GaNESS: Detecting CEνNS with noble gases.

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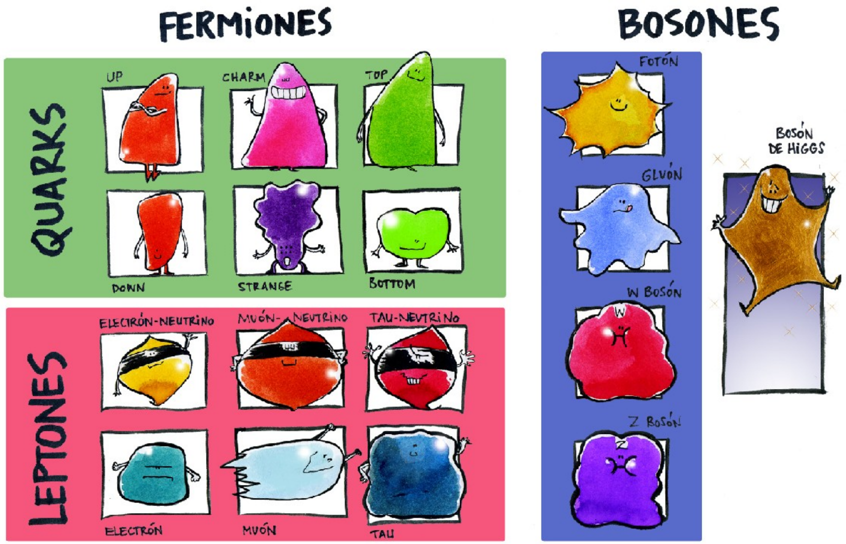
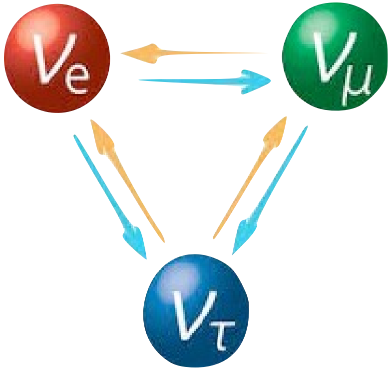
European Research Council
MARIE CURIE ACTIONS

XeSAT2023 - International Workshop on Applications of Noble Gas Xenon to Science and Technology

Neutrinos: what we know



@raquelberryfinn

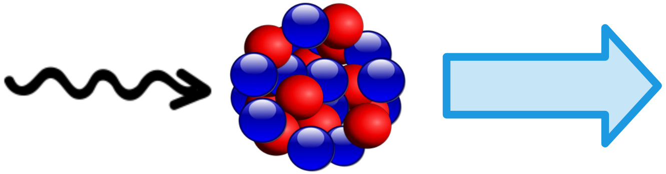


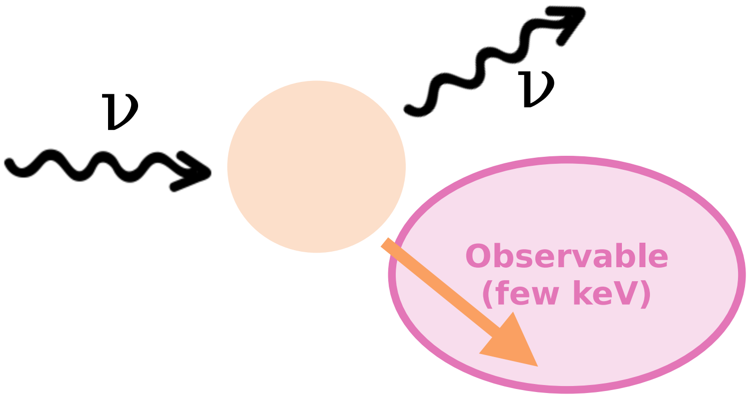
- Number density in Universe only outnumbered by photons.
- Have mass (even if lightest fermion).
  - 3 light neutrino states.
- 3 flavours.
  - Large mixing.
- Only interact weakly.
  - No color nor electric charge.
  - Tiny cross-section → Extremely hard to detect

Coherent Elastic Neutrino-nucleus scattering (CEνNS)

CEνNS

ν (~10s MeV)





Long wavelength, “sees” all nucleons simultaneously

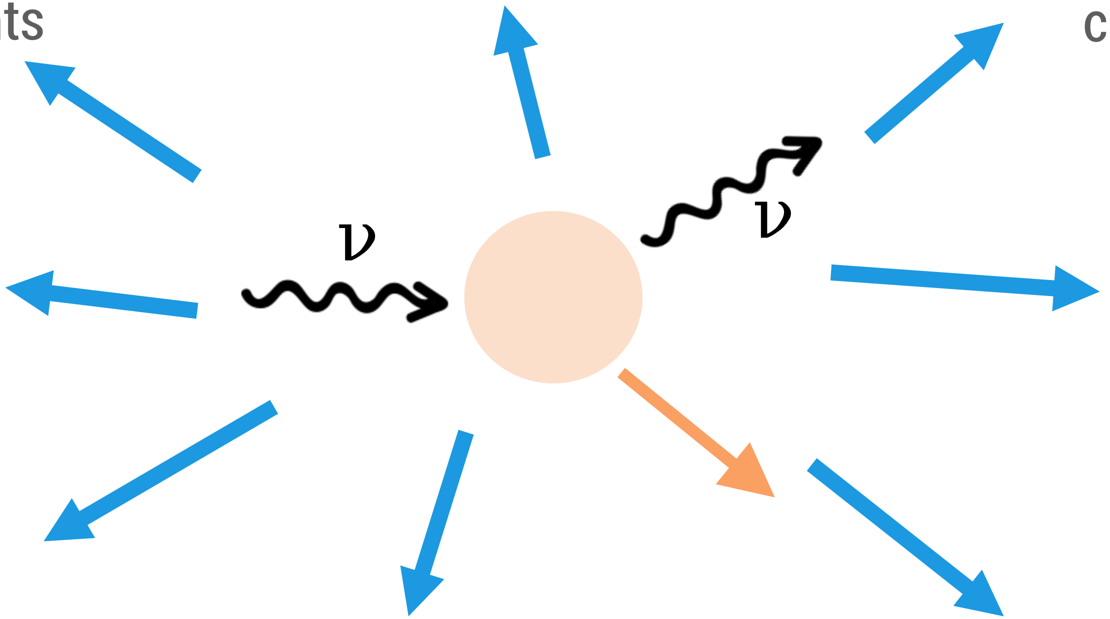
$$\sigma \sim N^2$$

Few kg detectors can be competitive

Predicted in SM for decades

First detected 6 years ago

Coherent Elastic Neutrino-nucleus scattering (CEνNS)



Complementary to oscillation experiments

Sensitivity to non-Standard interactions

Study of neutral currents

Sterile neutrinos

Study of nuclear structure

Neutrino magnetic moment

New types of dark matter particles

Effective neutrino charge radius

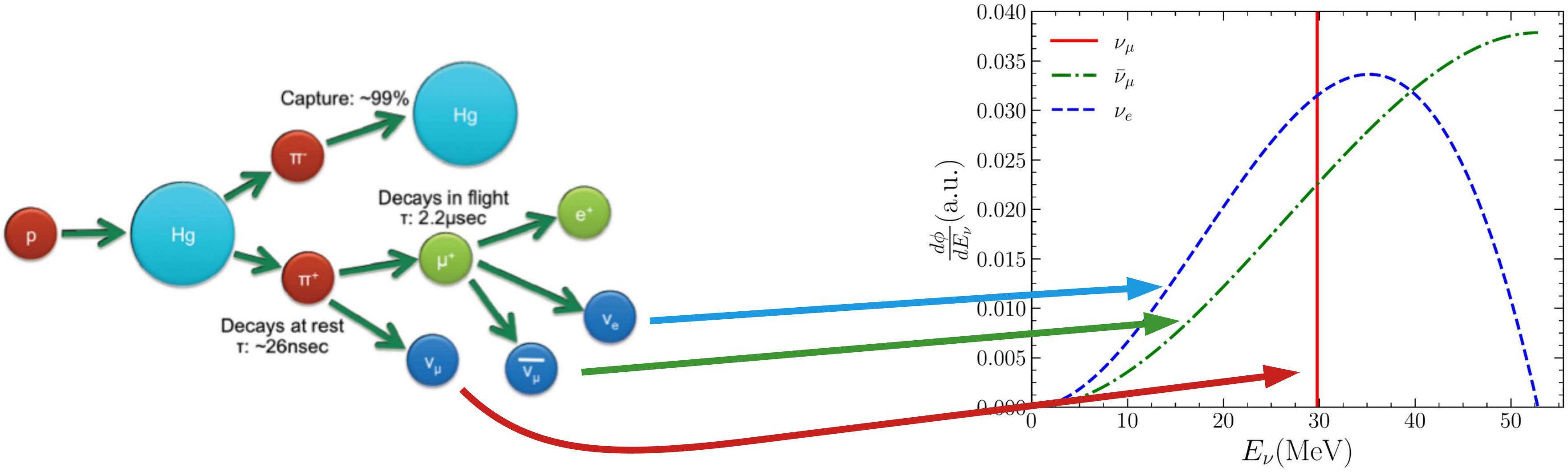
Detecting CEvNS: Source

Requirements

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

Candidates

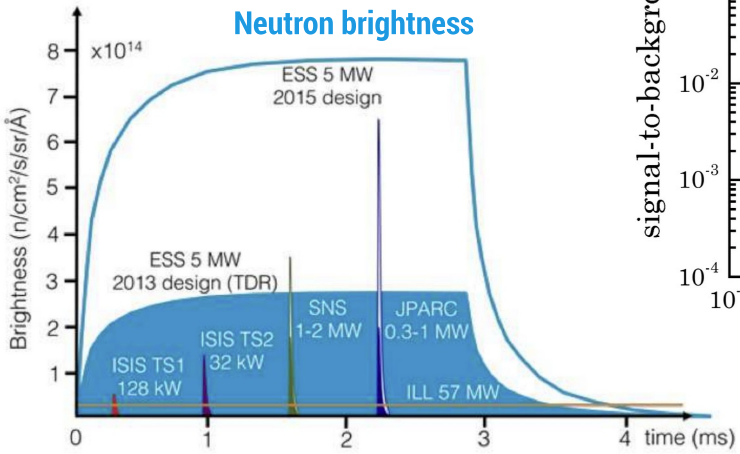
- **<u>Spallation sources</u>** (π^+ DAR)
- Nuclear reactors



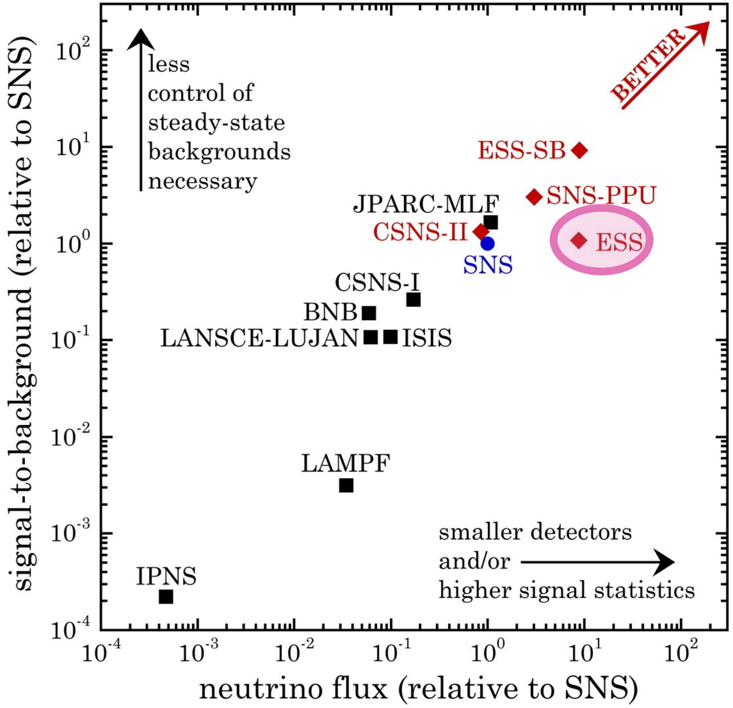
European Spallation Source (ESS)

- 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.

Neutron brightness

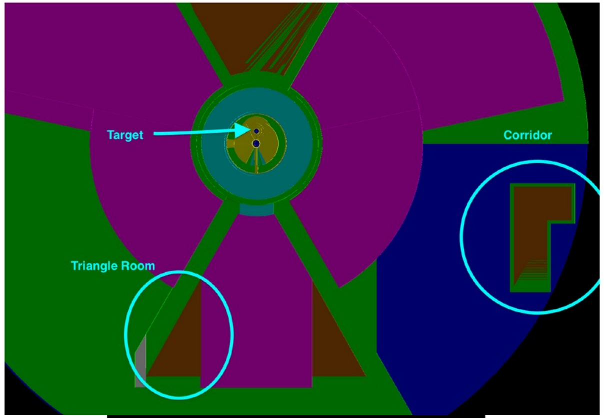


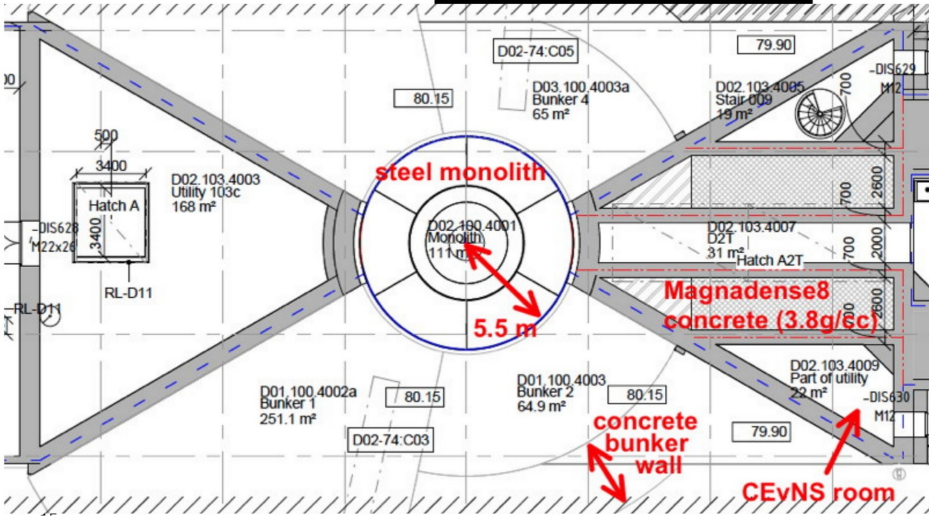
Neutrino production at different facilities



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.

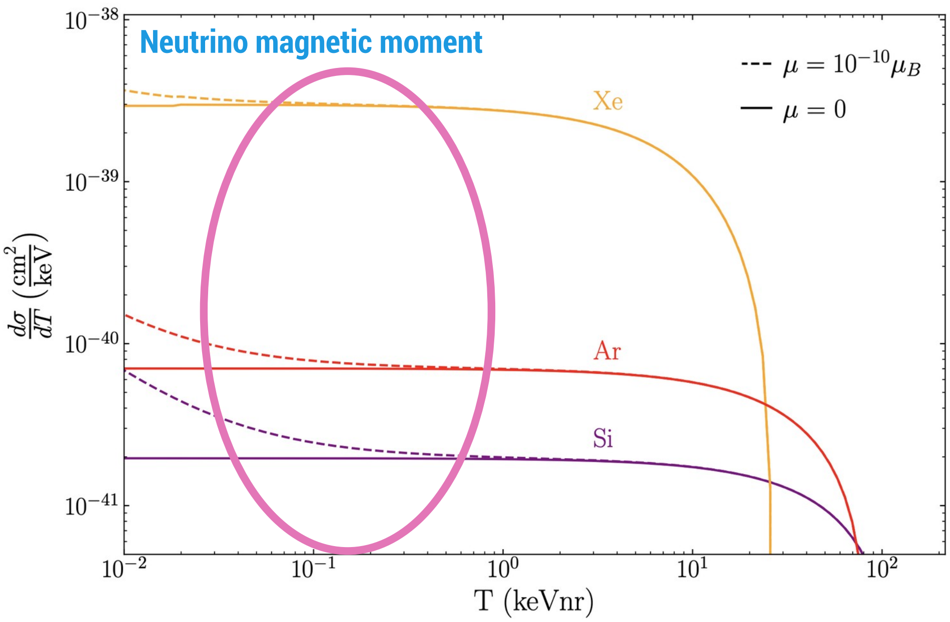


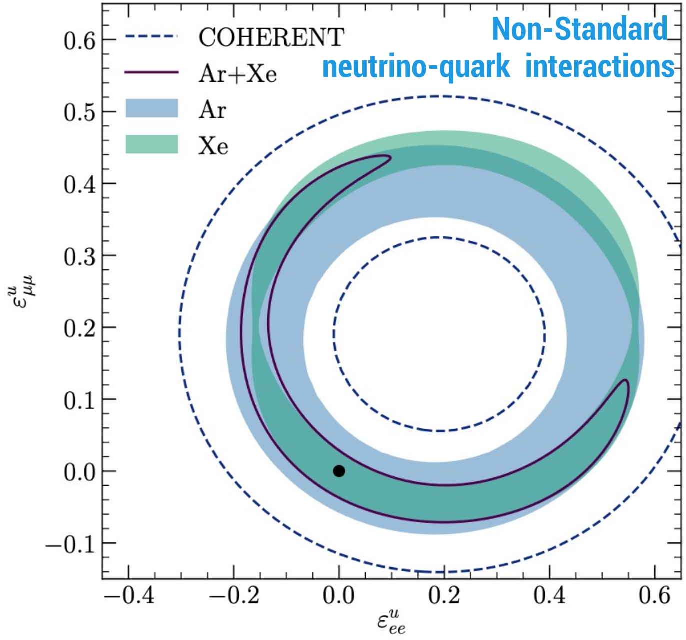


Detecting CEvNS: Detectors

Physics potential maximized with:

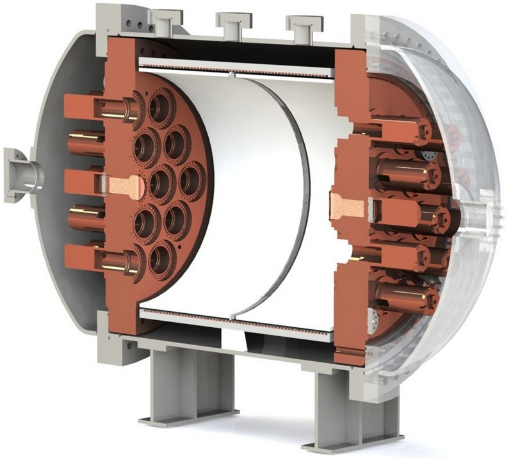
- Low energy threshold
  - Interesting physics at low energy
- Different nuclei
  - Breaks degeneracies

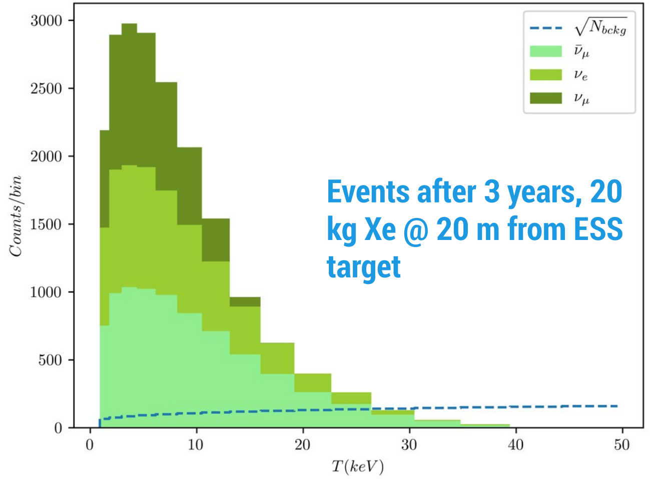




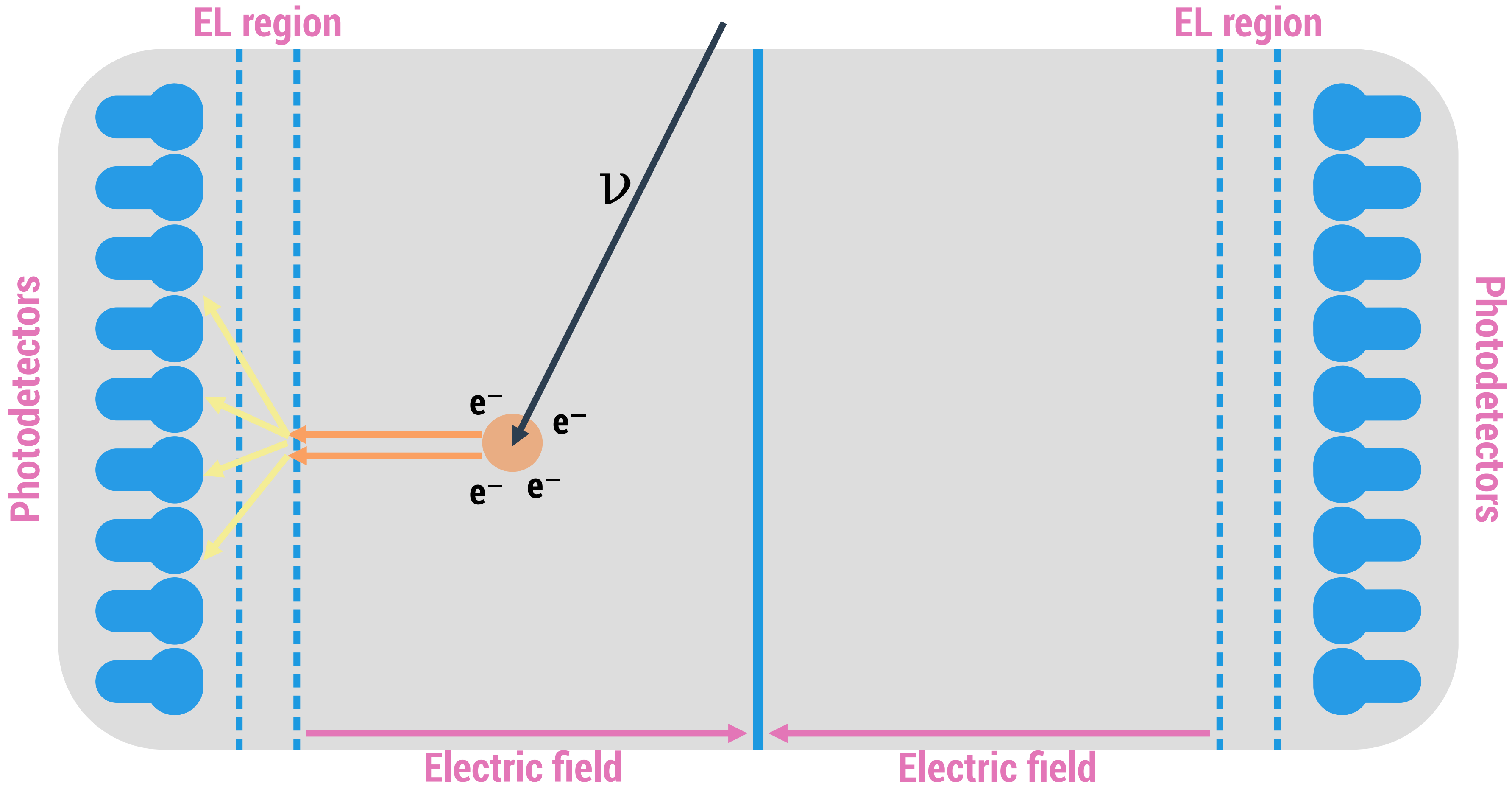
GaNESS: A high pressure noble gas TPC for CEνNS

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

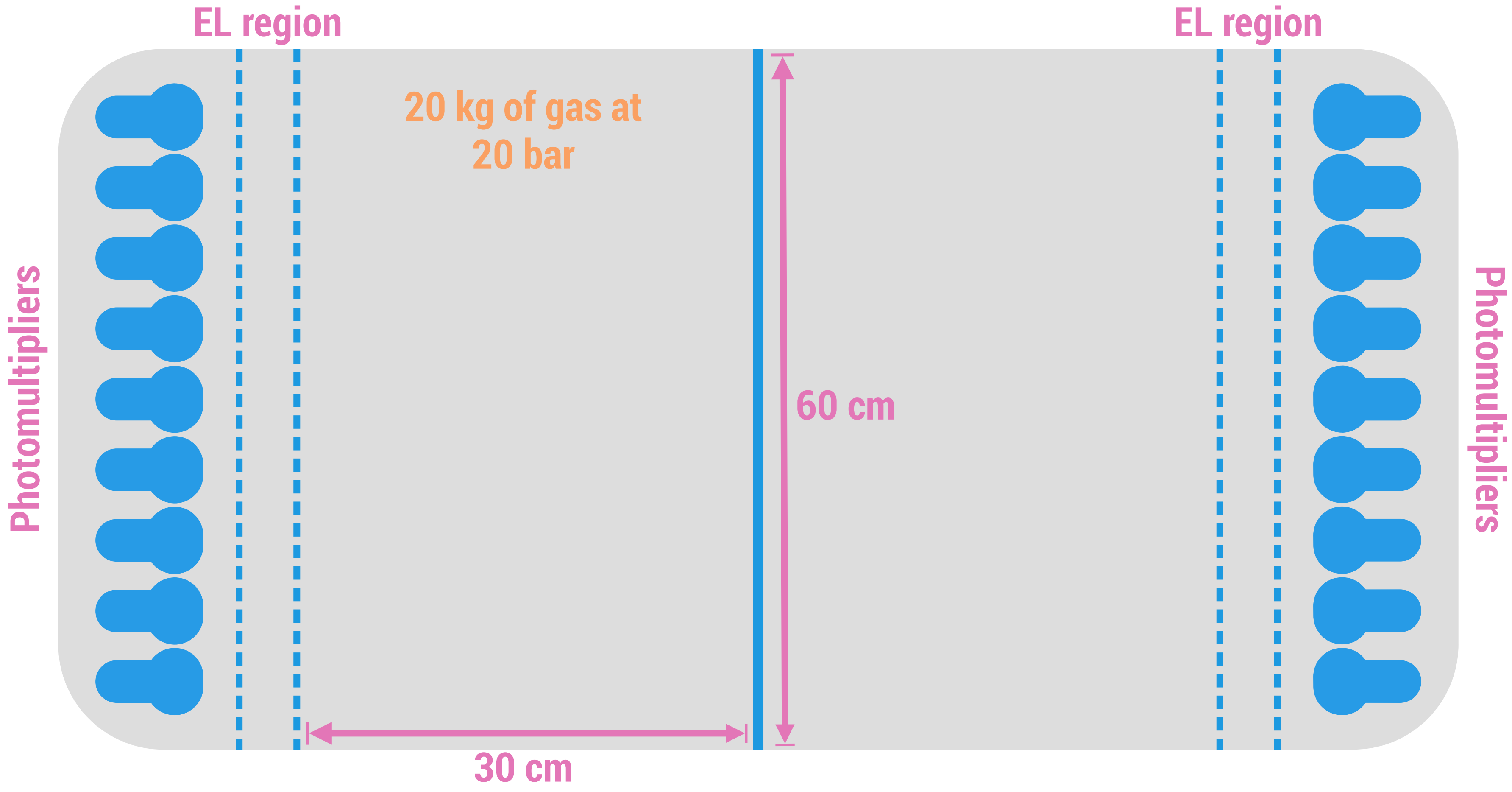




GaNESS: Detector concept



GaNESS: Detector concept

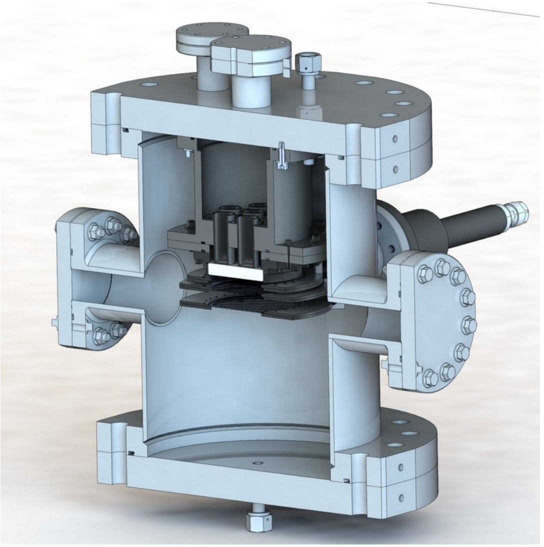


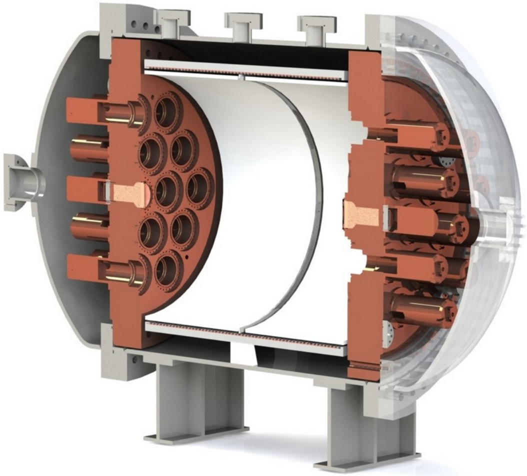
GaNESS project

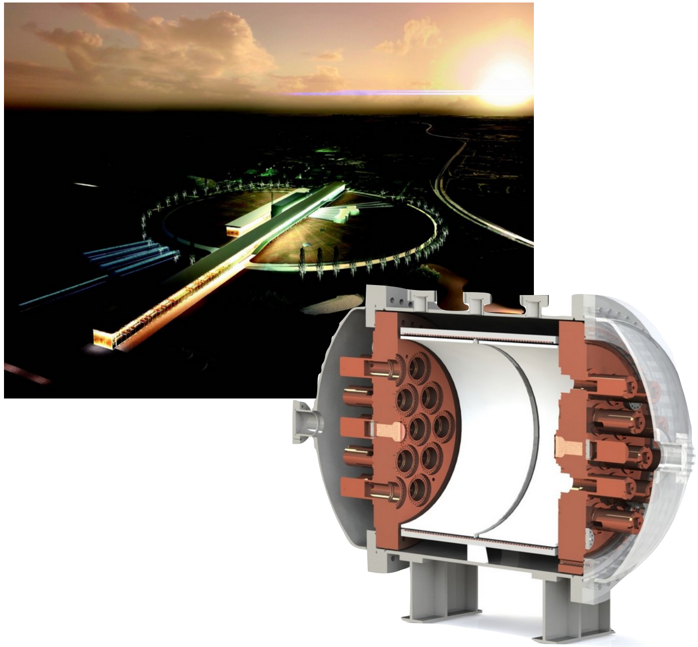
GaNESS Prototype (GaP)
- R&D
- Study of nuclear recoils

GanESS construction at DIPC

Operation GaNESS at ESS



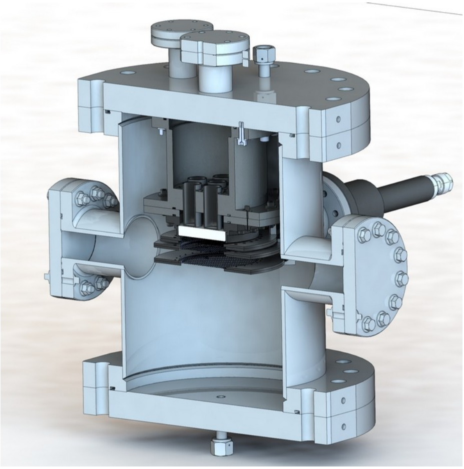


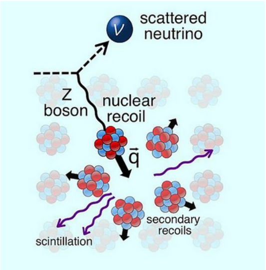


The Gaseous Prototype (GaP)

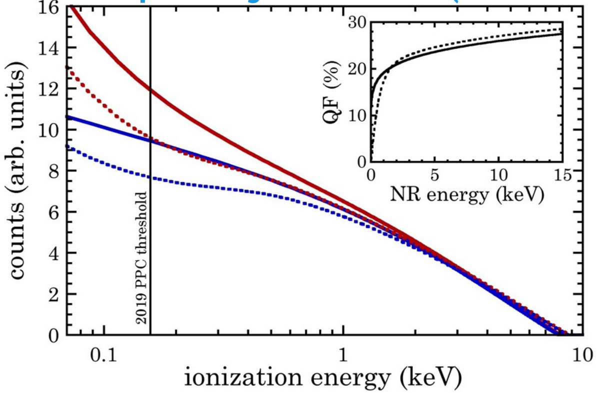
Goals

- 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).**





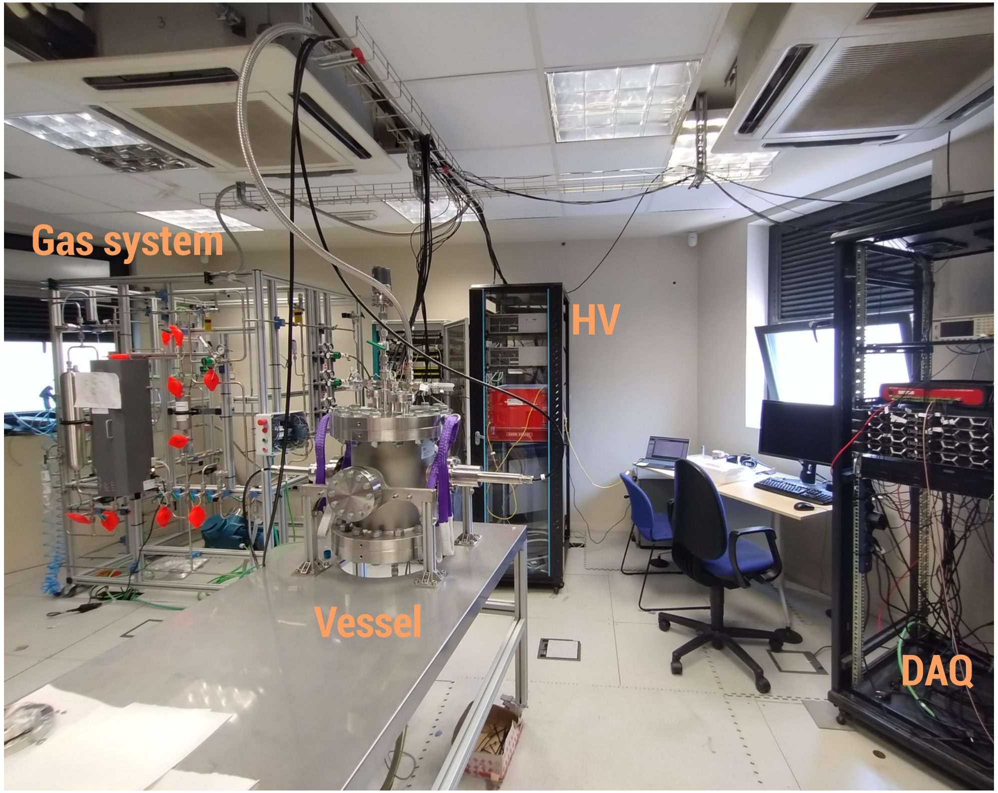
Differences in the expected distributions given different quenching factor models (solid/dashed)



Laboratory

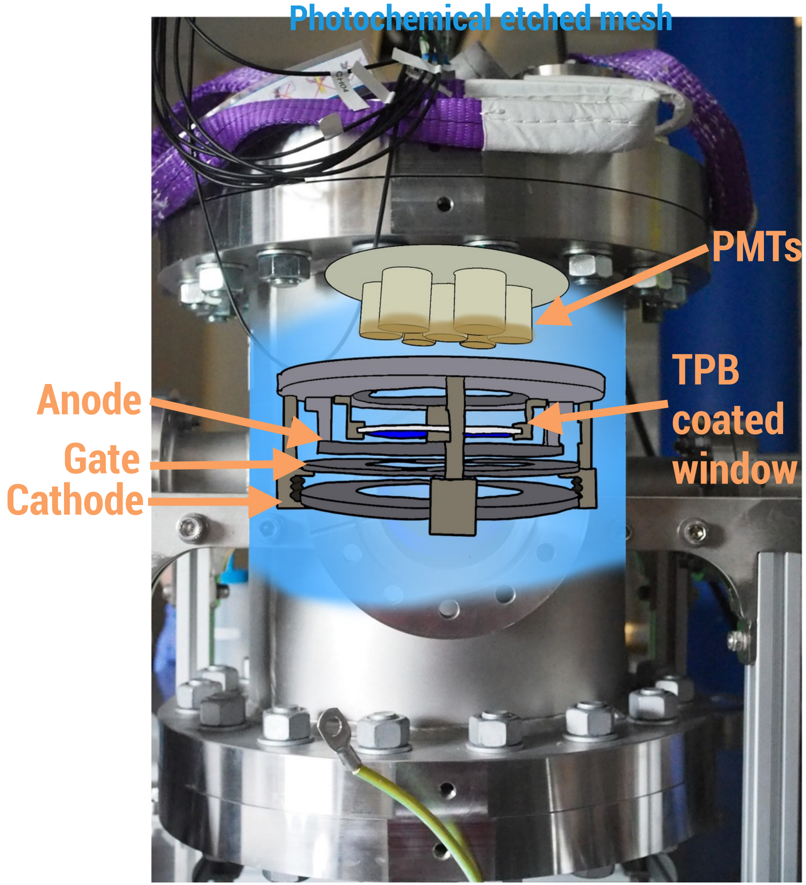
1 year ago

1 week ago

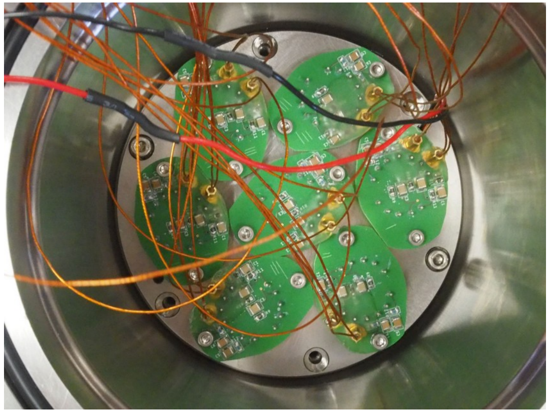


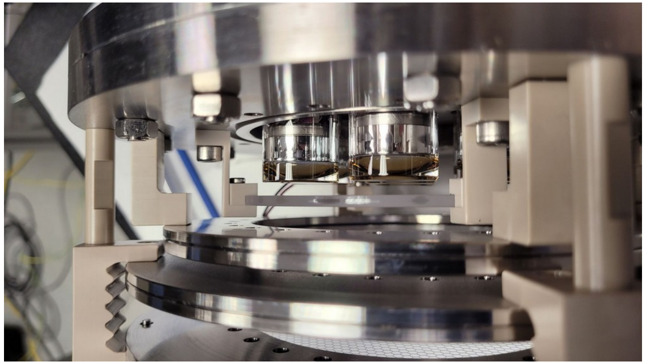
GaP design

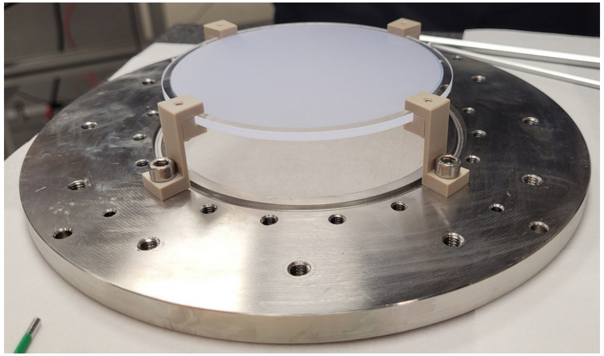
- Small vertical TPC:
  - 2 cm drift length.
  - 1.1 cm EL gap.
- 7 Hamamatsu R7378 PMTs on top.
  - TPB coated frontal window.
  - Pressure resistant window for second phase.

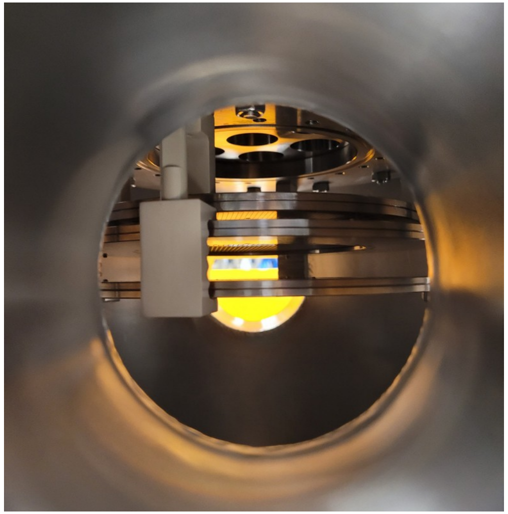


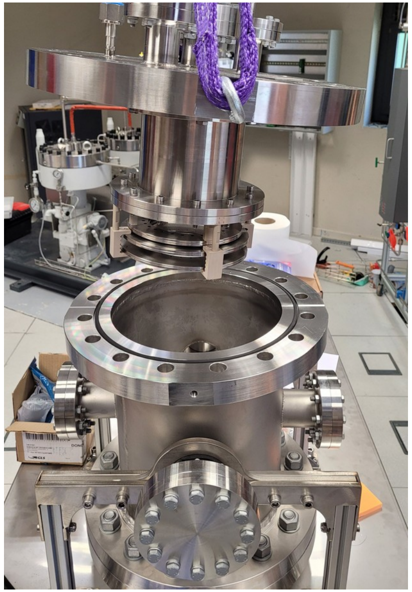
Inside GaP





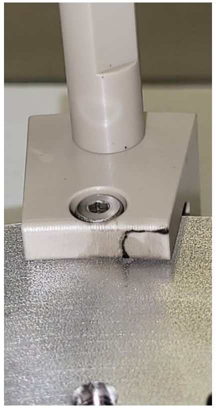


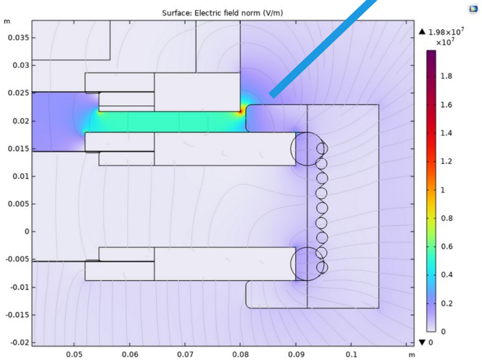


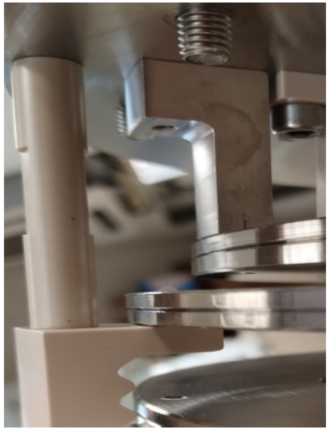


EL spark tests and troubleshooting

- First operation with Ar at pressure (up to 10 bar) a month ago.
- Lots of sparks at low fields.
  - Occurring at the PEEK holders.
  - Solved by holding the EL mesh from the bottom.





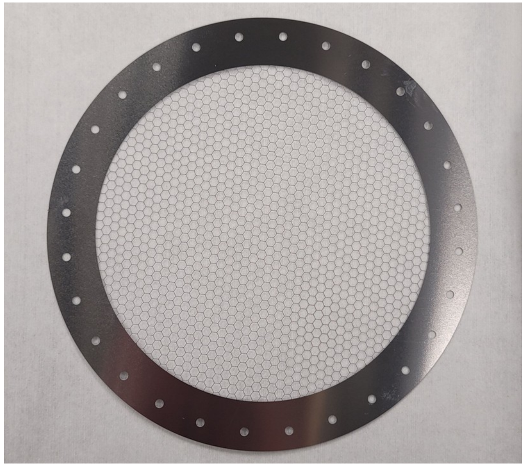


New PEEK holders

EL spark tests and troubleshooting

- Sparks through the mesh, now at higher field (still low).
- Possible suspects:
  - Imperfections in the EL grid.
  - High field regions around hexagon vertex.
- Scheduled: change to a wire mesh.

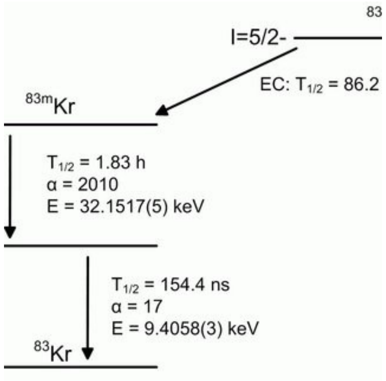
Photochemical etched mesh

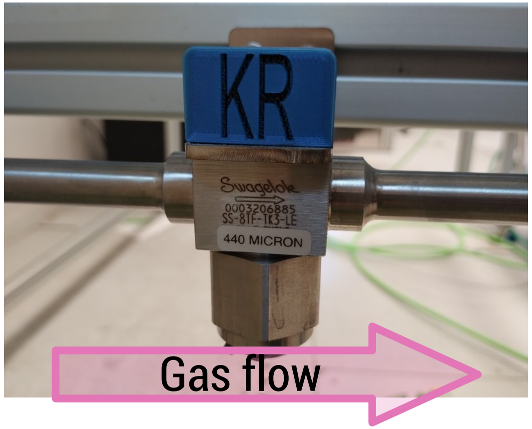


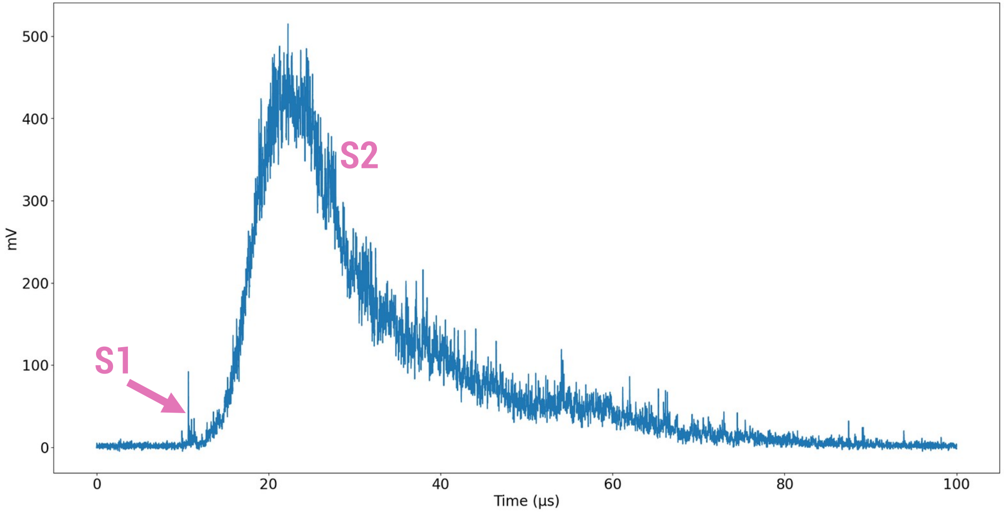
Wire mesh

GaP status

- Started data-taking last week!
- ^{83m}Kr source coupled to gas system.
- Ar at 7.5 bar.
- Low EL operation (~0.6 kV/cm/bar)
  - At the EL threshold.
  - Imperfections in the mesh producing higher field regions?
- Now trying to understand the detector!





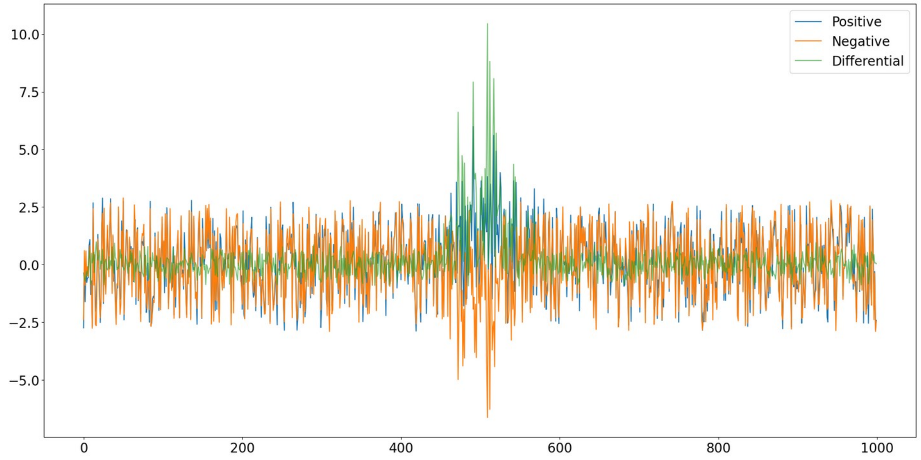


GaP short term plans

Coming weeks:

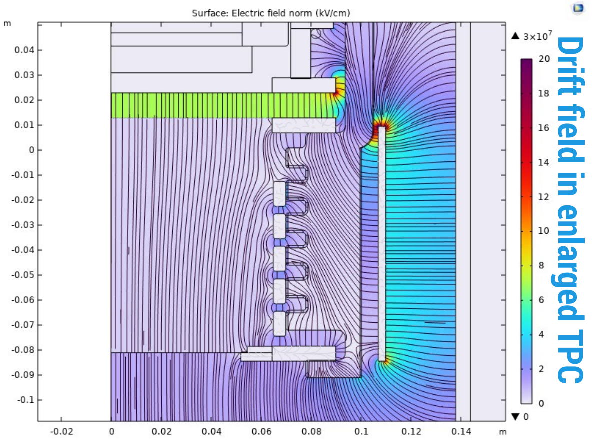
- Main goal: understand the detector with Ar.
  - Keep working with ^{83m}Kr.
  - Additional sources by the end of the month.
- Test wire mesh as EL gate.
- Slow controls for unattended operation.
  - TPC HV, PMT HV, Gas
- Develop new DAQ software:
  - More flexibility than commercial sw.
  - Trigger on differential signal.

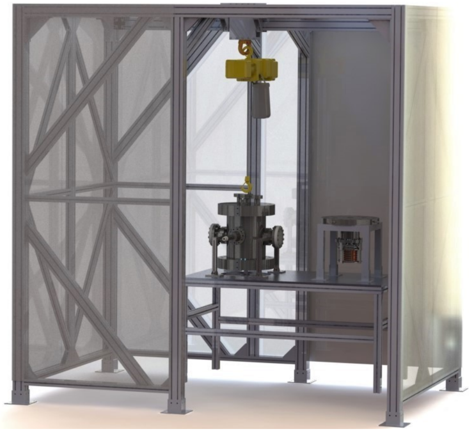
Source	Energy
^{83m}Kr	41.5 keV
^{241}Am	59.5
^{133}Ba	81, 356 keV
^{57}Co	122 keV
^{22}Na	511 keV
^{137}Cs	662 keV

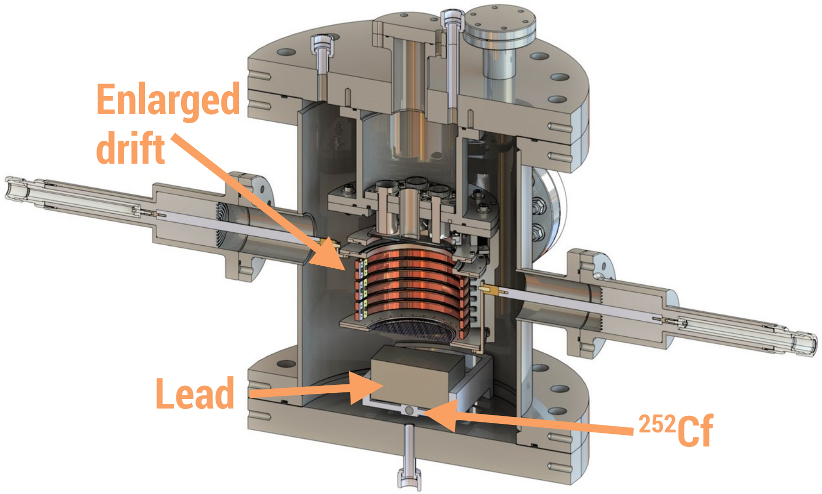


GaP medium term plans

- Start looking at nuclear recoils:
  - ^{252}Cf source
  - Needs to be exempt → Low activity (<1000 n/s)
  - Increase drift region (10 cm) to maximize interaction rate.
  - Lead shield blocks source-induced gamma background.
- Clean tent in autumn for cleaner operation.

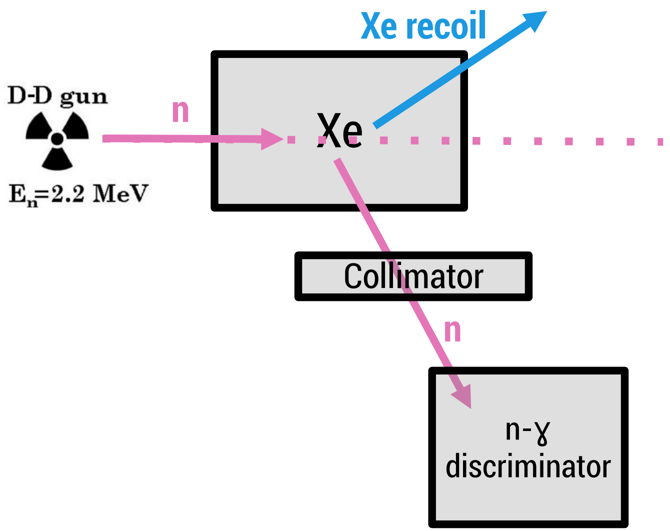






GaP medium-long term plans

- Move to Xe and repeat the studies done in Ar.
- Quasi-monoenergetic neutron sources for improved quenching factor measurements
  - D-D neutron generator → Tagging with backing detector.
  - Photoneutron sources:
    - ^{88}YBe (~153 keV n)
    - ^{124}SbBe (~24 keV n)



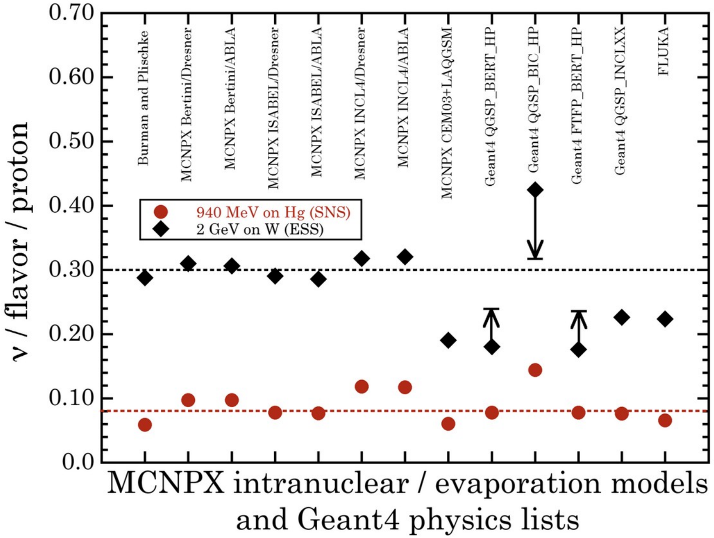
Summary

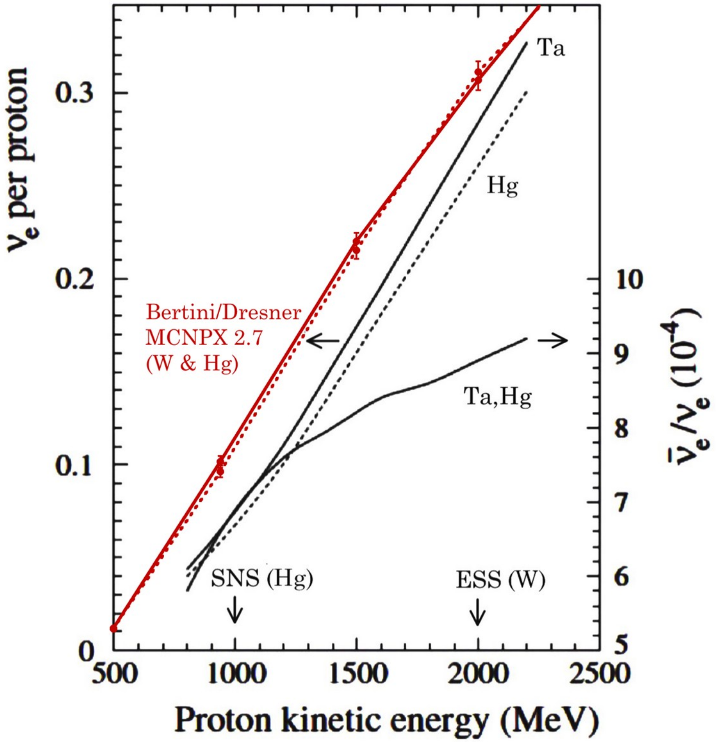
- CEvNS detection opens a new avenues in the search of physics beyond the Standard Model.
- ESS will become the largest low-energy neutrino source. Perfect facility to study this process.
- The GanESS project, will produce a detector to observe the process at the ESS with a variety of nuclei and large discovery potential.
- The GanESS Prototype (GaP) will allow to fully characterize the technique in the low energy regime.
- GaP data-taking and operation has just started with a focus, starting with gaseous Ar at moderate pressures (up to 10 bar).

Backup

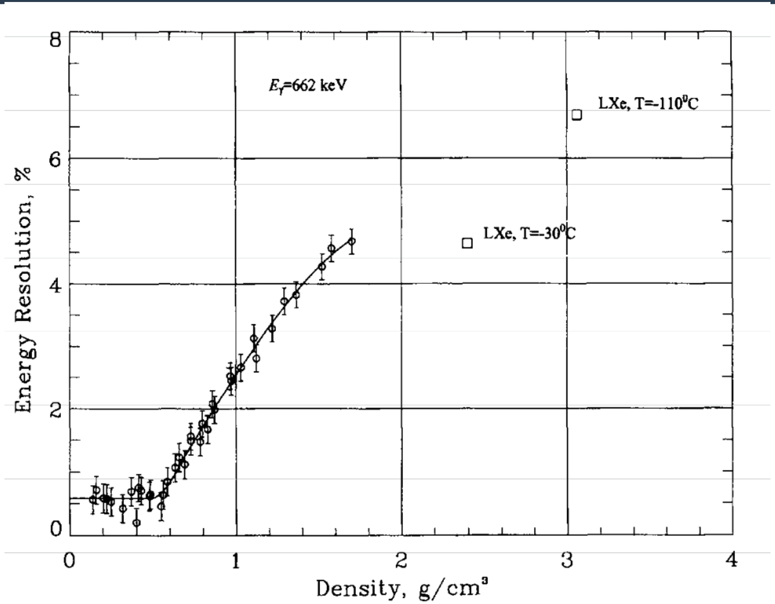
SNS vs ESS

	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



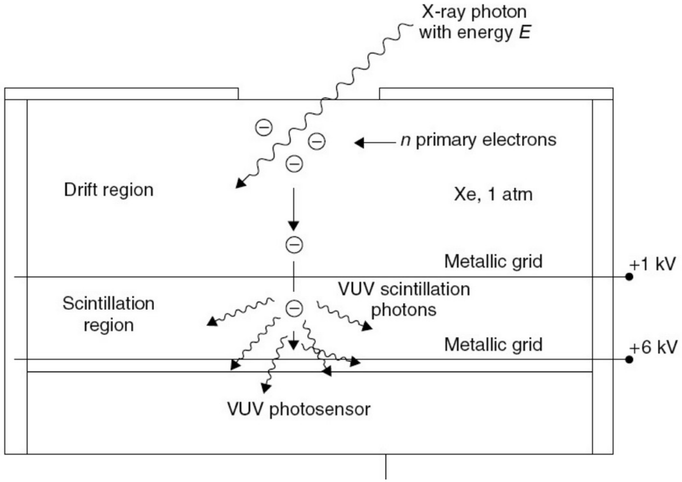


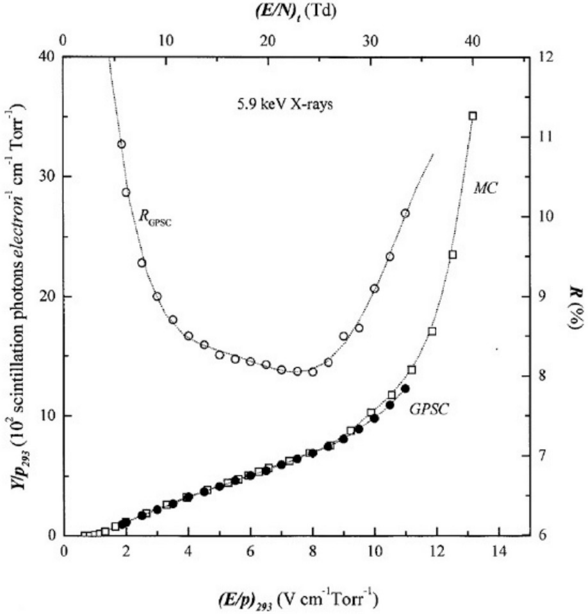
Energy resolution in HPGXe



- 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.

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.

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})	CEνNS $\frac{NR}{yr}$ @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_3F_8	10	0.1 c/kg-day	-	-	2	40	329.6	515