Next-generation CEνNS experiments at the ESS and beyond

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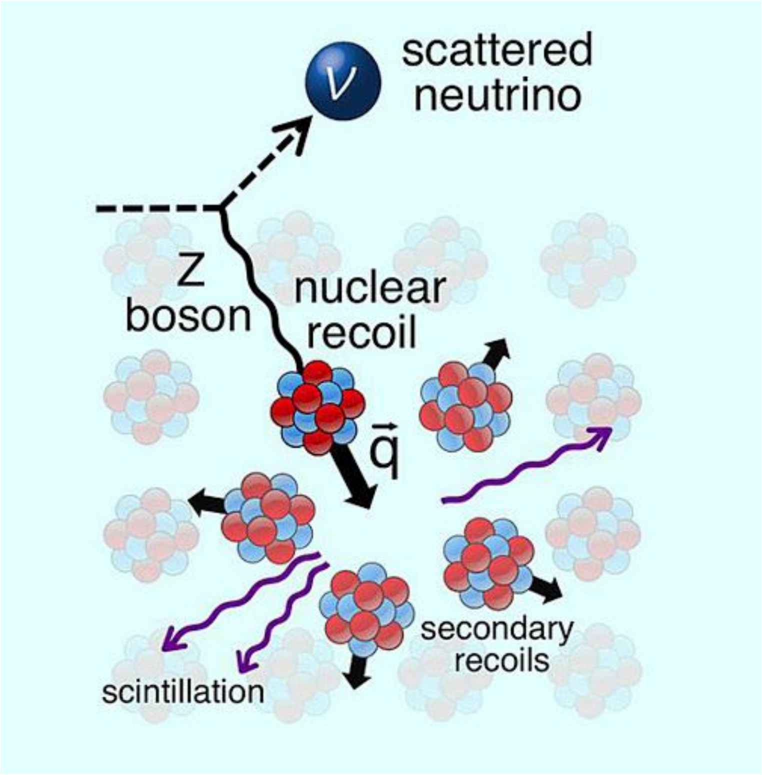
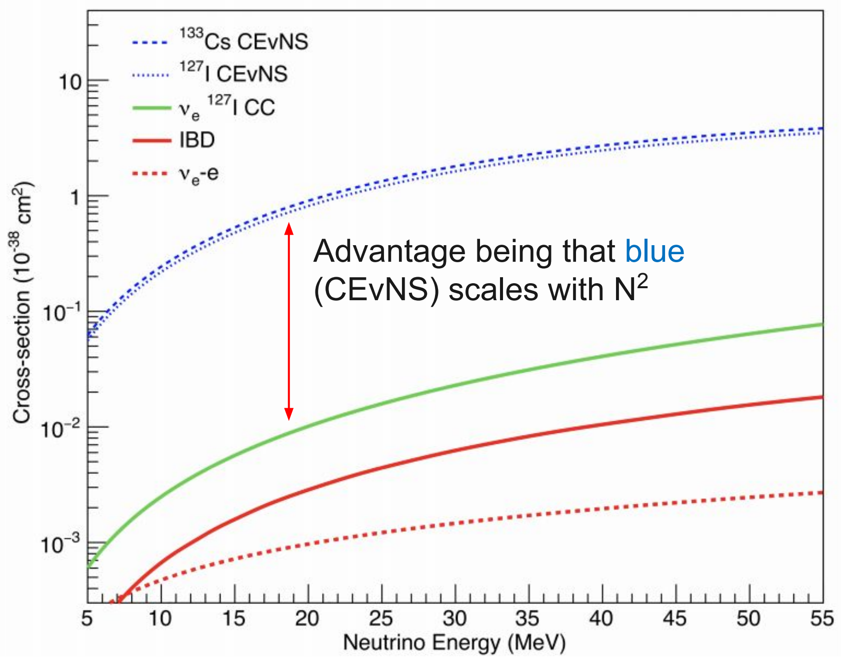
Coherent Elastic Neutrino-Nucleus Scattering (CEνNS)

D.Z. Freedman, Phys. Rev. D 9 (1974) 1389



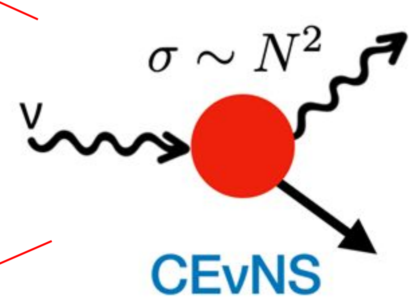


What you can do with it

Probe for non-standard interactions through cross section
(J.R. Wilson, PRL 32 (74) 849)
(J. Barranco et al., hep-ph/0508299, hep-ph-0512029)

Neutrino magnetic moment (enhancement of low-energy recoils) (A.C.Dodd et al, PLB 266 (91) 434)

Neutrino charge radius
(L.M.Krauss, PLB 269, 407)



technology-scale detectors

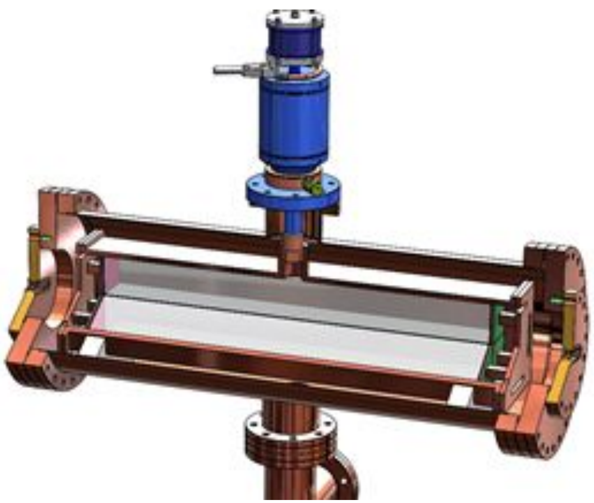
Sterile searches through oscillations (CEvNS is a flavor-blind process)
(A.Drukier & L.Stodolsky, PRD 30 (84) 2295)

Reduce systematics in dark matter experiments (eventually)

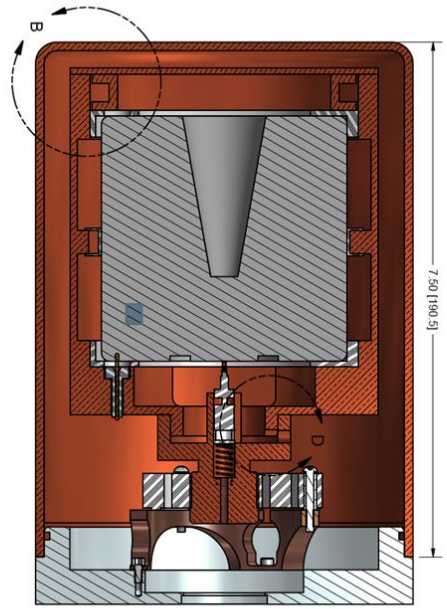
Probe for new neutral candidates

The detector team

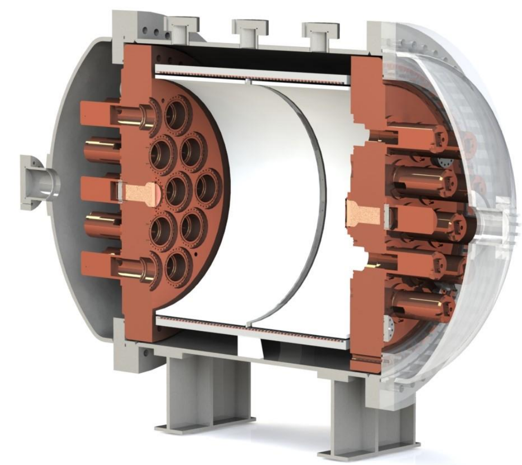
European Research Council



Cryogenic undoped CsI



p-type point contact Ge

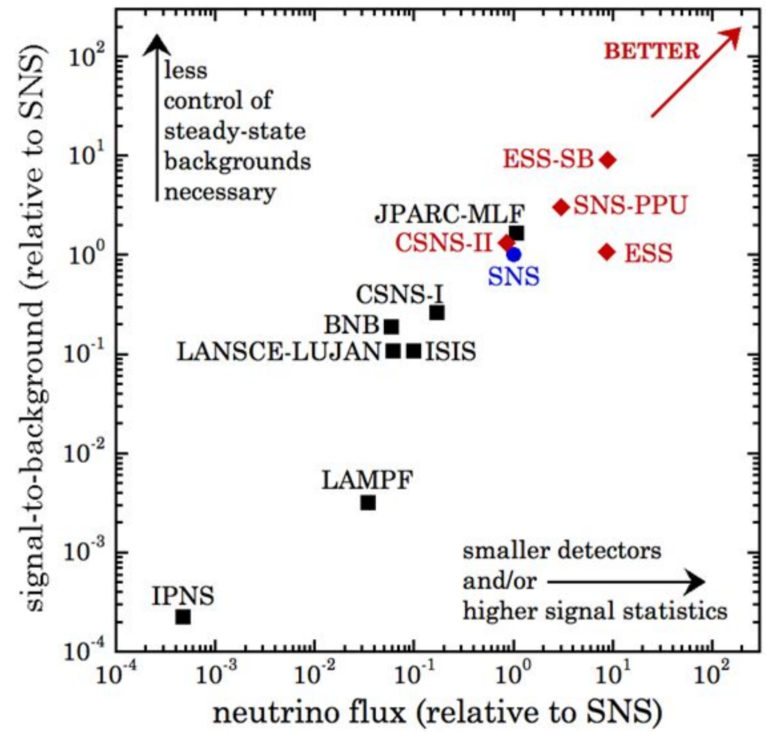


high pressure gas TPC

The best CEνNS detectors deserve the best CEνNS source

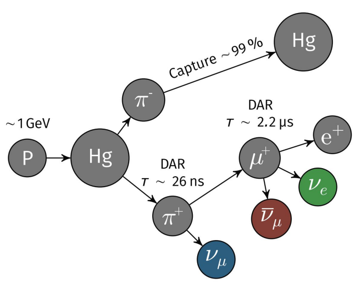
Enter… the European Spallation Source (ESS)

advantage: characteristic in both energy and time



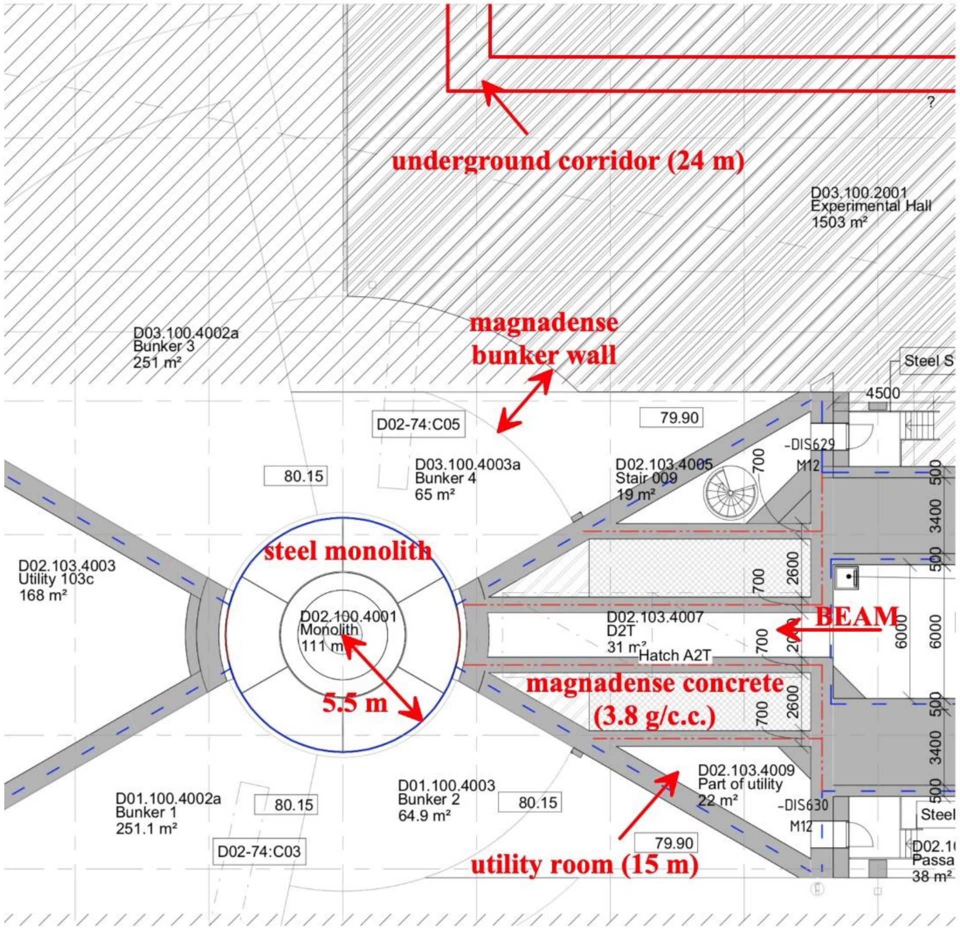
X10 the DAR ν production of the SNS
(=> signal statistics => sensitivity to new physics)

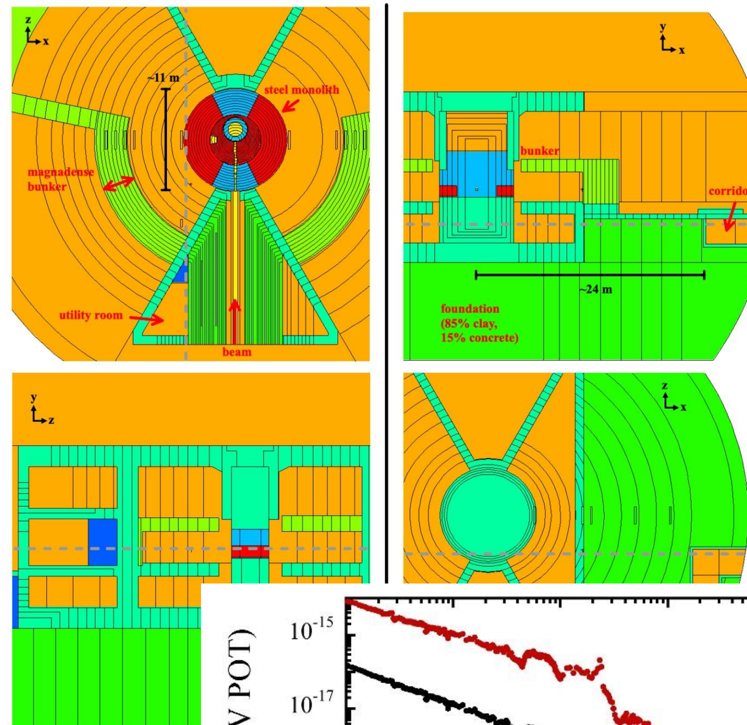
x2.5 SNS current (=> x2.5 SNS ν/p)
x2 SNS energy (=> ~x4 SNS ν/p)

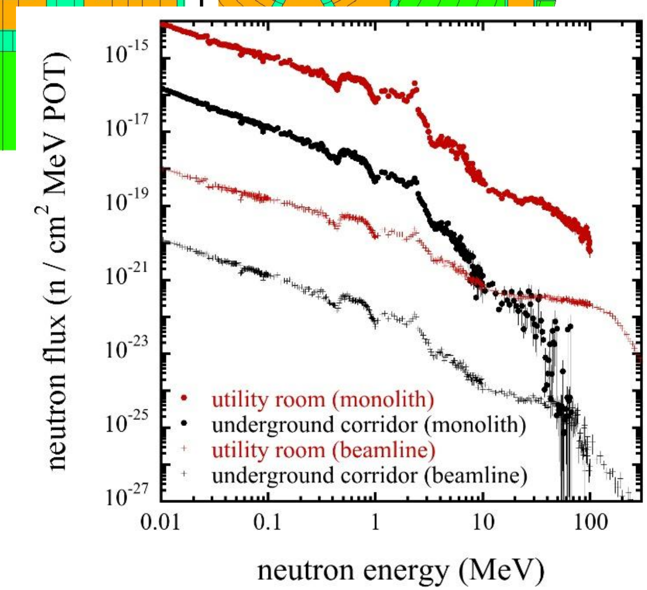


Detector Technology	Target nucleus	Mass (kg)	Steady-state background	E_{th} (keV$_{ee}$)	QF (%)	E_{th} (keV$_{nr}$)	$\frac{\Delta E}{E}$ (%) at E_{th}	E_{max} (keV$_{nr}$)	CEνNS $\frac{NR}{yr}$ @20m, $>E_{th}$
Cryogenic scintillator	CsI	22.5	10 ckkd	0.1	~10 [71]	1	30	46.1	8,405
Charge-coupled device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

ESS (a detector home)

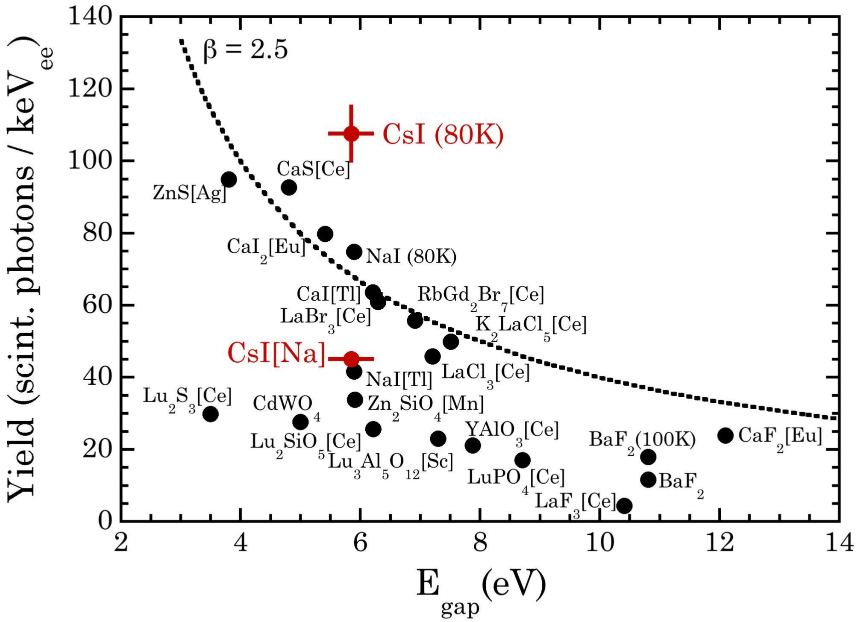






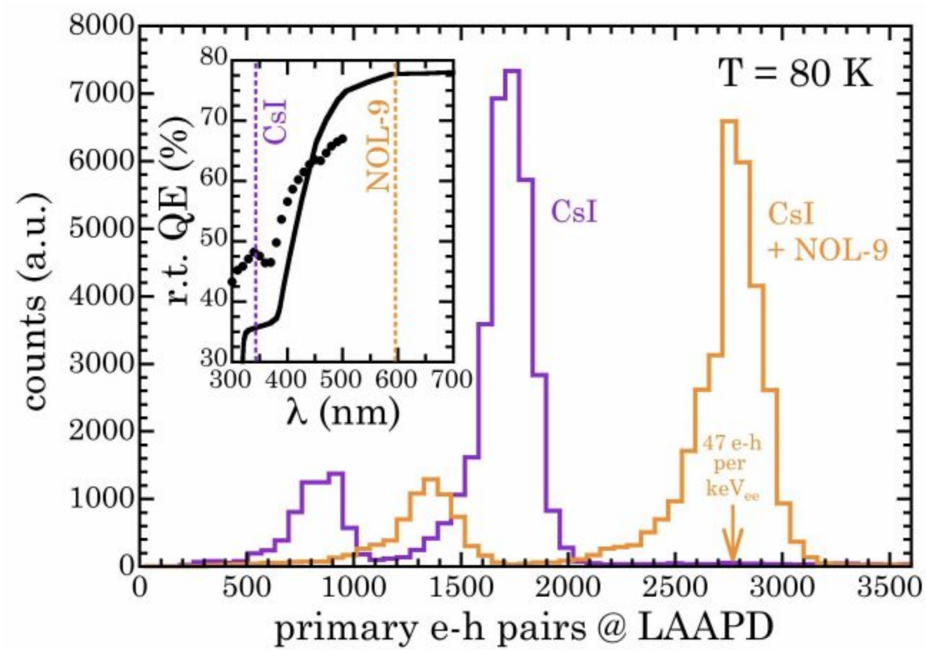
- Steady-state backgrounds subtractable
- beam-induced prompt neutrons are main background (candidate locations being evaluated)
- neutron camera for on-site measurements

Signs of a deeper frontier (pure CsI)



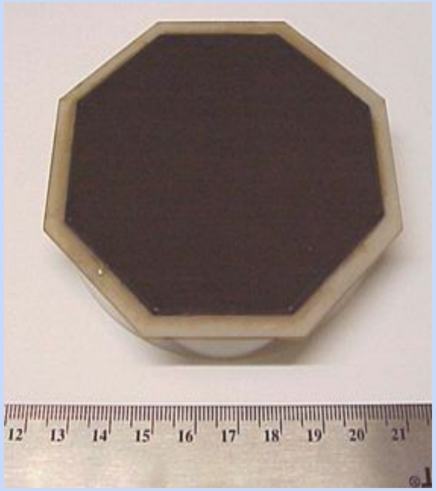
- natural evolution from CsI[Na] measurement at SNS
- combine much higher light yield (x2.5-3) and more efficient photosensors
- large mass increase to ~60 kg (seven 7x7x40 cm crystals)

- LAAPDs with waveshifters (NOL-9) to increase synergy
    - Thresholds < 55 eV
    - limited by LAAPD-induced low-energy population

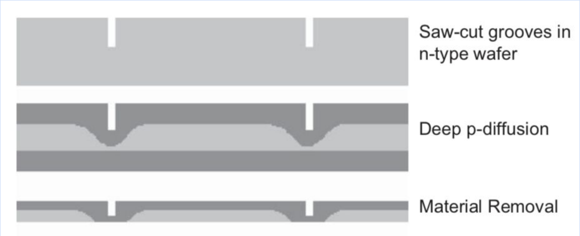


Joining of two houses

46 cm^2 LAAPD w/ 4 photon threshold from RMD



doping profiles boosting QE to visible spectrum



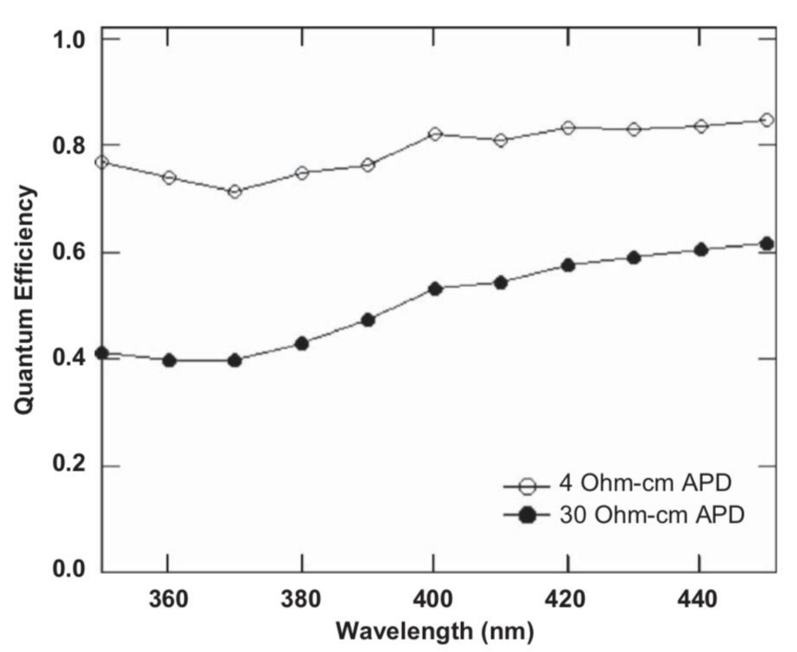
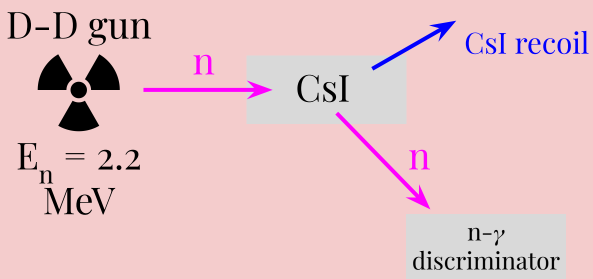
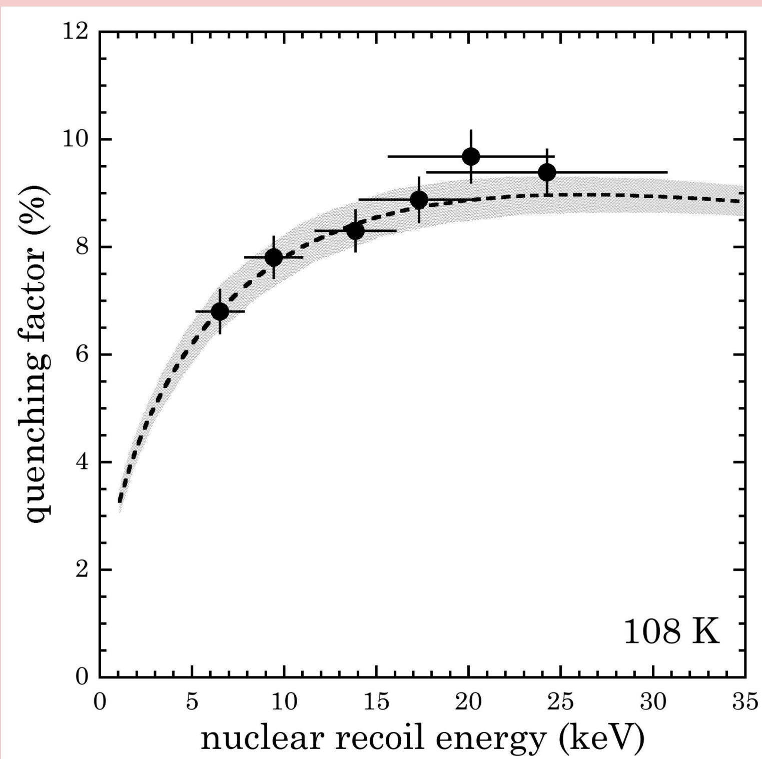


Fig. 3. Quantum efficiency vs. wavelength for a 4 and 30 Ω cm APD.

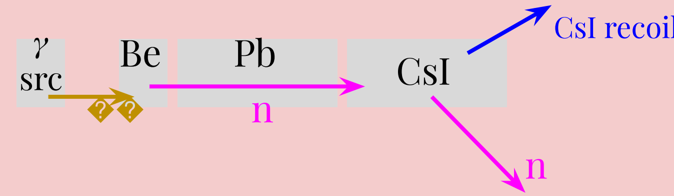
- can remove the complication of waveshifters if LAAPD QE can be brought to par
- R&D goals:
    - LAAPD sensitive to CsI light emission
    - radiopure cryostat stable at 80 K

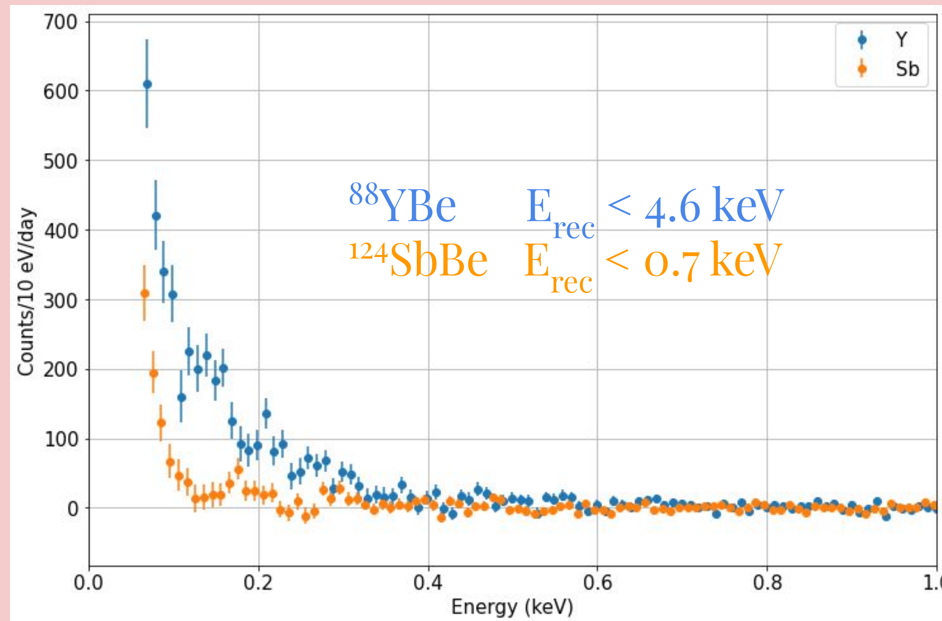
Cryogenic pure CsI quenching factor





arXiv:2101.03264





- switch Be with Al for background
- excess via signal - background
- **sub-keV recoils detected**

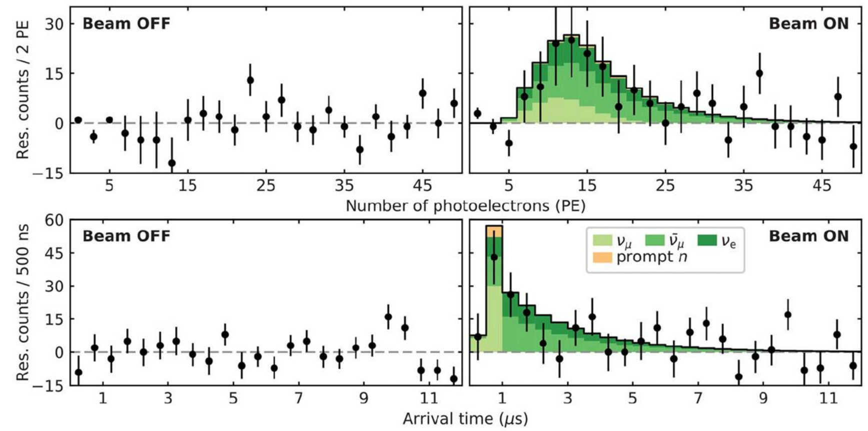
preliminary

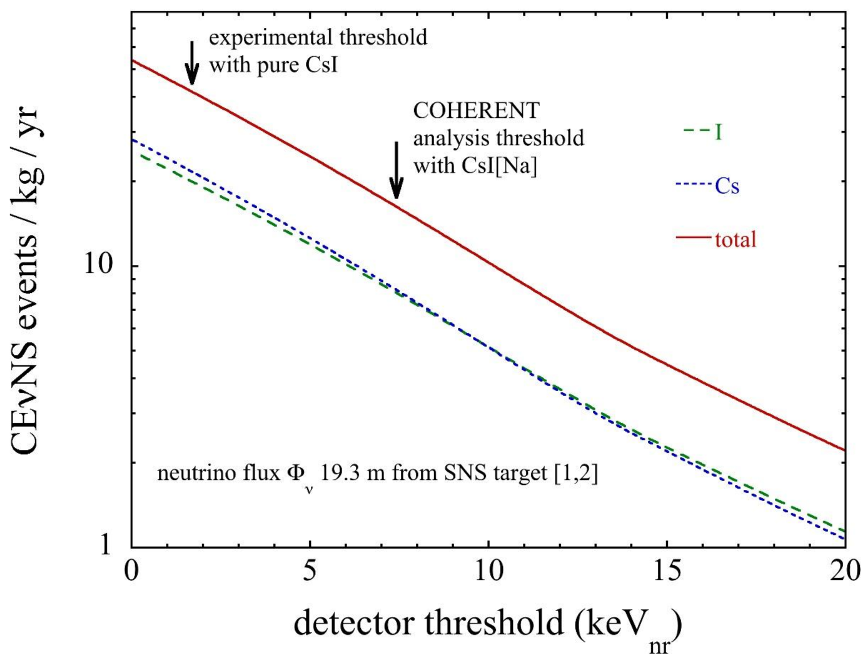
What does all that detector development get you? CºsI

CºsI

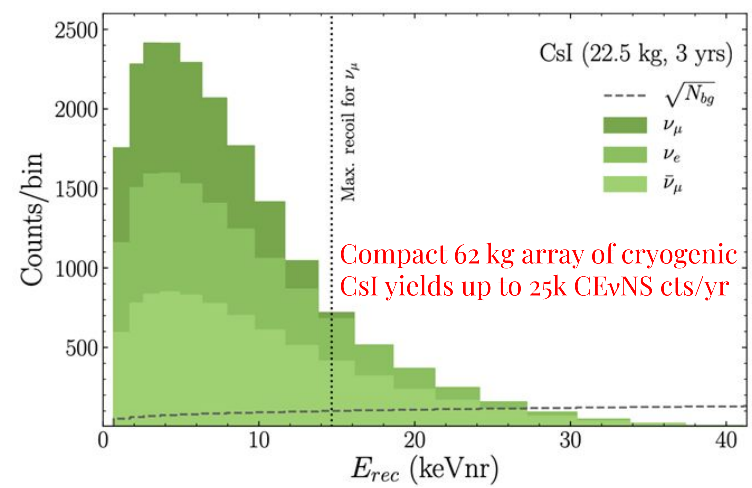
- QF that isn't a mystery
- High light yield
- Optimal QE
- Few-PE threshold

Moving from ~100 cts/yr



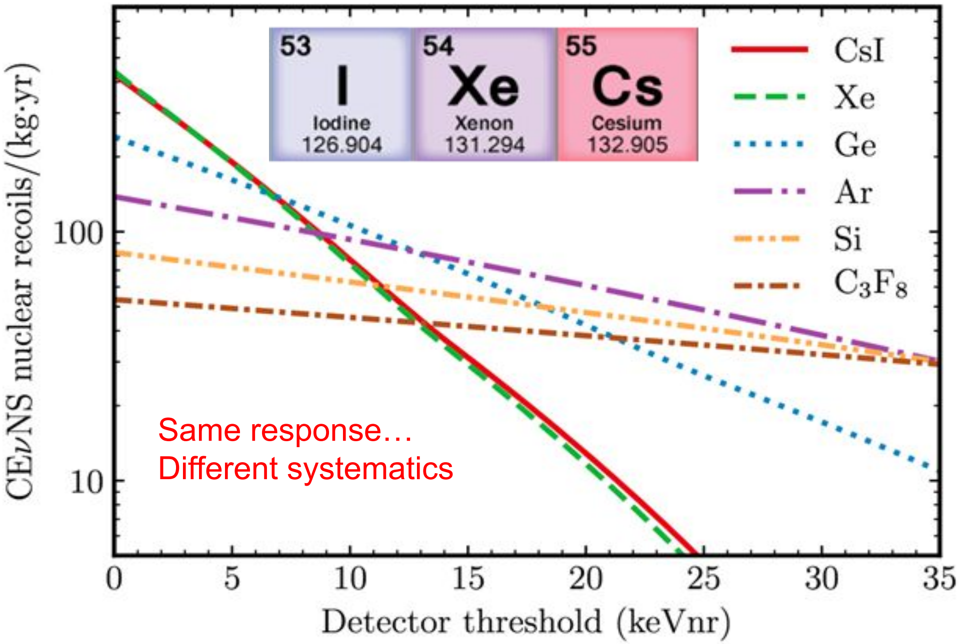


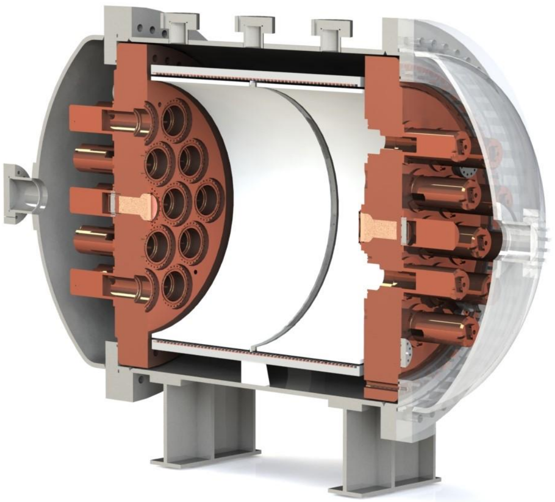
To ~25k cts/yr



Compact 62 kg array of cryogenic CsI yields up to 25k CEvNS cts/yr

Sister detectors (GaνESS)





- lack of cryogenics
- 1-2 e^- thresholds (~50 eV_{ee}) via EL
- Development already pushed by collaborators in NEXT
  - low bckgr
  - high pressures
- variety of nuclei » Ar, Kr, Xe

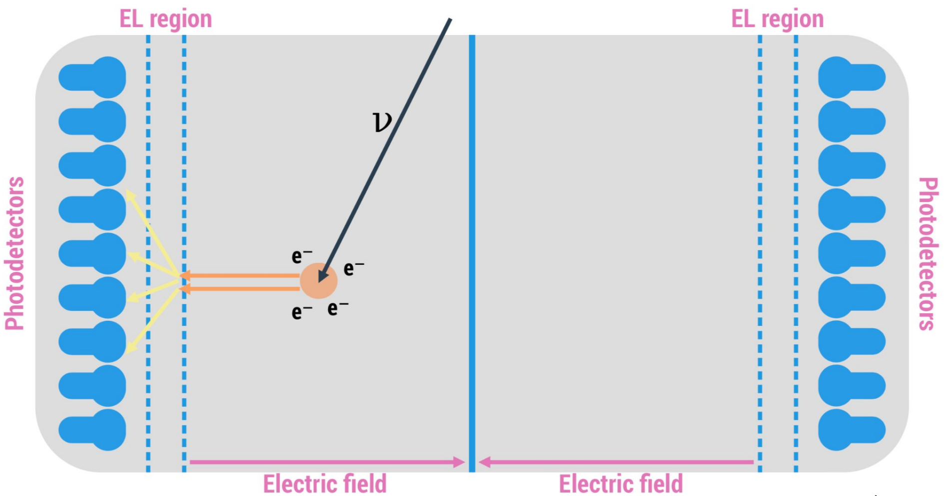


Fig: A. Simón

GaνESS's gaseous prototype (GaP)

- opportunity to evaluate the technique in different conditions
    - multiple targets (Ar, Kr, Xe)
    - pressure up to 50 bar
- characterization of the low-energy response to nuclear recoils
    - **quenching factor measurements**
    - detection threshold

Currently characterizing ER signals with gaseous Ar at ~9.5 bar

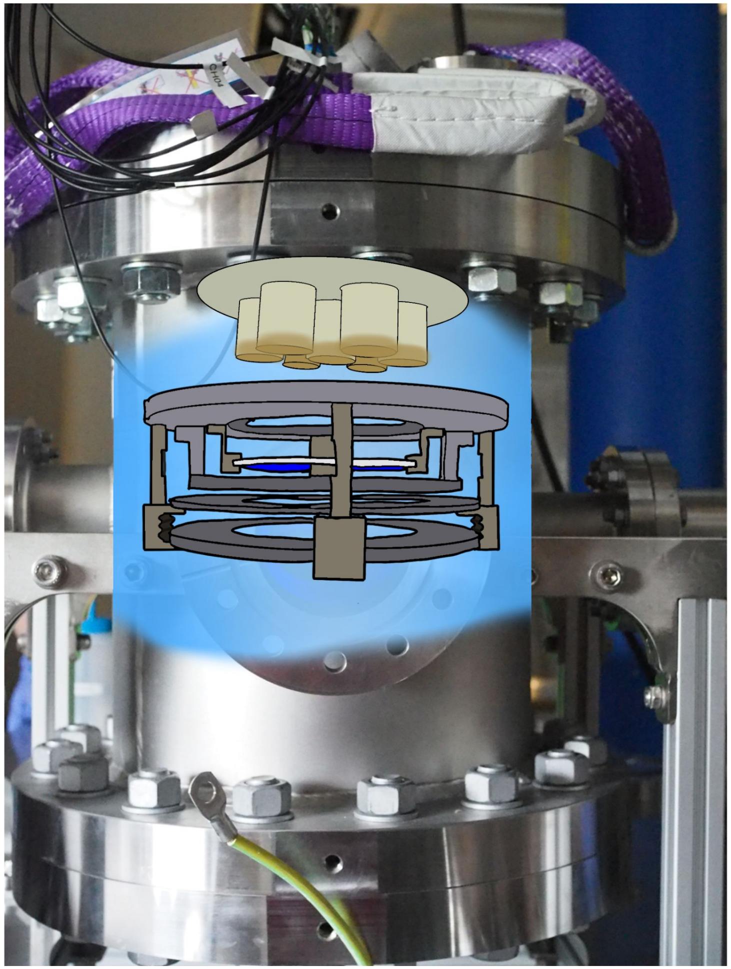
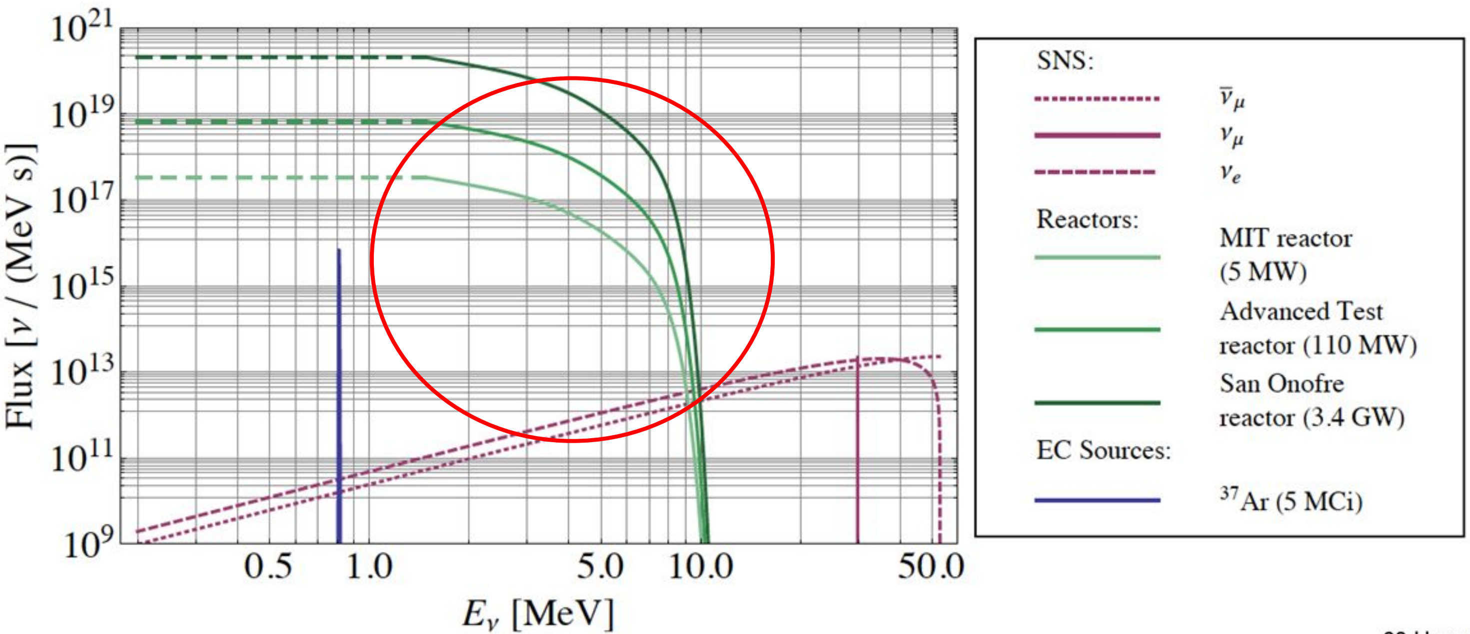
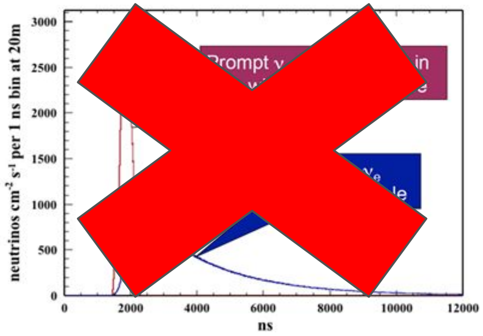


Fig: A. Simón

CEνNS sources (reactors)



Enectali Figueroa-Feliciano / νMass 2013 / Milano

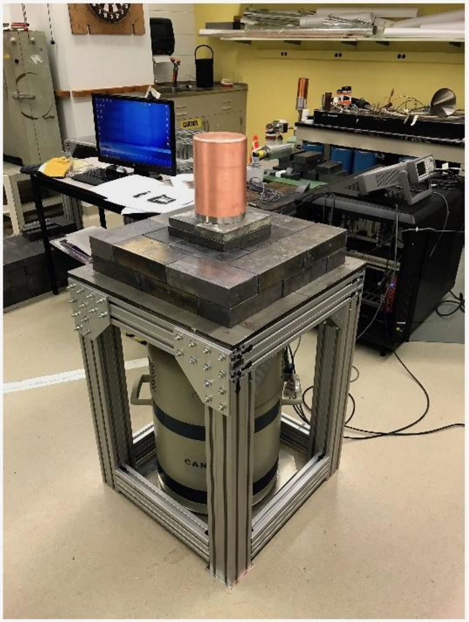


Low recoil energies… but high ν flux

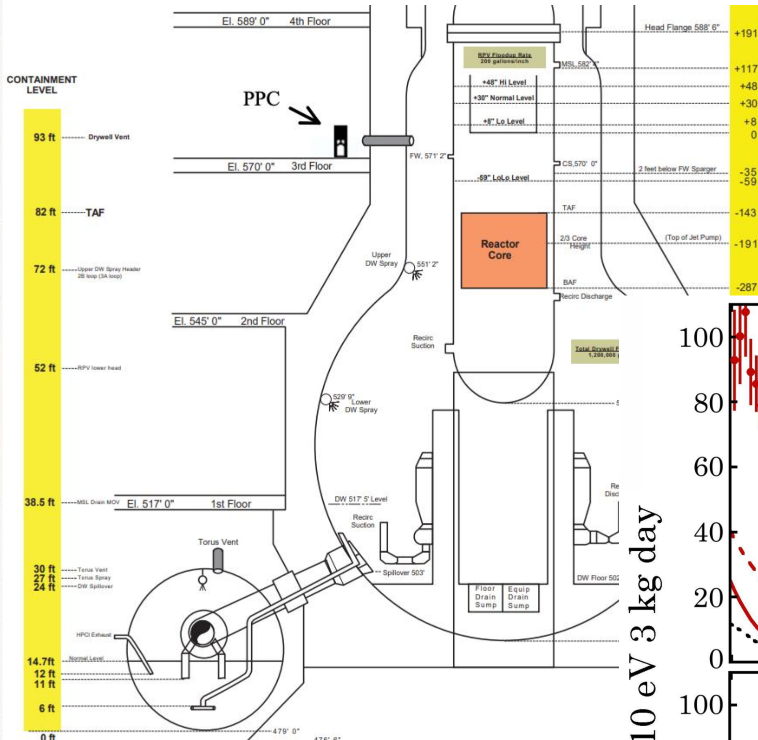
No background subtraction (steady-state source)… but some locations have excellent background reduction

Spallation produces x200 the neutrons per ν

Cutting teeth at Dresden-II



- Mass
- Radiopurity
- Energy Resolution
- Low Threshold



- Only a 60x60 cm footprint
- Took 3 people one day to assemble
- 4.8E13 $\nu/\mathrm{cm}^2\mathrm{s}$
- 10.4 m from core

Bayesian evidence ratio

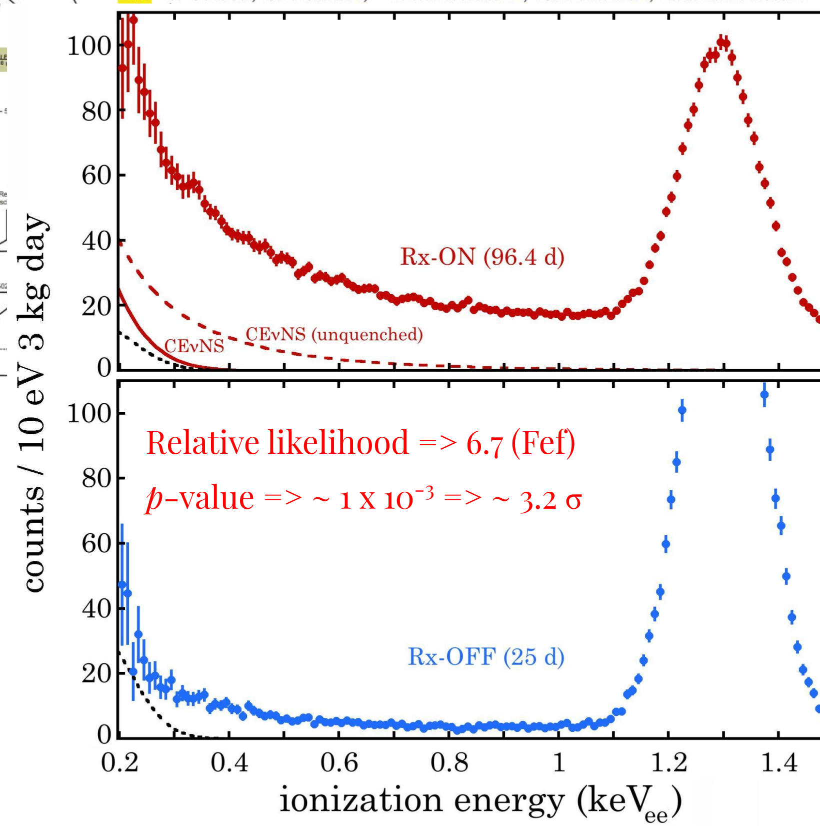
$\log_{10}(B_{10})$	B_{10}	Interpretation
0 to $\frac{1}{2}$	1 to 3.2	Weak
$\frac{1}{2}$ to 1	3.2 to 10	Moderate
1 to 2	10 to 100	Strong
>2	>100	Decisive

QF Model	B_{10} (MHVE)	B_{10} (KOP)
Fef	34.0	34.8
YBe	13.2	11.2
Lindhard	4.0	3.1

PHYSICAL REVIEW LETTERS **129**, 211802 (2022)

Measurement of Coherent Elastic Neutrino-Nucleus Scattering from Reactor Antineutrinos

J. Colaresi,[1] J. I. Collar,[2,*] T. W. Hossbach,[3] C. M. Lewis,[2] and K. M. Yocum[1]

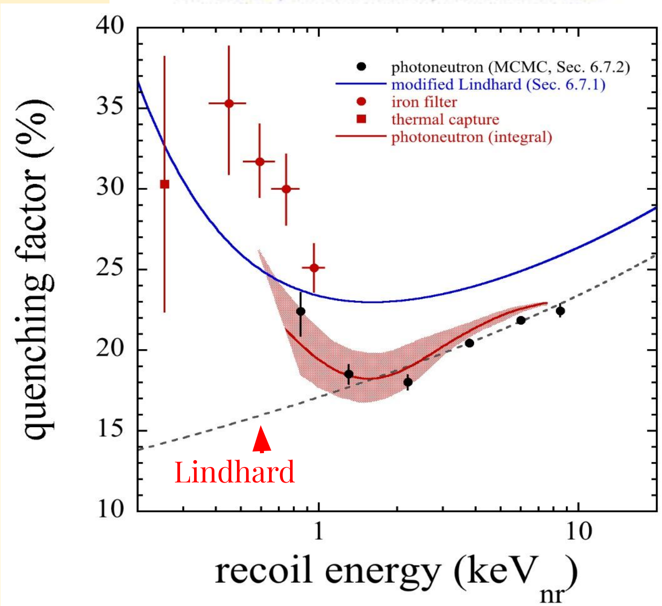


A project of passion: Ge NR response

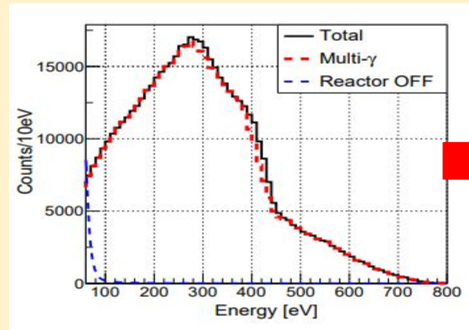
PHYSICAL REVIEW D 103, 122003 (2021)

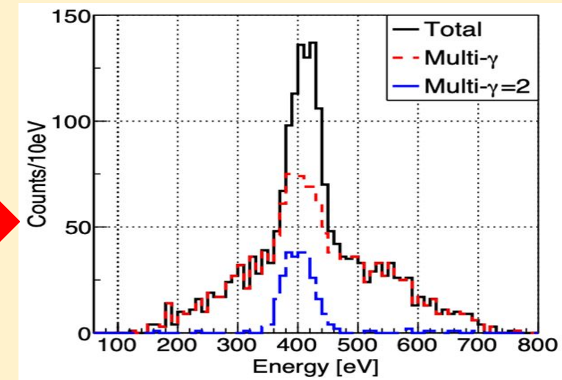
Germanium response to sub-keV nuclear recoils: A multipronged experimental characterization

J. I. Collar,* A. R. L. Kavner, and C. M. Lewis



***comments on CONUS QF paper: arXiv:2203.00750**





Calibration of nuclear recoils at the 100 eV scale using neutron capture

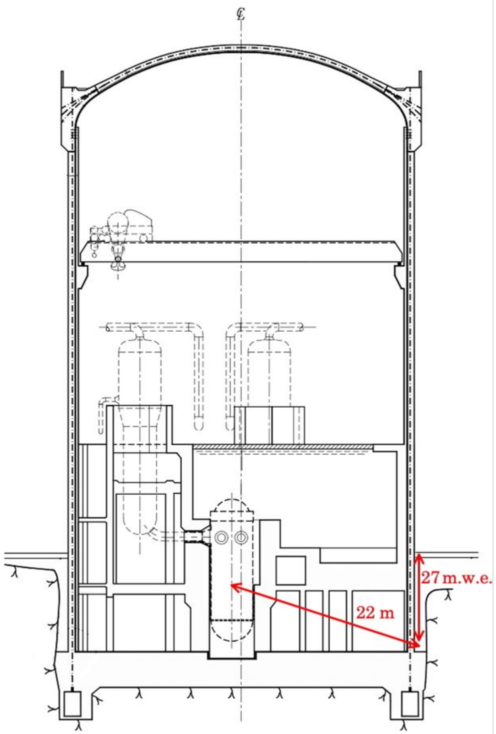
L. Thulliez,[a] D. Lhuillier,[a,*] F. Cappella,[b] N. Casali,[b] R. Cerulli,[c,d] A. Chalil,[a] A. Chebboubi,[e] E. Dumonteil,[a] A. Erhart,[f] A. Giuliani,[g] F. Gunsing,[a] E. Jericha,[h] M. Kaznacheeva,[f] A. Kinast,[f] A. Langenkämper,[f] T. Lasserre,[a,f] A. Letourneau,[a] O. Litaize,[e] P. de Marcillac,[g] S. Marnieros,[g] T. Materna,[a] B. Mauri,[a] E. Mazzucato,[a] C. Nones,[a] T. Ortmann,[f] L. Pattavina,[d,i] D.V. Poda,[g] R. Rogly,[a] N. Schermer,[f] O. Serot,[e] G. Soum,[a] L. Stodolsky,[j] R. Strauss,[f] M. Vignati,[b,k] M. Vivier,[a] V. Wagner[f] and A. Wex[f]

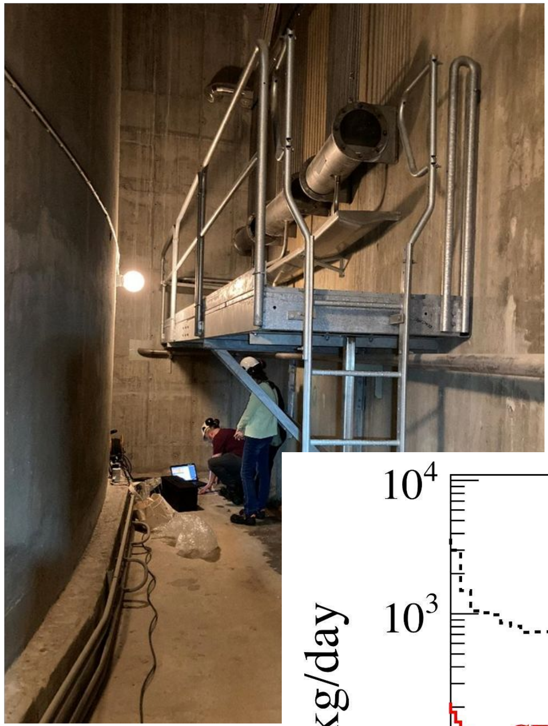
2021 JINST 16 P07032

- 0.4 keV$_{nr}$ ↠ if Lindhard, it won't be visible
- A binary test for the form of the QF below 1 keV

CsI @ OSURR

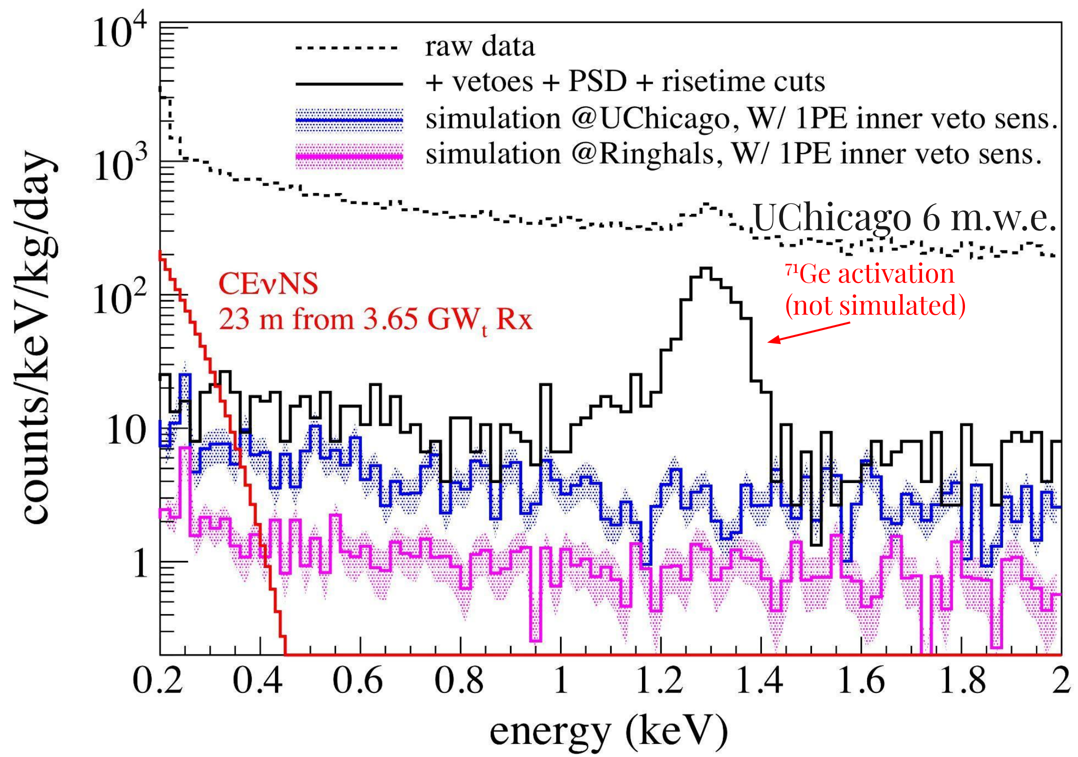
The next pre-ESS step: Ringhals





still with just a 60x60 cm footprint

- ^{3}He counter(s)
- NaI
- plastic scint
- overburden
- radon



30 m.w.e. in tendon gallery

Signal-to-background of ~ 40 expected (present was ¼)

refurbished specs » significantly reduced threshold

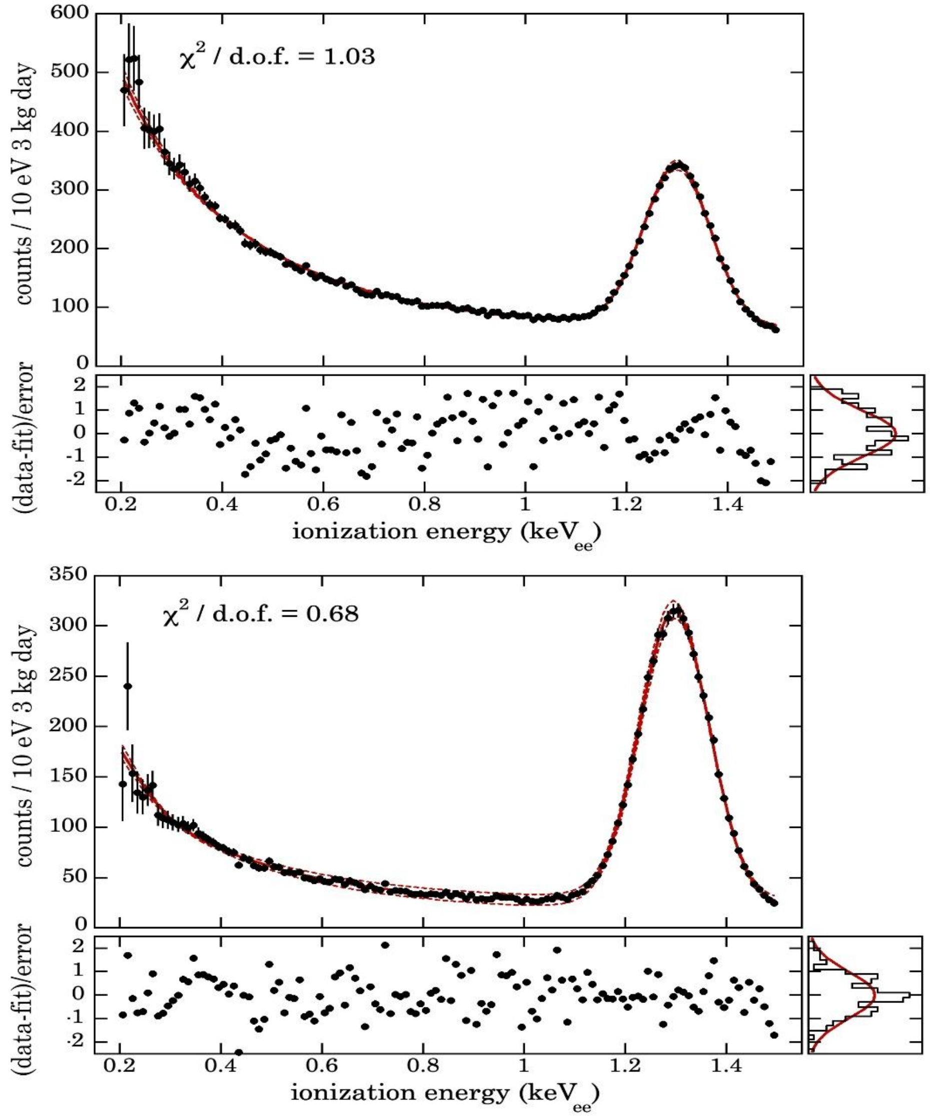
Thanks

Questions?

Extra: Background Model

No moderator

1 inch moderator



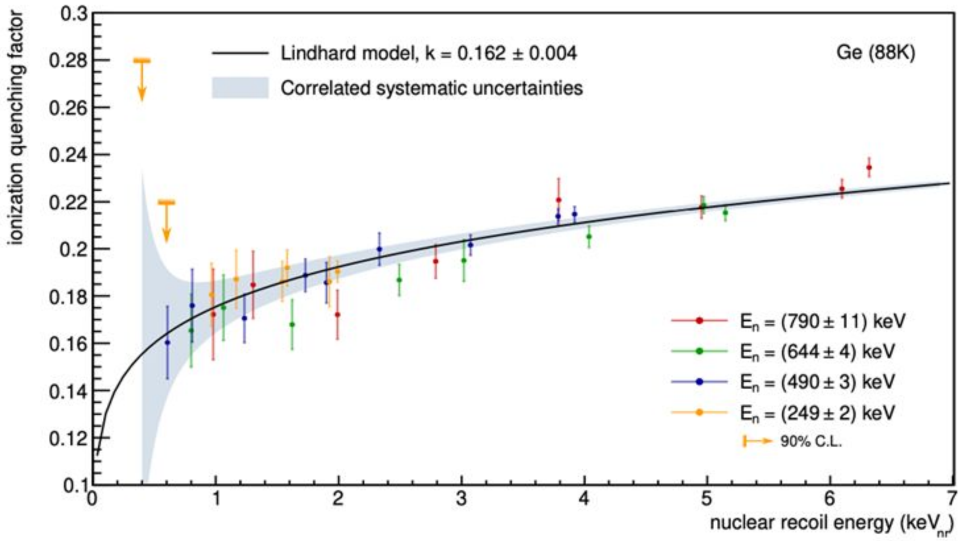
~1 keV wide ROI

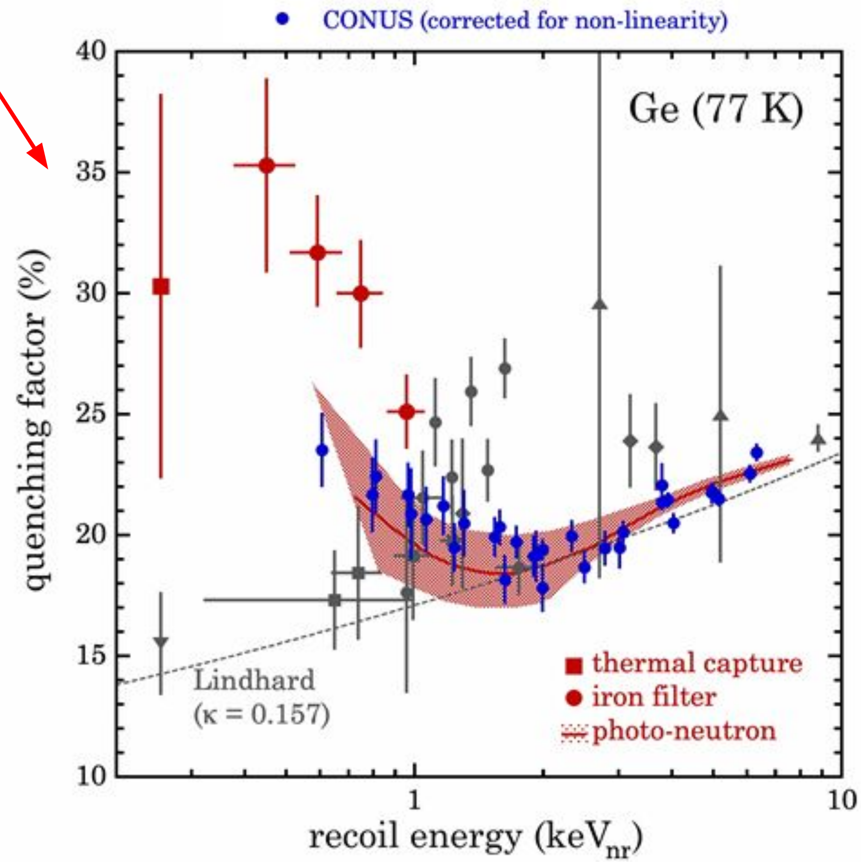
epithermals => $E_n^{-(1+\alpha)}$
where $\alpha \sim 0.2$
(best-match agrees)

no “shark tooth” peaks (fast)

simple falling exponential

Extra: QFs in Ge





two main points:

- improvised 2-point energy scale uncertainty ⤖ (Monte Carlo used to demonstrate)
- underestimated treatment (flat 10 eV) of ballistic deficit from DAQ ⤖ quoted numbers used to infer the correction (see right)
    - paper revision in response appears to soften ballistic deficit correction

*comments on CONUS sub-keV QF paper: arXiv:2203.00750