Gaseous detectors for Neutrino-nucleus coherent scattering at the ESS

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XIX International Workshop on Neutrino Telescopes (Venice)

Neutrino-nucleus coherent scattering

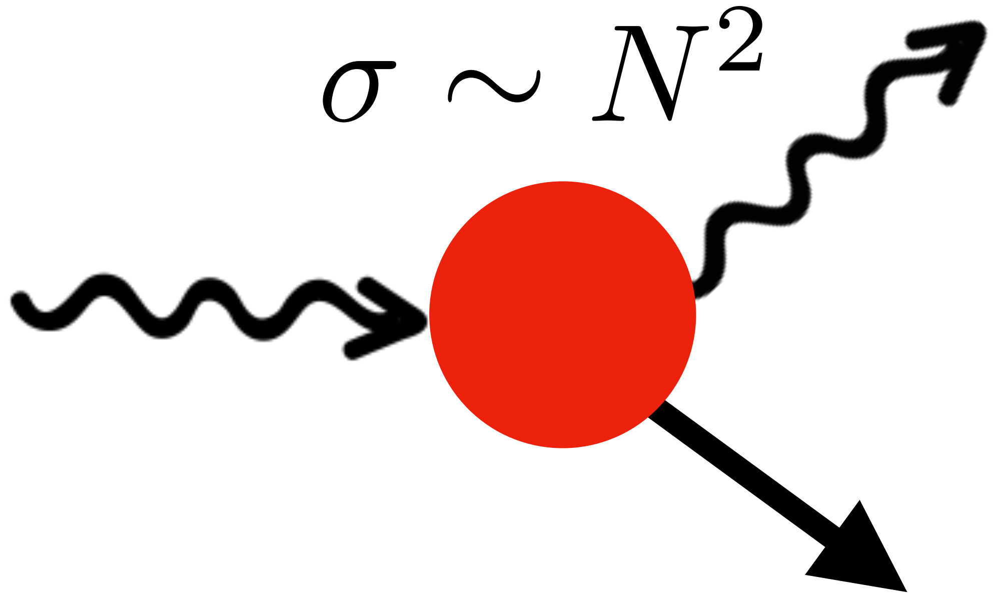
Old known in the Standard model.

qR<1

Long wavelength, “sees” all nucleons simultaneously

Neutrino energies up to a few tens of MeV

$\sigma \sim N^2$

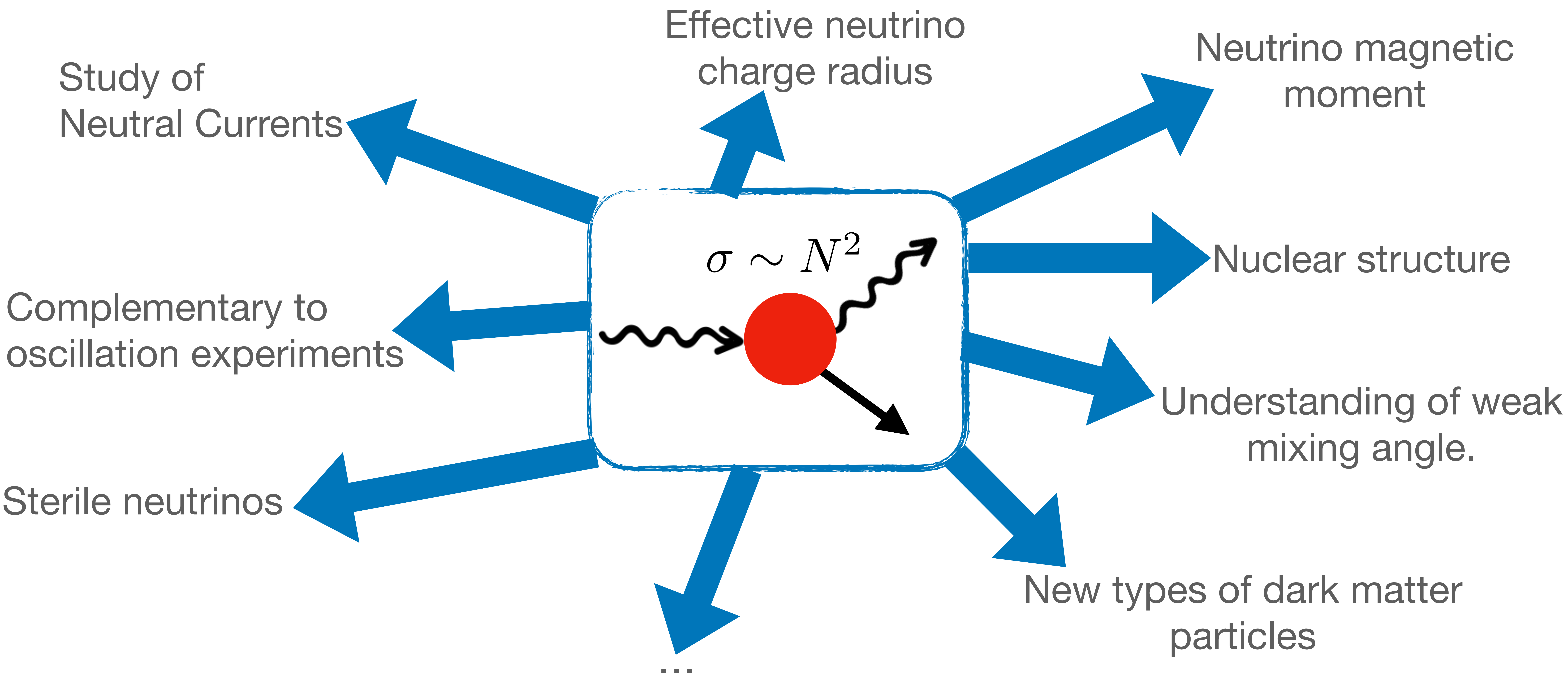


Nucleus recoil energies ~1keV

- Large enhancement to cross-section for En < few tens of MeV.
- Very low nuclear recoil energies, few keV.
- Energy threshold ideally << 1keV.
- 43 yrs until successful detection… combination of source & detector technology was missing
- Cryogenic bolometers and many other methods proposed over the last four decades.

Neutrino-nucleus coherent scattering

Very rich physics



Coherent ν-N scattering

Detection

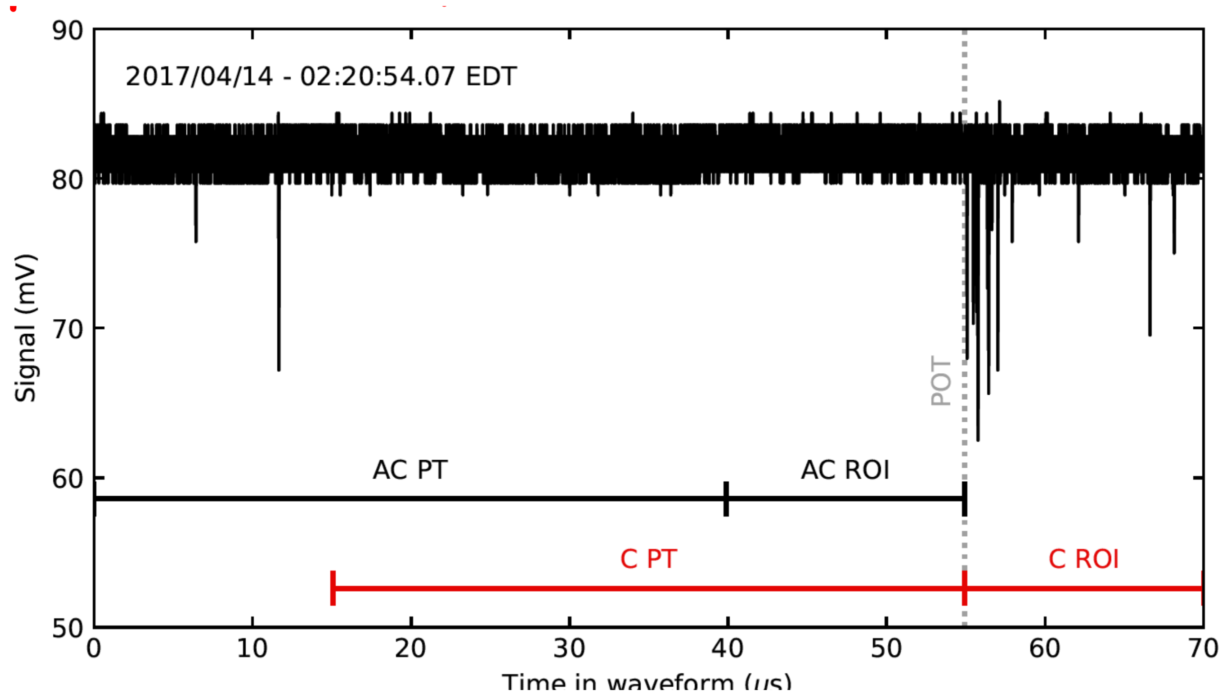
- CEνNS was experimentally demonstrated by the COHERENT experiment 43 years following its theoretical description, using the Spallation Neutron Source (SNS), at the Oak Ridge National Laboratory, USA.

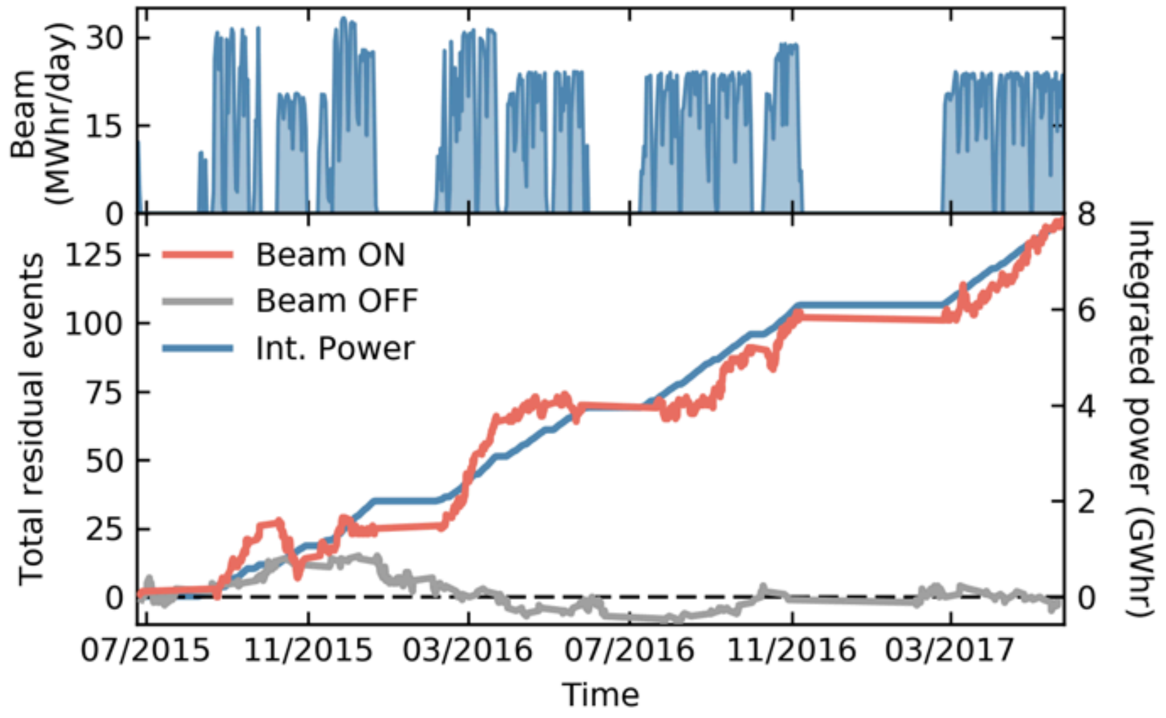
- A low-background 14.6 kg CsI[Na] scintillator was employed as the detecting medium.

First Observation of CEvNS

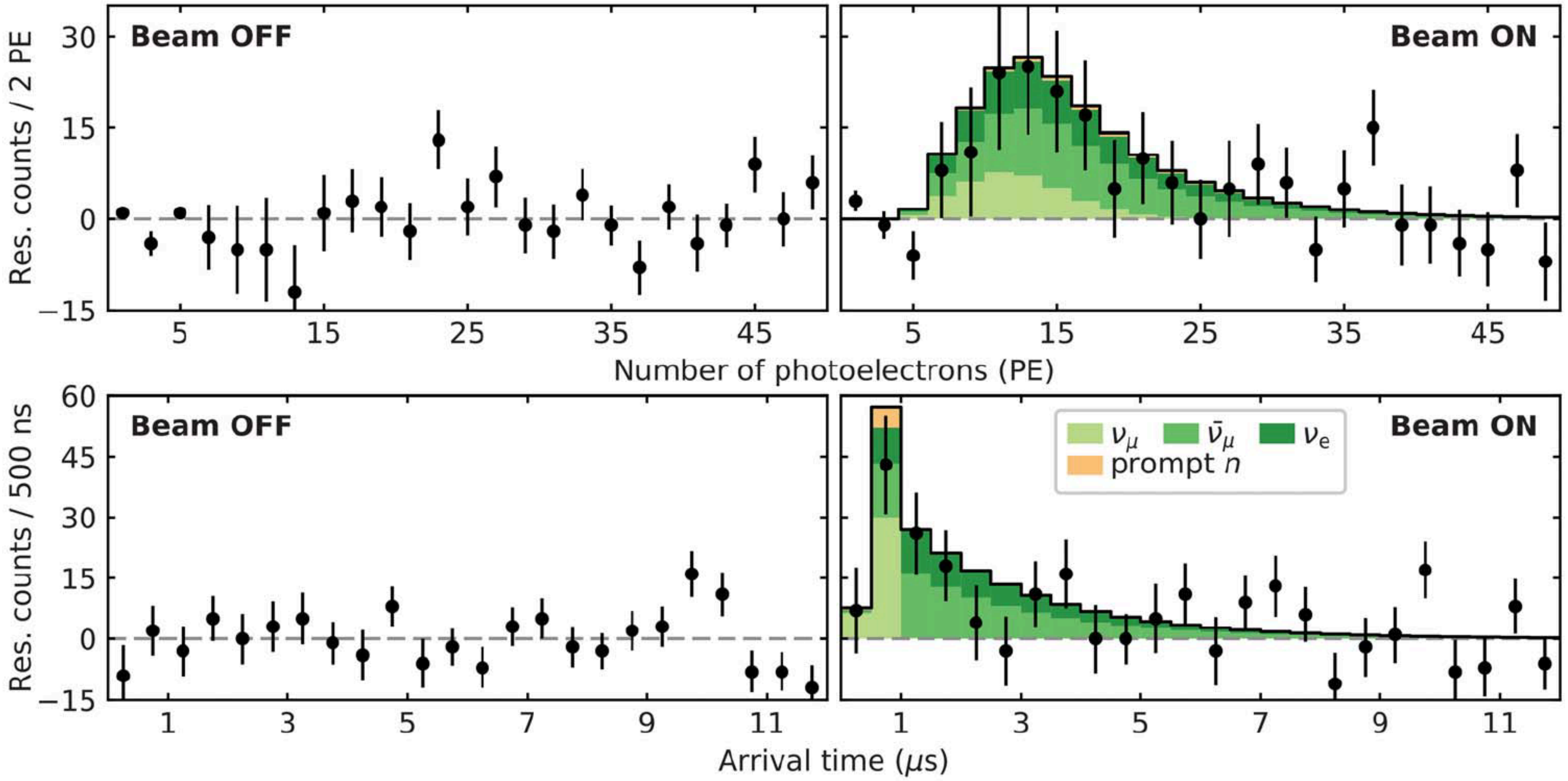
(6.7 sigma, 15 months of data, ~3.5 years total)

Signal and back regions
(Blind optimisations of cuts)





Strong correlation to instantaneous beam power.



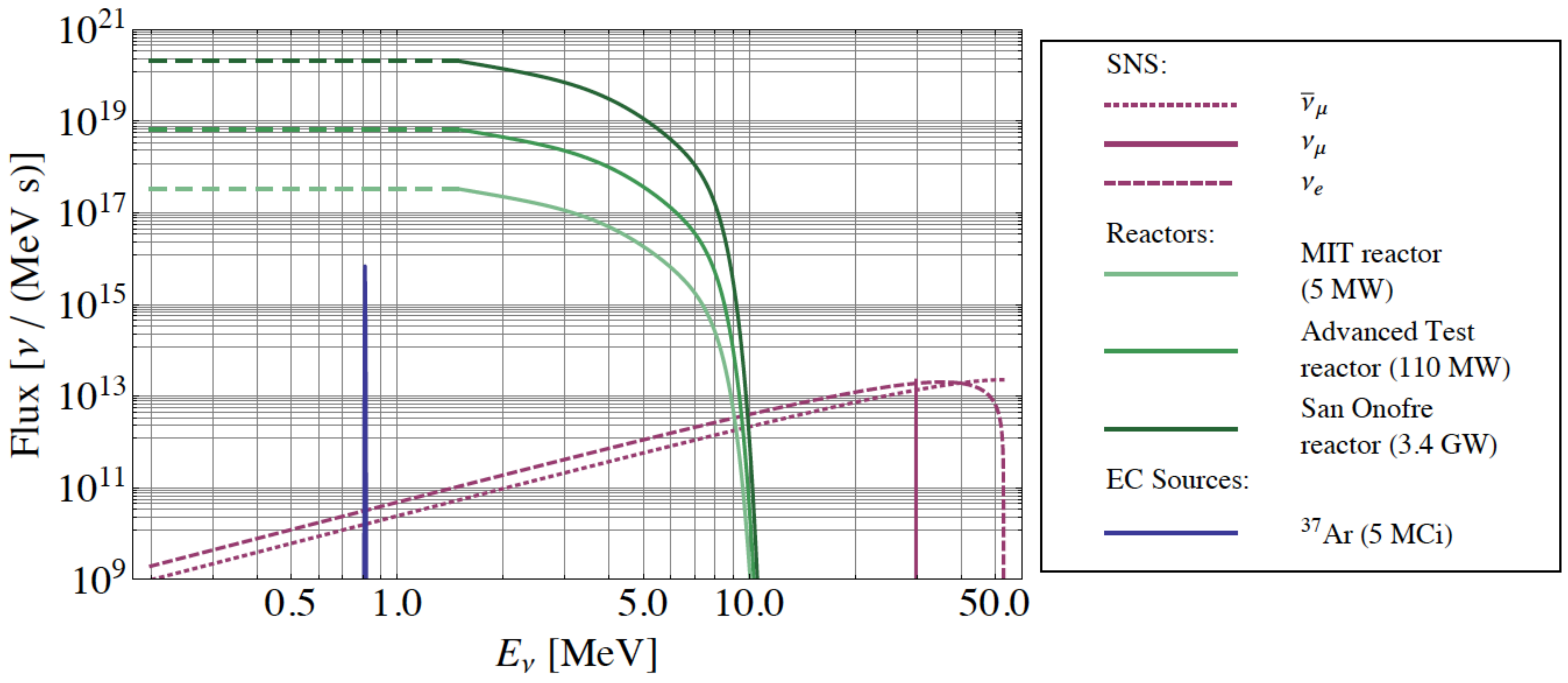
Histograms are SM predictions

Negligible beam-related backgrounds

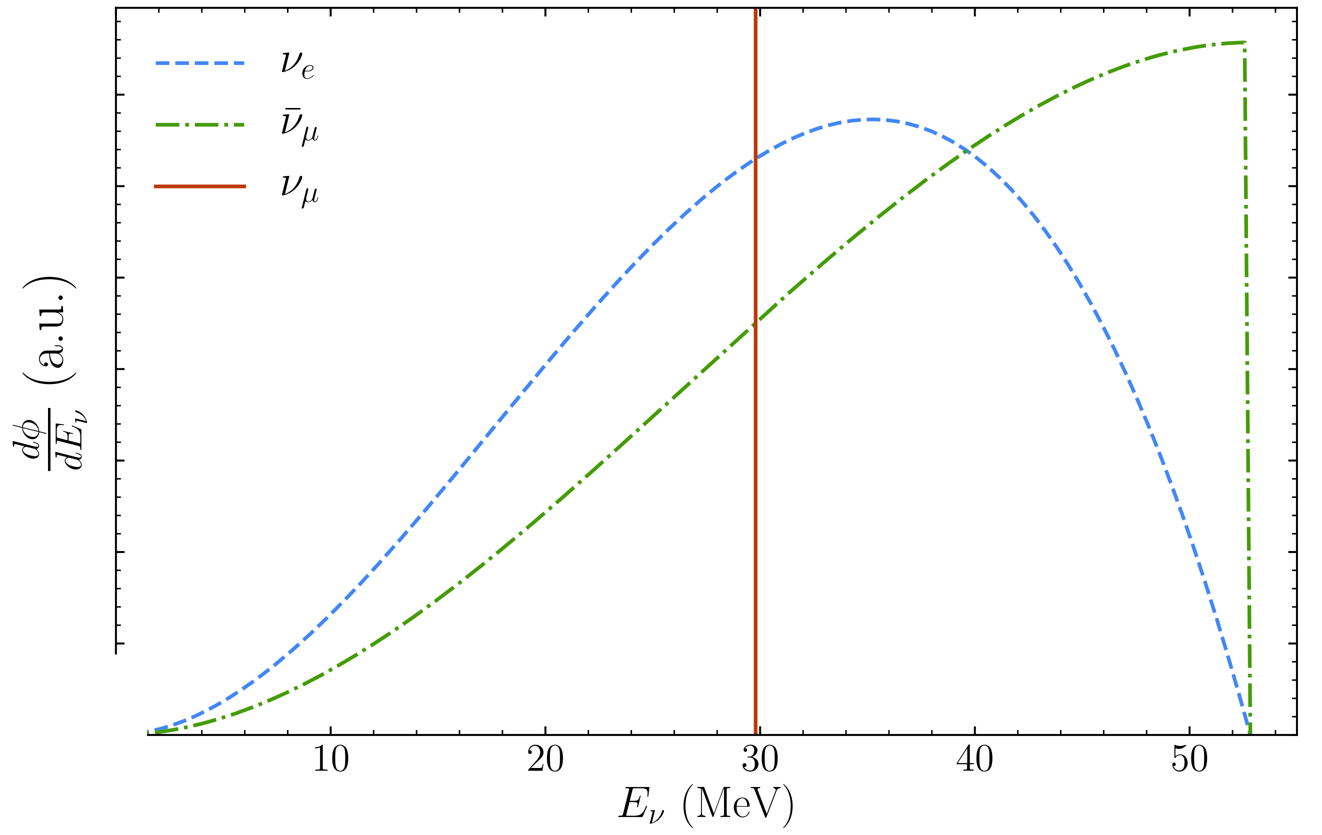
Coherent ν-N scattering

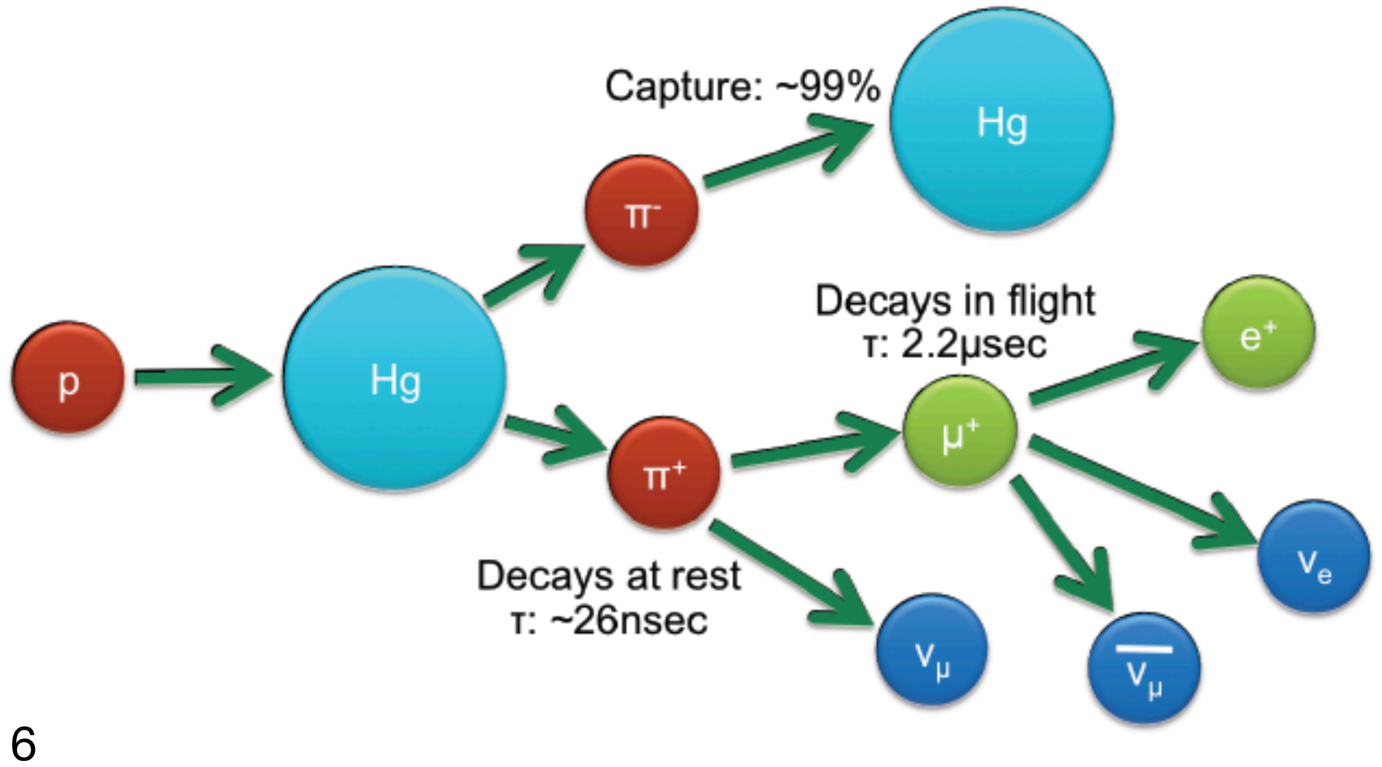
Sources

- CEvNS sources, must be sufficiently intense in yield, and low enough in neutrino energy so the coherence condition can be satisfied
- |Q|<1/R, where |Q| is the momentum transfer and R is the radius of the nucleus).
- **Spallation sources** produce nuclear recoils as energetic as allowed by the coherence condition, facilitating its detection.
- Pulsed beam timing reduced the impact of steady-state backgrounds



Enectali Figueroa-Feliciano / νMass 2013 / Milano





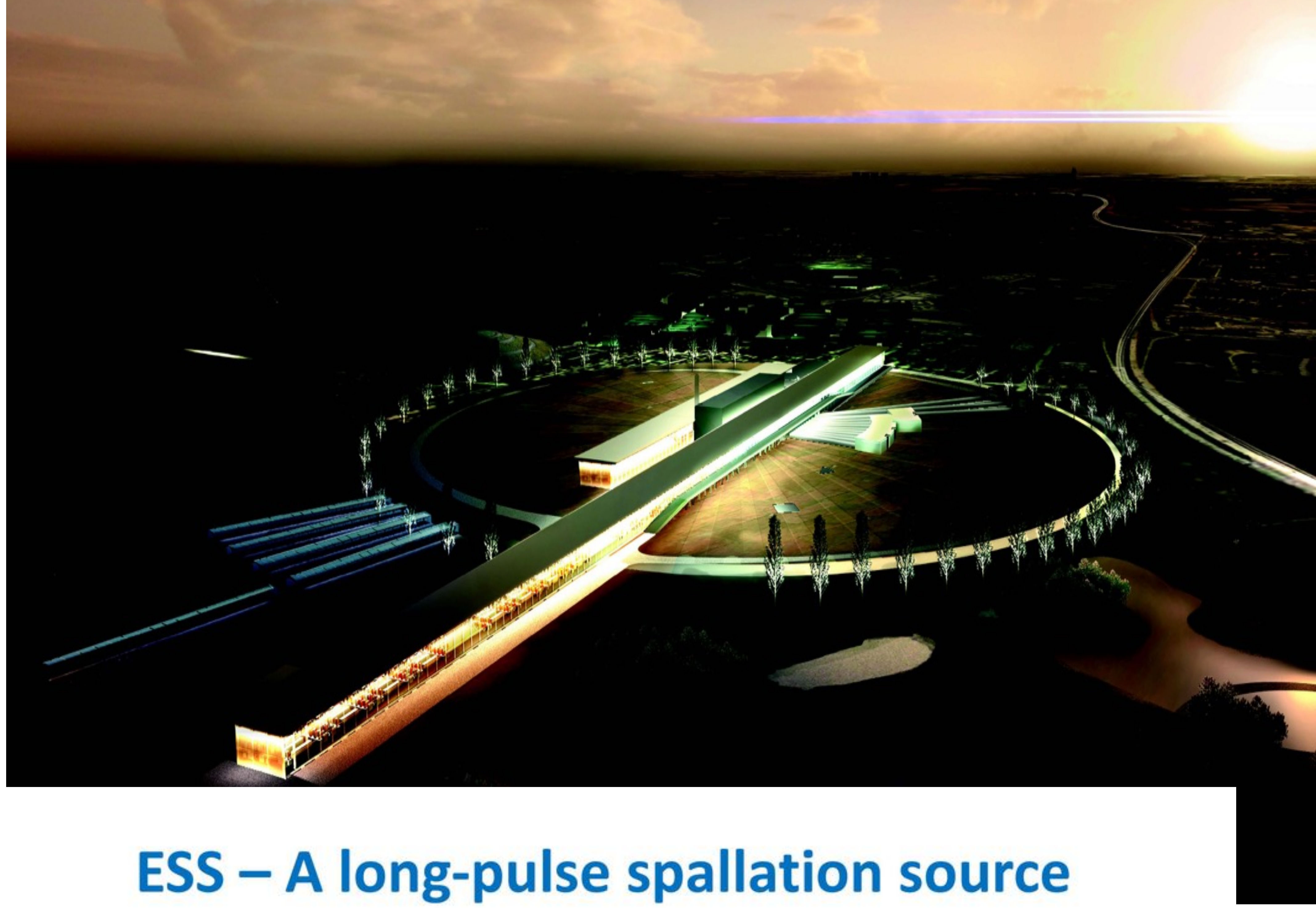
A new opportunity for CEvNS

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.

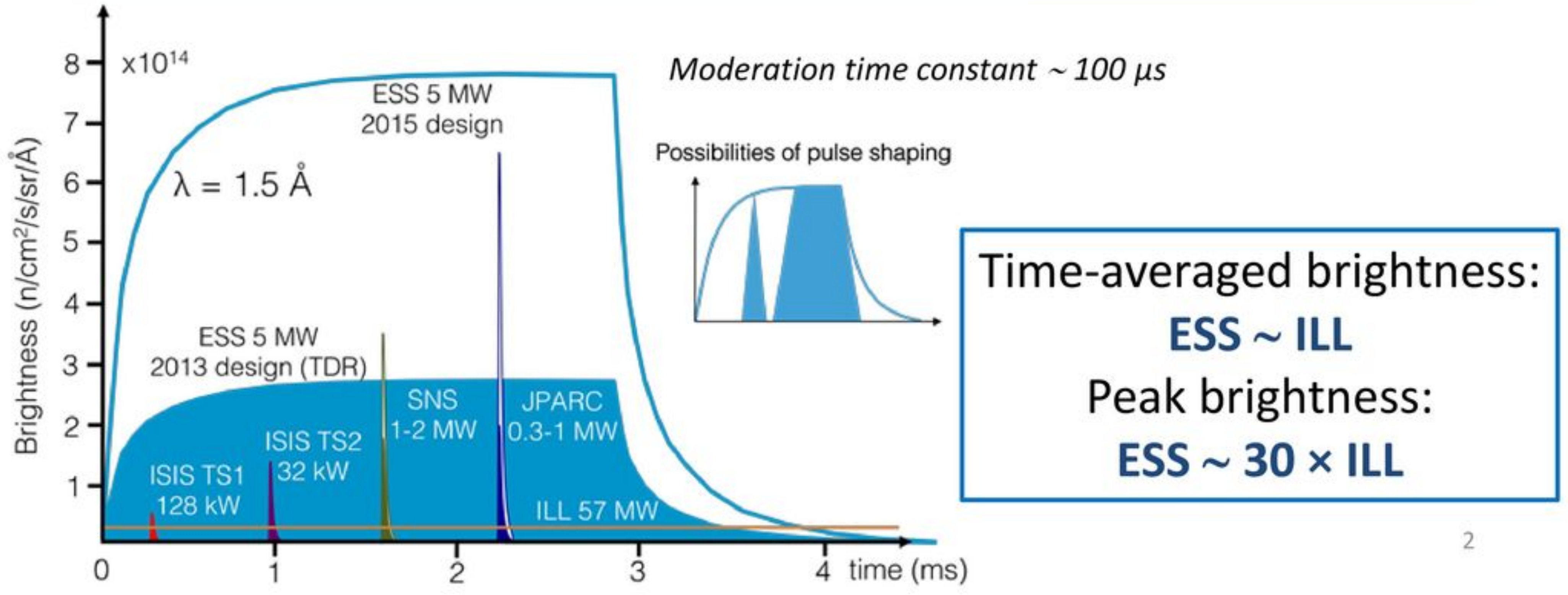
- It will also provide an **order of magnitude increase** in neutrino flux with respect to the SNS.

- A great opportunity for Europe to lead this physics!



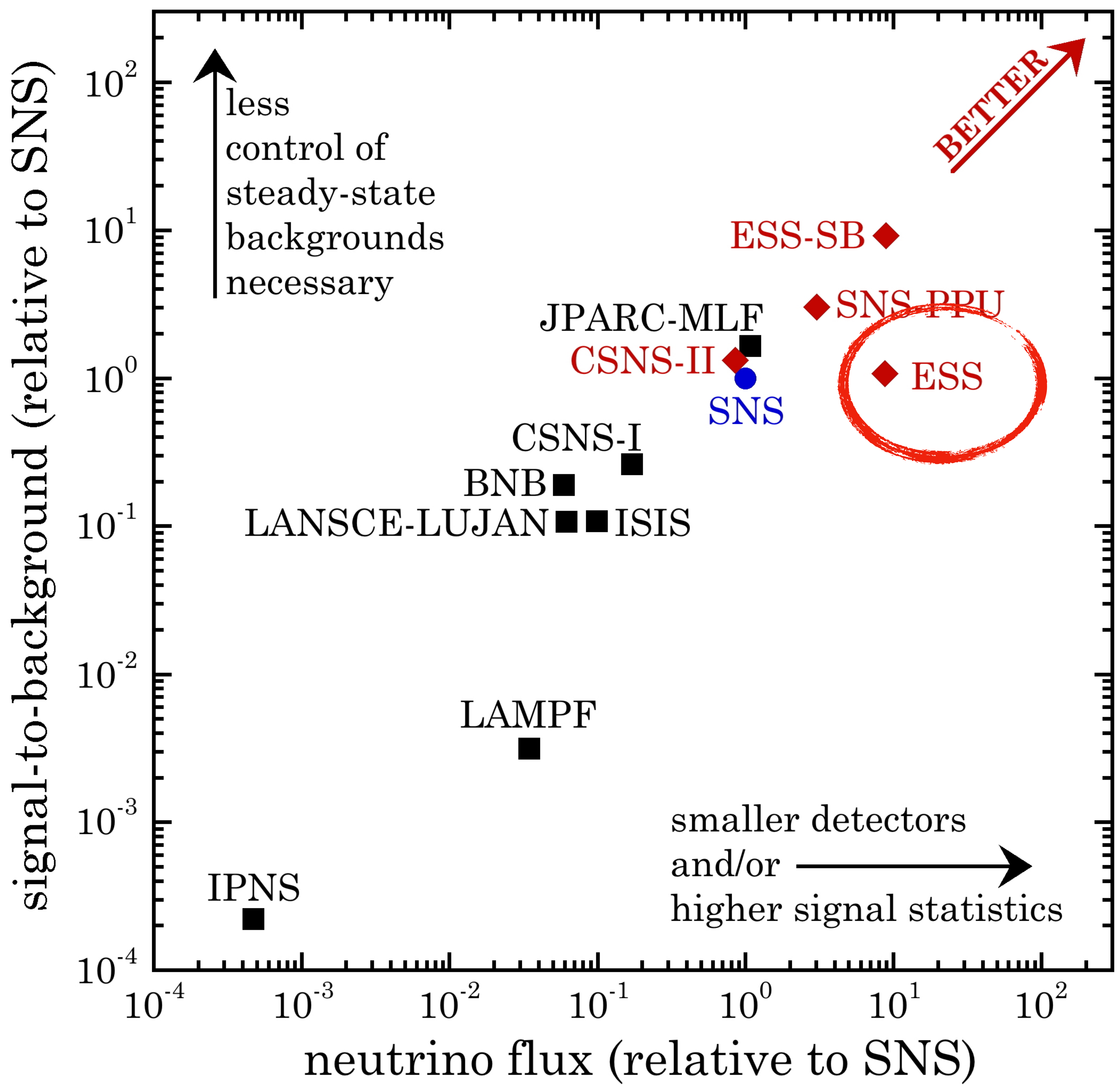
ESS – A long-pulse spallation source

	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

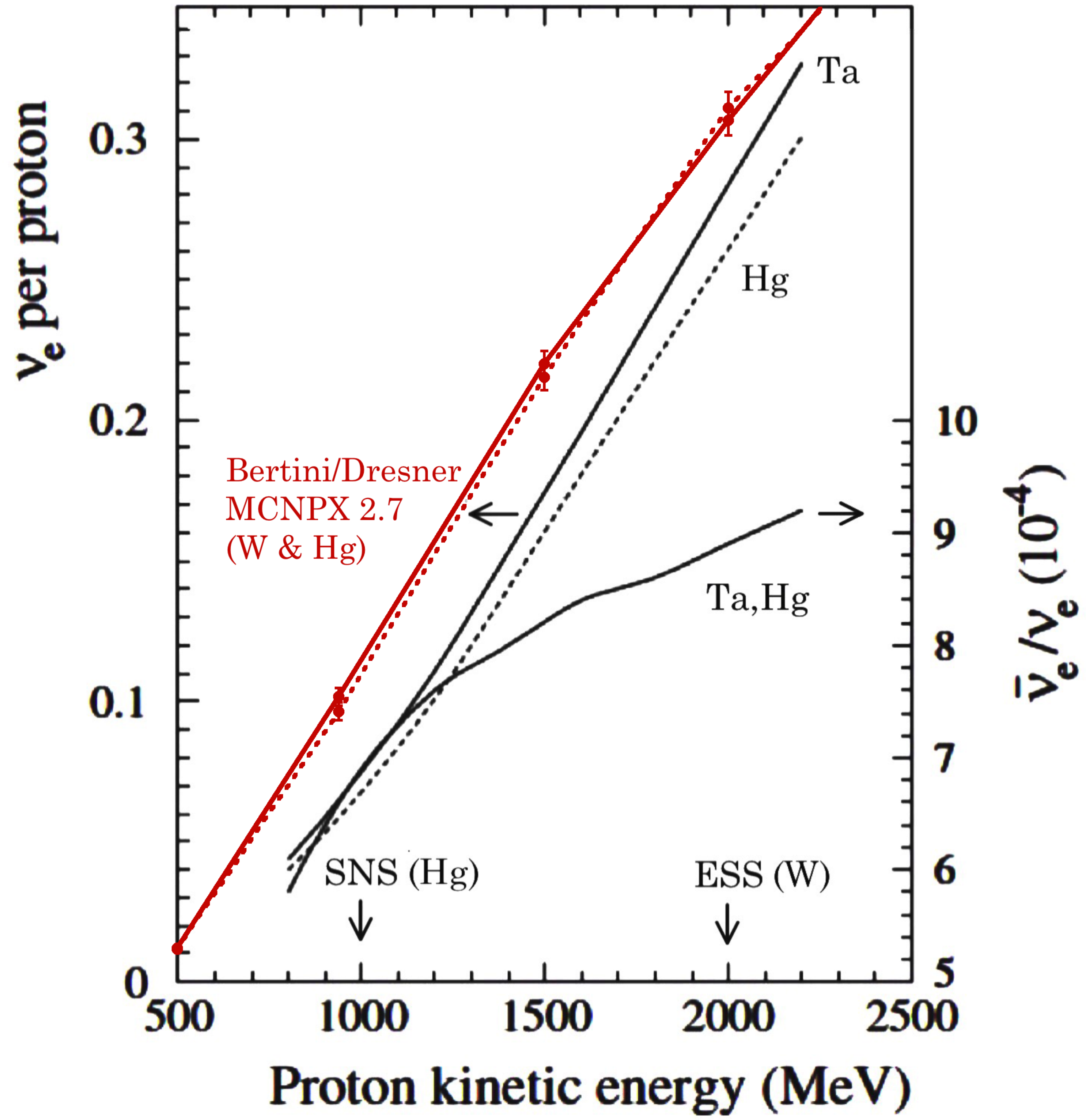


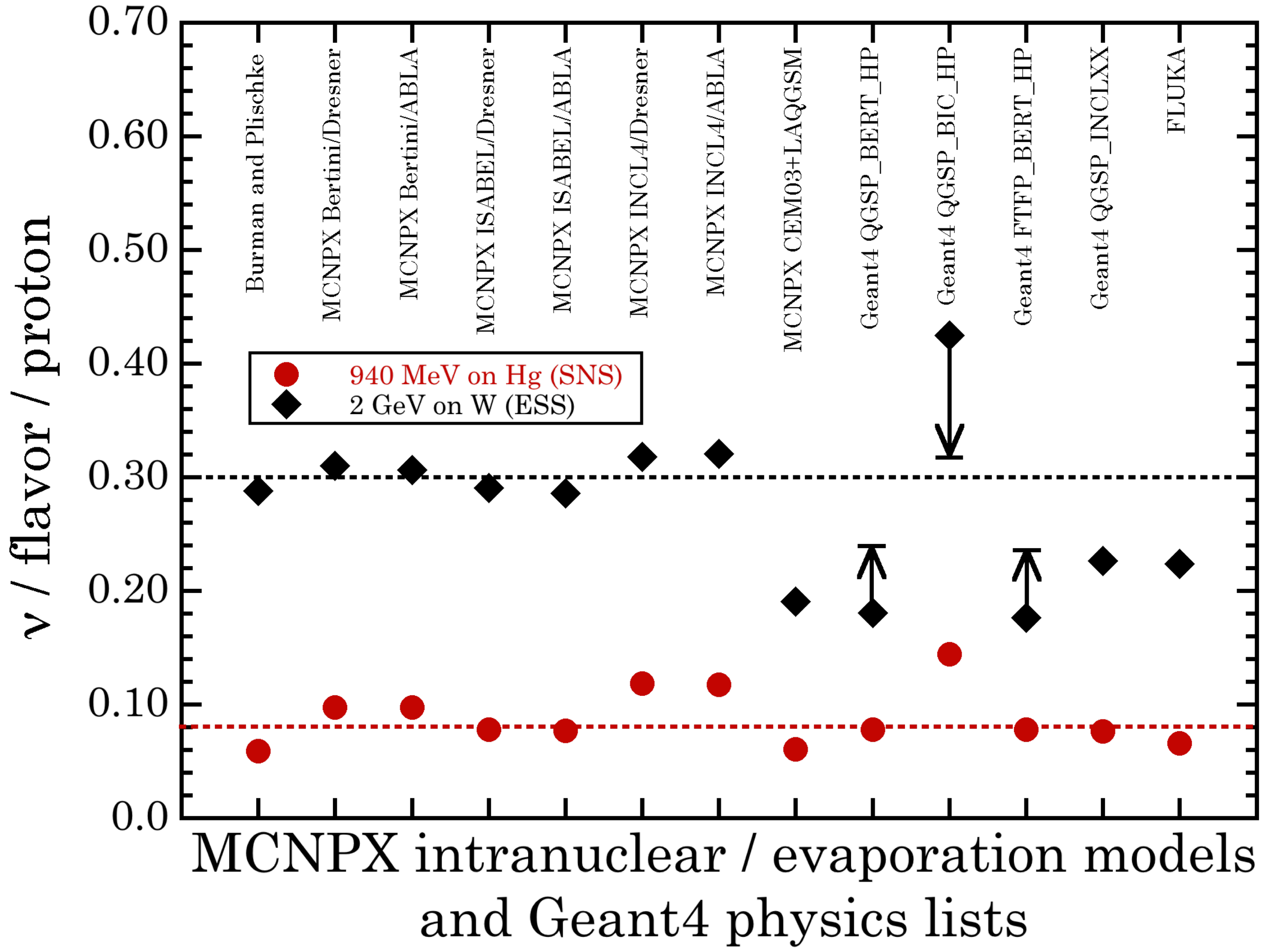
- ESS will produce the largest low energy neutrino flux of the next generation facilities.
- This is a unique opportunity that allows the use of small detectors.
- Diversity of technologies not statistically limited guarantees the phenomenological exploitation of the measurements.

A new opportunity for CEvNS

ESS vs SNS

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

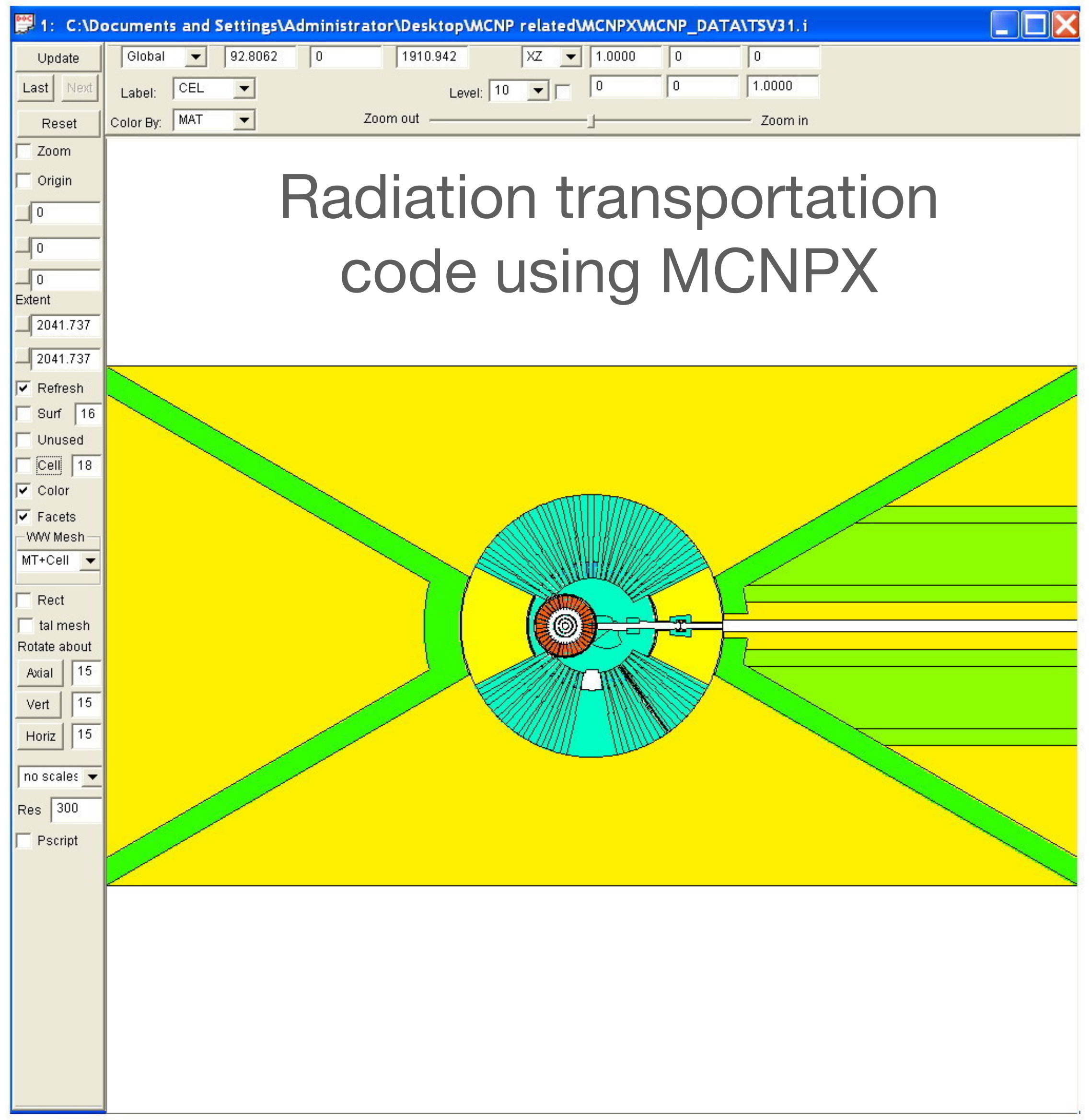


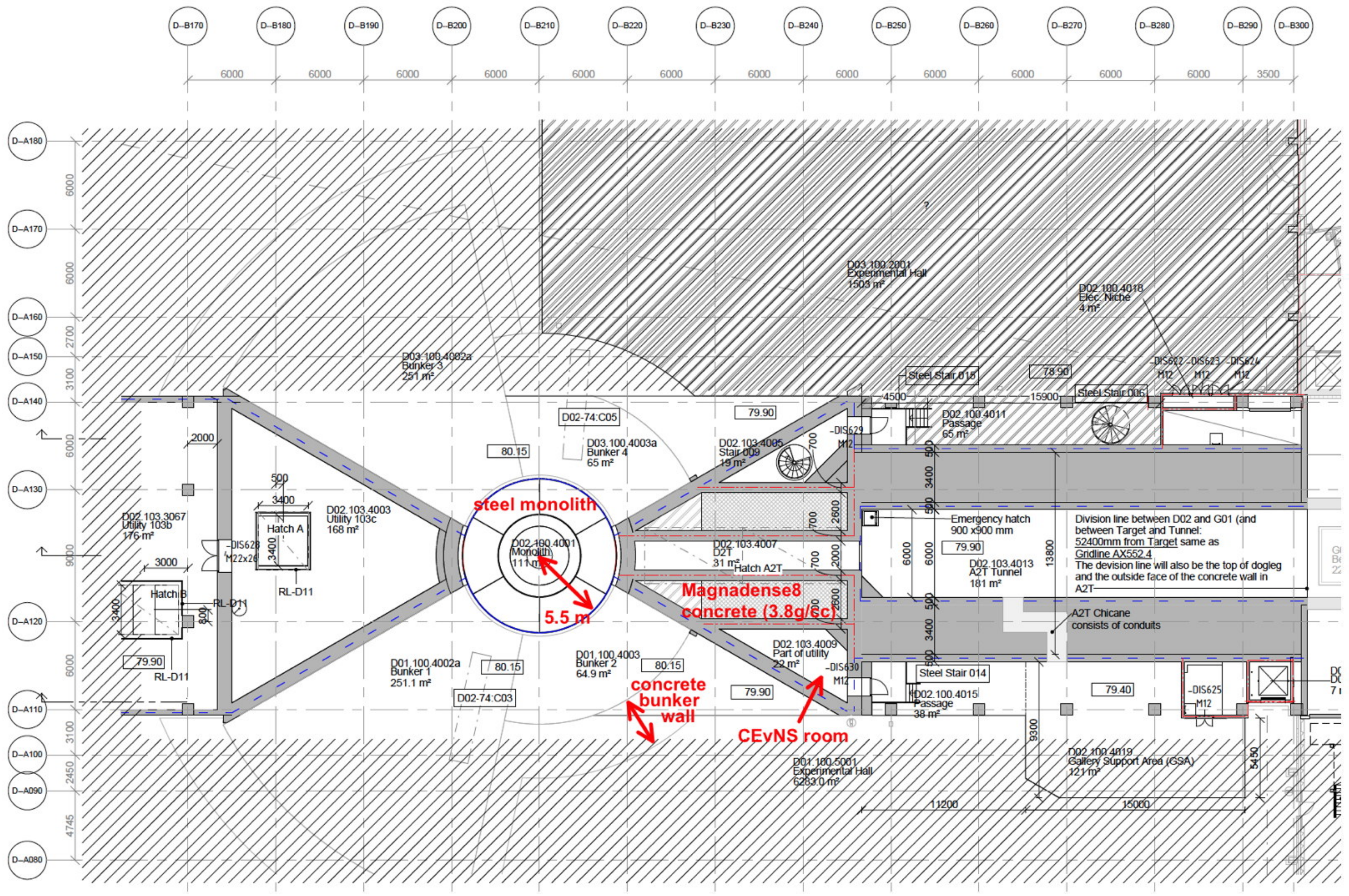


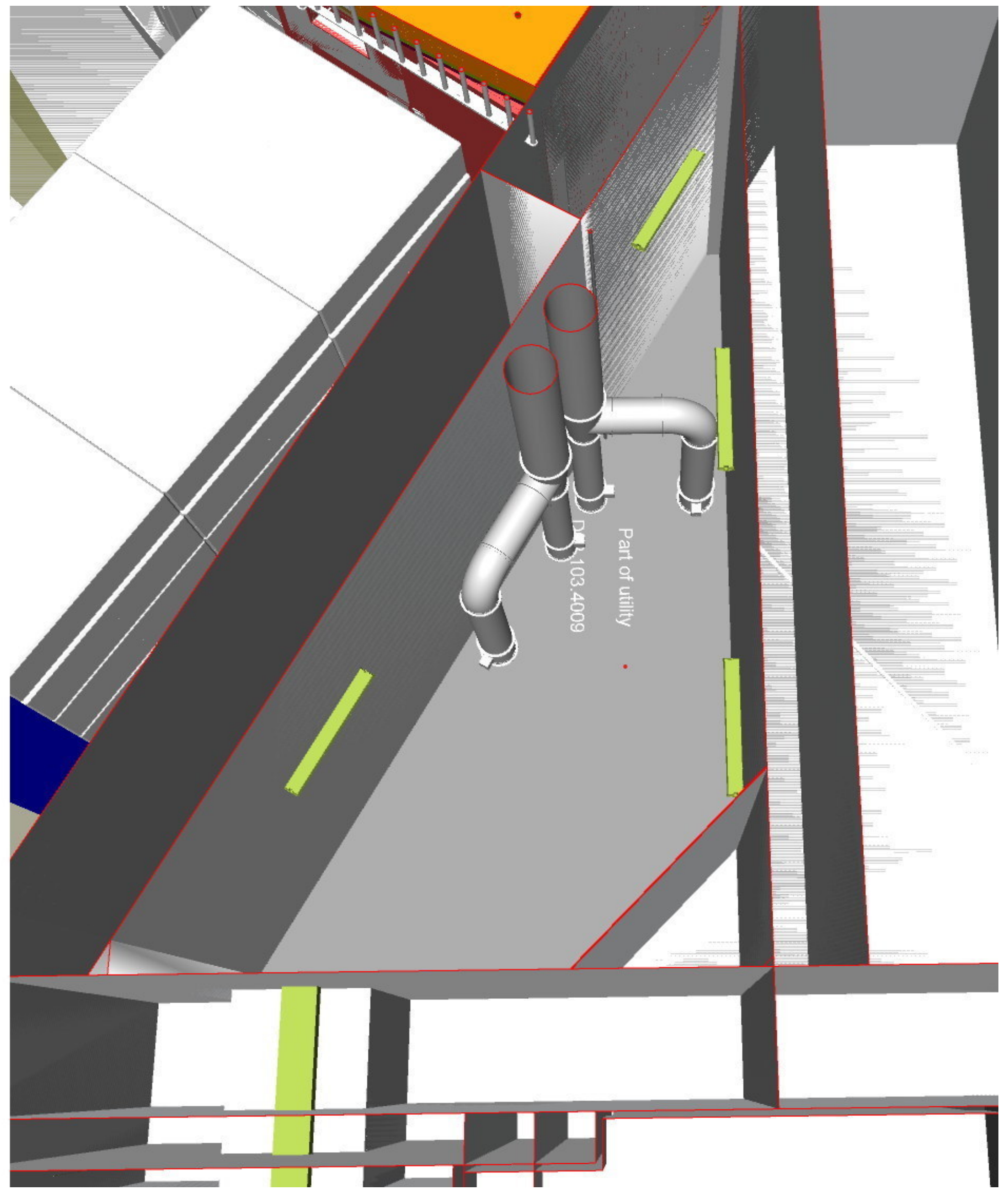
A new opportunity for CEvNS

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 and J. Collar (U. Chicago).
- Two promising locations have already been identified.
- Steady-state background can be subtracted.





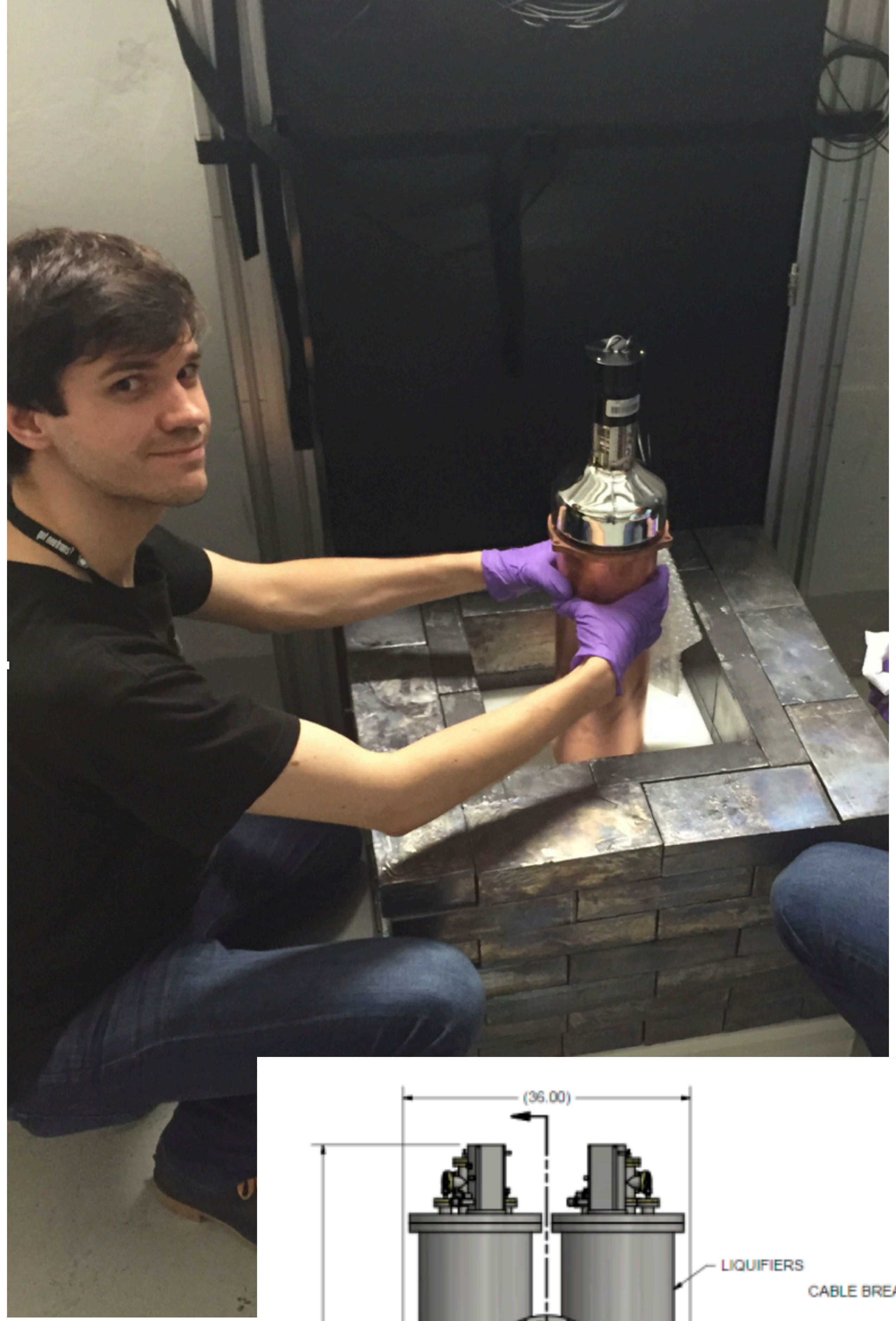


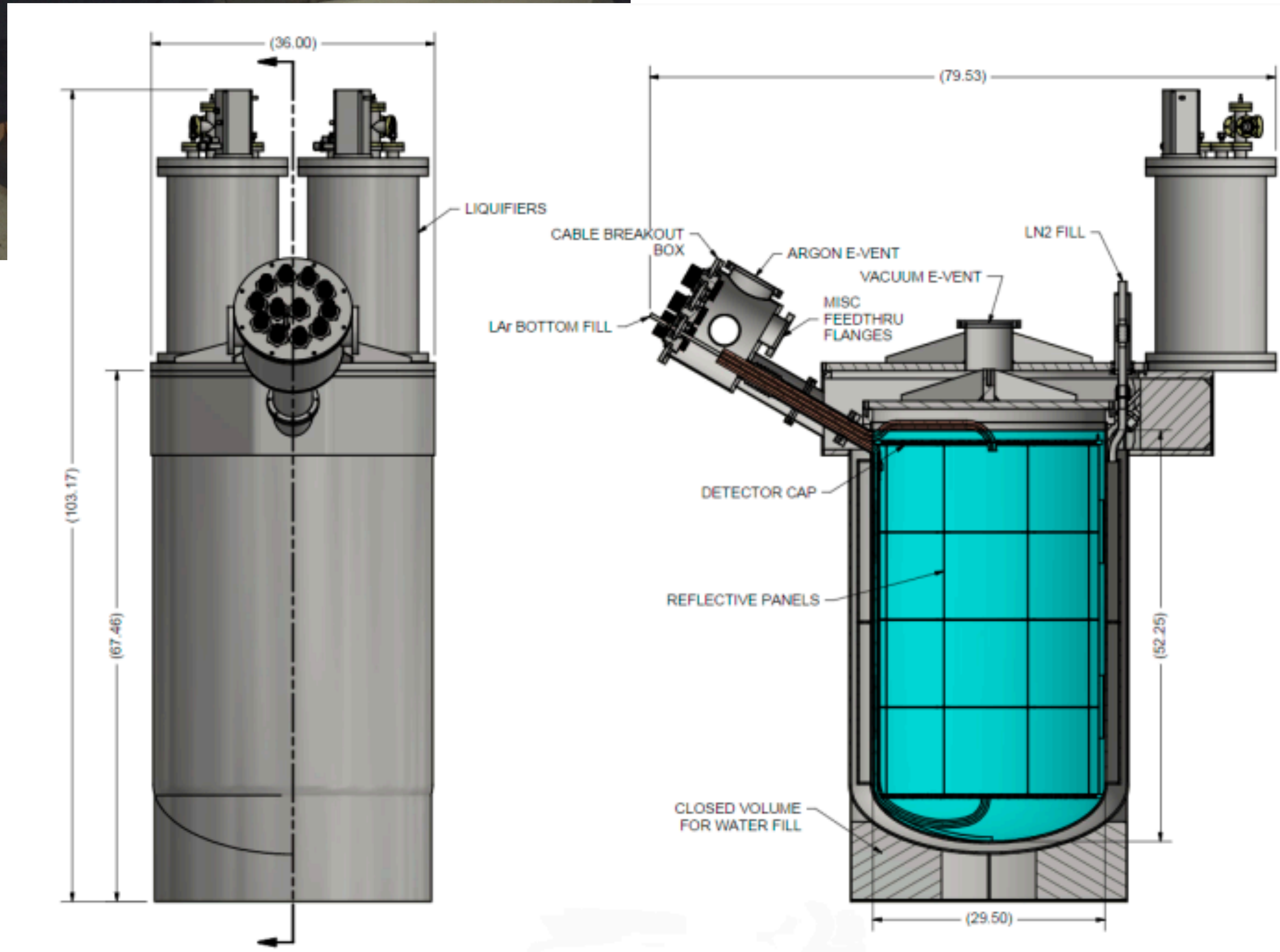
Adding elements of the building structure using NAVISWORKS 3-D layouts

Coherent ν-N scattering

Detectors

- The single observable from CEvNS is a recoiling nucleus, which generates a signal in the few keV to sub-keV energy range.
- This requires detectors with ultra-low detection threshold. A common business with the Dark Matter Industry.
- Huge cross section (compare with all other neutrino interactions) allows “miniature detectors”





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Coherent Elastic Neutrino-Nucleus Scattering at the European Spallation Source

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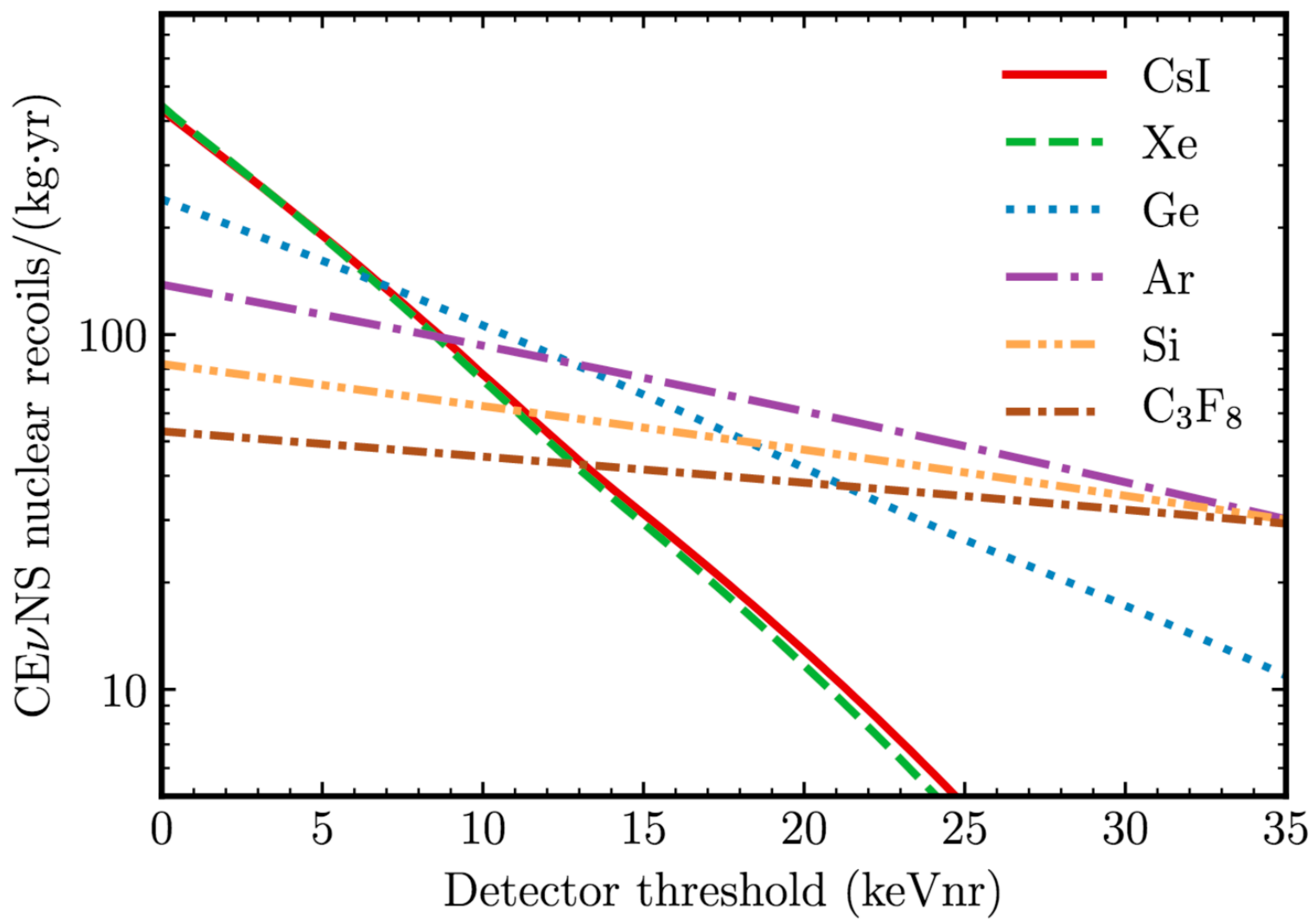
Detector Technology	Target nucleus	Mass (kg)	Steady-state background	E_{th} (keV_{ee})	QF (%)	E_{th} (keV_{nr})	$\Delta E/E$ (%) at E_{th}	E_{max} (keV_{nr})	CEνNS NR/yr @20m, >E_{th}
Cryogenic scintillator	CsI	22.5	10 ckkd	0.1	~10 [71]	1	30	46.1	8,405
Charge-coupled device	Si	1	1 ckkd	0.007 (2e⁻)	4-30 [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



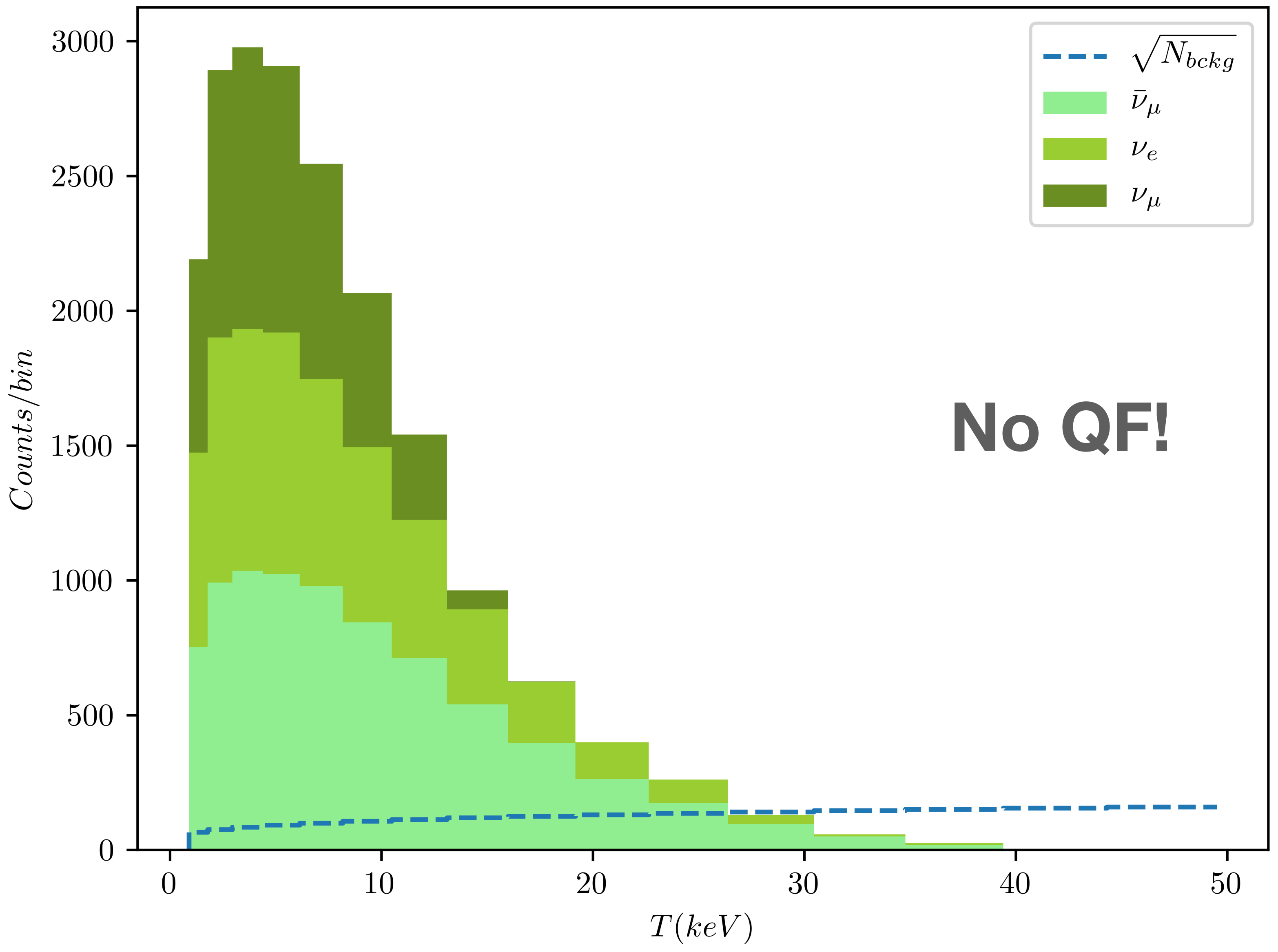
- **Technologies sensitive to 1 keVnr nuclear recoils**
- **Interesting physics concentrates at low-E (e.g. n magnetic moment). Also, maximum statistics.**

- **Interesting CsI/Xe overlap (same response, different systematics)**

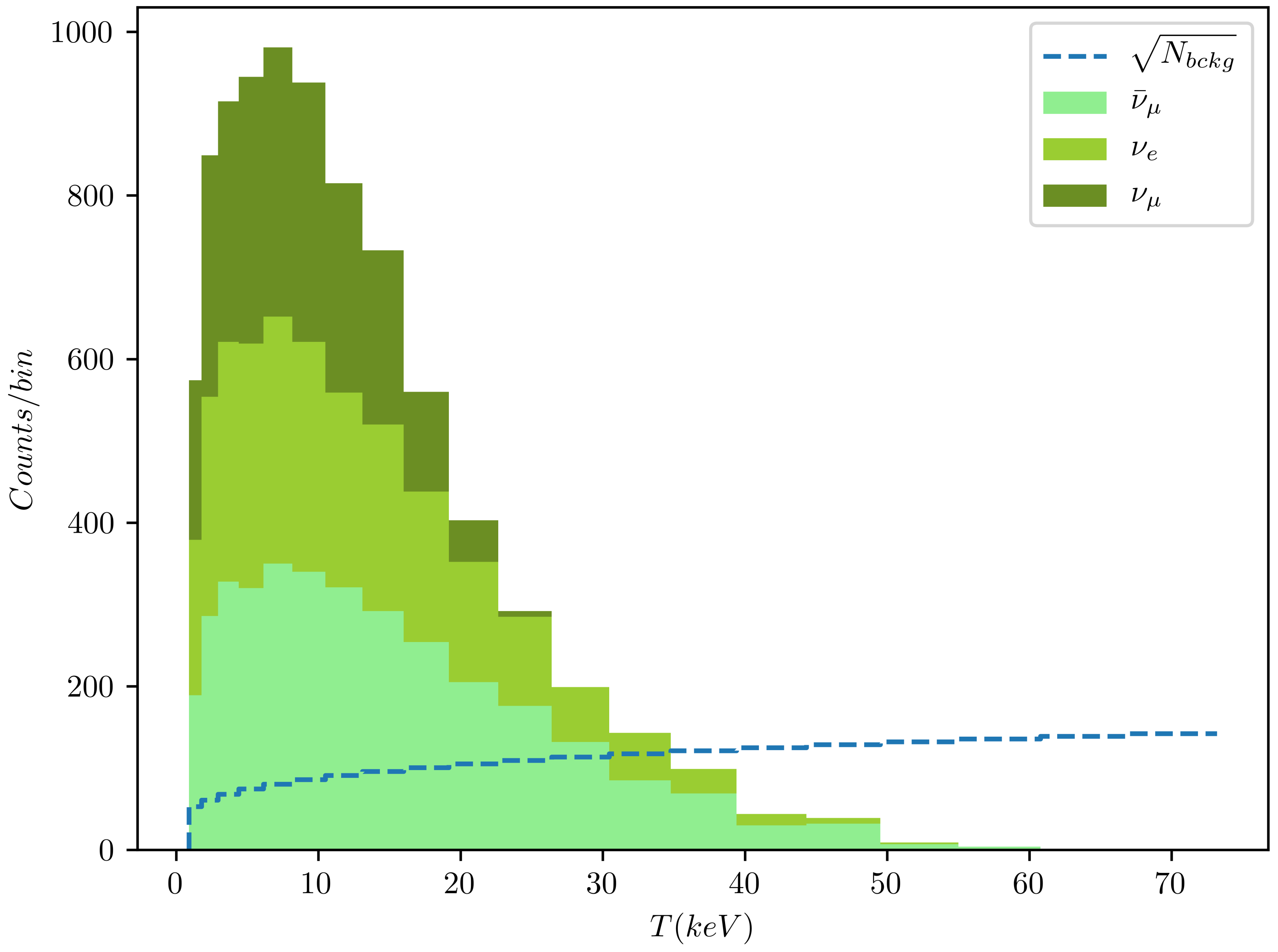
Gaseous detectors?

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

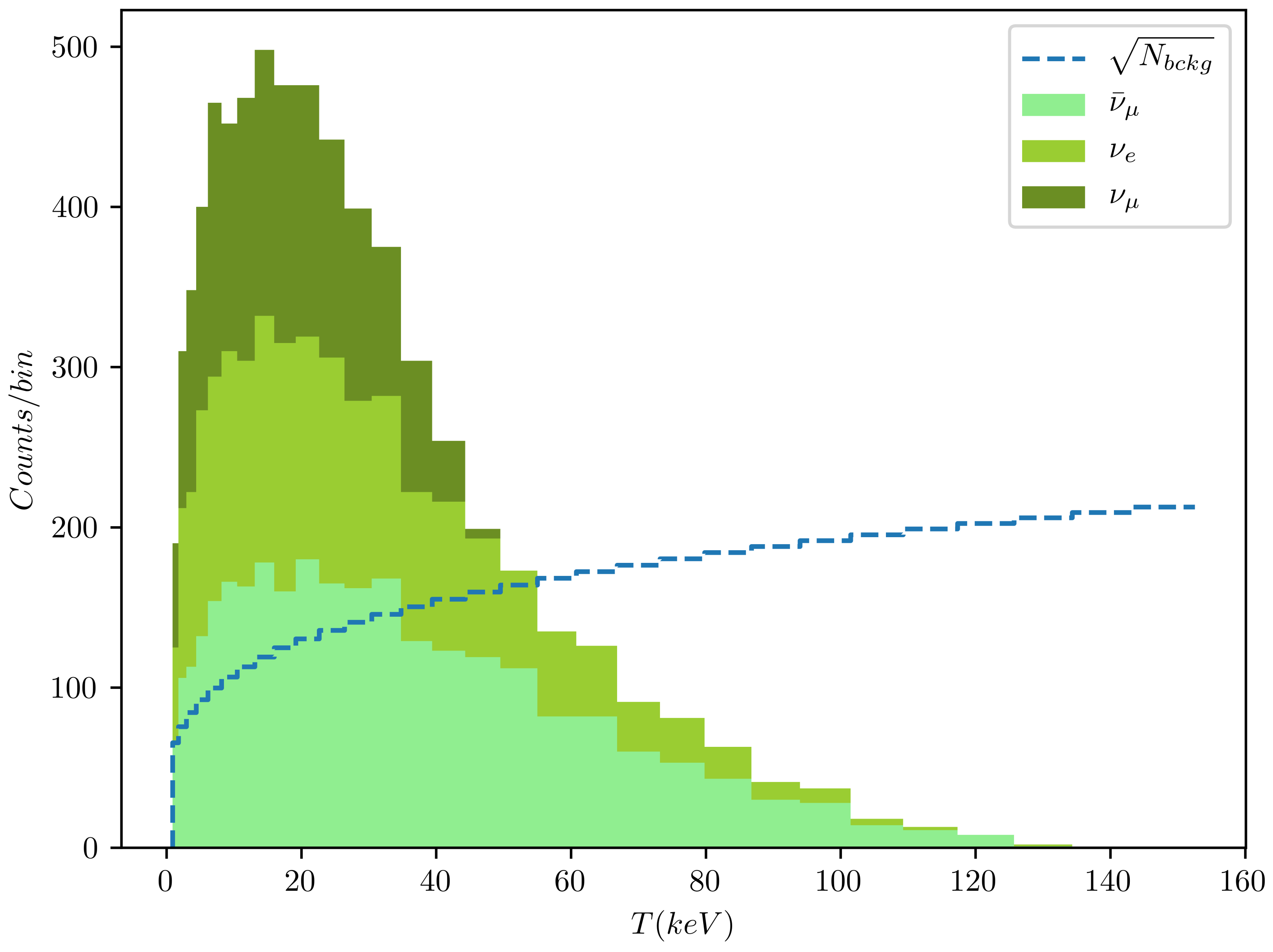
Thanks to the large neutrino flux produced by the ESS, detectors with ~20 kg won't be limited by statistics



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



Same detector filled with Krypton

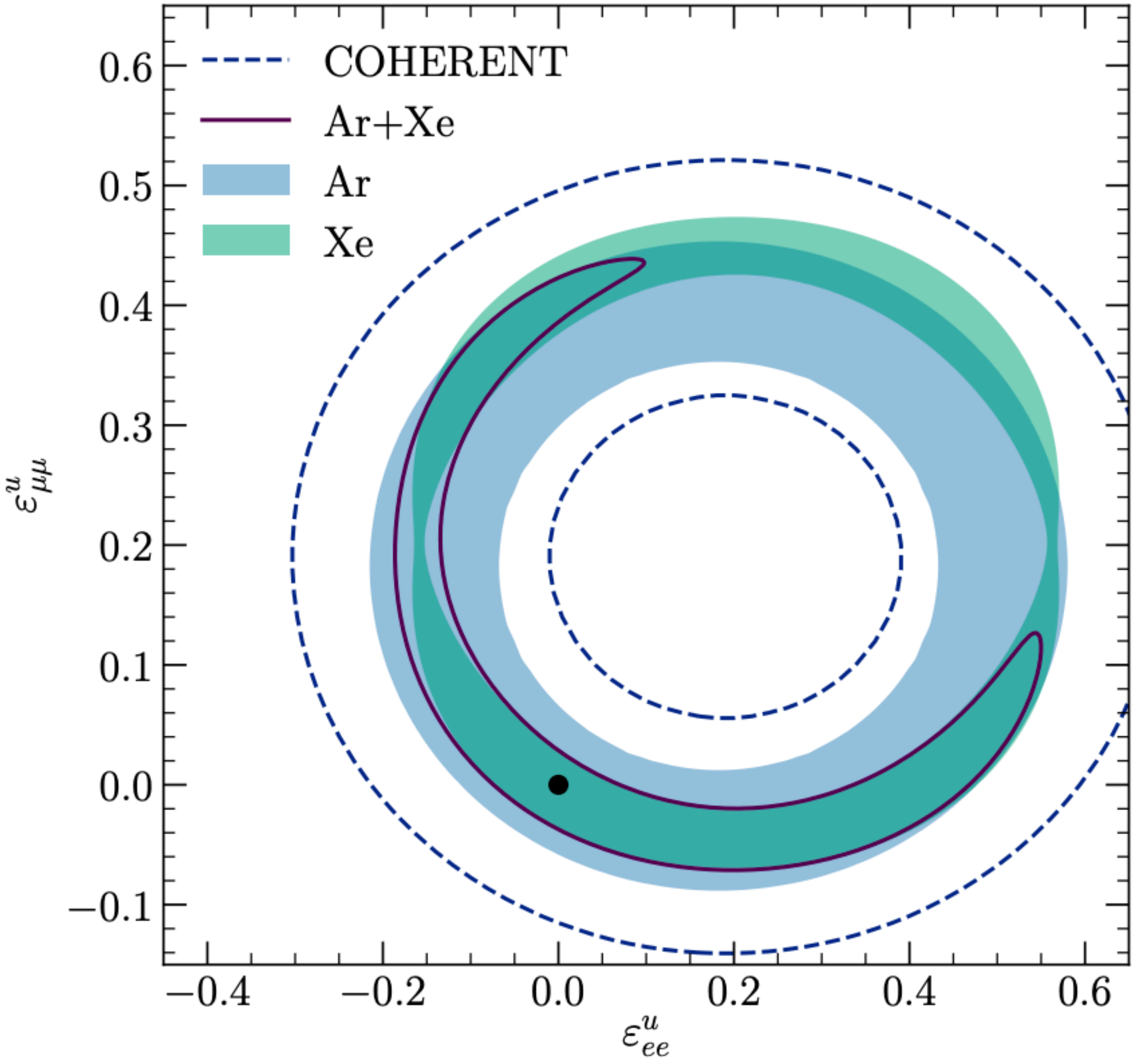


Same detector filled with Argon

Gaseous detectors?

High pressure gaseous detector have other advantages:

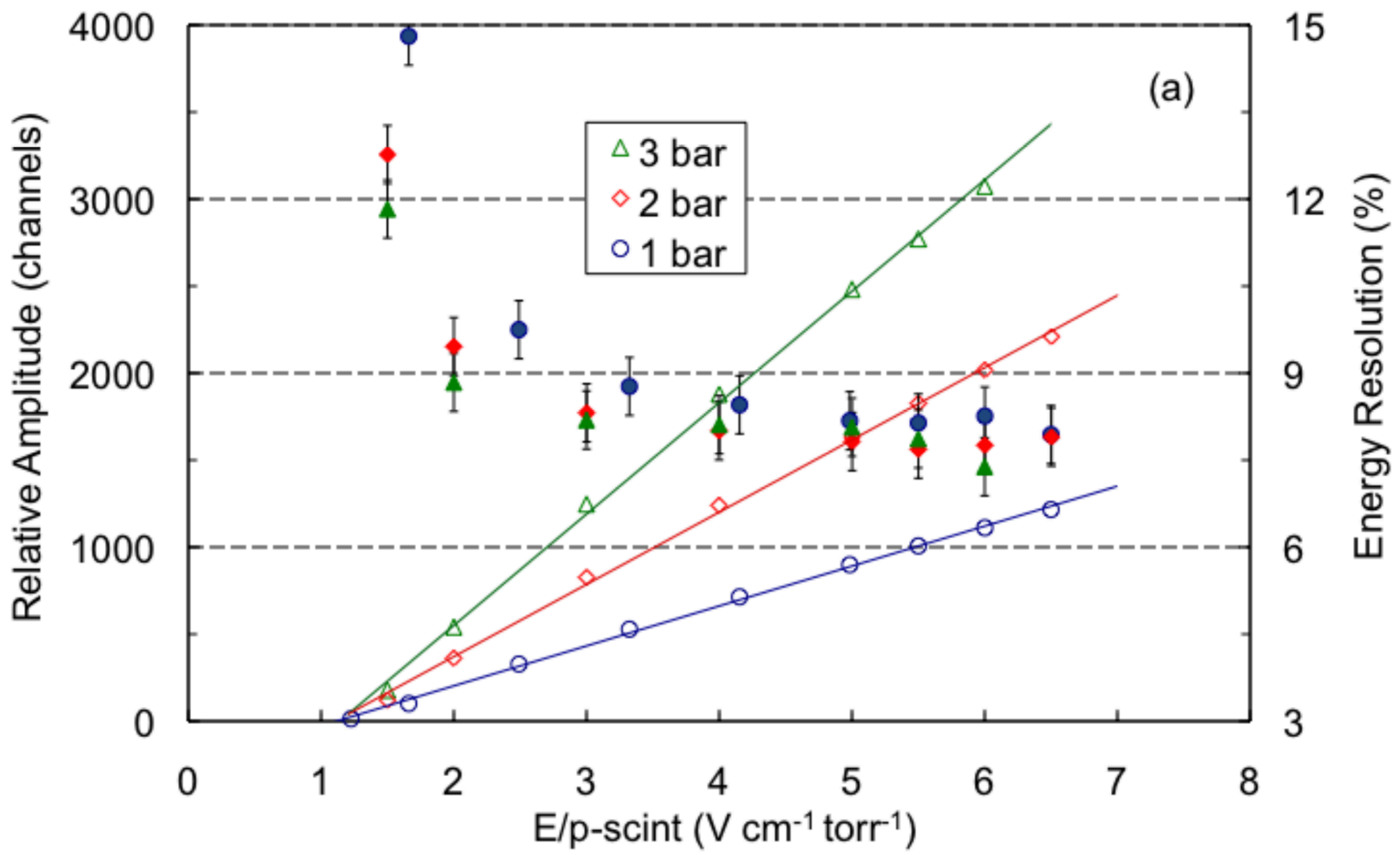
- Simpler, no need of a cryogenic system.
- Larger EL amplification.
- Allow to operate with different nuclei in the same set-up with minimal increase of the costs.
- High pressure xenon technology developed by the NEXT collaboration for bb0v searches.
    - Most of the solutions already developed for low-background experiments.
    - Some R&D will be needed for very low energies, and possible higher pressures.



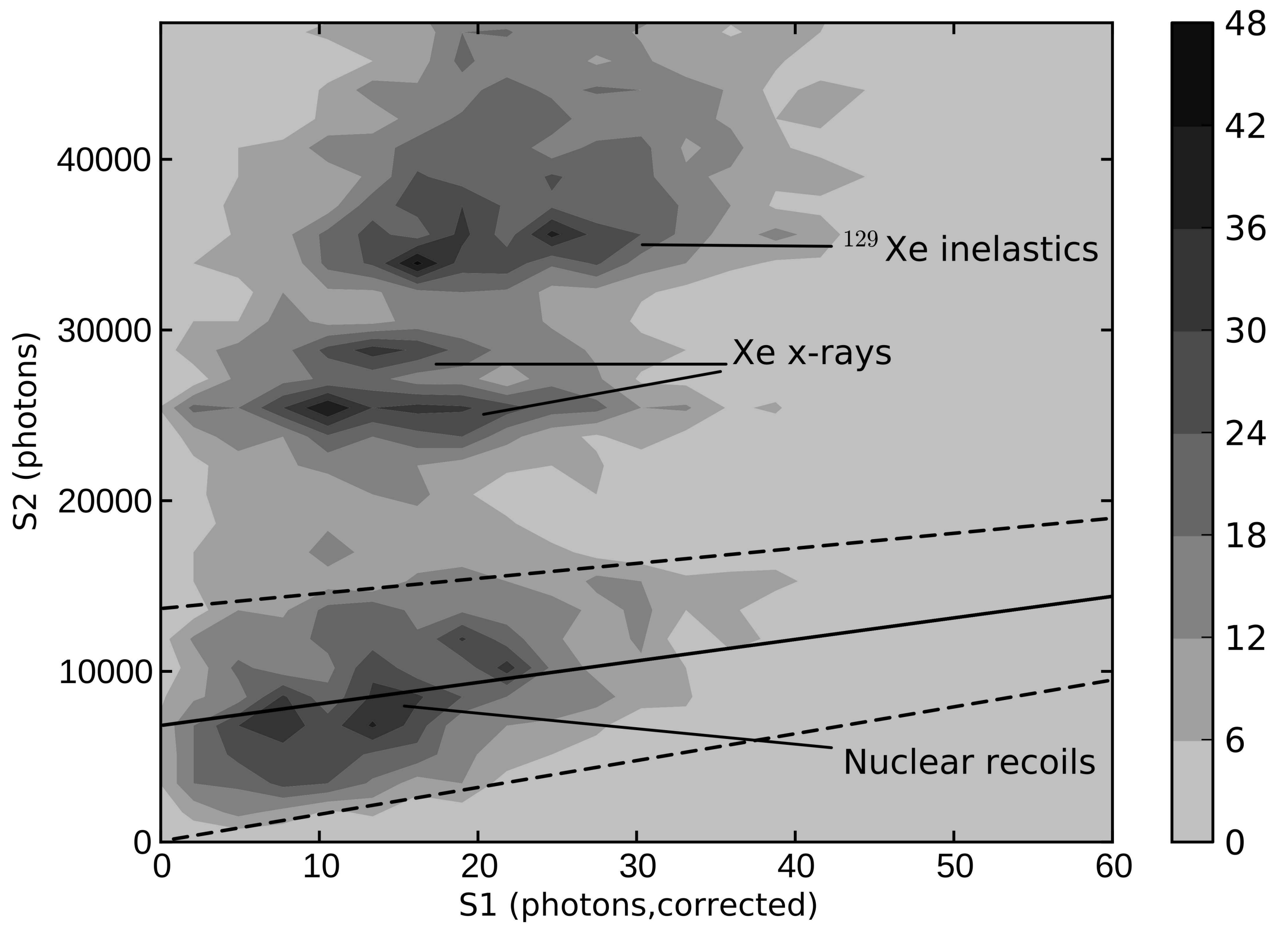
Sensitivity to non-standard neutrino interaction for a detector running with Xe only, Ar only, and a combination of both

Gaseous detectors?

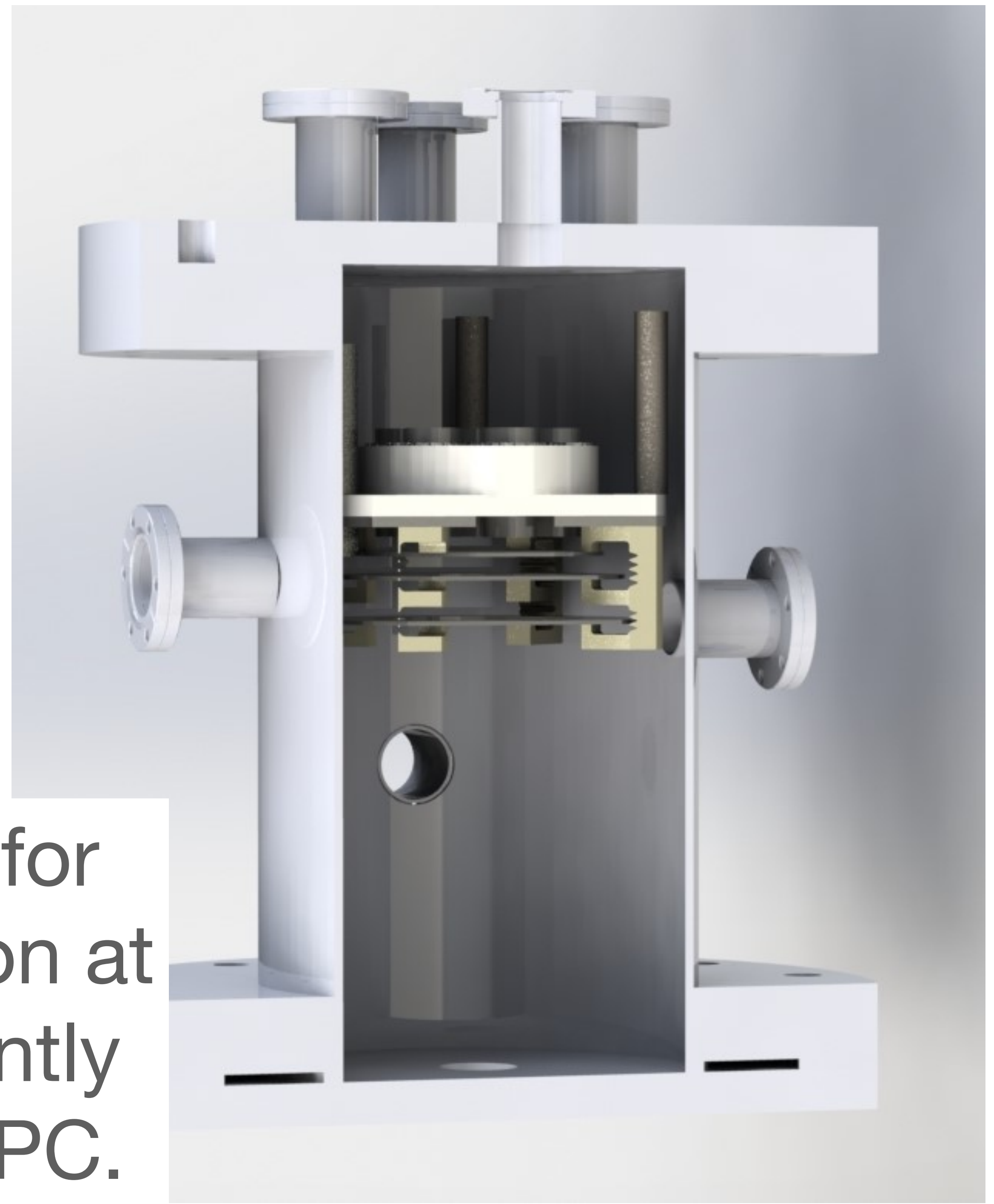
- Electroluminescence amplification increases with pressure. Signals as low as 1-2 ionized electrons can be detected. This reduces the expected energy threshold to less than 1 keVee.
- We'll also need larger voltages.
- Dedicated studies of the response of gaseous detectors to few-keV nuclear recoils will be necessary to reduce the present uncertainty on the quenching factor.
- A dedicated set-up is being designed at DIPC that will also serve to test the technology at very low energies and take decision for the large detector.
- Optimisation of the optics for different emission spectra needed to operate with different gases.
- R&D for very high pressures will allow to increase the mass in lighter gases.



Dependance of EL yield with the reduced field for different Xe pressures

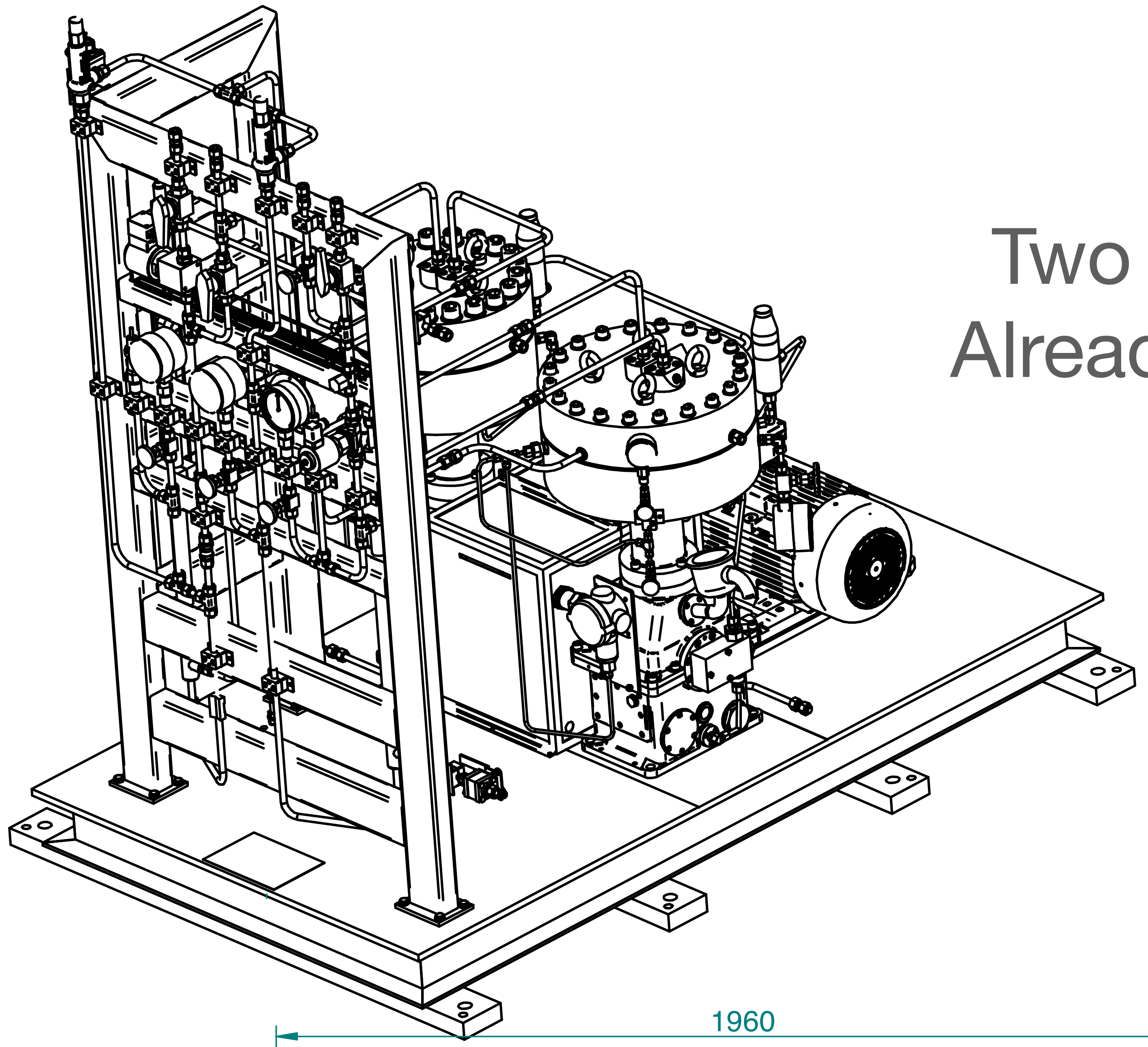


S2 vs S1 signals in xenon gas.

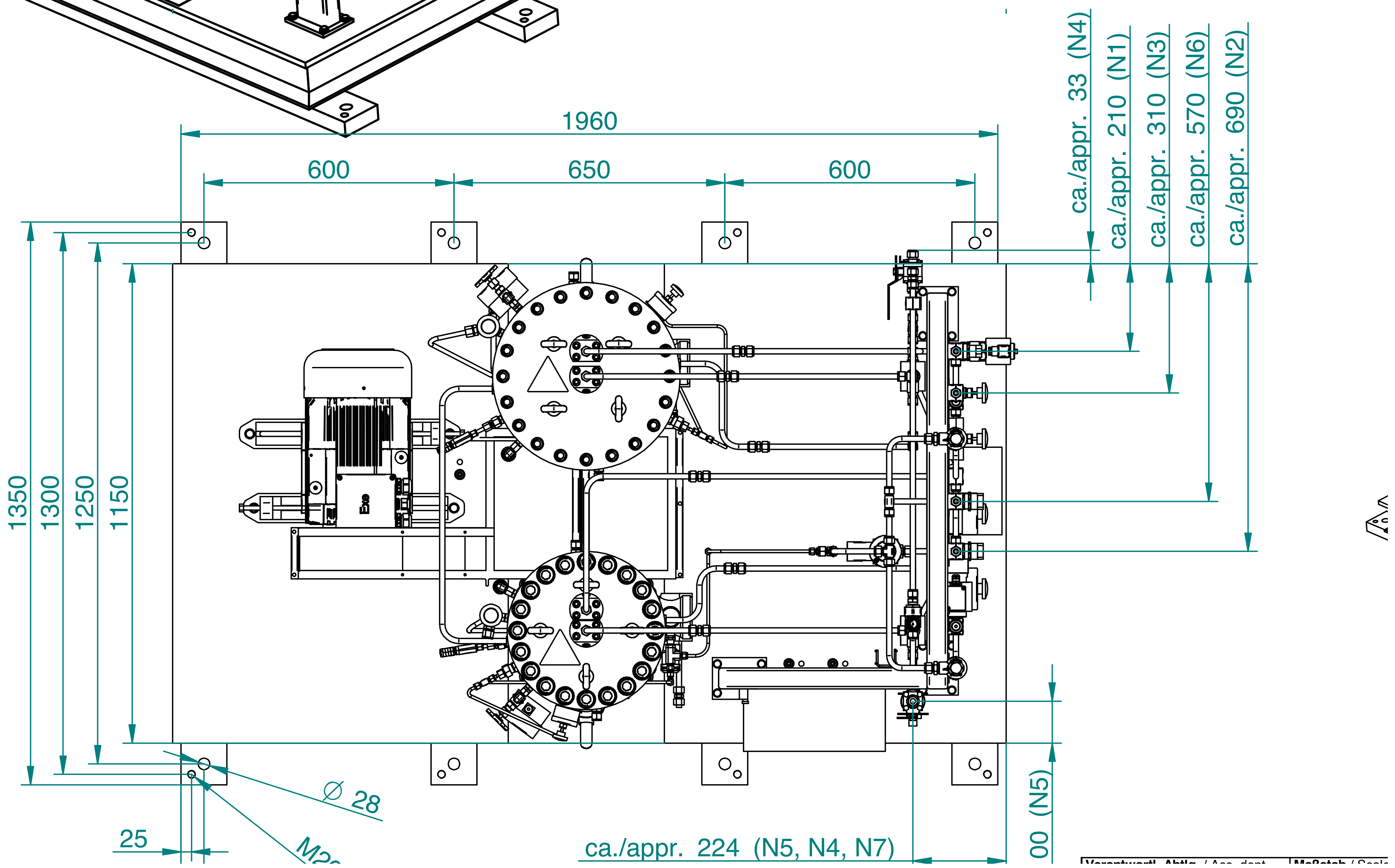


Dedicated set-up for the QF determination at low energies currently under design at DIPC.

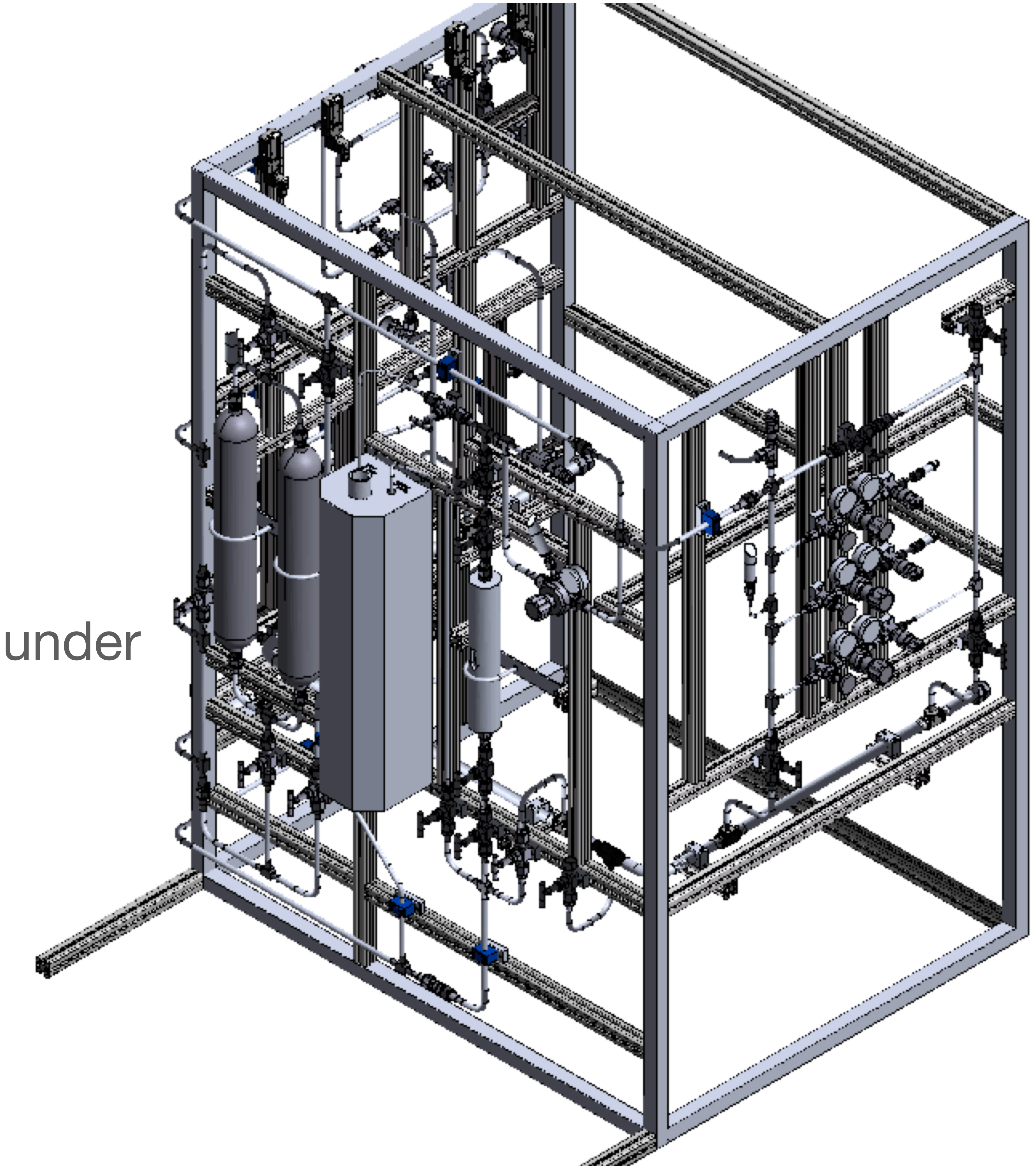
High pressure noble gases laboratory being equipped at the DIPC



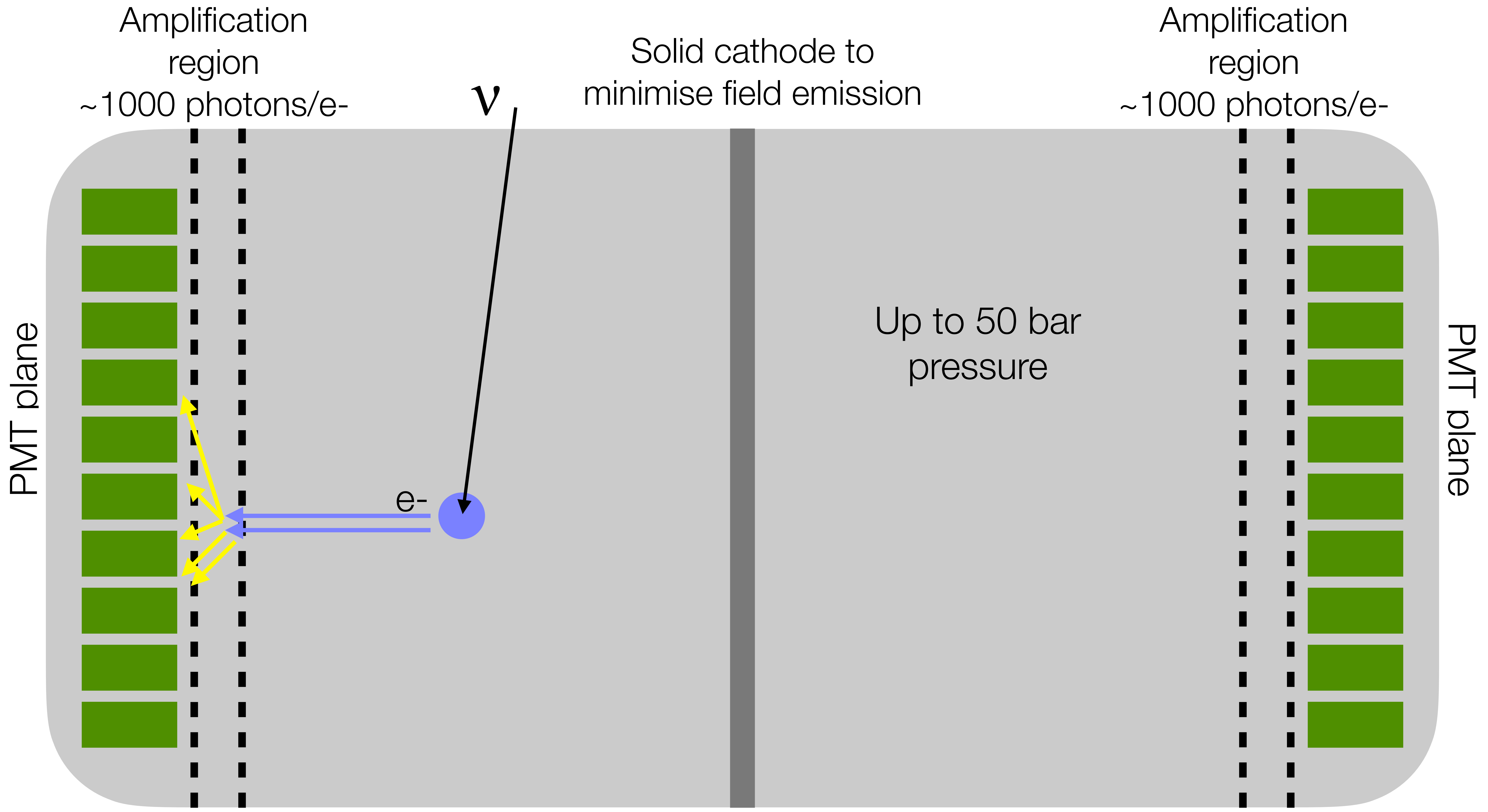
Two stages 10 to 50 bar compressor.
Already designed for the large detector.
Ready in the next months.



Gas circuit already under construction



Gaseous detector for Neutrino physics at the ESS (**GaNESS**)



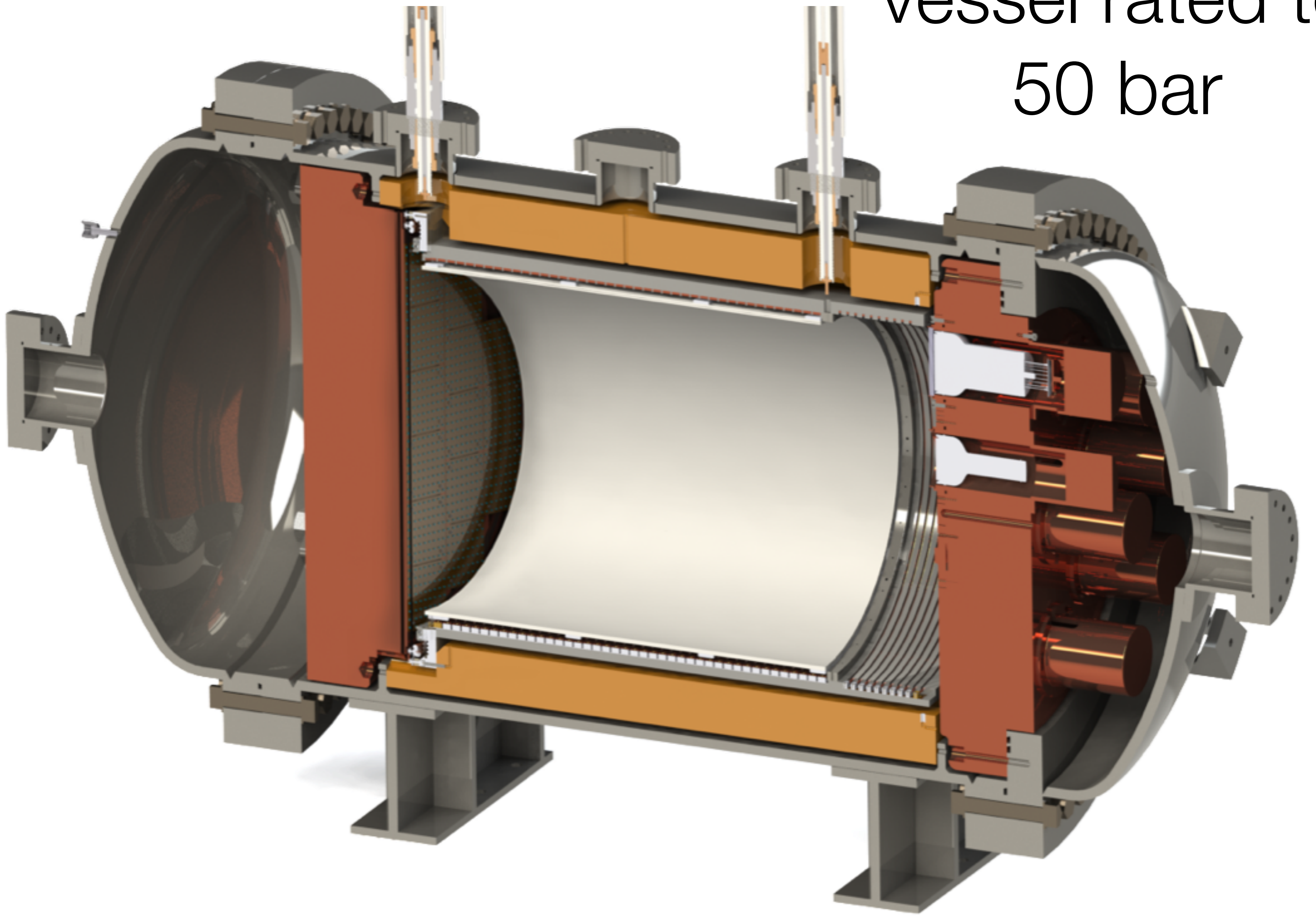
Symmetric detector with two PMT planes to be sensitive to tiny signals.
Large optical coverage with minimal dark current. Expected to be sensitive to single electrons.

Avoid using WLS to prevent spurious signals from possible re-emission.

NEXT-NEW

Tracking plane with SiPMs

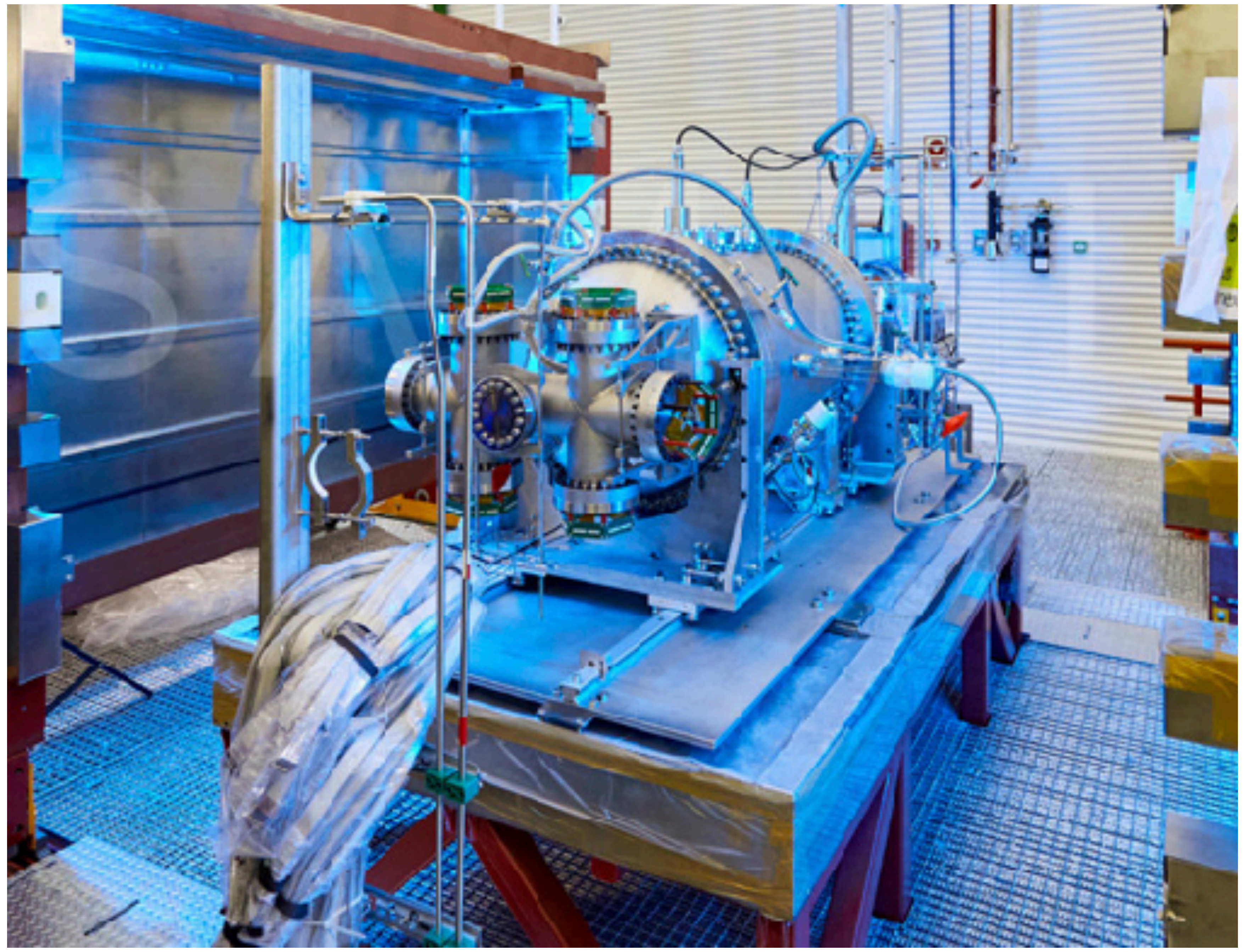
Pressure vessel rated to 50 bar



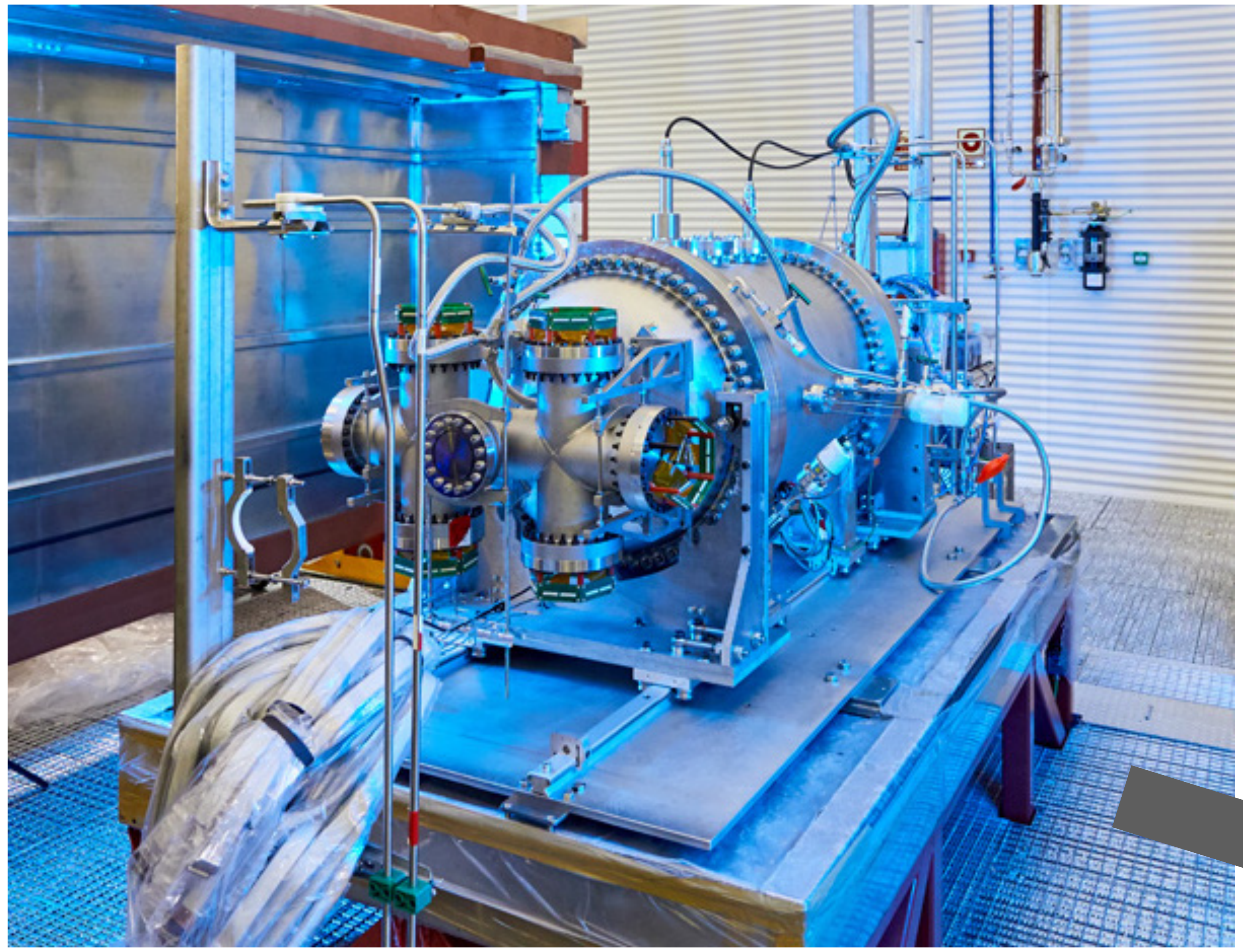
Copper shield:
6cm in the main body,
12 cm in the end caps

Energy plane with PMTs

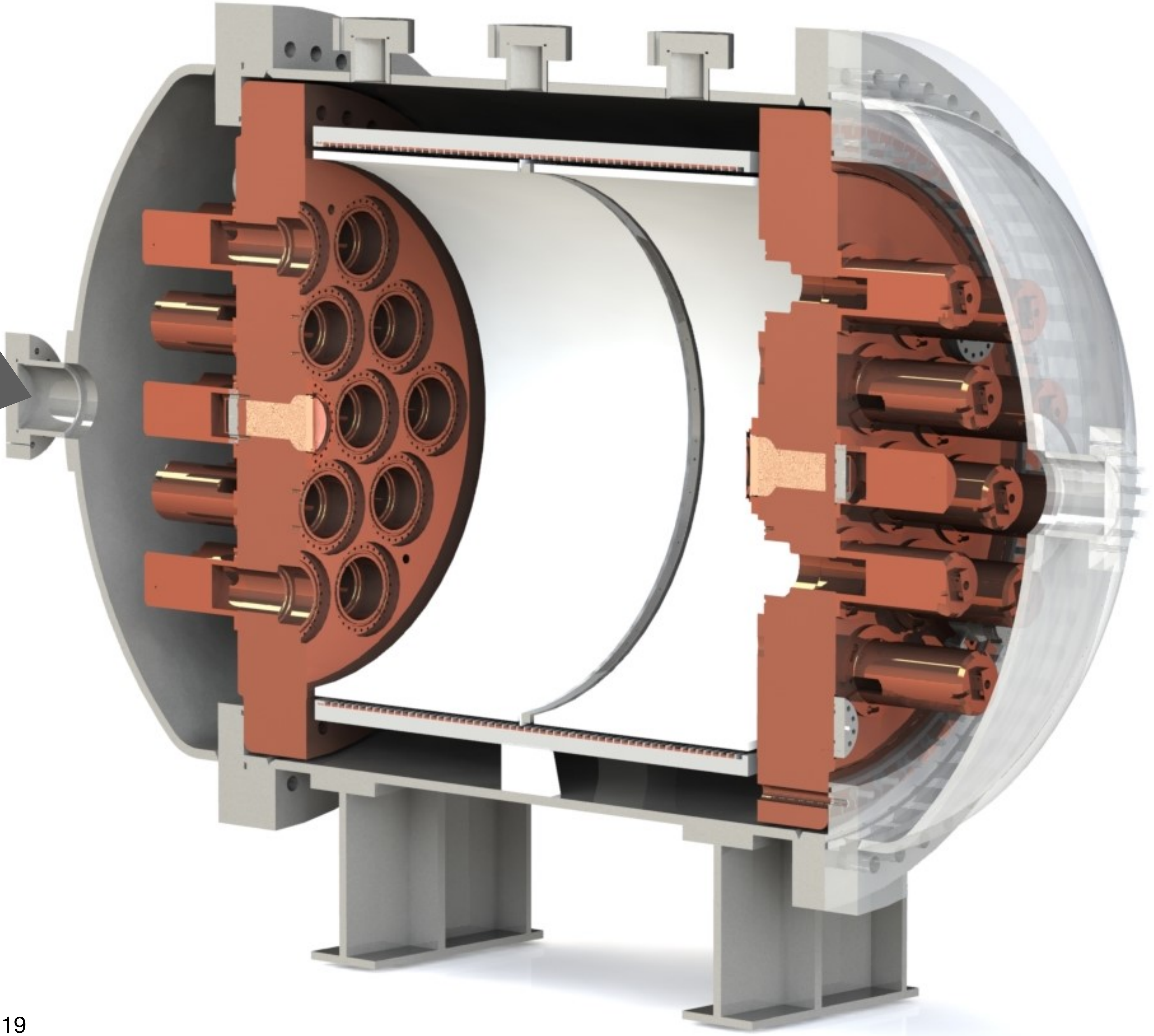
Taking data at the LSC



Detector can be optimised for operation at the ESS



Most of the technology developed for NEXT, can be directly applied to this detector.



Working on the design, it will need to be updated using MC and information of the R&D phase.

Detector final size will depend on ESS chosen location

We need to optimise PMT coverage & Understand detector response with different emission spectra (Use of gas mixtures?)

Much work to do before ESS protons-on-target

- CEvNS detector construction/modifications
- Quenching Factor studies
- Neutron back measurements & simulations
- Location at the ESS
- Neutrino flux characterisation
- Phenomenology

EUROPEAN SPALLATION SOURCE

Coherent Elastic Neutrino-Nucleus Scattering at the ESS

Expression of Interest

J.I. Collar,[e] J.J. Gomez-Cadenas,[d,g] F. Monrabal,[d,g] P. Privitera,[e] A. Algora,[j] L. Arazi,[m] F. Ballester,[k] D. Baxter,[e] C. Blanco,[e] M. Blennow,[q] F. Calviño,[n] G. Carlsson,[t] J. Cederkall,[t] P. Coloma,[j] C.E. Dahl,[c,f] D. Di Julio,[t,u] C. Domingo-Pardo,[j] T.J.C. Ekelöf,[x] I. Esteban,[b] R. Esteve,[k] M. Fallot,[s] E. Fernandez-Martinez,[p] P. Ferrario,[d,g] H.O.U. Fynbo,[v] P. Golubev,[t] M.C. Gonzalez-Garcia,[a,b,h] A.M. Heinz,[w] J. A. Hernando,[i] P. Herrero,[d] V. Herrero,[k] P. Huber,[o] A.R.L. Kavner,[e] E.B. Klinkby,[u] C.M. Lewis,[e] M. Lindroos,[u] N. Lopez-March,[k] E. Lytken,[t] P.A.N. Machado,[f] M. Maltoni,[p] J. Martín-Albo,[j] T.M. Miller,[u] F.J. Mora,[K] G. Muhrer,[u] J. Muñoz-Vidal,[d] E. Nacher,[J] T. Nilsson,[w] P. Novella,[j] C. Peña-Garay,[l] K. Ramanathan,[e] J. Renner,[i] J. Rodriguez,[k] B. Rubio,[j] J. Salvado,[b] V. Santoro,[u] T. Schwetz,[r] J.L. Tain,[j] A. Takibayev,[u] A. Tarifeño-Saldivia,[n] J.F. Toledo,[k] U. Uggerhøj,[v] and L. Zanini[u]

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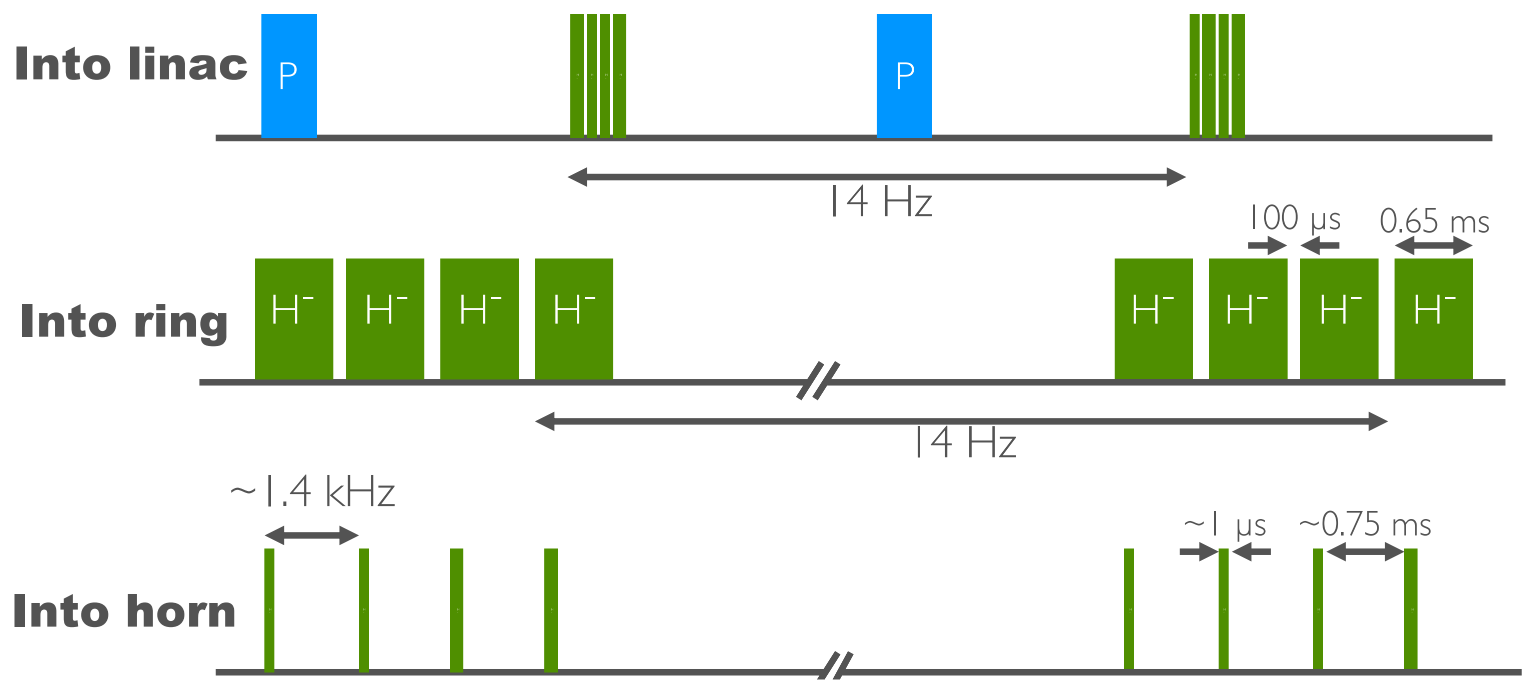
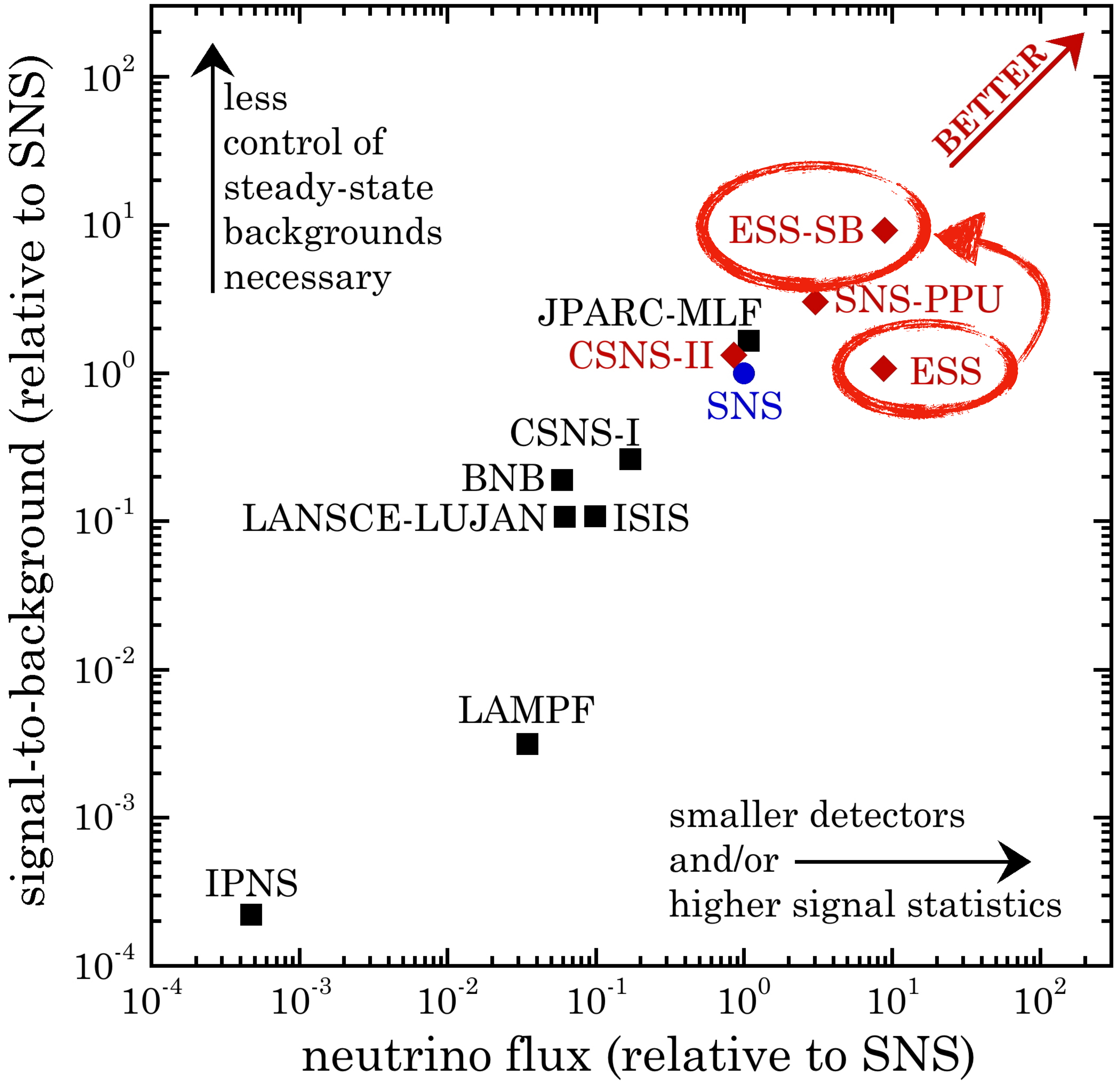
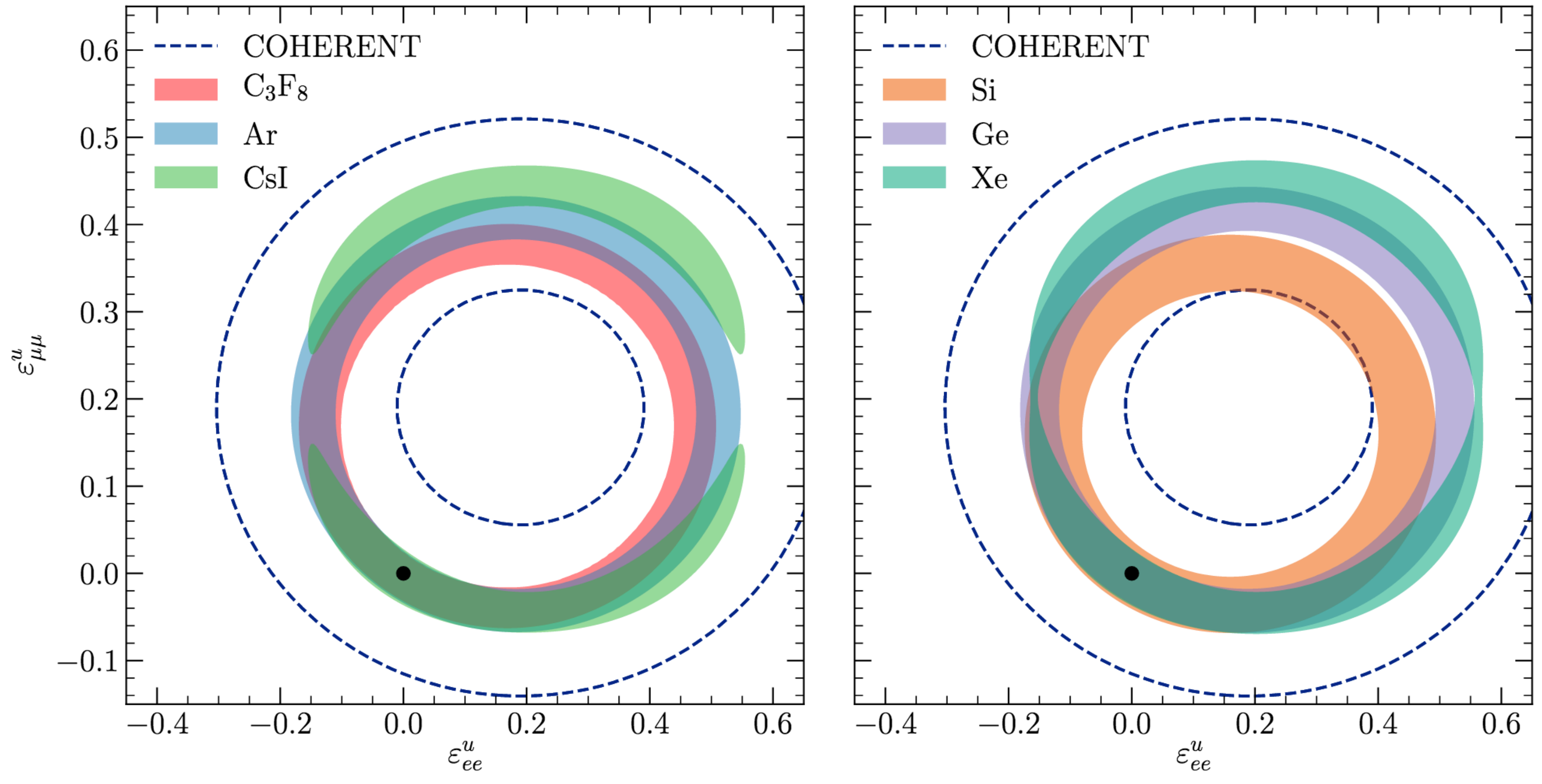
EoI under review

Next level: ESSνSB

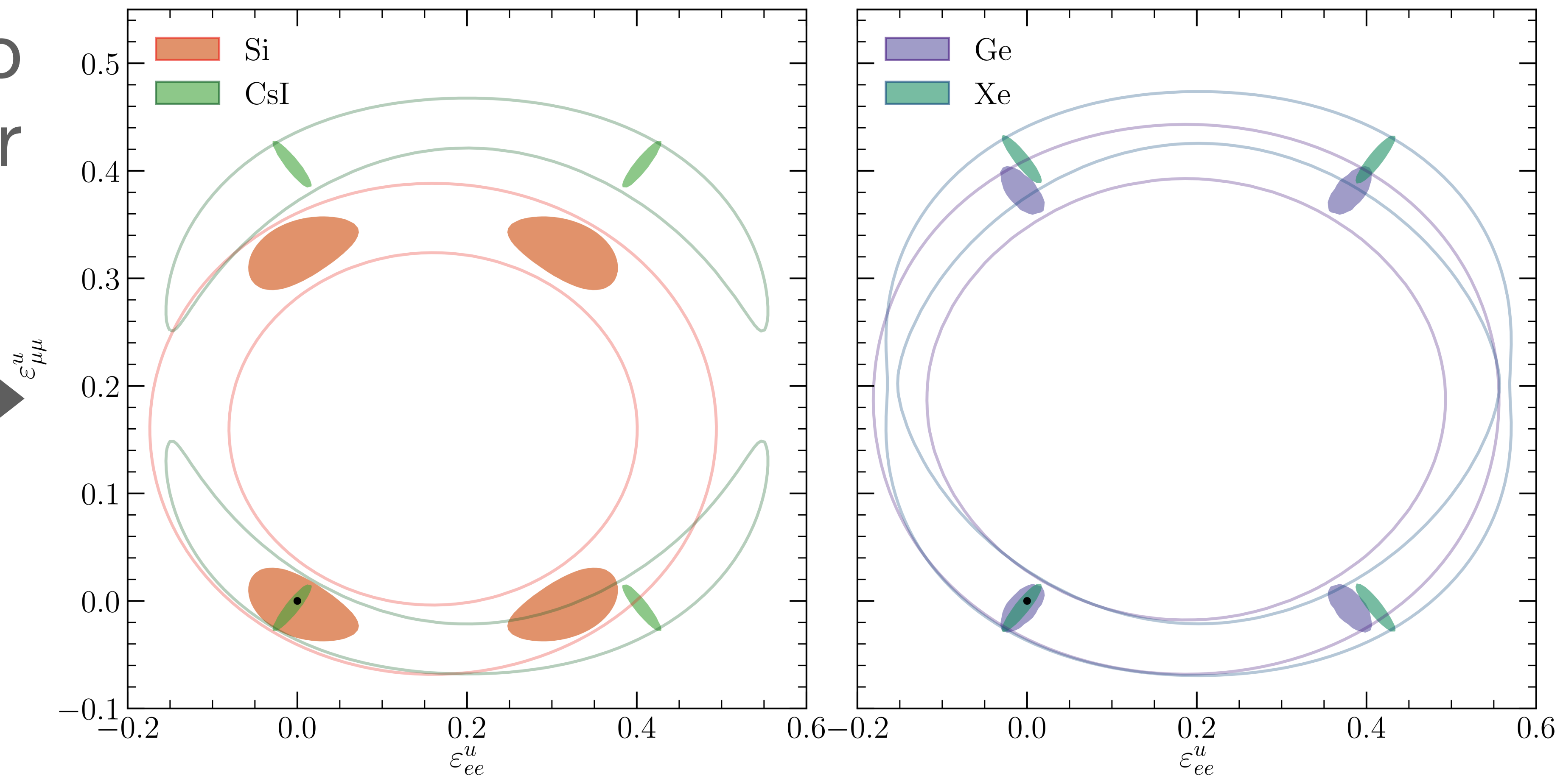
- ESSνSB pulse compression brings:
  - Background drops with duty factor by x70
  - Timing information (prompt vs delayed ν's)







Improvement not limited to NSI, timing opens up other physics possibilities



Preliminary study from I. Esteban, C. Gonzalez-García, P. Coloma

Conclusions

- CEvNS detections opens a large number of phenomenological proposals.
- ESS will become the largest low-energy neutrino source. Perfect facility to study this process.
- The best source deserves an effort to operate the best possible detectors.
- Medium size gaseous detectors can observe the process at the ESS.
- They offer interesting opportunities to explore all physics of the CEvNS.
- An effort already on-going at the DIPC to develop the necessary infrastructures to develop this project.
- Future upgrades of the ESS with pulse compression will enhance sensitivities of this technology to new physics.