DEAP-3600 Dark Matter Search at SNOLAB

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(for the DEAP collaboration)

PASCOS 2014, 25 June 2014, Uniwersytet Warszawski

DEAP-3600 Collaboration

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SNOLAB/Laurentian **B. Cleveland, F. Duncan, R. Ford**, **C.J. Jillings,** T. Pollmann

SNOLAB I. Lawson, K. McFarlane, P. Liimatainen, O. Li, E. Vazquez Jauregui

TRIUMF **F. Retiere,** P-A. Amaudruz, D. Bishop, S. Chan, C. Lim, A. Muir, C. Ohlmann, K. Olchanski , V. Strickland

Rutherford Appleton Laboratory **P. Majewski**

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

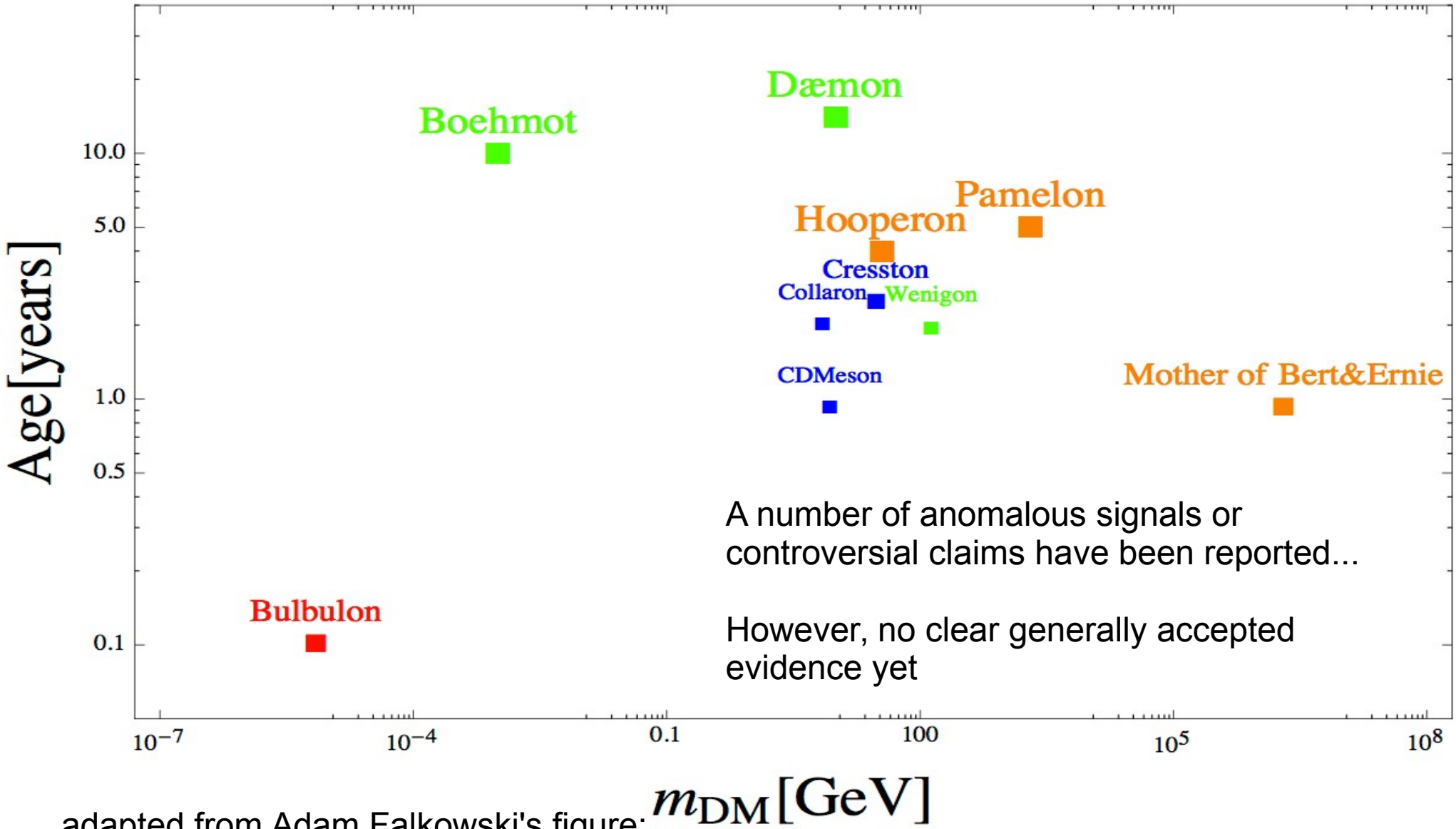
University of Sussex **S.J.M. Peeters**

+ Close links with the MiniCLEAN collaboration

Outline

- WIMP dark matter search status
- Latest projections for simple SUSY models
- Liquid argon as a target
- DEAP-3600 detector
- Background mitigation
- Irreducible neutrino backgrounds
- Prospects for a multi-tonne single-phase LAr detector
- Summary

All dark matter so far...

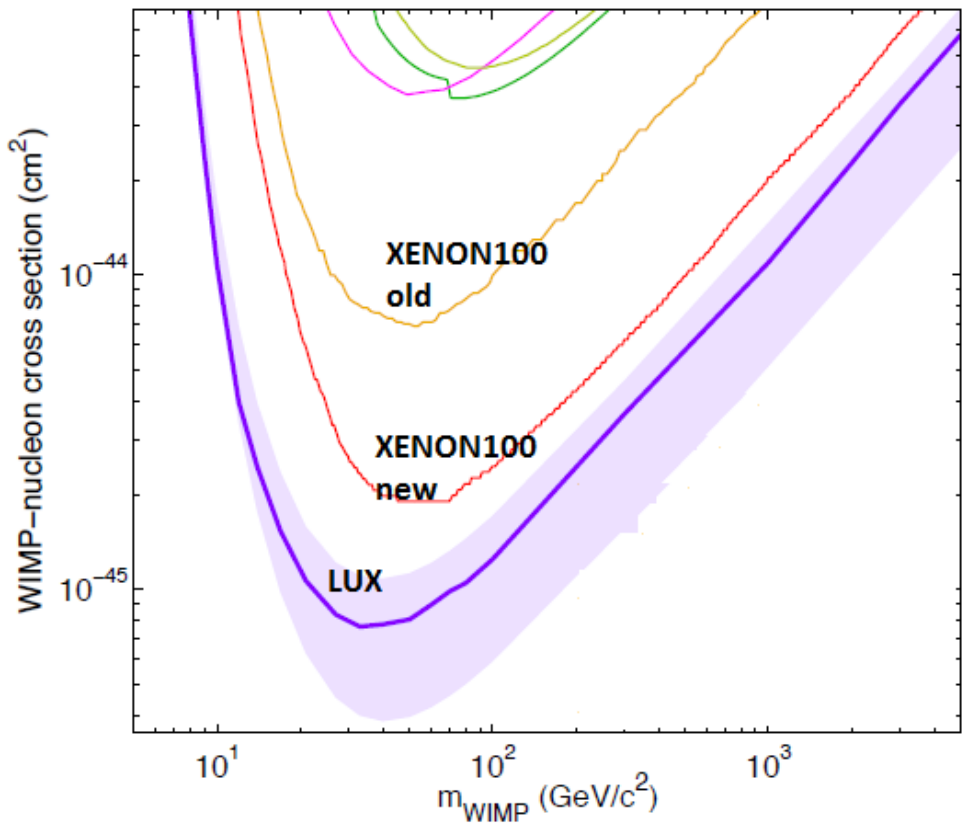


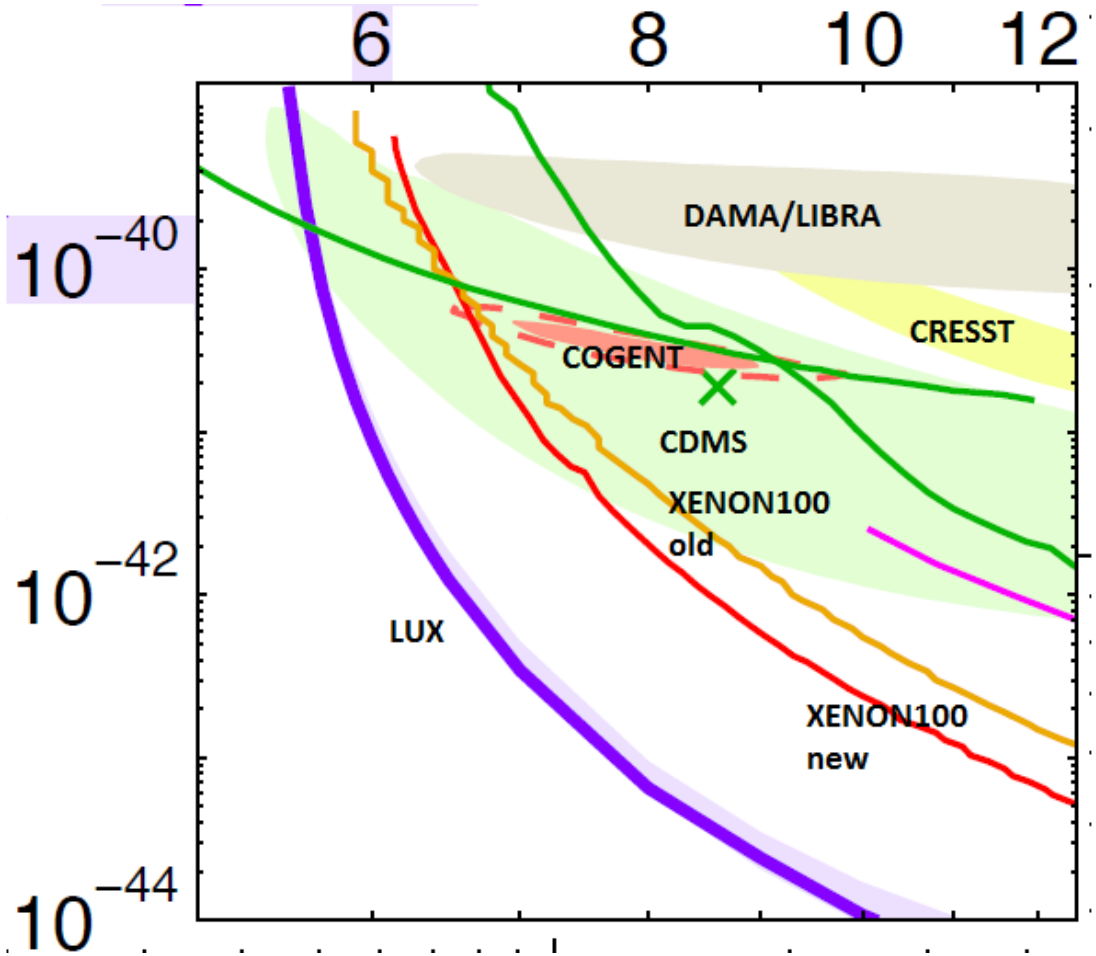
A number of anomalous signals or controversial claims have been reported...

However, no clear generally accepted evidence yet

adapted from Adam Falkowski's figure:
http://resonaances.blogspot.com/2014/03/weekend-plot-all-of-dark-matter.html

Current searches

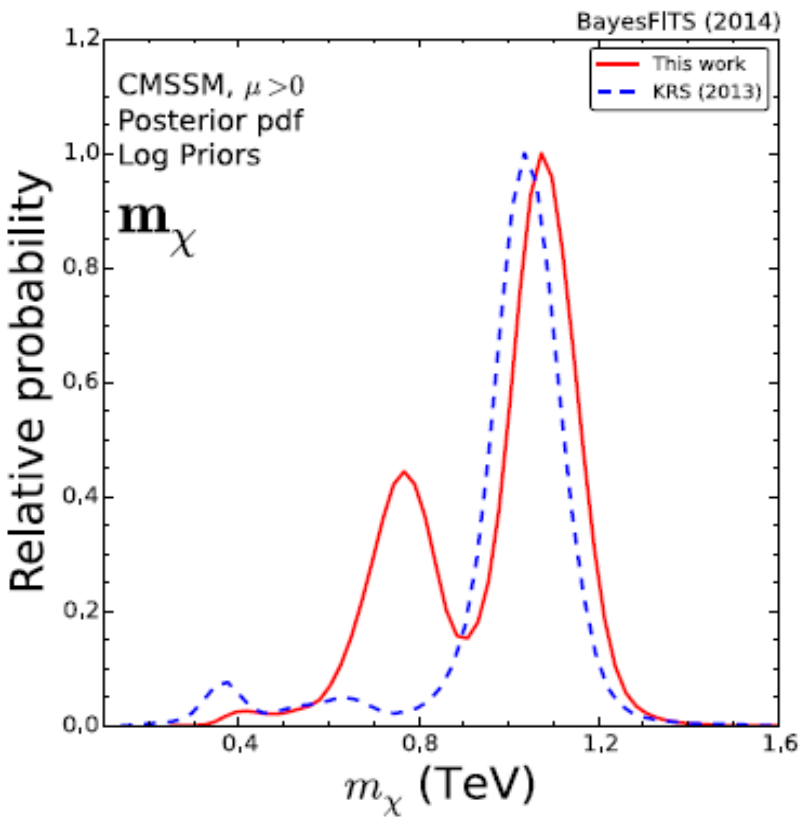


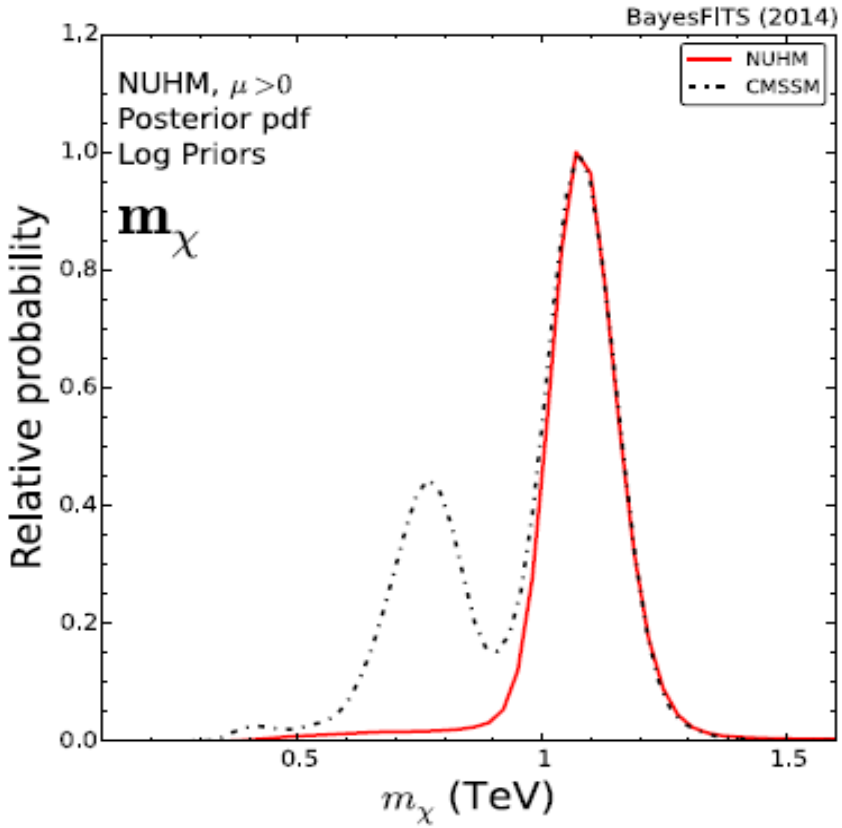


Adapted from LUX Collaboration, PRL112,091303 (2014)

- Unclear situation and significant tension at low energies
- Since recently, dominance of liquid noble gas detectors

Latest experimental results favour ~1TeV WIMPs (cMSSM and NUHM)



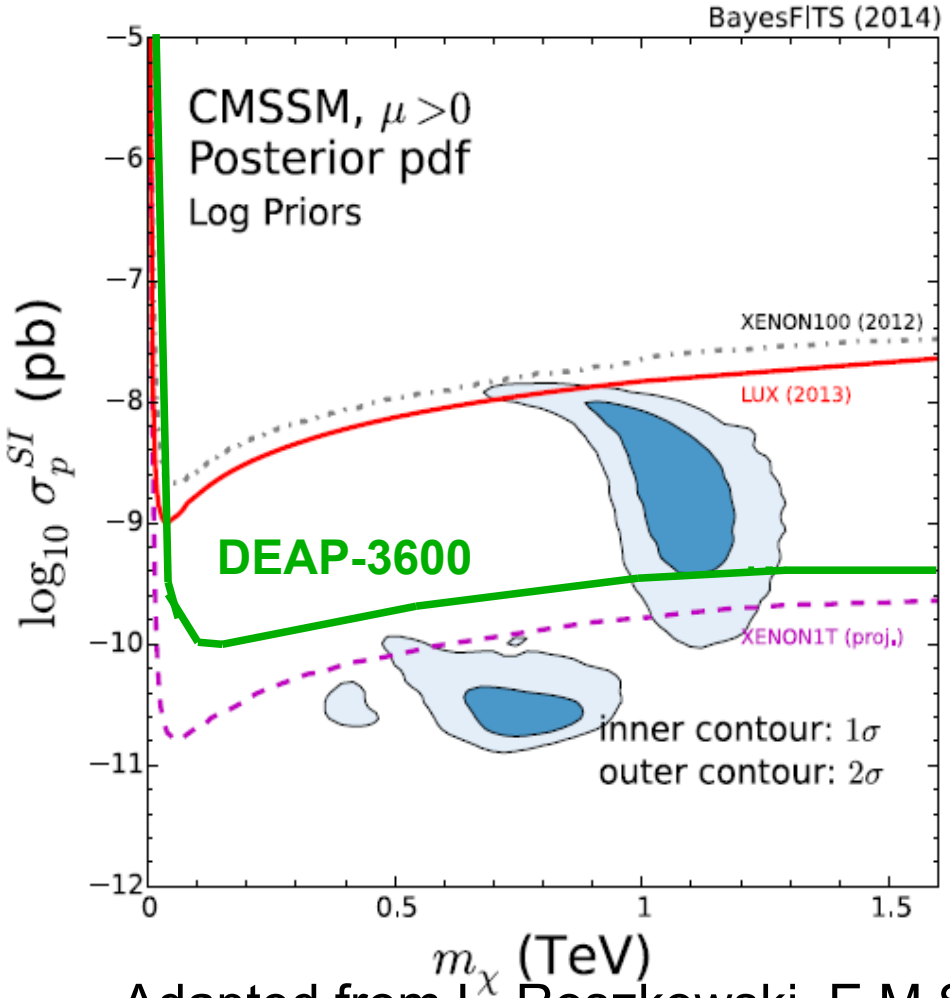


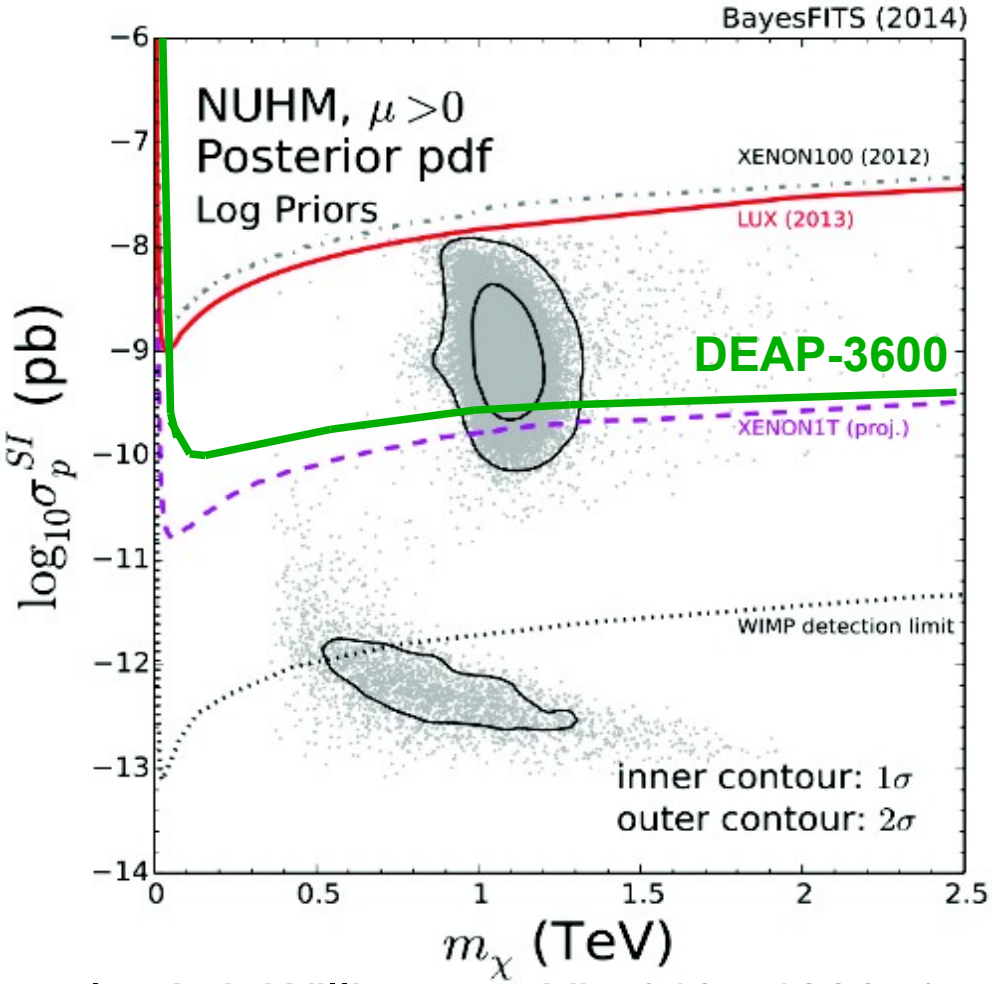
L. Roszkowski, E.M Sessolo, A.J. Williams, arXiv:1405.4289v1

(includes LHC and the recent LUX limit)

=> see talk by A. Williams (Tue afternoon, session B)

Within reach for 1-tonne detectors





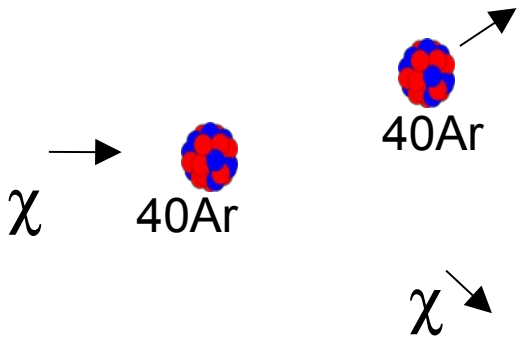
Adapted from L. Roszkowski, E.M Sessolo, A.J. Williams, arXiv:1405.4289v1

(includes LHC and the recent LUX limit)

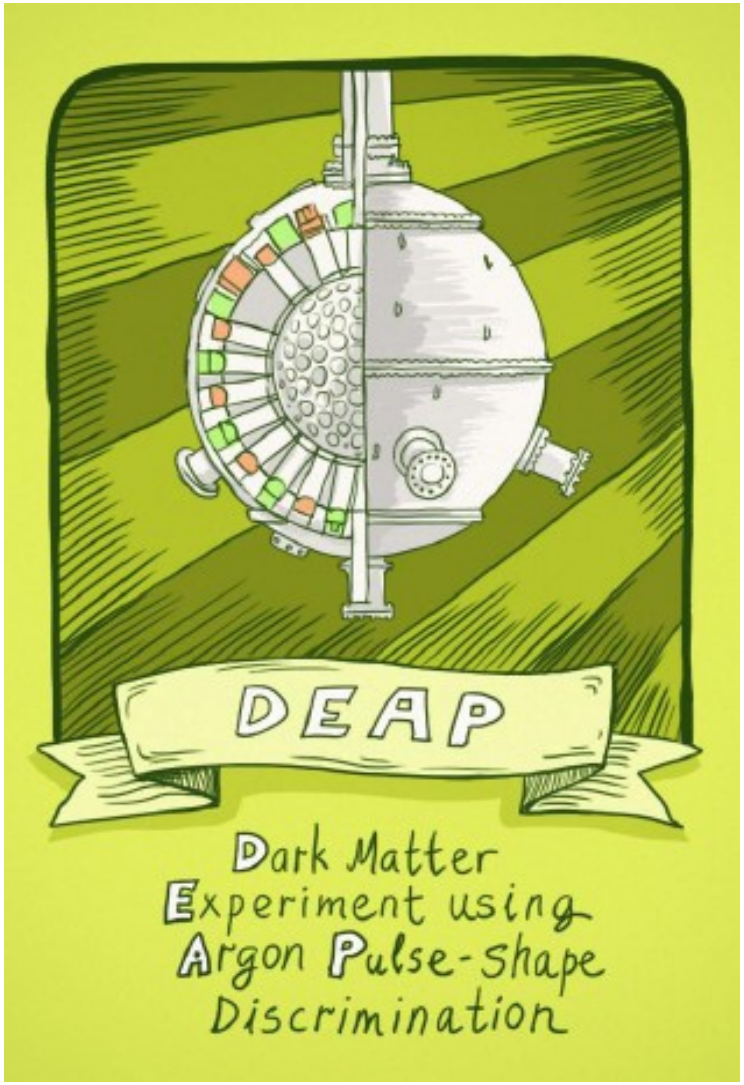
Other models...

- A fairly robust prediction, with a number of other *simple* models giving a preferred mass of ~few hundred GeV - ~1 TeV
  - p9-MSSM (Phys. Rev. D 88, 055012)
  - ...
- A variety of other (*more complex*) models giving predictions at rather low ~1-10 GeV WIMP mass
- (And of course other dark matter candidates are there, too)

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

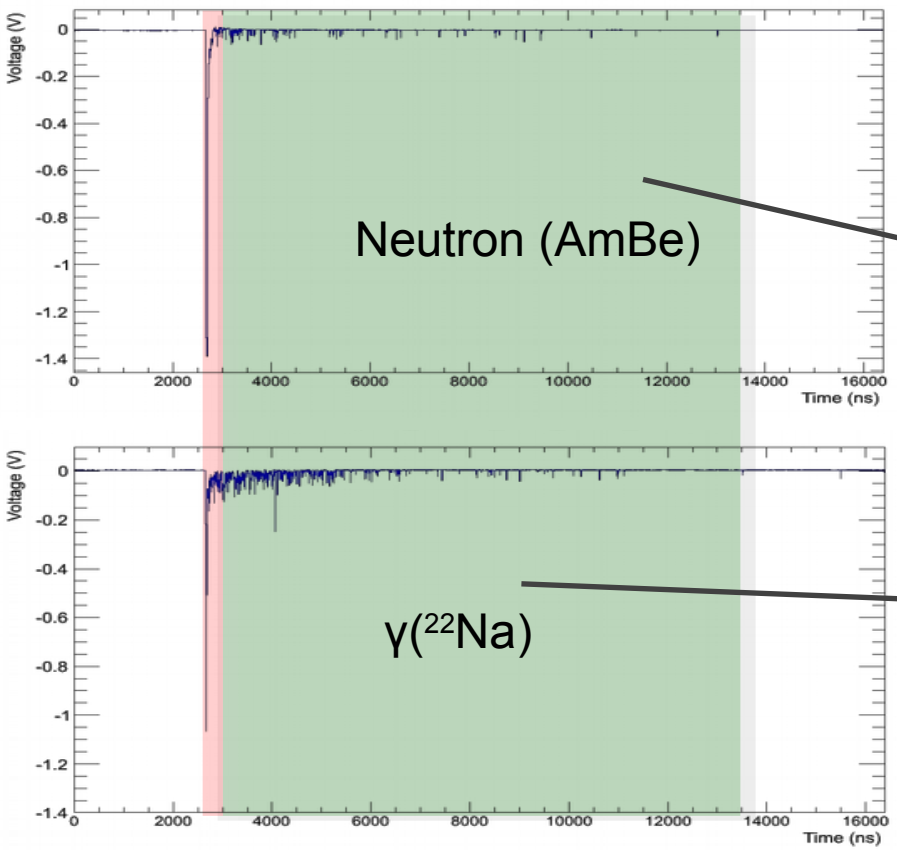


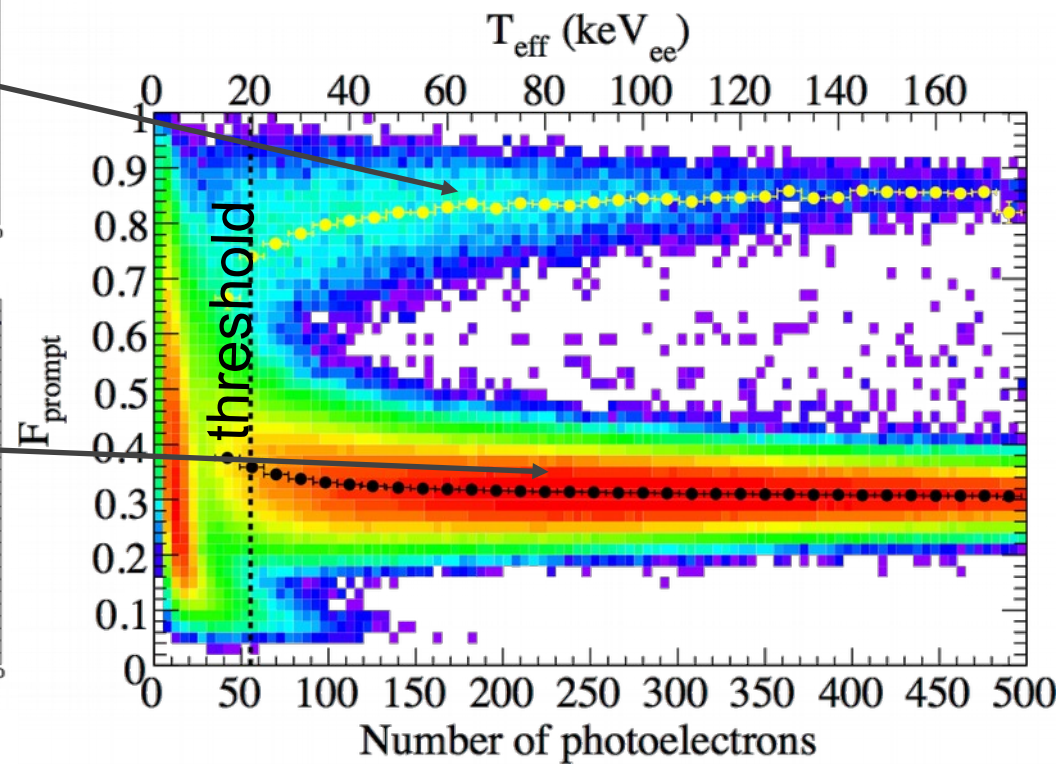
Pulse shape discrimination (PSD)

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

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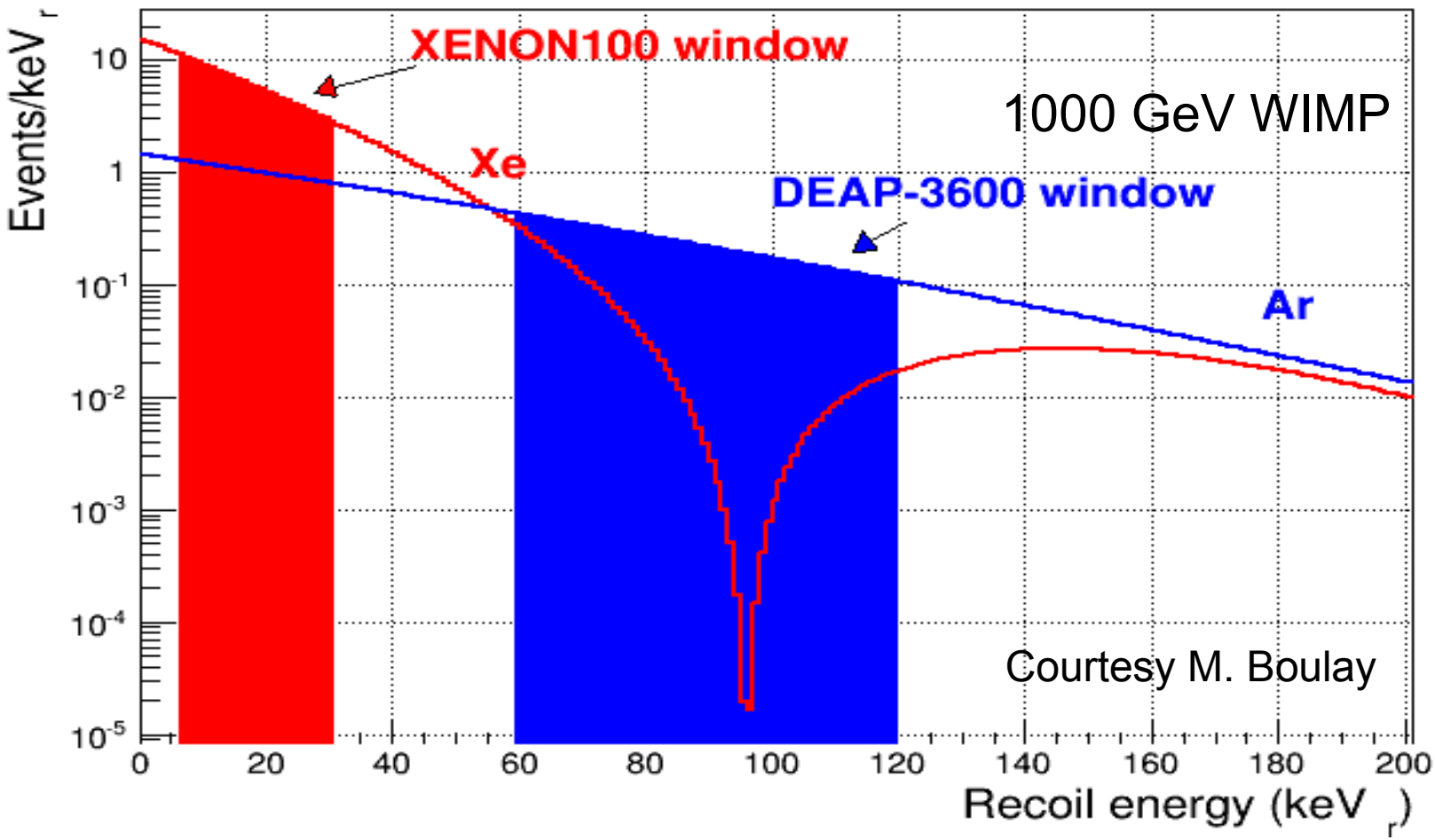
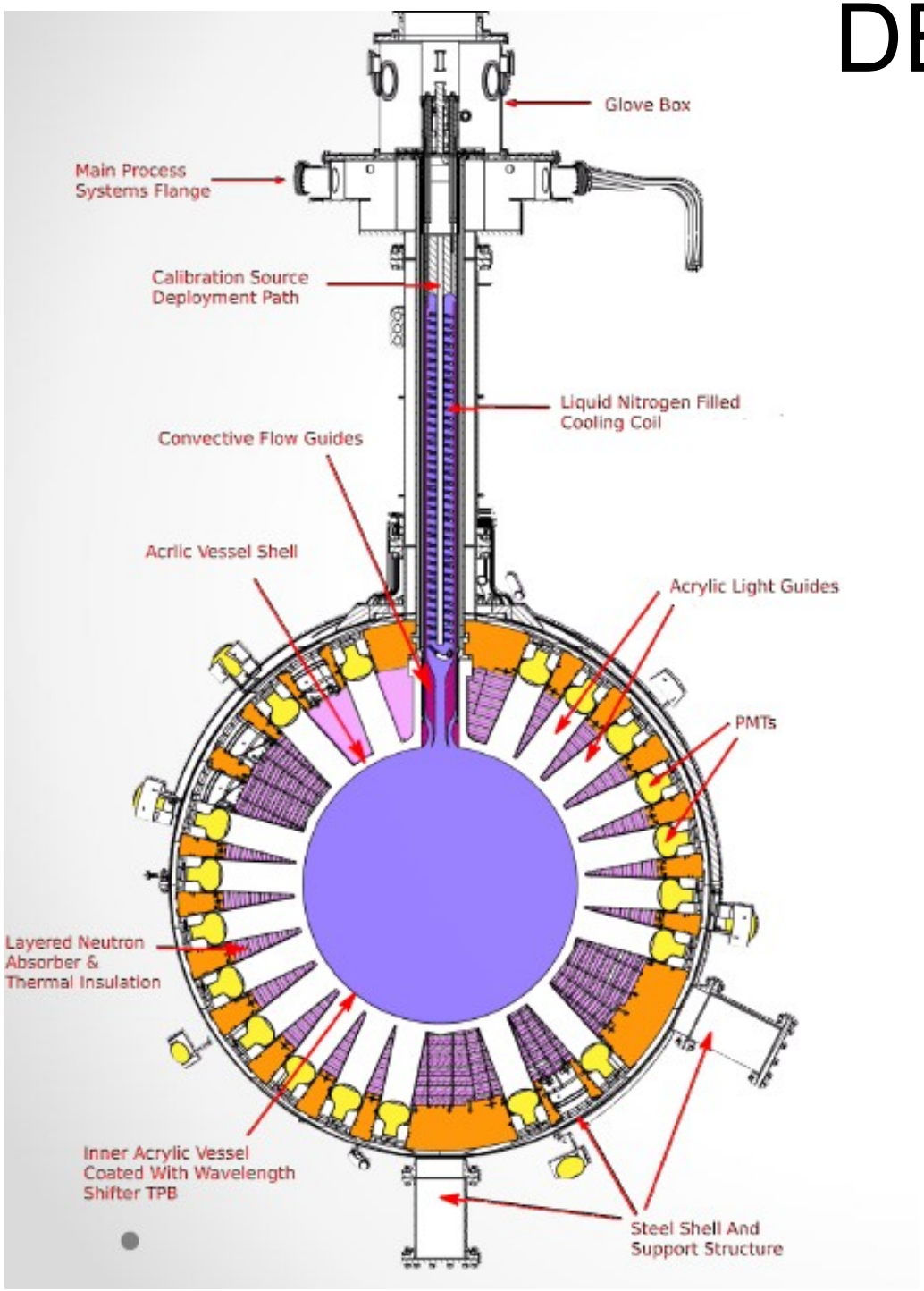
Xe and Ar for direct WIMP scattering



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

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

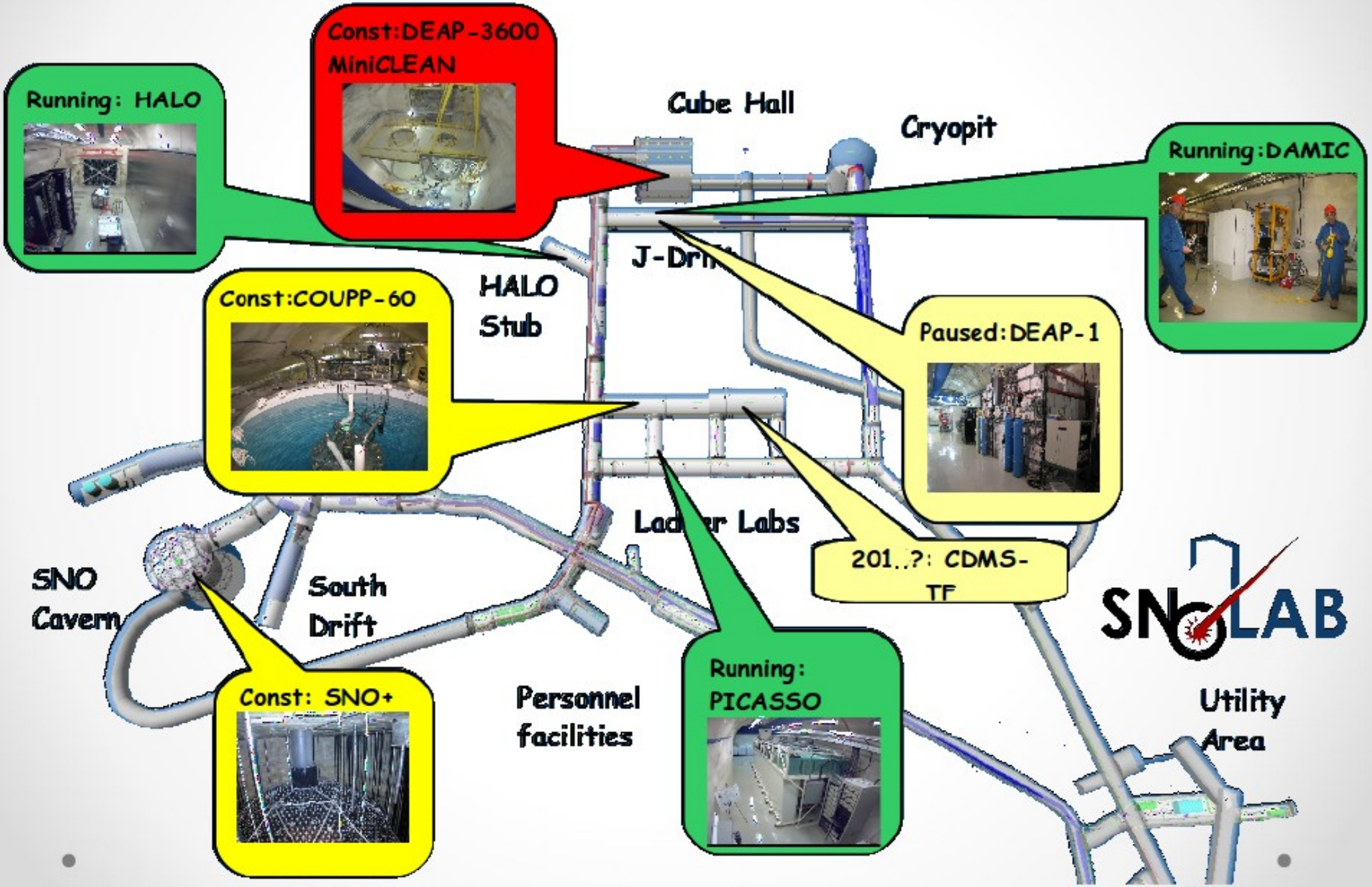
255 Hamamatsu R5912 HQE PMTs 8-inch (32% QE, 75% coverage)

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**

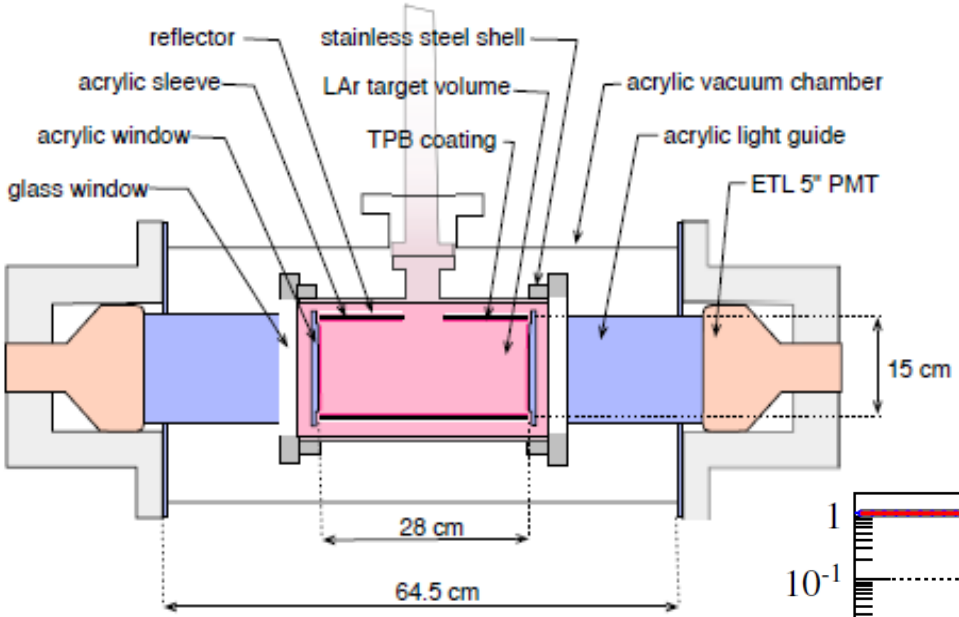
Background mitigation

- **b/g events:** dominated by ^{39}Ar rate, 1 Bq/kg
  PSD is very powerful in liquid argon, distinguish from recoils

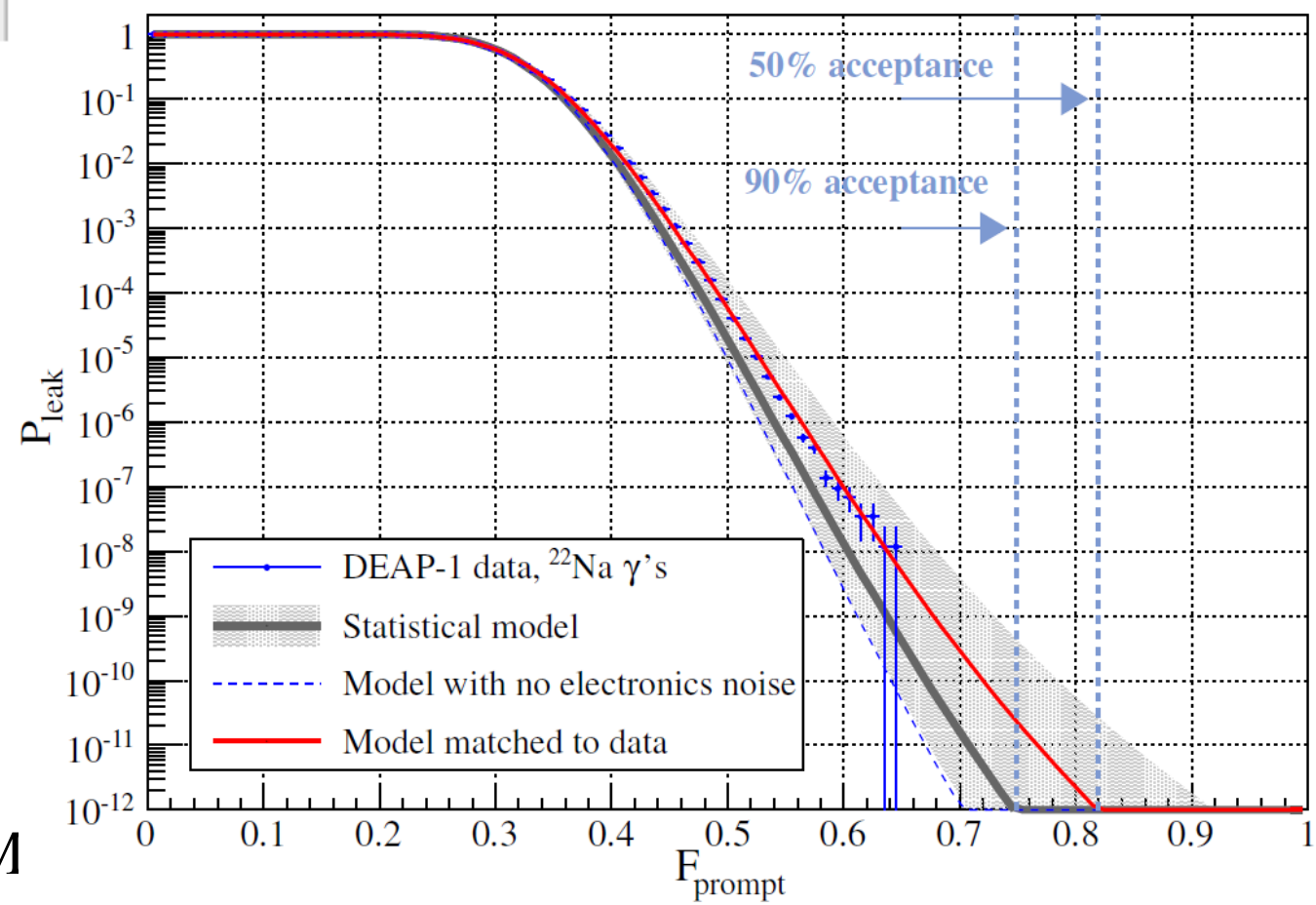
- **neutron recoils:** (α,n)+fission, μ-induced
  NO neutrons! SNOLAB depth, clean detector materials
  (strict material screening & assay, quality assurance /
  co-operation with suppliers),
  shielding

- **surface events:** Rn daughters and other surface contamination
  Clean surfaces in-situ, position reconstruction, 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.

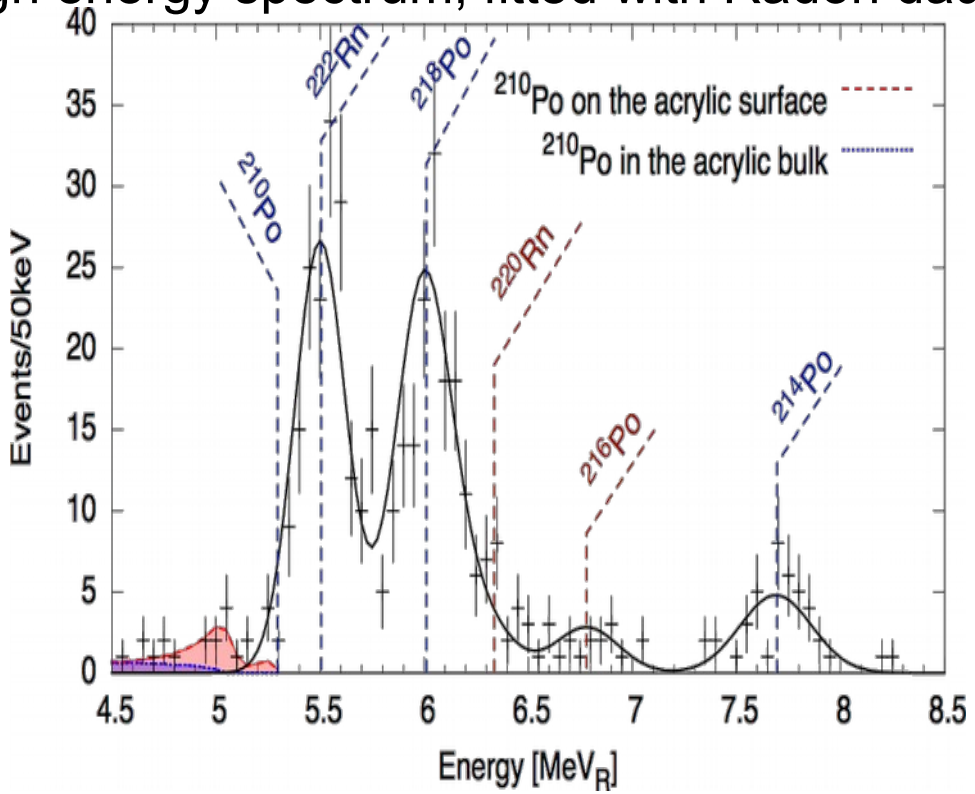


P.-A. Amaudruz et al., submitted to Astroparticle Physics

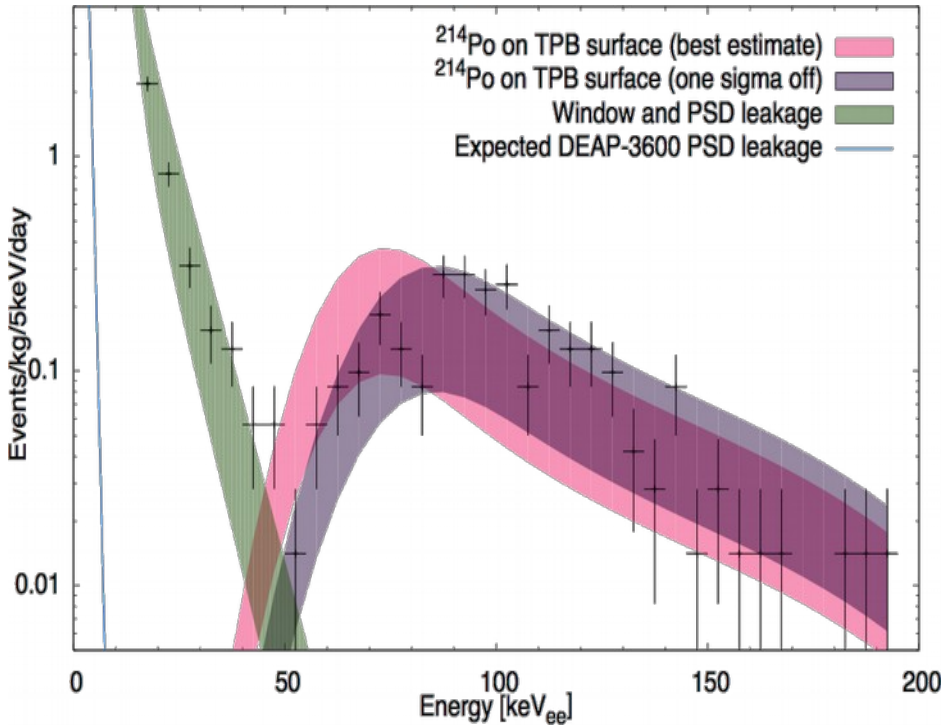
M

Surface backgrounds

High energy spectrum, fitted with Radon daughters



Low energy spectrum in ROI



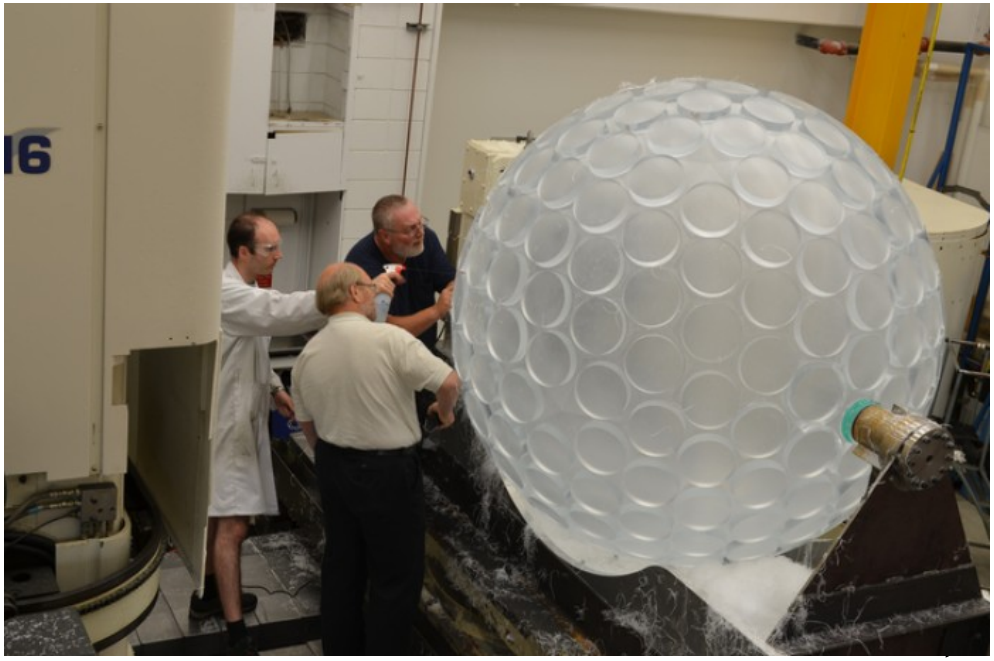
arXiv:1211.0909

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)

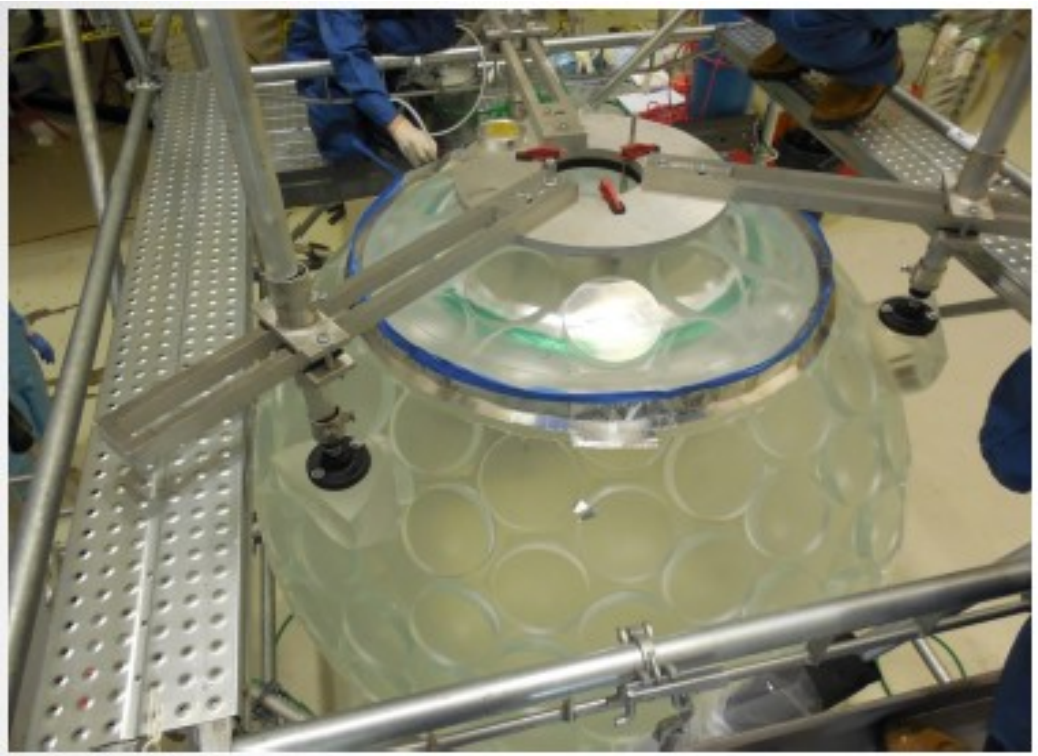
Construction highlights: acrylic vessel

RPT Colorado

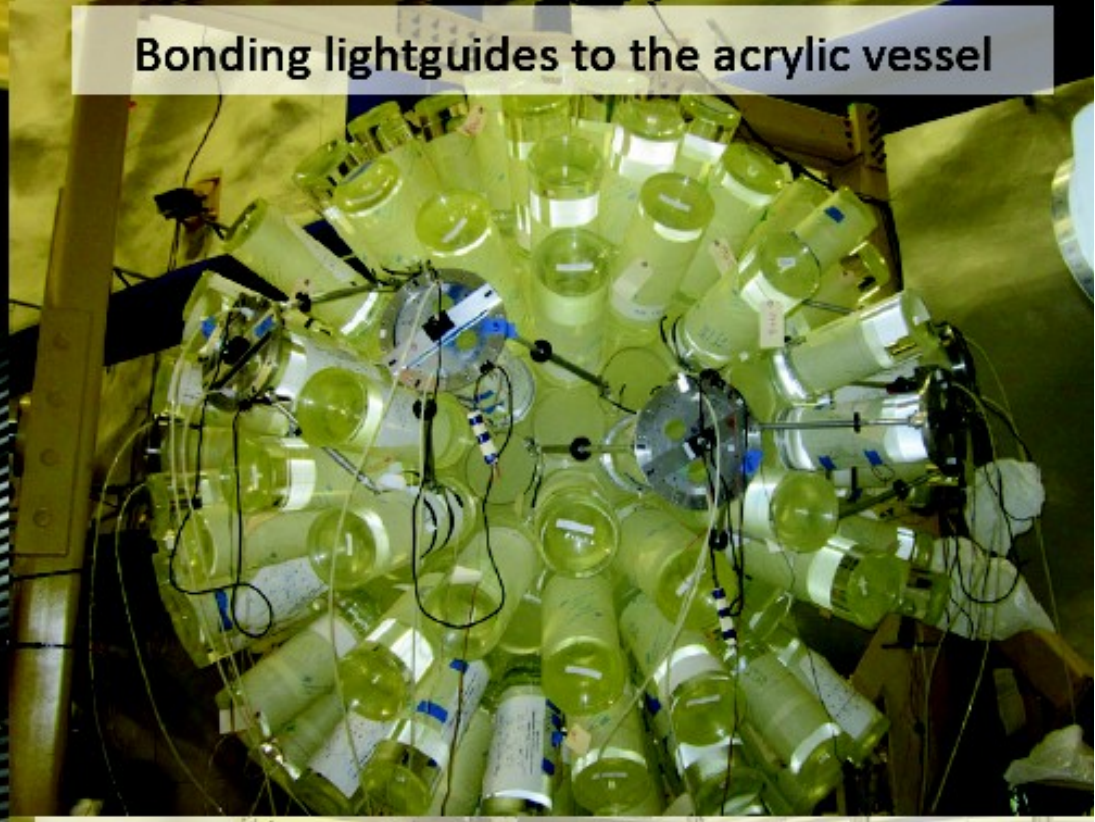


University of Alberta, Edmonton

Underground bonding



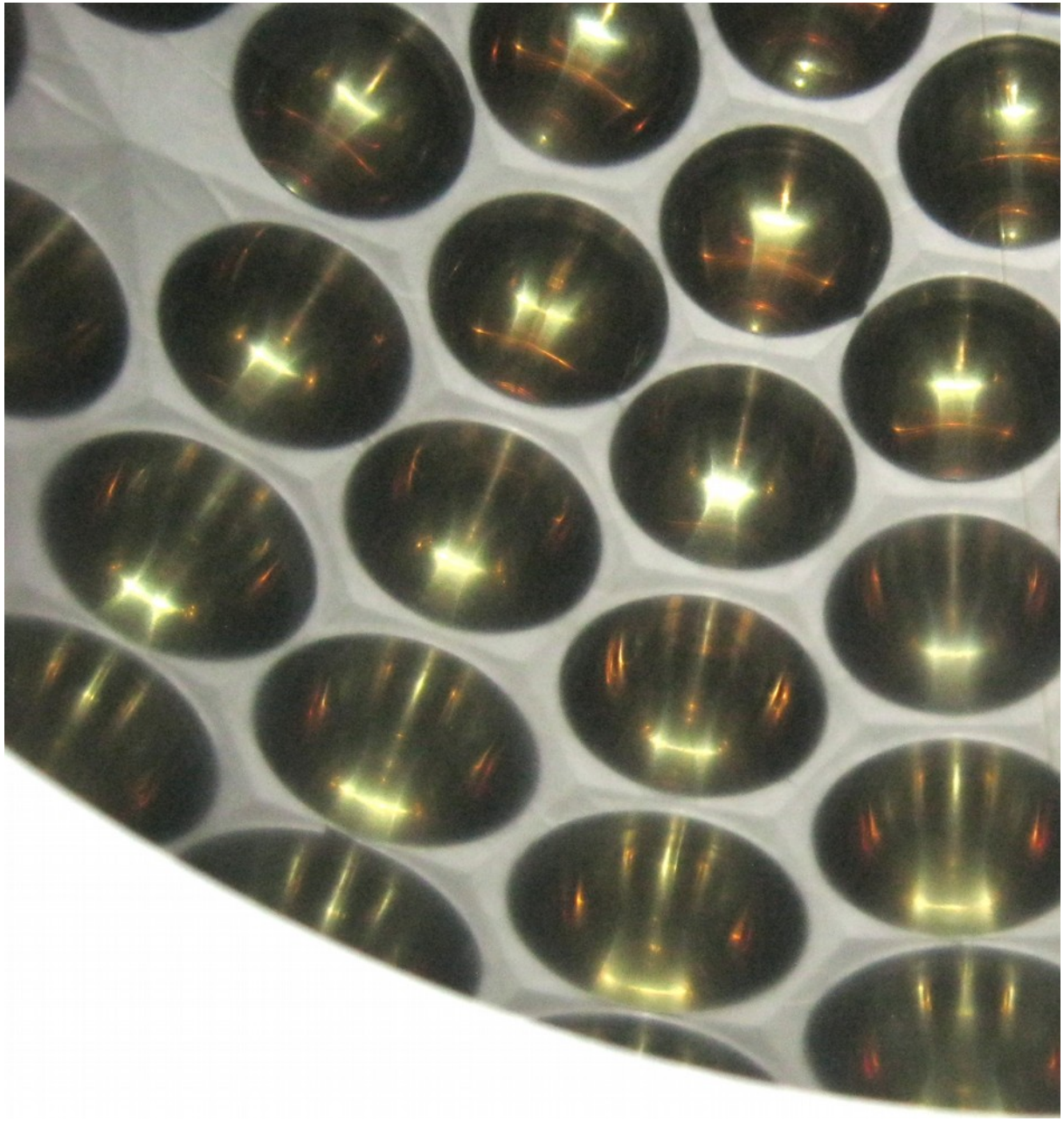

Vacuum testing the steel sheel


Bonding lightguides to the acrylic vessel


Completed acrylic vessel – lightguide assembly

Reflector & PMT installation

Picture taken from the inside of the detector after the reflector and PMT installation




Liquid Nitrogen Cooling

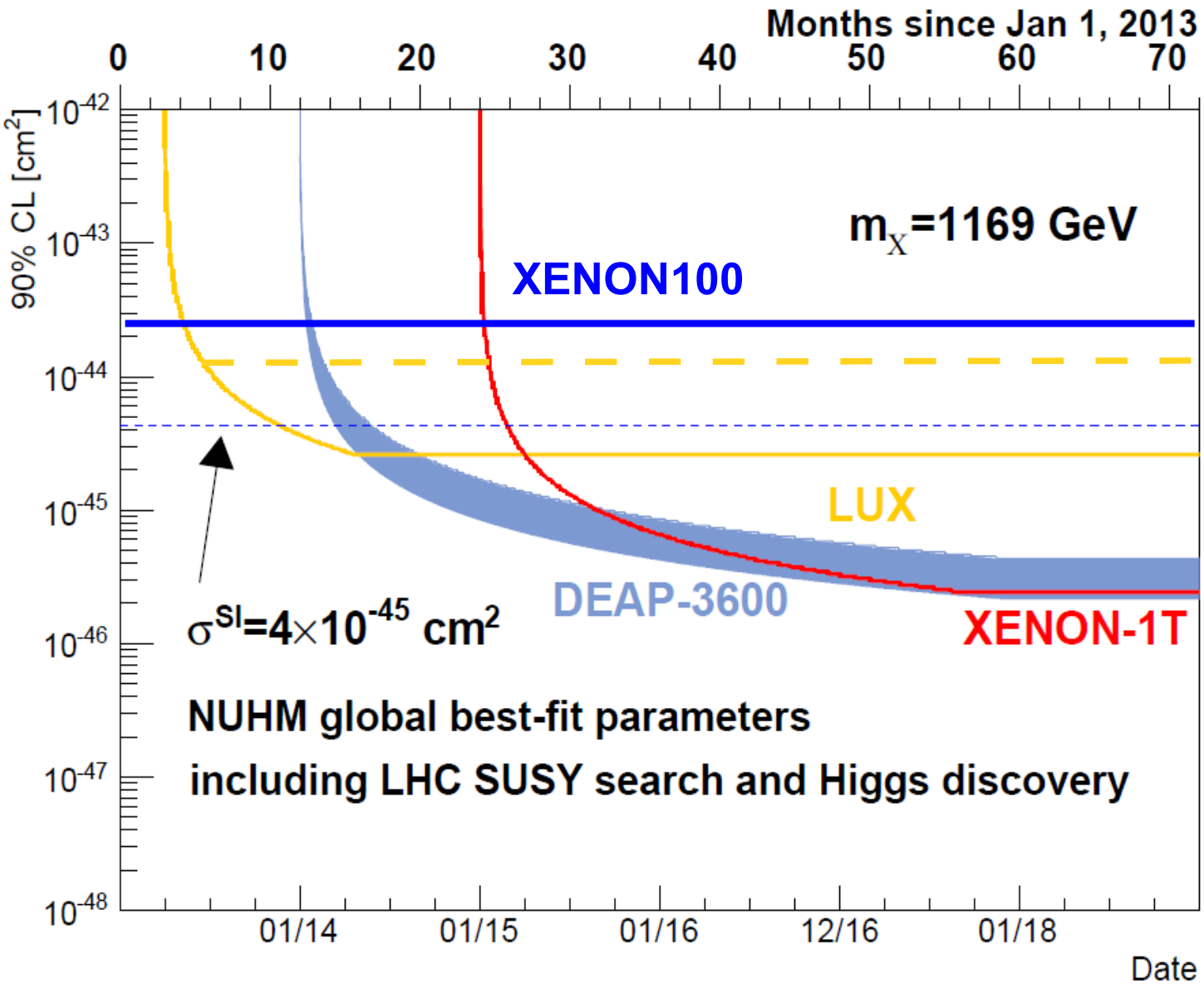

Condenser
Radon Trap
SAES Getter


Cooling Coil


TBP Deposition Source


Electronics - TRIUMF

Time scale



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

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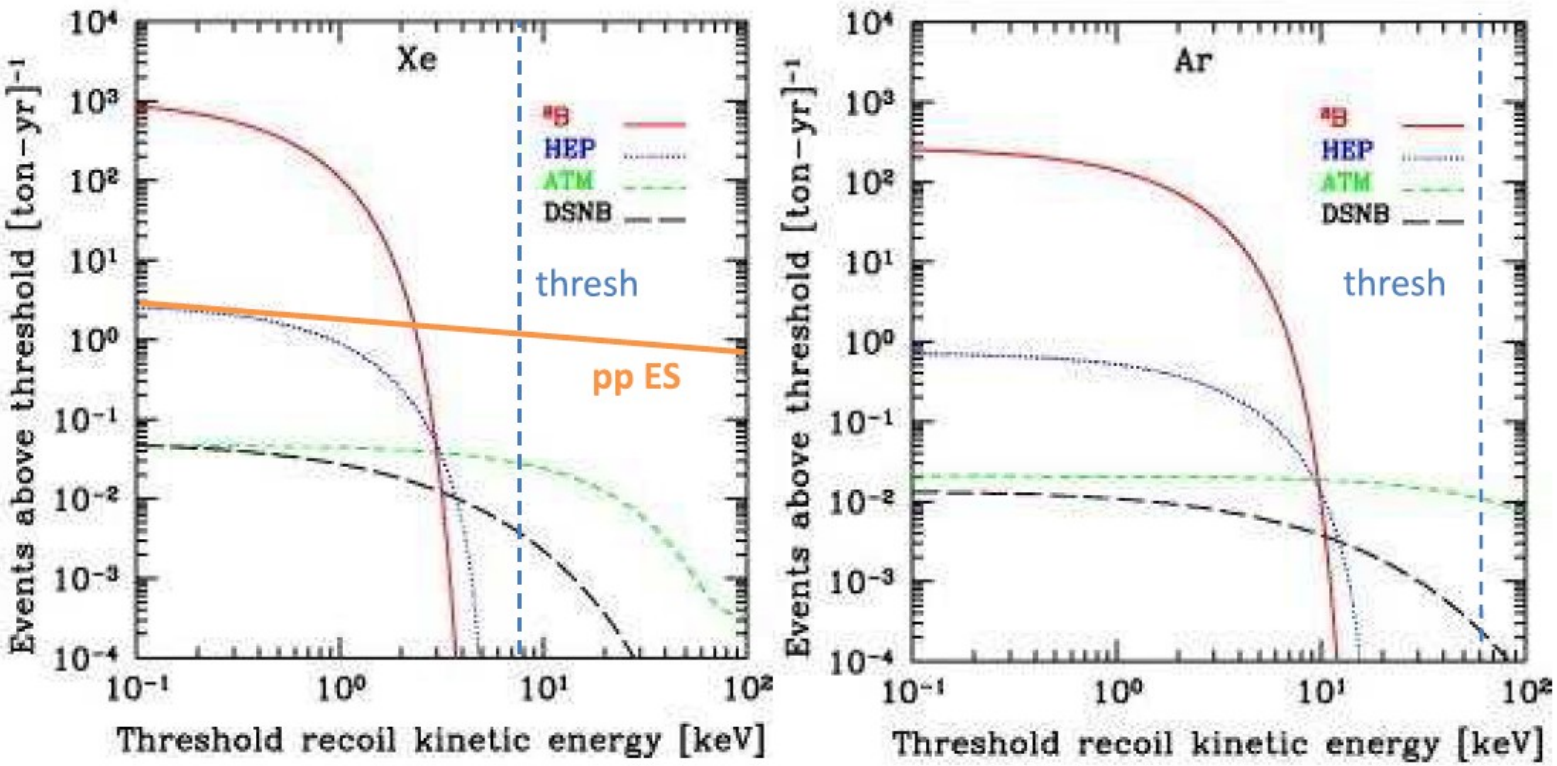
Single phase Ar limited by coherent scattering of atmospheric neutrinos



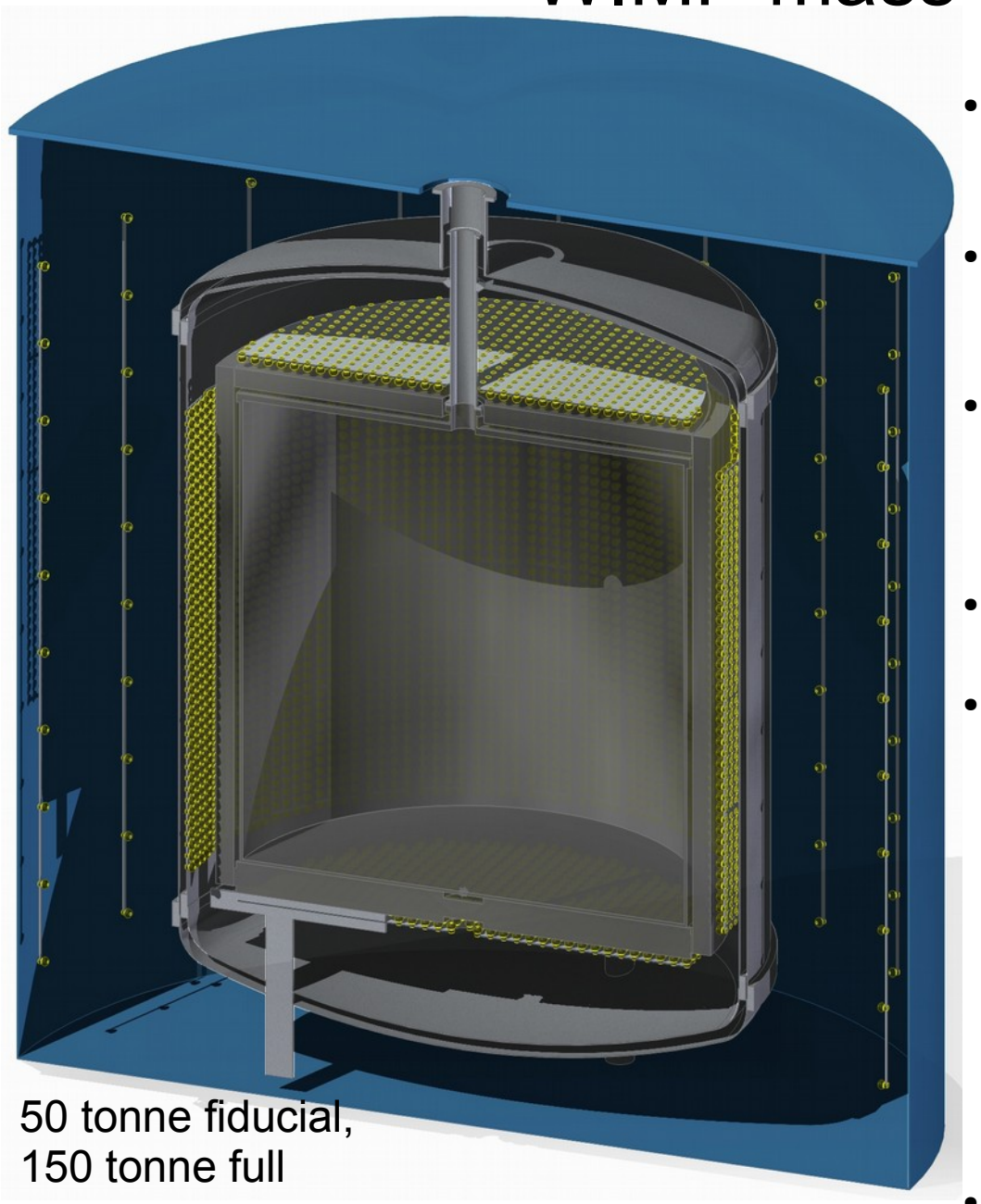
Adapted from L.E. Strigari, New J. Phys. 11 (2009) 105011

- Our current focus on DEAP-3600
- But already starting to think about a competitive next generation detector
- Very attractive possibility for a precision mass measurement

(if a signal at ~10^{-46} cm^2 is seen)

Superior PSD in Ar allows to get rid of contribution from elastic scattering of pp neutrinos on electrons.

WIMP mass sensitivity



50 tonne fiducial,
150 tonne full

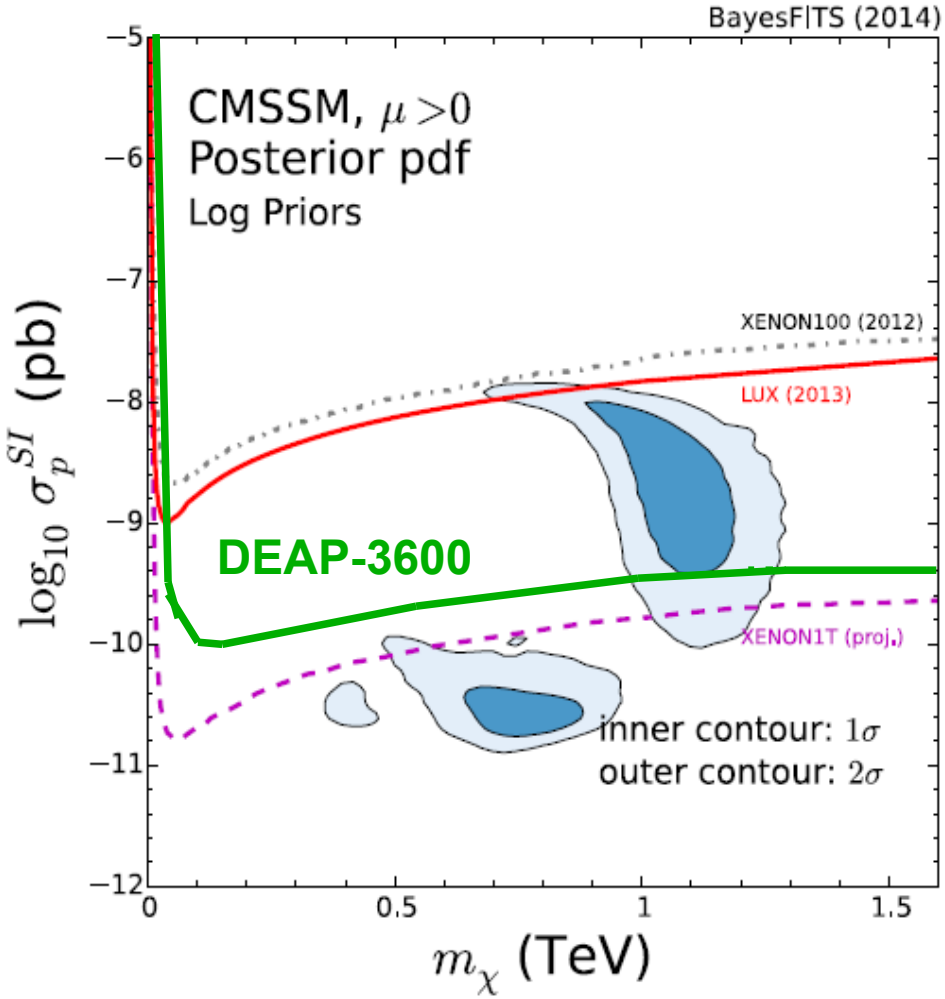
- Technology can be scaled to very large target masses, > 100 tonnes or **10^{-48} cm^2** sensitivity
- Larger detector allows for better position reconstruction, which makes surface contamination easier to mitigate
- Relaxed targets on surface contamination significantly simplify many aspects of construction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

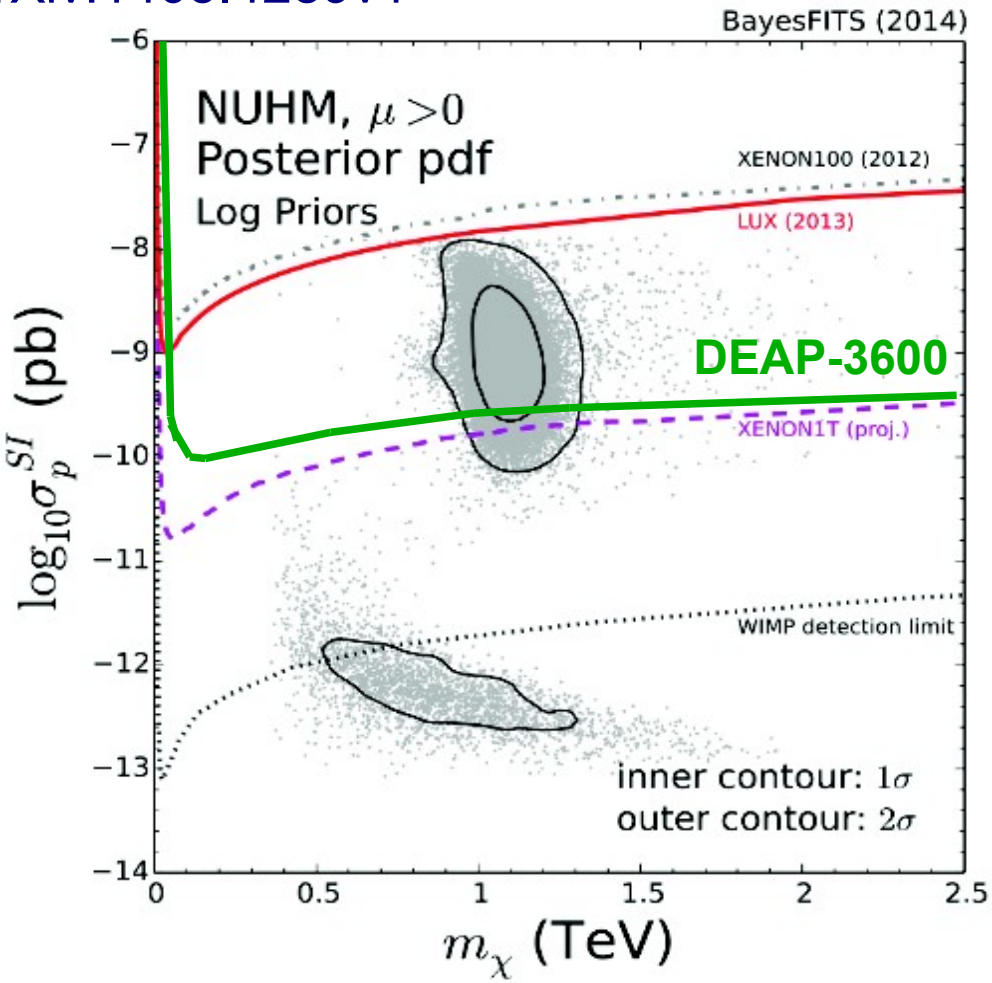
- Chosen parameters:
  - 44’ diam. water tank
  - 24’ diam. Steel Shells
  - 4400 8” HQE PMTs
  - 12” acrylic shielding panels
  - 17’ diam. 2” thick acrylic
  - vessel with flanged lid
  - 150 tonnes argon in AV (50 tonnes fiducial)

- Modest R&D underway

Within reach for 1-tonne detectors

arXiv:1405.4289v1



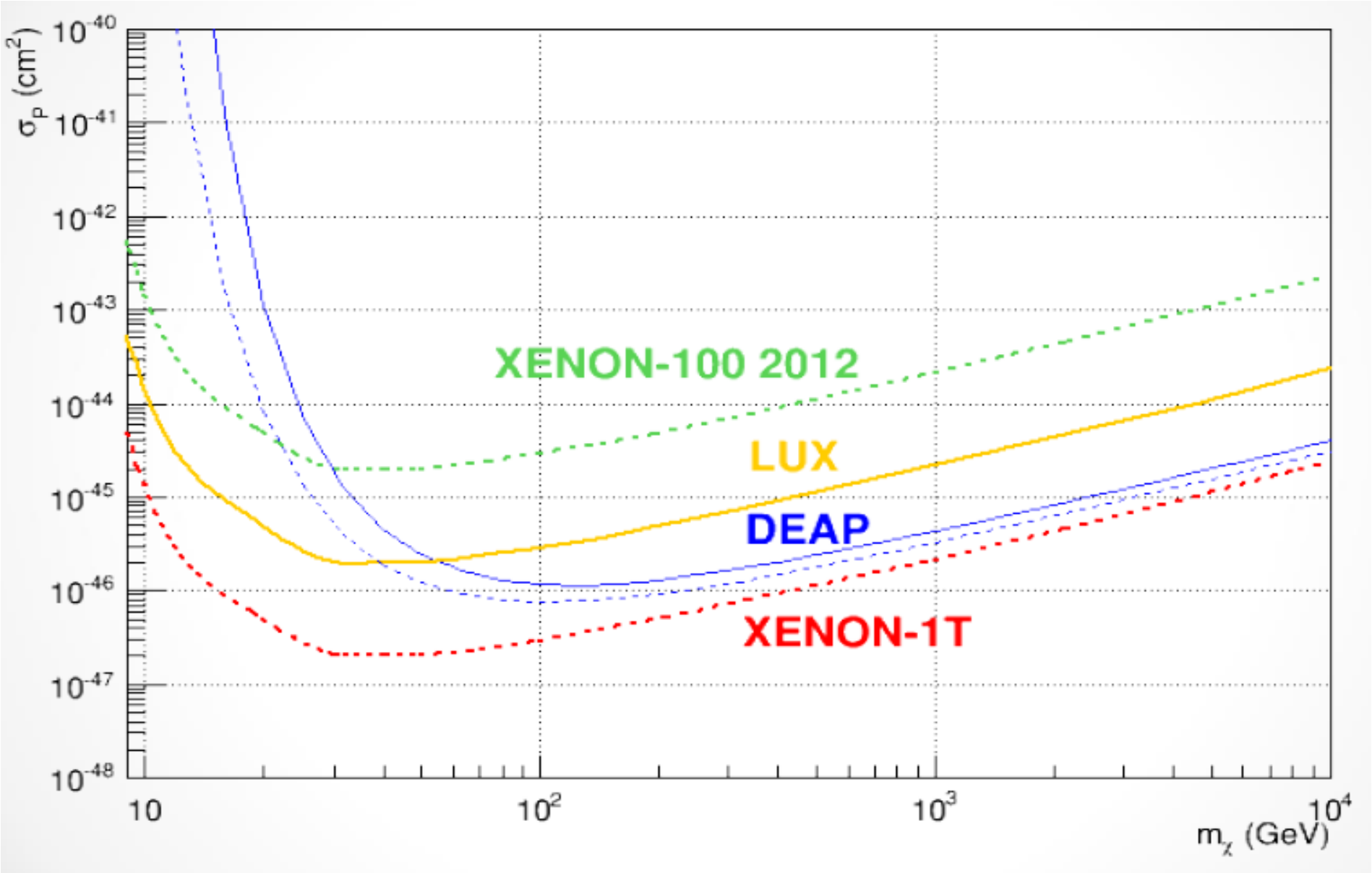


Large detector can conclusively probe the allowed CMSSM parameter space and most of the NUHM allowed parameter space.

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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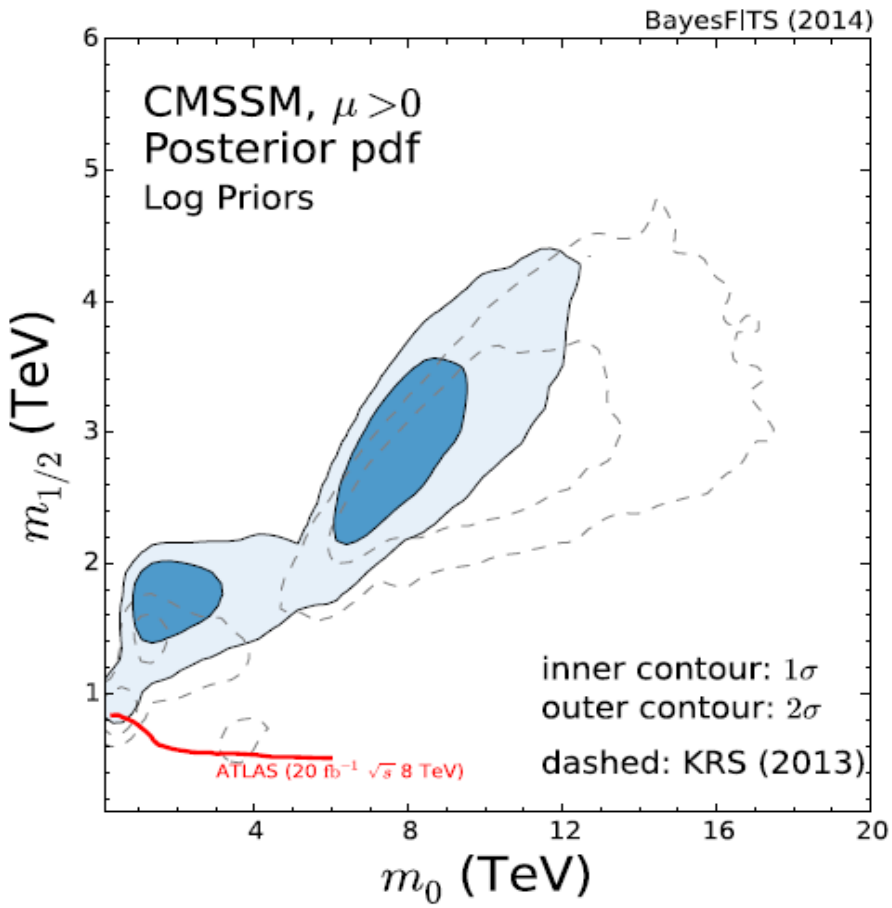
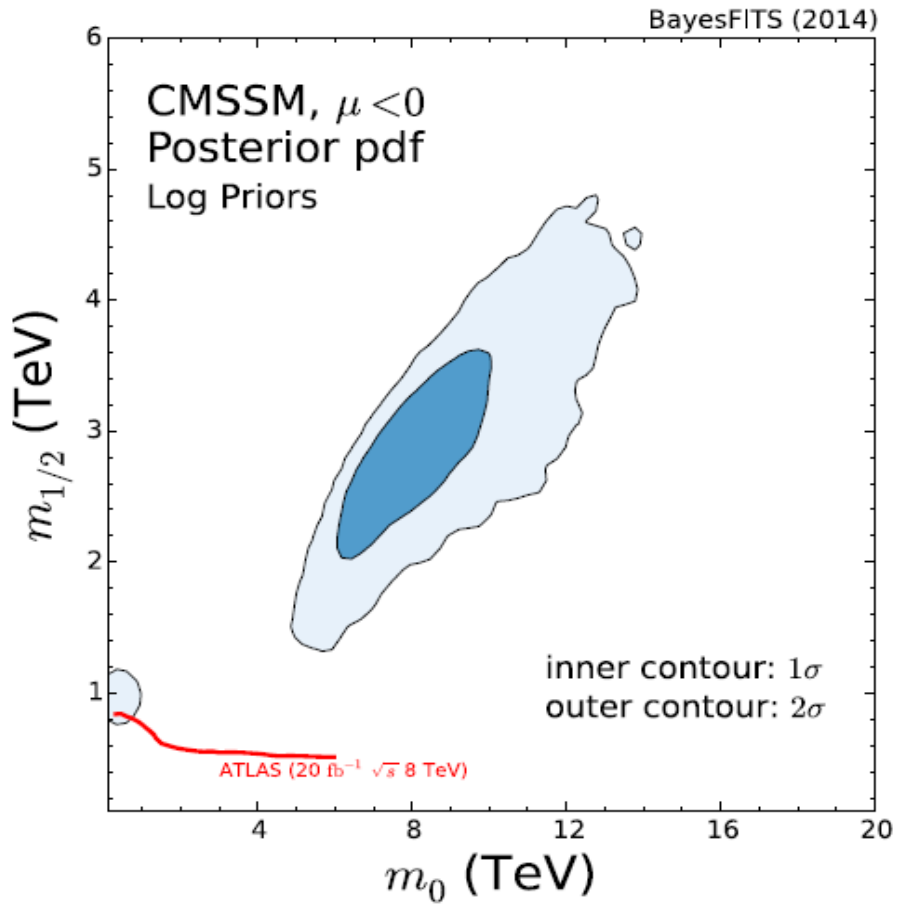
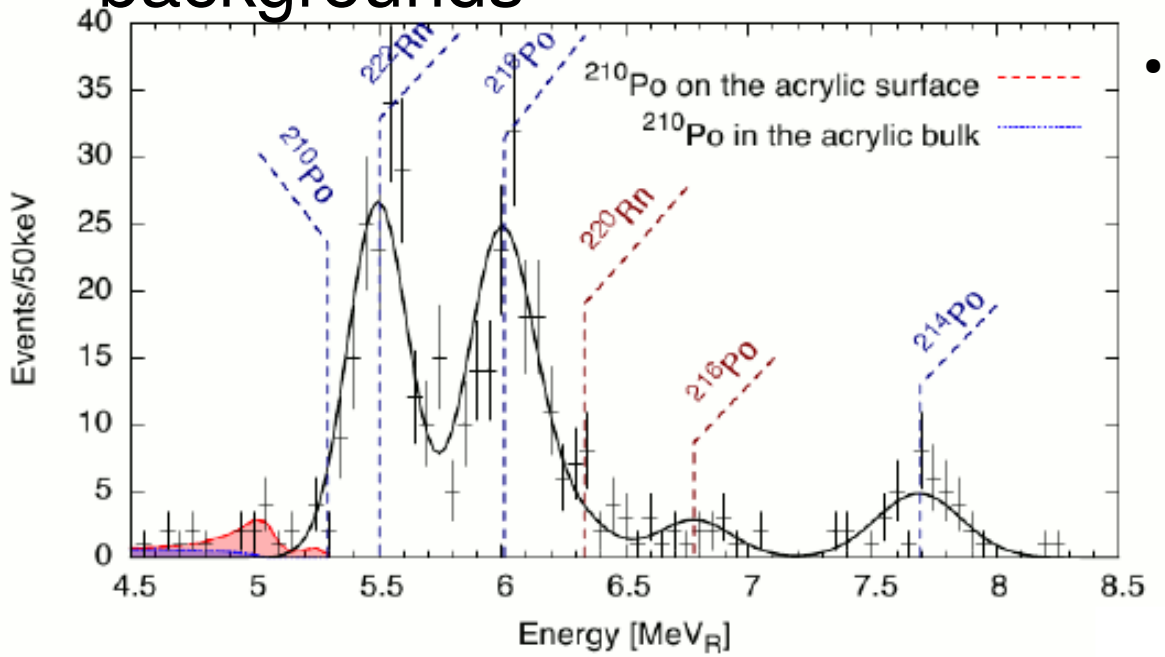
Backup

CMSSM parameter space

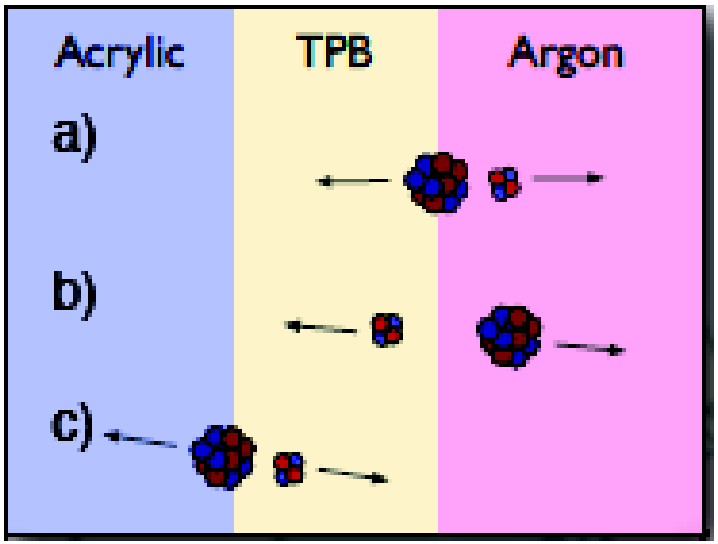




DEAP-1: Good understanding of surface backgrounds



- Find ^{214}Po "sticks" to wall



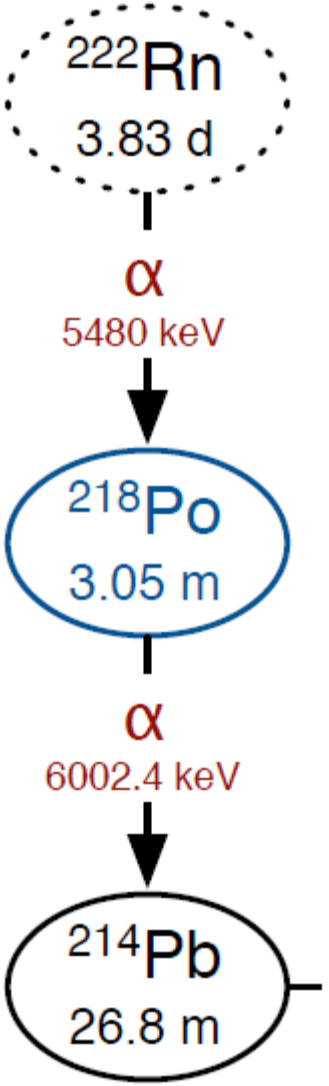
^{222}Rn :

120 μBq in DEAP-1

Compare for example:

360 μBq in EXO-200

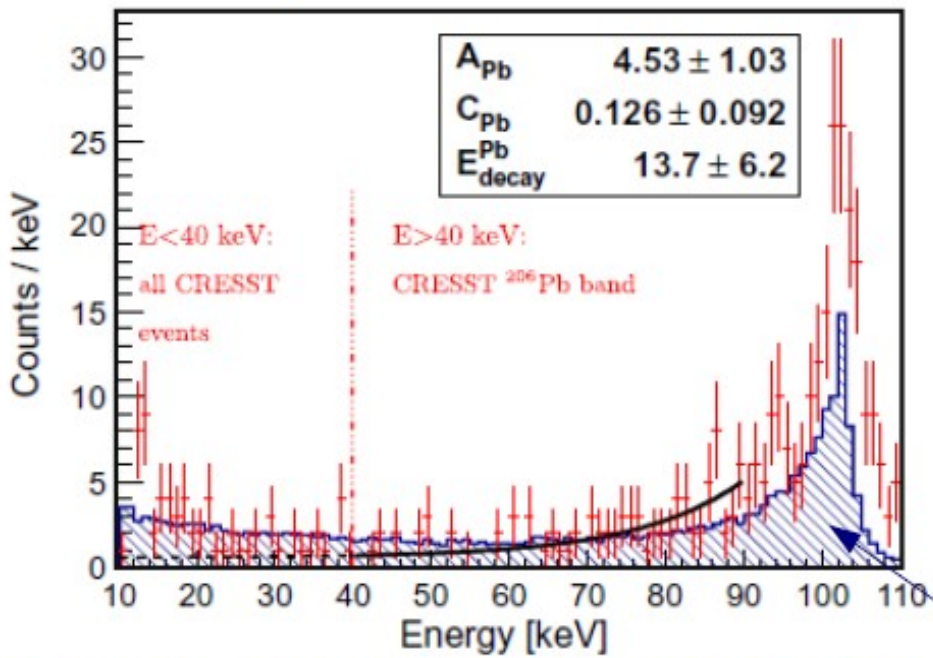
[PRL 109 032505 (2012)]

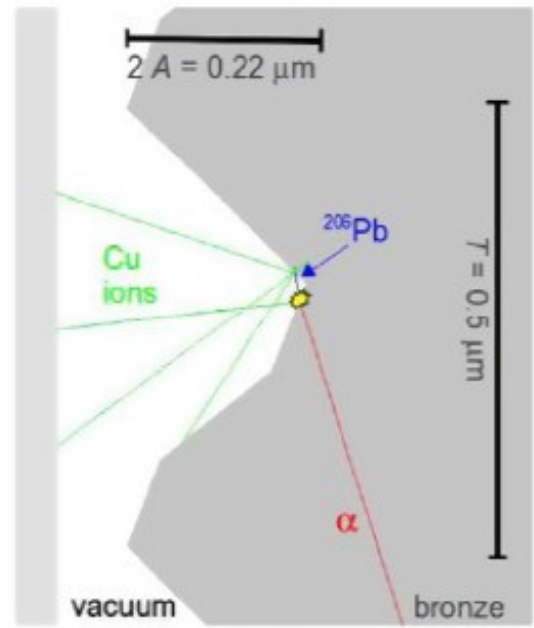


Non-trivial effects due to surface roughness

- 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