Looking for Needles in Haystacks: **SNOLAB Experiments**

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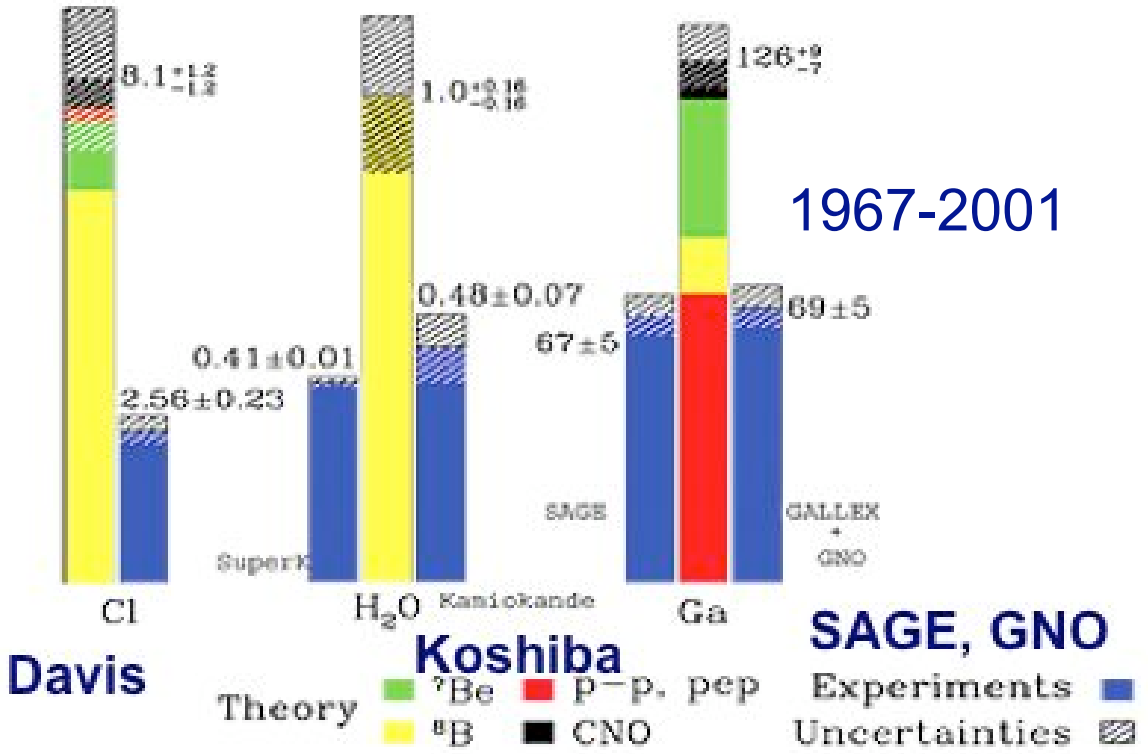
Many thanks to SNOLAB and the various experiments for providing material for this presentation (in particular M Boulay, M Chen, J Farine, N Fatemighomi, A Hime, A McDonald, MC Piro, NJT Smith, C Virtue, V Zacek)

Early SNO and the Solar Neutrino Problem

- Sun produces electron neutrinos ν_e
- Experiments measure mainly ν_e



1967-2001

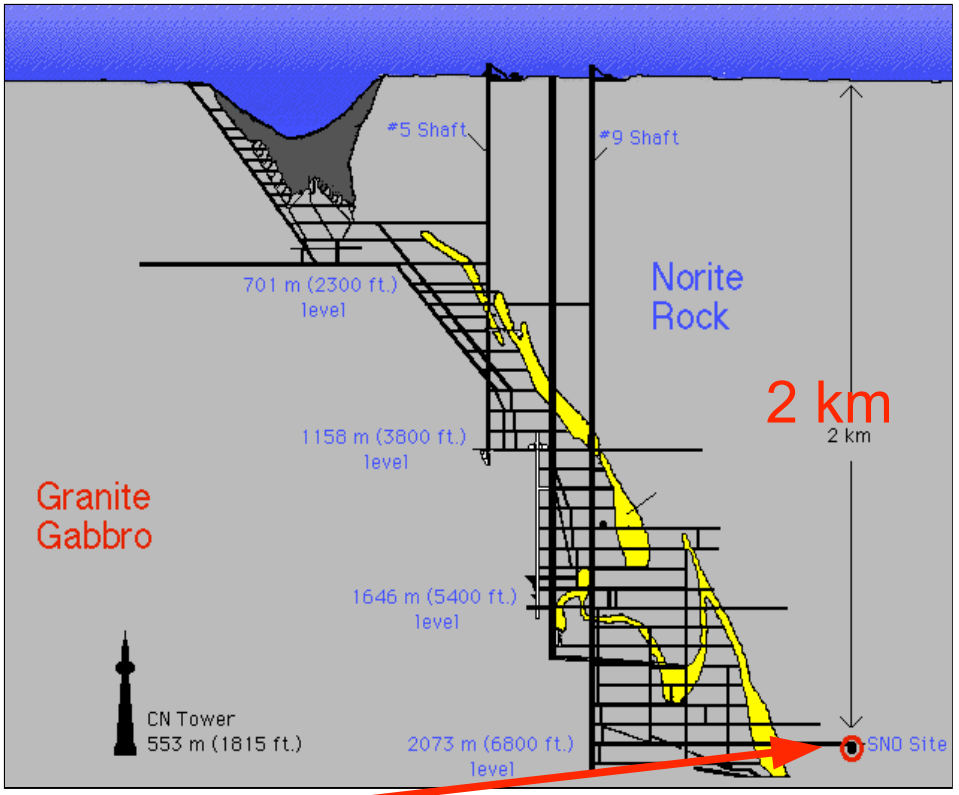
- The Sudbury Neutrino Observatory (SNO, 1998-2006):
  - Water Cerenkov detector
  - 1 kT heavy water measured:
    - Electron neutrinos:
      - Charged current (CC) on deuteron
      - Elastic scattering (ES) on e^-
    - All neutrinos:
      - Neutral current on deuteron
      - Some ES on e^-

- Where did the neutrinos go ?
  - Solar physics ?
  - Particle physics ?

- Validated solar models
- Demonstrated ν change flavors: ν oscillations

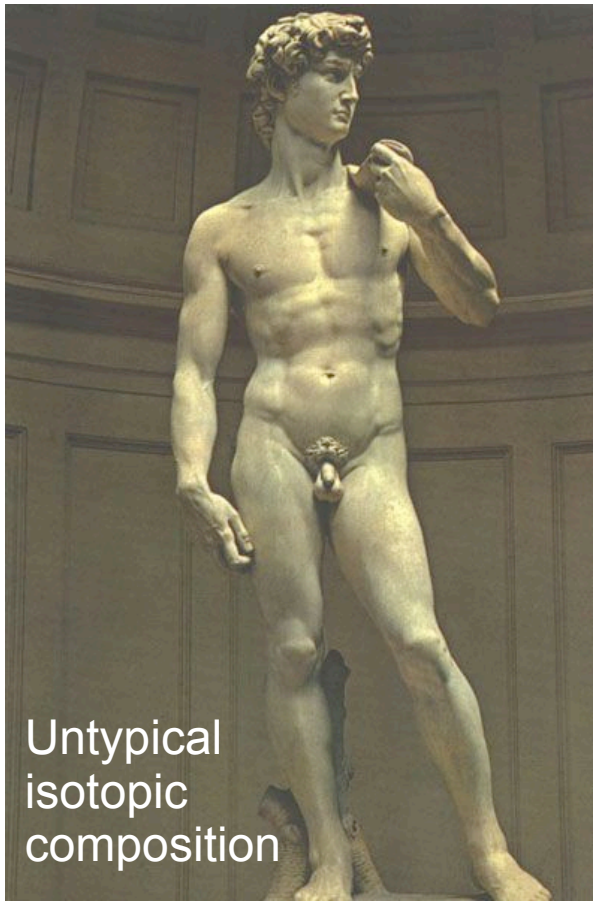
SNO Underground

- SNO observed O(1) CC evt/T/year
- Would have been impossible at Earth's surface (eg 1 cosmic muon/cm^2/mn)
- Was possible
  - in the Creighton mine, Sudbury,ON



Example of ambient radioactivity: human

- Typical human radioactivity: 8 kBq

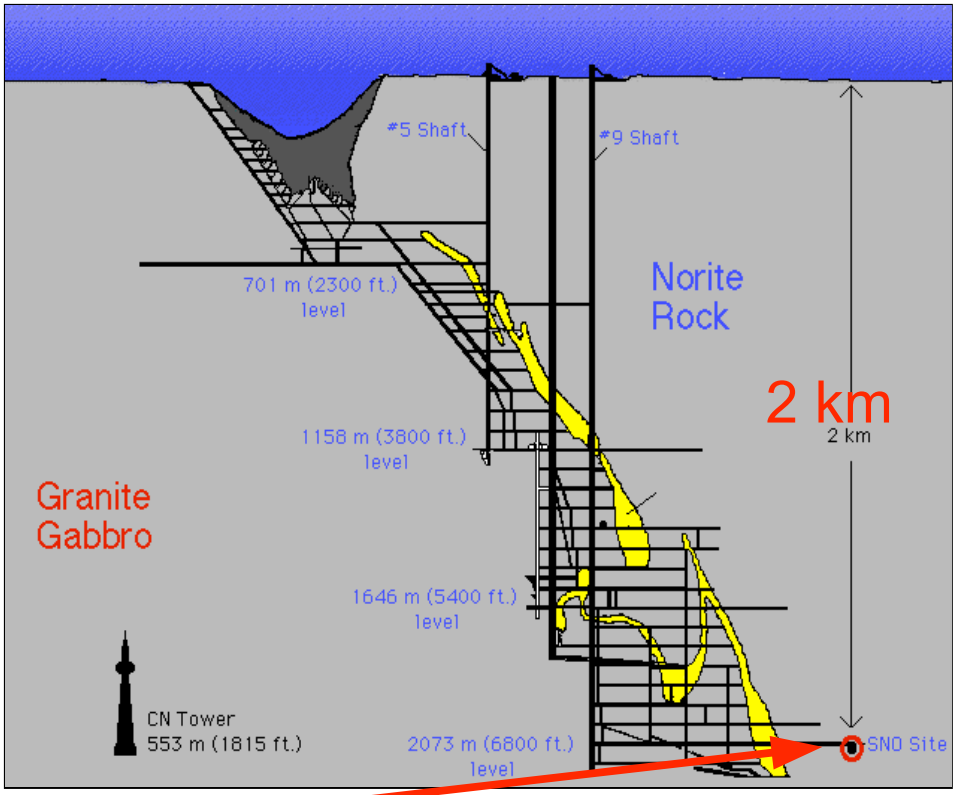


- Main contributions:
  - ^{40}K: $T_{1/2} = 1{,}3*10^9$ y
    - 89% β^-: E < 1,3 MeV
    - 11% γ: E = 1,5 MeV
  - ^{14}C: $T_{1/2} = 5730$ y
    - 100% β^-: E < 156 keV

8 kBq/80 kg = 100 disintegrations /s/kg

SNO Underground

- SNO observed O(1) CC evt/T/year
- Would have been impossible at Earth's surface (eg 1 cosmic muon/cm^2/mn)
- Was possible
  - in the Creighton mine, Sudbury,ON
  - and with draconian low-background techniques

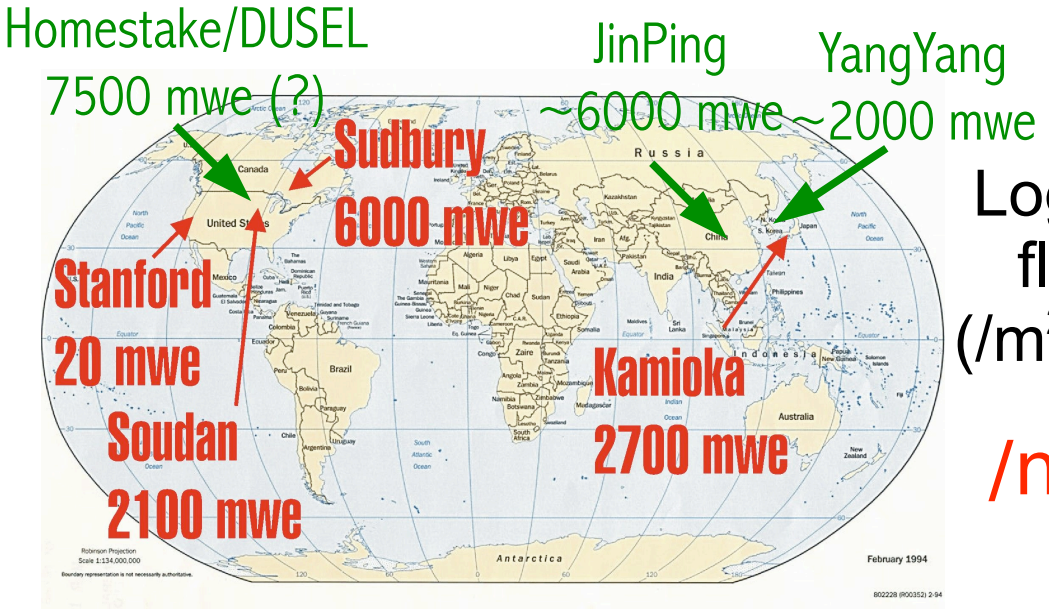


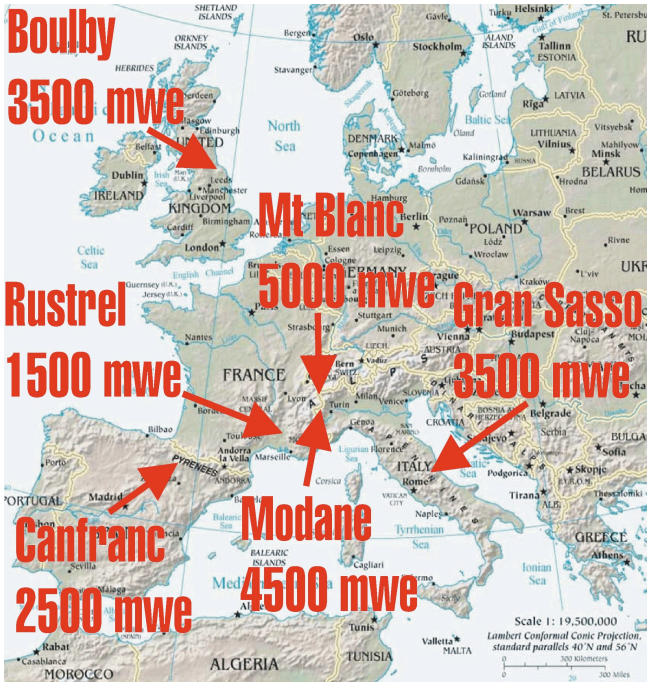
- Experiment housed in clean room ("Over 70000 showers")
- All materials screened for low radioactivity

Building on the success of SNO: SNOLAB

- SNOLAB: expansion around SNO at Creighton mine
- Goal: to provide a deep (6 kmwe), clean (class 2000 cleanroom) environment with infrastructure and engineering support for an international program of astroparticle physics
- Focus: rare event searches (dark matter, solar neutrinos, SN neutrinos, double beta decay …)
- Funding: federal and provincial (NSERC/CFI/MRI/FedNOR)
- Management: partnership between four Universities (Carleton, Queen's, Laurentian, Montréal)
- Schedule: "Final clean" completed March 2011 – inauguration May 2012 (several experiments already underway)
- Backgrounds:
  - Muons: 0.27 /m^2/d
  - Fast neutrons: 4.6 10^{-2} /m^2/s
  - Rn: 130 Bq/m^3

Escaping the Haystack in Mines and Tunnels: Going Underground to Reduce Background



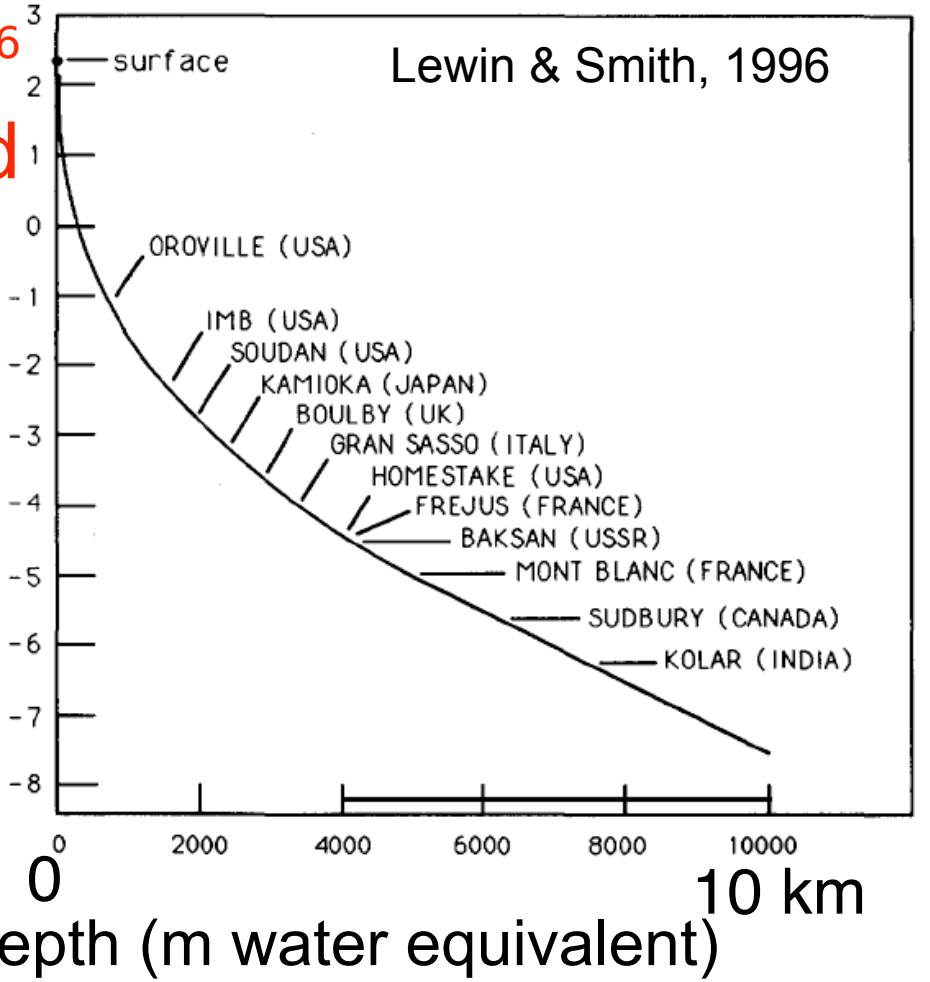


Cosmic muon flux reduced

Log(μ flux) (/m²/s)

10^6 /m²/d

4 /m²/d



DUSEL Delayed ?

17 Dec 2010: Science

U.S. SCIENCE POLICY

NSF Won't Build Underground Lab; Scientists Hope That DOE Will

Plans to convert an abandoned gold mine in South Dakota into the world's largest underground lab may have to be scaled back and could fall apart entirely after the National Science Foundation's (NSF's) oversight board rejected the current proposal.

ity would allow for a suite of physics experiments whose results could be revolutionary, such as searches for particles of the mysterious dark matter whose gravity binds the galaxies and for a kind of radioactivity that would blur the distinction between matter

Feb 2011: President's FYI 2012 budget:

TERMINATION: DEEP UNDERGROUND SCIENCE AND ENGINEERING LABORATORY

National Science Foundation

The Administration proposes to eliminate National Science Foundation (NSF) funding for pre-construction planning and design for the proposed Deep Underground Science and Engineering Laboratory (DUSEL) because the construction and operation of such a large, costly, and complex particle physics facility is outside of NSF's core mission responsibilities.

Funding Summary
(In millions of dollars)

	2010 Enacted	2012 Request	2012 Change from 2010
Budget Authority	36	0	-36

SNOLAB: the competition

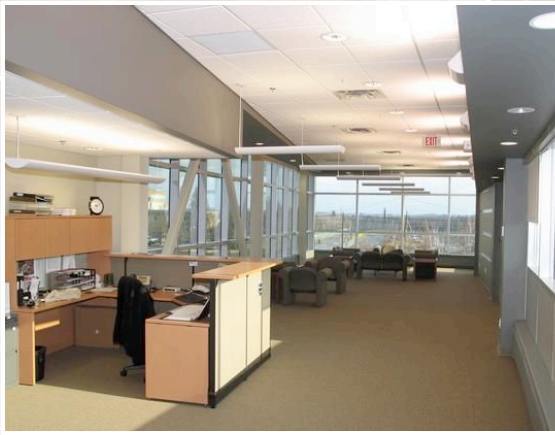
- USA (DUSEL)
  - Delayed sine die
- Europe (LSM)
  - ULISSE extension being discussed at 4500 mwe
  - Funding decision expected early 2012
  - Not ready before 2016 ?

NOT LOOKING GOOD

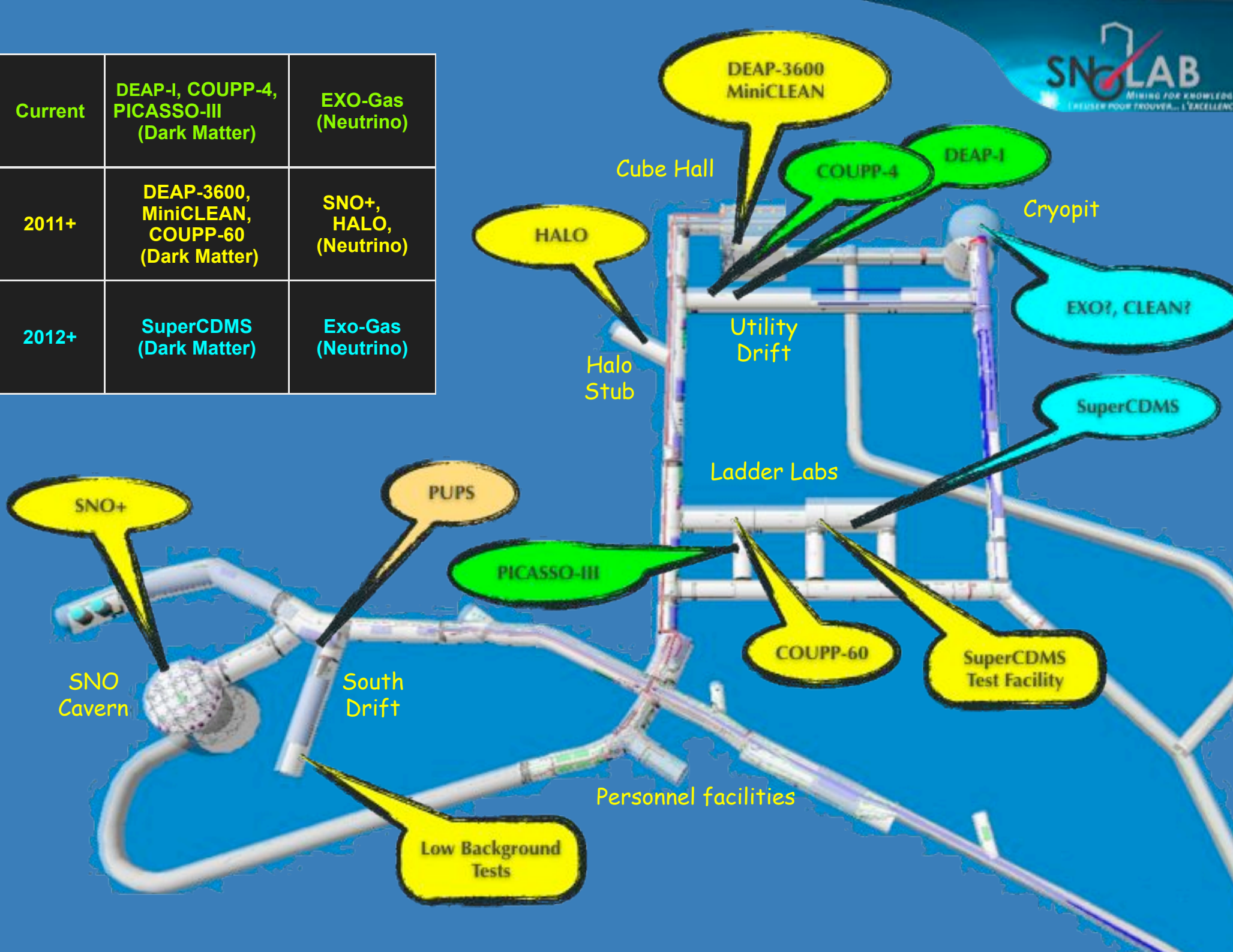
- China (JinPing)
  - New player in a difficult field...
  - ... should not be underestimated

→ Golden window of scientific opportunity for SNOLAB

Surface Facilities



Current	DEAP-I, COUPP-4, PICASSO-III (Dark Matter)	EXO-Gas (Neutrino)
2011+	DEAP-3600, MiniCLEAN, COUPP-60 (Dark Matter)	SNO+, HALO, (Neutrino)
2012+	SuperCDMS (Dark Matter)	Exo-Gas (Neutrino)

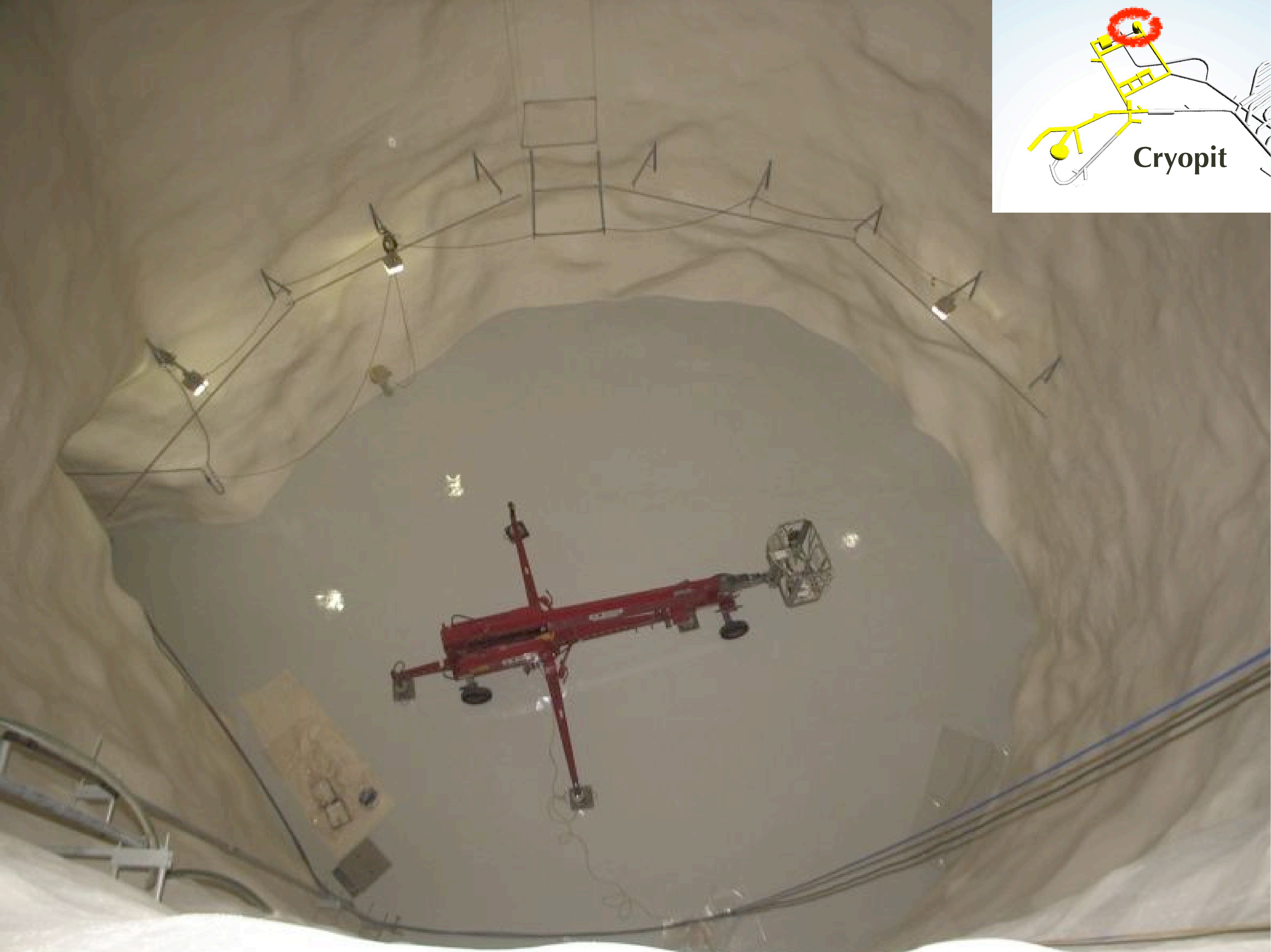



6800
Lab Entry

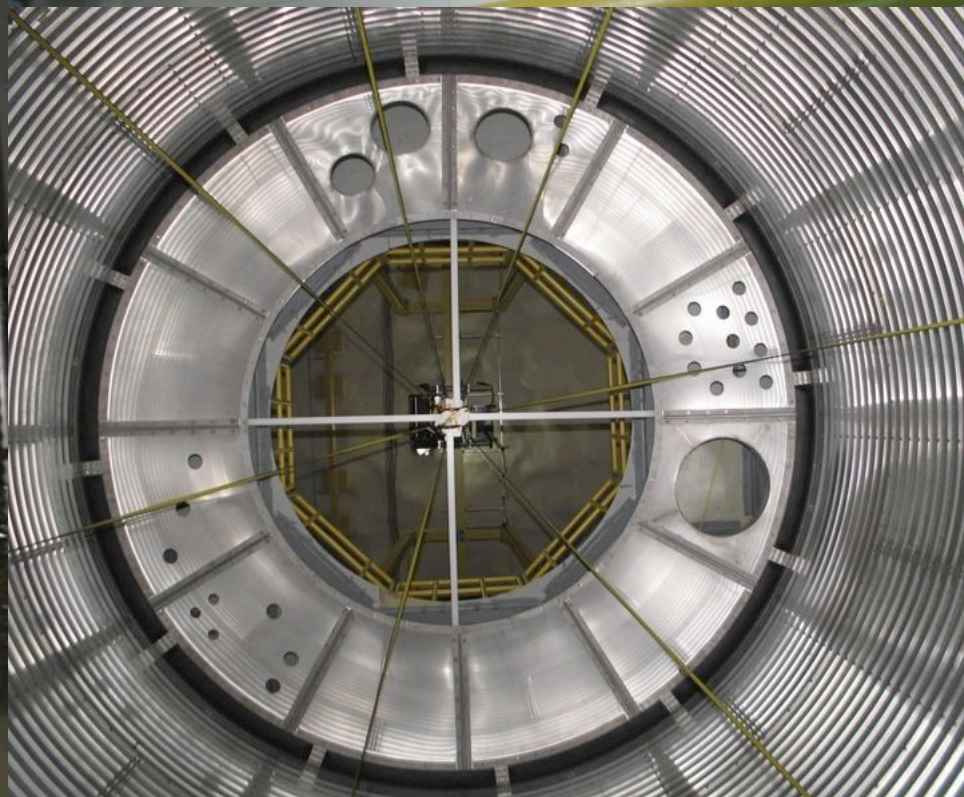

Lab Entry


Personnel
Facility


Galley/Ref
uge


Cryopit


Cube
Hall



Tentative location for SCDMS and STF

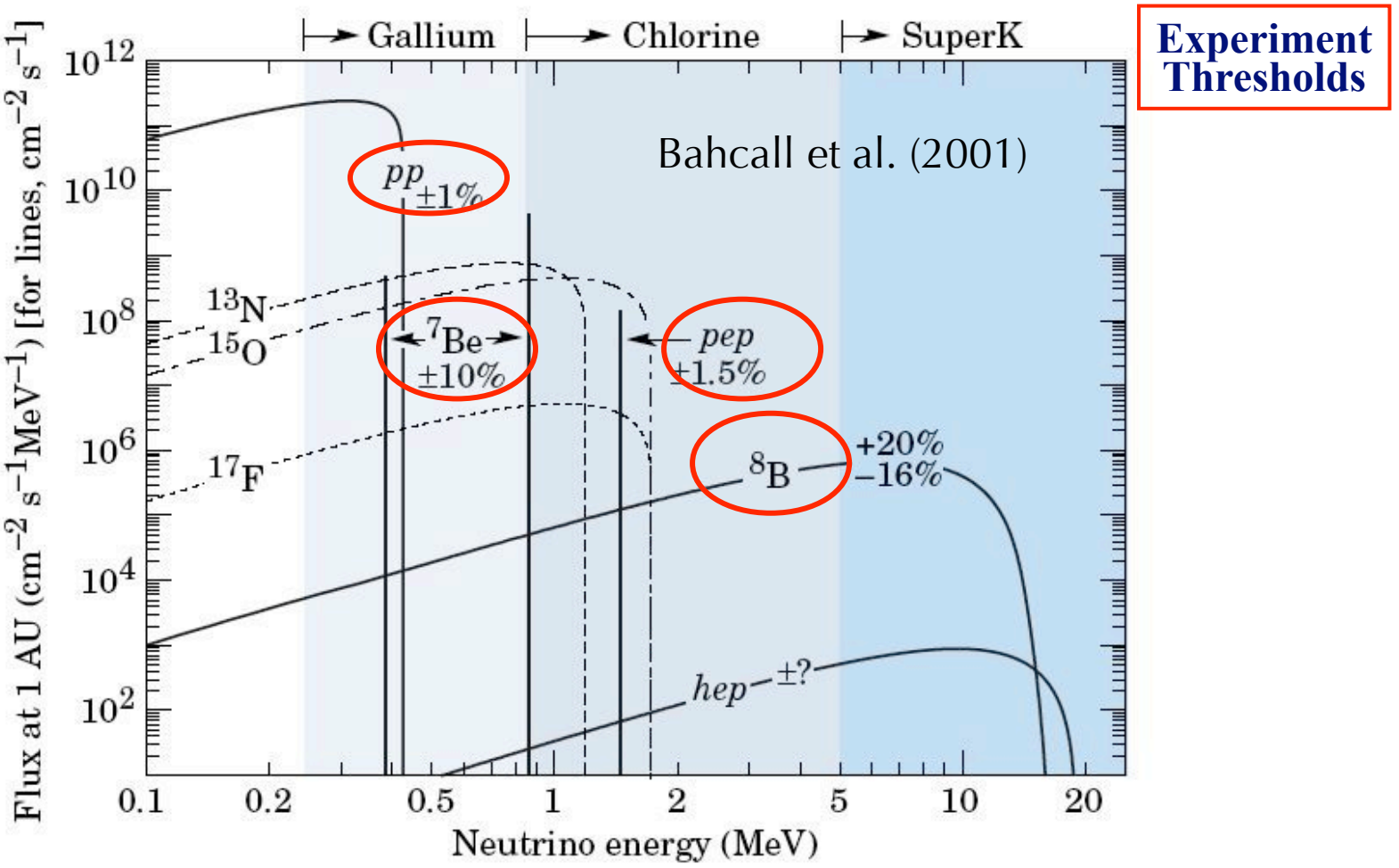

Ladder
Labs

SNOLAB Program

Experiment	Solar nu	0nuBB	Dark Matter	SuperNovae	Geo nu	Other	Space allocated	Status
SNO+	√	√		√	√		SNO Cavern	Construction
PICASSO-III			√				Ladders Labs	Underway
DEAP-1			√				J'-Drift	Underway
DEAP-3600			√				Cube Hall	Construction
MiniCLEAN			√				Cube Hall	Construction
HALO				√			Halo Stub	Construction
PUPS						Seismicity	Various	Completed
SuperCDMS			√				Ladder Labs	Request
EXO-gas		√					Ladder Labs	Request
COUPP			√				Ladder Labs	Underway
DarkSide			√				Ladder Labs	Request
COBRA		√					Ladder Labs	Request

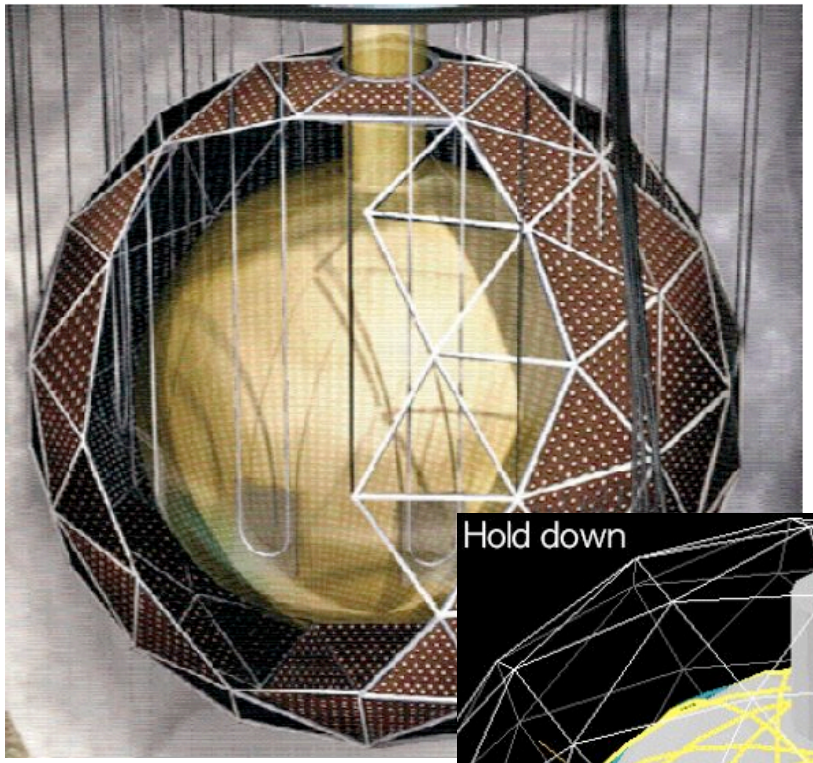
Solar Neutrinos at SNOLAB: SNO+

- Improve understanding of solar cycle and of oscillation parameters
- Replace D_2O by organic scintillator (LAB) to reach lower threshold: 250 keV ie pep and ^{7}Be ν (or lower, ^{14}C background permitting)

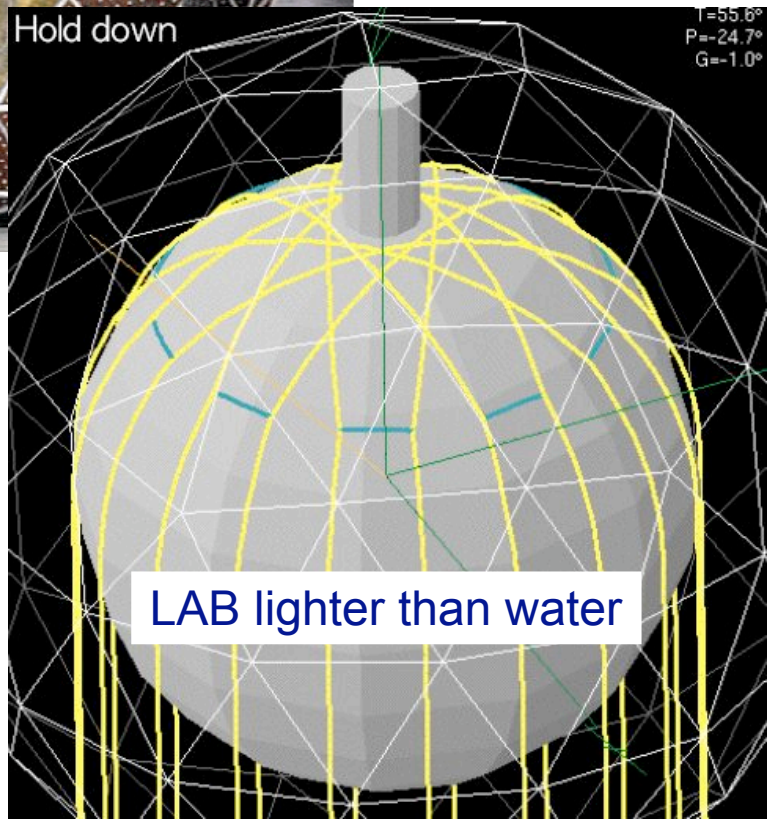


Upgrading SNO to SNO+

D2O heavier than water



12 m diam
acrylic vessel
in H2O shield



- Timeline:
  - Run with water: 2012
  - Start filling LAB: early 2013 (50 T/week)
  - Start solar neutrino run: 2013
  - Then load Nd for $\beta\beta0\nu$ run

Neutrinoless double beta decay: SNO+ loaded with Nd

- $\beta\beta0\nu$: (Z,A) -> (Z+2,A)+2e^-
- Possible only if ν
  - have mass (yes they do)
  - and are their own antiparticle
- KKDC claim in Ge: m_ν = 350 meV

SNO+ sim:

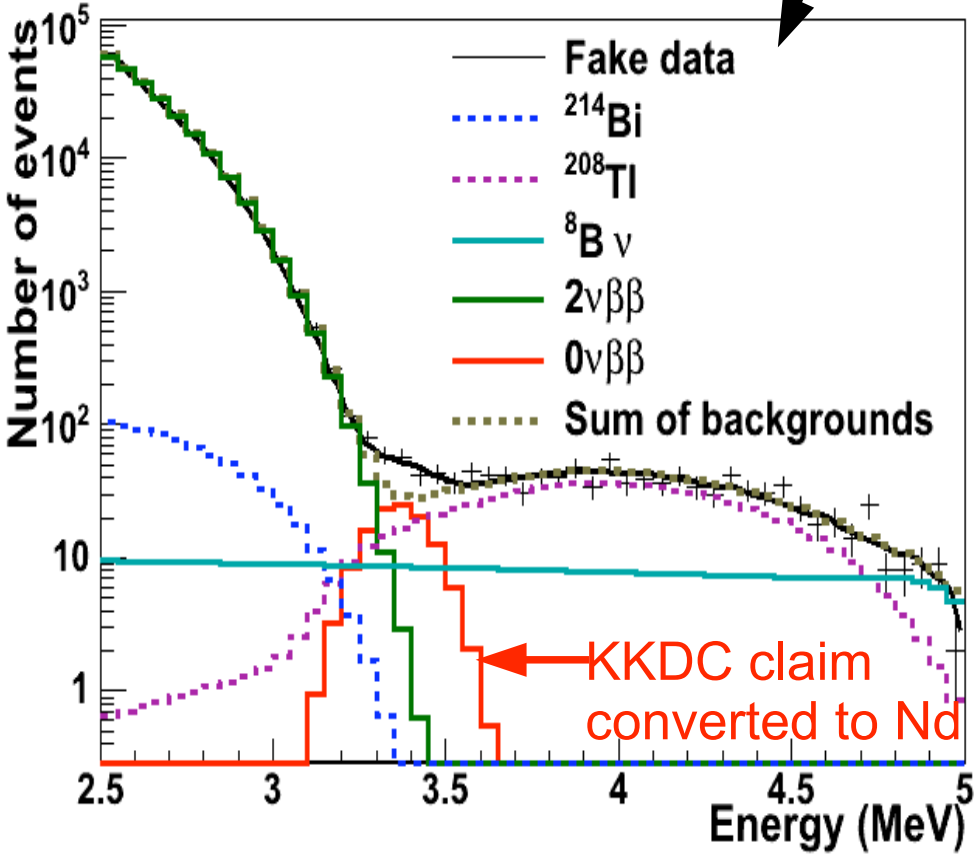
With <m>=350 meV we expect 120 0νββ events

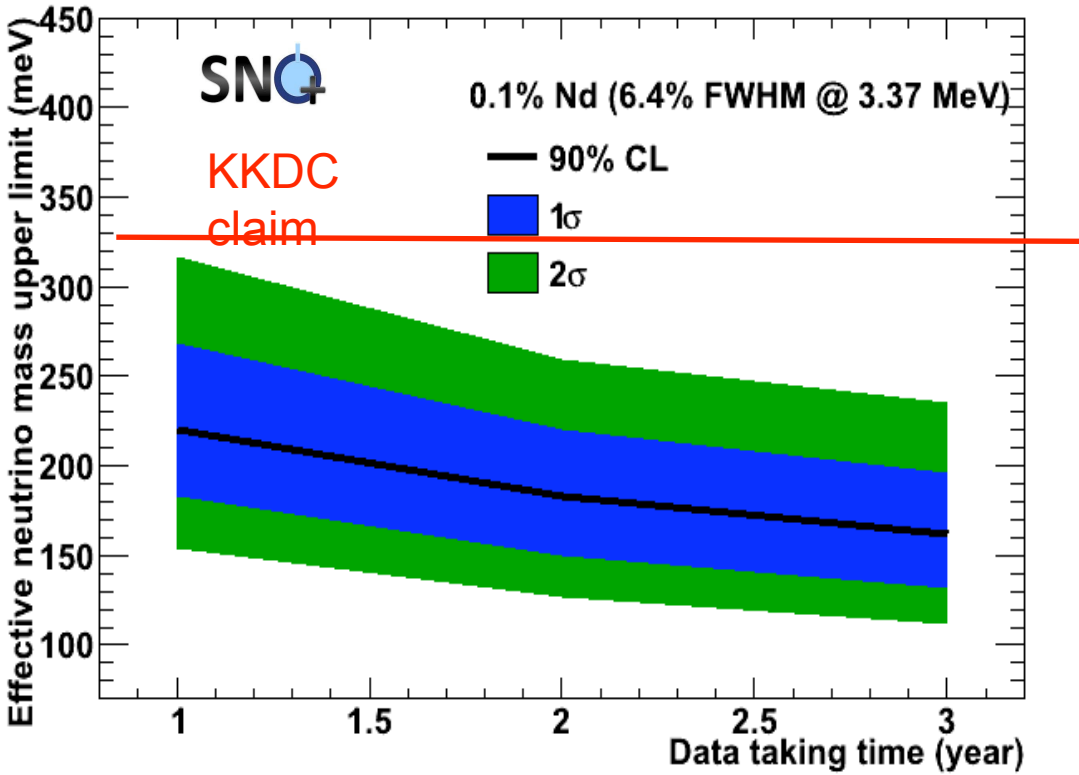
Assuming 43.7 kg 150Nd

400 nhits/MeV ~6.4% FWHM @3.37 MeV

IBM-2 matrix element

3 years running and 50% fid. Vol.

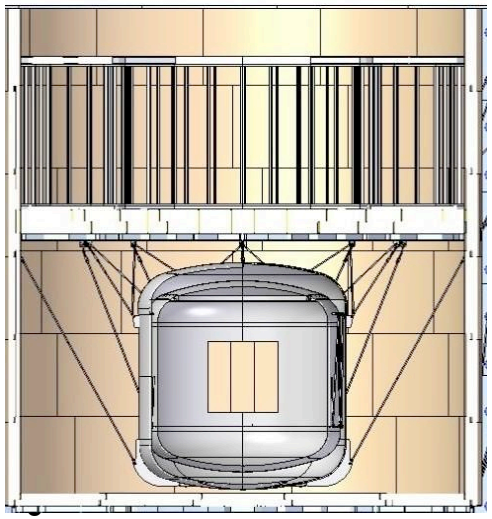




Should be able to verify KKDC claim fairly quickly

Other neutrino experiments

- Enriched Xenon Observatory (EXO)
  - $\beta\beta0\nu$ decay of ^{136}Xe to ^{136}Ba
  - 2-10 T LXe
  - TPC
  - Ba^{++} tagging



  - Prototype has made first observation of $\beta\beta2\nu$ in Xe at WIPP: arXiv:1108.4193v1

(see K Graham's talk)

- Helium and Lead Observatory (HALO)
  - Aims to provide long-term, scalable ν_e and ν_X detection for SN community
  - ν interact with recycled Pb (80 T), n detected by recycled ^{3}He counters (200 g)

CC:

$$\nu_e + {}^{208}\mathrm{Pb} \rightarrow {}^{207}\mathrm{Bi} + n + e^-$$

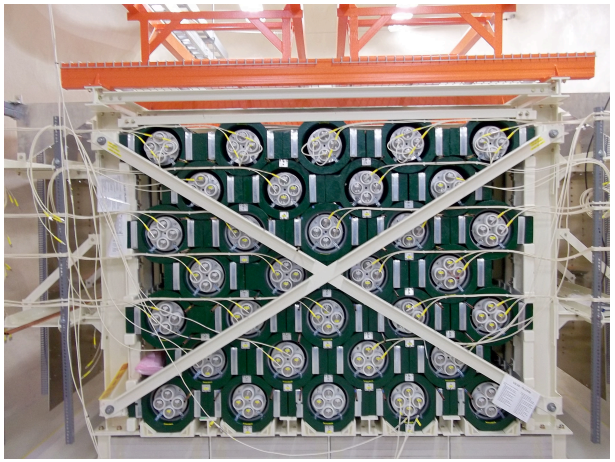
$$\nu_e + {}^{208}\mathrm{Pb} \rightarrow {}^{206}\mathrm{Bi} + 2n + e^-$$

NC:

$$\nu_x + {}^{208}\mathrm{Pb} \rightarrow {}^{207}\mathrm{Pb} + n$$

$$\nu_x + {}^{208}\mathrm{Pb} \rightarrow {}^{206}\mathrm{Pb} + 2n$$

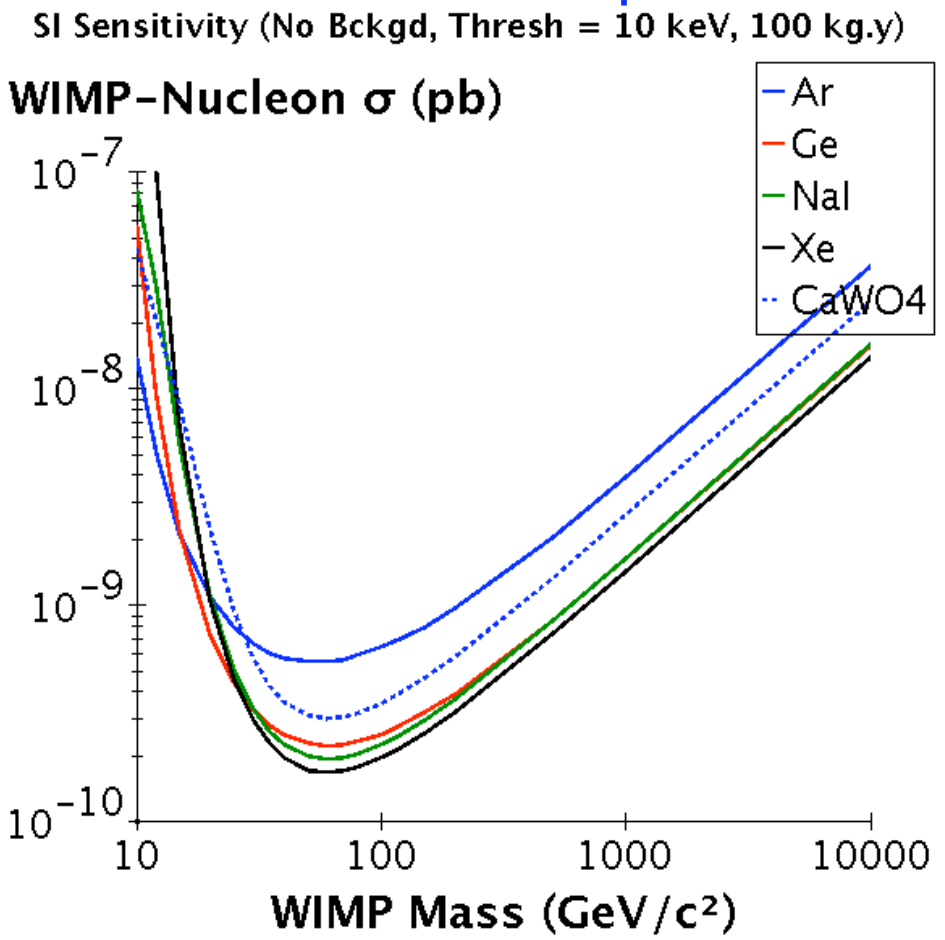
  - Detector being assembled, should be calibrated during summer 2012



Lower energy rare events: **dark matter**

- Majority of matter in Universe is dark: only appears through gravitational interactions
- May be made of weakly interacting massive particles (WIMPs)
- Many extensions of standard model predict suitable WIMPs
- Complementary approaches to detection:
  - Accelerator searches
  - Indirect searches
  - Direct searches:
    E = O(10 keV),
    < 1 evt/kg/month

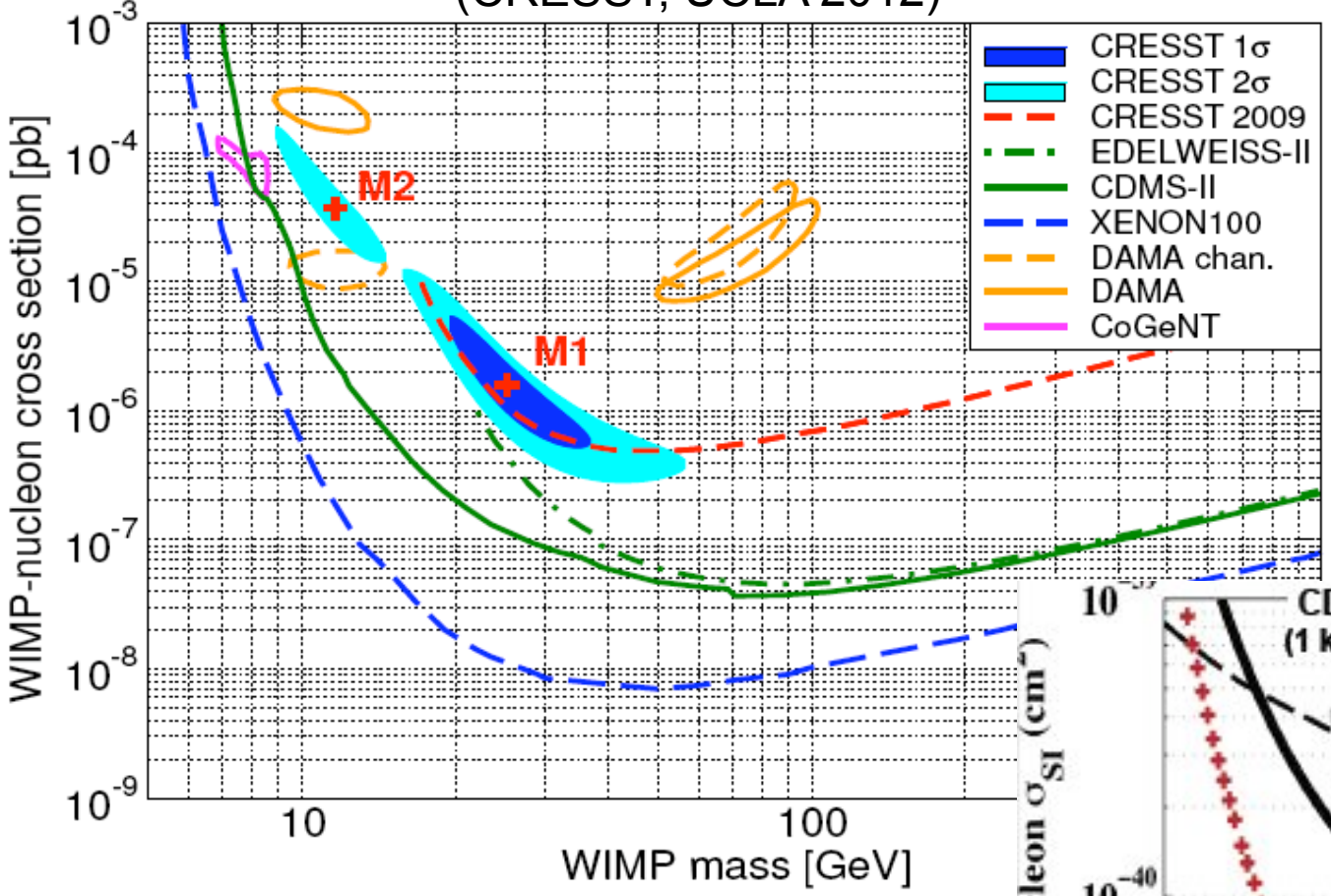
- Sensitivities of ideal experiments

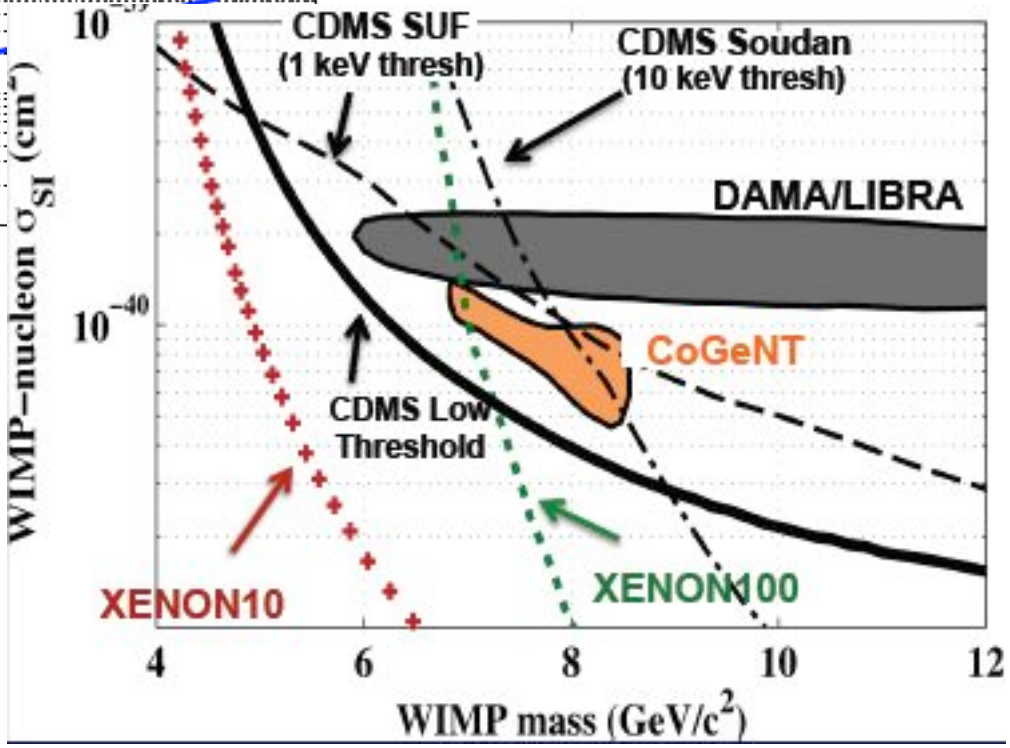


- In practice: what technology is best to obtain decent threshold and exposure with background rejection?

The chase for dark matter heats up

(CRESST, UCLA 2012)



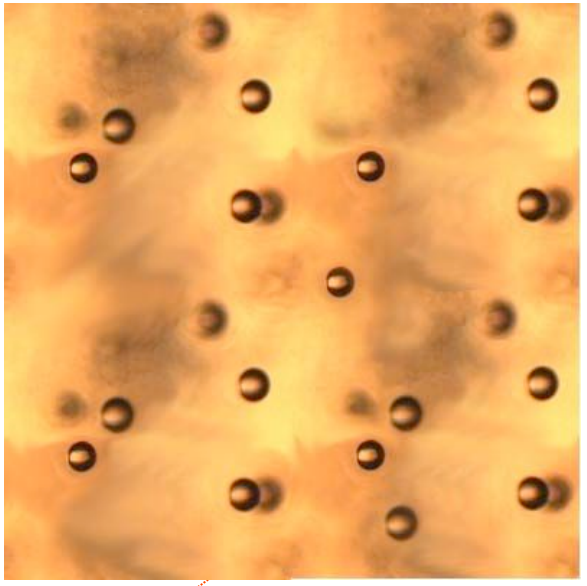


Current program: Dark Matter at SNOLAB

- Noble Liquids: DEAP-I, MiniCLEAN, & DEAP-3600, DarkSide
  - Single Phase Liquid Argon uses pulse shape discrimination. Two-phase (DarkSide)
  - Prototype DEAP-I operational in SNOLAB now, relocated to 'J' Drift. Successful demonstration of PSD and test bench for DEAP/CLEAN design/operations and background assessment.
  - Construction for DEAP-3600 and MiniCLEAN underway. Full DEAP-3600 capital funding granted (with SNO+)
  - Will measure Spin Independent cross-section.
- Superheated Liquid / Bubble chamber: PICASSO, COUPP
  - Superheated droplet detectors and bubble chambers. Insensitive to MIPS radioactive background at operating temperature, threshold devices
  - PICASSO currently operational in SNOLAB, relocated to Ladder Labs, demonstration of alpha rejection and test bench for scale-up of detector volumes.
  - COUPP-4kg deployment completed, 60kg summer this year.
  - Will measure Spin Dependent cross-section primarily, COUPP has SI sensitivity
- Solid State: SuperCDMS
  - State of the art Ge crystals with ionisation and phonon readout.
  - Currently operational in Soudan. Next phase will benefit from SNOLAB depth to reach desired sensitivity. Test facility in Ladder Labs under development.
  - Mostly sensitive to Spin Independent cross-section.

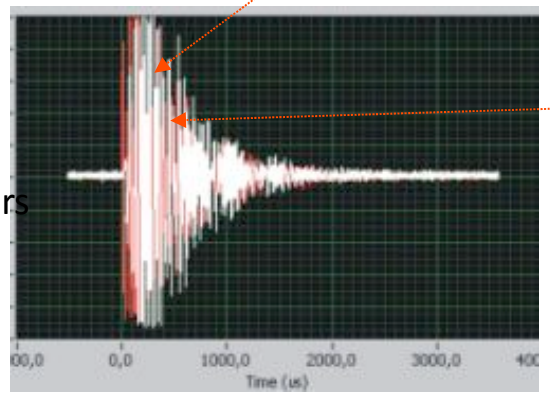
Picasso

- 150 μm droplets of C4F10 dispersed in polymerised gel *
- Droplets superheated at ambient T & P (Tb= - 1.7 oC)
- Radiation triggers phase transition
- Events recorded by piezo-electric transducers
- Operating temperature determines energy threshold



Main attractive features:

- **low threshold 45OC → Eth = 2 keV**
- **inexpensive! 0.19 k$/kg (C4F10)**
- **insensitive to γ - background**



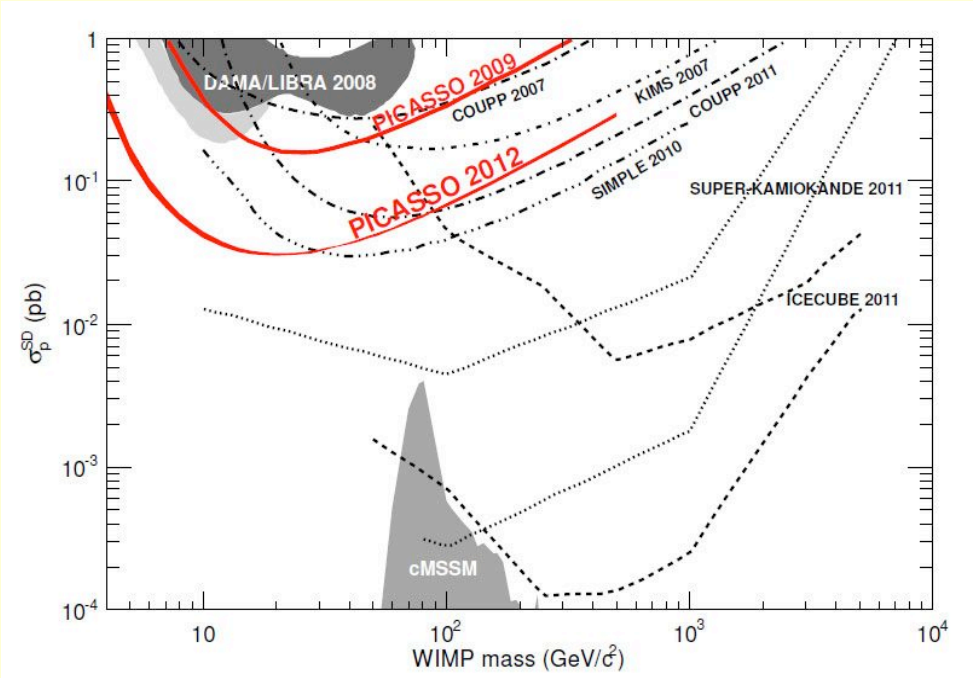
* Inspired by personal neutron dosimeters @ Bubble Technology Industries, ON

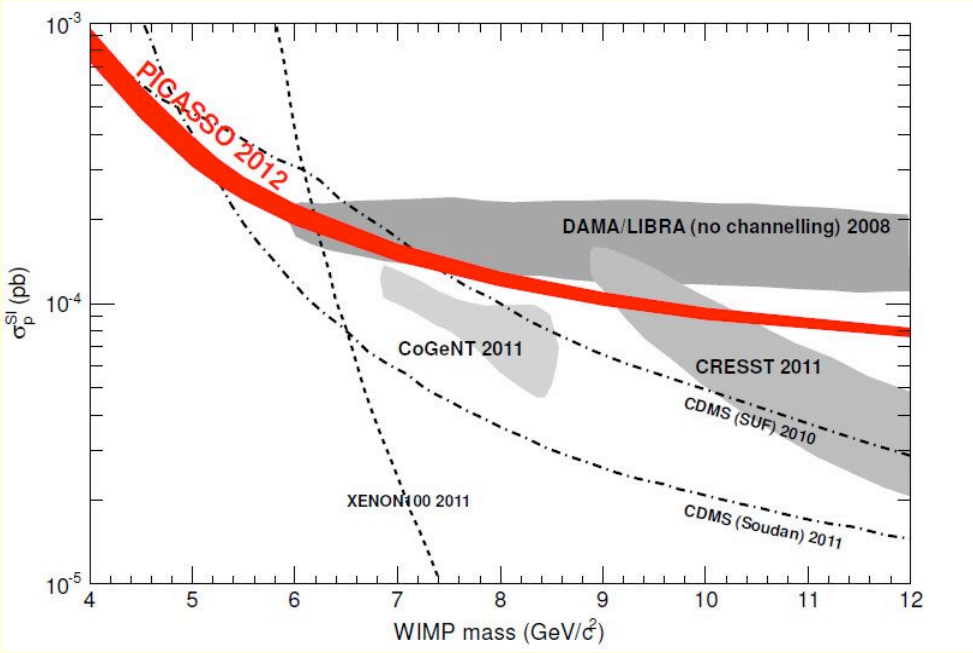
See talks by MC Piro and A Kamaha

New Physics Results (submitted to Phys. Lett. B)

Since 2008: 32 detectors, 2.6 kg C_4F_{10}, 115 kg.d

« Constraints On Low Mass WIMP interactions on 19F from PICASSO » arxiv: 1202.1260





SD- sector:

· Results factor 5 better than 2009

· DAMA « channeling » now ruled out

SI-sector:

· Most of DAMA /LIBRA excluded

Status:

- Now moved to ladder labs
- Faster electronics should allow improved rejection of αs

Dark Matter: COUPP

- Superheated CF_3I target
- Depositions of enough energy ($>E_T$) in a small enough volume ($<R_c$) create bubbles
  - F. Seitz, Phys. Fluids **1**, 2 (1958)
- Cameras watch and issue a trigger
- Re-liquefy the target with 60 second compression

4 kg @ SNOLAB

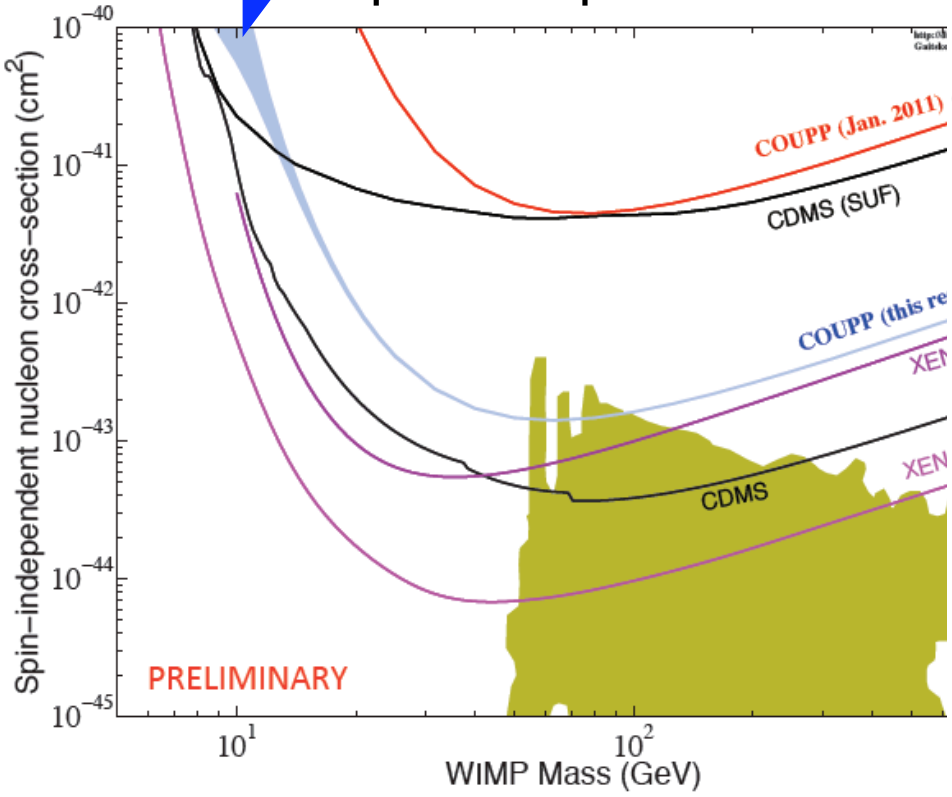
COUPP: Preliminary Results from 400 kg.d

(J Hall, UCLA 2012)

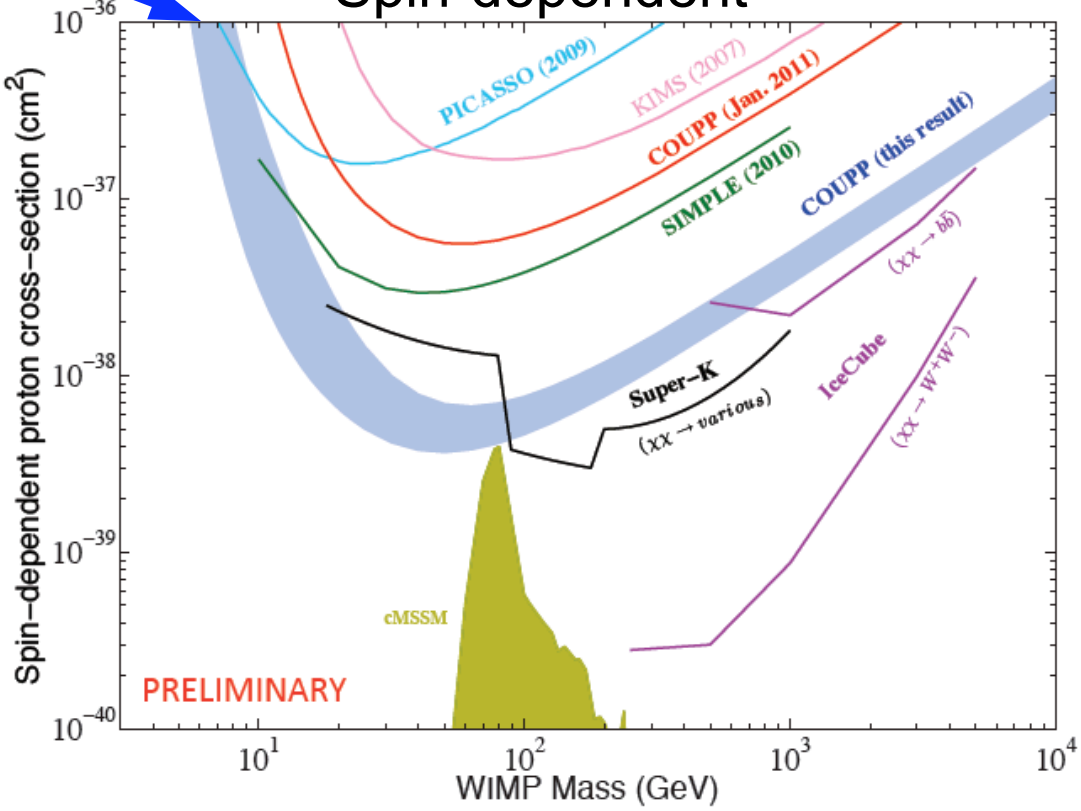
20 evts

Uncertainty on C & F threshold

Spin-independent

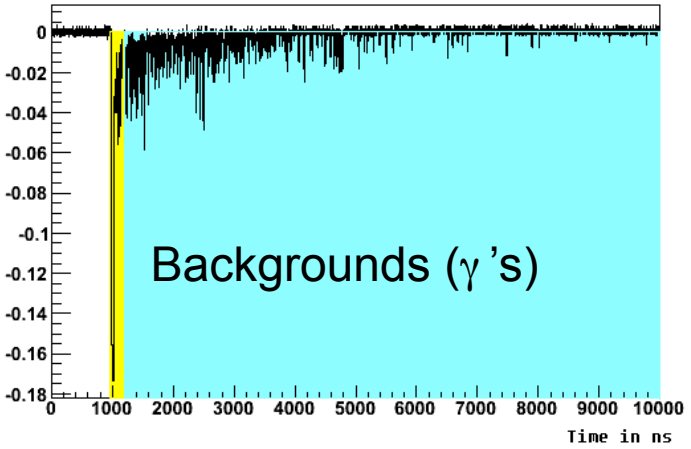


Spin-dependent

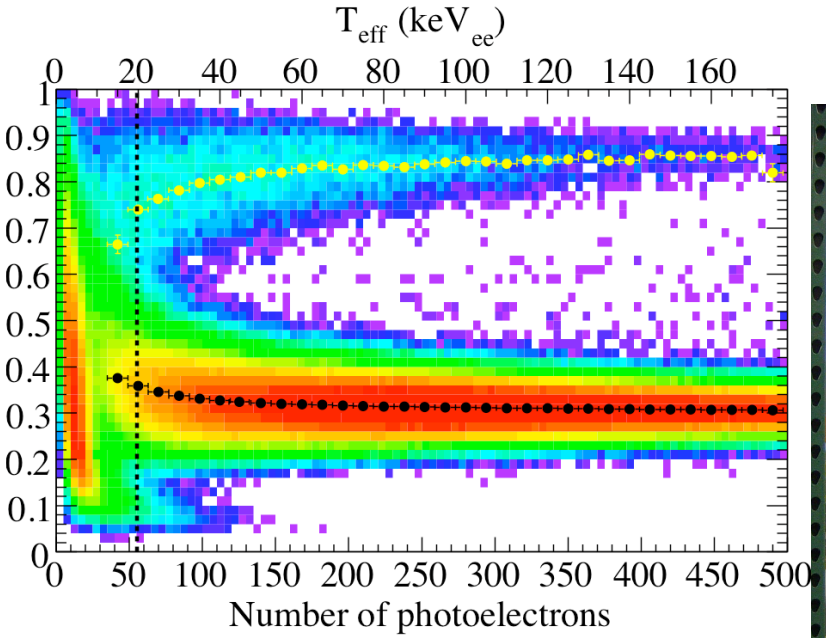


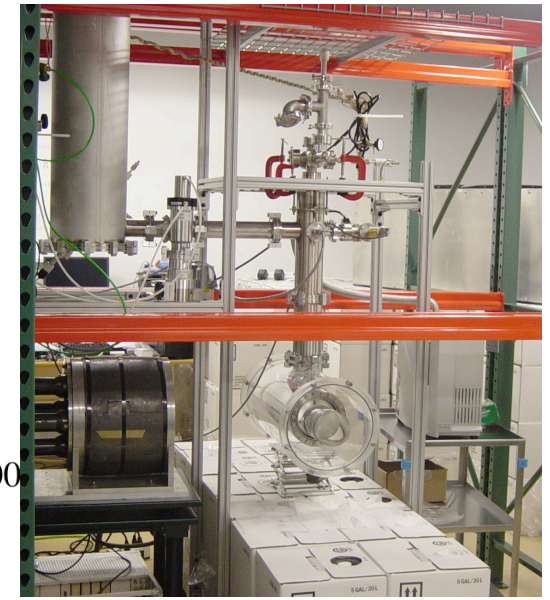
60 kg detector planned for SNOLAB summer 2012

DEAP: Single phase LAr with PSD (see L. Veloce's talk)

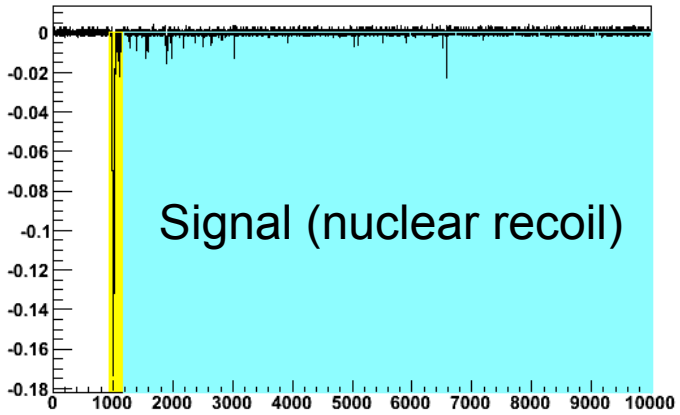


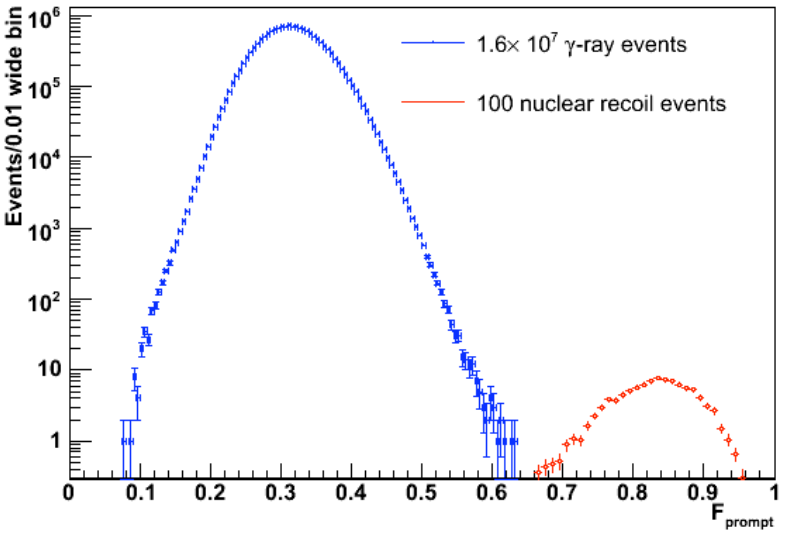
Yellow: Prompt light region
Blue: Late light region





DEAP-1 at SNOLAB
7 kg prototype



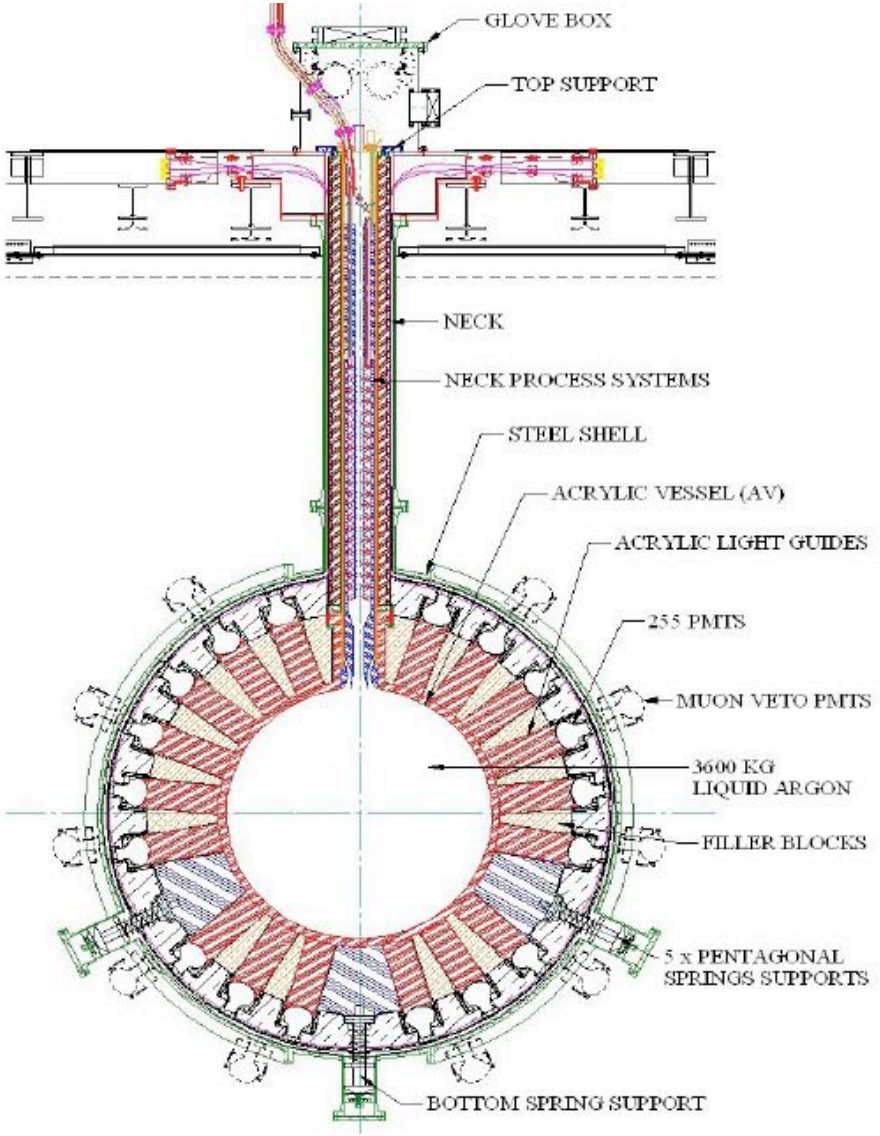


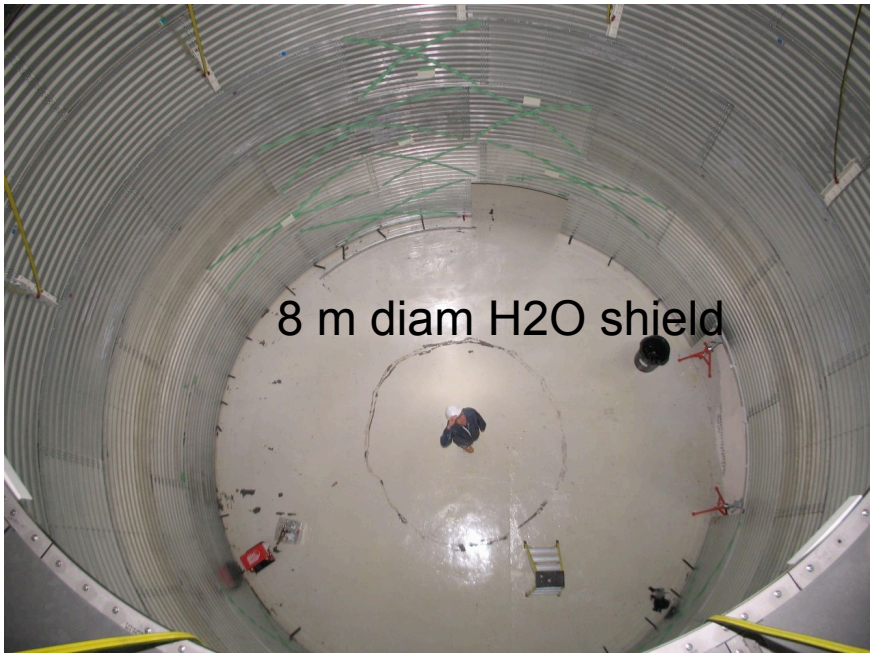
$$F_{prompt} = \frac{\mathrm{PromptPE}(150\mathrm{ns})}{\mathrm{TotalPE}(9\mu\mathrm{s})}$$

Background suppression better than 3×10^{-8}
120-240 pe

DEAP 3600 at SNOLAB

- 1 T fiducial under construction

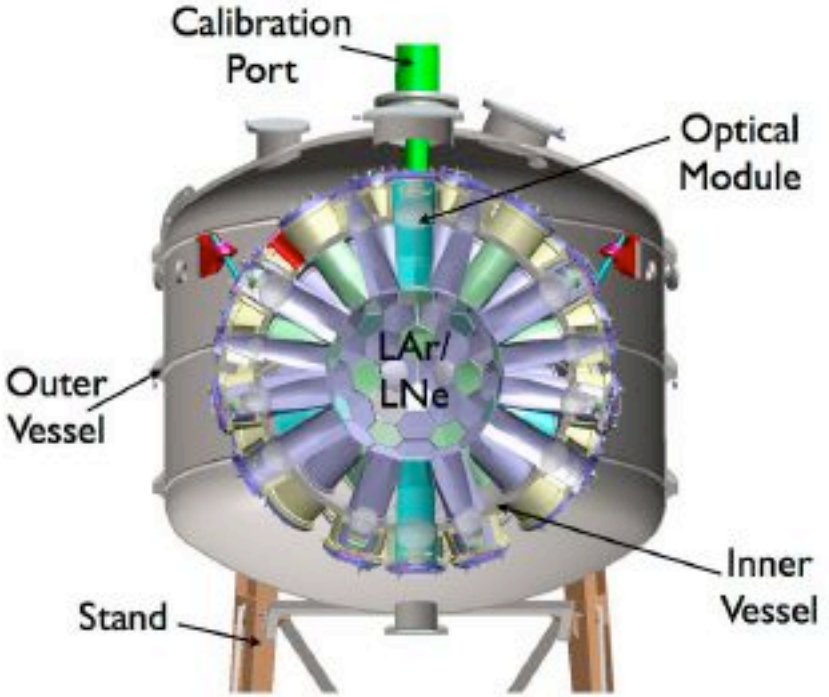


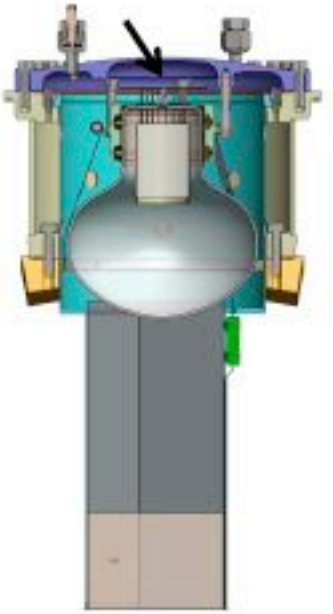


- Goal 10^{-10} rejection at 120 pe analysis threshold ie 60 keV
- 8 pe/keVee
- May go a bit lower in threshold with depleted Ar

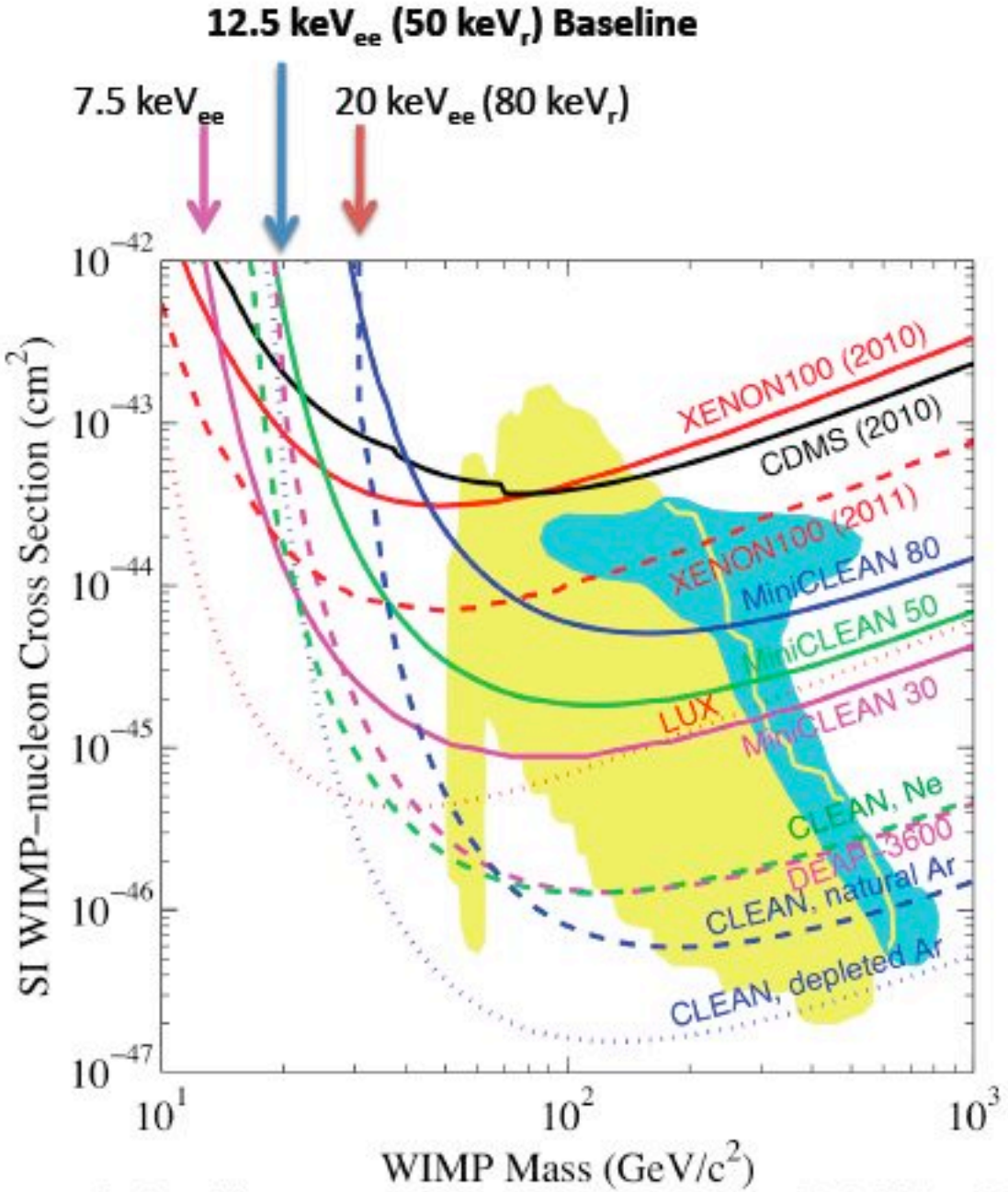
MiniCLEAN Modular Design

- Radon-free assembly …
- "Cold" design allows both LAr & LNe …
- 4π coverage to maximize light-yield at threshold …
  - 3D Position Reconstruction
  - Particle-ID via Pulse-shape discrimination
- No electric fields … PMTs only active component …
- Fast signals (τ_3 = 1.6 μs) avoid pulse-pileup in LAr …





Sensitivity



Backgrounds

^{39}Ar in Target

Fast Neutrons from PMTs

Surface Radon Progeny

⌄

Particle-ID

Fiducialization & Tagging

Fiducialization & Particle-ID

⌄⌄

Pulse Shape Discrimination

Position Reconstruction

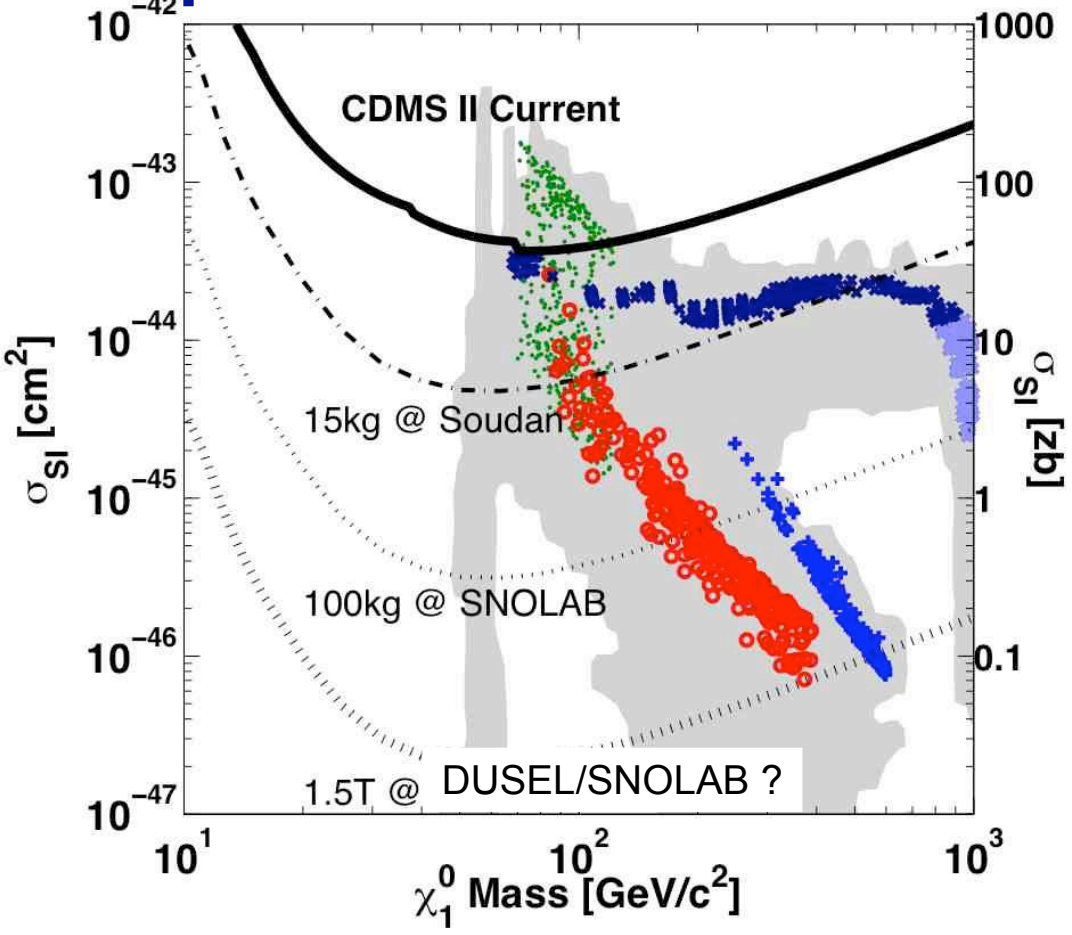
⌄

Light Yield

Dark Matter: SuperCDMS

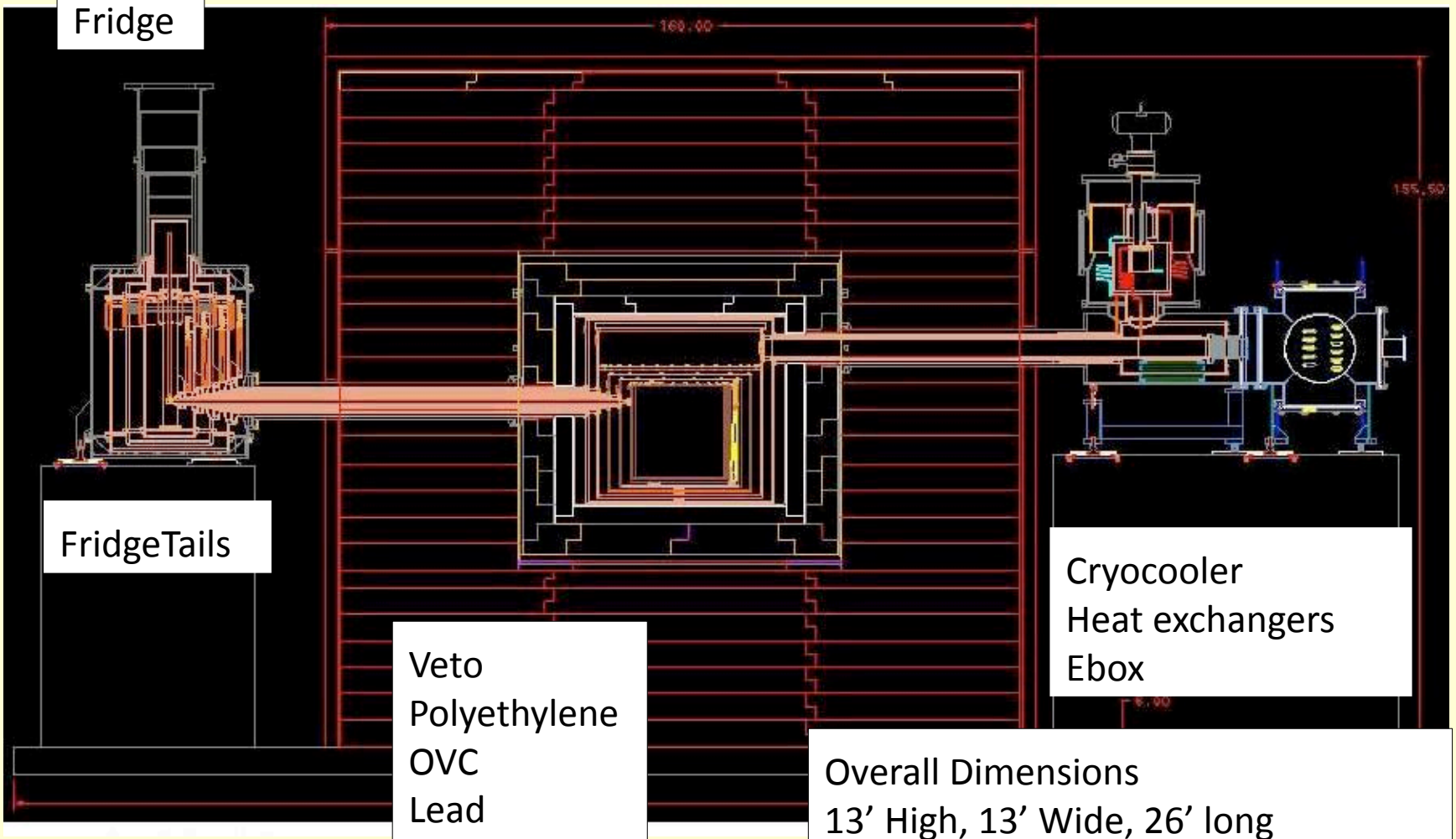
See Y Ricci's talk

- Cryogenic detectors with excellent background rejection
- 10 kg iZIPs running at Soudan, MN
- Only 2100 mwe → will be limited by cosmogenic background
- 100 kg phase planned for SNOLAB

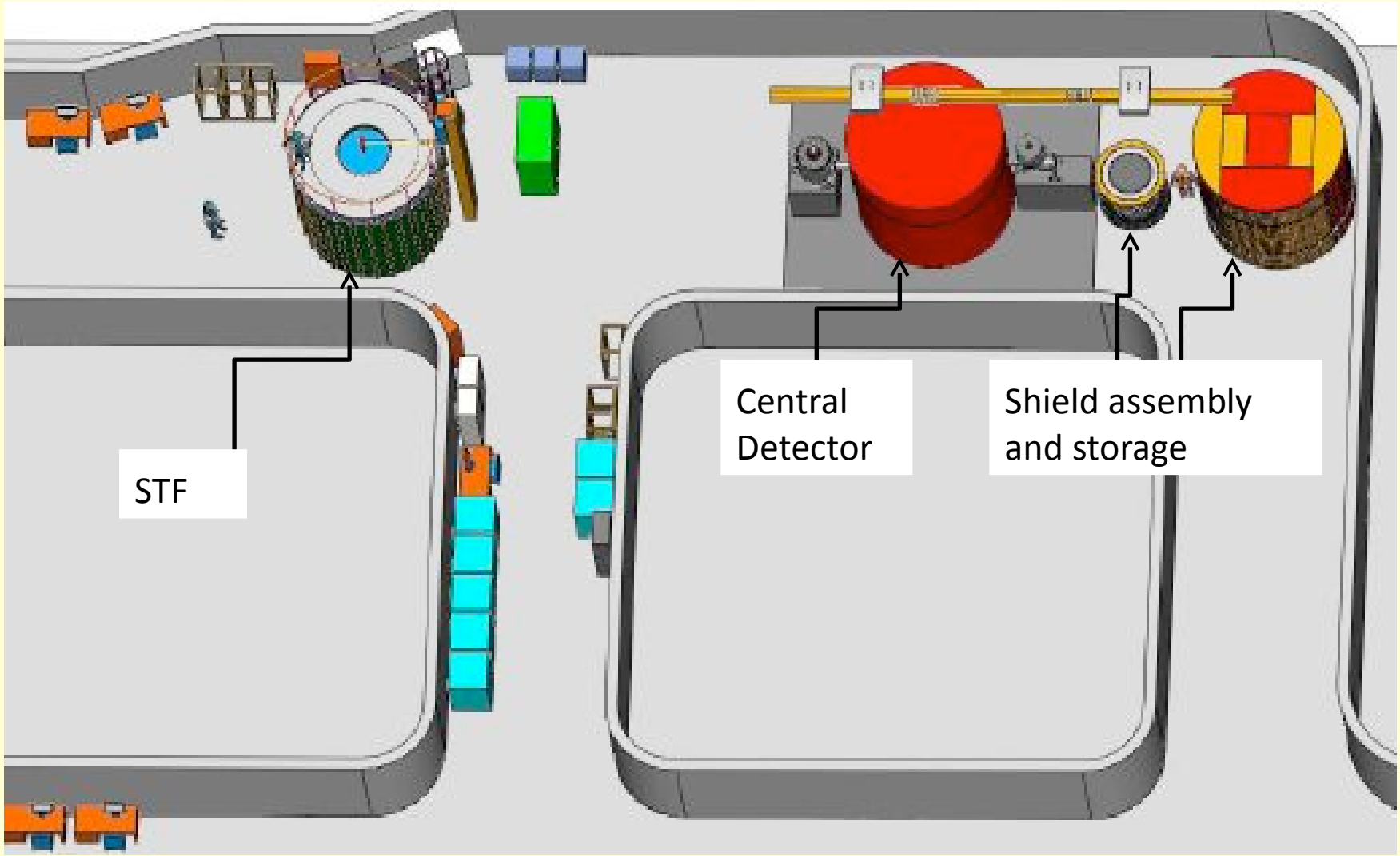


- Tentative timeline for SNOLAB:
  - CFI, NSF/DOE funding requests 2012
  - Start construction 2013
  - Start data taking 2015

General Elevation



SNOLAB Ladder Lab Layout



SNOLAB

- Building on the success of SNO
- One of the deepest and cleanest labs in the world: golden window of scientific opportunity
- Multi-faceted rare-event program, many different technologies
- Experiments already producing world-leading results
- Several other experiments poised to come online