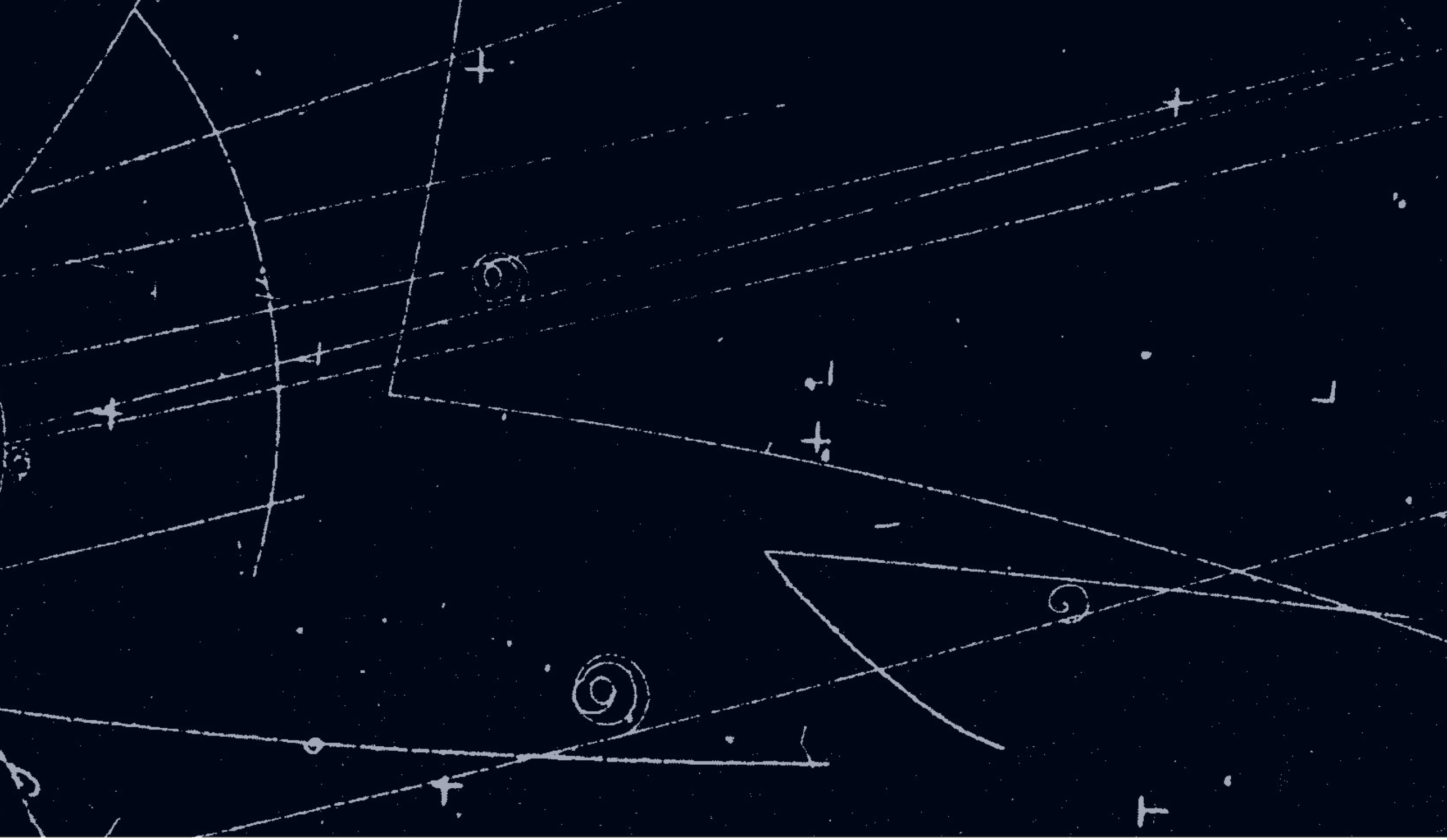


DarkLight@ARIEL experiment context and plans

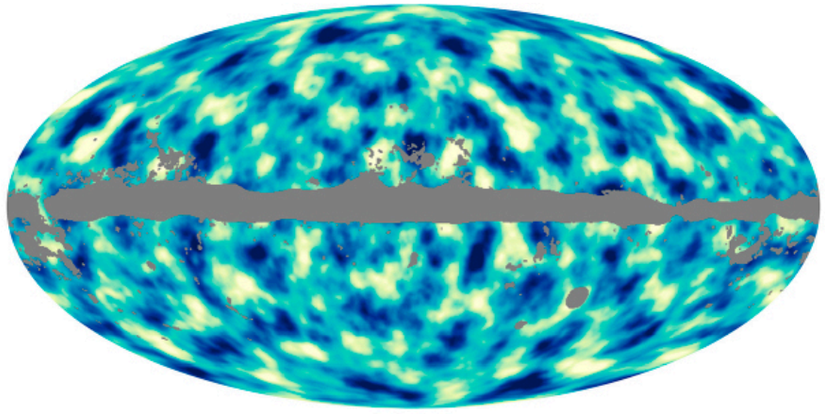
Kate Pachal
TRIUMF

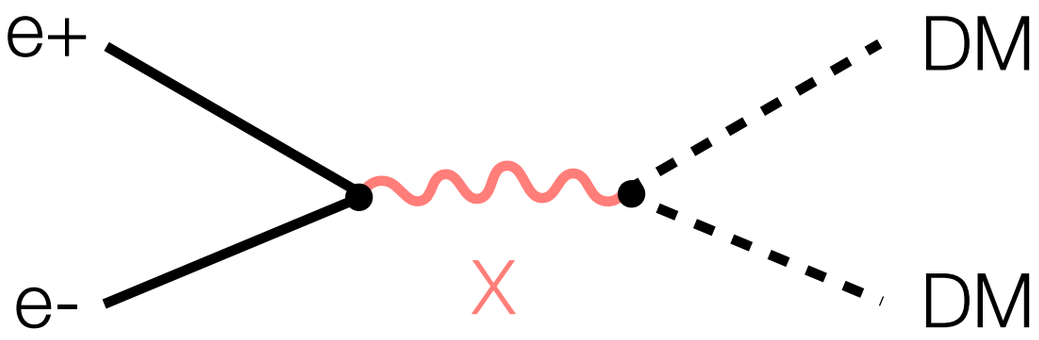
Introduction

- DarkLight@ARIEL is a **new experiment** to be built **at TRIUMF** searching for low-mass e+e- resonances
  - Following previous work/proposal at JLab
  - **Compelling scientific motivation** and a strong international collaboration covering all relevant areas of expertise
  - **Strong support** at TRIUMF and positive feedback from NSERC
- Today: brief overview of **physics motivation**, then outline **current and future work**
  - Designs for full experiment well under way, with initial installations for test experiments in place
  - Long-term plans are converging, with dependence on CFI funding

Uniting dark matter with particle physics experimental anomalies

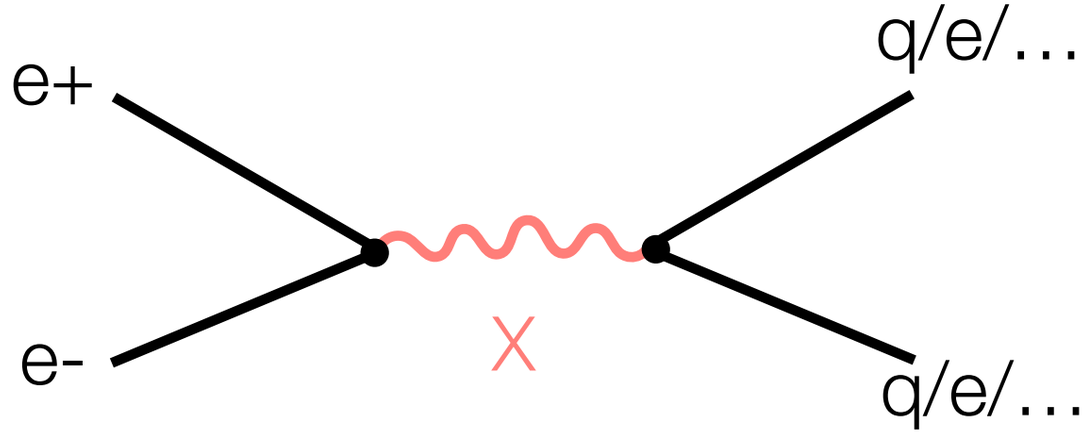
Dark matter remains one of the biggest unsolved mysteries of particle physics





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

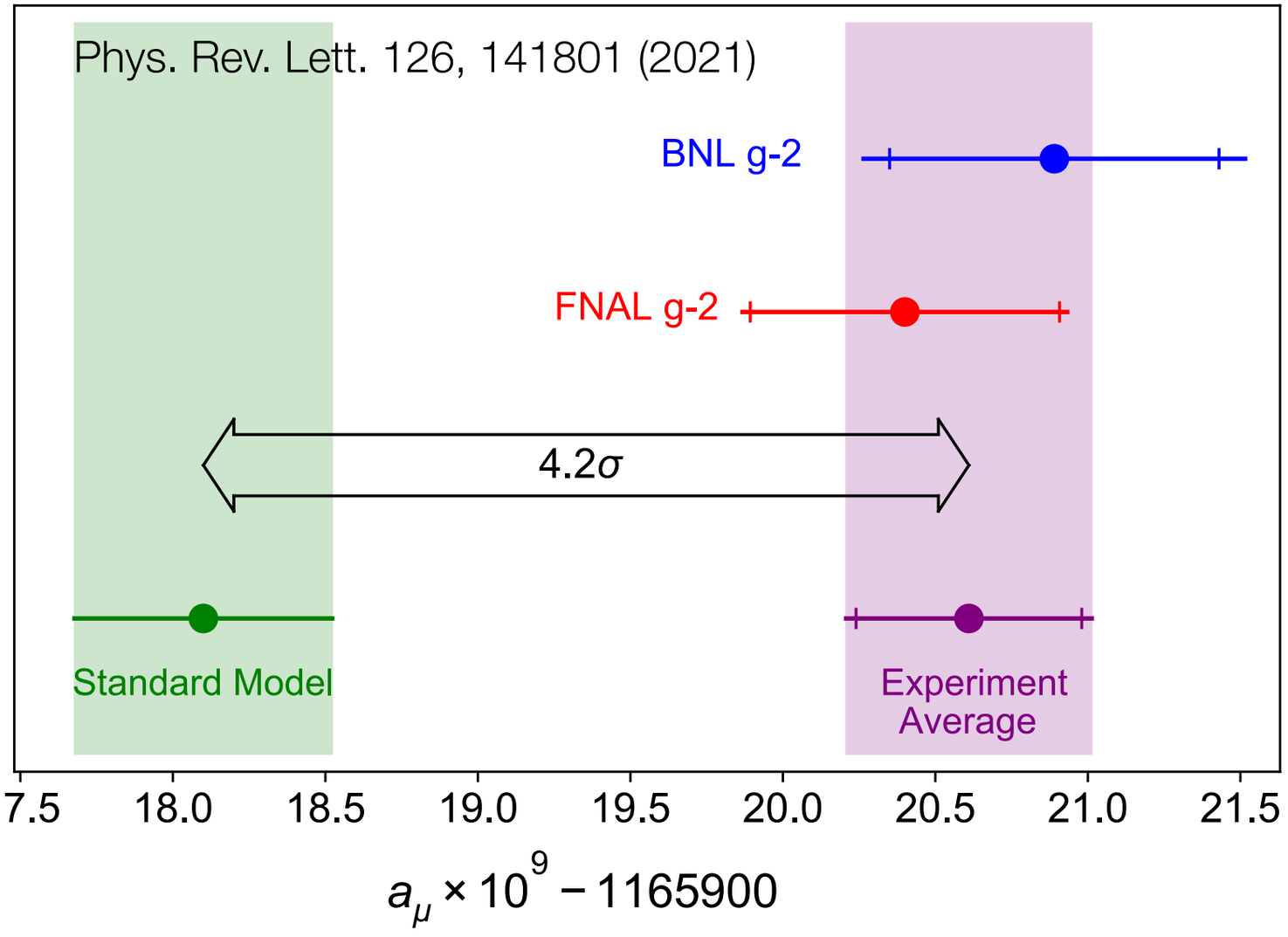
Depending on relative couplings and masses of SM versus dark sector particles, visible decays can dominate

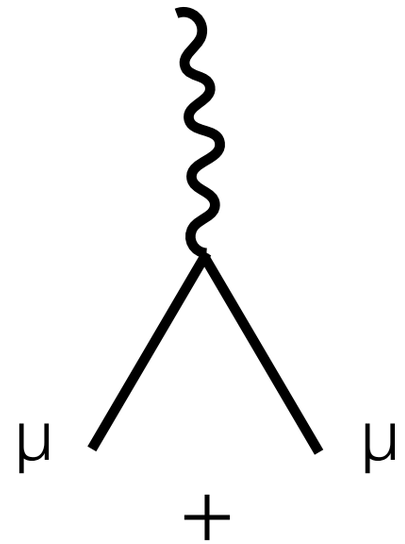


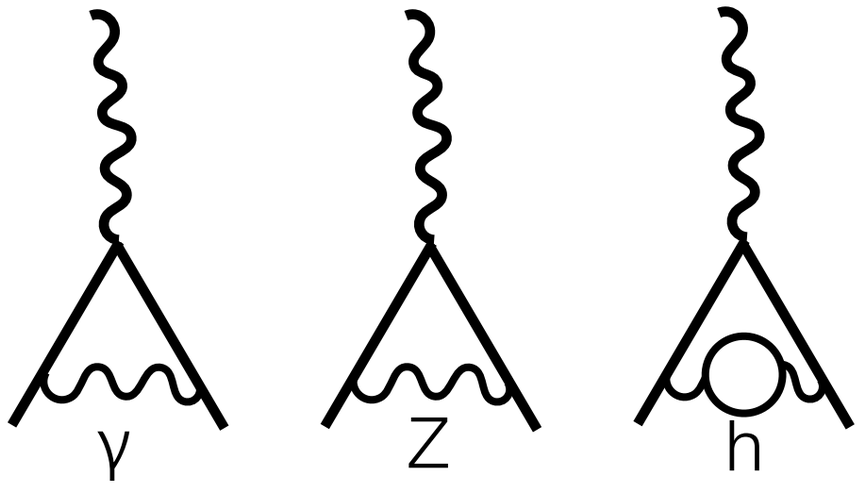
Where to look for such a particle?
Some experimental hints ….

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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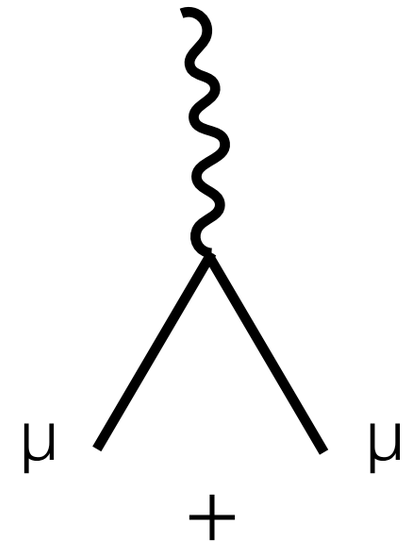

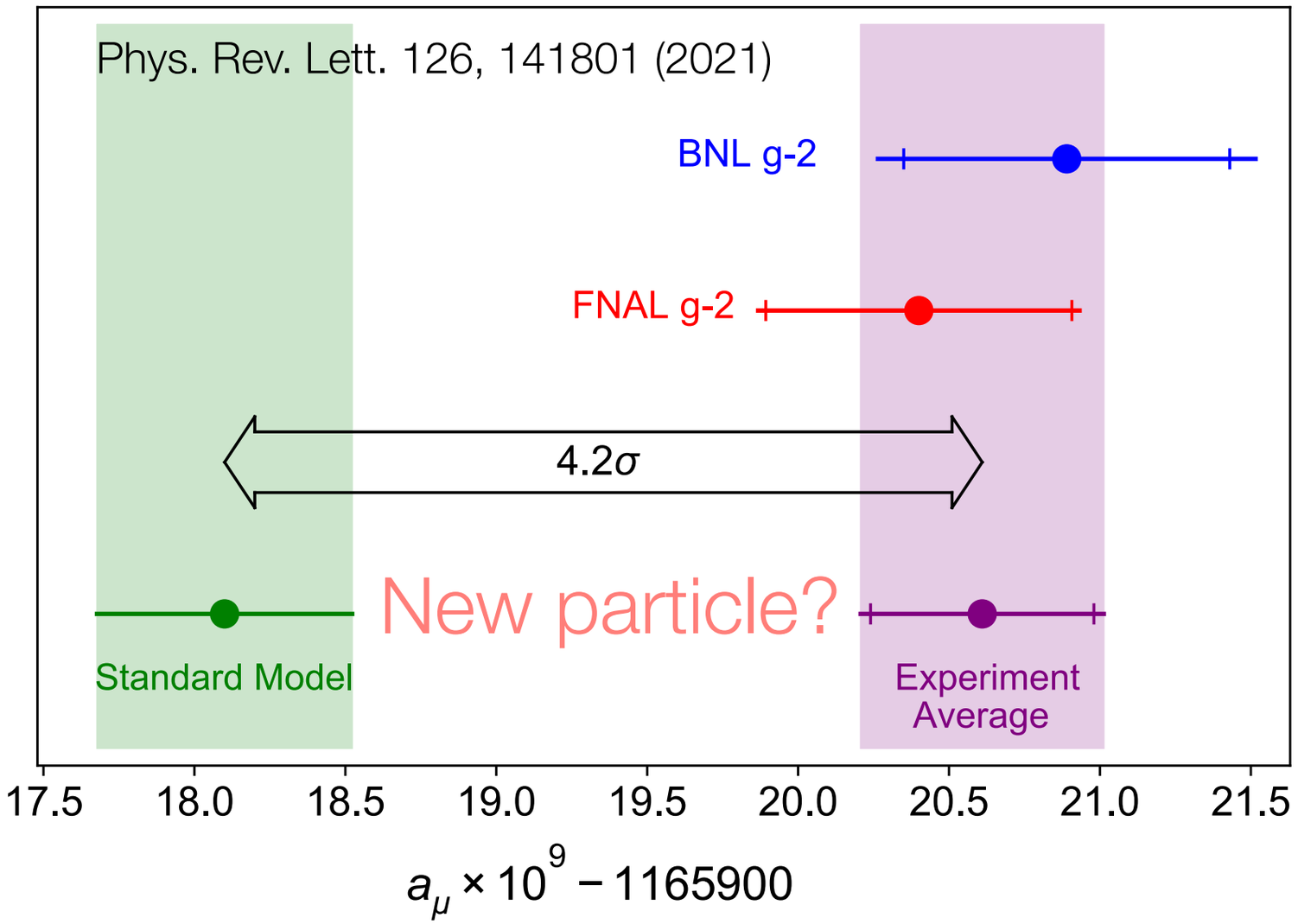

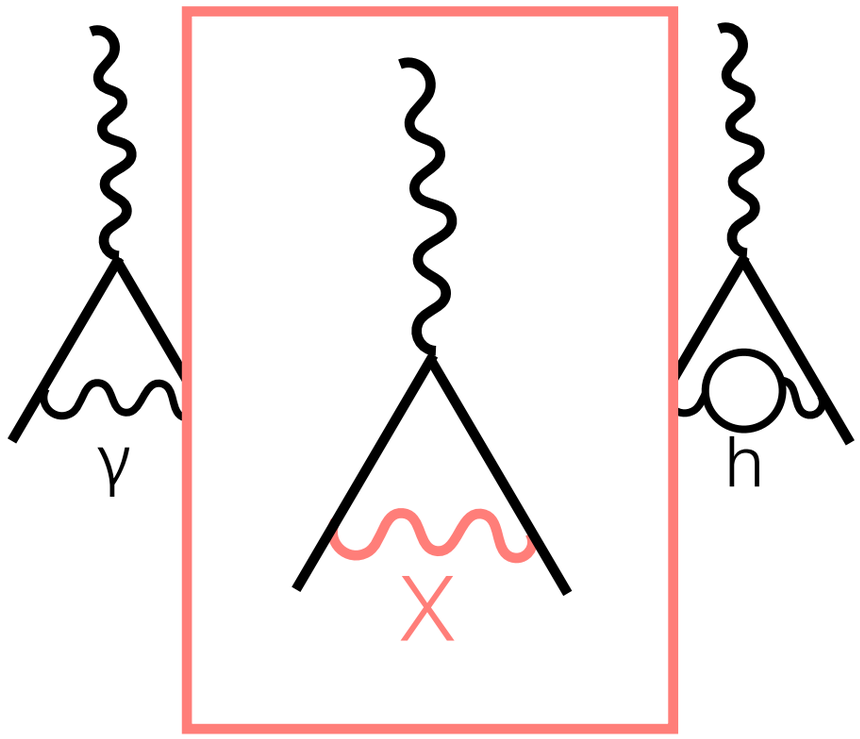

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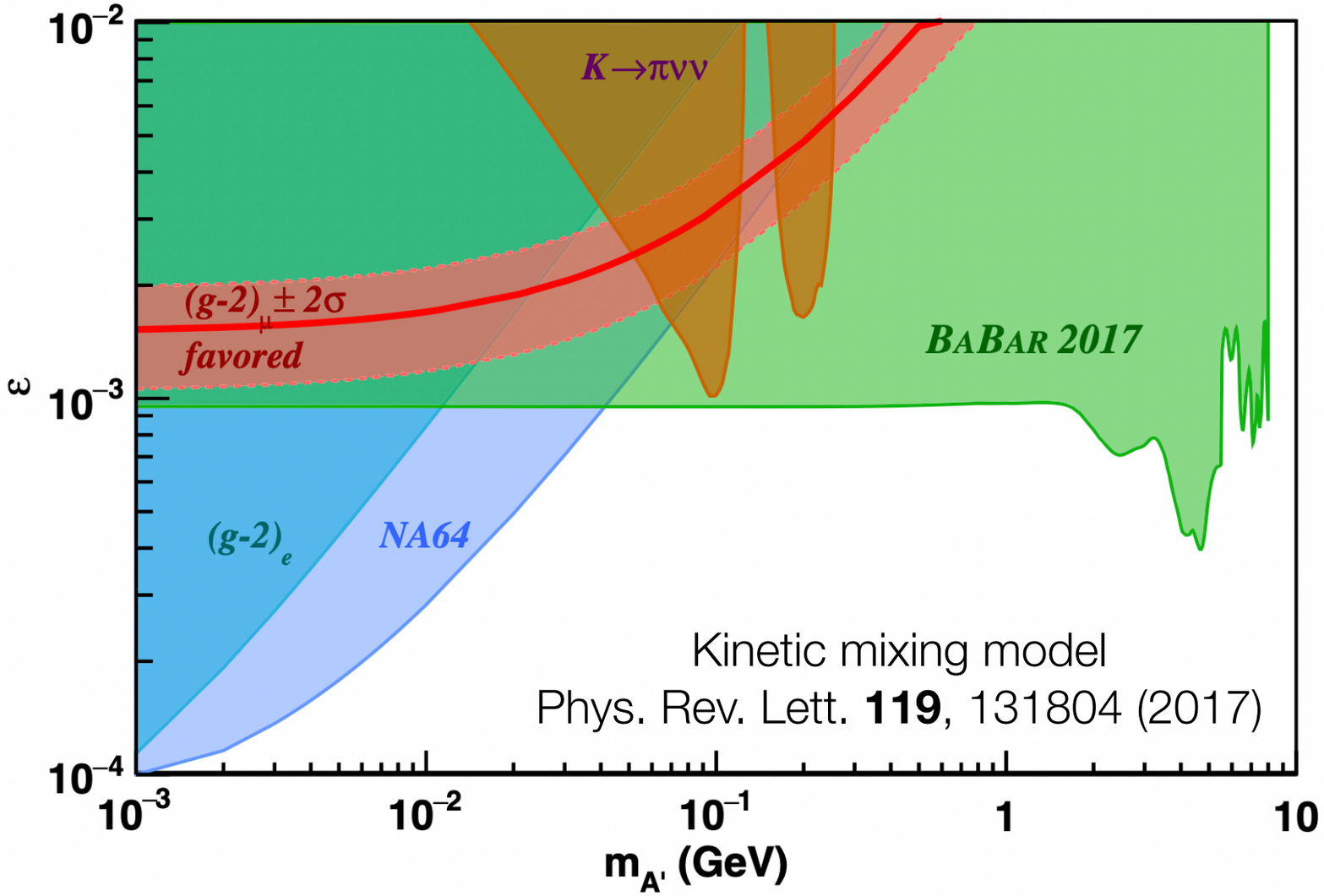

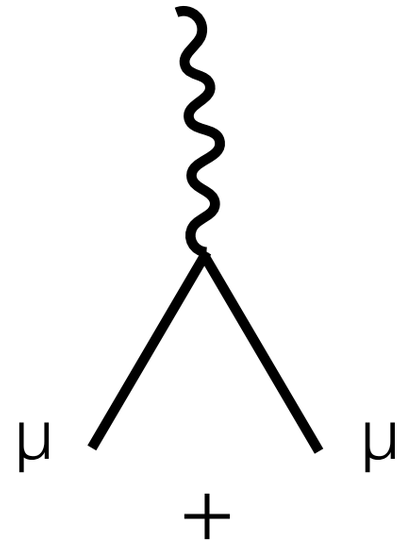

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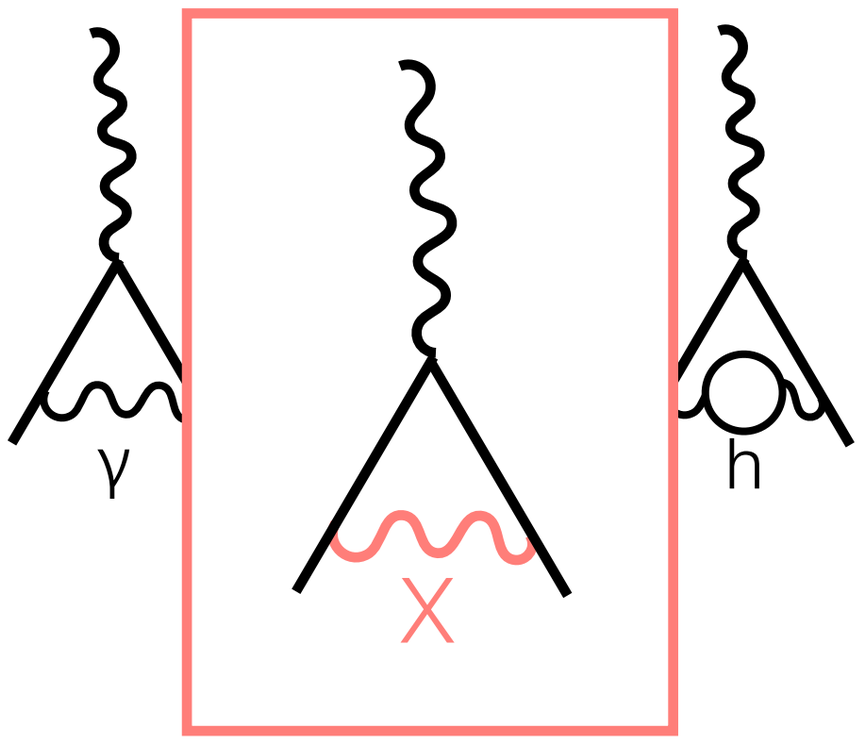
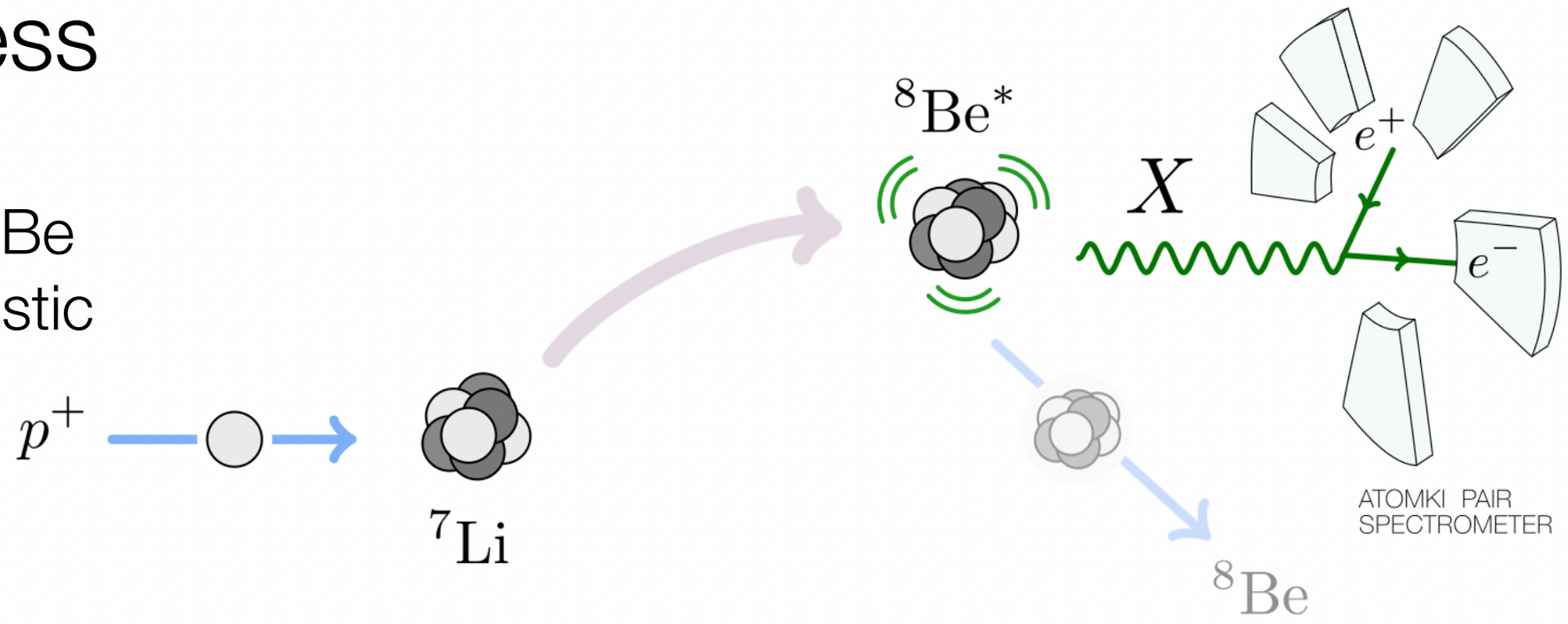


Light BSM boson: the X17 excess

Phys. Rev. D 95, 035017 (2017)

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



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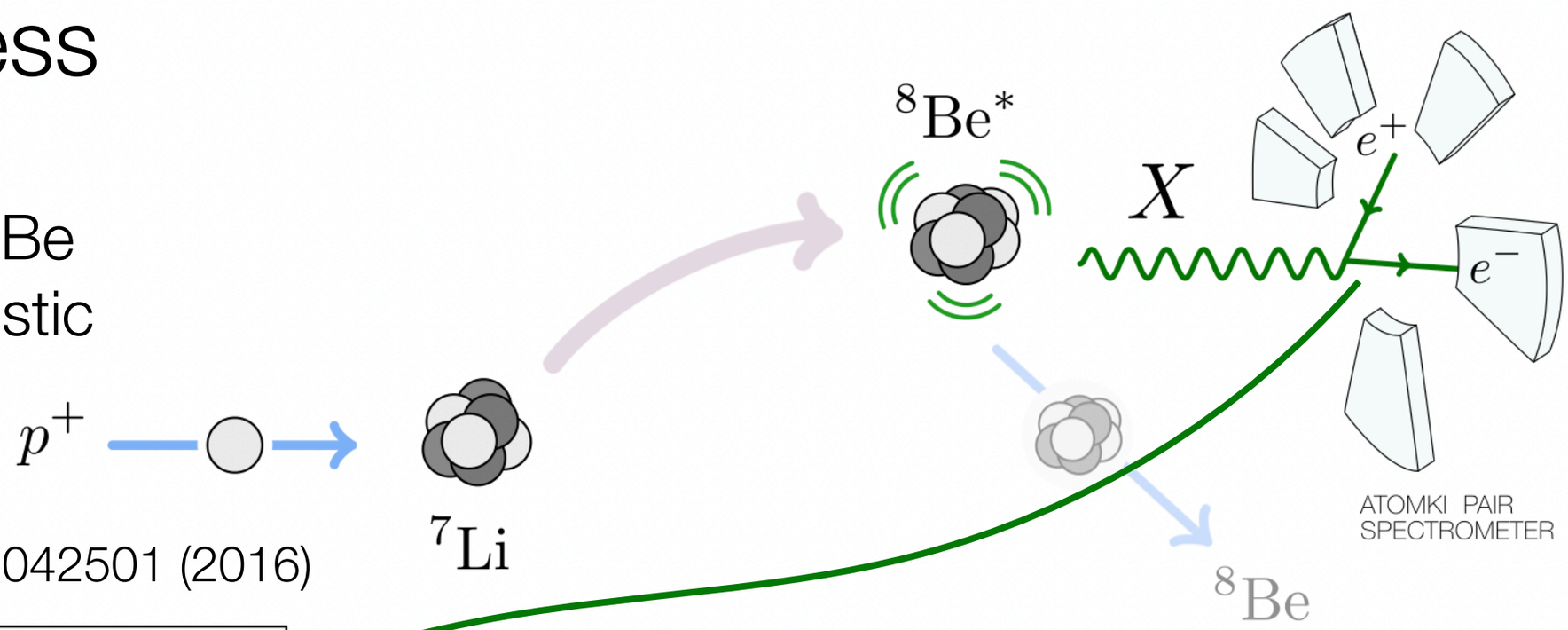
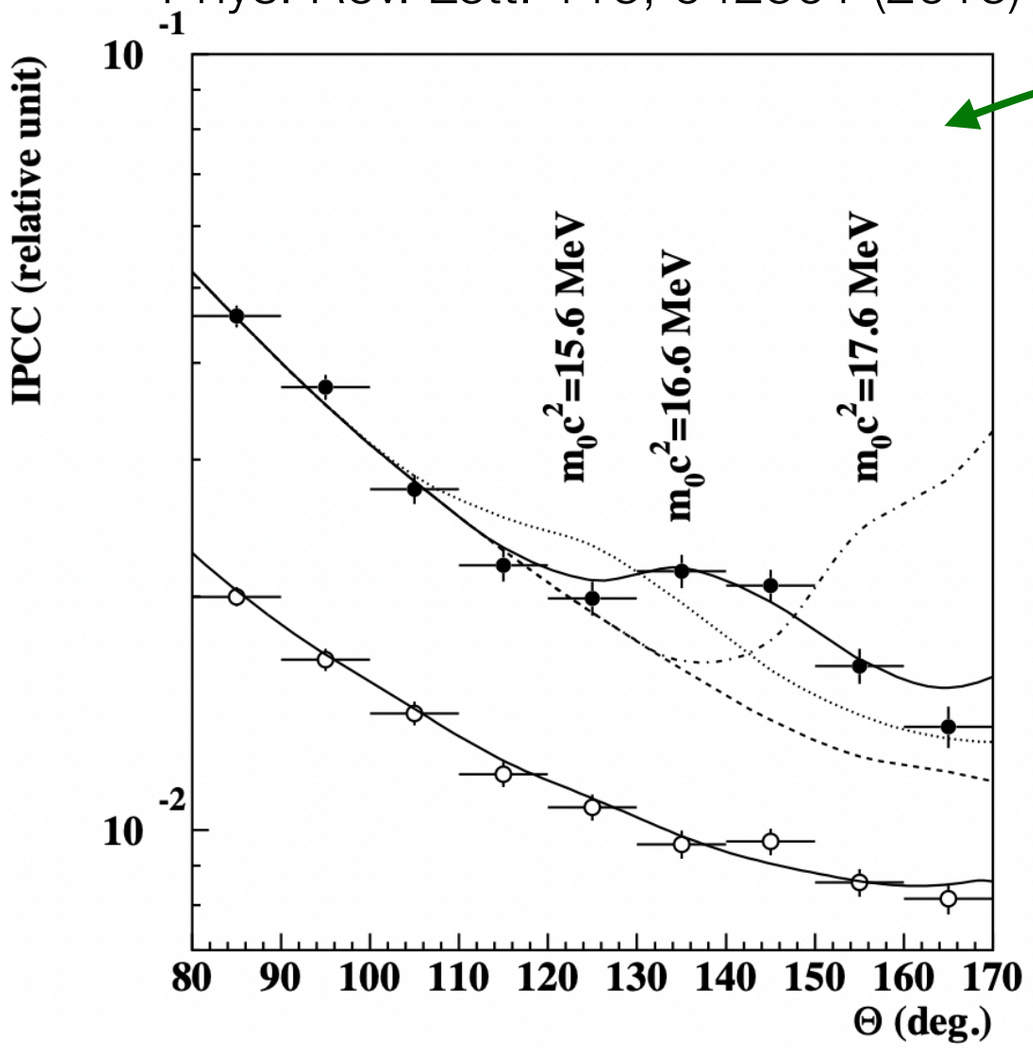


Phys. Rev. Lett. 116, 042501 (2016)



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

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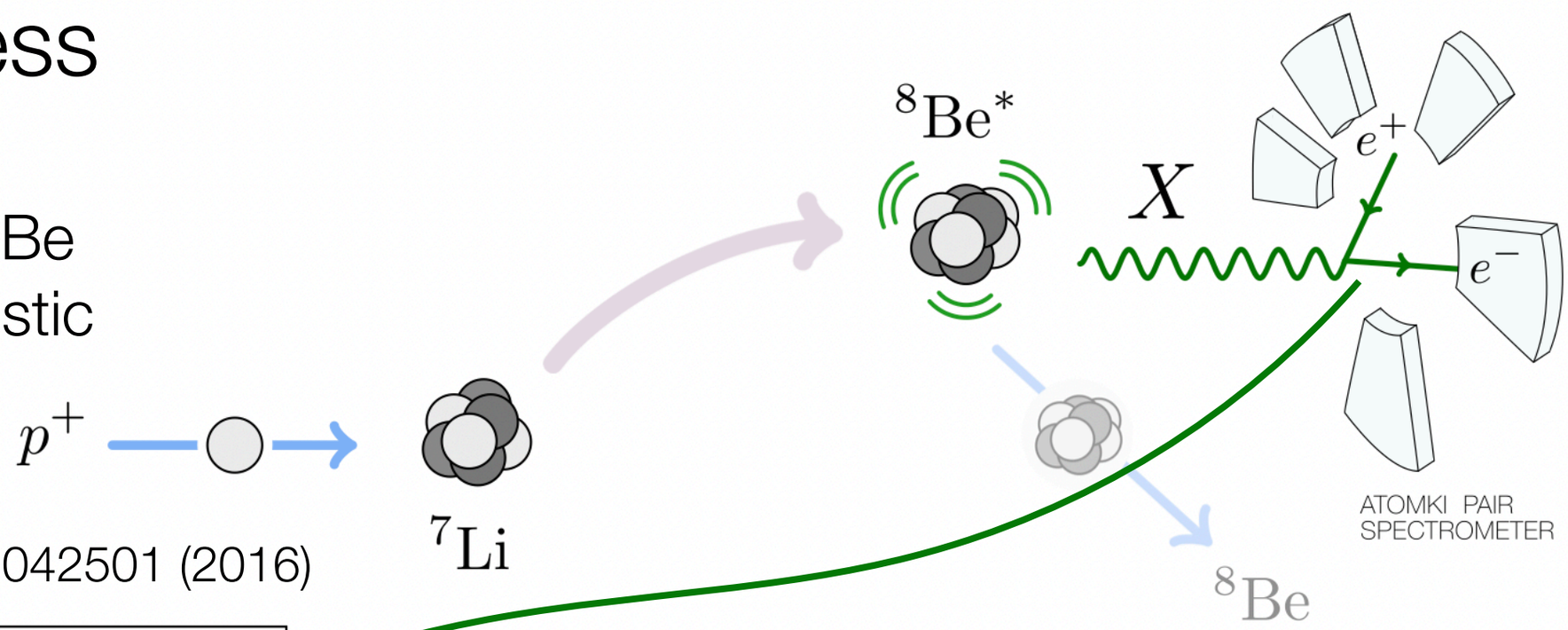

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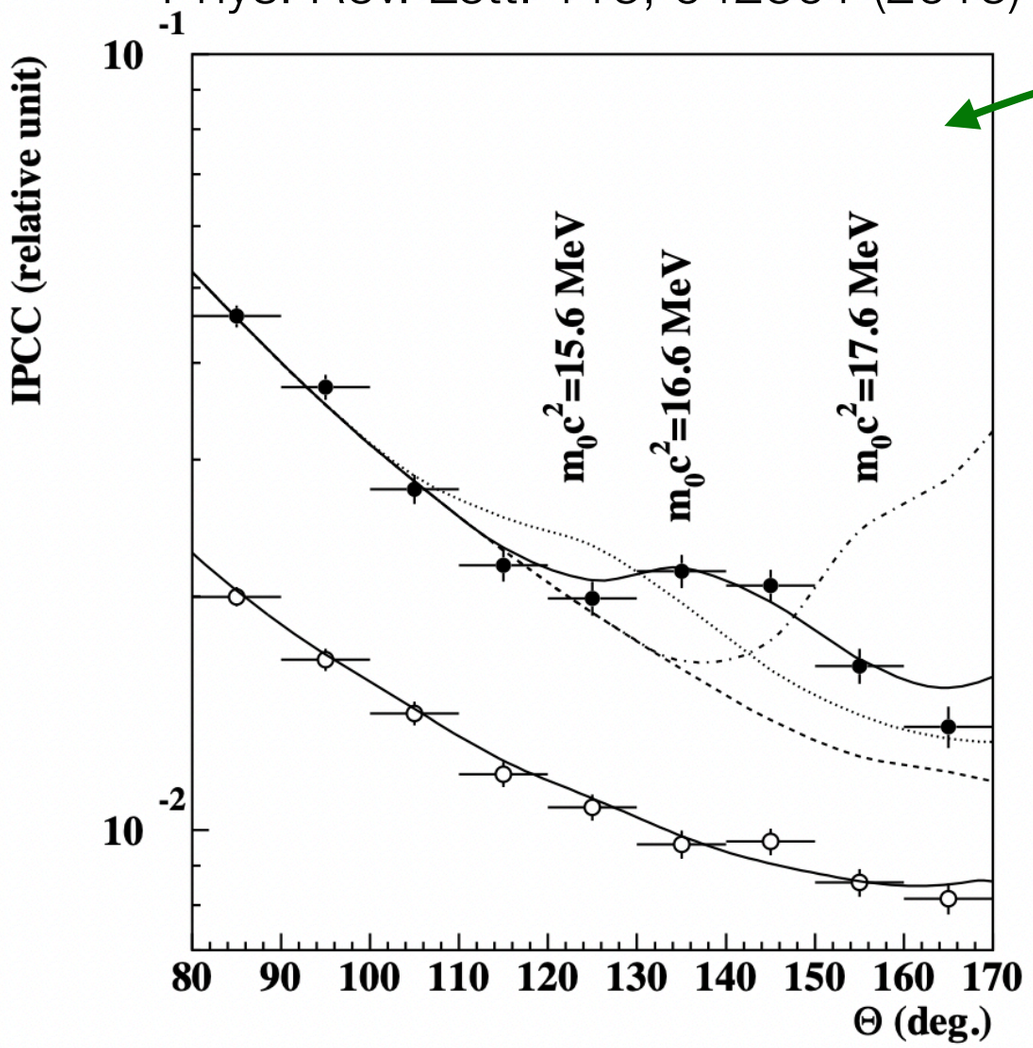


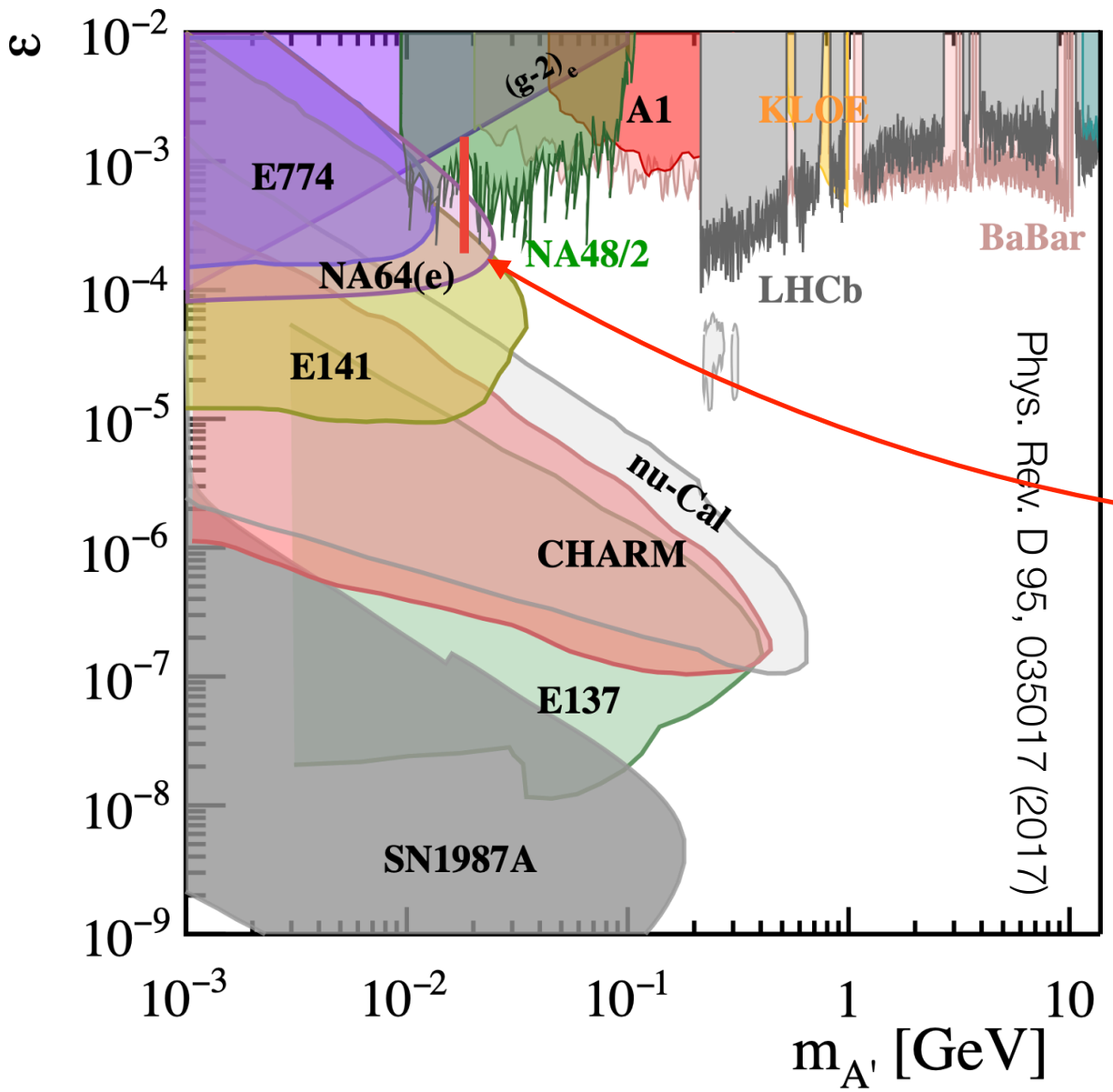
Invariant mass and opening angle of e+e- pair show high-significance resonant signal

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

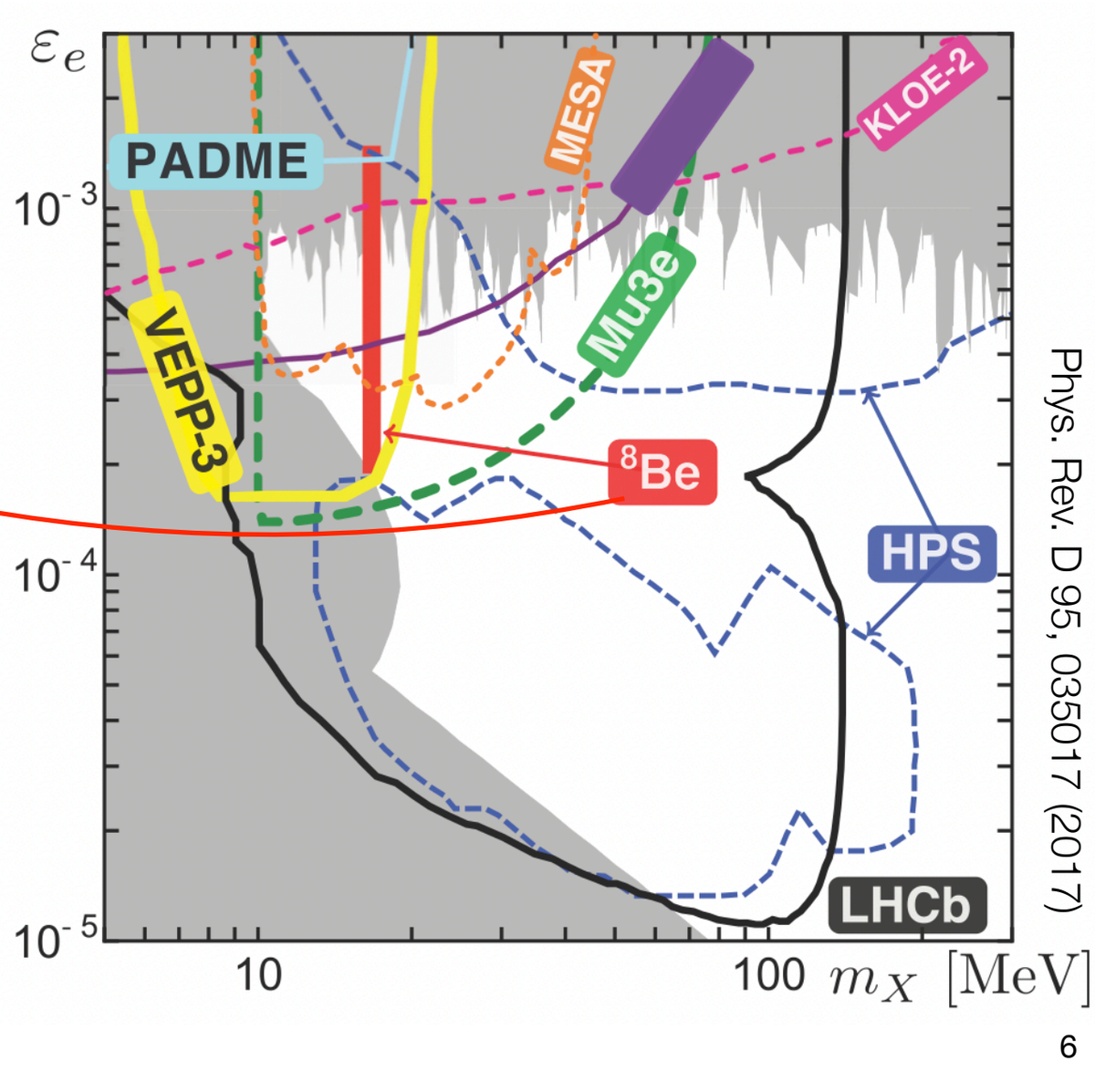
Or, compatible with new boson coupling to electrons with mass ~ 17 MeV

New boson experimental limits: very model dependent statements

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



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



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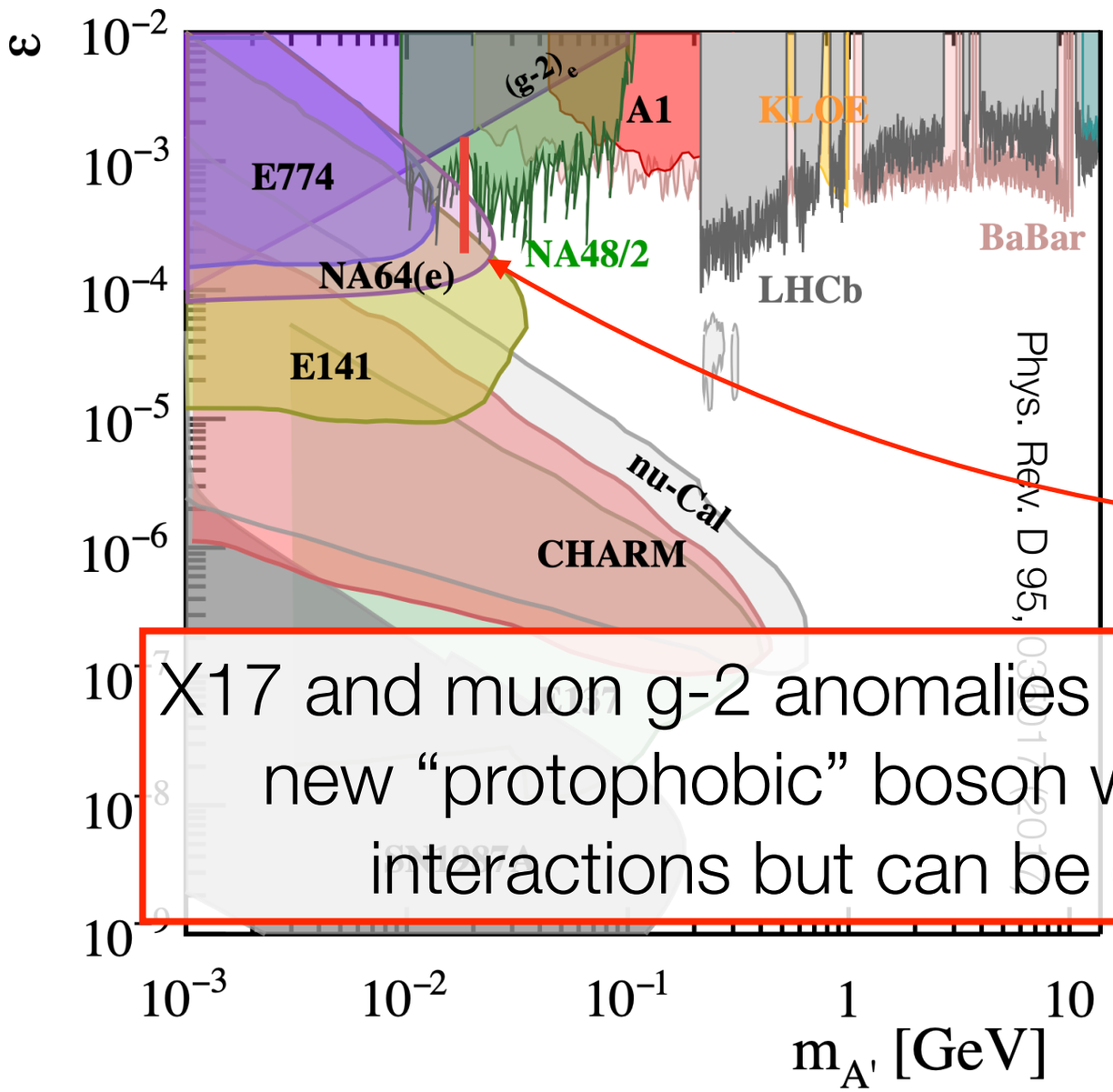

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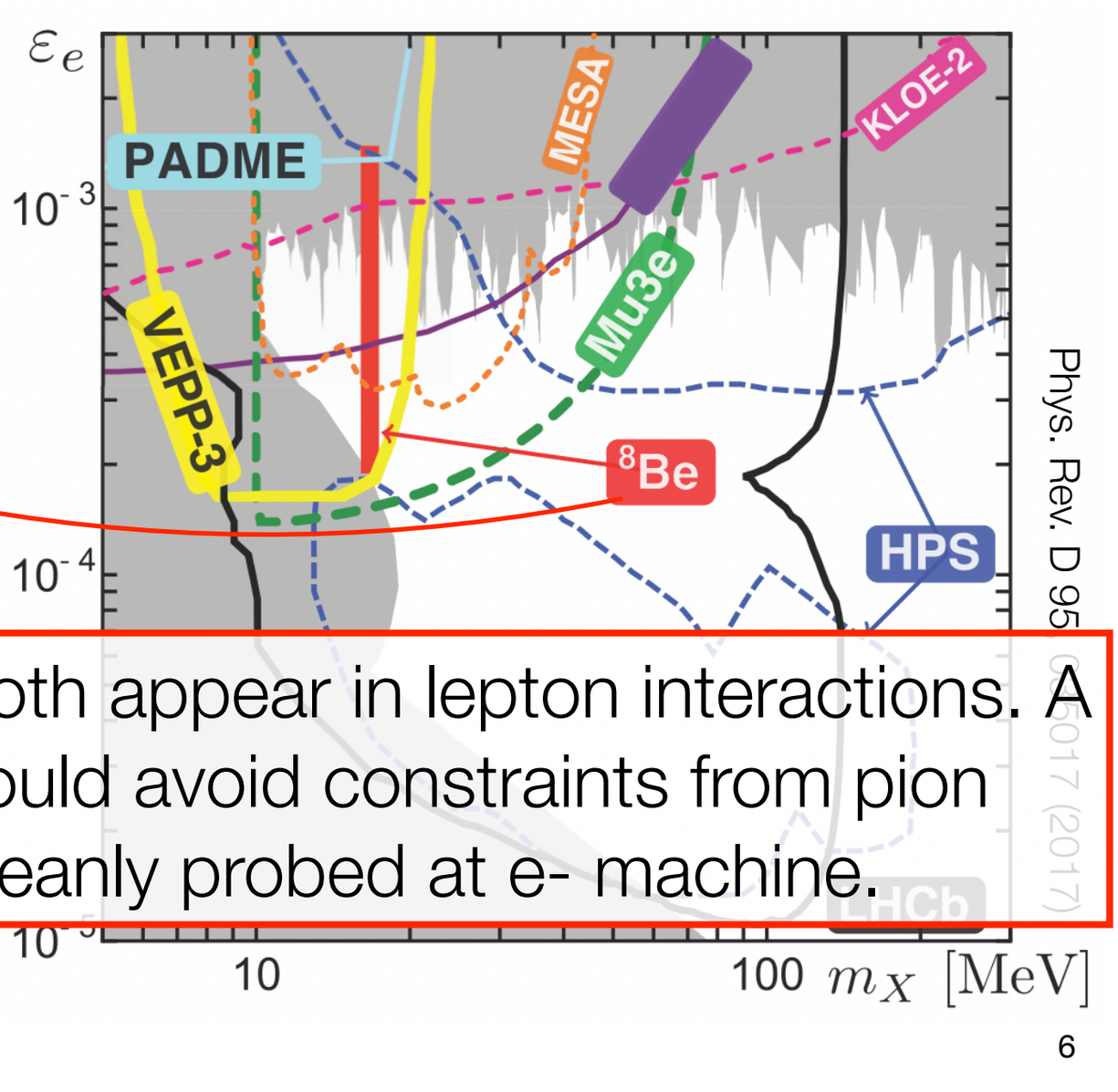
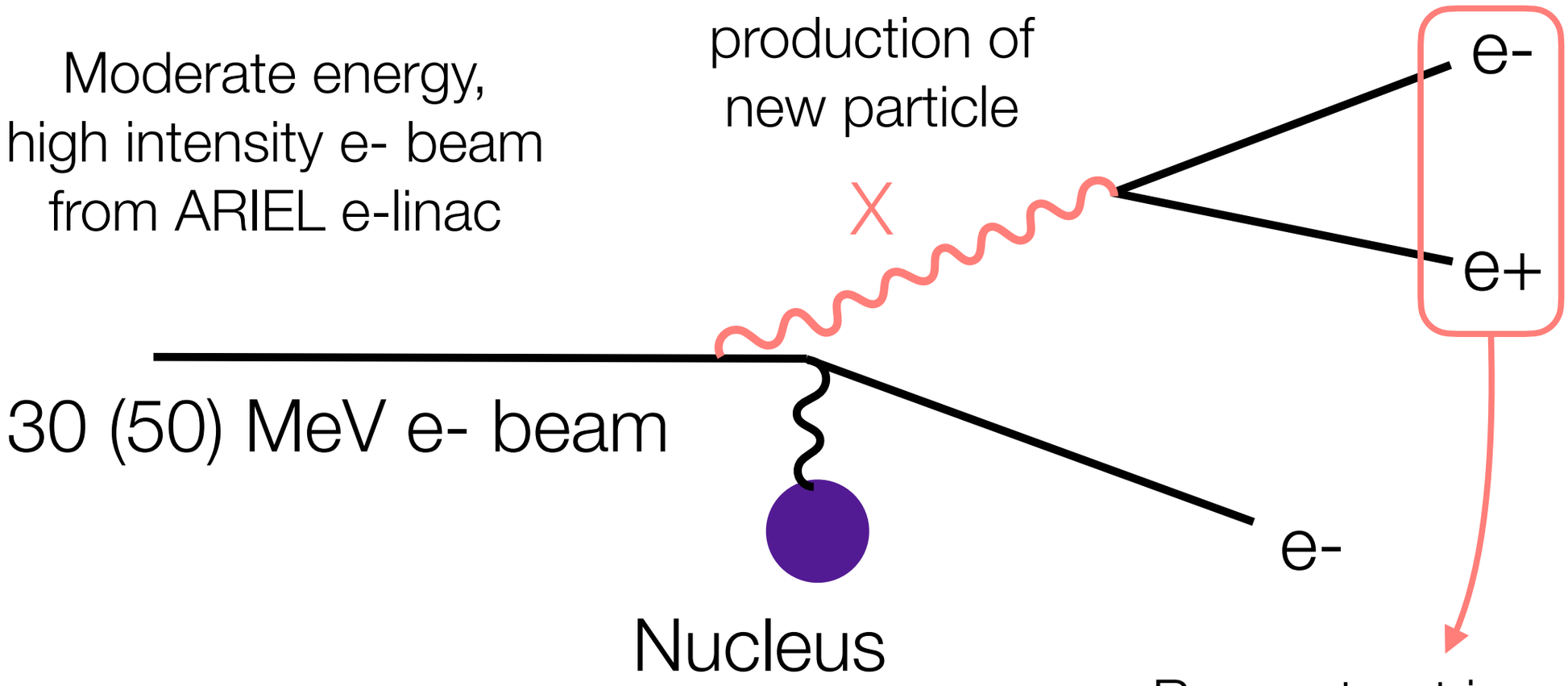


X17 and muon g-2 anomalies both appear in lepton interactions. A new "protophobic" boson would avoid constraints from pion interactions but can be cleanly probed at e- machine.

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

Collaboration

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
St. Mary's University, Halifax, Nova Scotia, Canada
Stony Brook University, NY, USA
TRIUMF, Vancouver, British Columbia, Canada
University of Manitoba, Canada
University of Winnipeg, Manitoba, Canada

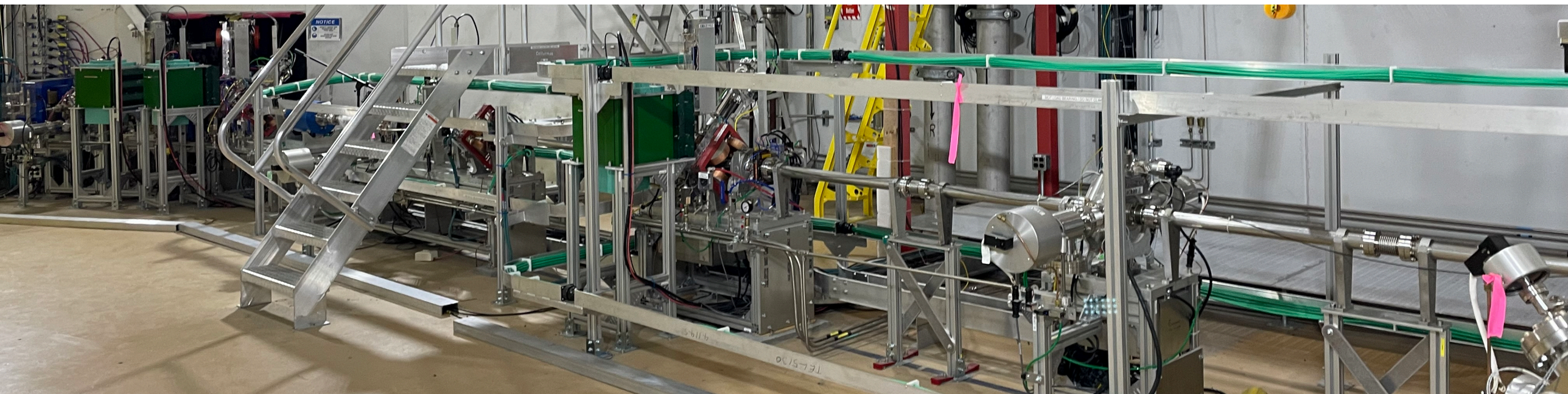
M. Hasinoff

R. Kanungo

S. Yen, K. Pachal, T. Planche, B. Laxdal, O. Kester

W. Deconinck

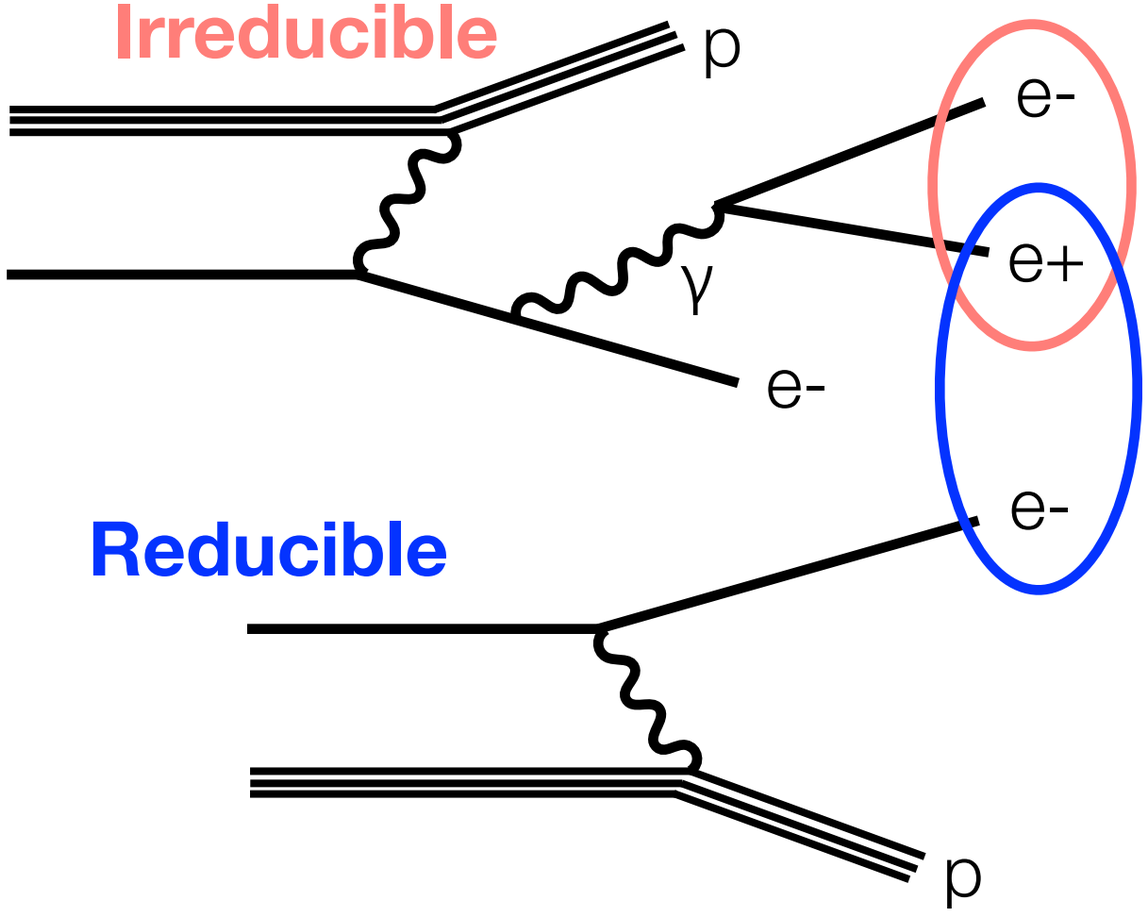
J. Martin

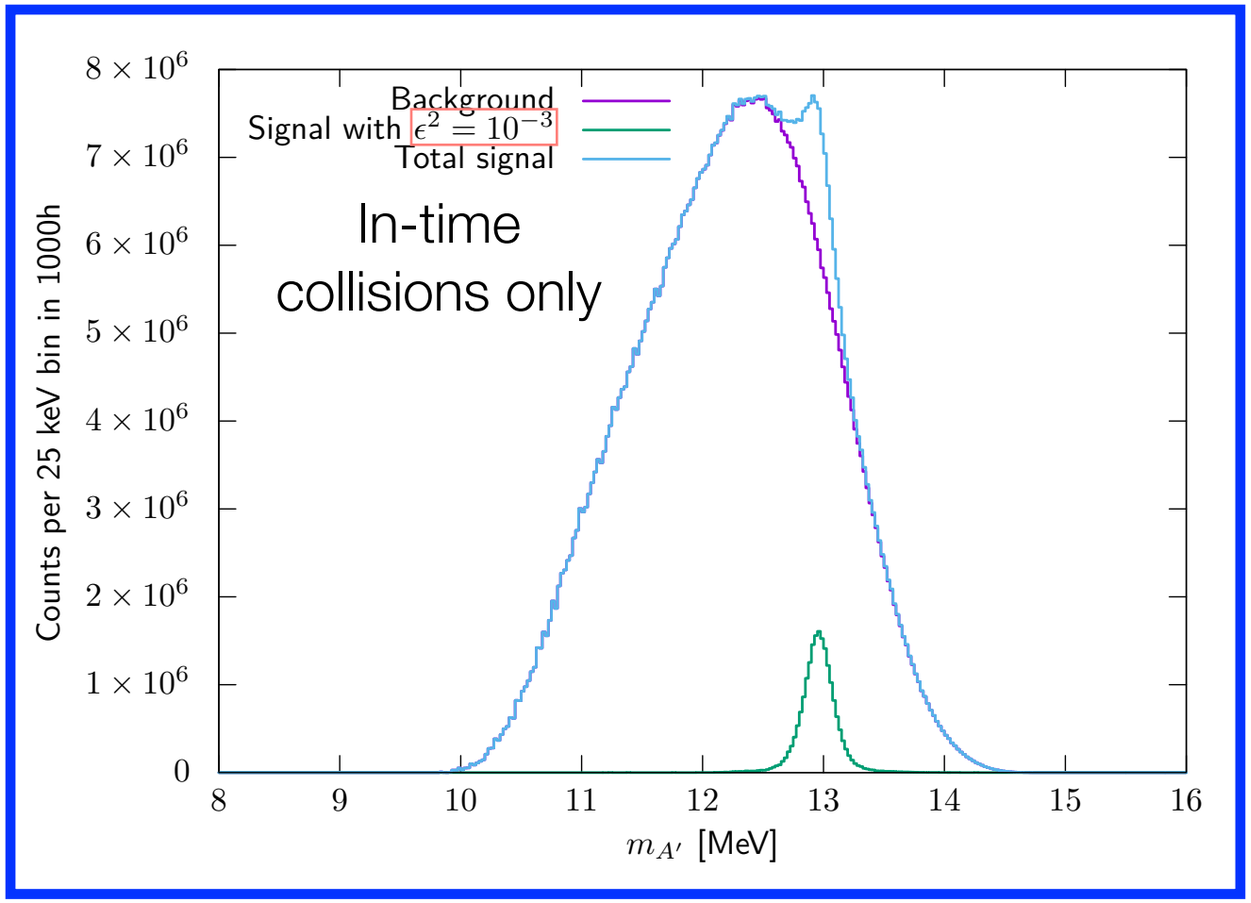


Background processes

- Vastly dominant background is e+ from pair production combined with e- from simultaneous scattering event. **Coincidence**-based trigger is key

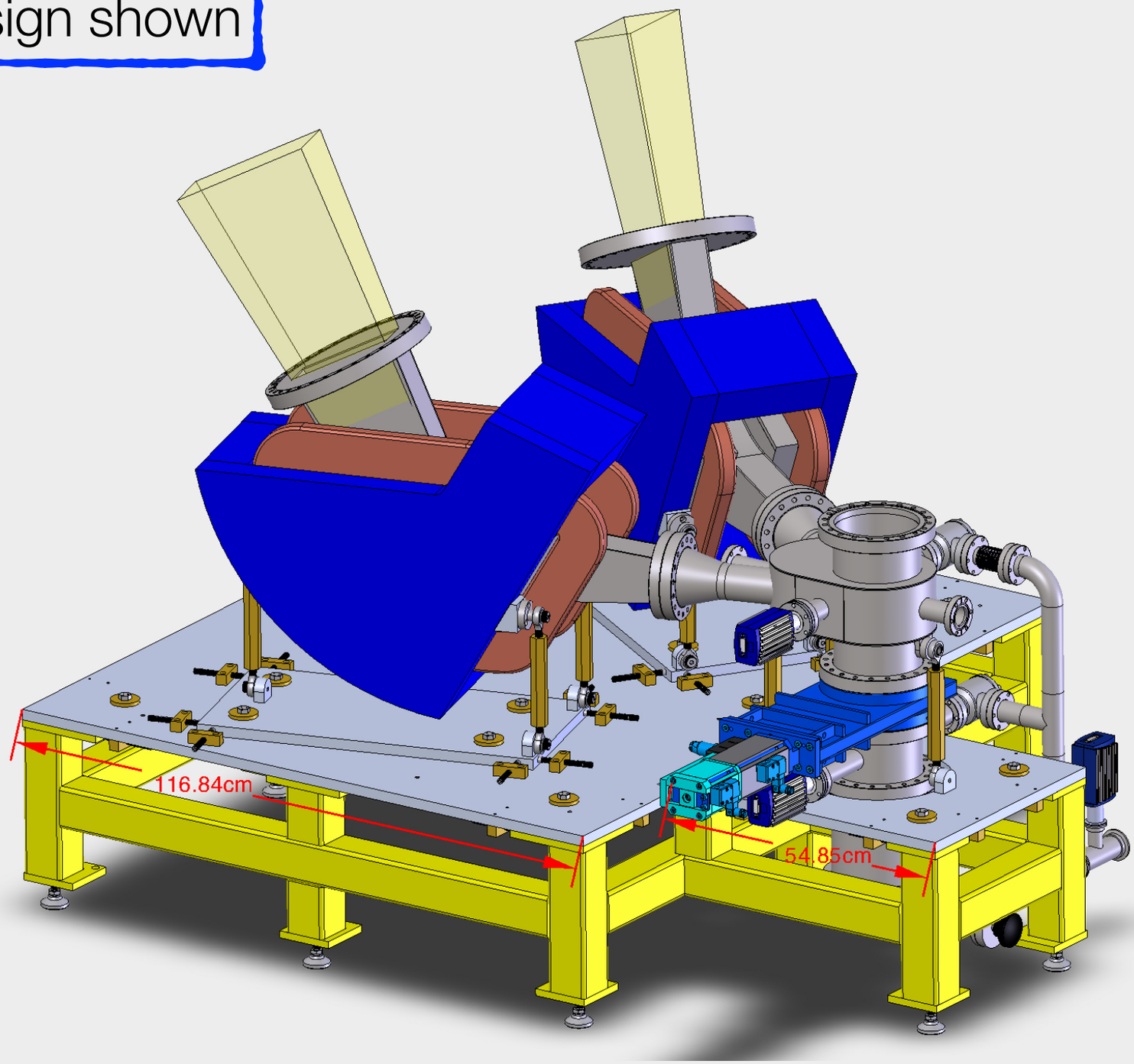
- Two ways to control rates: 1) angular position of detectors 2) timing resolution << bunch spacing (1.5 ns)





Experiment overview

Preliminary design shown



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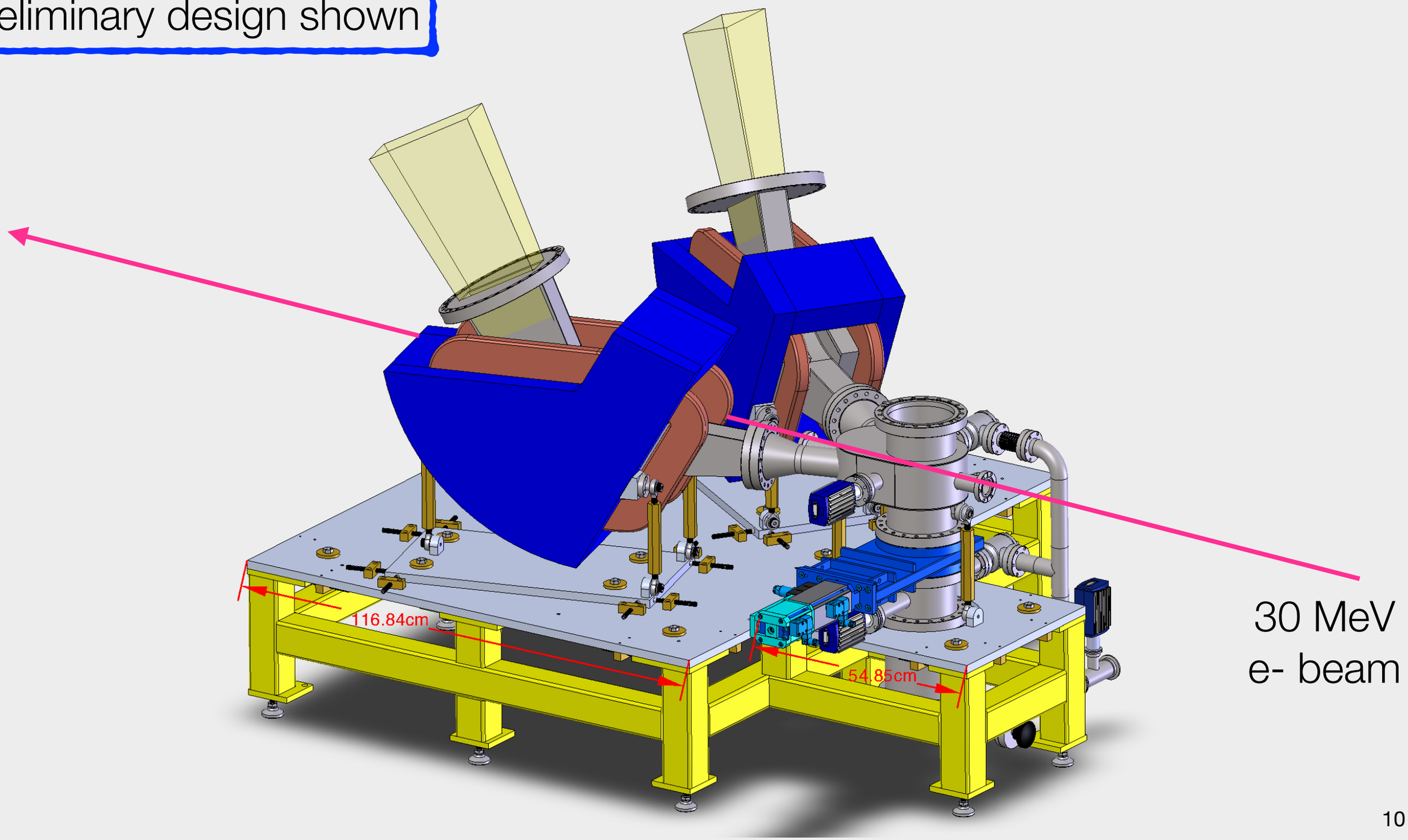

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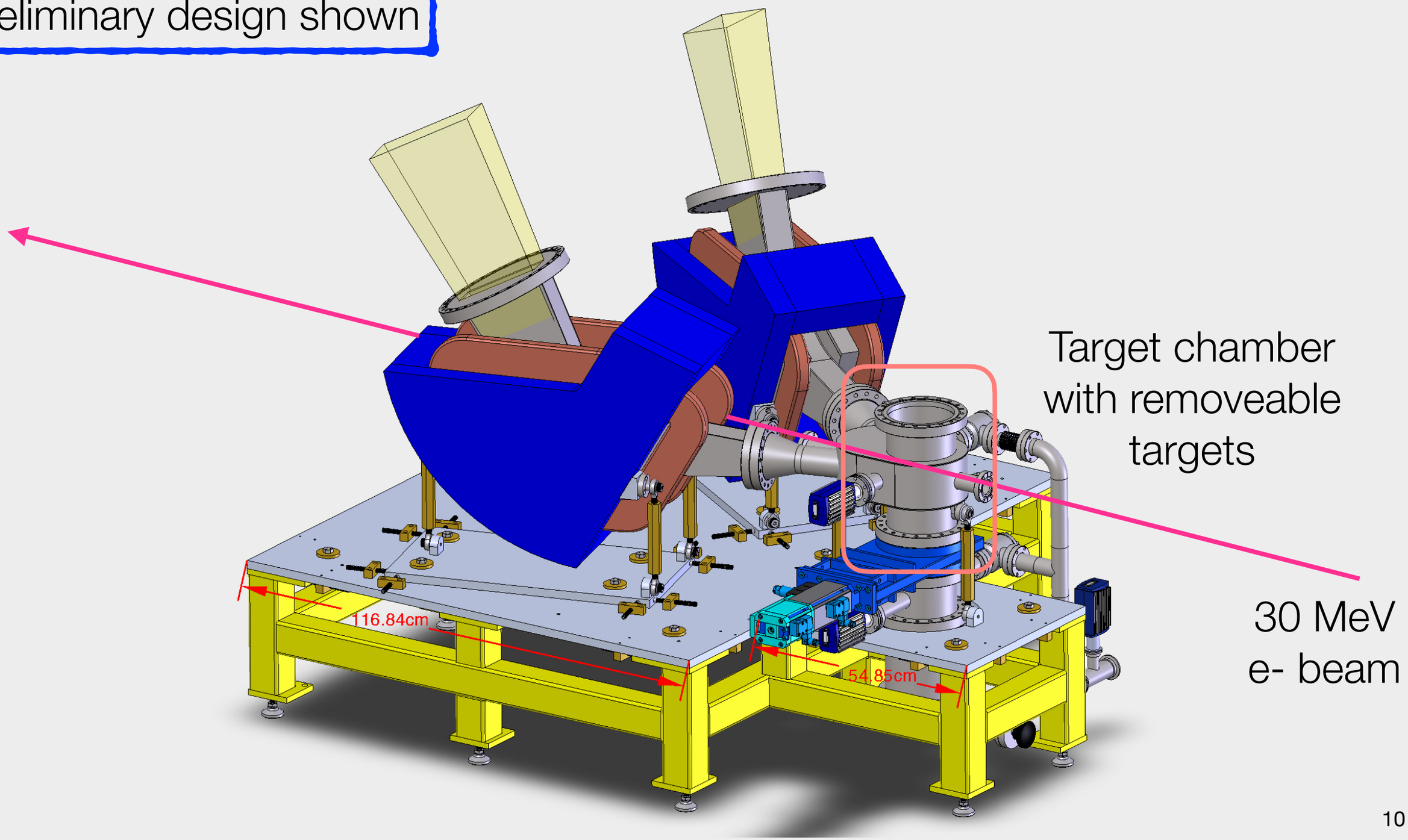

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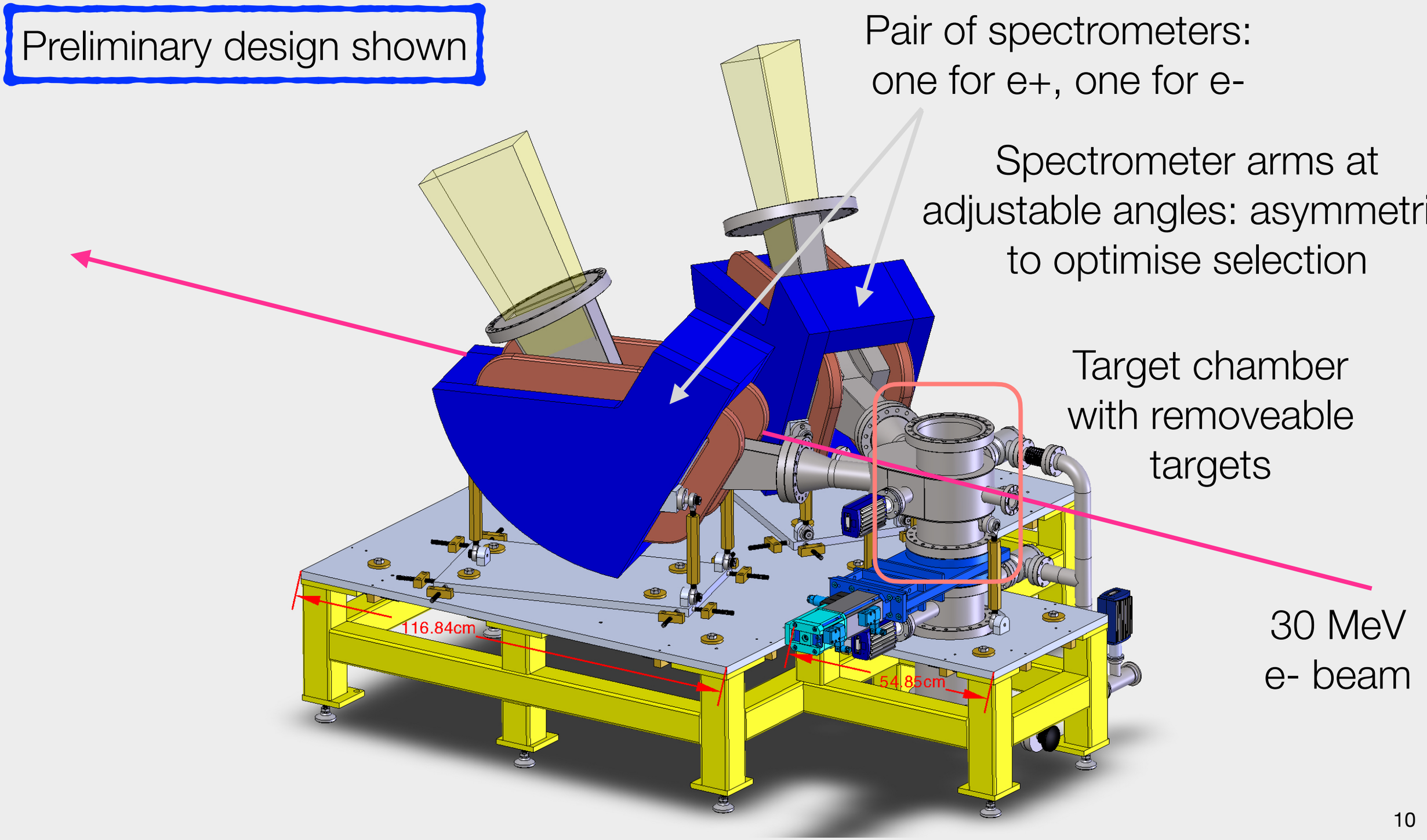


Pair of spectrometers:
one for e+, one for e-

Spectrometer arms at adjustable angles: asymmetric to optimise selection

Target chamber with removeable targets

30 MeV e- beam

Experiment overview

Preliminary design shown

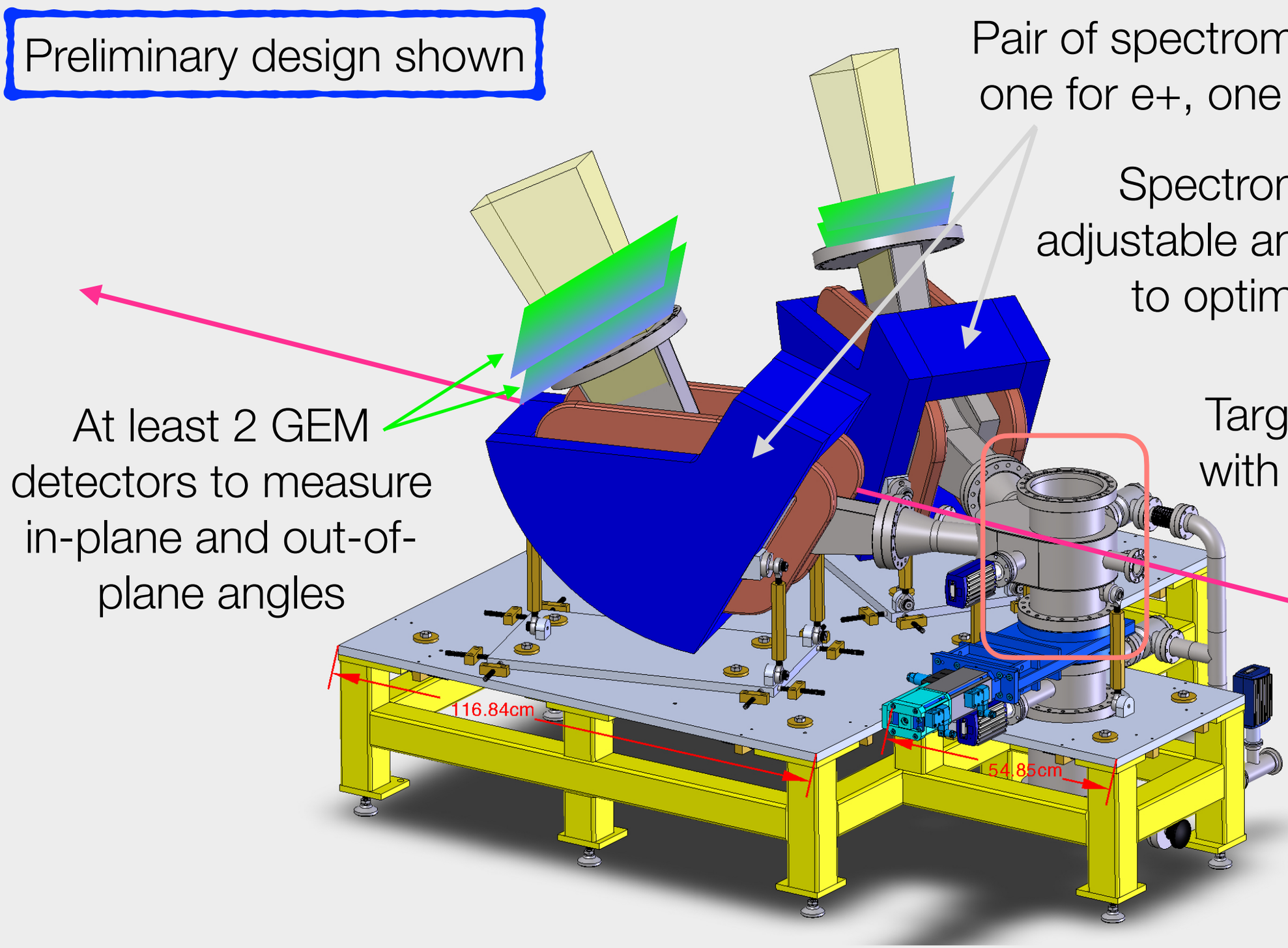
Pair of spectrometers:
one for e+, one for e-

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



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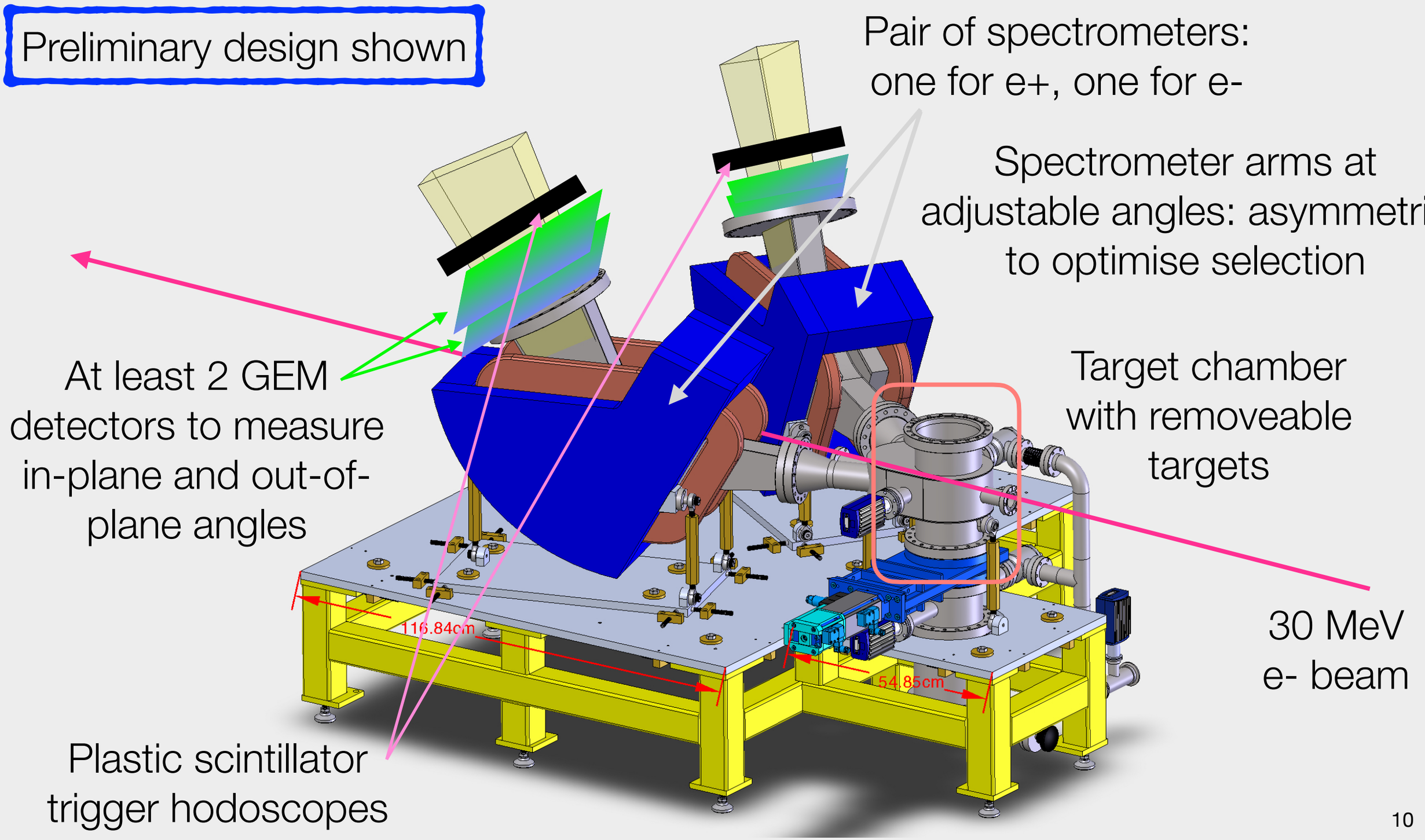
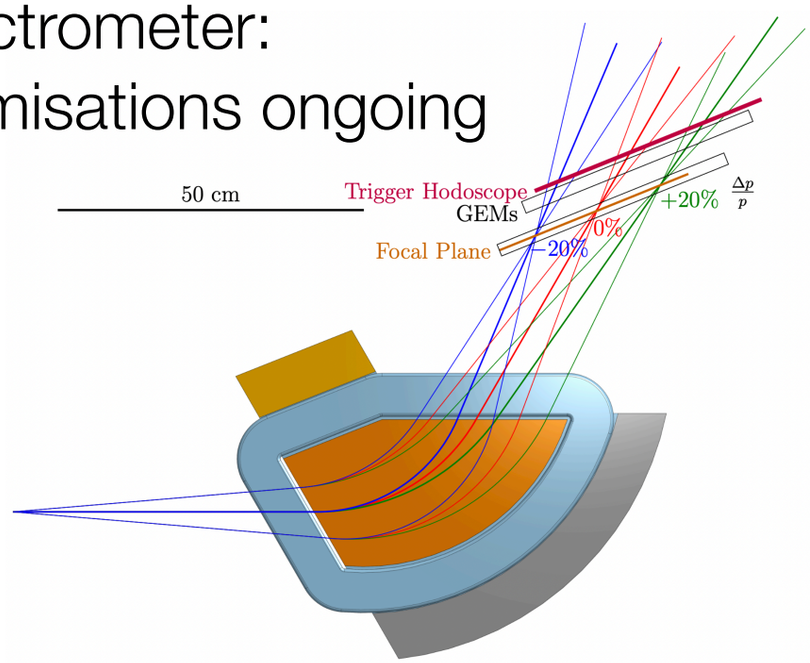
Preliminary design shown

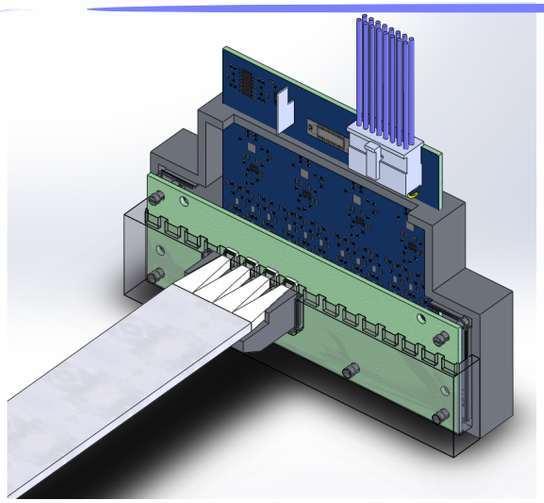


Status summary

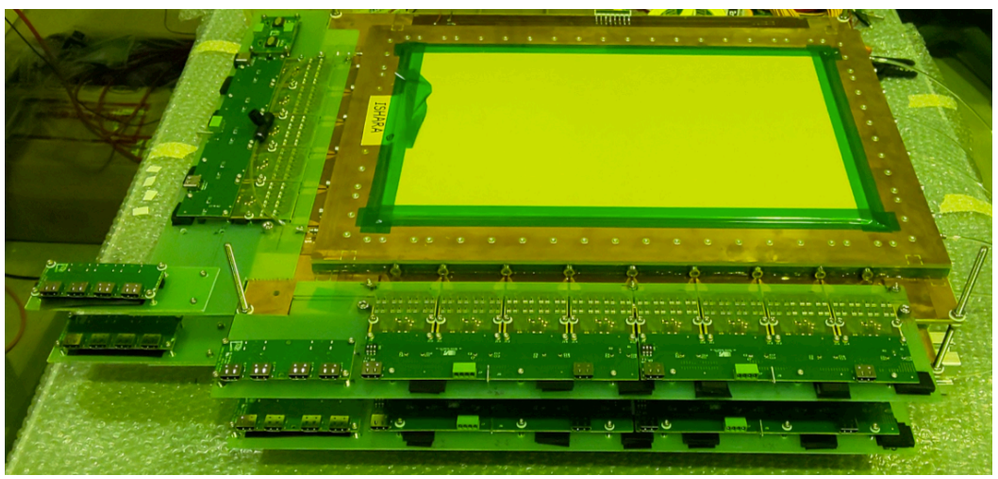
Spectrometer: optimisations ongoing



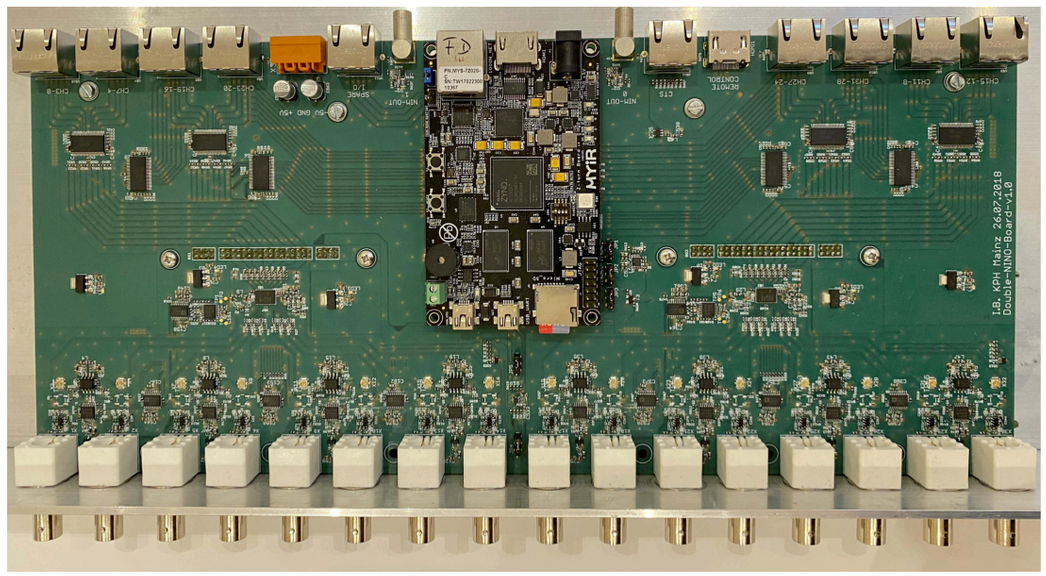
Triggers: testing first prototype



GEMs: complete

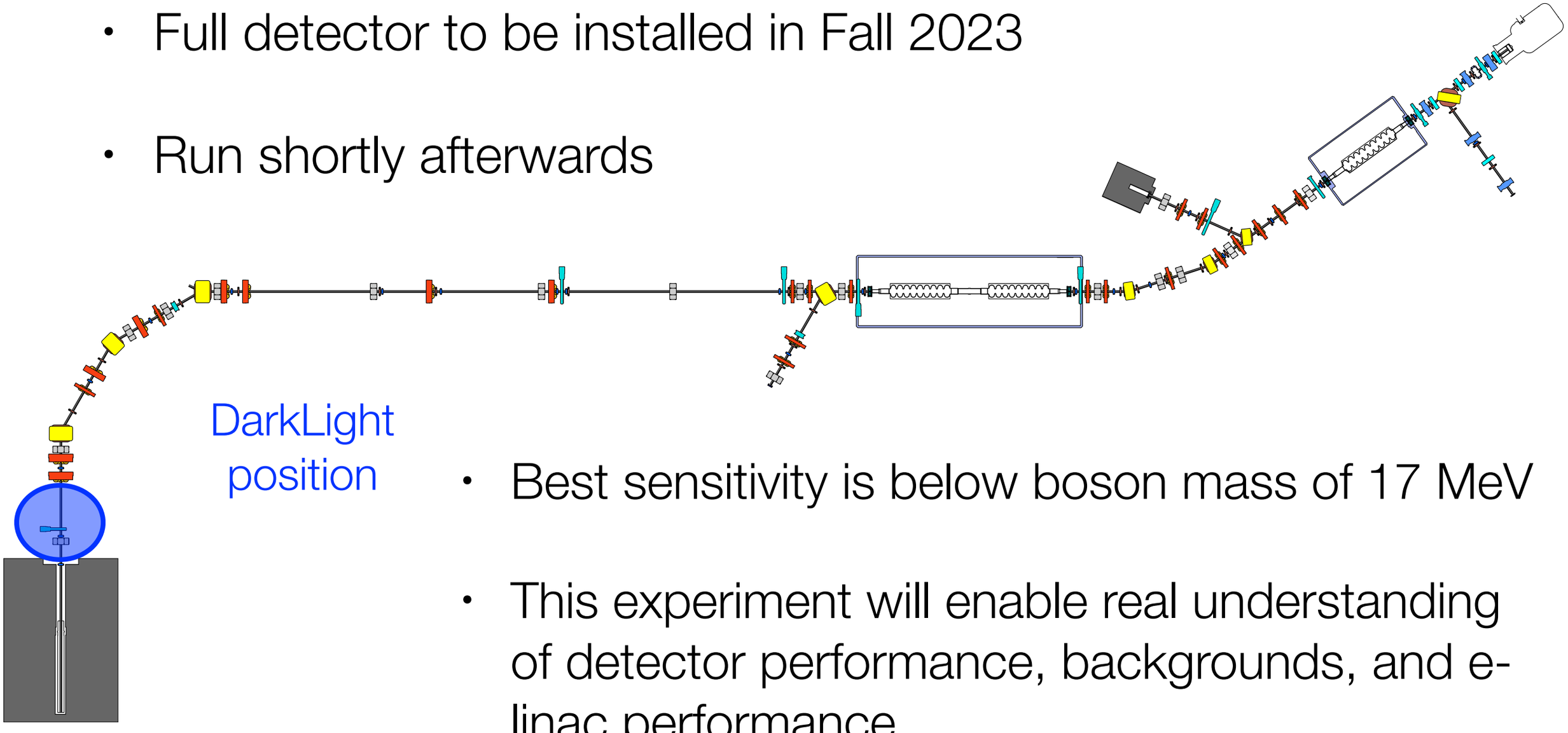


DAQ: testing available systems



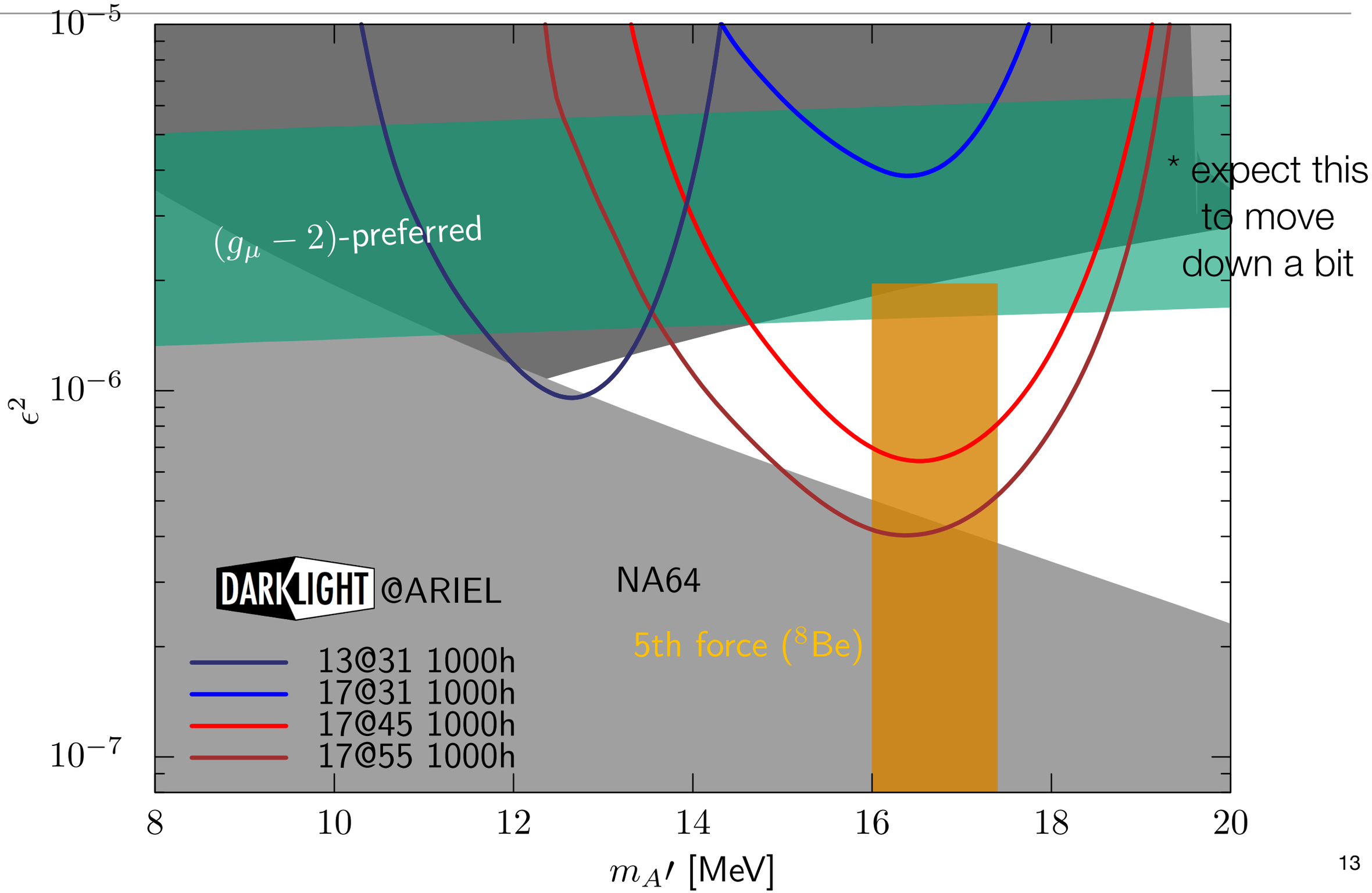
30 MeV running with current ARIEL e-linac

- First experimental stage is a full run (18 fb^{-1}) at 30 MeV
  - Full detector to be installed in Fall 2023
  - Run shortly afterwards



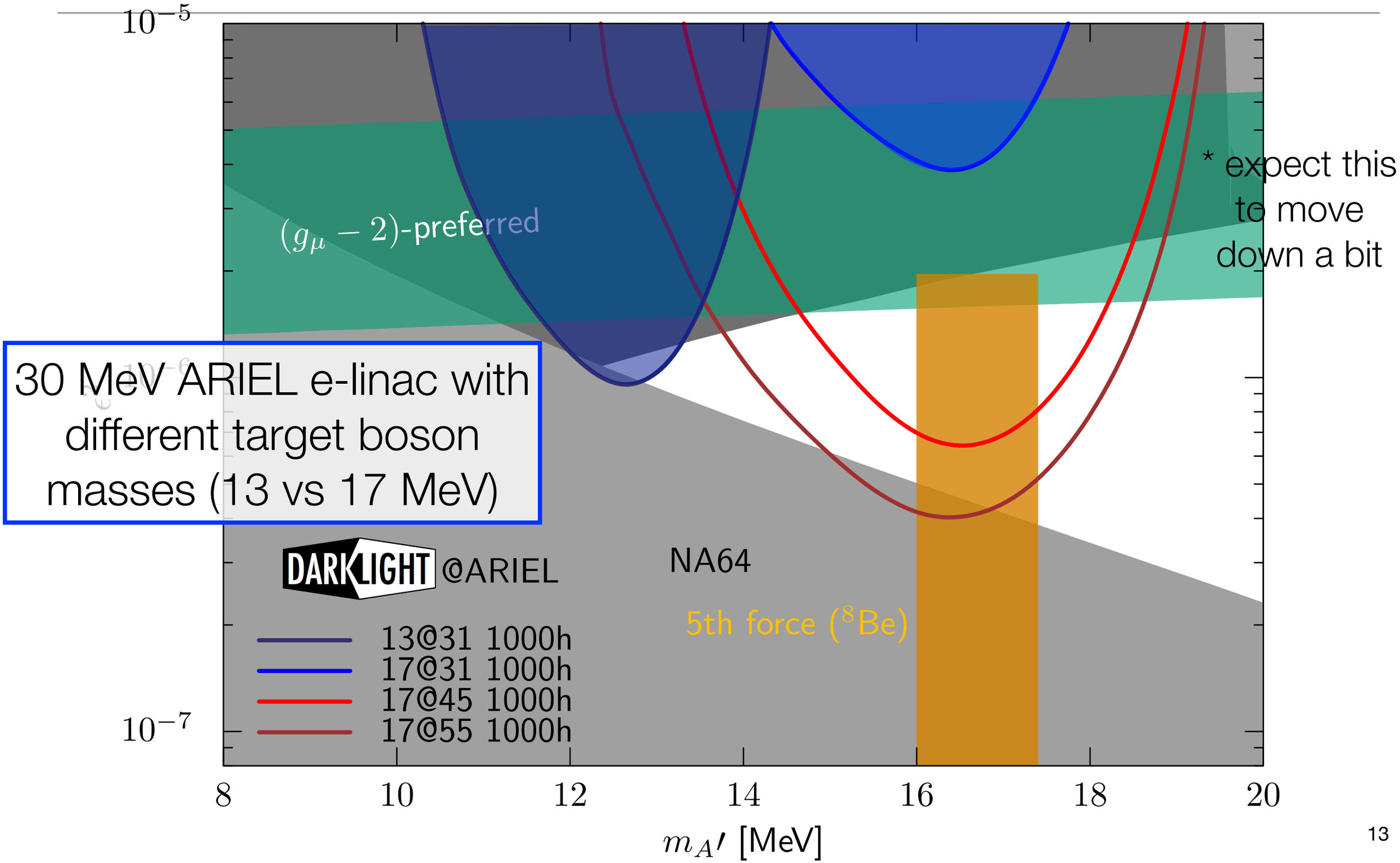
- Best sensitivity is below boson mass of 17 MeV
- This experiment will enable real understanding of detector performance, backgrounds, and e-linac performance

Sensitivity at 30 and 50 MeV accelerators



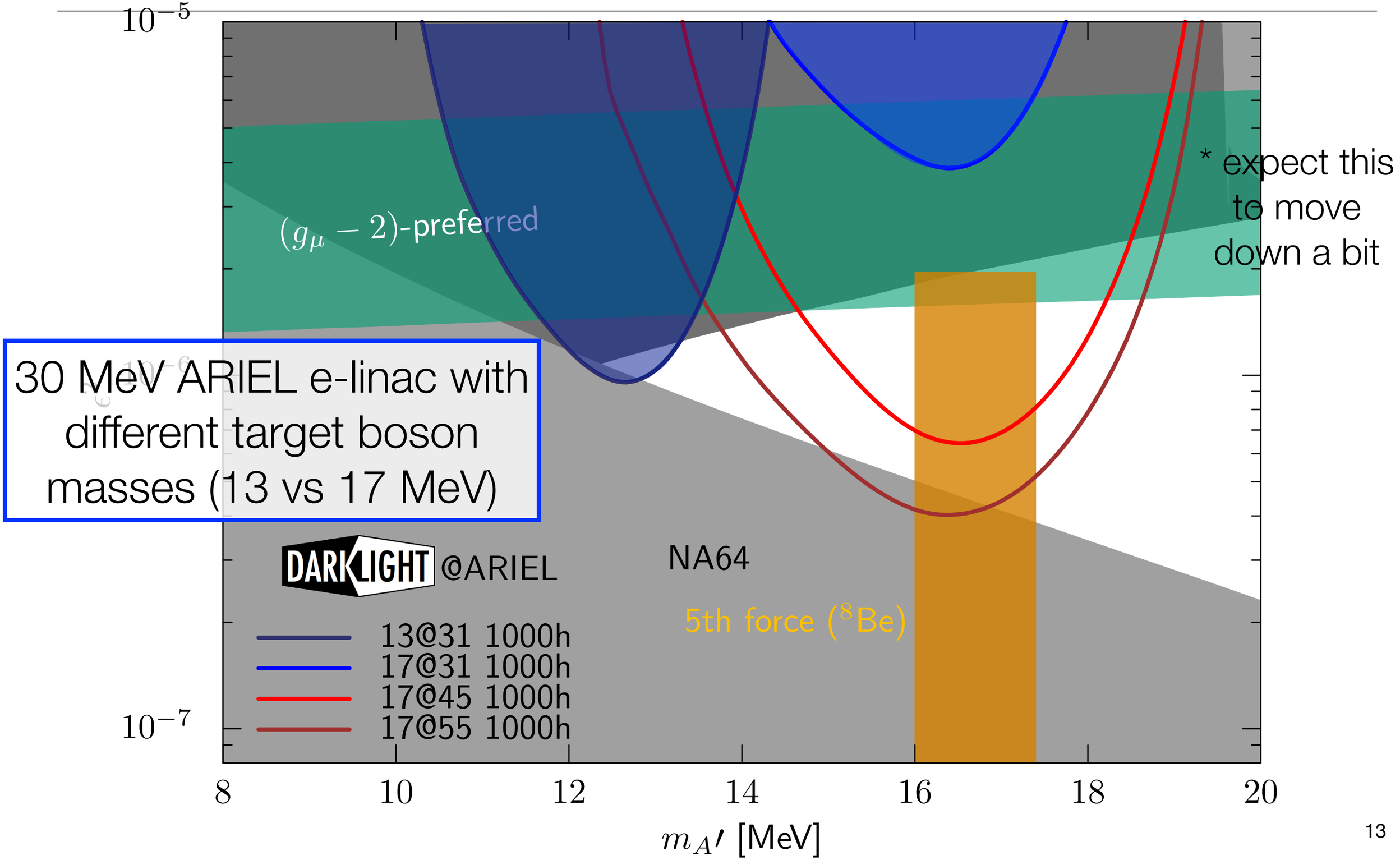
* expect this to move down a bit

Sensitivity at 30 and 50 MeV accelerators



Sensitivity at 30 and 50 MeV accelerators

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

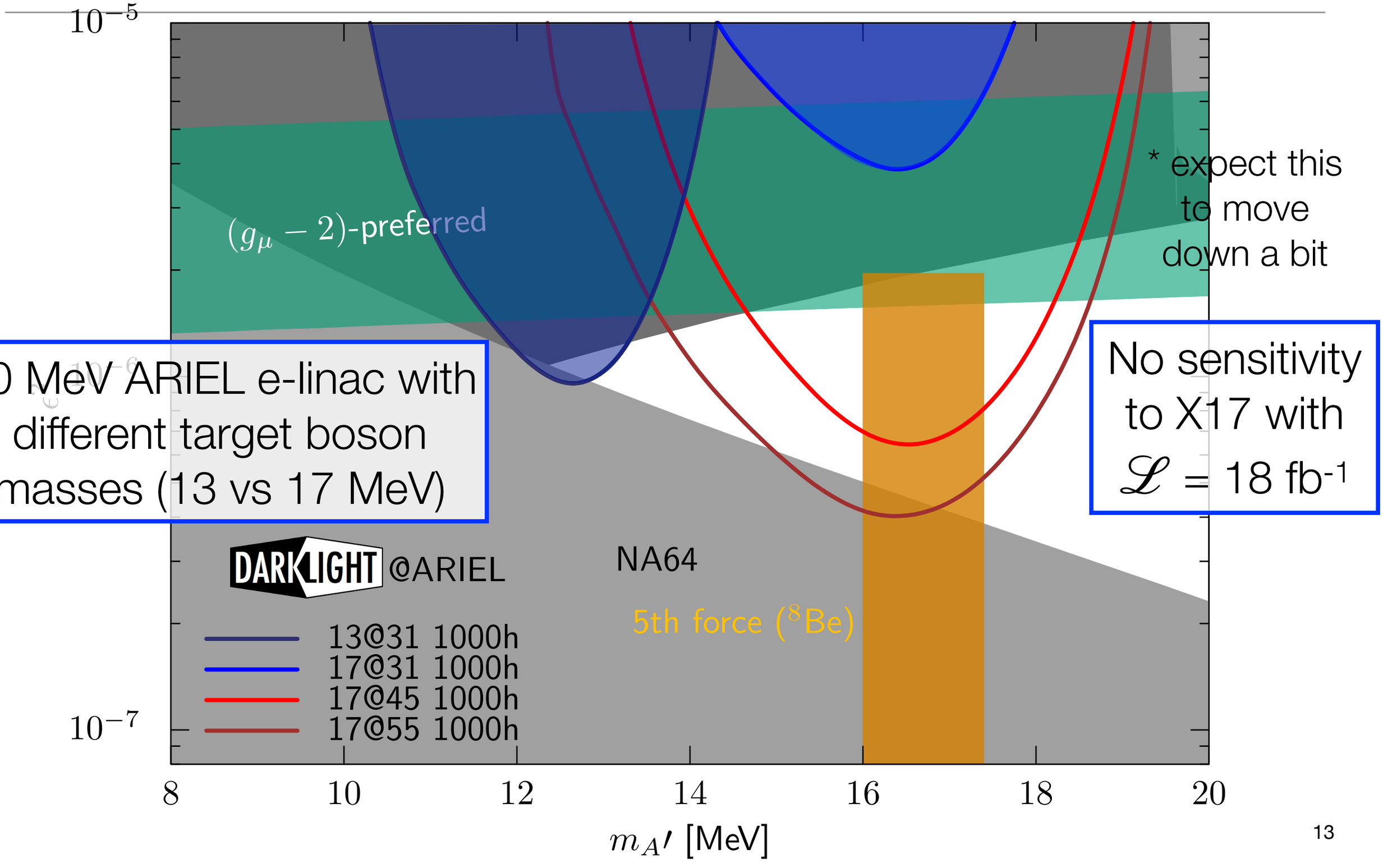


30 MeV ARIEL e-linac with different target boson masses (13 vs 17 MeV)

* expect this to move down a bit

Sensitivity at 30 and 50 MeV accelerators

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



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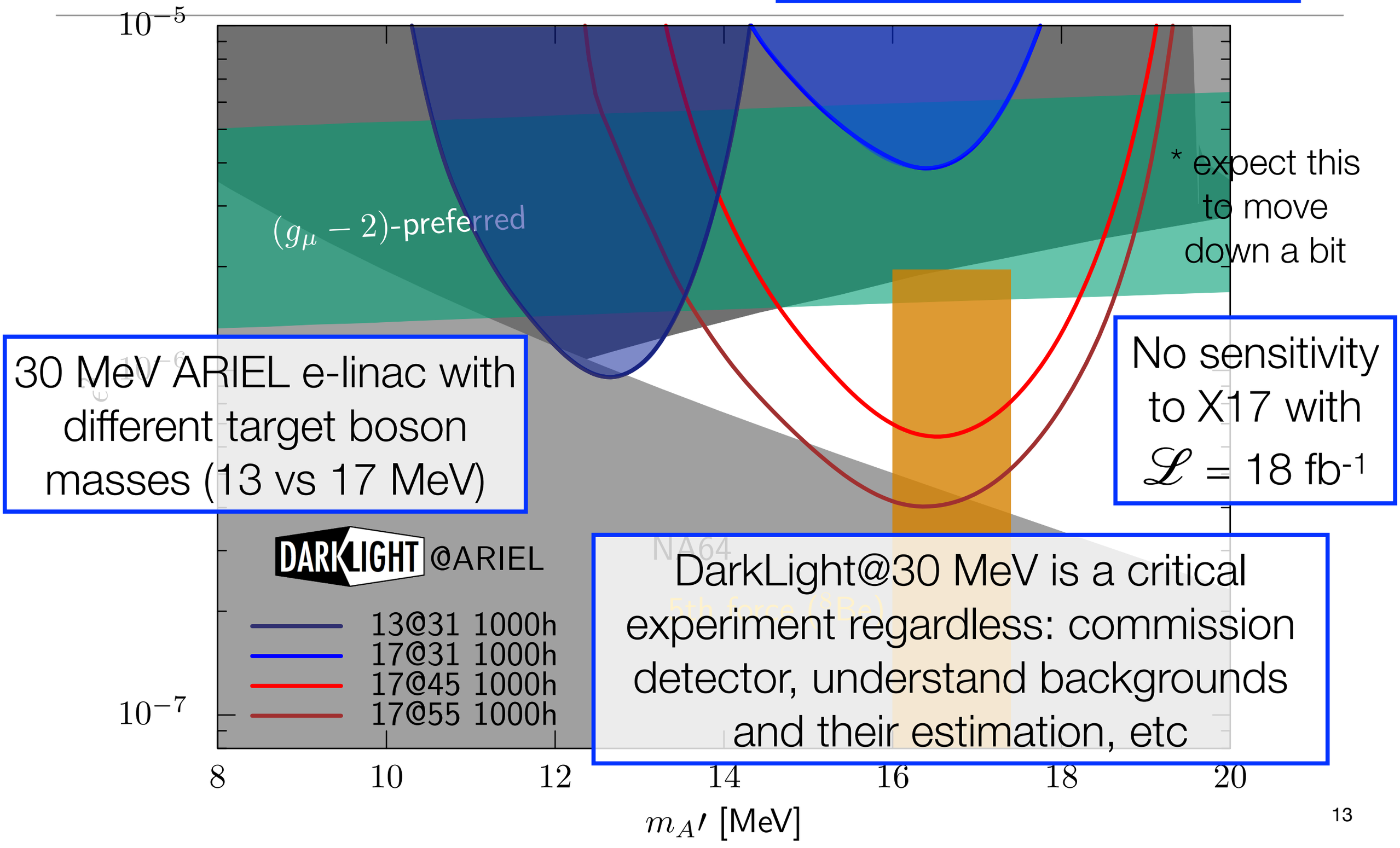
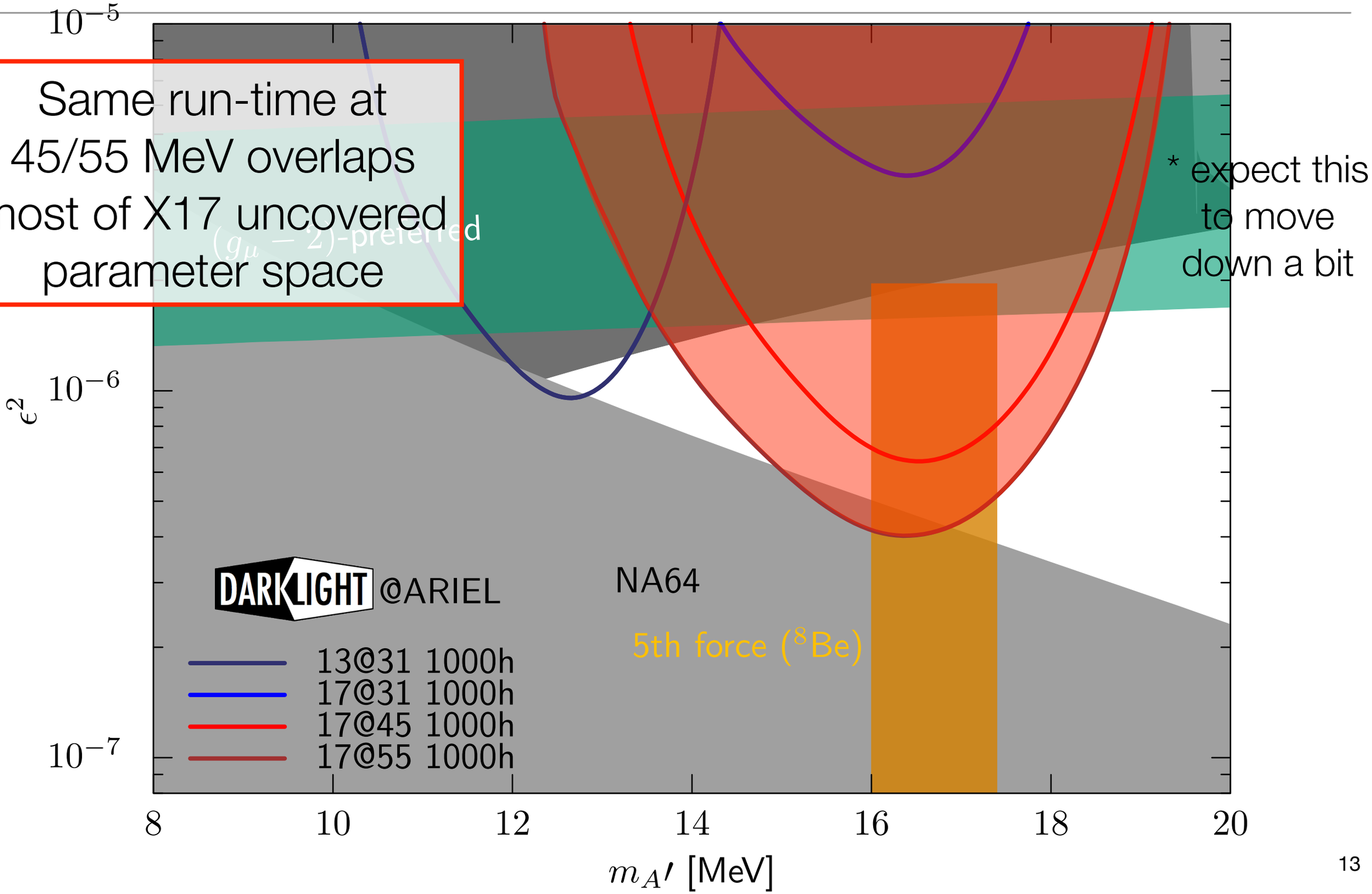


Sensitivity at 30 and 50 MeV accelerators

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



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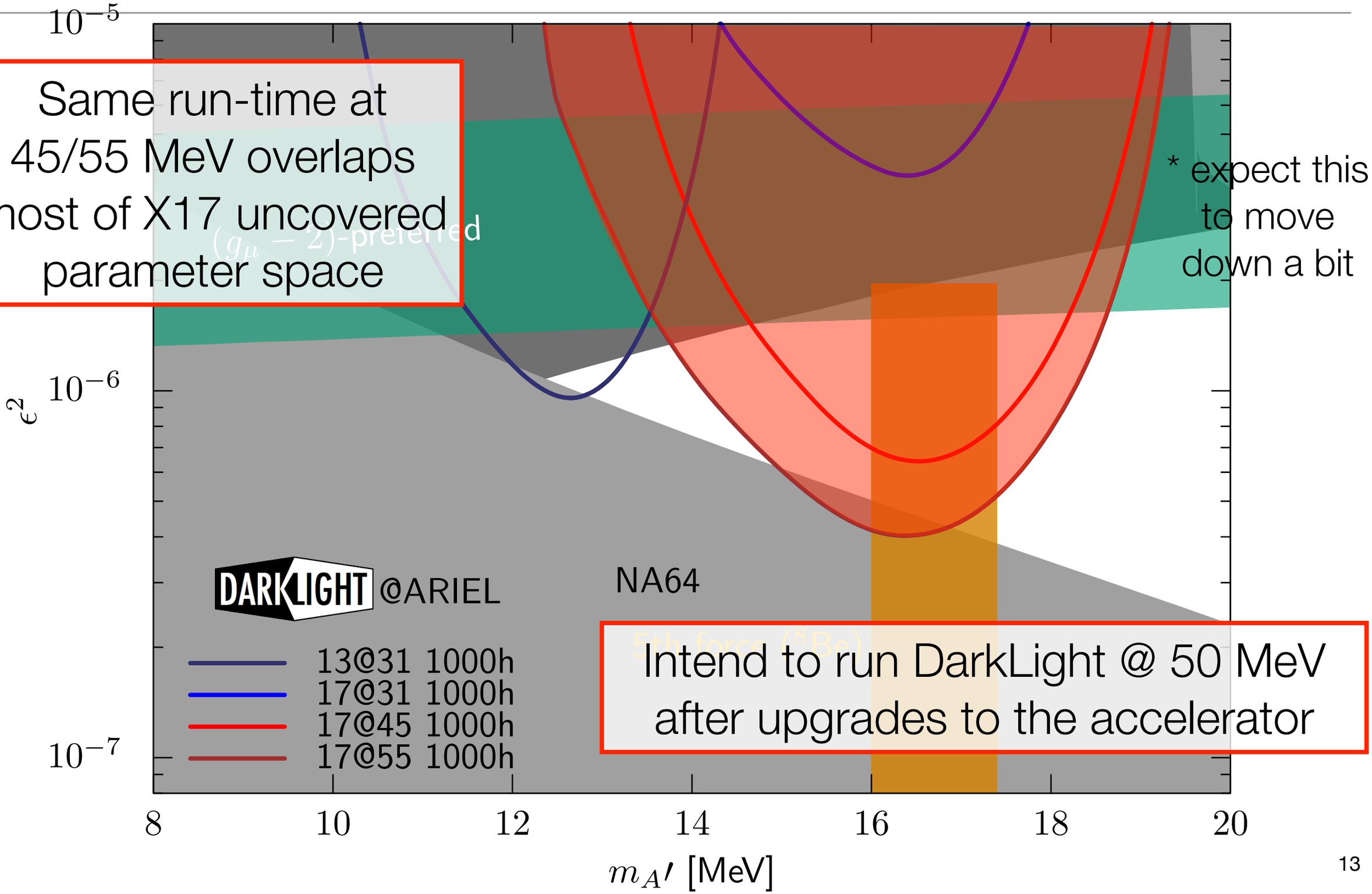


* expect this to move down a bit

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

New cryomodule

Beam pipes

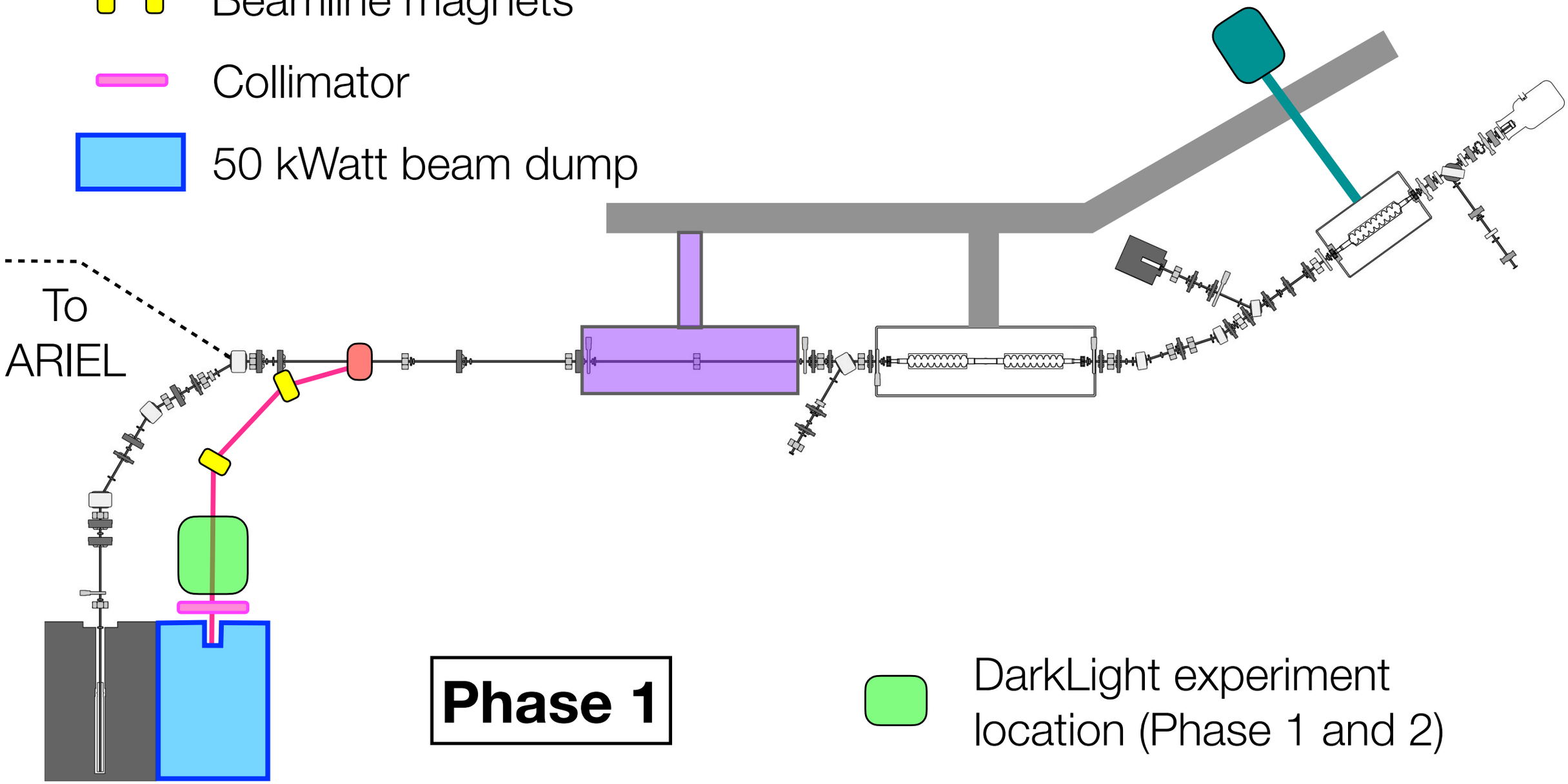
Beamline magnets

Collimator

50 kWatt beam dump

Solid state amplifier

Dipole magnet



Phase 1

DarkLight experiment location (Phase 1 and 2)

New cryomodule

Beam pipes

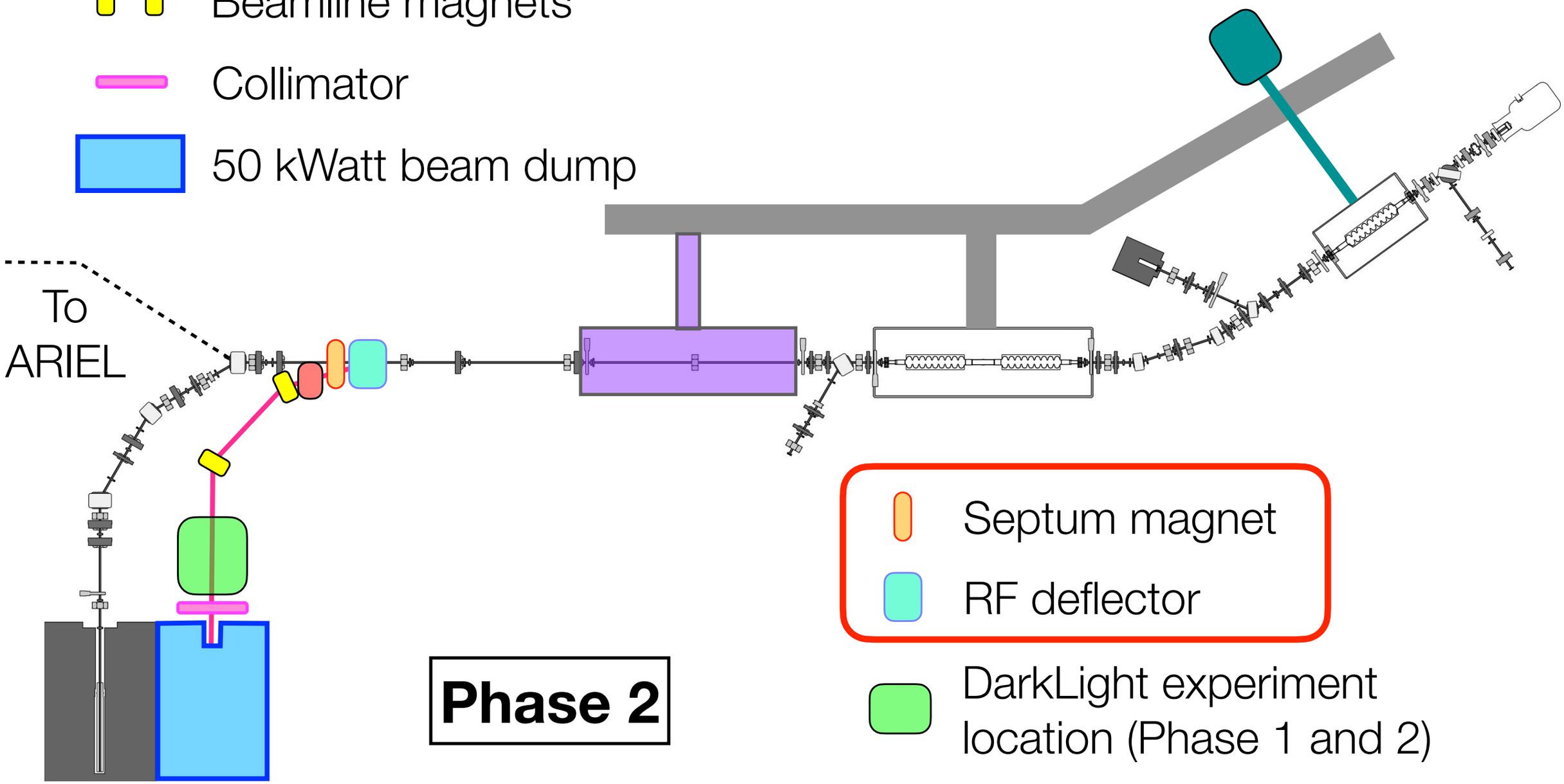
Beamline magnets

Collimator

50 kWatt beam dump

Solid state amplifier

Dipole magnet



Septum magnet

RF deflector

DarkLight experiment location (Phase 1 and 2)

Phase 2

Timeline and milestones

Spring 2021: beam time approved @ TRIUMF

Dec 2021: test chamber installed in beamline

Feb 2022 CFI passed selection round at universities

Feb 2022: Passed TRIUMF Gate 1

April 2022: NSERC awarded

May 2022: workshop at TRIUMF, first collaboration meeting

Today

Rest of 2022: install existing spectrometer, initial test experiments

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

2024/2025: install second cryomodule; first run @ 50 MeV

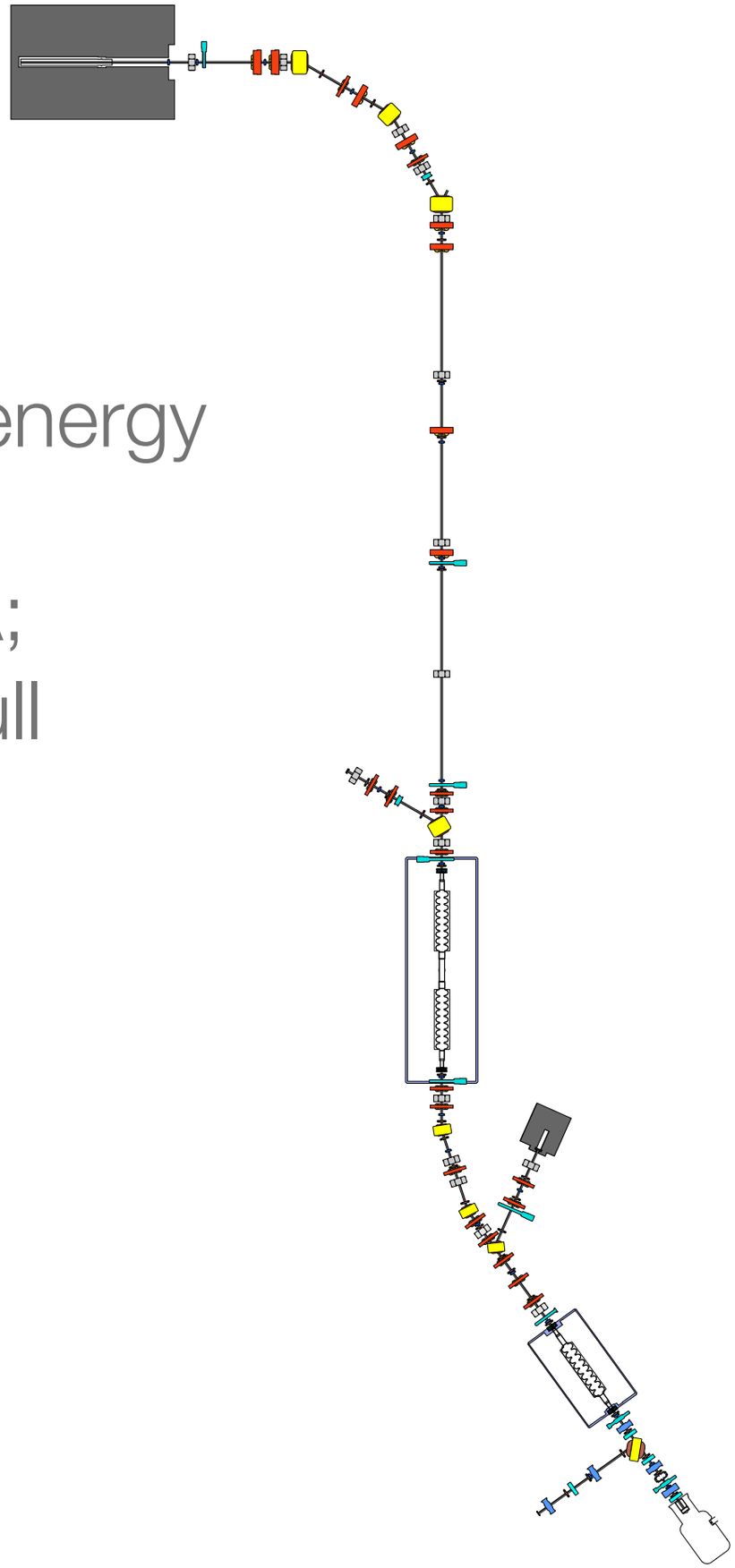
2025+: install infrastructure for parallel running with ARIEL

Thank you!

Backup slides

ARIEL e-linac facility

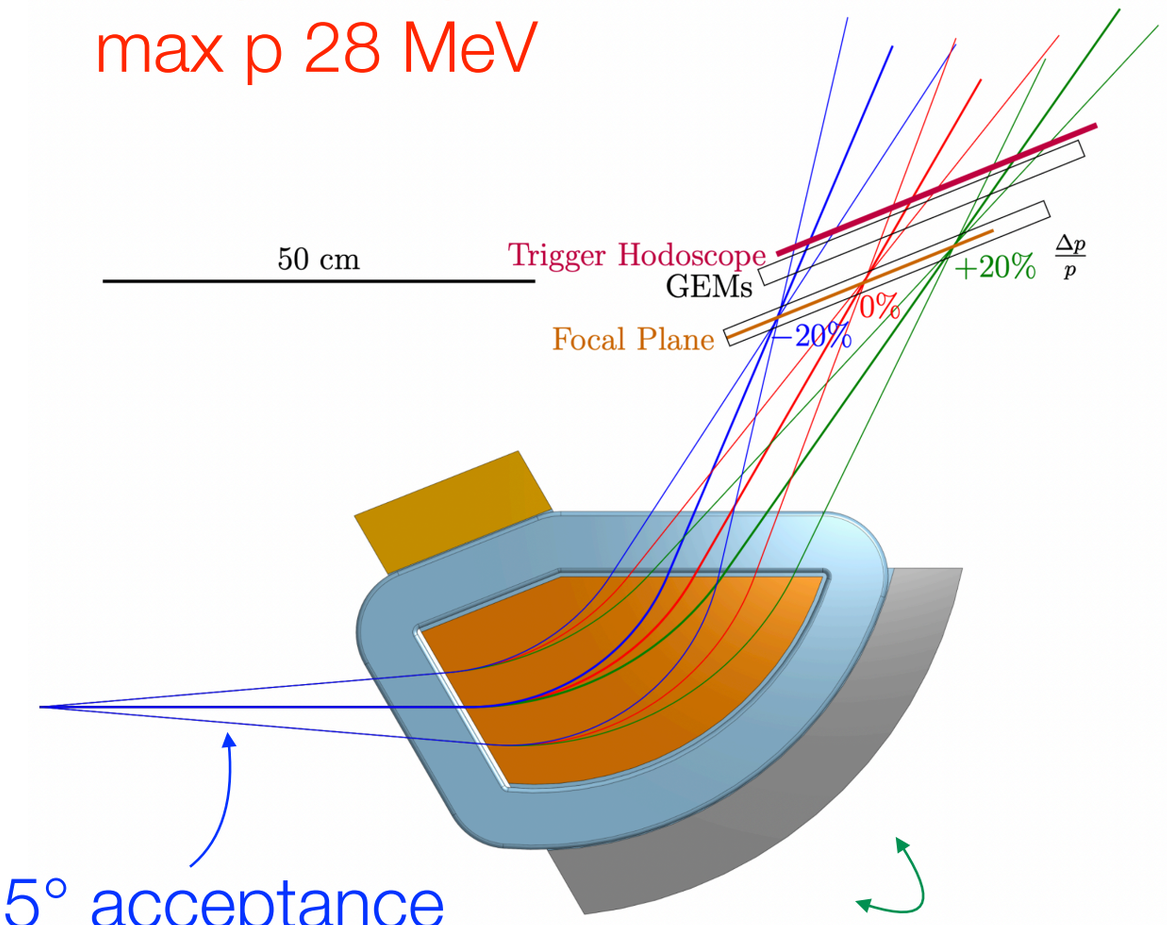
- 650 MHz frequency; currently 30 MeV energy
- Currents: Projections shown for 150 μA; considering designs that can support full design current of ~ a few mA
- Total design power ~ 100 kW
- Each bunch has ~ 9×10^6 electrons



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

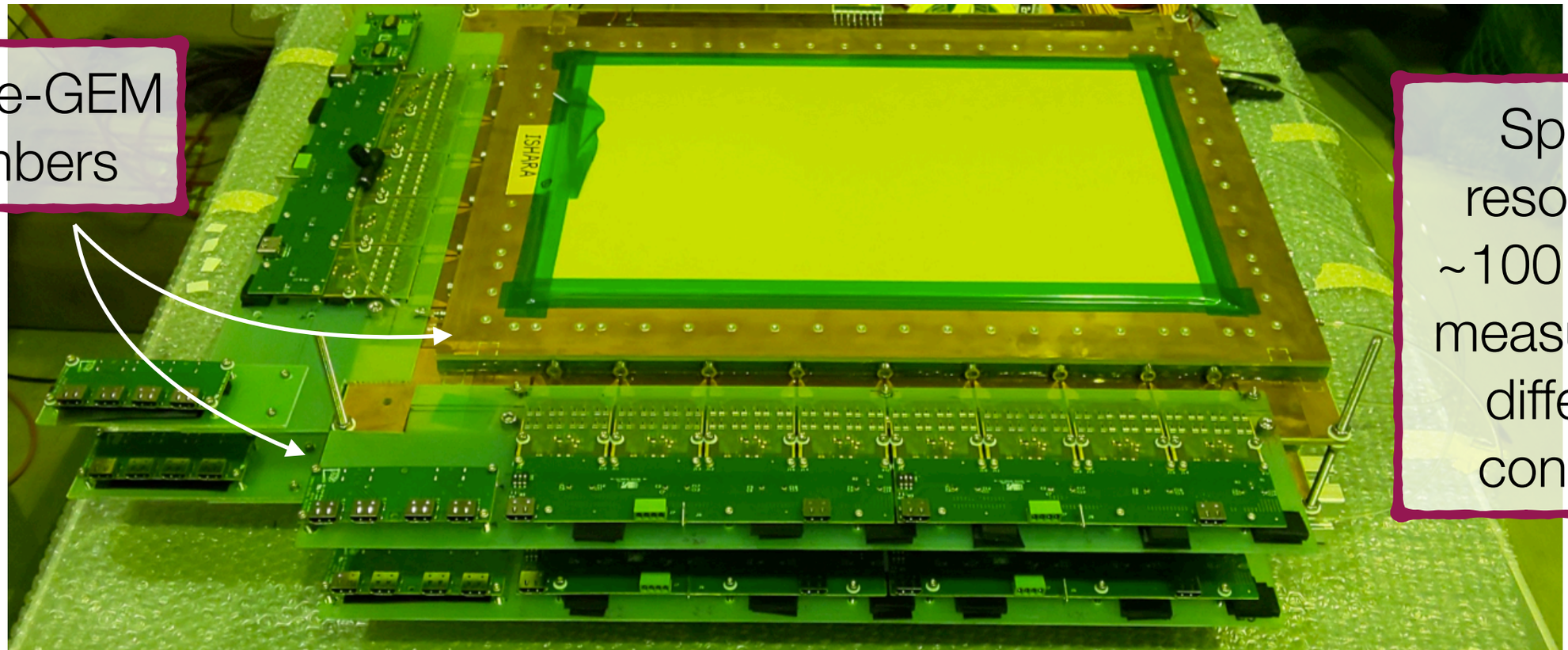


+/- 5° acceptance in this dimension

+/- 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 spring of 2023, along with sufficient readout electronics. Commissioning to be completed at JLab/ELPH in intervening months.

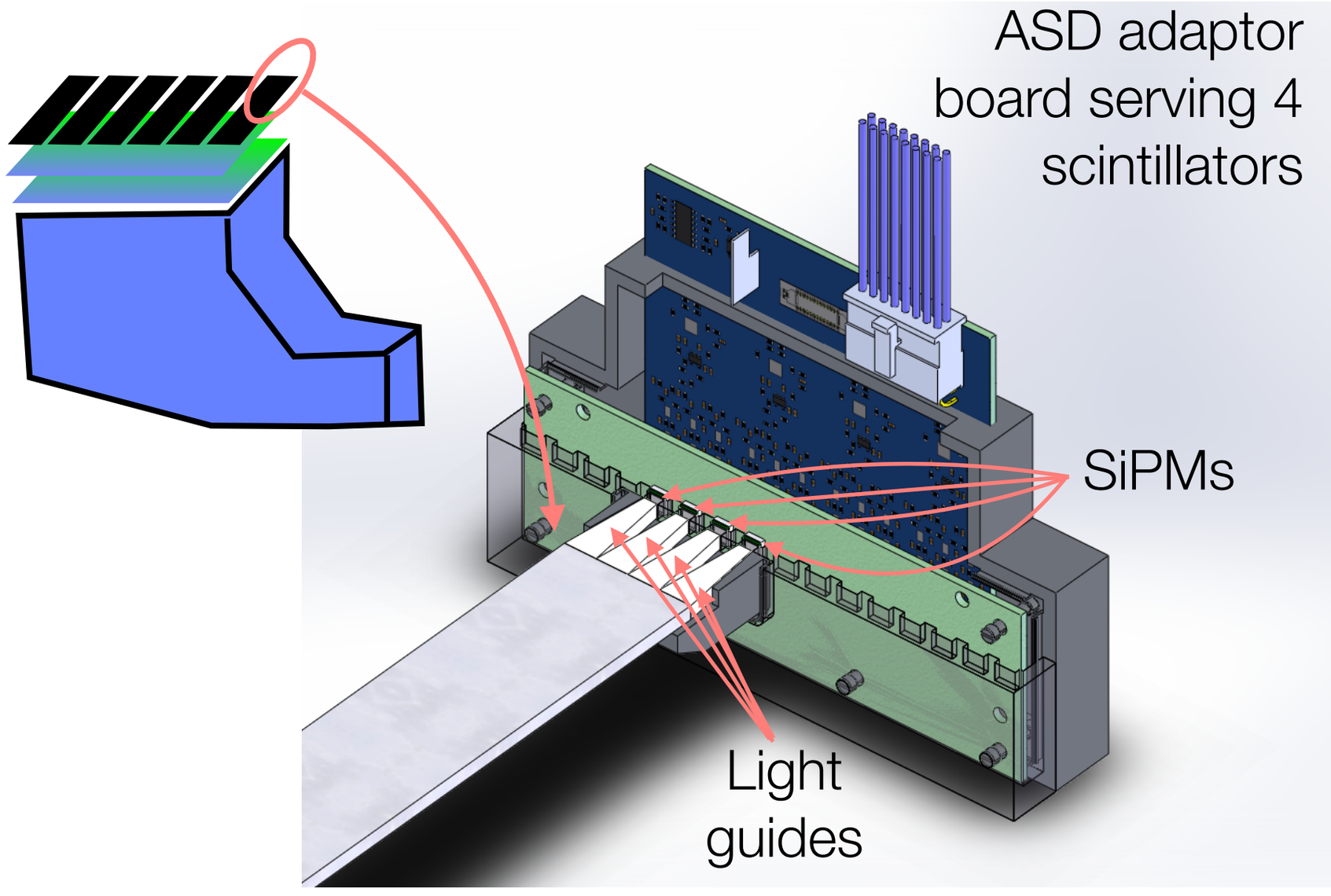


2x triple-GEM chambers

Spatial resolution ~100 μm as measured in different contexts

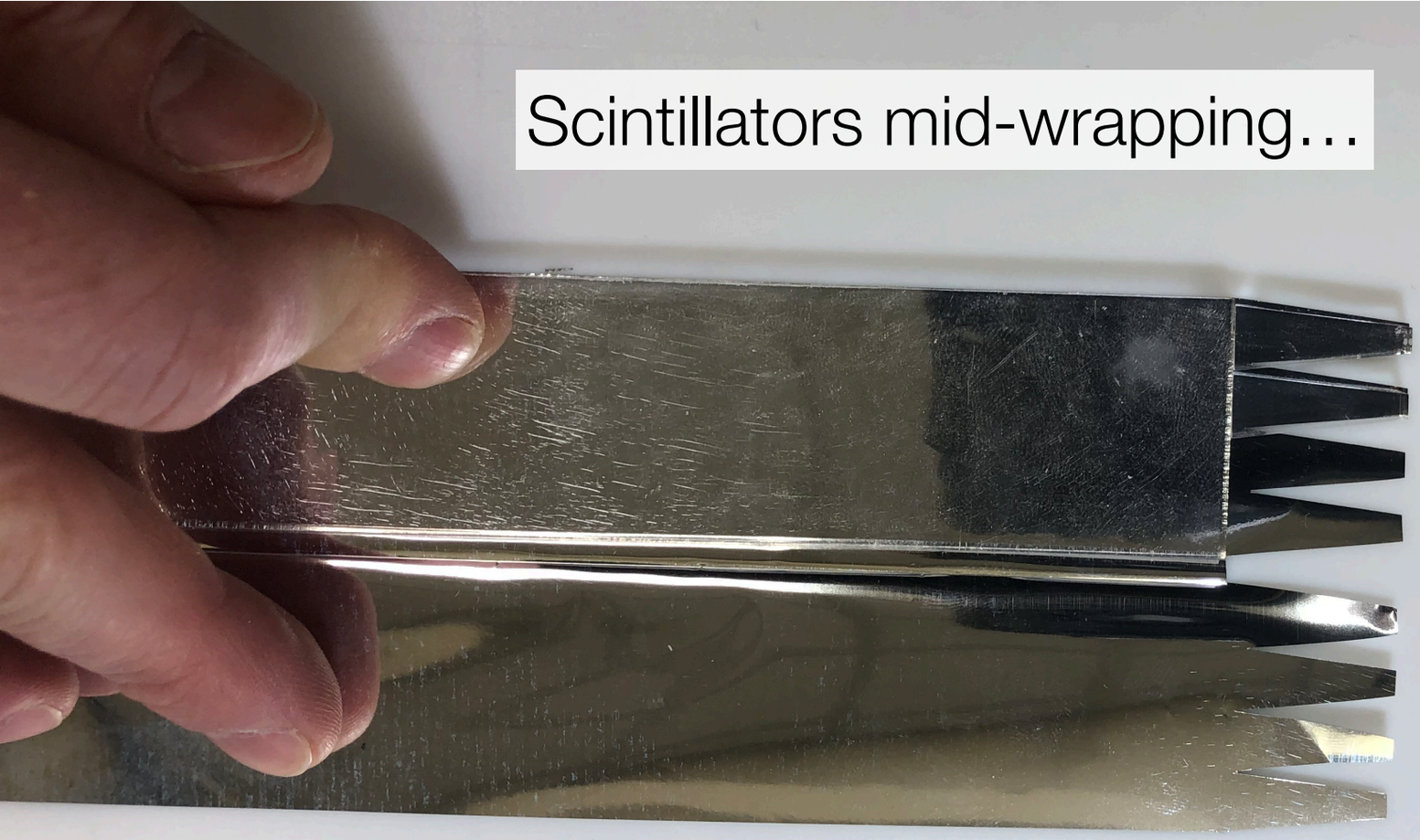
Experiment status: trigger detectors

- 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



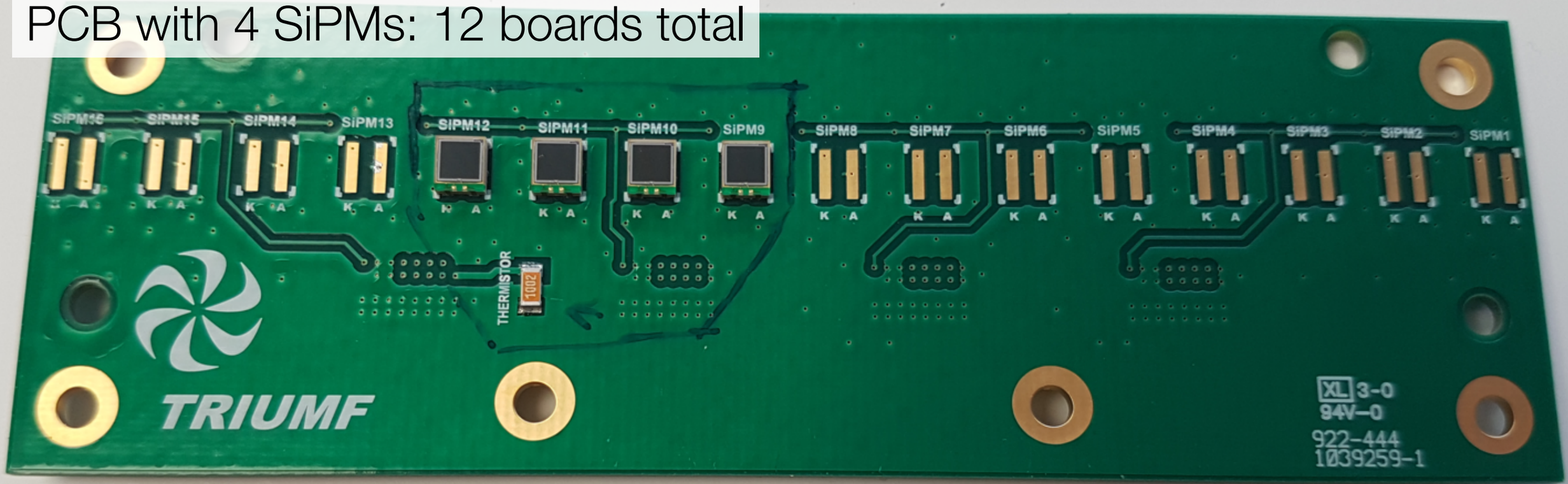
Prototype scintillator dimensions:
150 mm x 30 mm x 3 mm

Scintillators mid-wrapping…



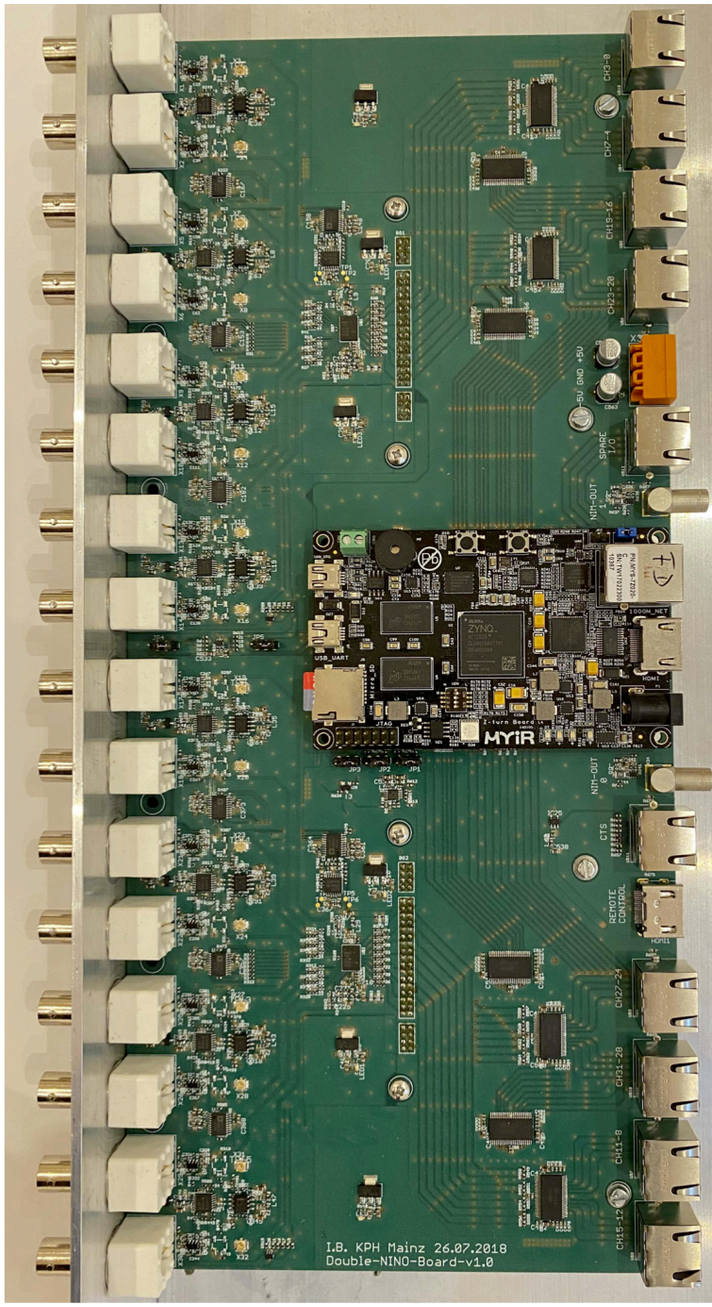
… and wrapped

PCB with 4 SiPMs: 12 boards total

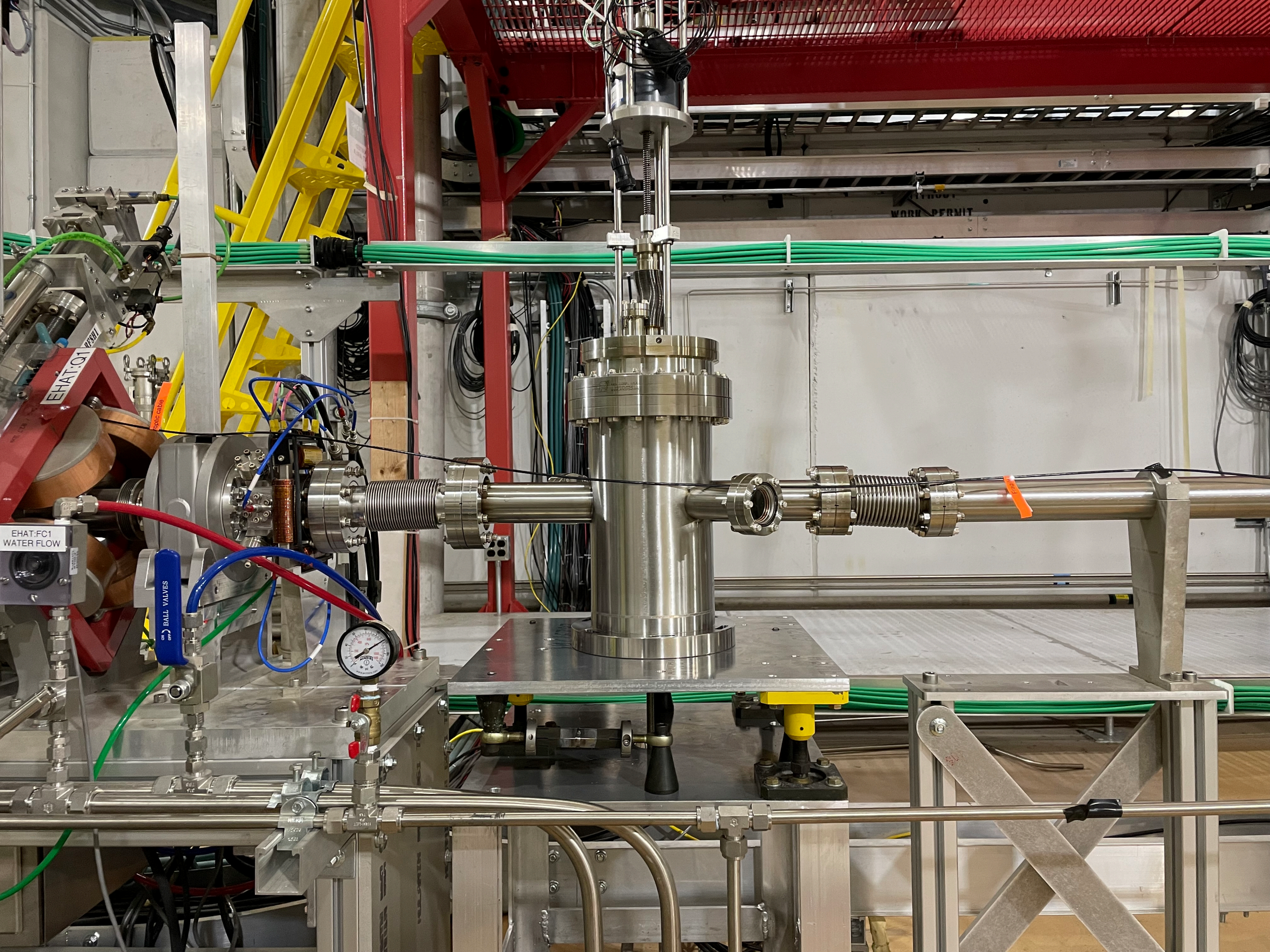


Experiment status: read-out and DAQ

- 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


EHAT:Q1
EHAT:FC1
WATER FLOW
BALL VALVES
WORK PERMIT

Complementary experiments

- Type 1: ATOMKI-like; intending to reproduce and validate experiment
- Montreal, Notre Dame among groups working on this
- No conflict with collider/accelerator goals
- Type 2: mixed hadronic-leptonic
- Leading experiment LHCb: will cover all X17 space (even with protophobic assumptions) with full Run 3 data
- Complementary to DarkLight, which can probe electron coupling independently of hadronic couplings
- Type 3: pure leptonic production
- Lots of experiments covering invisible decay: LDMX, Na64, …
- A few experiments with similar visible final state sensitivity.
- Na64 currently setting lower boundary. Future (2023+) runs with modified setup can probe higher ε
- MAGIX very powerful here but on longer timeline (2025+)