DEAP-3600 Dark Matter Search at SNOLAB

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(for the DEAP collaboration)

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DEAP-3600 Collaboration

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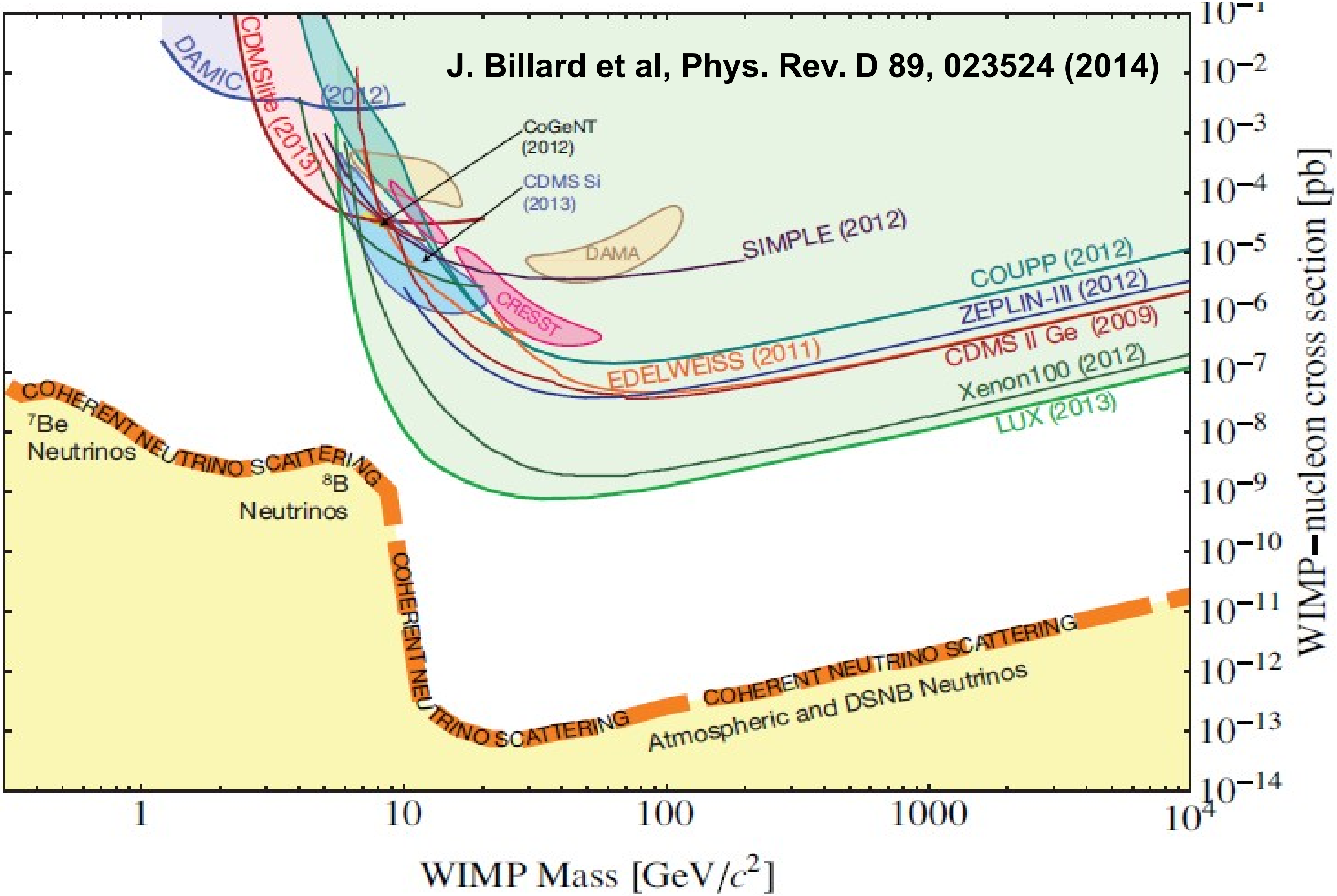
Royal Holloway University of London **J. Monroe,** J. Walding, A. Butcher, N. Seeburn

University of Sussex **S.J.M. Peeters**

+ Close links with the MiniCLEAN collaboration

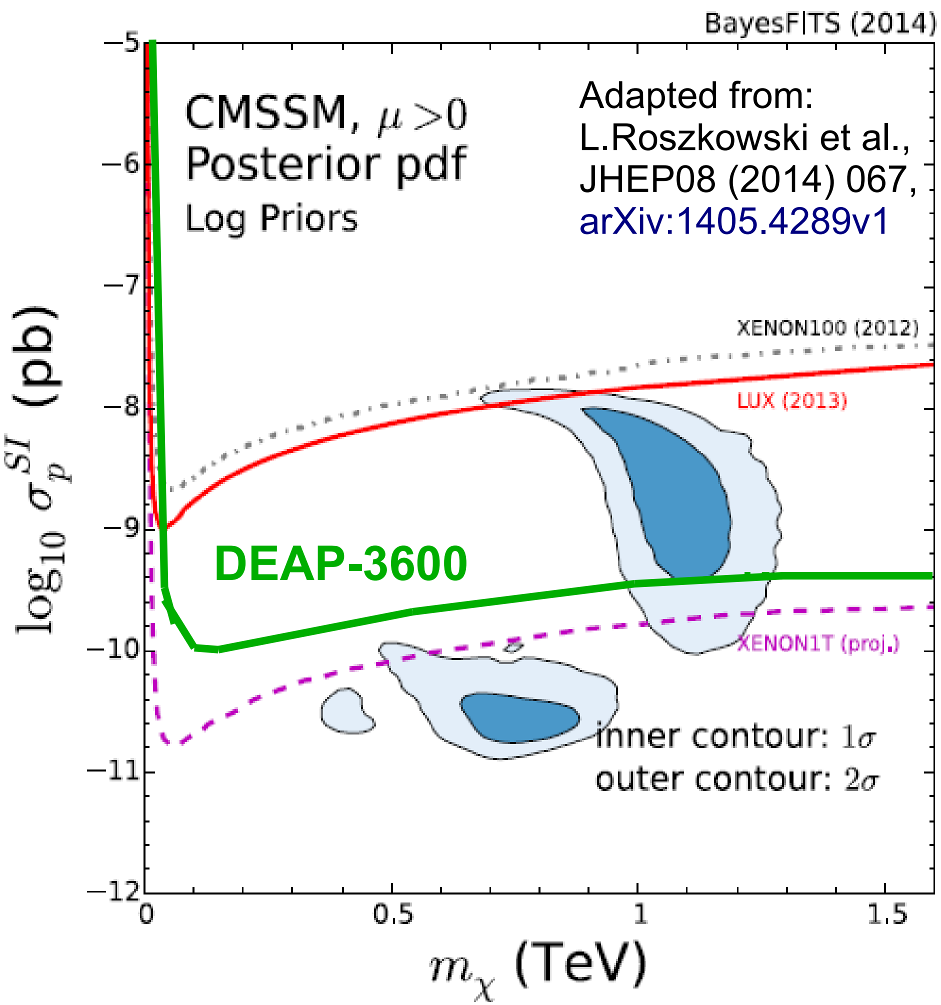
Current searches

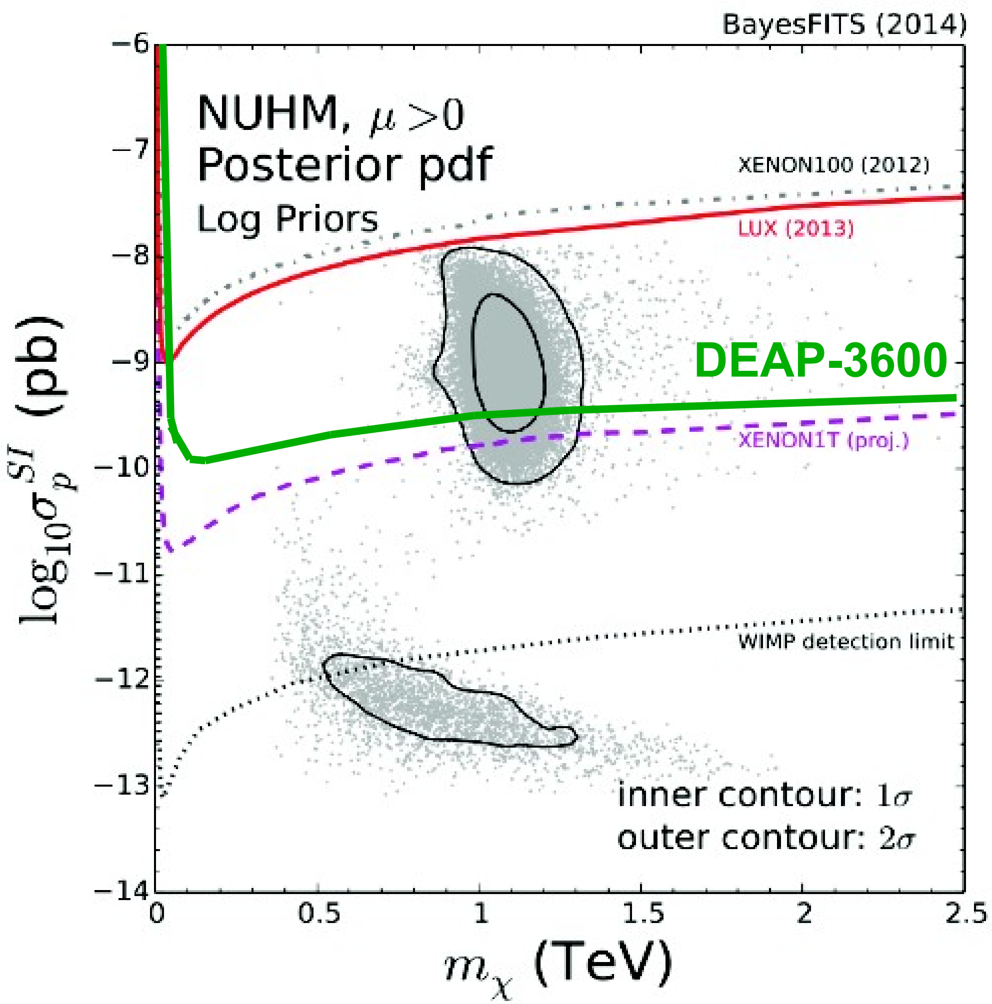


- Significant tension at low energies...
- Since recently dominance of liquid noble gas detectors
- Room for further improvements

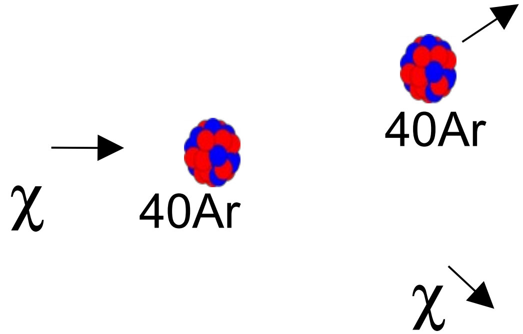
Physics reach for 1-tonne detectors

- All available experimental data combined (LHC, LUX, Planck) are still consistent with even the simplest versions of SUSY (cMSSM, NUHM)
- Remaining parameter space is directly probed by direct WIMP searches with tonne scale detectors
- Complementarity with LHC (cMSSM/NUHM are mostly out of reach of the 14TeV run!)





Liquid argon as a robust and scalable dark matter target



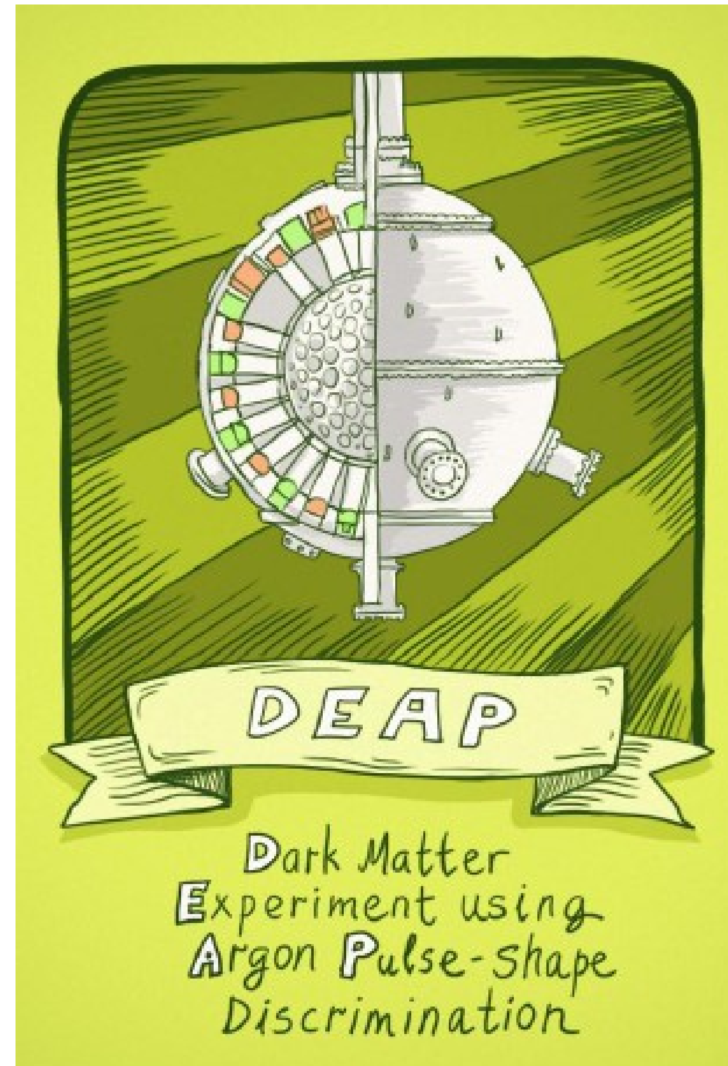
- Well-separated singlet and triplet lifetimes in argon allow for good pulse-shape discrimination (PSD) of β/γ's using **only scintillation time information**

- **PSD to 10^{-8} demonstrated with DEAP-1** (Astroparticle Physics 25, 179 (2006) and arXiv:0904.2930)

- For DEAP-3600 projected to 10^{-10} at 15 keVee, sufficient to remove background from cosmogenic ^{39}Ar

- Very large target masses possible, since no absorption of UV scintillation photons in argon, and no e-drift requirements.

- **1000 kg** argon target allows **10^{-46} cm^2** sensitivity (SI) with ~15 keVee (60 keVr) threshold, 3-year run

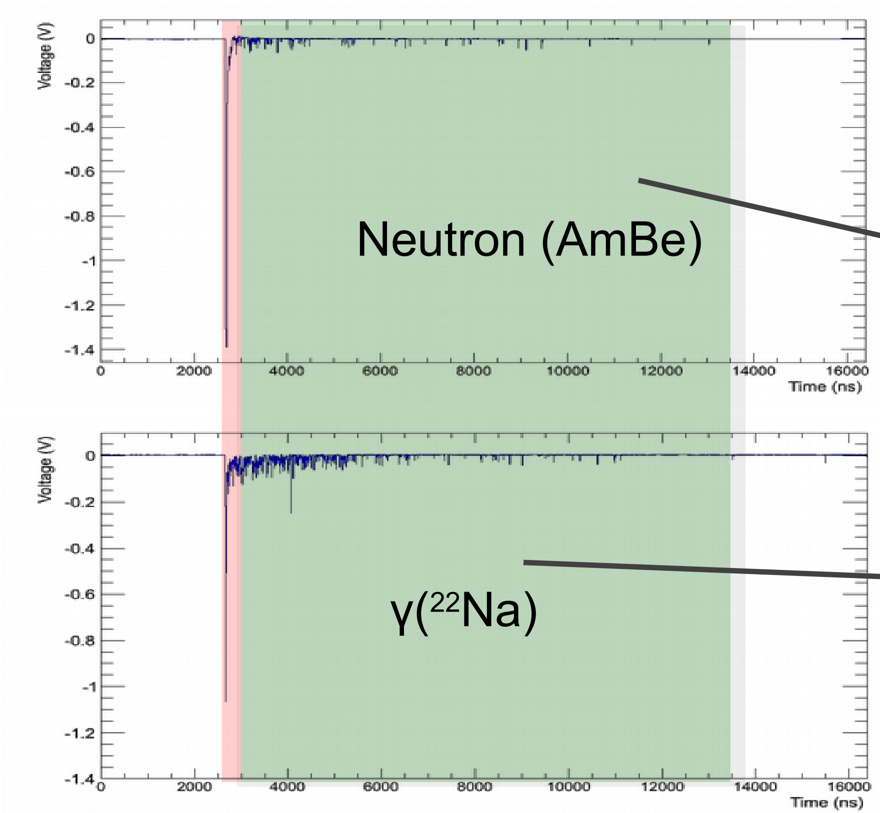


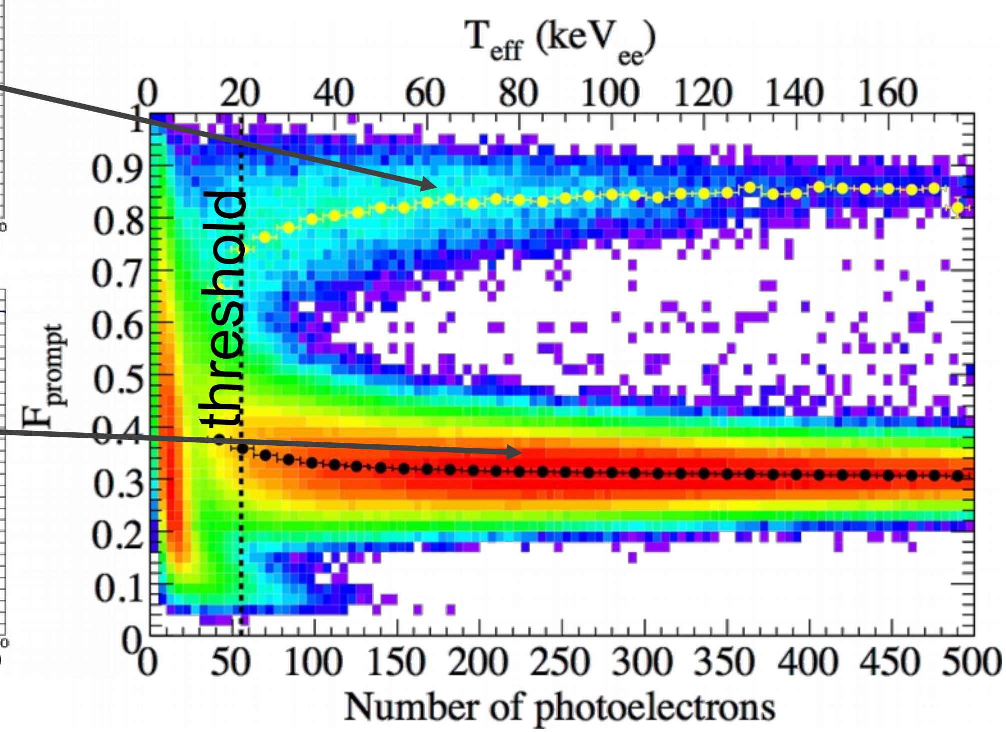
Pulse shape discrimination (PSD)

Ar singlet and triplet excited states have well separated lifetimes (7ns vs. 1.5us)

Electric signal from PMT: Photoelectron counting:

$$\text{FPrompt} = \frac{N_{prompt}}{N_{prompt} + N_{Late}}$$

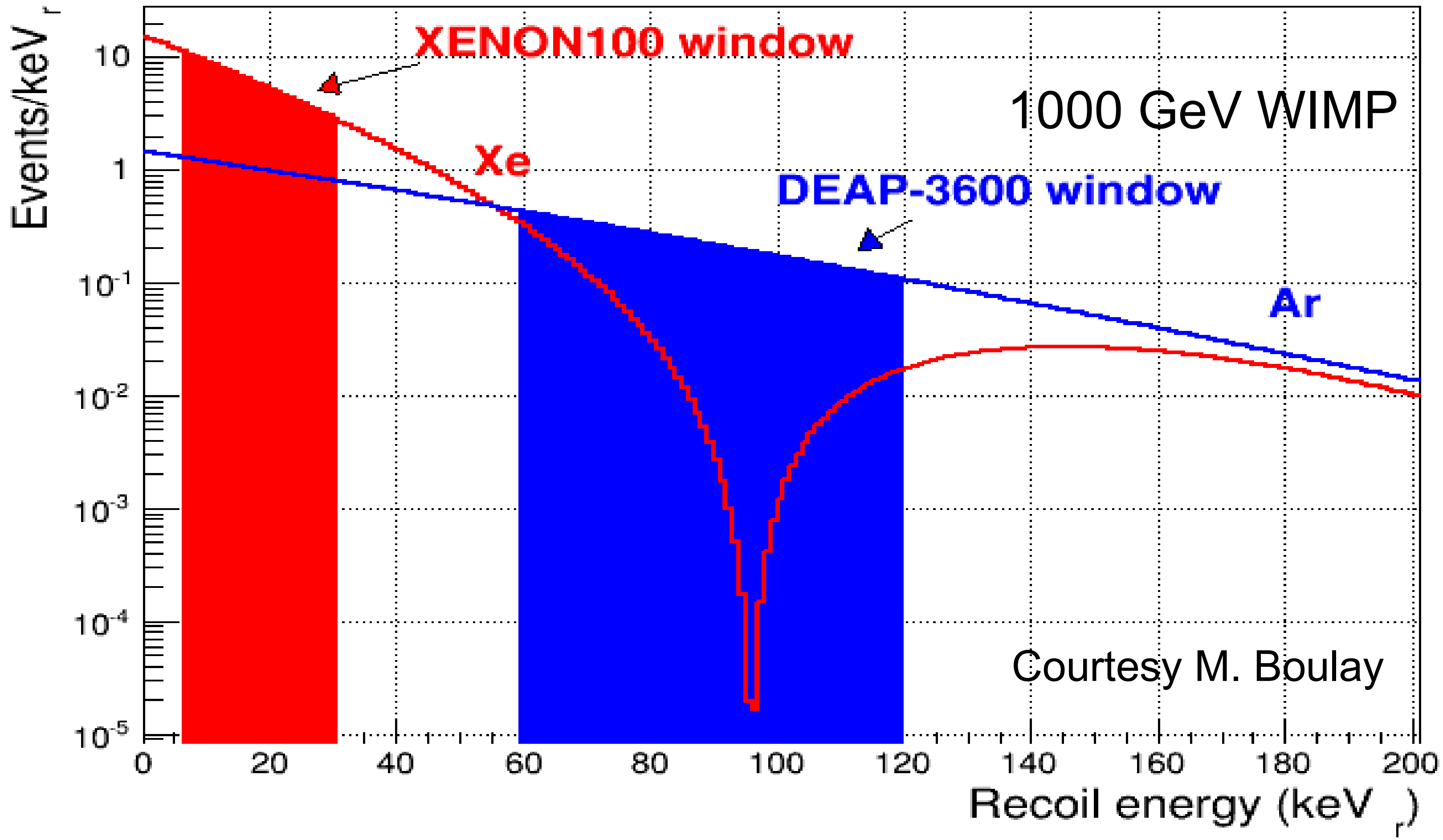




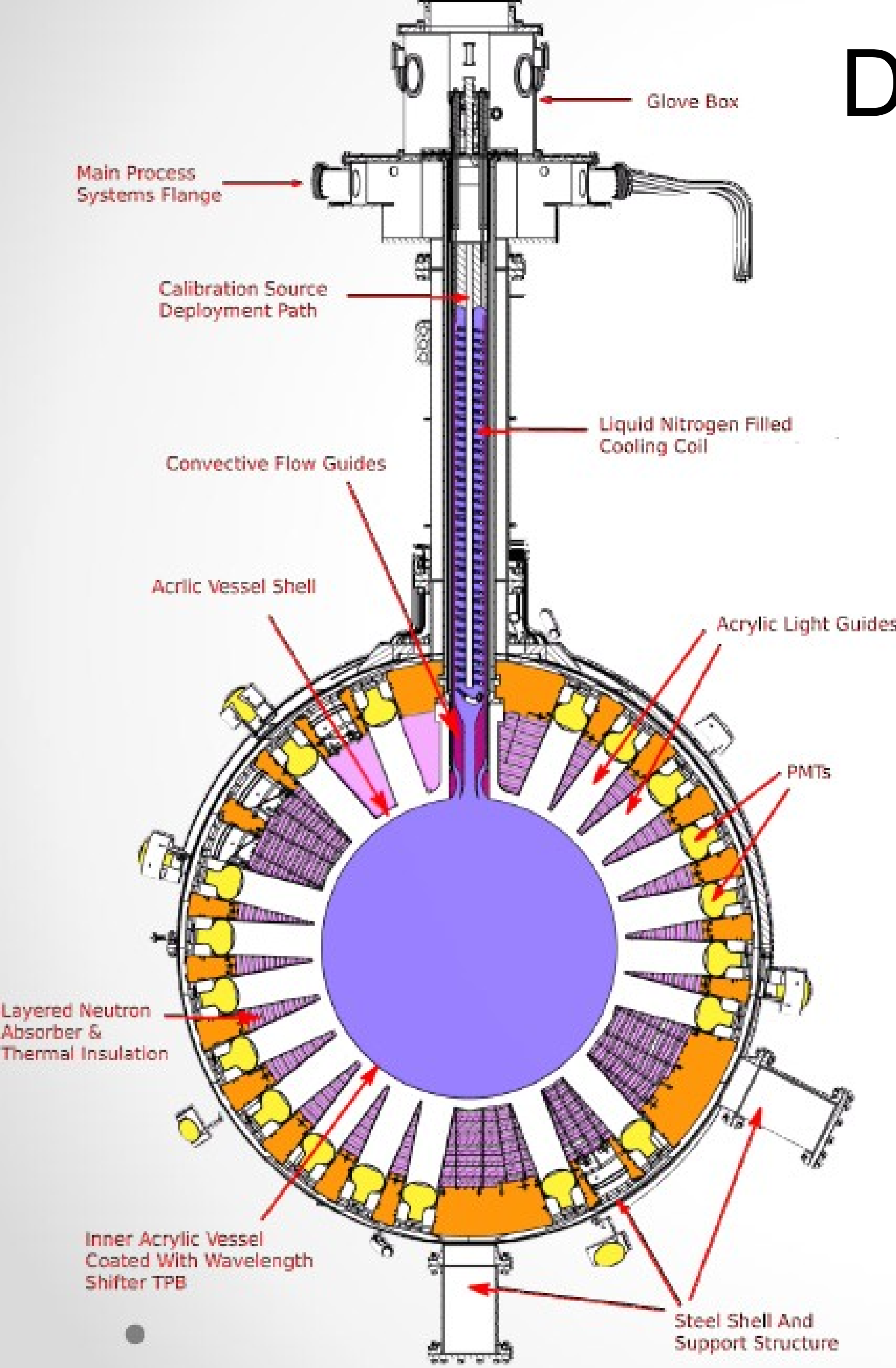
Prompt : 0-150ns
Late: 150ns-10μs

Single phase LAr:
scintillation channel is sufficient, no ionization channel

Xe and Ar for direct WIMP scattering



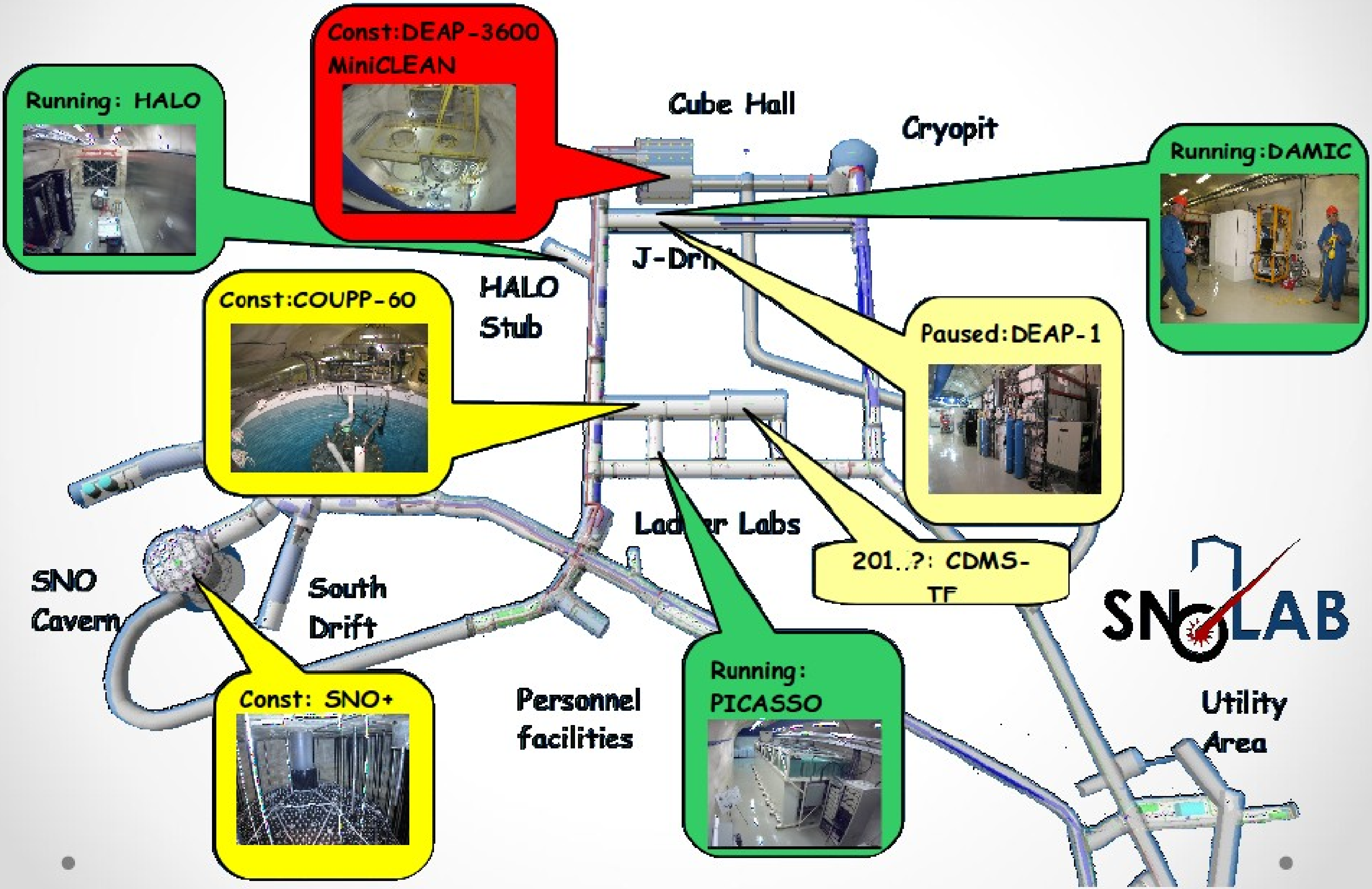
- Complementary
- For high WIMP masses Ar is very competitive with Xe
- Potential for very large and very sensitive searches



DEAP-3600 detector

- 3600 kg argon target (1000 kg fiducial) in sealed ultraclean Acrylic Vessel
- Vessel is “resurfaced” in-situ to remove deposited Rn daughters after construction
- 255 Hamamatsu R5912 HQE PMTs 8-inch (32% QE, 75% coverage)
- 50 cm light guides + PE shielding provide neutron moderation
- Detector immersed in 8 m water shield, instrumented with PMTs to veto muons
- Located 2 km underground at SNOLAB

SNOLAB Subury Ontario Canada



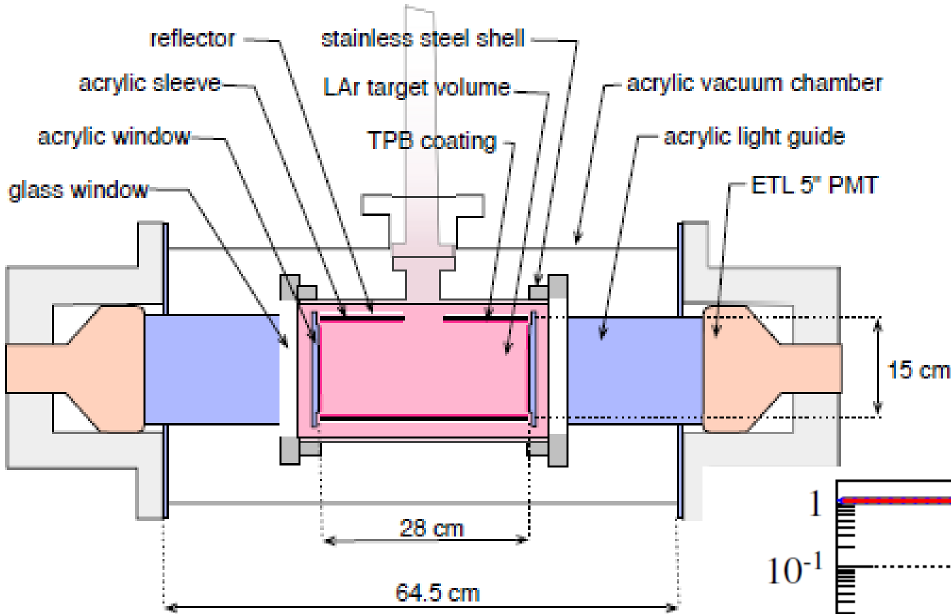
Backgrounds budget

Background	**Target**
Radon in argon	< 1.4 nBq/kg
Surface α's (tolerance using conservative pos. resolution)	< 0.2 μBq/m2
Surface α's (tolerance using ML position resolution)	< 100 μBq/m2
Neutrons (all sources, in fiducial volume)	< 2 pBq/kg
Bg events, dominated by 39Ar	< 2 pBq/kg
Total Backgrounds **(3 Tonne-year in fiducial volume and Region of Interest)**	**< 0.6 events**

Background mitigation

- **β/γ events:** dominated by ^{39}Ar rate, 1 Bq/kg
  - PSD is very powerful in liquid argon, distinguish from recoils
- **neutron recoils:** (α,n)+fission, μ-induced
  - NO neutrons! SNOLAB depth, clean detector materials (strict material screening & assay, quality assurance / co-operation with suppliers),
  - shielding
- **surface events:** Rn daughters and other surface contamination
  - Clean surfaces in-situ
  - Position reconstruction + fiducialization
  - Limited exposure to radon

PSD with DEAP-1



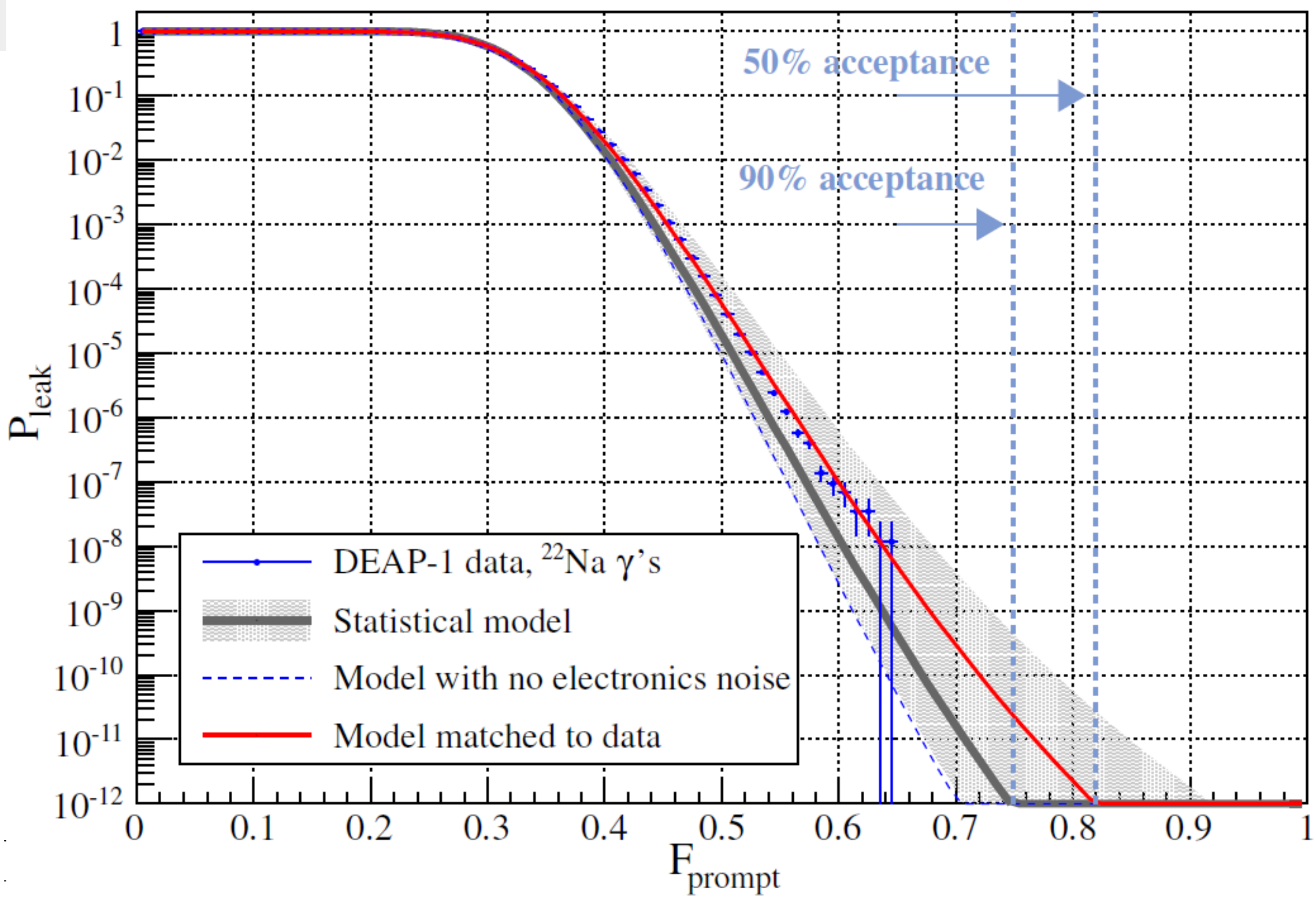
- PSD of ~10^{-10} required to beat down backgrounds from ^{39}Ar (a beta emitter).
- Measured with a tagged gamma source using DEAP-1 at SNOLAB

Measured the gamma leakage upper limit:

< $2.8 \cdot 10^{-8}$ (90% C.L.)

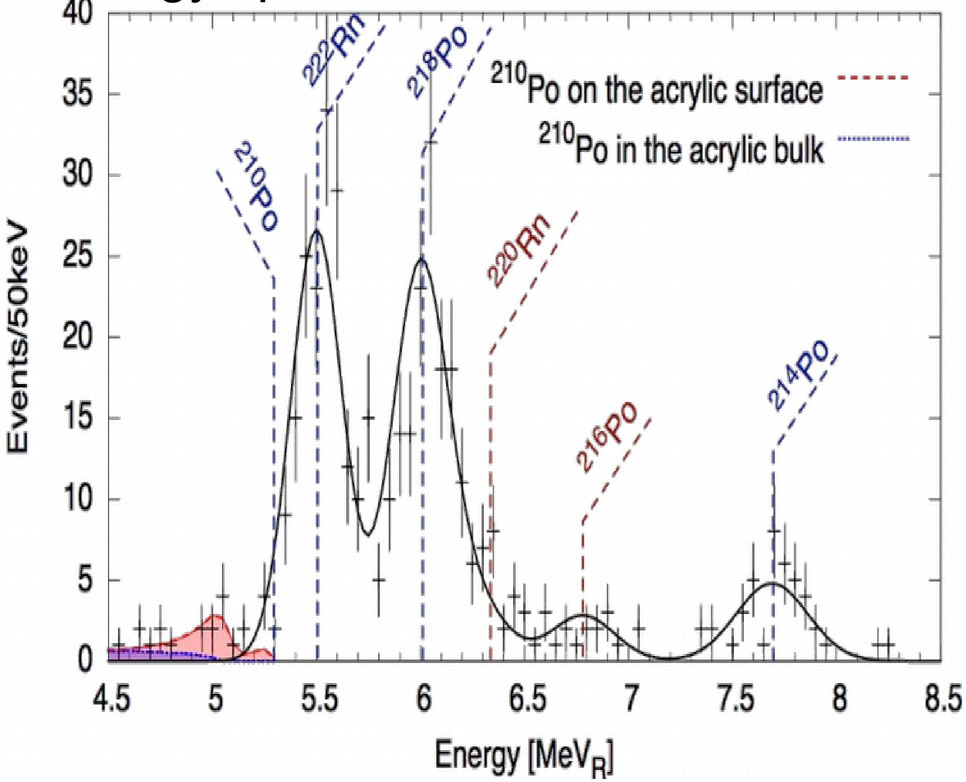
(for 43-86 keV$_{ee}$ recoil energy range and 90% nuclear recoil acceptance)

P.-A. Amaudruz et al., submitted to Astroparticle Physics

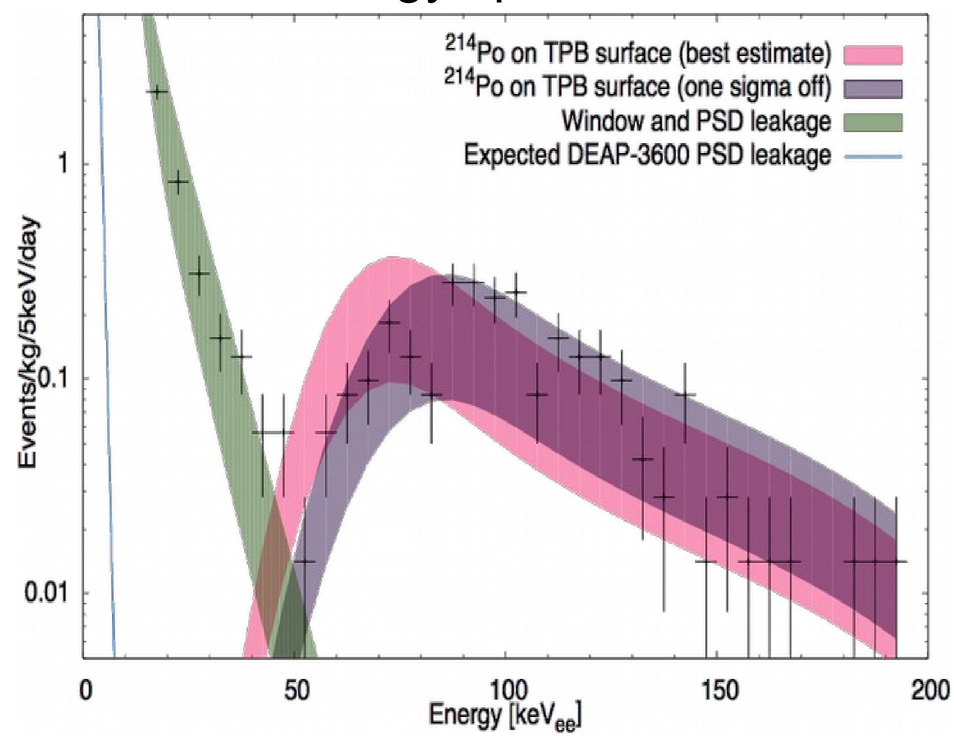


Surface backgrounds

High energy spectrum, fitted with Radon daughters



Low energy spectrum in ROI



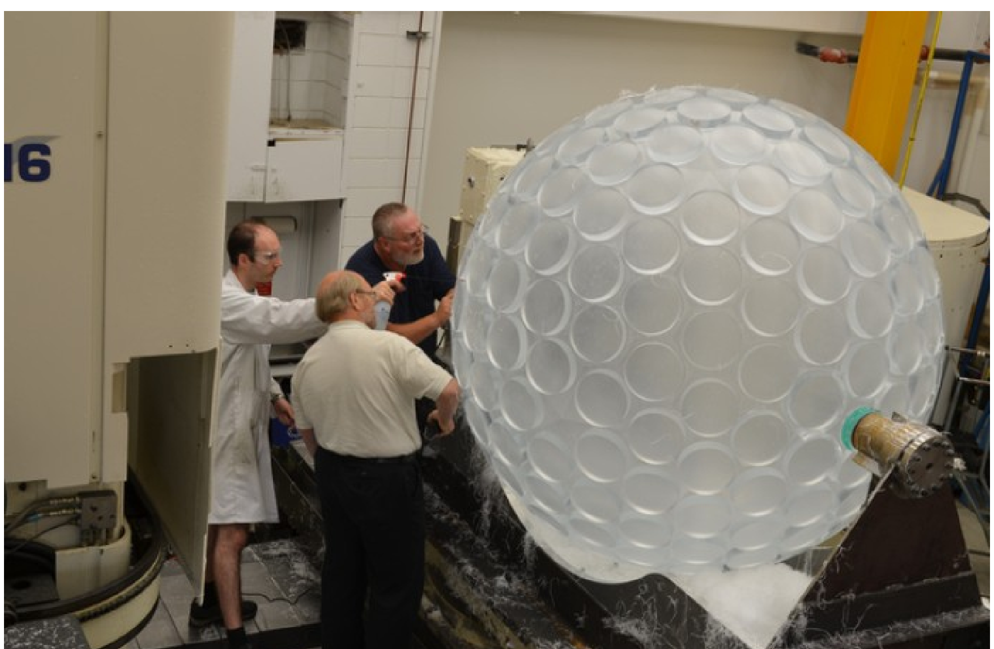
arXiv:1211.0909

Low energy cut off + improved PSD => NO α background in WIMP window

Detailed surface background model, suggested a 'conventional' explanation to the excess of events seen by CRESST-II, see:
MK, M. Boulay, T. Pollmann, Astropart. Phys. 36, 77 (2012)

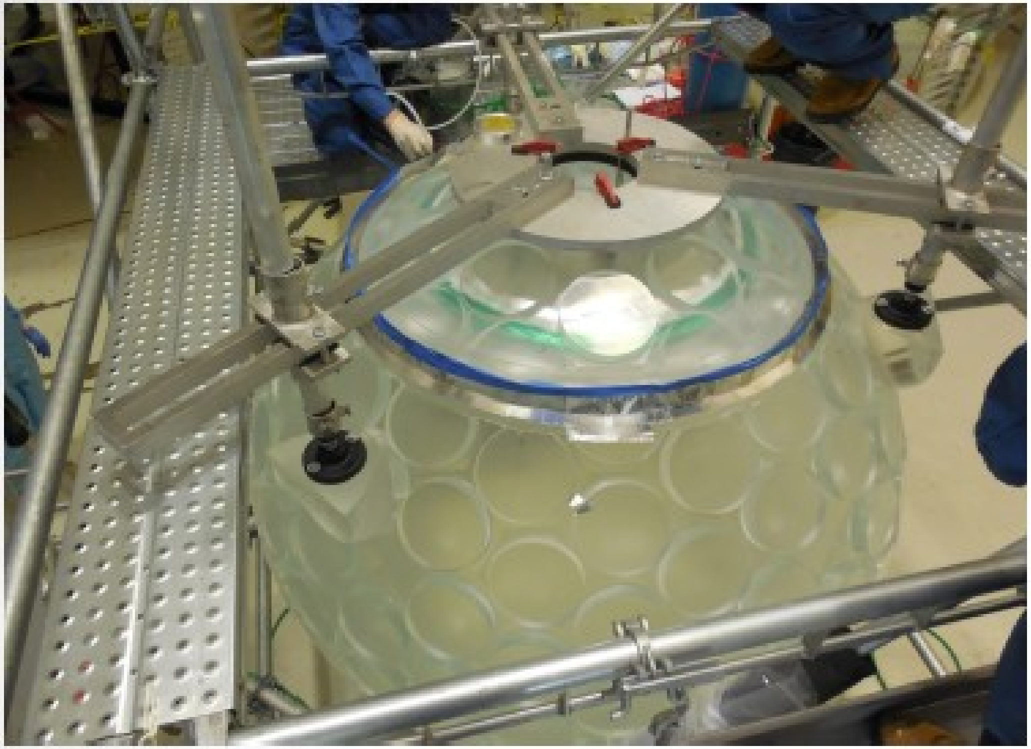
Construction highlights: acrylic vessel

RPT Colorado

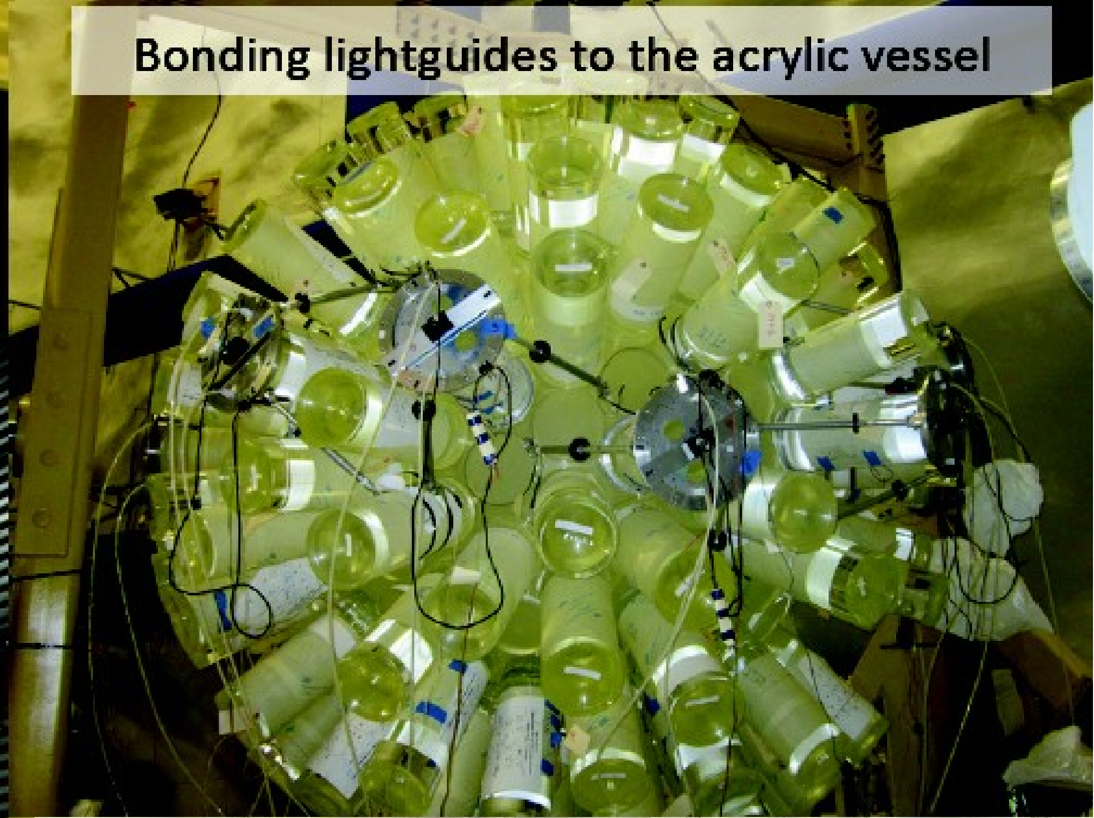


University of Alberta,
Edmonton

Underground bonding

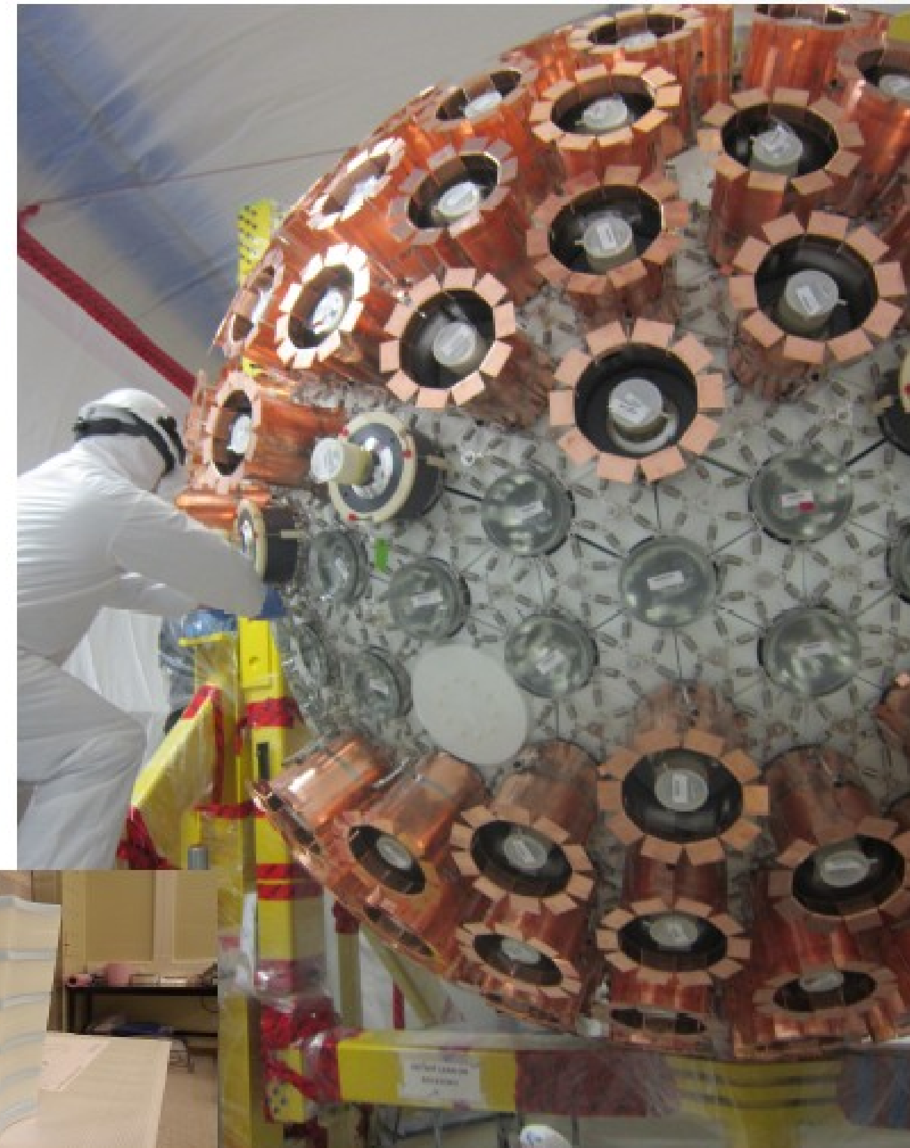


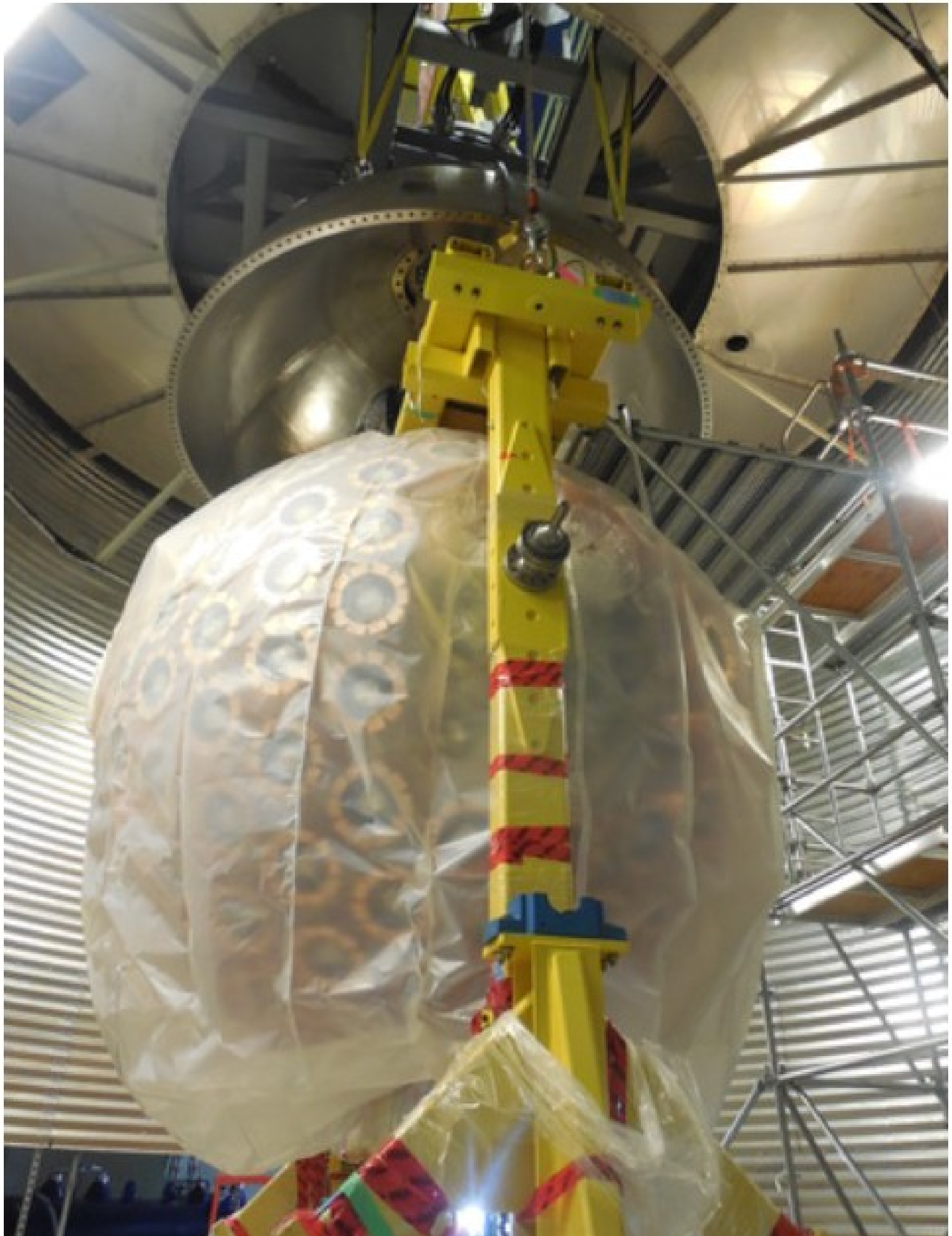

Vacuum testing the steel sheel

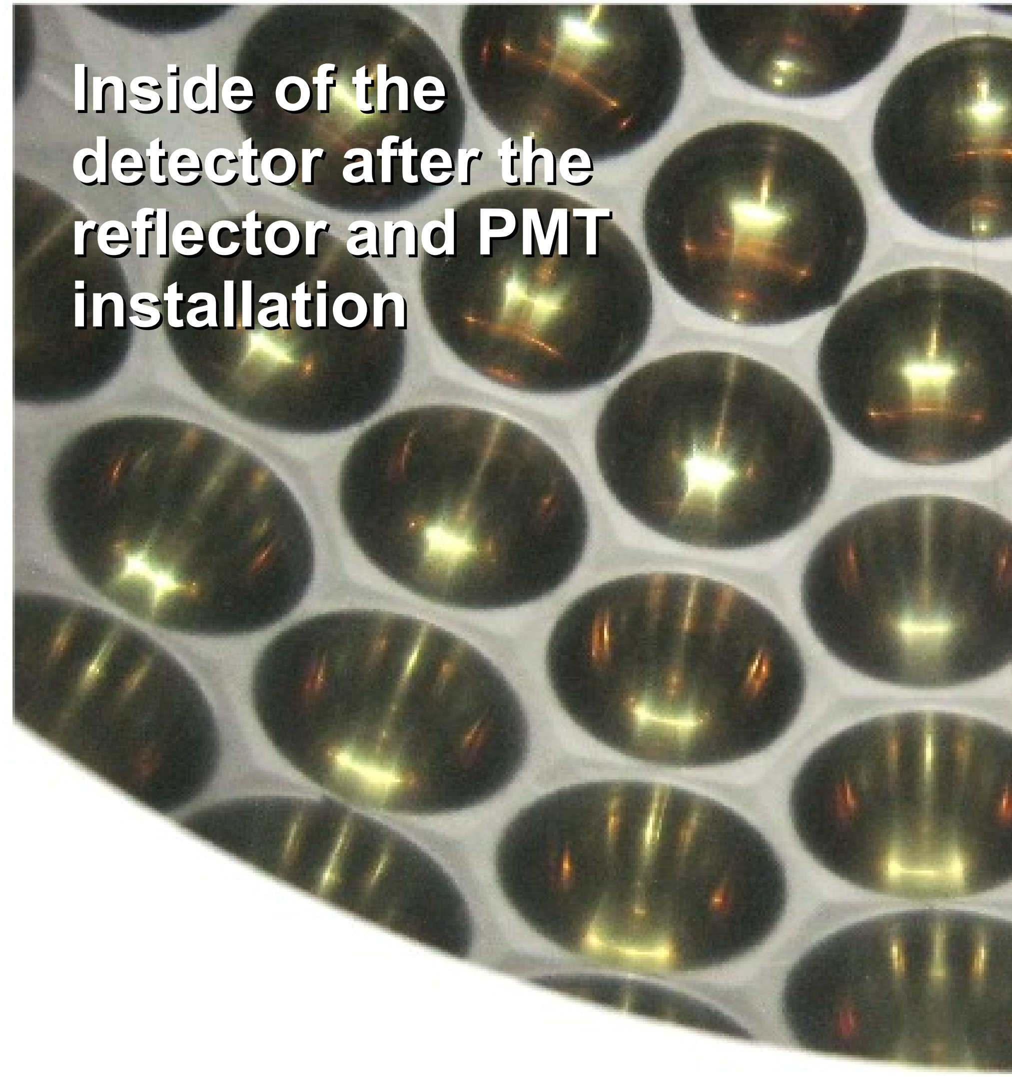

Bonding lightguides to the acrylic vessel


Completed acrylic vessel – lightguide assembly

Reflector & PMT installation

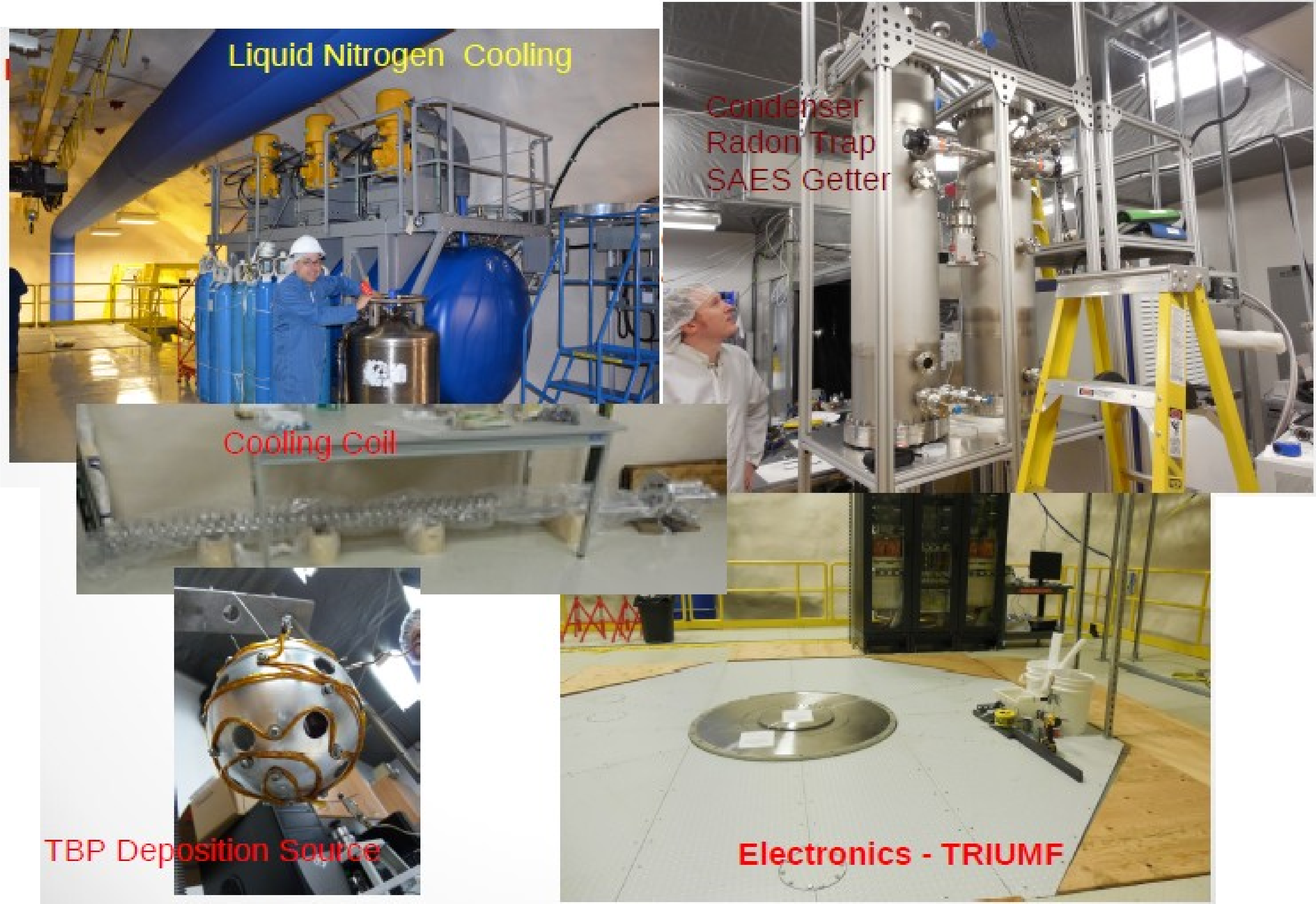




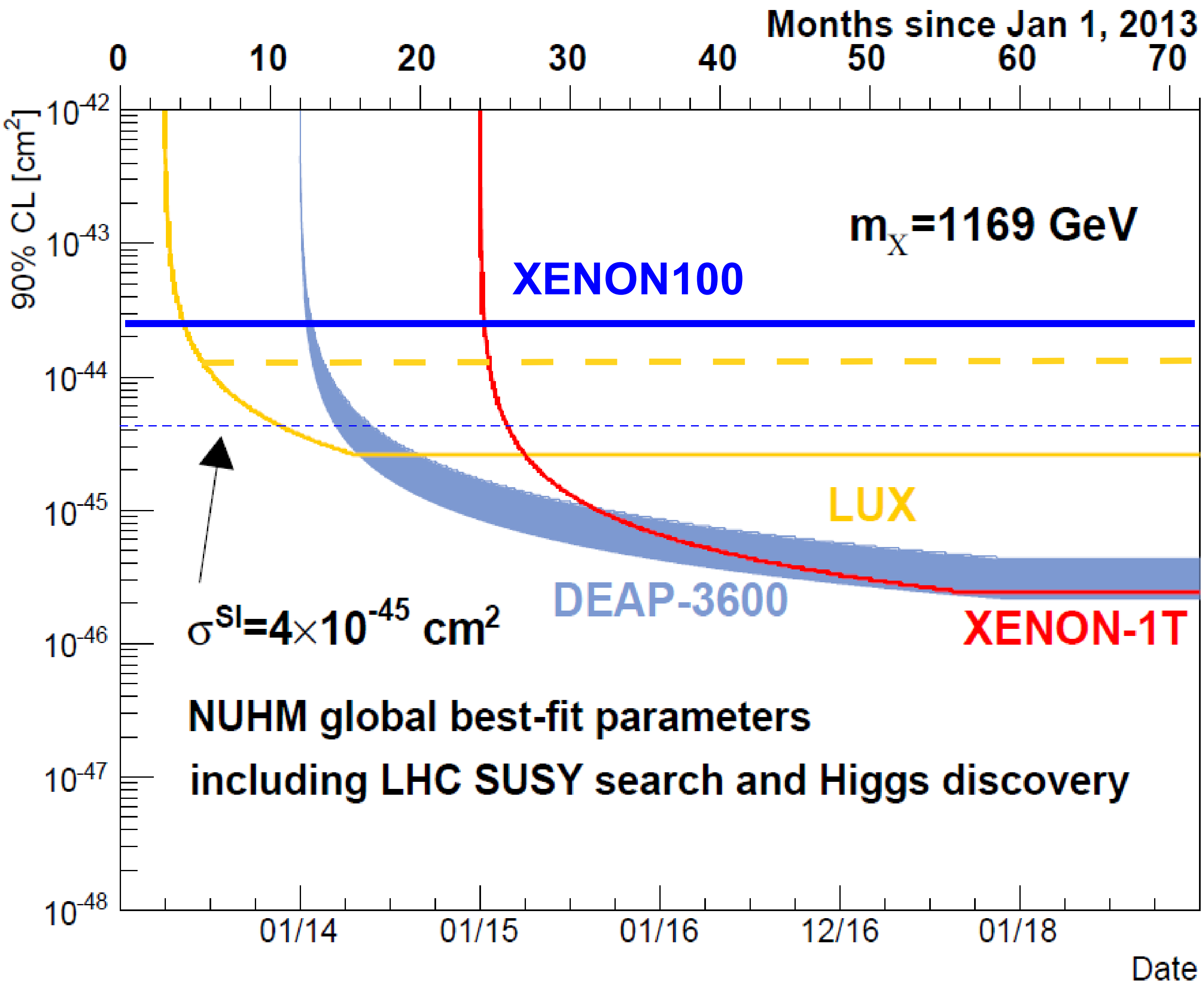


Installation of the instrumented acrylic vessel in the steel shell

Other subsystems

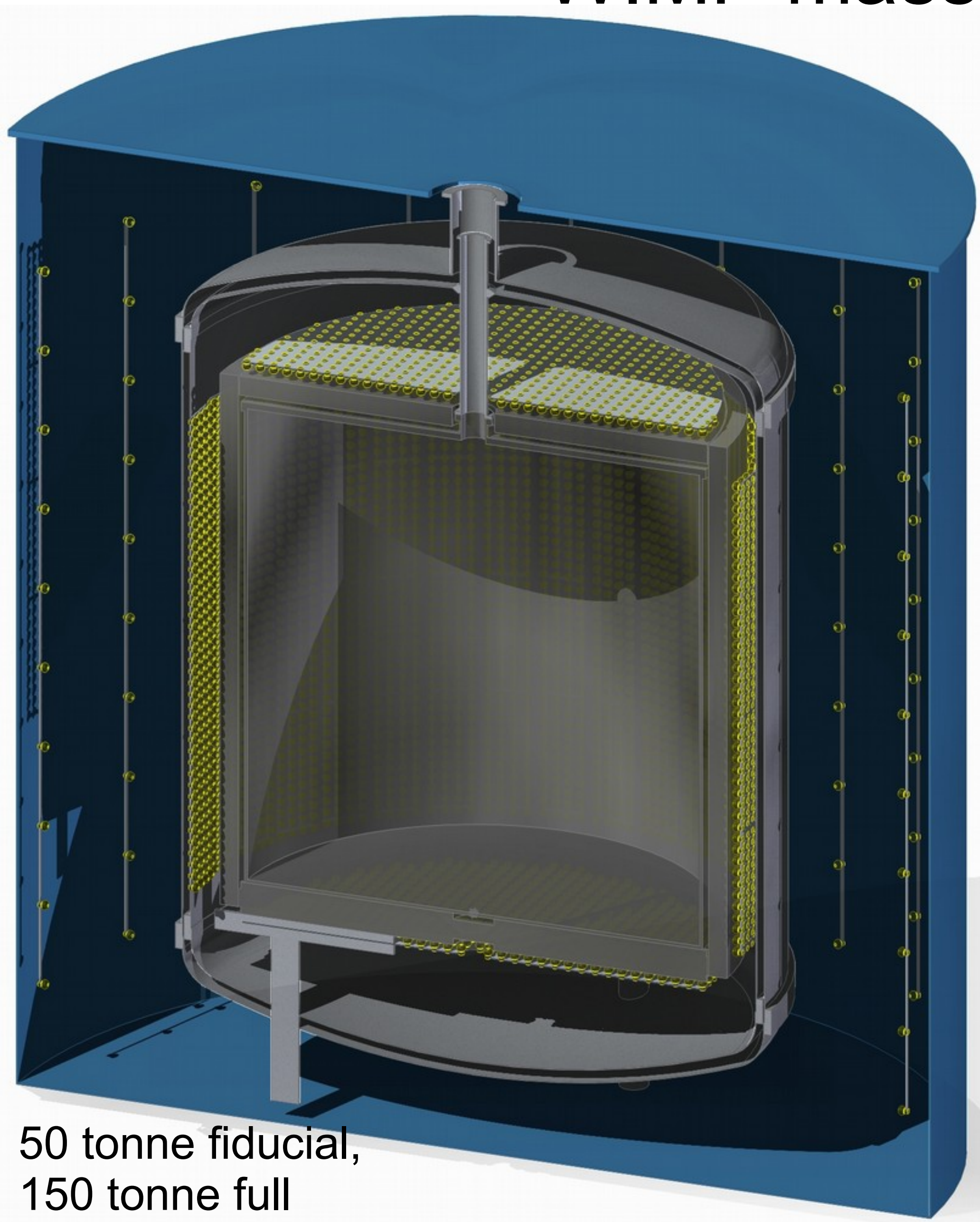


Time scale



- Some delay with respect to the plot: ~6 months
- Next installation steps:
  - Resurfacing
  - Wavelength shifter deposition
  - Cooldown
- Commissioning starts soon
- Competitive limits after ~2 months of data taking

WIMP mass sensitivity

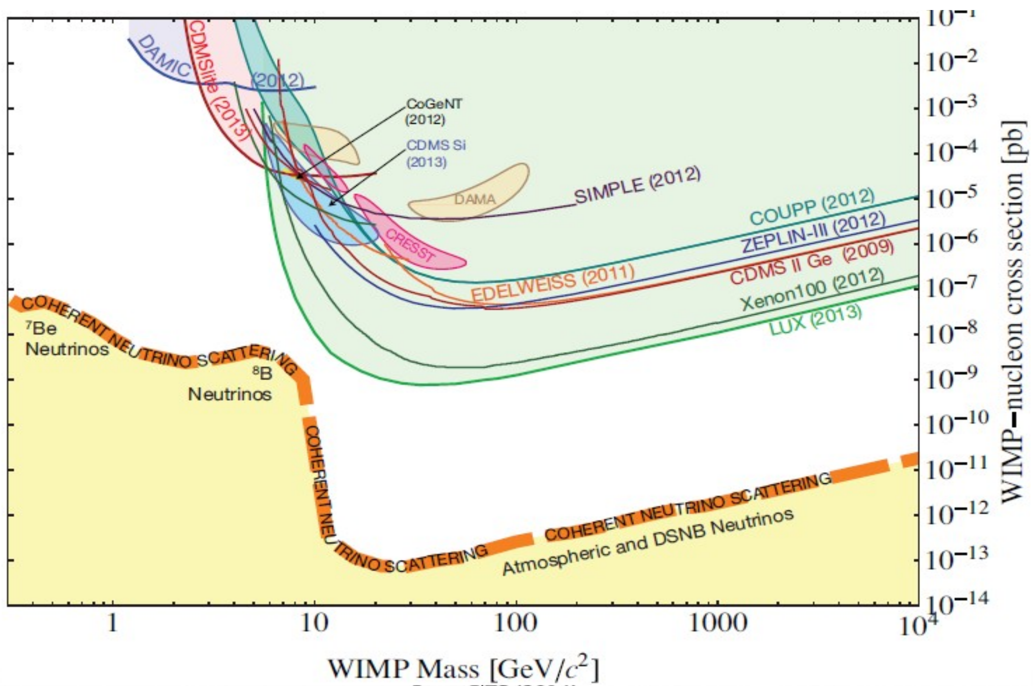


- Technology can be scaled to very large target masses, > 100 tonnes or **10^{-48} cm^2** sensitivity (10^{-12} pb)
- Larger detector allows for better position reconstruction, which makes surface contamination easier to mitigate
- Relaxed targets on surface contamination significantly simplify many aspects of construction and assembly (compared to DEAP-3600)
- Large detector will require Depleted Argon

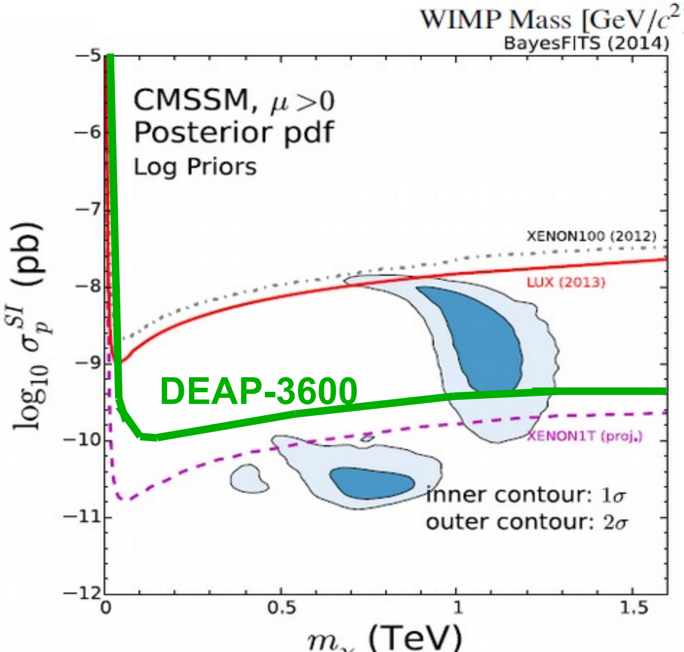
- Chosen parameters:
  - 44’ diam. water tank
  - 24’ diam. Steel Shells
  - 4400 8” HQE PMTs
  - 12” acrylic shielding panels
  - 17’ diam. 2” thick acrylic
  - vessel with flanged lid
  - 150 tonnes argon in AV (50 tonnes fiducial)

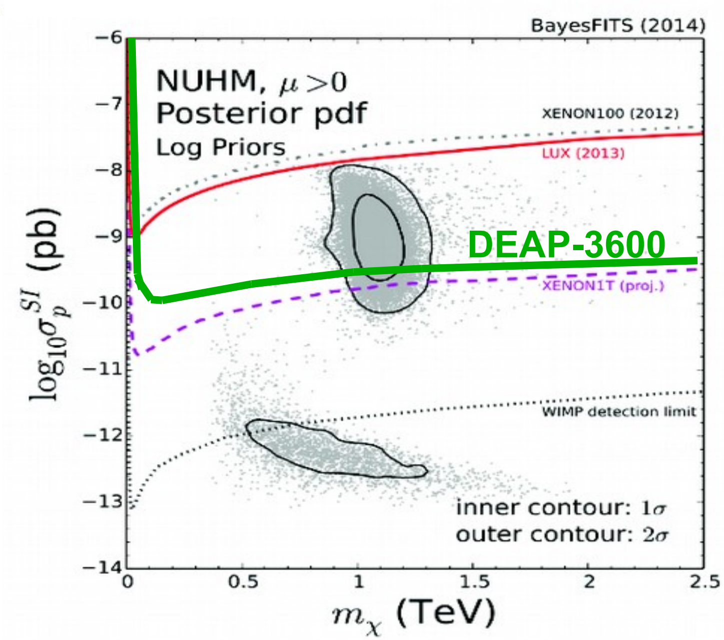
- Modest R&D underway

50-tonne Ar detector



- 50 tonne Ar detector can exhaust the available parameter space above the neutrino floor
- Due to superior PSD, Ar is not sensitive to *pp* neutrino-electron elastic scattering, which limits ~10 tonne Xe detectors (assuming ER rejection of 0.995)





- Large detector can conclusively probe the allowed CMSSM parameter space and most of the NUHM allowed parameter space.

arXiv:1405.4289v1

M. Kuźniak, ICHEP 2014

Summary

- ~1 TeV WIMPs favoured by the simplest and most widely considered models (cMSSM and NUHM). Within reach for the upcoming round of direct detection experiments.

- DEAP-3600 construction is nearly complete.
- Detector online later this year, with competitive sensitivity for WIMP masses >150 GeV.

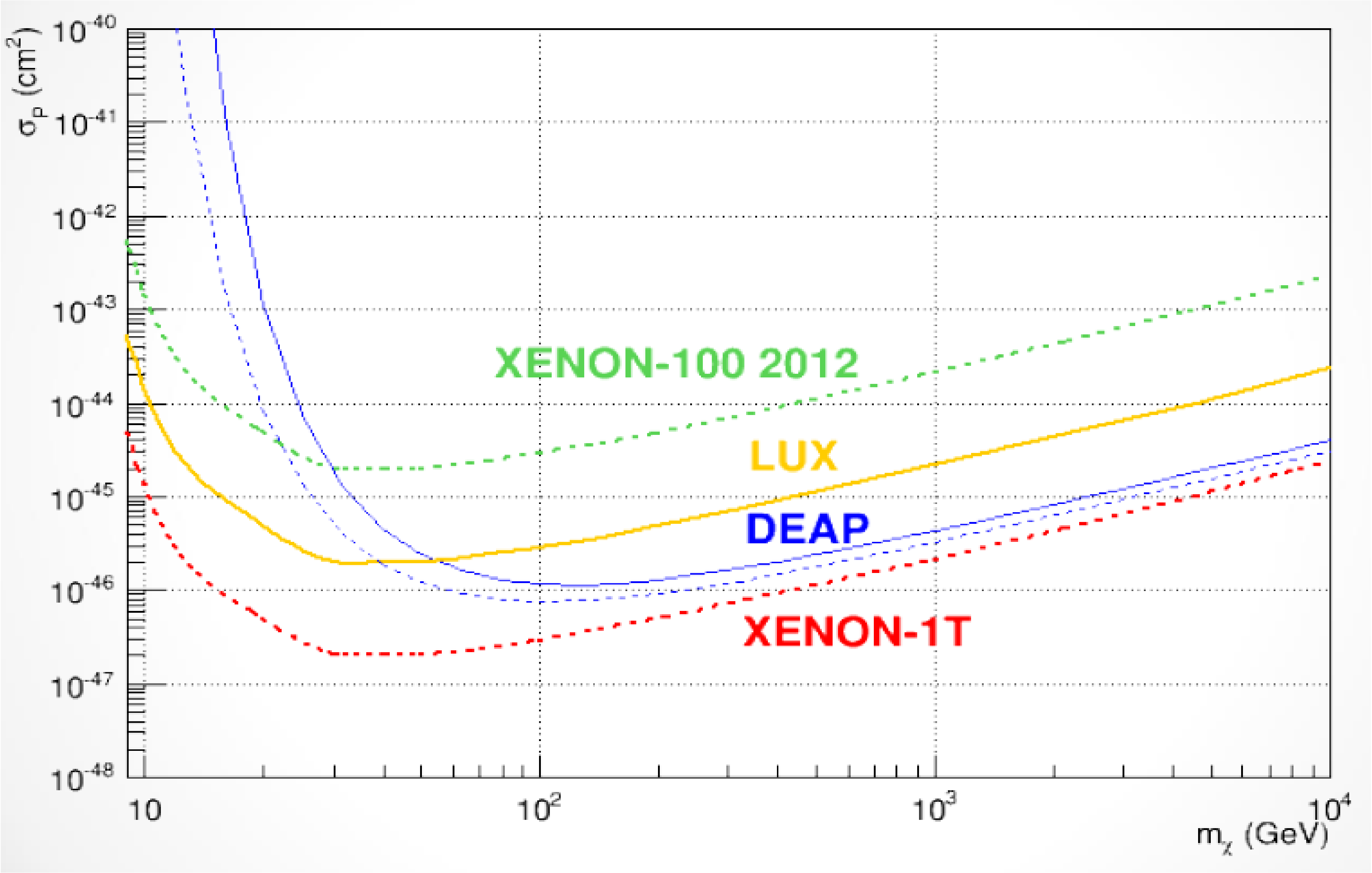
- We have demonstrated sufficient control over surface backgrounds and excellent PSD in DEAP-1.

- Some conceptual effort on the next generation detector.

- In the single-phase technology, larger scale makes life much easier.

- Attractive way towards a precision WIMP mass measurement (if a WIMP signal is seen by 1-tonne scale experiments). Single-phase LAr is ideally suited for this purpose.

Stay tuned!



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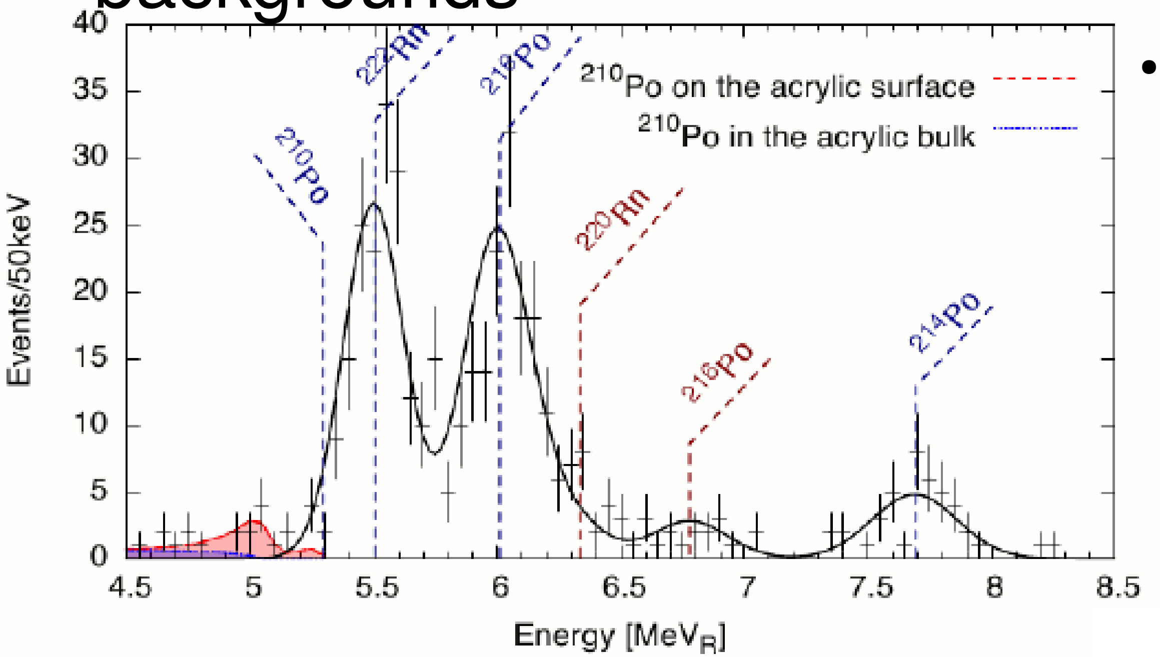
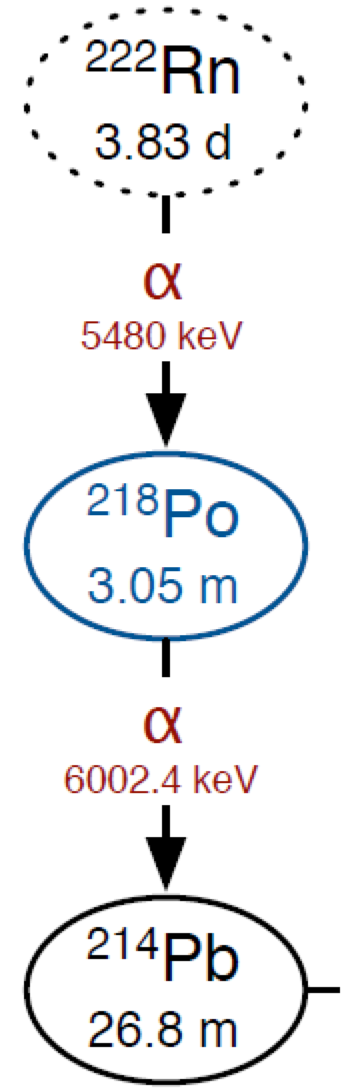
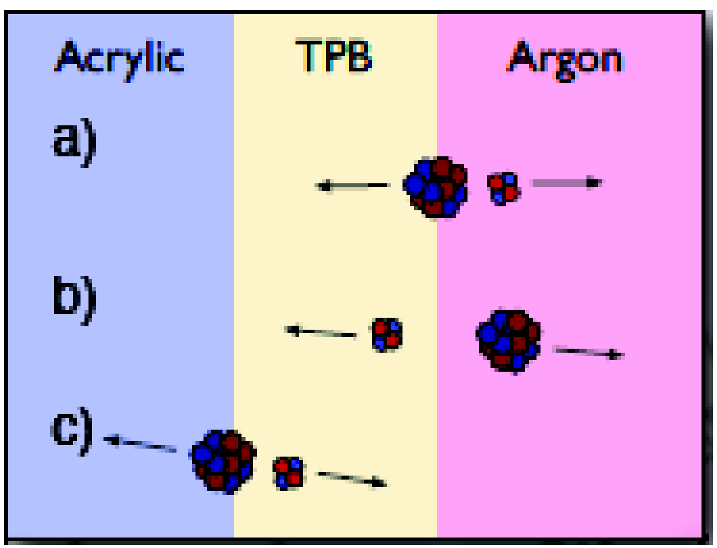
Backup

DEAP-1: Good understanding of surface backgrounds



- Find ^{214}Po “sticks” to wall





^{222}Rn :

120 µBq in DEAP-1

Compare for example:

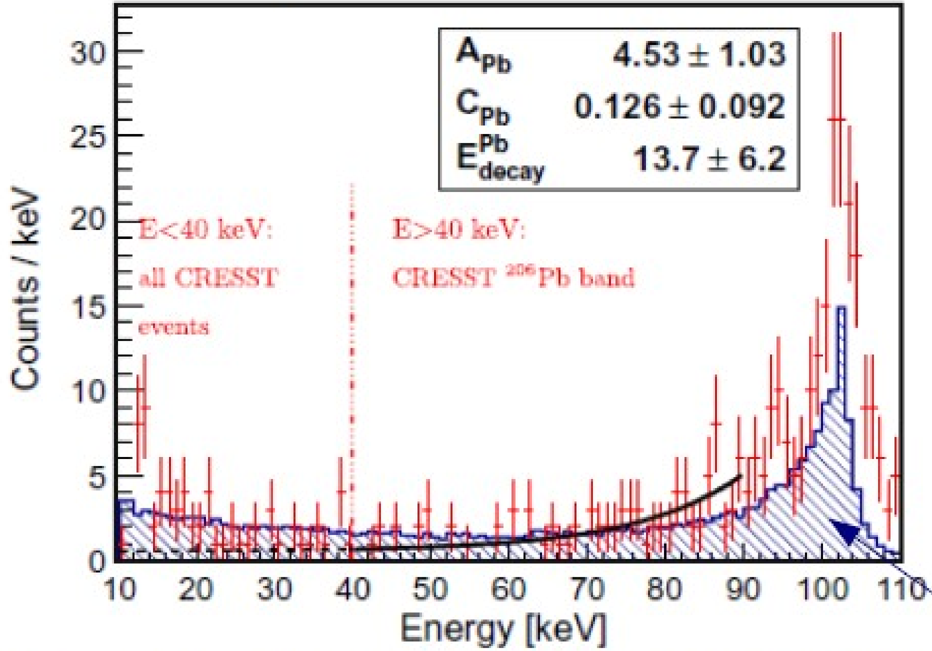
360 µBq in EXO-200

[PRL 109 032505 (2012)]

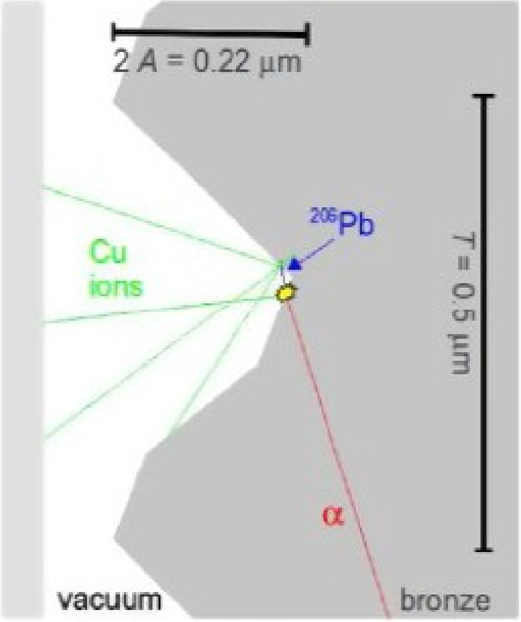
Non-trivial effects due to surface roughness

- Coupled with surface contamination it can lead to tails at low energies
- It is impossible to account for surface roughness using simple tools such as SRIM
- Can be properly simulated using Geant4 with one of its common extensions:
  => physics list from example "TestEm7" in the standard distribution

- Possible explanation of the CRESST-II event excess at low energies



M Kuźniak et al. Astropart. Phys. 36, (2012) 77



Geant4 + realistic surface + TestEm7

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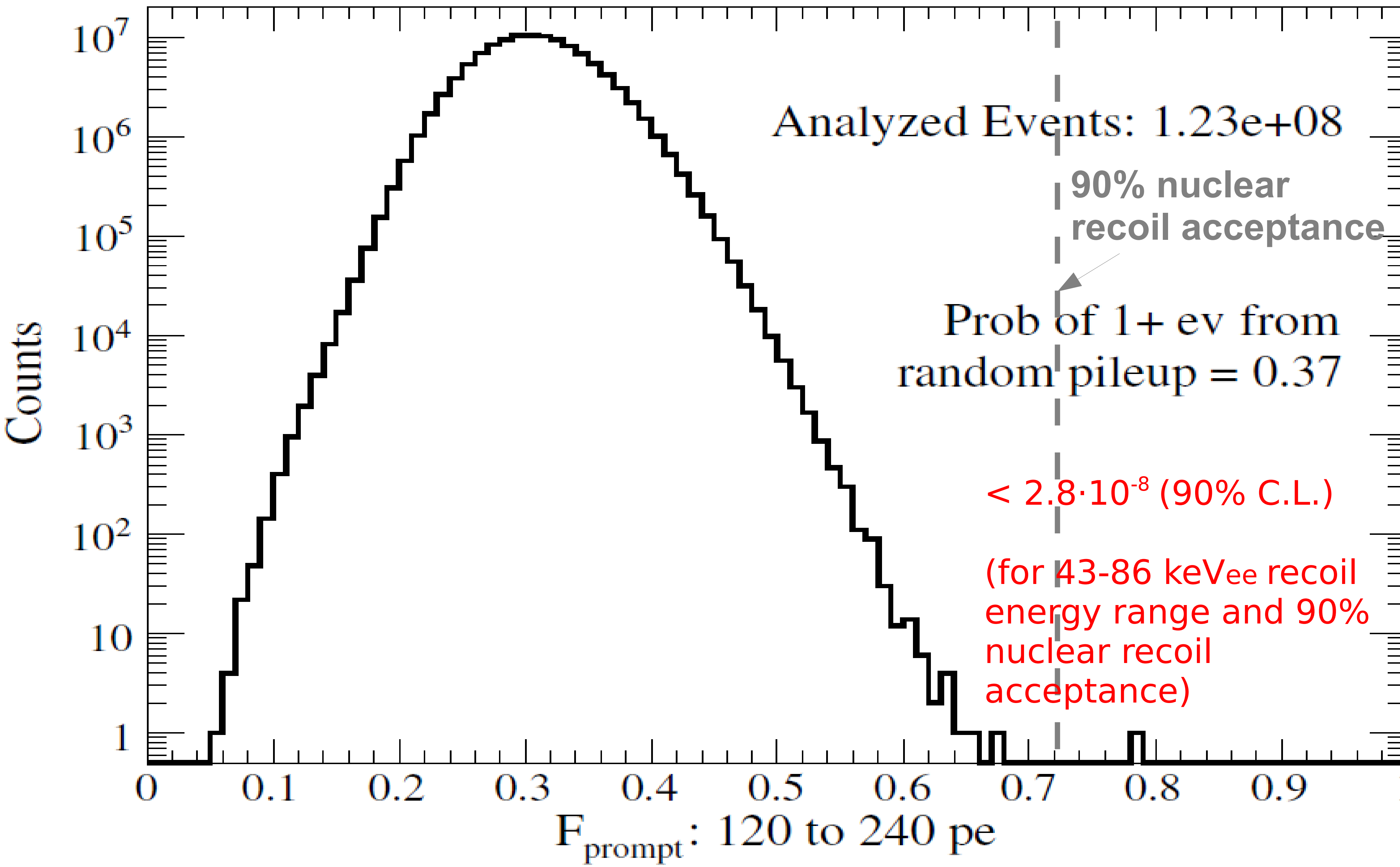
DEAP-1 limits on PSD leakage



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