(SNO) SNO+ Physics Plans, Overview, and Light Injection Calibration System

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Jornadas do LIP, Lisboa
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Outline

- Final Solar neutrino results from SNO
- SNO+ Detector developments
- SNO+ Physics goals
  - Neutrinoless double beta decay
  - Solar Neutrinos
  - Antineutrinos: from reactor and Earth's radioactivity
- Overview of LIP activities
- Light injection calibration system

The SNO 3-phase program

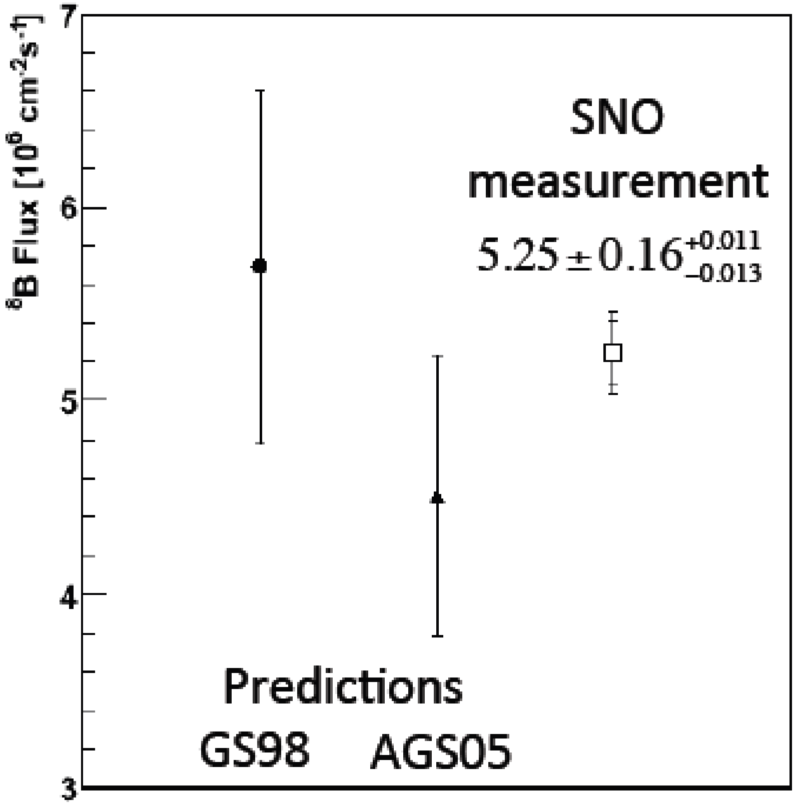
- Neutrons produced in NC reaction detected in 3 ways

Phase	I (D2O)	II (salt)	III (3He)
Period	Nov 99-May01	July 01 – Sep 03	Nov 04 – Nov 06
added	pure D_2O	salt	40 ^{3}He proportional counters
detection	n+^{2}H→ ^{3}H+6.25 MeV	n+^{35}Cl→ ^{36}Cl+8.6 MeV	n+^{3}He→ ^{3}H + p
main features	good CC	enhanced NC	event-by-event CC-NC separation
single-phase detailed paper	Phys. Rev. C75:045502 (2007)	Phys. Rev. C72:055502 (2005)	nucl-ex/1107.2901 subm. to Phys. Rev. C
combined analysis	Phys. Rev. C81:055504 (2010)		
	nucl-ex/1109.0763 subm. to Phys. Rev. C		

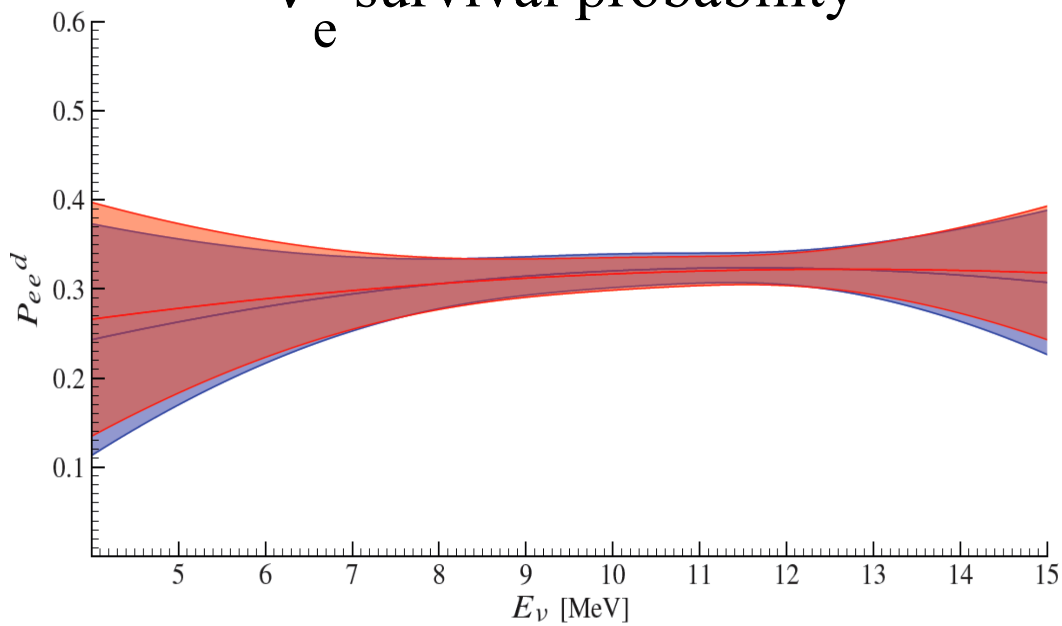
PhD thesis of Nuno Barros, defense next week!

3-phase combined results

Total flux of Boron8 neutrinos



ν_e survival probability

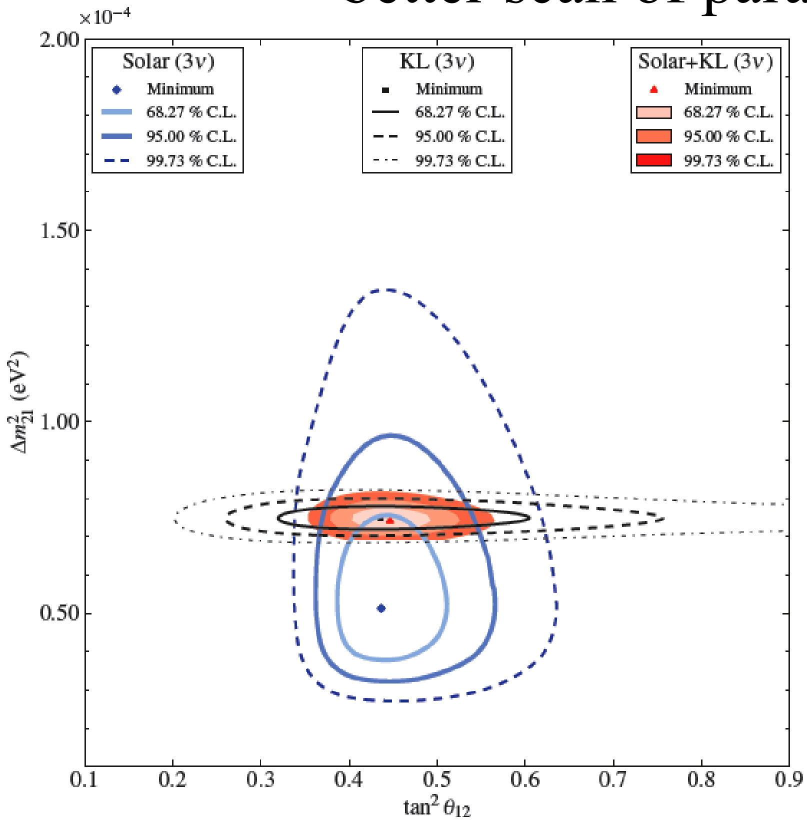


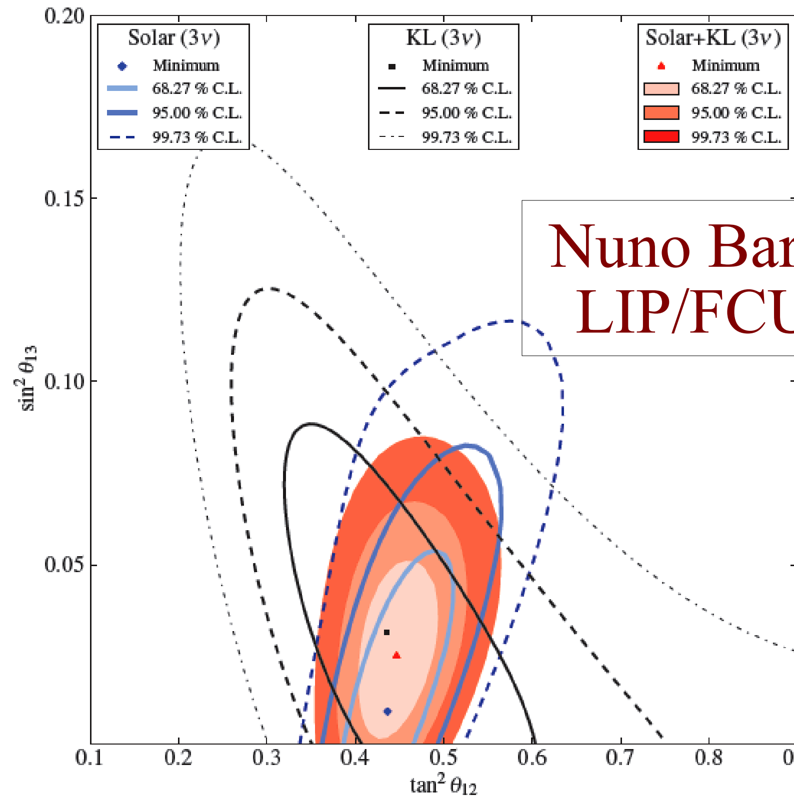
3.9% total uncertainty !

20% improvement over previous SNO results

Oscillation parameters

- <u>Improvements in oscillation analysis. Main one:</u>
analytic approximation in LMA calculation allowed better scan of parameter space





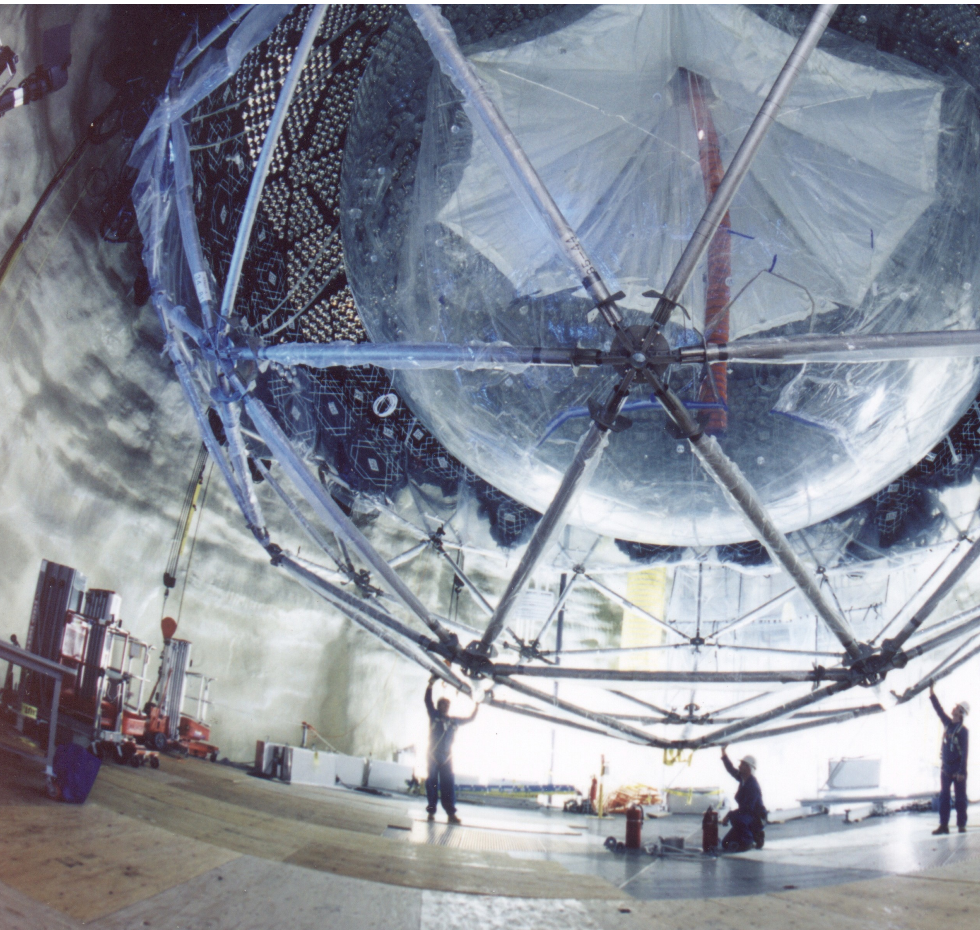
Nuno Barros
LIP/FCUL

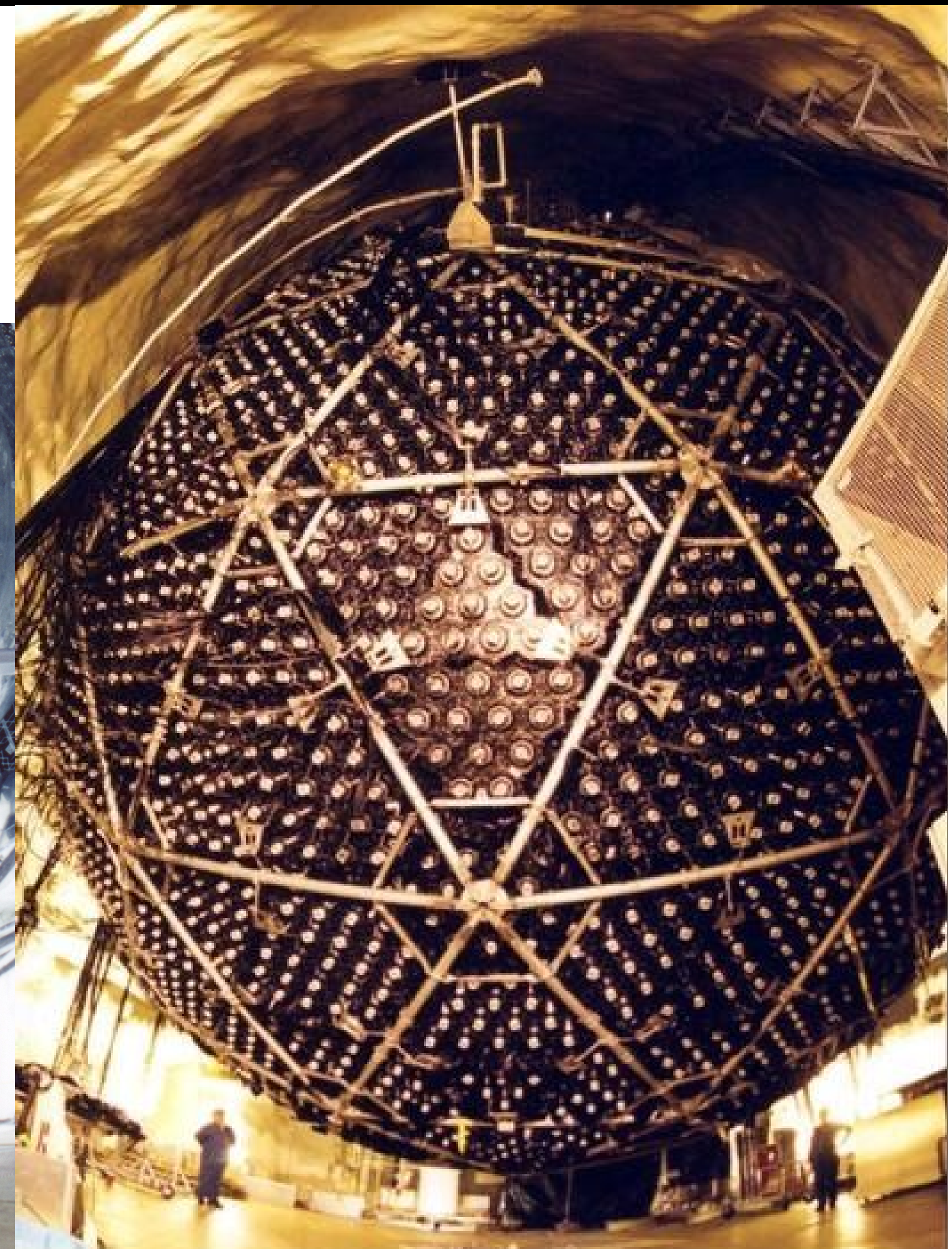
$$\tan^2\theta_{12} = 0.446^{+0.030}_{-0.029} \qquad \Delta m^2_{21} = \left(7.41^{+0.21}_{-0.19}\right)\times 10^{-5}\,\mathrm{eV}^2 \qquad \sin^2\theta_{13} = 0.0251^{+0.0176}_{-0.0146}$$

$$< 0.0534\ (95\%\mathrm{C.L.})$$

Sudbury Neutrino Observatory

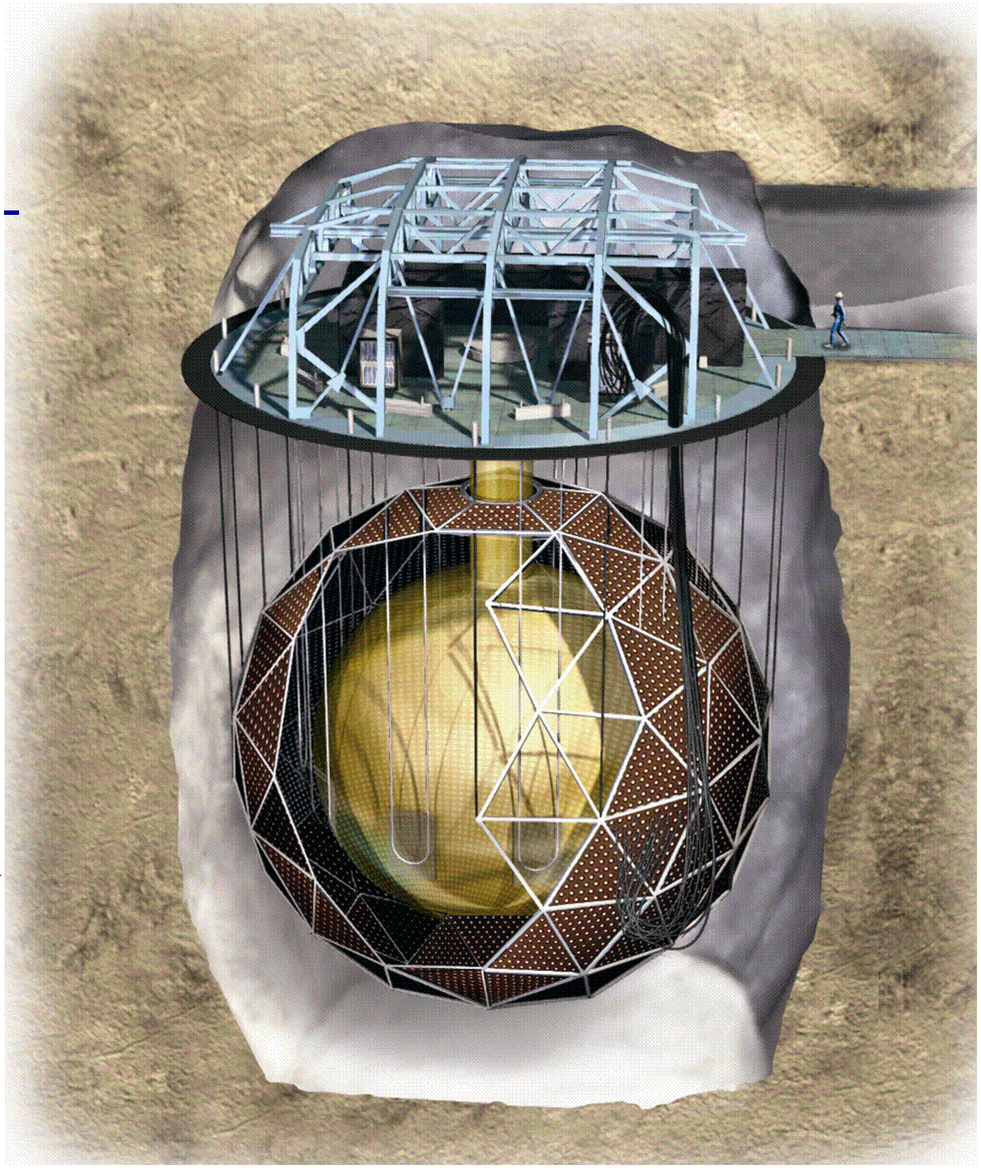
- SNO
  - Deepest large underground detector
  - What advantages in re-using it with scintillator after the heavy water?





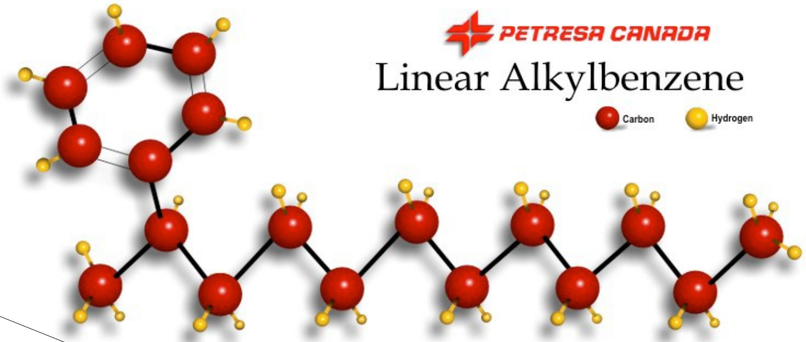
SNO+

- 1000 t of D_2O replaced by liquid scintillator
  - Neodymium-loaded at 0.1%-0.3%
  - 138 kg of Nd-150
- 9000 PMTs
  - 3.5 % resolution at Nd endpoint (3.37 MeV)
- Water shield
  - 1700 + 5300 tons UPW
- New rope system to hold down the 6 m radius acrylic vessel

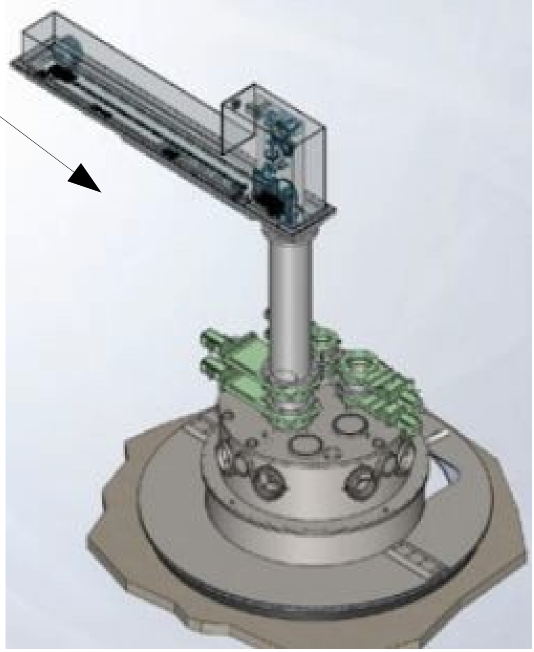


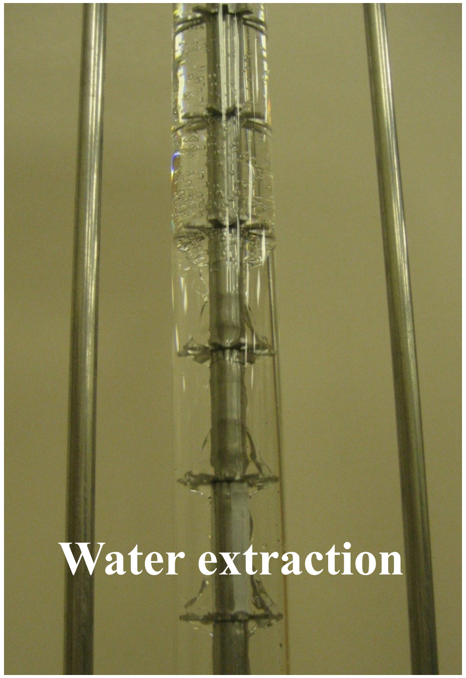
Many developments needed

- New scintillator
- Purification plants
- Hold buoyancy of Acrylic Vessel
- Acrylic vessel sanding
- Re-design calibration systems
- PMT repairs
- Upgrade of electronics and trigger



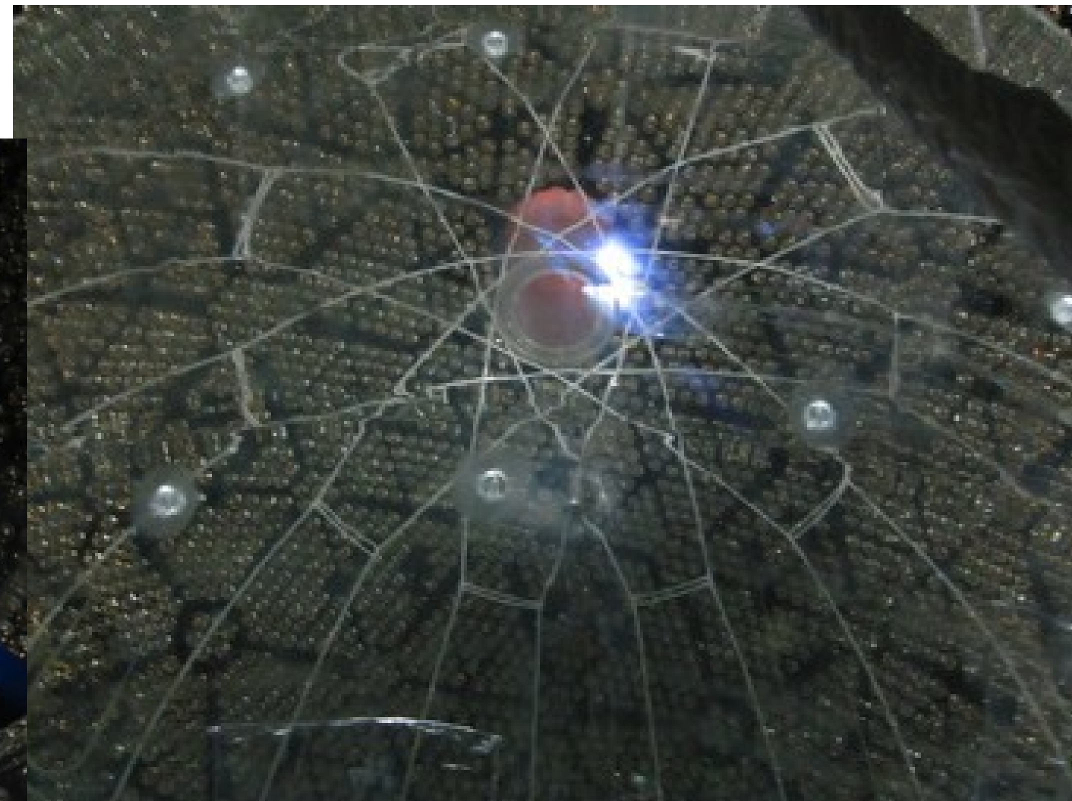
Test plants at SNOLAB

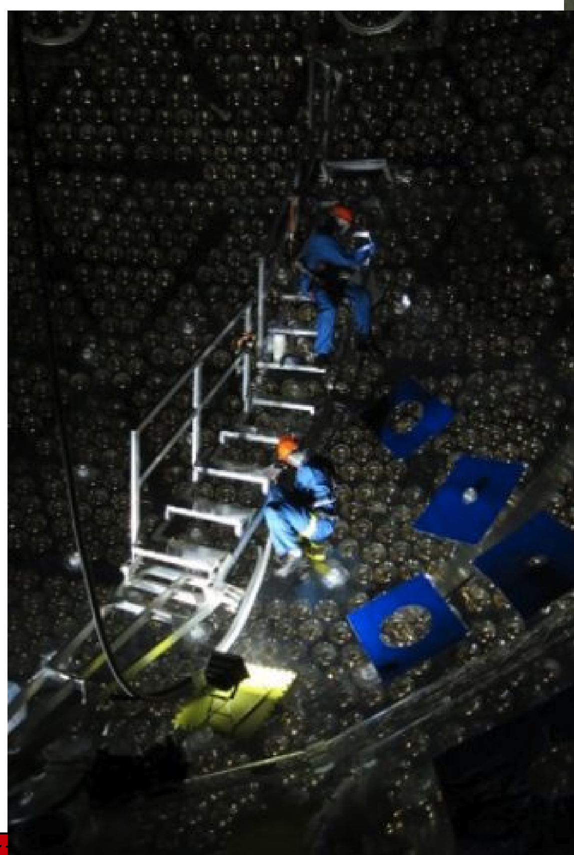




Work on Acrylic Vessel

- Scintillator lighter than water
  - need to hold AV down
  - rope installation January 2012

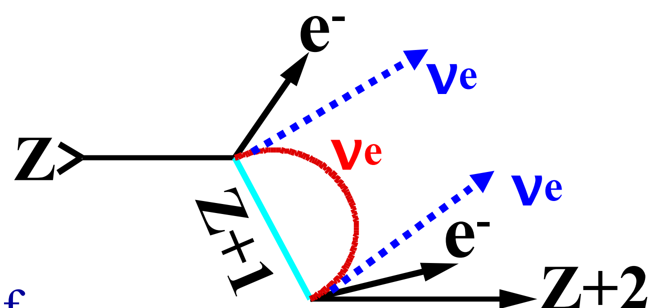




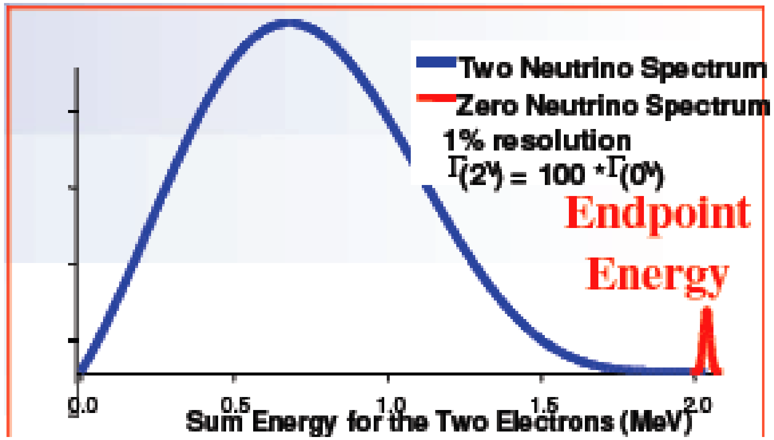
- Next step: sanding inner surface

Neutrinoless double beta decay

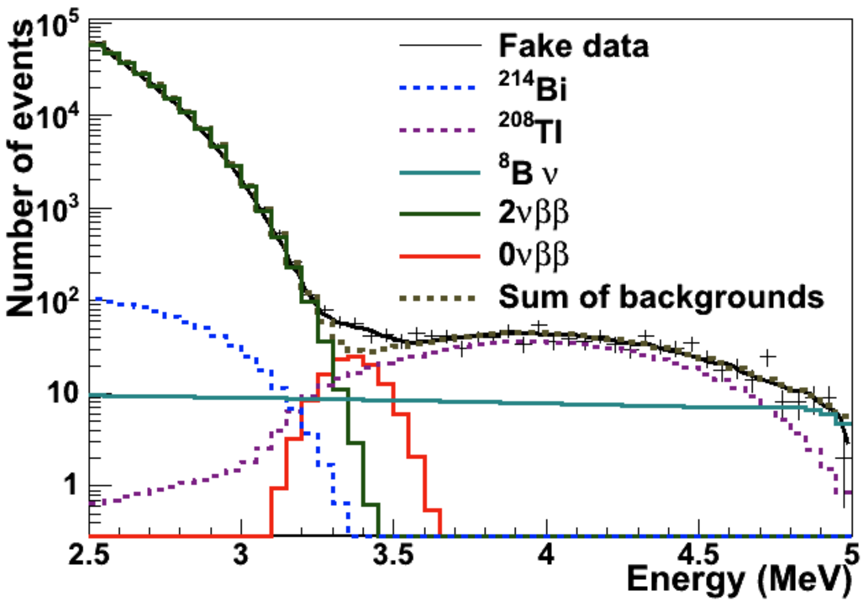
- A fundamental process
  - Are neutrinos their own anti-particles?
    - lepton number violation and Majorana character of neutrinos
  - Rate depends on effective mass, a function of the absolute masses and mixing matrix



- Impressive challenge
  - High uncertainties in nuclear matrix elements, crucial for comparison of ≠ experiments
  - Extremely rare process: need tens of kg of rare isotopes
- Why liquid scintillators ?
  - Downside is the low energy resolution
  - Advantage is the liquid scintillators allow larges masses and low background
  - Choose high Q-value isotope



SNO+ plus Neodymium



^{150}**Nd:**

- ***Largest phase space of all 0νββ isotopes***
- ***High 3.3 MeV end-point***
- ***5.6% abundance***
- ***Relatively cheap***
- ***Demonstrated to be in solution in LAB for over 3 years at high concentrations***

Backgrounds: Phil Jones' parallel talk

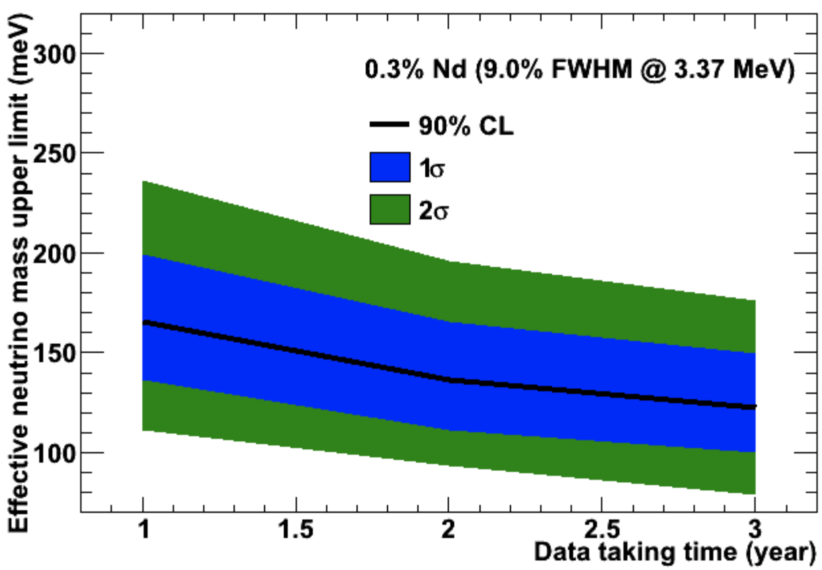
Effective neutrino mass: 320 meV

^{150}Nd mass: 44 kg (0.1% Nd conc)

400 hits/MeV (~ 6.5% @ 3.3 MeV)

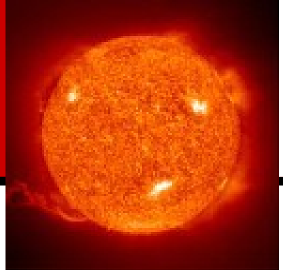
3 years of data with 80% livetime

Fiducial cut: R =0.8x R_0
(50% of the mass)



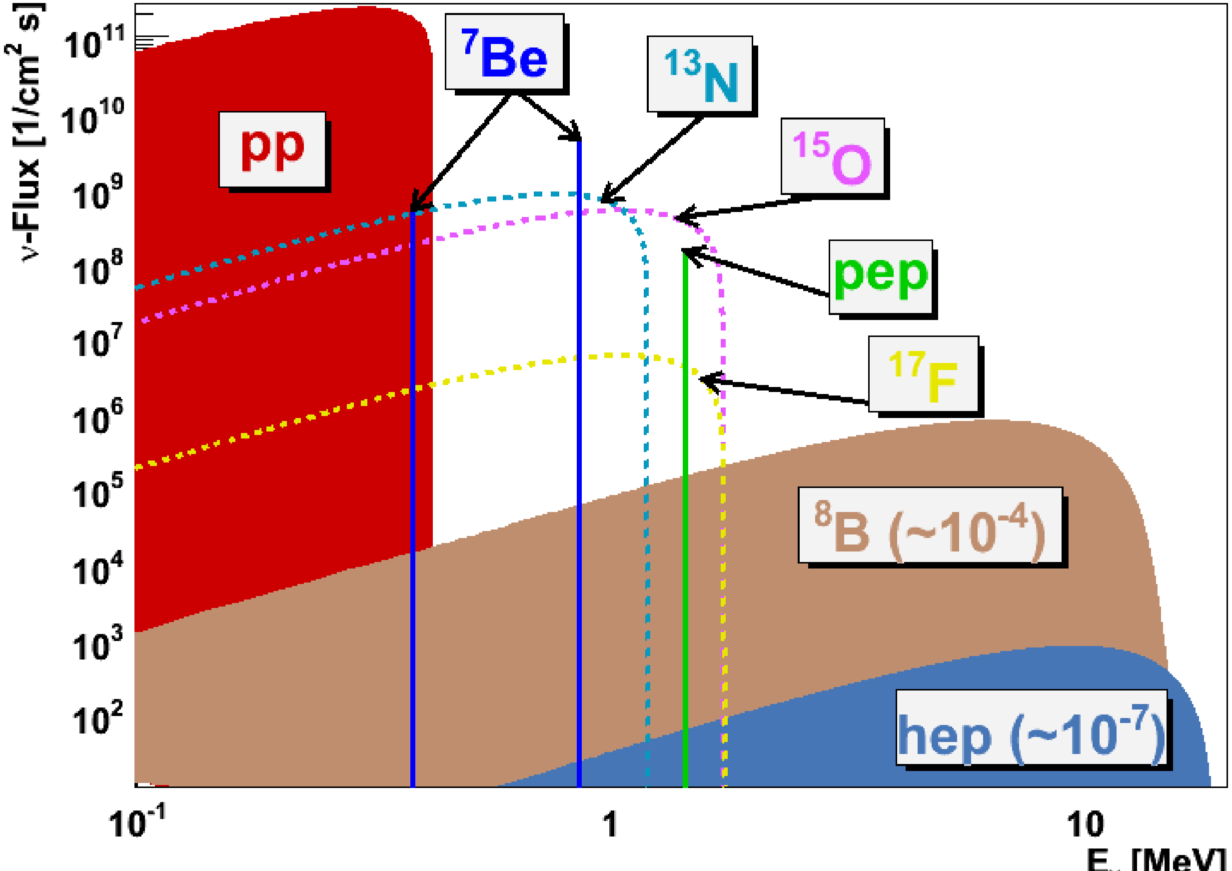
Other isotopes should be possible !

Solar Neutrinos



pp
- highest flux, well predicted
- measurement in real-time ?

Beryllium-7
- measured by Borexino
- high-precision day-night assimetry ?

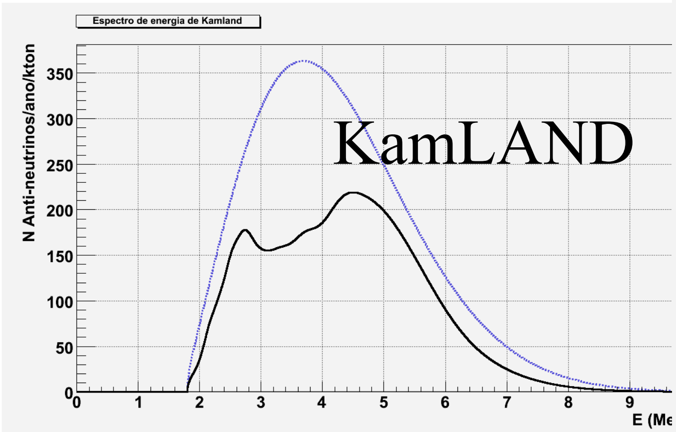


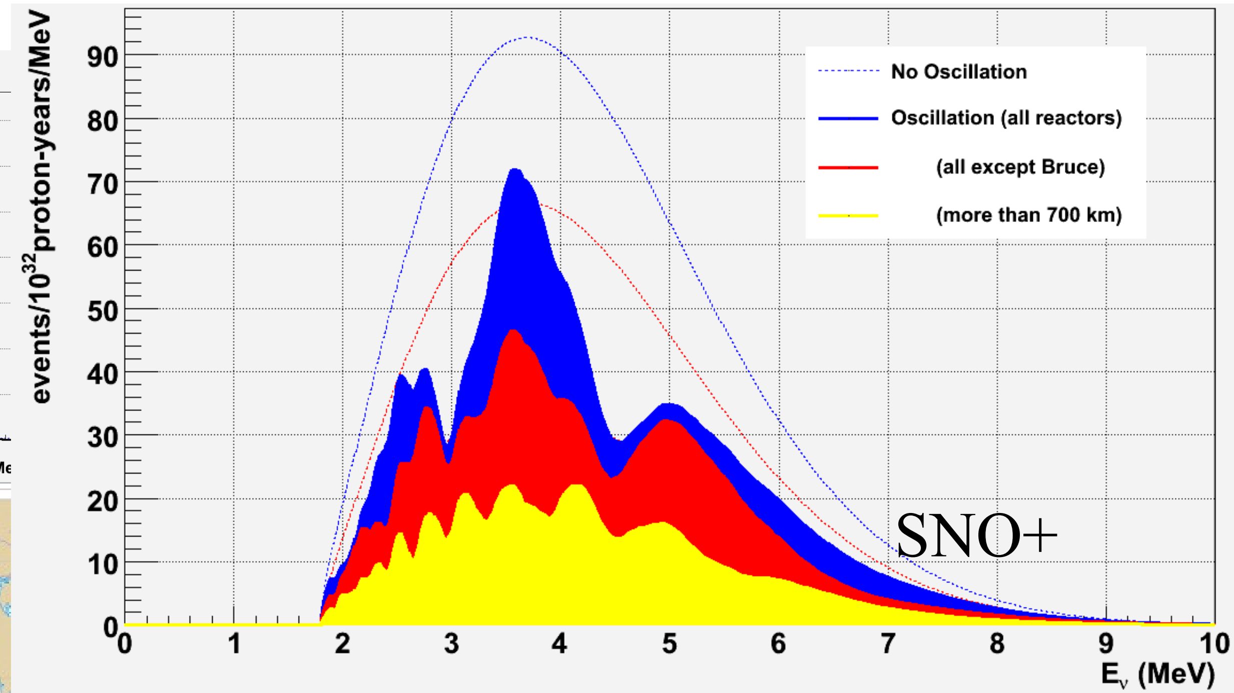
pep
- monoenergetic, well-predicted
- precision measurement of survival probability
- sensitivity to new Physics

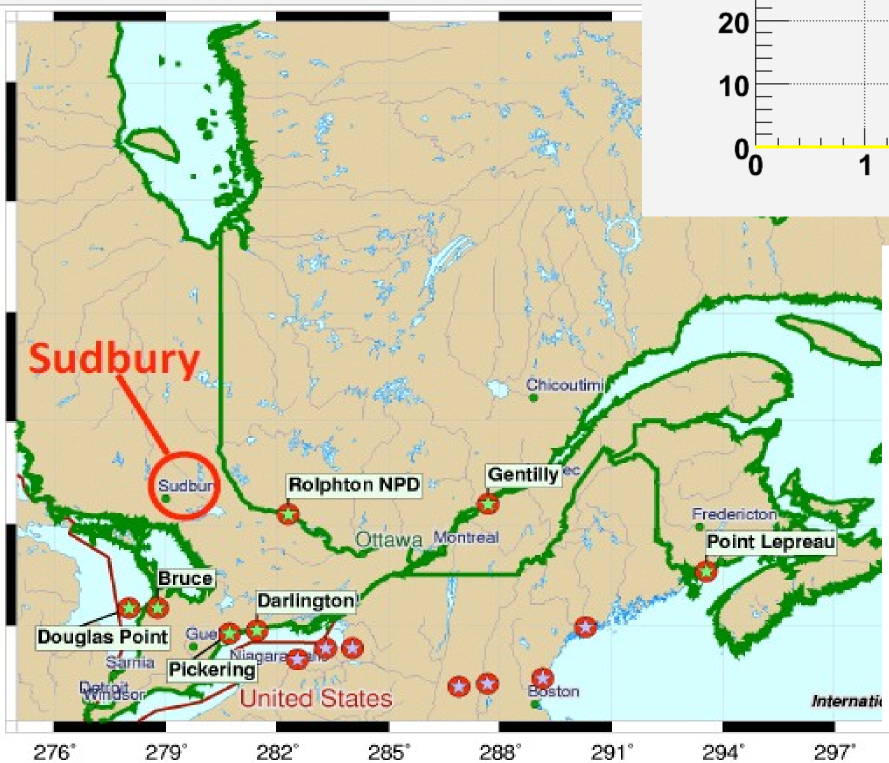
CNO
- from a different set of reactions
- constrain Solar Physics

Boron-8
- > 3.5 MeV, well measured at SNO, SK
- and below ?

Reactor Neutrino Physics







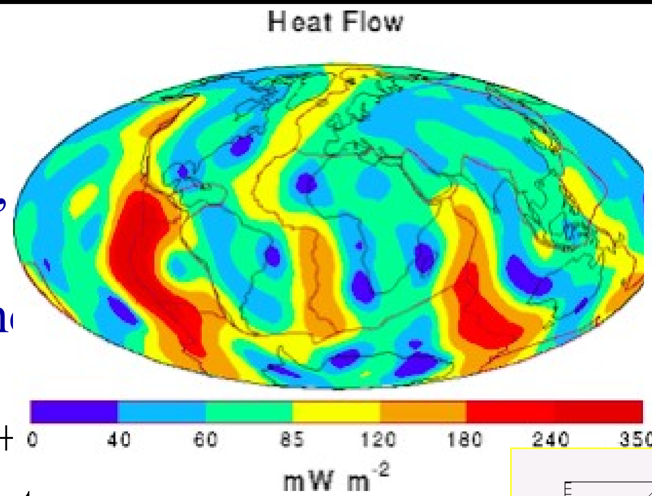
- Smaller number of reactors than at Kamioka
- Flux 5x smaller, but...
- More distinctive spectrum
- Sensitivity to 2nd, 3rd, 4th oscillation minima

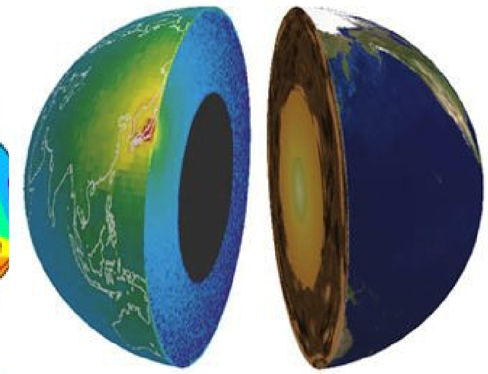
Geo-neutrinos

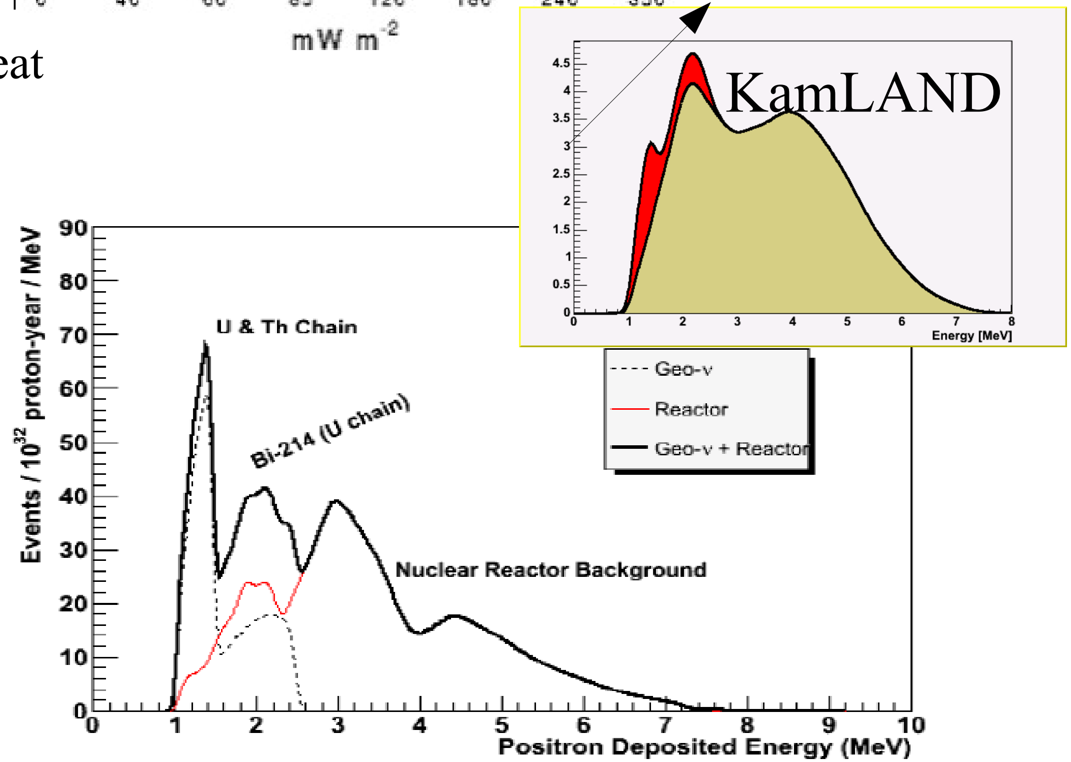
- **Production**
  - Anti-neutrinos from U-238, Th-232 and K-40 on Earth
  - Contributions from crust an mantle depend on location
    - 20% from mantle at SNO+
    - Check models of Earth heat production

$$\overline{\nu}_e + p \rightarrow e^+ + n$$

- **Detection**
  - Around 20 events per year (efficiencies included)
  - Smaller background from reactors than KamLAND







The LIP team

- Lisbon
  - Sofia Andringa
  - Nuno Barros (now at Dresden)
  - Luís Gurriana
  - Amélia Maio
  - José Maneira
  - Luís Seabra
- Coimbra
  - Rui Alves
  - João Carvalho
  - Nuno Dias
  - Joaquim Oliveira
  - Américo Pereira

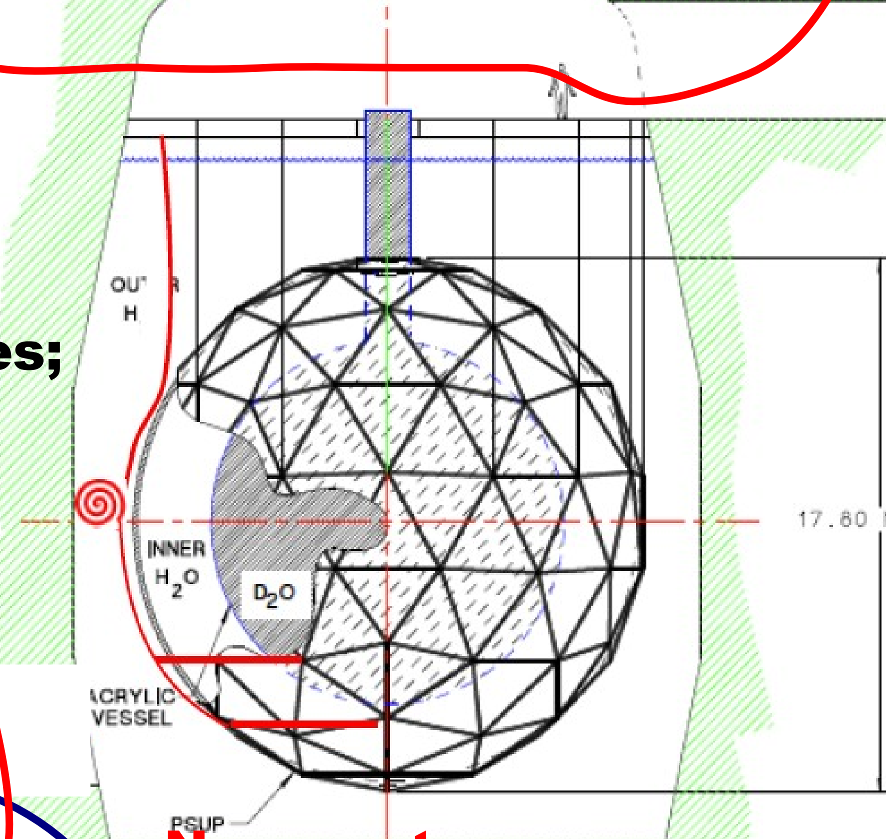
LIP activities / responsibilities

- Detector
  - Light injection calibration system for SNO+ PMTs
    - Design, test, production, installation of fiber part (LEDs by Sussex)
  - Optical calibration. Measurement of media attenuations and PMT angular response with laserball.
    - Responsibility for the Optics working group
- Physics sensitivity studies
  - Solar neutrinos
  - External backgrounds (for solar and double beta decay)
  - Antineutrino Physics
    - reactor neutrino oscillations and geo-neutrinos
    - Responsibility for this working group
- General
  - Chair of SNO+ Collaboration Board
  - Member of Analysis Coordination Committee

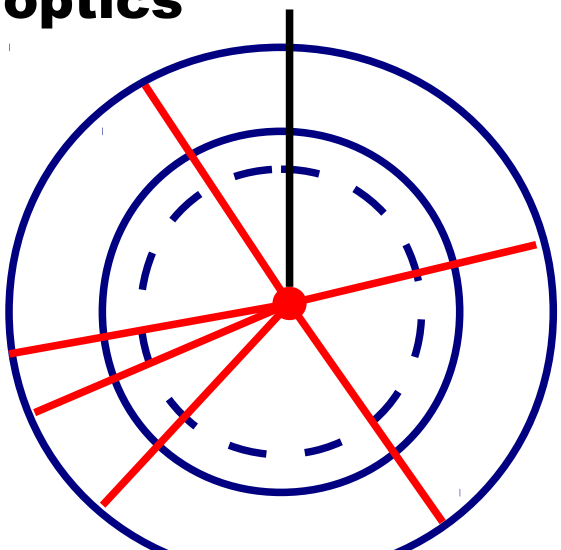
Calibrations in SNO/SNO+

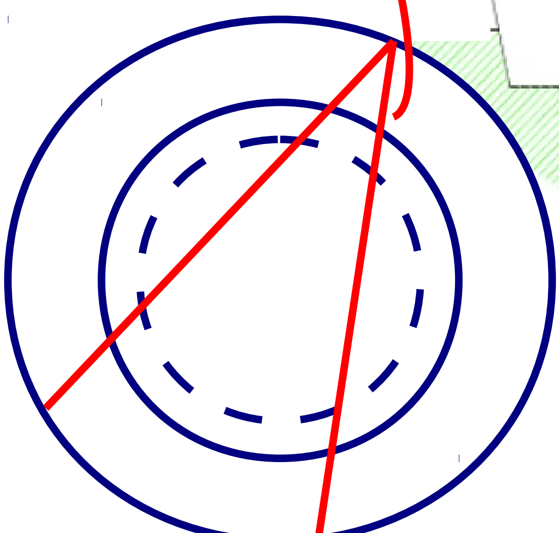
Position reconstructed from time of flight to 9450 PMTs;

Energy reconstruction from position and optical properties;



SNO used a "Laser Ball" to calibrate PMTs (monthly) and monitor heavy and "light" water optics





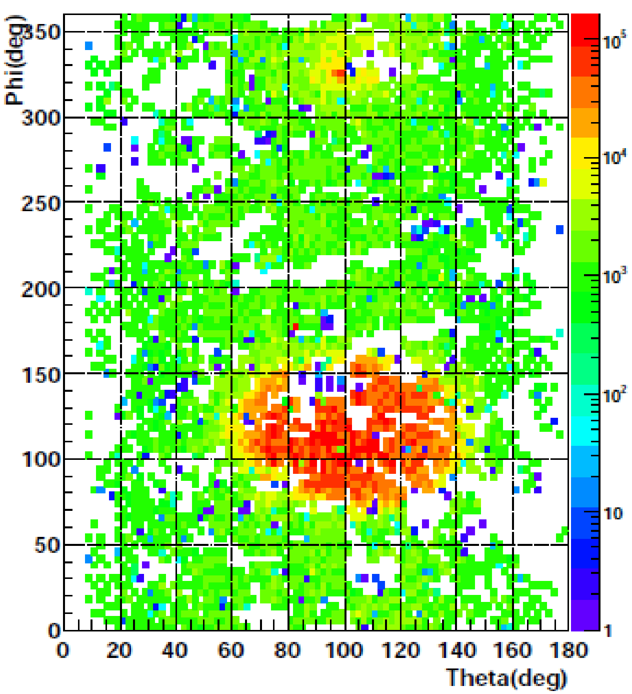
New system:
Light injected from outside

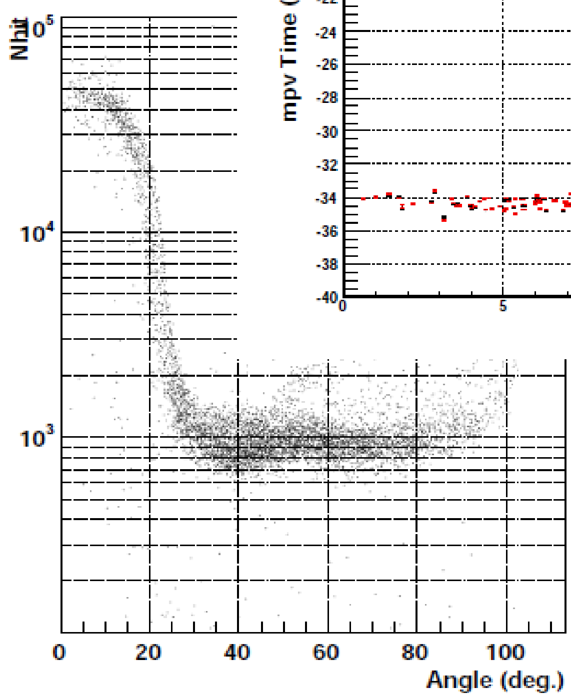
- **can be used more often!**
- **Wide beams to reach all PMT from only 92 locations**
- **Narrow beams for optics**

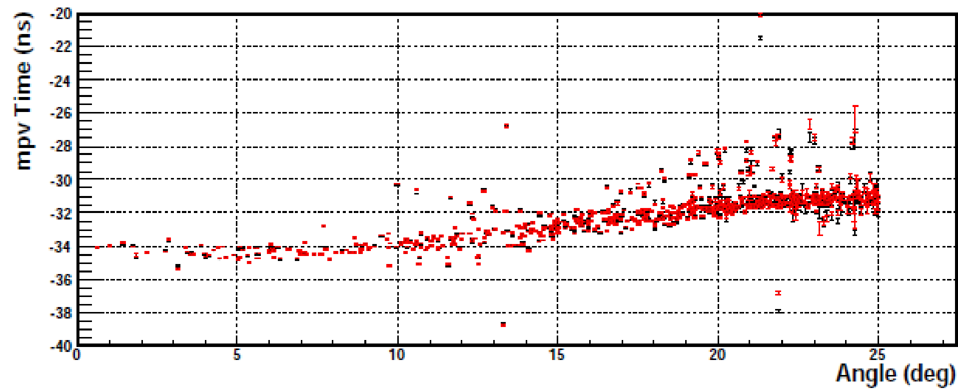
Optical Fibers for SNO+

European hardware contributions to SNO+ (Portugal + UK groups)
Designs profited from previous experience (JM in Borexino) and selection and testing from experience of the ATLAS/CFNUL lab!
--> cheap and robust (double) 1mm diam. PMMA optical fibers for PMT calibrations and synchronization (quartz fibers for optical calibration)

Feasibility in 2008 water-run



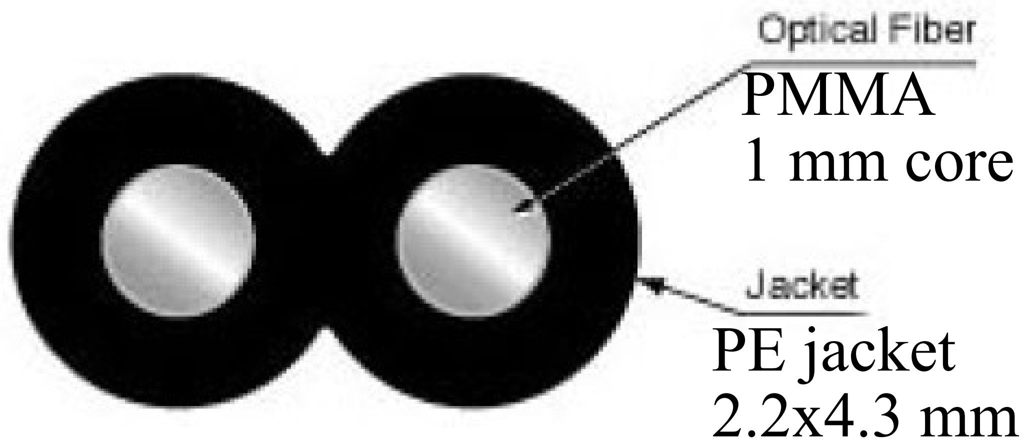




Reached < 1ns precision
~20 deg aperture

TELLIE Material

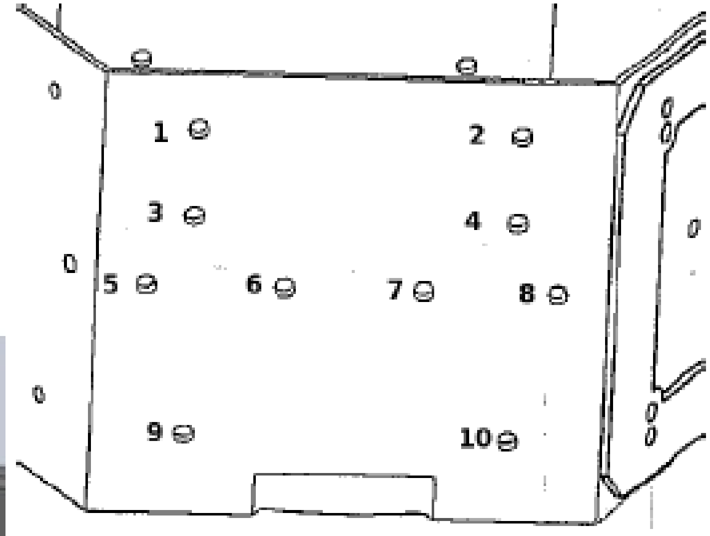
- Fibres
  - 110 double fibres (92 + spare)
  - 45 m length
- Wet-end connector
  - duplex latching
- Dry-end connector
  - ST

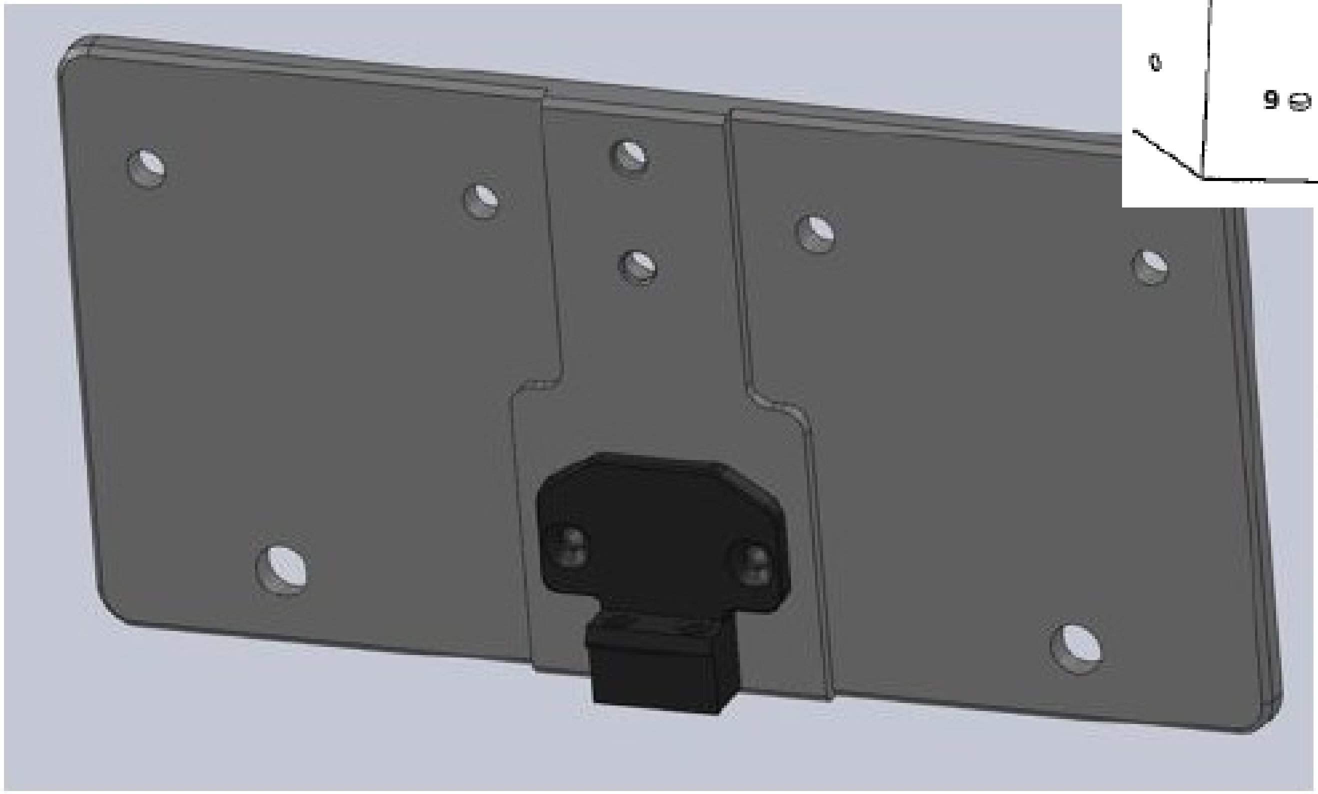


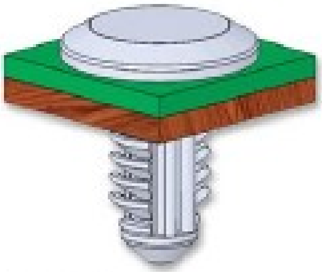
The ends were covered with the Teflon tape

Mount plates

attaching to hex cells







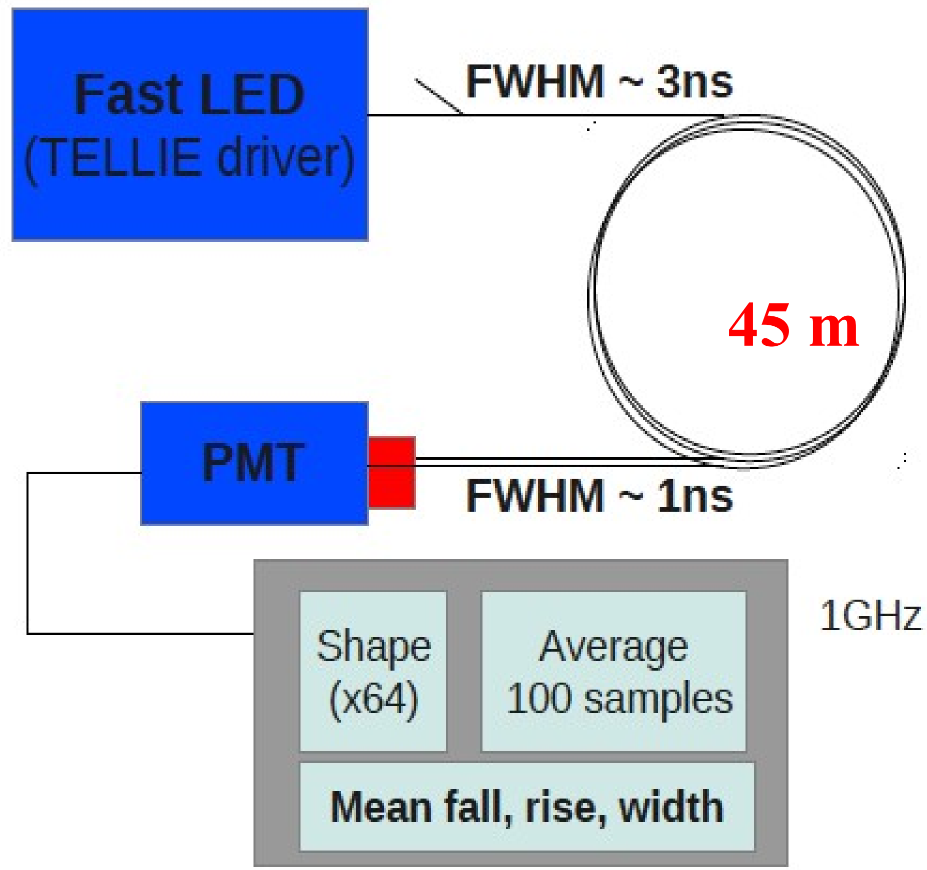
Tests of all materials

- Water compatibility tests
  - done at Brookhaven
    - samples in water for several months
  - Long fiber, no connectors
  - Short fiber with both connectors
    - (dry-connector covered)
  - Plastic rivets
  - Mounting plate
    - black POM (delrin)
    - white POM and PETG
- Radioactivity tests
  - Gamma assay done in UG Germanium counter, at SNOLAB
  - Tested U238, U235, Th232, K40
    - PMMA fibers much better than quartz
    - Radioactivity budget about 1.5 PMTs (but we have 9500 PMTs...)

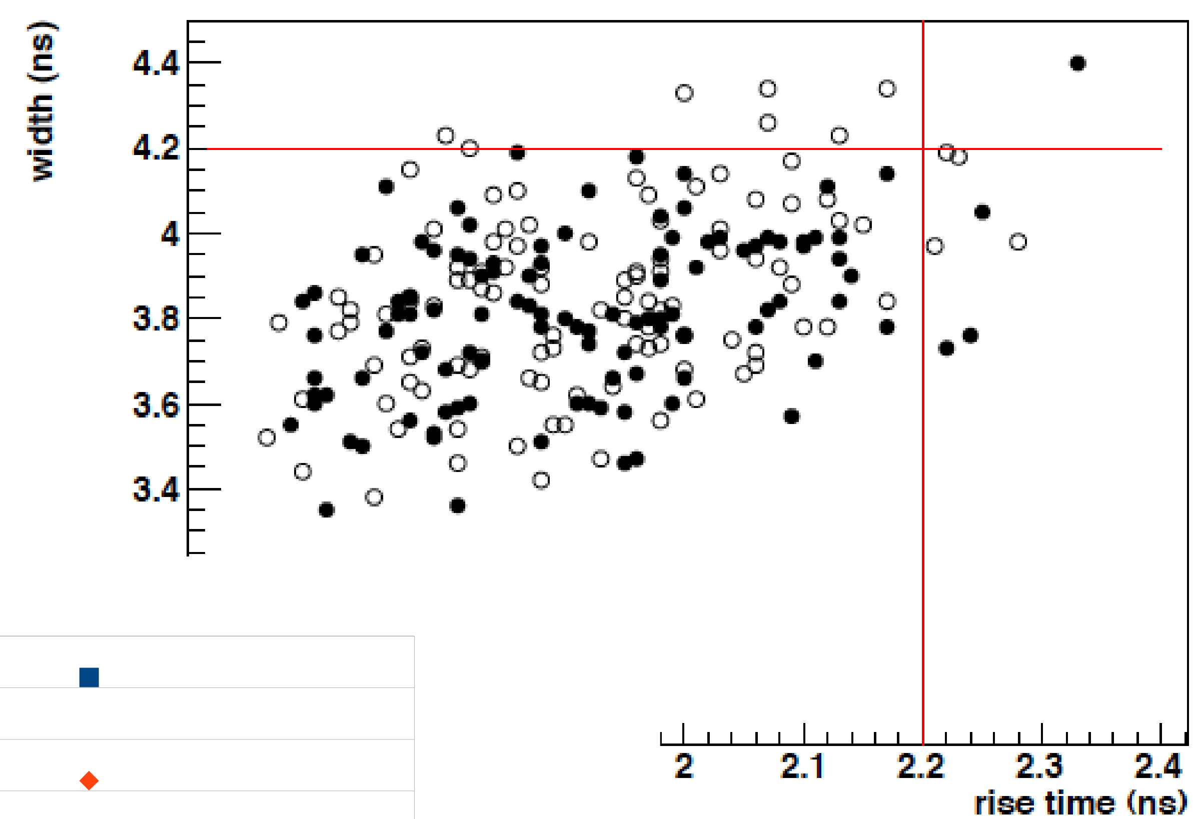
Quality Control, Lx, Dec.2011

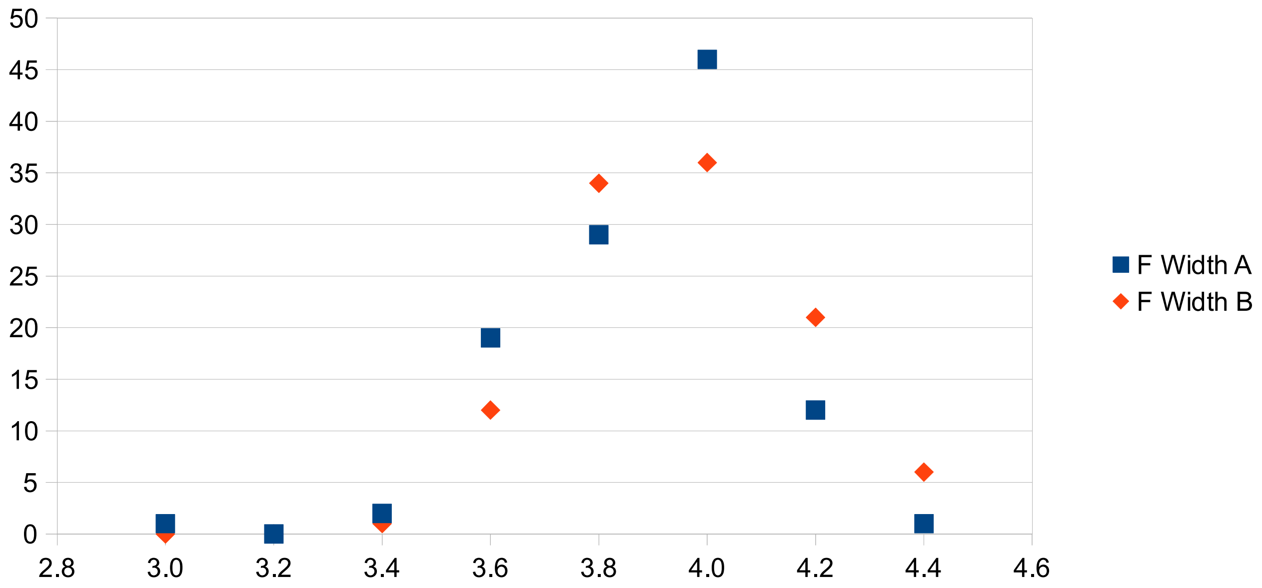
Tested 2x110 fibers for timing, transmittance and angular opening

1 – timing characteristics checked with pulsed LED and fast scope
(similar to the final driver in SNO+, by the Sussex Univ. group)




Tek Run
Trig'd
a 99.98µs 148.4µV
b 99.99µs 7.937mV
Δ9.614ns Δ7.789mV
1 50.0mVΩ
Value Mean Min Max Std Dev
1 Rise Time 3.879ns 3.808n 3.663n 3.914n 47.23p
1 Fall Time 2.323ns 2.328n 2.138n 2.591n 81.42p
1 −Width 3.607ns 3.690n 3.499n 3.898n 67.36p
4.00ns
T→▼99.9904µs
5.00GS/s
1000 points
1 ∖−1.00mV
Save Screen Image
Save Waveform
Save Setup
Recall Waveform
Recall Setup
Assign Save to Image
File Utilities
8 Dec 2011
21:17:02

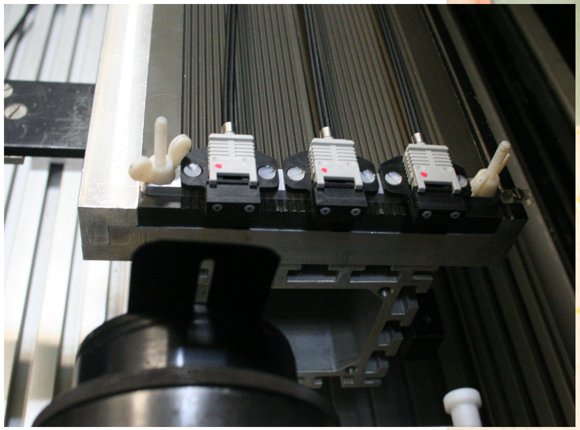


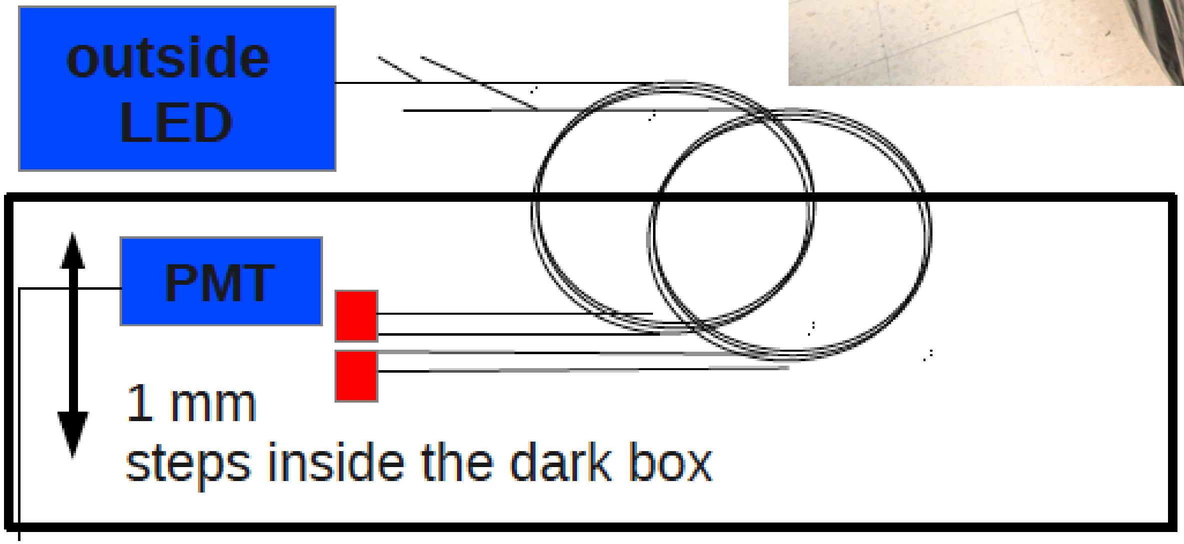


Time width (ns)

Angular measurements

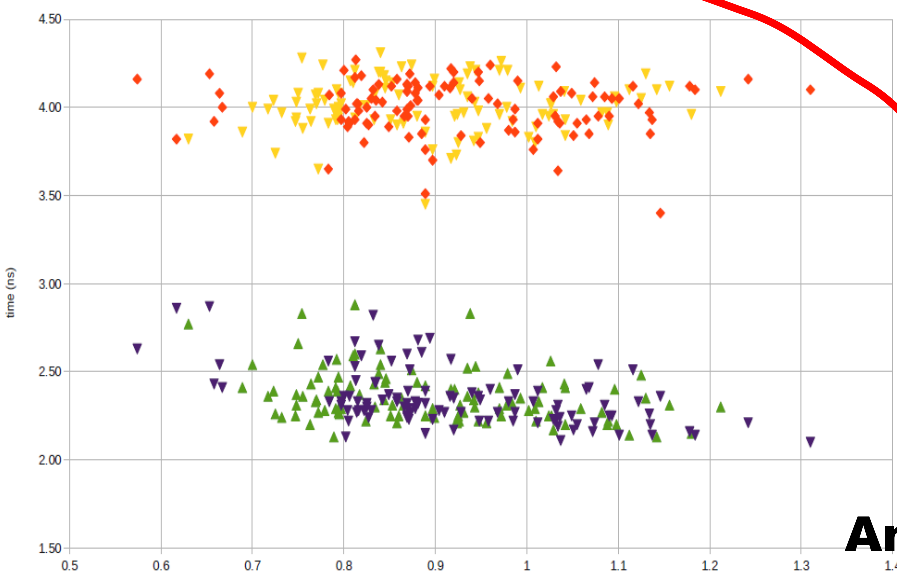
setup for 3 cable measurements

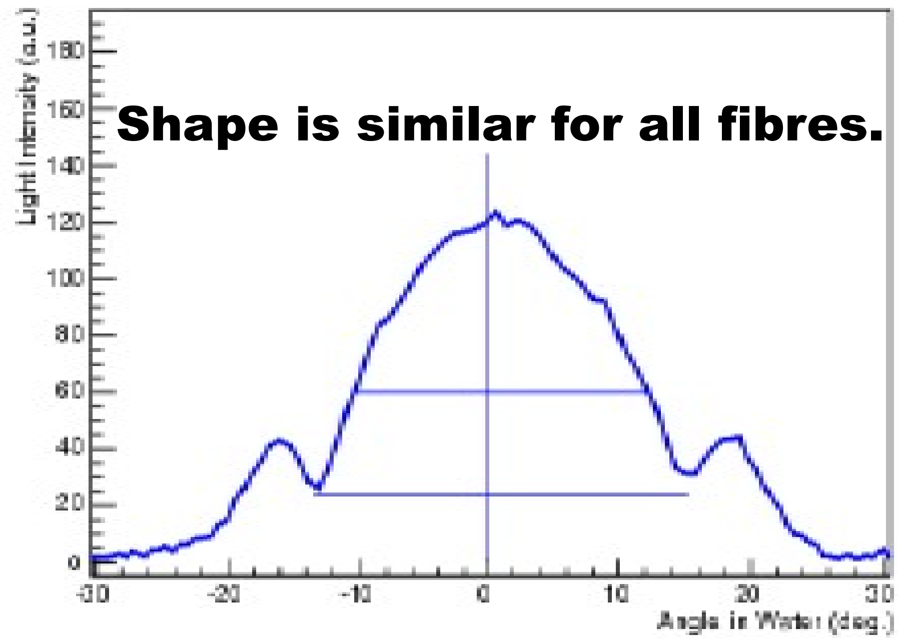




Quality Control, Lx, Dec.2011

Tested 2x110 fibers for timing, transmittance and angular opening
Very stable results, almost all fibers within requirements



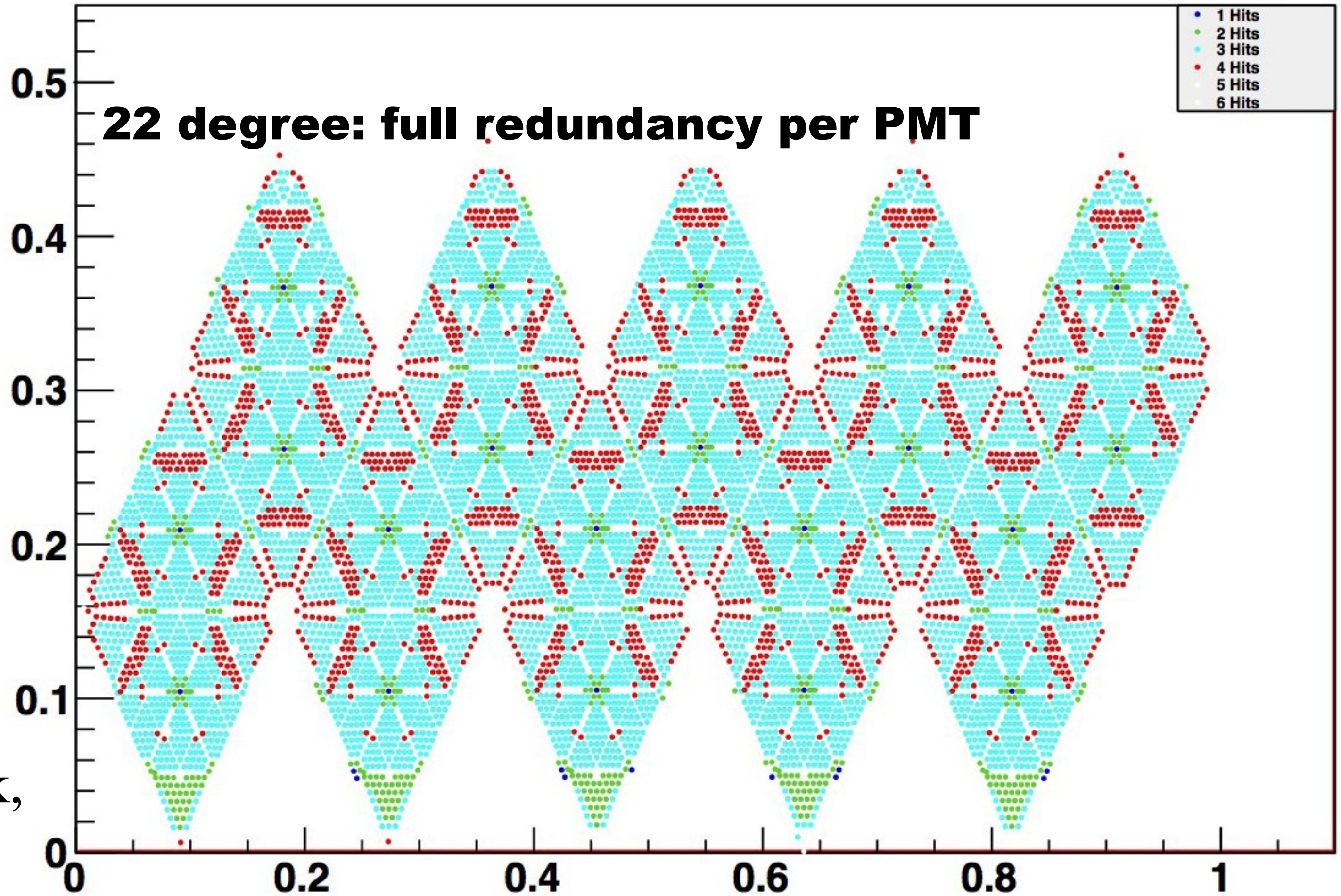


15 % spread in transmission;
(reproducible measurement at installation phase)
<10% dispersion in time width

Angles converted to angles in water:
HWHM = 11 deg.; HW20% = 14.5 deg.
(up to 20 deg. with side-lobes)
< 1deg. variation per fiber

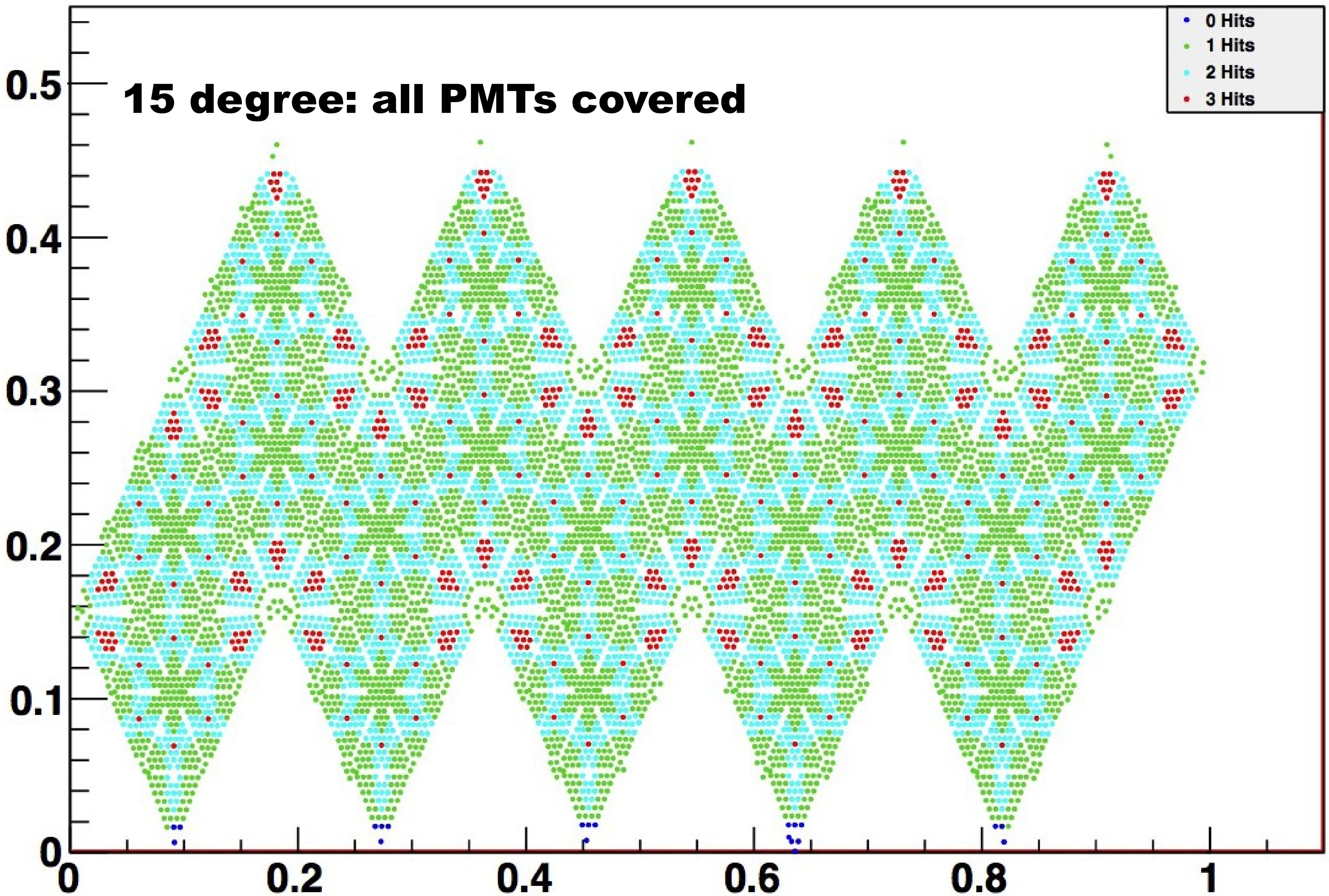
Simulations of PMT coverage

Simulations with all known scintillator properties agree with previous studies.
The initial 91 points give enough redundant coverage with only central cone.
Spares in extra positions might be useful to cover lower part of detector.

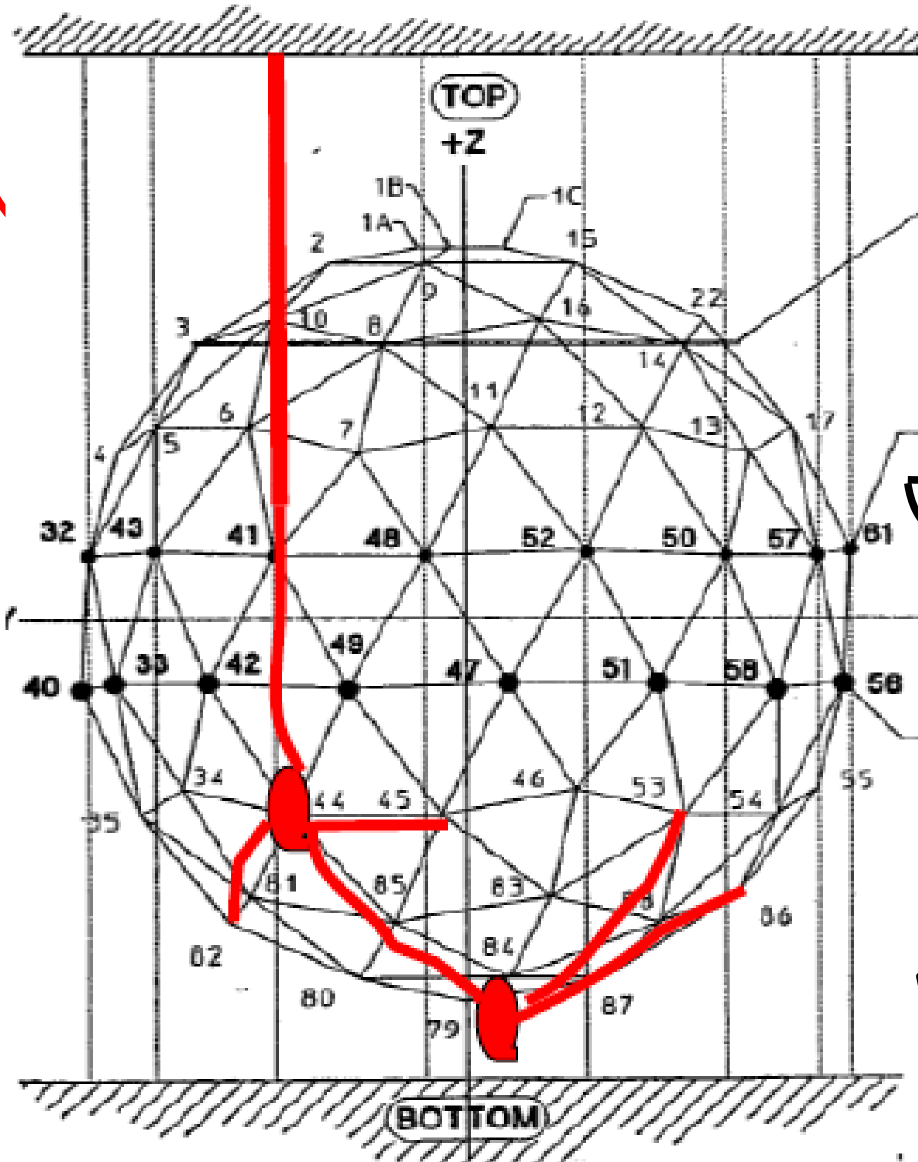


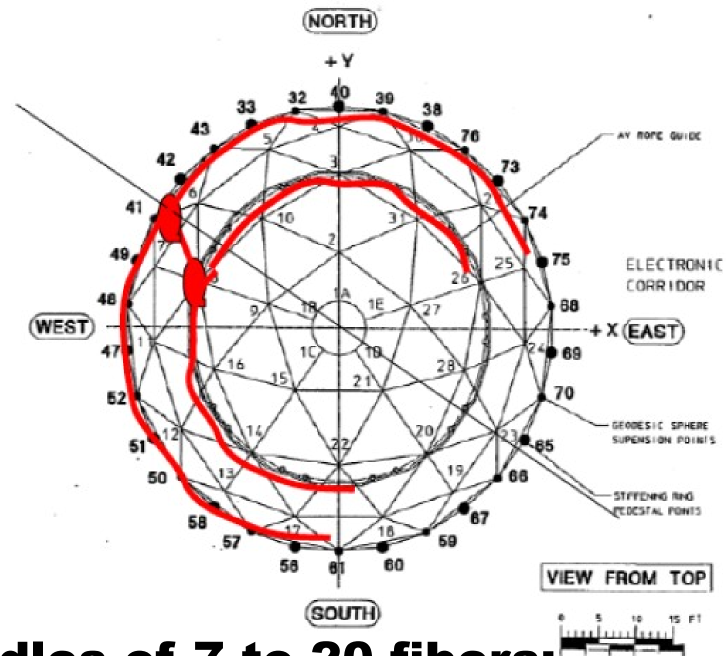
Ken Clark, Oxford

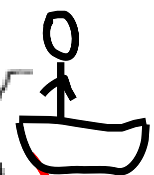
Simulations of PMT coverage

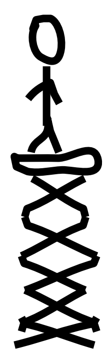


Installation Plans







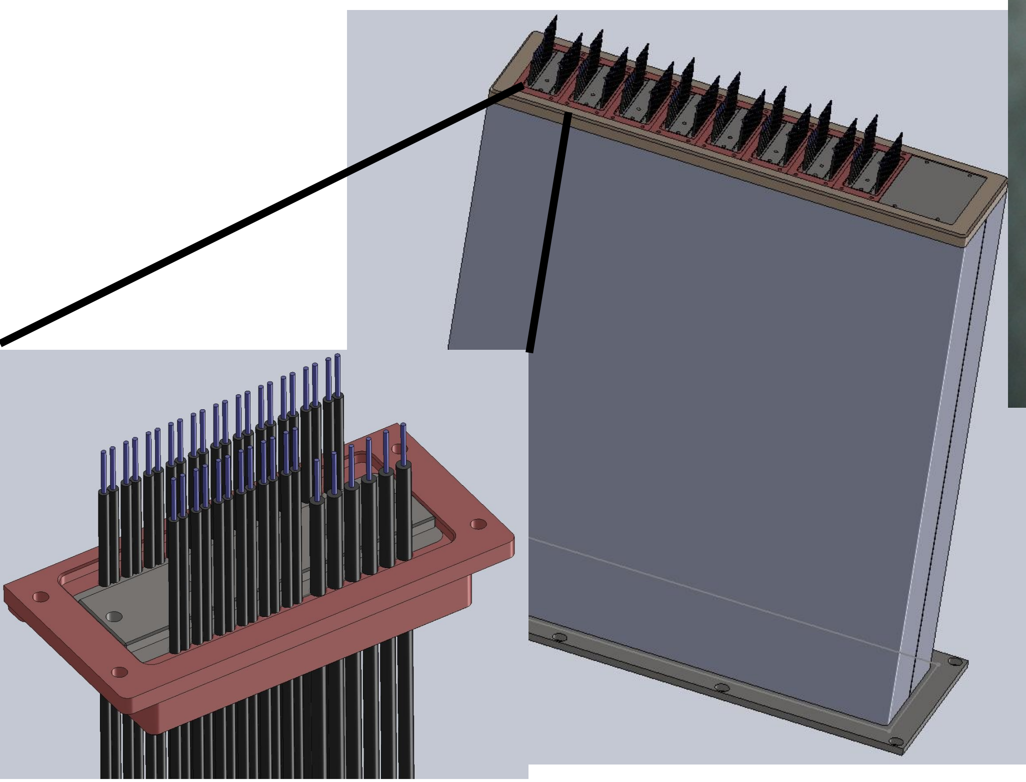


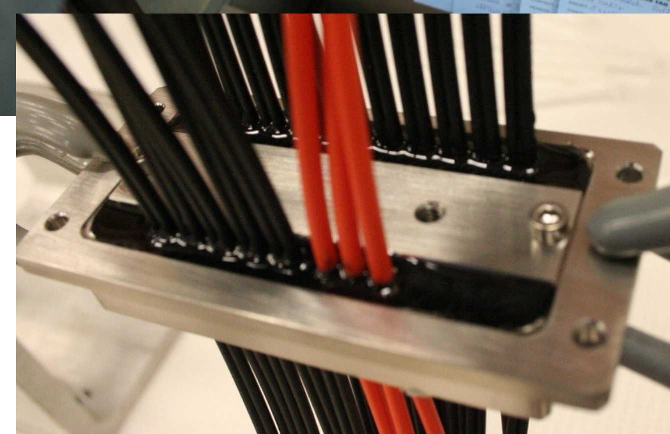
8 bundles of 7 to 20 fibers:

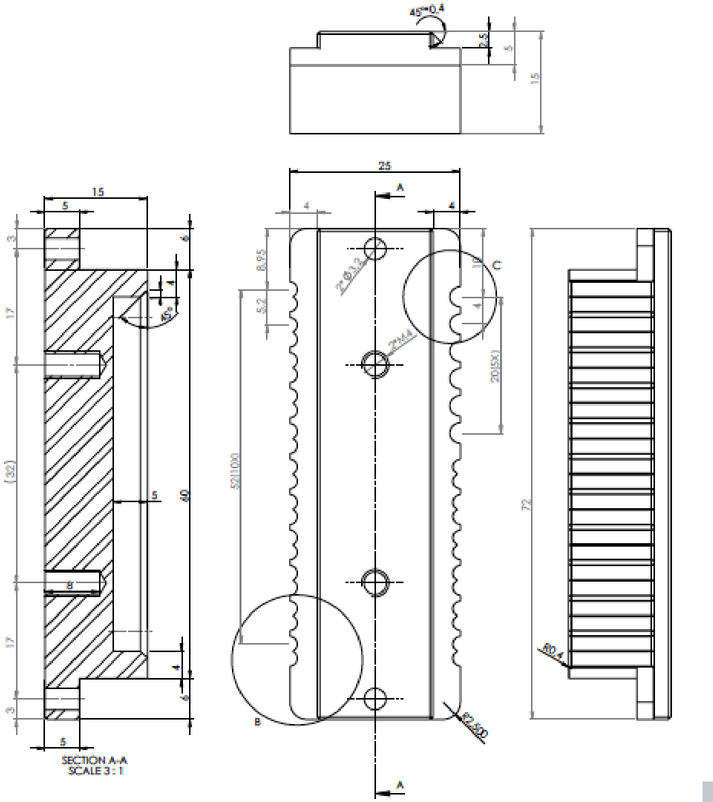
- **2 installed from bottom;**
- **5 circling by boat**
- **1 last with special path**
- **1 spare bundle always ready!**

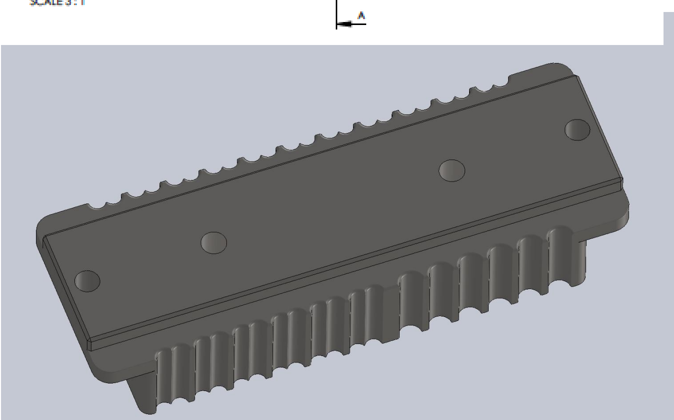
The flange-box

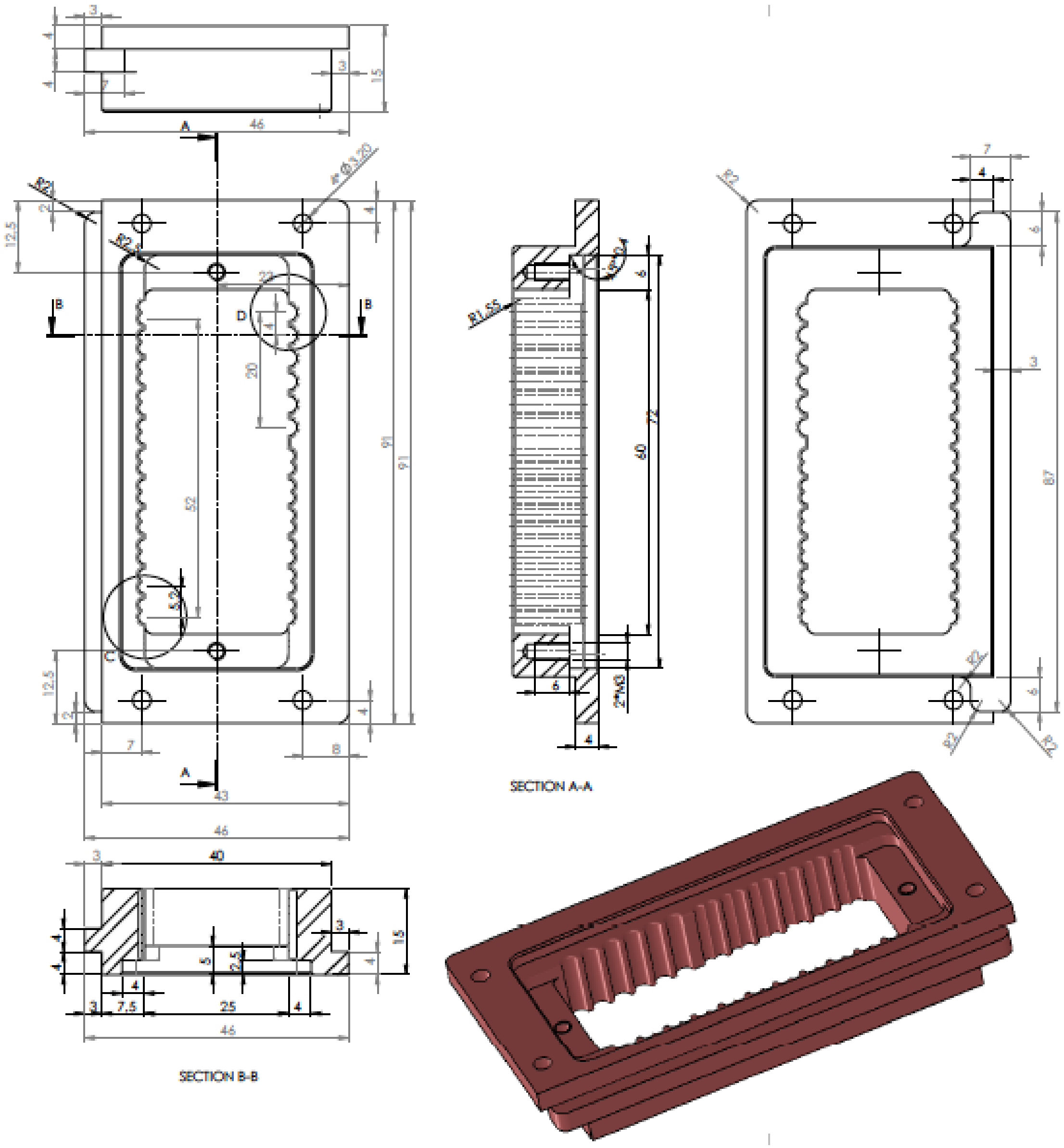
- Feed-through from electronics deck to detector cavity
  - Box instead of flange to allow work at deck surface level
  - Designed and built at LIP-Coimbra






SECTION A-A
SCALE 3 : 1

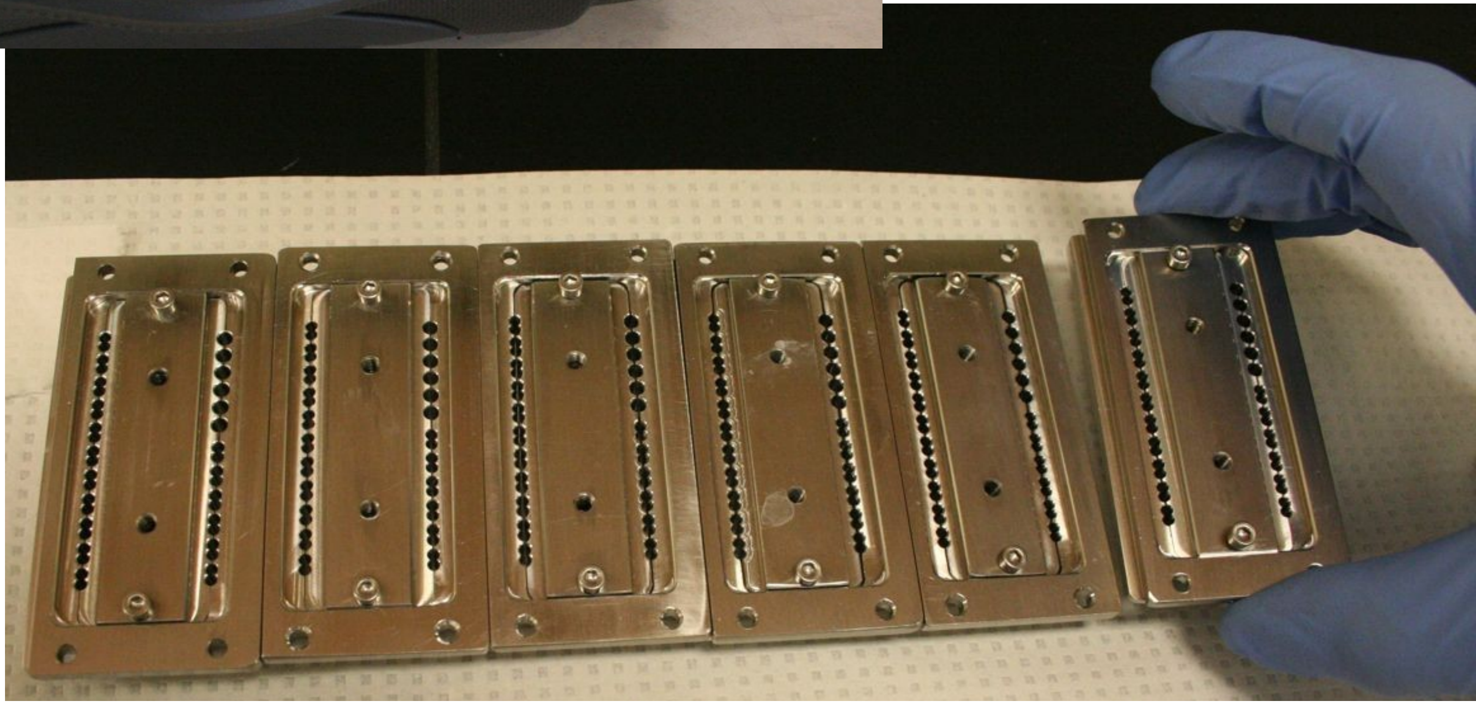



SECTION A-A
SECTION B-B

The flange-box

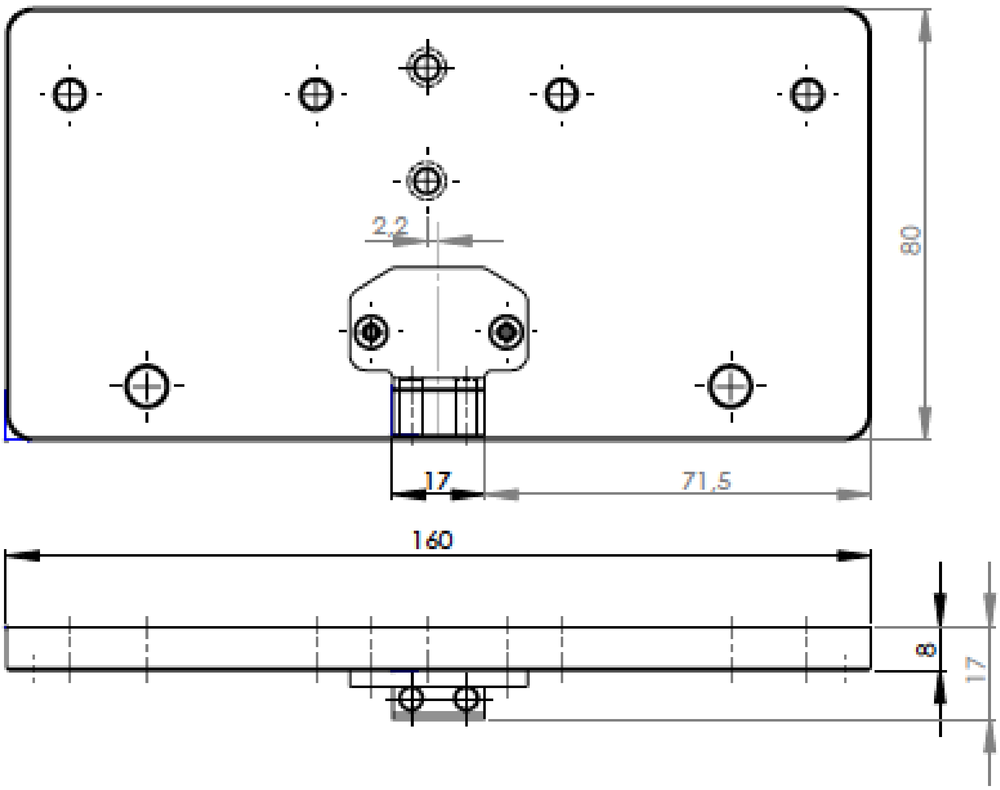
Special shipment...

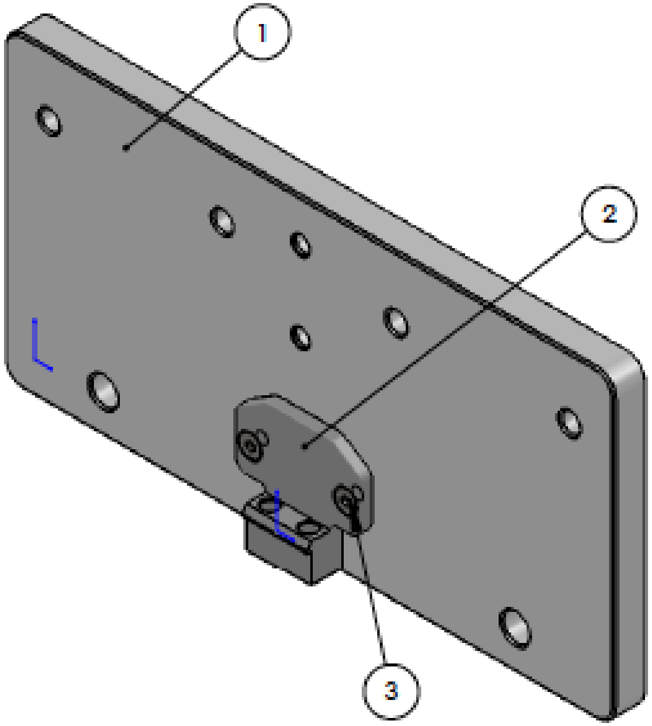
Feed-through detail



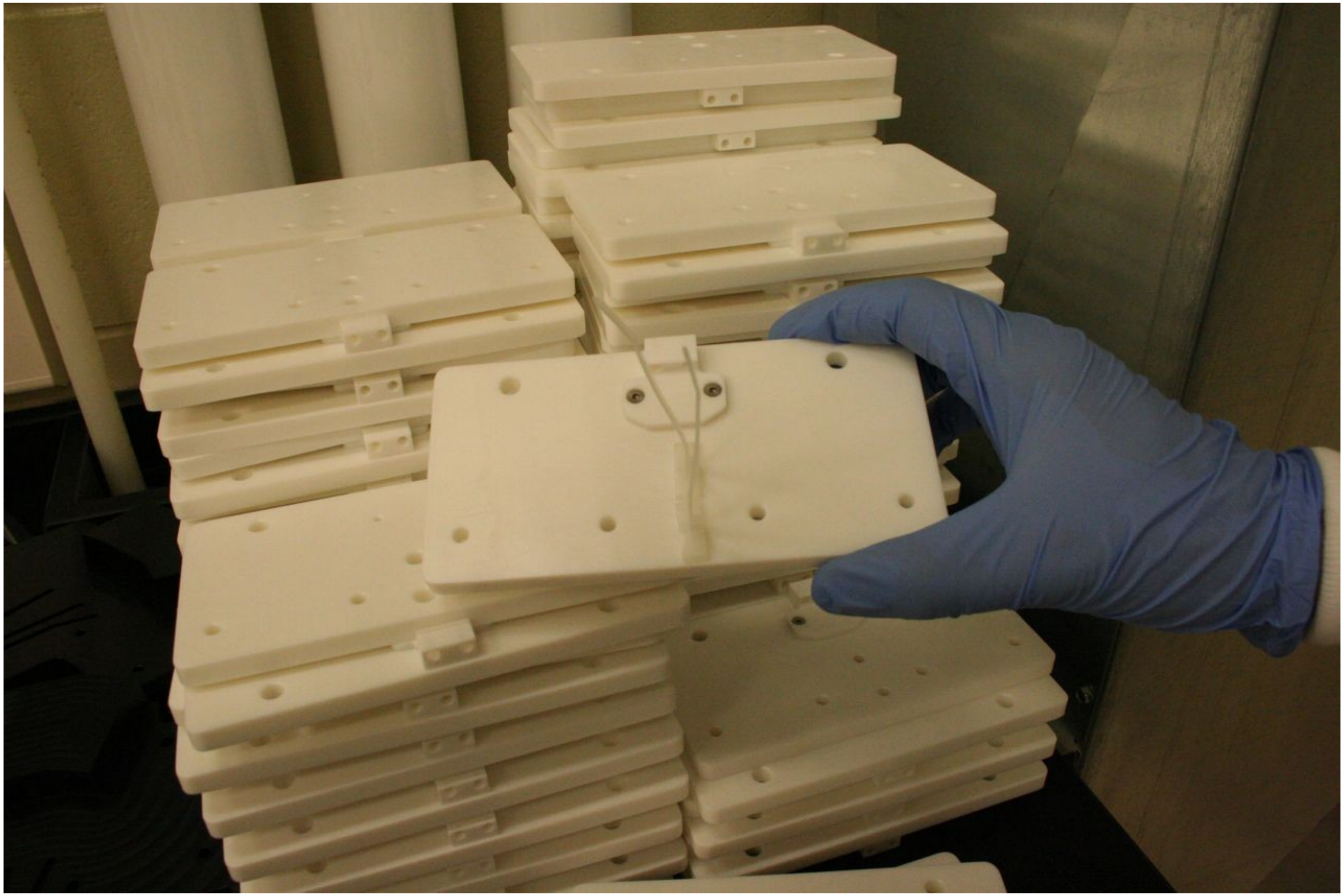
all stainless steel

Mounting plate





Mounting plates



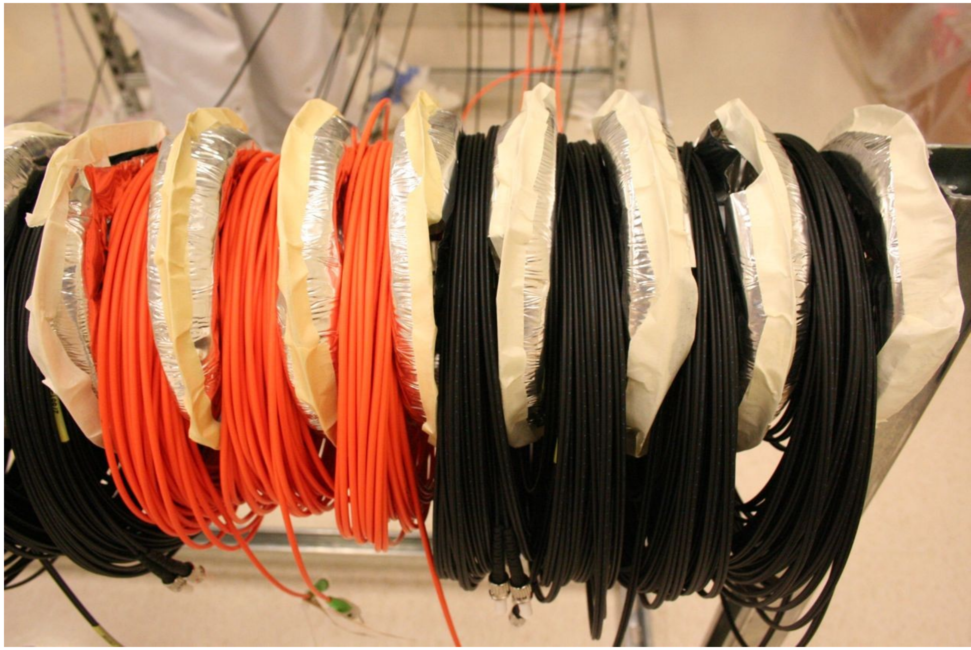
120 PET plates, made at the LIP-Coimbra workshop

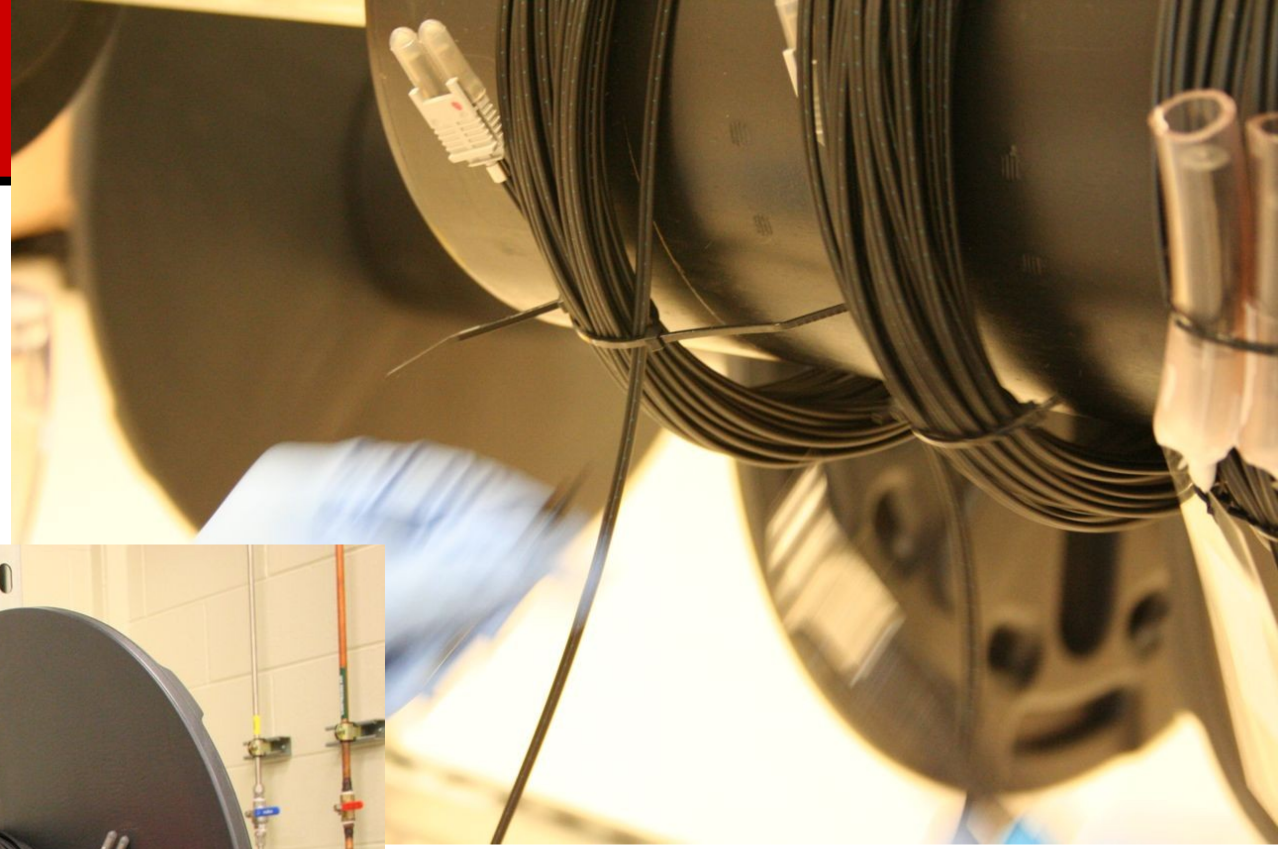
Fiber preparation

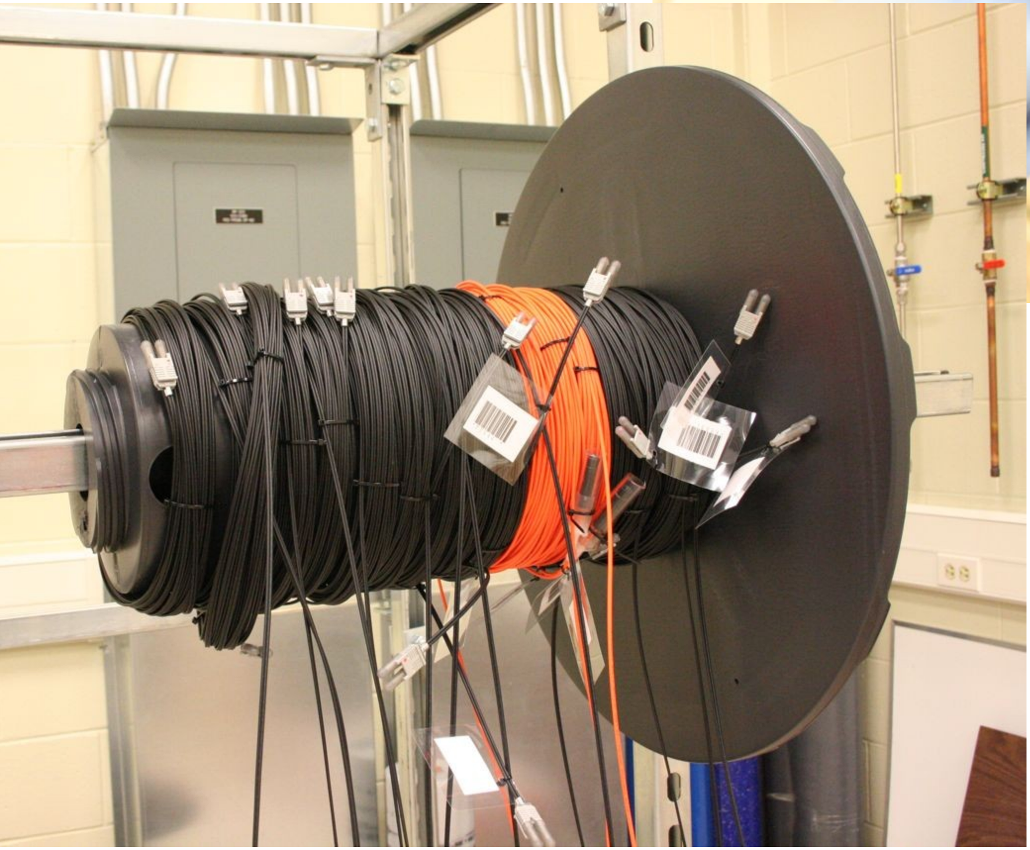
Fibers and all materials cleaned and prepared in clean-room

Then roll all of them into 8 spools

Stove burner guards are a fiber bundler's best friend



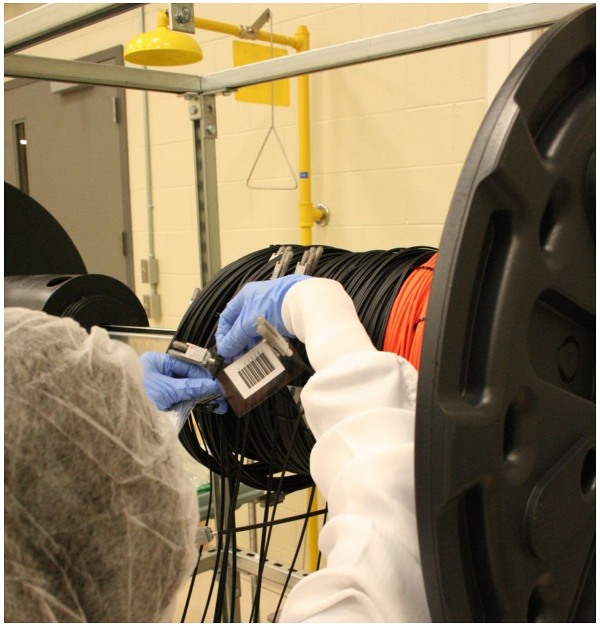




The first x meters of fiber
are rolled individually
and packed side-by-side

from then on,
all fibers are
bundled together

labels on each fiber cable



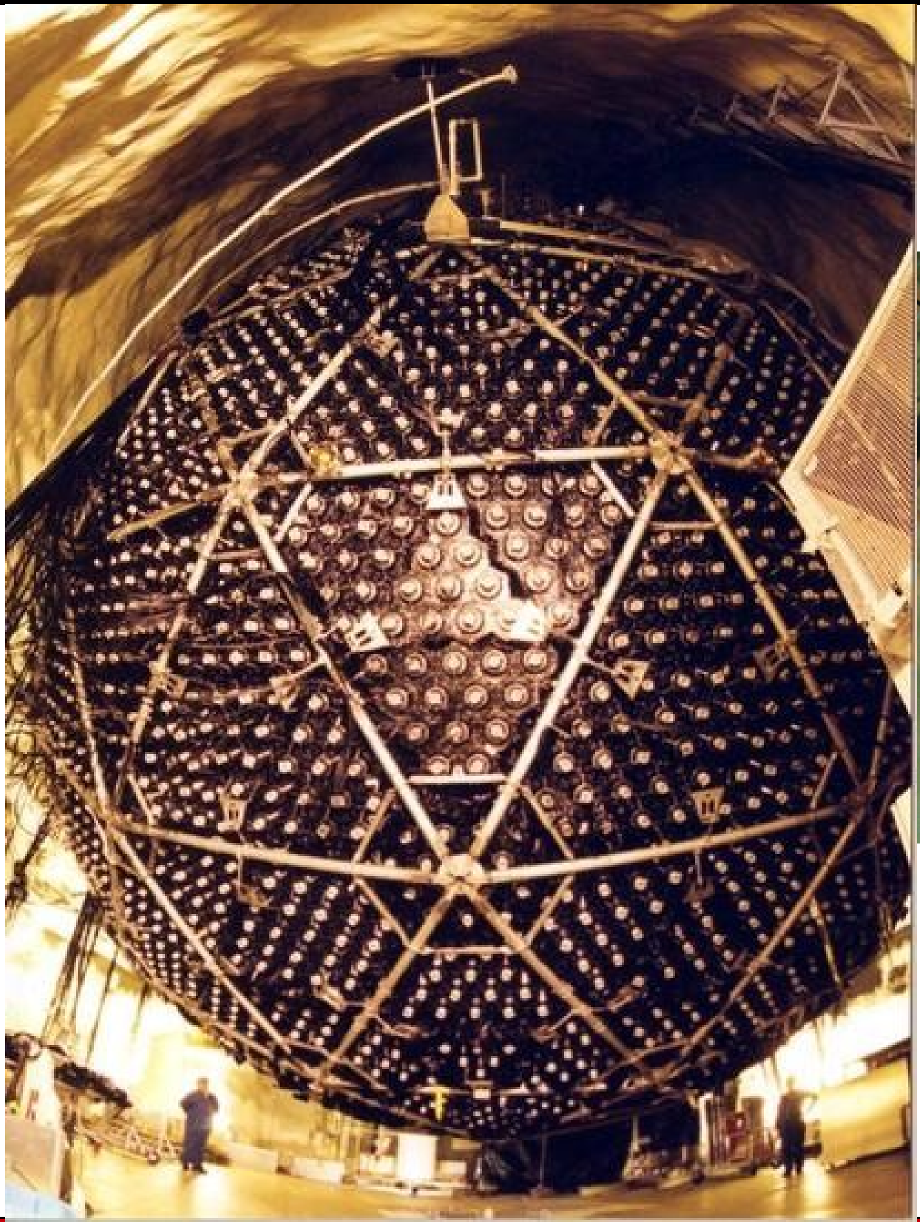
The fight against chaos

results in well-aligned dry-ends

The team

- Luís, José, Simon, Sofia, Ian, Gwen, James, Ken

Now underground



- Big detector
- Not easy access...
- Logistics challenge

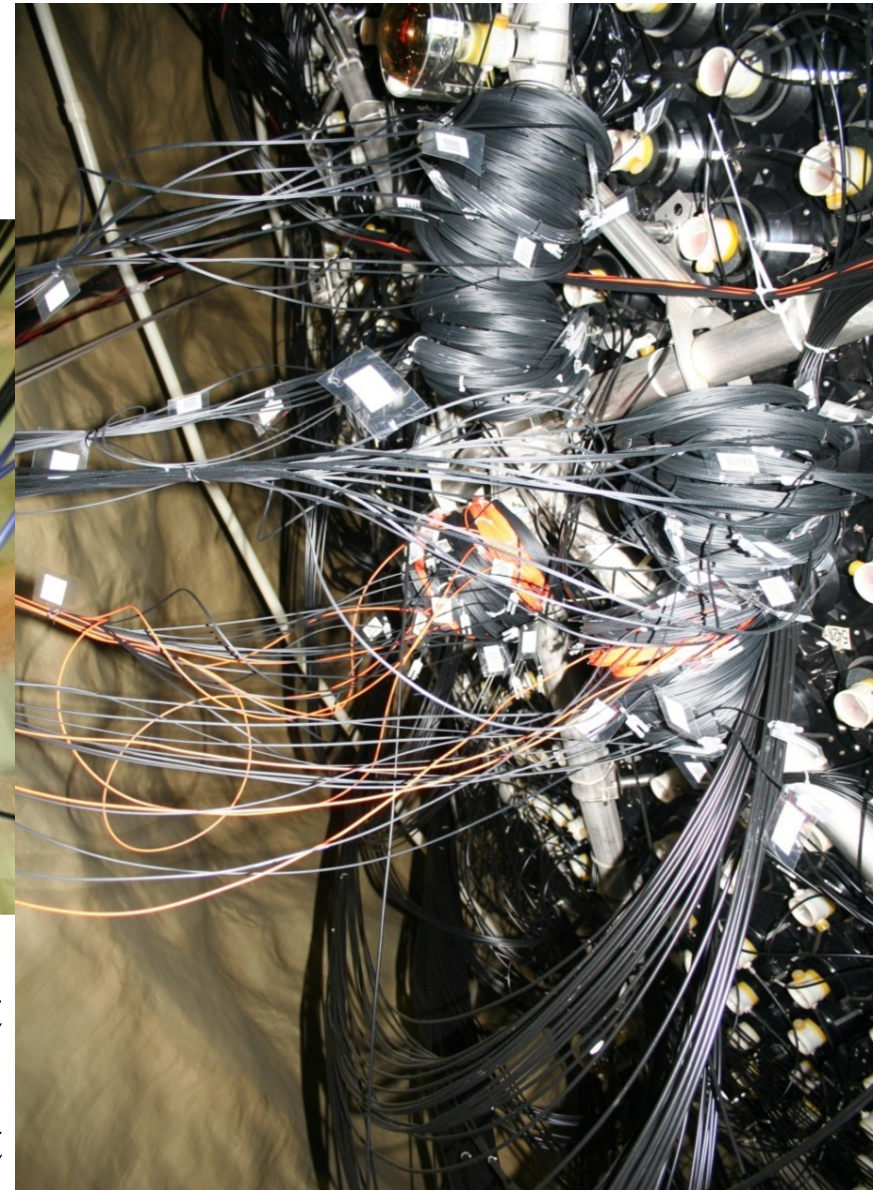
Bundle preparation

- Fiber spools were brought to cavity floor
- "Dry end" of fibers were pulled up

Routing and mounting

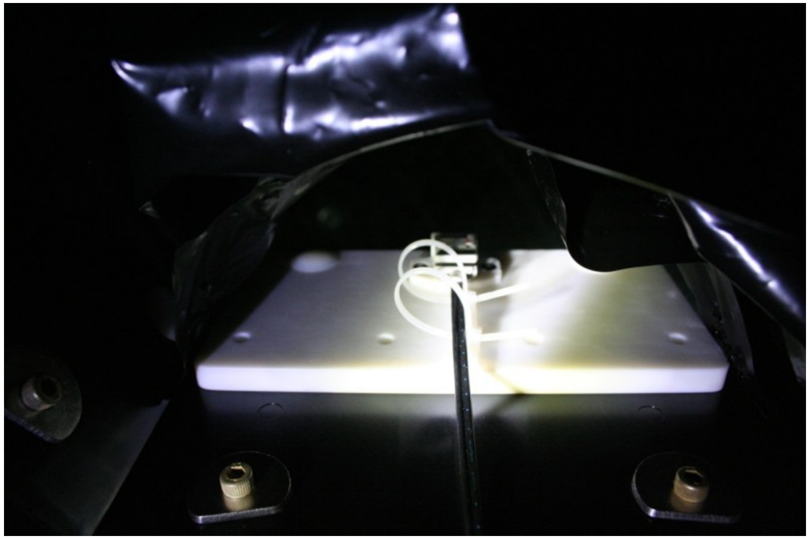
Using Genie lift

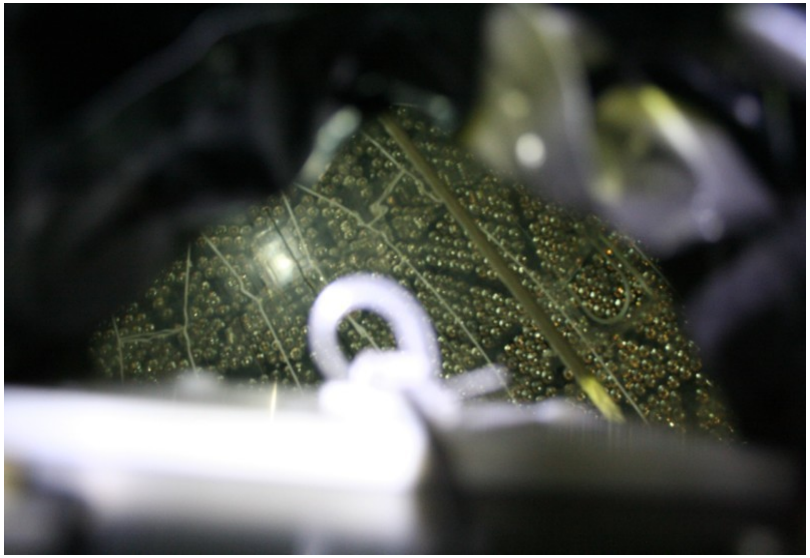
Need to avoid all the 9500 PMT cables (heavy...)

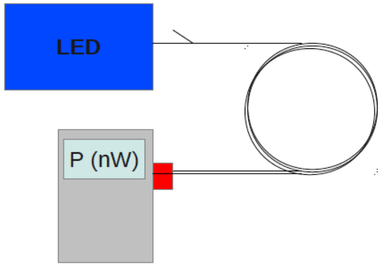


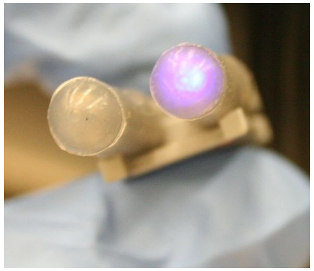
Remaining fiber bundles at high level, waiting to be installed by boat

Mounting fiber end









- Checked all fibers after routing
  - same source and power meter used in Lisbon
  - only 0.5 of 110 fibers broken!

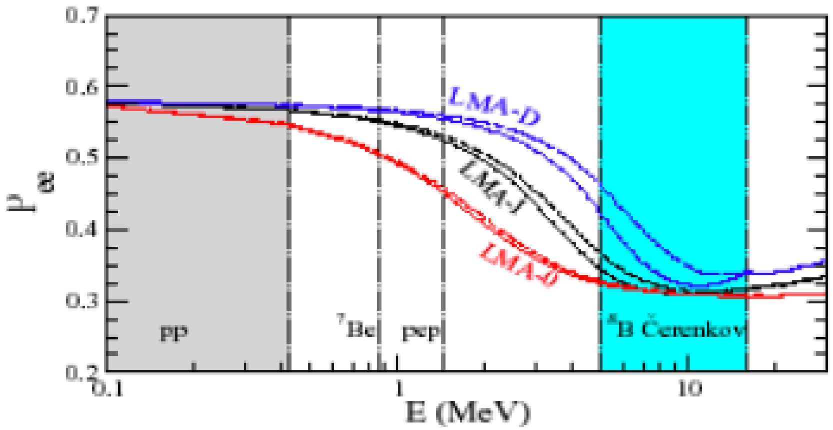
Overview and next steps

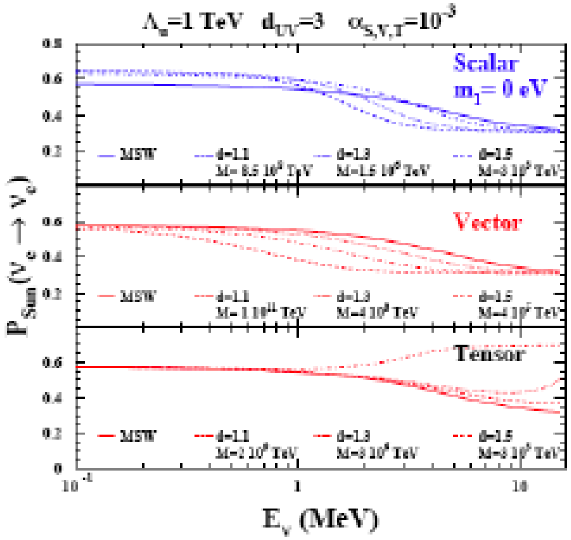
- Summer 2012 air-run
  - commission 1/3 of installed system
  - test synchronization algorithms
- Winter 2012/13 water fill
  - installation of remaining 2/3
- Spring 2013 water-run
  - commissioning of full system
  - comparison with laserball
  - provide fist calibration
- Winter 2013/14 scintillator-run
  - Summer 2014 introduce Neodymium
  - check scintillator effects
  - set-up/automatize regular calibration plans

Extra slides

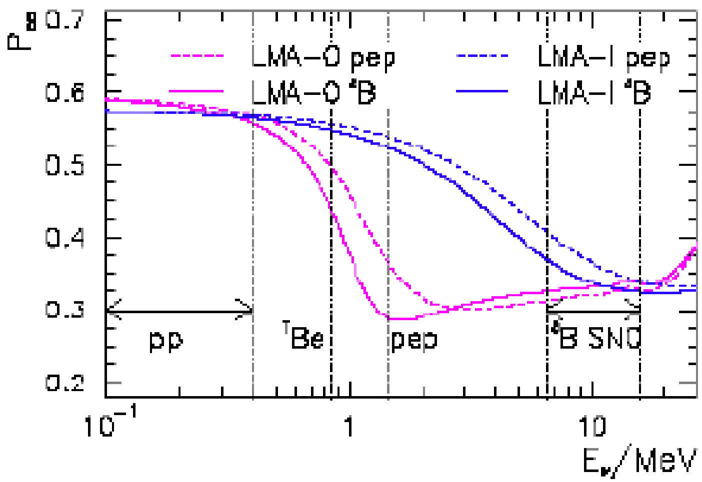
pep neutrino oscillations

Miranda, Tortola, Valle, hep-ph/0406289 (2005)

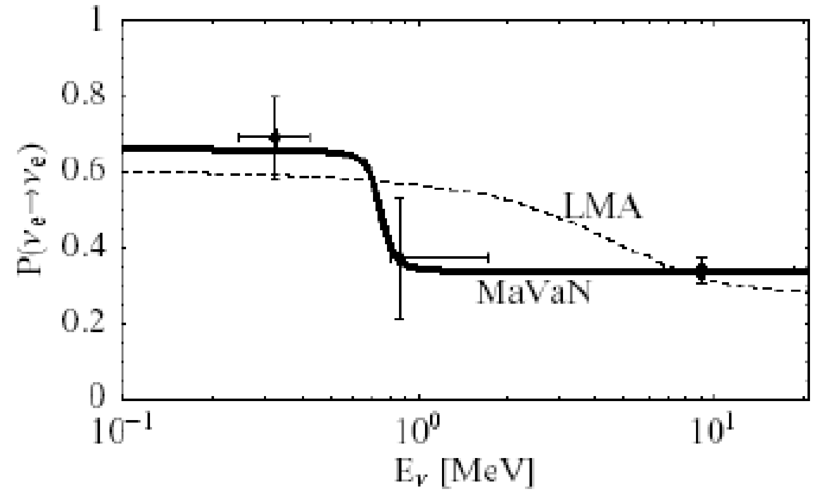




M. C. Gonzalez-Garcia, P. C. de Holanda, E. Masso and R. Zukanovich Funchalc, hep-ph/0803.1180



Friedland, Lunardini, Peña-Garay, PLB 594, (2004)



Barger, Huber, Marfatia, PRL95, (2005)

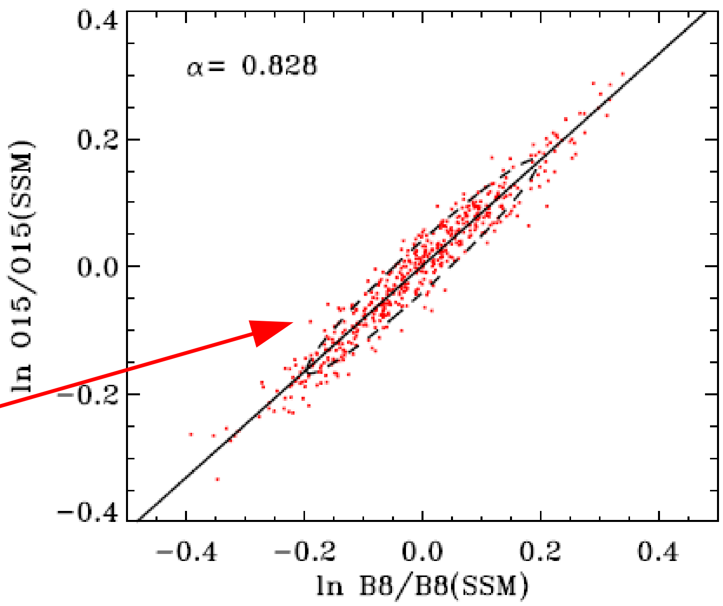
New questions about the Sun

- Metal abundances and helioseismology
  - Improved 3-D models give a 30% lower metallicity (X)
  - But then the sound speeds disagree with helioseismology!
  - What if the Sun's metallicity is not homogenous?
    - According to Haxton and Serenelli, the core could have a higher X than the convective zone
- Can neutrinos (and SNO+) help?
  - CNO neutrinos depend linearly on X
  - Temperature dependence same as ^{8}B

$$\frac{R^{SNO+}(CN)}{R^{SSM}(CN)} = \frac{X(C+N)}{X^{SSM}(C+N)} \left(\frac{R^{SK}(^8B)}{R^{SSM}(^8B)}\right)^{0.828} \times [1 \pm 0.03(SK) \pm 0.026(\text{res env}) \pm 0.049(\text{LMA}) \pm 0.071(\text{nucl})]$$

  - A measurement of CNO neutrinos at SNO+ can help pin down the Sun's metallicity

Haxton, Serenelli, astro-ph/0902.0036v1



Comparative advantages

- There's already Borexino and KamLAND, why another liquid scintillator detector?
- Size
  - 780 tons of scintillator, compared to 300 tons (Borexino)
- Depth
  - SNO+ is at 6080 mwe, while Borexino is at 3500 mwe and KamLAND at 2700 mwe.
    - Low cosmogenic backgrounds.
    - Best location for a precision measurement of the pep solar neutrino flux
    - … and CNO discovery
- Resolution:
  - SNO+ has ~9000 PMTs, compared to ~2200
  - with Nd loading: 5% at 1 MeV, 3.5 % at 3.4 MeV

Why SNO+ for pep?

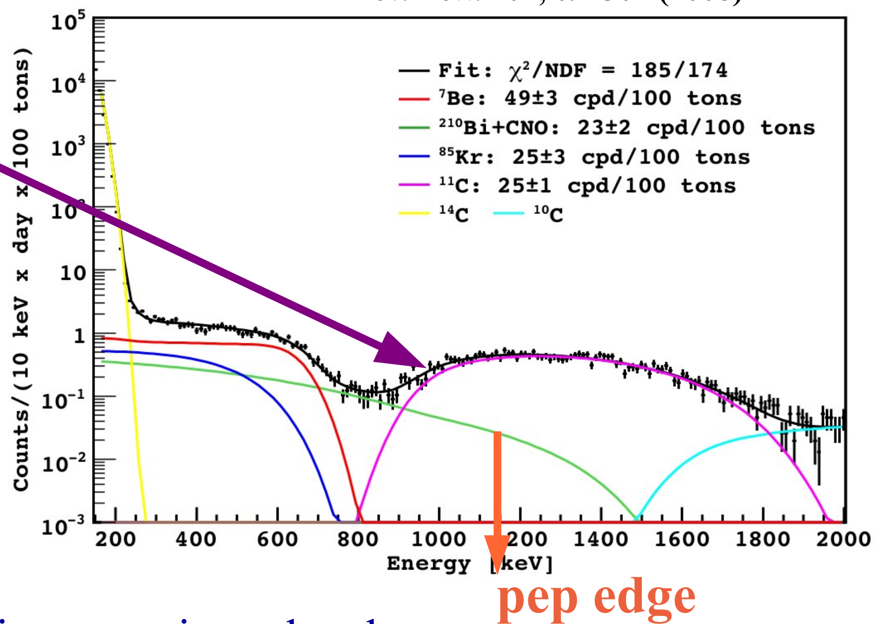
- Cosmogenic backgrounds
  - Carbon-11 decays cover pep and CNO energy window
    - Seen by Borexino and KamLAND

C-11 counts within 0.8-1.3 MeV

	^{11}C rate		B_0
	[cts/d/100 tons]	[$10^{-4}/\mu$/m]	[cts/d/100 tons]
KamLAND	107	48	37
Borexino	15	52	5.1
@ SNOLab	0.15	55	0.056

Franco, Galbiati et al., Phys.Rev.C71:055805,2005

Borexino Collaboration, Phys. Rev. Lett. 101, 091302 (2008)



- Depth matters
  - Carbon-11produced by cosmic muons hitting organic molecules
  - SNO+ (6080 mwe) 100 times better than Borexino (3500 mwe), 600 times better than KamLAND (2700 mwe)
    - Borexino developing C-11 cut, SNO+ will not need it