ASTRONEU contribution to Supernova detection with a Spherical Proportional Counter

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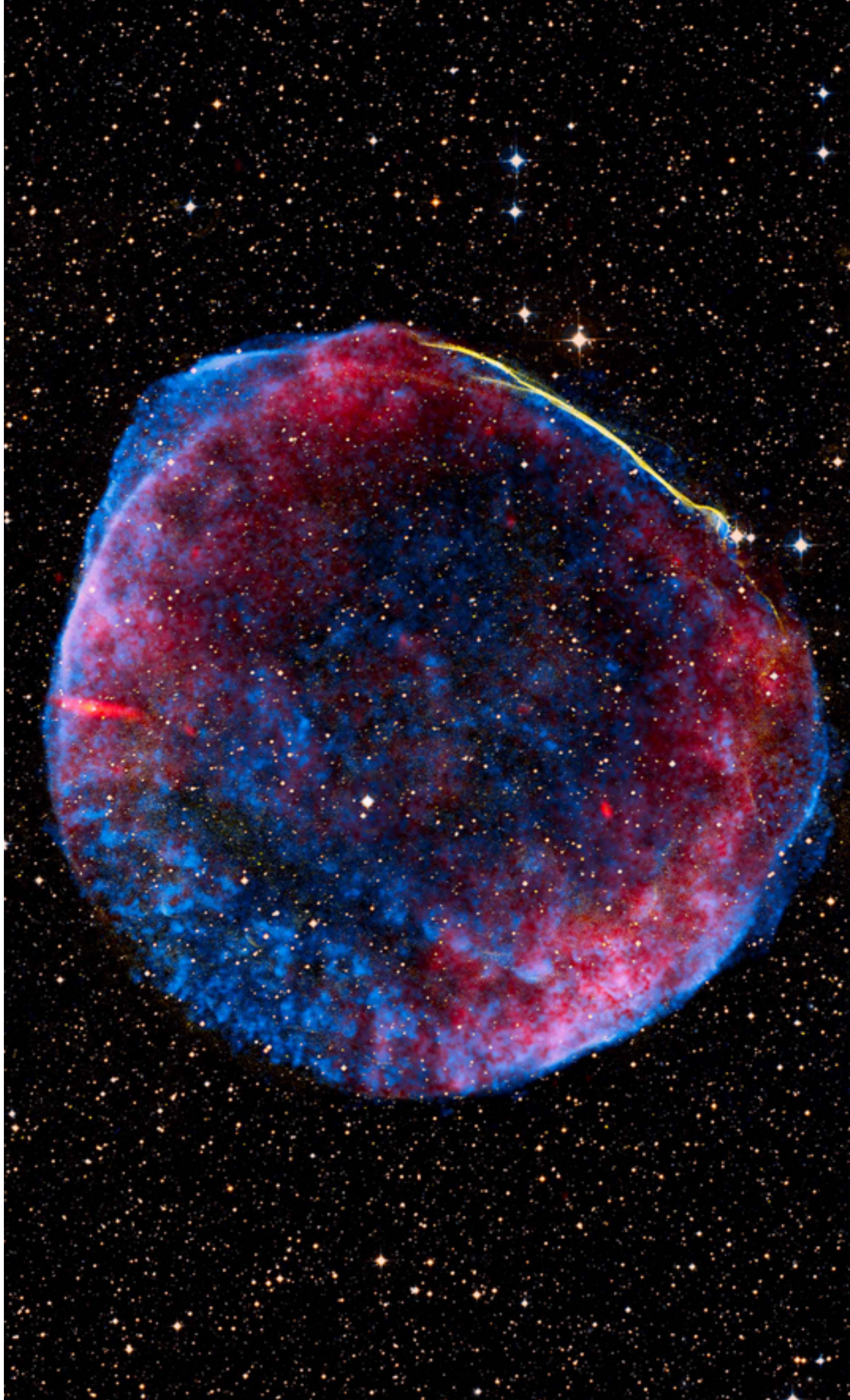
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

Outline

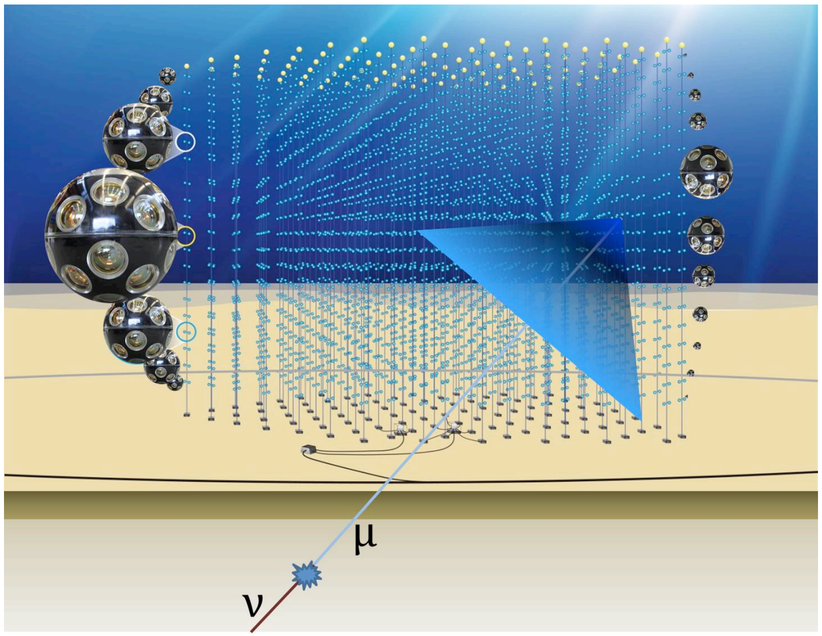
- Undersea Neutrino Telescope for Supernova detection
- The Spherical Proportional Counter (SPC)
- Coherent Scattering of neutrinos on nuclei
- Supernova emission spectra
- Detection of Supernova with the SPC



A feasibility study for the detection of SuperNova explosions with an Undersea Neutrino Telescope

Nucl.Instrum.Meth. A725 (2013) 89-93, DOI: 10.1016/j.nima.2012.11.157

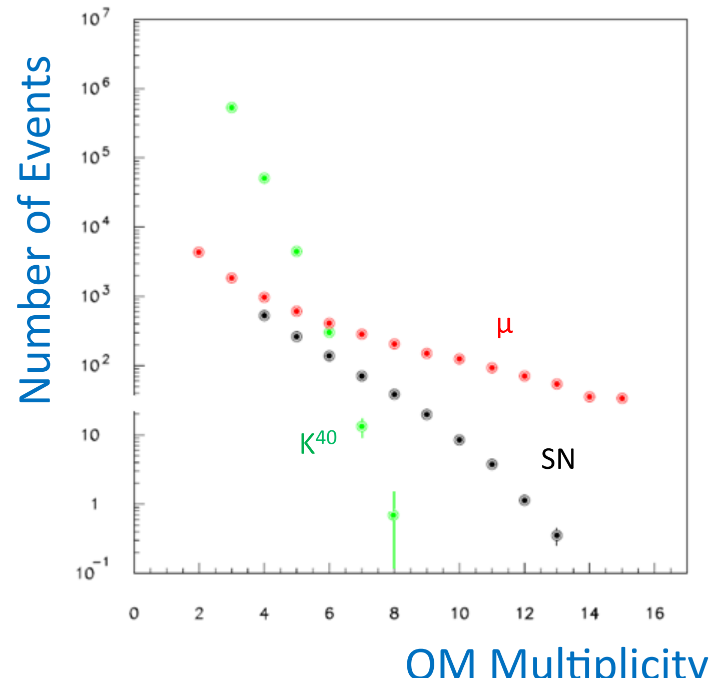
Assuming a KM3NeT with ~6000 Digital Optical Modules (DOM)



31 3” PMTs (~30% max QE) inside a 17” glass sphere

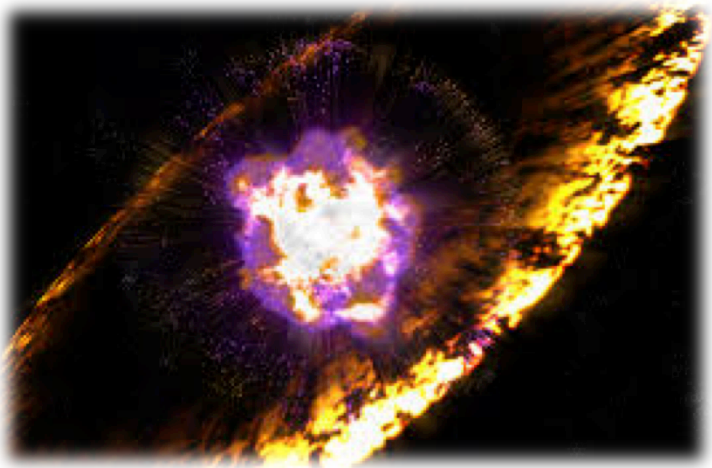
Coincidence between the small PMTs of the same OM

Expected Number of Events : ~120 over background

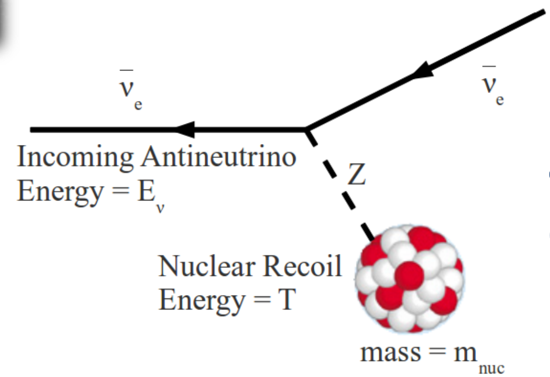


Apply selection criteria (OM Multiplicity, Charge per PMT and Number of neighbor active OMs)

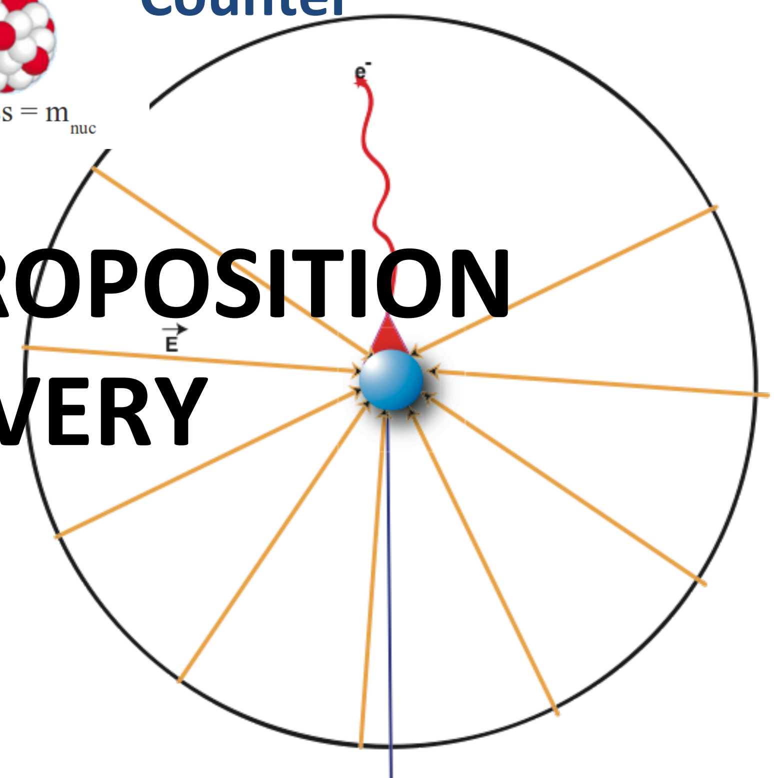
D_{max}=23 kpc for 5 σ discovery



Coherent neutrino-nucleus scattering

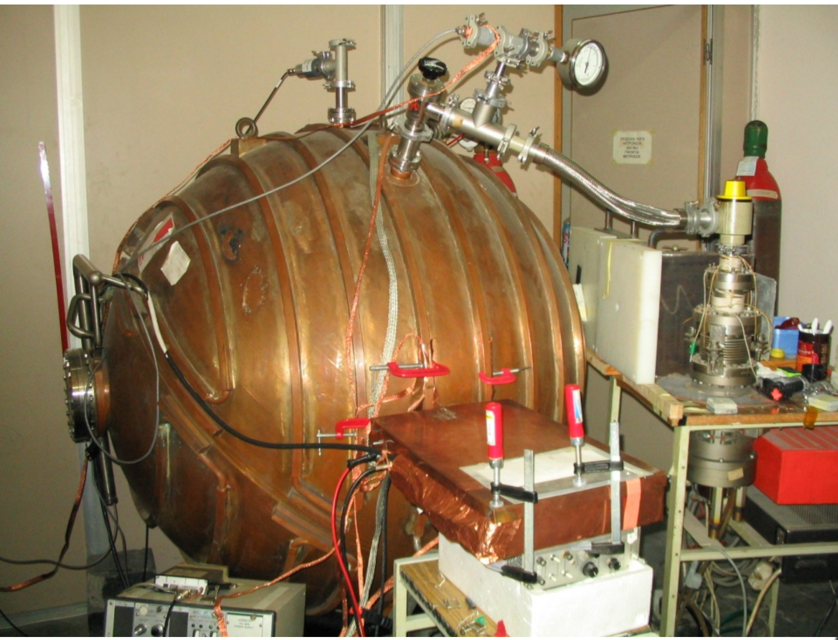


Spherical Proportional Counter

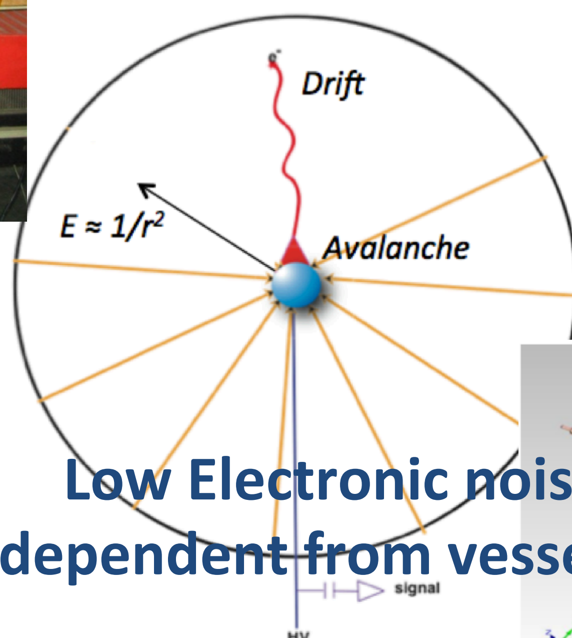


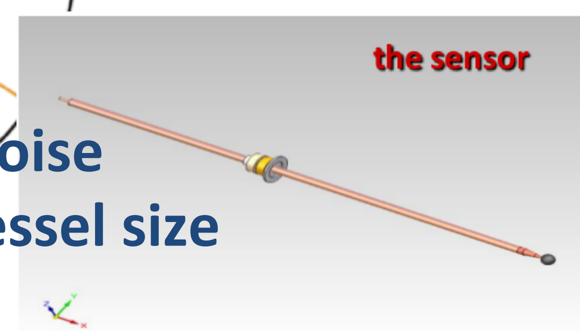
ANOTHER ASTRONUE PROPOSITION FOR SUPERNOVA DISCOVERY

The Spherical Proportional Counter (SPC)



- Volume = 1 m^3
- Gas fillings Ar, Xe, Ne, He …
- Gas leak < 5 × 10^{-9}mbar/s.
- Pressure up to 5 bar
- Internal electrode at high voltage.
- Read-out of the internal electrode 3-16 mm





$C \approx 4\pi\varepsilon_0 R_{in} \approx 0.1pF$ → **Low Electronic noise**
Independent from vessel size

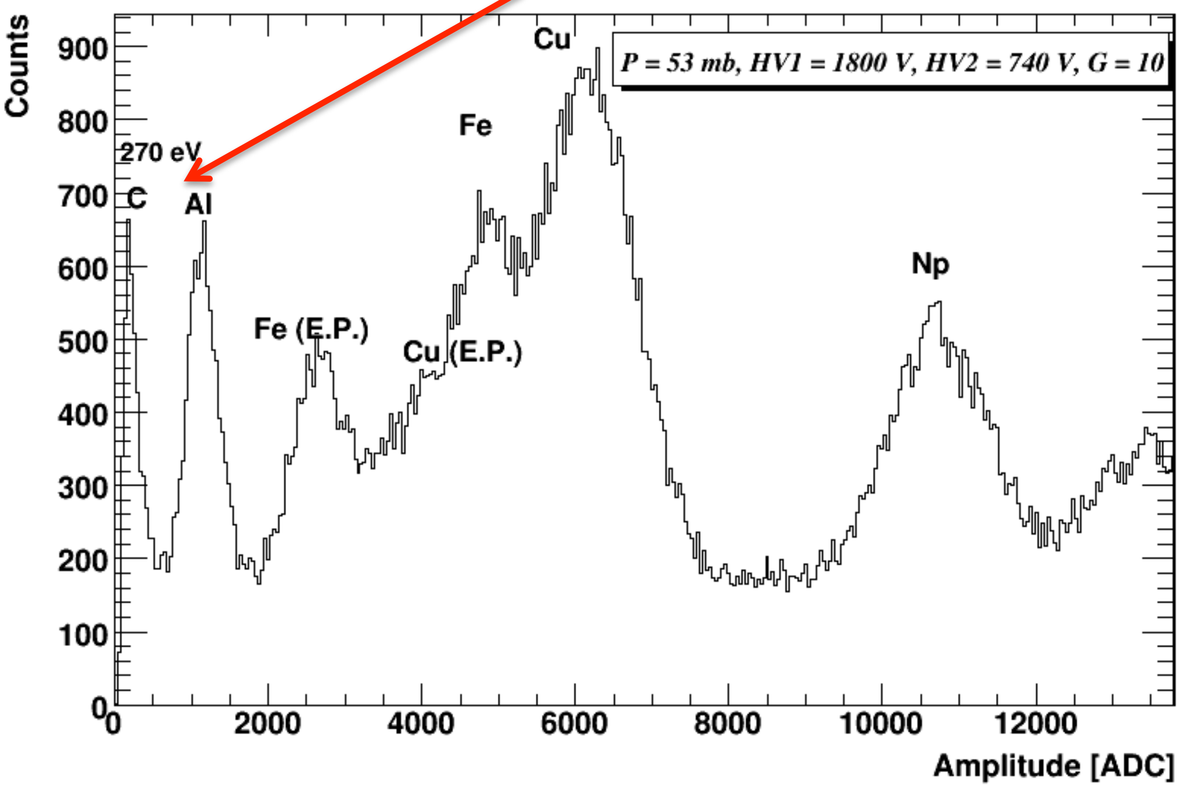
Key Advantages of the SPC

Amplification Capability

Very Low Capacitance (Size independent)

→ **Sub-keV threshold** → Handling of Large Mass targets with one channel

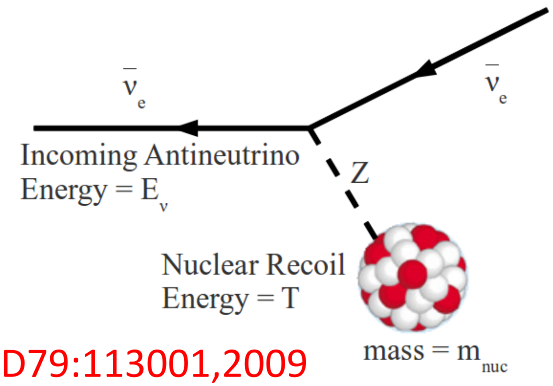
Carbon at 270 eV !!!



- Fiducialization capability
- Point like energy deposition isolation with PSA

Detecting neutrinos through the coherent neutrino-nucleus elastic scattering

Reaction cross section
ν +(*A*,*Z*) → ν' +(*A*,*Z*)'



Phys.Rev.D79:113001,2009

$$\frac{d\sigma}{dT_A}(T_A,E_\nu) = \frac{G_F^2}{2\pi}\left(\frac{N^2}{4}\right)F_{coh}(T_A,E_\nu)$$

With

$$F_{coh}(T_A,E_\nu) = F(Q^2)\left(1+\left(1-\frac{T_A}{E_\nu}\right)^2 - \frac{Am_N T_A}{E_\nu^2}\right)$$

N: neutron number
Q^2: transferred momentum

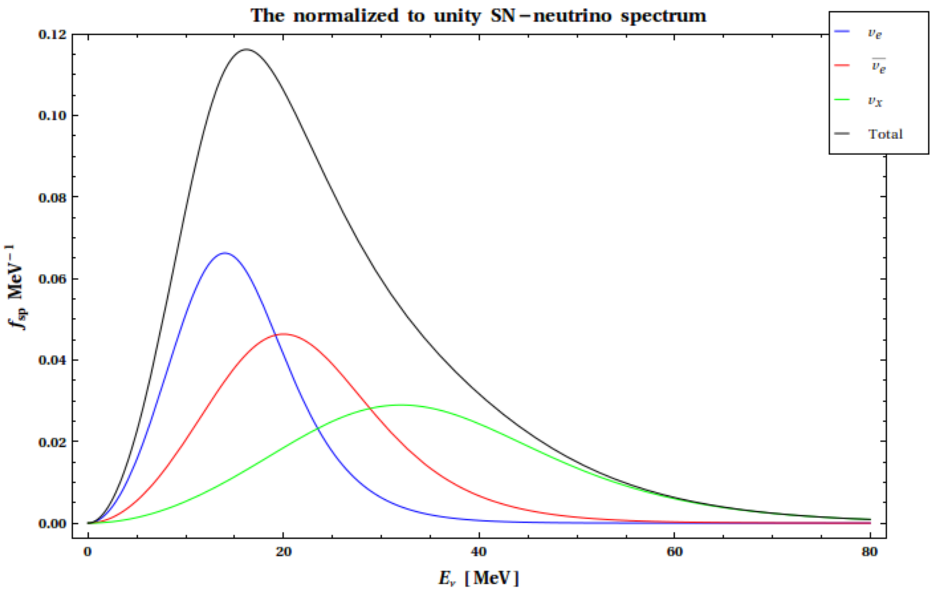
- Neutral current weak interaction
- The neutrino ''sees'' the nucleus as a whole
- Does not distinguish between neutrino flavors
- Cross section depends on the transferred momentum Q

Cross section increased by N^2 !!!

Detecting the low energy nuclear recoil

SN neutrino spectrum

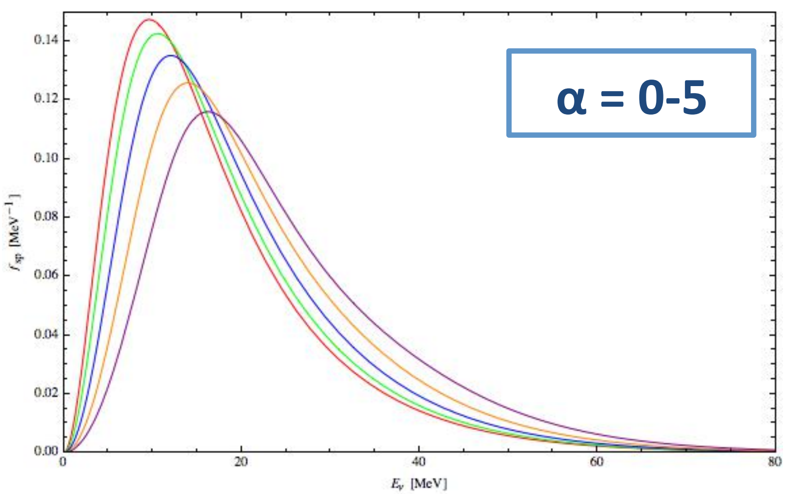
J.Vergados, arXiv:1103.1107 [hep-ph]



- Fermi-Dirac pinched distribution
- Total energy $U_\nu = 3\times10^{53}$ ergs equally distributed among the neutrino flavors

$$\frac{dN}{dE_\nu}(E_\nu, T_\nu, a) = N_\nu \frac{1}{F(a)} \frac{E_\nu^2}{e^{E_\nu/T_\nu - a} + 1}$$

$N_\nu = U_\nu / \langle E_\nu \rangle$ → Number of neutrinos



α is introduced due to differences in the astrophysical models

$\uparrow a \Rightarrow \downarrow \Phi_\nu$ because $\uparrow \langle E_\nu \rangle$

Calculation of the detector response to the Reactor neutrinos

Calculating total cross sections for non-''monochromatic'' sources

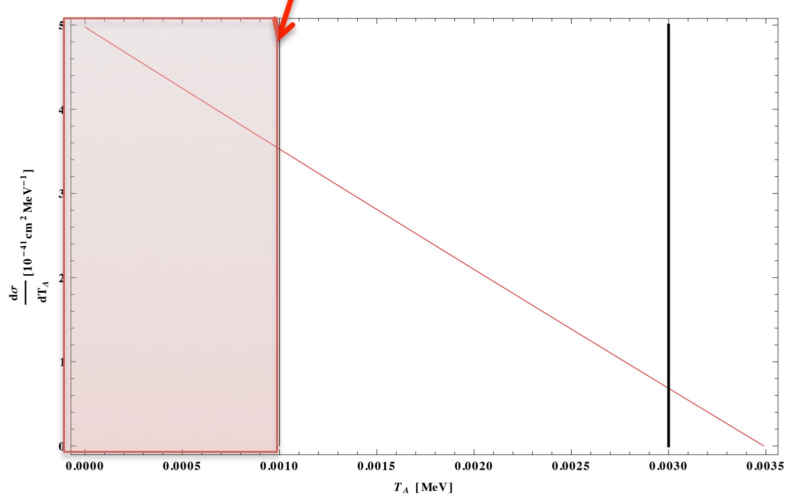
Folded Cross Section

$$\frac{d\sigma}{dT_A}(T_A) = \int_{Ethrs}^{E\nu \max} \left(\frac{d\sigma}{dT_A}(T_A, E_\nu) \right) \cdot f_{sp}(E_\nu, \mathrm{T}_A, \alpha) dE_\nu$$

T_{thrs} ≅ Detection Threshold

Total Cross Section

$$\sigma_{tot}(A,N) = \int_{T_{Athrs}}^{T_{A\max}} \frac{d\sigma}{dT_A}(T_A) dT_A$$



Event Number

$$N_{ev}(a, T_\nu) = \Phi_\nu \cdot \sigma_{tot}(a, T_\nu, T_{thrs}) \cdot N_d(P, T_0, R)$$

Calculation Results

SPC: radius R = 4 m, Gas Pressure P = 10 atm, Temperature T_0 = 300 K

SN: distance L = 10 kpc (distance with highest probability for SN collapse)

Worst Case α = 0

Argon

α = 0	Threshold		
	0 keV	1 keV	3 keV
σ_{tot} [fb]	3.47	2.22	1.12
Events	74	52	29

Xenon

α = 0	Threshold		
	0 keV	1 keV	3 keV
σ_{tot} [fb]	41.7	10.2	0
Events	894	273	0

Best Case α = 4

α = 4	Threshold		
	0 keV	1 keV	3 keV
σ_{tot} [fb]	11.1	9.6	8.1
Events	167	149	119

α = 4	Threshold		
	0 keV	1 keV	3 keV
σ_{tot} [fb]	238.5	79.4	32.4
Events	1922	1295	605

Calculation Results

SPC: radius R = 10 m, Gas Pressure P = 10 atm, Temperature T_0 = 300 K

SN: distance L = 10 kpc (distance with highest probability for SN collapse)

Worst Case α = 0

Argon

α = 0	Threshold		
	0 keV	1 keV	3 keV
σ_{tot} [fb]	3.47	2.22	1.12
Events	1162	810	549

Xenon

α = 0	Threshold		
	0 keV	1 keV	3 keV
σ_{tot} [fb]	41.7	10.2	0
Events	13968	4271	0

Best Case α = 4

Argon

α = 4	Threshold		
	0 keV	1 keV	3 keV
σ_{tot} [fb]	11.1	9.6	8.1
Events	2609	2332	1857

Xenon

α = 4	Threshold		
	0 keV	1 keV	3 keV
σ_{tot} [fb]	238.5	79.4	32.4
Events	30037	20234	9460

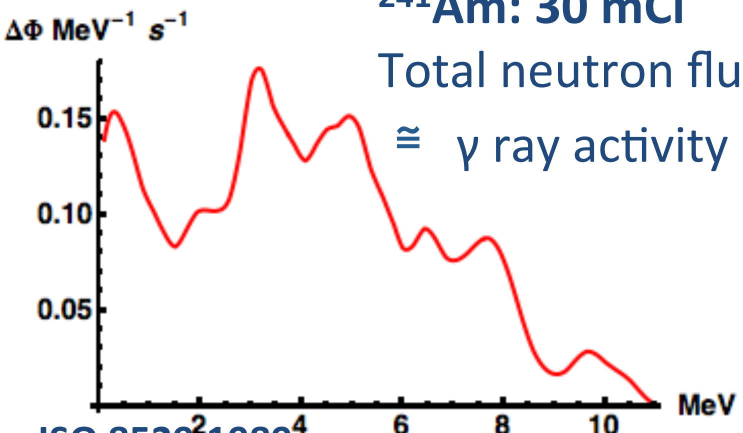
Detecting low energy nuclear recoils at the Lab

Producing Ar recoils with an Am-Be source

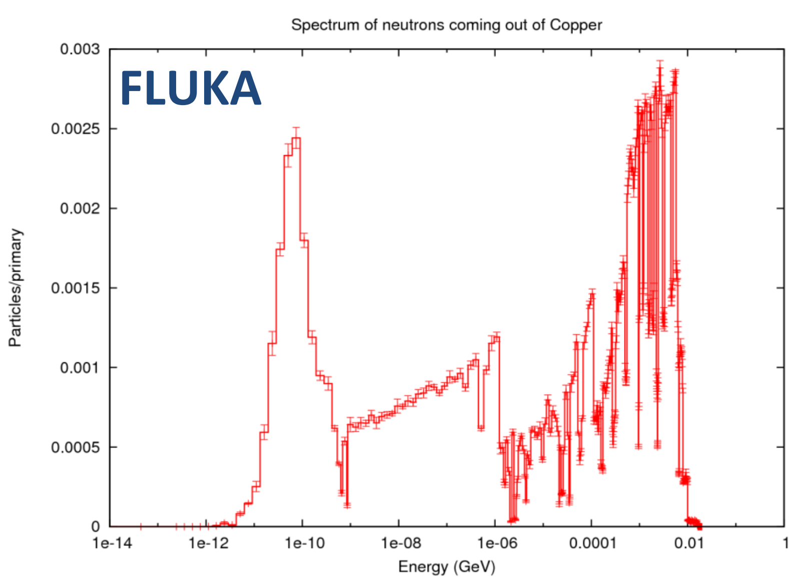
^{241}Am: 30 mCi

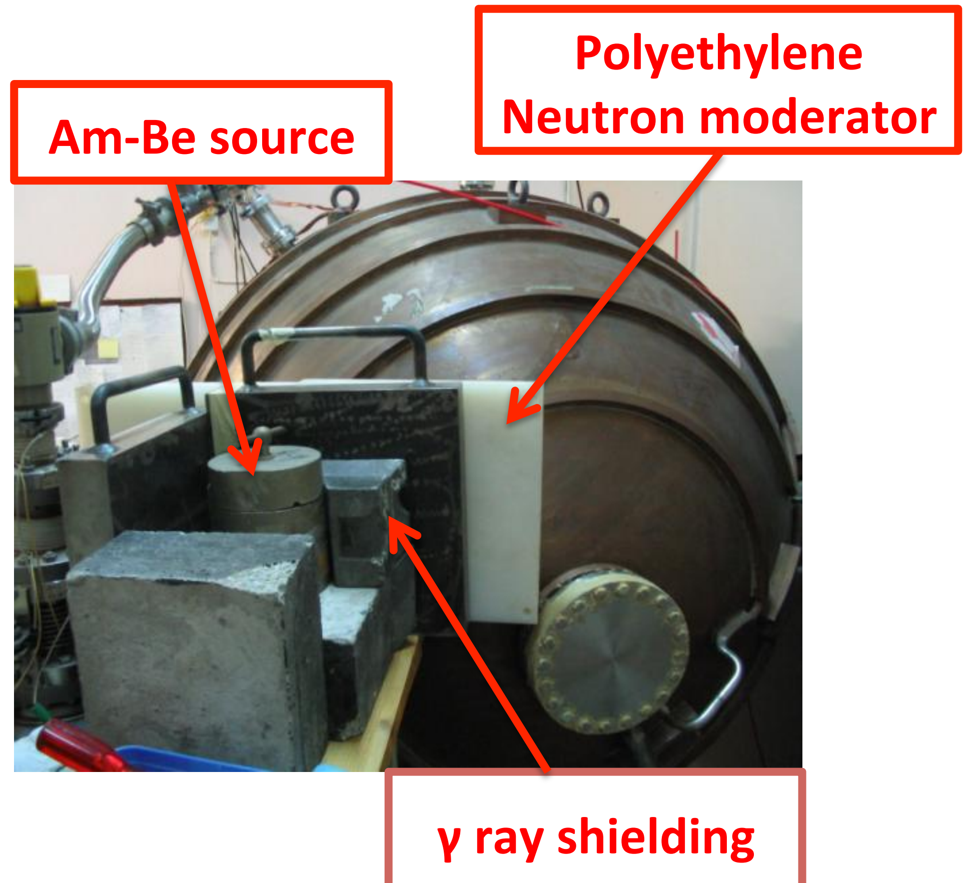
Total neutron flux : 6.6×10^4 n/sec

≅ γ ray activity of the source



ISO 8529:1989





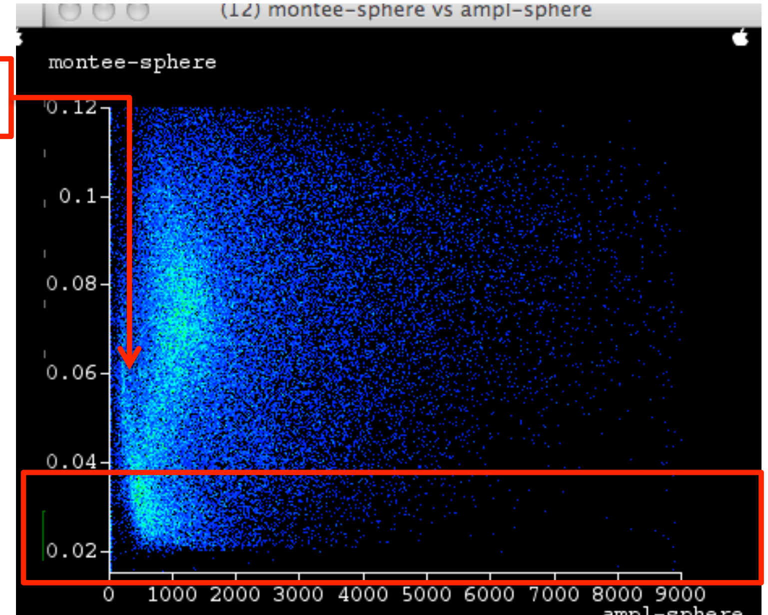
Examining Amplitude vs Risetime Plots

Conditions

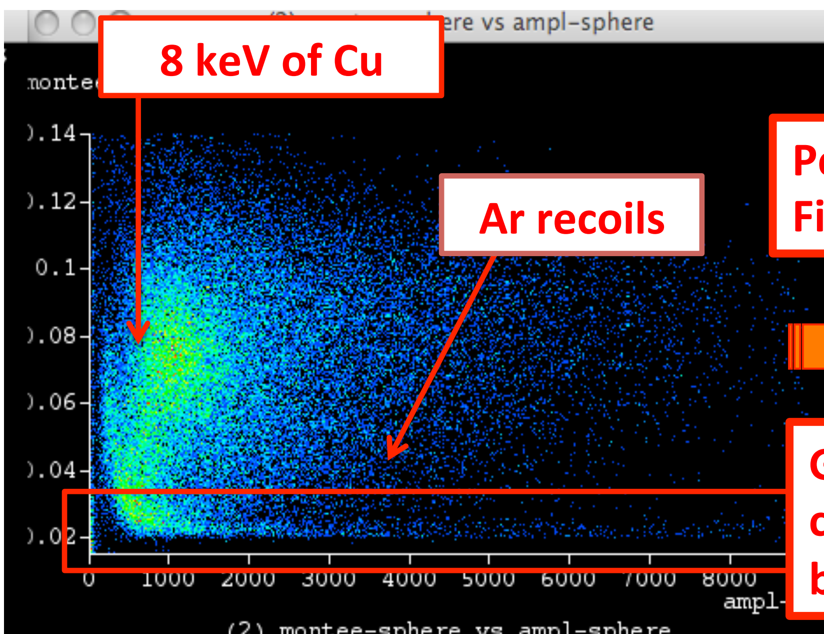
Gas Mix: 91% Ar + 5% CH_4 + 4% N_2

Pressure: 250 mbar

No Source Calibration Run

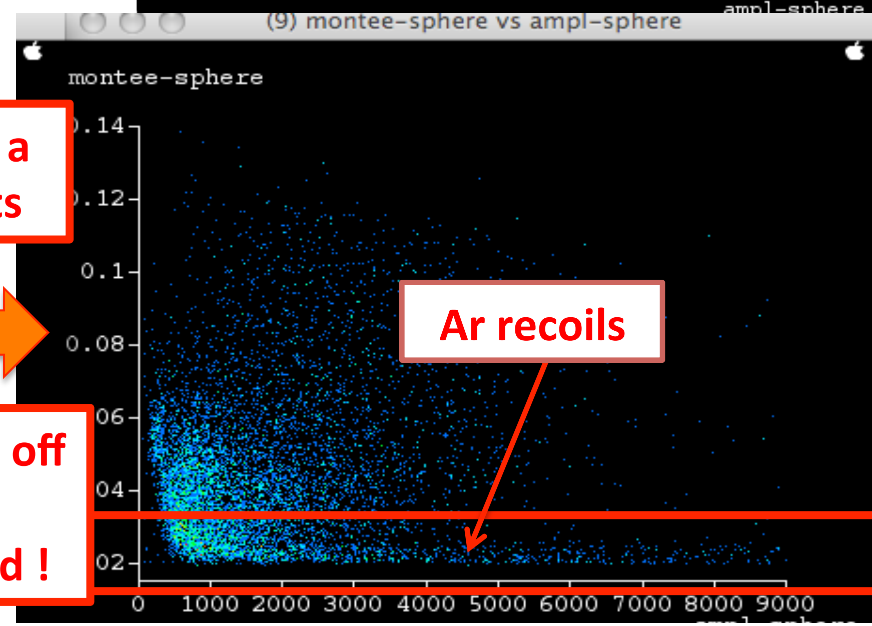


Am-Be source Run



Performing a Fiducial Cuts

Getting rid off cosmic background !



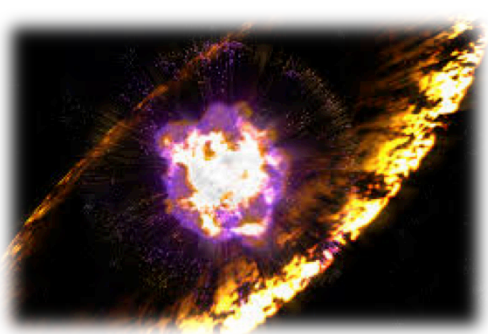
Summary

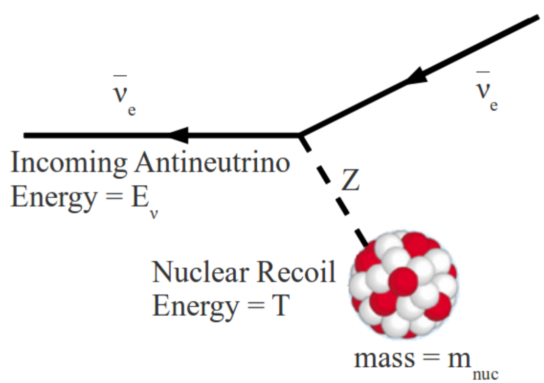
Supernova detection by exploiting the *ν-(A,N)* coherent scattering is Possible !!!

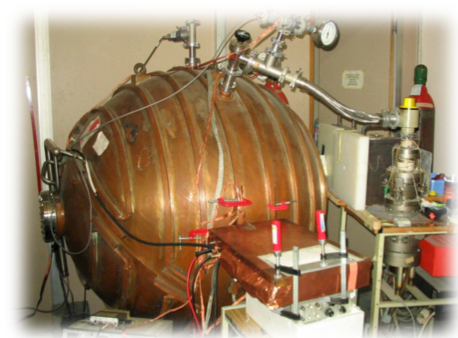
Detector demands

- Sub keV energy threshold
- Low noise
- Large mass
- Good energy resolution
- Background Rejection capabilities

SPC meeting demands
+Simple design
+Low cost
+Low maintenance

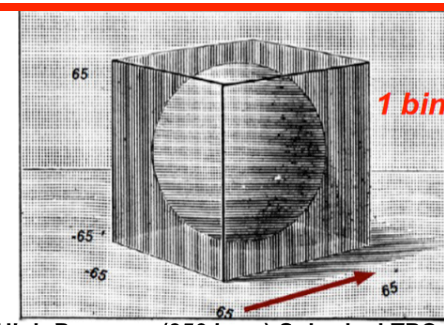






Next Steps

Gain studies at High Pressure > 10 atm
- **Simulation**
- **Experimental Evaluation**

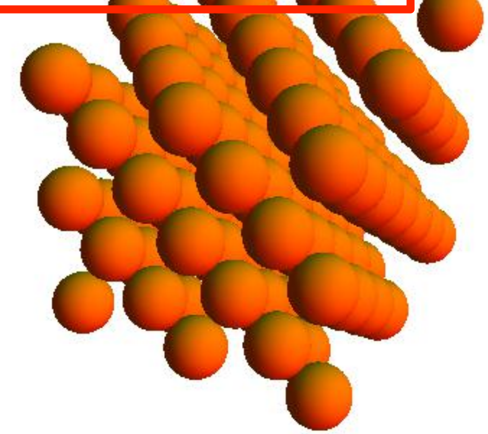


High Pressure (350 bars) Spherical TPC for Neutrino Detection, using a hyperbaric chamber
HOU-DEMOKRITOS

Experiment

- Detection of recoils at lower Energies ~100 eV
- Study the Background at ~100 eV
- Go up in Pressure 2-4 atm
- Go up in Detector Volume Φ 1-2 m

Calculate the Response of an SPC grape to SN neutrinos !



Simulations

- Study the detector response to low energy recoils with GARFIELD++
  - Pulse production
  - E/M energy deposition