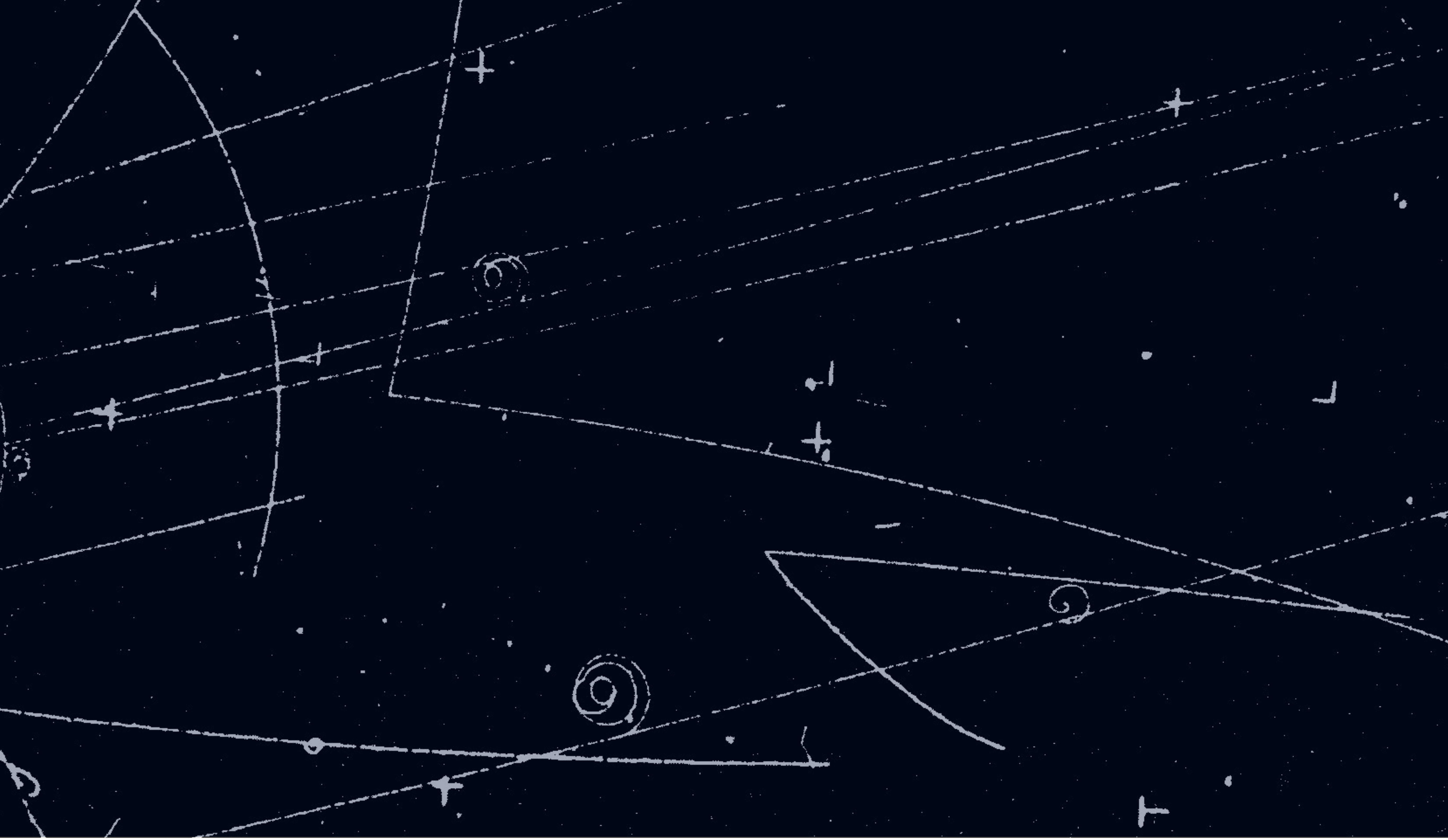


DarkLight experiment for the 5 year plan

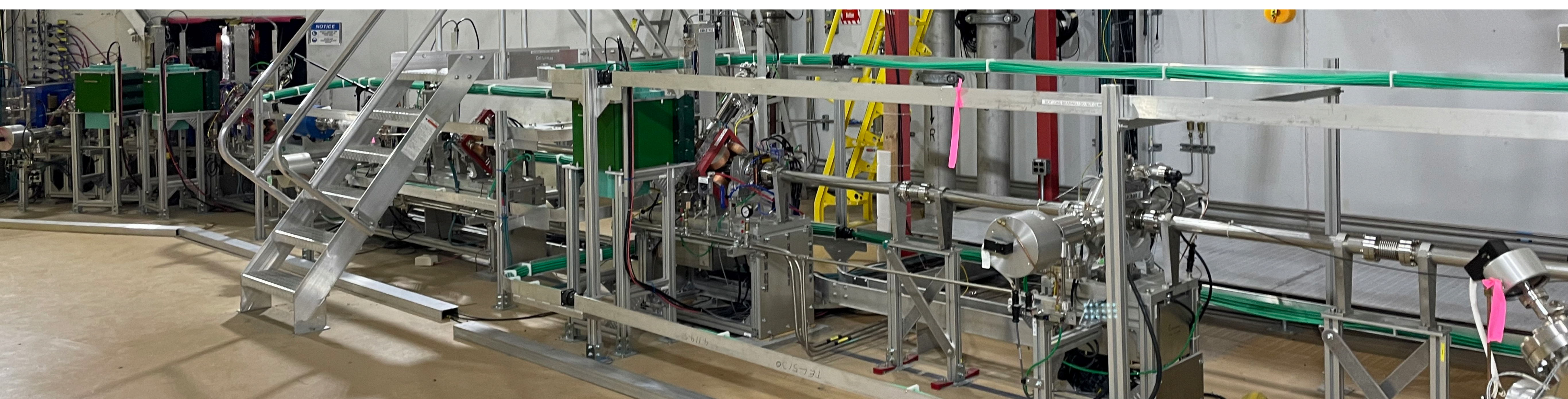
Kate Pachal
TRIUMF

Overview

- DarkLight has been approved by PP-EEC for 1300 hours beam time at the 30 MeV ARIEL e-linac
- Experiment construction + 30 MeV operation will finish before 2025
- However, longer-term goals involve an energy increase for the e-linac and further data collection runs at 50 MeV
- First stage is planned for 2024, second stage likely 2026+
- Accelerator upgrades for 50 MeV running will present possibilities for other future experiments at ARIEL e-linac
- Actively seeking ideas: workshop at TRIUMF in May will brainstorm opportunities with the community

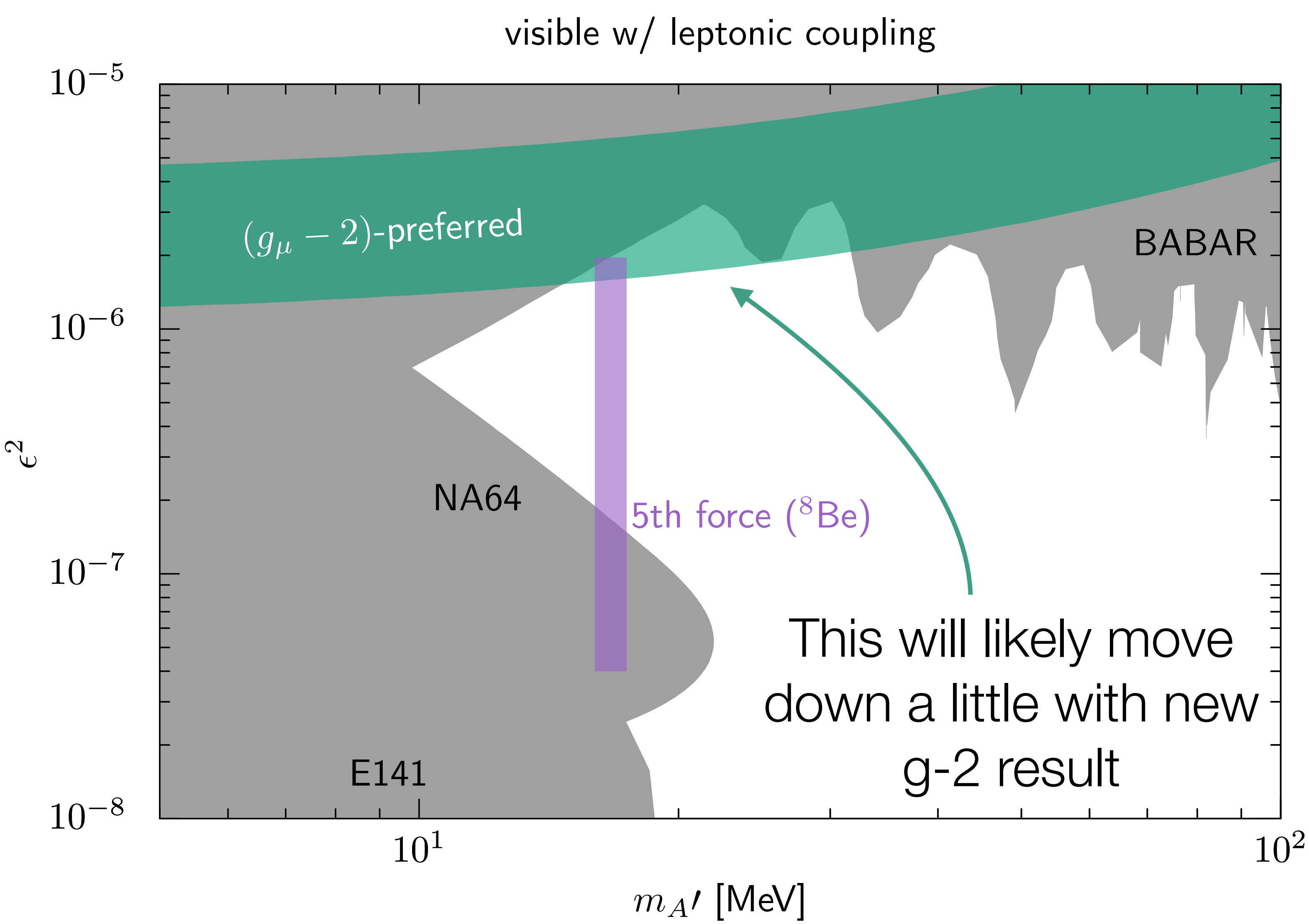
Collaboration

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



Physics target: new boson with suppressed coupling to protons

This plot: new boson limits from e+e- interactions only



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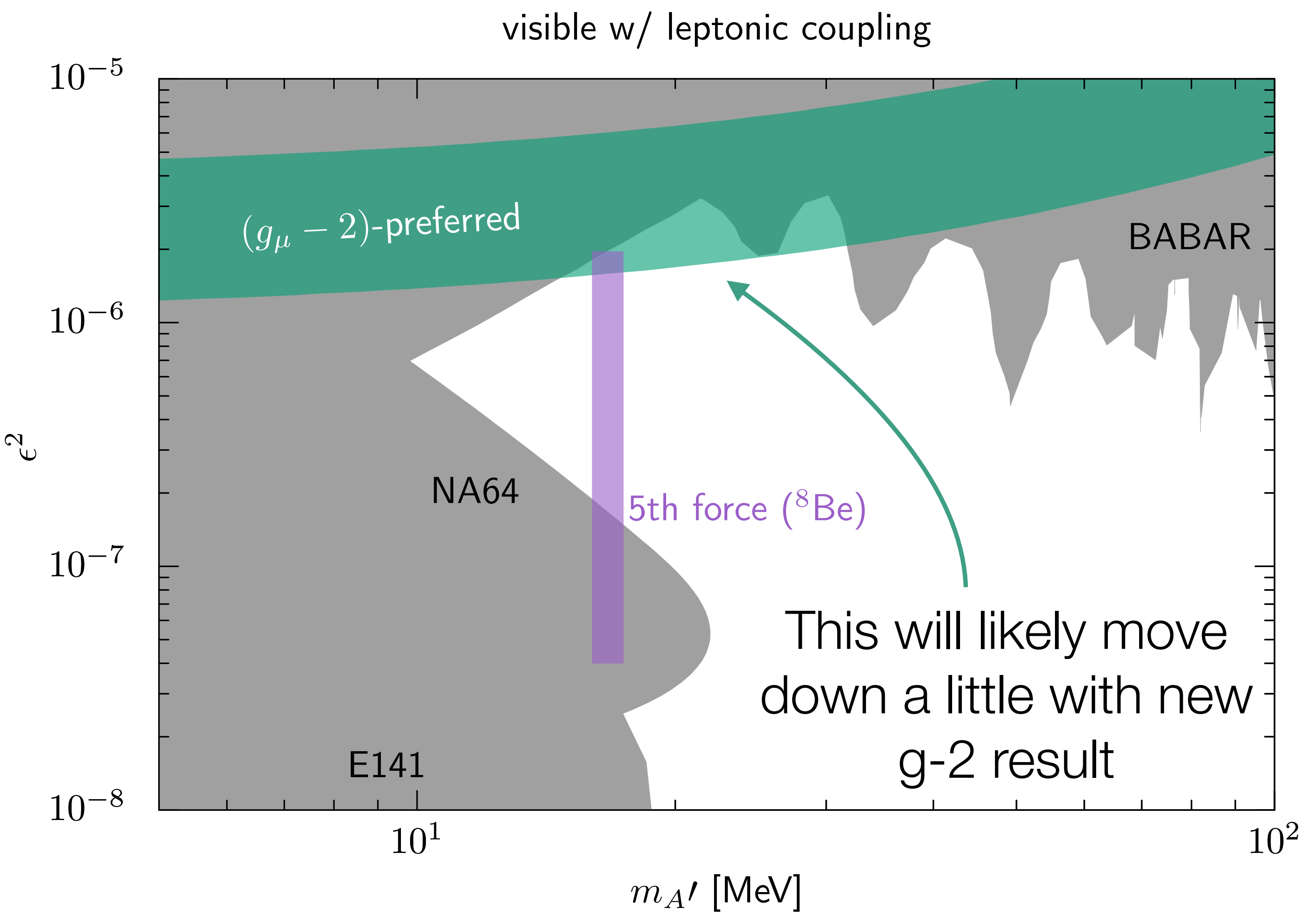


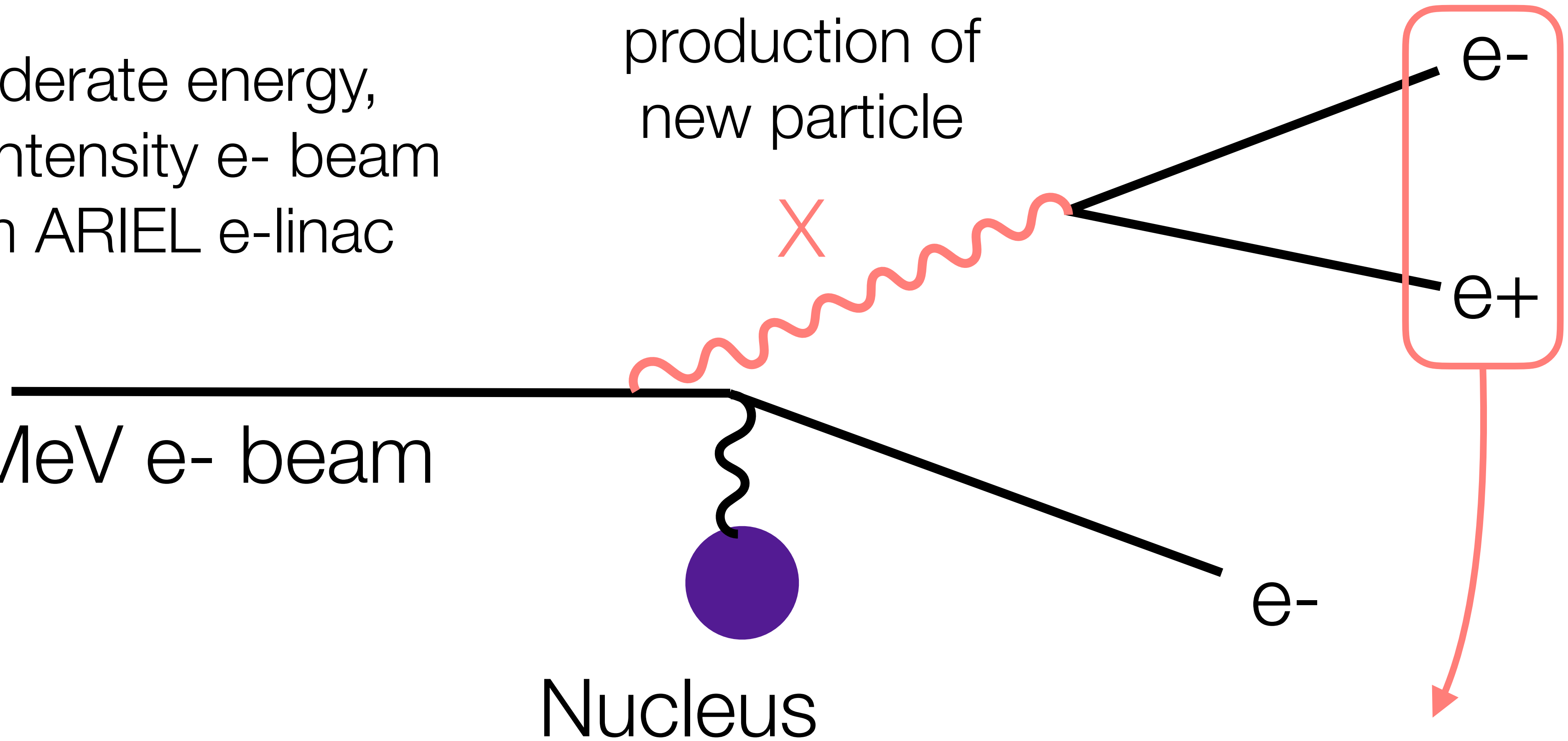
X17 and muon g-2 anomalies both appear in lepton interactions.
"Protophobic" boson would avoid constraints from pion interactions but can be cleanly probed at e- machine.

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

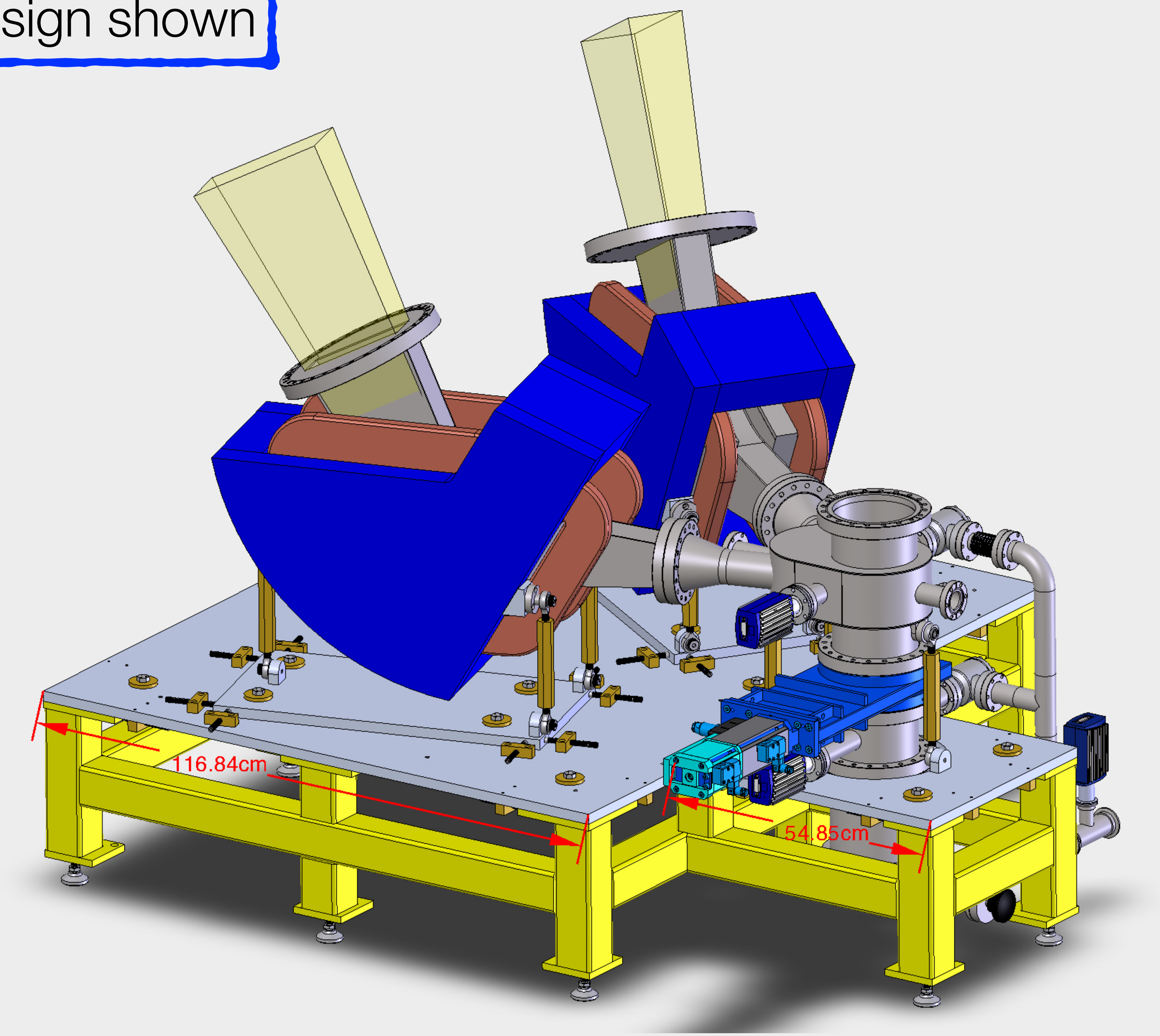


High-N target optimised for minimum multiple scattering: baseline target is 1 μm Tantalum foil

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

Experiment overview

Preliminary design shown



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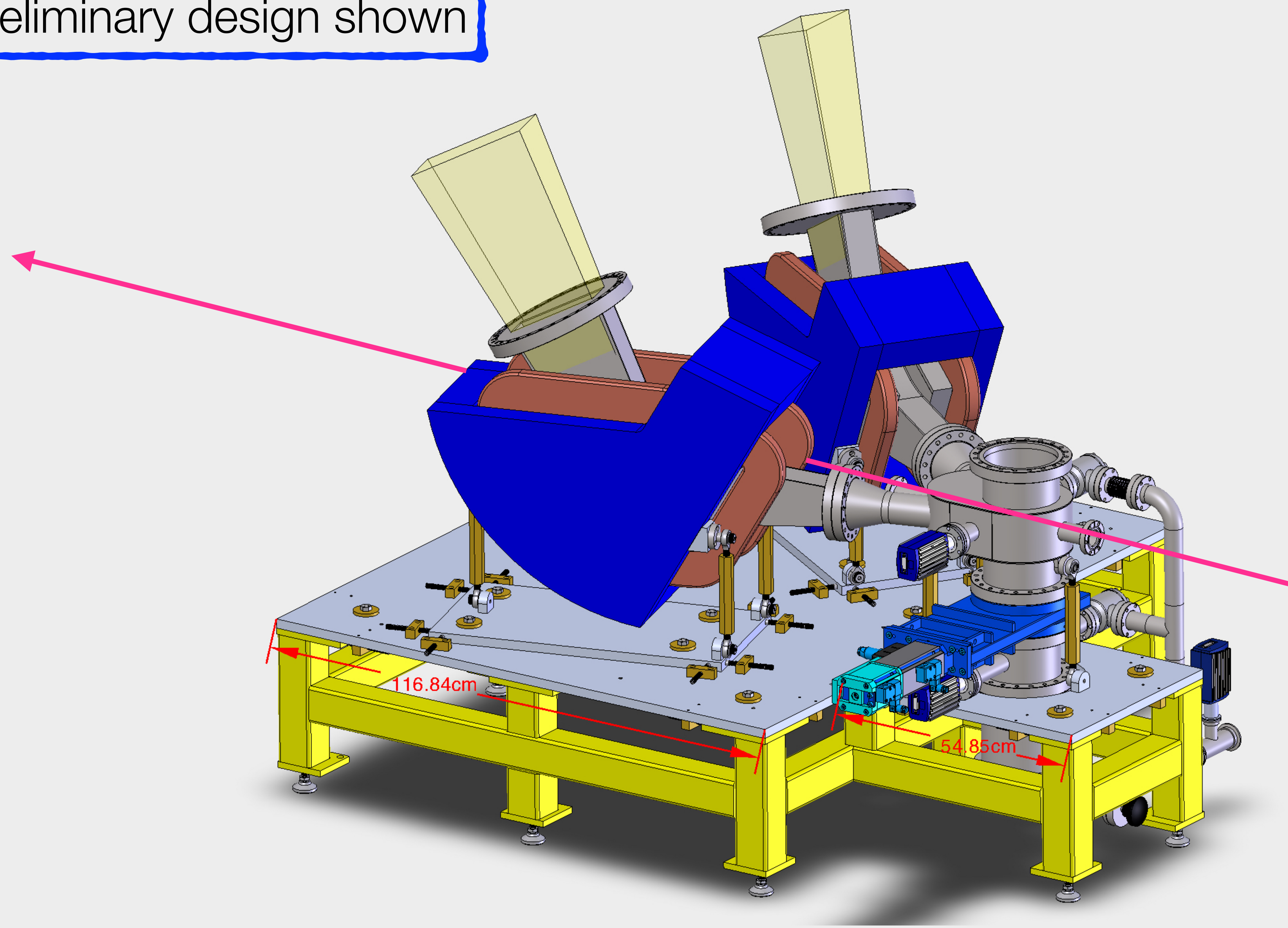
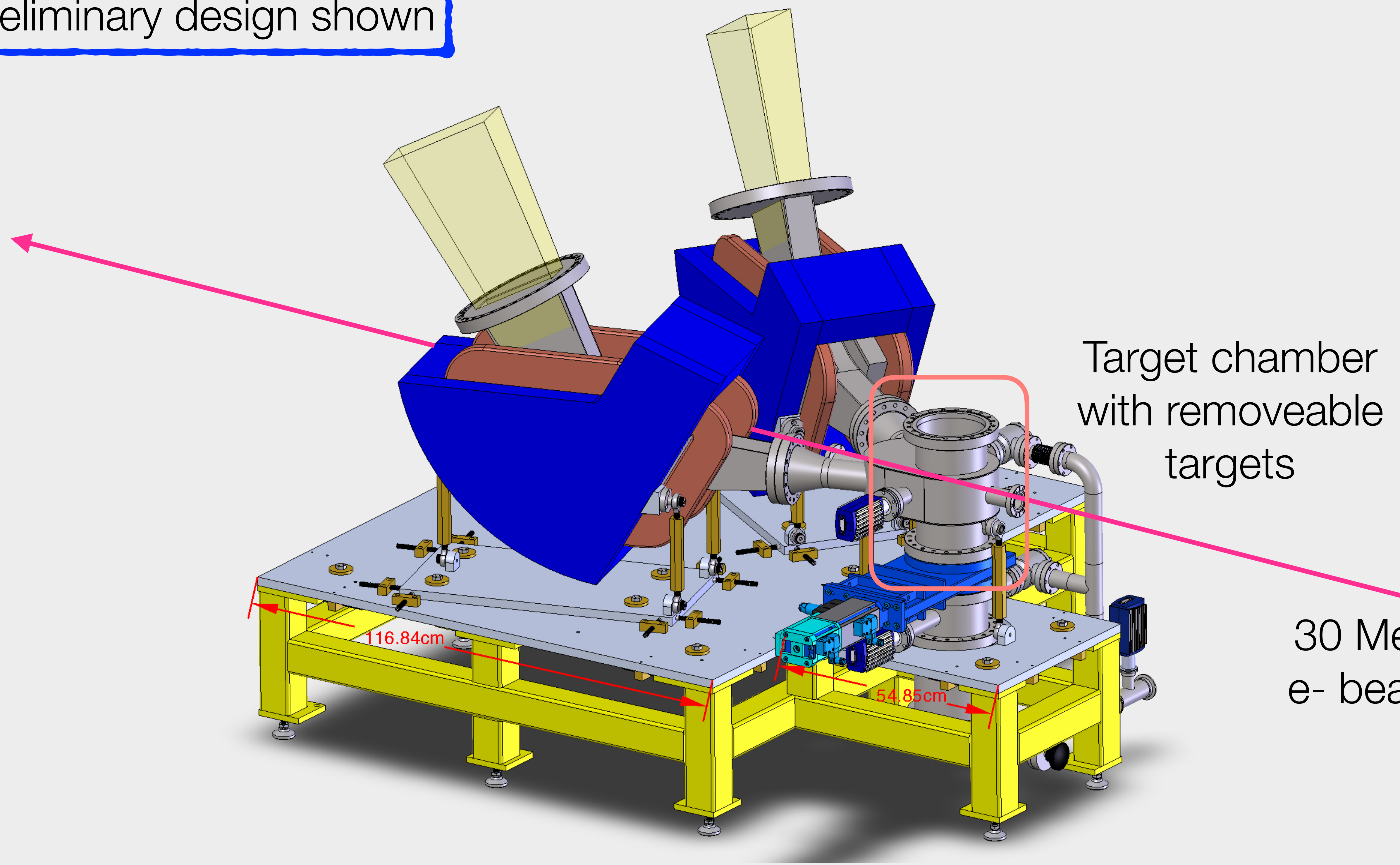


30 MeV
e- beam

Experiment overview

Preliminary design shown

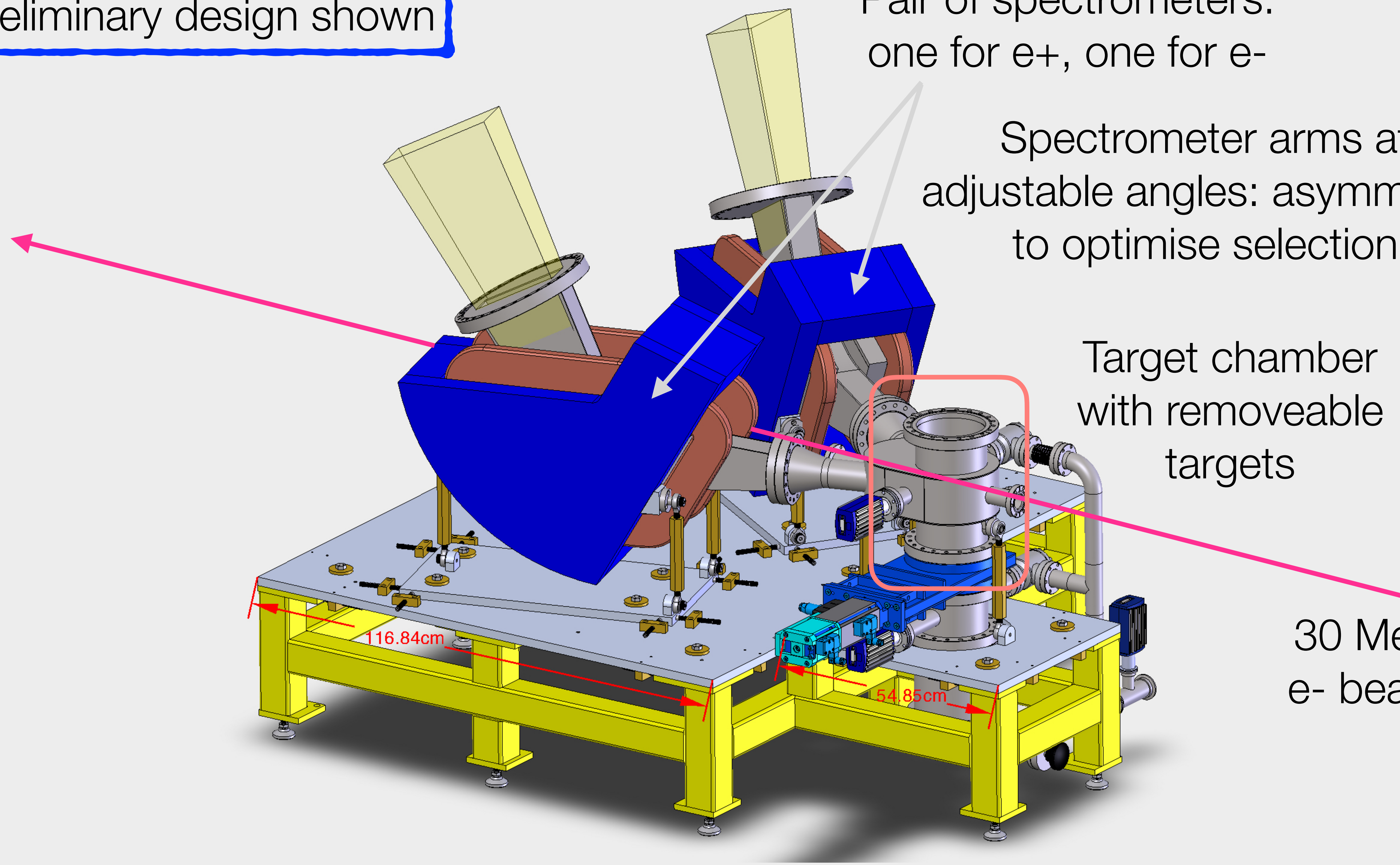


Target chamber with removeable targets

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

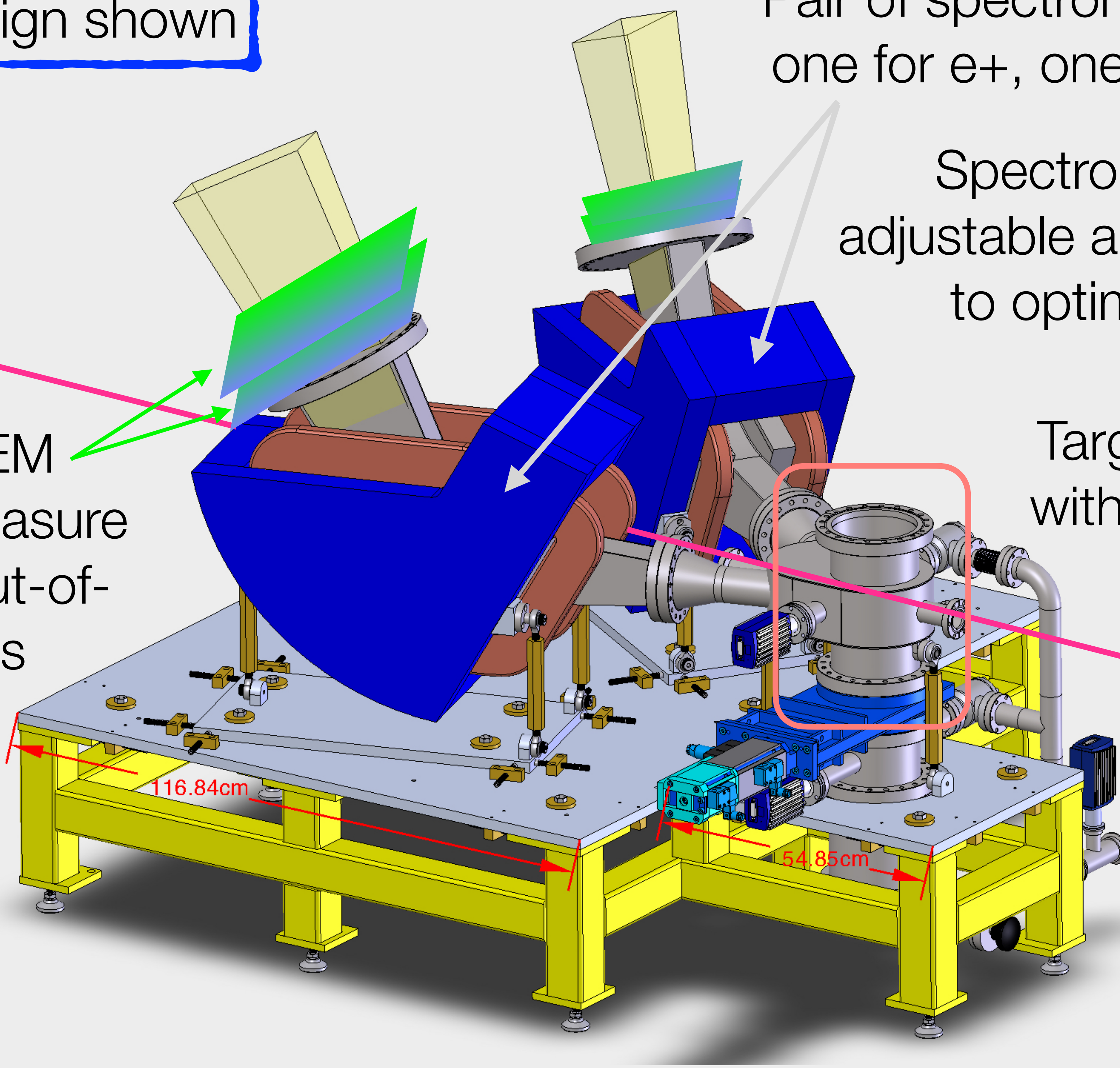
Pair of spectrometers:
one for e+, one for e-

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



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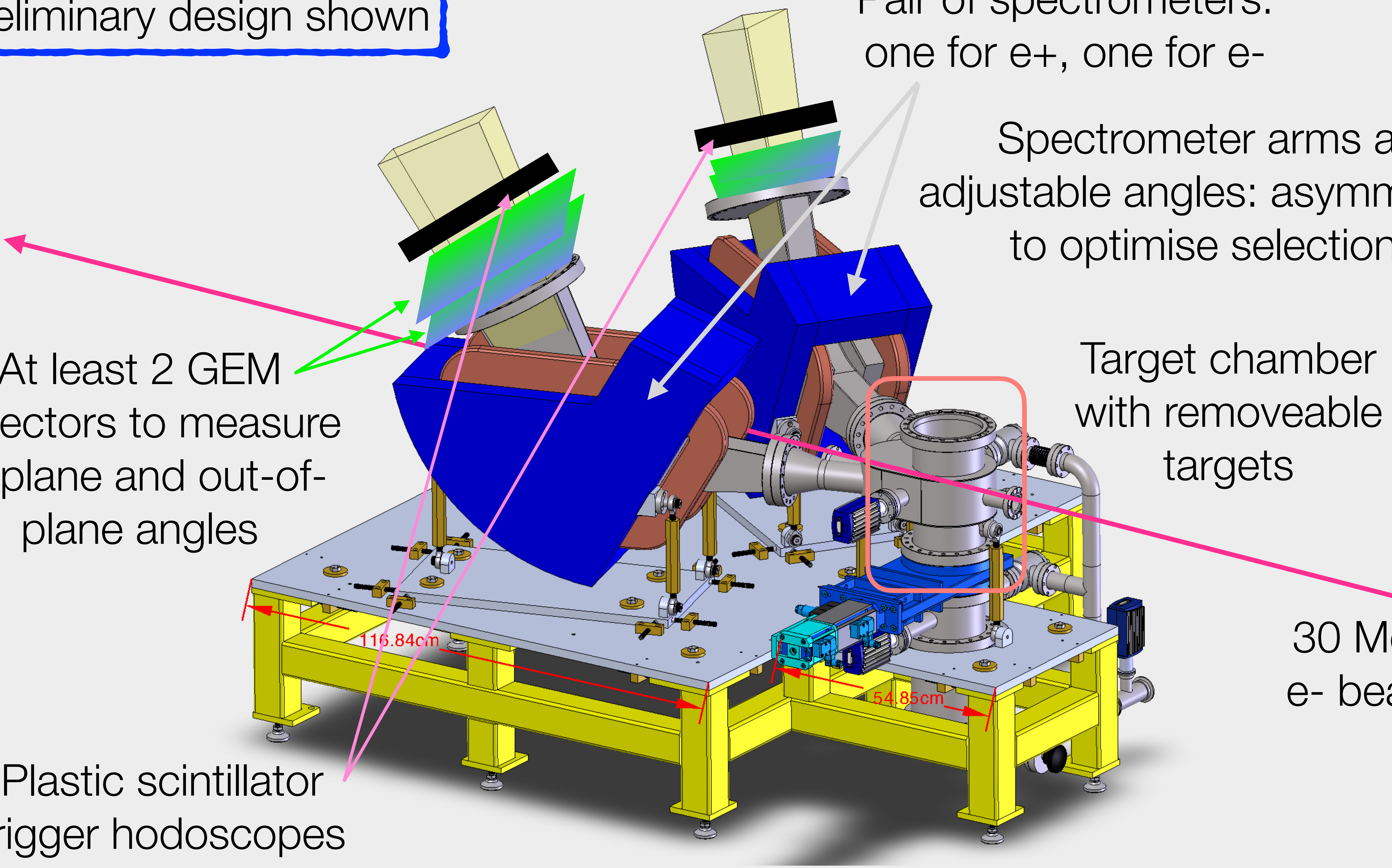


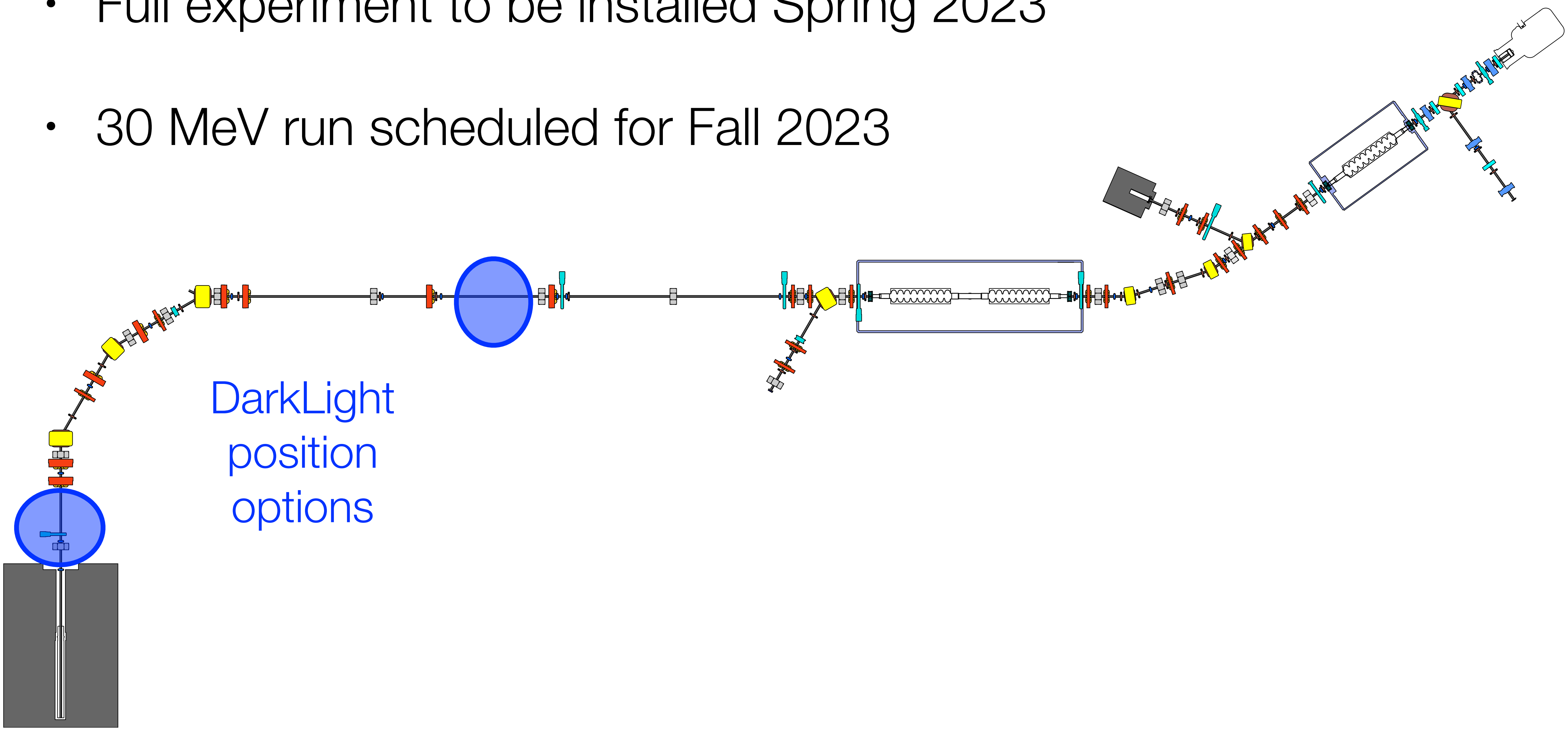
Target chamber with removeable targets

30 MeV e- beam

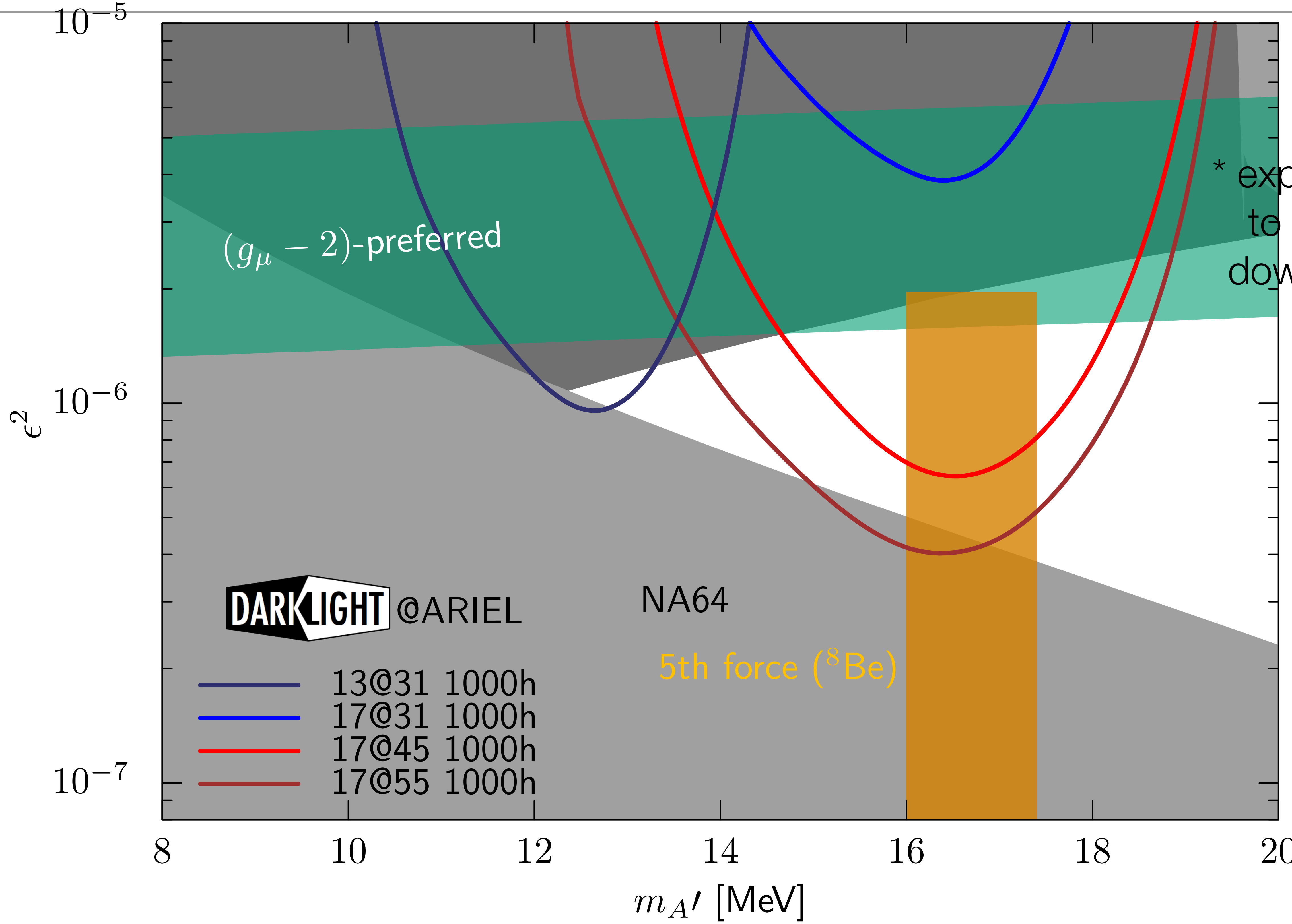
Plastic scintillator trigger hodoscopes

Immediate future: 30 MeV running with current ARIEL accelerator

- Detector development ongoing now
- Full experiment to be installed Spring 2023
- 30 MeV run scheduled for Fall 2023

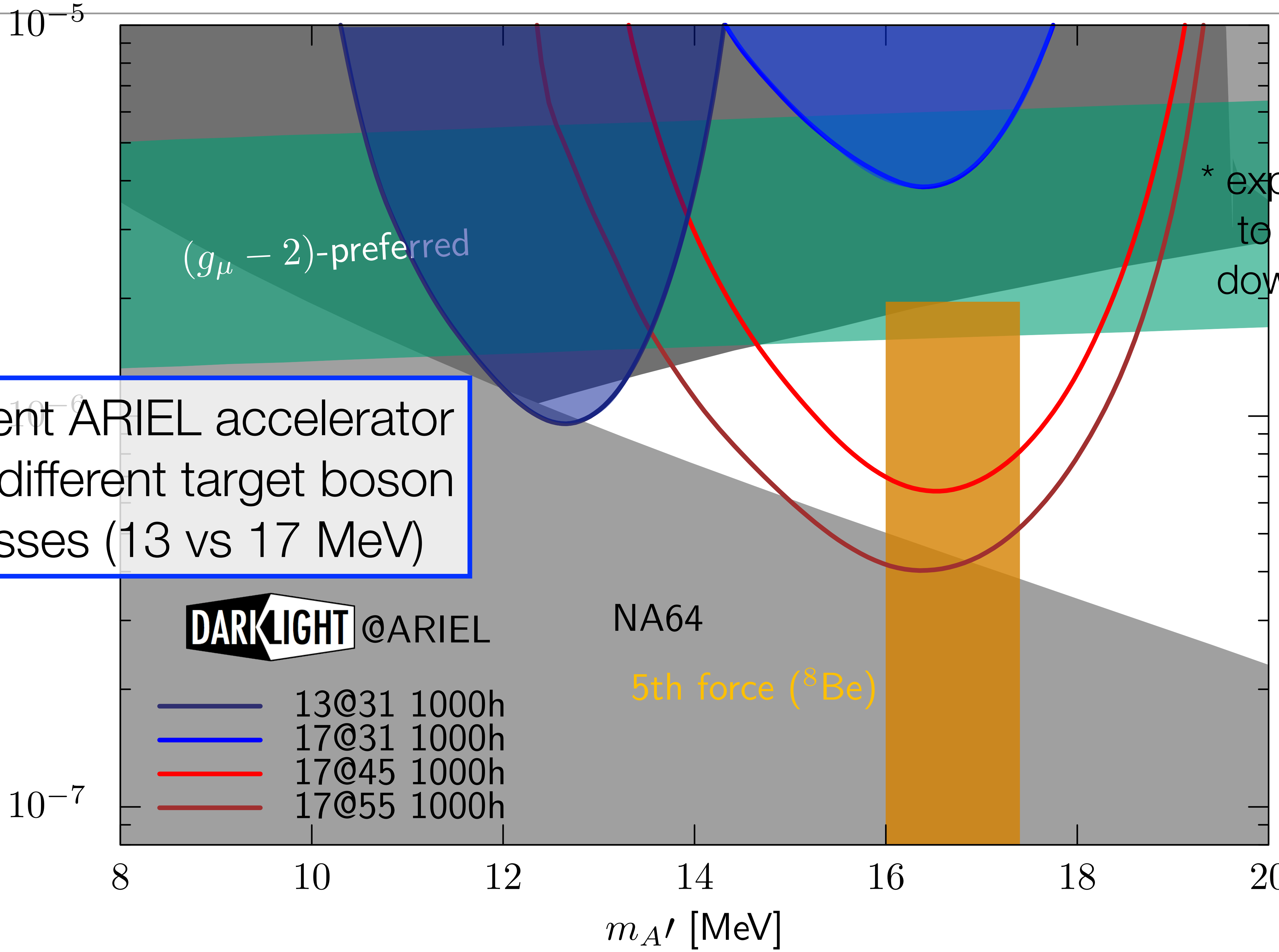


Sensitivity at 30 and 50 MeV accelerators



* expect this to move down a bit

Sensitivity at 30 and 50 MeV accelerators

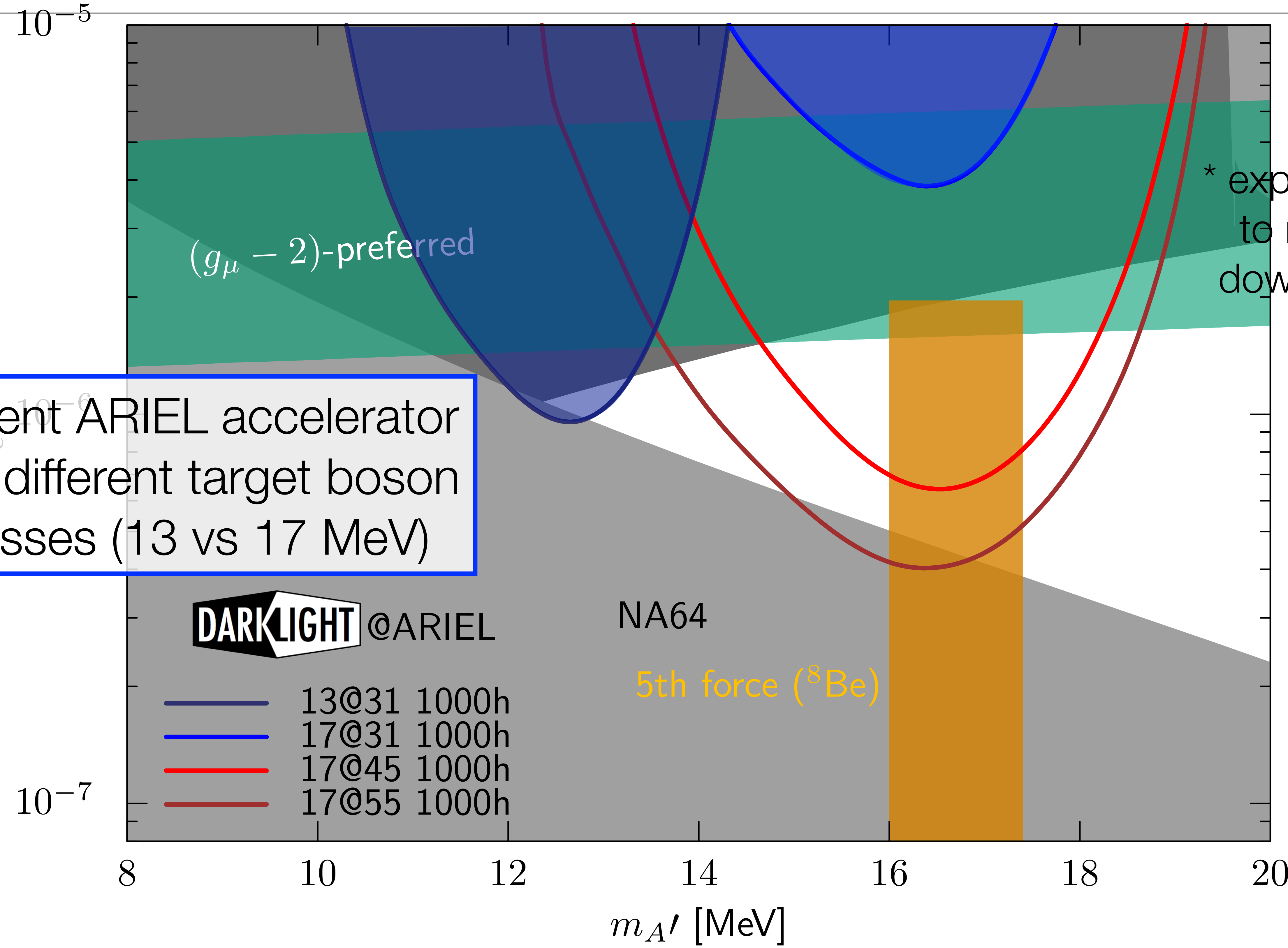


Current ARIEL accelerator with different target boson masses (13 vs 17 MeV)

* 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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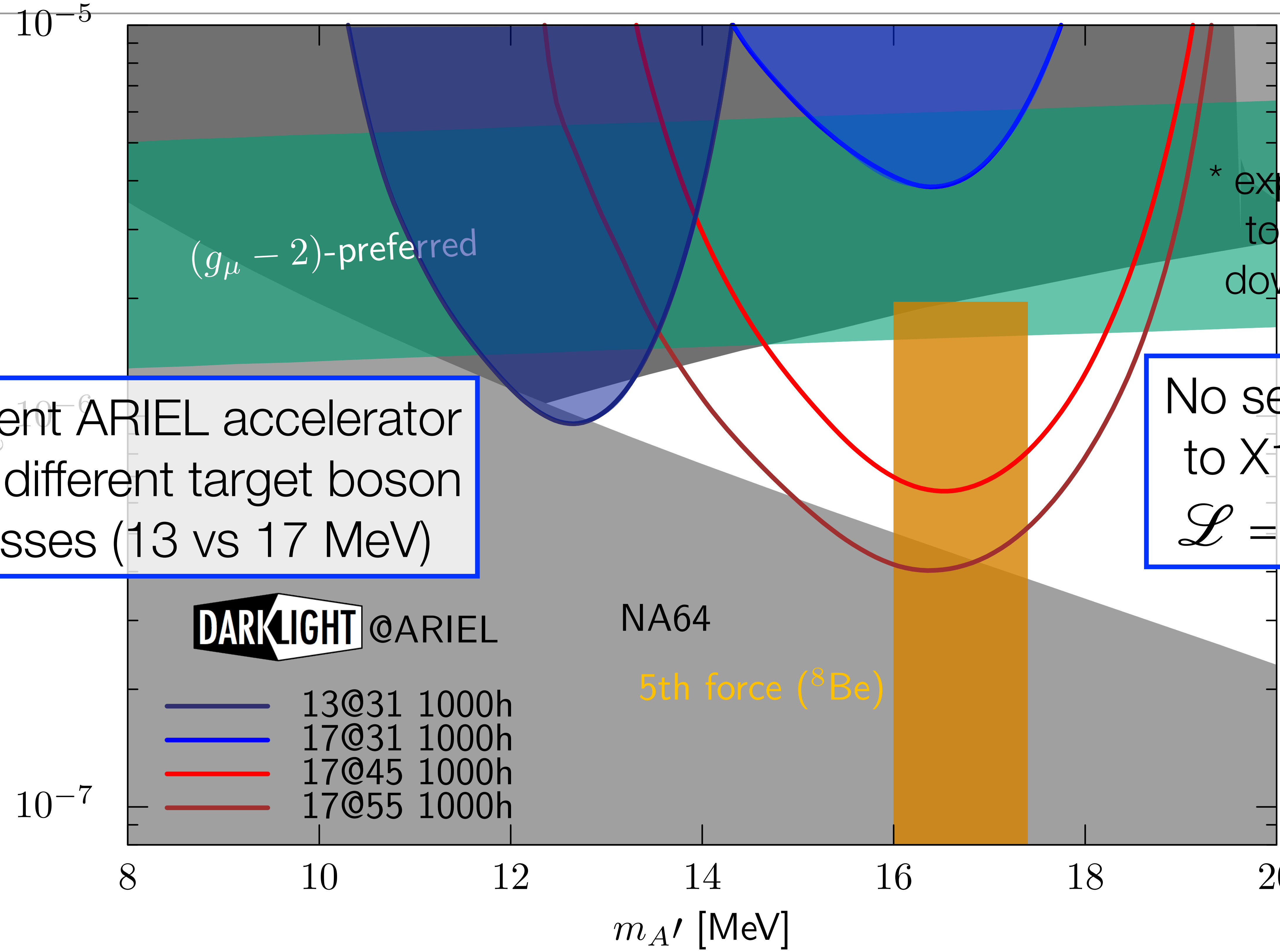

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Current ARIEL accelerator with different target boson masses (13 vs 17 MeV)

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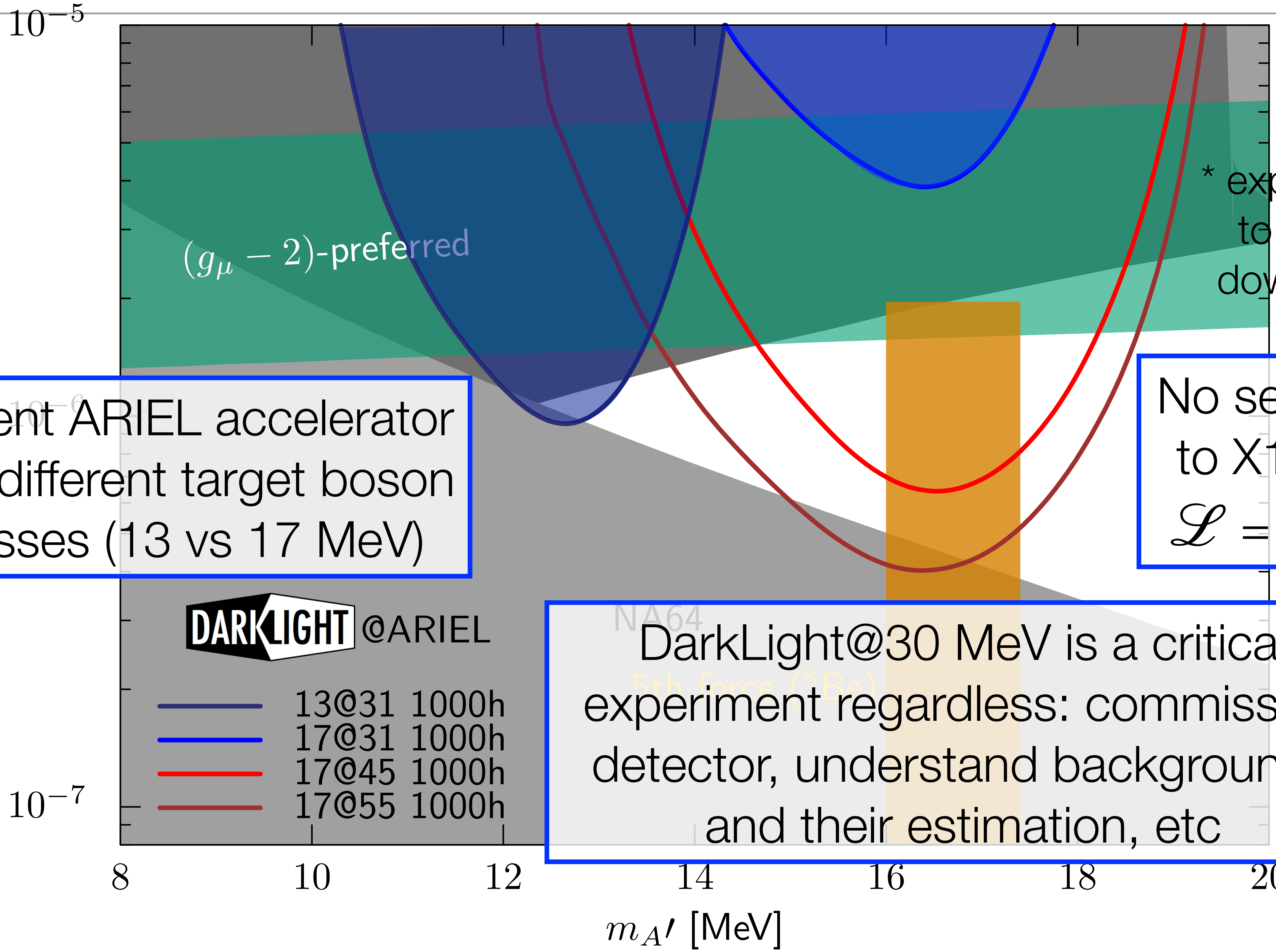


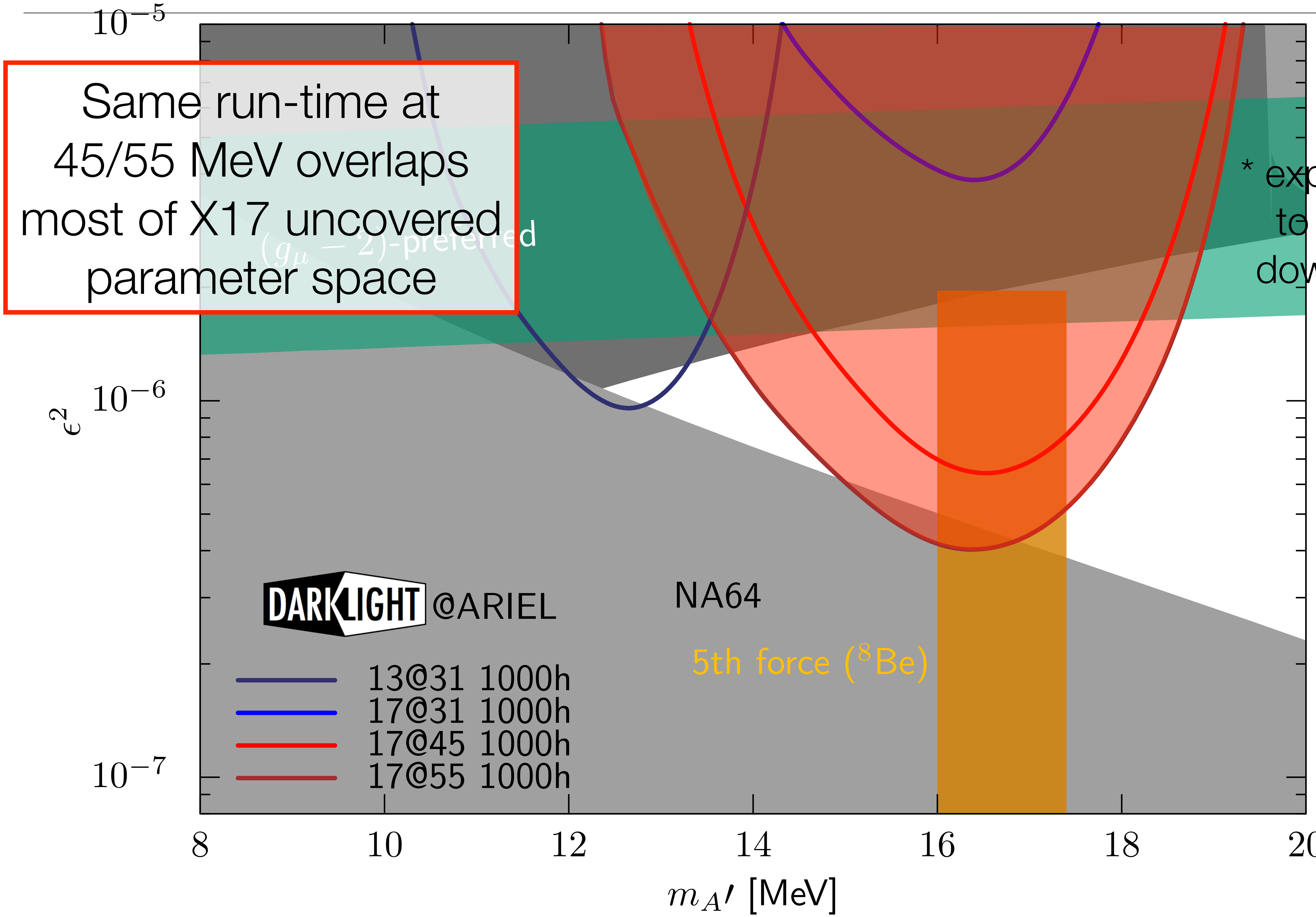
* expect this to move down a bit

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



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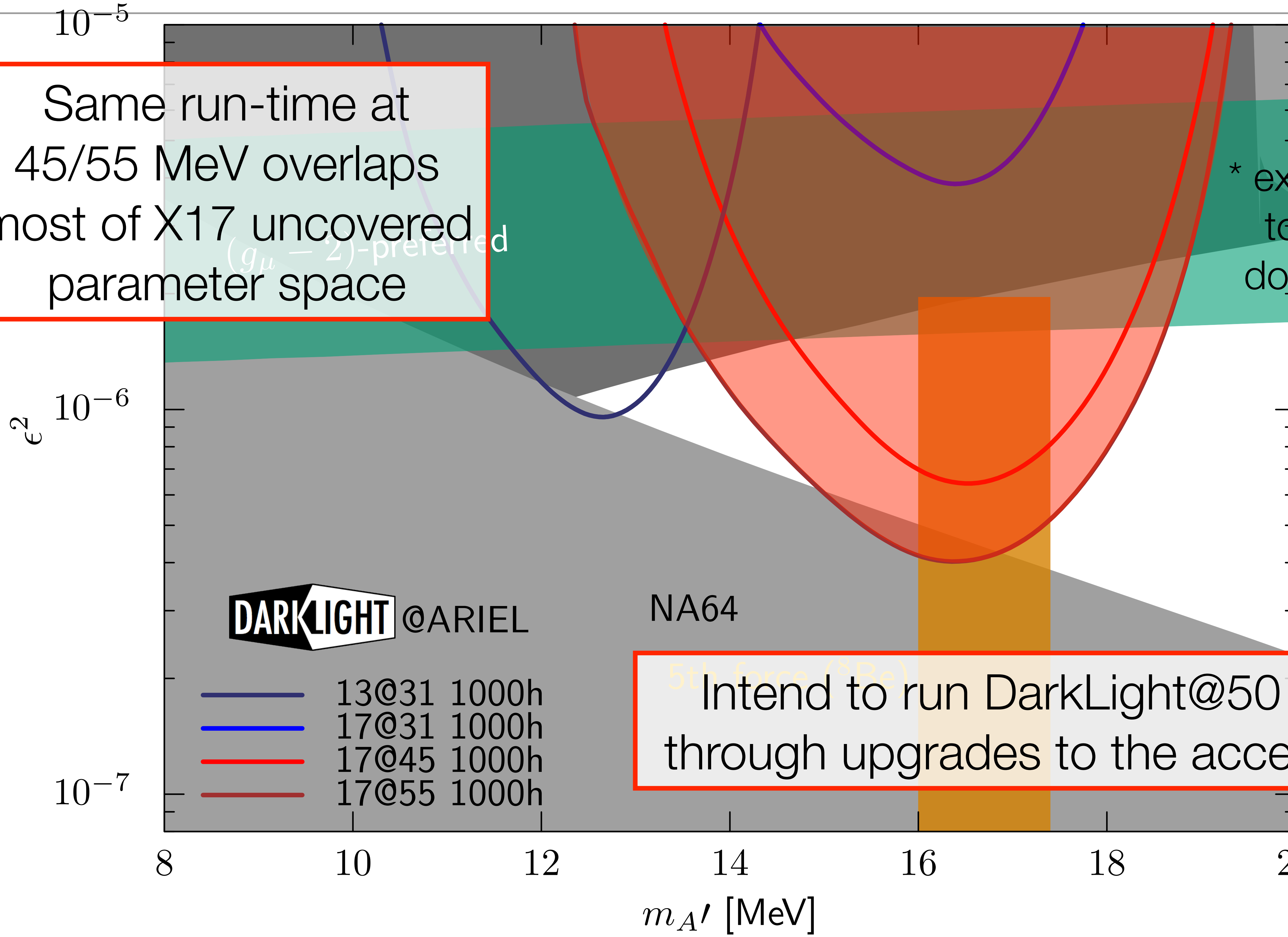
Sensitivity at 30 and 50 MeV accelerators



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

* expect this to move down a bit

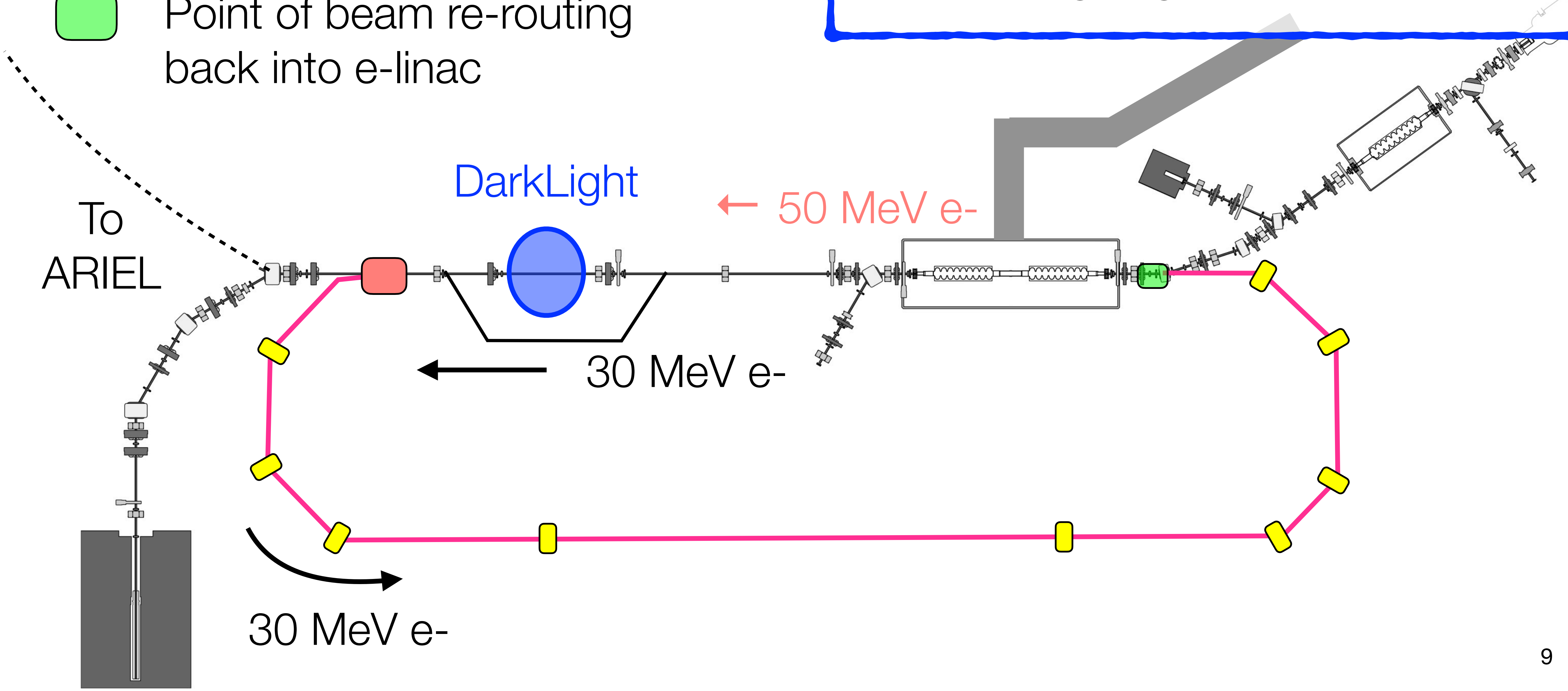
Intend to run DarkLight@50 MeV through upgrades to the accelerator

Stage 1 (running ~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: planned additions

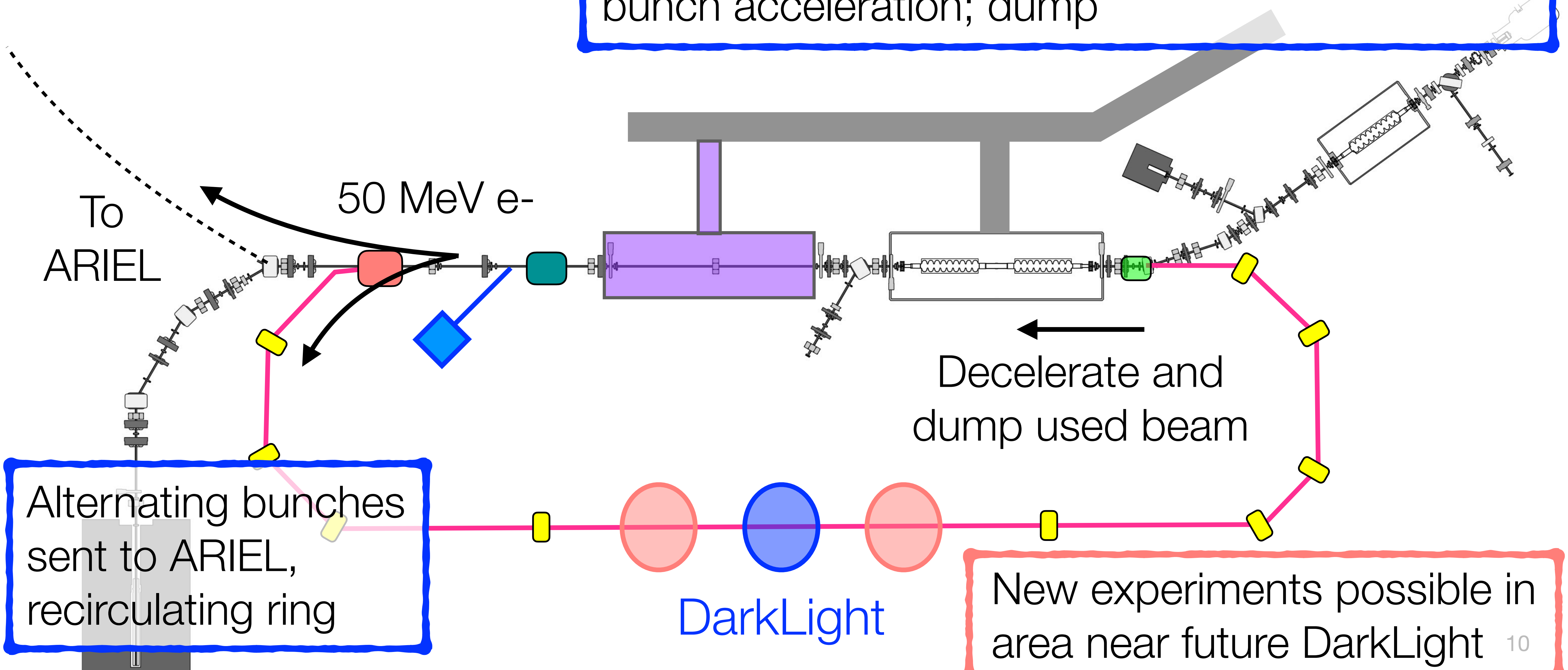
All bunches will pass through recirculating ring, then to dump.



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

- New cryomodule
- RF deflector
- 10 MeV beam dump

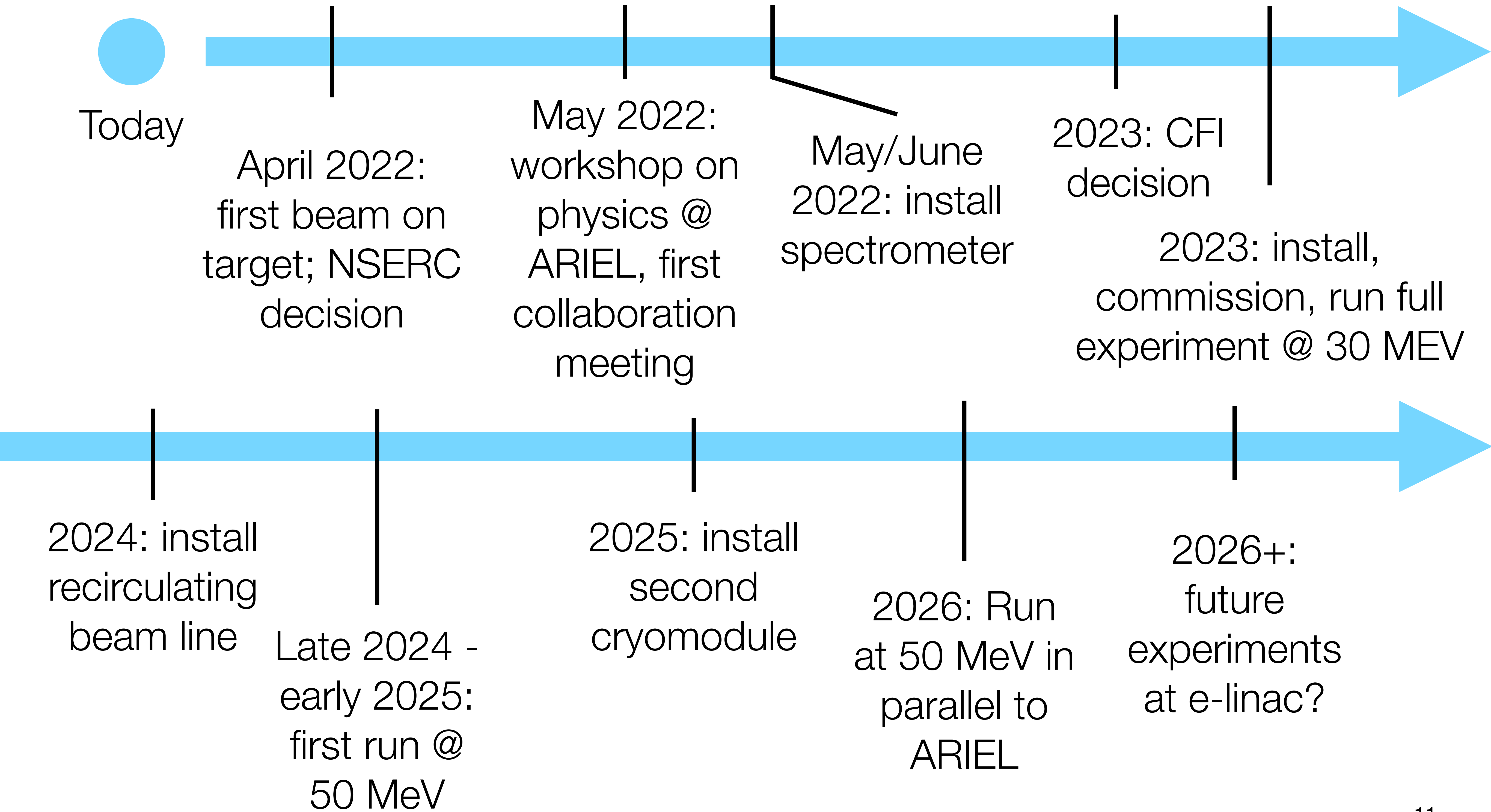
Energy recovery LINAC: path length of recirculating ring adjusted to offset bunches to 180 out of phase with accelerating bunches. Decelerate to 10 MeV simultaneous with new bunch acceleration; dump



Alternating bunches sent to ARIEL, recirculating ring

New experiments possible in area near future DarkLight

Timeline

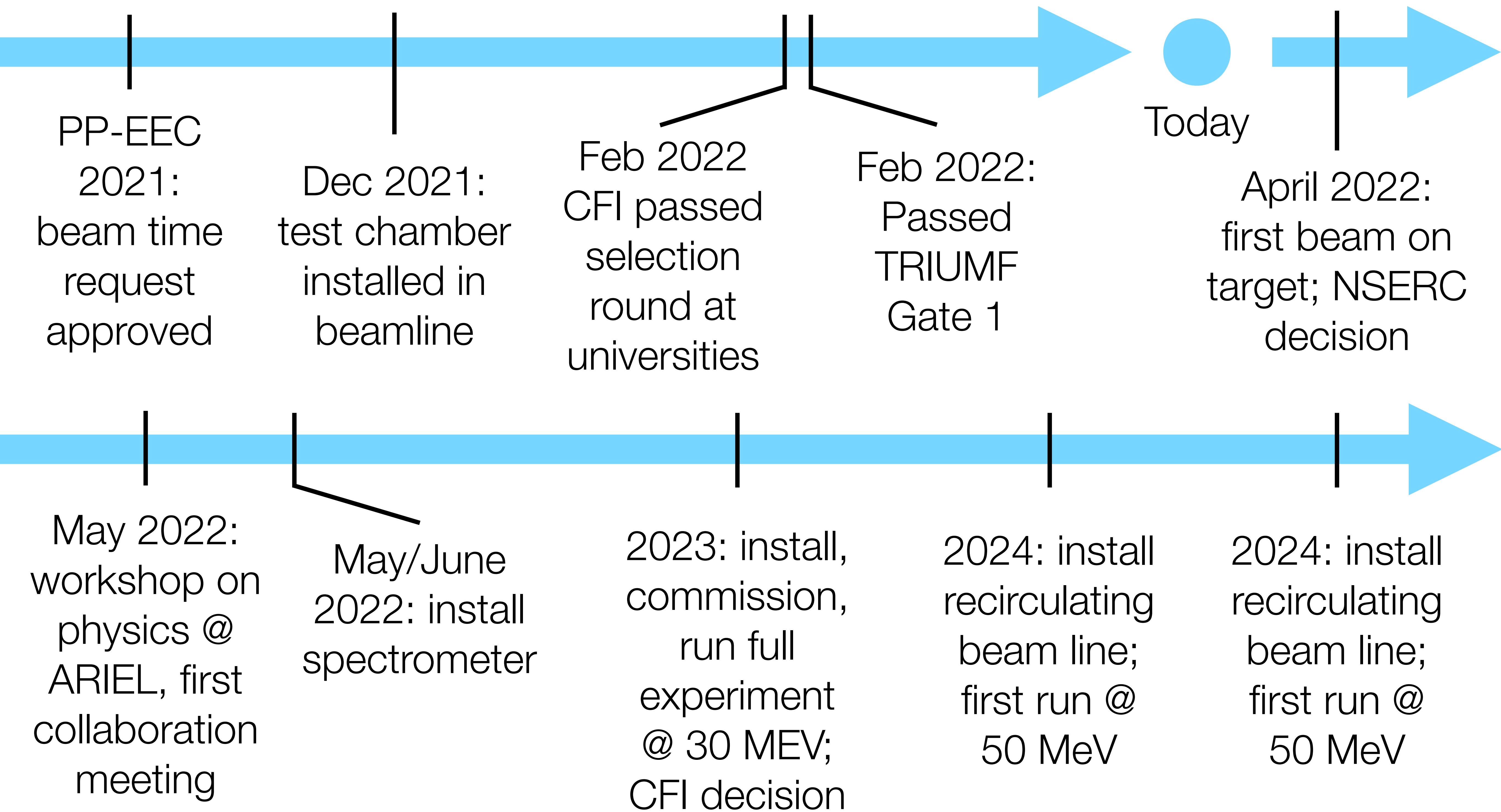

Today
April 2022: first beam on target; NSERC decision
May 2022: workshop on physics @ ARIEL, first collaboration meeting
May/June 2022: install spectrometer
2023: CFI decision
2023: install, commission, run full experiment @ 30 MEV
2024: install recirculating beam line
Late 2024 - early 2025: first run @ 50 MeV
2025: install second cryomodule
2026: Run at 50 MeV in parallel to ARIEL
2026+: future experiments at e-linac?

Conclusions

- DarkLight has **compelling scientific motivation** and a **strong international collaboration** covering all relevant areas of expertise
- Research program spans ~ 5 years beginning now
  - First runs will be complete before 2025
  - **Long term plan includes e-linac energy increase to 50 MeV** along with beam setup that will allow experiments to run in parallel with ARIEL
- **Hosting workshop at TRIUMF** in May for DarkLight + other new ideas for ARIEL e-linac based experiments

Thank you!

Timeline and milestones

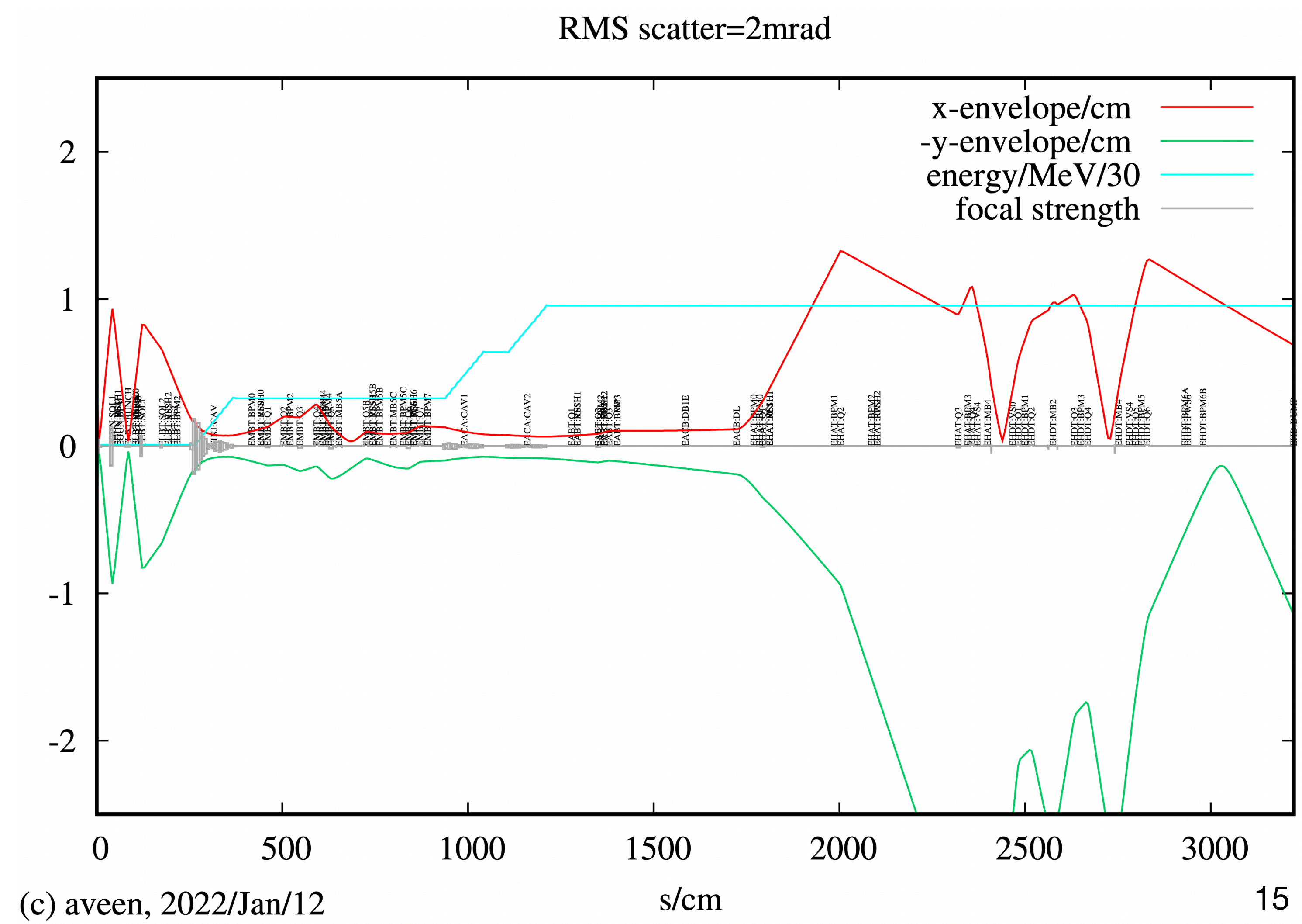


Target and beamline interplay

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

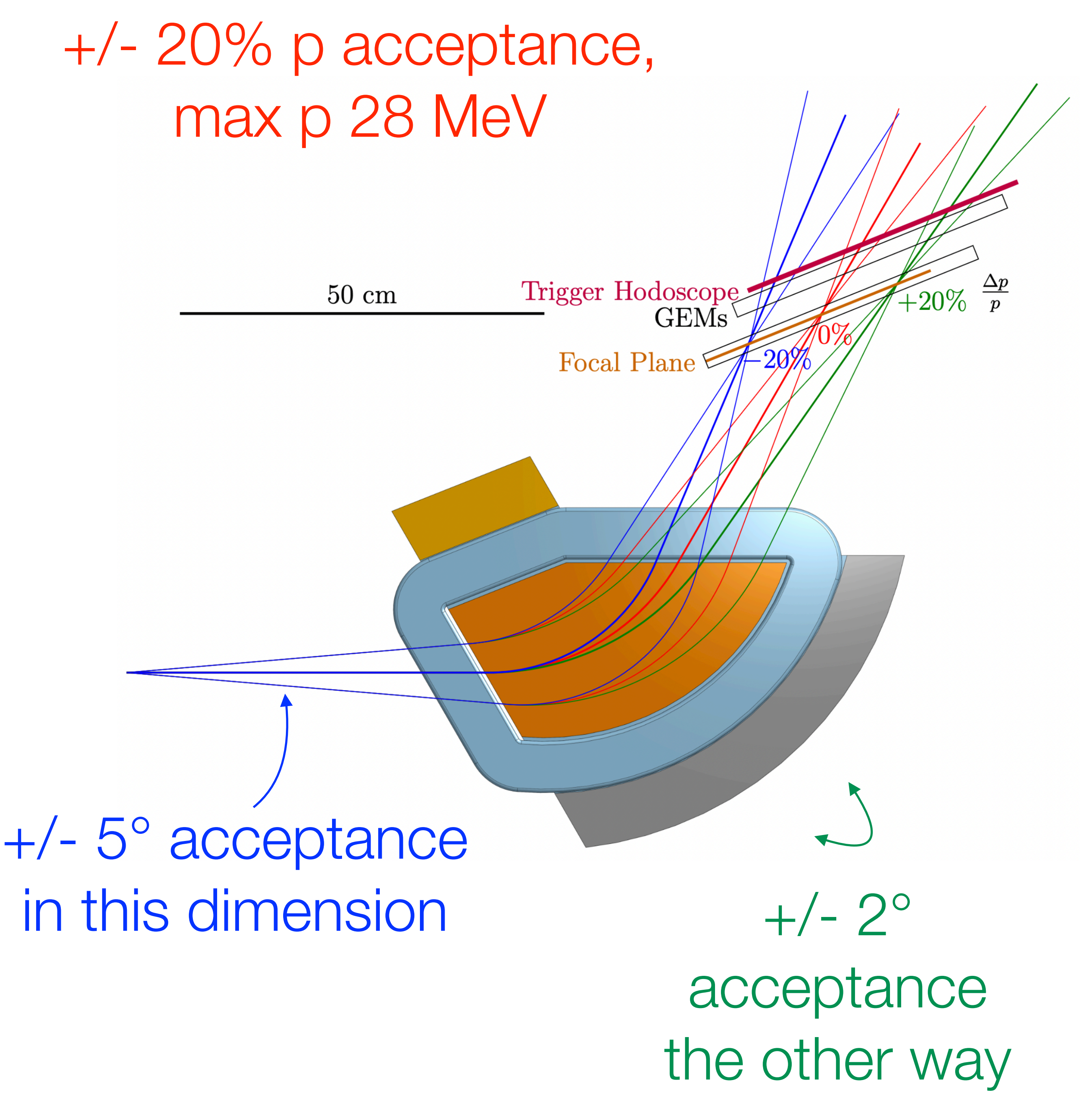
- Now, detailed studies ongoing on impact of target foil on beam. Dispersion is high relative to what beam optics were designed for

- 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



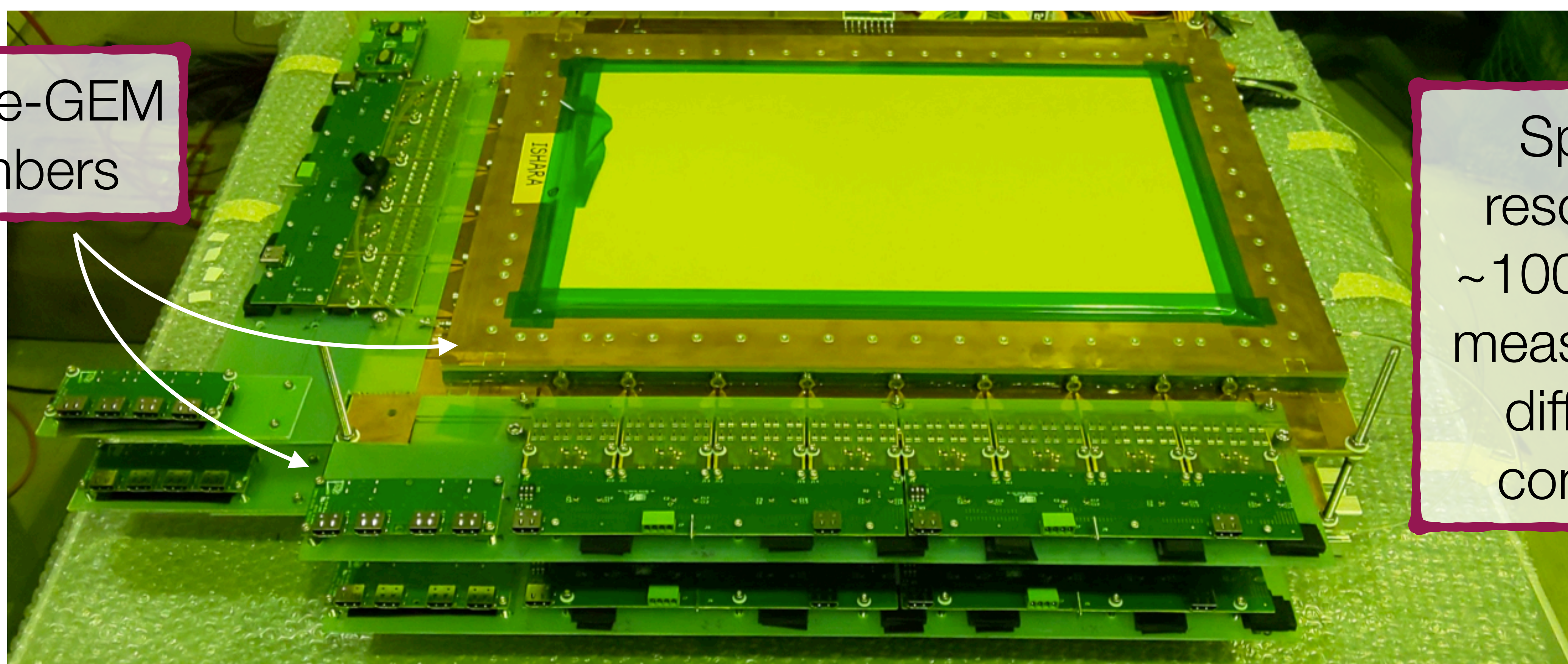
Experiment status: spectrometers

- 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



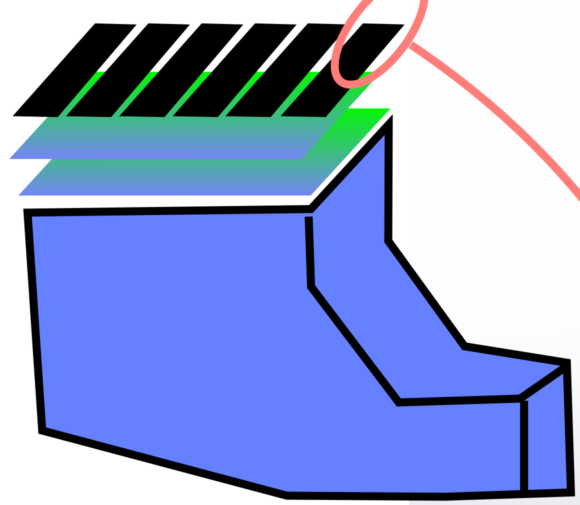
Experiment status: GEM detectors

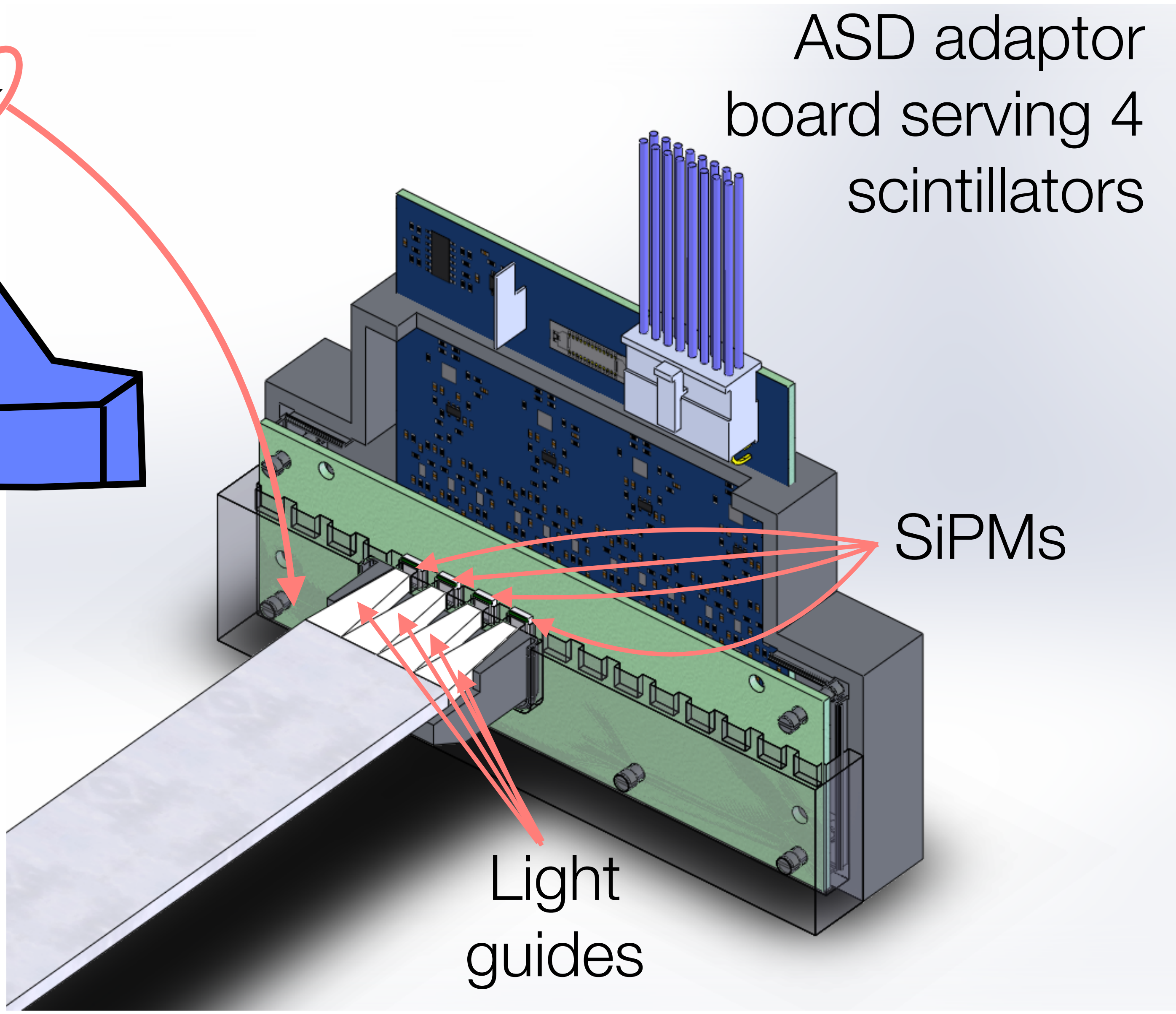
- **Already completed** by Hampton University group with NSF funds
- GEMs: dimension 25 x 40 cm triple-GEMs built using improved techniques developed at CMS. Some modules already in use
- Six GEM chambers will be available for DarkLight use by spring of 2023, along with sufficient readout electronics. Commissioning to be completed at JLab/ELPH in intervening months.



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

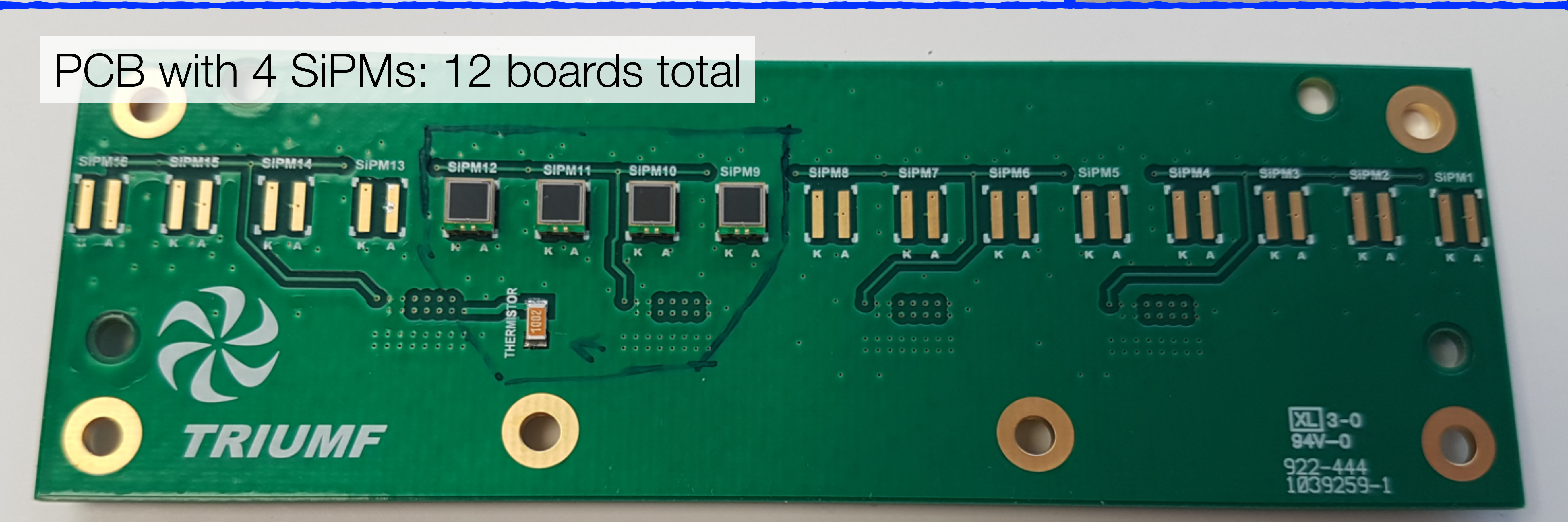




Prototype scintillator dimensions:
150 mm x 30 mm x 3 mm

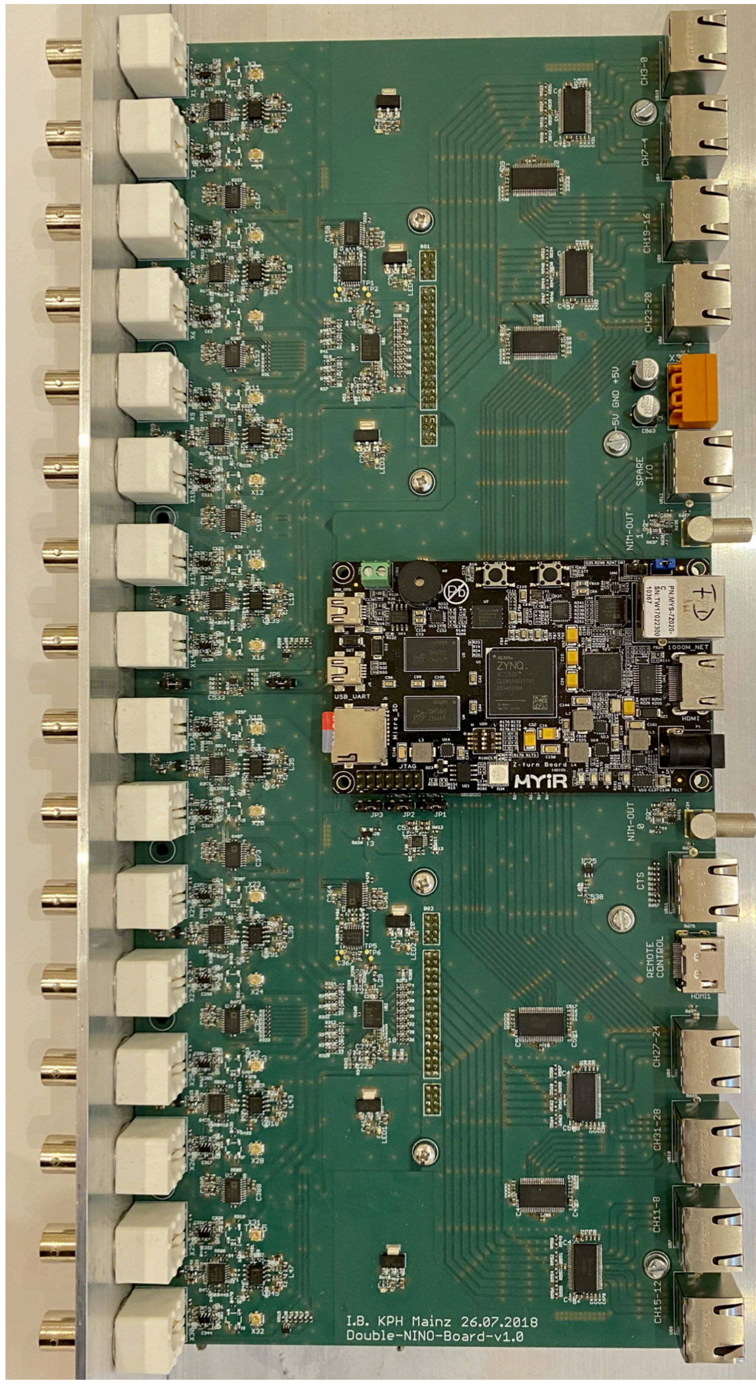

Scintillators mid-wrapping…


… and wrapped
TDE3024

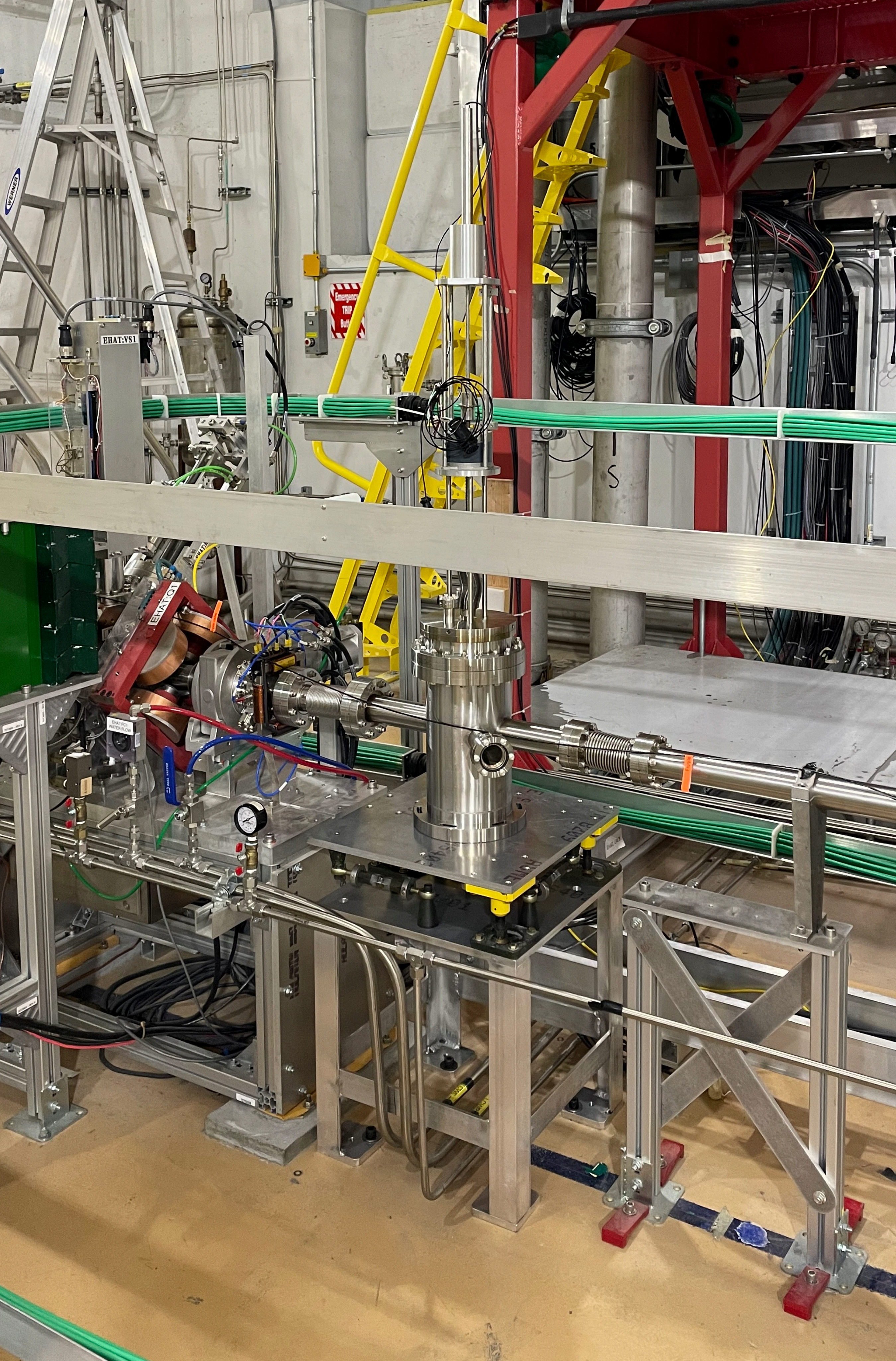

PCB with 4 SiPMs: 12 boards total
SiPM15
SiPM14
SiPM13
SiPM12
SiPM11
SiPM10
SiPM9
SiPM8
SiPM7
SiPM6
SiPM5
SiPM4
SiPM3
SiPM2
SiPM1
THERMISTOR
TRIUMF
94V-0
922-444
1039259-1

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