Searching for New Forces with DarkLight

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DARKLIGHT

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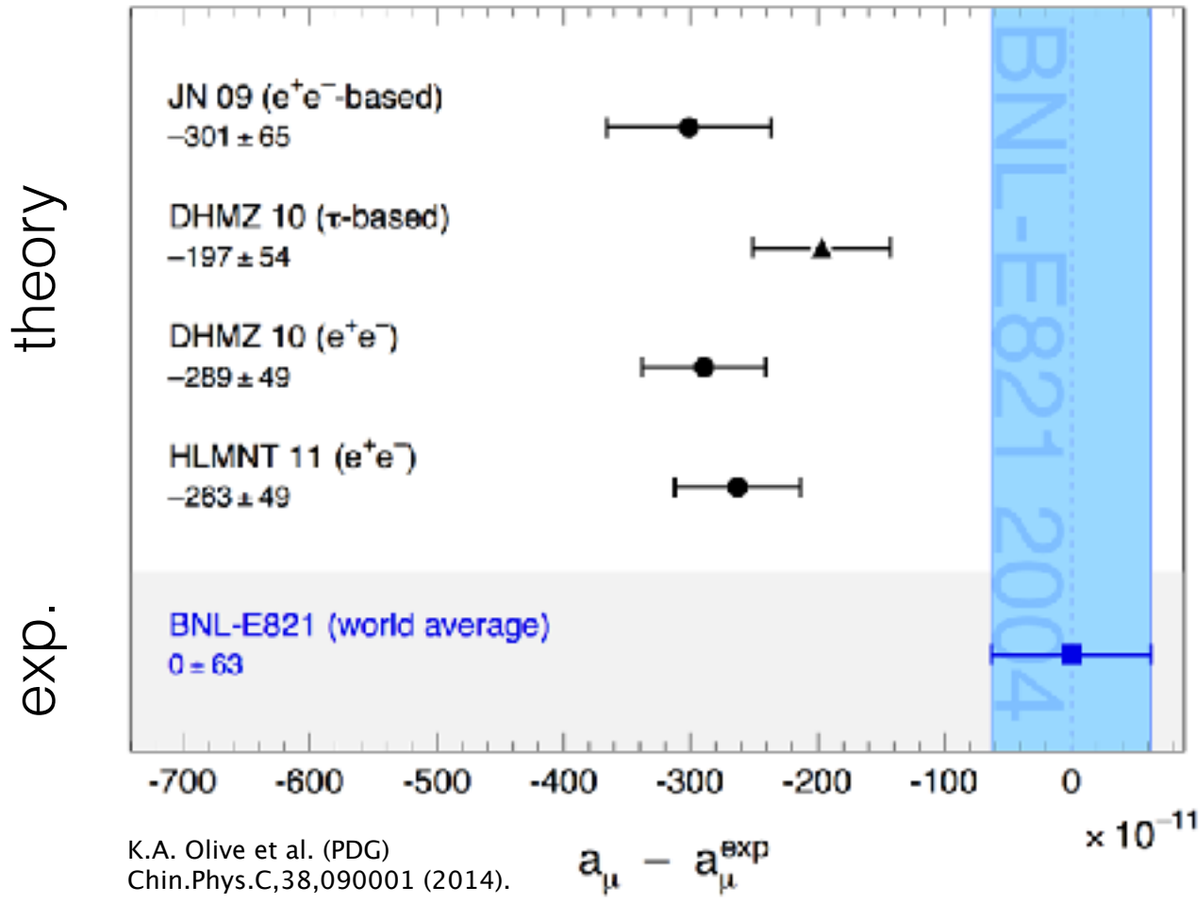
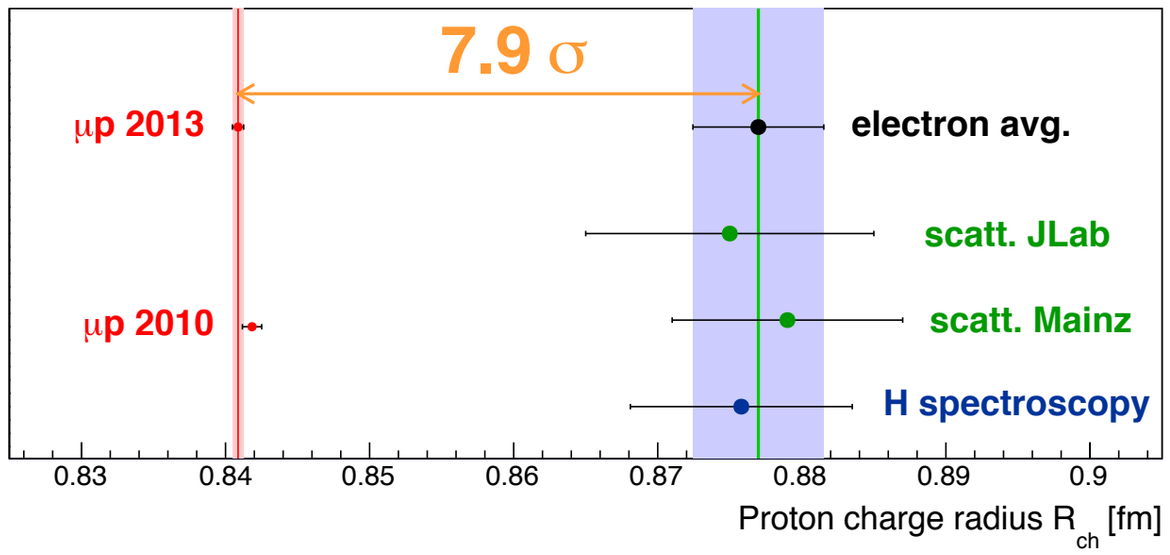
Searching for New Forces with DarkLight

- Anomalies and Motivation
- DarkLight Concept
- LERF Beamtime
- Prospects at CEBAF Injector

Motivating a Dark Photon

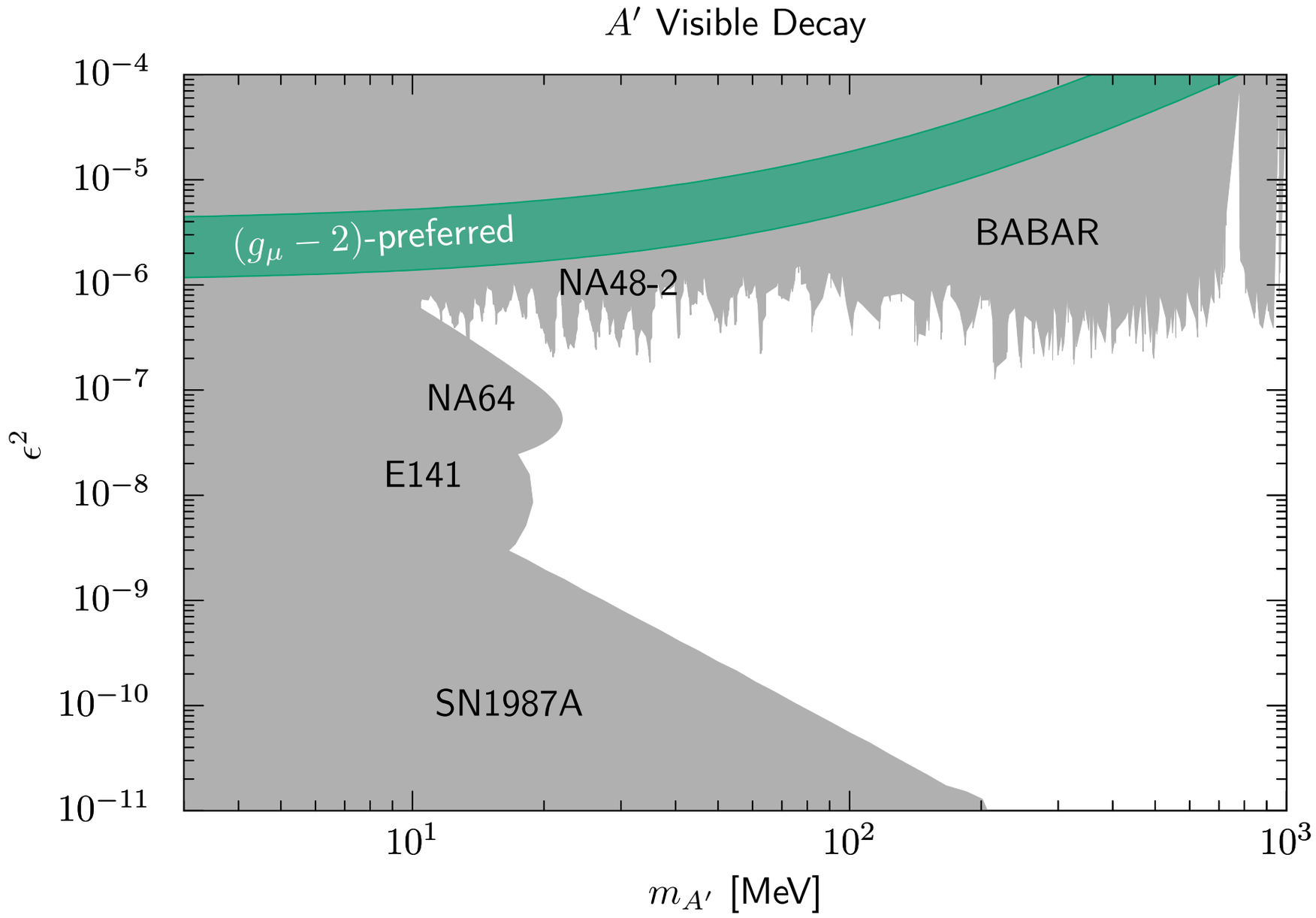
- Want DM decay or annihilation mechanism
- Muon g-2 measurement is 3.6σ > theory
- Help for proton radius ?



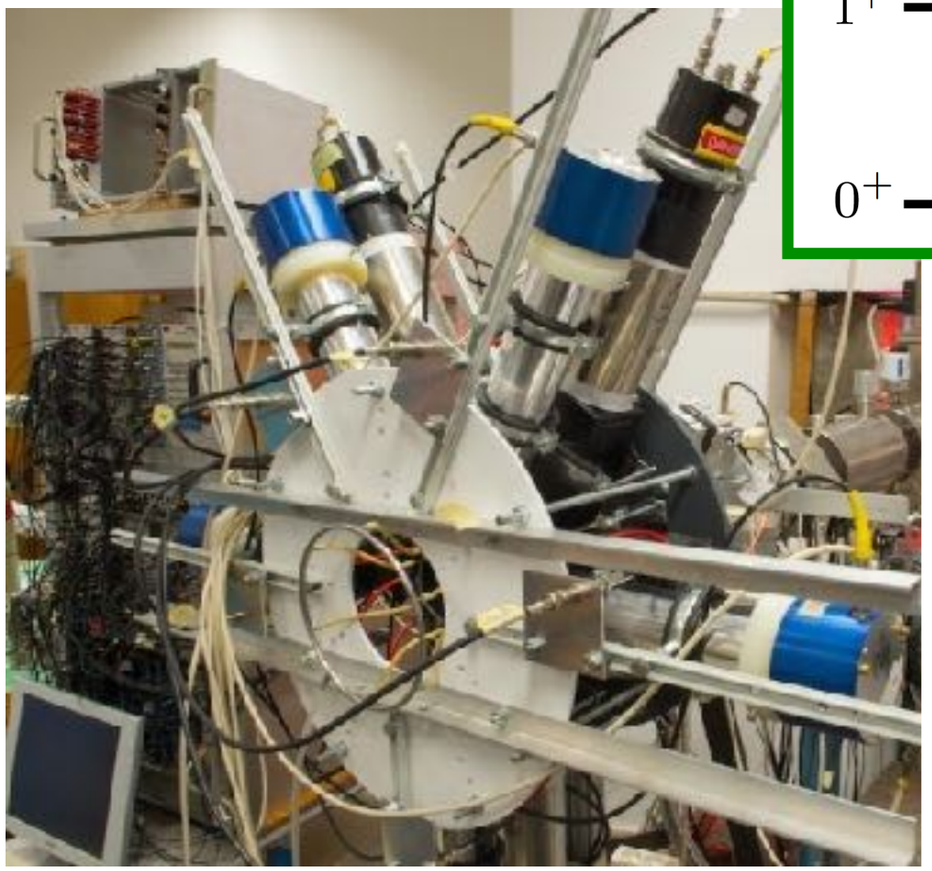


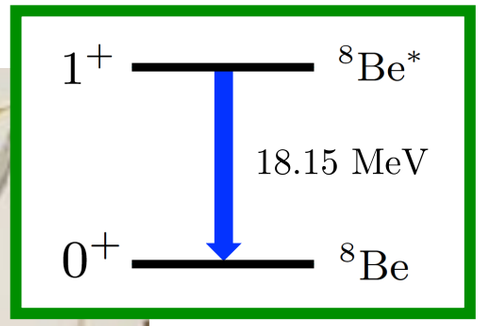
Looking for A' Decay

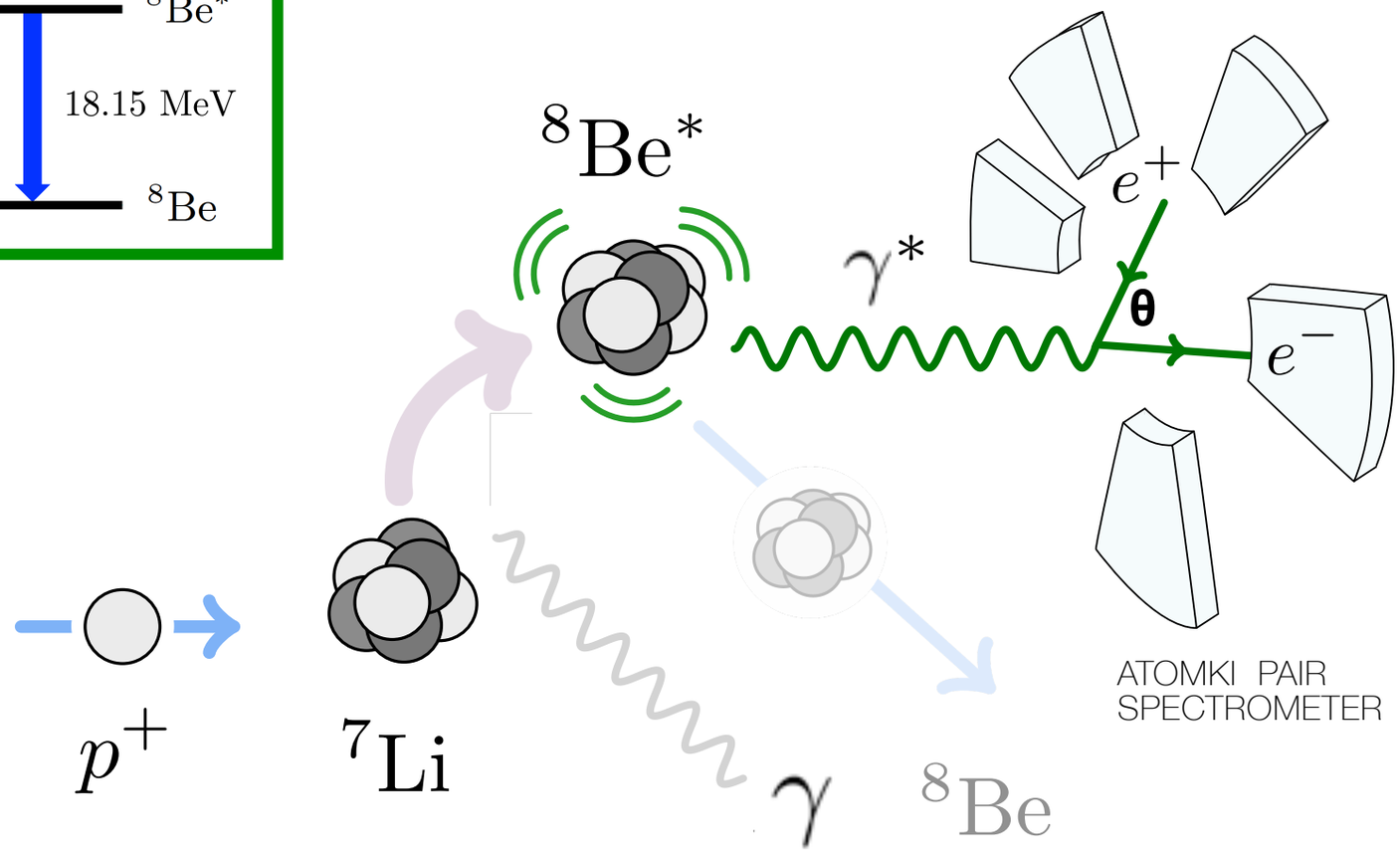
- can decay invisibly (BR to LDM 100% $m_A > 2m_{LDM}$)
- or visibly (BR to SM 100%, $m_A > 2m_{SM}$):



Beryllium Anomaly



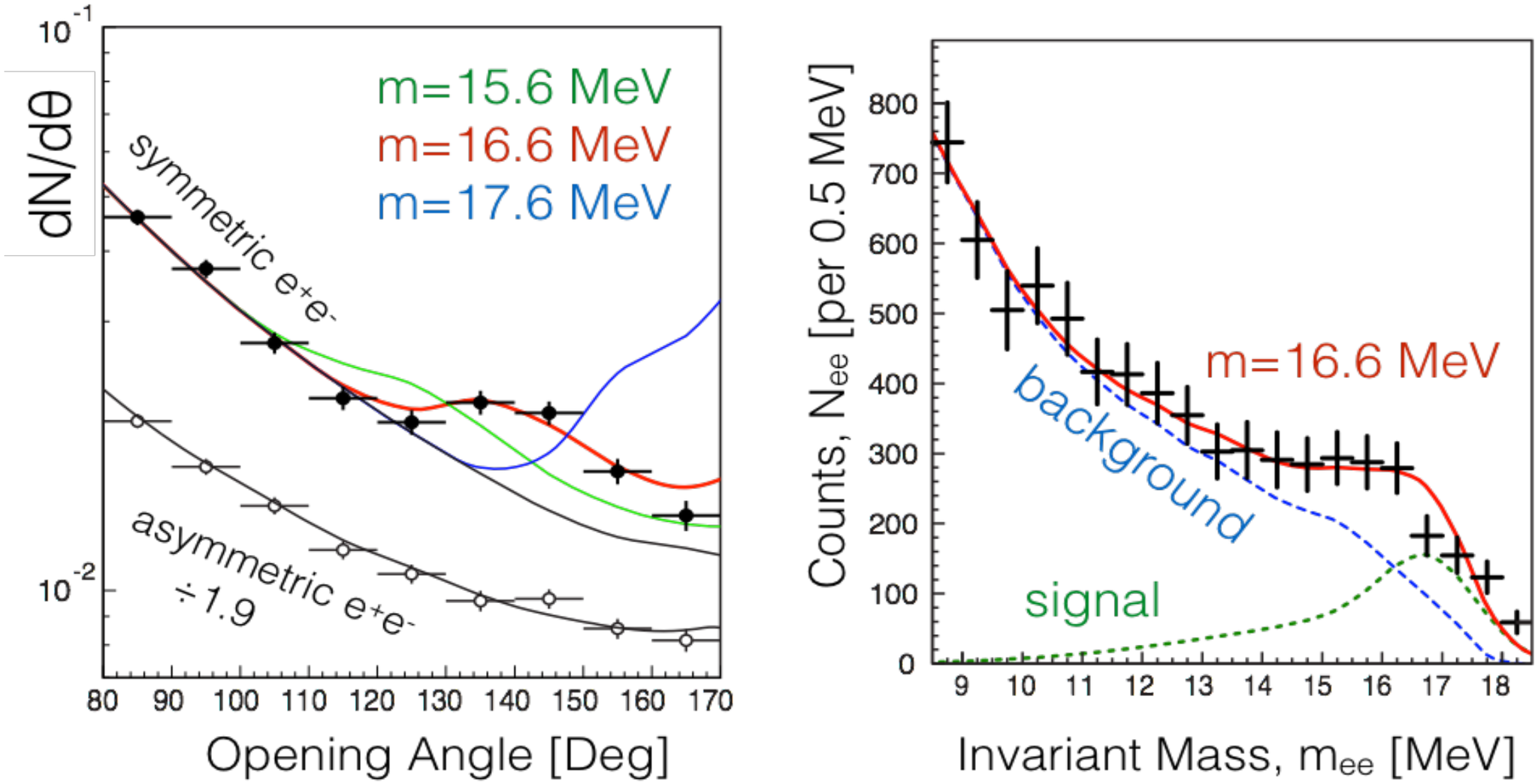




(Borrowed from Fornal arXiv:1707.09749)

- ~few MeV protons on ^{7}Li targets
- populating 17.6 and 18.15 MeV 1^+ states of ^{8}Be
- E and Θ measured for e^+e^- pairs

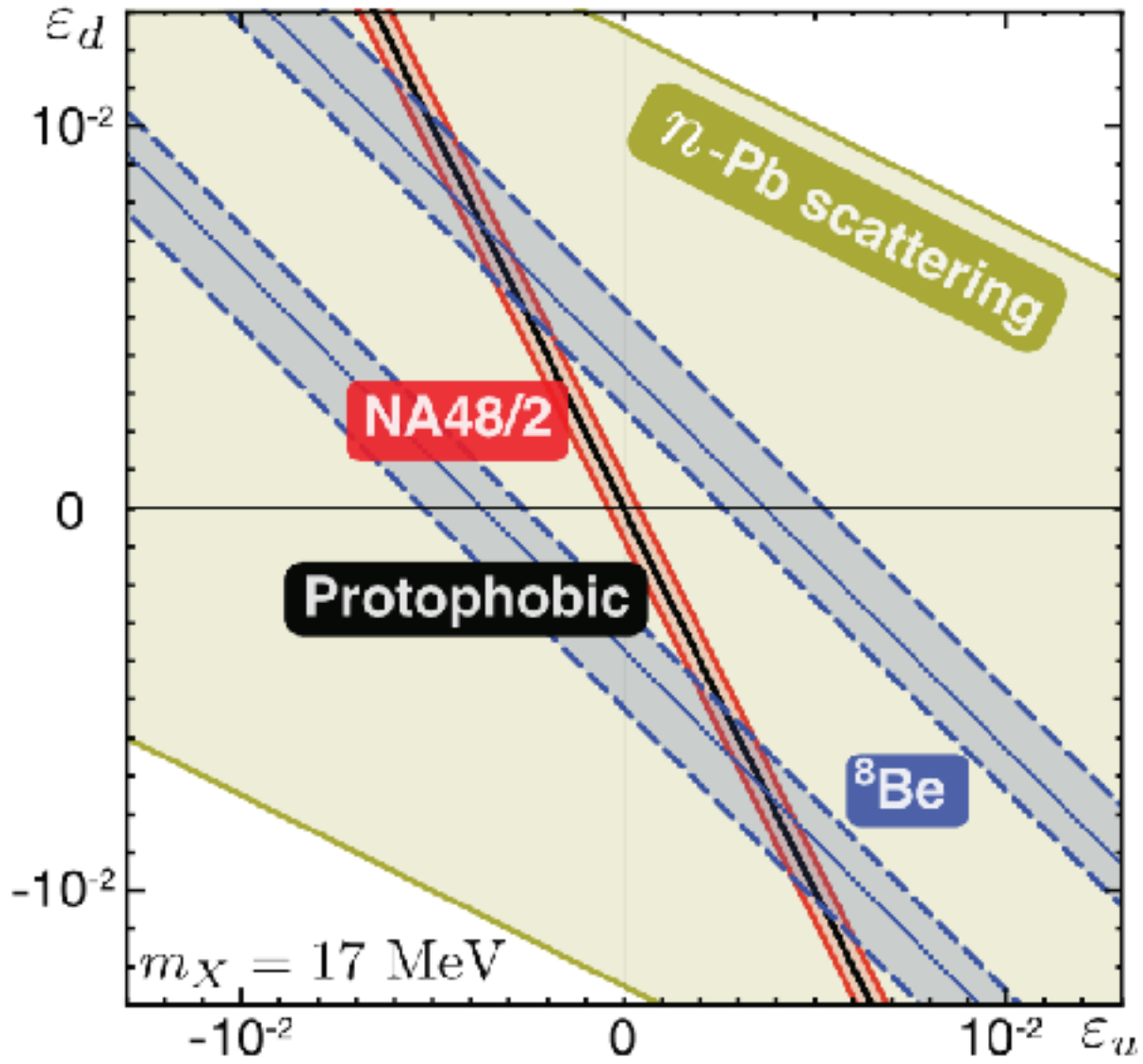
Unexpected ^{8}Be Resonance



- Model fit χ^2/d.o.f. ~ 1, and high significance (6.8σ)
- Bump isn't a last-bin effect
- Effect behaves sensibly (only on resonance, only for symmetric-energy pairs)

Protophobia?

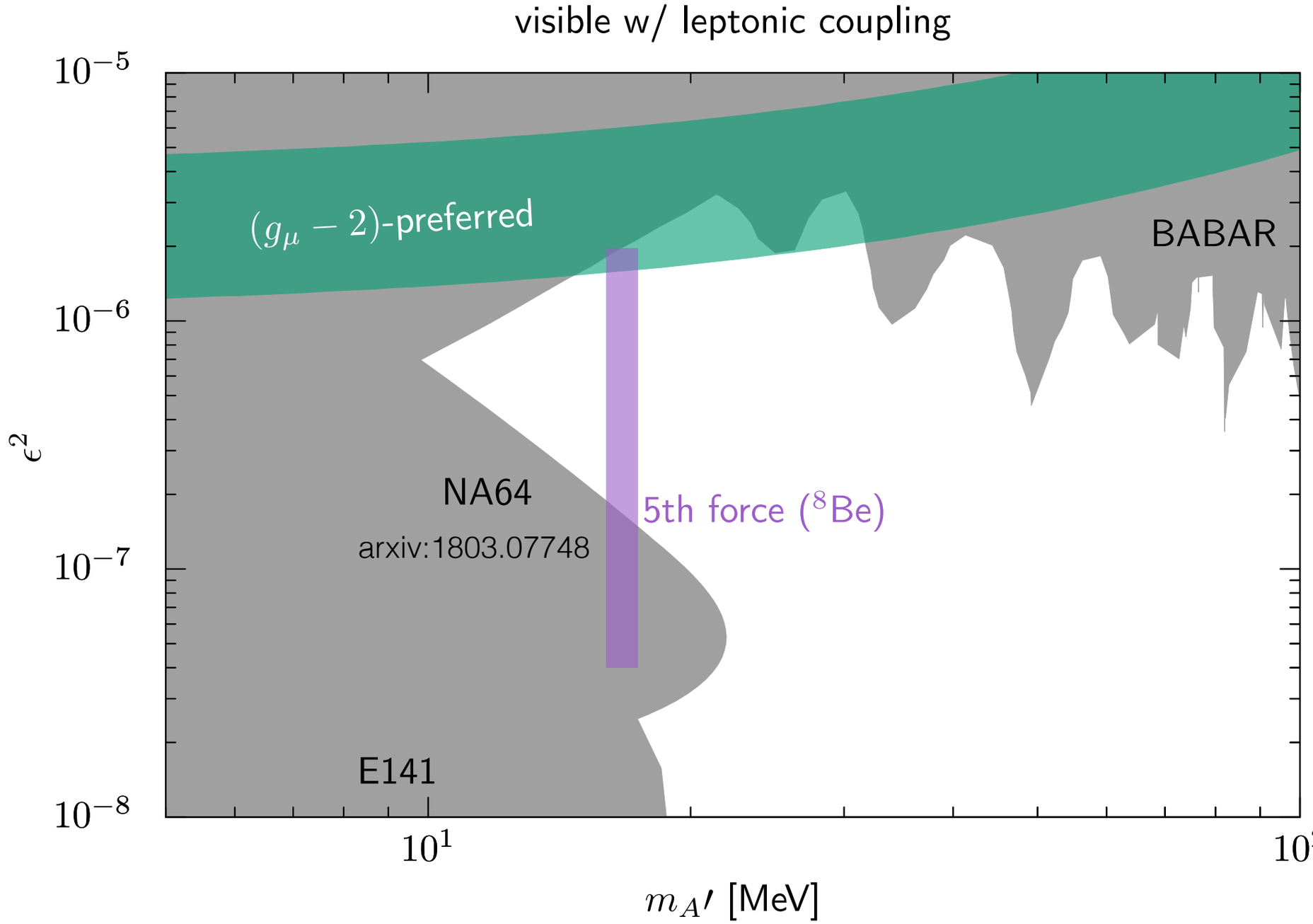
- Signal conflicts with simple charge-coupling model
- Allow particles to have independent couplings
- Pion couplings suppressed
- Ratio of proton and neutron couplings no less 'natural' than for Z



arXiv:1604.07411

Electron Coupling Parameter Space

- Hadronic experiments less sensitive



DarkLight Concept

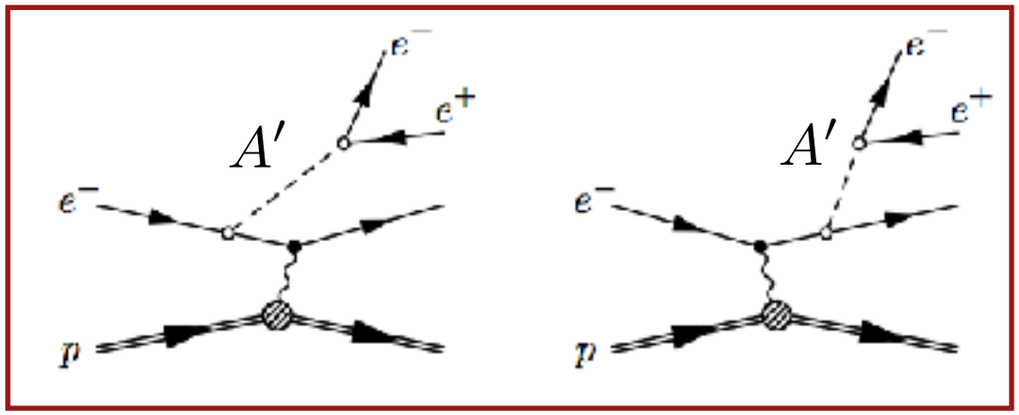
"Detecting A Resonance Kinematically with eLectrons Incident on a Gaseous Hydrogen Target

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

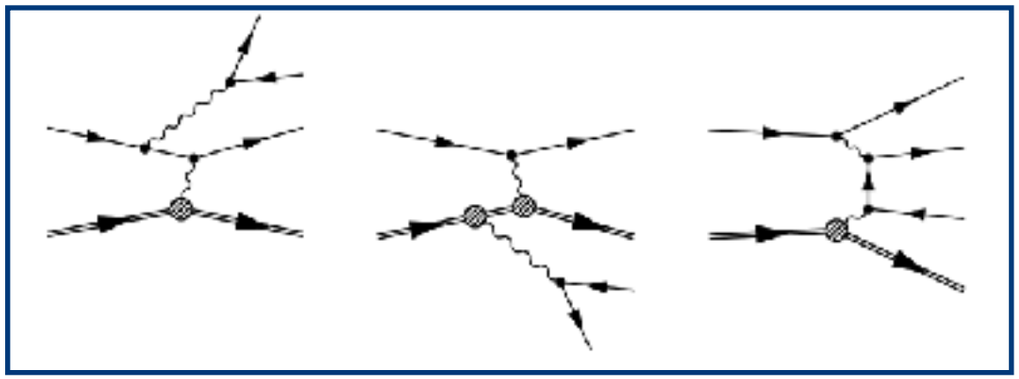
DarkLight Concept

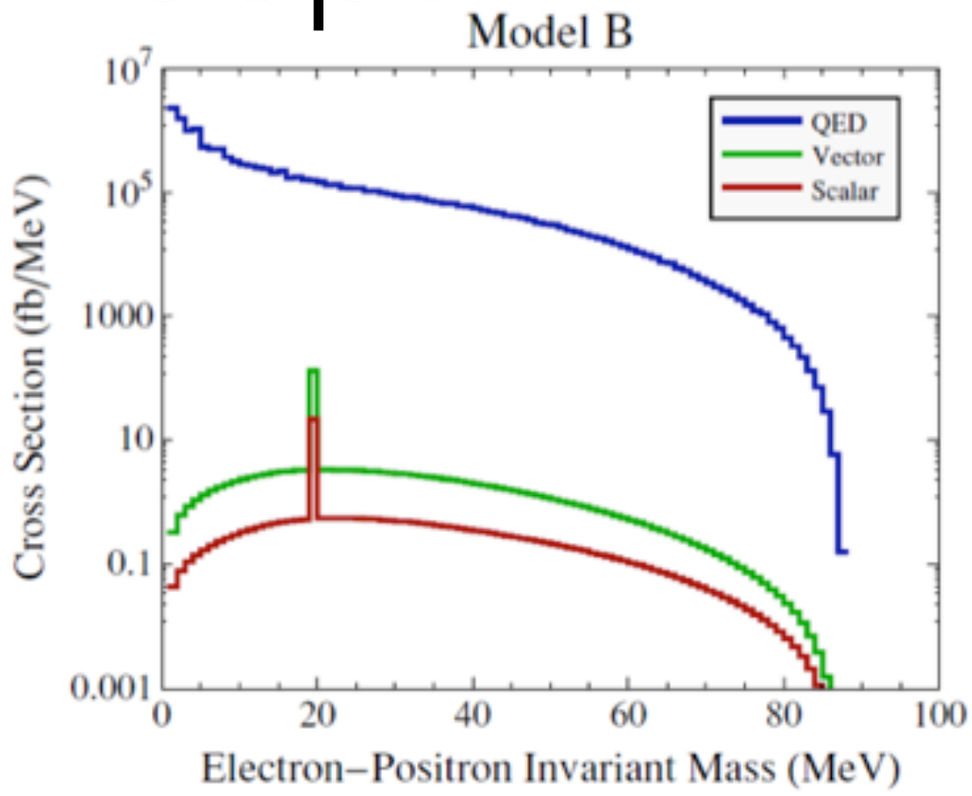
- Detect all final state particles to suppress backgrounds
- Search for peak in e^+e^- mass

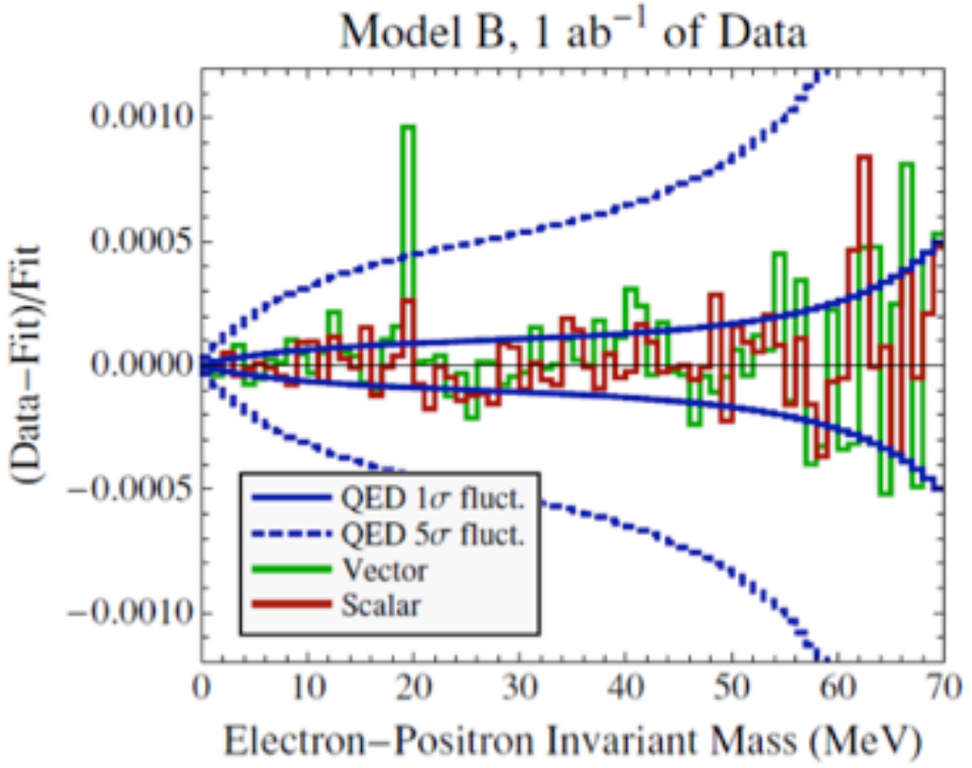
A' Signal



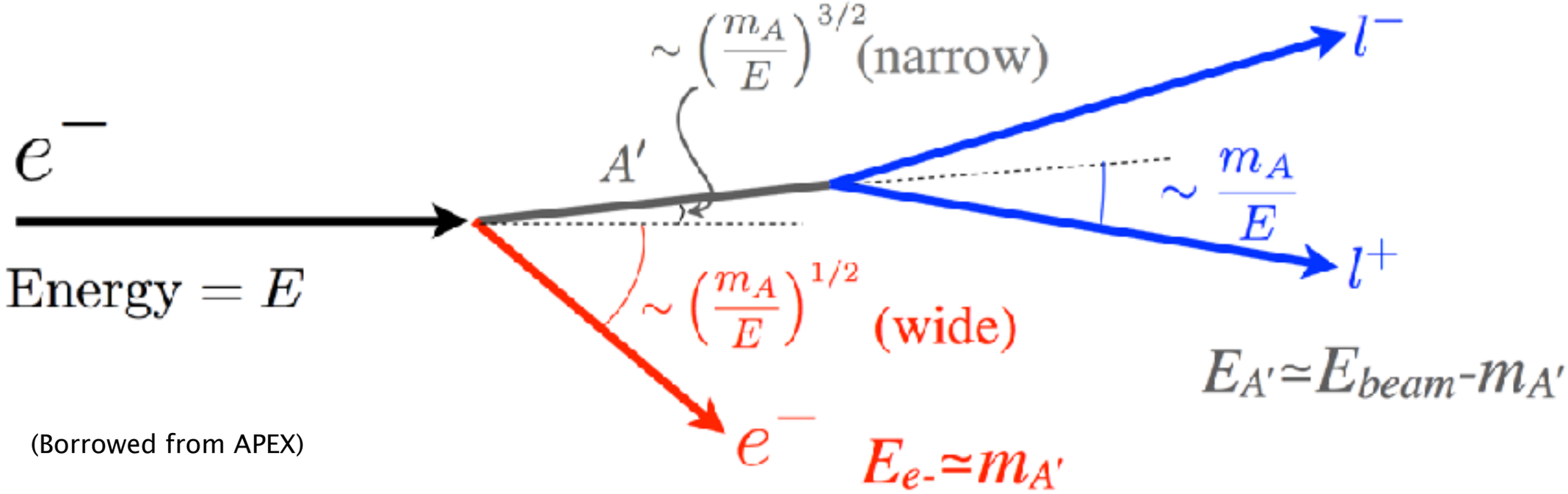
QED Background







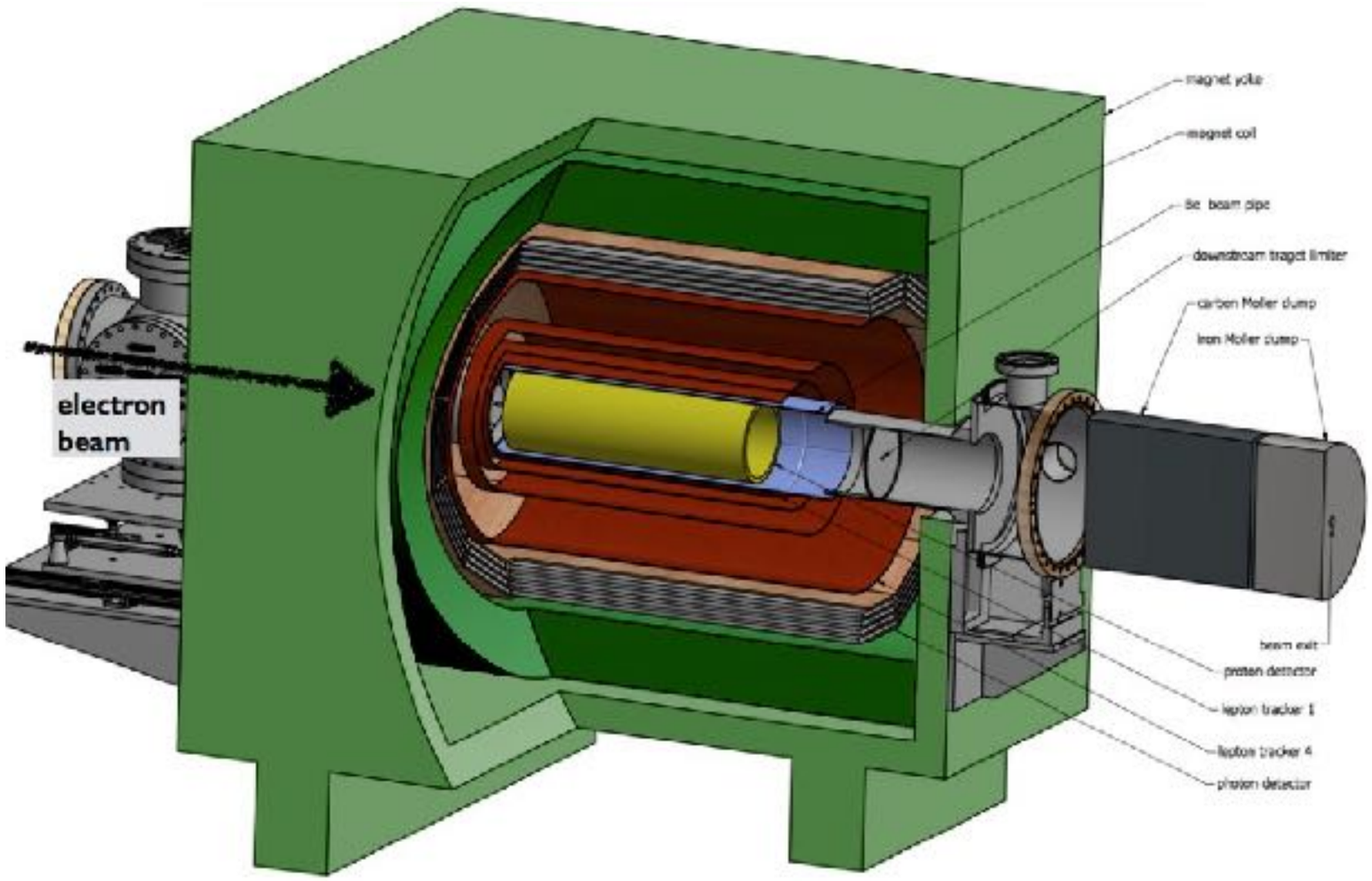
Production Kinematics



(Borrowed from APEX)

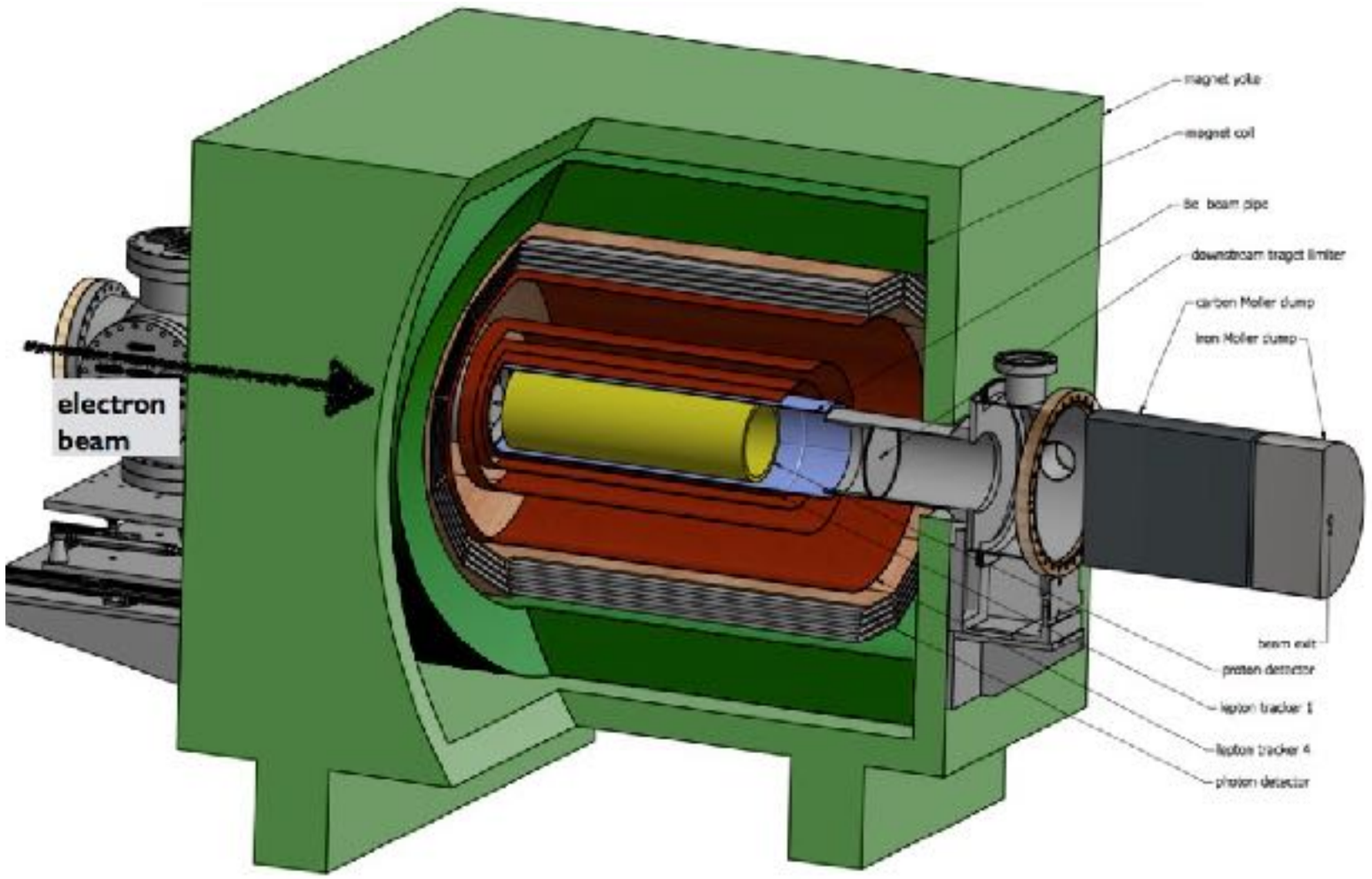
- A' carries large fraction of beam energy -- at large boost, decay products go forward.
- Recoil proton carries little energy

DarkLight Concept



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

Design Highlights



- Need a windowless gas target
- and a solenoid
- in an ERL beam

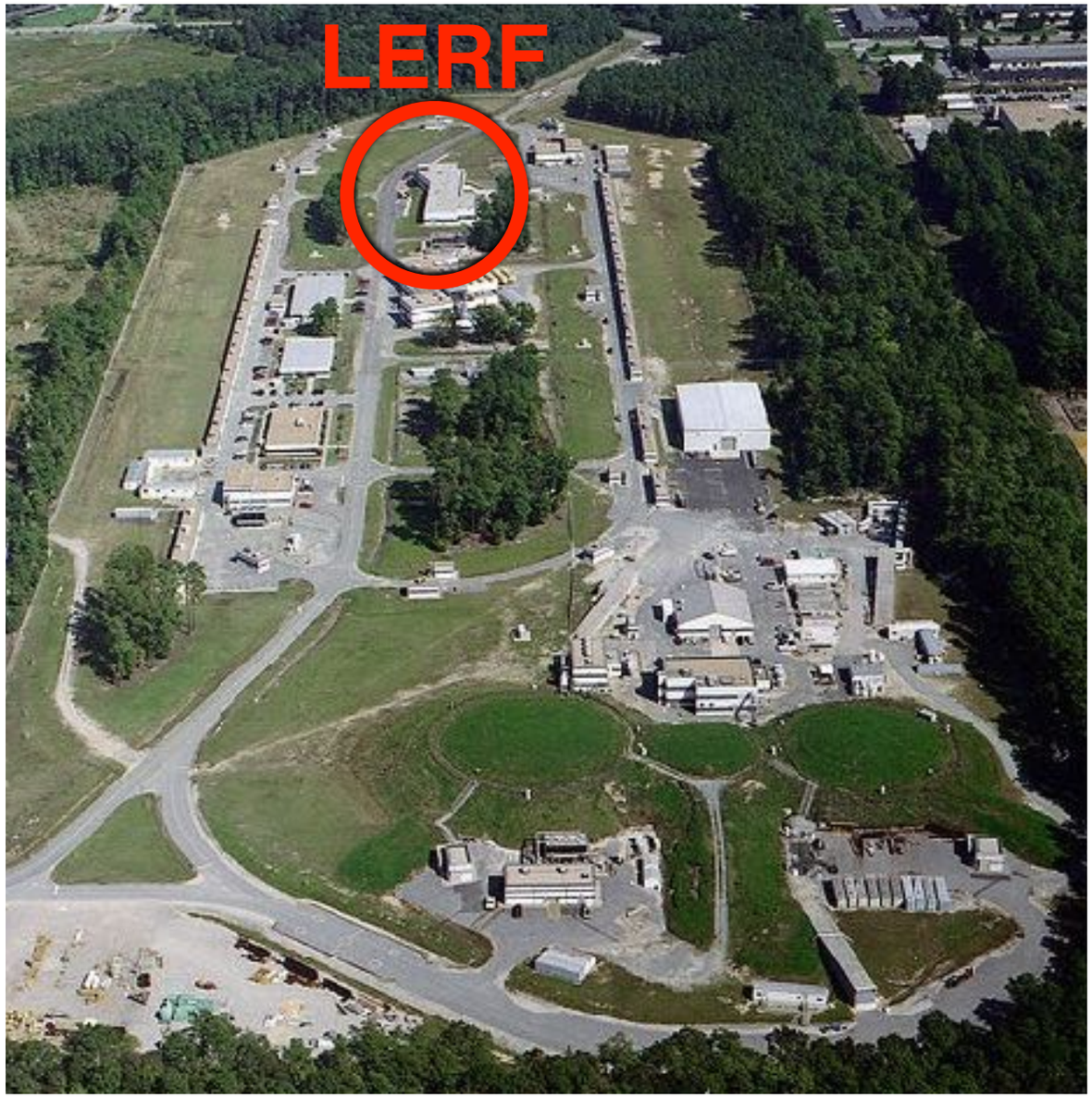
DarkLight Phases at LERF

- 0: Beam stability test at LERF (2012)

NSF MRI funded:

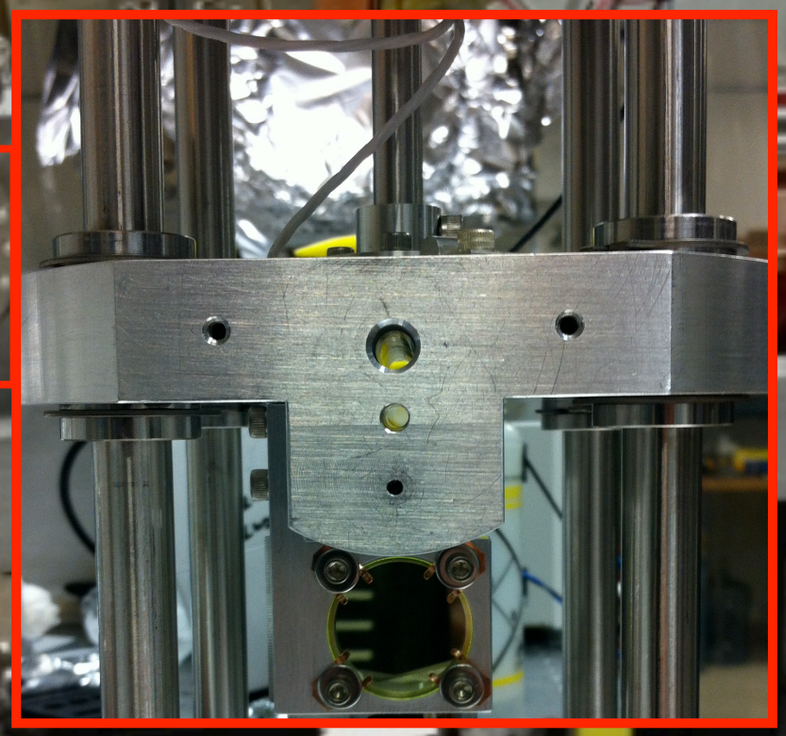
- 1A: Learn to operate LERF with Solenoid + Target (2016)
- 1B: Measure radiative Møller rates (spectrometer design)
- 1C: Proof-of-principle with partial coverage detector in solenoid

- 2: High-statistics measurement with full DarkLight detector



2012 Beam Test

- 0: Beam stability test at LERF (2012)



- Test block installed at FEL (future LERF)
- Demonstrated precision beam steering.

Phys. Rev. Lett. 111, 165801 (2013)
Nucl. Instr. Meth A729, 233 (2013)
Nucl. Instr. Meth. A729, 69 (2013)

2016 Target Test

- 0: Beam stability test at LERF (2012)

NSF MRI funded:

- 1A: Learn to operate LERF with Solenoid + Target (2016)

- First operation of solenoid in ERL beam (successful energy recovery)
- Windowless gas target with multi-stage pumping achieved ~2.5 Torr in tests
- Prototype detector telescope operated parasitically

Another wrinkle...

- LERF reconfigured for LCLS cavity studies -- no ERL beam available for foreseeable future

- 1B: Measure radiative Møller rates (spectrometer design)
- 1C: Proof-of-principle with partial coverage detector in solenoid

Another wrinkle...

- LERF reconfigured for LCLS cavity studies -- no ERL beam available for foreseeable future

- 1B: Measure radiative Møller rates (spectrometer design)
- 1C: Proof-of-principle with partial coverage detector in solenoid

- 1B: Use the same spectrometer design, but measure at 2.5 MeV at MIT's High Voltage Research Lab

- 1C: redesign to focus on ^{8}Be anomaly. Submitting proposal to use spectrometer design at JLab's CEBAF injector

1B at HVRL

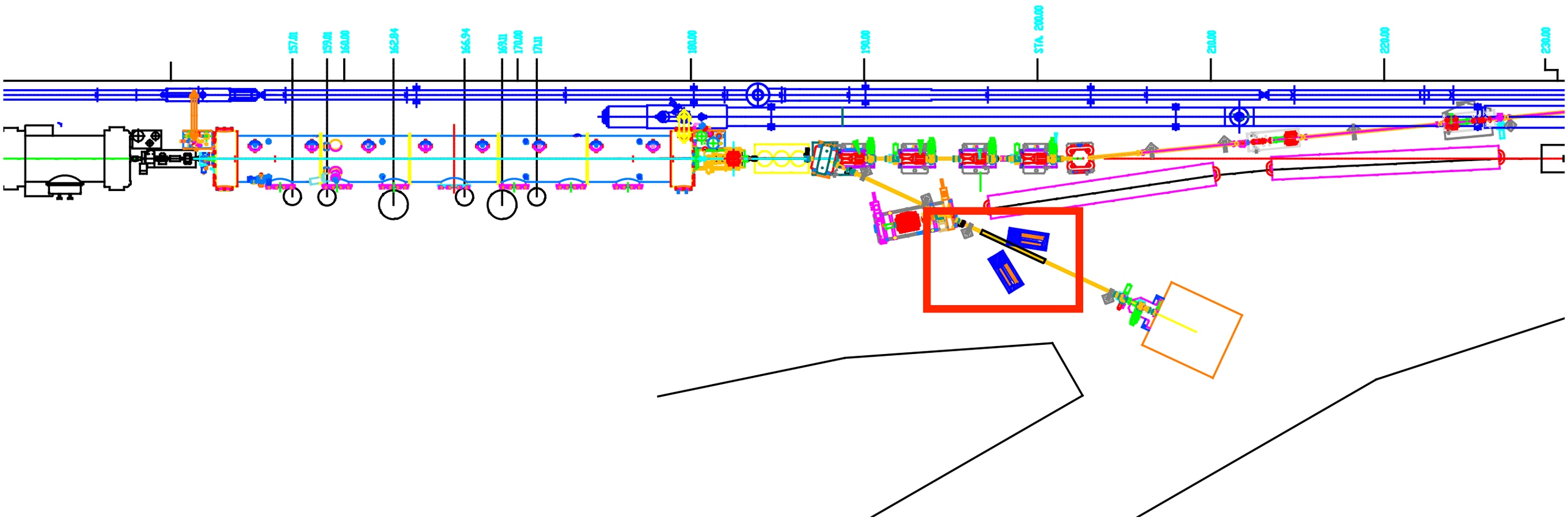
- Moller kinematics at 2.5 MeV beam similar to 100 MeV -- Same detector
- Installed and commissioning now
- Expect to finish taking data this year.

Revised DarkLight Concept

"Detecting A Resonance Kinematically with eLectrons Incident on a **Tantalum Foil Target**

- 100+ uA electron beam on thin foil target to overcome small coupling (~ab^{-1}/h)
- **Optimized for ^{8}Be Anomaly region specifically.**
- At 45 MeV to rule out pion production and open up decay kinematics
- With spectrometers for reconstruction of just the e^+e^- pair

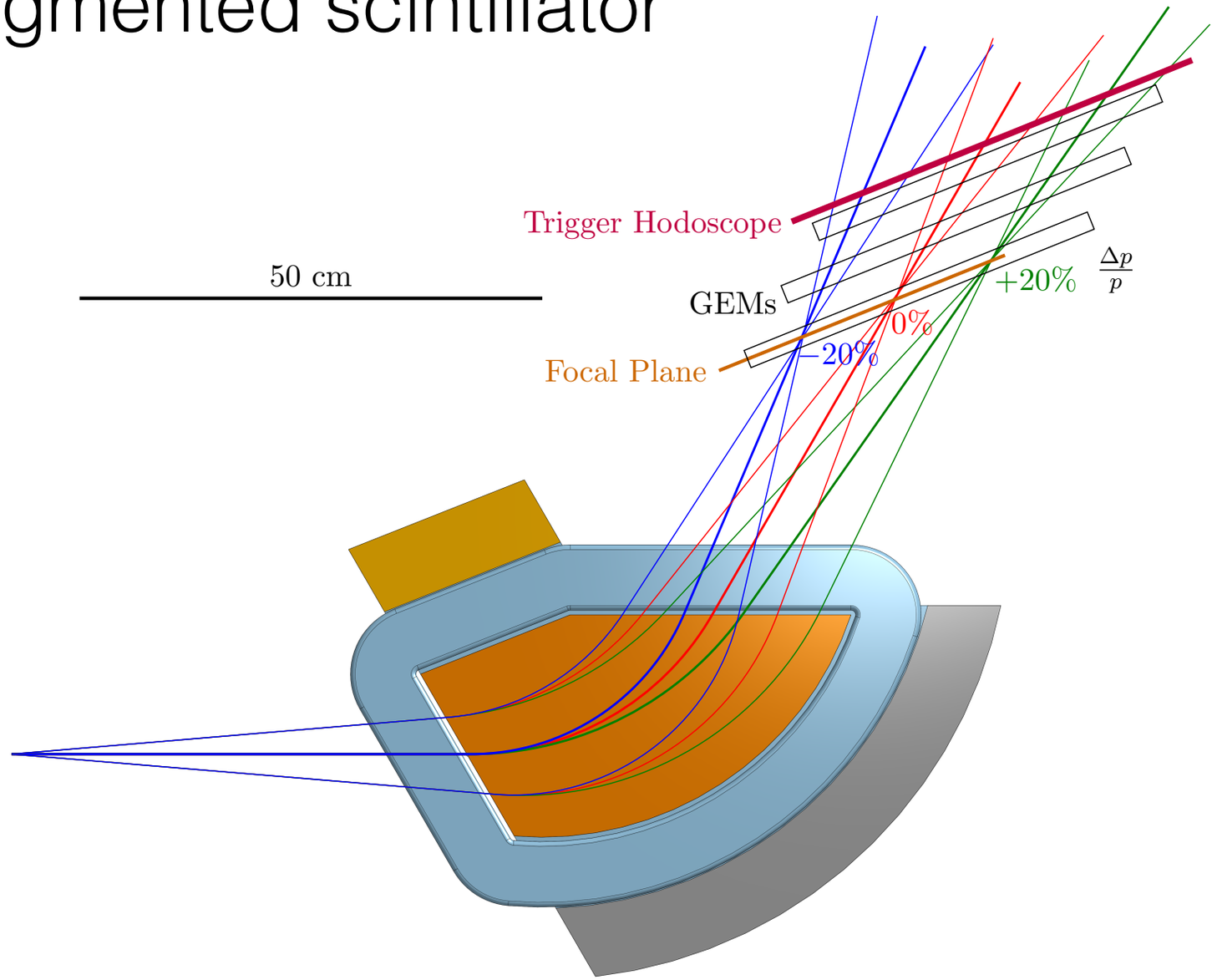
CEBAF Injector



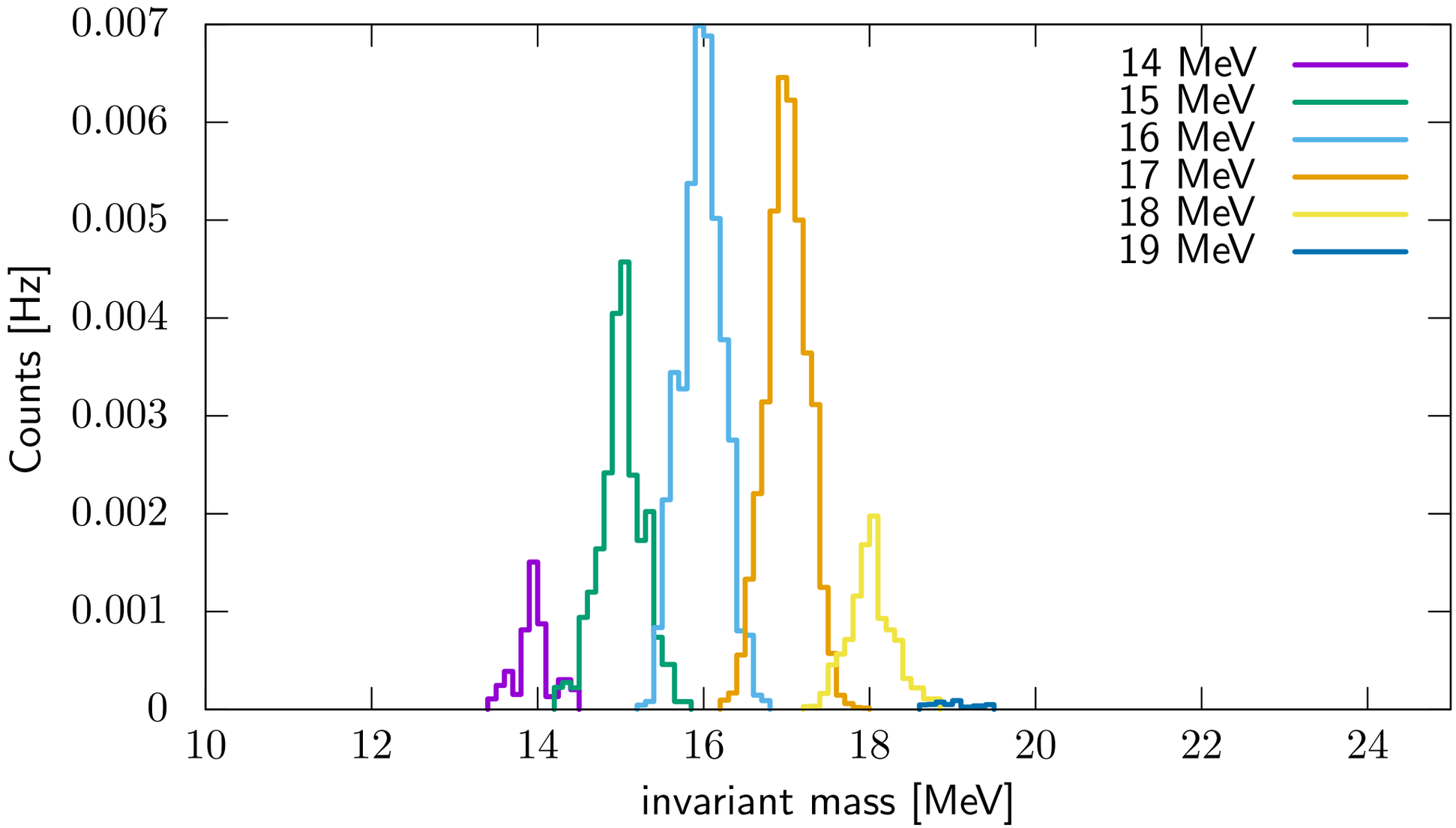
- "4D" line at injector
- 45 MeV beam balances between planarity and opening angle.
- Asymmetric angles (16° and 33°) balances A' and elastic rates

Spectrometer Design

- Identical design, different field strength:
- 3 GEM layers + segmented scintillator
- ±20% momentum
- ±2 in-plane,
  ±5 out-of-plane
- 28 MeV e^+ at 16°
- 15 MeV e^- at 33°



Signal



- Conservative estimate of 250 keV mass resolution

Backgrounds

Type	Rate
QED irreducible background	coincidence: 55 Hz
	single e^+: 120 kHz
Elastic e-p + internal Brems.	single e^-: 6 MHz
Giant resonance electroproduction	200 kHz
Quasielastic electron scattering	160 kHz
Møller electron rate	0 (outside spectrometer acceptance)
Accidental coincidence rate	500 Hz

Backgrounds

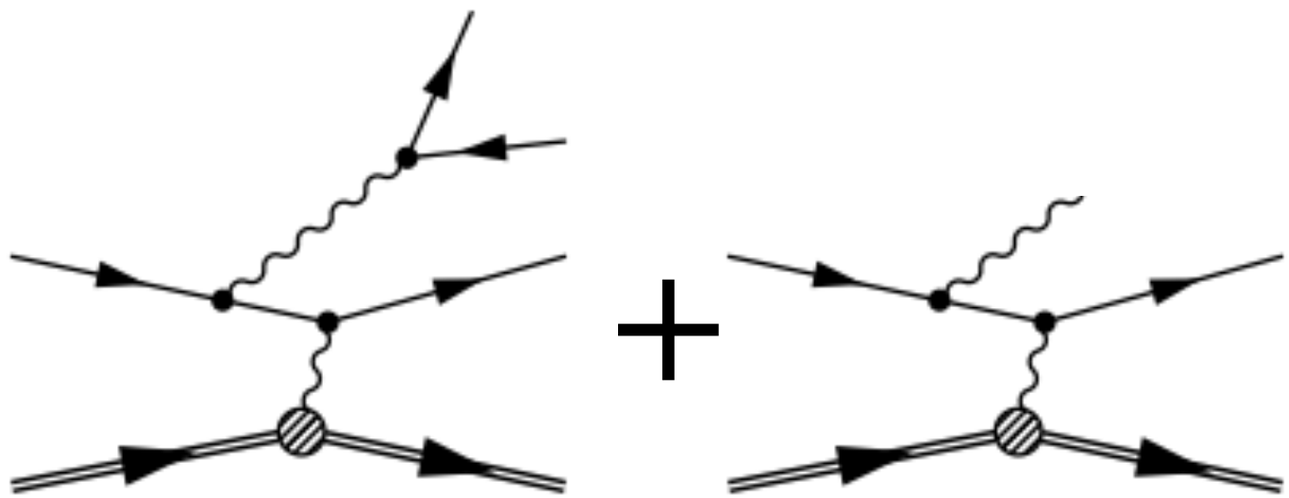
- Limited acceptance: single e^+ far more likely than complete e^+e^- pair ==> elastic e^- fills in as missing partner!

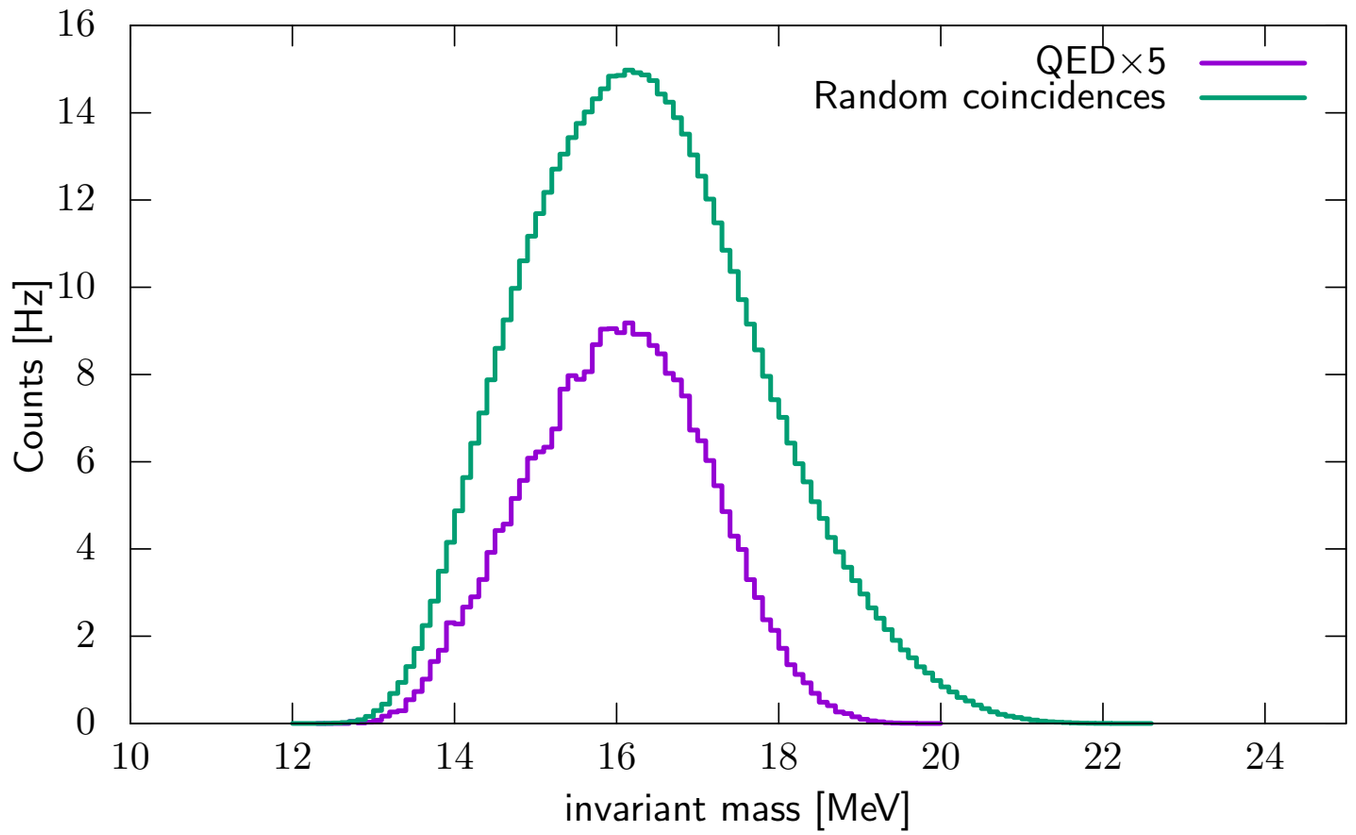
$$S \sim \mathcal{L}$$

$$B \sim \mathcal{L}^2$$

$$\mathrm{FOM} \sim \frac{S}{\sqrt{B}}$$

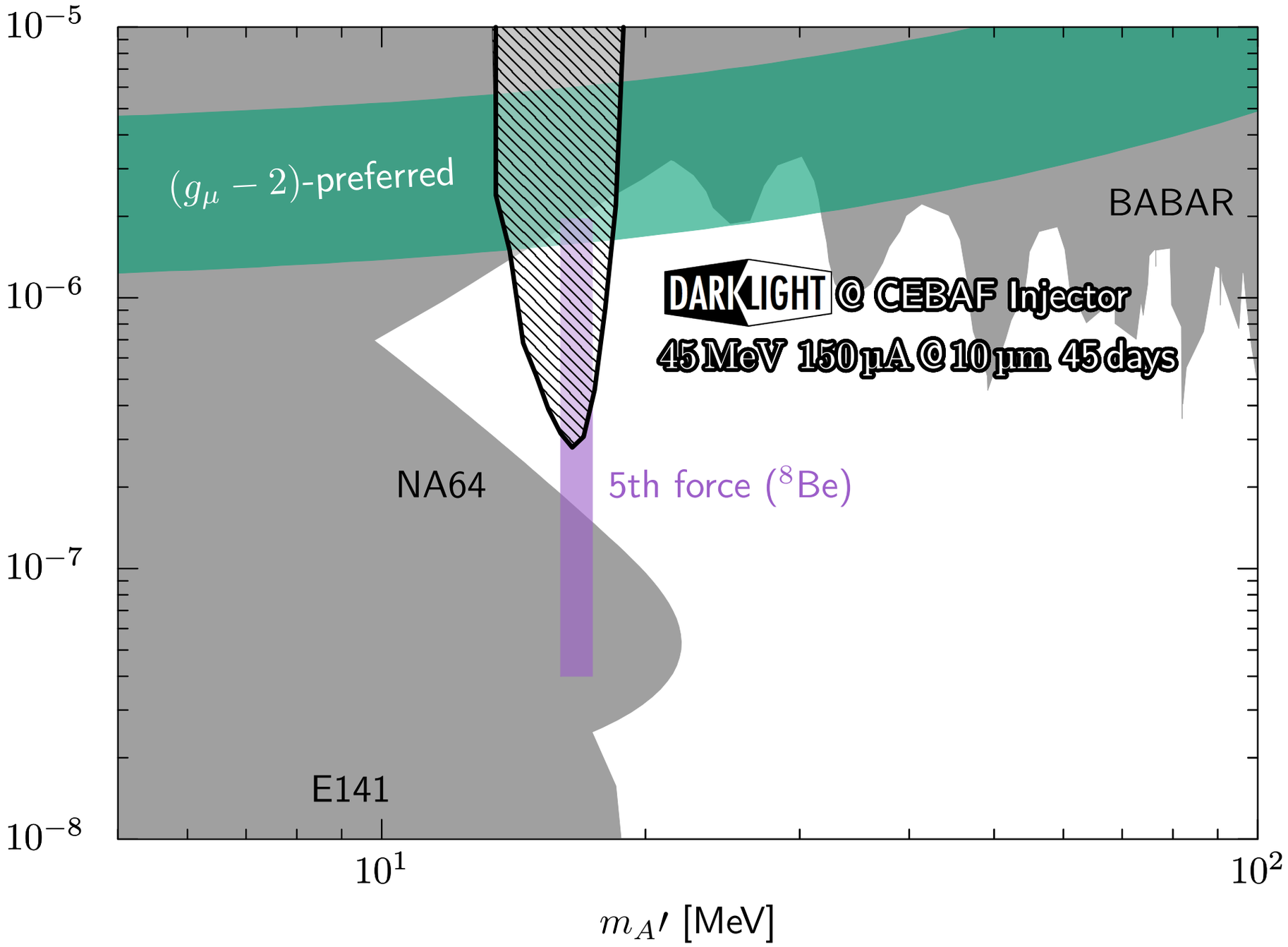
- At high $\mathcal{L}$, FOM scales with wall clock, not $\mathcal{L}$





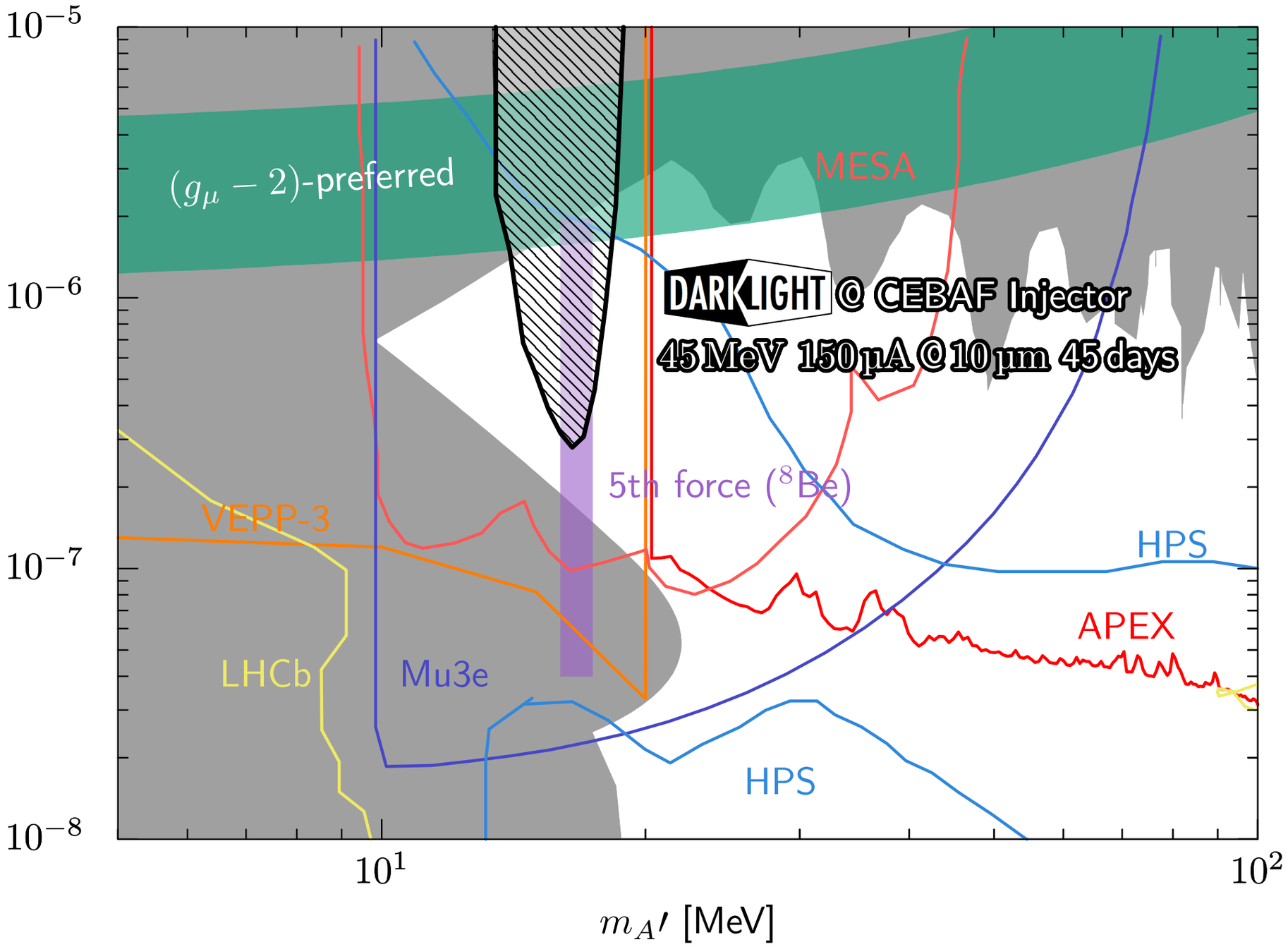
Projected Reach

- Starting summer 2019 / 2020, beam permitting



Projected Reach

- What it could look like ~after LHC Run 3



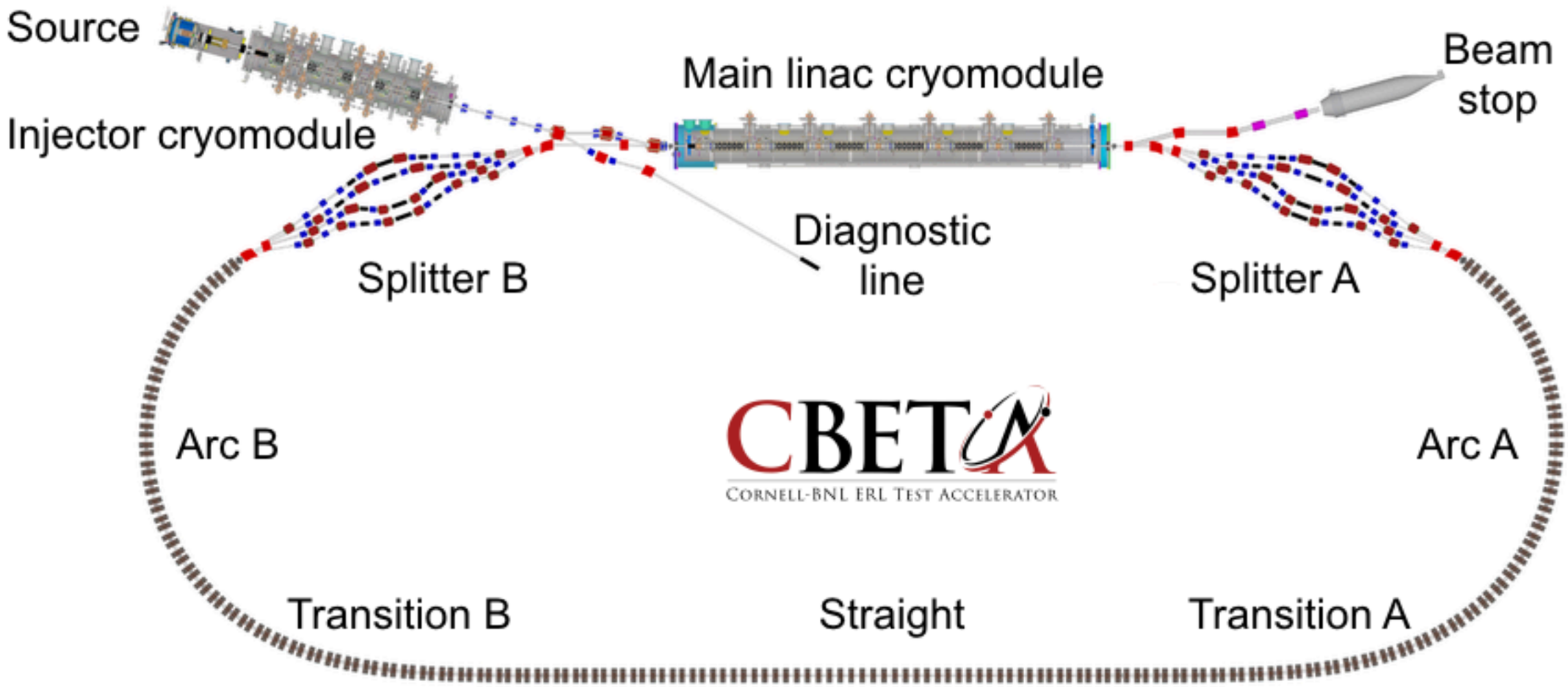
Summary

- ^{8}Be anomaly at 16.6 MeV -- multiple couplings to measure.

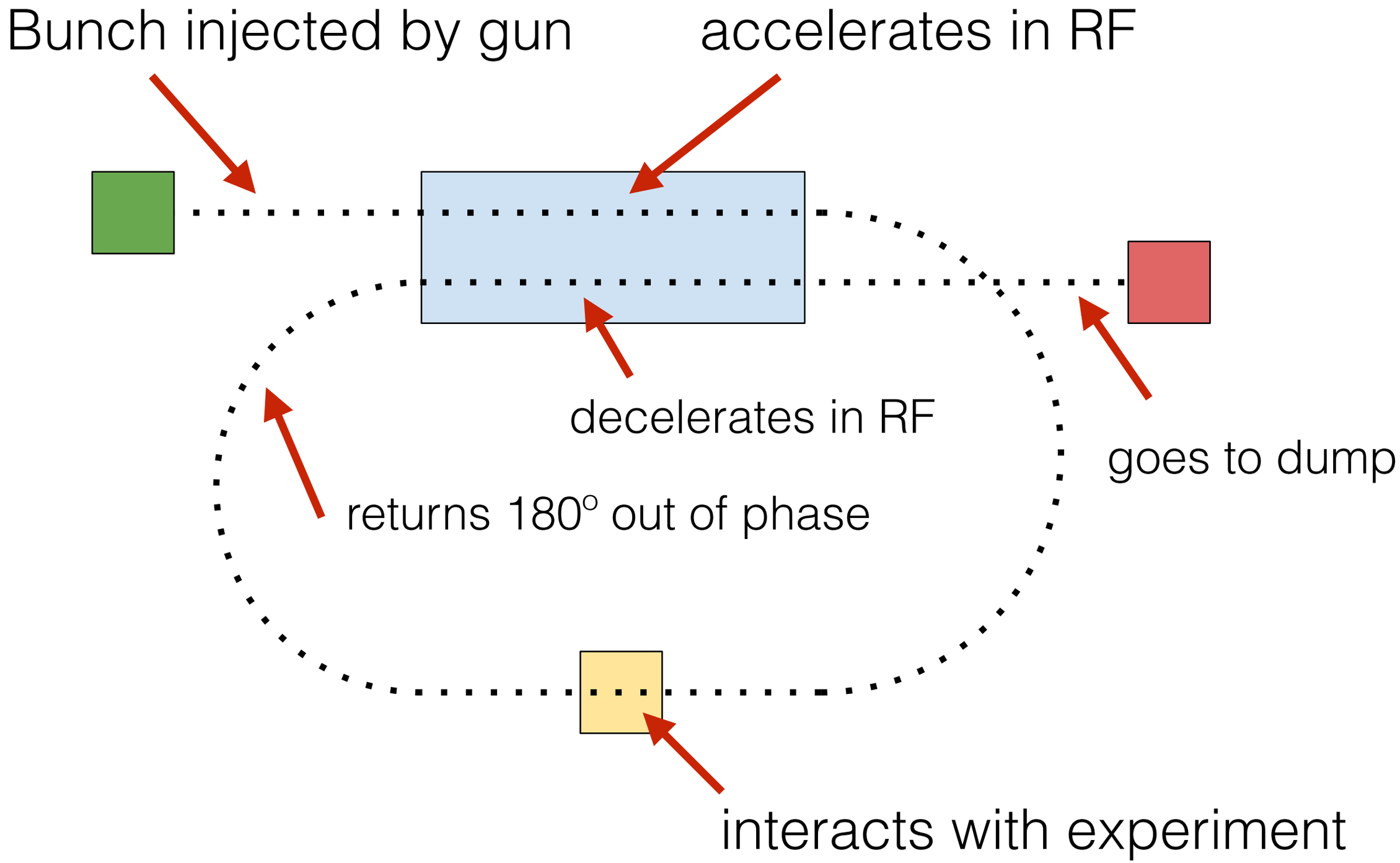
- 1A -- gas target and solenoid operated in LERF beam (summer 2016)
  - LERF shifts to LCLS cavity development
  - 1B -- measuring Radiative Moller spectrum at MIT now (2018)
  - 1C -- CEBAF injector search covers most of ^{8}Be
    - submitting proposal shortly (in a few days)
    - could be ready to run as soon as summer 2019

Stay Tuned

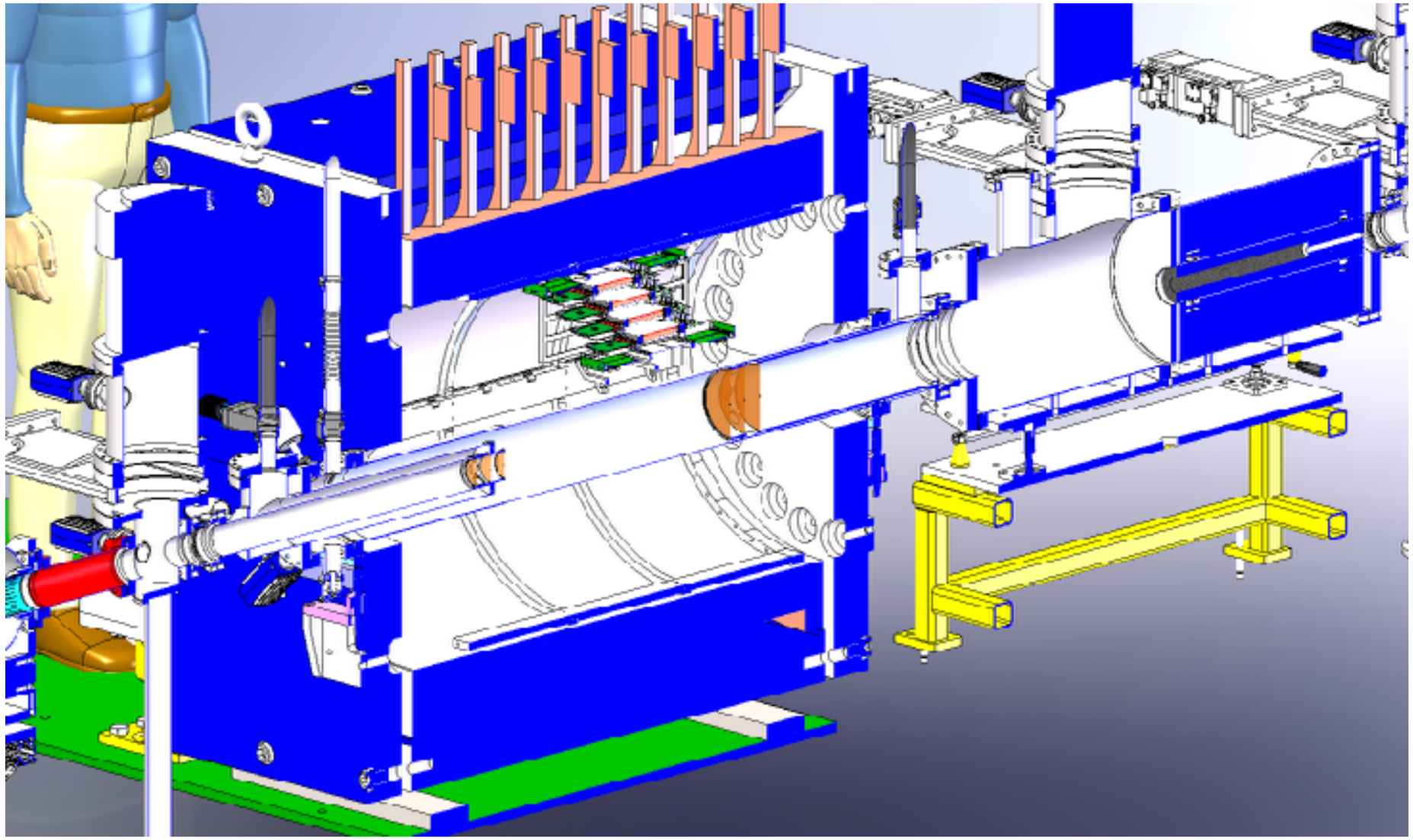
Phase 2 at CBETA?



Energy Recovery Linac



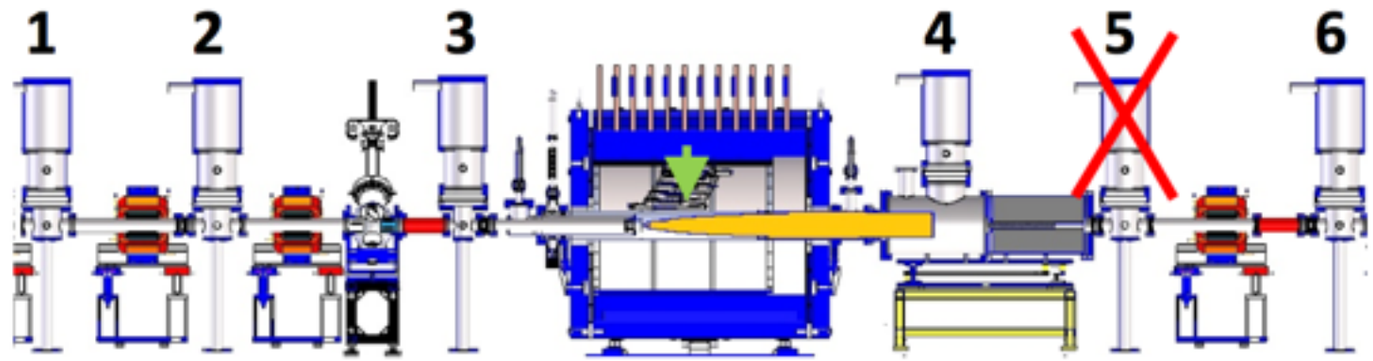
Alignment Problems

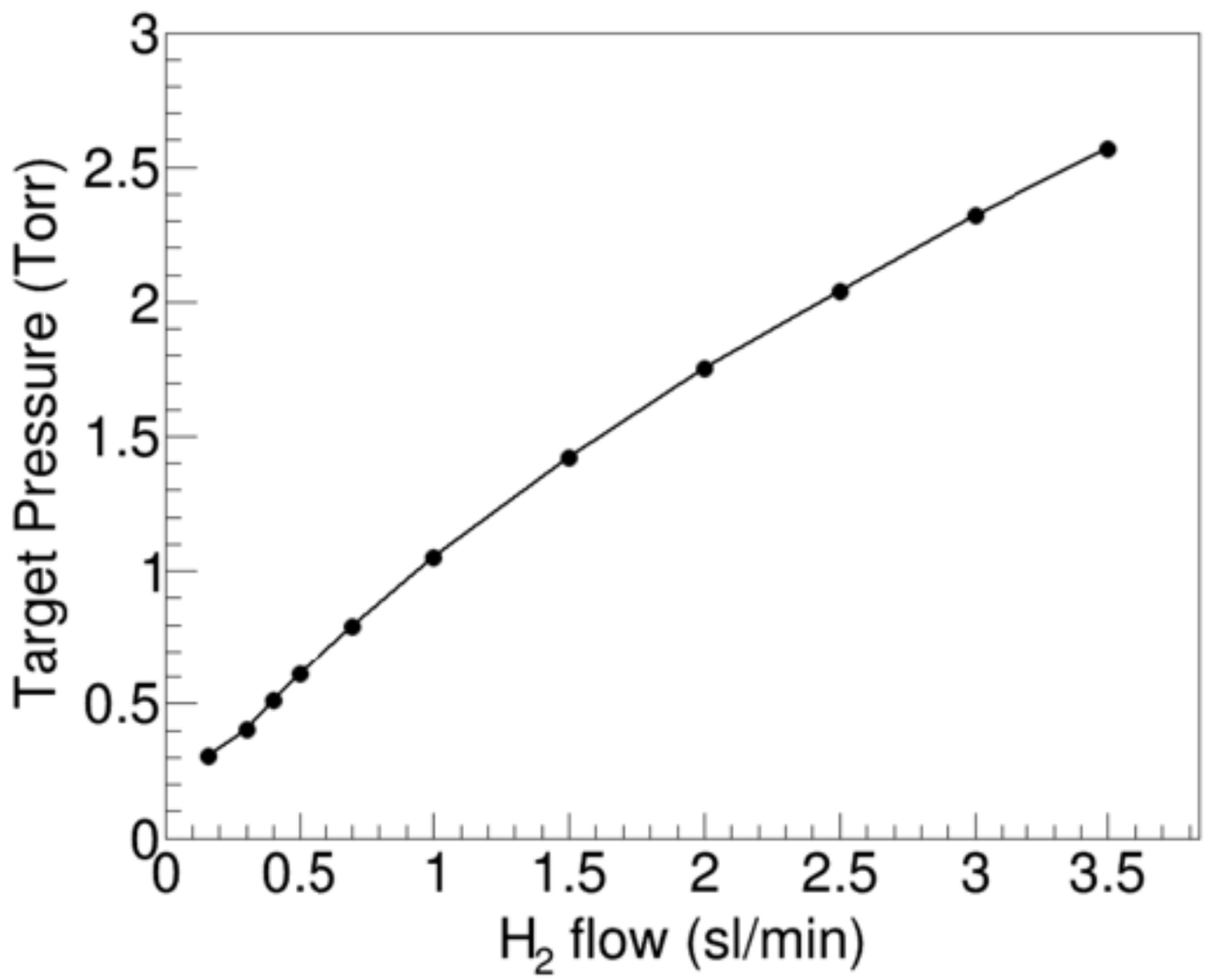


- One Baffle misaligned within cartridge
- Cartridges not aligned with each other -- not enough beam steering available.

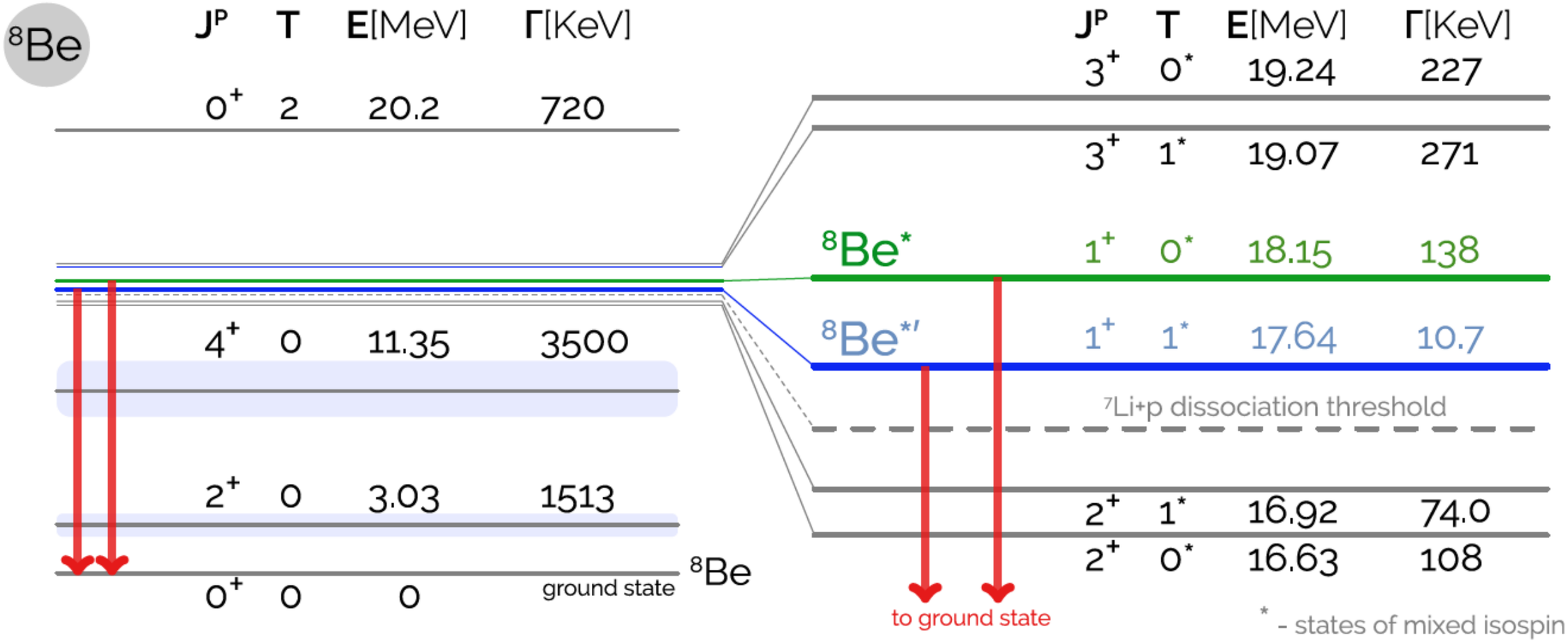
Pumping Problems

- Not all Turbos operating
- Outermost baffles (in pump stations) not installed
  - beamline getters vulnerable
  - H2 max flow limited.
  - (but running at Bates now)



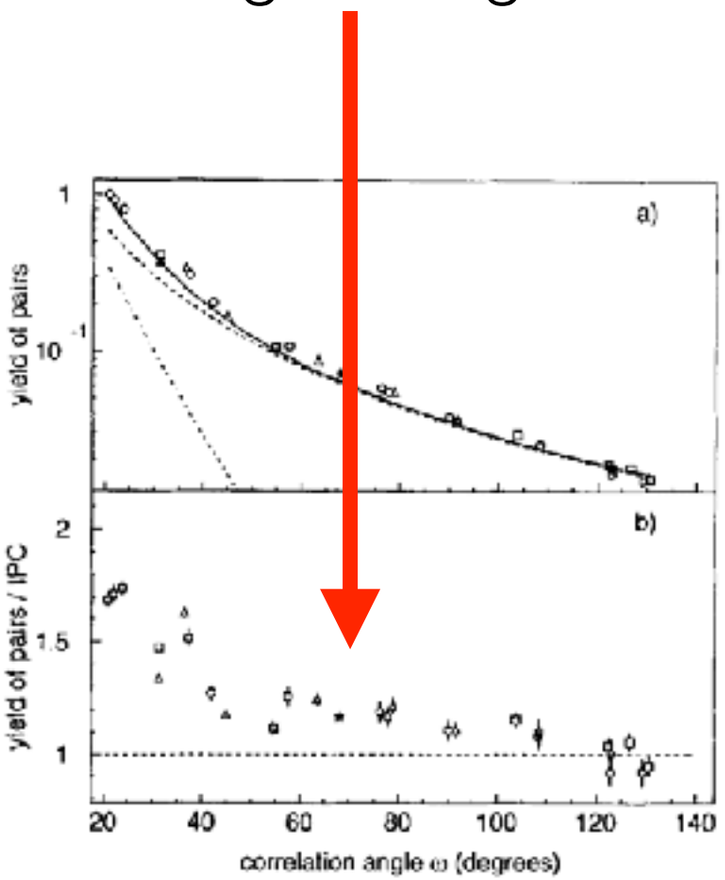


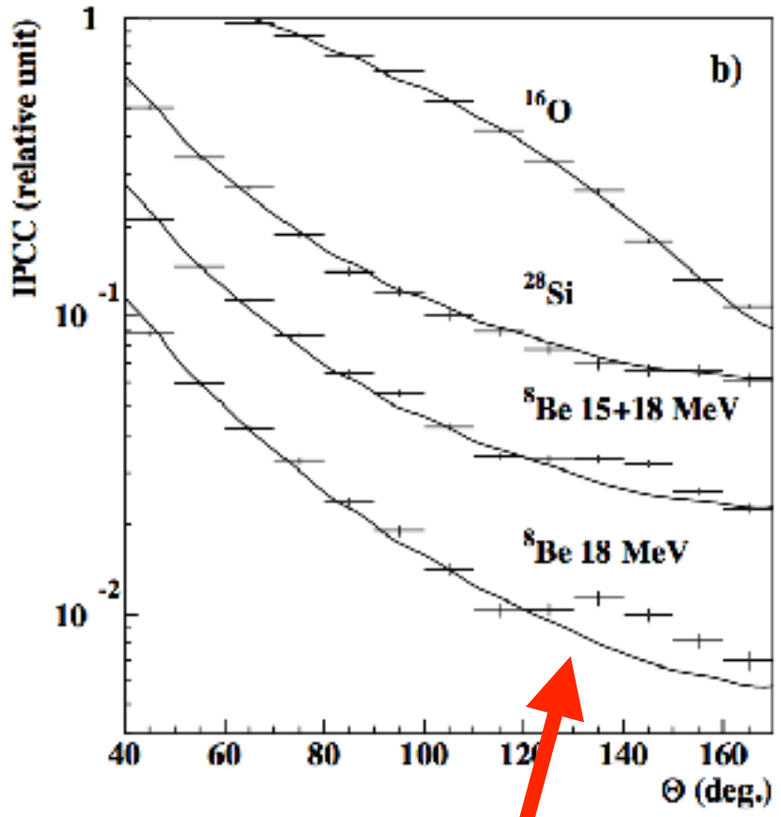
More on ^{8}Be


8Be
Jᴾ T E[MeV] Γ[KeV]
0+ 2 20.2 720
4+ 0 11.35 3500
2+ 0 3.03 1513
0+ 0 0
8Be ground state
8Be*
8Be*'
Jᴾ T E[MeV] Γ[KeV]
3+ 0* 19.24 227
3+ 1* 19.07 271
1+ 0* 18.15 138
1+ 1* 17.64 10.7
7Li+p dissociation threshold
2+ 1* 16.92 74.0
2+ 0* 16.63 108
to ground state
* - states of mixed isospin

More on ^{8}Be

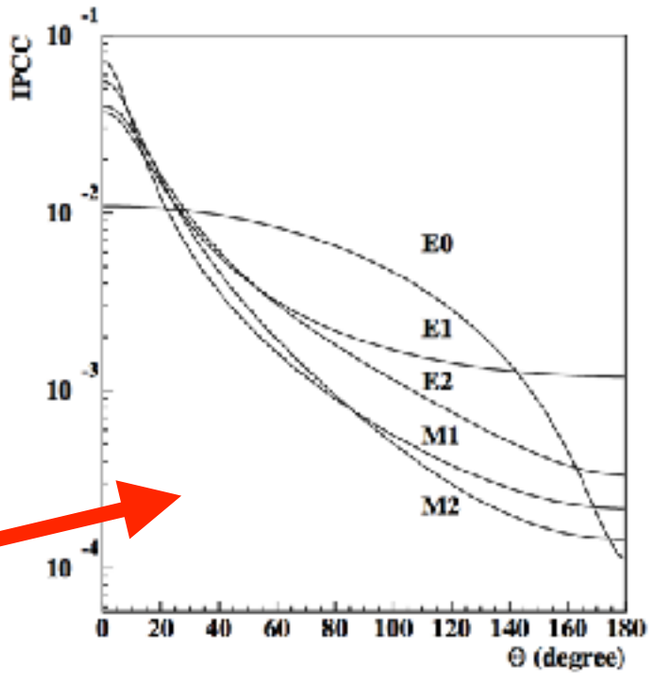
1996 signal was broad excess. Contamination from neighboring state?





2015 signal is collected in a bump.

Additional multipole terms can't make this shape easily



[de Boer et al. PLB 368, 235 (1996).]

Motivating a Dark Photon

- Want DM decay or annihilation mechanism
- Muon g-2 measurement is 3.6σ > theory
- Help for proton radius ?