Recent Results from DarkSide-50

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for the DarkSide Collaboration: http://darkside.lngs.infn.it/collaboration

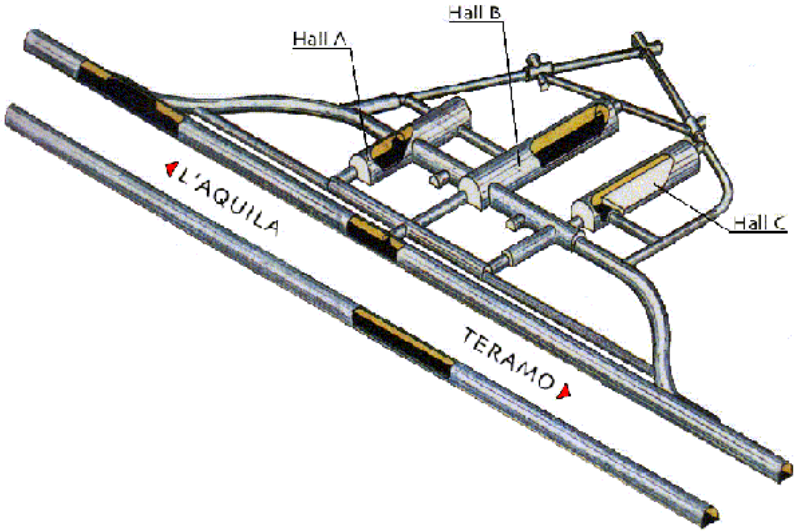
The DarkSide Dark Matter Search Program

- Direct-detection search using LAr-TPC (see below)
- Designed for and achieves background-free operation
- Sited in LNGS at 3800 mwe
- Surrounded by 30 + 1000 ton active veto system
- Target of “underground argon”, 150 kg total 36.9 kg fiducial since 4/2015
- Staged program with detectors of increasing size

LNGS

There's more than one way to get under 3800 mwe of rock... For example, you can just drive in (including semi's).

3 Experimental halls 100m long and 20 x 18 m wide/tall

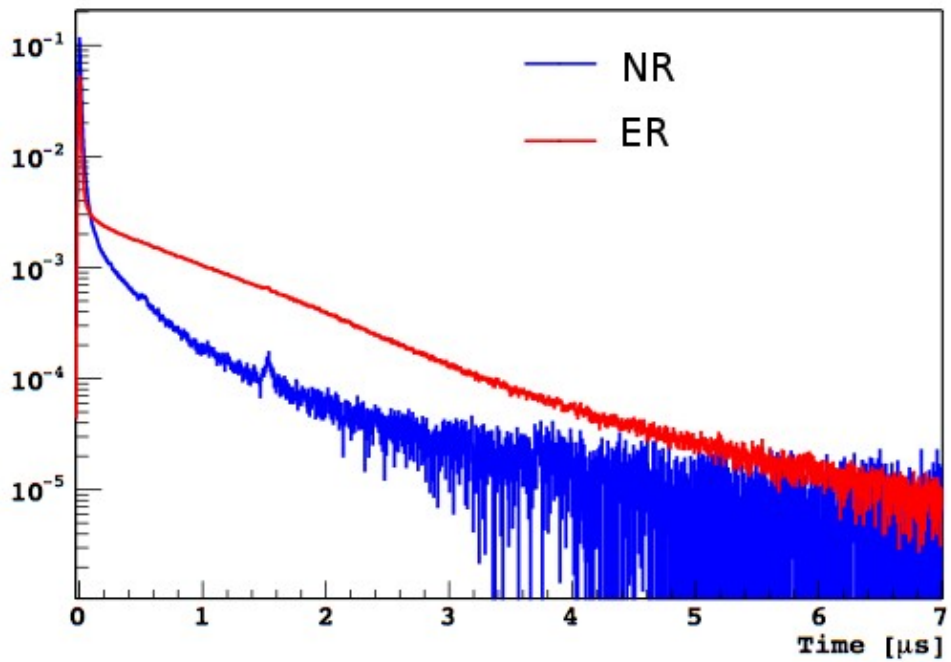


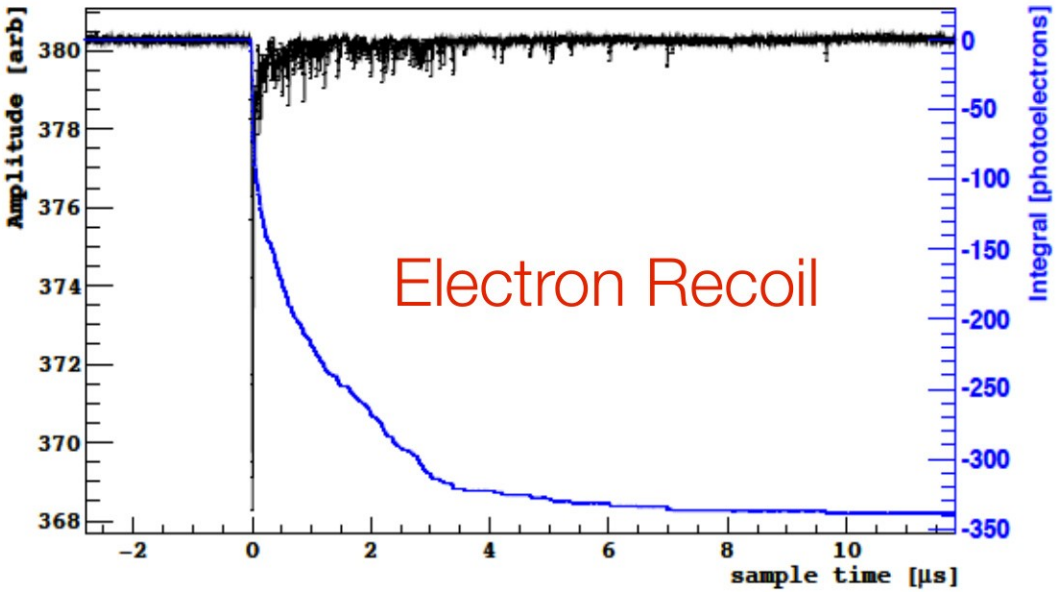
LNGS

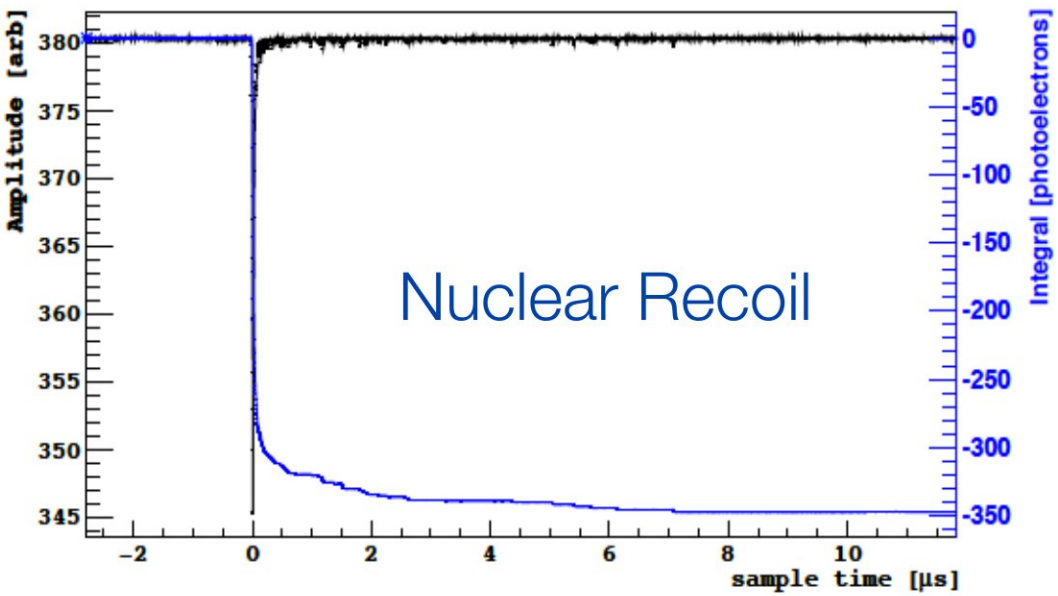
20-ton overhead crane, 1 kton water Cherenkov veto tank (before DS-50 support structures installed)

What's Special About DarkSide?

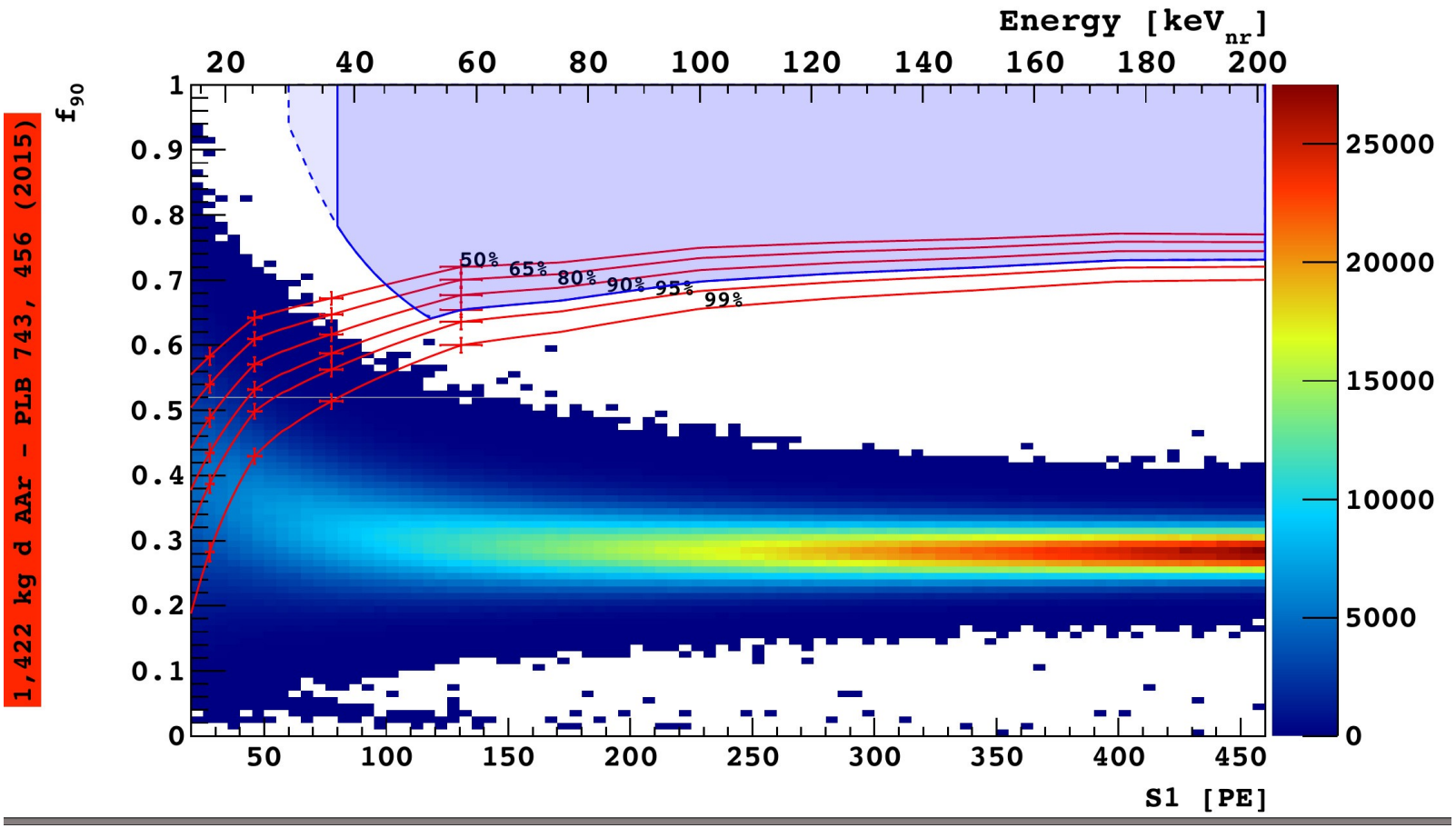
Pulse Shape Discrimination-
signal pulses (nuclear recoils)
are VERY different from background
(electron recoil) pulses







That's Discrimination!



- Published PSD vs. pulse height for 1422 kg d AAr exposure
- 1.5×10^7 ER events in WIMP energy range
- Zero NR events
- This discrimination would allow background-free 5.5 ton-yr UAr exposure, see below.

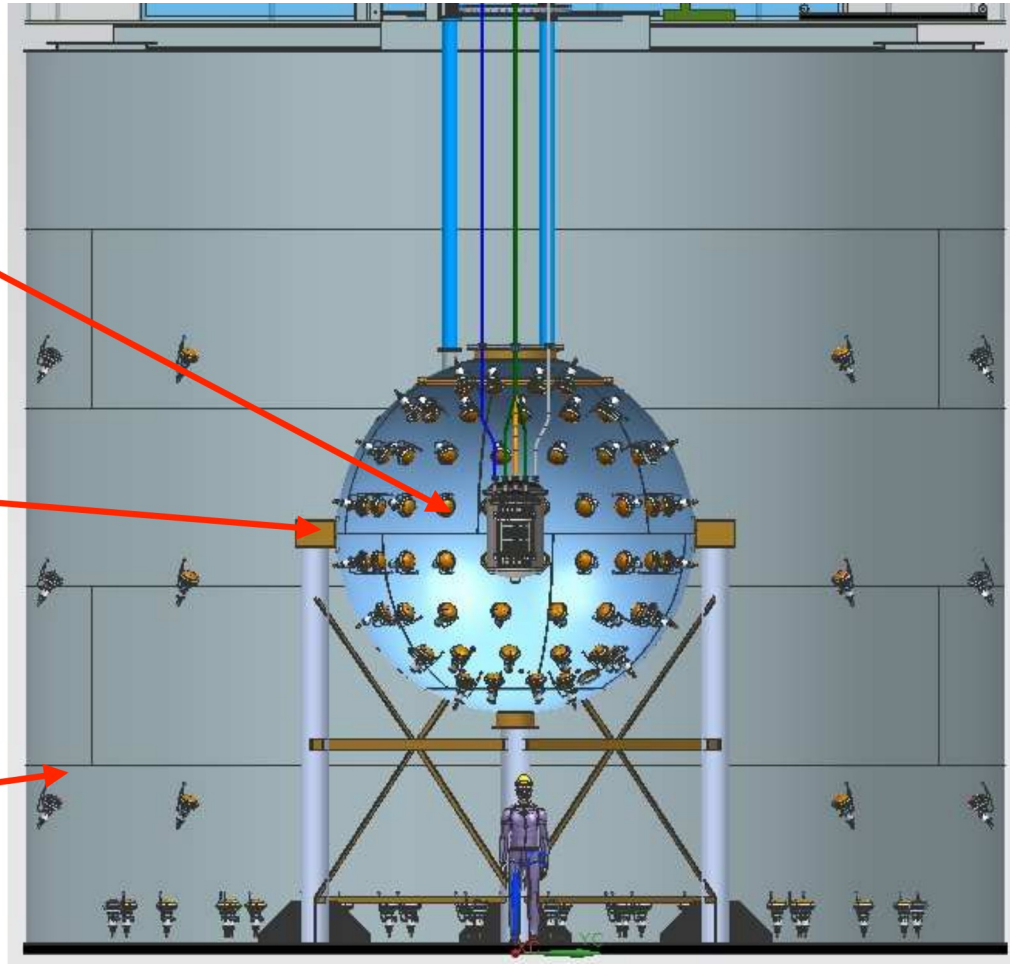
What Else is Special About DarkSide?

3800 mwe => ~ 1.1 muons/m^{2}hr, which can produce neutron background.

Liquid Argon TPC
153 kg ^{39}Ar-Depleted
Underground Argon
Target

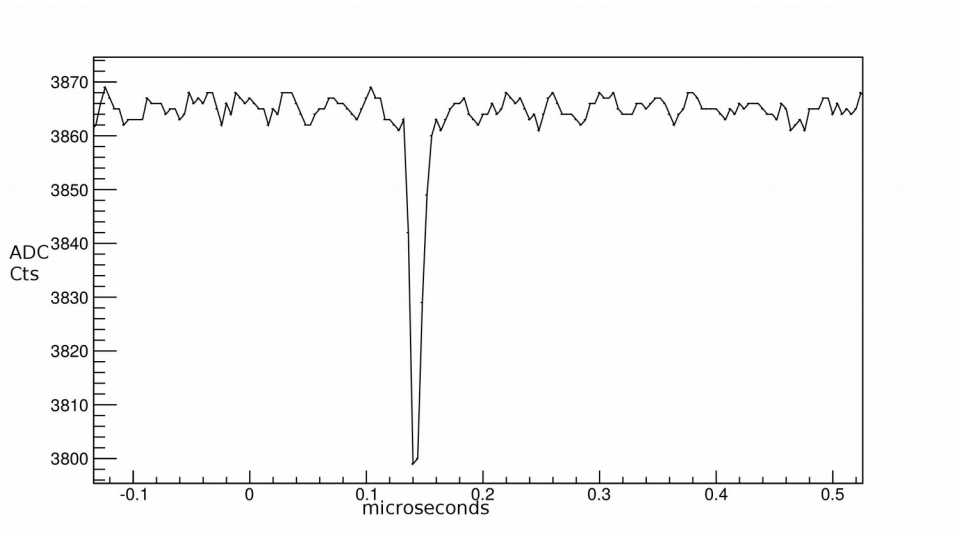
4 m Diameter
30 Tonnes
Liquid Scintillator
Neutron Veto

10 m Height
11 m Diameter
1,000 Tonnes
Water Cherenkov
Muon Veto



- calibrated veto efficiency well above 99%
- measure and reject cosmo- and radiogenic neutrons (arXiv:1512.07896)

And don't forget...



Extremely sensitive analog electronics-

- Plot exhibits S/N for 1 PE pulse
- Cold PMT preamps
  - 24V/V effective gain
  - Full scale range ~1500 PE
- 7.0 +/- 0.3 PE/keVee at 200 V/cm

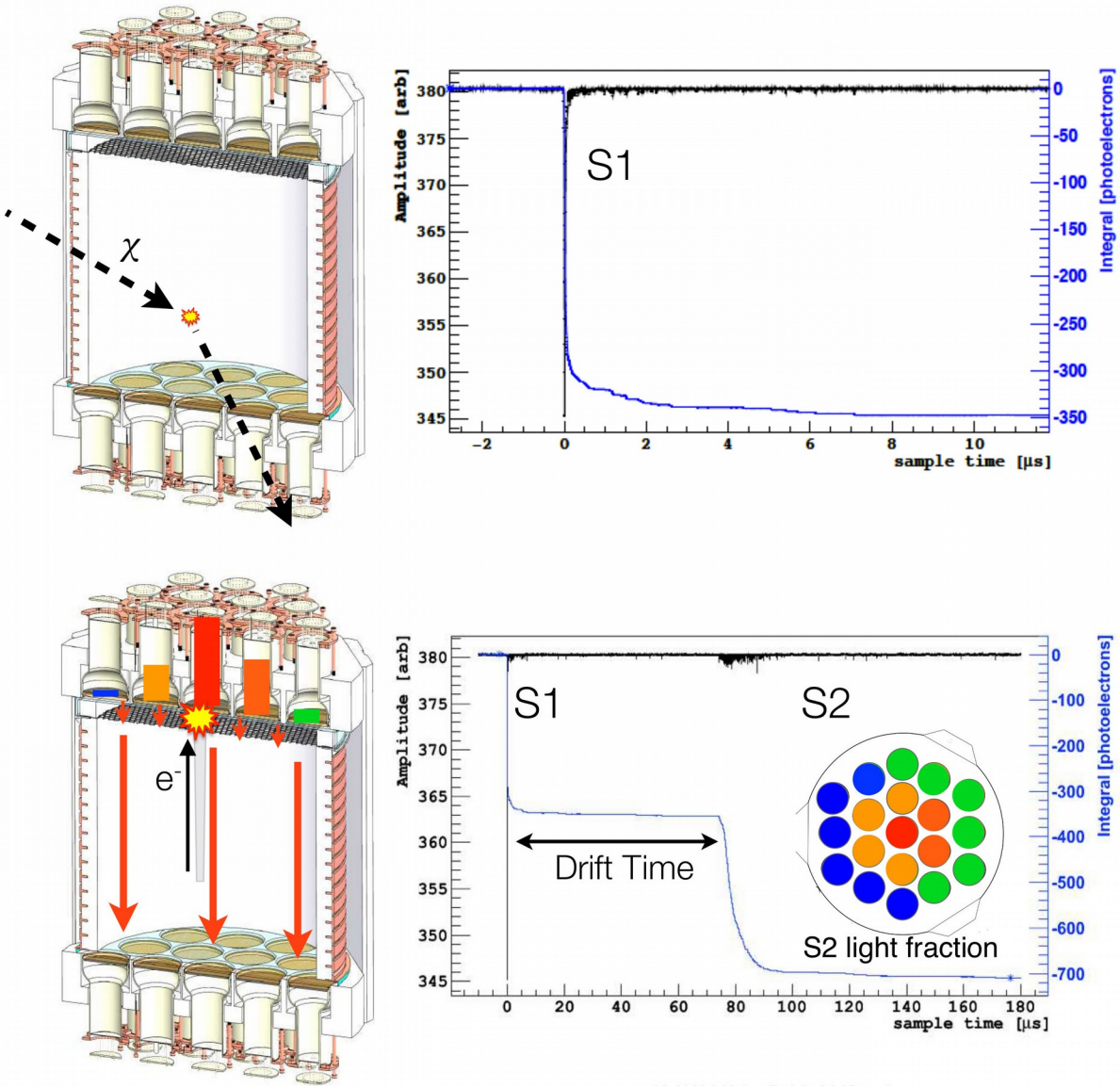
Extremely pure-

- measured ~1 μBq/kg U/Th daughter alpha emitters in LAr
- electron attachment lifetime > 5000 μS (max drift time 375 μs)

Extremely stable-

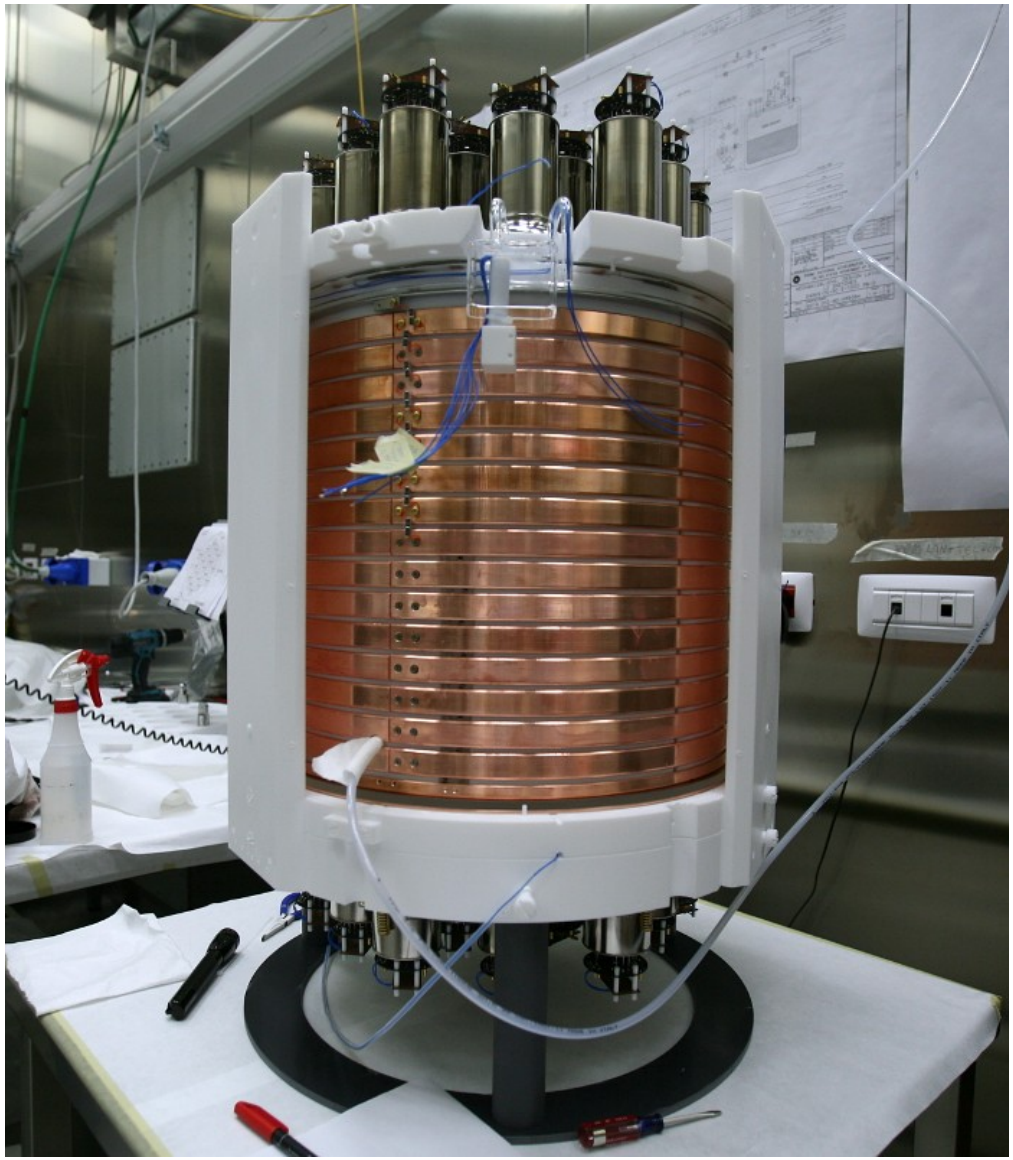
- continuous recirculation through hot Zr getters
- active volume pressure stability $\lesssim$ 0.6 mbar
- active volume temperature stability $\lesssim$.02 K

The WIMP detector- LAr-TPC



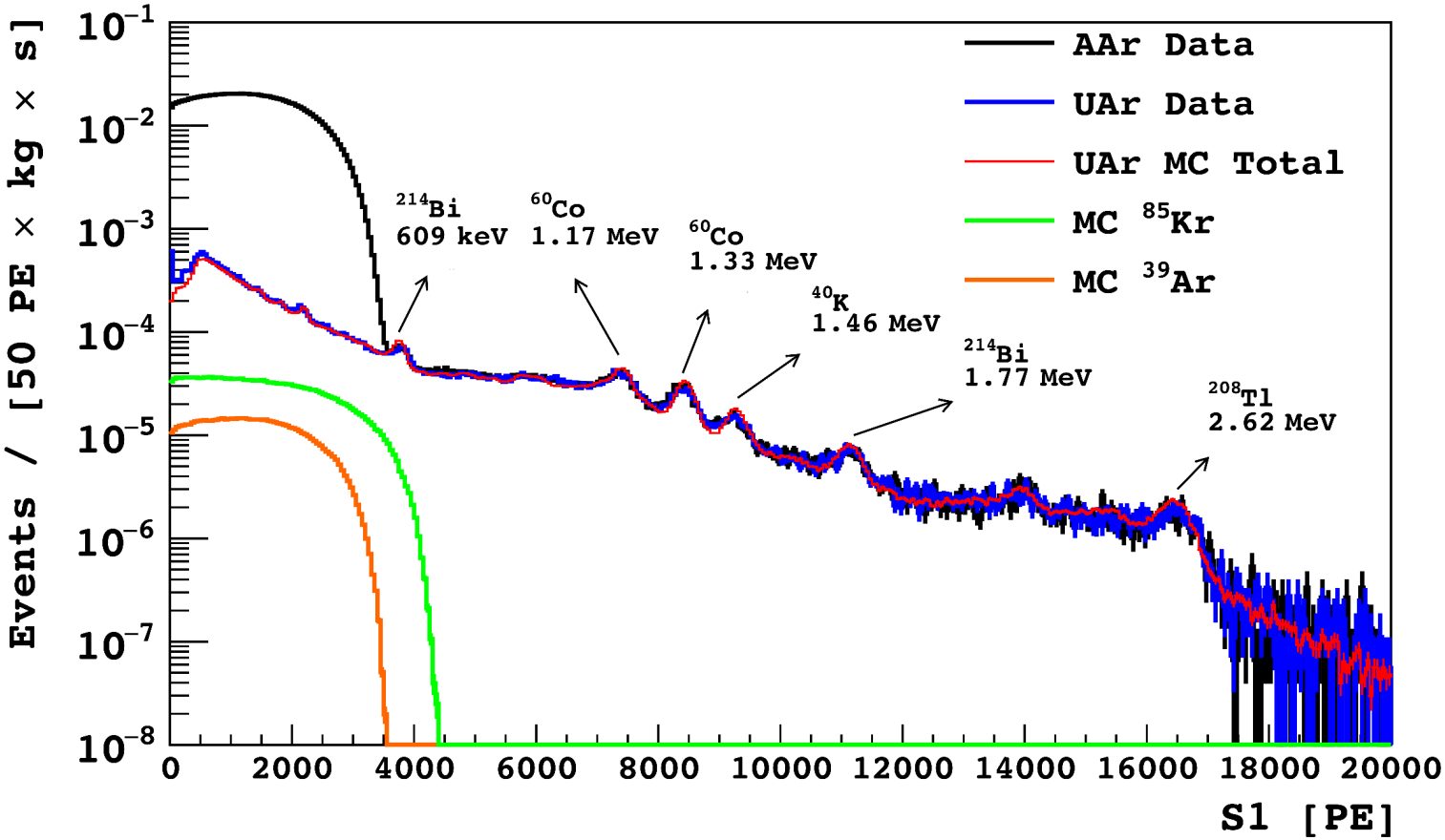
- Nuclear Recoil **excites** and **ionizes** the liquid argon, producing **scintillation** light (S1) that is detected by the photomultipliers
- The electrons are extracted into the gas region, where they induce **electroluminescence** (S2)
- The time between the S1 and S2 signals gives the vertical position.
- x-y position of events are reconstructed from fraction of S2 in each PMT.

The TPC



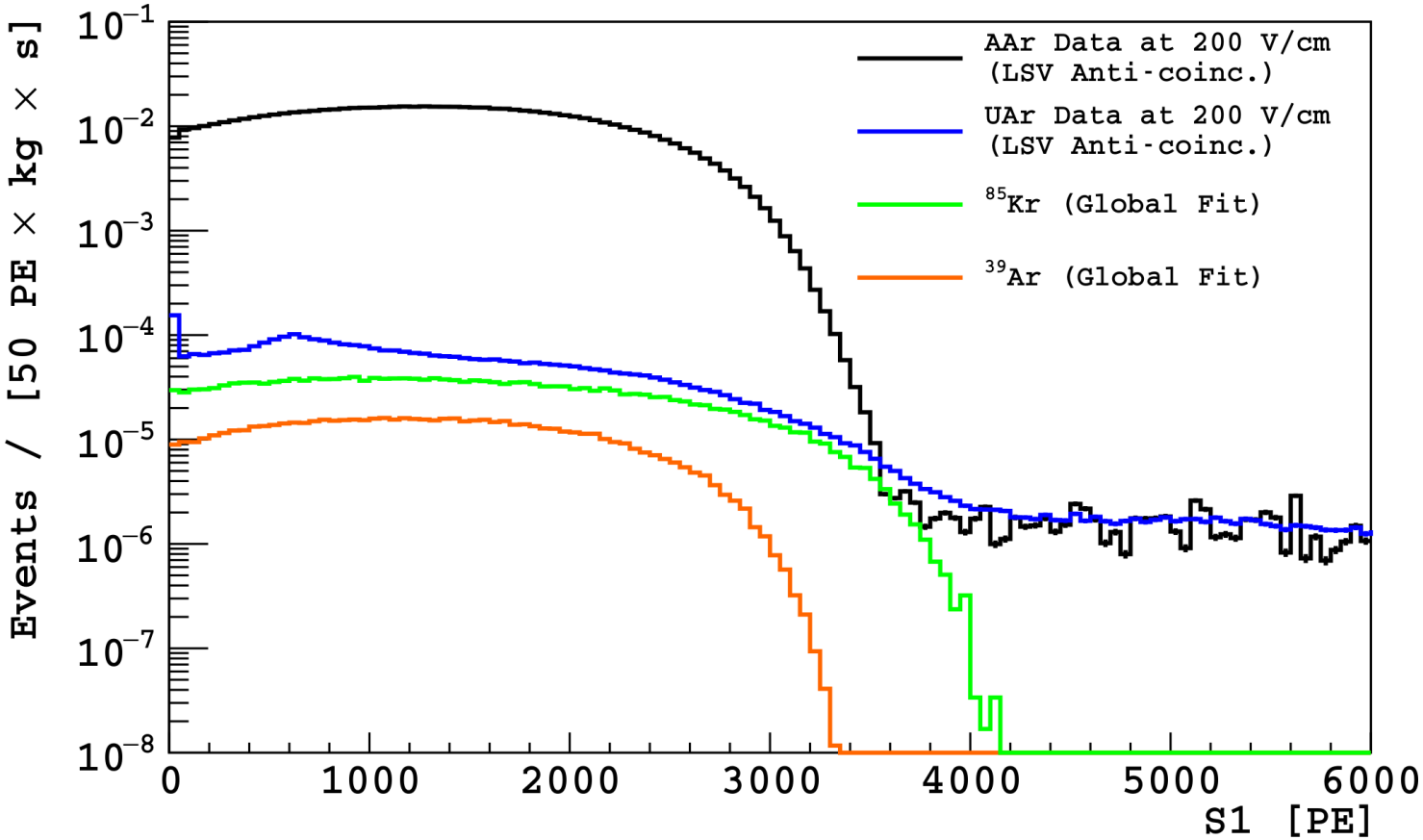
- 153 kg total, 36.9 kg fiducial LAr
- active volume lined with vacuum-evaporated TPB wavelength shifter
- anode & cathode electrodes of transparent conductor films on silica windows
- PE yield 7.0 +/- 0.3 PE/keVee at 200 V/cm
- PE yield for nuclear recoils quenched by 0.3 +/- .013 (ScENE, Phys. Rev. **D 91**, eid 092007 (2015))

The Target: UAr



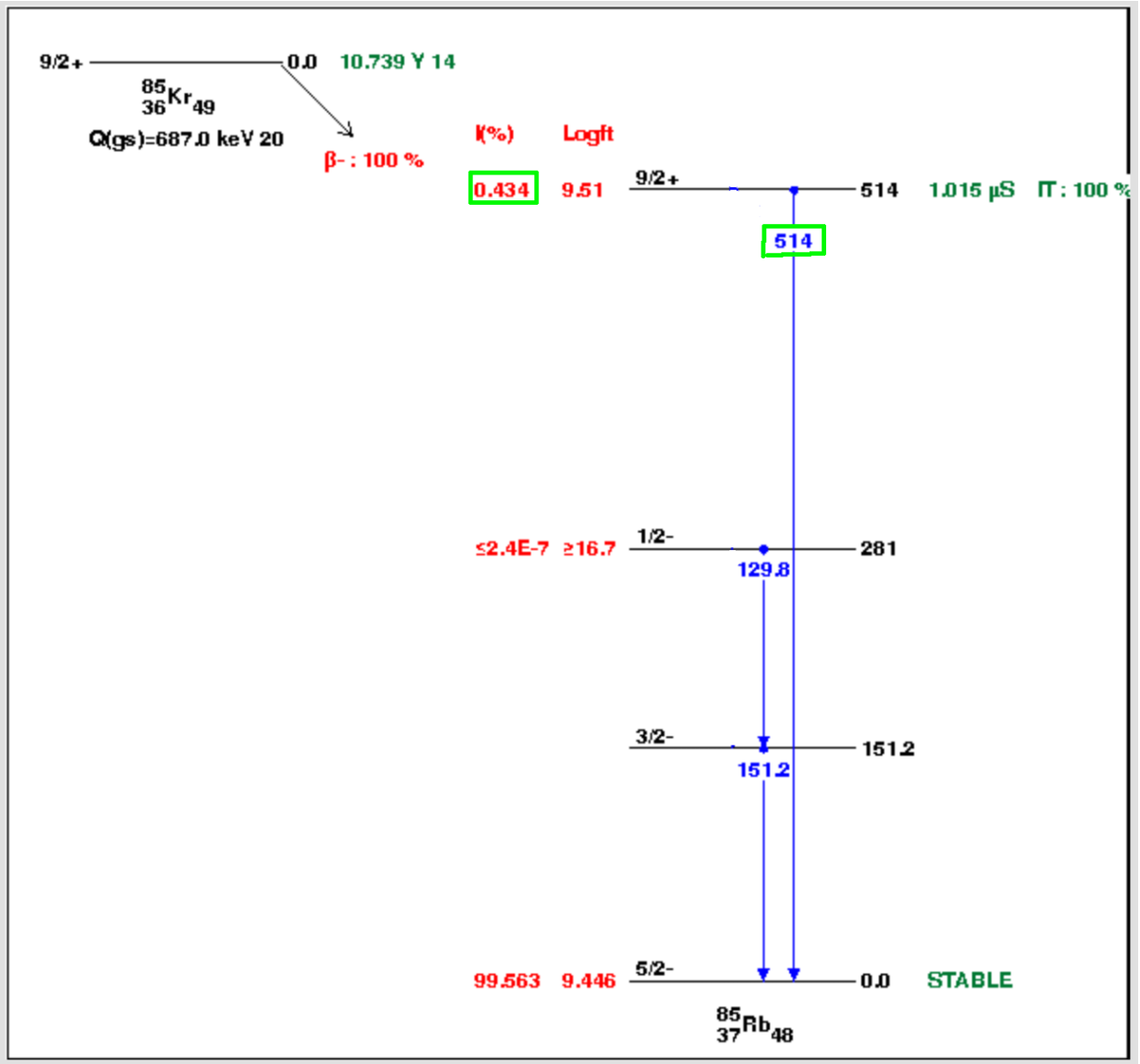
- Purified >150 kg from natural gas well source in multi-year effort
- ^{39}Ar; 0.73 ± .11 mBq/kg, down by about 1400 from AAr
- small surprise: ^{85}Kr; 2.05 ± .13 mBq/kg (but not a problem)
- drift lifetime and PE yield are the same as for AAr

Discovering the 85-Kr



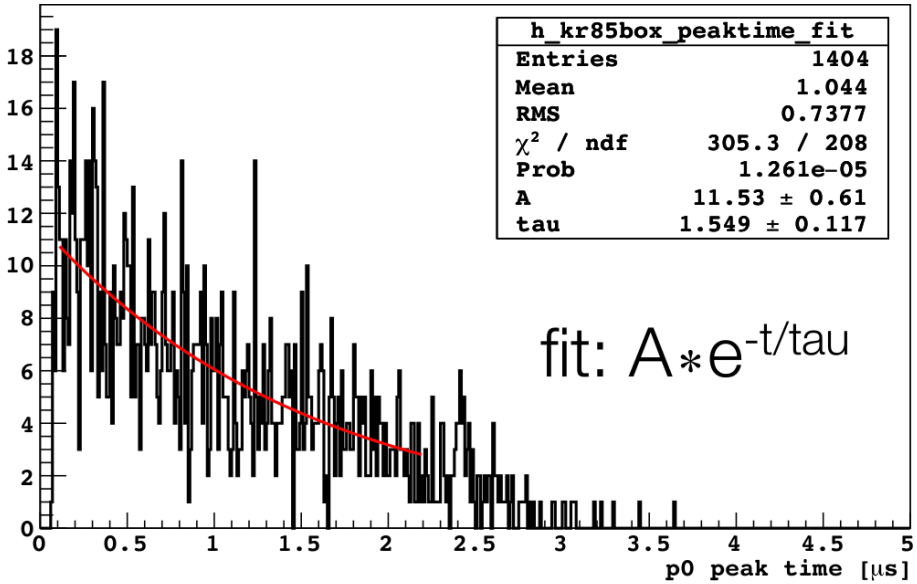
- "G4DS" (full GEANT4 physics MC) fit to endpoint region of ^{39}Ar required additional contribution
- ^{85}Kr suspected from Borexino experience... fit worked with ~2:1 ^{85}Kr:^{39}Ar

Confirming the 85-Kr

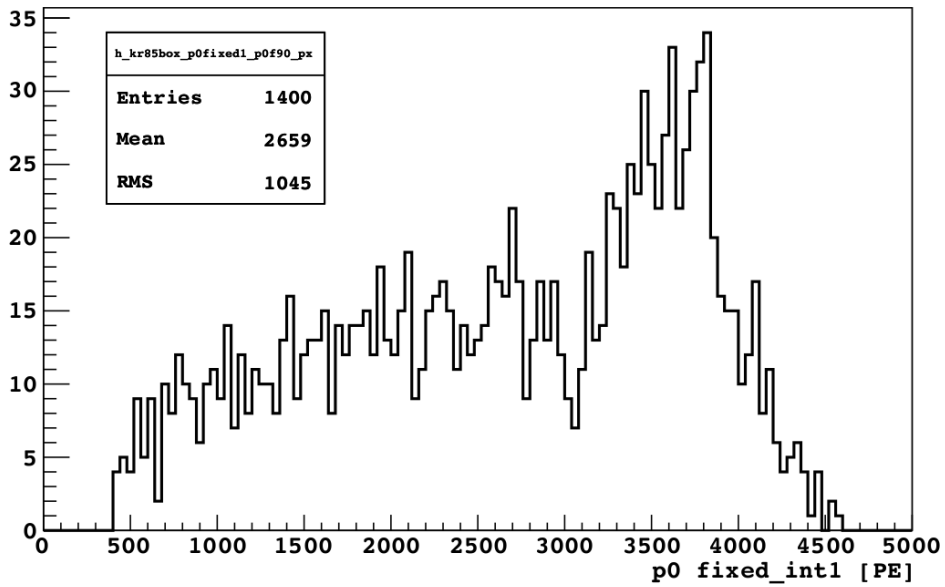


- 0.4% β-γ branch via ^{85m}Rb (514 keV, 1.0 µs)
- double-S1 signature
- Expected decay rate from G4DS ~30/ day
- events were sought and identified at rate expected from G4DS fit!

Confirming the 85-Kr



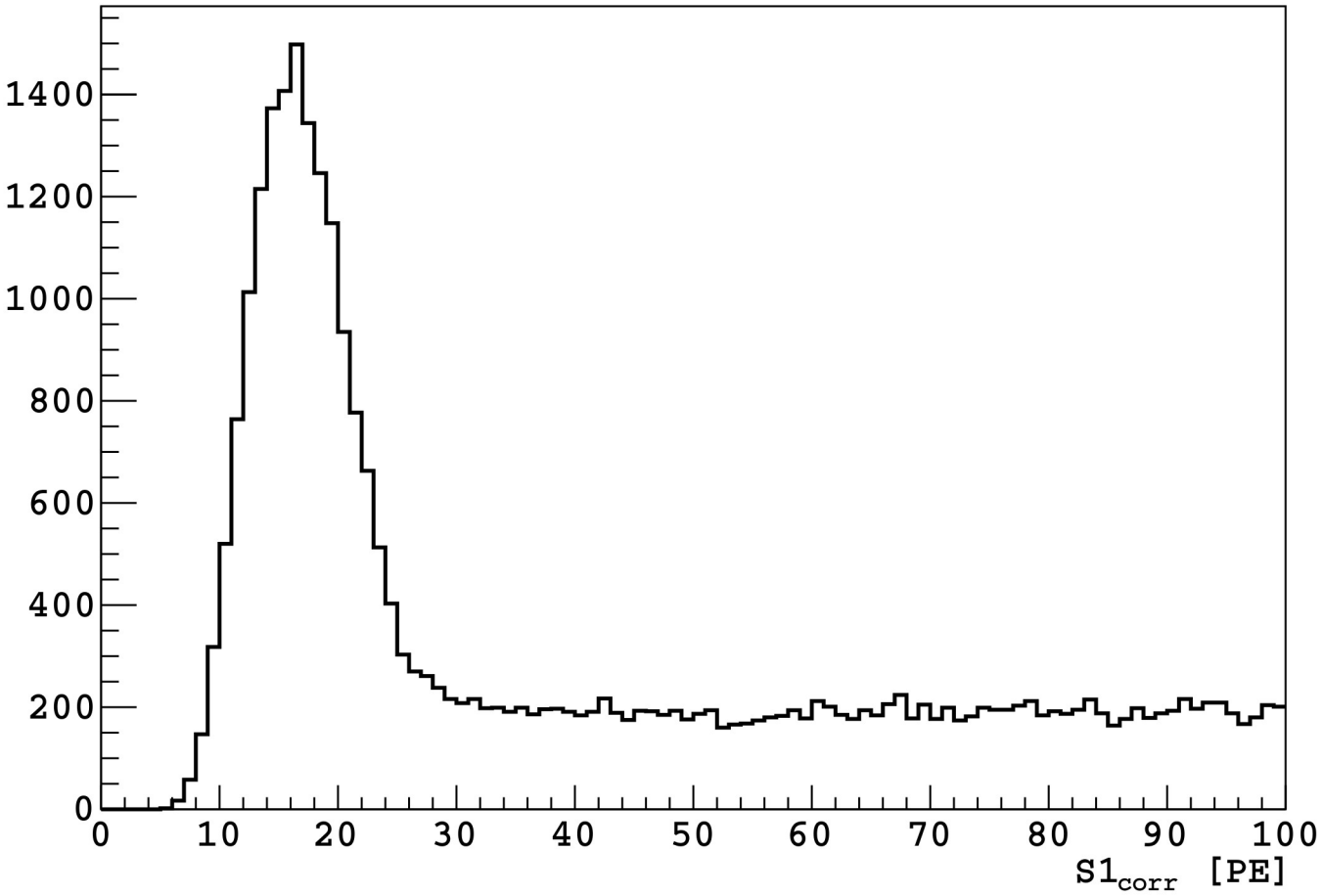
Decay time distribution



β + γ energy spectrum

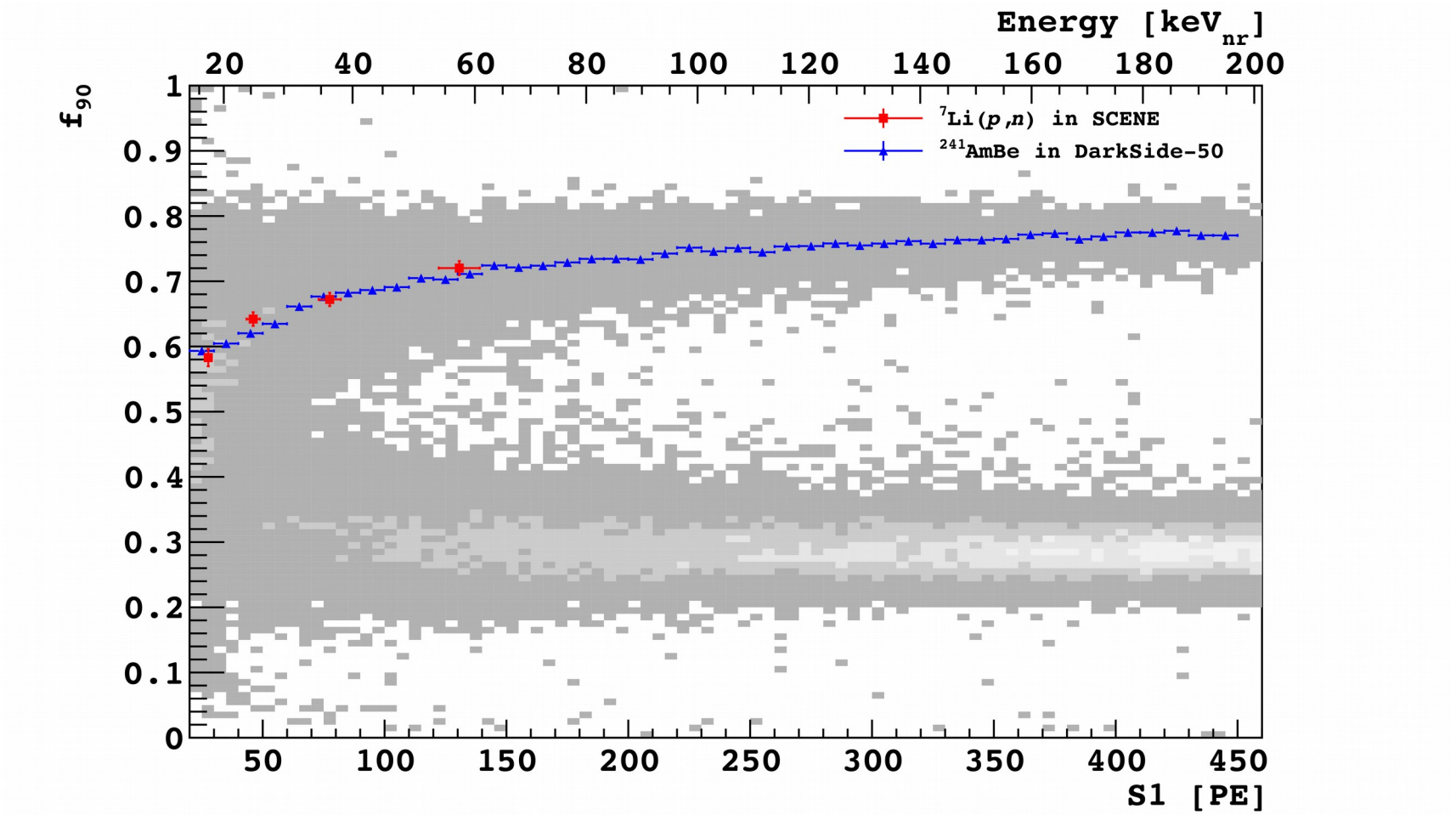
Both agree with G4DS expectations

Sensitivity at low energy



- Just after UAr fill: ^{37}Ar peak (EC, 2.4 keV Auger, $t_{1/2}$=35 days)
- From UAr cosmic ray activation in transit (now decayed away)
- Verified not to be a threshold/trigger artifact

Response of PSD to Nuclear Recoils



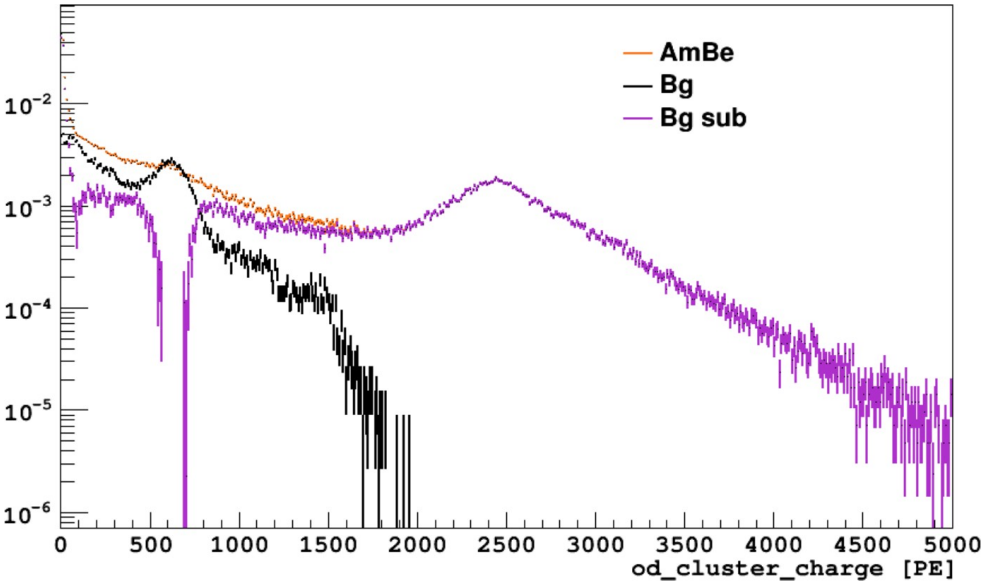
- Red: f_{90} vs. S1 for NR from ScENE experiment (Phys. Rev. **D 88**, 092006 (2013))
- Blue: in situ AmBe on DS-50

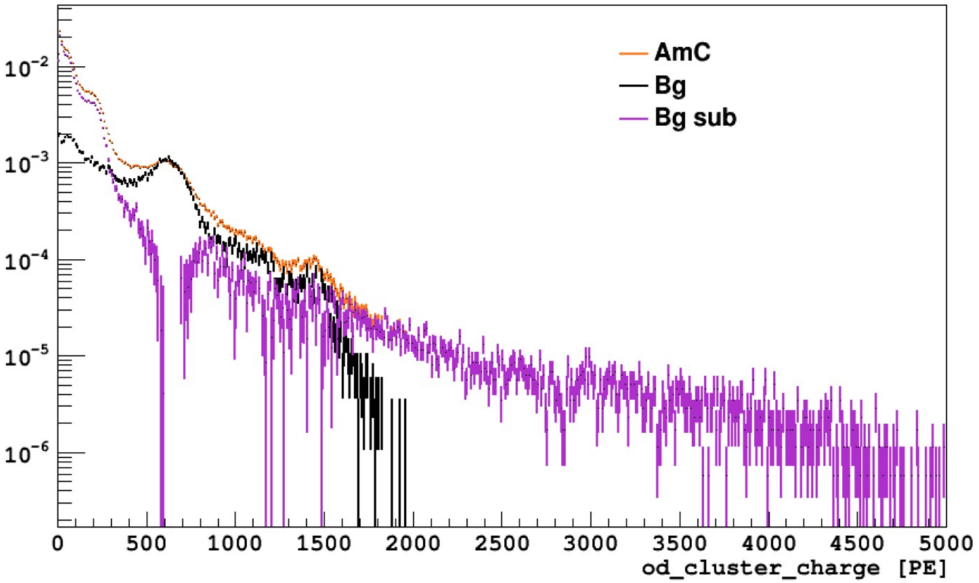
The Neutron Vetoes

- LSV: 30 tons PC + 5% Tetramethyl borate + PPO
- Very low ^{14}C (~300 Hz triggers)
- 110 PMT's, 1.25 GSPS digitizers from NI

- PE yield 0.59 ± .1 PE/keV @ 60-Co
- Calibrated neutron veto eff. >99%

Newest NR Calibration; AmC

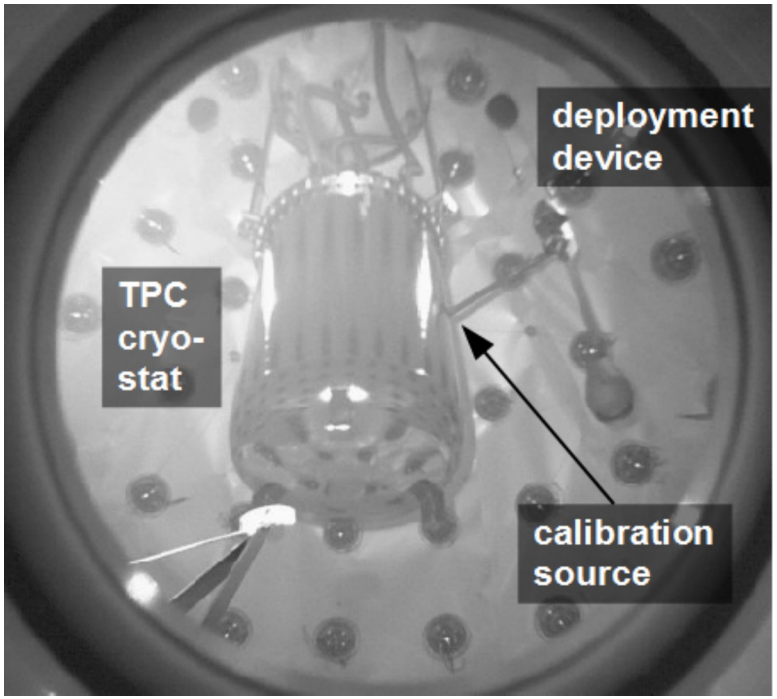




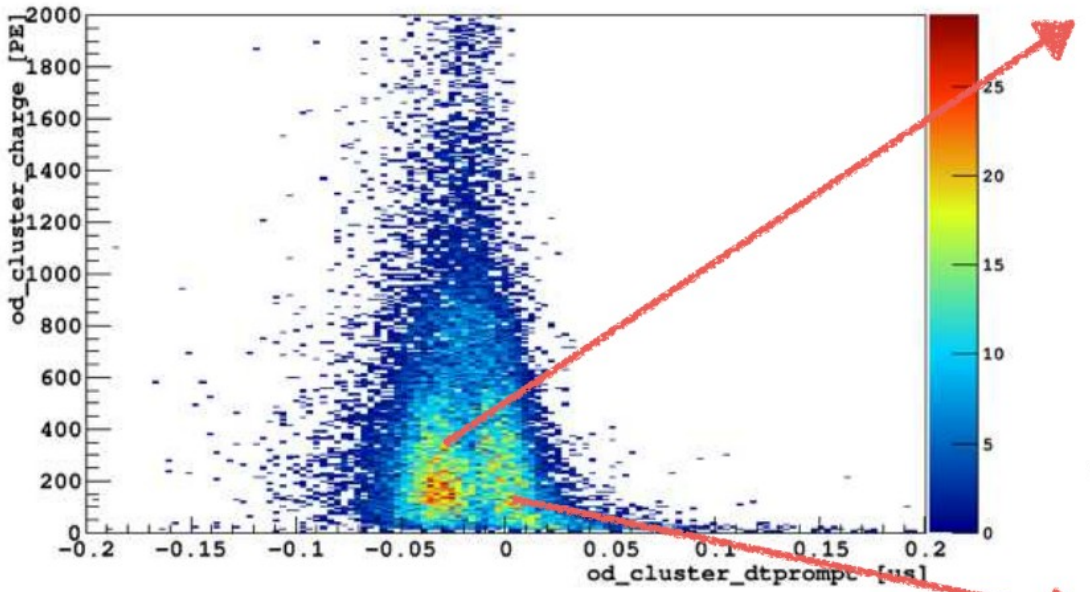
^{241}Am-^{13}C (α,n)^{16}O neutron source inserted in LSV using CALIS

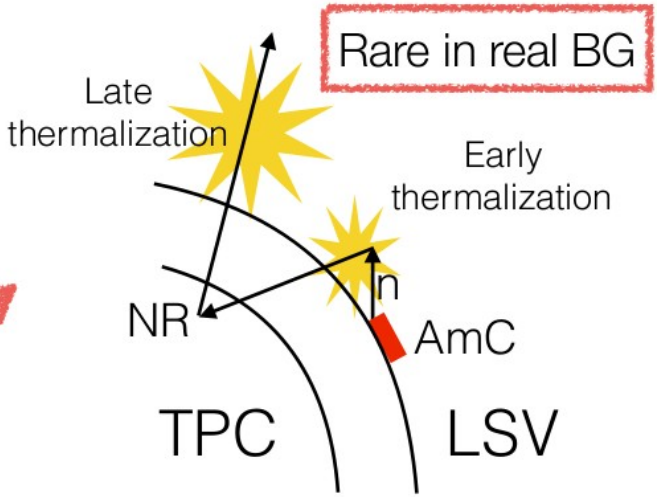
- only 59 keV γ coincident with n
- monoenergetic 4 MeV neutrons
- yield per α ~1/100 of AmBe
- deployed in DS-50 Dec-January
- for precision veto efficiency study

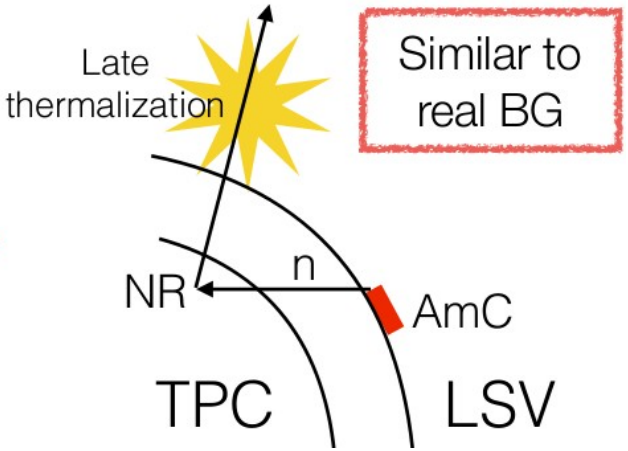
(AmC also developed by Daya Bay)



AmC Self-Tagging Scheme

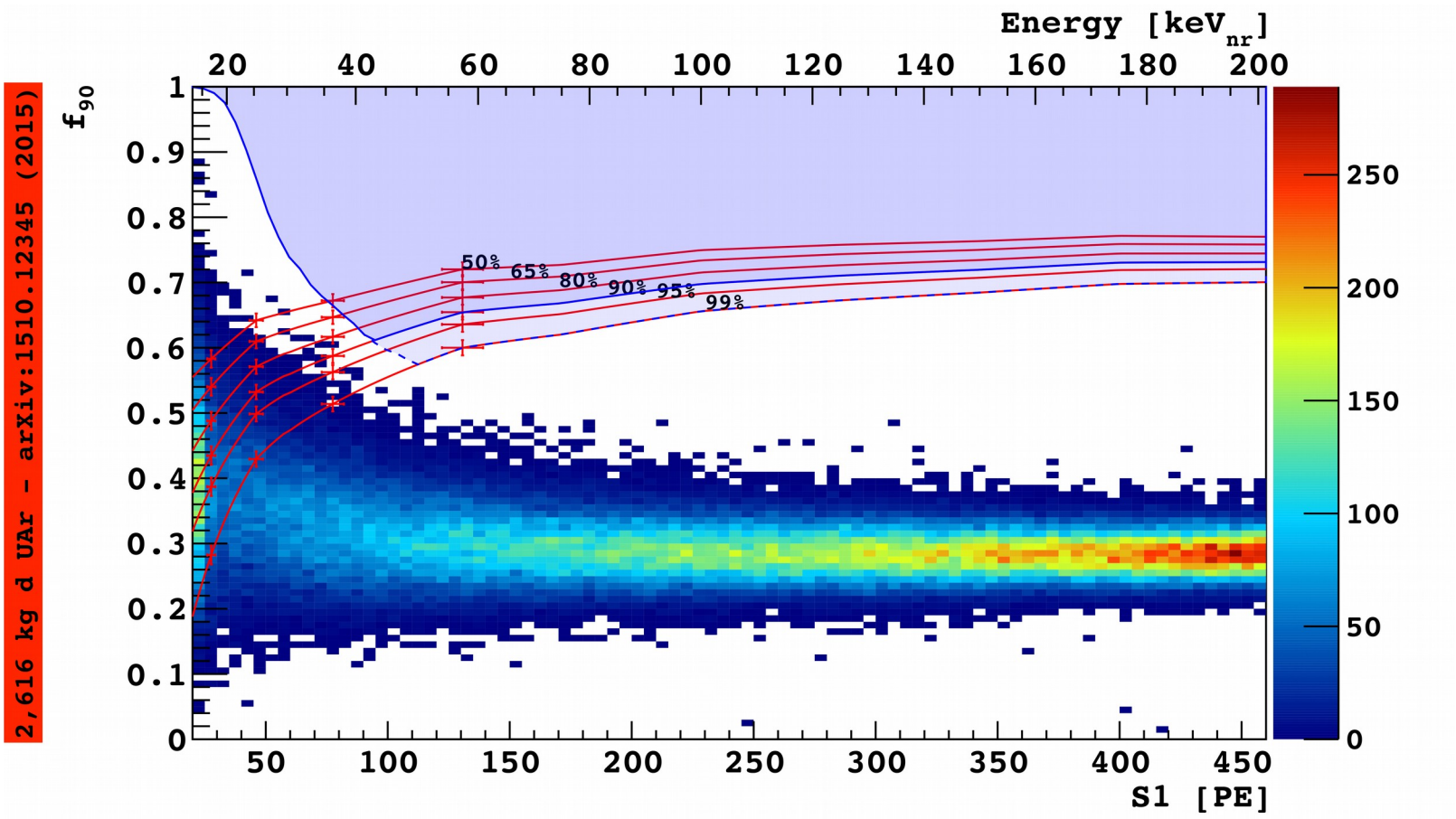






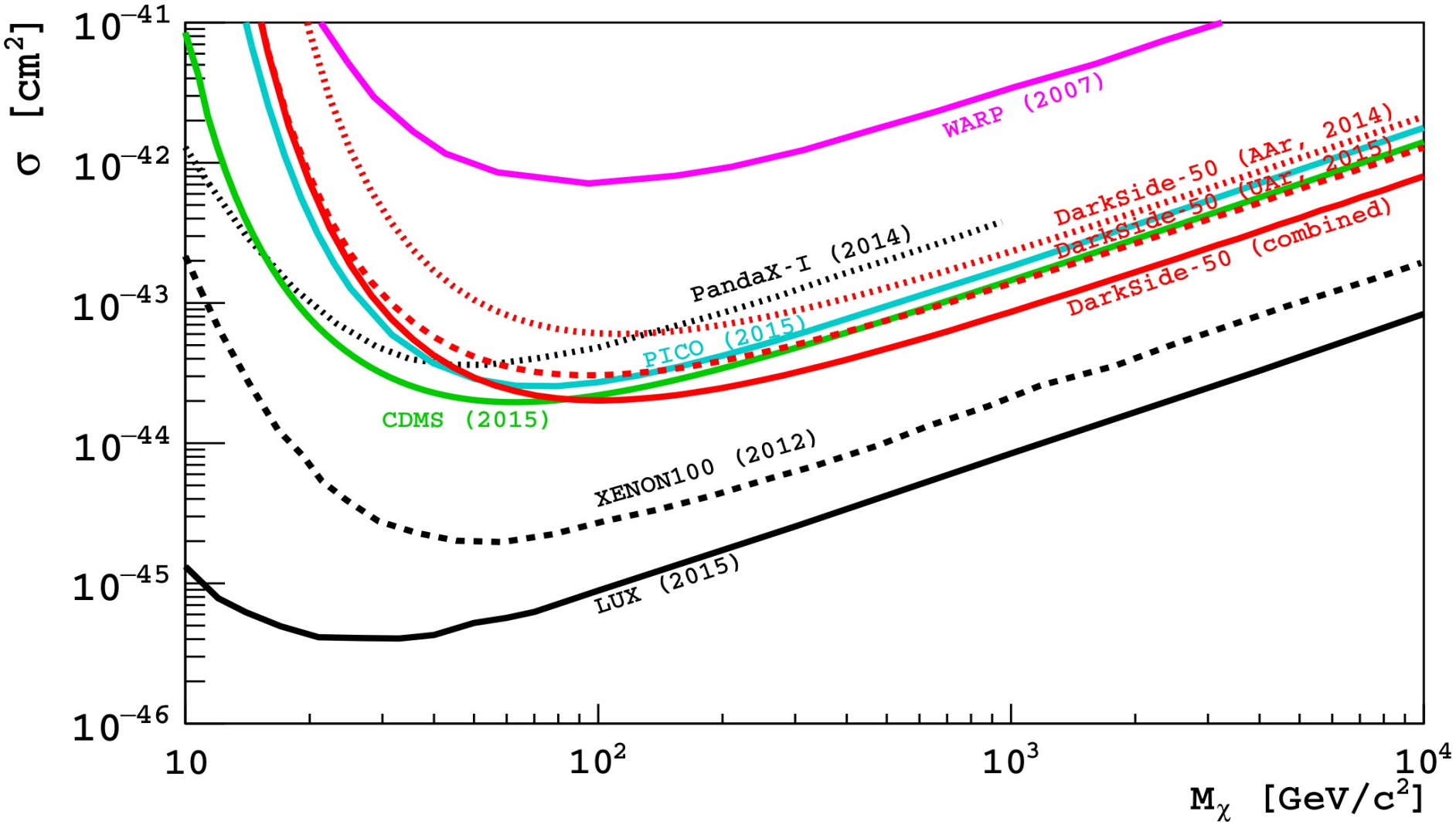
Delay time vs. pulse height for LSV events
with identified NR in TPC. Note two timing groups.

Background Free UAr Data thru 7/2015



2616 ± 43 kg d exposure (ArXiv 1510-12345)
Analysis very similar to previous AAr run (PLB 743, 456 (2015))

WIMP-exclusion result AAr + UAr (ArXiv 1510-12345)

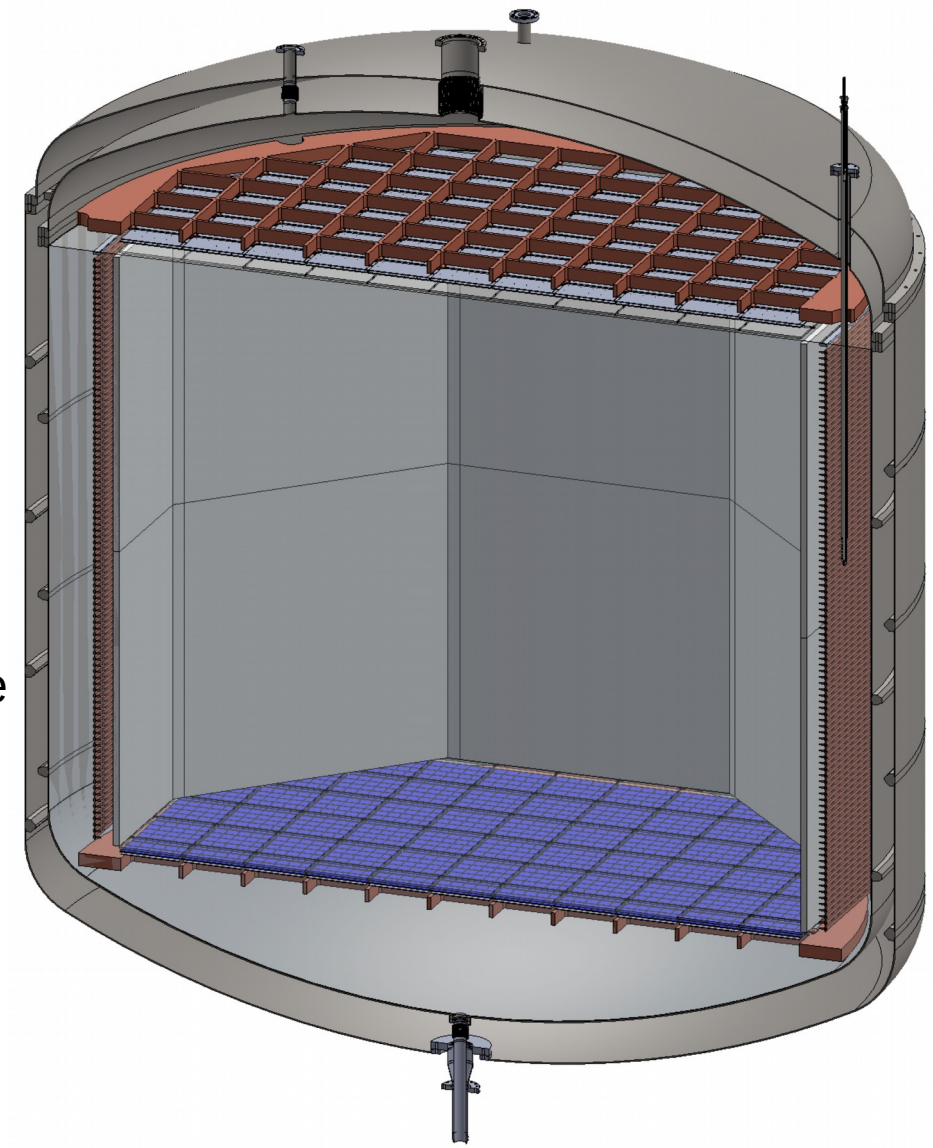
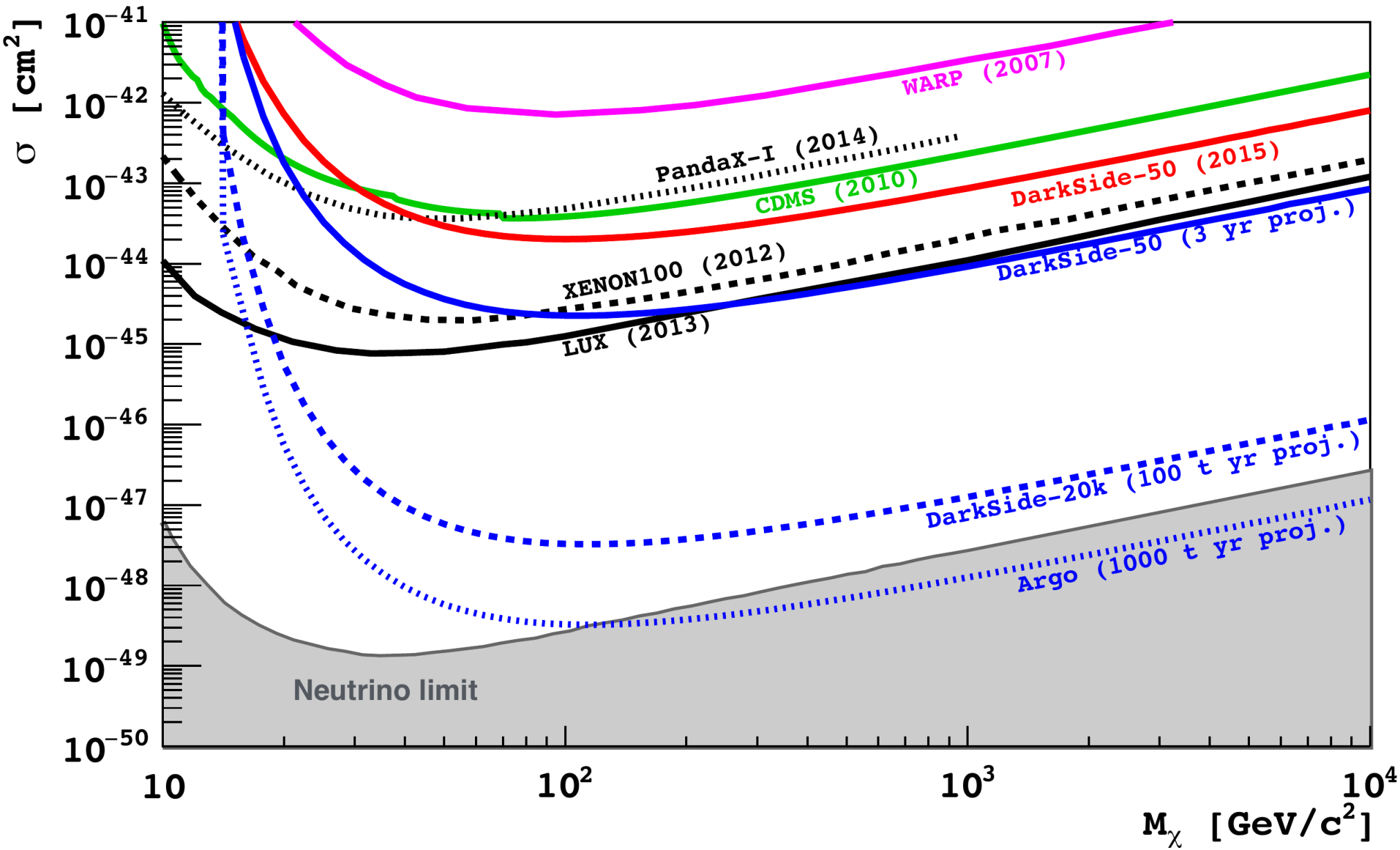


Just over 4000 kg d total, third-best limit at high WIMP mass

Of Course, Nobody is Content with Third-Best...

DS-20k

- Proposed to INFN and NSF 12/2015
- 20 Tonne fiducial mass
- New LSV + WCD veto system
- New INFN-funded UAr & DAr plants
- Aiming for:
  100 ton-yr **background-free** exposure
  $\sigma(WN) < 10^{-47}$ cm^2 at 1 TeV/c^2



DS-20k Projected Limits