Search for new Physics in e^+e^- Final states with an Invariant Mass of 10-20 MeV using the ARIEL Electron Accelerator

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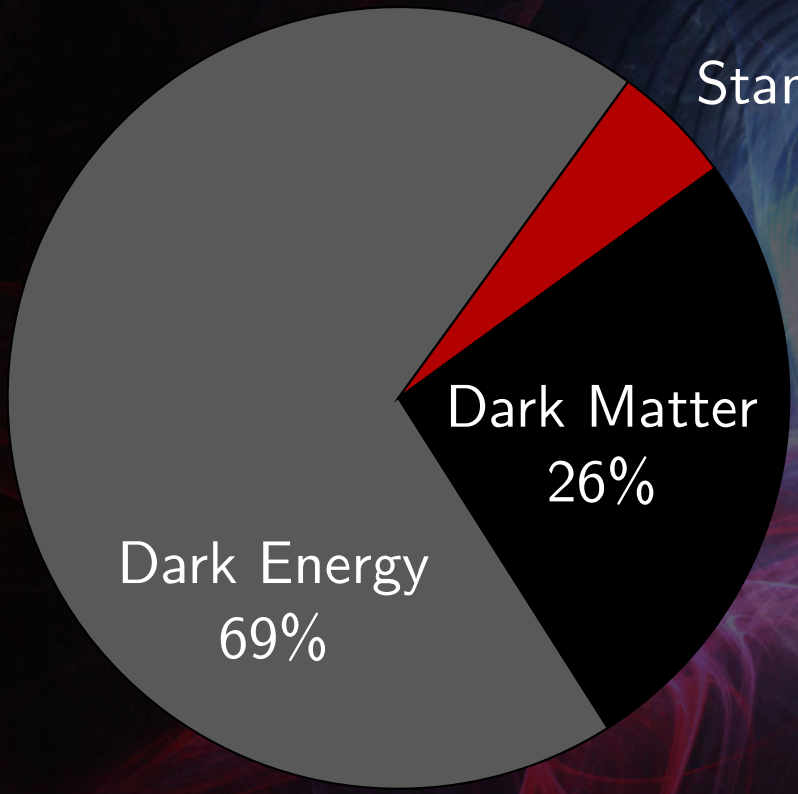
The Standard Model is really just a sliver.



18 Physics Nobel Prizes since 1950

+

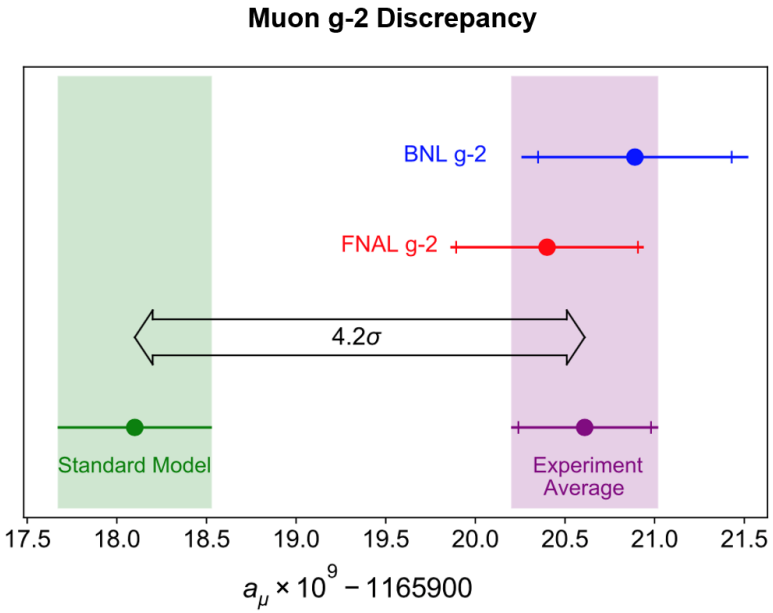
Something else

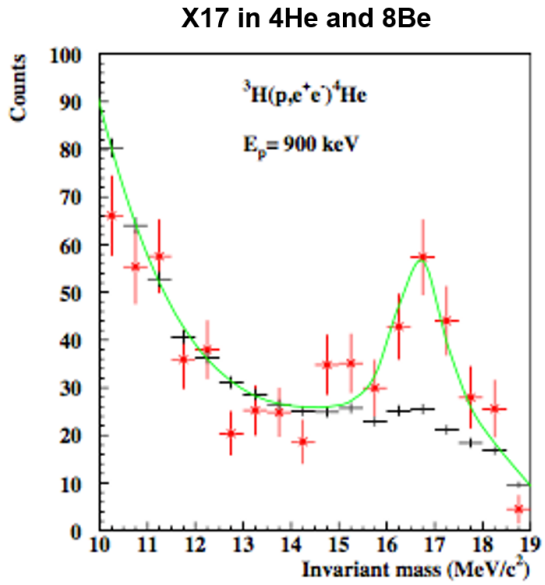
Search for Beyond the Standard Model physics

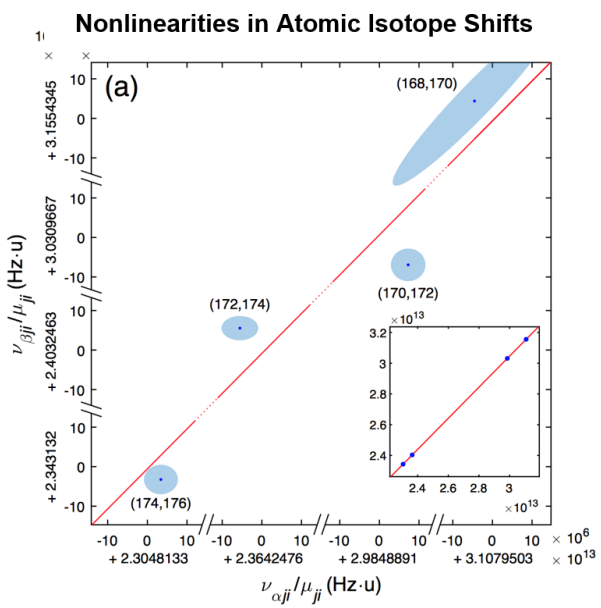
- Parameter space large for simple, infinite for complex models

Anomalies as lamp posts

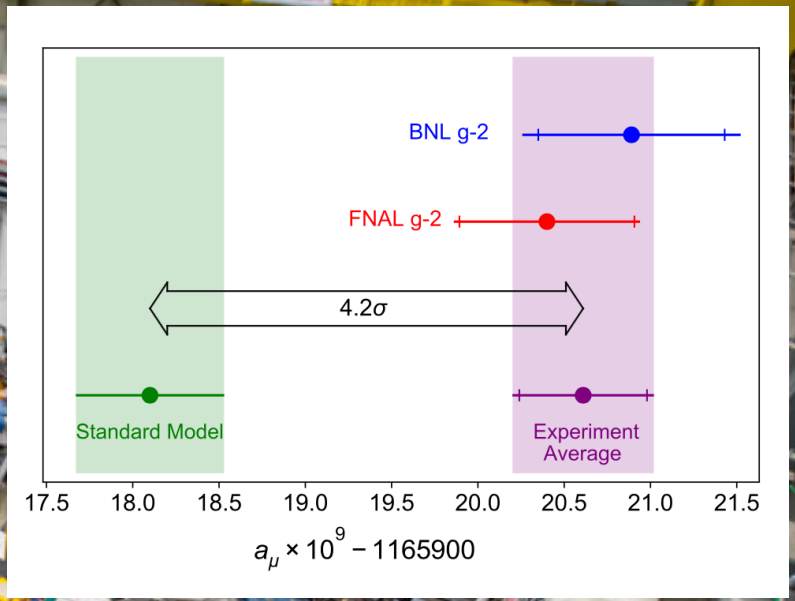
- Can we see hints of dark matter in SM anomalies?
- ... or other BSM physics?
- In nuclear / particle (atomic) physics:





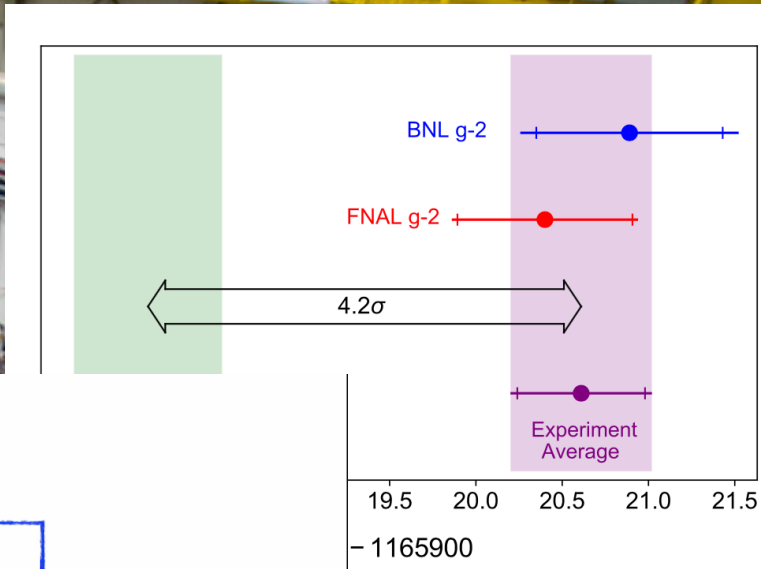


Muon g-2

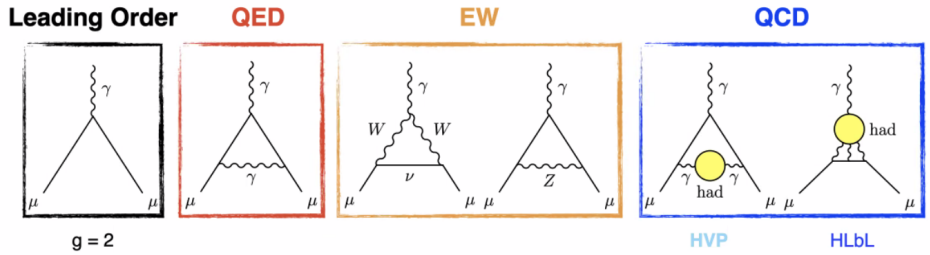


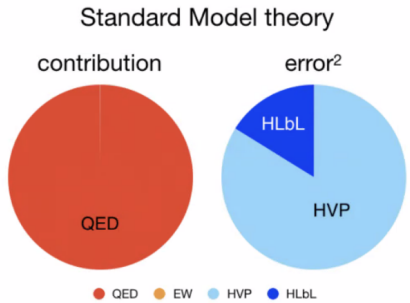
PRL 126 141801 (2021)

Muon g-2



Recently in the news: muon g-2





HVP: ***hadronic*** vacuum polarization

HLbL: ***hadronic*** light-by-light

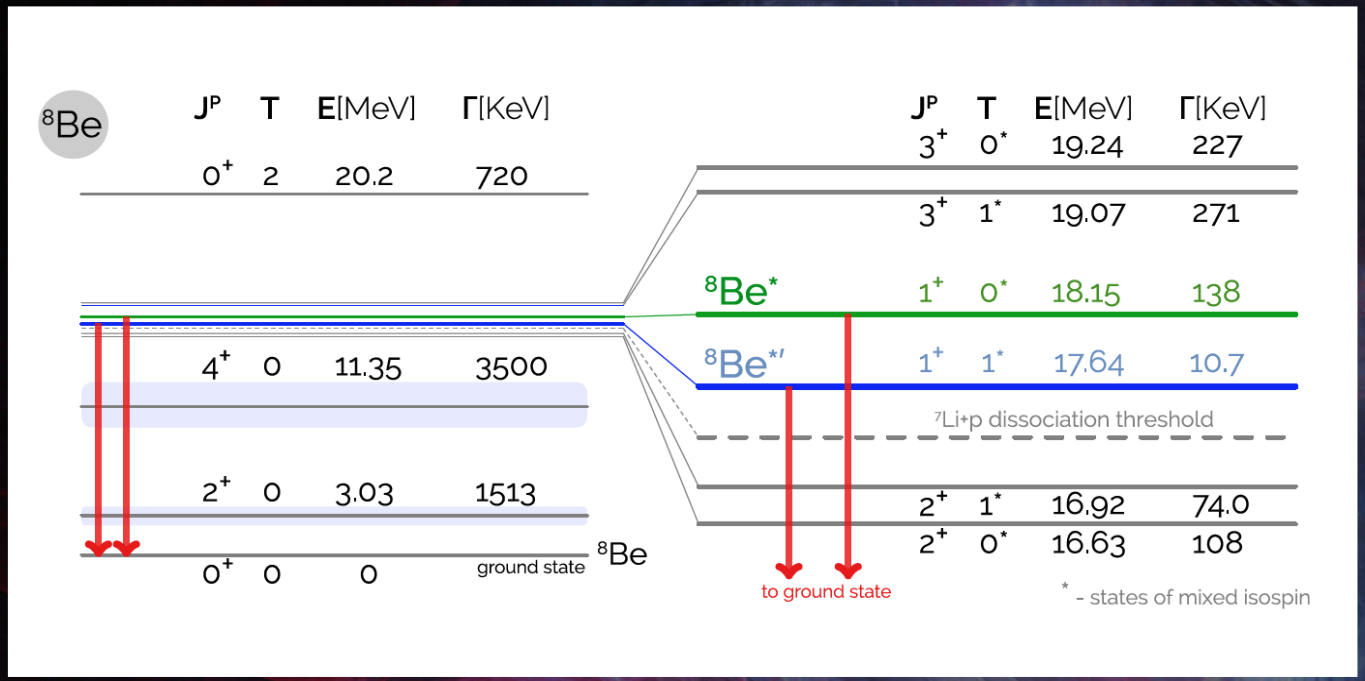
Image: Muon g-2 Theory Initiative

41801 (2021)

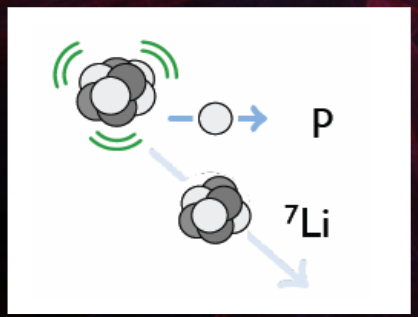
Atomki anomaly: ^8Be

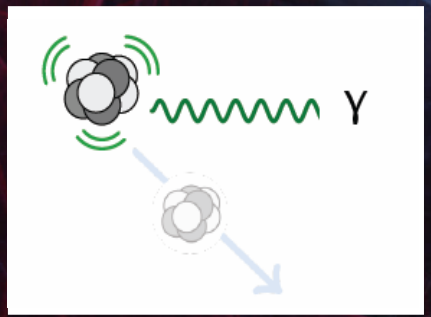
Many images from arXiv:1707.09749

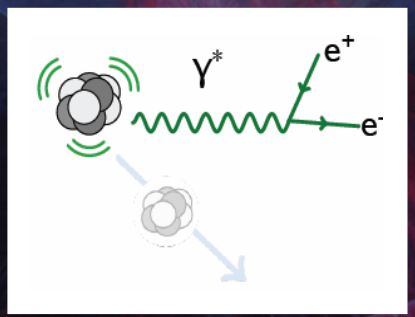
- ^8Be: two narrow, highly energetic states, decay to GS via E/M



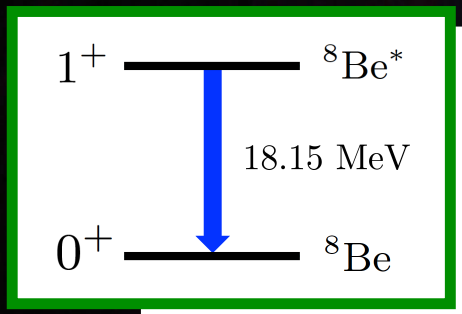
- Decay modes of $^8Be(18.15)$





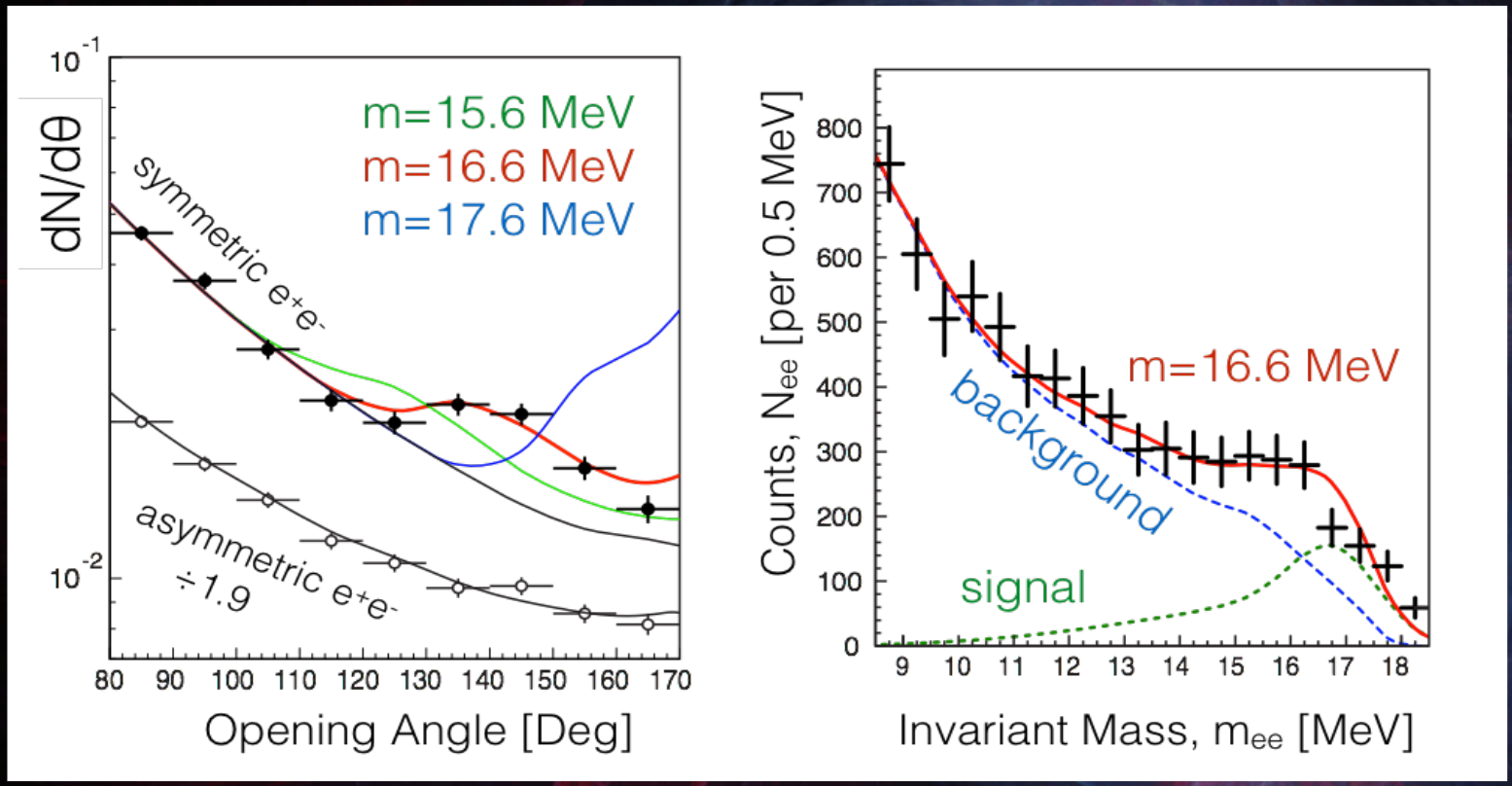


The Atomki experiment



1.04 MeV proton beam on ^7Li to $^8Be(18.15) + \gamma$. Followed by decay. Looked at $e^{\pm}$ pairs from internal conversion.

The Beryllium anomaly



(from: arXiv:1707.09749v1, modified from PRL 116 042501 (2016))

Can this be BSM?

- In simple models, region is covered by experimental tests.

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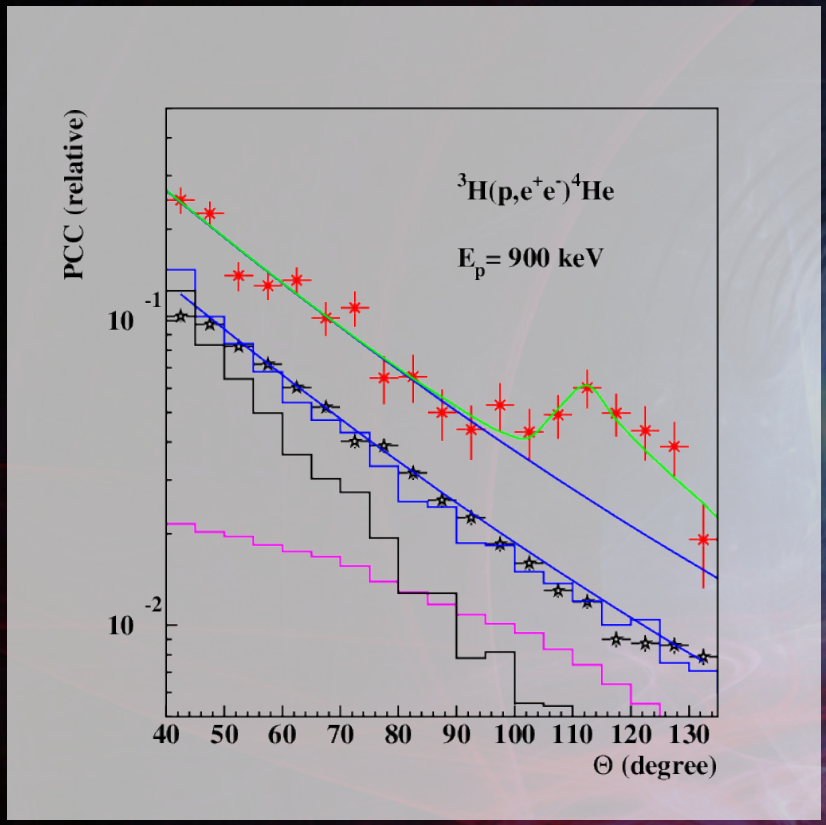
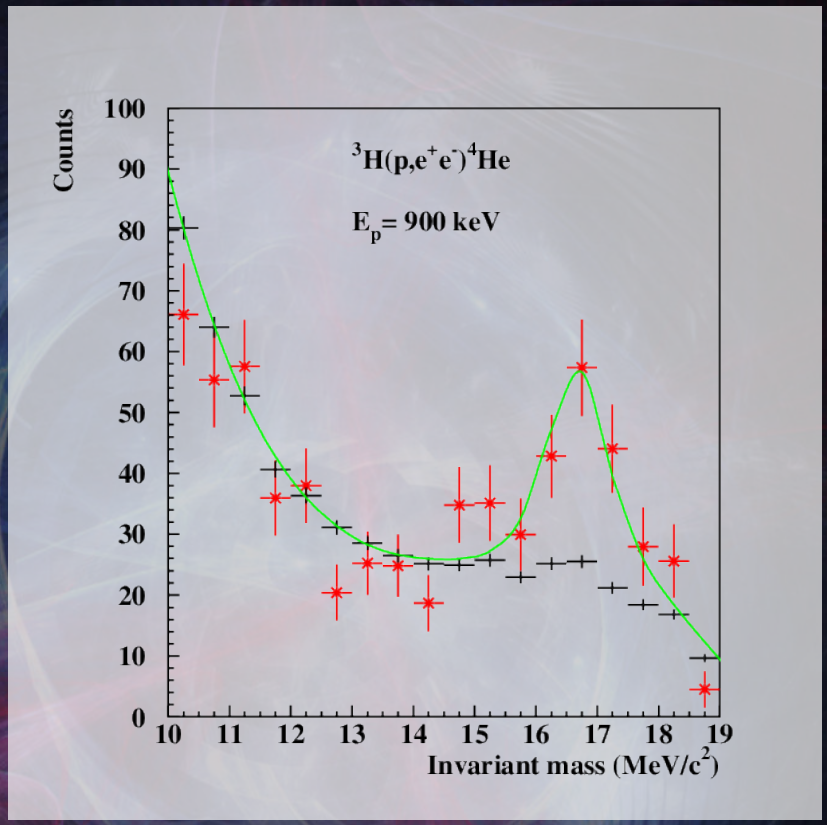
- In simple models, region is covered by experimental tests.
- Feng et al. (PRL 117, 071803 (2016)): Proto-phobic force to evade current limits
  - Atomki observes coupling to leptons. Most exps test hadronic coupling.
  - Actually: $\frac{\epsilon_p}{\epsilon_n}$ coupling below $\pm 8\%$. Z^0 is $\sim 7\%$. We need O(20) particles for the SM. That's 5%. So O(100) for DM?

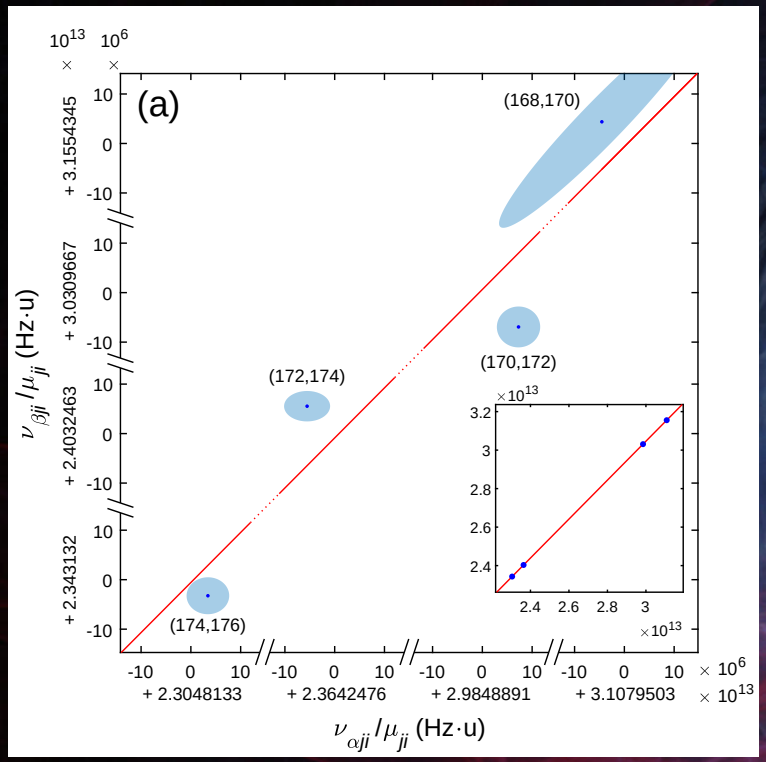
New results on $^3H(p,\gamma)^4He$ arXiv:1910.10459 [nucl-ex]

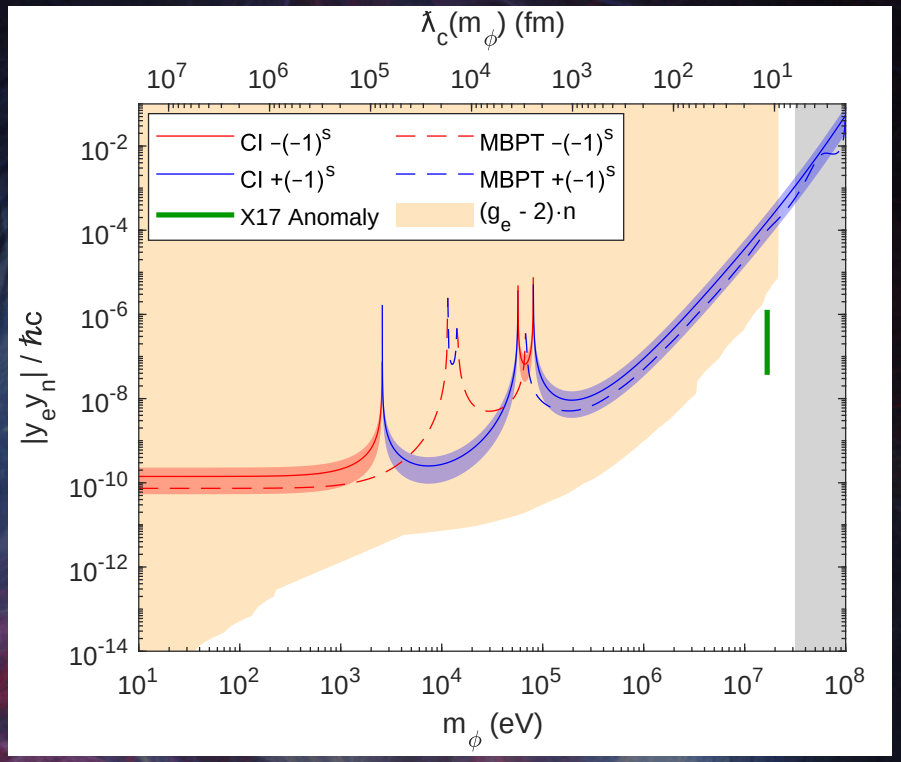




- Updated experimental setup: more detectors, reduced background
- Bump appears at different angle, but same mass: $^4He : 17.01 \pm 0.16$ MeV $^8Be : 16.84 \pm 0.16$ MeV
- Rumor: More results coming soon

Isotope shifts / King plots





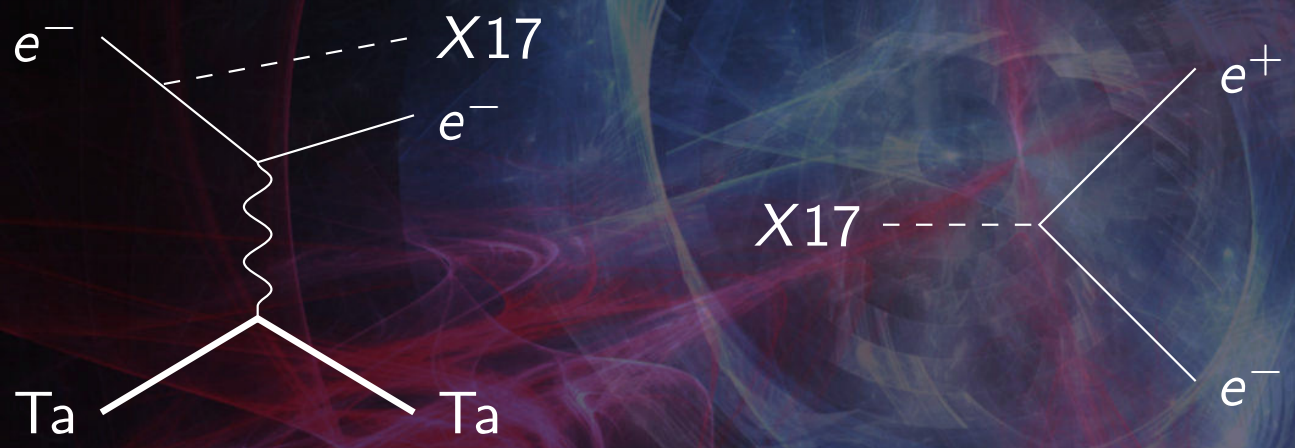
I. Counts et al. Phys. Rev. Lett. 125, 123002 (2020)

- King Plot: super-ratios of isotope transition frequencies should be linear
- Ytterbium shows nonlinearities: new electron-neutron interaction?

How can we measure an X at an electron accelerator?

Measure

$e^- Ta \rightarrow e^- Ta X$ followed by $X \rightarrow (e^- e^+)$



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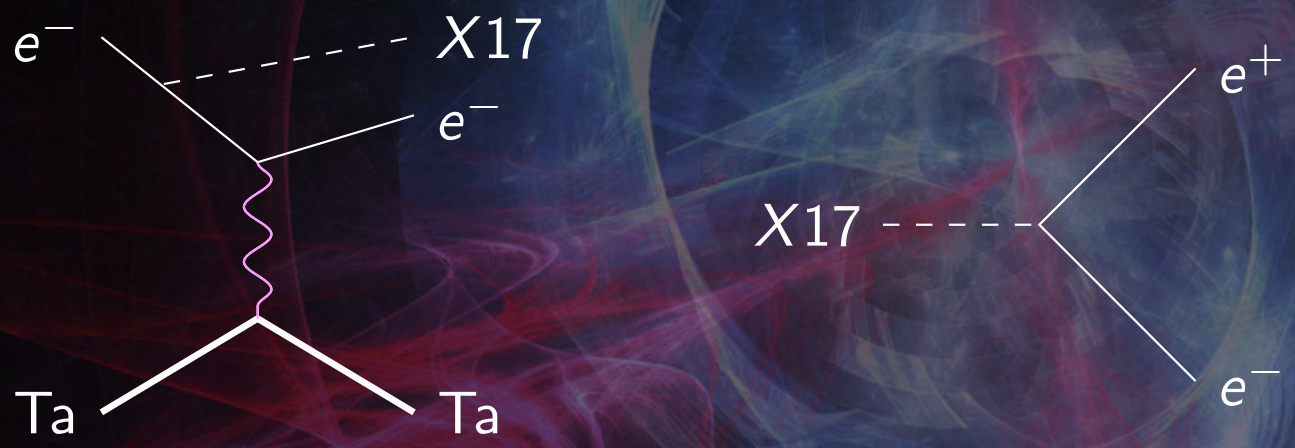


- Photon flux suppresses other production

How can we measure an X at an electron accelerator?

Measure

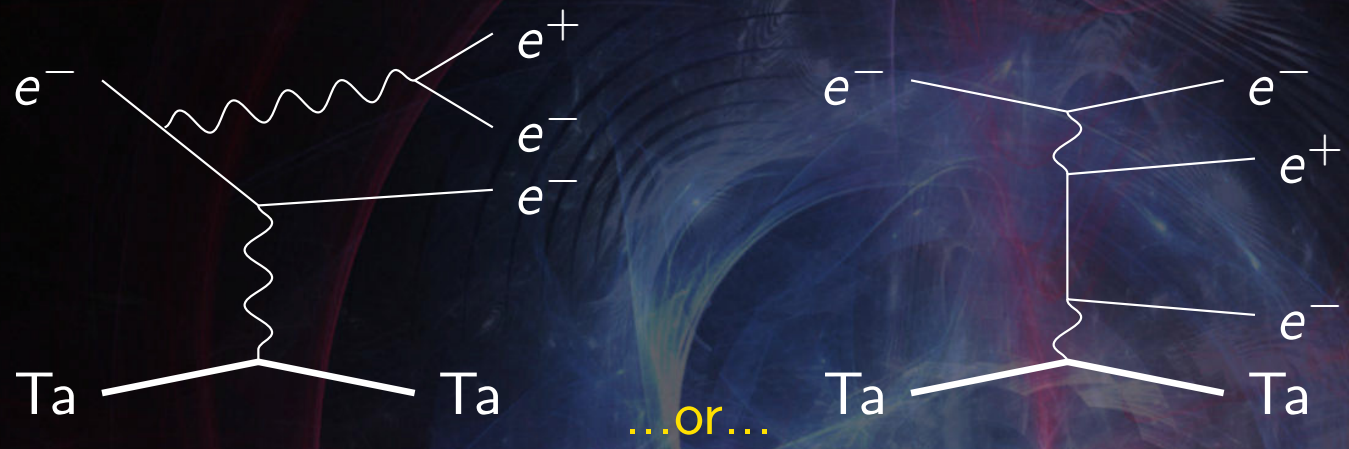
$$e^- Ta \rightarrow e^- Ta\, X \text{ followed by } X \rightarrow (e^- e^+)$$

- Photon flux suppresses other production
- Detect $e^{\pm}$ pair in two spectrometers:

$$m(e^+ + e^-) = m(X17)$$

Backgrounds

Irreducible:



- Pick any electron plus positron. Scales with $\mathcal{L}$

Backgrounds

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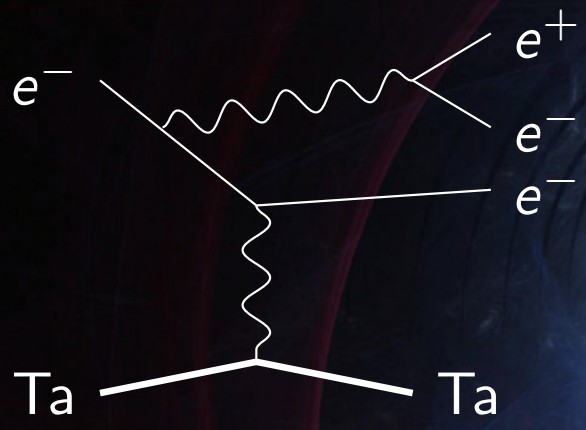
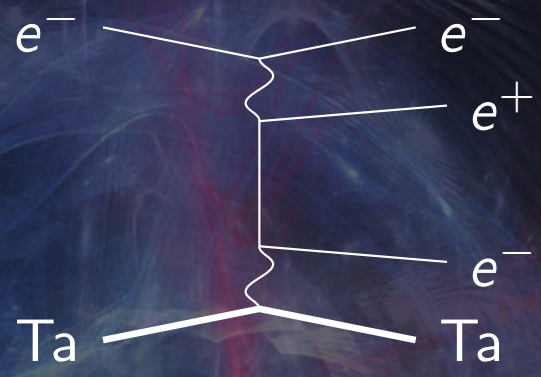


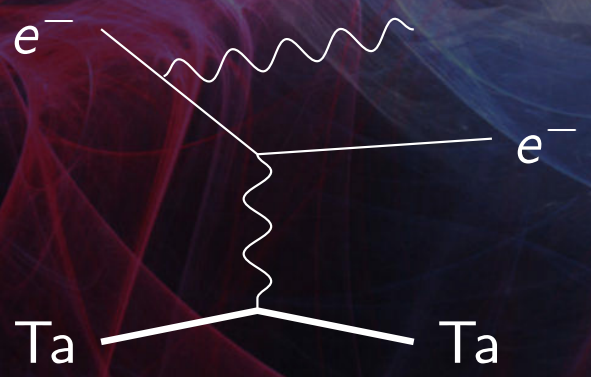
...or...



- Pick any electron plus positron. Scales with $\mathcal{L}$

Random:

- Pick positron from before ... and... electron from:



- Scales with $\mathcal{L}^2$

Figure of merit

- Search is a bump hunt: Narrow peak on smooth background
- FoM:

$$FoM = \frac{S}{\sqrt{B}} \propto \frac{p_{signal}\mathcal{L}}{\sqrt{p_{irred.}\mathcal{L} + p_{random}\mathcal{L}^2}}$$

Figure of merit

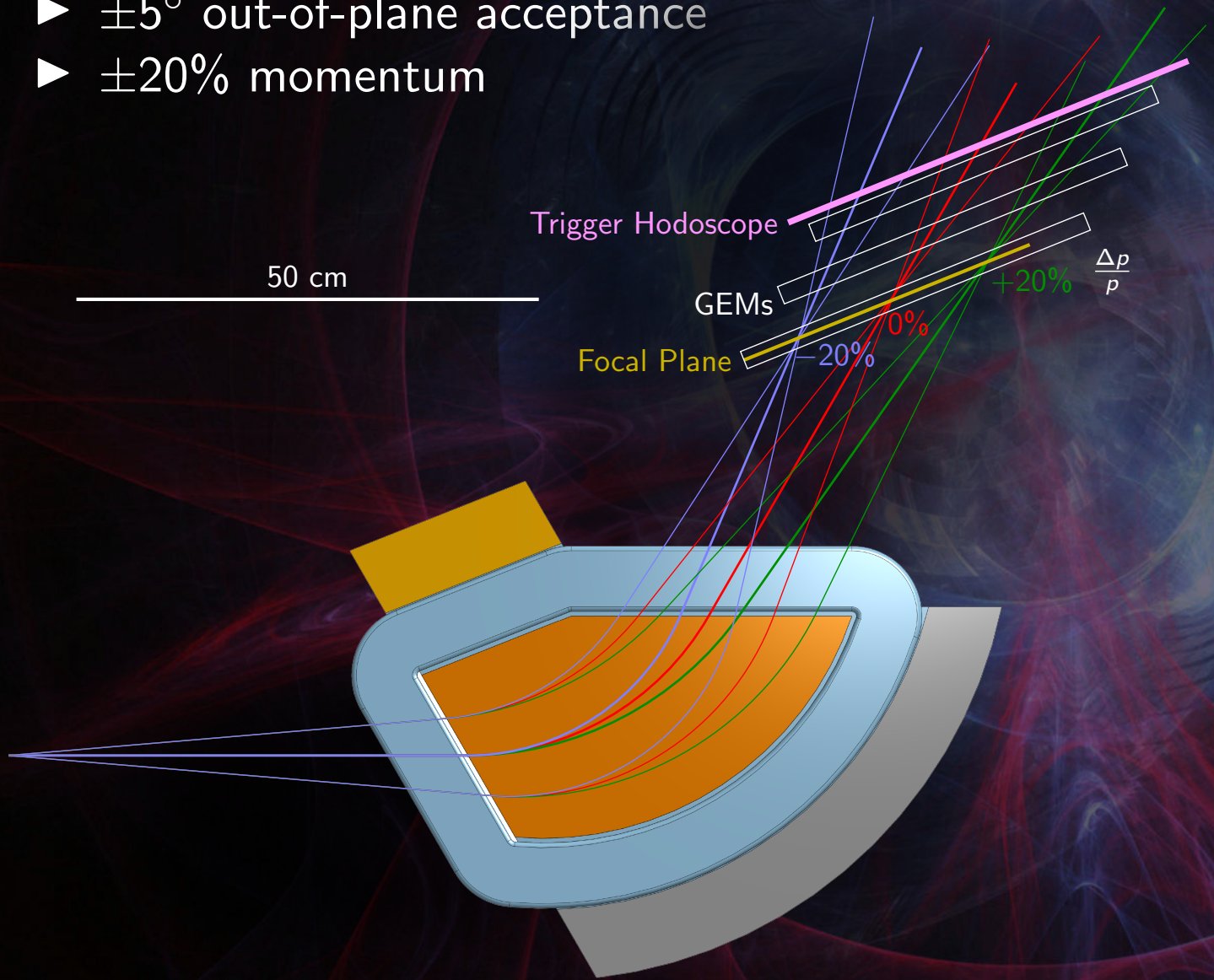
- Search is a bump hunt: Narrow peak on smooth background
- FoM:

$$FoM = \frac{S}{\sqrt{B}} \propto \frac{p_{signal}\mathcal{L}}{\sqrt{p_{irred.}\mathcal{L} + p_{random}\mathcal{L}^2}}$$

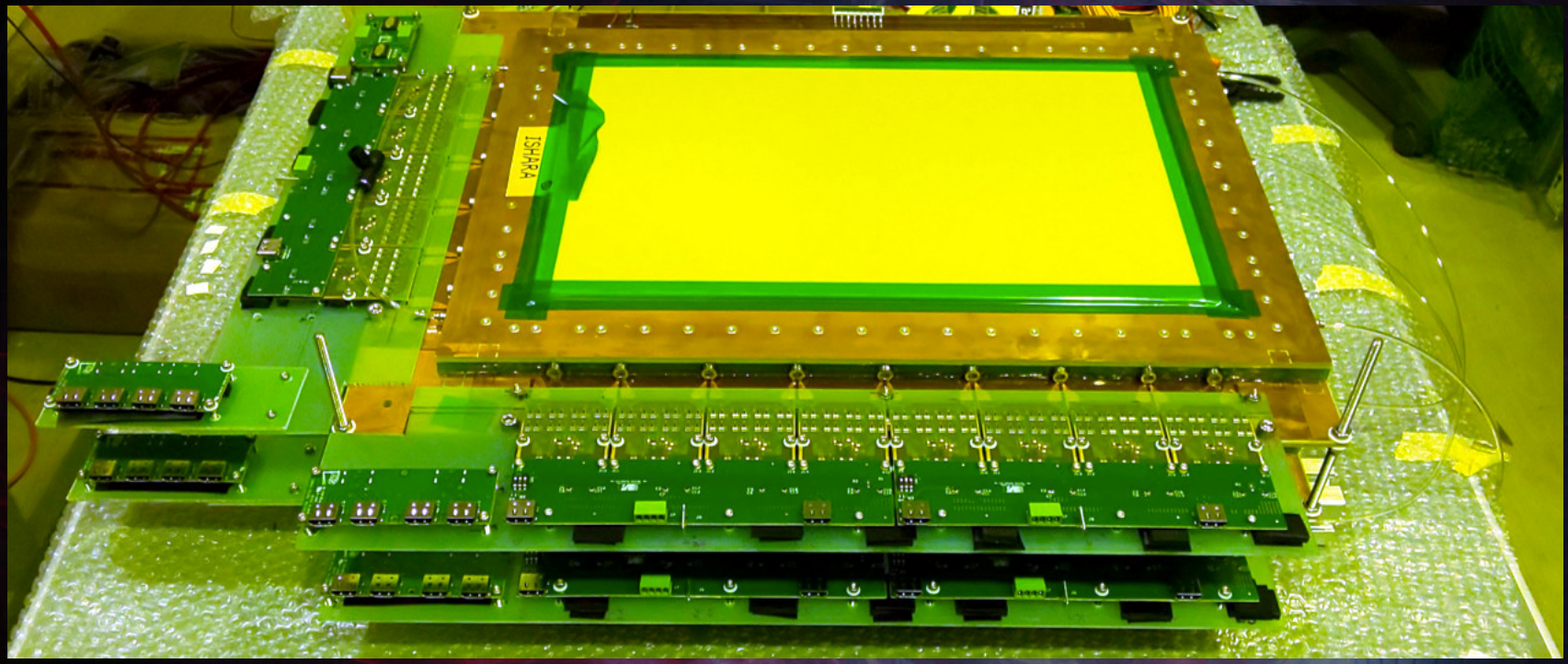
- FoM independent of $\mathcal{L}$ for larger $\mathcal{L}$

Spectrometers

- up to 28 MeV central momentum
- $\pm 2^\circ$ in-plane acceptance
- $\pm 5^\circ$ out-of-plane acceptance
- $\pm 20\%$ momentum



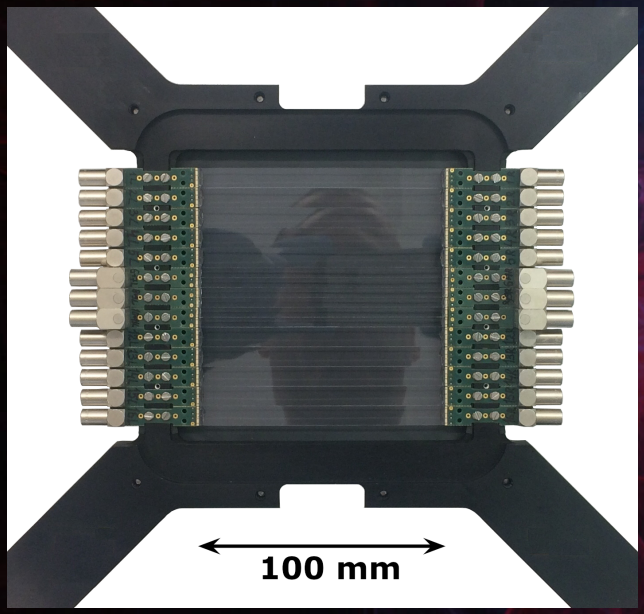
Tracking detectors

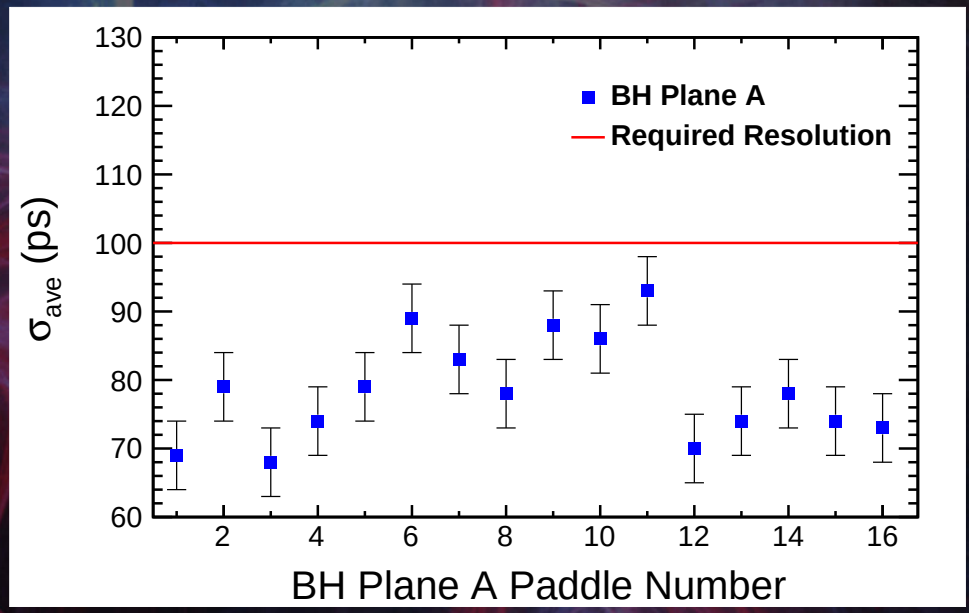


- 25x40cm Triple-GEMs built by HU
- APV+MPD4 readout (similar to JLAB SBS)
- Sufficient planes already available

Trigger detectors

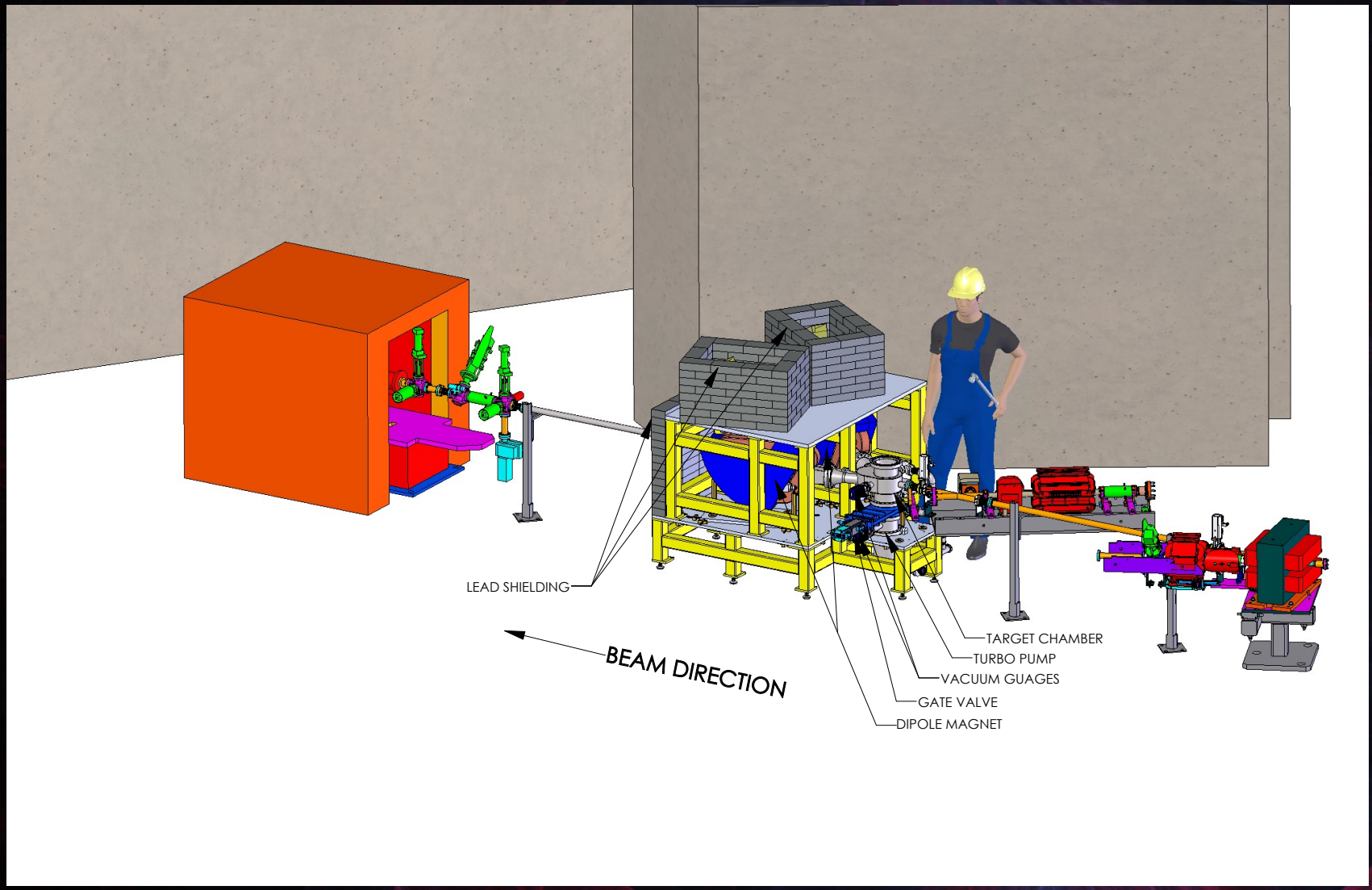
- Scintillator Hodoscope, 10 segments/spectrometer
- Need timing resolution of < 500 ps
- MUSE beam hodoscope: 2 mm thick scintillator, SiPM readout: < 100 ps
  - Tested up to 8 mm wide, 15 cm long.



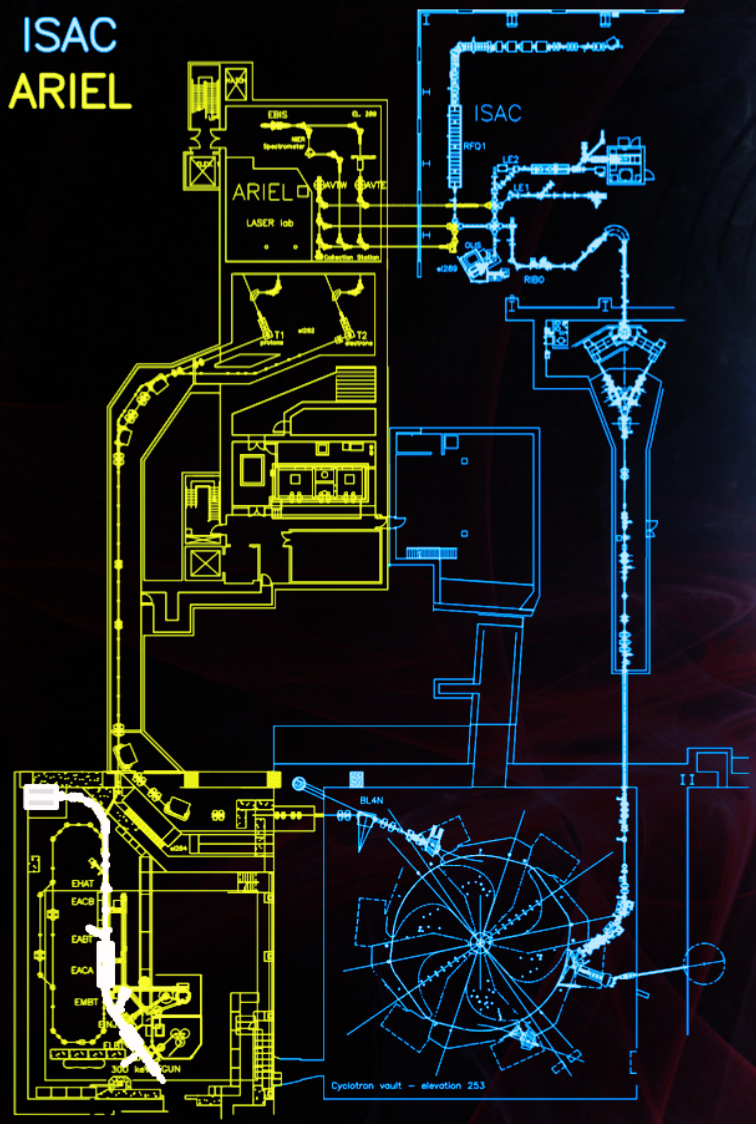


(T. Rostomyan et al., NIMA 986 164801)

3D rendering



Advanced Rare Isotope Laboratory (ARIEL)



TRIUMF ARIEL
ADVANCED RARE ISOTOPE LABORATORY

- Electron Linac
  - Nominal 50 MeV (3 cryomodules)
  - Beam optics up to 75 MeV
  - 10mA, duty cycle 0-100%
  - To date: only white part
- Rare Isotope Beams
  - one new proton and electron BL
  - triple capabilities

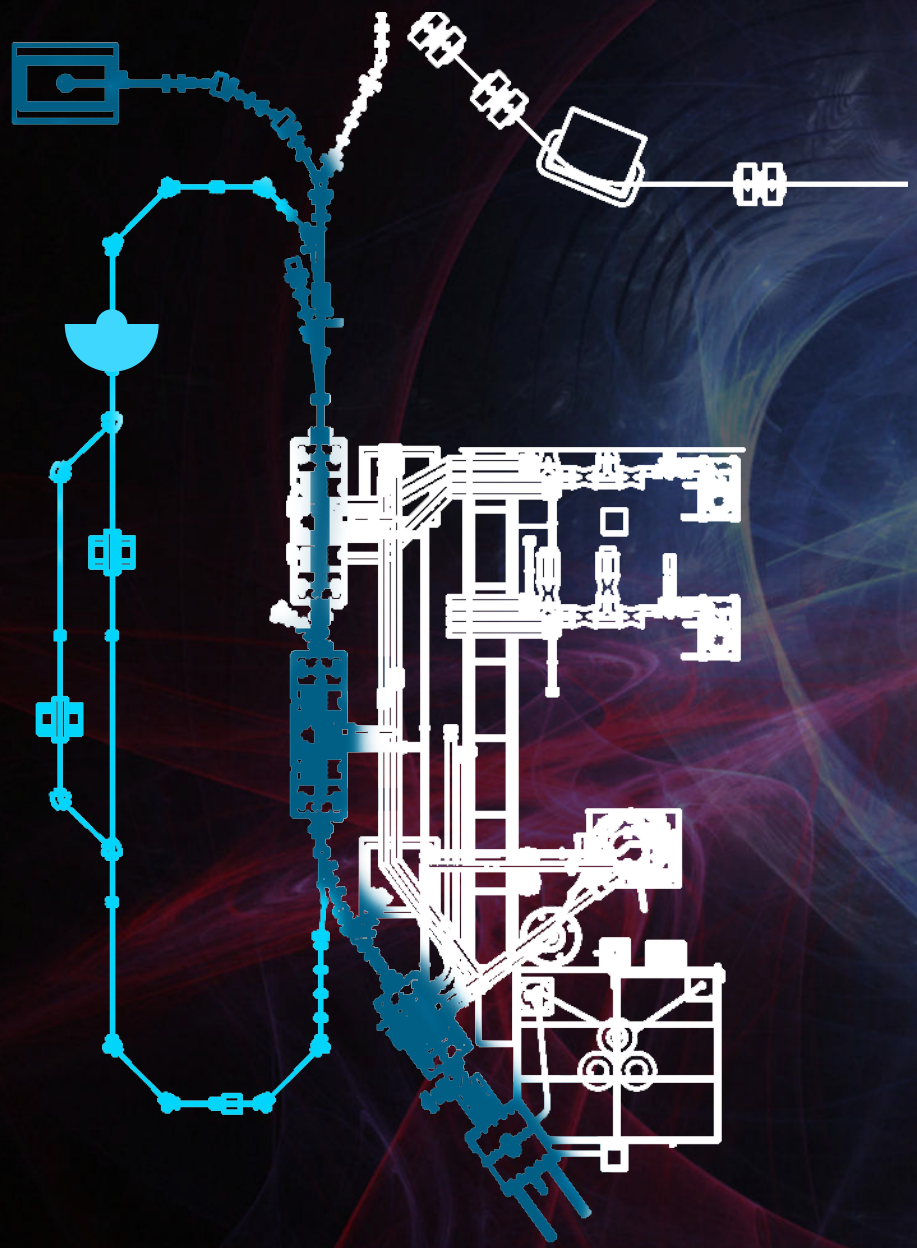
Staged running

Staged running

Stage 0

- Minimal modification
- Up to 31 MeV

Staged running



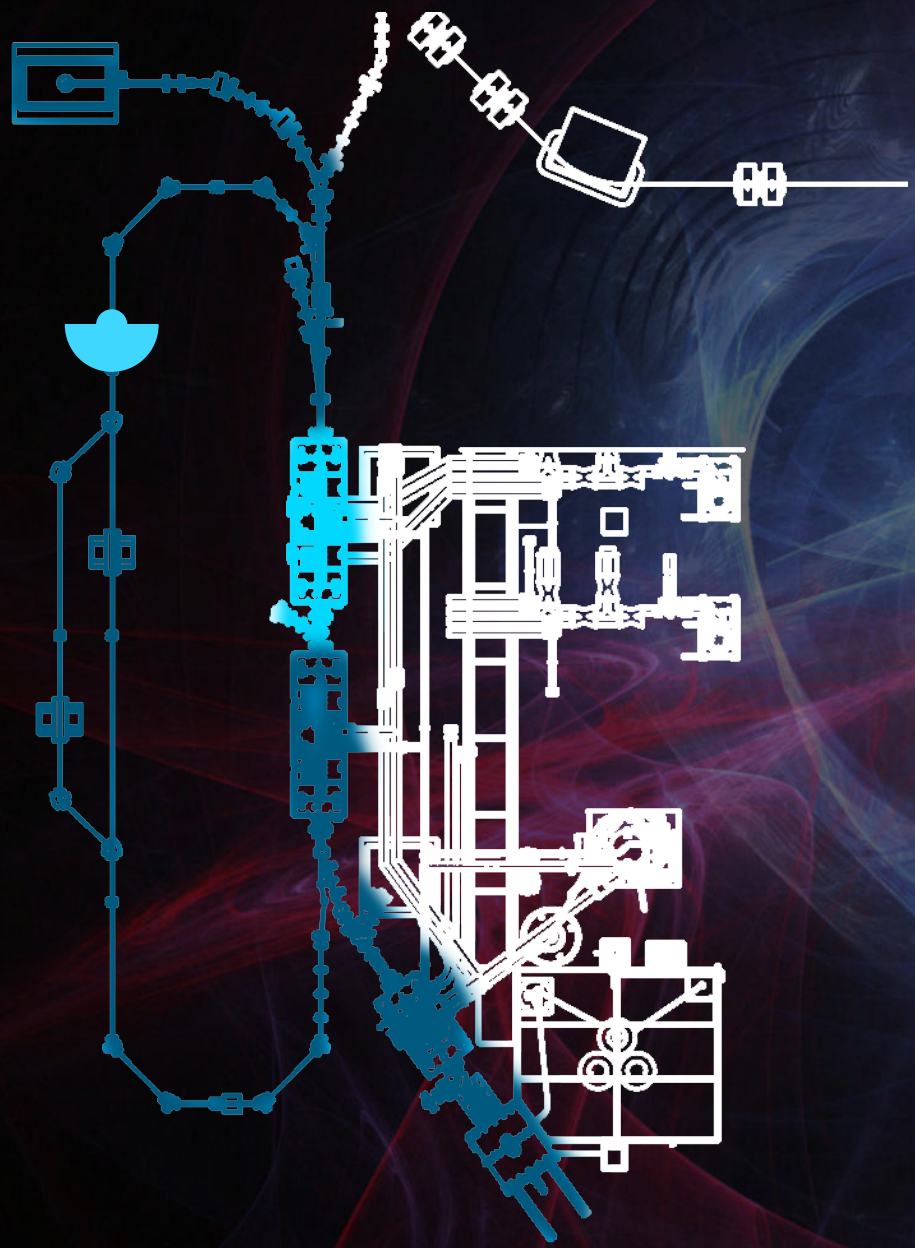
Stage 0

- Minimal modification
- Up to 31 MeV

Stage 1

- Recirculation
- Up to 50 MeV

Staged running



Stage 0

- Minimal modification
- Up to 31 MeV

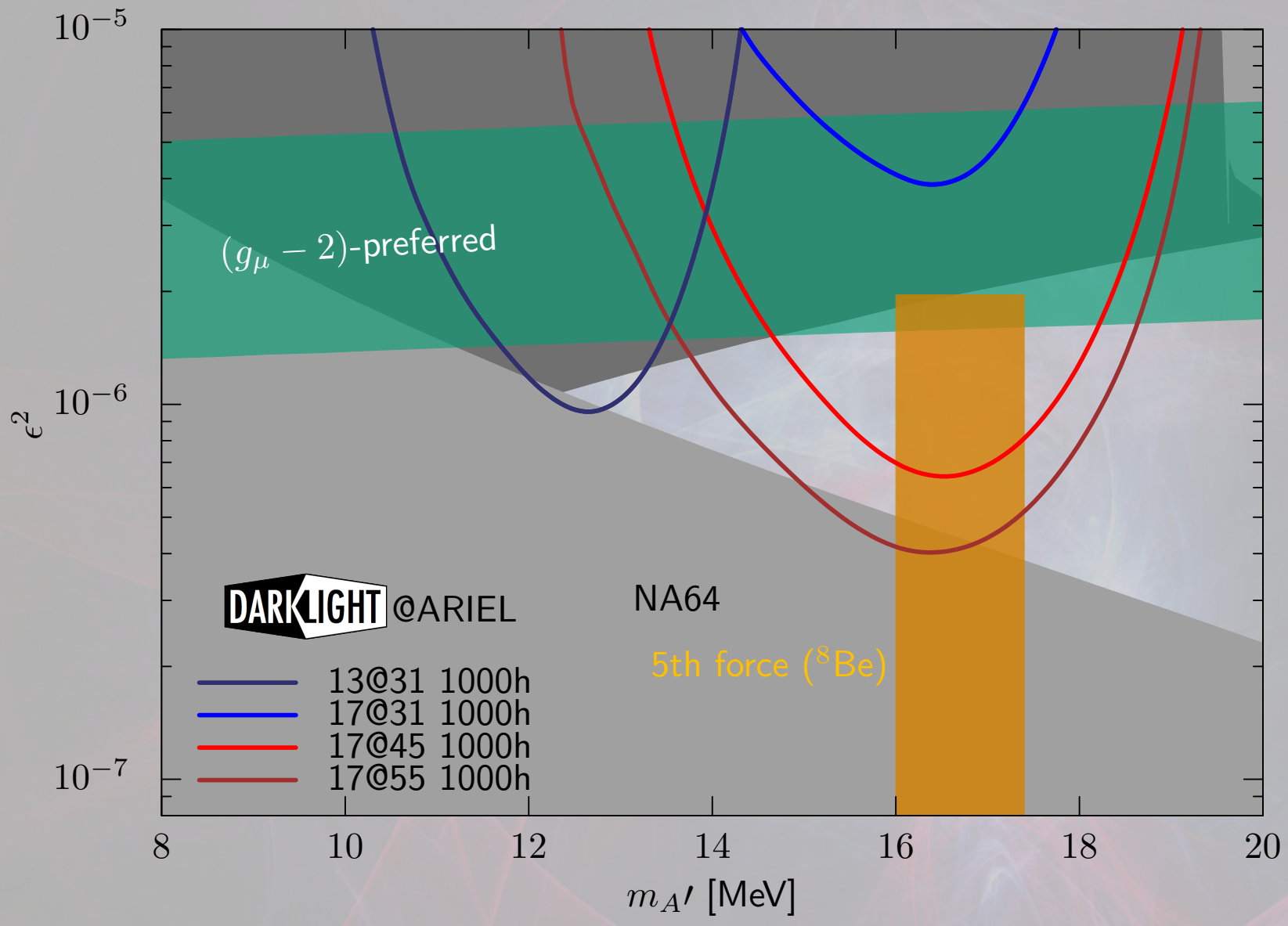
Stage 1

- Recirculation
- Up to 50 MeV

Stage 2

- Second cryo module
- Simultaneous ARIEL+DL

Projected reach



Ongoing activities + status

- PP-EEC (TRIUMF's PAC) approved DL for 1300h of beamtime
- Tuning spectrometer design
- Test beam for target + background this October/next spring
- Planning workshop to develop larger physics program using ARIEL + spectrometers (Funded by APS Moore foundation)
- Data taking $\approx$ 2023