

# **Short Baseline Oscillations of $\nu_e$ and $\bar{\nu}_e$ from Intense On-Line Radioactive Sources in LENS**

**Short Baseline Neutrino Workshop 11  
Fermilab May 12-14, 2011**

**R. S. Raghavan  
Virginia Tech**

**With Sanjib Agarwalla, Derek Rountree, Joe Wolf, Tristan Wright  
For the LENS Collaboration**

# **Intense (MCi) Radioactive Sources**

## **Long Considered in context of Solar Neutrino –Detectors**

**PURPOSE:** Neutrino Calibration of CC –Capture,  
Nu magnetic moment Search

Remote Reactor Produced:

- 65Zn L. Alvarez (1973)
- 51Cr R. S. Raghavan (1978)
- 37Ar W. Haxton (1979)
- 90Sr G. Bellini & R. S. Raghavan (B'Xino Prpsl 1991)
- Se92 V. Kornoukov et al (2004)

On Site Accelerator produced

- 8B Marrs et al (1973)
- 12N Adelberger et al (1993)

**The only source made so far is 51Cr for Gallex, SAGE  
by remote Nuclear Reactors**

# LENS—New application

## Unique features:

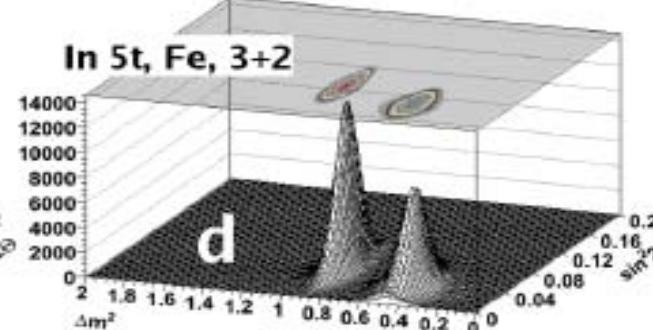
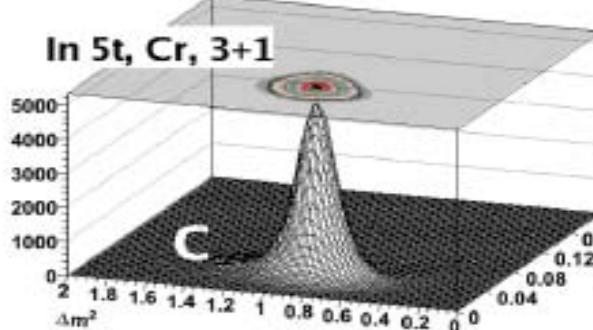
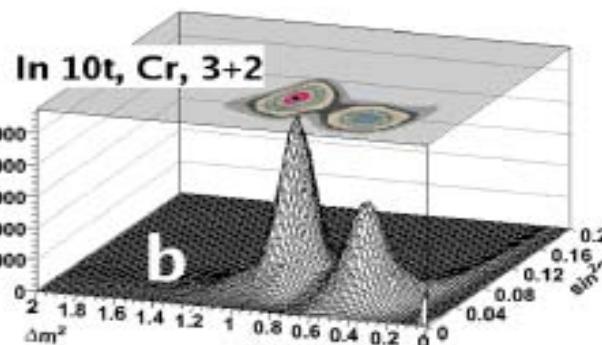
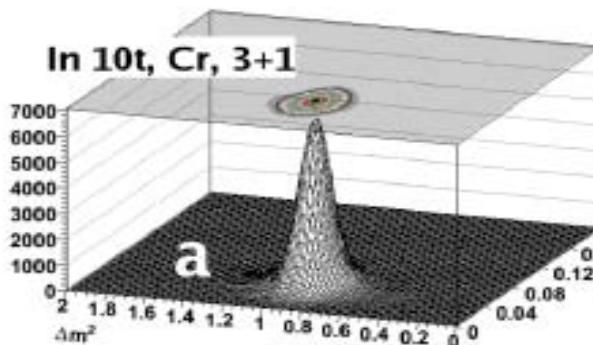
- Unsurpassed Background Control
- Very high granularity  
→Sharp event localization
- Small sources →  $\Delta L \sim 30$  cm
- Energy resolution →  $\Delta E$  small
- L/E in the right range: meters/MeV

MCi 51Cr for calibration part of LENS program

2007—New idea to apply the same experiment for Short Baseline Osc.

The first proposal to observe SB oscillation directly and explicitly, contained entirely in LENS. Dimensions of LENS (2-4m) tailored for contained waves for  $\Delta m^2 \sim 1 \text{ eV}^2$

**Data on Sterile Osc. Essential for Precision Calibration of nu capture cross section: Natural convergence of physics objectives**



Grieb et al  
PR D75, 2007

51Cr in LENS

# Present Focus

- On-Site Source Production—avoid transportation problems
- Internal and External Geometries
- Multiple sources for long lived cases
- Continuous production for short lived cases
- Nue, Nuebar Sources, Simultaneous measurement?
- Fission Sources (spontaneous, fast n induced)  
a la SCRAMM—aim for nuebar spectra for many fission sources

Source	Mean Life (s)	Prod. Reaction (MeV)	Power (kW)	Target Mass	$\sigma$ (mb)	E(v) (MeV)	v /year @ Source
$^6\text{He}(\bar{\nu}_e)$	1.17	$^9\text{Be}(n,\alpha)$	DT on site generator	300 kg	100	0-3.5	$2 \times 10^{22}$
$^{12}\text{N}(\nu_e)$	0.016	$^{12}\text{C}(p,n)$ (35)	(350)	0.7g	4	0-16.3	$4 \times 10^{22}$
$^{51}\text{Cr}(\nu_e)$	$3.45 \times 10^{-6}$	$^{50}\text{Cr}(n,\gamma)$ ( $n_{th}$ ) $^{52}\text{Cr}(n,2n)$	Nuc. Reactor DT on site n-generator	50kg 500 kg	16000 100	0.753	$10^{24}/10\text{MCi}$ $10^{23}/\text{y}$

TGT	Tag Reaction	$\sigma(\text{cm}^2)$	Tech	Tag $\gamma$ MeV	Delay $\tau$ ( $\mu\text{s}$ )	$L_{\text{max}}$ m	$\varepsilon$	$E_{\text{th}}$ MeV
p	$\bar{\nu}_e p \rightarrow e^+ n (\tau) \gamma$	$6 \times 10^{-42}$ @ 10 MeV	LS	2.2	$\sim 200$	$\sim 3$	$\sim 1$	0.2
$^{115}\text{In}$	$\nu_e^{115}\text{In} \rightarrow e^-$ $^{115}\text{Sn}^*(\tau) 2\gamma$	$3 \times 10^{-44}$ @ 0.8 MeV	LENS	0.616	4.5	$\sim 3$	0.67	0.1

# Source Details

$^6\text{He}$ : (100% beta: Endpt = 3.5 MeV; Tau = 1.15 s)

He production rate: ( $n,\alpha$ ) cross section = 0.1 b 20 cm thick BeO blanket:

$$S = 3.5 \times 10^{14} \times 10^{-25} \times 1.44 \times 10^{24} \times 3.1 \times 10^7 = 16 \times 10^{20} = 1.6 \times 10^{21}/\text{y}$$

Thick blanket  $\rightarrow$  50 cm – Rate =  $12/1.44 = 8.33 = 1.33 \times 10^{22}/\text{y}$

Thin Blanket rate =  $1.5 \times 10^{21}$

Thick Blanket rate =  $1.25 \times 10^{22}$

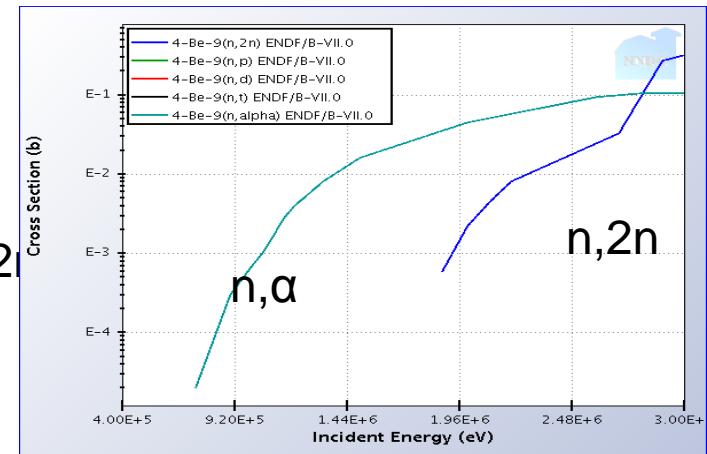
Maximum for  $10^{15}\text{n/s}$  (LBNL) = x3, x3 (estimate from n2n multiplication)

$\rightarrow$  Neutrino rate  $\sim 1.25 \times 10^{23}/\text{y}$

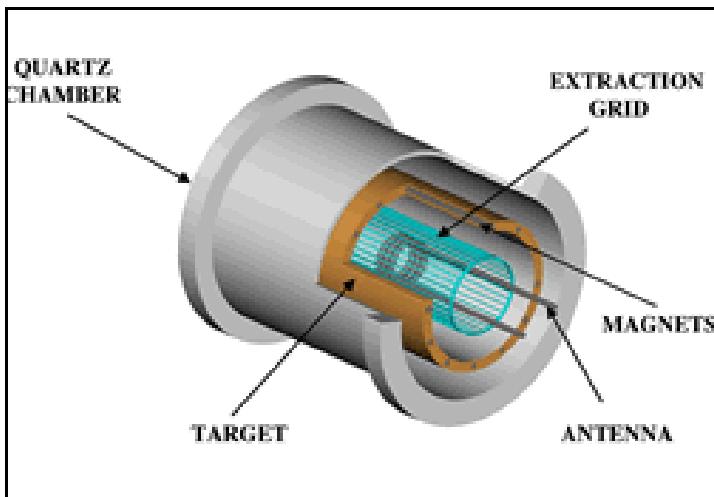
N-multiplication due to (n,2n):  $n,\alpha$

In the dT reaction (14.1 MeV) hardly any neutrons are lost to n,2n because even after successive n,2n extra neutrons are produced and the neutron flux grows with enough energy to make the Be(n, $\alpha$ ).

Rough estimate, x3 enhancement



# Compact Sources for 14 MeV n production: Info from LBNL website

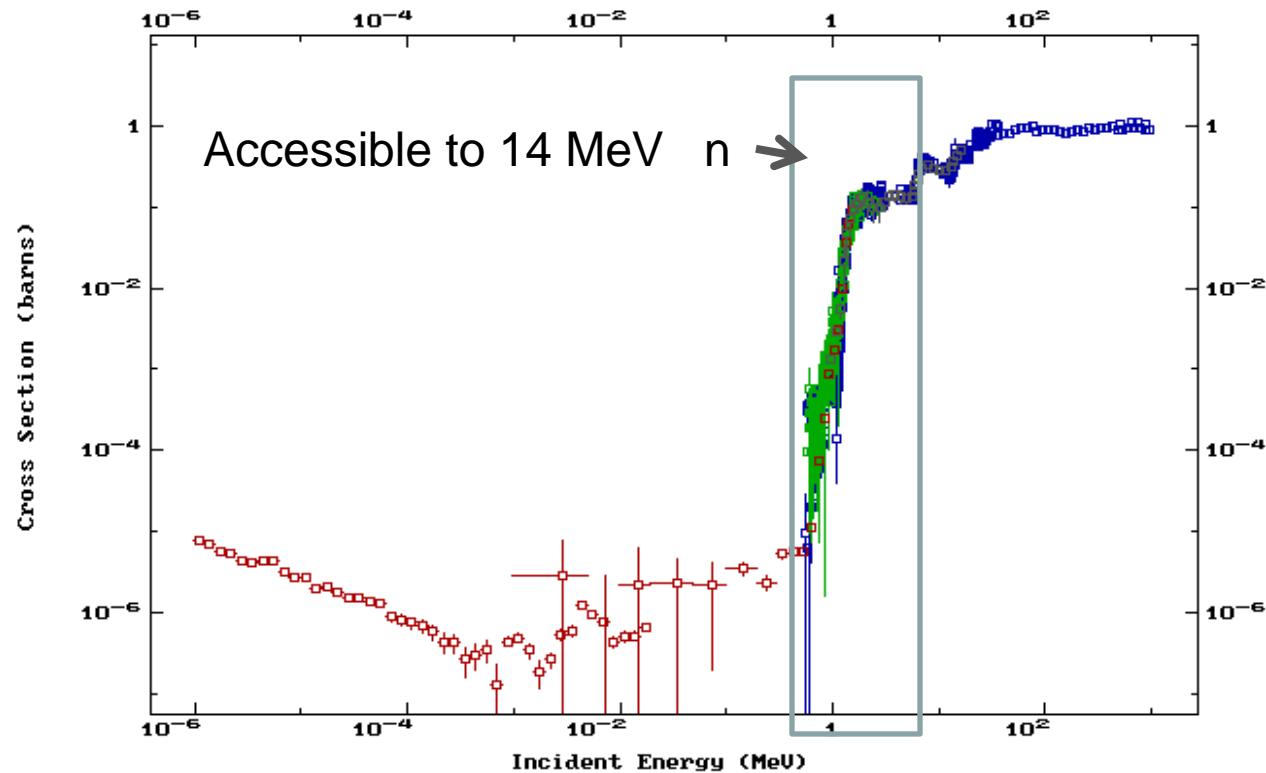


A cylindrical neutron generator configured to approximately 20 cm in length.

The single target coaxial neutron generator with dimensions of **26 cm in diameter and 28 cm in length** is expected to generate a 2.4 MeV D-D neutron flux of  $1.2 \times 10^{12}$  or a **14 MeV D-T neutron flux of  $3.5 \times 10^{14}$  n/s.**

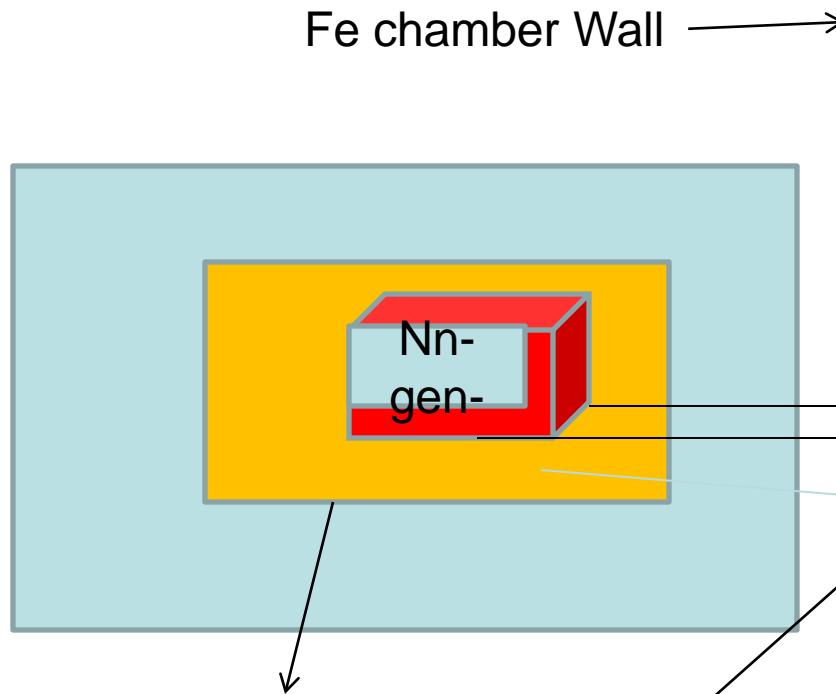
An adaptation of the coaxial generator design uses a versatile nested configuration with multiple plasma and target layers where ion beams can impinge on both sides of the targets to enhance neutron yield. A generator with this nested design and dimensions of 48 cm in diameter and 35 cm long should generate a neutron output 10 times higher than the single target generator described above. Thus, D-D neutron output higher than  $10^{13}$  n/s and **D-T neutron output of  $10^{15}$  n/s should be attainable.**

98-TH-232(N,F)  
EXFOR Request: 38921/1, 2011-May-14 01:11:45

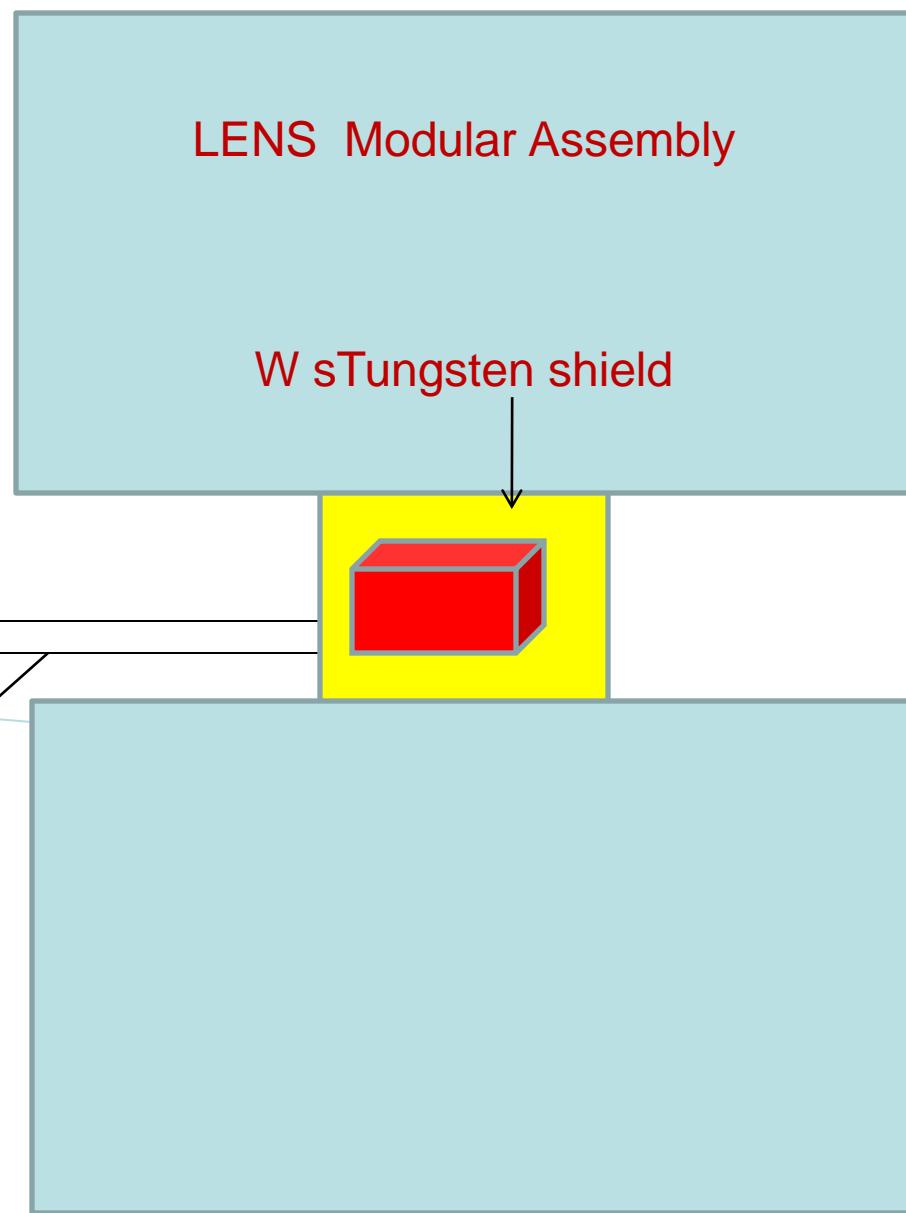


**Neutron multiplication via Th lining of n-generator target inducing fast-fission of Th that releases more neutrons**

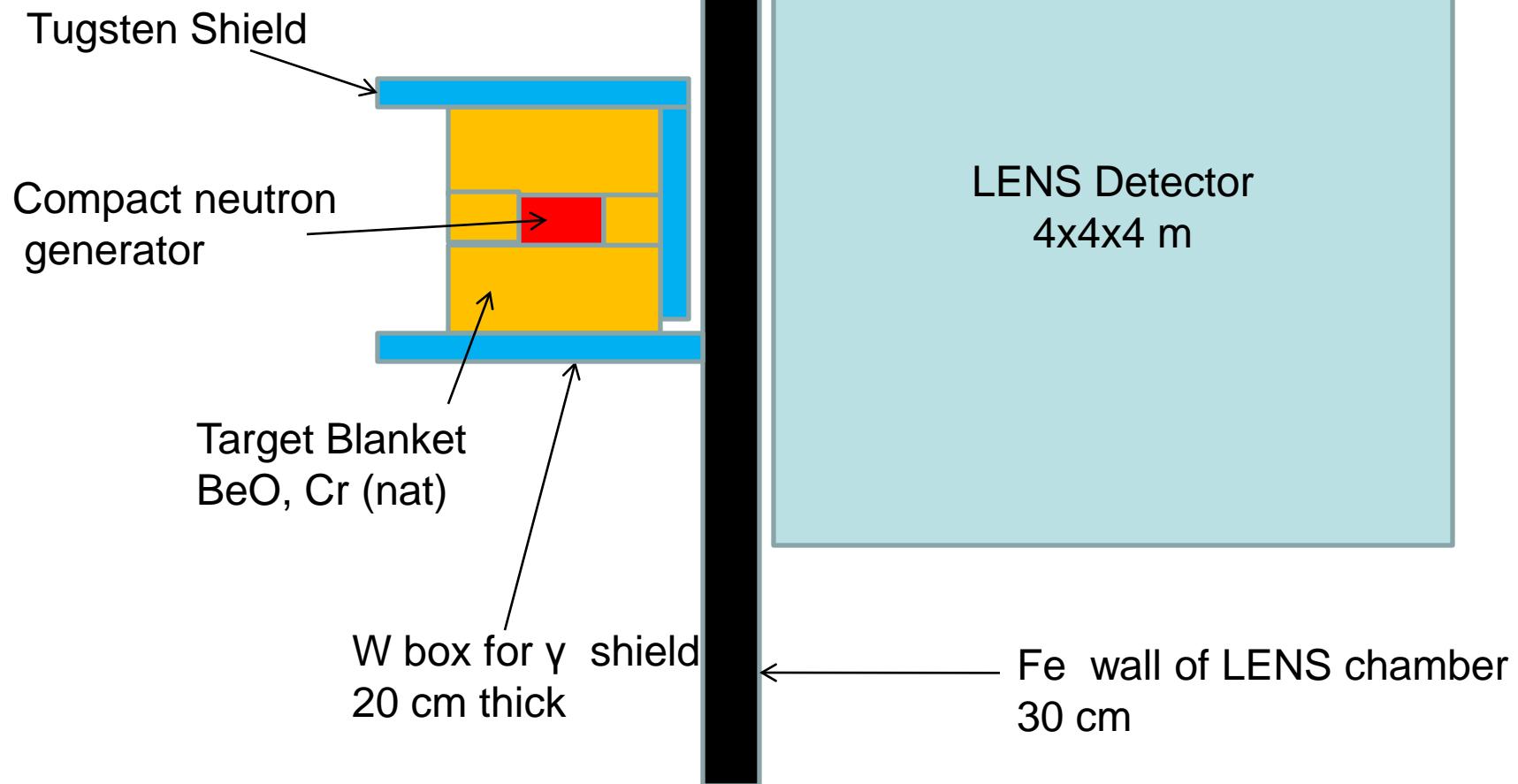
## On site Irradiation and Source insertion into modular detector

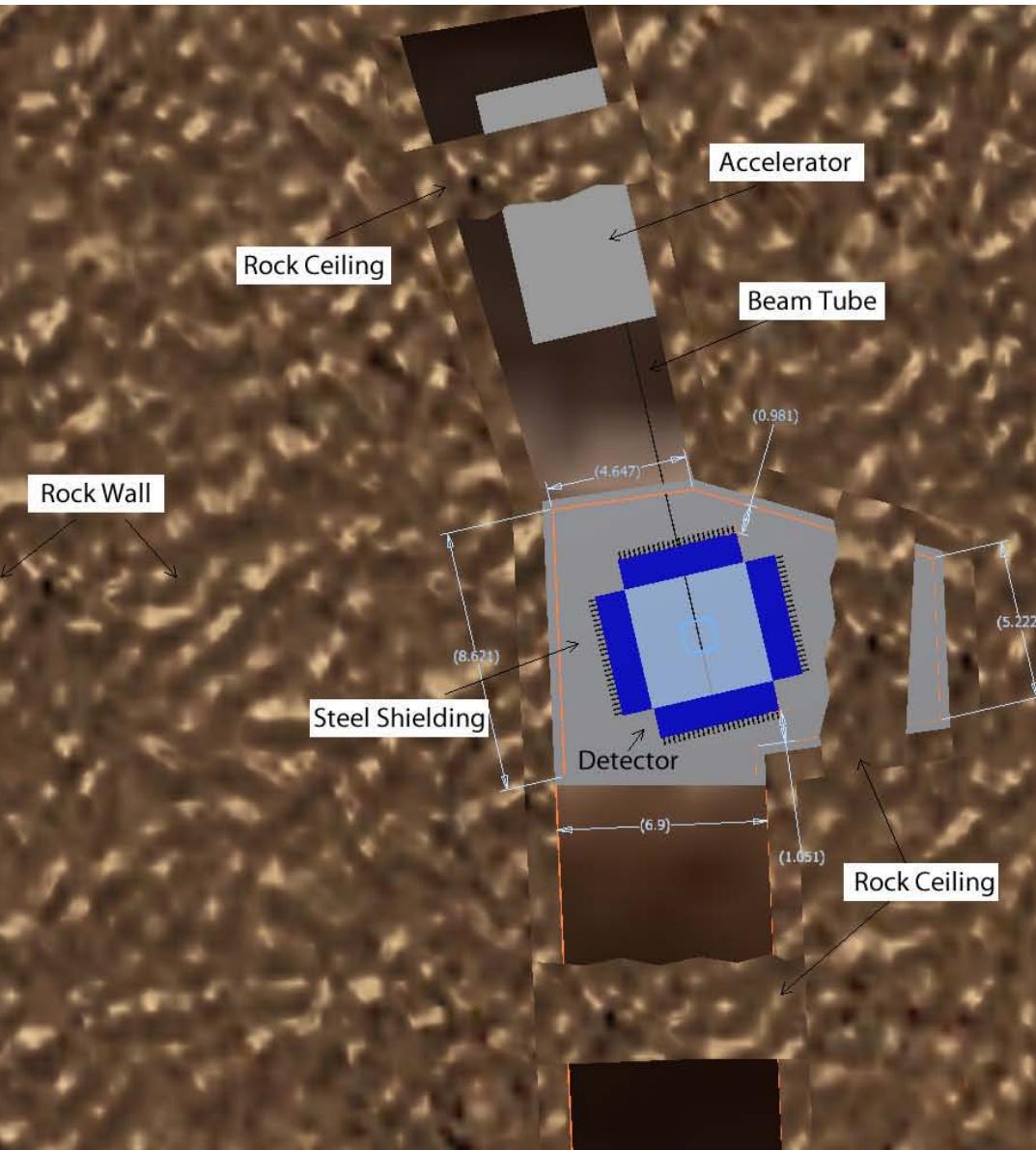


## LENS Chamber

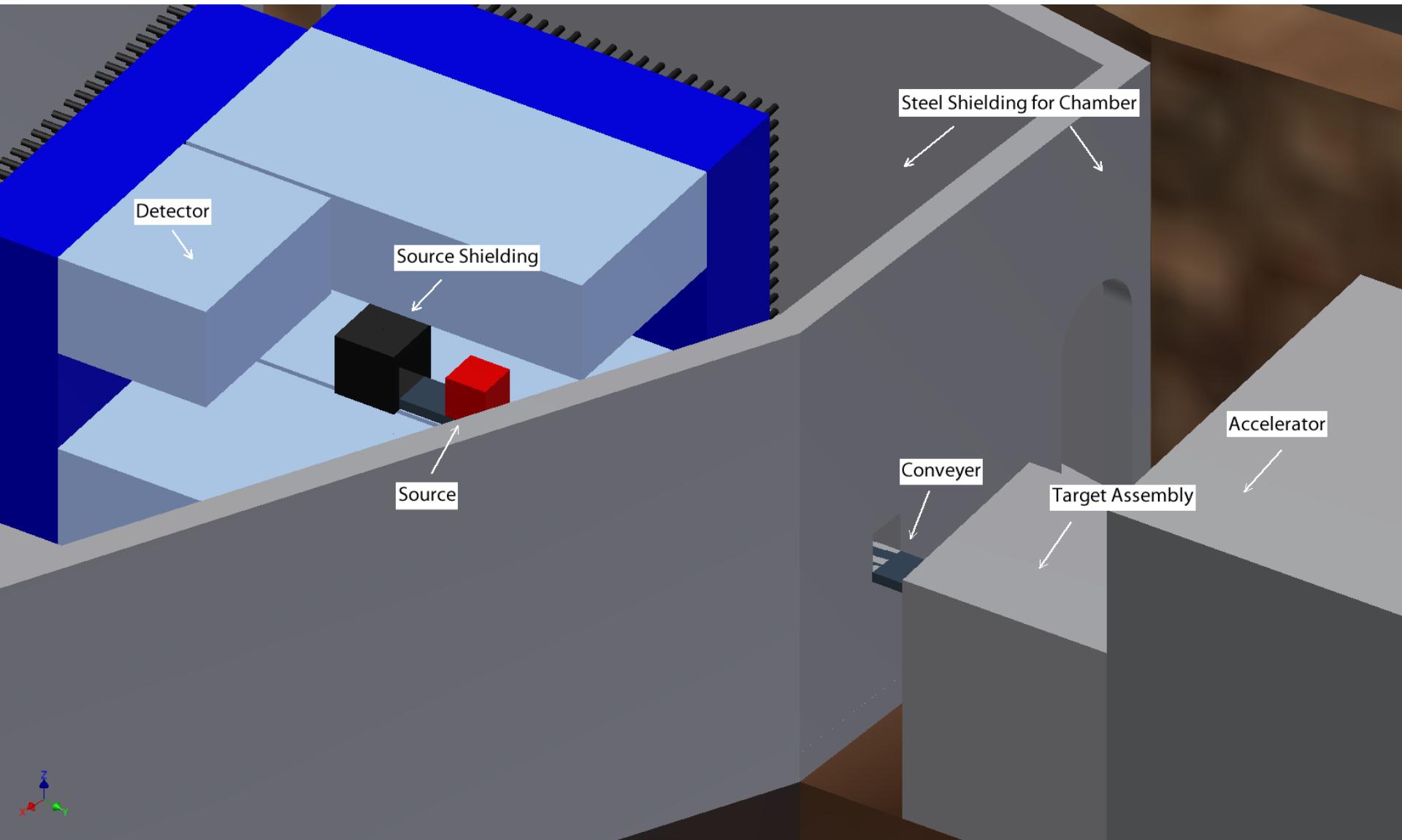


# On-Site Production of Neutrino Source for SB Osc Search in LENS





R. S. Raghavan SBNW11  
Fermilab May 12-14 2011



R. S. Raghavan SBNW11  
Fermilab May 12-14 2011

# The Kimballton Underground Facility



Fermilab May 12-14 2011



# Background

- Bremsstrahlung (Internal (EC), Thick Target ( $\beta\pm$ ))
- $\gamma$ 's from Contaminant activities from other target reactions as well as impurities in target

## Background Management

- Reaction tags

Time Coincidence (the Indium tag (nue), nuebar+p –neutron

- Space coincidence

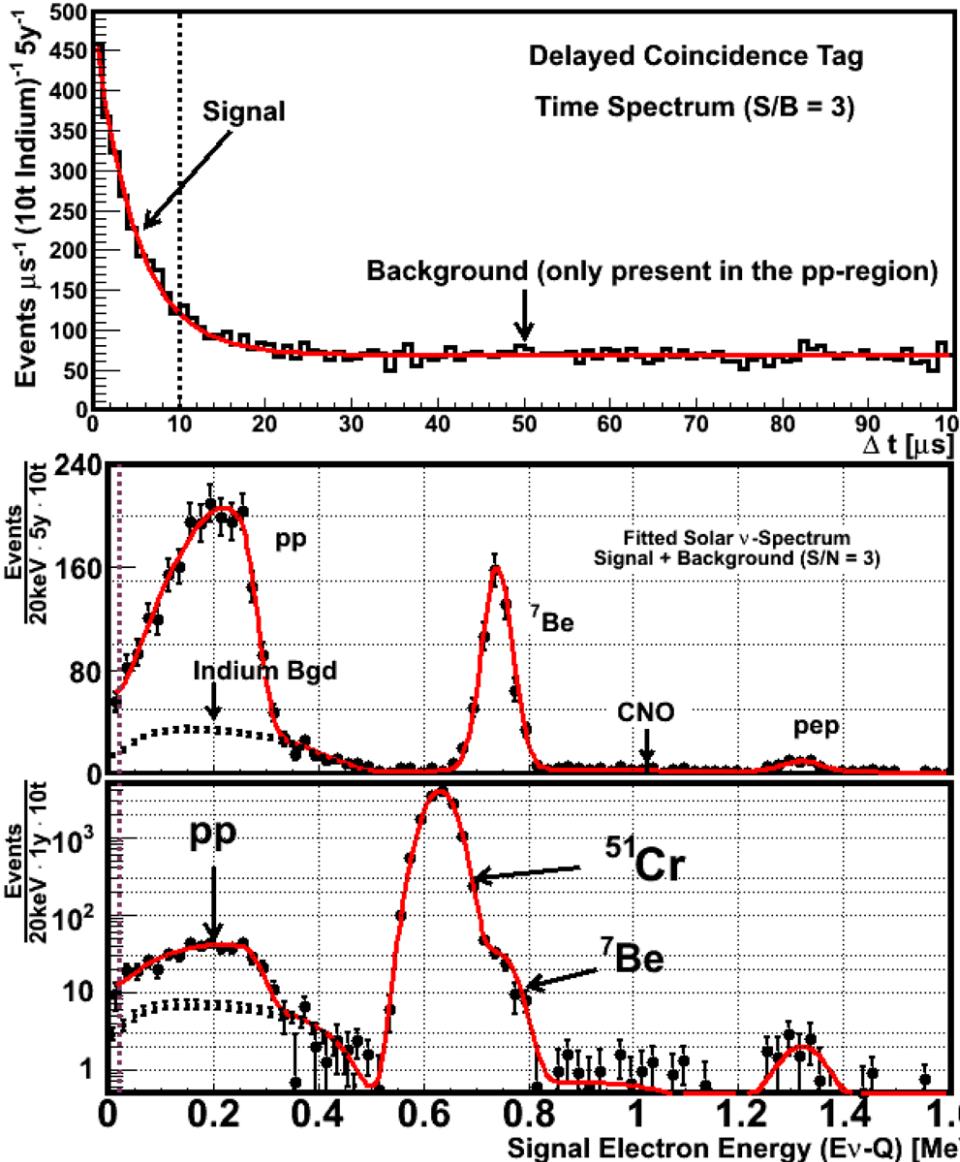
- Overall suppression: 3x10E-14 for nue; 6x10E-4 for nuebar

- Tungsten Shielding 10cm: 2x10E-12 For 500 keV  $\gamma$

- 2.5x10E-4 for 2 MeV

## Backgrounds ENORMOUS

Crucial role of Time and Space Tags (nuebar tag less efficient than the nue tag of the indium reaction



Simulated 5-year solar  $e$  signal spectra in LENS.

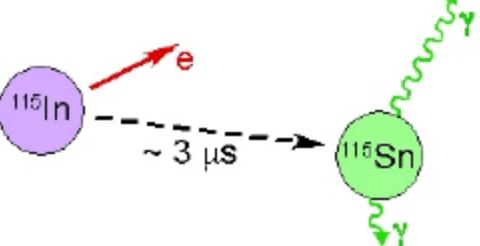
Top panel: delayed coincidence time spectrum fitted to the isomeric lifetime 4.76 s.

Middle panel: energy spectrum (with 2000 pp events) at delays  $< 10 \mu\text{s}$ , and random coincidences (from the pure decay of In target) at long delays.

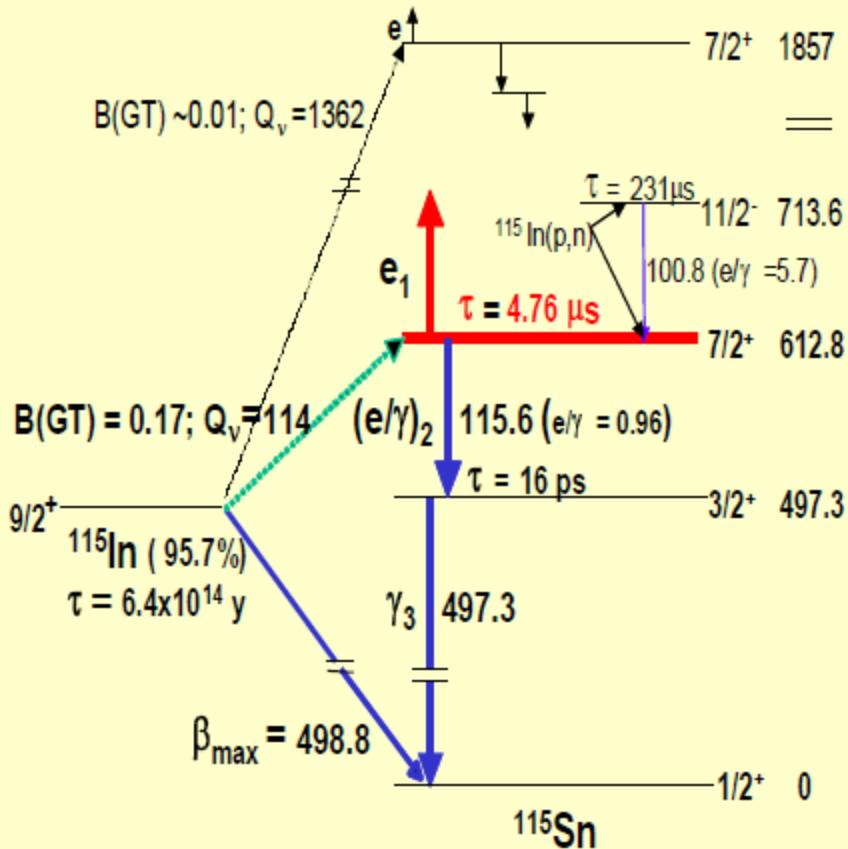
Bottom panel: Spectrum from 4 100 day exposure to a 10 Mci source of  $^{51}\text{Cr}$  with the scaled solar spectrum included. The Cr signal has 1:3 104 events with 0:1% background (from the  $^7\text{Be}$  line).

## LENS-pp $\nu$ -Detection With Signal

RSR –Phys Rev Lett 37, 259m 1976



### The Indium Low Energy Neutrino Tag



### Unique:

- Specifies  $\nu$  Energy
- $E_\nu = E_e + Q$
- ALL LE nu's from the sun**
- Lowest  $Q$  known  $\rightarrow 114 \text{ keV}$   
 $\rightarrow$  access to 95.5% pp nu's
- Target isotopic abundance  $\sim 96\%$
- Powerful delayed coinc. Tag

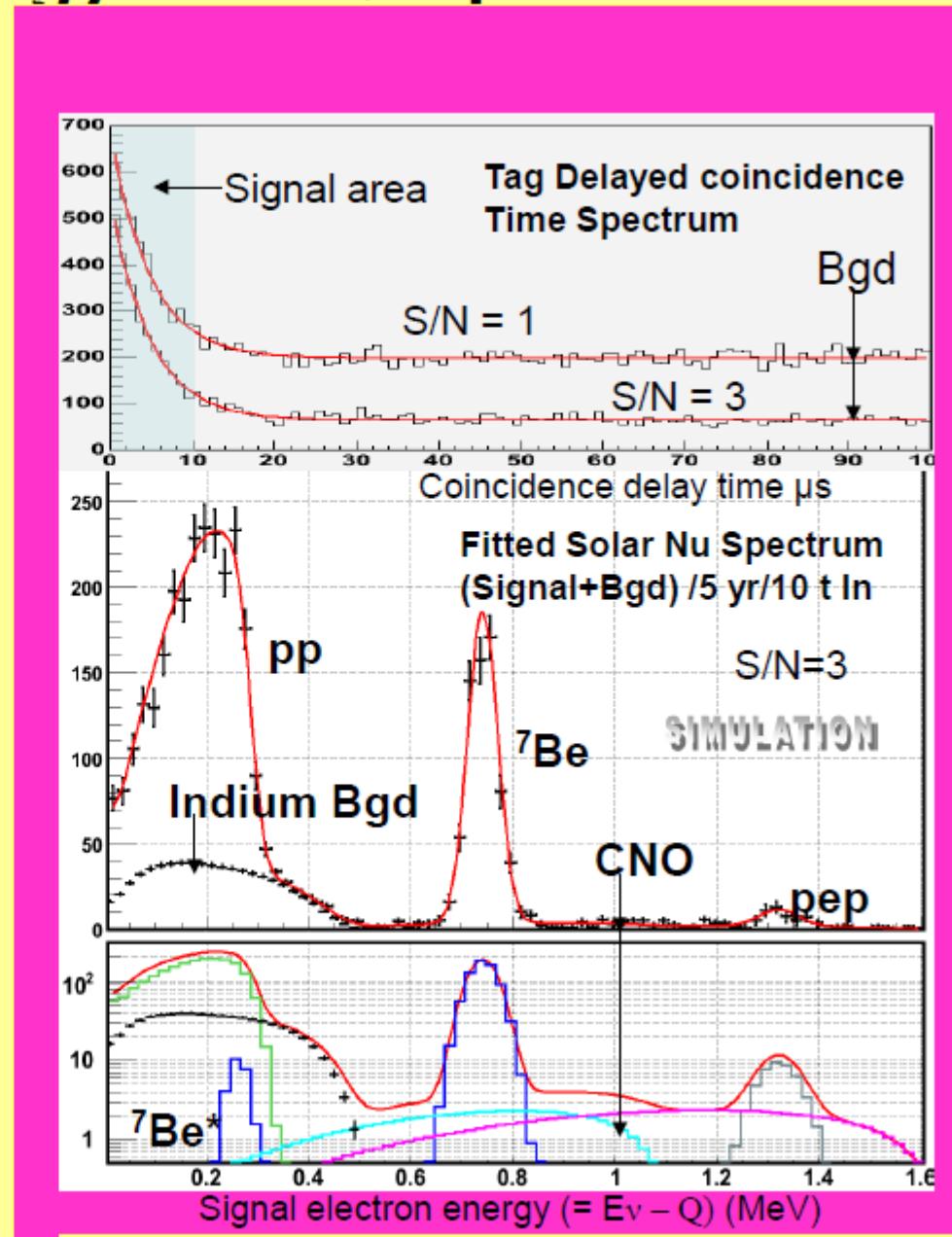
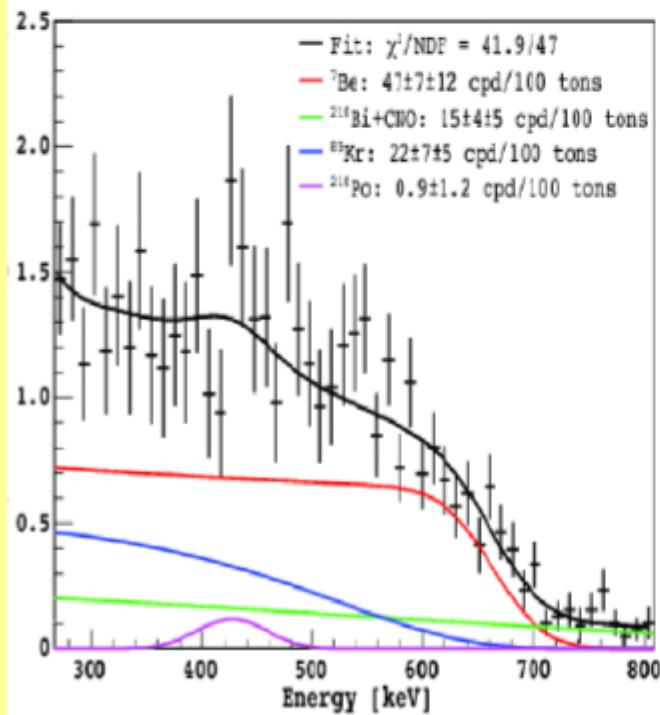
Can suppress bgd =  $10^{11} \times$  signal

1. Time & Space coinc.  $\rightarrow$  Granularity  
( $10^7$  suppression already)
2. Energy Resolution—important for In betas  $< 500 \text{ keV}$ ;  $\sum \text{Tag} = 613 \text{ keV}$   
 $\rightarrow$  Liquid Scintillator  $\rightarrow$  Properties
3. Other analysis cuts

# LENS Goal: Low Energy Solar $\nu$ -Spectrum

Neutrino Signature !

- (cf Borexino event –no tag  
→ Radiopurity  $<10^{-13}$  g/g  
(Cf. Borexino  $10^{-17}$  g/g)
- ALL Bgd: MEASURED Live with Signal
- *No uncertainty of bad*



# TECHNOLOGY: Basic Tools for Background Strategy

*Granularity:* B varies as  $m/M$ ; S/N varies as  $1/m$   
 $M$ =mass of In in cell;  $M$  total mass of Indium

*Energy resolution:* overlap of residual background features on solar signal

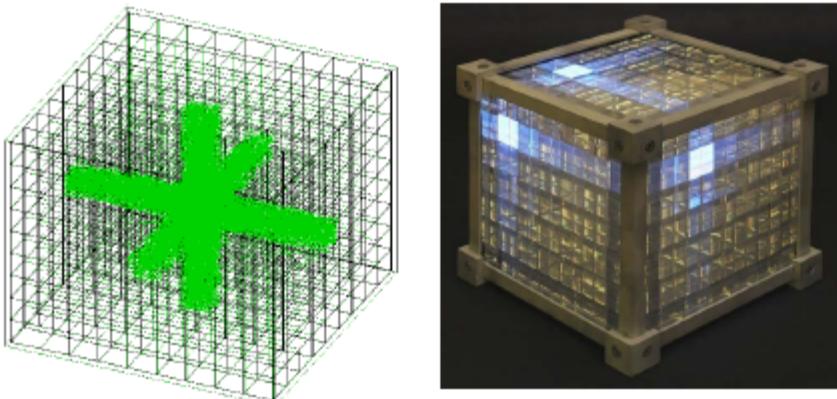
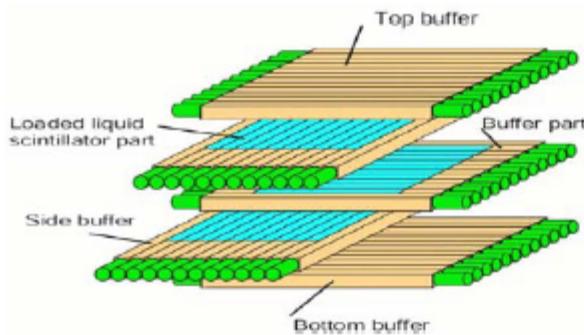
# Evolution of LENS Granular Designs

Design Idea

Cell Resolution

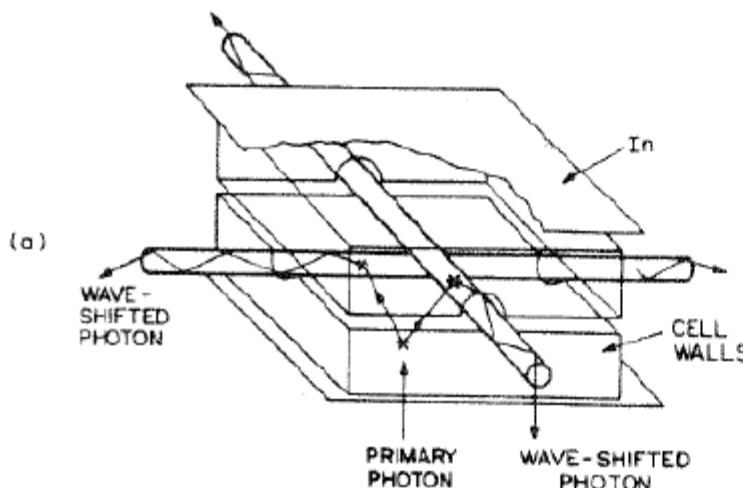
1D Longitudinal  
Array (1998)

$$\begin{aligned} M/m &= 2 \times 10^4 \\ m &= 350 \text{ g In} \\ (M &= 10 \text{ t}) \end{aligned}$$



3D Scintillation  
Lattice Chamber:  
(1983, 2005)

$$\begin{aligned} M/m &= 2.5 \times 10^5 \\ m &= 35 \text{ g} \\ (M &= 10 \text{ t}) \end{aligned}$$



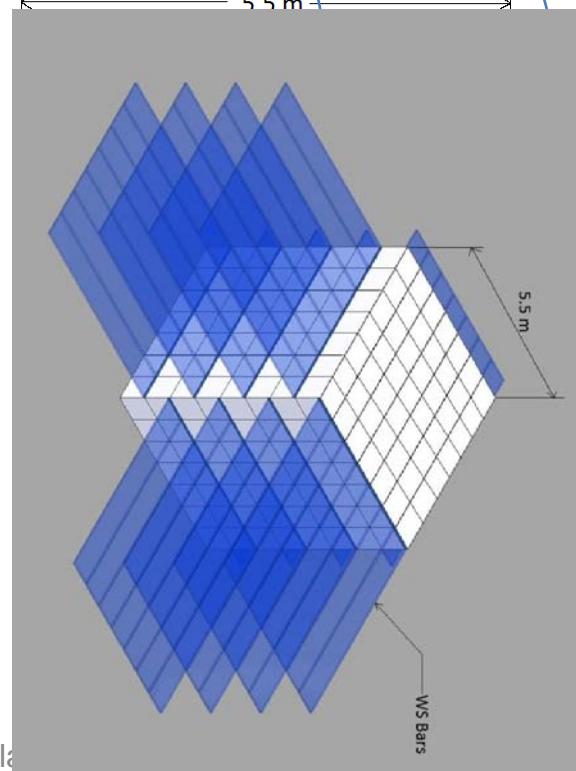
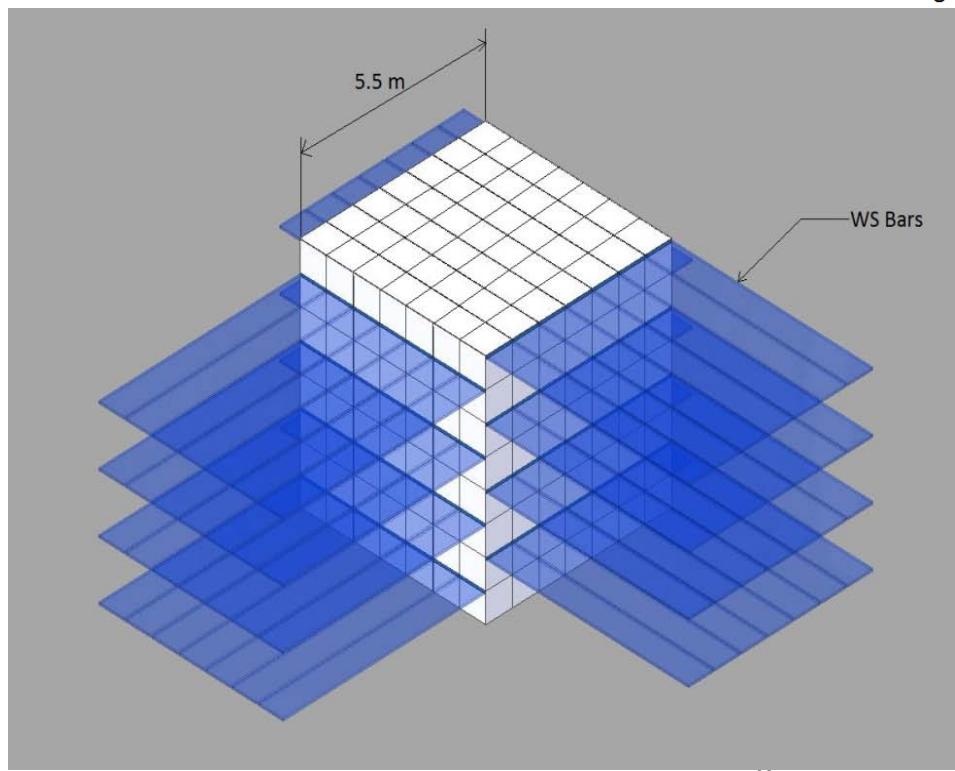
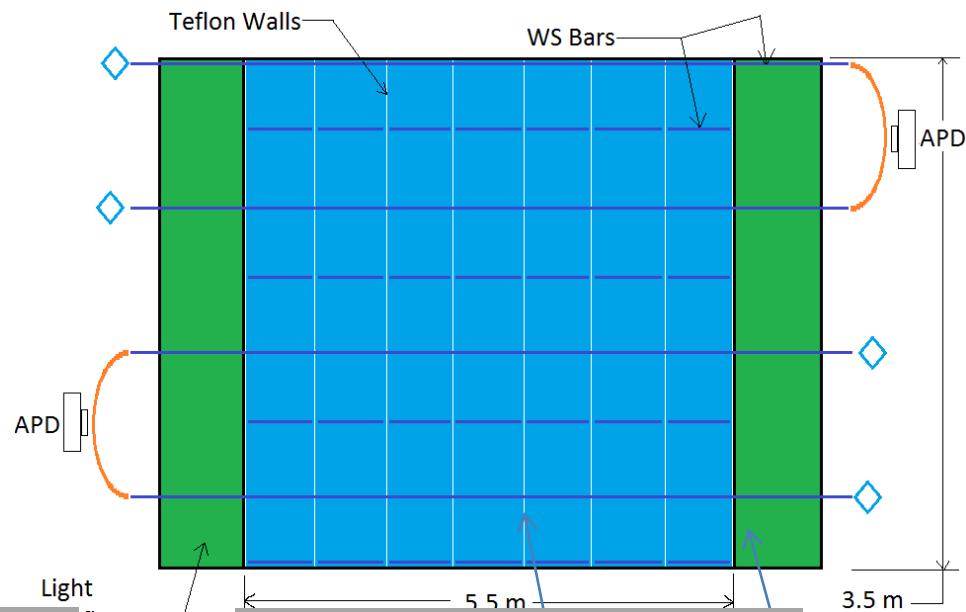
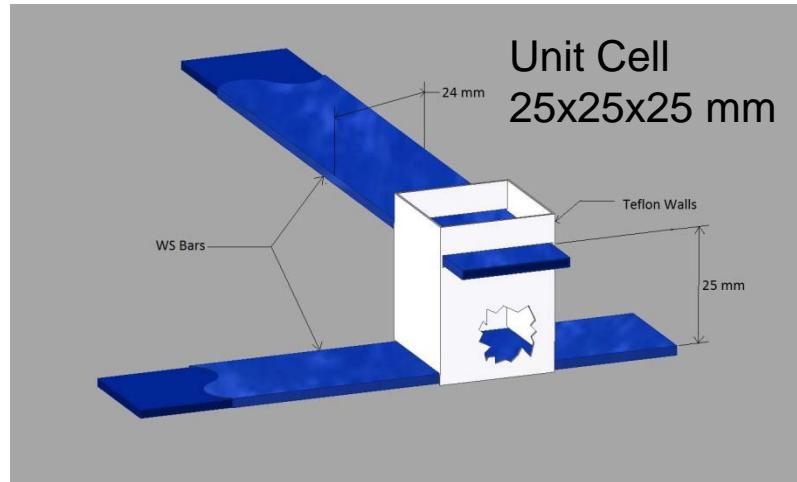
Fluorescence Conv.  
Chamber:  
(1980  
RSR-Nu81

$$M/m = 5 \times 10^8$$

AIM NOW: Just gain  $\times 10 \rightarrow M/m \sim 10^6$

Nu2010

# LENS –Granular Detector



# New advantages of Flu Conv

- Decoupling of light production and light transport to detectors
  - In Scintillator need not be optimised to att. Length—only light
  - Frees us to use much higher loading ~15-30% without fear of strong attenuation due to In
  - Removes restriction to liquids—gels, even powders possible
- Light transport free of In—longer paths possible and optimized separately
  - Use bars 2cmx3mmx5m
- The signal luminous area << detector surface area
  - Photocoverage area typically x100 smaller than for lattice design
  - Cost and background reduced significantly
  - Brings APD into the picture without breaking the bank
- Geometry of bars makes design integration of buffer by
  - the same detection system

Table 1 Signal/Noise/T ln y; (Bgd (E) = Energy cut on Compton Shower outside vertex only; Bgd(T) Topology Cut)

pe/MeV	S/t ln/year	Lattice: m = S/N 34g/cell $N = [Bgd(E) + Bgd(T)]/t \ln \gamma$ (see Appendix)		NuFLU: m=3g/cell $N=Bgd(E)+Bgd(T)/t \ln \gamma$	S/N
200	40	275+8=283	0.14	25+0.75=26	1.5
300	"	83+8=91	0.44	7.5+0.75=8.3	4.8
400	"	19+8=27	1.5	1.7+0.75=2.2 5	18
900	"	0 + 8=8	5	0+0.75=0.75	53

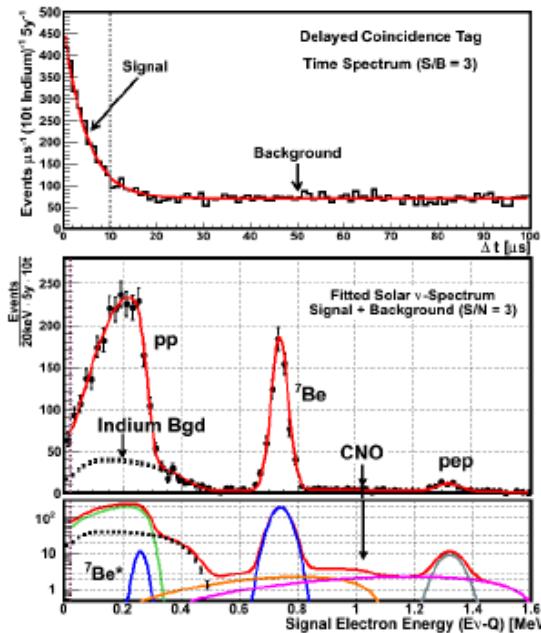
# Indium $\beta$ -Background Discrimination

Background rejection steps for pp detection (other neutrinos detected free of Indium background):

- A. Time/space coincidence in the same cell required for trigger;
- B. Tag requires at least three 'hits';
- C. Narrow energy cut;
- D. A tag topology: multi- $\beta$  vs. Compton shower;

Classification of events according to hit multiplicity;

\*\*Cut parameters optimized for each event class  
→ major factor in improved efficiency;



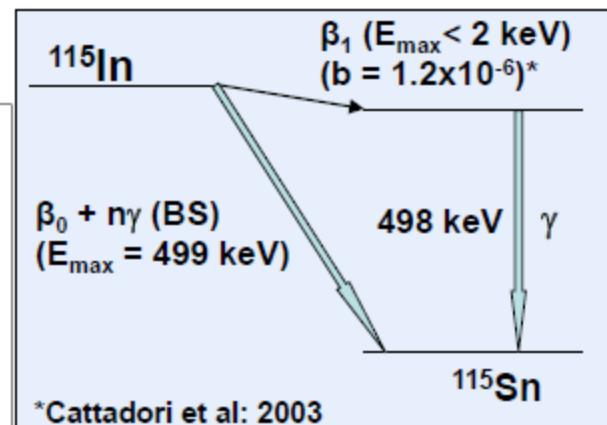
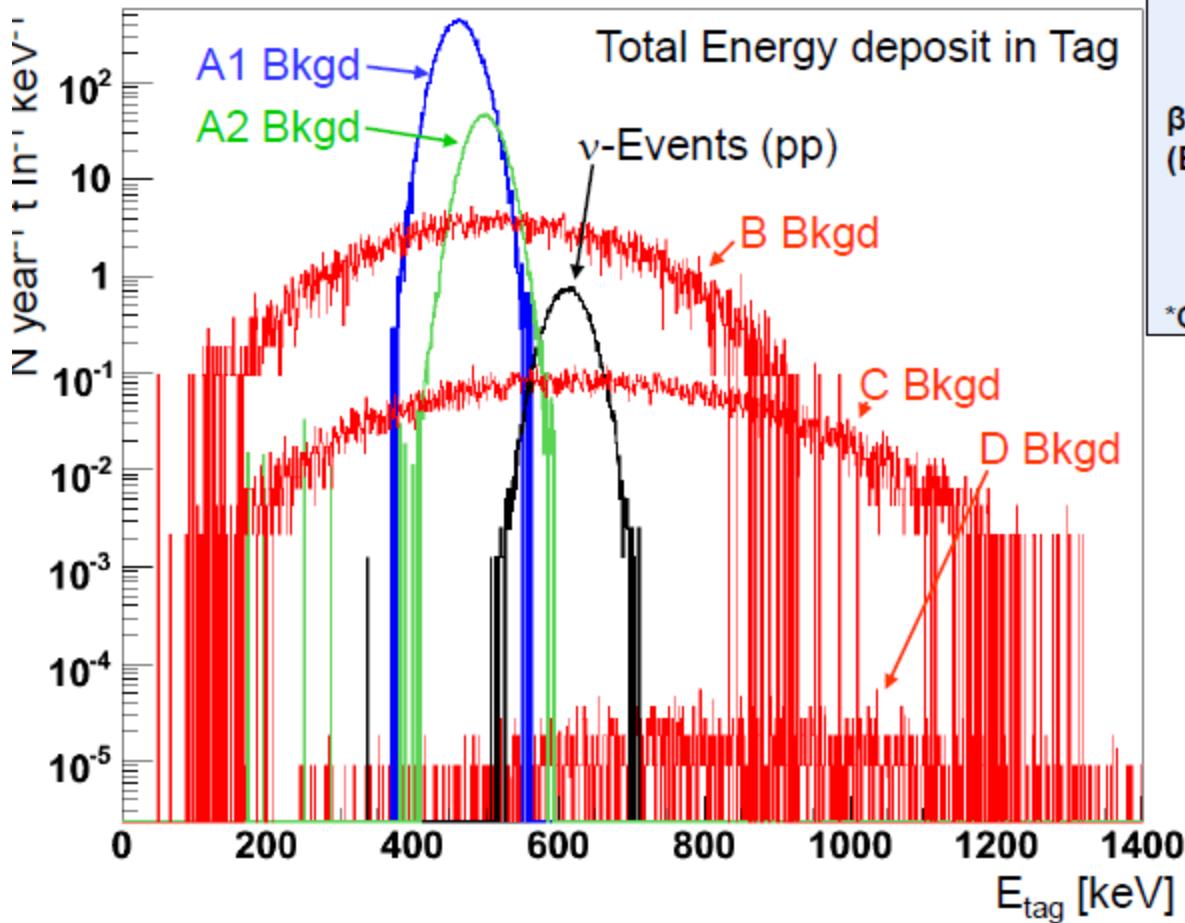
Results of GEANT4 Monte Carlo simulation (cell size = 7.5cm, final result S/N=3; Bgd suppression  $6 \times 10^{11}$ )

	Signal (pp) $y^{-1} t \text{In}^{-1}$	Bgd (In) $y^{-1} (t \text{In})^{-1}$
RAW rate	62.5	$79 \times 10^{11}$
A. Tag in Space/Time delayed coincidence with prompt event in vertex	50	$2.76 \times 10^5$
B. + $\geq 3$ Hits in tag shower	46	$2.96 \times 10^4$
C. +Tag Energy = 614 keV	44	306
D. +Tag topology	40	$13 \pm 0.6$

Reduction by  $\sim 3 \cdot 10^7$  through time/space coincidence

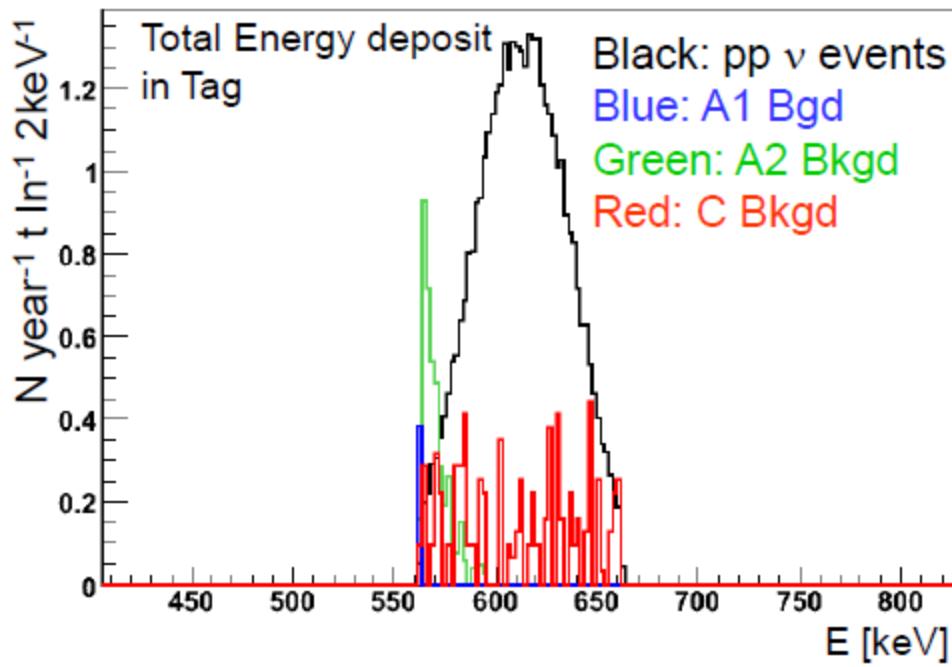


# Tag Energy



Powerful energy  
Separation for A1 & A2  
Background

Not so powerful for B,C,D  
Background



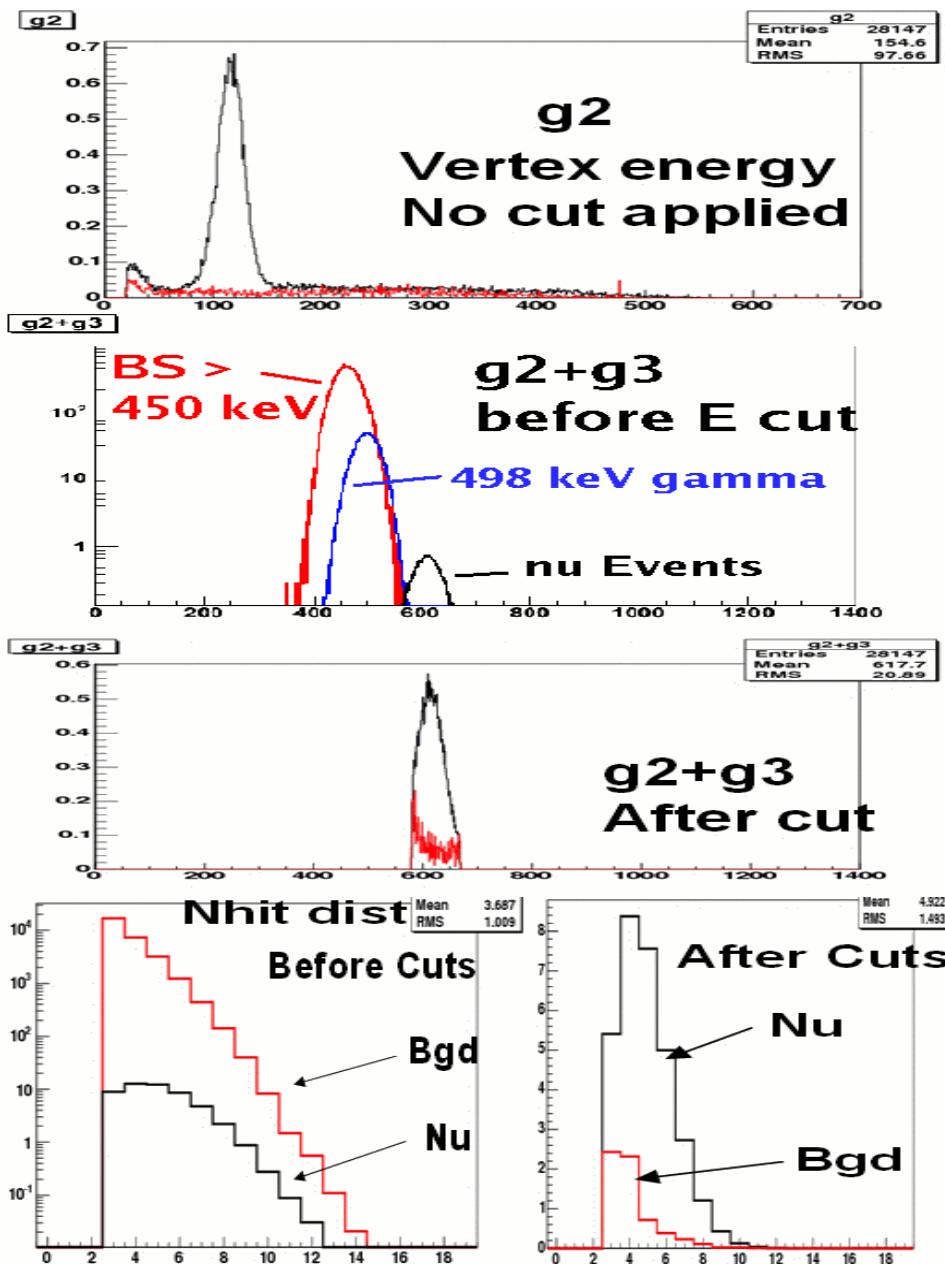
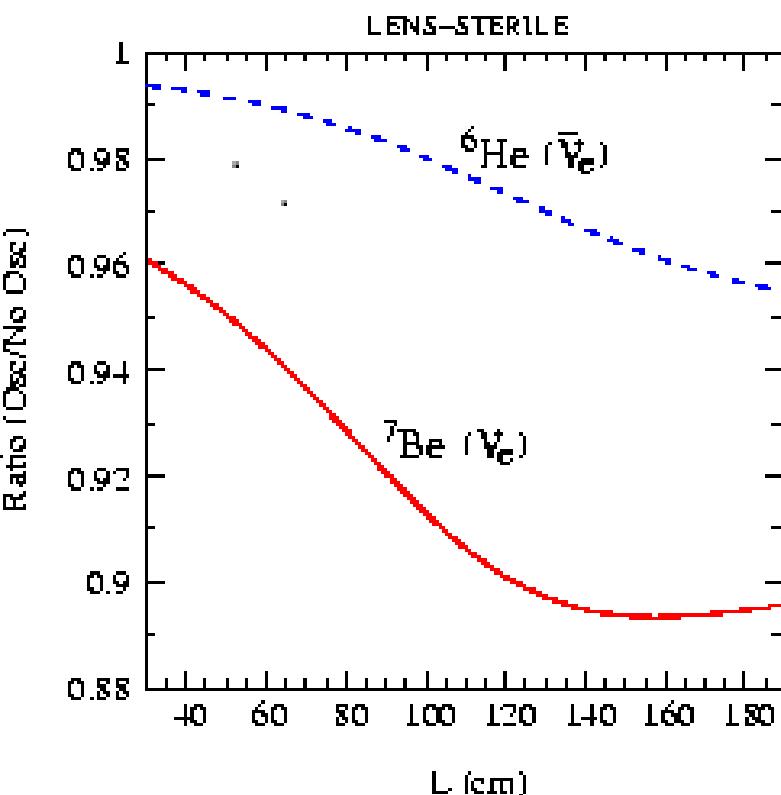


Figure 14: Typical results of analysis cuts on background (red) and signal (black) events in LENS.

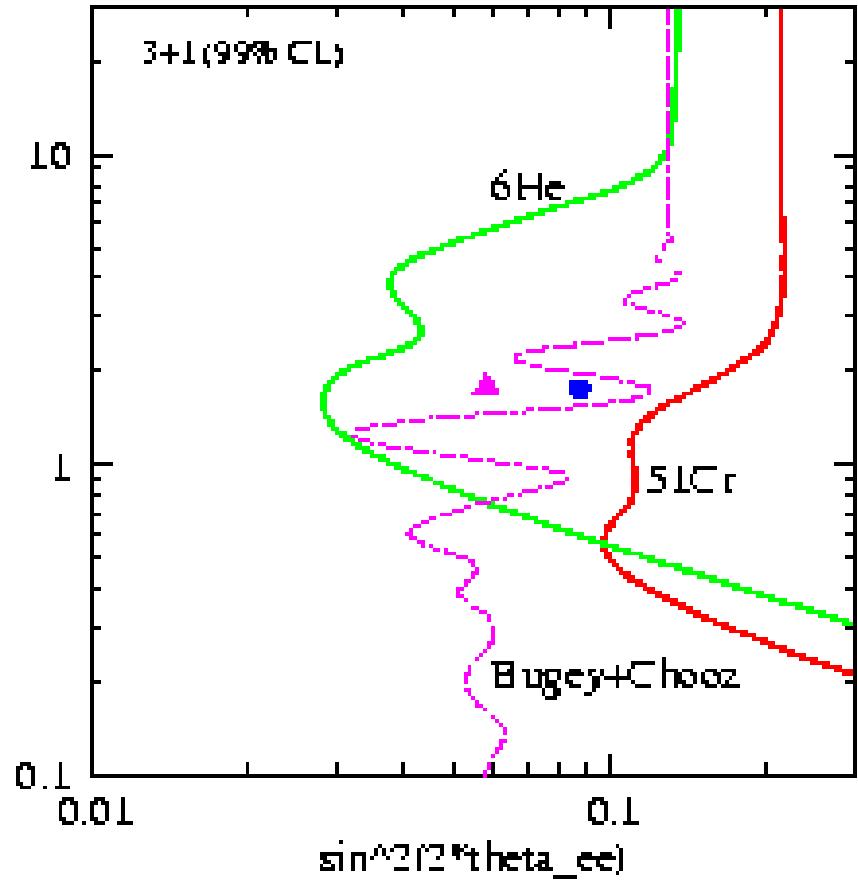
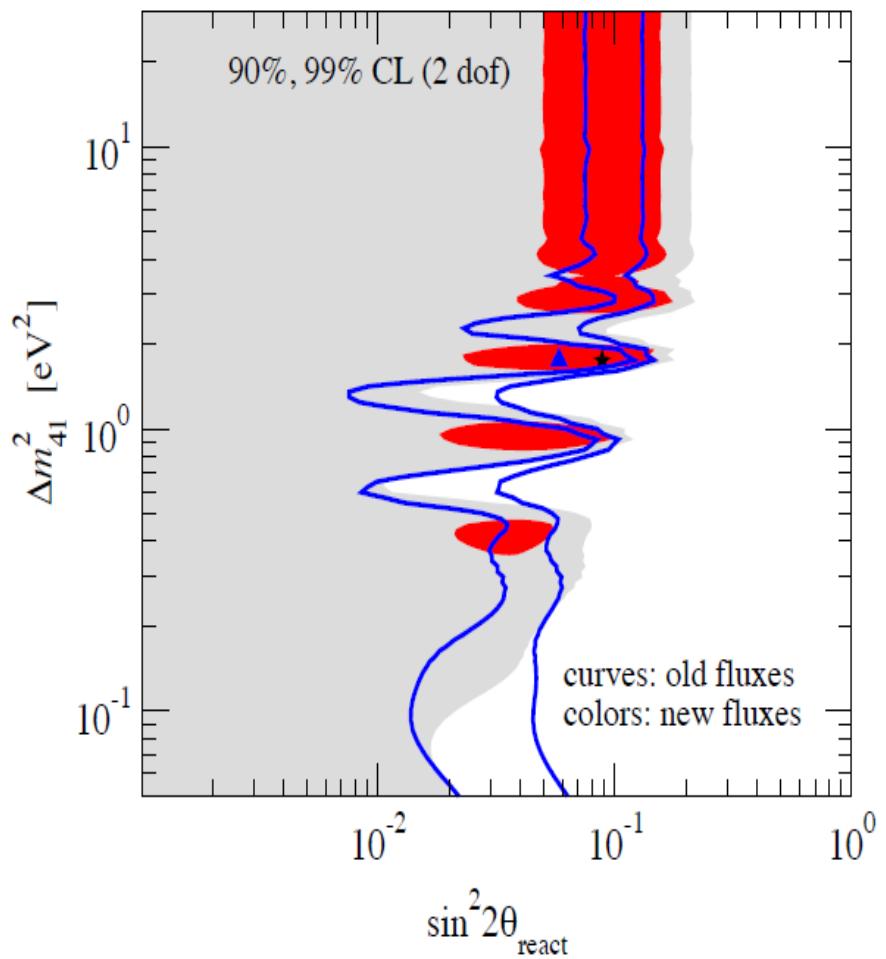
## Oscillation Patterns

Source	nue fluence	Unoscillated	Oscillated
51Cr nue	1.06x10^24	8591	7840
6He nuebar	5.5x10^21	42671	41652

Internal source Lmax ~2m  $\Delta L = 30\text{cm}$ ;  $\Delta E = 0$  for Cr,  $\sim 10\text{cm}$  for He  
3+2 model Best fit parameters



Oscillation Recovery observable in 4m pathlengths External Source geometry!  
Interference effects due to 2 frequencies



# **Summary and Conclusions**

- Selected Intense Sources
- Local on-site Production
- Nue and Nuebar Sources
- Tight Geometries— Small source extensions
- Source Detector geometries good for competitive search for  
 $\Delta m^2 \sim 0.2 \text{ to } 5 \text{ eV}^2$
- Relatively Inexpensive

**Physics extendable to nuebar spectra  
of fission sources**

**Astrophysical aims of LENS not affected.**