DarkLight@ARIEL experiment status update

Kate Pachal
TRIUMF o.b.o.
the DarkLight collaboration

A quick introduction to DarkLight@ARIEL

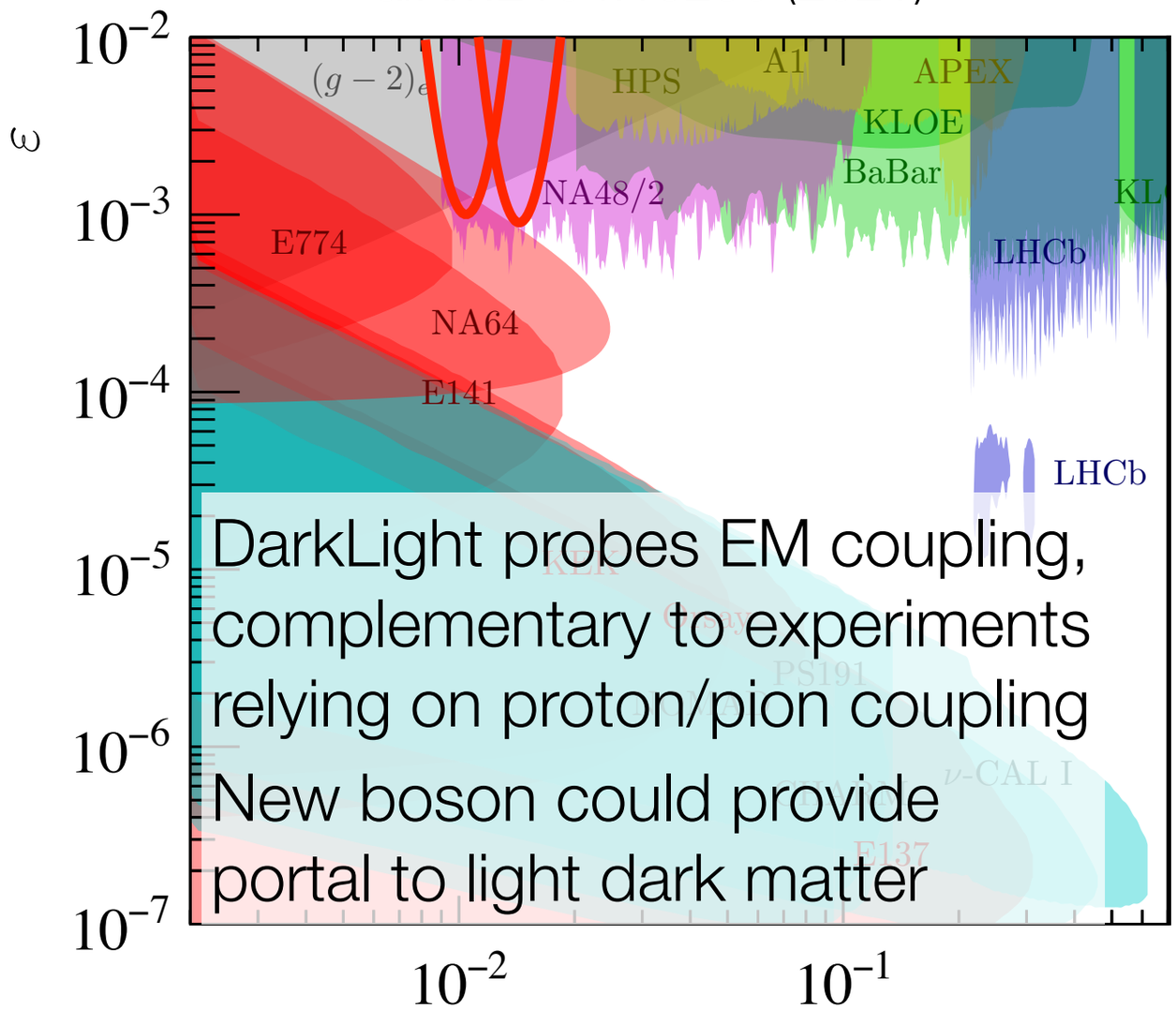
- DarkLight@ARIEL is a **new experiment** to be built **at TRIUMF** searching for new particles in low-mass e+ and e- pairs scattered from a thin foil
  - Following previous work/proposal at JLab
  - International collaboration covering all relevant areas of expertise

- Today, as requested, a brief **status update**
  - Some elements of full experiment designed and beginning to be built; with others, addressing remaining open questions
  - Hoping to install experiment around **end of this year**, subject to external factors
  - Still iterating on longer-term plans

Motivations

Model-independent search for dark photons

arXiv:2104.10280 (2021)



DarkLight probes EM coupling, complementary to experiments relying on proton/pion coupling

New boson could provide portal to light dark matter

Low-energy electron scattering measurements

By varying beam energy, can make some interesting measurements with very little beam time. Examples:

- Radiative corrections to Moller scattering
- Bethe-Heitler cross sections
- Workshop at TRIUMF began exploring additional possibilities (see JoP Conf. Ser. 2391)

The DarkLight @ ARIEL experiment

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

Radiative production of new particle

X

e-

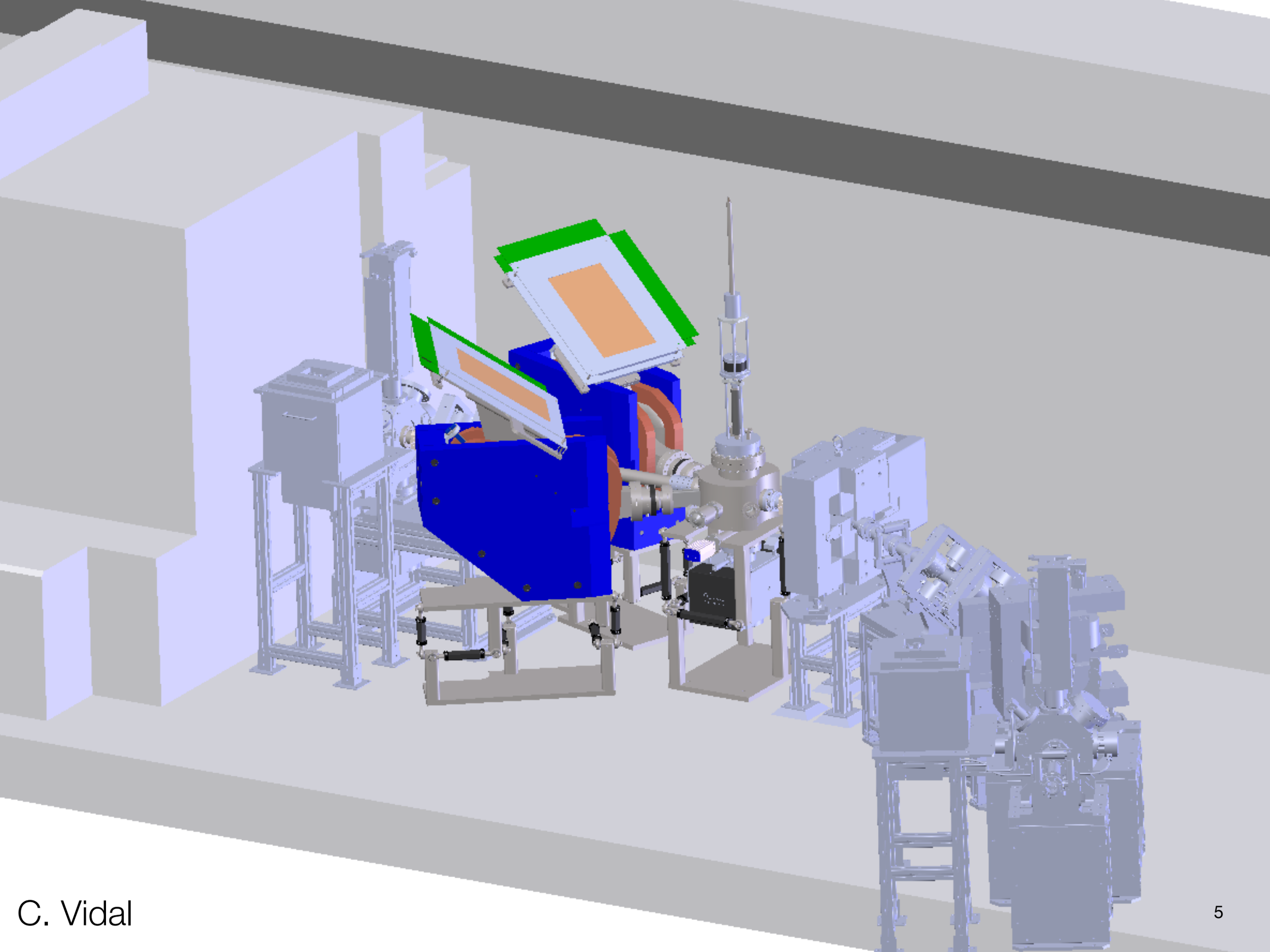
e-

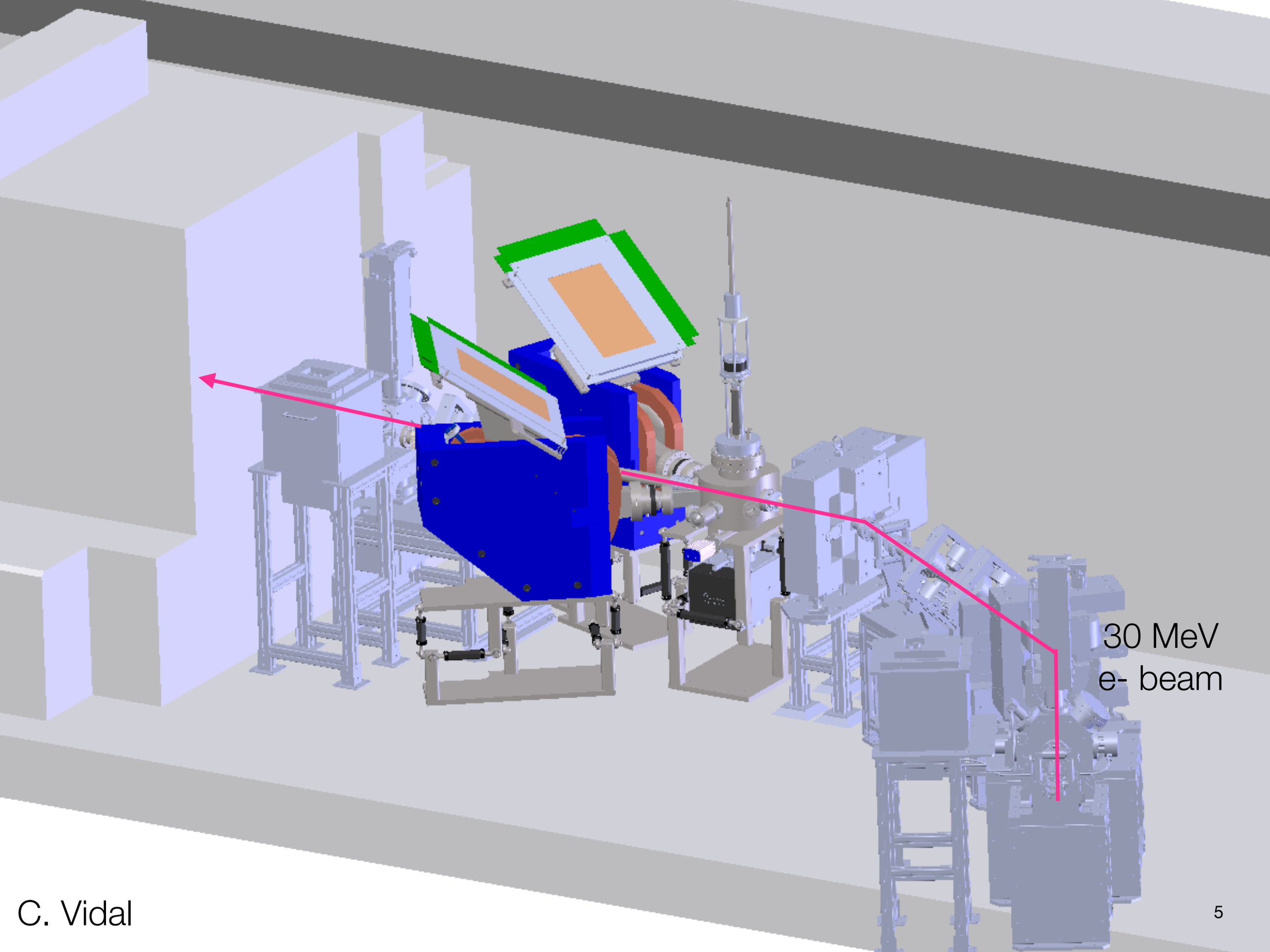
e+

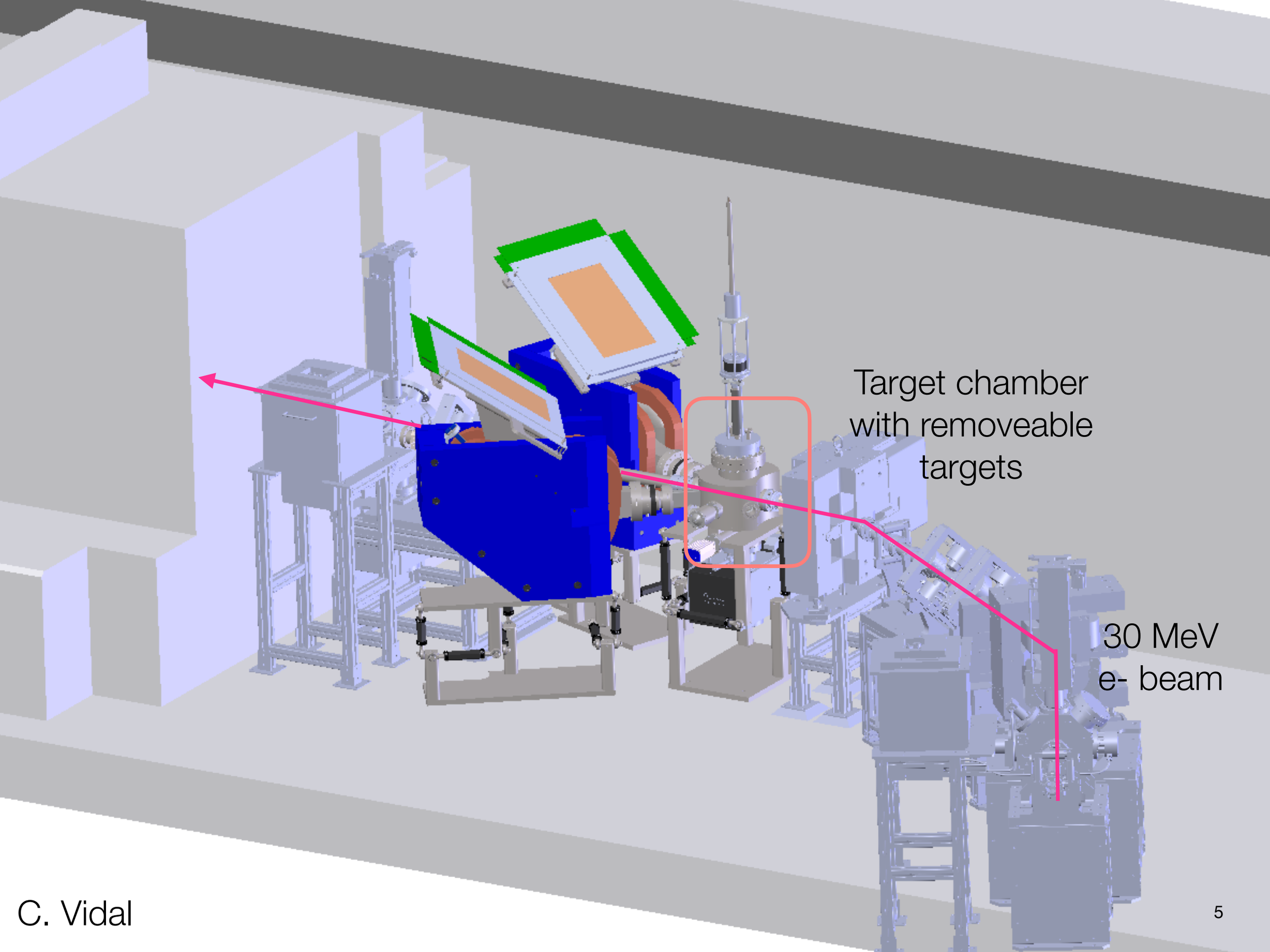
Broad opening angle: measure e+ and e- in spectrometers on opposite sides of beamline

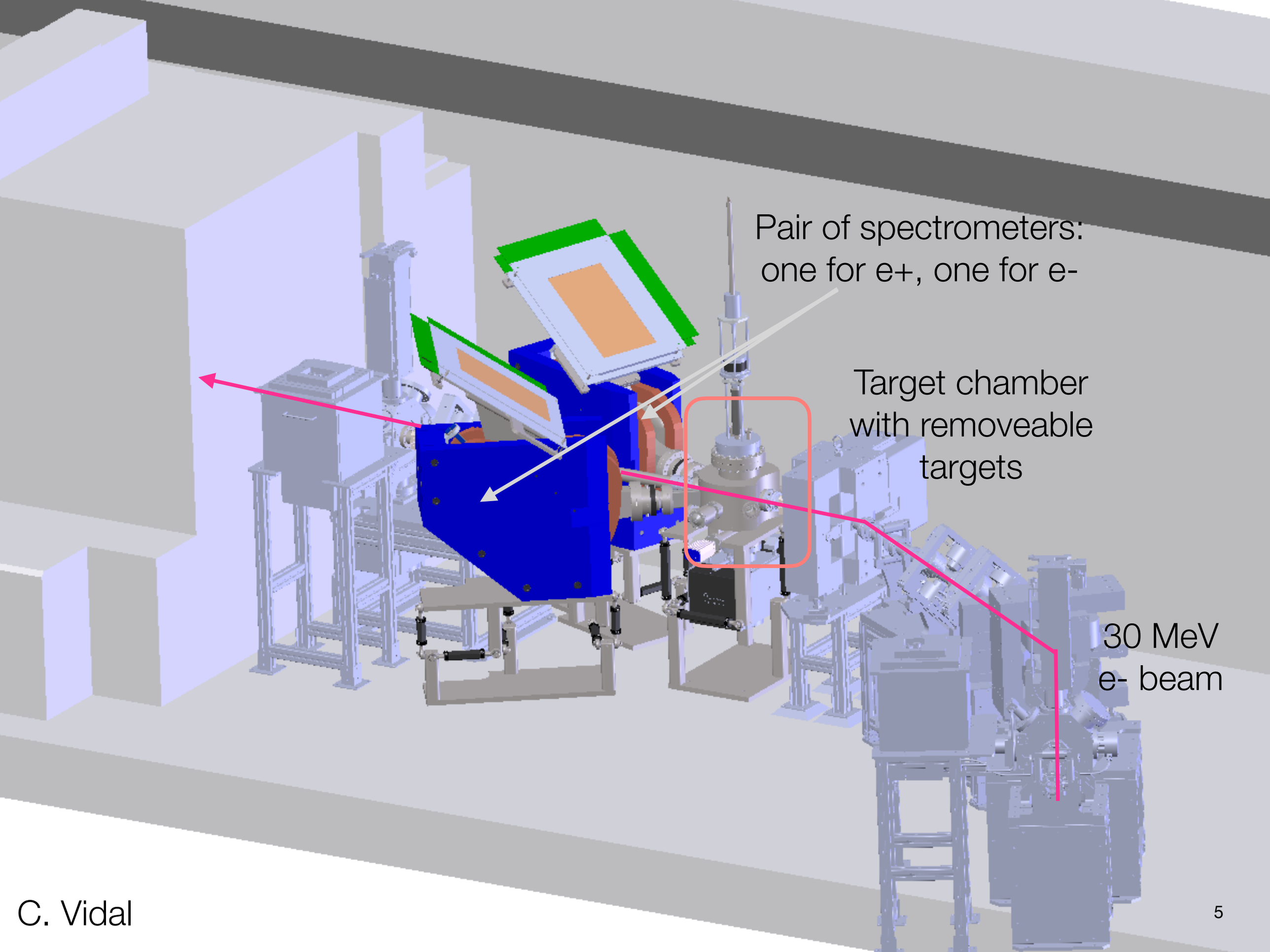
High-N target optimised for minimum multiple scattering: baseline target is 1 μm Tantalum foil

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




30 MeV
e- beam


Target chamber
with removeable
targets
30 MeV
e- beam


Pair of spectrometers:
one for e+, one for e-
Target chamber
with removeable
targets
30 MeV
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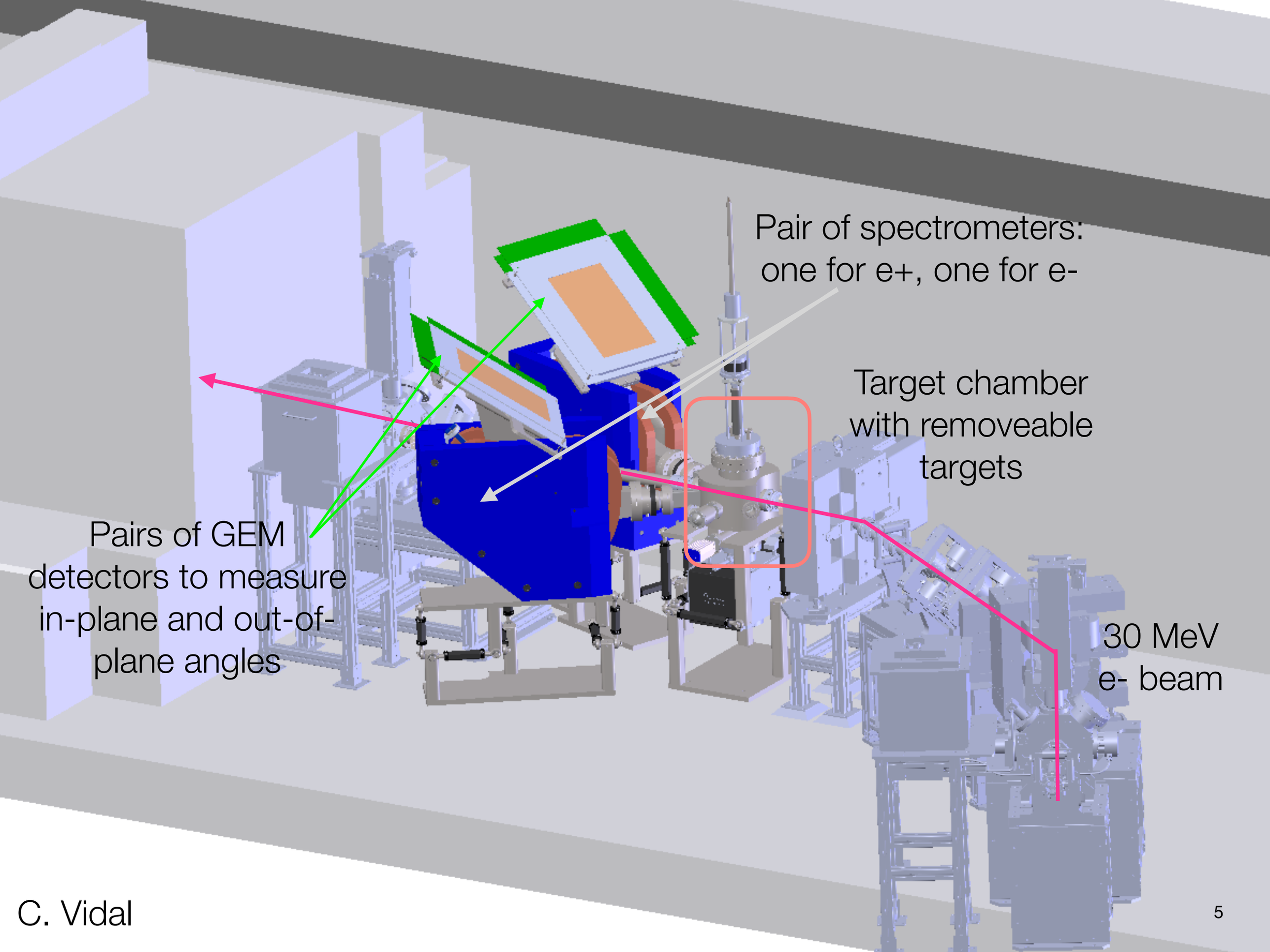
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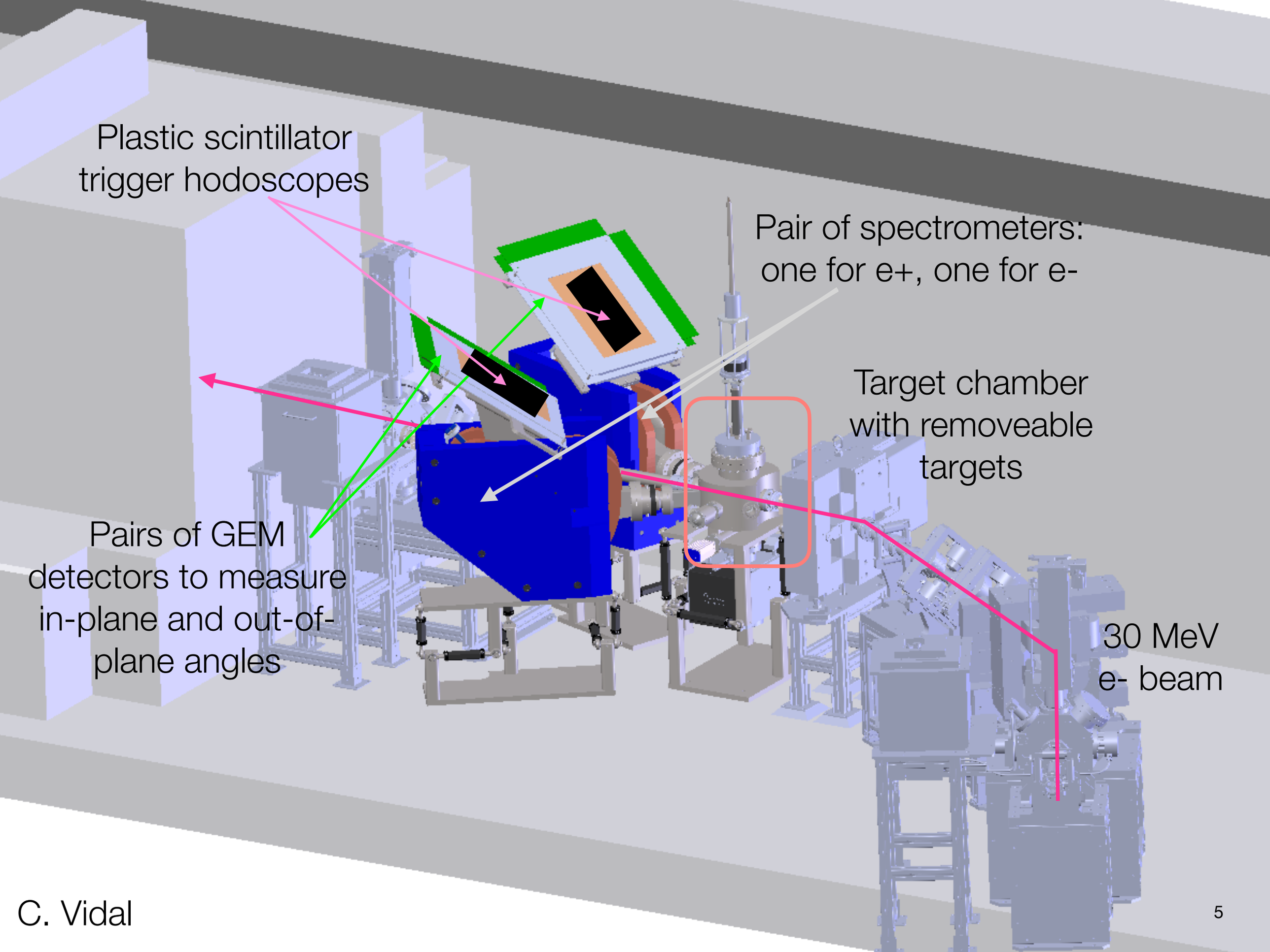

Plastic scintillator trigger hodoscopes
Pair of spectrometers: one for e+, one for e-
Target chamber with removeable targets
Pairs of GEM detectors to measure in-plane and out-of-plane angles
30 MeV e- beam

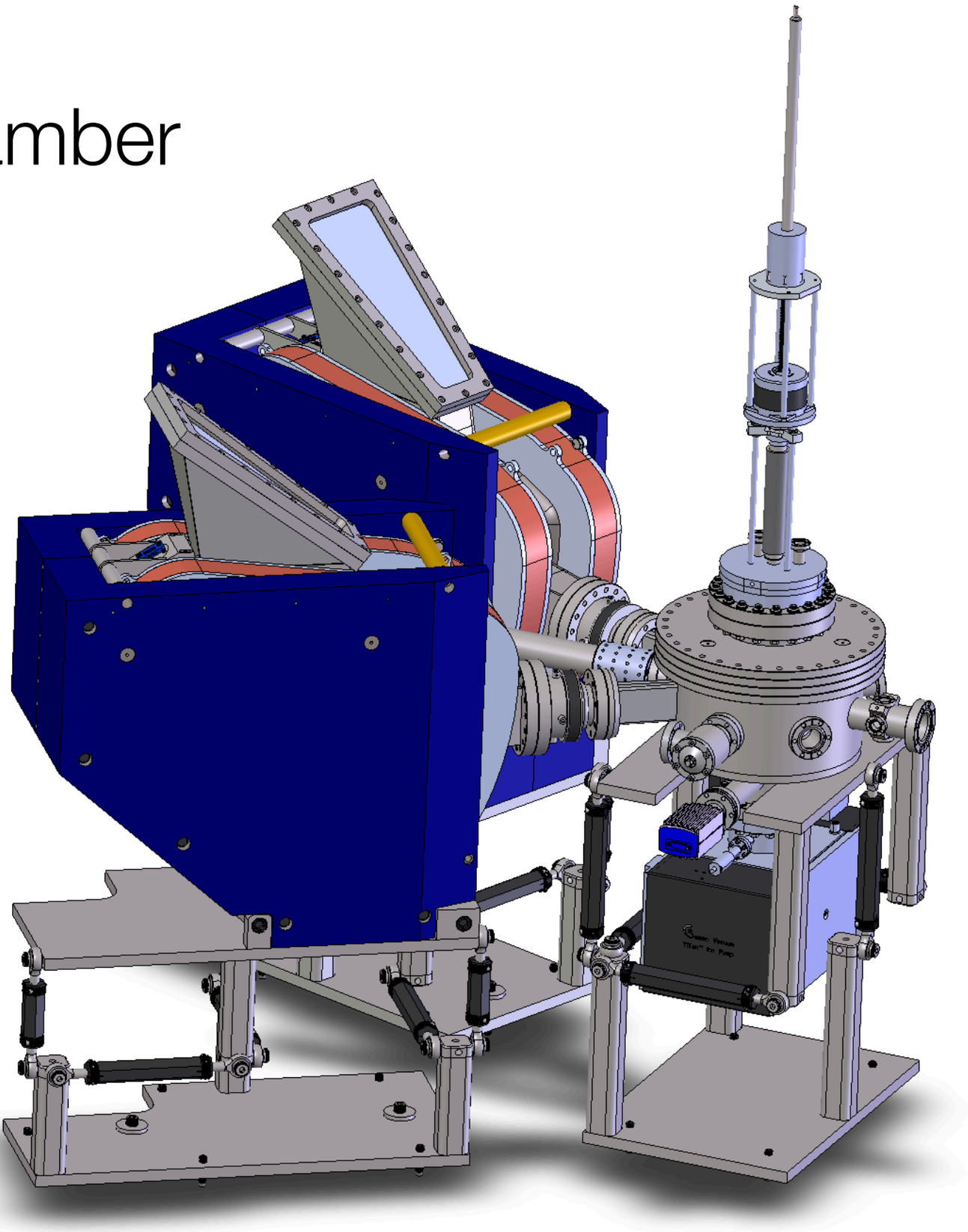
Status: magnets and chamber

Dipole spectrometer design signed off; in discussion with external company for manufacture

Three permanent quadrupoles for beam optics already obtained

Steel vacuum chambers with aluminum thin windows on exit now beginning production

Last open question is how to reduce back scattering of high energy electrons



C. Vidal, E. Ihloff, J. Kelsey (MIT)

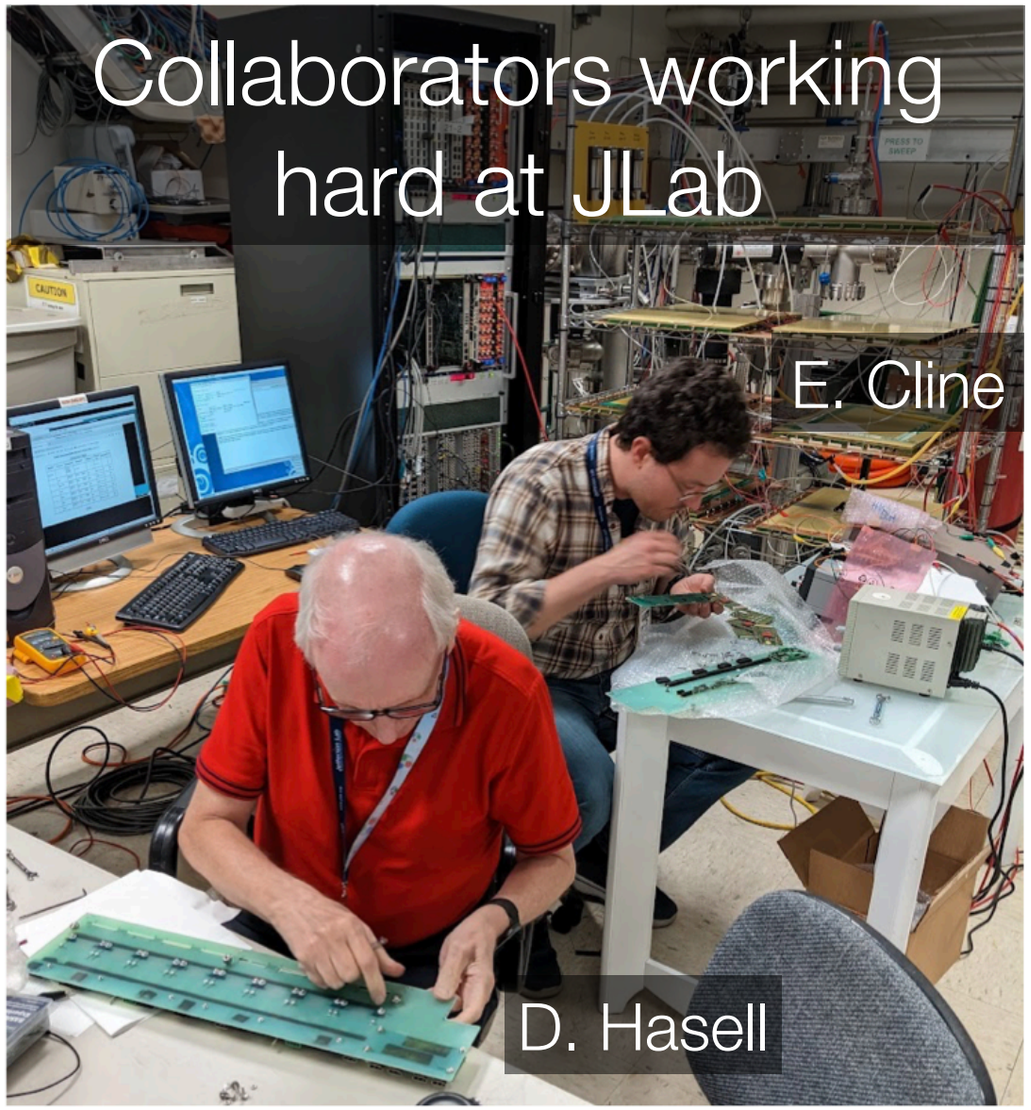
Status: GEMs

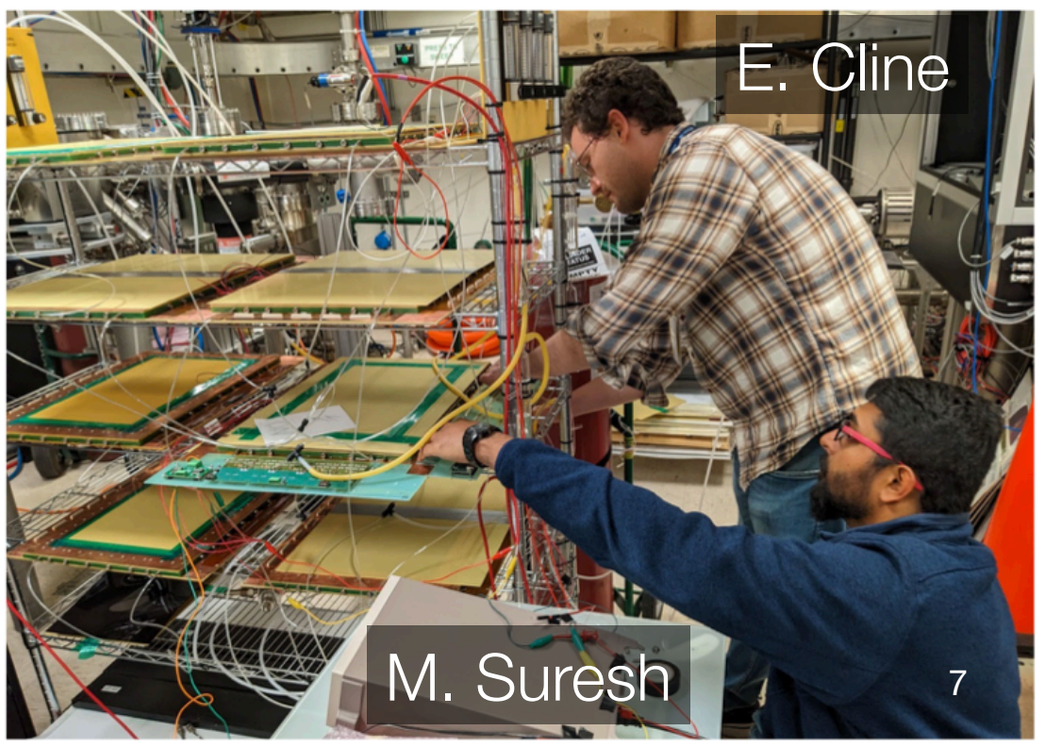
Tracking uses GEMs built by Hampton University

Four GEMs holding high voltage and ready for use. First 2 will be shipped to TRIUMF in July

Big shout-out to MIT and Hampton groups for getting them to this stage!

Ongoing challenges/tasks: obtain more read-out electronics, integrate with trigger



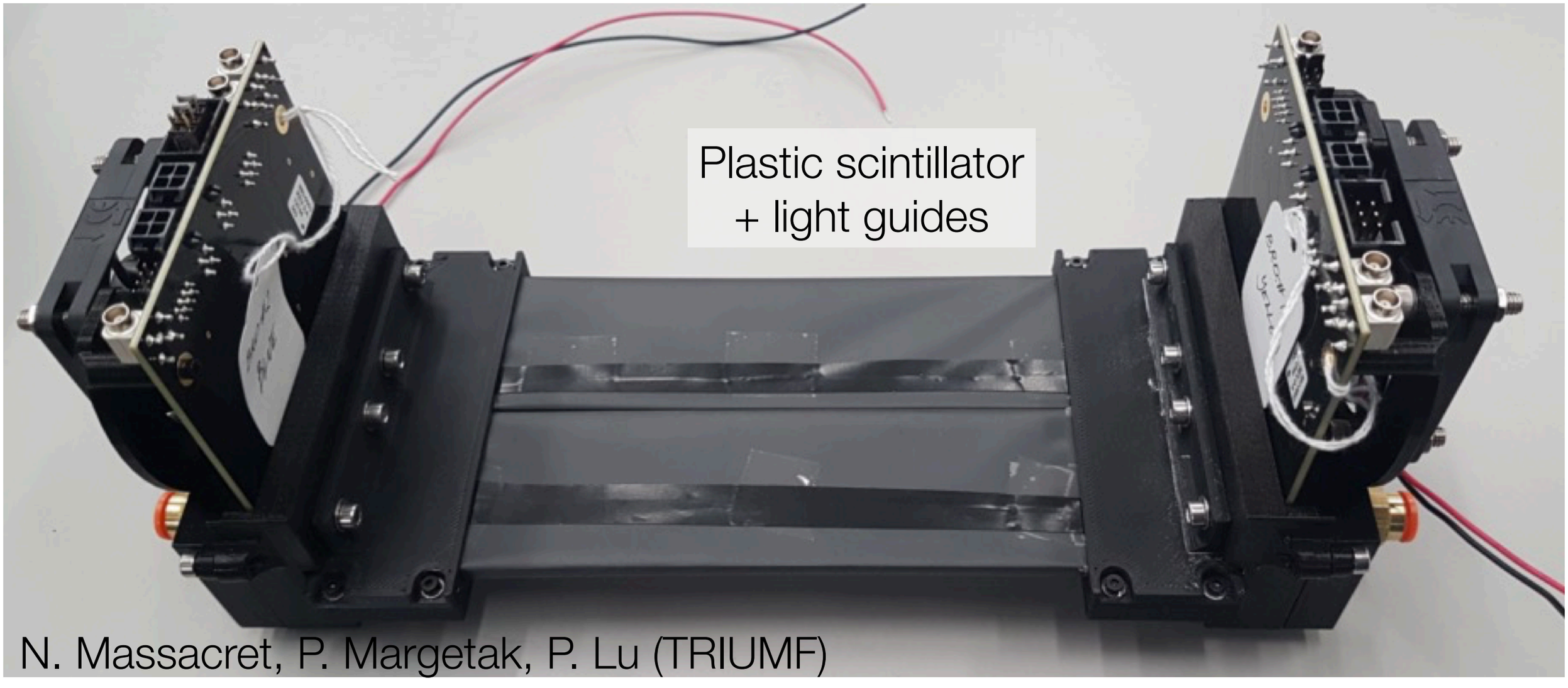


Status: trigger scintillators

2nd prototype beginning testing this week

New read-out cards hosting 12 SiPMs each

ToT readout only, no analog pulse shape info



N. Massacret, P. Margetak, P. Lu (TRIUMF)

4x each of these units per spectrometer arm

Materials ready for full production

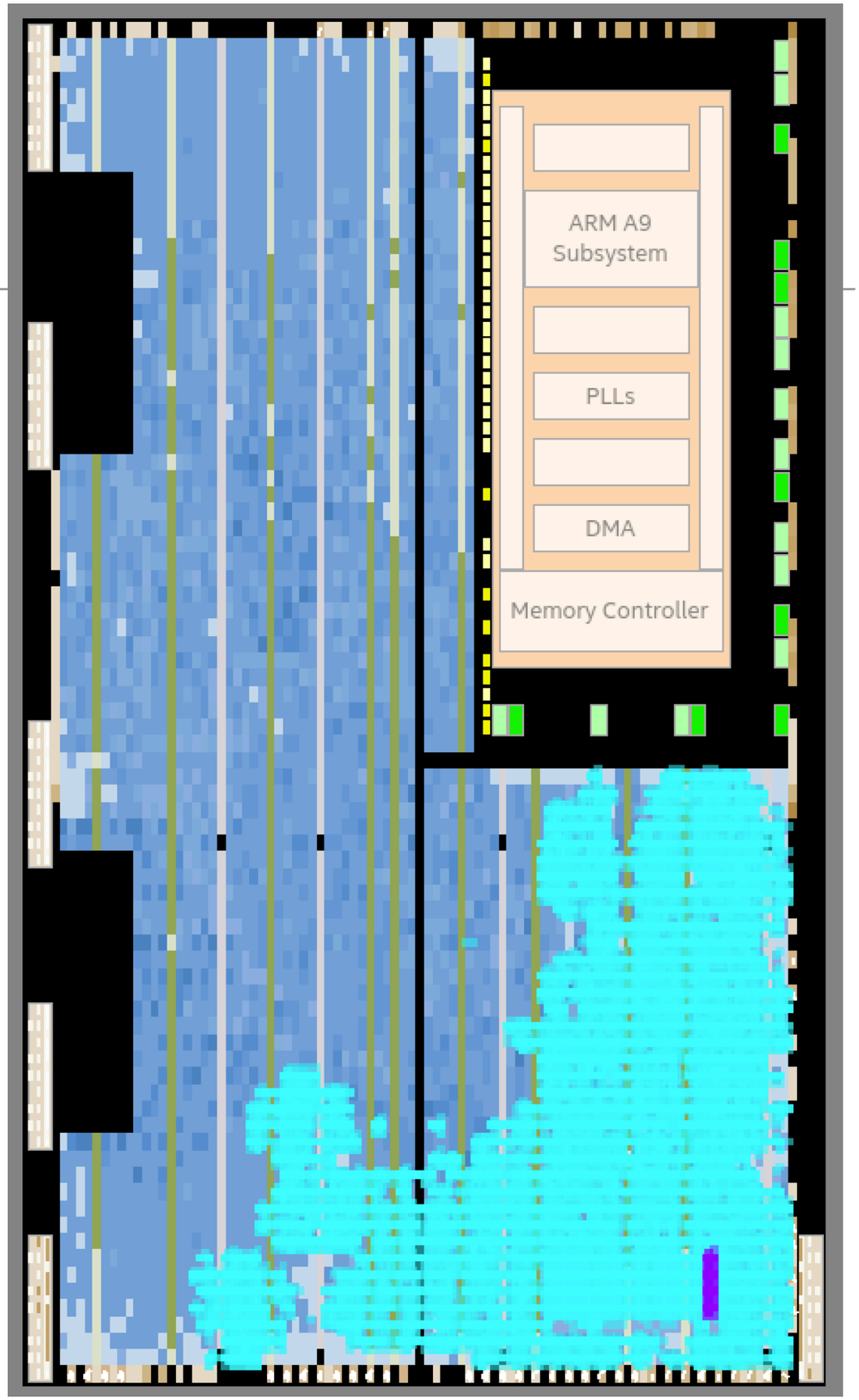
Goal timing resolution ~100 ps (v1: 350 ps)

Status: data acquisition

Coincidence trigger logic being implemented using Cyclone V FPGA (K. Olchanski, TRIUMF)

At right: 18 TDCs programmed, leaving most of FPGA still free for coincidence logic and other tasks

Other software frameworks based on existing ones, using MIDAS for DAQ and adapting reconstruction code from MUSE



Status: accelerator integration

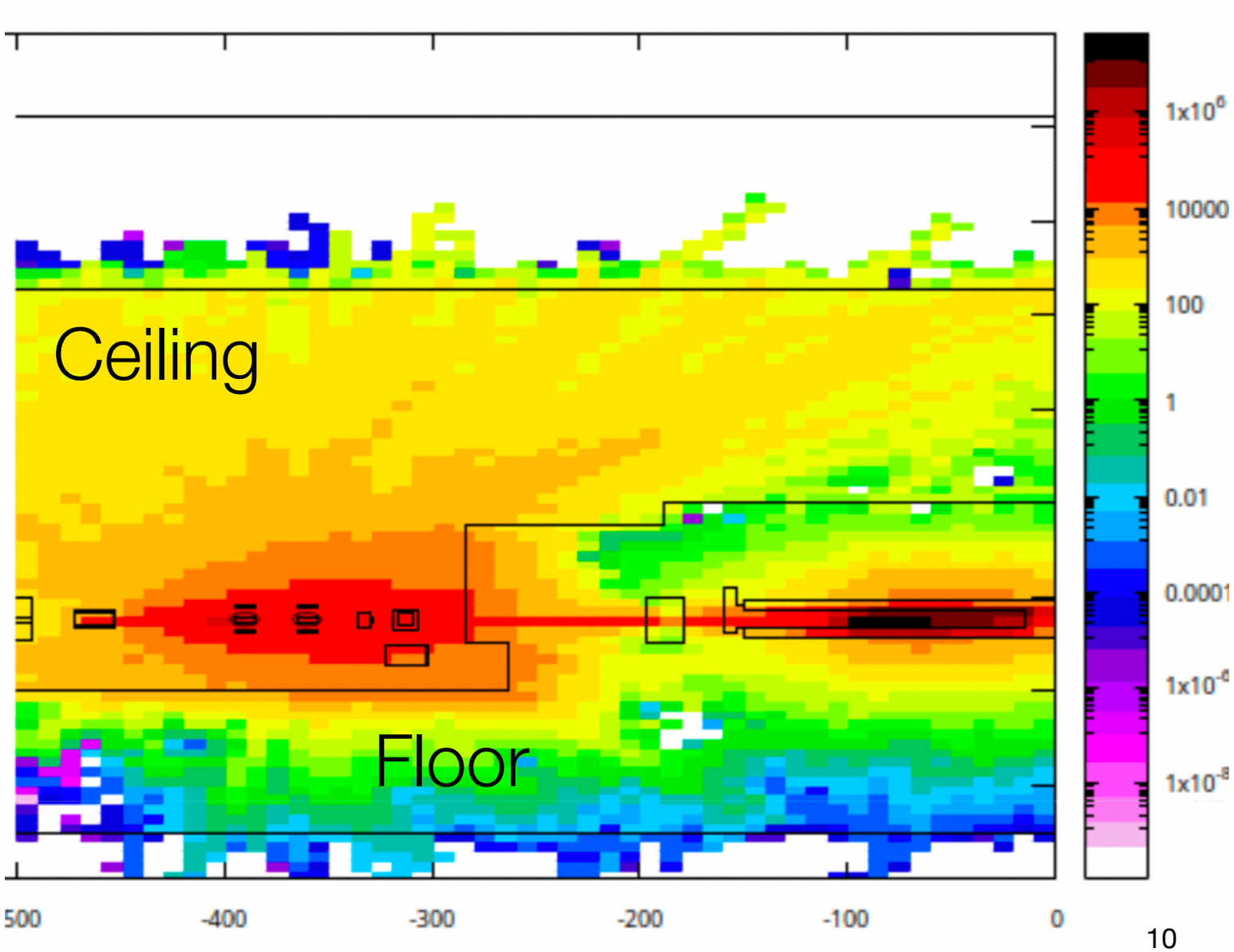
Beam optics plan developed by A. Mahon, T. Planche, S. Rädel (TRIUMF)

Radiation safety is significant challenge

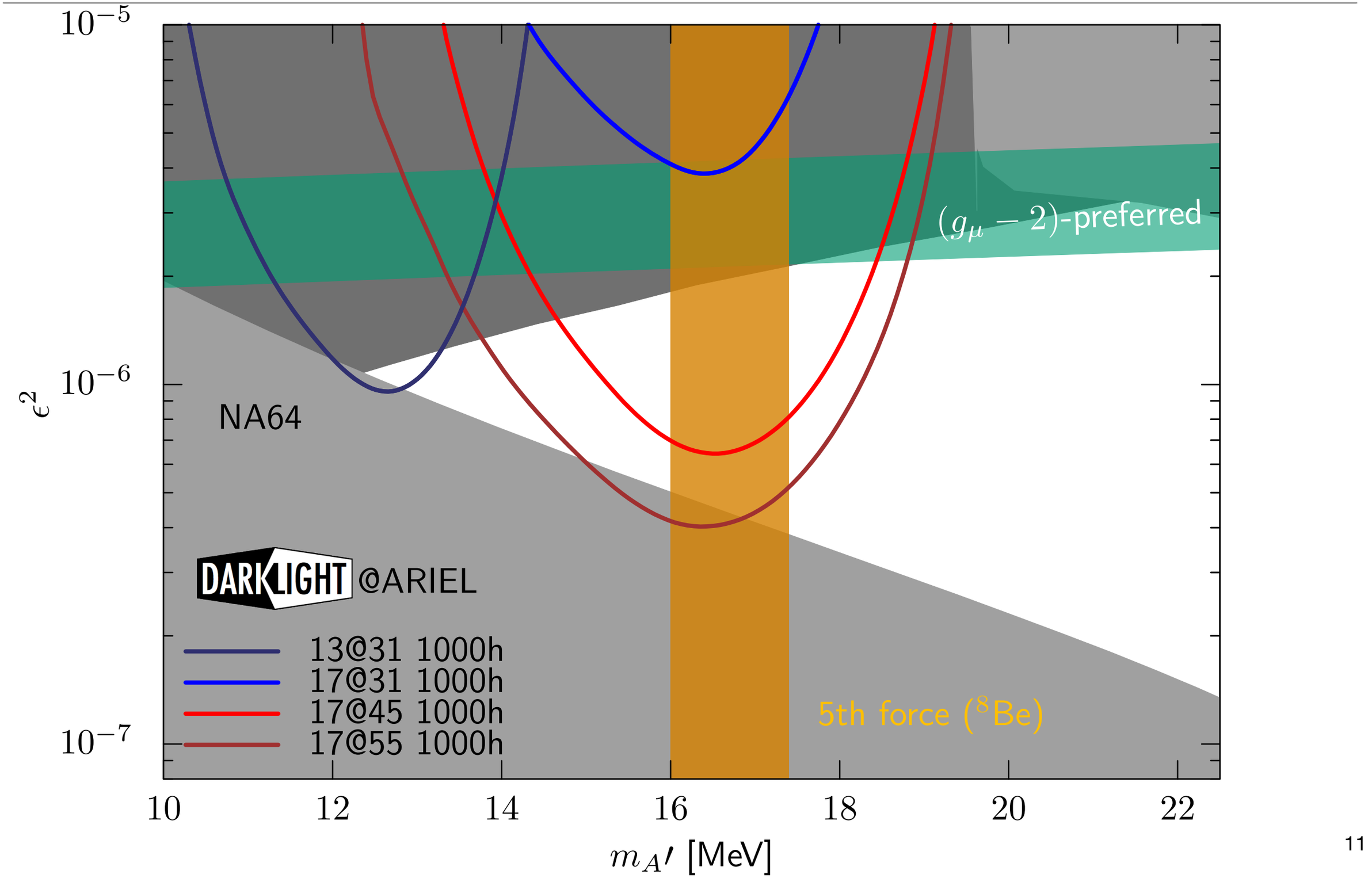
Successful beam transportation up to 2σ, but still exploring mitigation of remaining dose

E. Cline (MIT) producing FLUKA simulations to inform shielding design, new license

Dose from photons [mSv/h]



Projected dark photon sensitivities



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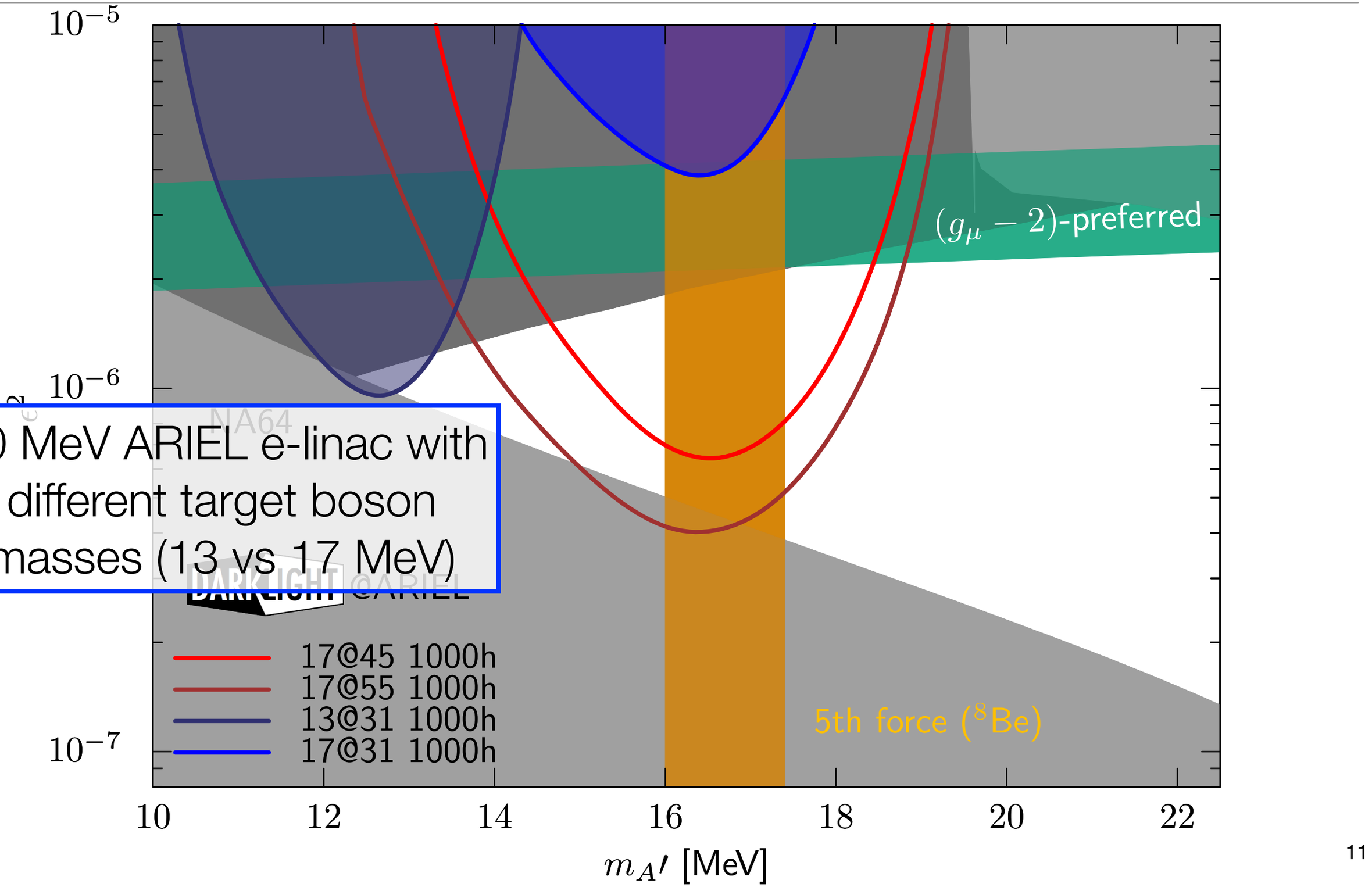
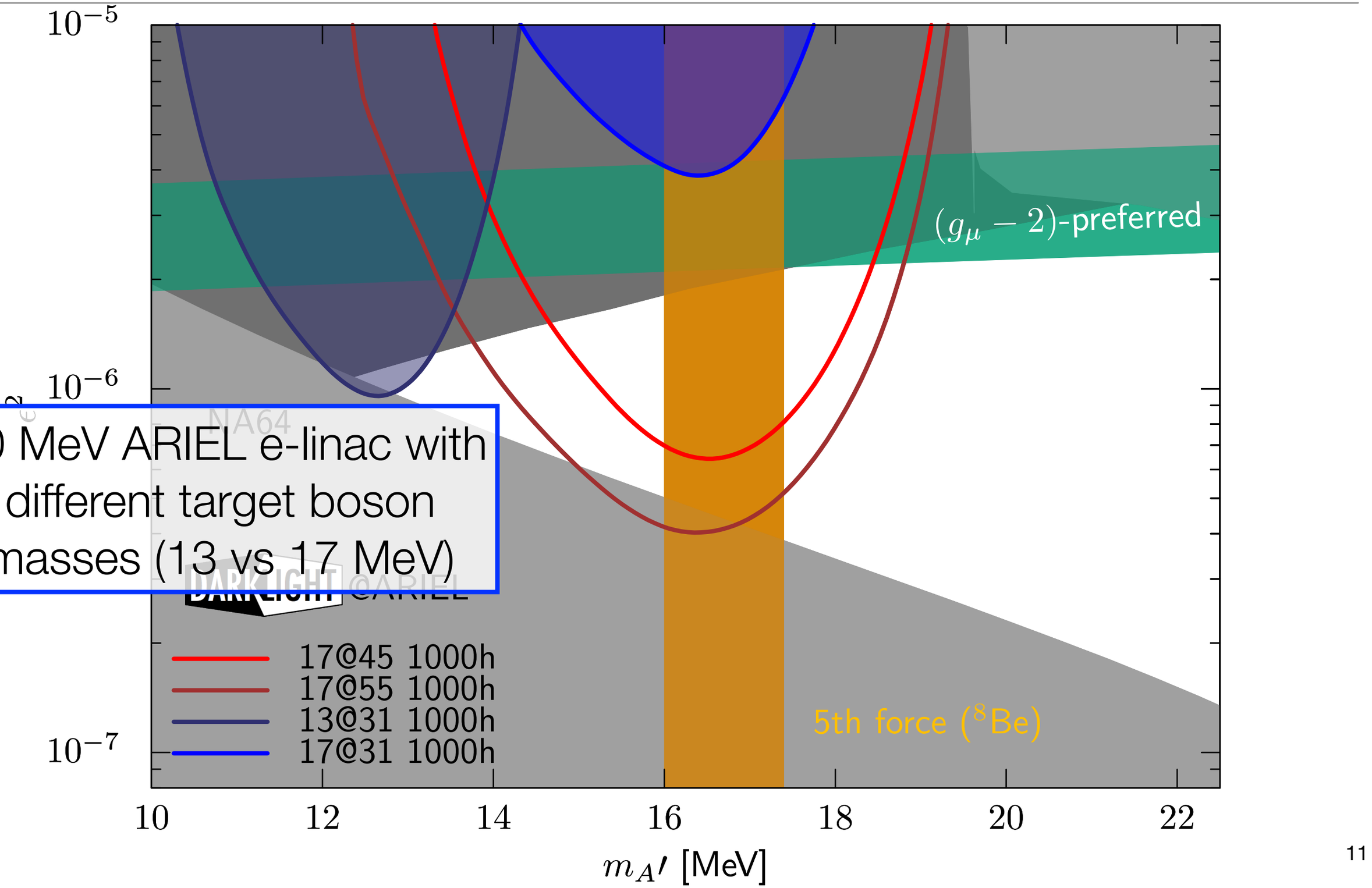


30 MeV ARIEL e-linac with different target boson masses (13 vs 17 MeV)

Projected dark photon sensitivities

Limited sensitivity outside already probed regions



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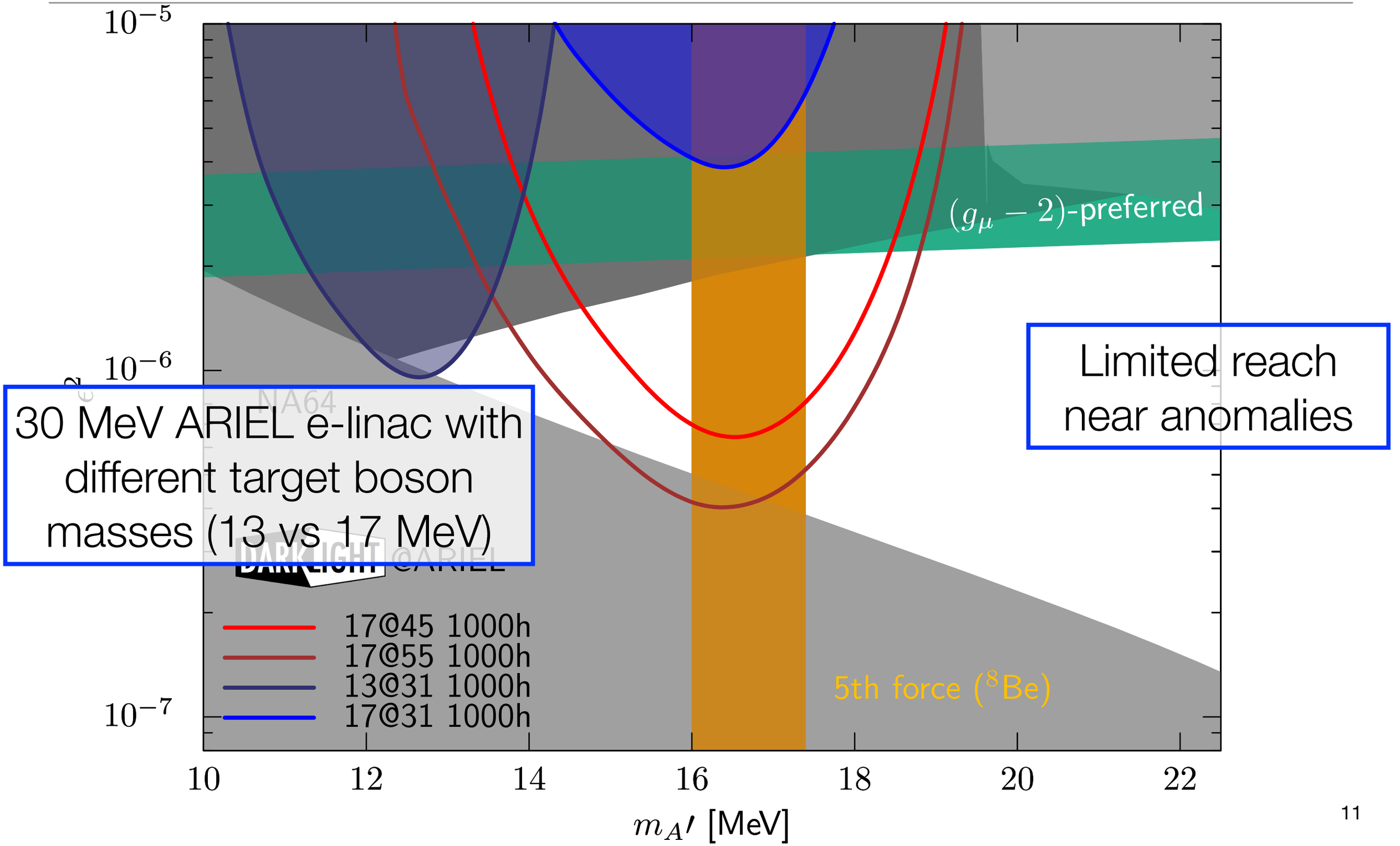

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Projected dark photon sensitivities

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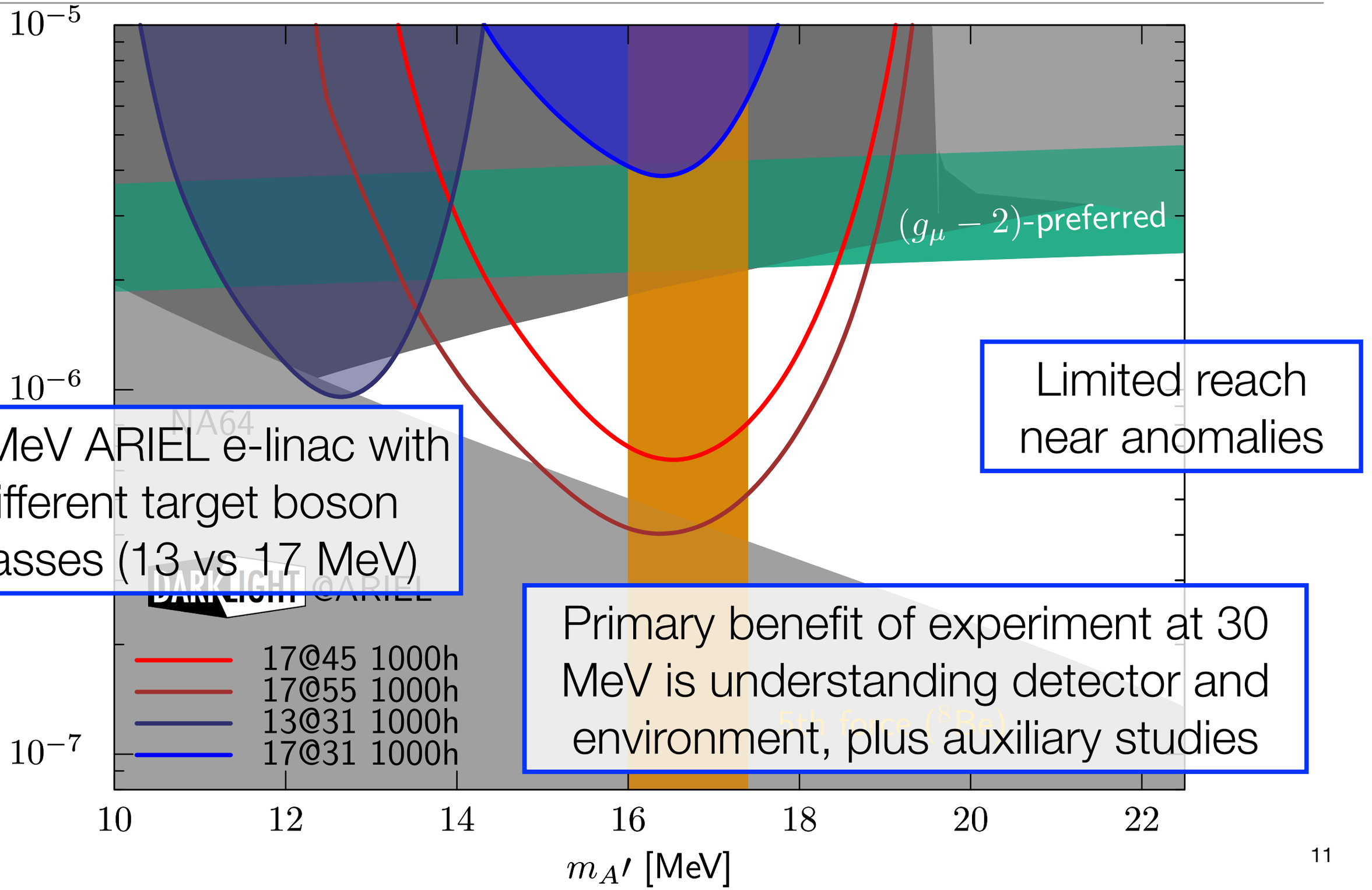


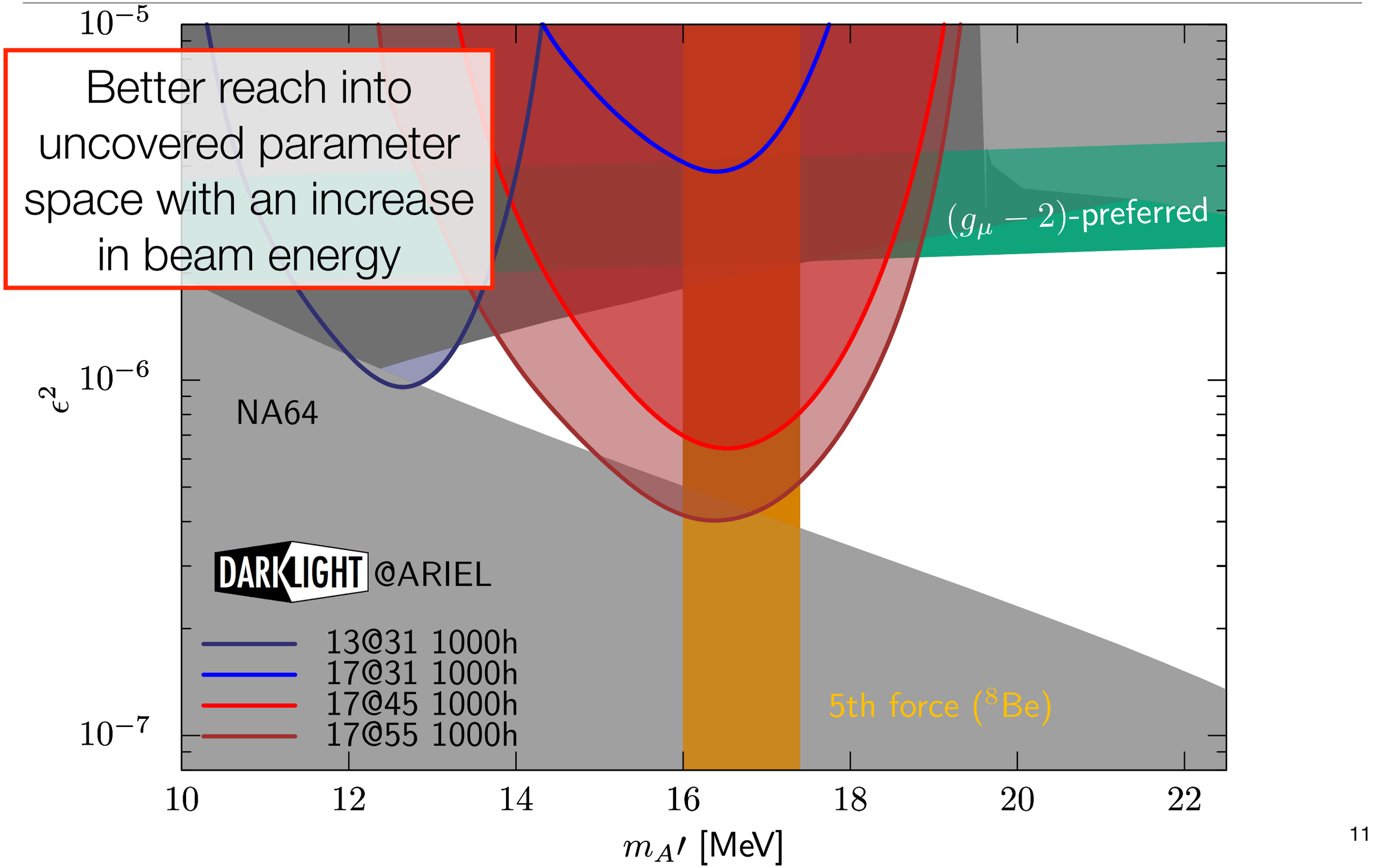
30 MeV ARIEL e-linac with different target boson masses (13 vs 17 MeV)

Limited reach near anomalies

Primary benefit of experiment at 30 MeV is understanding detector and environment, plus auxiliary studies

Projected dark photon sensitivities

Better reach into uncovered parameter space with an increase in beam energy



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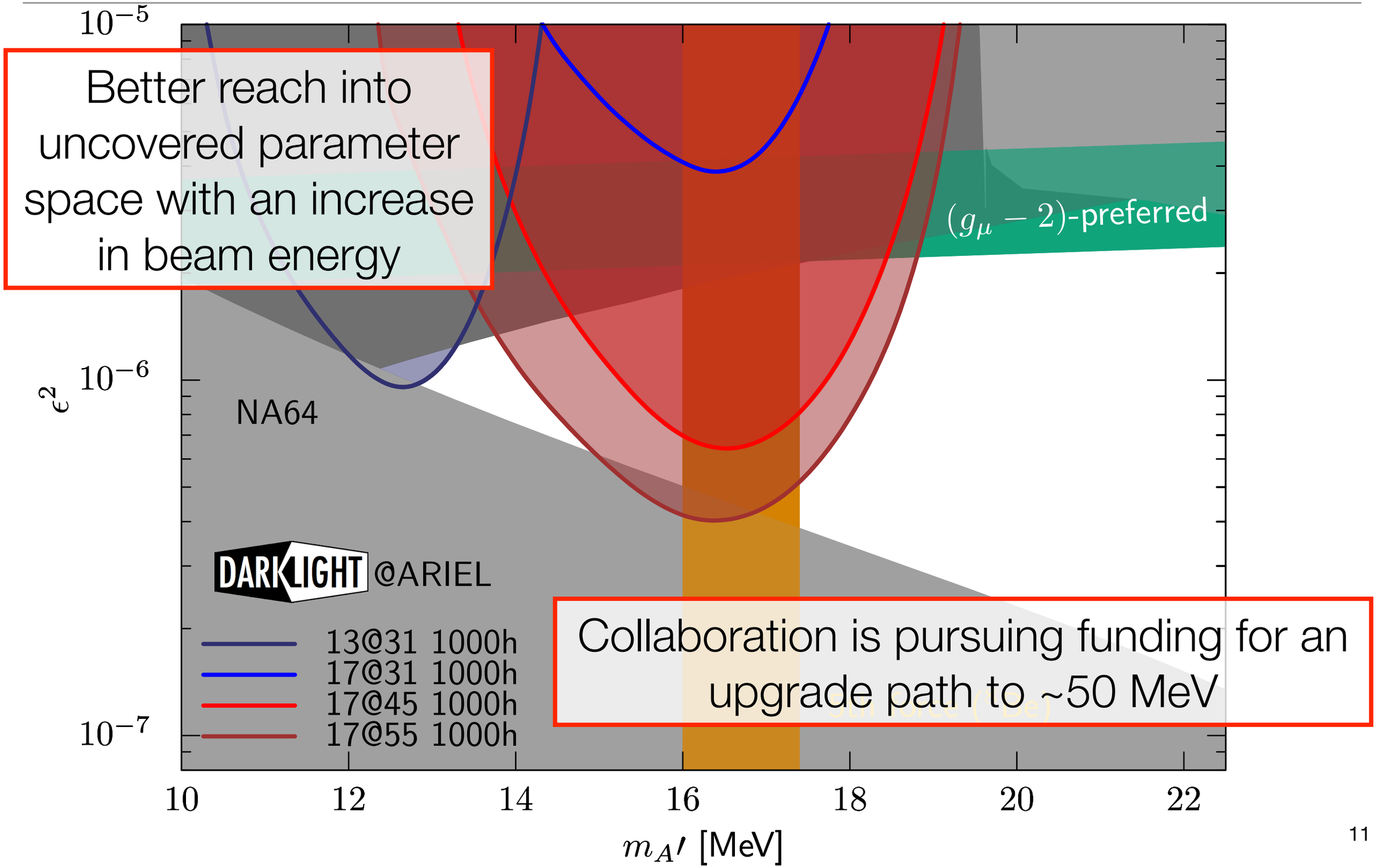
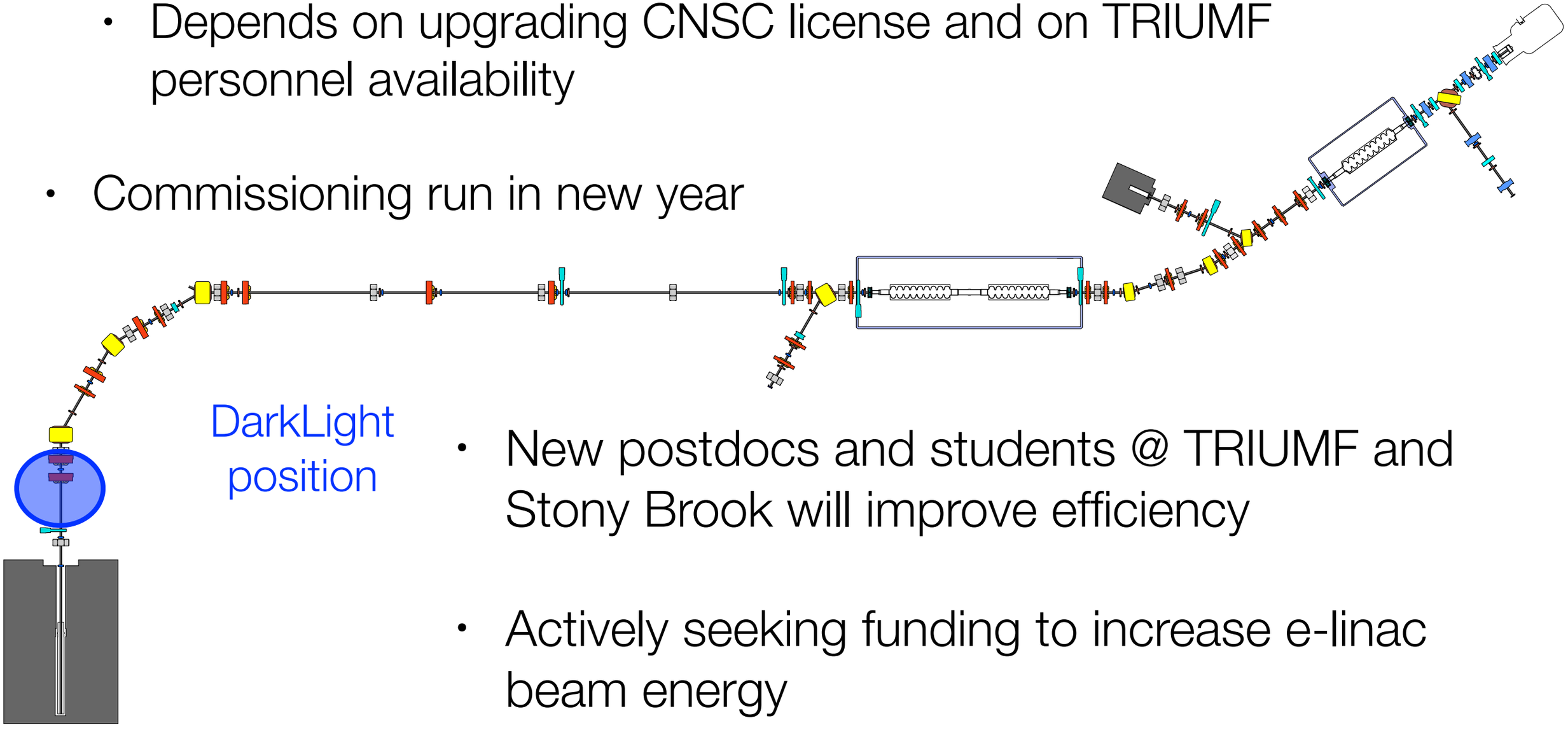


Next steps

- Current plan: detector to be installed starting Dec 2023
  - Depends on upgrading CNSC license and on TRIUMF personnel availability
- Commissioning run in new year



- New postdocs and students @ TRIUMF and Stony Brook will improve efficiency
- Actively seeking funding to increase e-linac beam energy

Thank you!

Backup slides

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

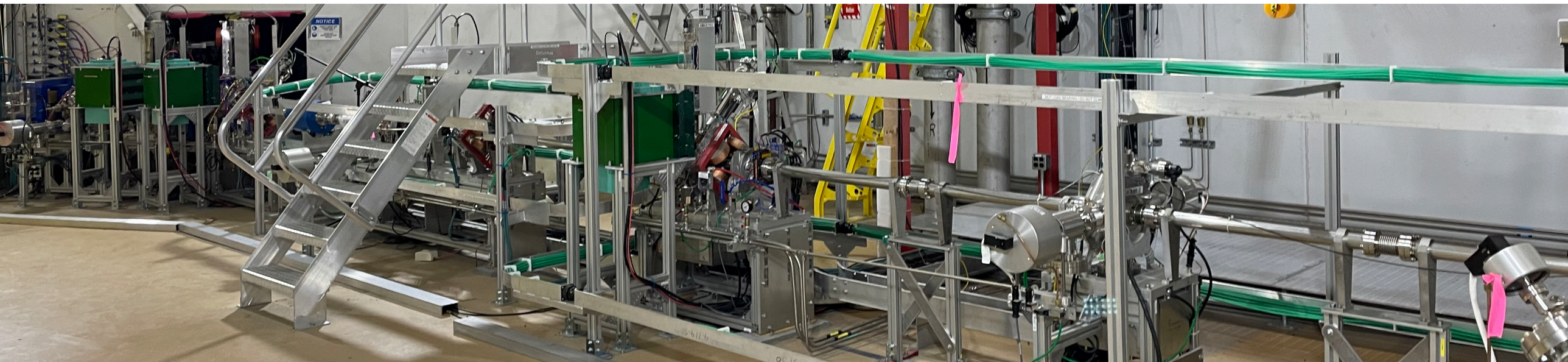
Stony Brook University, NY, USA

TRIUMF, Vancouver, British Columbia, Canada

University of Mainz, Germany

University of Manitoba, Canada

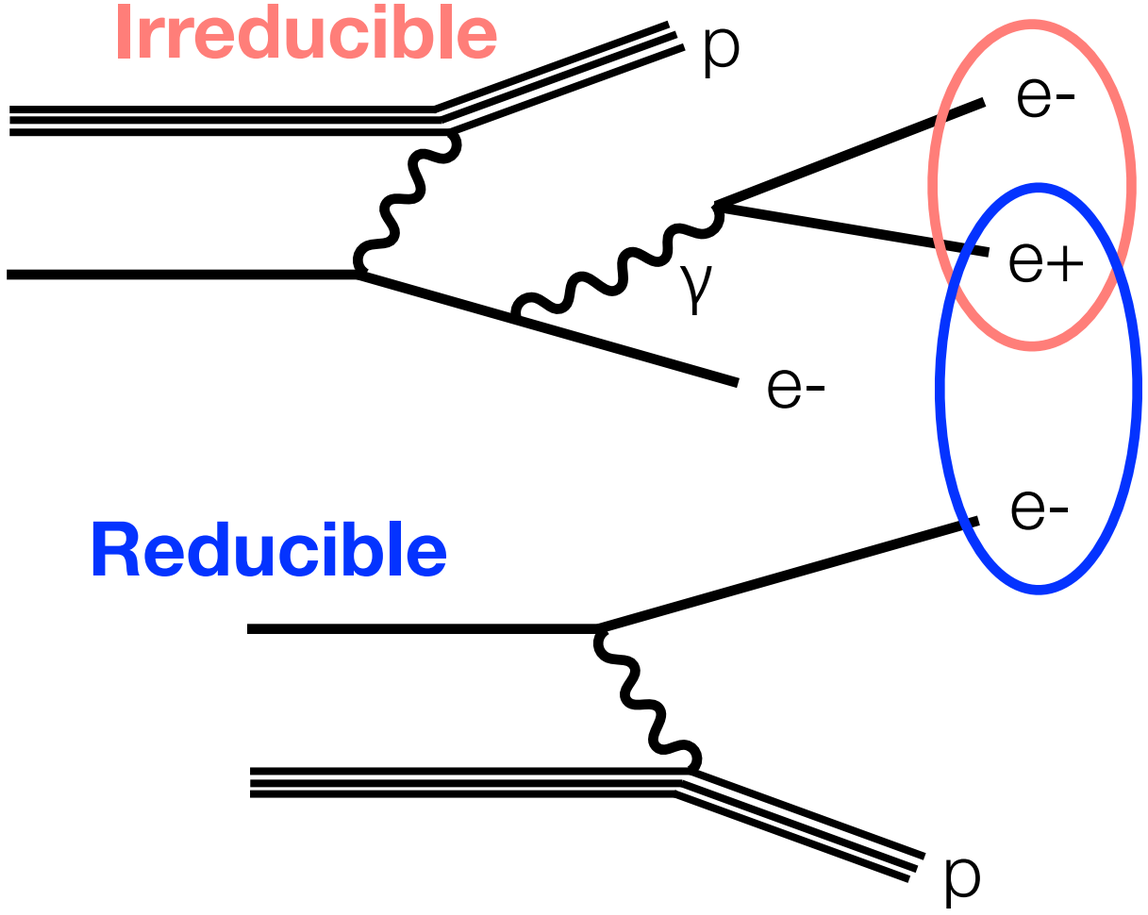
University of Winnipeg, Manitoba, Canada

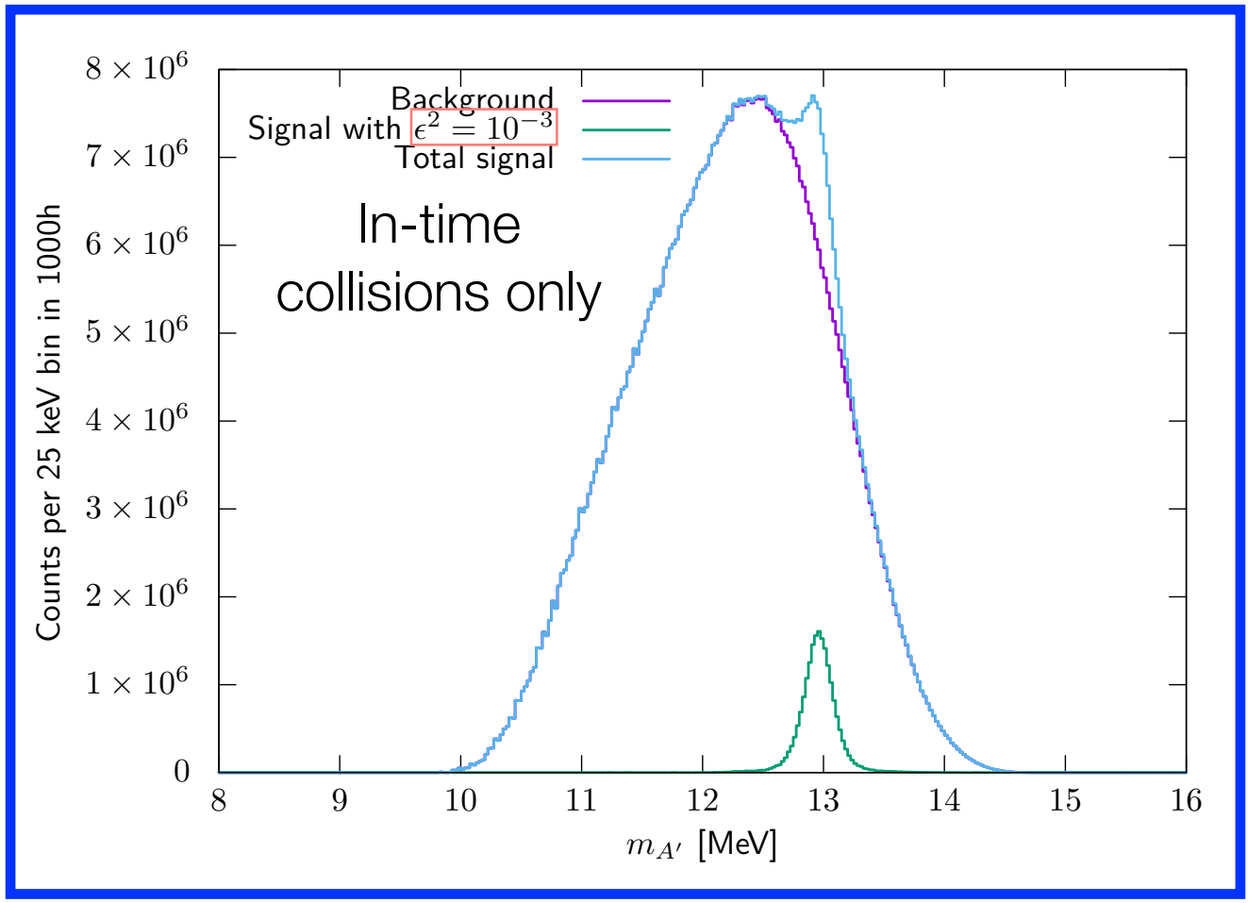


Background processes

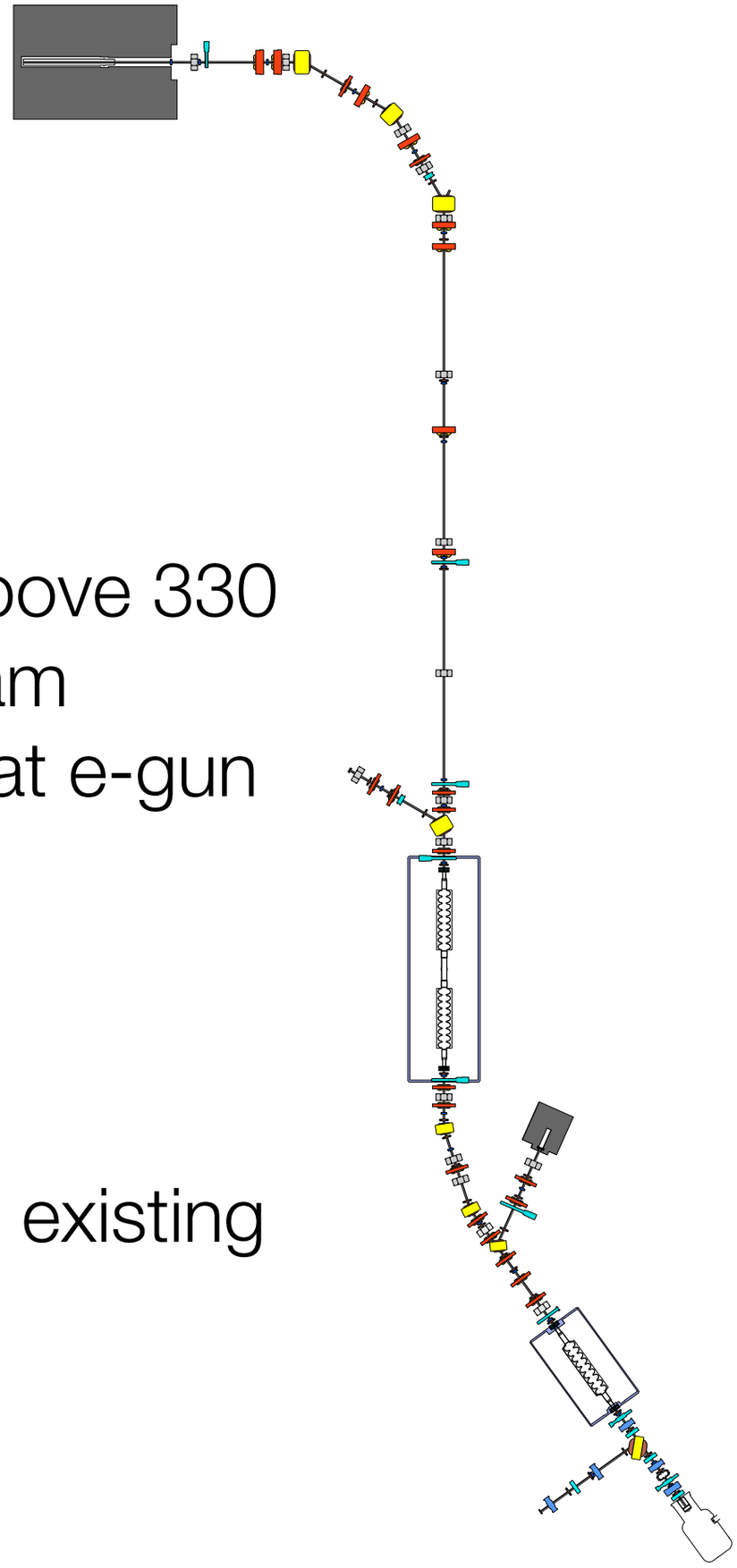
- Vastly dominant background is e+ from pair production combined with e- from simultaneous scattering event. **Coincidence**-based trigger is key

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





ARIEL e-linac facility

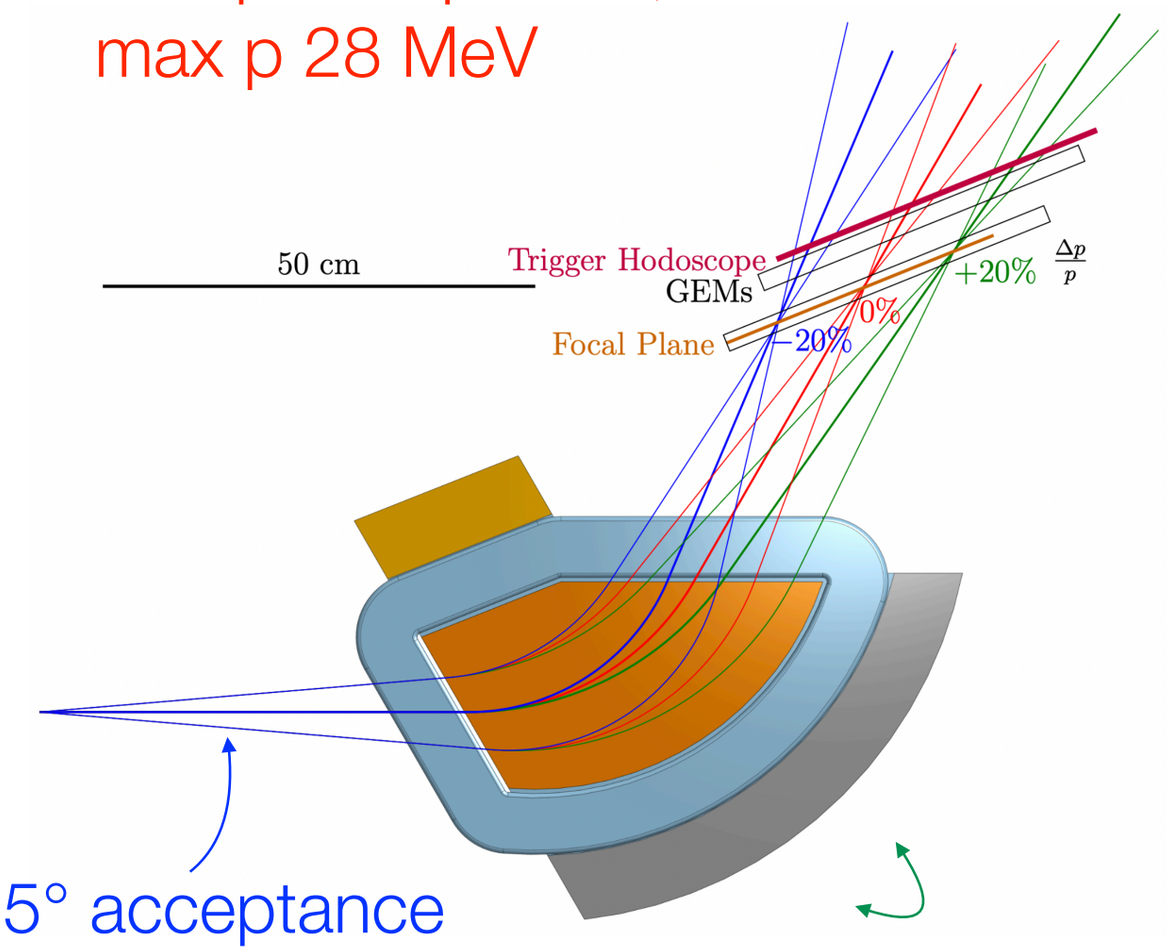


- 650 MHz frequency; 30 MeV energy
- Currents: at 100% duty factor, can't run above 330 μA without overwhelming 10 kW rated beam dump. Running below 300 μA is unstable at e-gun and tends to drift.
  - For certain studies,
- Total design power ~ 100 kW, but not with existing dump
- Each bunch has ~ 9×10^6 electrons

Experiment status: spectrometers

- Two identical dipole spectrometers, 0.3 T
- Simulations in magnetic field with multiple scattering to optimise mass resolution (~ 150 keV)

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

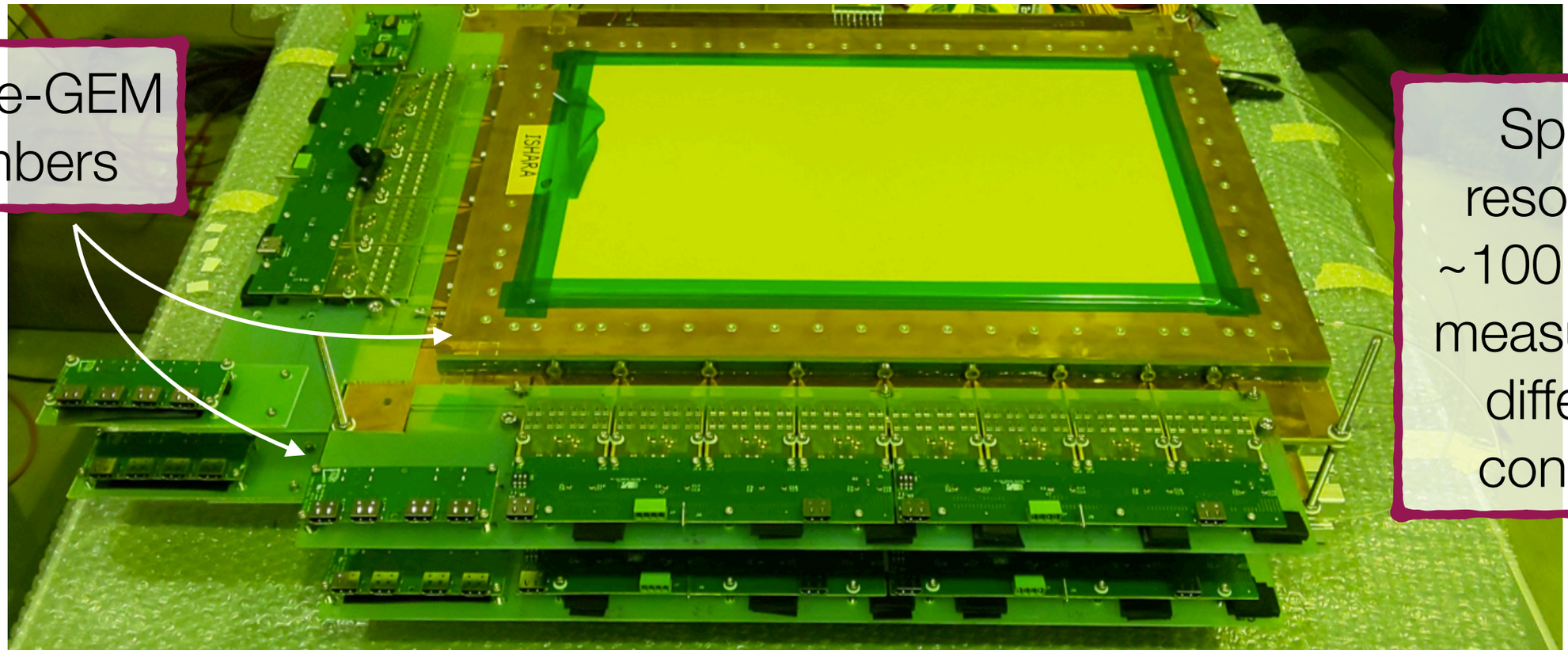


+/- 5° acceptance in this dimension

+/-1.5° 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

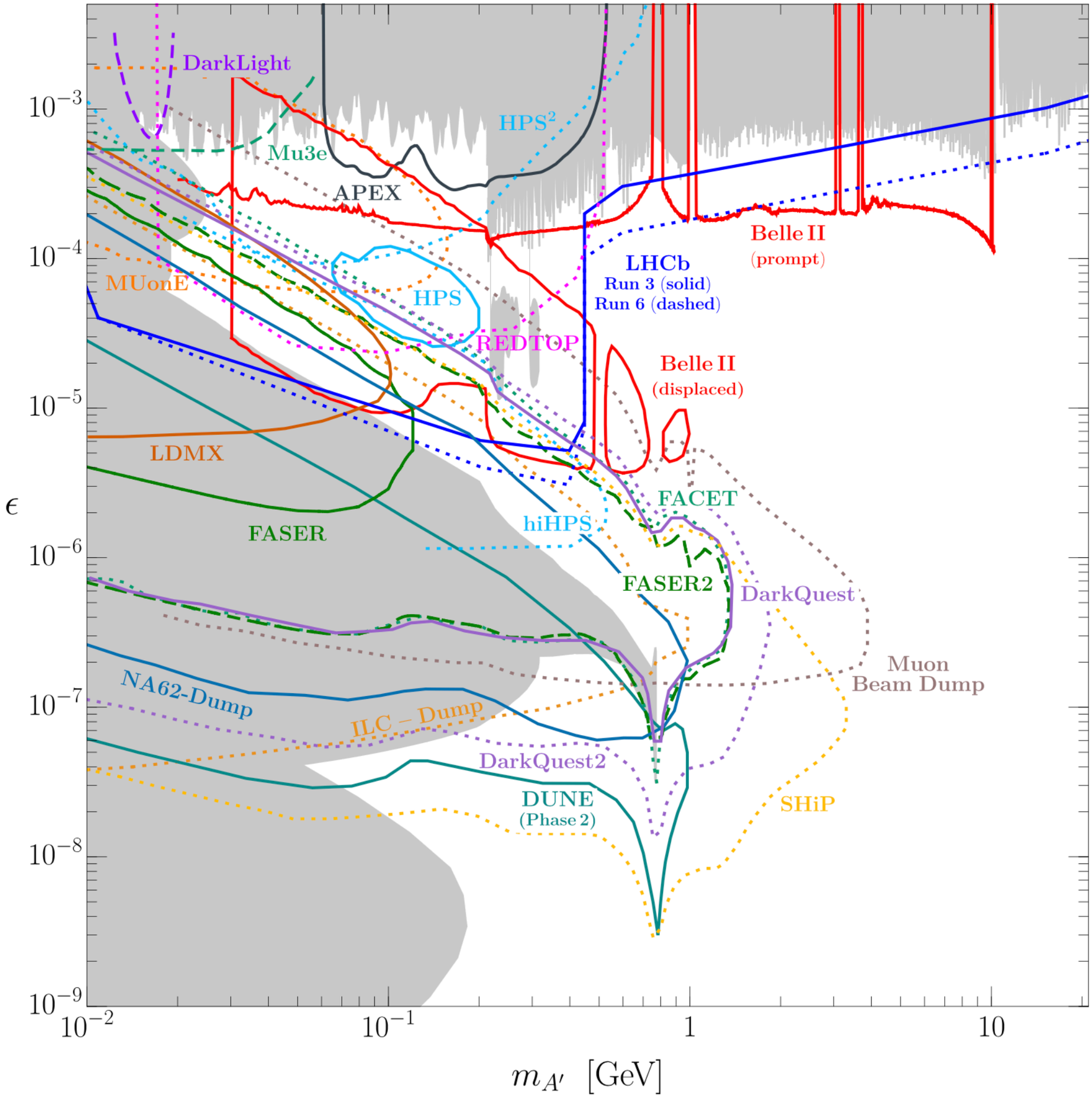
Spatial resolution ~100 μm as measured in different contexts

Complementary and competitor 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+)
- PADME announced planned result right at 17 MeV, but very narrow band: still leaves scope for complementary measurements


DarkLight
Mu3e
APEX
HPS^2
Belle II
(prompt)
LHCb
Run 3 (solid)
Run 6 (dashed)
MUonE
HPS
REDTOP
Belle II
(displaced)
LDMX
FACET
FASER
hiHPS
FASER2
DarkQuest
Muon
Beam Dump
NA62-Dump
ILC – Dump
DarkQuest2
DUNE
(Phase 2)
SHiP
10^{-3}
10^{-4}
10^{-5}
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ϵ
10^{-2}
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1
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$m_{A'}$ [GeV]