Testing reactor antineutrino anomaly with neutrino sources

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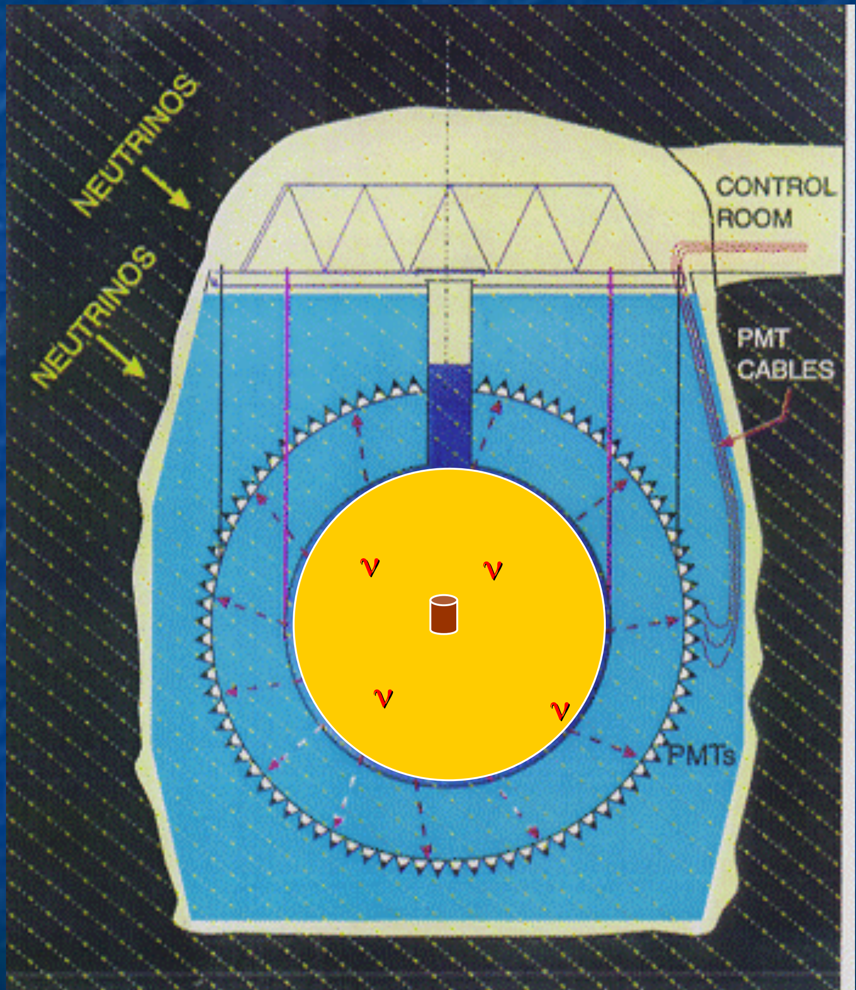
Principle



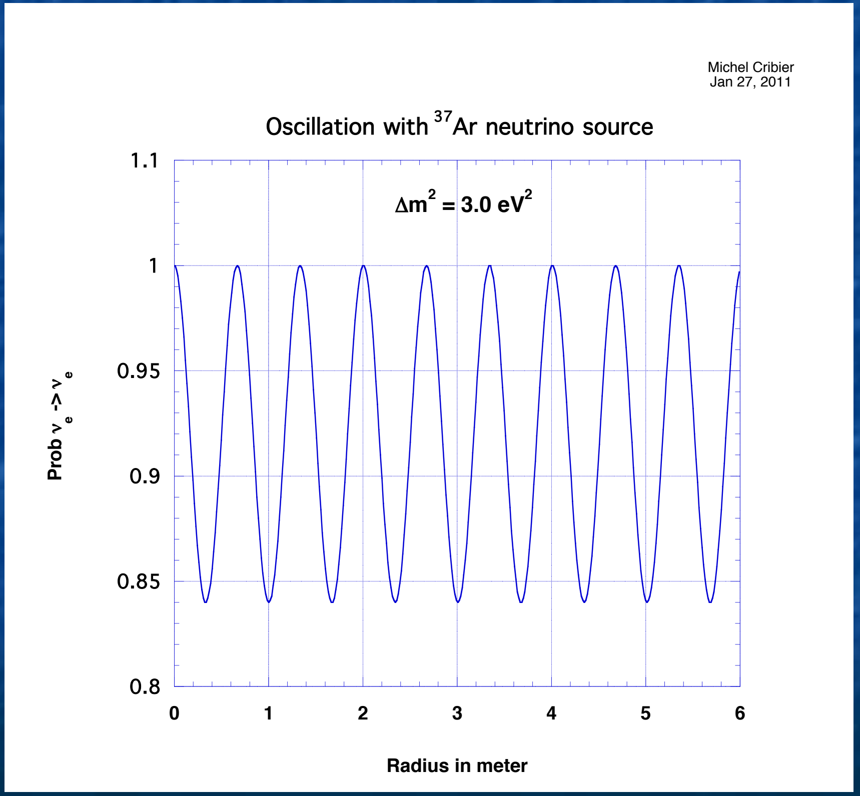
- A strong ν source in the middle of a large detector
- Elastic scattering on electrons
- A good resolution in position

Basic formula

$$\frac{dN}{dr}(r) = \frac{A_0 \times \tau \times \exp(-{T_0}/{\tau})}{\cancel{4\pi r^2}} \times \left(1.-\exp(-{T_e}/{\tau})\right) \times \cancel{4\pi r^2} \times \tilde{\sigma}(E^e_{\min}, E^e_{\max}) \times N_e \times P_{ee}(1.27\frac{\Delta m^2}{E_\nu} r) \quad in \ \ cm^{-1}$$

Bq sec $\qquad cm^2 \qquad e^-/cm^3$

- A real oscillation function of the radius
  - No distortion
  - Direct proof
  - Distinct signatures in time, space from backgrounds
  - Limited by spatial resolution σ_r for $\Delta m^2 \approx 6$ eV^2 ; $L_{osc} \approx \sigma_r$
- More sophisticated analysis
  - Frequency scan
  - Fold all phases



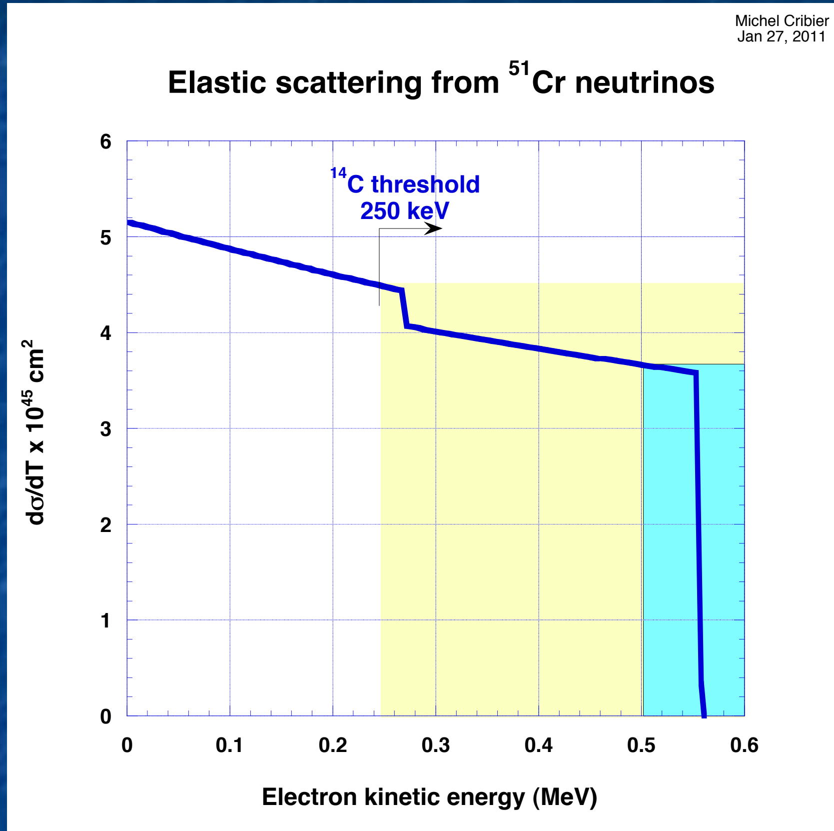
Elastic interaction cross section

- Cross section

$$\frac{d\sigma}{dT_e} = \sigma_0 \left[g_L^2 + g_R^2 \left(1 - \frac{T_e}{E_\nu}\right)^2 - g_L g_R \frac{T_e}{E_\nu^2} \right]$$

$$\sigma_0 = \frac{2G_F^2 m_e^2}{\pi \hbar^4} = 8.8083\ 10^{-45}\ cm^2$$

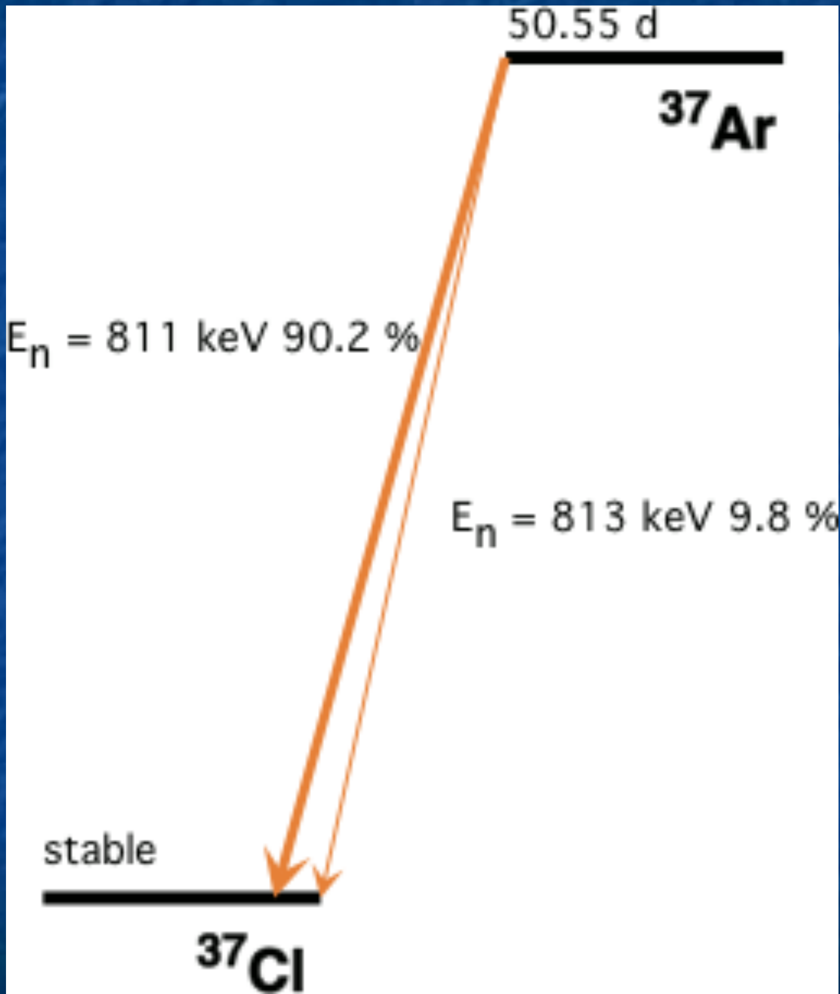
- Compton edge
- T_{max} : $T^e_{max} = \frac{2E_\nu^2}{m_e + 2E_\nu}$
- High statistics



σ in 10-45 cm2

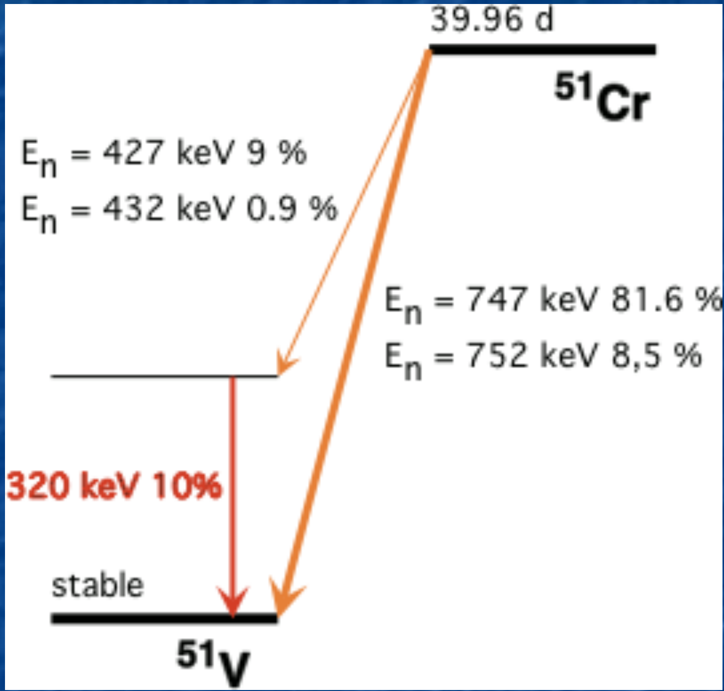
Source	total σ	> 250 keV σ	> 250 keV # inter	> 500 keV σ	> 500 keV # inter	delay	#days	#int/d
51Cr	4,68	2,32	41984	0,41	7330	5	120	706
37Ar	5,5	3,1	60913	0,94	18471	14	152	711
65Zn	5,39	3,75	221363	2,62	154891	7	360	884

^{37}Ar neutrino source



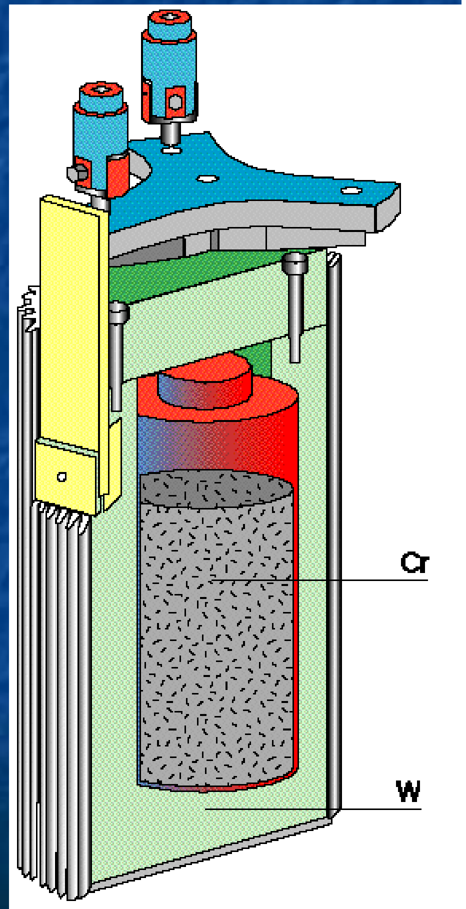
- Recipe for 1 MCi *(russian style)*
  - Take 330 kg of natural Ca0
  - Cook it in a **fast neutron** flux (> 2 MeV) for 160 d
    - BN600 in Russia
  - Poor it in acid to extract gases (Ar)
  - Fill a can (6 liter STP/MCi)
  - Keep it fresh
    - 13 W
- Already made it once
  - 0.4 MCi in SAGE
- Reliable absolute activity measurement < ≈ 1% ?
  - Diluted sample in proportional counter
- No impurities ; only Auger & soft X-rays (2.4 keV)

^{51}Cr neutrino source

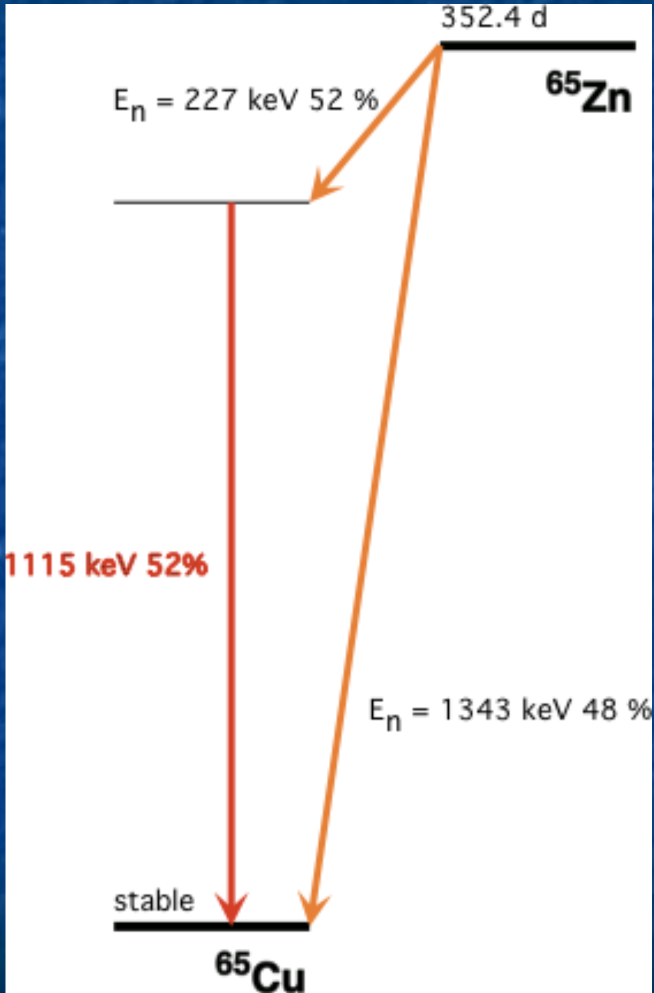


- γ 320 keV in 10 %
  - Heavy shielding (tungsten)
  - 180 W/MCi

- Recipe *(french style)*
  - Take 40 kg of enriched in ^{50}Cr (4%->38%)
    - Still in Saclay
  - Cook it in a **thermal neutron** flux for 25 d
    - Siloé at Grenoble (dismantled)
    - Osiris ?
  - Serve it hot
    - 300 W
- Already made it 3 times
  - 2 x 2 MCi in Gallex
  - .6 MCi in SAGE

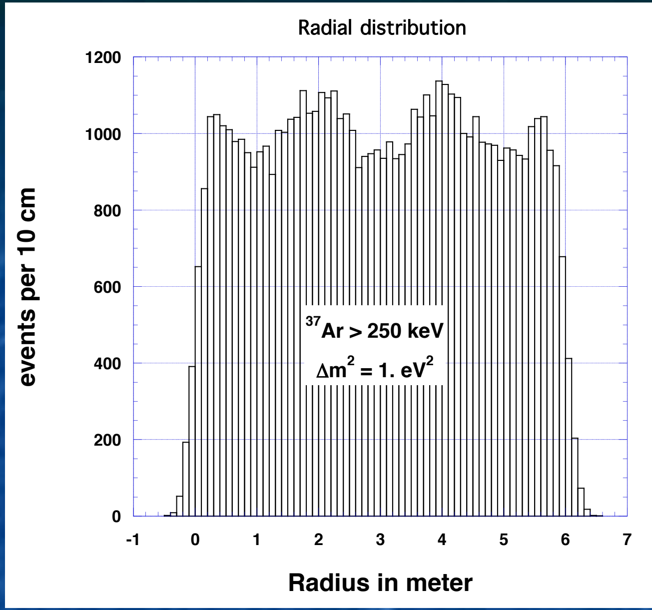


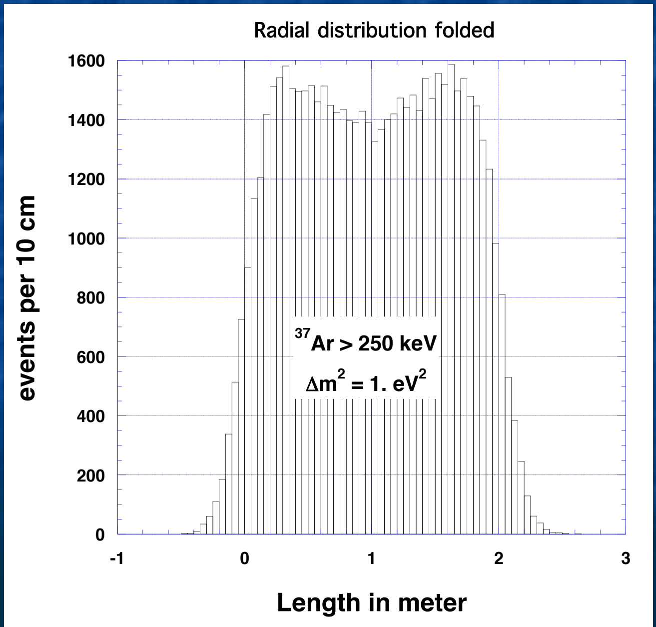
^{65}Zn neutrino source



- Possible recipe
  - For 1 MCi
  - Take ≈ 100 kg of nat. Zn
  - Cook it in a **thermal neutron** flux (≈ 10^{15} n/cm2.s) for ≈ 30 days
- γ 1.156 MeV in 50.6 %
  - 3460 W/MCi !!!
- Advantage
  - higher E_ν => bigger L_{osc}
- Much less intense source already made
  - Axion searches

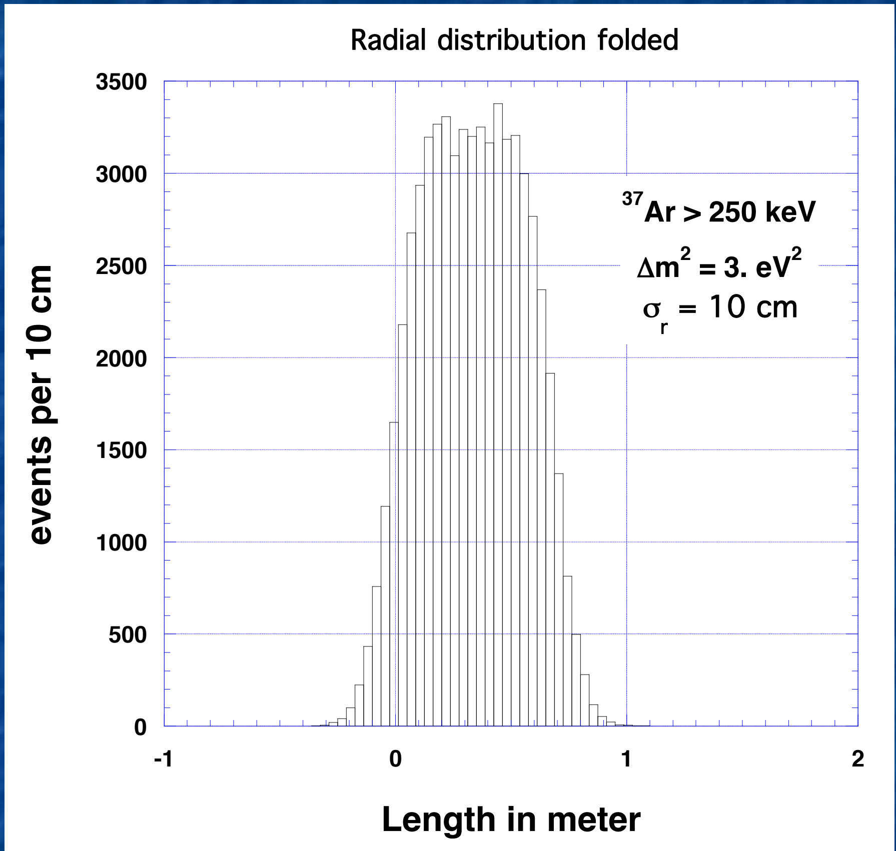
Experiment in SNO+





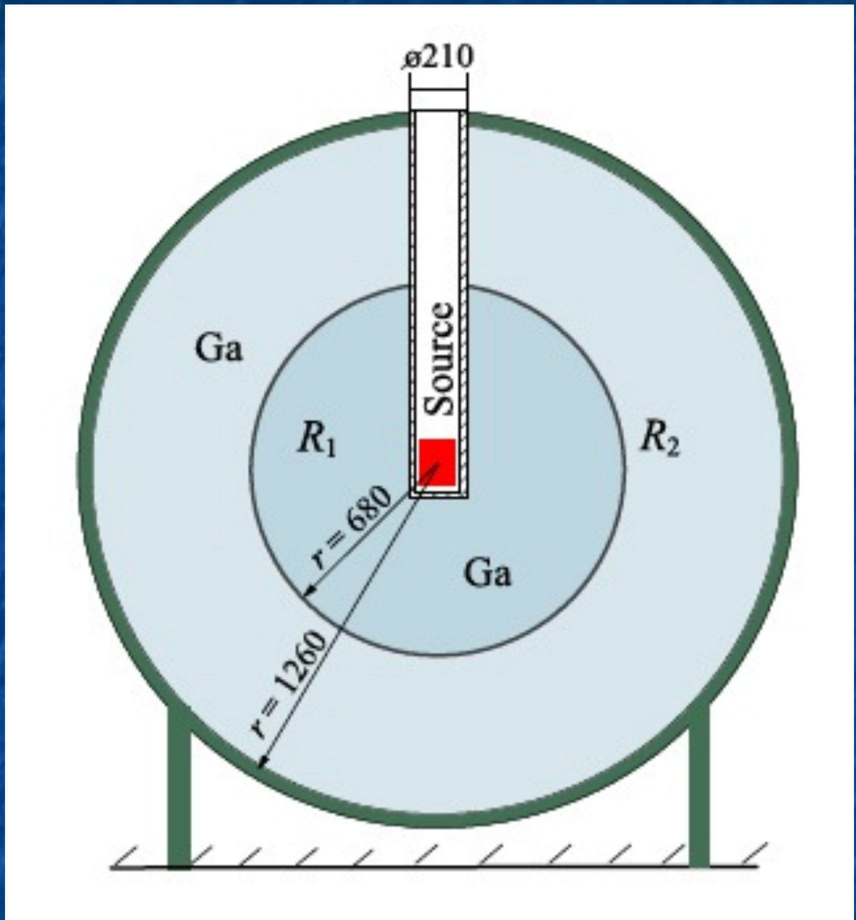
- « 1 MCi » in the center of the detector
  - Activity at end of irradiation
- Simulation with real number of events
  - Taking into account delay due to preparation, transport…
- No efficiency cuts
- No background
- For other detectors
  - Scale with
    - Radius of tank
    - # e^-/cm^3

Limitations



- Need a very good spatial resolution ≈ 10 cm
- Rather limited sensitivity in Δm^2
  - below 3 eV^2
  - Interesting range ?
- With ^{37}Ar and well known cross-section
  - Rate => $\sin^2(2\theta_{new})$

Similar projects



- ^{51}Cr in metalic Ga
  - *V. Gavrin et al. arXiv:1006.2103*
  - *Why not ^{37}Ar ?*
- ^{51}Cr in LENS
  - *R. Raghavan et al.* *PRD 75, 093006*
- Borexino
  - *See M.Wurm/S.Schoenert*

Conclusions

- After short base line reactor experiments (like Nucifer), if Δm^2 in the range 0.5 - 3 eV^2, a ν source experiment seems the right thing to do
- Technical problems have been solved already in the past
- Politics, safety rules…changed and makes such an effort challenging
- ^{37}Ar or ^{51}Cr, no clear preferences : make the one we can

Fabrication of the ^{51}Cr ν source

- Enrichment in ^{50}Cr
  - < 0.5 % of 50Cr used per source
- Small grains
  - ≈ 1 mm^3 size
- Maximisation of the n flux ≈ 5.2 10^{13} $n/cm^2.s$

Isotopic composition of chromium and thermal neutron capture cross-section (measured at 2200 m/s).

	Isotopic composition of natural Cr	Isotopic composition of the enriched Cr used in GALLEX	Thermal neutron capture cross-sections (barns) [12]
^{50}Cr	4.35%	38.6%	15.9
^{52}Cr	83.8%	60.7%	0.76
^{53}Cr	9.5%	0.7%	18.2
^{54}Cr	2.35%	<0.3%	0.36

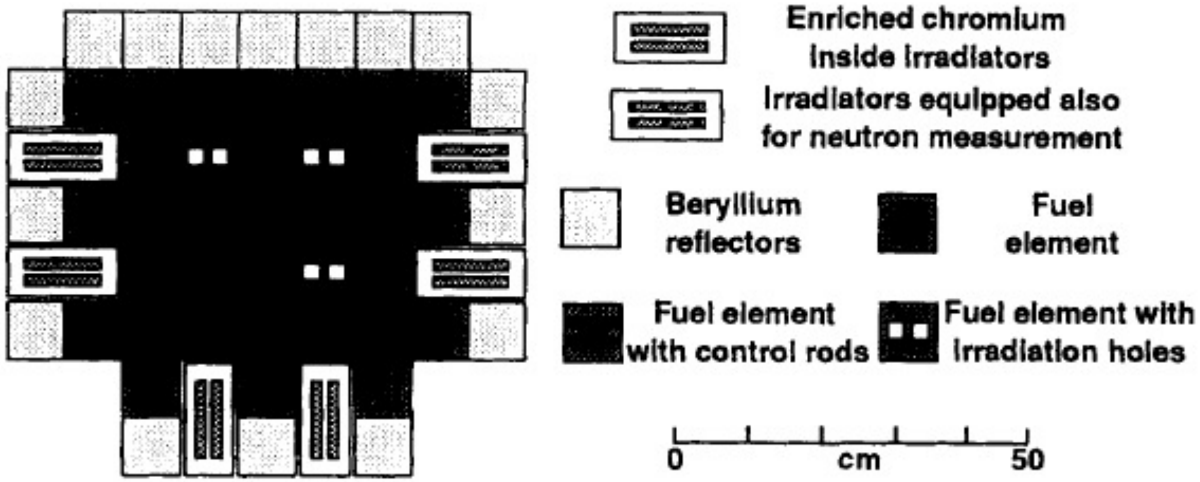


Fig. 2. Special Siloé core configuration for chromium irradiation.