SNO and the new SNOLAB

SNOLAB: A New International Facility for AstroParticle-Physics Research

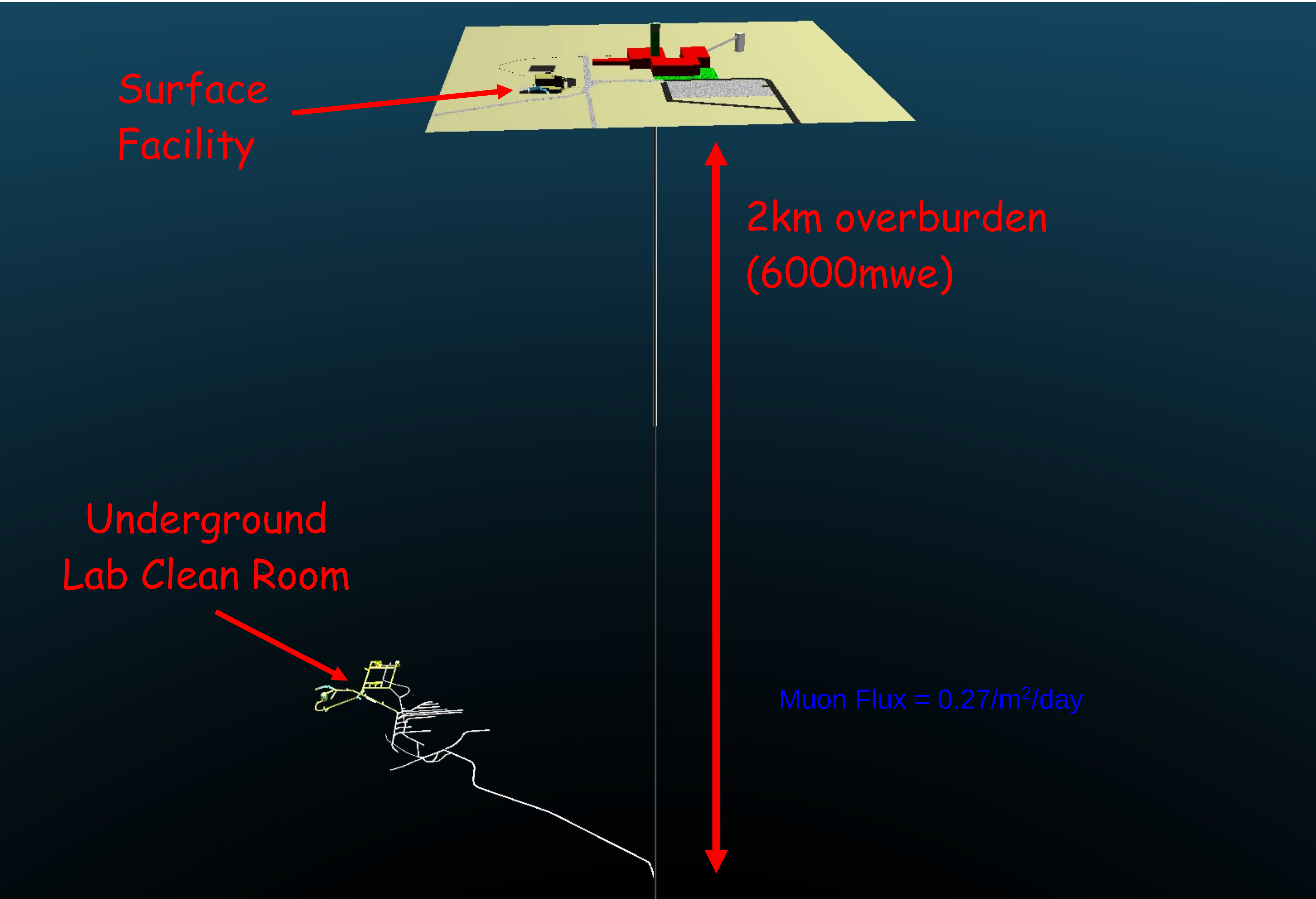
- Overview and Status of the facility
- Current Scientific programme, including
- Status of SNO analysis

Art McDonald Queen's University

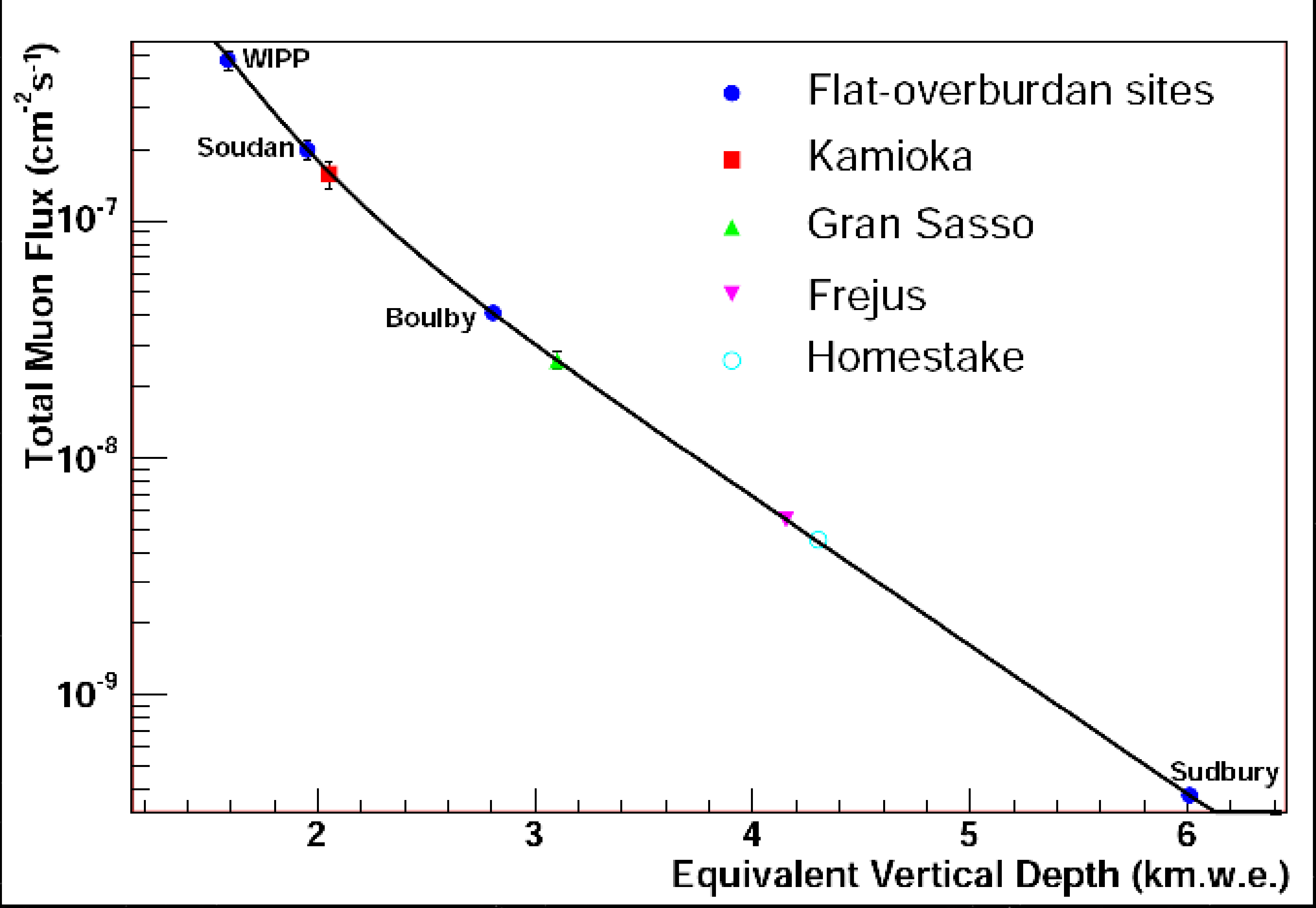
The Motivation for SNOLAB:

- To promote an International programme of Astroparticle Physics
- To provide a very deep experimental laboratory to shield sensitive experiments from penetrating Cosmic Rays
- To provide a very clean laboratory: Entire lab at better than class 2000 to mitigate against contamination of experiments.
- Focus on dark matter, double beta decay, solar & SN experiments requiring depth and cleanliness of SNOLAB. Also provide space for prototyping of future experiments.
- Large scale expt's = ktonne, not Mtonne.
- The goal has been to create a significant amount of space for an active experimental programme and support the current generation of experiments as early as possible.

SNOLAB



Surface
Facility
2km overburden
(6000mwe)
Underground
Lab Clean Room
Muon Flux = 0.27/m^2/day



WIPP
Soudan
Boulby
Sudbury
Flat-overburdan sites
Kamioka
Gran Sasso
Frejus
Homestake
Total Muon Flux (cm^{-2}s^{-1})
10^{-7}
10^{-8}
10^{-9}
2
3
4
5
6
Equivalent Vertical Depth (km.w.e.)

SNOLAB Underground facilities

The Sudbury Neutrino Observatory: SNO

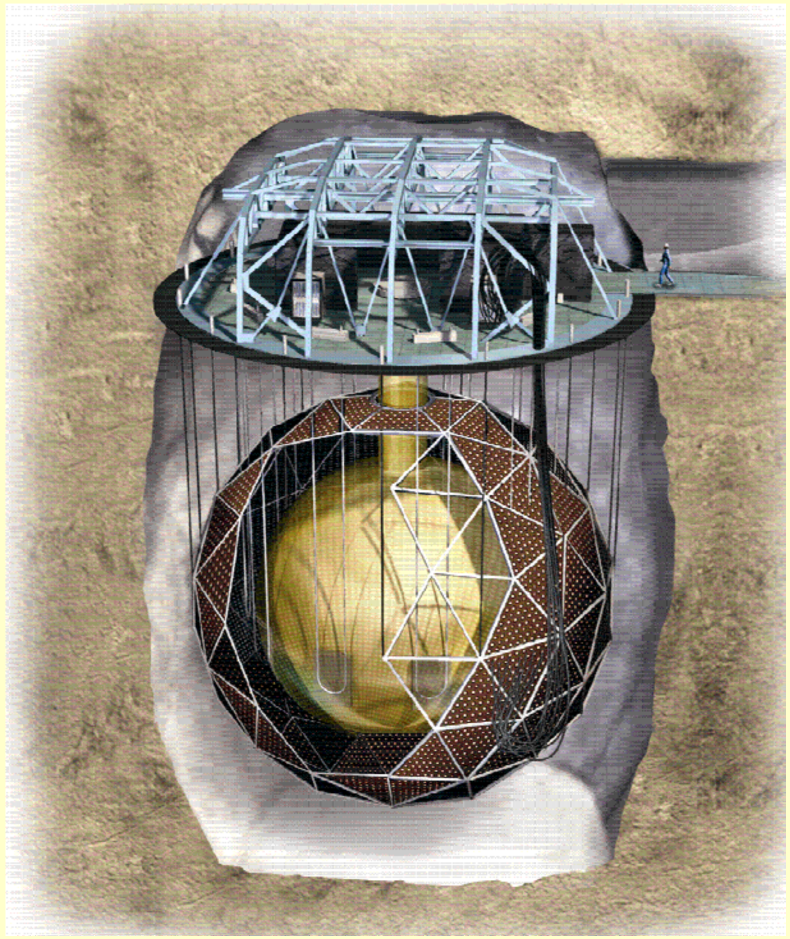
Acrylic vessel (AV)
12 m diameter

1000 tonnes D_2O
($300 million)

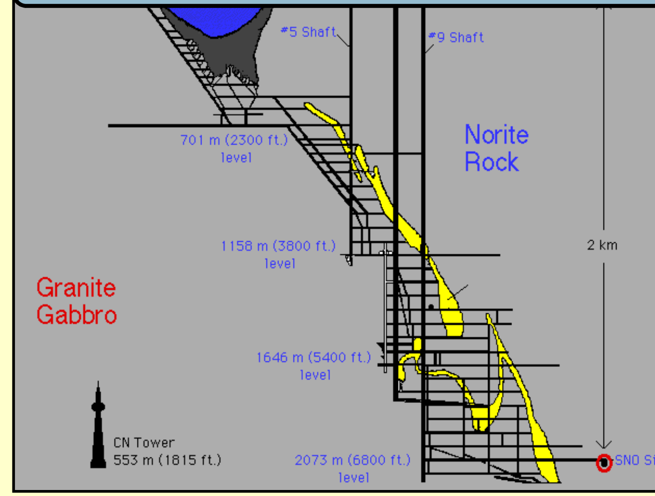
1700 tonnes H_2O
inner shielding

5300 tonnes H_2O
outer shielding

~9500 PMT's



6800 feet (~2km) underground

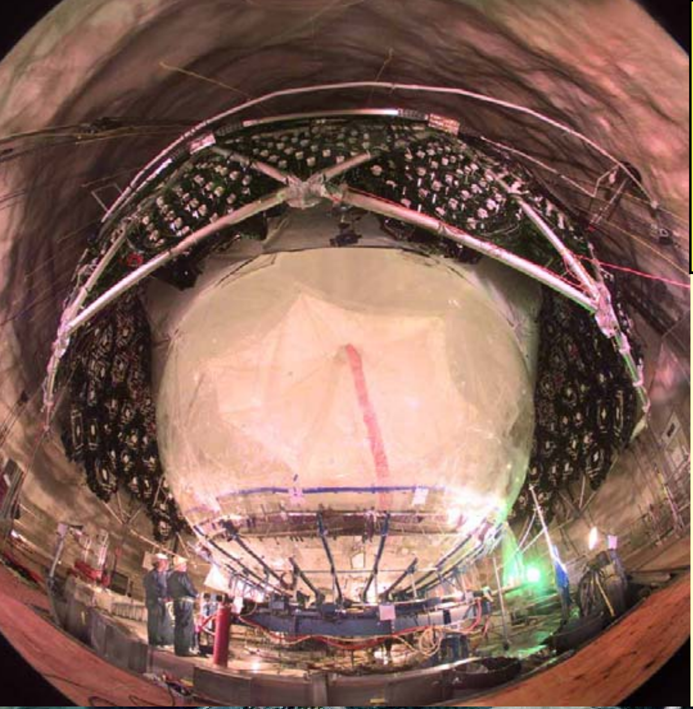


Creighton mine
Sudbury, CA

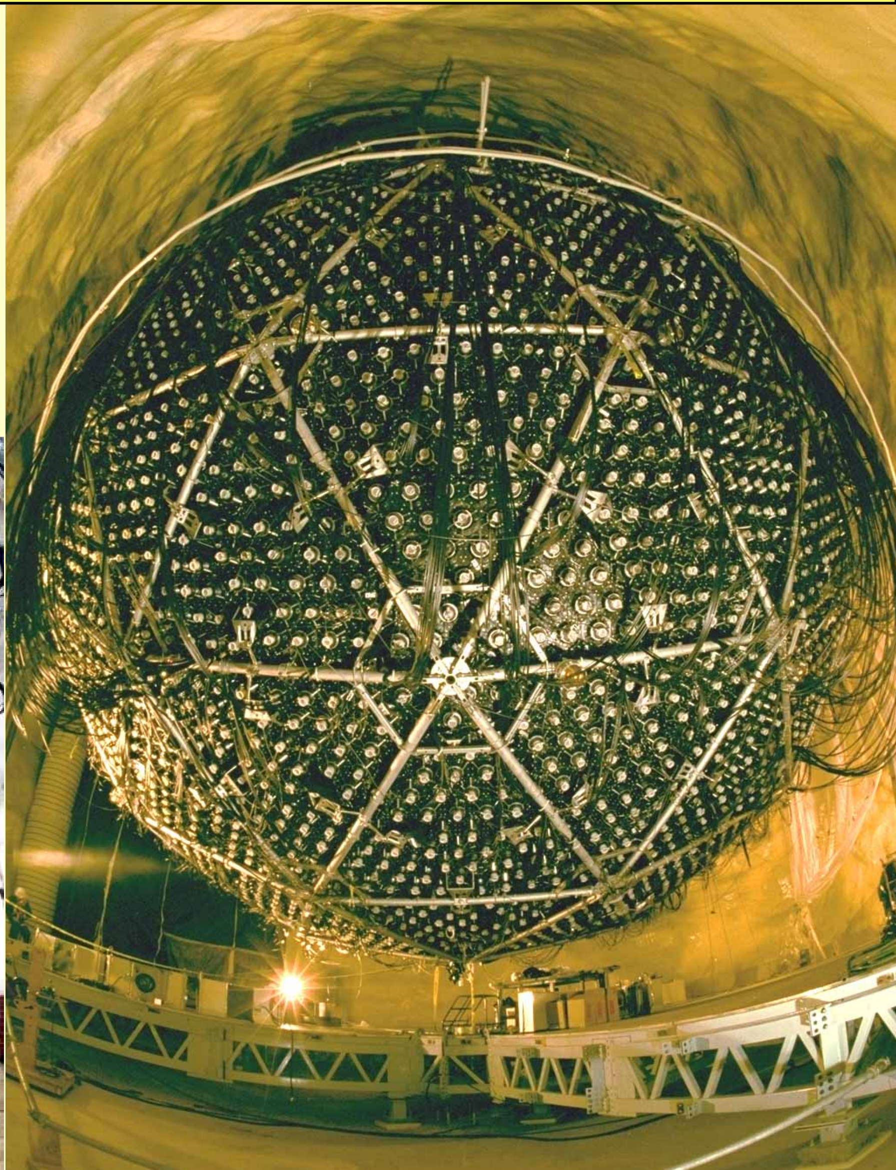
- Entire laboratory
Built as a Class 2000
Clean room
- Low Radioactivity
Detector materials

The heavy water has been returned and development work is in progress on SNO+ with liquid scintillator and ^{150}Nd additive for double beta decay.

SNO: One million pieces transported down in the 9 ft x 12 ft x 9 ft mine cage and re-assembled under ultra-clean conditions. Every worker takes a shower and wears clean, lint-free clothing.



Over 70,000 Showers to date and counting



Surface Facilities


Lab
Entrance


Personnel
Facility


Ladder
Lab


Cube Hall


Cryopit

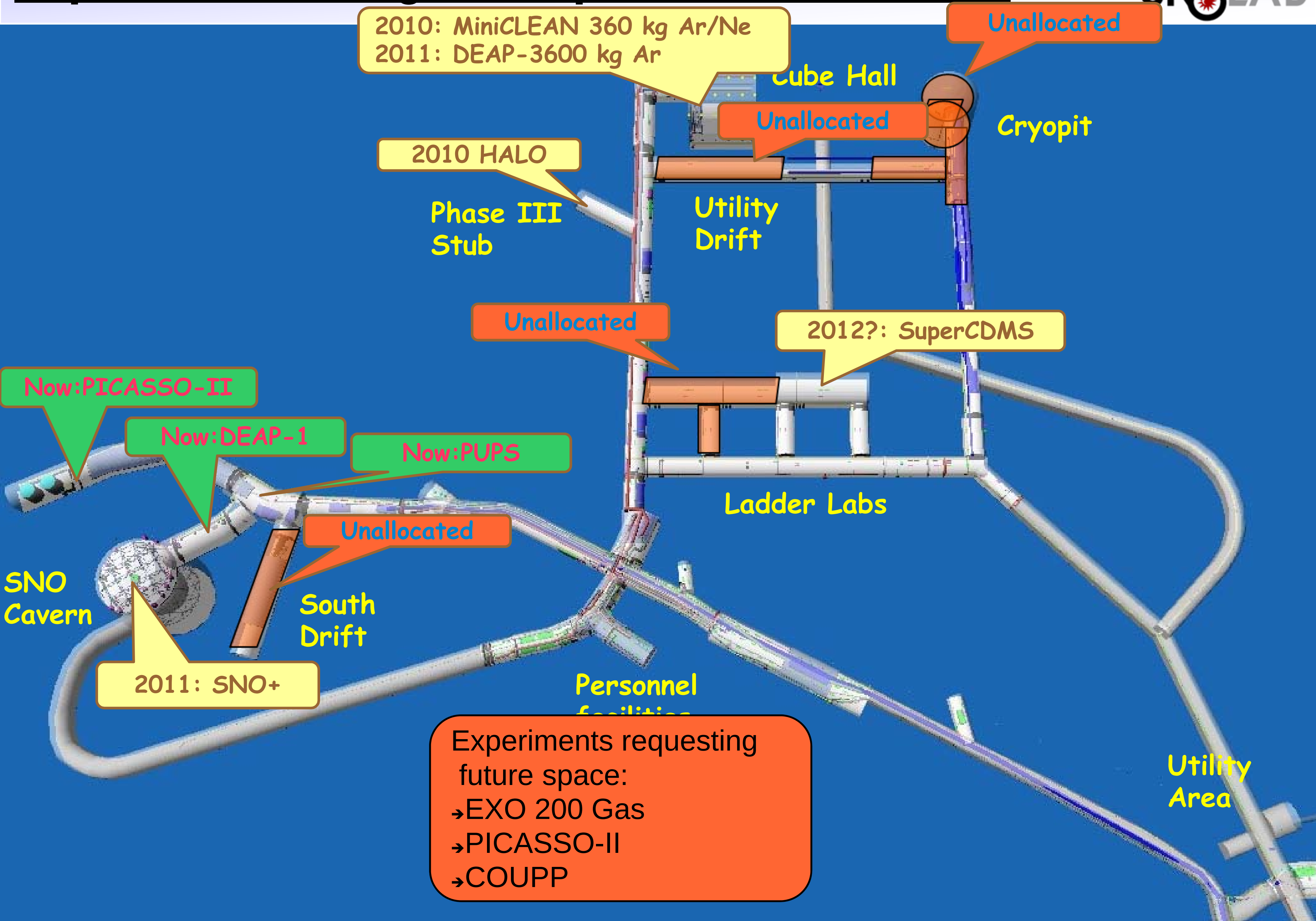
SNOLAB Schedule

- Underground Construction (Cube Hall, Cryopit, Ladder Labs, Lab Entrance)
  - Excavation 100% complete.
  - Outfitting began June 2007. Now essentially complete.
  - Spaces available now for experimental infrastructure installation..
  - Final infrastructure (Chiller, MPC, waste water plant) commissioned
  - Commissioning and final cleaning started in November, 2008. Ongoing with installation of experiments.
- Surface Facility
  - Operational since 2005
- Experimental Program
  - Initial assignments of space underground.
  - Current allocations to: PICASSO, DEAP I, SNO+, DEAP-3600, MiniCLEAN SuperCDMS, HALO.
  - July: CFI funding for DEAP-3600, SNO+: $26.4 Million (incl/matching)
  - Anticipated or under discussion: EXOgas 200, COUPP, 2-phase LAr, low background counters to measure ^{39}Ar, future Cobra upgrade…

SNOLAB Experimental Program

Experiment	Solar Nu	0nuBB	Dark Matter	Super nova	GeoNu	Other	Space Allocated	Status
SNO+	X	X		X	X		SNO Cavern	Install 2009
PICASSO			X				SNO Utility Room	Running
DEAP-1			X				SNO Control Room	Running
MiniCLEAN 360			X				Cube Hall	Install 2009
DEAP 3600			X				Cube Hall	Install 2009
EXO		X						Install 2010?
SuperCDMS			X				Ladder Labs	Install 2010?
HALO				X				Install 2009
PUPS						Seismic	Various Locations	Running

Experimental Program: Operational Schedule



Experiments requesting future space:

- EXO 200 Gas
- PICASSO-II
- COUPP

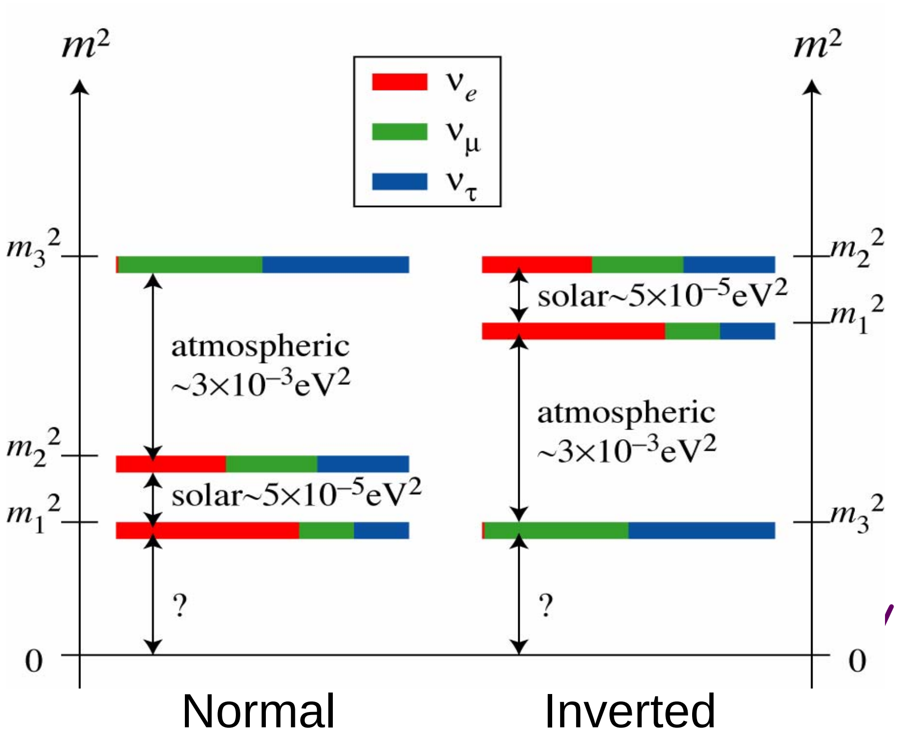
Neutrino-Less Double Beta Decay

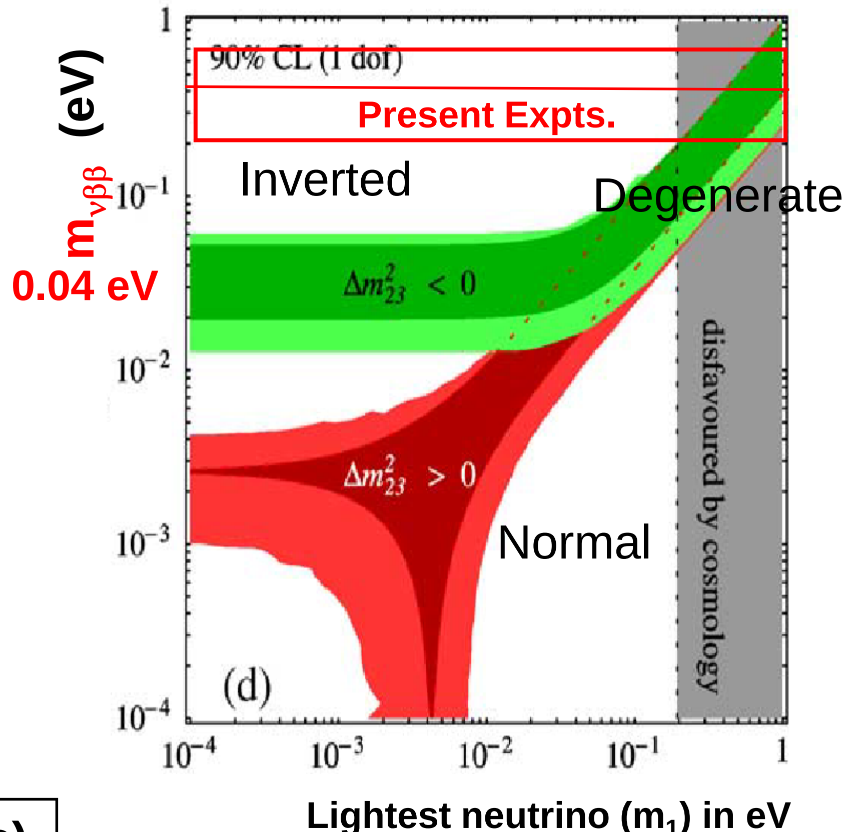
$$T_{1/2} = F(Q_{\beta\beta},Z)\ |M^{0\nu}|^2\ \langle m_{\nu\beta\beta}\rangle^2$$

$$m_{\nu\beta\beta} = |\textstyle\sum_i U_{ei}^{\ 2}\ m_i\ |$$

$$m_{\nu\beta\beta} = |m_1 \cos^2\theta_{13}\cos^2\theta_{12} + m_2\ e^{2i\alpha}\cos^2\theta_{13}\sin^2\theta_{12} + m_3\, e^{2i\beta}\sin^2\theta_{13}|$$

Mass Hierarchies





SNOLAB: ^{150}Nd (SNO+), ^{136}Xe (EXO-gas)

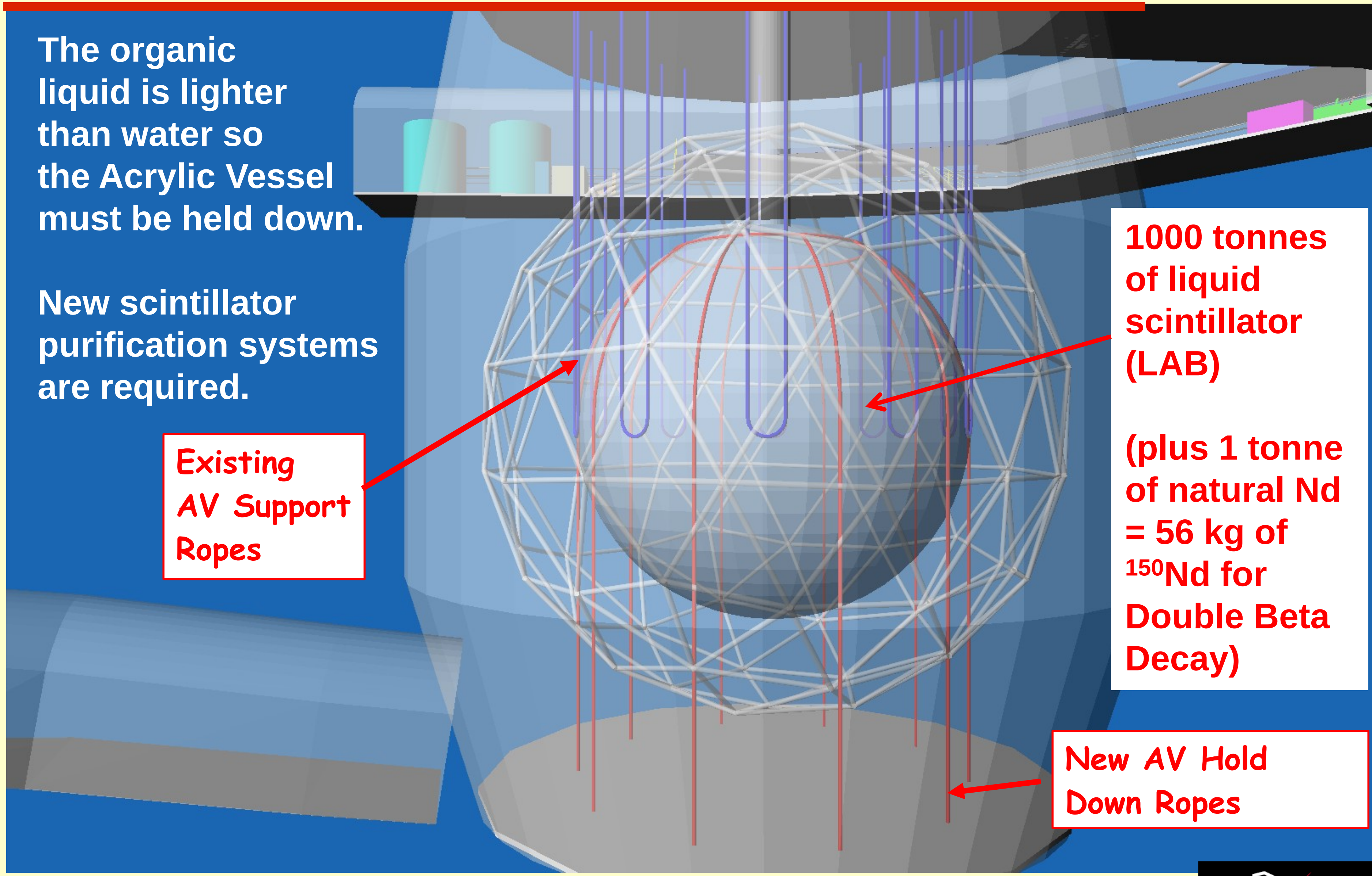
SNO+: Neutrino-less Double Beta Decay: ^{150}Nd

- Nd is one of the most favorable double beta decay candidates with large phase space due to high endpoint: 3.37 MeV.
- Ideal scintillator (Linear Alkyl Benzene) has been identified. More light output than Kamland, Borexino, no effect on acrylic.
- Nd metallic-organic compound has been demonstrated to have long attenuation lengths, stable for more than 2 years.
- 1 tonne of Nd will cause very little degradation of light output. (Successful test in 2008 with small chamber in center of SNO)
- Isotopic abundance 5.6% (in SNO+ 1 tonne Nd = 56 kg ^{150}Nd)
- Possible enrichment of ^{150}Nd or perhaps increase in the amount of natural Nd via nanoparticles.
- SNO+ Capital proposal fully funded.
- Plan to start with natural Nd in 2011.
- Other physics: CNO solar neutrinos, pep solar neutrinos to study neutrino properties, geo-neutrinos, supernova search.

  (No ^{11}C background at this depth.)

(See talks by Kraus, Peeters in parallel sessions)

SNO+ : Liquid Scintillator with Nd for Double Beta Decay + Solar, geo - ν



Otherwise, the existing detector, electronics etc. are unchanged.

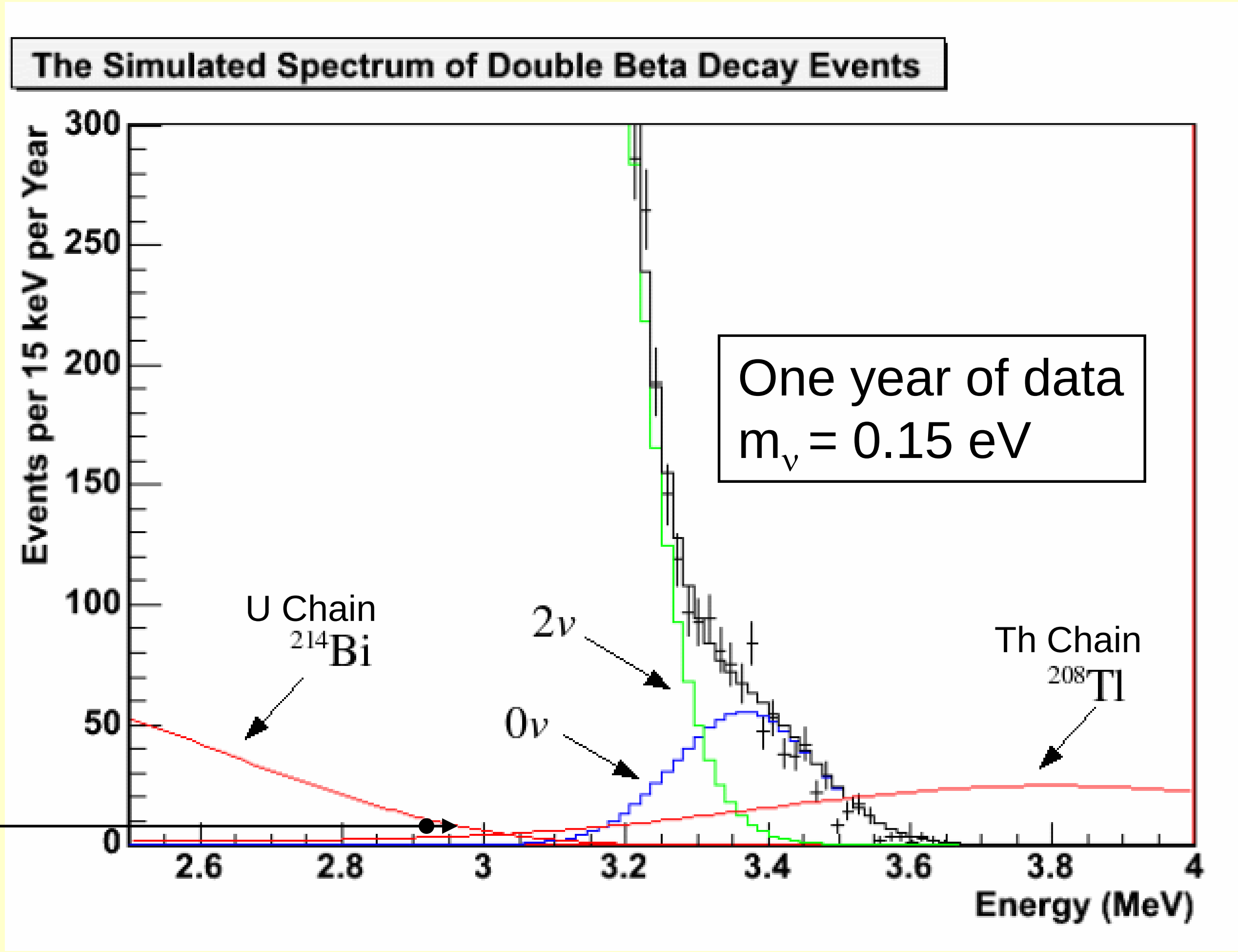
SNOLAB Mining for knowledge Creuser pour trouver... l'excellence

SNO+ (^{150}Nd ν - less Double Beta Decay)

0ν: For example: 1057 events per year with 500 kg ^{150}Nd-loaded liquid scintillator in SNO+.

Simulation assuming light output and background similar to Kamland. (Borexino has done better)

~Flat ^{8}B Solar ν "background"



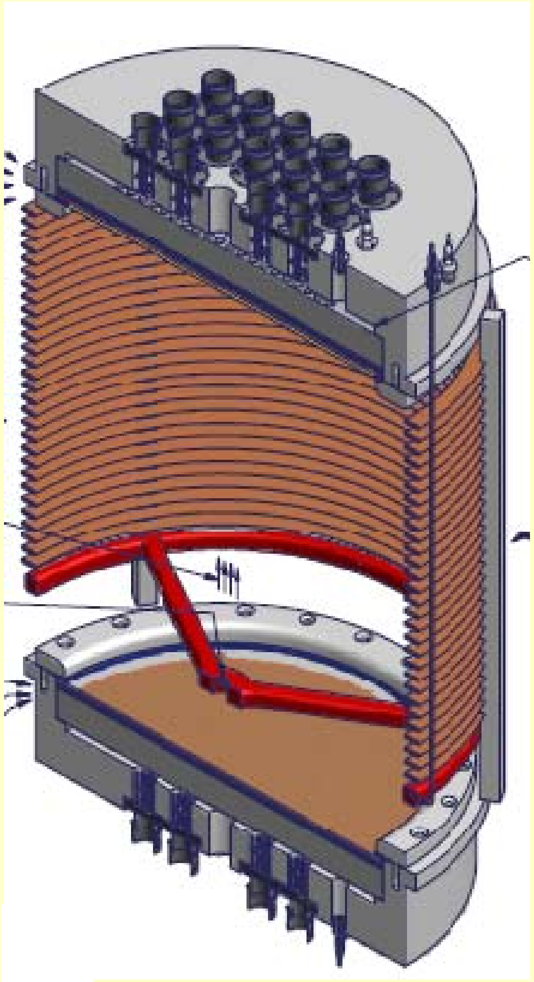
Sensitivity Limits (3 yrs):
1000 kg natural Nd (56 kg isotope): $m_{\nu\beta\beta}$ ~ 0.1 eV (start 2011)
With 500 kg ^{150}Nd: $m_{\nu\beta\beta}$ ~ 0.04 eV

EXO-gas R & D

• Part of the EXO double beta decay collaboration, led by David Sinclair of Carleton, in addition to their work on a 200kg liquid ^{136}Xenon detector, is working on R&D for a pure Xe gas detector, with observation of the double beta decay via electroluminescence and extraction of the Ba daughter ions and identification via mass spectrometry.

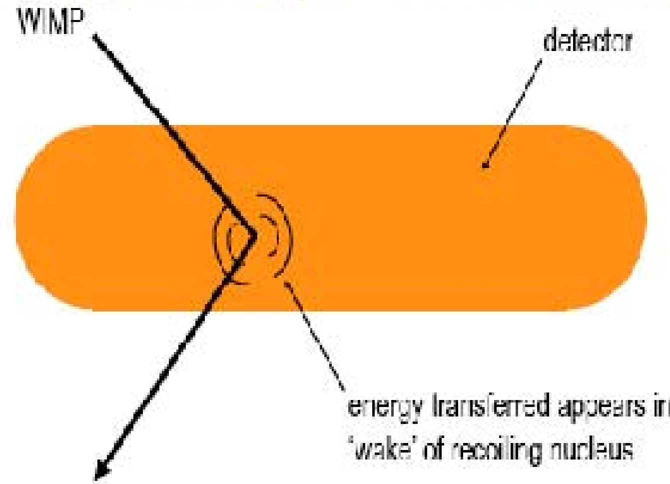
• Electroluminescence will be detected by a design being developed with CsI that is based on the FERMILAB RICH counters.

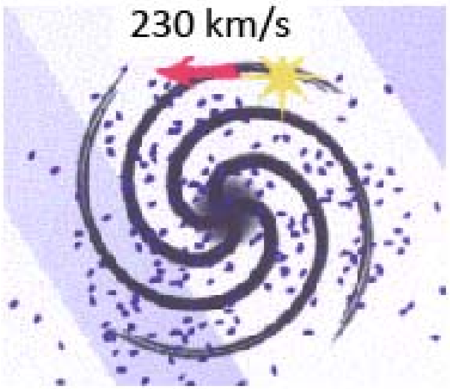
• Extraction and mass spectrometry of the Ba ions will build on a successful design in operation at the Leuven Radioactive Beam Source.

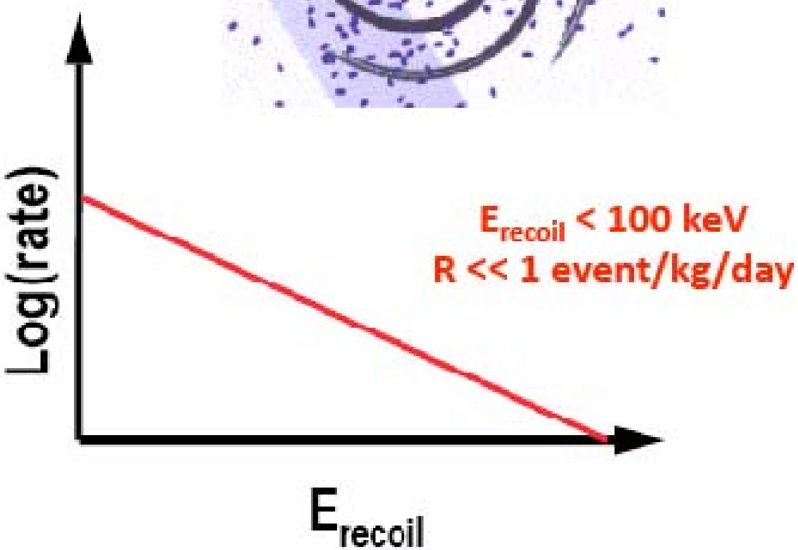


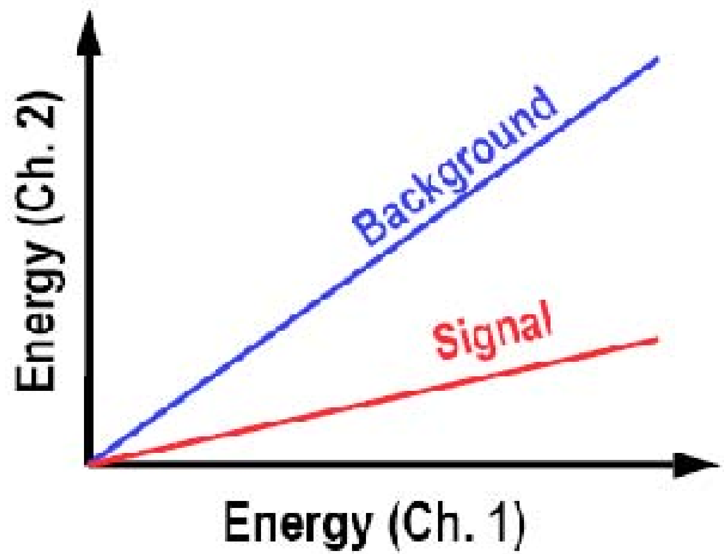
Direct Dark Matter Detection

Surfing Through the WIMP-WIND









Variety of techniques used to discriminate: Light, Heat, Ionization, bubbles

Dark Matter at SNOLAB

Noble Liquids: Deap I, MiniClean-360, & DEAP-3600 :

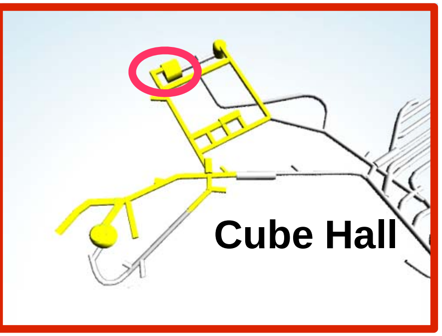
- Single Phase Liquid Argon or Neon.
- Uses pulse shape discrimination (PSD) based on timing of decay light
- Prototype DEAP I Installed in SNOLAB now. Very successful demonstration of PSD. To be followed by MiniClean, DEAP-3600
- Will measure Spin Independent cross-section.

Superheated Liquids: PICASSO, COUPP

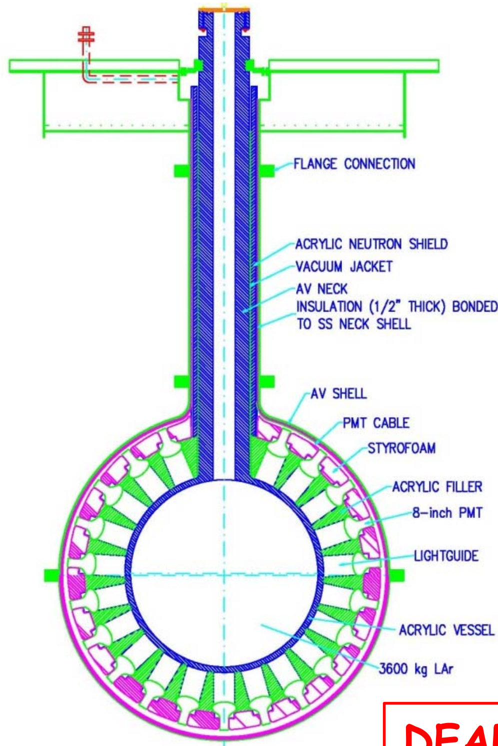
- Superheated droplet detector. Insensitive to minimum ionizing radioactive background at operating temperature.
- PICASSO Currently Operational in existing SNO lab. Next phase will need SNOLAB space. COUPP has requested space for 60 kg detector
- Will measure Spin Dependent and Independent cross-sections.

Solid State: SuperCDMS

- State of the art Ge crystals with ionization and phonon readout.
- Currently operational in Soudan. Next phase will benefit from SNOLAB depth to reach desired sensitivity.
- Primary sensitivity for Spin Independent cross-section.

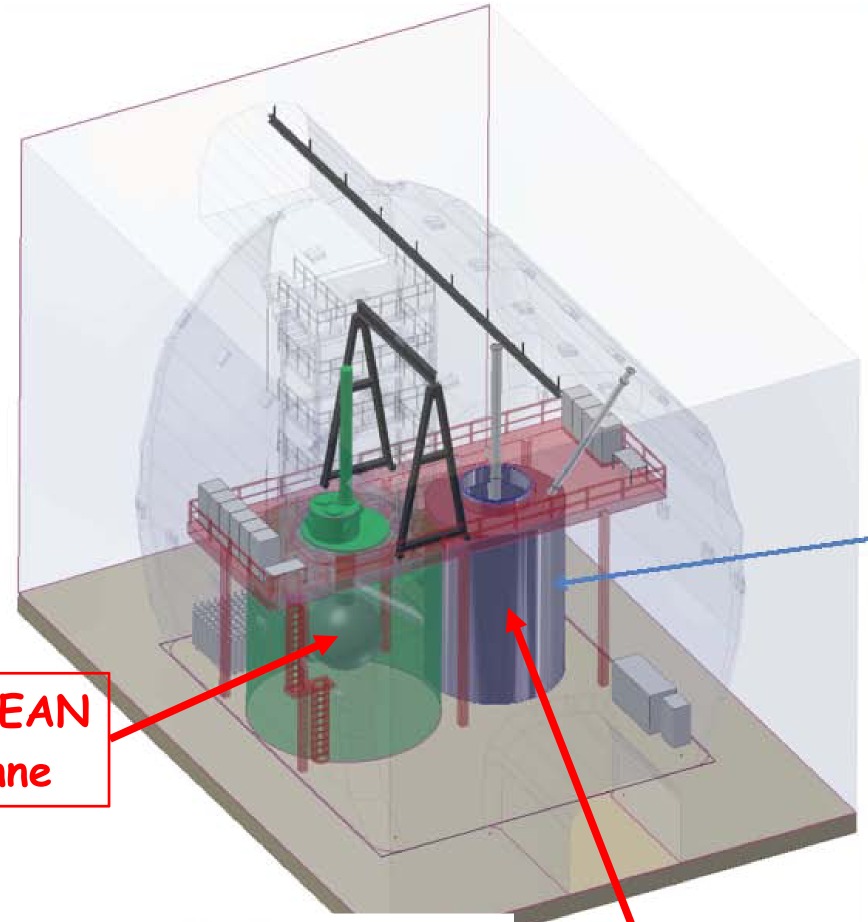


Cryogenic Liquid Detectors



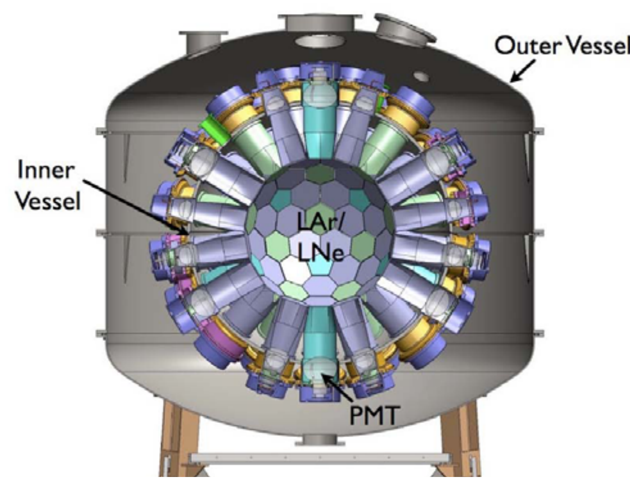
Dark Matter Search with Liquid Argon: DEAP-1 (7 kg Ar) (Running); Future: Mini-Clean (360 kg Ar or Ne) and DEAP-3600 (3.6 tonnes Ar)

WIMP-Induced Nuclear recoils in Ar are discriminated from beta and gamma radioactivity (^{39}Ar) by timing of the light emitted.

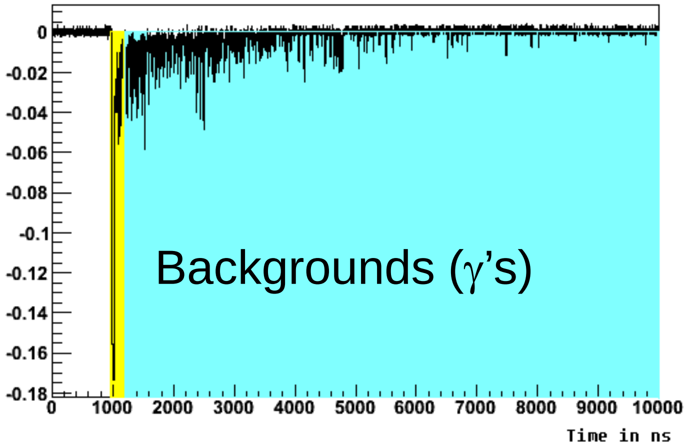


DEAP/CLEAN
3.6 tonne

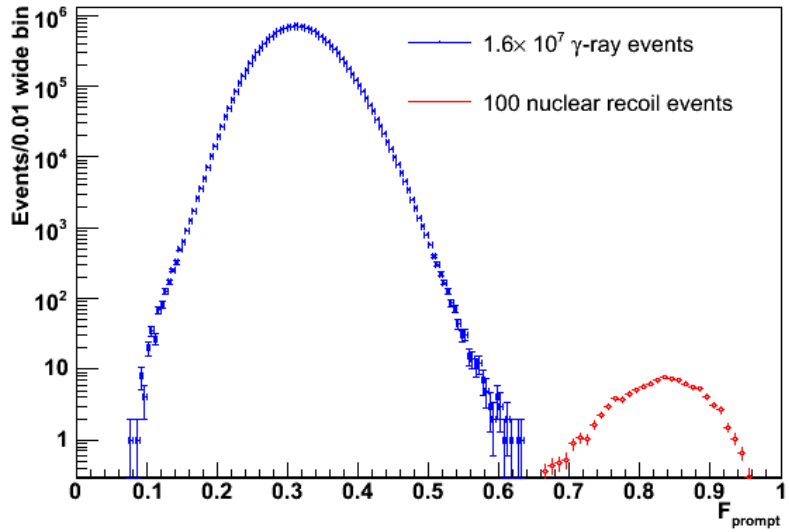
MiniCLEAN
360 kg



Dark Matter Search at SNOLAB with Liquid Argon

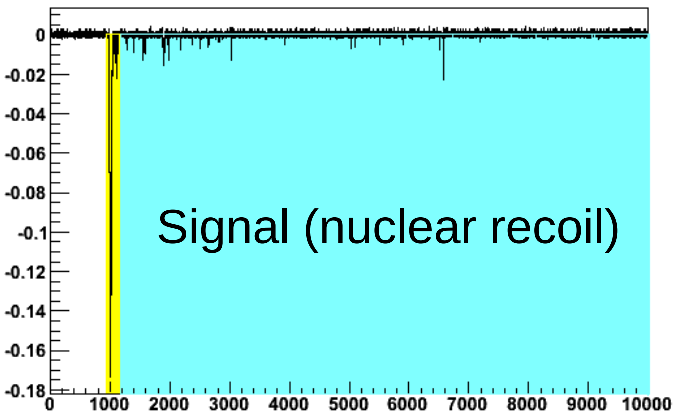


Yellow: Prompt light region
Blue: Late light region

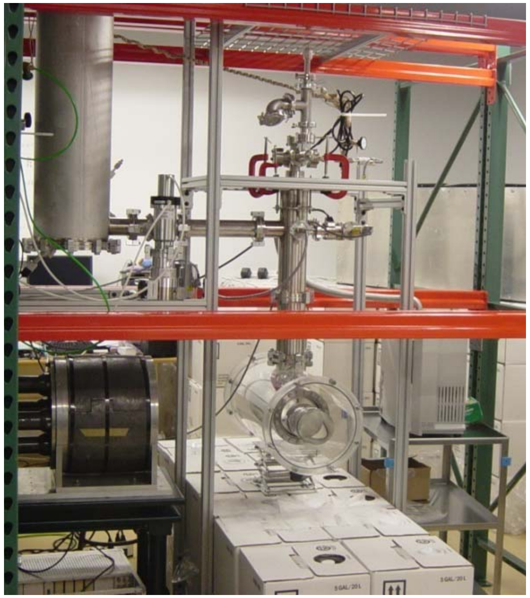


Background suppression better than 2.6 E-8 demonstrated to date with DEAP-1

DEAP-1 at SNOLAB 7 Kg Liquid Ar



$$F_{prompt} = \frac{\text{PromptPE}(150\text{ns})}{\text{TotalPE}(9\mu\text{s})}$$



For DEAP - 3600 suppression of > 10^{-9} is required for ^{39}Ar in atmospheric Ar.

Note also that sources of Ar depleted x 20 in ^{39}Ar have been found and are being developed with the Princeton group.

CDMS Cryogenic Ge detectors: Measure Temperature and Ionization

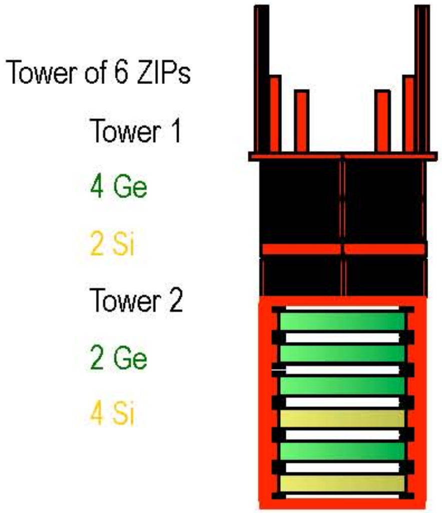
Detectors with excellent event-by-event background rejection

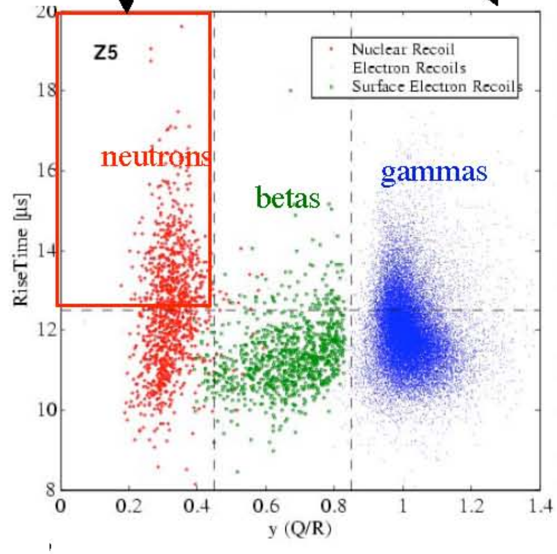
Use charge/phonon AND phonon timing

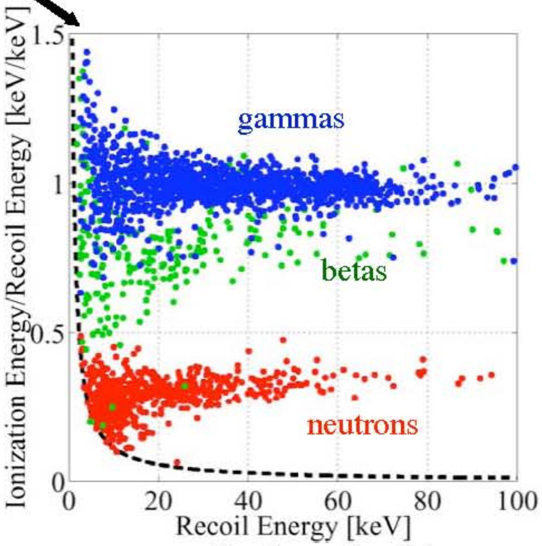
Measured background rejection:

99.9998% for γ's, 99.79% for β's

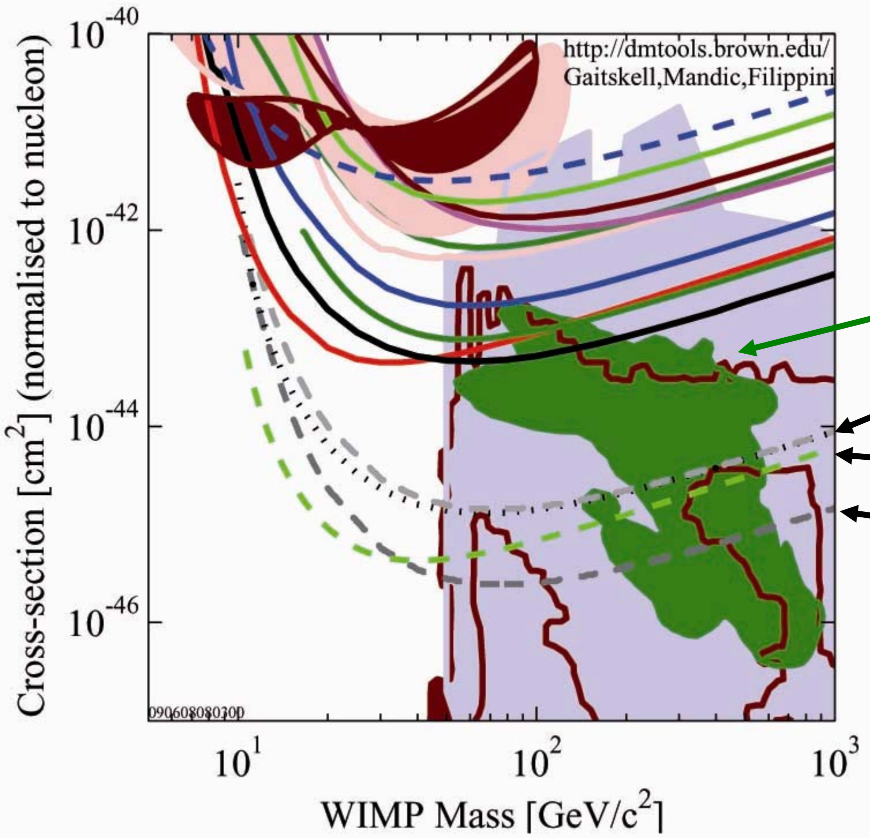
Clean nuclear recoil selection with ~ 50% efficiency







Dan Bauer - Fermilab



Predictions:
Minimal Super-Symmetric Models

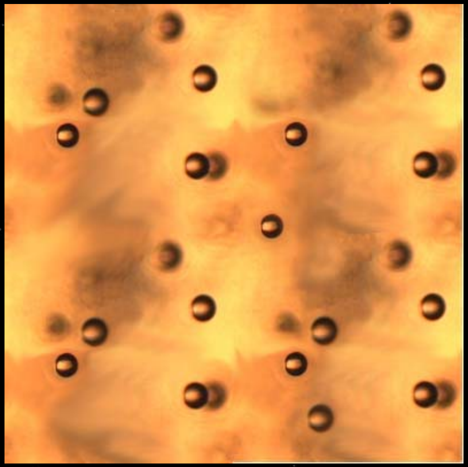
SuperCDMS, MiniClean @ SNOLAB
LUX @ Sanford LAB
Deap 3600 @ SNOLAB

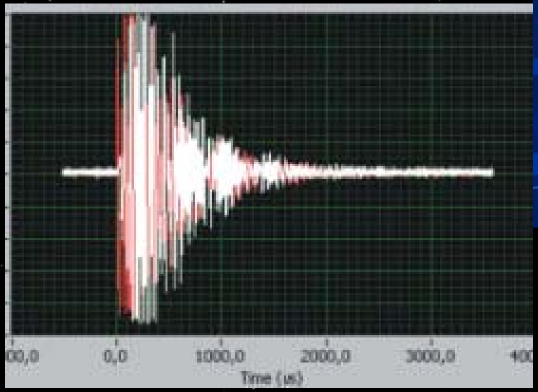
Physics Reach:

Spin-Independent Interactions

PICASSO detectors: Spin-dependent Interactions

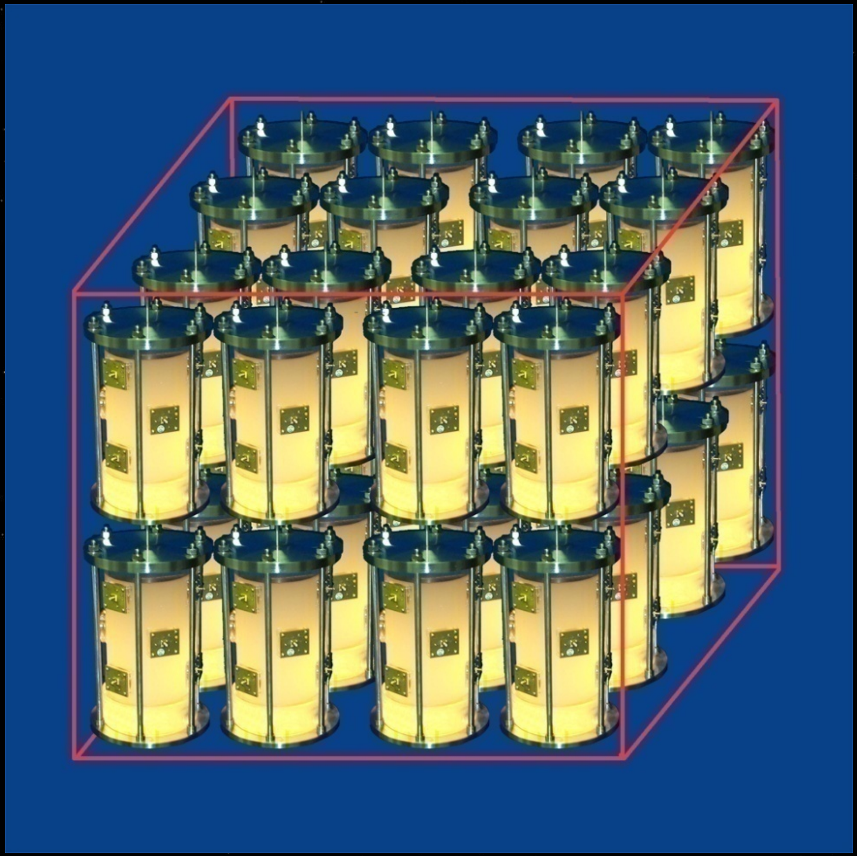
- Super heated C_4F_{10} droplets
  - 200um,
  - held in matrix in polymerized gel
  - act as individual bubble chambers
- When MIP deposits energy
  - F^{19} recoils: Large sensitivity
  - Superheated liquid vaporizes forming small bubbles along MIP's track
  - Bubbles grow, turning entire C_4F_{10} droplet to vapour
  - resulting acoustic signal registered by piezo electric sensors
  - Demonstrated ability to discriminate between WIMP recoils and alpha background radioactivity





PICASSO detector status

- Now Complete
  - 32 detectors, 9 piezos each
  - total active mass of 2248.6g
  - 1795.1g of Freon mass
  - Temperature & Pressure control system
- 40 hr data taking
- 15hr recompression

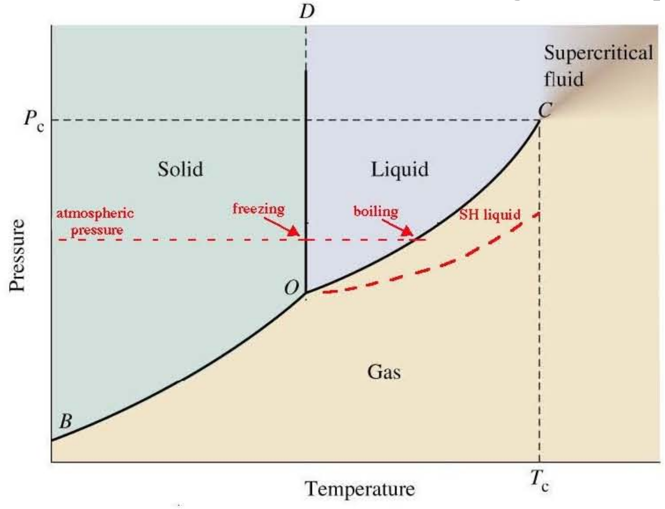


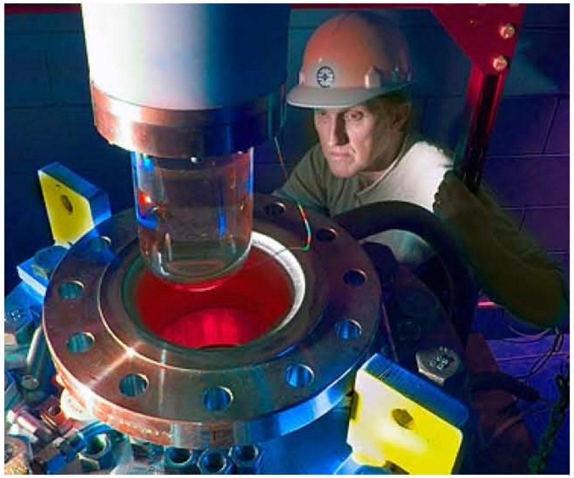
COUPP

Using a bubble chamber for WIMP detection

- "COUPP" = Chicagoland Observatory for Underground Particle Physics:
  - University of Chicago (Juan Collar, Spokesman)
  - Fermi National Accelerator Laboratory
  - Indiana University of South Bend
- Revives the reliable technology of bubble chambers for the pursuit of dark matter
- The detector is extraordinarily insensitive to electron recoil events
- Technology can be extrapolated to very large detector masses

Uses CF3I to obtain sensitivity to spin dependent and independent interactions



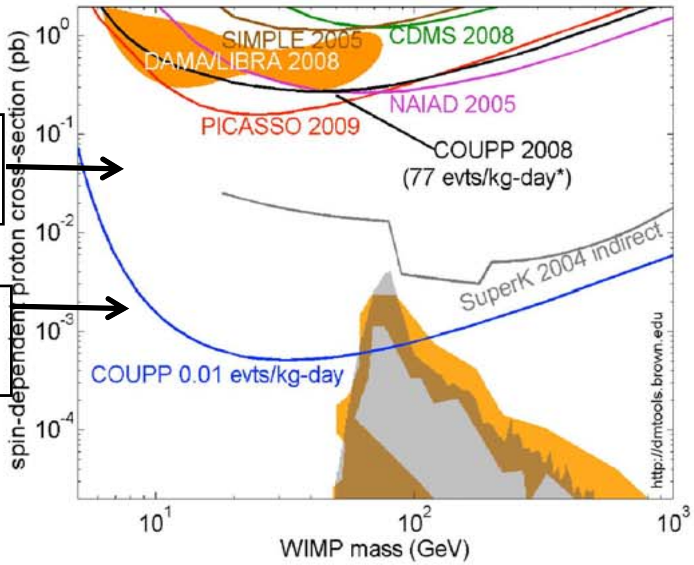


COUPP-60 Projected Limits

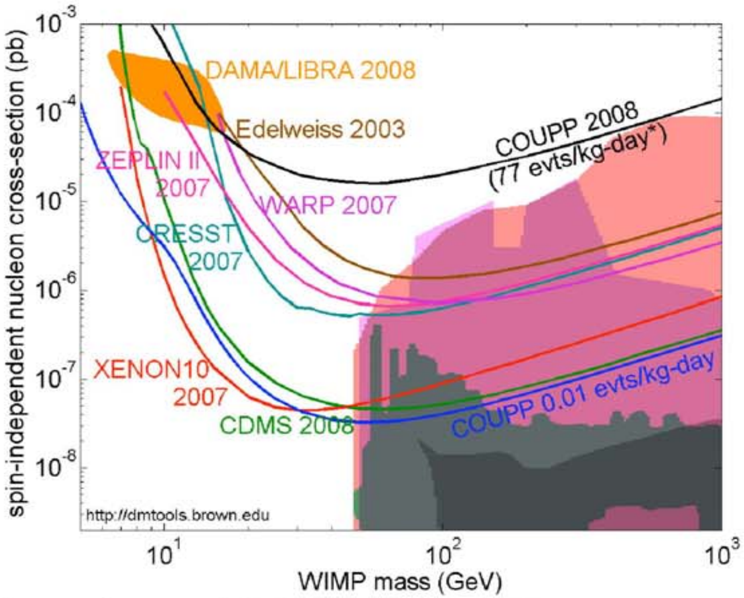
Spin-dependent proton:

PICASSO Phase Ib

PICASSO Phase II



Spin independent:



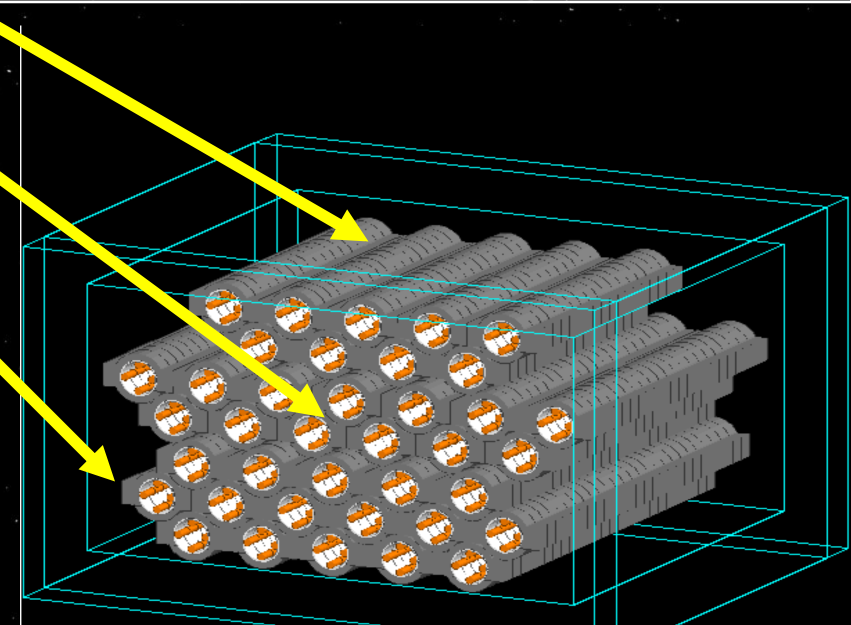
(Projected limits assume no background subtraction and 8 KeV threshold)

If fluid purity is improved and acoustic discrimination works, then 0.01 events/kg-day is quite achievable at SNOLAB

H elium **A** nd **L** ead **O** bservatory

Pb: Most sensitivity to electron neutrinos.
~ 50 events for SN at center of Galaxy.

HALO: A lead detector for supernova neutrinos in SNOLAB

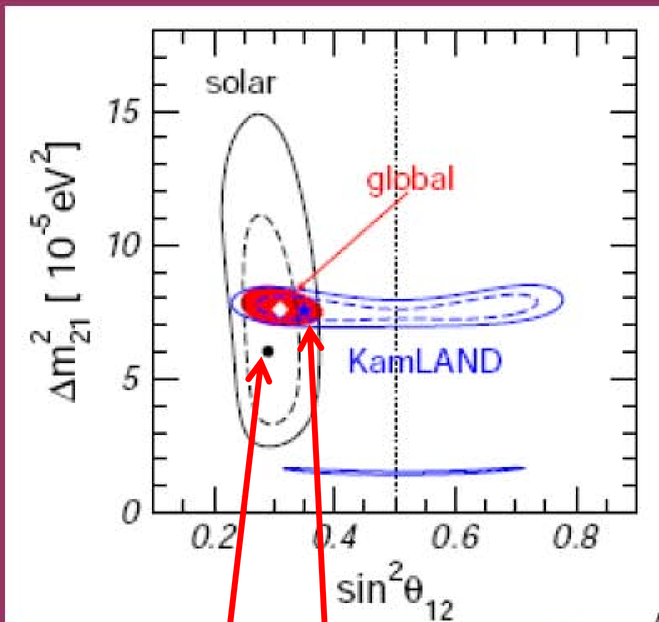


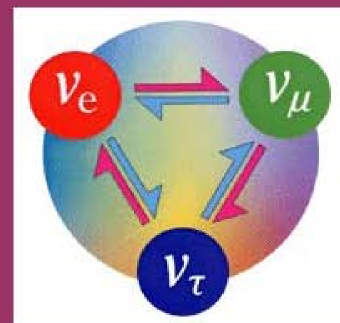
HALO-1: 80 tons of existing Pb
& SNO Neutron Detector Array

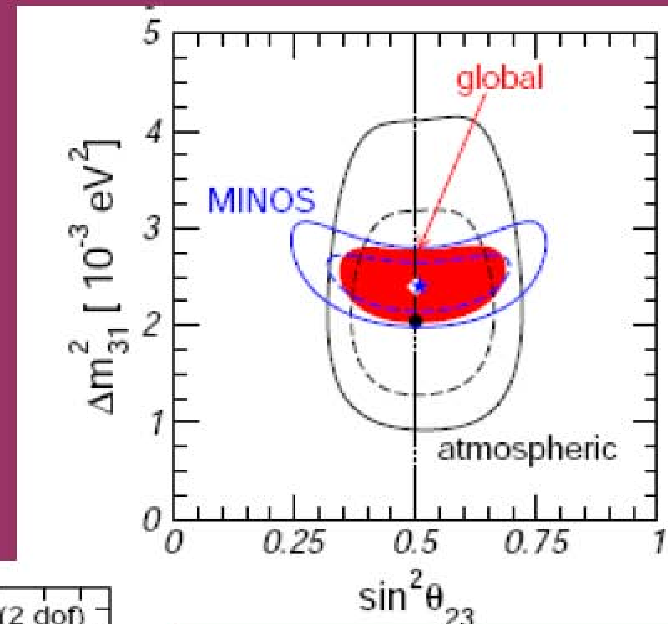
NEUTRINO OSCILLATIONS 2009

Maltoni et al, NJP 6 (2004) 122

Schwetz et al, NJP 10 (2008) 113011





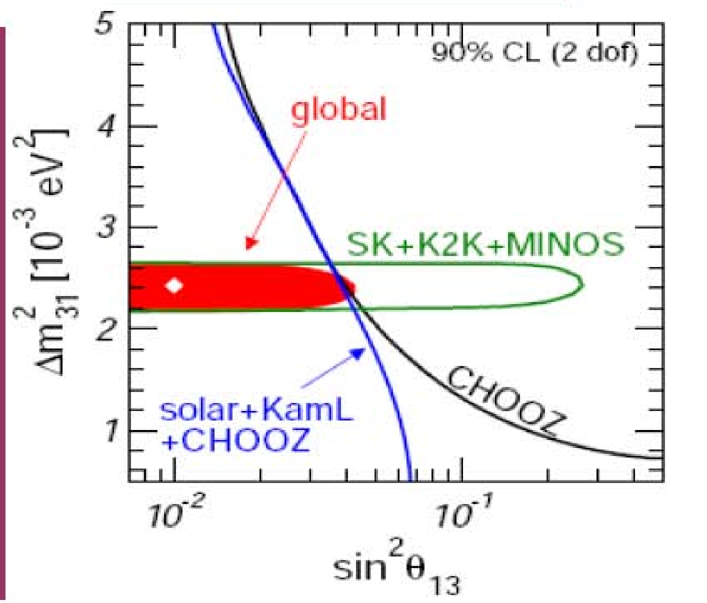


Note small tension: SNO vs KamLAND

Homestake, SAGE+ GALLEX/GNO, Super-K, SNO

Borexino

KamLAND (180 Km)



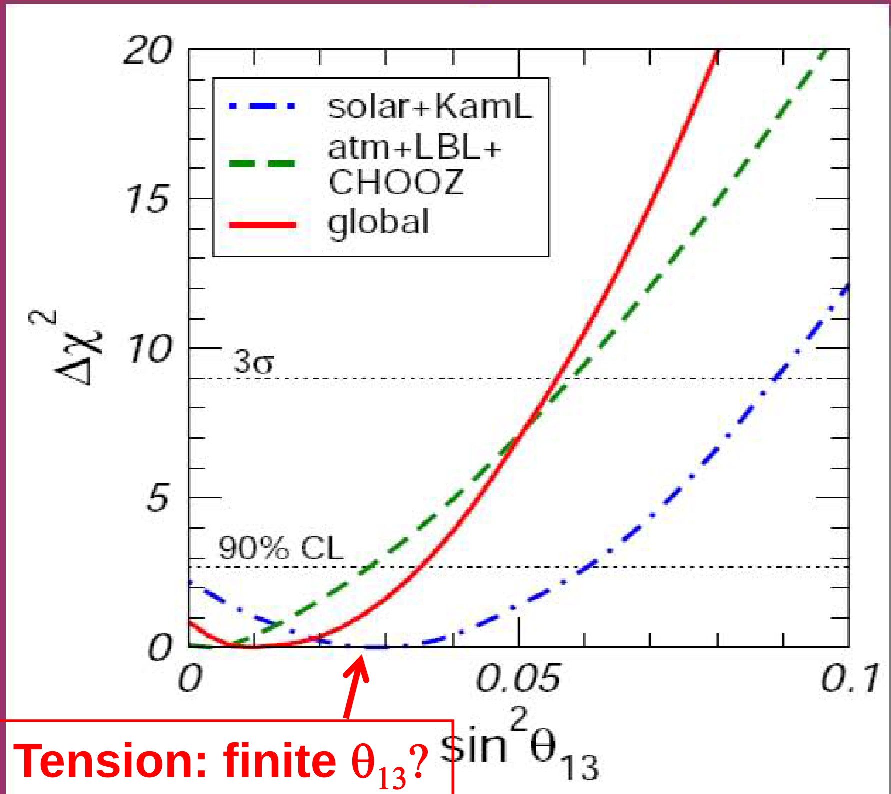
... Super-K

K2K (250 Km)

MINOS (735 Km)

STATUS OF THETA13

Schwetz et al NJPhys.10:113011,2008



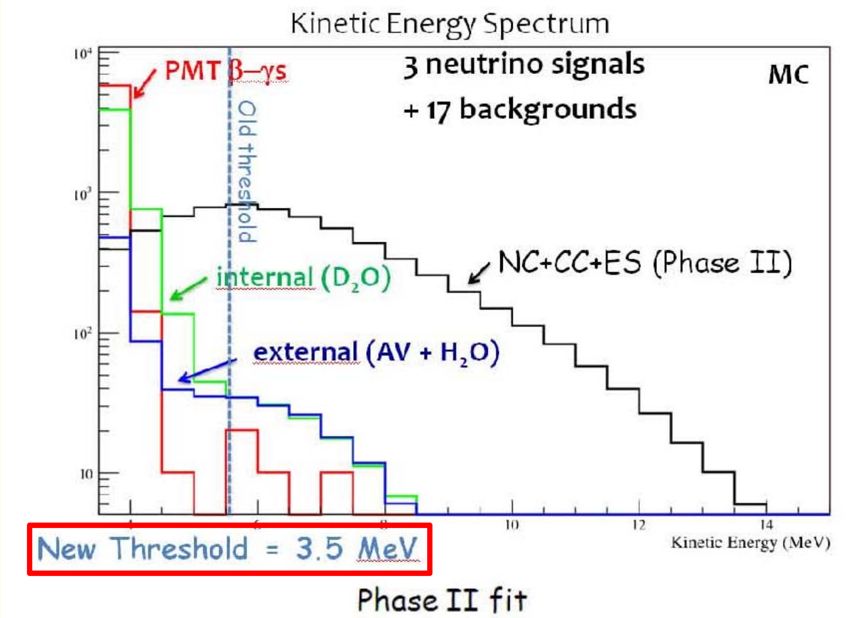
c.f. Fogli et al, 2008 & MINOS

$$\sin^2\theta_{13} \leq \begin{cases} 0.060\ (0.089) & \text{(solar+KamLAND)} \\ 0.027\ (0.058) & \text{(CHOOZ+atm+K2K+MINOS)} \\ 0.035\ (0.056) & \text{(global data)} \end{cases}$$

Valle@TAUP09 03/07/2009

New SNO analysis soon with lower threshold, smaller uncertainties on CC/NC so $\sin^2\theta_{12}$. Hence also $\sin^2\theta_{13}$

Talks by N. de Barros, A. Hallin



With lower threshold:
CC events(electron ν) up by 20%
NC events (all active ν) up by 70%

Systematic uncertainties better defined so overall accuracy for CC/NC much better

CONCLUSIONS

- **SNO analysis is nearly complete and new more accurate results will be submitted for publication very soon.**

- **SNOLAB construction is complete and major areas are clean and ready for use.**

- **WE ARE WELCOMING THE WORLD FOR NEXT GENERATION EXPERIMENTS REQUIRING THE LOWEST COSMIC RAY BACKGROUNDS AND ULTRA-CLEAN CONDITIONS.**