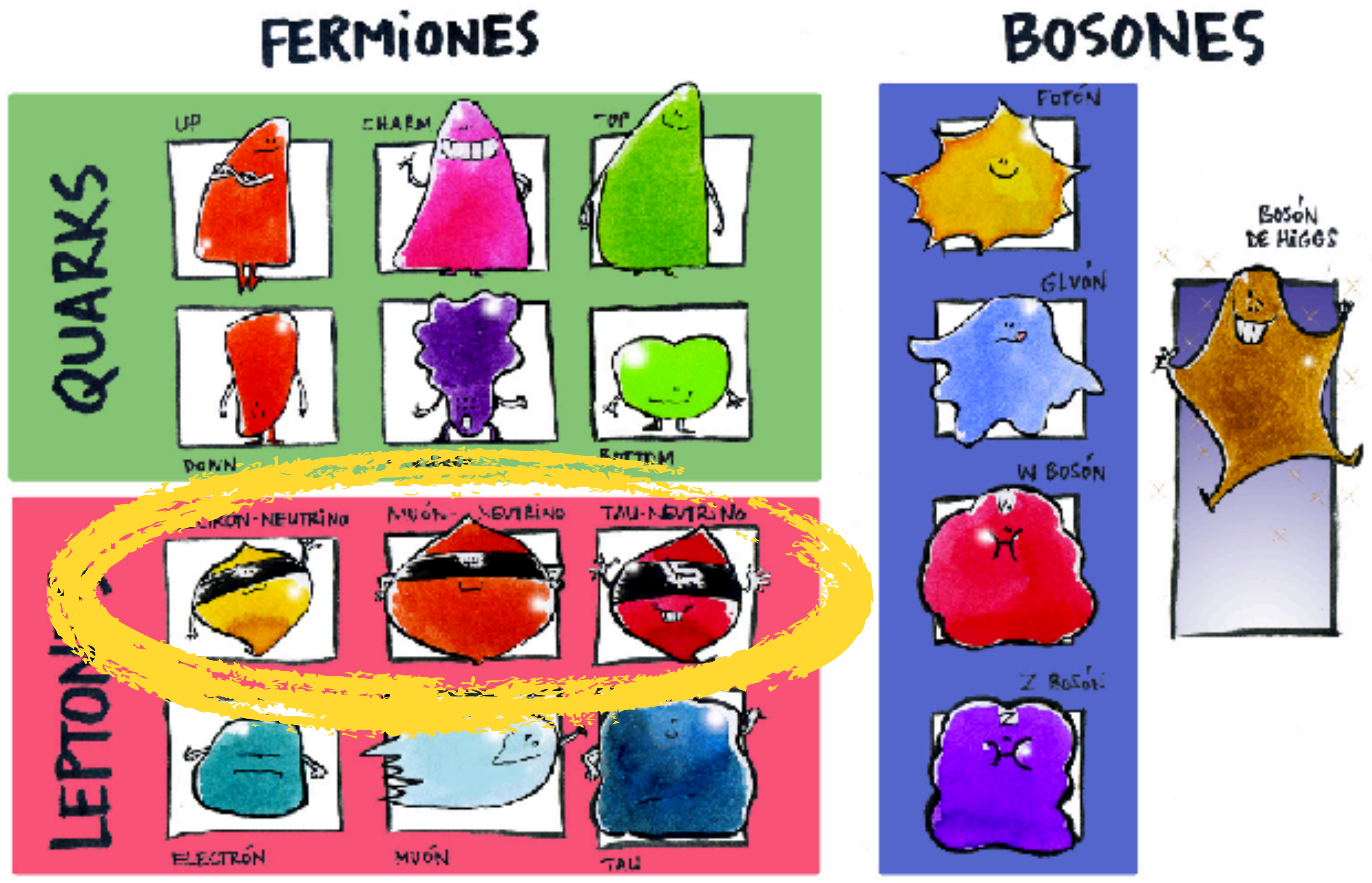
Gaseous detectors for neutrino physics at the ESS

GanESS

F. Monrabal

XeSat, Coimbra May 2022

Neutrinos: what we know



@raquelberryfinn

Interact only weakly

No color, no electric charge

Three light ($<m_Z/2$) neutrino states

ν_e, ν_μ, ν_τ flavors

Neutrino number density in Universe only outnumbered by photons

$n(\nu+\bar{\nu}) \approx 100\ \mathrm{cm}^{-3}$ per flavor

From neutrino oscillations:

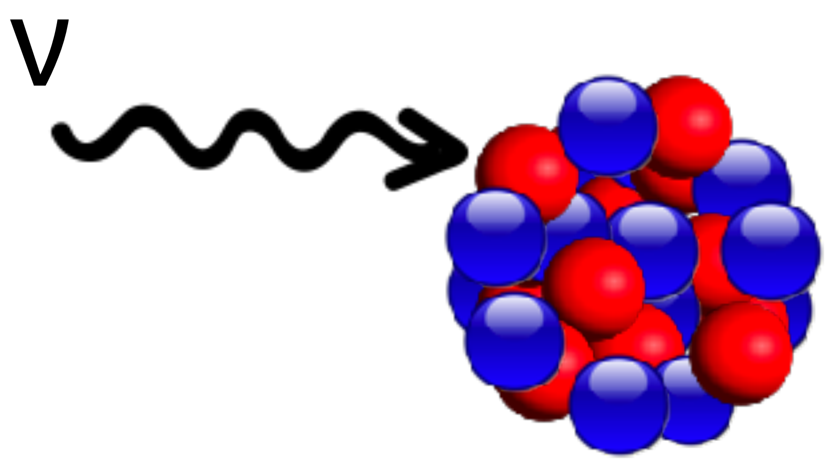
Neutrinos are massive (lightest known fermions)

Large flavor mixing

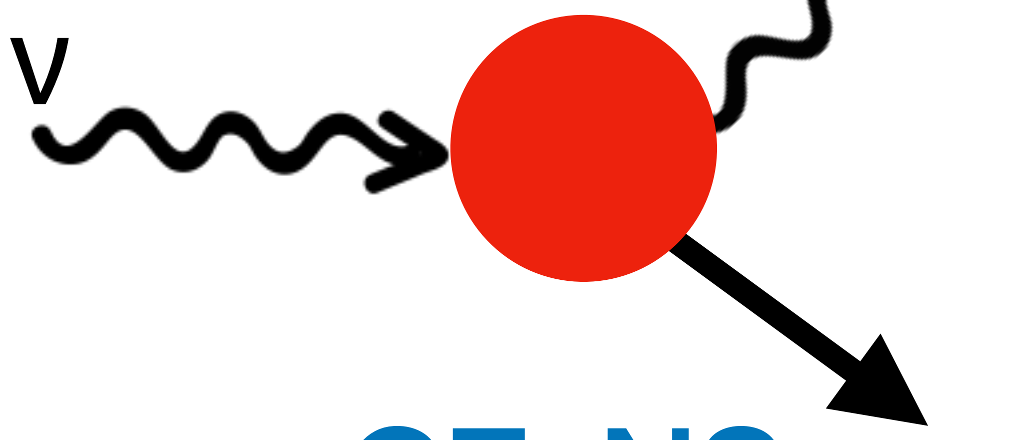
Neutrino detectors

COHERENT NEUTRINO NUCLEUS SCATTERING

Coherent Elastic Neutrino-nucleus scattering



Long wavelength, “sees” all nucleons simultaneously



$\sigma \sim N^2$

CEvNS

Cross section increases as N^2. Four orders of magnitude increase for large nucleus!

First observation published only 4 years ago.

Coherent Elastic Neutrino-nucleus scattering

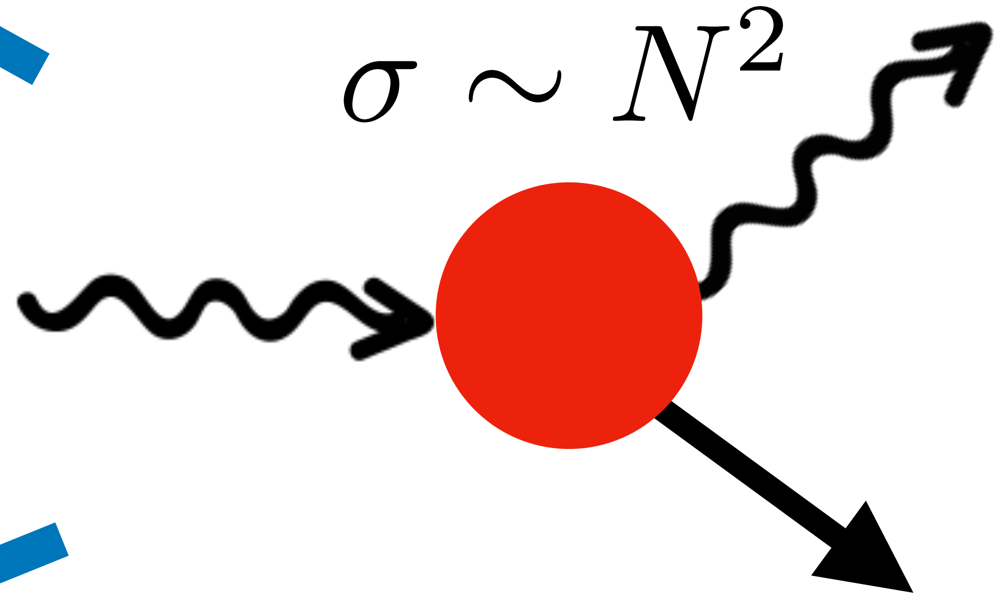
Very rich physics

Sensitivity to Non-Standard Interactions

Complementary to oscillation experiments

Study of Neutral Currents

$\sigma \sim N^2$



Study of the Nuclear structure

Sterile neutrinos

Effective neutrino charge radius

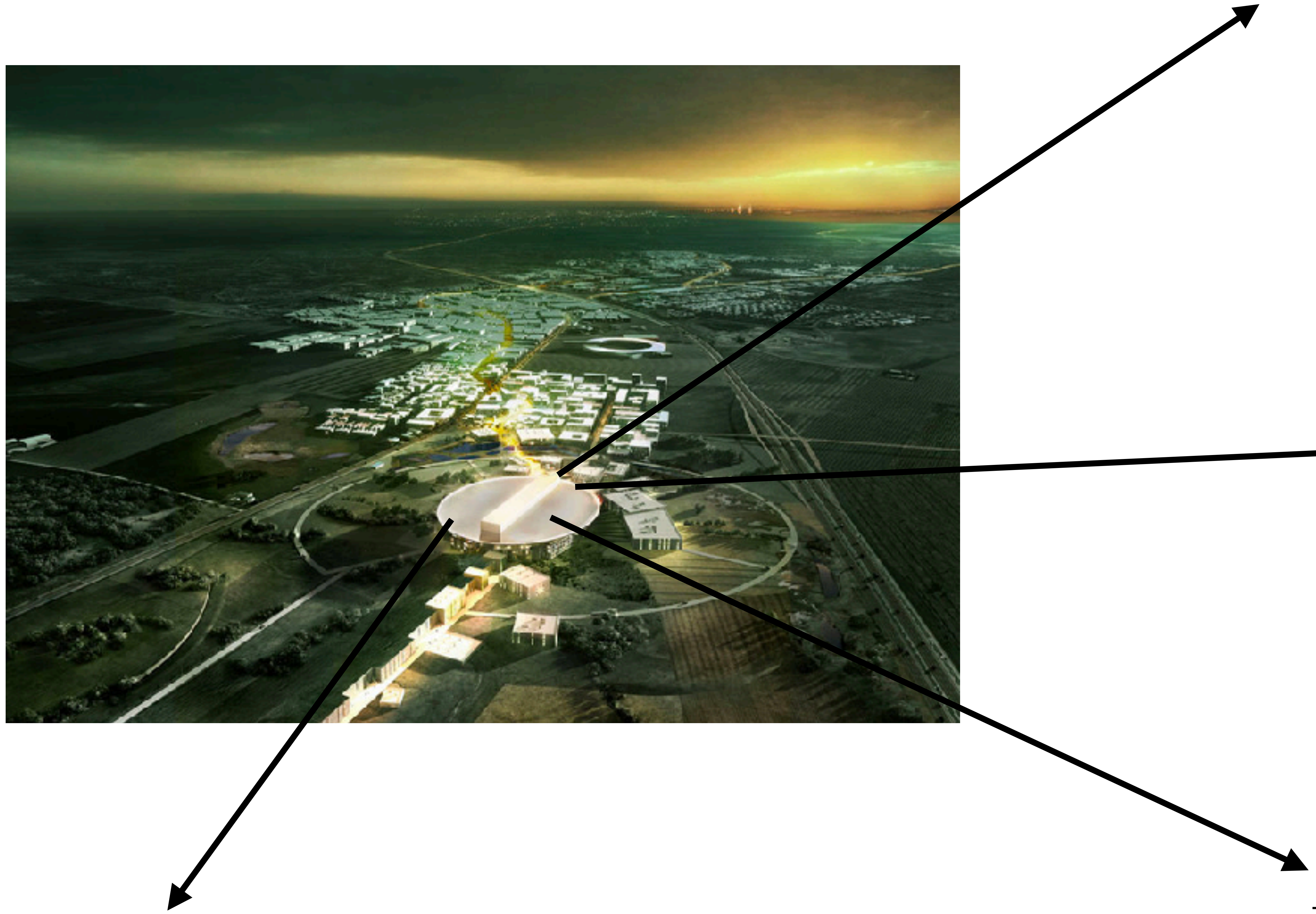
Neutrino magnetic moment

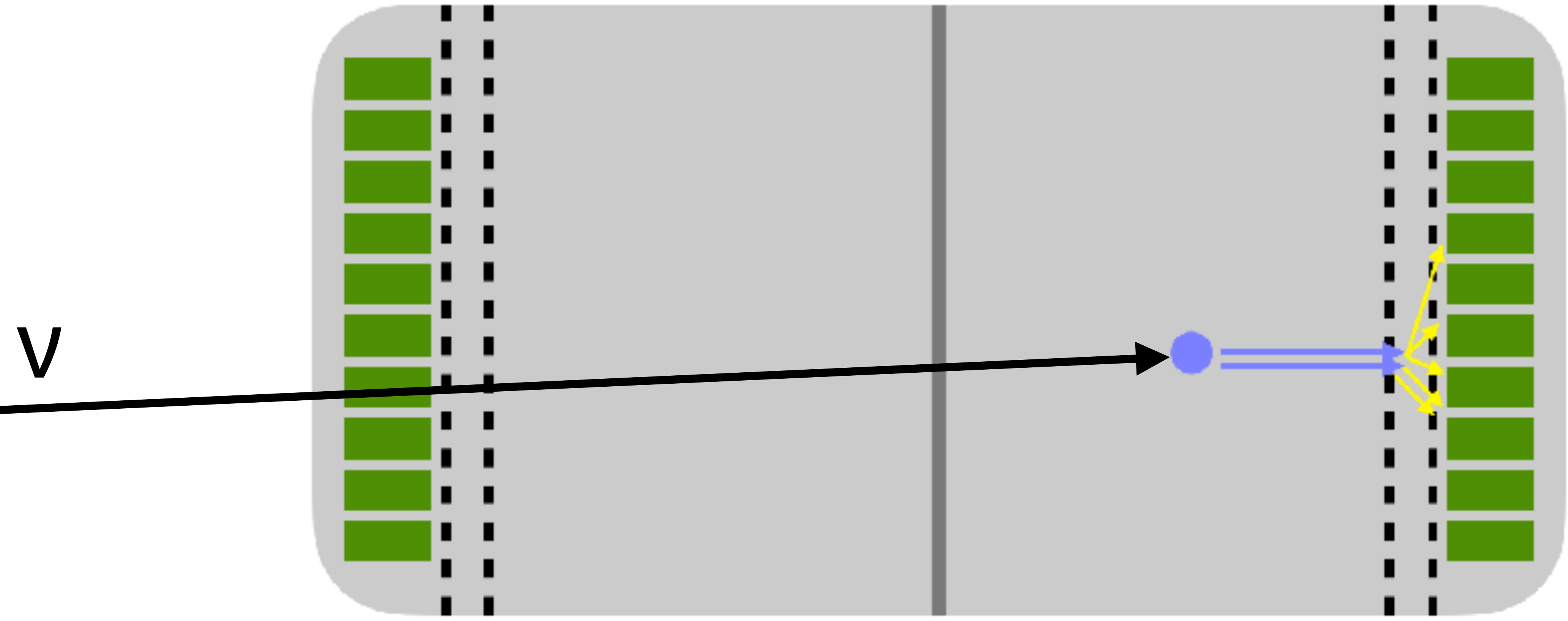
…

New types of dark matter particles

Detecting CEvNS

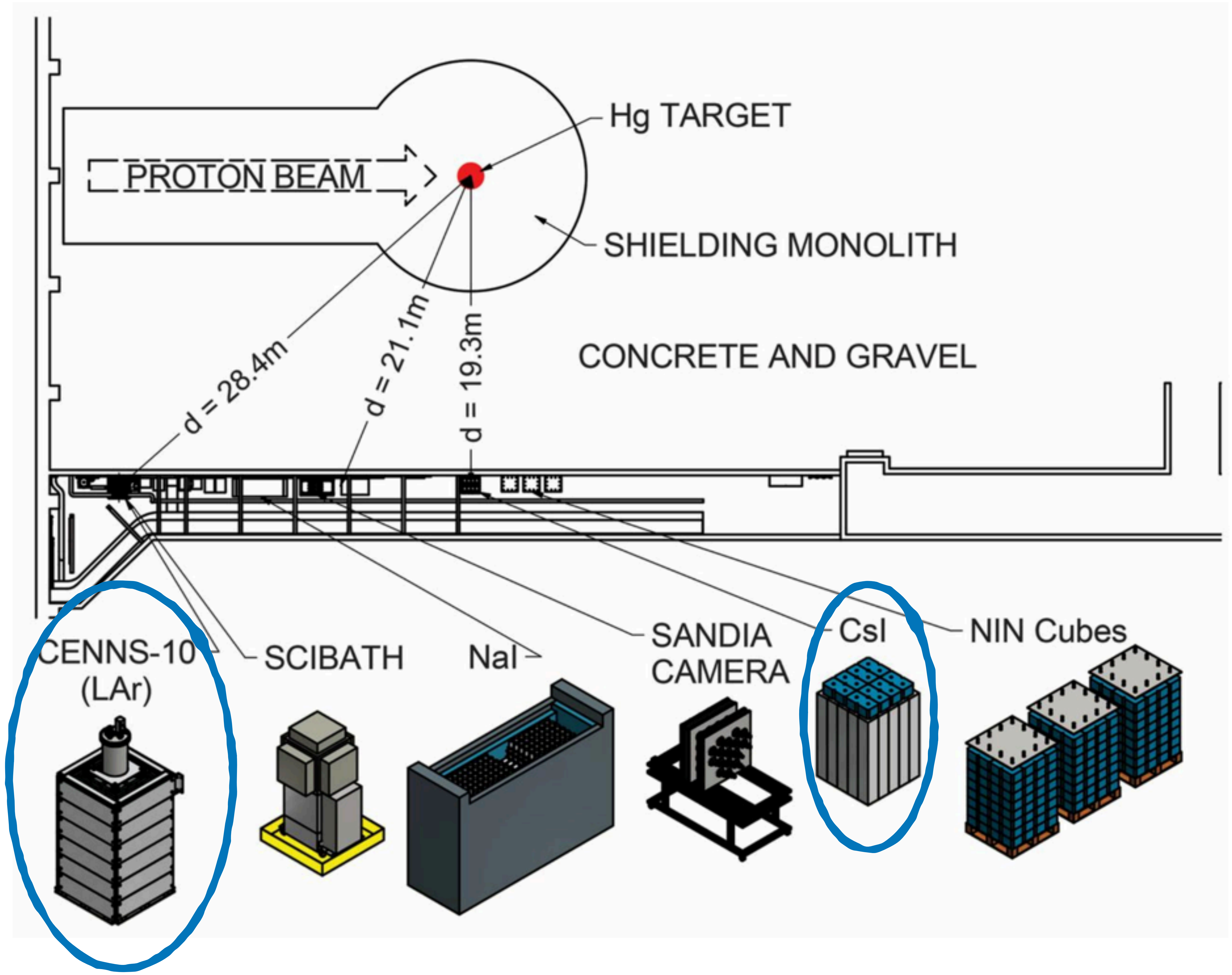
CEvNS sources, must be sufficiently intense in yield, and low enough in neutrino energy so the coherence condition can be satisfied.



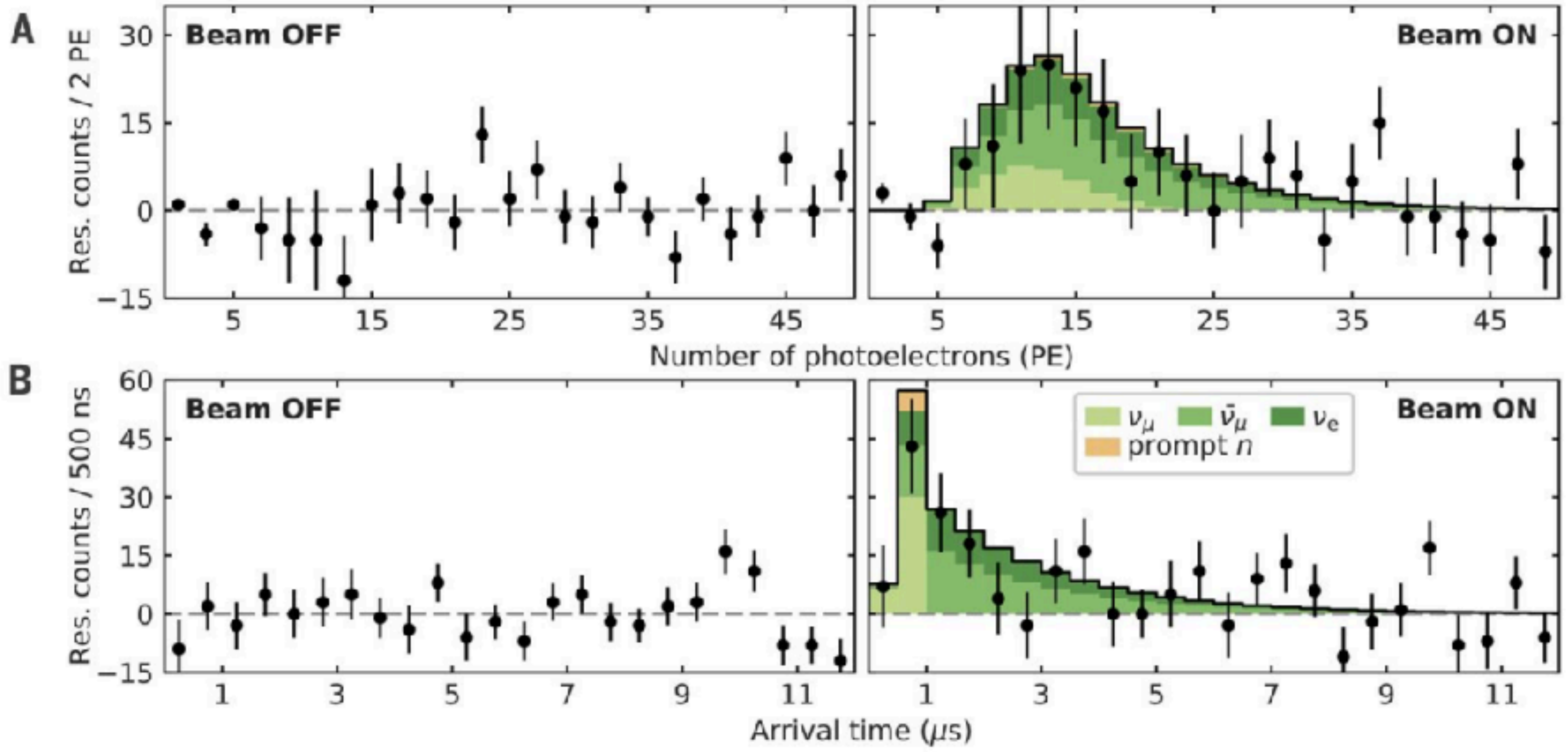


~10 kg size detectors.

Detecting CEvNS: First observation



Science 357, 1123–1126 (2017)



Detection of the coherent scattering less than 5 years ago demonstrates a new mechanism to observe neutrinos.

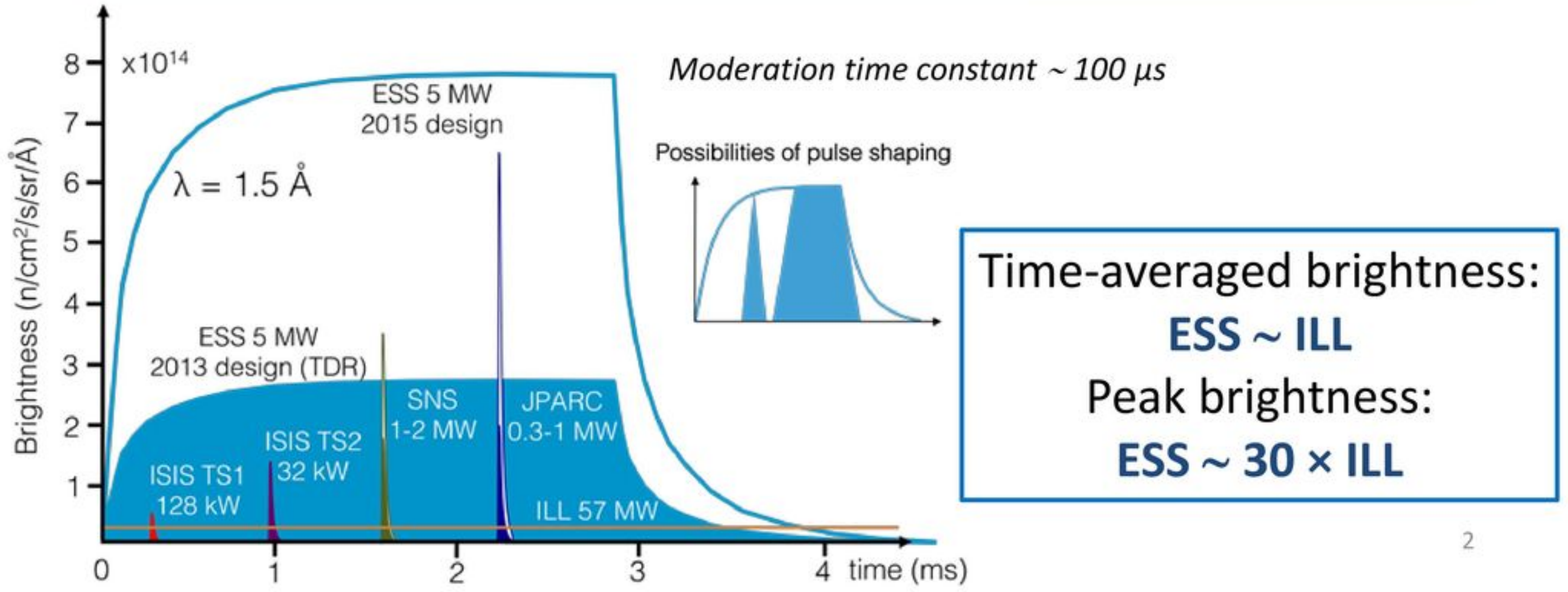
A new opportunity for CEvNS

The European Spallation Source (ESS)

- The ESS will combine the world’s most powerful superconducting proton linac with an advanced hydrogen moderator, generating the most intense neutron beams for multi-disciplinary science.
- It will also provide an **order of magnitude increase** in neutrino flux with respect to the SNS.
- A great opportunity for Europe to lead this physics program!

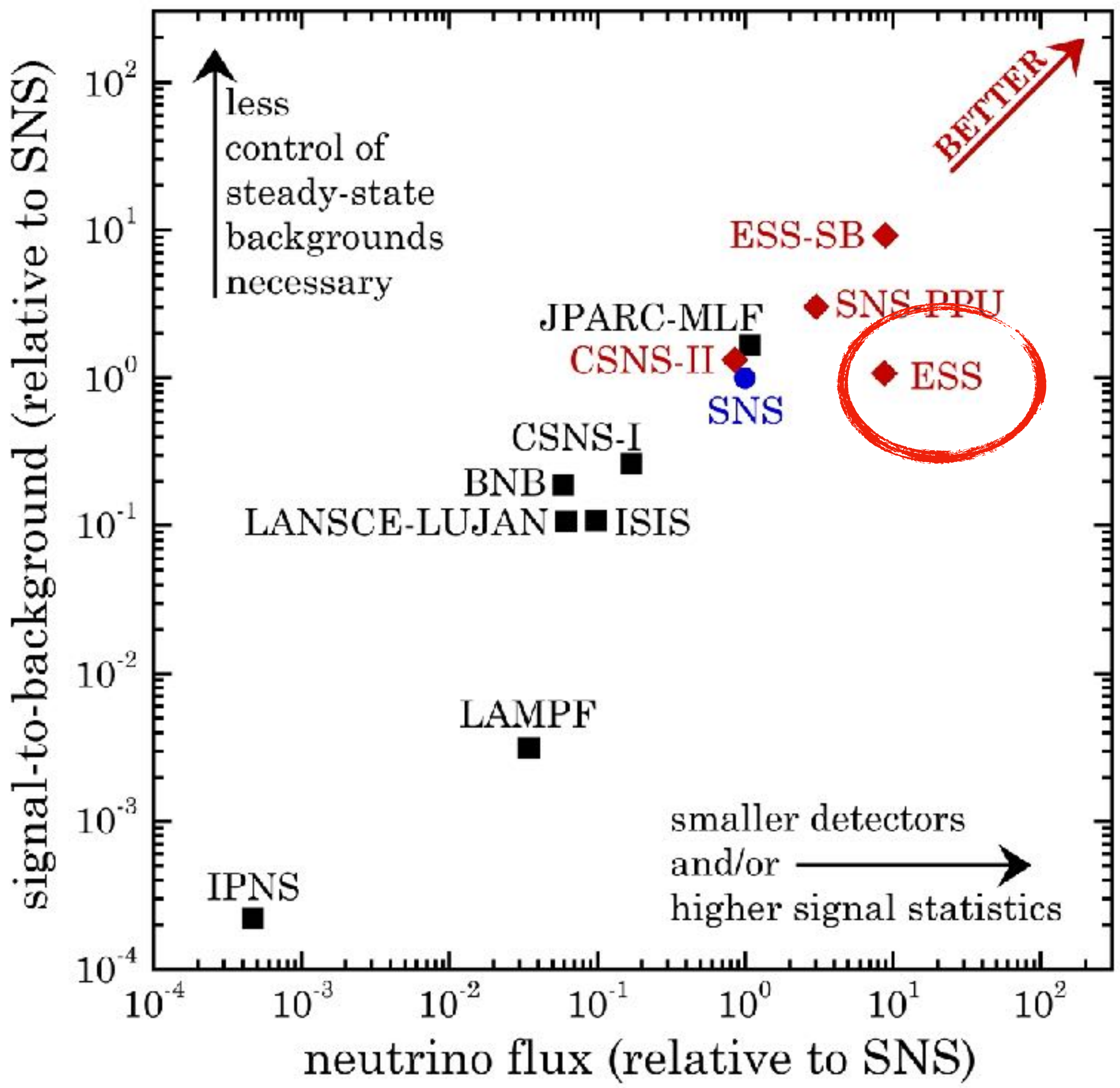
ESS – A long-pulse spallation source

	SNS	ESS
Average power	1.4 MW	5 MW
Proton pulse length	*695 ns*	*2.86 ms*
Peak power	34 GW	125 MW
Energy per pulse	**24 kJ**	**357 kJ**
Pulse repetition rate	60 Hz	14 Hz



A new opportunity for CEvNS

Comparison with current and future facilities

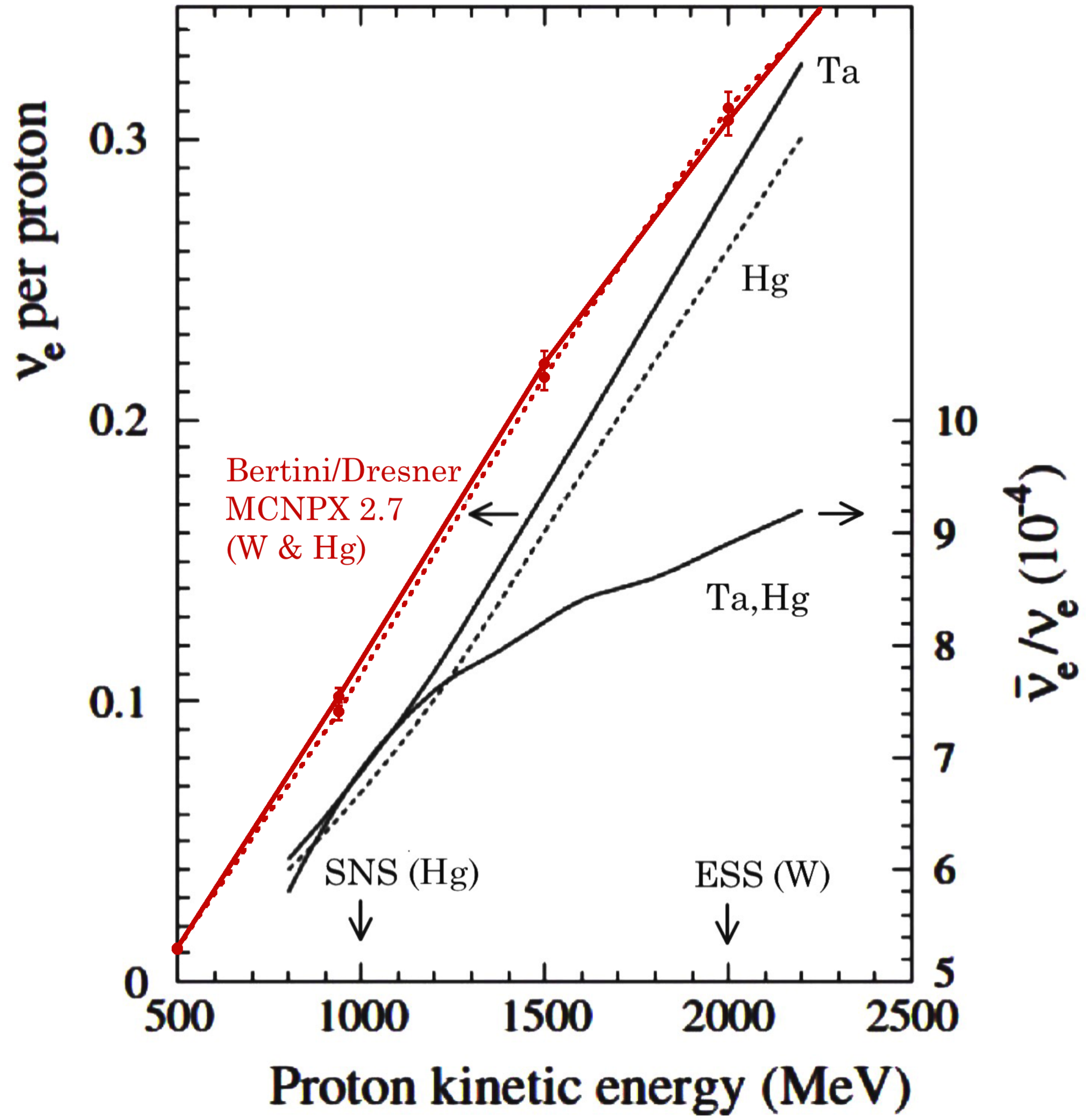


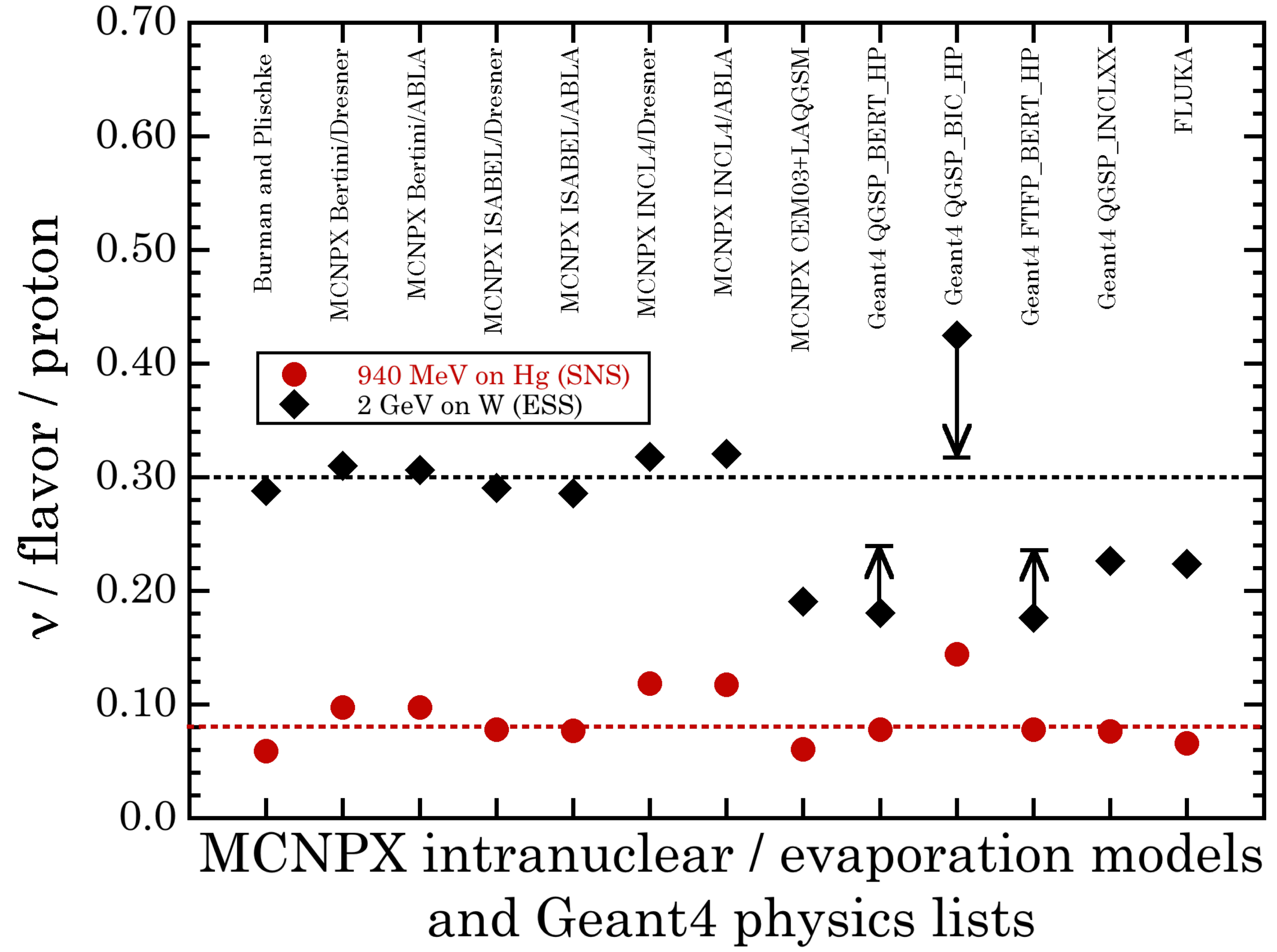
- ESS will produce the largest low energy neutrino flux of the next generation facilities.
- This is a unique opportunity that allows the use of small detectors.
- Diversity of technologies not statistically limited guarantees the phenomenological exploitation of the measurements.

A new opportunity for CEvNS

ESS vs SNS

- ν production @ ESS is x9.2 @ SNS
- Neutrino flux depends on proton current and on proton energy. ν/p grows with Ep
- signal-to-background depends on square root of duty cycle (slightly better signal/bckg at ESS).

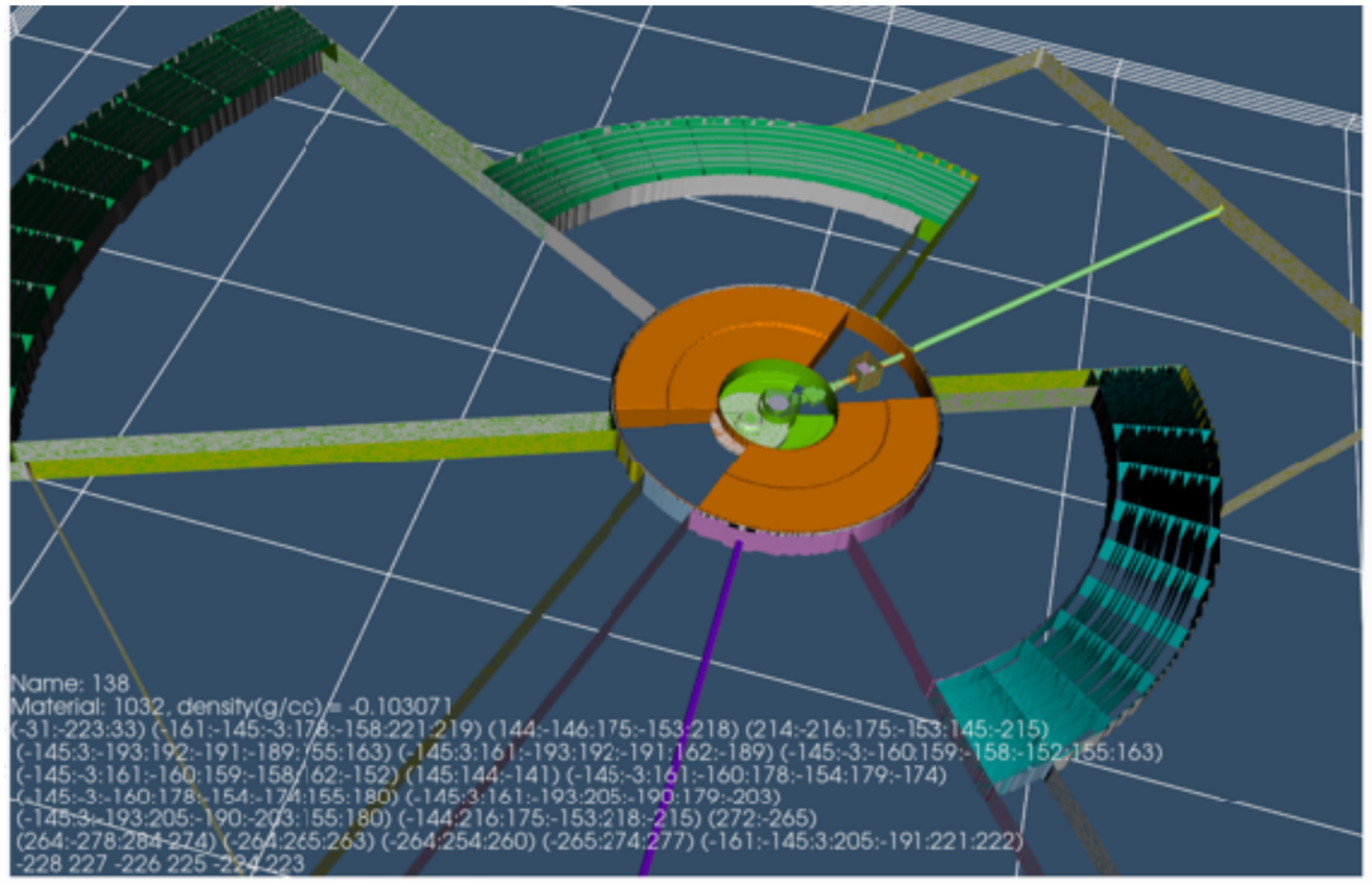




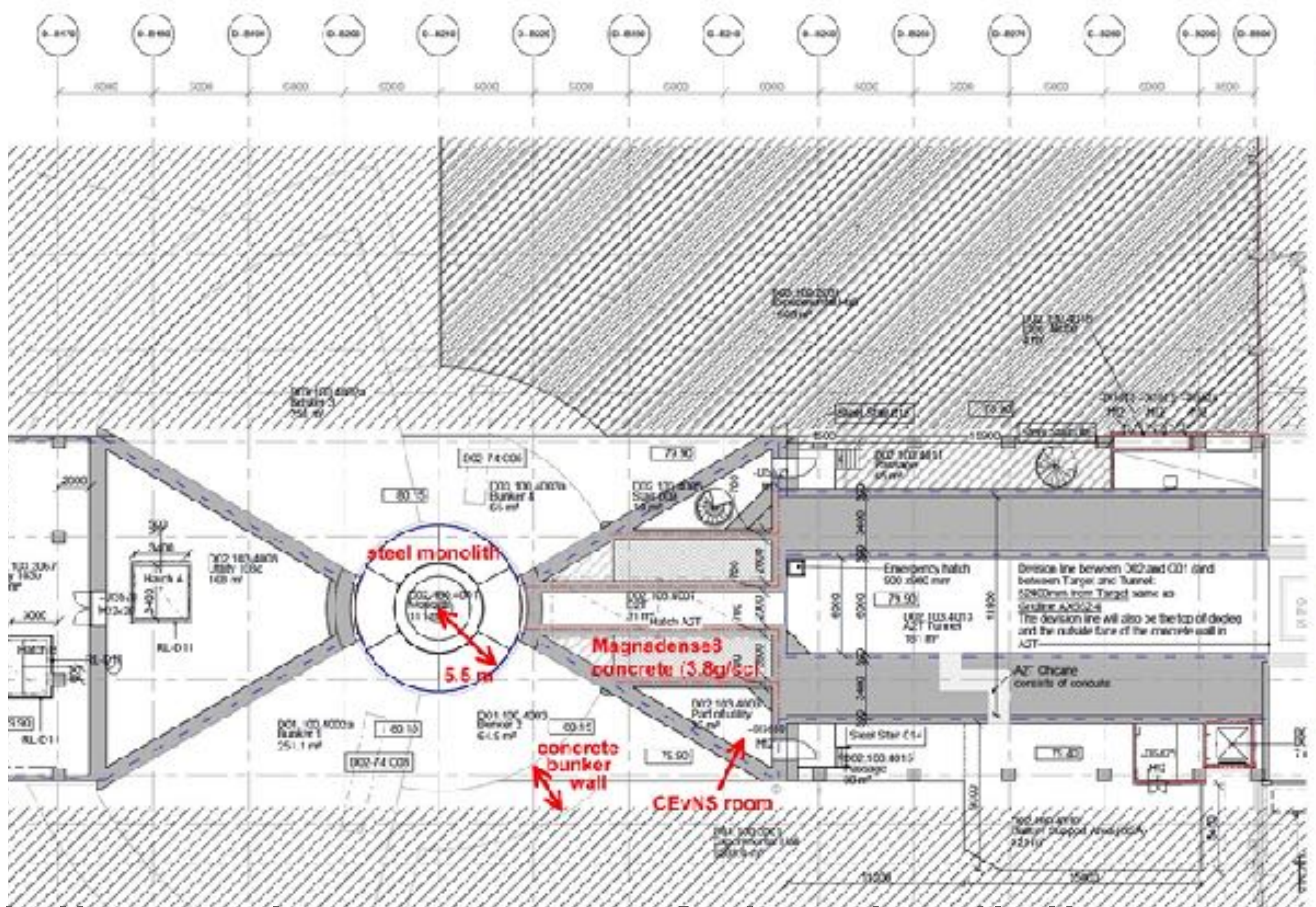
A new opportunity for CEvNS

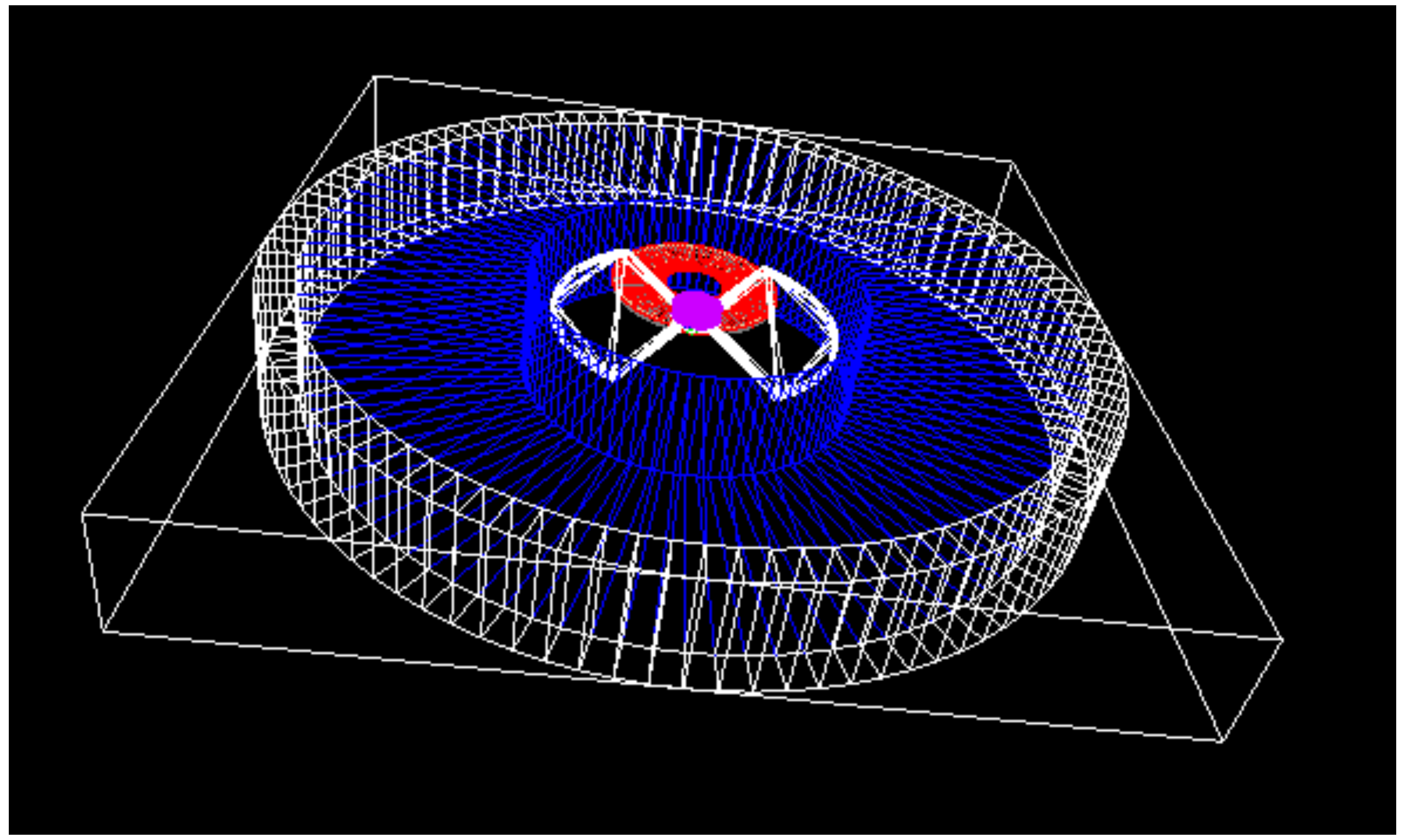
Background at the ESS

- We need to find locations where the prompt neutrons from the ESS tungsten target do not compete with CEvNS signals.
- Working together with ESS personnel, Ben Gurion University and U. Chicago.
- Two promising locations have already been identified.
- Steady-state background can be subtracted.



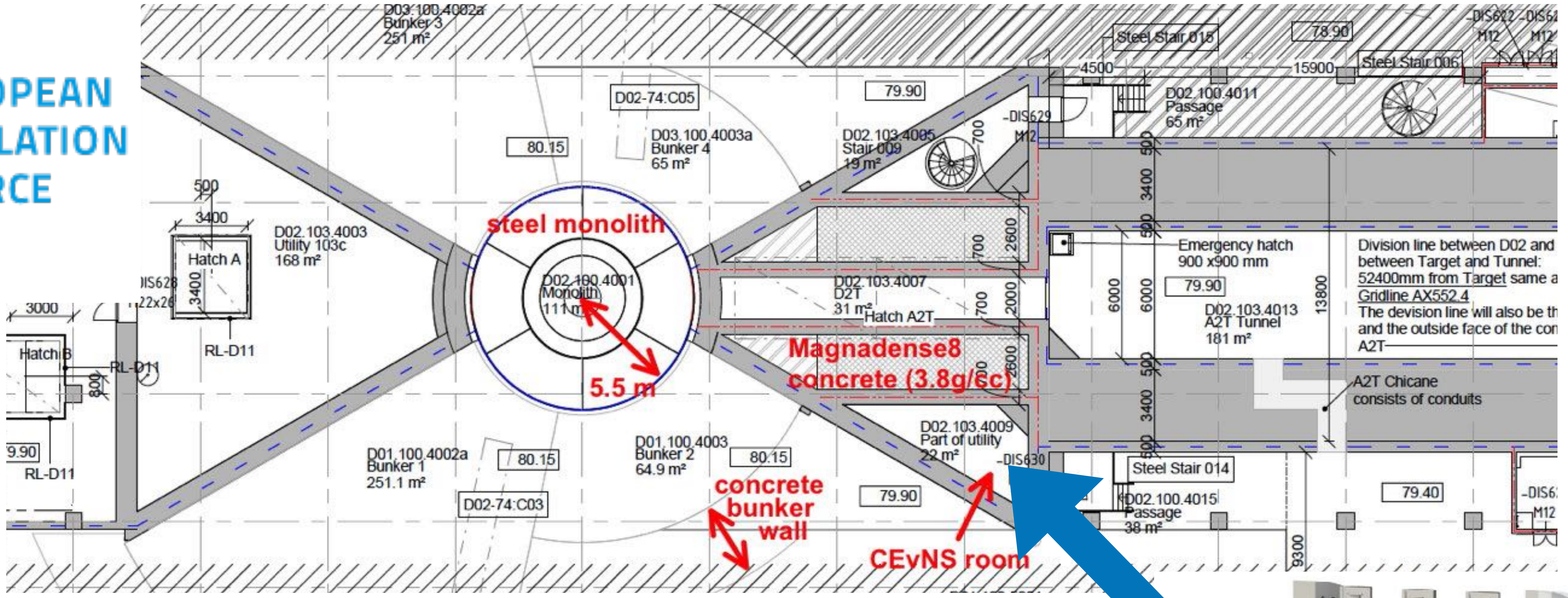
transportation code using

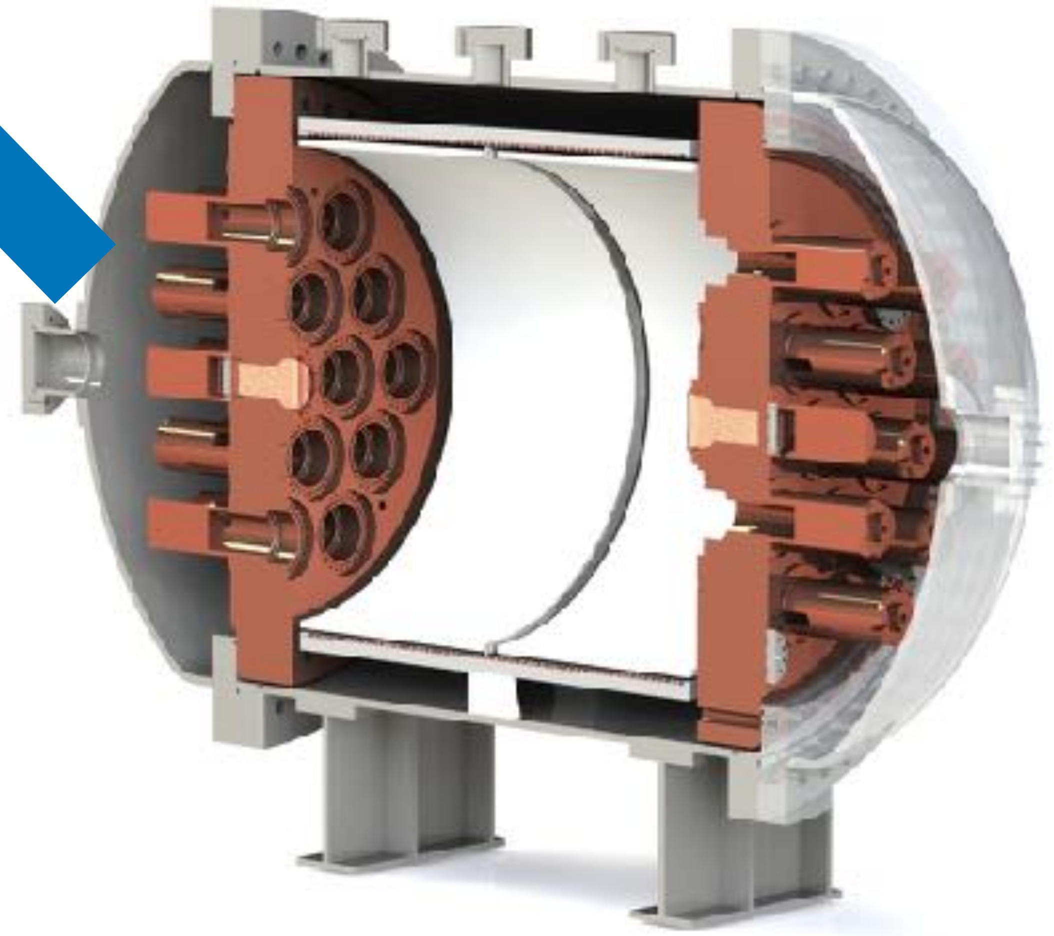




Adding elements of the building structure using NAVISWORKS 3-D layouts

Detecting CEvNS: Future observations





Need to find an appropriate place within the ESS facilities.

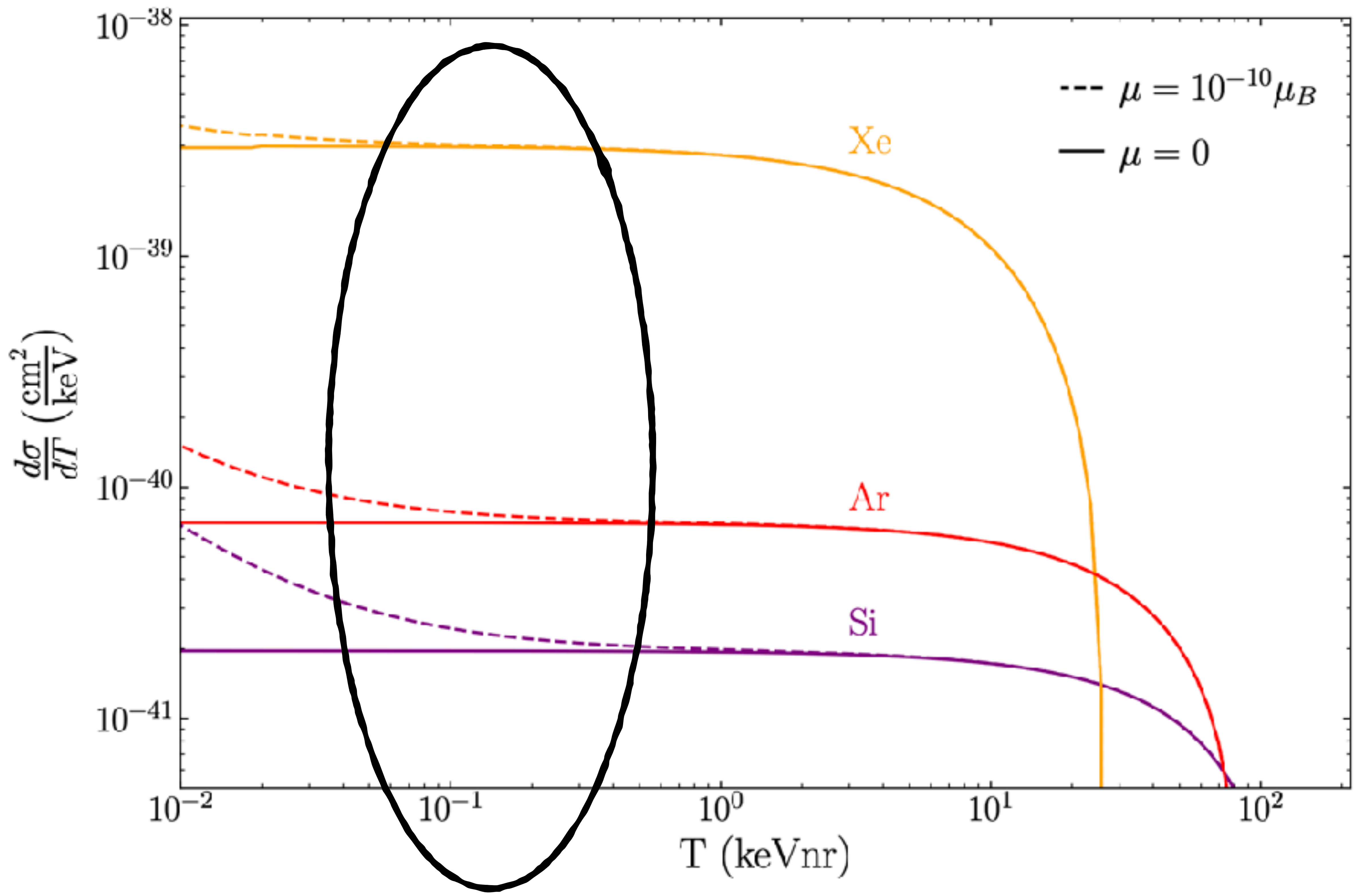
Two locations already under study.

Detecting CEvNS

Detectors

Neutrino magnetic moment, new physics!

Ultra low energy threshold is crucial



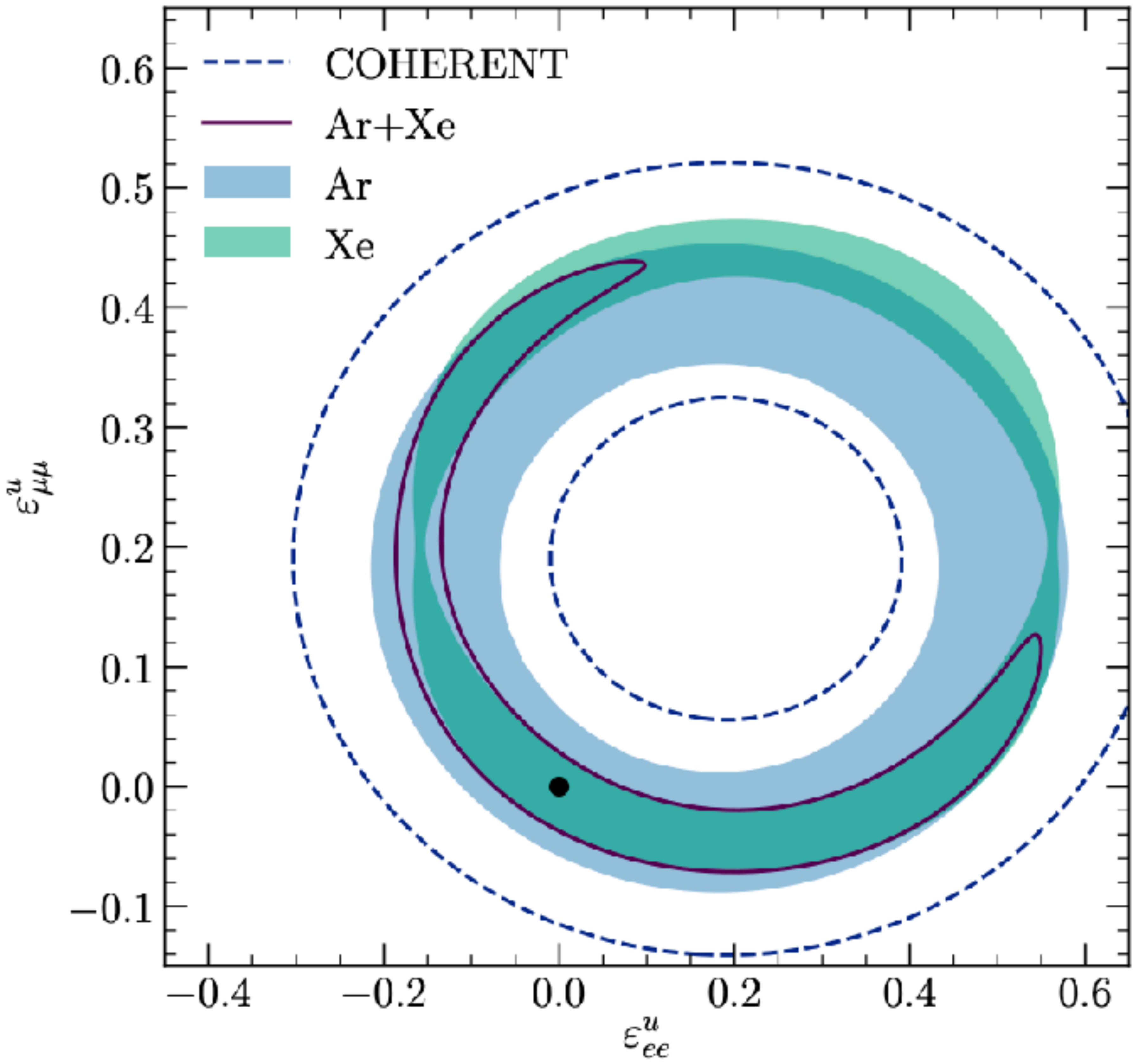
Interesting physics concentrates at low energies

Detecting CEvNS

Detectors

Non-Standard neutrino-quarks interactions

Operation with different nuclei helps breaking degeneracies

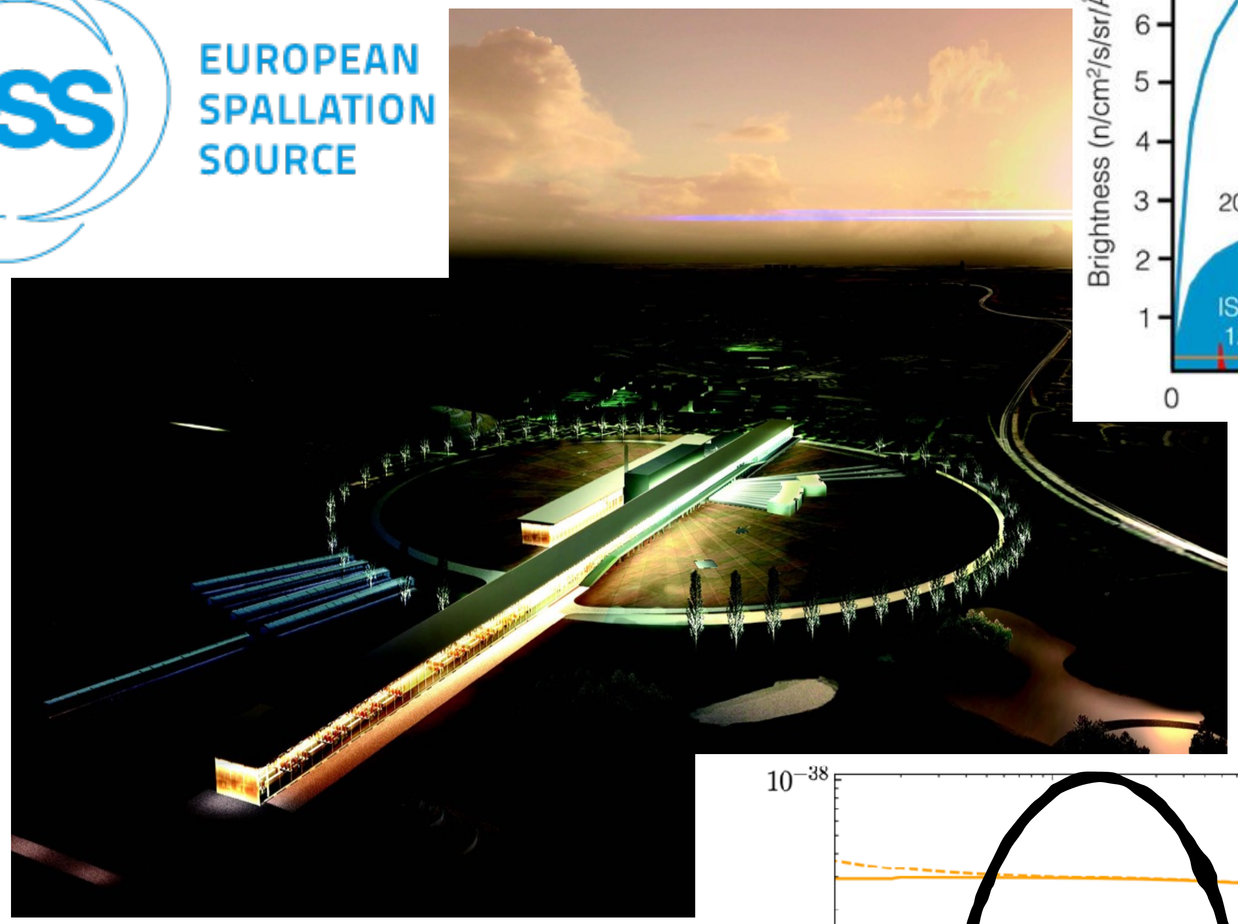


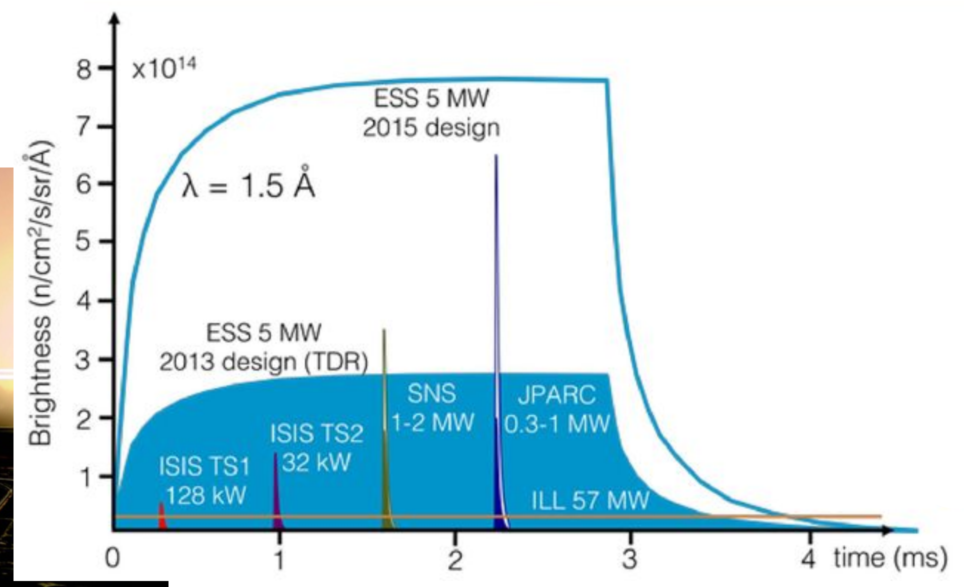
A full experimental program must allow for operation with different targets.

Detecting CEvNS

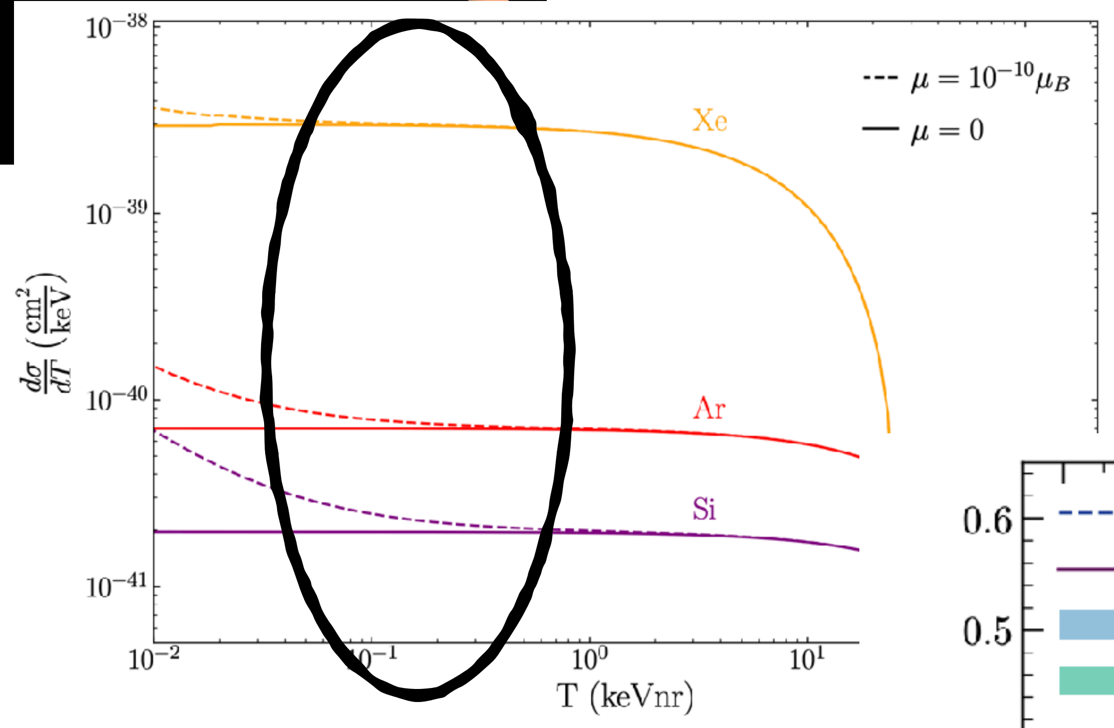
Specs.

EUROPEAN SPALLATION SOURCE

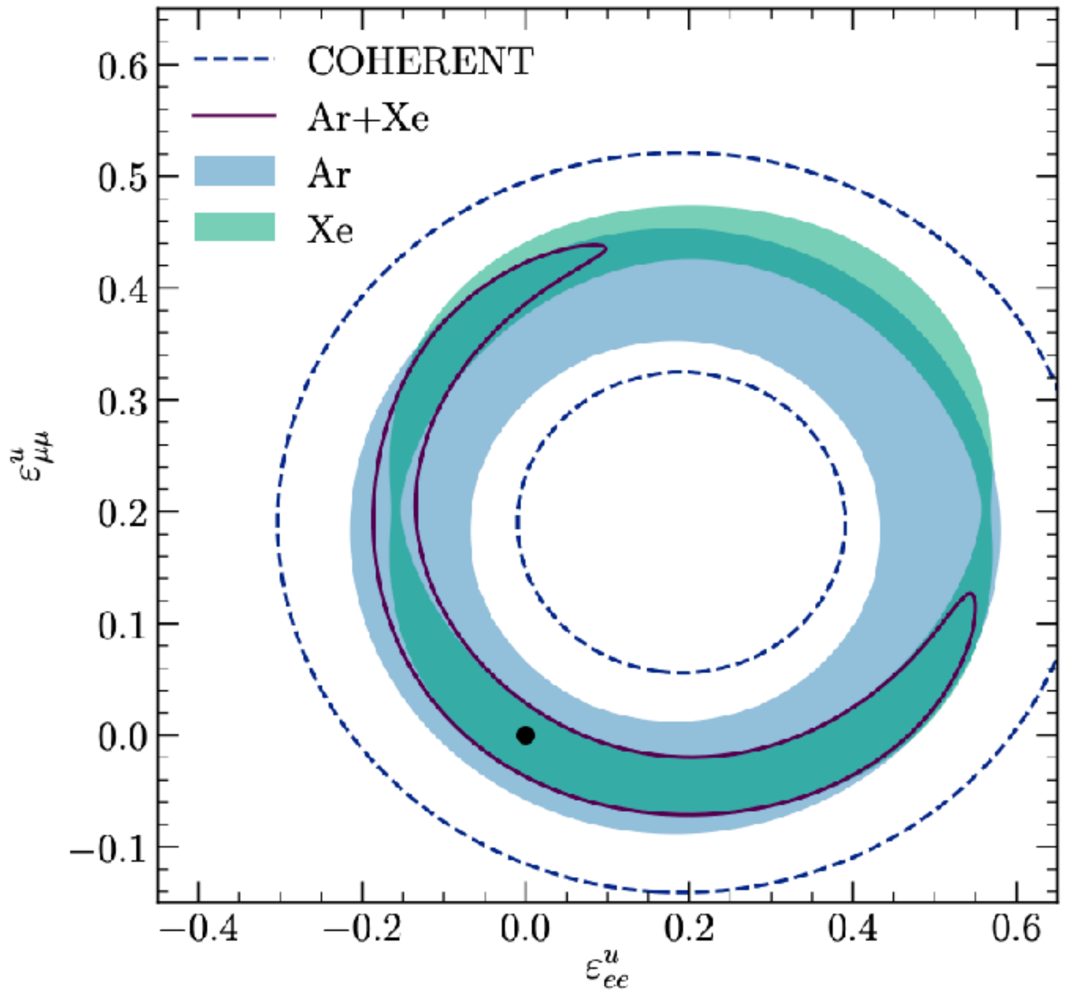




- Large flux of MeV neutrinos



- Detectors with low energy threshold



- Operation with different nuclei

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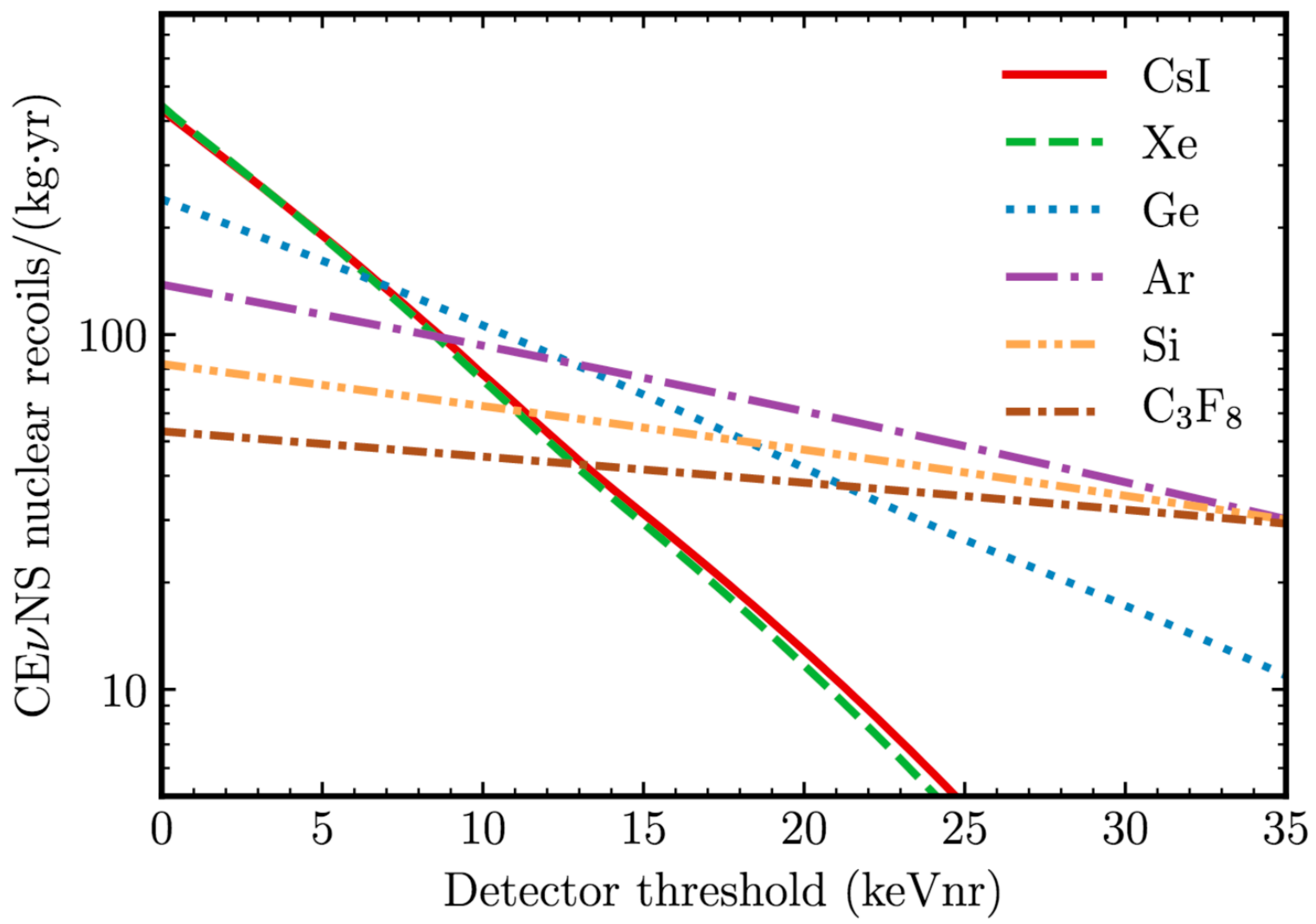
Coherent Elastic Neutrino-Nucleus Scattering at the European Spallation Source

D. Baxter,[1] J.I. Collar,[1,*] P. Coloma,[2,†] C.E. Dahl,[3,4] I. Esteban,[5,‡] P. Ferrario,[6,7,§] J.J. Gomez-Cadenas,[6,7,¶] M. C. Gonzalez–Garcia,[5,8,9,**] A.R.L. Kavner,[1] C.M. Lewis,[1] F. Monrabal,[6,7,††] J. Muñoz Vidal,[6] P. Privitera,[1] K. Ramanathan,[1] and J. Renner[10]

Detector Technology	Target nucleus	Mass (kg)	Steady-state background	E_{th} (keV_{ee})	QF (%)	E_{th} (keV_{nr})	$\Delta E/E$ (%) at E_{th}	E_{max} (keV_{nr})	CEνNS NR/yr @20m, $>E_{th}$
Cryogenic scintillator	CsI	22.5	10 ckkd	0.1	~10 [71]	1	30	46.1	8,405
Charge-coupled device	Si	1	1 ckkd	0.007 (2e⁻)	4-30 [97]	0.16	60	212.9	80
High-pressure gaseous TPC	Xe	20	10 ckkd	0.18	20 [104]	0.9	40	45.6	7,770
p-type point contact HPGe	Ge	7	15 ckkd	0.12	20 [118]	0.6	15	78.9	1,610
Scintillating bubble chamber	Ar	10	0.1 c/kg-day	-	-	0.1	~40	150.0	1,380
Standard bubble chamber	C_3F_8	10	0.1 c/kg-day	-	-	2	40	329.6	515

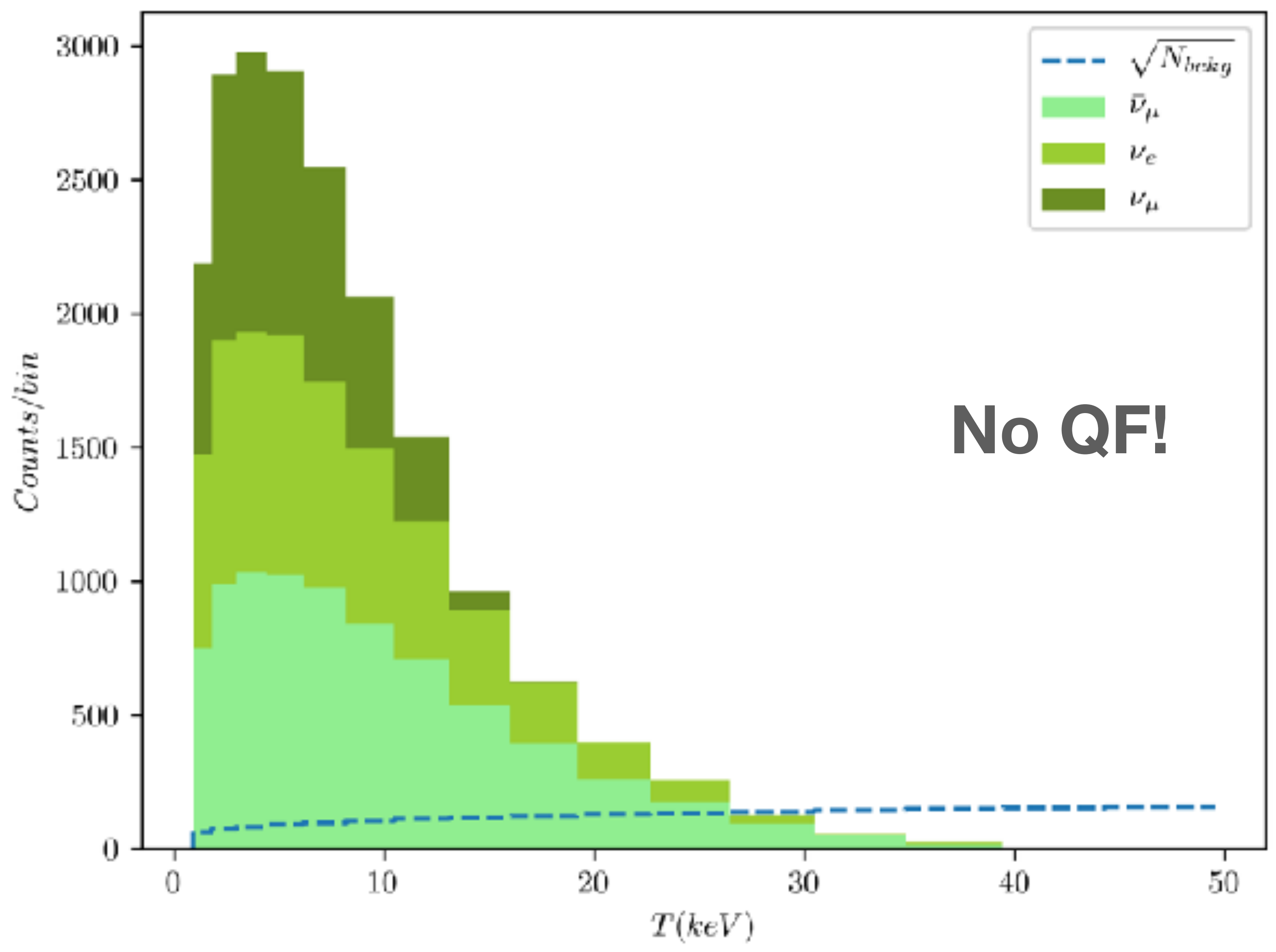


- Technologies sensitive to 1 keVnr nuclear recoils:
  - Interesting physics concentrates at low-E (e.g. n magnetic moment).
  - Maximum statistics.
- Interesting CsI/Xe overlap (same response, different systematics)
- Gas detectors one of the relevant technologies.

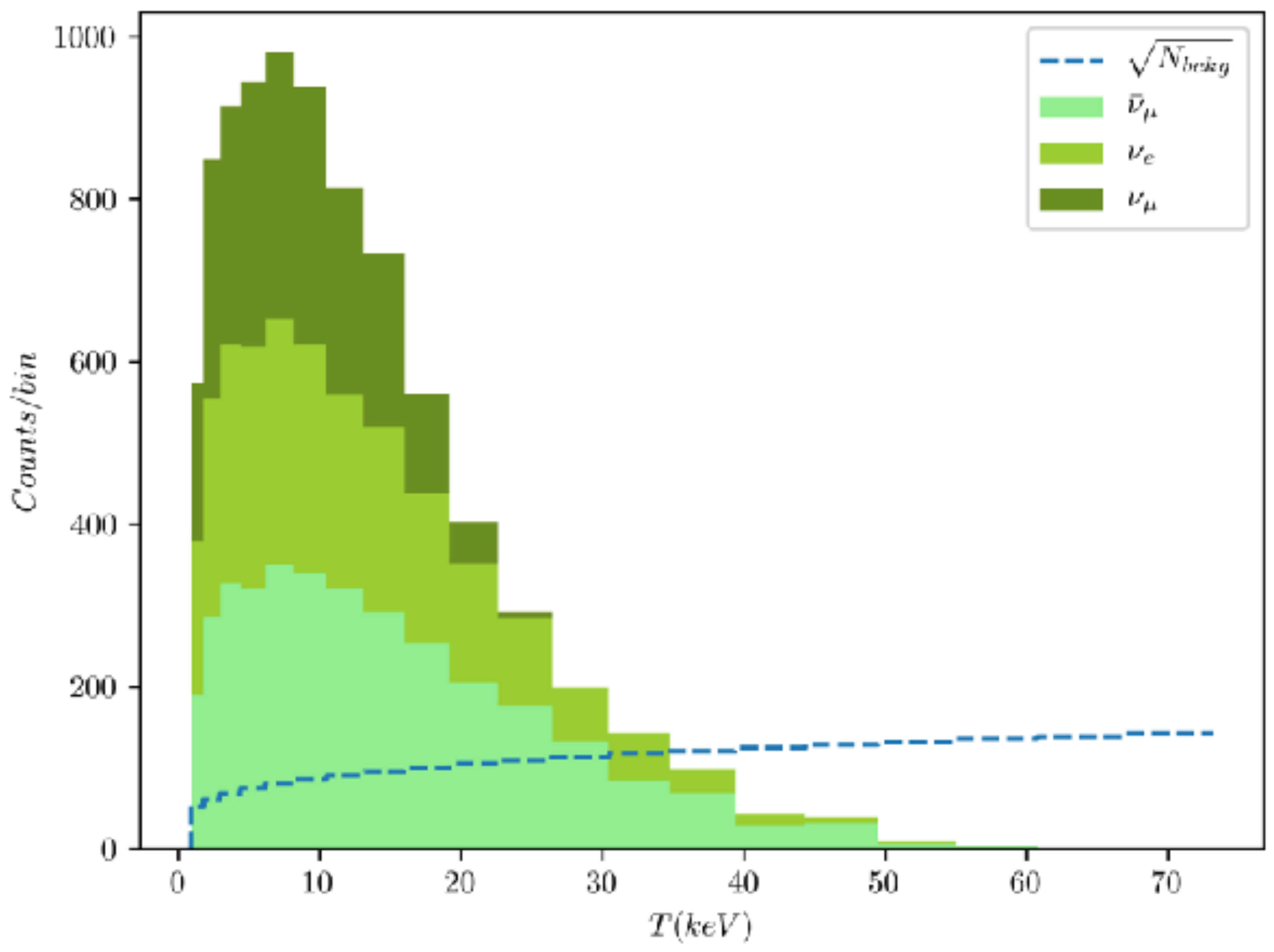
Gaseous detectors?

The main problem with gaseous detectors is their relatively low density when compared with solid scintillators (CsI) or liquid detectors.

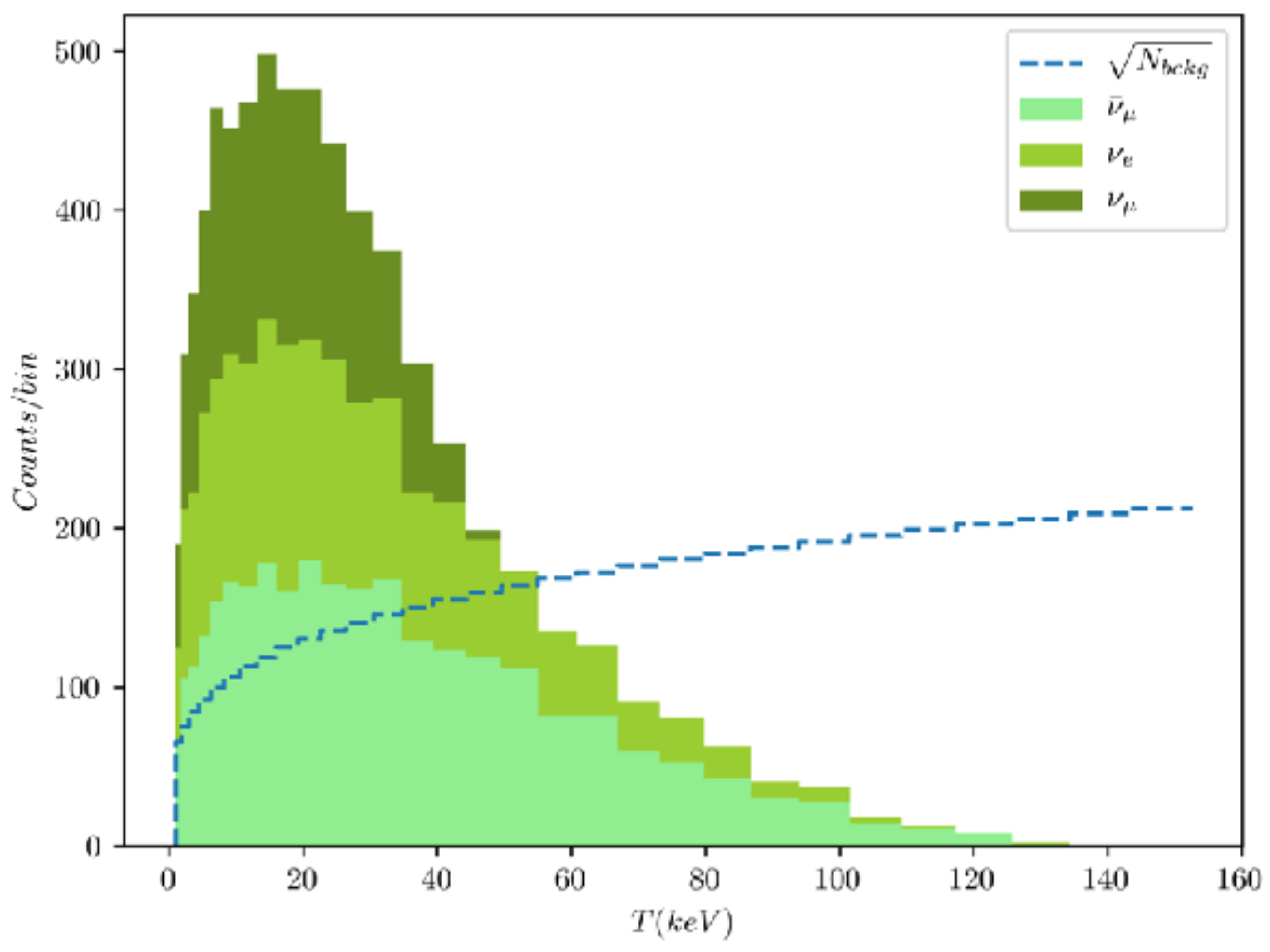
Thanks to the large neutrino flux produced by the ESS, detectors with ~20 kg won't be limited by statistics



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



Same detector filled with Krypton

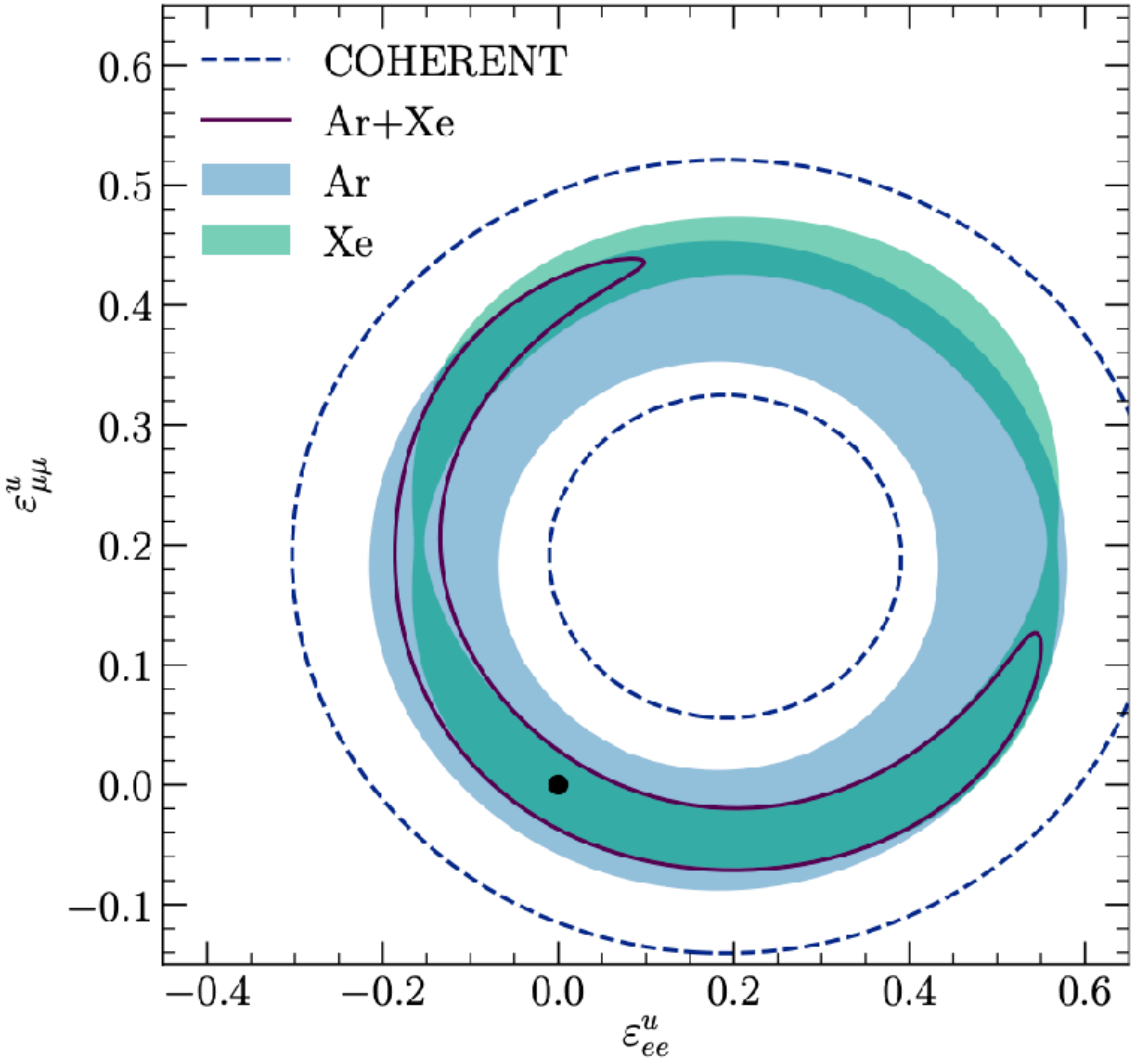


Same detector filled with Argon

Gaseous detectors?

High pressure gaseous detector have other advantages:

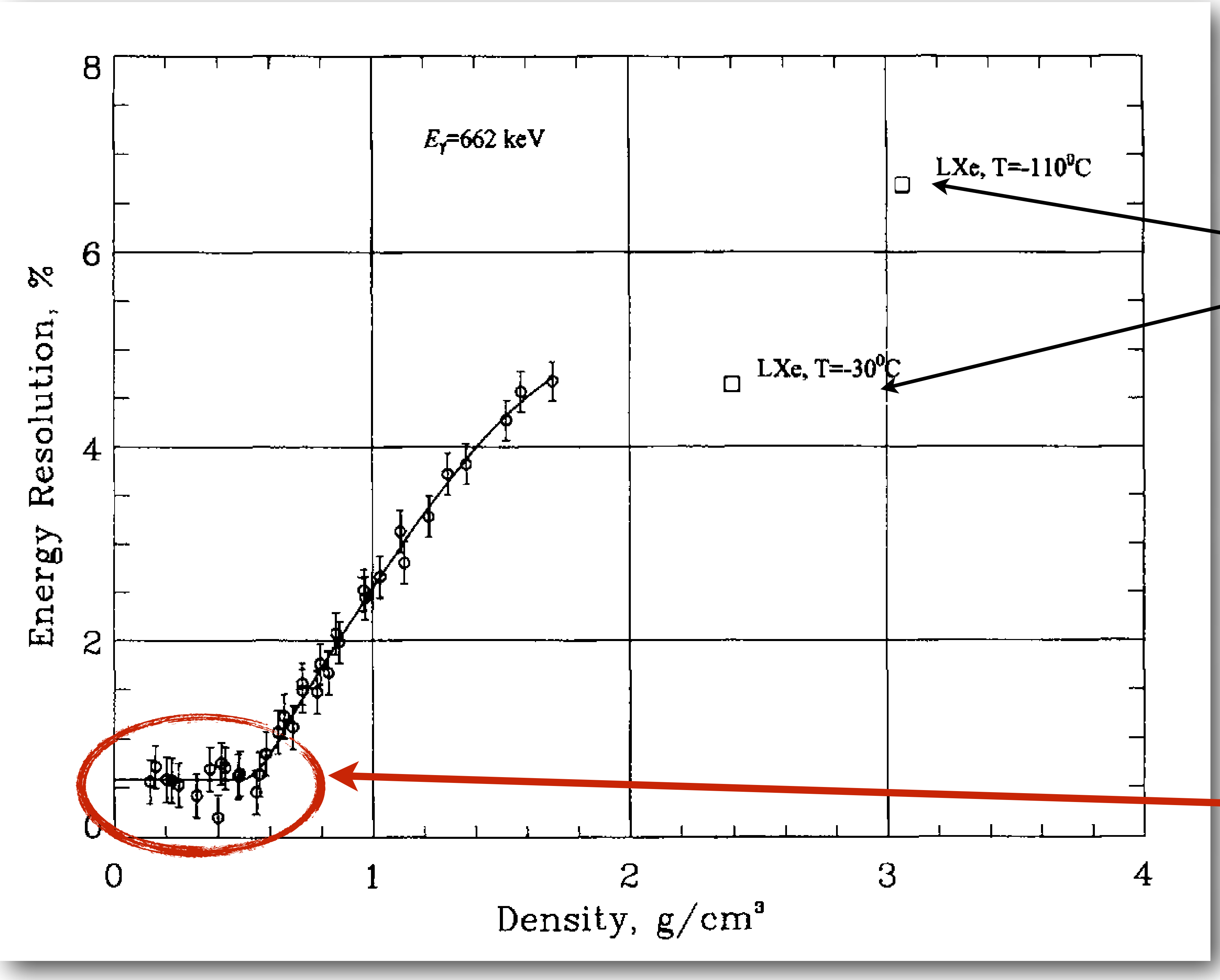
- Simpler, no need of a cryogenic system.
- Larger EL amplification: Signals as low as 1-2 ionized electrons can be detected. This reduces the expected energy threshold to less than 1 keVee.
- Allow to operate with different nuclei in the same set-up with minimal increase of the costs.
- High pressure xenon technology developed by the NEXT collaboration for bb0v searches.
    - Most of the solutions already developed for low-background experiments.
    - Some R&D will be needed for very low energies, and possible higher pressures.



Sensitivity to non-standard neutrino interaction for a detector running with Xe only, Ar only, and a combination of both

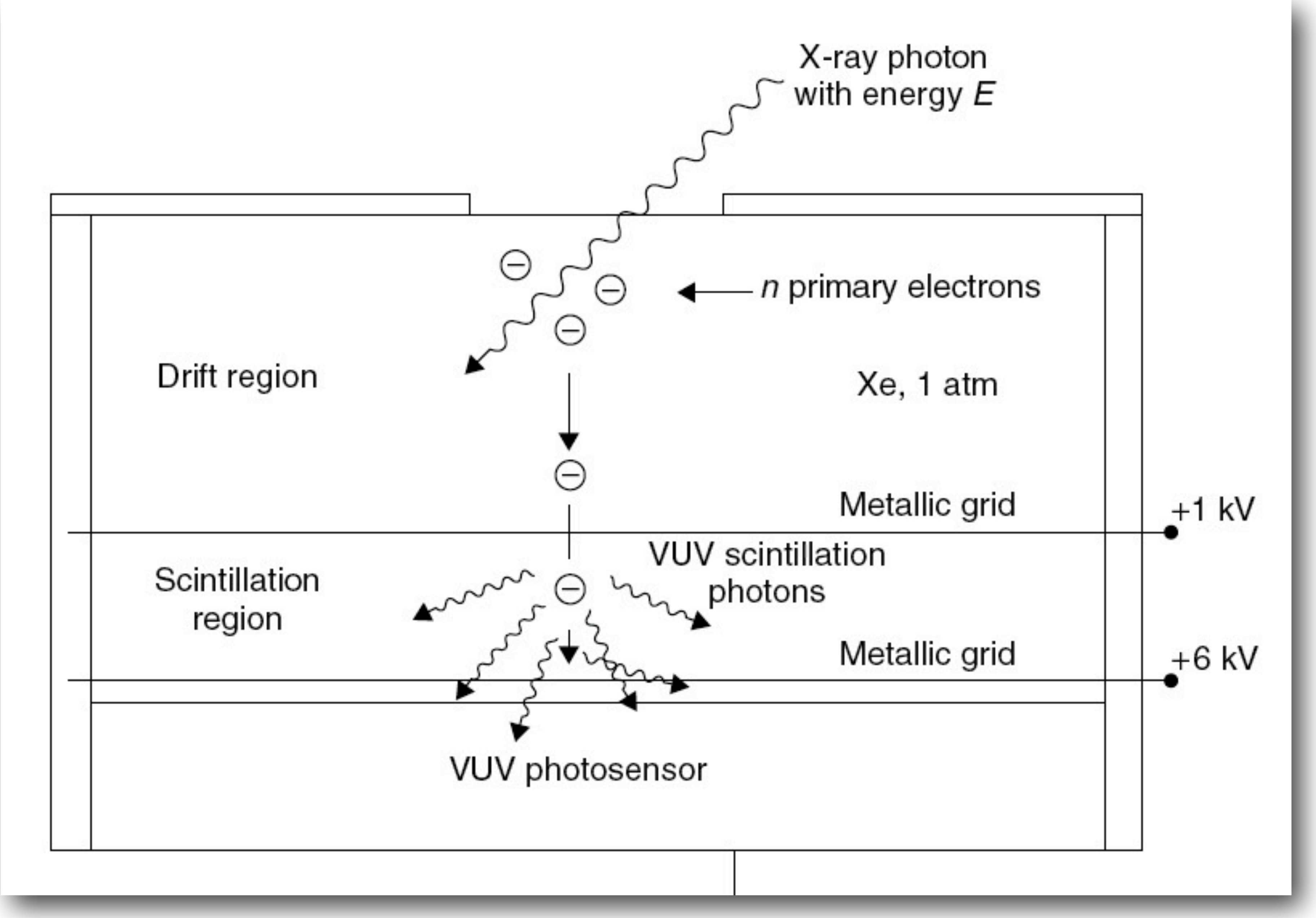
Energy resolution in HPXe

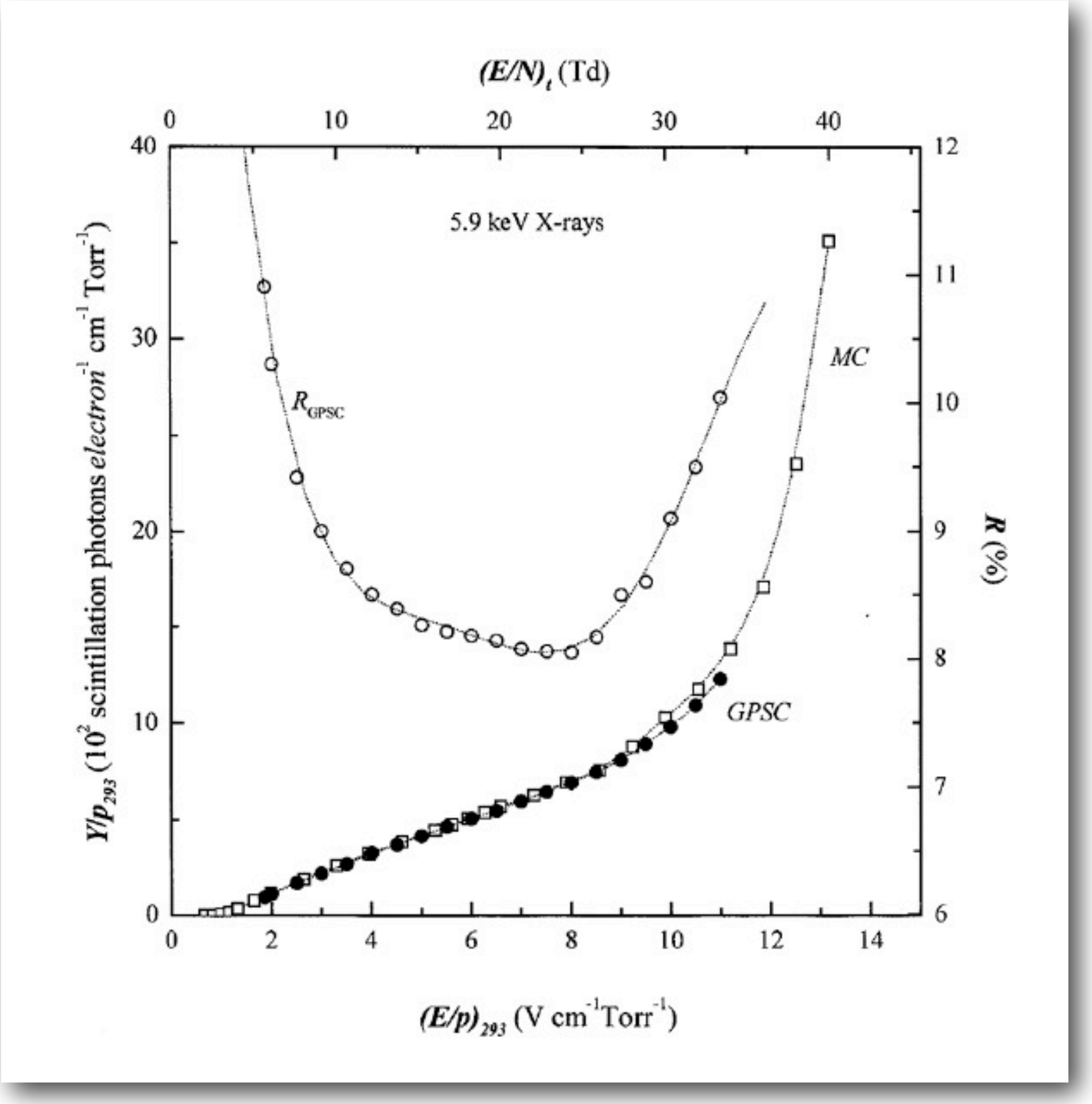
Bolotnikov and Ramsey,
NIM A 396 (1997)



- Very good energy resolution up to ~50 bar.
- Best experimental result: 0.6%@662keV.
- It will allow for a better spectrum reconstruction, thus better sensitivity to deviations from SM.

Amplification preserving resolution: Electroluminescence

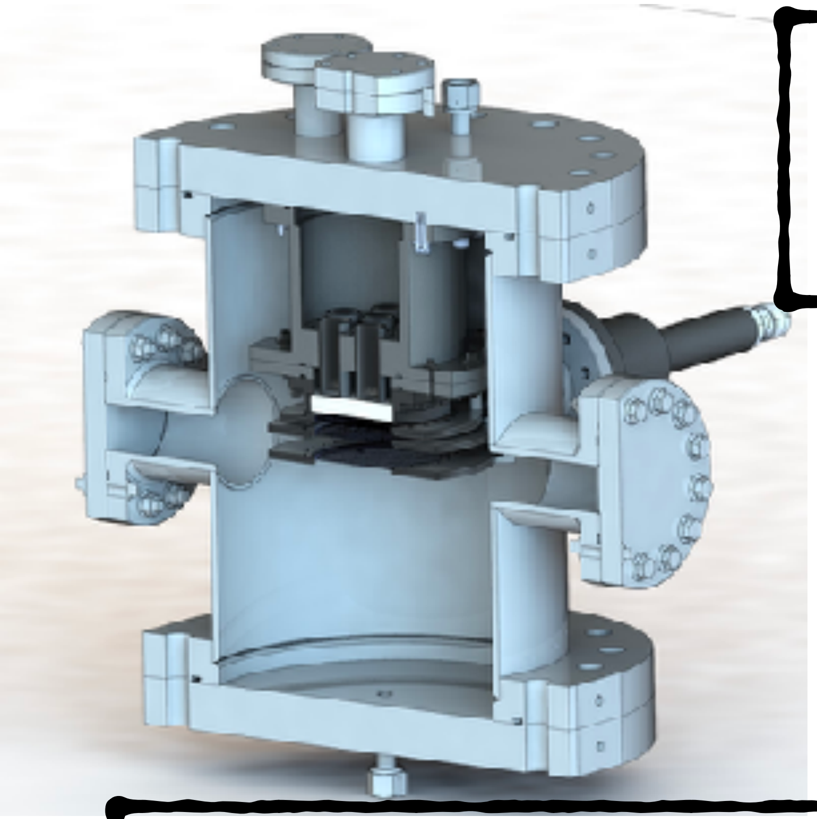




- Emission of scintillation light after atom excitation by a charge accelerated by a moderately large (no charge gain) electric field.
- Linear process, huge gain (1500 ph./e-) at $3 < E/p < 6$ kV/cm/bar.
- Almost no extra fluctuations during the amplification process.
- More stable at high pressure, no need of quenchers.

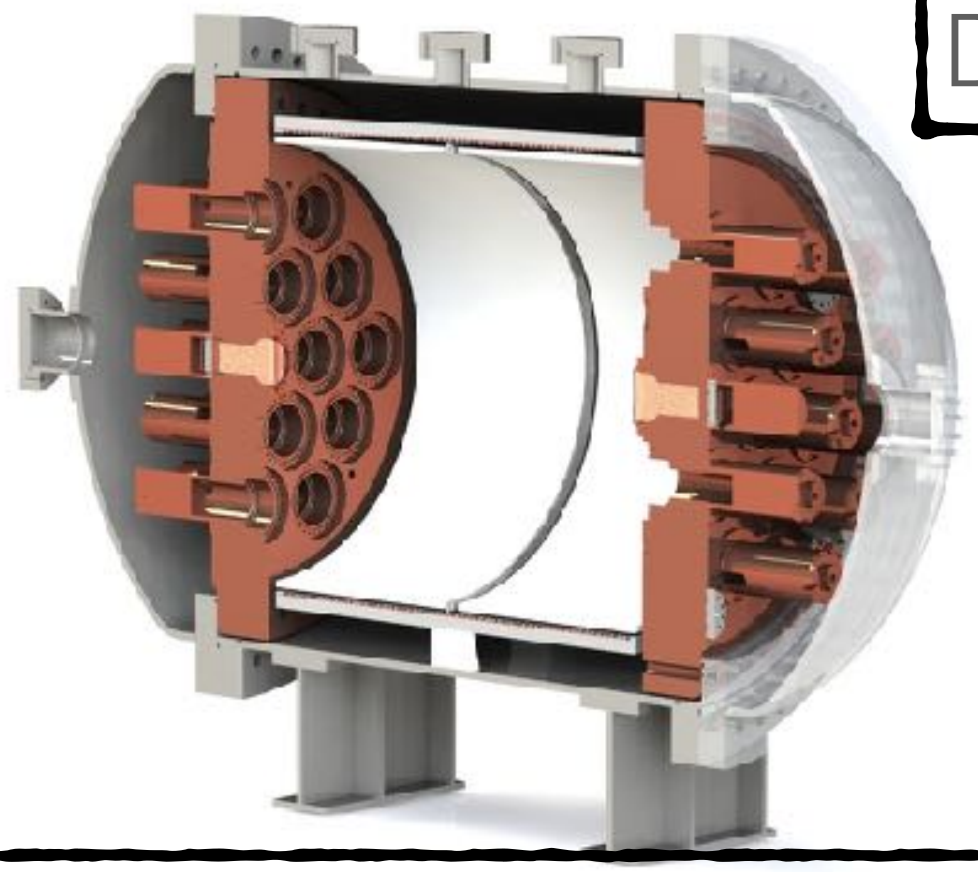
GaNESS project

Initial steps



Gaseous Prototype (GaP)

R&D,
Study of
nuclear recoils



Detector construction, GanESS@DIPC

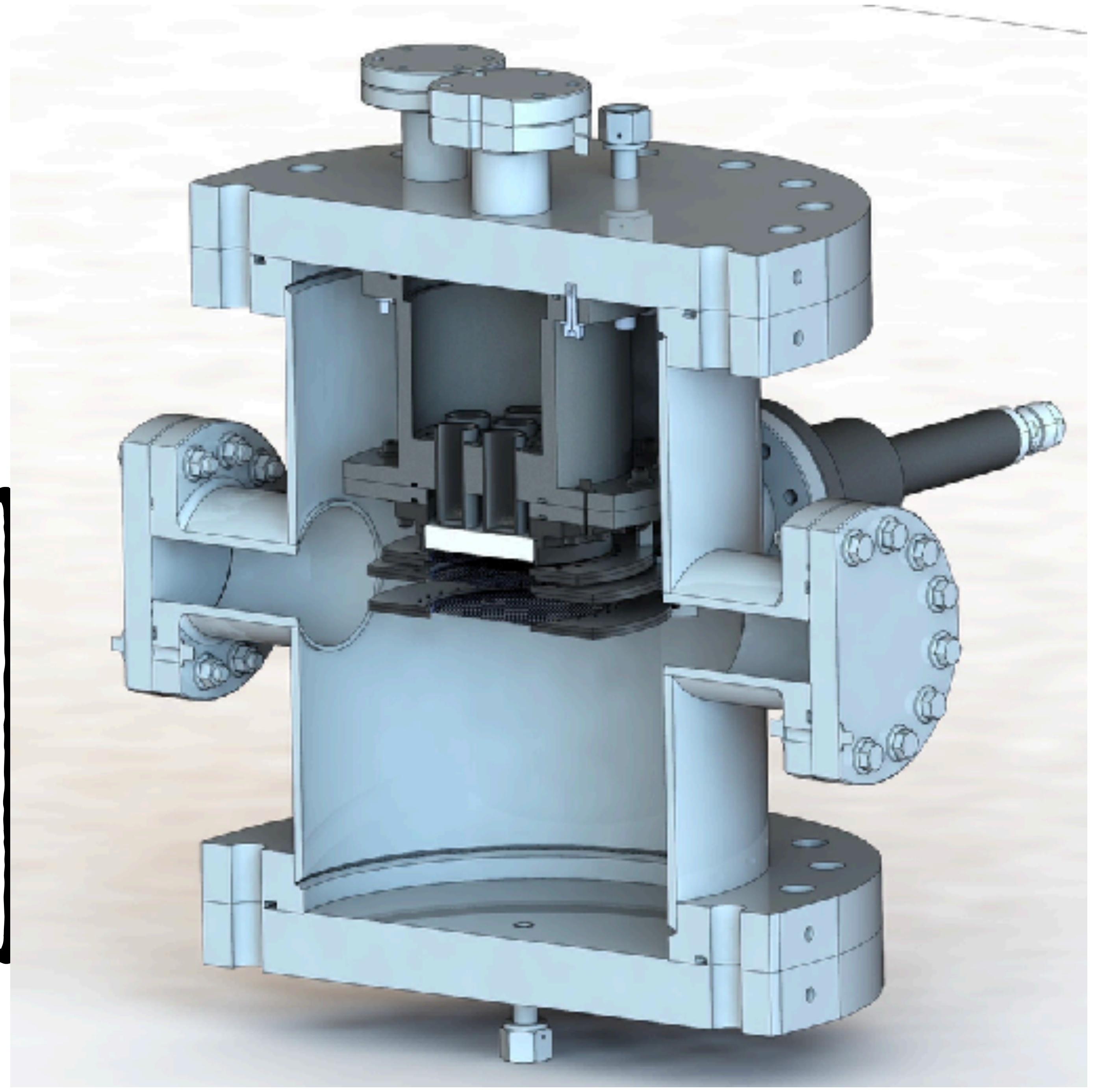
High pressure technology developed by the PI within the NEXT experiment

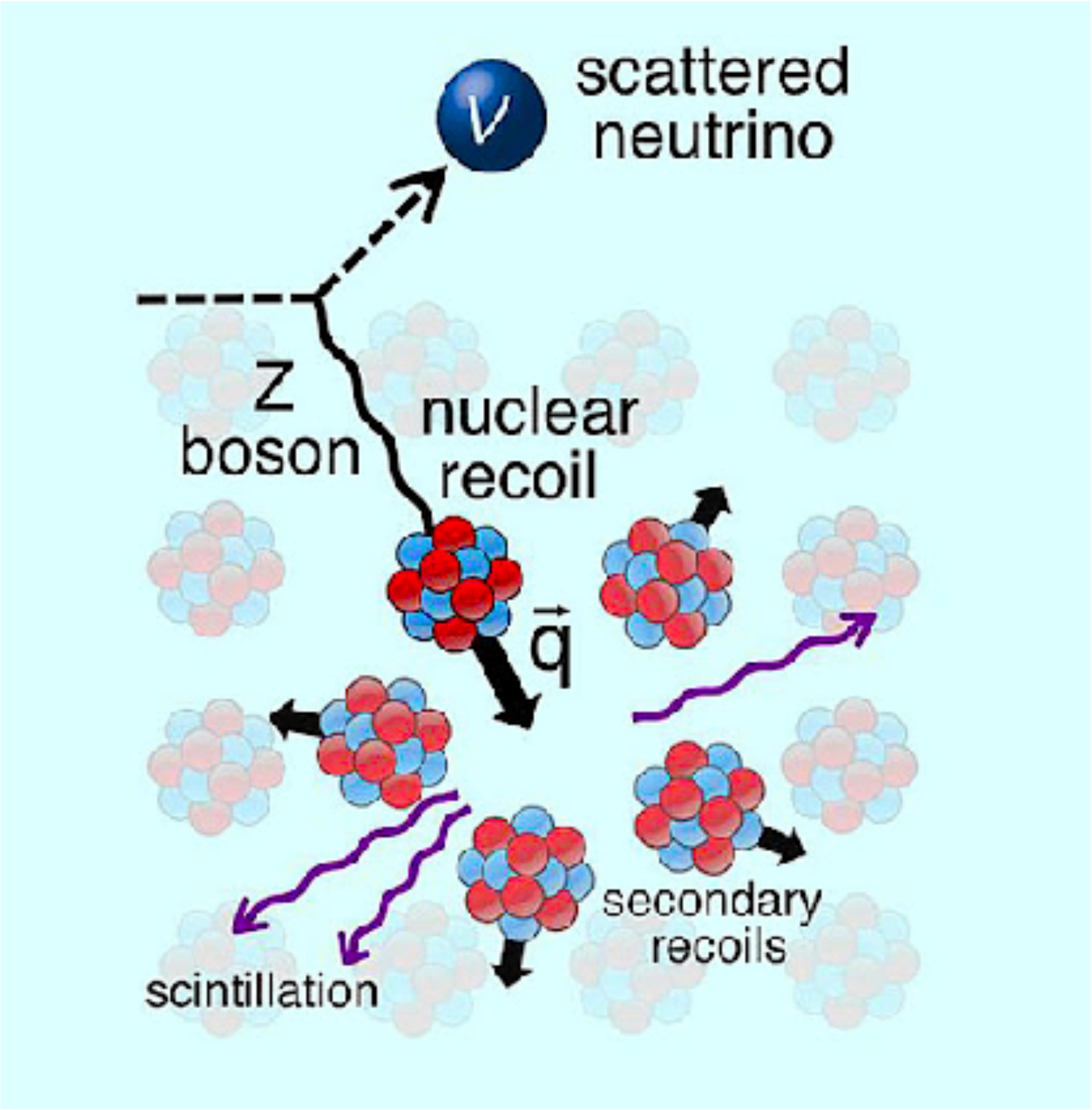
Operation GanESS@ ESS

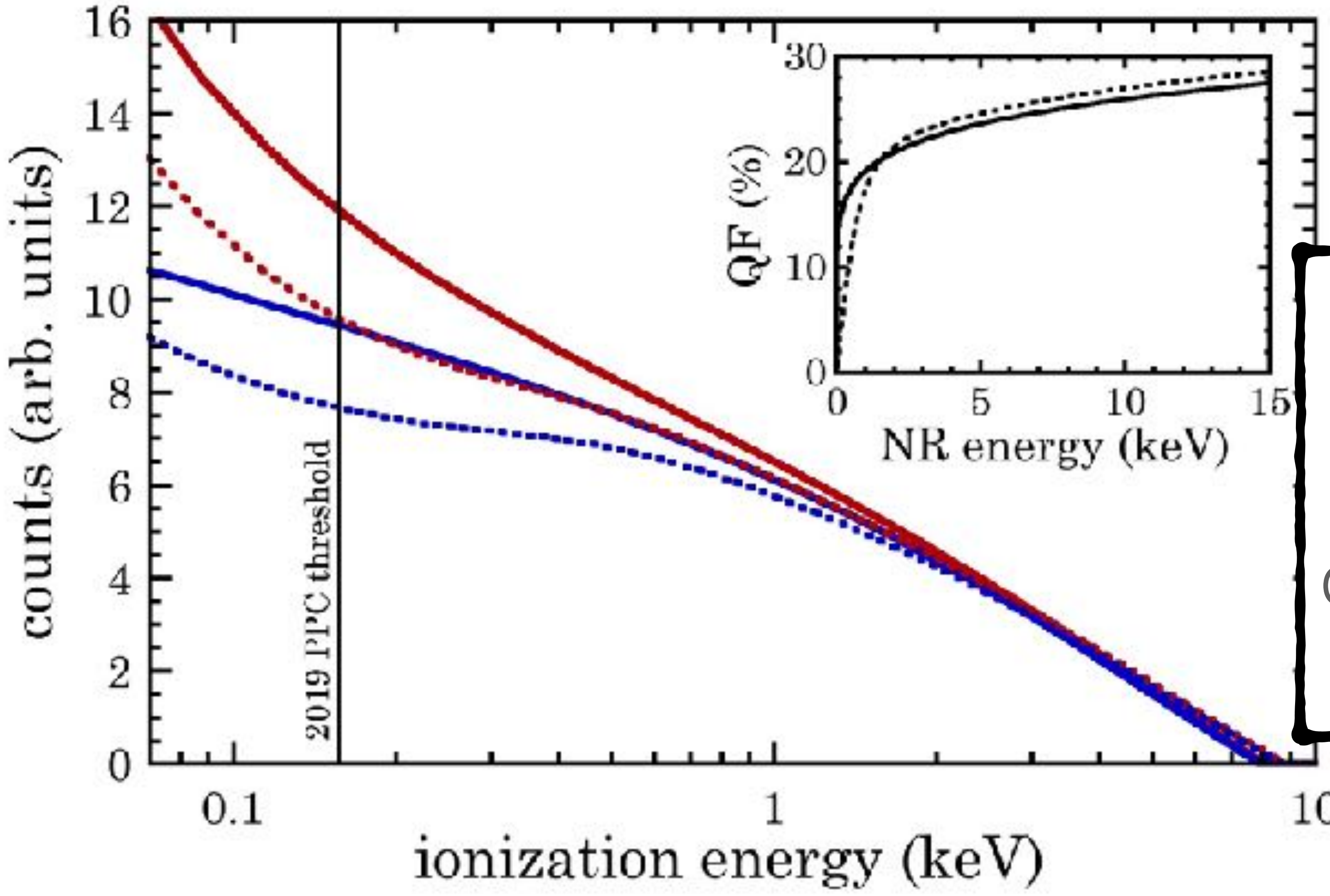
GaNESS project: GaP

The Gaseous Prototype (GaP) system

- Test for high pressure (up to 50 bar) and operation with different gases.
- Characterisation of the **response to nuclear recoil** at low energies.

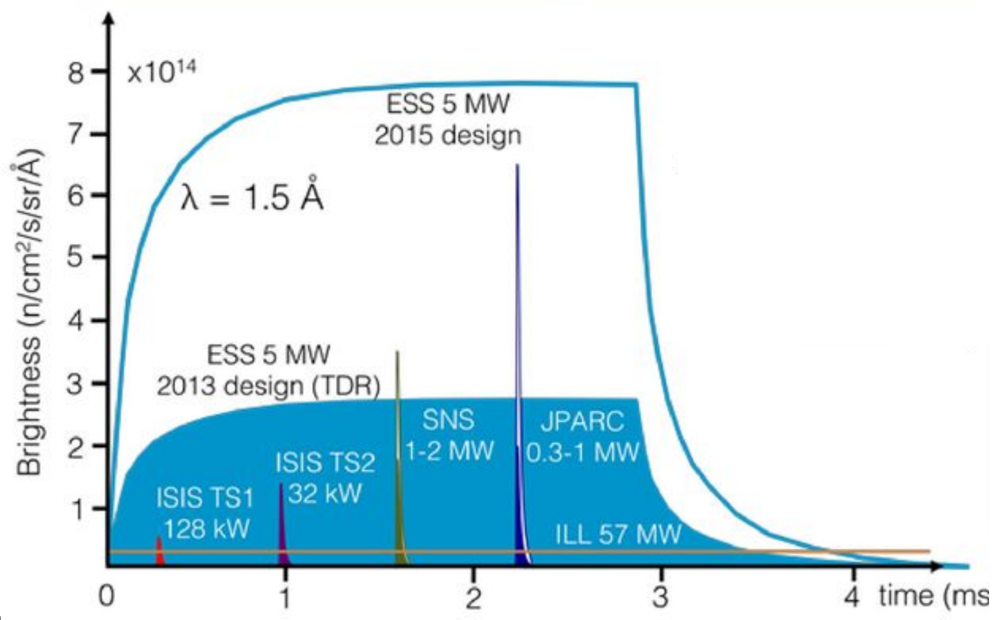


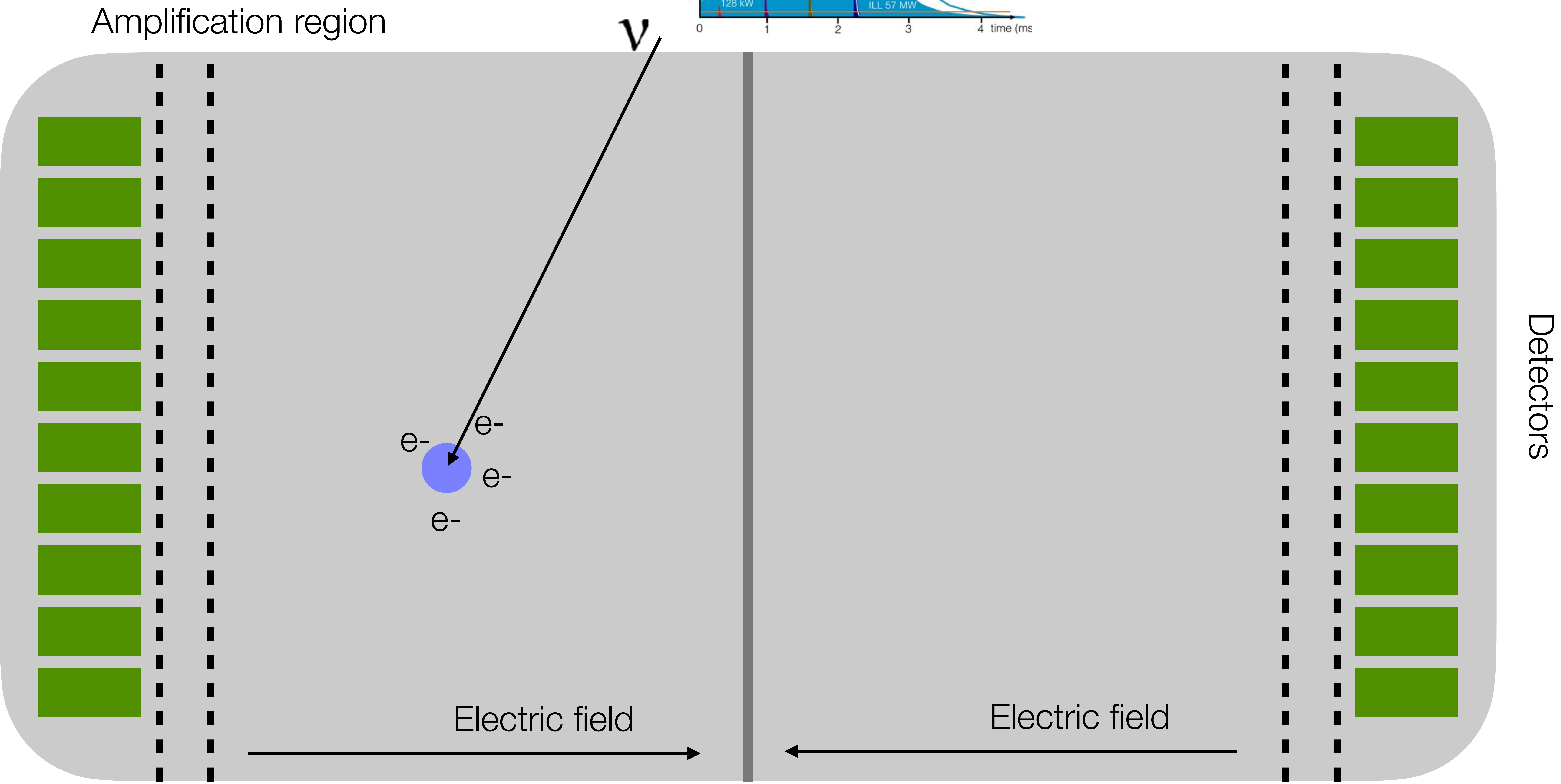




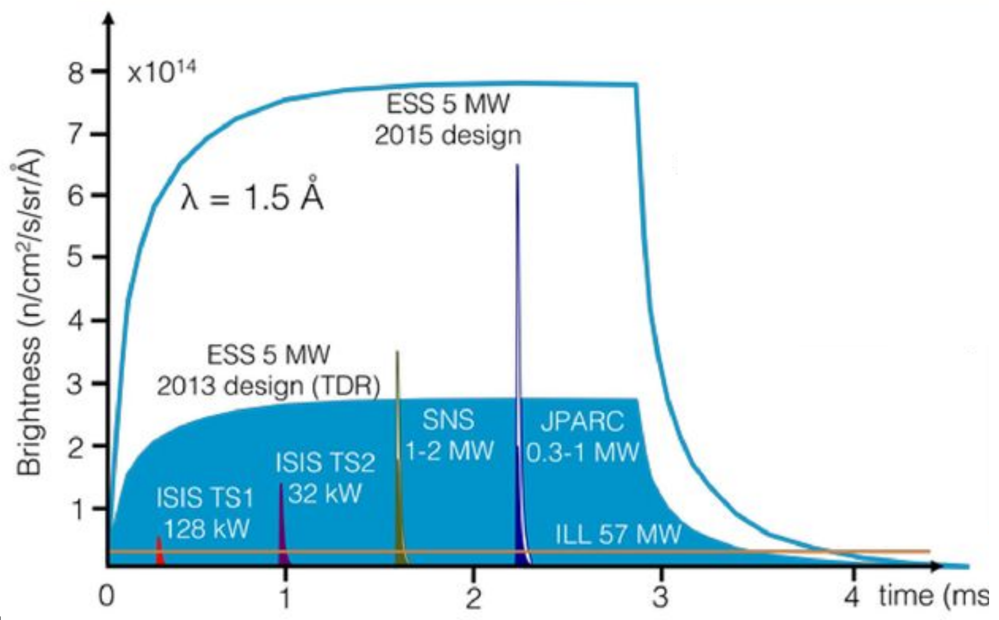
Expected number of events for different values of the neutrino magnetic moment (blue-red) and different models of the quenching factor (solid-dashed)

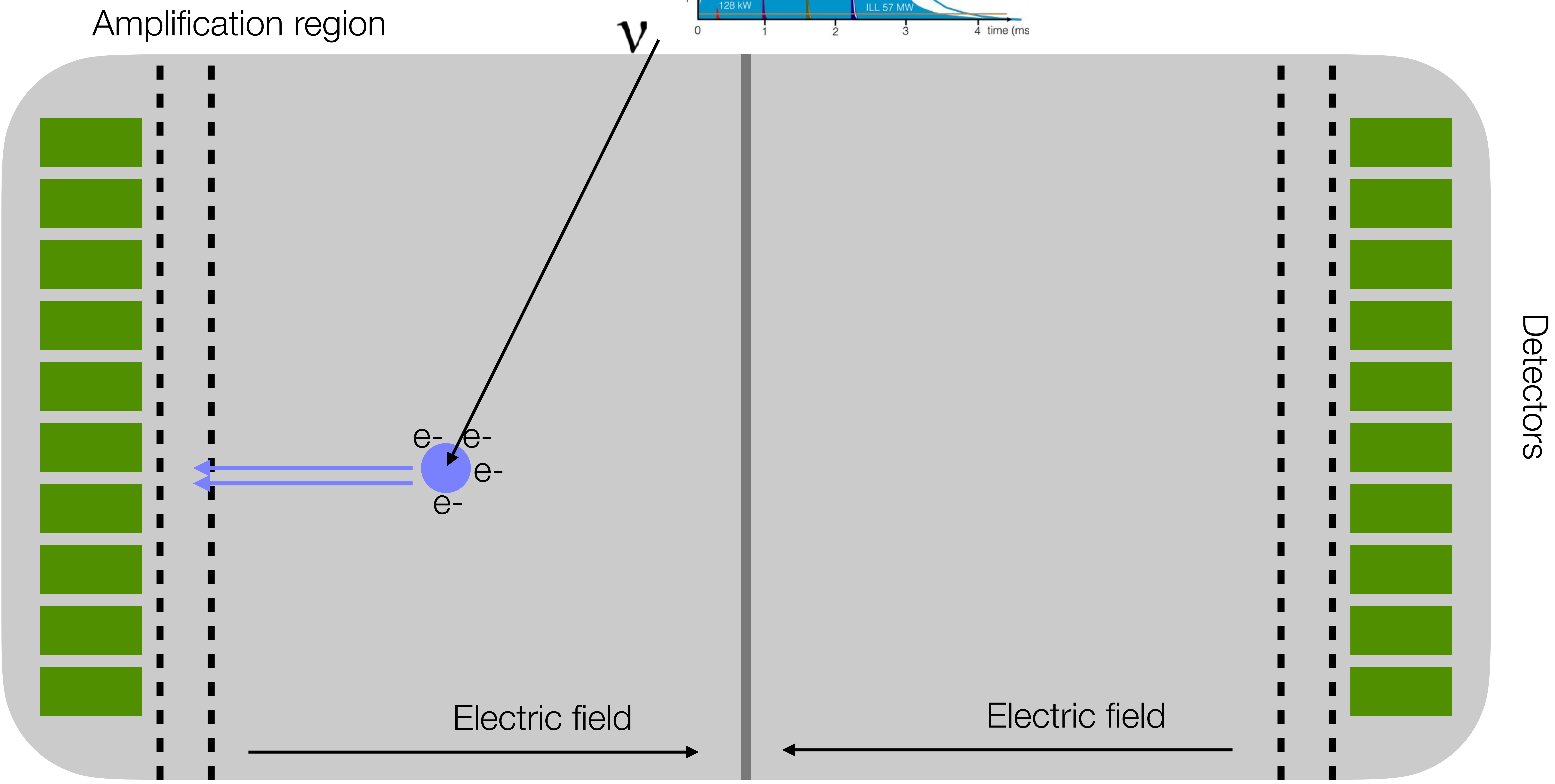
GanESS concept



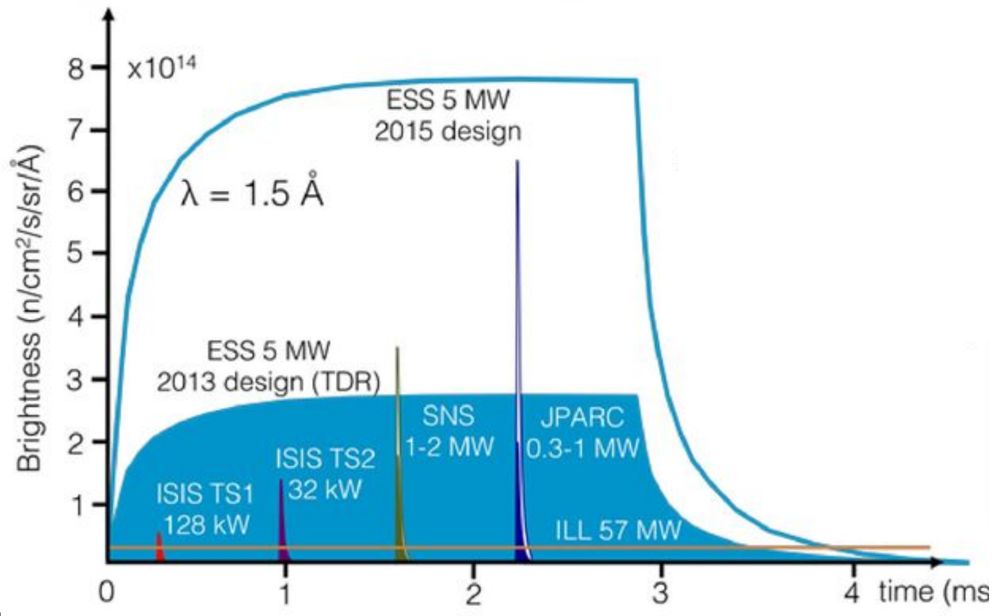


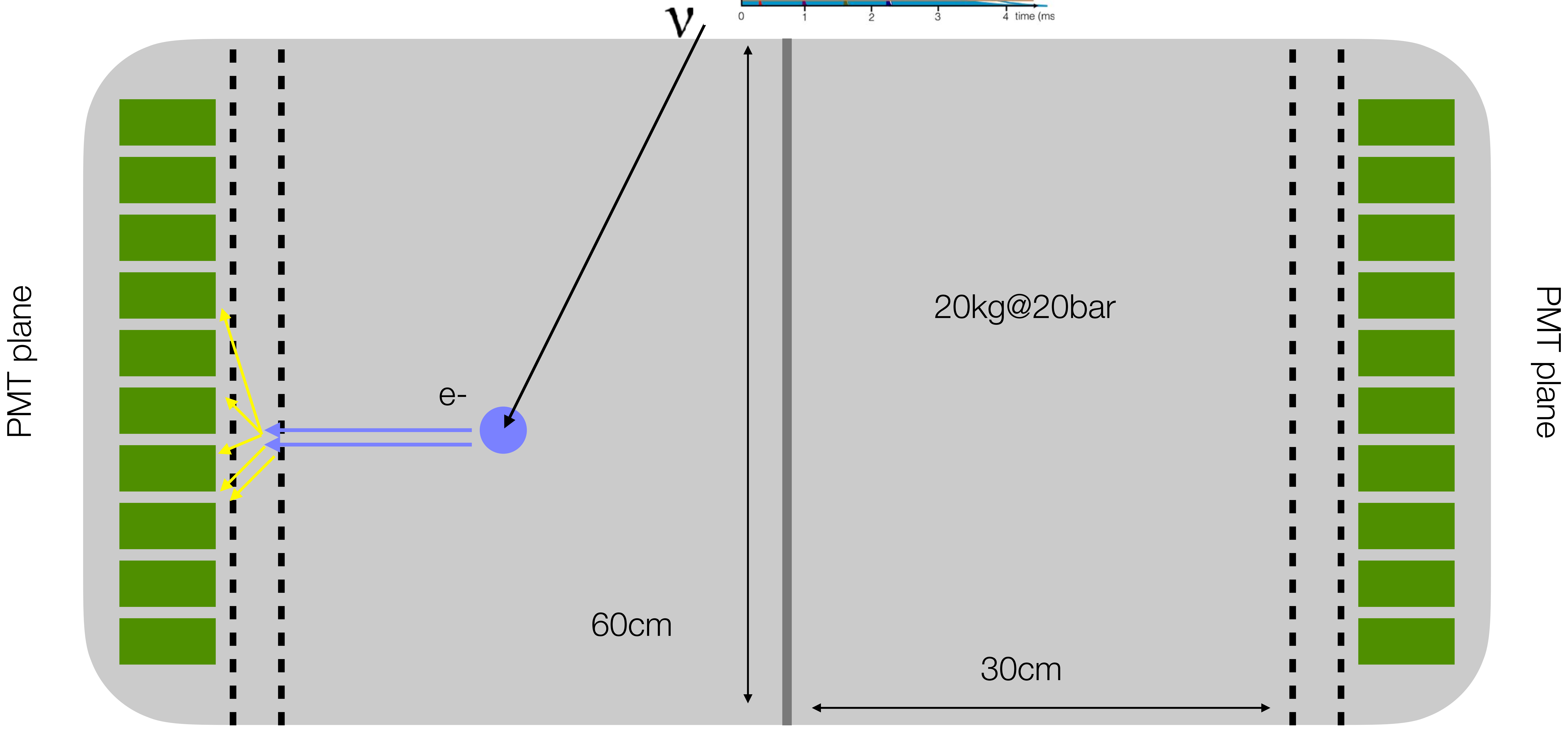
GanESS concept





GanESS concept

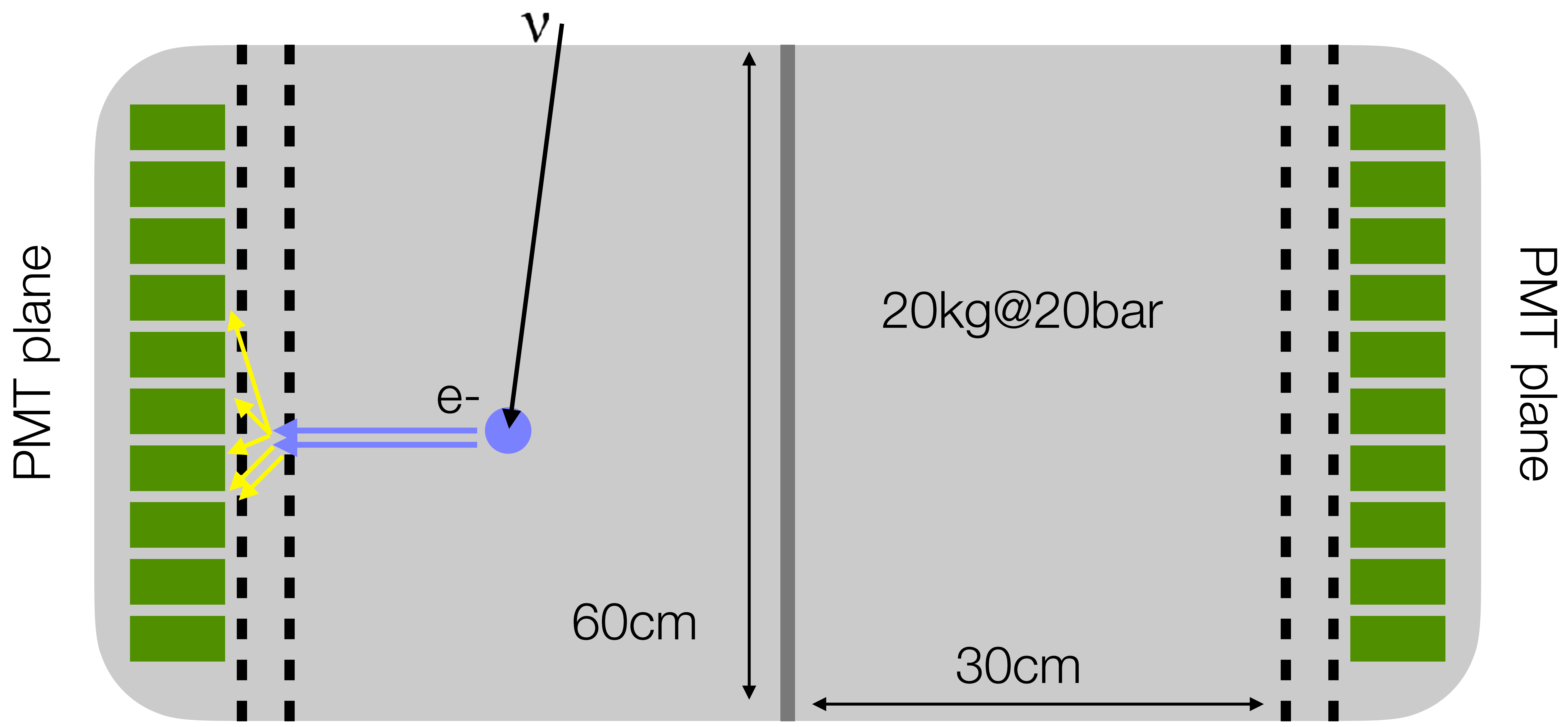




GaNESS project

The GanESS detector

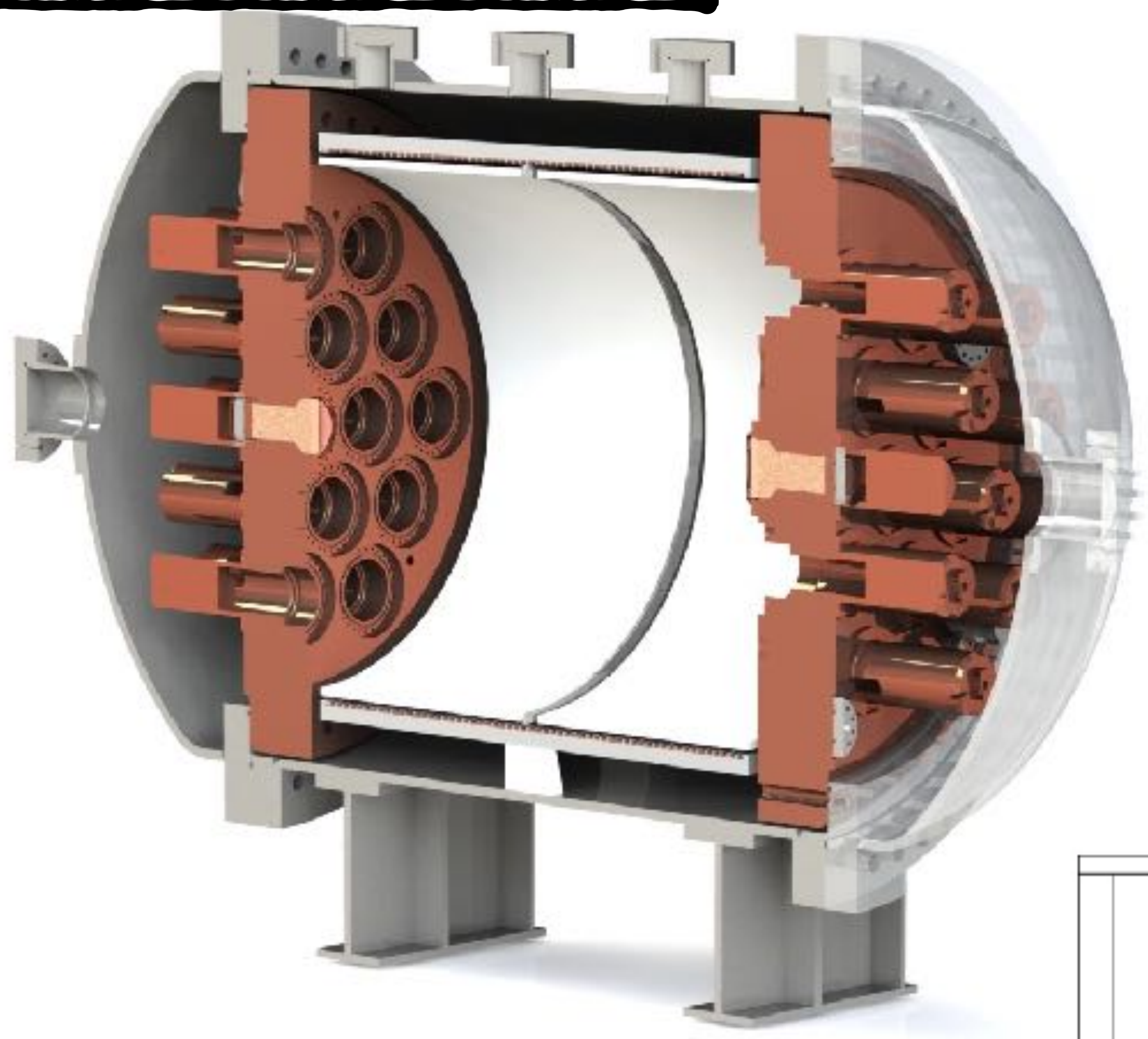
- Optimised for **reduced threshold**.
- Operation with **different gases**.

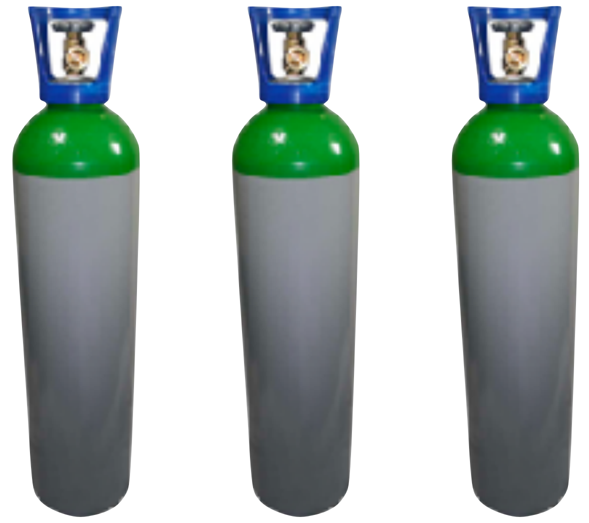


GaNESS project

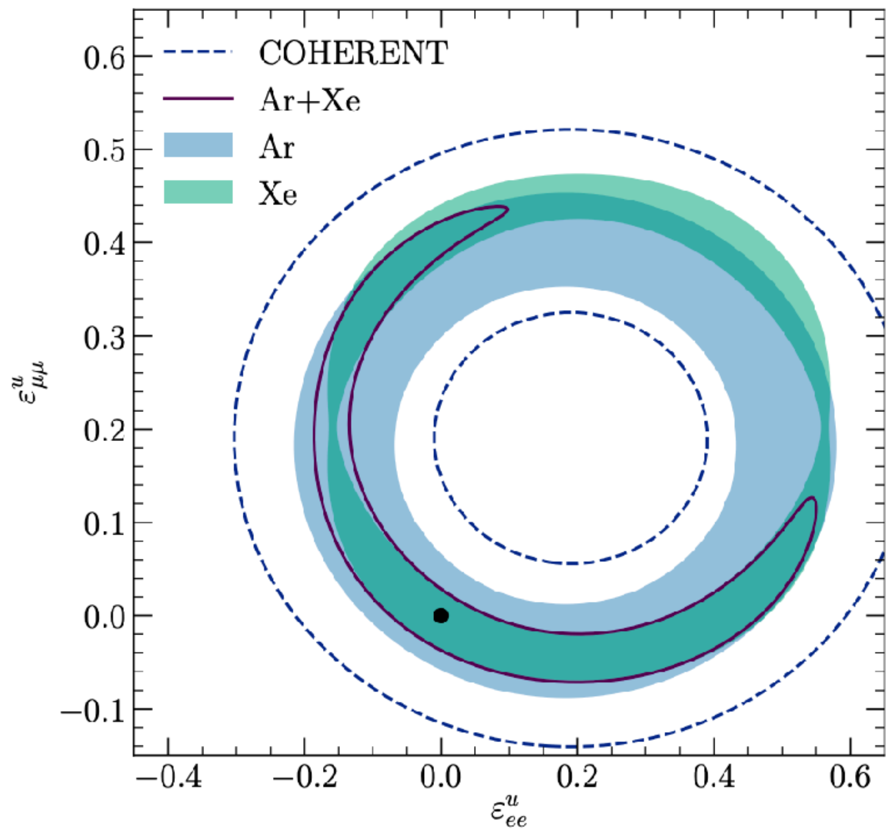
Gaseous TPC

Detector construction

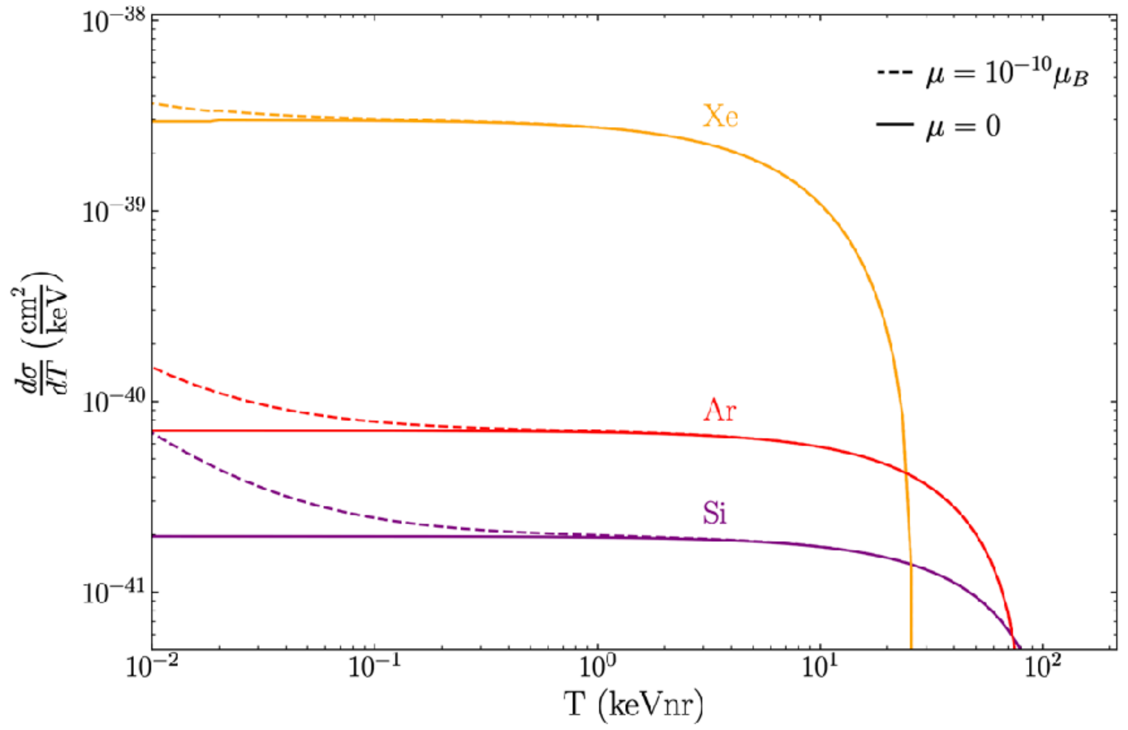


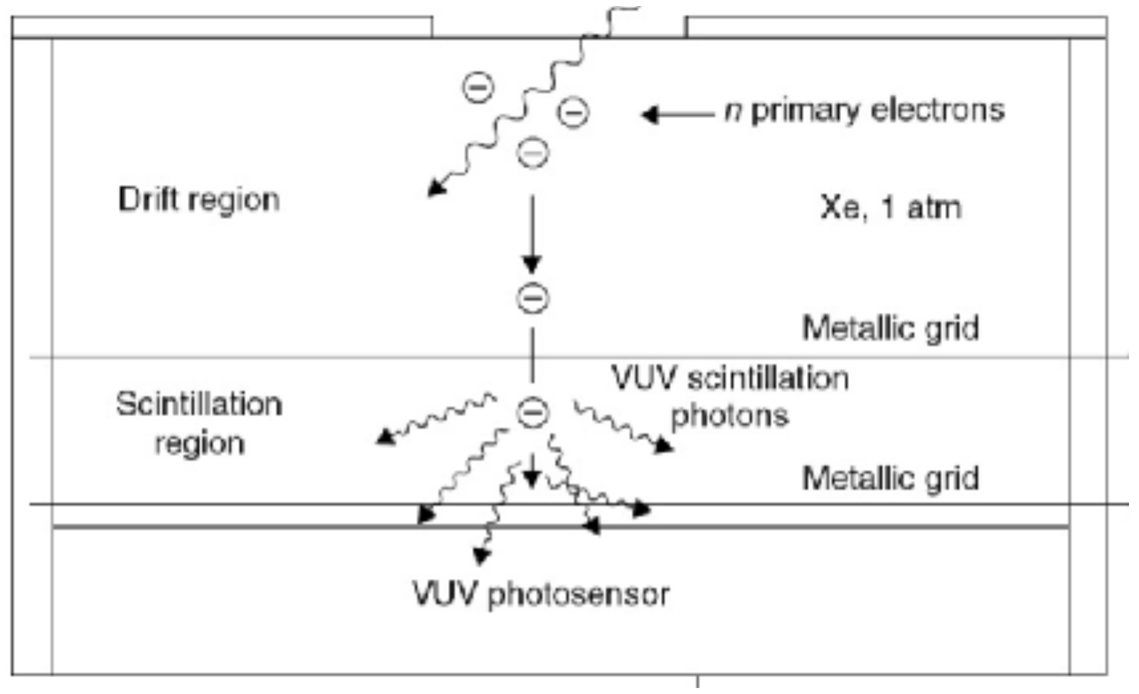


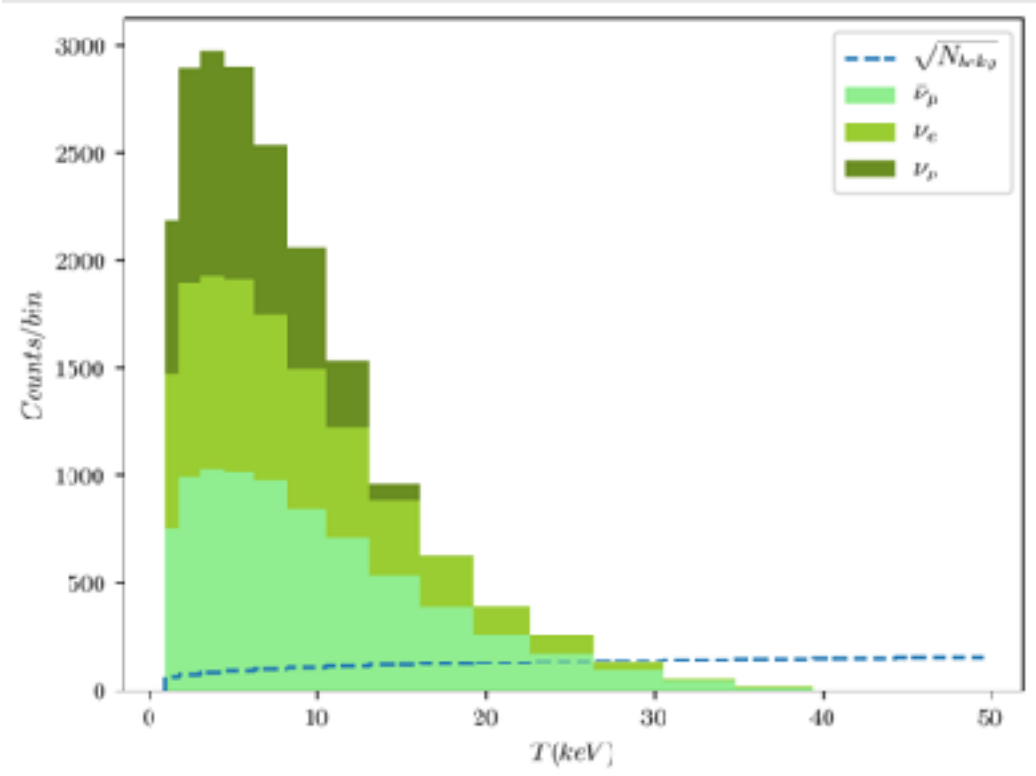
Xe Ar Kr



Physics exploitation



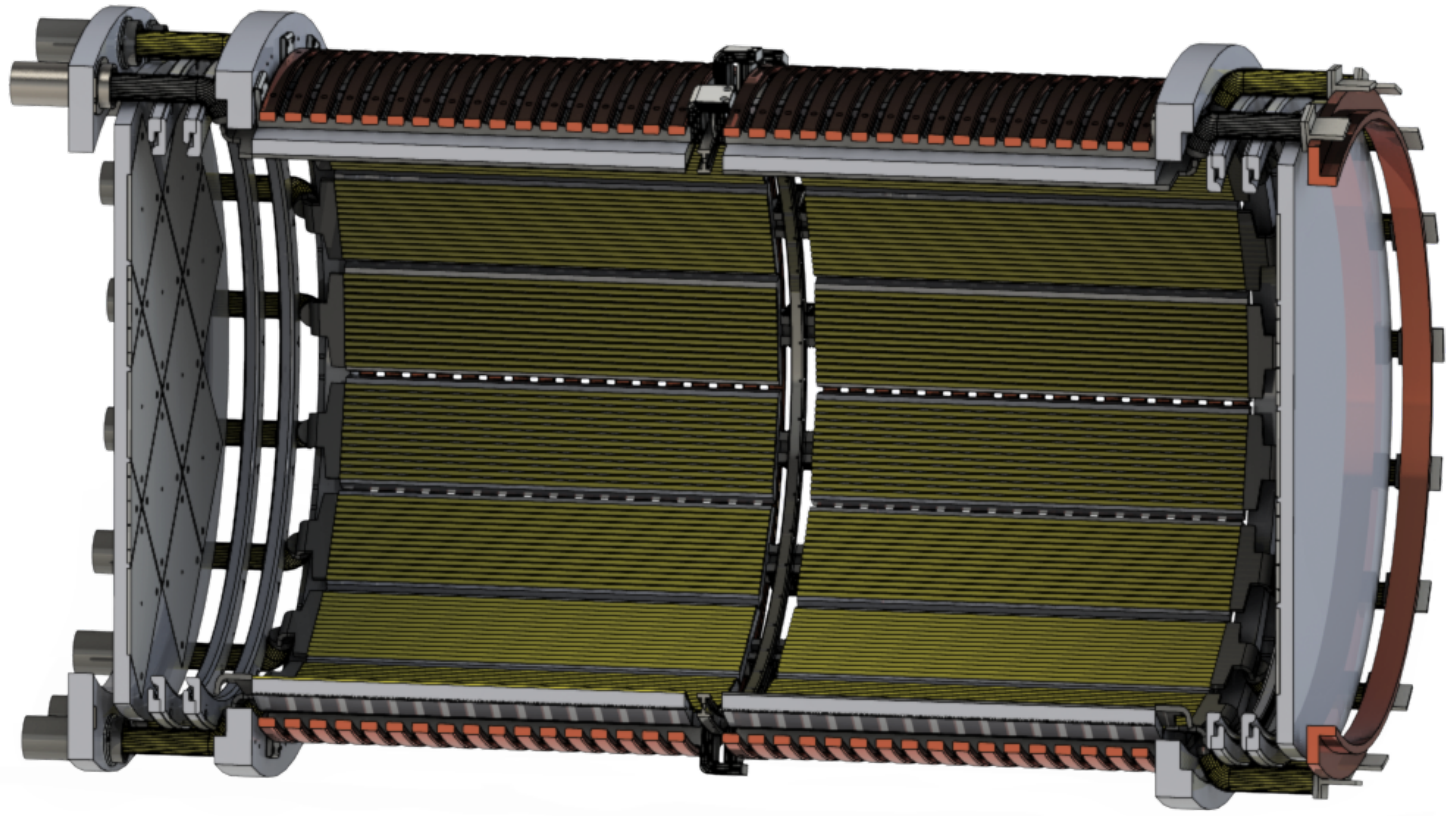




GanESS Status

Design of large detector

Symmetric medium size detector being designed



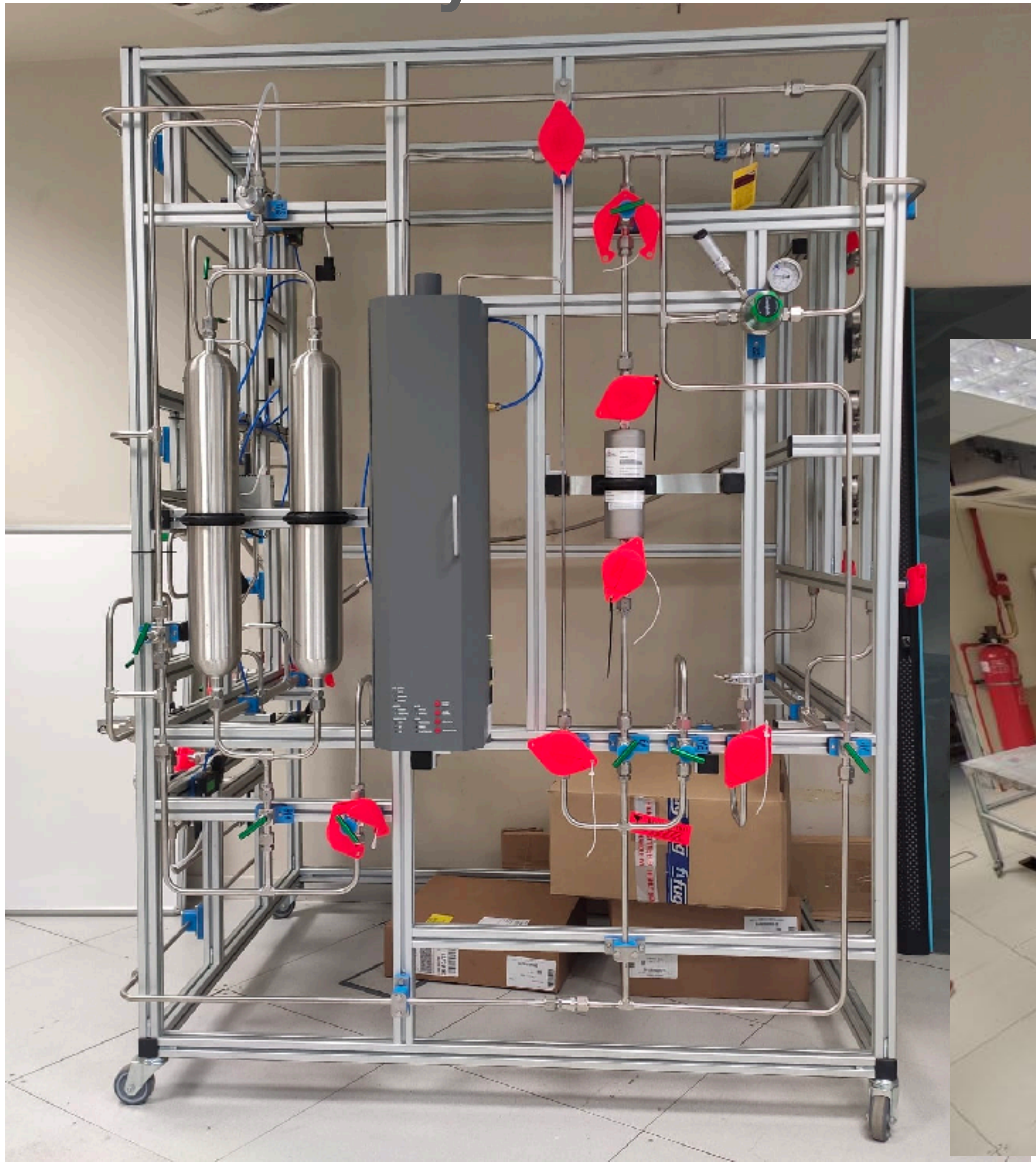
Explore the possibility to introduce optical fibres to optimise light collection:

- Possibility to observe S1
- More uniform detector response

Test final solutions to be operated at the ESS

GanESS Status

Laboratory

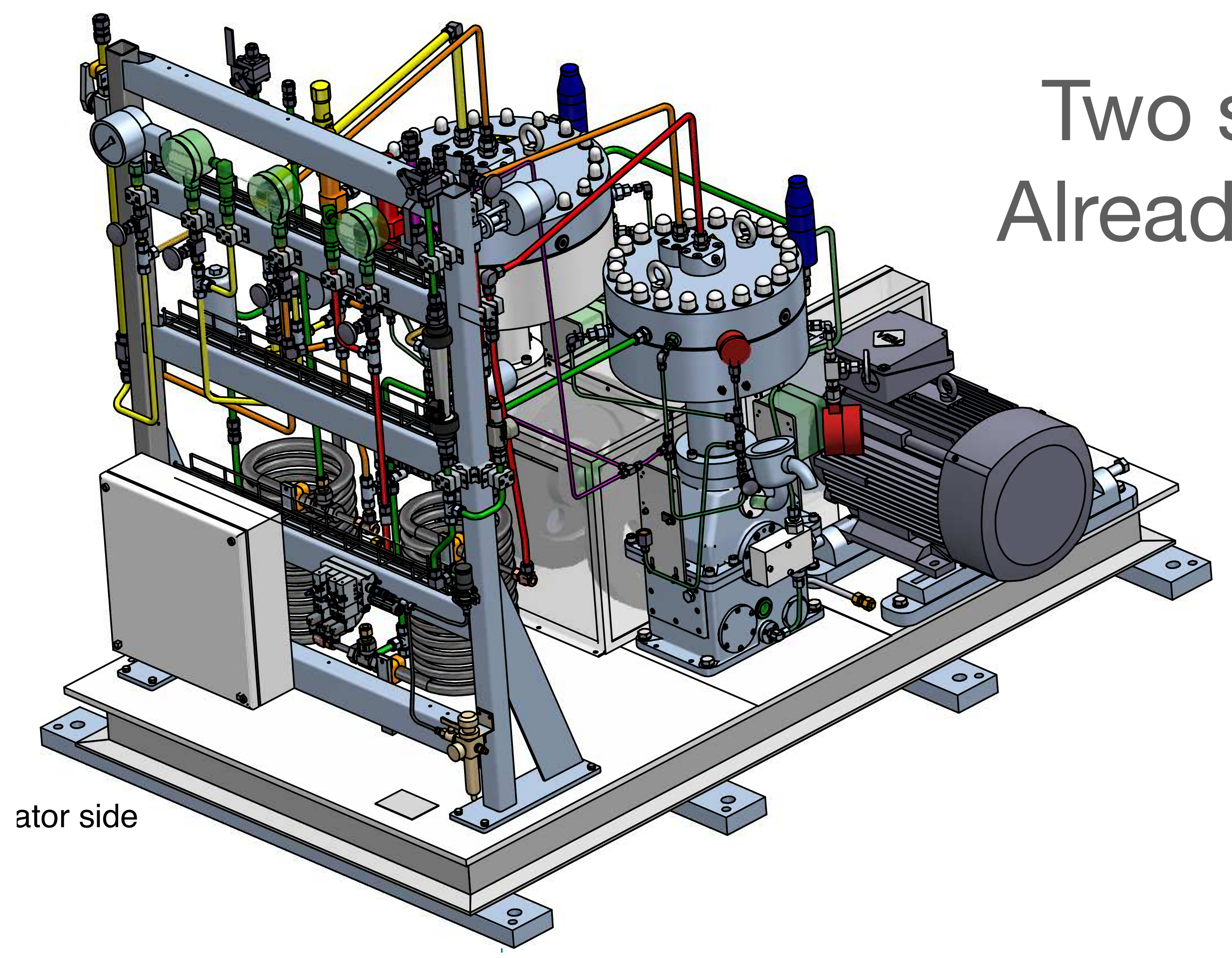


Gas circuit already at the DIPC

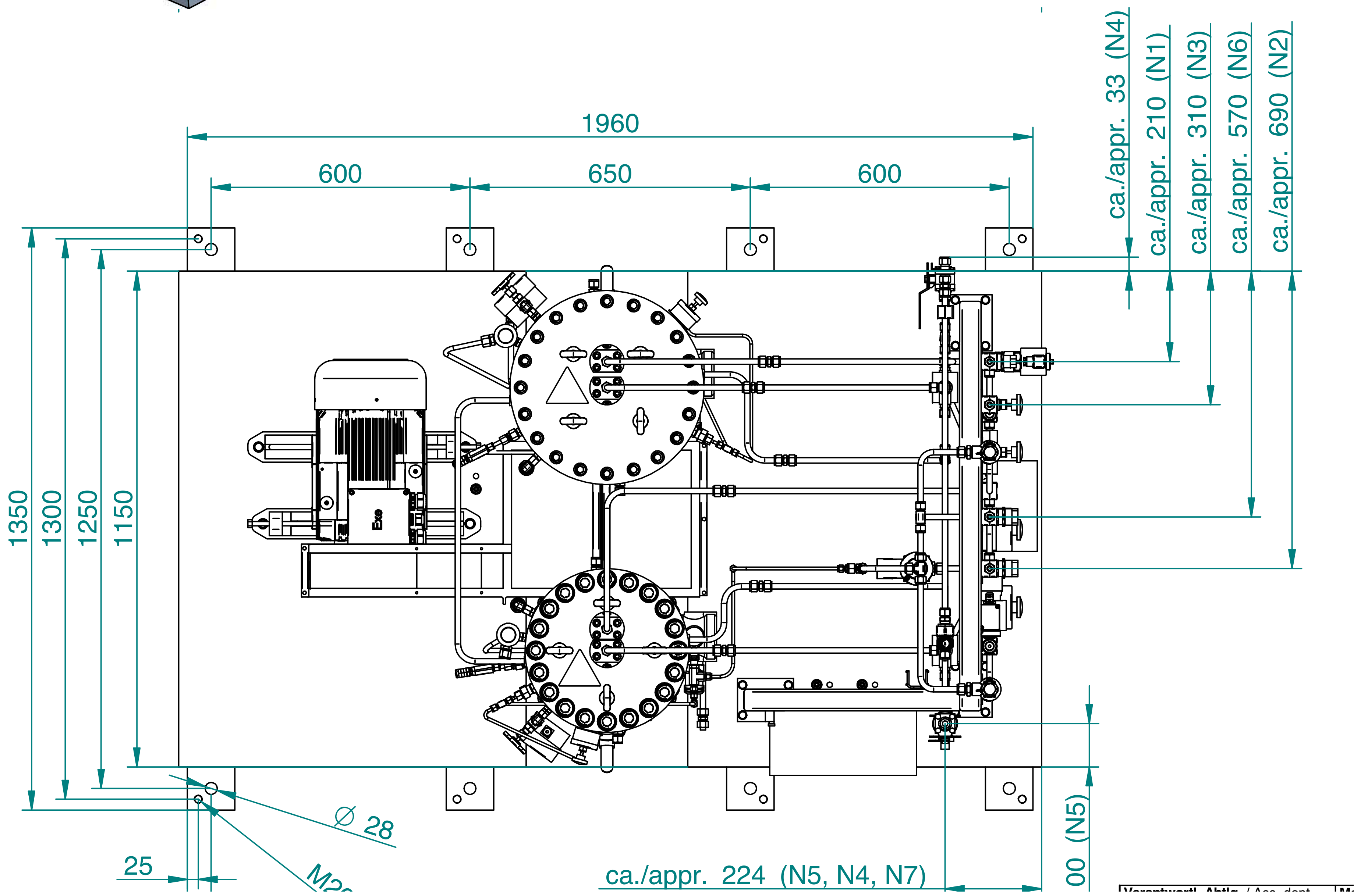
Power supplies and HV modules ready

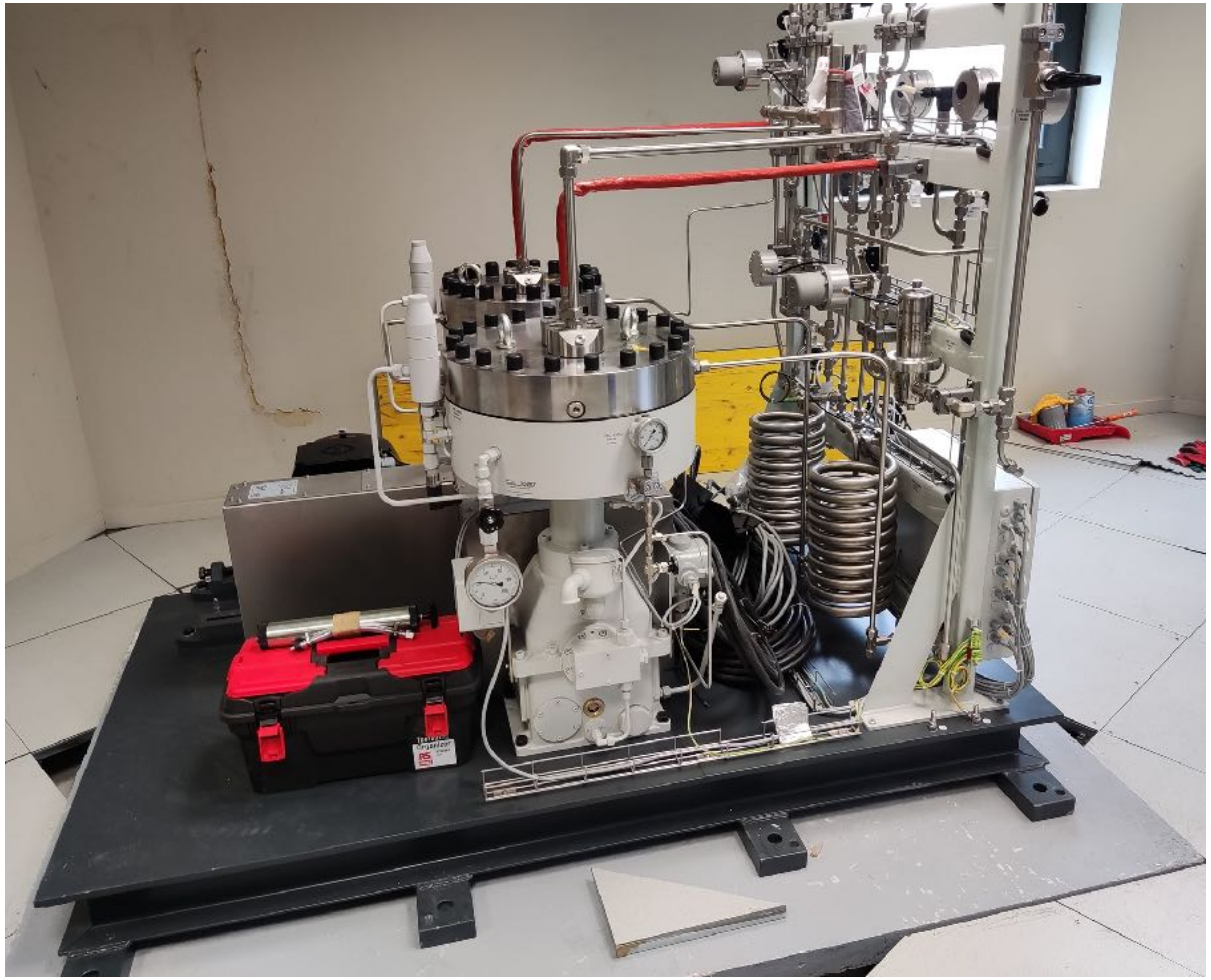
Lab to be ready along summer!

High pressure noble gases laboratory being equipped at the DIPC



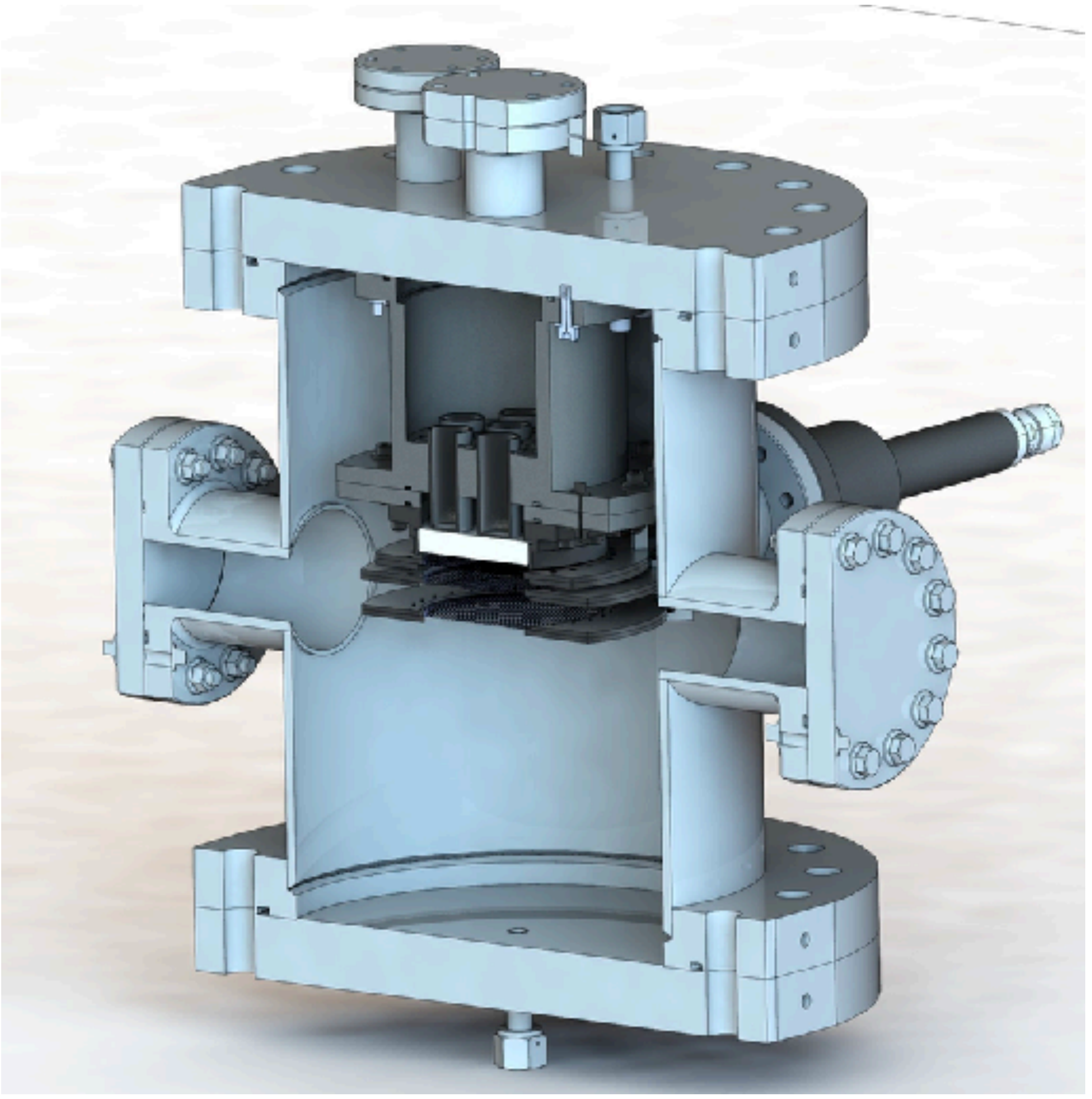
Two stages 10 to 50 bar compressor.
Already designed for the large detector.
Ready next month.





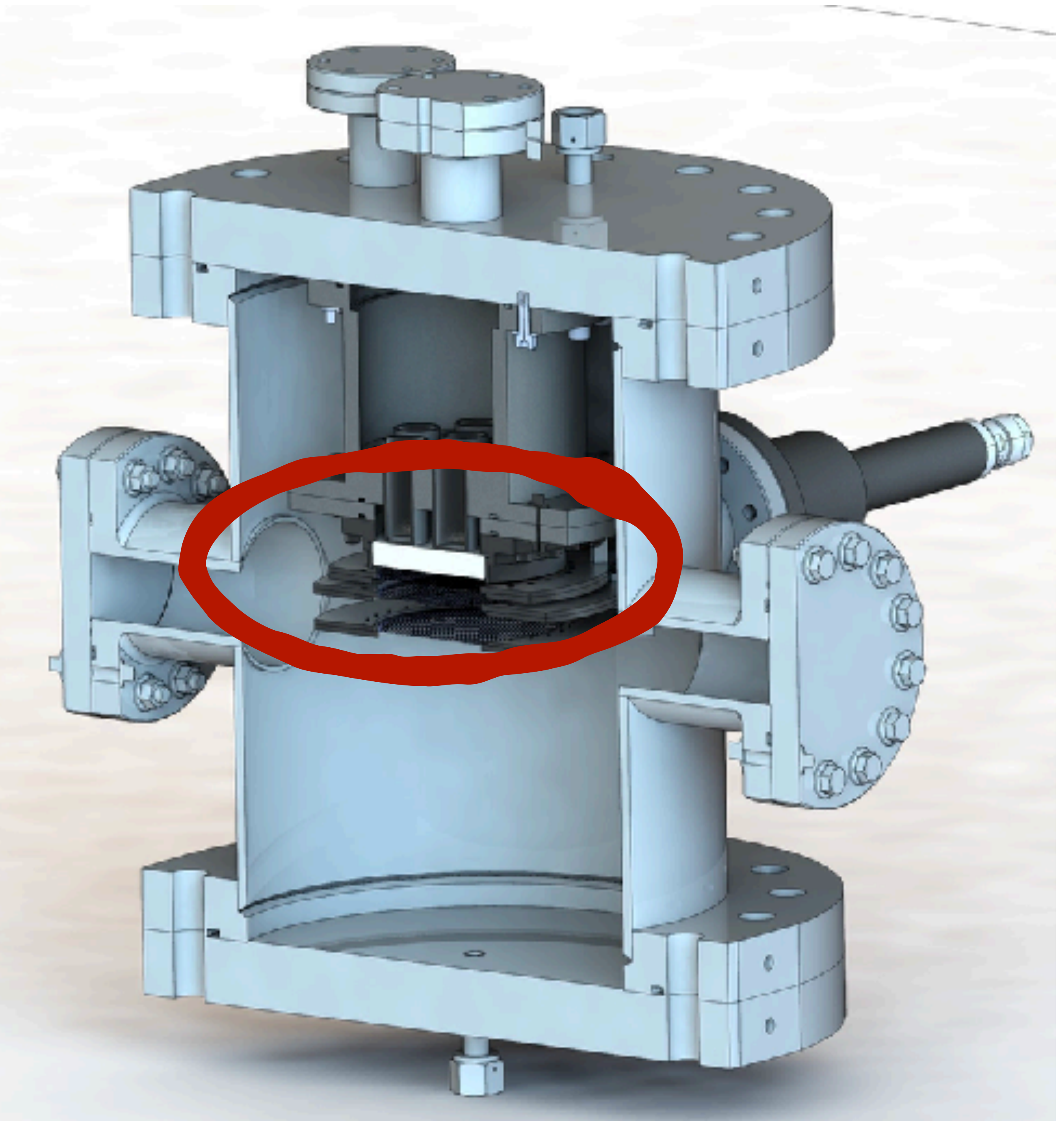
GanESS Status

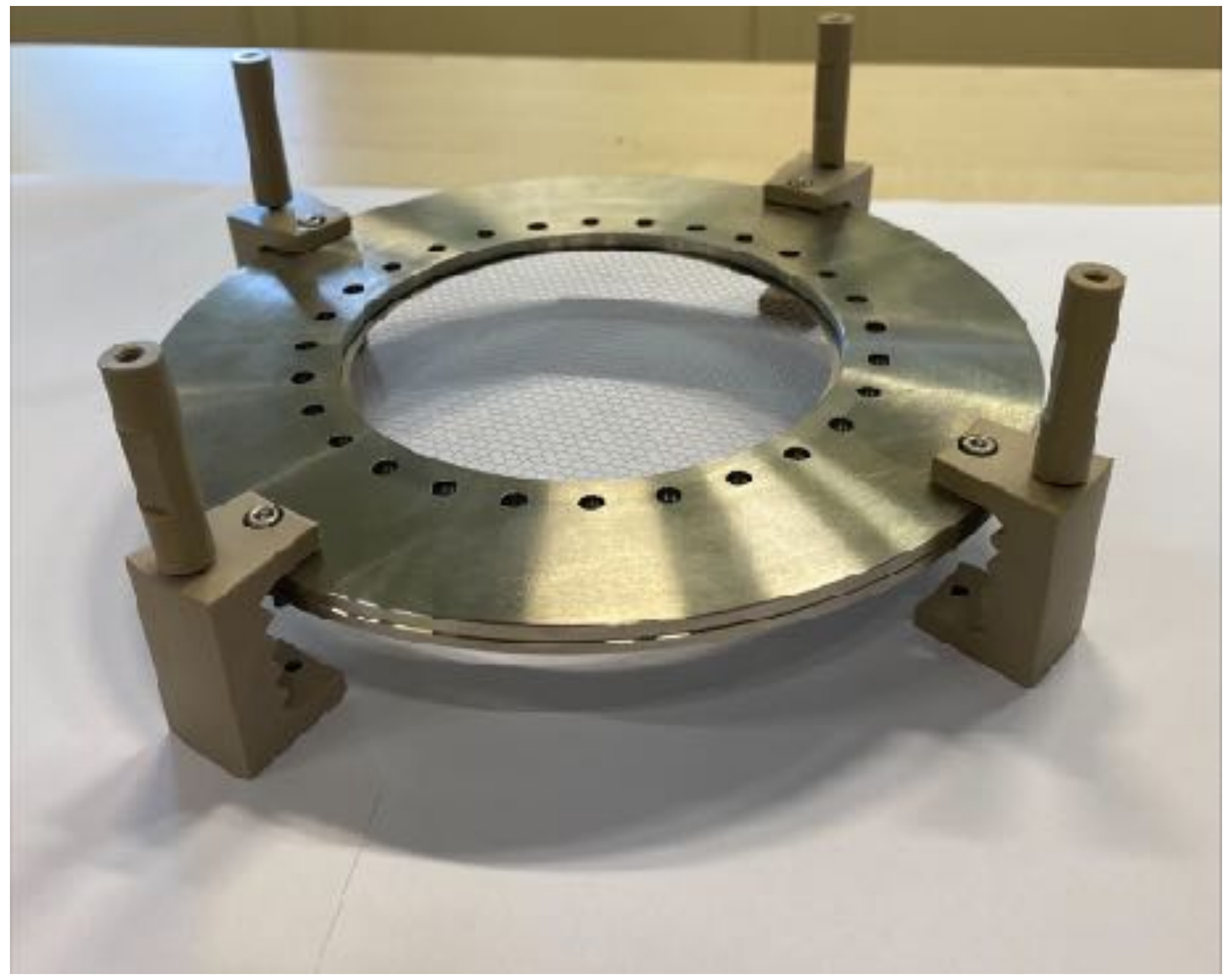
The Gaseous Prototype (GaP) system



- GaP vessel almost ready to operate (pressure tests passed last week).
- PMTs and inner pieces already at DIPC.
- Expected initial operation along summer.

GanESS Status





- Support for PMTs ready to be assembled.
- Protective window in design for a second phase.

GanESS Summary

- CEvNS detection opens a **new avenues in the search of physics beyond the Standard Model**.
- **ESS** will become the largest low-energy neutrino source. Perfect facility to study this process.
- The **GanESS project**, will produce a detector to observe the process at the ESS with a variety of nuclei.
- **GanESS** offers an opportunity to **lead a world-class neutrino program** in the coming years with a **large discovery potential**.