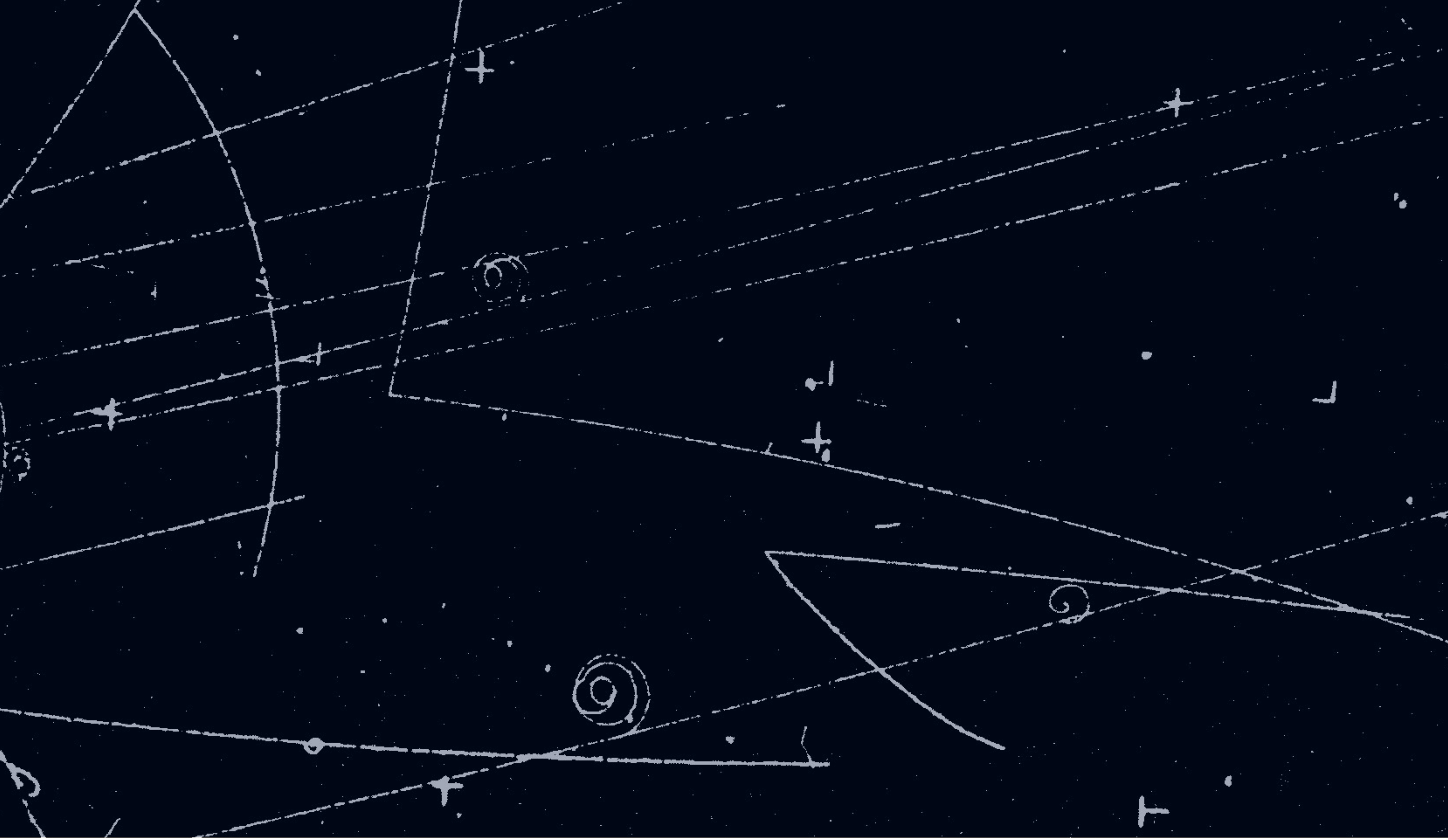
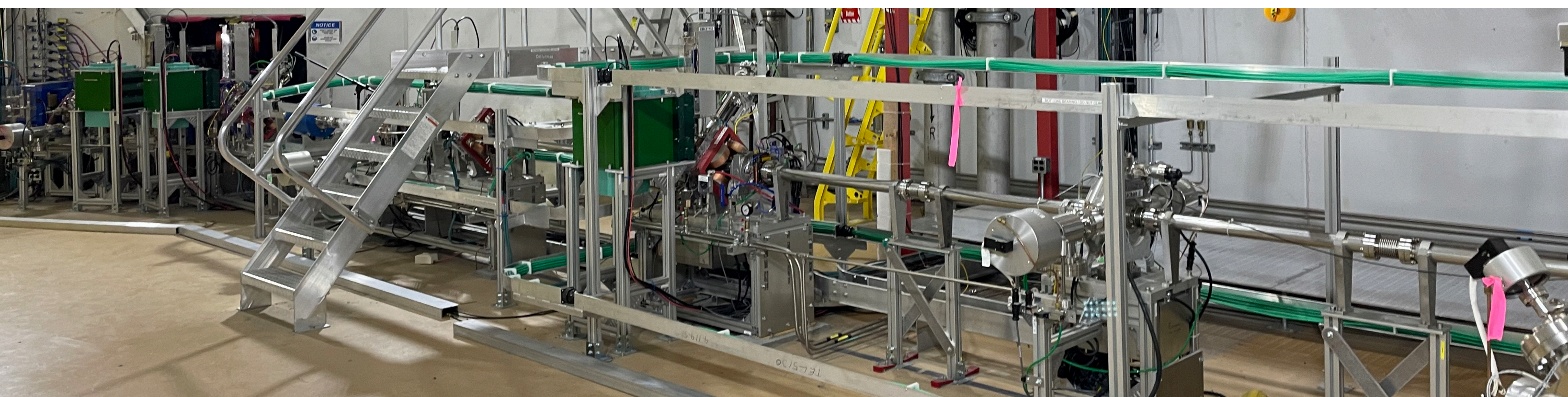


DarkLight experiment status update and plans

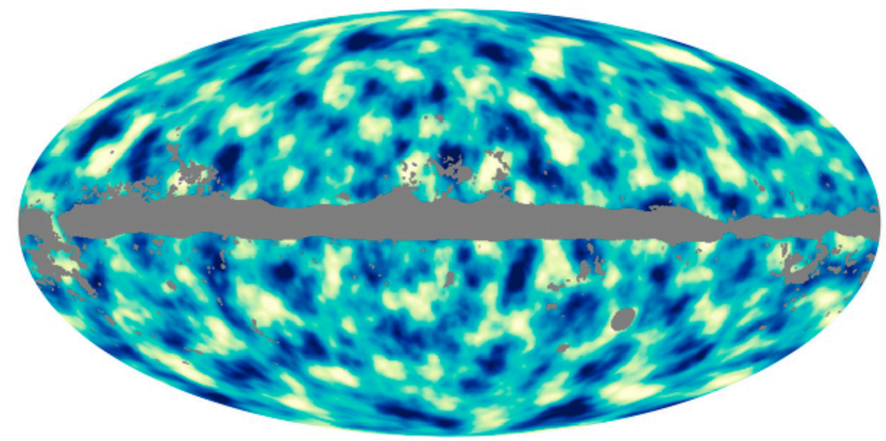
The DarkLight collaboration

Introduction

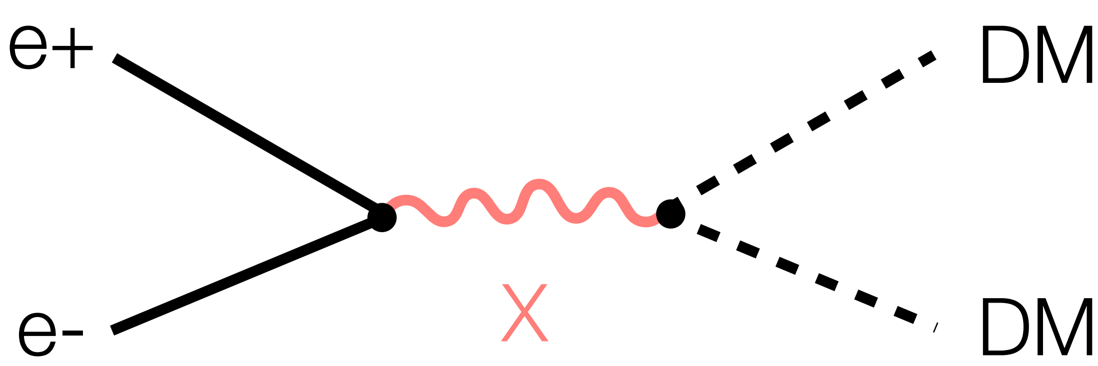
- Last PP-EEC, DarkLight requested beam time at TRIUMF as a new experiment.
- Since then, significant forward progress
- Today: brief overview of physics motivation, then discuss current and future work
    - Designs for full experiment well under way, with initial installations for test experiments in place
    - Long-term plans are solidifying



Uniting dark matter with particle physics experimental anomalies

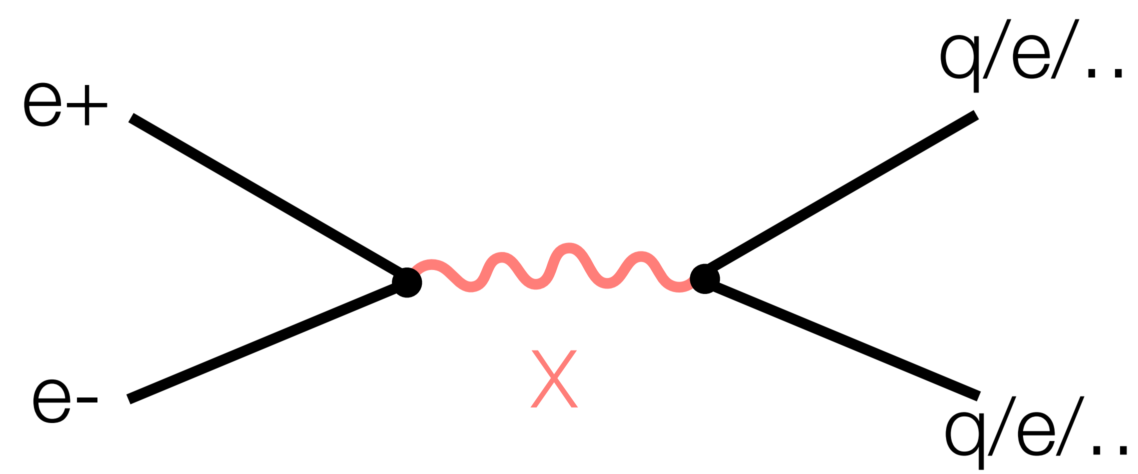


Dark matter remains one of the biggest unsolved mysteries of particle physics



Many many possibilities, but among them: s-channel boson could act as a mediator to dark sector

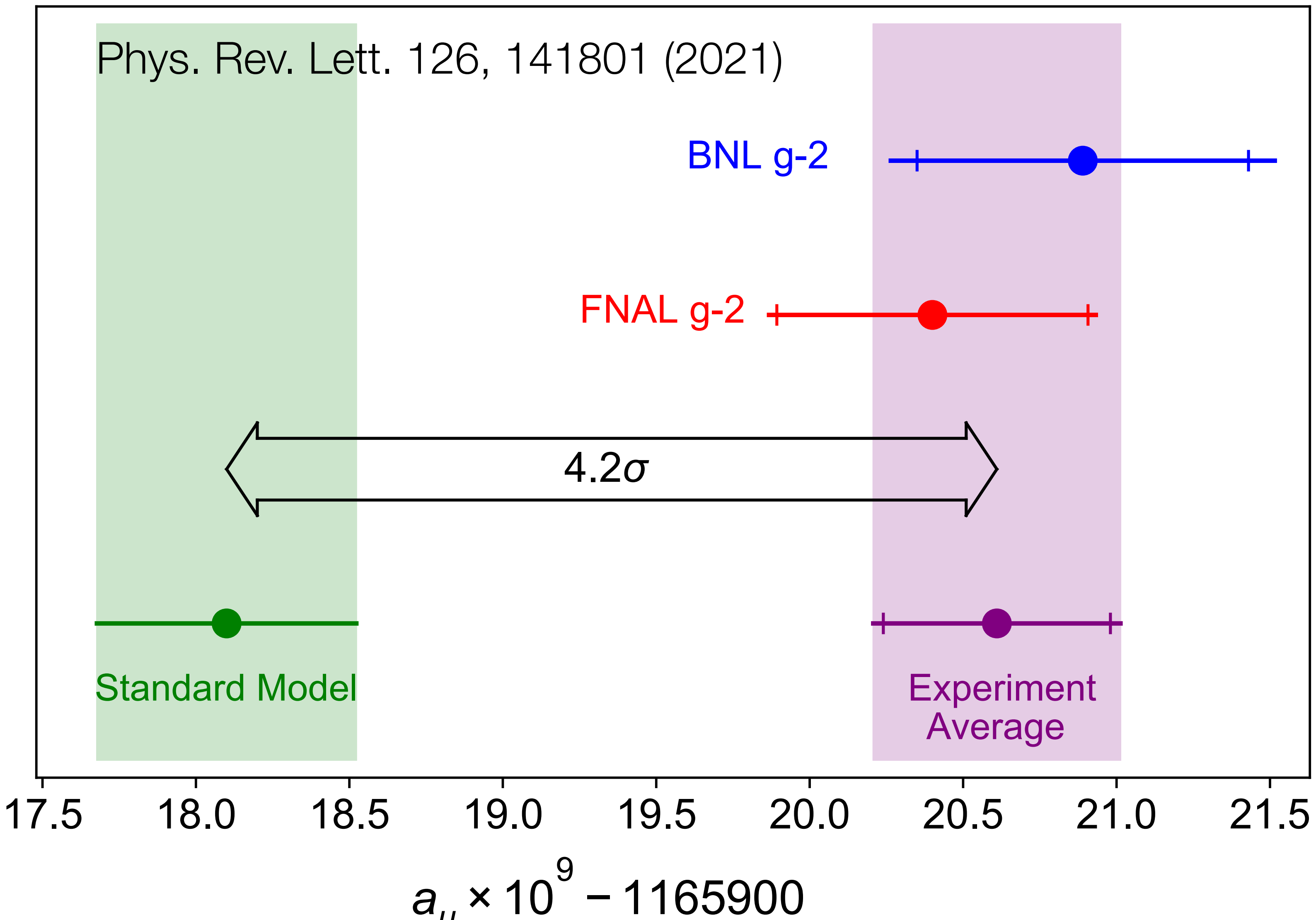
Depending on relative couplings and masses of SM versus dark sector particles, visible decays can dominate

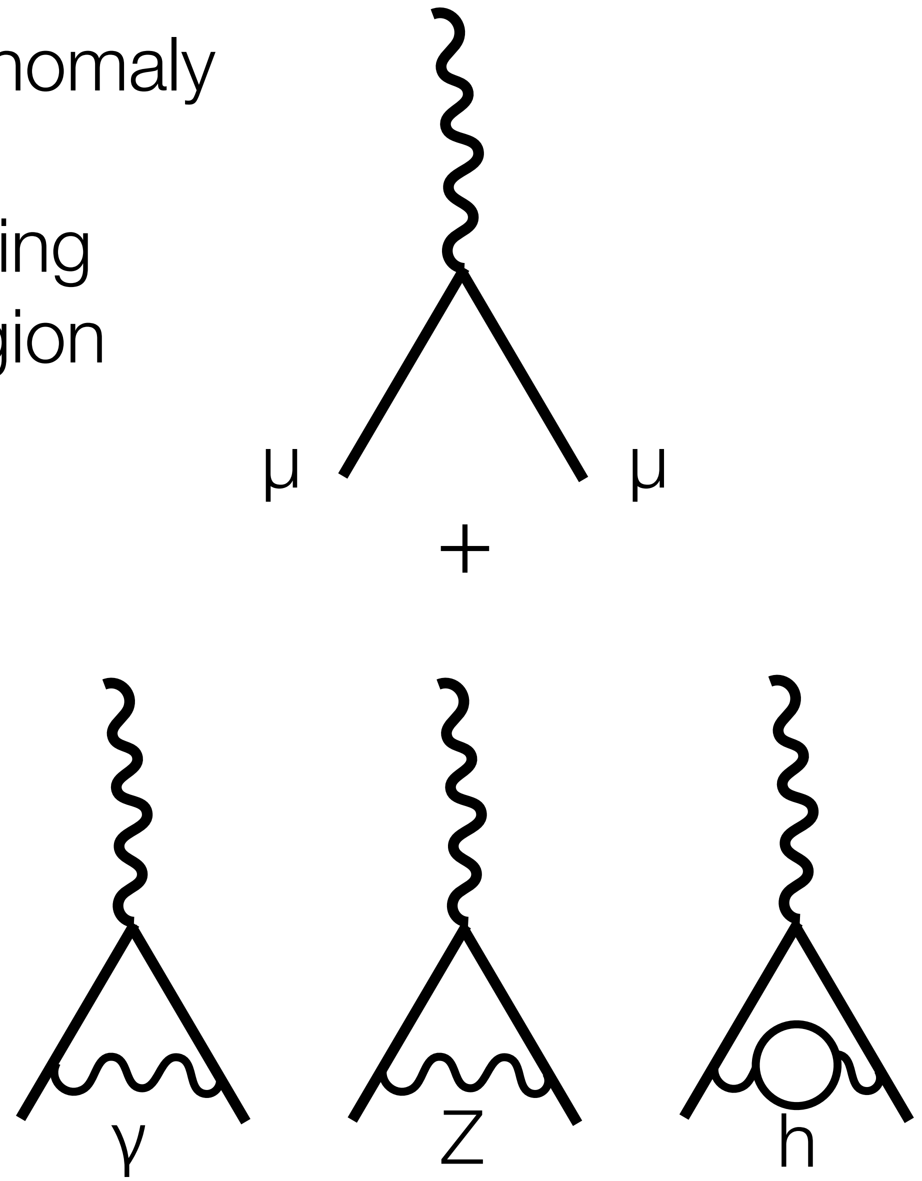


Where to look for such a particle?
Some experimental hints ….

Light BSM boson: g-2 anomaly

Many investigations into source of 4.2 σ muon g-2 anomaly
One possibility: new massive boson
Would be low mass, moderate coupling - kinetic mixing model disfavoured, but experimentally accessible region





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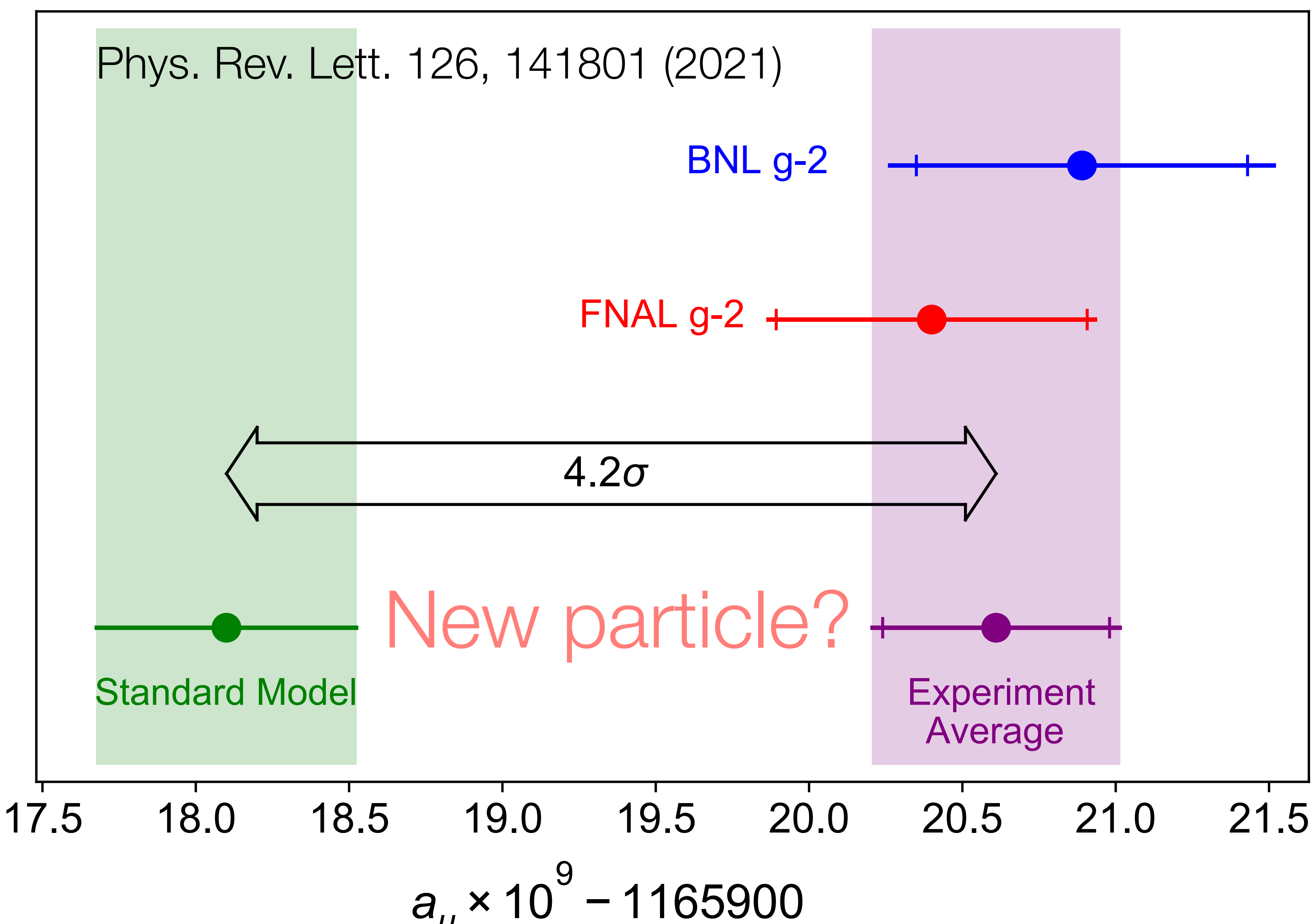

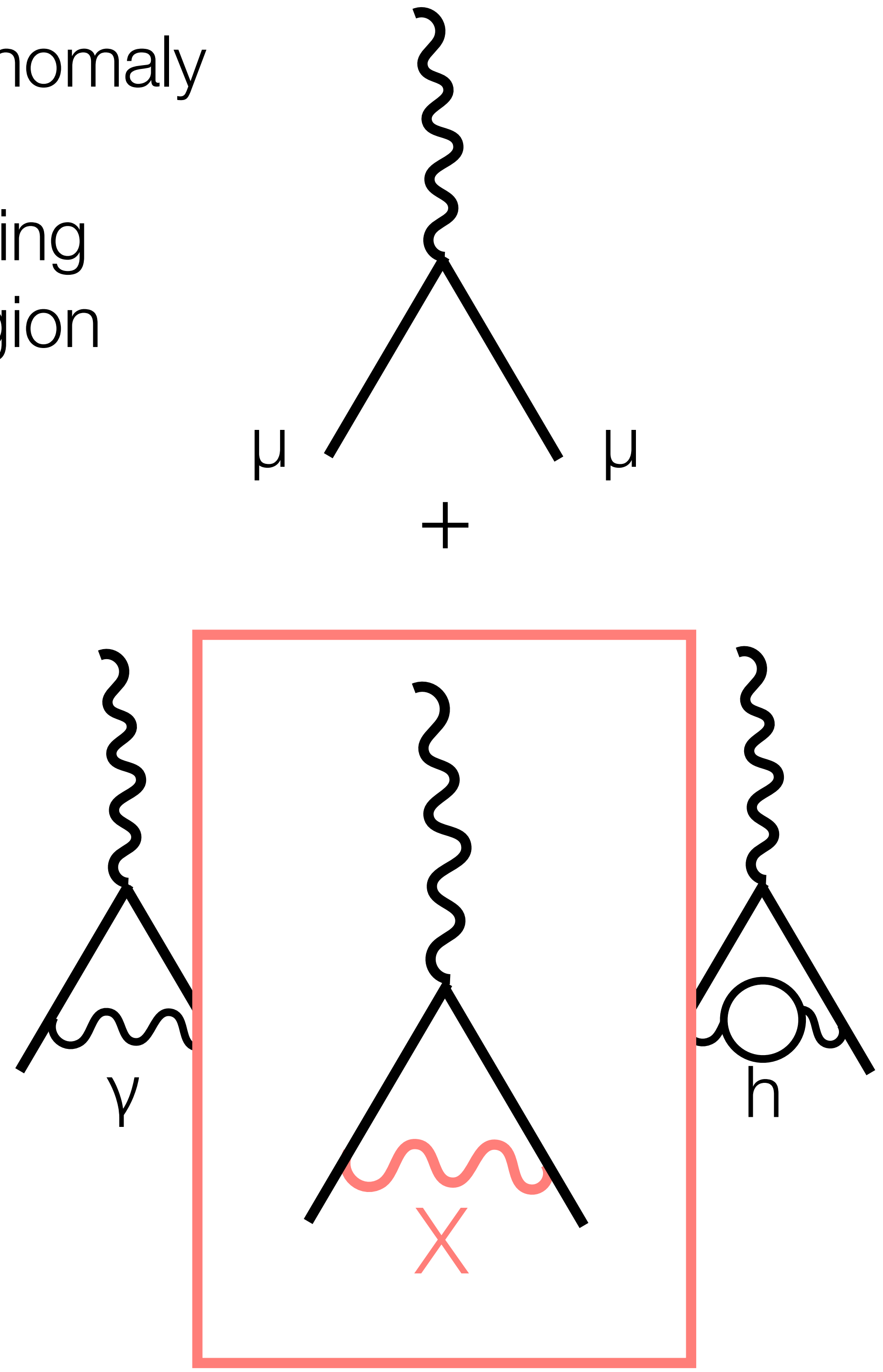

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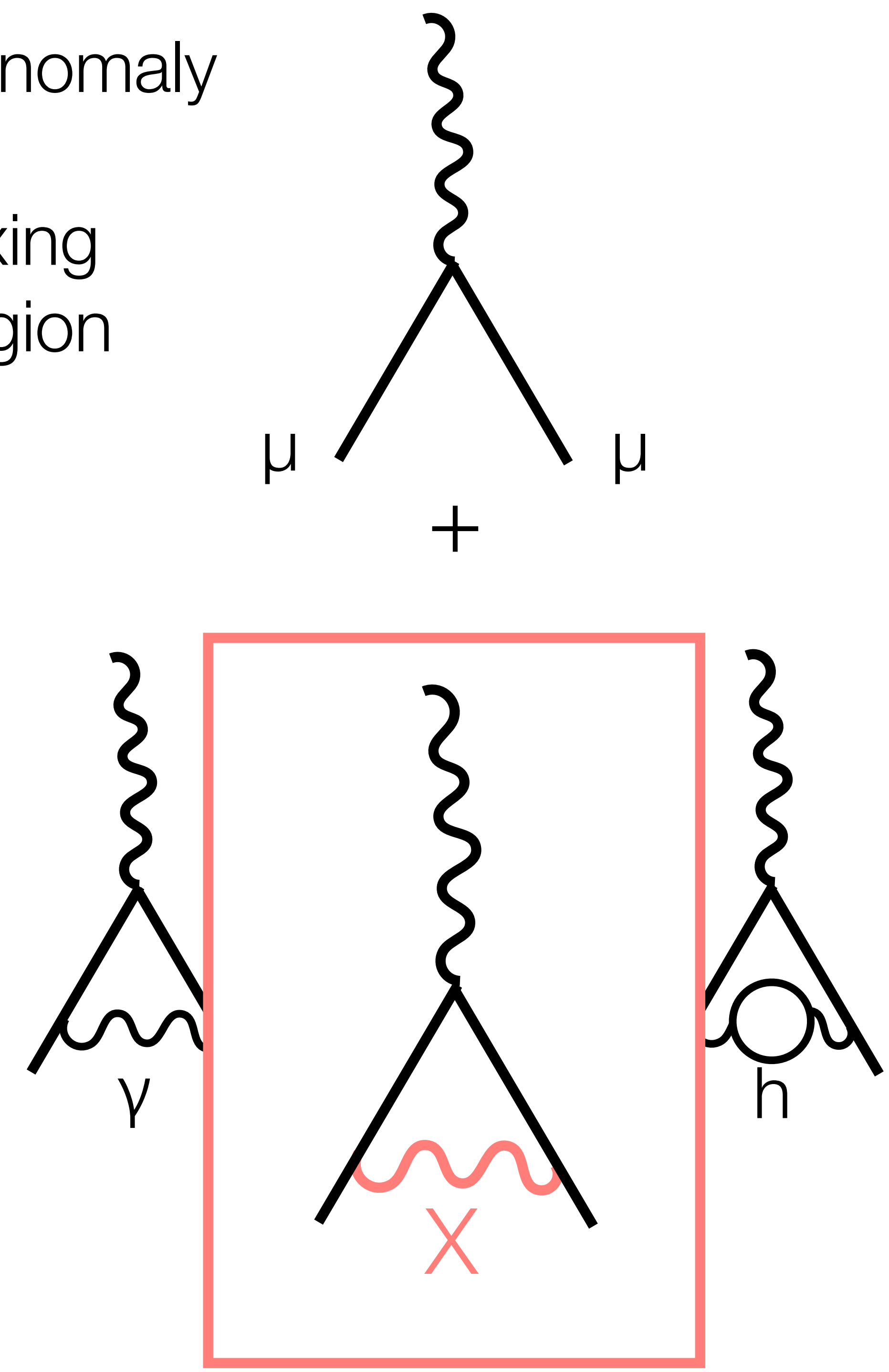
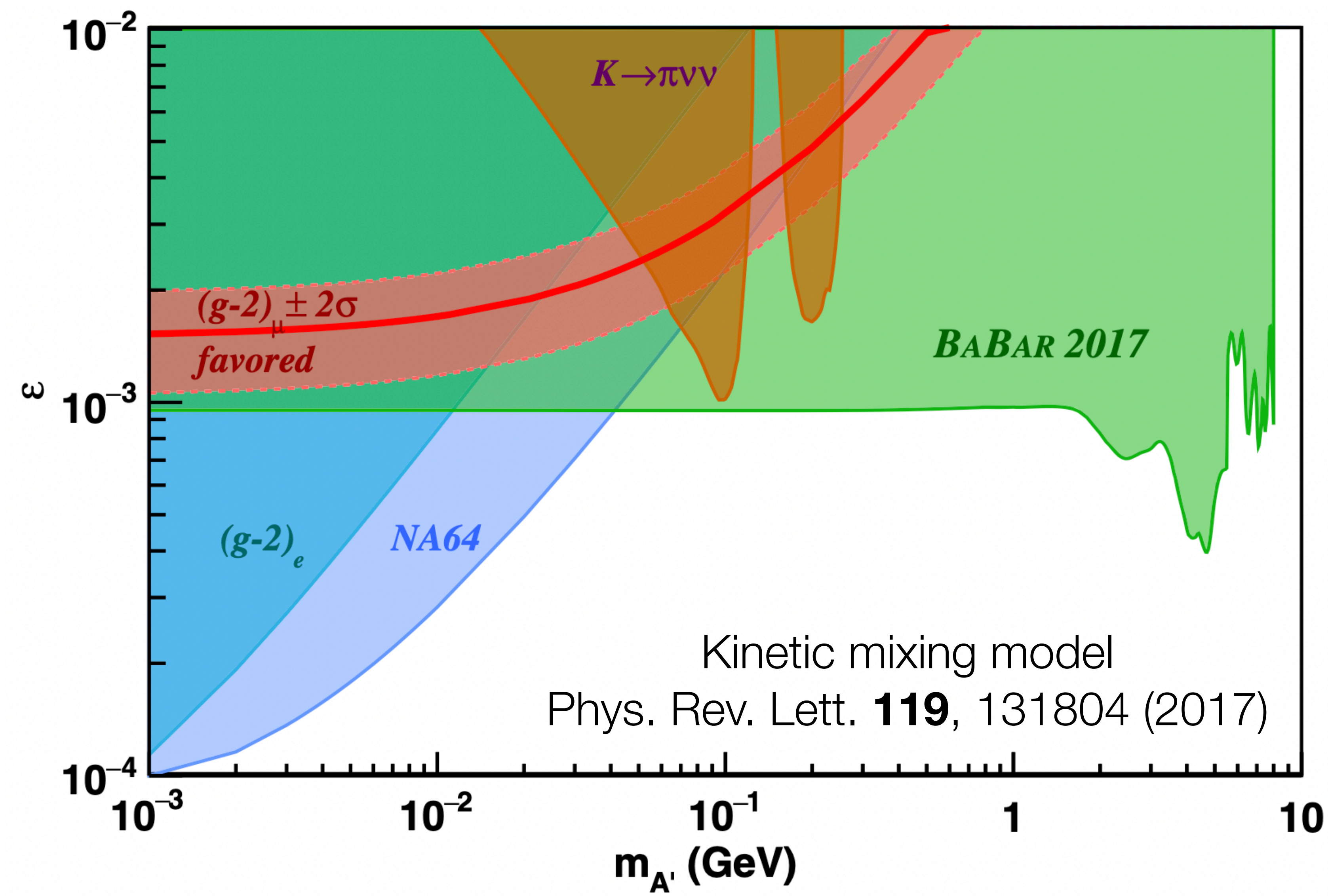
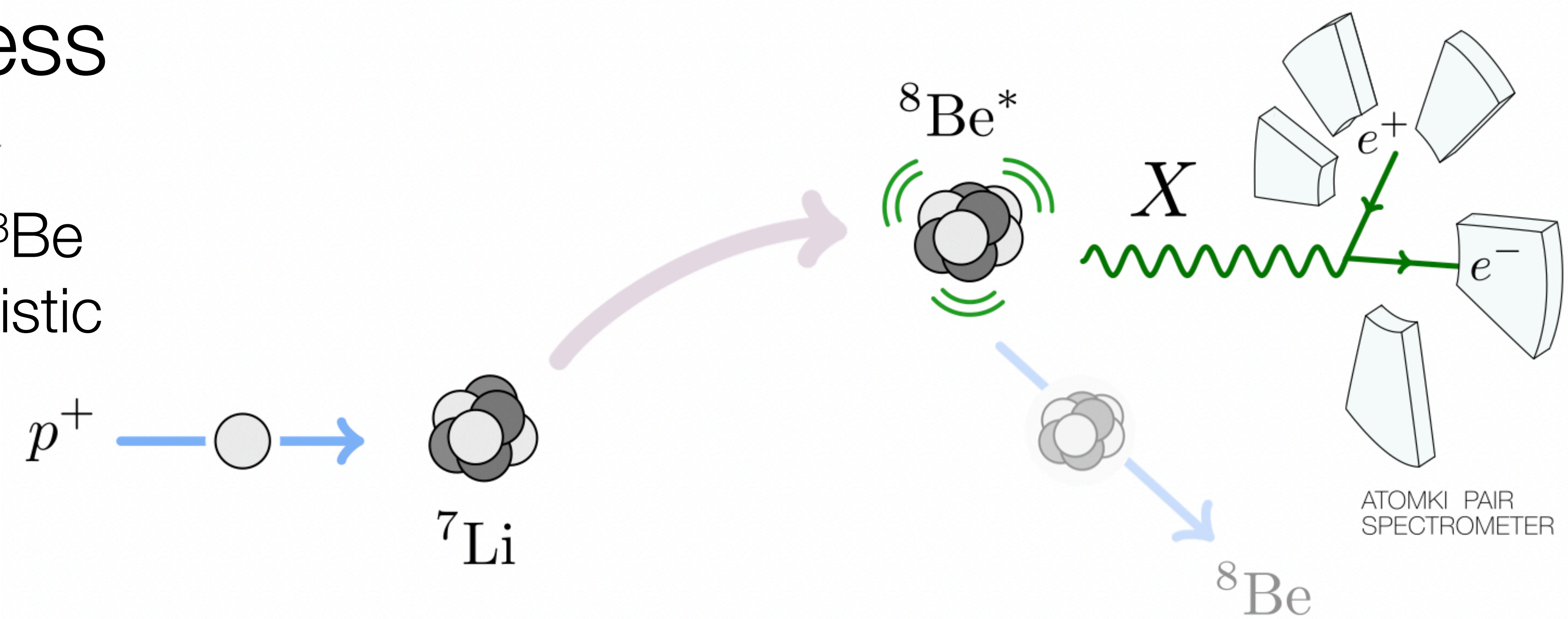




Light BSM boson: the X17 excess

Phys. Rev. D 95, 035017 (2017)

Decay of excited ^{8}Be through characteristic energy levels



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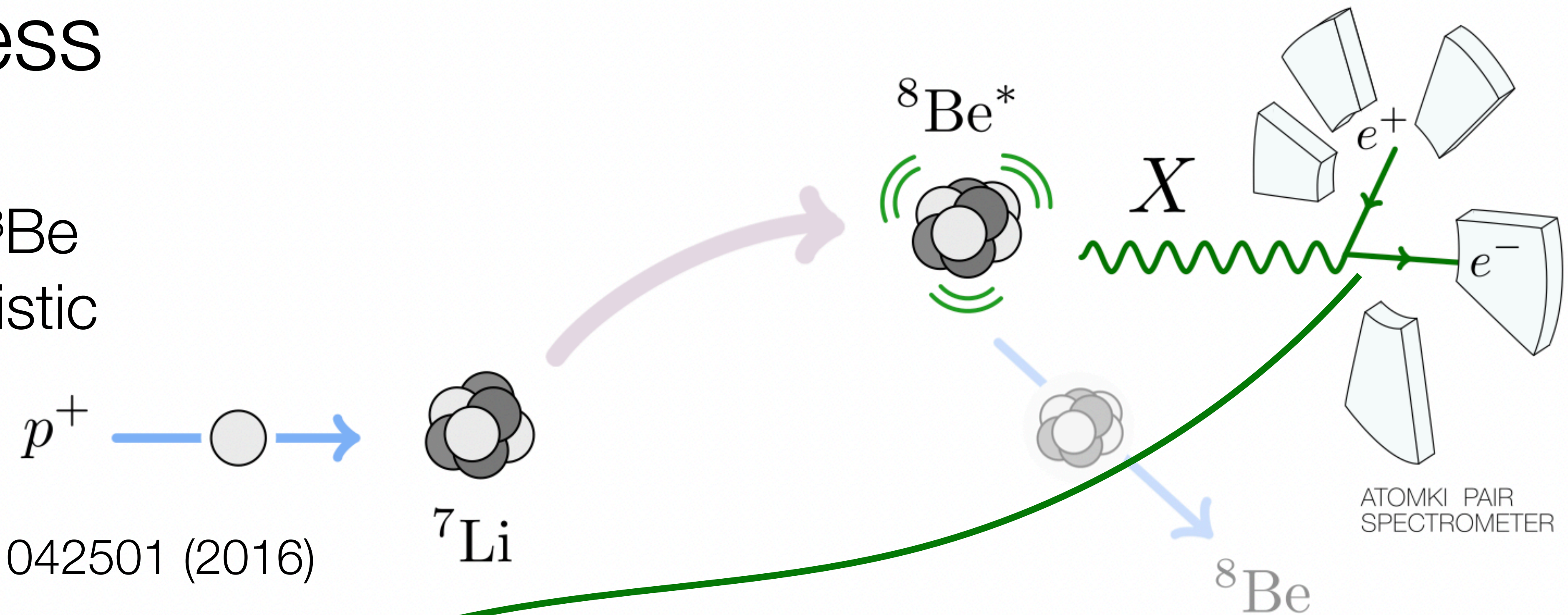

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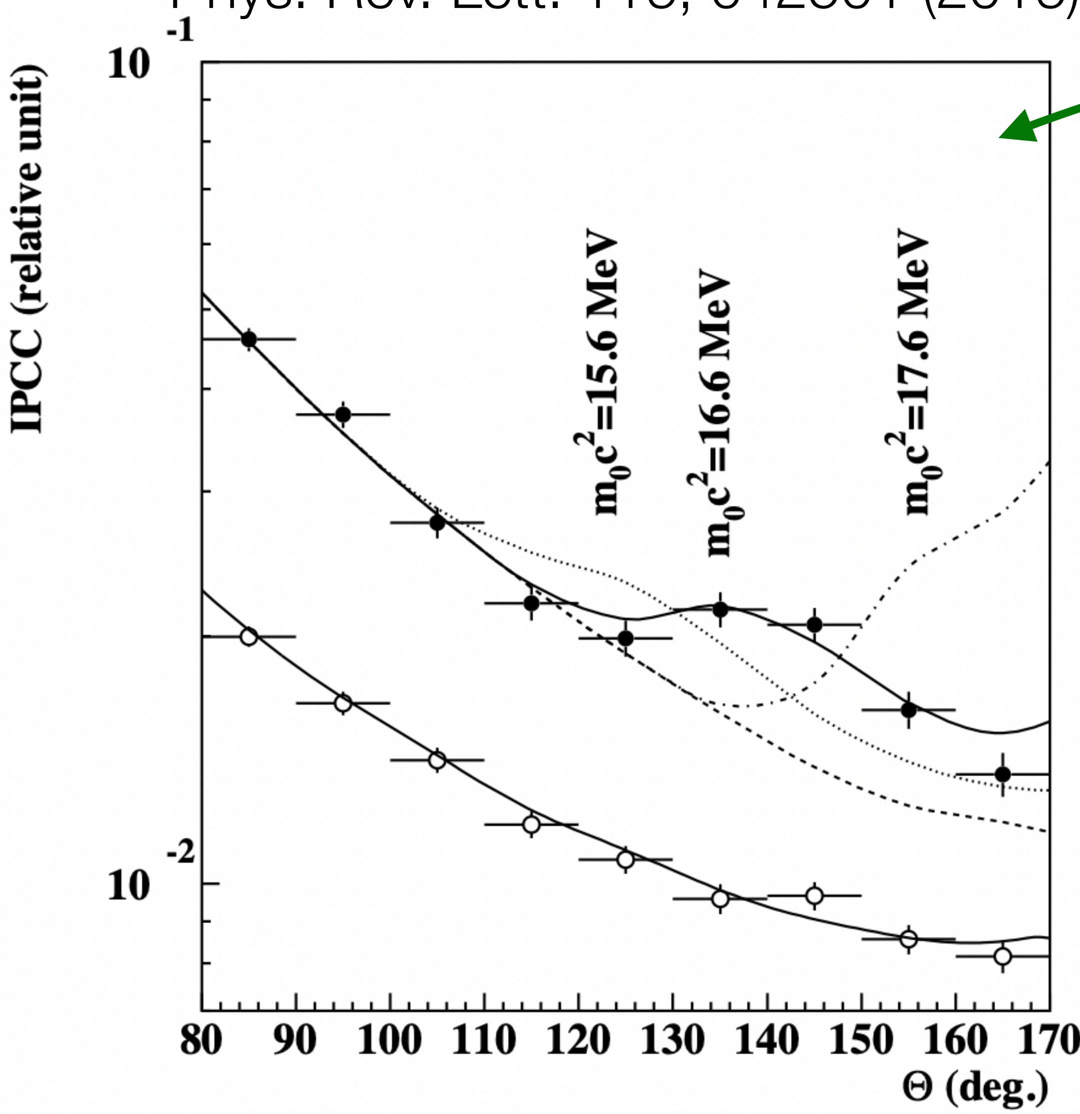

Invariant mass and opening angle of e+e- pair show high-significance resonant signal

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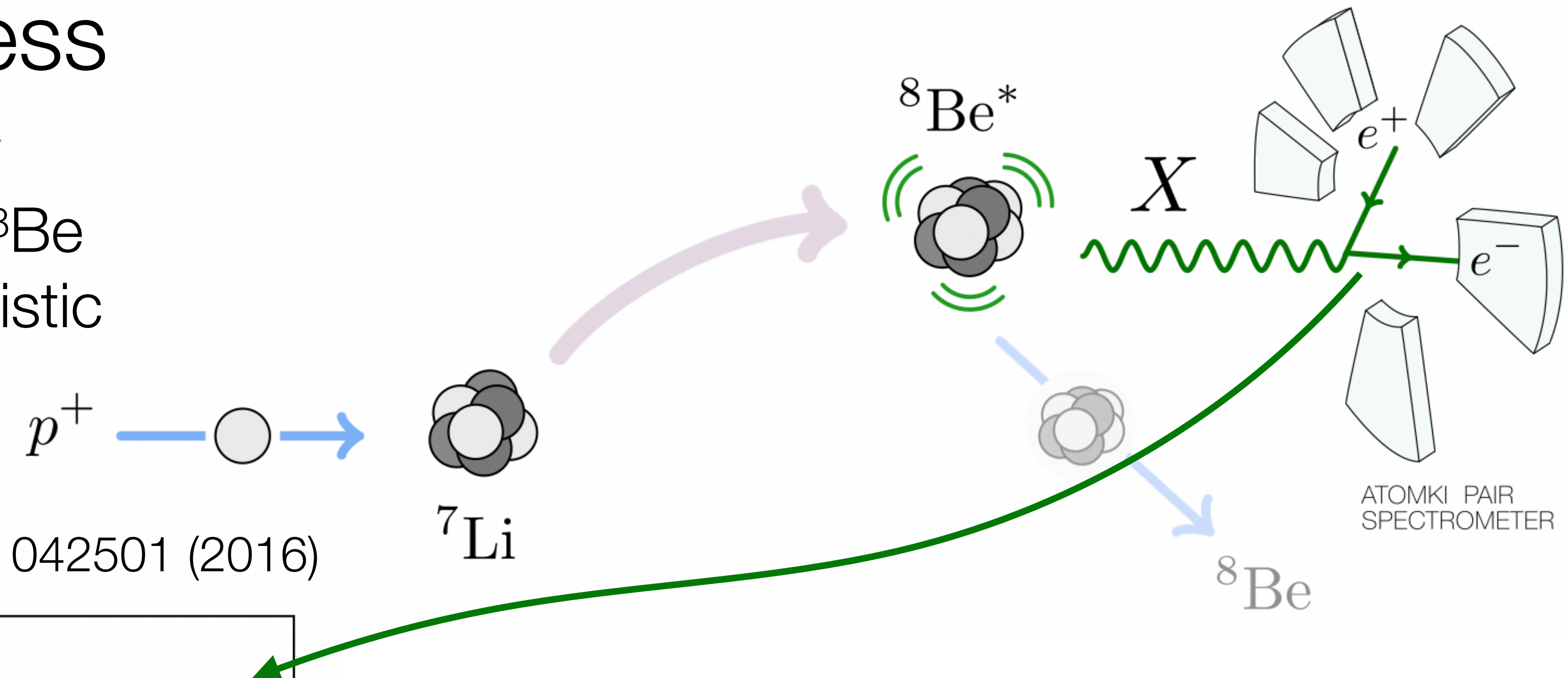

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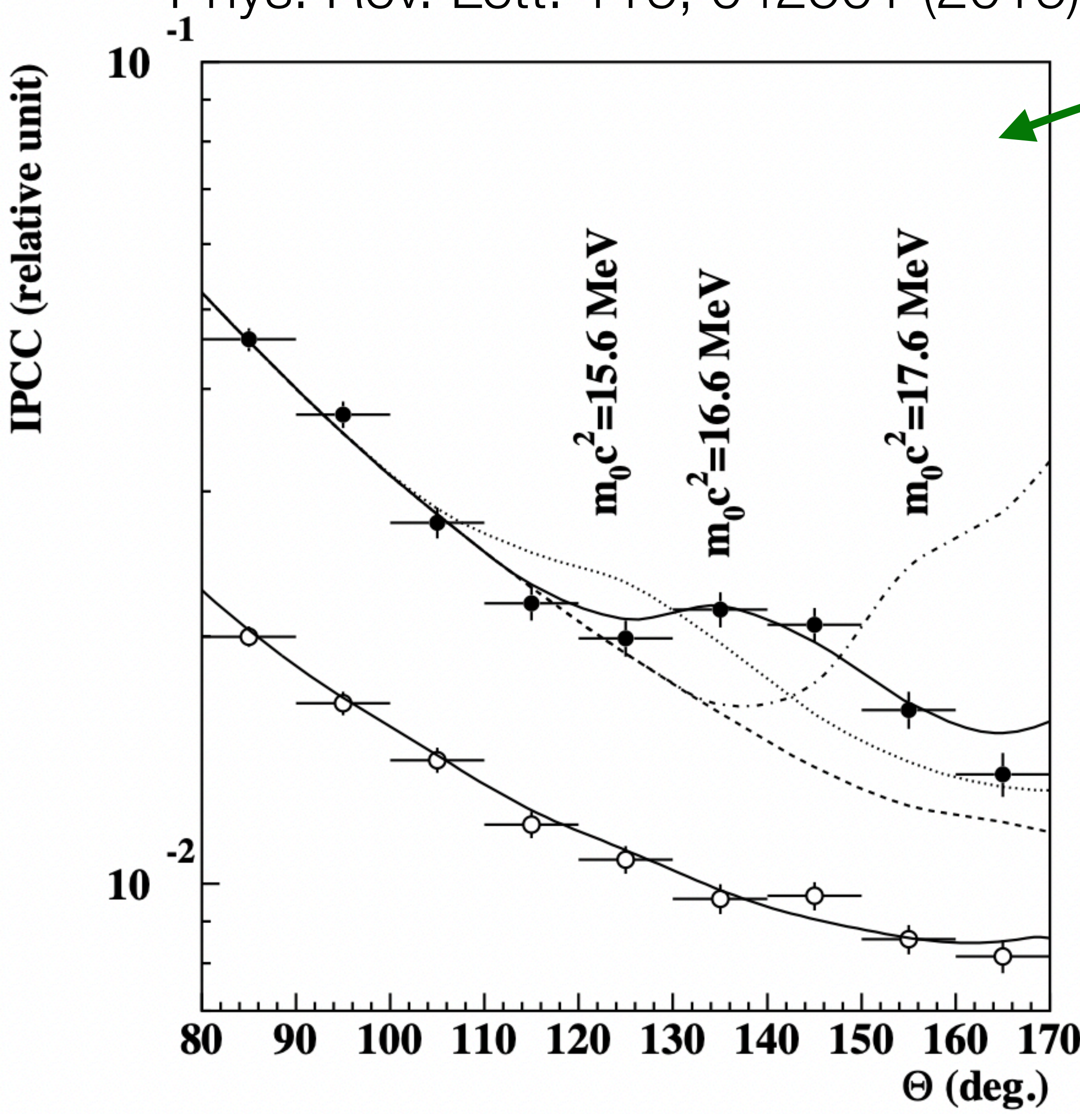


Invariant mass and opening angle of e+e- pair show high-significance resonant signal

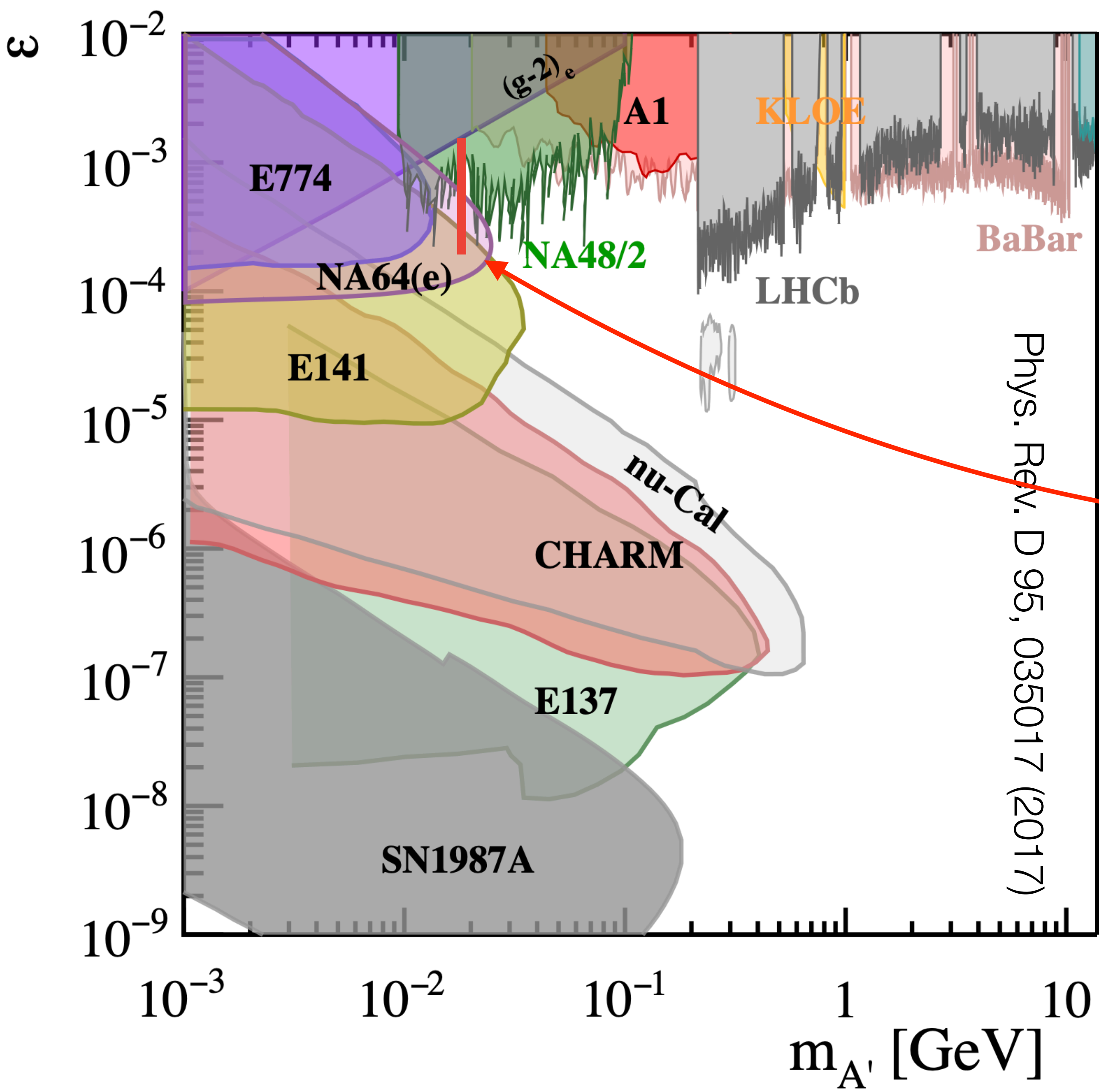
Not-yet-understood detector effect? Unexpected SM cause? Possibly!

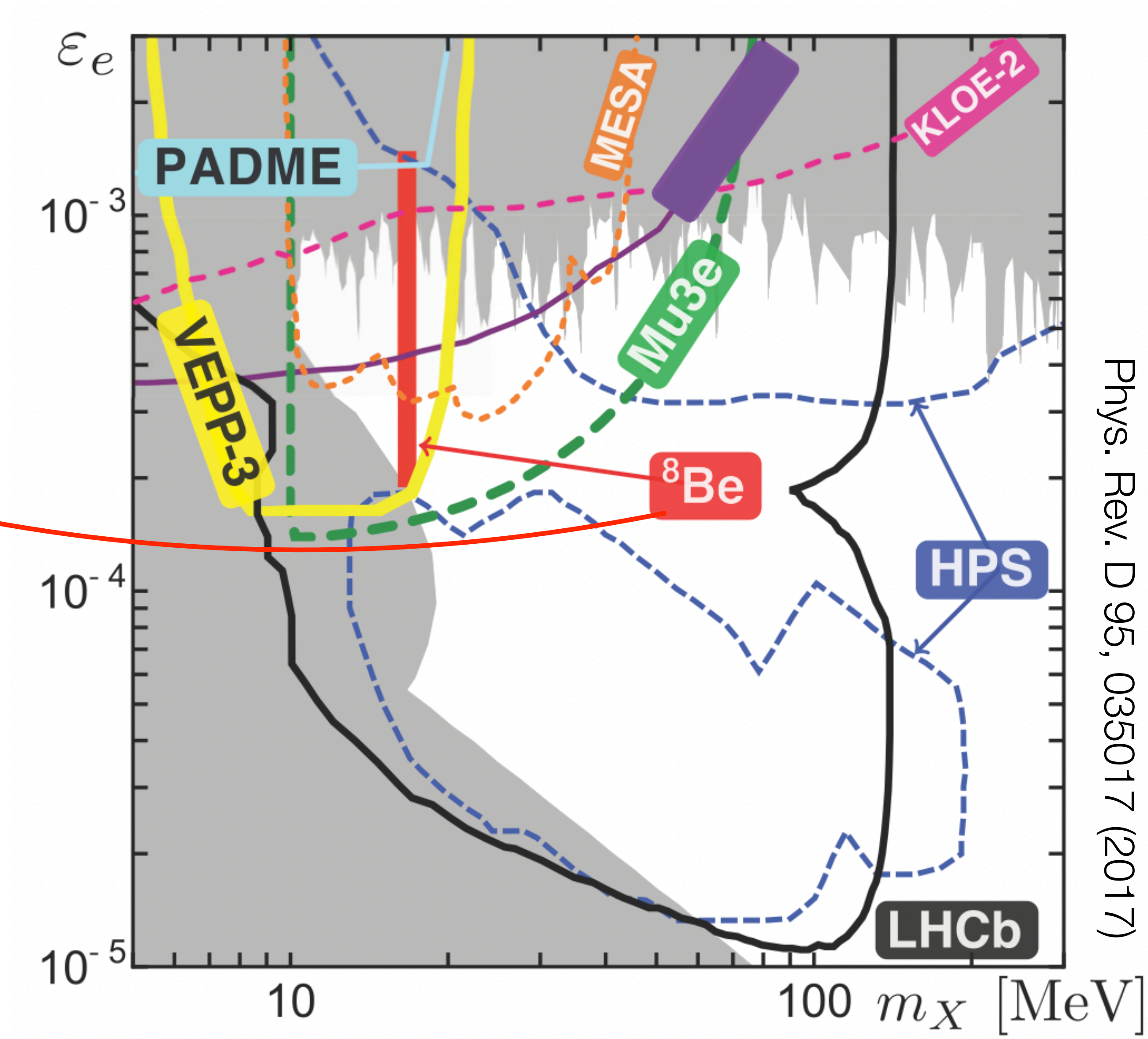
Or, compatible with new boson coupling to electrons with mass ~ 17 MeV

New boson experimental limits: very model dependent statements

Dark photon, visible decays: single universal coupling ε proportional to SM γ couplings

Heavy boson with reduced coupling to protons. This plot: limits from e+e- interactions only





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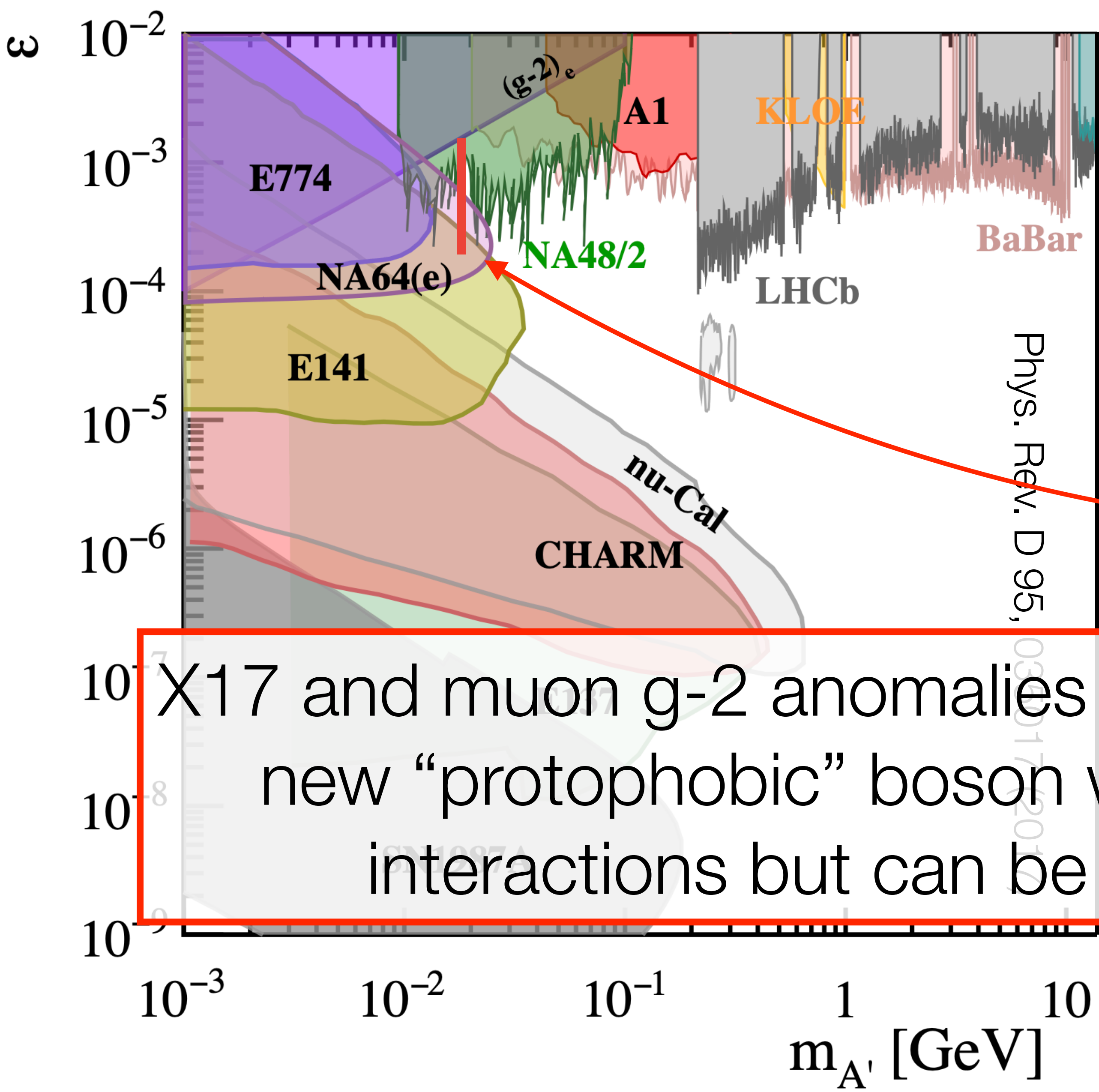
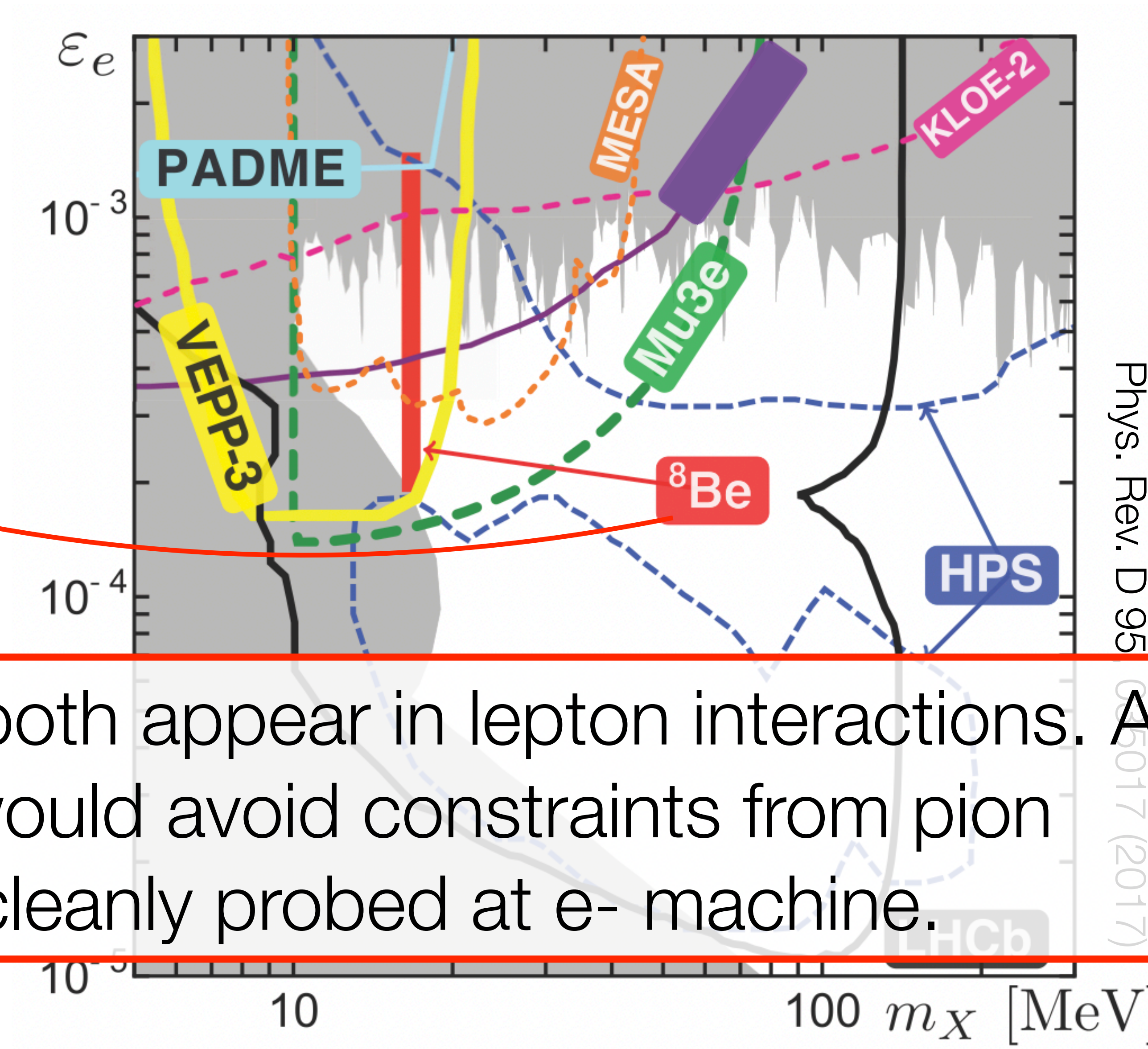




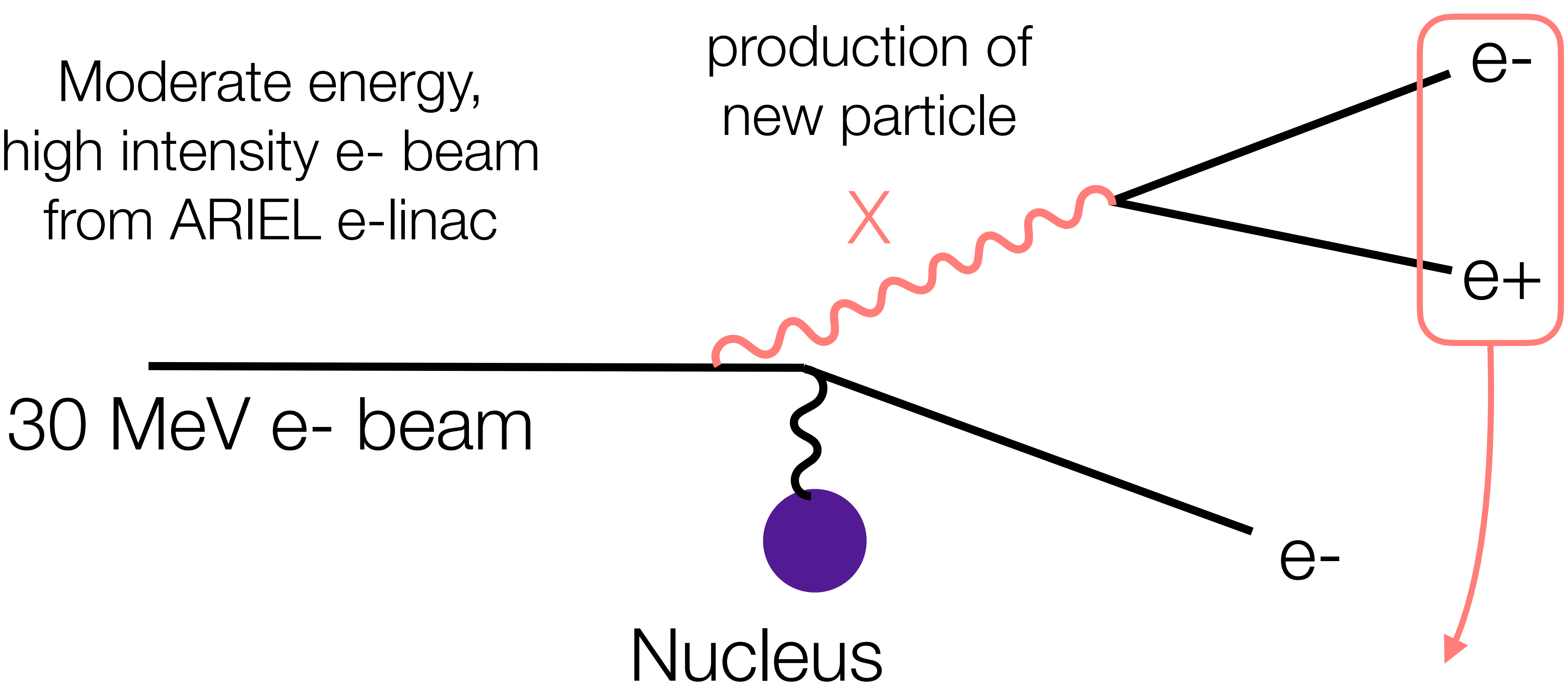
X17 and muon g-2 anomalies both appear in lepton interactions. A new "protophobic" boson would avoid constraints from pion interactions but can be cleanly probed at e- machine.

The DarkLight @ ARIEL experiment

Moderate energy, high intensity e- beam from ARIEL e-linac

Radiative production of new particle

Broad opening angle: measure e+ and e- in spectrometers on opposite sides of beamline

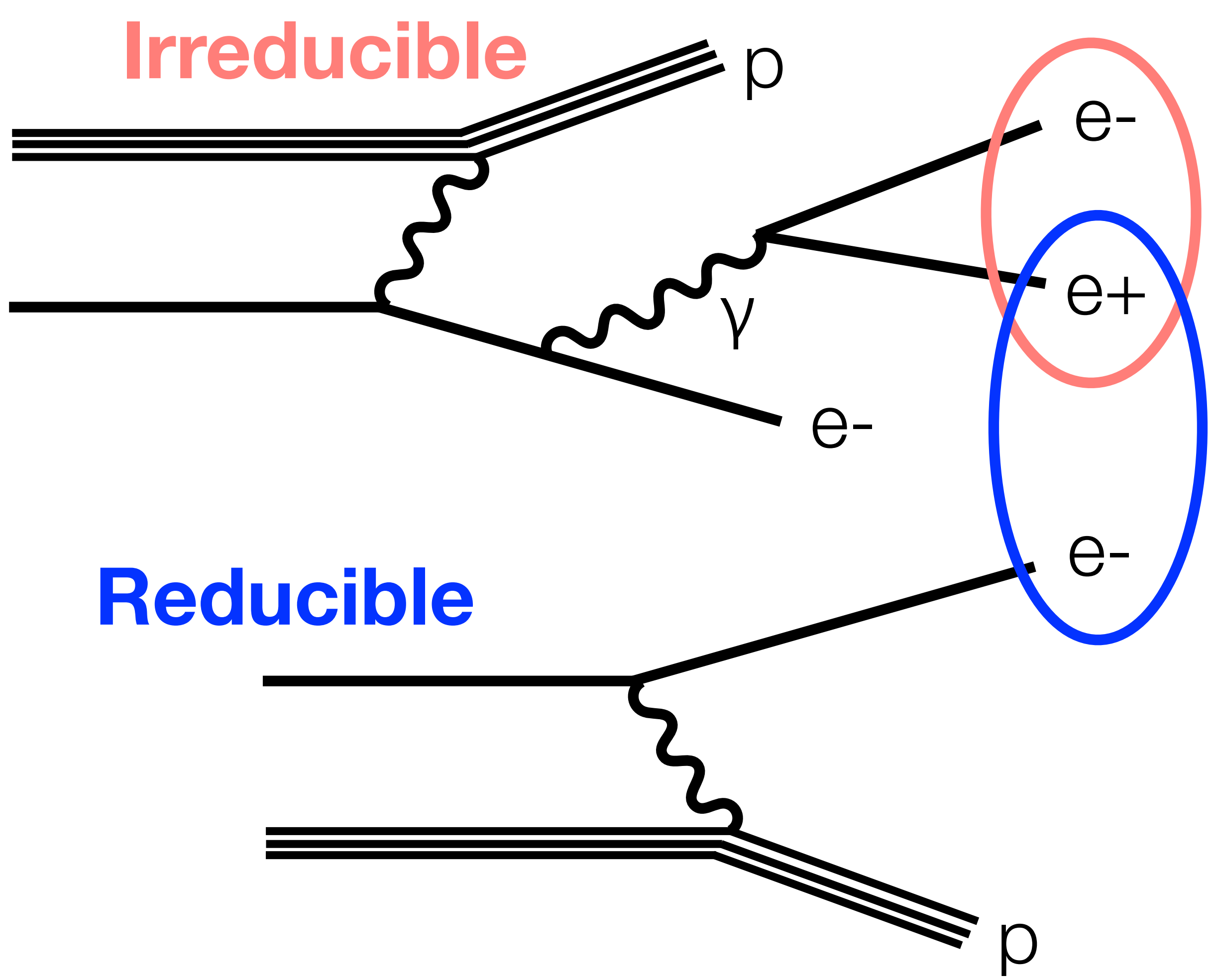


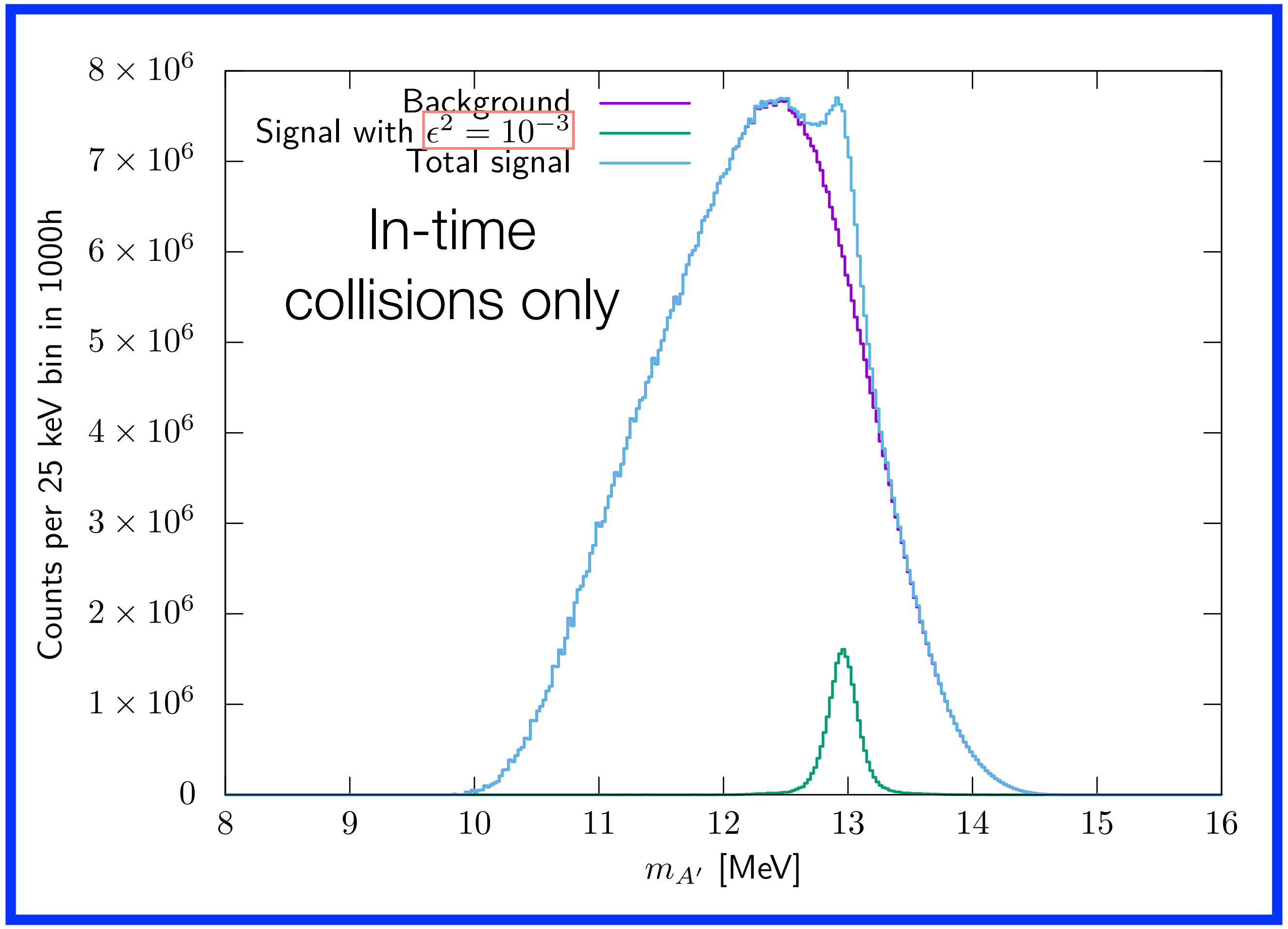
High-N target optimised for minimum multiple scattering: baseline target is 1 μm Tantalum foil

Reconstruct invariant mass of e+e- pair and search for resonant peak over smooth SM background

Background processes

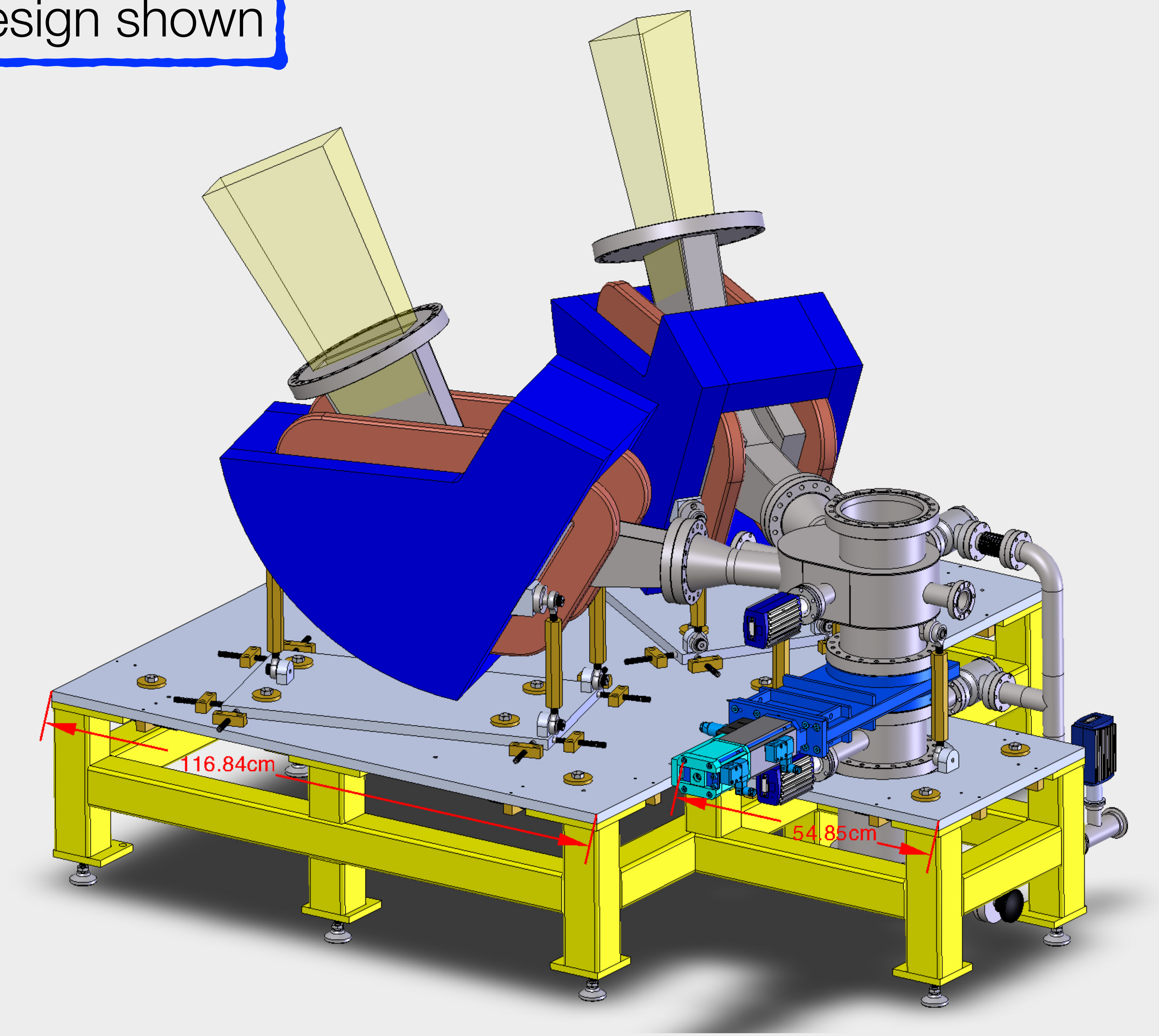
- Vastly dominant background is e+ from pair production combined with e- from simultaneous scattering event. **Coincidence**-based trigger is key
- Two ways to control rates: 1) angular position of detectors 2) timing resolution << bunch spacing (1.5 ns)





Experiment overview

Preliminary design shown



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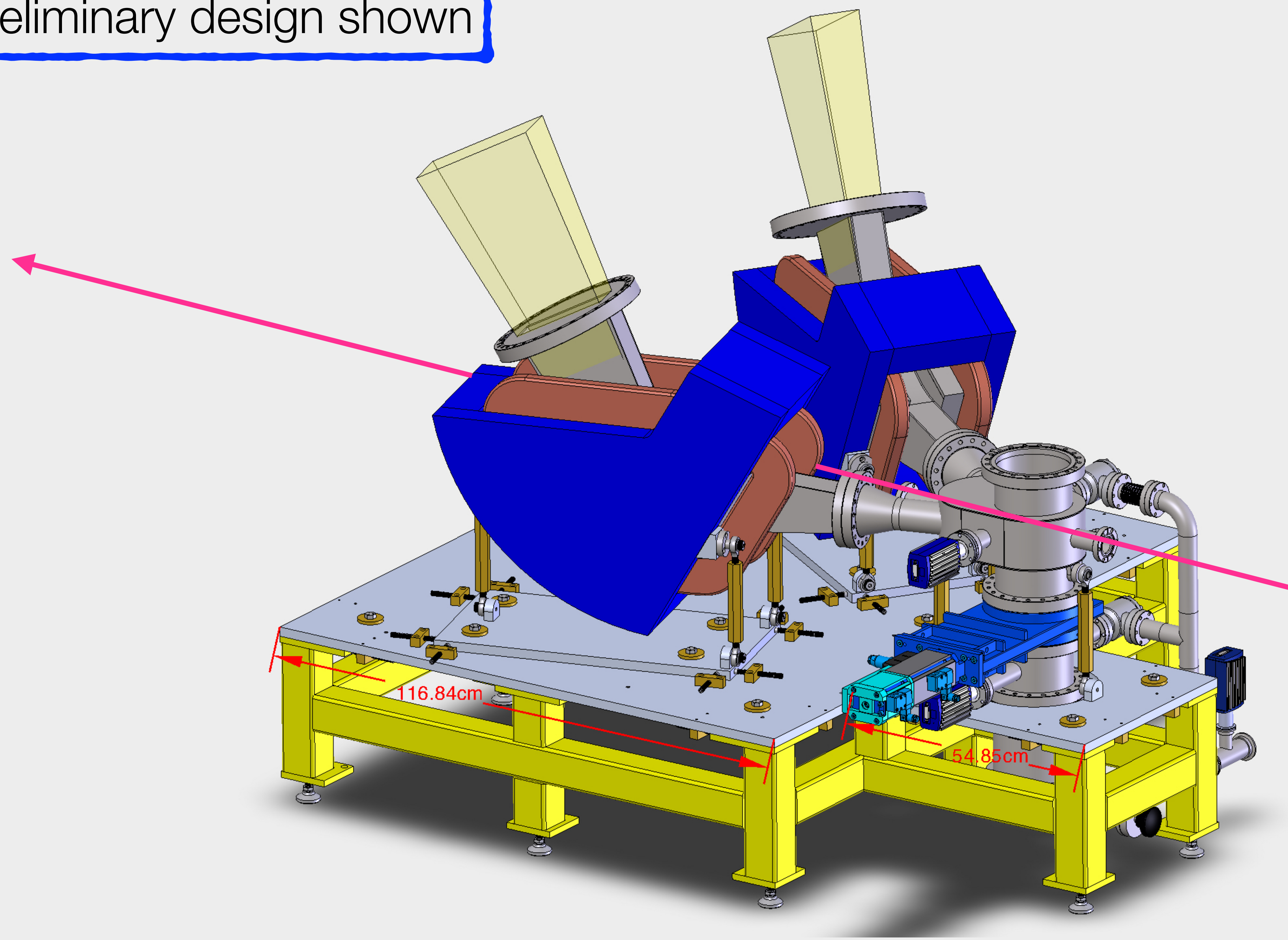
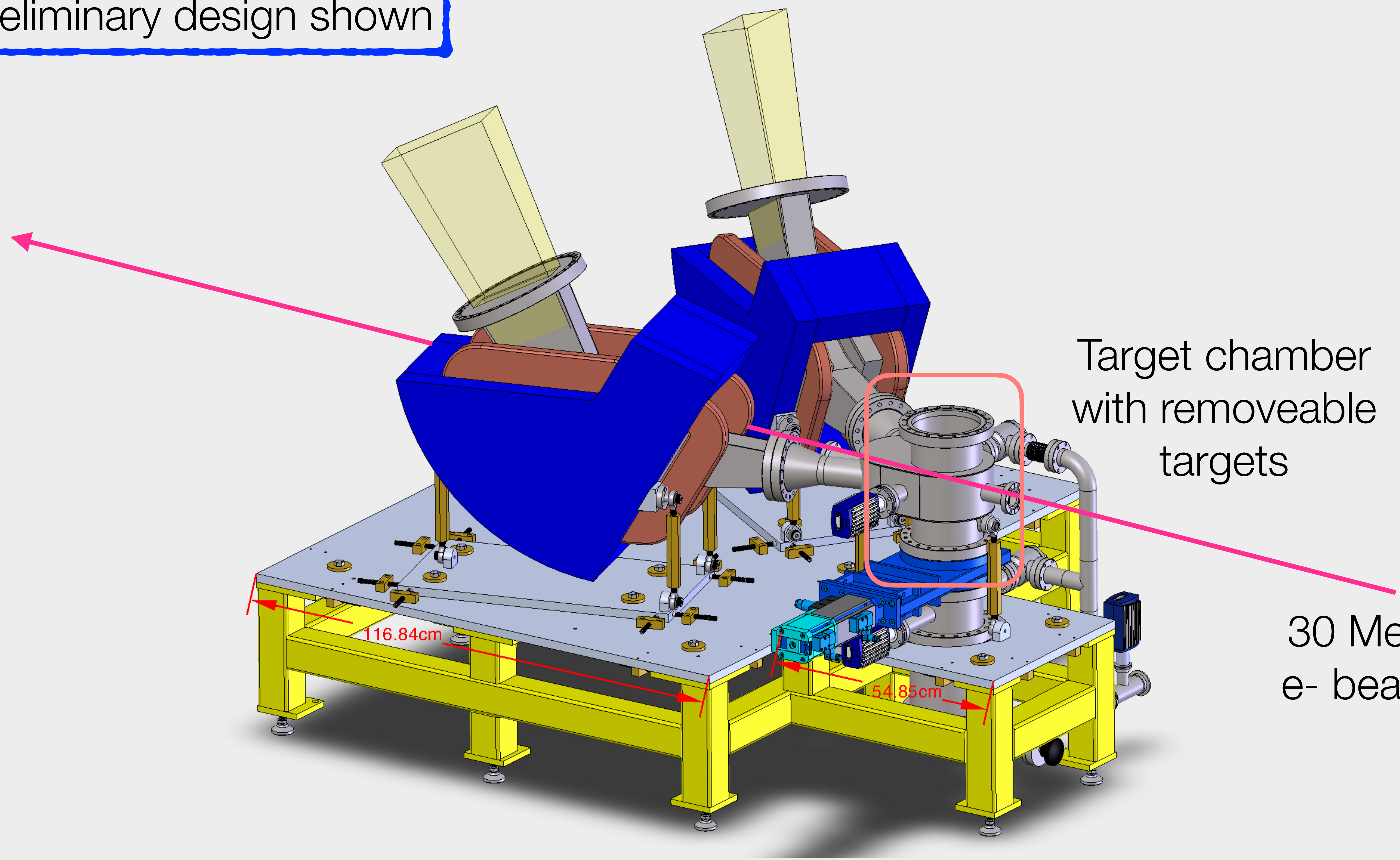


30 MeV
e- beam

Experiment overview

Preliminary design shown

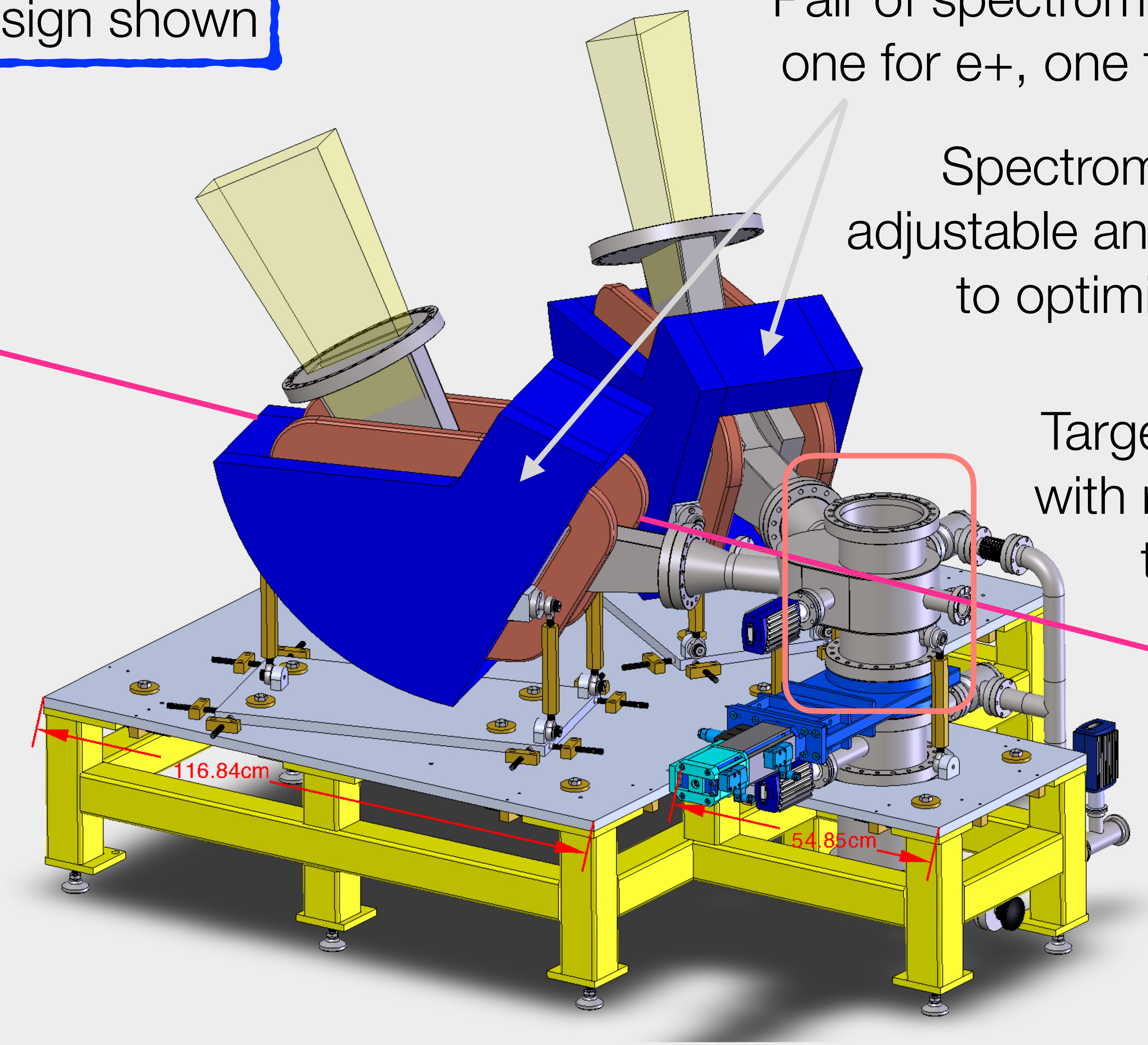


Target chamber with removeable targets

30 MeV e- beam

Experiment overview

Preliminary design shown



Pair of spectrometers: one for e+, one for e-

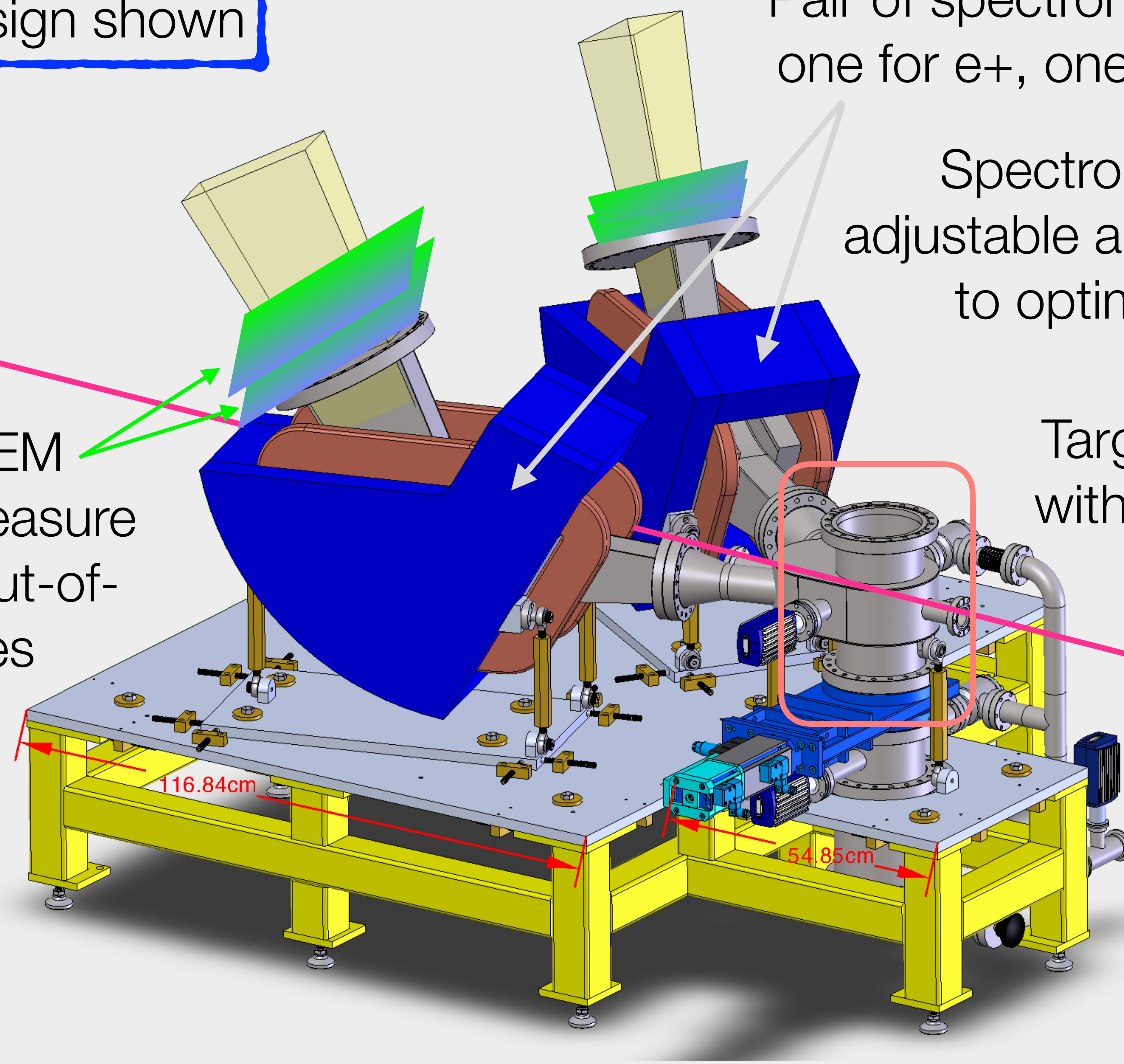
Spectrometer arms at adjustable angles: asymmetric to optimise selection

Target chamber with removeable targets

30 MeV e- beam

Experiment overview

Preliminary design shown



Pair of spectrometers: one for e+, one for e-

Spectrometer arms at adjustable angles: asymmetric to optimise selection

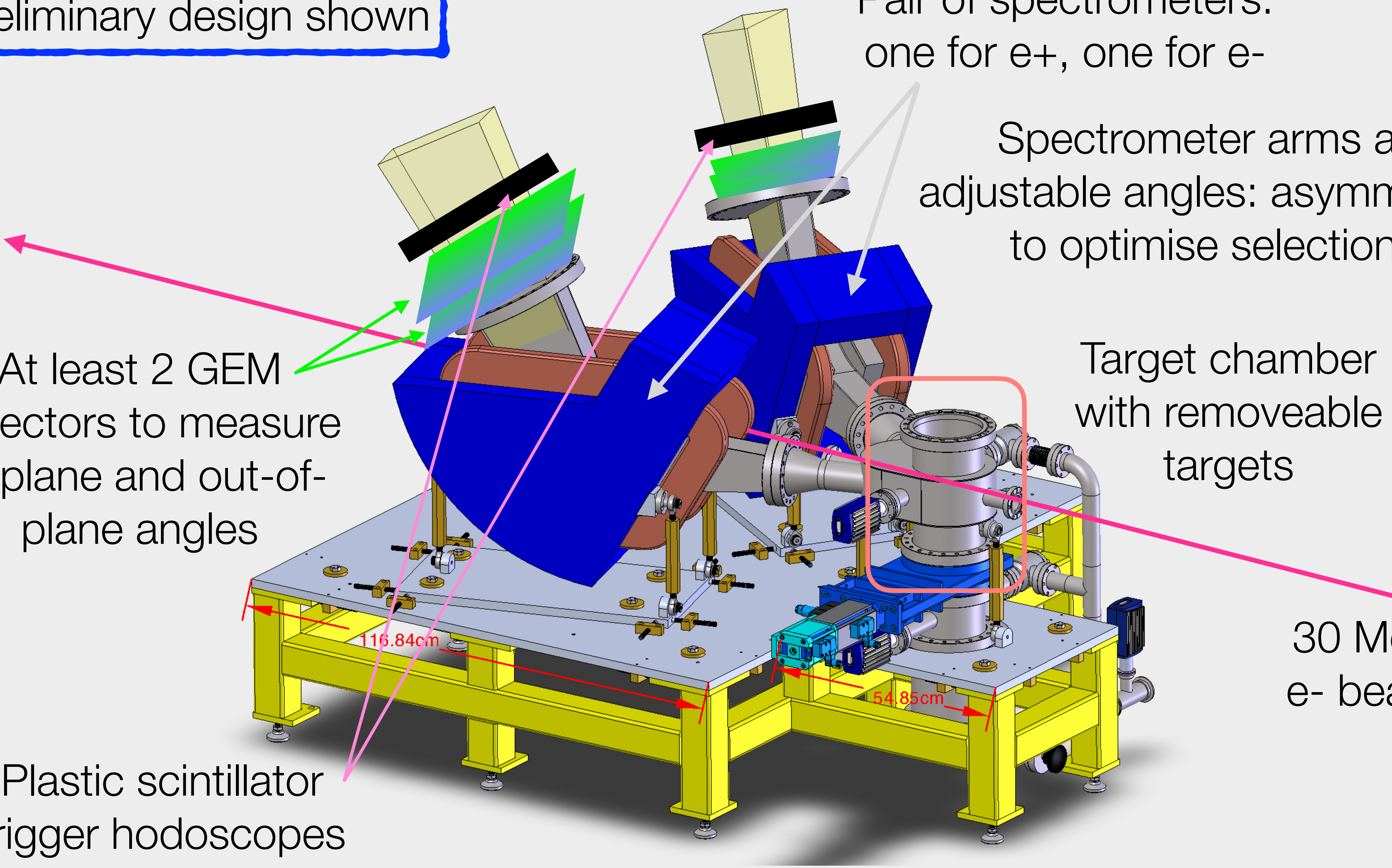
At least 2 GEM detectors to measure in-plane and out-of-plane angles

Target chamber with removeable targets

30 MeV e- beam

Experiment overview

Preliminary design shown



Collaboration and commitments

Arizona State University, Tempe, AZ, USA
University of British Columbia, Canada
Hampton University, Hampton, VA, USA
TJNAF, Newport News, VA, USA
Massachusetts Institute of Technology, Cambridge, MA, USA
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Trigger design, construction, read-out electronics

Spectrometer design, simulation, construction; target and target chamber

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Trigger design, construction, read-out electronics

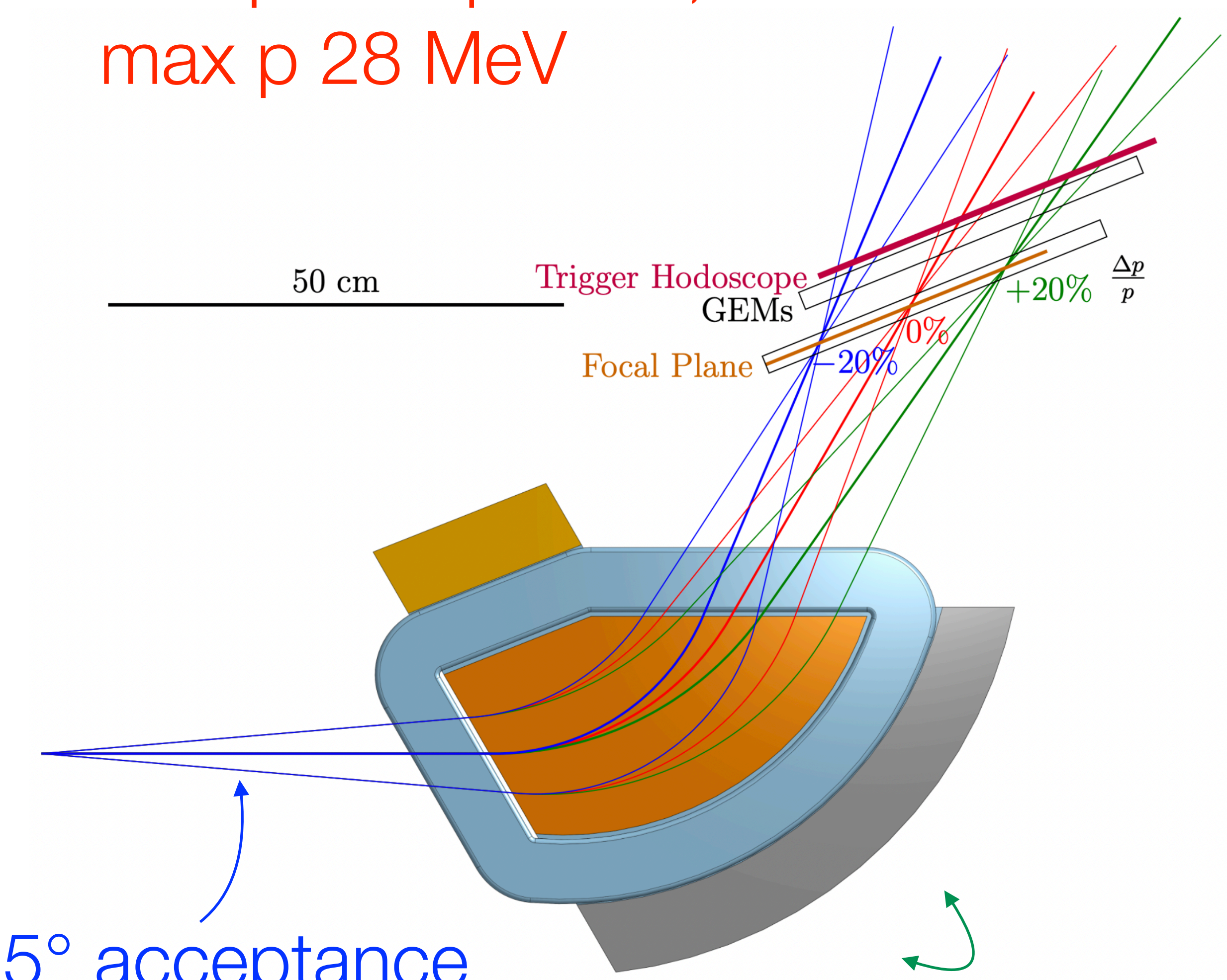
Spectrometer design, simulation, construction; target and target chamber

Accelerator upgrades and experiment integration into ARIEL

Experiment status: spectrometers

- Two identical dipole spectrometers, 0.32 T
- Simulations in magnetic field with multiple scattering to optimise mass resolution (~ 120 keV)
- Main constraint: space
  - Minimum size of magnet + size of beamline restrict possible angles for spectrometer

+/- 20% p acceptance, max p 28 MeV

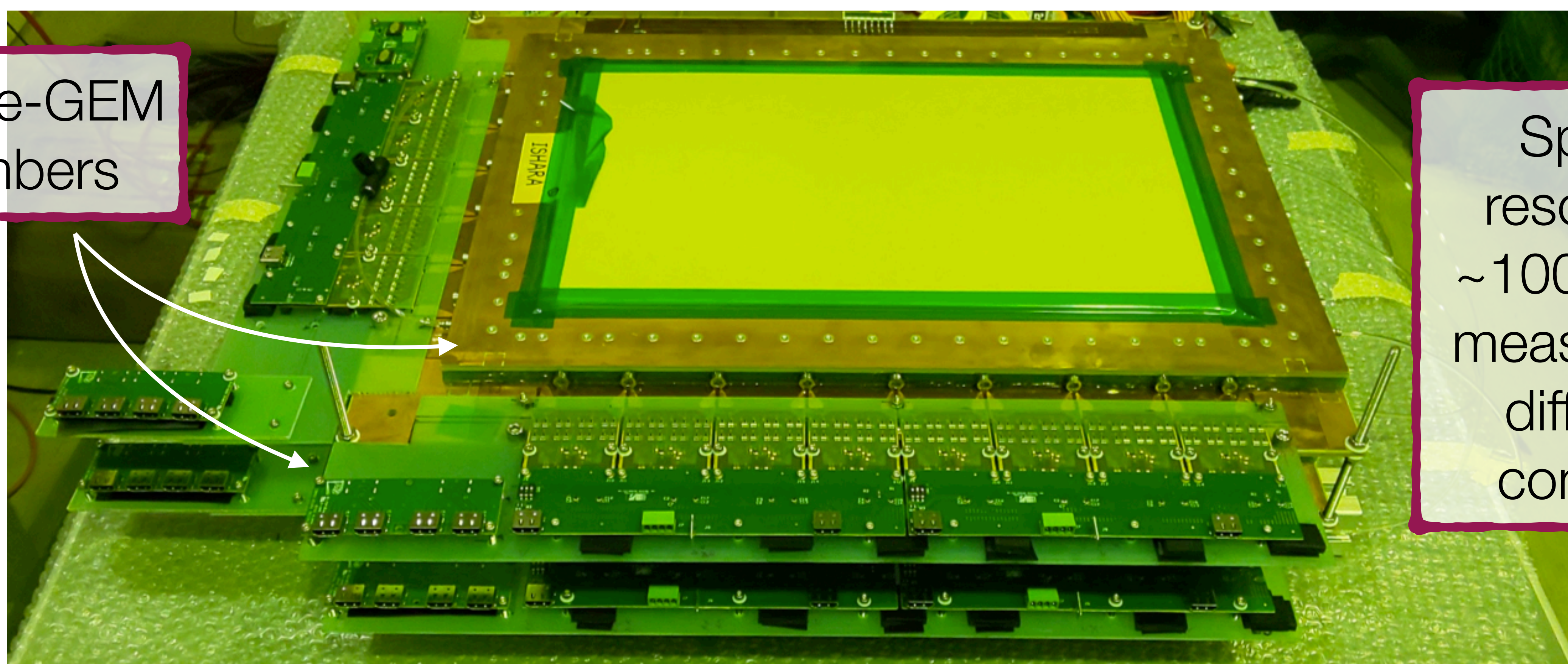


+/- 5° acceptance in this dimension

+/- 2° acceptance the other way

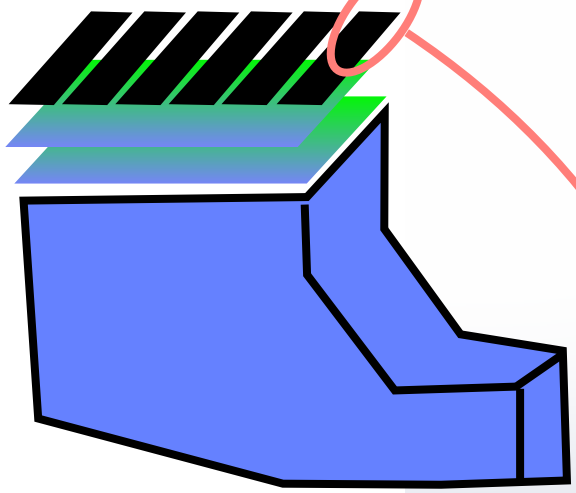
Experiment status: GEM detectors

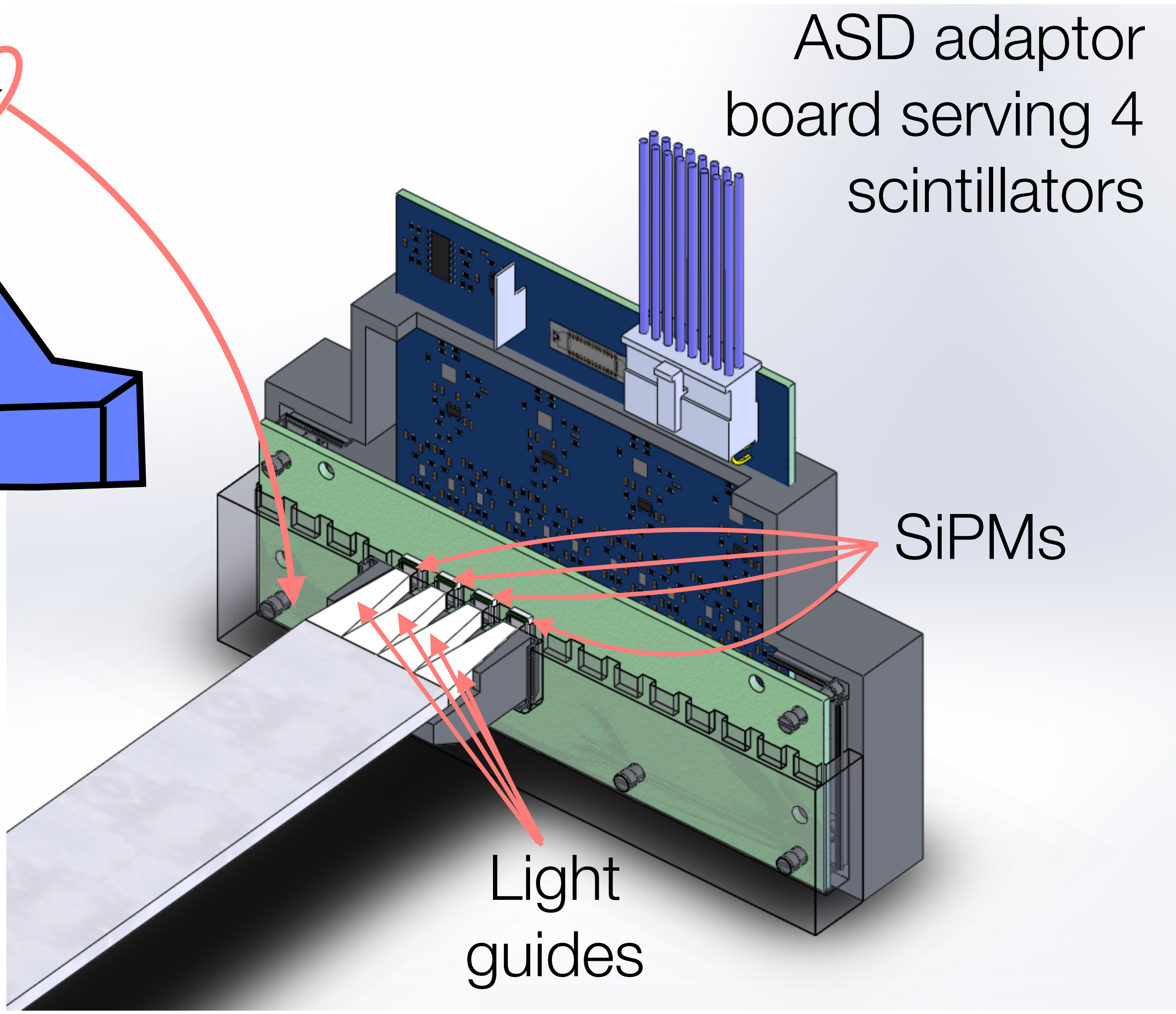
- **Already completed** by Hampton University group with NSF funds
- GEMs: dimension 25 x 40 cm triple-GEMs built using improved techniques developed at CMS. Some modules already in use
- Six GEM chambers will be available for DarkLight use by end of 2022, along with sufficient readout electronics. Commissioning to be completed at JLab/ELPH in intervening months.



Experiment status: trigger detectors

- Key figure of merit: timing resolution < 500 ps (ideally ~200)
- Trigger design: 8 - 10 strips of fast plastic scintillator segmented along direction of momentum dispersion
- Read-out is via SiPMs, four per side per strip
- First prototypes being created at TRIUMF now

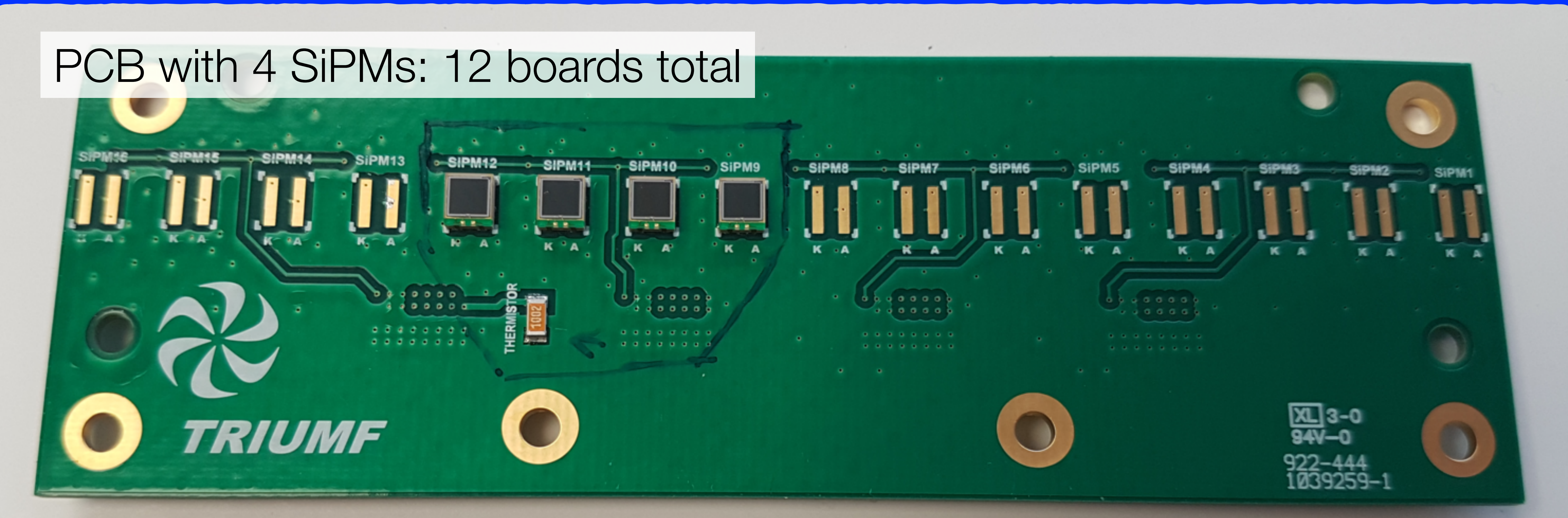




Prototype scintillator dimensions:
150 mm x 30 mm x 3 mm

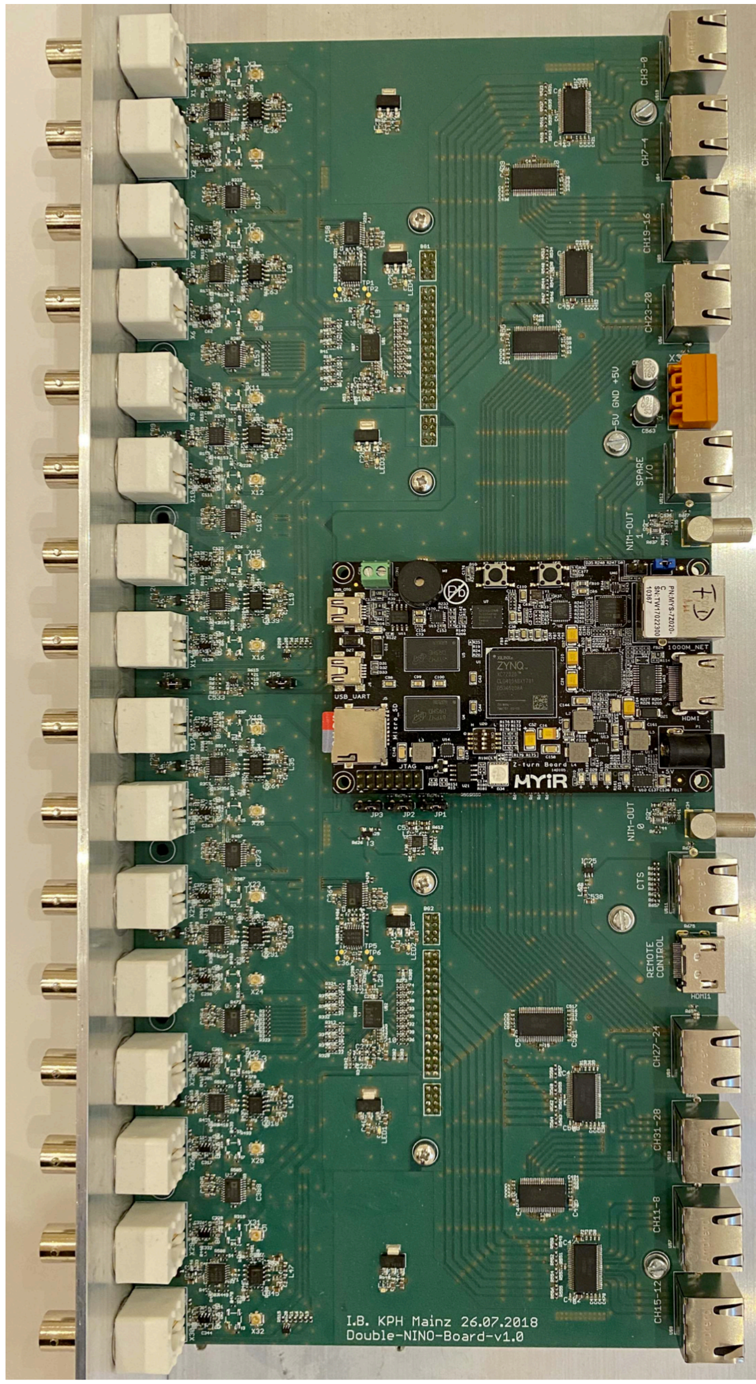

Scintillators mid-wrapping…


… and wrapped

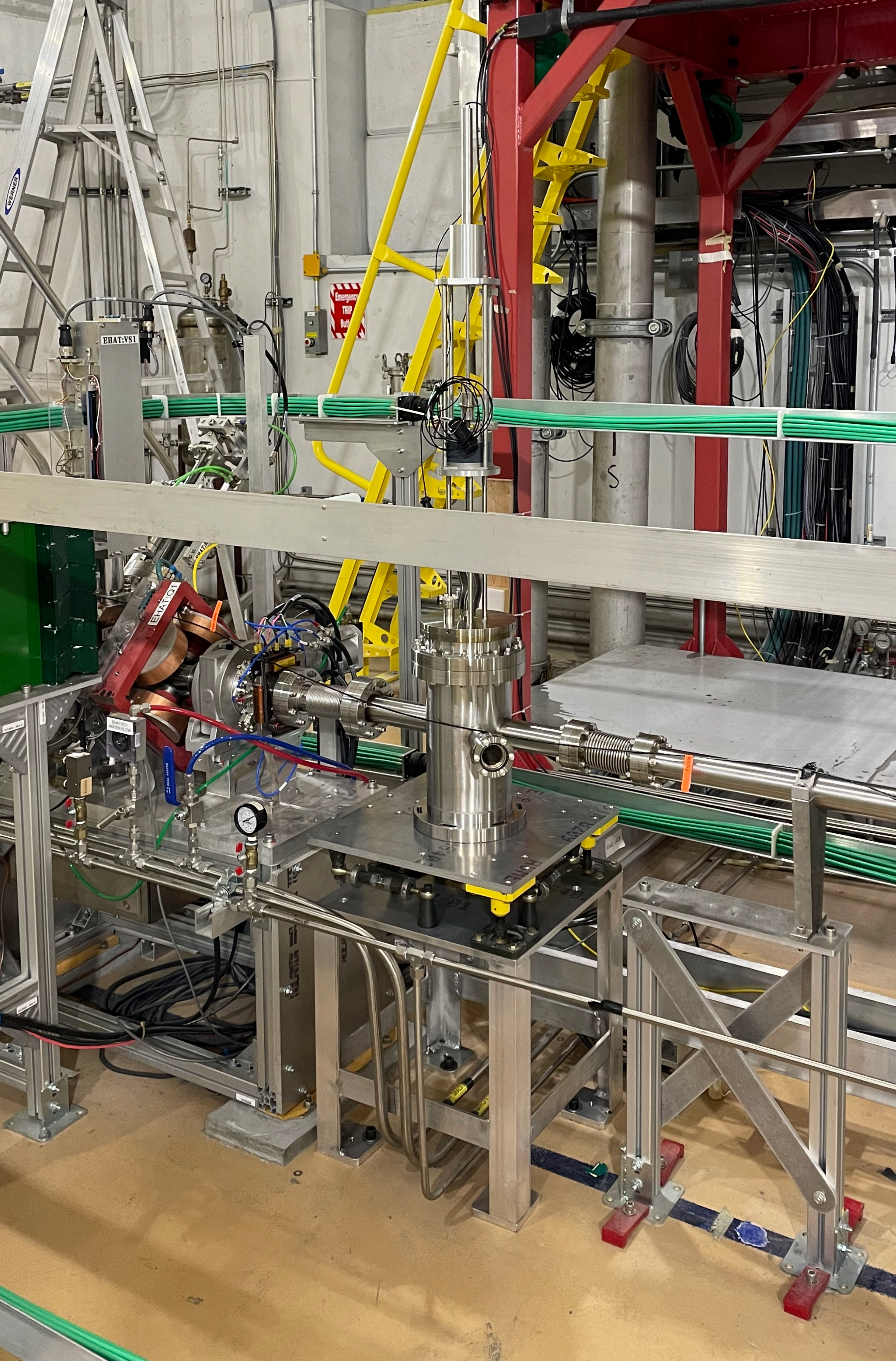

PCB with 4 SiPMs: 12 boards total
TRIUMF

Experiment status: read-out and DAQ

- GEM read-out electronics already in place: timing ~ 200 μs using APV chips to MPDs to VME modules with a fast readout mode
- Trigger uses coincidence of scintillator outputs
  - Discrimination step, then FPGA will determine coincidence between individual scintillator strip pairs
- Investigated various existing systems
  - Likely to begin from trigger design of MAGIX experiment: similar timing resolution and a compact design
- DAQ software will be handled by Stony Brook + TRIUMF



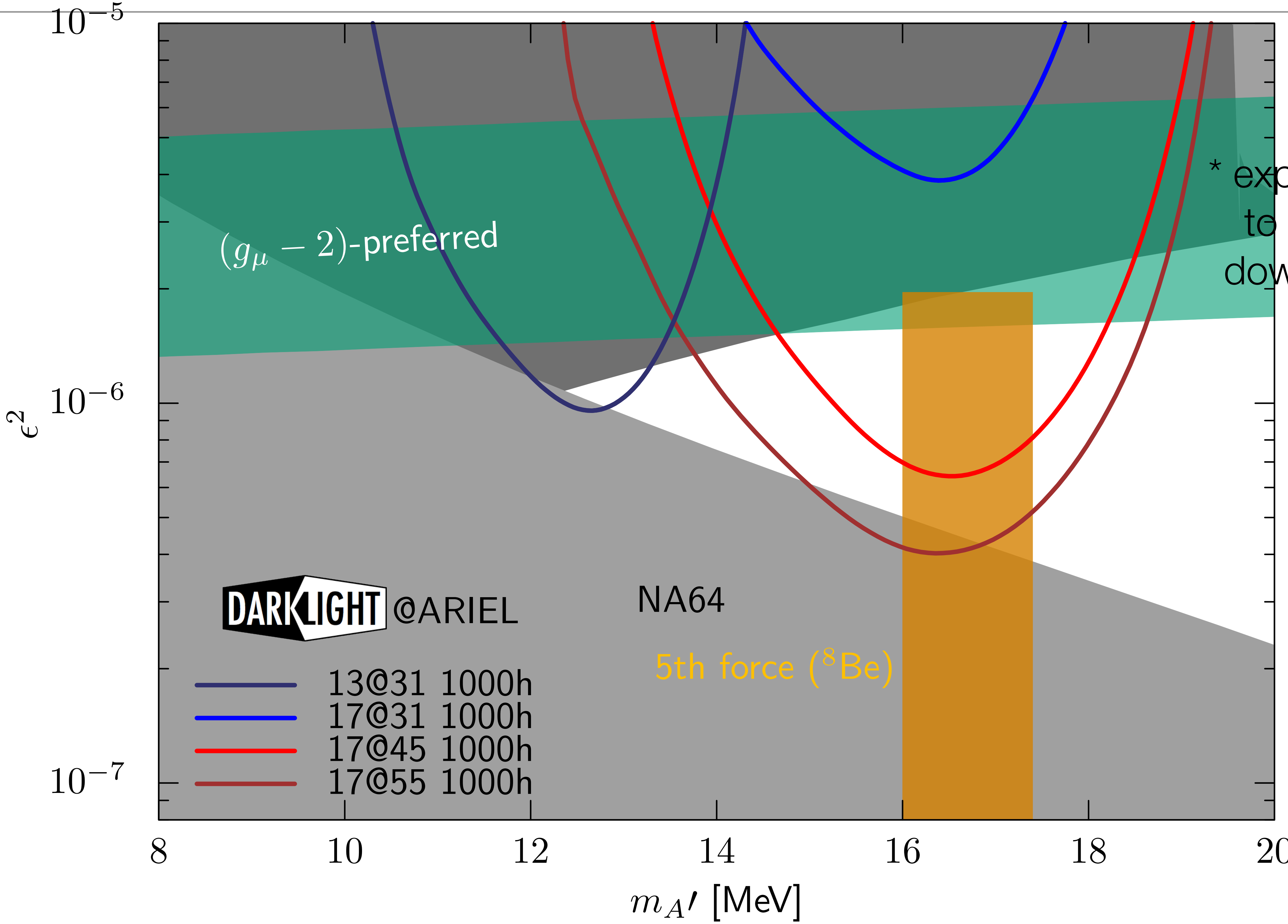
MAGIX board with 32 inputs & FPGA
H. Merkel



Initial test experiments

- Test chamber with moveable foil targets **now installed** in e-linac
- Within **next month, do thermal tests**: monitor with optical and thermal cameras while putting small beam current on target
- Later **this spring/summer**, install available test **spectrometer**
  - Existing magnet & simple detectors will be shipped from MIT
  - With some current on target, measure background levels in detectors and around target area

Sensitivity at 30 and 50 MeV accelerators



* expect this to move down a bit

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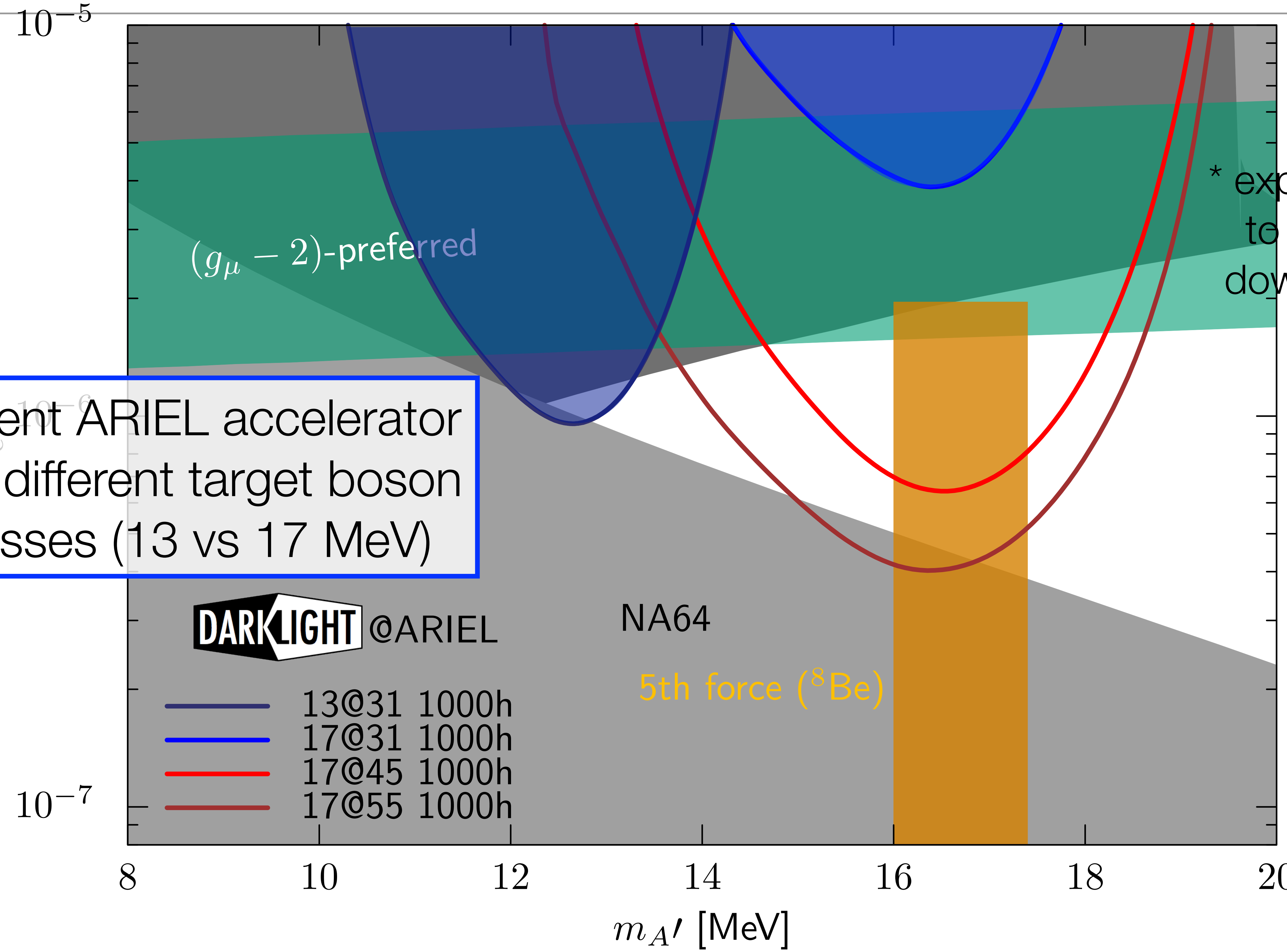

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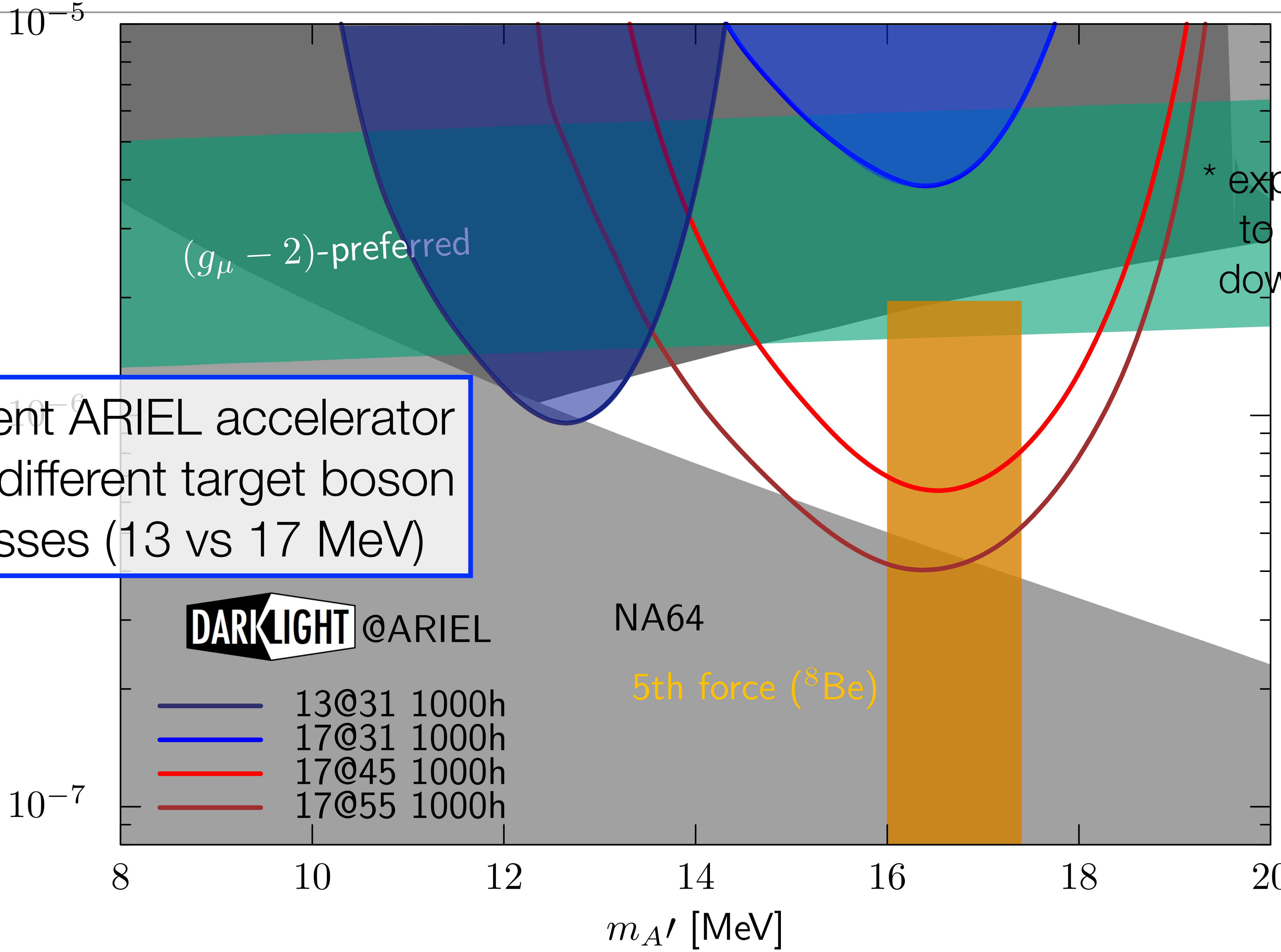
Current ARIEL accelerator with different target boson masses (13 vs 17 MeV)

Sensitivity at 30 and 50 MeV accelerators

Overlap with g-2 favoured region is only in already-excluded areas



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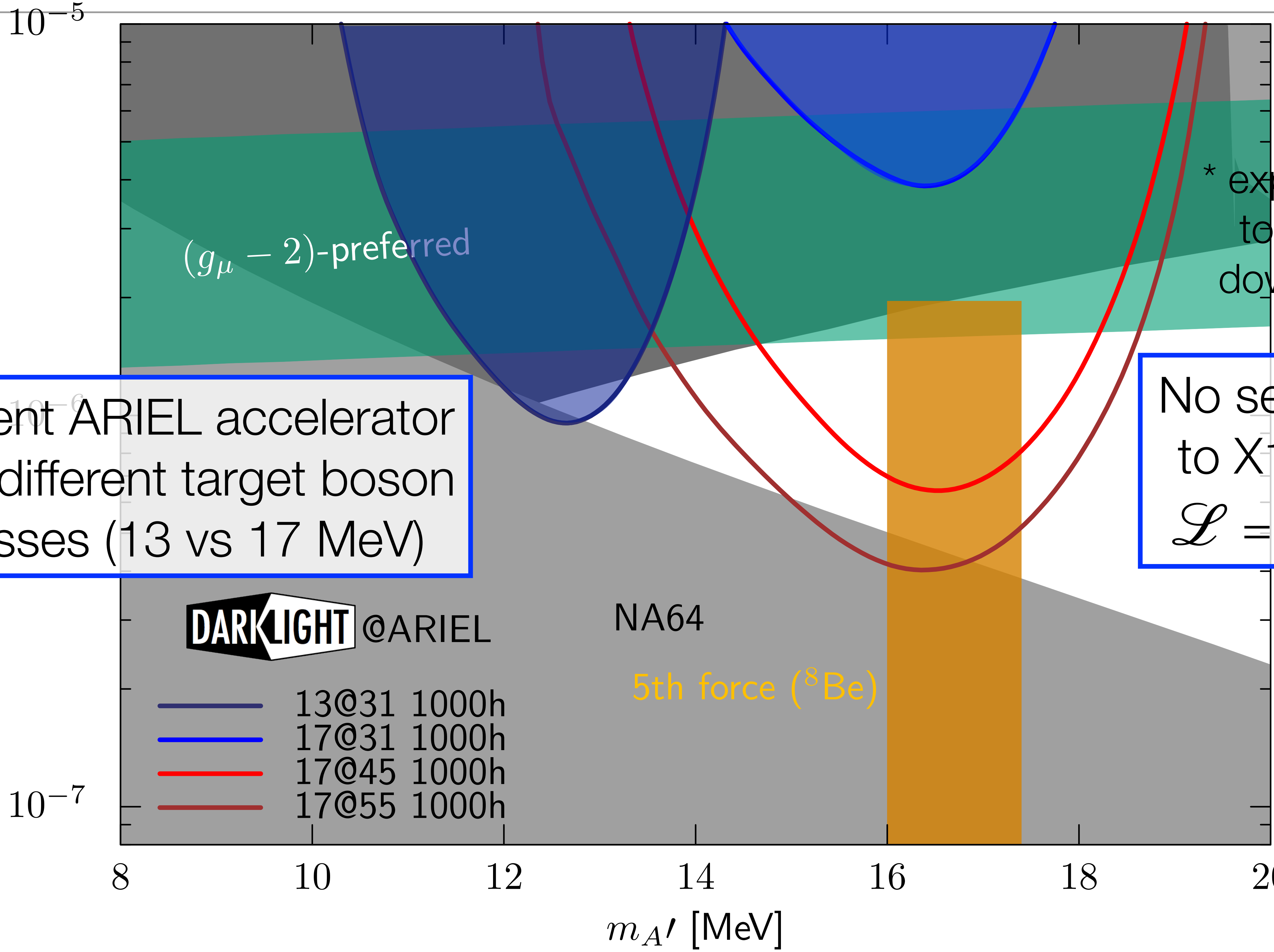

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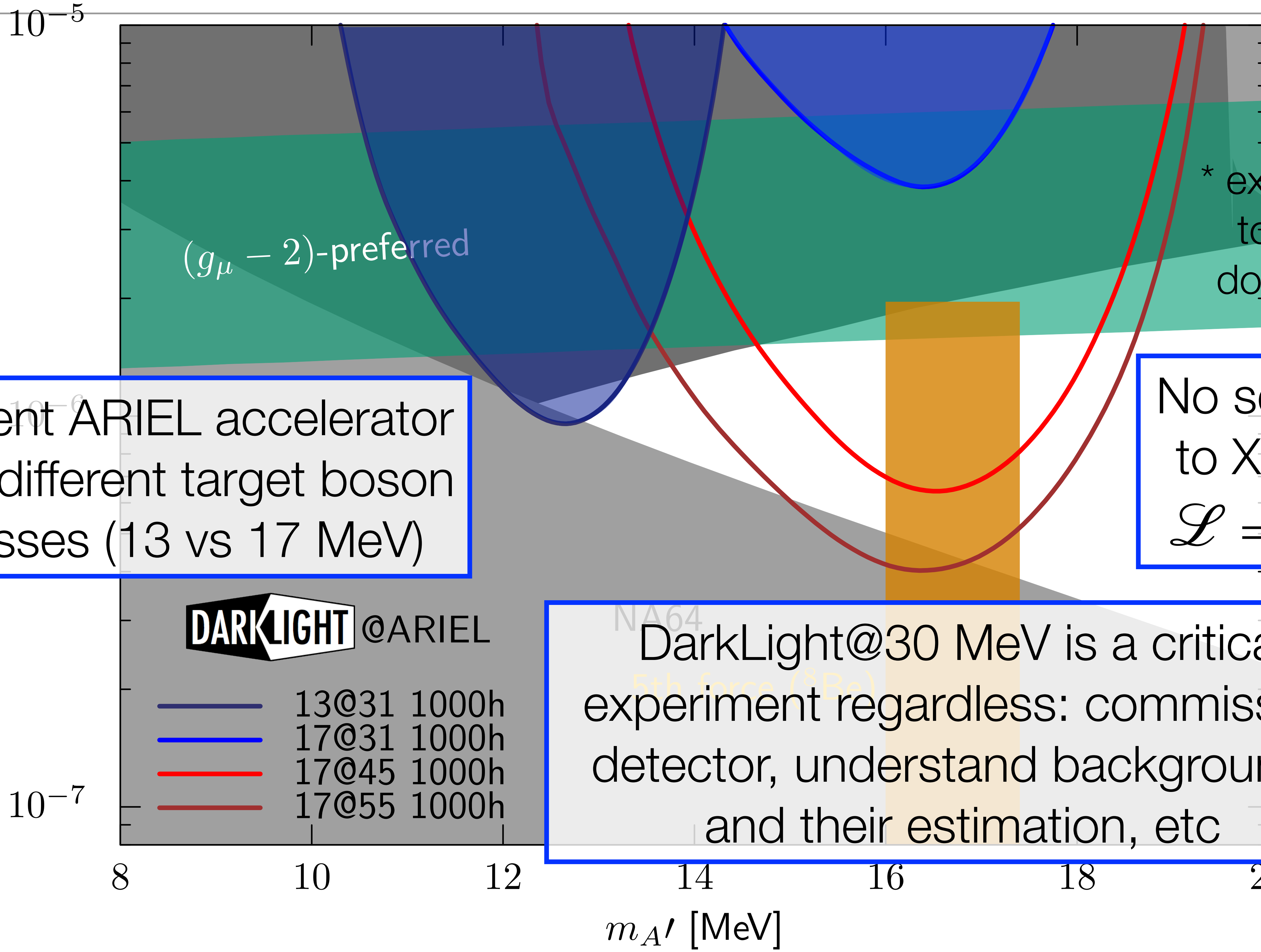

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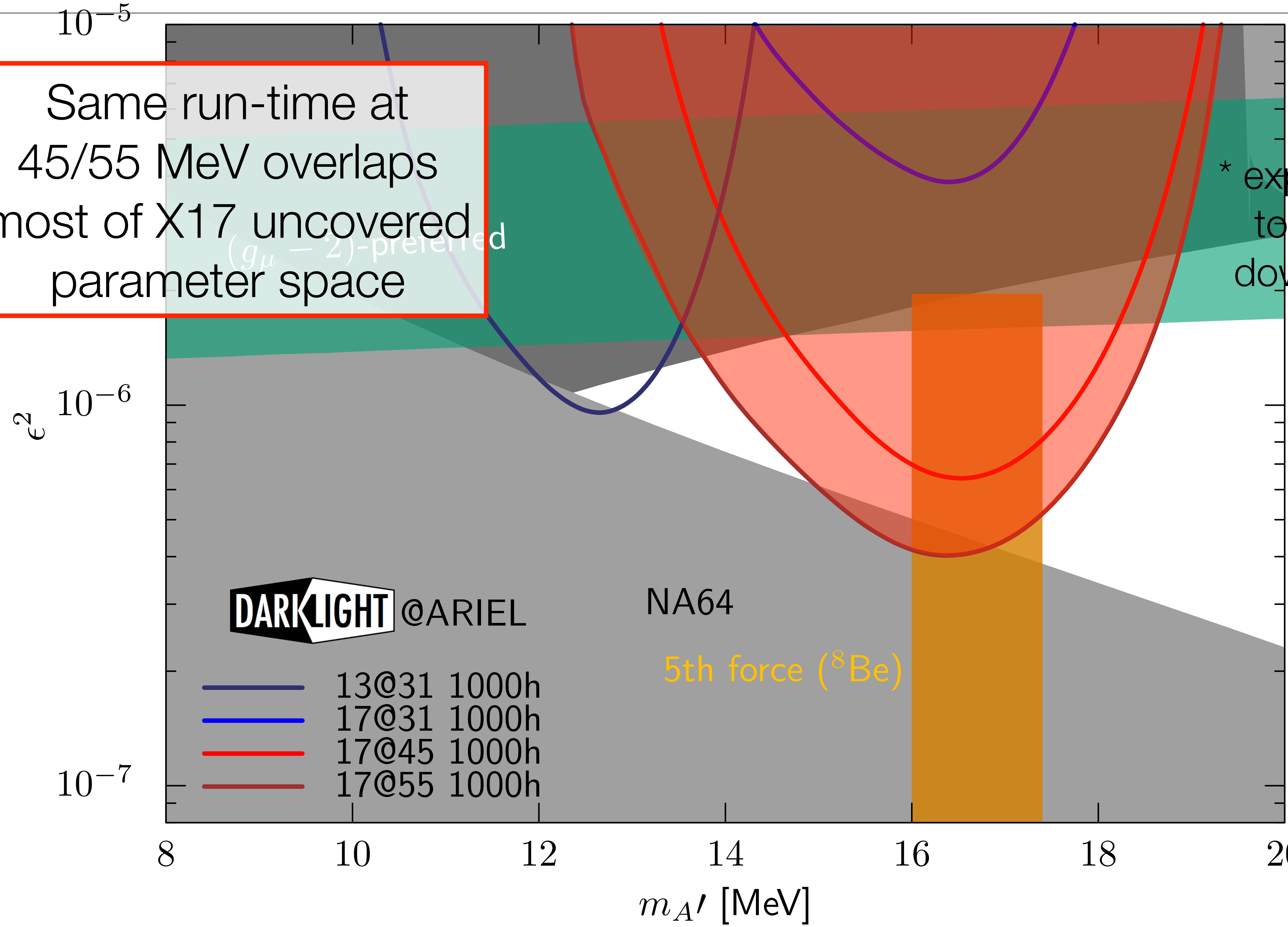
Current ARIEL accelerator with different target boson masses (13 vs 17 MeV)

No sensitivity to X17 with $\mathscr{L}$ = 18 fb^{-1}

DarkLight@30 MeV is a critical experiment regardless: commission detector, understand backgrounds and their estimation, etc

Sensitivity at 30 and 50 MeV accelerators



Same run-time at 45/55 MeV overlaps most of X17 uncovered parameter space

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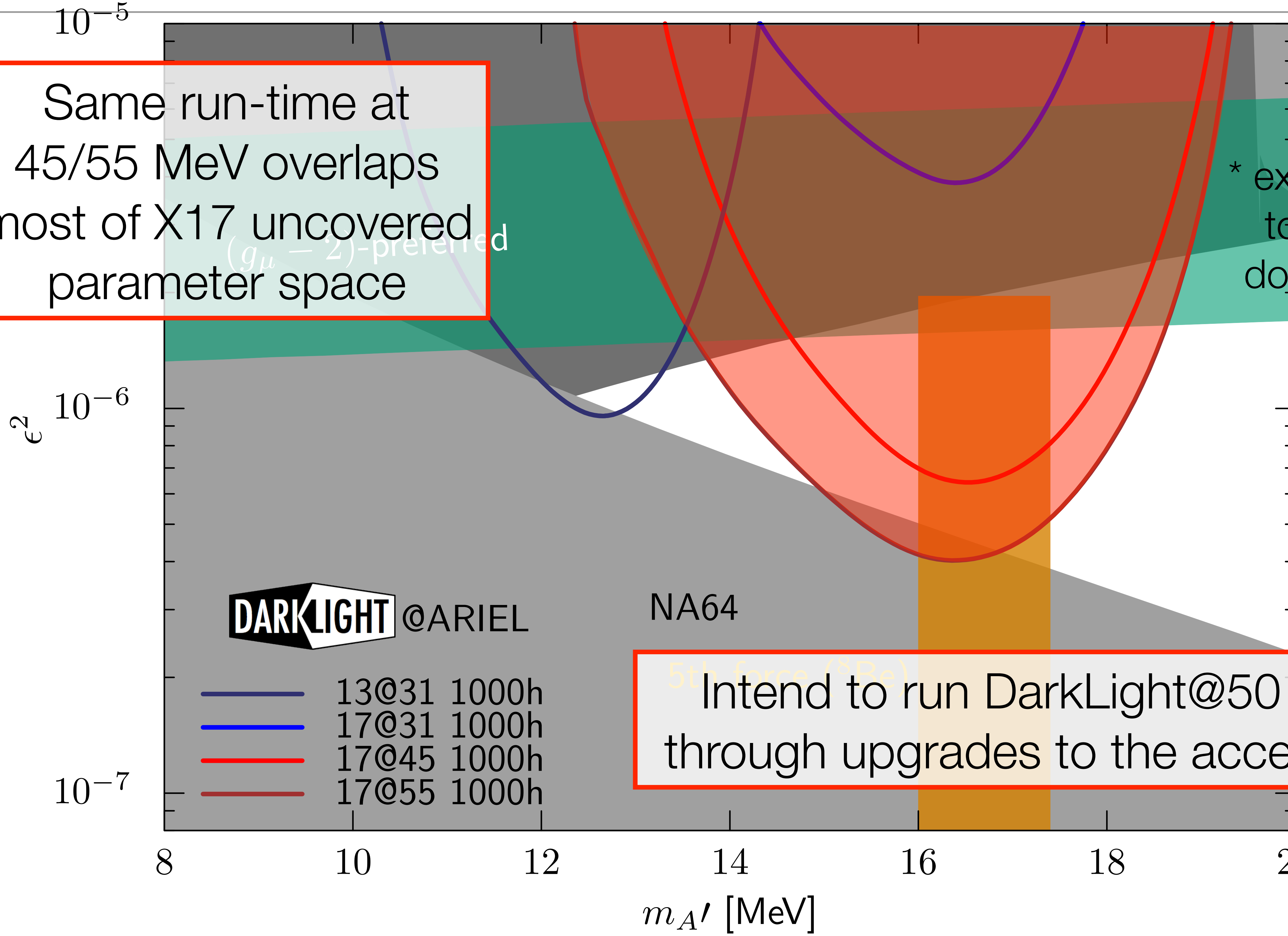
Sensitivity at 30 and 50 MeV accelerators



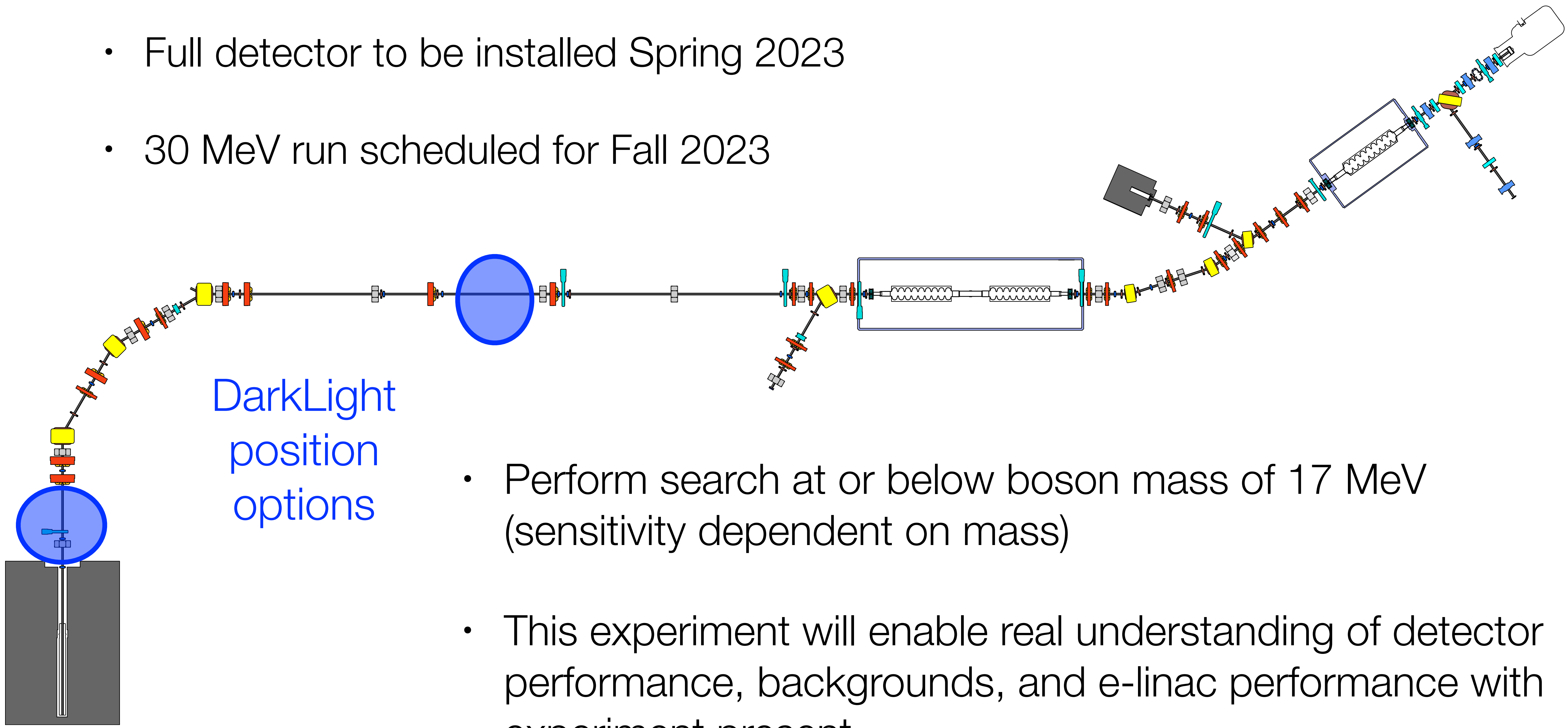
Same run-time at 45/55 MeV overlaps most of X17 uncovered parameter space

* expect this to move down a bit

Intend to run DarkLight@50 MeV through upgrades to the accelerator

Stage 0: 30 MeV running with current ARIEL accelerator

- First true experimental stage is a full run (integrated luminosity 18 fb^{-1}) at 30 MeV, approved for 1300 hrs beam-time at previous PP-EEC
    - Full detector to be installed Spring 2023
    - 30 MeV run scheduled for Fall 2023



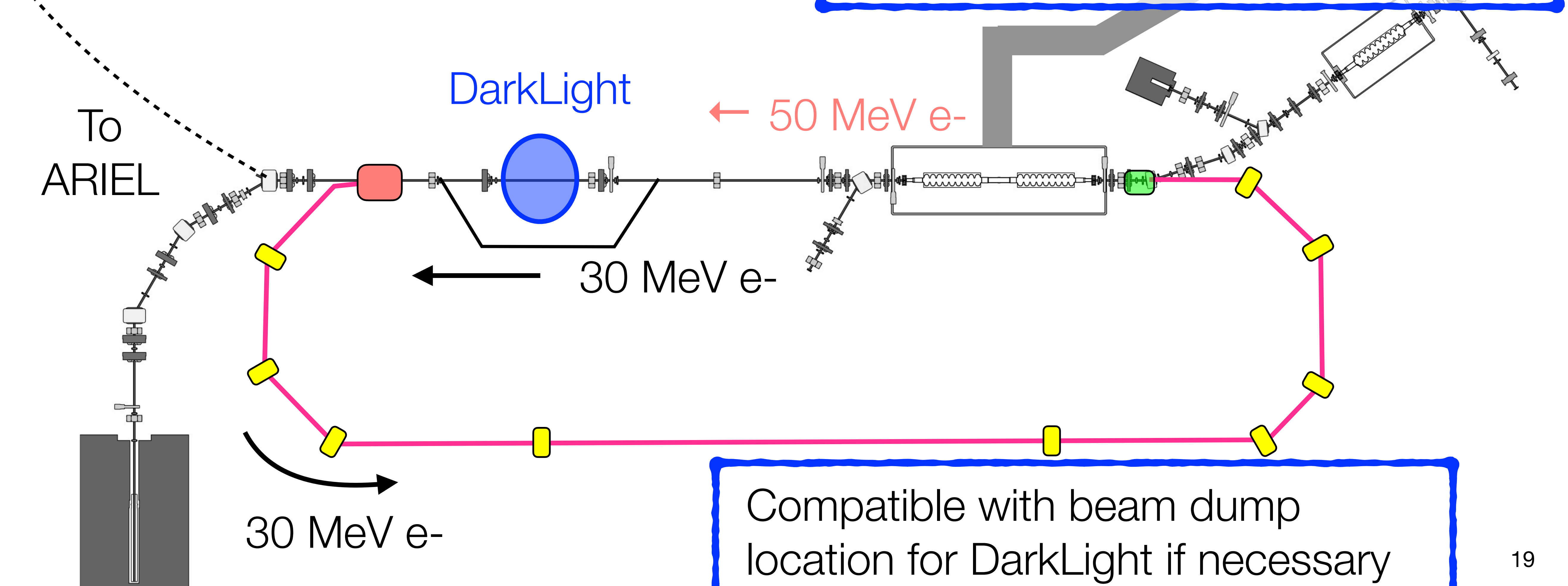
- Perform search at or below boson mass of 17 MeV (sensitivity dependent on mass)
- This experiment will enable real understanding of detector performance, backgrounds, and e-linac performance with experiment present

Stage 1 (running Fall 2024): Recirculating ring for energy increase to 50 MeV

- Beam pipes for recirculation
- Ring magnets
- Septum magnet
- Point of beam re-routing back into e-linac

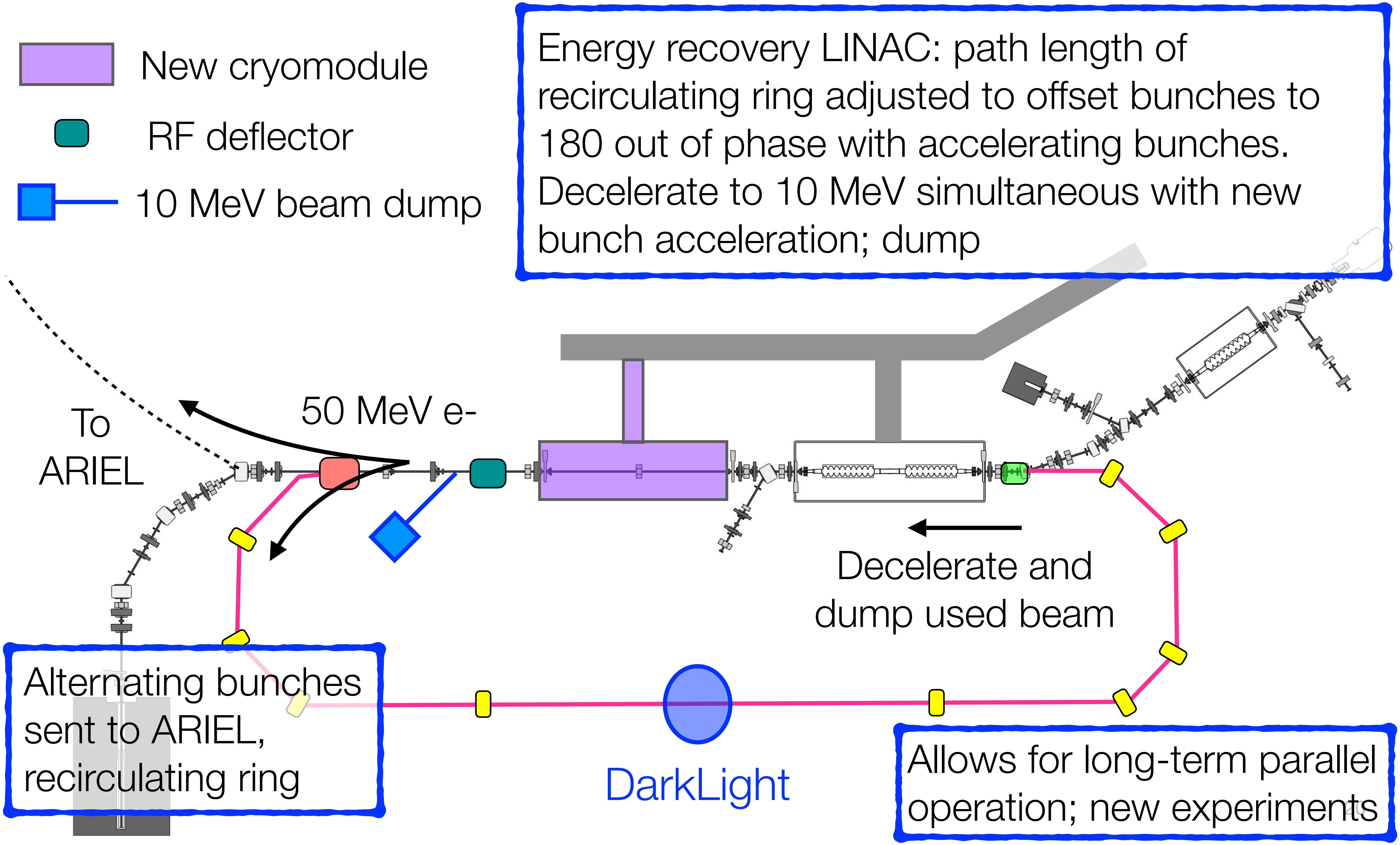
Greyscale: existing infrastructure.
Colourful: required; in CFI request

All bunches will pass through recirculating ring, then to dump. Chicane directs only 2nd pass through DarkLight.



Compatible with beam dump location for DarkLight if necessary

Stage 2 (2026+):
Energy recovery linac for parallel running with ARIEL



Timeline and milestones

PP-EEC 2021: beam time request approved

Dec 2021: test chamber installed in beamline

Feb 2022 CFI passed selection round at universities

Feb 2022: Passed TRIUMF Gate 1

Today: PP-EEC 2022

Today

April 2022: first beam on target; NSERC decision

May 2022: workshop on physics @ ARIEL, first collaboration meeting

May/June 2022: install spectrometer

2023: install, commission, run full experiment @ 30 MEV; CFI decision

2024: install recirculating beam line; first run @ 50 MeV

Conclusions

- DarkLight has **compelling scientific motivation** and a **strong international collaboration** covering all relevant areas of expertise
- **Significant progress** since initial PP-EEC request last year
  - Target chamber installed, additional tests with existing magnet planned shortly
  - Experimental design ongoing. First trigger prototypes being constructed, simulation of magnet design progressing
  - Active coordination on target, energy upgrades, etc with TRIUMF accelerator division
  - Funding applications in progress, with good feedback so far
- **Hosting workshop at TRIUMF** in May for DarkLight + other new ideas for ARIEL e-linac based experiments

Thank you!

Target and beamline interplay

- Initial studies conducted assuming 1µm Ta foil target: good balance between interaction rate and amount of multiple scattering for experiment

- Now, detailed studies ongoing on impact of target foil on beam. Dispersion is high relative to what beam optics were designed for

- Exploring variations in target or experiment placement through simulations

  - Move early stages of experiment to location nearer to beam dump

  - Use target with only partial beam interception