The Borexino Solar Neutrino Experiment

Joint Nuclear Physics Meeting
APS and JPS

Hawaii, September 17, 2005

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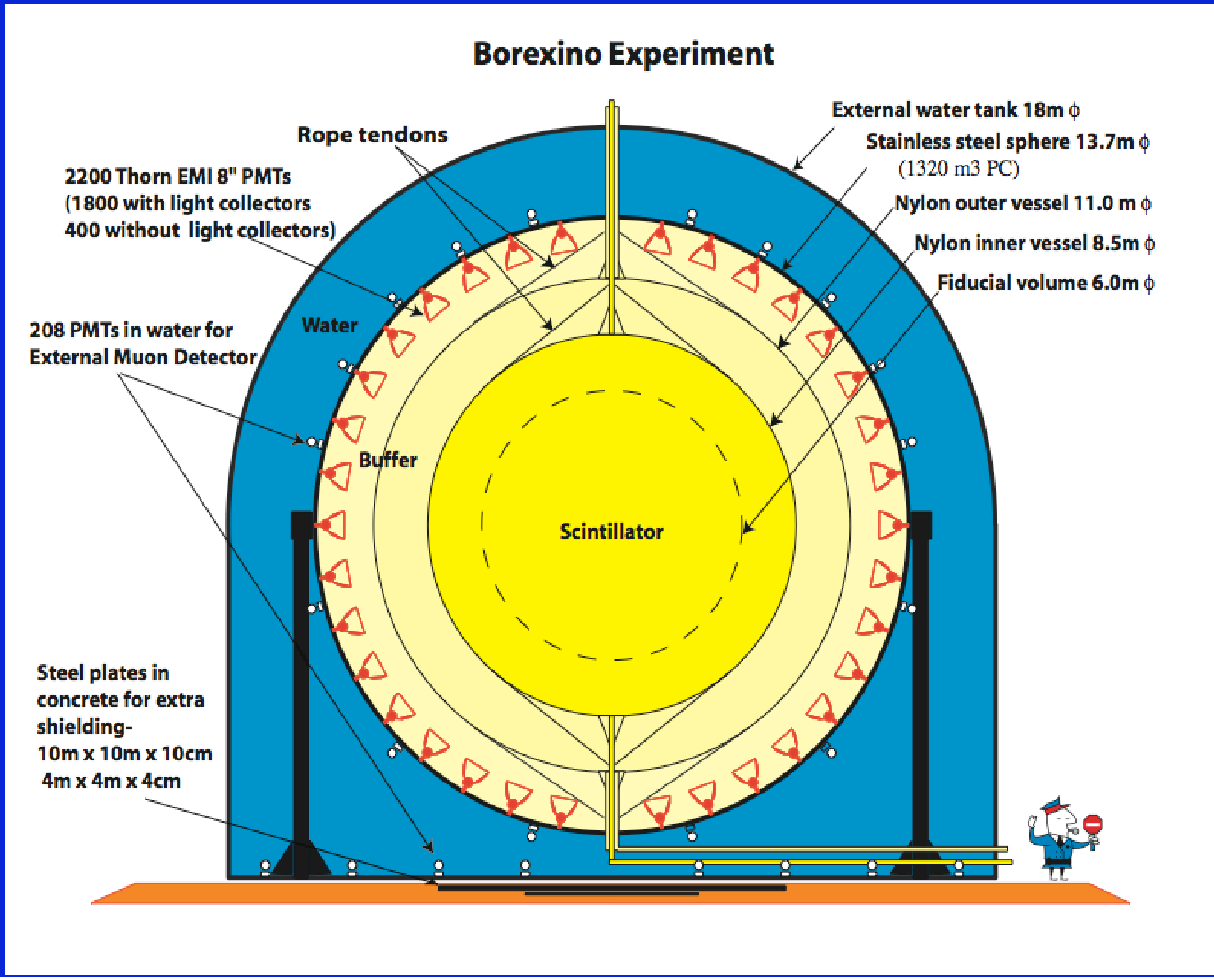
Dedicated to John Bahcall

- For contributions to the field of solar neutrinos.
- For inspiring scientists who work in it.
- For his interest in the details of the experiments.
- For his support of Borexino.

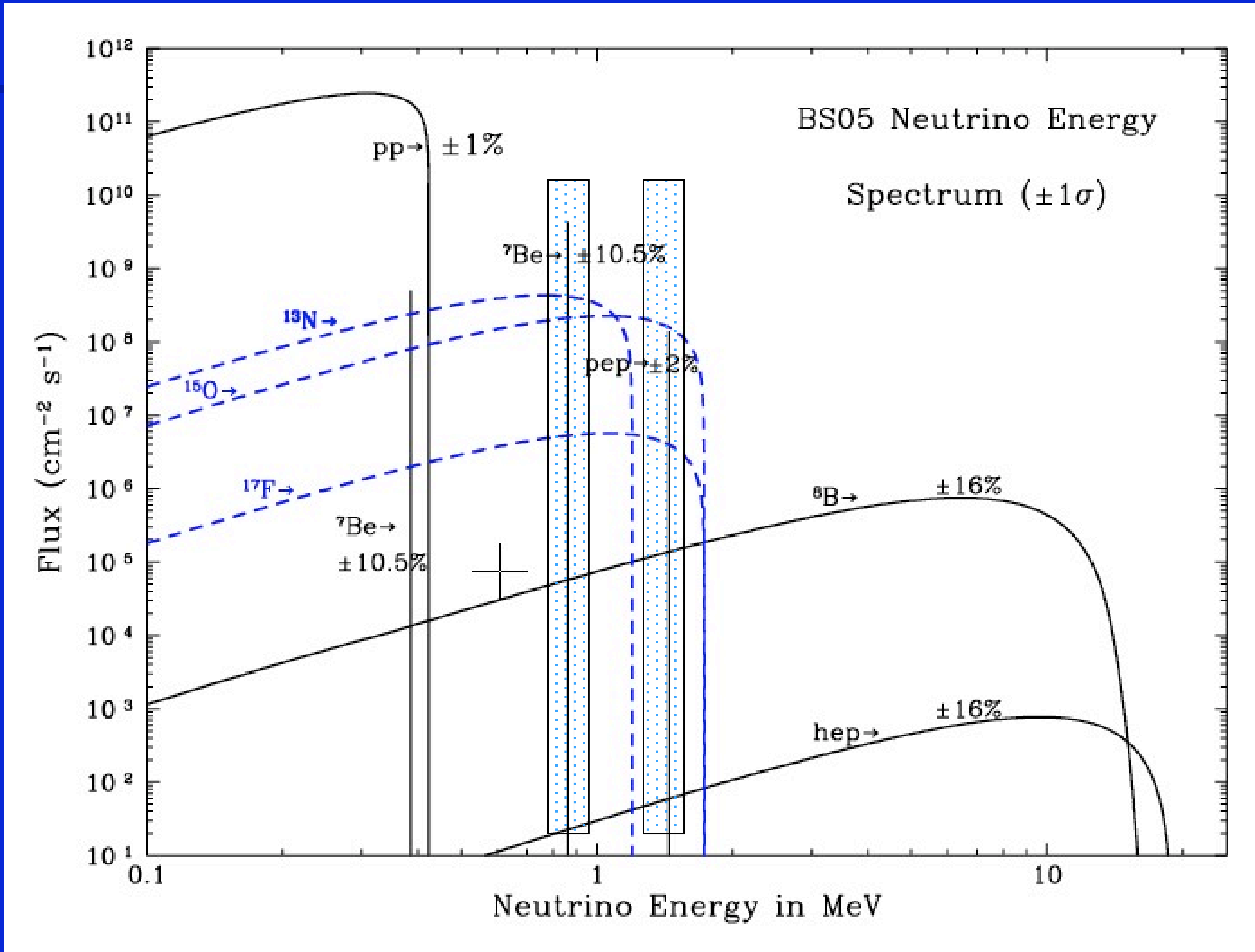
Science with Borexino

- Neutrino
- The Sun
- The Earth
- Supernovae

The Borexino Detector

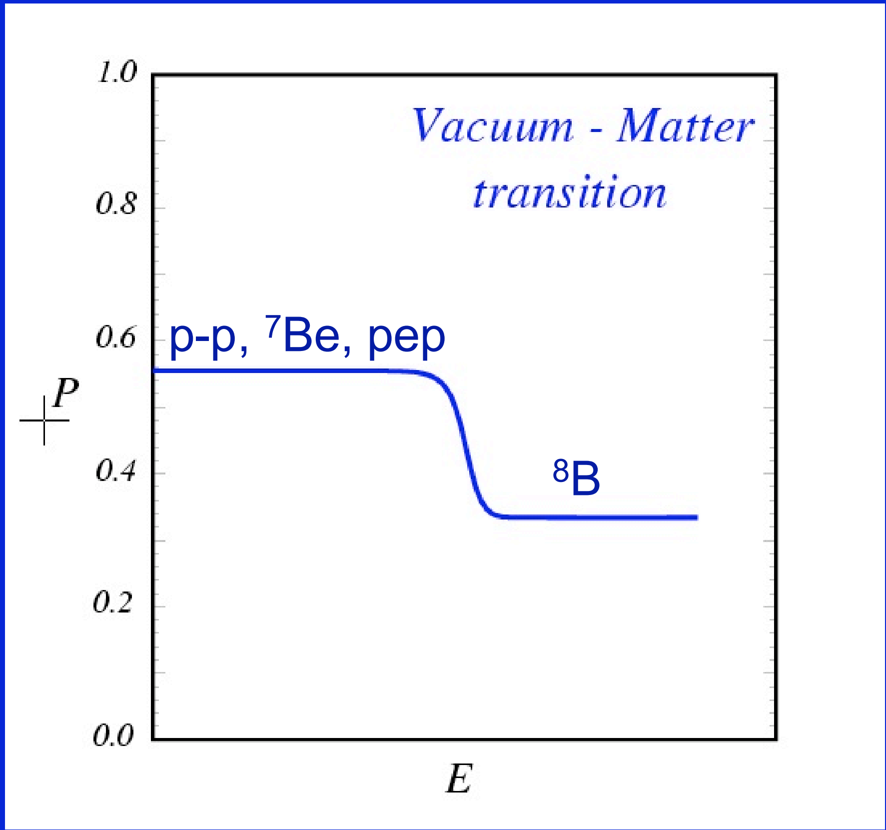


Solar Neutrinos



Neutrinos - do we know it all?

- Measure flux of low energy ^{7}Be and pep solar neutrinos
- Test MSW theory of neutrino oscillations
  - Observe transition from matter to vacuum oscillations
- Search for new exotic phenomena
  - Sterile neutrinos, etc.



What makes the Sun shine?

- Measure the major neutrinos from the sun: ^{7}Be and pp (through pep)
- Test understanding of the fusion processes that power the sun.
- Test for new physics
  - Other sources of energy?
  - Compare the photon luminosity to neutrino luminosity

Reaction		Termination (%)
1a) $p + p \rightarrow {}^{2}\mathrm{H} + e^{+} + \nu_e$	(pp)	99.77
or		
1b) $p + e^{-} + p \rightarrow {}^{2}\mathrm{H} + \nu_e$	(pep)	0.23
2) ${}^{2}\mathrm{H} + p \rightarrow {}^{3}\mathrm{He} + \gamma$		100
3a) ${}^{3}\mathrm{He} + {}^{3}\mathrm{He} \rightarrow \alpha + 2p$		84.92
or		
3b) ${}^{3}\mathrm{He} + {}^{4}\mathrm{He} \rightarrow {}^{7}\mathrm{Be} + \gamma$		15.08
${}^{7}\mathrm{Be} + e^{-} \rightarrow {}^{7}\mathrm{Li} + \nu_e$	(^{7}Be)	15.07
${}^{7}\mathrm{Li} + p \rightarrow 2\alpha$		15.07
or		
${}^{7}\mathrm{Be} + \mathrm{p} \rightarrow {}^{8}\mathrm{B} + \gamma$		0.01
${}^{8}\mathrm{B} \rightarrow {}^{8}\mathrm{Be}^{*} + e^{+} + \nu_e$	(^{8}B)	0.01
or		
3c) ${}^{3}\mathrm{He} + p \rightarrow {}^{4}\mathrm{He} + e^{+} + \nu_e$	(hep)	10^{-5}

^{7}Be neutrino measurement

5% precision in the flux will improve our knowledge of the oscillation parameters (especially θ) *[Lisi,Palazzo,Rotunno, HEP-ph/0403036]*

5% precision in the estimate of the ^{7}Be flux will significantly improve constraint on CNO luminosity.

Pep neutrino measurement

Particularly interesting to test the energy region where transition between vacuum-dominated and MSW-dominated oscillation occurs;

Expected rate:1-2 counts/day;

Gran Sasso is favored over Kamland, being deeper (less ^{11}C background): expected (<u>signal/noise~0.4</u>);

Possibility to apply three-fold coincidence cut to reduce ^{11}C background (<u>signal/noise>2</u>); *[Phys.Rev.C 71,055805 (2005)]*

Muon induced ^{11}C Beta Background & pep neutrinos

CRISTIANO GALBIATI *et al*.

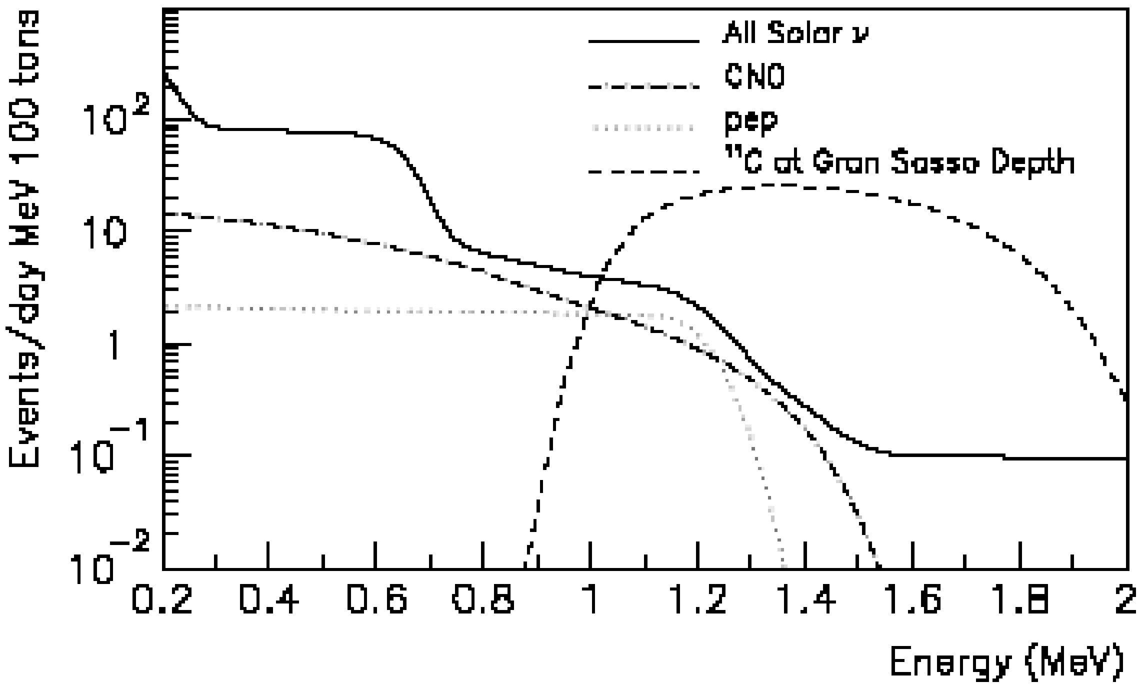


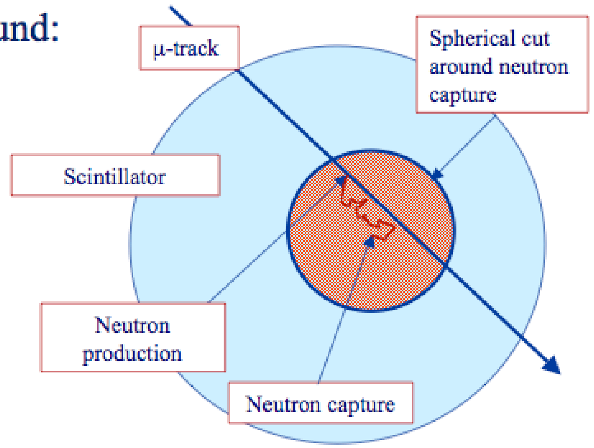
FIG. 1. Energy spectrum of electrons scattered by *pep* (dotted line) and CNO neutrinos (dash-dotted line), for the MSW-LMA

Rejection of ^{11}C Background

Implication in Borexino

How to reduce ^{11}C background:

- **Software cut**
  - spherical volume around the reconstructed $\gamma_{2.2\ \mathrm{MeV}}$
- **Muon veto cut**
  - cylindrical volume around the muon track



^{11}C is removed <u>blinding</u> the intersection the spherical volume for 5-10 ^{11}C-lifetime

Main challenge: keeping low the total <u>dead volume x time</u>

Davide Franco – NOW 2004

Pep, CNO, & ^{11}C rates in Borexino 100 ton F.V.

- Pep rate: ~2.1 ev/day
- CNO rate: ~3.5 ev/day
- Pep+CNO (0.8-1.3 MeV) ~2 ev/day

- Signal to ^{11}C background ~2
  - Loss due to cut ~7%
- 5-year pep+ CNO precision ~3%

- U, Th @ 10^{-17} g/g ~0.6ev /day

The Earth

- Temperature gradients in earth's crust show that energy is generated inside the earth.
- Source of heat in the earth is not fully understood, but natural radioactivity of K, U, Th is an important source.
- Measure anti-neutrinos from U and Th in the earth determines heat from important source.
- Most signal comes from the earth's crust.
  - Test crust model of earth (based on seismic data)
  - Global network of detectors needed.

Geoneutrinos in KamLAND

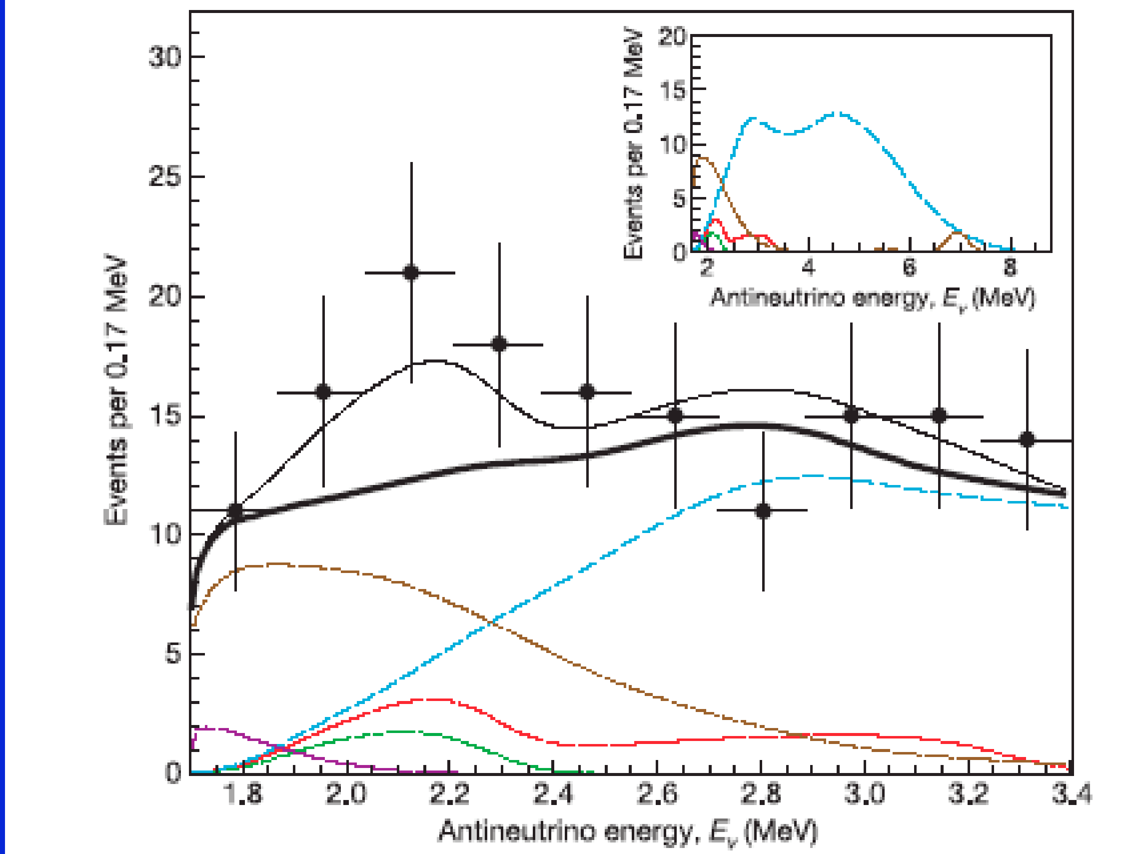
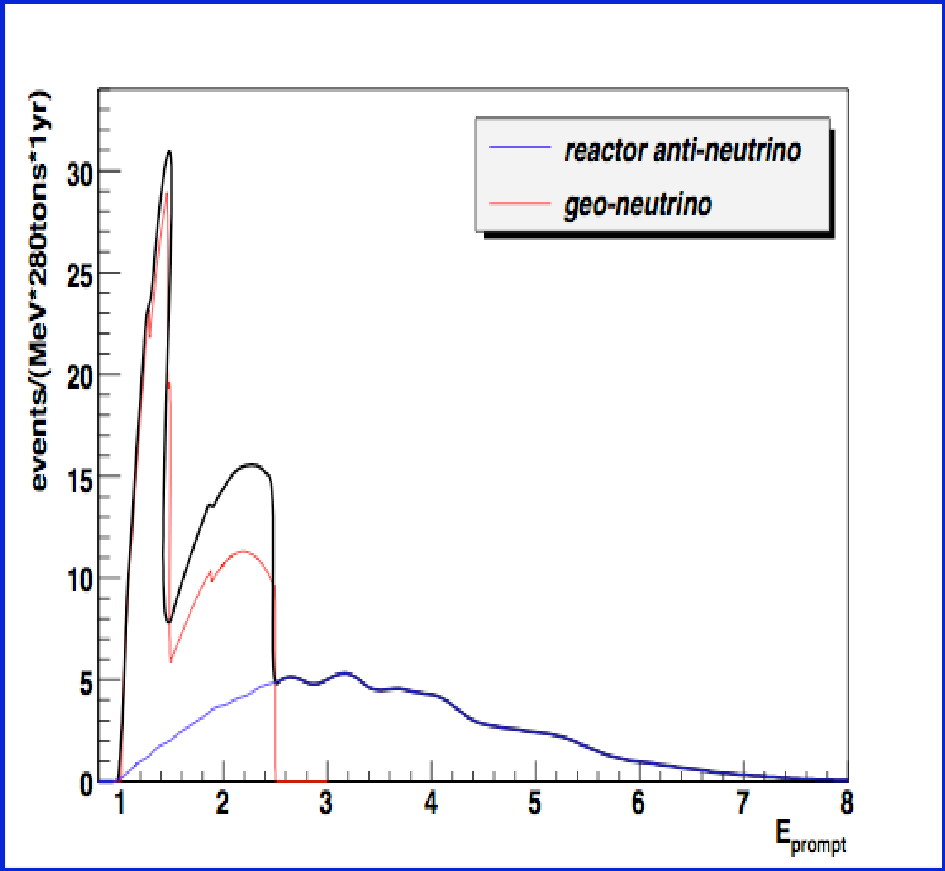


Figure 3 | $\bar{\nu}_e$ energy spectra in KamLAND. Main panel, experimental points

Geo-neutrinos expected in Borexino

- Geo-neutrino rate:
  18/yr
- Reactor neutrino rate: 18/yr
- No reactors in Italy
- Nearest reactors in southern France

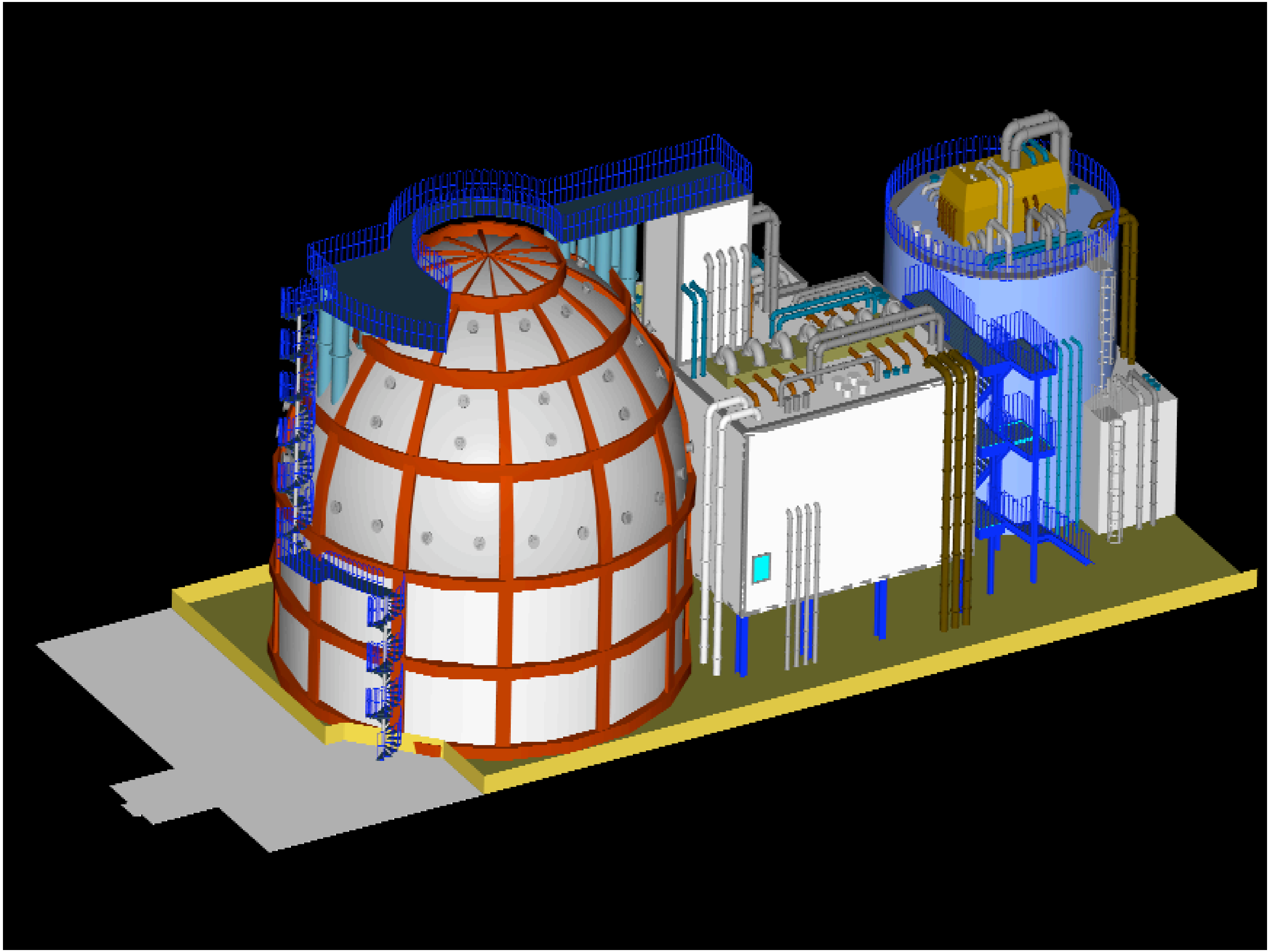


Galactic Supernova neutrinos

- In 300 tons of BX scintillator
  - ~17 events from NC $^{12}C(\nu_x, \nu_x)^{12}C^*$(15.1 MeV)
  - ~80 CC inverse beta decay events
    - $^{12}C(\nu_e, e^+)^{12}B$; $^{12}C(\nu_e, e^-)^{12}N$
  - ~100 elastic scattering events: $\nu_x + p \rightarrow \nu_x + p$
- Charged and neutral currents separable
- Obtain energy spectrum of neutrinos

Current Status of Borexino

- Detector construction completed during period of limited access
- Earlier CTF tests of purification showed promise for Borexino, but possible problems with ^{85}Kr and ^{210}Po.
- Off-line studies yielded important progress for reducing ^{85}Kr and ^{210}Po.
  - Better N_2 for stripping; studies of ^{210}Po migration.
- New CTF test underway



PMT's, Electronics and Data Acquisition System

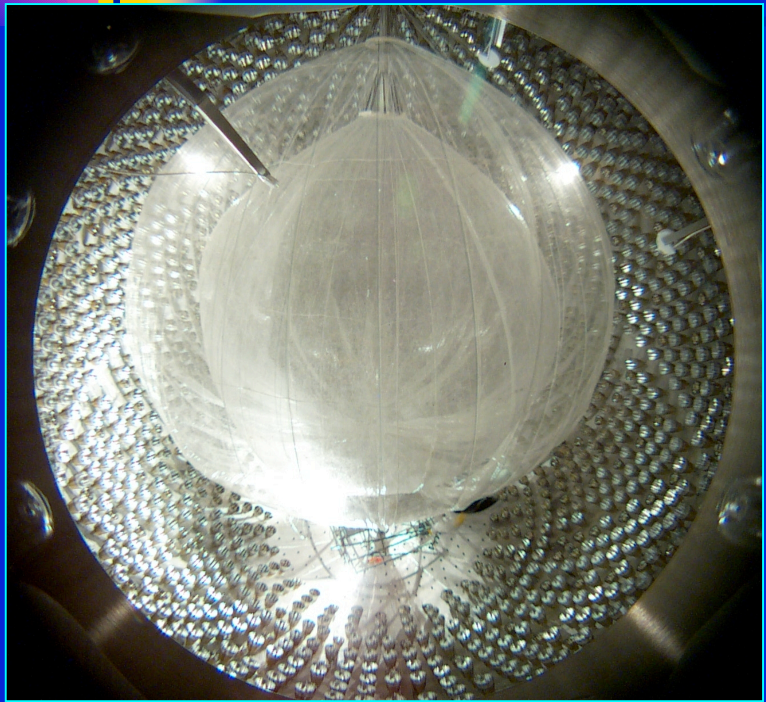
- The Borexino Detector, i.e. the PMT array, the electronics chain, the laser calibration systems and the data taking infrastructure, is now complete.
  - Several test campaigns (the "Air Runs") using laser systems and radioactive sources were performed.
  - Goals of these Air Runs were:
    - Test the integrity and functionality of the Photomultipliers
    - Test the laser systems
    - Test the electronics and the triggering system
    - Test and Debug of the Online software system
    - Develop, Test and Debug of the Offline Data Analysis Software
    - Check that the performance of the detector of scintillator events are as good as expected

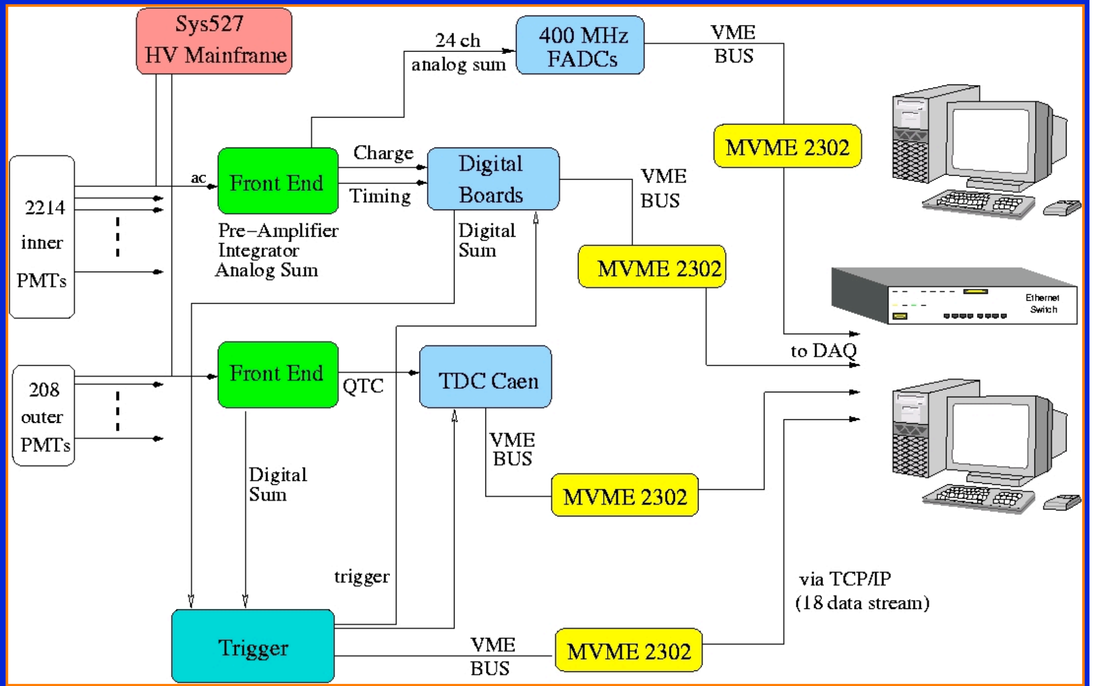
Component of system tested in "air runs"

- 2212 inner PMTs
  - HV system
  - Front End Cards
  - Time and Charge measurement
  - Trigger system
  - FADC system
  - Scalers
- 208 outer detector PMTs
  - HV system
  - Front End
  - Digital cards
  - Trigger
  - Scalers
- Laser calibration system
  - 3 different wave-lengths
  - timing and PC transparency monitor
  - Interface with trigger and DAQ
- Data Acquisition
  - 27 computers
  - network infrastructure
  - data storage
  - online monitor
  - data base system
  - 95000 lines of code

The system

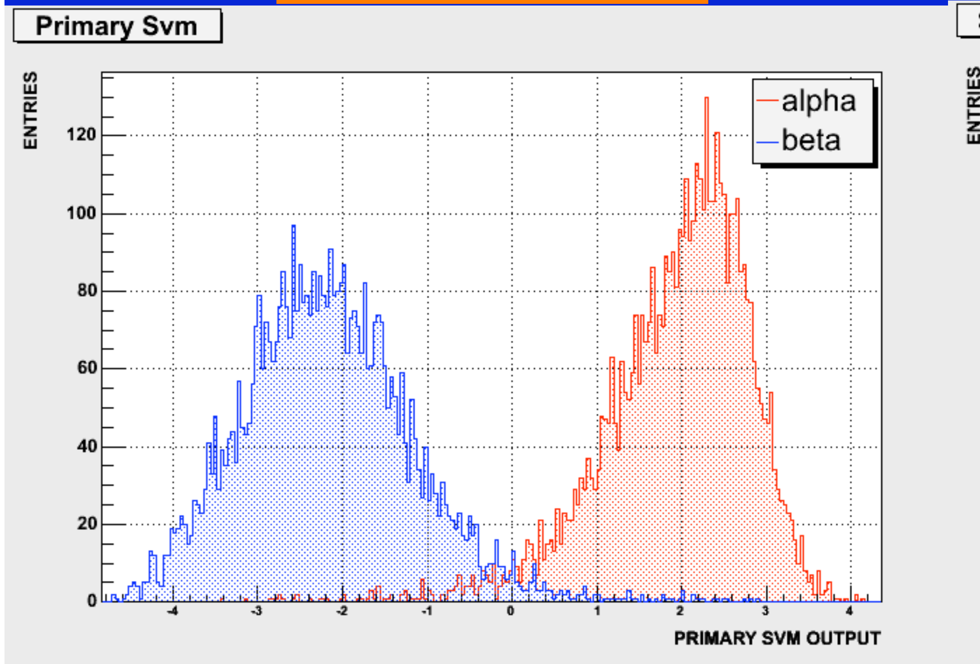
Apr. 2004



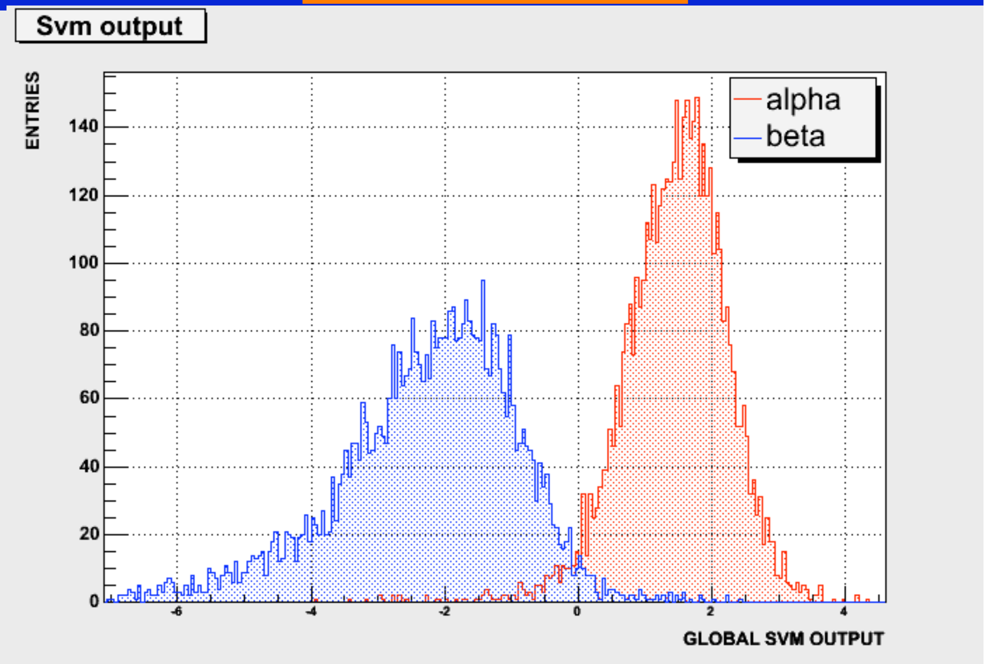


α/β discrimination power (on Bi-Po events)

Primary SVM



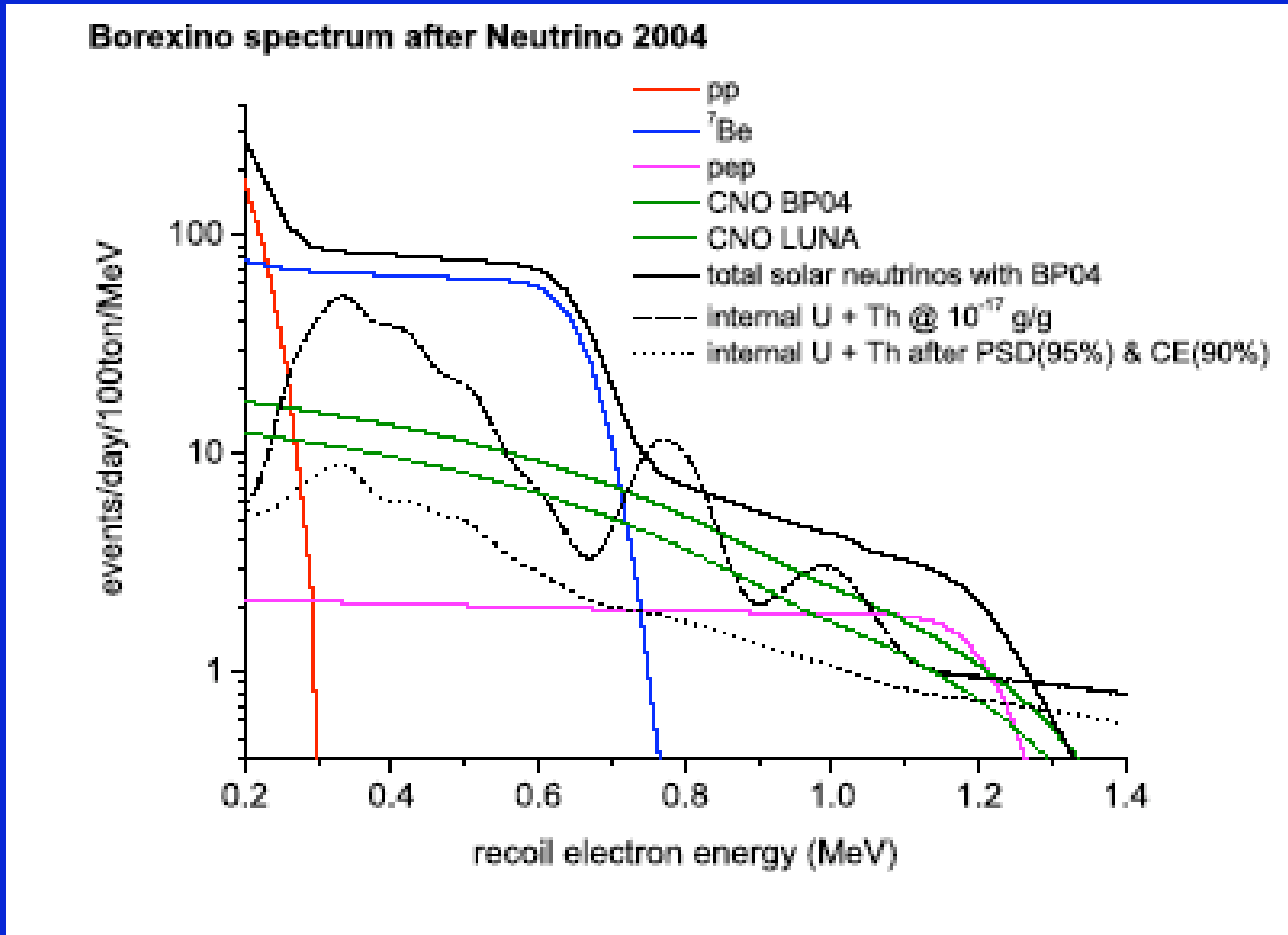
Global SVM



Background issues

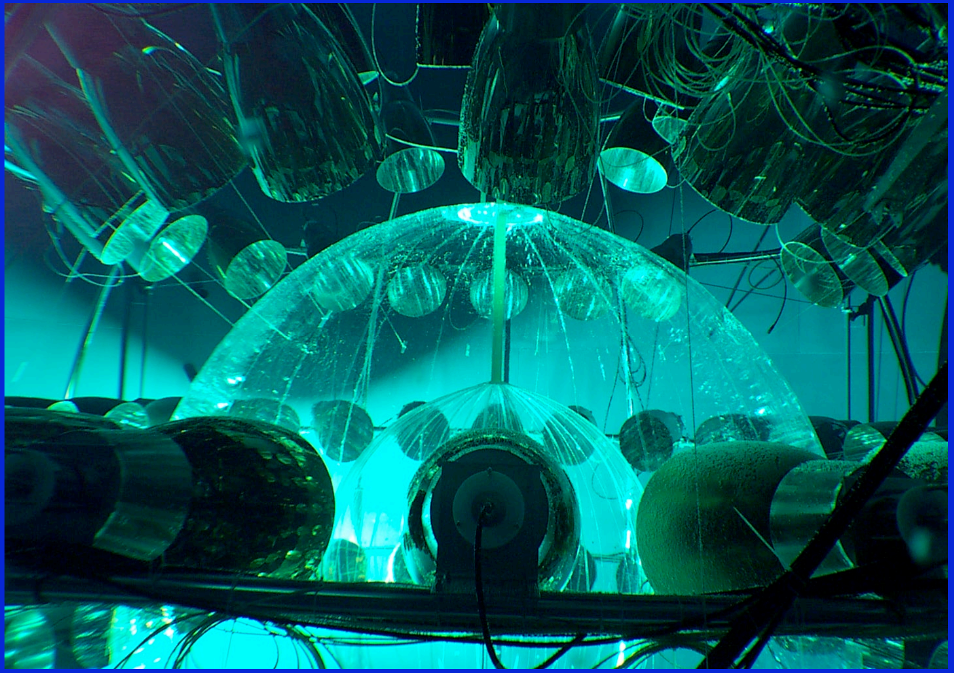
- Radioactivity within the scintillator
  - ^{14}C is OK
  - U, Th @ 10^{-16} g/g seem OK, but want $<10^{-17}$ g/g
  - ^{85}Kr seems OK with new N_2 gas stripping
  - ^{222}Rn daughters
    - High level of ^{210}Po alphas seen
    - ^{210}Pb ^{210}Po ^{210}Bi chain could be problem (surface contamination).
    - 222->218->214 decays seem OK: all tag-able
  - CTF distillation test underway
- External and Cosmic ray induced OK

Signal and Background in BX

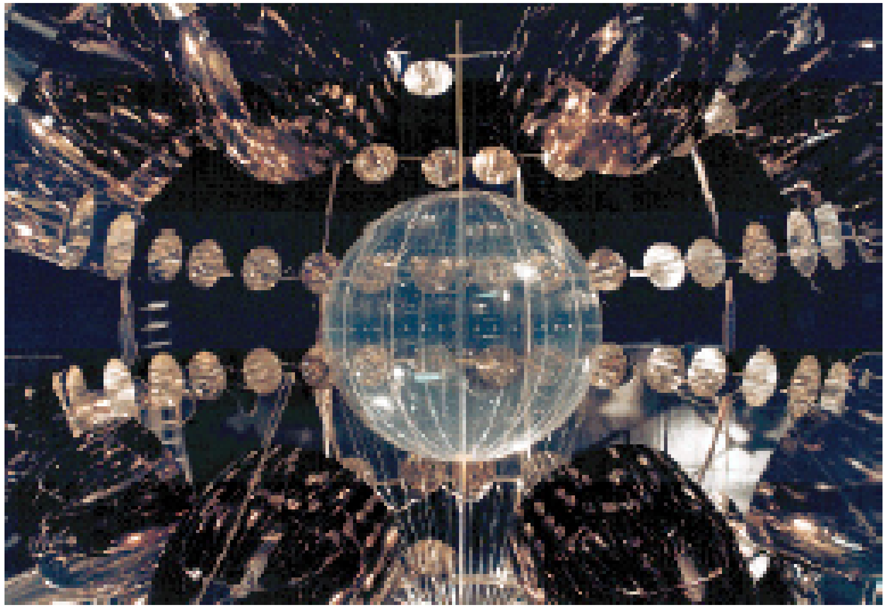


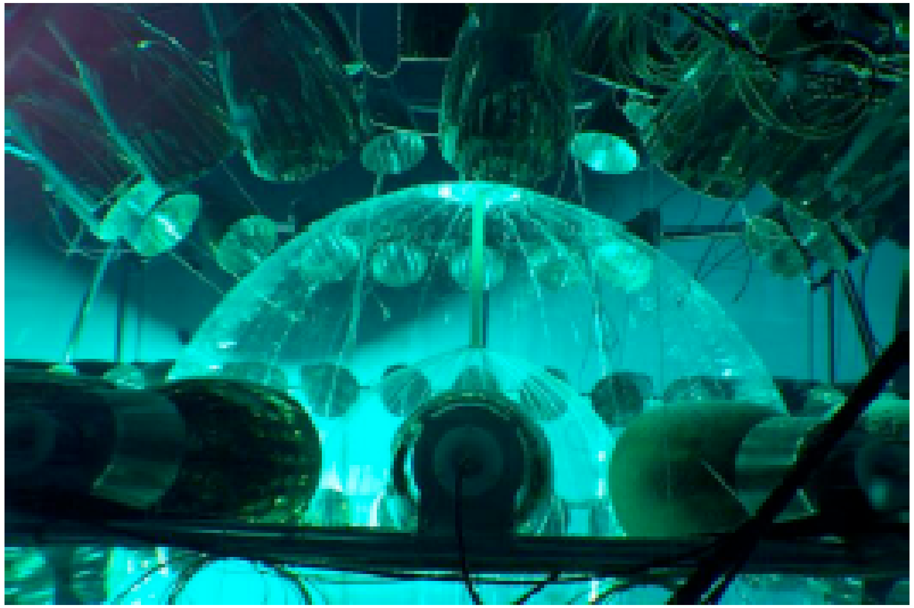
Counting Test Facility

- CTF running continuously since 2002
- Results to date
  - U, Th < 10-16 g/g
- Main backgrounds
  - Radon daughters
  - 210Pb, 210Po, 210Bi
- Tagging demonstrated



CTF1 and CTF2/3





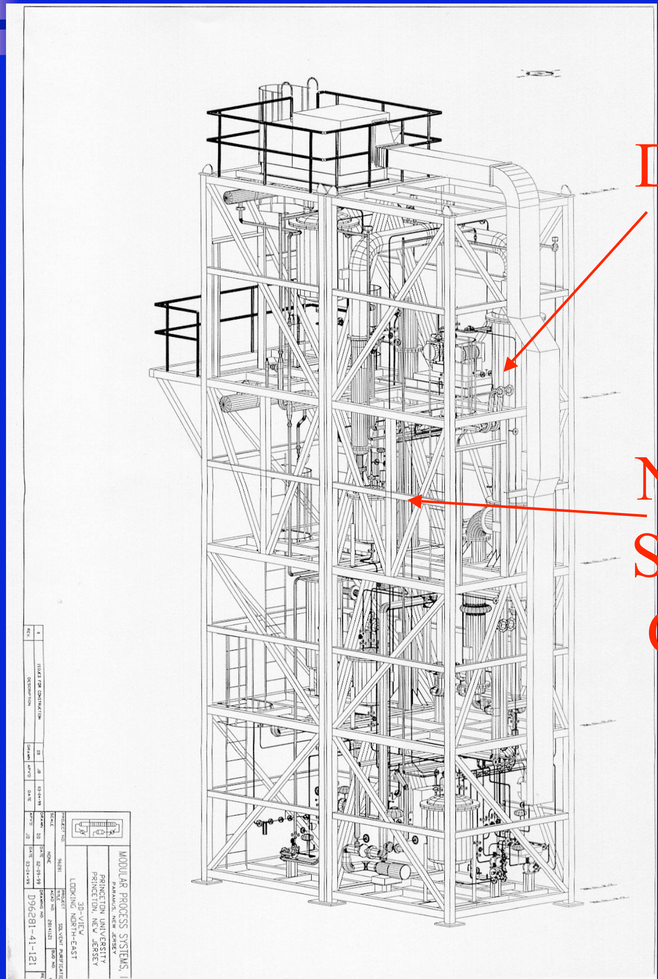
Prototype of Nested Vessels Tested in Princeton Gym

Installation of nested vessels

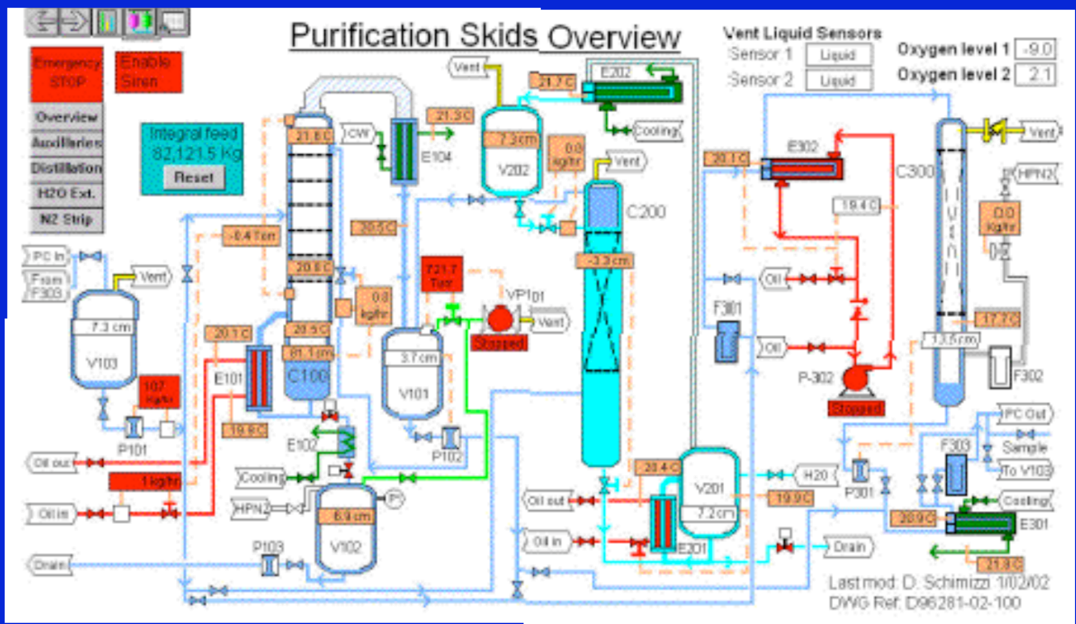
Scintillator Purification Plants

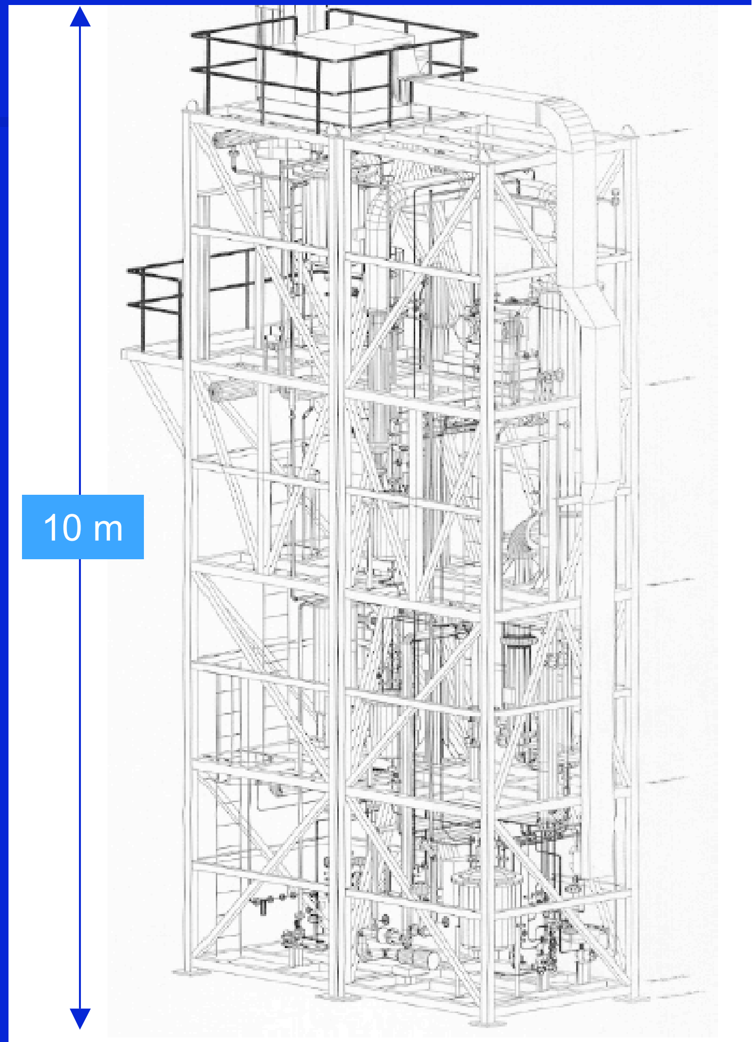
- Distillation, water extraction, and nitrogen stripping of PC at 1 m^3/hr
- Distillation of concentrated PPO+PC in CTF purification plant at 20 liters/hr
- New nitrogen plant for ultra-high purity N_2 gas

Purification Skids



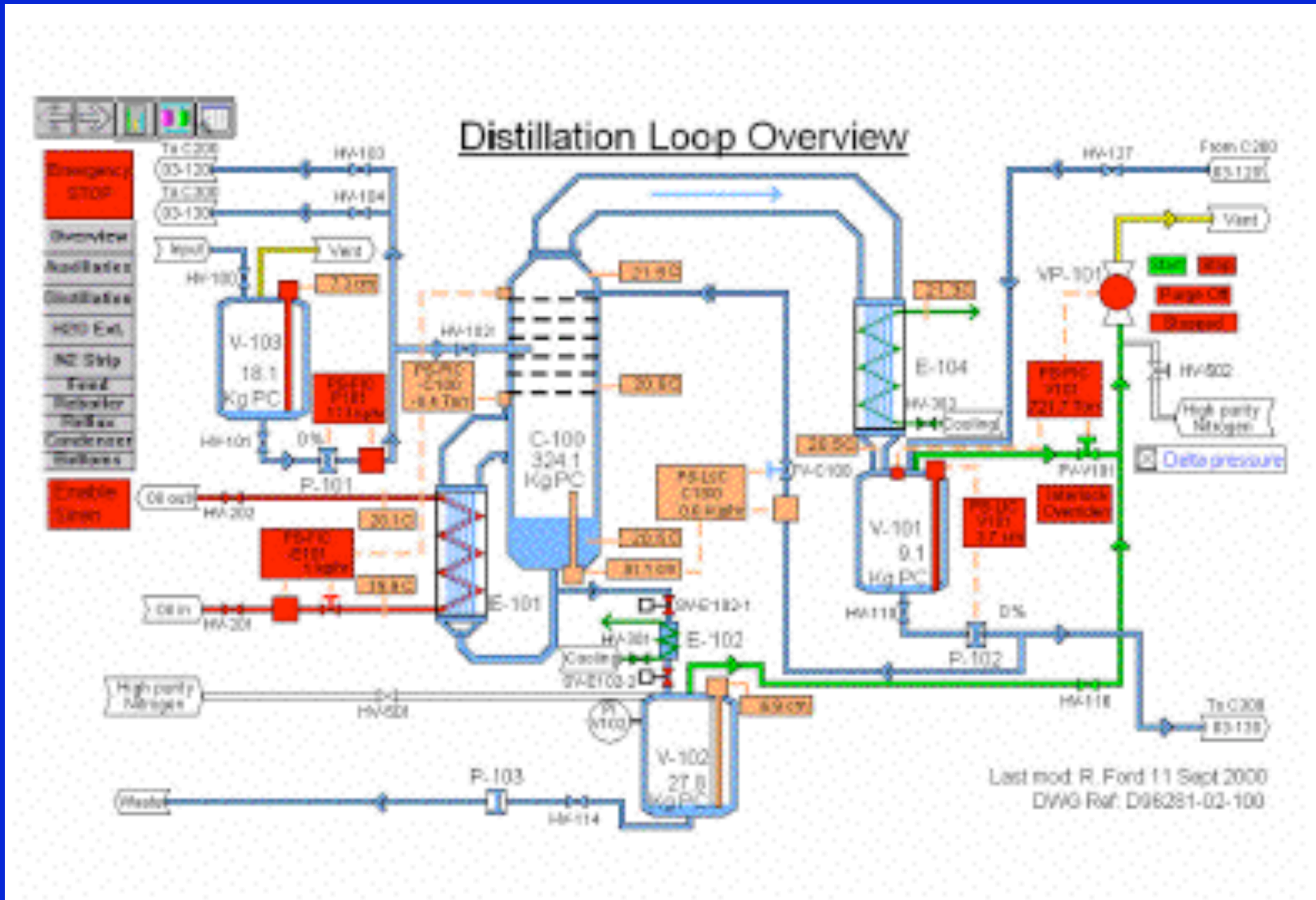
Purification Skid





Four-story portable plant

Multistage Distillation for removal of K, Th, U (^{210}Po)



THE GRAN SASSO NATIONAL LABORATORIES

INFN Istituto Nazionale di Fisica Nucleare

Laboratori Nazionali del Gran Sasso


External facilities
Administration
Public relationships support
Secretariats (visa, work permission
Outreach
Environmental issues
Prevention, safety, security
General, safety, electrical plants
Civil works
Chemistry
Cryogenics
Mechanical shop
Electronics
Computing and networks
Offices
Assembly halls
Lab & storage spaces
Library
Conference rooms
Canteen

The Underground Halls of the Gran Sasso Laboratory

- Halls in tunnel off A24 autostrada with horizontal drive-in access
- Under 1400 m rock shielding (~3800 mwe)
- Muon flux reduced by factor of $\sim 10^6$ to ~ 1 muon/m^2/hr
- BX in Hall C ~20mx20mx100m

To Rome ~ 100 km

Status of Laboratory

- Legal restrictions lifted
- Laboratory infrastructure upgraded
  - floors sealed
  - new water drainage system underway
  - new drinking water collection system underway
- Future laboratory upgrades (air handling, etc.) should not impact Borexino schedule


VIETATO FUMARE
NO SMOKING
MAN

Schedule

- BX schedule no longer impacted by laboratory upgrades
- CTF Test of Distillation: Fall ‘05
- Water filling of BX: Start Fall ‘05
- Scintillator filling: Start Spring ‘06
- Data taking: Start Fall ‘06
    - We’ll see…

Summary

- Excellent opportunities for scientific discovery
- Legal restrictions on BX and LNGS over
- Collaboration intact with ~ 50 FTE's
- Detector and associated plants completed.
- Commissioning and testing underway.
- Progress on lowering ^{85}Kr and ^{210}Po backgrounds.
- Test of purification and start of filling this year.

Borexino Collaboration

- Italy
  - Milan
  - Genoa
  - LNGS
  - Perugia
- Germany
  - Munich (TUM)
  - Heidelberg (MPI)
- U.S.
  - Princeton
  - Virginia Tech
- Canada
  - Queens
- Russia
  - Moscow Kurchatov
  - Dubna
- France
  - College de France
- Poland