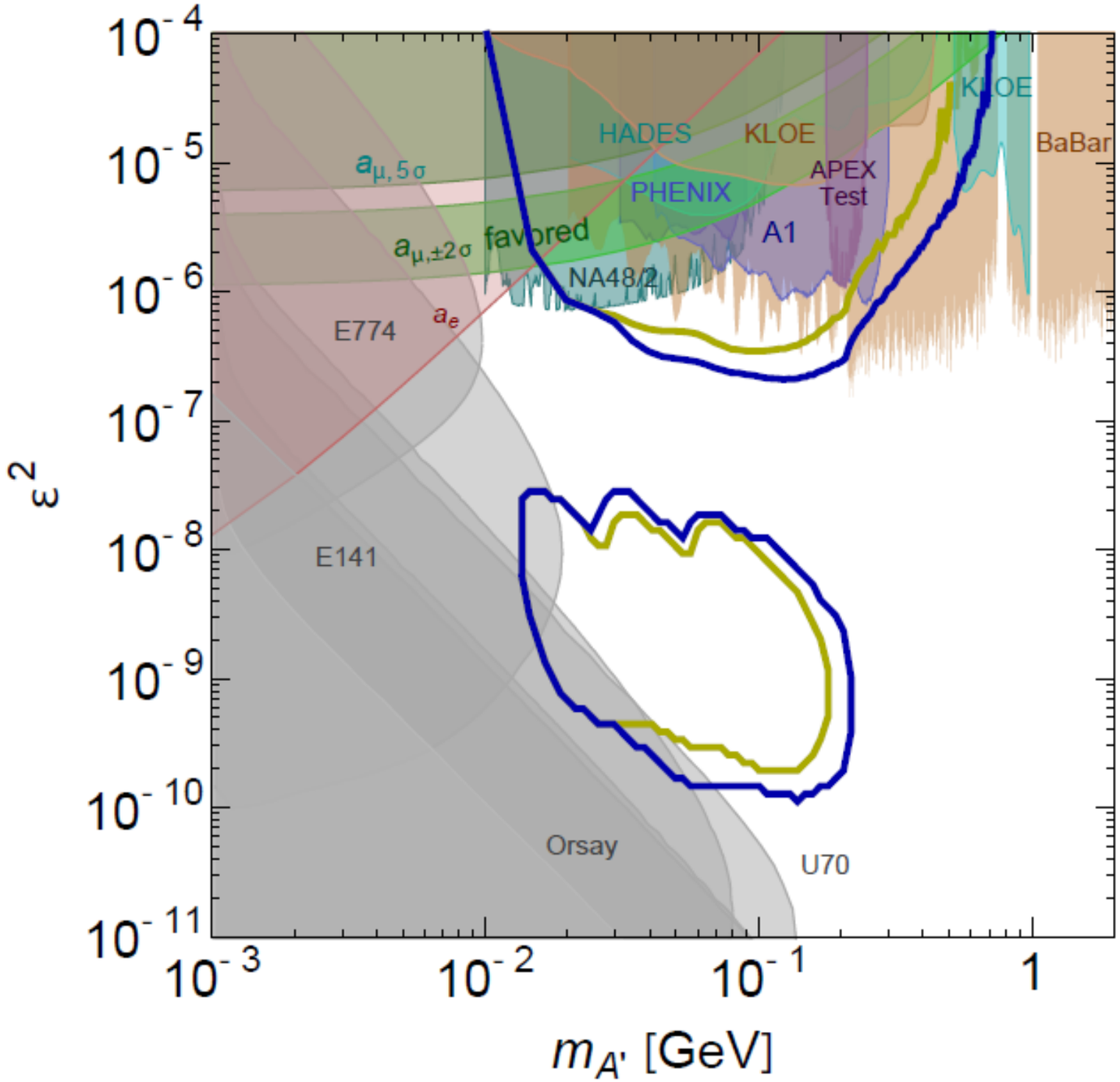
Bump Hunt + Vertexing:
Look for signal over background, reduce background with vertexing.

Very high luminosities: Intensity Frontier Physics.

P. Schuster, R. Essig et al, Intensity Frontier WS '11 summary paper.

BEST: *Bjorken, Essig, Schuster, Toro, Phys.Rev. D80 (2009) 075018*

Full HPS Reach



Near term Running (Yellow)

1 week with 50nA @ 1.1 GeV
1 week with 200nA @ 2.2 GeV
2 weeks with 300nA @ 4.4 GeV

Additional Running (Blue):

2 weeks with 200nA @ 2.2 GeV
2 weeks with 300nA @ 4.4 GeV
3 weeks with 450nA @ 6.6 GeV

Times are "PAC" times = Calendar time/2

Opportunistic run Fall 2015
TBD Spring 2016

Summary

- We have roughly 1/3 PAC week with Si at 0.5 mm
  - 15 mrad acceptance
- Beamline, ECal, Trigger and SVT all worked well
  - Beam background and trigger rates are consistent with simulations.
- Lots of work to do ..
  - Check Trident Yield in the data
  - ECal energy calibration
  - SVT alignment
  - Understanding the vertex tails
- But a physics result may be in reach

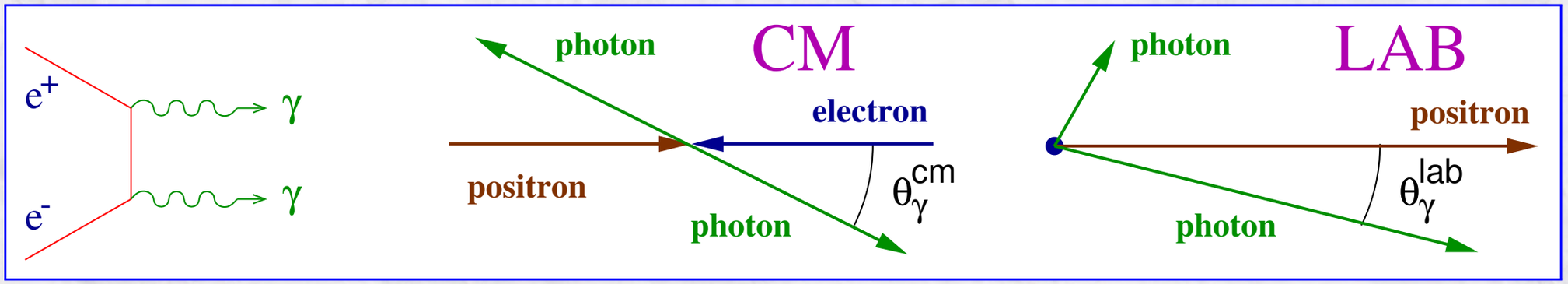
Search for a **Dark Photon:** proposal for the experiment at VEPP–3.

I.Rachek, B.Wojtsekhowski, D.Nikolenko

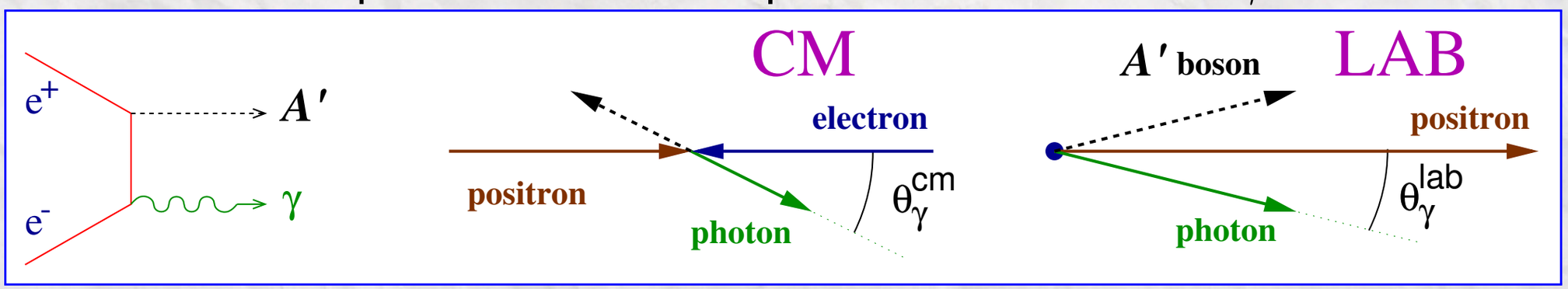
IEBWorkshop
Cornell University
June 18, 2015

A′ from annihilation of beam's positrons and target electrons

instead of standard two-photon annihilation $e^+e^- \to \gamma + \gamma$



. . . annihilation with the production of dark photon $e^+e^- \to A' + \gamma$:

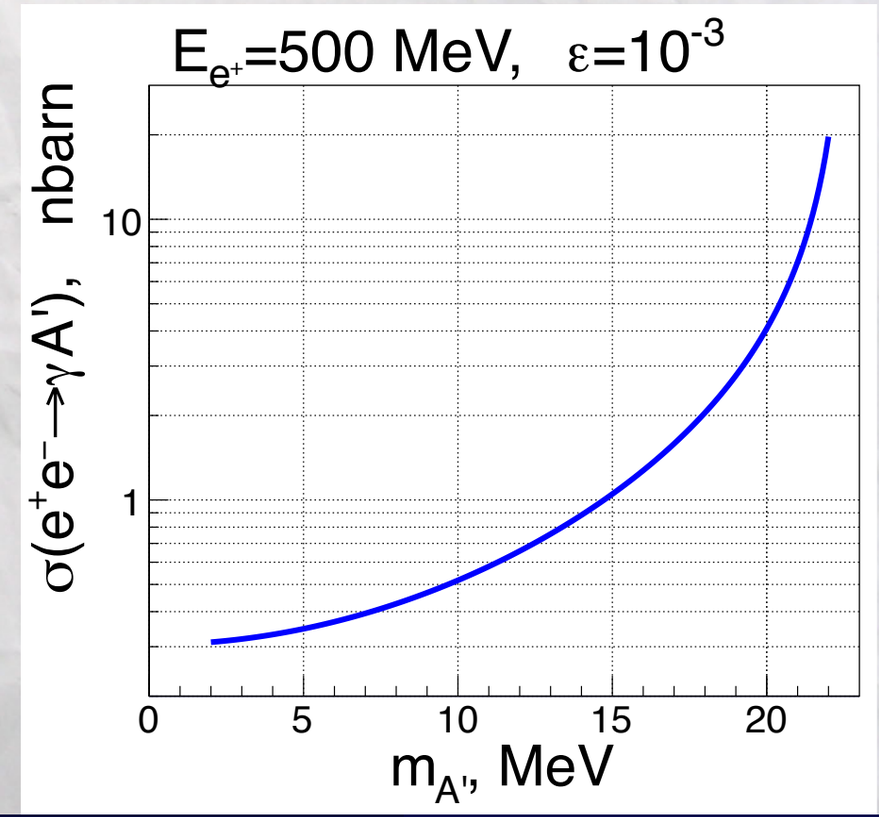


differential cross section (in Lab System):

$$\frac{d\sigma}{dy} \approx \varepsilon^2 \cdot \frac{\pi r_0^2}{y\gamma_+}\left[\frac{(1+\mu)^2}{1-(y+\mu)} - 2y\right]$$

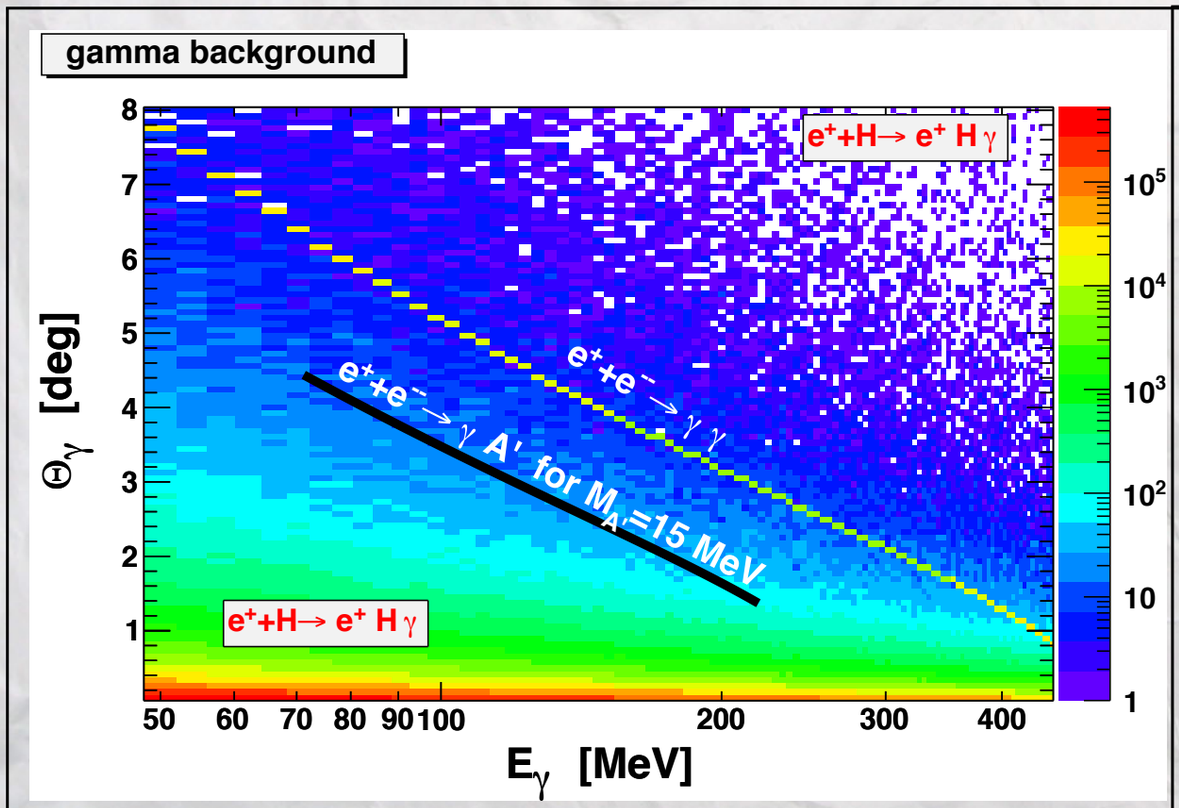
where

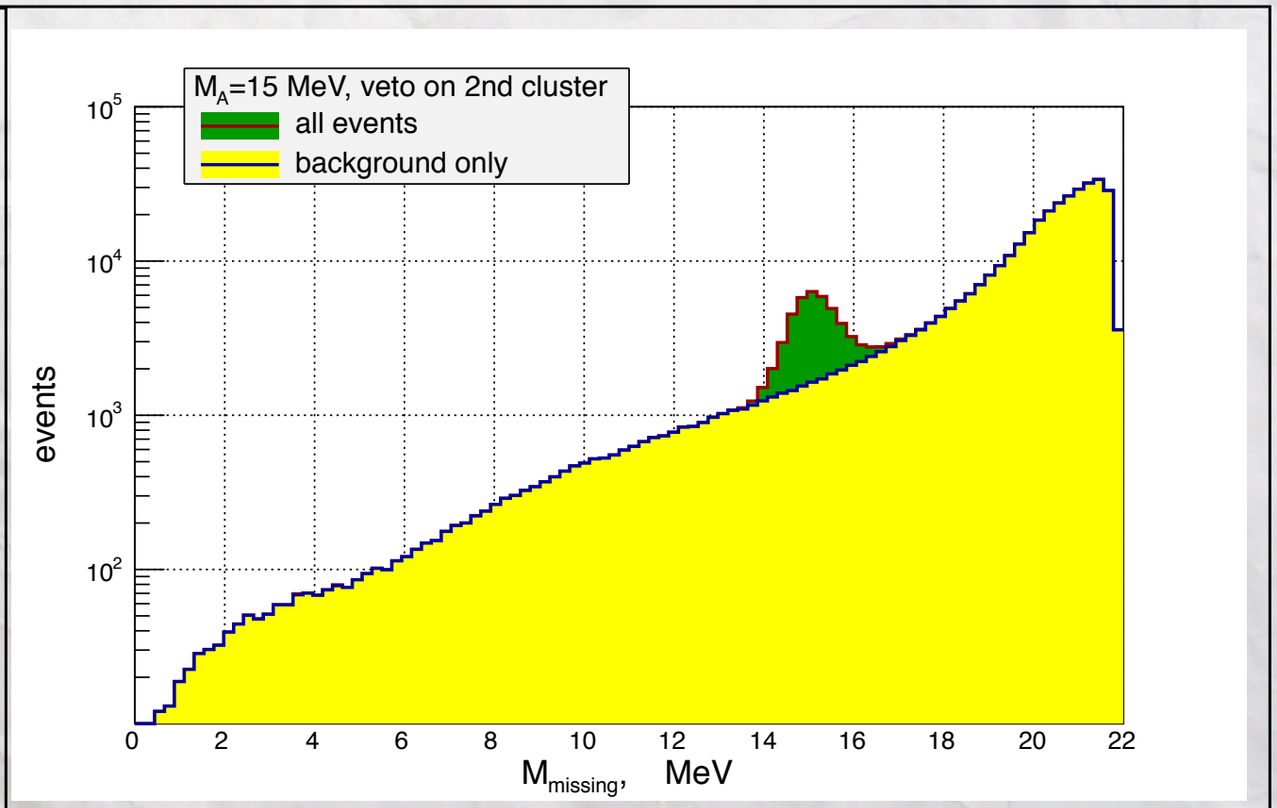
$y = E_\gamma^{lab}/E_+$, $\mu = M_A^2/s$



The concept of search in annihilation

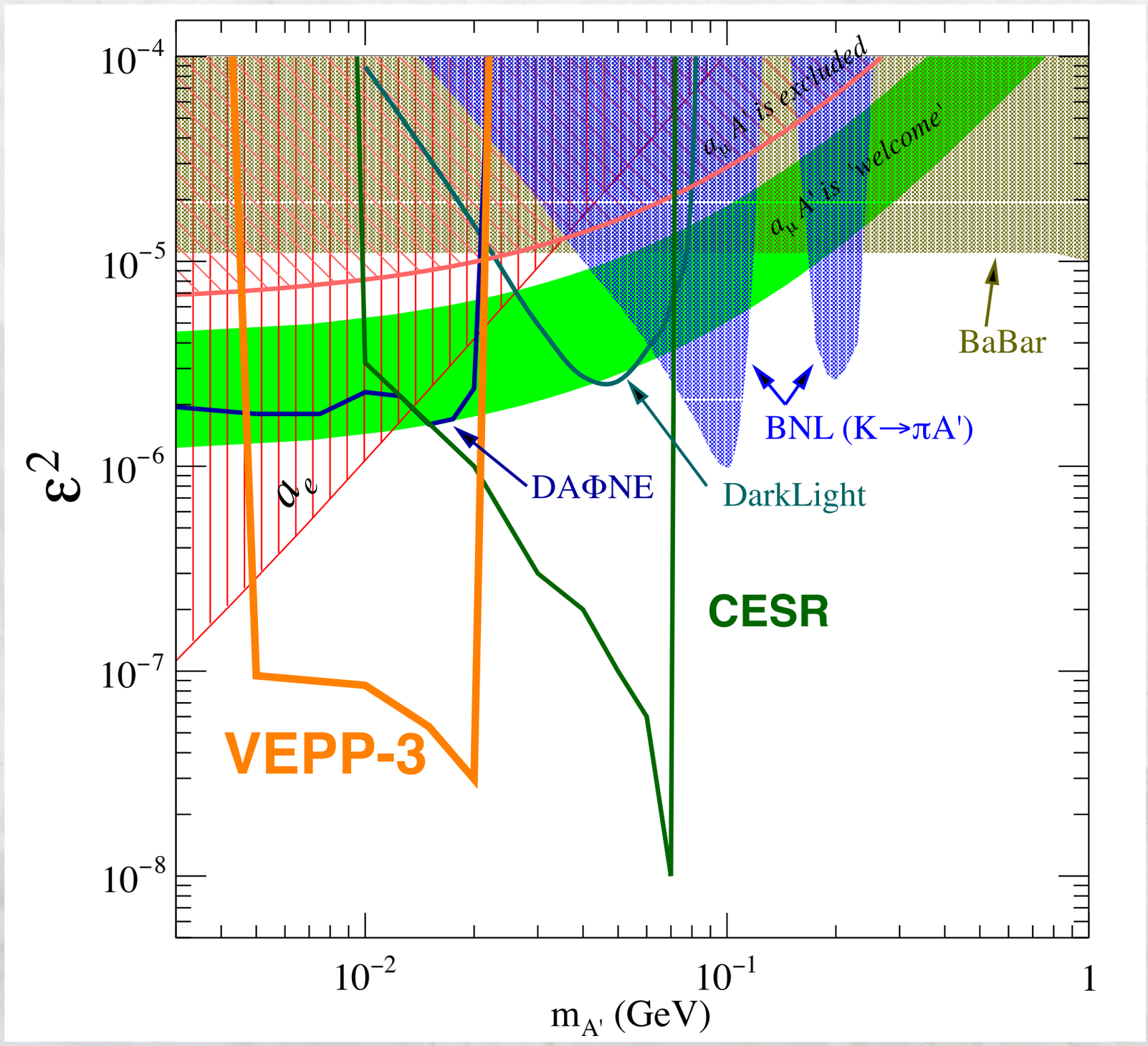
- measure energy and emission angle of γ-quantum
- search for a "bump" on top of QED background
- A'-boson should appear in a missing mass spectrum as a peak above QED background:
- peak width is defined by energy and angular resolutions of the γ-detector





Search sensitivity: decay mode-independent search of A'

Invisible decay of A'



Existing constraints

decay mode-independent:

- muon $(g_\mu - 2)$
- electron $(g_e - 2)$

invisible:

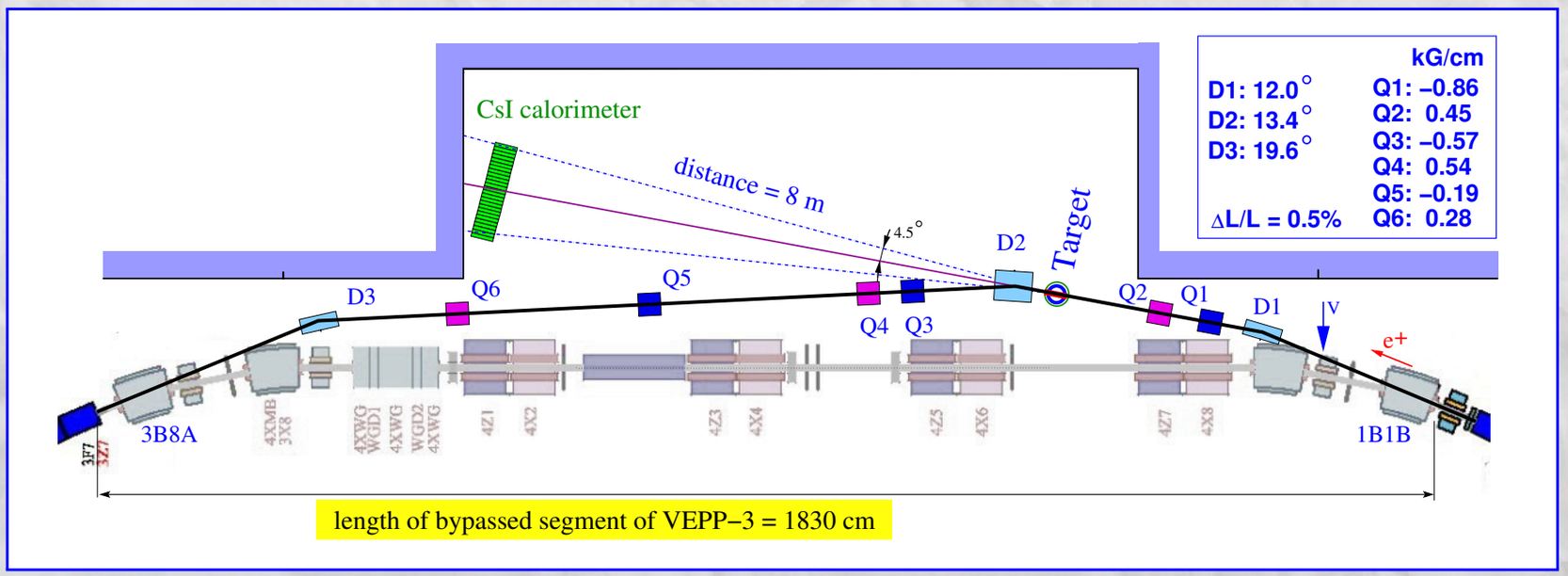
- BaBar $\Upsilon(1S) \to \gamma A'$
- BNL: K$\to \pi A'$

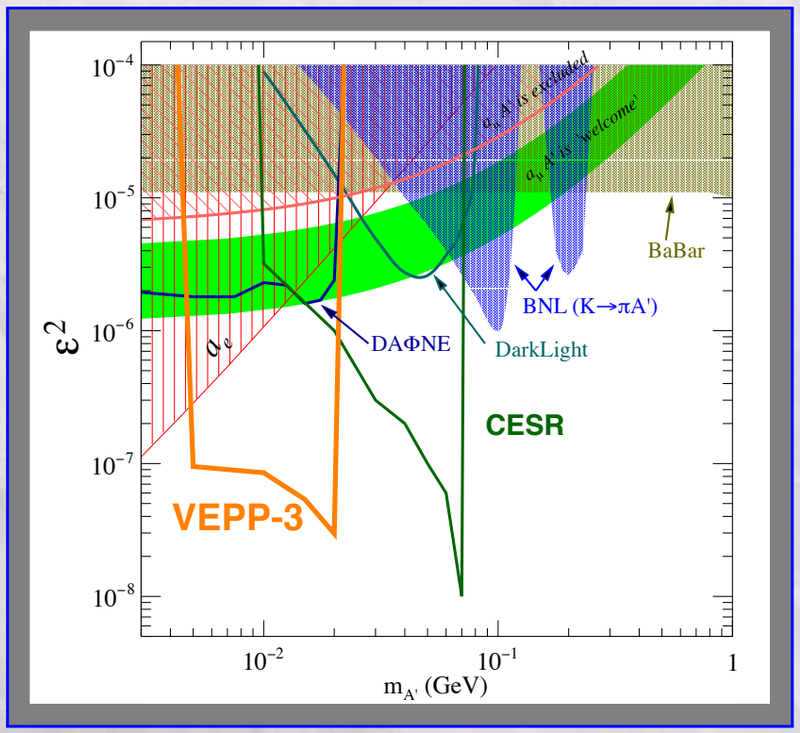
Proposed measurements

	$\mathcal{L}$	duration, s
VEPP-3:	10^{33},	10^7
CESR:	10^{34},	10^7
DAΦNE:	10^{28},	$2 \cdot 10^7$
DarkLight	$6 \cdot 10^{35}$	$2 \cdot 10^6$

Conclusion

- A decay mode independent search for a dark photon is effective in a setup with an intense positron beam and an internal hydrogen gas target.
- Crystals from the CLEO endcap EM-calorimeter would be a good choice for the photon-detector.
- If the proposal is accepted the measurement at the ByPass at VEPP-3 can be prepared and performed in 3-4 years.
- Budker Institute has a good opportunity to contribute to the worldwide hunt for a dark photon.





The DARKLIGHT Approach

- motivation
- apparatus
- method
- milestones

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

Jan Balewski

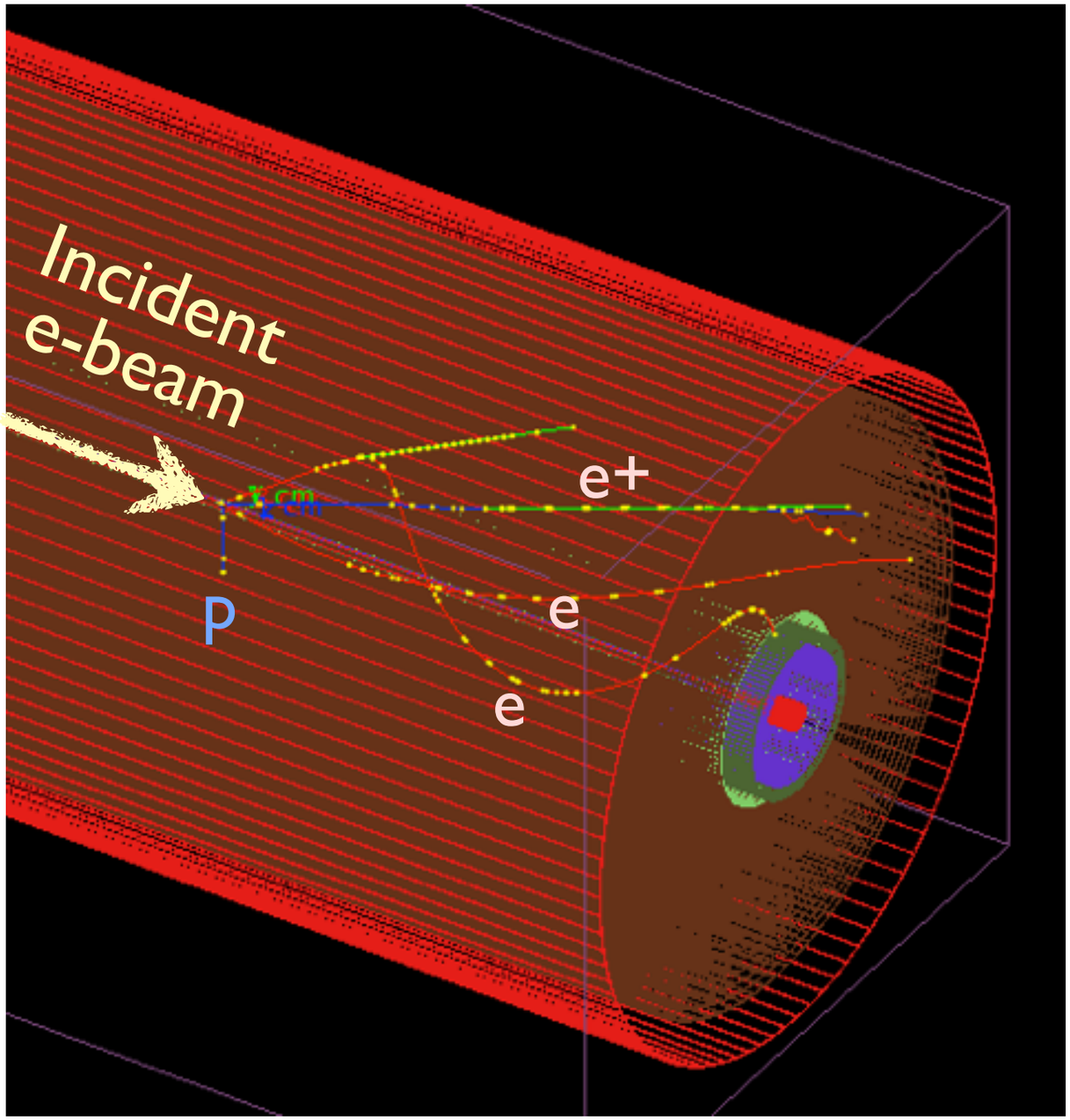
MIT

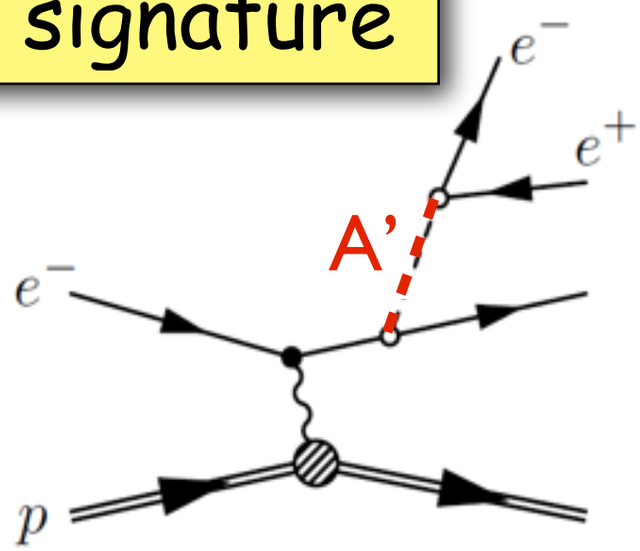
LNS
Laboratory for Nuclear Science

Principle of detecting of dark matter signature

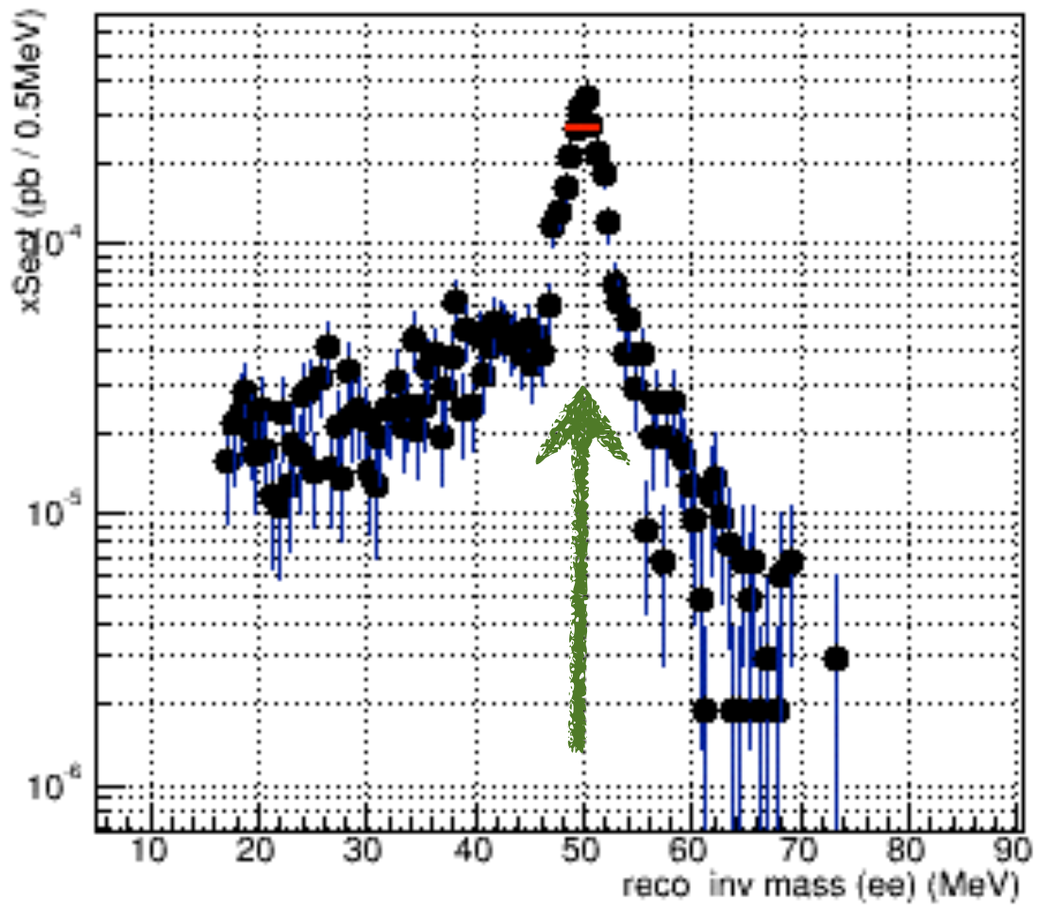
Ee=100 MeV

e p → e- p A'(30 MeV) →e+ e-

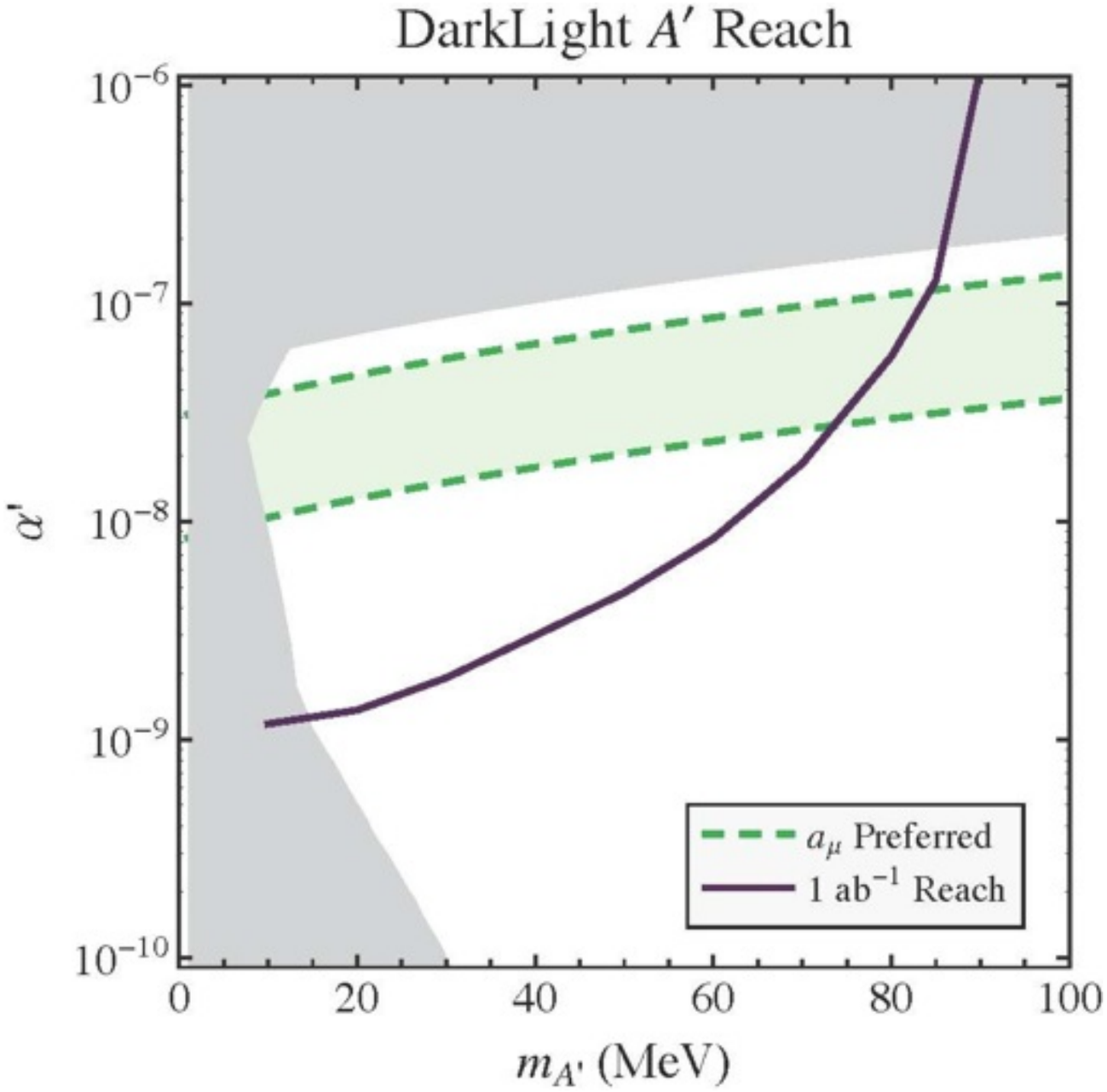




reconstructed **A' signal**
assumed mass of A'=50 MeV



Sensitivity A'→e+e-



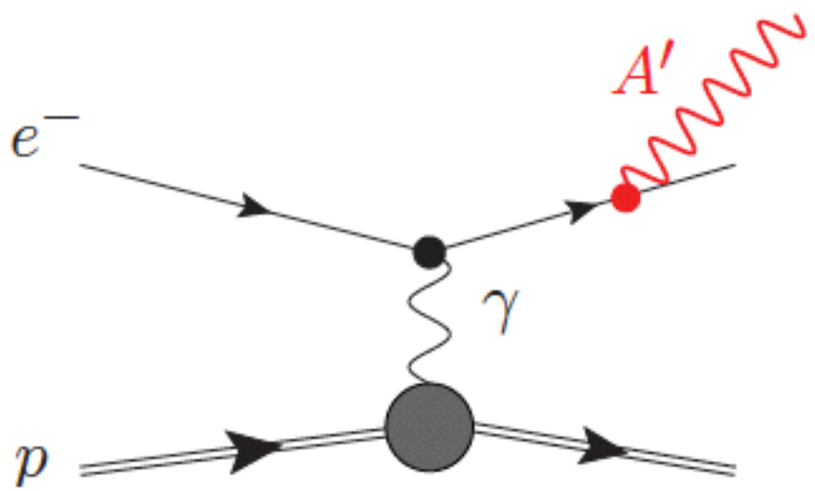
- Precision test of QED radiative processes in electron-proton elastic scattering as $Q^2 \rightarrow 0$
- Completely calculable
- Complete reconstruction of final-state
- 5σ discovery limit
- 1 ab^{-1} attained in several months of data taking with 10 mA at 100 MeV on 10^{19} cm^{-2} target
- Green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

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

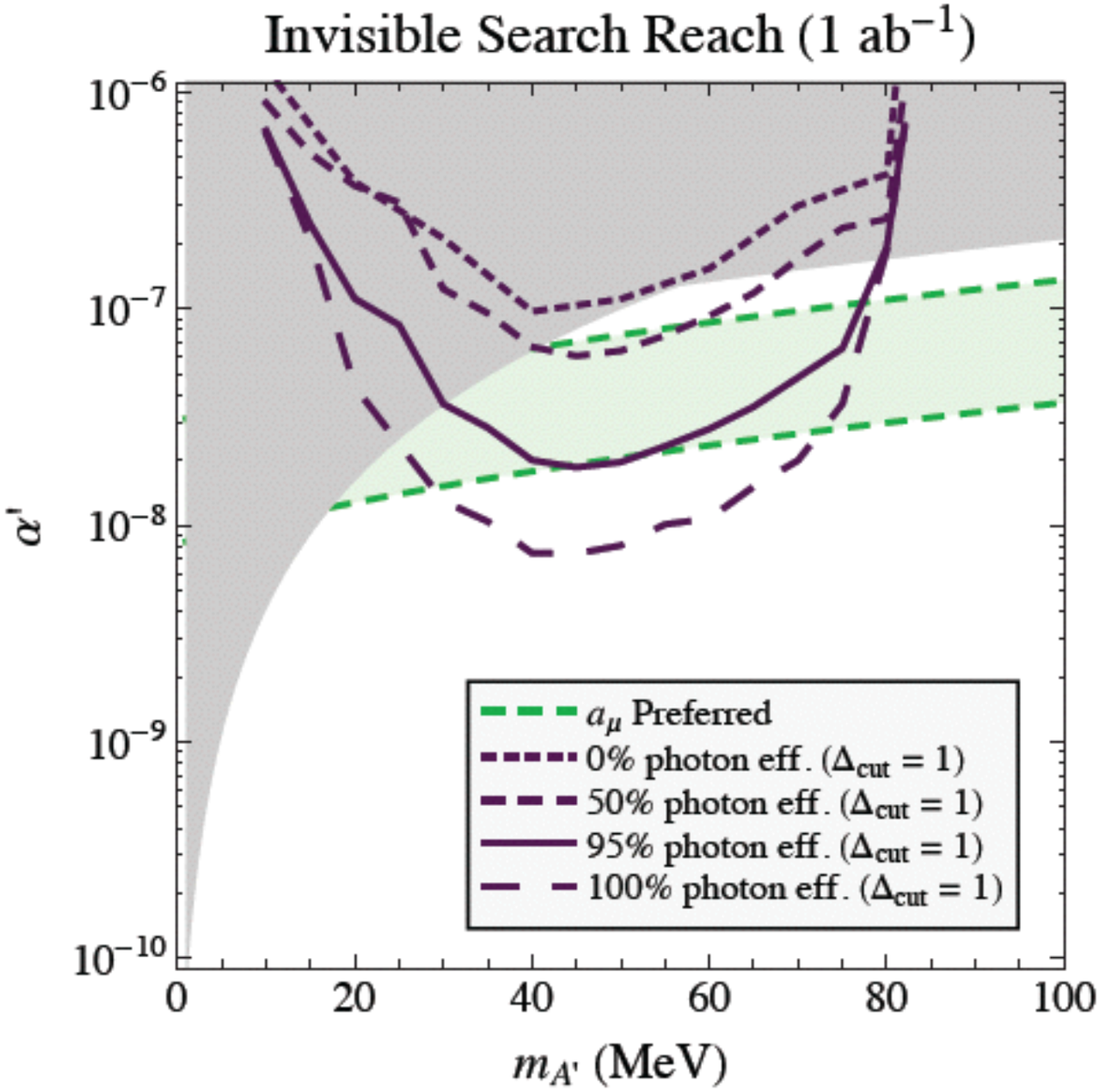
Sensitivity A'→invisible

Bremsstrahlung:

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



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



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

e^- Beam Dump eXperiment(s) to Search for Light Dark Matter

Gordan Krnjaic

& **Eder Izaguirre, Philip Schuster, Natalia Toro**

1307.6554 & 1403.6836

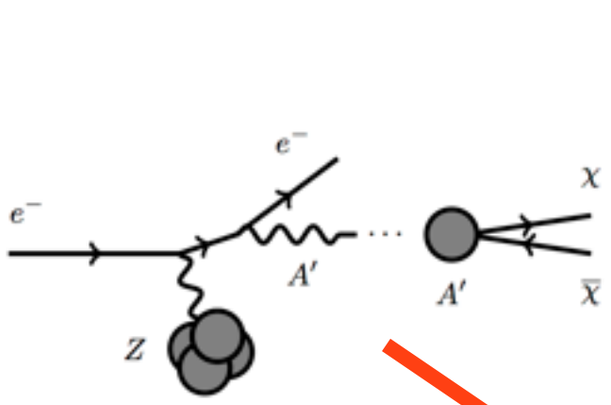
& **The BDX Collaboration**

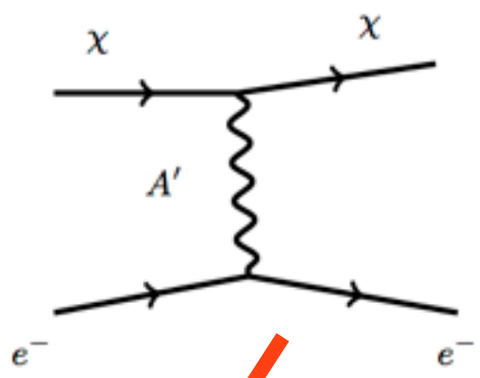
1406.3028

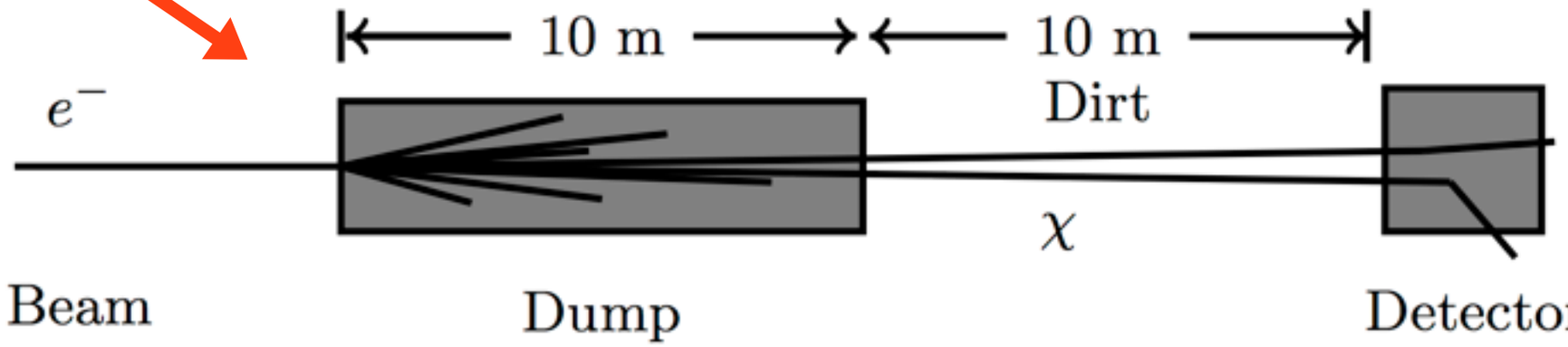
Intense Electron Beam Workshop

Cornell University, June 18, 2015

Basic Setup







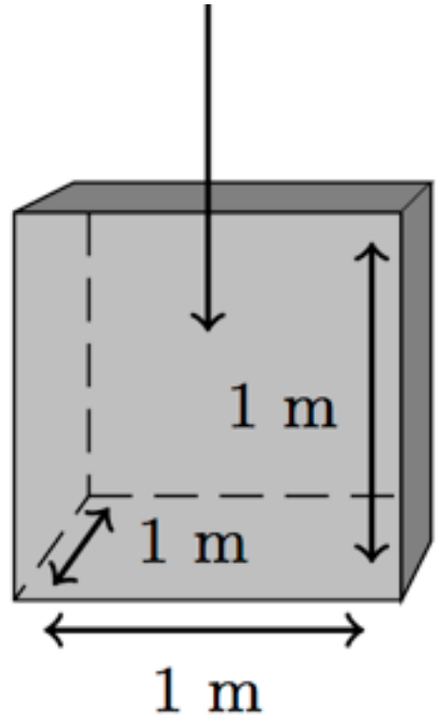
12 GeV beam energy (JLab)

200-300 MeV beam energy (Cornell)

Average current ~ $100\mu A$

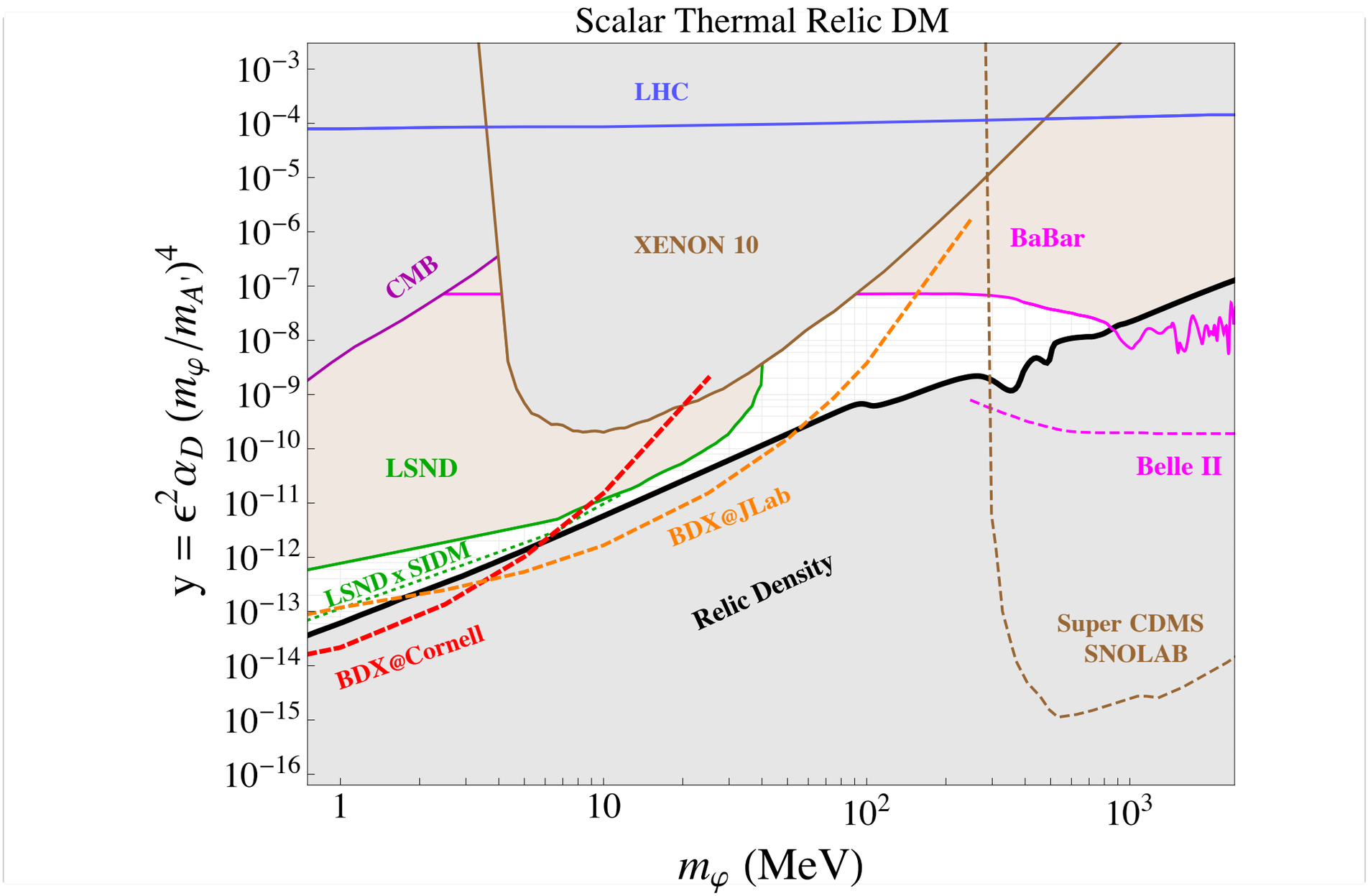
10^{22} EOT (~ 1 yr.)

Fiducial volume $= 1\mathrm{m}^3$



Plastic Scintillator
@ 15 m.w.e. depth

Thermal Target Reach



10^{22} EOT

BaBar, LSND, LHC, E137,BDX:

Cornell e-linac, 400 MeV beam

$$\alpha_D \times \left(\frac{m_\chi}{m_{A'}}\right)^4 = \frac{1}{81}$$

Summary

Electron beam-dump searches are powerful

Convincing discovery potential

Negligible beam BG, reducible cosmic BG

High luminosity & low cost

Can probe light thermal DM

Cover scenarios other methods can't

Complement visible *A'* searches

Cover nearly all remaining $(g-2)_\mu$ territory

Run parasitically at existing facilities

Jefferson Lab, Cornell, SLAC, Mainz, Fermilab (?)

Stay tuned

BDX positive review from JLAB PAC-42