DarkSide Experiments @ LNGS

Direct DM Search Using Underground Argon

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for the DarkSide Collaboration

SPC2014 @ SJTU, Shanghai
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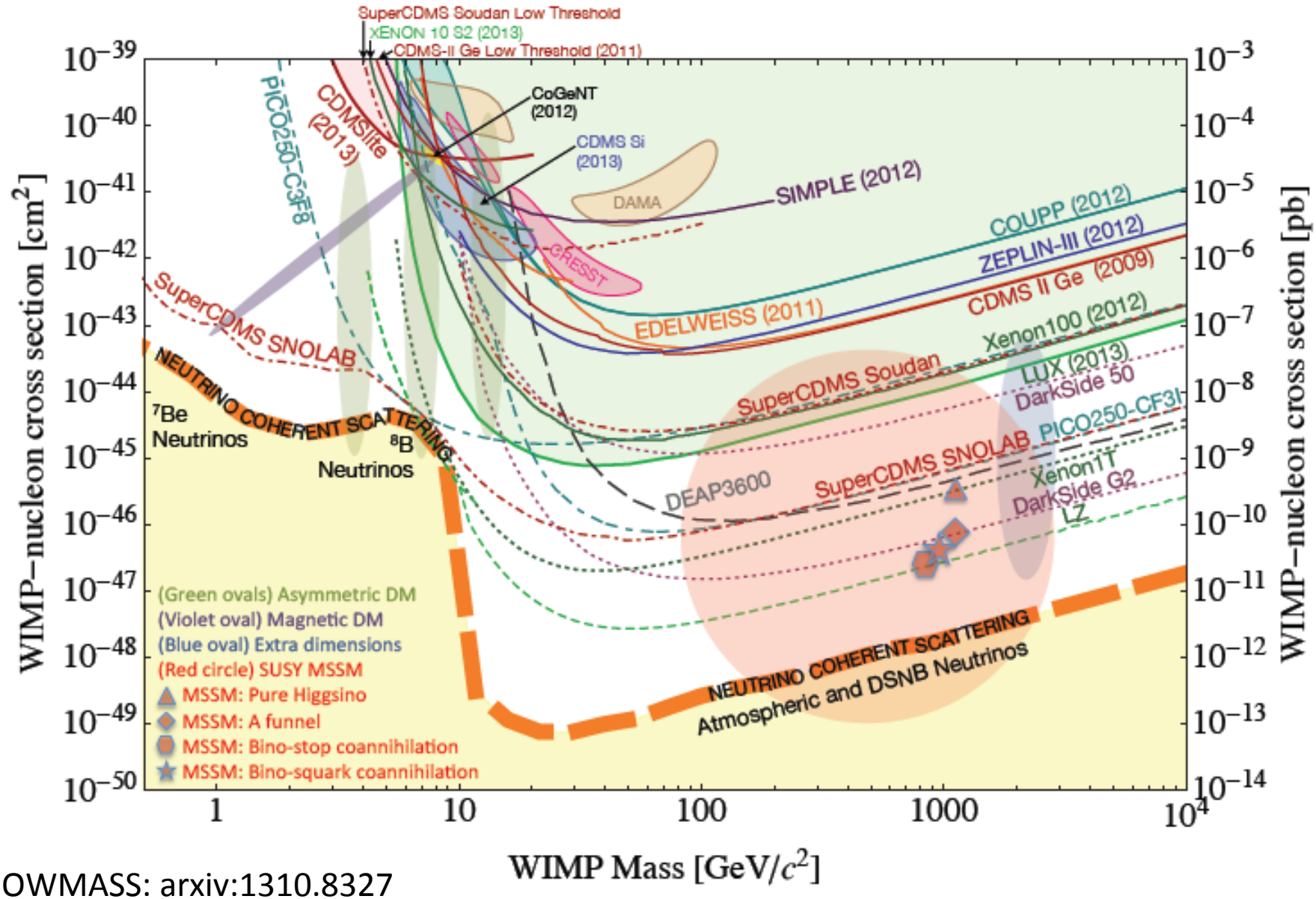
WIMPs Signal and Background

- Signal:
  - Low Energy Nuclear Recoils (1 – 100 keV)
  - Low Rate (~ few counts/year/ton at 10^{-47} cm^2)
  - No Specific Features in Recoils Spectrum
- Background:
  - Dominated by Electron Recoils (ER) from e, γ Radioactivity
  - Nuclear Recoils (NR) from Radiogenic Neutrons
  - Solar neutrinos (for G3 Detector):
    - ✓ Elastic Scattering interactions will limit the sensitivity depending on the ER rejection power of the experiment
    - ✓ Neutrino-nucleus coherent interactions sets the limiting sensitivity

DarkSide 50 and G2 Sensitivity

Achieve sensitivity of $\sigma \sim 2 \times 10^{-47}$ cm^2 in 18 ton-year



SNOWMASS: arxiv:1310.8327

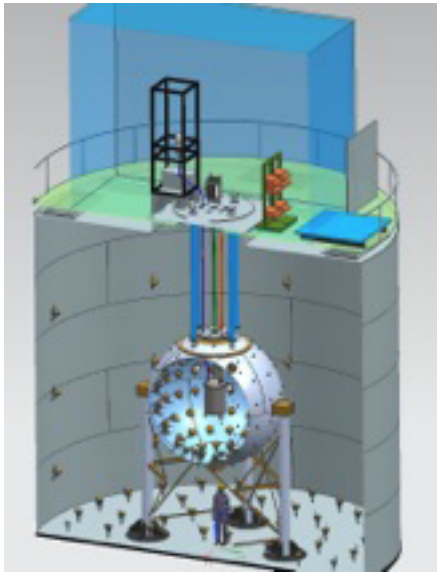
Why Use UAr for Direct Dark Matter?

- Good Intrinsic Scintillator: 40 ph/keVee; (128nm VUV)
  - VUV can be wave-shifted with 4-pi TPB and light yield of ~8 pe/keVee achieved
- Powerful PSD in Scintillation Signal (~ 10^7 – 10^{11})
  - Separates ER background from WIMP induced NR Signal.
- Simple Cryogenic and Gas Handling System with Inline Filter
- Can be Highly Purified for Long Electron Drift
- Good Ionization Detector for TPC (supplement S1 PSD)
  - Well Defined Fiducial Volume.
  - Additional S2/S1 Discrimination (~ 10^2).
- Easily Scalable to Large Masses.
- Underground Argon (UAr) has low ^{39}Ar (< 6.5 mBq/kg)

DarkSide Background Rejection Strategy

- Screening and selection of detector materials
- **Two-Phase Ar TPC**: 3D-**TPC** fiducialization**; S1** PSD, **S2/S1 cut**
- **Active Neutron veto** based on a boron-loaded liquid scintillator detector
- Underground argon (**UAr**) with reduced (> 150) cosmogenic ^{39}Ar
- Large Shield: **Water Cherenkov Detector (**muon veto**)**
- **LNGS:** Deep Underground site to shield Cosmic Rays

LNGS, Italy (3400 mwe)



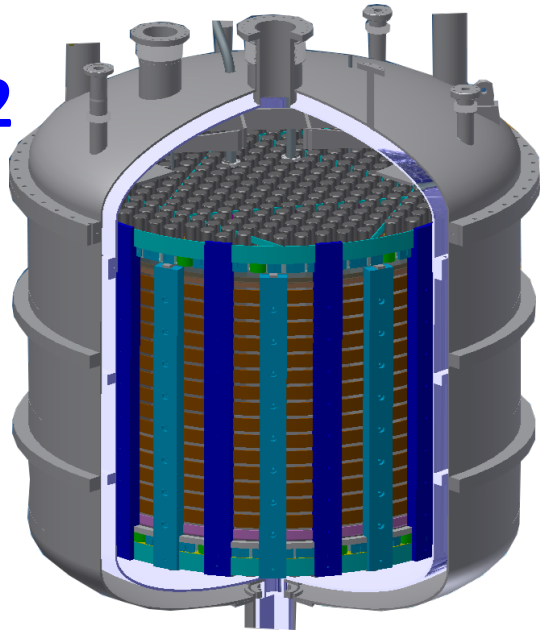
11m x 10m Water tank

2-Phase TPC

4m diameter spherical n-veto

The Staged DarkSide Projects @ LNGS

DS G2



- DarkSide-10 (2010-2012) Prototype, Princeton & LNGS runs;
- DarkSide-50 (2013-2016) G1 detector with sensitivity 10^{-45}cm^2;
- DarkSide-G2 (from 2016) 5 tons detector with sensitivity 10^{-47}cm^2
- And Beyond

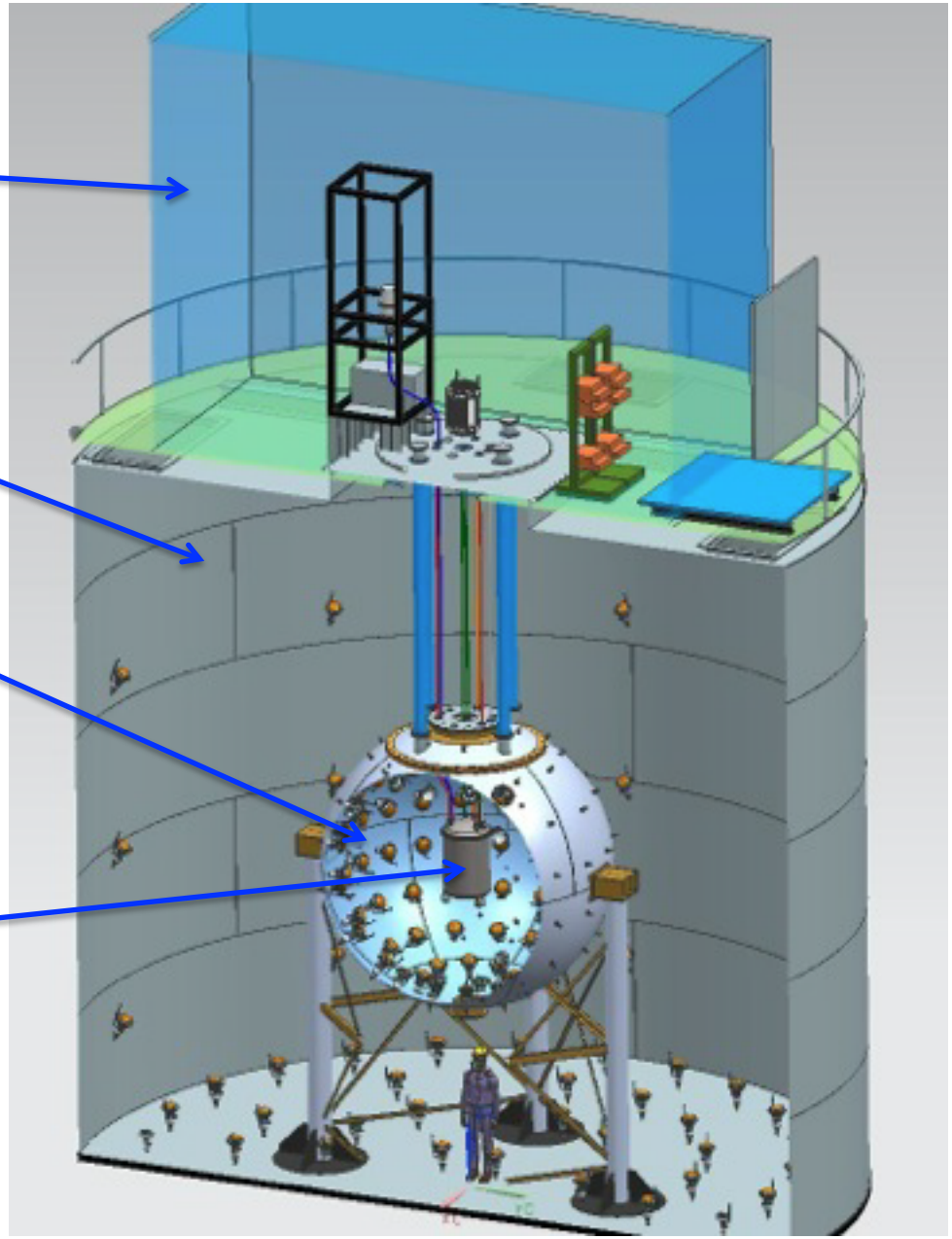
DS Facilities @ LNGS

Rn-free clean rooms
(10-15 mBq/m^3 in 110 m^3) Used for assembling TPC and deployment

Water Cherenkov muon veto:
10^3 m^3 H_2O with 76/80 8" PMTs

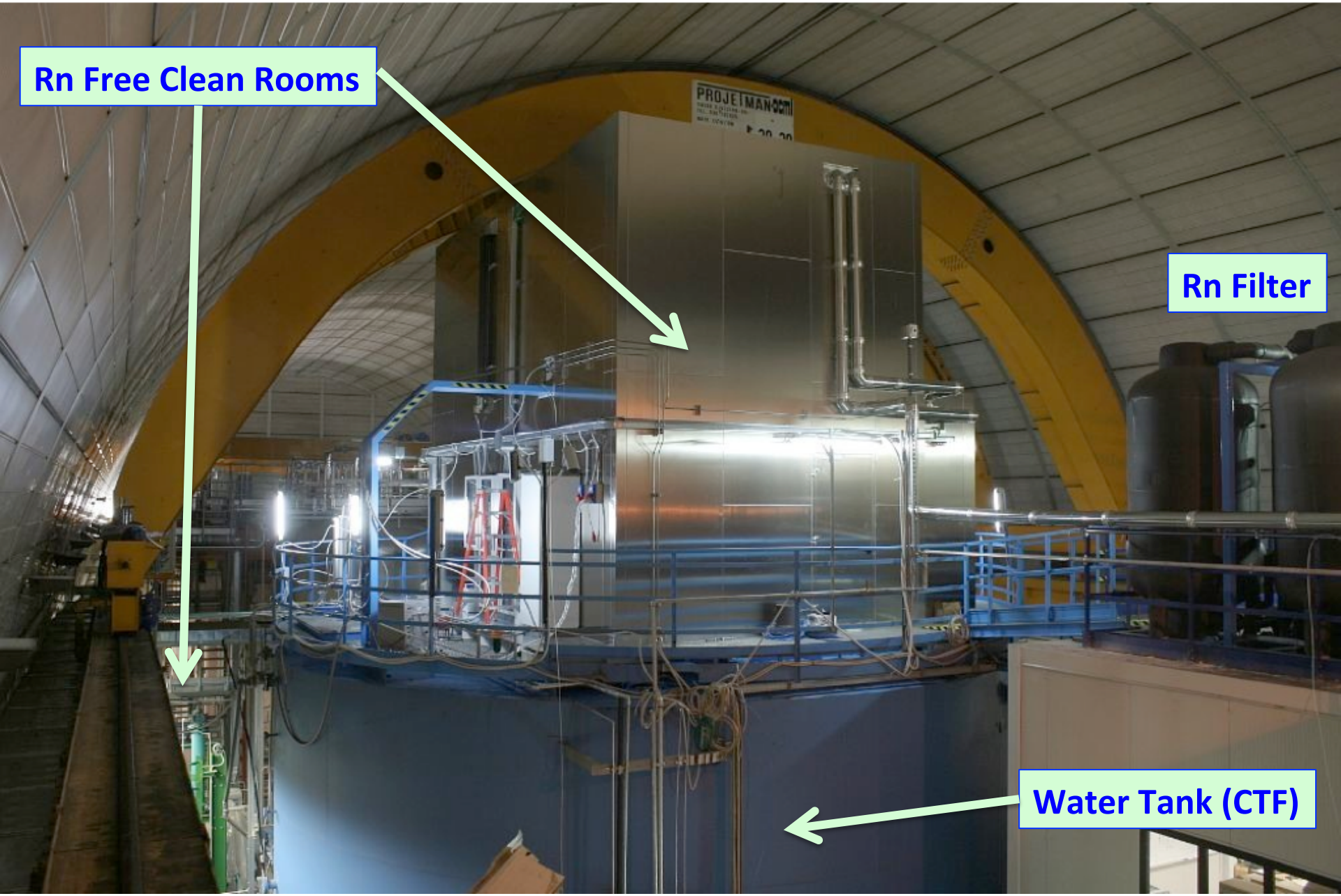
Boron-loaded liquid scintillator
(50% TMB + 50% PC) as neutron veto with 108/110 8" PMTs

150kg Ar Two-Phase TPC
Two x 19 3" PMTs arrays,
Presently using AAr, (1Bq/kg ^{39}Ar),
Will use UAr (6.5 mBq/kg ^{39}Ar)

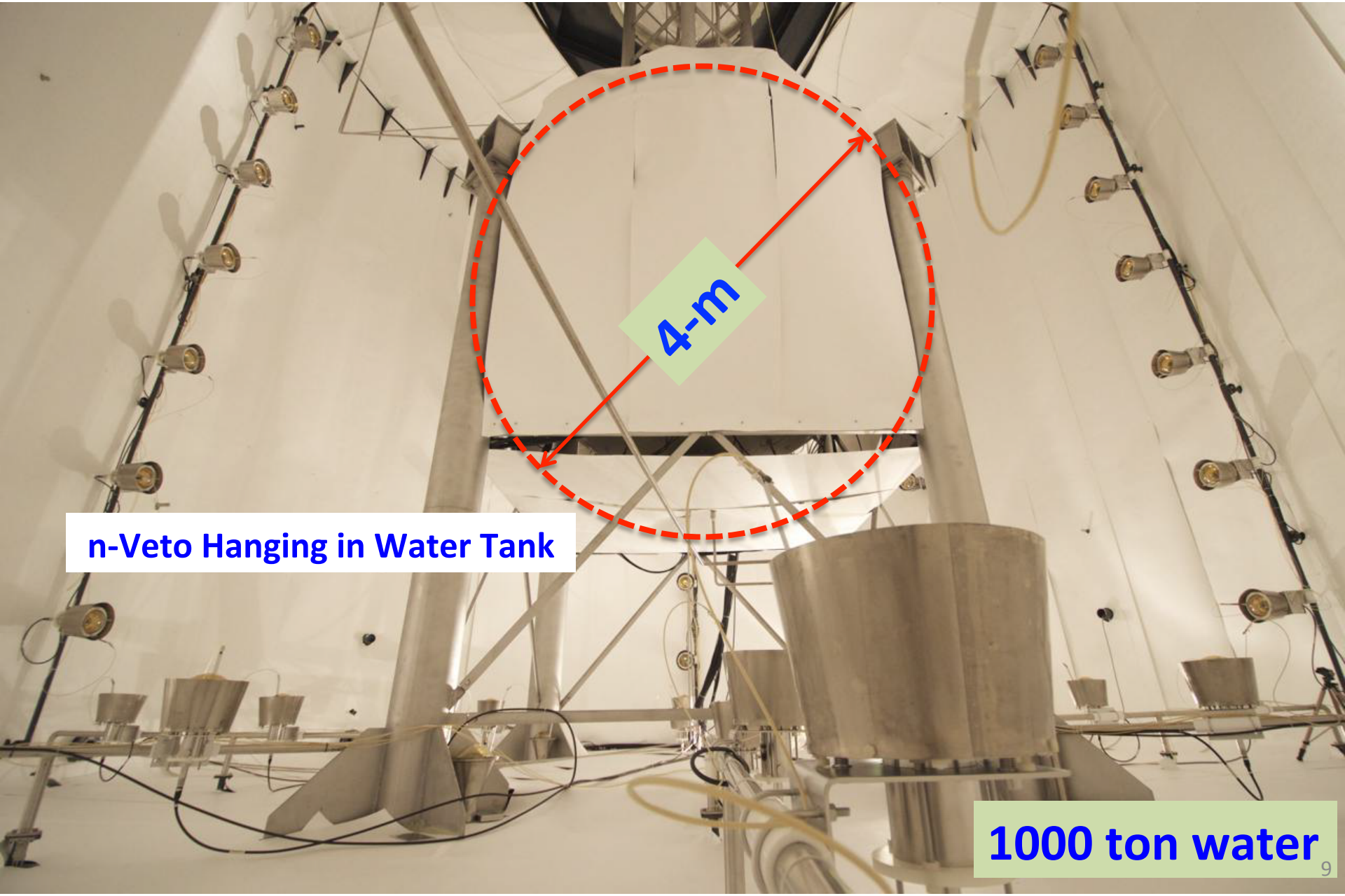


- **High Purity Water processing plant**
- **LS processing plant**
- **LN2 source Storage & delivery system**

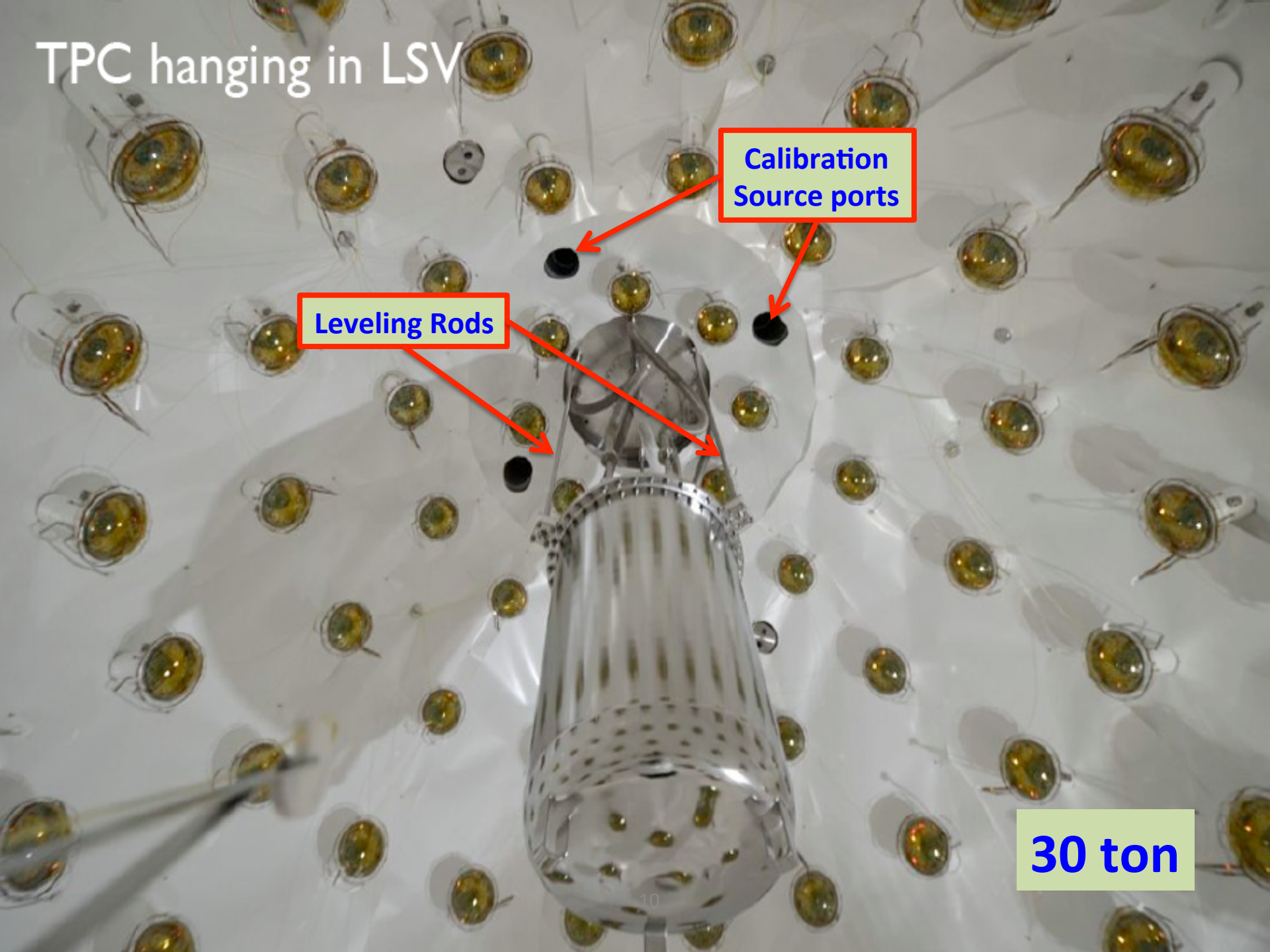
DarkSide 50 and G2 at LNGS, Hall C



Liquid Scintillator Sphere for n-Veto



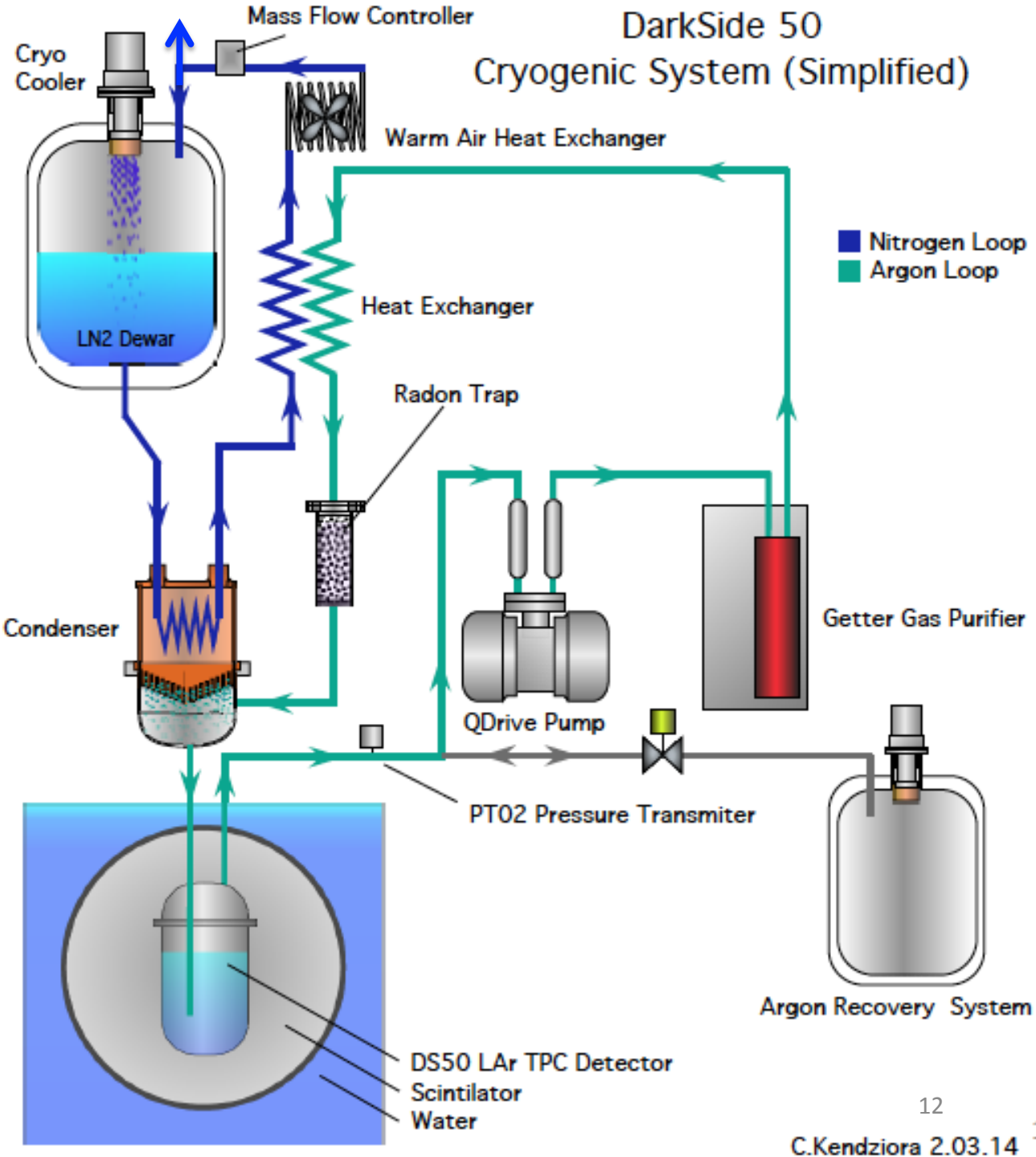
TPC hanging in LSV



PMTs with
Cold-Amps in LAr
R11065 PMTs
PMT Gain = 3 x 10^5
PMT HV ~ 1200 V
Noise 3 μV on 200 MHz
DS50 TPC

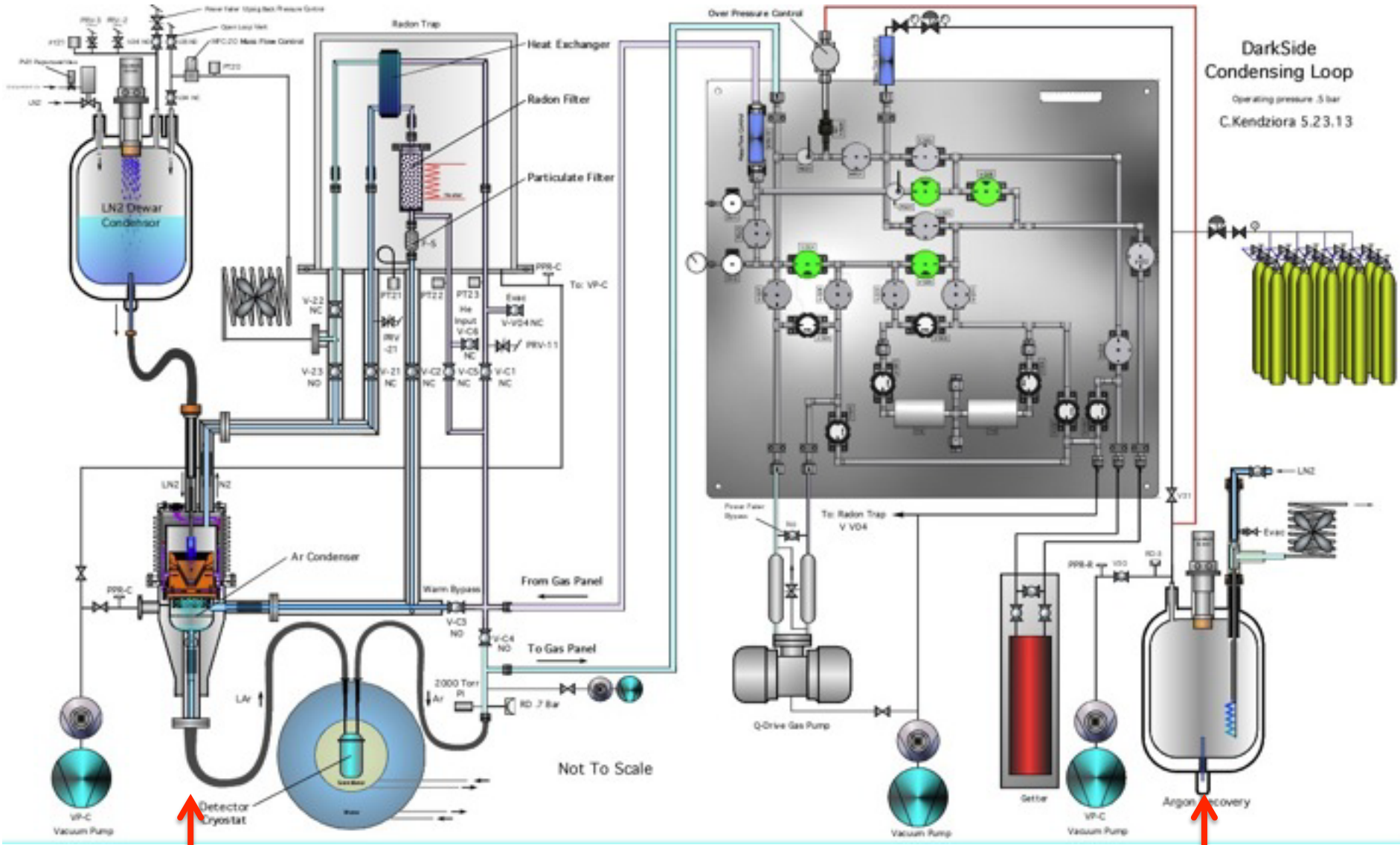
Cryogenics & Gas Handling With N2 & Ar Closed Loops

- Gravity feed LN2 loop to Cool down the Ar
- N2 return gas to pre-cool the incoming Ar gas
- Ar condenser liquefies the pre-cooled Ar gas
- Cryogenic LAr transfer line delivers clean LAr to the TPC
- Ar return Gas gets purified and sent back to the detector



C.Kendziora 2.03.14

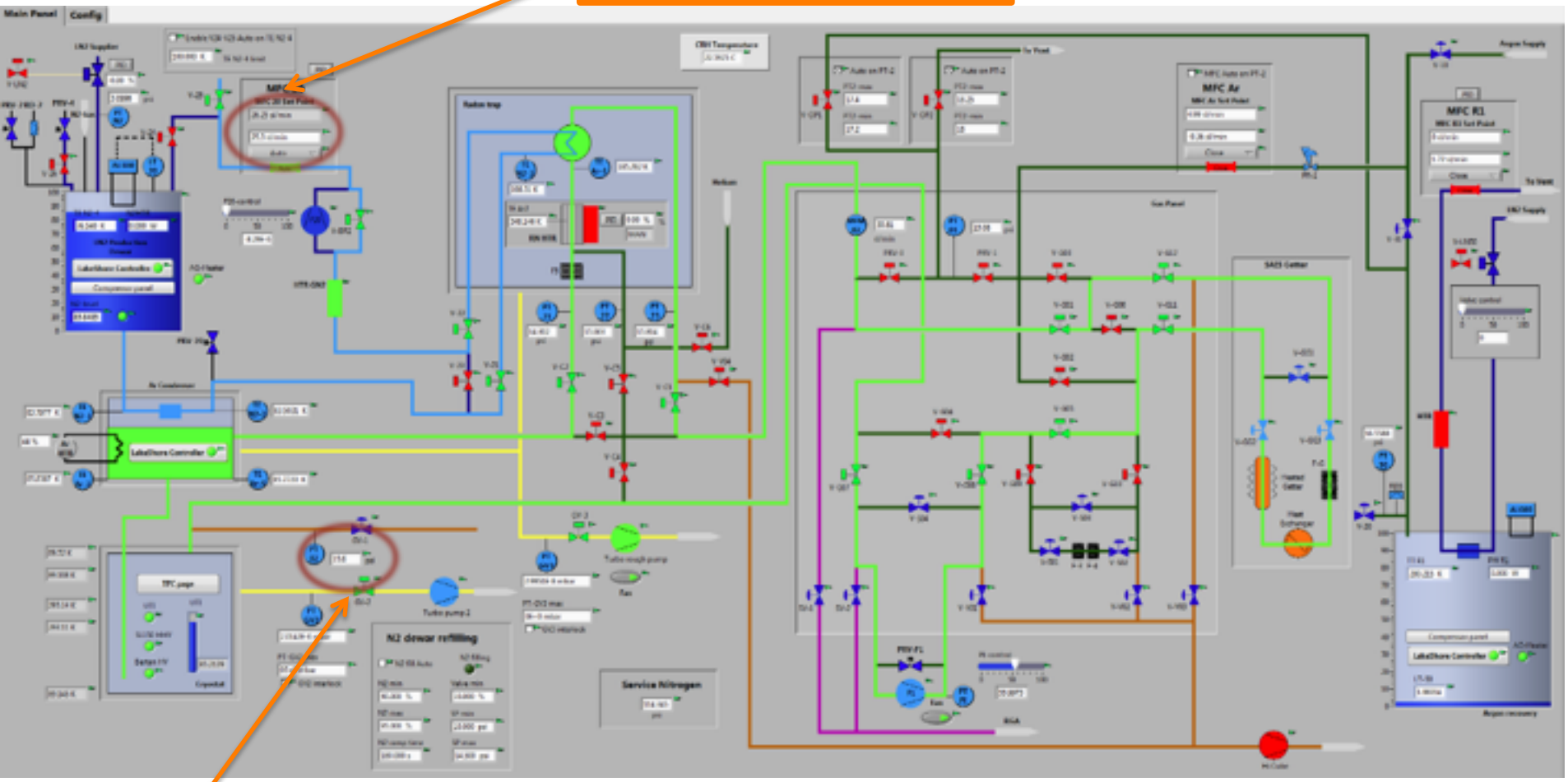
DarkSide 50 Cryogenics and Gas Handling P&ID



Upgrade Condenser and Recovery for G2 with the Rest Unchanged

Cryogenics & Gas Handling System Slow Control Screen Shot

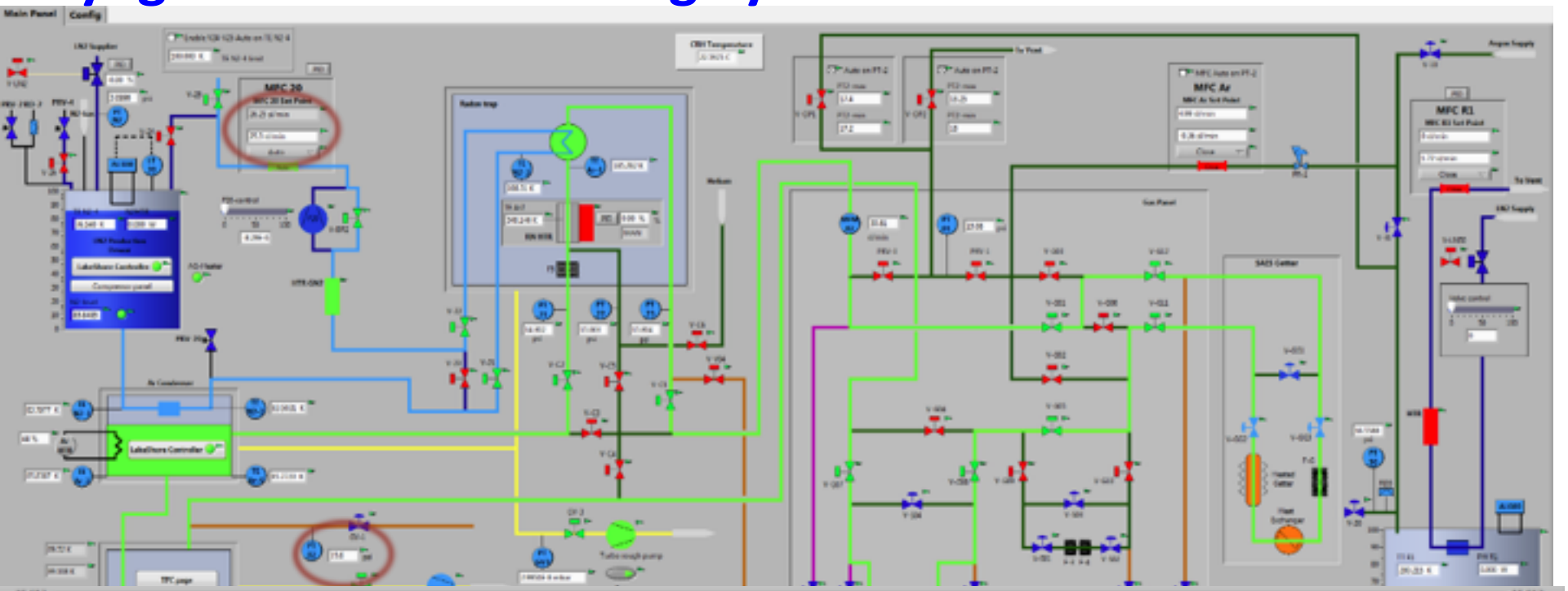
Cooling N2 Flow Control

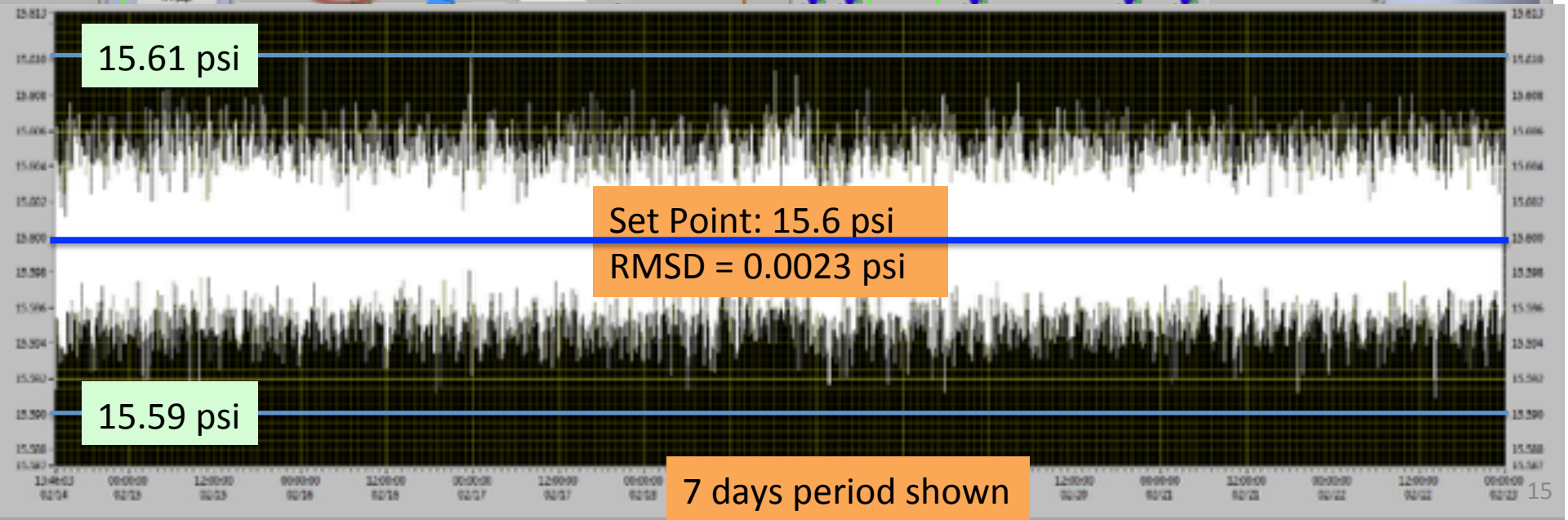


System Pressure

(System-P) => PID => (N2 Flow)

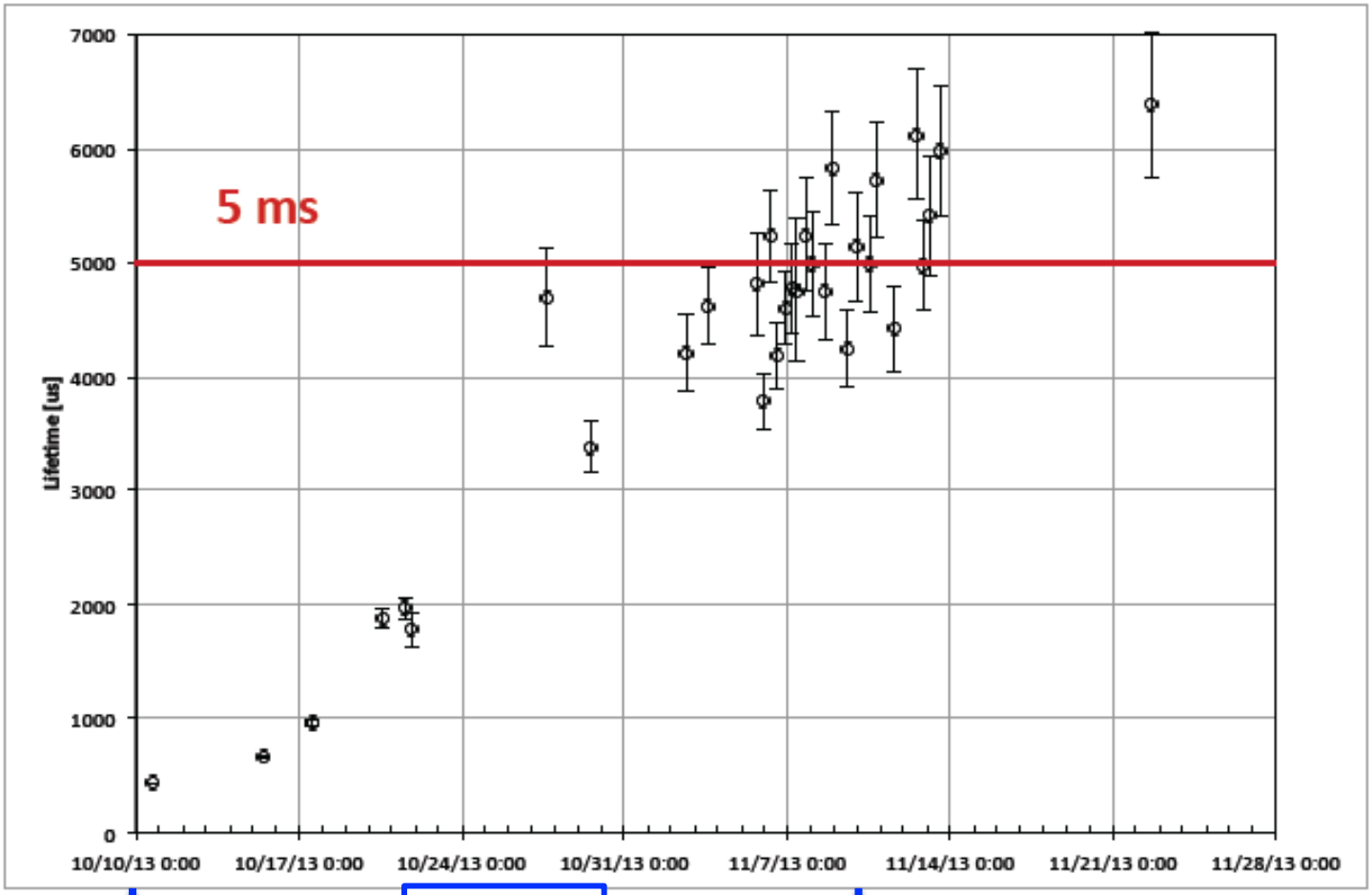
Cryogenics & Gas Handling System Slow Control Screen Shot





Electron Lifetime (Argon purity)

- Gas Phase Purification (30slm).
- Standard SAES Getter For Oxygen & Nitrogen Impurities.
- Charcoal Filter To Remove Radon.
- **>5 ms to compare with max drift time of ~ 400 μs**



1-month

DarkSide-50 TPC

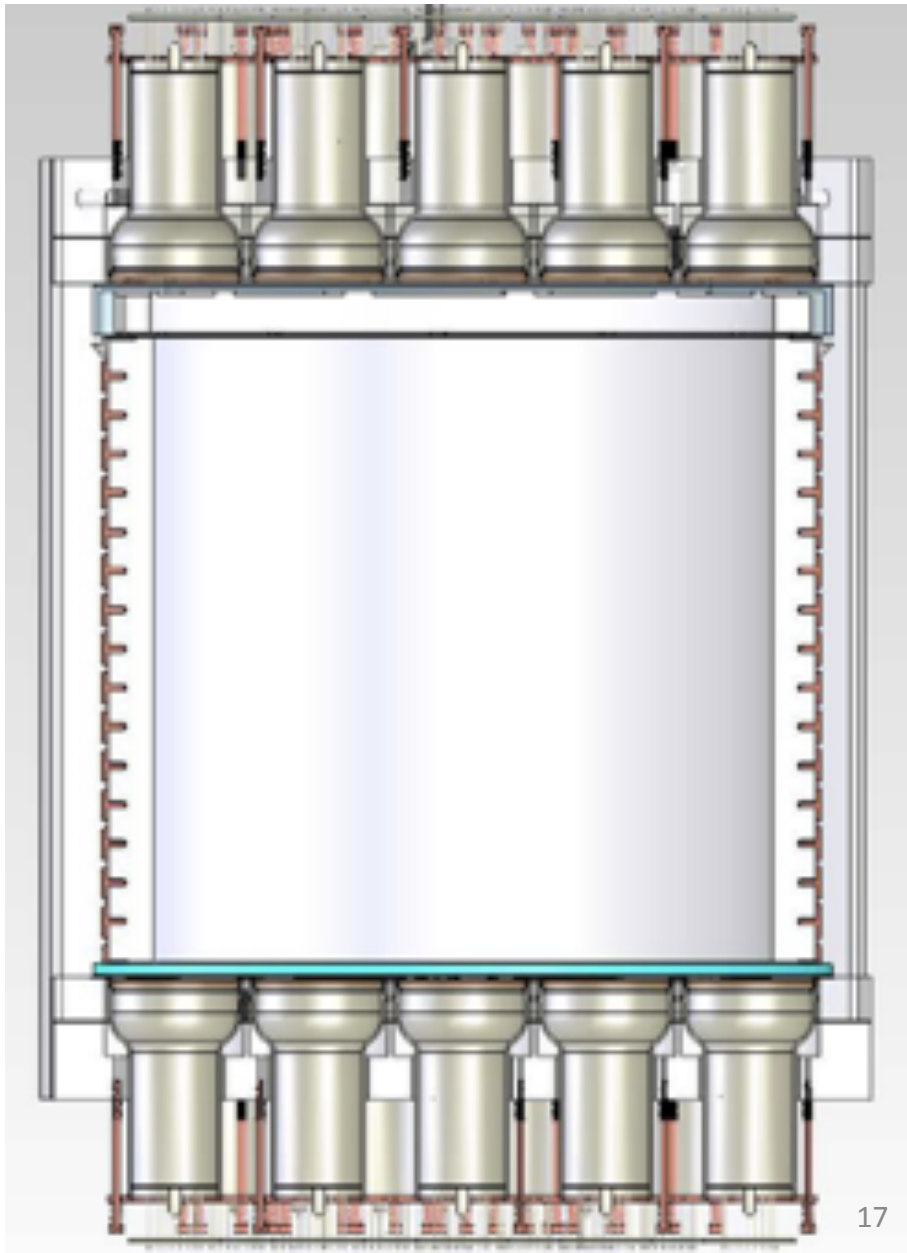
PTFE Cylinder:
h=36cm, d= 36cm, inner surface is coated with Tetra Phenyl Butadiene (wavelength shifter)
46kg (44kg fiducial)

38 3" Hamamatsu PMTs;
R11065: 19(top) + 19(bottom)
Cold Amplifier (low PMT HV)

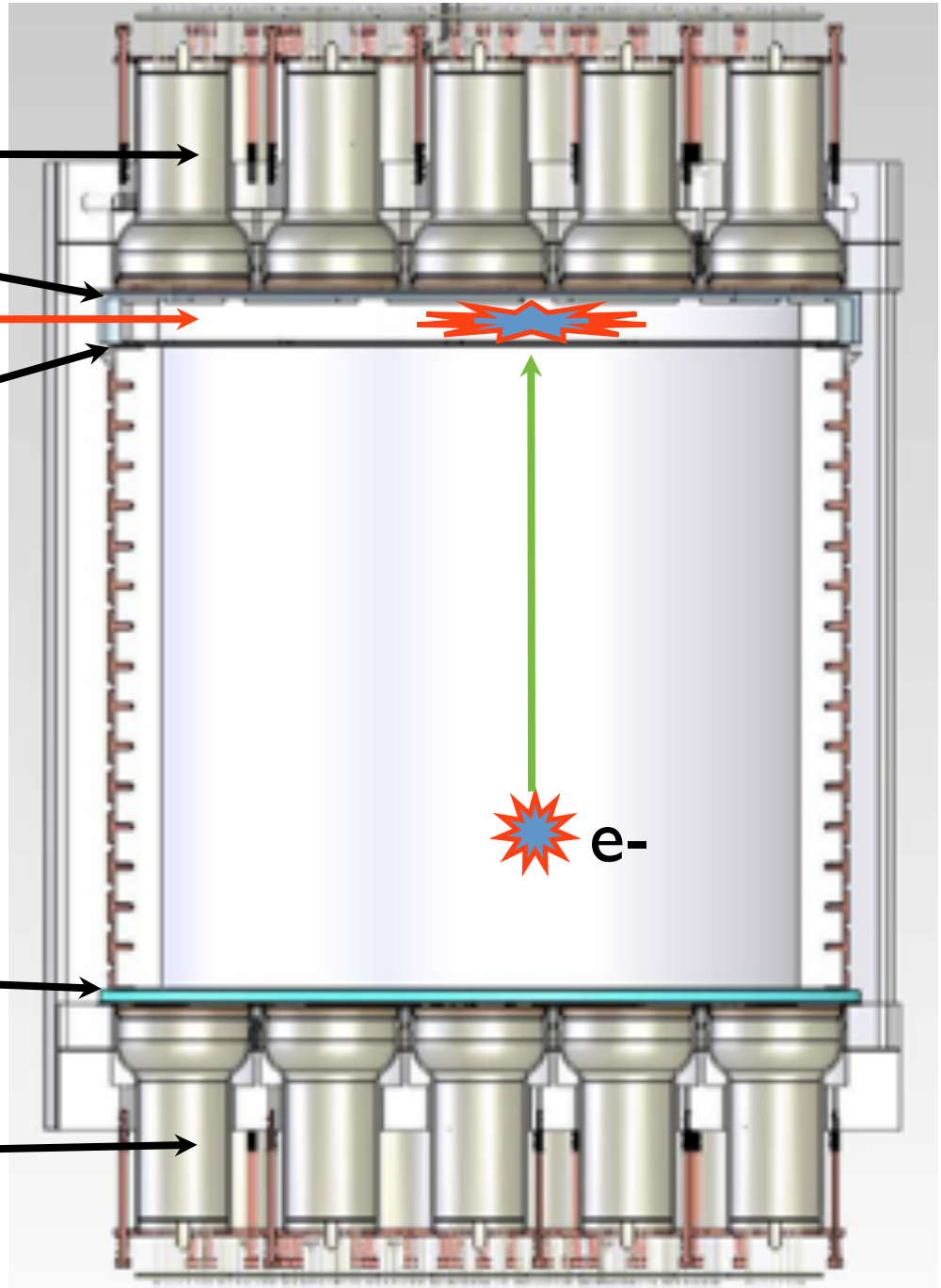
Field Shaping Copper Rings (Uniformity);
Typical electric field:
E_{drift} = 200V/cm, E_{lum} =2.8 kV/cm

Cathode & Anode;
Indium Tin Oxide Transparent Layers (15nm) on the Fused Silica Windows. &TPB Coated.

Fused Silica Diving Bell
holding gas pocket for S2 creation.



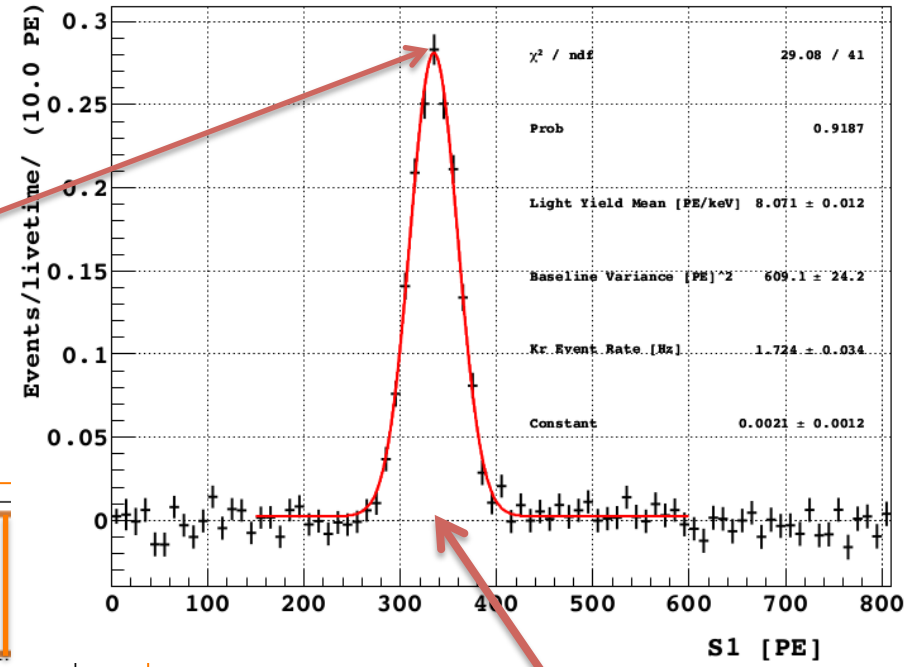
Two-Phase Ar-TPC

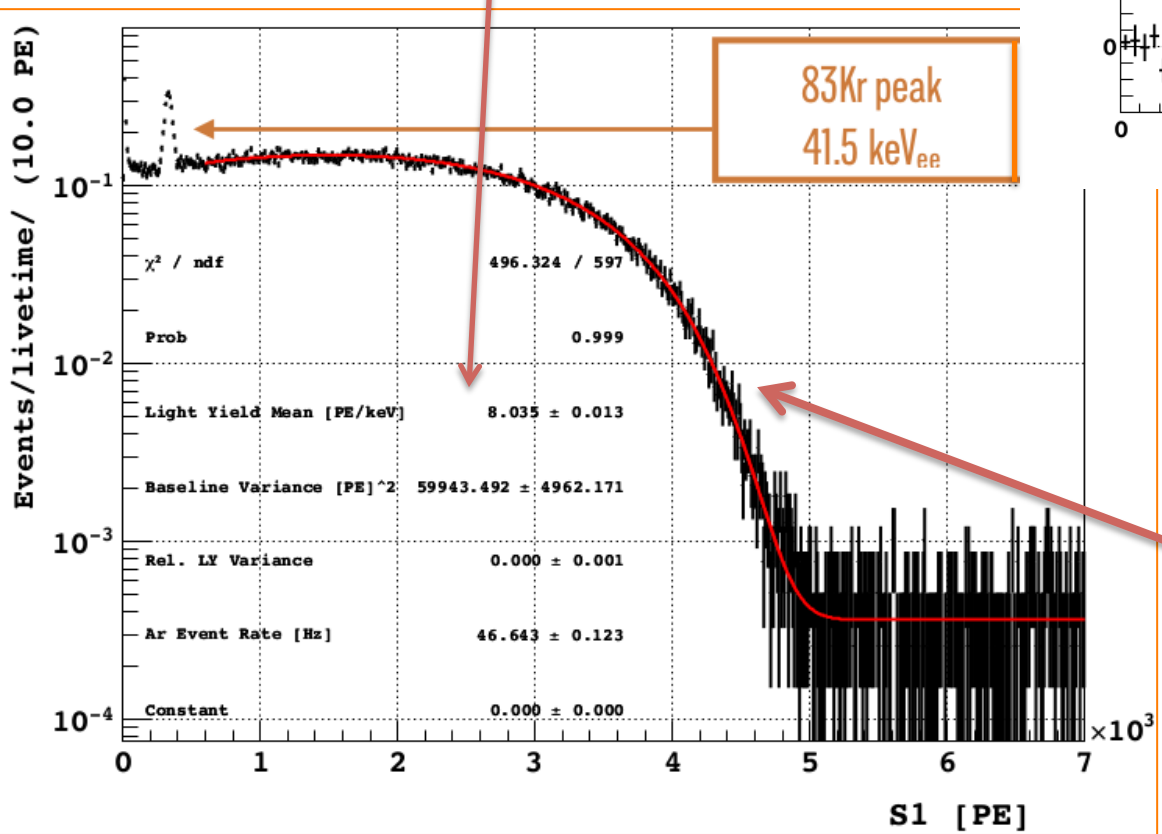


S1:
6ns & 1.6μs

Light yield @ null field

Light Yield ~ 8 pe/keV$_{ee}$ at **null field**





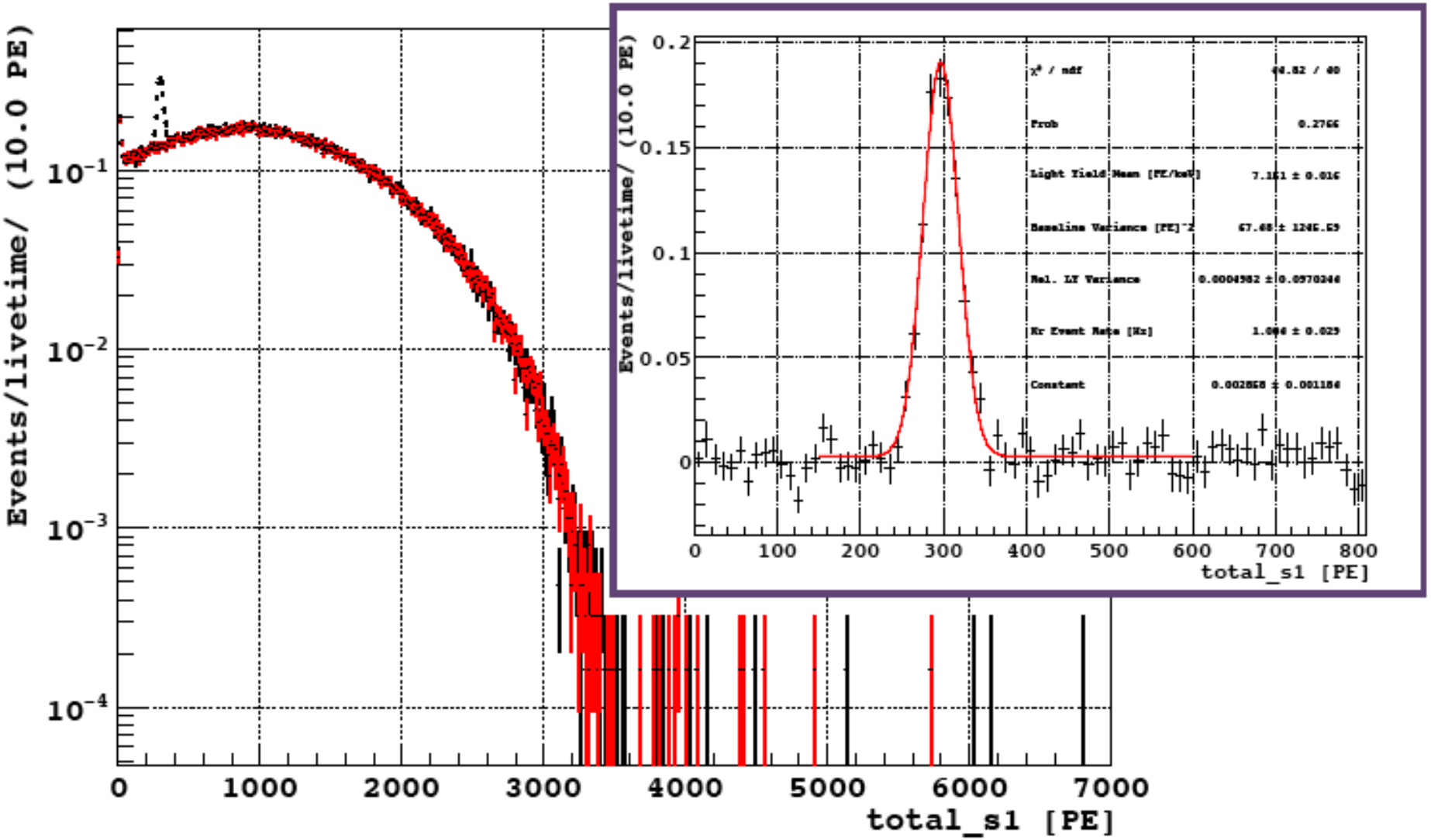
83Kr peak
41.5 keV$_{ee}$

^{83m}Kr peak
41.5 keV, $T_{1/2}$=1.83h

^{39}Ar spectrum
565 keV

Light Yield

7 p.e./keVee @ 200V/cm



S1 Pulse Shape Discrimination in LAr

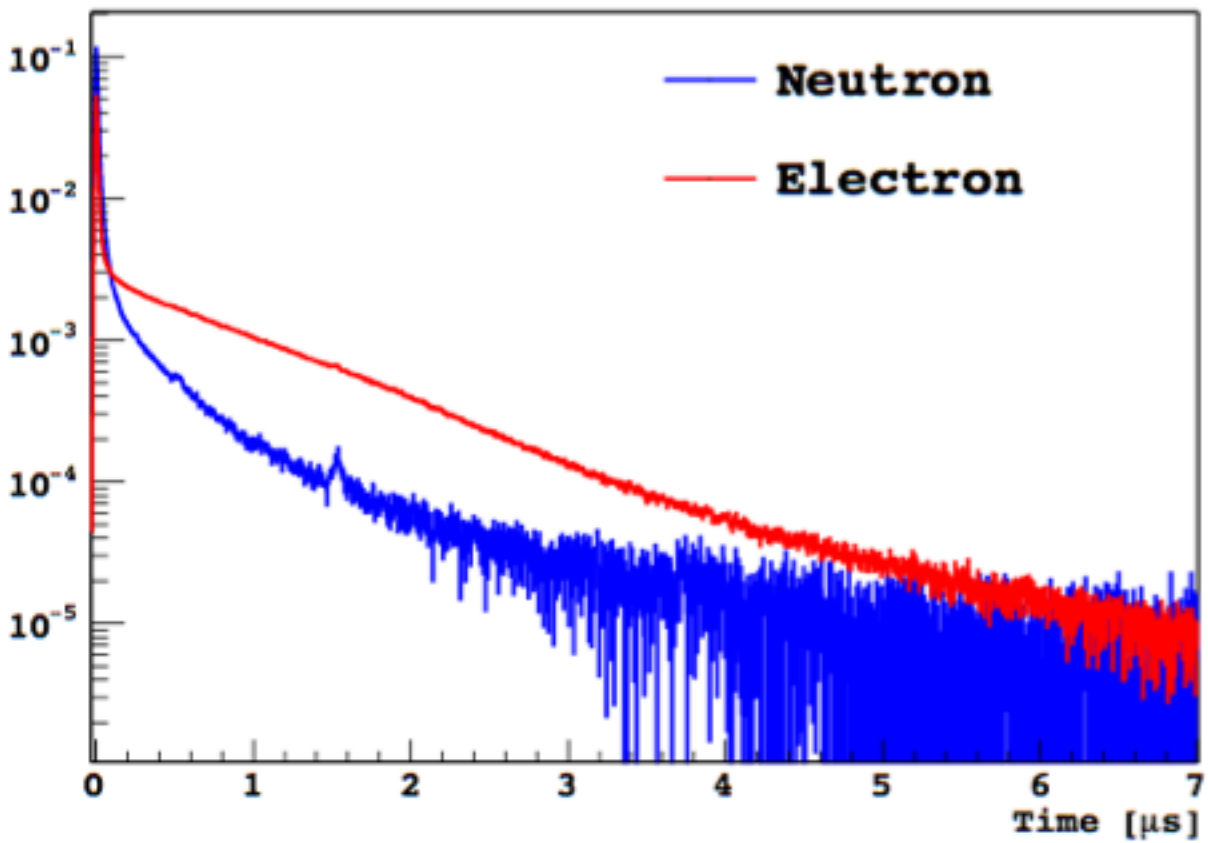
$$f(t) = \left[\frac{q}{\tau_F} e^{-t/\tau_F} + \frac{1-q}{\tau_S} e^{-t/\tau_S} \right]$$

$$\tau_F = 6ns$$

$$\tau_S = 1.6\mu s$$

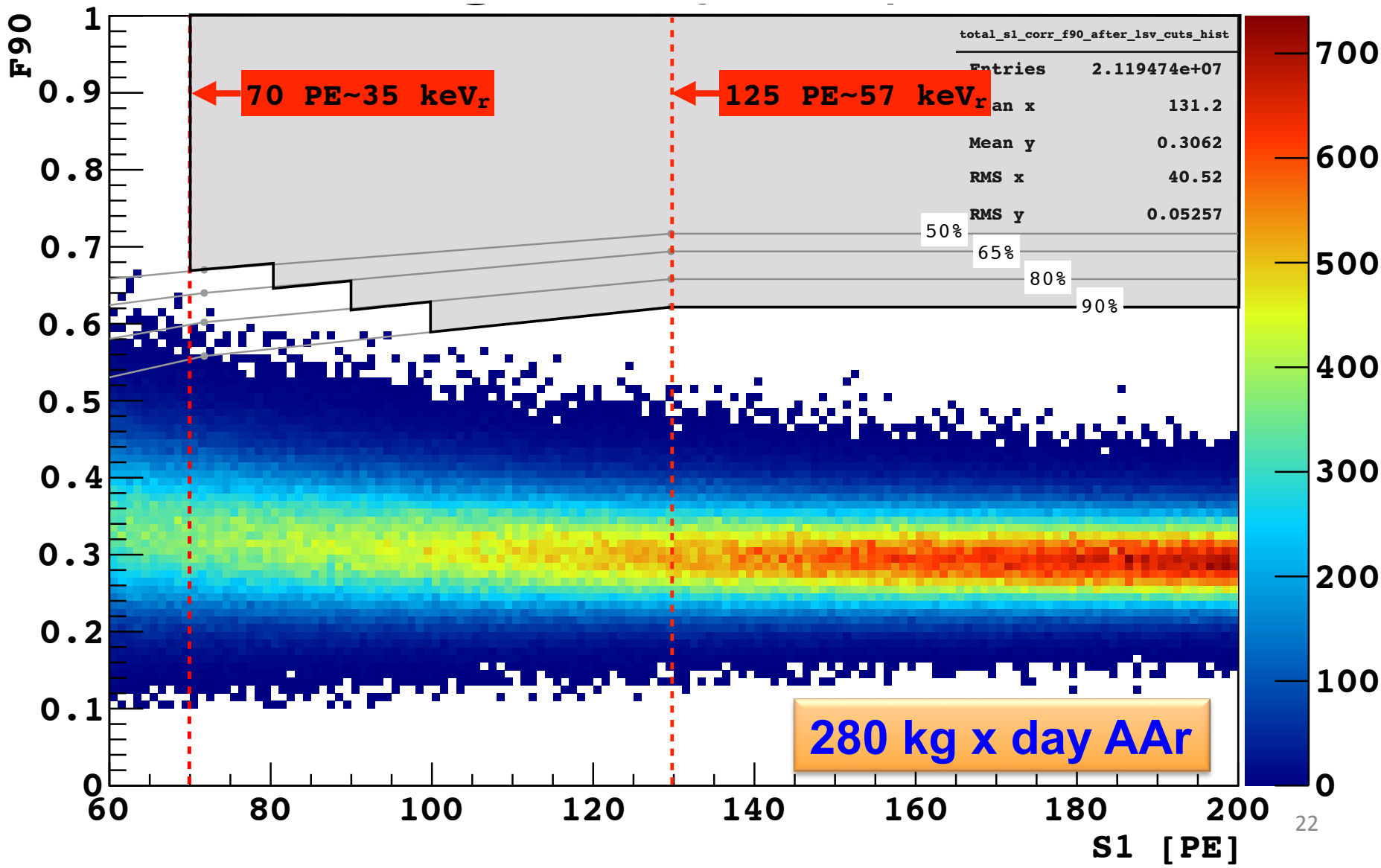
$$q = F90 = \left\{ \begin{array}{c} 0.3ER \\ 0.7NR \end{array} \right\}$$

S1 PSD:
Singlet and triplet fraction difference of NR or ER giving ~10^7 – 10^{11} rejection



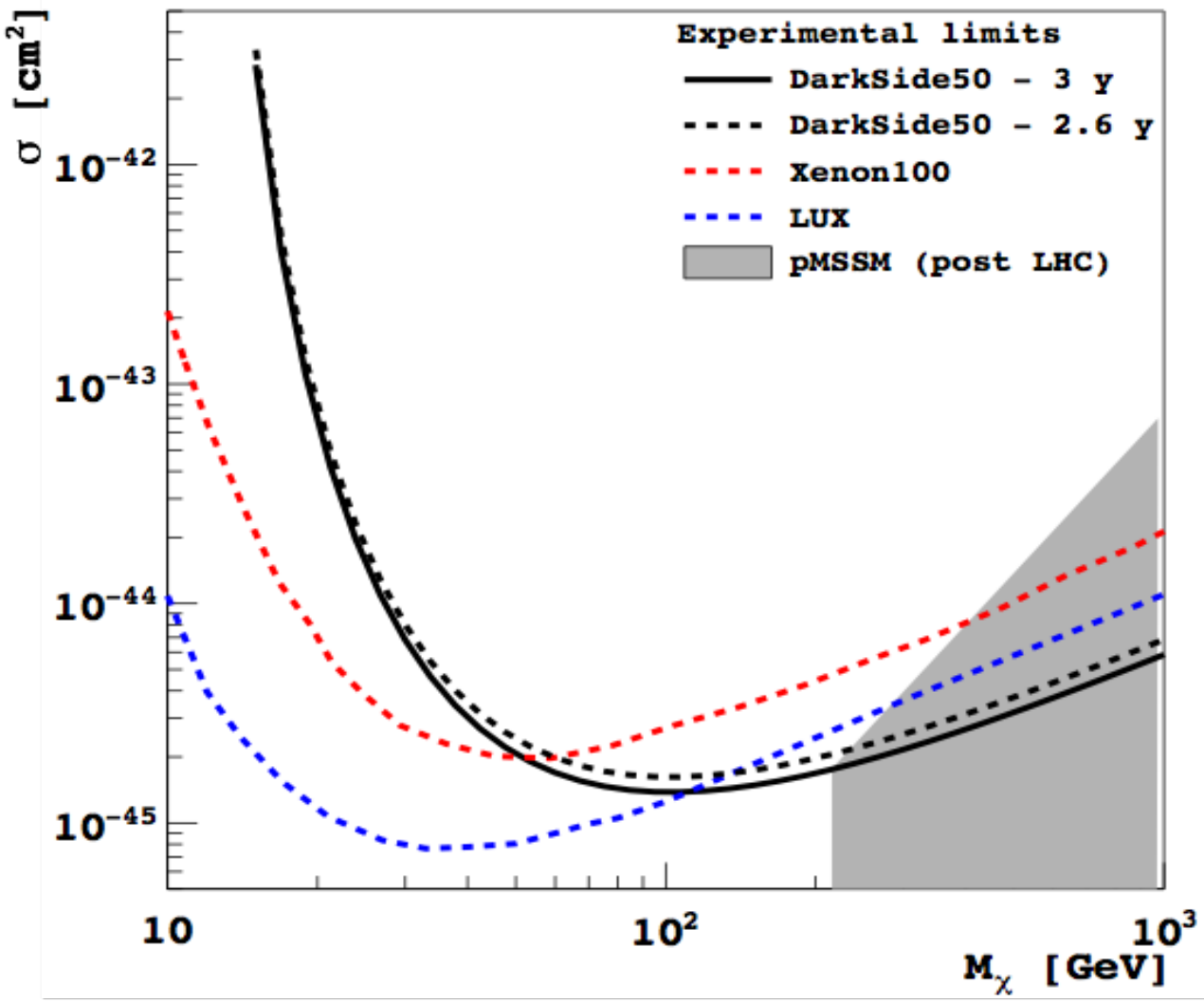
Pulse Shape F_{90}

$3x10^7$ events. Z-cut (drift time) only, no x-y and no S2/S1

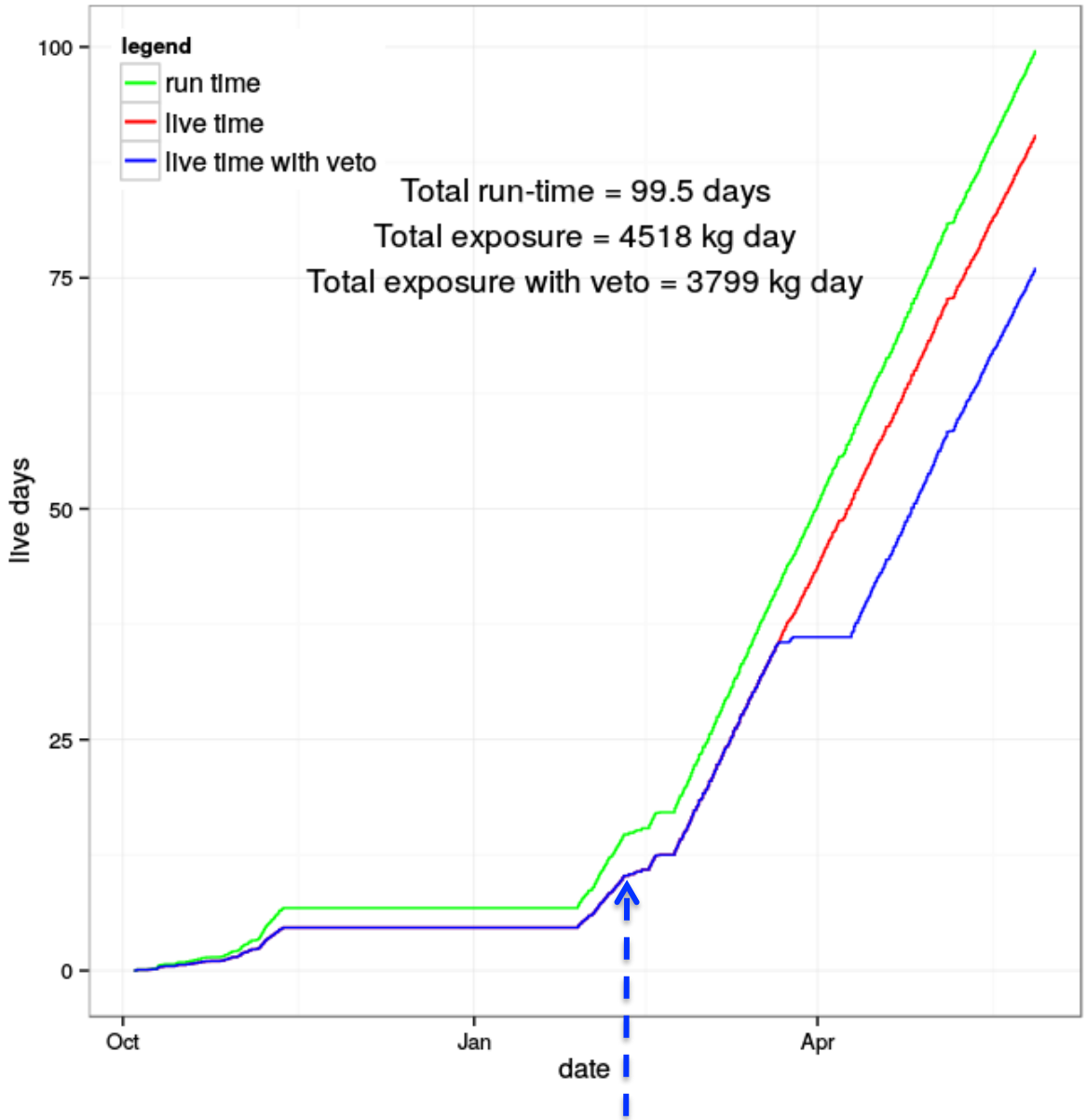


DS-50 Expected Sensitivity with UAr

Threshold: 35keVr,
Fiducial: 44.1kg,
Z-cut only,
no x-y,
no S2/S1,
Using F90 curves measured from SCENE @200V/cm



DarkSide 50 Exposure Using Atmospheric Argon



6.3 days data Presented at UCLA DM14 (by Grandi)

Summary of DS-50

- In Operation with Atmospheric Ar since Oct 2013
- Cryogenics and Gas Handling System Stable
- TPC HV System Stable
- **"TPC", "Neutron Veto" and "Muon Veto"** Commissioned
  - Analyzed 280 kg x day
  - neutron veto light yield ~ 0.5 p.e./keVee
- No background in PSD in upper 50% NR Acceptance Region in $3x10^7$ Events
- **LY @ null field ~ 8 p.e./keV$_{ee}$**
- Rn Contamination from Bi-Po < 0.85 μBq/kg_Ar
- Collected ~3800kg-days Data.

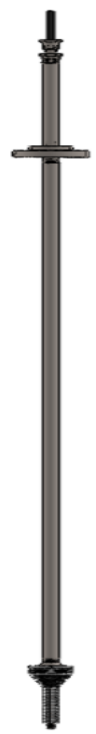
DarkSide G2 Conceptual Design

The DarkSide-G2 inner detector:

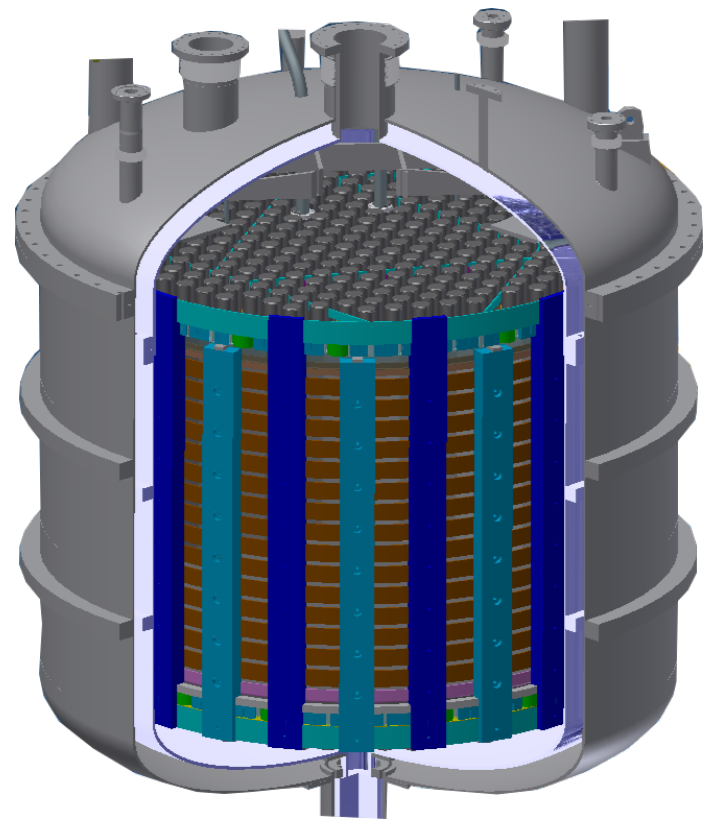
- Scaled up DarkSide-50 TPC.
- high light yield & radio-purity.
- material selection ongoing
- SS (cryostat, PMT support)
- Copper field cage
- PTFE reflective surface (w/TPB)
- Fused silica anode window (w/TPB)
- 4-π Wavelength shifter Coverage
- HVFT design ready compact with flared tip (Tested up to 200kV) G2 requirement with 150% contingency = 75kV
- DS50 gas handling philosophy
- 3” or 4” PMTs (or SiGHT) light sensors R&D on going

DS50 Facilities are design to host DS-G2 with minimum modification:

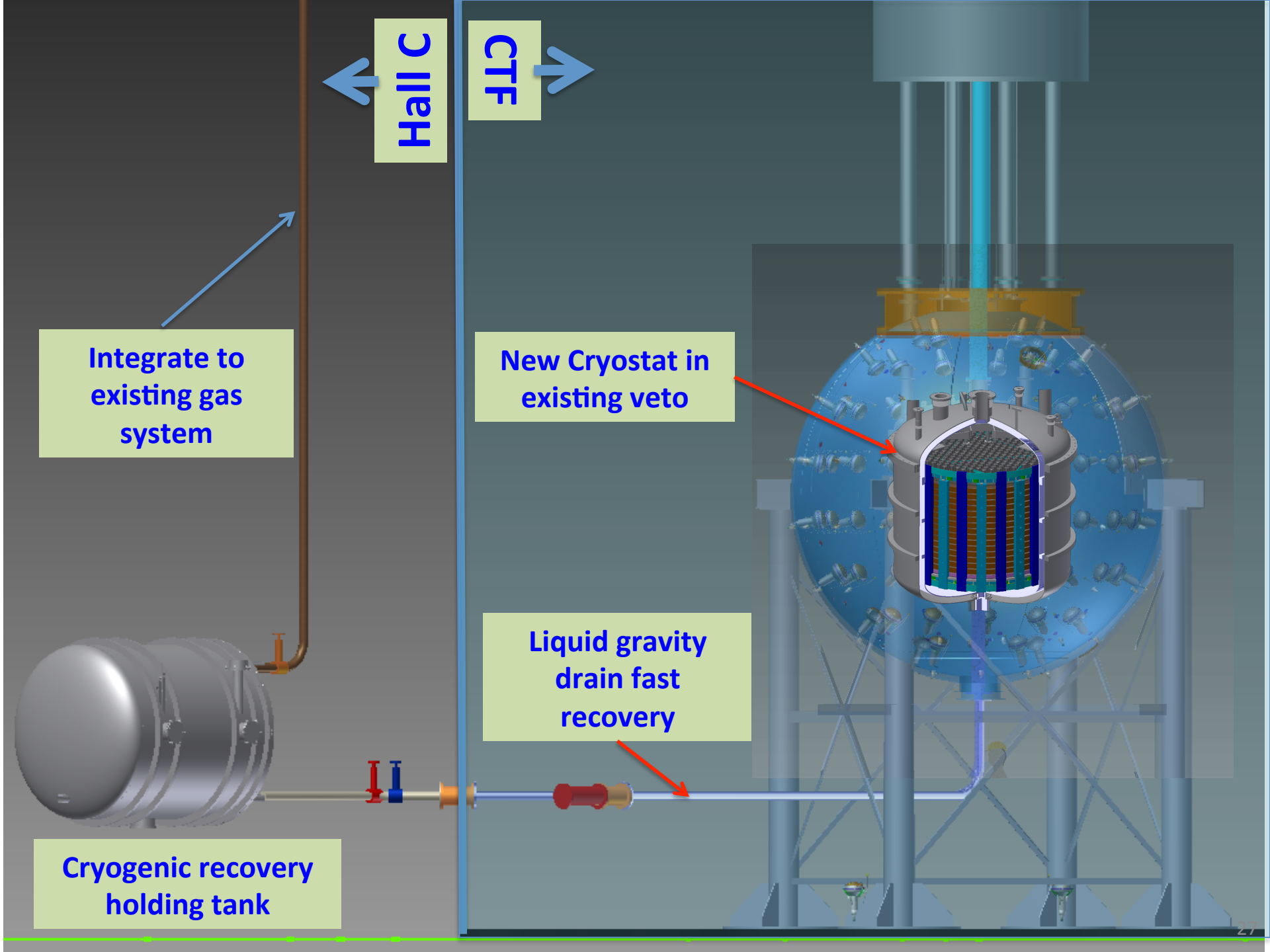
- modest cryogenic and gas handling upgrade.
- New liquid phase recover system,
- new cryostat and new TPC
- replace veto sphere top flange



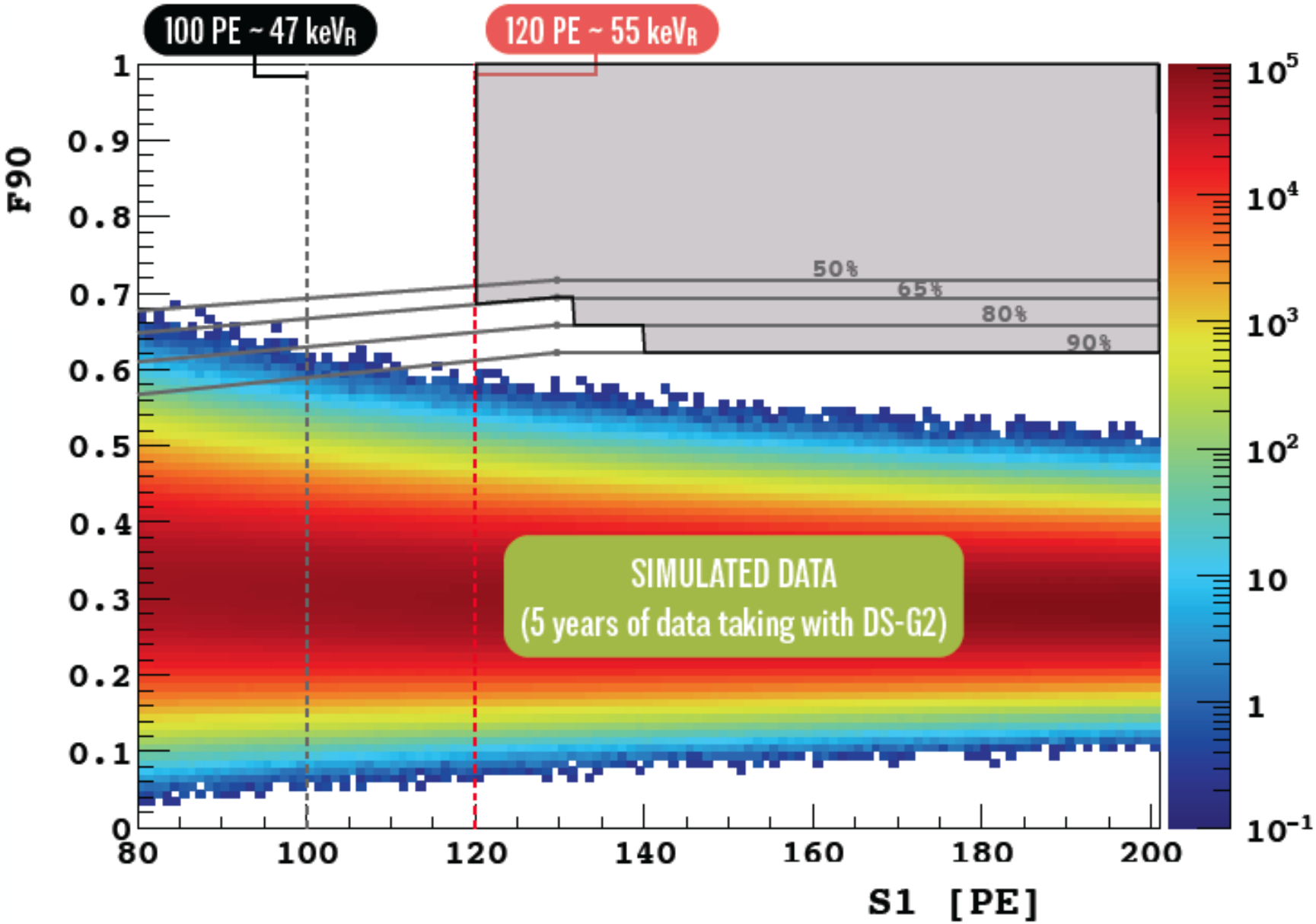
HVFT



3.8 ton fiducial UAr

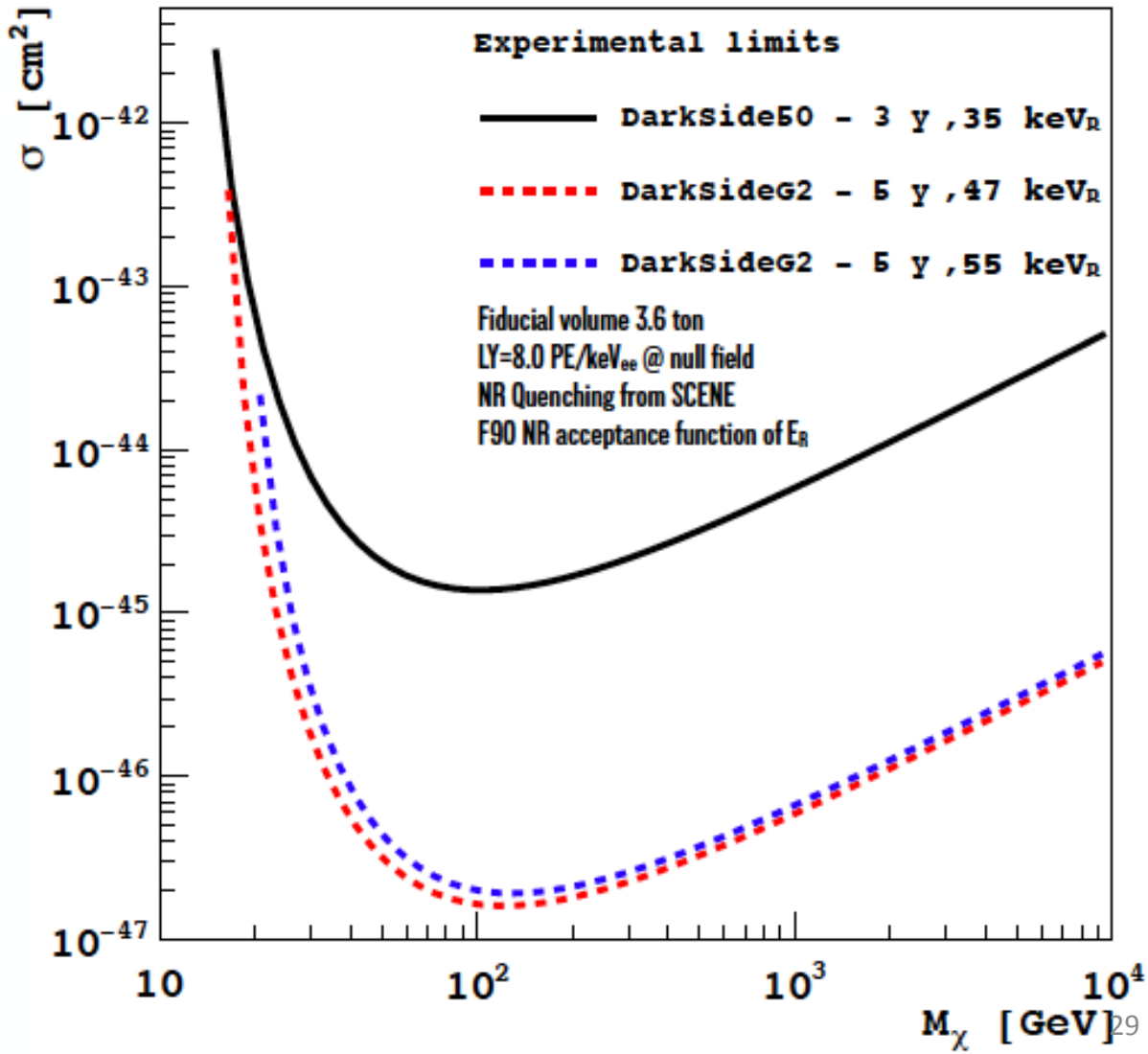

Hall C
CTF
Integrate to existing gas system
New Cryostat in existing veto
Liquid gravity drain fast recovery
Cryogenic recovery holding tank

PSD Model for DS-G2 Extrapolation



DS-G2 Expected Sensitivity with UAr (90% C.L)

- Same LY as in DS-50;
- PSD as per F90 model based on DS-50;
- no rejection from S2/S1;
- fiducialization along z axis-only;
- NR quenching and F90 acceptance curves from SCENE @ 200V/cm;
- zero neutron-induced events according to present background MC study;



Future of DarkSide program:

- Program is following "G2 down-selection" process. If funded, commissioning of DS-G2 detector in 2017.

DarkSide-50 is a key to DarkSide-G2:

- Successful integration of Borexino facilities and expertise in radio-pure liquid scintillator and water deployment.
- No major delays in the project's schedule.
- DS-50 performance and background budget are used to reliably infer G2 sensitivity and to identify and mitigate risk factors.
- Existing facilities for faster deployment of the G2 system.
- Veto system for background rejection/ characterization in situ.

The DarkSide Collaboration

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