LENS, MINILENS STATUS

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For
The LENS Collaboration

TAUP 07
Sendai, Japan
Sep 13, 2007

Virginia Tech

LENS—Low Energy Neutrino Spectroscopy

Tagged ν-capture reaction in Indium-115

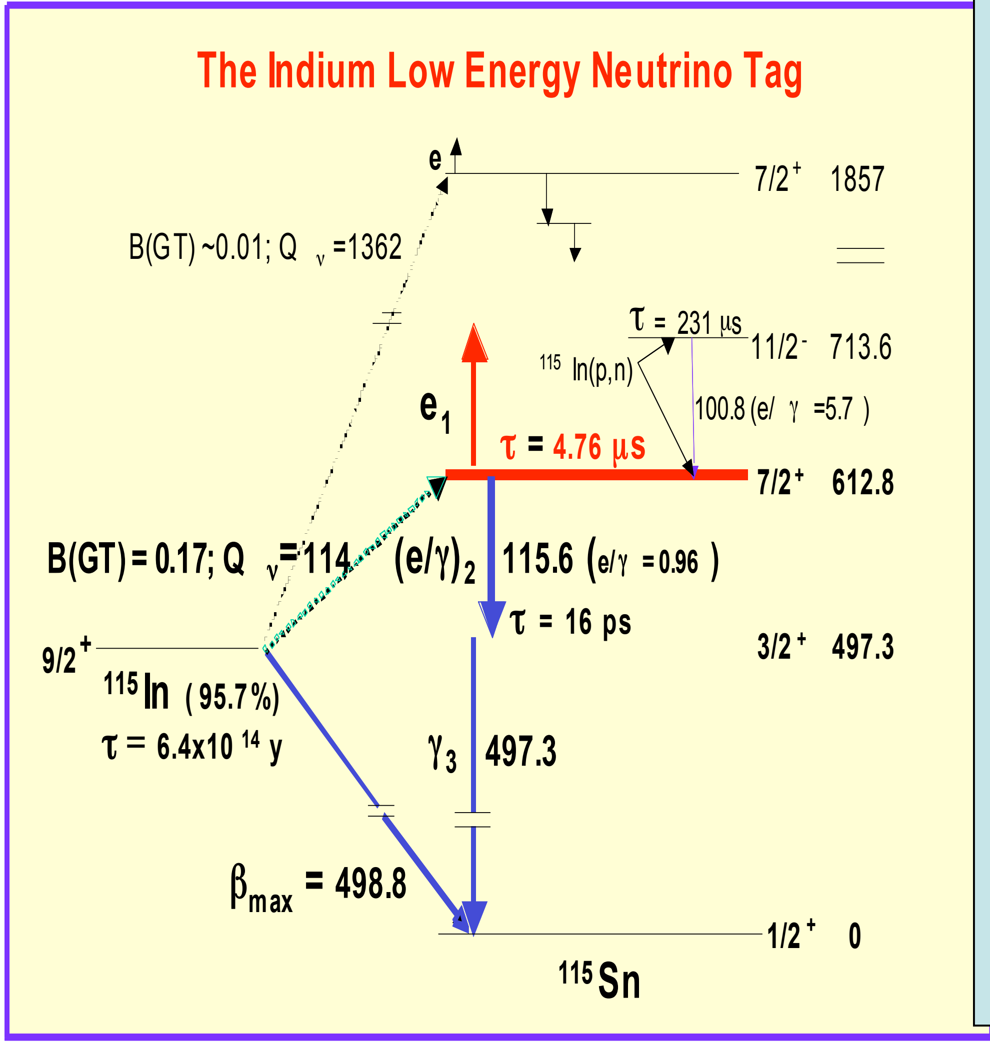
$$\underbrace{\nu_e + {}^{115}In \longrightarrow \underset{\uparrow}{e^-}}_{} + {}^{115}Sn^* \underset{\uparrow}{\longrightarrow} \underset{\uparrow}{2\gamma} + {}^{115}Sn$$

signal delay Tag cascade

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

R&D Funded now by NSF
[Placed in MUST FUND Category by two Review Panels]

LE$NS Detection Scheme



Unique:

- **Specifies** ν**Energy**

  $E_\nu = E_e + Q$

→ Complete LE nu spectrum

- 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

Downside:

- Bgd from ^{115}In radioactivity to

  (pp nu's only)→ rate= 10^{11} x signal

Tools:

1. Time & Space coinc.→ Granularity

   (10^6 suppression)

2. Energy Resolution

   In betas <500 keV; ∑Tag = 613 keV

3. Other analysis cuts

Expected Result: Low Energy Solar ν-Spectrum

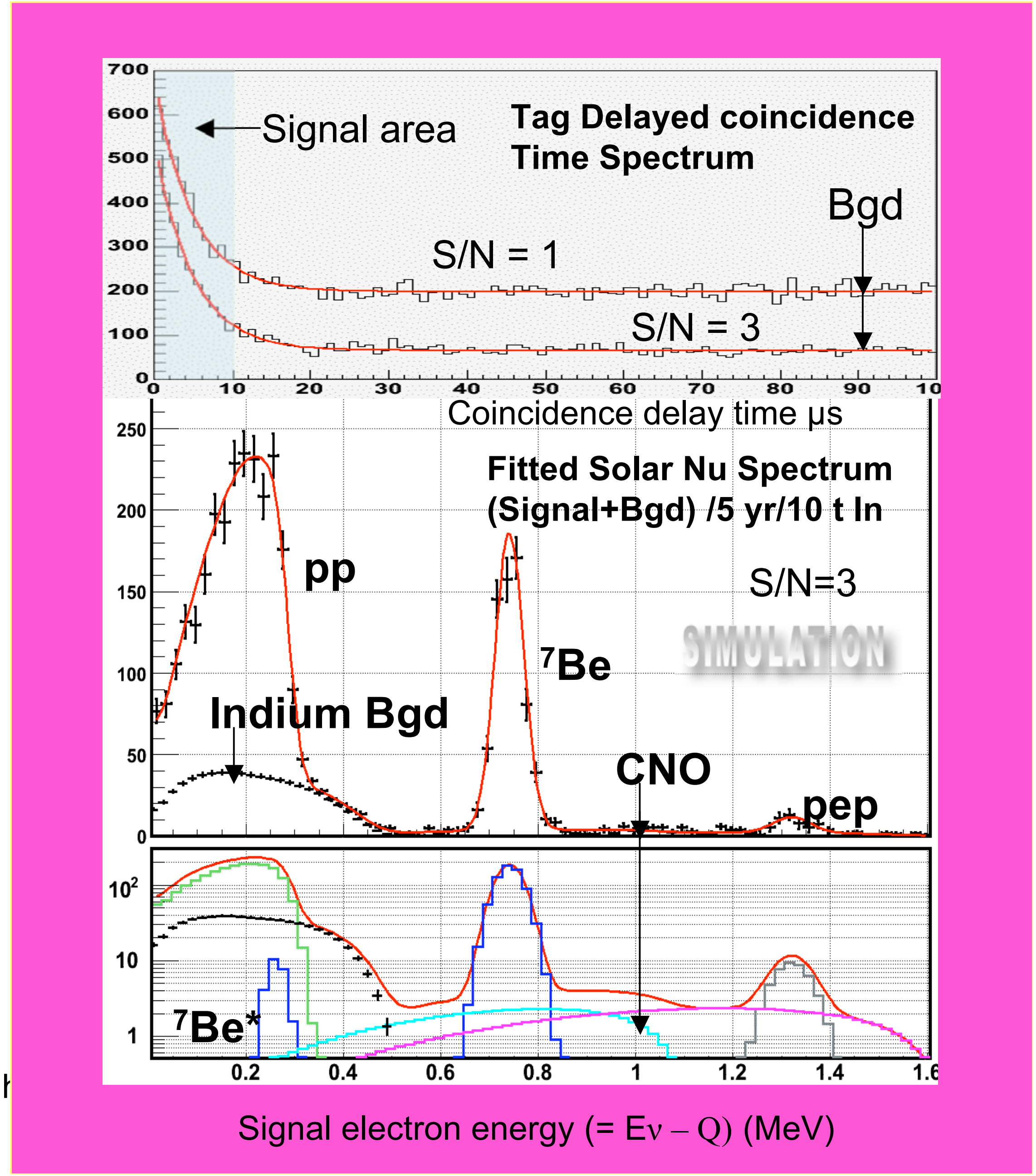
LENS-Sol Signal
=
SSM(low CNO) + LMA
x
Detection Efficiency ε

pp: ε = 64%
^{7}Be: ε = 85%
pep: ε = 90%

→ Rate: pp 40 /y /t In
→ 2000 pp ev. / 5y→ ±2.5%
→ Design Goal: S/N ≥ 3

Access to pp spectral *Shape* for the first time

Ragh



Science from LENS—Hi precision low energy Nu fluxes (pp→ 3-4%)

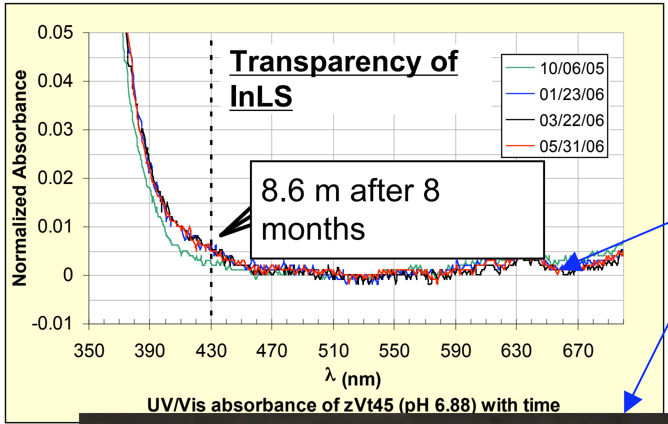
1. Neutrino Physics –Energy dependence of P_{ee}
   → Oscillation Phenomenology
2. Solar Luminosity vs Photon Lluminosity—Astrophysics/Neutrino physics
3. Gamow Energy of pp fusion—Energy production in sun
4. Physics beyond Std model—Sterile Neutrinos from LENS+Source
5. Solar model independent Fluxes –CC+NC (LENS + Borexino)

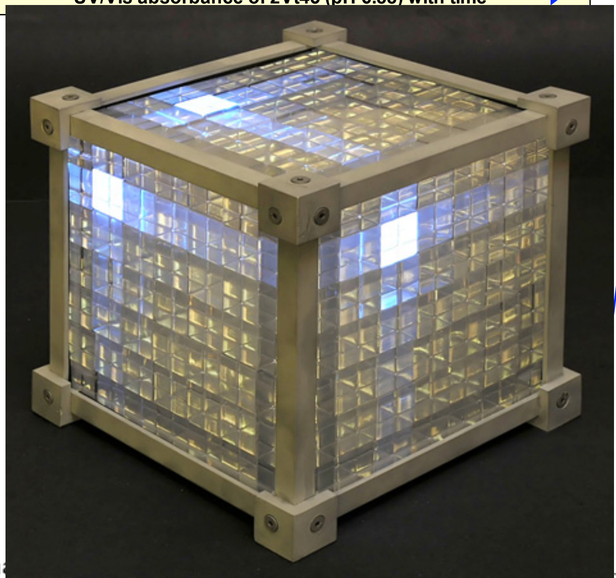
New Technology of LENS

Developed in last three years

Technology and Bgd Control

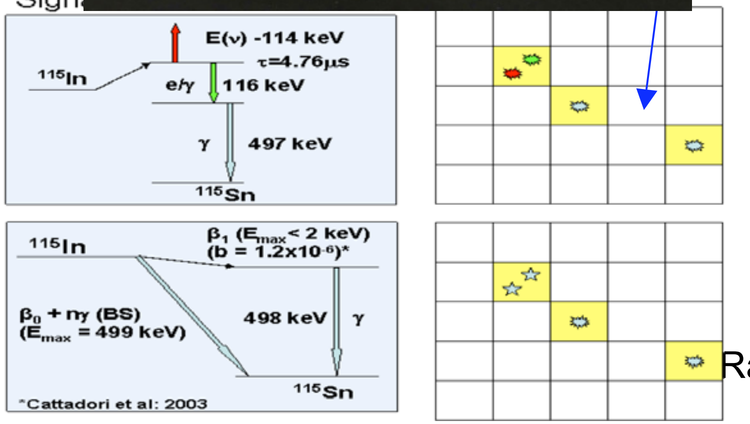
< Towards **Hi Precision** pp neutrino flux >





- **Hi Quality InLS**
- **New Detector Design**
- **Background Analysis Insights→ -115 In decay bgd suppressed →S/N ~3 for first time**

	Status
Design of Detector	**Cubic Lattice Chamber**
InLS: In content **Light attenutation 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%**



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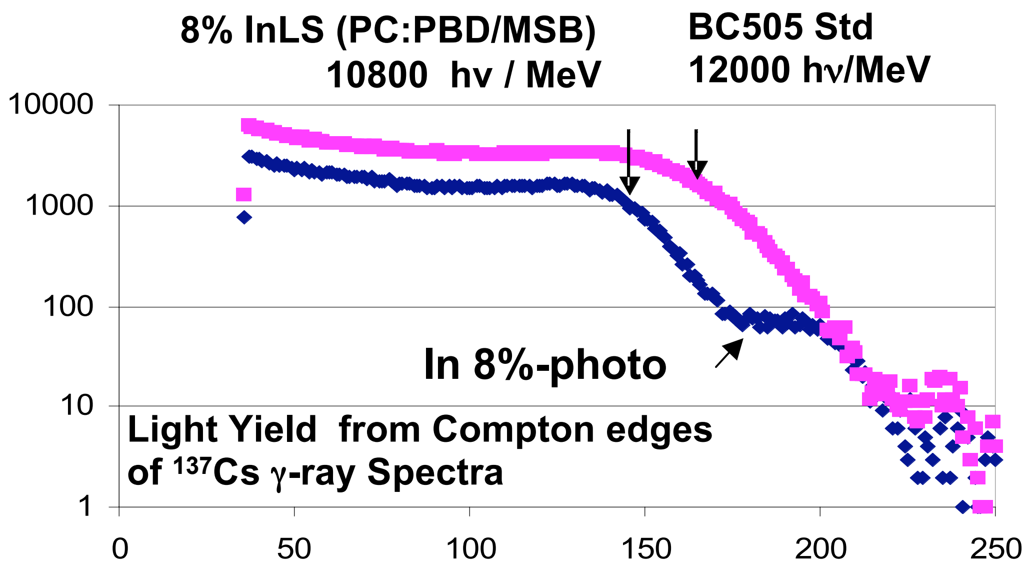
Indium Liquid Scintillator Status

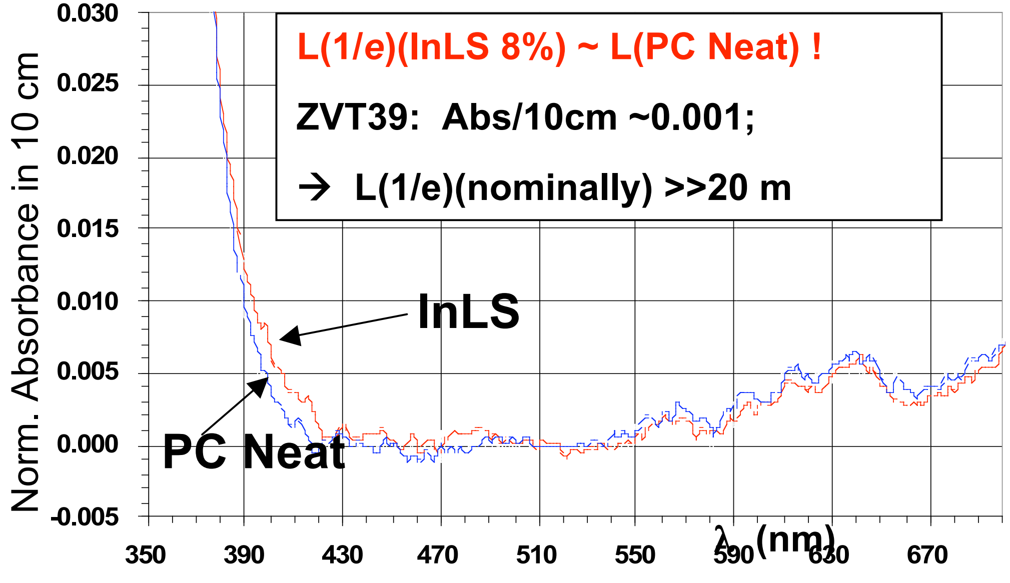
Milestones unprecedented in metal LS technology

LS technique relevant to many other applications



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

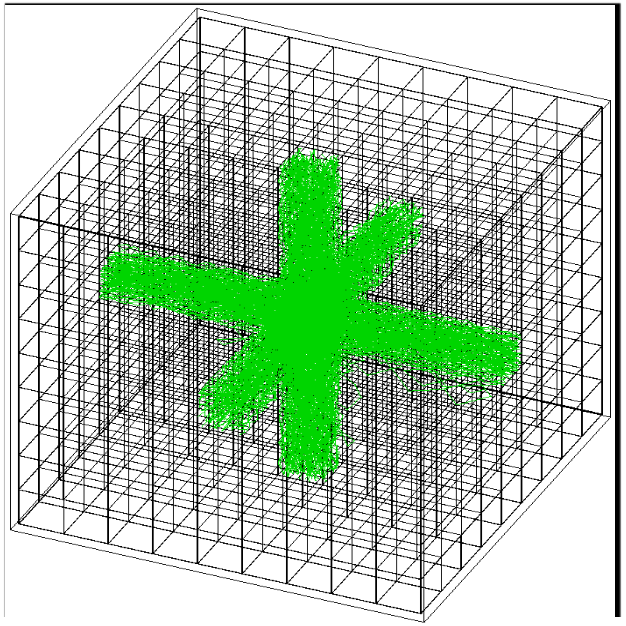


Basic Bell Labs Patent,
Chandross,
Raghavan

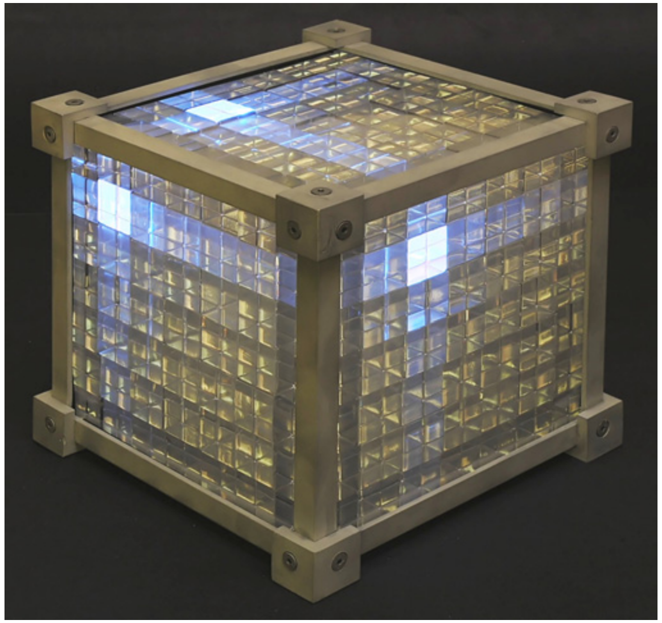
Raghav

New Detector Technology –hi event position localization

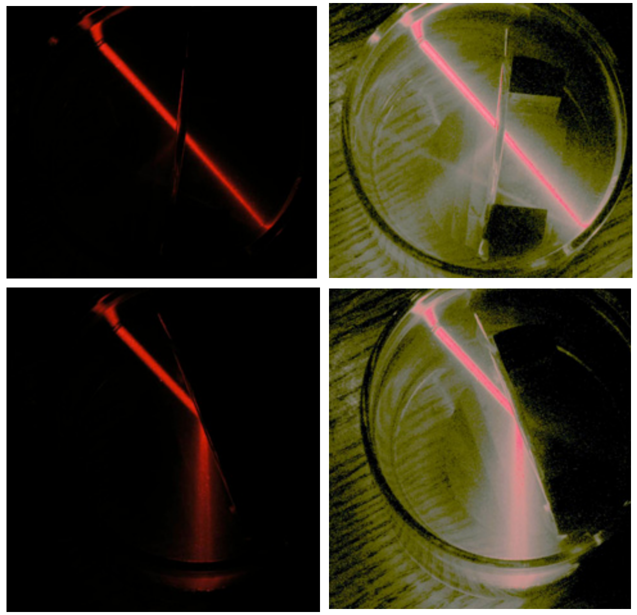
The Scintillation Lattice Chamber



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

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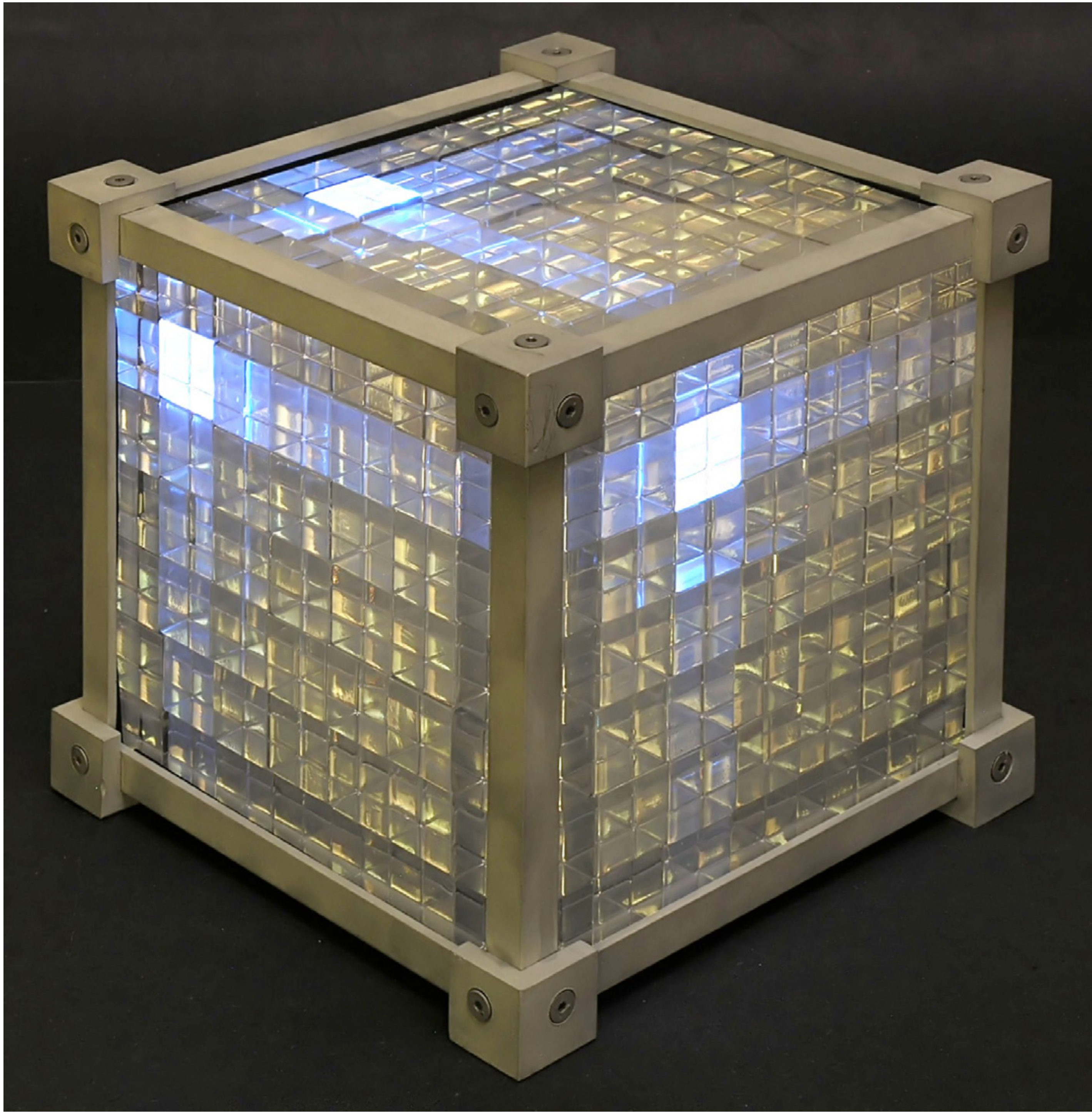
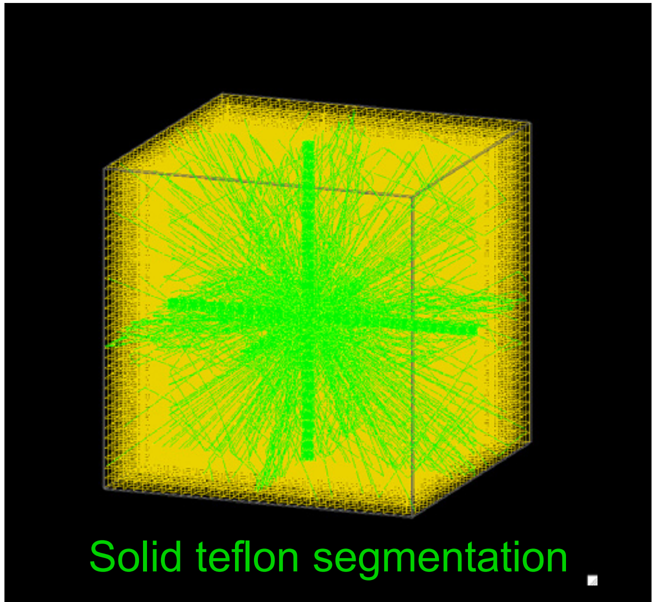
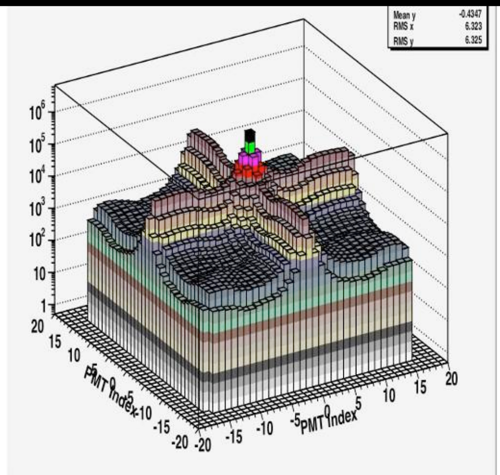


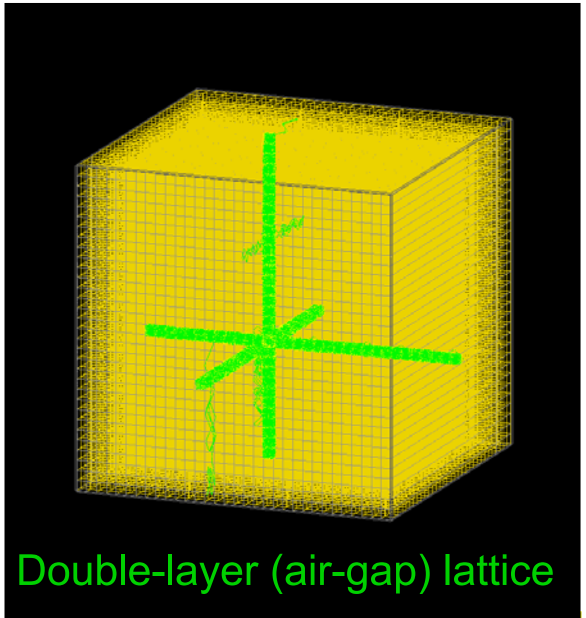
Lattice Structure

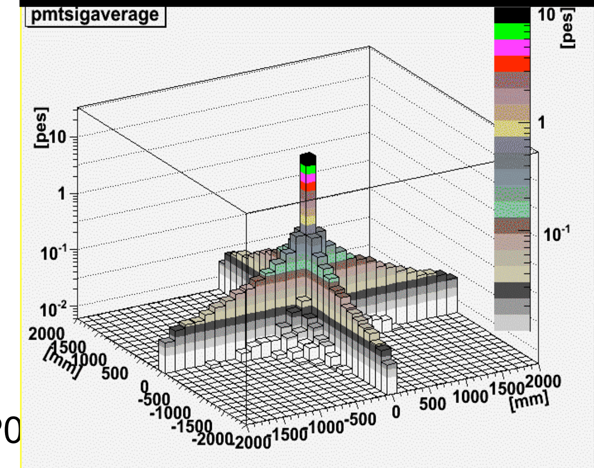
Single Foil

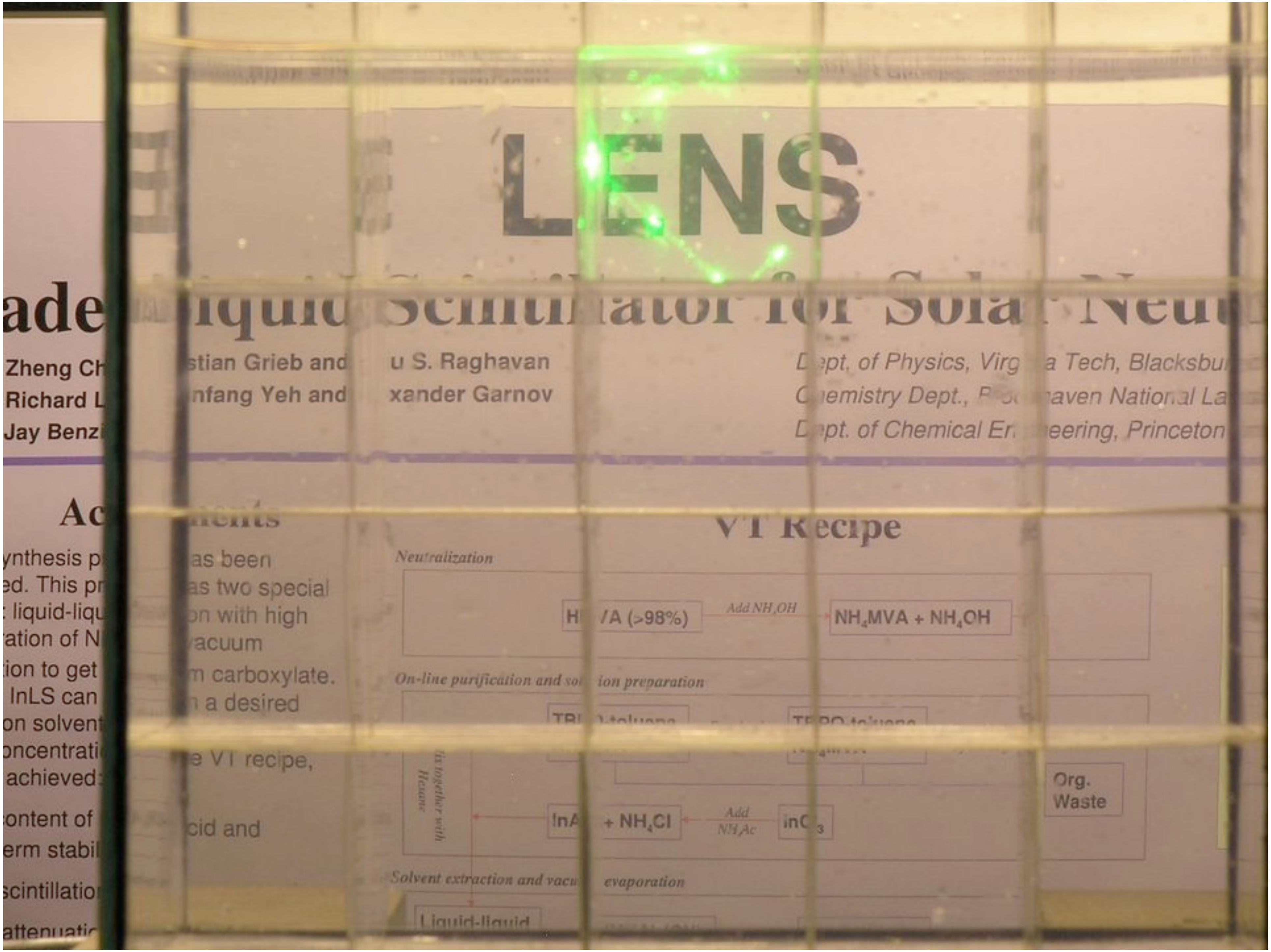




Double Foil






LENS
Scintillator for Sola
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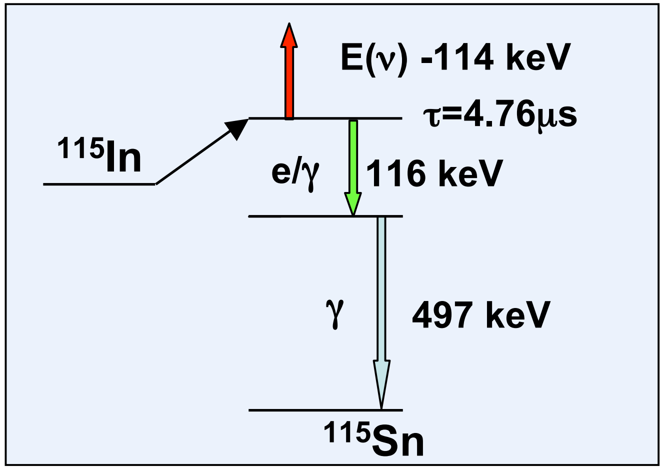
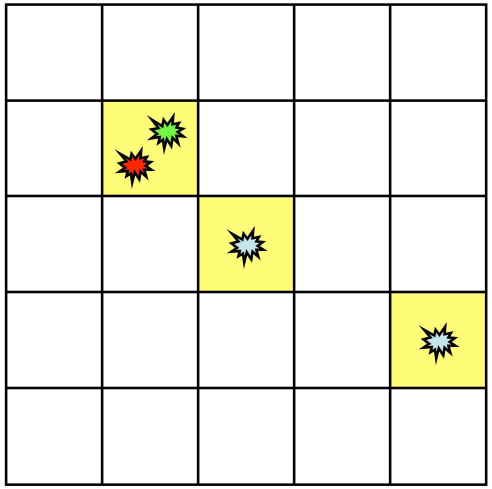
u S. Raghavan
nfang Yeh and
xander Garnov
Dept. of Physics, Virg
a Tech, Blacksbu
Chemistry Dept.,
aven National La
Dept. of Chemical En
eering, Princeton
VT Recipe
Neutralization
/A (>98%)
Add NH_4OH
$NH_4MVA + NH_4OH$
On-line purification and sol
ion preparation
Org. Waste
$+ NH_4Cl$
Add NH_4Ac
Solvent extraction and vacu
evaporation
Liquid-liquid

Indium β^--Background Structure – Space / Time coincidence

Signal

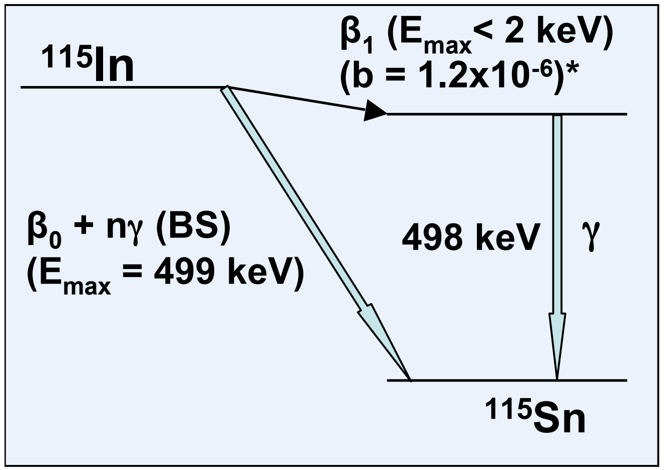


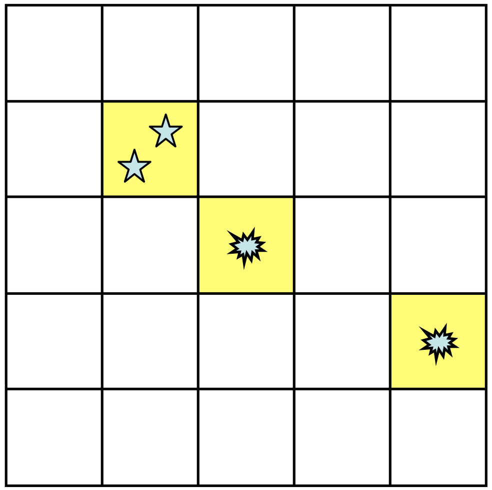


Signal Signature:

Prompt e^- ( ) followed by low energy (e^-/γ) ( ) and Compton-scattered γ ( )
->time/space coincidence
-> tag fixed energy 613keV
->compton scattered shower

Bgd





Background:

Random time and space coincidence between two β-decays ( );
Extended shower ( ) can be created by:

a) 498 keV γ from decay to excited state;
b) Bremsstrahlungs γ-rays created by β;
c) Random coincidence (~10 ns) of more β-decays;

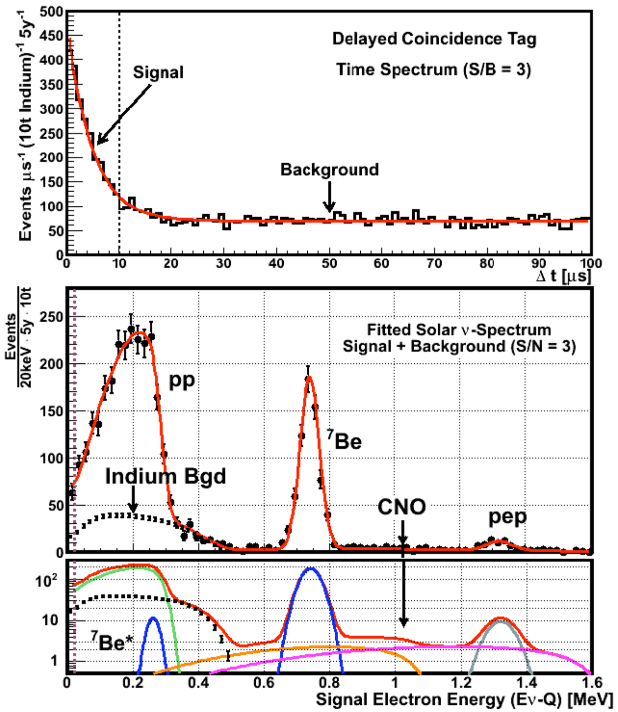
Or any combination of a), b) and c).

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
improved efficiency;



Results of GEANT4 Monte Carlo simulation (cell size = 7.5cm, S/N=3)	**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 ~$3 \cdot 10^{7}$ through time/space coincidence

Neutrino Phenomenology – from LENS

In the first 2 years (no calibration with ν-source needed):

- **Test of MSW LMA physics** - *no specific physics proof yet !*

  P_{ee}(pp)=0.6 (vac. osc.) $P_{ee}(^8B)$=0.35 (matter osc.), as predicted?
- **Non-standard Fundamental Interactions?**

  Strong deviations from the LMA profile of $P_{ee}(E)$?
- **Mass Varying Neutrinos?**

  (see above)
- **CPT Invariance of Neutrinos?**

  so far LMA only from Kamland $\bar{\nu}_e$, is this true also for ν_e "neutrinos" ?
- **RSFP/ Nu magnetic moments**

  Time Variation of pp and ^{7}Be signals? (No Var. of ^{8}B nus !)

  (Chauhan et al JHEP 2005)

Low Energy Neutrinos:

Only way to answer these questions !

Solar Luminosity: Neutrino vs. photon

Energy Balance:

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

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

Solar luminosity as measured by *photon* flux

Will be met under these conditions:

1. Fusion reactions are the *sole* source of energy production in the sun
2. The sun is in a quasi-steady state (change in 40,000 years is negligible)
3. The neutrino oscillation model is correct & no other physics involved;

From a single detector:

⇨ Test of astrophysics, solar model;
Test of neutrino physics (LMA-MSW at low E, NSI, mass-varying νs, $\Theta_{13,}$ …);

Neutrino inferred Luminosity of the Sun - Experimental Status

Main contributions:		
pp	0.91	
^{7}Be	0.074	
(CNO	0.014)	
^{8}B	0.00009	

Measured **neutrino fluxes at the earth:**

^{8}B	(SK, SNO) known very well
$^{7}Be + {}^{8}B$	(Cl) sensitive mostly to ^{8}B
$pp + {}^{7}Be + {}^{8}B$ (Ga)	
^{7}Be	(Borexino, Kamland – in the future)

⇨ in principle can deduce pp-ν flux

Problem: disentangling fluxes from individual neutrino sources

Experimental status – No useful constraint!

$$L_{\nu\,(\text{inferred})} / L_{h\nu} = 1.4 \left({}^{0.2}_{0.3} \right)_{1\sigma} \left({}^{0.7}_{0.6} \right)_{3\sigma}$$

J.N.Bahcall and C.Peña-Garay, JHEP **0311**, 4 (2003)

$$L_{\nu\,(\text{inferred})} / L_{h\nu} = 1.2(0.2)$$

R.G.H.Robertson, Prog. Part. Nucl. Phys. **57**, 90 (2006)

Temperature in the Solar Core impacts Neutrino *Energies, not just relative fluxes*

Relative kinetic particle energies add to the Q-value of capture and fusion reactions.

Not all energies contribute evenly:

pp-fusion:
Gamow Peak at 5.2 keV
pp endpoint shifted up by~5.2keV

$$E_0 = 5.91 keV \cdot (T / 1.5 \cdot 10^7 K)^{2/3}$$

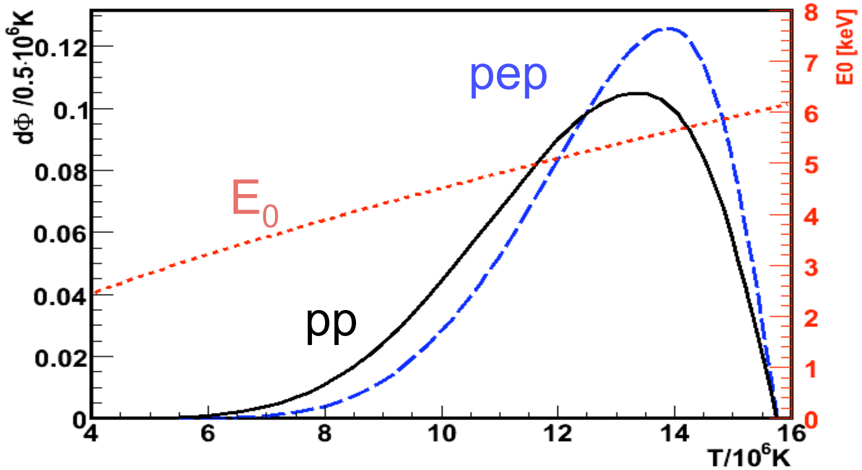
^{7}Be electron capture: maxwellian energy distribution shifts mean energy of ^{7}Be ν line by Δ<E> ~ 1.29 keV

pep: combination, delta Δ<E> ~ 6.6 keV

hep: $E_0 = 10.73 keV \cdot (T / 1.5 \cdot 10^7 K)^{2/3}$

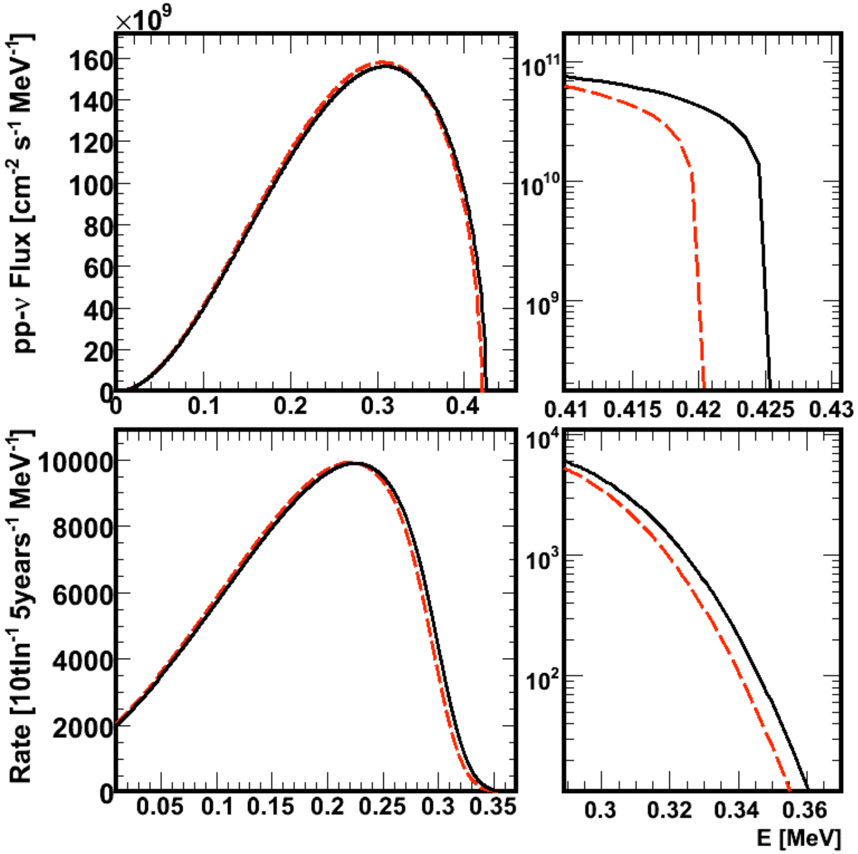
J.N. Bahcall, *Phys. Rev. D* **44**(6), 1644(1991)

pp- and pep neutrino production temperature and related Gamow peak energy:



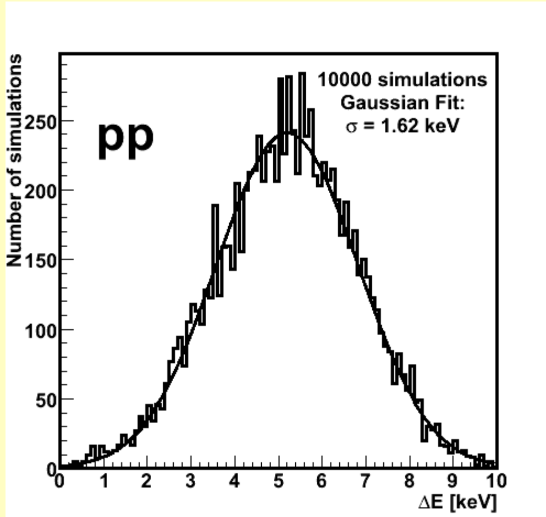
J.N. Bahcall, *Phys. Rev. D* **49**(8), 3923 (1994)

Probing the Temperature Profile of Energy Production in the Sun with LENS



Top: pp-ν spectrum with/without Gamow shift

Bottom: Signal spectrum in LENS with/without Gamow shift
12t Indium - 6years - δE/E=6% at 300keV



Measured Gamow shift in improved LENS: 10000 simulations with ~3000 pp ν events each σ=1.62keV

C. Grieb and R.S. Raghavan, Phys.Rev.Lett.98:141102,2007

Conclusion: Slightly improved LENS can detect the predicted Gamow shift in the pp-ν endpoint ΔE=5.2keV with 95% confidence.

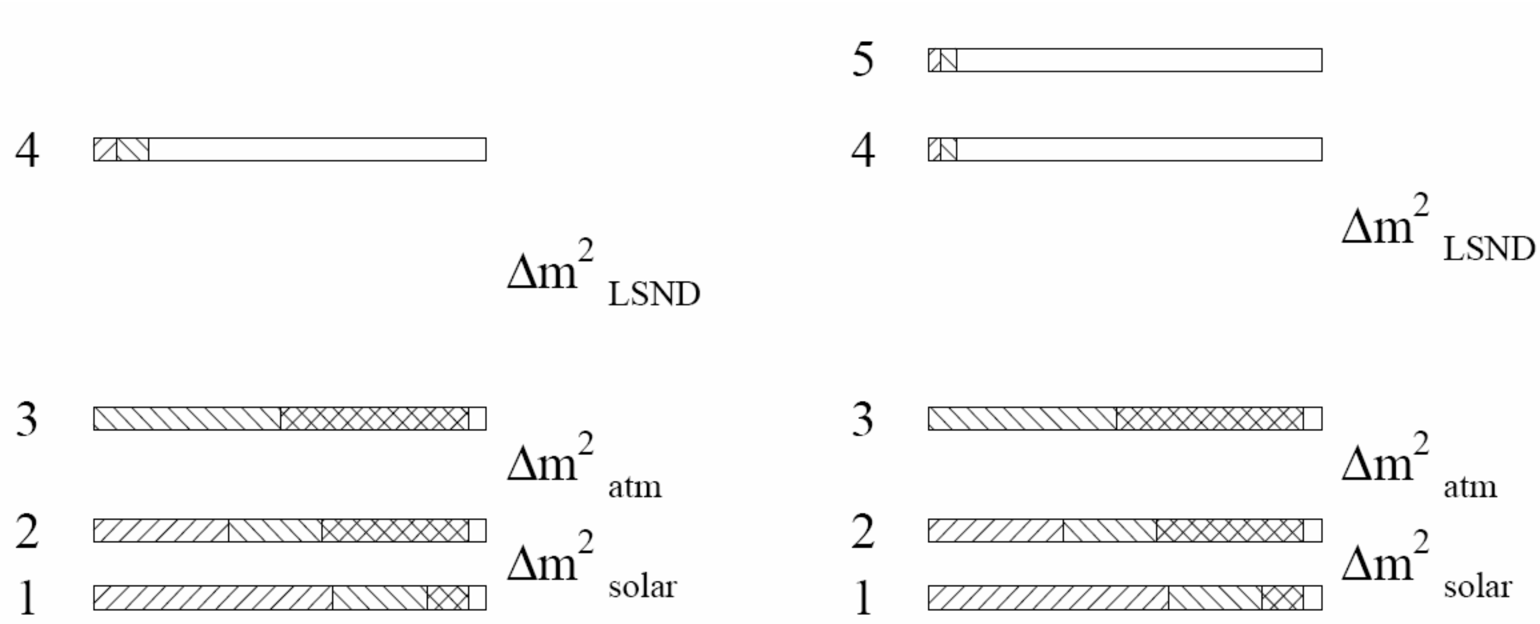
Sterile Neutrinos – Physics beyond the Standard Model

- Fourth (fifth) mass state with high mass splitting triggered by LSND appearance of $\bar{\nu}_e$ from $\bar{\nu}_\mu$ beam at *short* base line ~30m!

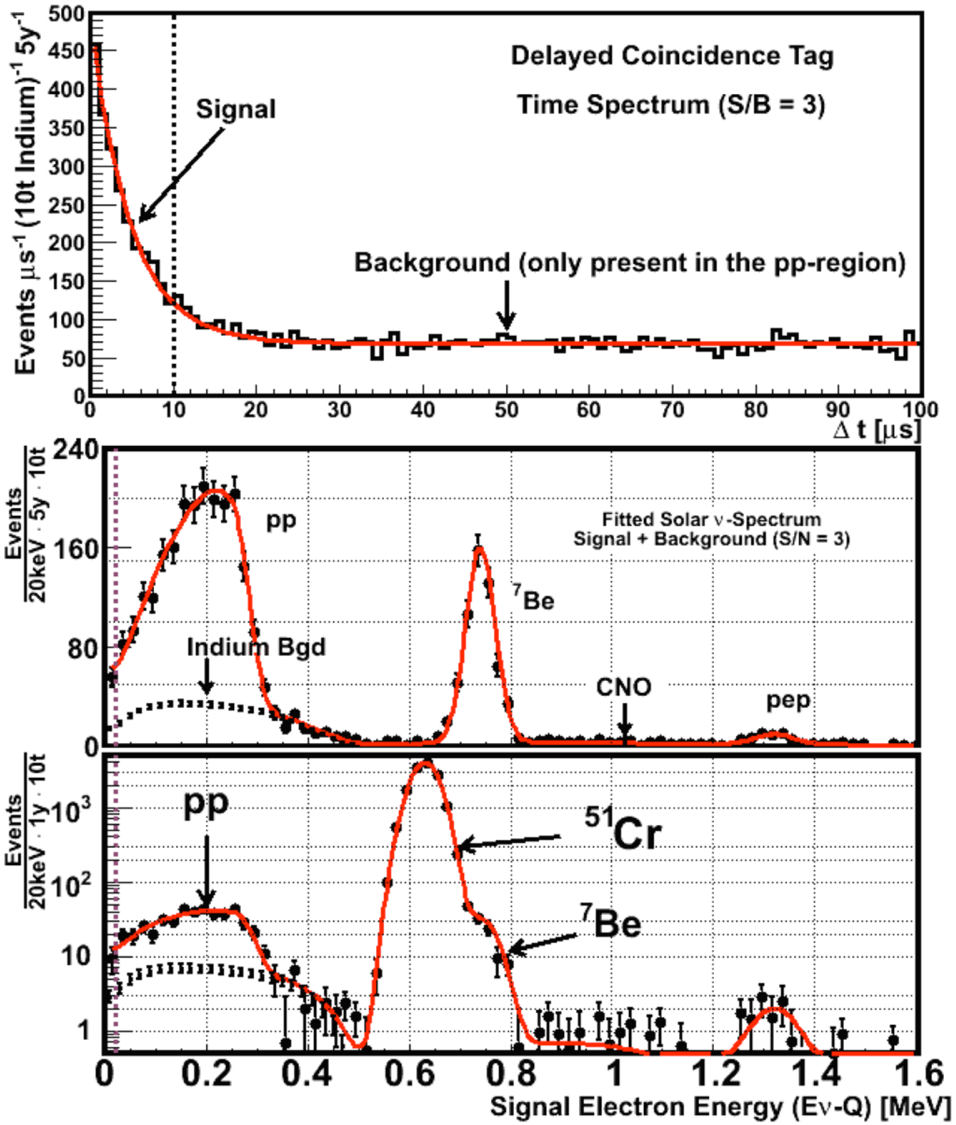
- Implies $\Delta m^2 \sim 1 eV^2$

- Also motivated from cosmology

(3+1) (3+2)



Sorel et. al., Phys.Rev.D70:073004,2004.



LENS Sterile

Cr source inside LENS

Active - Sterile Neutrino Oscillations in LENS

Survival probability of ν_e:

$$\boxed{P_{ee} \approx 1 - 4U_{e4}^2(1 - U_{e4}^2)\sin^2 x_{41} - 4U_{e5}^2(1 - U_{e5}^2)\sin^2 x_{51}}$$

- Cross terms such as $U_{e4}^2 U_{e5}^2$ are neglected
- $\boxed{x_{ij} = 1.27\Delta m_{ij}^2(eV^2)L(m)/E_\nu(MeV)}$

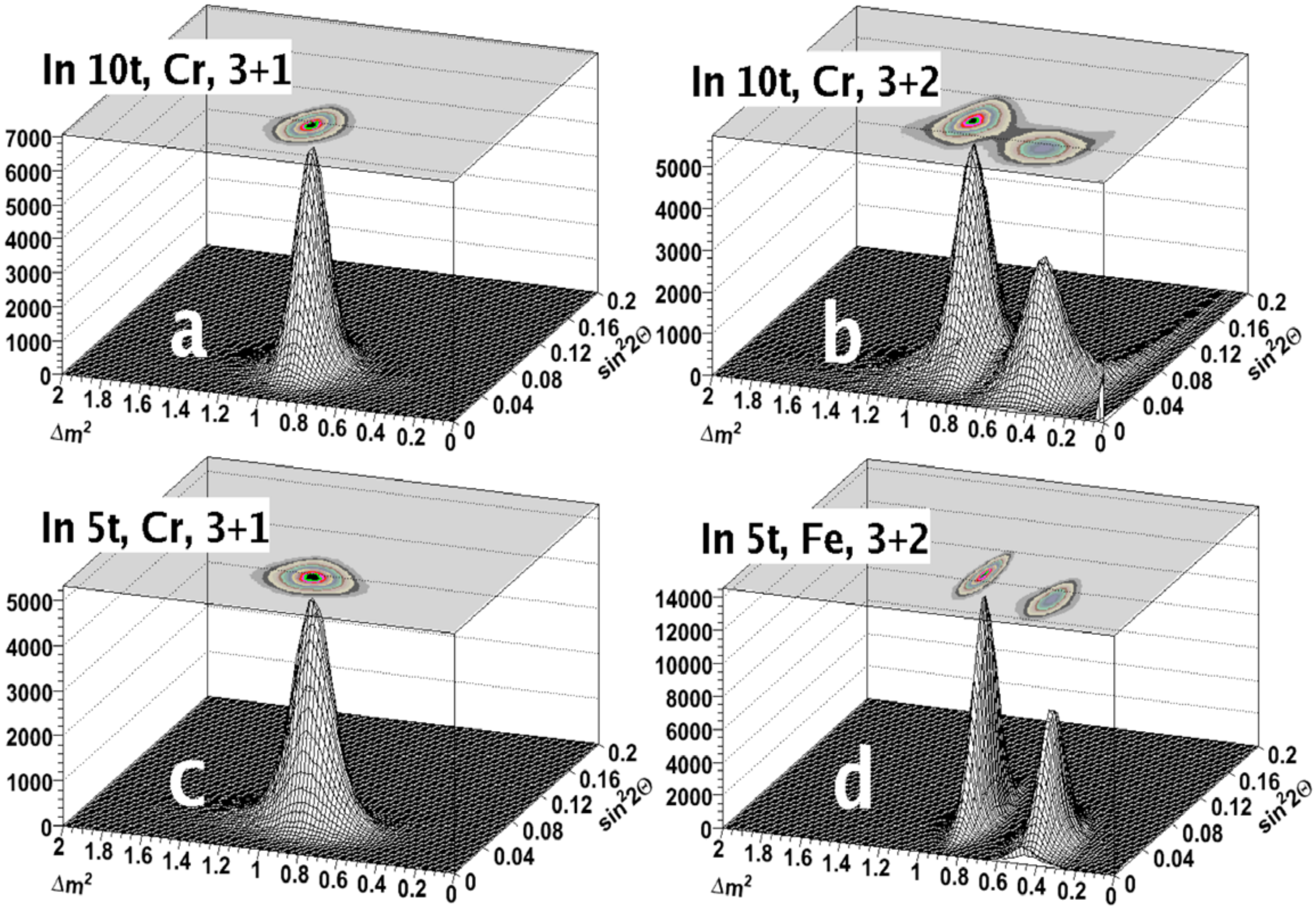
Model	Δm_{ij}^2 (eV^2)	U^2	$\sin^2 2\theta_{ee}$ $=4U^2(1-U^2)$
3+1	0.92_{14}	0.0185	0.073
3+2a	0.92_{14}	0.0146	0.057
	22.1_{15}	0.0013	0.005
3+2b	0.46_{14}	0.0081	0.032
	0.89_{15}	0.0156	0.062

Active – sterile mass splittings and mixing parameters compatible with LSND and the null SBL data (from Sorel et al., Phys. Rev.D70:073004,2004)

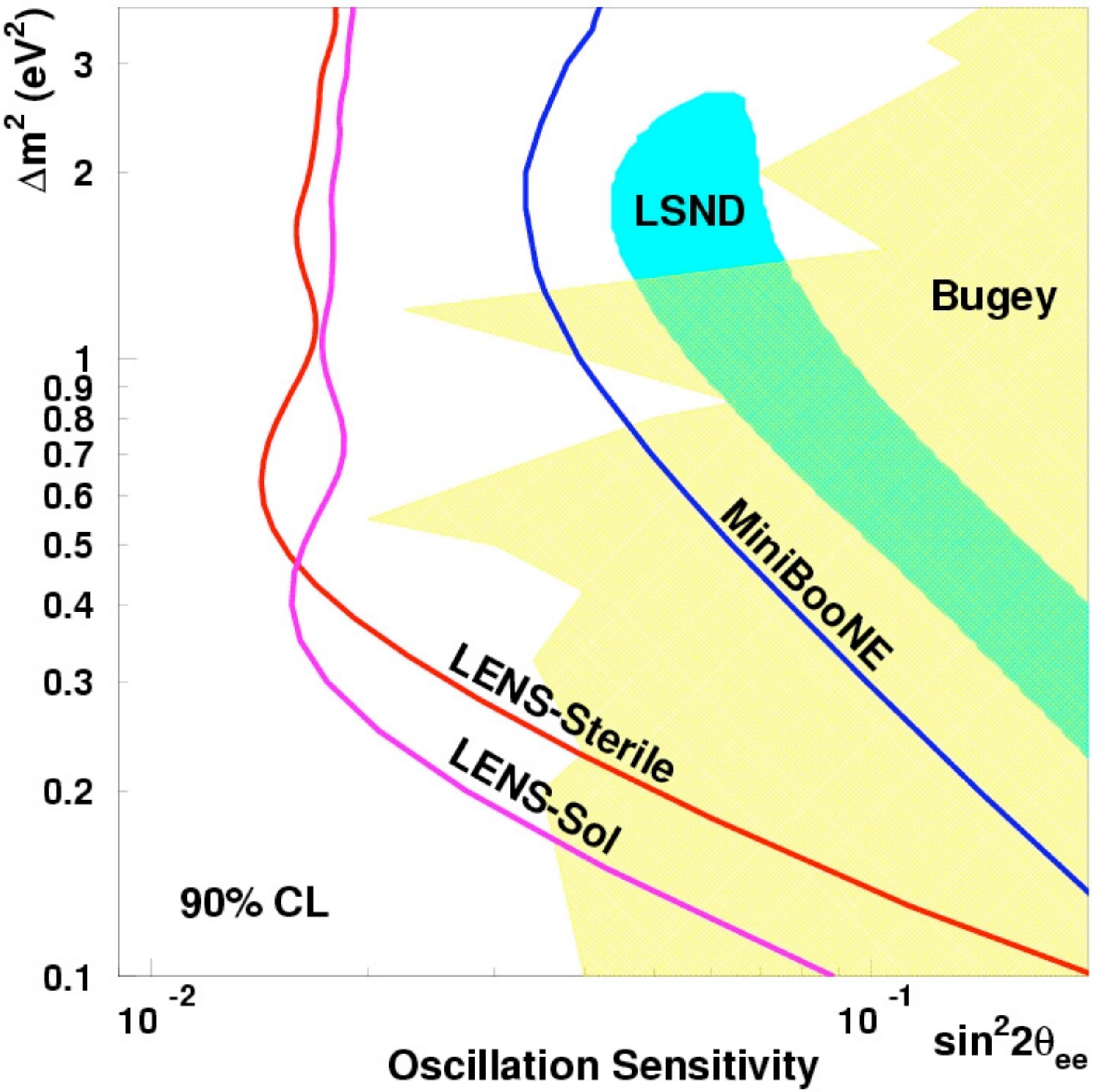
With $\Delta m^2 \sim 1$ eV^2
and $E_\nu \sim 0.753$ MeV (from ^{51}Cr),
full flavor recovery occurs in ~2m,
directly observable in a lab-scale detector.

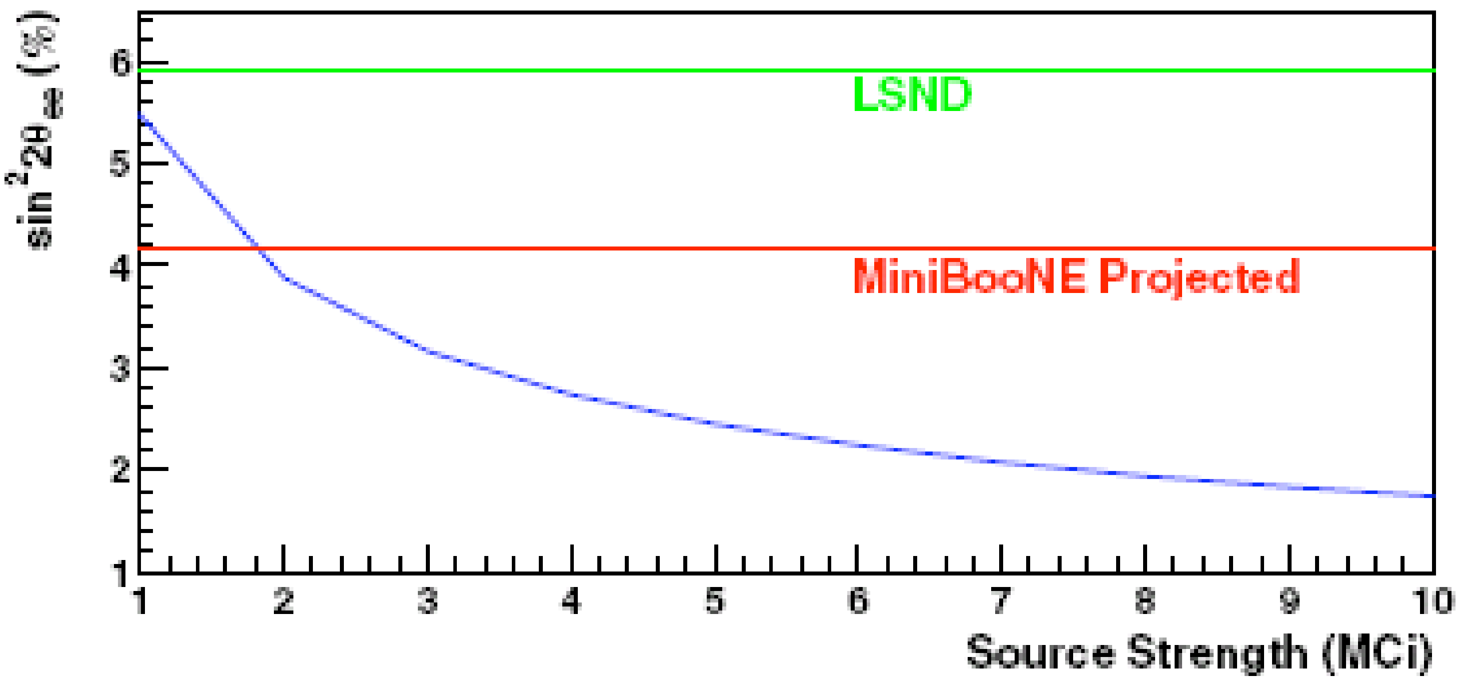
Configuration	ρ_{In} (wt. %)	$d_{detector}$ (meters)	m_{In} (tons)	m_{total} (tons)
A – LENS-Sol	8	5.1	9.9	125
B – LENS-Sterile	15	3.3	5.1	34

Statistical precision of oscillation parameter measurement in LENS



Active – Sterile Oscillation Sensitivity with LENS





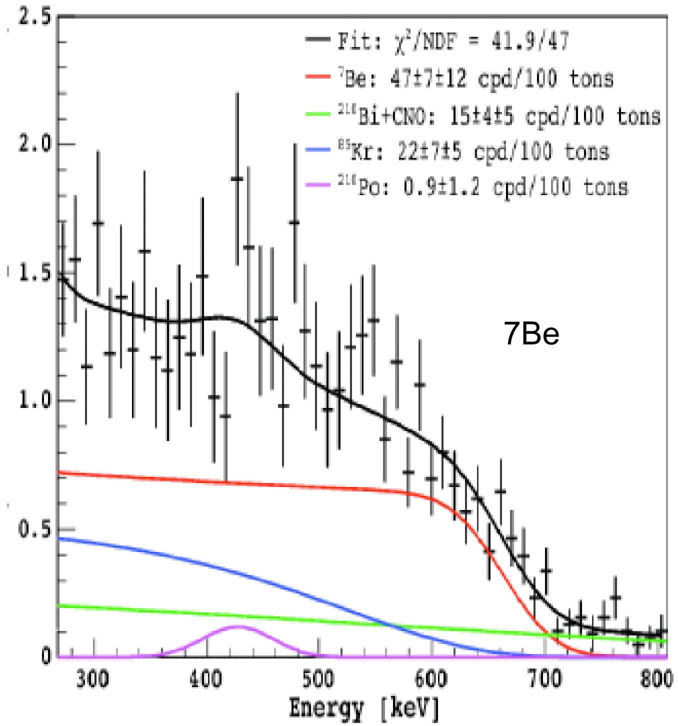
C. GRIEB, J. M. LINK, AND R. S. RAGHAVAN PHYSICAL REVIEW D **75**, 093006 (2007)

Solar Nu's –Contd:

Model independent fluxes Borexino & LENS

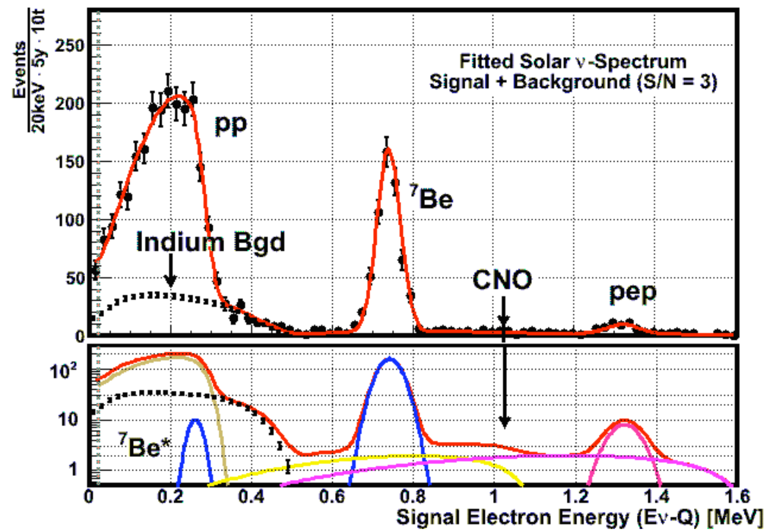
Borexino Signal

(CC + NC) $\nu_e + \nu_x$



LENS Signal

(CC)) ν_e **only**



→Possibility of obtaining solar neutrino

→Fluxes independent of Solar models

MINILENS

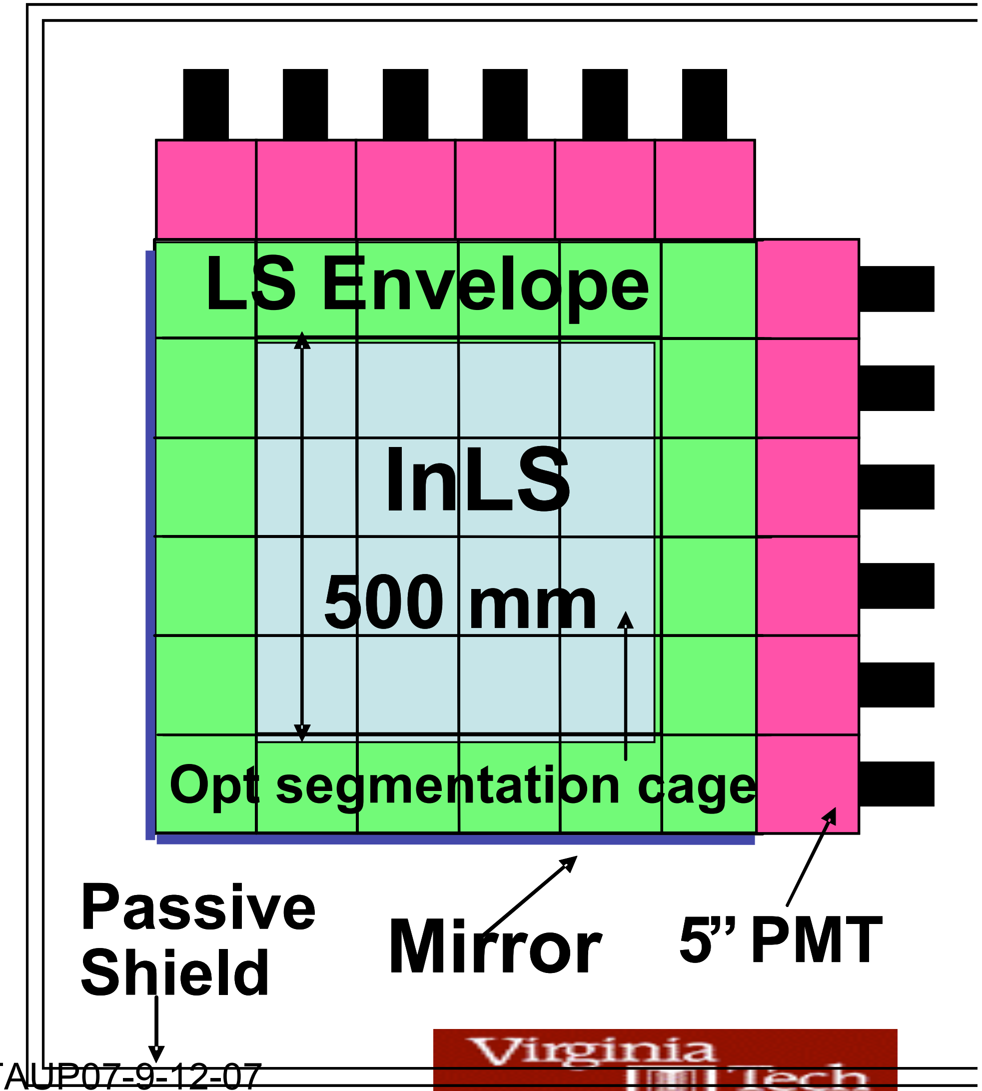
Final Test detector for LENS

Goals for MINILENS

- **Test detector technology**
  → Medium Scale InLS production
  → Design and construction

- **Test background suppression of In radiations by 10^{-11}**
  → Expect ~ 5 kHz In β-decay singles rate; adequate to test trigger design, DAQ, and background suppression schemes

- **Demonstrate In solar *signal* detection in the presence of high background (via "proxy")**



⇨ **Direct blue print for full scale LENS**

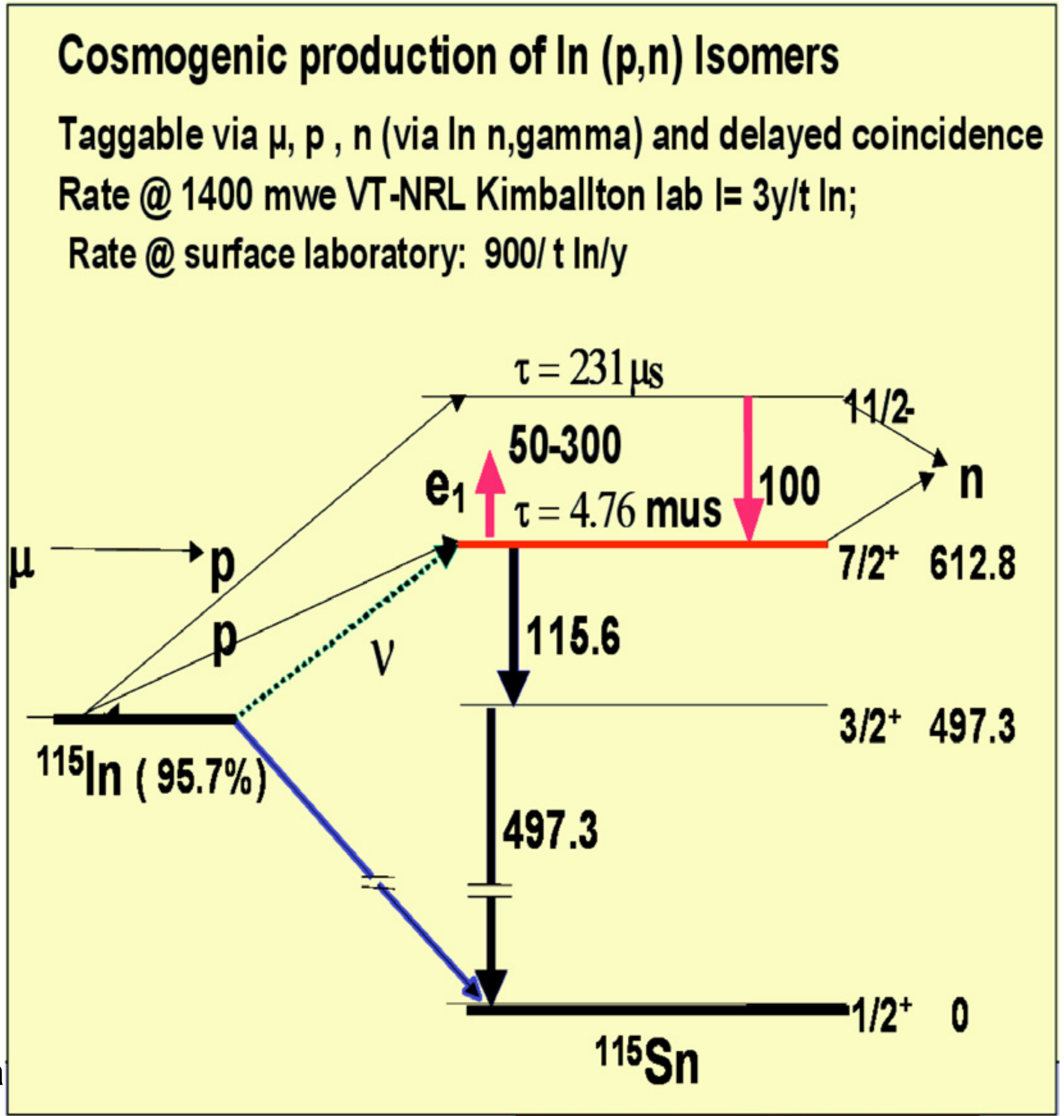
Proxy pp-ν events in MINILENS

Proxy pp nu events in MINILENS from cosmogenic ^{115}In(p,n)^{115}Sn isomers

- **Pretagged via μ, p tracks**
- **Post tagged via n and 230 μ s delay**

→ Gold plated 100 keV events (proxy pp), Tagged by same cascade as In-ν events

→ Demonstrate *In-ν Signal* detection even in MINILENS



Raghava

The Kimballton Underground Facility

Depth 1400 mwe


ABBOTT
ABBOTT TRAILWAYS


Hertz Equipment Rental
888-777-2700
GS-2032

LENS Collaboration
(Russia-US: 2007)

Russia: INR (Moscow): I. Barabanov, L. Bezrukov, V. Gurentsov, V. Kornoukhov, E. Yanovich;

U. S.:

BNL:	R. L. Hahn, M. Yeh;
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North Carolina State:	Albert Young
Louisiana State:	J. Blackmon, C. Rascoe, Q. Zeng;
Princeton U. :	J. Benziger;
South Carolina State:	Z. Chang,
Virginia Tech:	C. Grieb, M. Pitt, R.S. Raghavan, D. Rountree, R.B. Vogelaar;