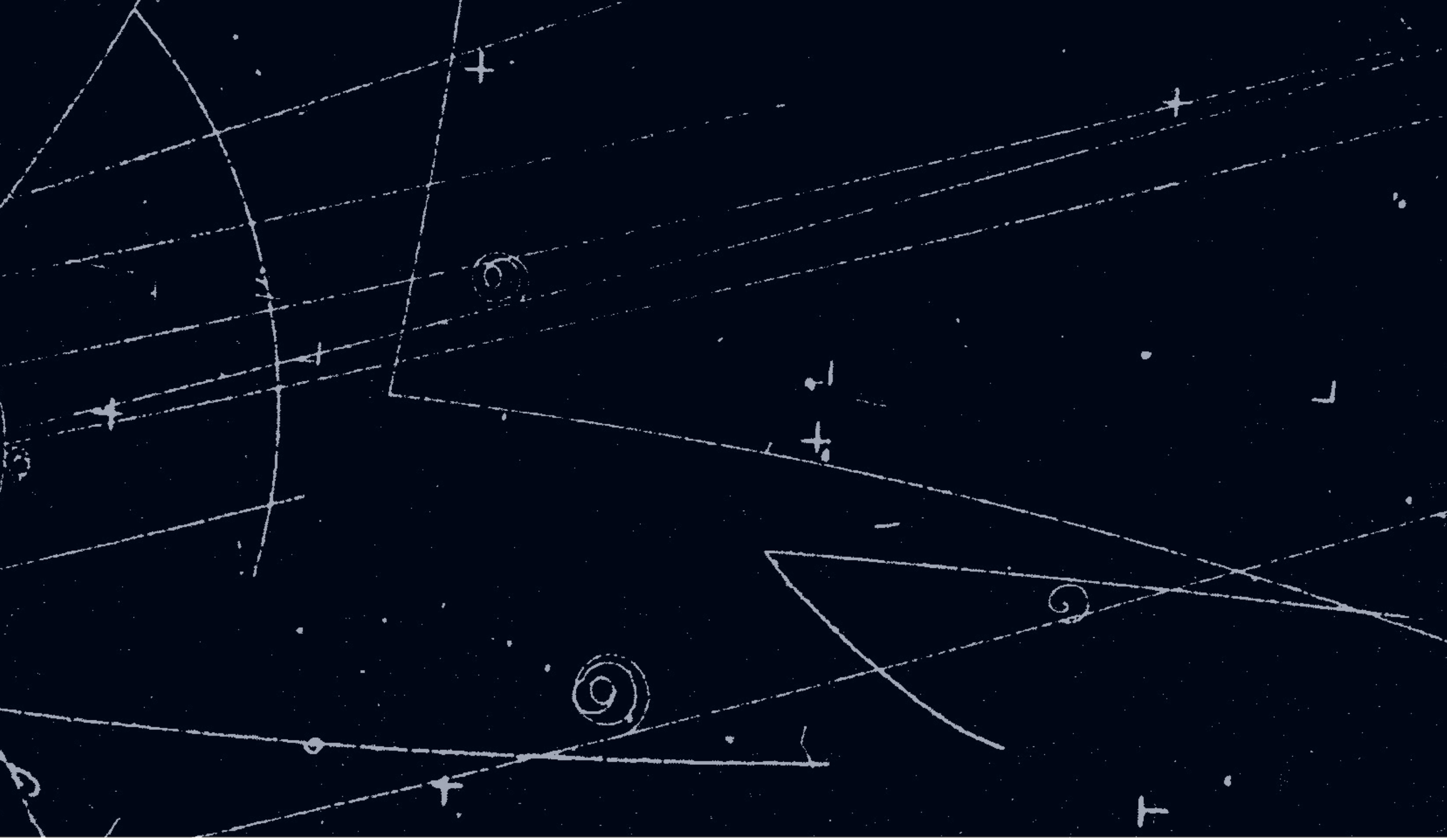

The DarkLight@ARIEL experiment

Kate Pachal
TRIUMF
o.b.o the DarkLight collaboration

Introduction

- DarkLight@ARIEL is a **new experiment** to be built **at TRIUMF** searching for low-mass e+e- resonances
  - Following previous work at JLab
  - Compelling scientific motivation and a strong international collaboration covering all relevant areas of expertise

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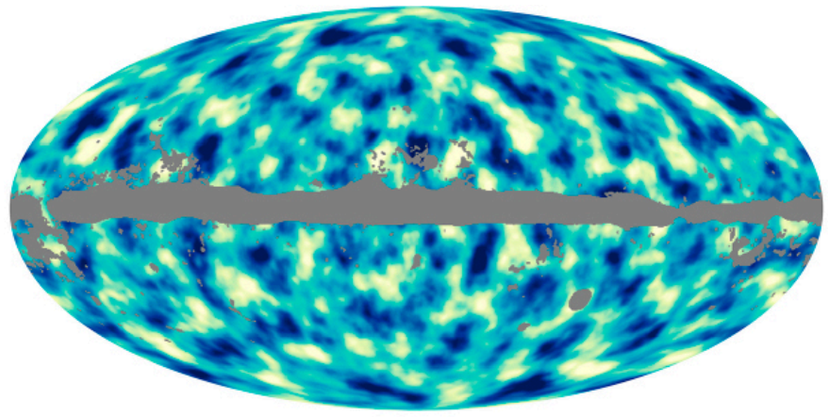
  - Following previous work at JLab
  - Compelling scientific motivation and a strong international collaboration covering all relevant areas of expertise
- Today: brief overview of **physics motivation**, then outline **current status**
  - **Construction** of full experiment **about to begin**, with initial installations for test experiments in place
  - **Future plans** are converging, with dependence on funding

Uniting dark matter with particle physics experimental anomalies

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



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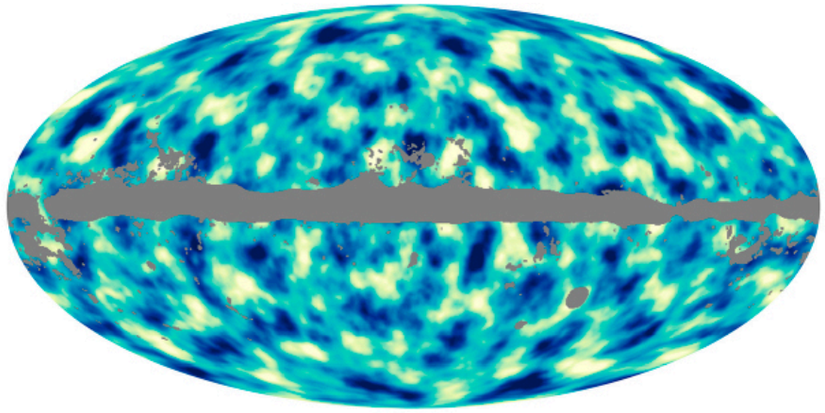

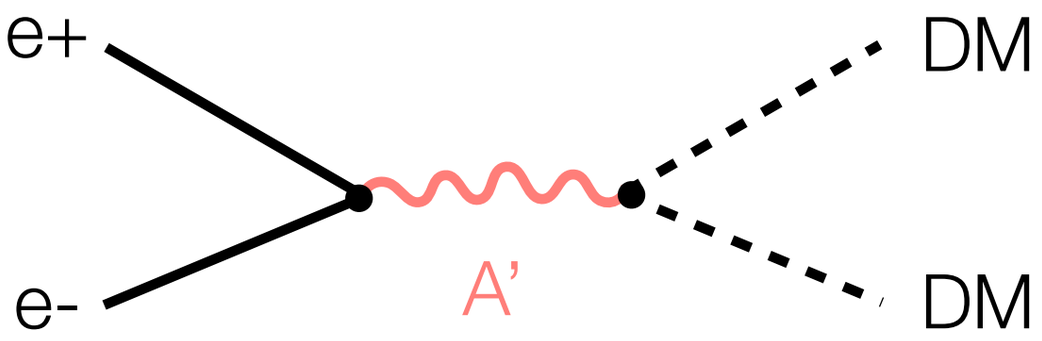

Many many possibilities, but among them: s-channel boson could act as a mediator to dark sector

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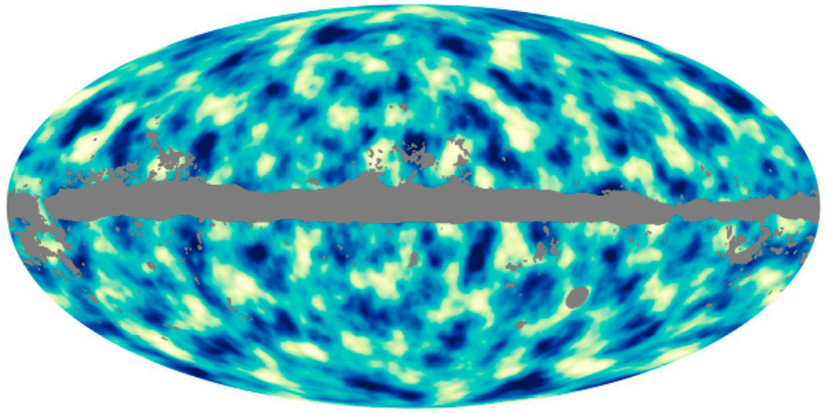

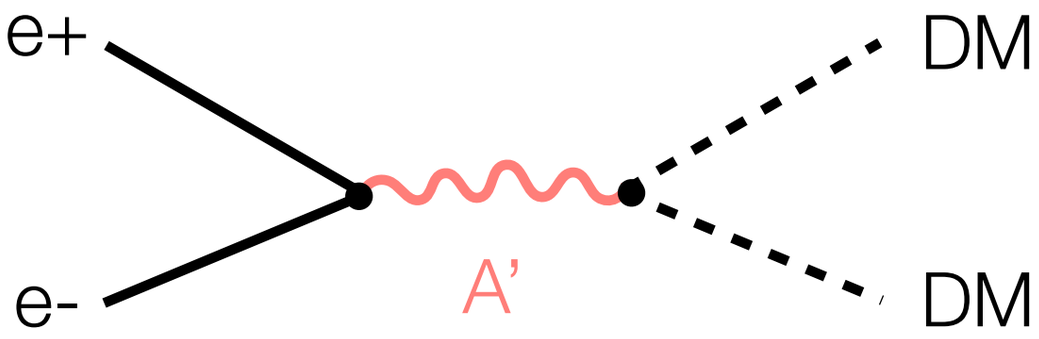

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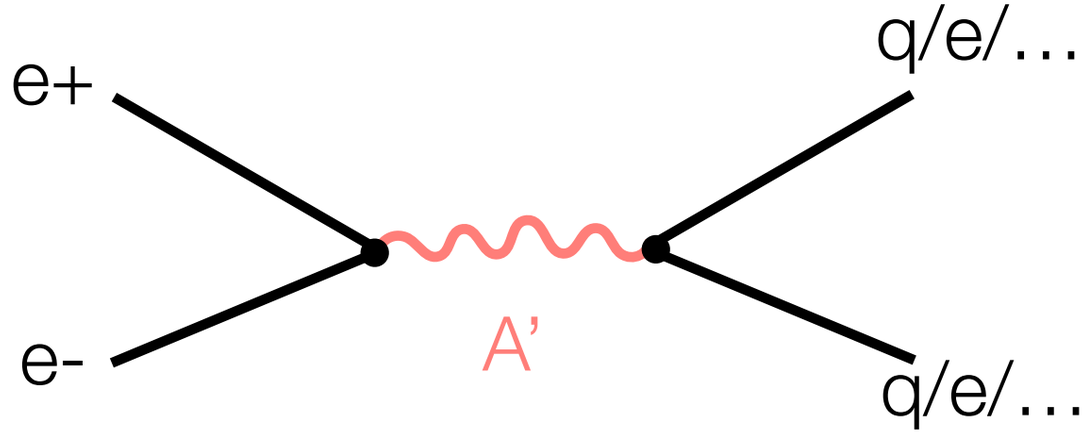
Depending on relative couplings and masses of SM versus dark sector particles, visible decays can dominate



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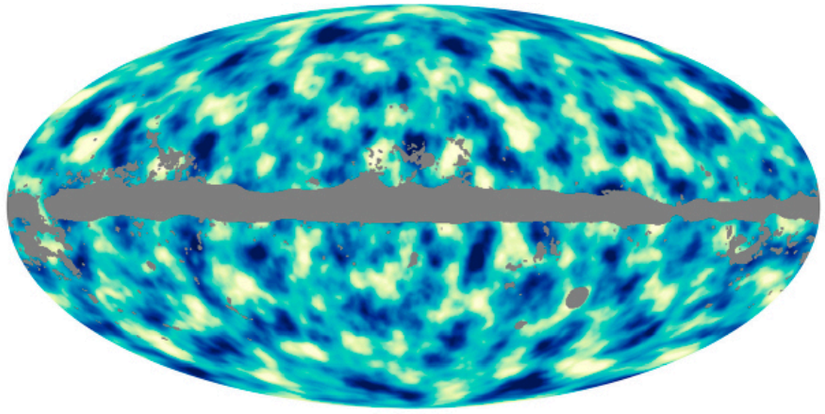

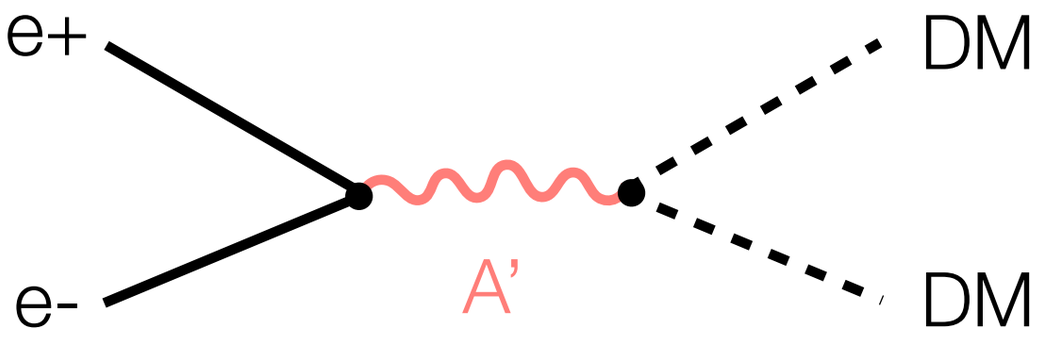

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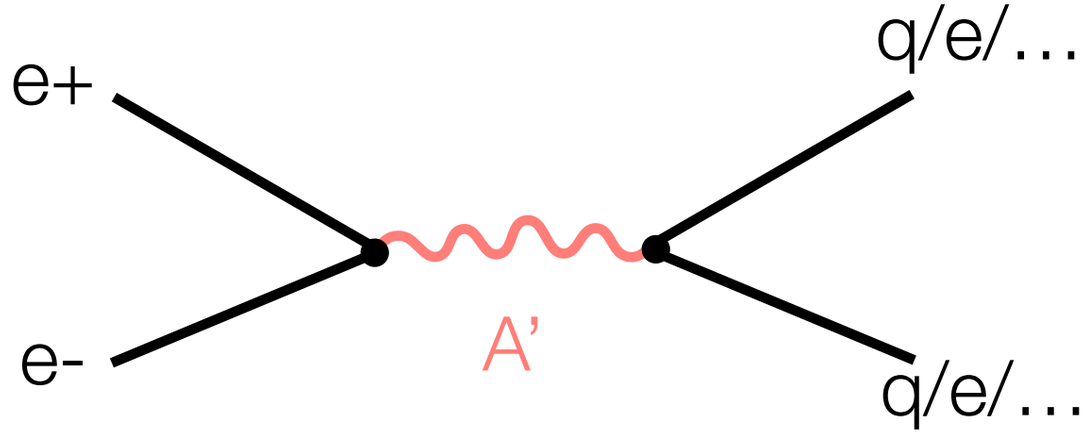
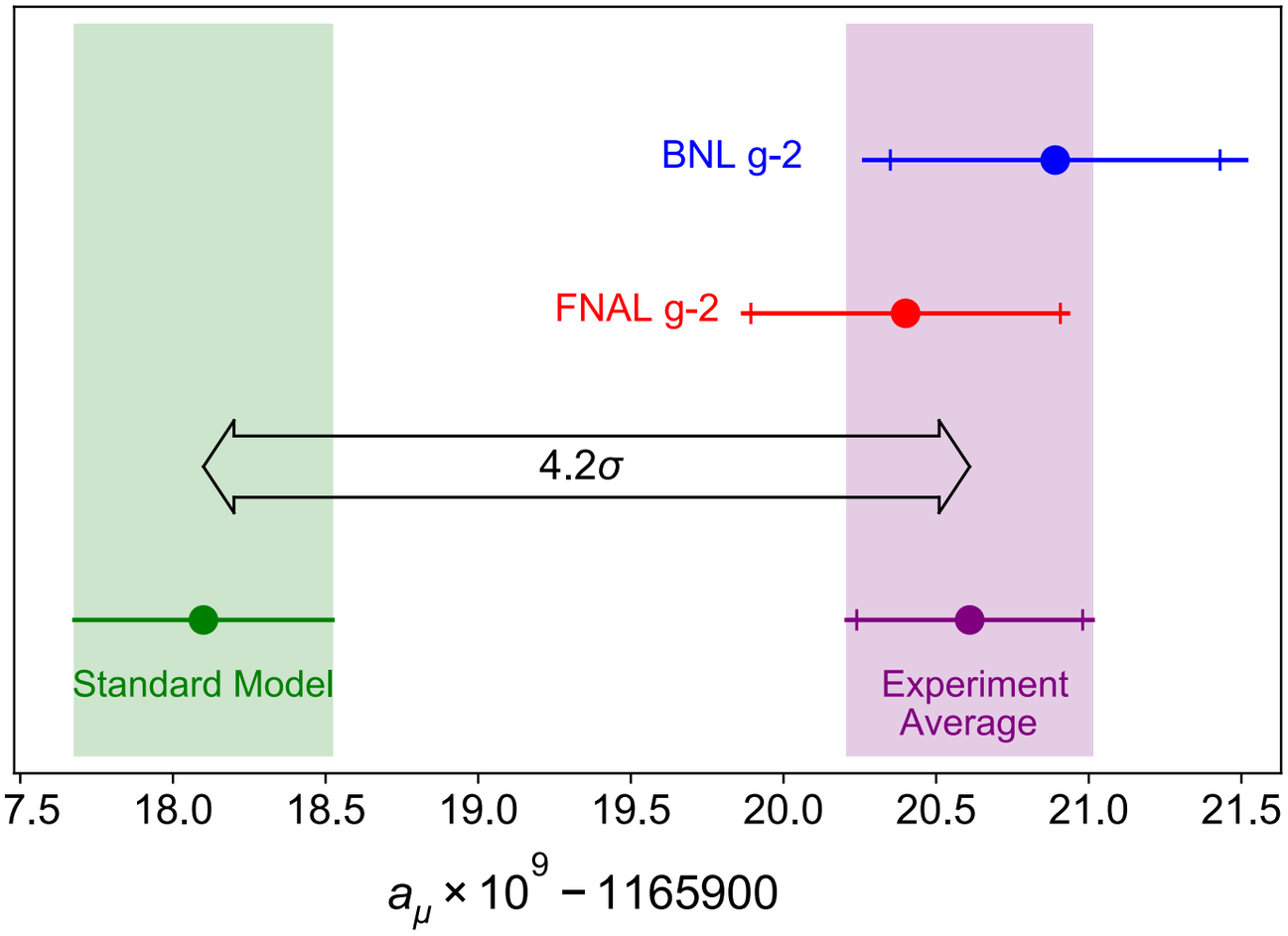


Where to look for such a particle?
Some experimental hints ….

Light BSM boson: existing experimental oddities

Muon g-2: 4.2(?) σ discrepancy



Muon g-2 collaboration,
Phys. Rev. Lett. 126, 141801 (2021)

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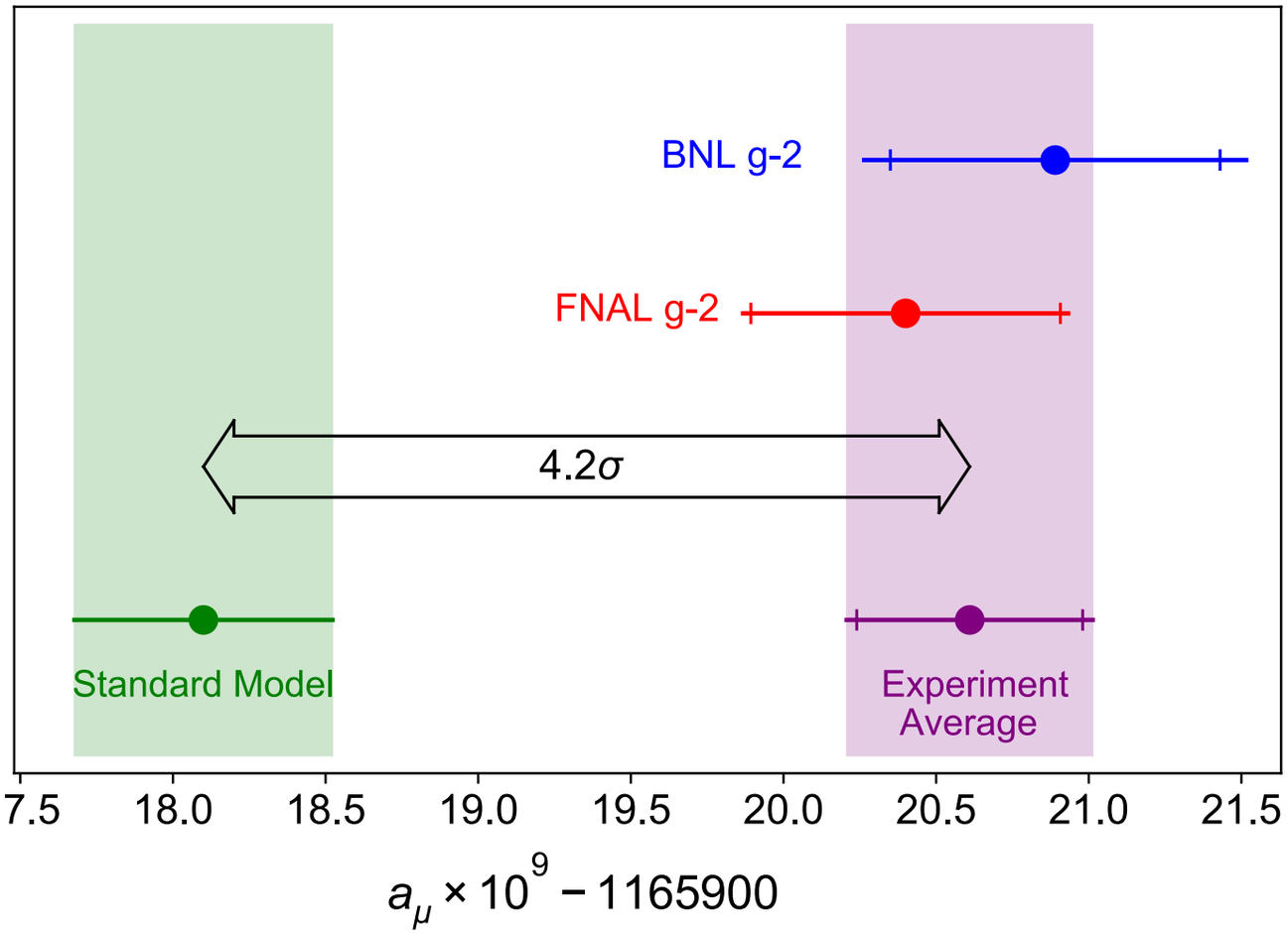

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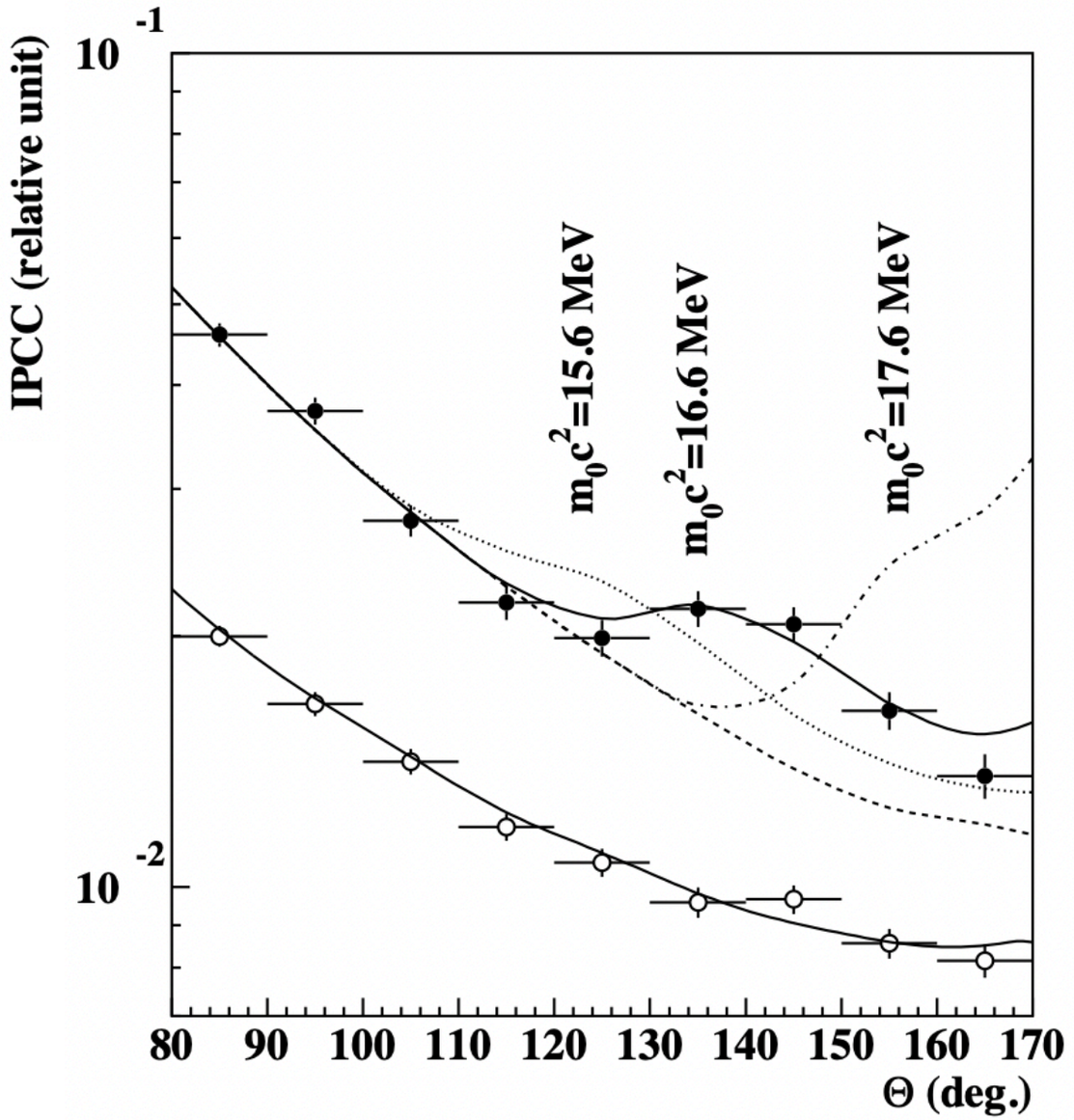
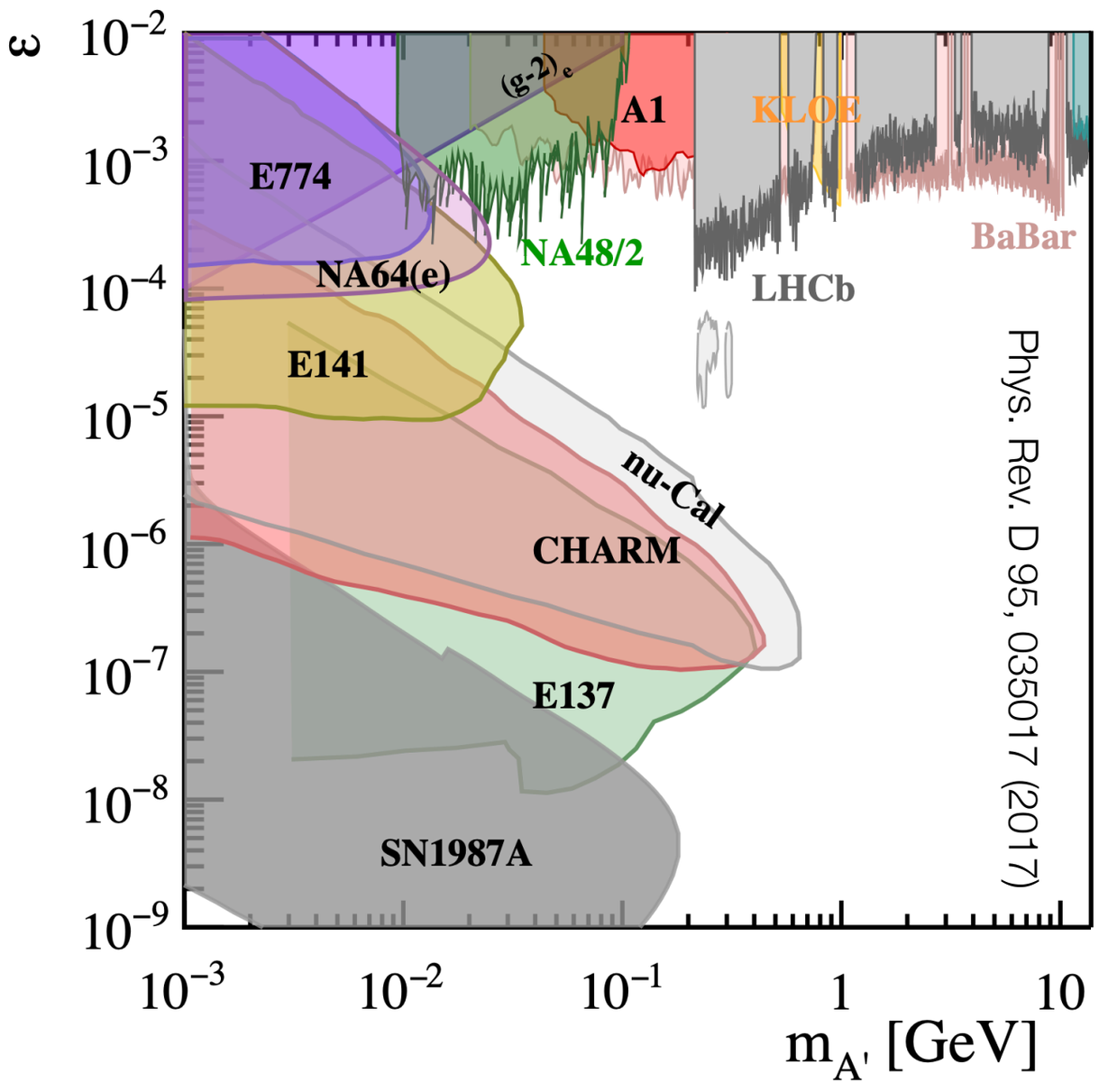
"X17" anomaly



ATOMKI Institute for Nuclear Research,
Phys. Rev. Lett. 116, 042501 (2016)

Model dependence of exclusion limits

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



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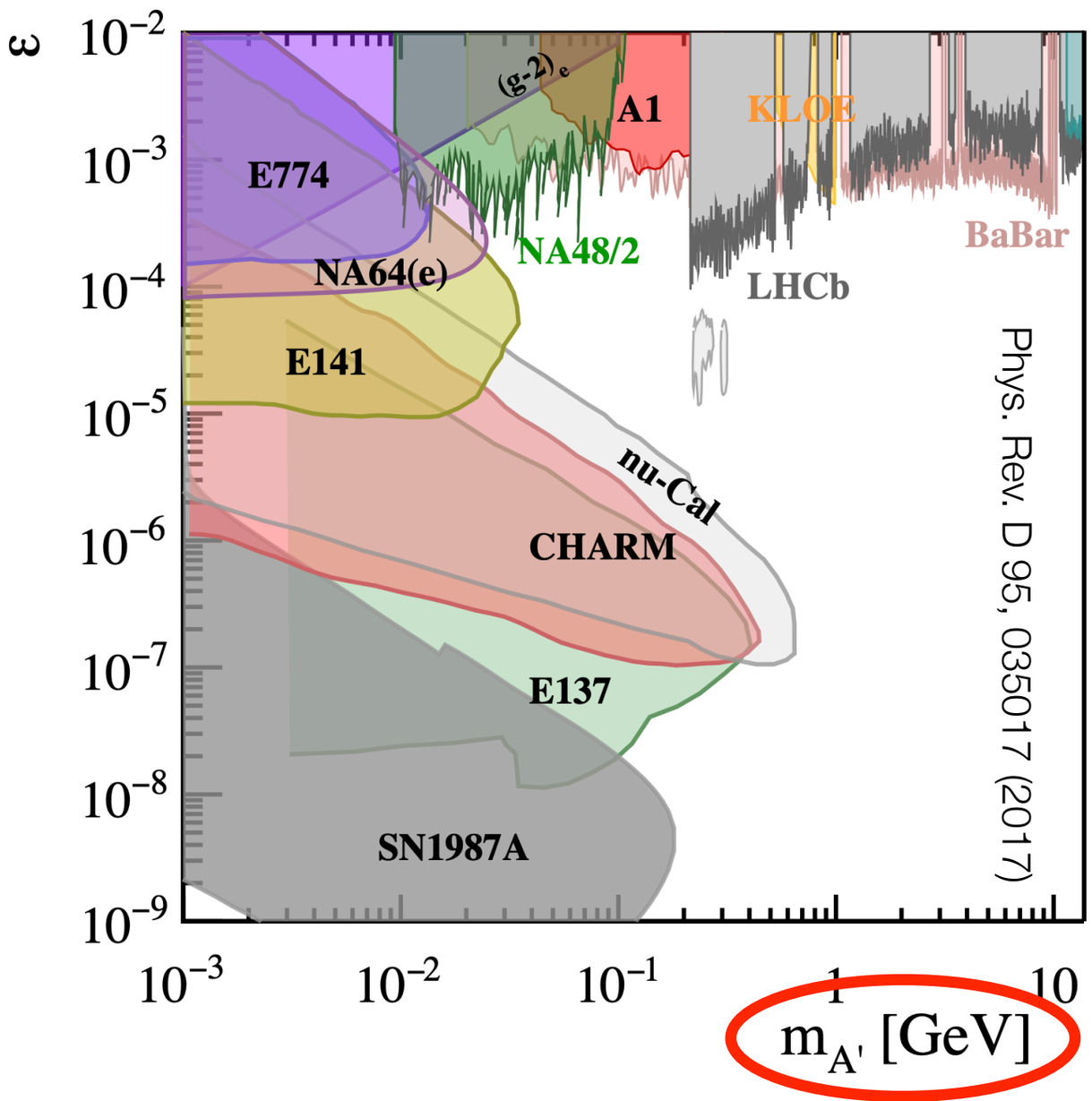

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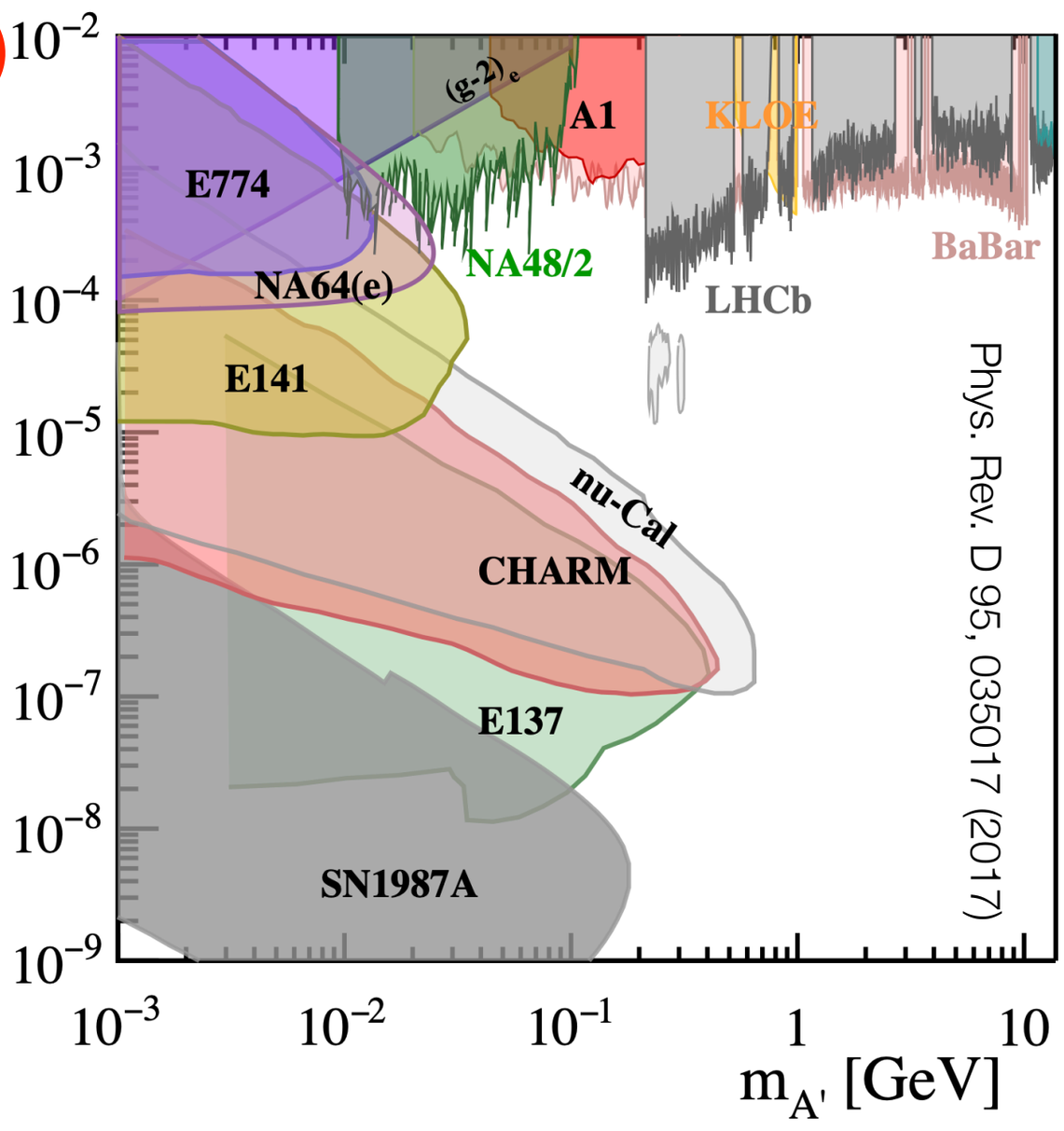

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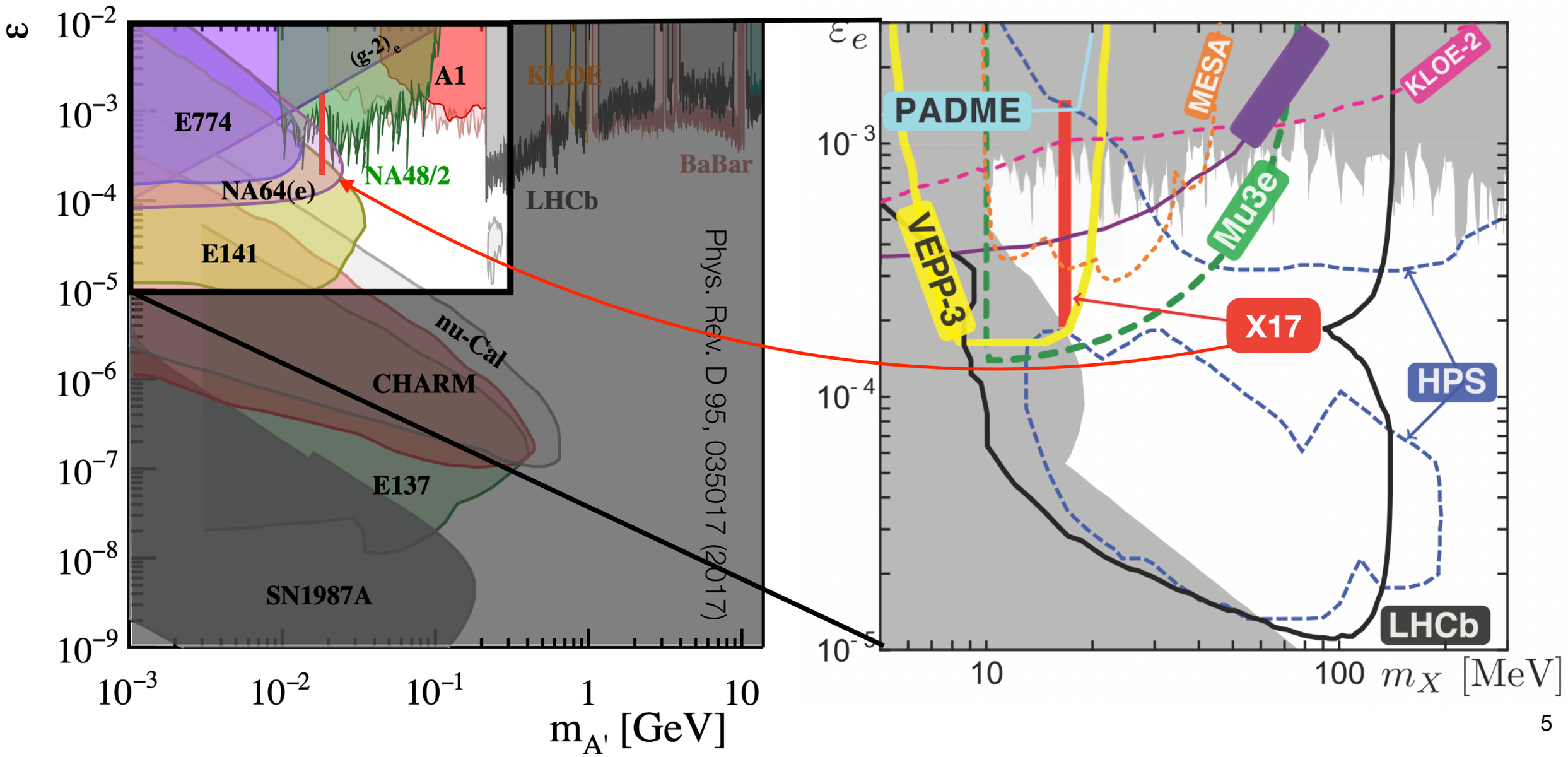

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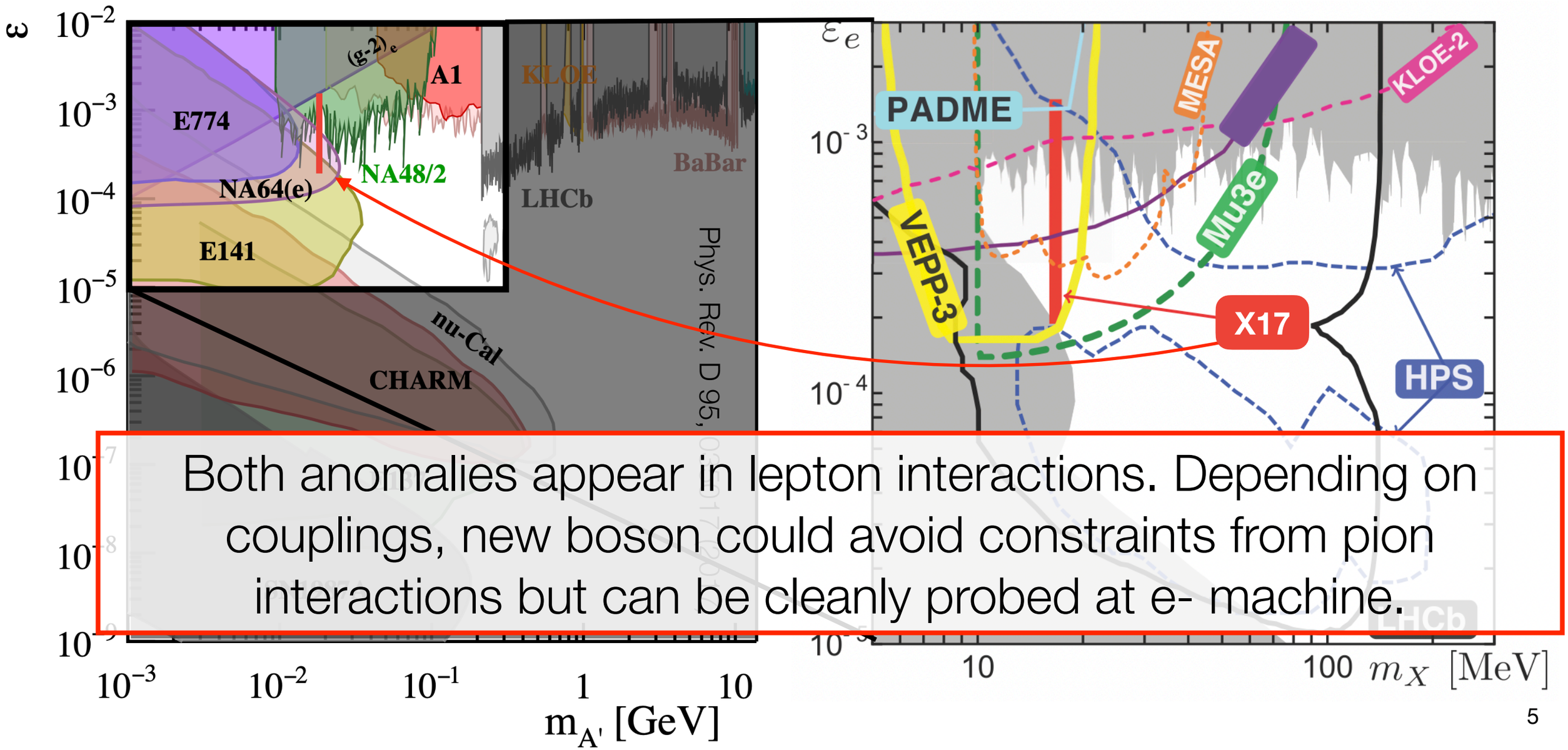
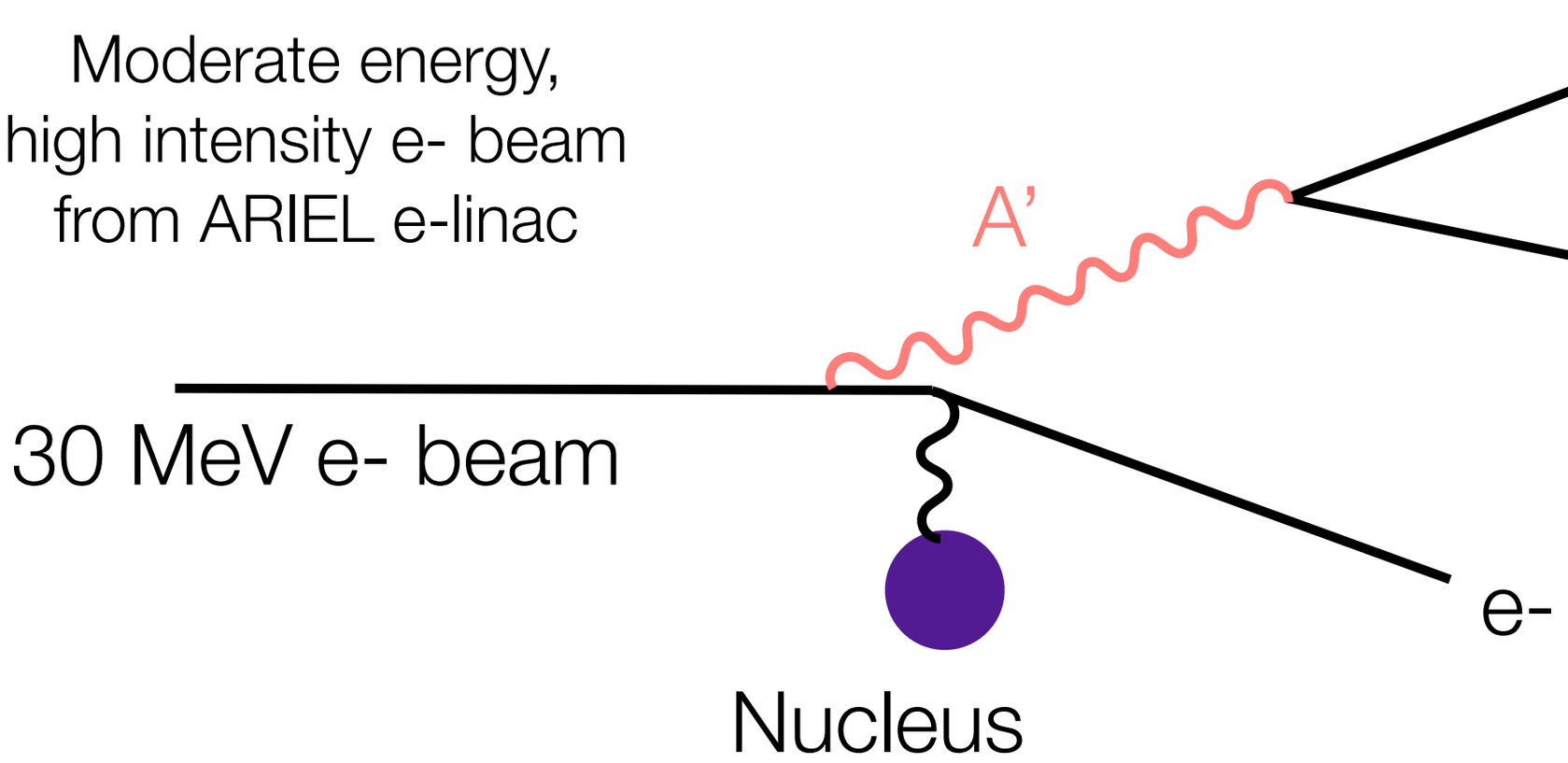


Both anomalies appear in lepton interactions. Depending on couplings, new boson could avoid constraints from pion interactions but can be cleanly probed at e- machine.

The DarkLight @ ARIEL experiment

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



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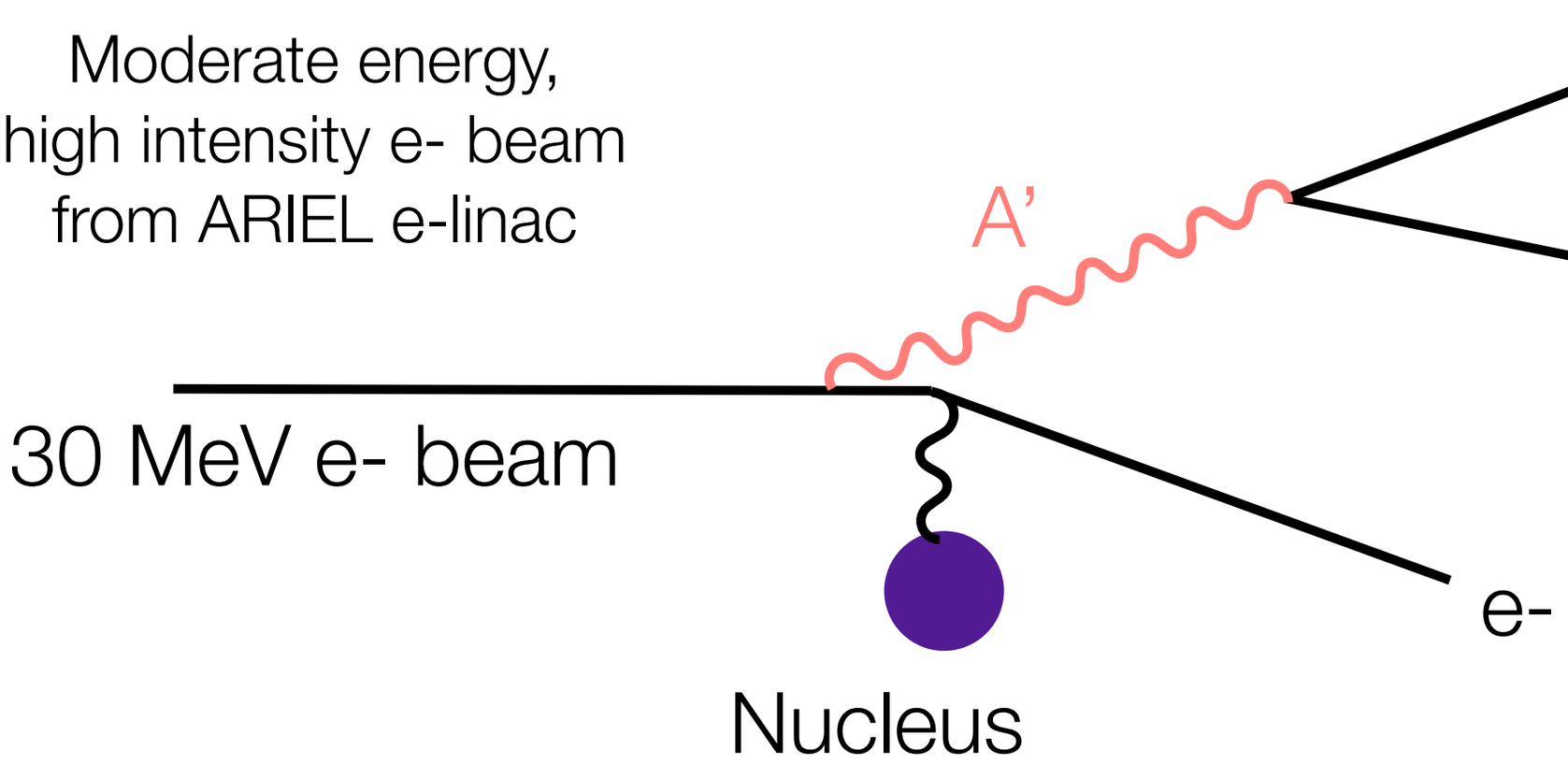

High-density target:
baseline is 1 μm
Tantalum foil

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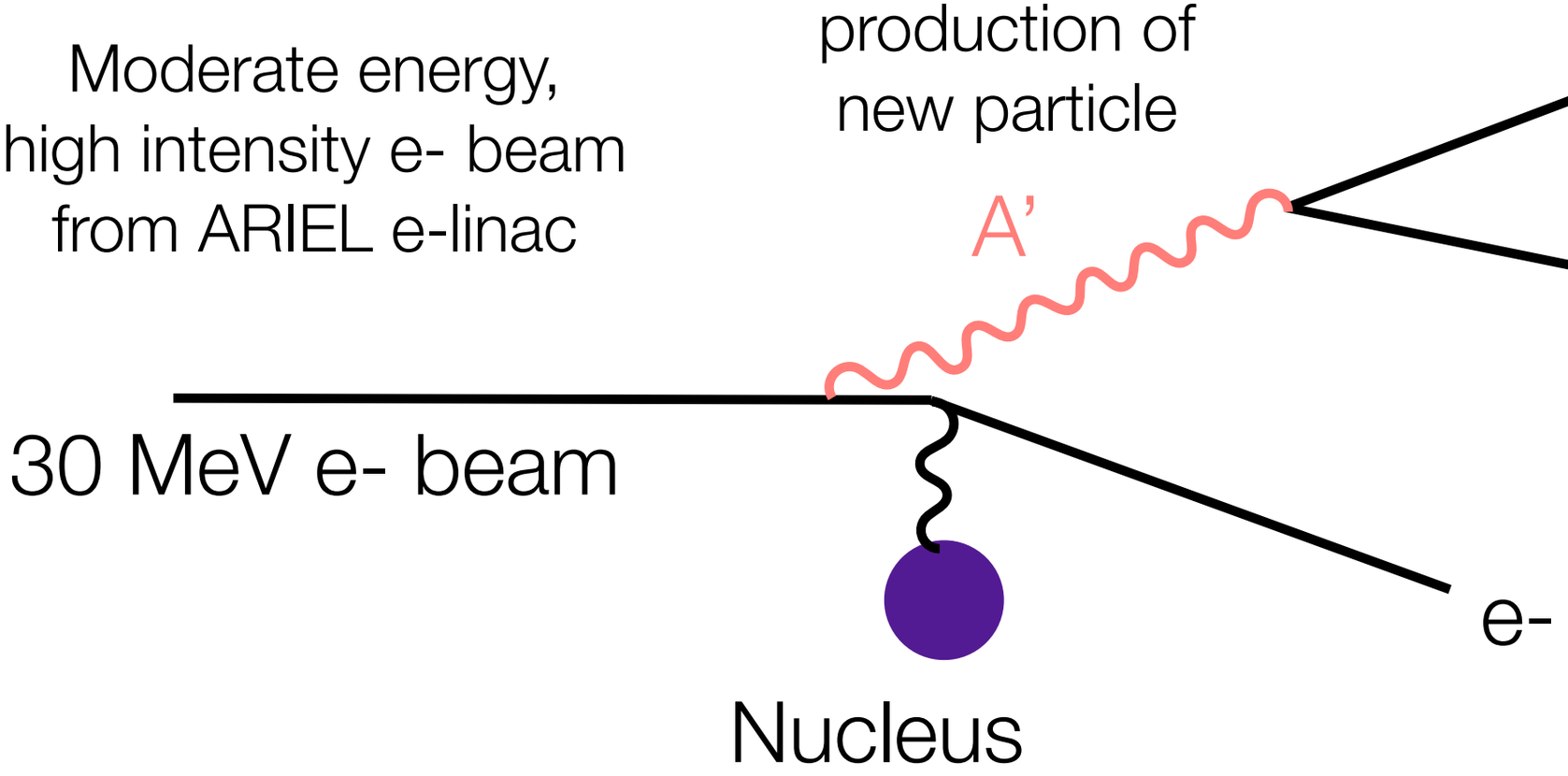
Radiative production of new particle



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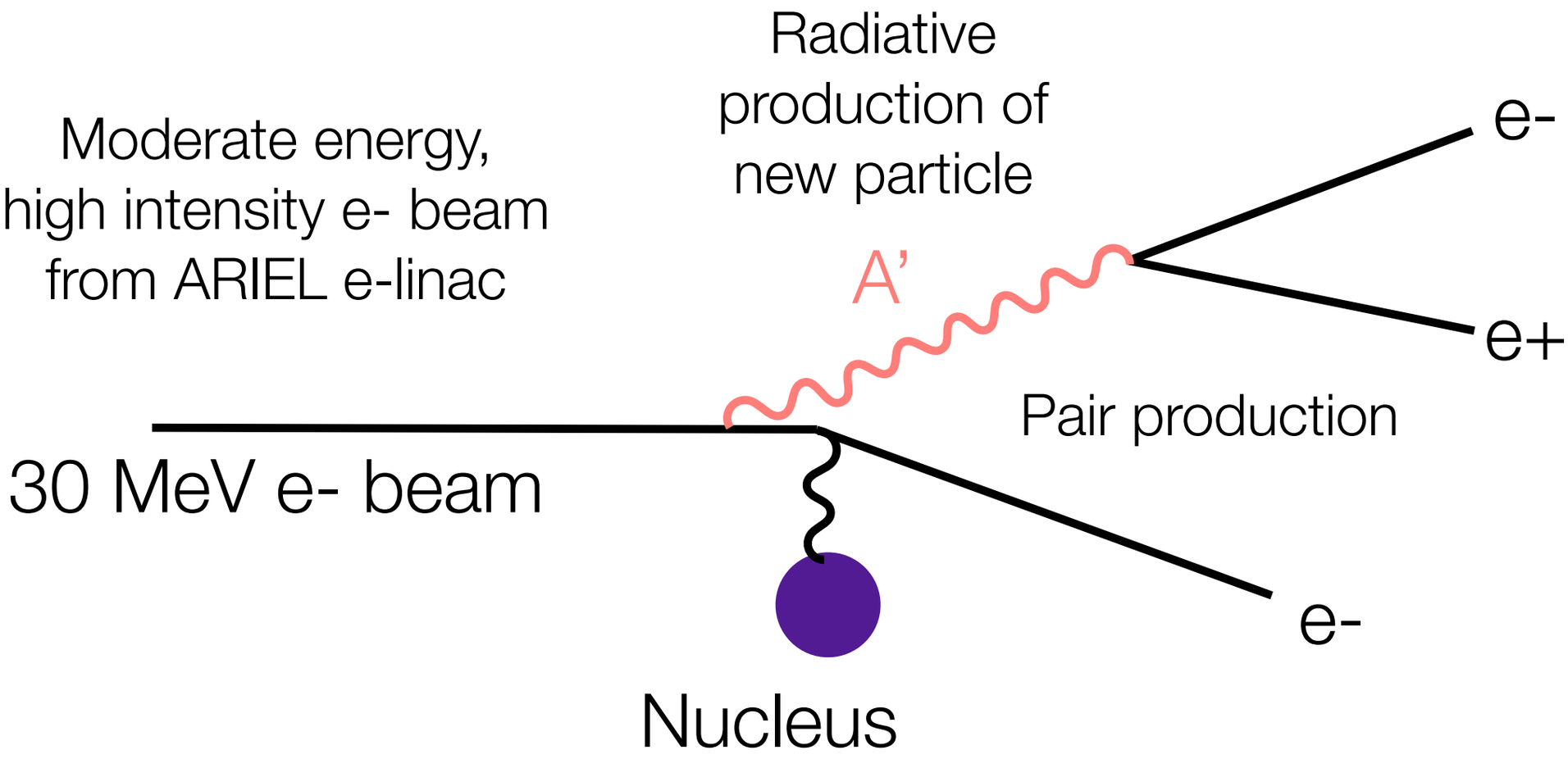

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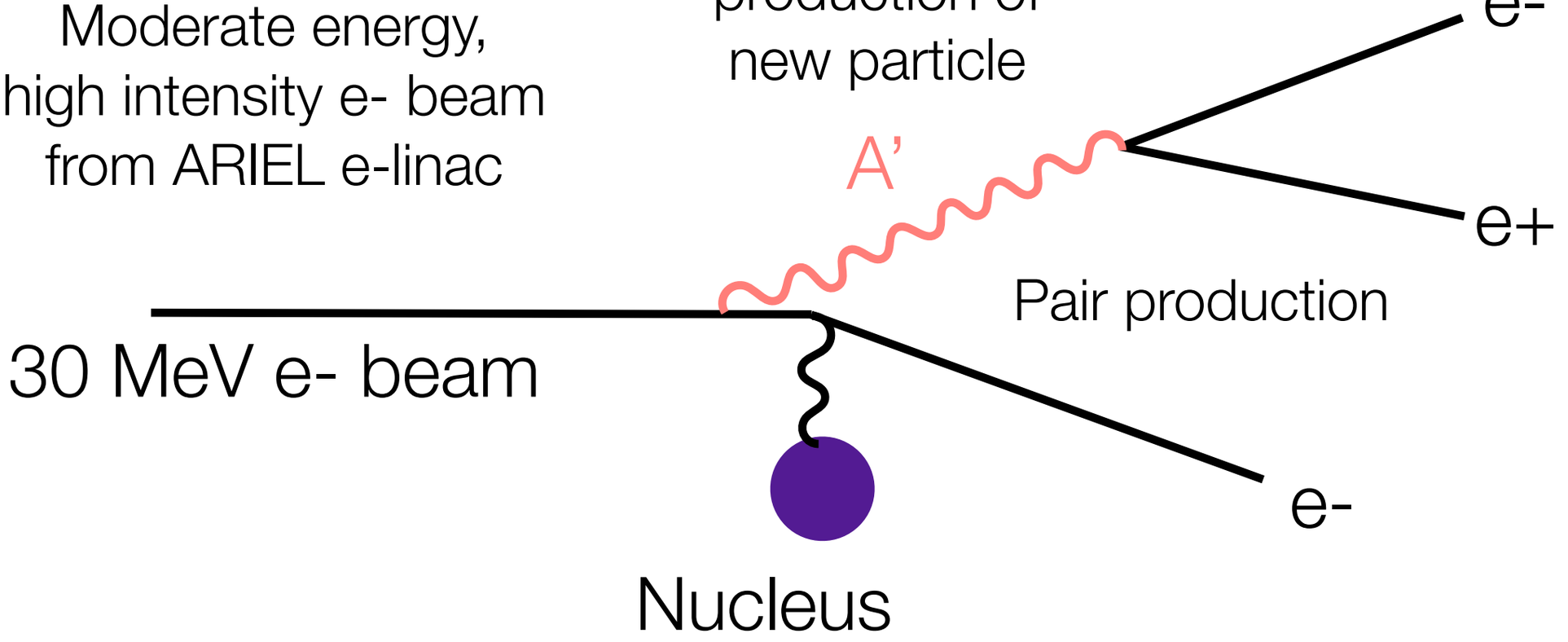

Broad opening angle: measure e+ and e- in spectrometers on opposite sides of beamline

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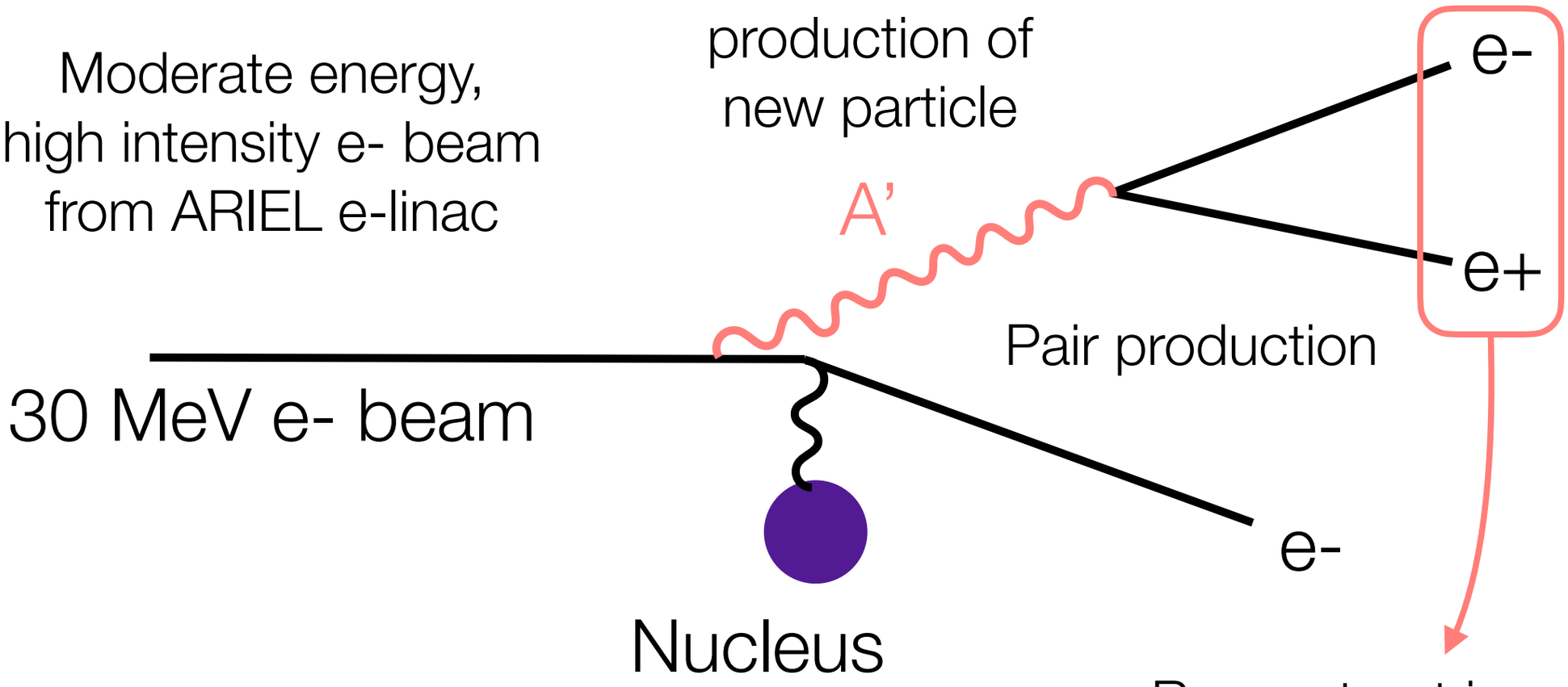
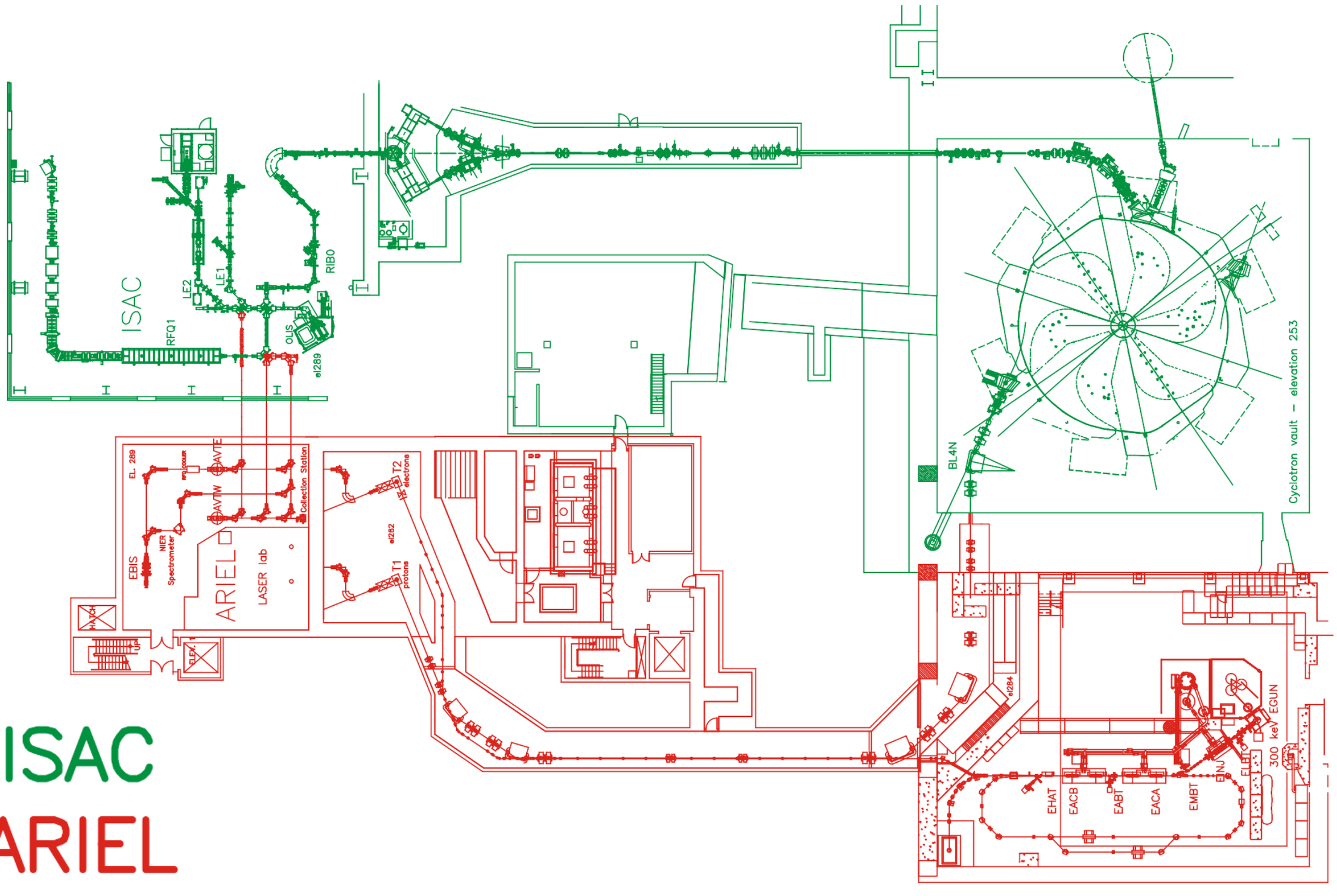


Broad opening angle: measure e+ and e- in spectrometers on opposite sides of beamline

High-density target: baseline is 1 μm Tantalum foil

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

The accelerator: TRIUMF ARIEL e-linac



ISAC

ARIEL

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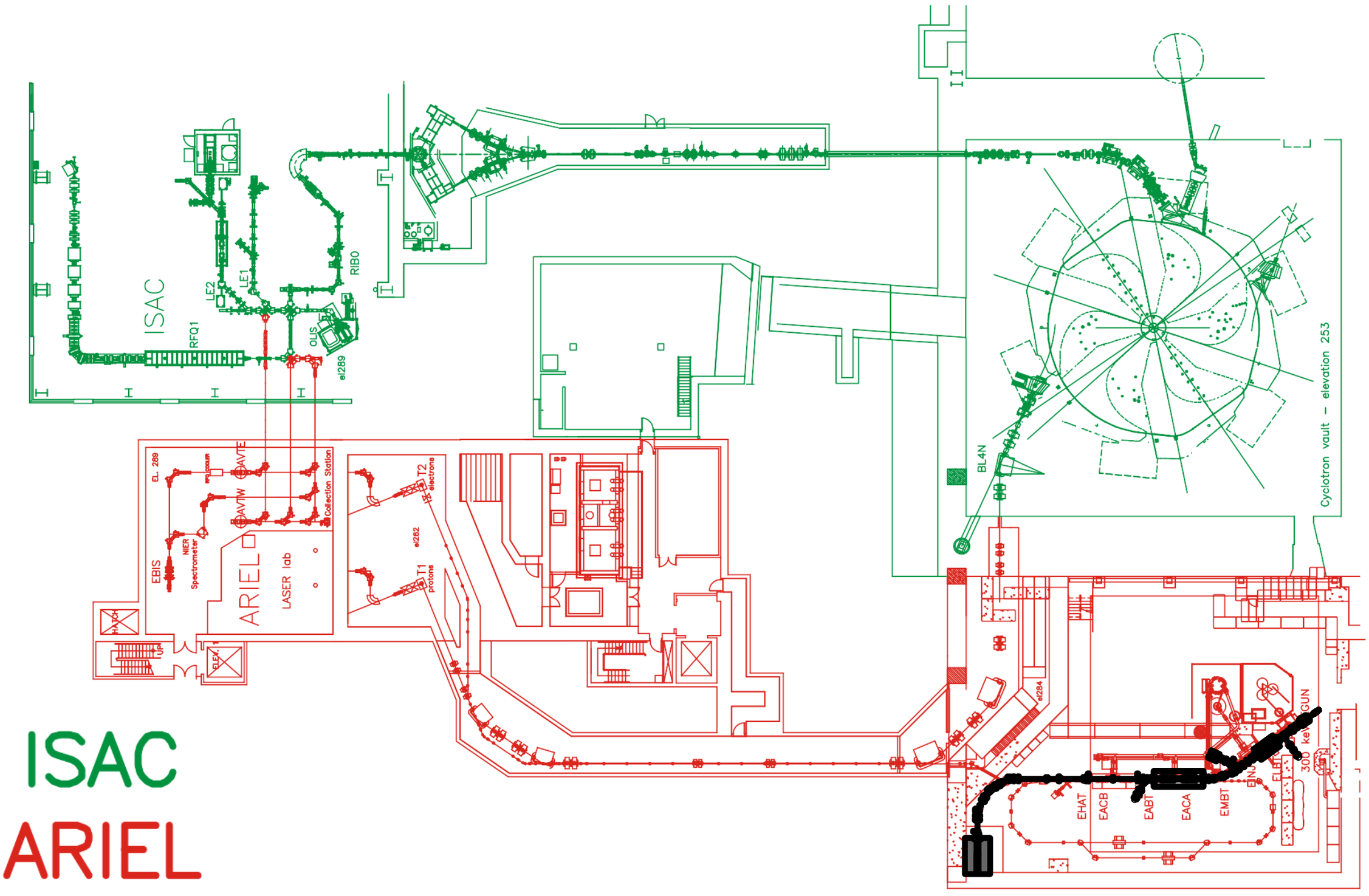
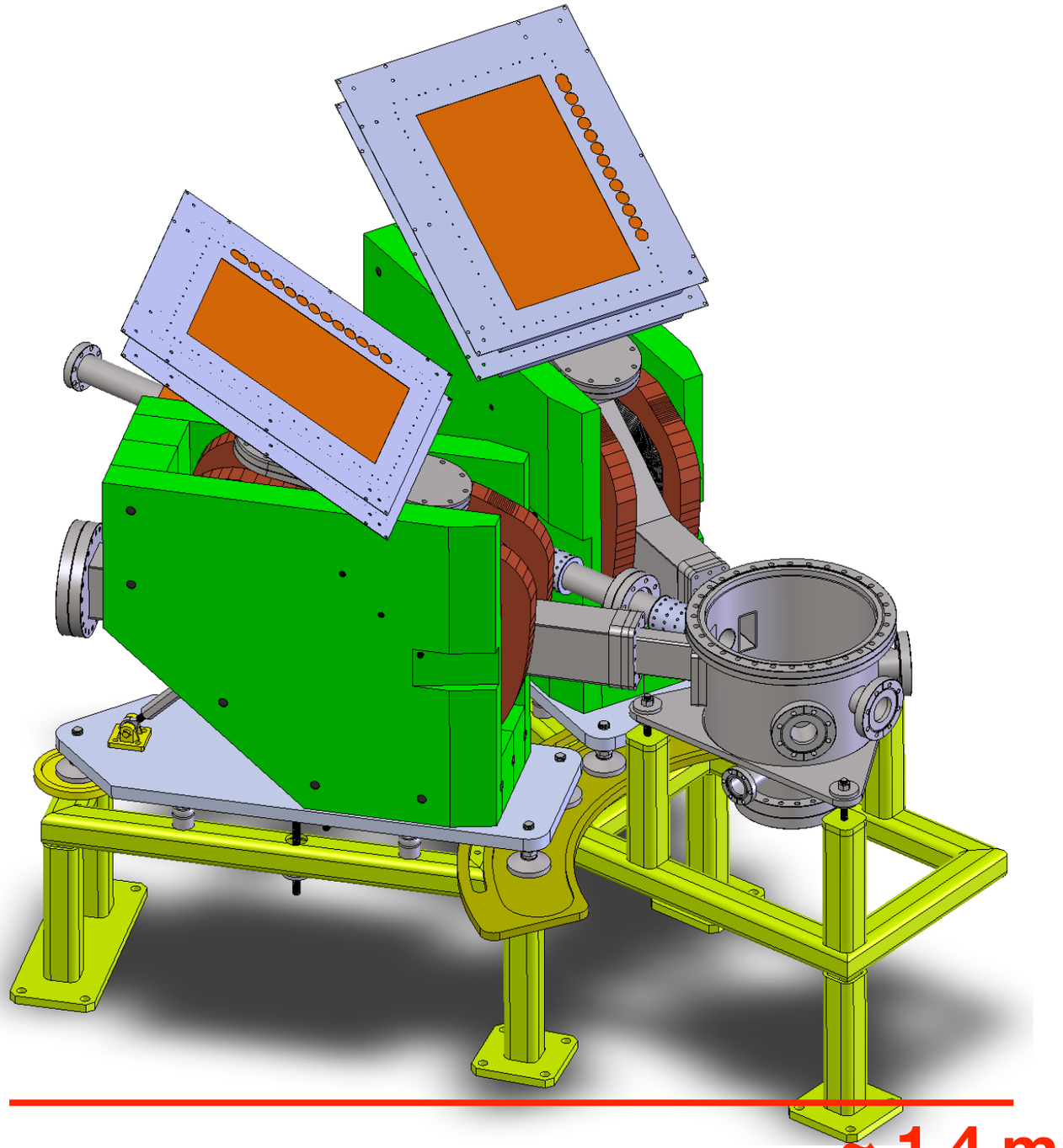


Experiment overview



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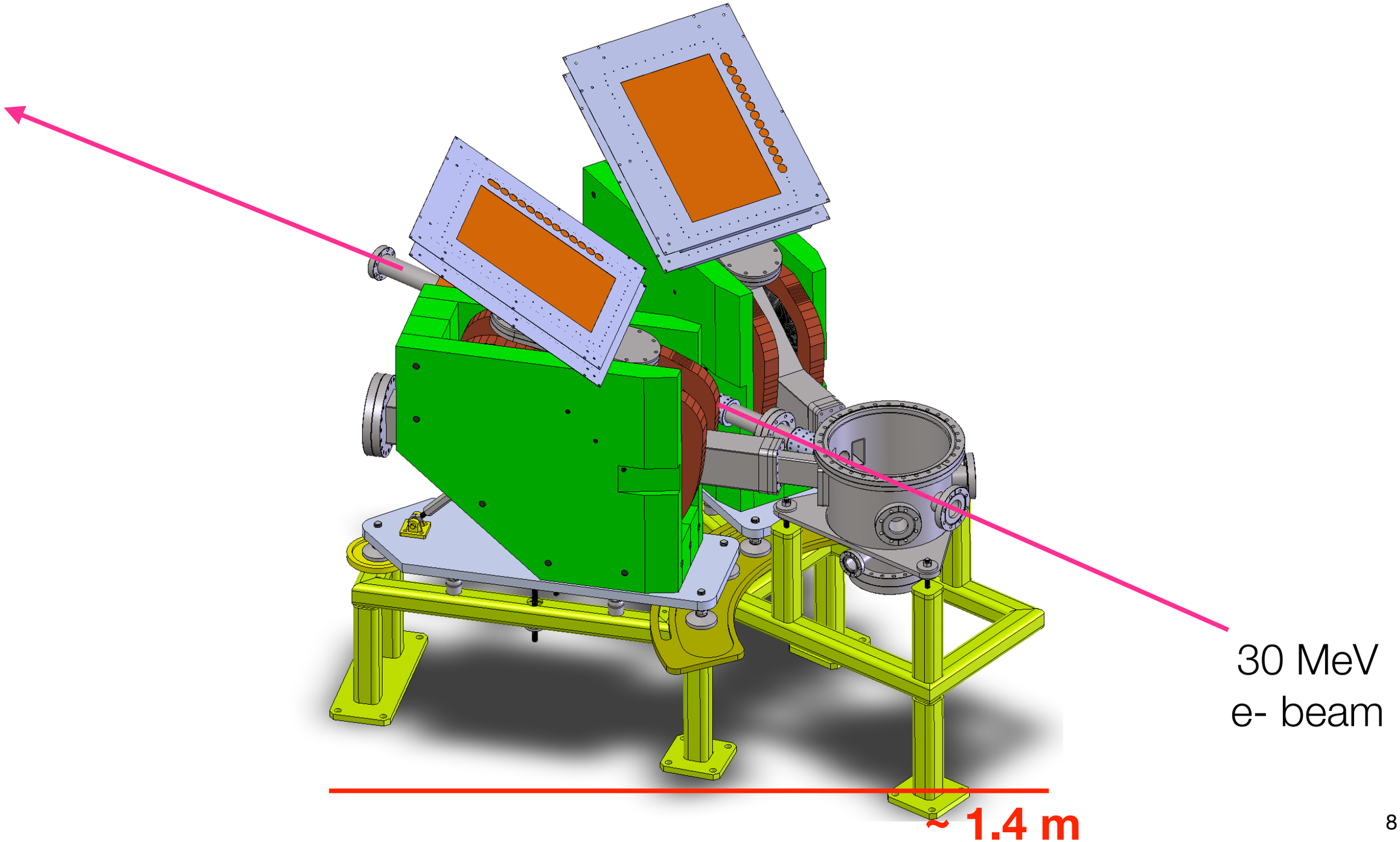

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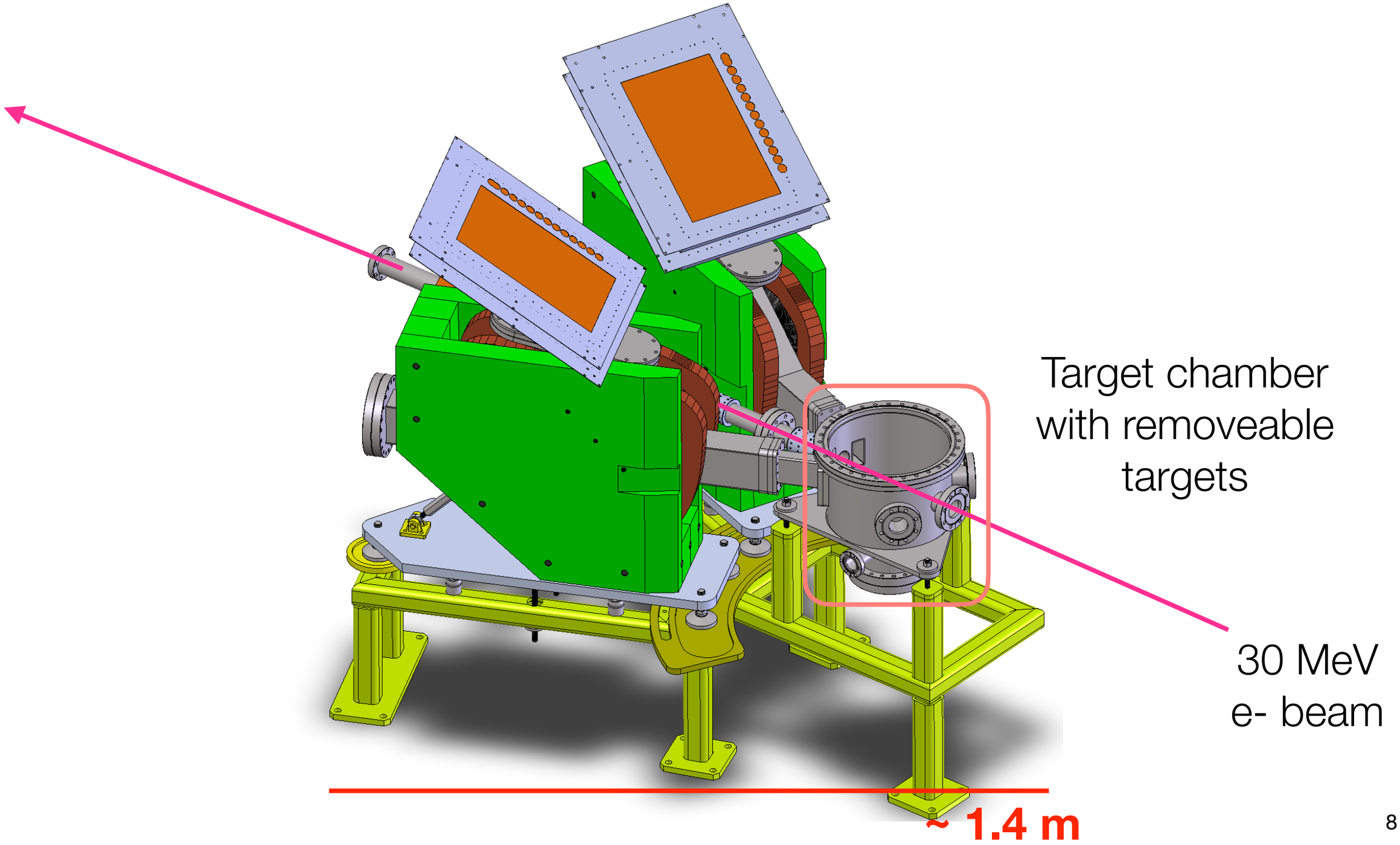

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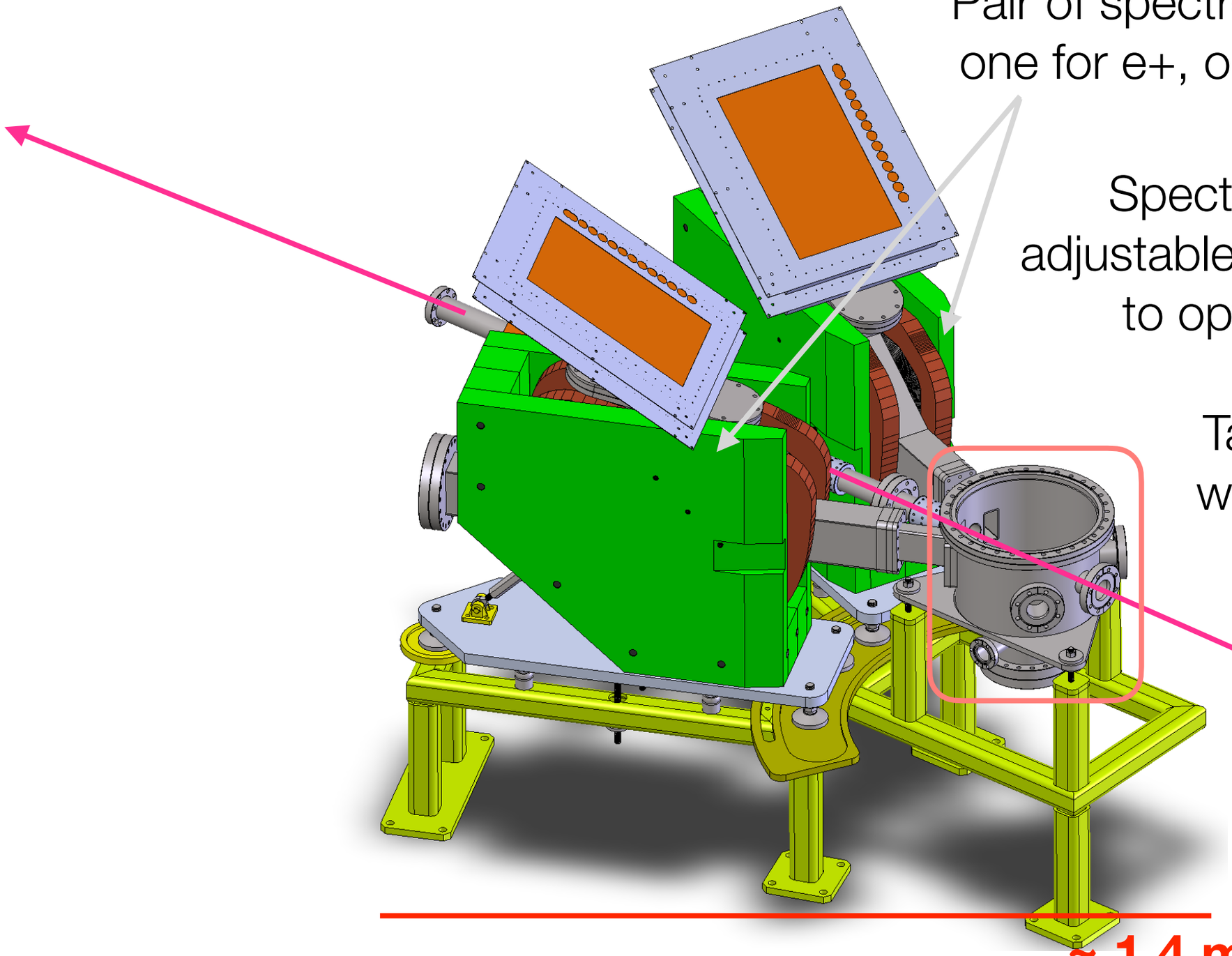

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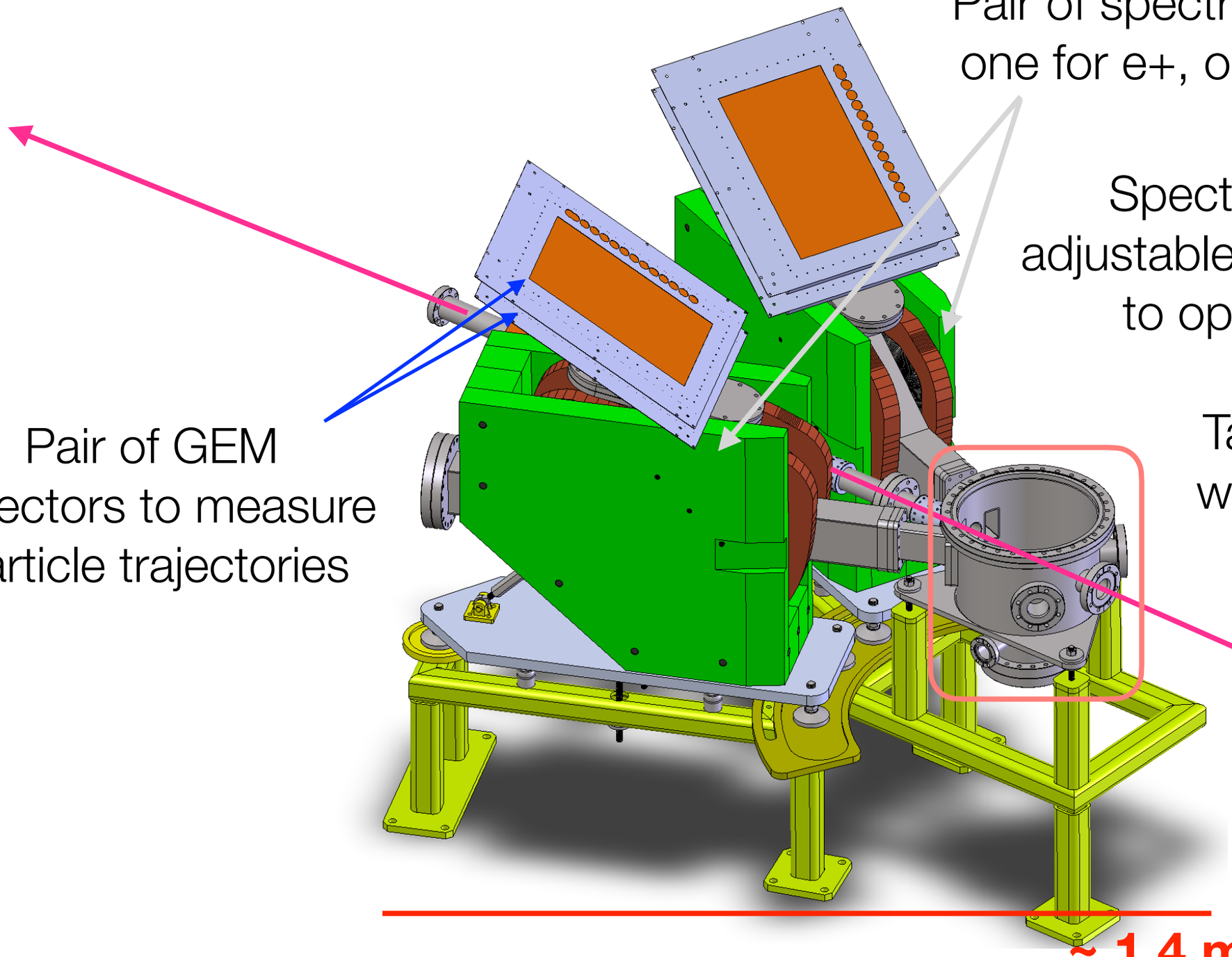

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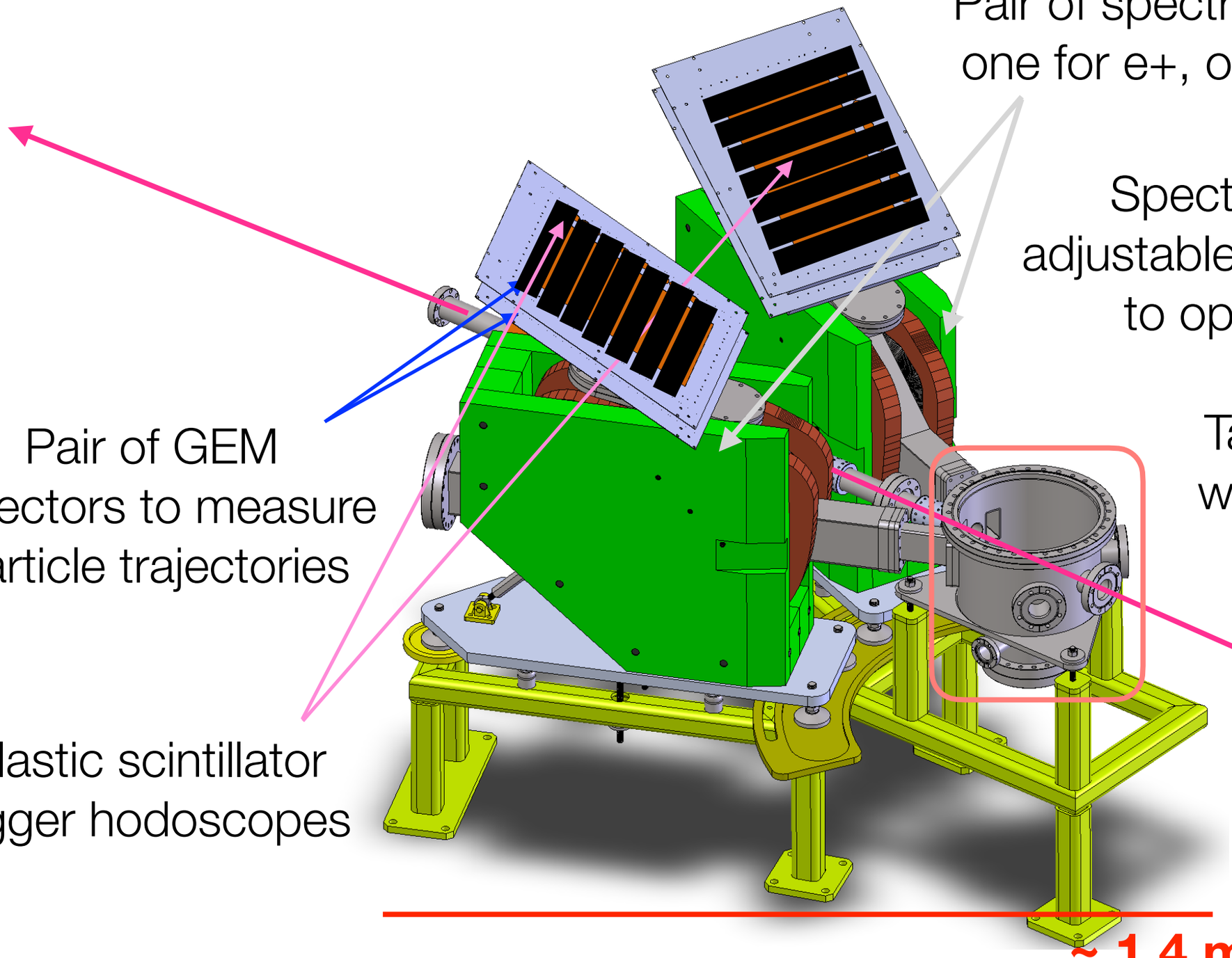
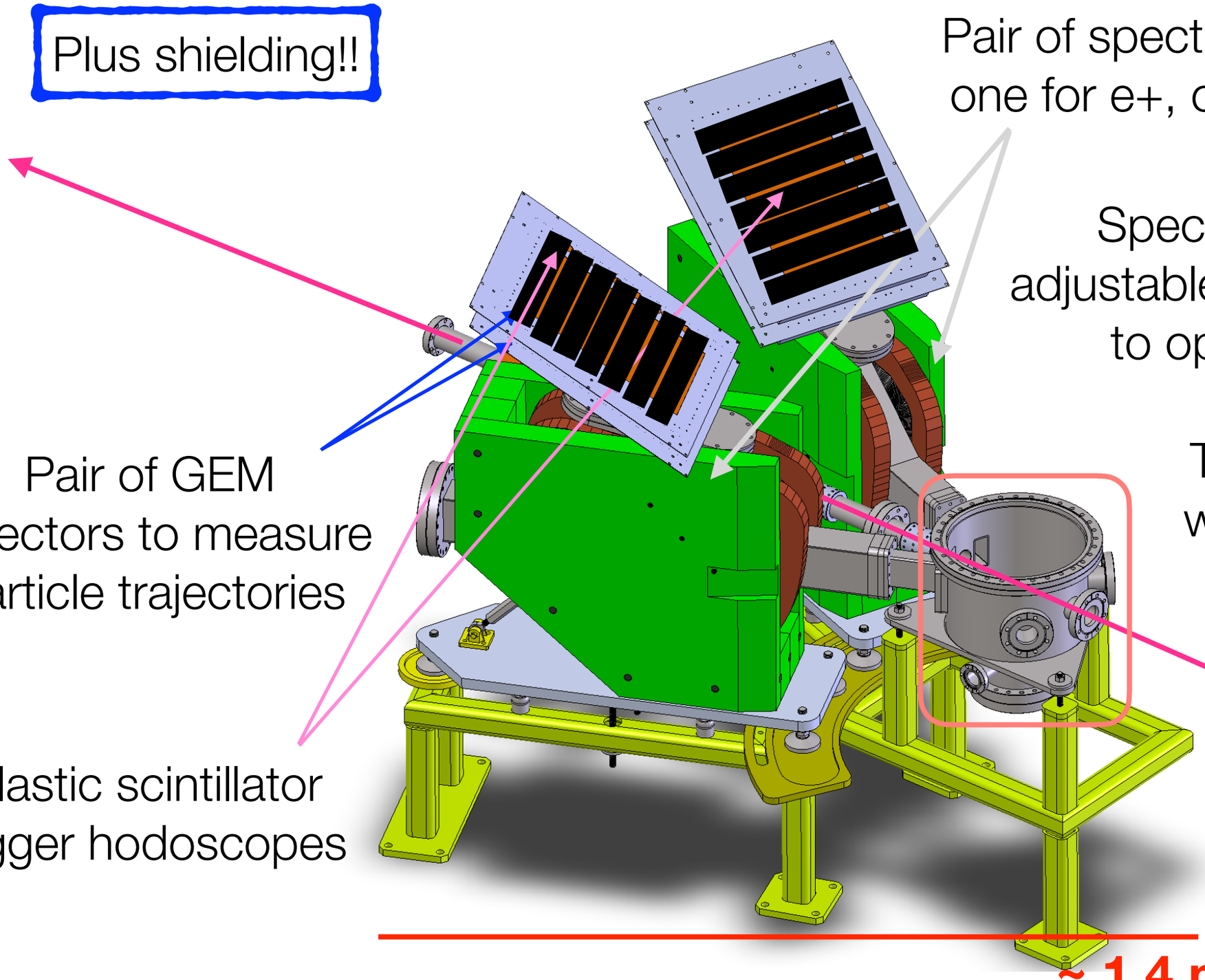


Experiment overview

Plus shielding!!



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

Spectrometer arms at adjustable angles: asymmetric to optimise selection

Pair of GEM detectors to measure particle trajectories

Target chamber with removeable targets

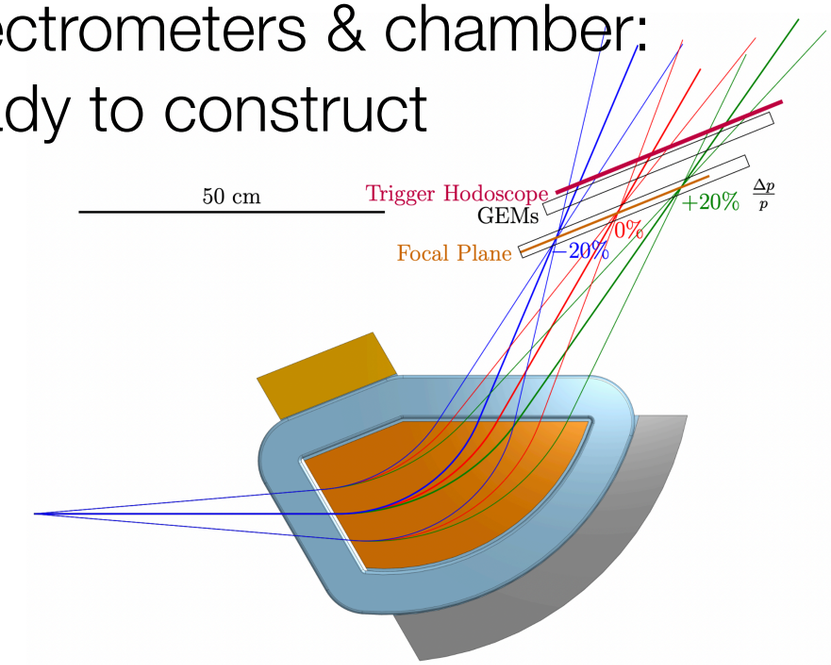
Plastic scintillator trigger hodoscopes

30 MeV e- beam

~ 1.4 m

Detector components status

Spectrometers & chamber: Ready to construct



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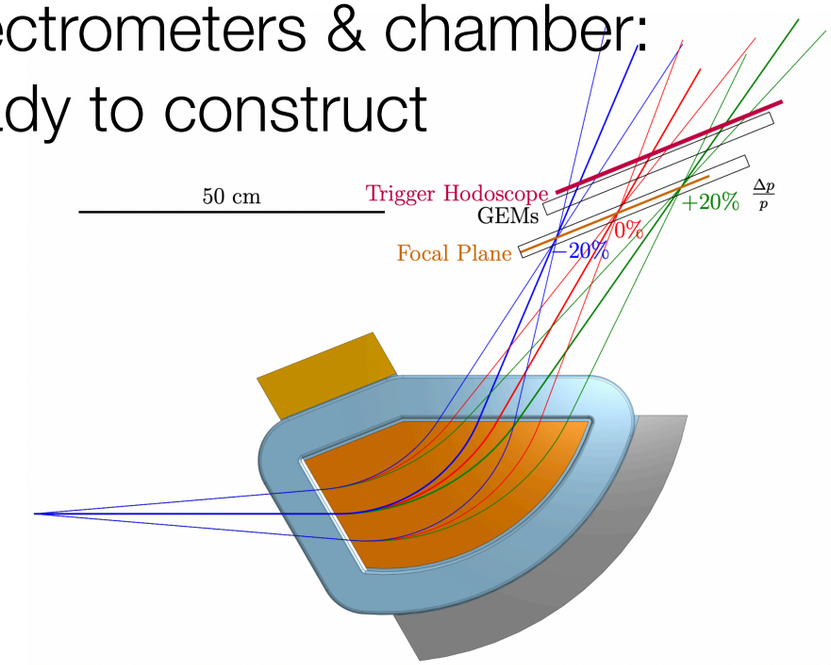

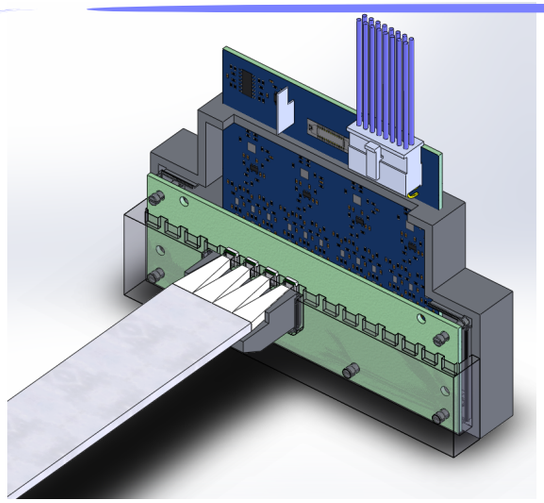

Triggers: testing 2nd prototype

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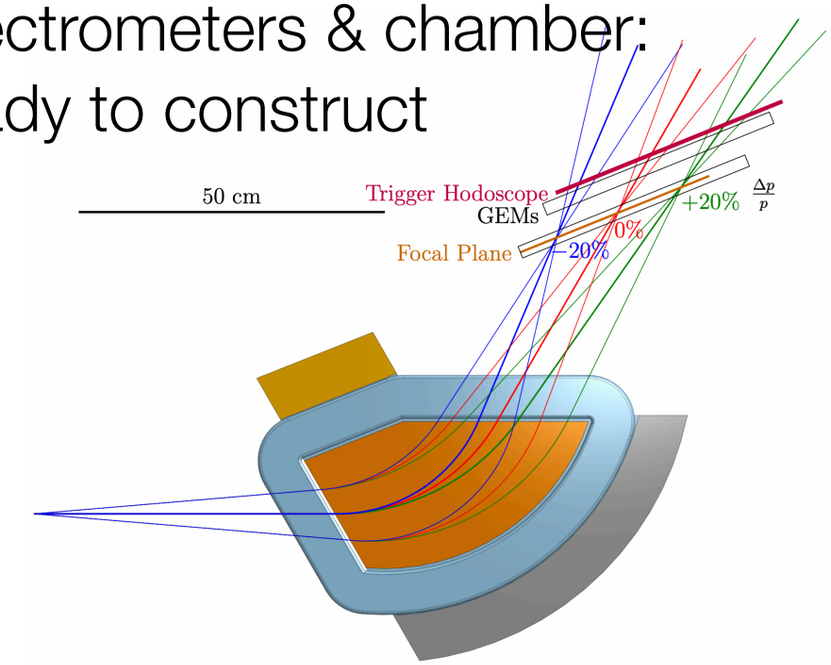

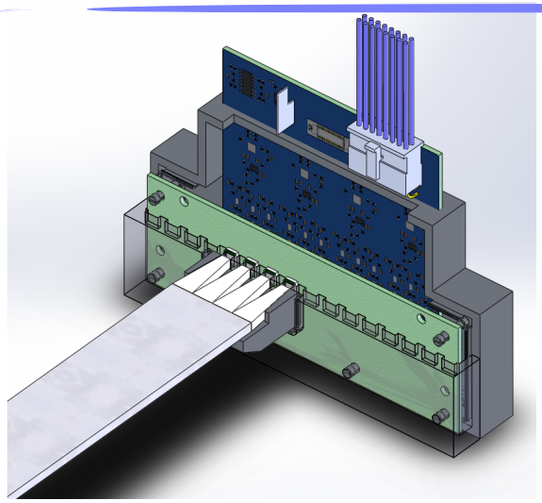

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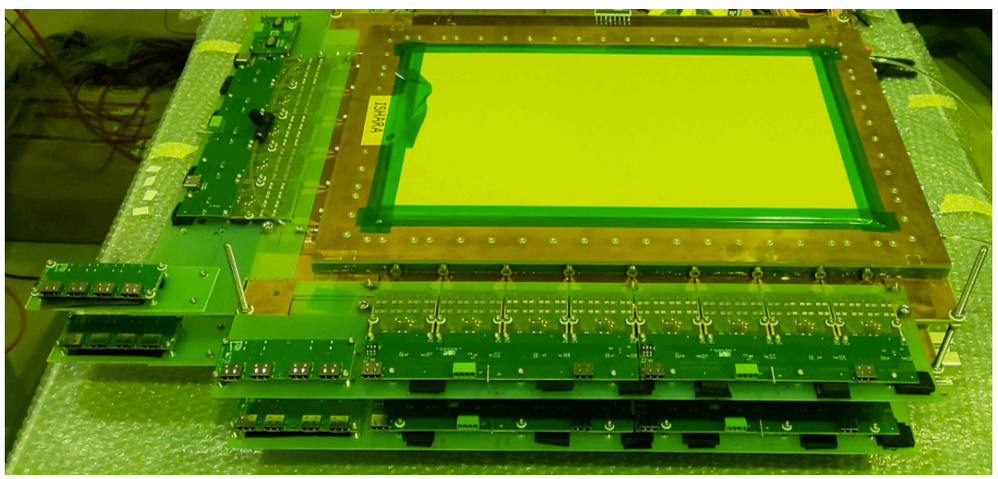

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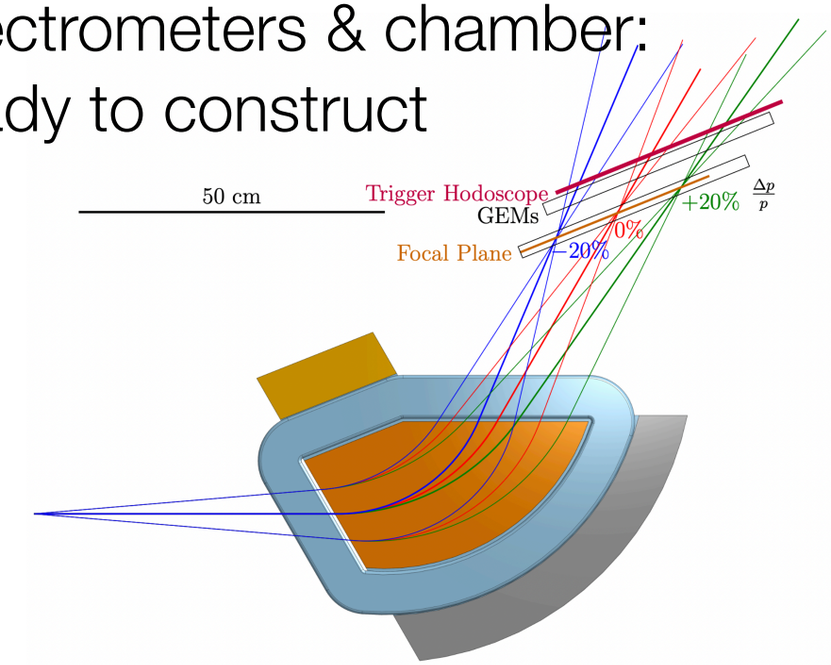

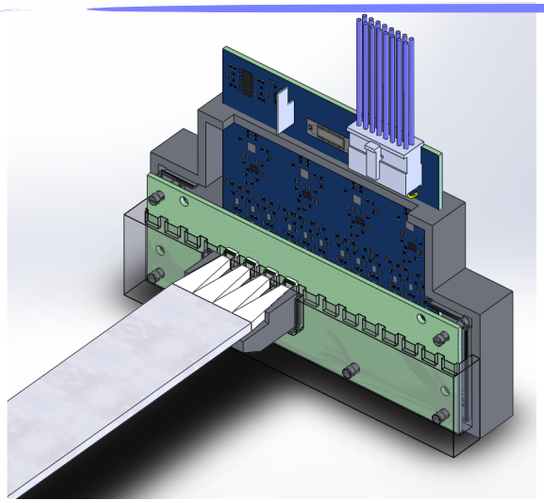

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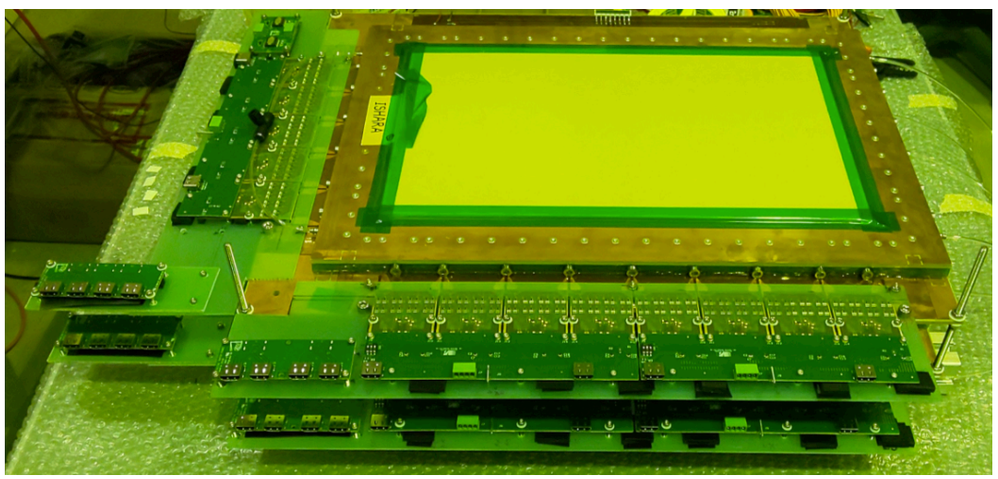
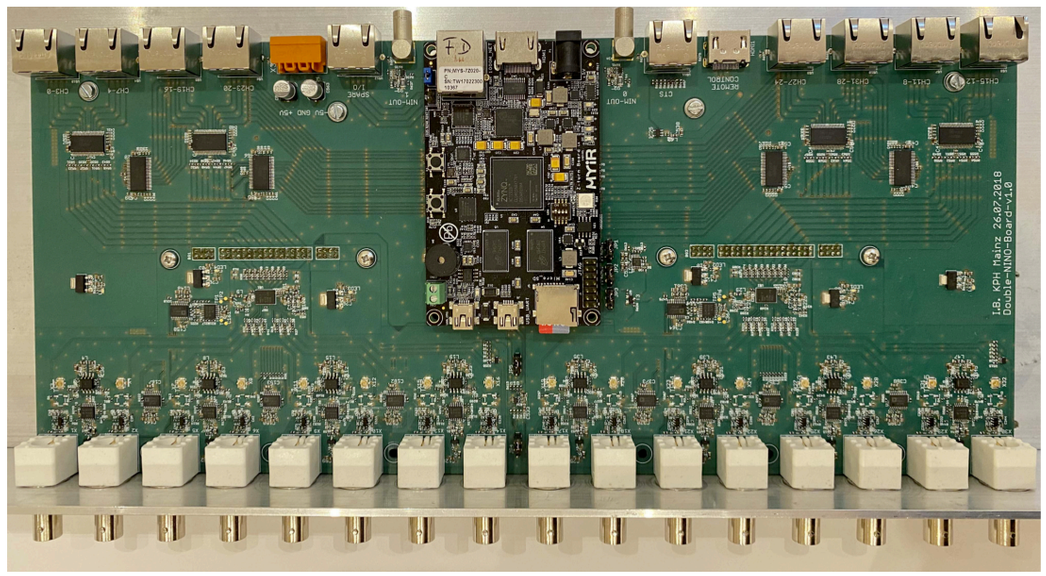
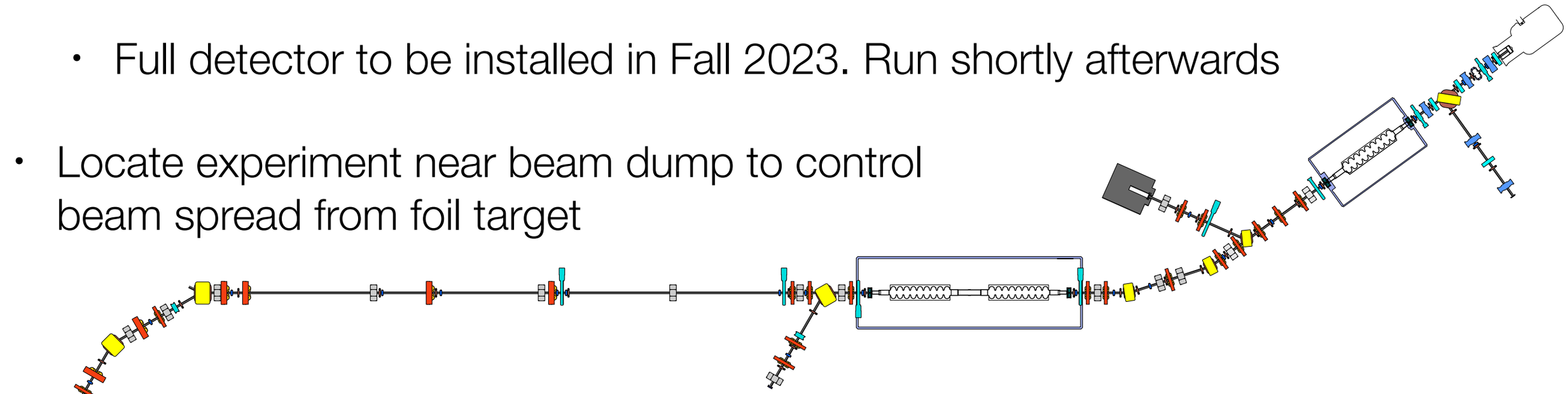


Readout/DAQ: in progress



30 MeV running at the 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
- Locate experiment near beam dump to control beam spread from foil target



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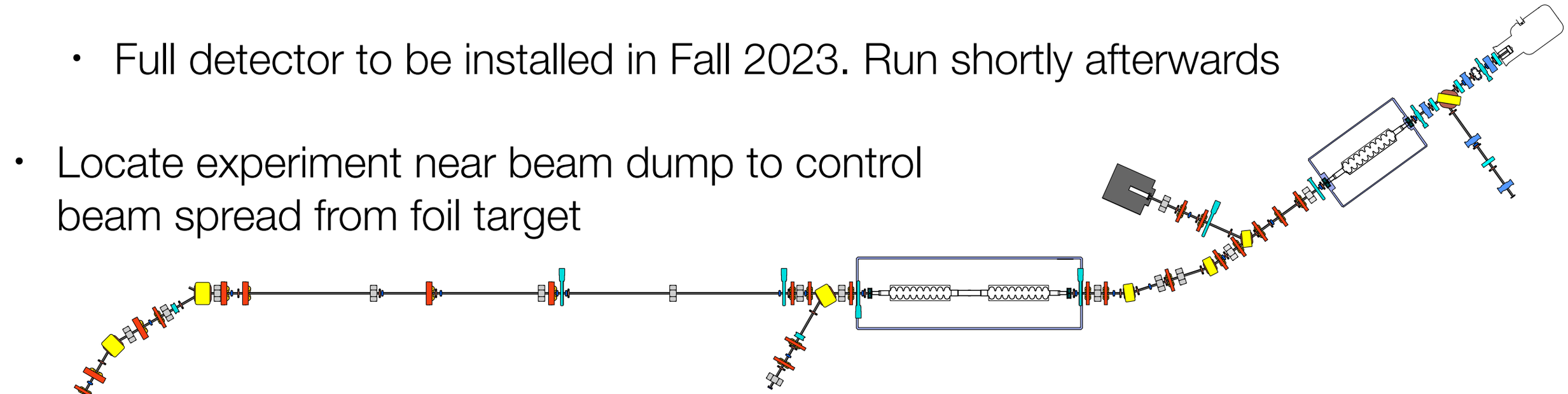
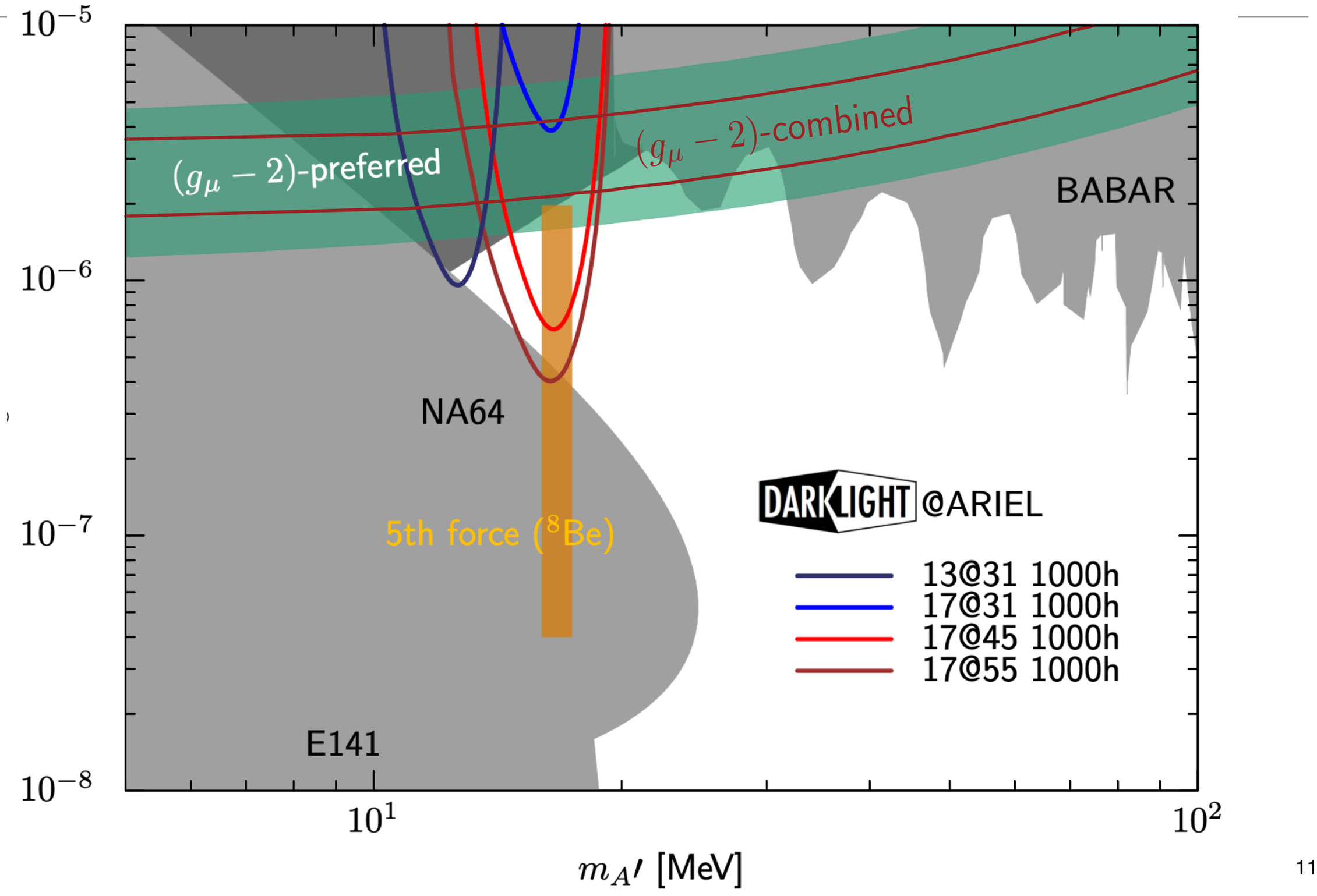


DarkLight position

Sensitivity at 30 and 50 MeV accelerators



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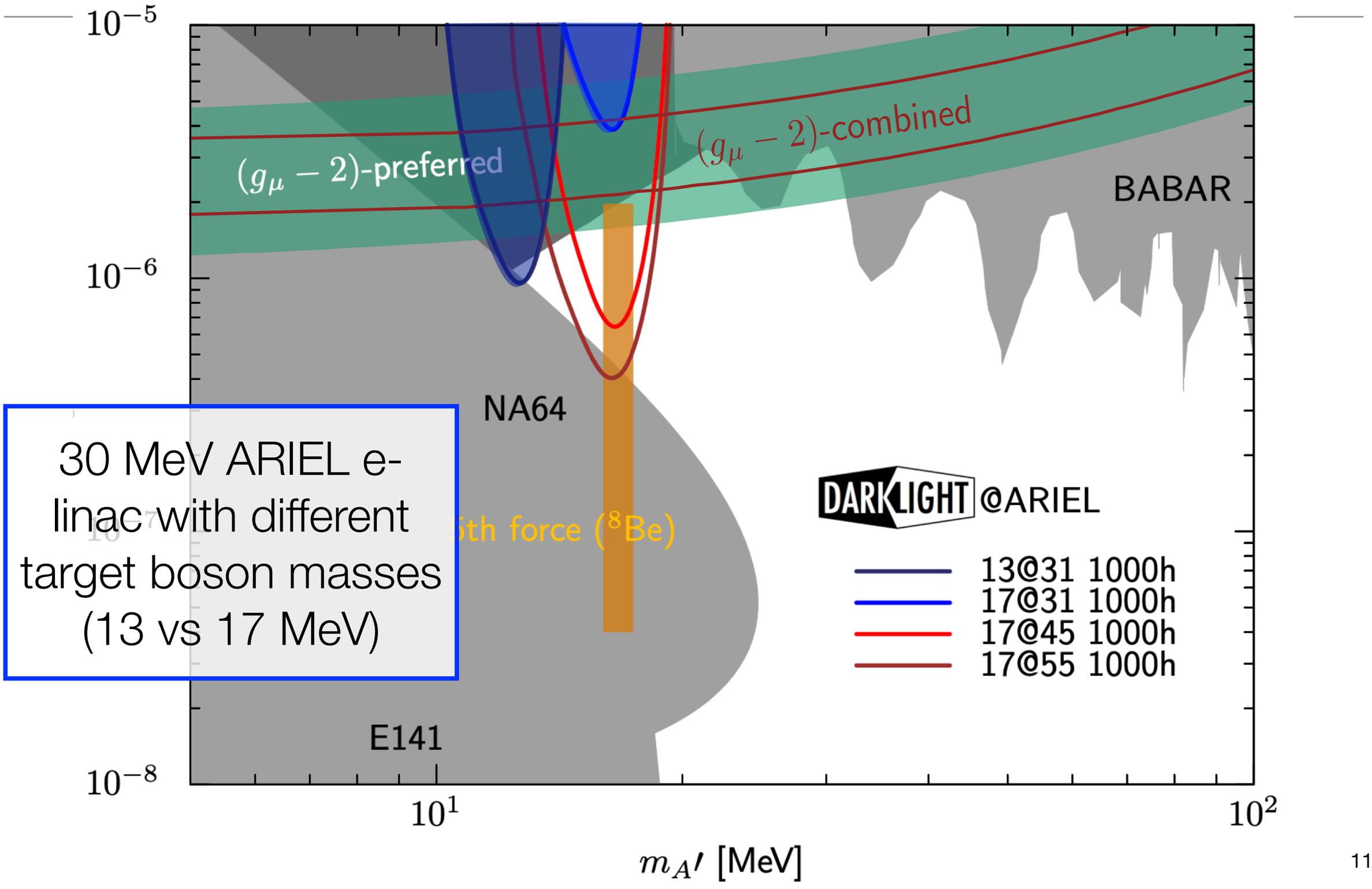
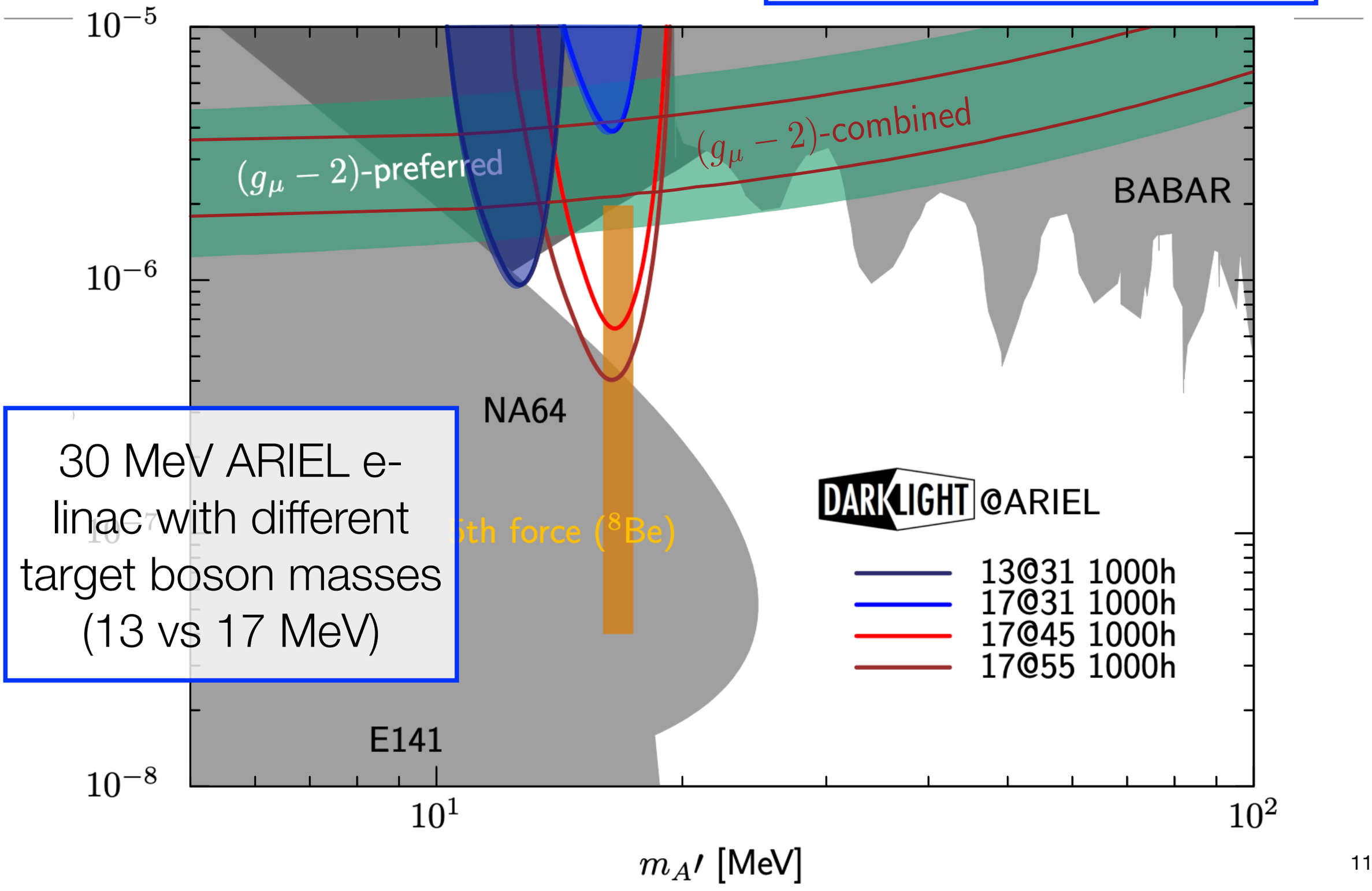


30 MeV ARIEL e-linac with different target boson masses (13 vs 17 MeV)

Sensitivity at 30 and 50 MeV accelerators

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



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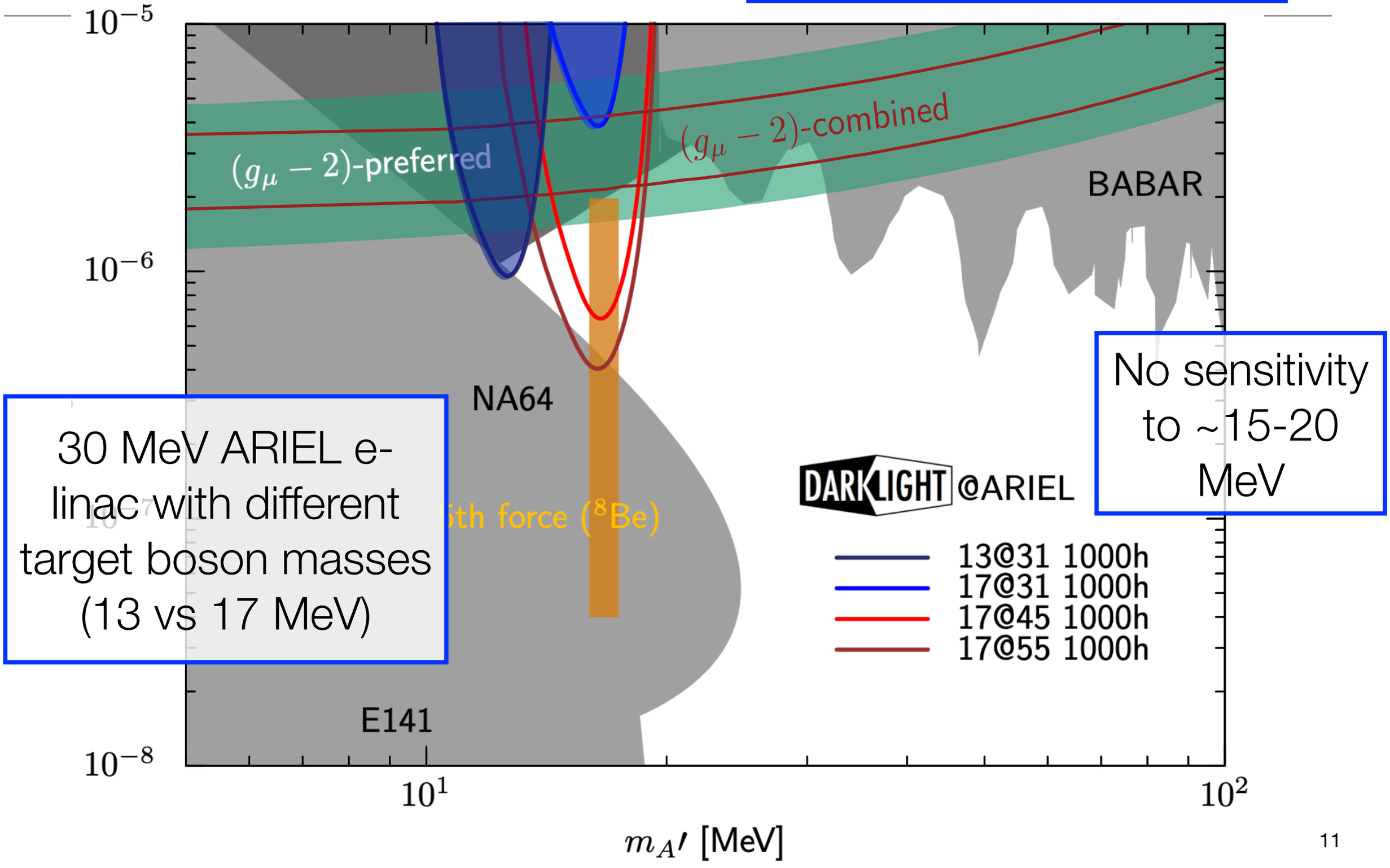
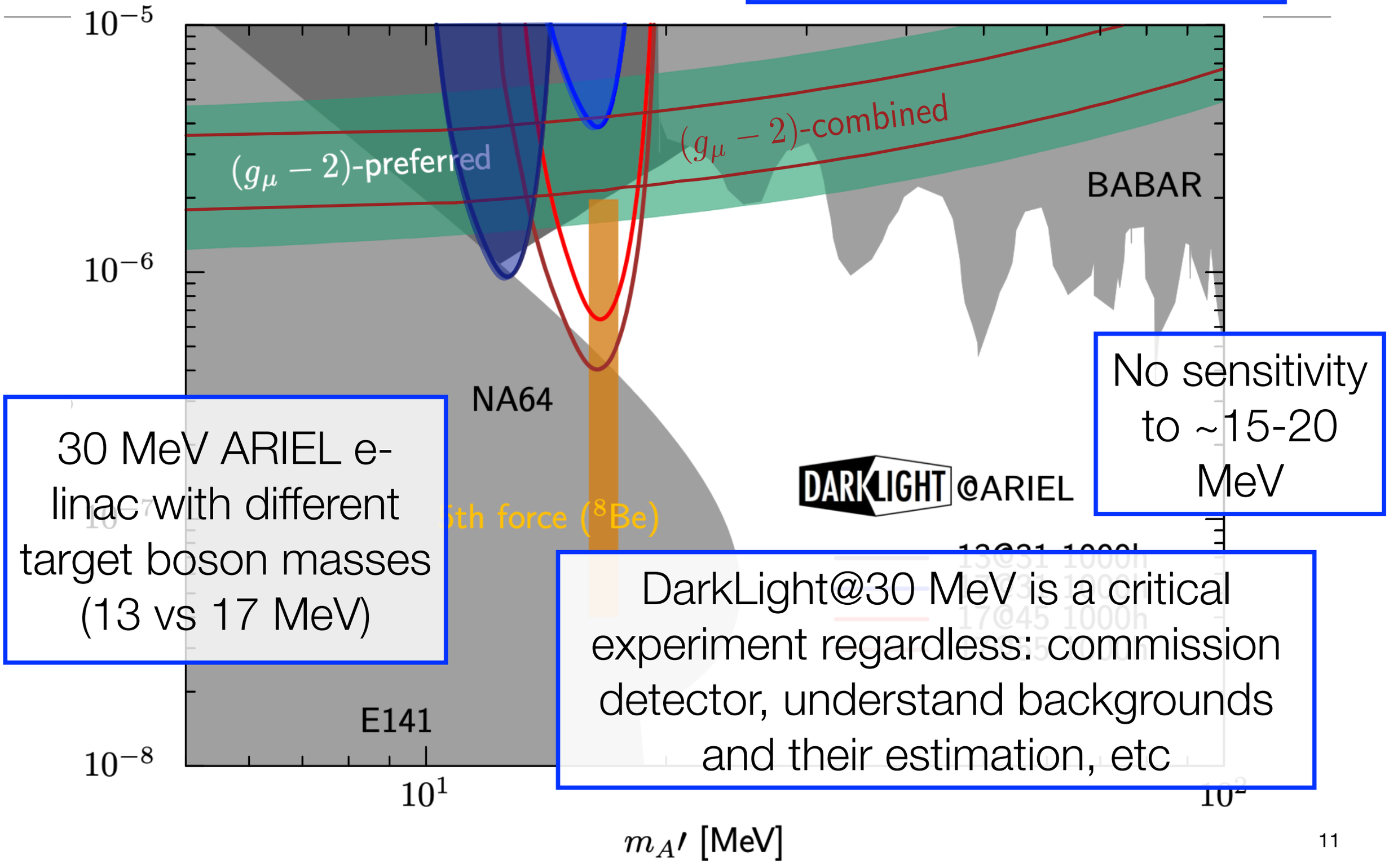


30 MeV ARIEL e-linac with different target boson masses (13 vs 17 MeV)

No sensitivity to ~15-20 MeV

Sensitivity at 30 and 50 MeV accelerators

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



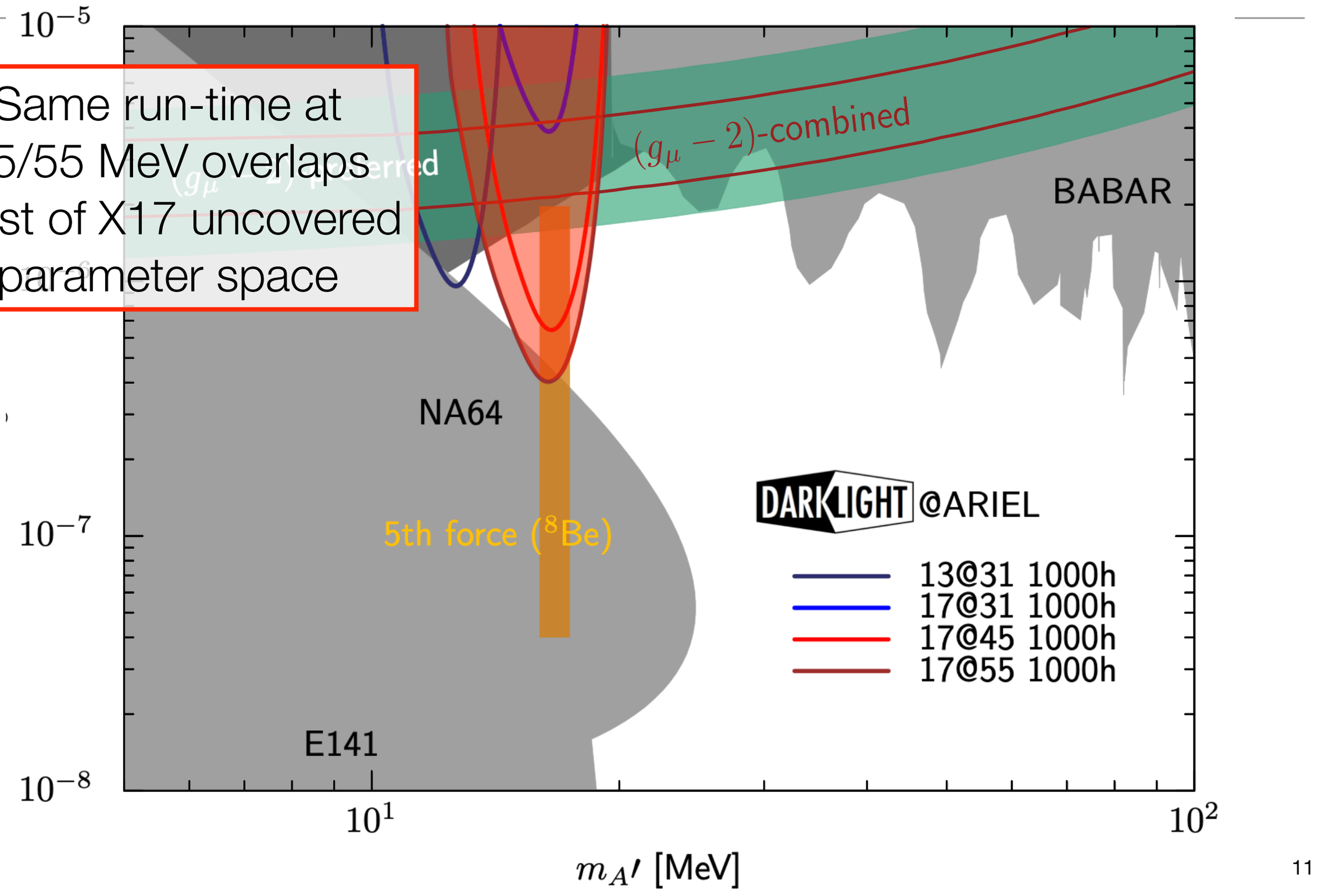
30 MeV ARIEL e-linac with different target boson masses (13 vs 17 MeV)

No sensitivity to ~15-20 MeV

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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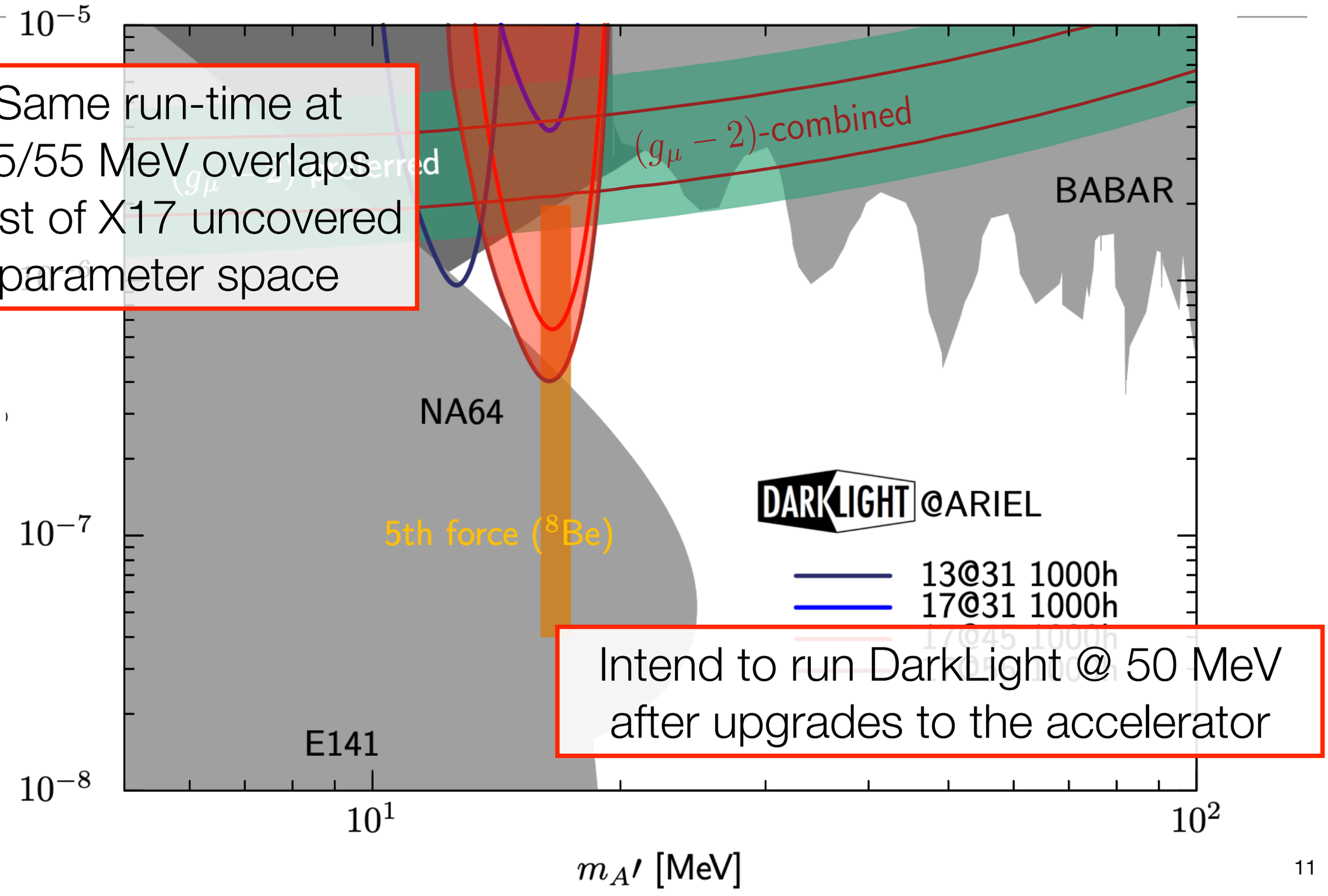


Intend to run DarkLight @ 50 MeV after upgrades to the accelerator

DarkLight timeline

Spring 2021: beam time approved @ TRIUMF

Dec 2021: test chamber installed in beamline

May 2022: workshop at TRIUMF, first collaboration meeting

August 2022: First beam on targets, background tests

Winter 22/23: convergence of experiment design

Today

Fall 2023: install experiment and begin background measurements

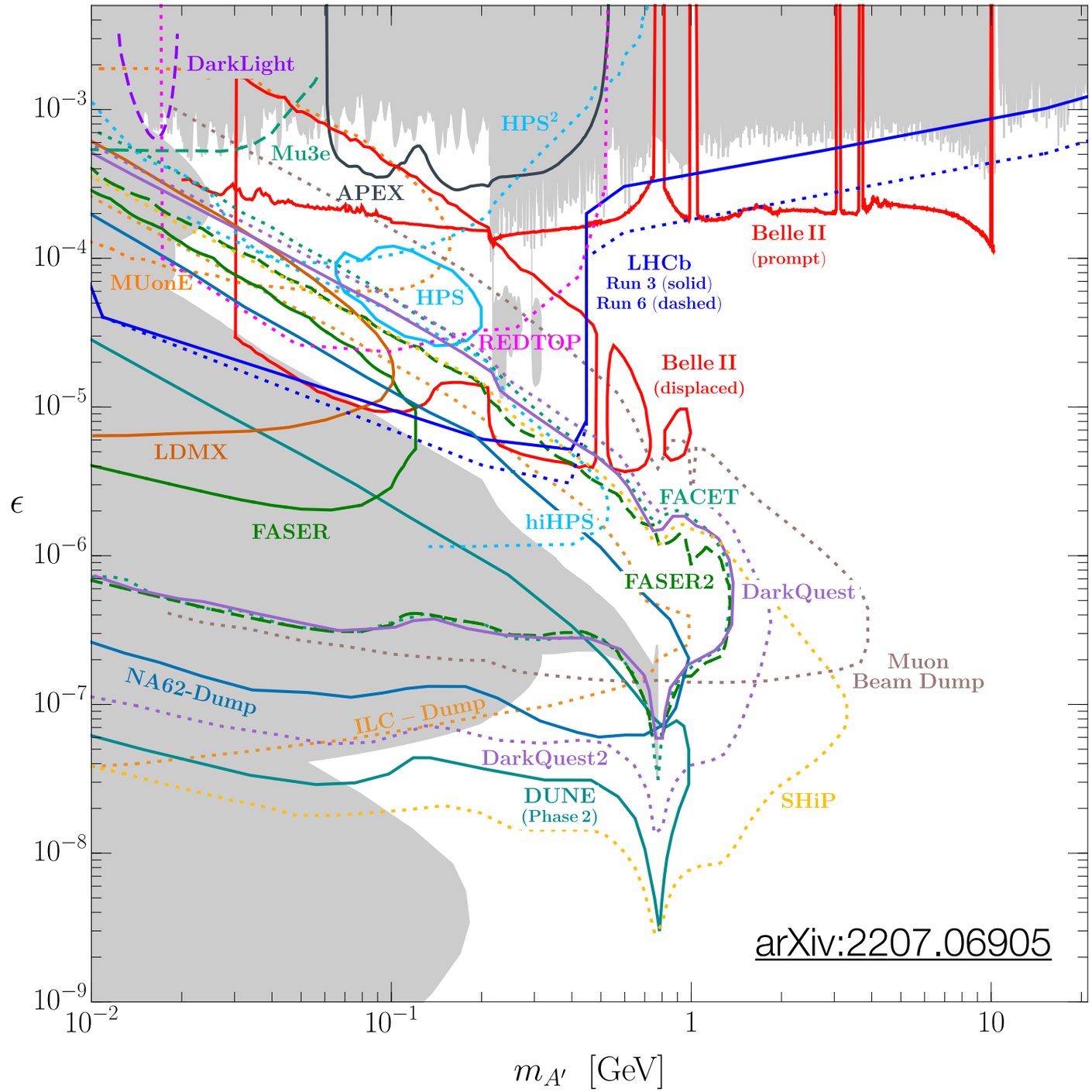
Winter 23/24: Run full experiment @ 30 MEV

2024/2025: energy upgrade (TBC); first run @ 50 MeV

2025+: finish data taking, plan next experiments!

Conclusions

DarkLight is under way at TRIUMF



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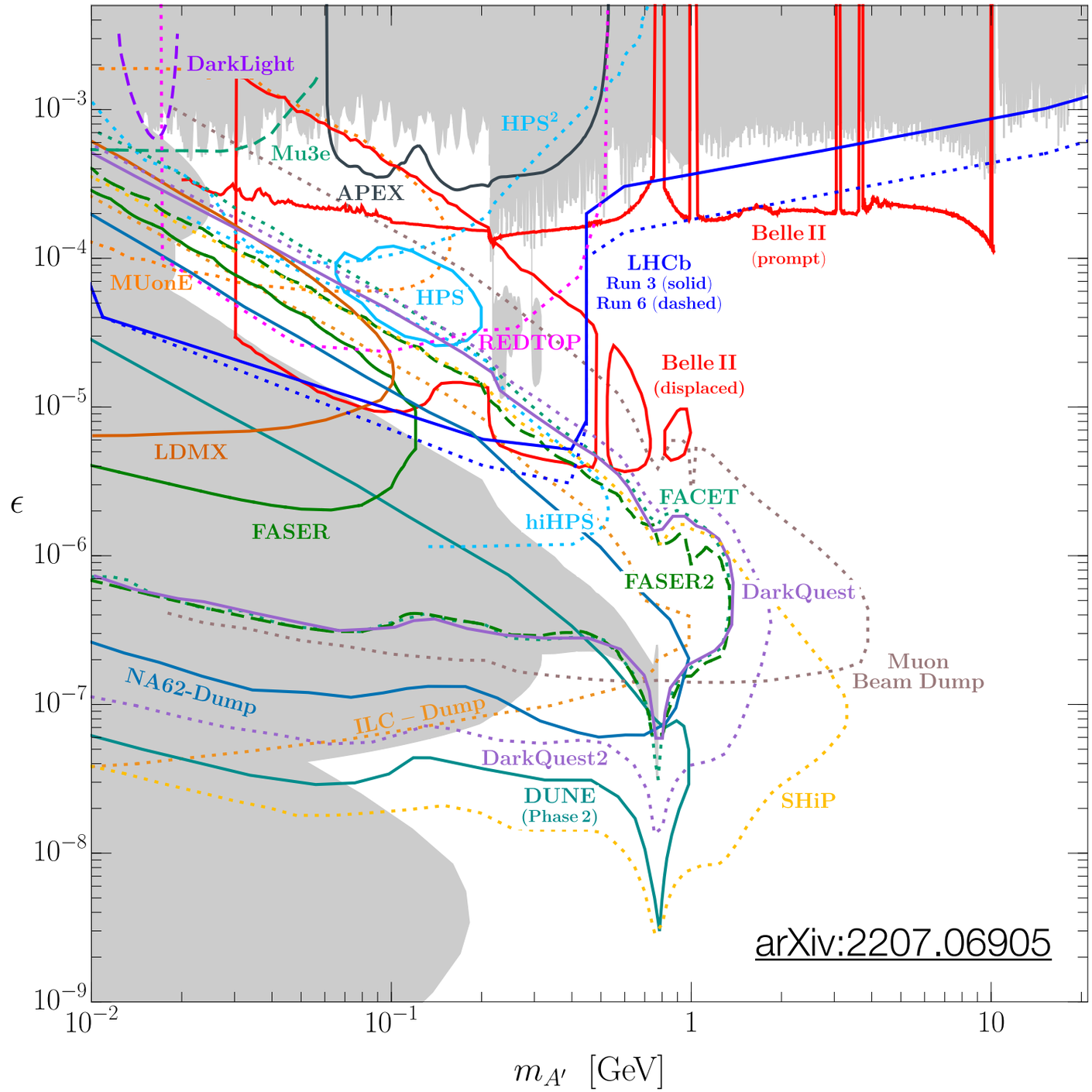
Probing an interesting and accessible region - lots of community **interest & efforts** focusing here



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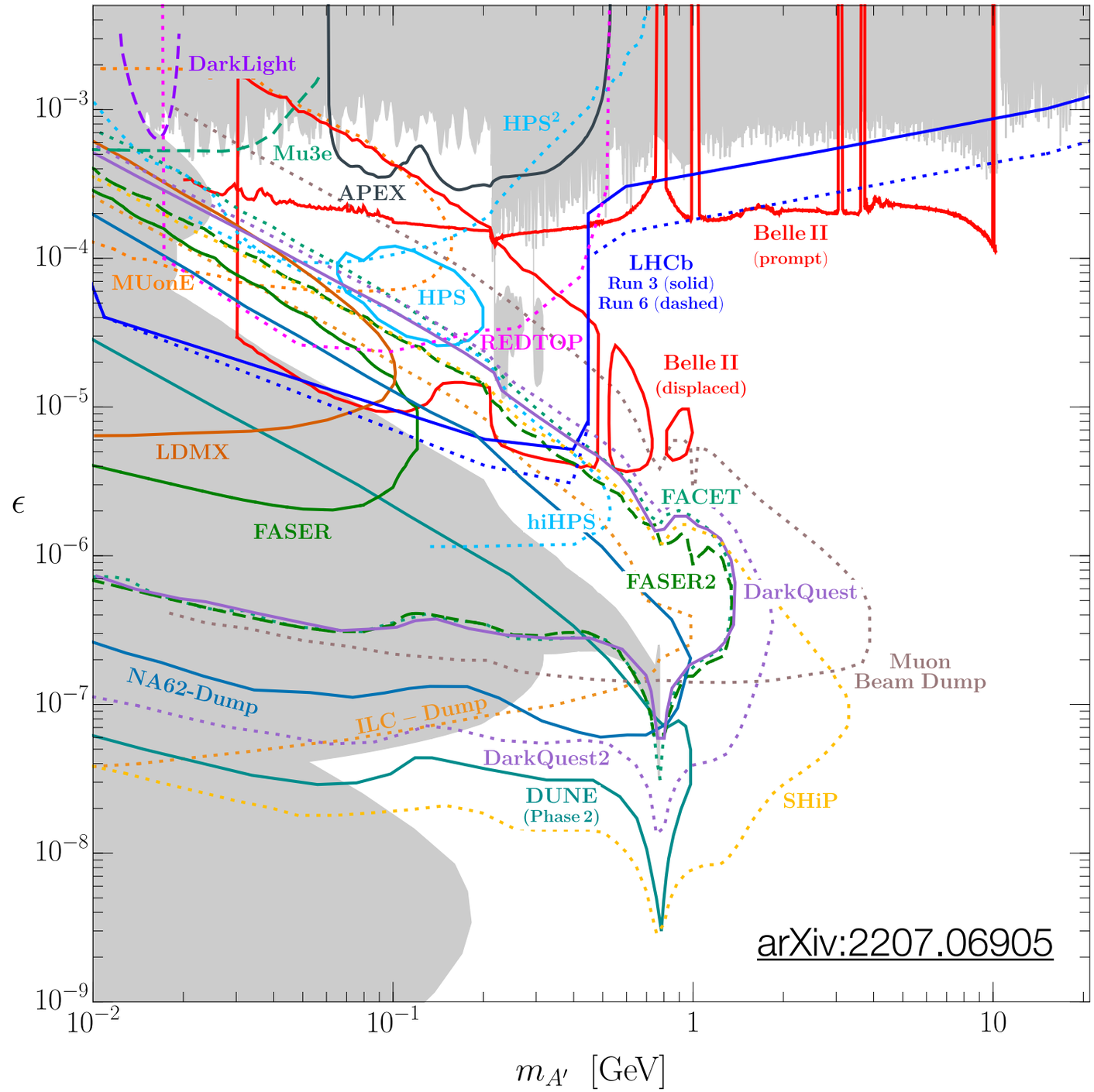
DarkLight will **add to continual progress** from many experiments searching for new bosons and dark matter at accelerators



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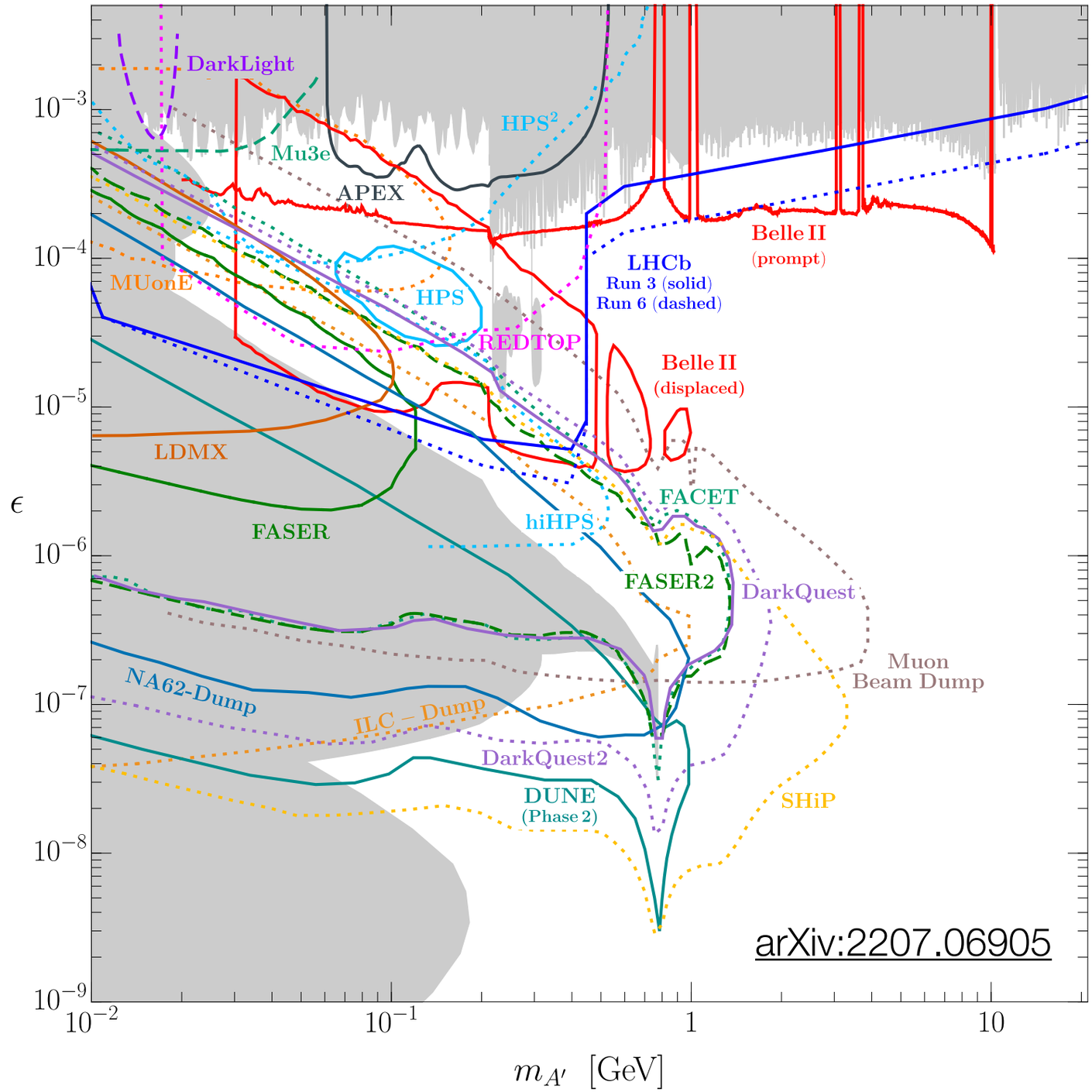


Exciting results to look forward to in next years!

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

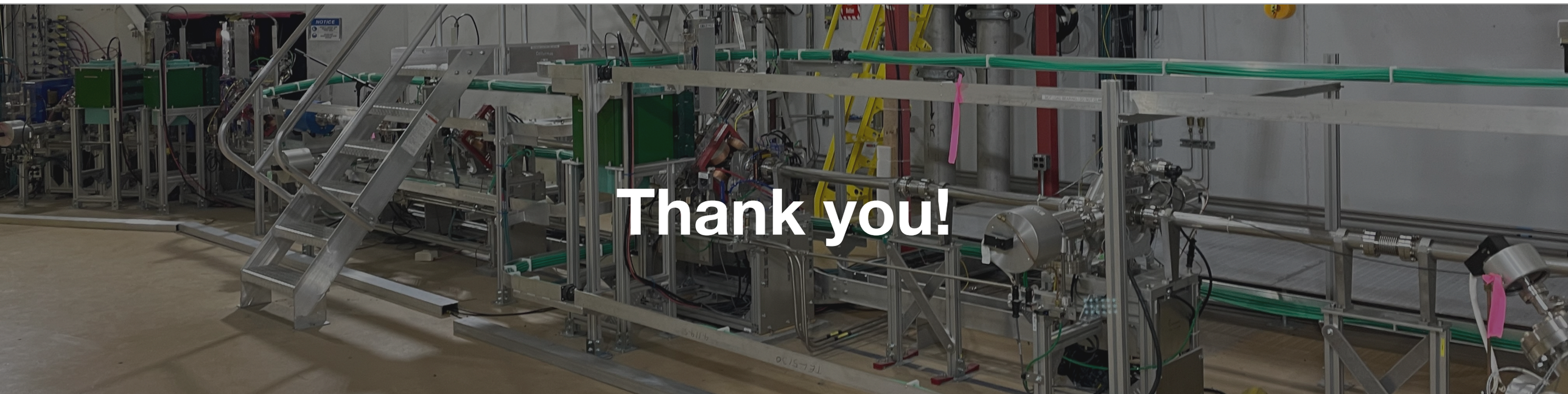
Stony Brook University, NY, USA

TRIUMF, Vancouver, British Columbia, Canada

University of Mainz, Germany

University of Manitoba, Canada

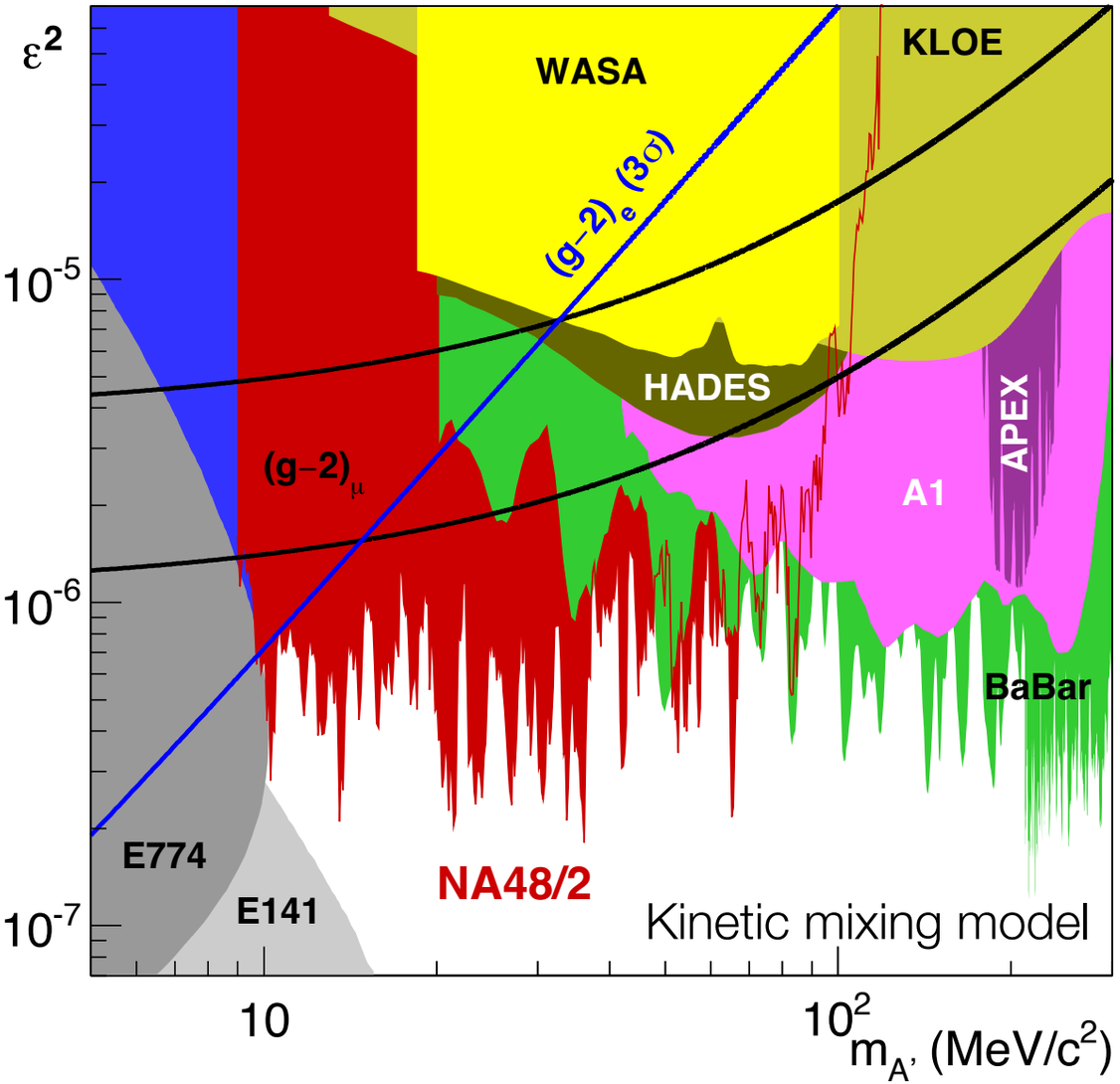
University of Winnipeg, Manitoba, Canada



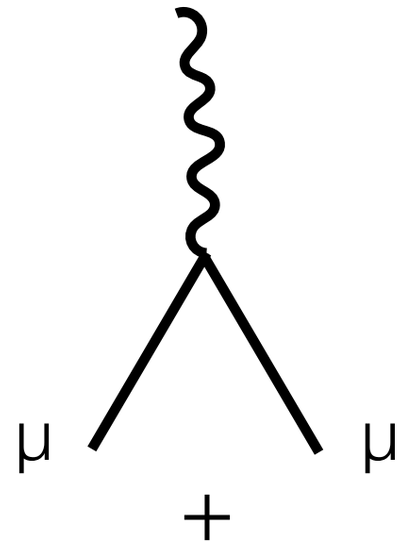
Backup slides

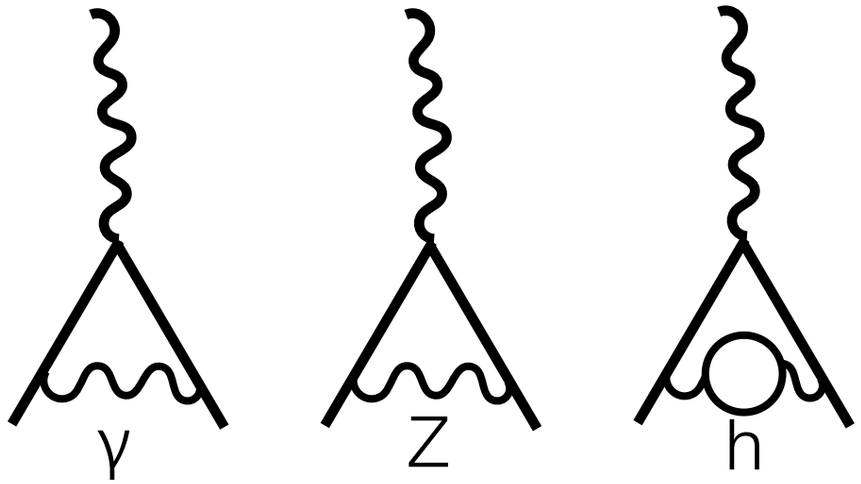
Light BSM boson: g-2 anomaly

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



NA48 collaboration,
Phys.Lett. B746 (2015) 178-185





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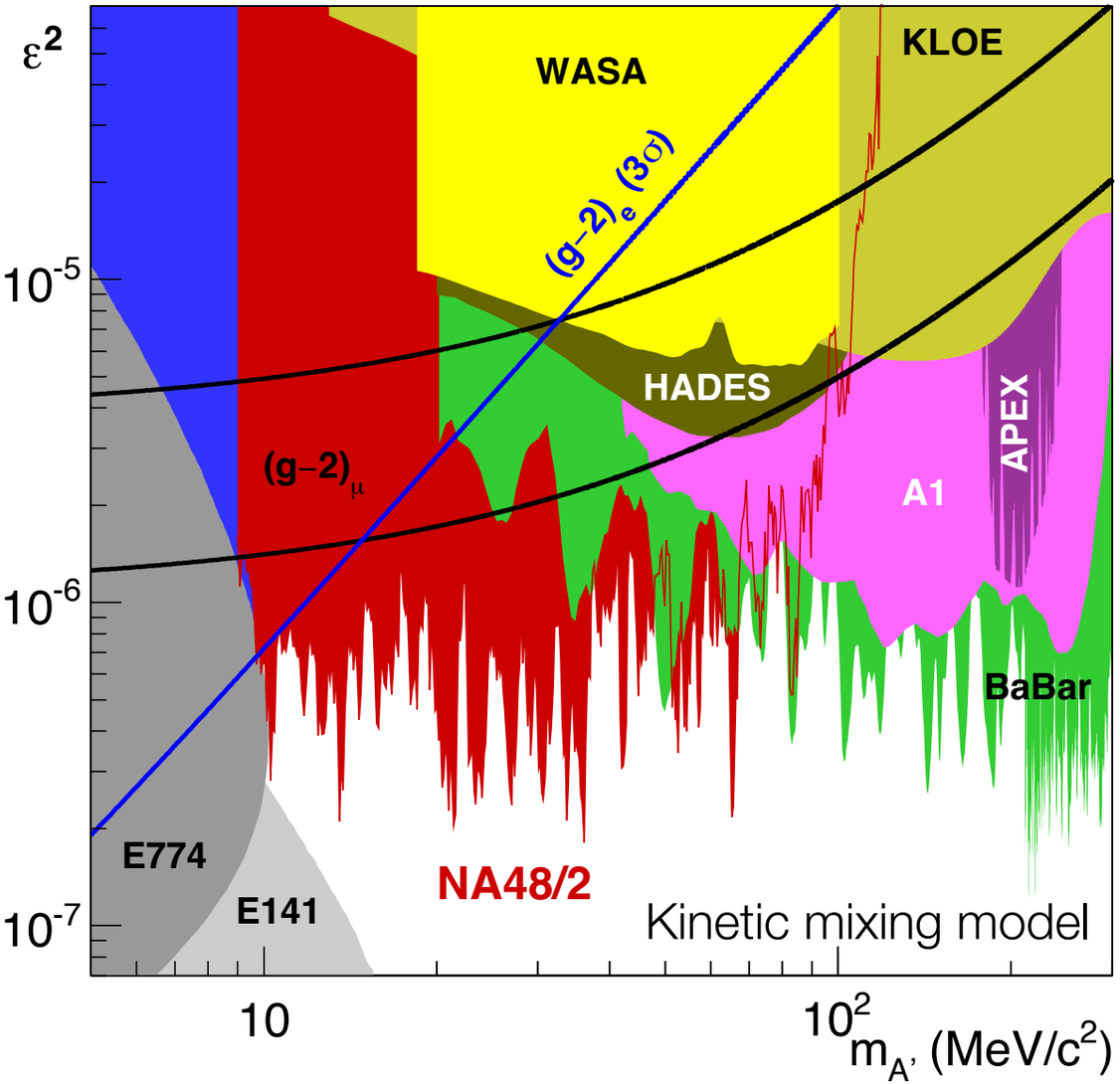

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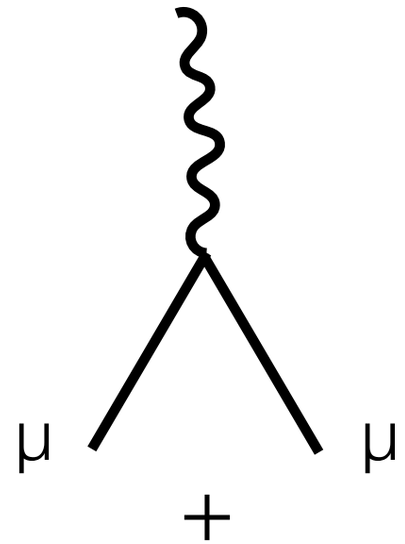
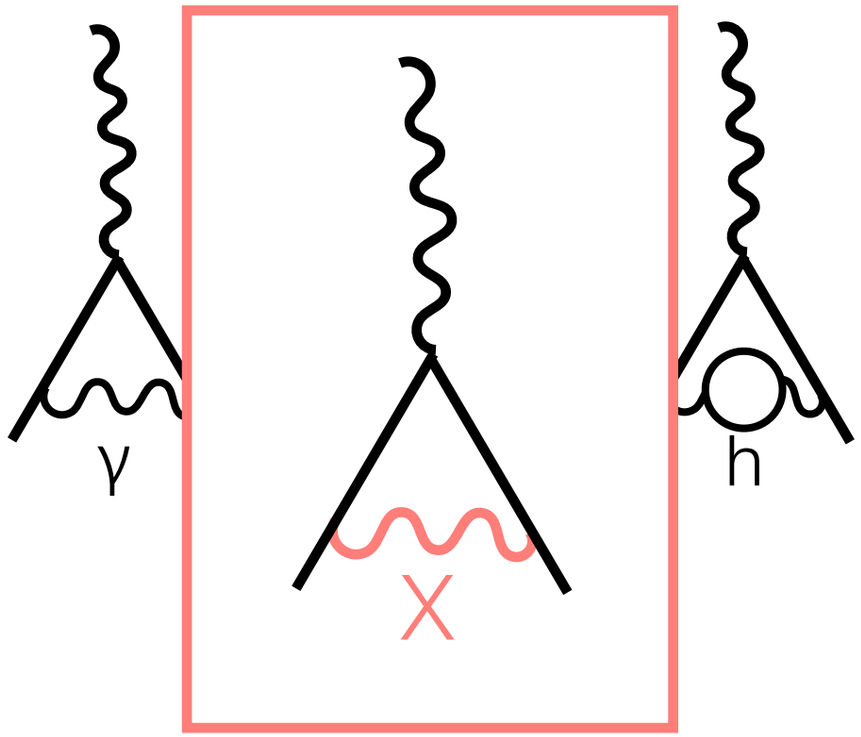
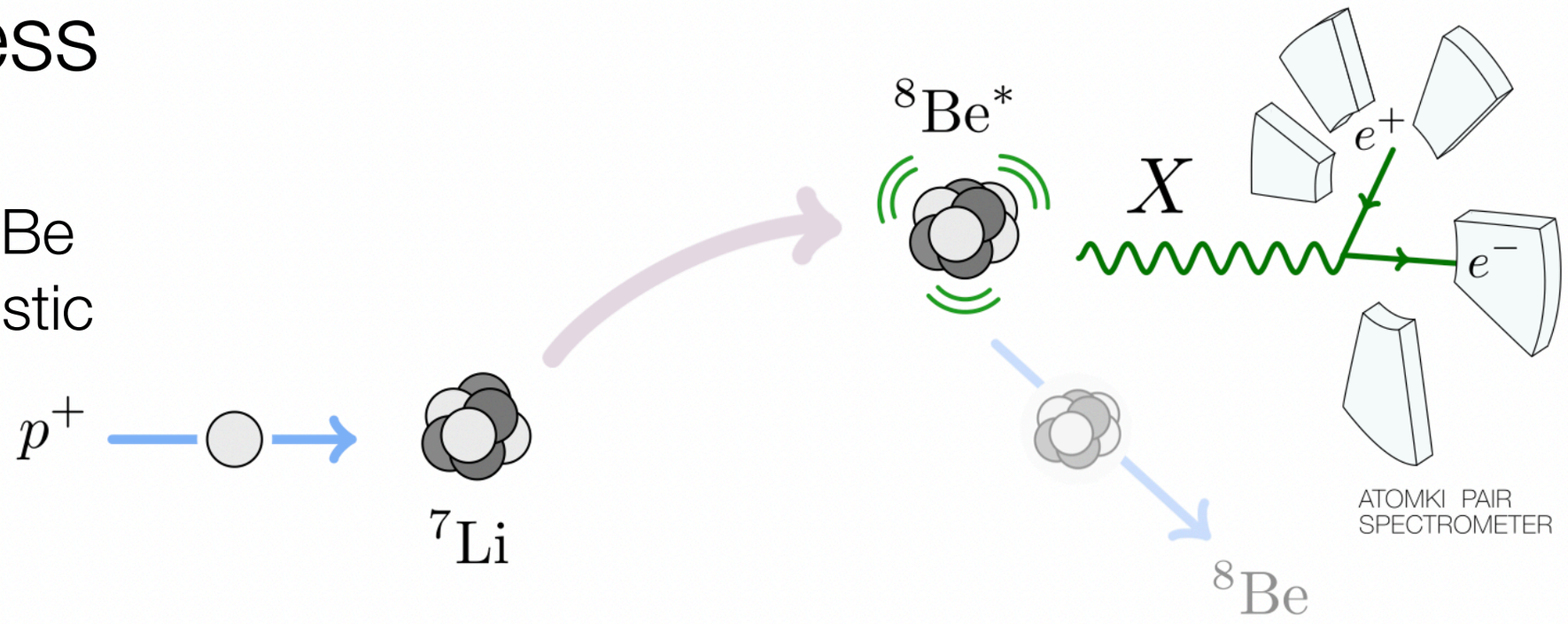




Light BSM boson: the X17 excess

Phys. Rev. D 95, 035017 (2017)

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



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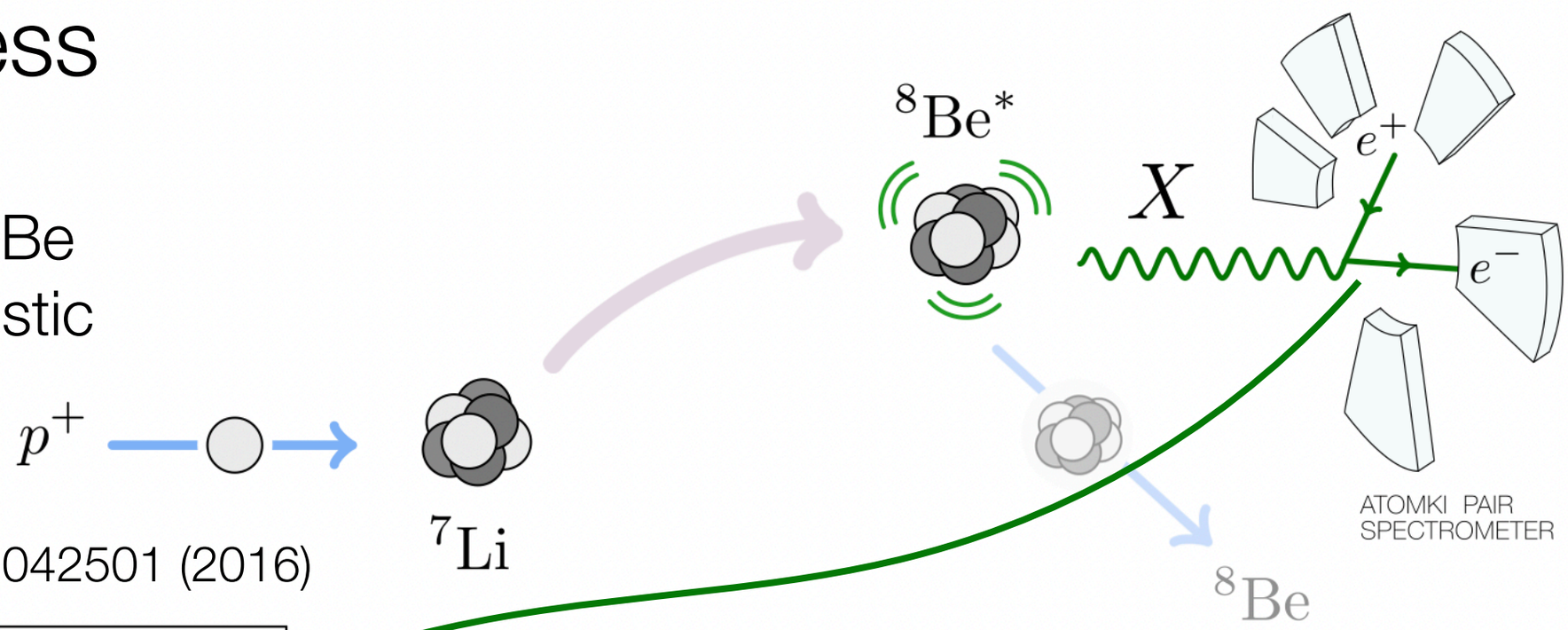

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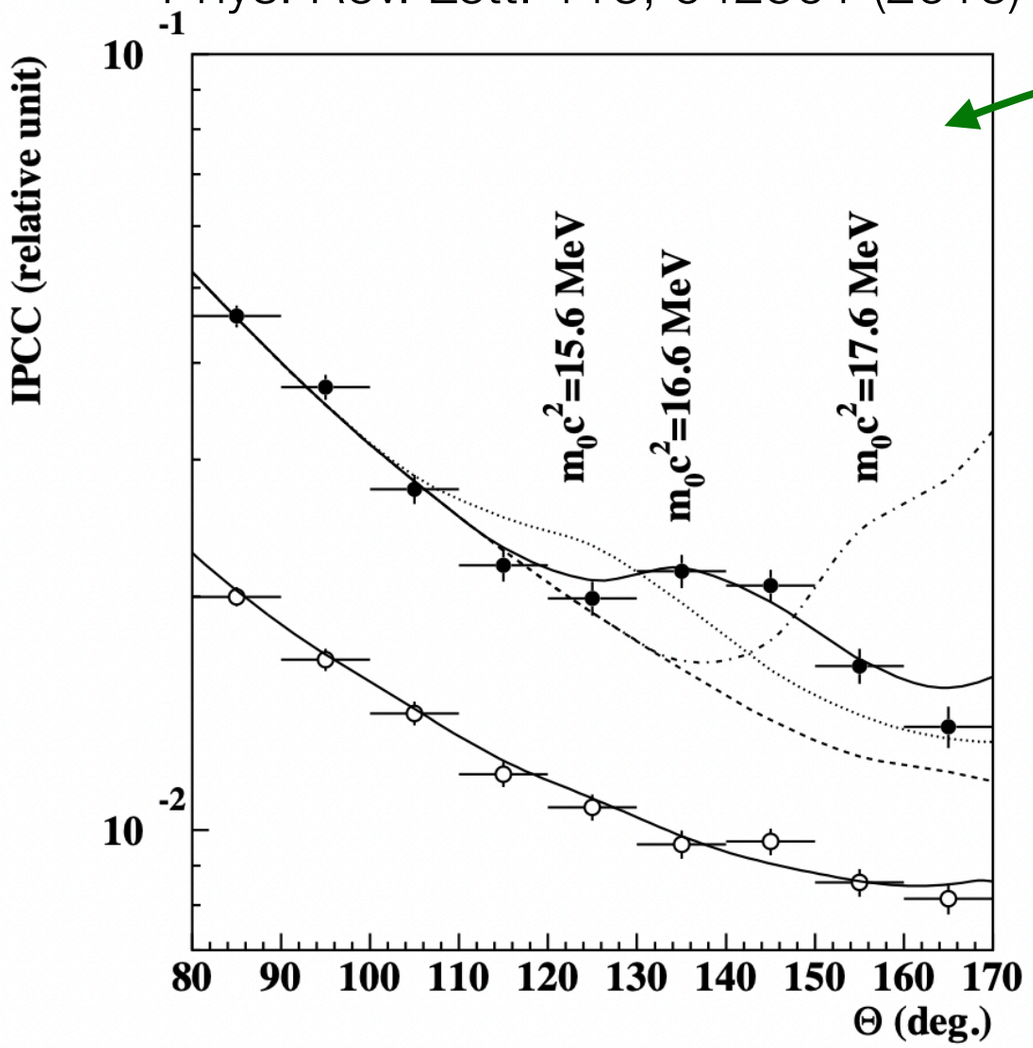

Invariant mass and opening angle of e+e- pair show resonant signal

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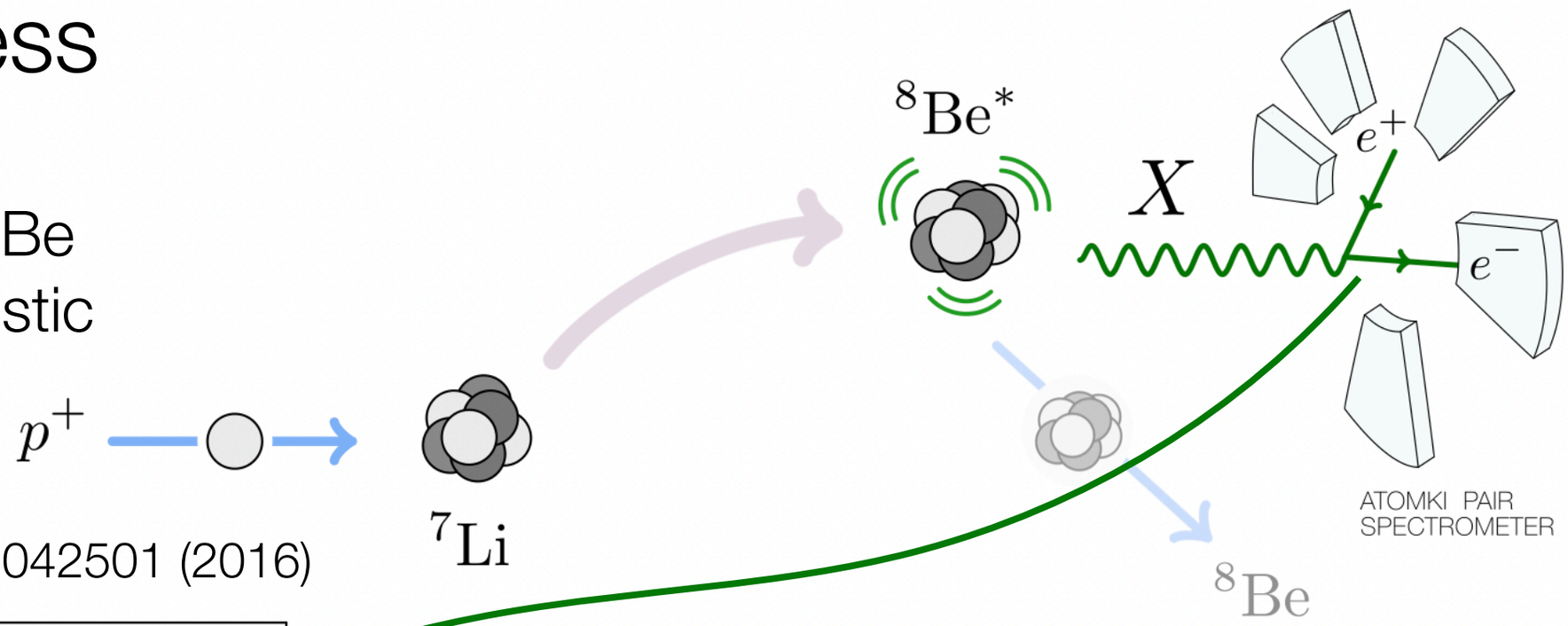

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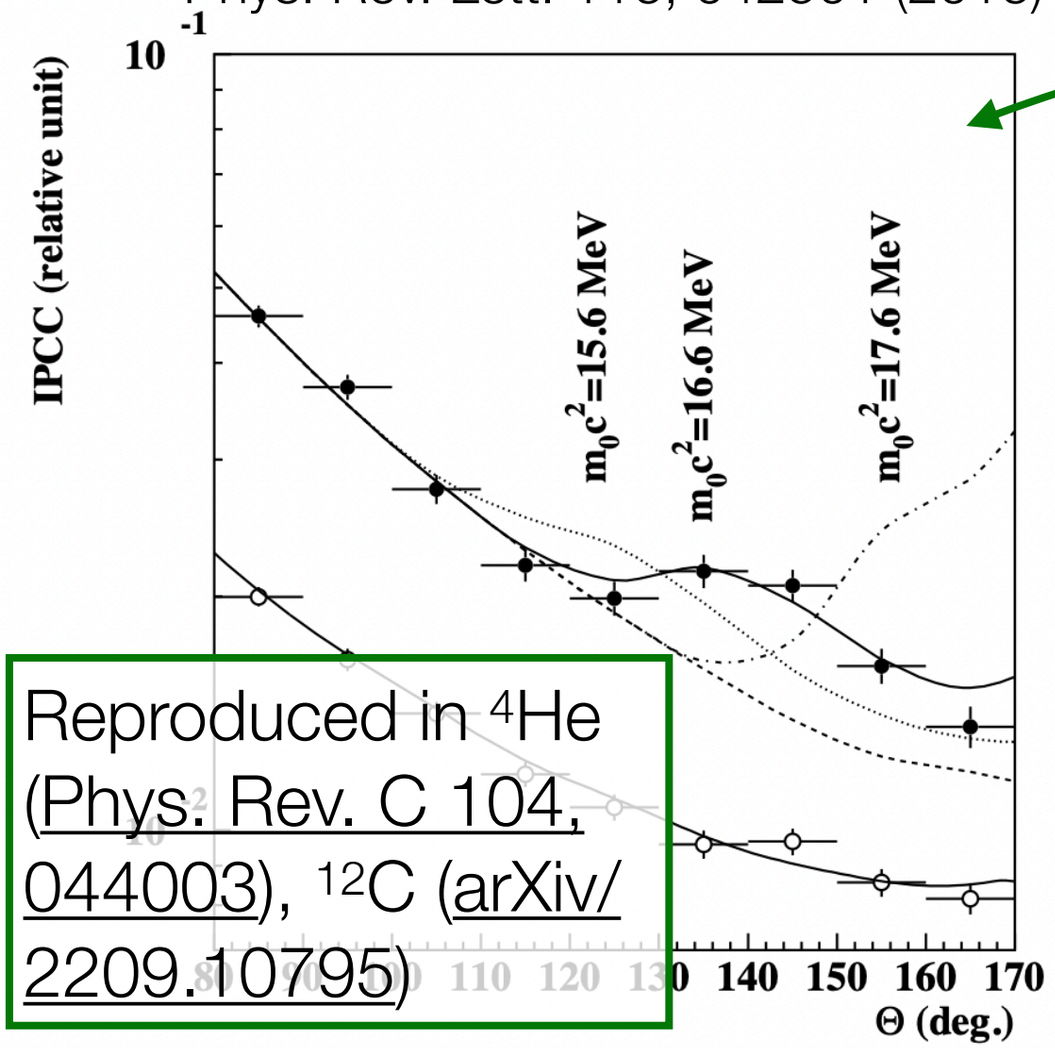

Reproduced in ^{4}He (Phys. Rev. C 104, 044003), ^{12}C (arXiv/2209.10795)

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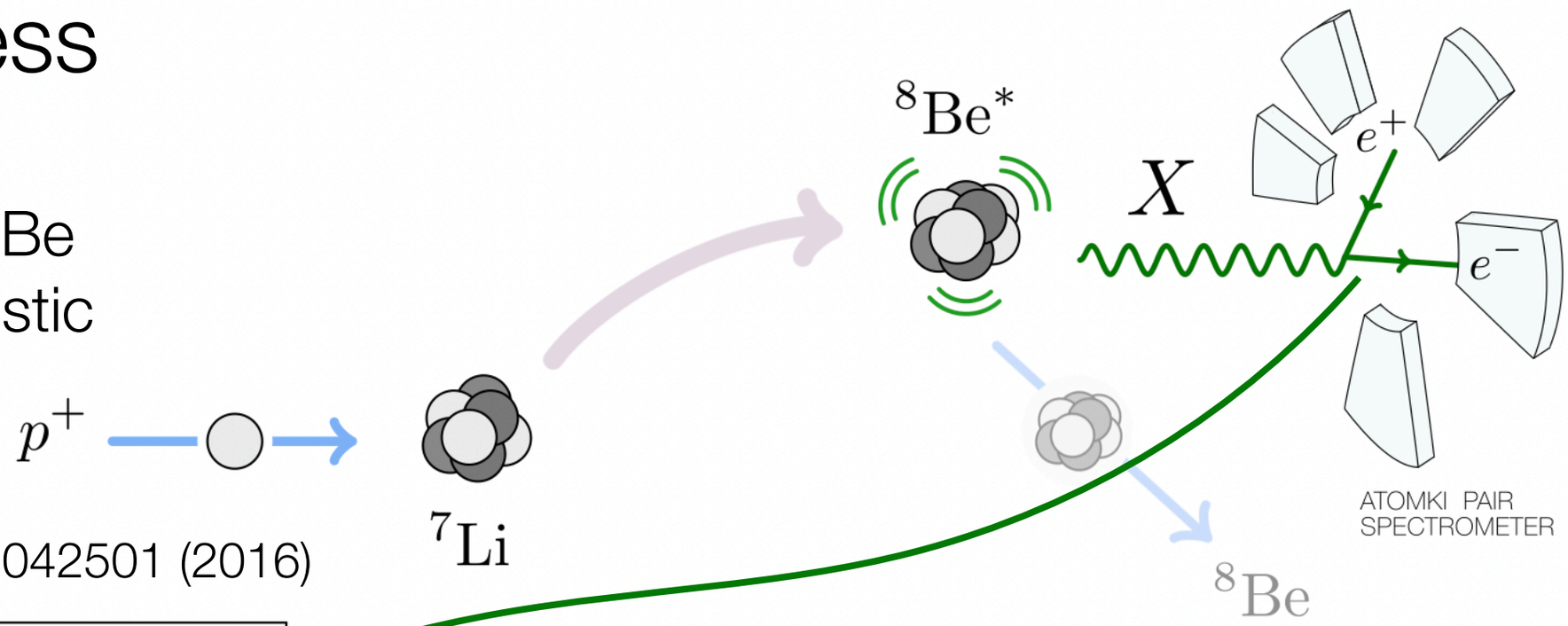

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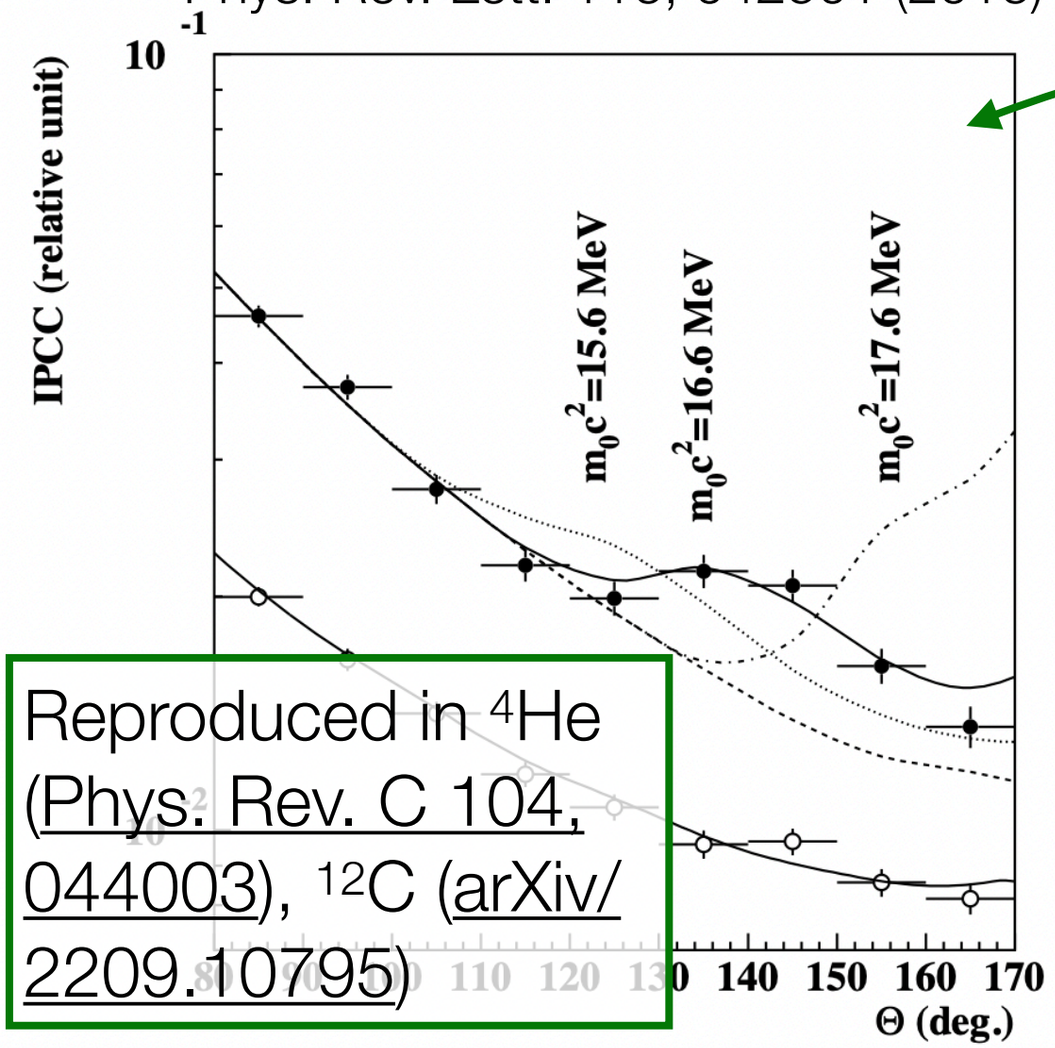

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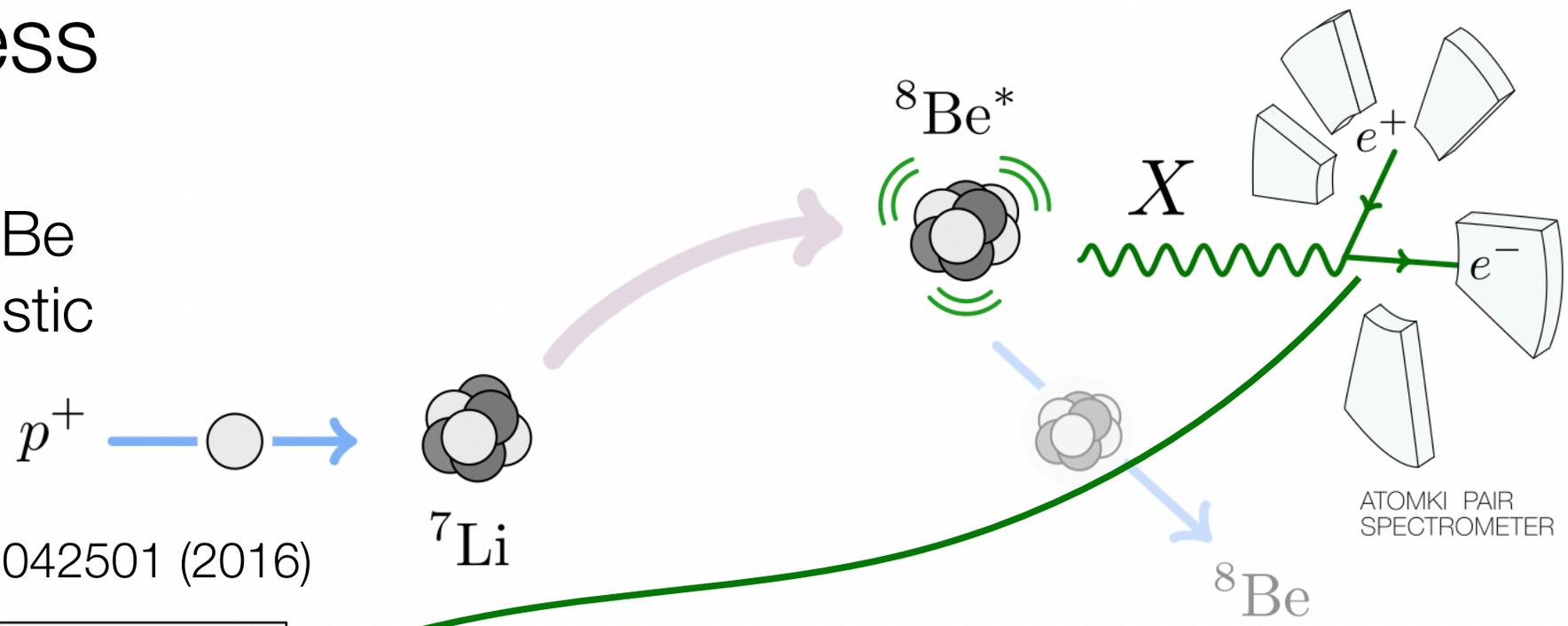

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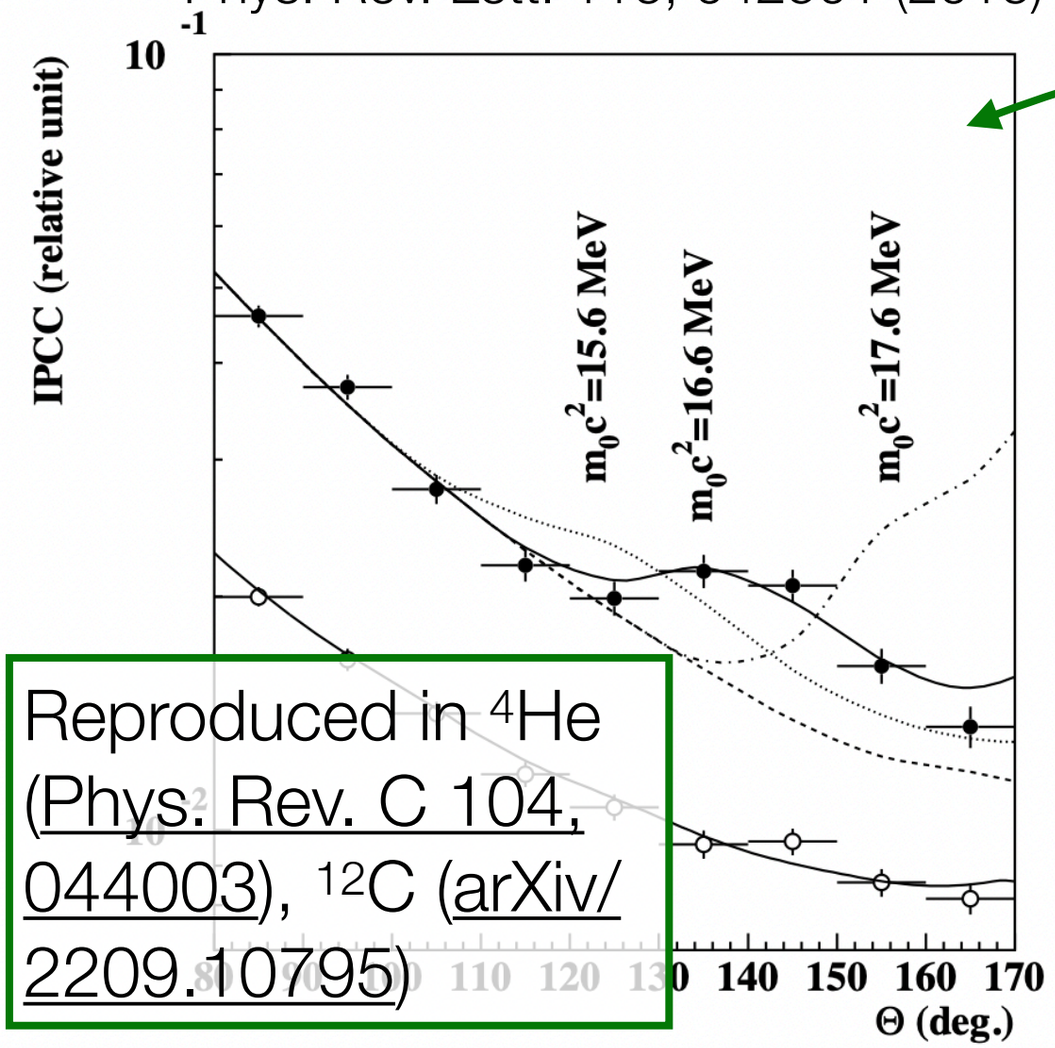

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Invariant mass and opening angle of e+e- pair show resonant signal

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

Or, compatible with new boson with mass ~ 17 MeV

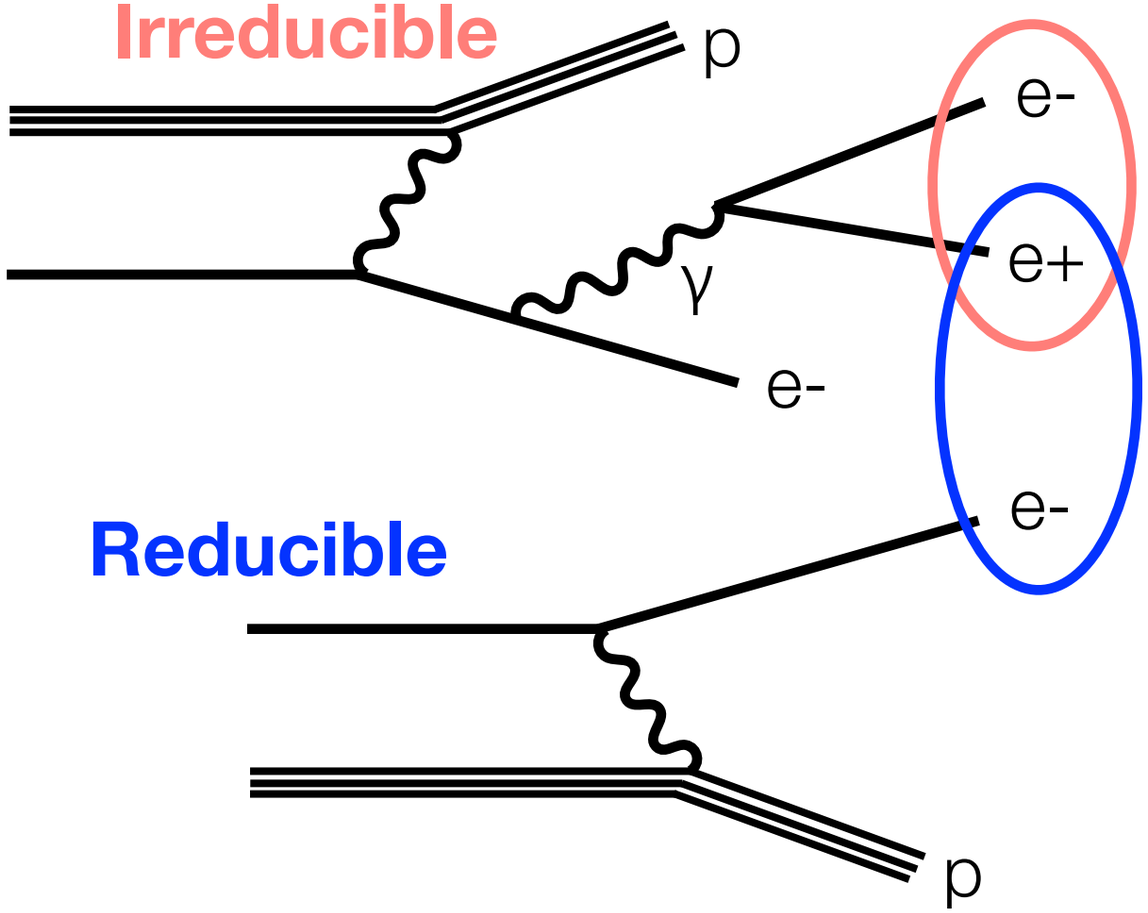
Complementary experiments

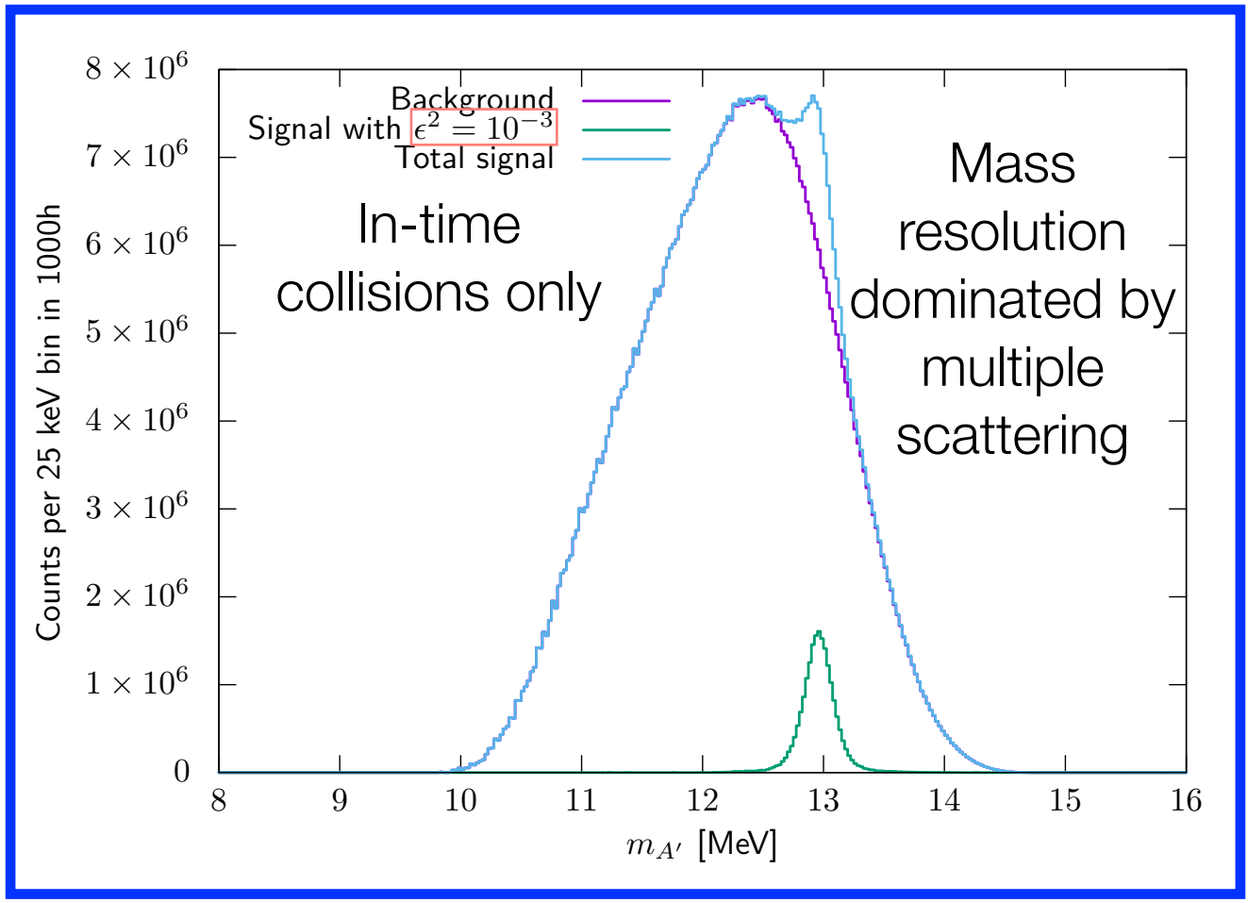
- Type 1: ATOMKI-like; intending to reproduce and validate experiment
- Montreal, Notre Dame among groups working on this
- No conflict with collider/accelerator goals
- Type 2: mixed hadronic-leptonic
- Leading experiment LHCb: will cover all X17 space (even with protophobic assumptions) with full Run 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+)

Background processes

- Dominant background is e+ from pair production combined with e- from simultaneous scattering event. **Coincidence** is key

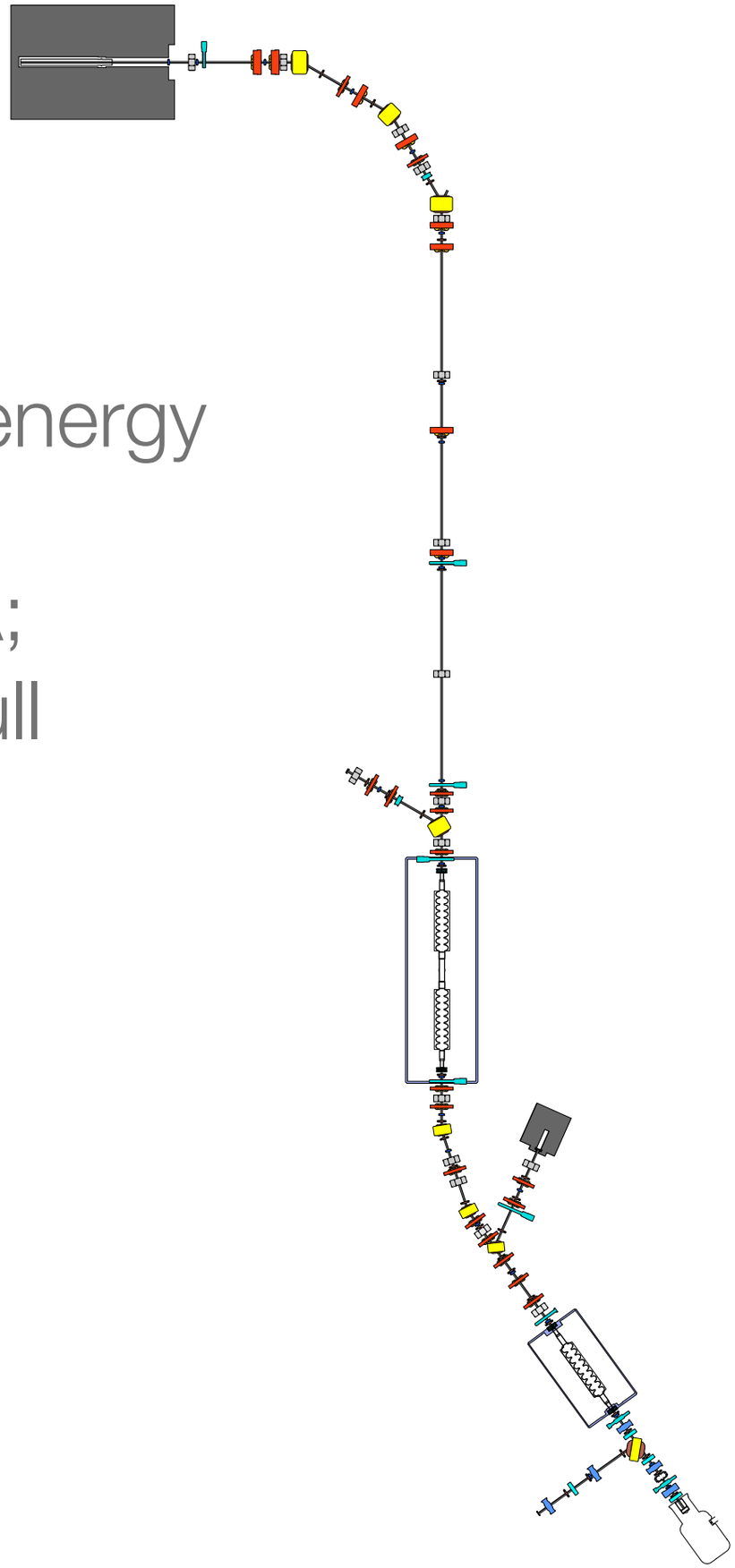
- Two ways to control rates: 1) angular position of detectors 2) timing resolution < bunch spacing (1.5 ns)





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



Why ARIEL?

- Low energy, high intensity beam.
    - Energy not much above the production threshold is nice because it gives an opening angle that we can easily pick up with spectrometers
    - Peak intensity of 10 mA gives us plenty of instantaneous luminosity - don’t need to run forever
- Finally, because the e-linac is available! No need to share beam time with any other targets until ~phase 2, at which point parasitic running will be an option

New cryomodule

Beam pipes

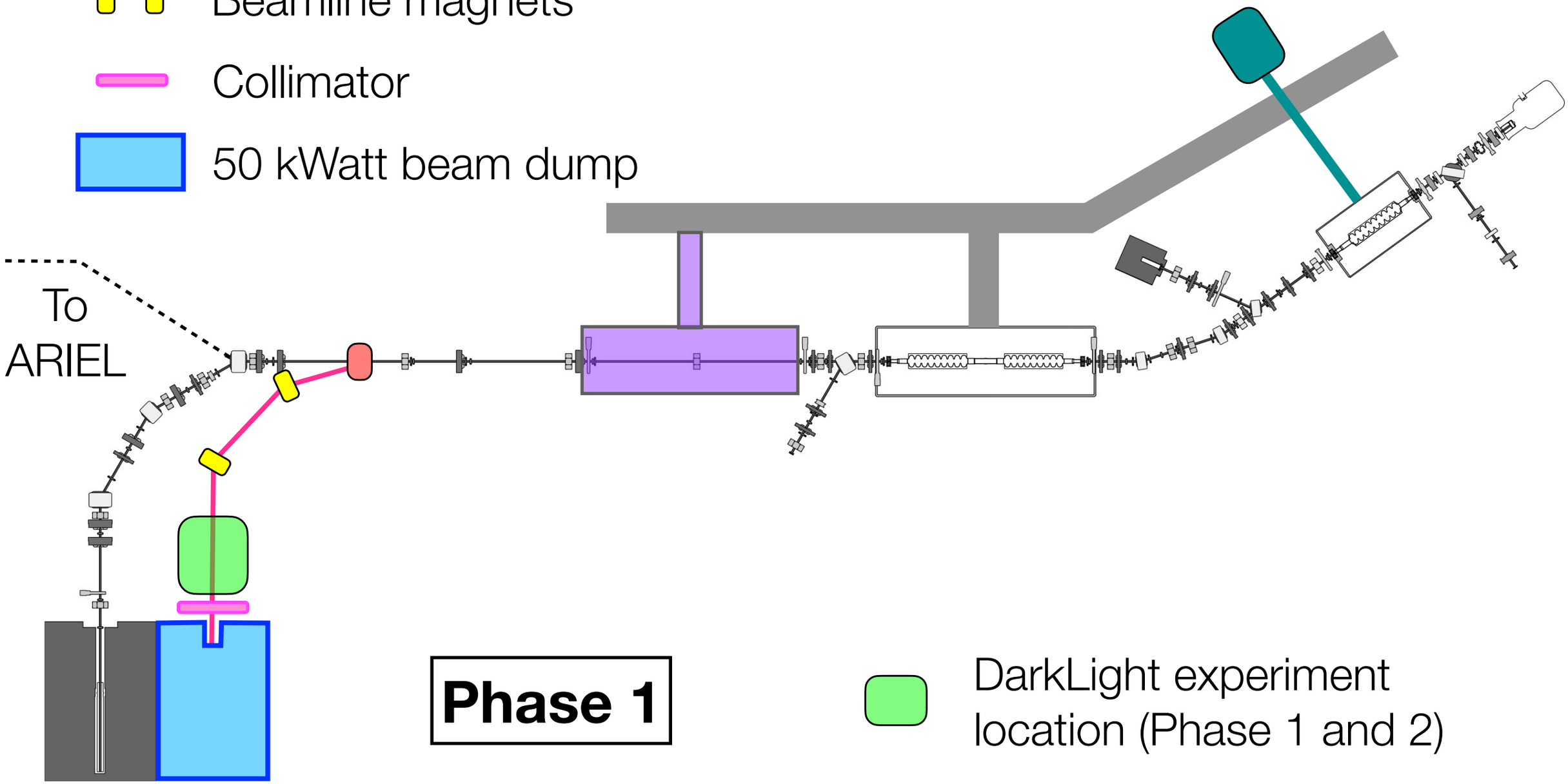
Beamline magnets

Collimator

50 kWatt beam dump

Solid state amplifier

Dipole magnet



Phase 1

DarkLight experiment location (Phase 1 and 2)

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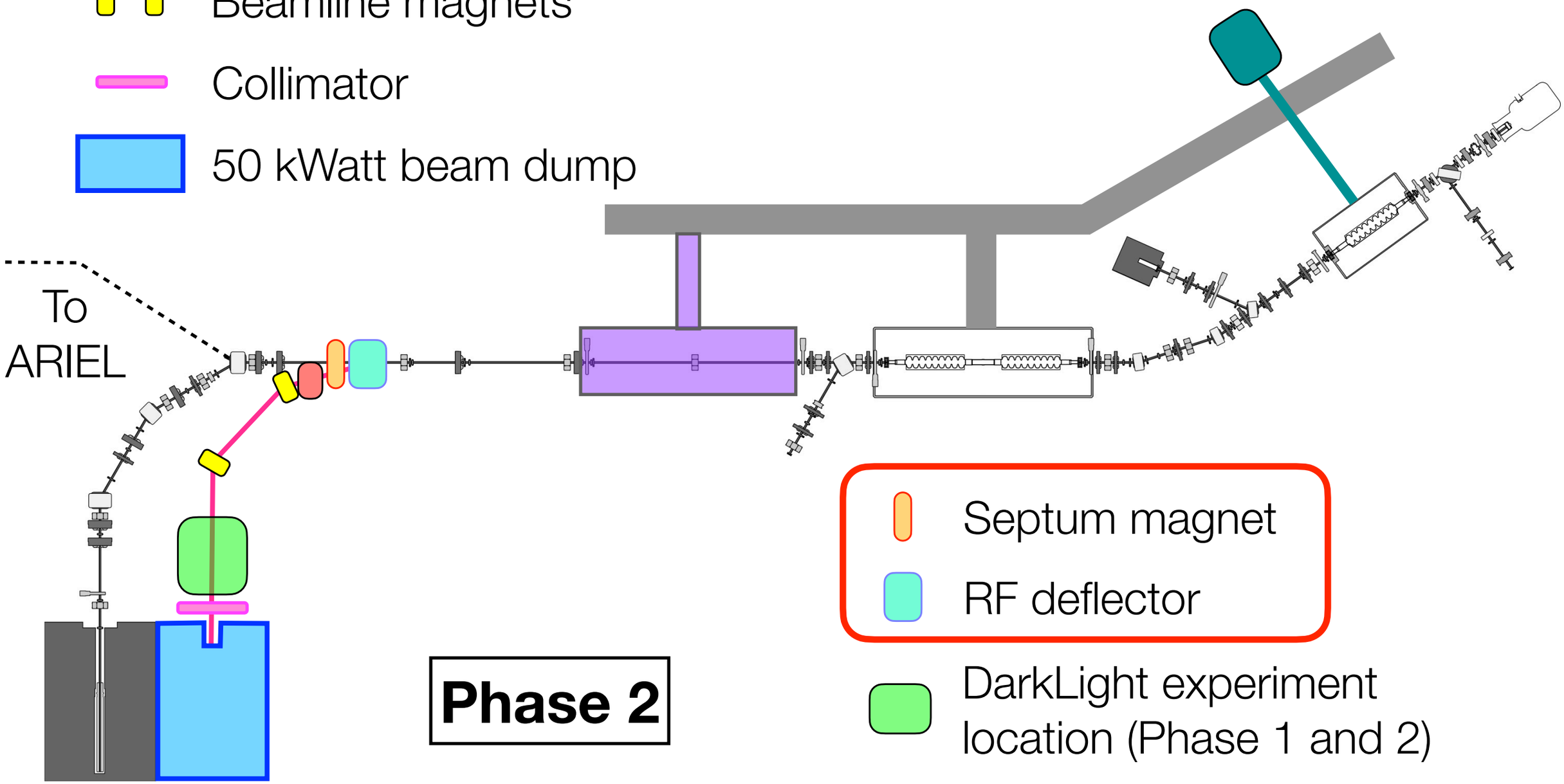
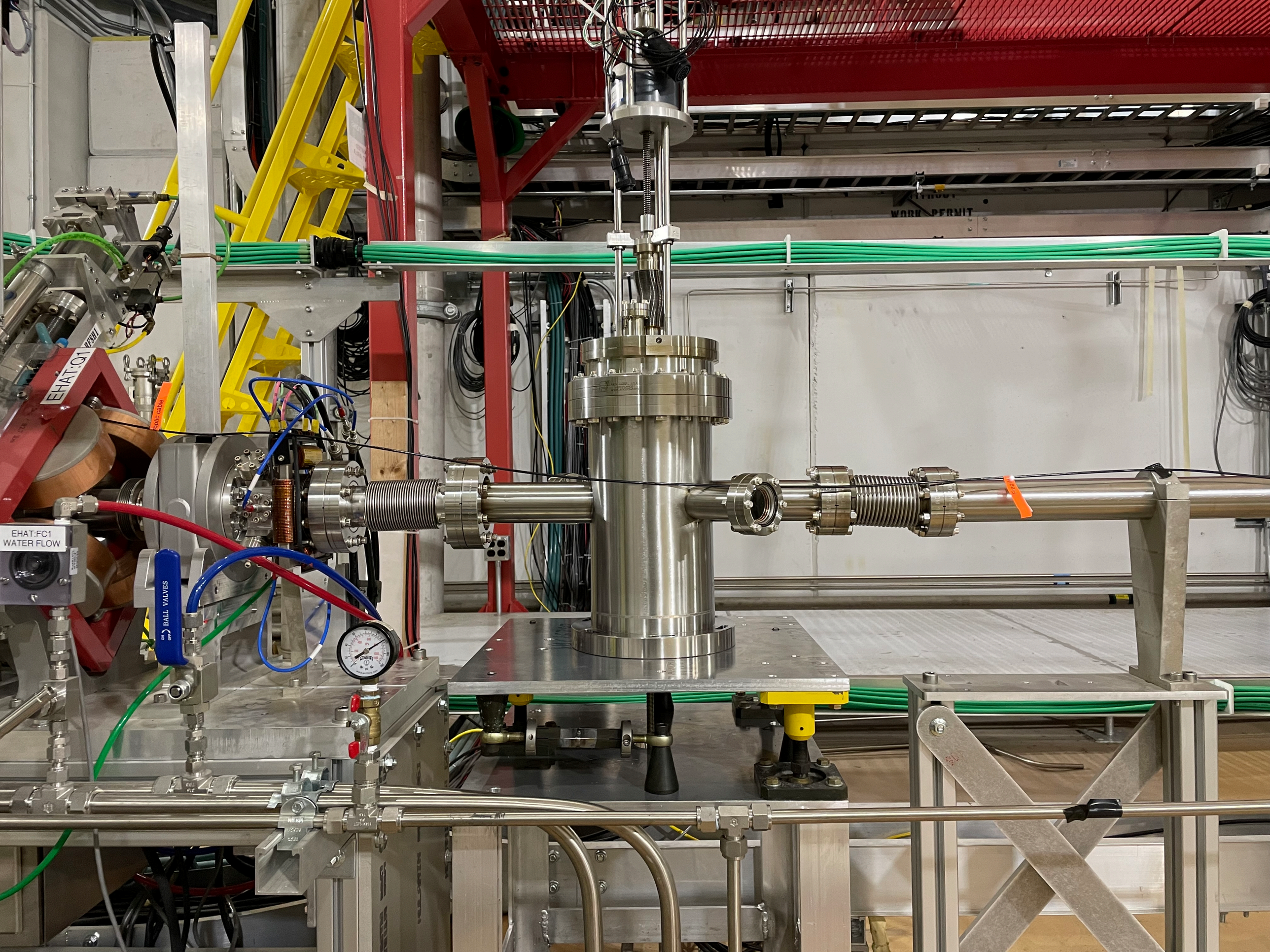


Septum magnet

RF deflector

DarkLight experiment location (Phase 1 and 2)

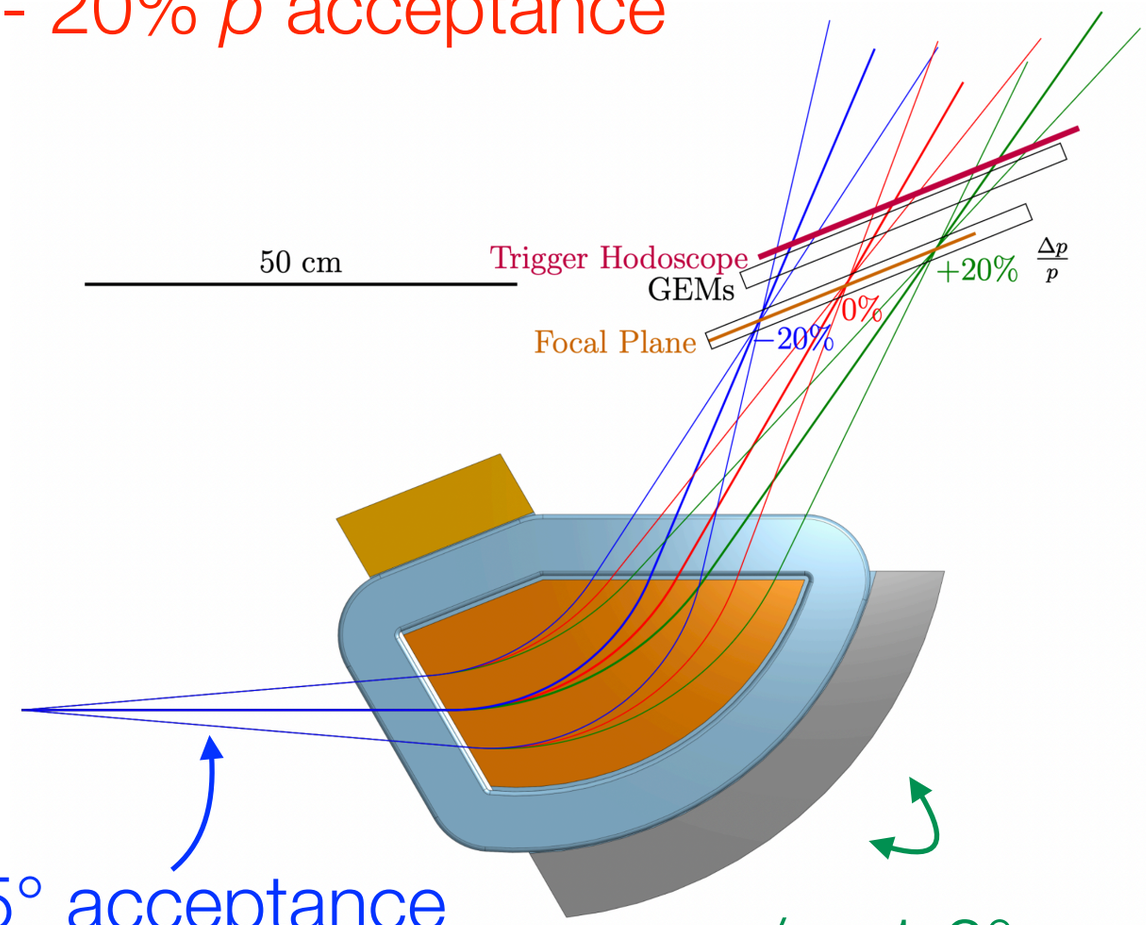
Phase 2


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

Experiment components: spectrometers

- Two identical dipole spectrometers, 0.32 T
- Design nearing completion
- Try to maximise acceptance, minimise scattering of high-E electrons into detectors
- Metrics of success: low background and best possible mass resolution

+/- 20% *p* acceptance

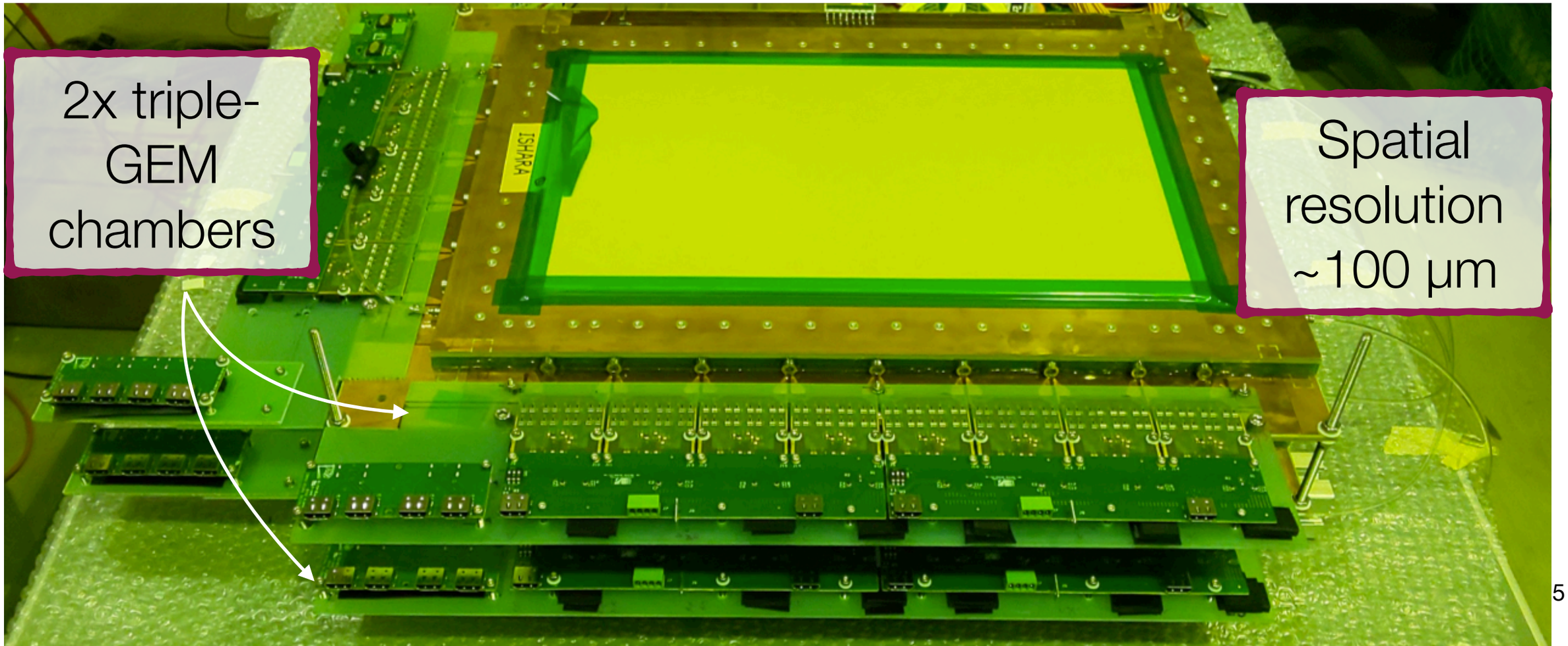


+/- 5° acceptance in this dimension

+/- ~1.6° acceptance the other way

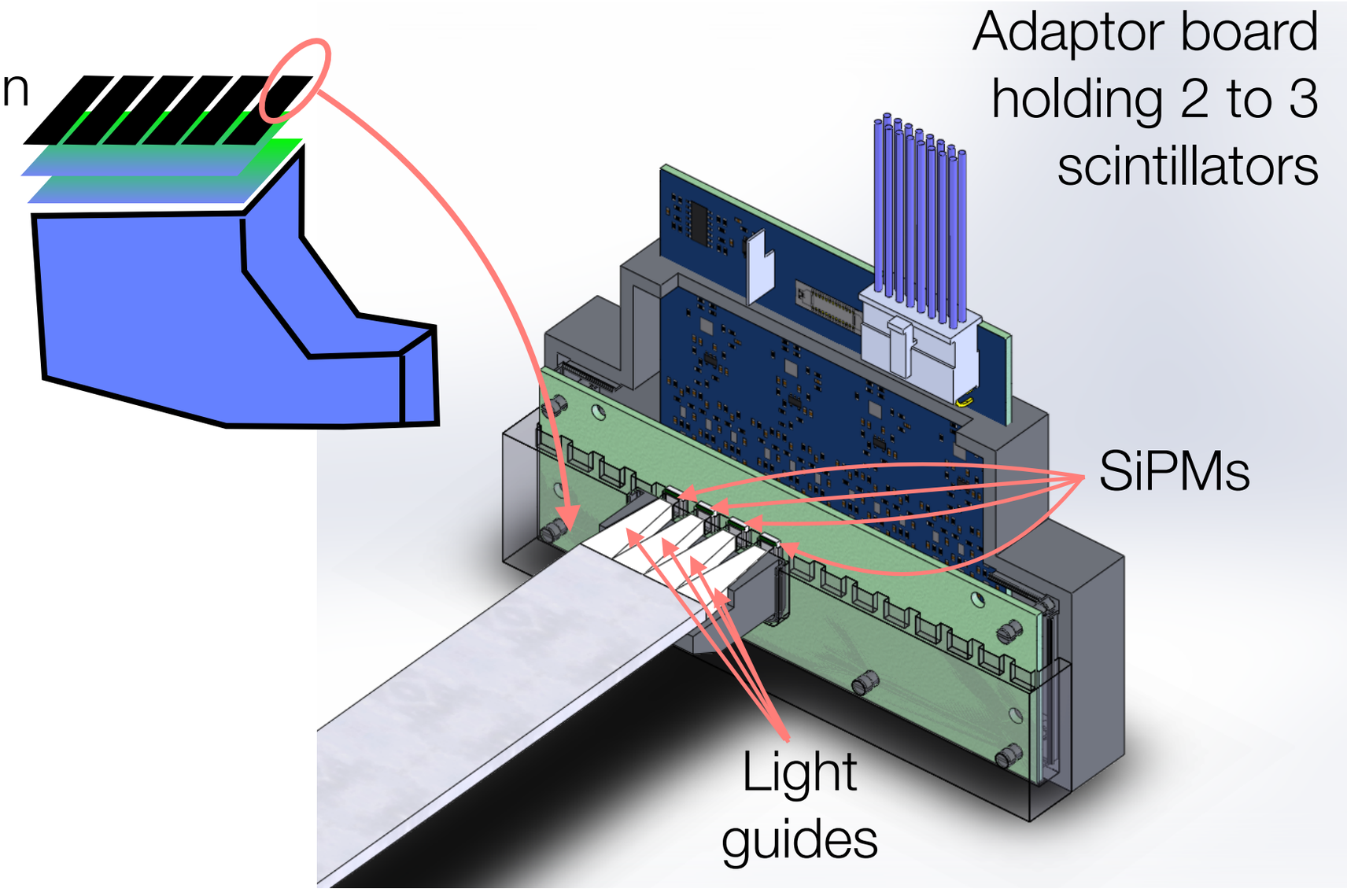
Experiment components: GEM detectors

- 25 x 40 cm triple-GEMs **already completed** by Hampton University collaborators
- Commissioning in progress (JLab/ELPH)
- GEM fast readout mode takes ~ 200 μs
- Timing resolution probably ~ 10 ns depending on details of readout etc. Tests ongoing



Experiment components: trigger detectors

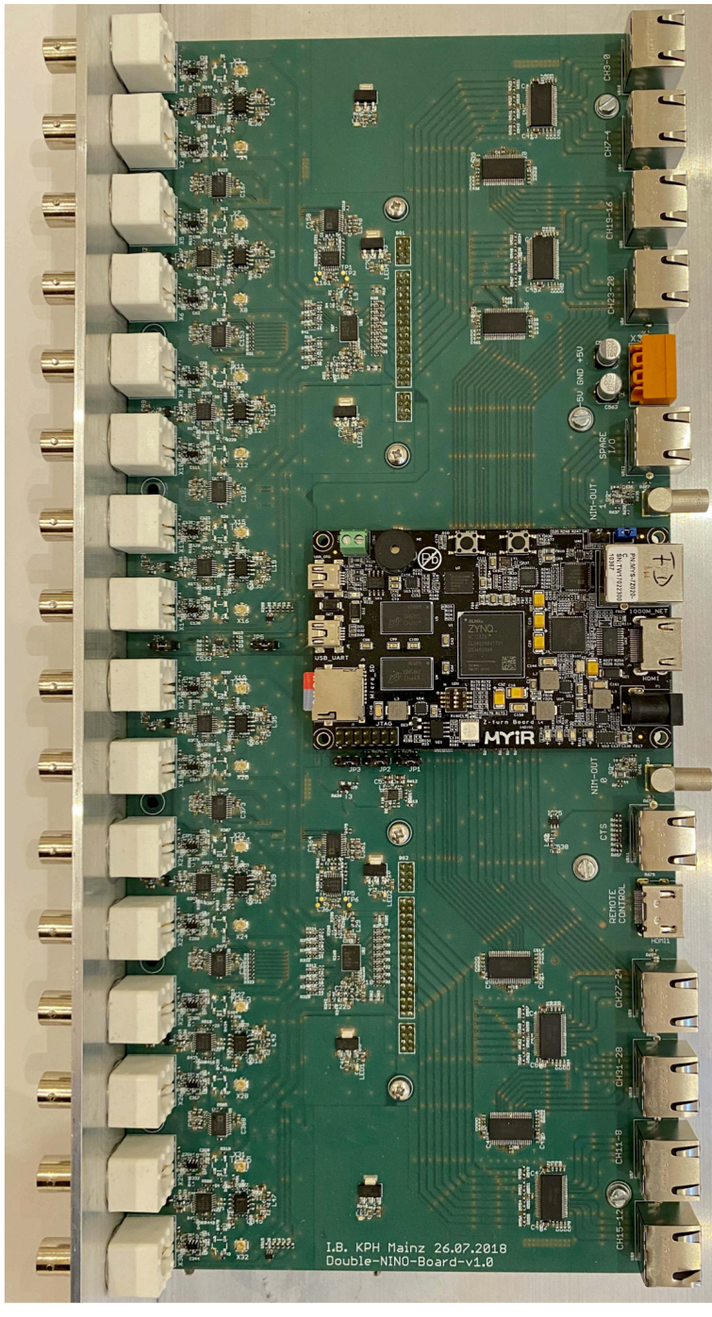
- Key performance metric: timing resolution ~200 ps
- 8 - 10 strips of fast plastic scintillator read out via SiPMs
  - Shielding will be important for longevity
- Prototype testing at TRIUMF under way
- DAQ design in progress



Exact dimensions and number of SiPMs remains open

Experiment status: read-out and DAQ

- GEM read-out electronics already in place: timing ~ 200 μs
- 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 design from one of DarkSide or alpha-g DAQ boards also designed and manufactured at TRIUMF
  - Also investigating MAGIX experiment board



MAGIX board with 32 inputs & FPGA
H. Merkel

Rates and detector timing

Bunch spacing is 1.5 ns

Rates for various backgrounds from simulation (Preliminary!):

Setup	Irreducible QED	Singles e^+	Singles e^-	Random coinc.
13@31	9.1 Hz	30.2 kHz	3.6 MHz	168 Hz
17@31	0.83 Hz	18.2 kHz	751 kHz	21 Hz
17@45	11.2 Hz	32.3 kHz	2 MHz	98 Hz
17@55	71.4 Hz	45.1 kHz	8.5 MHz	589 Hz

Trigger rate will be coincidence rate: max ~600 Hz > 1.5 ms between triggers

Singles e- poses greatest challenge: trying to keep this under ~5 MHz to keep within prediction of GEM timing resolution