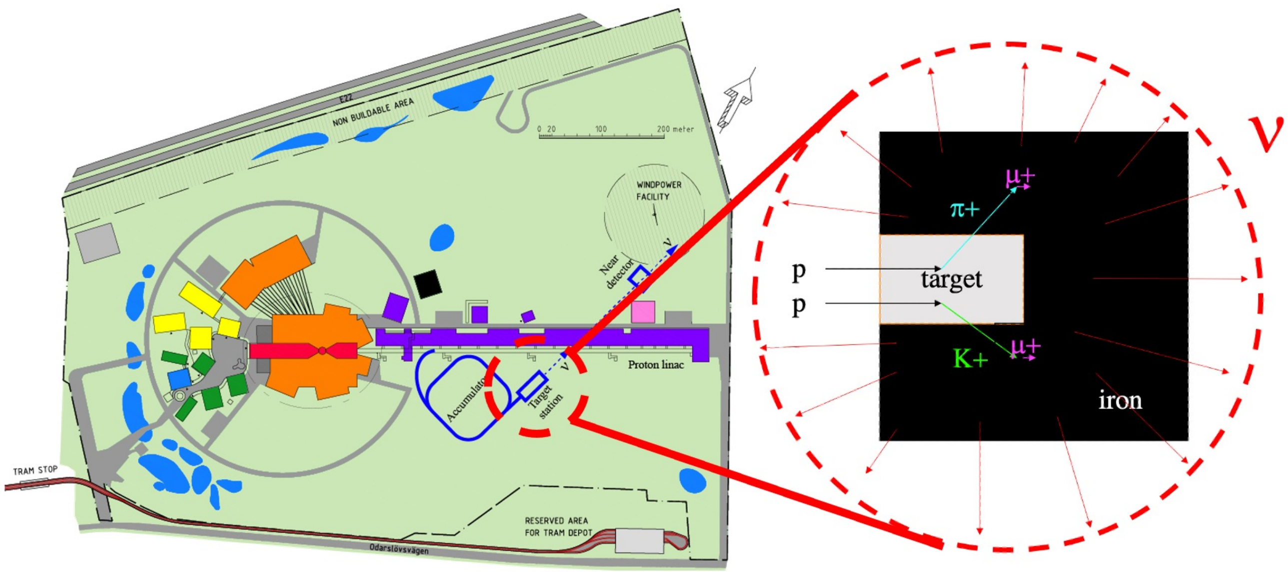
Prospects for "Decay-at-Rest" & Coherent Scattering At ESS



NuFact ESS Workshop , Sept 7, 2021, Janet Conrad, MIT

Why the interest?

Precision!
DAR flux energy distributions and flavor content are very well described.
There are 3 low-energy cross sections that are very well known!

Quick!
Most experiments being proposed are <$10M (US accounting)
Many experiments use small detectors – even new state-of-art technology is affordable given size.

Not your same-old approach!
Opens new types of searches.

Outline

Fluxes (ESS vs. Others)
Three "Classic" Interactions
More Physics Opportunities

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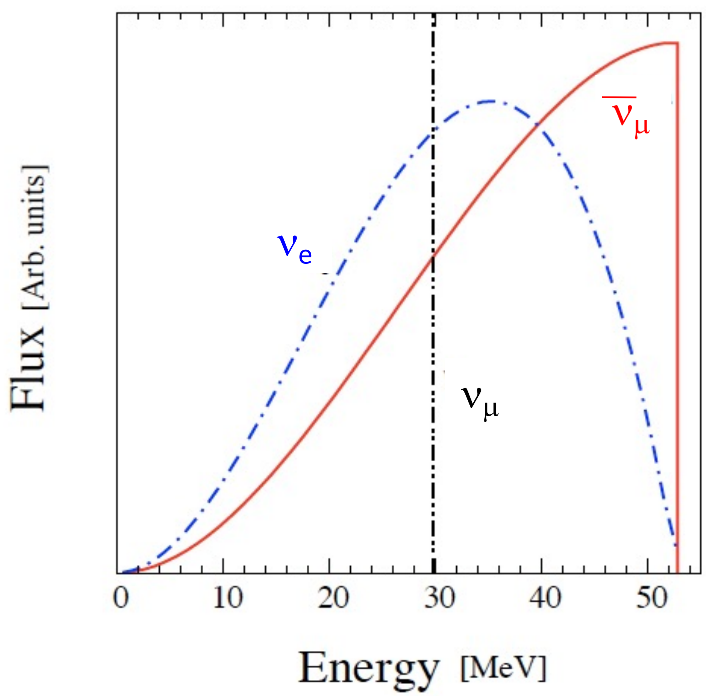
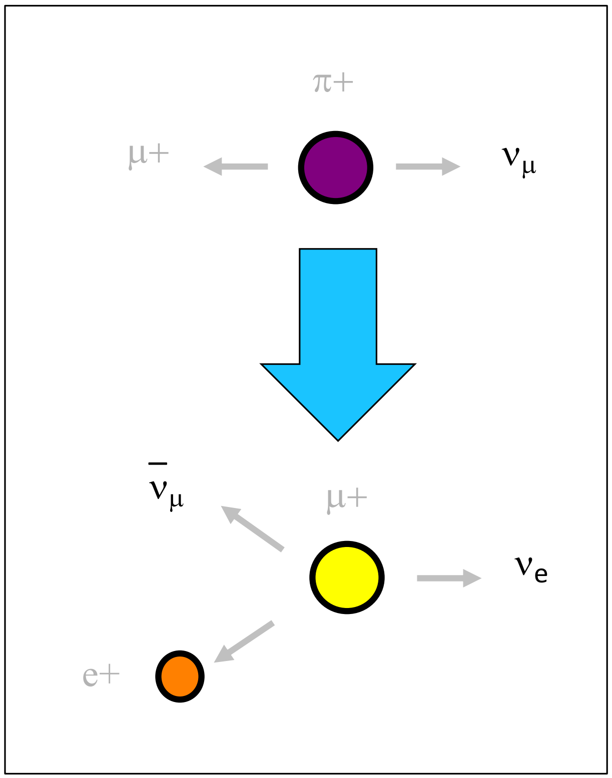
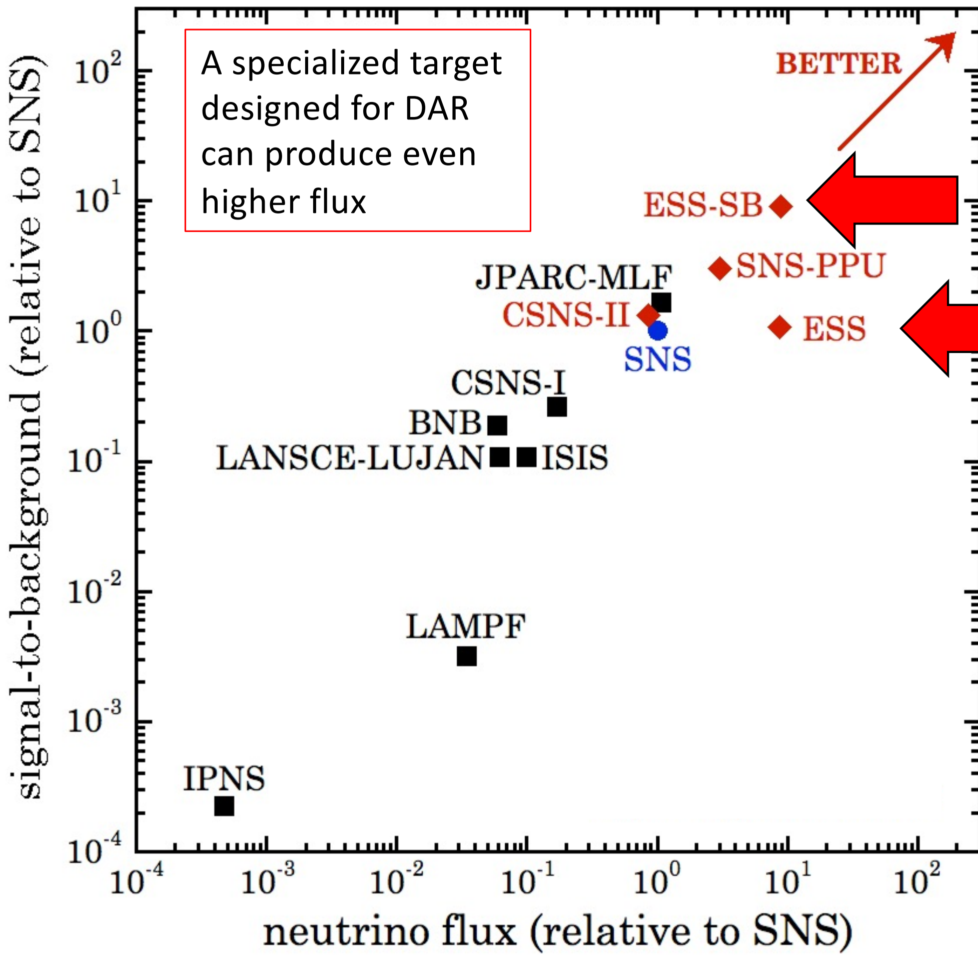
Most of the running
and proposed experiments use
Pion/muon decay-at-rest fluxes





π- chain absorbed, so negligible $\bar{\nu}_e$

The π/μ DAR landscape



Short pulse upgrade

At start

It's not just about power... energy matters!

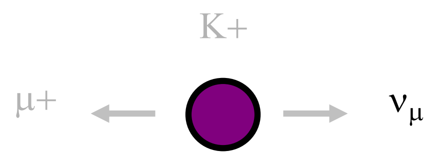
High Beam Energy Produces More Pions...

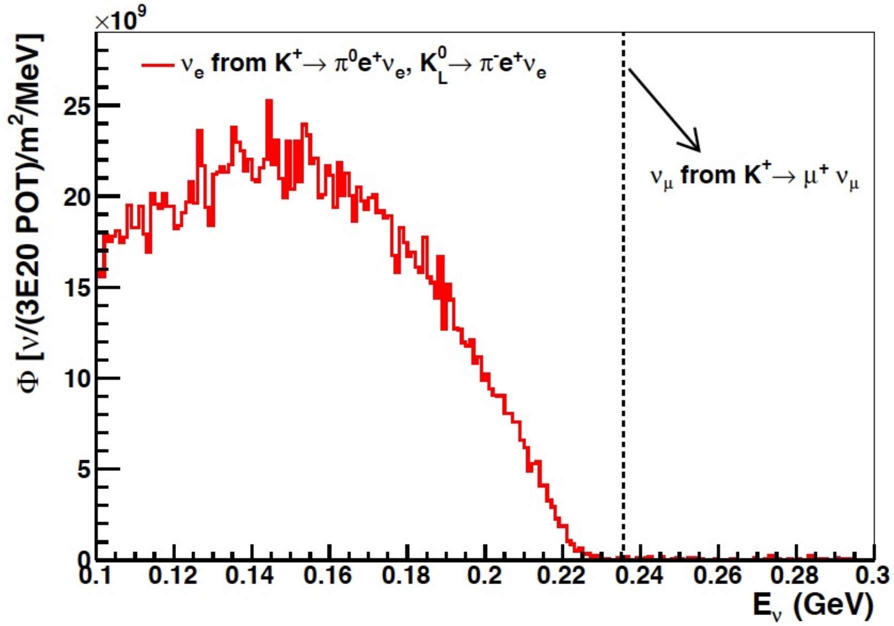
Production data on p+Be target...

Produced Hadron	Exclusive Reaction	M_X (GeV/c^2)	$\sqrt{s_{thresh}}$ (GeV)	E^{beam}_{thresh} GeV	KE of beam (MeV)	
π^+	$pn\pi^+$	1.878	2.018	1.233	295	
π^-	$pp\pi^+\pi^-$	2.016	2.156	1.54	602	
π^0	$pp\pi^0$	1.876	2.011	1.218	280	
K^+	$\Lambda^0 pK^+$	2.053	2.547	2.52	1582	*Very few locations!*
K^-	ppK^+K^-	2.37	2.864	3.434	2496	
K^0	$p\Sigma^+K^0$	2.13	2.628	2.743	1805	

...And Even Opens Up KDAR

Kaon decay-at-rest ("KDAR")





A high energy Monoenergetic 236 MeV muon neutrino!

Electron neutrino content, that extends above 100 MeV and lies below the monoenergetic line

Spitz, arXiv:1203.6050

Lots of accelerators produce kaons,

But you want KDAR with minimal DIF

Two best sources for the near future are:

JPARC MLF: 3 GeV protons @ 1 MW

And

ESS: 2.5 GeV protons @ 5 MW

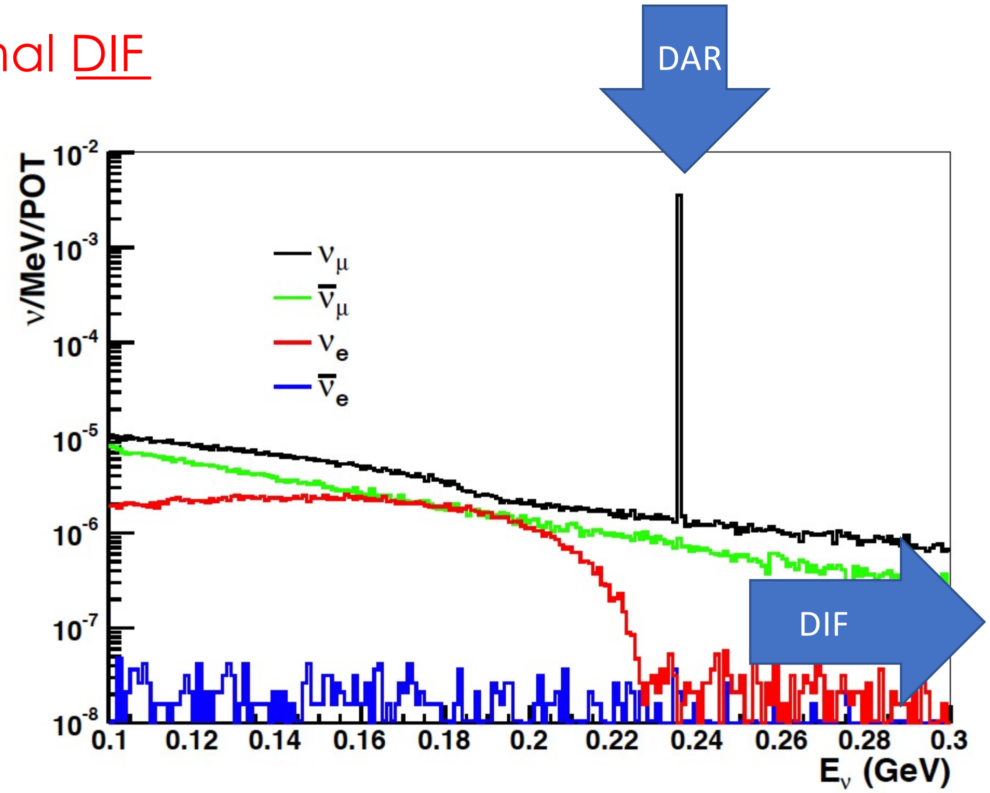


FIG. 1. The neutrino flux from 100-300 MeV provided by the 3 GeV proton-on-mercury JPARC-MLF source. The 236 MeV charged kaon decay-at-rest daughter ν_μ is easily seen.

Spitz, arXiv:1402.2284

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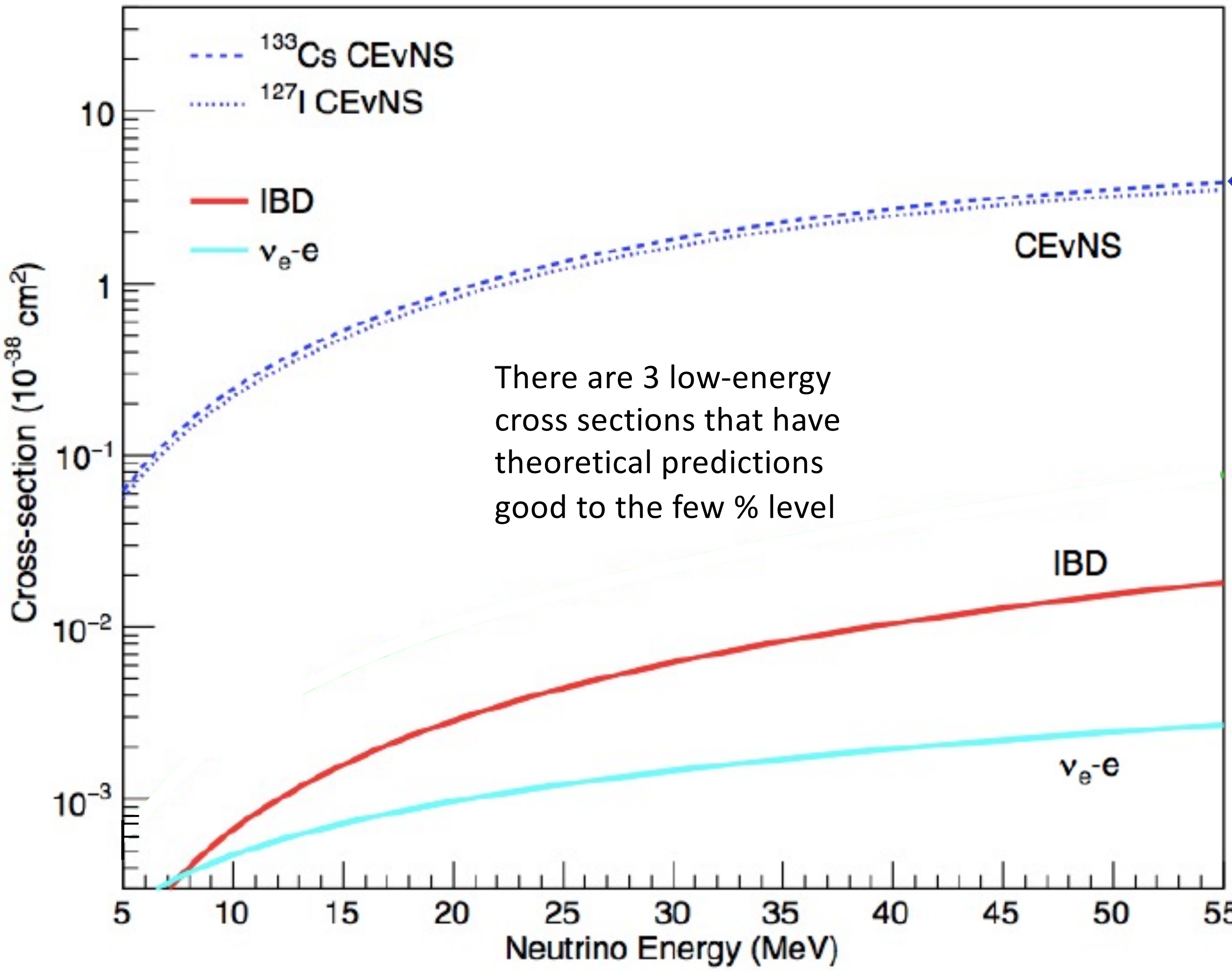
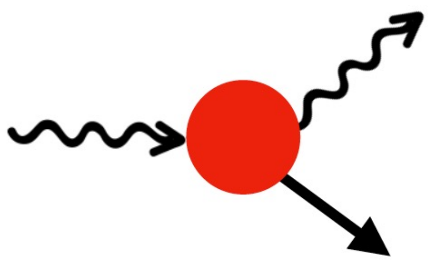


Most recently observed & stirring lots of interest

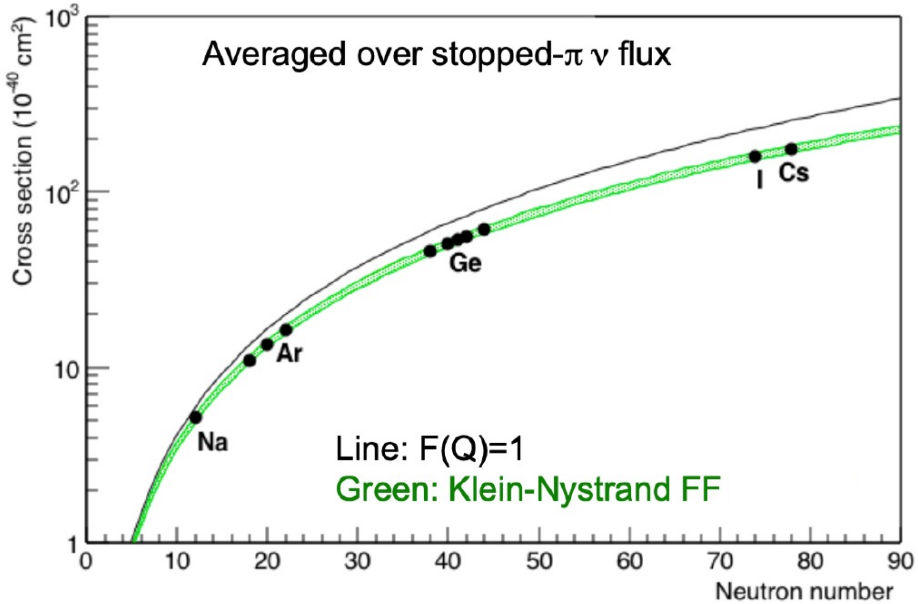
$$\frac{d\sigma_{SM}(T,E_\nu)}{dT} = \frac{G_F^2}{2\pi}\frac{Q_W^2(Z,N)}{4}F^2(Q^2)M\left[2-\frac{2T}{E_\nu}+\left(\frac{T}{E_\nu}\right)^2-\frac{MT}{E_\nu^2}\right]$$

$$Q_W = N-(1-4sin^2\theta_W)Z$$

X-section of the process is proportional to N^2
It allows for moderate size detectors (~10 kg)



For large N also smaller recoil energies



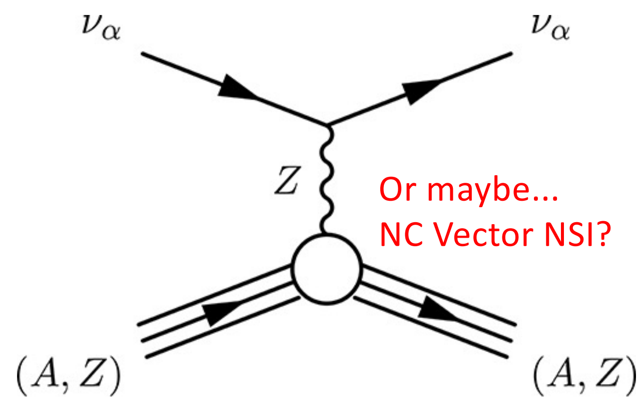
Large cross section → small detectors → range of N → improved physics reach

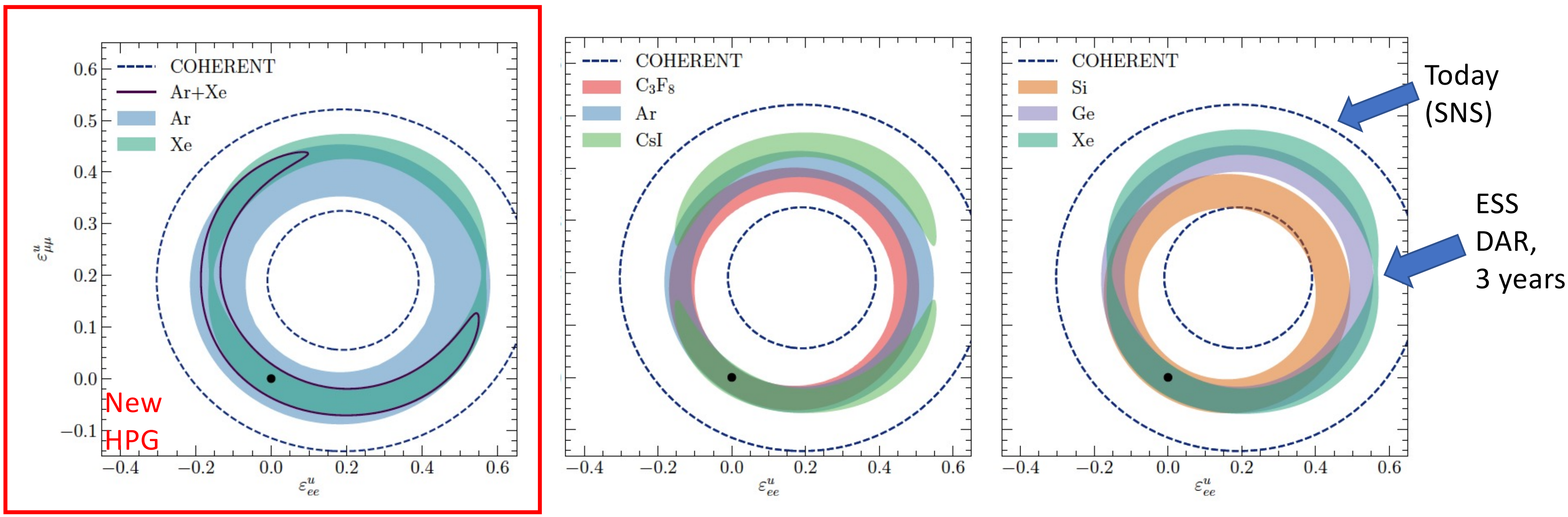
Regular Article - Experimental Physics | Open Access | Published: 20 February 2020

Coherent elastic neutrino-nucleus scattering at the European Spallation Source

D. Baxter, J. I. Collar, P. Coloma, C. E. Dahl, I. Esteban, P. Ferrario, J. J. Gomez-Cadenas, M.C. Gonzalez-Garcia, A. R. L. Kavner, C. M. Lewis, F. Monrabal, J. Munõz Vidal, P. Privitera, K. Ramanathan & J. Renner

Journal of High Energy Physics **2020**, Article number: 123 (2020) | Cite this article

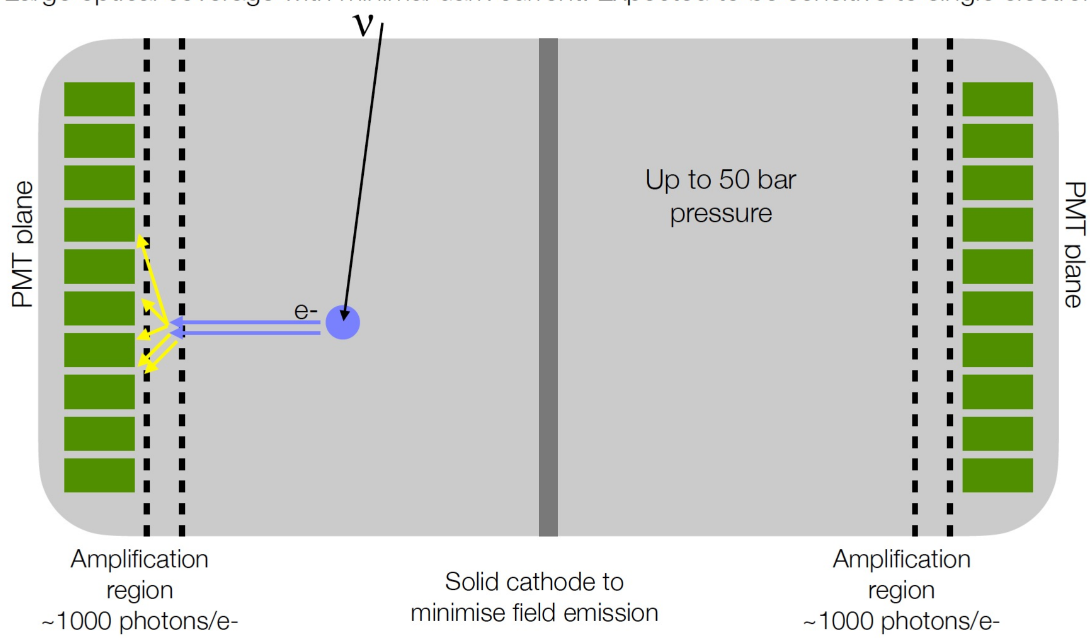




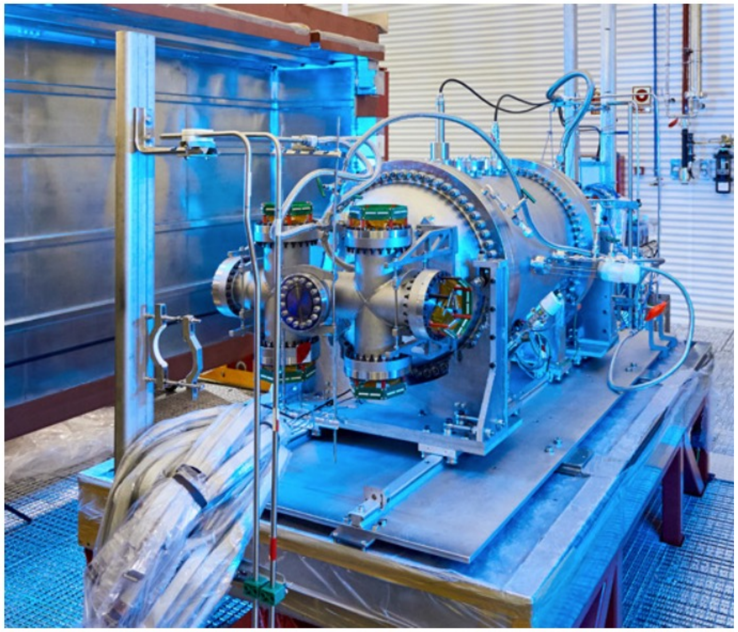
Gaseous detector for Neutrino physics at the ESS (**GaNESS**)

DAR programs offer great venues for detector development

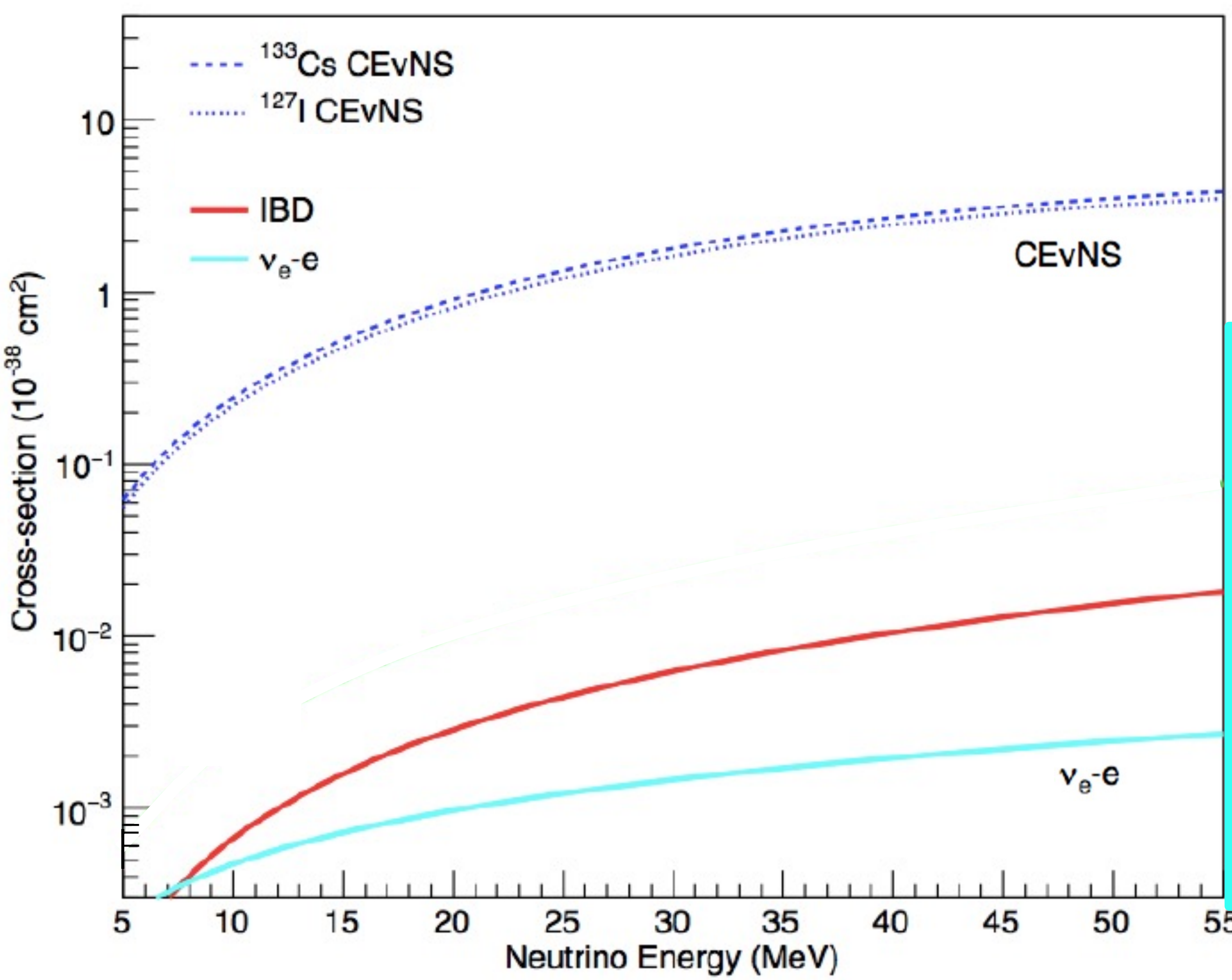
Symmetric detector with two PMT planes to be sensitive to tiny signals.
Large optical coverage with minimal dark current. Expected to be sensitive to single electrons.



NEXT-New detector



HPG detectors are also proposed for $0\nu\beta\beta$ and for DUNE-near

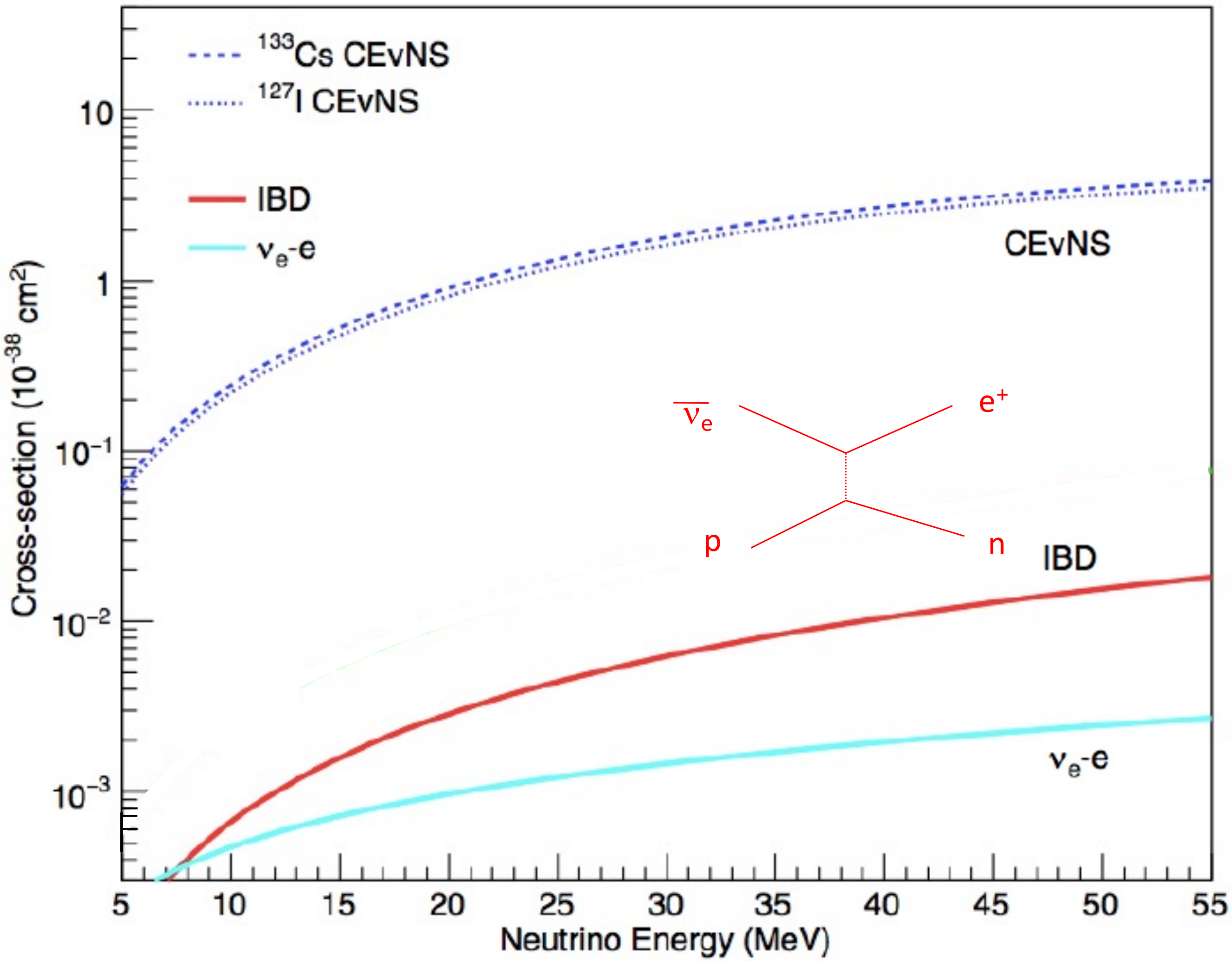


ν_e ES:

Forward signal
In HPG detector

Similar/
complementary
physics
to CEvNS

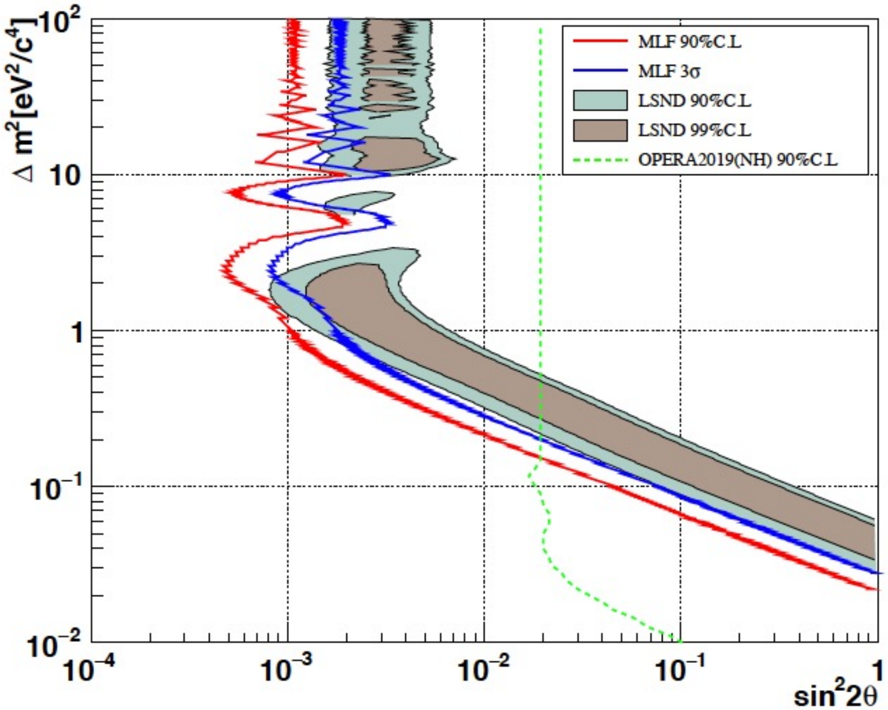
A purely
lepton-lepton
Interaction.



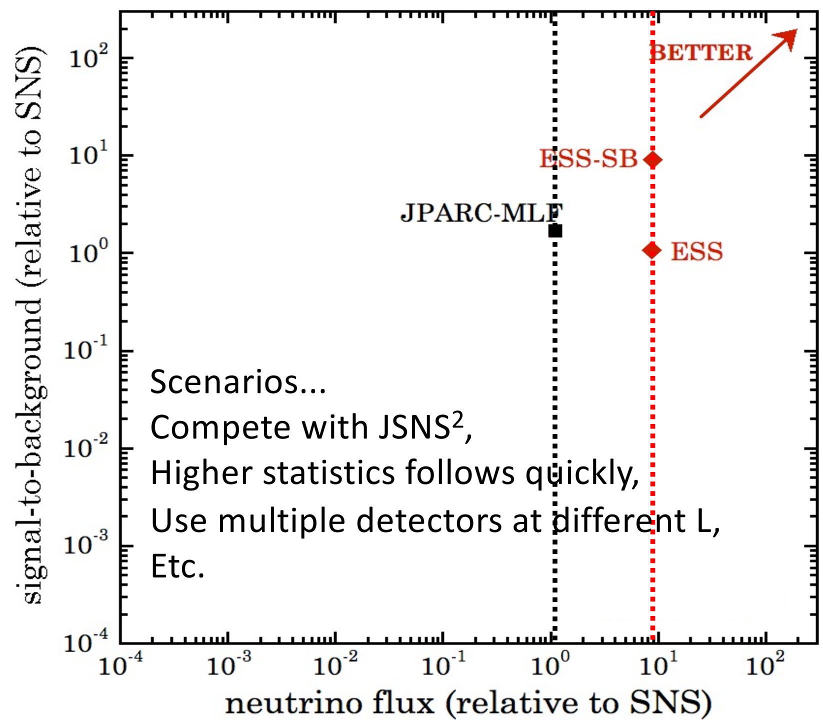
Neutrino energy is fully reconstructed!

Sterile neutrino searches "a la LSND" are statistics-limited

JSNS^2 II (planned upgrade, 5 years)



ESS can give $\mathcal{O}(10)$ gain for same size detector



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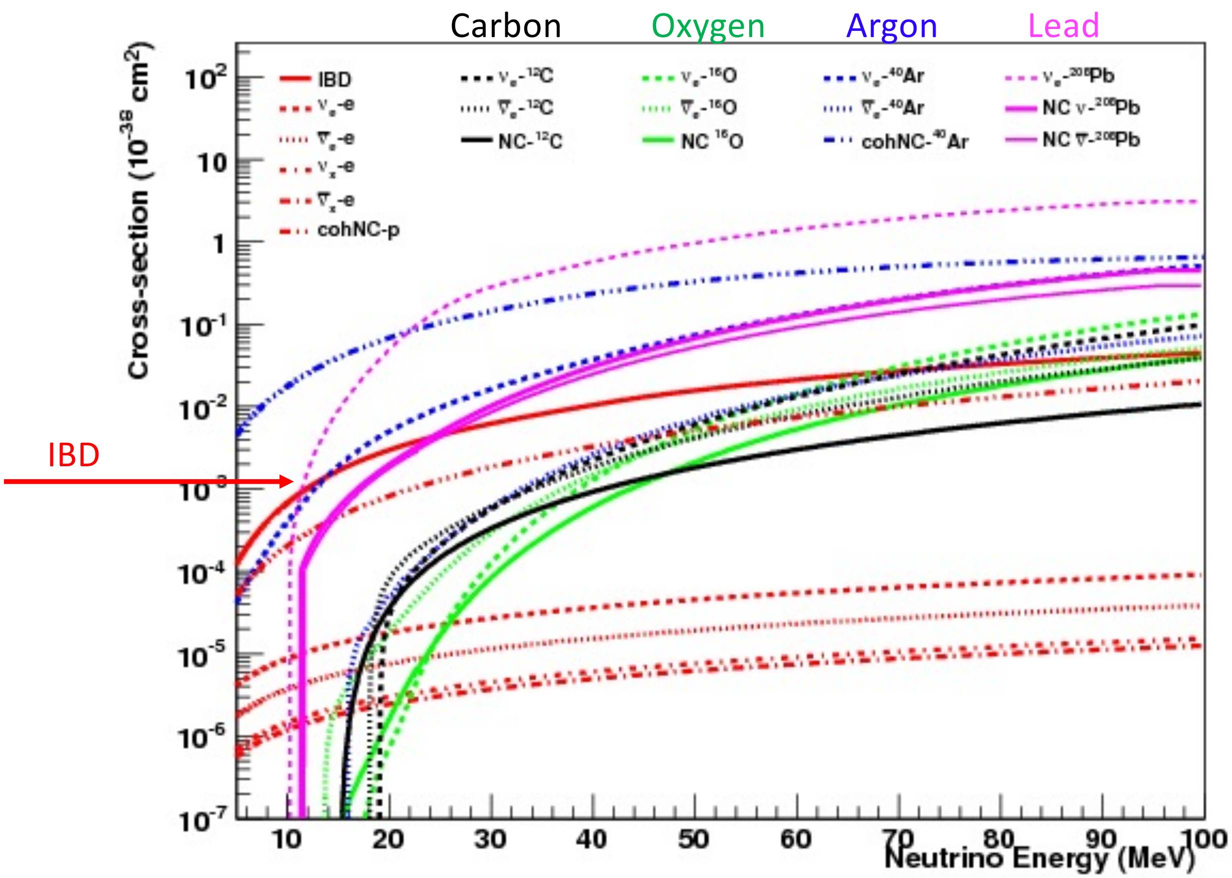
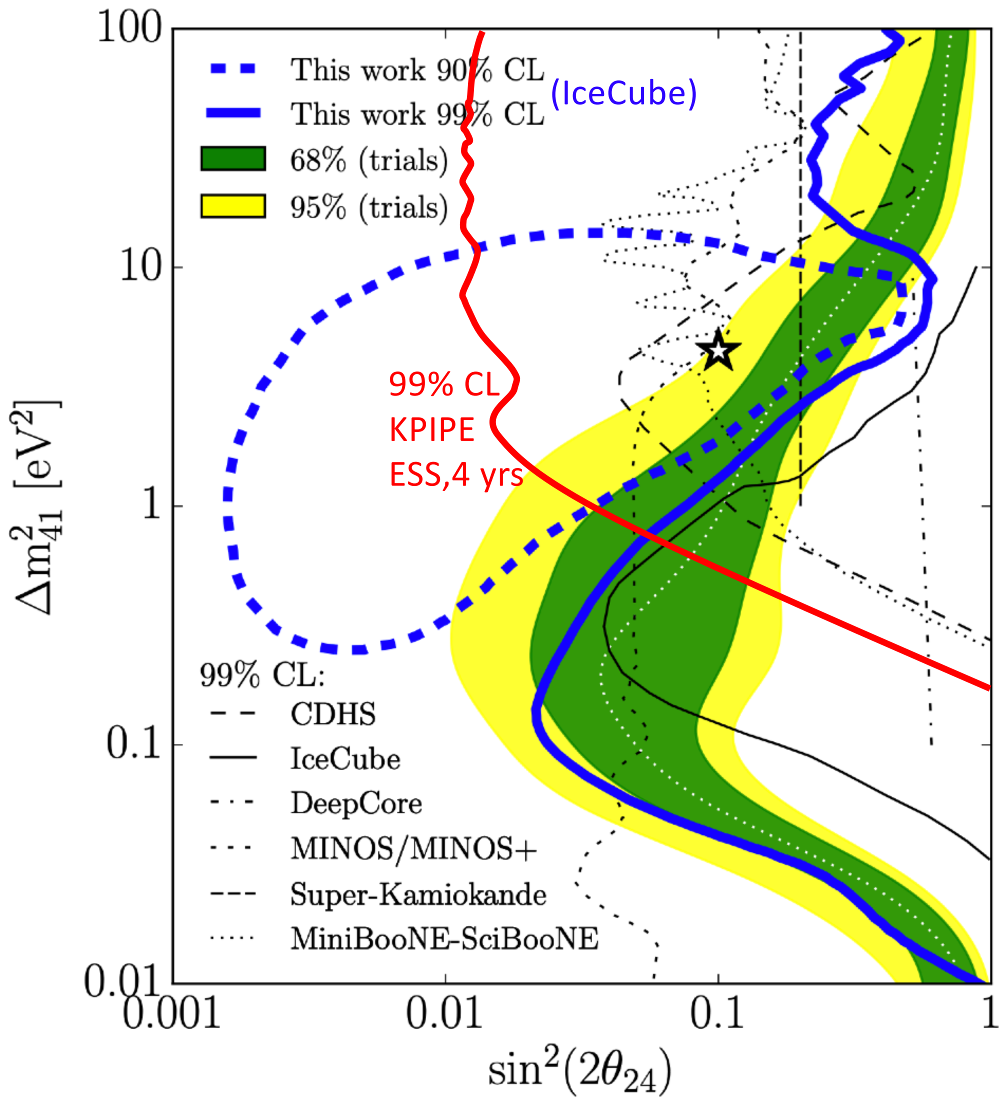
There are many other materials used for detectors!
But many cross sections are poorly known.

Materials commonly used in Supernova detection:



NC (solid) and CC ν_e (dashed) scattering from nuclei

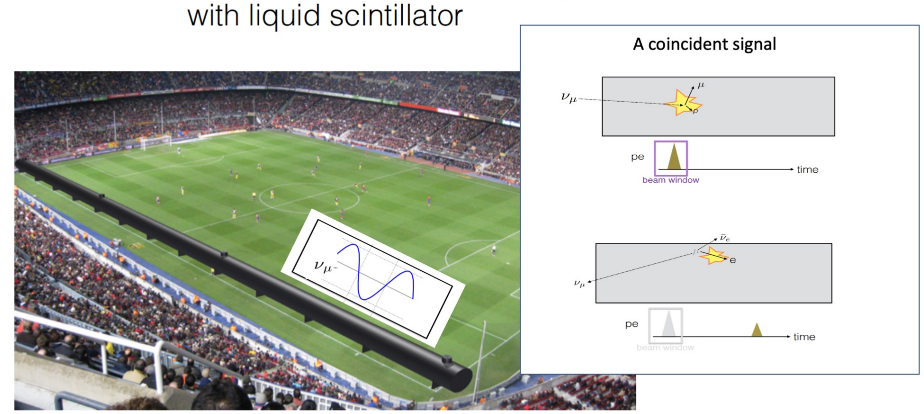
Scattering from electrons



The KDAR Flux offers unique new programs

Example: "KPIPE"
A search for muon neutrino disappearance
with a monenergetic neutrino

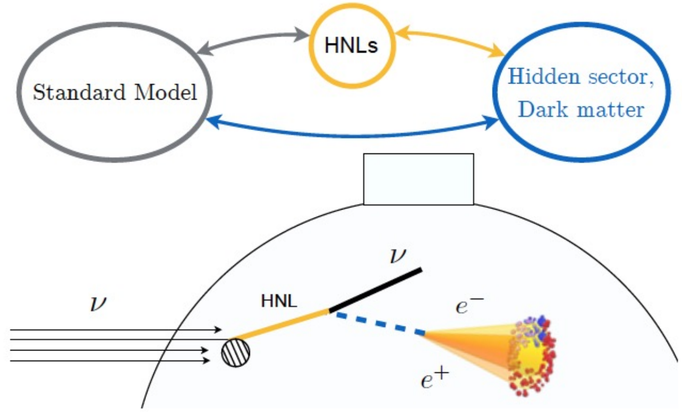
A (BIG) pipe, 3 m diameter and 120 m long, filled with liquid scintillator



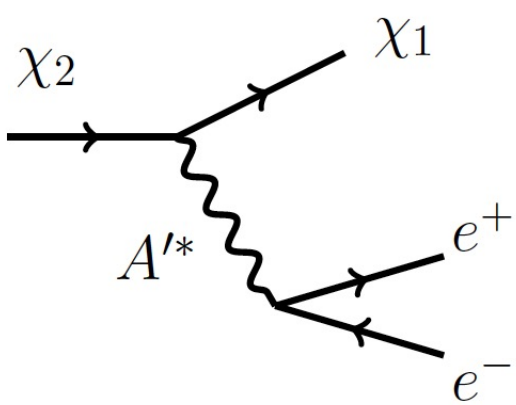
Adapted from https://arxiv.org/abs/2005.12942

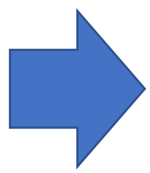
Testing
Many new models for
Heavy Neutral Leptons/
Dark photons

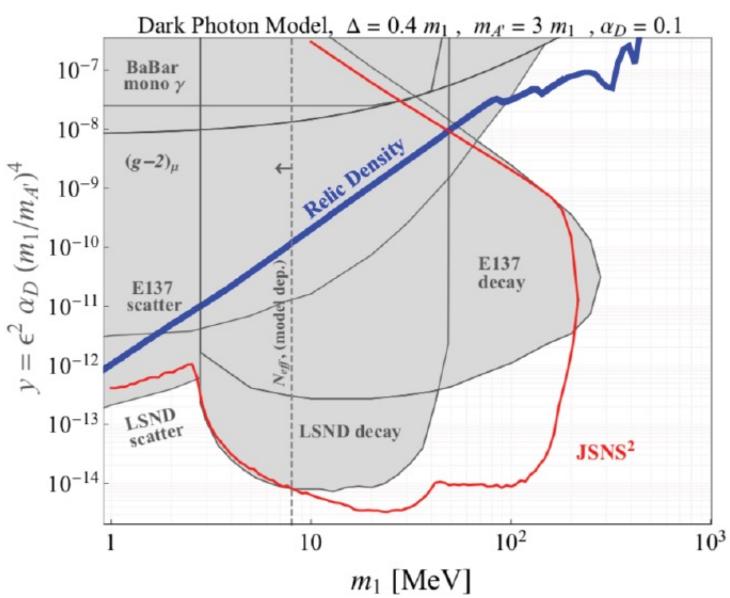
C. Arguelles, M. Hostert, Y. Tsai, PhysRevLett. 123, 261801 (2019)



ESS will have sensitivity to models that can explain the MiniBooNE Excess







ESS has greater reach due to More than twice the power and more space for an optimized detector!

Jordan,Kahn,Krnjaic,Moschella,Spitz, https://arxiv.org/abs/ 1806.05185

Take aways: The ESS DAR Program Offers

Interesting and timely physics: SBL oscillations, cross sections, dark photons, **BSM tests through CEνENS** and neutrino-electron scattering... More!

ESS is a unique opportunity for those interested in decay-at-rest sources. It wins on power, energy, ability to optimize the neutrino production.

The DAR program is also a unique opportunity for ESS to start-up the neutrino program quickly.

It is a real opportunity, all around.

Thank you!

Back ups

Thank you to Juan Collar,   Francesc Monrabal and JJ Gomez Cadenas
For thier inputs/plots on the coherent scattering program

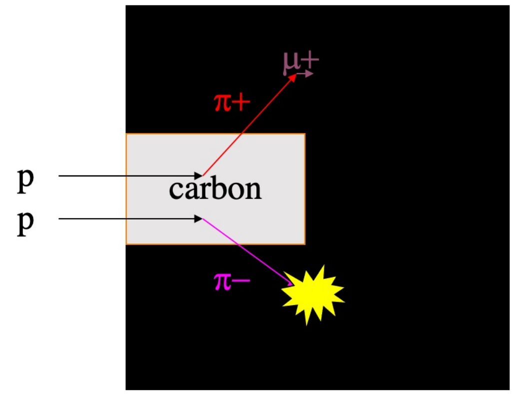
Spallation sources produce neutrons on purpose,
And are not designed to be very efficient neutrino sources!

→ *Optimizing against neutrons at a dedicated target site will give ESS* ***additional flux compared to competitors***

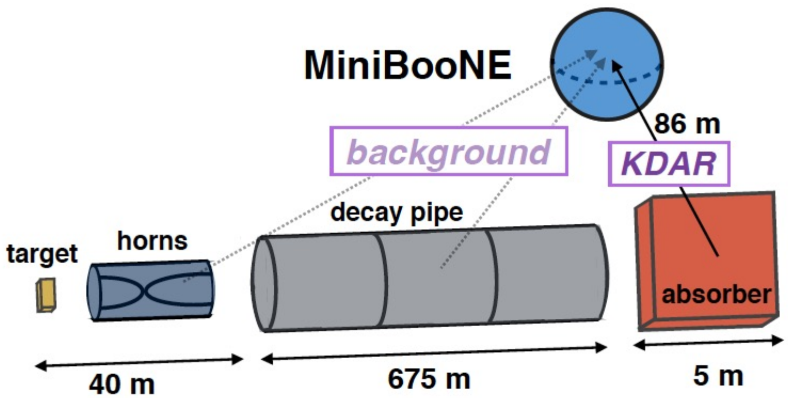
A good DAR target will:

- Minimize neutron production-- wastes beam energy!
- Shield for neutron backgrounds
- Maximize $\pi-$ capture

Use a light target (C, H_2O)
embedded in a heavy target

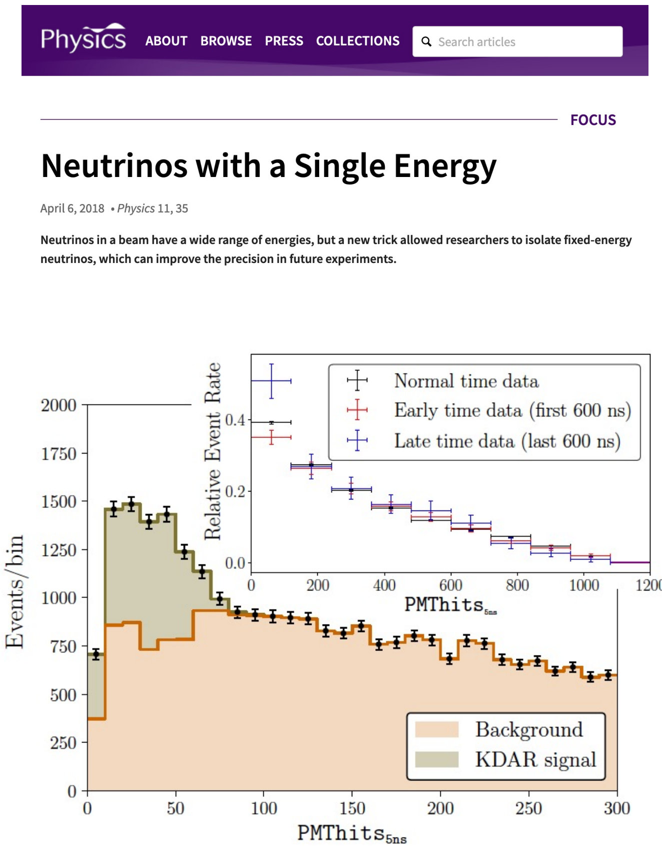


KDAR 236 MeV ν_μ interactions have been seen at MiniBooNE!



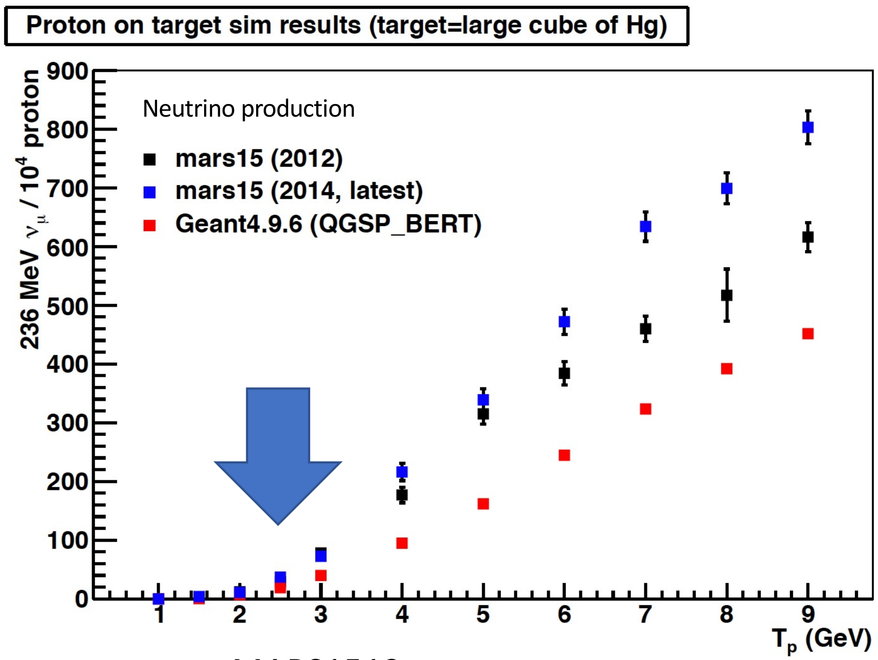
An example of why running
With DIF as well as DAR is painful

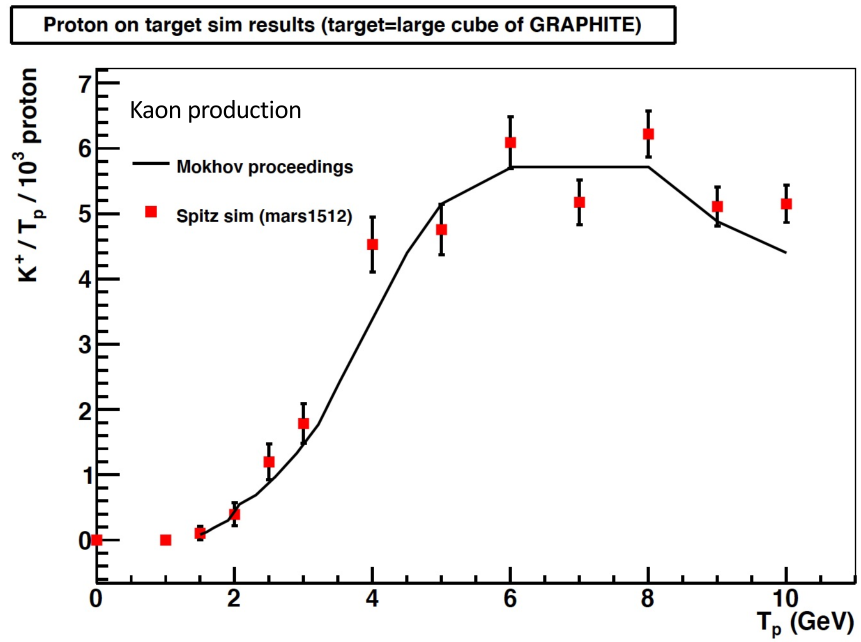
https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.120.141802



MLF vs ESS and thoughts on KDAR rates

MLF is running at 3 GeV protons on target. The ESS plan is for 2.5 GeV protons.
The reduced energy causes ~x2 reduction of the KDAR rate:





MARS1512:
34 KDAR numu per 10000 POT.

Geant4.9.6 (QGSP_BERT):
20 KDAR numu per 10000 POT

Large differences in absolute
Predicted rate!
Needs further study is absolute rate must be known well.
(this should be able to be greatly improved!)