Towards the Experimental Observation of Neutrino Nucleus Coherent Scattering

Vivek Sharma

On behalf of TEXONO Collaboration

Institute of Physics, Academia Sinica, Taiwan
Banaras Hindu University, Varanasi, India

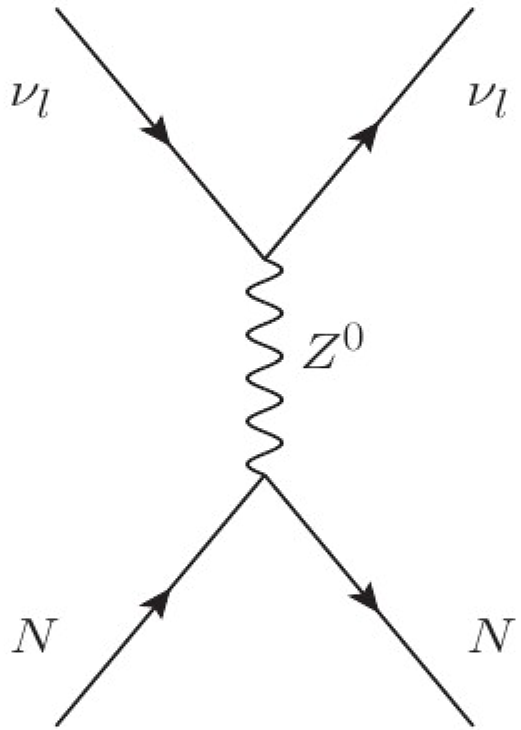
Outline of Talk ..

- Introduction.
- Neutrino Sources.
- Global Status on CENNS.
- TEXONO Facilities.
- CENNS at KSNL.
- Background and Threshold.
- Sensitivity of Experiment.
- Summary.

Coherent Neutrino-Nucleus Scattering

A neutrino interacts with a nucleus of neutron number "N" via exchange of Z - Boson.

$$\nu + N \longrightarrow \nu + N$$



$$\frac{d\sigma_{\nu A_{el}}}{dq^2}(q^2, E_\nu) = \frac{1}{2}\left[\frac{G_F^2}{4\pi}\right]\left[1 - \frac{q^2}{4E_\nu^2}\right][\varepsilon Z - N]^2 F(q^2)$$

Where G_F is fermi constant, E_ν is incident neutrino energy, Z(N) is Atomic(Neutron) number of nuclei and q is three momentum transfer.

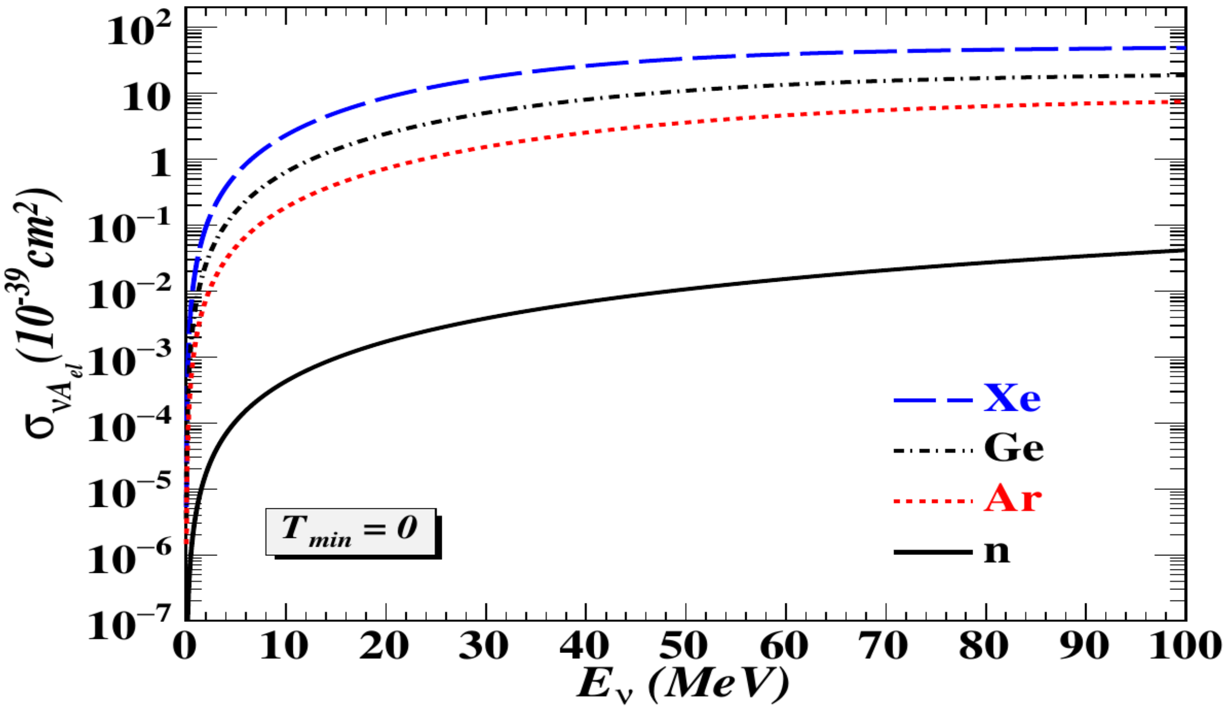
$F(q^2)$ is nuclear form factor approaches to ~1 at small momentum transfer.

Coherent Neutrino-Nucleus Scattering

Total Cross-Section of CENNS:

$$\sigma_{\nu A_{el}} = \int_{q^2_{min}}^{q^2_{max}} \left[\frac{d\sigma_{\nu A_{el}}}{dq^2}(q^2, E_\nu)\right] dq^2$$

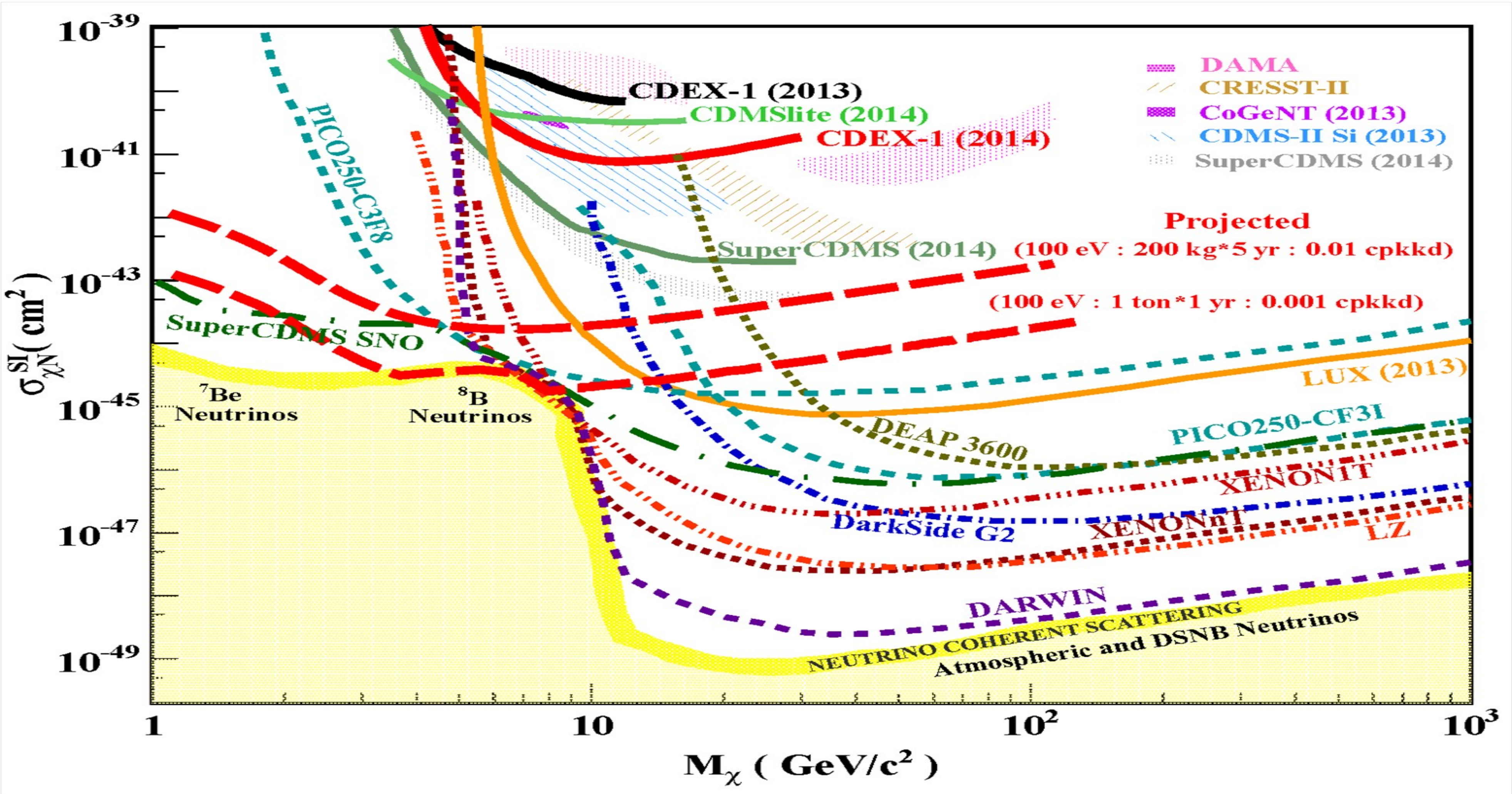
$$\sigma_{\rm tot} = \frac{G_F^2 E_\nu^2}{4\pi}[Z(1 - 4\sin^2\theta_W) - N]^2$$



Heavier nuclei ⟶ larger cross-section

- This process is coherent upto ~<50 MeV neutrino
- Cross-section is well-defined in Standard Model.
- Not been observed experimentally.

Spin-Independent Dark Matter Search and Irreducible Background



Necessary to Study the irreducible NNCS background for Dark matter search.

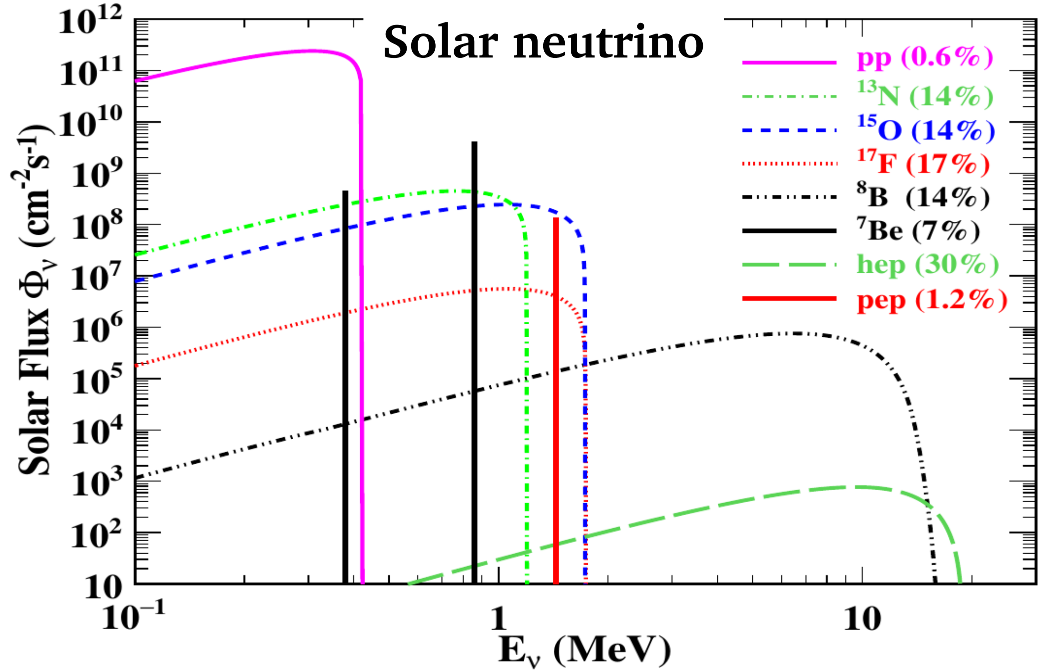
Requirements to observe CENNS

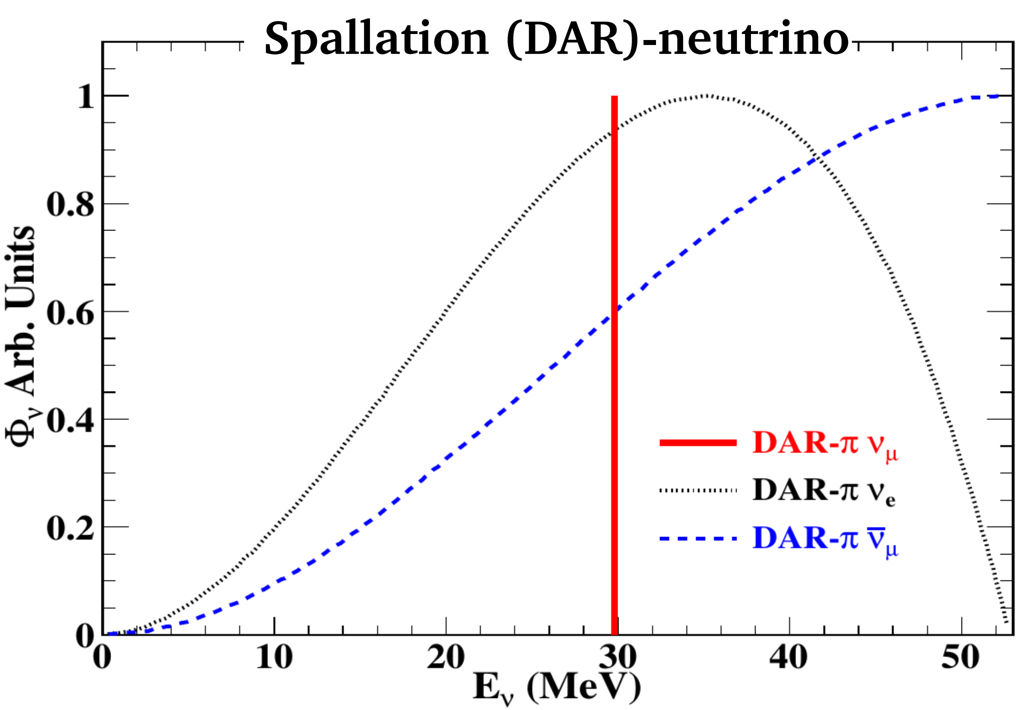
- **High Neutrino Flux**
- **Lower Threshold**
- **Better Resolution**
- **Quenching Factor**
- **Understanding of Background**
- **Better Shielding from Gamma, Neutrons etc..**
- **Sufficient Source On/Off Statistics**

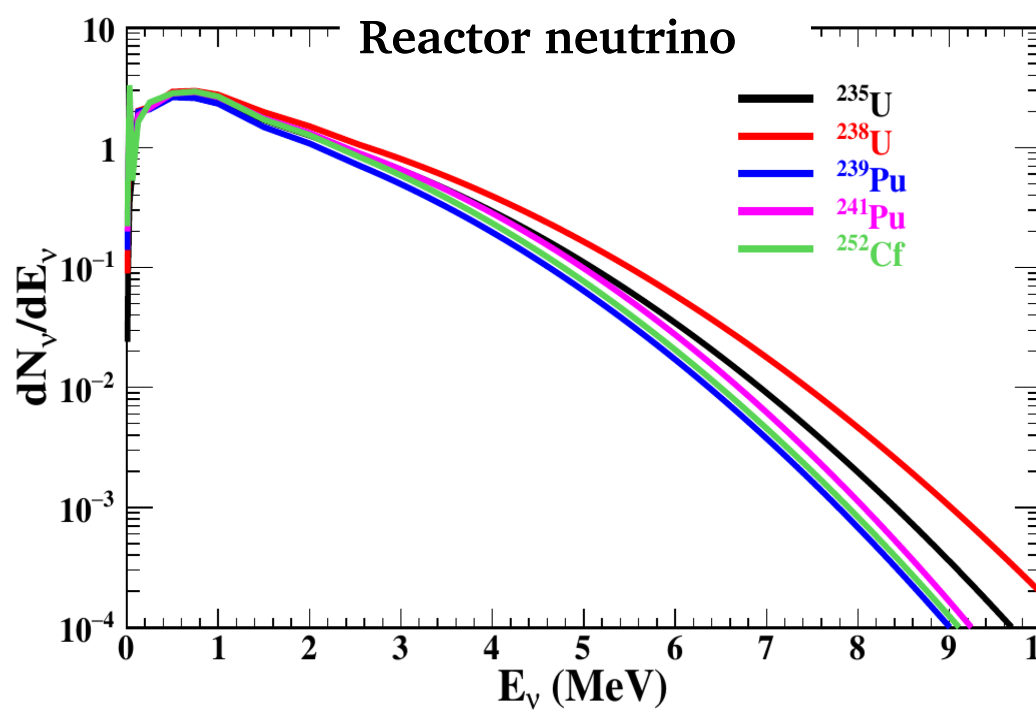
Neutrino Sources for CENNS

Promising Neutrino Sources:

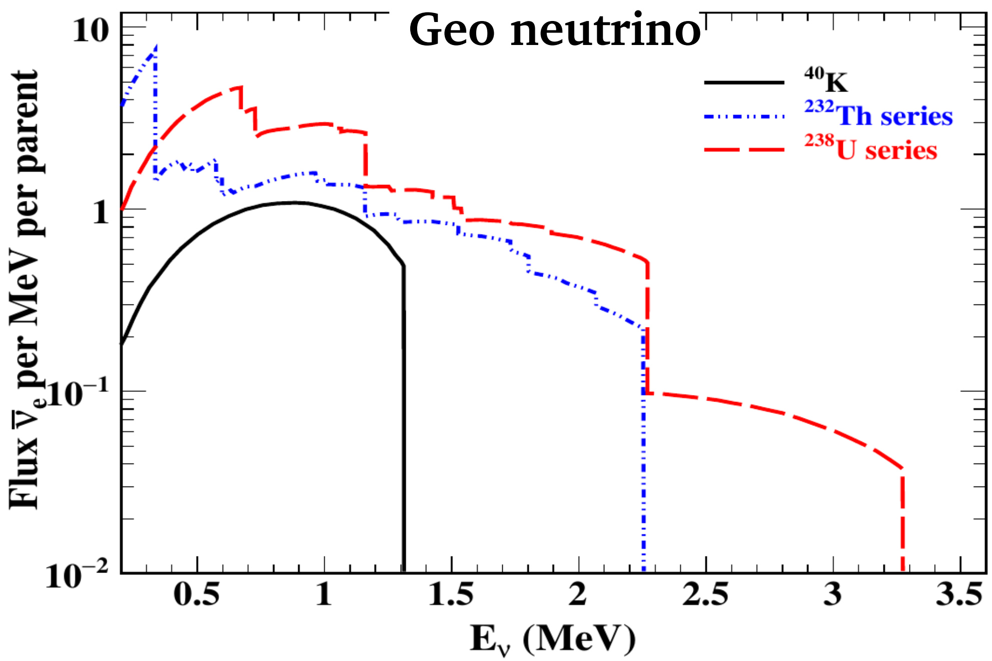
- Solar Neutrinos.
- Spallation Neutrinos.
- Reactor Neutrinos.

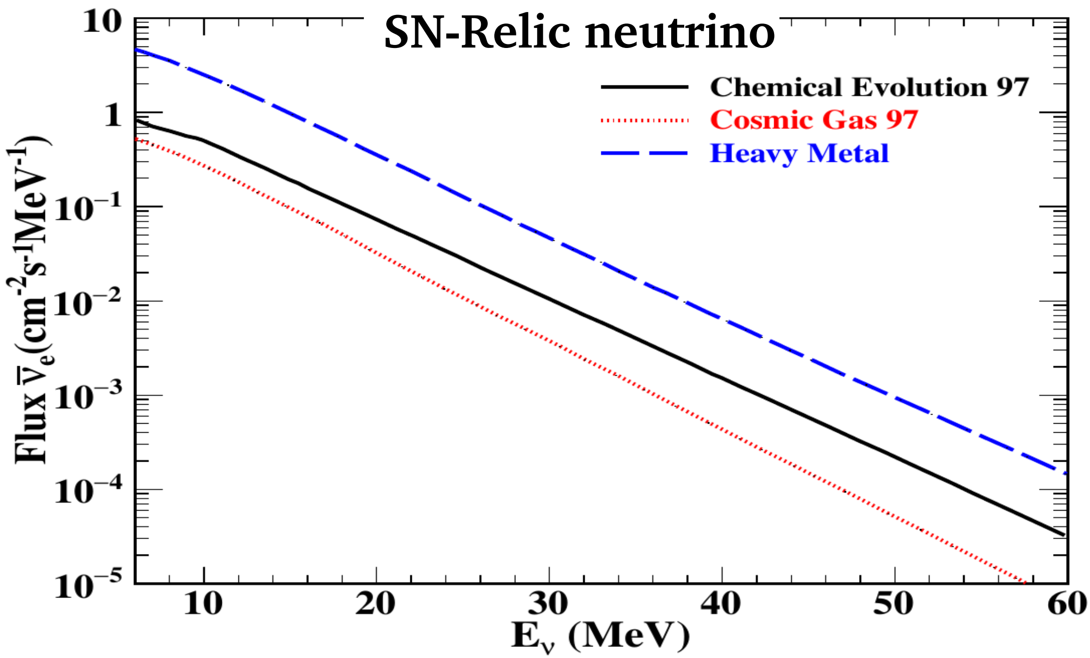






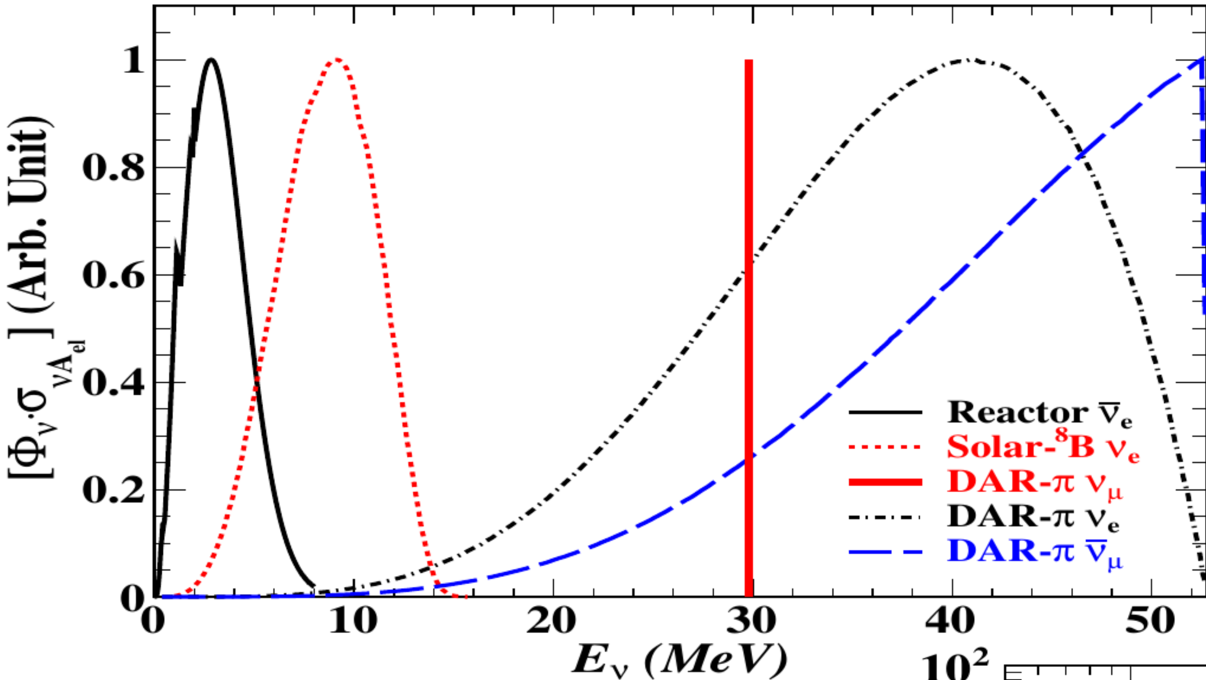
Other low Intensity Neutrino Sources





Neutrino Source	Reactor	DAR	Solar	Geo	SN-Relic
Flux	~2 × 10^{17} s^{-1} per MW	~10^{15} s^{-1}	~2.7 × 10^6 cm^{-2}s^{-1} (^{8}B)	~10^6 cm^{-2}s^{-1}	~10^2 ν_e cm^{-2}s^{-1} >16 MeV
Pros. Cons.	Huge and Pure neutrino Flux, Few MeV	Various flavors, ν-like backgrounds	Small flux	Small flux	Small flux

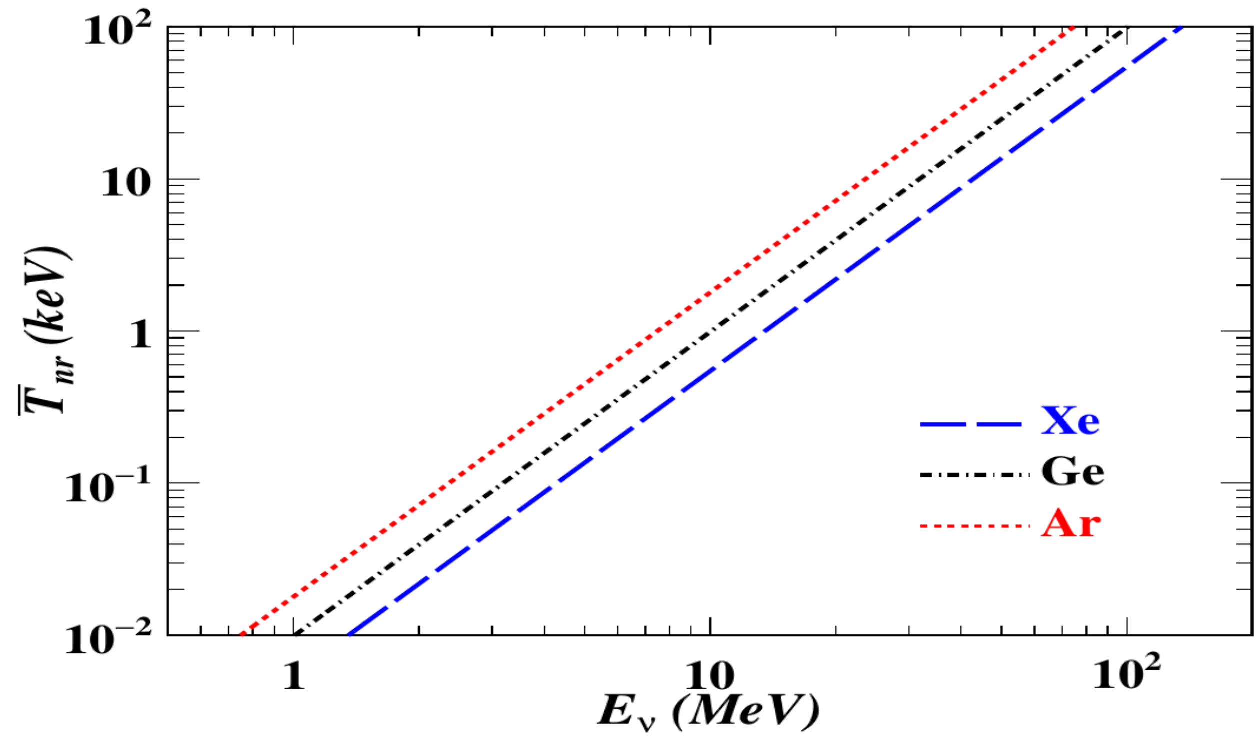
Experimental approach towards CENNS



The weightage region to probe CENNS can be predicted by $[\Phi_\nu \cdot \sigma_{\nu Ael}]$ Plot for various neutrino sources.

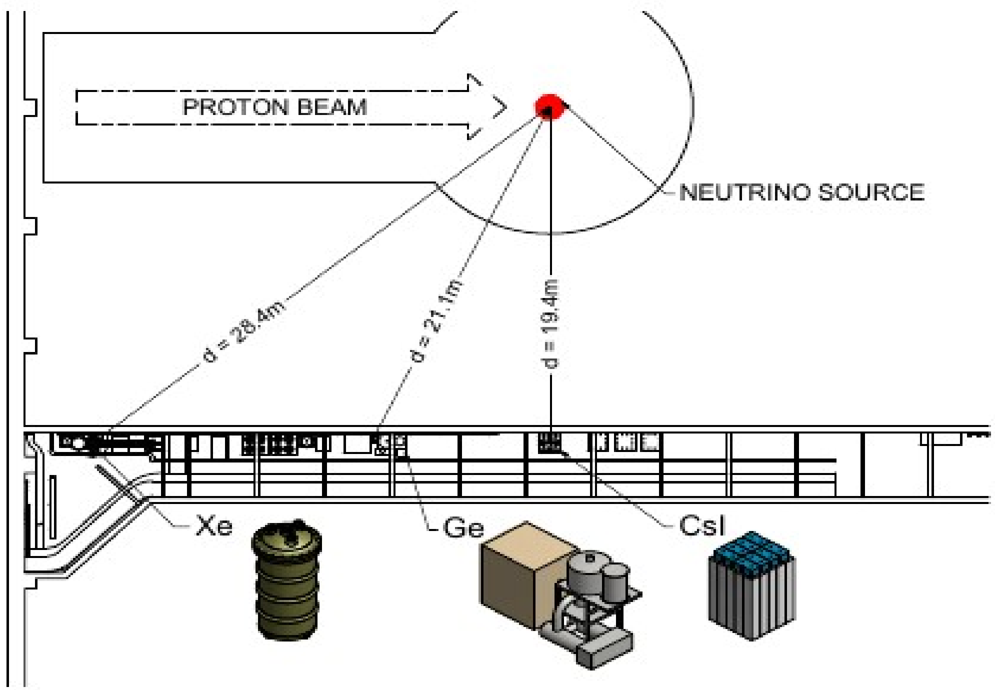
Averaged nuclear recoil for CENNS interaction:

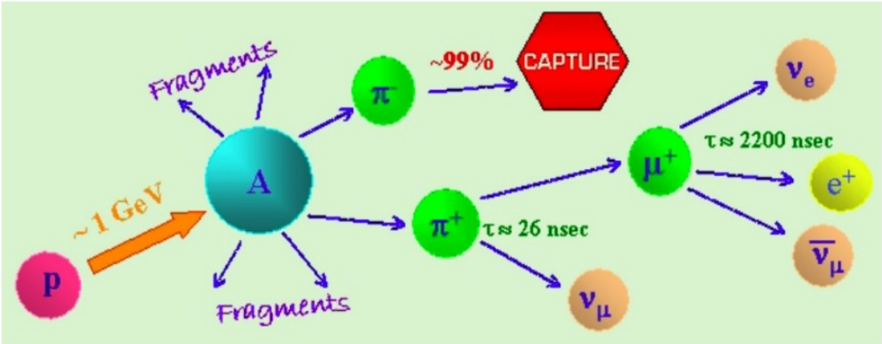
$$\bar{T}_{nr} = \frac{2}{3} T_{max} \simeq \frac{2E_\nu^2}{3M}$$



COHERENT at SNS (ORNL)

- 10^{14} proton of energy ~1 GeV are bombarded in bunches with 700 ns wide bursts.
- Beam is used to bombard on liquid mercury target with 60 Hz POT frequency.
- As a by product neutrinos with a flux ~ 2e+07 $cm^{-1}s^{-1}$ is produced at 20 m from spallation target.





$$\pi^+ \to \mu^+ + \nu_\mu \ , \qquad \mu^+ \to e^+ + \nu_e + \overline{\nu}_\mu$$

ArXiv: 1509.08702v1, sept 2015

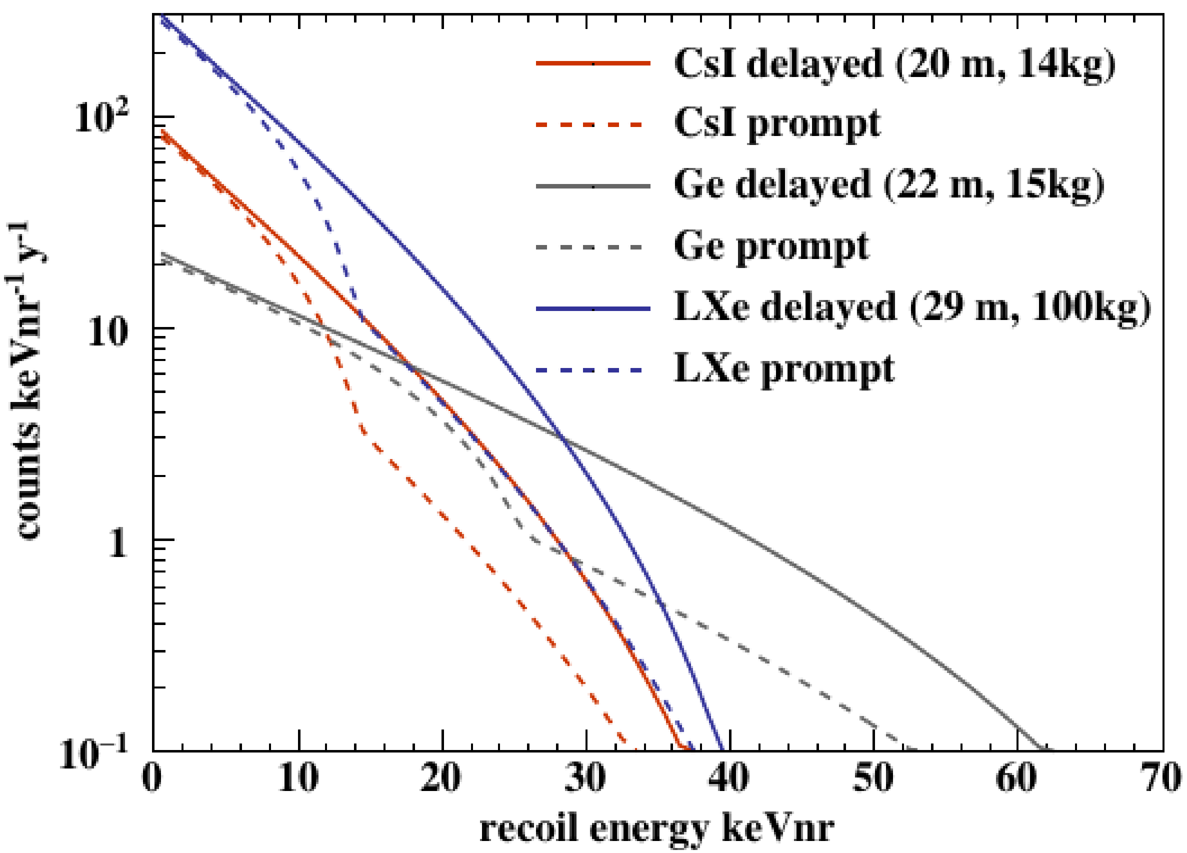
Neutrino Signal at SNS (ORNL)

ν-N Scattering Counts in a detector :

Differential:
$$\frac{dR_{\nu N}}{dT} = \rho_{nucleus} \int_{E_\nu} \frac{d\sigma_{\nu N}}{dT} \frac{d\phi}{dE_\nu} dE_\nu$$

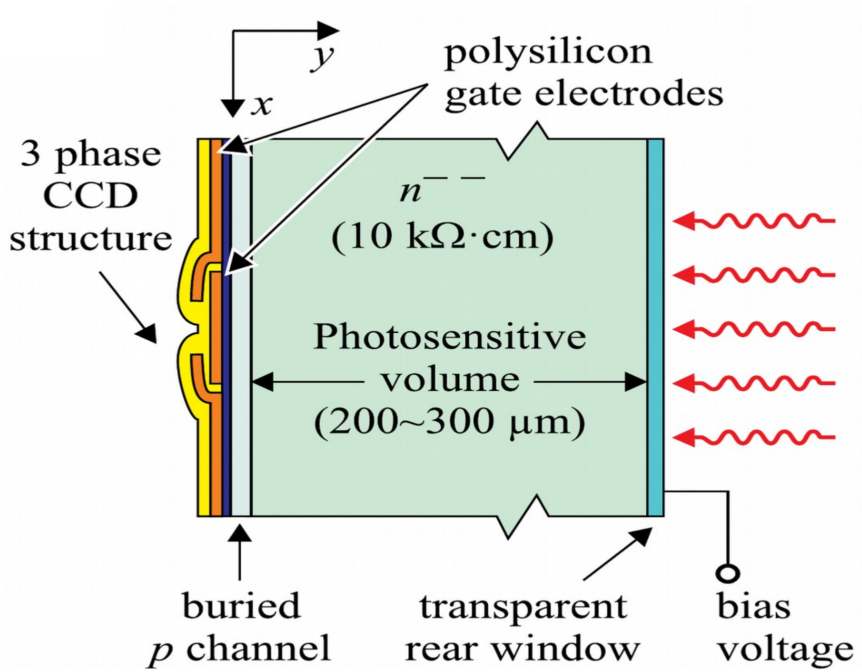
Total:
$$N_{events} = t \times \phi_\nu \times N_{nuclei} \int_{E_{min}}^{E_{max}} dE_\nu \int_{T_{thrd}}^{T_{max}} \lambda(E_\nu) \frac{d\sigma_{\nu A_{el}}}{dT}(E_\nu, T) dT$$

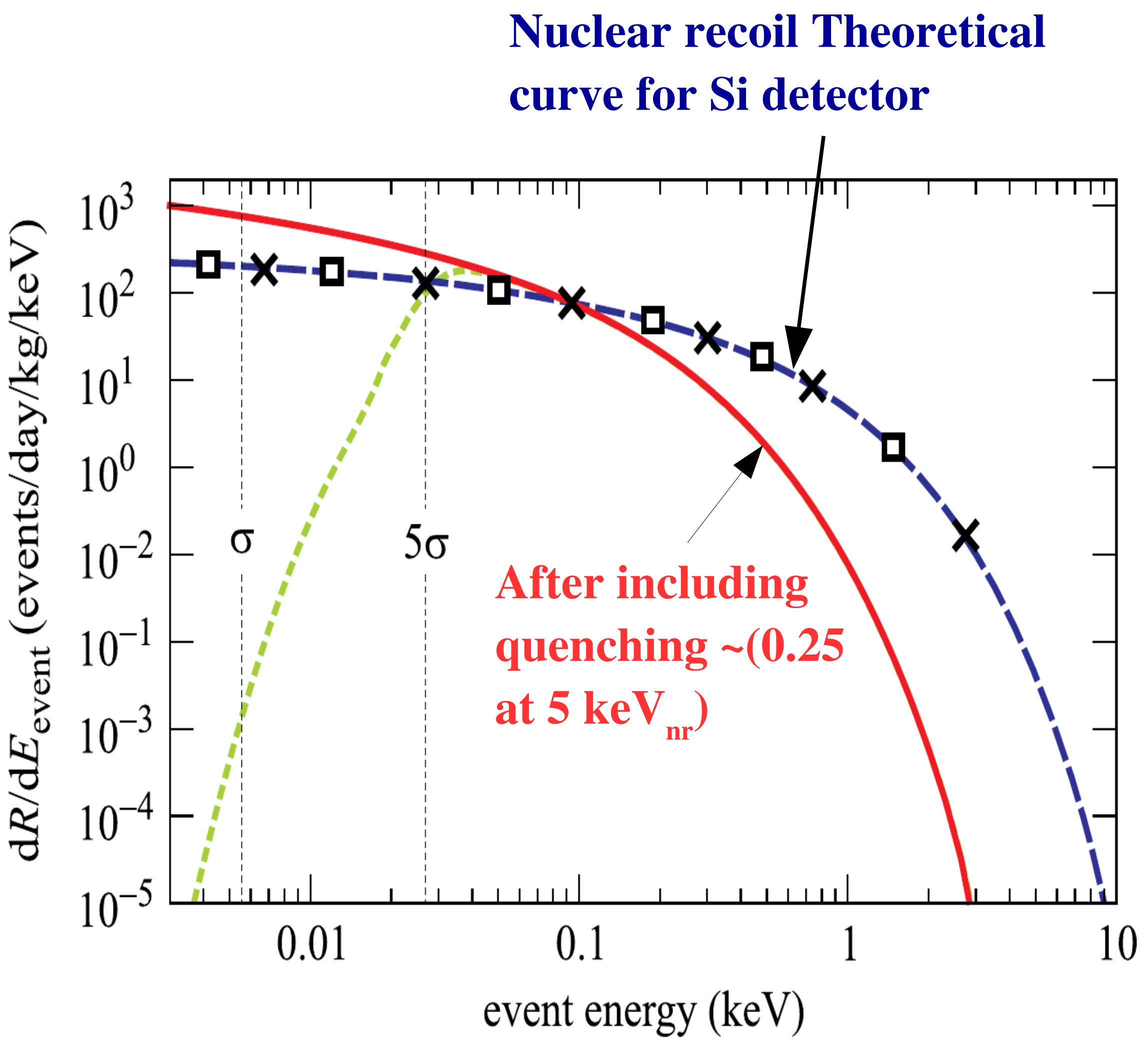
where, t is exposure time, N_{nuclei} is number of target nuclei, Φ_ν is neutrino flux, E_ν is incident neutrino energy and T is nuclear recoil energy



Other CENNS Experiments

CONNIE Experiment



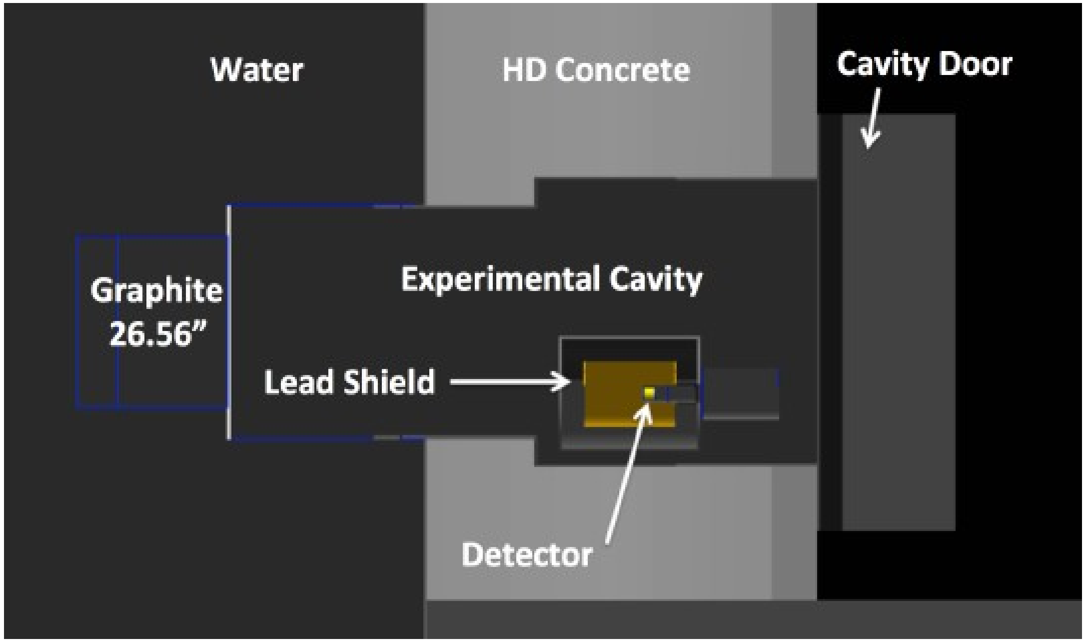


- Reactor Power = 3.95 GW
- Distance from core = 30 m
- Neutrino Flux ~ 7.8×10^{12} cm^{-2}s^{-1}
- At 0 keV threshold ~ 33 events kg^{-1}day^{-1} are expected.
- Detector mass = 5.2 g
- Net mass of prototype = 52 g

Phys. Rev. D. 91, 072001 (2015)

Other CENNS Experiments

MINER Experiment

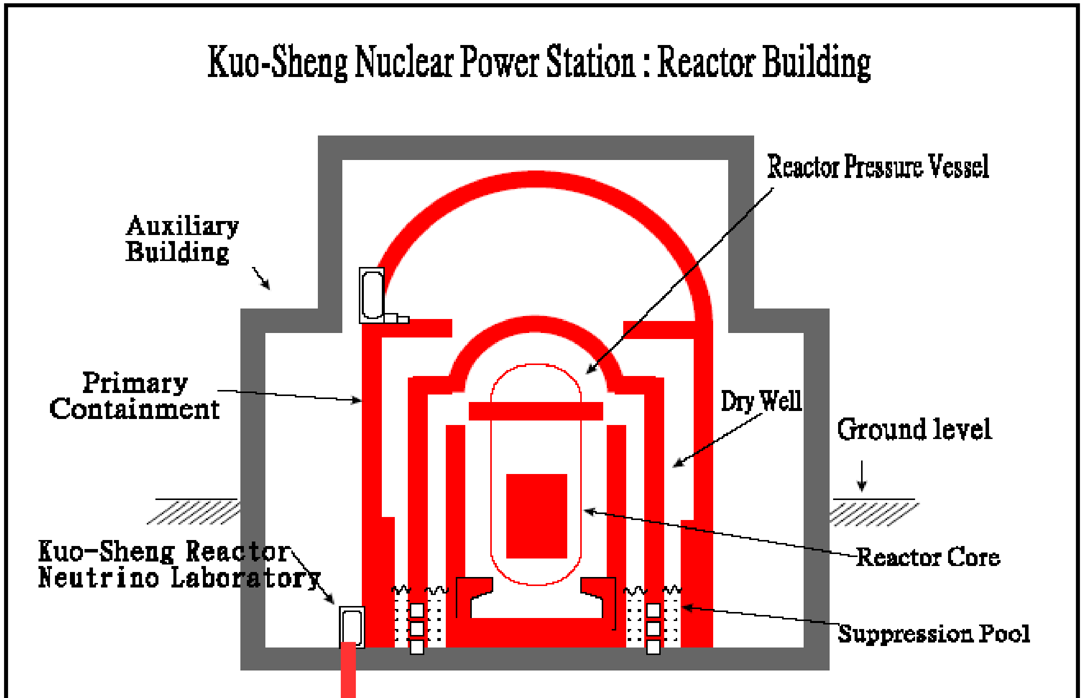


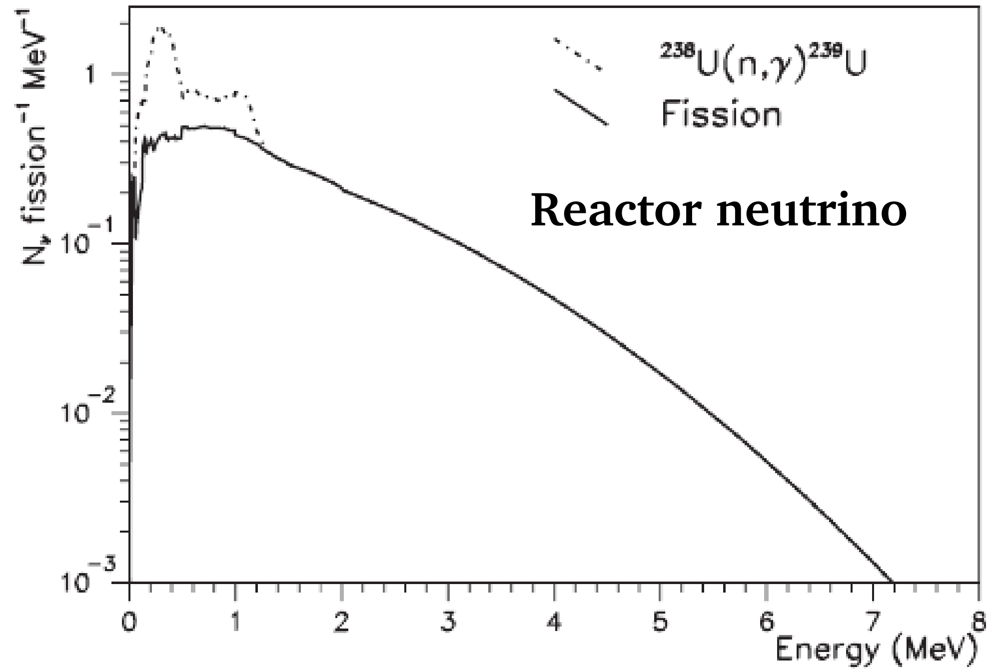
- Germanium and Silicon detectors.
- Reactor Power = 1 MW
- Distance from core = 2.3 m
- Neutrino Flux ~ 4×10^{11} cm^{-2}s^{-1}
- Huge thermal, fast neutron and gamma flux.
- Background of 100 per kg-day in 10-1000 eV$_{nr}$
- Expected count rate ~ 20 kg^{-1} day^{-1} recoil energy between 10 – 1000 keV$_{nr}$

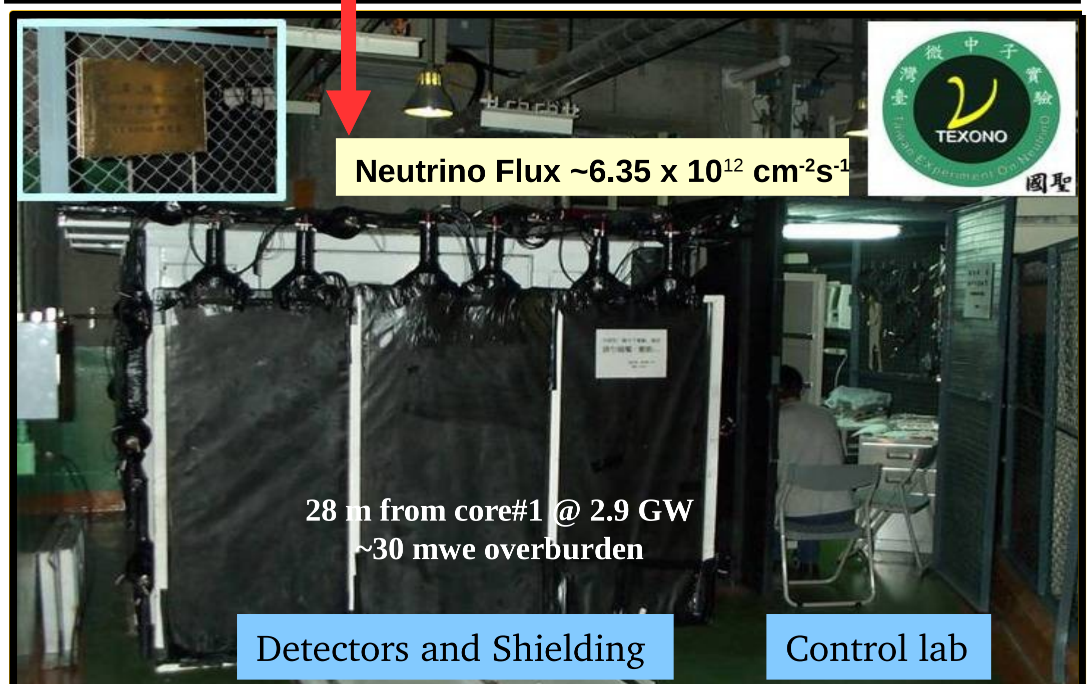
← **Experimental Cavity**

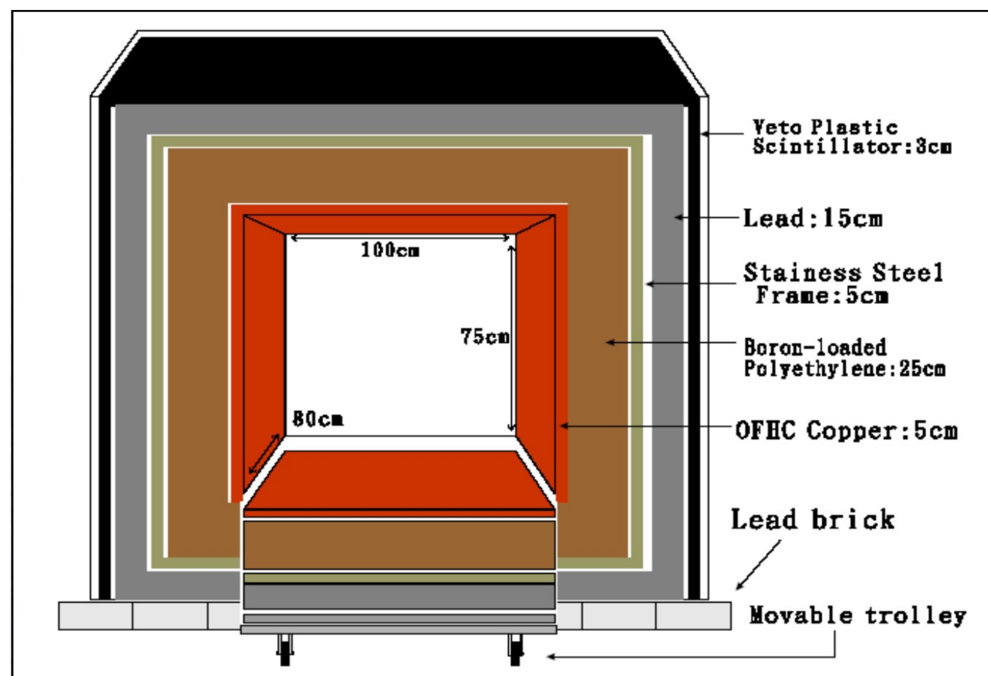
arXiv: 1609.02066v1

Kuo-Sheng Reactor Laboratory (KSNL)

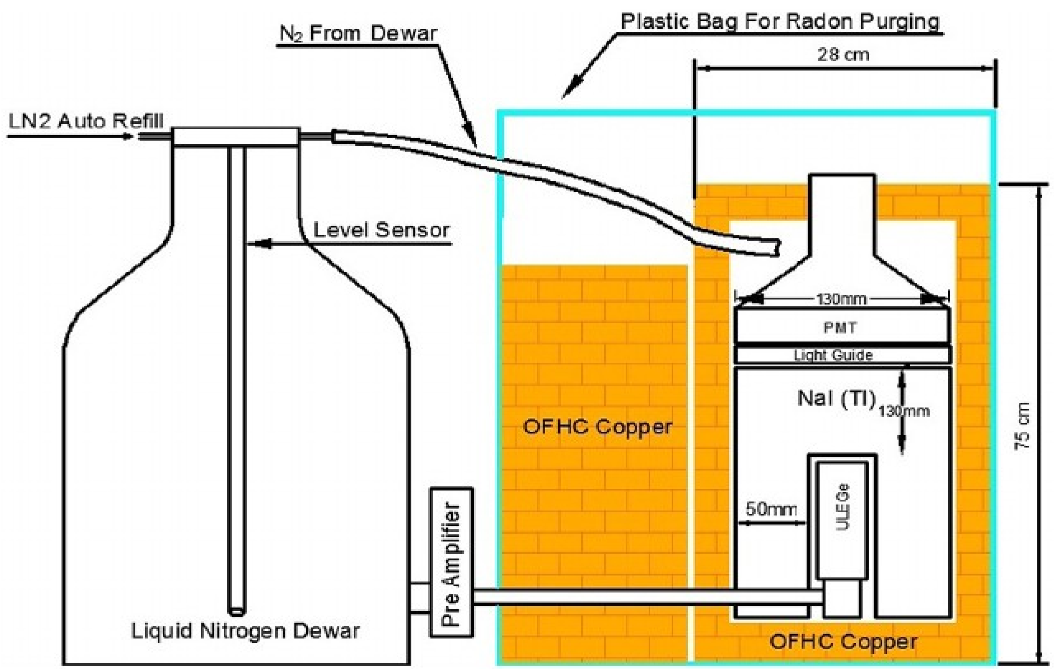


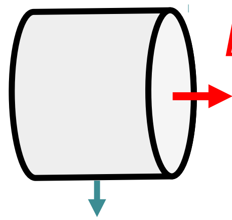


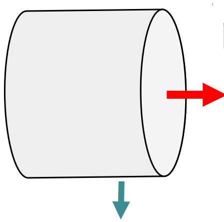


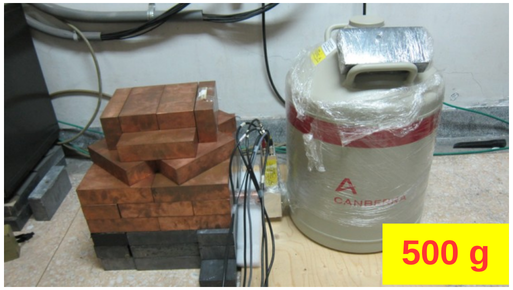


Hardware and Thresholds





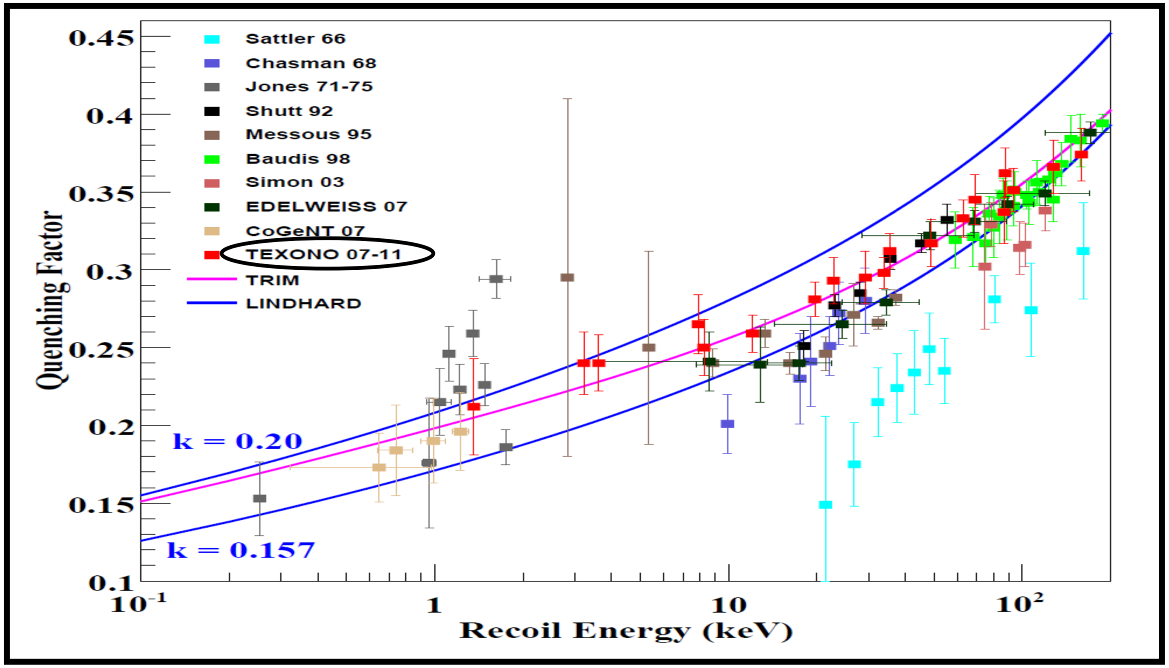


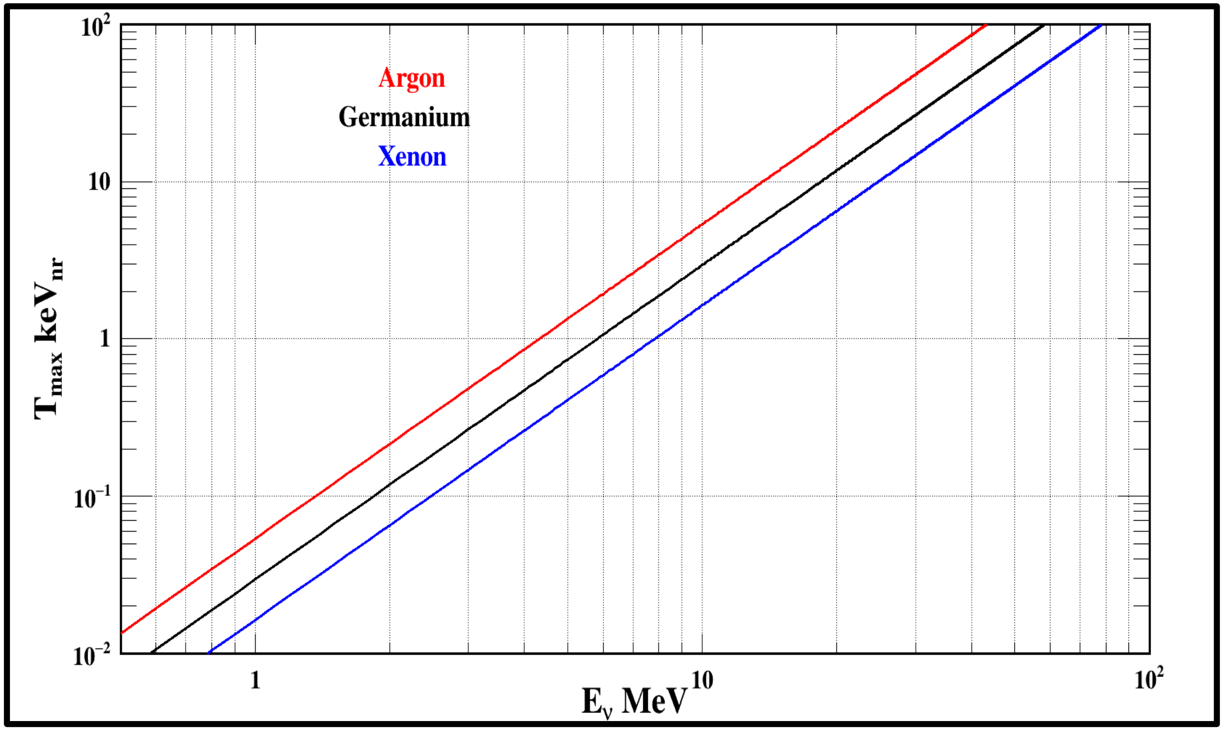


Generation	Mass (g)	Pulsar FWHM (eV_{ee})	Threshold (eV_{ee})
G1	500	130	500
G2	900	100	300
G3	1430	< 60	< 150

Quenching Factor and Recoil Energy

TRIM is used for Quenching factor, obtained from fitting on various experimental data ...





Maximum recoil energy from a given neutrino depends on the mass of target nuclei

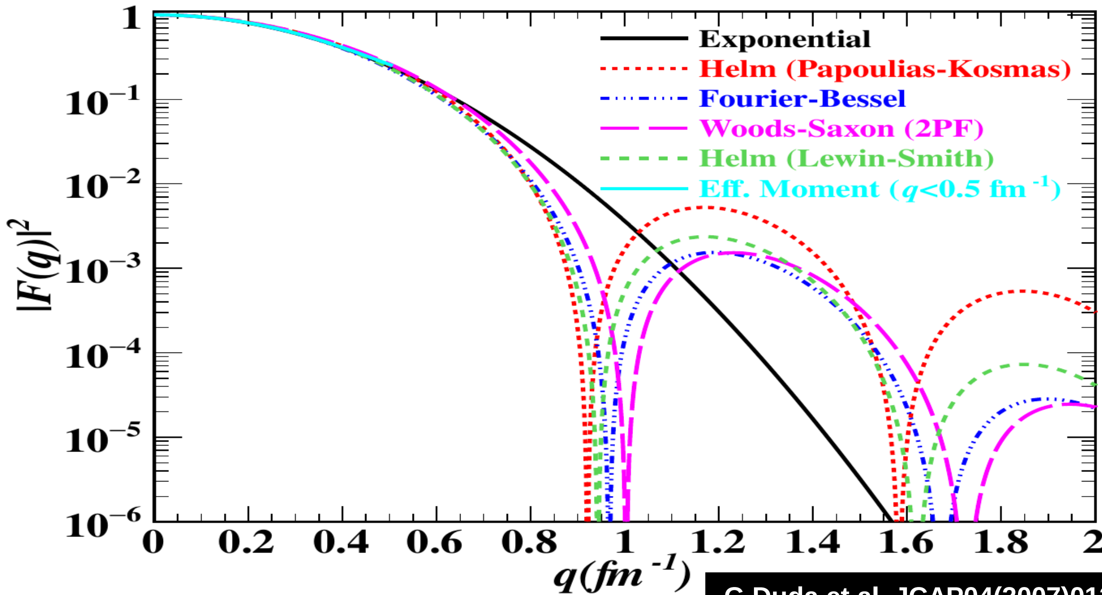
$$T_{max} = \frac{2E_\nu^2}{2E_\nu + M_N}$$

A 4 MeV neutrino gives a maximum nuclear recoil of ∼500 eVnr it corresponds to ∼ 110 eV electron equivalent energy

Form Factor..

Form-Factor is fourier transformation of Charge distribution in the nucleus:

$$F(q) = \frac{1}{A} \int \rho(r) e^{-i\mathbf{q}.\mathbf{r}} d^3 r$$



G.Duda et.al, JCAP04(2007)012

Simplest Charge Distribution Model:

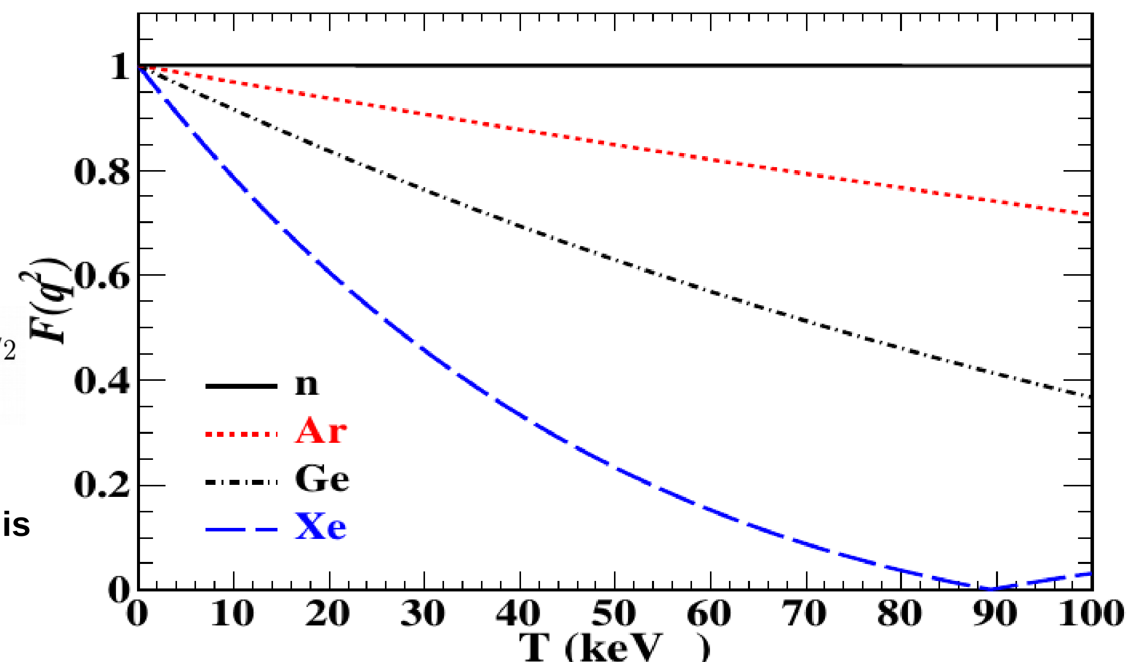
$$\rho(r) = \begin{cases} \frac{3Ze}{4\pi R^3}, & \text{for} \quad r \leq R \\ 0, & \text{for} \quad r > R \end{cases}$$

Surface Charge Distribution:

$$\rho_1(r) = \frac{1}{(2\pi s^2)^{3/2}} e^{-r^2/2s^2}$$

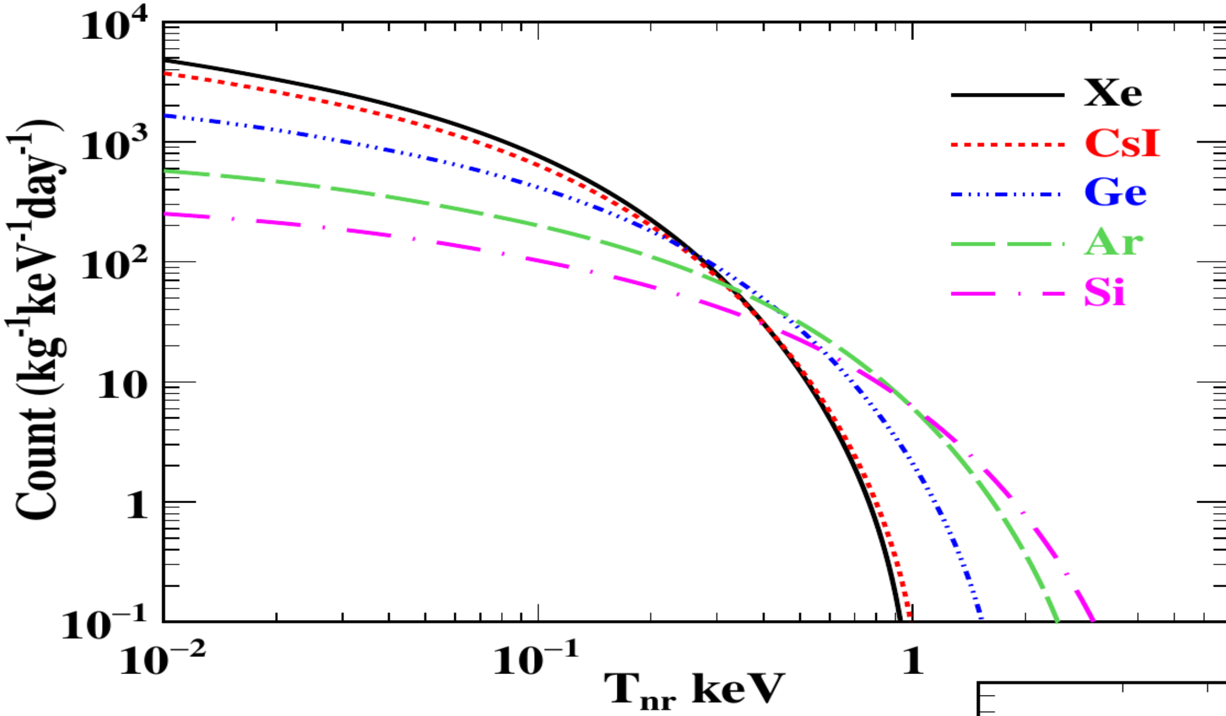
Helm Model Form-Factor:

$$F(q) = \frac{3j_1(qR)}{qR} e^{-(qs)^2/2} = 3\frac{\sin(qR) - qR\cos(qR)}{(qR)^3} e^{-(qs)^2/2}$$



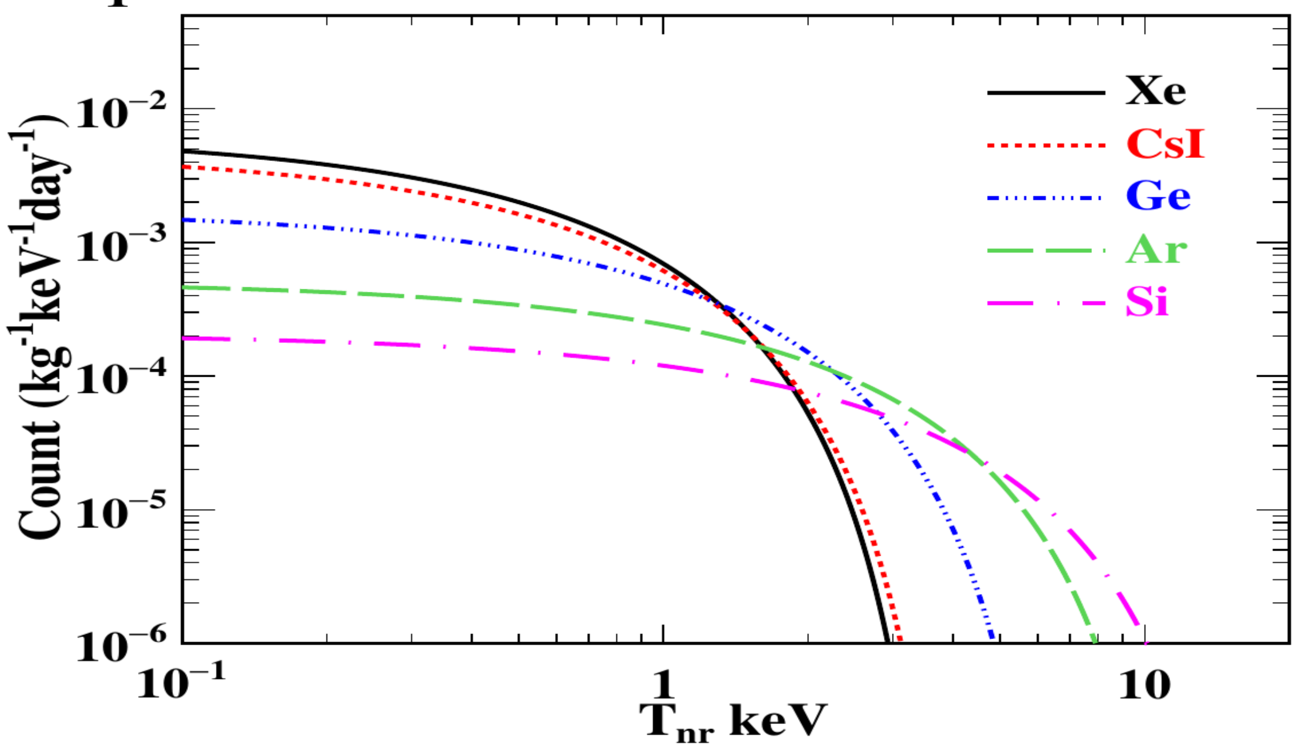
Where, j1 is the first-order spherical Bessel function, R is target nuclei radius and s is surface thickness.

CENNS at KSNL



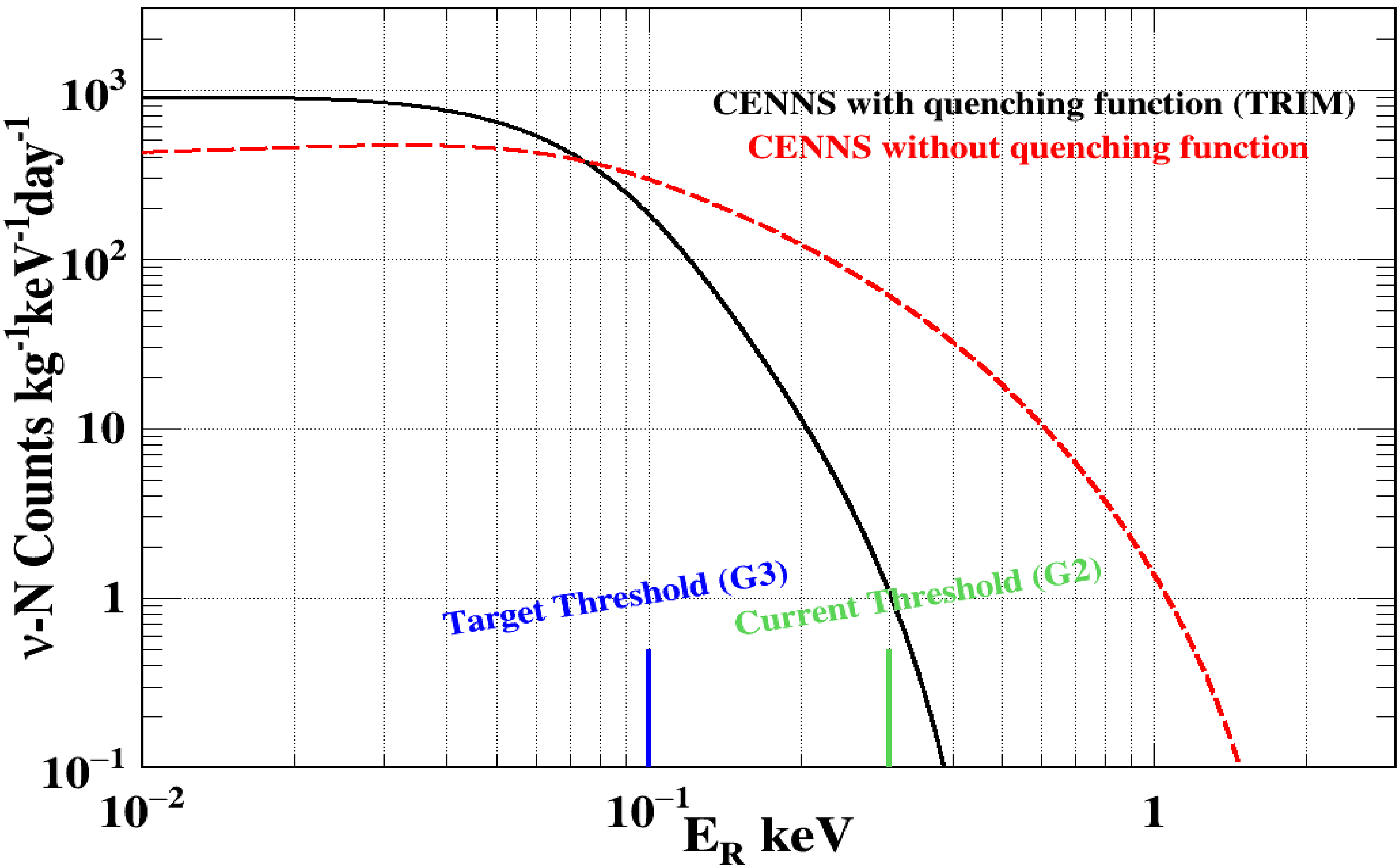
CENNS Differential rate in various detectors due to reactor neutrino

CENNS Differential rate in various detectors due to ^{8}B Solar neutrino



CENNS at KSNL with Reactor neutrino..

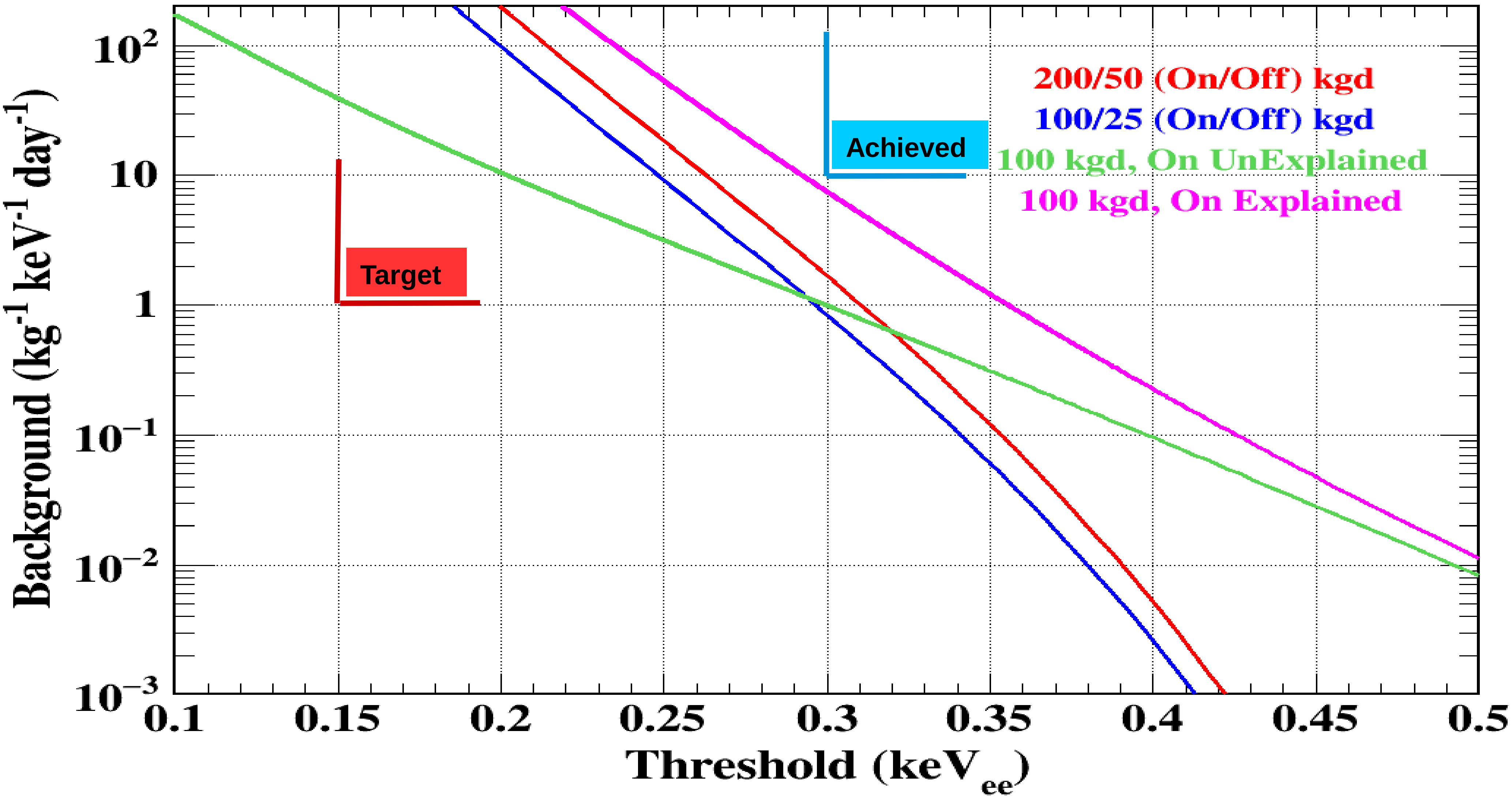
CENNS count at 300 eV is :
~1 CPKKD (Differential)
~0.03 CPKD (Integral)



Threshold and Background at KSNL

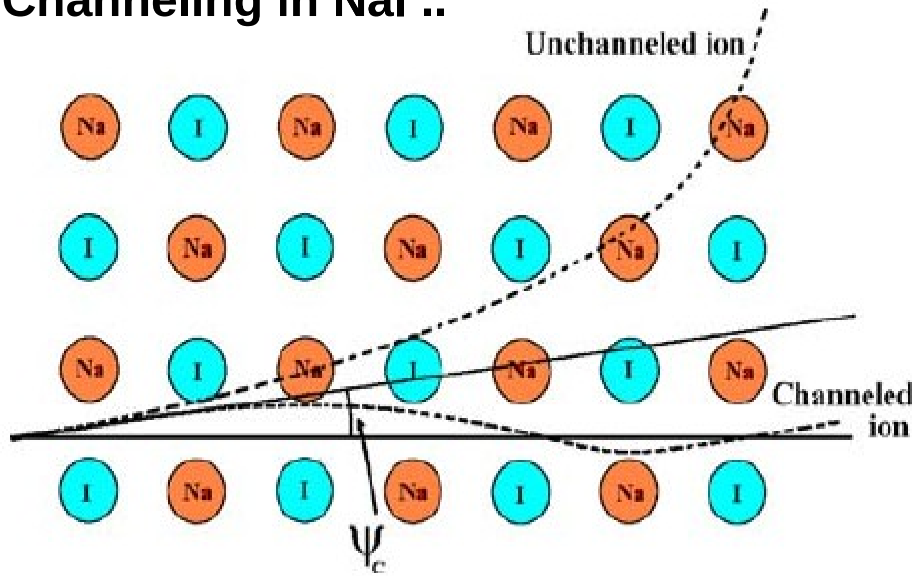
Current Status and Future Goal to Probe CENNS as predicted in Standard Model ..

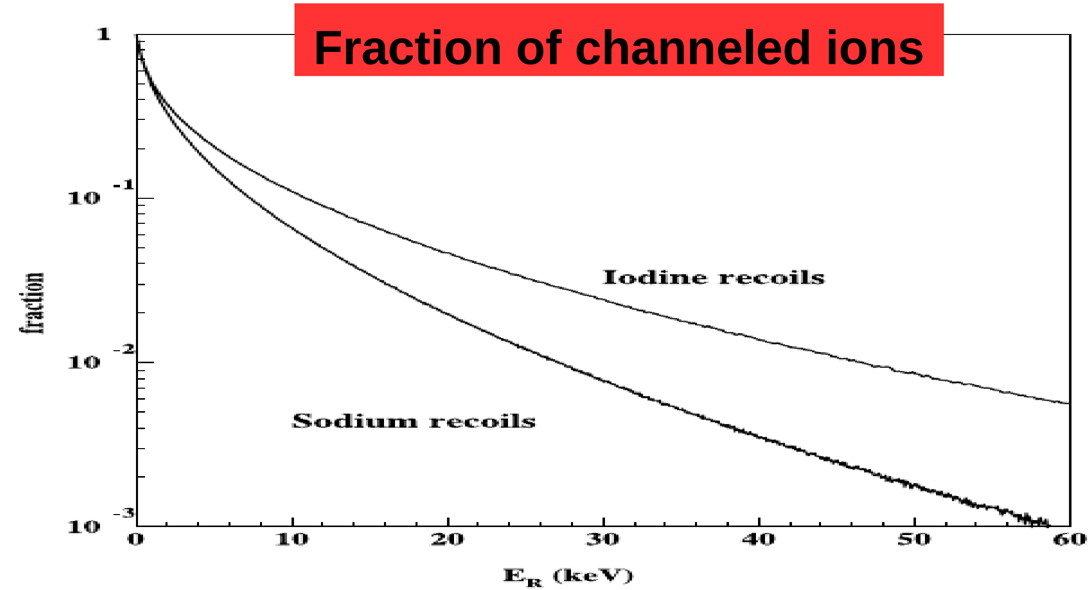
$$\nu + N \rightarrow \nu + N$$



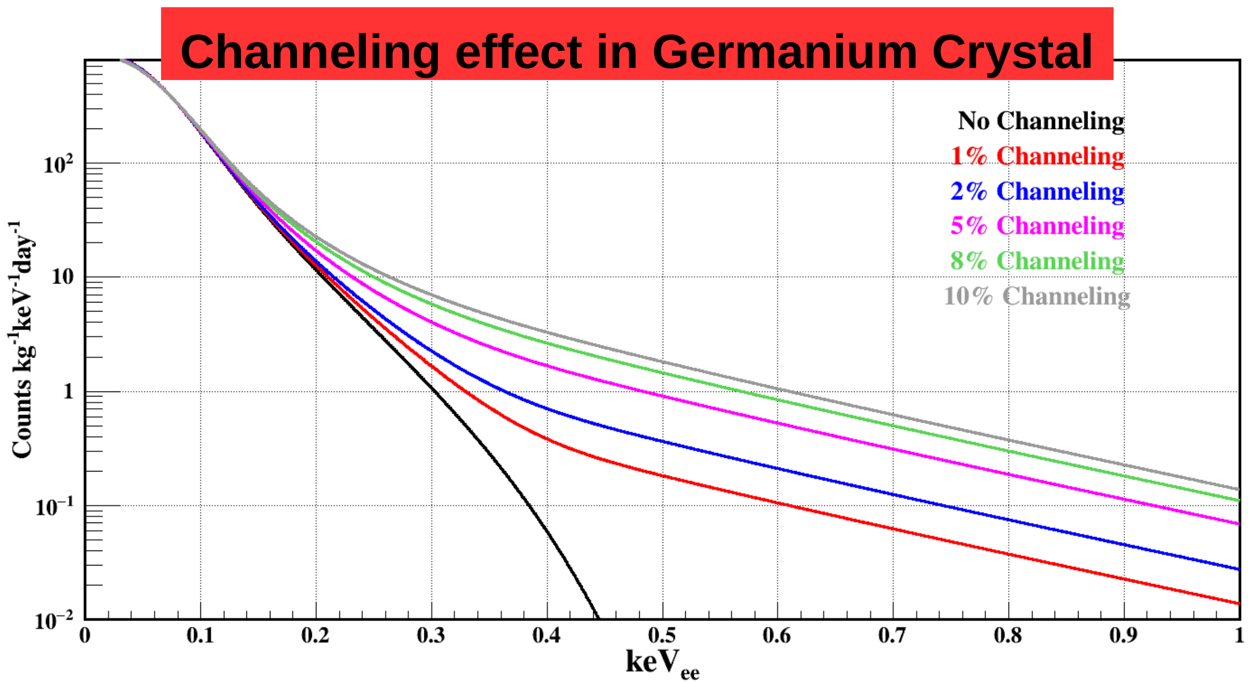
Channeling Fraction

Channeling in NaI ..





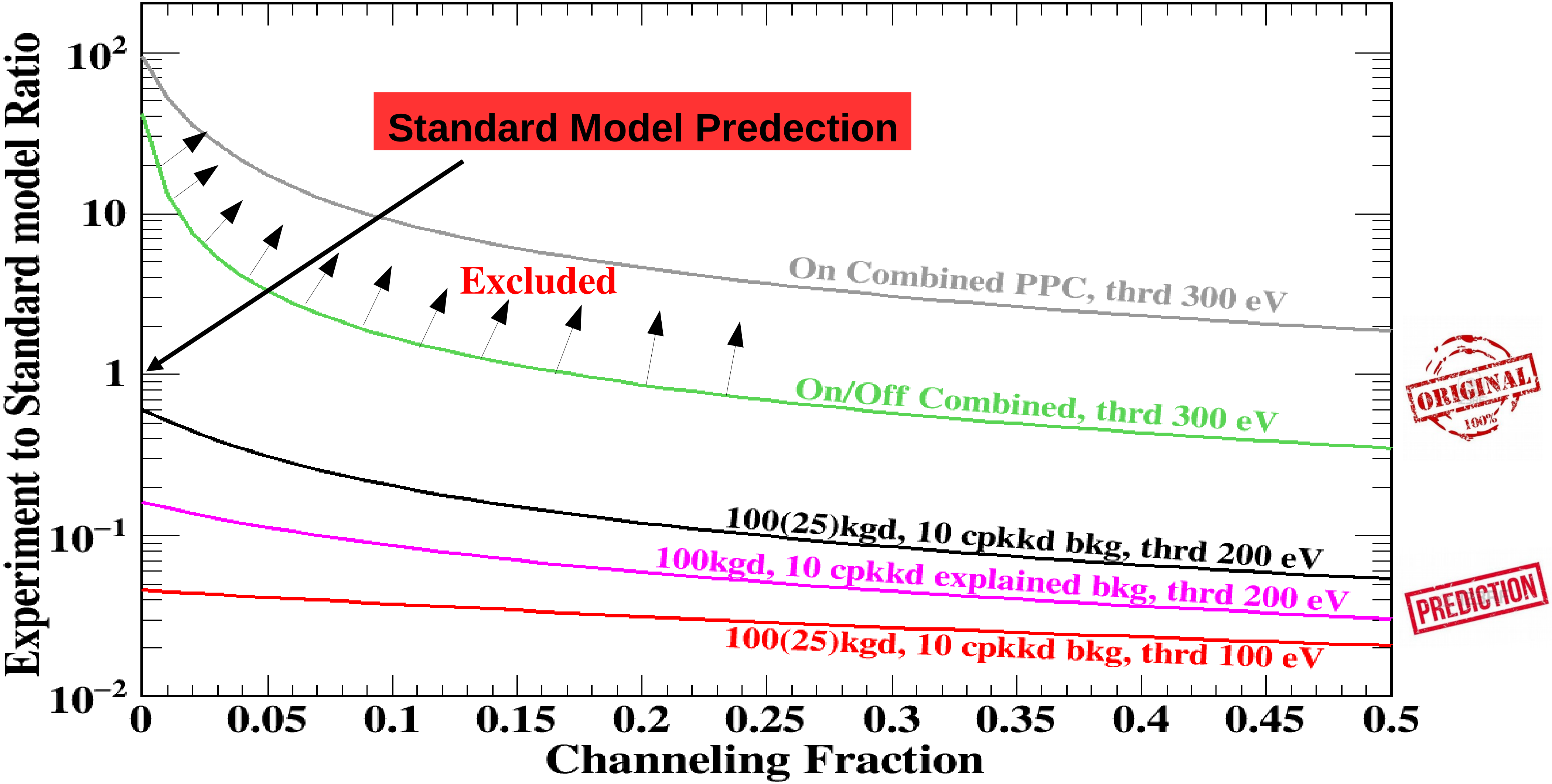
Bernabei et al. 2008, Eur. Phys. J. C53, 205



- Channeling increase counts at higher energy.
- Quenching factor is assumed to be ~1
- Estimated Channeling in NaI is ~3 %

Sensitivity Towards CENNS ..

- Better to have High On/Off Statistics
- Threshold required below ~200 eV



Conclusion and Summary ..

- Ultra low energy threshold 300 eV is achieved.
- Lower threshold and background with higher mass is expected from future detector.
- To understand sub-keV background, various measurement and simulations are going on.
- Roadmap is ready to probe CENNS in near future.

Thank You ..