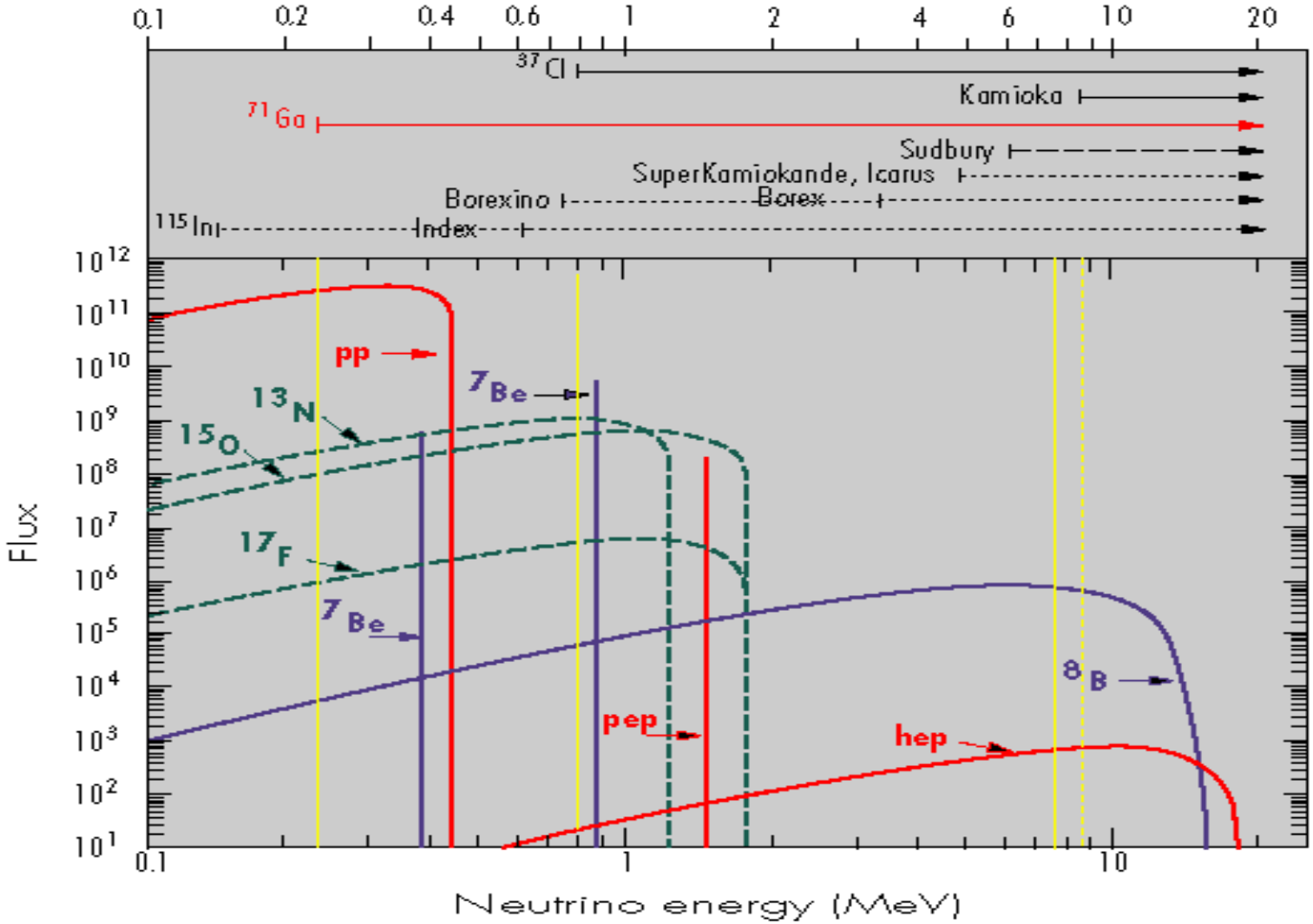
Borexino: ready to fill…



Cut-away model of fully built system.

Physics Driven

APS Neutrino Study 2004: Borexino: This experiment, at the Gran Sasso Laboratory in Italy, is aimed at a measurement of solar neutrinos with energy spectrum sensitivity and ability to measure the flux from ^{7}Be decays. Construction is essentially complete, but operations have been delayed. It is hoped that operations can begin in 2005. As we discuss in Recommendations, a prerequisite in physics with solar neutrinos is a determination of the ^{7}Be neutrino flux to an accuracy of 5% or better.

Measuring the ^{7}Be neutrino flux will:

- test if $\phi(^7\text{Be,pred})\nu_e=(0.665\pm0.015)\phi(^7\text{Be,solar model})$
- confirm LMA mechanism
- perhaps reveal the presence of sterile neutrinos
- provide an independent method to determine S_{34}
- provide next step towards determining neutrino luminosity of the sun
- improve pp ν-flux determination from Ga experiments

Additional Science Opportunity

the precautions taken to enable measurement of the ^{7}Be flux may allow measurement of pep (& CNO) flux as well

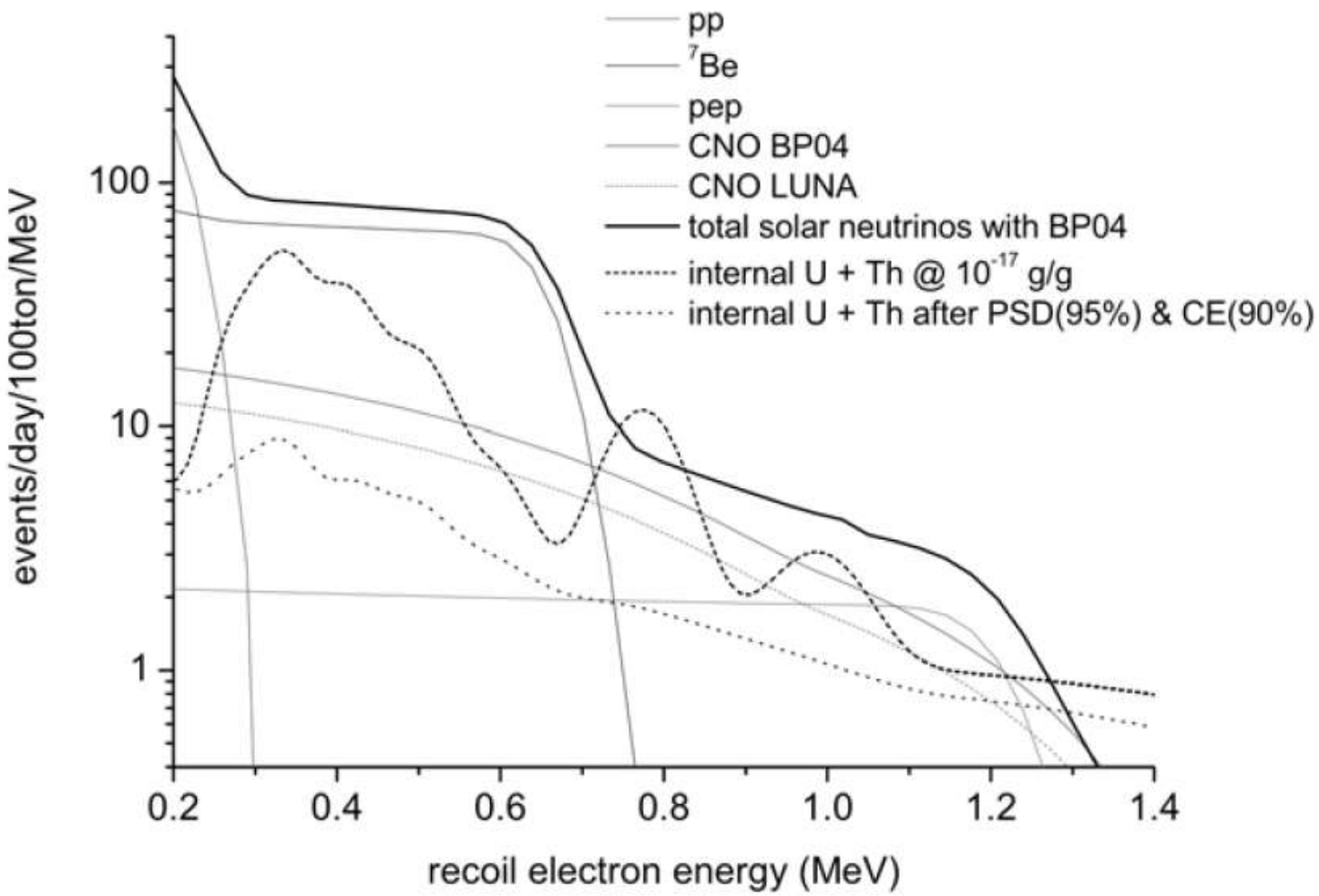
- We recommend development of an experiment to make precise measurements of the low-energy neutrinos from the sun. So far, only the solar neutrinos with relatively high energy, a small fraction of the total, have been studied in detail. A precise measurement of the low-energy neutrino spectrum would test our understanding of how solar neutrinos change flavor, probe the fundamental question of whether the sun shines only through nuclear fusion, and allow us to predict how bright the sun will be tens of thousands of years from now.

Measuring the pep neutrino flux will:

be equivalent to measuring the pp flux
place excellent limits on non-standard physics
provide a complimentary measurement to a CC pp neutrino detector

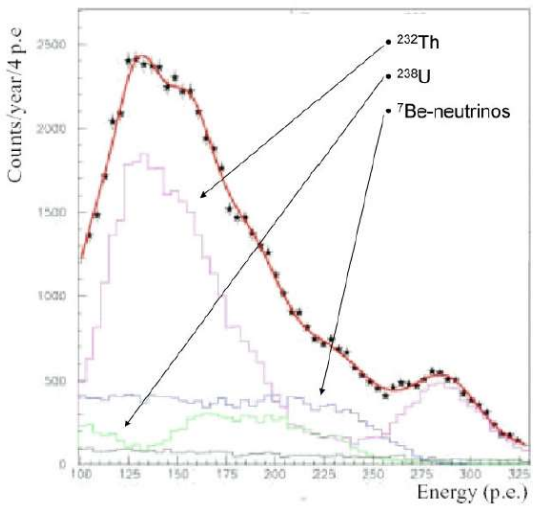
Geoneutrinos and Supernovae neutrinos will also be measured concurrently as a natural complimentary use of the detector.

If We Find 10^{-17} g/g Purity…

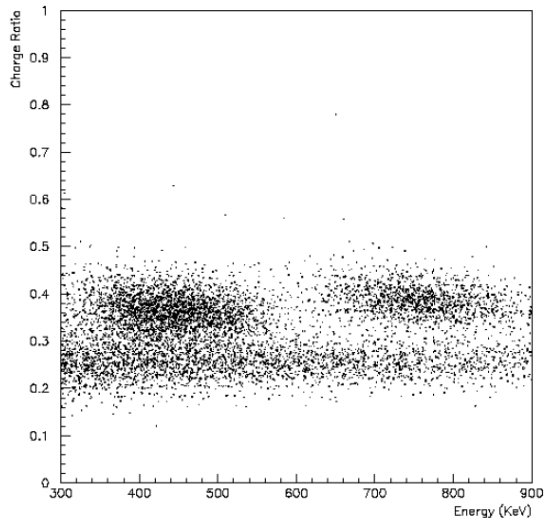


Rely on cosmogenic ^{11}C being tagged.

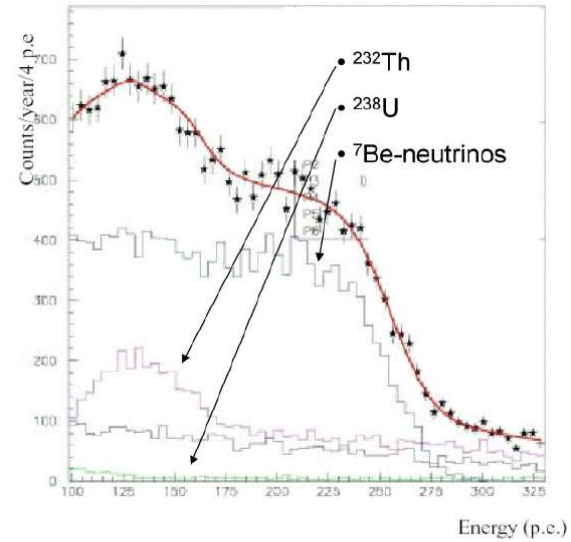
Challenges @ 10^{-16} g/g purity



raw spectra expected at 10^{-16} g/g U,Th



alpha/beta separation using tail-to-total ratio



residual spectra ***after*** all background cuts have been made

^{238}U: $^{238}U(\alpha)^{234}Th(\beta)^{234}Pa(\beta)^{234}U(\alpha)^{230}Th(\alpha)$
$^{226}Ra(\alpha)^{222}Rn(\alpha)^{218}Po(\alpha)^{214}Pb(\beta)^{214}Bi(\beta)$
$^{214}Po(\alpha)^{210}Pb(\beta)^{210}Bi(\beta)^{210}Po(\alpha)^{206}Pb$

^{232}Th: $^{232}Th(\alpha)^{228}Ra(\beta)^{228}Ac(\beta)^{228}Th(\alpha)^{224}Ra(\alpha)$
$^{220}Rn(\alpha)^{216}Po(\alpha)^{212}Pb(\beta)^{212}Bi(\beta)^{212}Po(\alpha)^{208}Pb$

Best in CTF to date:

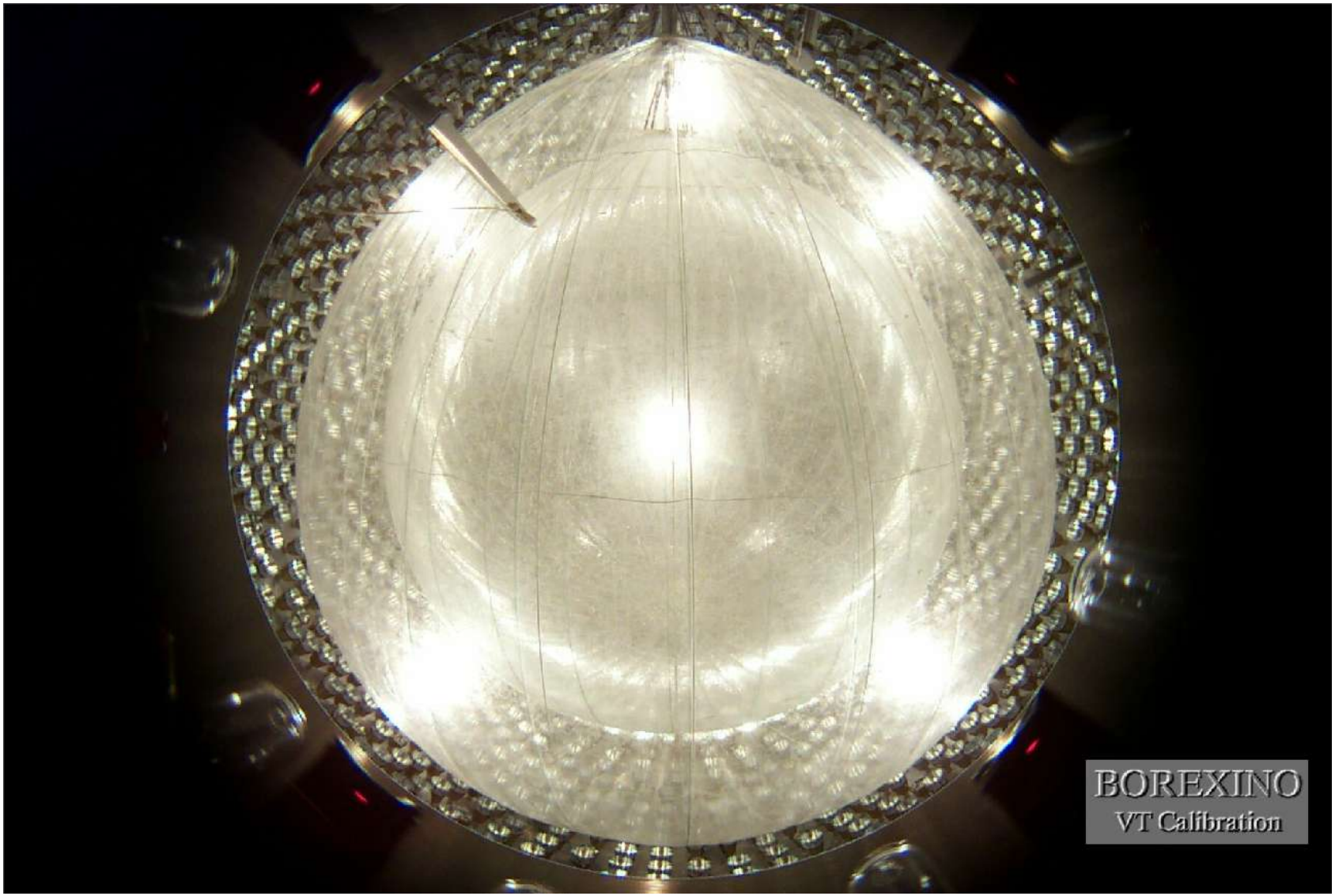
^{238}U: $(3.0 \pm 0.3) \times 10^{-16}$ g/g

^{232}Th: $(6.5 \pm 0.9) \times 10^{-16}$ g/g

Detector Status

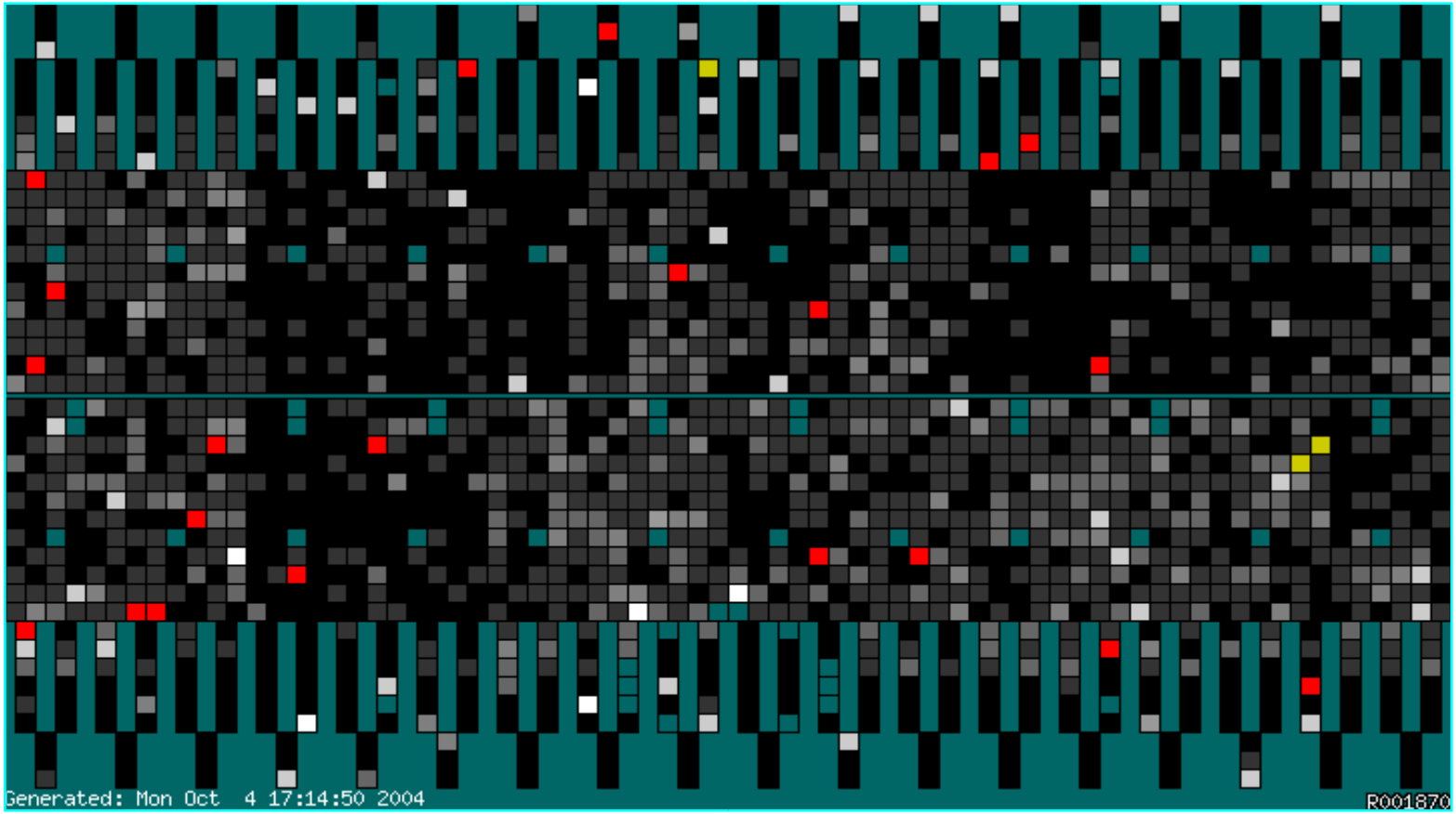
- all major hardware systems installed
- final cleaning and testing nearing completion
- needed purity of N_2 achieved, CTF capable of testing purity/cleanliness of systems
- filling operations poised for execution
- detector calibration methods prepared
- data collection electronics and analysis software ready
- multiple purification methods ready to be used as needed

Inside the Detector



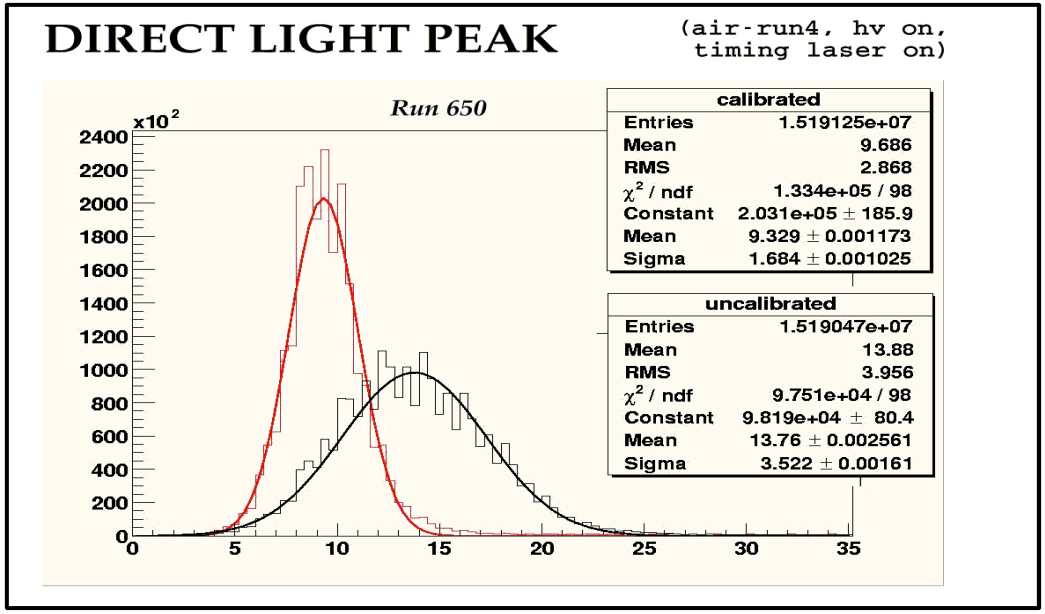
Detector PMT status: June 2004

- normal
- bright
- dead
- uncabled



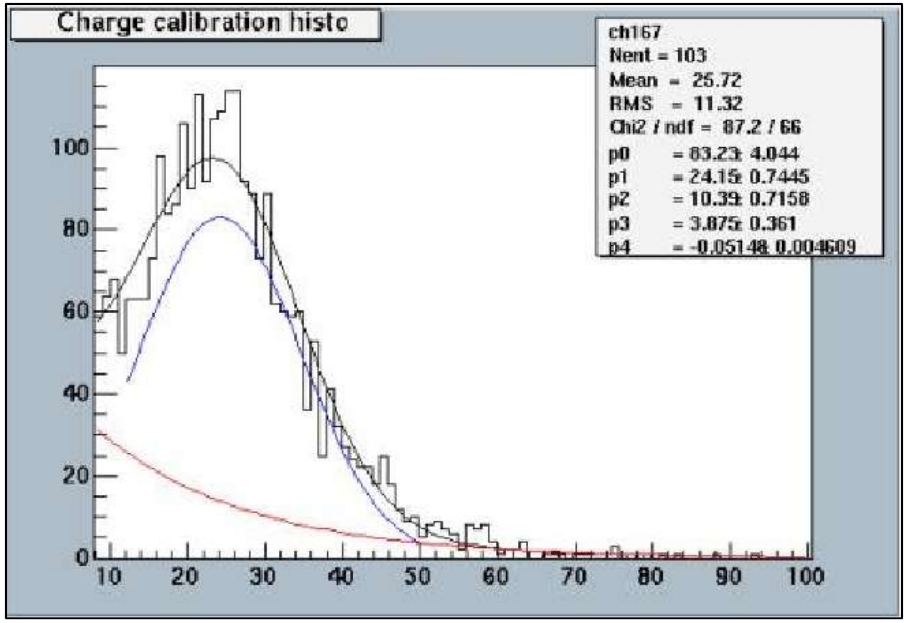
Time and Charge calibrations

PMT timing and gain accomplished with laser and optical fiber system



σ ~ 1.6 ns with 2000 PMTs

automatic charge calibration and allignment of PMTs



Borexino Calibration Strategy

Borexino Parameters

Energy Scales

- Beta
- Alpha
- Gamma

Position Reconstruction

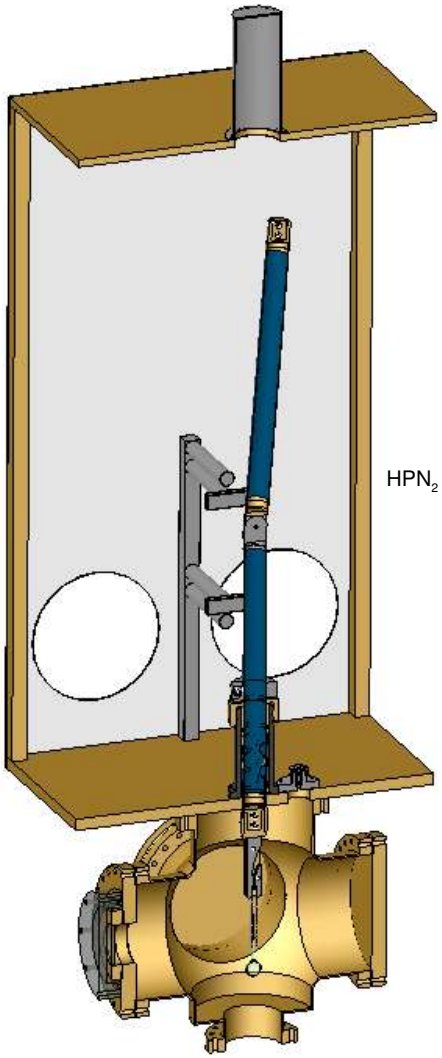
- Fiducial Volume
- Correlated Events
- Internal/External/Surface

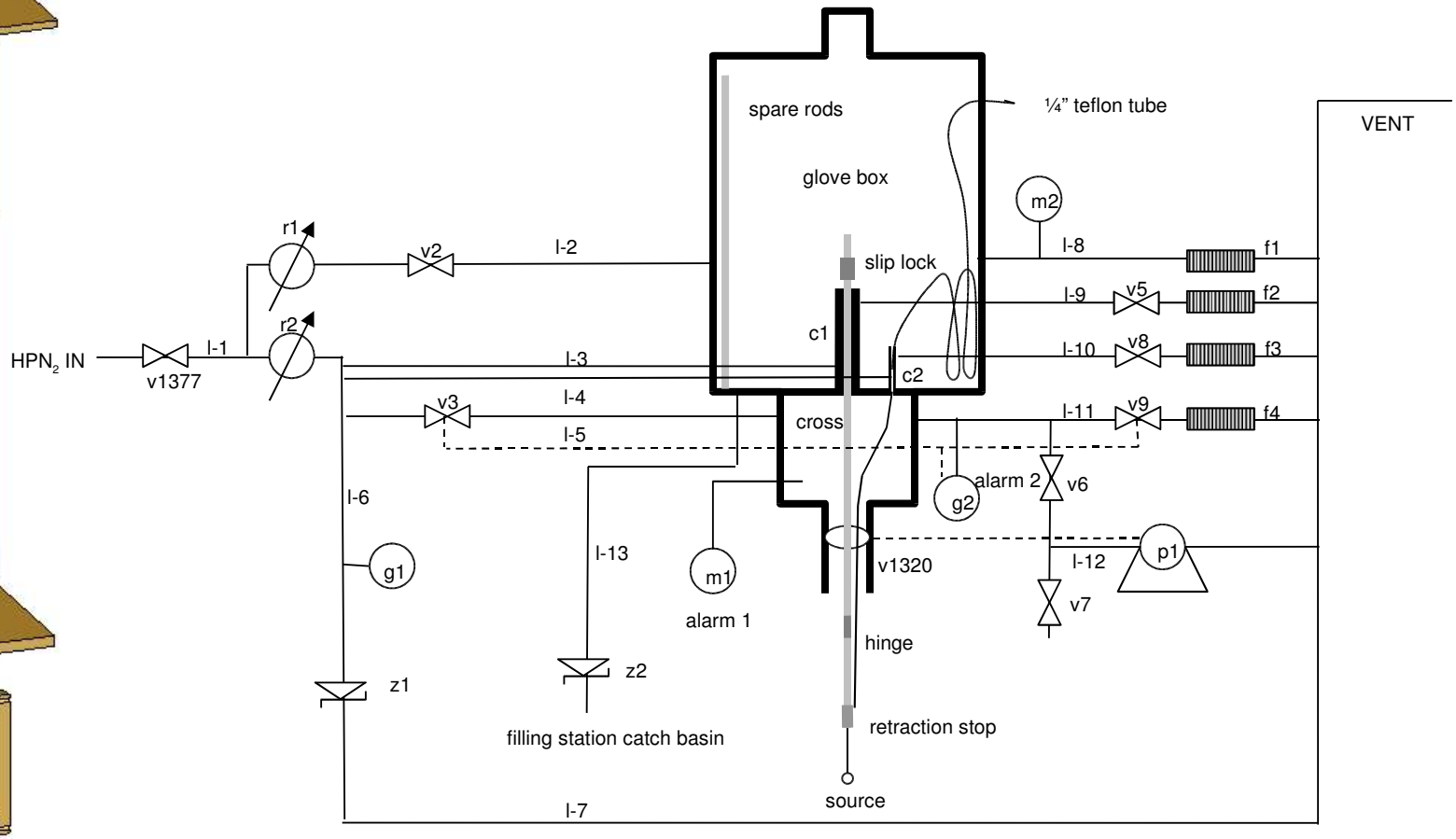
α/β Separation

Stability

- Chemical
- Optical
- Mechanical
- Solar Signature

Source Insertion System





Design based on successful CTF version.

VT Calibration Control

Main Commands

Camera parameters | Camera control | Fit | Locate LED

VT Calibration - Locate LED

Various commands

Get Saved | Save | Move Upload to Saved | Project lines from sel. cams | Find (w Tweak) @ calc. xyz | Reinitialize

View Camera:

- Camera 1
- Camera 2
- Camera 3
- Camera 4
- Camera 5
- Camera 6
- Camera 7
- Camera 8

Selected Image Actions

- Save as Background
- Reset Image
- Find LED
- Load calculated x,y into cursor
- Load/Save to Tweak Master
- View Peak Info (only available at Zoom 32
- Tweak Master Reset
- Tweak Reset
- Tweak All
- Tweak View
- Overlay

Selected Cameras:

- [x] Camera 1
- [x] Camera 2
- [ ] Camera 3
- [ ] Camera 4
- [ ] Camera 5
- [ ] Camera 6
- [ ] Camera 7
- [ ] Camera 8

Color	Mouse Position	Cursor Position	Calculated Position
R 35	x 696.4	x 16.4	x 16.4
G 1	y 109.7	y 69.7	y 69.7
B 0			

Options

- [ ] Subtract Background
- [x] Select Image
- [x] Normalize Image
- [ ] Find Pseudo Centroid

Color Option

Color | Red | Green | Blue

Zoom

1/8 | 1/4 | 1/2 | 1 | 2 | 4 | 8 | 16 | 32

Enter LED Coordinates

227.9 | 108.3 | 0.0 | Polar | Rectangular | Calculate

Enter Parameters for centroid

Centroid Range 10 | Sel. Thresh. 15

Insertion Rod & Tube Inventory

Number of rods above hinge	9	Straight Tether Length (cm)	1180.0	LED r (pred)	227.9
Number below hinge (n-no hinge)	2	Tether Short by (cm)	63.4	LED t (pred)	108.3
Extension in Glove Box (cm)	40.0	Arm Angle (degrees)	53.3	Toggle View Geometry	

Reconstruct Locations

LED				Source (depends upon rod geometry)			
x	216.4	r	227.9	x	232.4	r	247.0
y	-0.1	theta	108.3	y	-0.1	theta	109.8
z	-71.5	phi	360.0	z	-83.5	arm angle	53.3

Current Index of Refraction: 1.0

Reconstruct

VTCalib

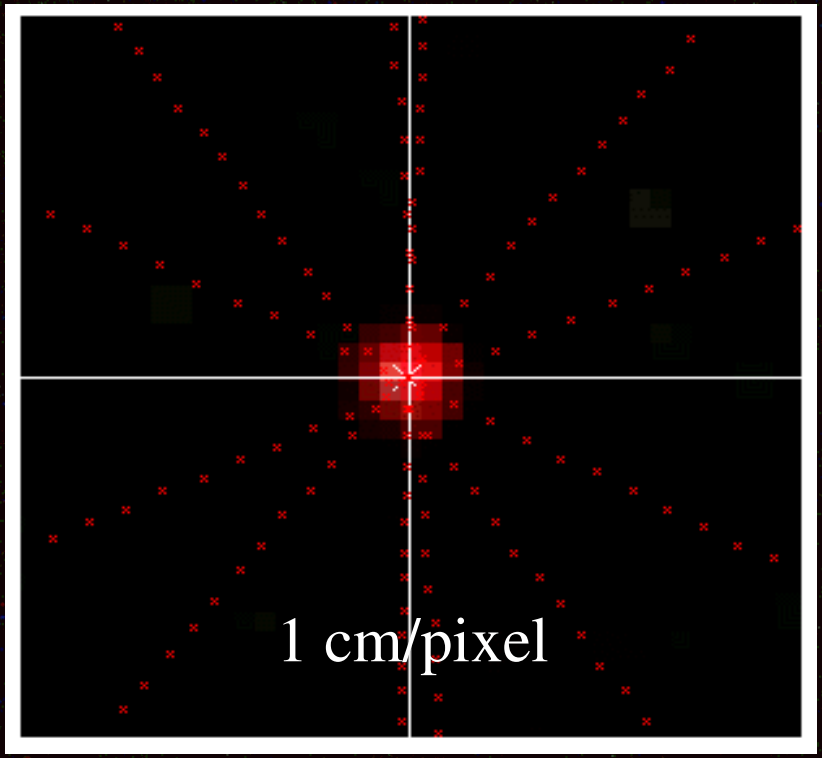
Vtcalib

Glovebox

Inner Vessel

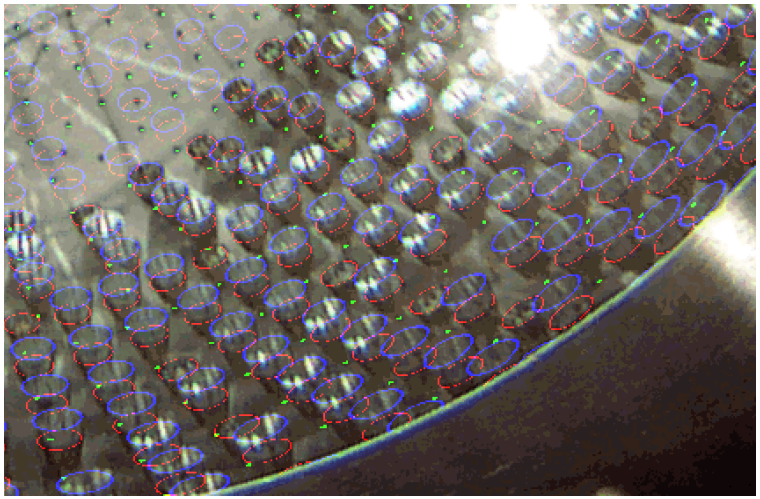
VTCalib

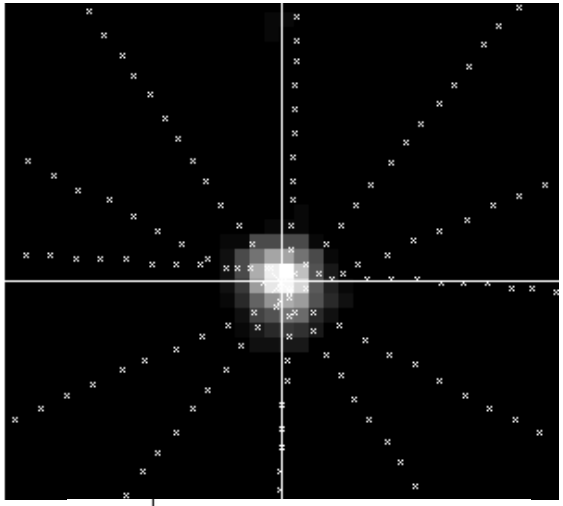
```
associated
i, calx, caly = 1, -139.438, -104.541
i, calx, caly = 2, 16.434, 69.740
i, calx, caly = 3, 184.116, -90.316
i, calx, caly = 4, -122.214, -118.979
i, calx, caly = 5, 187.144, -111.480
i, calx, caly = 6, -0.827, 94.915
i, calx, caly = 7, 171.346, 38.446
i, calx, caly = 8, 0.000, -170.271
 1 regenerated
 1 regenerated
 2 regenerated
 2 regenerated

 Range:          0.000
 x0,y0,z0:     216.386     -0.086    -71.476
 x,y,z:        216.386     -0.086    -71.476
 Camera  1 dist =    0.0125734927
 Camera  2 dist =    0.0125734881
```

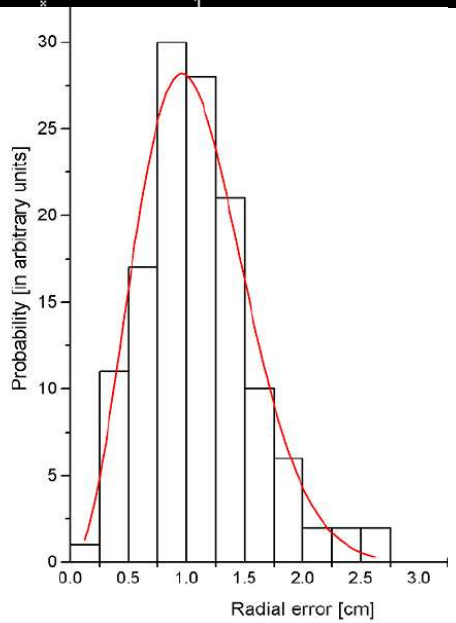


BOREXINO
VT Calibration

Source Location Method



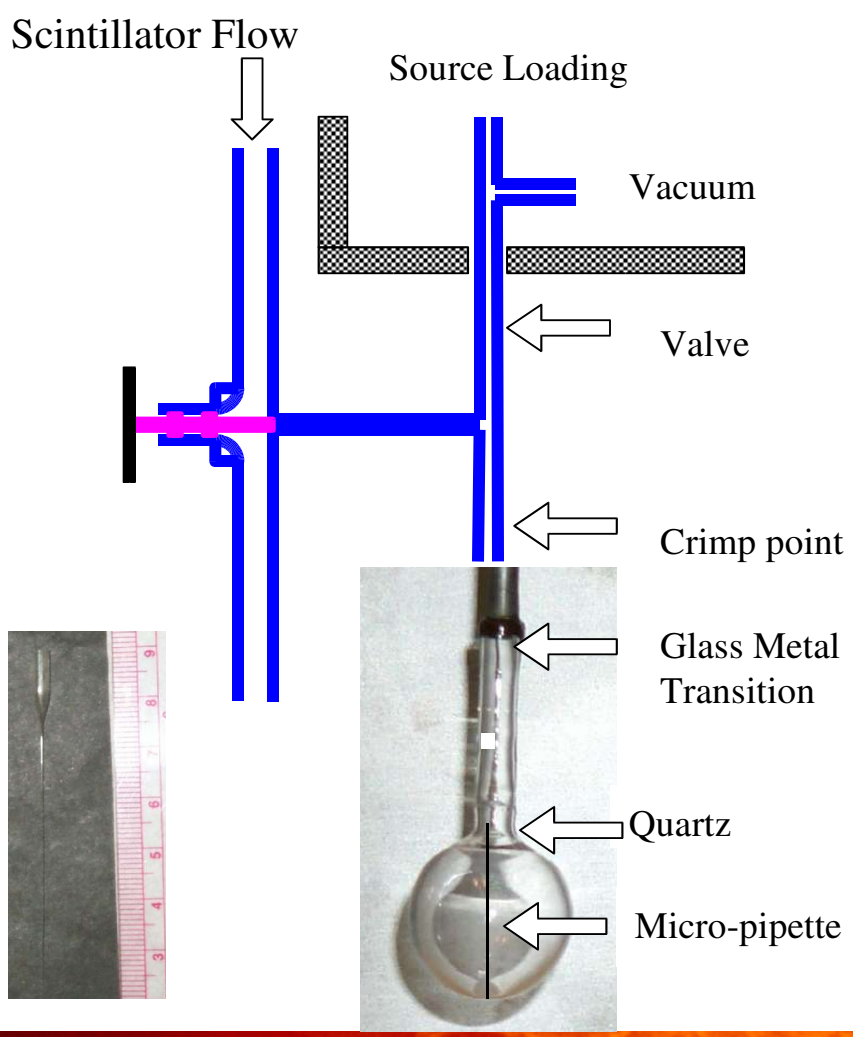




Camera assembly; calibrating the image; triangulating the source (each pixel is about 1 cm at the detector center); position error distribution.

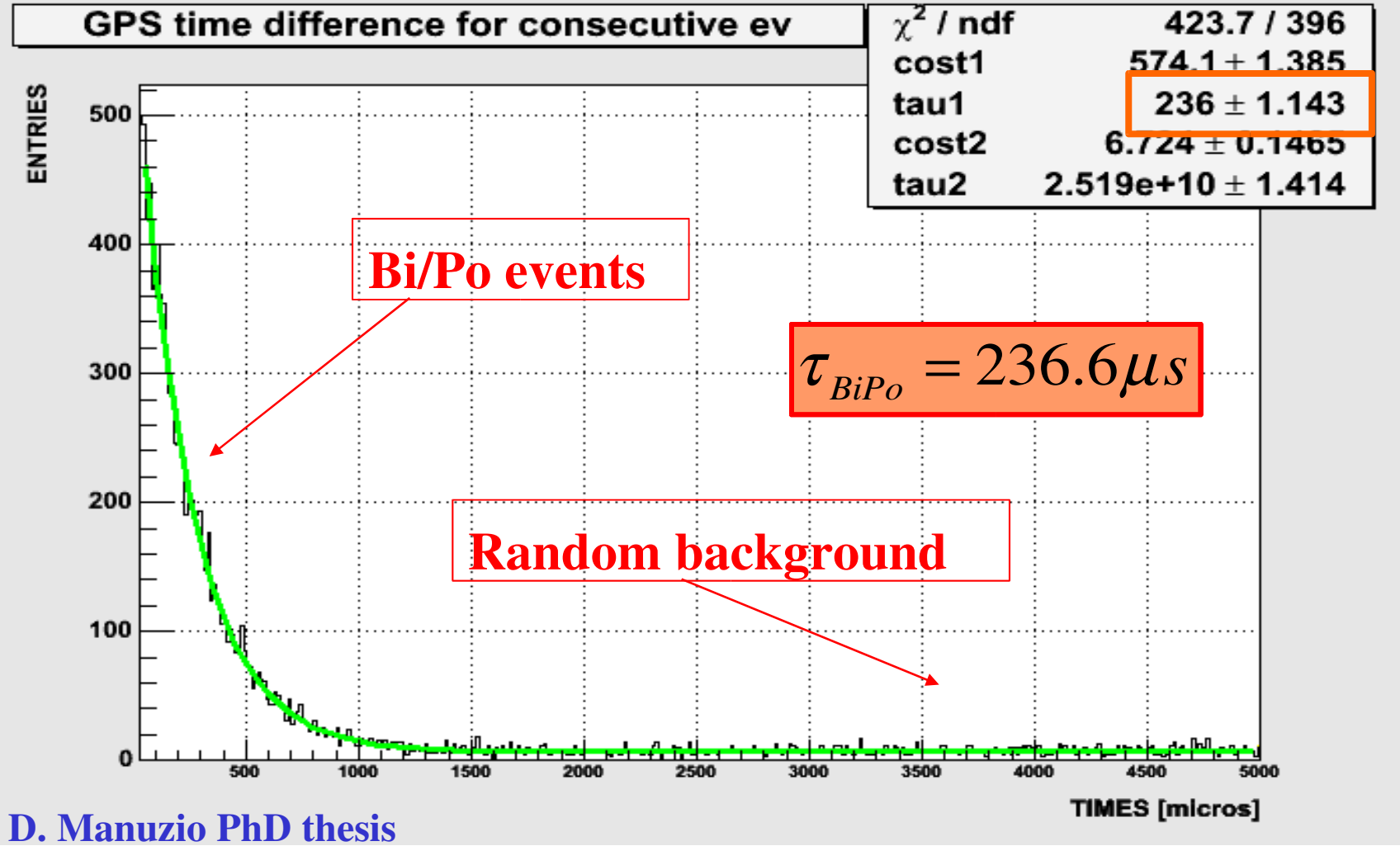
about 2 cm position accuracy (~2% fiducial volume accuracy)

Radioactive Sources (~10 Bq typical)



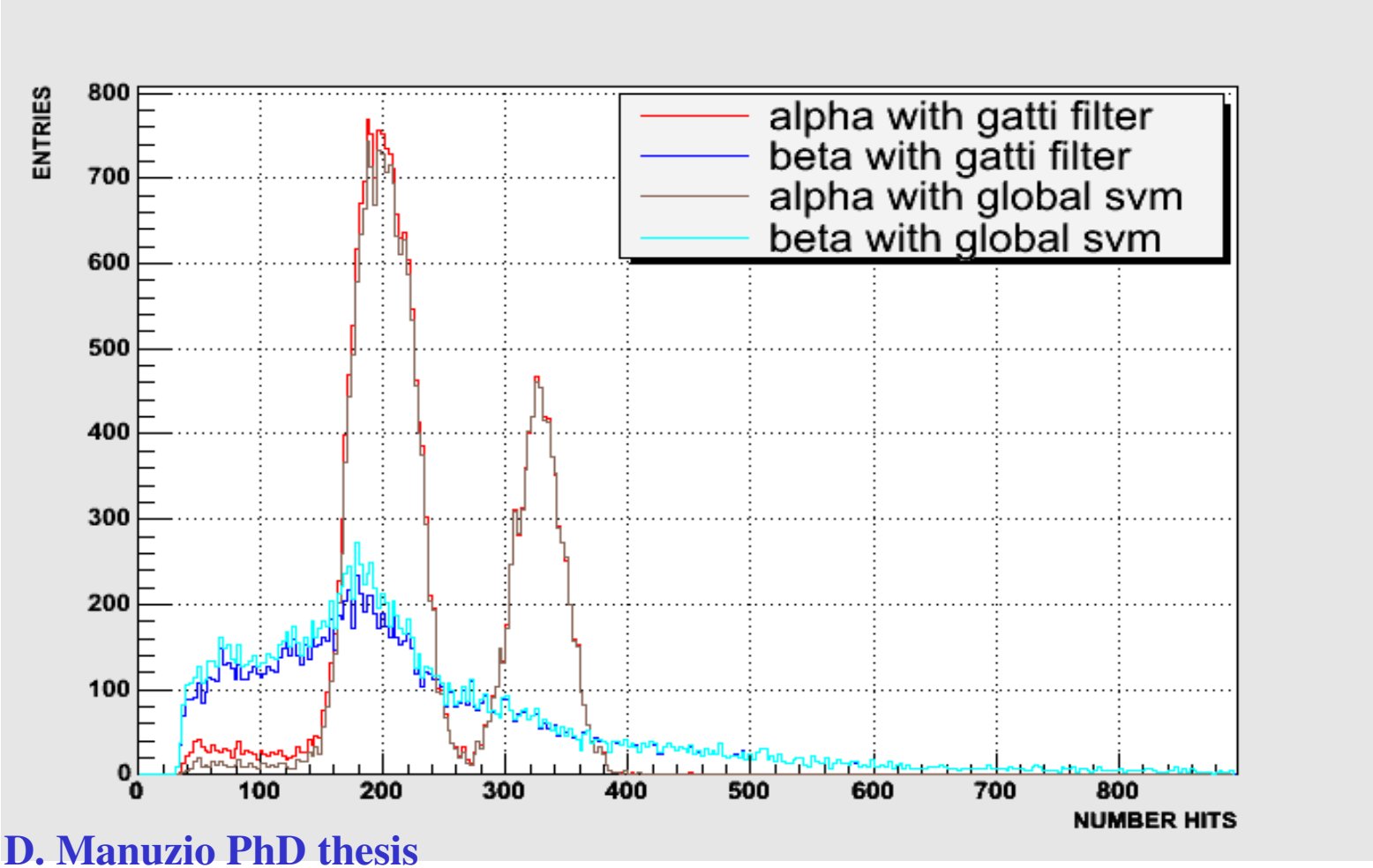
- ^{7}Be (pure γ, 478 keV, 53d)*
- ^{32}P (pure β, 1709 keV, 14d)*
- ^{35}S (pure β, 167 keV, 87d)
  ^{69}Zn (pure β, 925 keV, 57m)
- ^{90}Y (pure β, 2274 keV, 64h)
  ^{91}Y (pure β, 1545 keV, 59d)
- ^{99}Tc (pure β, 293 keV, 10^5y)
- ^{113}Sn (44% e_k, 392 keV, 115d)*
  ^{137}Cs (9% e_k, 662 keV, 30y)
  ^{143}Pr (pure β, 931 keV, 14d)
  ^{210}Bi (pure β, 1161 keV, 5d)
- ^{238}U (4.2 MeV α)*
- ^{232}Th (4.0 Mev α)
- ^{40}K, ^{14}C, ^{85}Kr, ^{222}Rn & daughters
- etc…

Bi-Po life-time (air run in Borexino)



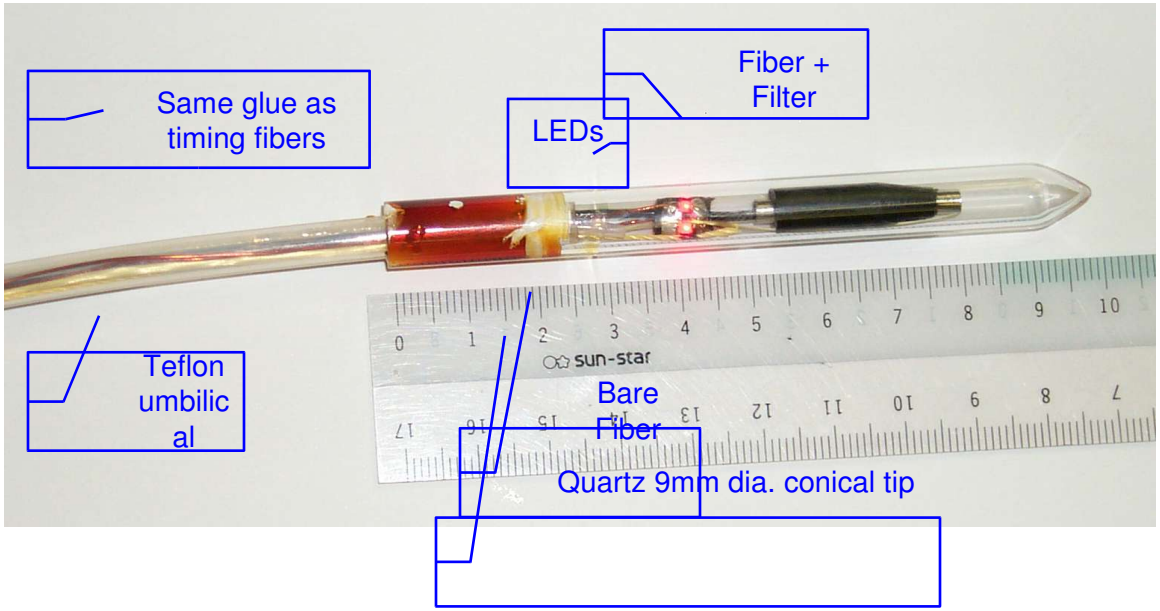
D. Manuzio PhD thesis

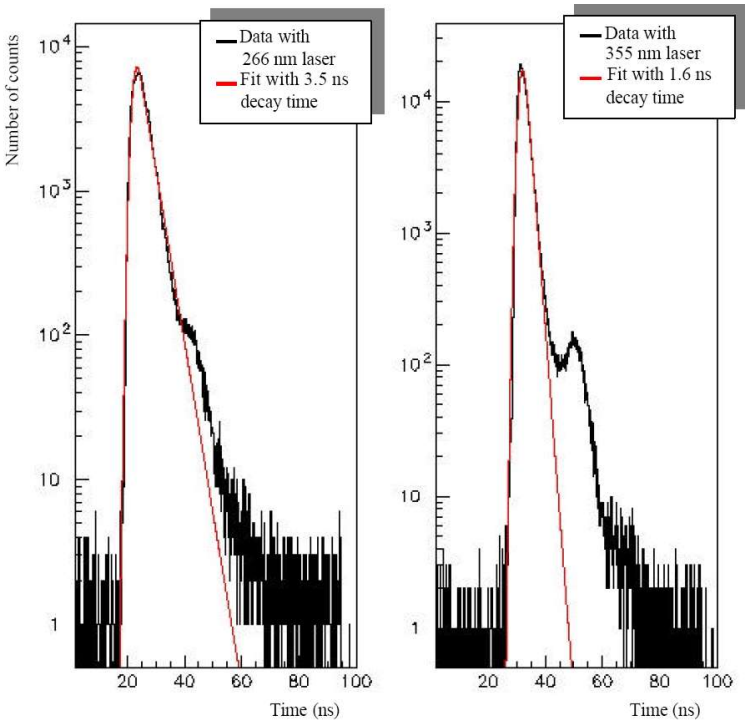
α/β discrimination power



D. Manuzio PhD thesis

Fiber Optic Internal Source

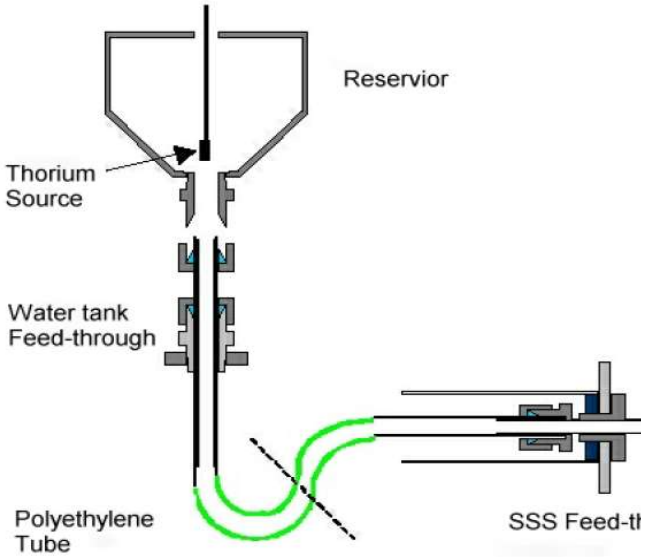


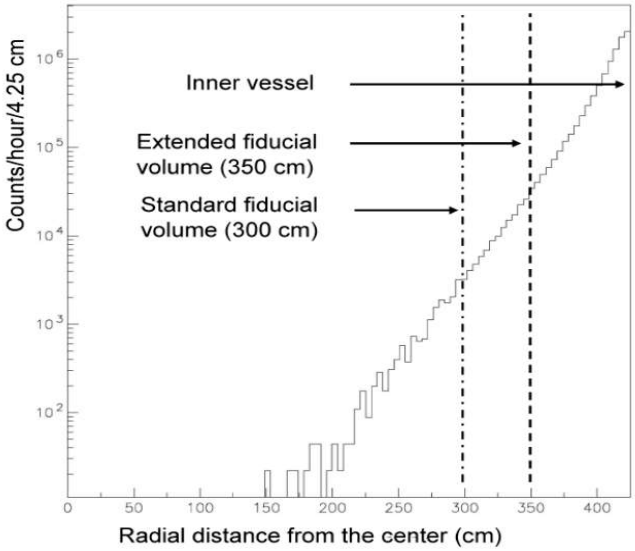


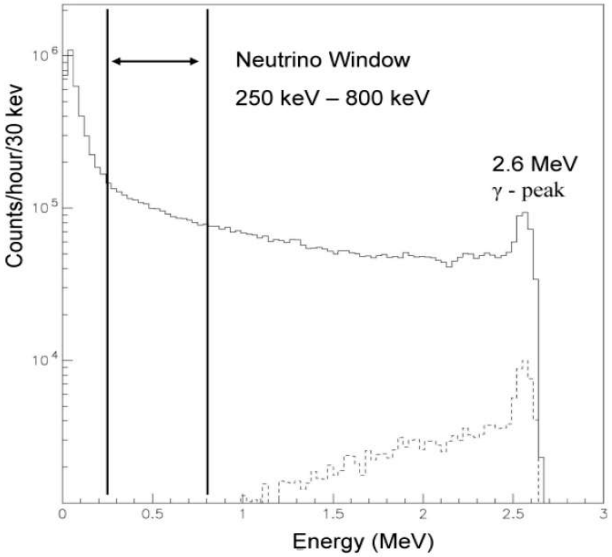
Preliminary fiber optic light source. The quartz housing allows the UV light to propagate several centimeters before being absorbed by the pseudocumene, thus minimizing self-shielding. The Teflon tube for Borexino will be 17 m long and used to pull sources off the vertical axis by actuating a hinge in the insertion rod.

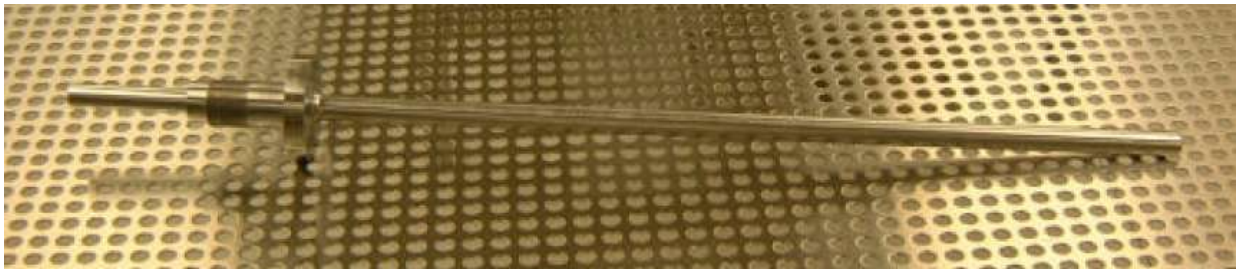
External Source

Stability & Monte Carlo tested without contamination risk by using an external source.









External source insertion system; radial distribution of events within the inner vessel of the detector; energy distribution of events – note that the 2.6 MeV line is still visible and can be used for calibration (200 μCi Th source)

External Optic System

IV, IB, OB optical properties tested, and reflections tested using laser beams directed through these volumes.

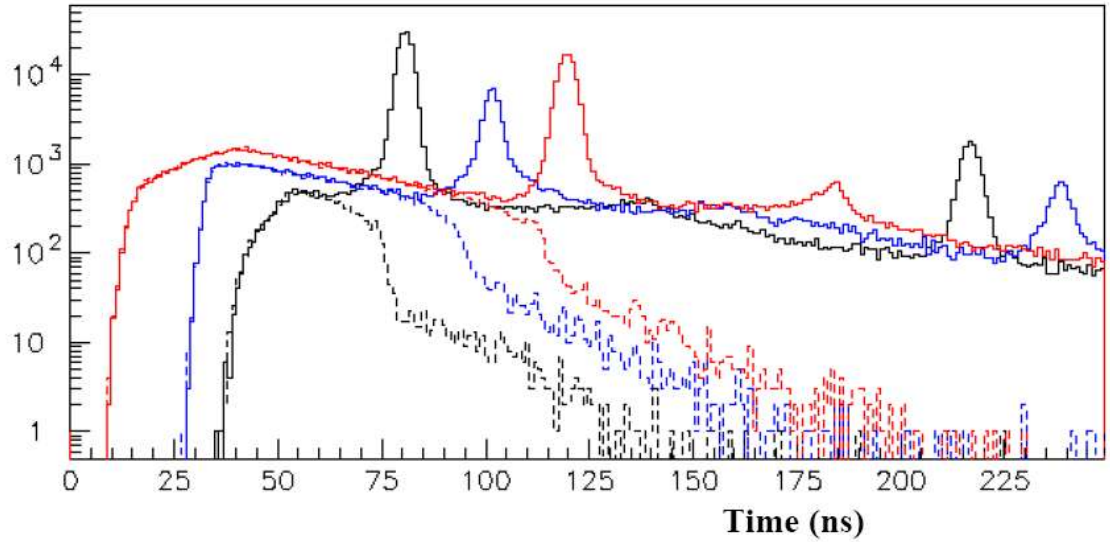
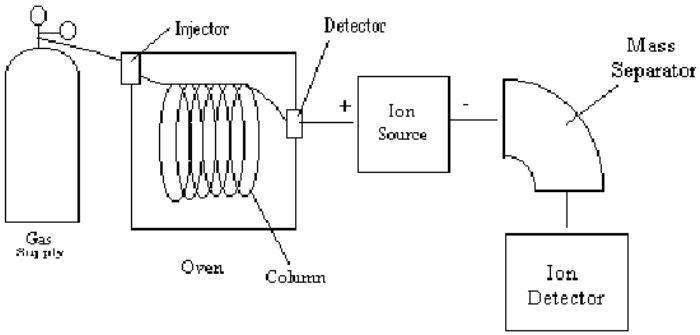
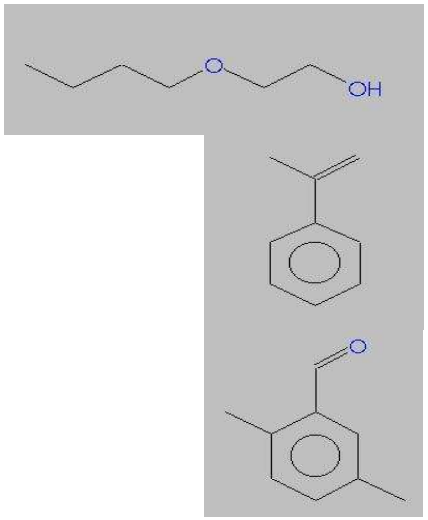


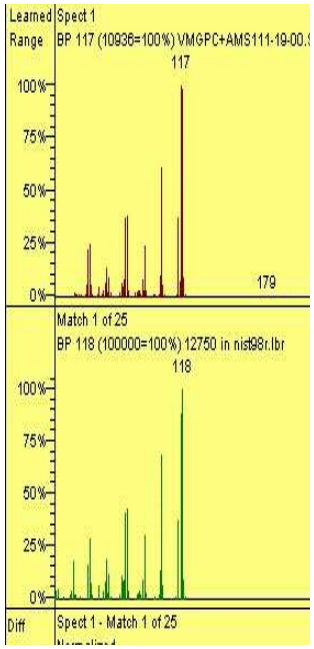
Figure 4.26 - Time spectra of the upper hemisphere PMTs in response to a downward pointing laser beam.

Scintillator Chemical Stability



- 2-Butoxyethanol
  - BP: 171 °C (1.01 BP_{PC})
- α-Methylstyrene
  - BP: 163 °C (0.96 BP_{PC})
- 2-5 Dimethylbenzaldehyde
  - BP: 220°C (1.30 BP_{PC})
- 3-5 Dimethylbenzaldehyde
  - BP: 220 °C (1.30 BP_{PC})





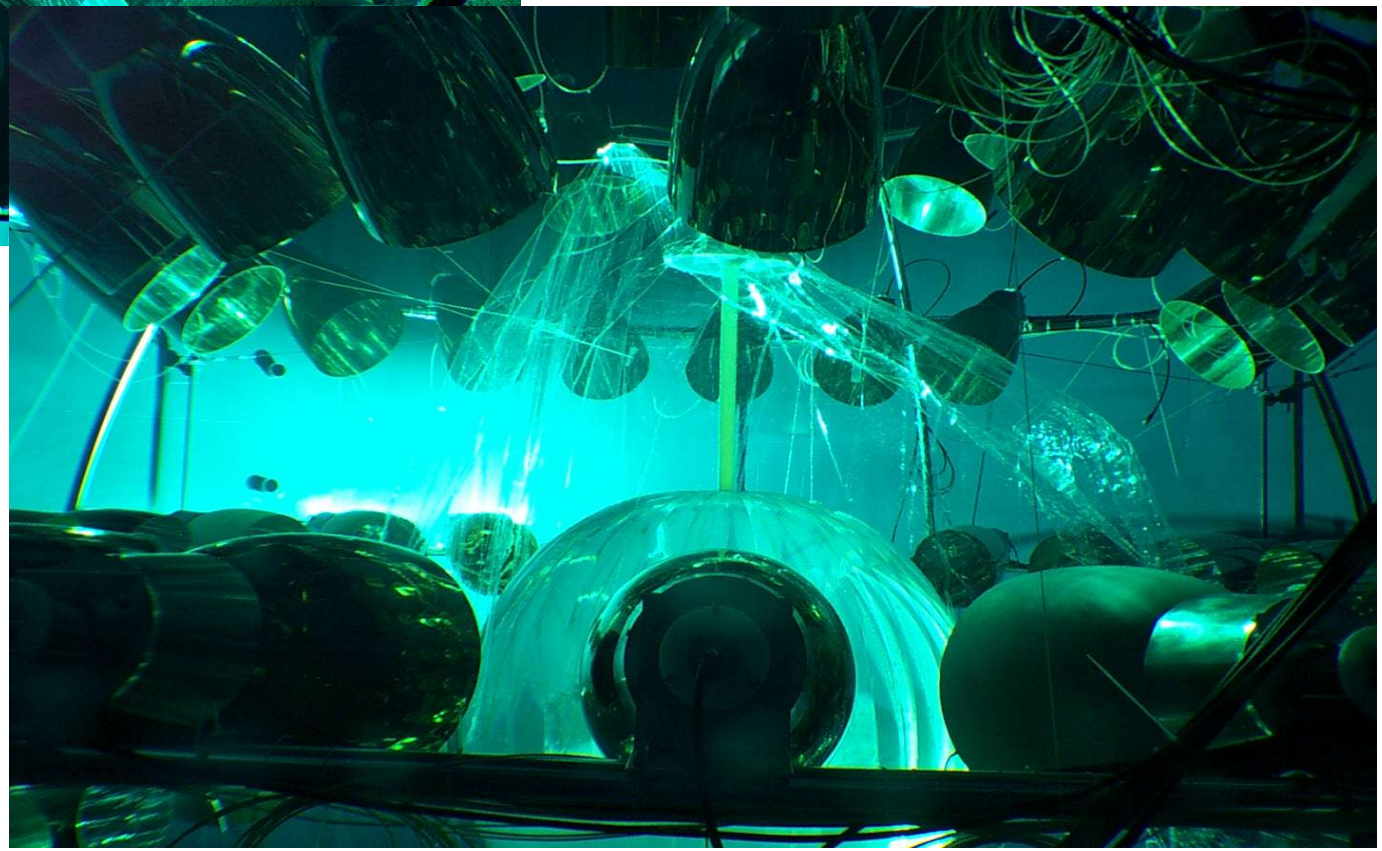
Impurities, or change in scintillator chemistry resulting from purification, are easier to find with a gas chromatography – mass spectroscopy sampling program. This data is critical to know *before* there are optical ramifications.

LNGS Status

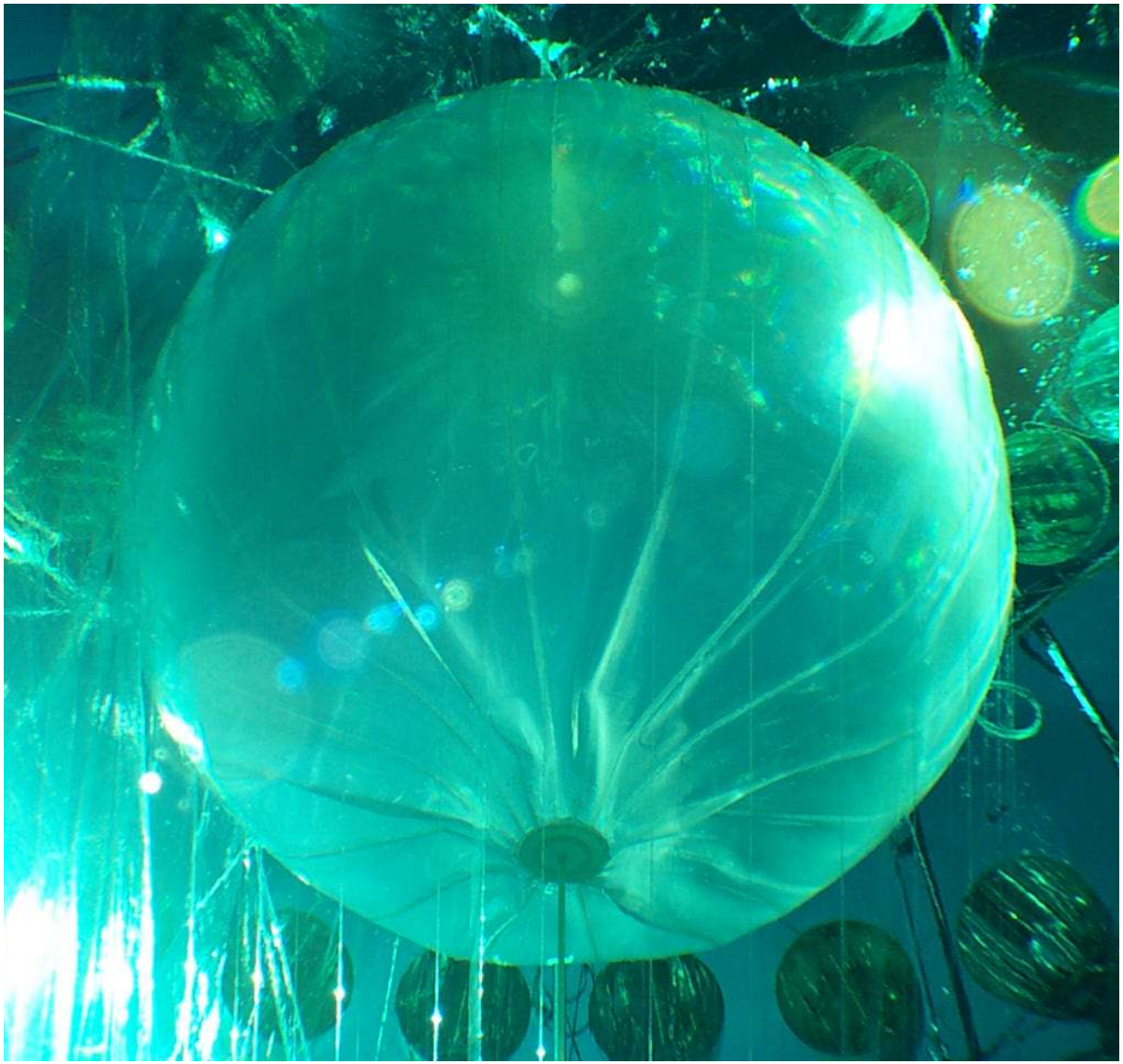
- LNGS committed to enable operation of not only Borexino, but many other experiments
- needed infrastructure improvements of laboratory for safe operation nearly completed
- legal barriers passed
- cautious and careful restart, in partnership with all concerned parties

CTF (taken Sept 2002)

- test systems
- not sensitive at required Borexino purity levels

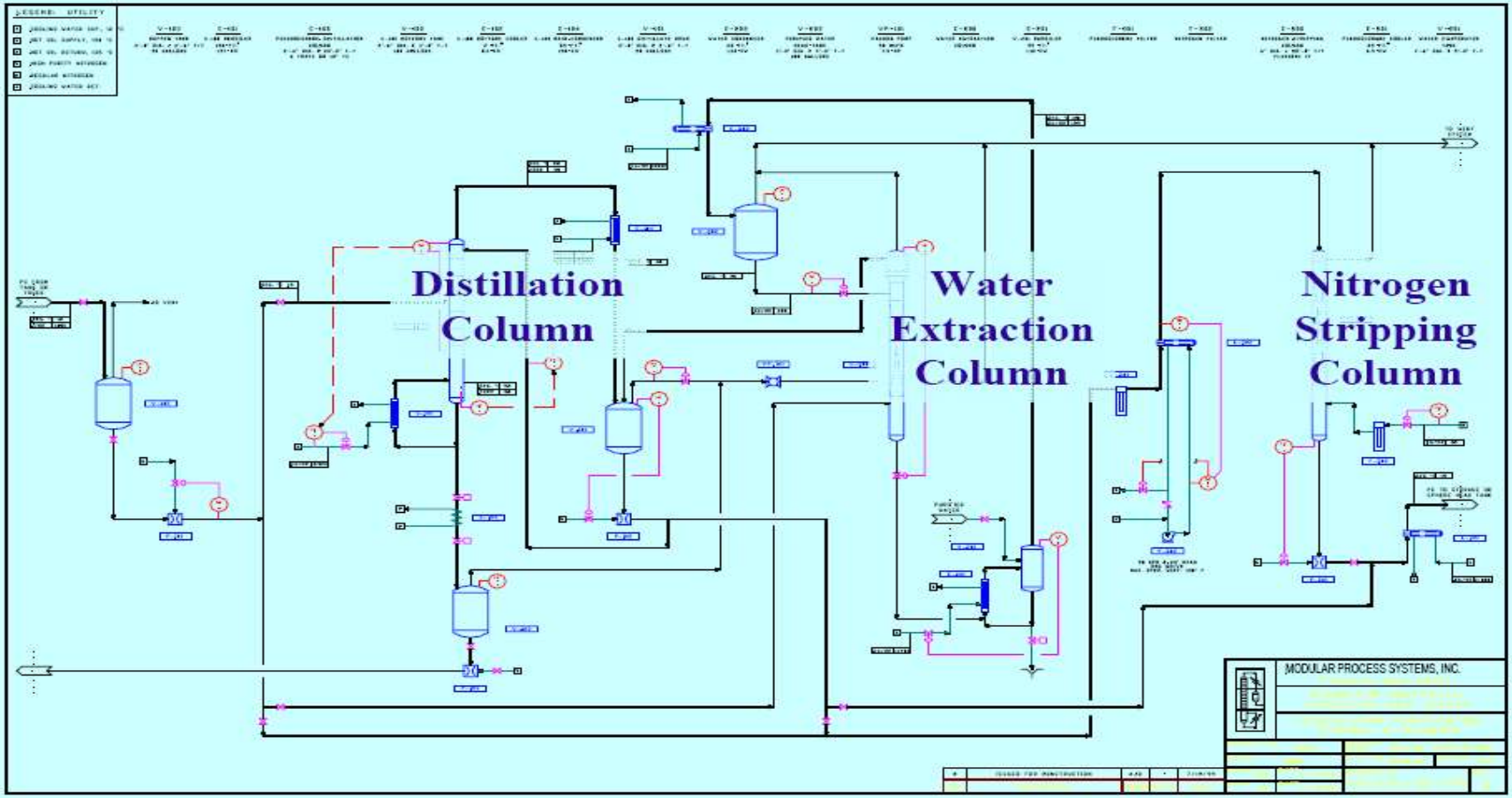


Over two years of being locked out has taken its toll:

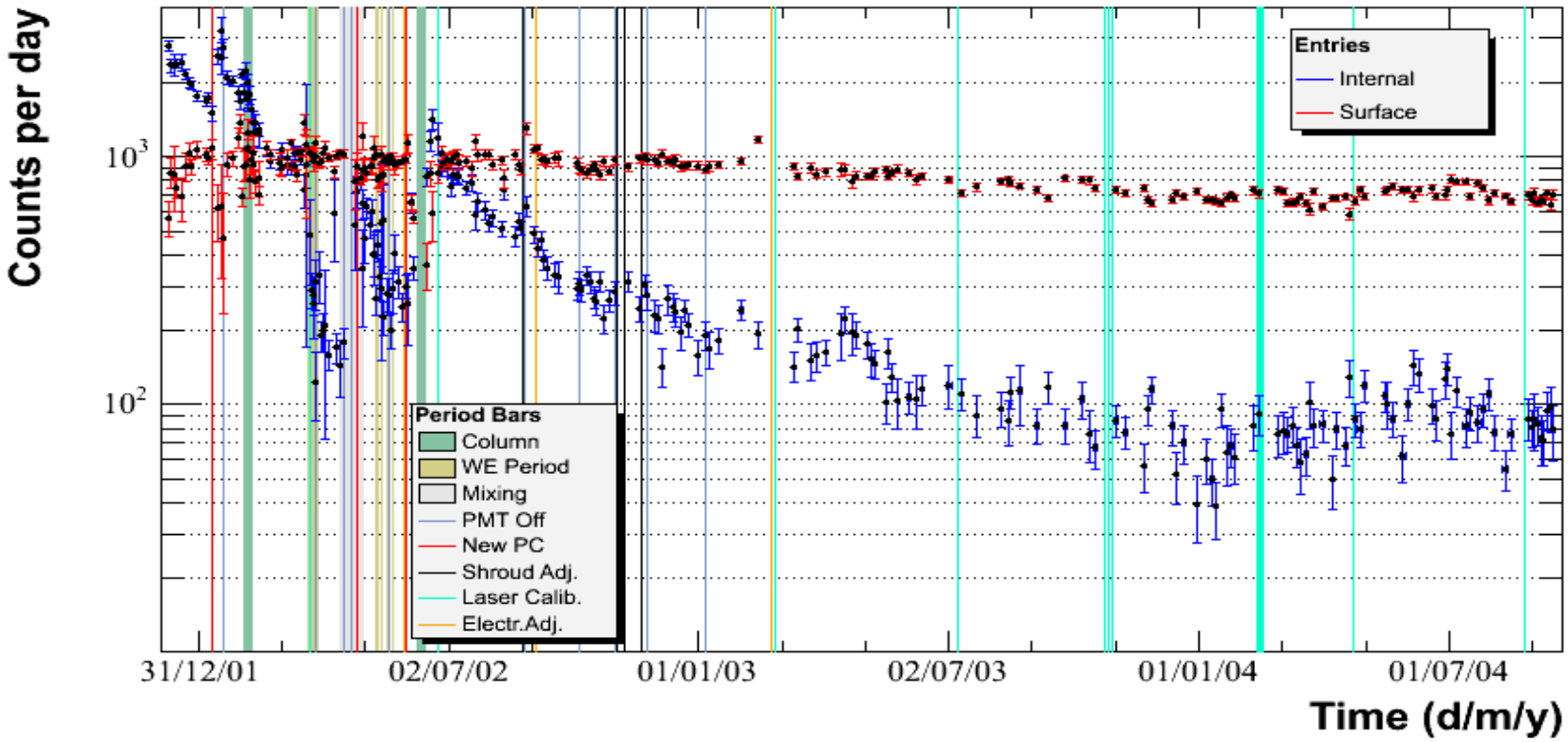


Need CTF for global systems check.

Borexino Purification System



Internal counts from Radial Analysis



5 types of backgrounds are simulated

1. Internal backgrounds (PC)

(b) ^{238}U chain in secular equilibrium; ^{222}Rn (3.8 days); ^{210}Pb (22.3 y); ^{210}Po (138.4 days);

(c) ^{232}Th chain in secular equilibrium;

(d) ^{40}K; ^{85}Kr; ^{39}Ar;

5. Nylon bulk contamination:

(f) ^{238}U chain in secular equilibrium; ^{222}Rn (3.8 days);

(g) ^{232}Th chain in secular equilibrium;

(h) ^{40}K;

3. Inner Vessel Surface contamination:

^{222}Rn (3.8 days); ^{210}Pb (22.3 y); ^{210}Po (138.4 days);

4. External backgrounds (water):

(l) ^{238}U chain in secular equilibrium; ^{222}Rn (3.8 days);

(m) ^{232}Th chain in secular equilibrium;

(n) ^{40}K; ^{85}Kr;

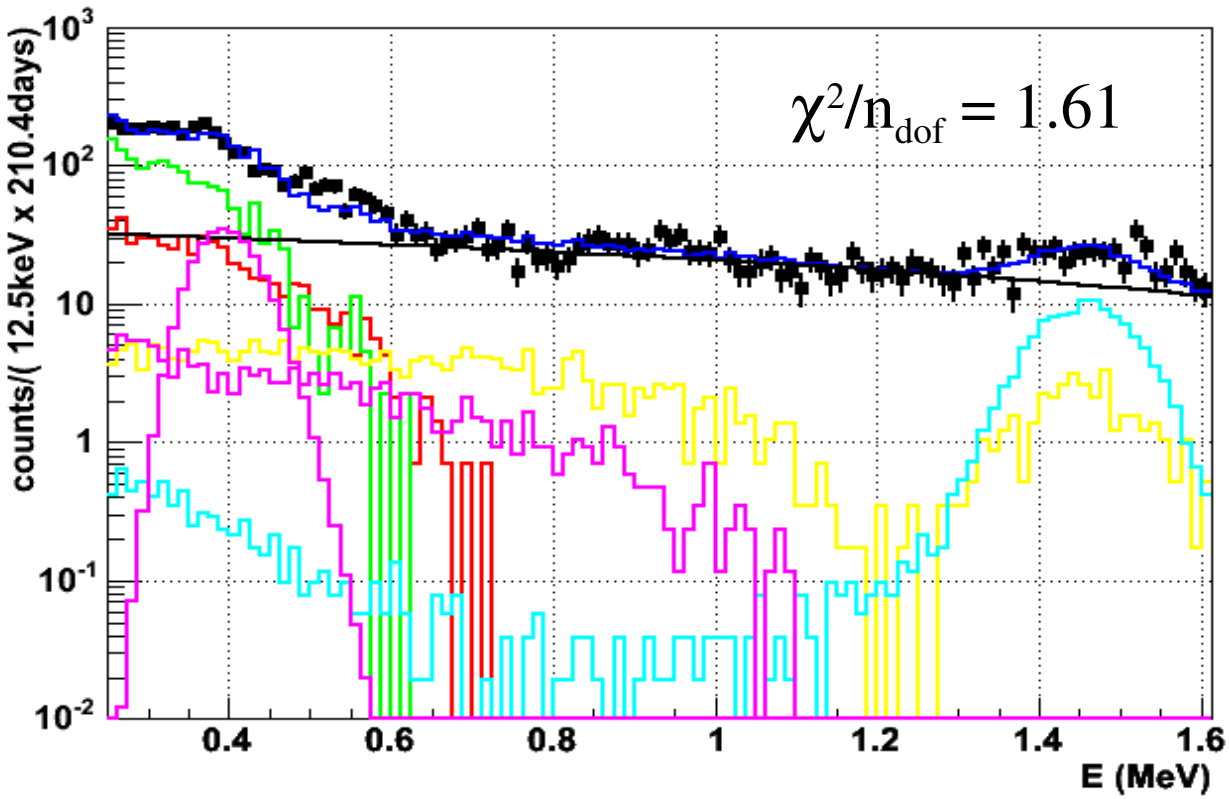
5. External backgrounds (PMTs):

(p) ^{238}U chain in secular equilibrium;

(q) ^{232}Th chain in secular equilibrium;

(r) ^{40}K;

Energy fit – example



Huge number of parameters (>25): beyond capability of CTF to distinguish

- After 3 years of data taking, the current analysis prove that with the current ~ 80 c/d in the bulk (normalized to total volume) we are very near the limit of sensitivity of CTF
  1) All analysis are consistent but unstable
  2) Very difficult to disentangle different contributions unambiguously

- The picture we have now is:

  - ~ 80 c/d total in Neutrino Window
    - ~ 12 ^{85}Kr
    - ~ 28 ^{39}Ar

    these two contributions are highly correlated
    - ~ 5 Bi-Po in equilibrium
    - ~ 30 ^{40}K + external background, strongly correlated, difficult to disentangle
    - ~ 7 Rn chain

Operations Schedule

Short term milestones

- Master solution preparation
  - November 14
- US skids commissioning with water
  - November 21
- Refilling of shroud and PC removal in CTF
  - December 5
- US skids commissioning with PC
  - December 14
- CTF filling
  - December 20

2006 Tasks	# of weeks
Water Fill SSS	12
SSS Water Data Run	10
Fill Water Tank	8
Water Tank Water Data Run	4
Scintillator Fill	24

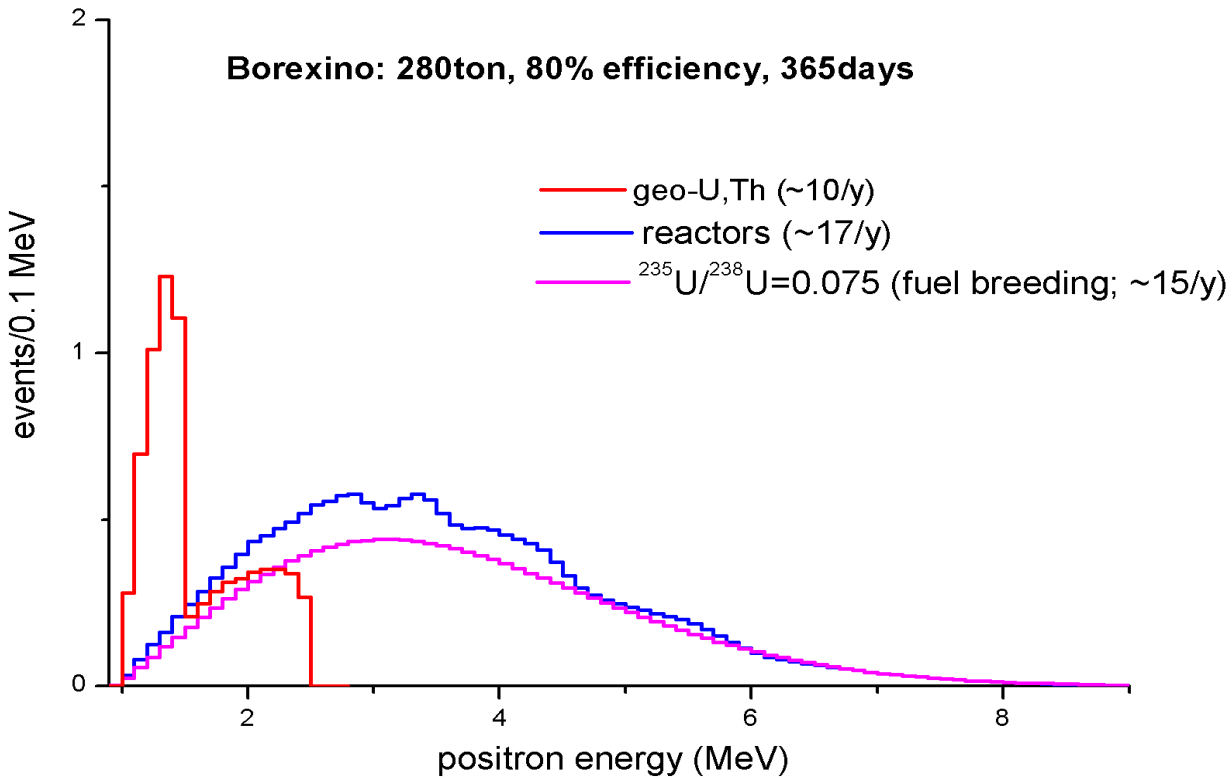
Physics start near end of 2006; 3-5 yrs minimum.

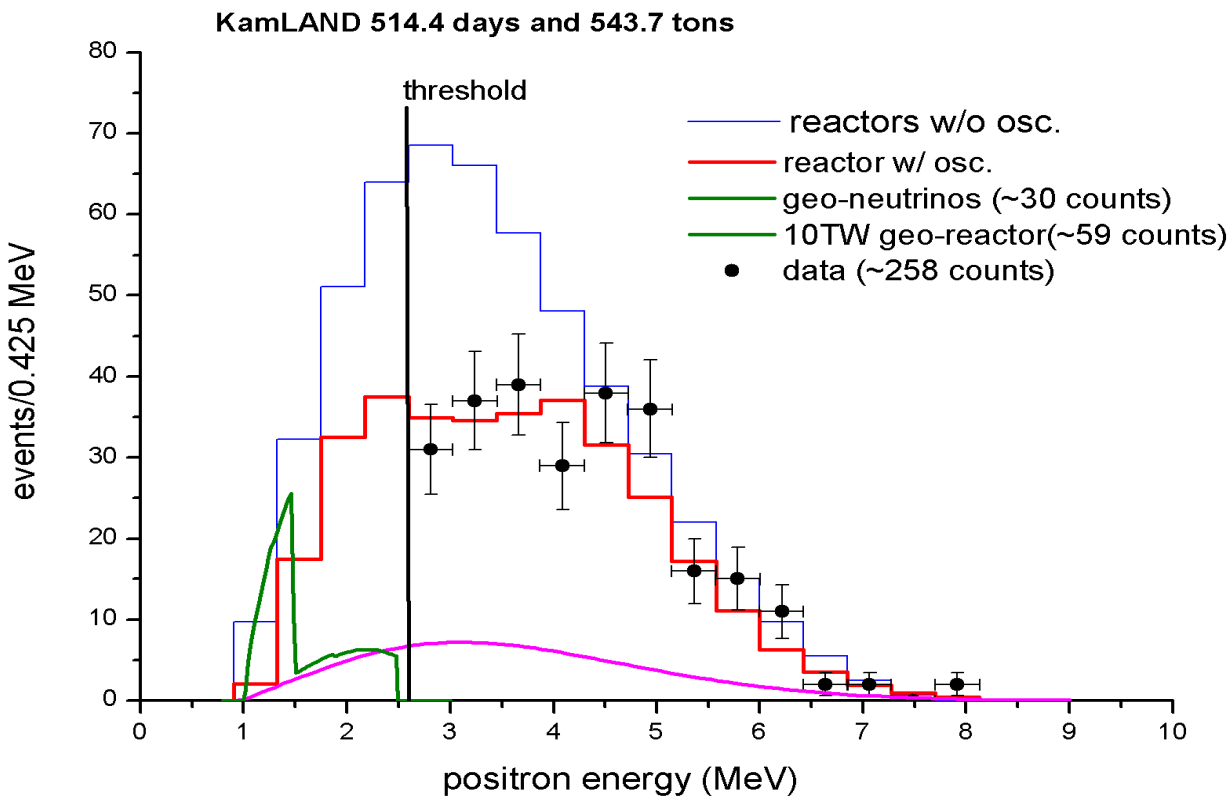
α/β discrimination results

Z	SVM			
	α(%)		β(%)	
	5	1	95	99
0	98.4	93.1	1.2	5.6
50	98.3	94.1	1.1	7.5
150	98.3	89.9	1.4	8.2
250	98.5	87.3	1.7	9.4
400	92.2	68.9	5.5	23.5

- CTF data: 10 α c/d in 4 t, yielding about 200 c/d in Borexino
  - With this (optimistic) α/β separation, we are almost at the required purity level (with 98% → 4 counts/day expected)

Anti-neutrino from Earth: Spectrum



A 10 TW geo-reactor can be identified at the level of 2σ in 1 years

Anti-neutrinos in KamLAND for comparison