DARKLIGHT 1c

Search for New Physics in e+e- Final States Near an Invariant Mass of 17 MeV

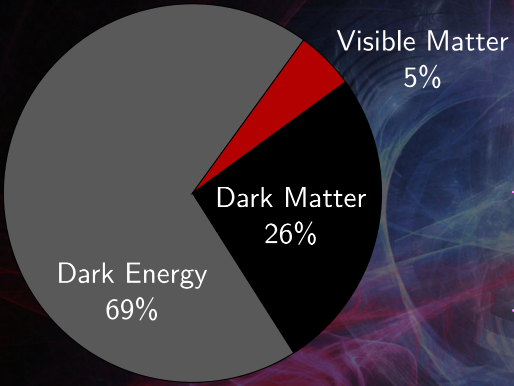
Jan C. Bernauer

November 2020

RBRC RIKEN BNL Research Center

Stony Brook University

The Standard Model is just a sliver



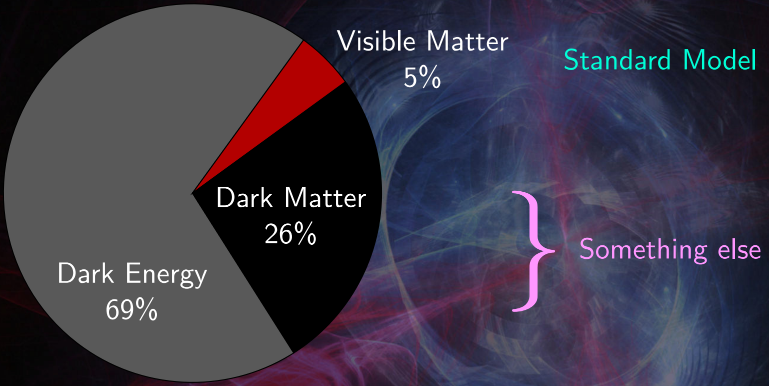
Standard Model

Something else

Search for BSM physics

- Phase space large for simple, infinite for complex models

The Standard Model is just a sliver



Search for BSM physics

- Phase space large for simple, infinite for complex models
- Two approaches: Cover large area – or look at anomalies
  Beryllium/Helium anomaly, $g_\mu - 2$, proton charge radius

X17

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Rekindled Atomki anomaly merits closer scrutiny

20 December 2019

Atomki's new high-resolution $LaBr_3$ spectrometer, which will record gamma–gamma pairs from excited nuclei. Credit: Atomki

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20 December 2019

Atomki's new high-resolution $LaBr_3$ spectrometer, which will record ga
excited nuclei. Credit: Atomki

The plot thickens for a hypoth "X17" particle

Additional evidence of an unknown particle from a Hungarian lab gives to NA64 searches

27 NOVEMBER, 2019 | By Ana Lopes

The NA64 experiment at CERN (Image: CERN)

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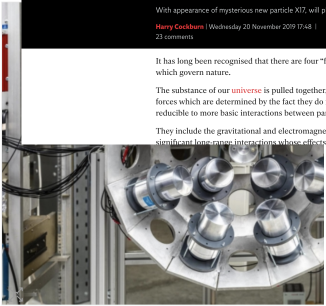

Atomki's new high-resolution $LaBr_3$ spectrometer, which will record ga excited nuclei. Credit: Atomki

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Scientists may have discovered fifth force of nature, laboratory announces

With appearance of mysterious new particle X17, will physicists have to call time on hunt for dark matter?

Harry Cockburn | Wednesday 20 November 2019 17:48 |
23 comments

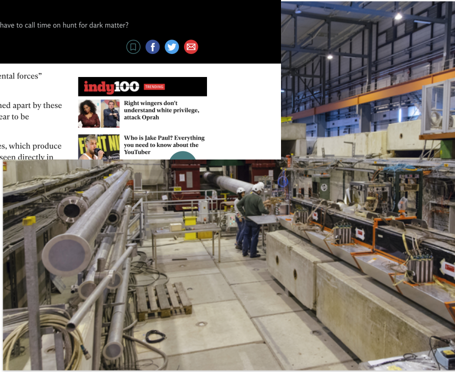
It has long been recognised that there are four "fundamental forces" which govern nature.

The substance of our universe is pulled together, or pushed apart by these forces which are determined by the fact they do not appear to be reducible to more basic interactions between particles.

They include the gravitational and electromagnetic forces, which produce significant long-range interactions whose effects can be seen directly in

The plot thickens for a hypoth "X17" particle

from a Hungarian lab gives



The NA64 experiment at CERN (Image: CERN)

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25 noviembre 2019

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5 agosto 2020

Qué se sabe de la devastadora explosión en Beirut que dejó al menos 137 muertos y miles de heridos

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X17

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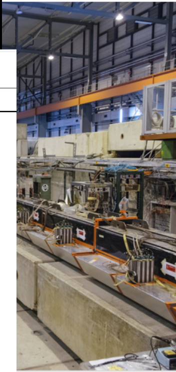

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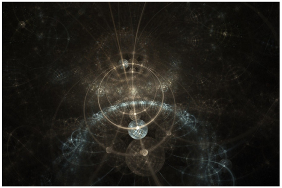
What is the Fifth Force?

Scientists in Hungary claim to have found a new particle that reveals a fifth force of nature.

By Eric Betz | March 10, 2020 7:05 PM



A team of researchers say they've discovered a new force that exists outside the textbook four fundamental forces of nature. (Credit: Pexabay/Insspirito)

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By Ryan Prior, CNN
Updated 2:44 PM ET, Sat November 23, 2019

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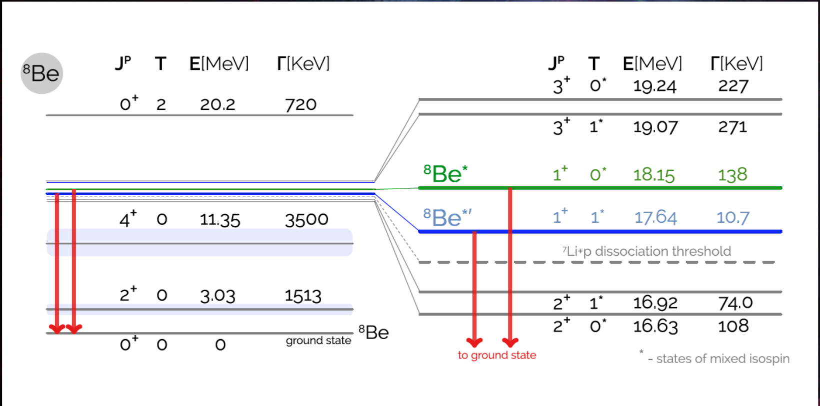
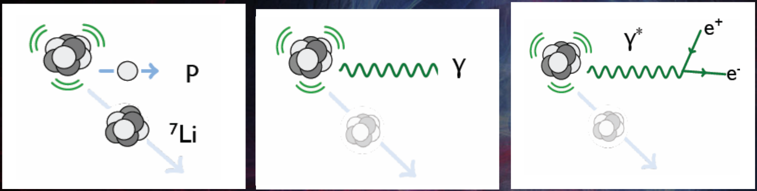
^{8}Be is special

Many images from arXiv:1707.09749

^{8}Be is special: two narrow, highly energetic states which can decay to ground state via E/M

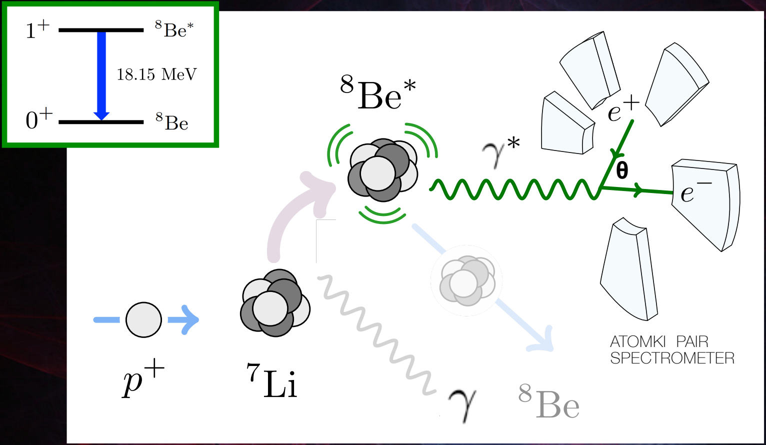


Decay modes of $^{8}Be(18.15)$



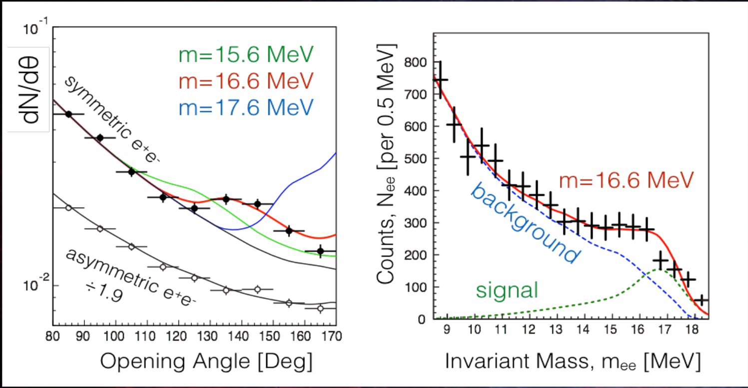
Hadronic, electromagnetic and through internal pair conversion

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.

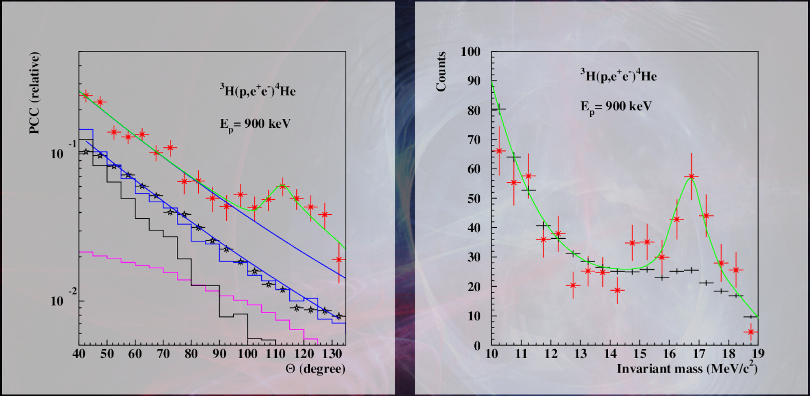
The Beryllium anomaly



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

- Feng et al. (PRL 117, 071803 (2016)): Proto-phobic force to evade current limits

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



- Updated experimental setup: reduced background
- Bump appears at different angle, but same mass: ^4He : 17.01 ± 0.16 MeV ^8Be : 16.84 ± 0.16 MeV

Why believe it?

- This model has $\chi^2/d.o.f.$ of 1.07, significance of 6.8σ
- Bump, not last bin effect
- Remeasured with new detector: A J Krasznahorkay et al 2018 J. Phys.: Conf. Ser.1056 012028
- Compatible masses in ^8Be and ^4He, and compatible couplings (Feng et al. arXiv:2006.01151)
- Non-linearities in Isotope shifts (King-plots), observed (I. Counts et al., arXiv:2004.11383)
    - Hard to distinguish from higher order SM effects.

Why not believe it?

- DM boson interpretation is proto-phobic to evade NA48/2 limits
  - Actually: $\frac{\epsilon_p}{\epsilon_n}$ coupling below $\pm 8\%$. Z^0 is $\sim 7\%$

Why not believe it?

- DM boson interpretation is proto-phobic to evade NA48/2 limits
  - Actually: $\frac{\epsilon_p}{\epsilon_n}$ coupling below $\pm 8\%$. Z^0 is $\sim 7\%$
- Recently, alternative processes were proposed
  - arXiv:2003.05722v3 Hard $\gamma + \gamma$ process
  - arXiv:2005.10643 Anomalous Internal Pair creation

How can we measure it at an electron accelerator?

- This particle can be produced via Bremsstrahlung, predominantly ISR off the electron.
- Measure

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

- Irreducible background:

$$e^- \, Ta \rightarrow e^- \, Ta \, \gamma^\star \rightarrow e^- \, Ta \, e^+ e^-$$

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- Irreducible background:

$$e^- Ta \to e^- Ta\, \gamma^\star \to e^- Ta\, e^+ e^-$$

- two spectrometers, measure e^+ and e^- in coincidence
- Best kinematics:
  - highest production rate if X takes all electron energy. Rise in CS beats all.
  - with limited and same out-of-plane acceptance, symmetric angle optimal.

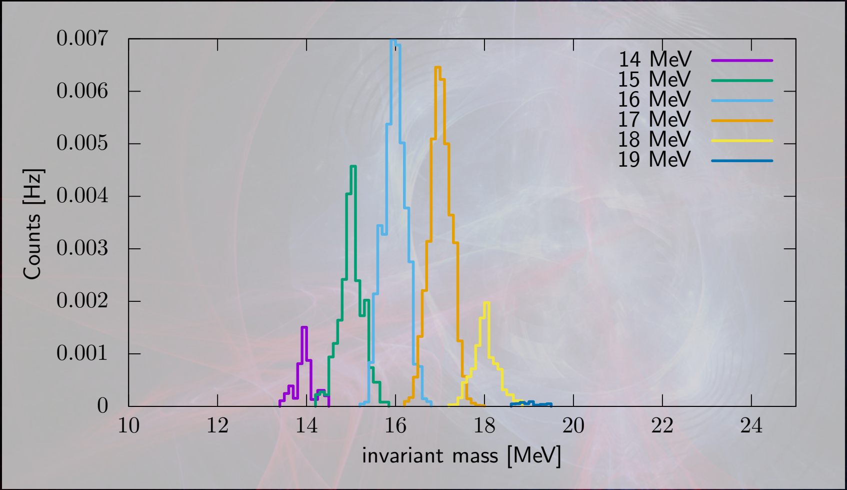
Background

- Main background is NOT the irreducible one. Random coincidences between
  - radiative elastic electrons
  - positrons from (virtual) photon pair-production where e^- is missed
- Can optimize by moving electron arm backward.

Possible setup

- 45 MeV beam, 150 μA on 10 μm tantalum foil $\longrightarrow$ about 52 inv. nb/s
- Two spectrometers
  - $\pm 2^\circ$ in-plane, $\pm 5^\circ$ out-of-plane
  - Positron spectrometer at 16°, 28 MeV
  - Electron spectrometer at 33.5°, 15 MeV

Counting rates: X signal



Background rates

QED irreducible: 55 Hz coincidences,

Background rates

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... but 120 kHz e^+ singles

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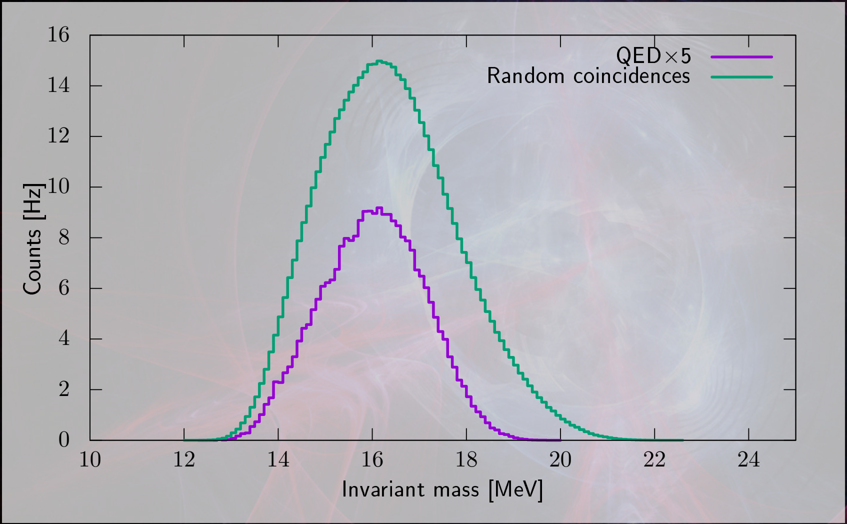
Initial state radiation $e^- p$: 6 MHz

$\longrightarrow$ Random coincidence rate 550 Hz

(at 1.3 GHz bunch rate)

This is the minimum trigger rate and sets the sensitivity.

Counting rates: Backgrounds



Dominated by accidental background

- Random coincidences dominate
- Scaling with instantaneous luminosity:
  - Signal $S \sim \mathcal{L}$
  - QED background $Q \sim \mathcal{L}$
  - Accidental background $A \sim \mathcal{L}^2$
  - Sensitivity $\frac{S}{\sqrt{Q+A}} \propto 1$ for $A \gg Q$

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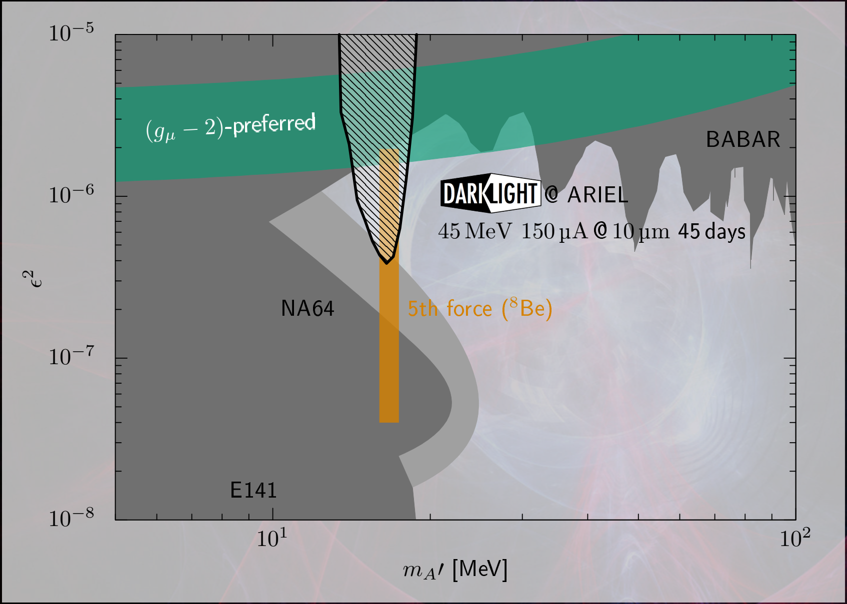
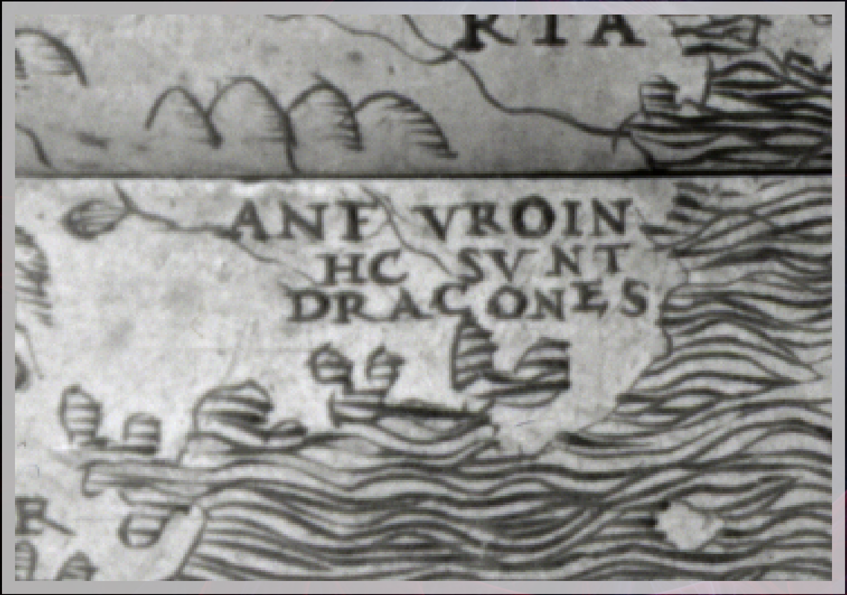
  - Sensitivity $\frac{S}{\sqrt{Q+A}} \propto 1$ for $A \gg Q$
- Sensitivity almost independent of luminosity. Scale is set by bunch-clock / time resolution
- Out-of-time "coincidences" give accurate measure of acceptance including efficiency.

Reach at 45 MeV



Run at smaller energies?



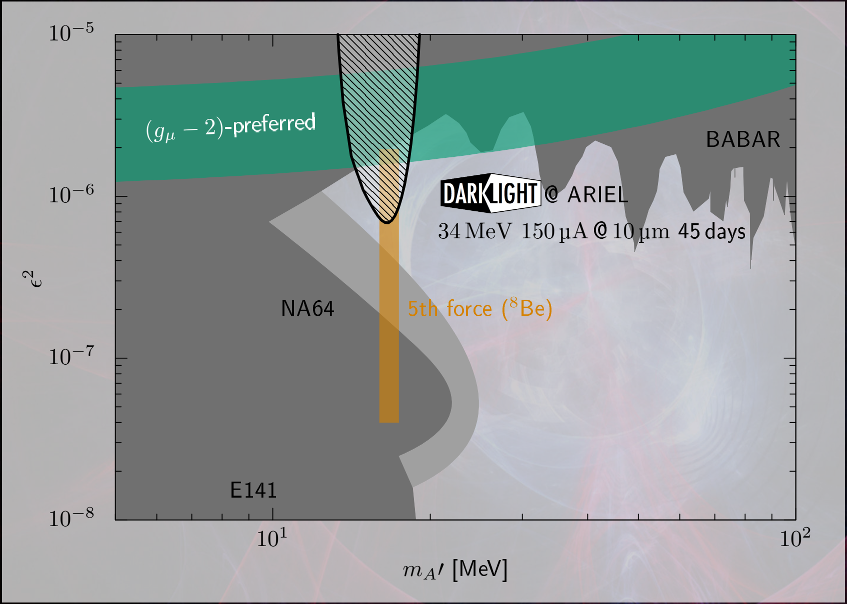
DL at 34 MeV?

- MadGraph fails at these energies!

DL at 34 MeV?

- MadGraph fails at these energies!
- New generator (from Mainz: Beranek et al. 10.1103/PhysRevD.88.015032)
  - Some tension with MadGraph. Have to understand this!
- Positron spectrometer at 21.75°, 19.25 MeV
- Electron spectrometer at 47°, 11.75 MeV
- Did not check resolutions – assumed the same.
- Random background 35 times irreducible background!

Reach at 34 MeV



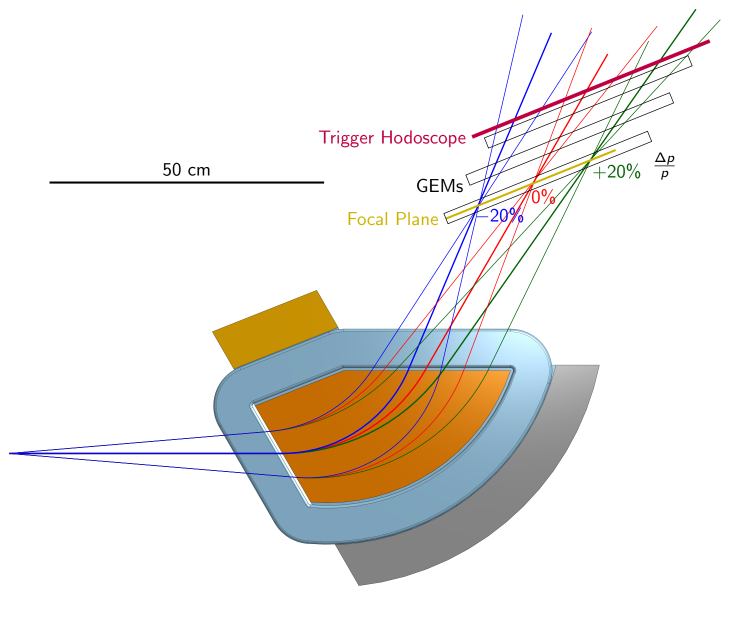
Should we run at 34 MeV?

- Achieving full coverage probably difficult.

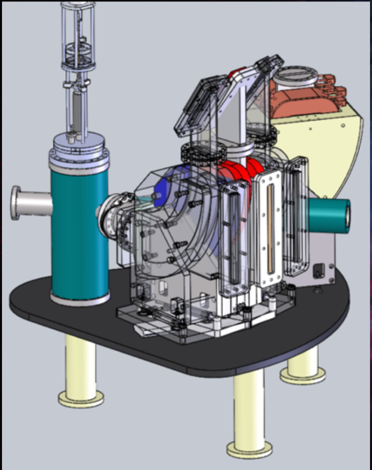
Should we run at 34 MeV?

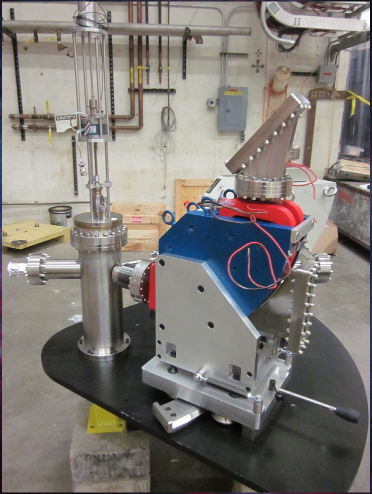
- Achieving full coverage probably difficult.
- Ideal tool to commission spectrometers.
- Crucial to identify, combat backgrounds
- Measure to refine model:
  - QED irreducible backgound
  - Single rates

Spectrometers

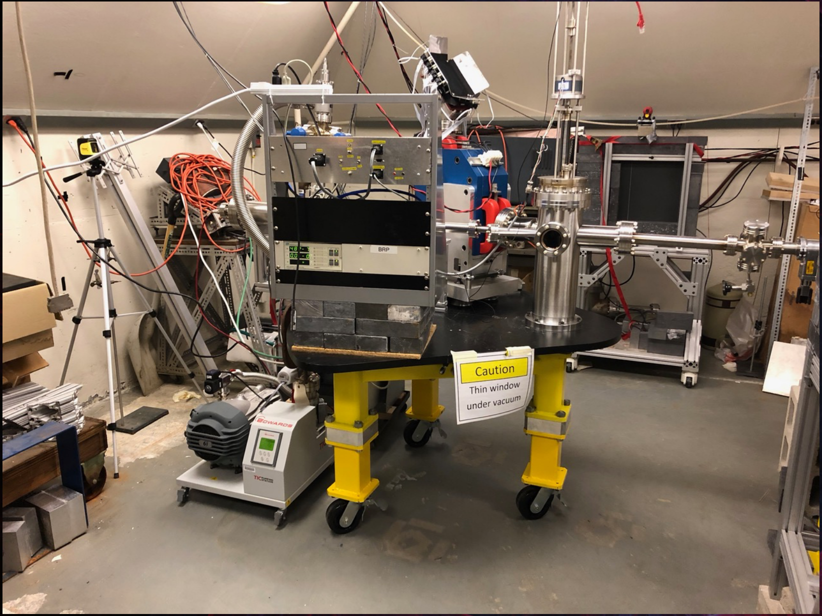


Experience: Møller at MIT HVRL

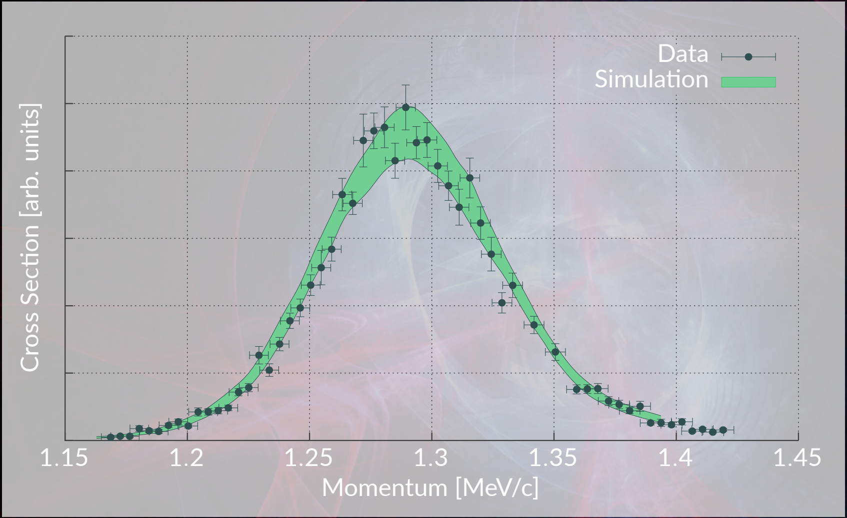




Møller experiment ran successfully



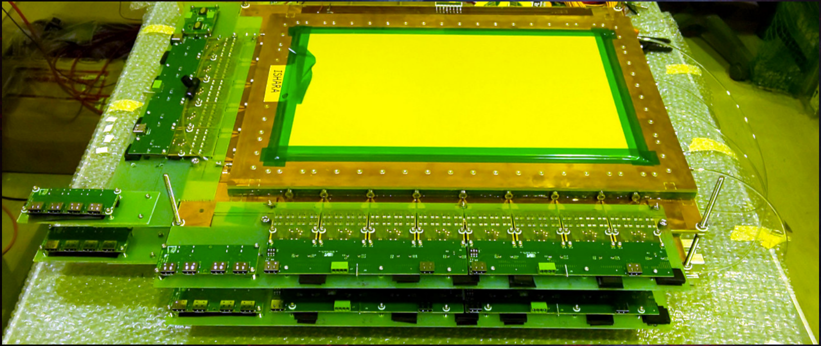
Example result



Epstein et al, Phys. Rev. D 102, 012006 (2020)

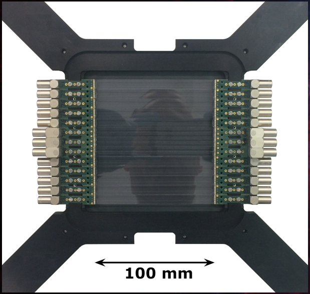
Tracking detectors

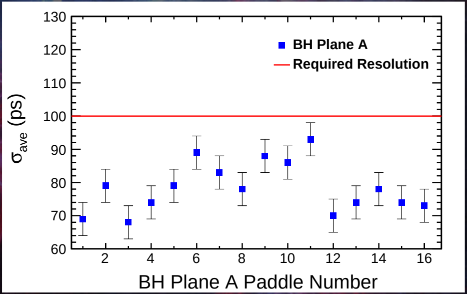
- Stack of three tGEMs, 25x40 cm, modified CERN design
- Readout via APVs and MPD4 (Same as SBS and PREX)
- Hampton group has built eight.



Trigger detectors

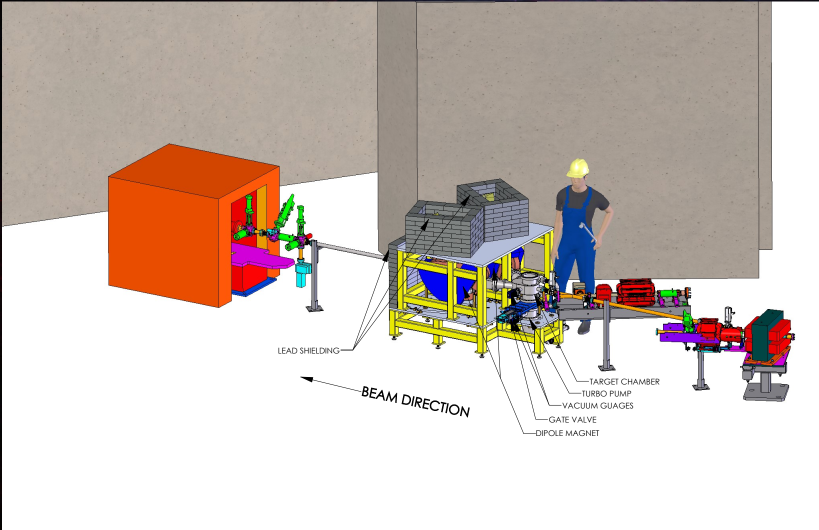
- Scintillator Hodoscope, 10 segments/spectrometer
- Needs timing resolution of < 500 ps
- MUSE beam hodoscope: 2 mm thick scintillator, SiPM readout: < 100 ps
  - Tested up to 8mm wide, 15 cm long.



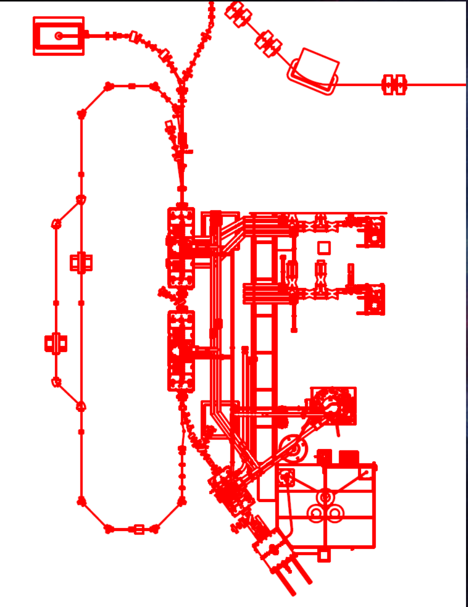


(T. Rostomyan et al., NIMA 986 164801)

3D rendering



Possible locations



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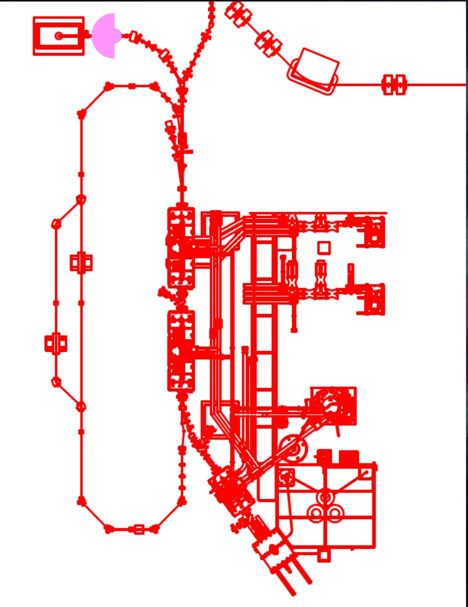

- Minimal modification
- Could use exisiting beam dump

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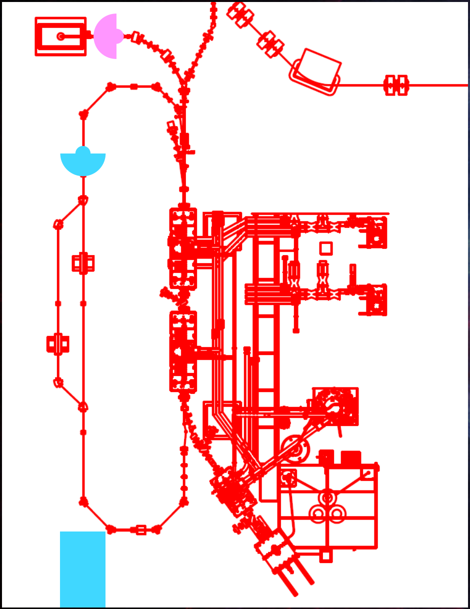

- Minimal modification
- Could use exisiting beam dump
- Cleaner environment: Beam dump far away
- Might be able to recover beam energy

Conclusion

- Atomki anomaly needs clarification, best from independent approach
- ARIEL well suited for direct search for X17
- Can produce useful data at 34 MeV, experiment best at 45-60 MeV
- Controlling backgrounds crucial!

The DARKLIGHT *Collaboration*

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Spectrometer design parameters

Kinematic var.	Acc.	Inv. mass res.	est. res. on focal plane	Error
in-plane angle	$\pm 2^\circ$	$22\ \frac{keV}{mrad}$	5mm/7cm$\rightarrow$1.4 mrad	$32\ keV$
out-of-plane angle	$\pm 5^\circ$	$5\ \frac{keV}{mrad}$	1.5°	$133\ keV$
momentum	$\pm 20\%$	$85\ \frac{keV}{\%}$	5mm/30cm$\rightarrow< 0.2\%$	$17\ keV$

- Spectrometer can measure two quantities on first plane (position), but has additional multiple scattering for third quantity (angle)

Spectrometer design parameters

Kinematic var.	Acc.	Inv. mass res.	est. res. on focal plane	Error
in-plane angle	$\pm 2^\circ$	$22 \frac{keV}{mrad}$	5mm/7cm$\rightarrow$1.4 mrad	32 keV
out-of-plane angle	$\pm 5^\circ$	$5 \frac{keV}{mrad}$	1.5°	133 keV
momentum	$\pm 20\%$	$85 \frac{keV}{\%}$	5mm/30cm$\rightarrow < 0.2\%$	17 keV

- Spectrometer can measure two quantities on first plane (position), but has additional multiple scattering for third quantity (angle)
- Simple dipole spectrometer, dispersive direction out-of-plane $\rightarrow$ out-of-plane angle is measured worst.
- Sum for two spectrometers: 194 keV, assumed 250 keV
- Have to do full simulation when realistic magnetic field is calculated.