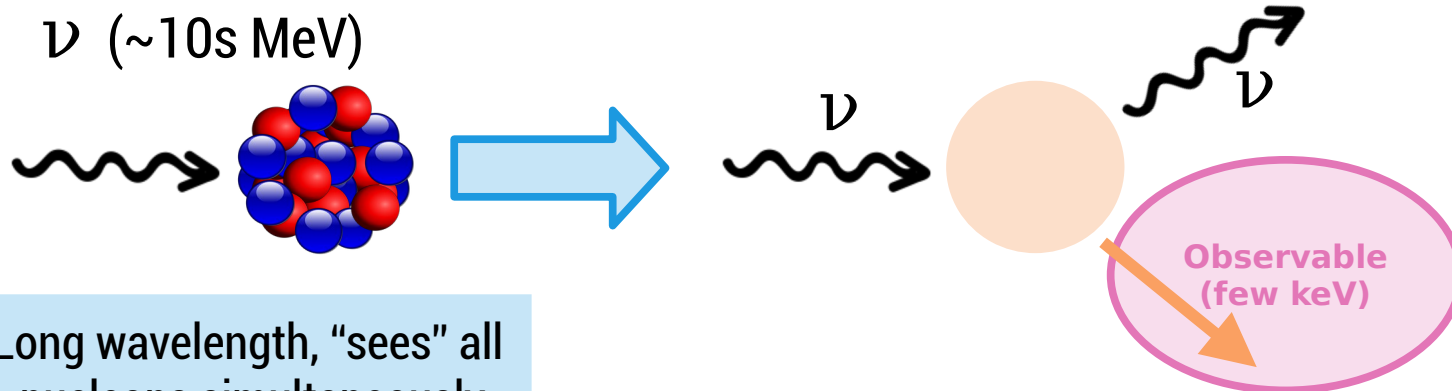


CEνNS at the European Spallation Source

A. Simón, J. Collar and F. Monrabal

Coherent Elastic Neutrino-nucleus scattering (CE ν NS)

CE ν NS



Long wavelength, "sees" all nucleons simultaneously

$$\sigma \sim N^2$$

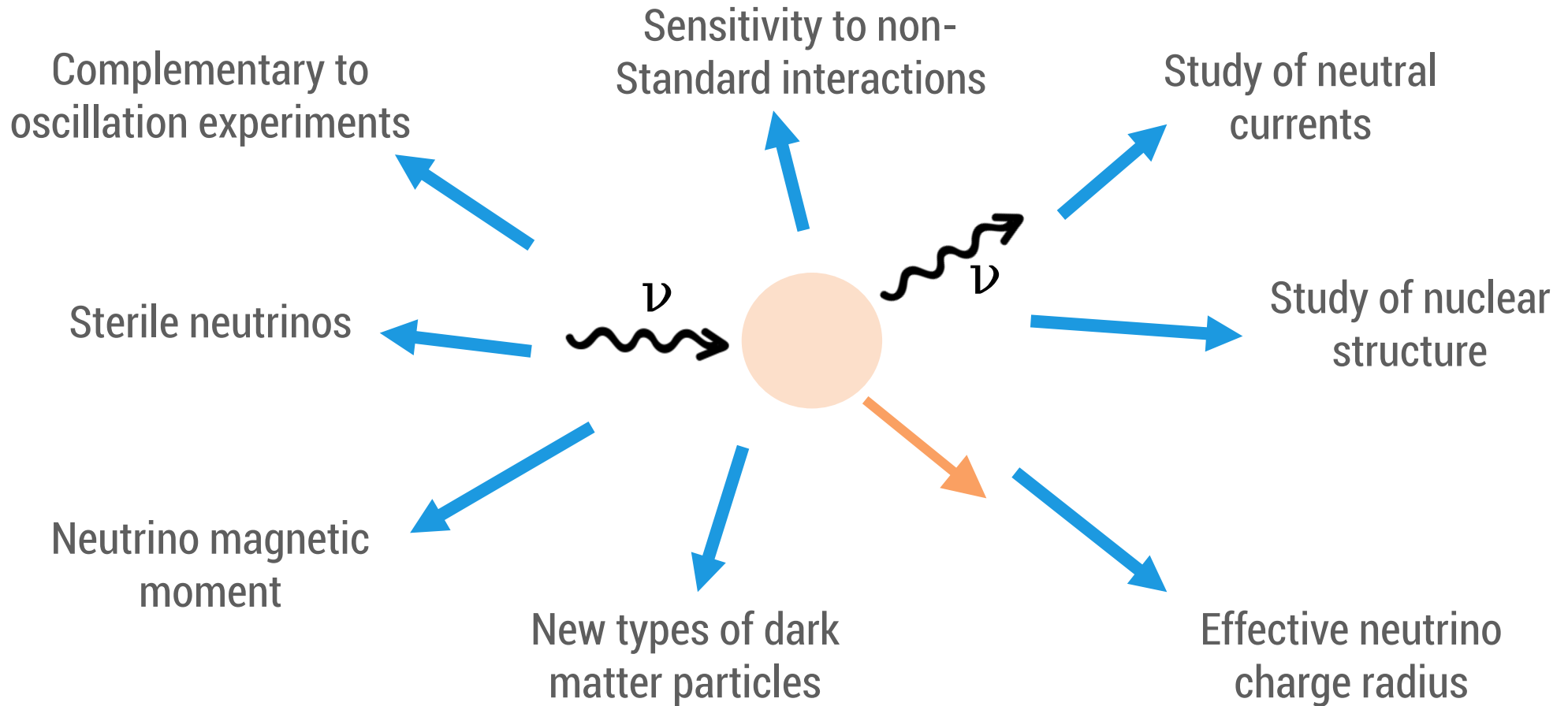
Few kg detectors
can be competitive

Predicted in SM for decades

First detected 6 years ago

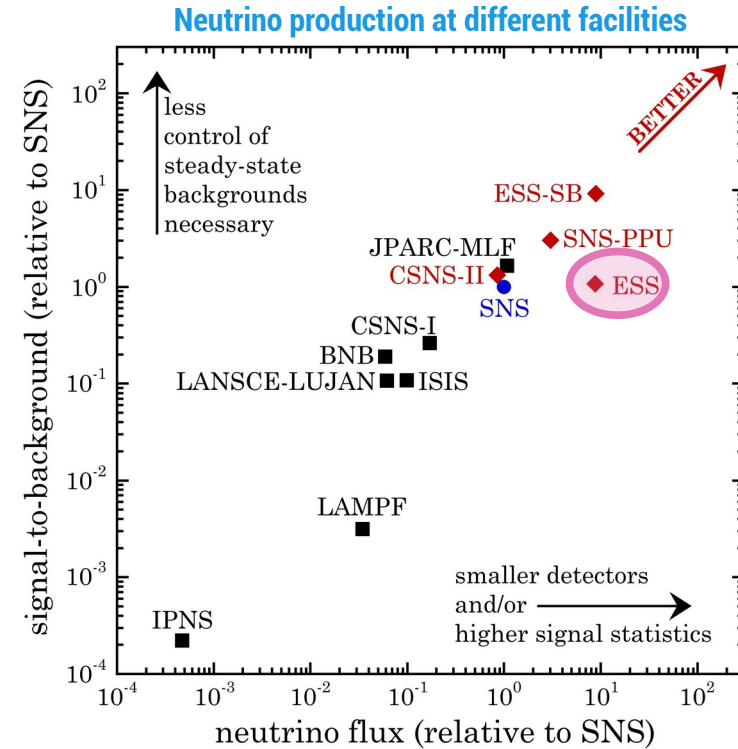
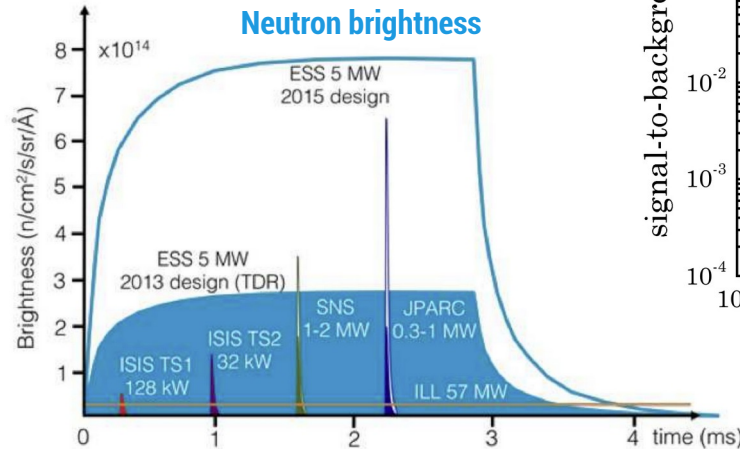


Coherent Elastic Neutrino-nucleus scattering (CE ν NS)



European Spallation Source (ESS)

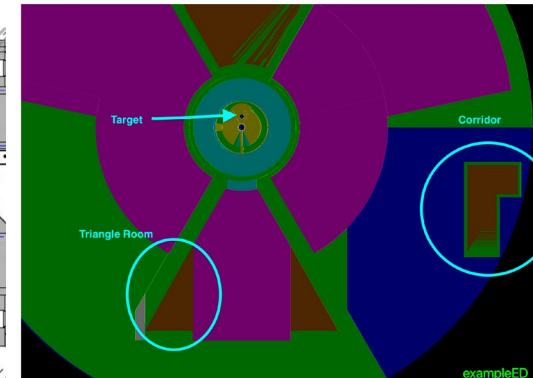
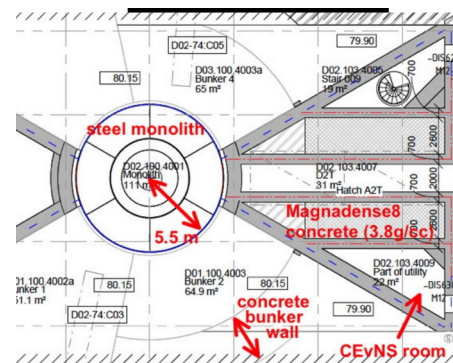
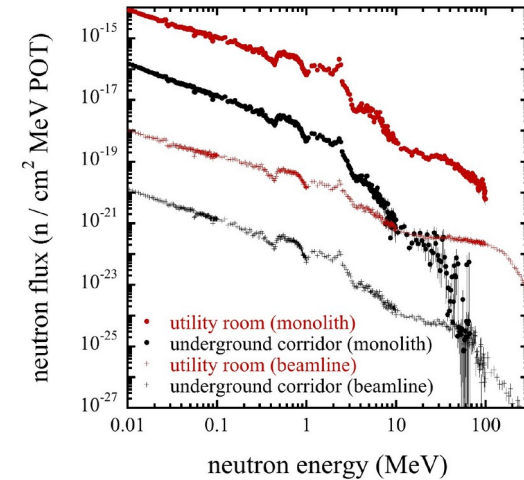
- The ESS will generate the most intense neutron beams for multi-disciplinary science.
- But also, the largest low-energy neutrino flux!
- ν production @ ESS is x9.2 @ SNS
- Similar s/b to SNS but much higher statistics.



Backgrounds at ESS

- Steady-state backgrounds can be subtracted.
- Beam-induced prompt neutrons are the main source of background.
- Simulations undergoing to evaluate deployment locations.
 - 2 candidate locations under study.
- On-site measurements planned:
 - Neutron camera in development at DIPC.

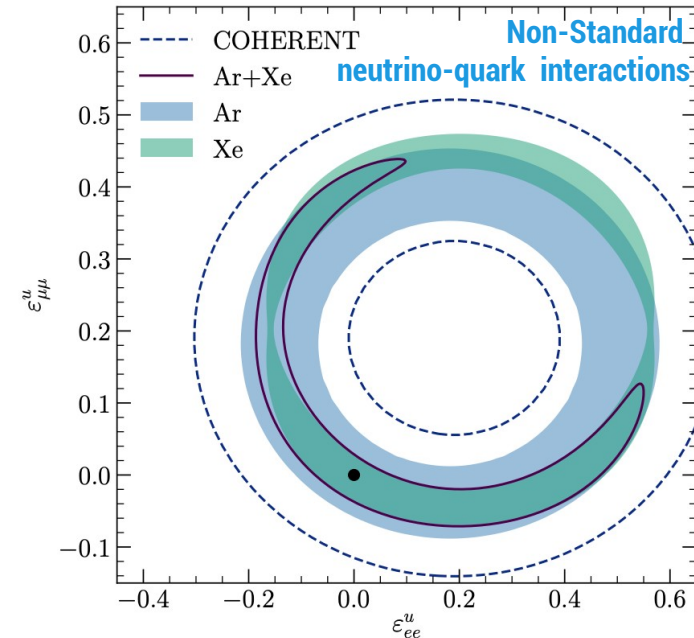
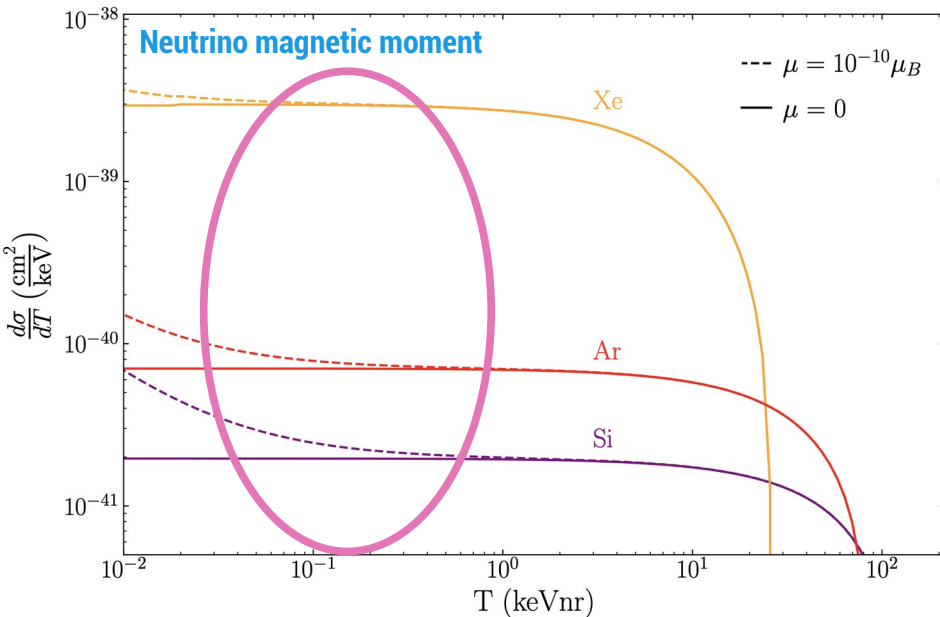
ESS neutron background (MCNP)



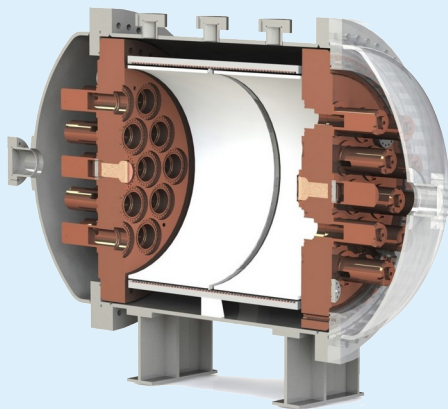
Detecting CEvNS

Physics potential maximized with:

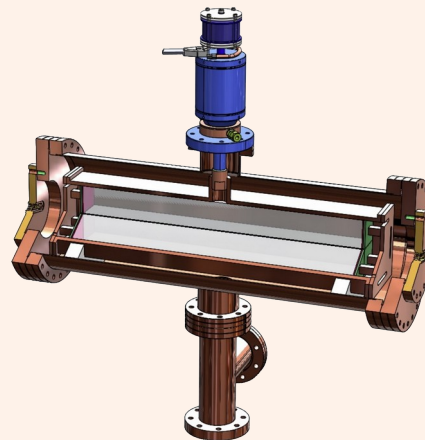
- Low energy threshold
 - Interesting physics at low energy
- Different nuclei
 - Breaks degeneracies



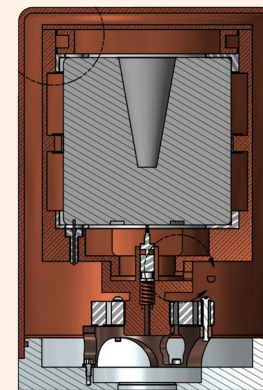
CEvNS experiments at ESS



High pressure noble gas TPC



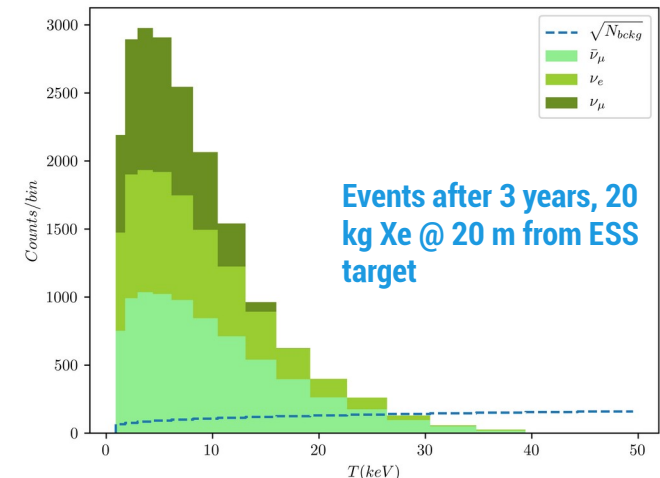
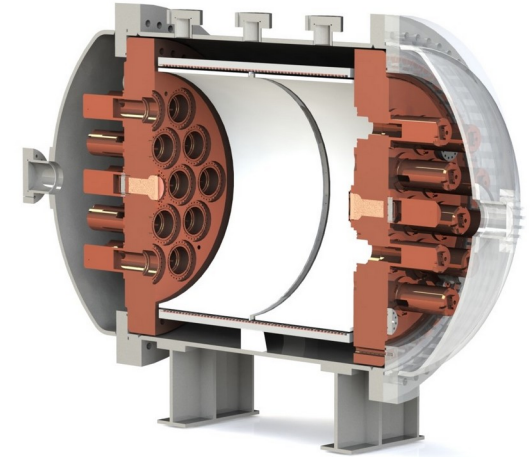
Cryogenic undoped CsI



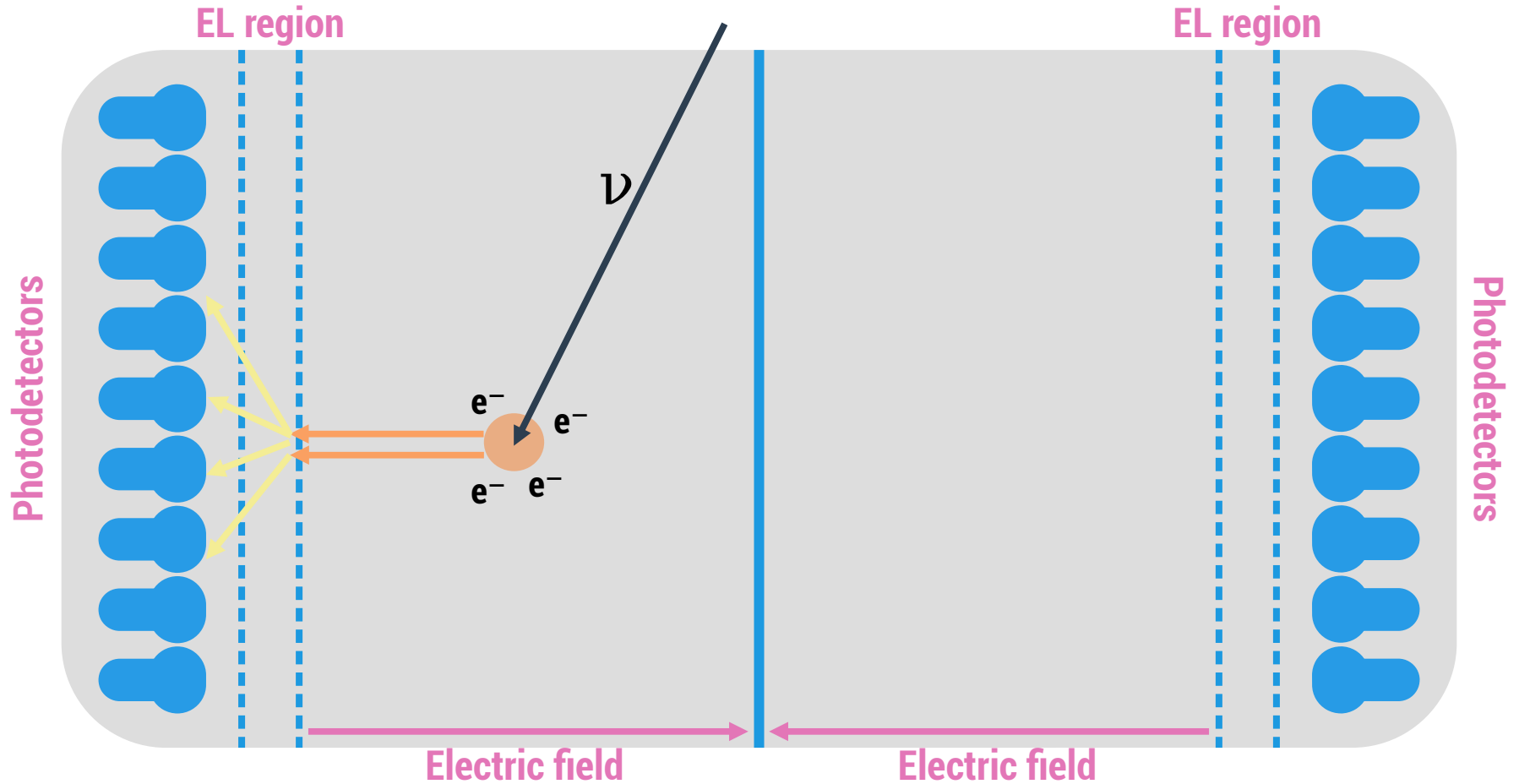
P-type point contact
germanium detector

Ga ν ESS: A high pressure noble gas TPC for CE ν NS

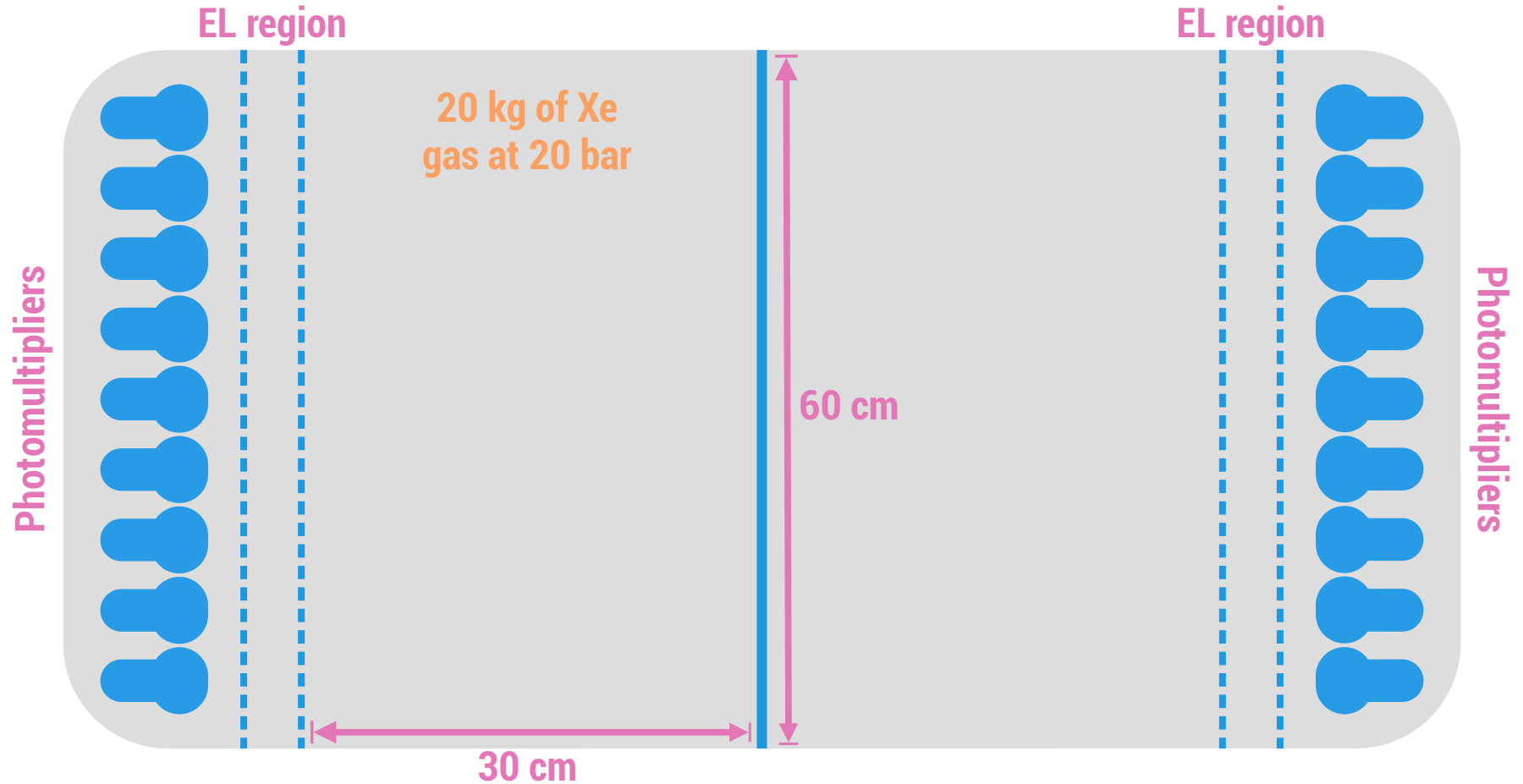
- Operation with different nuclei (Ar, Kr, Xe).
- Simple, no cryogenic operation
- Low energy threshold (down to 1-2 e $^-$ \rightarrow \sim 50 eVee) via electroluminescence (EL) amplification.
- Technology developed by the PI within NEXT experiment.
 - Low-background solutions already developed.
 - R&D for higher pressures and lower energy regime.
- Lower density than other techniques \rightarrow Bypassed by large ESS neutrino flux \rightarrow 20 kg detector is enough.



$\text{Ga}\nu\text{ESS}$: Detector concept



$\text{Ga}\nu\text{ESS}$: Detector concept

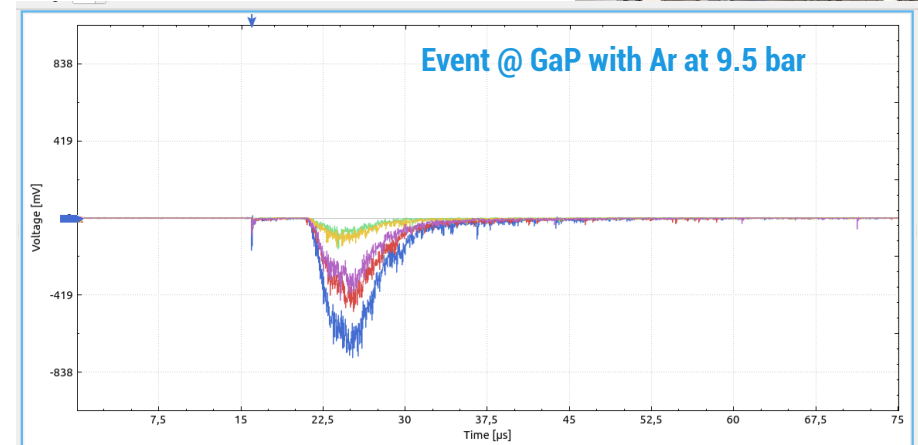
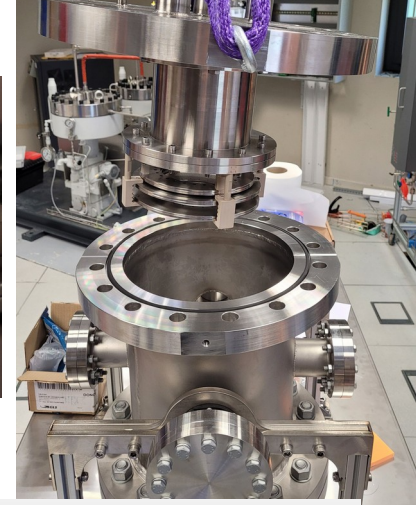
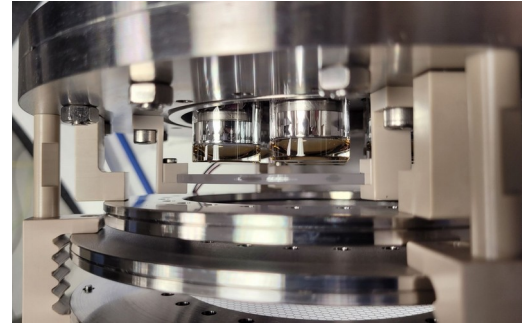


Ga ν ESS: The Gaseous Prototype (GaP)

Goals

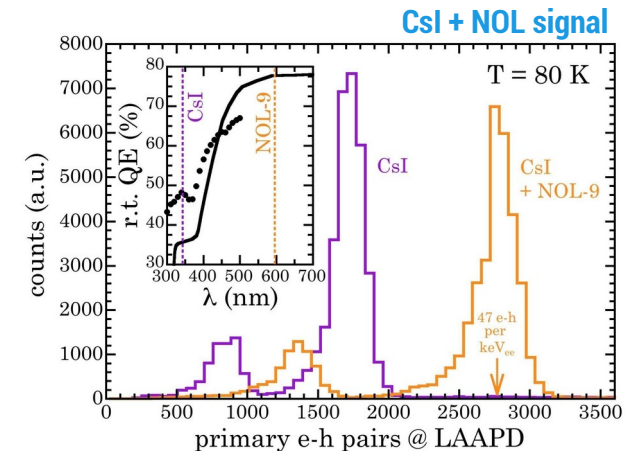
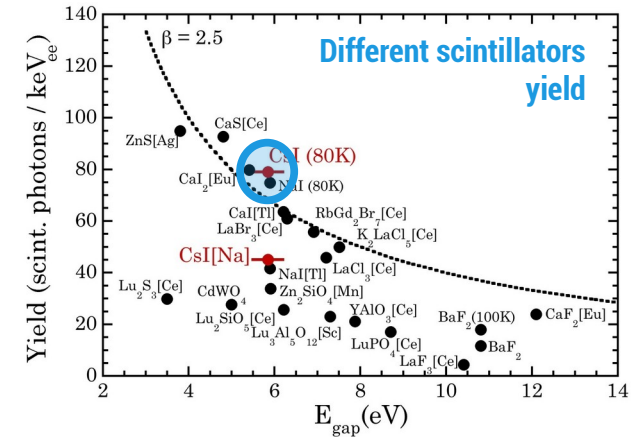
- Full evaluation of the technique with different gas conditions:
 - Different noble gases: Xe, Ar, Kr.
 - Pressure up to 50 bar.
- Characterization of the low energy response of the detection technique:
 - Detection threshold.
 - **Nuclear recoil response (quenching factor).**

Operating since this summer,
currently characterizing the electron
recoil signal in gas Ar at ~9.5 bar.



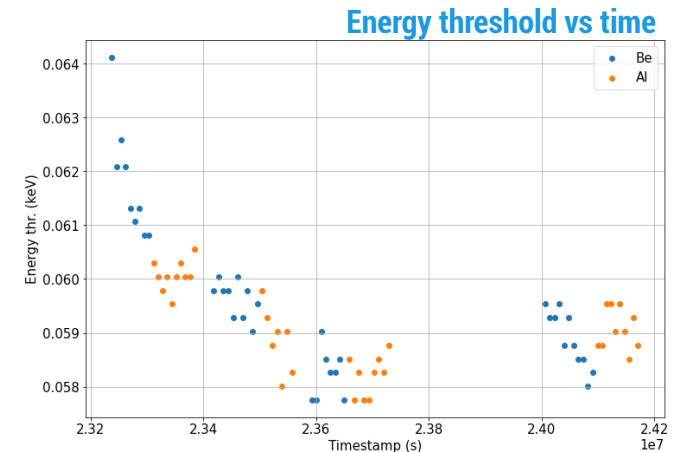
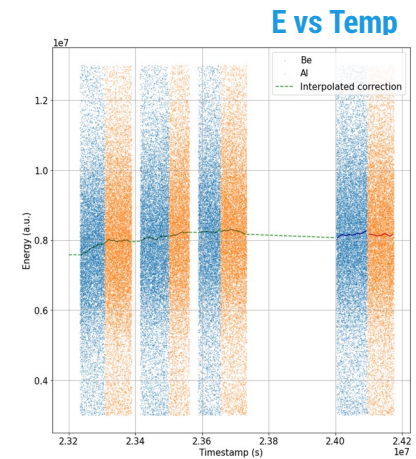
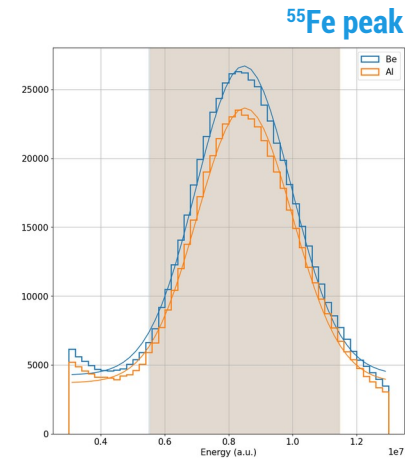
CoSI: Cryogenic pure CsI for CE ν NS

- 7 pure CsI crystals (7x7x40 cm, ~50 kg) cryogenically operated.
- Natural evolution from the first CE ν NS measurement, lead by the PI (CsI[Na] at SNS).
- Exploits the extraordinary yield of pure CsI at cryogenic temperatures
 - At 80K $\rightarrow \geq 2$ larger than CsI[Na].
- Detection threshold below 100 eV $_{ee}$:
 - Combination of LAAPD + wavelength shifter (NOL9).
- Strong R&D needed for:
 - Radiopure cryostat \rightarrow Superb temperature stability.
 - Development of LAAPD sensitive to CsI light emission.



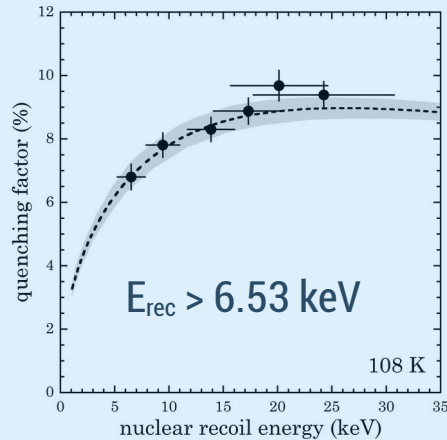
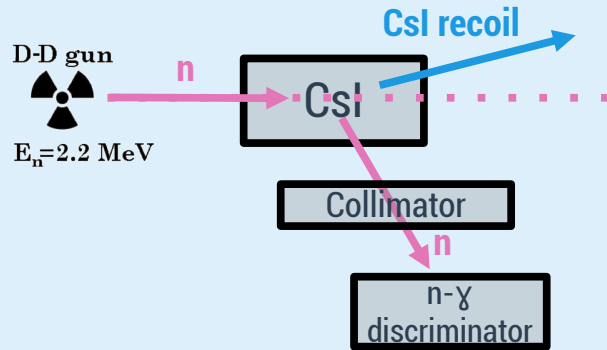
CoSI: Small scale demonstrator

- Small crystal (cylinder, 2.54x1.27 cm) + NOL-9 + comercial LAAPD (1.3x1.3 cm).
- LAAPD operated at 1412V (~3000 gain).
- Temperature variations corrected following the ^{55}Fe x-ray peak (sourced coupled to the cristal).
- Energy threshold below than 60 eV.
 - Limited by LAAPD induced low-energy population.



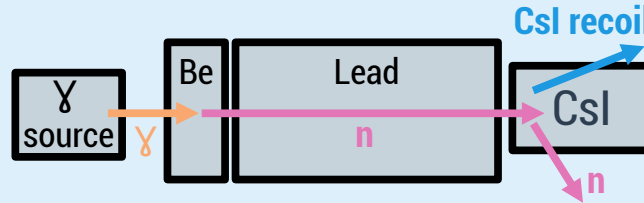
Cryogenic pure CsI quenching factor

D-D gun neutron scatter

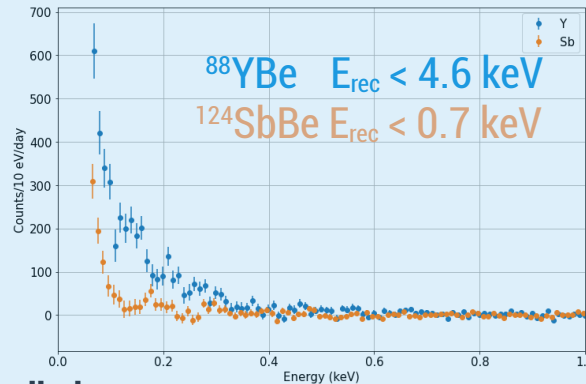


arXiv:2101.03264

Photoneutron sources

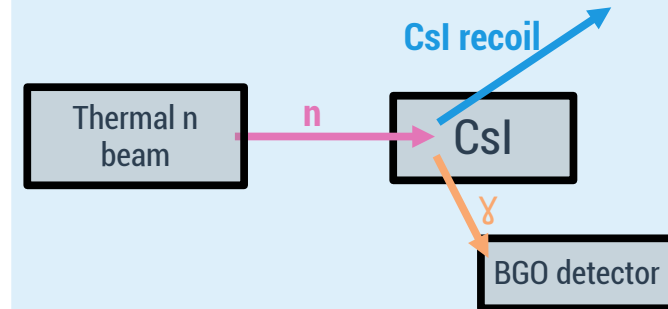


- Change Be for Al to obtain bckg.
- Get excess from signal – bckg.
- **Sub-keV recoils detected!**



Preliminary

Thermal neutron capture



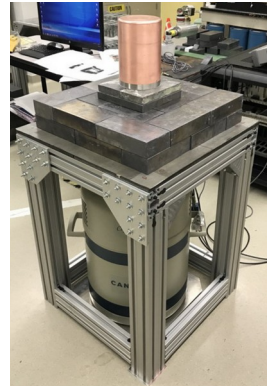
- Gamma-emission induced recoils of $\sim 180 \text{ eV}$.
- Data taken in OSURR in December.
- Analysis undergoing
- Sensitivity limited by CsI afterglow
 - Projected upper limit $\sim 15\%$

Preliminary

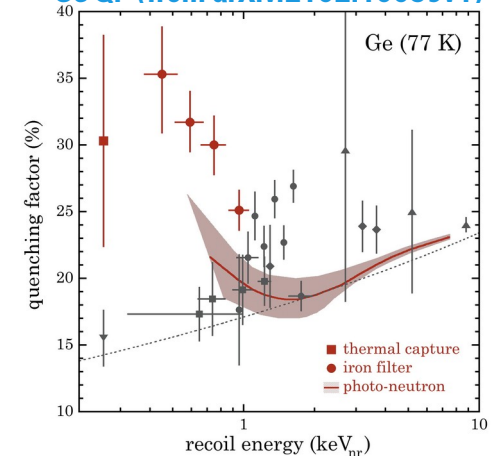
Germanium detector for CE ν NS

- 2 p-type contact germanium detectors of ~ 3 kg.
 - 1 already built with ~ 180 eVee threshold (used to detect CE ν NS from reactor neutrinos in Dresden-II)
 - 1 to be built during 2024 with a goal of ~ 80 eVee threshold.
- Threshold improvement driven by noise reduction (both parallel and series).
- Quenching factor already characterized, with tension in sub-keV range.
 - Precision measurements exploiting the gamma emission following thermal neutron capture scheduled for this year.

Dresden-II detector

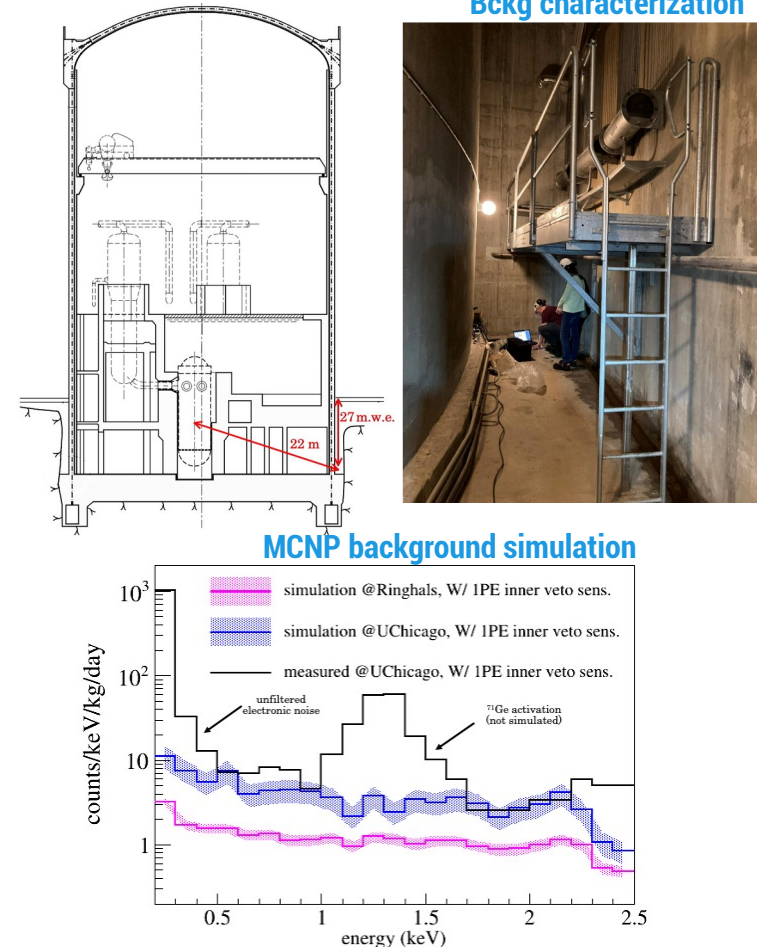


Ge QF (from arXiv:2102.10089v1)



Germanium detector for CE ν NS

- Dresden-II PPC will be deployed in Ringhals power plant tendon gallery.
 - 27 m.w.e burden
- Reduced noise prior to deployment.
- Background already characterized:
 - Expected signal-to-bckg > 40 according to MCNP simulations.



Summary

- CE ν NS 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.
- 3 different detection techniques are scheduled and funded to detect CE ν NS at ESS:
 - High pressure noble gas time projection chambers.
 - Cryogenic pure CsI crystals.
 - P-type point contact HPGe detectors.
- The threshold of the three techniques is expected to be below 100 eVee, with several thousands events detected per year.
- Side-by-side operation of the different detectors strongly boosts the physics potential of CE ν NS searches at ESS.

Backup

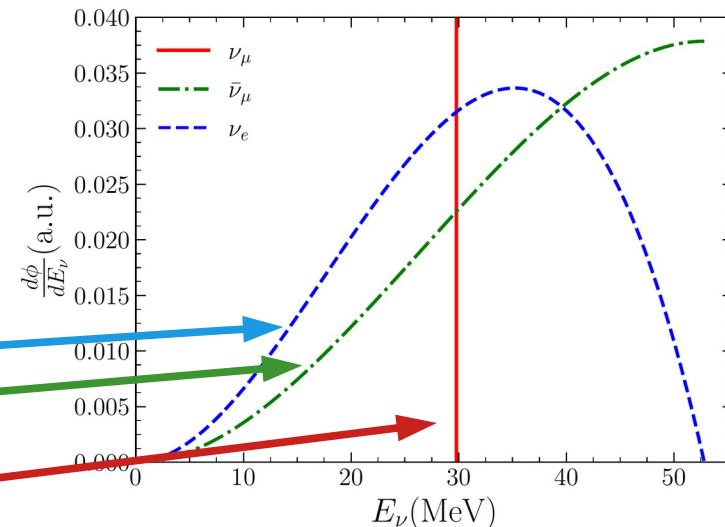
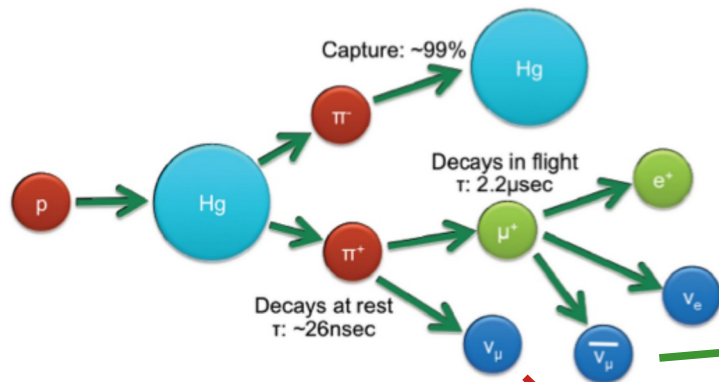
Detecting CEvNS: Source

Requirements

- Sufficiently intense in yield.
- Neutrino energy low enough.
 - Coherence condition: $|Q| < 1/R$

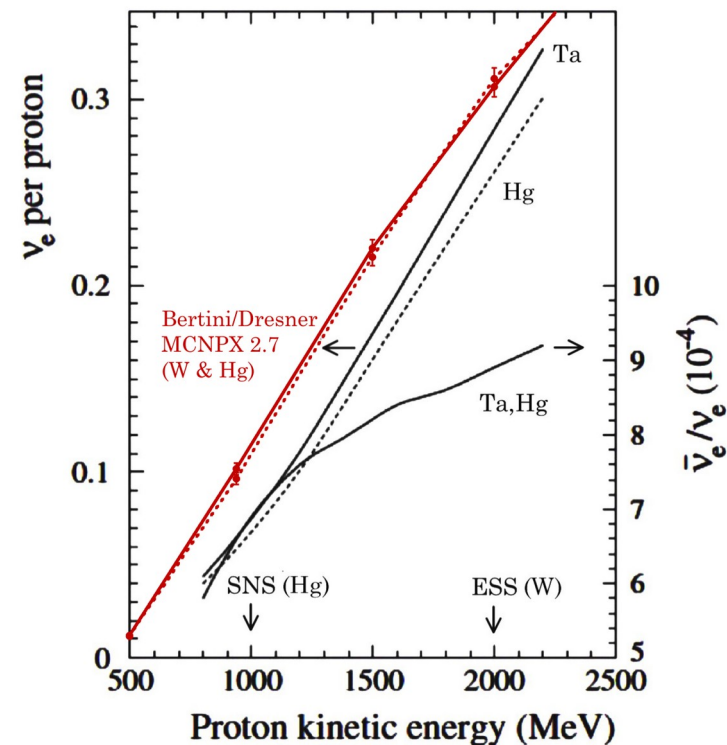
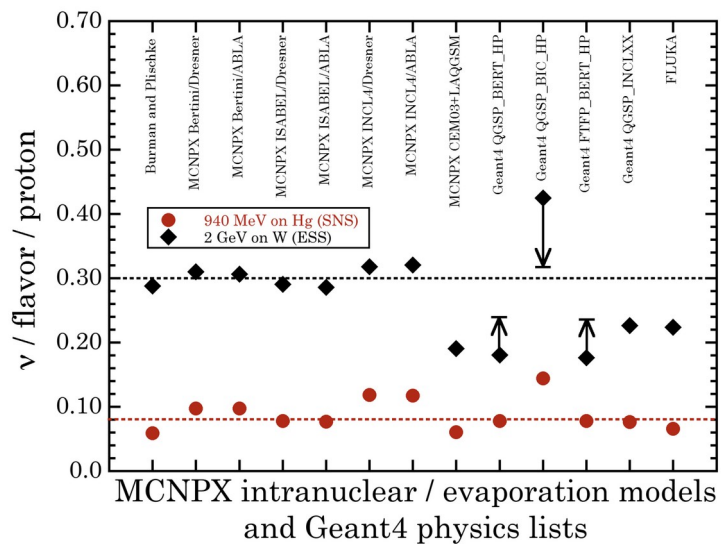
Candidates

- Spallation sources (π^+ DAR)
- Nuclear reactors



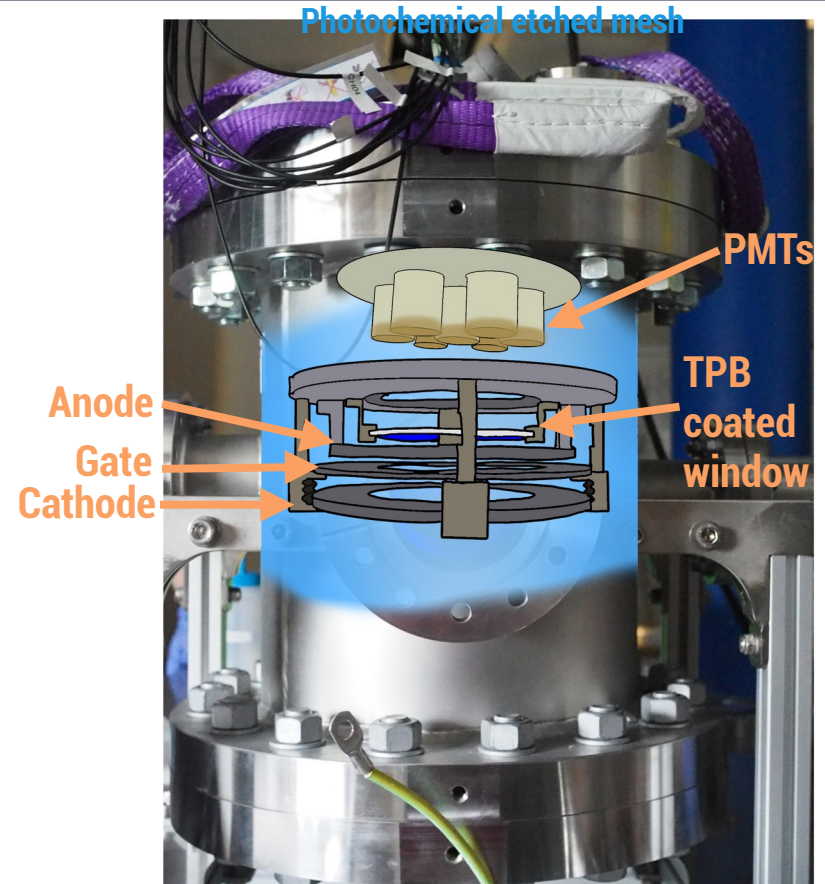
SNS vs ESS

	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

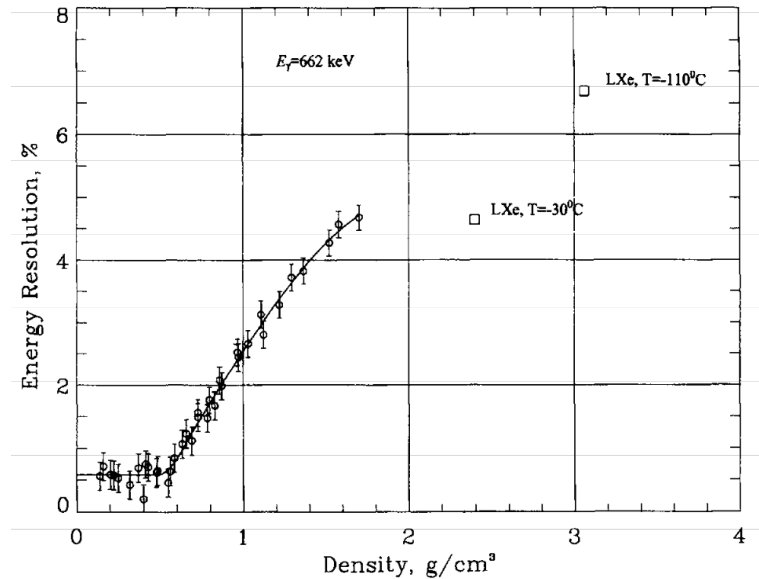


GaP design

- Small vertical TPC:
 - 2 cm drift length.
 - 1.1 cm EL gap.
- 7 Hamamatsu R7378 PMTs on top.
 - TPB coated frontal window.
 - Pressure resistant window for second phase.

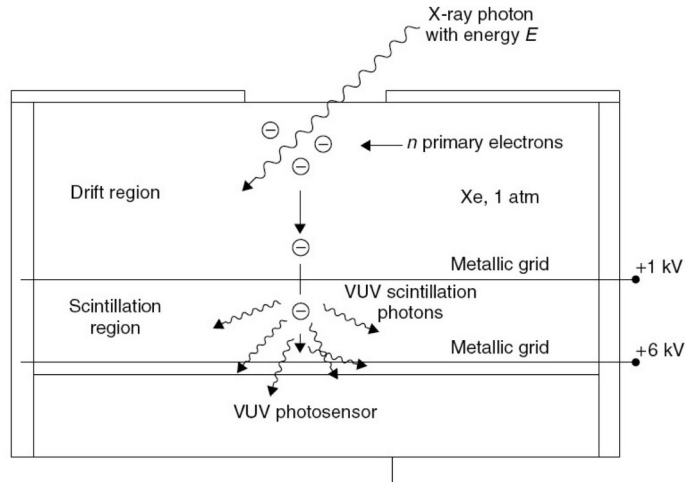


Energy resolution in HPGXe

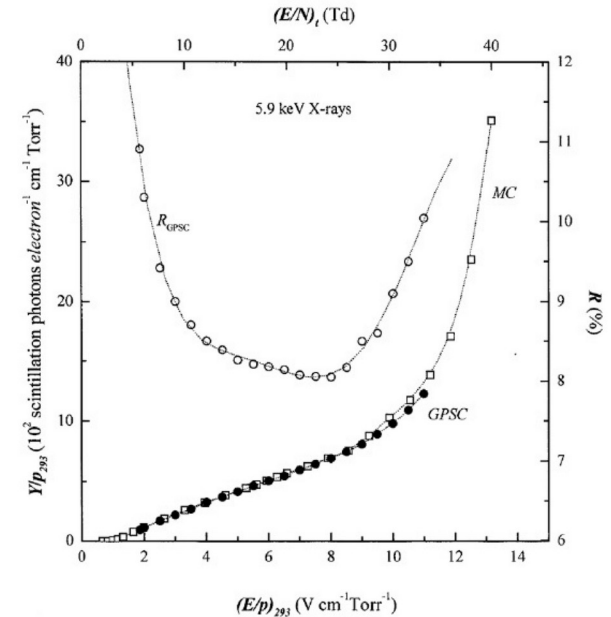


- Very good energy resolution up to ~50 bar.
- Best experimental result: 0.6% @ 662 keV.
- It will allow for a better spectrum reconstruction, thus better sensitivity to deviations from SM.

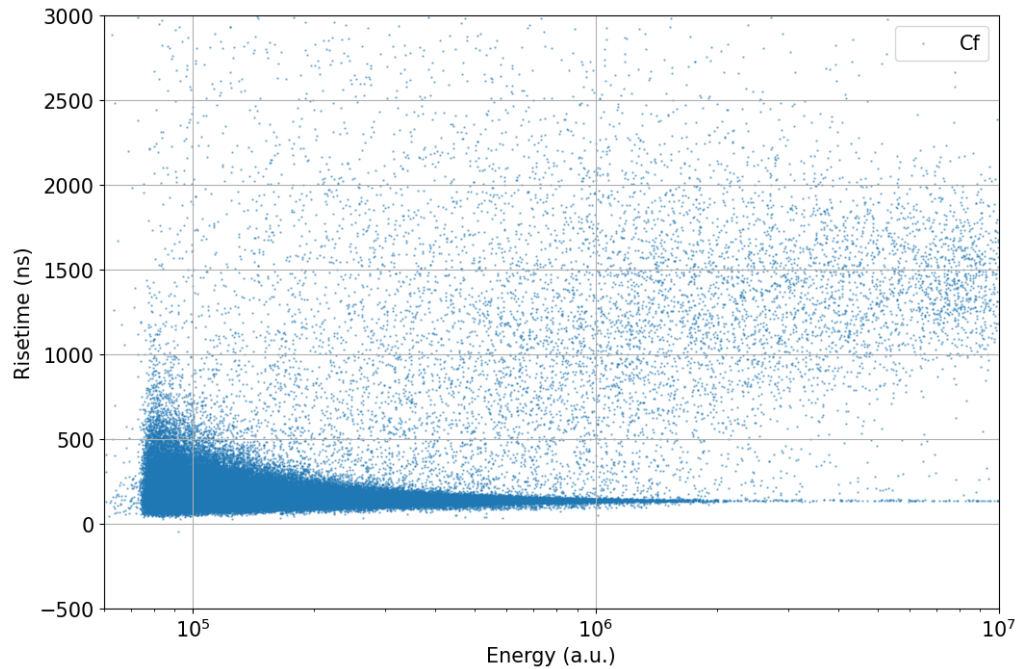
Electroluminescence



- 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.

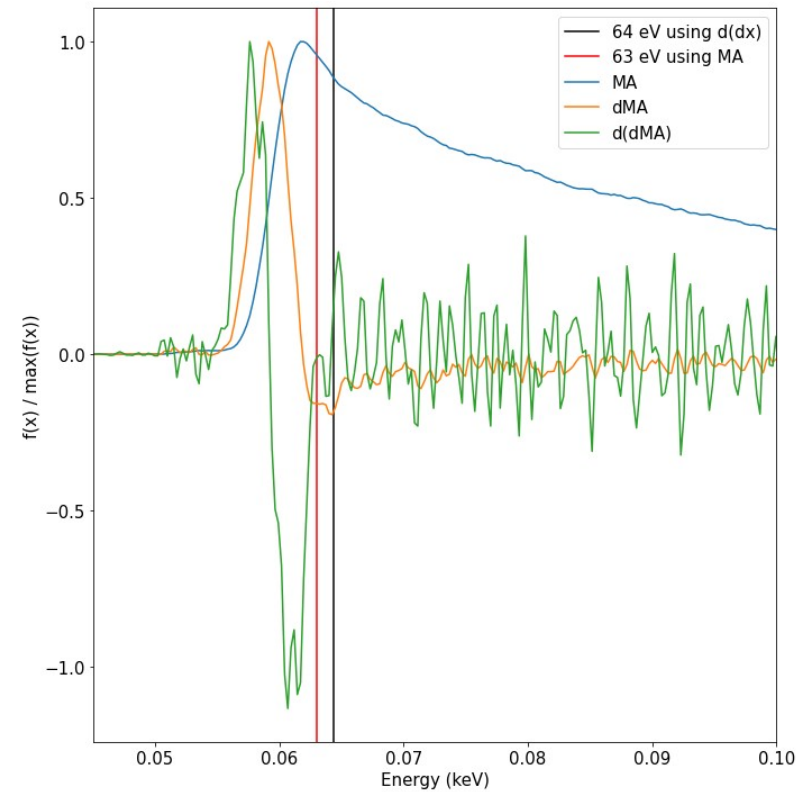


Csl threshold



Low-energy noise at LAAPD

Thr selection



Detector Technology	Target nucleus	Mass (kg)	Steady-state background	E_{th} (keV $_{ee}$)	QF (%)	E_{th} (keV $_{nr}$)	$\frac{\Delta E}{E}$ (%) at E_{th}	E_{max} (keV $_{nr}$)	CE ν NS $\frac{NR}{yr}$ @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	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 ₃ F ₈	10	0.1 c/kg-day	-	-	2	40	329.6	515