CEvNS at the ESS

F. Monrabal for the nuESS project

Magnificent CEvNS 2024
Valencia June 2024

ikur estrategia

dipc

erc
European Research Council
Established by the European Commission

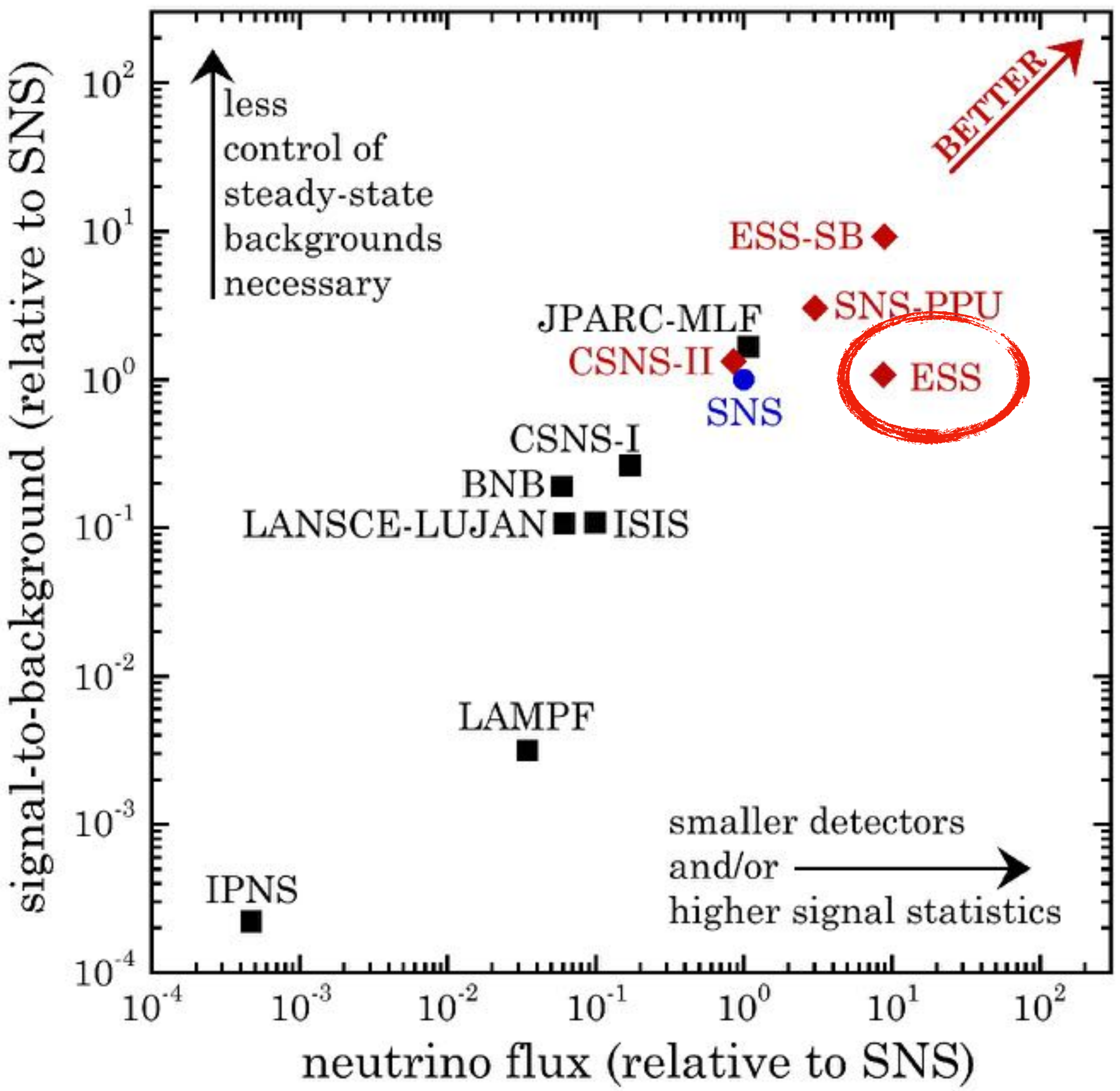
ikerbasque
Basque Foundation for Science


A NEW OPPORTUNITY FOR CEνNS
ess
EUROPEAN SPALLATION SOURCE
It will generate the most intense neutron beams for **multi-disciplinary science**
Neutrinos will be produced
The ESS will combine the **world's most powerful** superconducting proton linac with an advanced hydrogen moderator
Lund (Sweden)

A new opportunity for CEνNS

European Spallation Source (ESS)

Neutrino production at different facilities



J. High Energ. Phys. **2020,** 123 (2020)

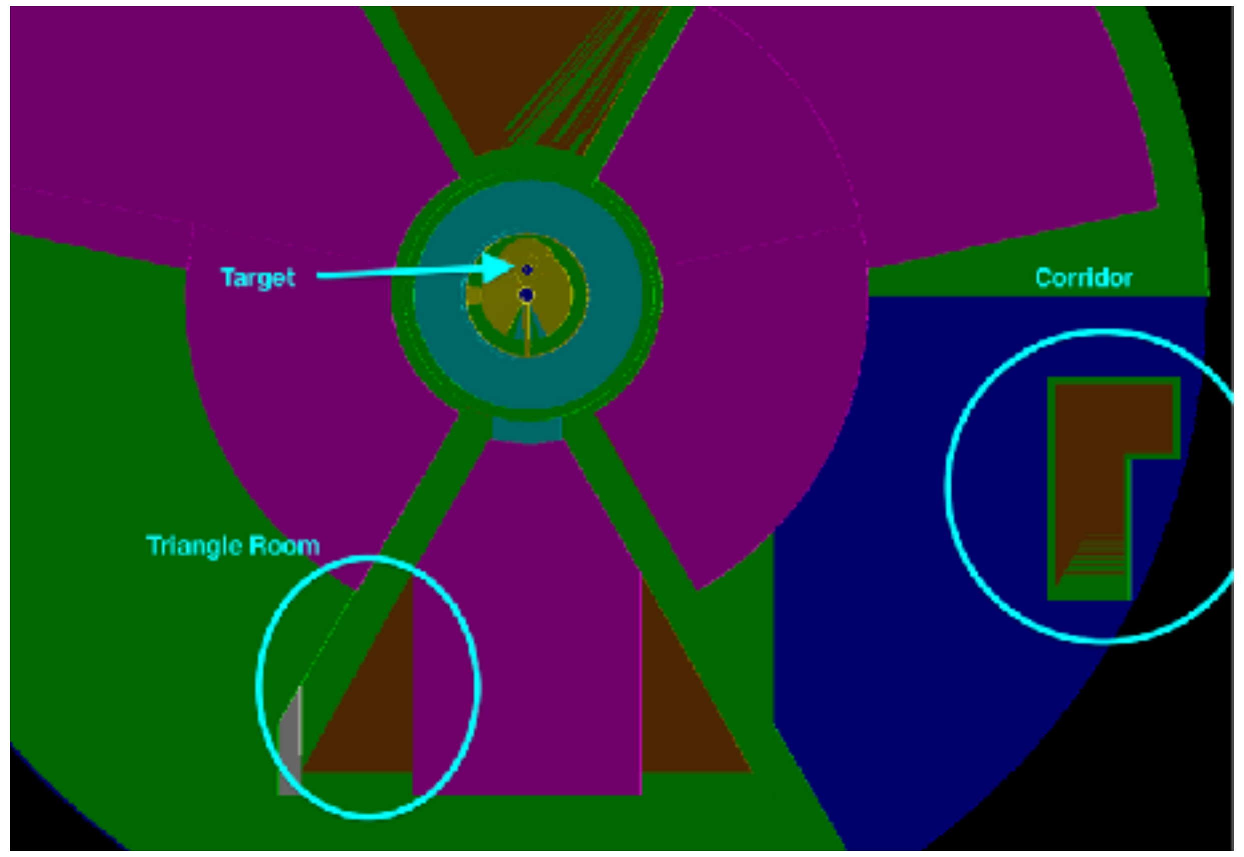
CEνNS : Large cross section
+
ESS : Large neutrino flux
=
Small detectors are allowed

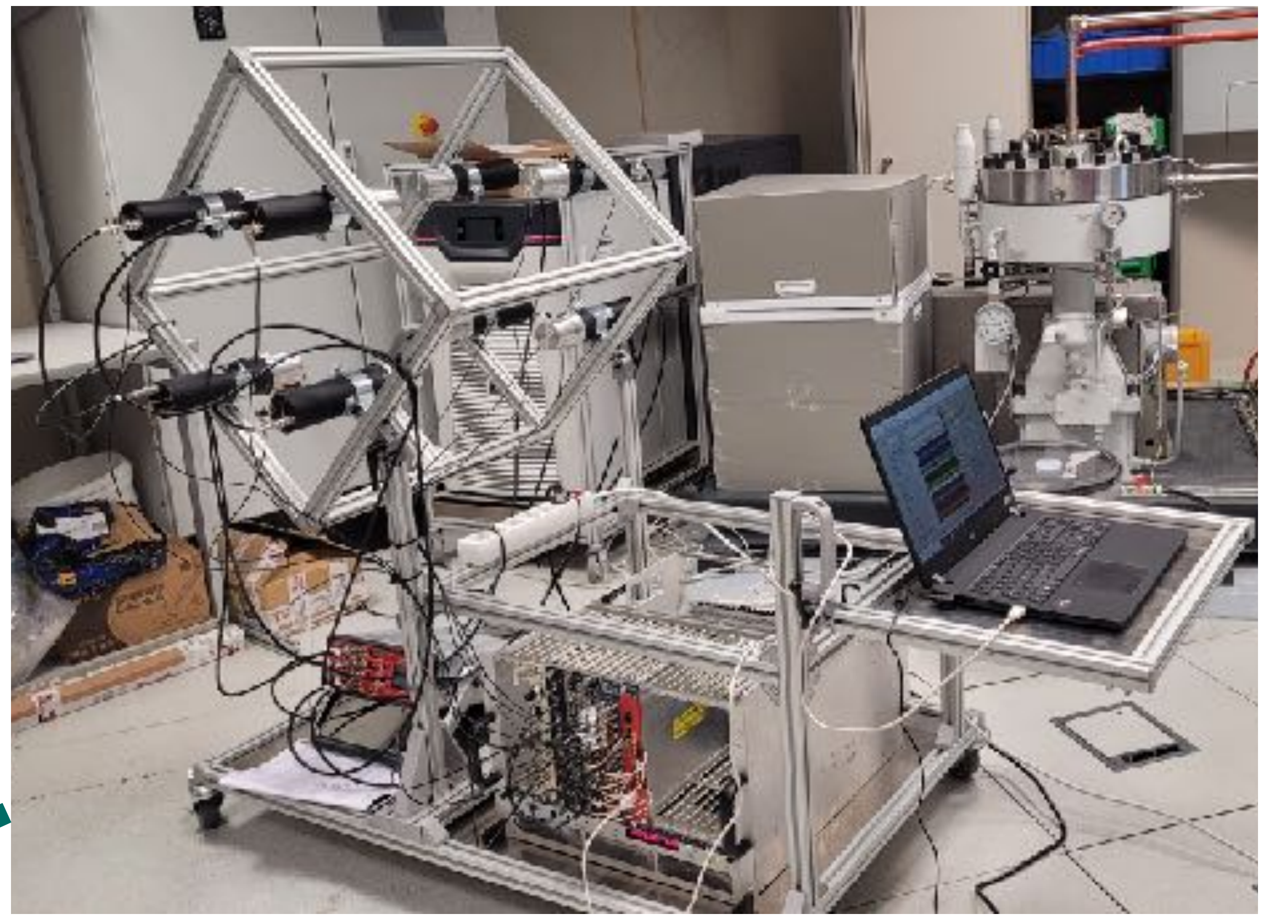
- The largest low-energy neutrino flux of the next generation facilities. ~8.5×10^{22} ν / flavour / year.
- ν production @ ESS is x9.2 @ SNS.
- Steady-state background can be subtracted. (Great advantage).
- Diversity of technologies **not statistically limited** guarantees the phenomenological exploitation of the measurements.

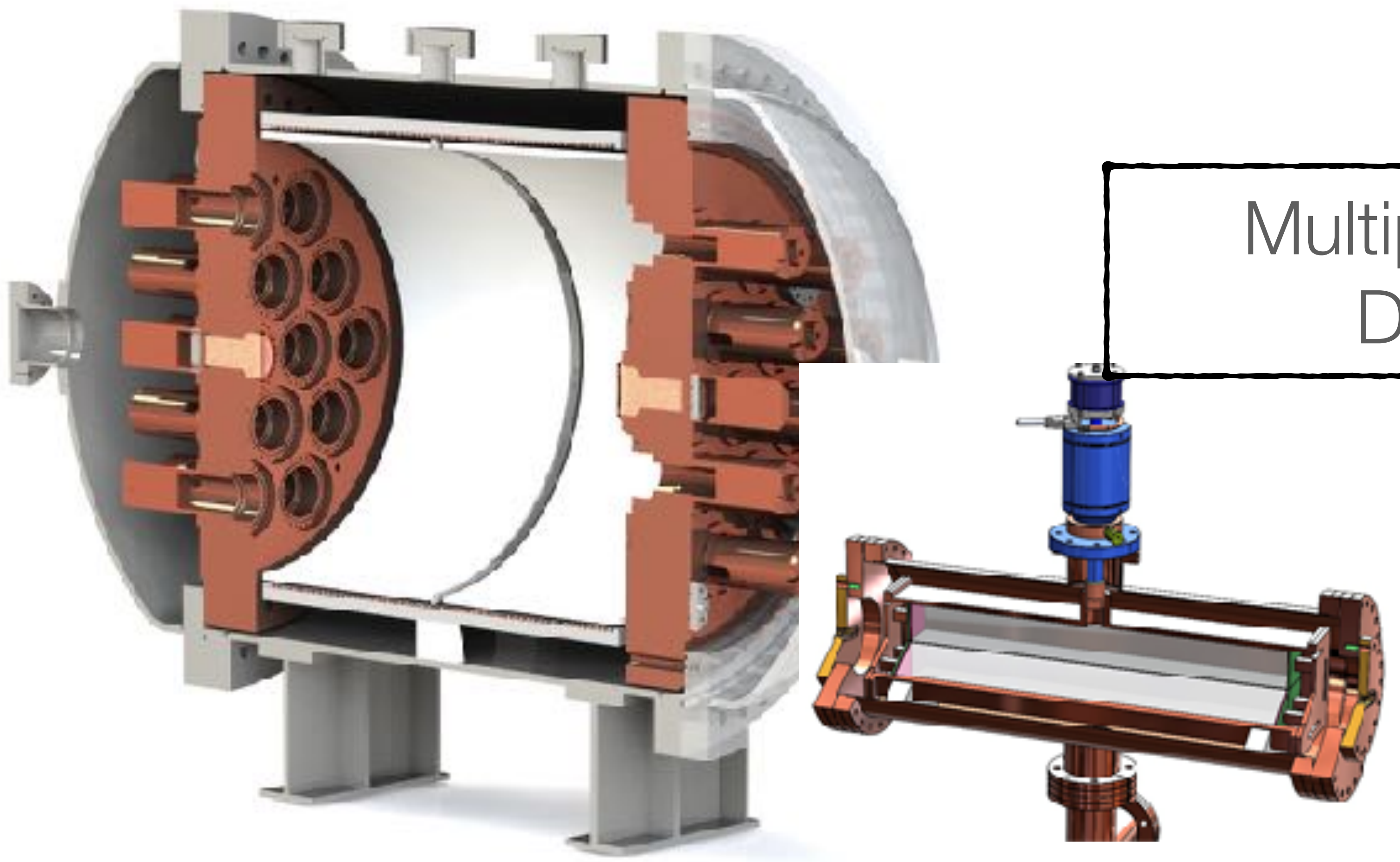
NuESS Programm

Neutron Camera:
Background model validation

Get to know the ESS

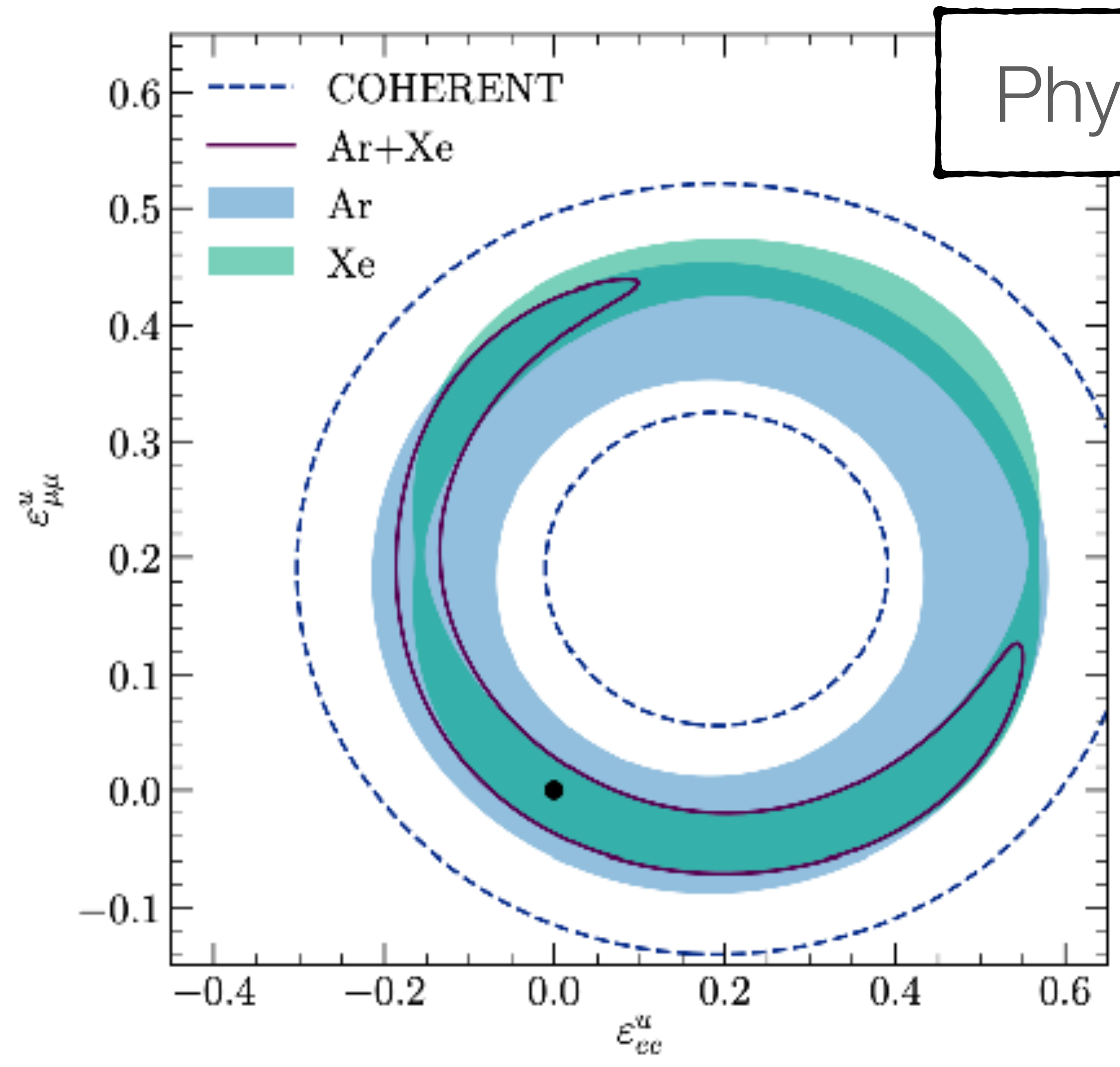






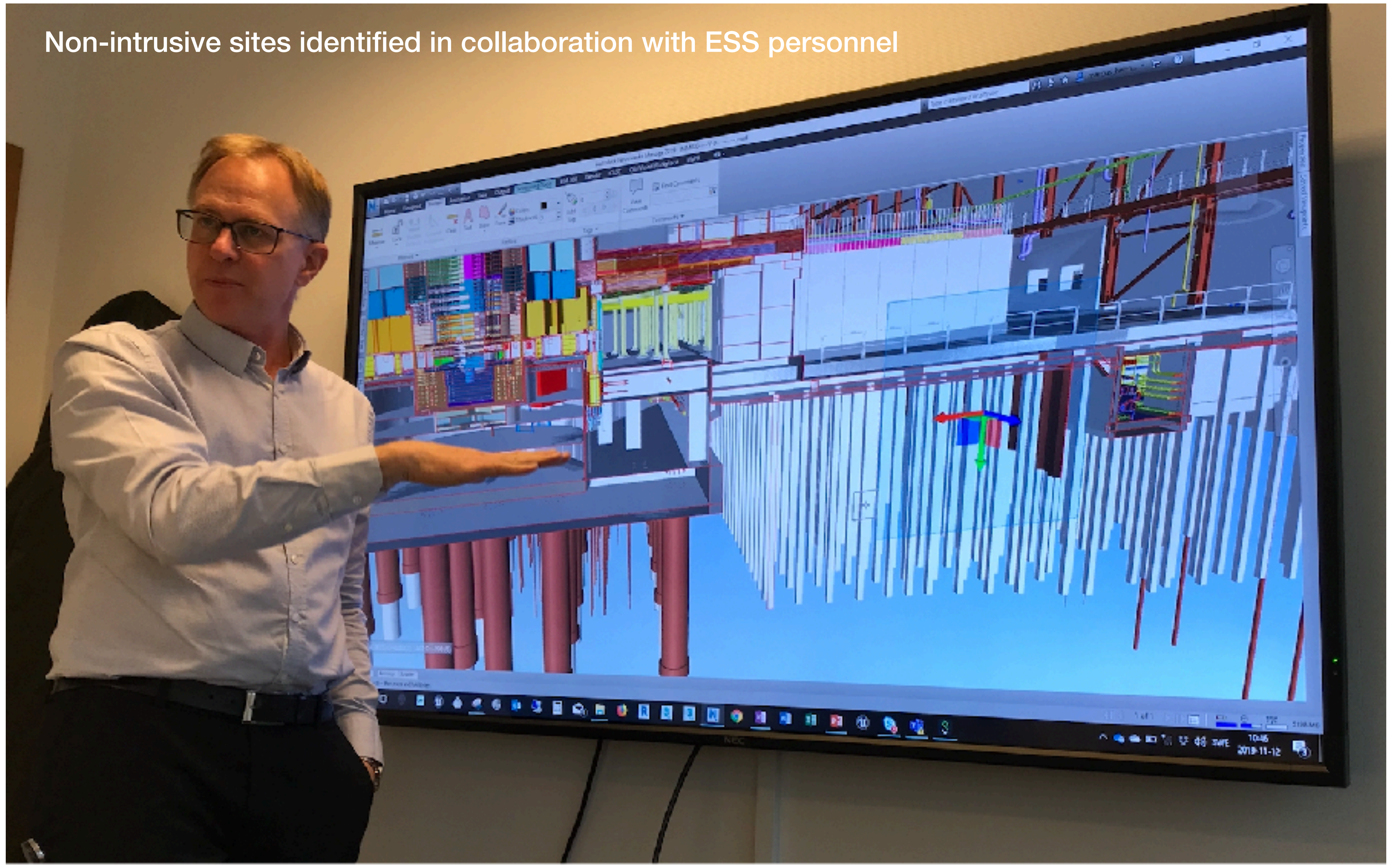
Multiple Neutrino
Detectors

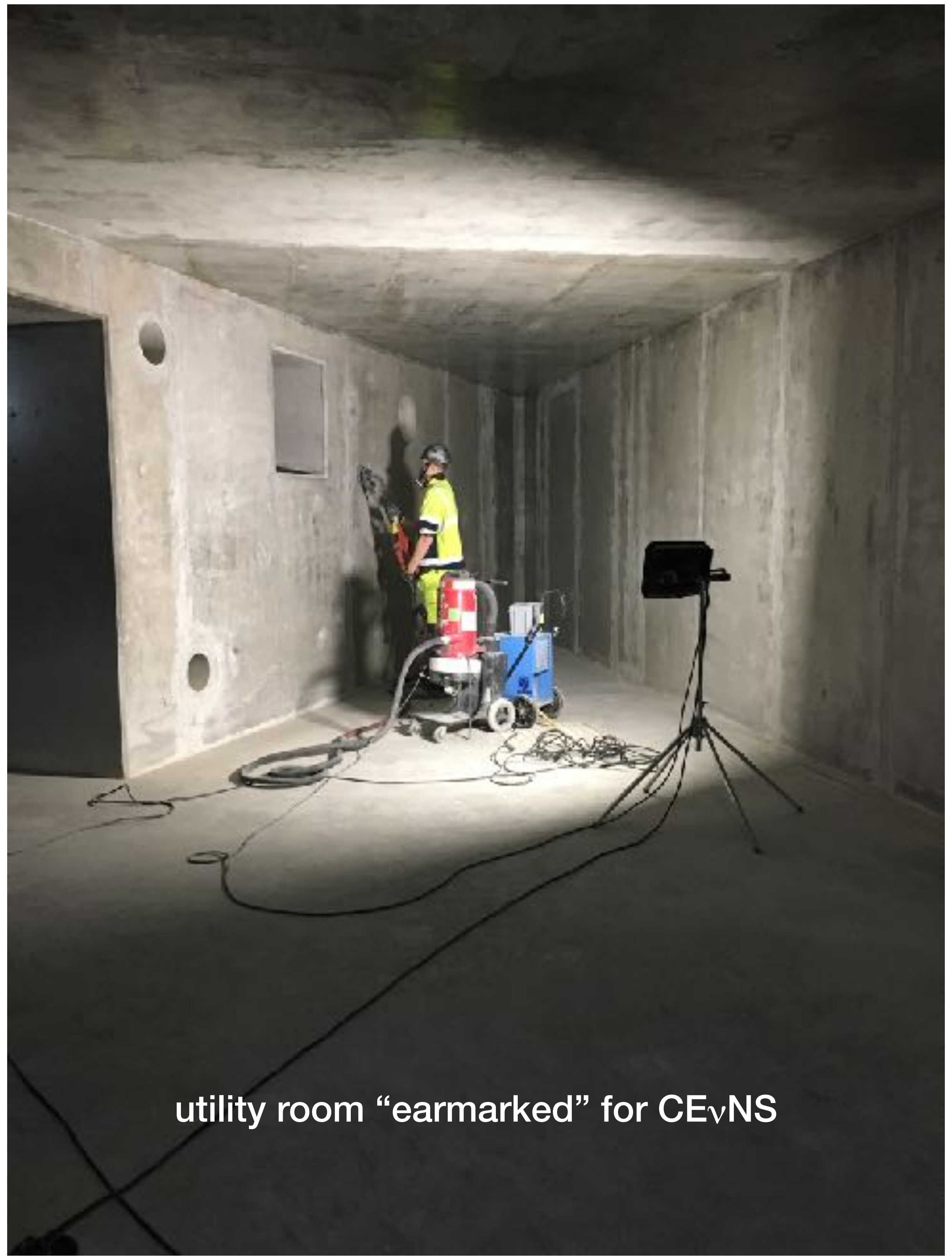
Physics exploitation



A new opportunity for CEνNS

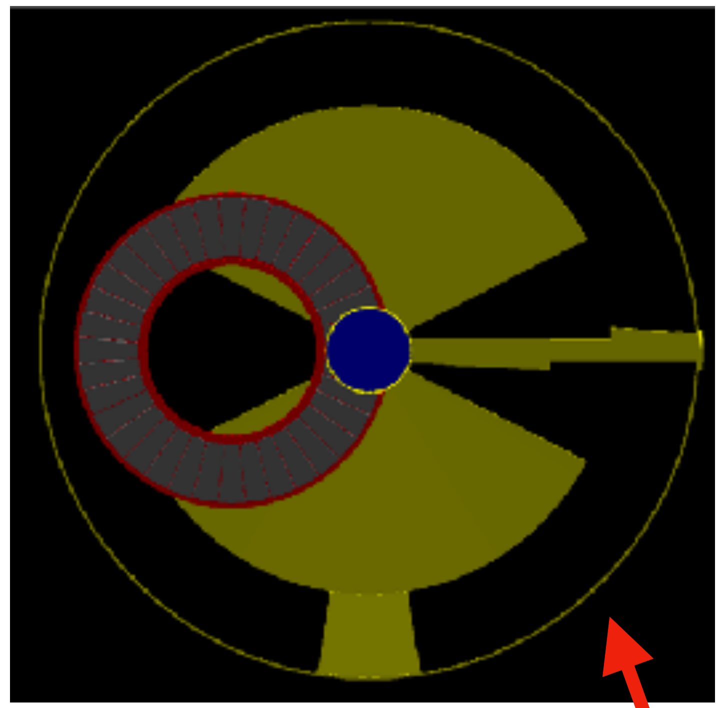
Perfect timing vis-à-vis ESS start. Possible sites identified and studied via simulation (background measurements in preparation)

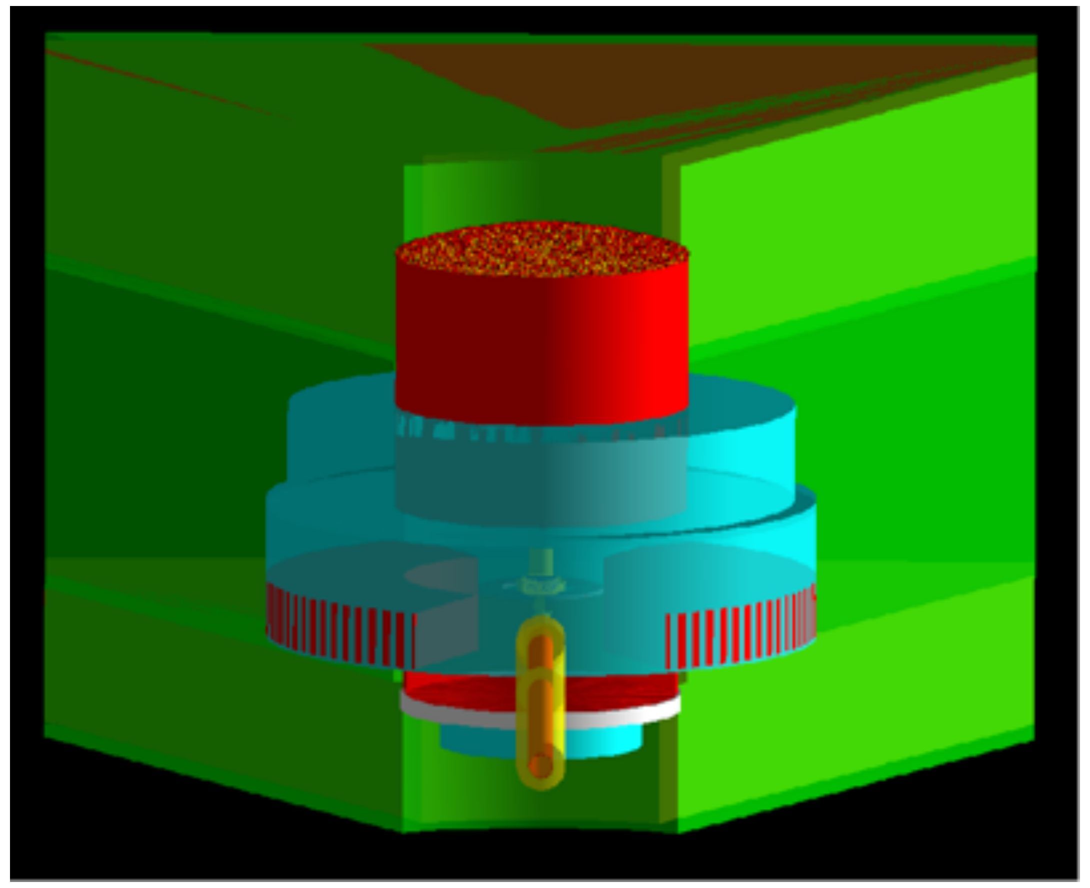


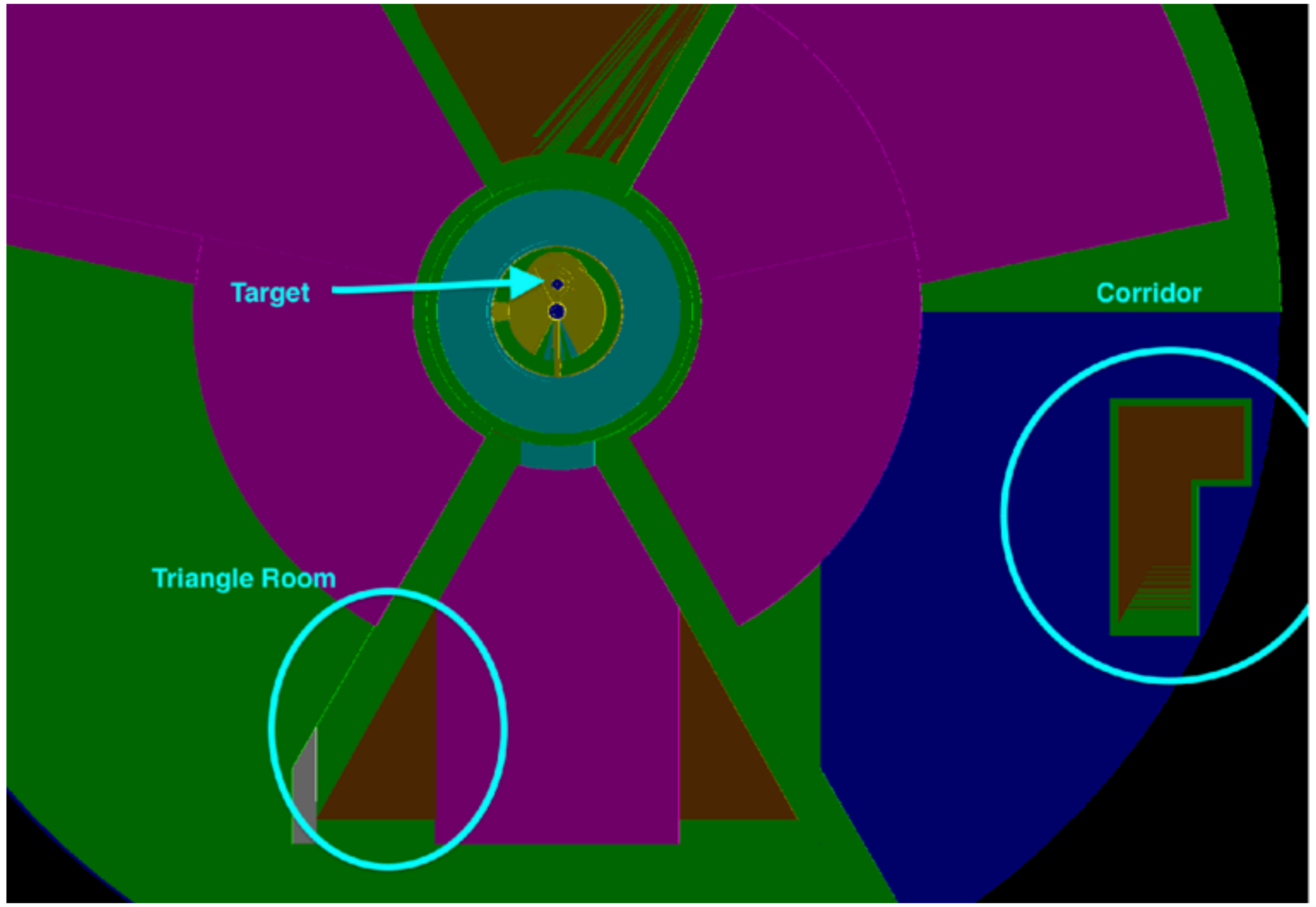


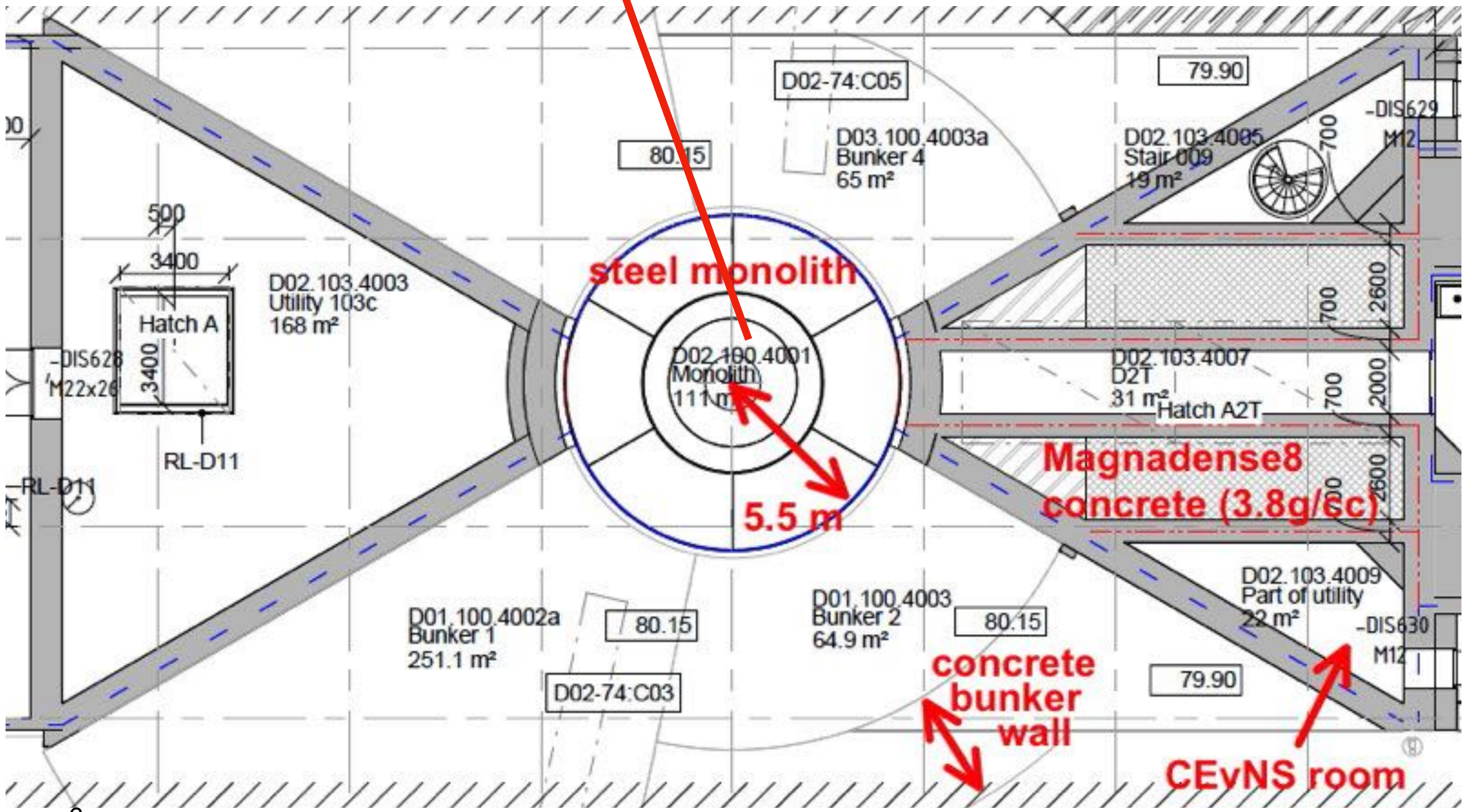
Background at the ESS

- Steady-state background can be subtracted.
- Beam-induced prompt neutrons could be the main source of background.
- Simulations undergoing to find locations within the ESS (two promising locations under study).
- Neutron Camera for on-site measurements.





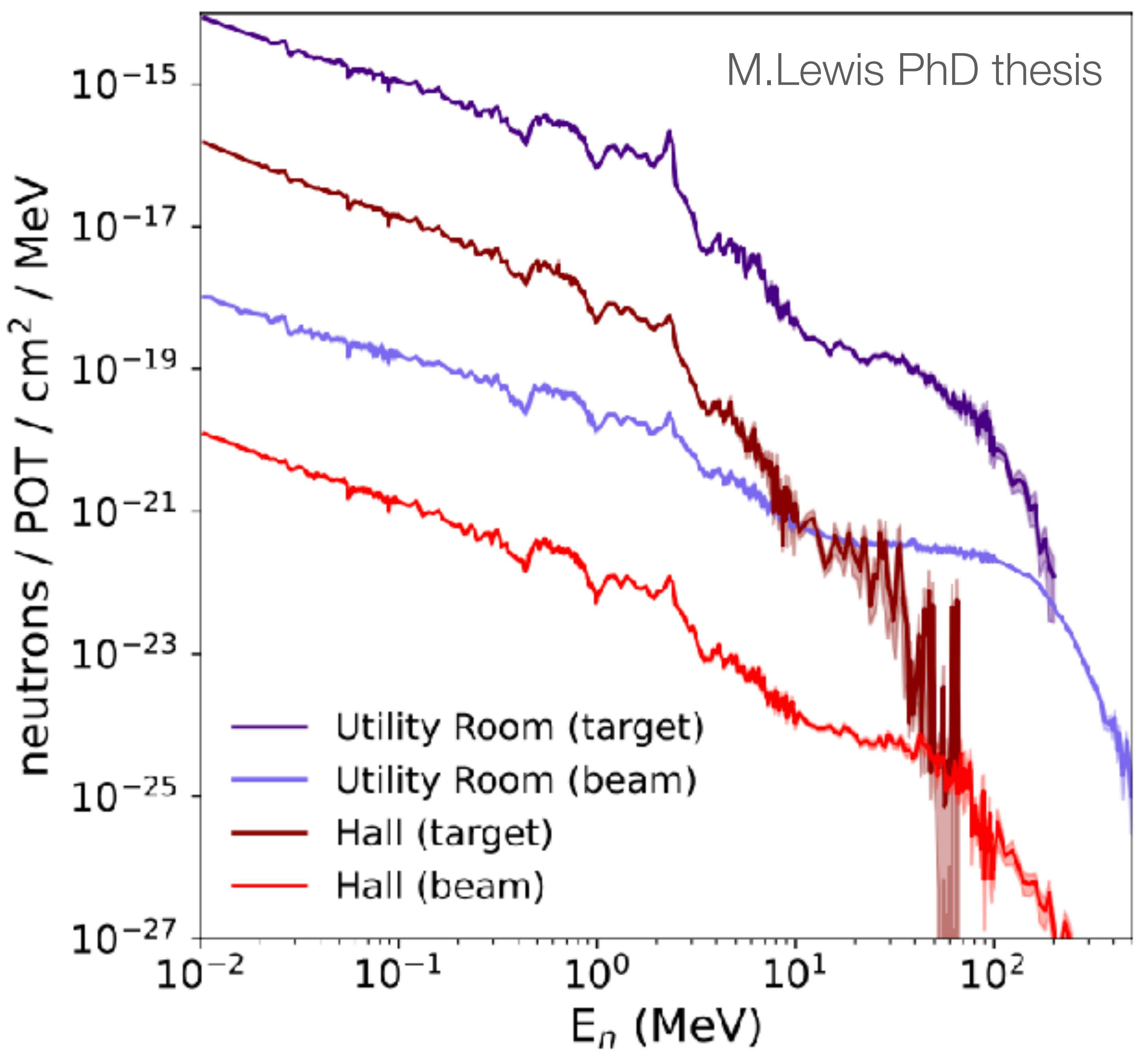


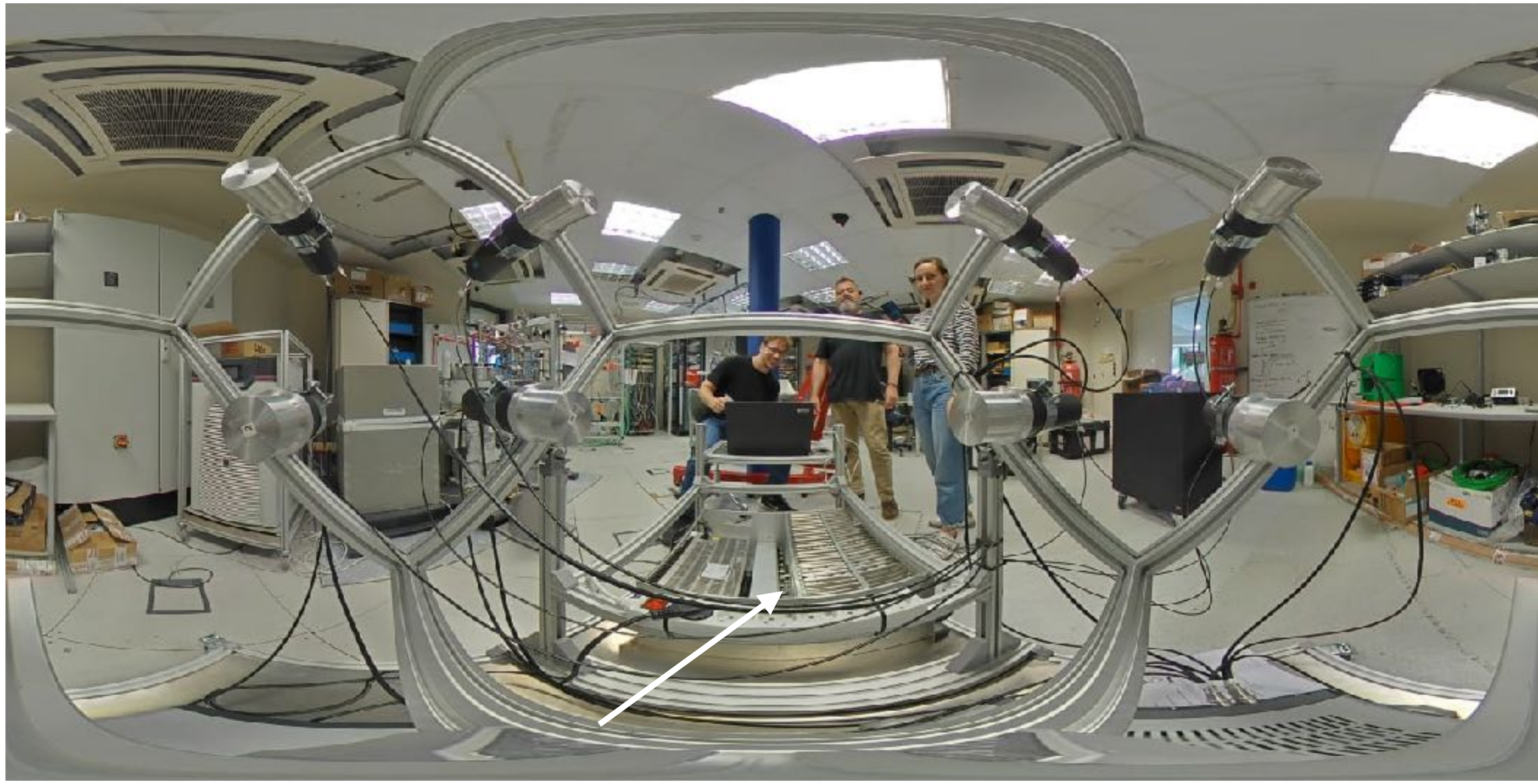


Background at the ESS

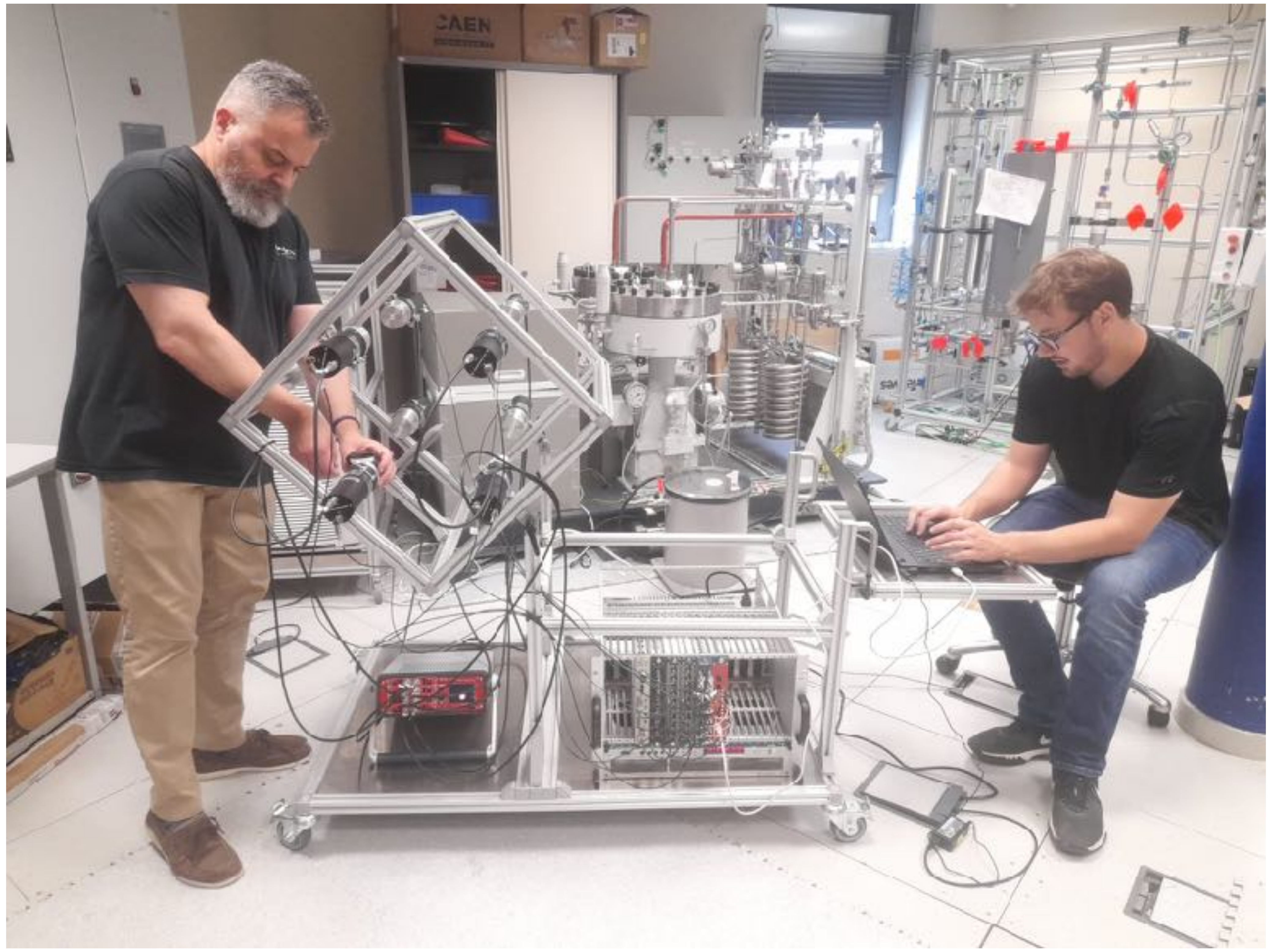
Running MCNP and Geant4 simulations to understand background in 2 different locations at the ESS.

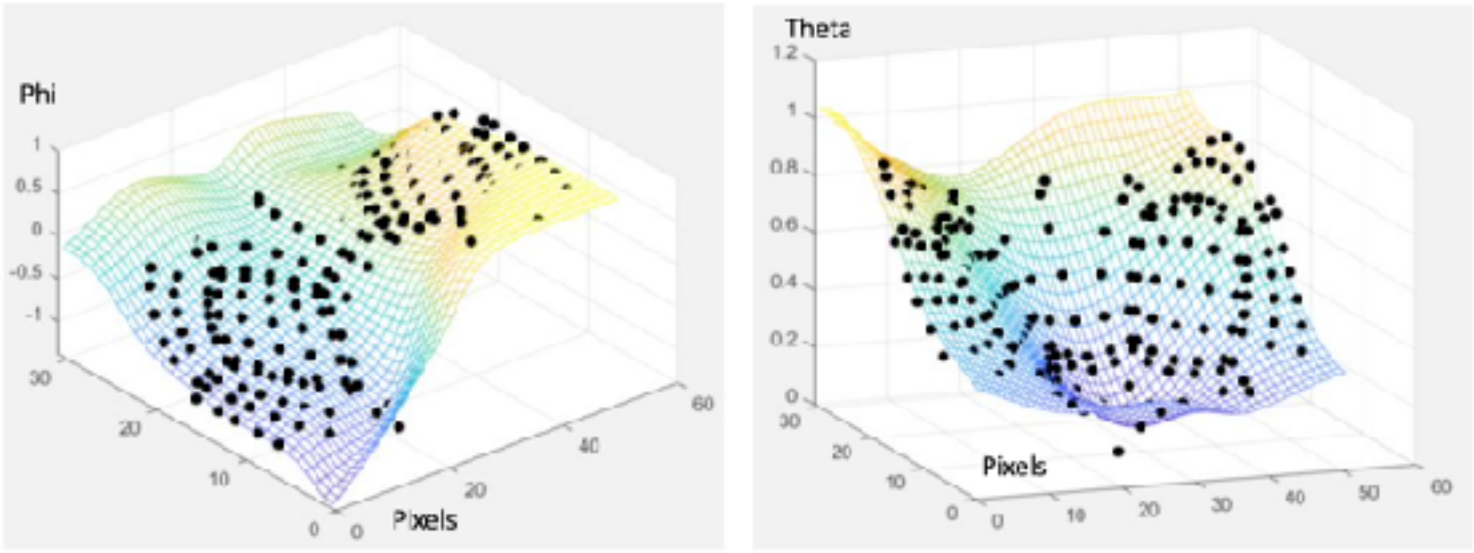
Neutron camera built at DIPC.
Will allow for neutron spectra and direction measurement.
Full characterisation and validation of n-flux@ESS





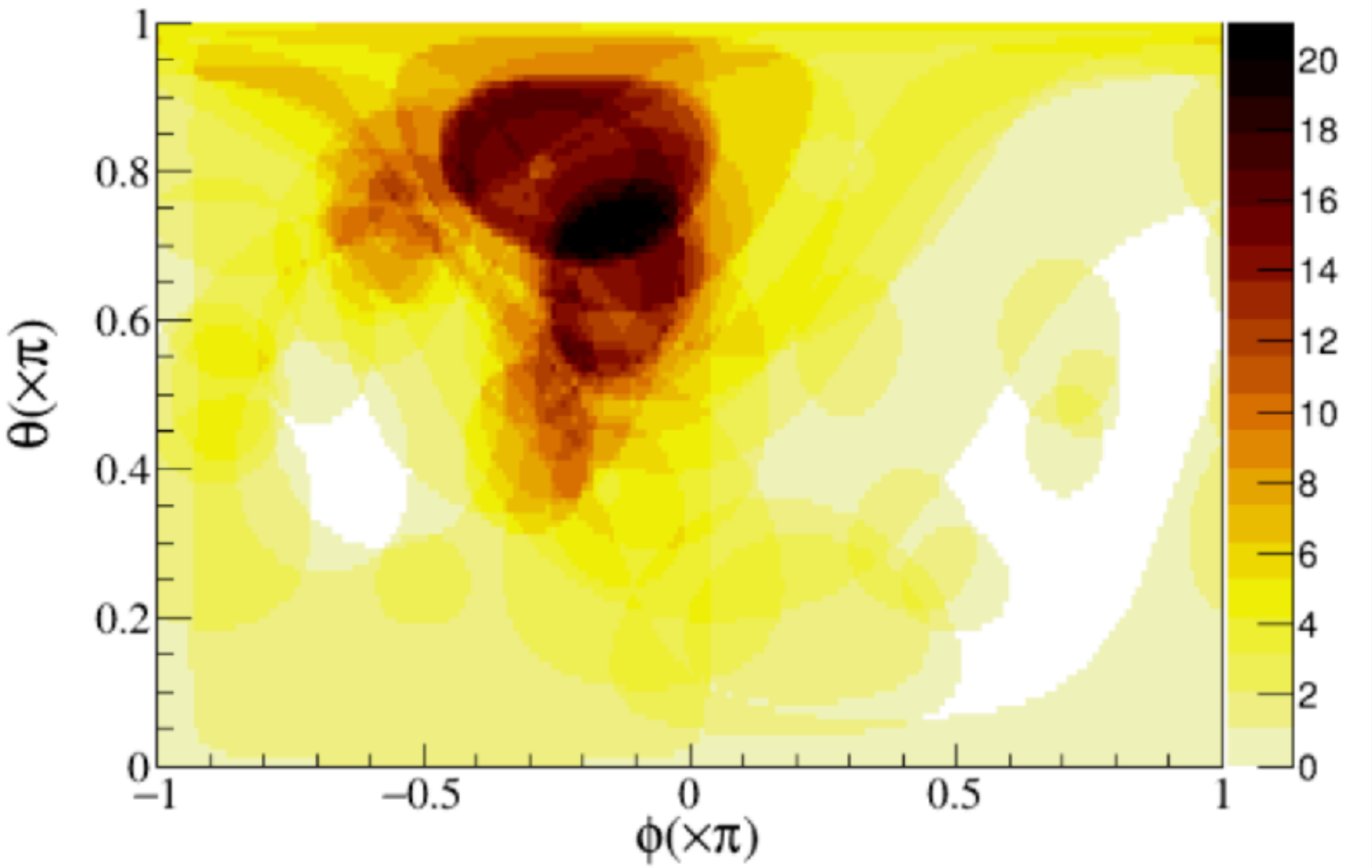
Neutron scatter camera ready for first POT





ANN-based spatial projection

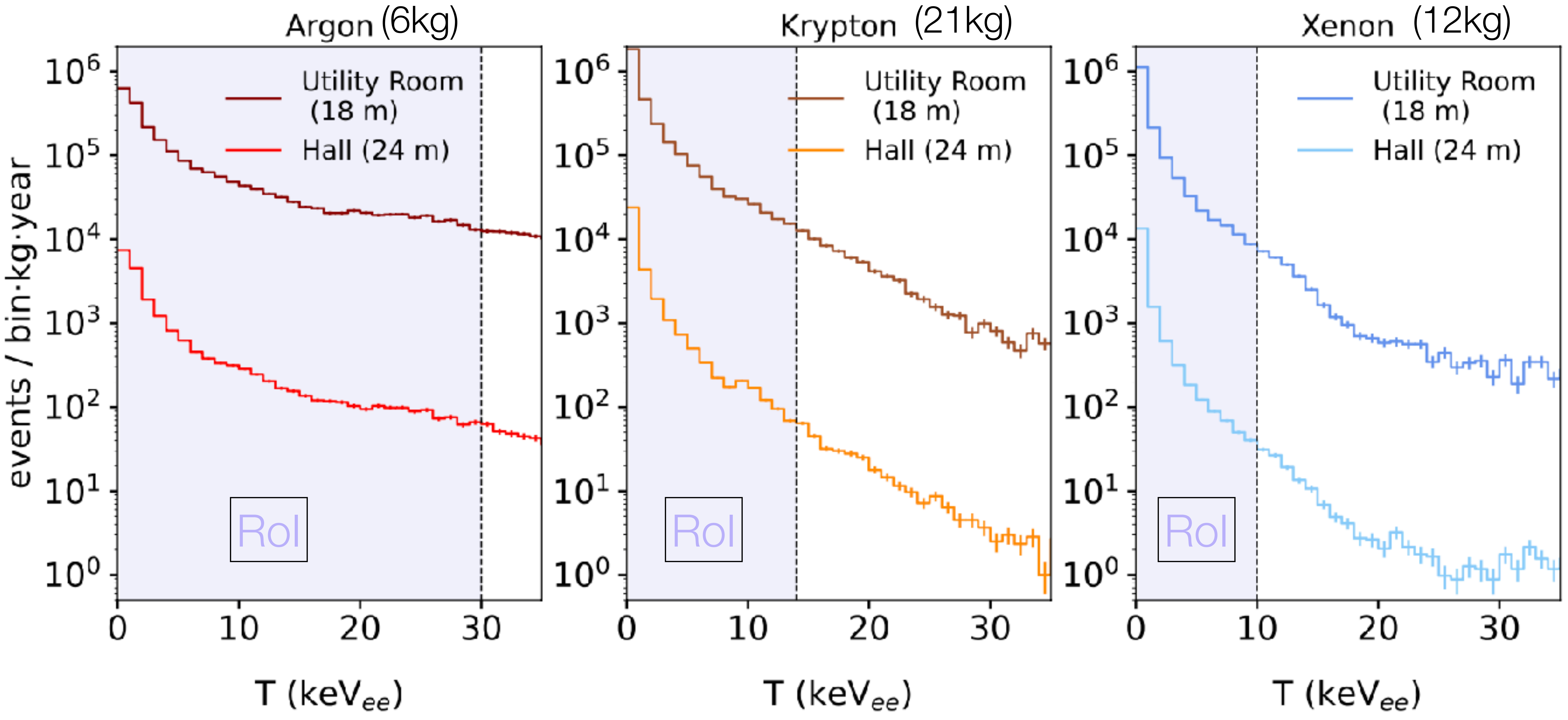
- Optimized for expected ESS neutron bckgs
- True 4π sensitivity (a novelty)
- Plastic scintillator with n/γ discrimination
- Portable (of interest to other ESS users)
- Determine n flux and origin (remedial action)



ESS neutron induced background

Detector at 20 bar

MCNP neutron simulation as reference

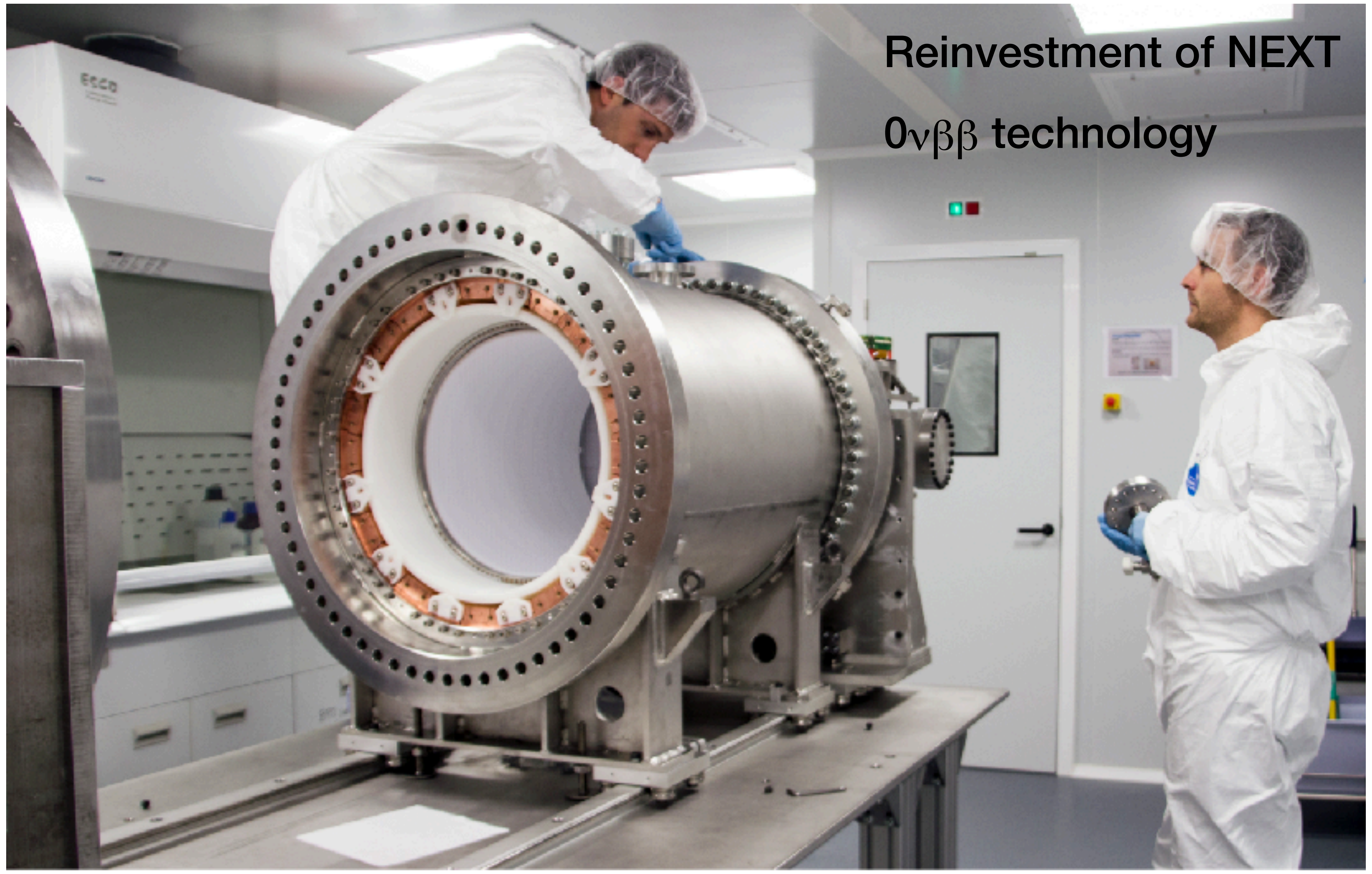


	Argon	Krypton	Xenon
Utility Room	$\sim 9.9 \cdot 10^6$ events/year	$\sim 2.3 \cdot 10^7$ events/year	$\sim 1.8 \cdot 10^7$ events/year
Hall	$\sim 8.5 \cdot 10^4$ events/year	$\sim 2.2 \cdot 10^5$ events/year	$\sim 1.5 \cdot 10^5$ events/year

M.Jiménez Master thesis

A new opportunity for CEνNS: detectors

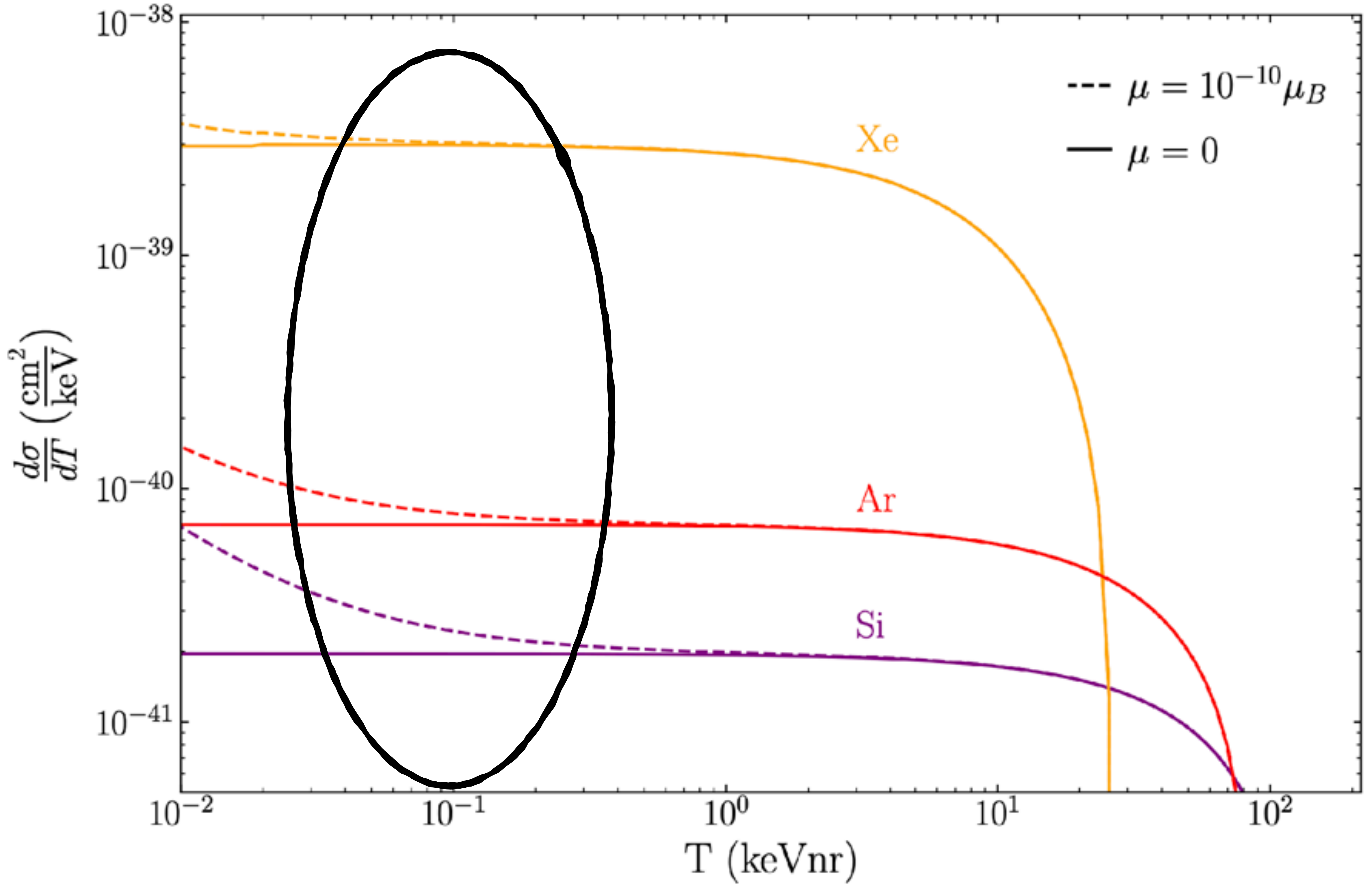
- New technology development for detectors at the ESS.
- Precision: removing statistical limitations is possible at the ESS with non-intrusive detectors
- Developing three technologies to meet challenge via two ERC actions. Benefit from their synergies.



A new opportunity for CEνNS: detectors

Physics exploitation

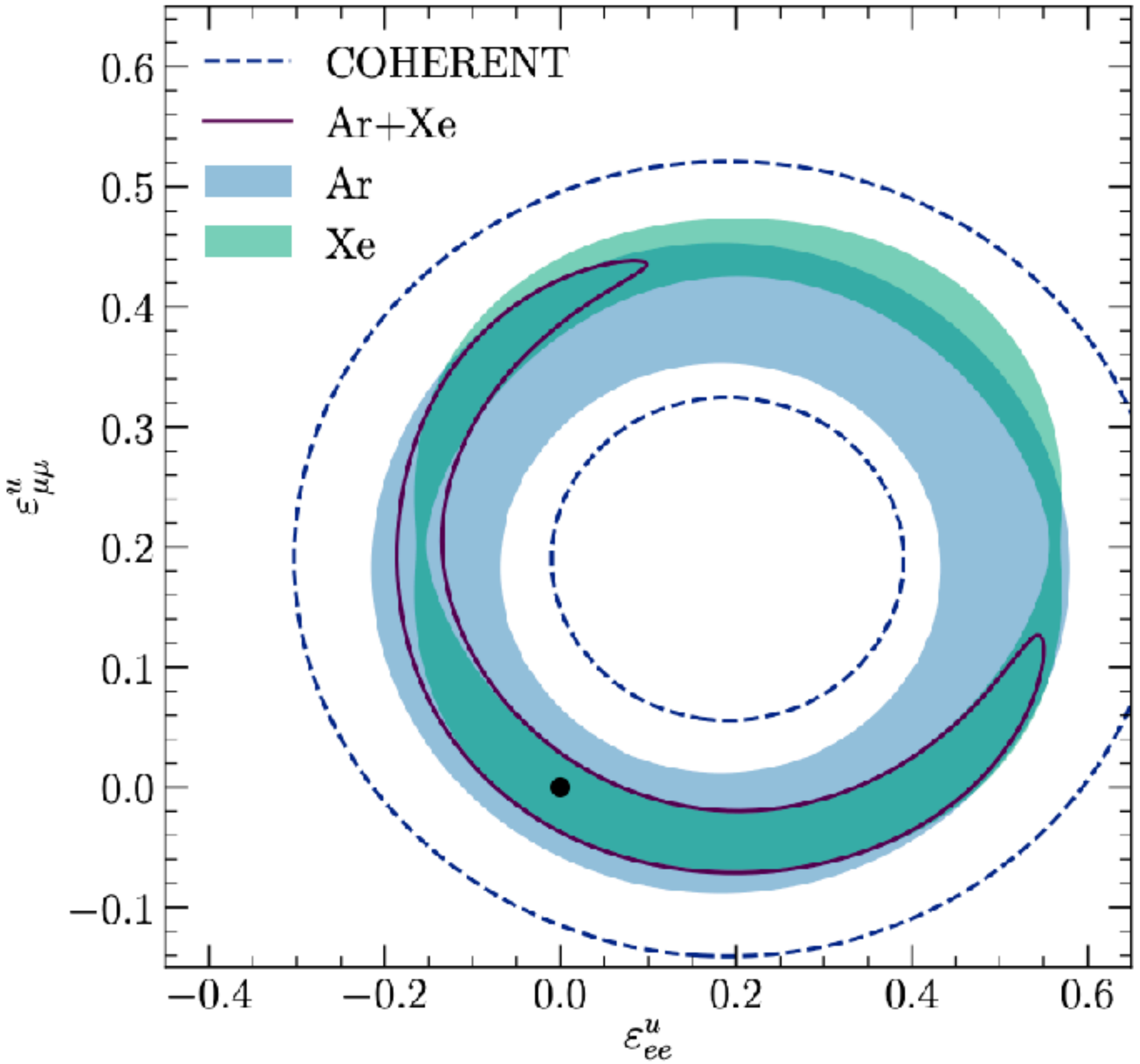
Low energy threshold: interesting physics at low energies



Neutrino magnetic moment

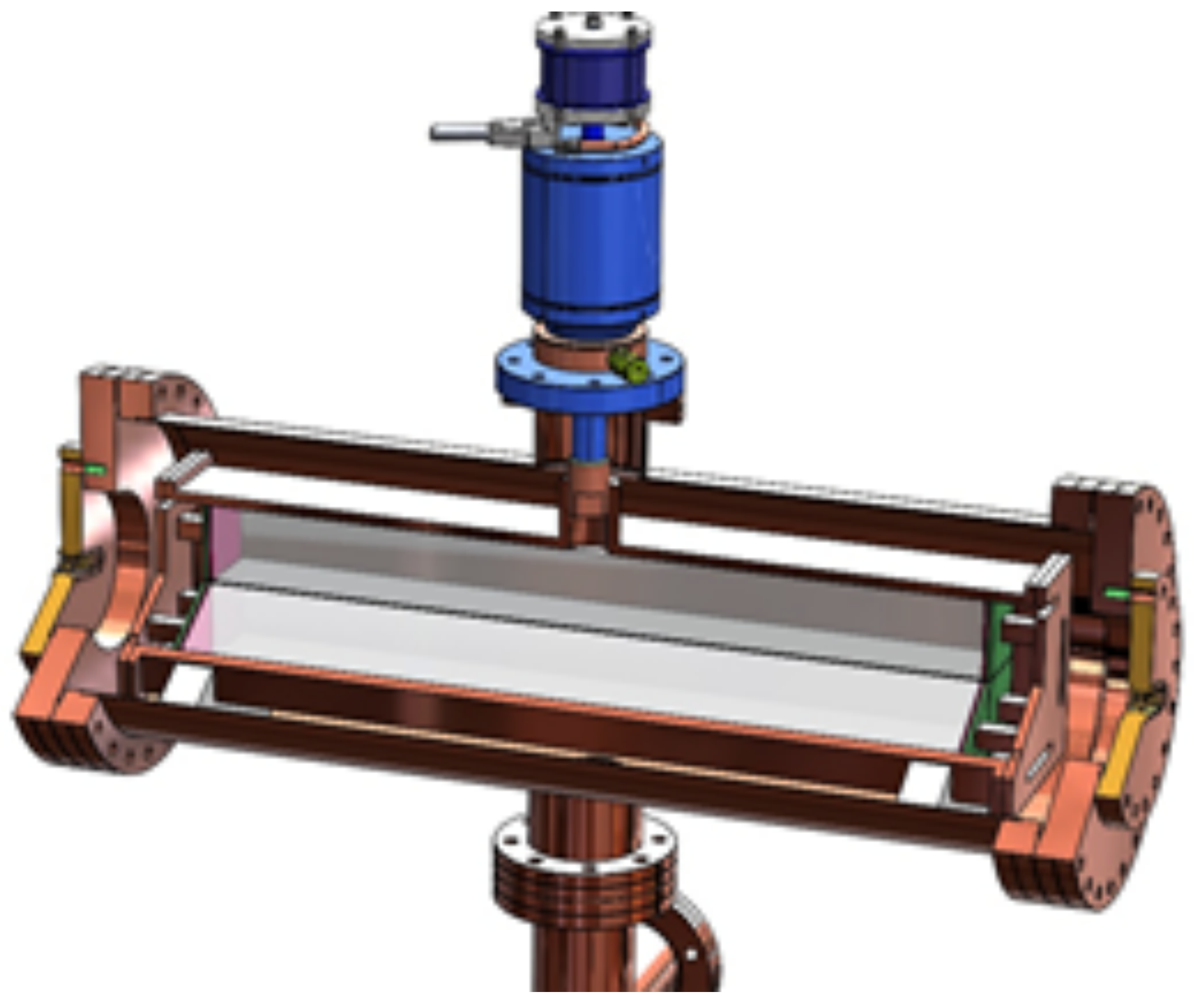
J. High Energ. Phys. **2020,** 123 (2020)

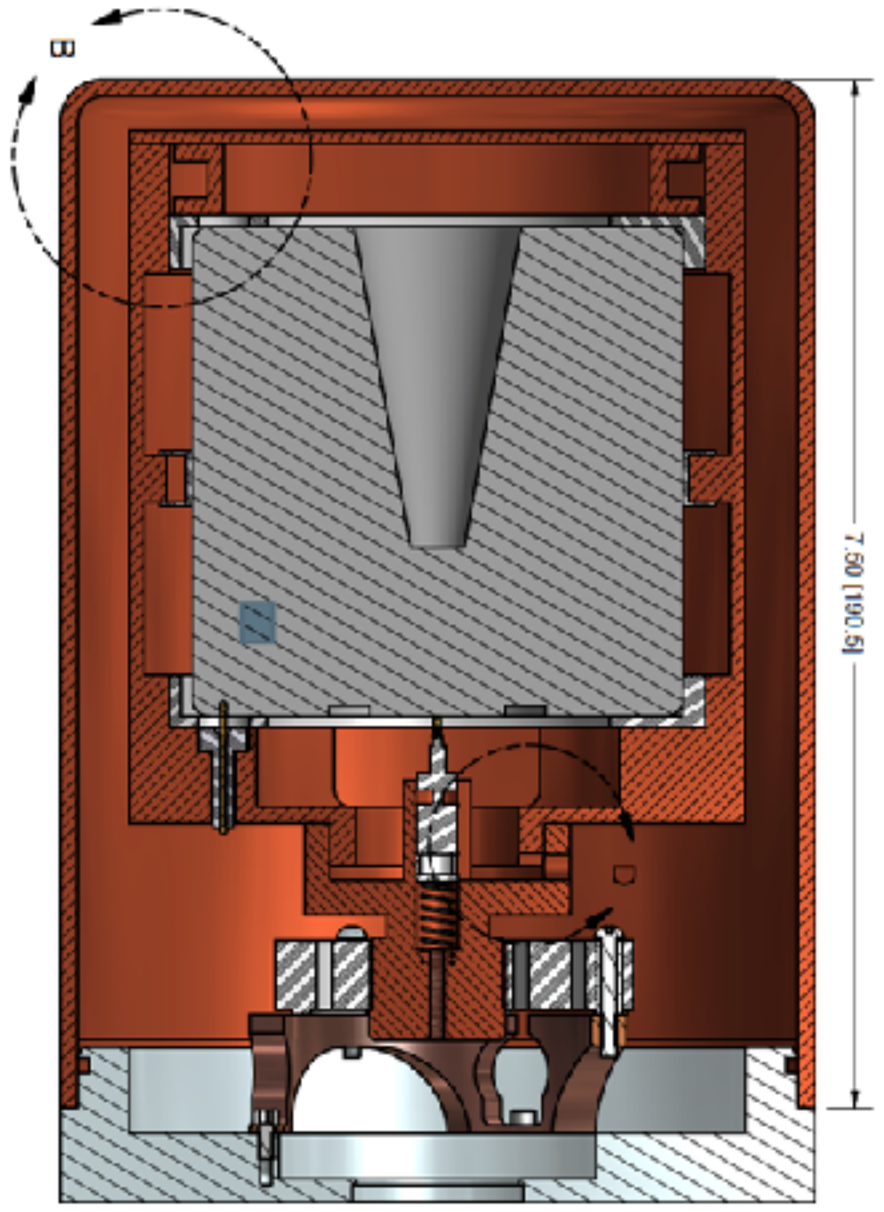
Different nuclei: break degeneracies

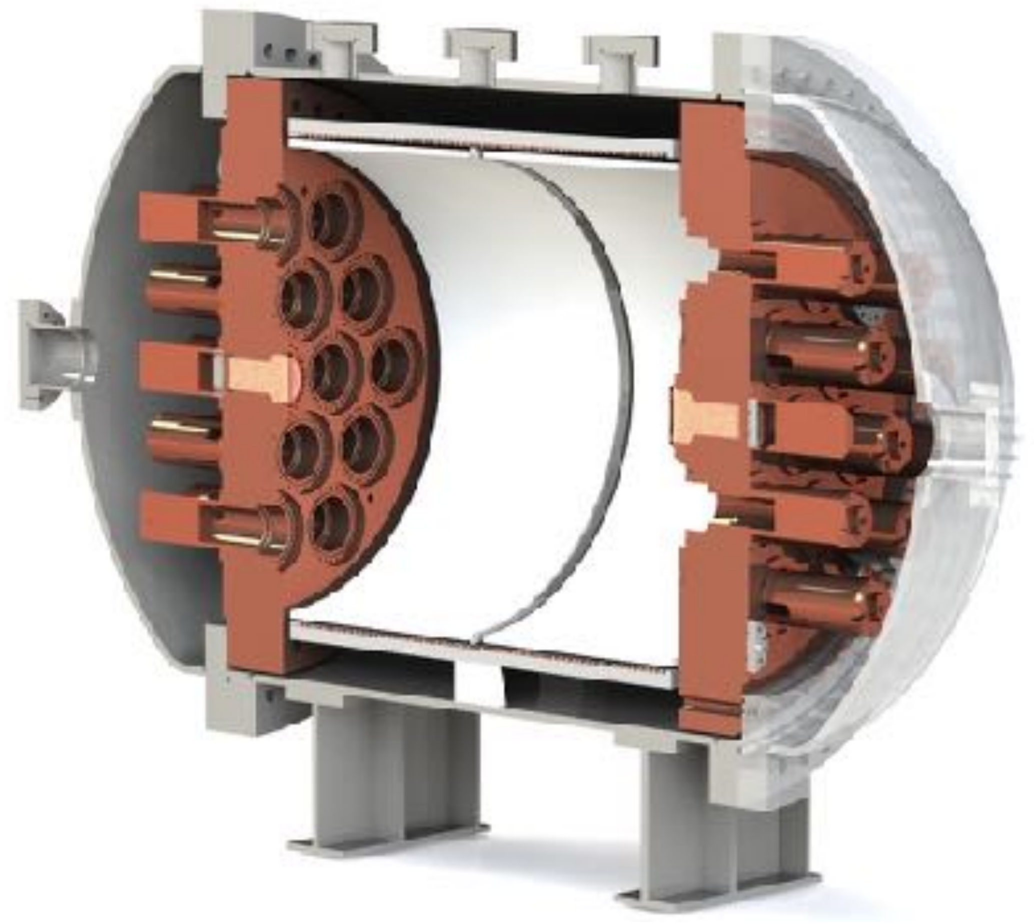


Non Standard neutrino-quark interactions

Funded detectors (thus far)







Cryogenic undoped CsI

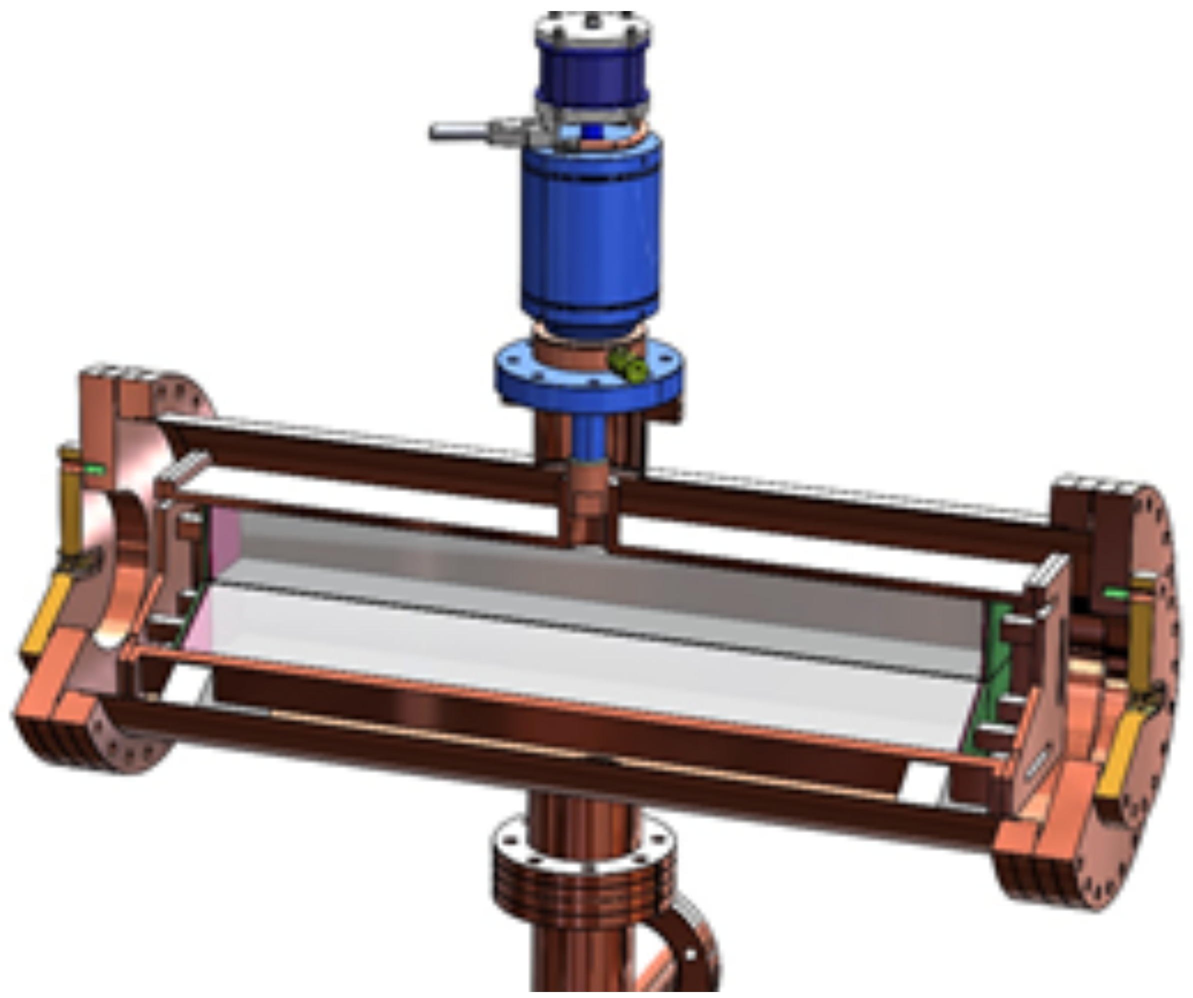
p-type point contact Ge

ERC-Advanced grant

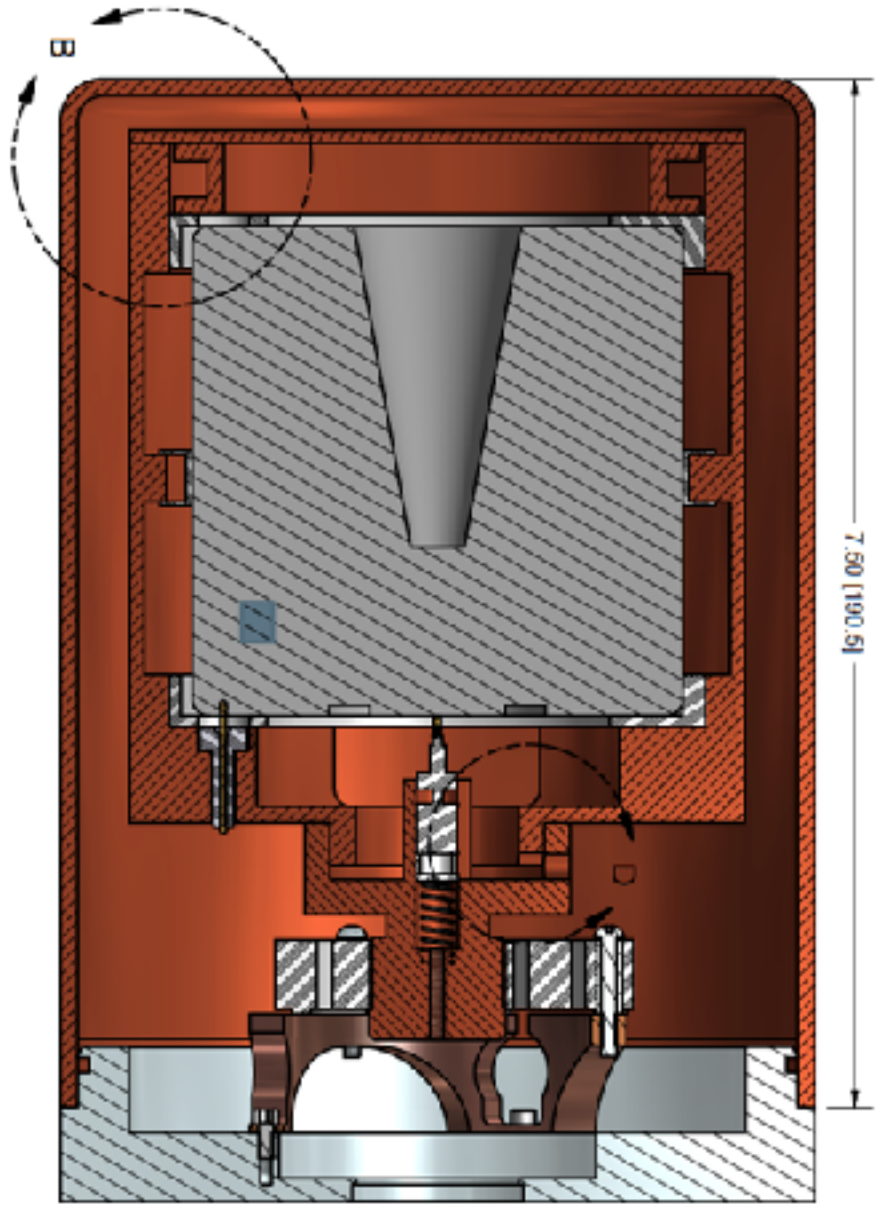
high pressure gas TPC

ERC-Starting grant

Funded detectors (thus far)

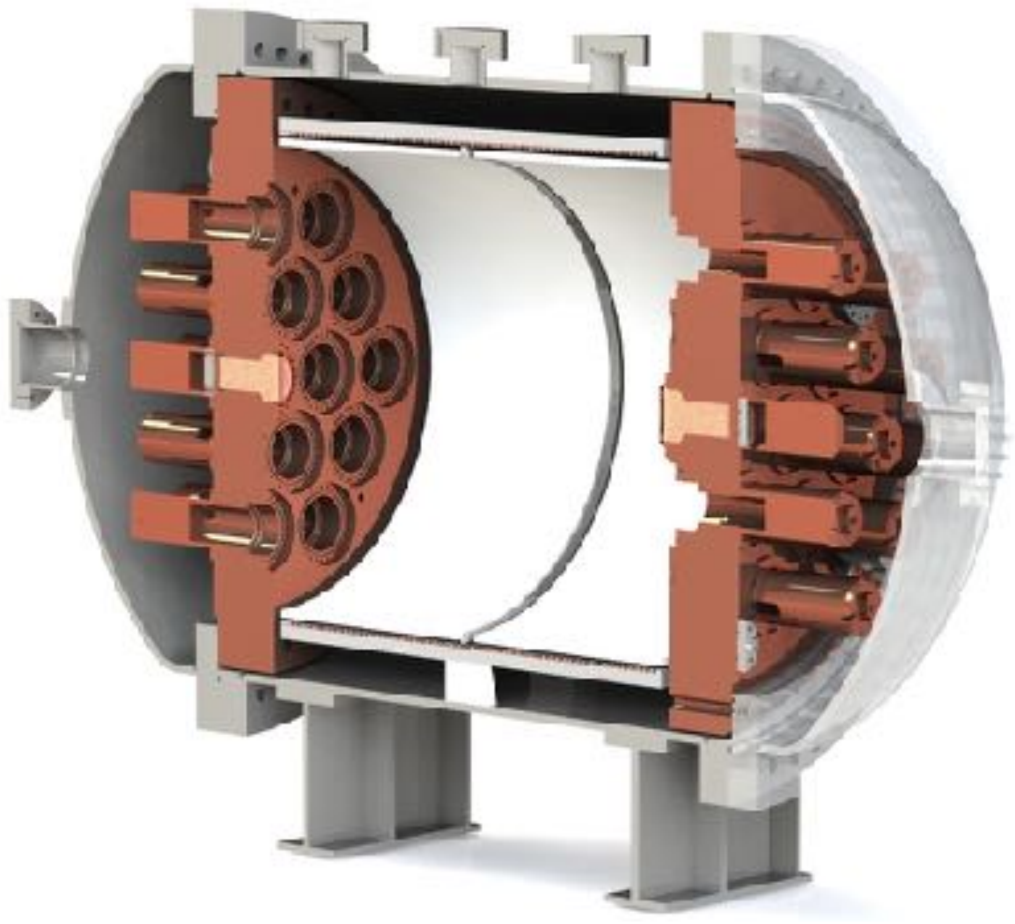


Cryogenic undoped CsI



p-type point contact Ge

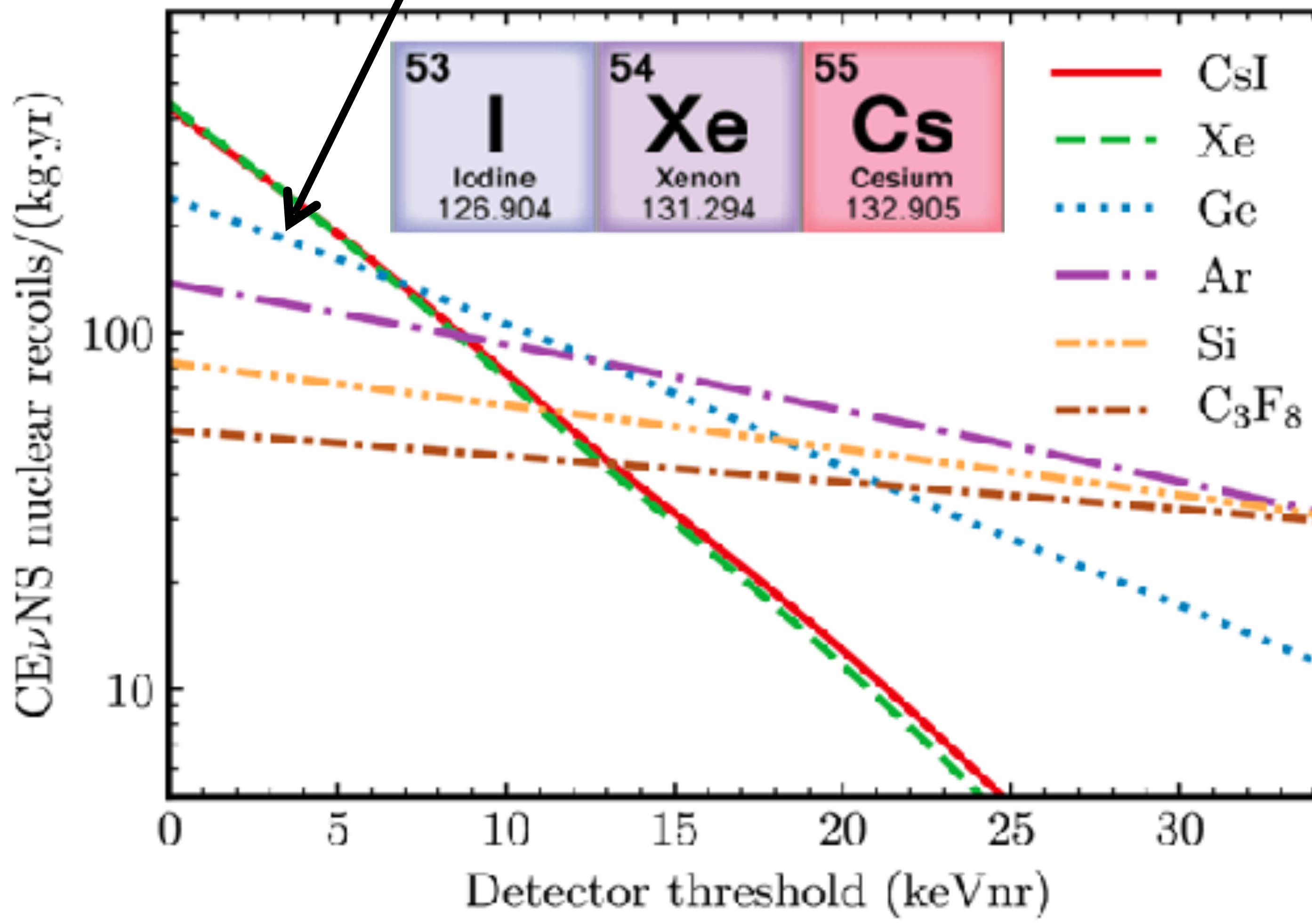
ERC-Advanced grant



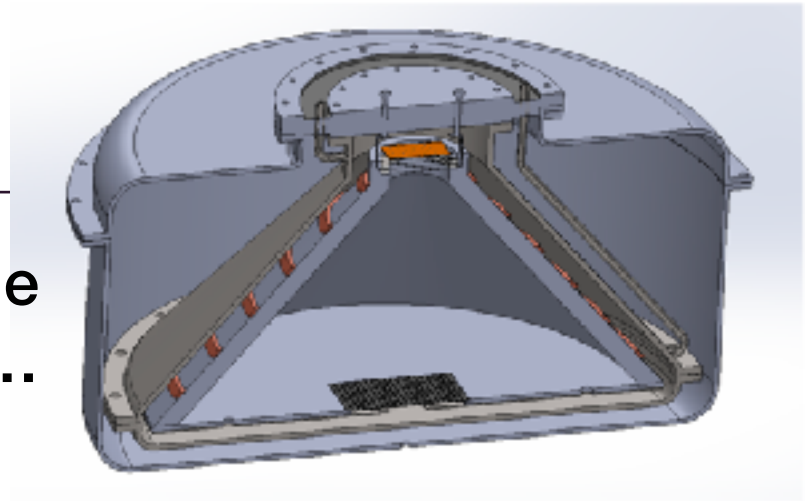
high pressure gas TPC

ERC-Starting grant

Same response…
Different systematics



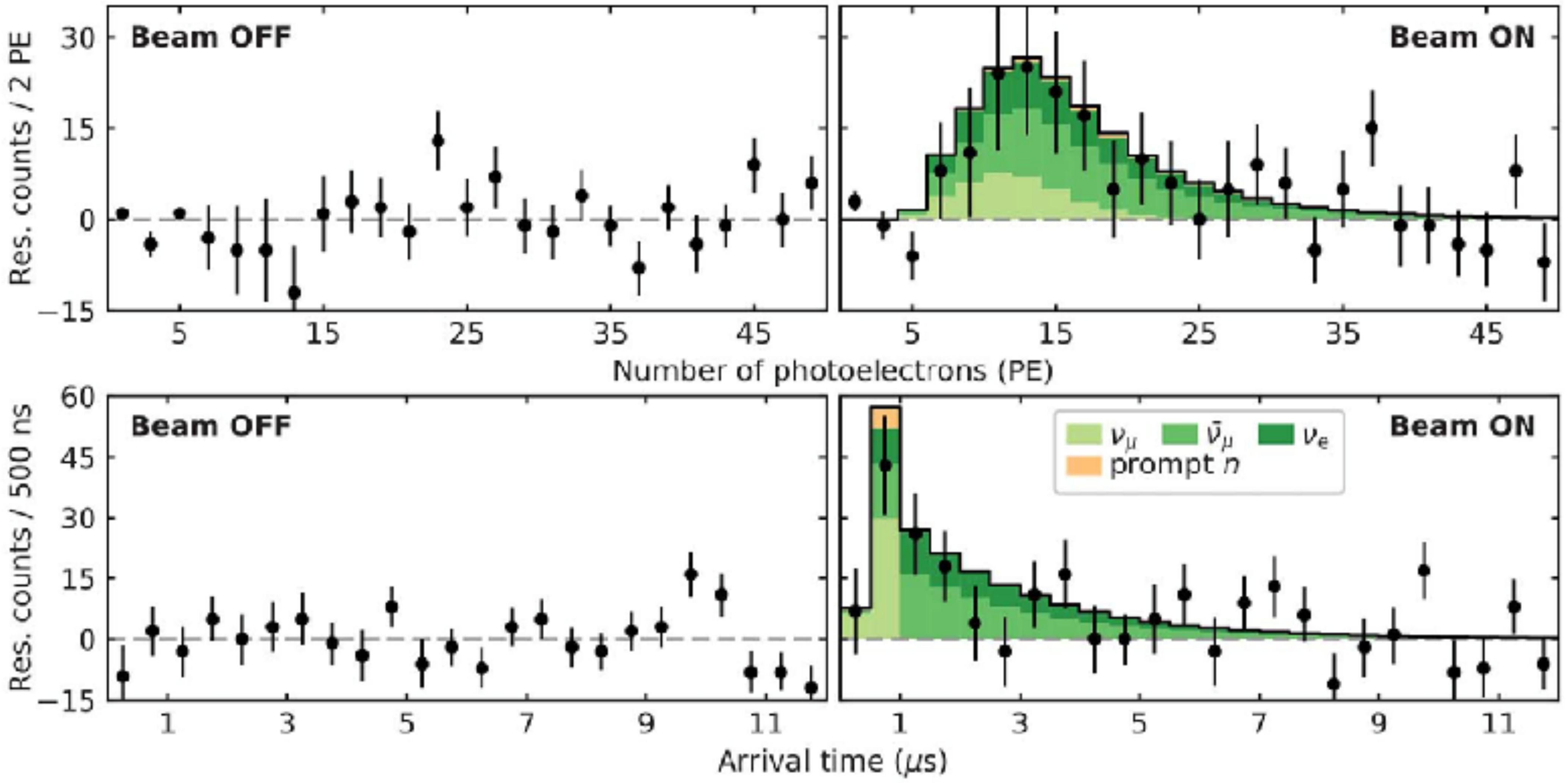
A COLINA visible above the horizon…



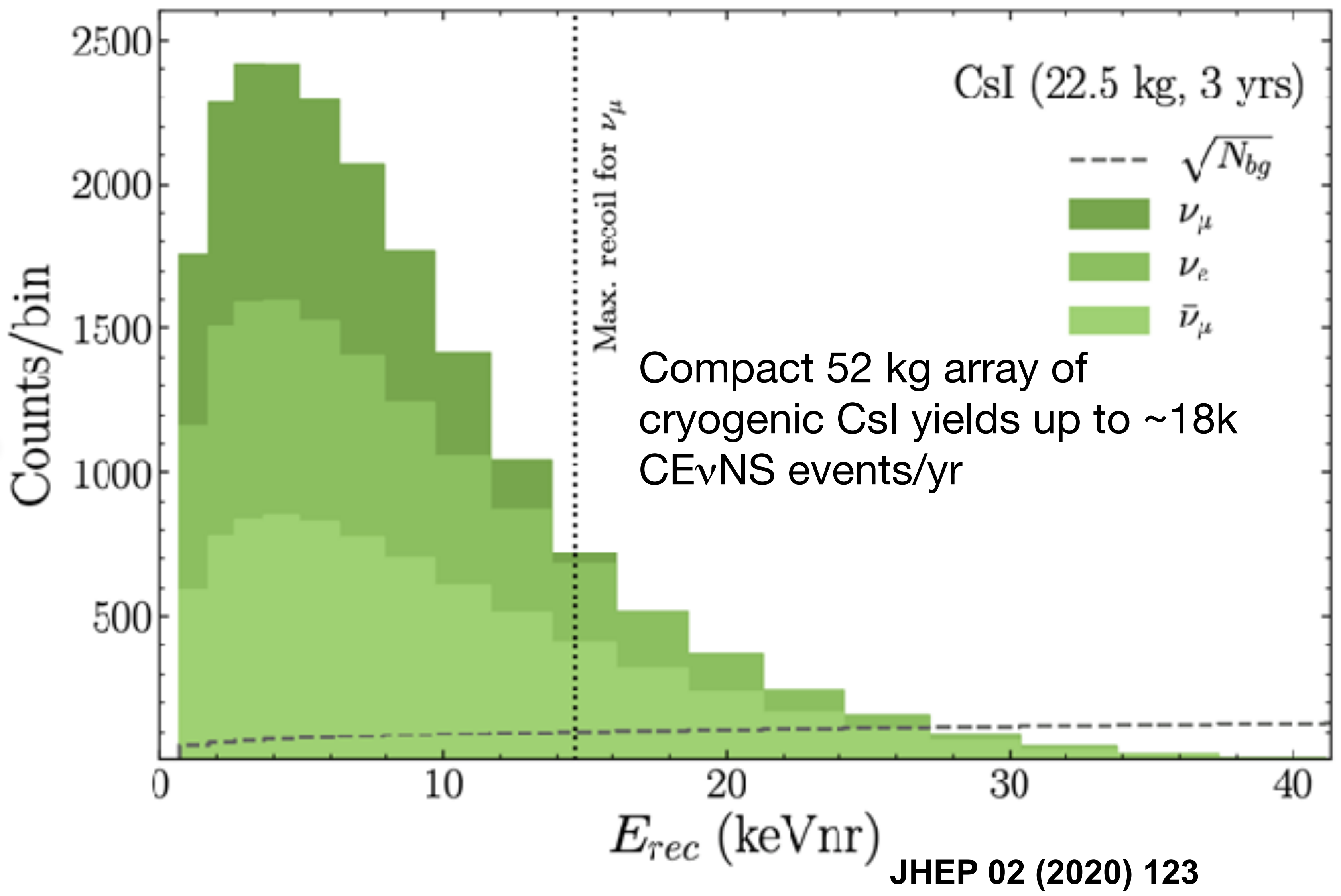
Cryogenic (87 K) undoped CsI array

- Natural evolution from CsI[Na] at SNS (same advantages of large σ, similar Cs-I mass, low afterglow)

Moving from ~100 events/yr…



…to ~18k events/yr

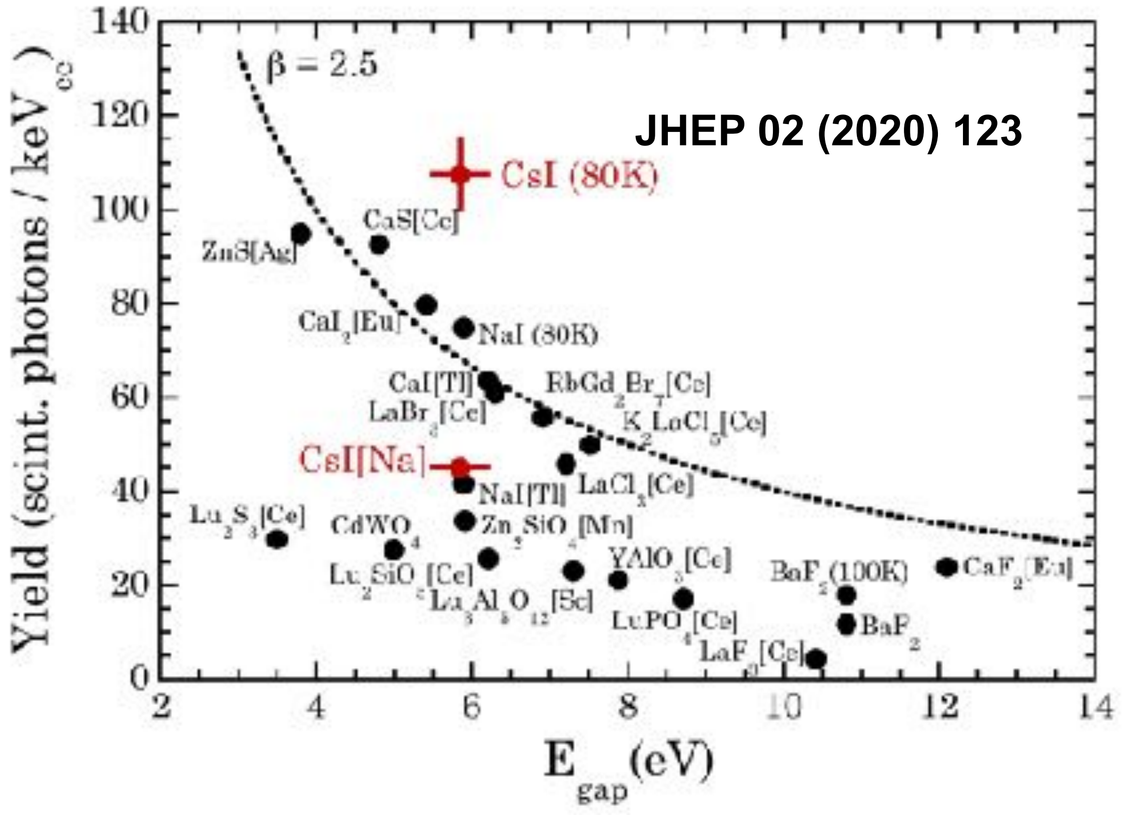


JHEP 02 (2020) 123

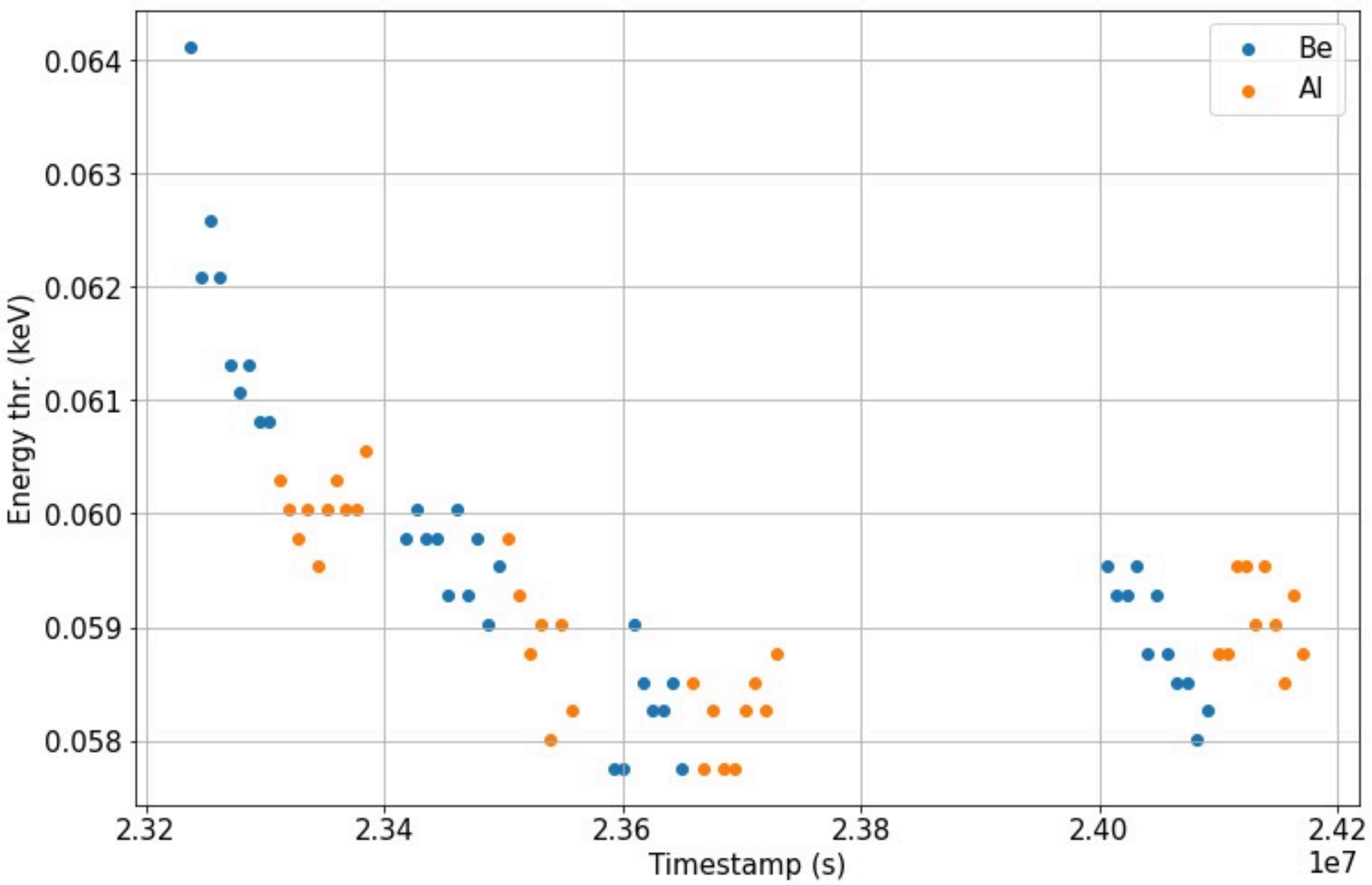
	52 kg cryogenic CsI @ ESS	750 kg LAr @ SNS
events per year	~18,000	~3,000
energy threshold	~ 1 keVnr	~20 keVnr
energy resolution	~47 e-h(Si)/keVee	~4.2 PE/keVee

Physics Reports 1023 (2023) 1–84

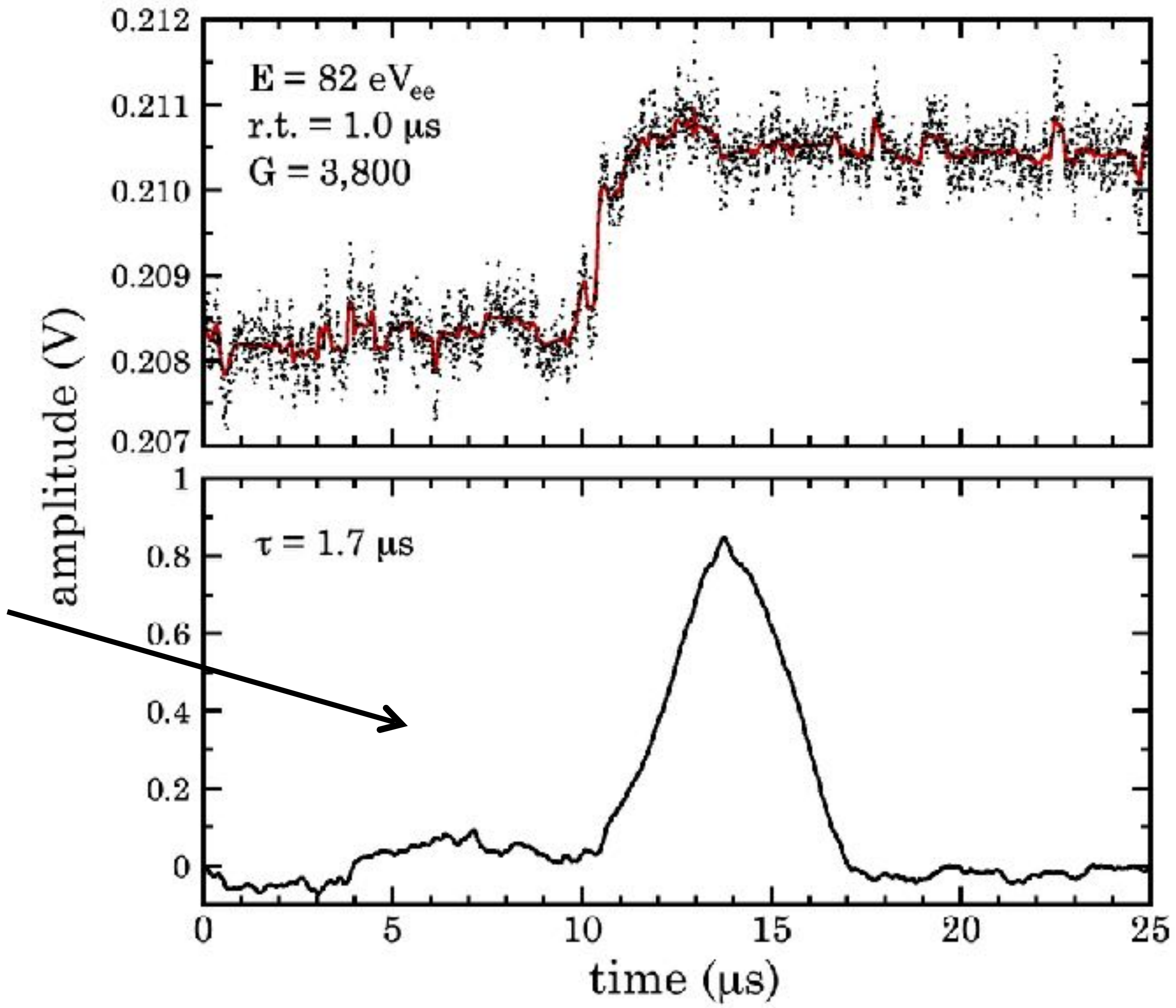
Cryogenic (87 K) undoped CsI array:



- Combine higher light yield (x2.5-3) and more efficient photosensors (x3 higher QE)
- Large mass increase to ~52 kg (seven 7x7x35 cm crystals)
- LAAPDs with >80% QE provide a measured < 55 eVee threshold in inorganic scintillator (!). Presently limited by charge-trapping noise in NTD silicon. R&D to bypass this in collaboration with industry (FAGOR semiconductors).

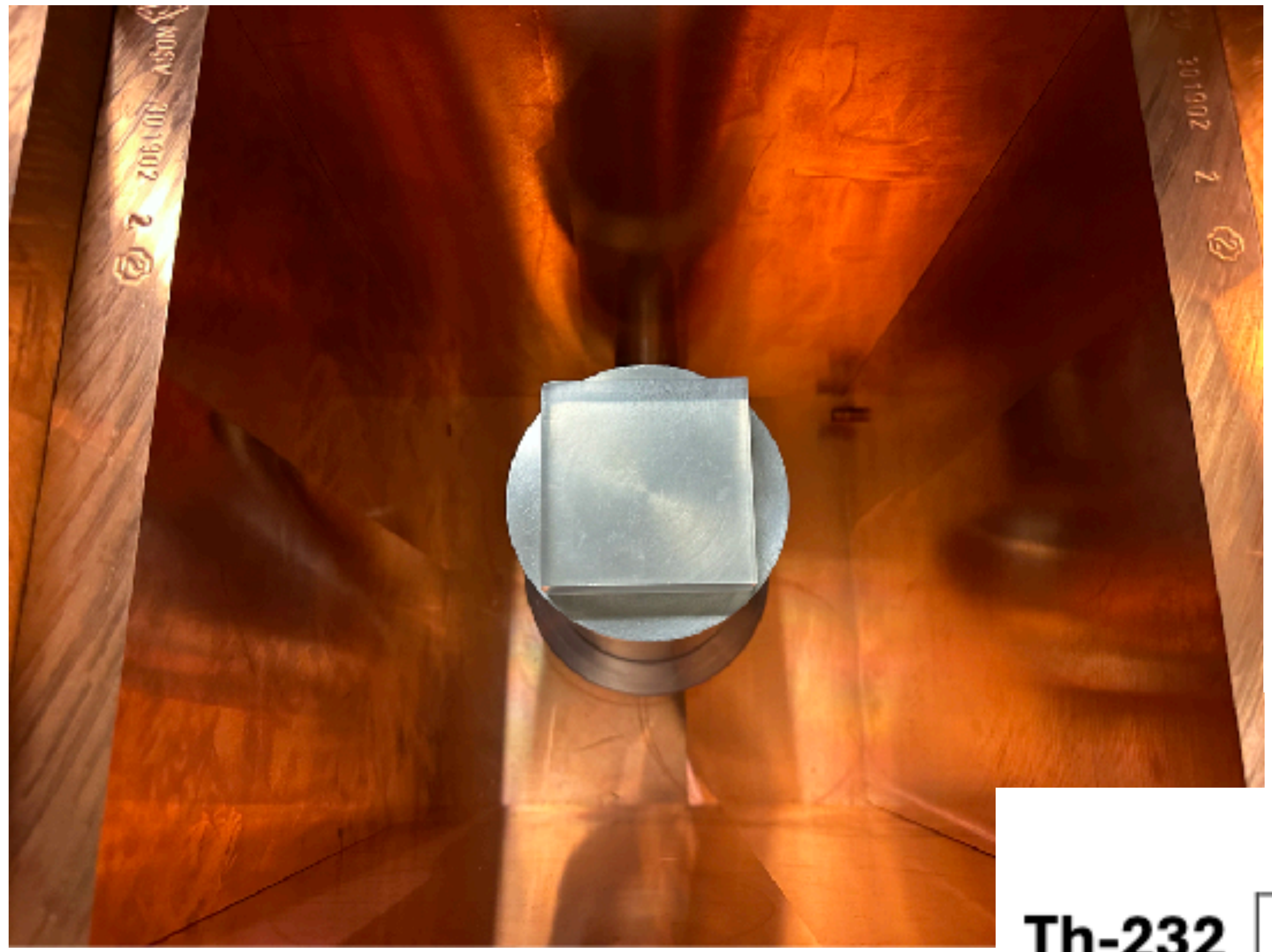


80K CsI read out by 1.7 cm2 LAAPD (notice signal-to-noise at 82 eV)



Cryogenic (87 K) undoped CsI array

- Much improved internal radiopurity w.r.t. SNS, advanced inner active LAr veto.
- Well-studied Quenching Factor down to threshold.



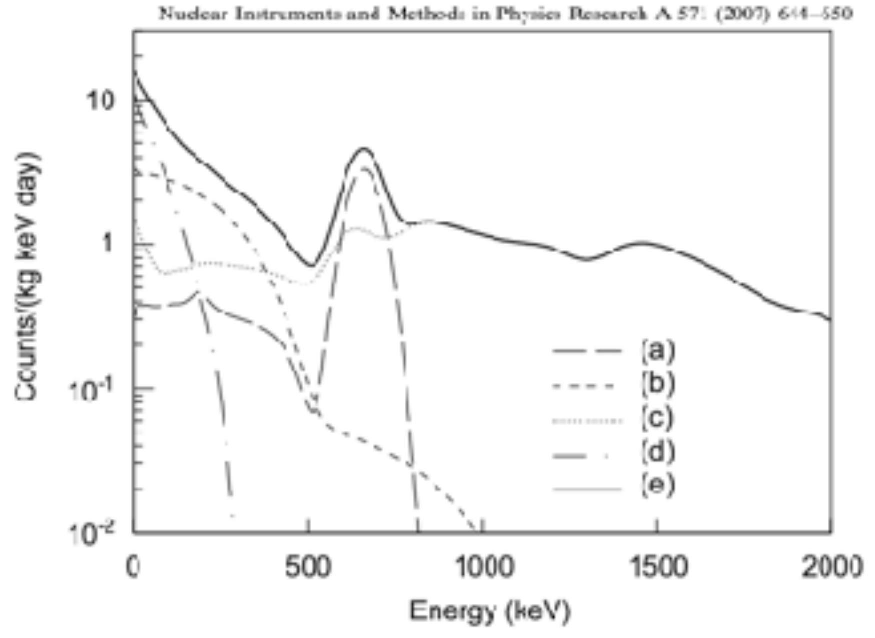
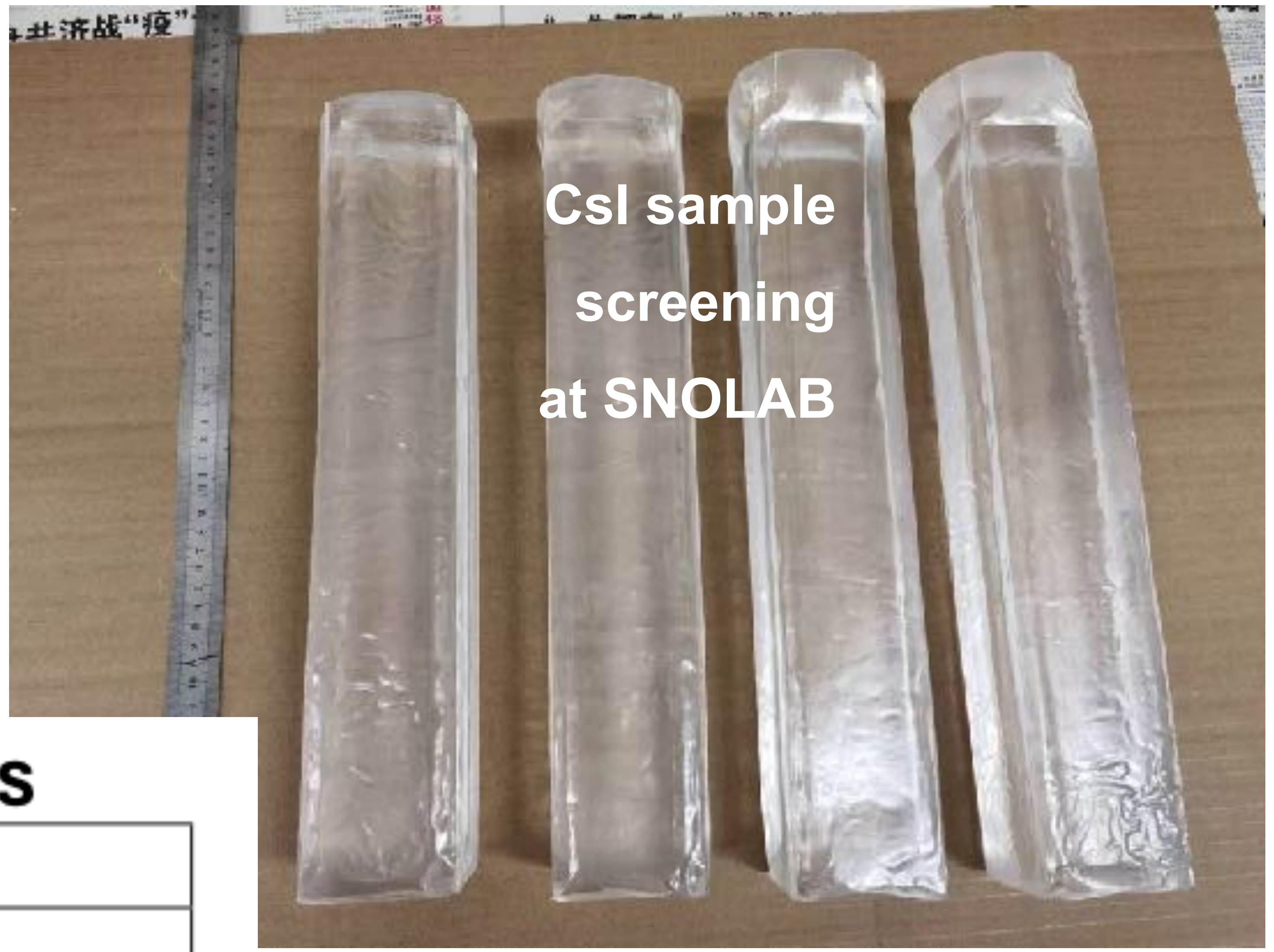


Fig. 3. Background spectra obtained using GEANT4 simulation for the $8 \times 8 \times 30\,cm^3$ CsI(Tl) crystal with 10 mBq/kg ^{137}Cs contamination, 30 mBq/kg ^{134}Cs contamination, and 10 ppb ^{87}Rb contamination: (a) spectrum of $^{137}Ba^*$; (b) beta-ray spectrum of ^{137}Cs; (c) ^{134}Cs spectrum; (d) ^{87}Rb spectrum; and (e) total summed spectrum.

Attention paid to Rb, Cs (low-E emitters)

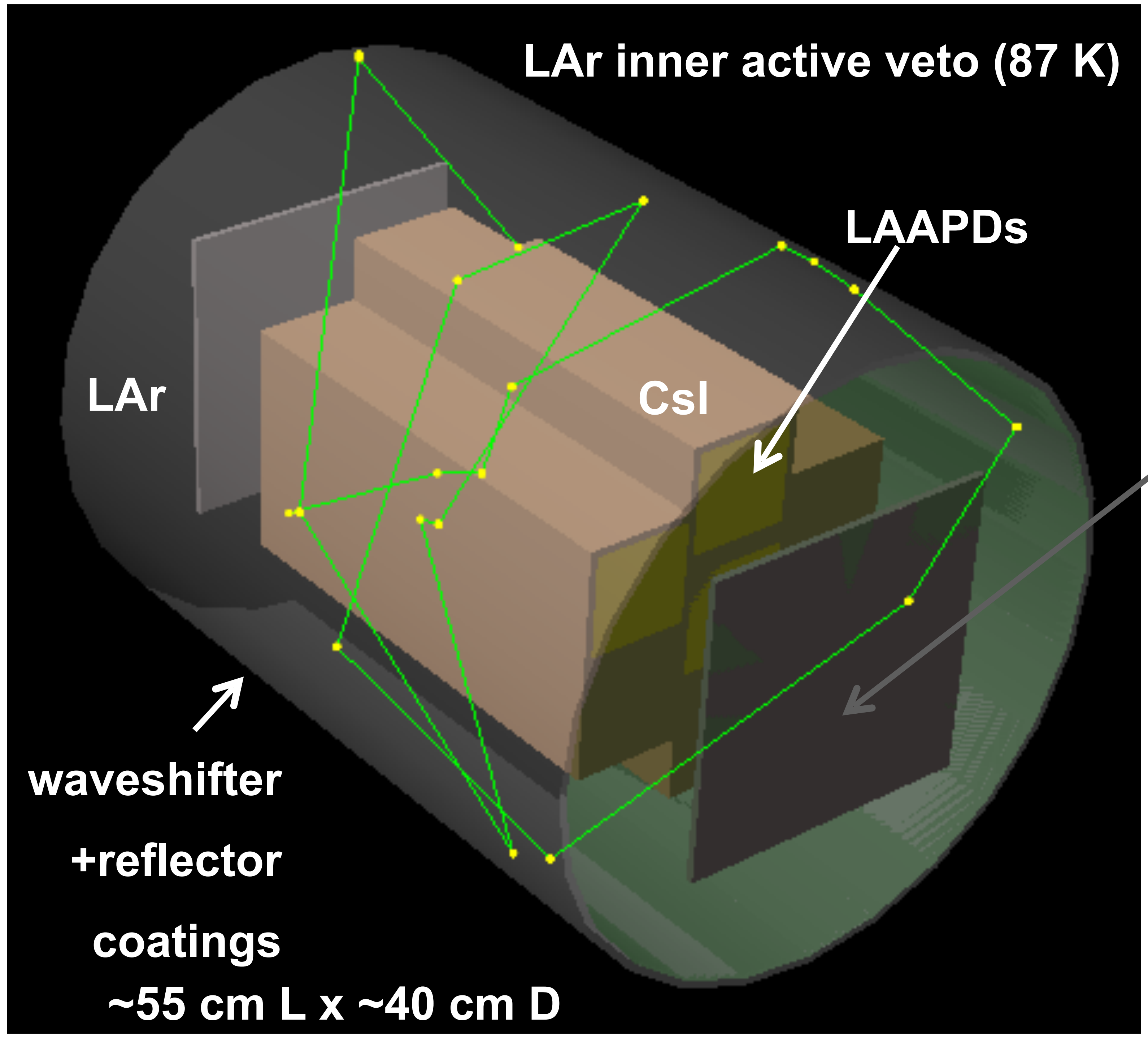
SICCAS low-background CsI selected:



	Amcrys CsI[Na] @ SNS	SICCAS CsI @ ESS
Th-232	<0.5 mBq/kg	0.03 mBq/kg
U-238	2.4 mBq/kg	0.09 mBq/kg
K-40	16.7 mBq/kg	<4.1 mBq/kg
Cs-137	27.9 mBq/kg	1.3 mBq/kg
Cs-134	25.9 mBq/kg	33 mBq/kg
Rb-85	101 ppb	15.5 ppb
Rb-87	38 ppb	1.8 ppb

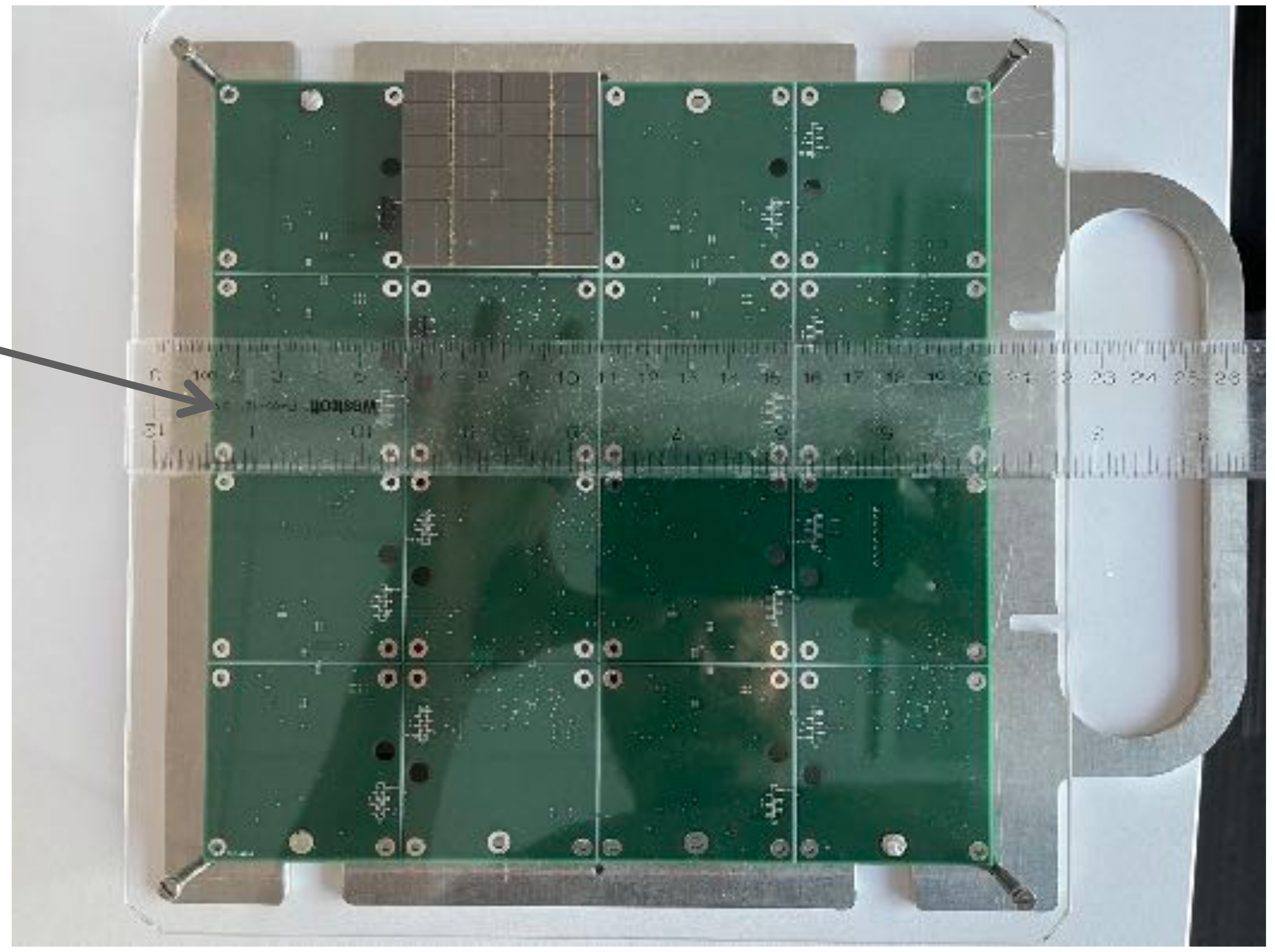
Cryogenic (87 K) undoped CsI array

- Developing an internal liquid Argon veto
- Much improved internal radiopurity w.r.t. SNS, advanced inner active LAr veto.

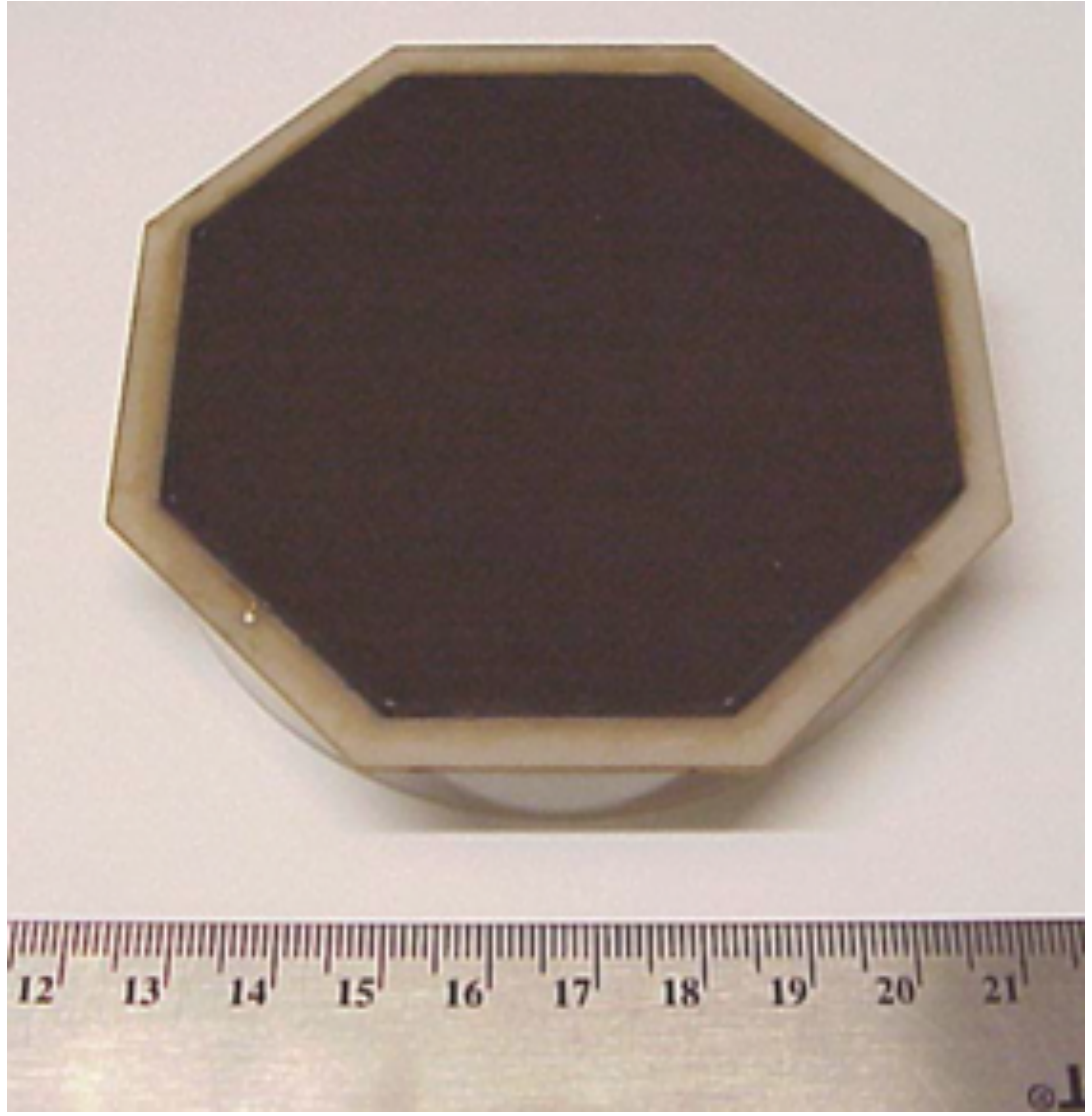


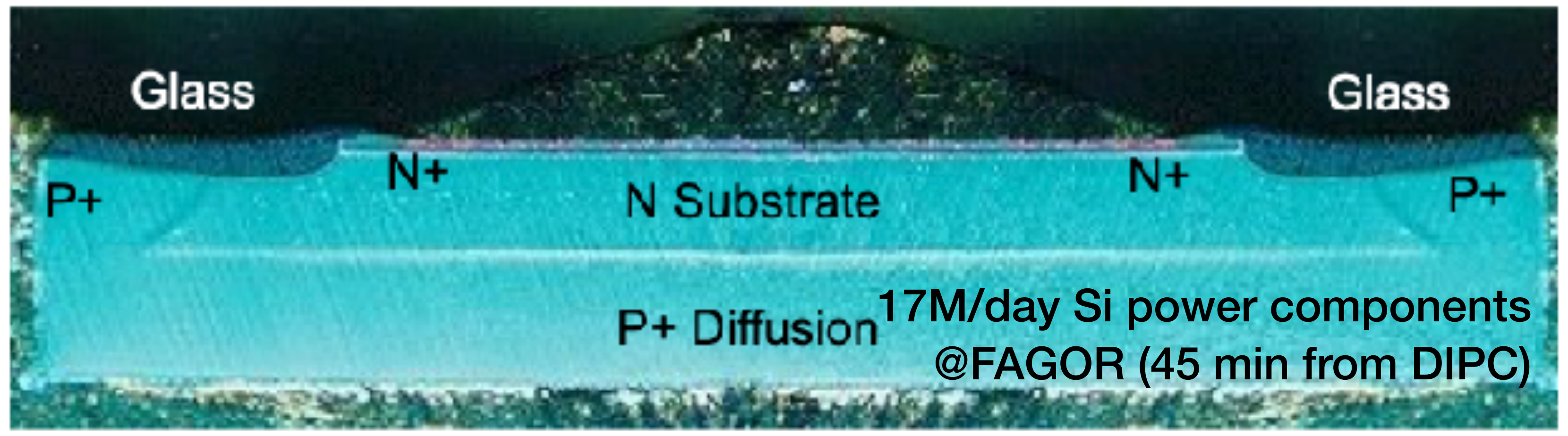
DarkSide-20k SiPM

20x20 cm low-field modules
~80 Hz dark rate @ 87 K
(single photon operation)
16 channel output

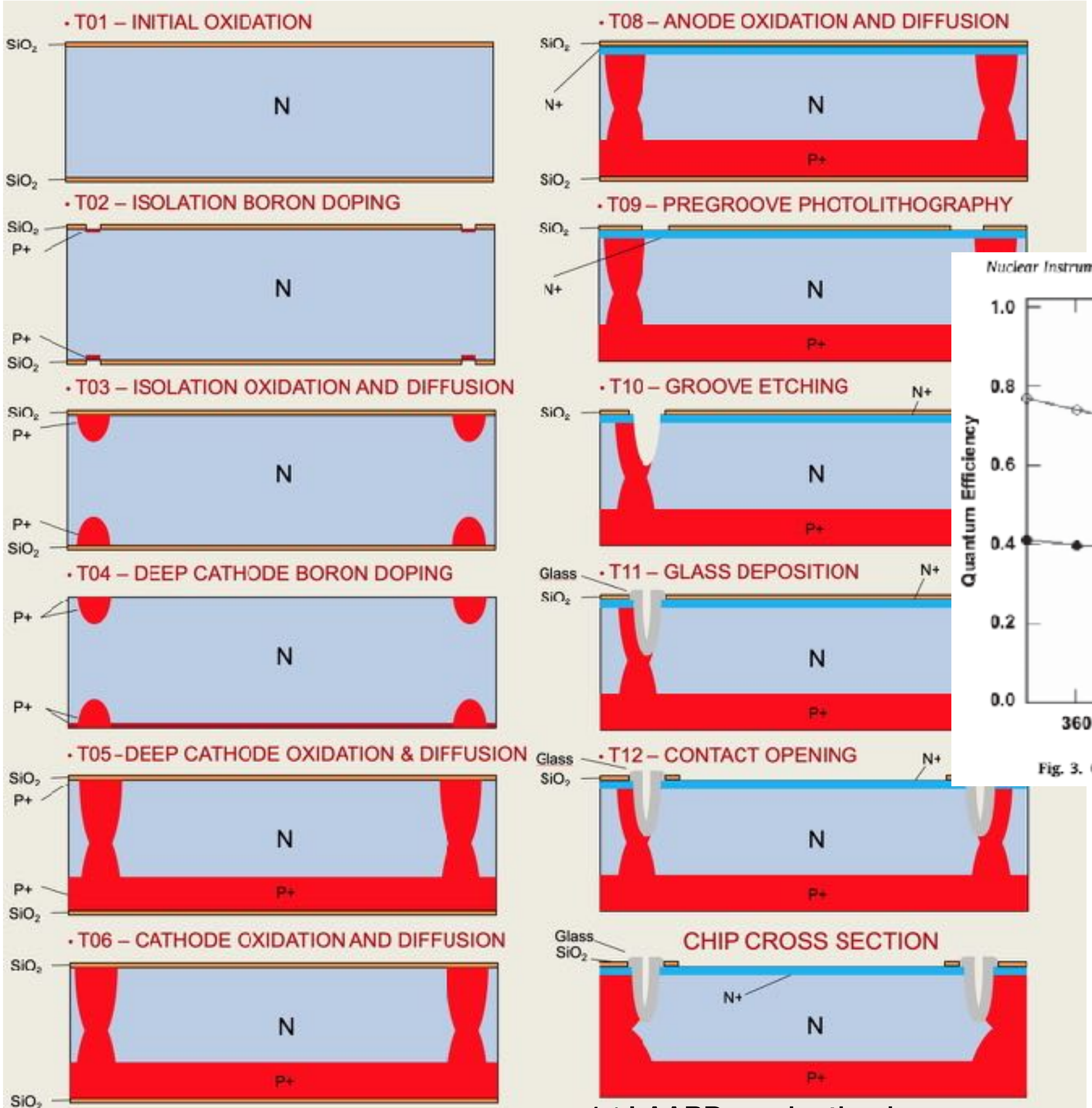


Collaboration with industry (and 1st spin-offs)





17M/day Si power components @FAGOR (45 min from DIPC)



Nuclear Instruments and Methods in Physics Research A 610 (2009) 207–209

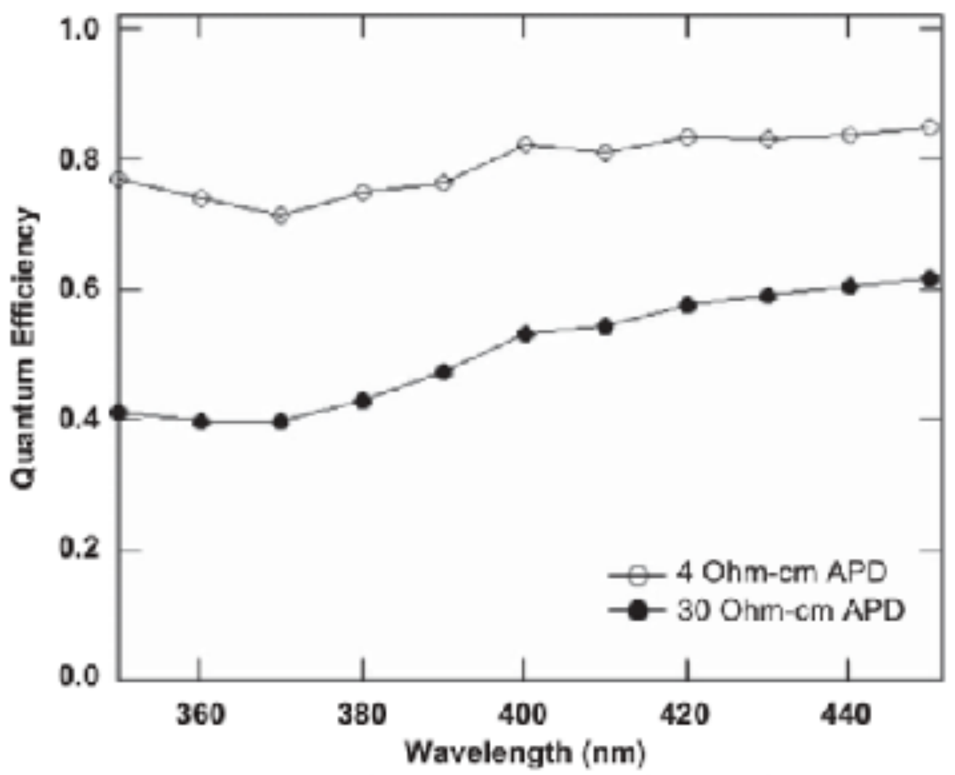
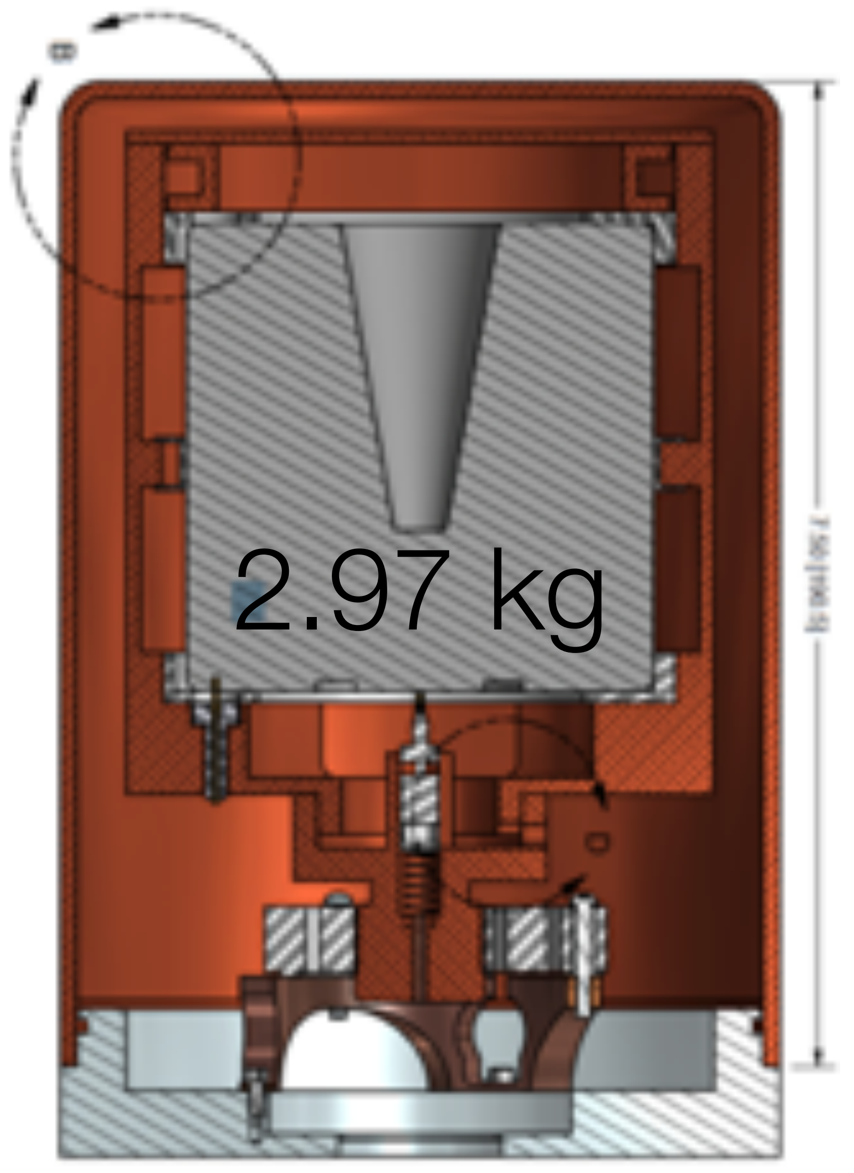


Fig. 3. Quantum efficiency vs. wavelength for a 4 and 30 Ω cm APD.

1st LAAPD production in progress

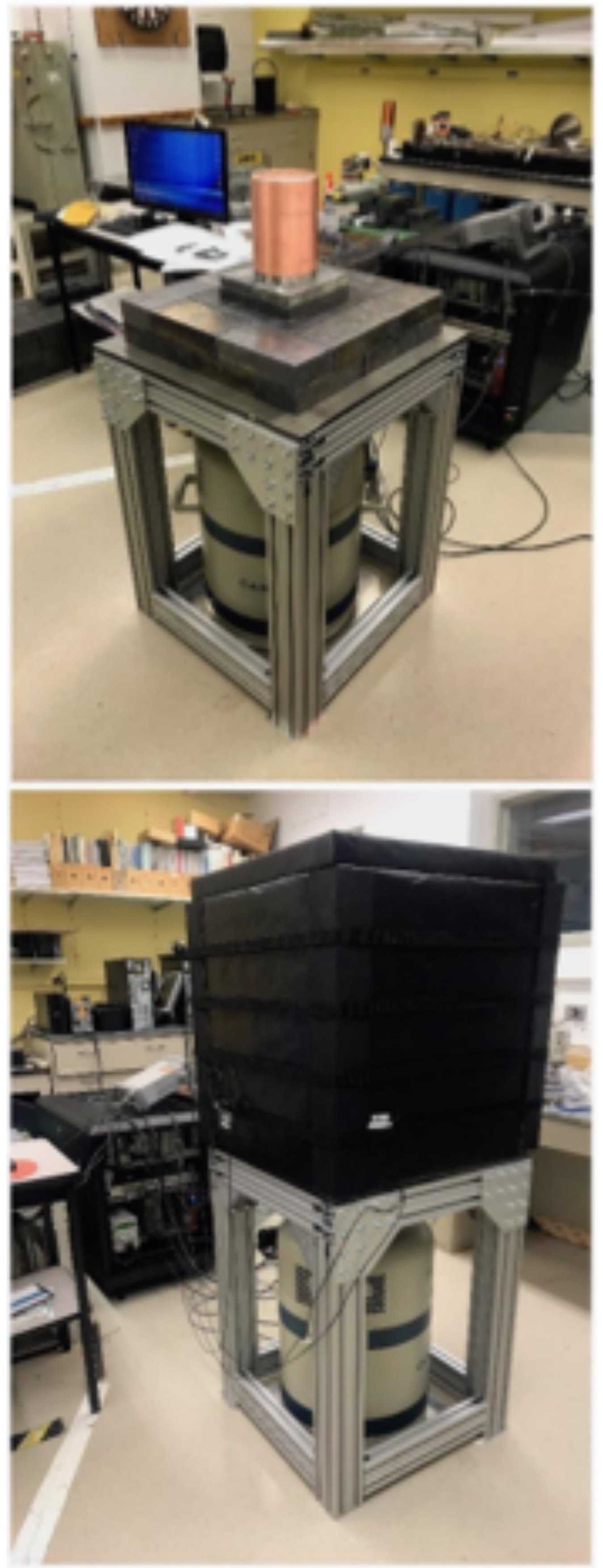
FAGOR
Fagor Electrónica

p-type point contact (PPC) Ge detector



p-type point contact Ge

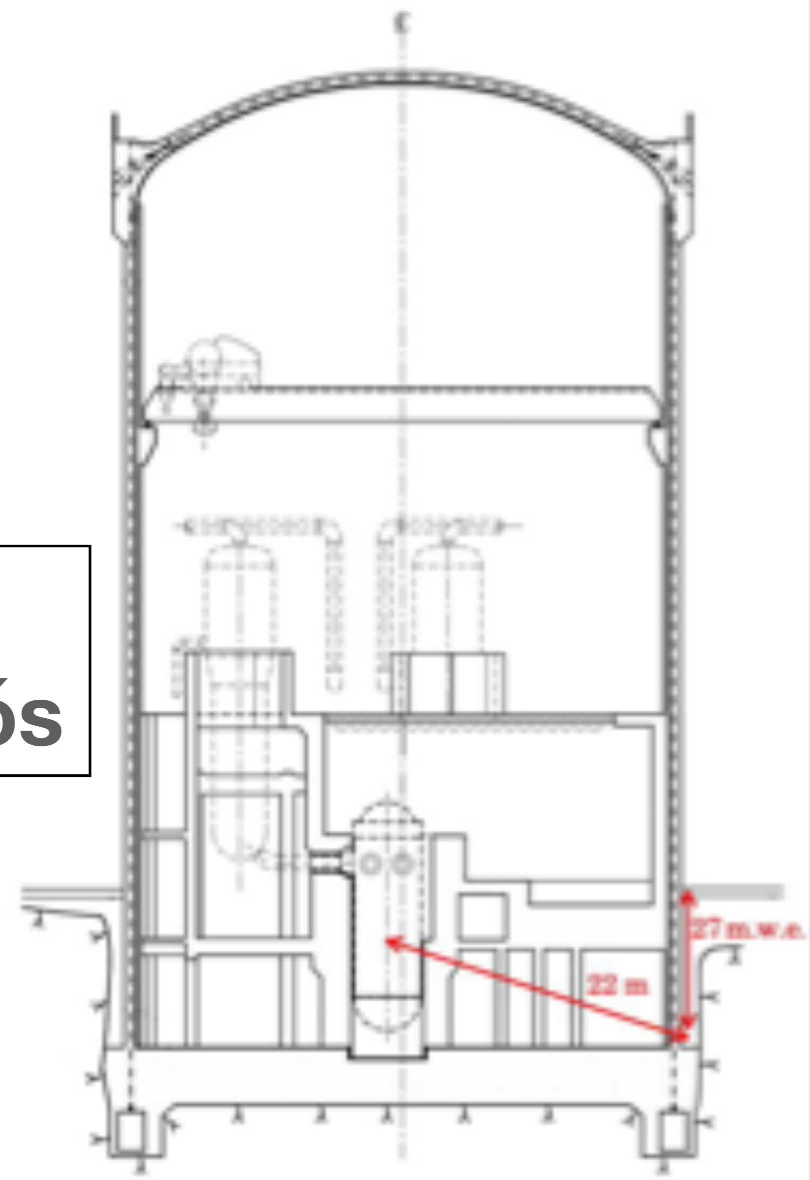
Pre-ESS step I:
Dresden-II



- Improved internal veto → Improved active background rejection
- Upgraded PM contact → Energy resolution
- Upgraded readout to Application specific integrated circuit (ASIC) → Noise reduction

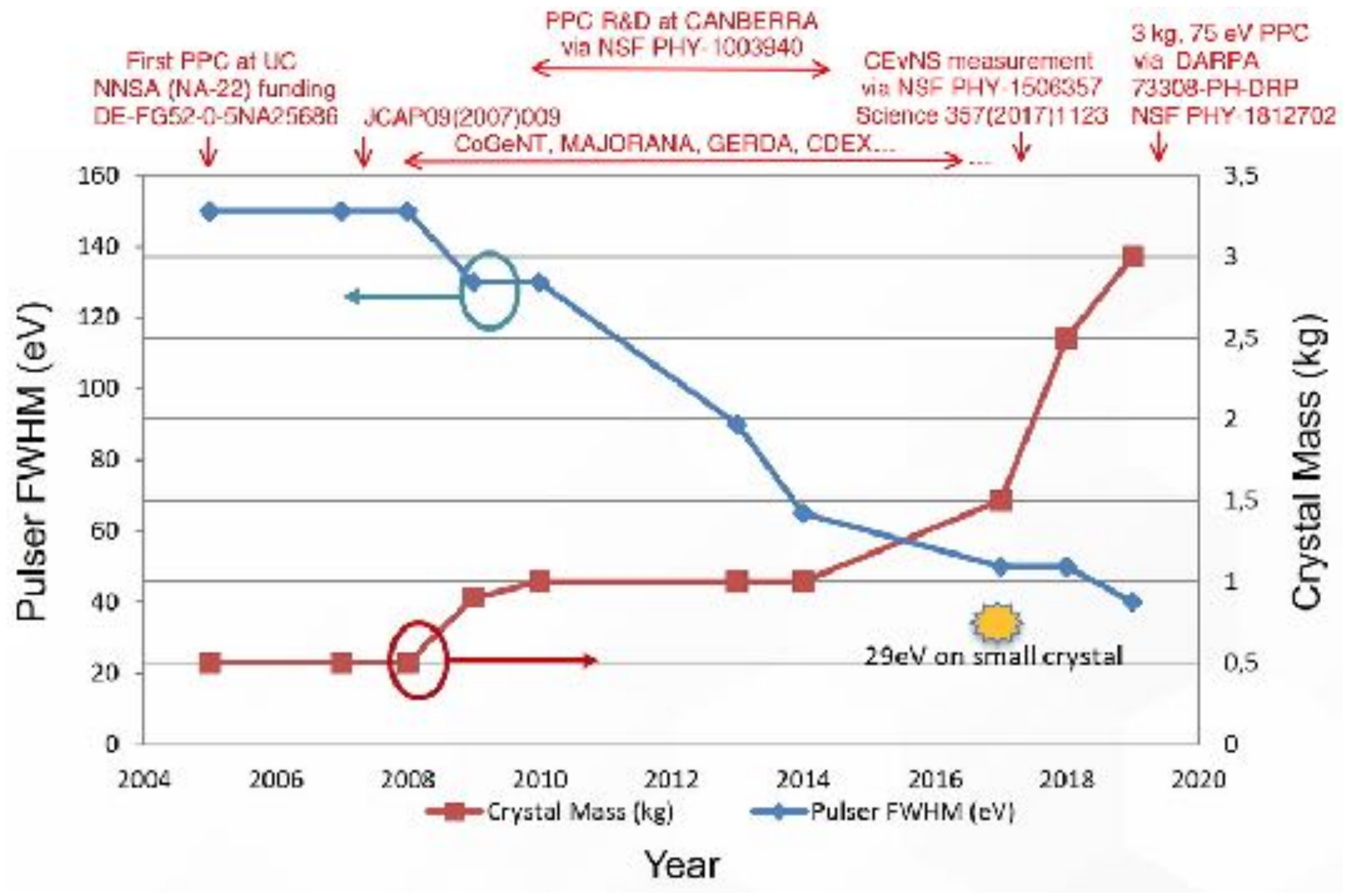
CEνNS at Reactors
Low threshold needed for low recoil energies

Pre-ESS step II:
Ringhals or Vandellós



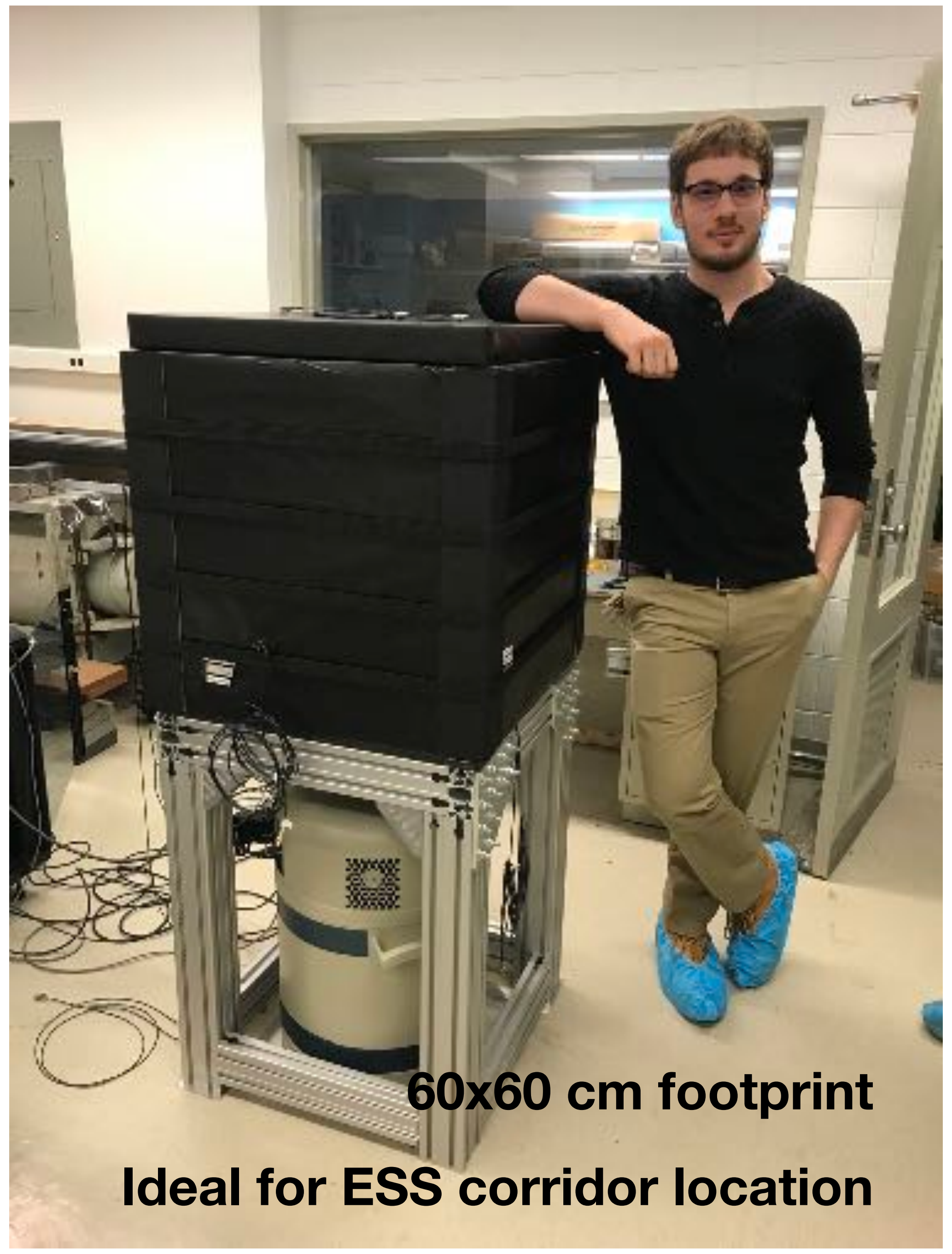
P-type Point Contact (PPC) germanium detectors

arXiv:nucl-ex/0701012



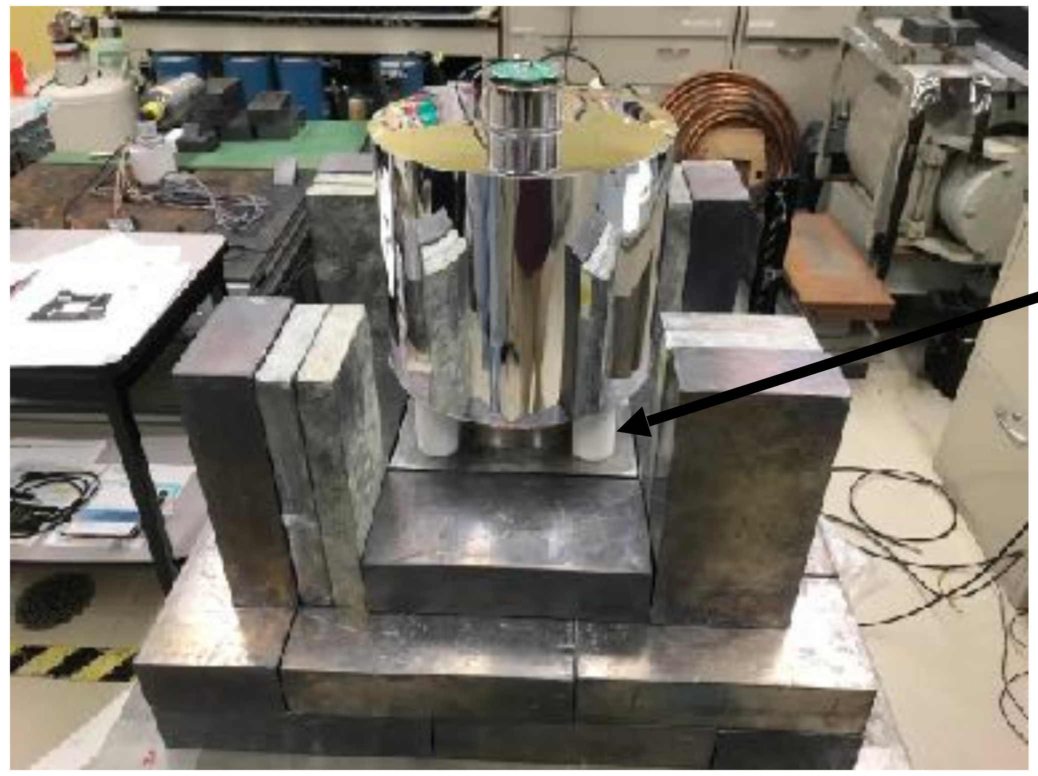
Entirely mature:

Ready for installation

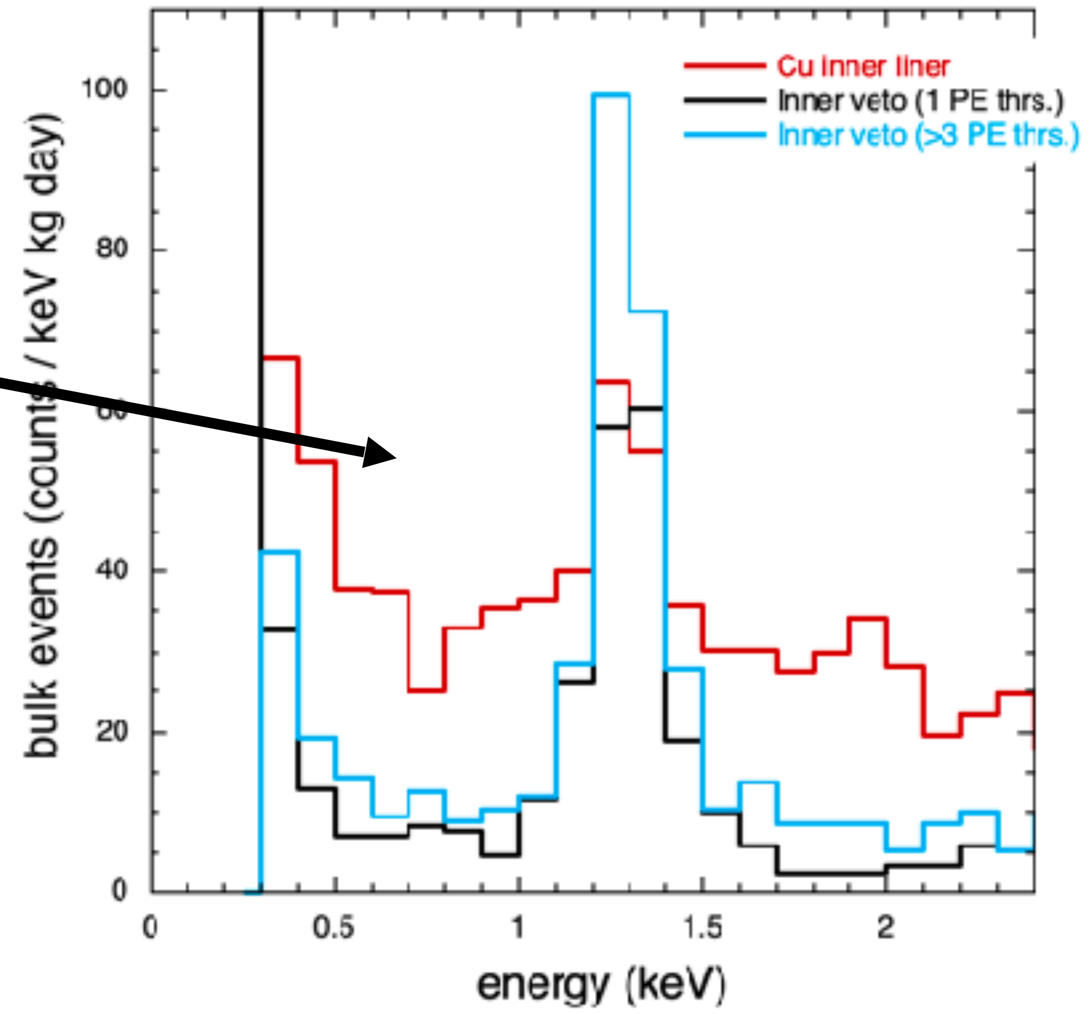


60x60 cm footprint

Ideal for ESS corridor location



Inner plastic scintillator veto is highly effective against beam-related neutron backgrounds

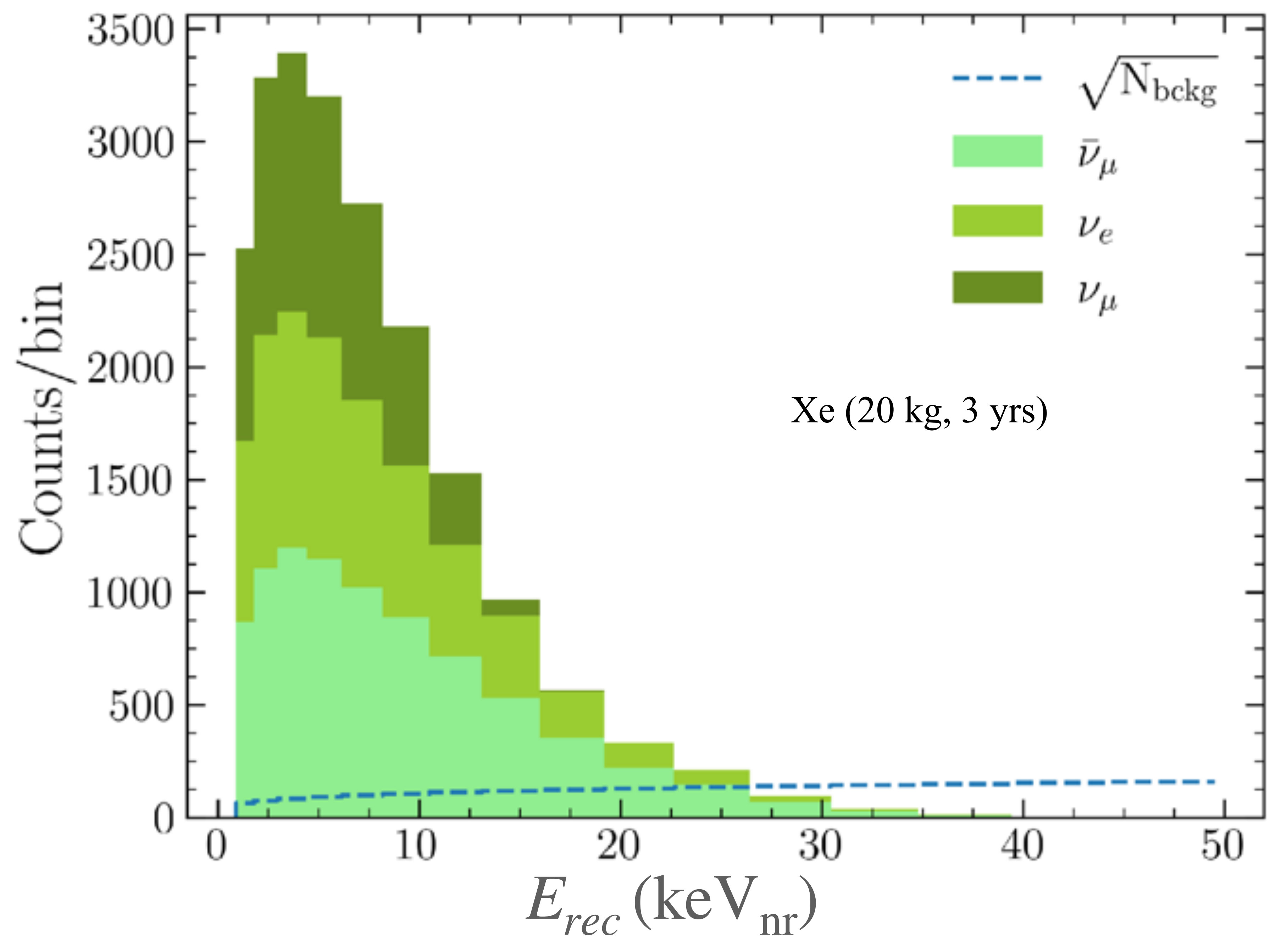


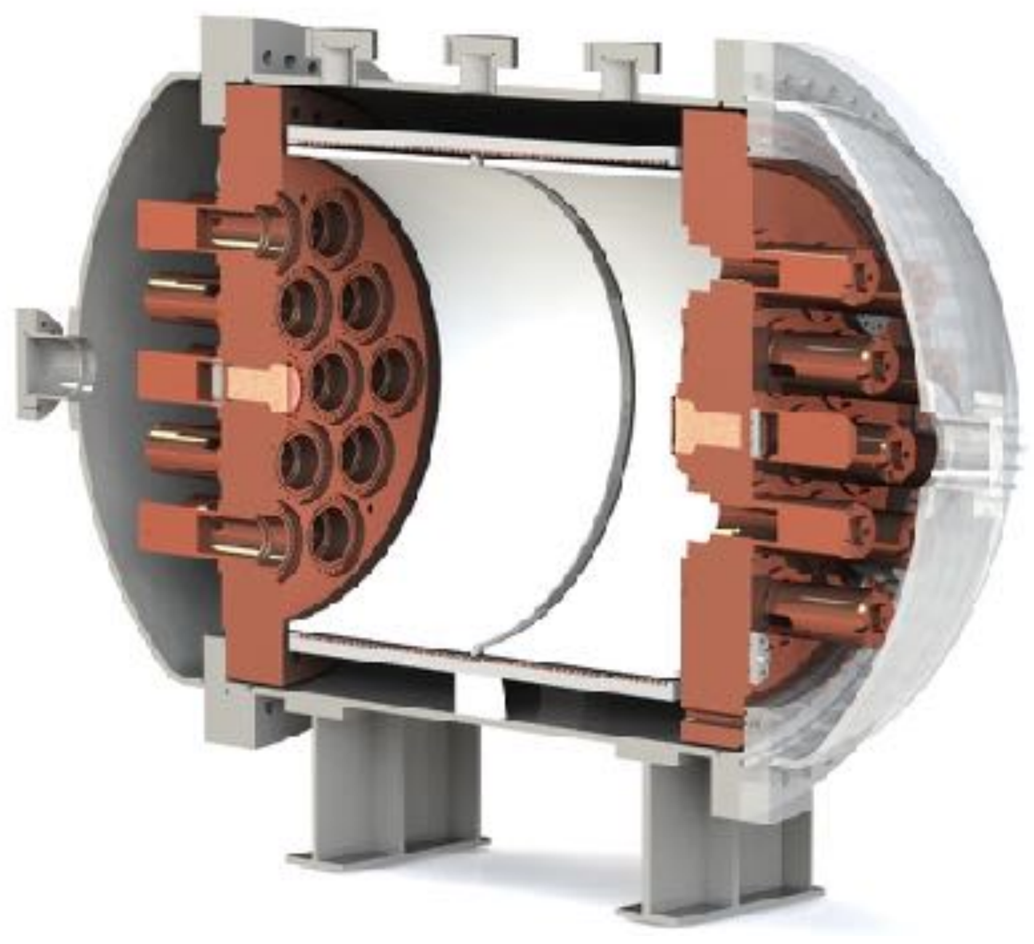
GanESS project

The GanESS detector

- Simpler, **no** need of a **cryogenic system**.
- Low energy threshold 1-2 e^{-}(<1keVee) via EL amplification.
- Allow to operate with **different nuclei (Kr, Ar, Xe).**
- Technology developed by the **NEXT collaboration**.
    - Most low-background solutions already developed.
    - R&D needed for high pressures and very low energy regime.
- Lower density than other techniques → Bypassed by large ESS neutrino flux

Events after 3 years running a
20 kg Xe detector at 20 m from ESS target

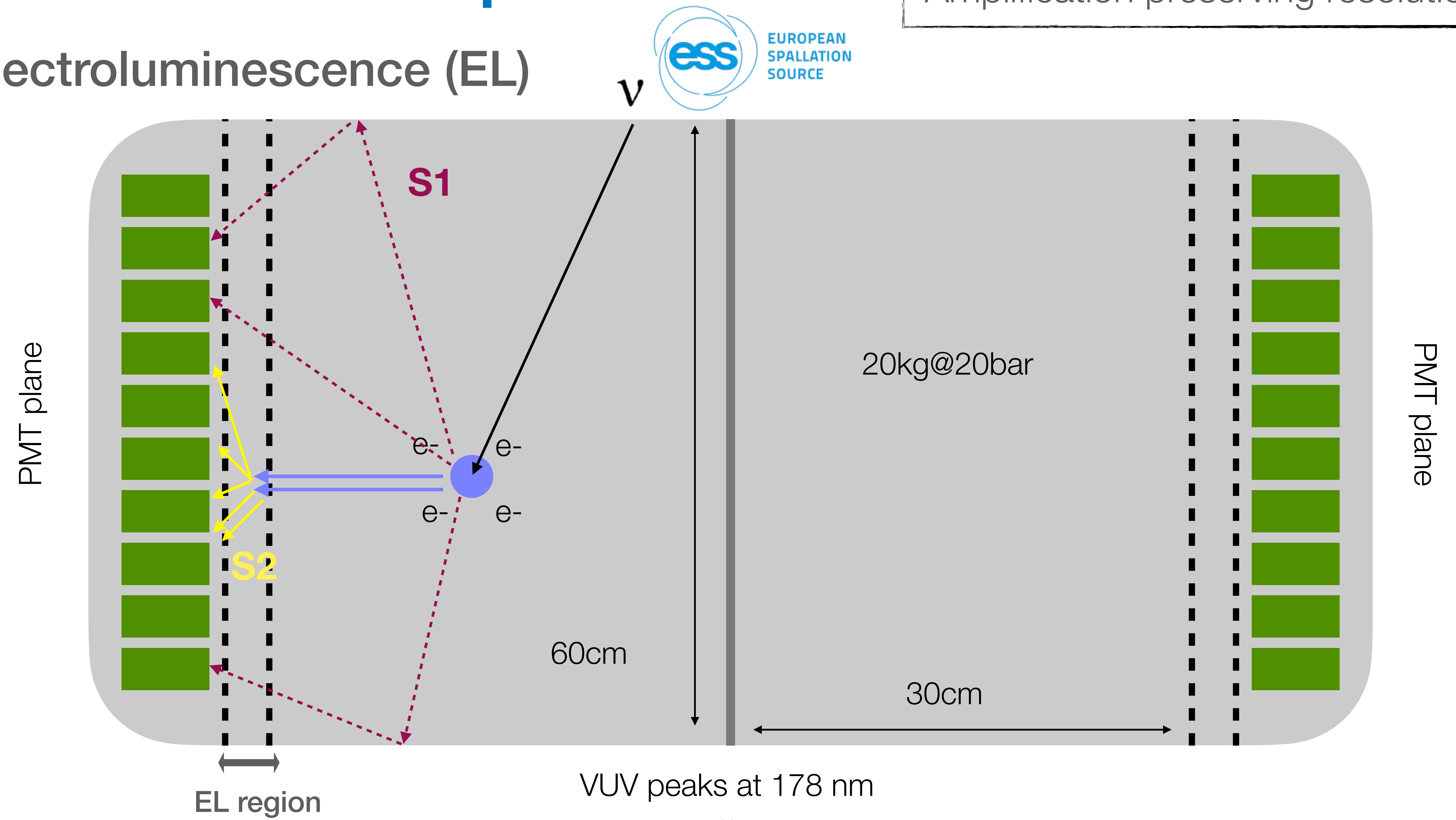




GanESS concept

Amplification preserving resolution

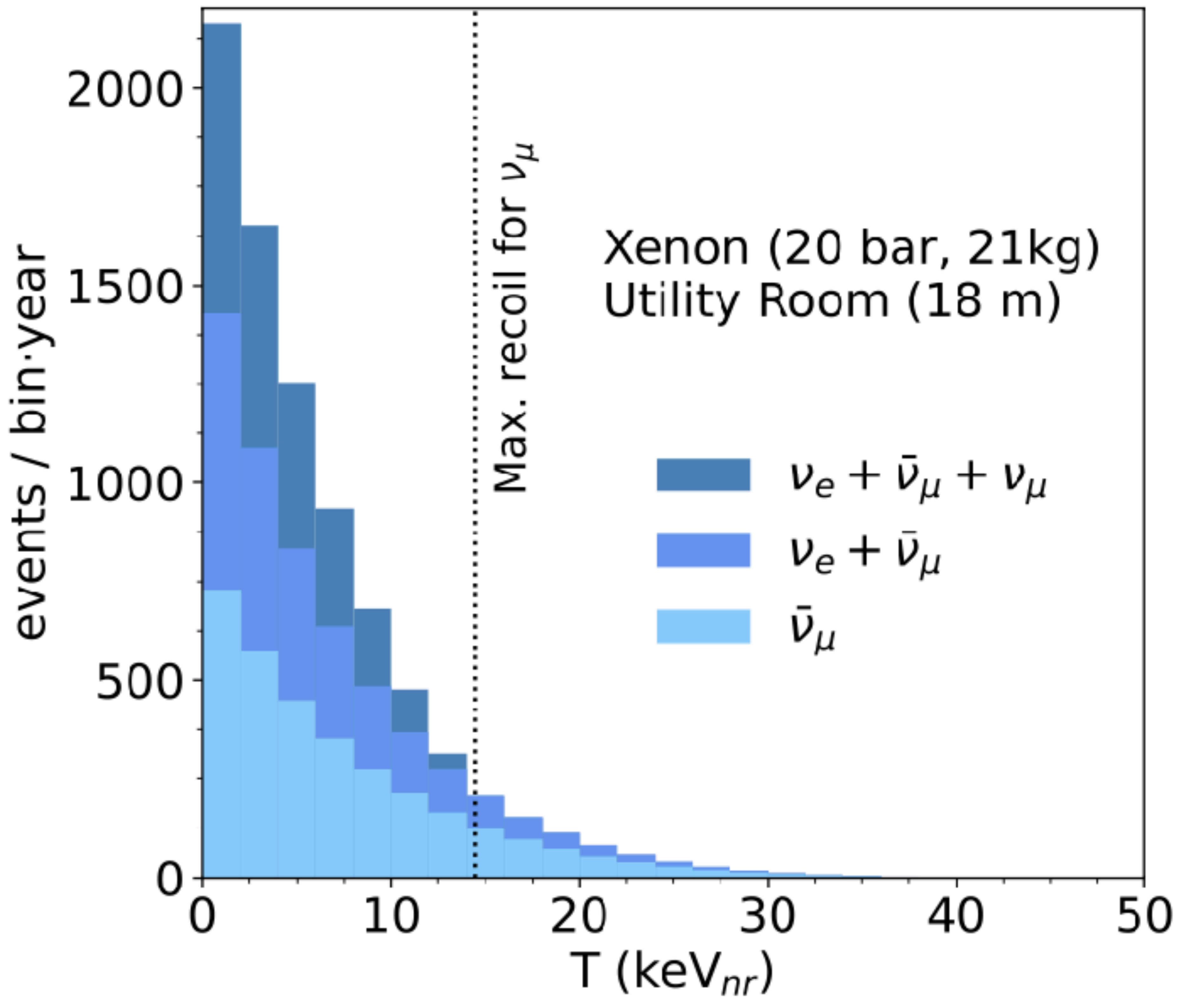
Electroluminescence (EL)



GanESS detection

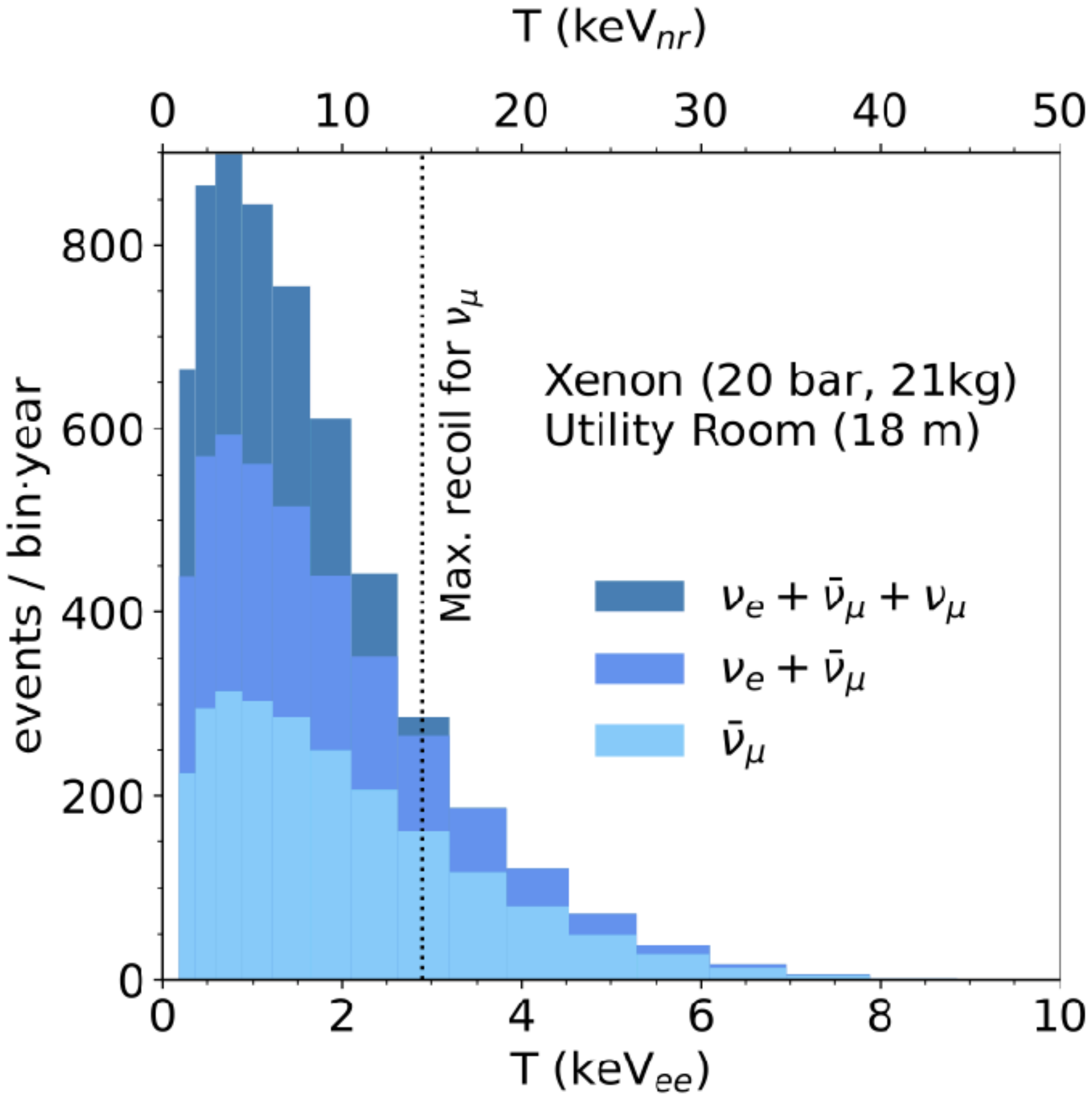
~5.8k CEνNS cts/yr with 20 bar Xenon (21kg) TPC

Expected CEνNS events in a year



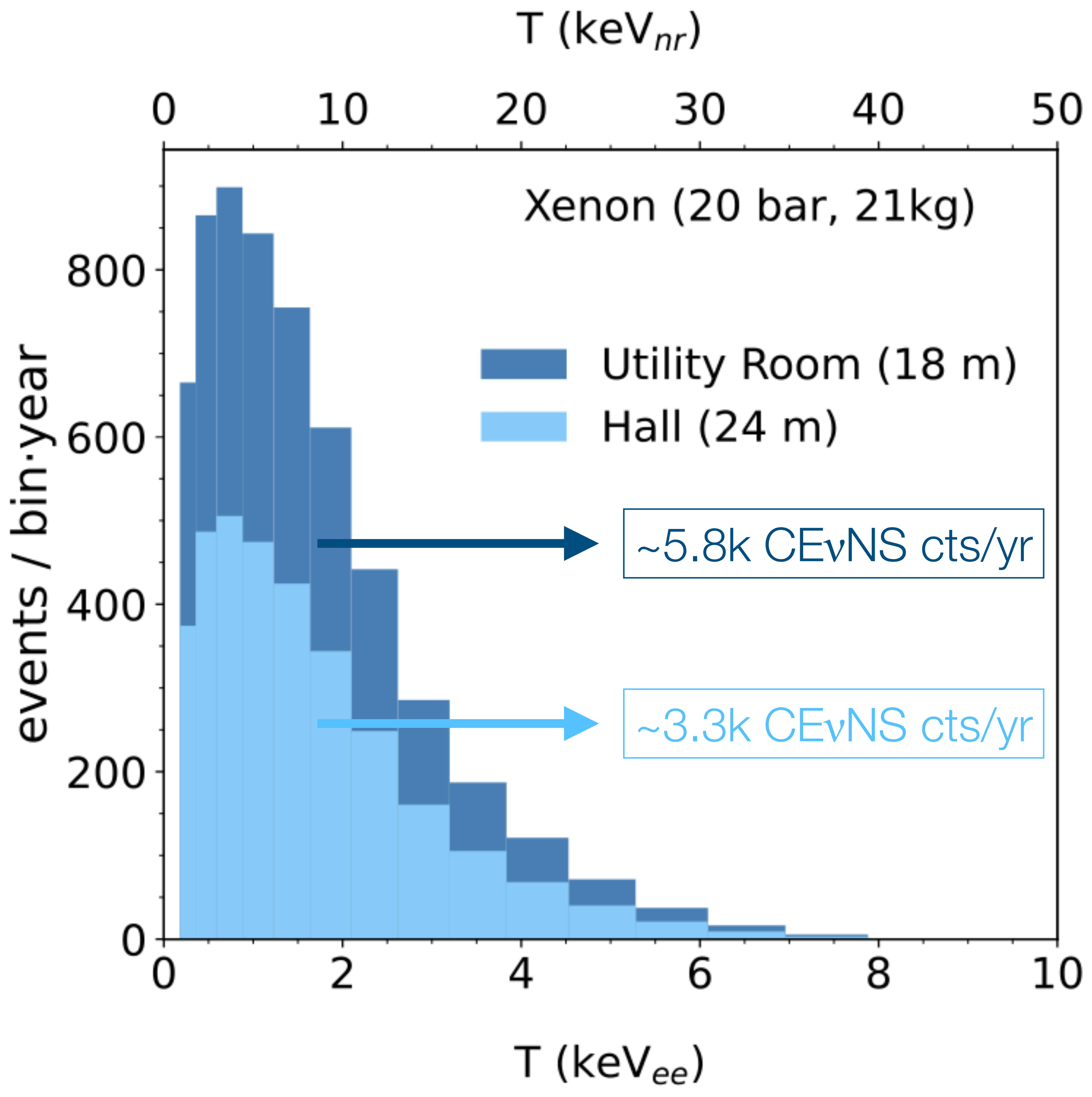
Assumptions

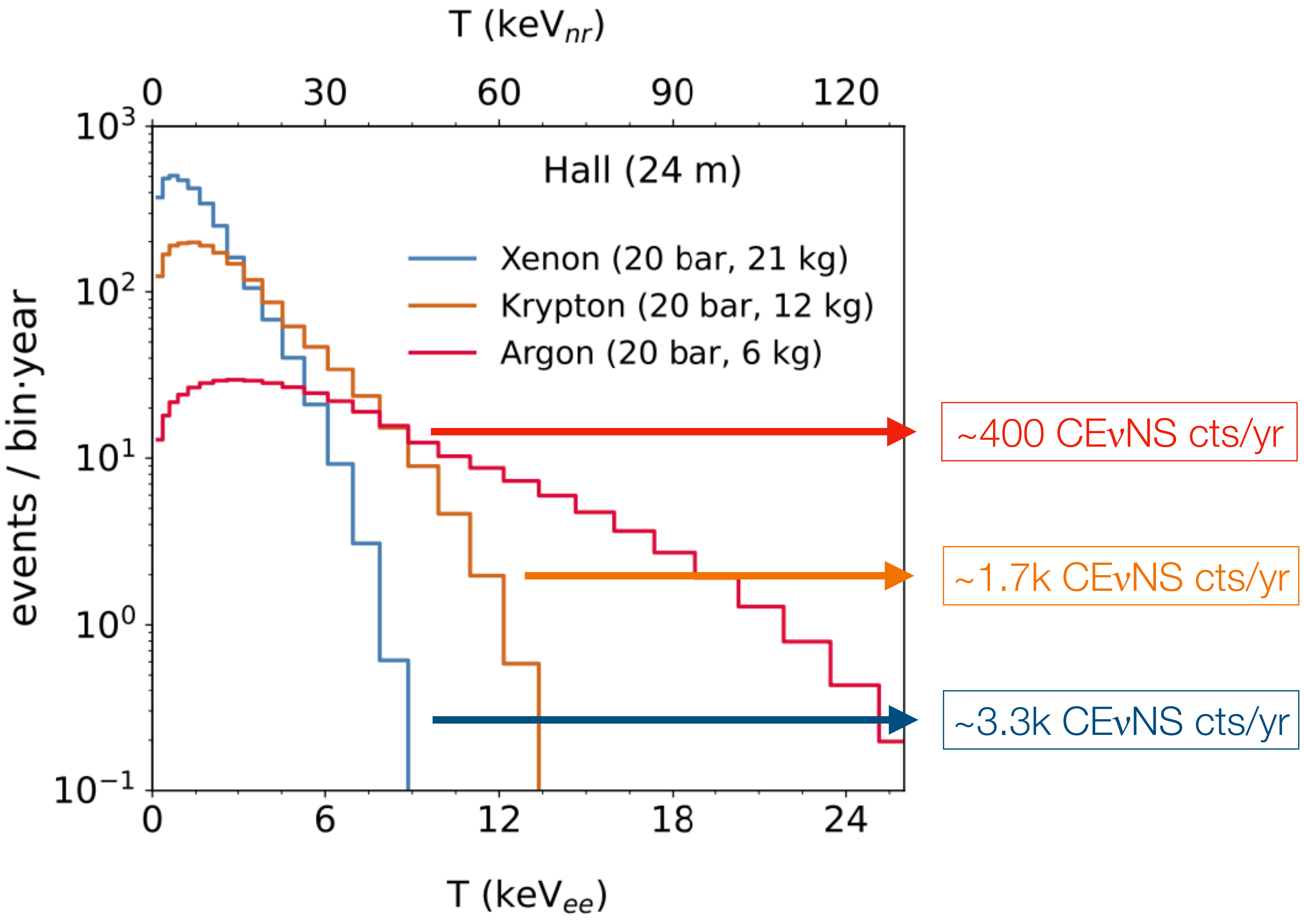
- Threshold = $0.9 keV_{ee}$
- $QF = 20\,\%$
- $\frac{\Delta E}{E} = 40\,\%$ % at E_{th}



GanESS detection

Expected CEνNS events in a year





M.Jiménez Master thesis

What is the quenching factor for GXe at low recoil energies?

How high can we go in pressure?

WE CANNOT GO BLIND TO THE ESS

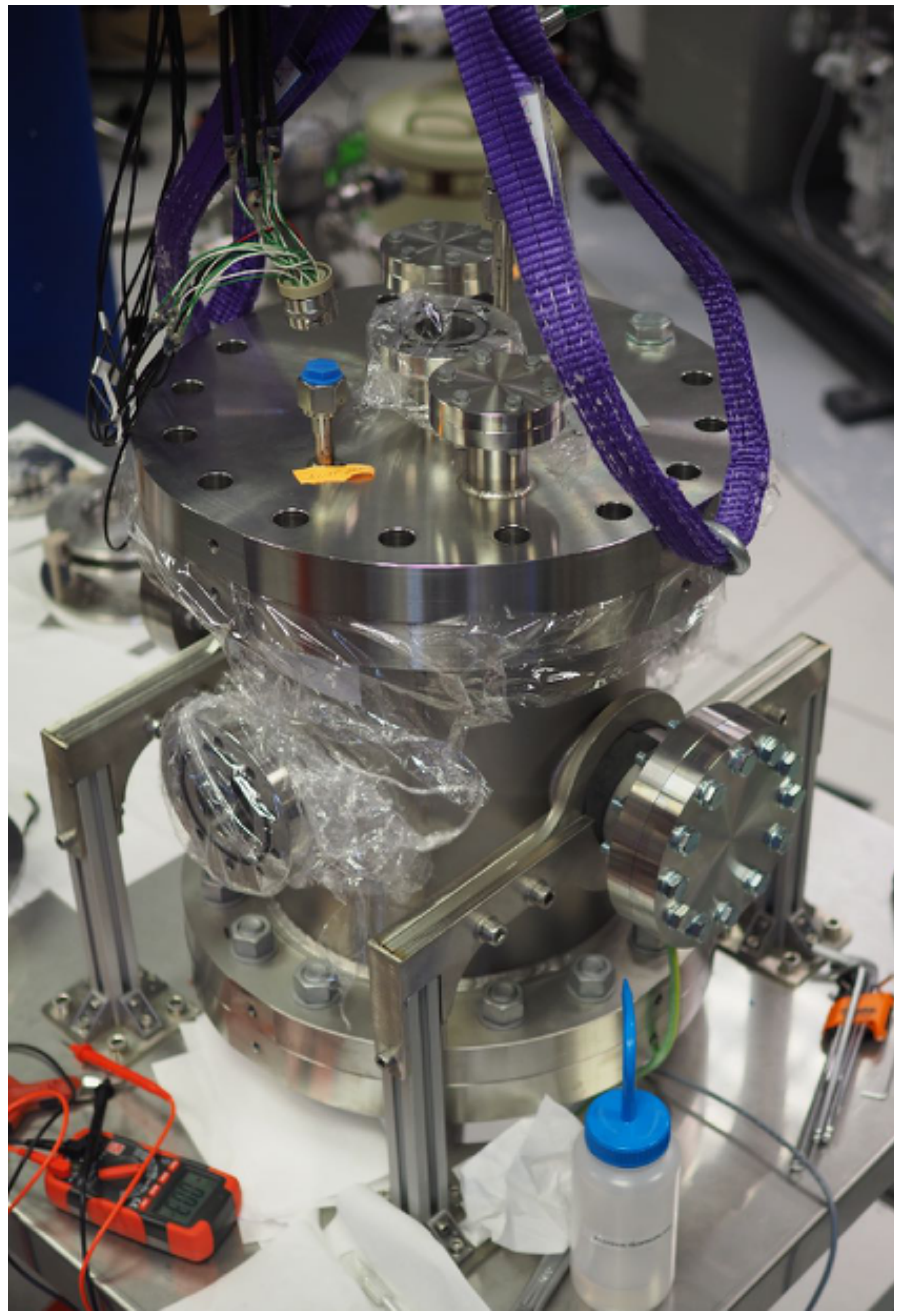
What is the lowest recoil we can see?

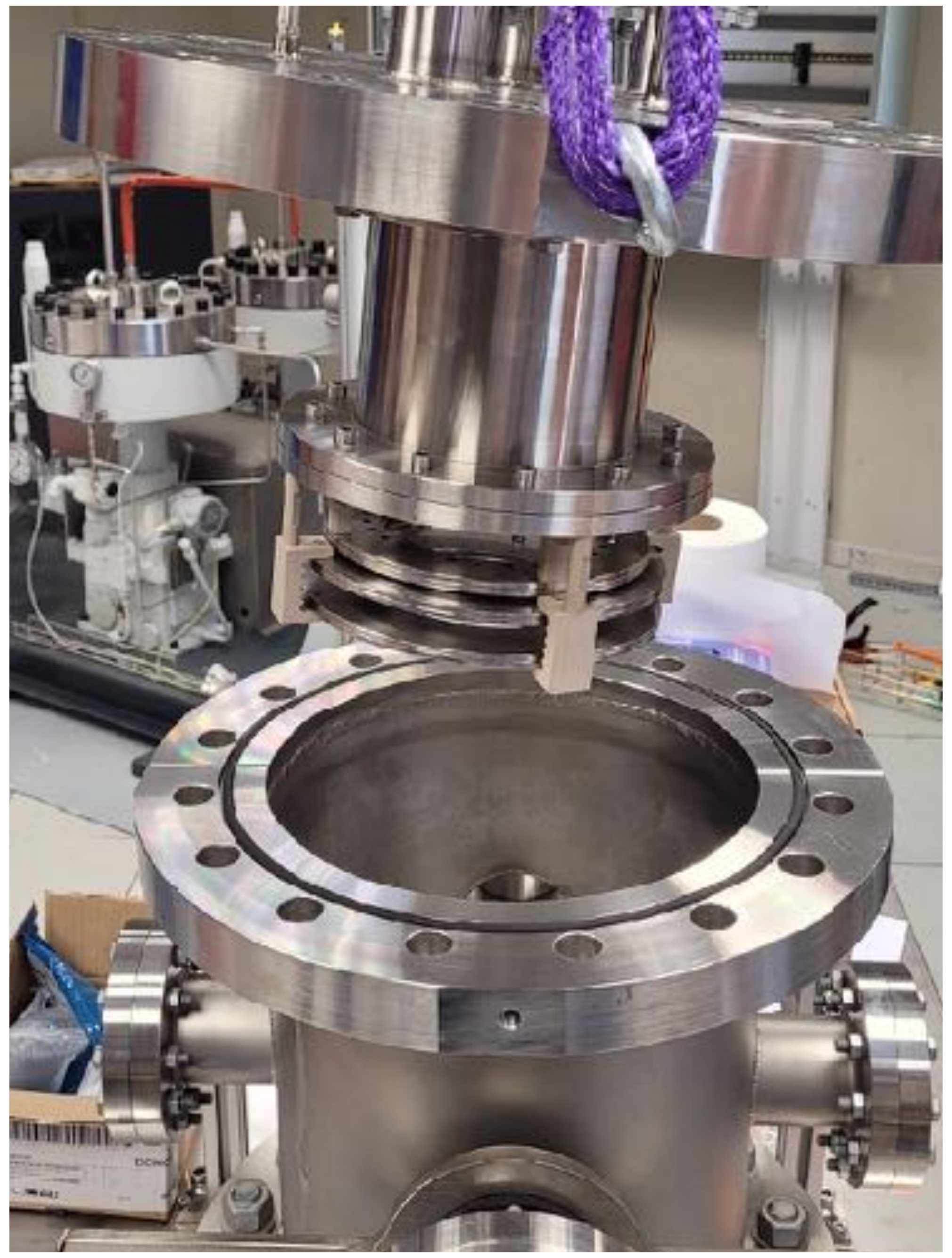
Can we improve the GAr QF measurement?

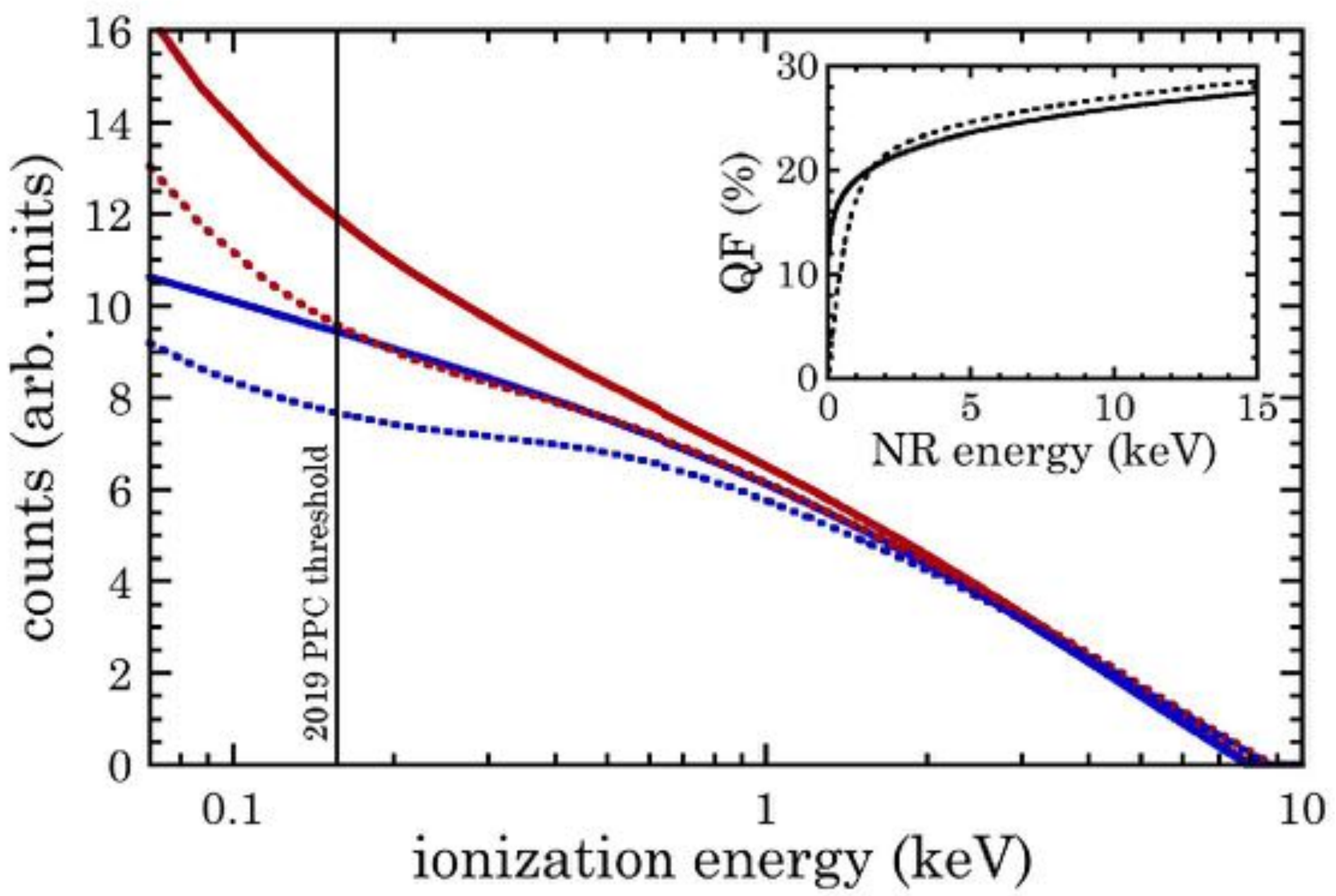
GanESS project: GaP

The Gaseous Prototype (GaP) system

- Opportunity to evaluate the technique in different conditions
  - Multiple noble gases: Xe, Ar, Kr.
  - Pressure up to 50bar.
- Characterization of low-energies **response to nuclear recoils**
  - Quenching factor measurements.
  - Detection threshold.

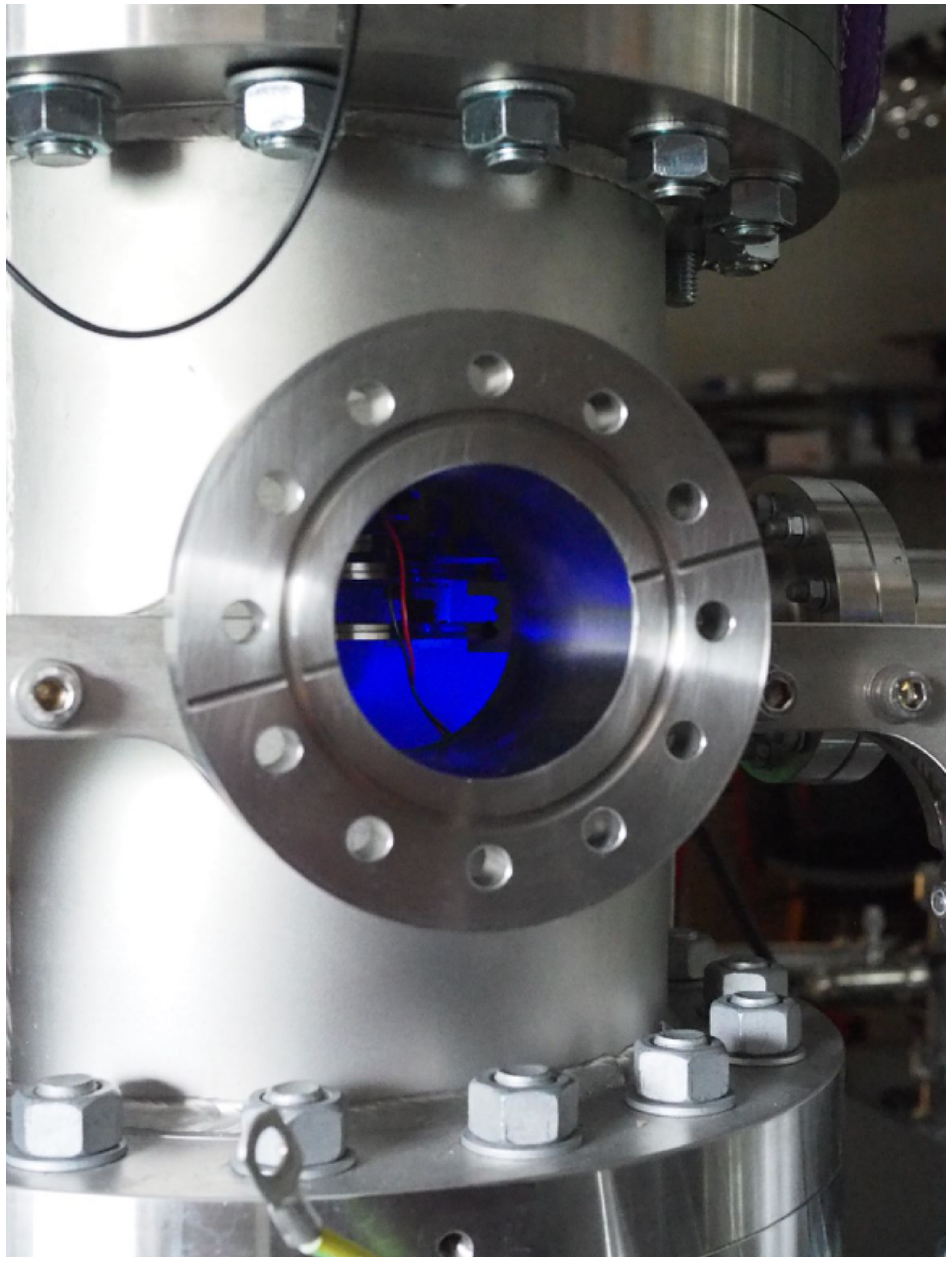


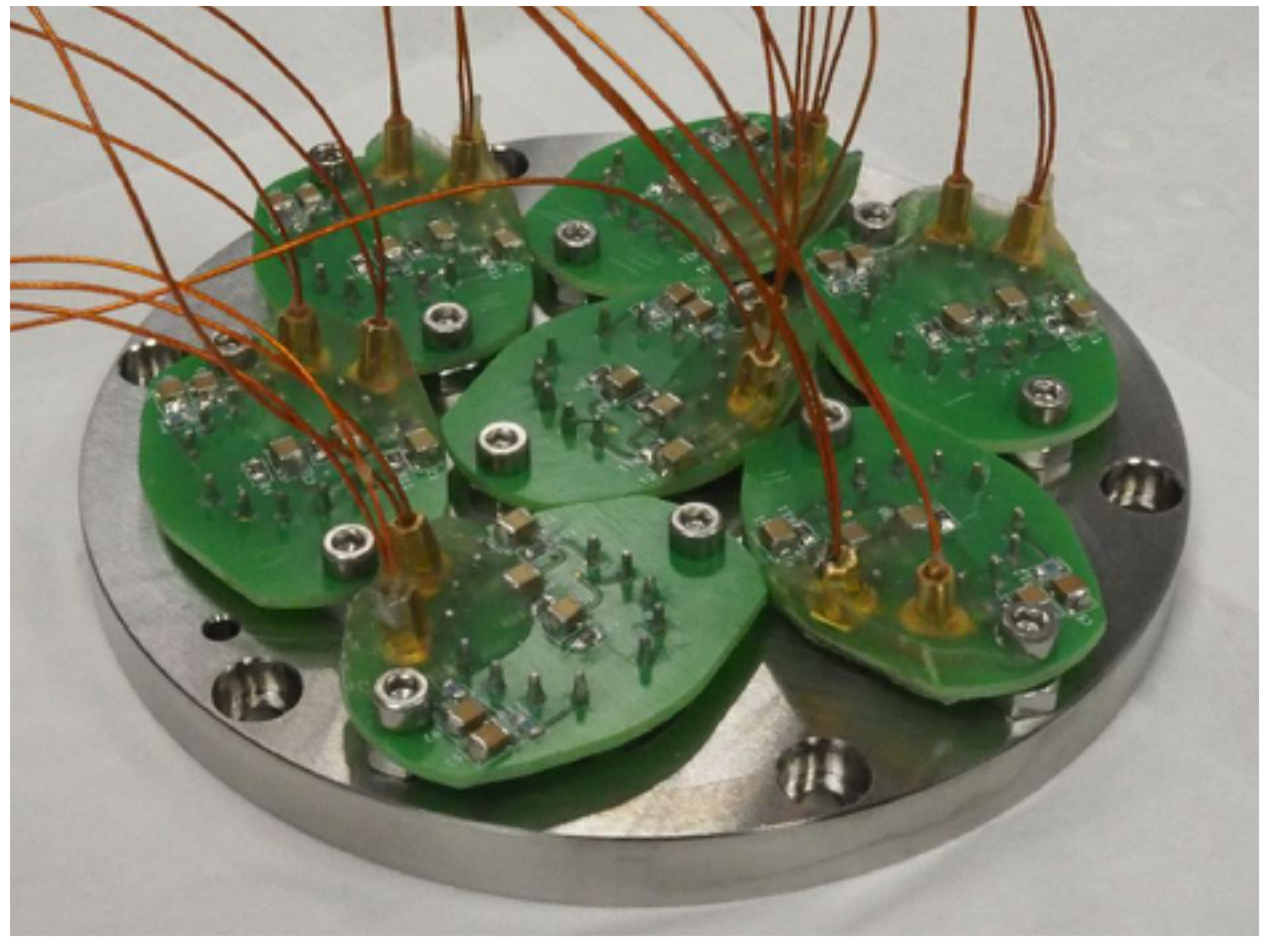


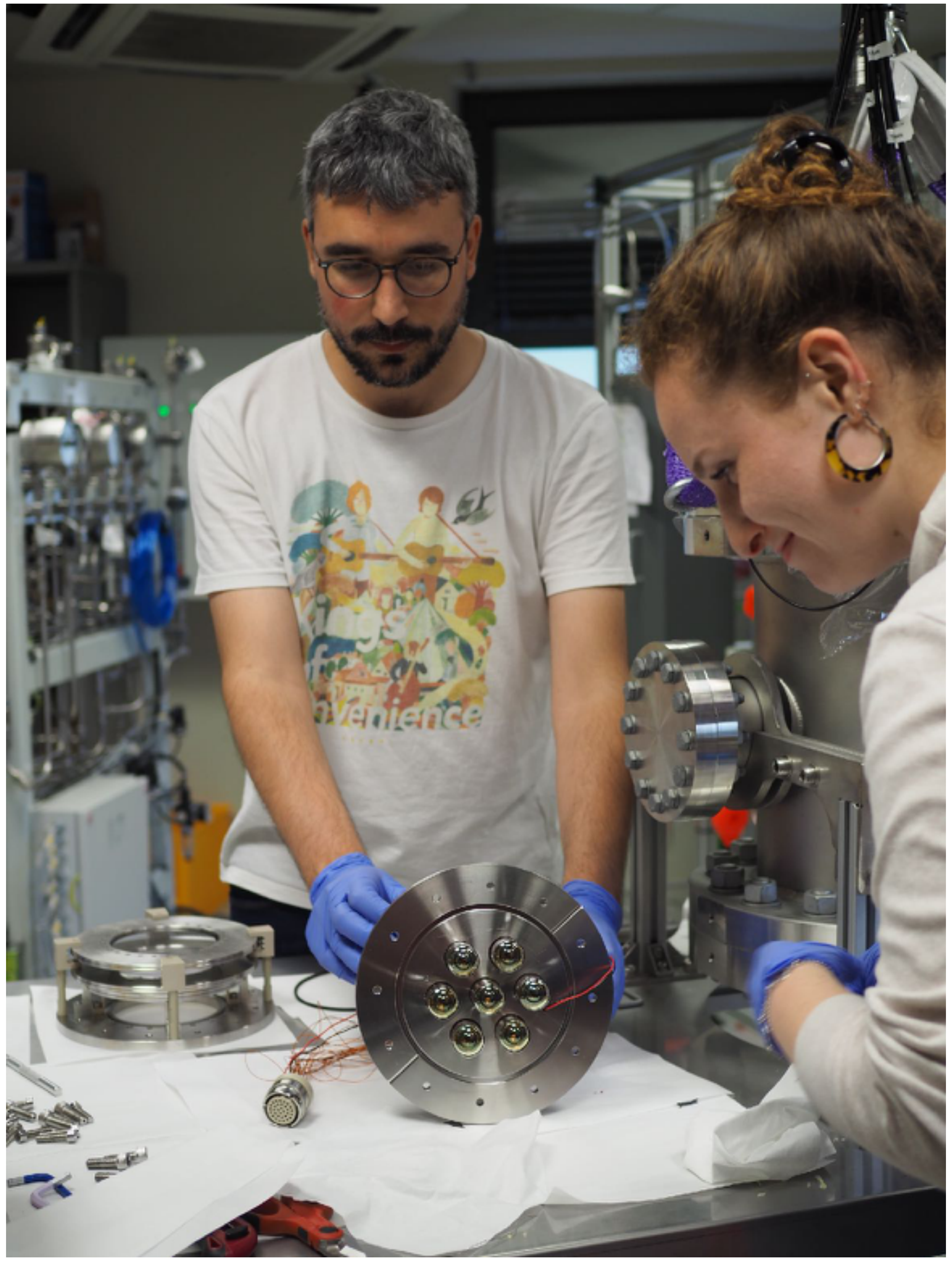


Differences in the expected distributions given different quenching factor models (solid/dashed)

The Gaseous Prototype (GaP) Assembly





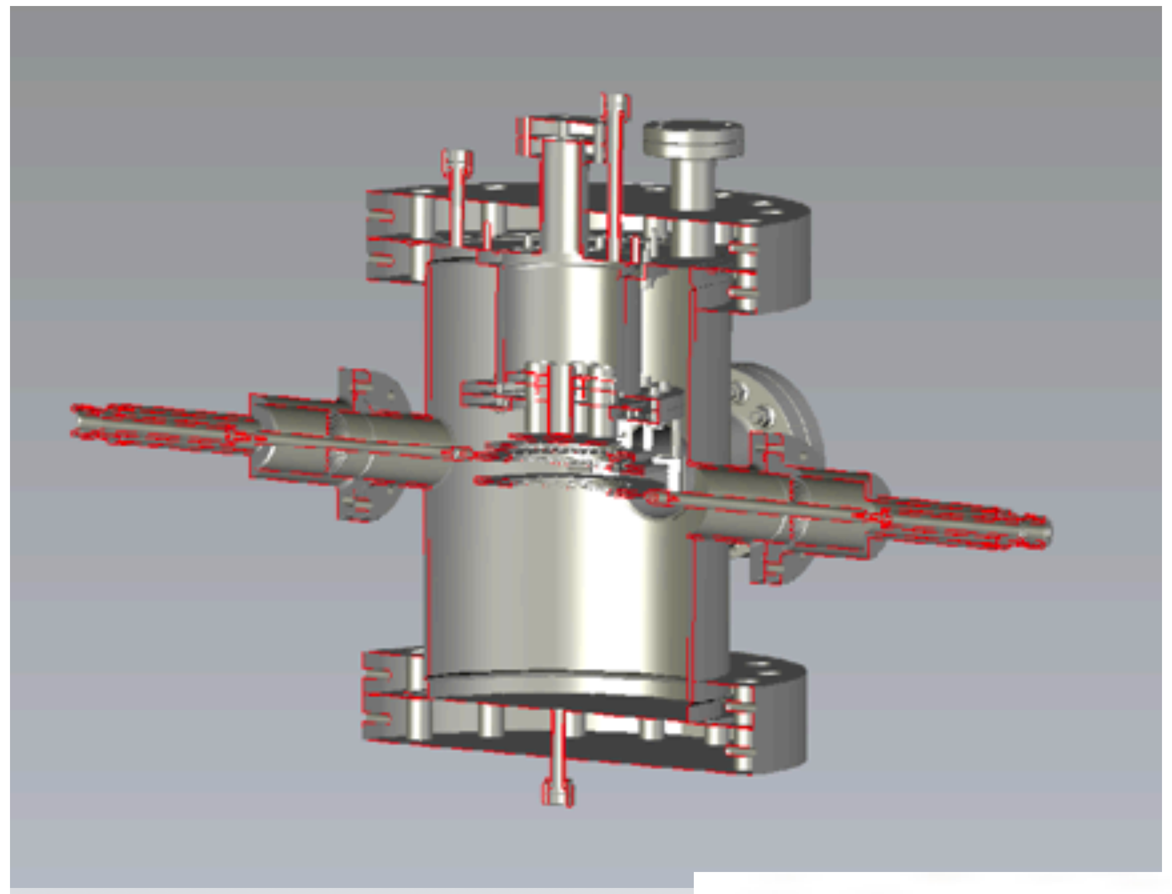


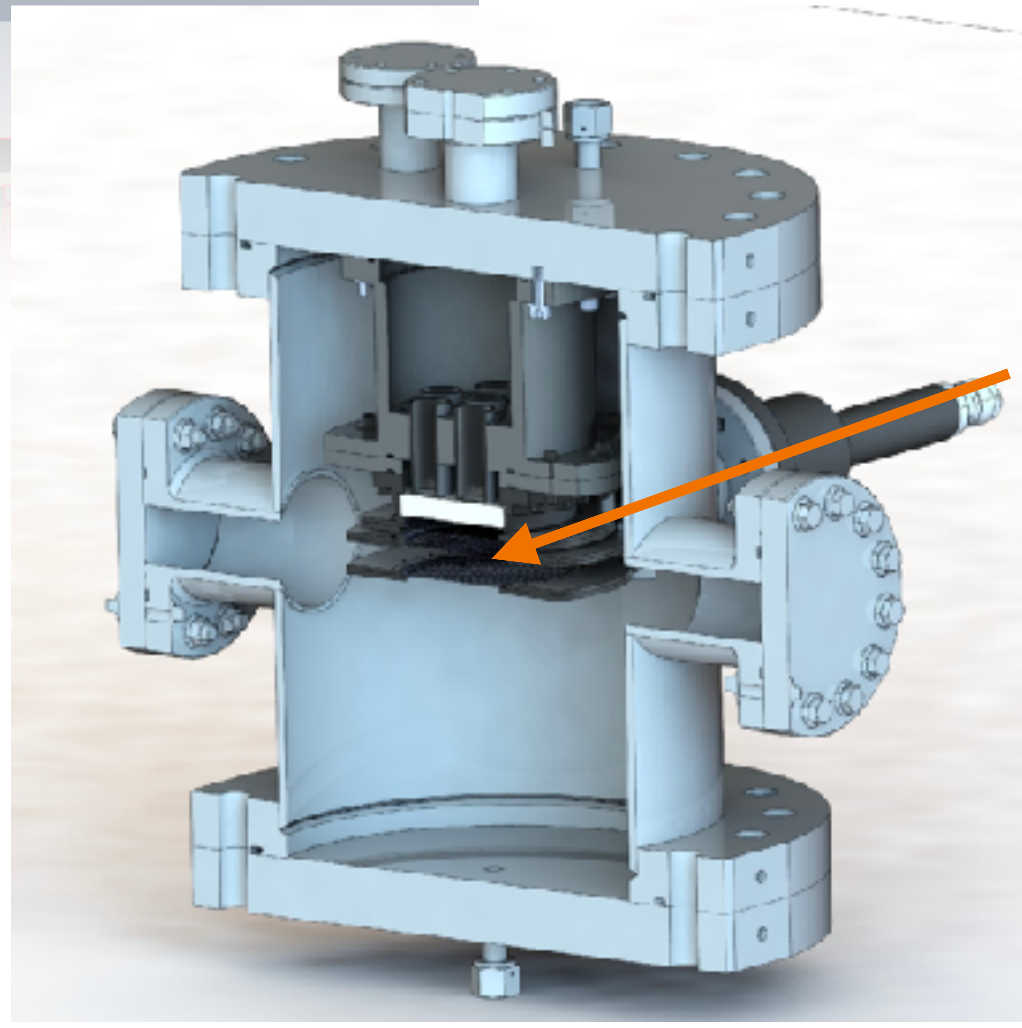
GaP design changes

Enlarging the Drift gap

Enlarge the active volume

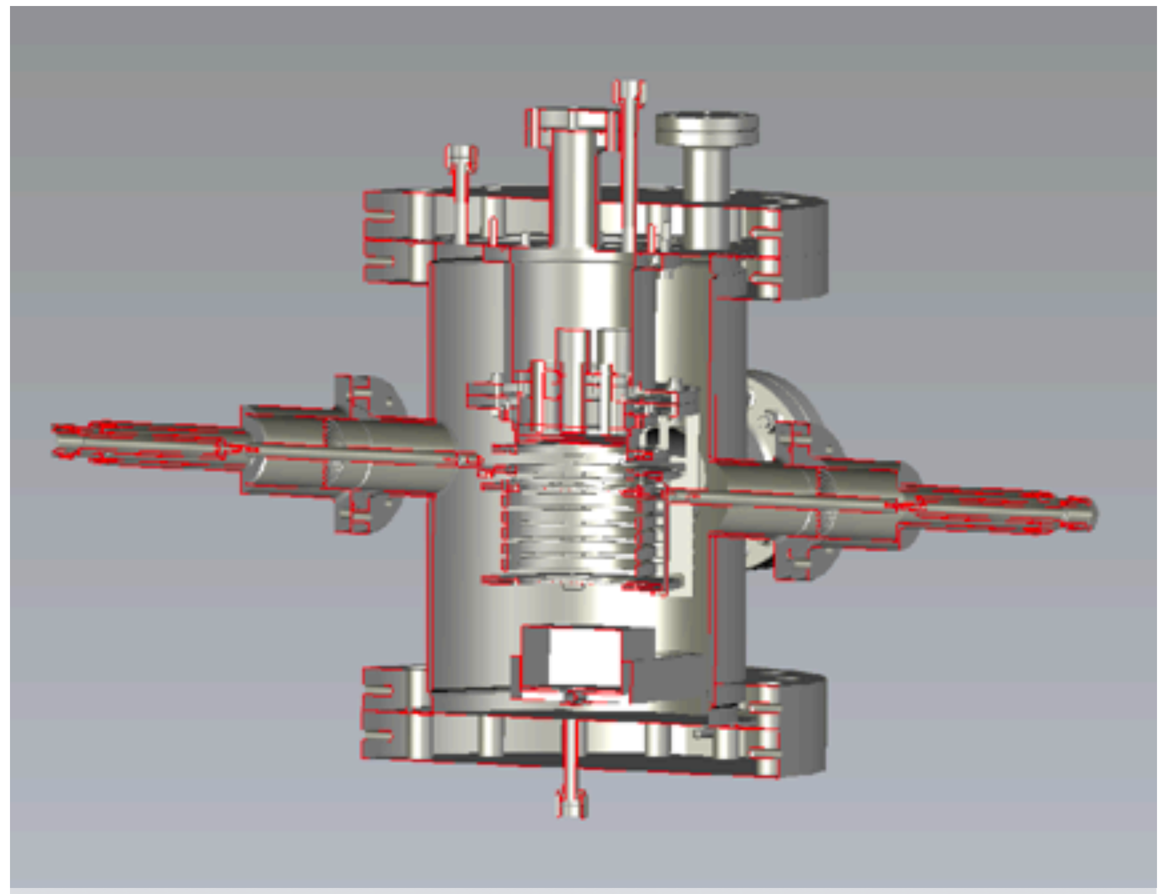
First phase design

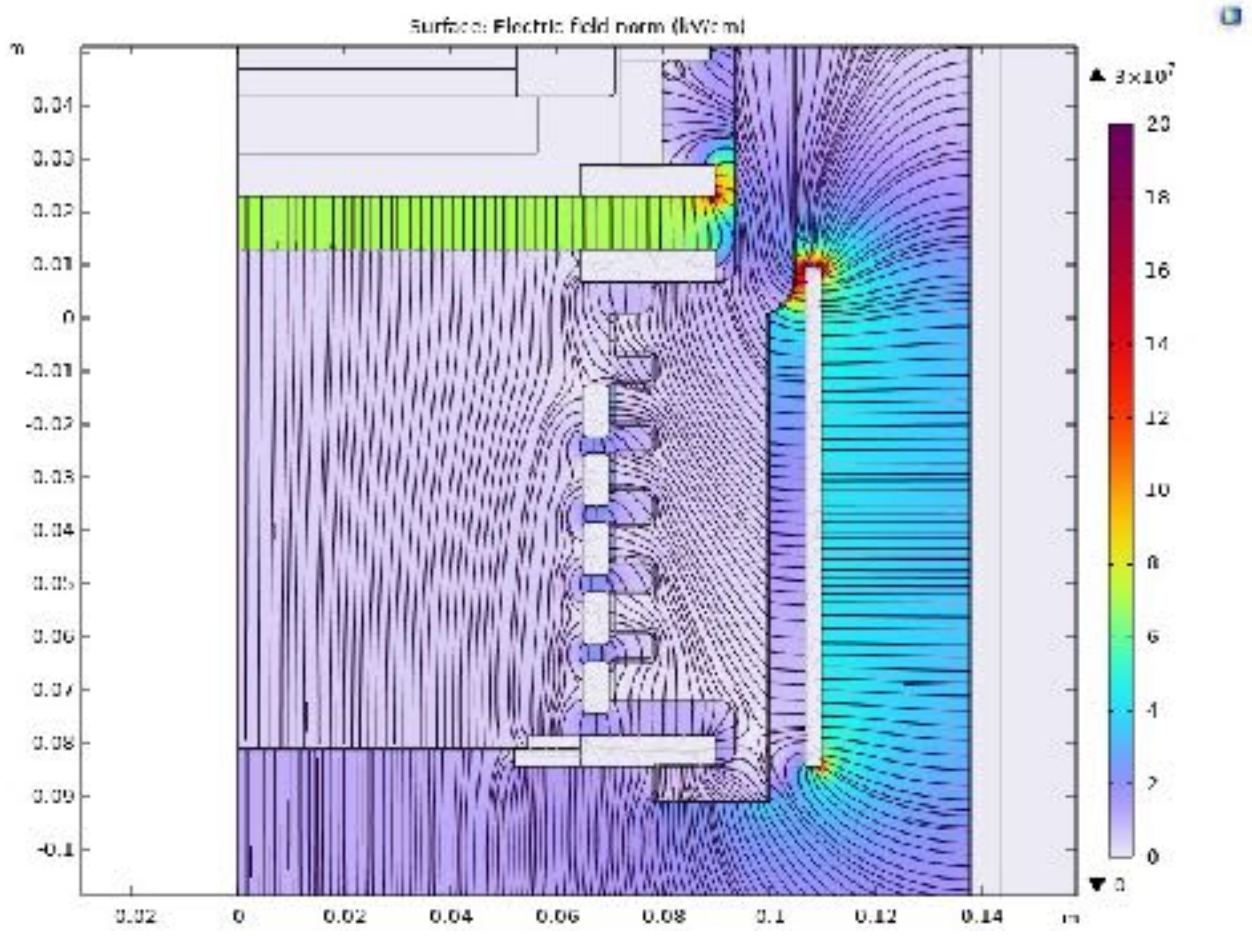




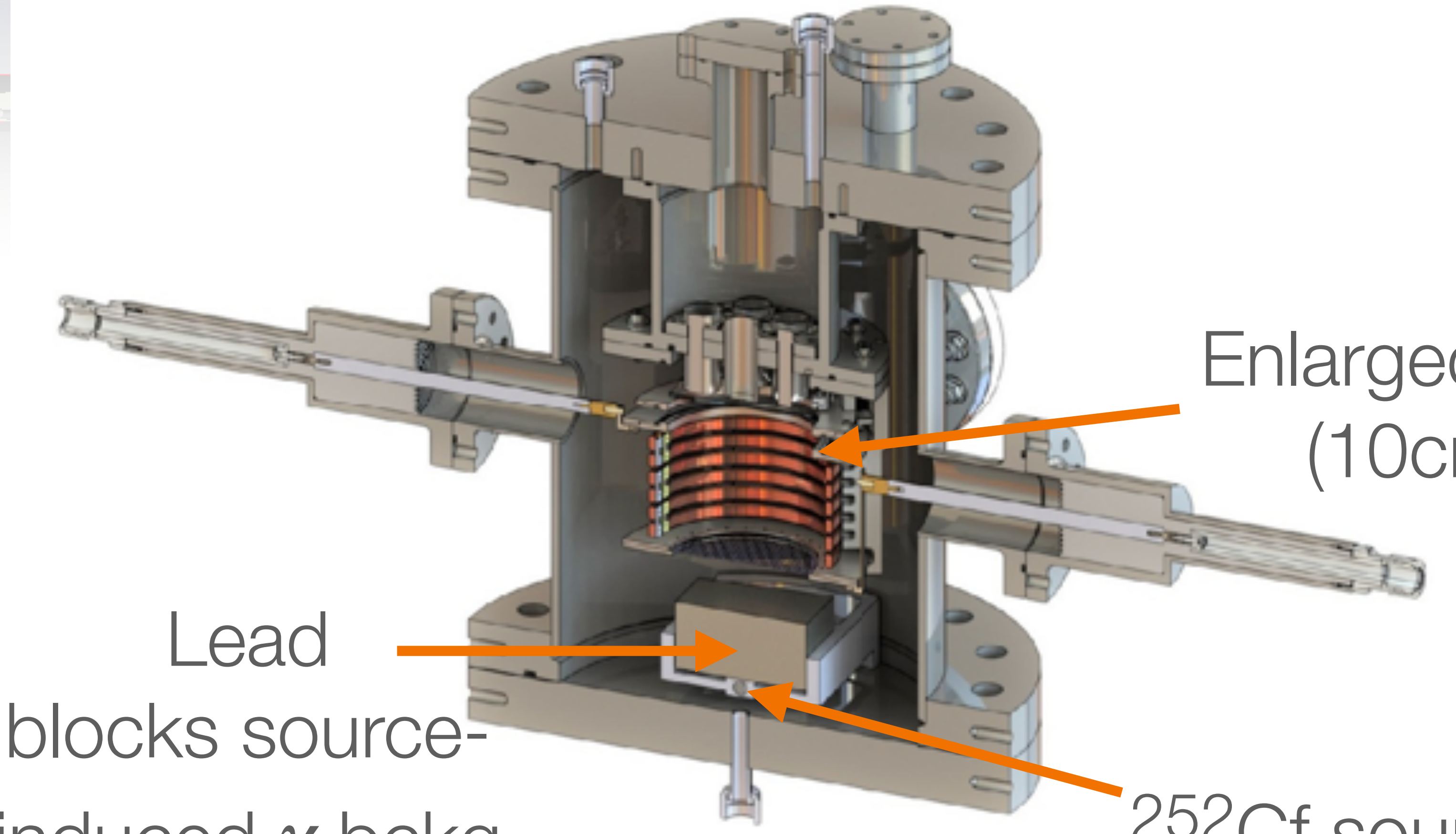
Drift length (2cm)

Field Cage design





Drift field in enlarged TPC



Enlarged drift (10cm)

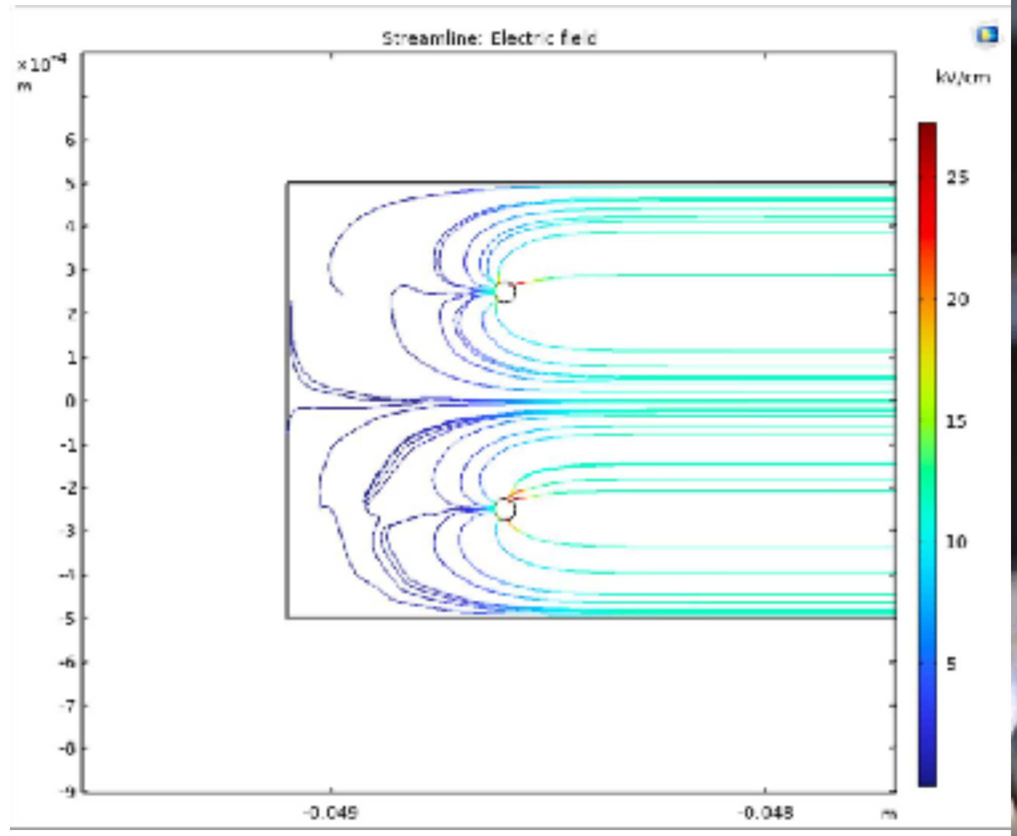
Lead blocks source-induced γ bckg

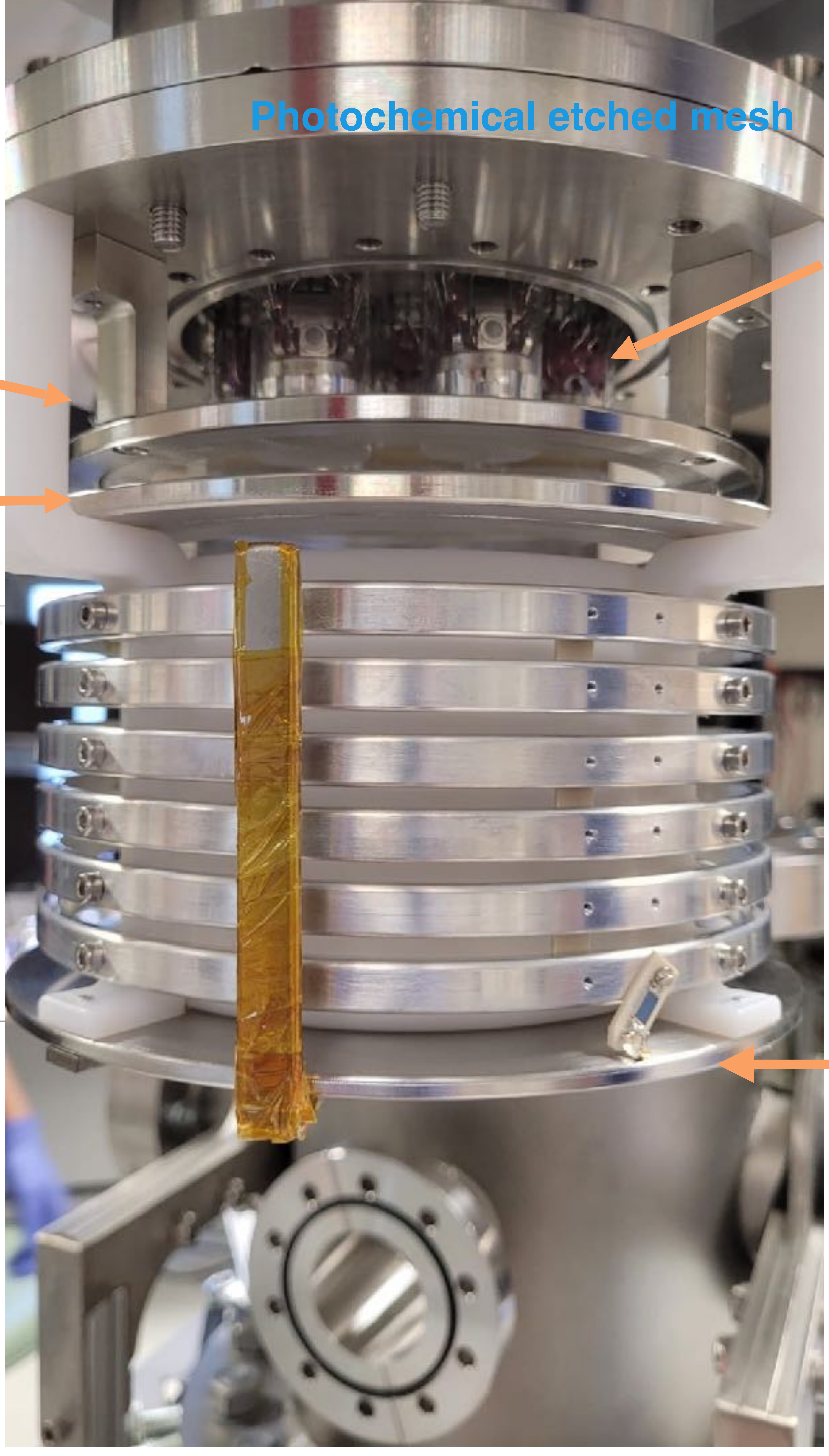
^{252}Cf source

GaP design

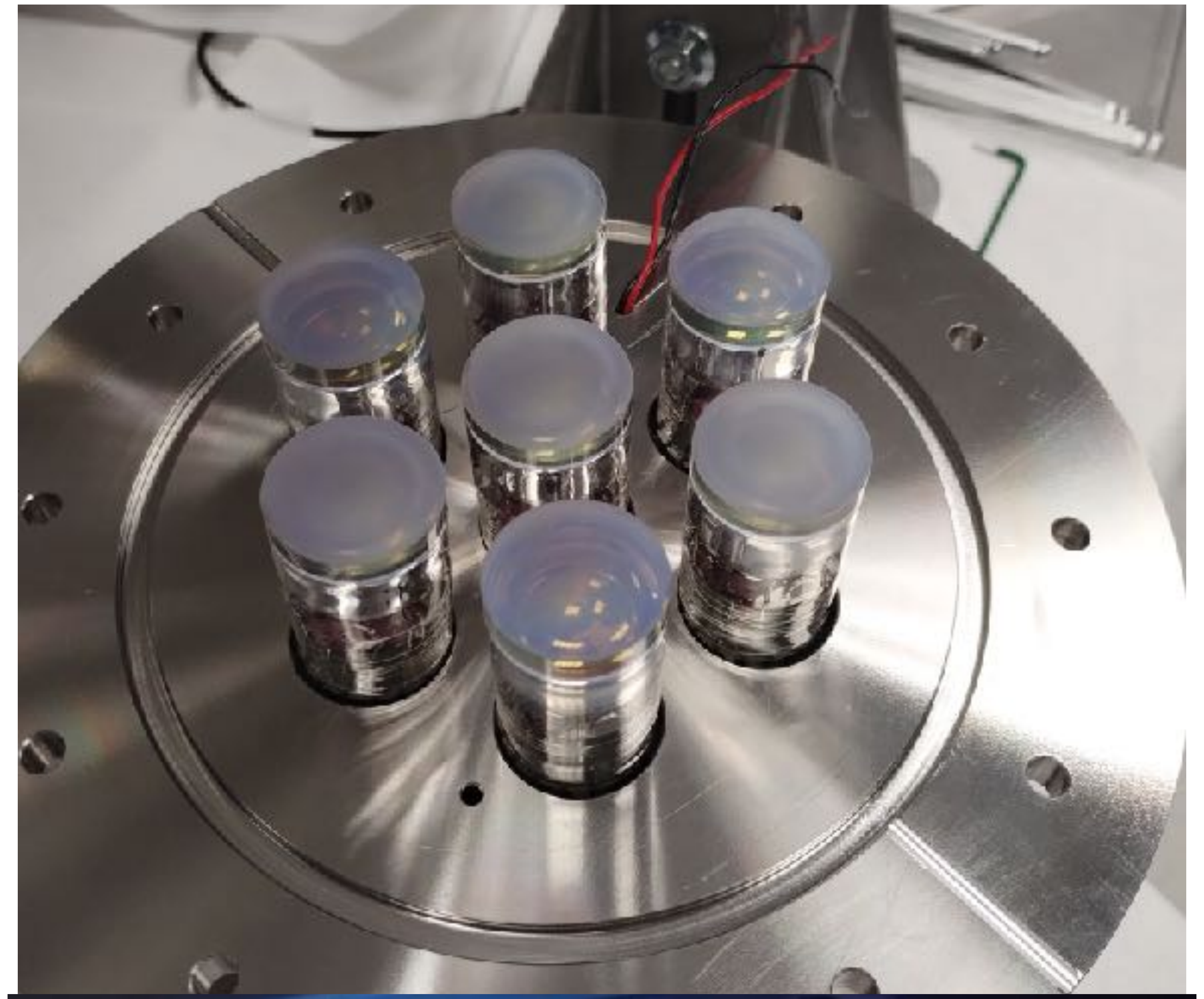
- Small vertical TPC:
  - 10 cm drift length.
  - 1.1 cm EL gap.

- 7 Hamamatsu R7378 PMTs on top.
  - TPB directly on PMTs.
  - Pressure resistant window or SiPMs for second phase.



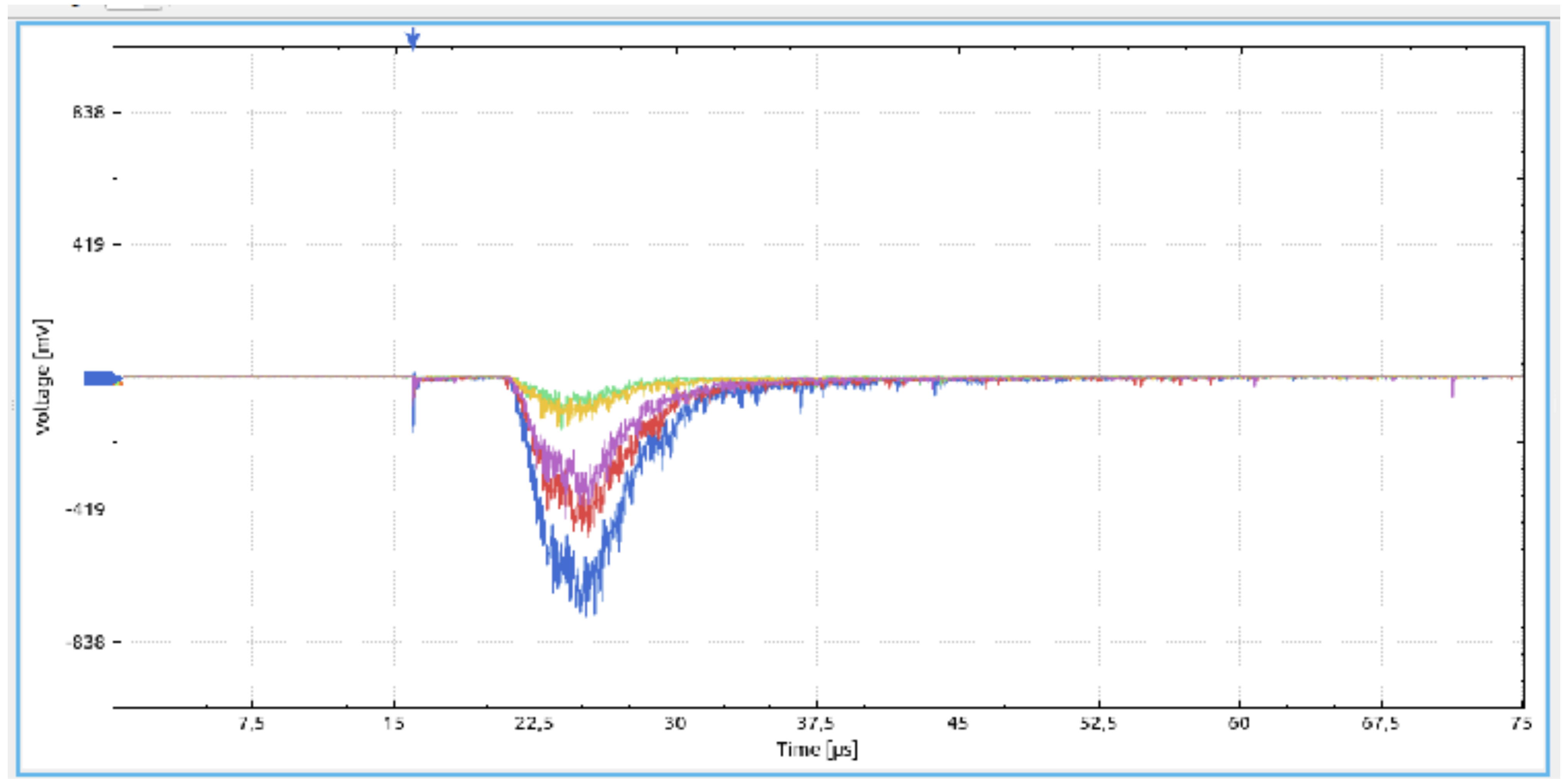


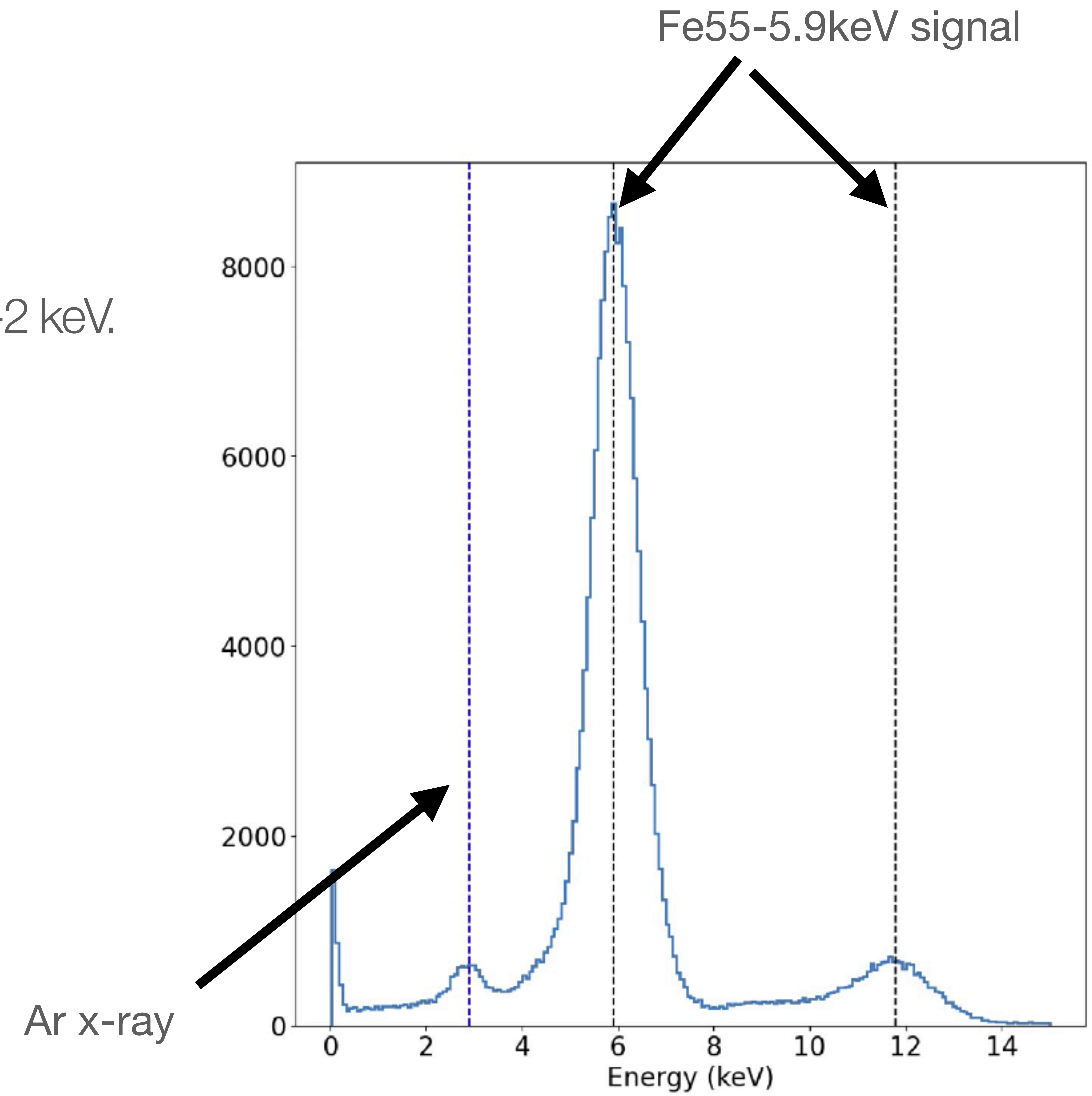
Inside GaP



GaP first run results

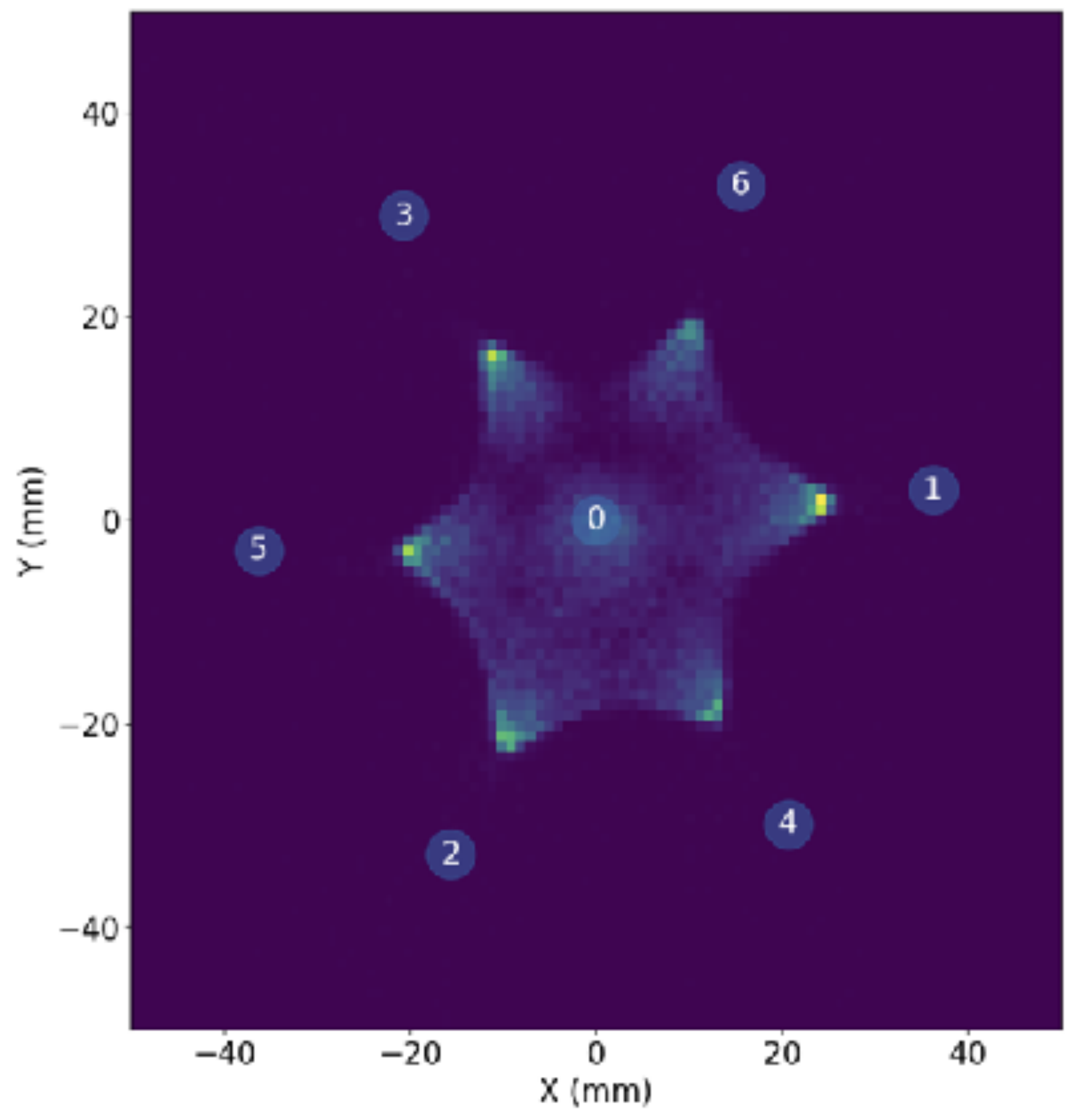
- Operation with Ar at different pressures (<10 bar)
- Operation with Fe55 source.
  - Fe source clearly visible, energy threshold at the level of 1-2 keV.
  - Kr provides response of the detector in all volume.

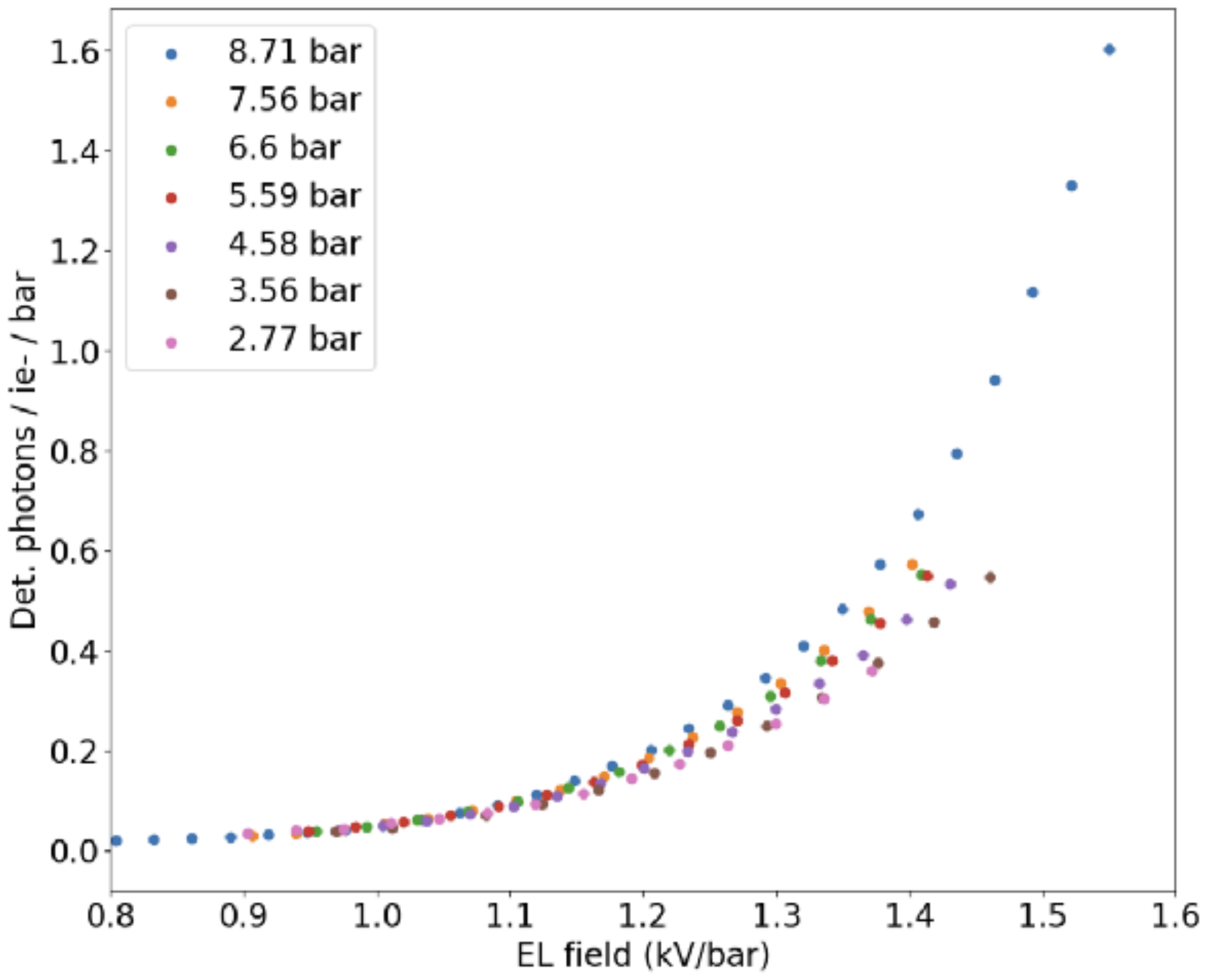


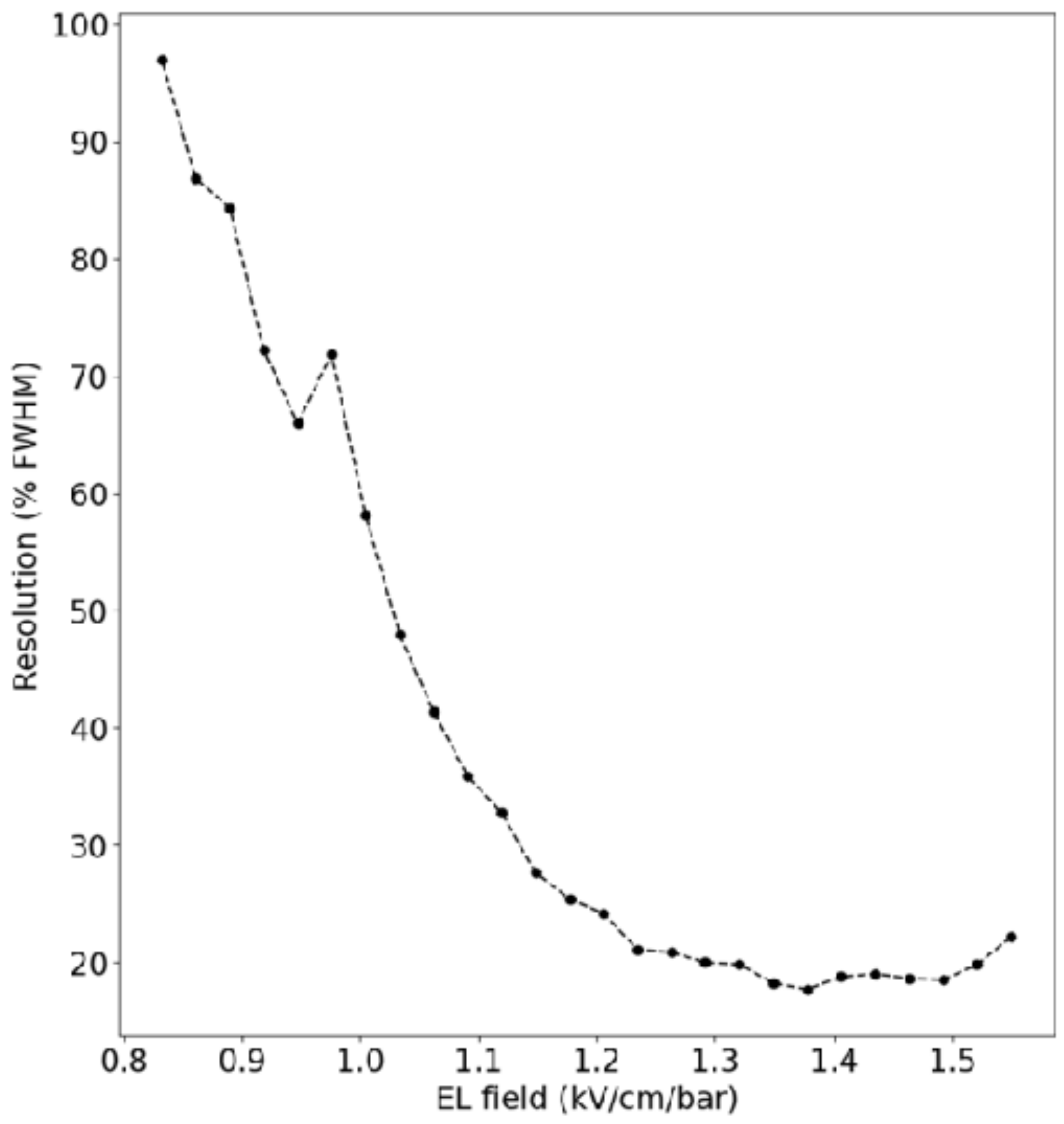


GaP first run results

- Operation with Rb/Kr source
  - Kr provides response of the detector in all volume.
  - Allows for understanding of the EL and light collection

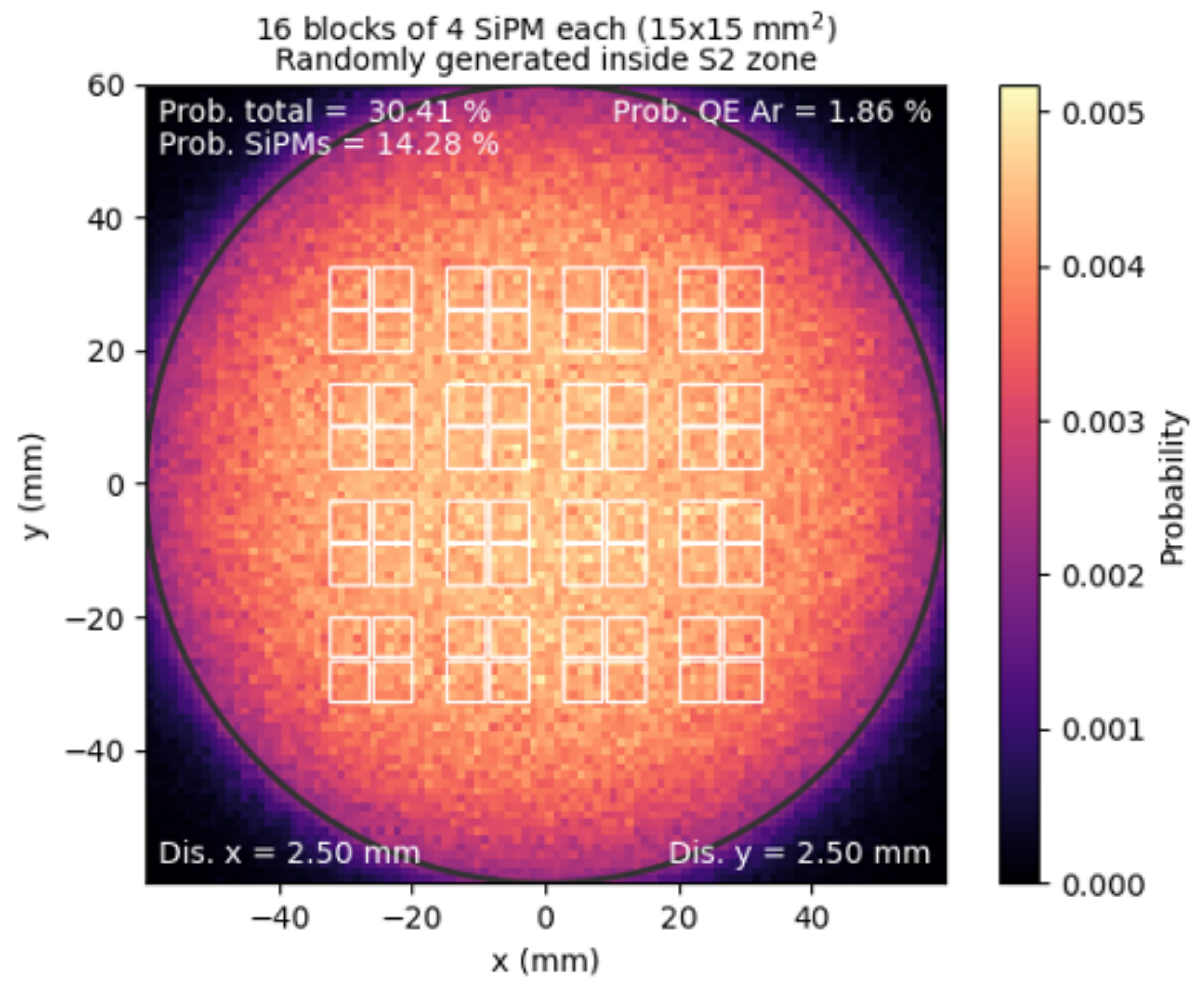


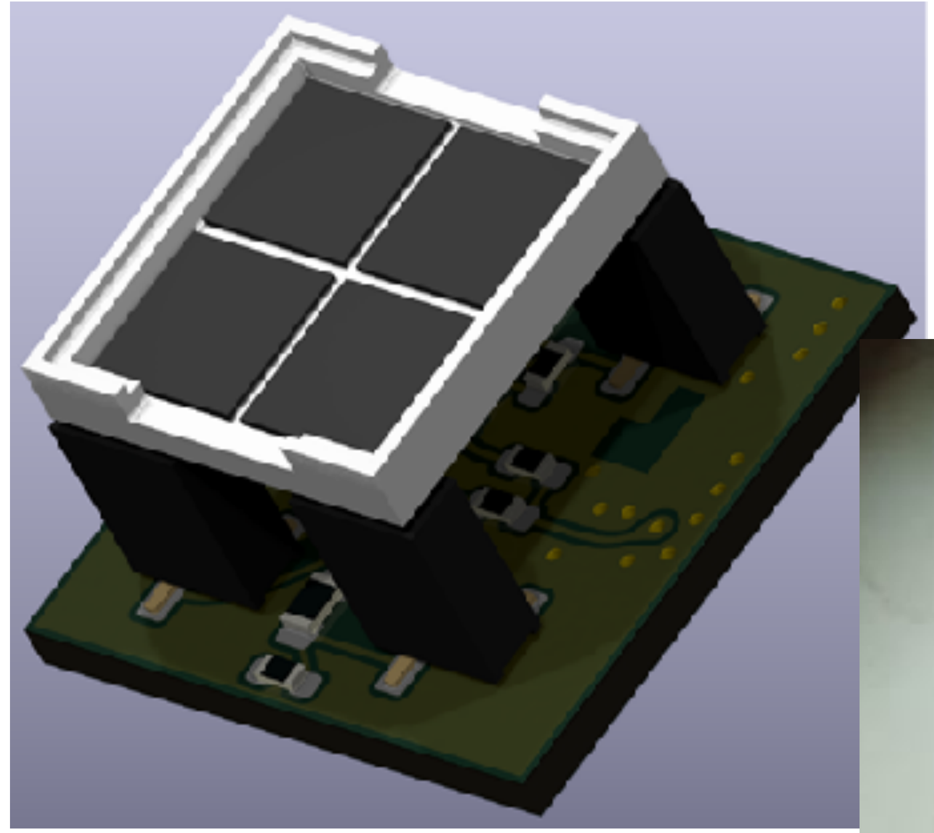


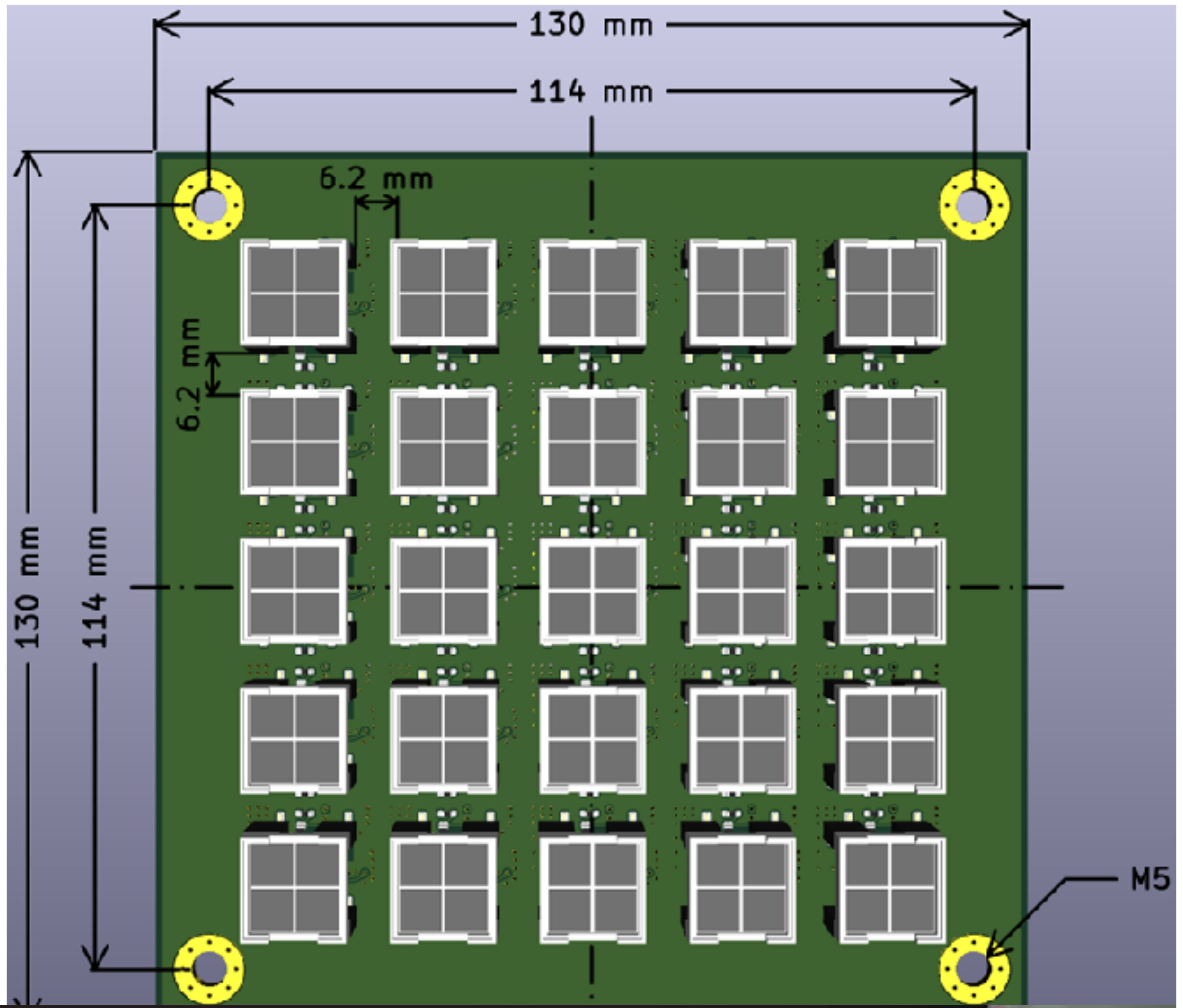


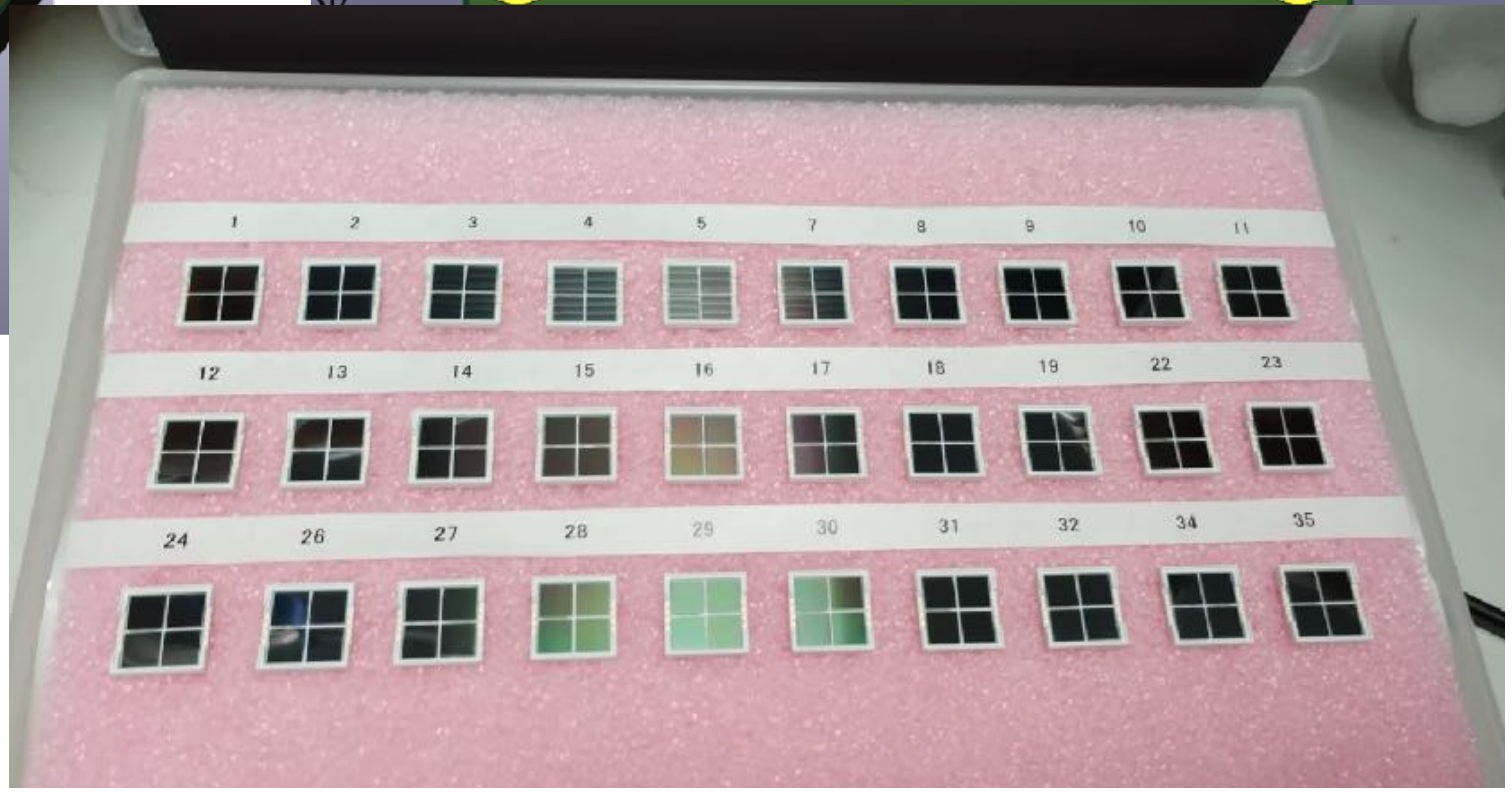
GaP next steps

- Operation with Ar-Xe (0.1%) and Xe at different pressures (>10 bar)
- Replace PMTs by SiPM to stand pressure





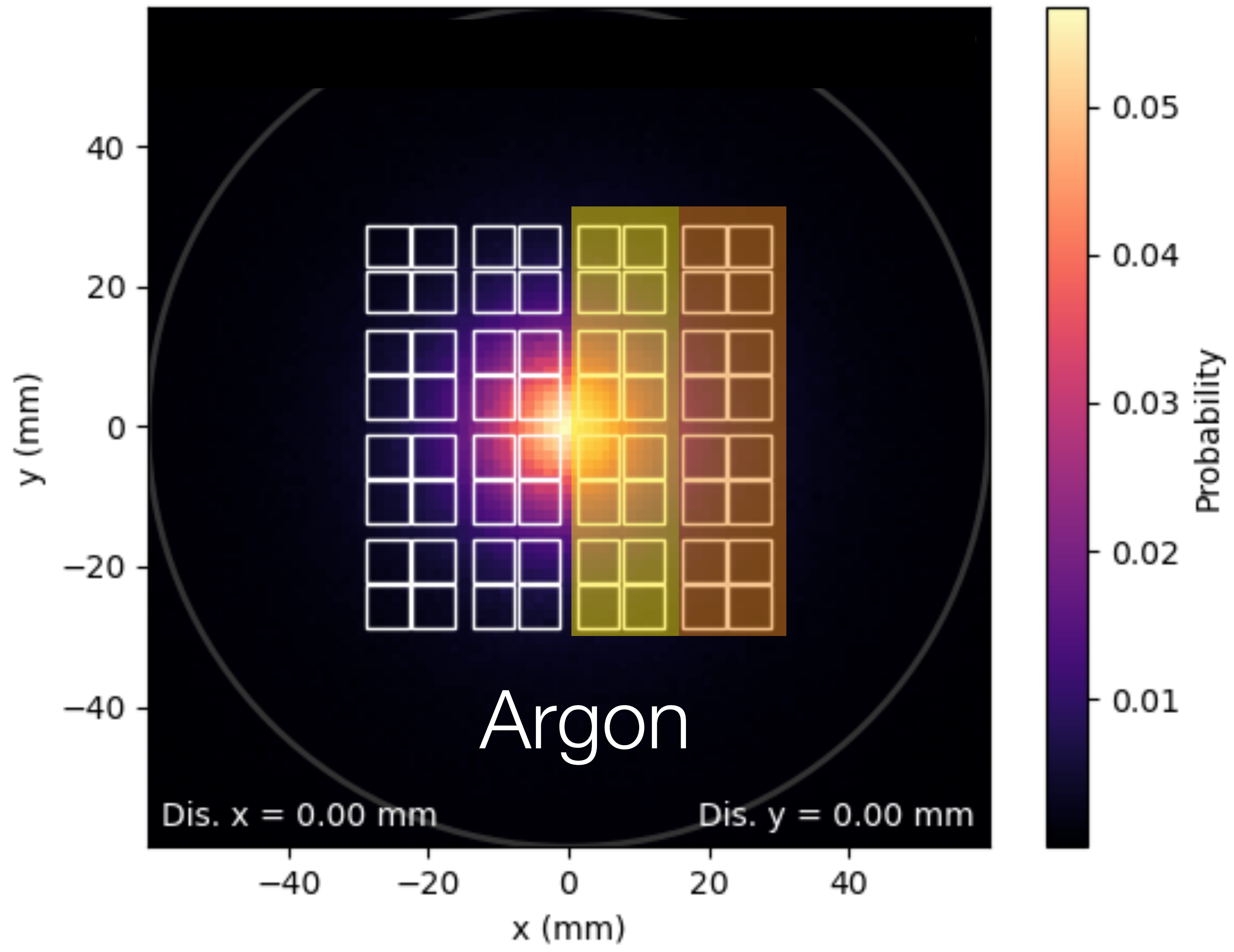




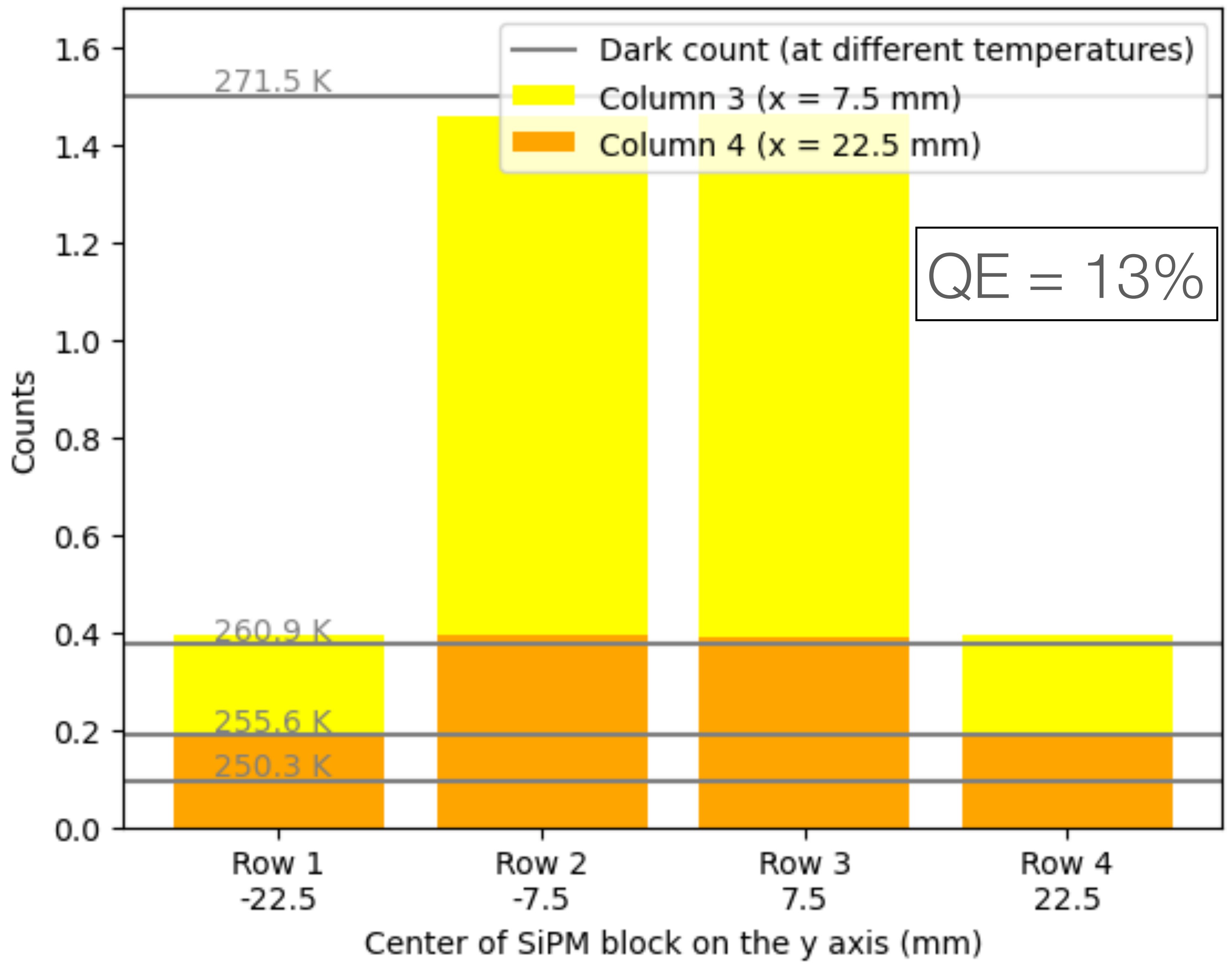
GaP with SiPMs

Prob. SiPMs (13% QE) = 2.37%

16x4 SiPM blocks, each 15x15mm^2



Counts per e^- in EL region



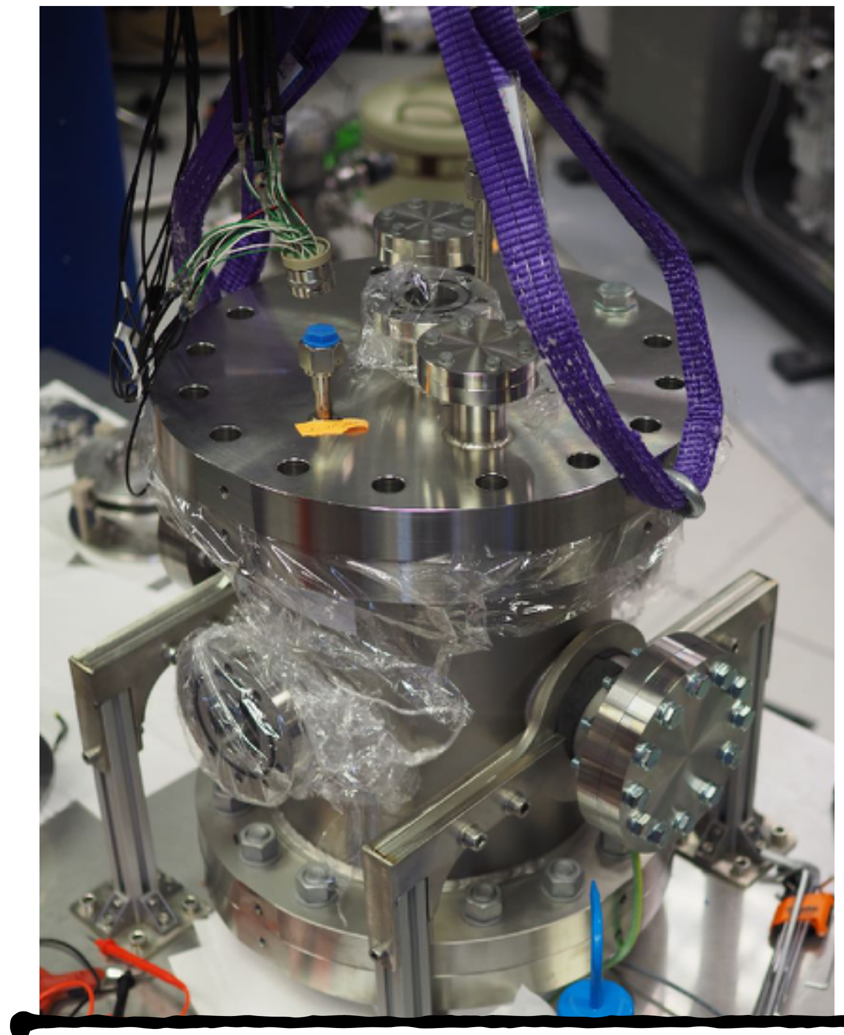
Dark counts per 3μs

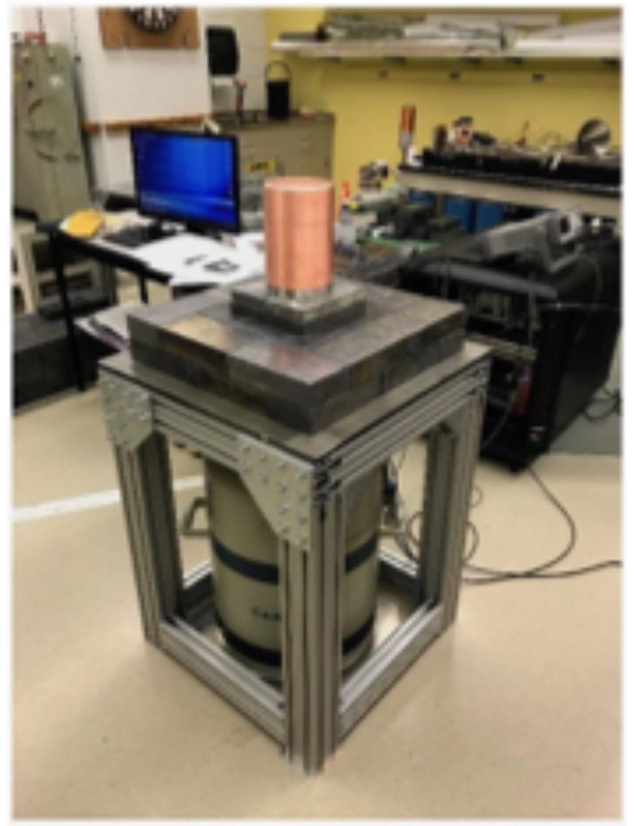
We might need to cool down the SiPMs

NuESS project

Timeframe

Get to know the detectors



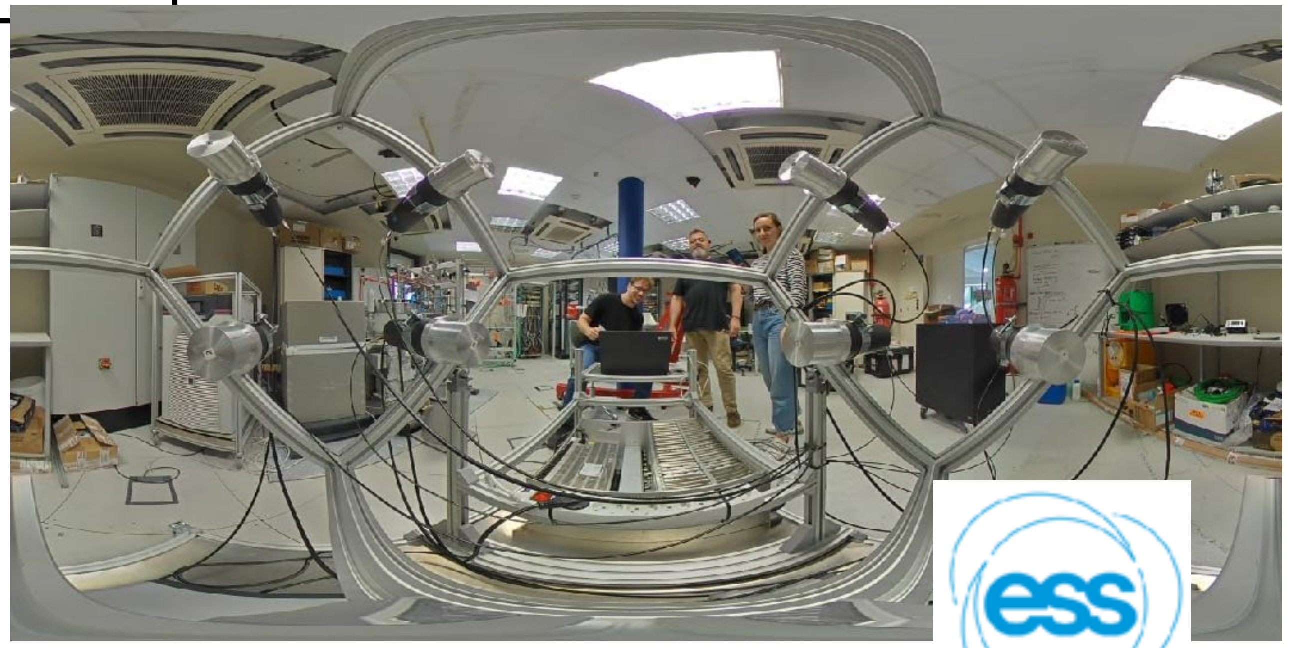


Validation of the technology

Nuclear Reactor

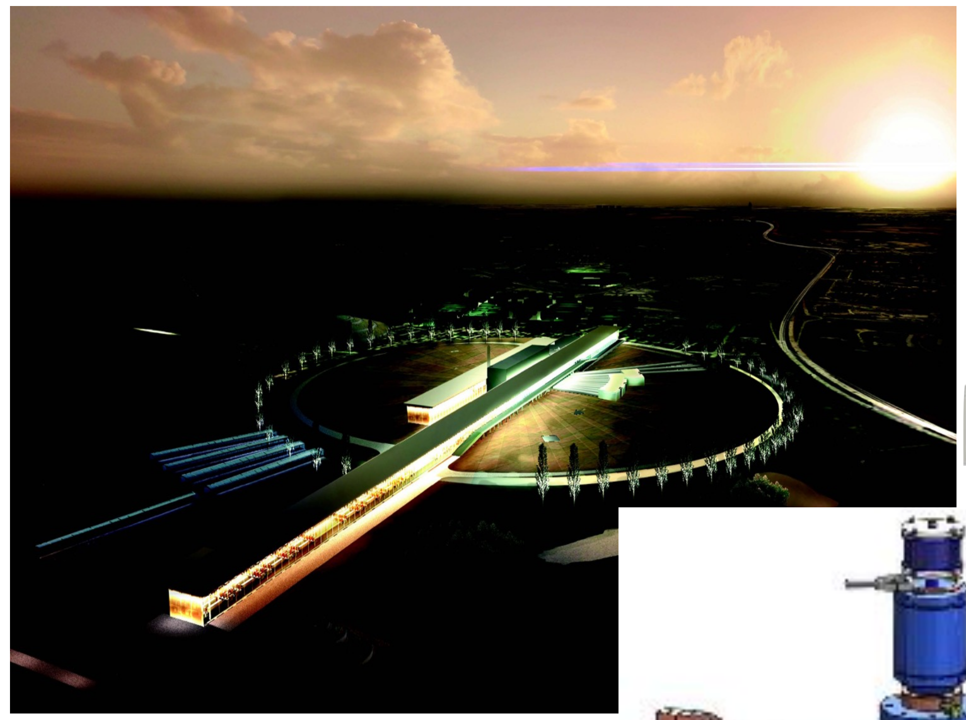
Summer 2024

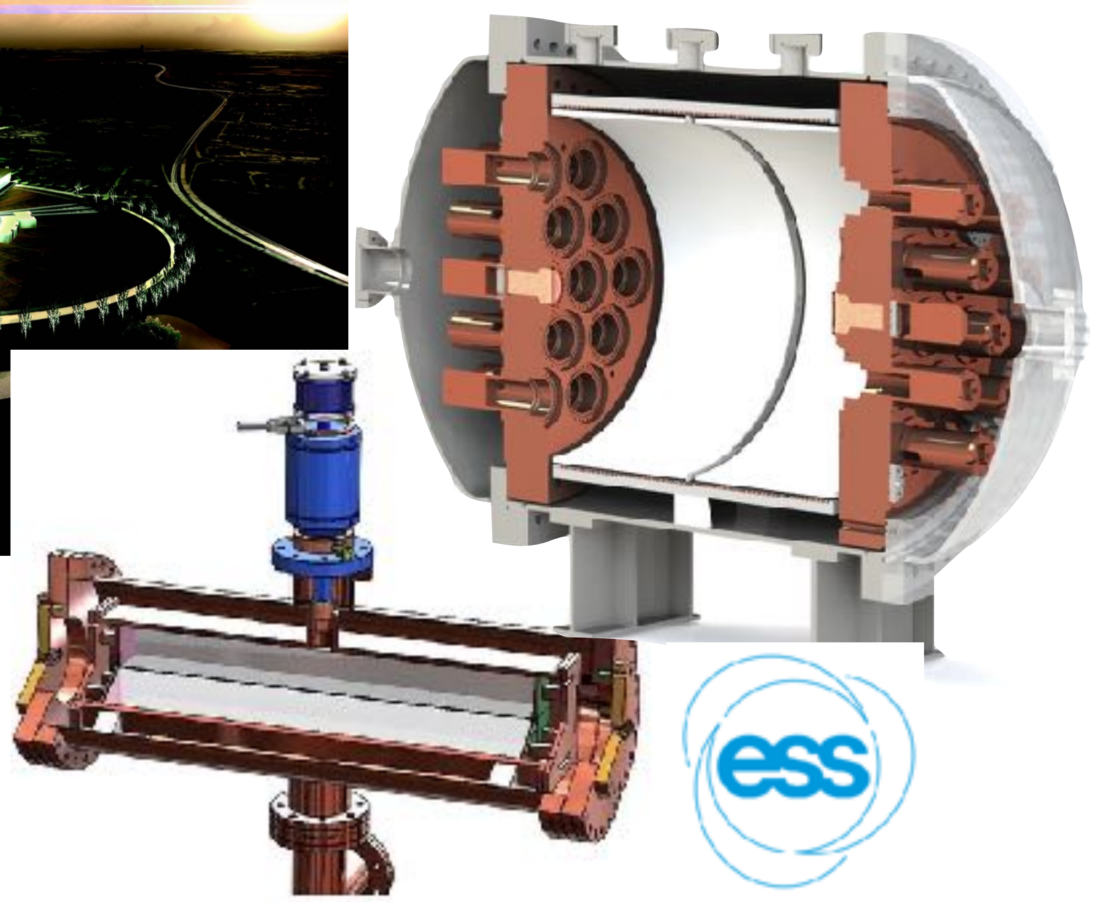
2025



2027

Operation @ESS





35

NuESS Support

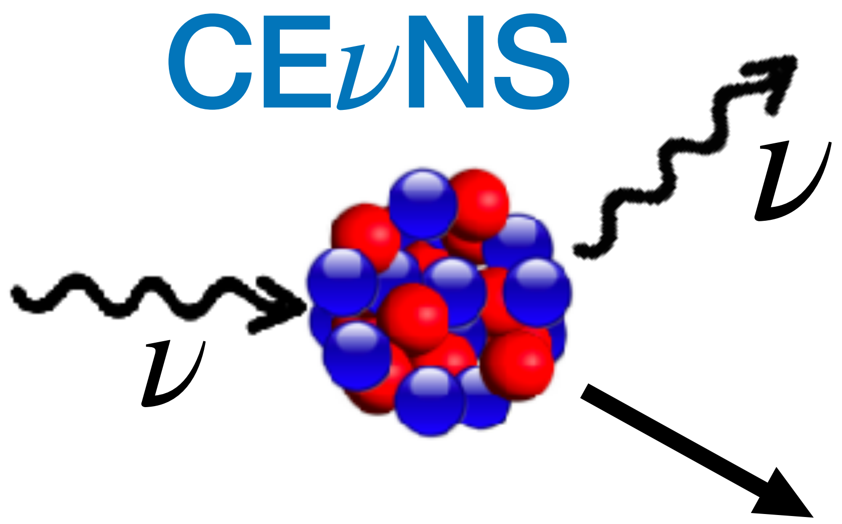
- NuESS has obtained 2 ERC grants (GanESS, StG; ESSCEnuNS, AdG)
- Neutrino physics is strongly supported at the **Basque Country**
- Neutrino physics, together with neutron physics (Neutrionics) is one of the flagship research lines in the BC.
- In particular, a dedicated **funding program to develop neutrino detectors** for the ESS has been allocated in the Basque Country during the last four years.
- **DIPC** is creating a new space for neutrino laboratory.
- Neutrino physics at the BC includes:
    - Neutrino physics at the ESS.
    - NEXT, HK
    - Applications to medical physics.

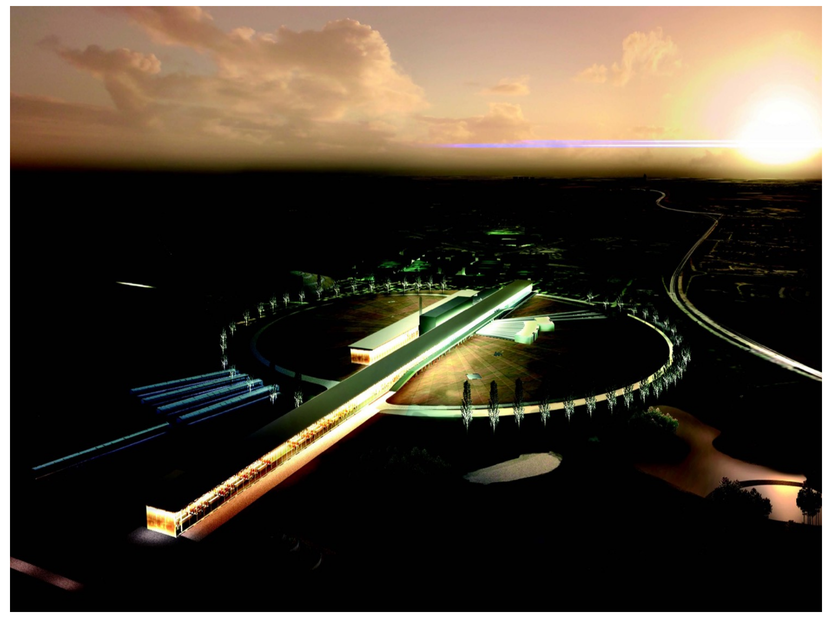
European Research Council

100 MEUR/ 10 yr IKERBASQUE program.
“Neutrionics” one of four poles.

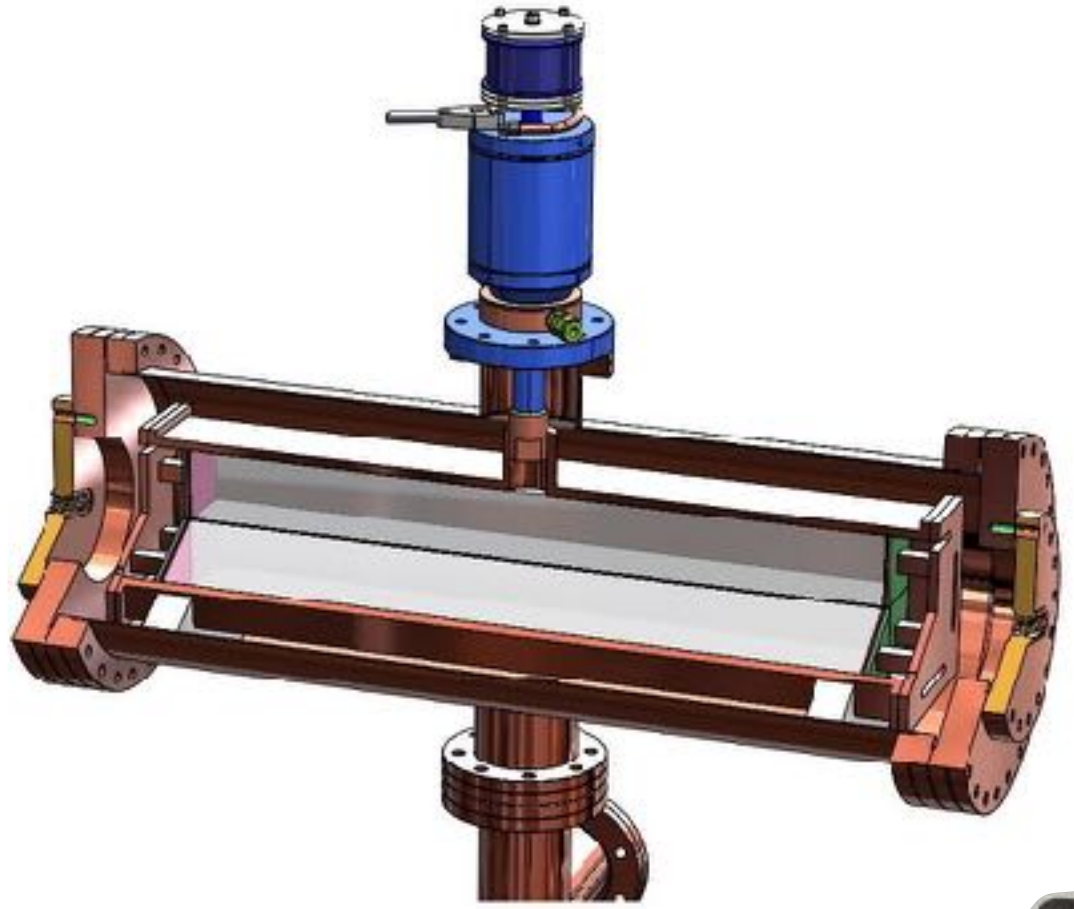
ikur estrategia

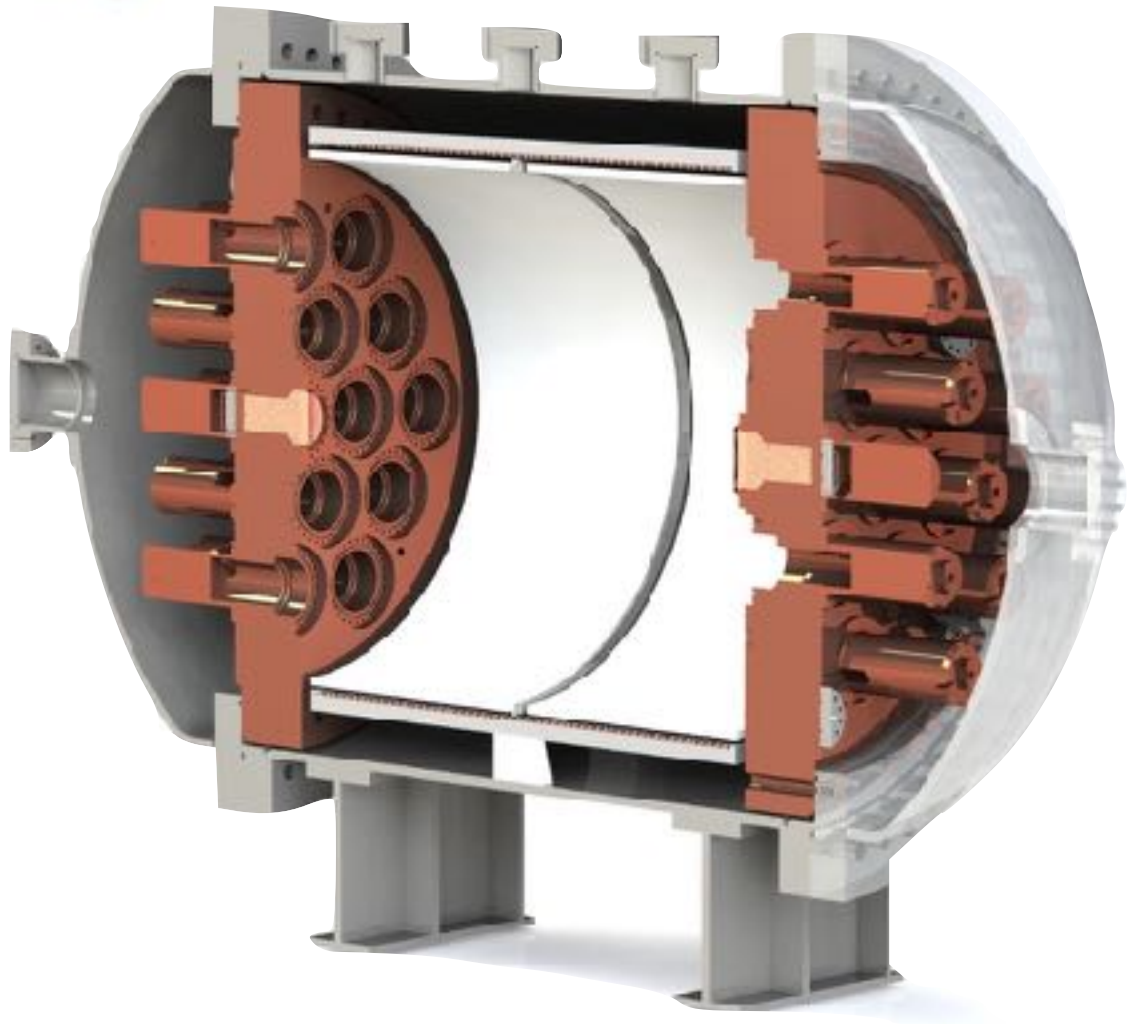
NuESS Summary





- CEνNS detection opens a **new avenue in the search of physics beyond the Standard Model**.
- **ESS** will become the largest low-energy neutrino source. It is the perfect facility to study this process.
- The **NuESS project**, will combine technologies to observe the CEνNS process at the ESS with a variety of nuclei.
- The **NuESS project**, is strongly supported financially and has guaranteed funds for the next 10 years.
- **NuESS** offers an opportunity to **lead a world-class neutrino program** in the coming years with a **large discovery potential**.






THANK YOU