First Result of Borexino Experiment and KamLAND Solar Phase

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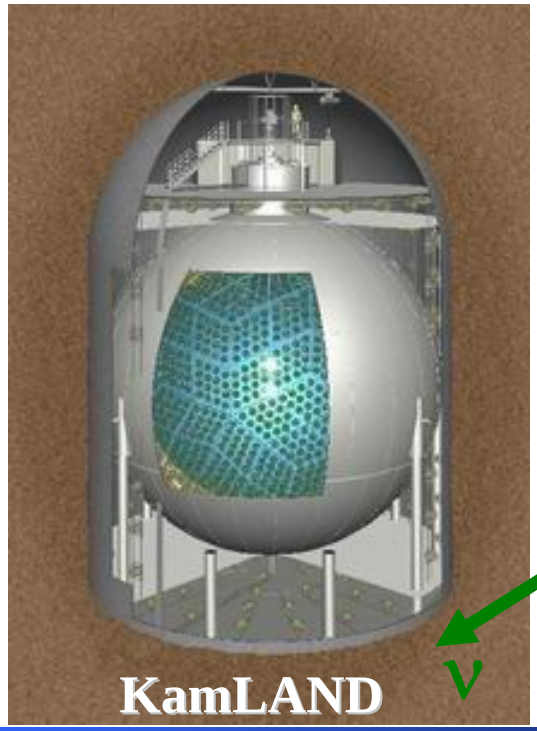
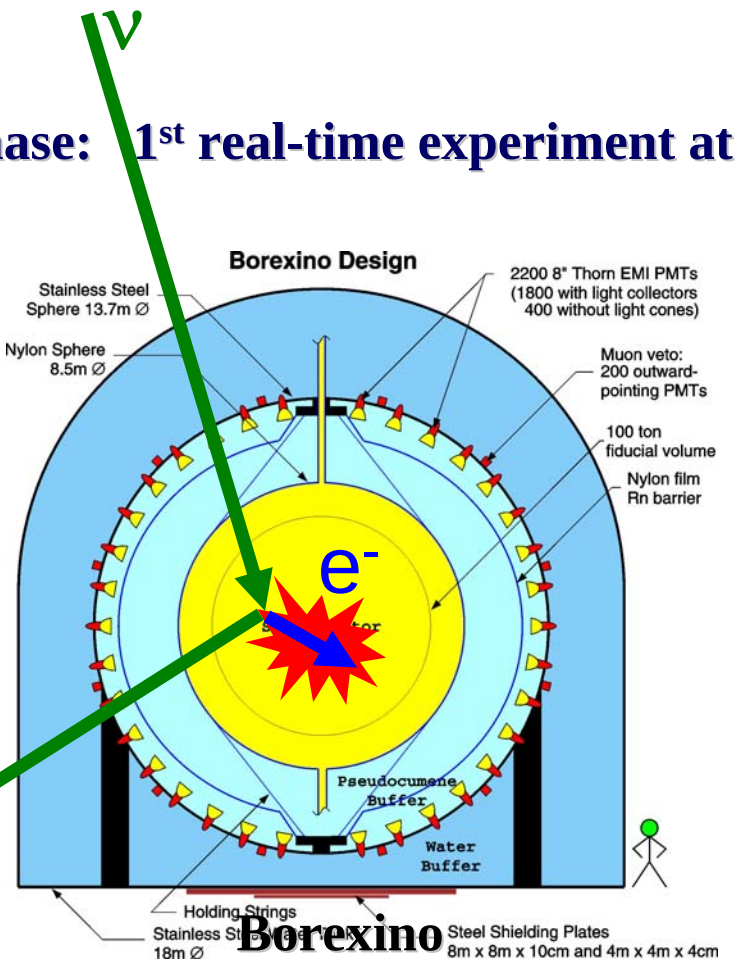
Solar neutrino physics

- **Two types of solar neutrino experiments**
  - Radiochemical experiments (low energy threshold, integrated flux)
  - Water experiments (real-time information, higher energy threshold ~ 5 MeV: Only ~10^{-4} of total flux)

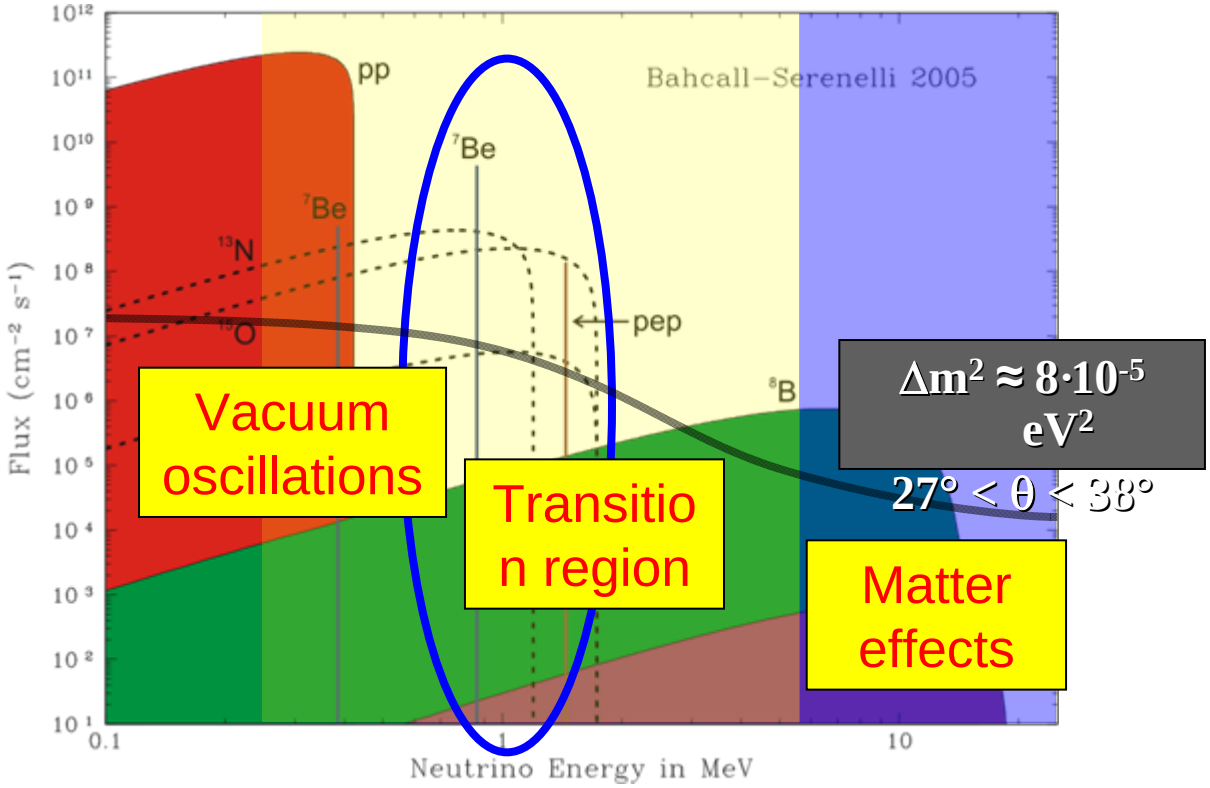
- **Borexino and KamLAND solar phase: 1st real-time experiment at low energies solar neutrino**





Solar neutrino spectrum

- **Current neutrino date is consistent with MSW/LMA solution, which predicts transition from matter enhanced oscillations at ^{8}B energy to vacuum oscillation at low energy.**
- **The survival probability increases from ~0.33 at high energy to up to ~0.6 at low energy.**



- **Measurement of ^{7}Be solar neutrino flux will test the predicted increase in the ν_e survival probability.**

Prediction of solar ν flux

- **Heavy elements abundance**
  - Strong disagreement with helioseismological measurement
- **Nuclear reaction cross sections (by LUNA)**
  - $^3He(\alpha, \gamma)^7Be$, $^{14}N(p, \gamma)^{15}O$

J.N. Bahcall and A.M. Serenelli, Astro. Phys. J. 621, 85 (2005)

Model	pp	pep	hep	^{7}Be	^{8}B	^{13}N	^{15}O	^{17}F
BP04(Yale)	5.94	1.40	7.88	4.86	5.79	5.71	5.03	5.91
BP04(Garching)	5.94	1.41	7.88	4.84	5.74	5.70	4.98	5.87
BS04	5.94	1.40	7.86	4.88	5.87	5.62	4.90	6.01
BS05(^{14}N)	5.99	1.42	7.91	4.89	5.83	3.11	2.38	5.97
BS05(OP)	5.99	1.42	7.93	4.84	5.69	3.07	2.33	5.84
BS05(AGS,OP)	6.06	1.45	8.25	4.34	4.51	2.01	1.45	3.25
BS05(AGS,OPAL)	6.05	1.45	8.23	4.38	4.59	2.03	1.47	3.31

GS98

AGS05

-10% -38%

S_{34} : 2.5% $S_{1,14}$: 8.4%

- The prediction of ^{7}Be flux depends both on the solar model and the cross section of $^3He(\alpha, \gamma)^7Be$ reaction. ← test of standard solar model

Solar neutrino status

- **Borexino succeeded firstly ^{7}Be observation.**
- **KamLAND plans to measure ^{7}Be and pep/CNO ν (purification work in progress)**

arXiv:0708.225lv2 [astro-ph]

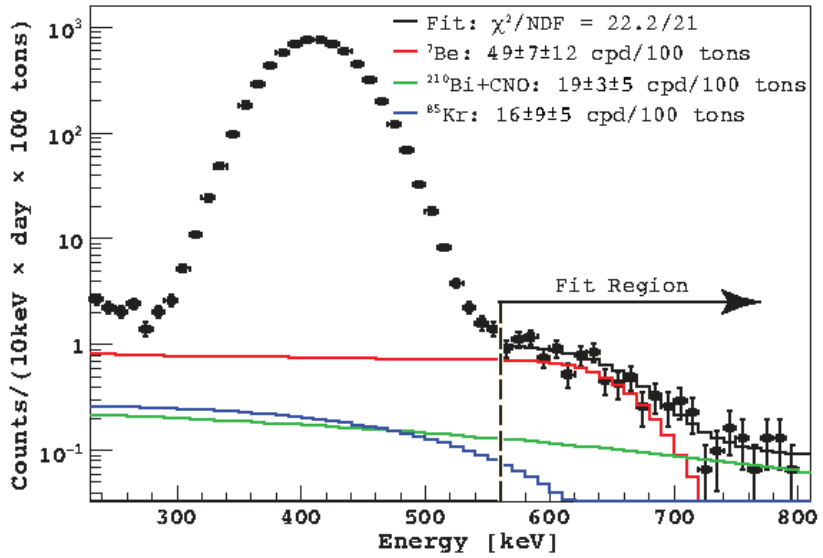


Fig. 5. The fit to the ^{7}Be region without using α/β statistical subtraction. The fit is done between 560 and 800 keV.

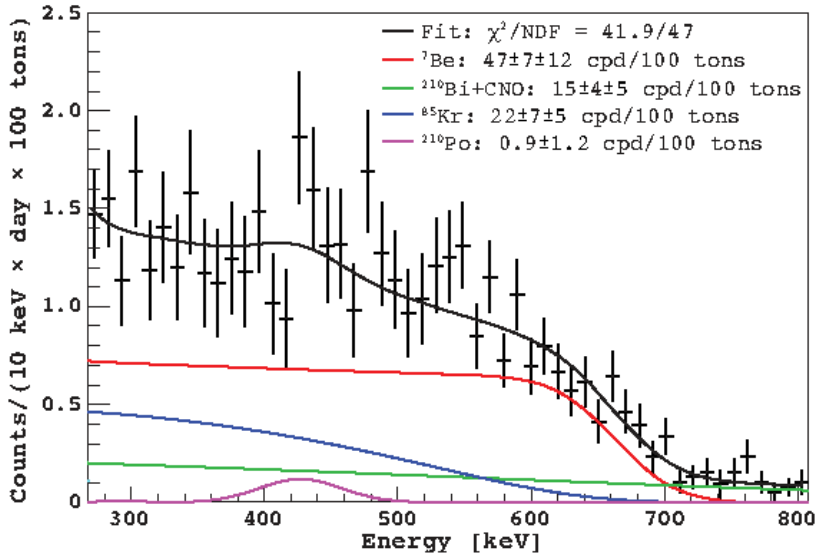


Fig. 6. Spectral fit in the energy region from 270 keV up to 800 keV after α/β statistical subtraction of the ^{210}Po peak.

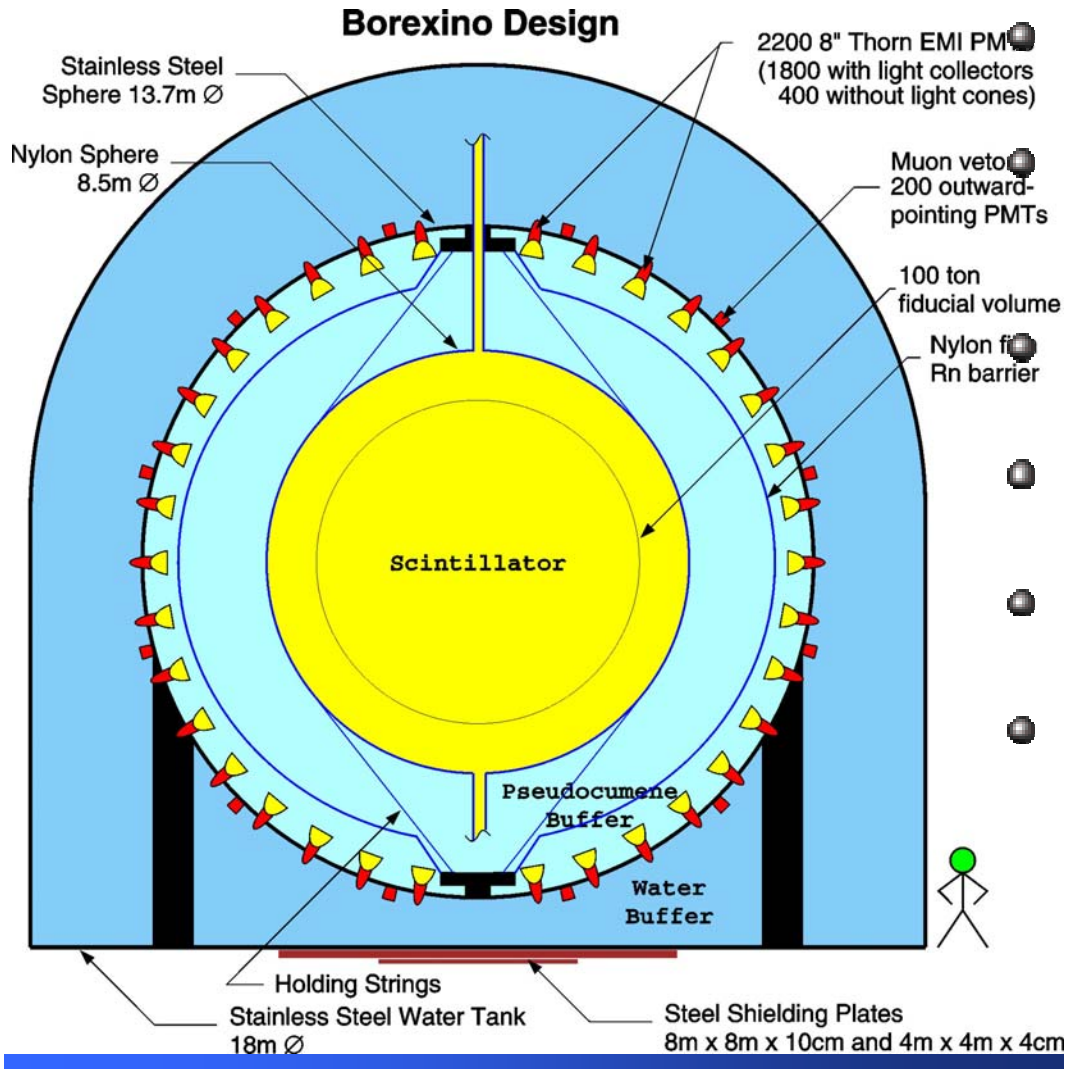
First Result of Borexino

Talk based on

- **arXiv:0708.225lv2 [astro-ph]**
- **talk presented on TAUP2007@sendai**

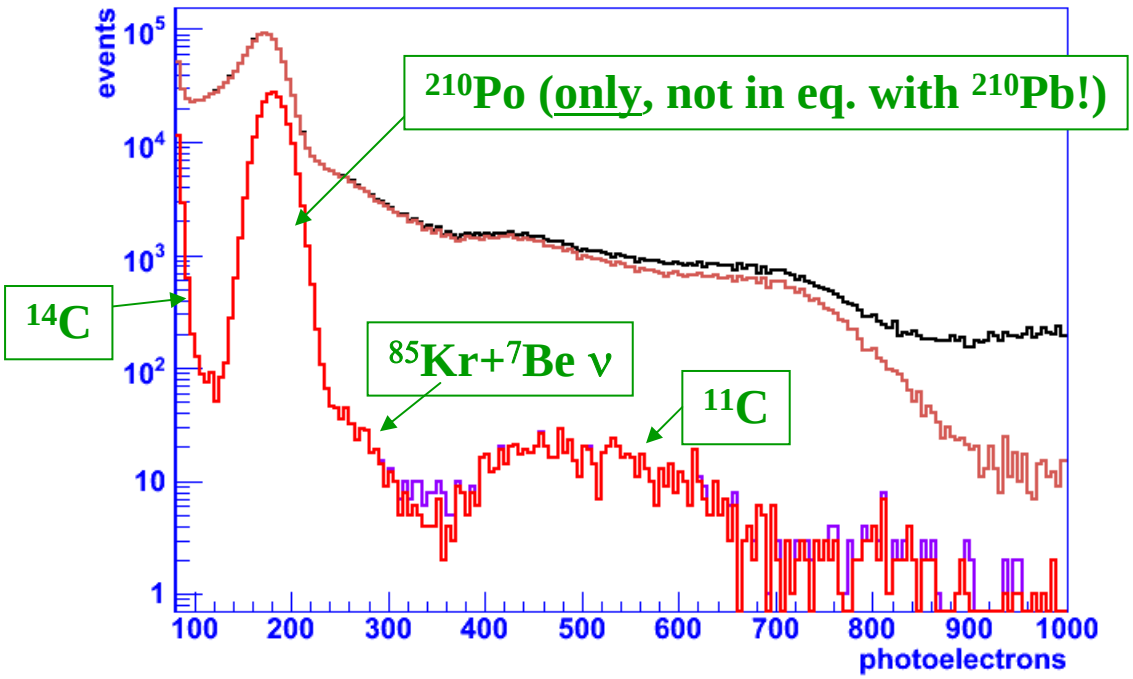
Borexino Detector

- Borexino is located on Gran Sasso Underground Lab. (4000 m water equivalent).



- 278 tons of LS contained in nylon vessel of 4.25 m radius (PC + PPO)
- 890 tons of ultra-pure buffer (PC + DMP quencher) contained in stainless steel sphere of 6.75 m radius
- External nylon vessel against Rn emanated from PMTs and stainless
- 2214 PMTs of 8 inch (1843 with optical concentrater)
- 2100 tons of ultra-pure water contained in a cylindrical dome
- 200 PMTs for detecting cherenkov light emitted by OD water

Observed spectrum in Borexino

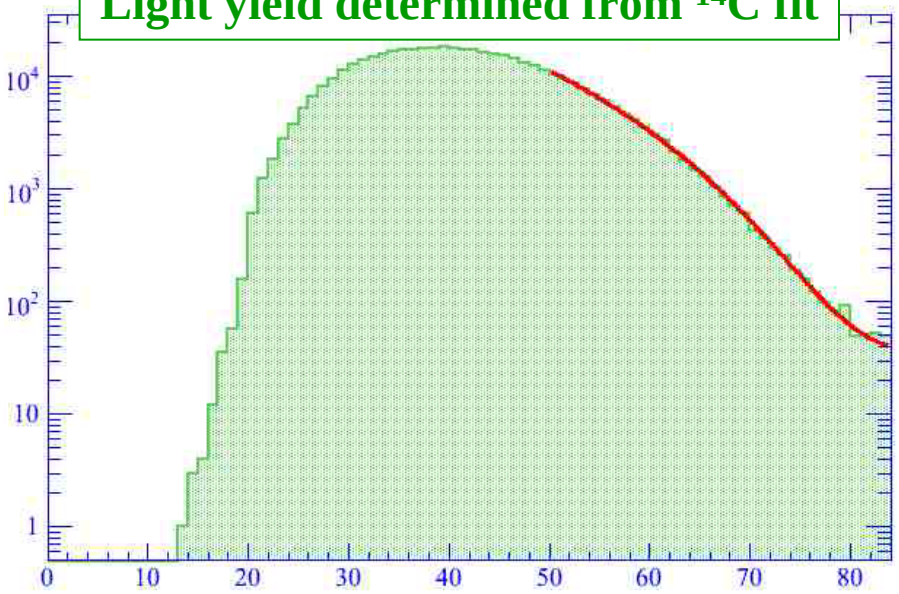


- μ cut
  - μ are not relavant BG for ^{7}Be
- Fiducial cut
  - External background is the dominant background component in NW, except in the ^{210}Po peak region
- spallation cut (within 2 msec after μ)
- ^{214}Bi-Po and Rn daughters removal

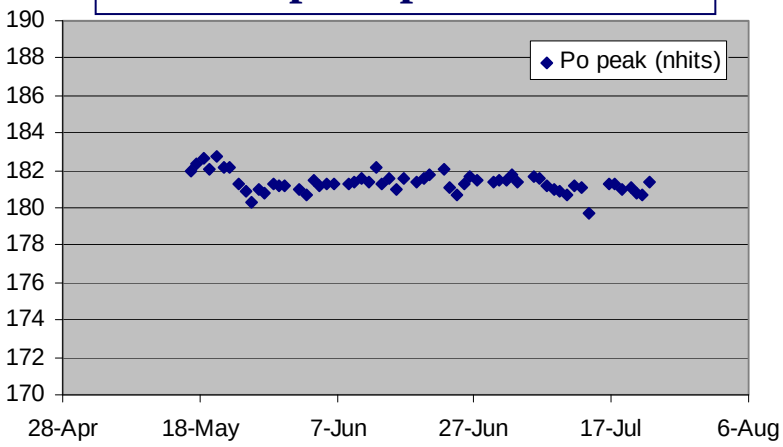
Energy calibration and stability

- Borexino group have not calibrated with inserted sources (yet)
  - Planned for the near future
- **So far, energy calibration determined from ^{14}C end point spectrum**
  - Energy stability and resolution monitored with **^{210}Po α peak**
  - Difficult to obtain a very precise calibration because:
    - ^{14}C intrinsic spectrum and electron quenching factor poorly known

Light yield determined from ^{14}C fit

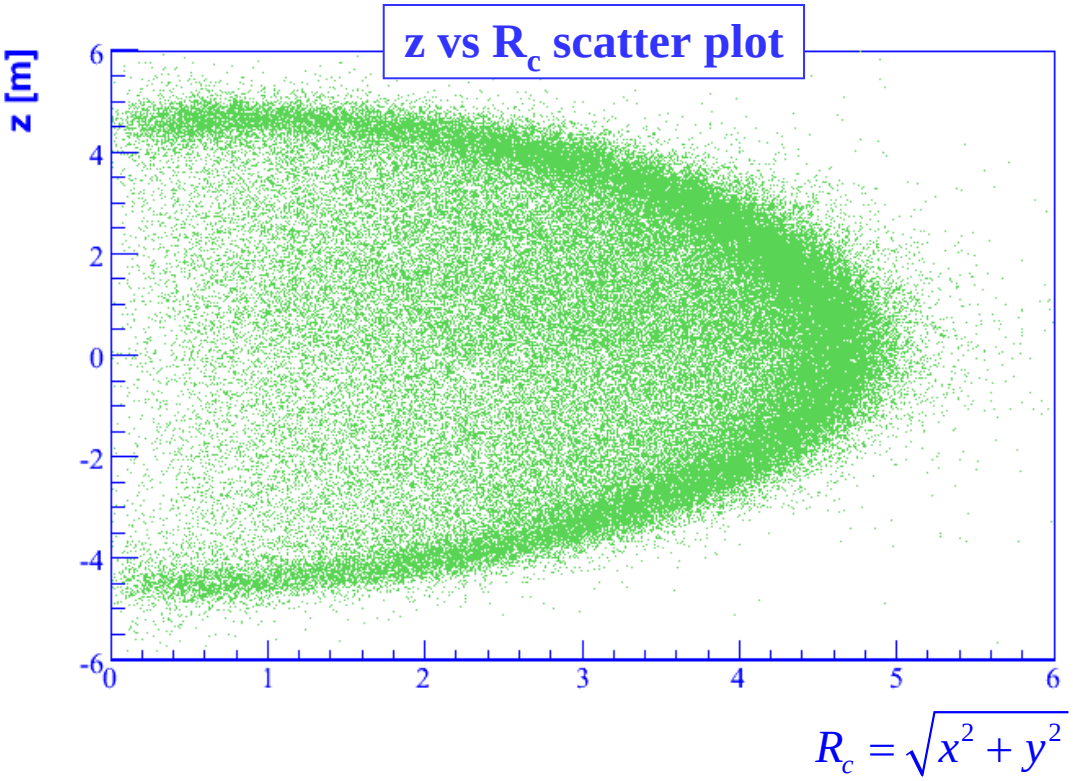


Light yield monitored with ^{210}Po peak position



Position reconstruction

- **Position reconstruction algorythms (we have 4 codes right now)**
  - time of flight fit to hit time distribution
  - developed with MC, tested and validated in CTF
  - cross checked and tuned in Borexino with ^{214}Bi-^{214}Po events and ^{14}C events



Resolution

^{214}Bi-^{214}Po (~800 KeV)

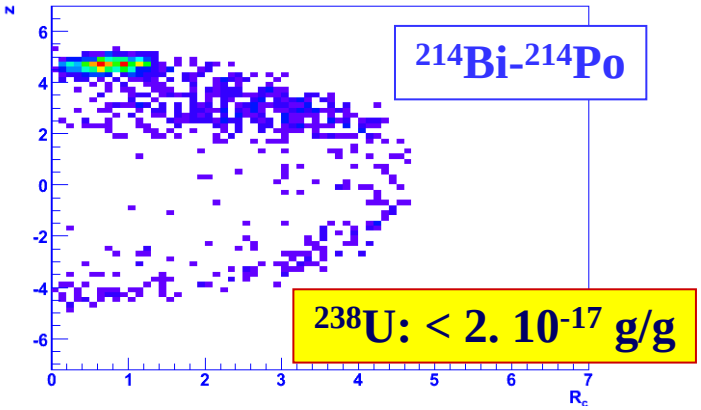
14±2 cm

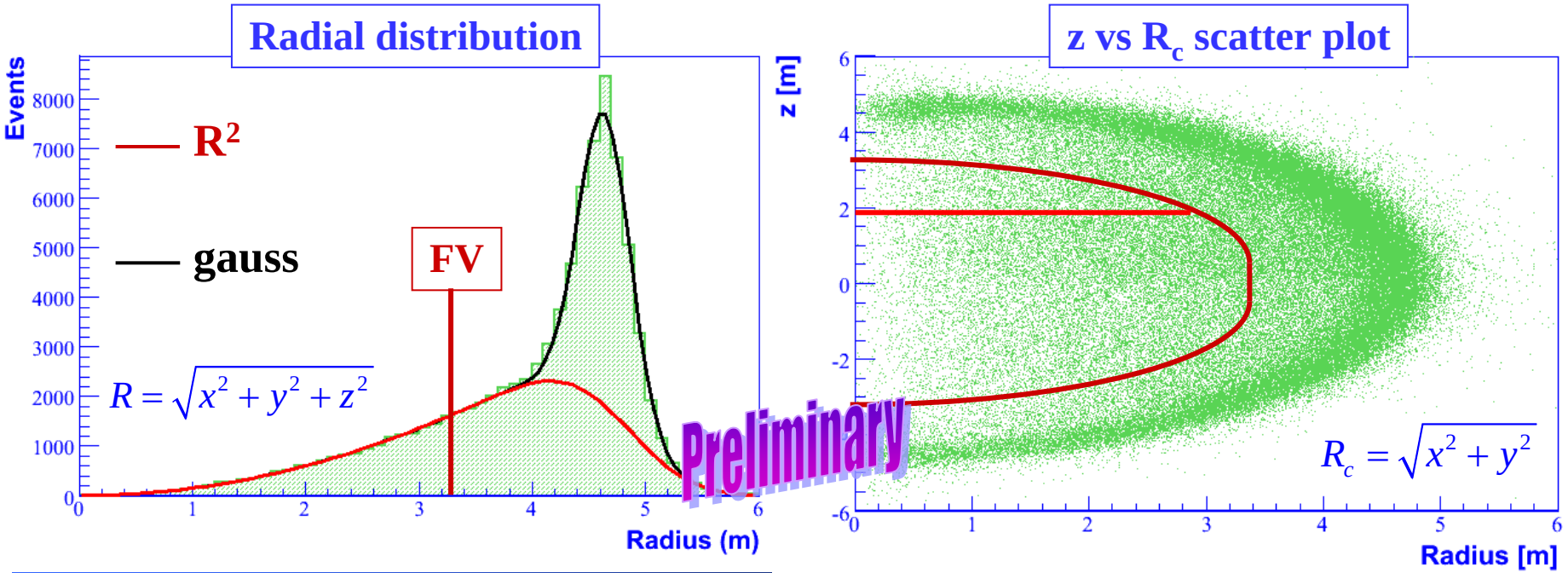
^{14}C (~100 KeV):

41±4 cm

Fiducial volume cut

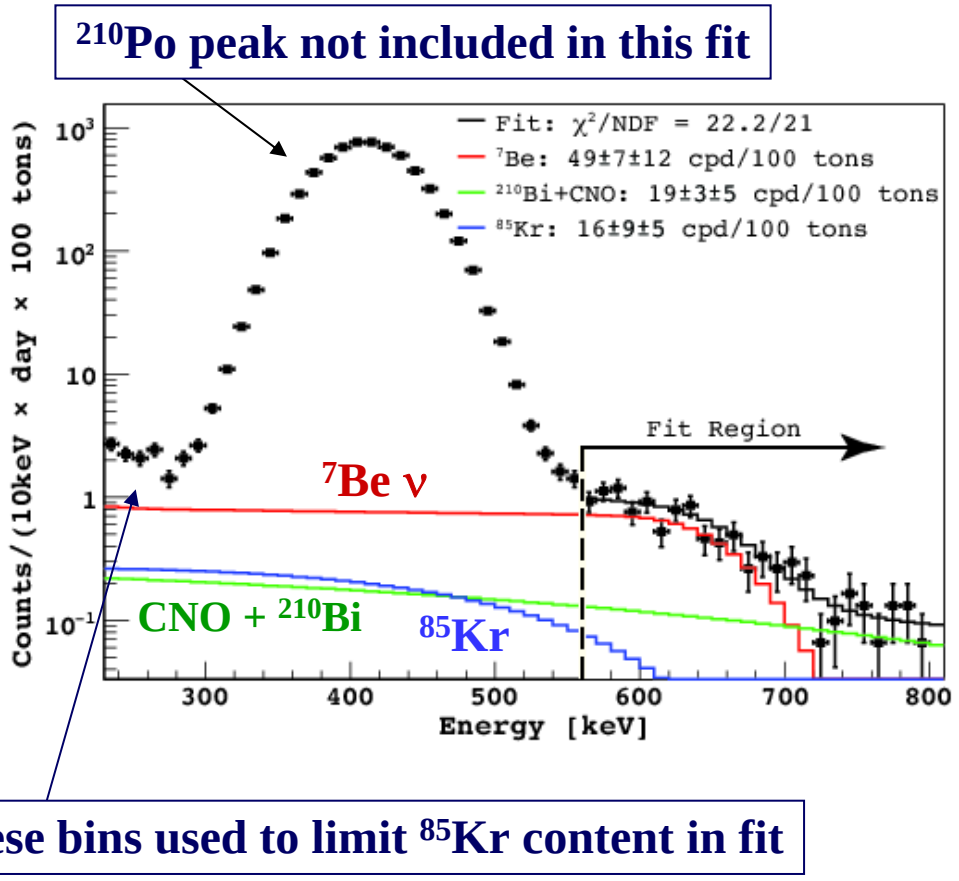
- **External background is large at the periphery of the IV**
  - γ from materials that penetrate the buffer
  - They are removed by a fiducial volume cut
    - **R < 3.276 m** (100 t nominal mass)
    - Another volumetric cut, **z < 1.8 m**, was done to remove some Rn events caused by initial scintillator termal stabilization (87.9 t)





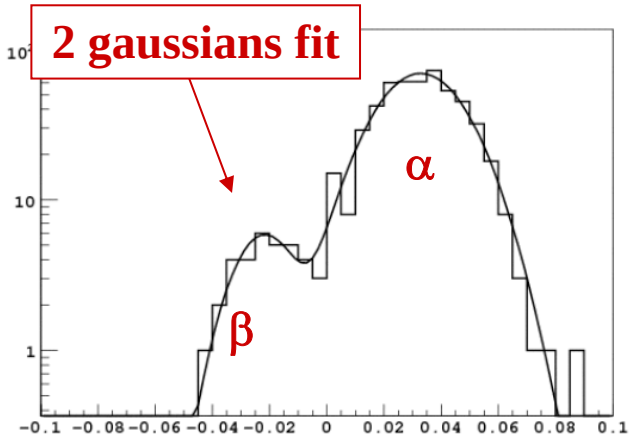
^{7}Be signal: fit without α/β subtraction

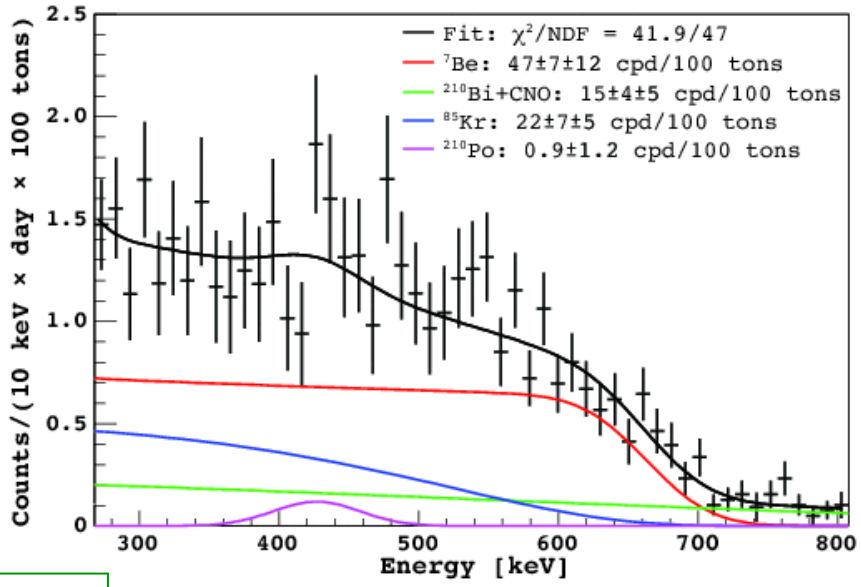
- Strategy:
  - Fit the shoulder region only
  - Use between ^{14}C end point and ^{210}Po peak to limit ^{85}Kr content
  - pep neutrinos fixed at SSM-LMA valu
- Fit components:
  - **^{7}Be ν**
  - **^{85}Kr**
  - **CNO+^{210}Bi combined**
    - very similar in this limited energy region
  - Light yield left free



^{7}Be signal: fit α subtraction of ^{210}Po peak

- **The large ^{210}Po background is subtracted in the following way:**
  - For **each energy bin**, a **fit to the α/β Gatti** variable is done with two gaussians
  - From the fit result, the **number of α particles in that bin is determined**
  - This number is subtracted
  - The resulting spectrum is fitted in the energy range between 270 and 800 KeV
    - A small ^{210}Po residual background is allowed in the fit
    - Results are totally consistent with those obtained without the subtraction





The two analysis yield fully compatible results

Comments on errors

- Statistical:
  - Right now, it includes combined the effect of statistics itself, the lack of knowledge of **^{85}Kr content**, and the lack of a **precise energy calibration**
  - These components are left free in the final fit, and contribute to the statistical error

- Systematic:
  - Mostly due to **fiducial volume determination**

  - With **45 days of data taking,** and **without an internal source calibration**, we estimate an upper limit of 25% for this error

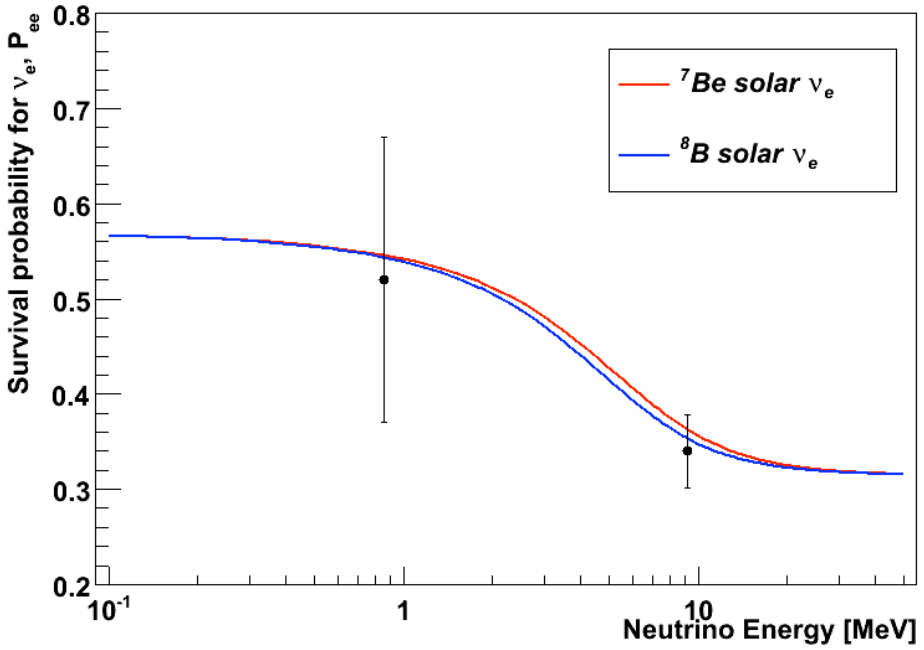
    - Can be much improved even without internal calibration with more statistics and better understanding of the detector response

Conclusions

- **Borexino has performed the first real time detection of ^{7}Be solar neutrinos**
  - **A clear ^{7}Be neutrino signal** is visible after a few cuts

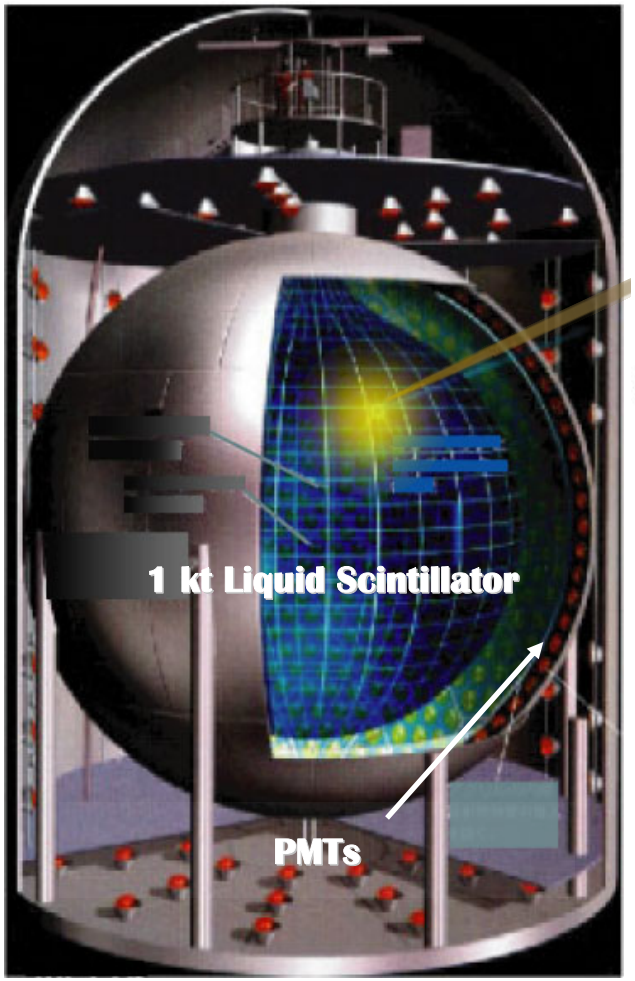
^{7}Be ν Rate: 47 ± 7 (stat) ± 12 (sys) counts/day/100t

  - The central value is well in agreement with MSW/LMA.
  - Significant improvements are expected shortly
    - Increase of Statistics ←
    - Energy calibration
    - Off-line ^{85}Kr measurement by mass spectroscopy



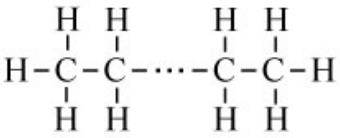
KamLAND solar phase

KamLAND Detector

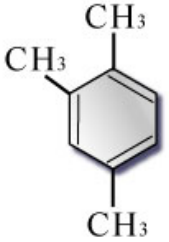


KamLAND Detector

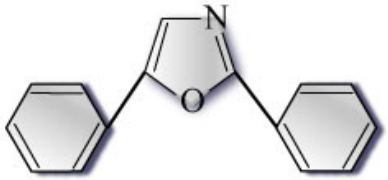
- Kamiokamine overburden : 2700m.w.e.
  Muon rate : 0.34Hz
- 1000 tons of Liquid Scintillator



Dodecane ($C_{12}H_{26}$) : 80%



Pseudocumene : 20%
(1,2,4-Trimethyl Benzene)

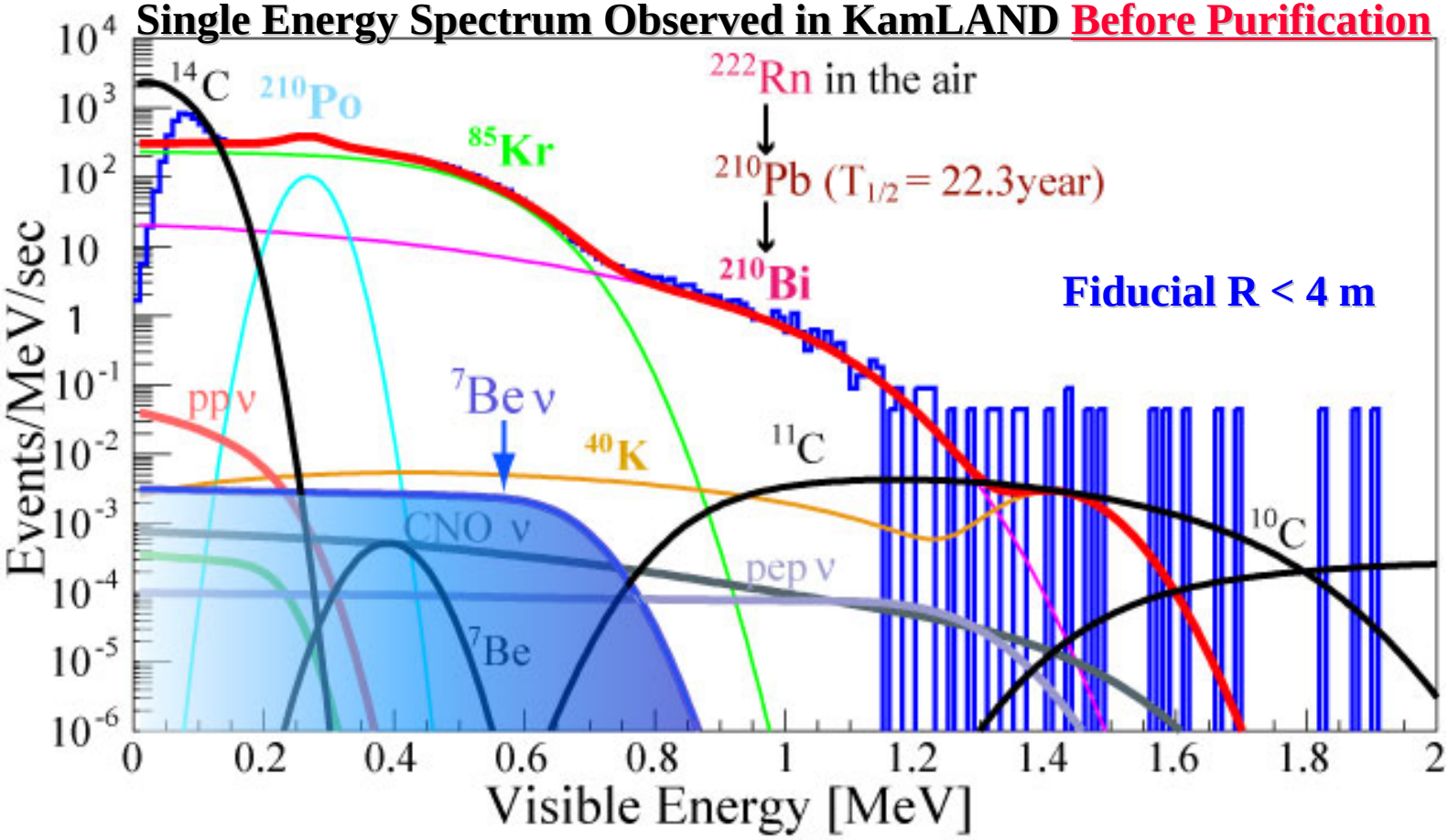


PPO : 1.5 g / l
(2,5-Diphenyloxazole)

- Mineral Oil : Buffer against external BG
- 1979 PMTs(17” 1325 + 20” 554)
- Photocathod coverage : 34%
- Outer water Cherenkov detector for muon veto

Purification Work in Progress

Internal Background of KamLAND



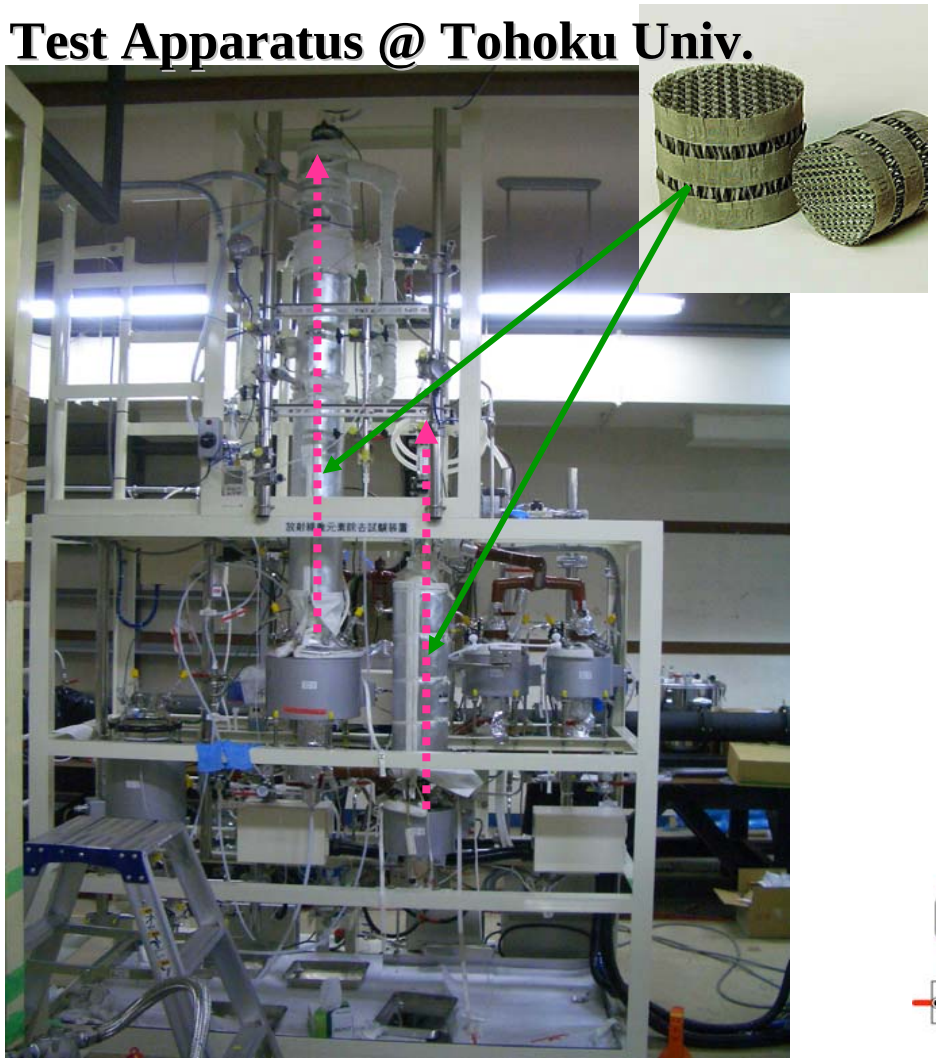
- **Main sources of background in the range of ^{7}Be neutrino**
  - ^{210}Pb(→ ^{210}Bi → ^{210}Po) , ^{40}K ← by distillation
  - ^{85}Kr ← by N_2 purging
- **pep/CNO neutrino ; ^{11}C** ← by tagging neutron

Required Reduction by Purification

	$T_{1/2}$	Activities (Before purif.)	Purification Goal	Required Reduction
^{210}Pb	22.3 y	40 mBq/m^3	1 μBq/m^3	$10^{-4} \sim 10^{-5}$
^{40}K	10^9 y	$2 \cdot 10^{-16}$ g/g	10^{-18} g/g	10^{-2}
^{238}U	10^9 y	$3 \cdot 10^{-18}$ g/g	10^{-18} g/g	OK
^{232}Th	10^{10} y	$5 \cdot 10^{-17}$ g/g	10^{-16} g/g	OK
^{85}Kr	11 y	400 mBq/m^3	1 μBq/m^3	$10^{-5} \sim 10^{-6}$
^{222}Rn	3.8 d		< 1mBq/m^3	---

R&D Study for Distillation

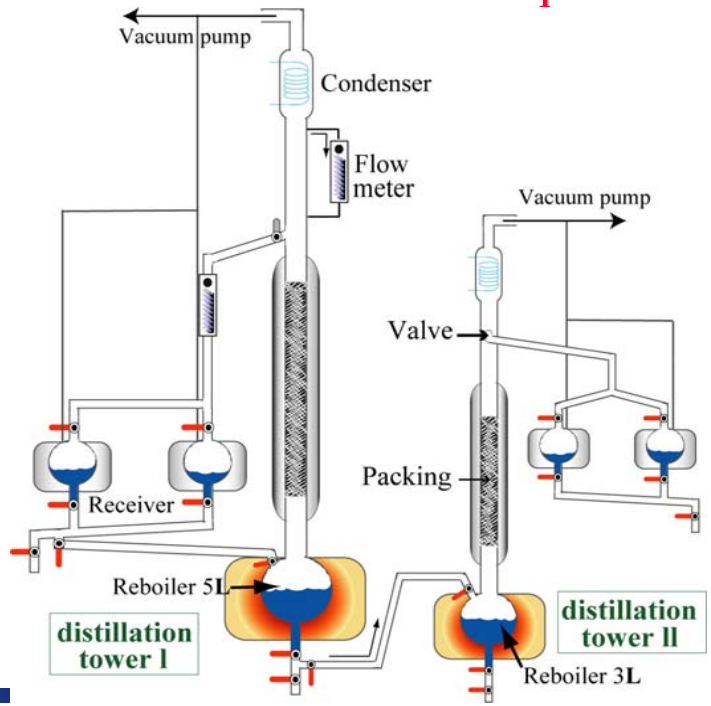
Test Apparatus @ Tohoku Univ.



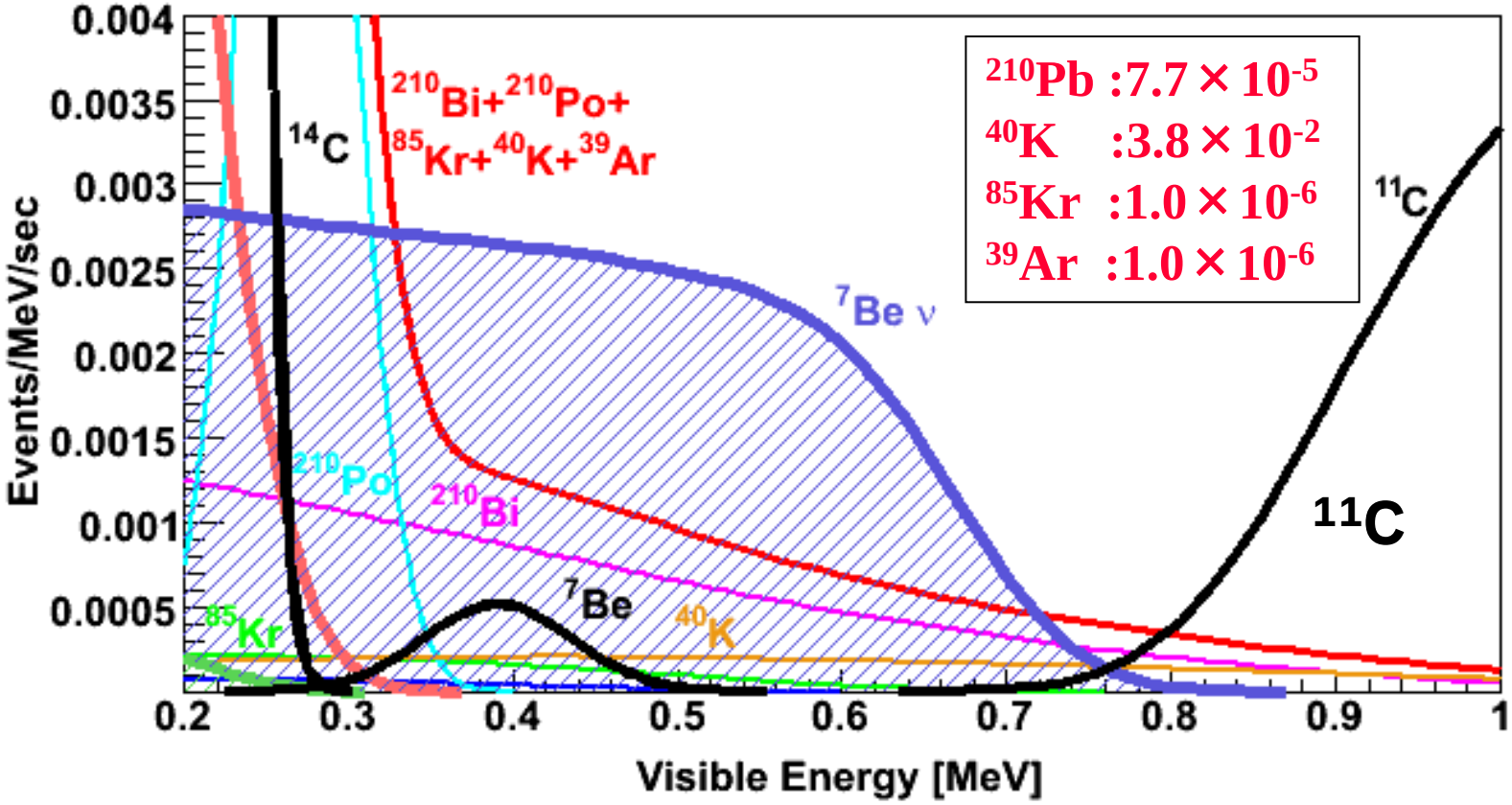
Achievement

Impurity	Reduction
^{210}Pb	$\sim 7 \times 10^{-5}$ (for ^{212}Pb)
^{40}K	$< 4 \times 10^{-2}$
^{85}Kr	$< 1 \times 10^{-5}$ (for ^{nat}Kr)
^{222}Rn	$\sim 6 \times 10^{-4}$

Almost achieved required level



Expected Spectrum after Purification

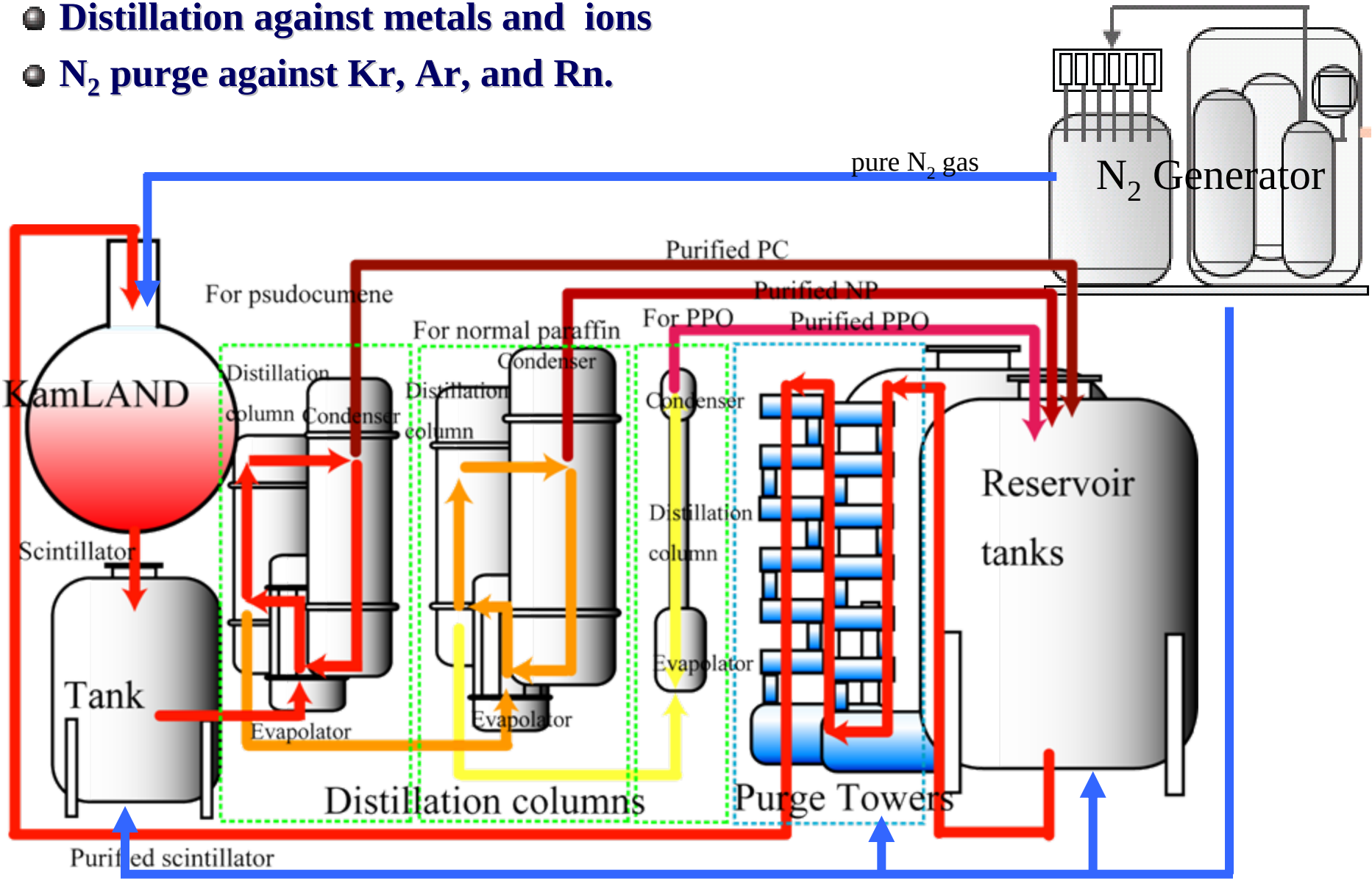


New Purification System

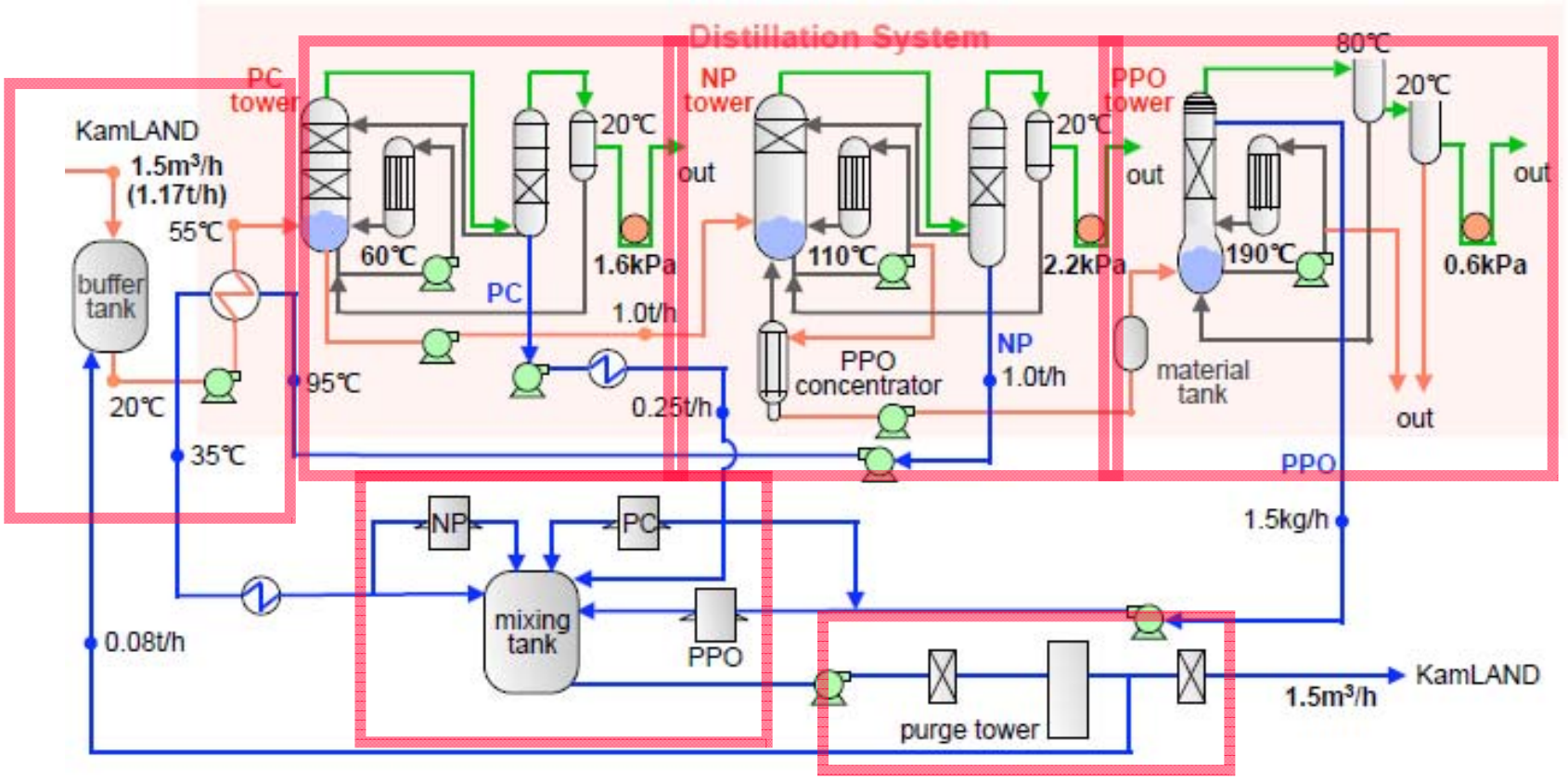
- 2002~ 2006
  R&D study with small and middle size test bench
- Summer in 2006 ~
  Construction
- Winter in 2006 ~
  Test operation to tune up parameters
- Spring in 2007 ~
  Online purification of KamLAND LS
- Suspended on August 2007

Concept of New Purification System

- **Distillation against metals and ions**
- **N_2 purge against Kr, Ar, and Rn.**



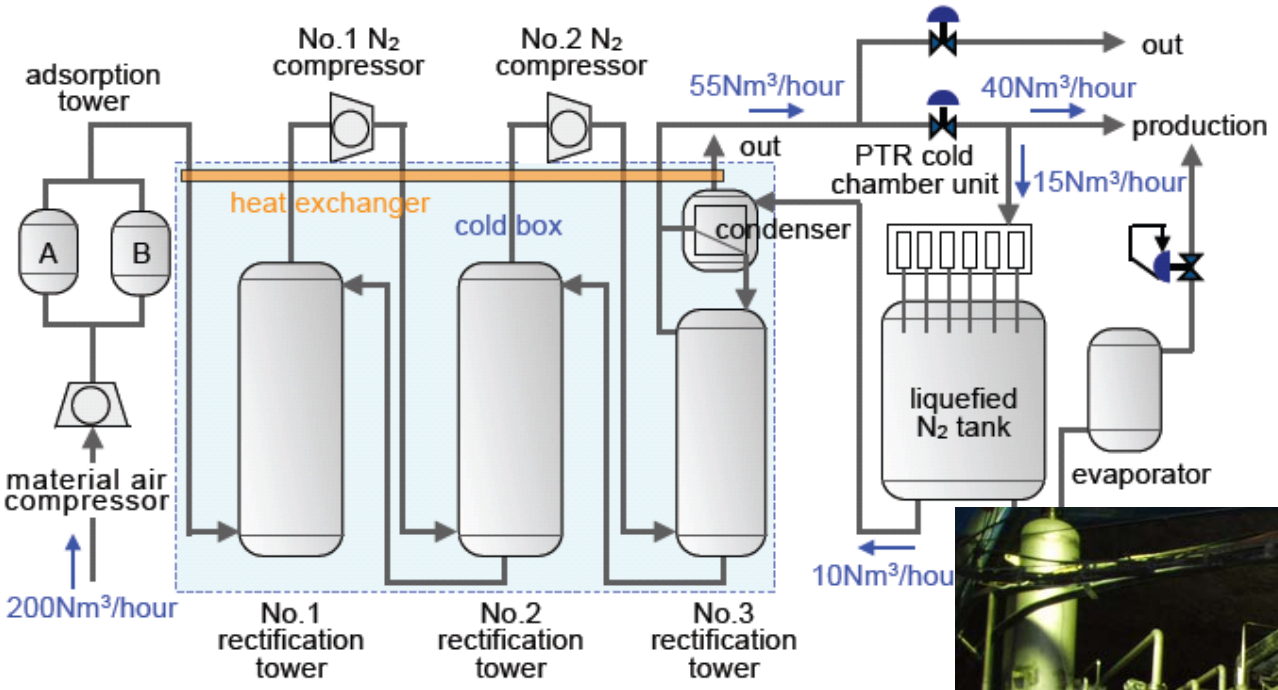
Distillation System



- Purging by N_2 gas, distilled PC, NP, and PPO (2m³) from KamLAND.
- Temperature and Density meter
  - Operating pressure ~2kPa
  - Boiling point ~ 100℃
  - Flow rate ~ 80~85 Nm³/h
  - Pressure is adjusted by pre-small tank.
- Rest at the bottom of NP tower → Dodecane + PPO(little concentrated)
  - → send to PPO concentrator (~140℃ under 2kPa), NP is evaporated back to NP tower.
  - → send to next tower

Dodecane ($C_{12}H_{26}$) : 80% Pseudocumene : 20% (1,2,4-Trimethyl Benzene) PPO : 1.5 g / l (2,5-Diphenyloxazole)

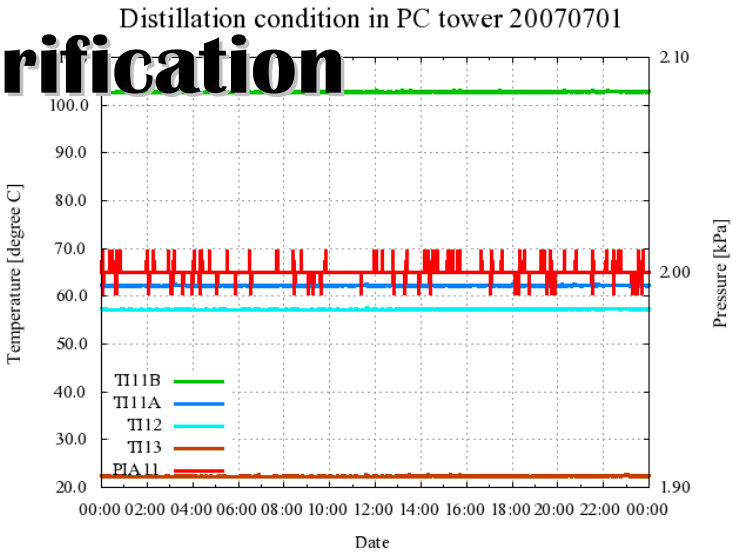
N_2 Generator



- **Newly developed/constructed N_2 generator**
  - Supply air : Rn less air from outside of mine
  - N_2 supply capacity : 40 Nm^3/h
    Emergency 5 Nm^3/h
- **Purity**
  - Ar 0.02 ~ 0.03ppm (measured)
  - Kr ~10^{-15} (not measured yet)
  - ^{222}Rn ~ 5μBq/m3 (measured at purif. Area)

Status during 1st Purification

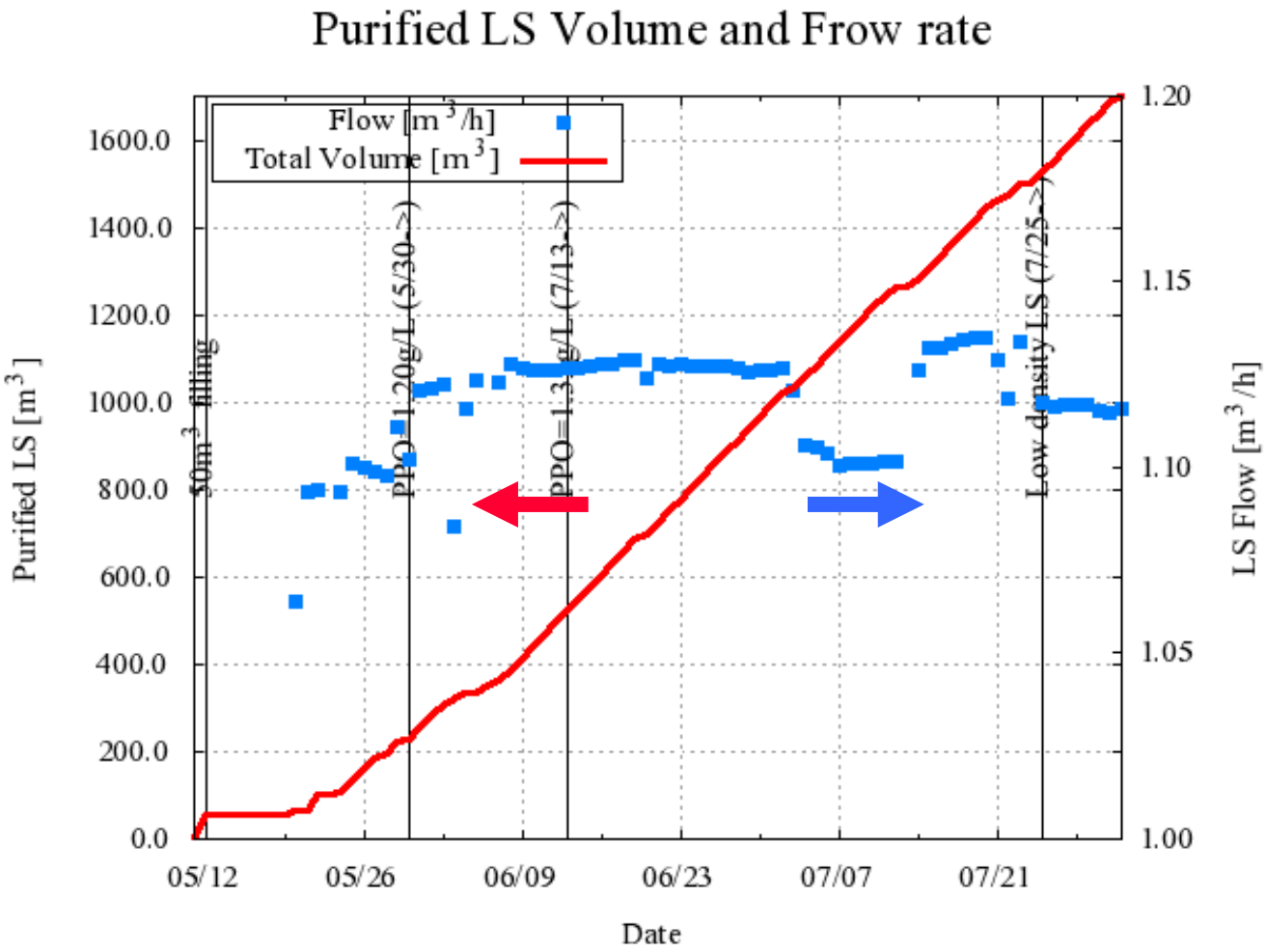
- **LS purification rate: *F*=0.9t/h**
- **Parameters were well controlled .**



Parameter	Pressure [kPa]	Temperature [C]
PC tower	**2.00 (Max-min: 0.08%)**	**62.4 (Max-min: 3.1%)**
NP tower	**2.00(Max-min: 0.17%)**	**96.9(Max-min: 0.85%)**
PPO tower	**0.60(Max-min: 0.48%)**	**174.8(Max-min: 0.69%)**
Purge tower	**40.0(Max-min: 0.00%) (*F*=30Nm^3/h)**	**$29.0^{+3.2}_{-2.8}$ (Tower A)** **$29.5^{+2.9}_{-2.5}$ (Tower B)**

1st Purification Period

- **Total 1699m^3 of LS was purified till Aug. 1st, 2007.**
  - Purified Volume / KamLAND volume = 1.4
  - Reactor and geo neutrino observation ware continuing .



Monitoring Quality

Background Reduction

- **Reduction factors for ^{210}Pb and ^{40}K were monitored by KamLAND**
  - The data were continuously taken during purification.
- **Rn concentration in purified LS (← less than 10 mBq/m^3 ; OK)**
  - Delayed coincidence of Bi-Po → miniLAND
  - Electrostatic collection method after trapping
- **Reduction factor of ^{85}Kr**
  - Cold trap + RGA

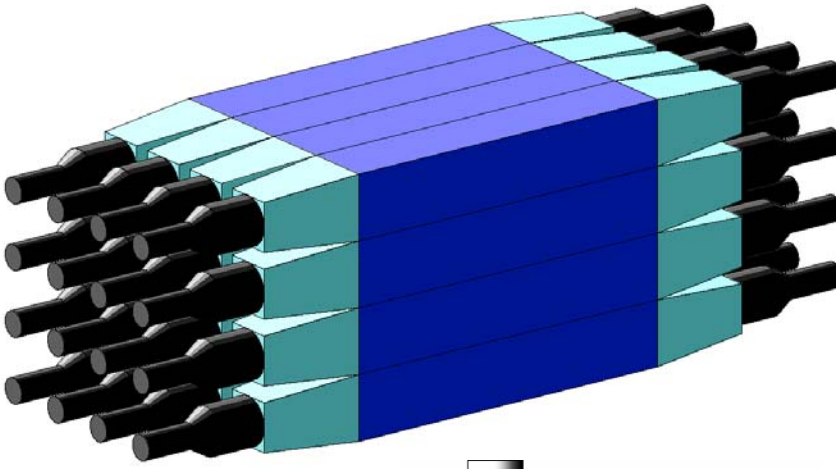
Optical property

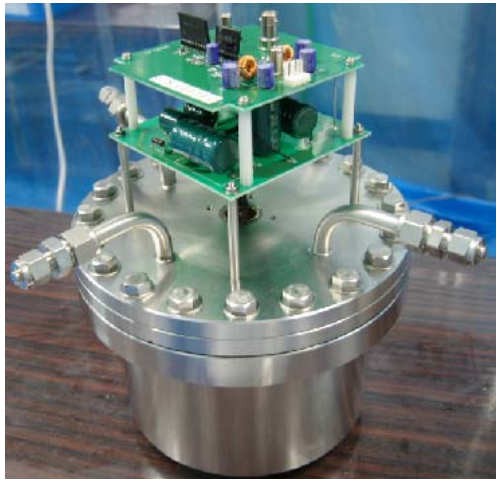
- **Attenuation length after distillation**
- **Light output**

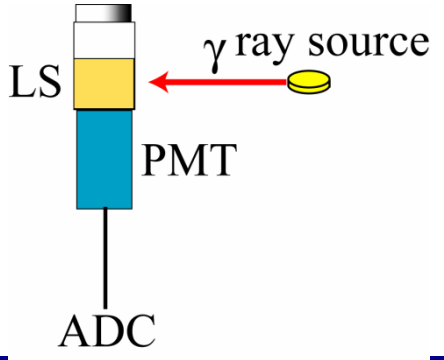
- **LS density**
- **PPO concentration**
  - GC

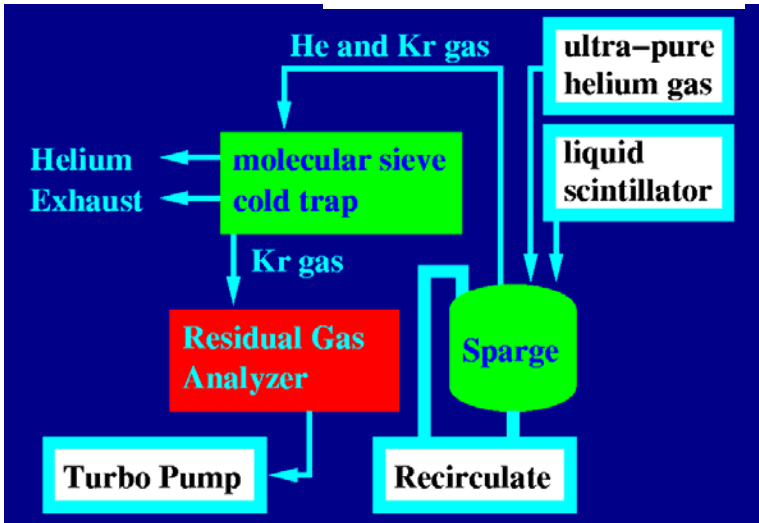
Status during 1st Purification

- ^{222}Rn measurement →OK (<10mBq/m^3)
  - miniLAND
  - Electro static collection method
- $^{Nat.}$Kr measurement
  - Cold trap + RGA
- Light yield and attenuation length of LS
- ^{222}Rn and ^{85}Kr are counted with KamLAND

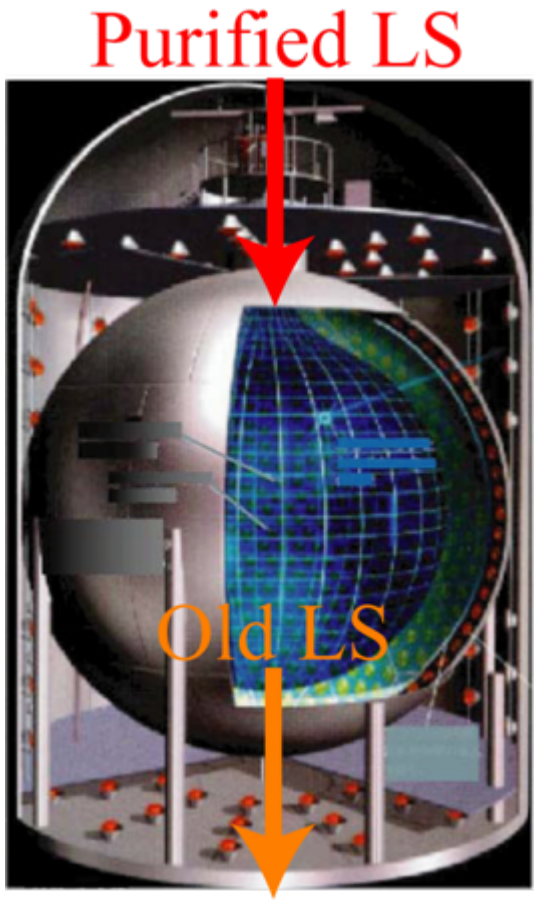


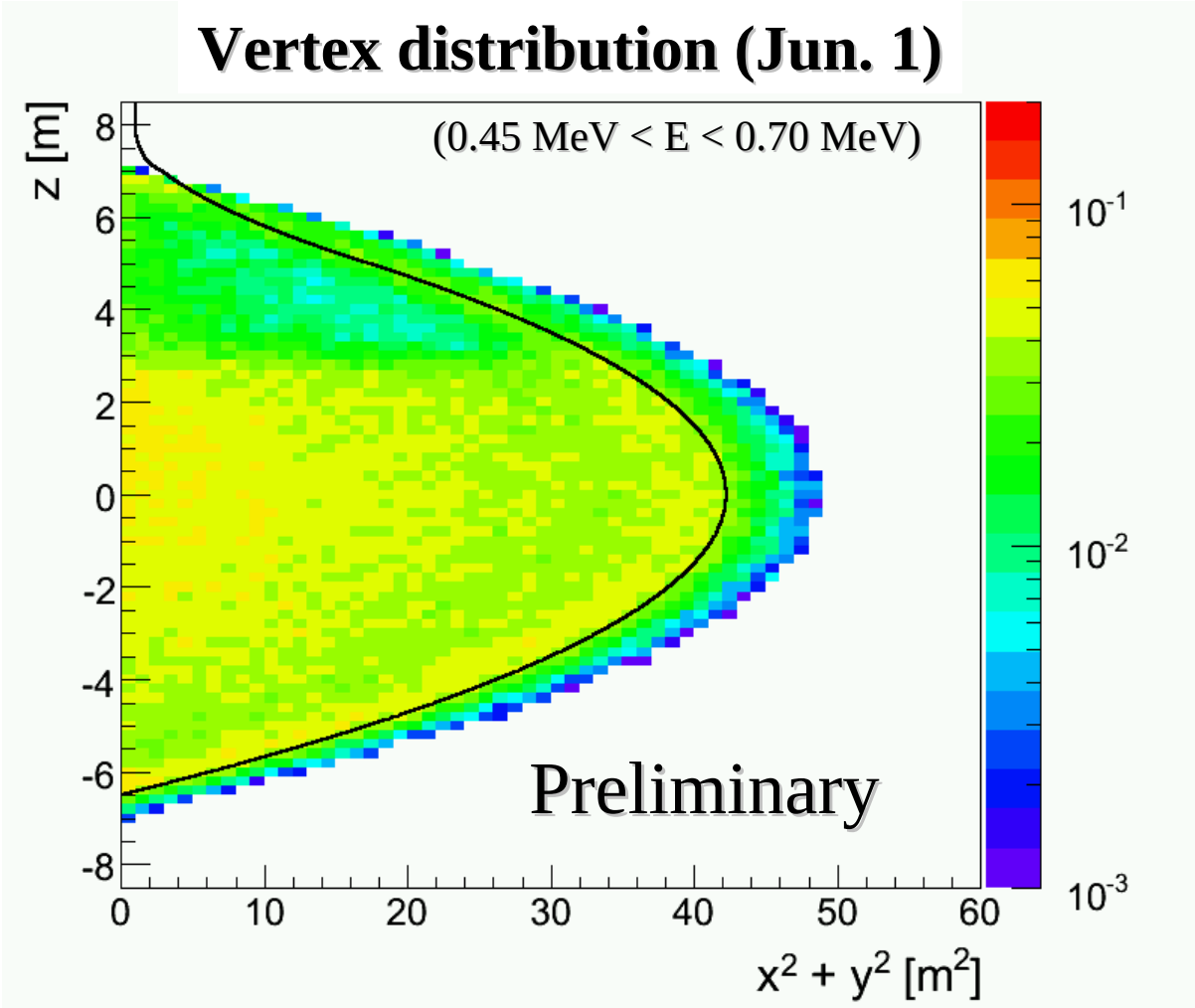




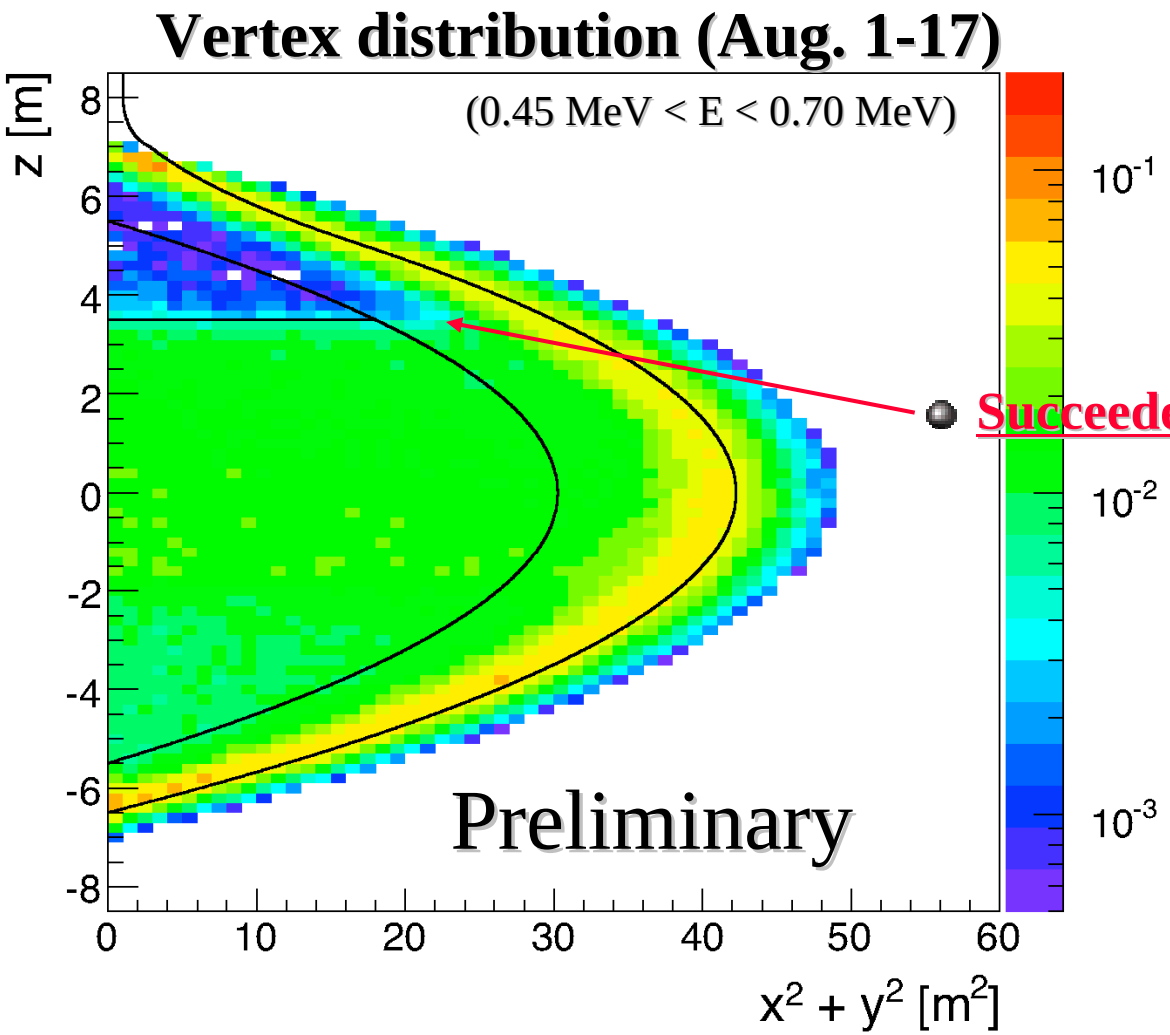


Status during the 1st purification





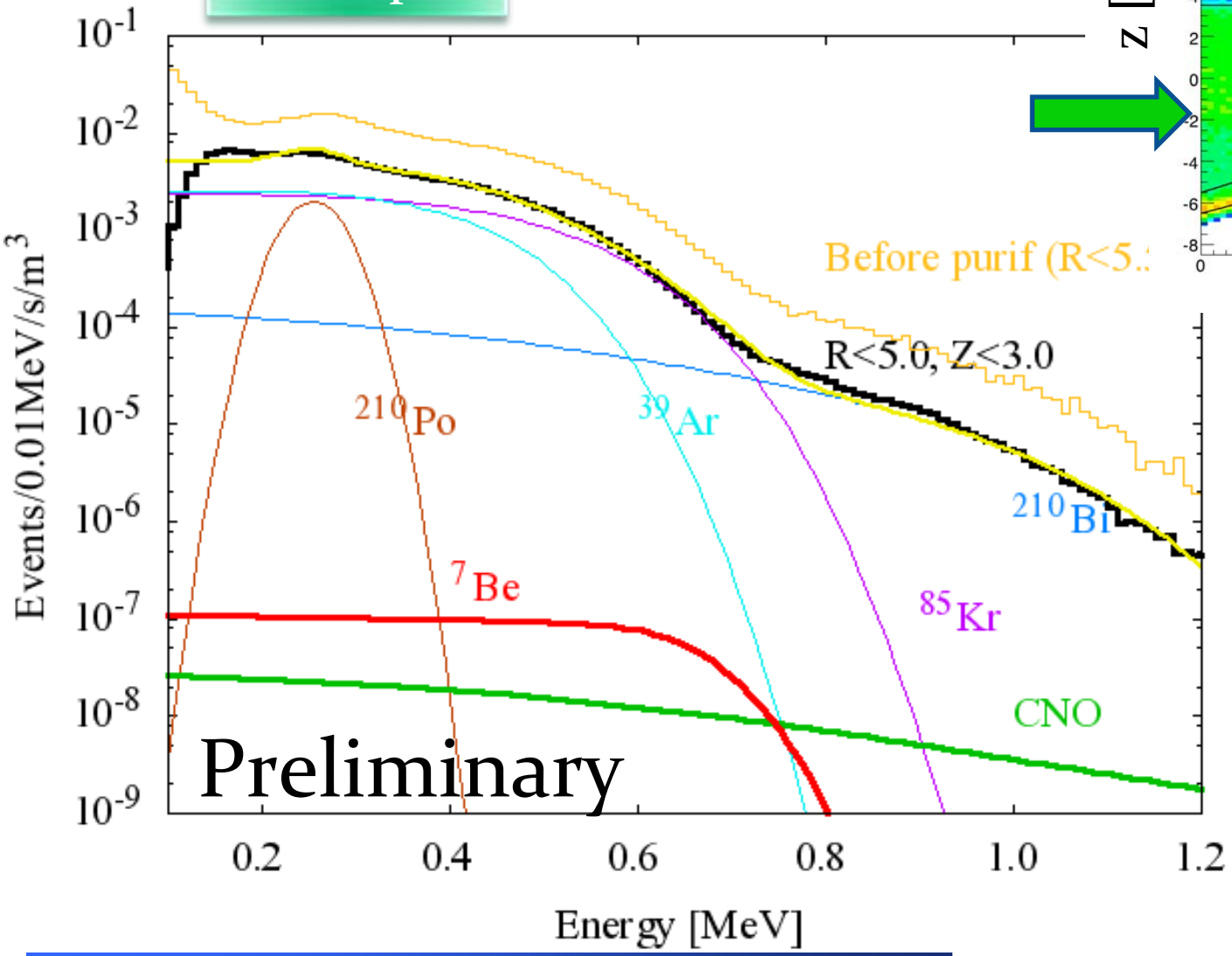
Status during the 1st purification

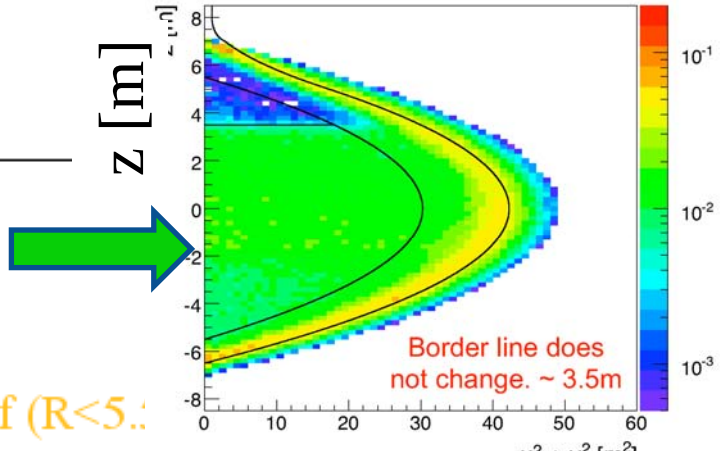


- **Lighter LS was installed.**
  - $\Delta\rho$ ~ 0.03%
  - Last 173m^3
  - 14.4% of KamLAND (Z>3.4m)
- **Succeeded to keep LS boundary.**

Status after purification

Lower part

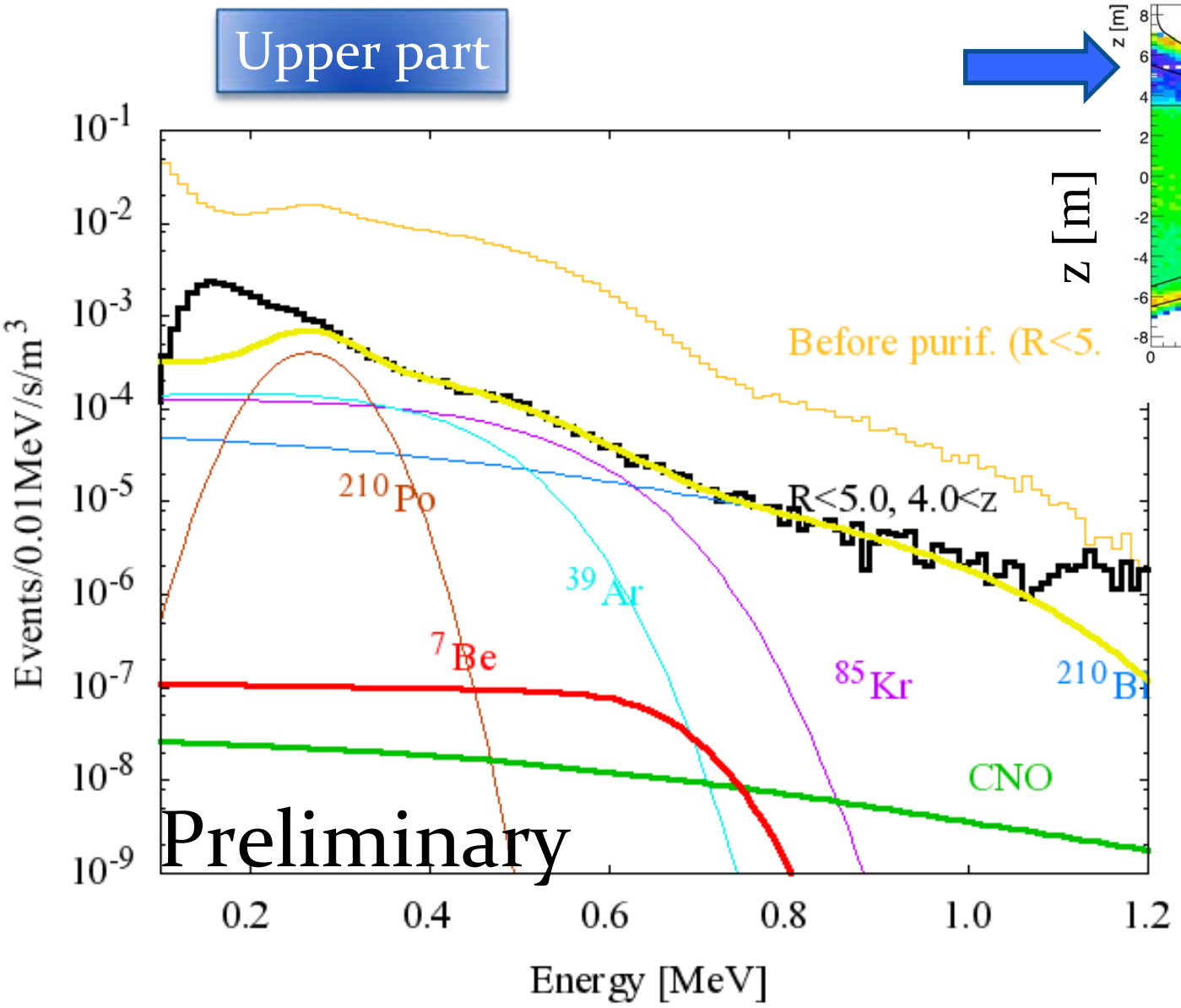


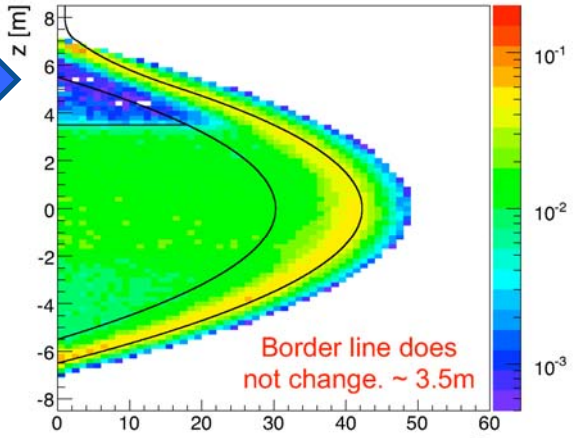


x^2+y^2 [m^2]

Status after purification

Upper part





z [m]

x^2+y^2 [m^2]

Status after the 1st purification (cont.)

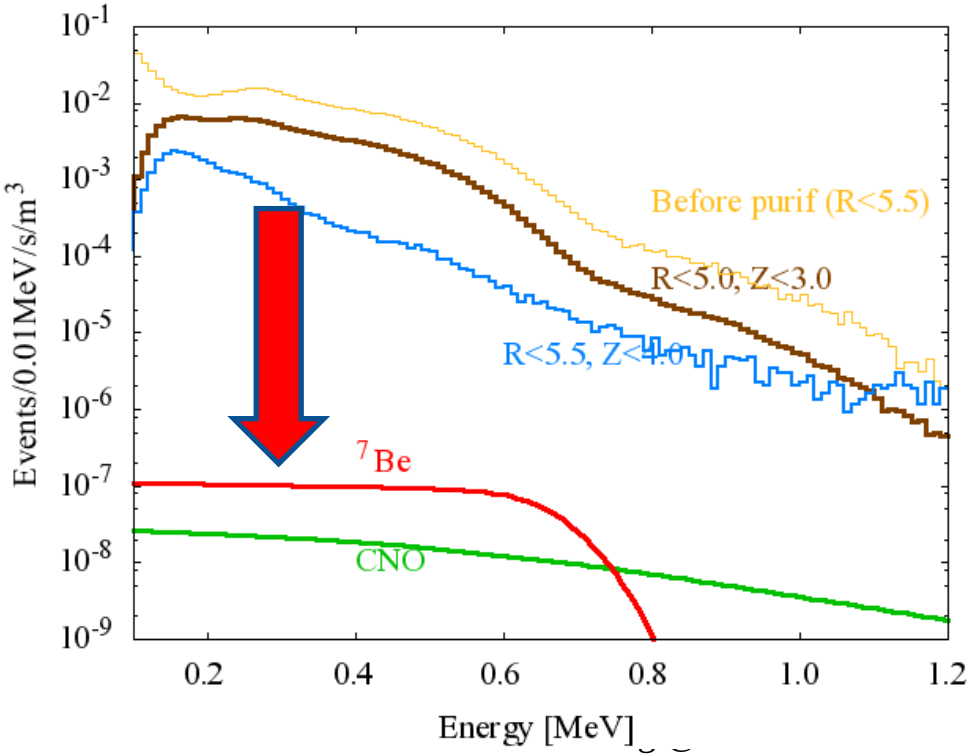
	^{210}Bi	^{210}Po	^{85}Kr	^{39}Ar	^{40}K	^{232}Th
Before mBq/m^3	34.9 (0.5)	39.5 (0.7)	421.3 (2.2)	108.0 (2.9)	18.4 (0.5)	1.0(0.1) μBq/m^3
After mBq/m^3	2.5 (0.1) 7.1(0.1)	8.8(0.1) 15.1(1.9)	4.5(0.3) 111.3(0.2)	6.4(0.3) 100.7(0.3)	< 3.7 90%CL	1.2(2.3) μBq/m^3
Ratio [%] After/Before	7.2(0.3) 20.3(0.4)	20.3(0.5) 38.2(4.9)	1.07(0.08) 26.4(0.2)	5.9(0.4) 93.2(2.5)	<20%	Need more statistics.

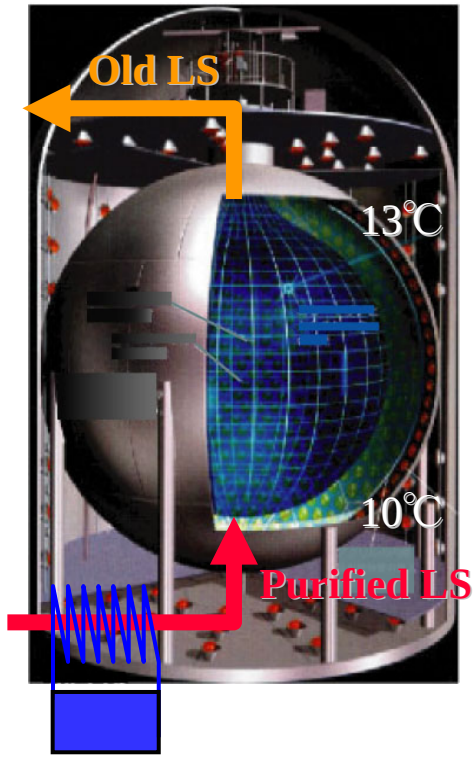
Red figure: Upper region (Z>4m)
Blue figure: Lower region (Z<3m)

- The activities are still high for ^{7}Be and pep/CNO ν, but ^{210}Po reduction helps reactor and geo ν measurement a lot because of less ^{13}C(α, n) background.

2nd purification campaign

- **We stopped our 1st purification activities .**
  - Blasting in Kamioka mine by next spring
- **We are going to upgrade our apparatus .**
  - To prevent mixing → install cooling system
  - more careful distillation ; for small ΔT, Δρ, ……
- **<u>And we start 2nd purification campaign after blasting.</u>**

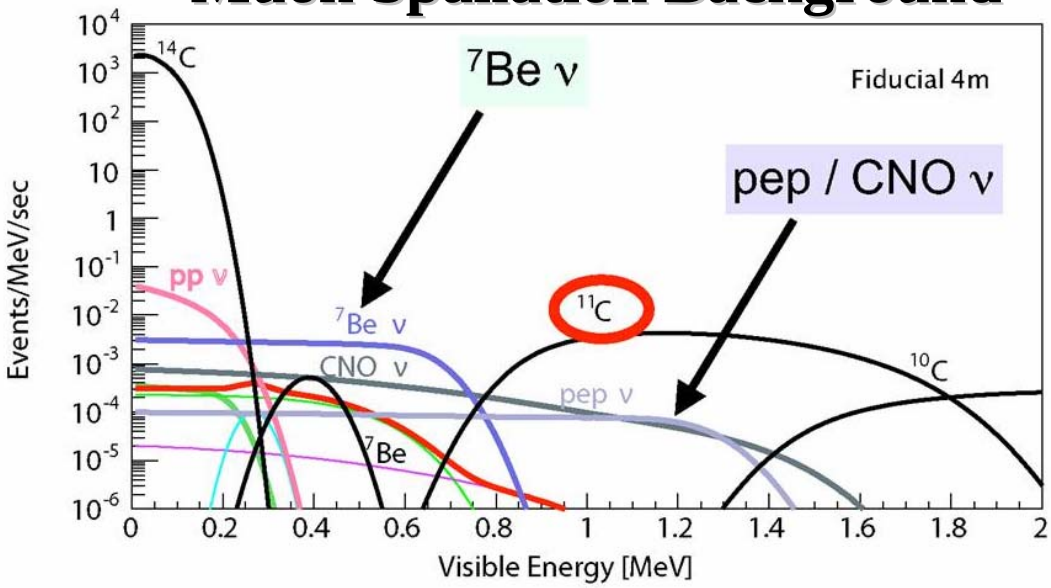




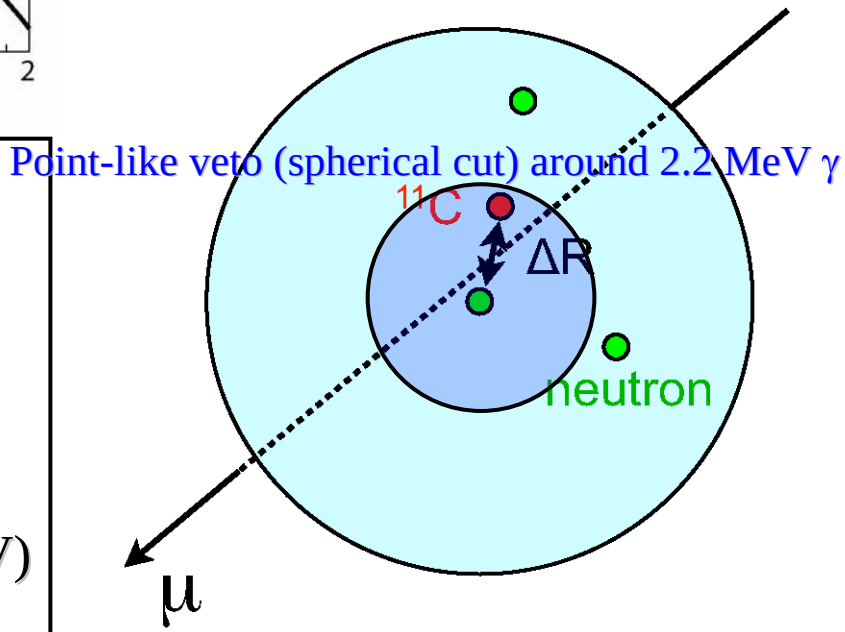
temperature controller
(~ 25℃ → ~ 10℃)

For pep/CNO neutrino measurement

Muon Spallation Background



- **pep/CNO ν are far below ^{11}C background, even if purification will be successfully done.**
- **New electronics is being developed.**
  - dead time free electronics for tagging neutron after μ



Triple coincidence events

- Cosmic μ
- Neutron (Capture time ~210μsec)
- ^{11}C (Lifetime=29.4min.)

$$\mu + {}^{12}C \rightarrow \mu + {}^{11}C + n$$

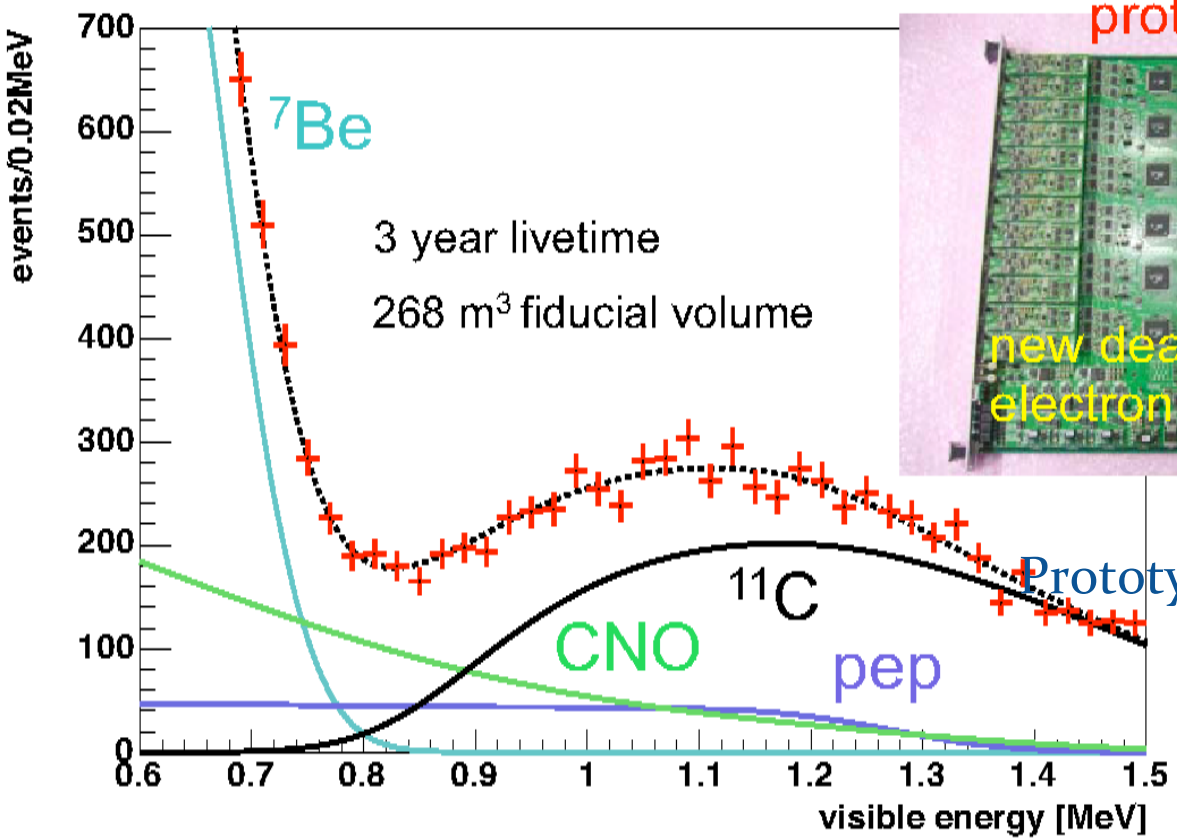
n capture → γ (2.2 MeV)

$$\downarrow$$

$$^{11}B + e^{+} + \nu_e$$

Energy spectra after ^{11}C rejection

95% of ^{11}C is rejected by neutron tagging



Prototype was tested.

- **Expected CNO ν+ *pep* ν flux error ~ 6% (Stat. error)**