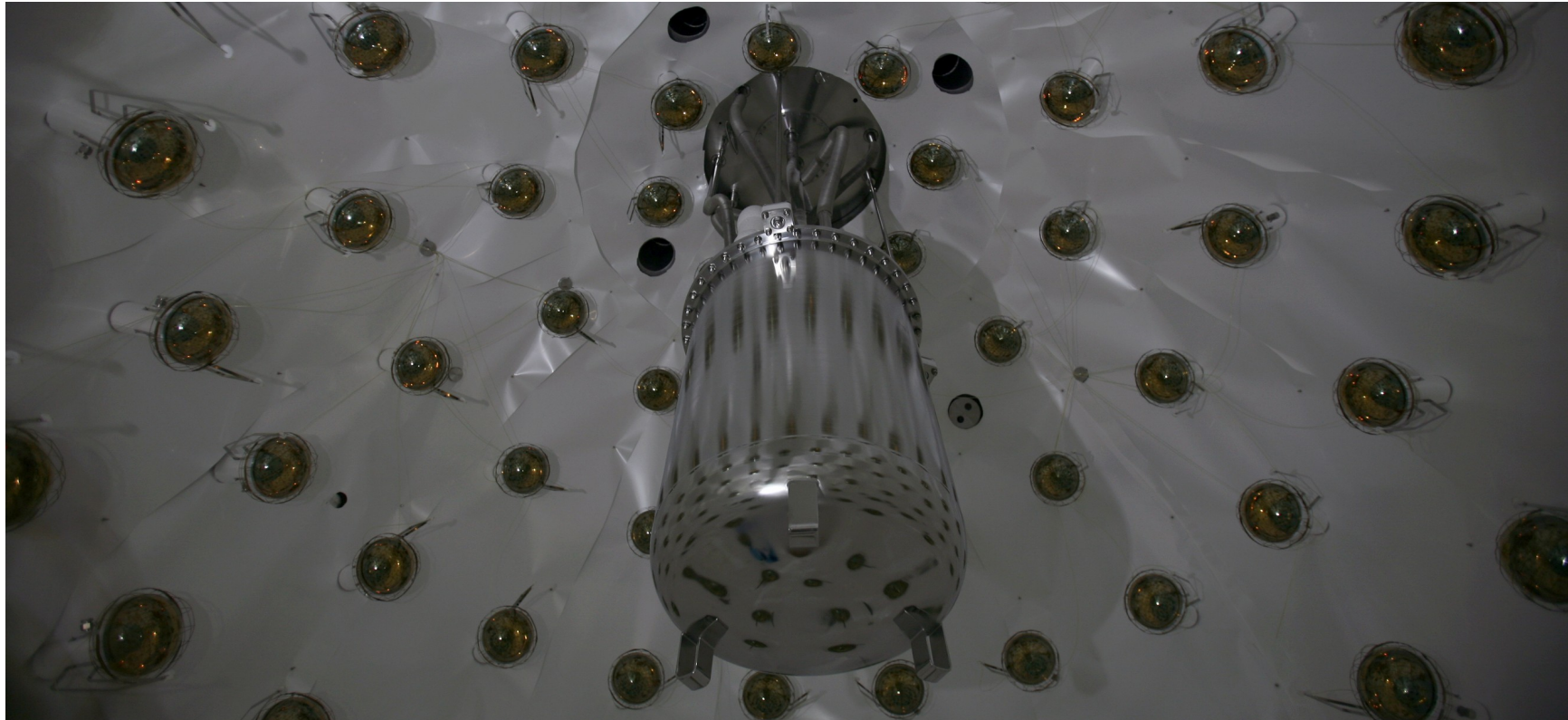


# Recent Results from DarkSide-50



C. J. Martoff, Temple University (NSF-PHY-1314483)  
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



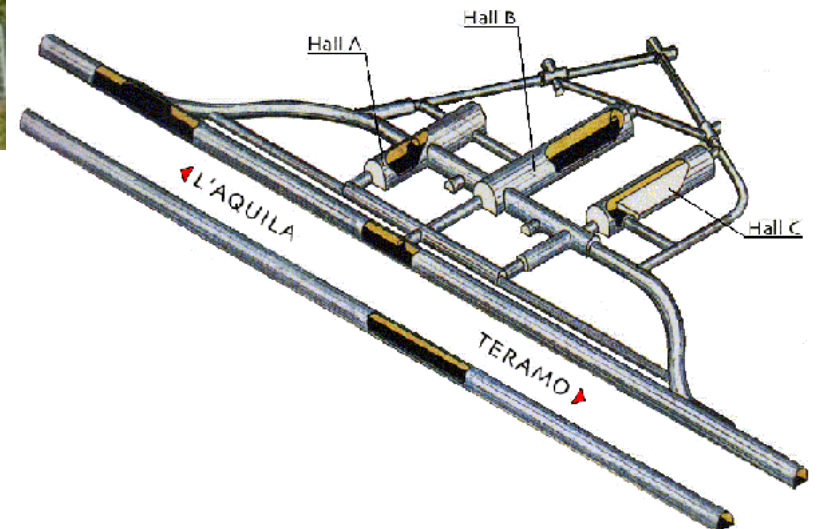


# LNGS



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)

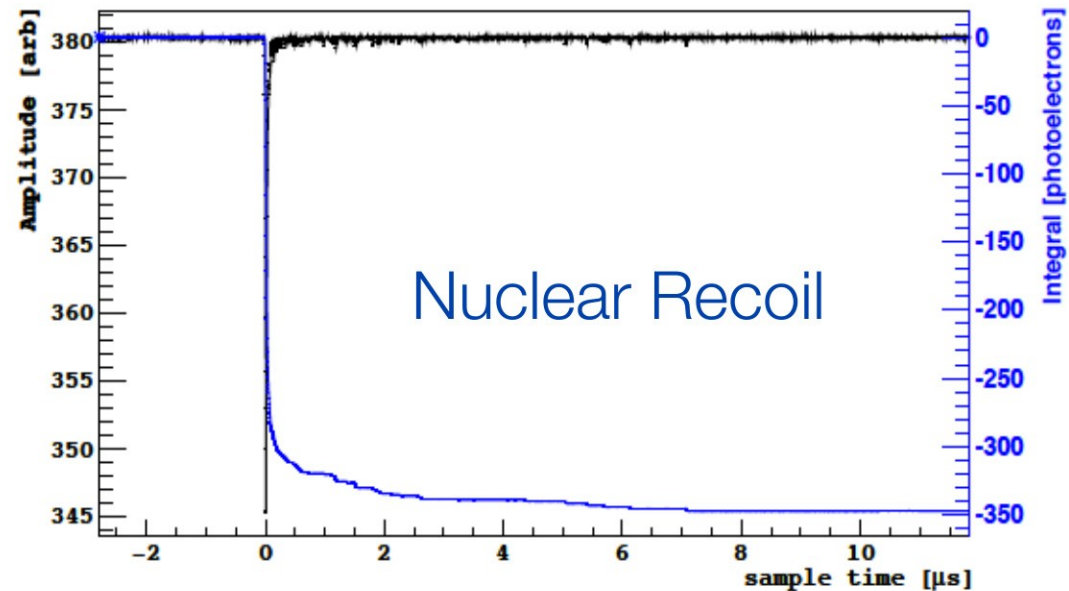
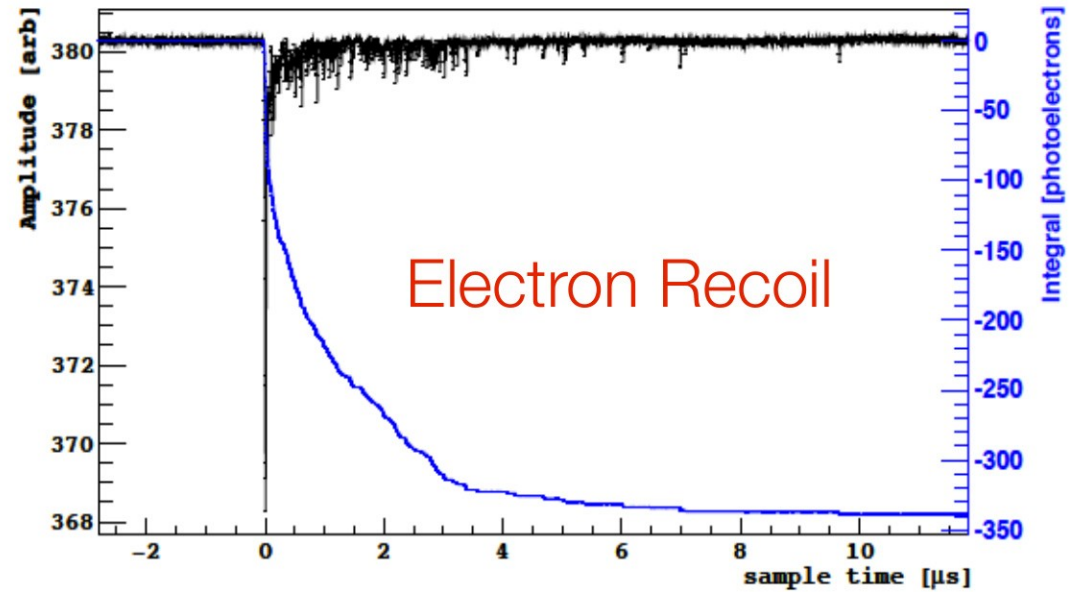
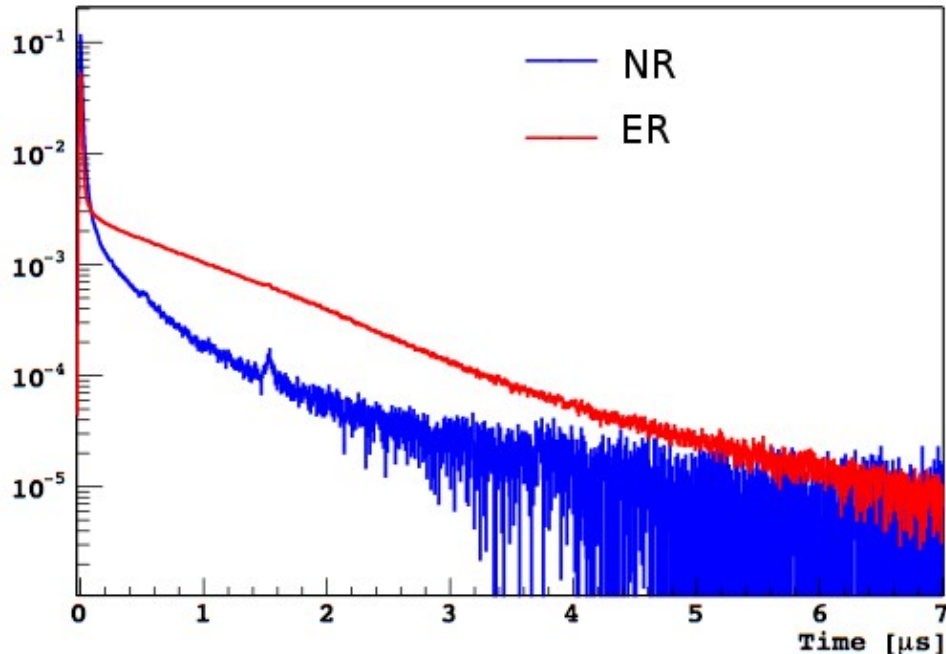
Mar 7, 2016

DS-50 (C. J. Martoff)  
Lake Louise Winter Institute

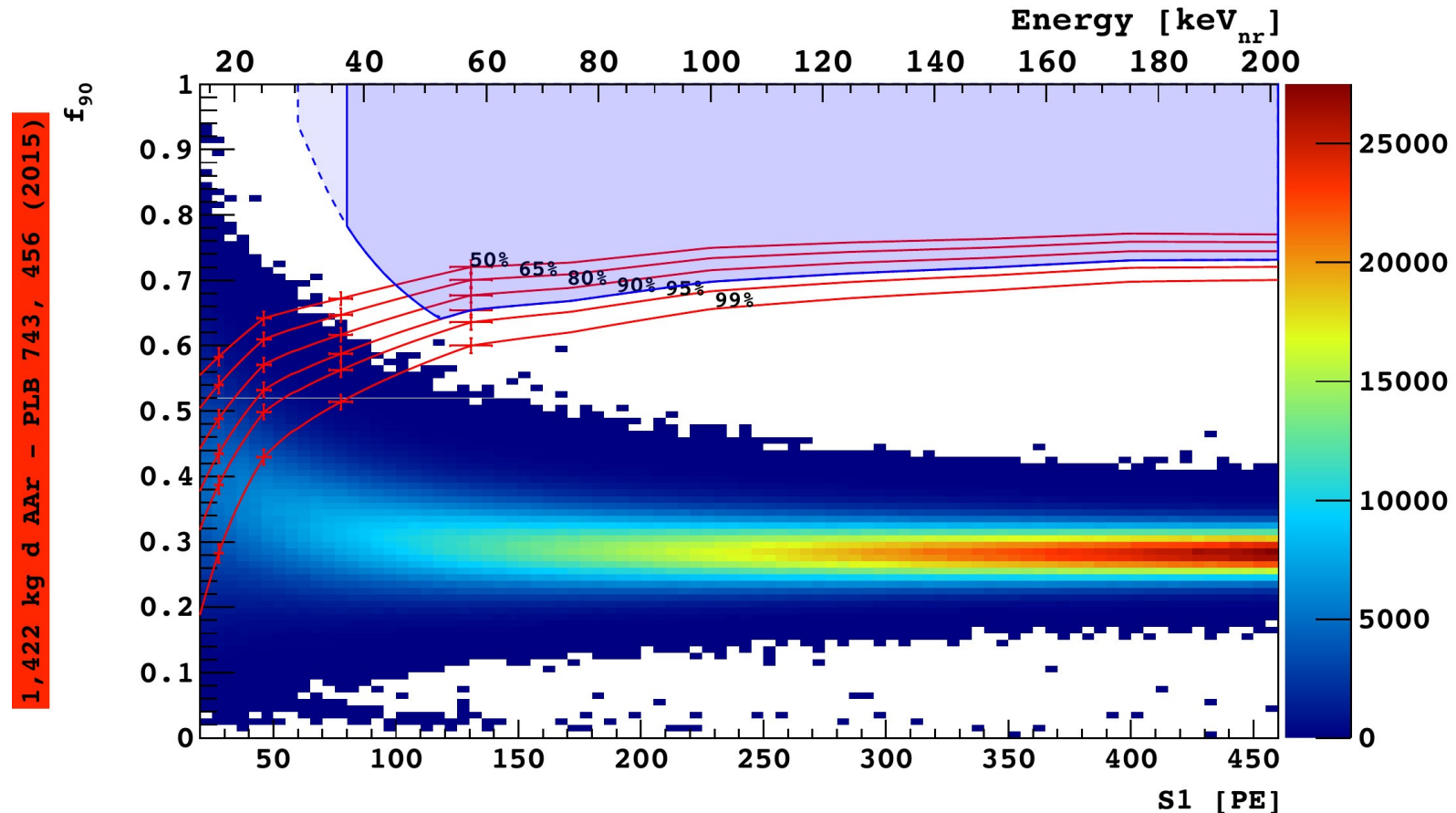


# What's Special About DarkSide?

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
- $1.5 \times 10^7$  ER events in WIMP energy range
- Zero NR events
- This discrimination would allow background-free 5.5 ton-yr UAr exposure, see below.

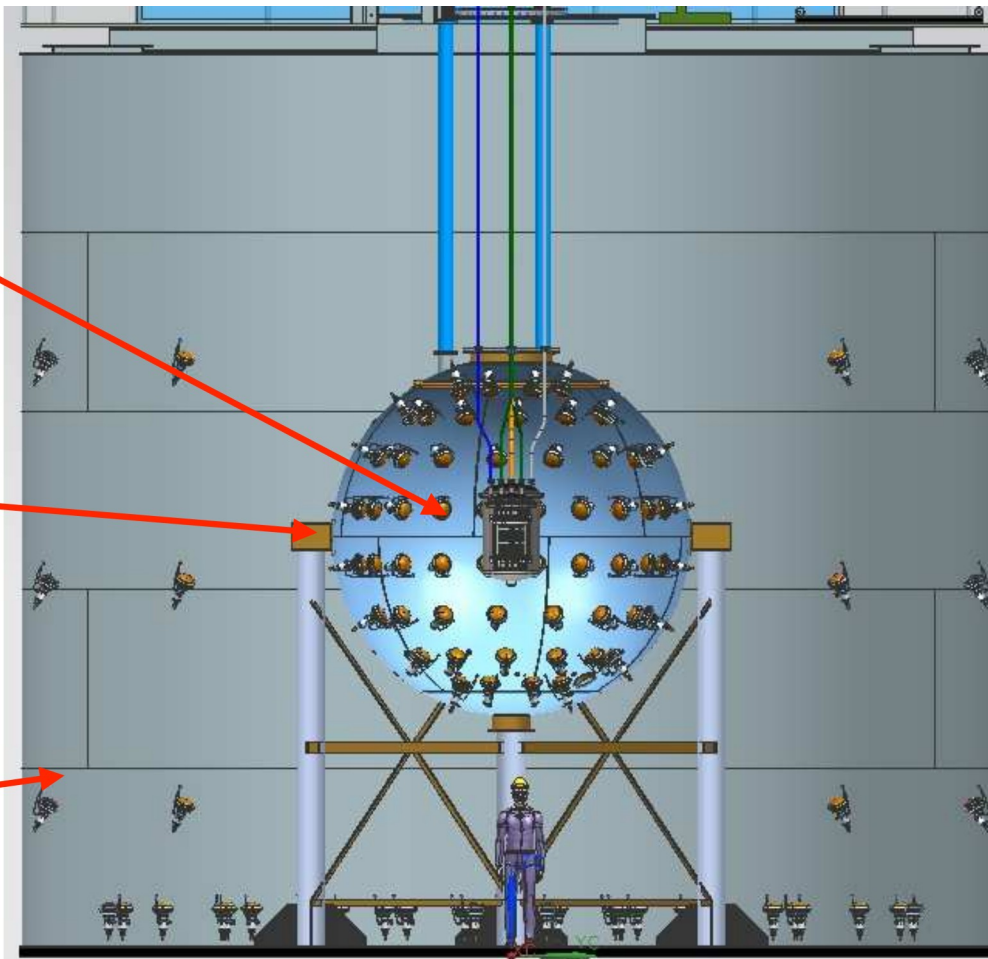
# What Else is Special About DarkSide?

3800 mwe => ~ 1.1 muons/m<sup>2</sup>hr, which can produce neutron background.

Liquid Argon TPC  
153 kg <sup>39</sup>Ar-Depleted  
Underground Argon  
Target

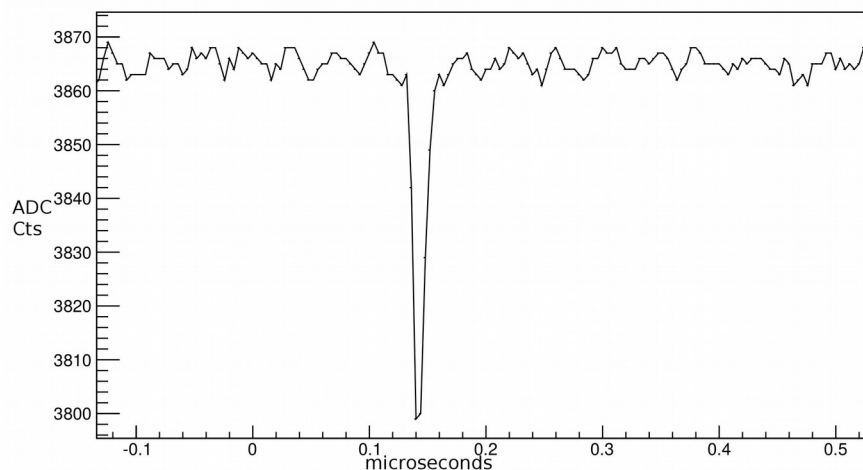
4 m Diameter  
30 Tonnes  
Liquid Scintillator  
Neutron Veto

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  $\sim$ 1500 PE
- 7.0  $\pm$  0.3 PE/keVee at 200 V/cm

### Extremely pure-

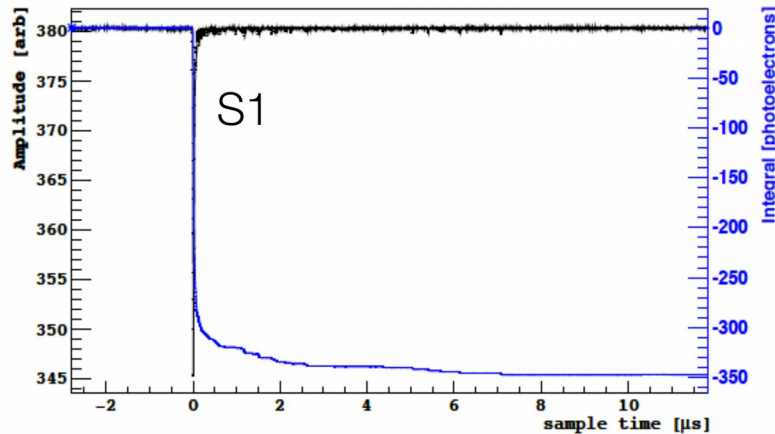
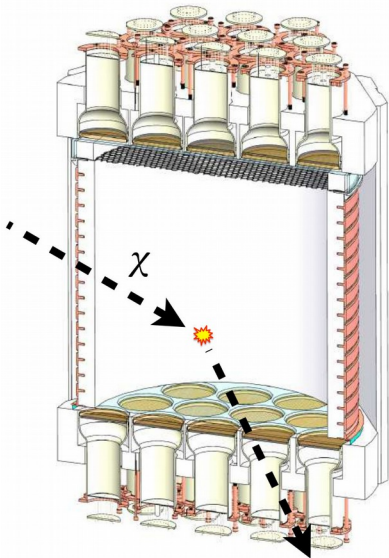
- measured  $\sim$ 1  $\mu$ Bq/kg U/Th daughter alpha emitters in LAr
- electron attachment lifetime  $>$  5000  $\mu$ S (max drift time 375  $\mu$ s)

### Extremely stable-

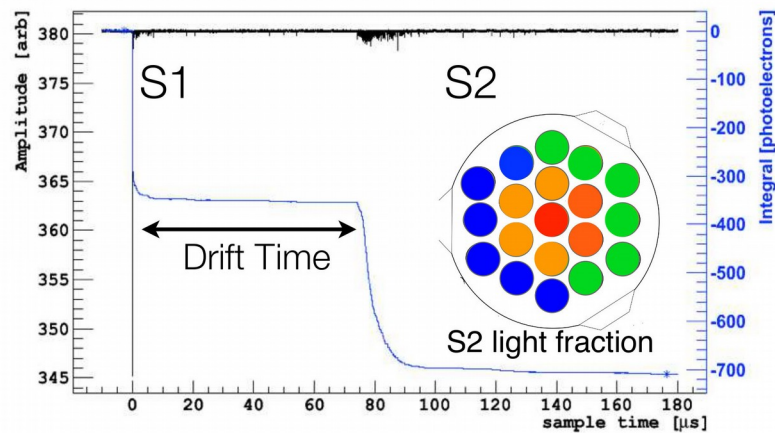
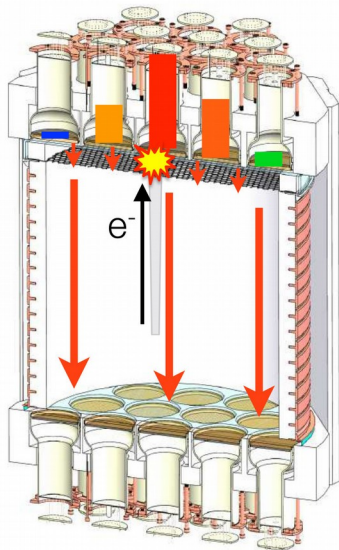
- continuous recirculation through hot Zr getters
- active volume pressure stability  $\lesssim$  0.6 mbar
- active volume temperature stability  $\lesssim$  0.02 K



# The WIMP detector- LAr-TPC

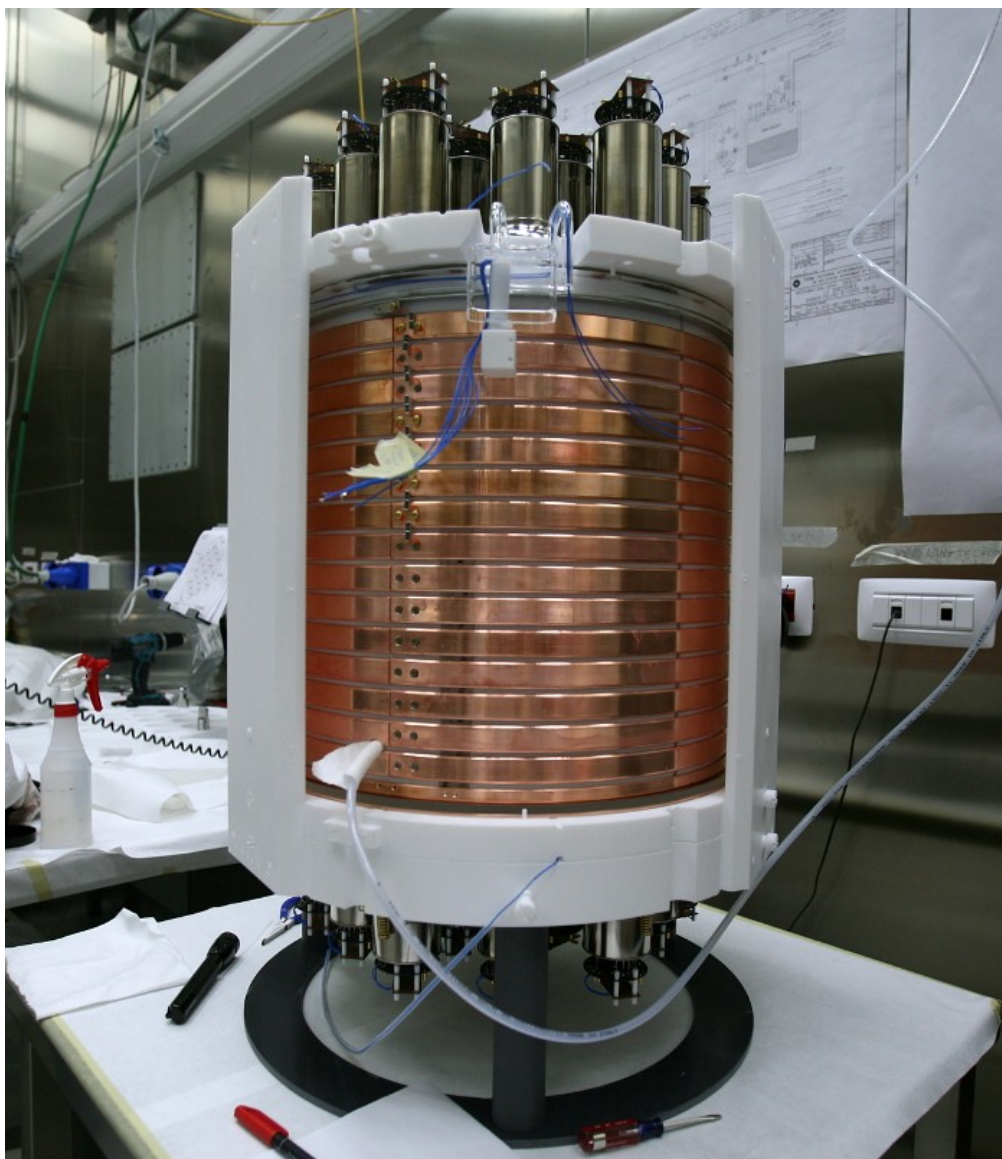


- Nuclear Recoil **excites** and **ionizes** the liquid argon, producing **scintillation** light (S1) that is detected by the photomultipliers



- 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.

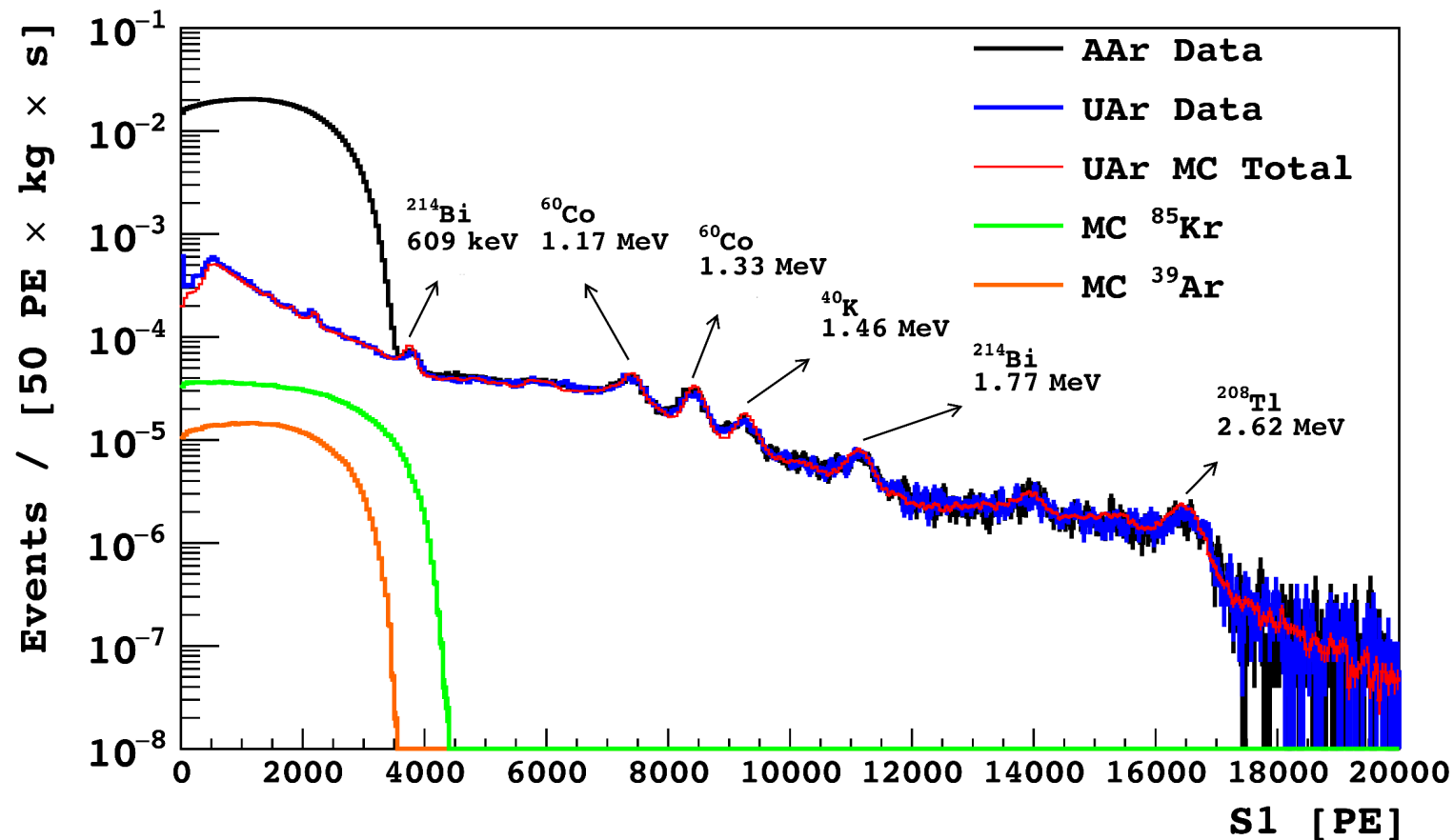
# The TPC



- 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  $7.0 \pm 0.3$  PE/keVee at 200 V/cm
- PE yield for nuclear recoils quenched by  $0.3 \pm .013$  (ScENE, Phys. Rev. **D 91**, eid 092007 (2015))

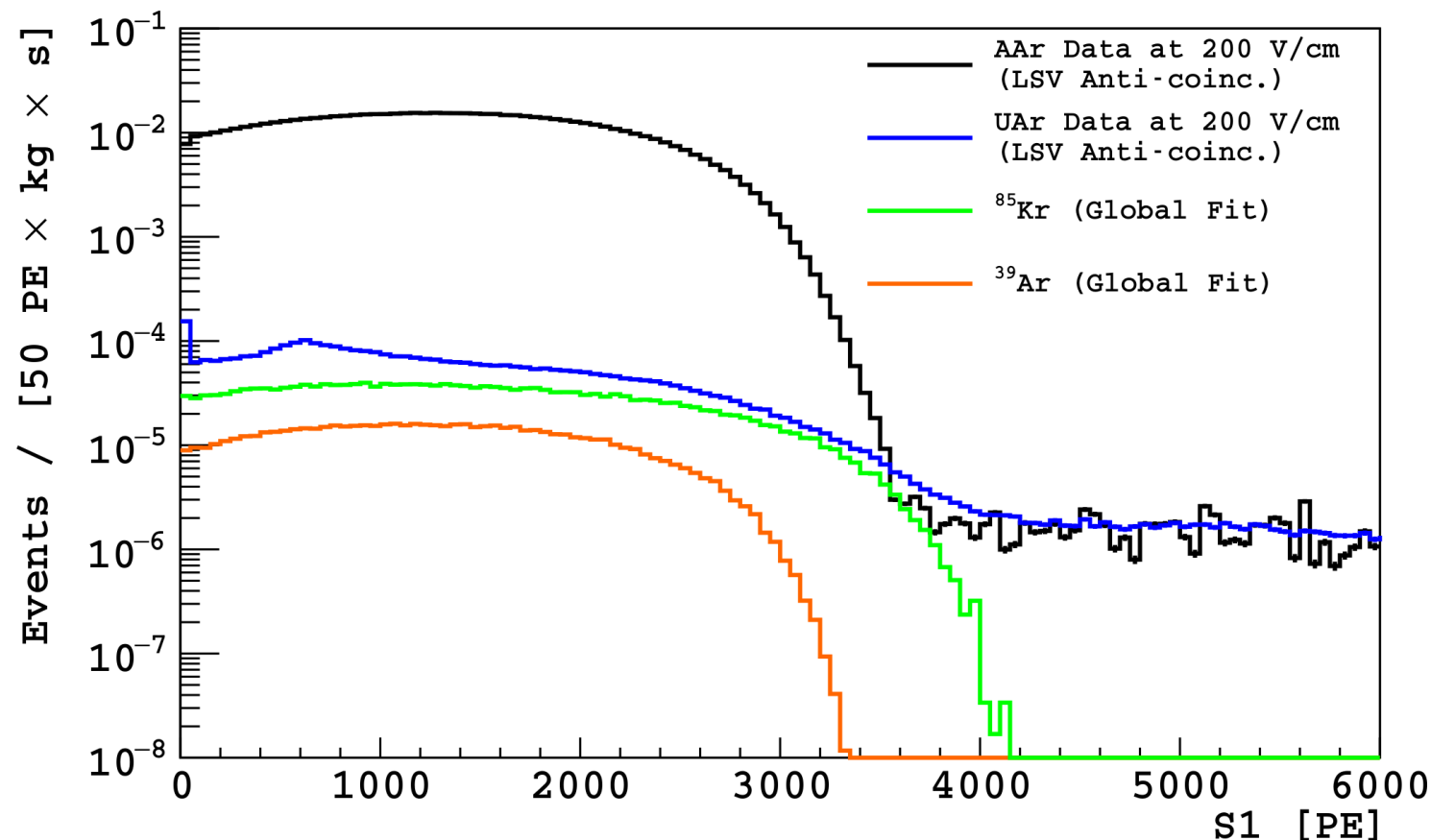


# The Target: UAr



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

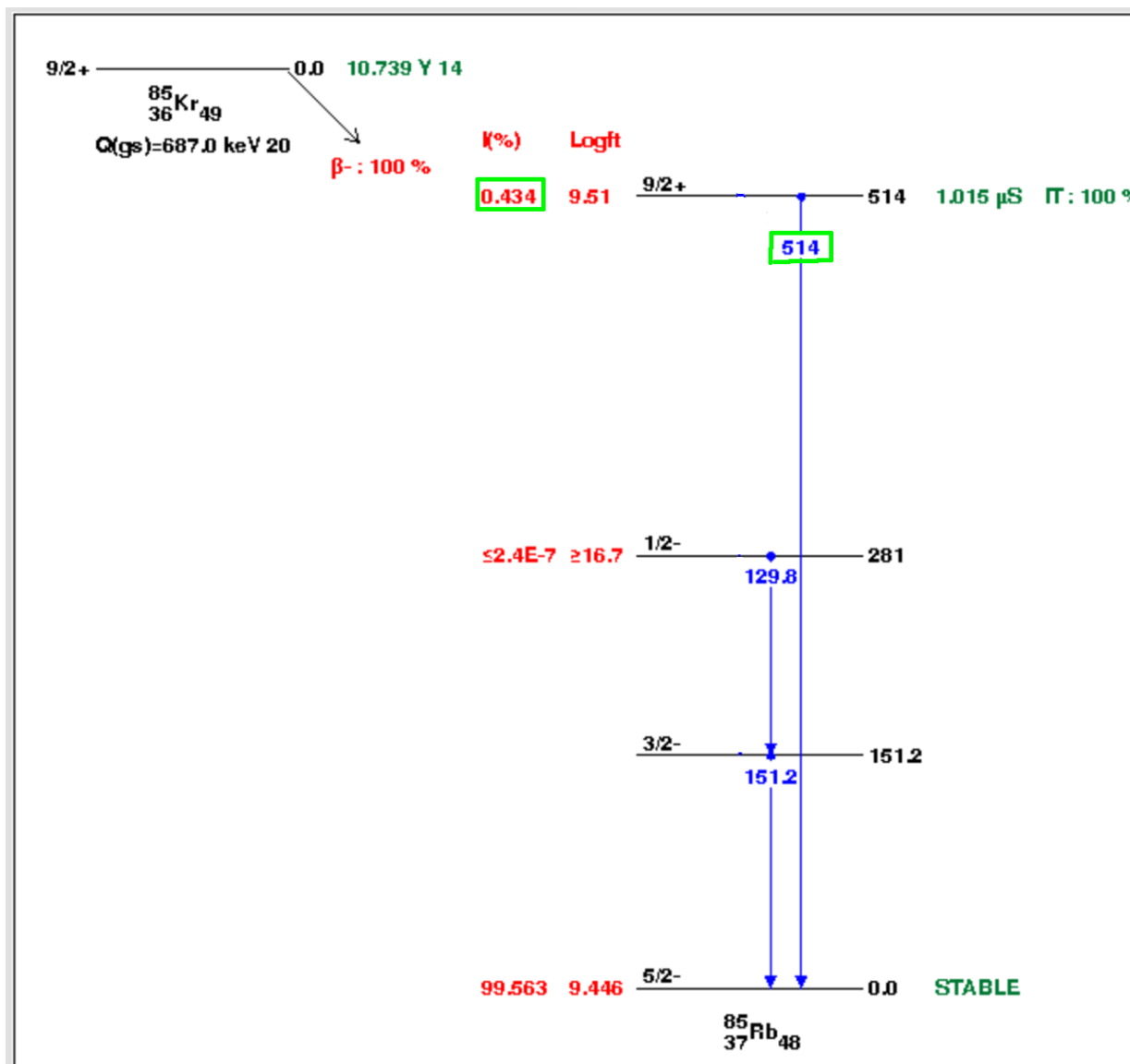
# Discovering the 85-Kr



- “G4DS” (full GEANT4 physics MC) fit to endpoint region of <sup>39</sup>Ar required additional contribution
- <sup>85</sup>Kr suspected from Borexino experience... fit worked with ~2:1 <sup>85</sup>Kr:<sup>39</sup>Ar

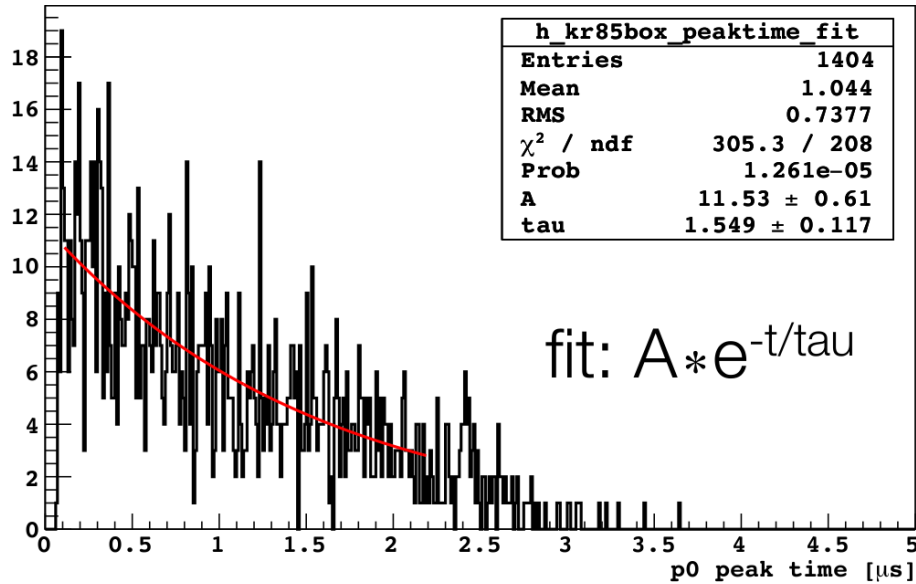


# Confirming the 85-Kr

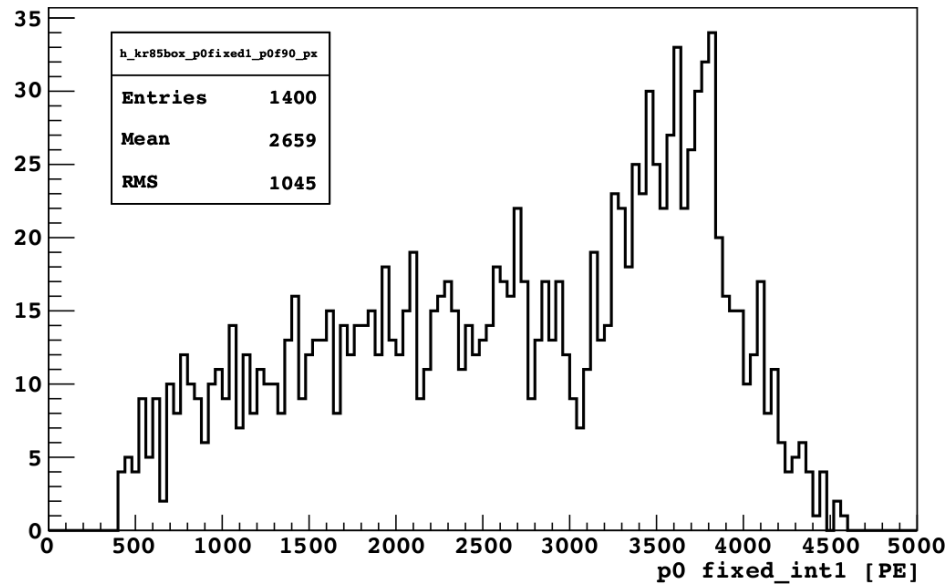


- 0.4%  $\beta$ - $\gamma$  branch via  $^{85\text{m}}\text{Rb}$  (514 keV, 1.0  $\mu\text{s}$ )
- double-S1 signature
- Expected decay rate from G4DS  $\sim 30$ / day
- events were sought and identified at rate expected from G4DS fit!

# Confirming the 85-Kr



Decay time distribution

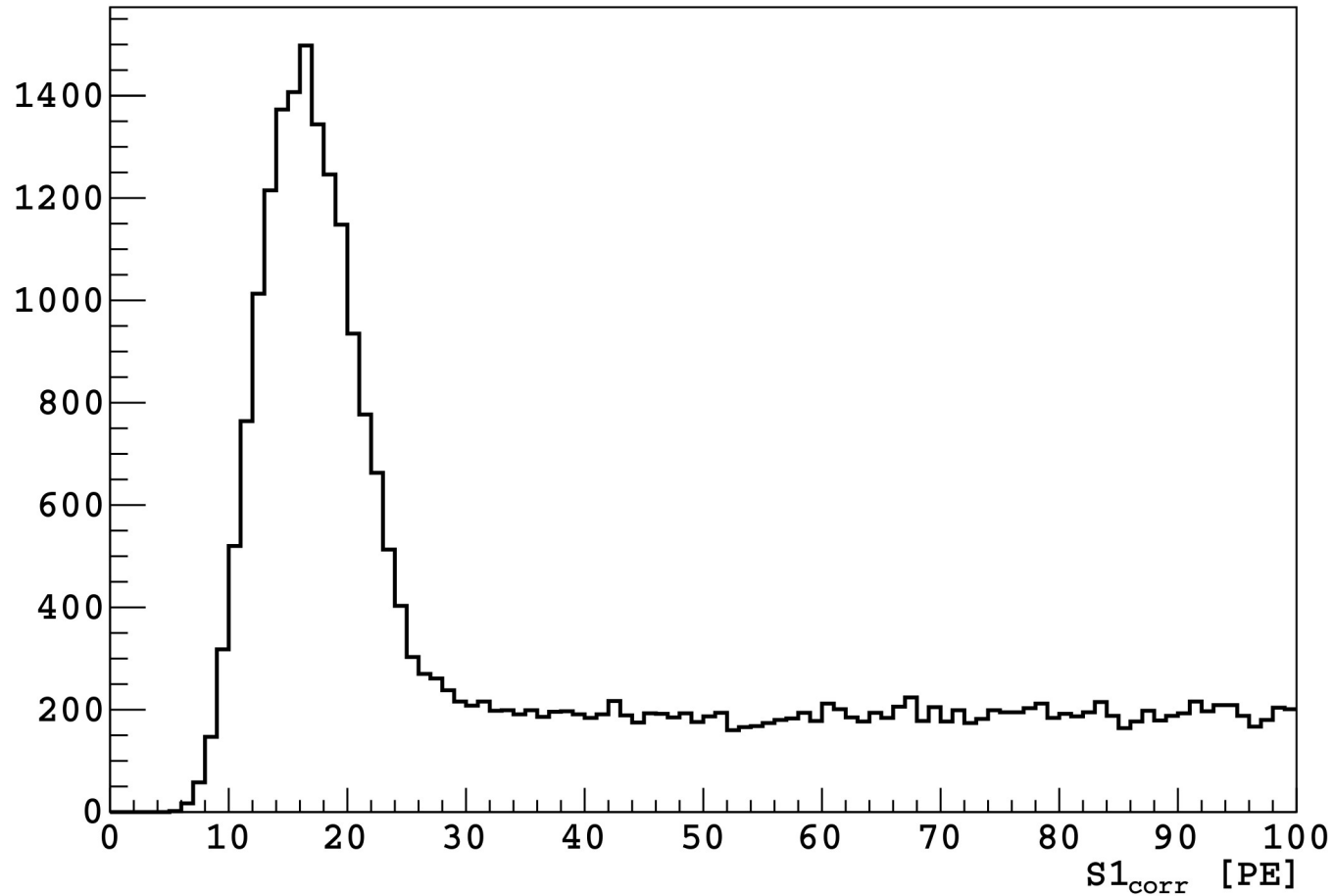


$\beta + \gamma$  energy spectrum

Both agree with G4DS expectations

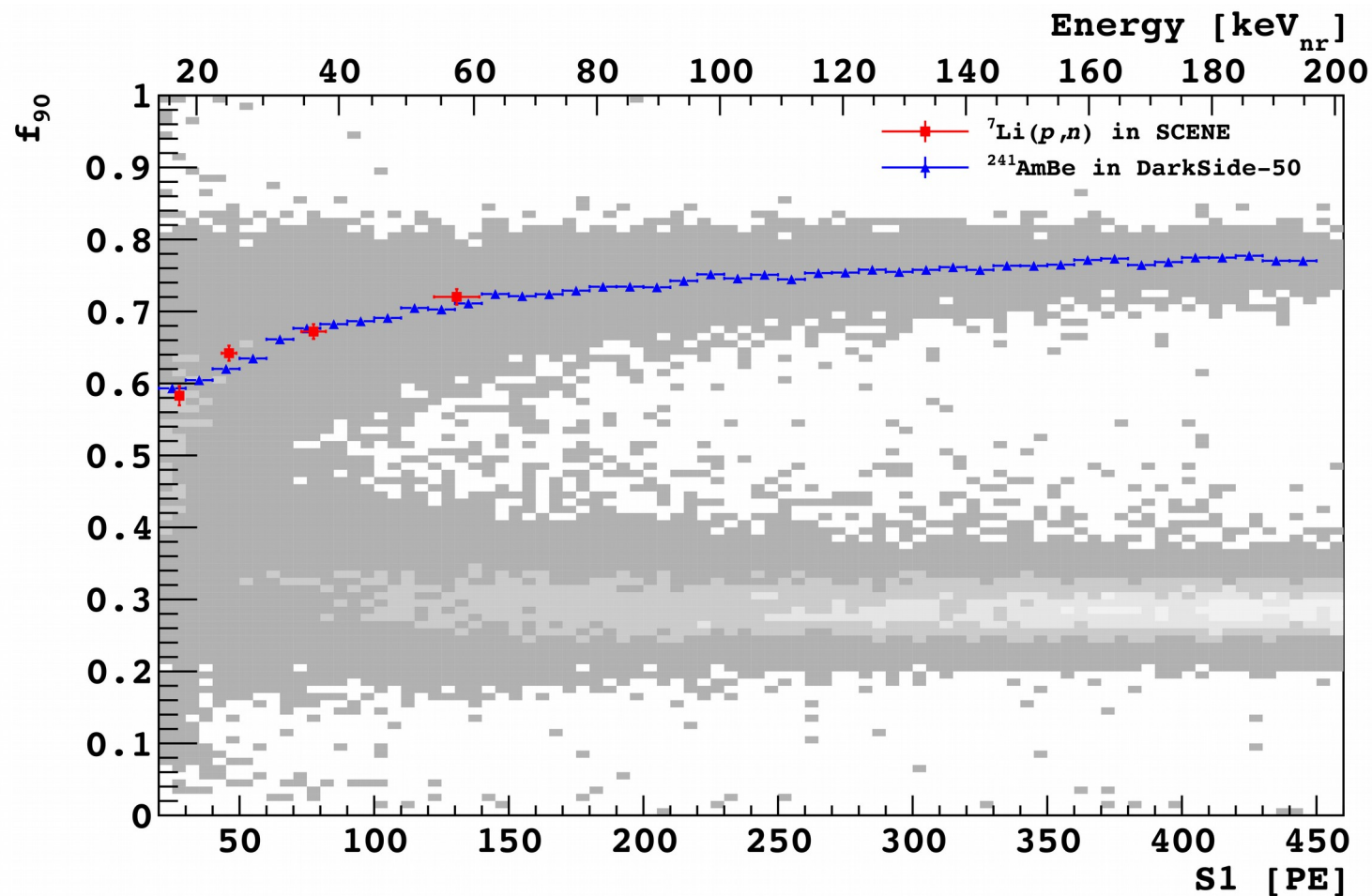


# Sensitivity at low energy



- Just after UAr fill:  $^{37}\text{Ar}$  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



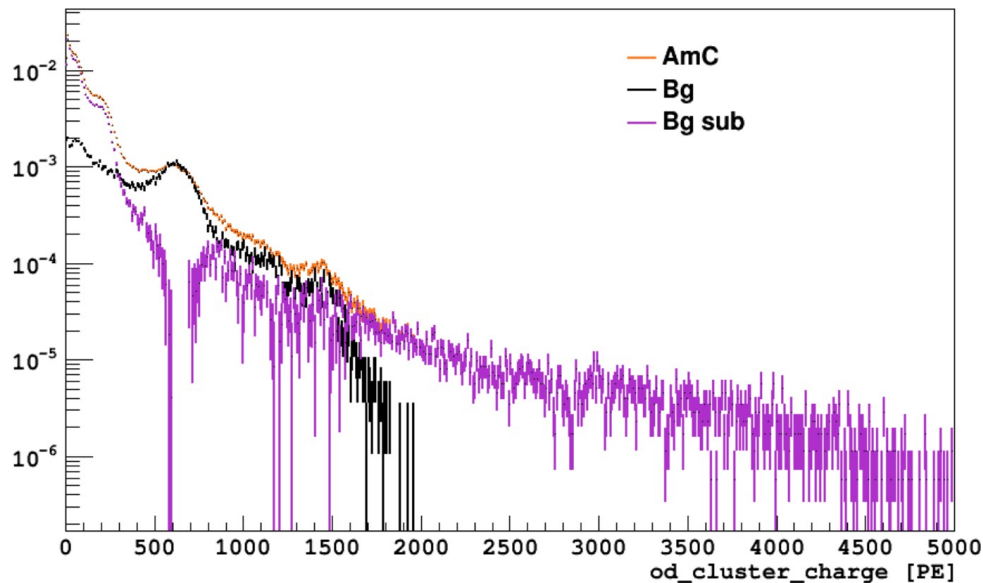
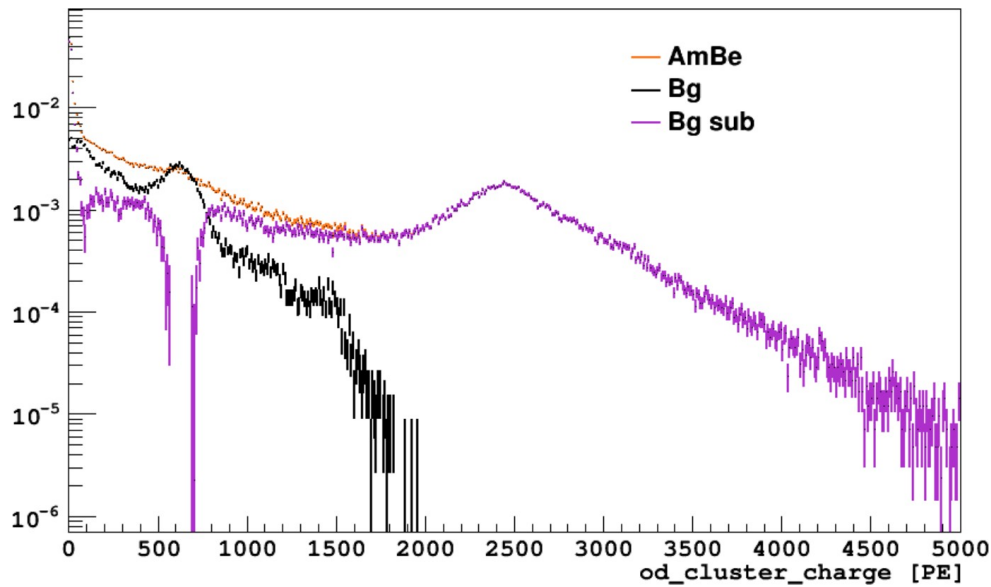
# The Neutron Vetoes



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

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

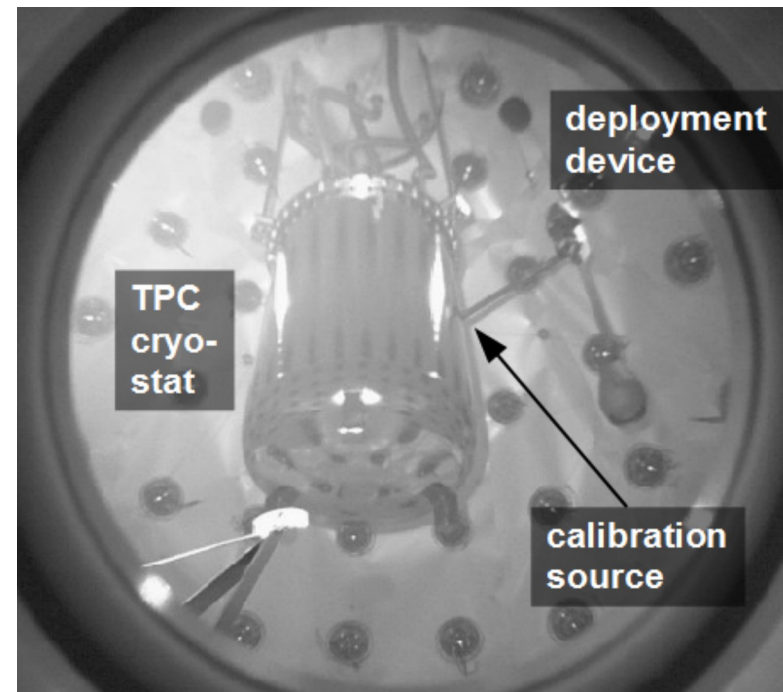
# Newest NR Calibration; AmC



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

- only 59 keV  $\gamma$  coincident with n
- monoenergetic 4 MeV neutrons
- yield per  $\alpha$   $\sim 1/100$  of AmBe
- deployed in DS-50 Dec-January
- for precision veto efficiency study

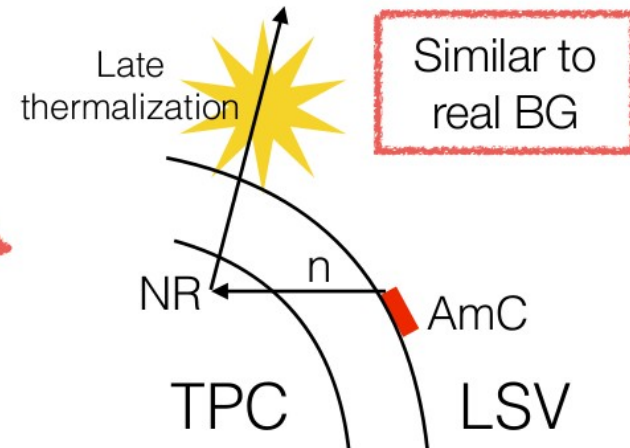
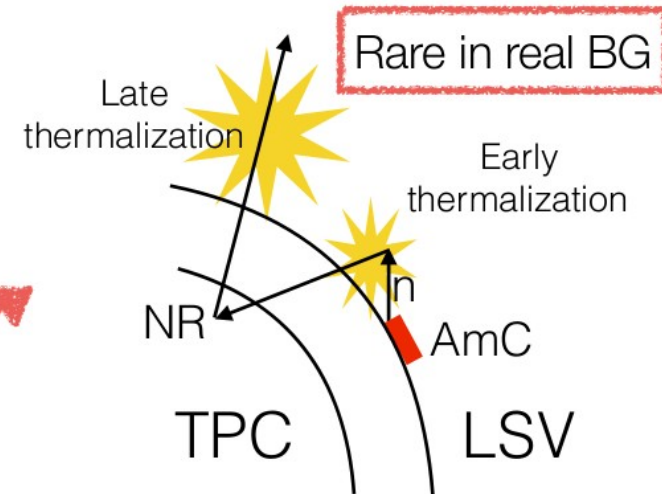
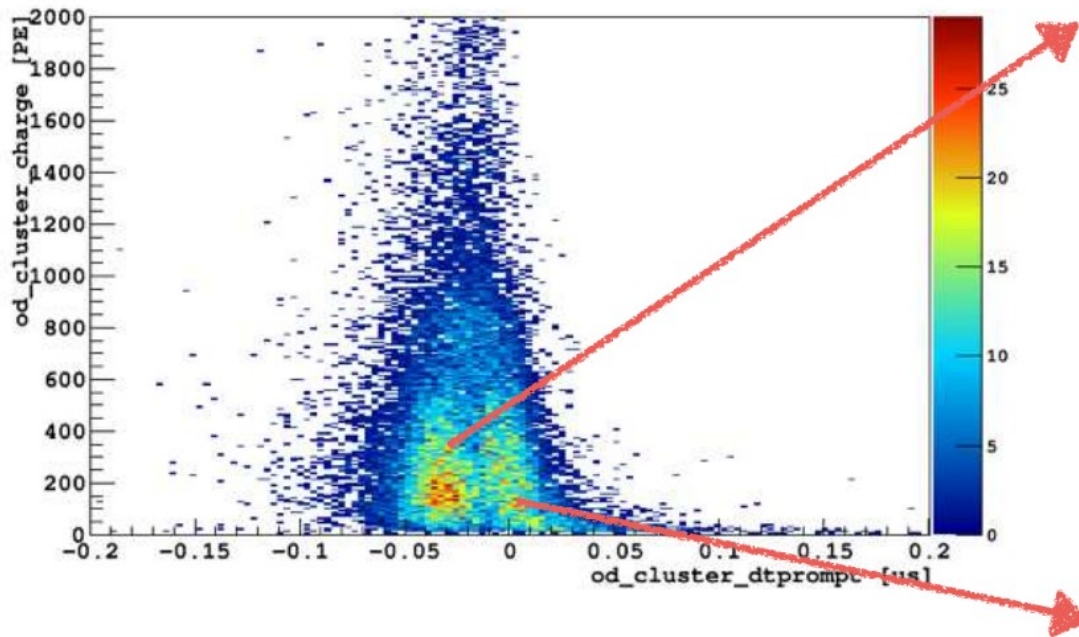
(AmC also developed by Daya Bay)



Mar 7, 2016

DS-50 (C. J. Martoff)  
Lake Louise Winter Institute

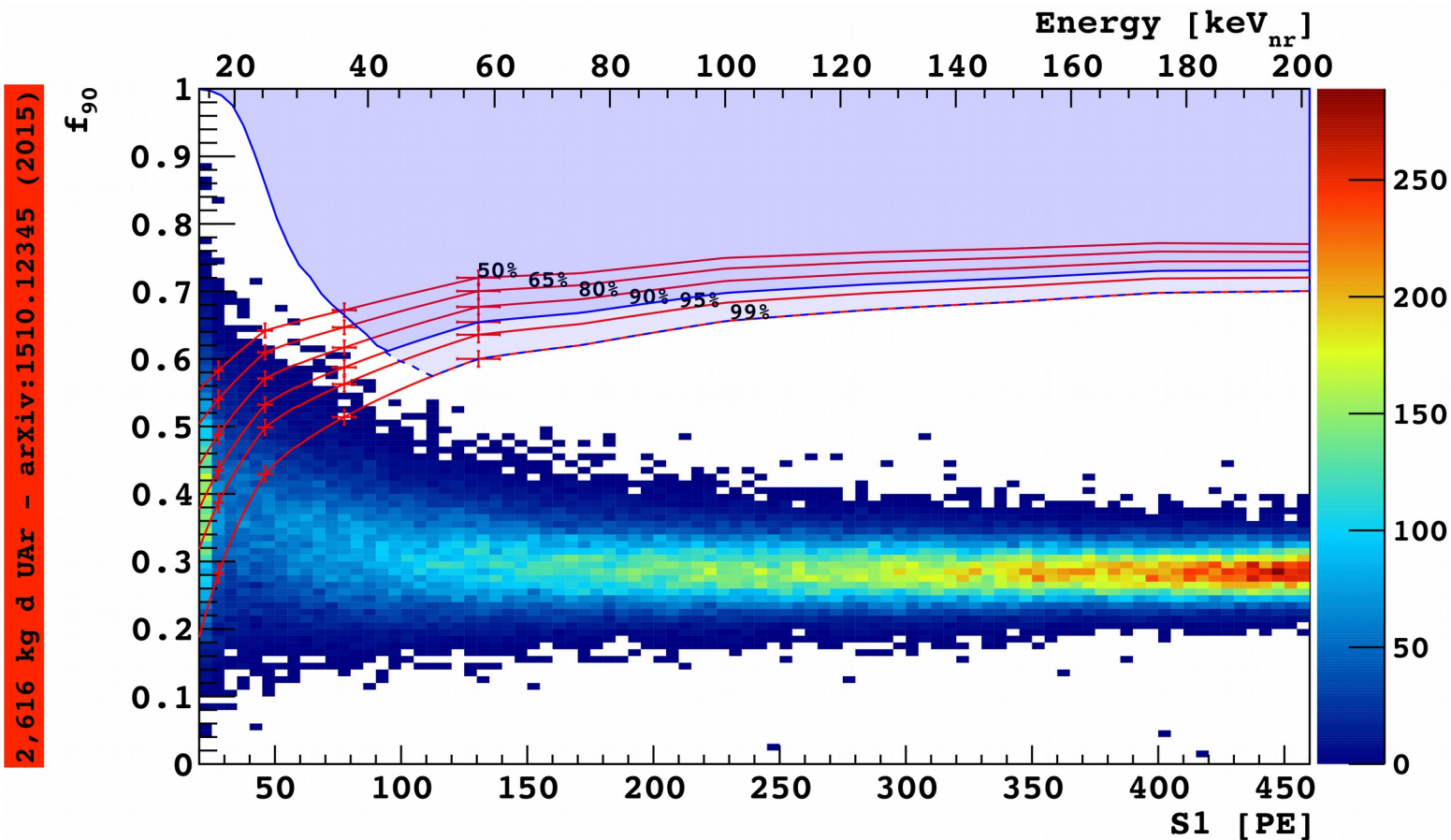
# AmC Self-Tagging Scheme



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

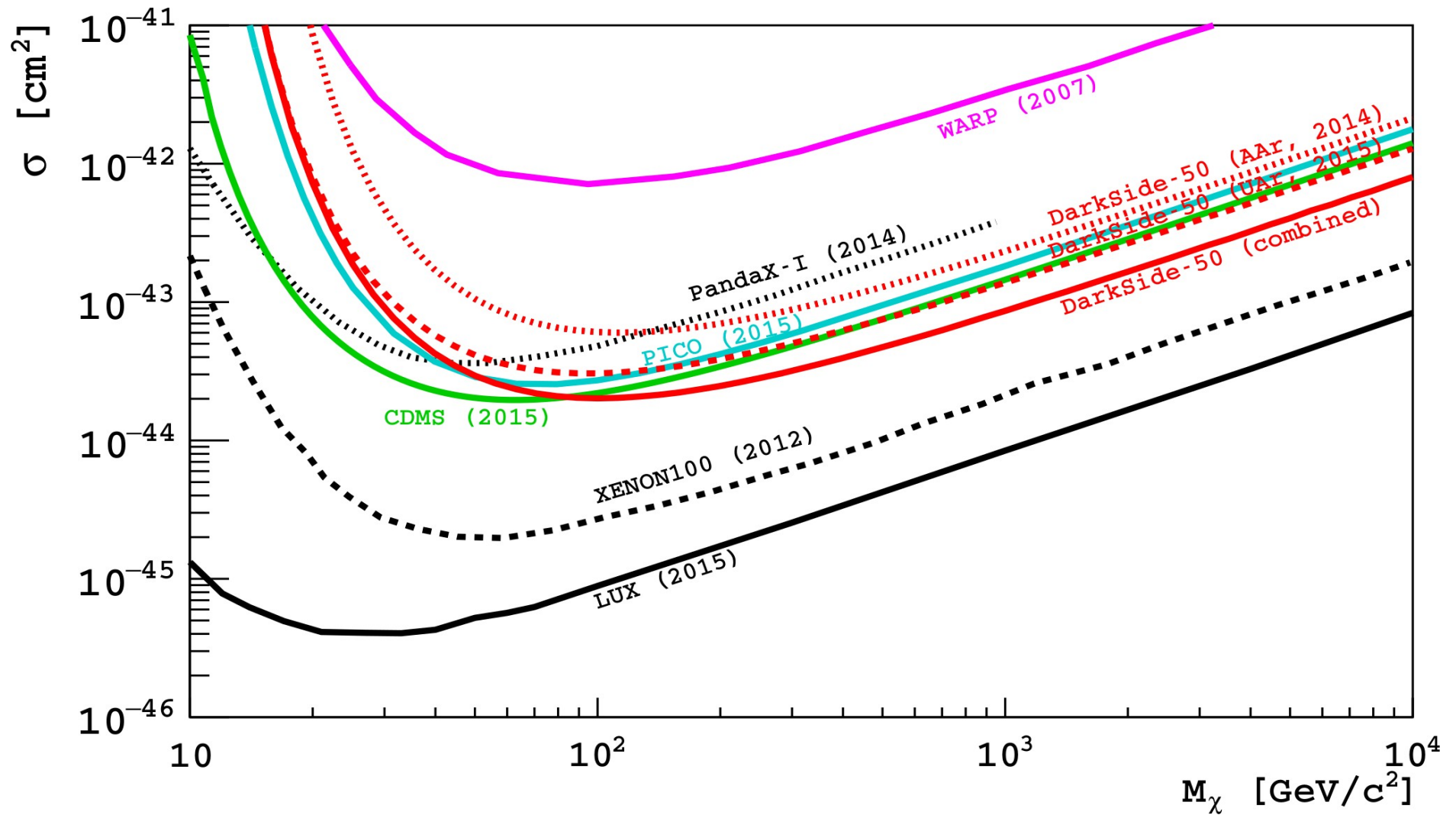


# Background Free UAr Data thru 7/2015



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)

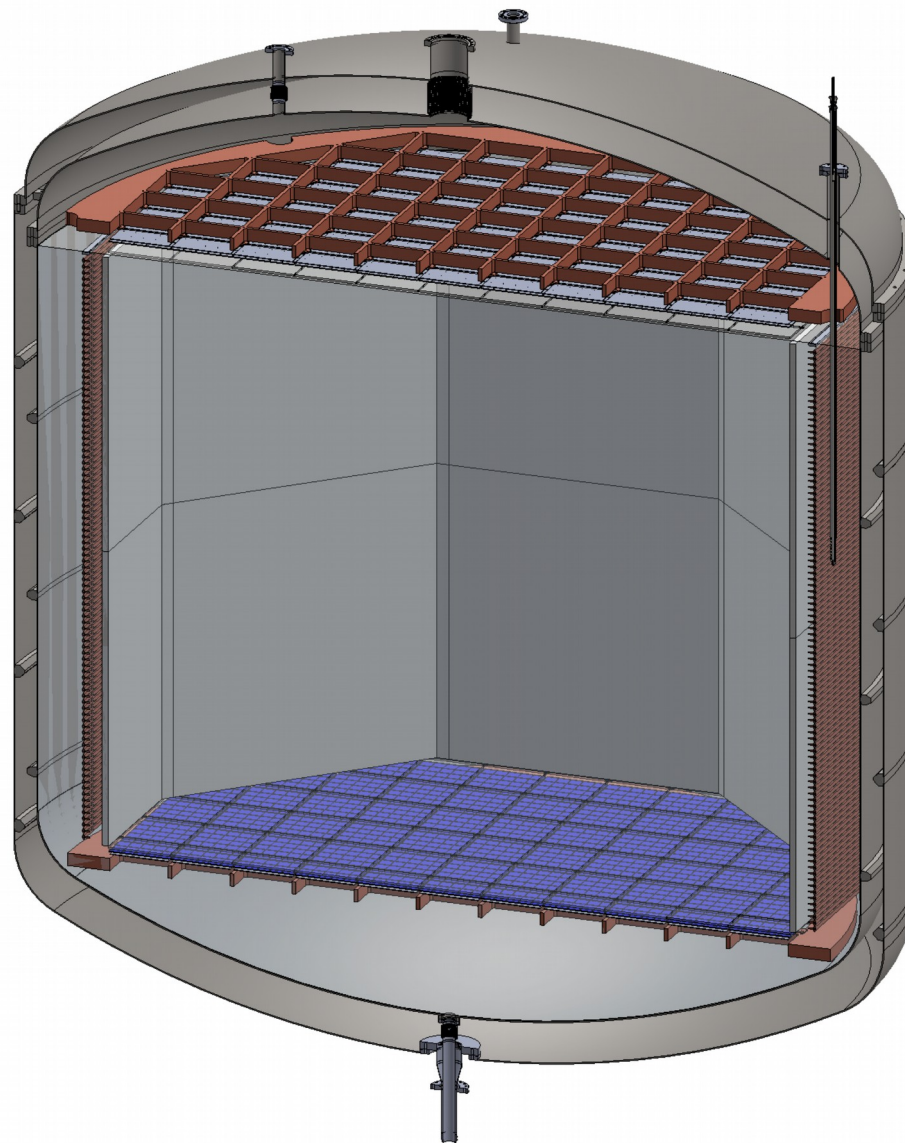


Just over 4000 kg d total, third-best limit at high WIMP mass

# 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
  - $\sigma(\text{WN}) < 10^{-47} \text{ cm}^2$  at 1 TeV/c<sup>2</sup>





# DS-20k Projected Limits

