TECHNISCHE UNIVERSITÄT DRESDEN

Mathematik und Naturwissenschaften Institut für Kern- und Teilchen Physik

SNO+ Double beta decay experiment

Valentina Lozza

On behalf of SNO+ Collaboration

NDM2012, 11.06.2012 – Nara

Outline

- SNO+ = SNO + Liquid Scintillator
  - New detector design (Hold down rope system + sanding)
  - Liquid scintillator
- Phases of Operation:
  - Scintillator phase
  - Nd loaded phase
- Neutrinoless double beta decay
  - Nd-150
  - Optimization of Nd concentration
  - Calibration
- Background levels
- Sensitivity
- Summary

SNO+ Detector

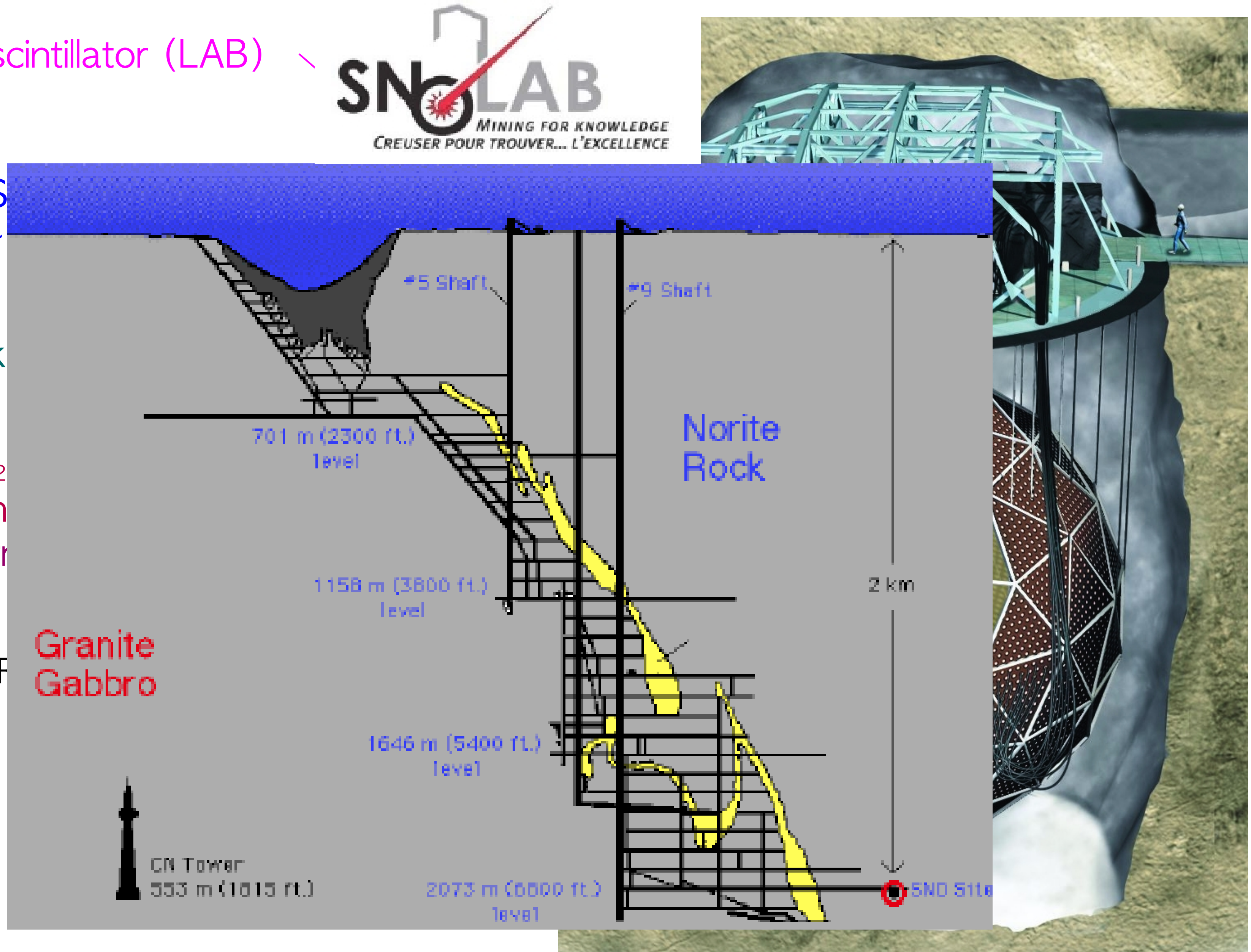
780t of liquid scintillator (LAB)
Active medium

PSUP = PMT S
~9500 PMT ~

Acrylic Vessel
ϕ=12 m, thick

Light water (H_2
- 1700t intern
- 5700t exterr

Urylon Liner and F



SNO+ Detector

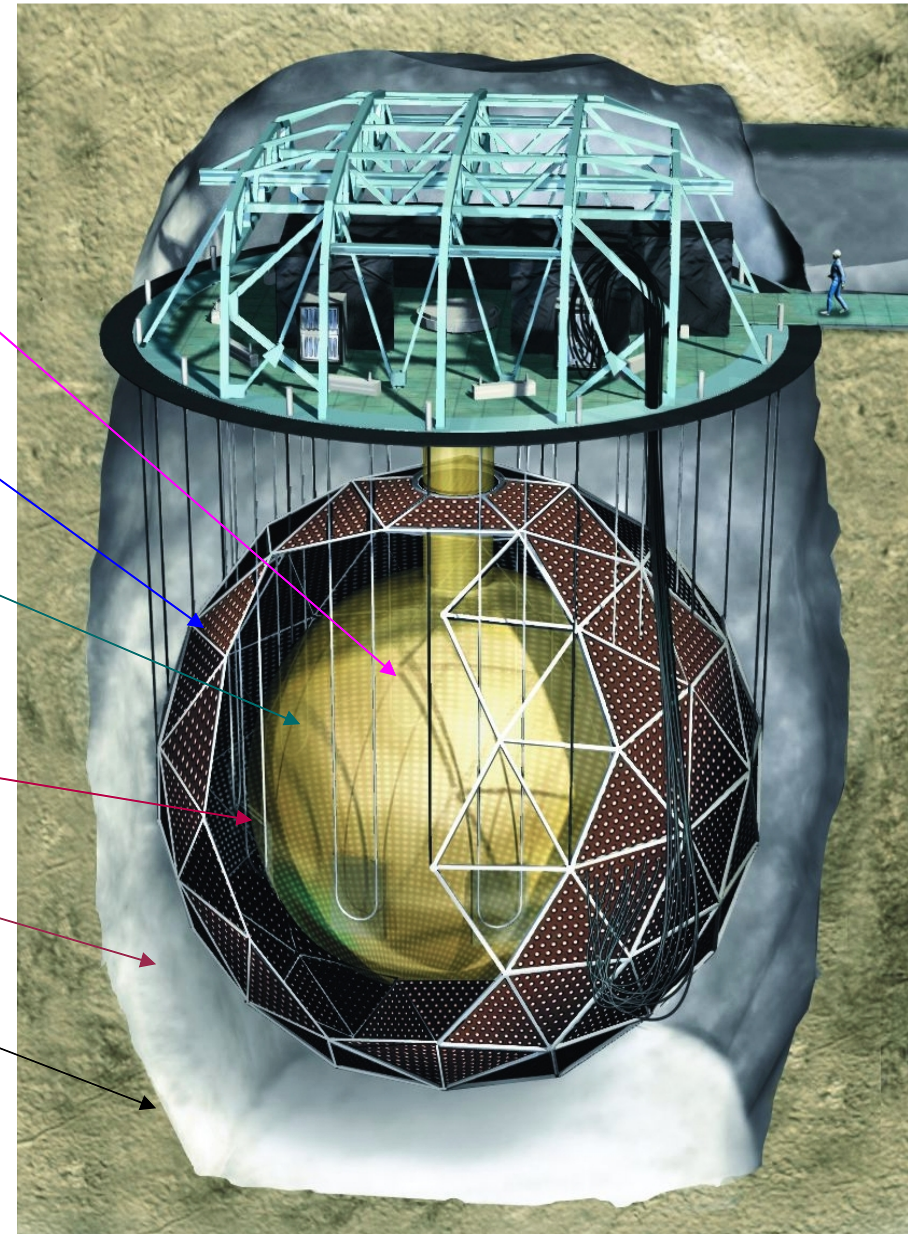
780t of liquid scintillator (LAB)
Active medium

PSUP = PMT Support Structure
~9500 PMT ~ 54% coverage

Acrylic Vessel
ϕ=12 m, thickness = 5 cm

Light water (H_2O) shielding
- 1700t internal
- 5700t external

Urylon Liner and Radon Seal

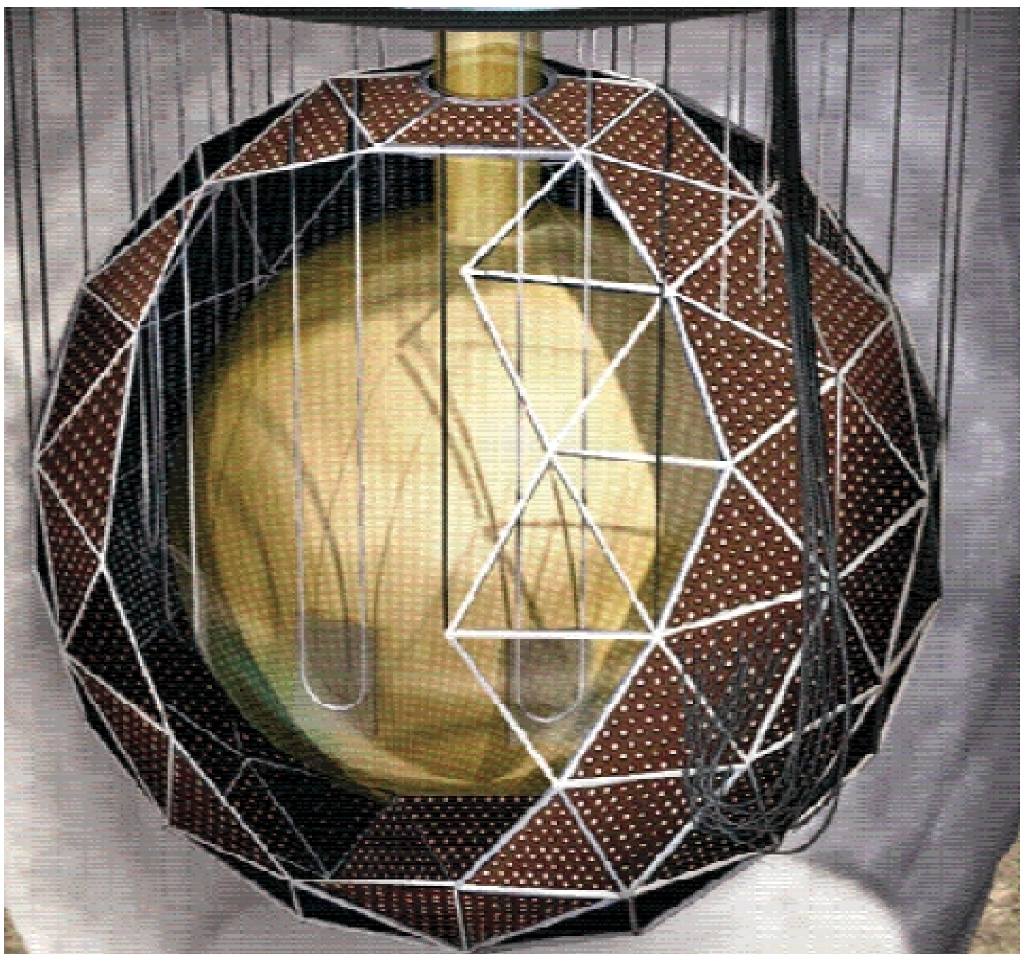


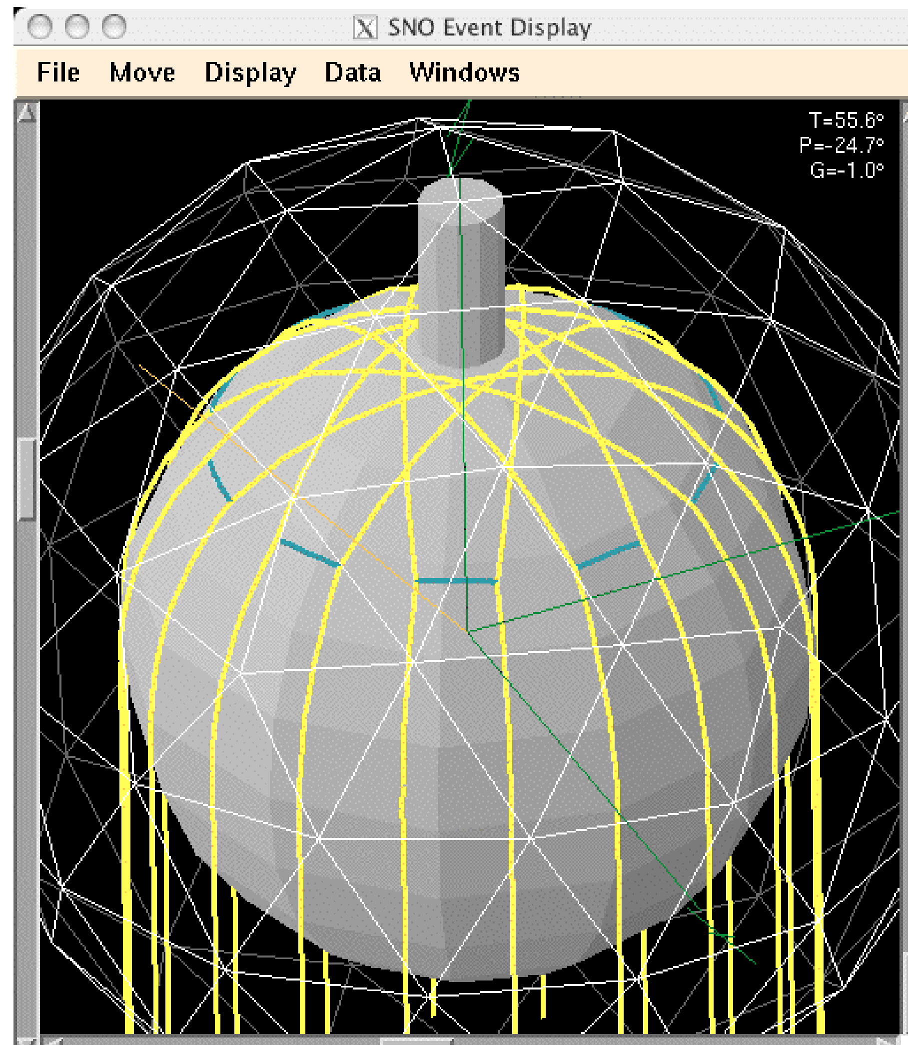
SNO+
New ropes hold down system

Liquid scintillator is lighter than water (ρ =0.86 g/cm^3)

From SNO → To SNO+

Hold up





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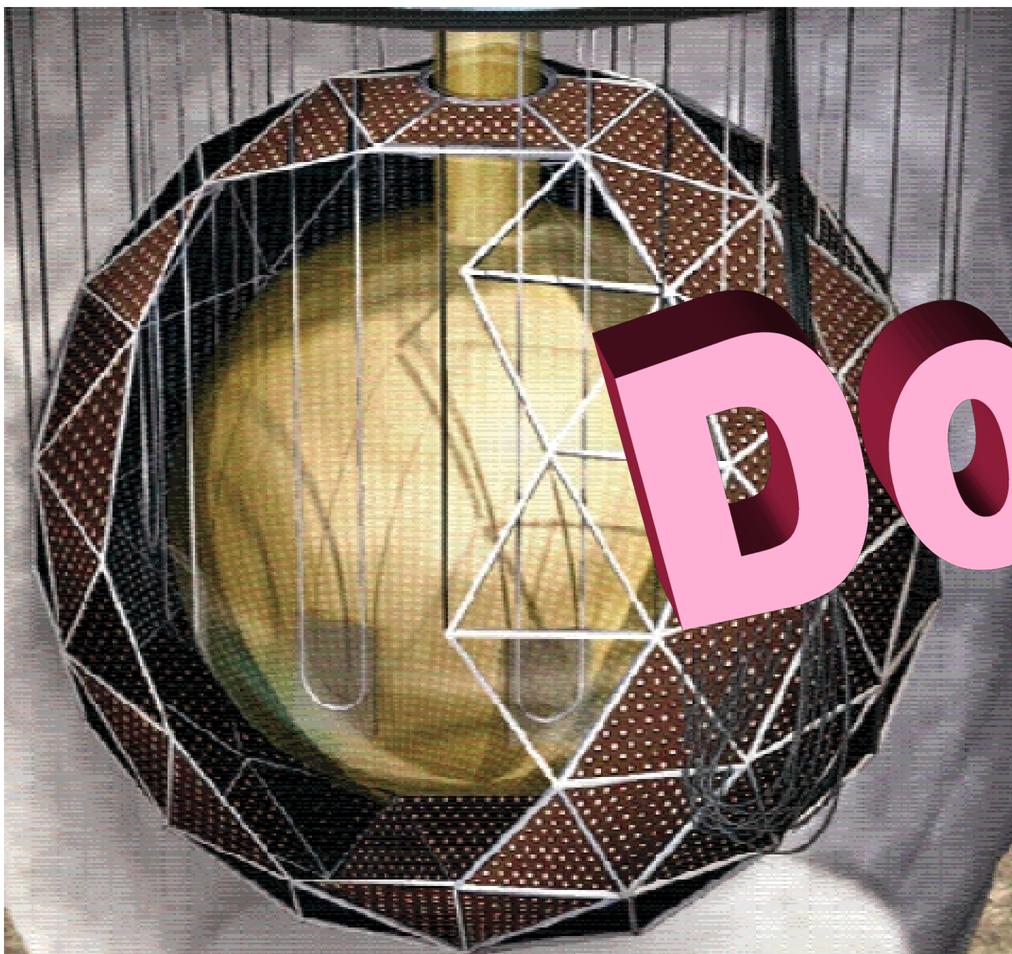
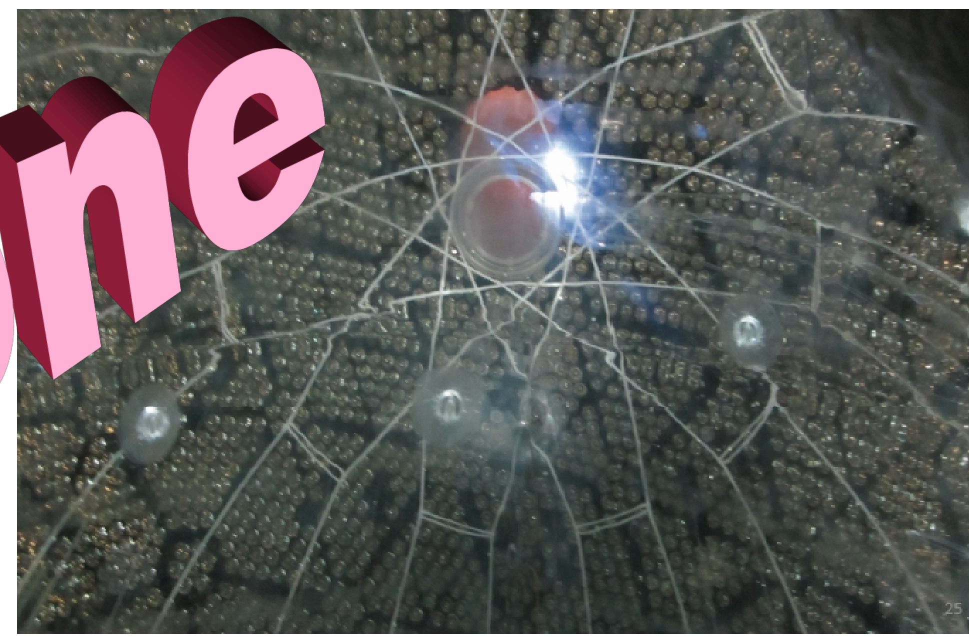
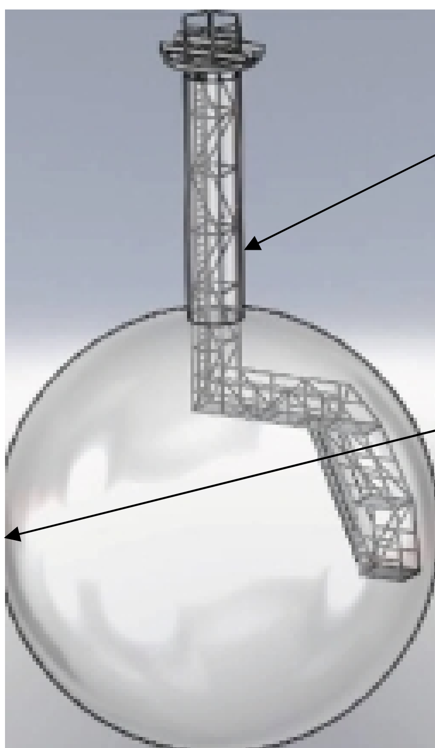




Done

SNO+
Sanding inner AV

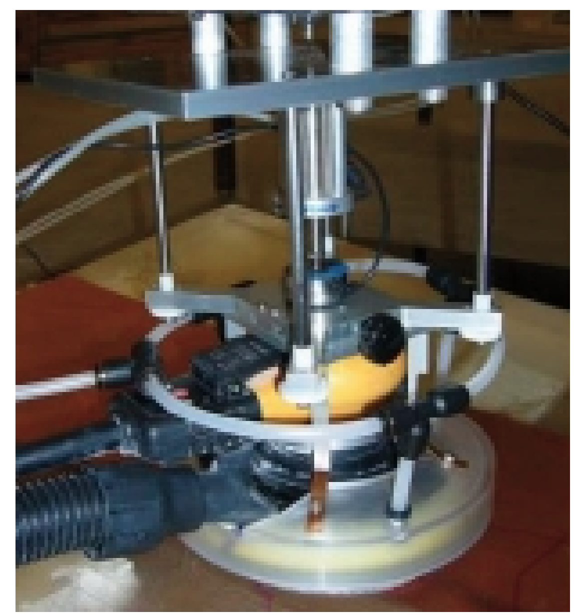
- Remove ^{210}Pb from the inner acrylic surface
- Installation of a Radon tight tent over the AV neck → radon reduced air in AV
- Installation of a sanding ladder for the sanding of the top half of the AV
- Use of automated sanding frame



Sanding ladder

Inner AV surface

Automated sanding frame



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SNO+
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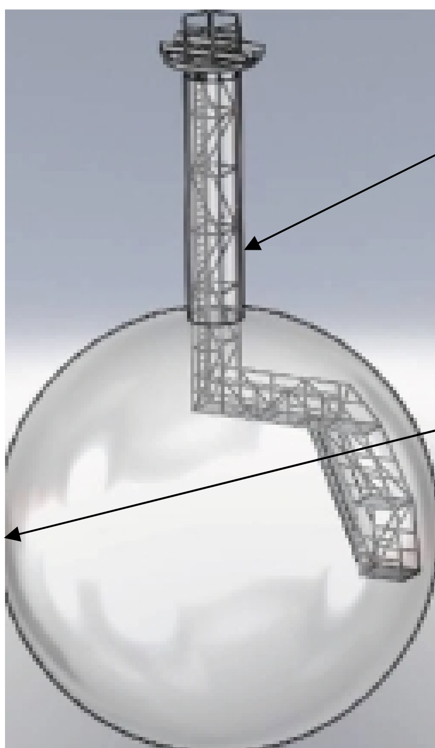
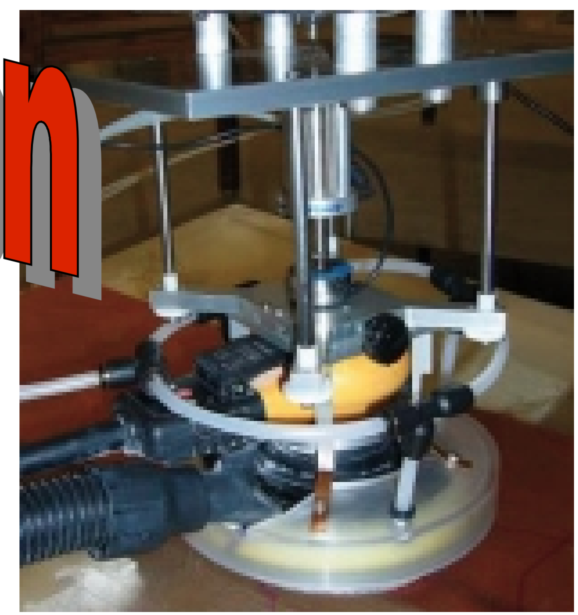


Sanding la er

surface

Start soon

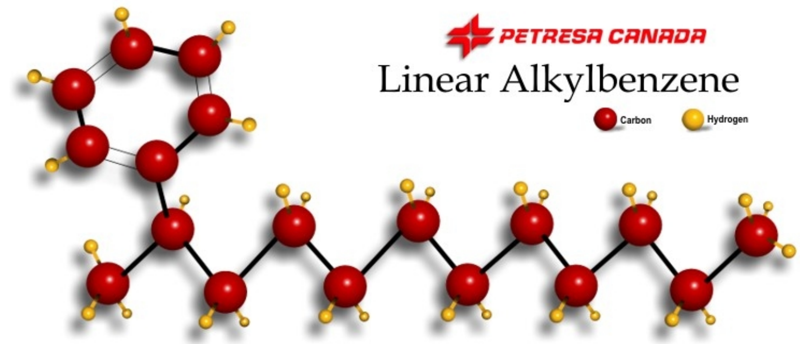
Automated sanding frame

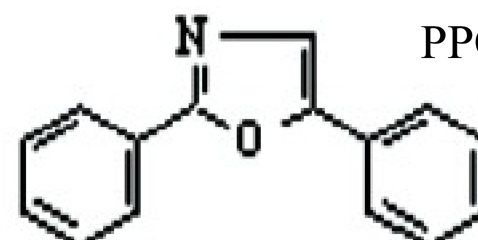


SNO+
Liquid scintillator LAB

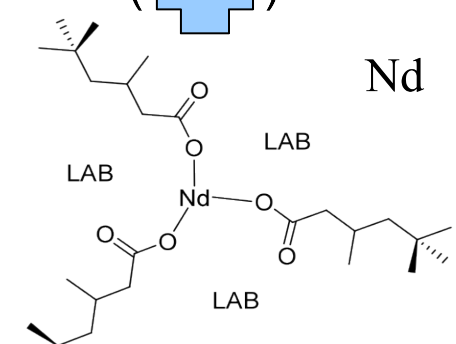
Linear alkylbenzene (LAB) identified as the liquid scintillator solvent

- ✓ Chemical compatibility with acrylic
- ✓ High light yield (~10,000 pe/MeV)
- ✓ High purity available
- ✓ Safe
- ✓ Low toxicity
- ✓ High flash point 140° C
- ✓ Boiling point 278-314° C
- ✓ Environmentally safe
- ✓ Low solubility in water 0.041 mg/L
- ✓ Inexpensive





PPO



Nd

Petresa Plant – Bécancour, QC

Nd-LAB

SNO+ Purification strategies

- Multi-stage distillation
  - Initial LAB cleanup for high radio-purity and optical clarity
  - Dual-stream PPO distillation for scintillator recirculation

- Pre-purification of PPO concentrated solution

- Steam/N2 stripping under vacuum

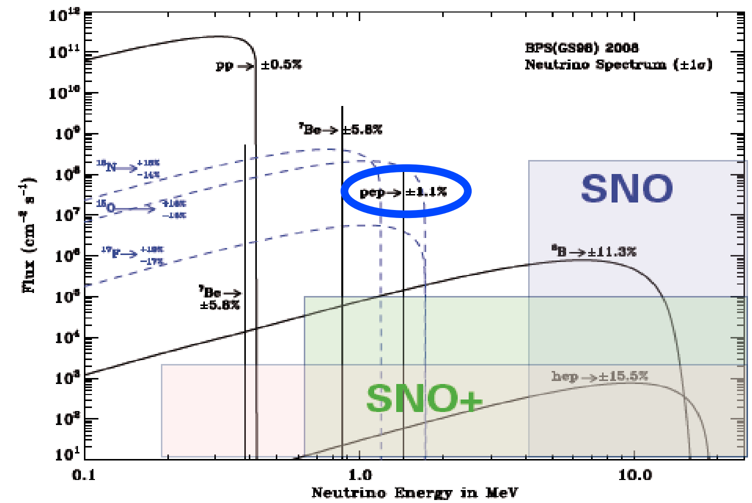
- during LS filling (19 LPM)
  - distillation (remove ^{232}Th, ^{238}U)
  - nitrogen and steam stripping (remove Rn, O_2, Kr, Ar)

- during detector operation (150 LPM)
  - water extraction (remove Ra, K, Bi)
  - steam stripping
  - micro filtration (remove dust)
  - metal scavenger adsorption columns (remove ^{210}Pb)

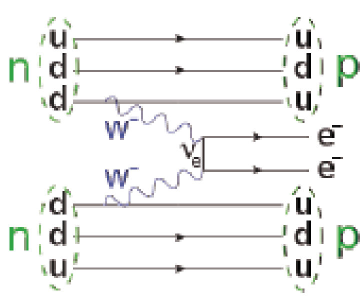
SNO+ Phases of operation

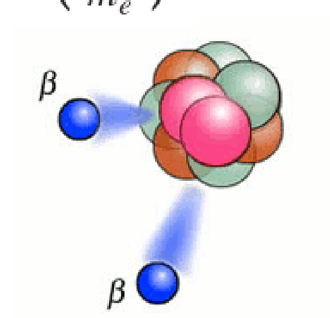
Two main phases of operation:

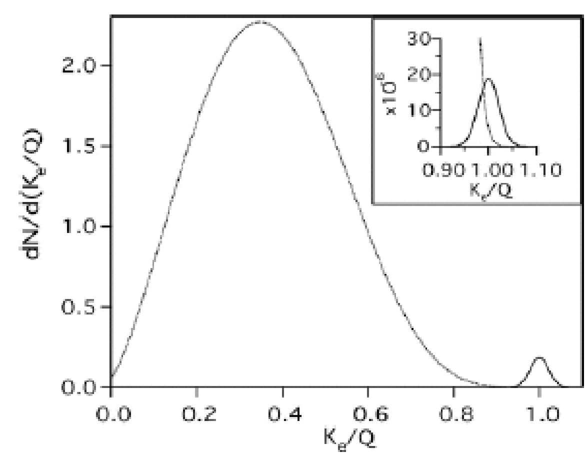
- ✓ Liquid Scintillator Phase
  - Solar Neutrinos
- ✓ Nd-Loaded phase
  - Neutrinoless Double-Beta decay



$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu}|M^{0\nu}|^2\left(\frac{\langle m_\nu\rangle}{m_e}\right)^2$$





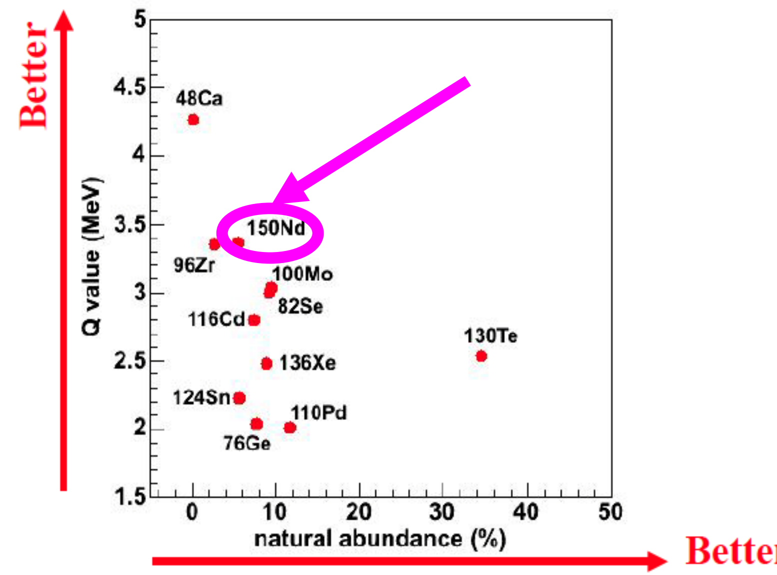


Other interesting studies: reactor-neutrinos, geo-neutrinos, supernovae neutrinos, nucleon decay, sterile neutrinos, ...

SNO+
Nd loaded phase

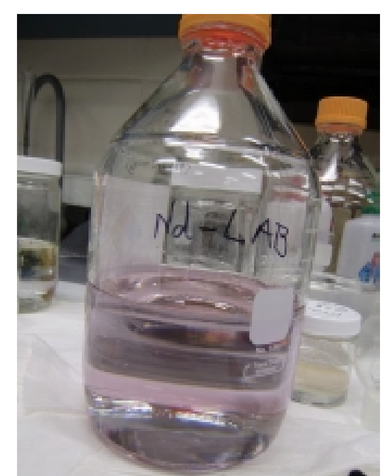
Neutrinoless double beta decay with liquid scintillator:

- ☺ Large mass, low background
- ☹ Poor energy resolution



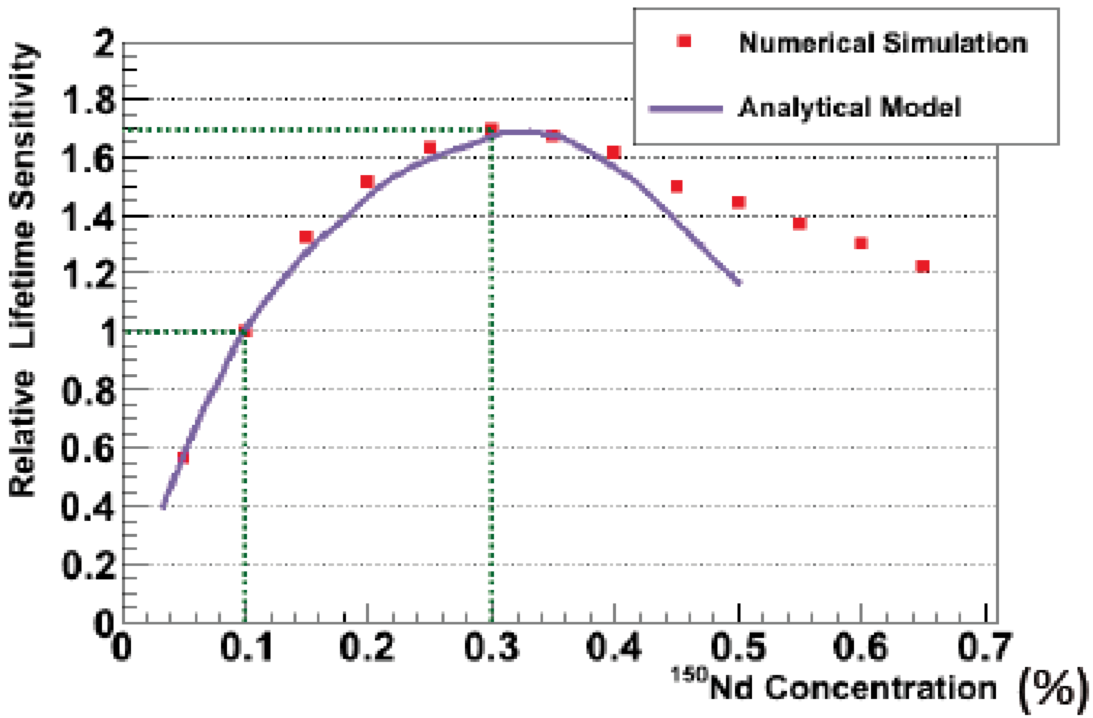
Use ^{150}Nd :

- ☺ High Q-value (3371 keV) → low background
- ☺ High natural abundance (5.6%)
- ☺ Successfully loaded in LAB
  0.1% ^{nat}Nd loading
  Optimized 0.3% ^{nat}Nd loading
- ☺ $0\nu\beta\beta$ rate in ^{150}Nd is one of the fastest (for the same effective Majorana mass)
  - largest phase space factor of all $\beta\beta$ isotopes
- ☺ Reasonable double beta decay half-life:
  ^{150}Nd ($2\nu\beta\beta$ g.s.) = 9.11×10^{18} yr
  ^{150}Nd ($2\nu\beta\beta$ 0^+ e.s.) ~ 1.3×10^{20} yr



Baseline 0.1% ^{nat}Nd loading → 44 kg of ^{150}Nd

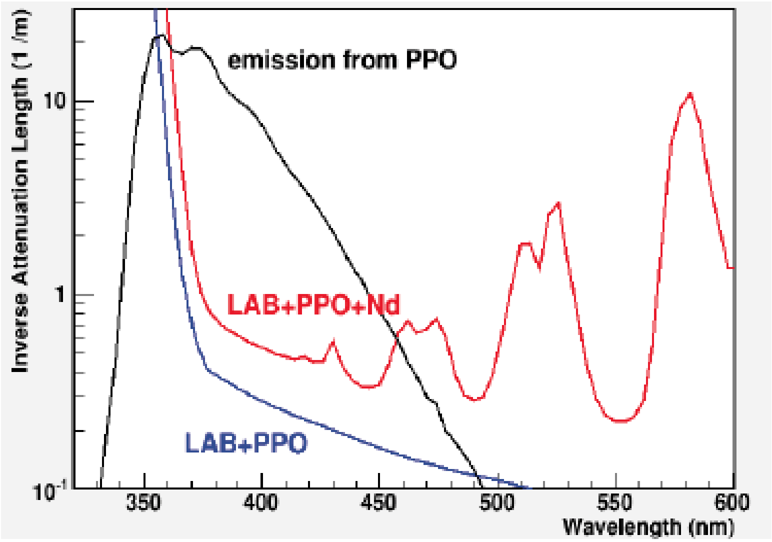
Increasing the quantity of Nd will increase the $0\nu\beta\beta$ signal

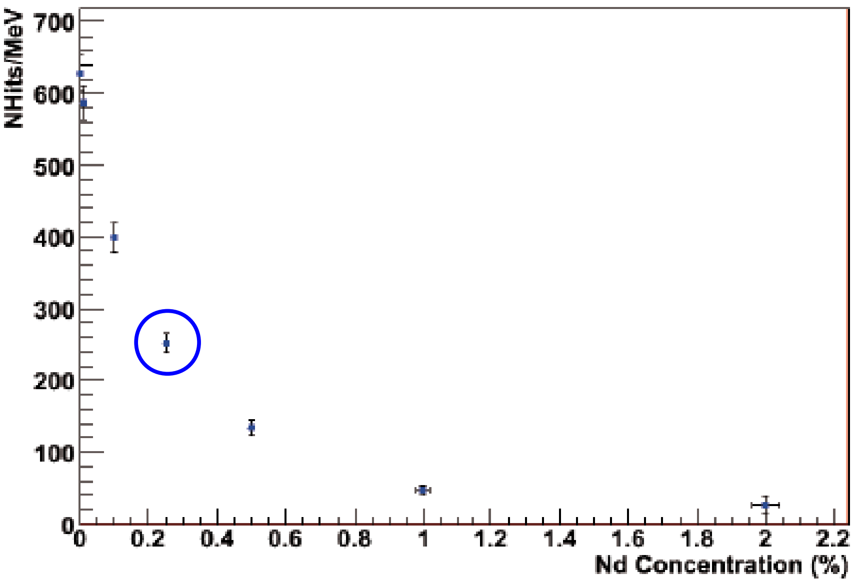


SNO+
Nd optimization

BUT will

- lower the energy resolution
- lower the light yield (p.e. per MeV)
- lower the optical transparency



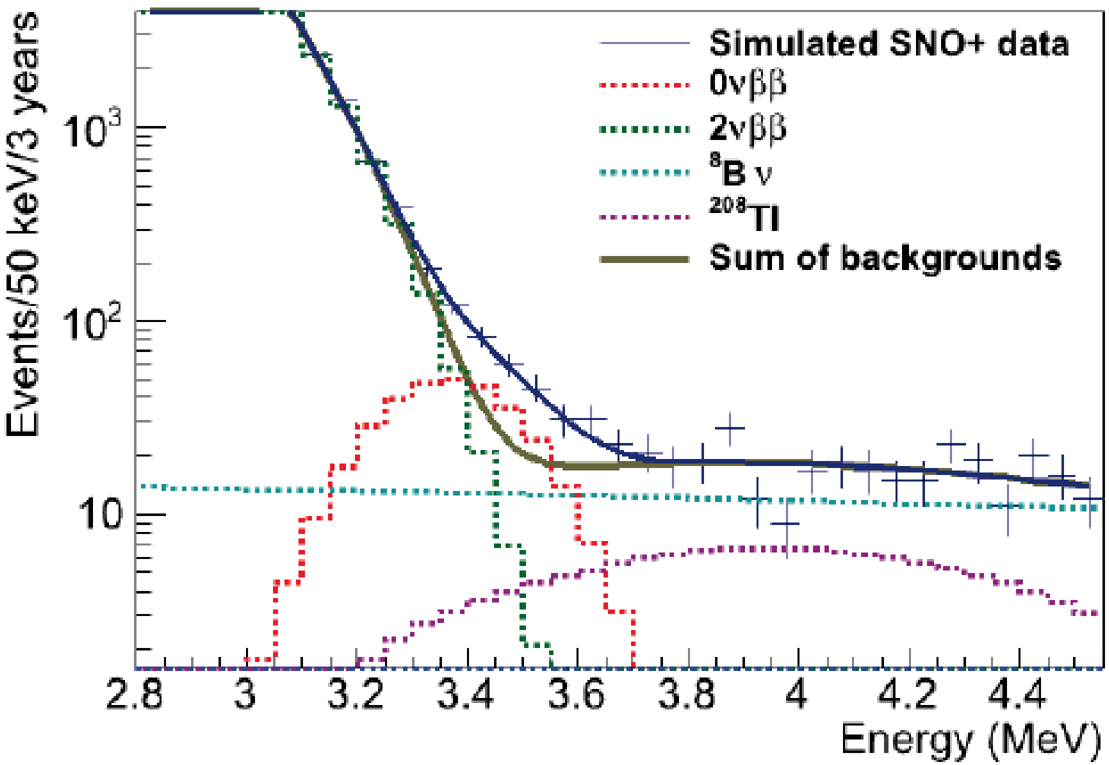


Good compromise → 0.3% ^{nat}Nd loading ~ 131 kg of ^{150}Nd

0.1% ^{nat}Nd loading: Light output of ~400 pe/MeV
Resolution: 6.4% FWHM @ 3.37MeV)

0.3% ^{nat}Nd loading: Light output of ~200 pe/MeV
Resolution: 9.0% FWHM @ 3.37MeV)

SNO+
Energy spectrum



- 0.3% ^{nat}Nd concentration
- Nuclear matrix element *IBM-2*
- Effective neutrino mass = 350 meV
- Fiducial volume cut = 50%
- Live years of data = 2.4 yr

↓

~360 0νββ events

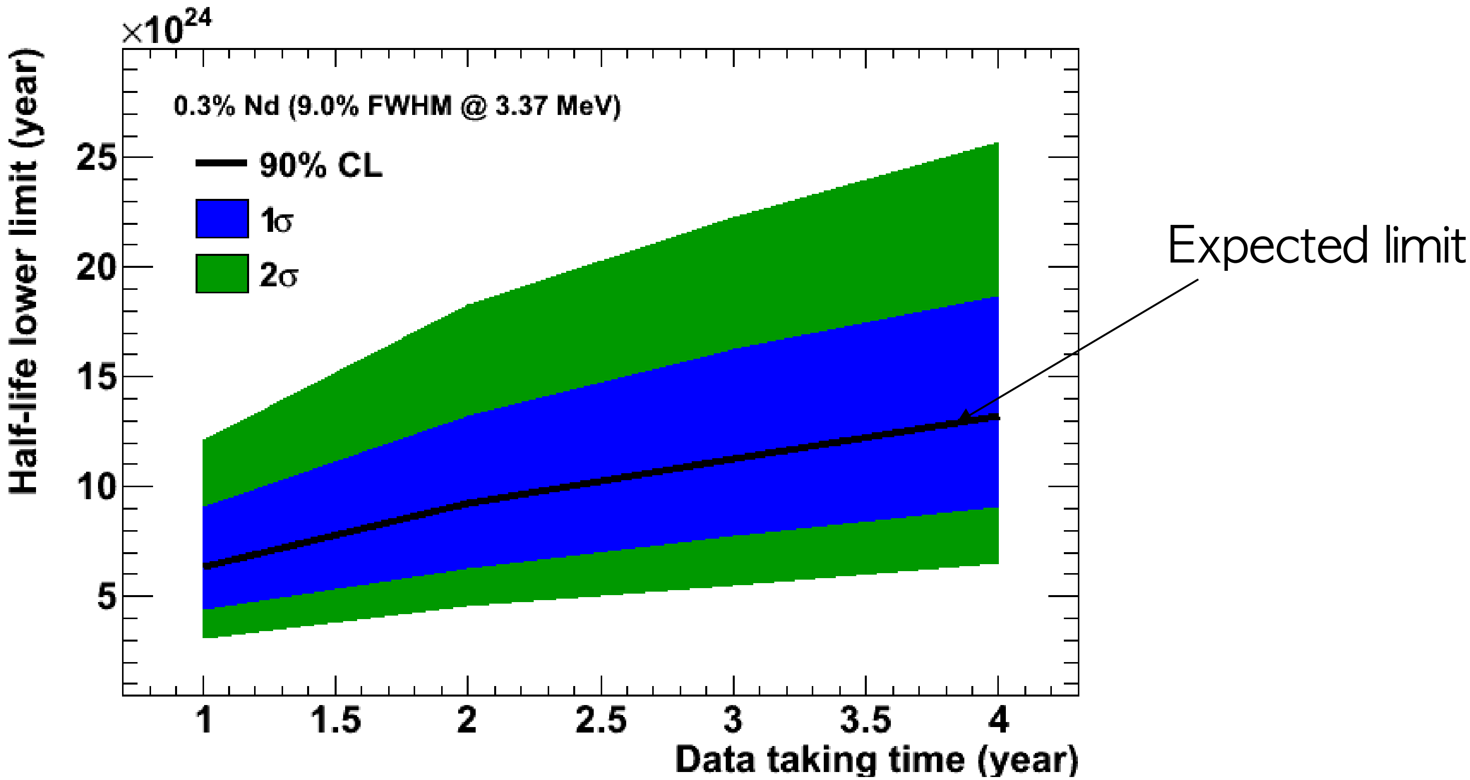
Background:

- Solar ^{8}B ~85 ev/yr
- ^{150}Nd 2ν2β g.s. + ex.s. included
- Bckg target level of Borexino

  ^{214}Bi 99.9% rejection with tagging technique

  ^{208}Tl 90% rejection with tagging technique

Half-life & mass sensitivity



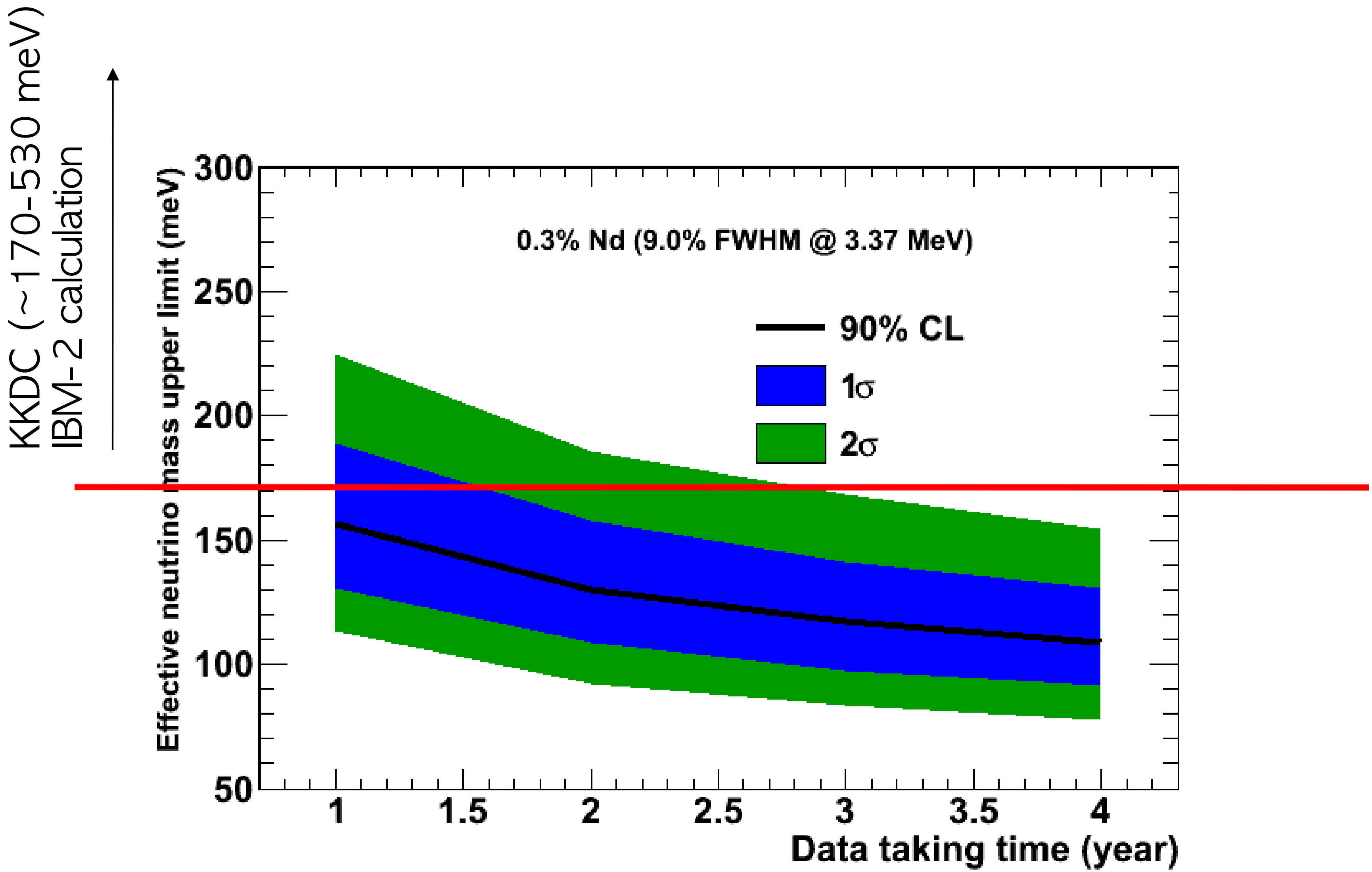
Background:

- 80% detector livetime + 50% FV
- Modified frequentist limit (LEP Cls method) is used
- Bckg target level of Borexino

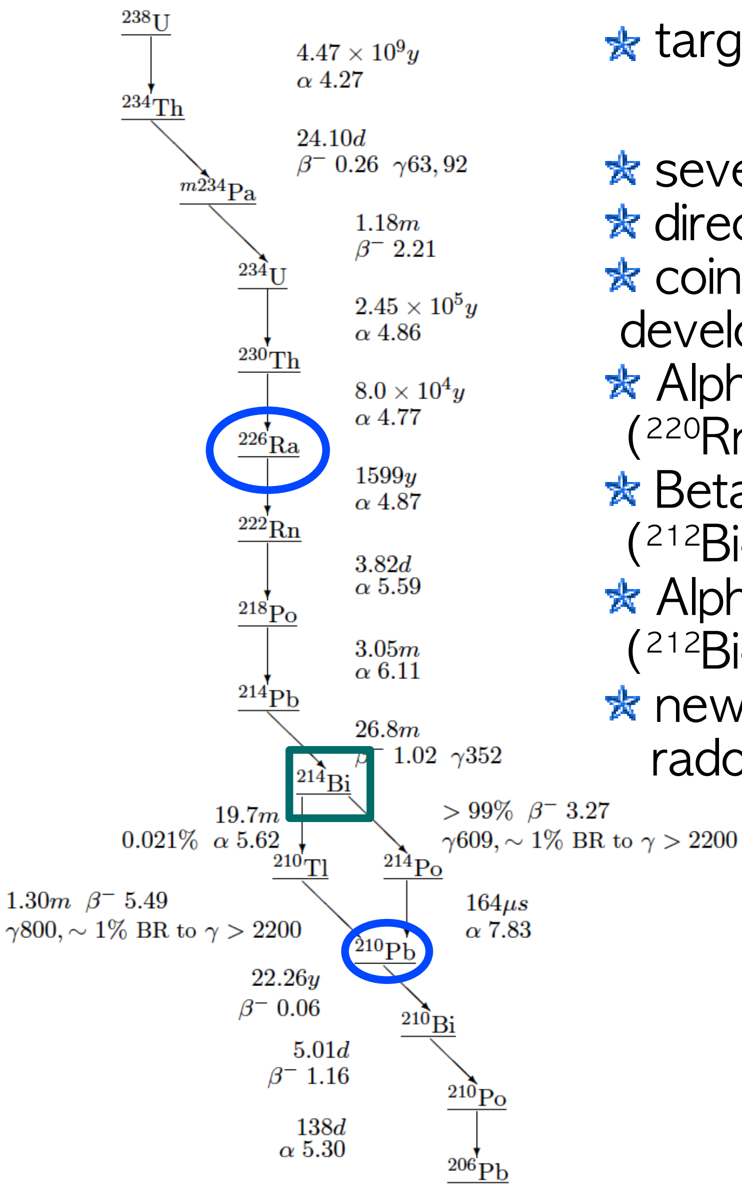
  ^{214}Bi 99.9% rejection with tagging technique

  ^{208}Tl 90% rejection with tagging technique

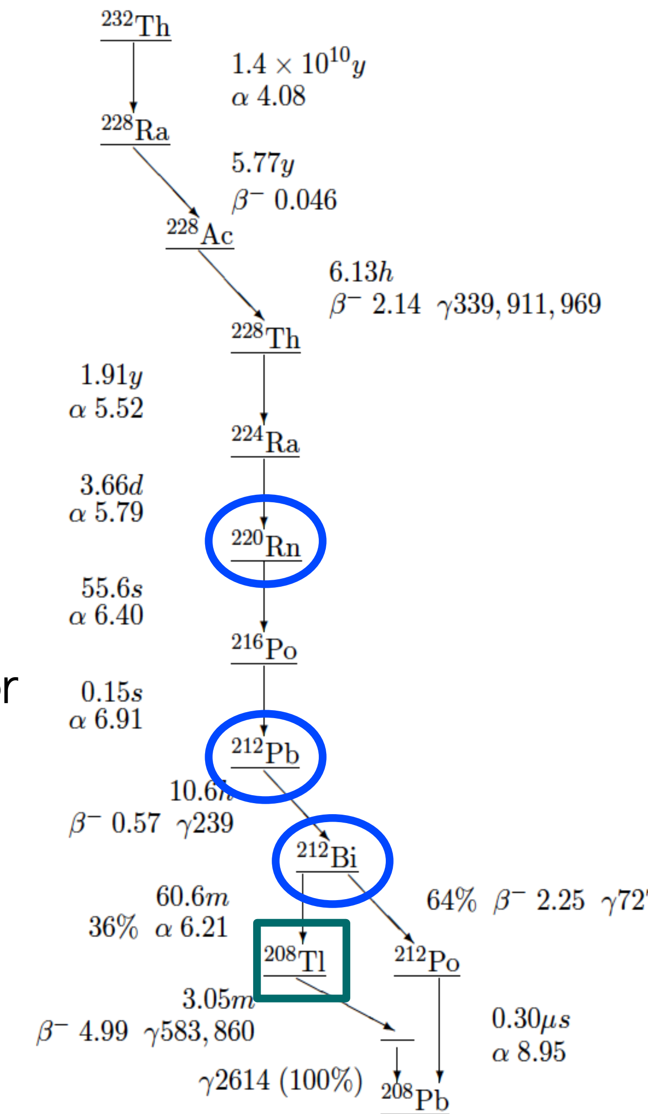
SNO+
Half-life & mass sensitivity



SNO+ Background



- target level ~ 10^{-14} g_U/g_{Nd}
  ~ 10^{-15} g_{Th}/g_{Nd}
- several α and β emissions
- direct background
- coincidence technique under development
- Alpha-alpha coincidences (^{220}Rn-^{216}Po-^{212}Pb)
- Beta-alpha coincidences (^{212}Bi-^{212}Po-^{208}Pb)
- Alpha-beta coincidences (^{212}Bi-^{208}Tl-^{208}Pb)
- new radon-sealed glovebox for radon reduction



SNO+
Nd background

$NdCl_3$ purification by pH-adjustment co-precipitation

	^{138}La µgLa/gNd	^{176}Lu µgLu/gNd	^{40}K µgK/gNd	^{227}Ac µBq/gNd
target	0.5	0.1	~0.08	2.7
$NdCl_3$ unpur.	480±30	3.1±0.2	6.0±0.9	183±19
NdCl3 pur.	〈 0.43	0.12±0.02	25±3	〈 6.2

Activation due to n, p

Long living isotopes can be produced by
- cosmogenic neutron and proton activation of the Nd samples while it is on surface
- underground neutron activation from the (α,n) reactions in the rock

Nuclide	$T_{1/2}$	Q / keV
^{143}Pm	265 d	1000
^{144}Pm	360 d	2330
^{146}Pm	5.5 a	1400/1500
^{147}Pm	2.6 a	220
^{148m}Pm	41 d	2470
^{139}Ce	140 d	280
^{141}Ce	32.5 d	580
^{144}Ce	285 d	320
^{138}La	10^{11} a	1000/1700

Direct or pile-up background

$$^{147}\mathrm{Ce} \xrightarrow[3290\mathrm{keV}]{1\mathrm{min}} {}^{147}\mathrm{Pr} \xrightarrow[2690\mathrm{keV}]{13\mathrm{min}} {}^{147}\mathrm{Nd} \xrightarrow[900\mathrm{keV}]{11\mathrm{d}} {}^{147}\mathrm{Pm} \xrightarrow[220\mathrm{keV}]{2.6\mathrm{a}} {}^{147}\mathrm{Sm} \xrightarrow[2300\mathrm{keV}]{10^{11}\,\mathrm{a}} {}^{143}\mathrm{Nd}$$

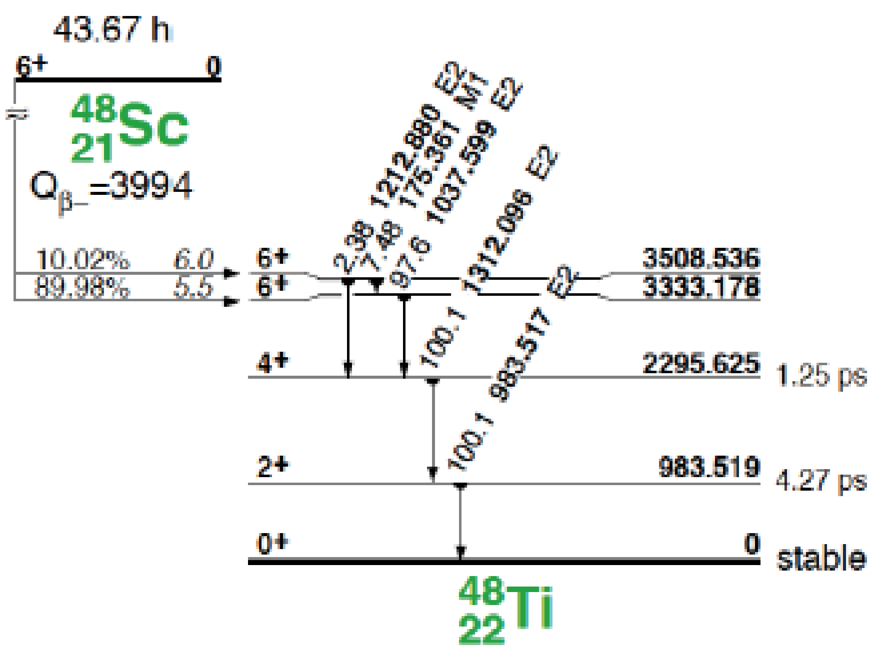
$$^{139}\mathrm{Nd} \xrightarrow[2790\mathrm{keV}]{30\mathrm{min}} {}^{139}\mathrm{Pr} \xrightarrow[2130\mathrm{keV}]{4.4\mathrm{h}} {}^{139}\mathrm{Ce} \xrightarrow[280\mathrm{keV}]{140\mathrm{d}} {}^{139}\mathrm{La}$$

$$^{144}\mathrm{Ce} \xrightarrow[320\mathrm{keV}]{285\mathrm{d}} {}^{144}\mathrm{Pr} \xrightarrow[3000\mathrm{keV}]{17\mathrm{min}} {}^{144}\mathrm{Nd} \xrightarrow[2000\mathrm{keV}]{2.3\cdot 10^{15}\,\mathrm{a}} {}^{140}\mathrm{Ce}$$

Pile-up background: ^{144}Nd, ^{176}Lu, ^{138}La, ^{14}C
Detailed simulation shows 99% rejection of pile-up events

Different calibration sources are used to check the energy scale, resolution, position and energy reconstruction, detector response uniformity

Source	AmBe	^{90}Y	^{65}Zn	^{60}Co	^{57}Co	^{24}Na	^{48}Sc	^{8}Li	^{16}N
Particle	n, γ	β	γ	γ	γ	γ	γ	β	γ
Energy(MeV)	4.4(γ)	2.2	1.1	2.5	0.122	4.1	3.3	10	6.1



^{48}Sc ($T_{1/2}$ = 43.67 h) beta-gamma source

- $\Sigma(E_\gamma)$= 3.33 MeV (90% branch)
- close to the ^{150}Nd Q-value (3.37 MeV)
- produced by 14 MeV-n activation of ^{nat}Ti
- produced on site or @ Dresden (sent by mail)

SNO+
Current Status

This year (2012)
- Detector upgrade
  - Sanding AV
  - Finish installation of the optical calibration system
  - Construction of the scintillation system
- Pure water fill

2013
- Pure water data
- Start filling the detector with scintillator
- Scintillator data

2014
- Nd-loaded phase

Summary

- SNO+ is the follow up of the SNO experiment replacing the heavy water by liquid scintillator
- Two phases of the experiment with different physical goals are planned:
  - A liquid scintillator phase for the search of low energy solar neutrinos (pep, CNO)
  - A Nd loaded phase for the search of neutrinoless double beta decay
    - Initial 0.1% ^{nat}Nd loading (~44 kg ^{150}Nd)
    - Optimized 0.3% ^{nat}Nd loading (~131 kg ^{150}Nd)
- Other exciting physical goals are reactor oscillation confirmation, geo-neutrinos in a geologically-interesting location, supernova neutrino watch, ...
- The sanding of the AV for ^{210}Pb will be completed by the end of this year
- SNO+ will start operation with water fill run in 2013