The LENS Experiment:
Spectroscopy of Low Energy Solar Neutrinos

R. S. Raghavan
Virginia Tech

Neutrino 2010- Athens Greece

June 19, 20010

LENS—Low Energy Neutrino Spectroscopy

Tagged v –capture reaction in Indium-115

$$\nu_e + {}^{115}In \rightarrow e^- + {}^{115}Sn^* \rightarrow 2\gamma + {}^{115}Sn$$

signal delay Tag cascade

LENS is the only CC detector developed to date for low energy solar neutrinos

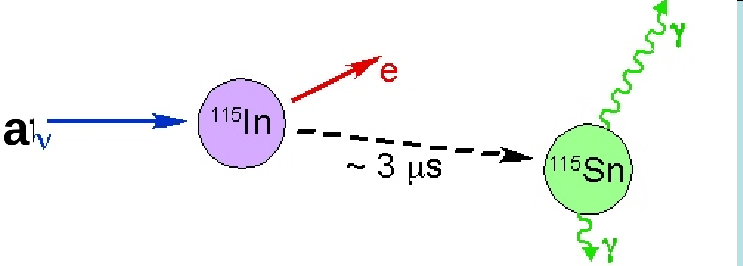
R&D Funded now by NSF (2 awards 2007,2008, 2010-2013)

LENS Collaboration (2004-

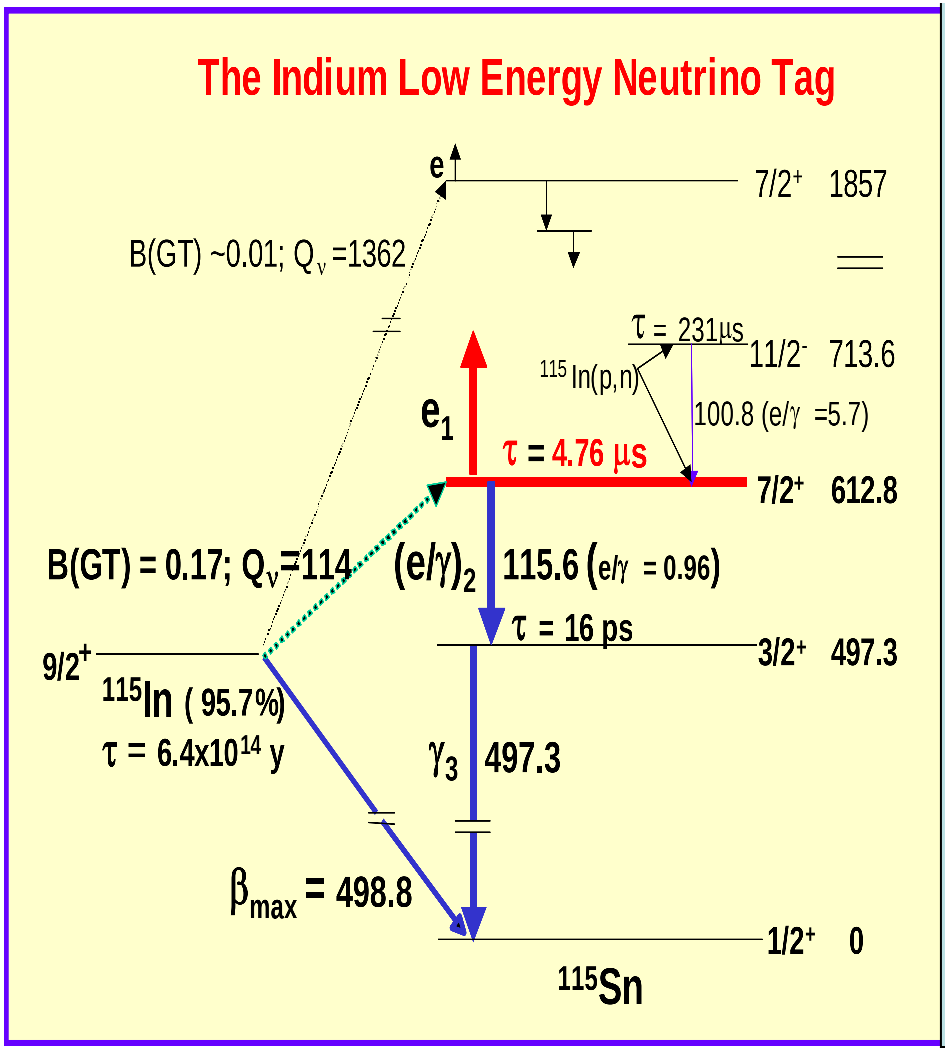
BNL:	**R. L. Hahn, L. M. Hu, M. Yeh**
Indiana U.	**Rex Tayloe**
U. North Carolina:	**A. Champagne;**
V. North Carolina State:	**H. Back Albert Young**
Louisiana State U:	**J. Blackmon, L. Linhardt, B. Moazen, L. C. Rascoe**
South Carolina State:	**Z. Chang**
Virginia Tech:	**M. Pitt, M.Joyce, J. Link, S. Manecki, L. Papp, R.S. Raghavan, D. Rountree, R.B. Vogelaar**

Recent Collaborators (with Appreciation and Thanks) (until 2004)
LENS-R&D:
Italy, France, Germany, Russia…

LENS-pp ν- Detection With Signa



RSR –Phys Rev Lett 37, 259m 1976


The Indium Low Energy Neutrino Tag

Unique:

- **Specifies ν Energy**

  $E_\nu = E_e + Q$
- **ALL LE nu's from the sun**
- **Lowest Q known→ 114 keV**

  →access to 95.5% pp nu's
- **Target isotopic abundance ~96%**
- **Powerful delayed coinc. Tag**

Can suppress bgd =10^{11} x signal

1. **Time & Space coinc.→ Granularity**

   (10^7 suppression already
2. **Energy Resolution—important for**

   In betas <500 keV; ∑Tag = 613 keV

→ Liquid Scintillator → Properties

3. **Other analysis cuts**

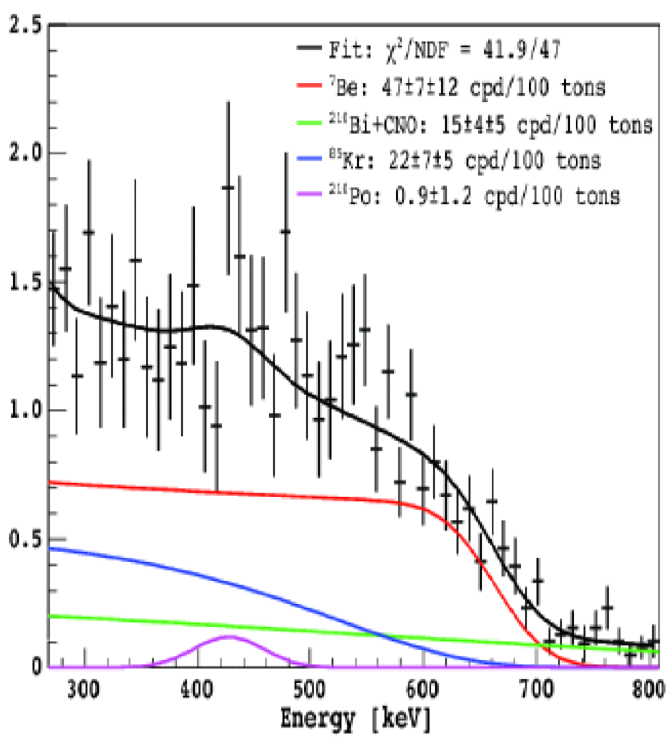
Raghavan—Nu2010

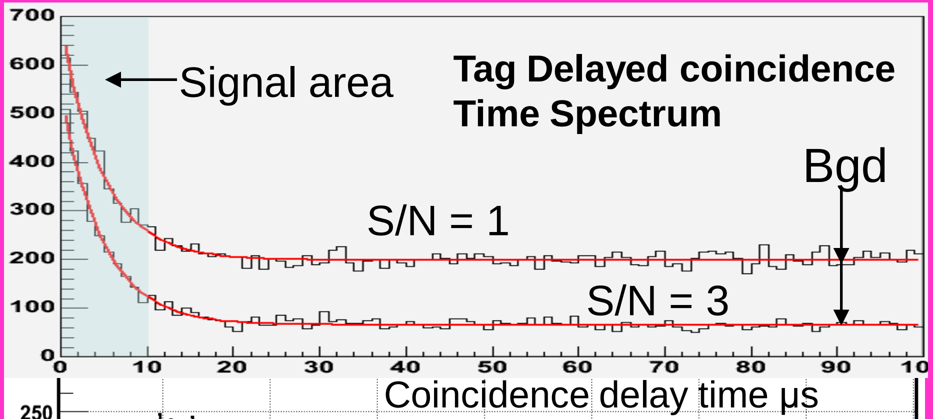
LENS Goal: Low Energy Solar ν-Spectrum

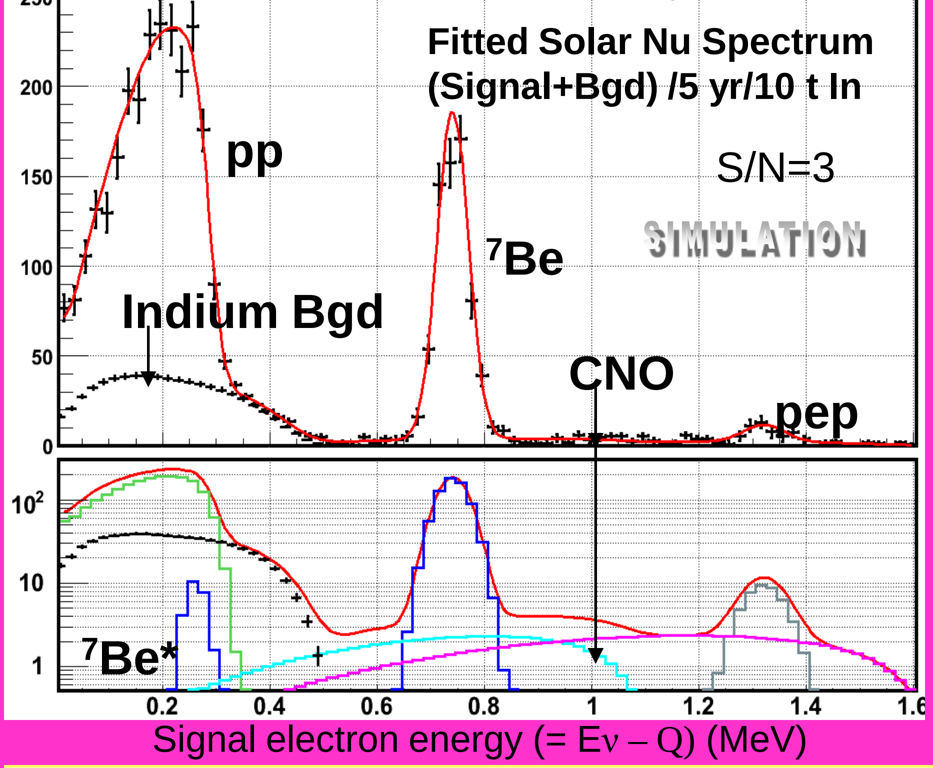
Neutrino Signature !

(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 bgd***







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

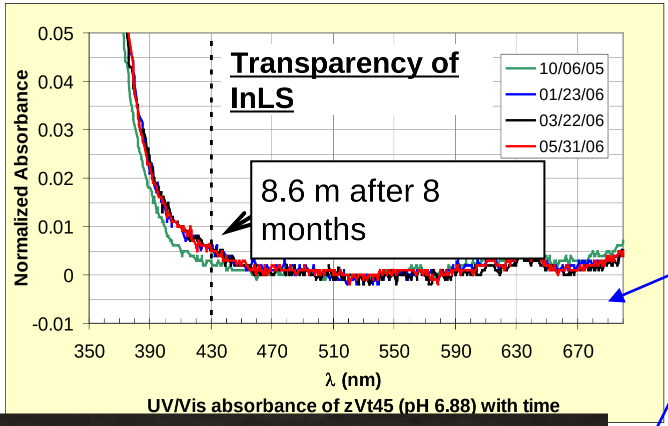
***Energy resolution*: overlap of residual background features on solar signal**

Technology and Bgd Control

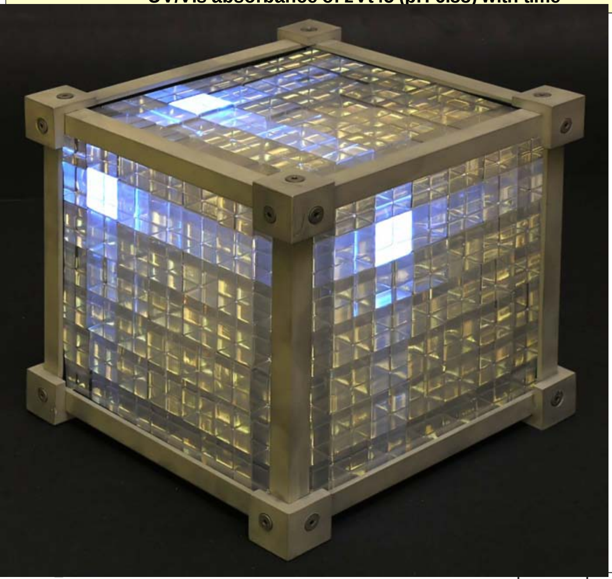
< Towards **Hi Precision** fluxes >

- **Hi Quality InLS**
- **Granular Detector Design**
- **Background Analysis Insights**

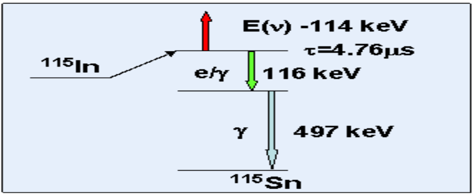
•→ In decay bgd suppressed →S/N ~3 for first time

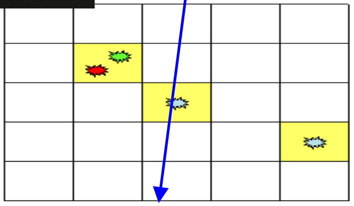


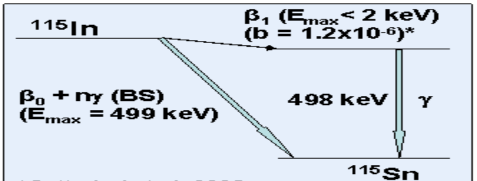
UV/Vis absorbance of zVt45 (pH 6.88) with time



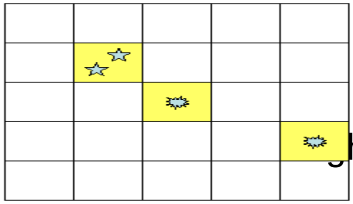
	Status
Design of Detector	**Cubic Lattice Chamber**
InLS: In content **Light attenuation L(1/e)** **Signal Eff Pe/MeV**	**>8%** **>8m** **900**
Indium Mass(1900 pp/5y)	**10 ton**
Total Mass	**125 ton**
PMT's	**13,300**
Neutrino detection eff.	**64%**







*Cattadori et al: 2003



Indium Liquid Scintillator Status

Milestones unprecedented in metal LS technology

LS technique relevant to many other applications

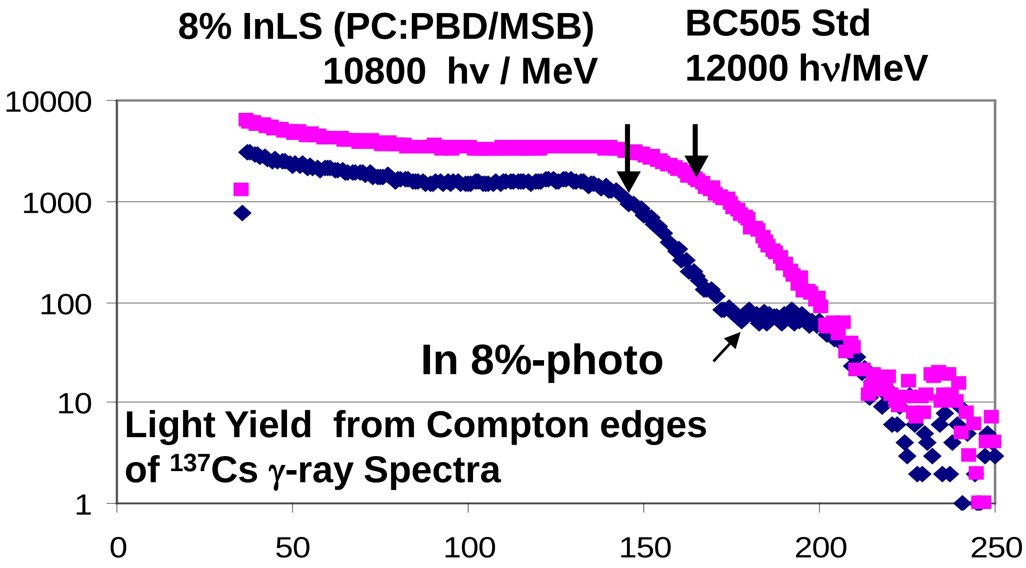
PC based InLS

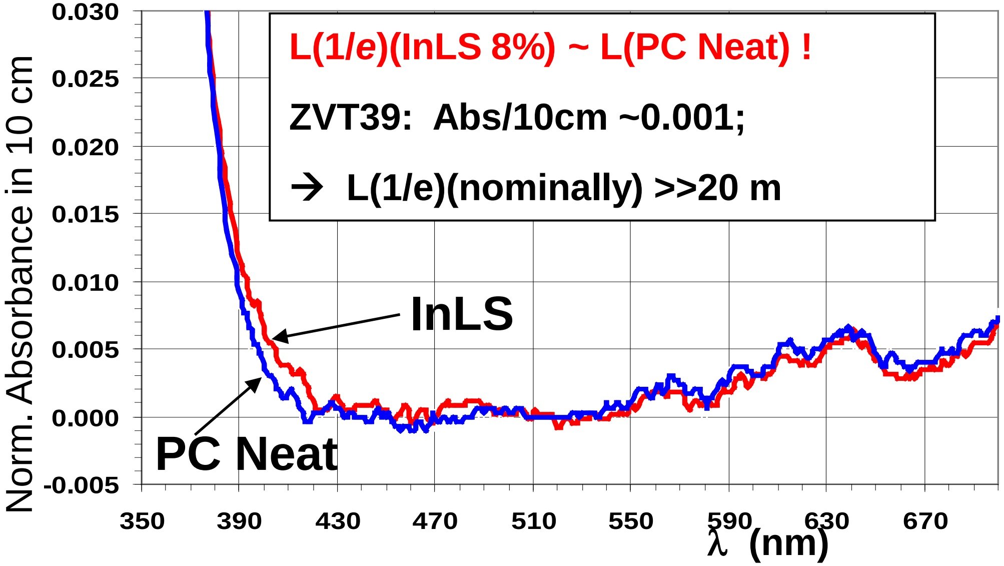
1. Indium concentration ~8%wt (higher may be viable)
2. Scintillation signal efficiency (working value): 8000 hν/MeV
3. Transparency at 430 nm: L(1/*e*) (working value): 8m
4. Chemical and Optical Stability: at least 1 year
5. InLS Chemistry – Robust

New = LAB based InLS

Basic Bell Labs Patents 2001, 2004,
Chandross, Raghavan

Ra





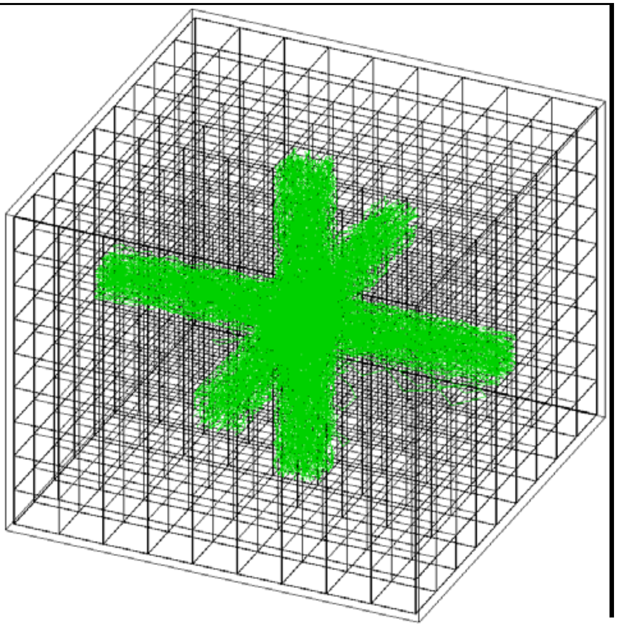
L(1/*e*)(InLS 8%) ~ L(PC Neat) !

ZVT39: Abs/10cm ~0.001;

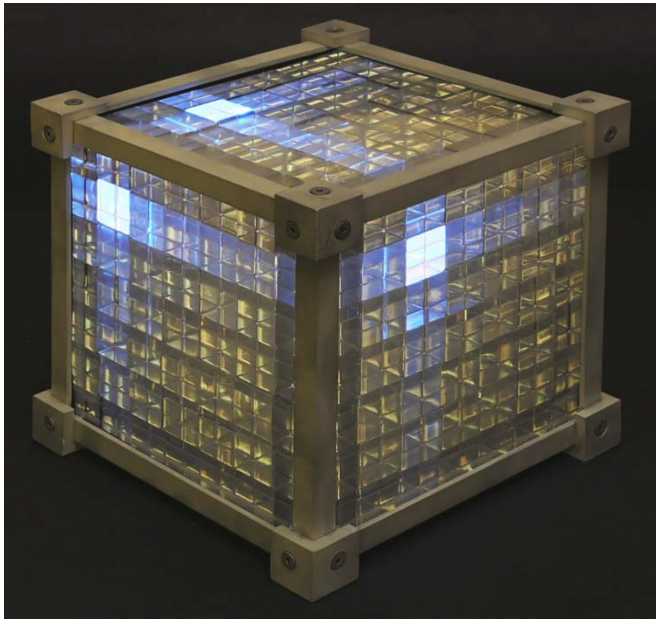
→ L(1/e)(nominally) >>20 m

New Detector Technology –hi event position localization

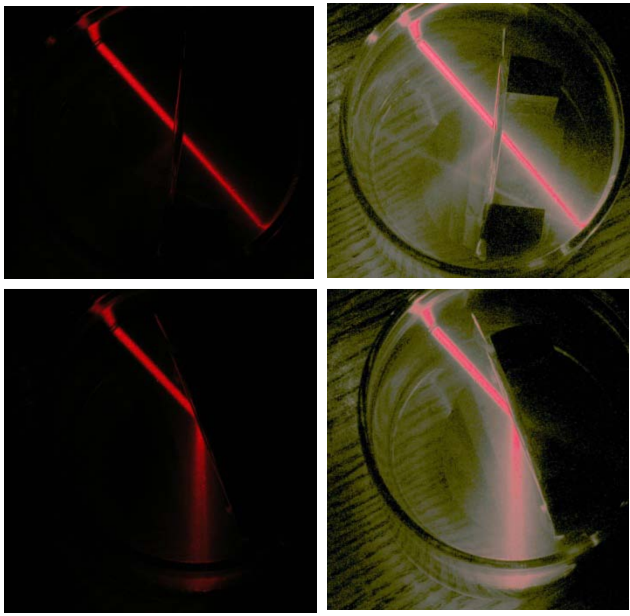
The Scintillation Lattice Chamber



Light channeling in 3-d totally Internally reflecting cubic Lattice GEANT4 sim. of concept.



Demonstration Acrylic Model



Test of double foil mirror in liq. @~2bar

3D Digital Localizability of Hit within one cube

- → ~75mm precision vs. 600 mm (±2σ) by TOF in longitudinal modules
- → x8 less vertex vol. → x8 less random coinc. → Big effect on Background
- → Hit localizability independent of event energy

Indium β^--Background Discrimination

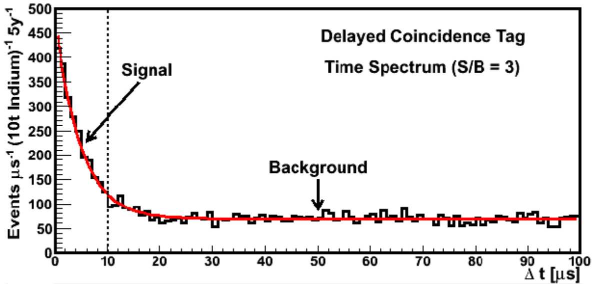
Background rejection steps for pp detection (other neutrinos detected free of Indium background):

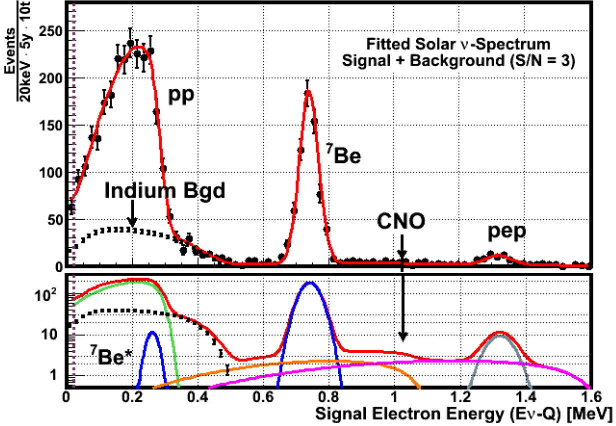
A. Time/space coincidence in the same cell required for trigger;
B. Tag requires at least three ‘hits’;
C. Narrow energy cut;
D. A tag topology: multi-β vs. Compton shower;

Classification of events according to hit multiplicity;

**Cut parameters optimized for each event class

-→major factor in improved efficiency;

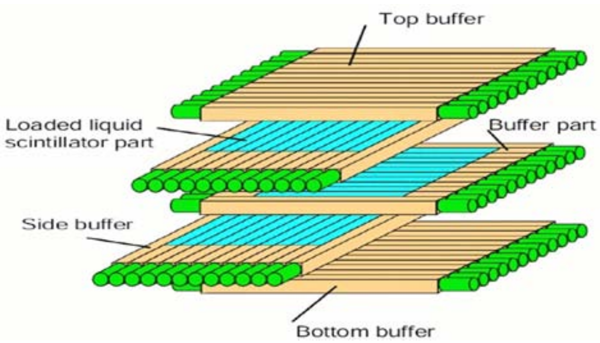


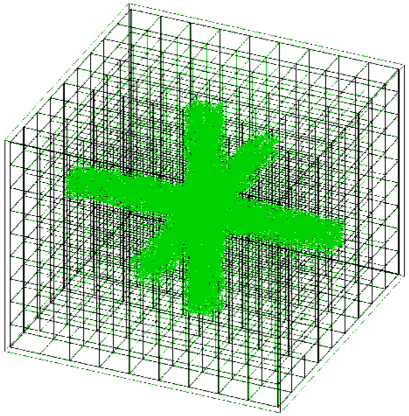


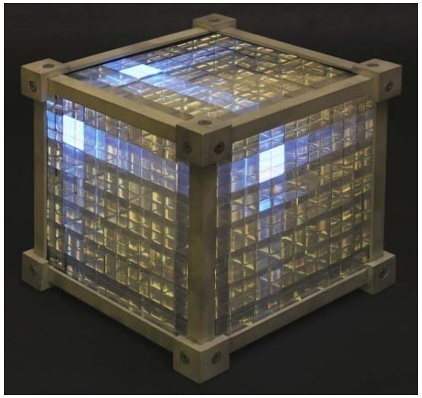
Results of GEANT4 Monte Carlo simulation (cell size = 7.5cm, final result S/N=3; Bgd suppression 6x10^11)	Signal (pp) y^{-1} t In)$^{-1}$	Bgd (In) y^{-1} (t In)$^{-1}$
RAW rate	**62.5**	**79 x 10^{11}**
A. Tag in Space/Time delayed coincidence with prompt event in vertex	**50**	**2.76 x 10^5**
B. + ≥3 Hits in tag shower	**46**	**2.96 x 10^4**
C. +Tag Energy = 614 keV	**44**	**306**
D. +Tag topology	**40**	**13 ± 0.6**

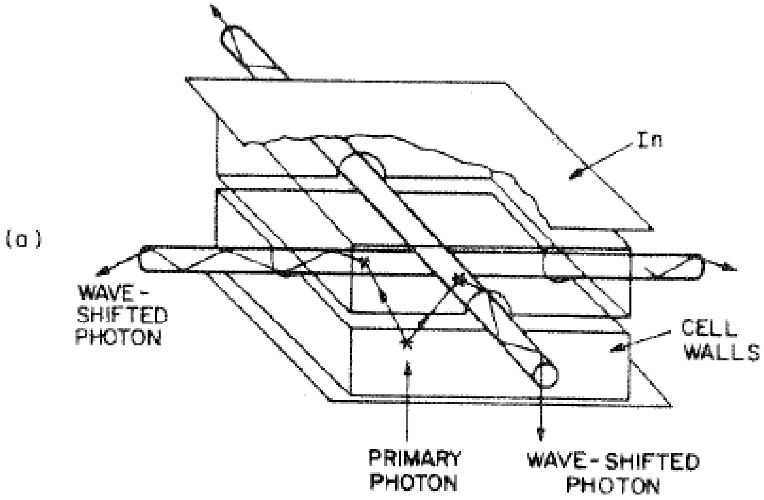
Reduction by ~3·10^7 through time/space coincidence

Evolution of LENS Granular Designs





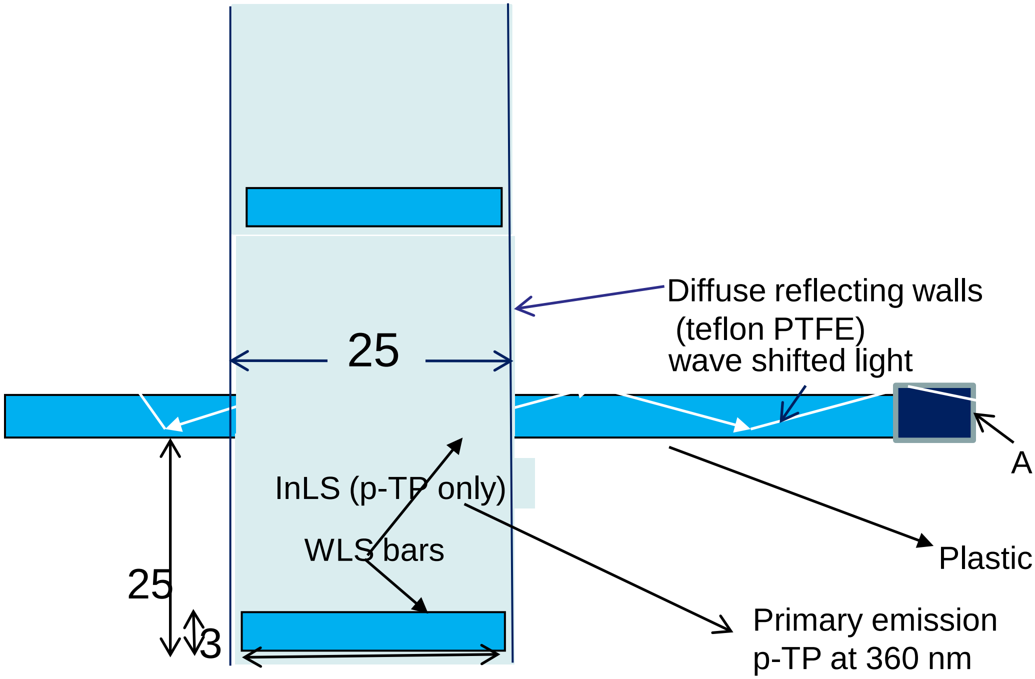




Design Idea	**Cell Resolution**
1D Longitudinal Array (1998)	**$M/m = 2\times10^4$** **m = 350g In** **(M = 10 t)**
3D Scintillation Lattice Chamber: (1983, 2005)	**$M/m = 2.5\times10^5$)** **m =35 g** **(M = 10 t)**
Fluorescence Conv. Chamber: (1980 RSR-Nu81	**$M/m = 5\times10^8$**

AIM NOW: Just gain x10➔$M/m\sim10^6$

LENS Nu Flu Chamber Detail
(conceptual dimensions—not to scale)



Diffuse reflecting walls
(teflon PTFE)
wave shifted light

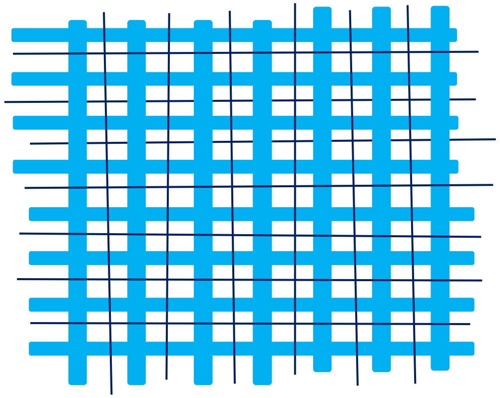
APD

InLS (p-TP only)

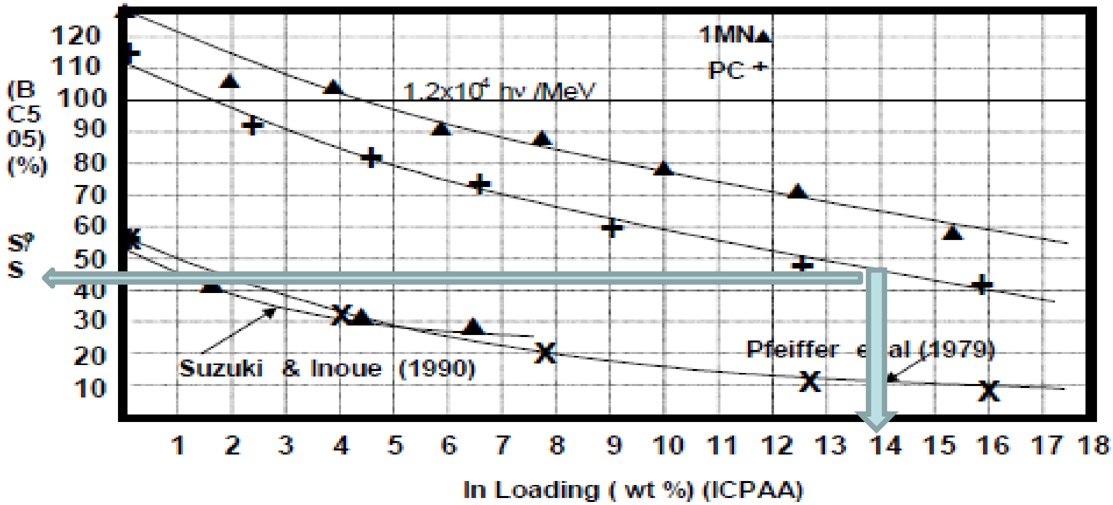
WLS bars

Plastic WLS bar

Primary emission
p-TP at 360 nm



Crosswise
stacked WS bars
in Teflon crate frame



RSR *Arkiv hep-ex 0601054*

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

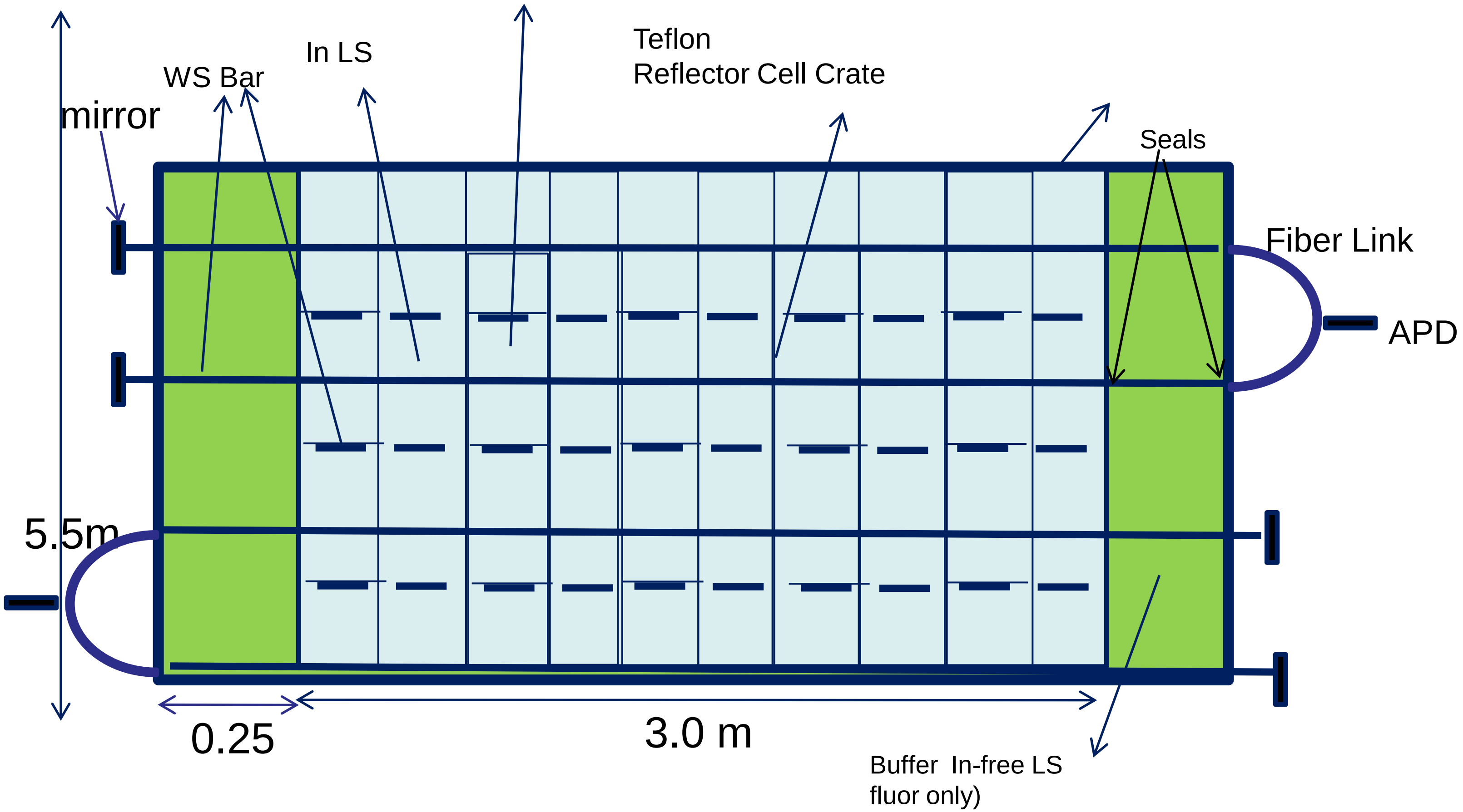
→Brings APD into the picture without breaking the bank

- Geometry of bars makes design integration of buffer by
- the same detection system

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

pe/MeV	S/t In/year	Lattice: m = 34g/cell N = [Bgd (E) +Bgd (T)]/t In y (see Appendix)	S/N	NuFLU: m=3g/cell N=Bgd(E)+Bgd(T)/t In/y	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=2.25	18
900	“	0 + 8=8	5	0+0.75=0.75	53

Lens NUFlu Chamber—3.5m3.5mx5.5m (including side buffer--~10 ton Indium



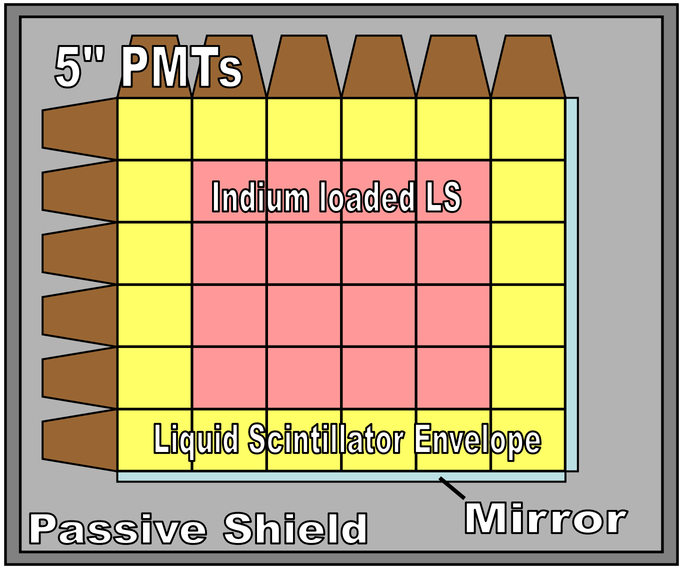
Raghavan—Nu2010

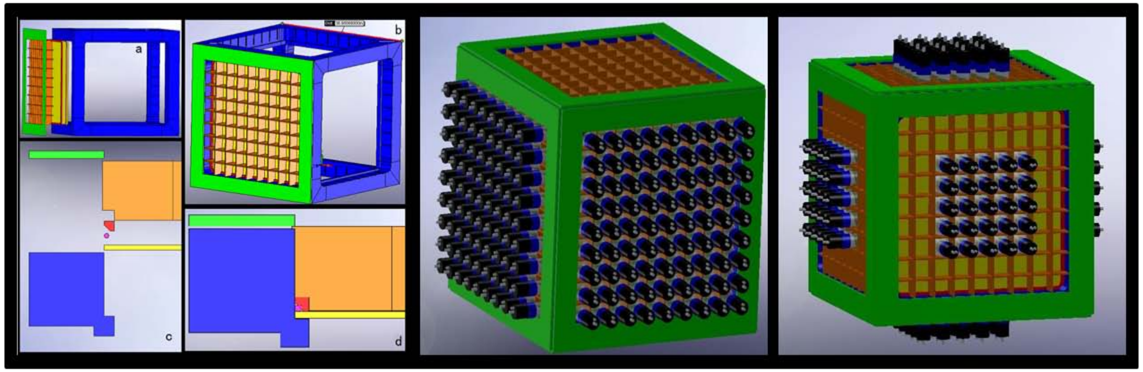
MINILENS

Final Test detector for LENS

Goals for MINILENS
8kg In; 125 liter InLS

- **Test detector technology**
  → Medium Scale InLS production
  → Design and construction
  Direct blue print for full scale LENS





The Kimballton Underground Facility

Science from LENS—Hi precision of complete low energy spectrum (Background free)

Nu rates (pp→ 3-4%)

1. Neutrino Physics –Energy dependence of P_{ee}
→ Oscillation Phenomenology MSW→Vac Osc—Surprise Scenarios

2. Solar Luminosity vs Photon Luminosity—Final check of the *Energy Source* of the sun via neutrinos--Astrophysics/Neutrino physics

3. Gamow Energy of pp fusion—Energy production in sun

4. Use of LENS technology: “LENS-Sterile”
Physics beyond Std model—Sterile Neutrinos from LENS+Cr (or Ar) Source

LENS and Borexino

measure the same flux with two different reactions, one based on CC (ν_e only) and the other on NC-sensitive ν_e and $\nu_{(\mu/\tau)}$. The capture cross section for the In ν_e capture can be written as:

$$\sigma_c = (R_L/R_B)\ [[p_{ee}\sigma_e + (1-p_{ee})\ \sigma_{\mu,\tau}]/\ p_{ee}]$$

in Borexino and LENS, pee is the ν_e survival probability and σ_e and $\sigma_{\mu,\tau}$ are the well-known scattering cross sections for ν(e, μ and τ)

Independent access to σ_c via Cr source mesurement

CNO in the Sun ? : Second Solar Nu Problem
Direct data from LENS-

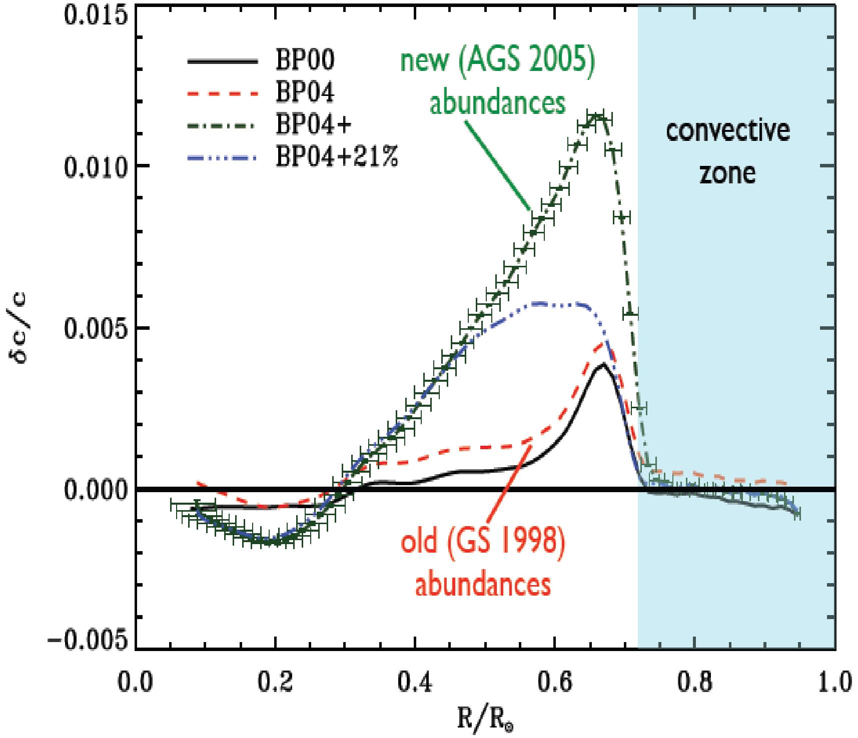
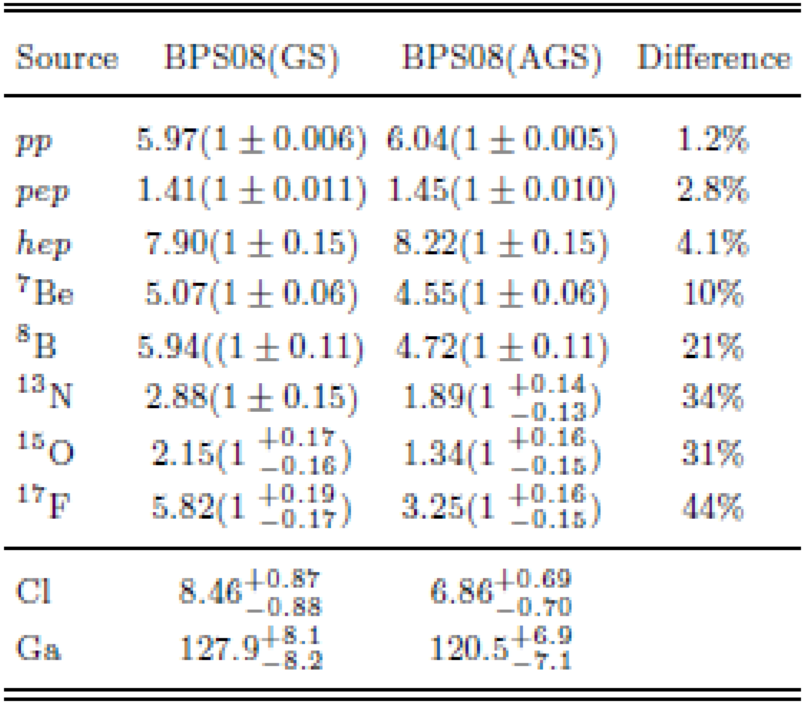


Fig. 3 Effect of revised solar abundances on helioseismology results [ref. 13]

Table 2. Predicted Fluxes for low (col 2) and high (col 3) abundances [ref. 14]. The measured ^{8}B flux from SNO salt phase is 5.54 vs. 4.72 (BPS 08, AGS)



Source	BPS08(GS)	BPS08(AGS)	Difference
pp	$5.97(1 \pm 0.006)$	$6.04(1 \pm 0.005)$	1.2%
pep	$1.41(1 \pm 0.011)$	$1.45(1 \pm 0.010)$	2.8%
hep	$7.90(1 \pm 0.15)$	$8.22(1 \pm 0.15)$	4.1%
^{7}Be	$5.07(1 \pm 0.06)$	$4.55(1 \pm 0.06)$	10%
^{8}B	$5.94((1 \pm 0.11)$	$4.72(1 \pm 0.11)$	21%
^{13}N	$2.88(1 \pm 0.15)$	$1.89(1\ ^{+0.14}_{-0.13})$	34%
^{15}O	$2.15(1\ ^{+0.17}_{-0.16})$	$1.34(1\ ^{+0.16}_{-0.15})$	31%
^{17}F	$5.82(1\ ^{+0.19}_{-0.17})$	$3.25(1\ ^{+0.16}_{-0.15})$	44%
Cl	$8.46^{+0.87}_{-0.88}$	$6.86^{+0.69}_{-0.70}$	
Ga	$127.9^{+8.1}_{-8.2}$	$120.5^{+6.9}_{-7.1}$	

Energy of the Sun
via Neutrino vs. photon
Possible because we measure 99.5% of energy producing reactions

Energy Balance:

Measured *neutrino* fluxes at earth
+ oscillation physics
nuclear reaction rates
energy release in the sun

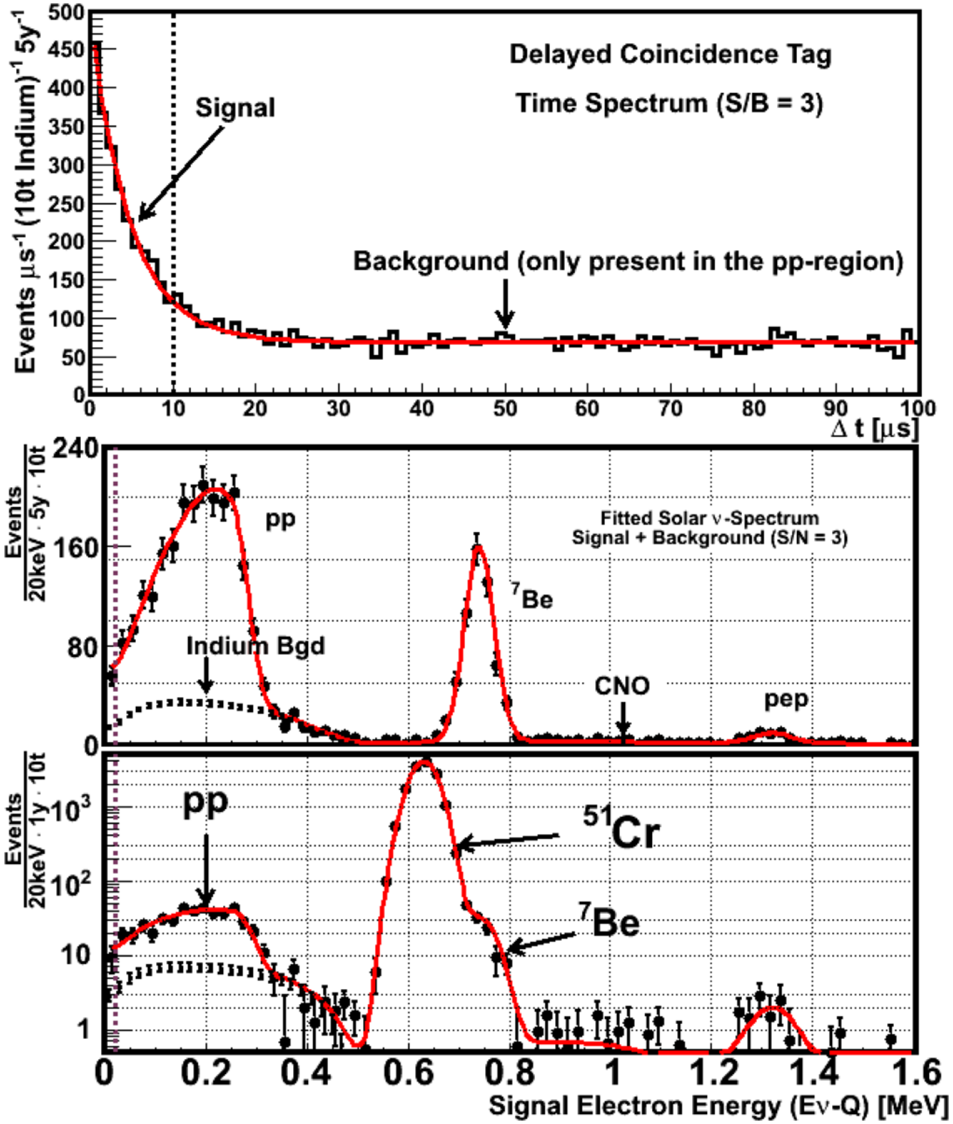
$$L_{\nu-\text{inferred}} \overset{?}{=} L_{h\nu}$$

Solar luminosity
as measured
by *photon* flux

TEST

- **Fusion reactions are the *sole* source of energy production in the sun**
- **Photons take 40000 ys to reach us: Neutrinos take 8 min. The two measurements the suns energy at two different times**

3, The neutrino oscillation model is correct & no other physics involved;



LENS Sterile

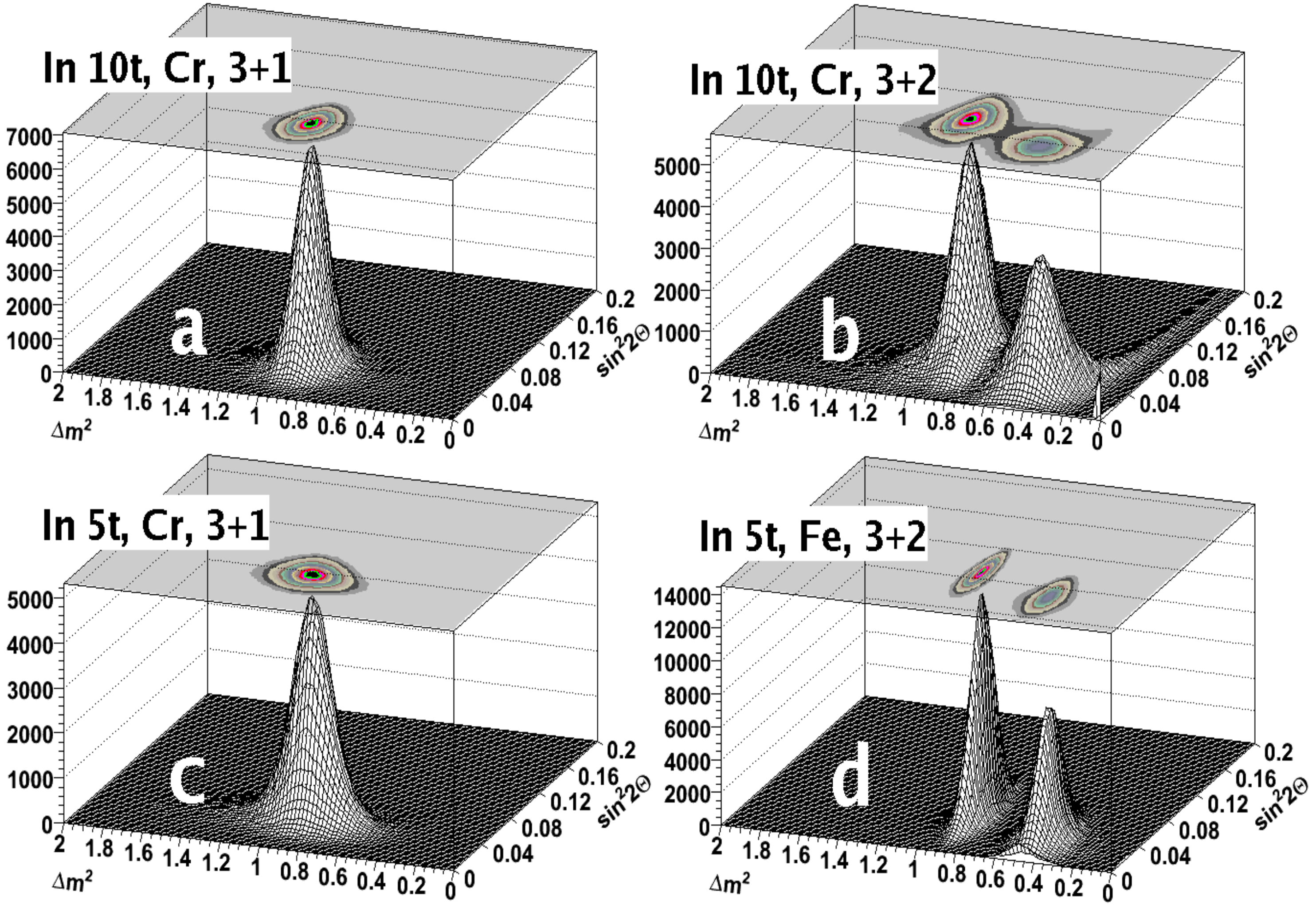
Cr source inside LENS

[C. Grieb, J. Link, RSR PRD 75, 093006 (2007)

Observe the Pee wave FROM Cr nu reactions inside the granular structure of LENS

Good for range of masses with Wave lengths of the order of Cell/detector dimensions

Statistical precision of oscillation parameter measurement in LENS



Active – Sterile Oscillation Sensitivity with LENS