Summary of the phenomenology and detection strategies session

Kate Scholberg
Michael Wurm

Signatures of SN neutrino oscillations	Amol Dighe
Low-energy neutrino-nucleus interactions	Natalie Jachowicz
Coffee break	
Supernova neutrino detection technologies	Clarence Virtue
Lunch	
Super-K+Gd for SN detection	Makodo Sakuda
SN neutrino signal in Icecube	Goesta Kroll
SN neutrinos in liquid scintillator detectors	Aldo Ianni
SN neutrinos in LVD	Walter Fulgione
Coherent scattering for SN neutrinos	Georgios Tsiledakis

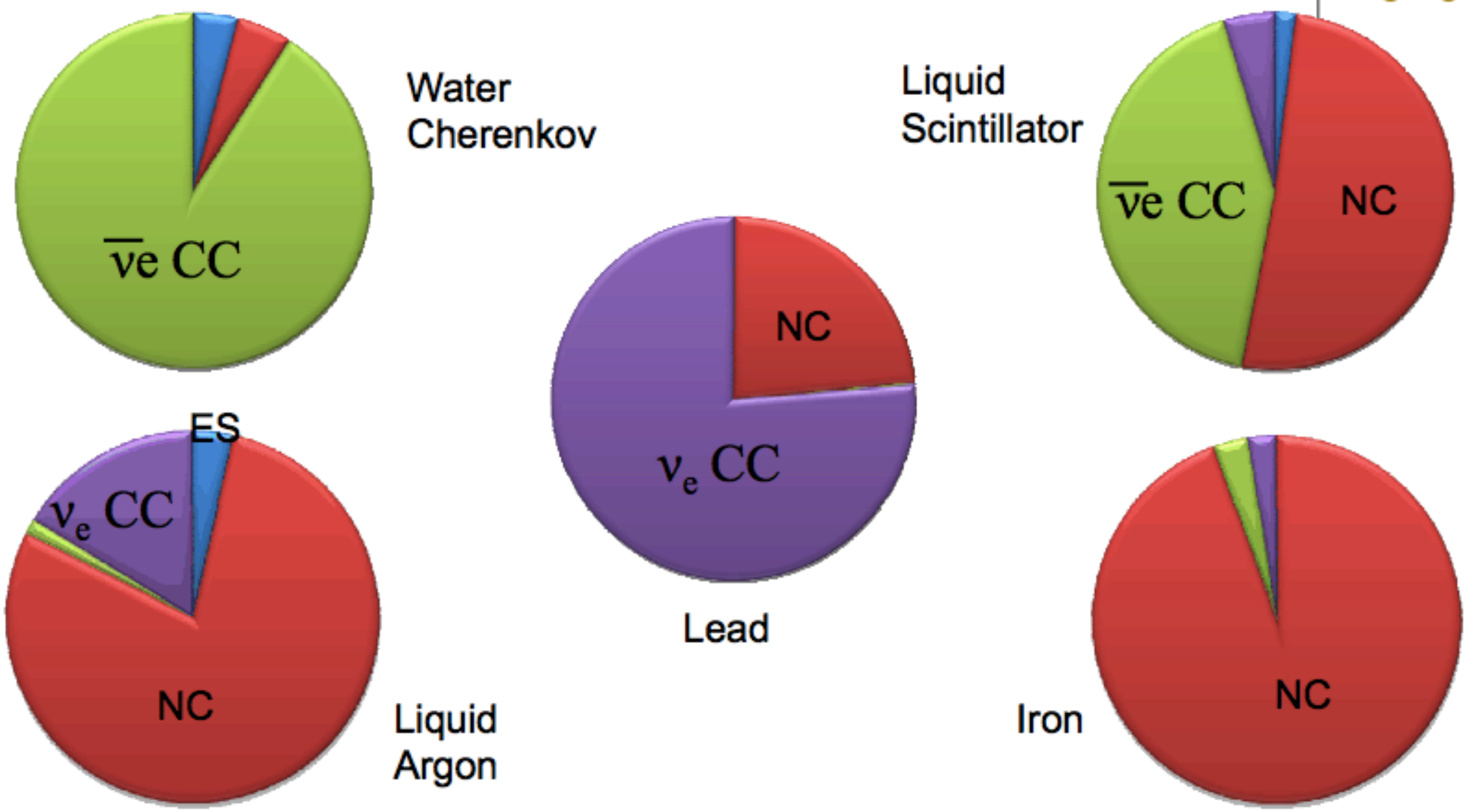
Thanks to all the speakers and to the participants for interesting discussion!

What is to be learned?

- Astrophysics
  - Explosion mechanism
  - Accretion process
  - Black hole formation (cutoff)
  - Presence of Spherical accretion shock instabilities (3D effect)
  - Proto-neutron star EOS
  - Microphysics and neutrino transport (neutrino temperatures and pinch parameters)
  - Nucleosynthesis of heavy elements
- Particle Physics
  - Normal or Inverted neutrino mass hierarchy, θ_{13}
  - Presence of axions, exotic physics, or extra large dimensions (cooling rate)
  - Etc.

C. Virtue

Flavour Sensitivities



A variety of technologies needed to access all of the flux!

C. Virtue

Signatures of supernova neutrino oscillations

Amol Dighe

Earth matter effects

- Identification of nonzero $p/\bar{p}$
- If primary fluxes are similar, identifying Earth effects is hard
- Multi-angle effects still to be understood
- Better results with ν_e spectrum $\Rightarrow$ Ar detector crucial

Shock wave effects

- Presence / absence independent of collective effects
- Stochastic density fluctuations: may partly erase the shock wave imprint
- Turbulent convections behind the shock wave: gradual depolarization effects

Neutronization burst signal

- Robust, but needs Ar detector with good time resolution

A. Dighe

Theory-independent measurements

Still too many uncertainties in fluxes, p and $\bar{p}$?

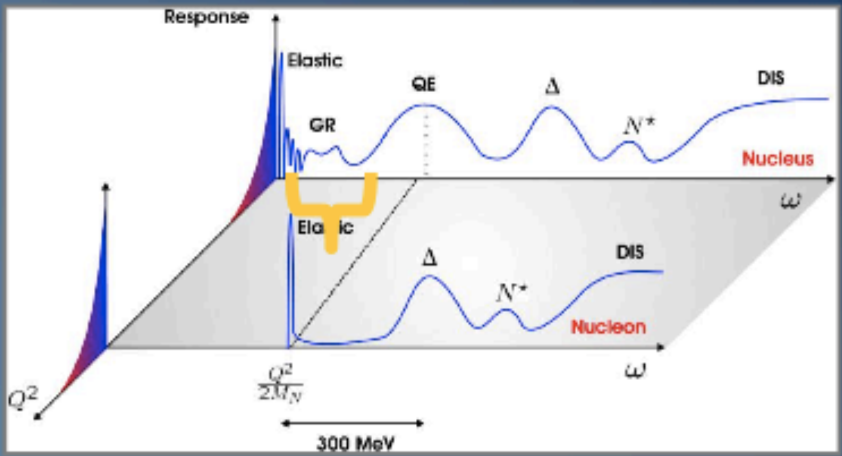
One can nevertheless make the following measurements / analyses:

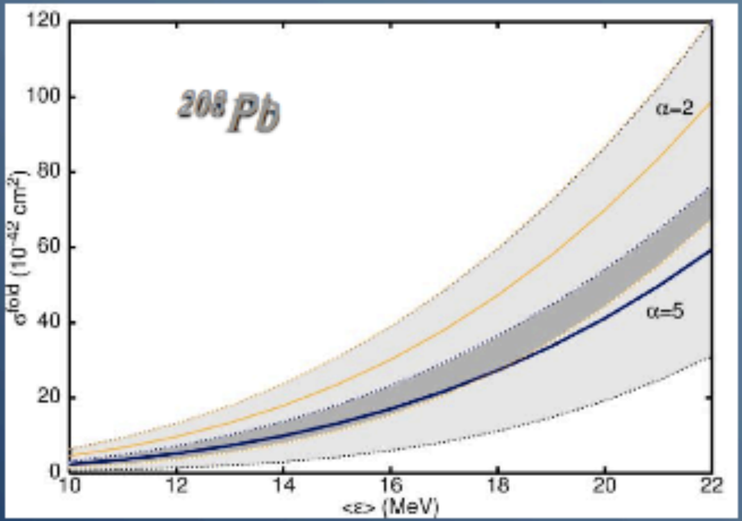
- ν_e and $\bar{\nu}_e$ spectra
- NC spectra through scintillation detectors
- single- and double-neutron events at Pb detectors
- Time modulation of flux, average energy, higher moments
- Time dependent, relative luminosities at two detectors
- Oscillatory spectral modulations for Earth effects
- Other non-thermal features in the spectrum

A. Dighe

Neutrino-hadron scattering ?

- little experimental data is available
  - small cross sections
  - no monochromatic neutrino beams





N.J. et al, PRC66, 065501 (2002) ;
E. Kolbe et al, PRC63, 025802 (2001) ;
J. Engel et al, PRD67, 013005 (2001)

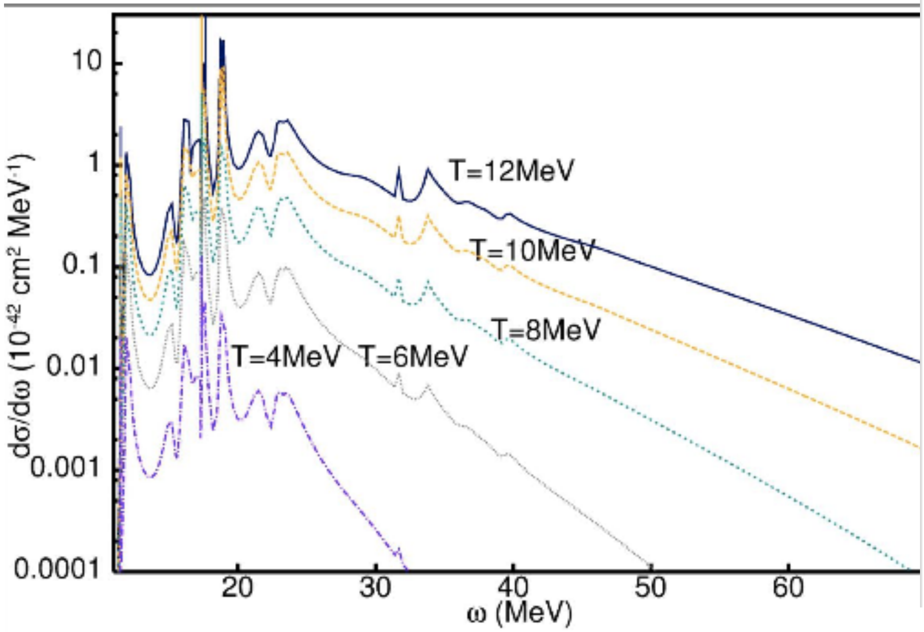
Uncertainties :

- one has to rely on theoretical predictions,
- uncertainties induced by model dependence
- and more fundamental uncertainties …

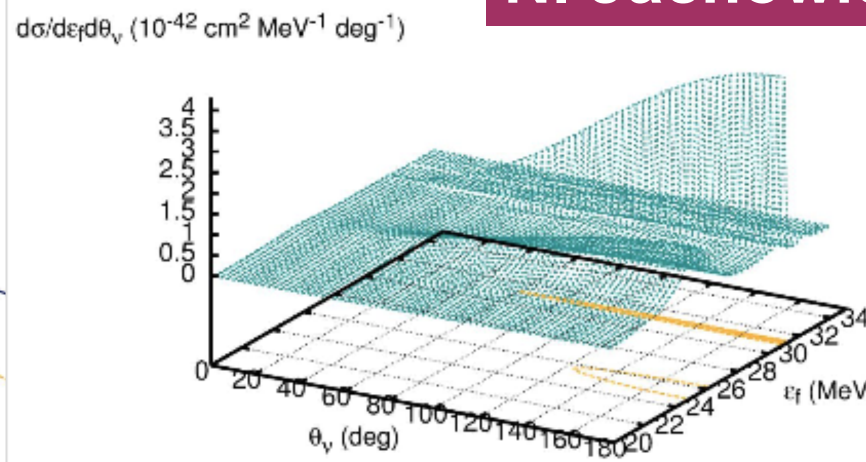
N. Jachowicz

Neutrino-nucleus cross-section calculations

N. Jachowicz



Spectra differential in nuclear excitation energy



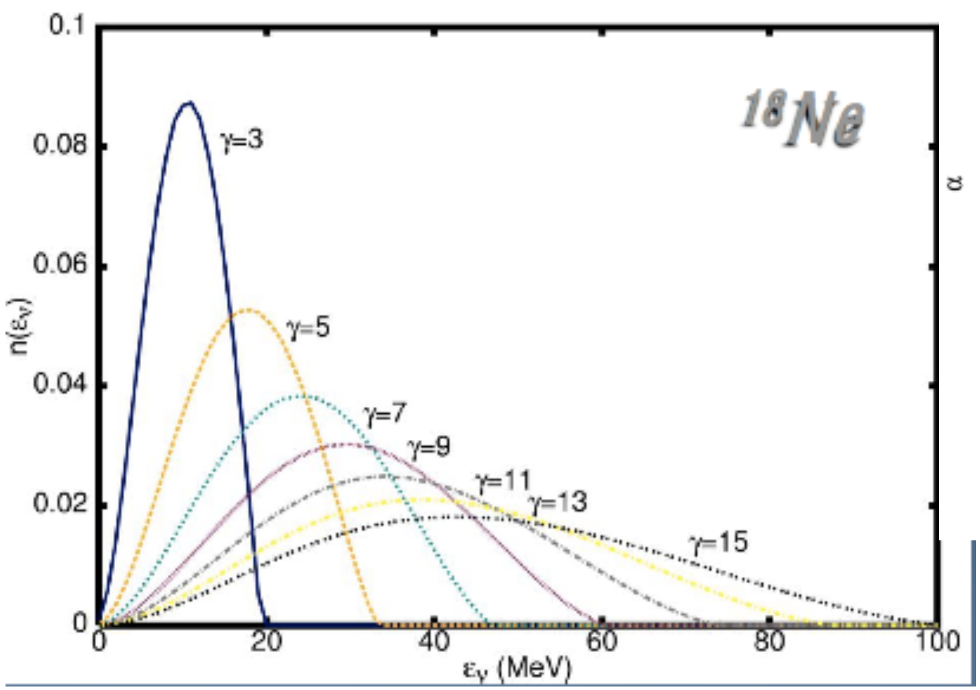
Angular information: very useful!

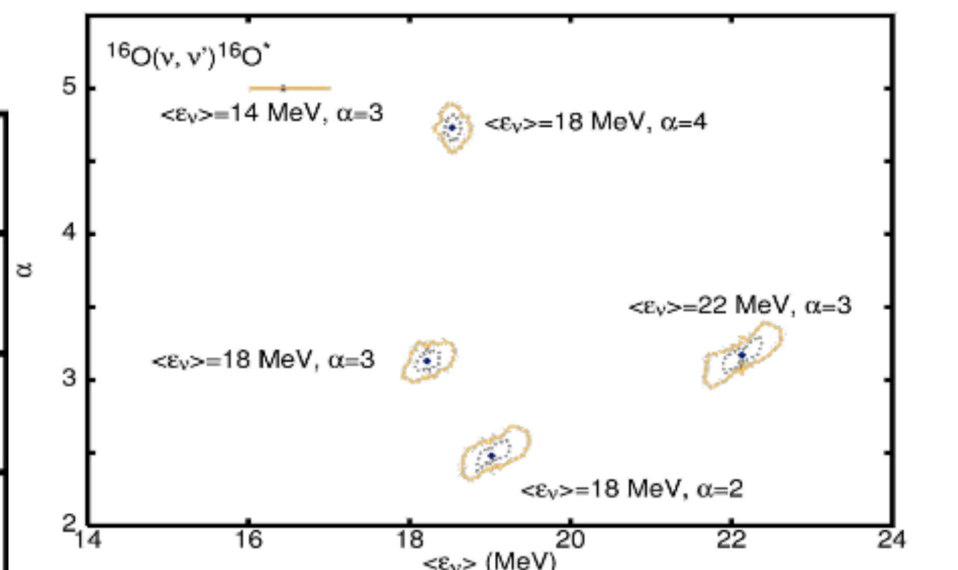
Note from an experimentalist: it would be extremely valuable to *have information on differential product spectra*, to help evaluate detector response to a given neutrino flux

"It's the nucleus' responsibility, not the neutrino's"

... can some experts help make the nucleus take some responsibility?

Use measured detector response to beta beams (with spectra tunable by boost) to disentangle neutrino spectra independent of details of nuclear response





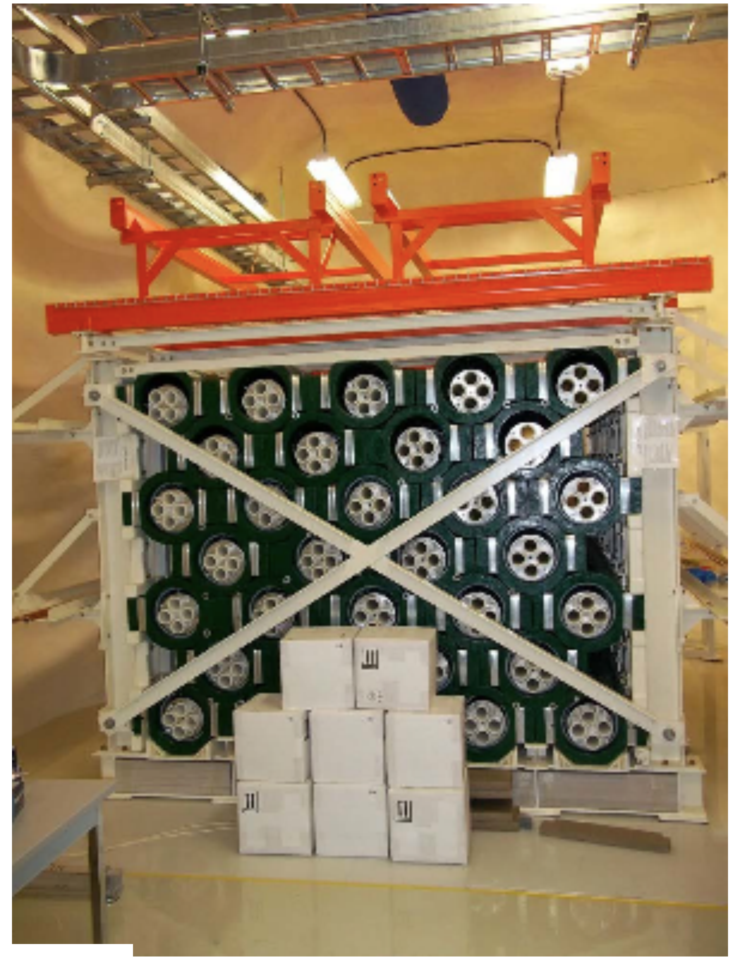
N.J., G. McLaughlin, PRL96, 172301 (2006) ; N.J., G. McLaughlin, C. Volpe, PRC77, 055501 (2008)

N. Jachowicz

HALO

being commissioned now..
operational by end of year!

- Lead Array (79 +/- 1% tonnes)
  - 32 three meter long columns of annular Lead blocks
  - 864 blocks total at 91kg each
- Neutron detectors
  - 4 three meter long ^{3}He detectors per column
  - 384 meters total length
  - 200 grams total ^{3}He
- Moderator
  - HDPE tubing
- Reflector (14 tonnes)
  - 15 cm thick graphite blocks
- Shielding (12 tonnes)
  - 30 cm of water



~ 88 neutrons liberated; ie. ~1.1 n/tonne of Pb

***~50% efficiency**

†- cross-sections from Engel, McLaughlin, Volpe, Phys. Rev. D 67, 013005 (2003)

Modest signal (>1987A!)... but future upgrades possible

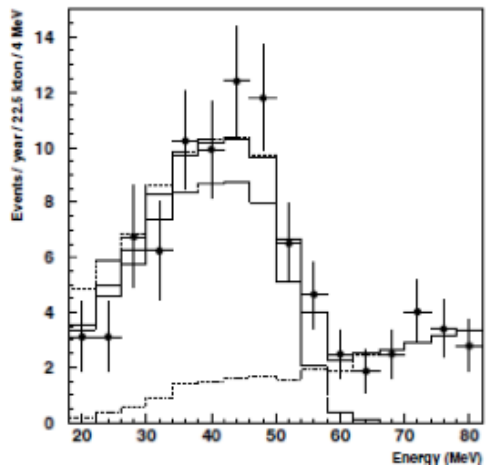
C. Virtue

New SK SN relic limit

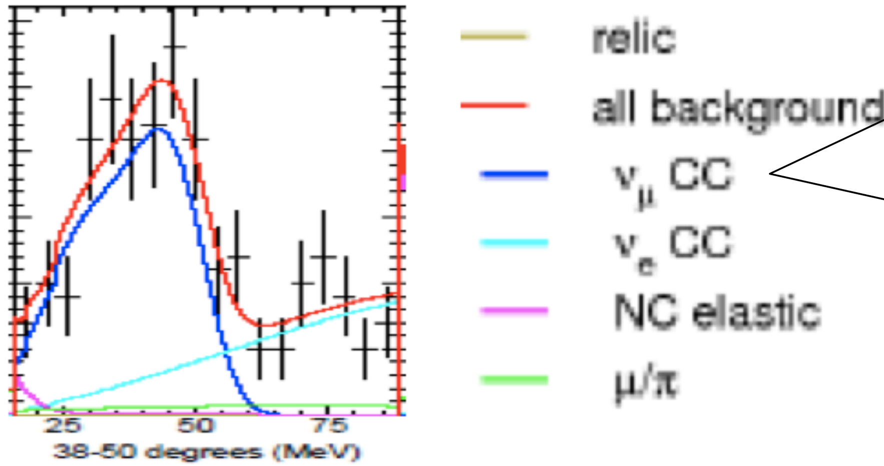
- Improvements: Spallation cut (E_{th}=16MeV←18MeV) and Cherenkov angle cut, Poisson statistics and MC calculations

  ($\sigma(\bar{\nu}_e + p \rightarrow e^+ + n)$, ATMν NC elastic+primary/secondary γ's, pion absorption)

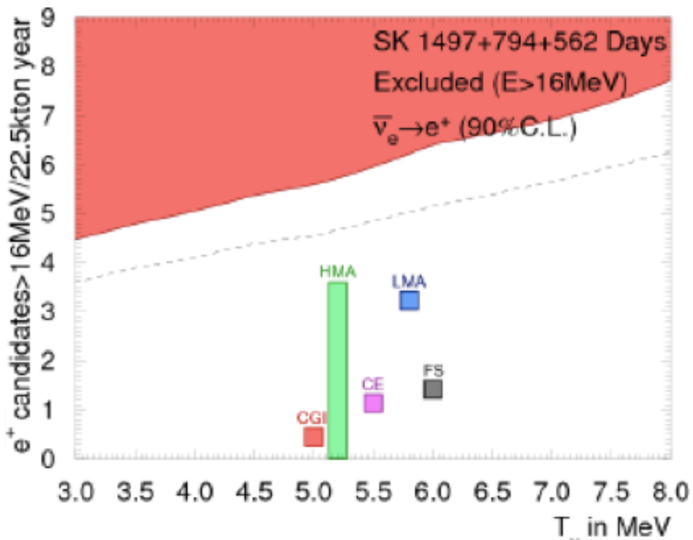
Malek et.al.(2003)



Bays et.al.(2011)



decay electrons from sub-Cherenkov threshold atmospheric-neutrino-induced muons



This result: flux<2.9 $\bar{\nu}_e$(1/cm²/sec) for E_e>16MeV @90%CL.

Malek(2003): flux<1.2 (1/cm²/sec) for E_e>18MeV

--Limit is not more stringent, but similar.

Need further bg reduction

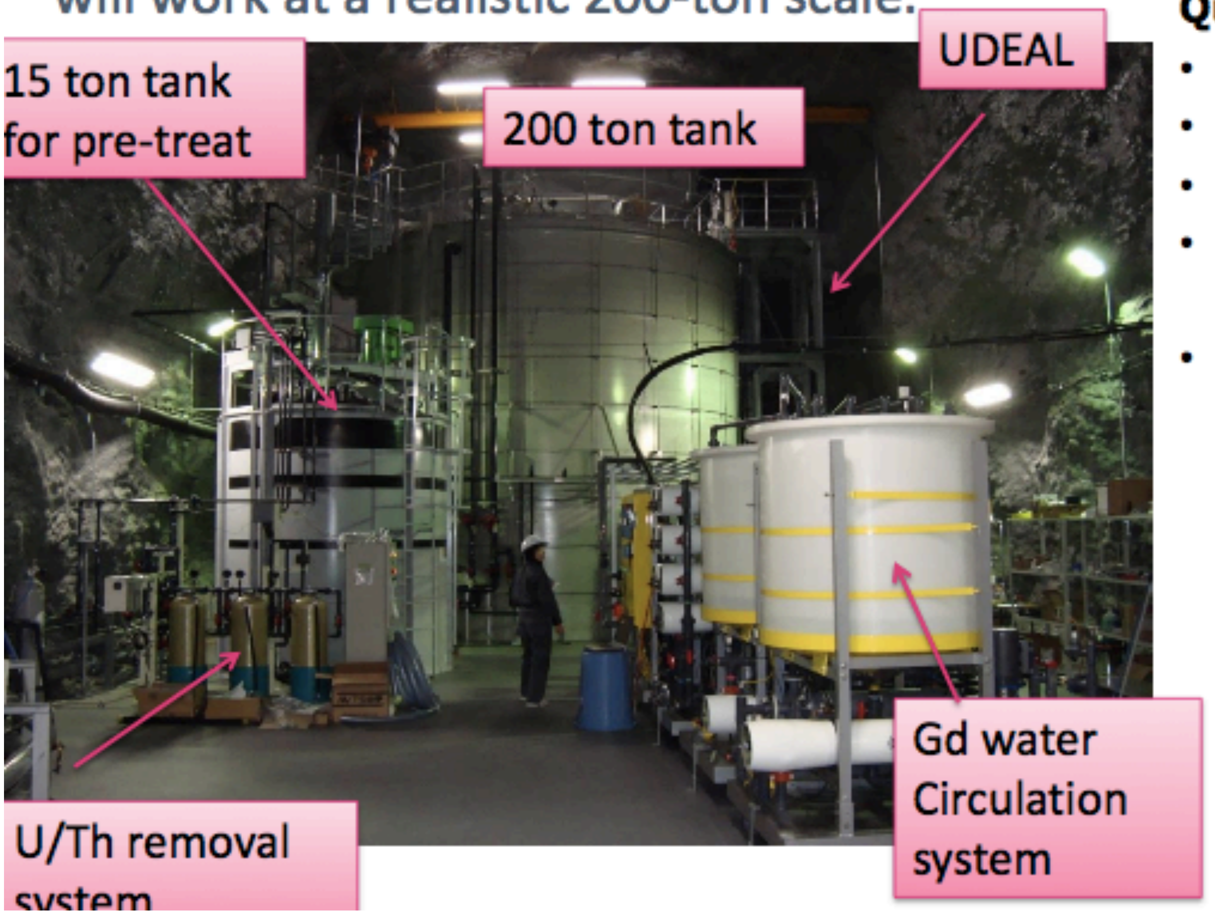
M. Sakuda

Study of potential atmospheric bg reduction by Gd tag of inverse beta decay: well underway!

3. 200-ton Prototype Detector [EGADS] (2009-2013)

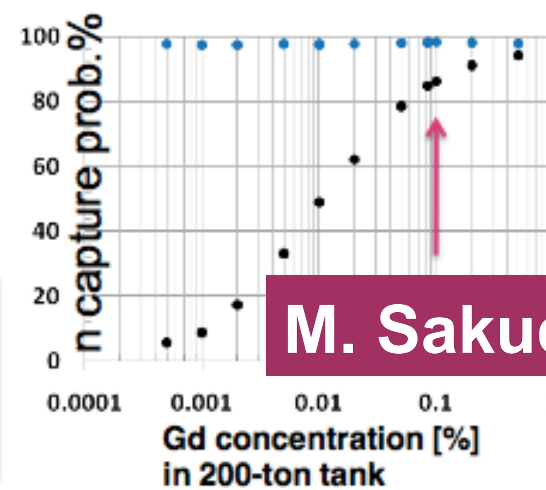
-Budget for 200-ton tank (EGADS) approved for 2009-2013 by JSPS (M.Nakahata,ICRR)

Purpose: Prove that a Gd-doped Water Cherenkov detector technology will work at a realistic 200-ton scale.



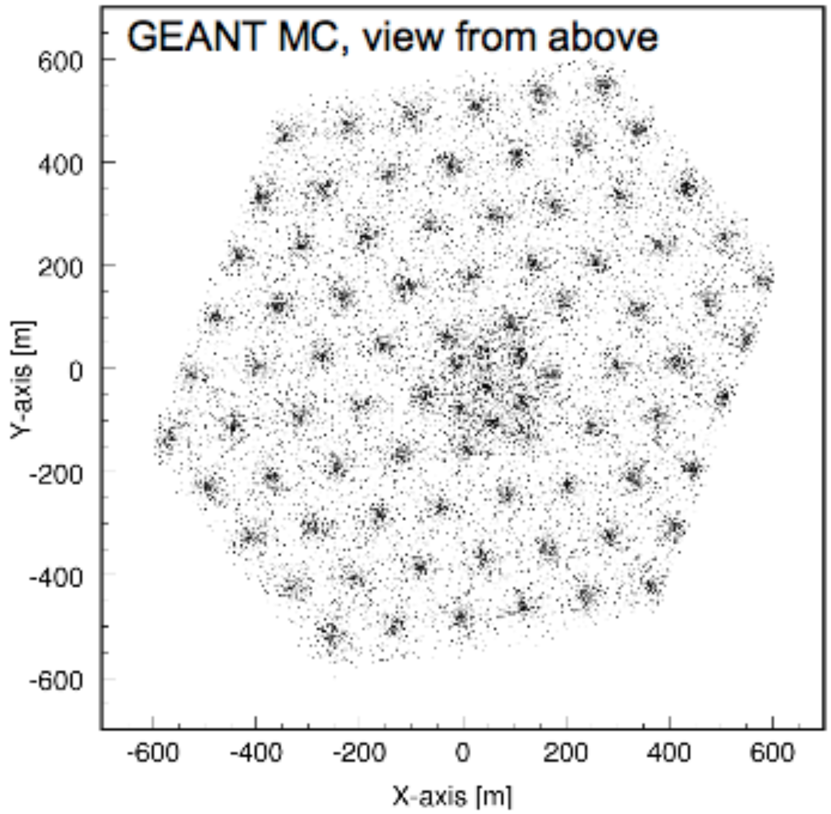
Questions to be answered:

- **Effect on materials?**
- **Water transparency?**
- **mix/remove Gd in water?**
- **Neutron tag efficiency? <90%max.**
- **Background rejection?**

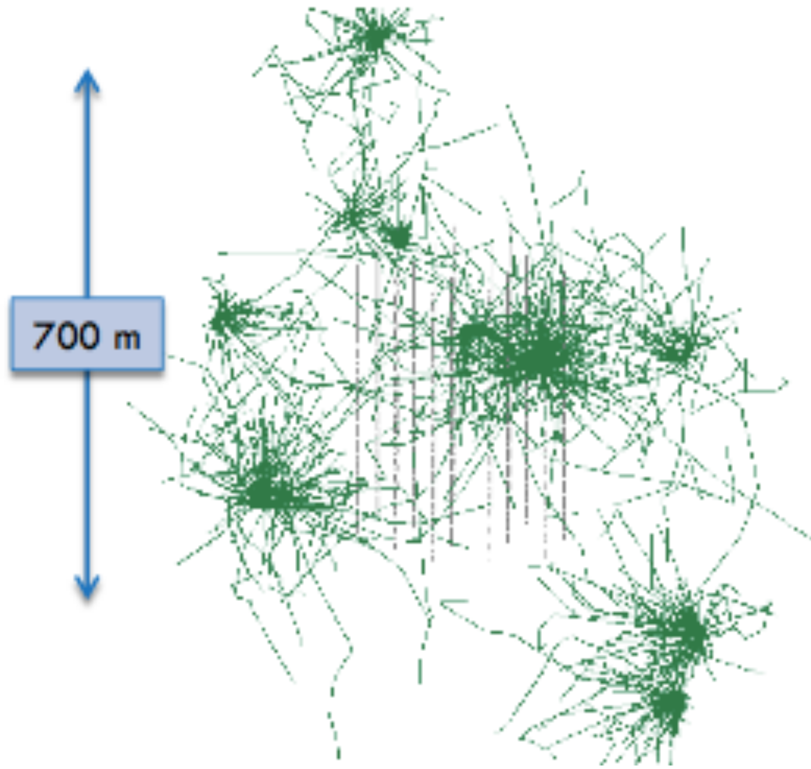


M. Sakuda

Interaction vertices in IceCube

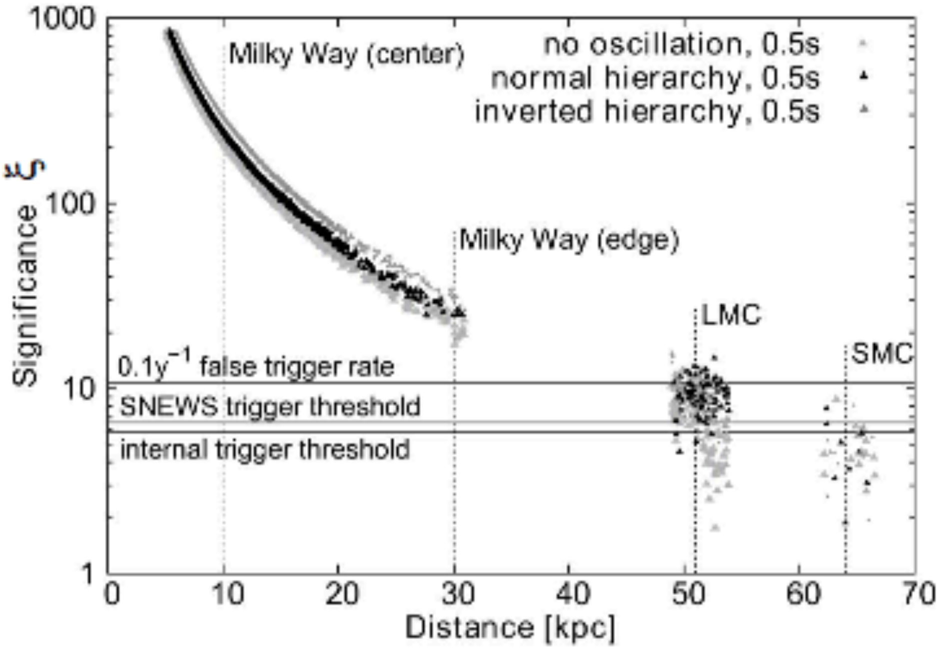


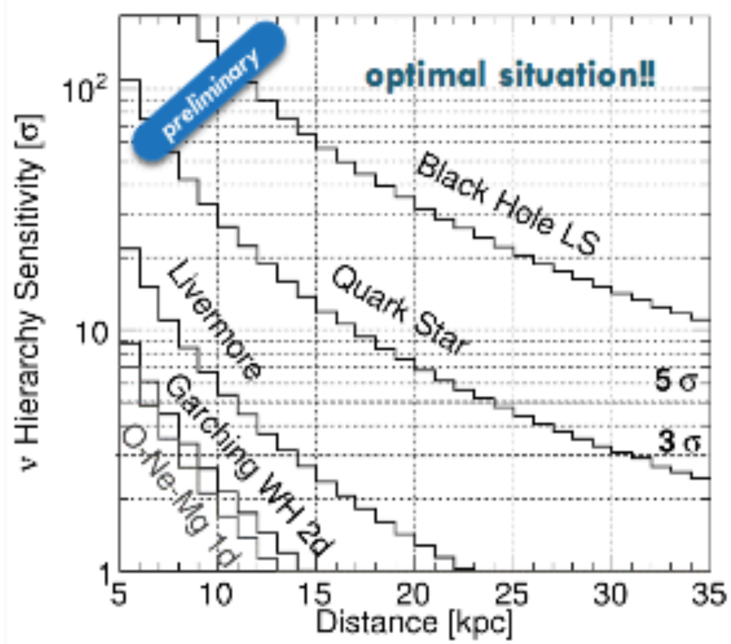
Cherenkov photons radiated by 10 e^+
(Avg. Energy 15 MeV, thinned out)



G. Kroll

Expected significance





ξ > 25 in Galaxy
ξ ~ 3-10 in Magellanic clouds

depends on detection technique as well
as model and neutrino properties …

G. Kroll

Neutrino-proton ES

ν_x spectral information

- Idea: *J. Beacom, W. Farr and P. Vogel, PRD 66 (2002) 033001*
- Recently revised: B. Dasgupta and J. Beacom, PRD 83 (2011) 113006

Detector	Threshold [MeV]	Events $<E_x>$=18 MeV		Events $<E_x>$=20 MeV
KamLAND	0.2	k_B=0.01+ 2nd order term	k_B 10% change	k_B=0.01+ 2nd order term
		68	65	93
Borexino	0.2	AmBe data (preliminary)	model w/k_B=0.011	AmBe data
		31	26	39
LENA-size	0.2	BX LS		
		5926		

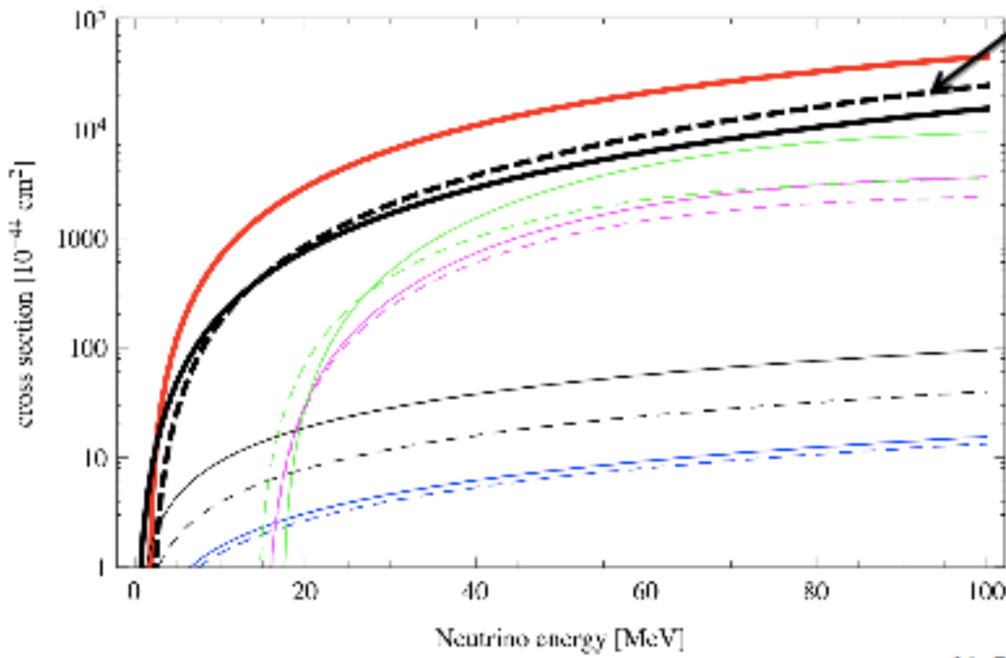
Fundamental: accurate measurement of proton quenching to reduce systematics in the determination of the incoming neutrino spectrum

A. Ianni

CC on ^{13}C: ν_e channel for LS?

$$\nu_e + {}^{13}C \rightarrow e^- + {}^{13}N(gnd) \quad E_{th} = 2.22\ \mathrm{MeV}$$

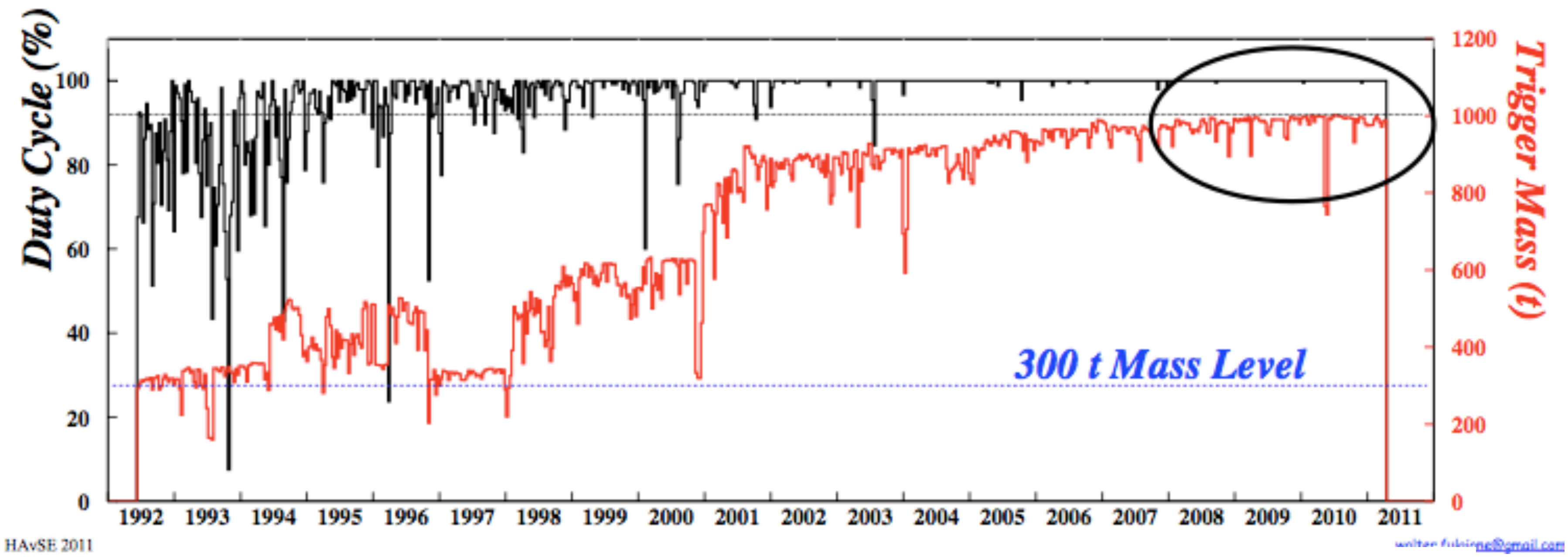
$$^{13}N \rightarrow {}^{13}C + e^+ + \nu_e \quad \tau = 862.6\ \mathrm{s}$$



AI, D. Montanino, F. Villante, PLB 627 (2005)

A. Ianni

- Next year LVD will celebrate twenty years of operation.



- The resulting 90% c.l. upper limit to the rate of gravitational stellar collapses in the Galaxy (D ≤ 20 kpc) is: 0.13 events/year

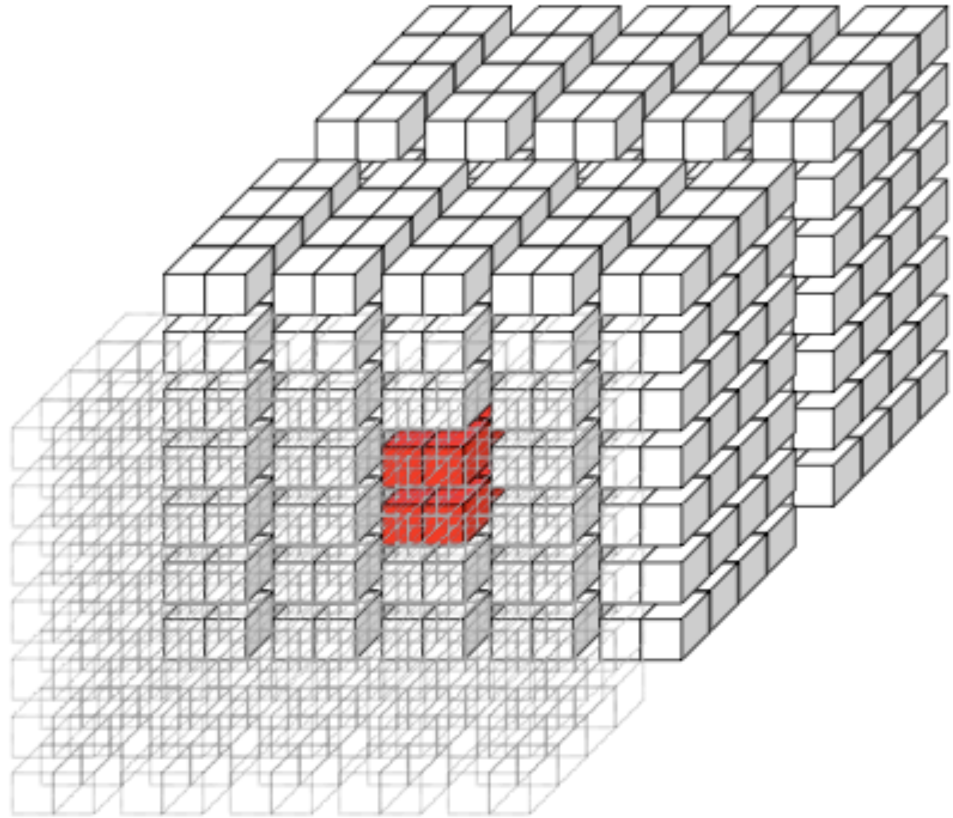
A great achievement!!

W. Fulgione

Future Possibilities for LVD

The LVD Core Facility

- An inner region inside the LVD structure could be effectively exploited by a compact experiment for the search of rare events, such as double beta decay or dark matter.
- This facility can be realized with a negligible impact on LVD operation and sensitive mass.



F.Arneodo and W.Fulgione, "A low background facility inside the LVD detector at Gran Sasso," JCAP 0902 (2009) 028. [arXiv:0808.1465 [astro-ph]].

+ Gd doping

GianmarcoBruno, Walter Fulgione, Ana Amelia Bergamini Machado, Alexei Mal'gin, Andrea Molinario, Amanda Porta and Carlo Vigorito JCAP 06 (2011) 024

W. Fulgione

Coherent Elastic Neutrino – Nucleus Scattering

$\nu + A \rightarrow \nu + A$

Neutral current

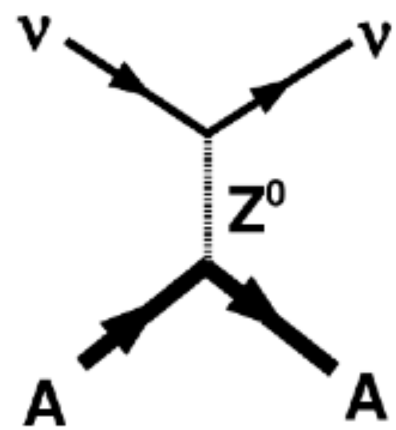
Coherent up to ~100 MeV

reactor, solar, spallation source, SN ν

$\sigma \sim 0.4 \times 10^{-44}\ N^2 (E\nu/\text{MeV})^2 \text{cm}^2$

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

Large σ ↑as Eν↑and scales as N^2



In the few-50 MeV range:

- Coherent ν-A elastic: $\sim 10^{-39}$ cm²
- ν-A charged current: $\sim 10^{-40}$ cm²
- $\bar{\nu}$-p charged current: $\sim 10^{-41}$ cm²
- ν-e elastic: $\sim 10^{-43}$ cm²

Potential SN detection channel:
few events/ton @ 10 kpc

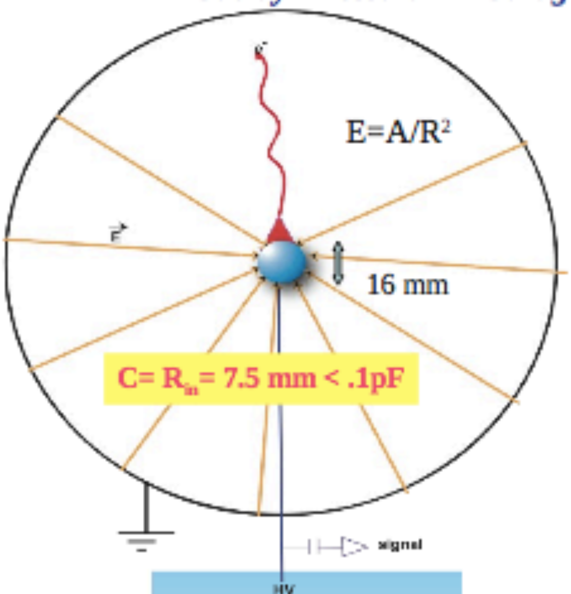
G. Tsiledakis

Novel idea for detection:
potentially very low energy threshold

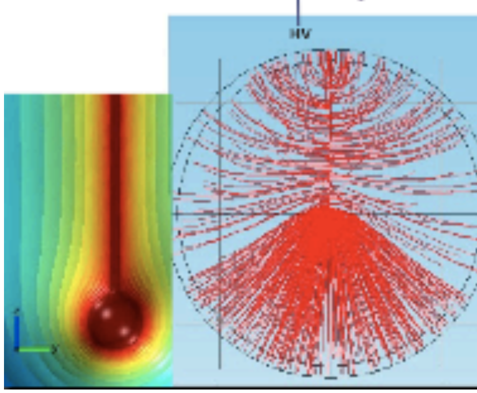
The Spherical Proportional Counter -Introduction

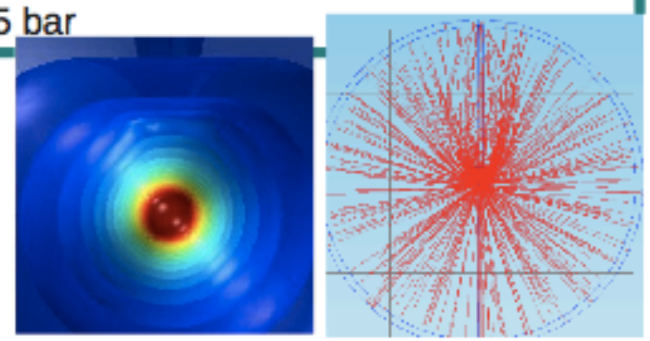
Radial TPC with spherical proportional counter read-out

Saclay-Thessaloniki-Saragoza



- A new detector was developed
- Spherical geometry
- Copper vessel with d ~ 1.3 m, 6 mm thick
- Proportional counter: small metallic ball with d ~ 16 mm in the centre ==> HV
- 2[nd] electrode (umbrella) 24 mm away from ball ==> electric field corrector
- Operation at seal mode
- Gas mbar - 5 bar





A Novel large-volume Sherical Detector with Proportional Amplification read-out, I. Giomataris et al., JINST 3:P09007,2008

G. Tsiledakis

Some final thoughts:

Inverse SN neutrino problem

very important!

Observe

- $\nu_e/\bar{\nu}_e$ spectra
- NC events
- time variation of the signal
- Earth matter effects

Determine

- Primary fluxes
- Shock propagation
- **Particle physics**

Note:in the US, the physicists, and the funding agencies, who will build the detectors care about this... and lab measurements could take some time

Not impossible, but many gaps still to be filled

A. Dighe

Understanding of detector response, and observability of physics signatures is critical for design (and funding) of the next generation of detectors

Are signatures really robust?
What could we actually infer given an actual neutrino signal? What physics questions could be answered crisply?

How do we optimize detectors to be sensitive to the cleanest physics signatures?
(argon vs water vs scint, energy threshold, siting ...)

A 'blind fake signal' to challenge the community?
... something to think about