ERLs for precision measurements on fixed targets

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What makes ERLs unique?

Storage Ring ⟷ ERL ⟷ External beam

Storage Ring

- large current
- seriously thin target
- compromised beam quality
- Lowest luminosity

ERL

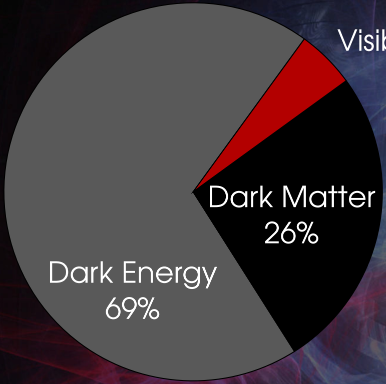
- medium current
- thin-ish target
- excellent beam
- medium luminosity

External beam

- lowest current
- thick target
- excellent beam
- highest luminosity

Will talk about two experiments that make use of thin target / high luminosity: DarkLight and MAGIX@MESA

The Standard Model is really just a sliver.



Standard Model

Something else

Search for Beyond the Standard Model physics

» Phase space large for simple, infinite for complex models

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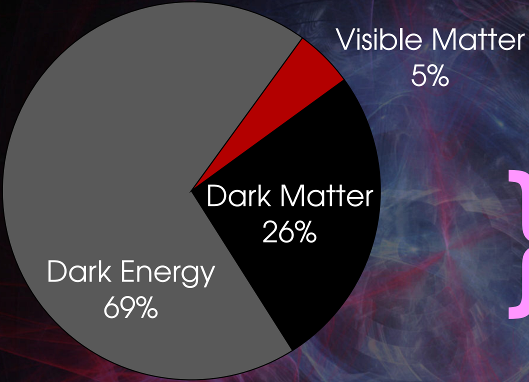


Standard Model

Something else

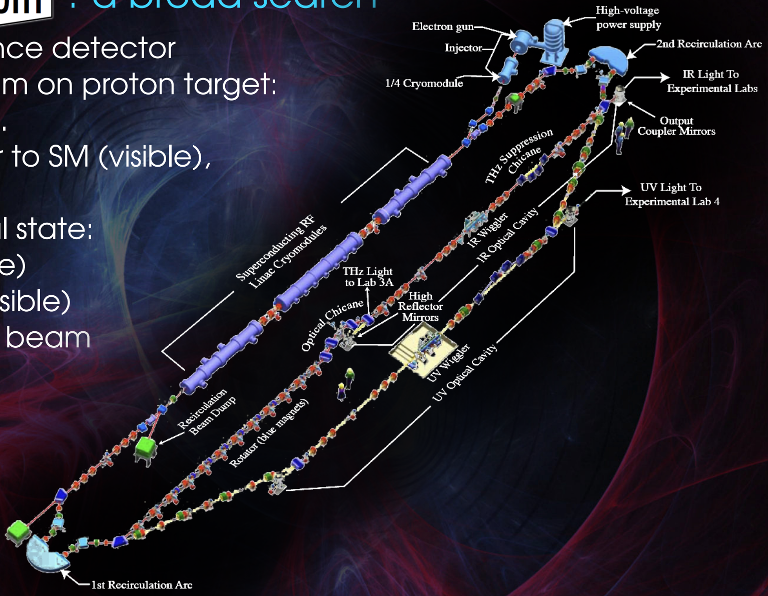
Search for Beyond the Standard Model physics

» Phase space large for simple, infinite for complex models

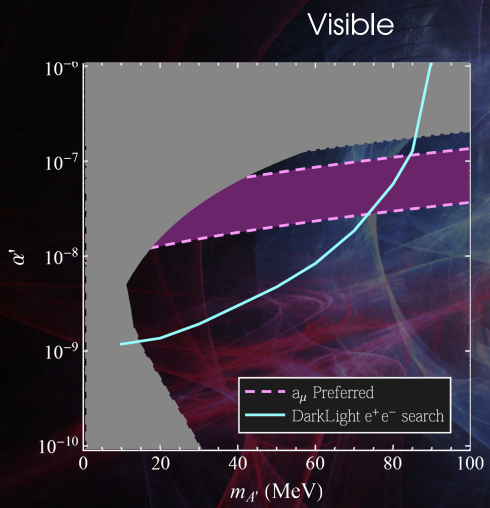
» Two approaches: Cover large area – or look at anomalies

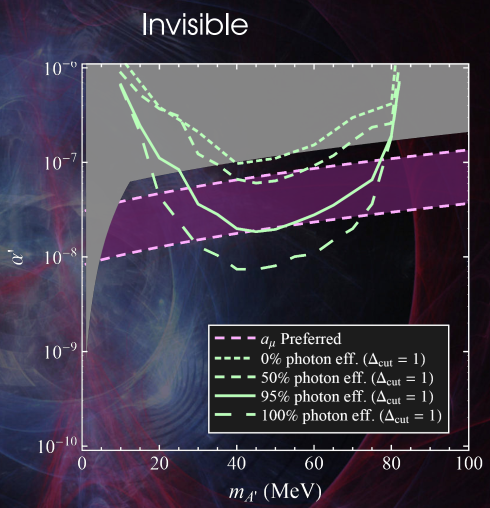
The original DARKLIGHT : a broad search

- Large acceptance detector
- Process: e^- beam on proton target: $e^- + p \to e^- p A'$.
- A' decays either to SM (visible), or DM (invisible)
- Measure full final state:
  - $e^- p$ (invisible)
  - $e^- p e^+ e^-$ (visible)
- 100 MeV, 10 mA beam of JLAB's LERF

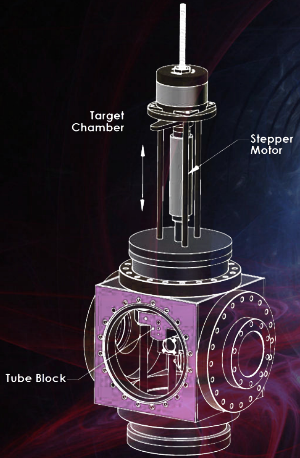


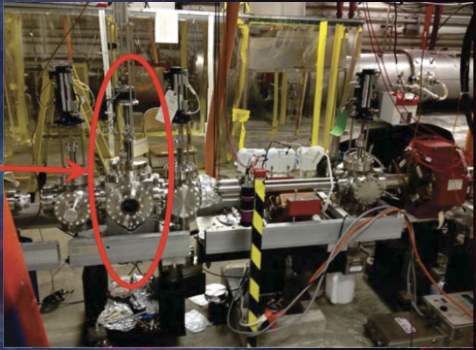
What could have been (at 1 ab^{-1})





Test beam in 2012





> 0.4 MW beam through 2 mm hole for > 400 min

Nucl. Instrum. Meth. A 729, 233-240 (2013)

DL @ LERF: no future

» Funding issues for LERF: Mothballed
» Un-mothballed in 2016 for a target commissioning run

Nucl. Instrum. Meth. A 939, 46-54 (2019)

» 2017: LERF repurposed for LCLS cavity tests. Later cannibalized for CEBAF. No ERL running. Only external beam at 50 MeV or less.

Search under lamp posts

- Much of area for simple models covered. But why should DM be simpler than SM?
- Instead of a wide search, search where something is amiss!

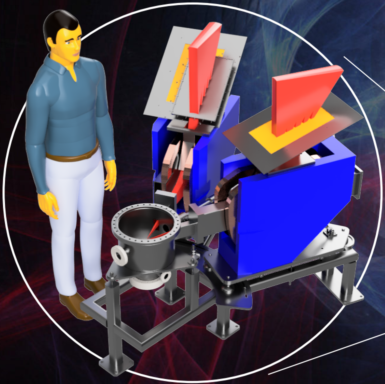
X17: Why look there?

- ATOMKI anomalies (^{8}Be, ^{4}He, ...)
- Isotope shift / King plots
- $g_\mu - 2$
- Proton radius puzzle

Possible solution: New, protophobic force with a carrier around 17 MeV

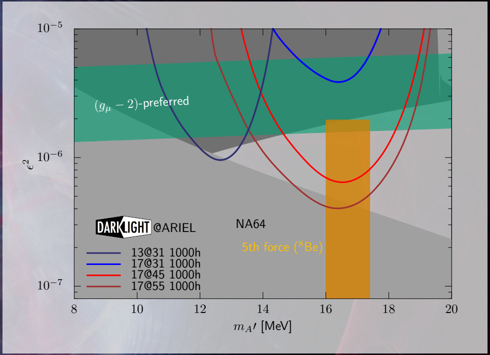
DarkLight@ARIEL

- Measure only e^+/e^- pair in spectrometers
- Beam energy 30-50 MeV
- Thin tantalum foil target



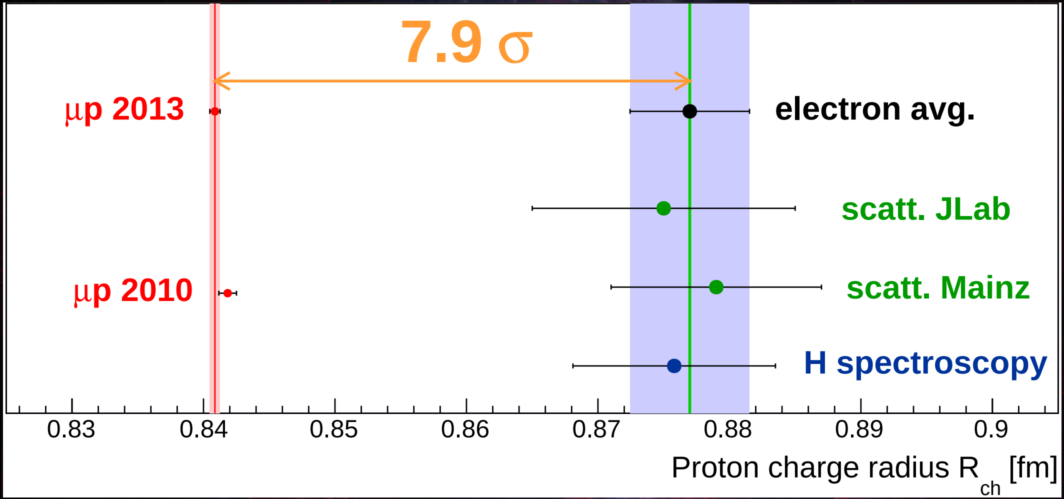
DarkLight@ARIEL Timeline and Reach

04/2021: Proposal approved
10/2022: TRIUMF review
04/2023: Test with prototype
11/2023: Install experiment
03/2024: Commission complete
04/2024: Take data at 30 MeV
late 2024/early 2025: Energy upgrade
End 2025: Take data at 50 MeV



Proton radius puzzle

Proton radius puzzle



Cross section for elastic scattering

$$\frac{\left(\frac{d\sigma}{d\Omega}\right)}{\left(\frac{d\sigma}{d\Omega}\right)_{\text{Mott}}} = \frac{1}{\varepsilon\left(1+\tau\right)}\left[\varepsilon G_E^2\left(Q^2\right) + \tau G_M^2\left(Q^2\right)\right]$$

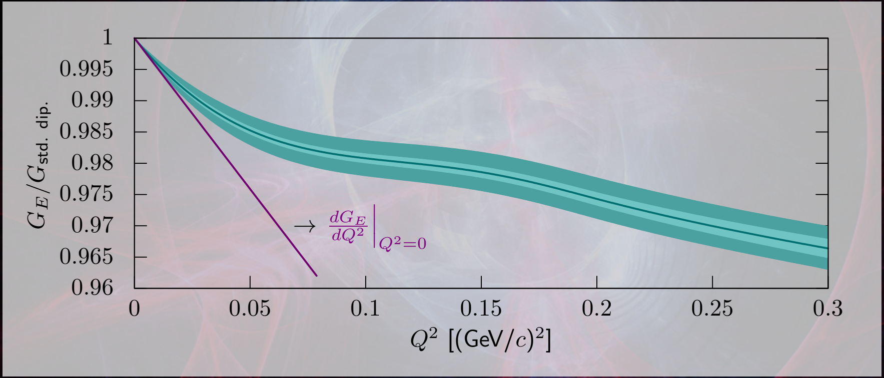
with:

$$\tau = \frac{Q^2}{4m_p^2}, \quad \varepsilon = \left(1 + 2\left(1+\tau\right)\tan^2\frac{\theta_e}{2}\right)^{-1}$$

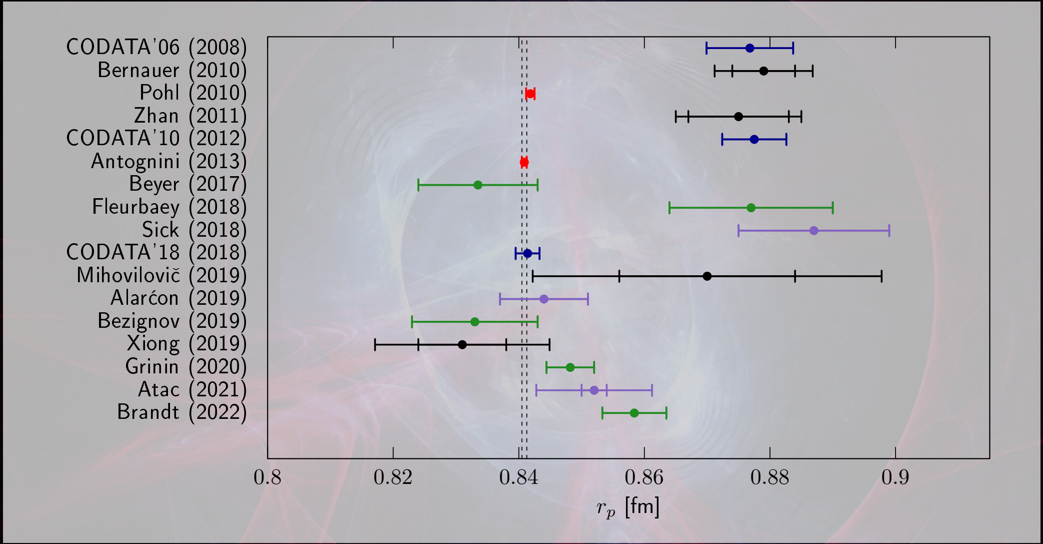
- Rosenbluth formula
- Electric and magnetic form factor encode the shape of the proton
- Fourier transform (almost) gives the spatial distribution, in the Breit frame

How to measure the proton radius

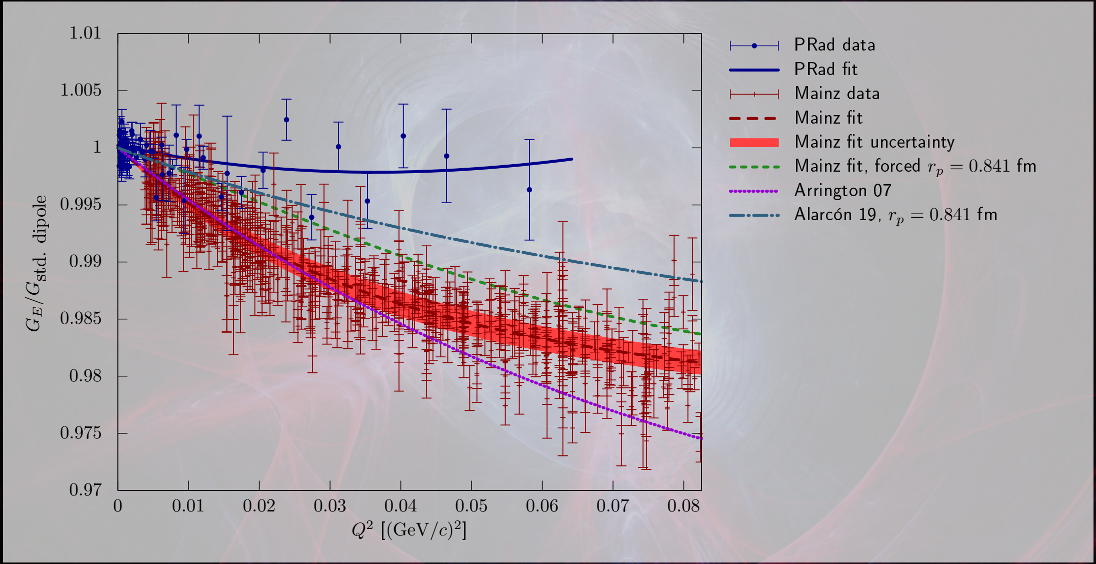
$$\left\langle r_E^2 \right\rangle = -6\hbar^2 \left. \frac{\mathrm{d}G_E}{\mathrm{d}Q^2} \right|_{Q^2=0} \qquad \left\langle r_M^2 \right\rangle = -6\hbar^2 \left. \frac{\mathrm{d}\left(G_M/\mu_p\right)}{\mathrm{d}Q^2} \right|_{Q^2=0}$$



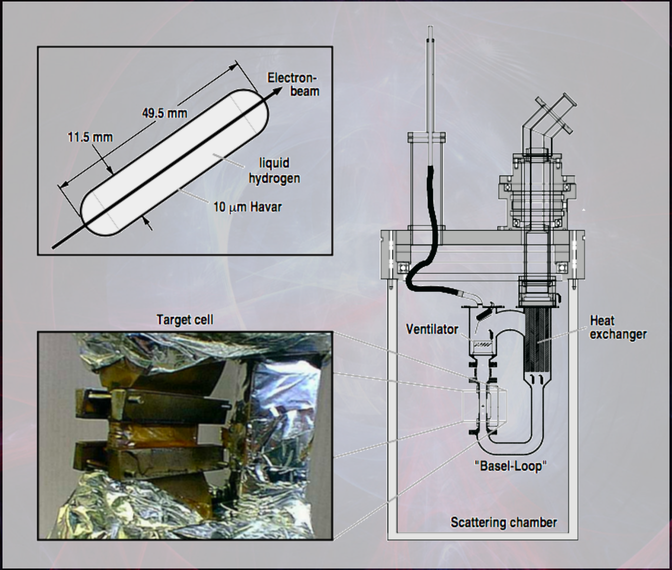
New results


CODATA'06 (2008)
Bernauer (2010)
Pohl (2010)
Zhan (2011)
CODATA'10 (2012)
Antognini (2013)
Beyer (2017)
Fleurbaey (2018)
Sick (2018)
CODATA'18 (2018)
Mihovilovič (2019)
Alarćon (2019)
Bezignov (2019)
Xiong (2019)
Grinin (2020)
Atac (2021)
Brandt (2022)
0.8
0.82
0.84
0.86
0.88
0.9
r_p [fm]

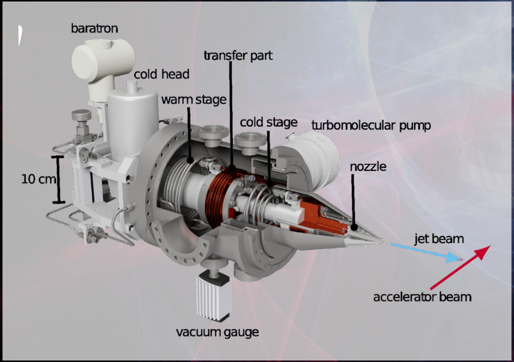
No agreement on form factor level



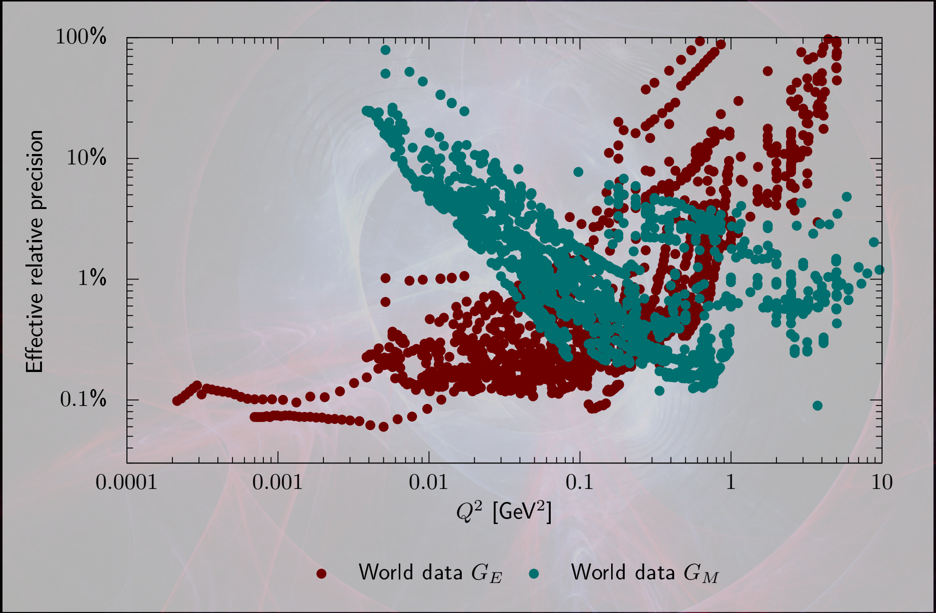
The root of almost all evil



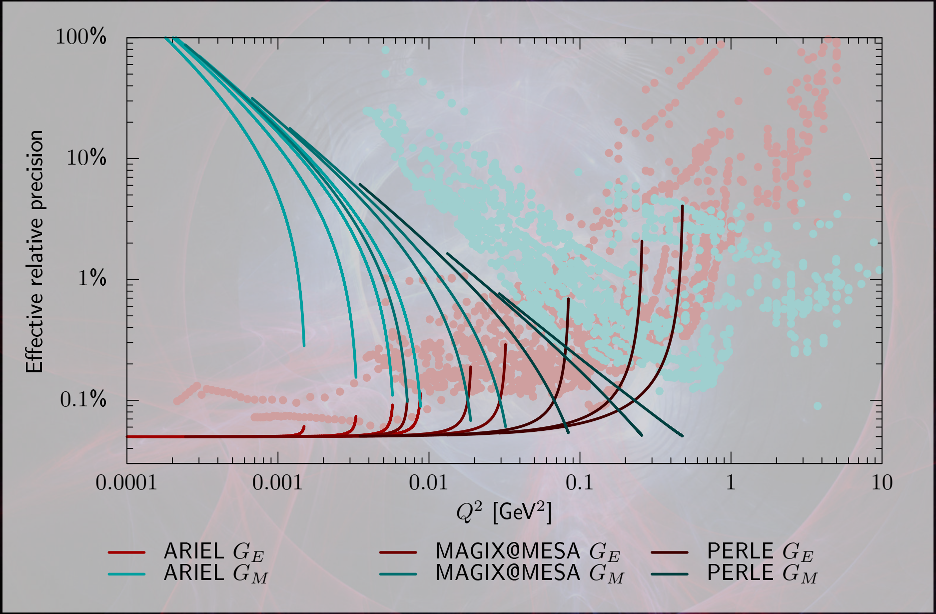
How can we improve? Gas jet target!



What do we know from scattering



What we could measure at ERLs



But wait, there is more

Can do the same for other targets: ^{3}He,^{4}He, N, O,...
Many low hanging fruits, many overlaps with atomic measurements!

Conclusions

ERLs open new possibilities for experiment design:

» Excellent beam parameters

» Thin targets but still large luminosity

» Typically not the highest energies

» Large NP/PP physics program!