COUPP500: a 500kg Bubble Chamber for Dark Matter Detection

Eric Vázquez Jáuregui

SNOLAB

Identification of Dark Matter 2012
Chicago IL, USA; July 26, 2012

The COUPP collaboration

- **KICP - University of Chicago**
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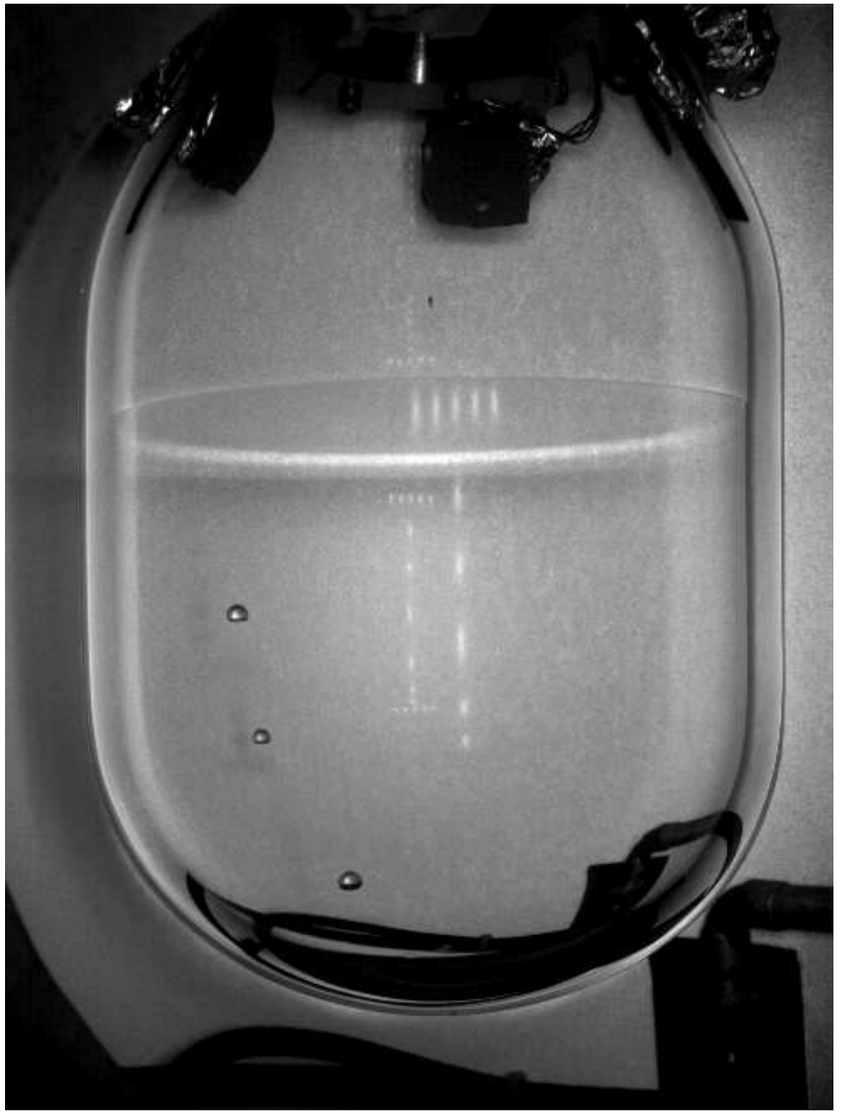
  R. Neilson, Alan E. Robinson
- **Indiana University South Bend**
  E. Behnke, T. Benjamin, Emily Grace,
  C. Harnish, I. Levine, T. Nania
- **Fermi National Accelerator Laboratory**
  Steve J. Brice, Dan Broemmelsiek,
  Peter S. Cooper, Mike Crisler, Jeter Hall,
  W. Hugh Lippincott, Erik Ramberg,
  Andrew Sonnenschein, Fermilab Engineers and Technicians
- **Northwestern University**
  C. Eric Dahl
- **Politecnica Valencia**
  M. Ardid, M. Bou-Cabo
- **SNOLAB**
  Eric Vázquez-Jáuregui
- **Virginia Tech**
  D. Maurya, S. Priya

COUPP bubble chambers

- Target material: superheated CF_3I spin-dependent/independent
- Particles interacting evaporate a small amount of material: bubble nucleation
- Cameras record bubbles
- Piezo sensors detect sound
- Recompression after each event



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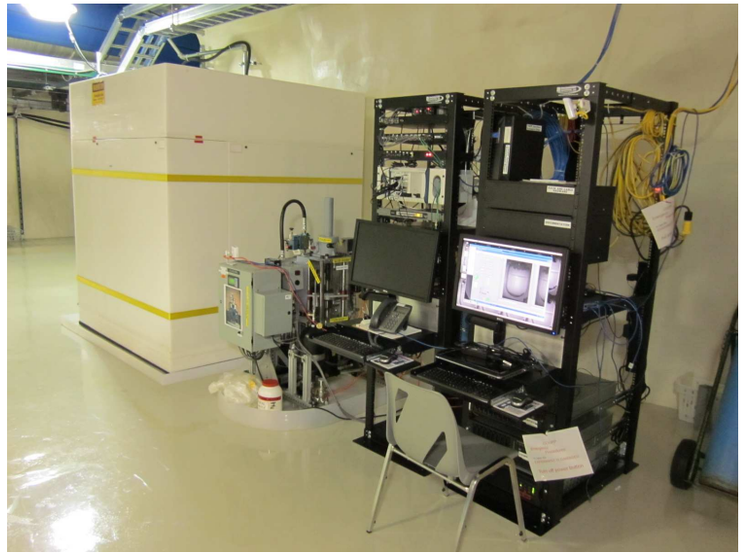
- **The ability to build large chambers cheaply and with a choice of target fluids**
- **The ability to increase the size of the chambers without changing the size or complexity of the data acquisition**
- **Sensitivity to spin-dependent and spin-independent WIMP couplings**

COUPP-4kg and COUPP-60kg

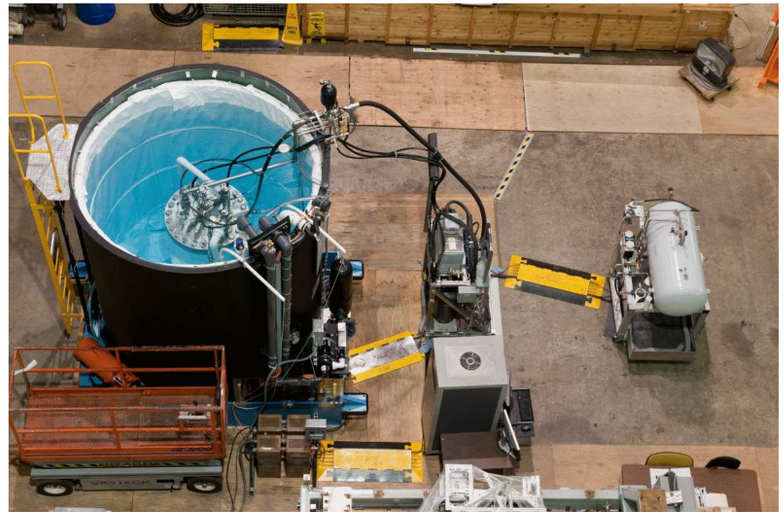
- Running at SNOLAB since 2010
- World leading spin dependent limits

(Michael B. Crisler talk)



- Engineering run at Fermilab in 2011
- Moving to SNOLAB
- Physics run in late 2012

(Andrew Sonnenschein talk)

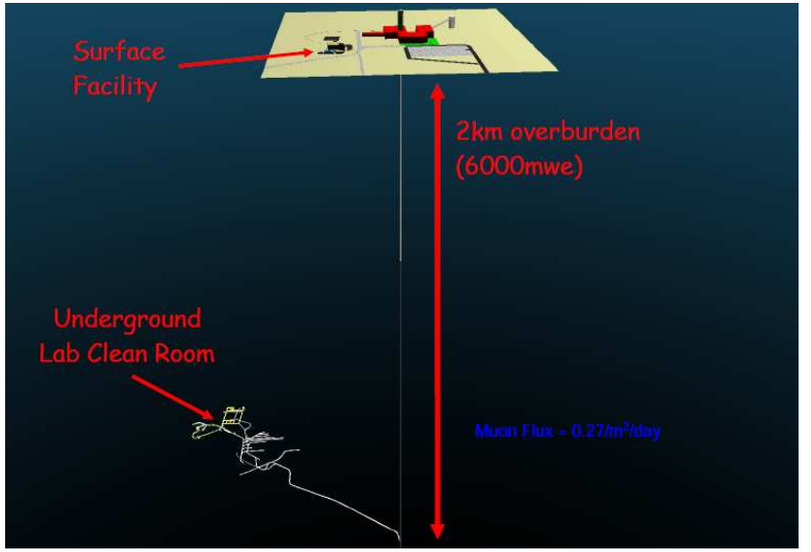


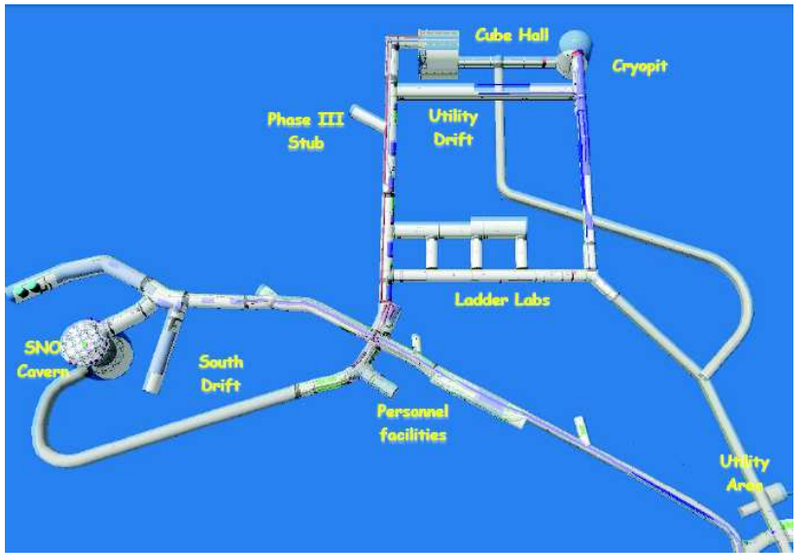
COUPP at SNOLAB

SNOLAB

deepest and cleanest large-space international facility in the world

- 2 km underground near Sudbury, Ontario
- ultra-low radioactivity background environment Class 2000
- Physics programme focused on neutrino physics and direct dark matter searches





COUPP at SNOLAB

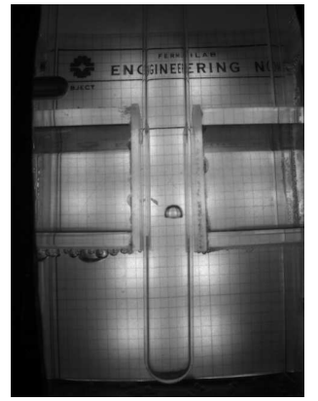
Calibrations

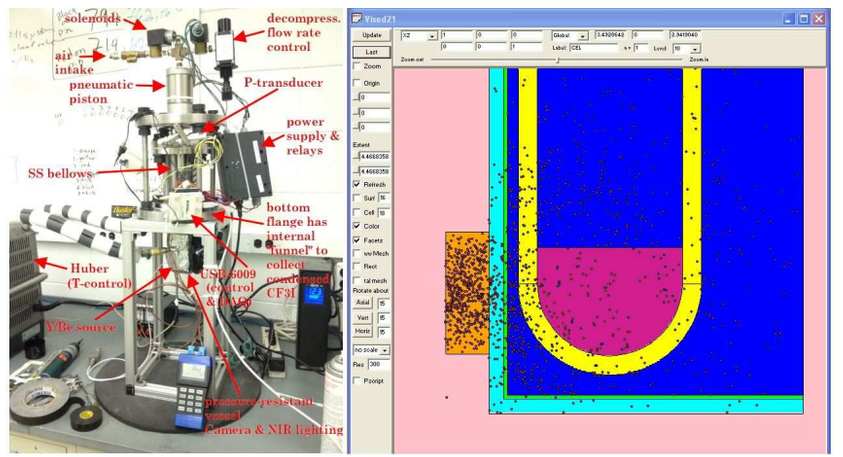
- γ and neutron calibrations
  - AmBe and ^{252}Cf
  - ^{60}Co and ^{133}Ba
- COUPP Iodine Recoil Threshold Experiment
- Low energy Iodine recoils
- π beam and silicon trackers

(Hugh Lippincott talk)

- ^{88}Y/Be calibration chamber
- Monochromatic low energy neutrons

(Alan E. Robinson talk)

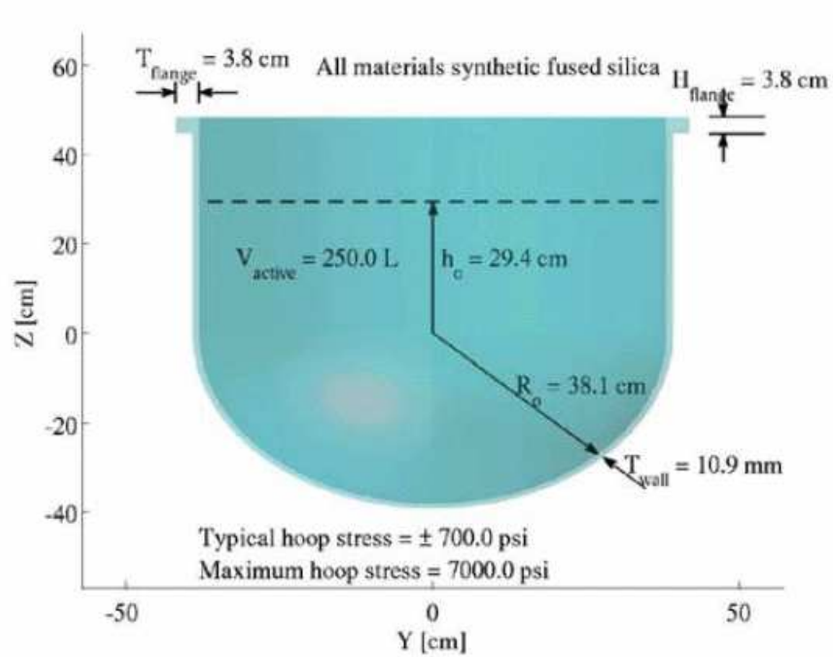




COUPP-500kg

- A tonne scale detector
- spin-independent sensitivity $9 \times 10^{-47} cm^2$, background-free year running
- Beyond next generation (G2) device
- <9M total cost (R&D funded by NSF, waiting on DOE)
- Possible to use alternative fluids (C_4F_{10})

R&D phase

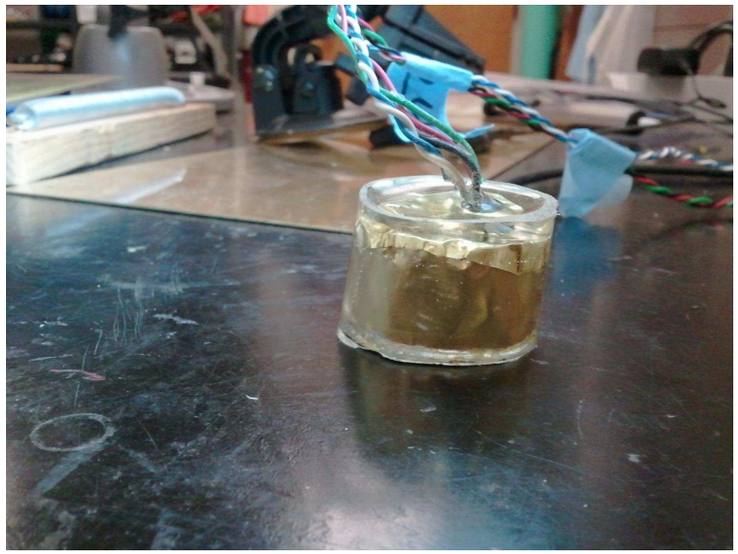


COUPP-500kg design

- Target fluid: CF_3I
  - C_4F_{10} at 15keV:
    SI rate $\times 17 \downarrow$
    (WIMP mass $\sim$100 GeV)
  - C_4F_{10} at 15(10)keV:
    SD rate $\times 4(18) \uparrow$
    (WIMP mass $\sim$10 GeV)
- Inner vessel assembly: ultra-high-purity synthetic fused silica jar
- Outer vessel: Stainless steel (ϕ= 60 inches)
- Acoustics sensors: piezoelectric acoustic transducers

COUPP-500kg design

- Outer neutron shielding:
  - neutron moderator
  - muon veto
  - temperature control
- Pressure control unit:
  - expand and recompress the chamber
  - regulate chamber pressure
- Data acquisition:
  - T and P sensors
  - machine vision cameras
  - acoustic transducers



R&D and calibrations

- **Calibration of low energy nuclear recoil response**
  - **CIRTE, ^{88}Y-Be, ...**

- **Calibration of gamma rejection**

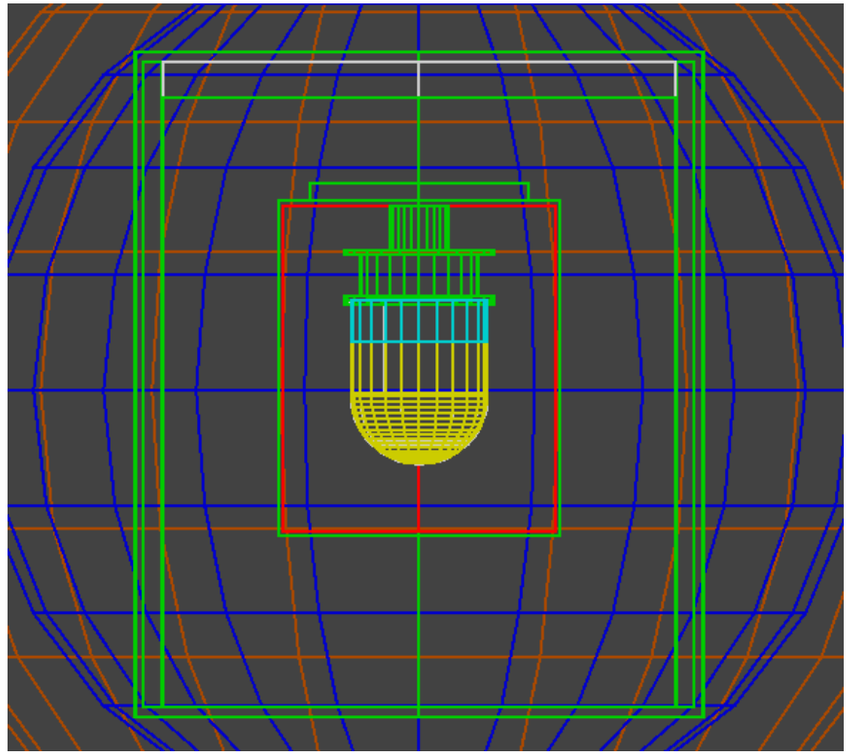
- **In-situ source for alpha calibration**

- **Bubble acoustics and acoustic sensors**

- **Extensive background simulation!**

COUPP-500kg simulations

- External backgrounds:
  - Rock neutrons
  - Muon induced neutrons
  - (γ,n) reactions
- Internal backgrounds:
  - U and Th: fission and (α,n) on light elements
  - ^{238}U direct decay
    - Materials: SS, quartz,...
    - Fluids: water, glycol, CF_3I
    - Radon
    - Mine dust
    - veto PMTs
    - Acoustic transducers



GEANT4 model

COUPP-500kg: external neutrons

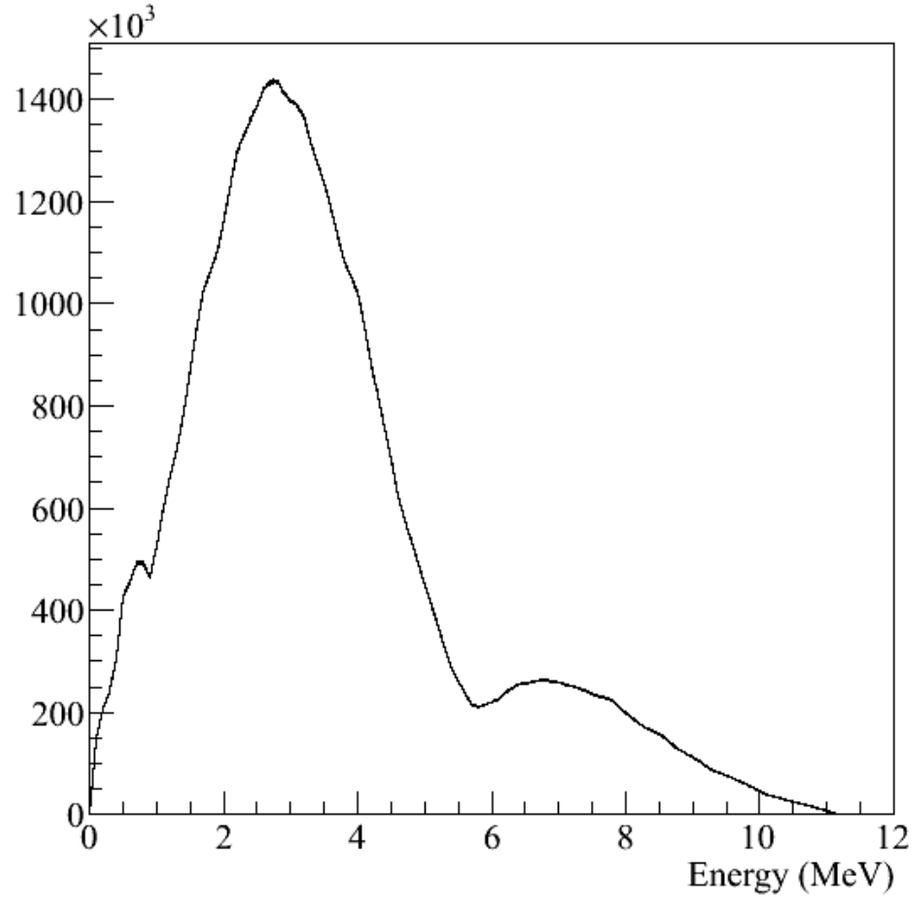
Fast neutrons from norite:
4000 n/m^2/day

Muon induced neutrons in:
rock, water, stainless steel

Water tank dimensions:

- ϕ = 6.8 m
- L = 7.4 m

$\sim$ 67 muons/day



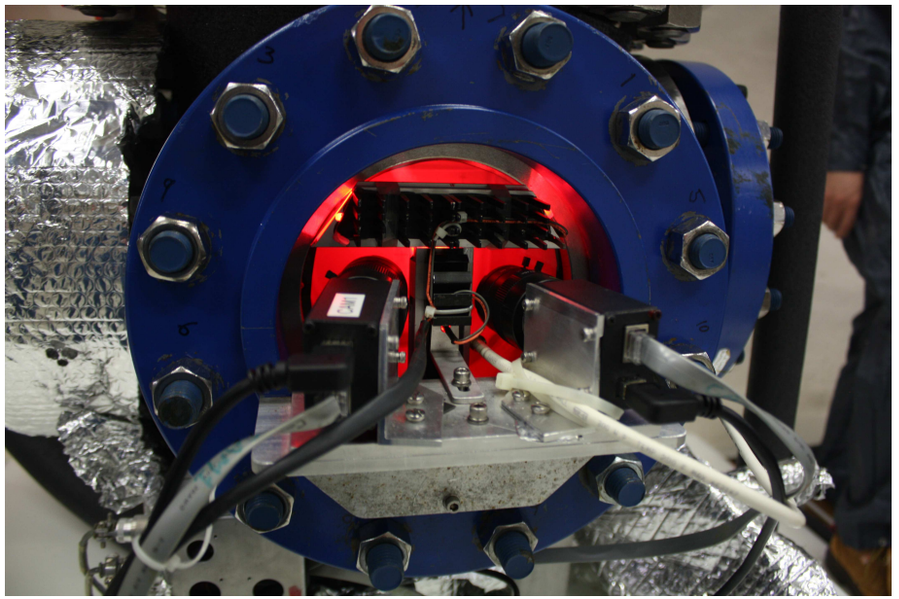
Neutron energy for (α,n) reaction in norite

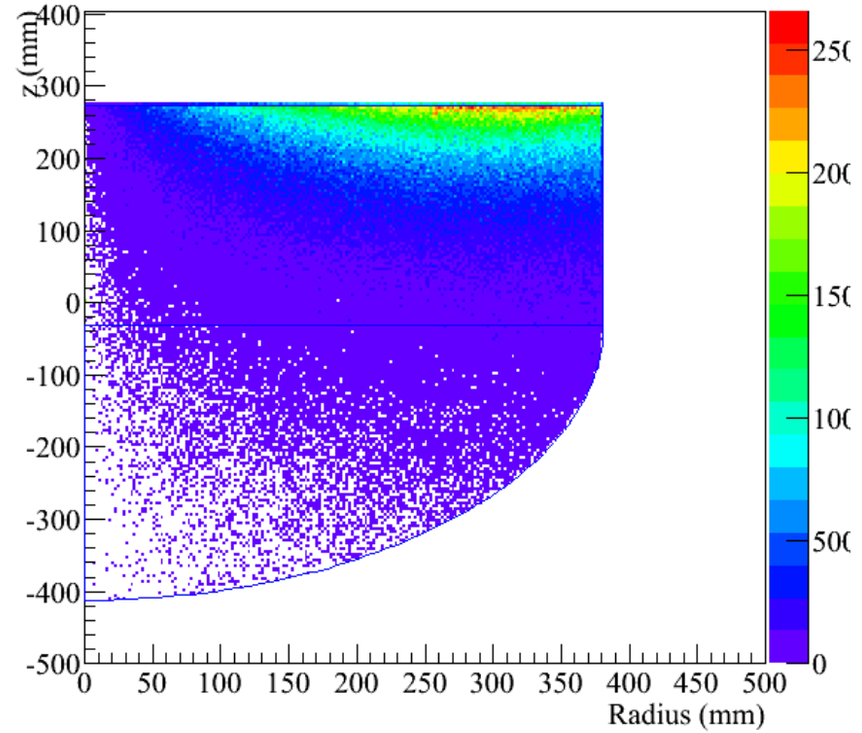
COUPP-500kg: fission and (α,n)

Stainless steel, quartz

Water (buffer and tank), propylene glycol

- ^{238}U, ^{232}Th, ^{235}U





Other backgrounds:

- Mine dust
- veto PMTs

COUPP-500kg: gammas, betas and (γ,n) reactions

Gamma and beta decays:

Interact by Compton scattering, photoelectric absorption, and pair production

Rejection factor: $\sim 10^{-10} - 10^{-12}$

COUPP-4kg at SNOLAB measured: $< 3 \times 10^{-11}$ at 15 keV

COUPP-500kg expected: 10^{-6} events/kg-day

(γ,n) reactions:

- **^{127}I(γ,n)^{126}I:**

  4×10^{-8} events/kg-day

  SNOLAB: $4\,\gamma/\mathrm{cm}^2/\mathrm{yr} > 9\mathrm{MeV}$

- **Other reactions:**

  $< 7 \times 10^{-10}$ events/kg-day

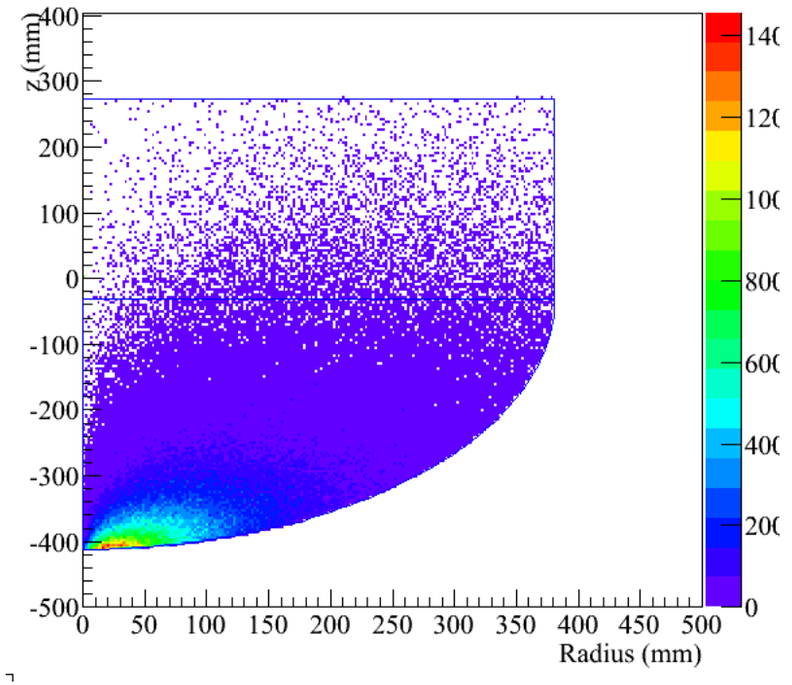
COUPP-500kg: acoustic transducers

Two positions simulated:

(10 ppb ^{238}U and ^{232}Th
0.1 ppb ^{235}U, 10 Bq/kg ^{210}Pb)

- side only, 25g
  2×10^{-8} events/kg-day
- bottom only, 25g
  3×10^{-7} events/kg-day

Acoustic simulation in progress
for design optimization



screening for salts used in the manufacture of piezoelectric transducers

around 15 samples (high purity germanium detector at SNOLAB)

COUPP-500kg: CF_3I purity

α decays
and neutrons from (α,n):

0.0159 ppt ^{238}U
0.0488 ppt ^{232}Th
0.0025 ppt ^{235}U
25 μBq/kg ^{222}Rn
25 μBq/kg ^{210}Pb

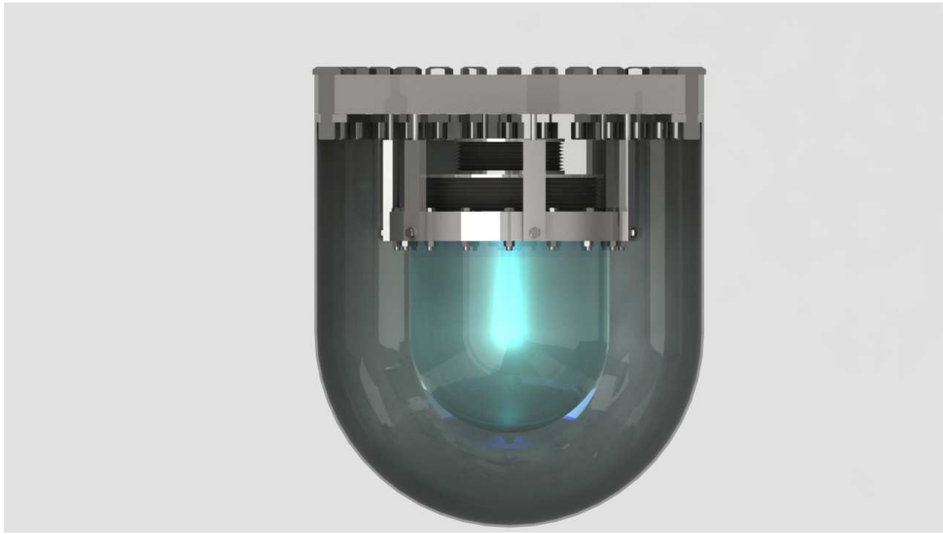
6×10^{-6} events/kg-day

vetoable: alpha + neutron

COUPP-500kg: radon

Radon deposition and
emanation on all surfaces

Radon diffusion in all fluids



Background Summary

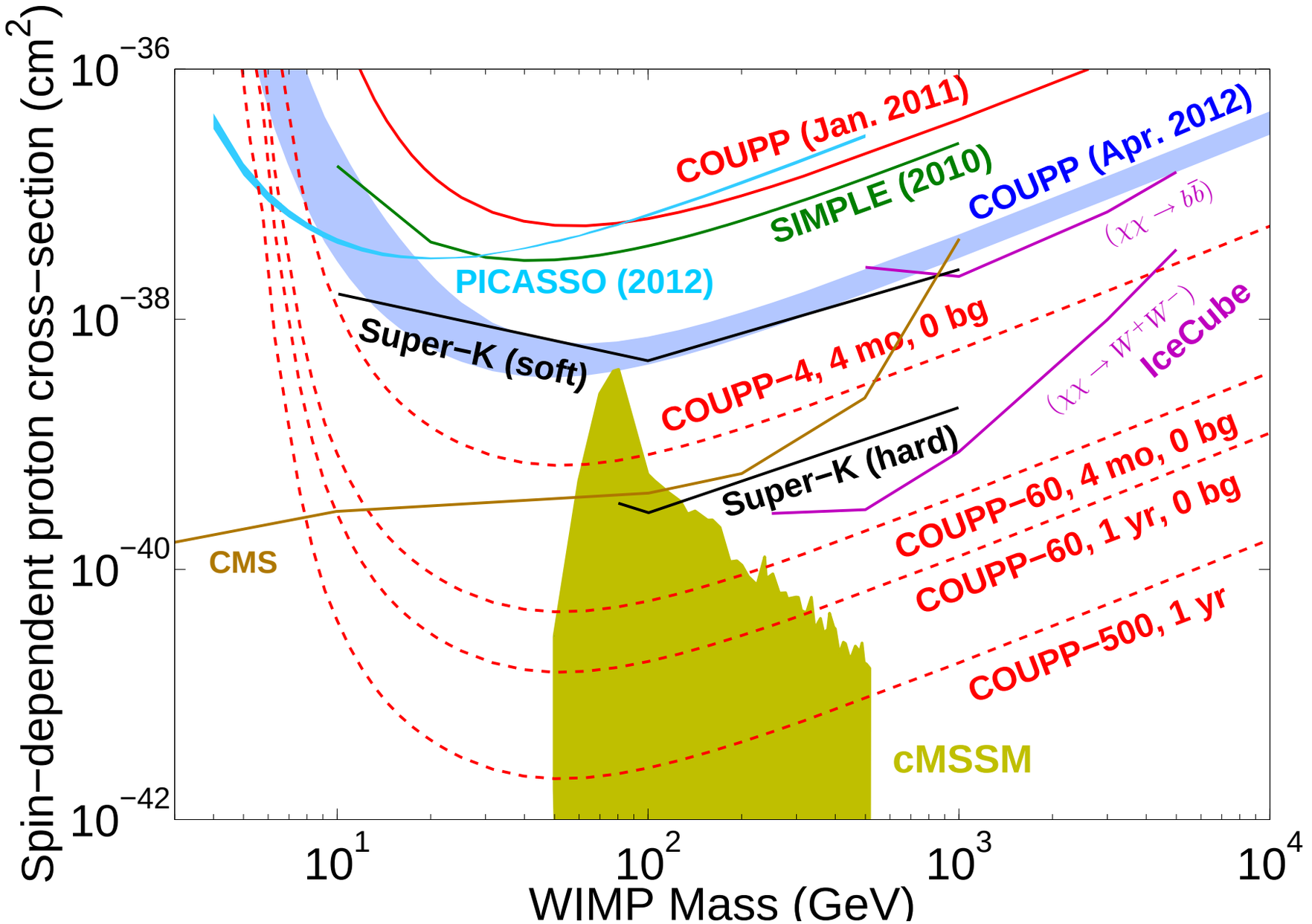
Neutron source	Rate	Single evts/yr	Multiple evts/yr
Rock	$\mathbf{4000 \pm 1000}$ n/m^2/d	$\boldsymbol{O(10^{-11})}$	$\boldsymbol{O(10^{-11})}$
Muon induced from rock	$\mathbf{5.4 \times 10^{-11}}$ n/cm^2/s	$\mathbf{0.0904 \pm 0.0131}$	$\mathbf{0.2544 \pm 0.0219}$
Muon induced from shield or detector	$\mathbf{67.11 \pm 1.85}\ \boldsymbol{\mu}$/d	$\mathbf{0.493 \pm 0.014}$	$\mathbf{1.050 \pm 0.030}$
U and Th in detector materials		$\mathbf{0.0504 \pm 0.0030}$	$\mathbf{0.1242 \pm 0.0068}$
↳ steel only	1ppb ^{238}U and ^{232}Th	$\mathbf{0.0360 \pm 0.0026}$	$\mathbf{0.0922 \pm 0.0062}$
↳ quartz only	$\mathbf{10^{-2}}$ppb ^{238}U and ^{232}Th	$\mathbf{0.0131 \pm 0.0012}$	$\mathbf{0.0290 \pm 0.0026}$
Radon deposition onto and diffusion into outer surface of quartz jar	Dep. Rate= $\mathbf{10^{-3}}$/m/y 100 Bq$^{\mathbf{222}}$Rn/m$^{\mathbf{3}}$ in air t=3 months A=2.21m$^{\mathbf{2}}$ S=10, d$_{\boldsymbol{e}}$=1.0 mm	$\mathbf{0.0198 \pm 0.0015}$	$\mathbf{0.0415 \pm 0.0030}$
Radon in water tank	S=0.25, 100 Bq/m$^{\mathbf{3}}$ Rn inner 18500L	$\mathbf{(1.83 \pm 0.28) \times 10^{-3}}$	$\mathbf{(5.17 \pm 0.60) \times 10^{-3}}$
Radon in heat exchange pipes	S=0.25 100 Bq/m$^{\mathbf{3}}$ Rn, 10L	$\mathbf{0.0230 \pm 0.0021}$	$\mathbf{0.0572 \pm 0.0052}$
Radon emanation from quartz and steel	A=34.81$\boldsymbol{m^2}$ 100 $\boldsymbol{\mu}$Bq/m$^{\mathbf{2}}$ Rn	$\mathbf{(1.39 \pm 0.13) \times 10^{-3}}$	$\mathbf{(2.93 \pm 0.26) \times 10^{-3}}$

Background Summary

Neutron source	Rate	Single evts/yr	Multiple evts/yr
Mine dust on top surfaces	0.01 g/m^2, 2.21 m^2 1.11 ppm ^{238}U 5.56 ppm ^{232}Th	$\mathbf{0.0127 \pm 0.0011}$	$\mathbf{0.0286 \pm 0.0026}$
^{127}I(γ,n)^{126}I	4.0 γ/cm^2/yr $>$ 9MeV	$\mathbf{< 0.0069}$	
other photonuclear		$\mathbf{< 1.3 \times 10^{-4}}$	
Piezoelectric acoustic transducers, 50g ↳ side only, 25g ↳ bottom only, 25g	10 ppb ^{238}U 10 ppb ^{232}Th 0.1 ppb ^{235}U 10 Bq/kg ^{210}Pb	$\mathbf{0.0577 \pm 0.0031}$ $\mathbf{0.0036 \pm 0.0002}$ $\mathbf{0.0541 \pm 0.0031}$	$\mathbf{0.142 \pm 0.008}$ $\mathbf{0.0072 \pm 0.0004}$ $\mathbf{0.134 \pm 0.008}$
CF_3I U and Th (α,n)	0.0159 ppt ^{238}U 0.0488 ppt ^{232}Th 0.0025 ppt ^{235}U 25 μBq/kg ^{222}Rn 25 μBq/kg ^{210}Pb	$\mathbf{1.078 \pm 0.061}$	$\mathbf{4.37 \pm 0.25}$
Other radon induced backgrounds	6mo. deposition on steel 92.6μBq/m^3 in IV	$\mathbf{(8.0 \pm 0.5) \times 10^{-6}}$	$\mathbf{(2.00 \pm 0.12) \times 10^{-5}}$
Total		$\mathbf{1.84 \pm 0.06}$	$\mathbf{6.08 \pm 0.25}$
Total unvetoable		$\mathbf{0.264 \pm 0.014}$	$\mathbf{0.663 \pm 0.025}$

4-page table, each $\sim 10^5 - 10^6$ years simulated

COUPP-500kg expected sensitivity at SNOLAB



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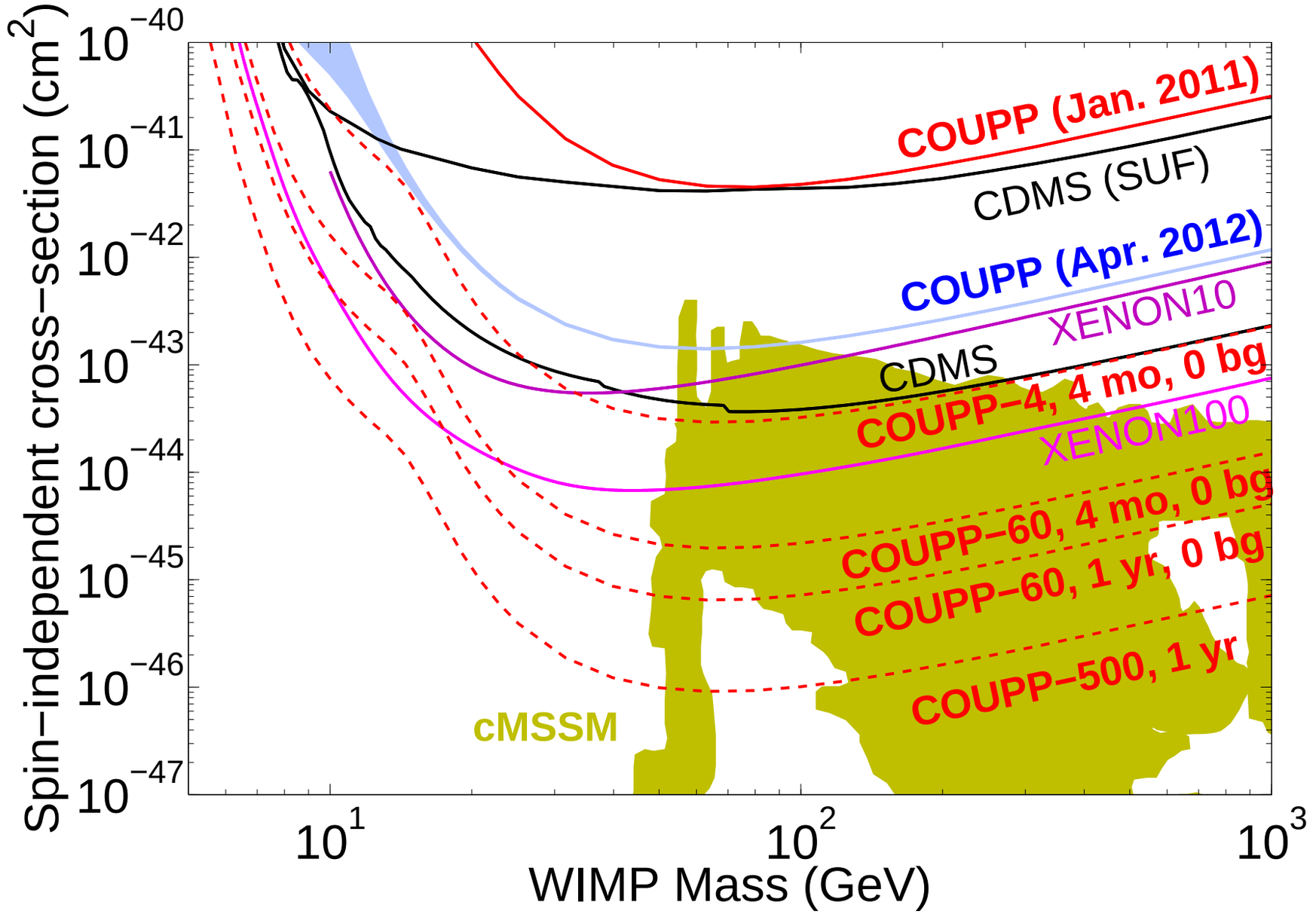

Schedule

- **2013:**
  - **Finish mechanical design of all major components**
  - **Order Outer Vessel**
  - **Prototype hydraulic system**
  - **Test pressure control at full scale**
  - **First tests of 3rd generation acoustic sensors**
  - **Select SNOLAB installation location**
- **2014:**
  - **Water tank construction at SNOLAB**
  - **Inner Vessel prototype testing at Fermilab**
  - **High purity fluid system construction**
  - **Control system and DAQ testing**

Schedule

- **2015:**
  - **Construction of final Inner Vessel**
  - **Installation of all equipment at SNOLAB**
  - **Commissioning**

Ready for Physics data taking in 2016!

Conclusions

COUPP family of detectors making huge improvements:

- **COUPP-4kg currently running at SNOLAB**
- **COUPP-60kg running by the end of the year**
- **Calibrations, calibrations and calibrations: CIRTE, ^{88}Y/Be, gamma, neutron, ...**

COUPP-500kg is the following target:

- **a tonne scale detector**
- **spin-independent sensitivity: $9 \times 10^{-47} cm^2$ (background-free year running)**
- **inexpensive and versatile**
- **ready for physics in 2016**

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More great and beautiful physics from COUPP just around the corner!