Direct Dark Matter Search with DarkSide-50

26/05/2014

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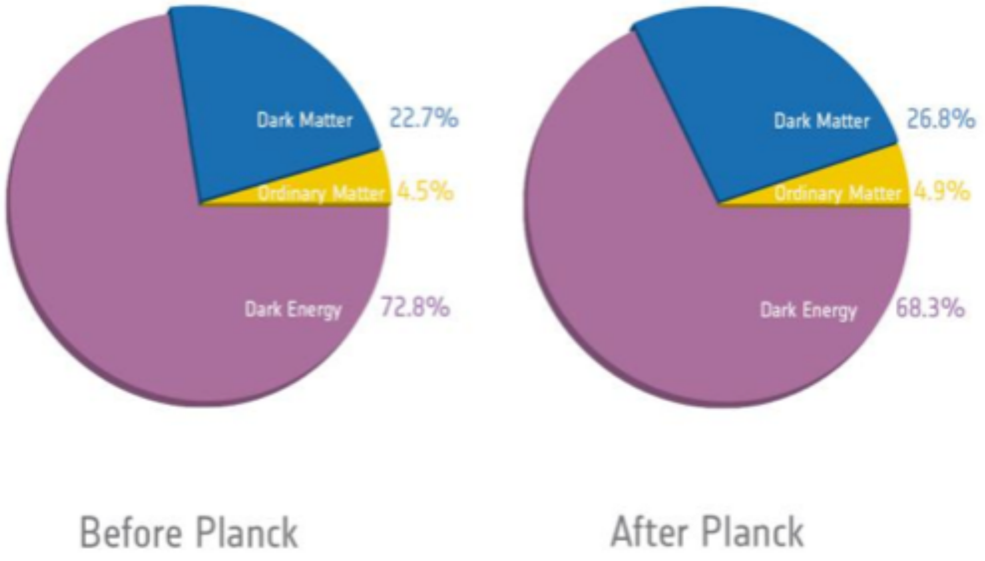
APC - CNRS

Dark Matter

Dark matter has already been **indirectly** discovered through:

- Galaxy clusters
- Galactic rotation curves
- Weak lensing
- Strong lensing
- Hot gas in clusters
- Bullet Cluster
- Supernovae
- CMB



Dark Matter Candidate

It interacts through gravitational force

It is electrically neutral

no other long range interaction is allowed, otherwise it would have formed "atoms" and , hence, stars etc.

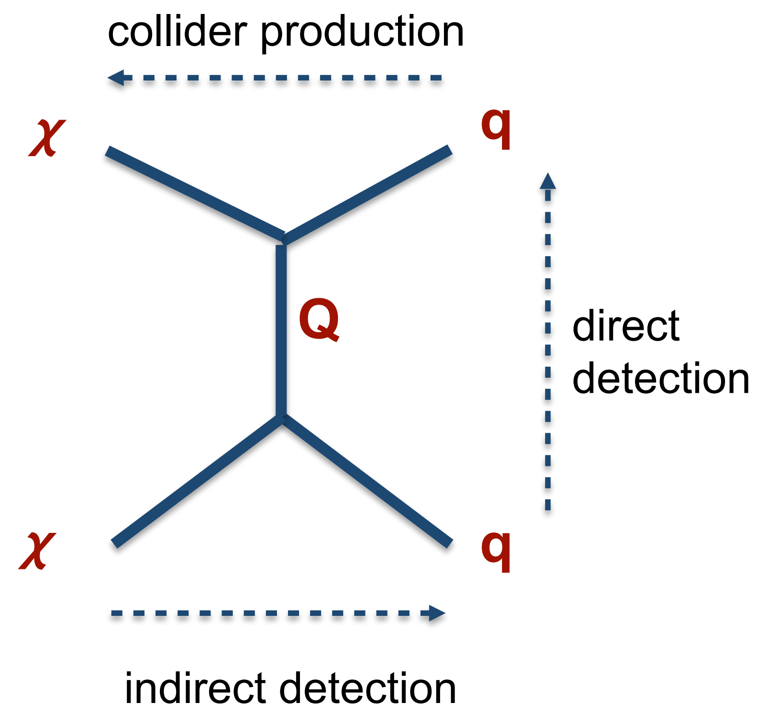
It does not strongly interact

otherwise it should have already been detected

It may weakly interact

WIMPs

Weakly Interacting Massive Particles



WIMP Direct Detection Ingredients

Large masses

- Low rate (~1 event/ton/yr @ 10^{-47} cm^2 in noble liquids)

Low energy thresholds

- Low energy nuclear recoils (< 100 keV)

Background suppression

- Deep underground
- Passive/active shielding
- Low intrinsic radioactivity
- Gamma background discrimination

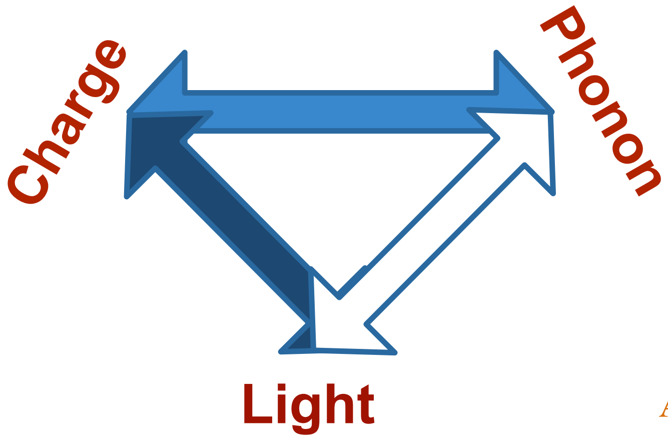
Direct Dark Matter Search

EDELWEISS
EUREKA

CDEX
CoGeNT
DRIFT
Genius
HDMS

IGEX-DM
MIMAC
Majorana
NEWAGE

Picasso
ROSEBUD
SIMPLE



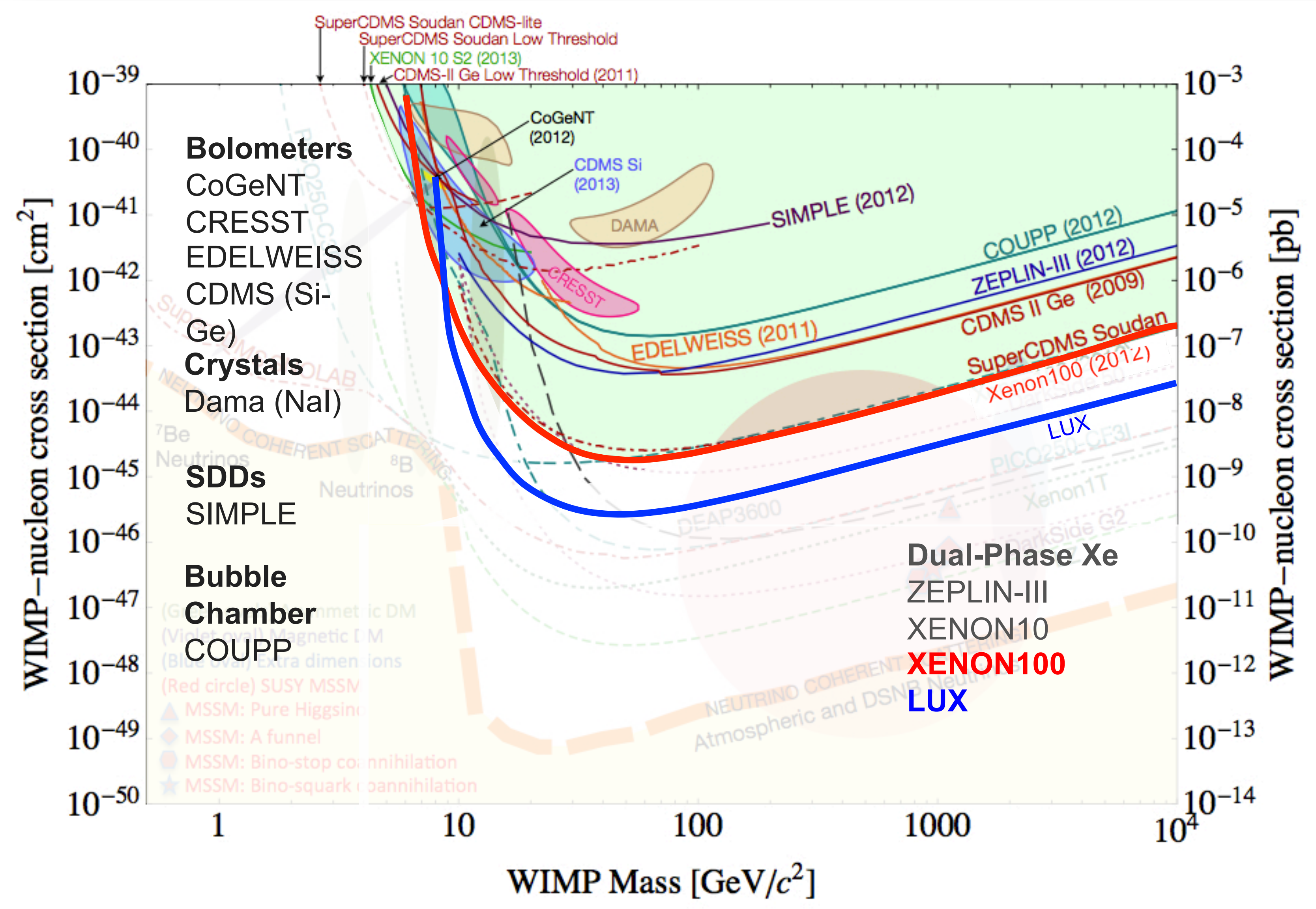
ArDM
DarkSide
LUX
NEXT

ORPHEUS
PandaX
XENON
WARP
Zeplin

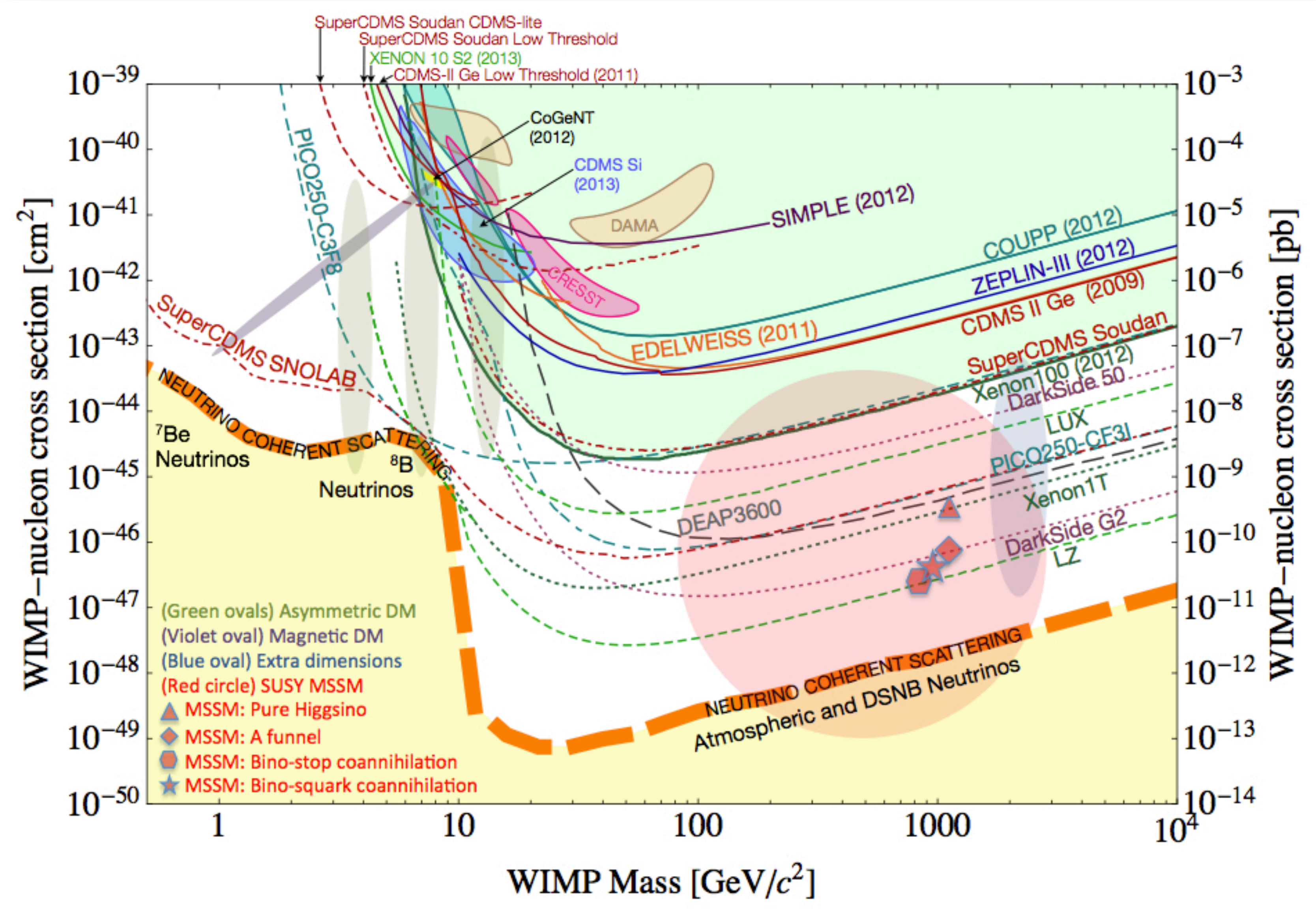
AMoRE
CDMS
CRESST

ANAIS
CASPAR
DAMA/LIBRA
DEAP/CLEAN
KIMS
NAIAD
XMASS

The WIMP Hunt



The WIMP Hunt



Noble Liquids

Relatively **inexpensive** and **dense**

Easy to **purify**
- most impurities freeze out
- low surface binding
- purification easiest for colder liquids

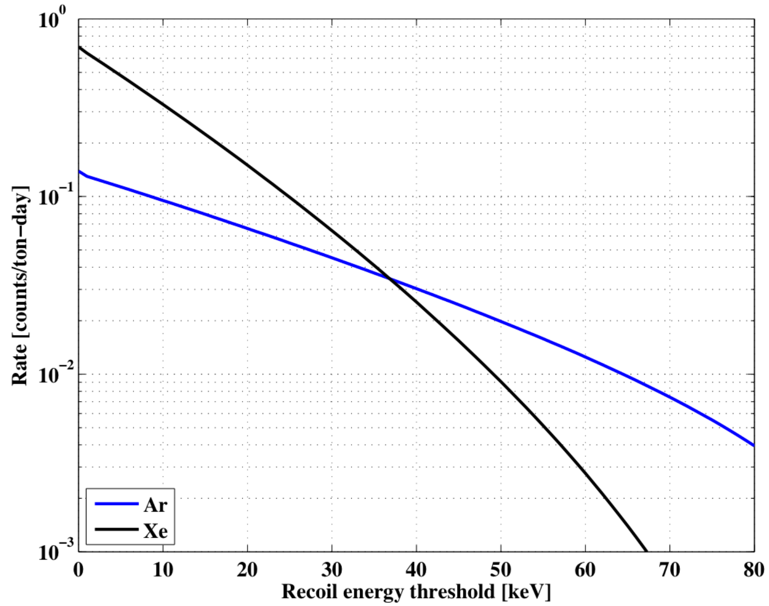
Ionization electrons and **scintillation** photons:
- complementarity on particle energy
- 3D localization when used in TPC

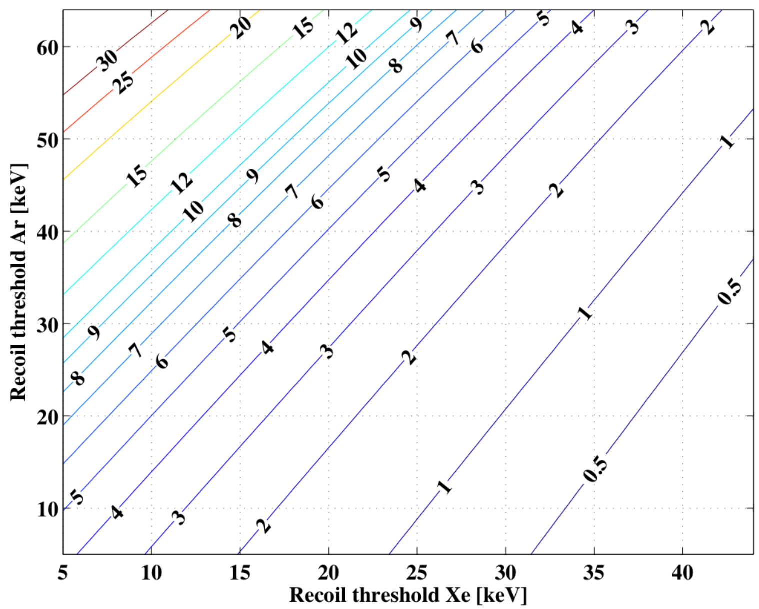
High ionization (W_{LAr} = 21.5 eV, W_{LXe} = 15.6 eV)

Very **high** scintillation **yield** (~40,000 photons/MeV)

Transparent to their own scintillation

High electron mobility and **low** electron **diffusion**





Noble Liquids

		LAr	*LKr*	*LXe*
Physical properties	Atomic number	18	36	54
	Boiling point at 1 bar, T_b (K)	87.3	119.8	165.0
	Density at T_b (g/cm^3)	1.40	2.41	2.94
Ionisation	W (eV)[1]	23.6	20.5	15.6
	Fano factor	0.11	~0.06	0.041
	Drift velocity (cm/μs) at 3 kV/cm	0.30	0.33	0.26
	Transversal diffusion coefficient at 1 kV/cm (cm^2/s)	~20		~80
Scintillation	Decay time[2], fast (ns)	5	2.1	2.2
	slow (ns)	1000	80	27/45
	Emission peak (nm)	127	150	175
	Light yield[2] (phot./Mev)	40000	25000	42000
	Radiation length (cm)	14	4.7	2.8
	Moliere radius (cm)	10.0	6.6	5.7

Excellent discrimination power!

Radiopurity:
- LXe: excellent radio-purity
- Atmospheric LAr: contaminated by cosmogenic ^{39}Ar
- Underground LAr: ^{39}Ar depleted

Underground Argon

Atmospheric Ar:

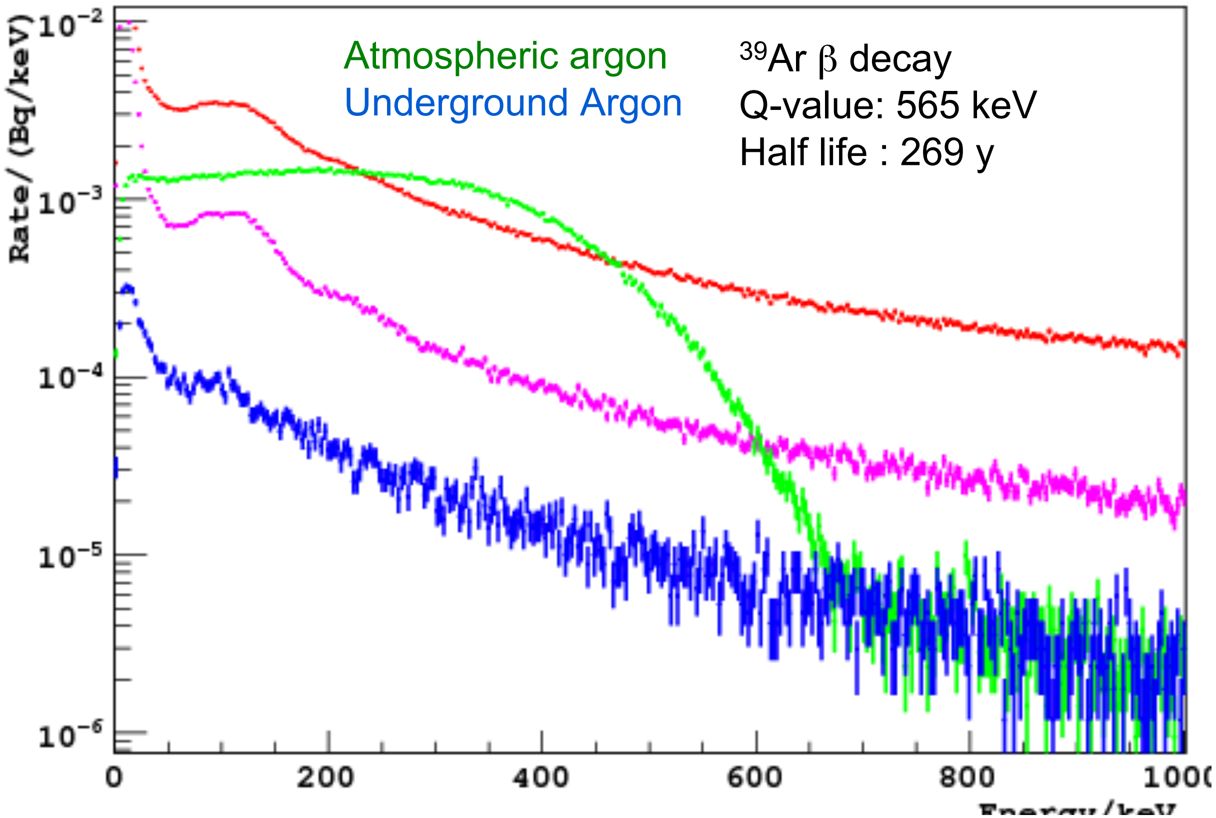
$^{39}Ar/^{40}Ar = 8 \times 10^{-16}$

Rate ~ **1 Hz/kg**

Underground Argon:

^{39}Ar < **6.5 mBq/kg**

(arXiv:1204.6011)

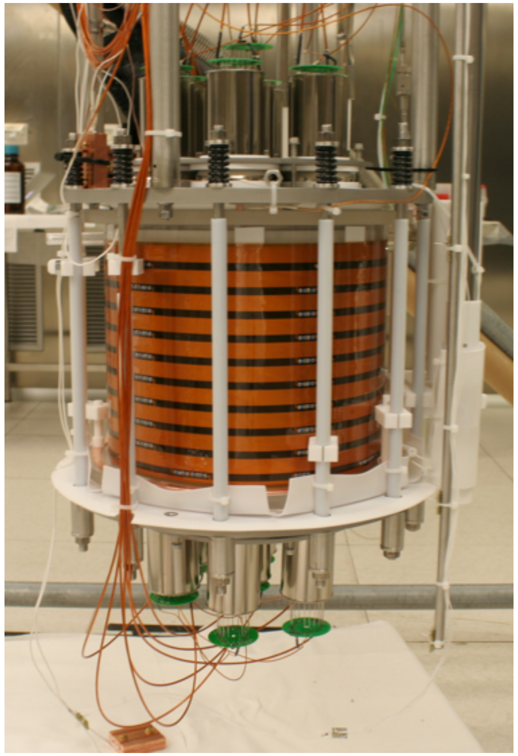


Depletion Factor > 150

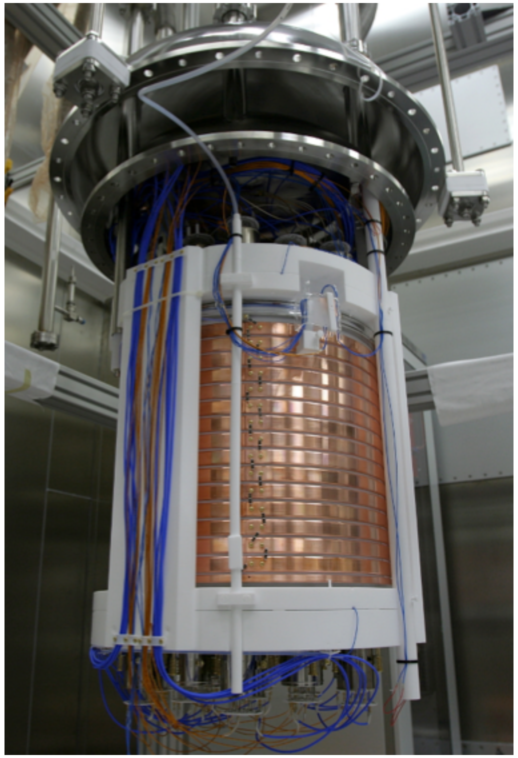
The DarkSide program at LNGS

Double Phase Liquid Argon TPC

DarkSide-10
2011-2013

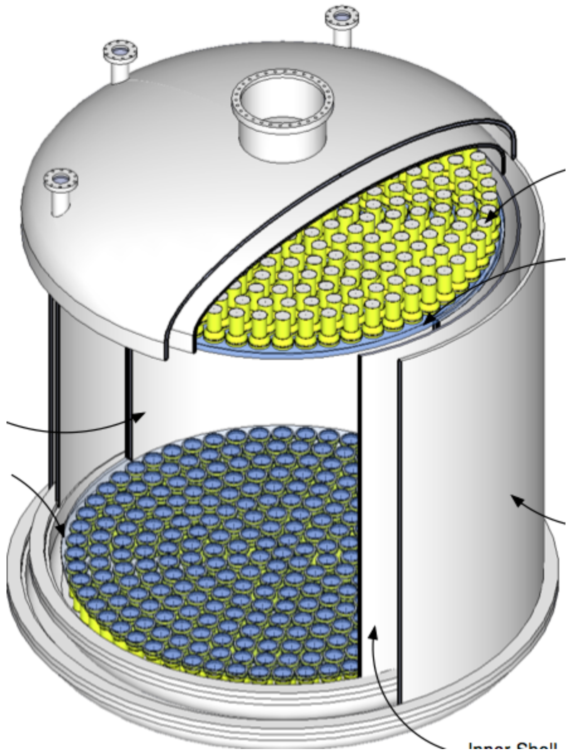


DarkSide-50
2013-201x



~10^{-45} cm^2

DarkSide-G2
2016-2020



~10^{-47} cm^2

The Dark Side Collaboration

Ukraine
KINR, NAS Ukraine – Kiev

CHINA
IHEP – Beijing

POLAND
Jagiellonian University – Krakow

FRANCE
Université Paris Diderot, CNRS/IN2P3, CEA/IRFU, Observatoire de Paris, Sorbonne Paris Cité – Paris
IPHC, Université de Strasbourg, CNRS/IN2P3 – Strasbourg

USA
Augustana College – SD
Black Hills State University – SD
Fermilab – IL
Princeton University – NJ
SLAC National Accelerator Center – CA
Temple University – PA
University of Arkansan – AR
University of California – Los Angeles, CA
University of Chicago – IL
University of Hawaii – HI
University of Houston – TX
University of Massachusetts – MA
Virginia Tech – VA

ITALY
INFN Laboratori Nazionali del Gran Sasso – Assergi
Università degli Studi and INFN – Genova
Università degli Studi and INFN – Milano
Università degli Studi Federico II and INFN – Napoli
Università degli Studi and INFN – Perugia
Università degli Studi Roma Tre and INFN – Roma

RUSSIA
Joint Institute for Nucelar Research – Dubna
Lomonosov Moscow State University – Moscow
National Research Centre Kurchatov Institute – Moscow
Saint Petersburg Nuclear Physics Institute – Gatchina

DarkSide Guidelines

Background suppression

Ultra-low background materials

- Depleted liquid argon
- Low background photo-detectors
- Low background material components

Active shields

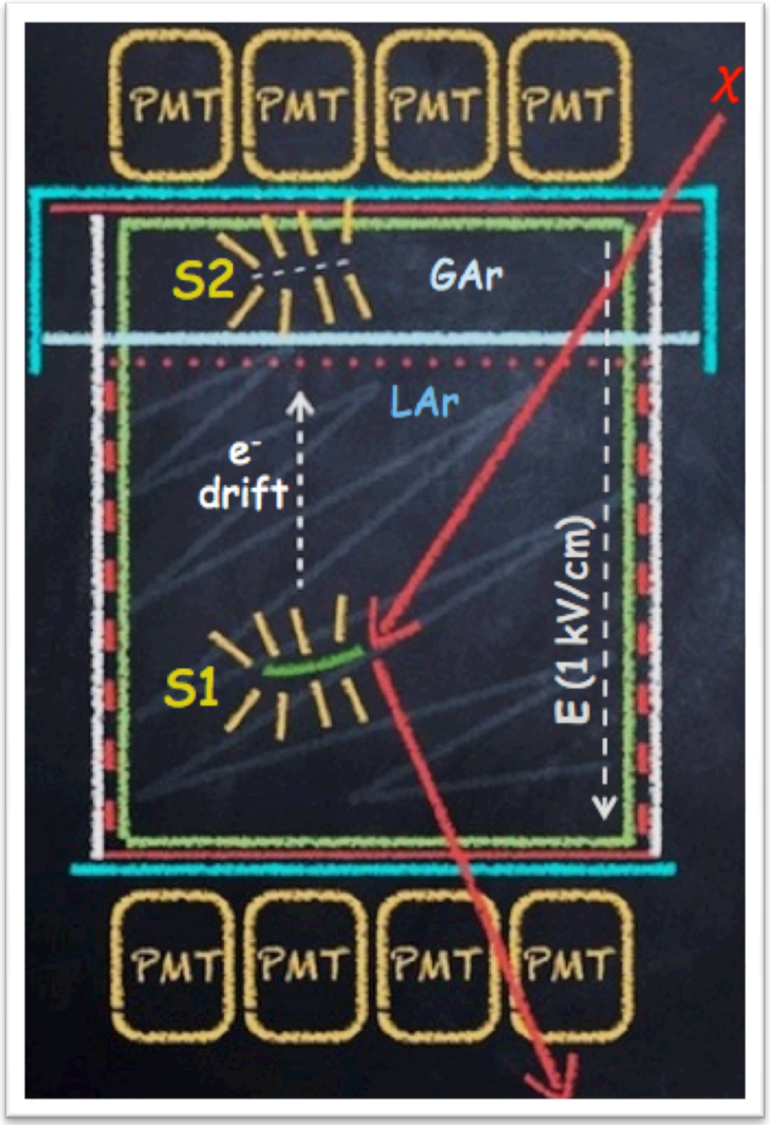
- Water Cherenkov against muons
- Borate scintillator against mu and n
- Multiple scattering with the TPC

Residual background identification

Background identification

- Pulse shape discrimination
- S1/S2 discrimination
- Neutron flux with borate scintillator
- Position reconstruction

Double Phase TPC



Liquid Argon Ionization and Scintillation

Light Emission via Excitation

$e^- + Ar \rightarrow Ar^* + e^-$

$Ar^* + Ar \rightarrow Ar_2^*$

$Ar_2^* \rightarrow Ar + Ar + \text{photon}$

Light Emission via Ionization

$e^- + Ar \rightarrow Ar^+ + 2e^-$

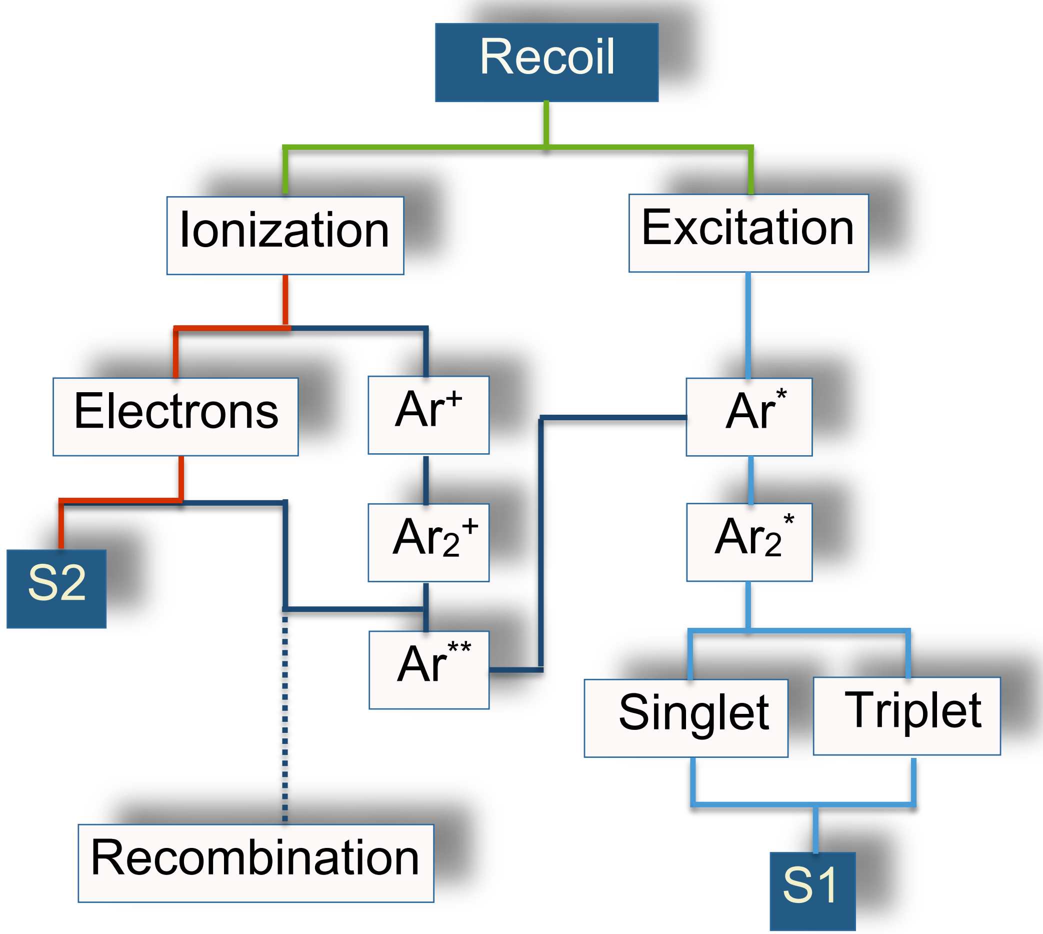
$Ar^+ + Ar + Ar \rightarrow Ar_2^+ + Ar$

$e^- + Ar_2^+ \rightarrow Ar^{**} + Ar$

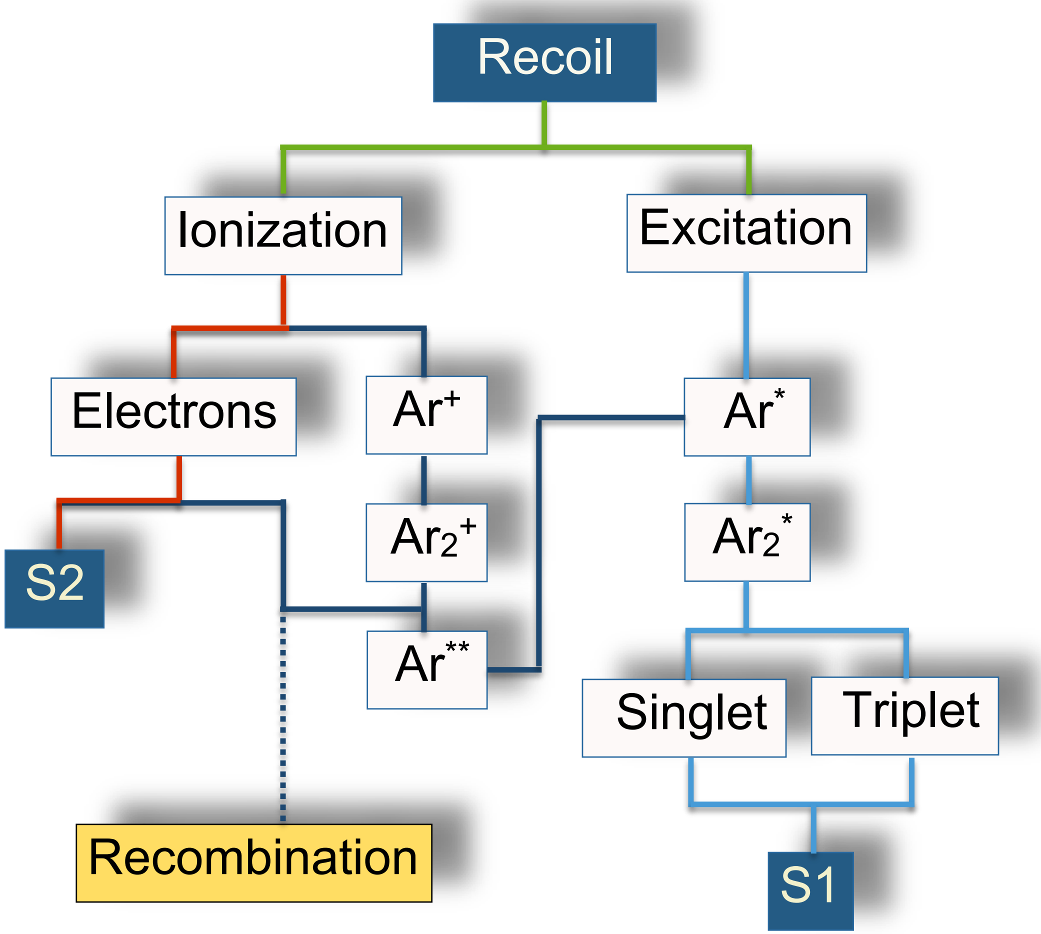
$Ar^{**} + Ar \rightarrow Ar^* + Ar + \text{heat}$

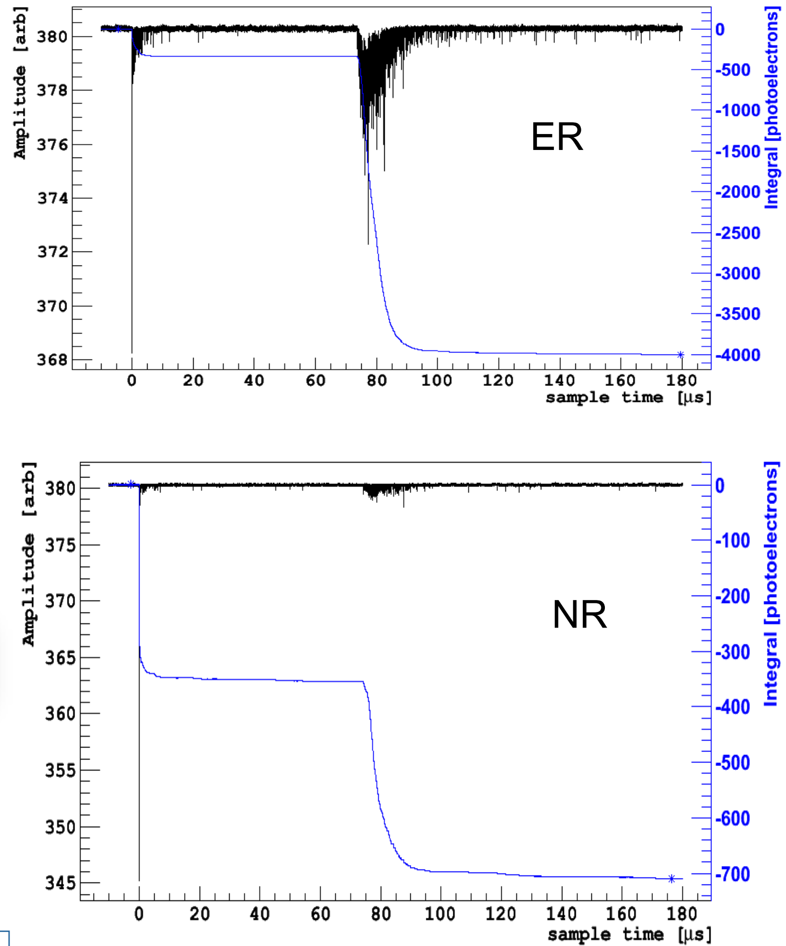
$Ar^* + Ar + Ar \rightarrow Ar_2^* + Ar + \text{heat}$

$Ar_2^* \rightarrow Ar + Ar + \text{photon}$



Background Discrimination: S1/S2

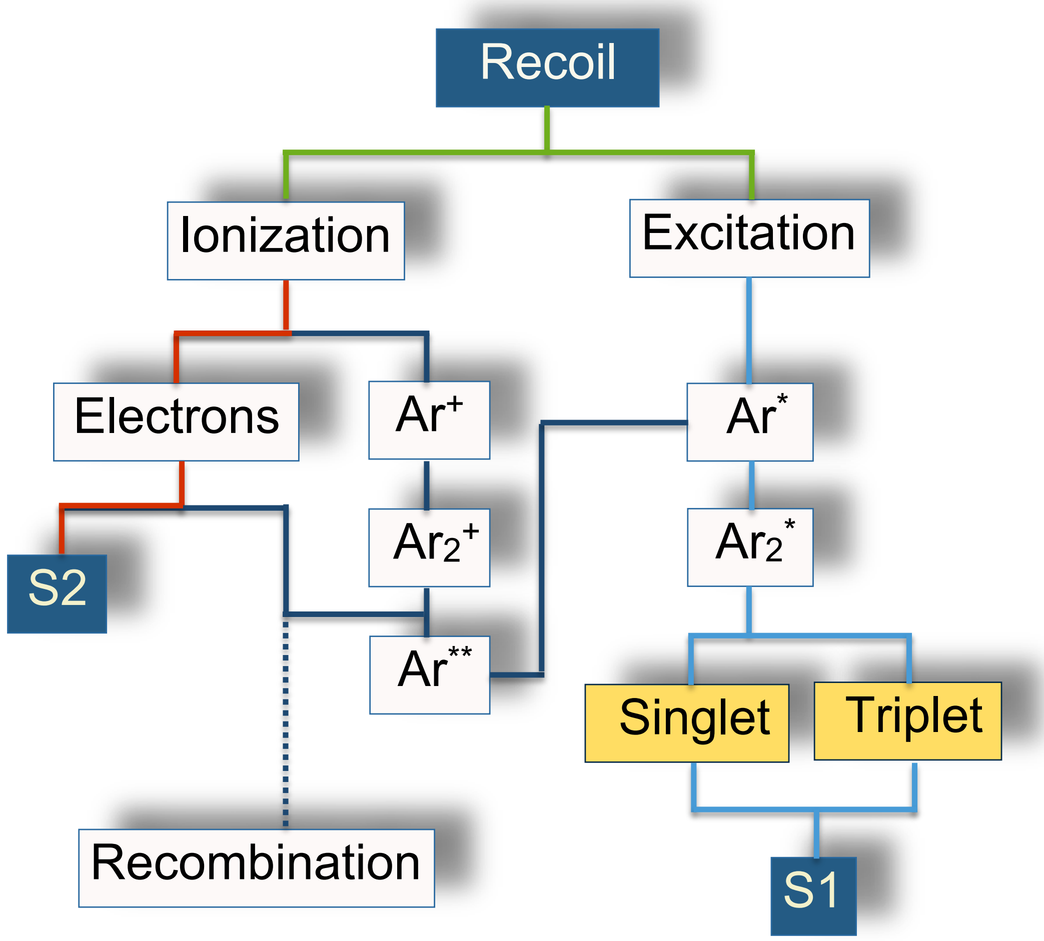


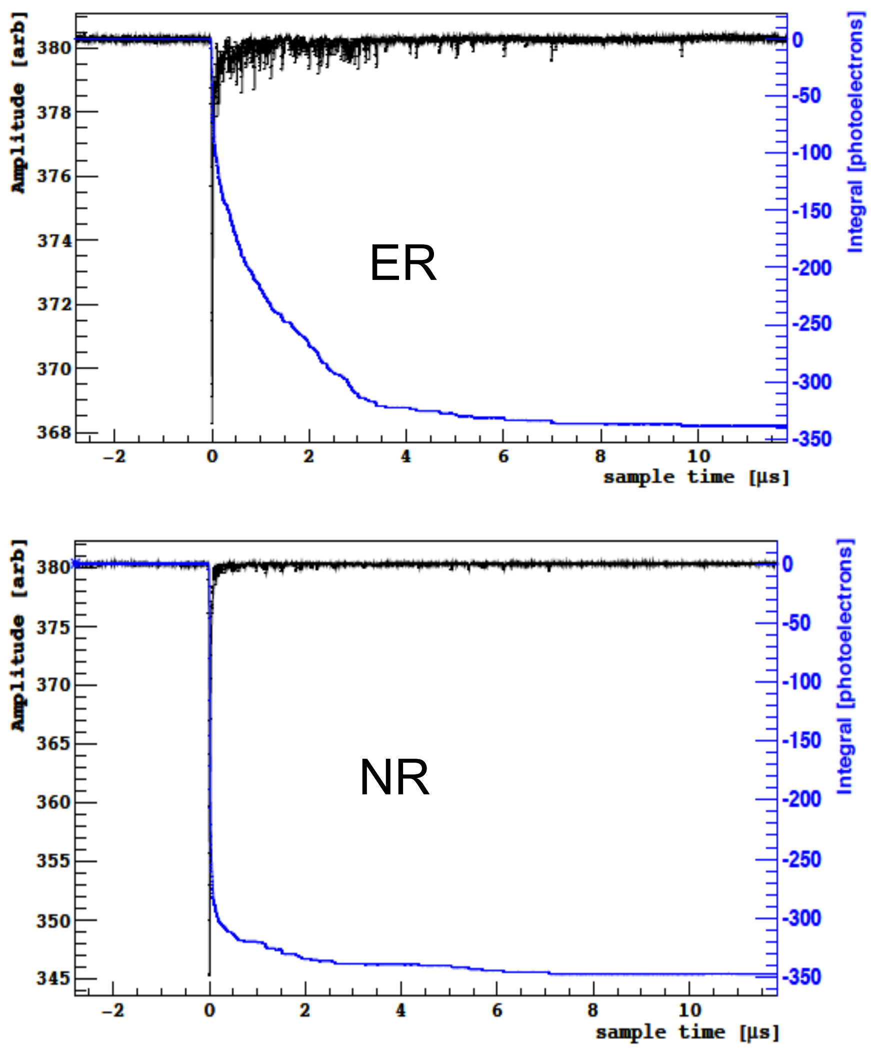


Rejection Factor: 10^2-10^3

Benetti et al. (ICARUS) 1993; Benetti et al. (WARP) 2006

Background Discrimination: S1 Pulse Shape





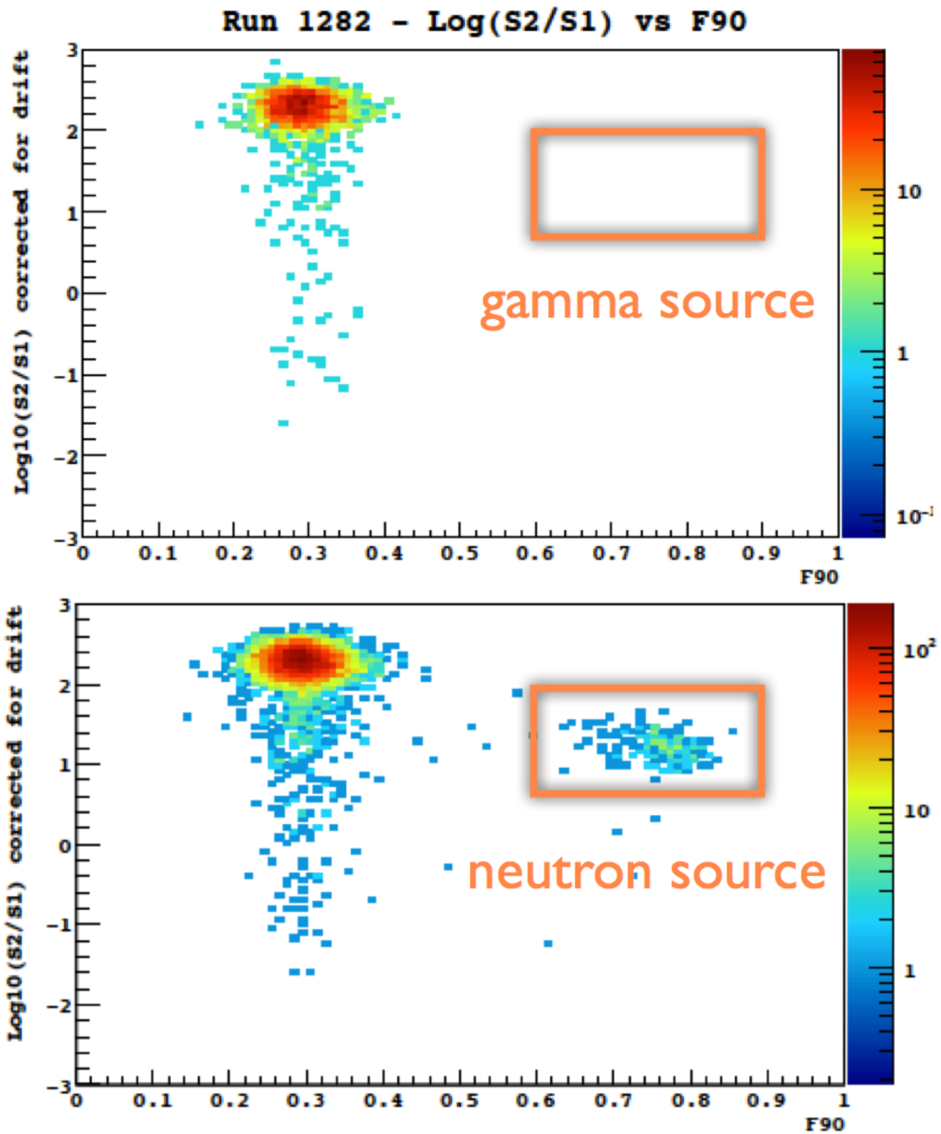
Rejection Factor: 10^8

WARP Astr. Phys 28, 495 (2008)

Particle Discrimination in LAr

- S1/S2
- PSD
- Position Reconstruction
- TPC multi-site event

Expected BG discrimination > 10^{10}

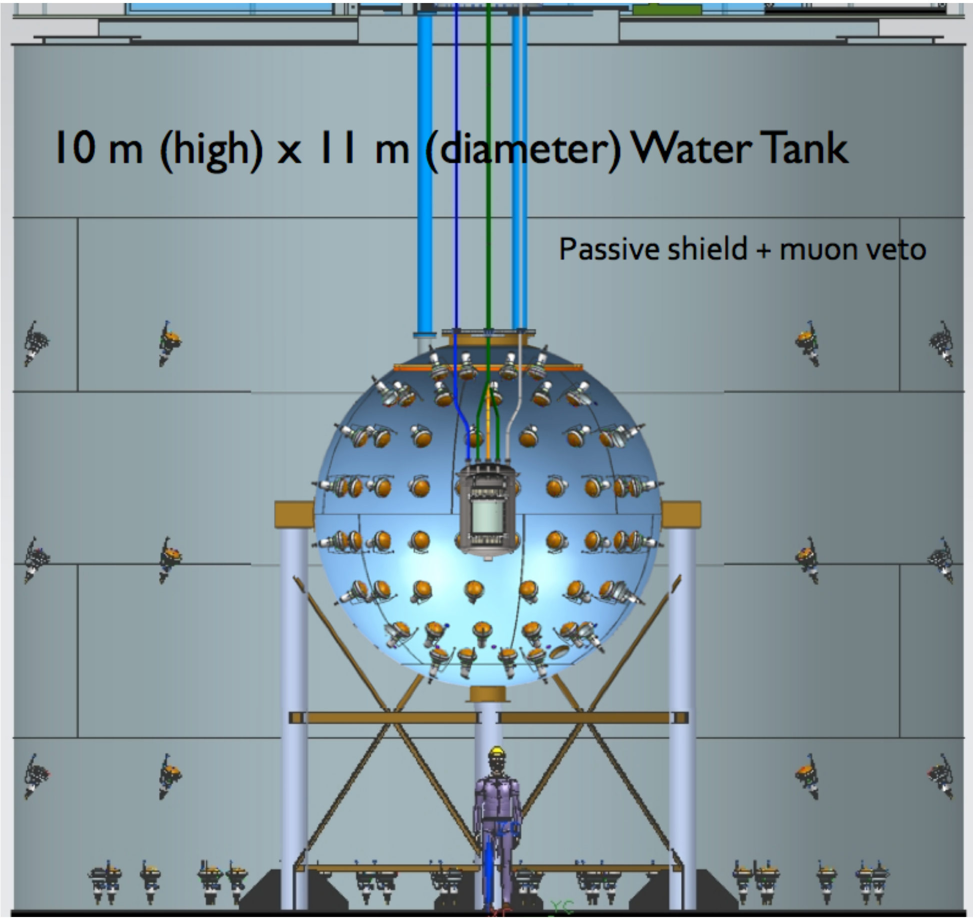


The Veto's

Active neutron veto:
- 20 ton boron-loaded scintillator
- 50% PC + 50% TMB
- 2 m radius sphere
- 110 Low Background PMTs

Active muon veto (passive neutron veto):
- 1000 ton ultra pure water
- 10 m height, 11 m diameter
- 80 upwards oriented PMTs

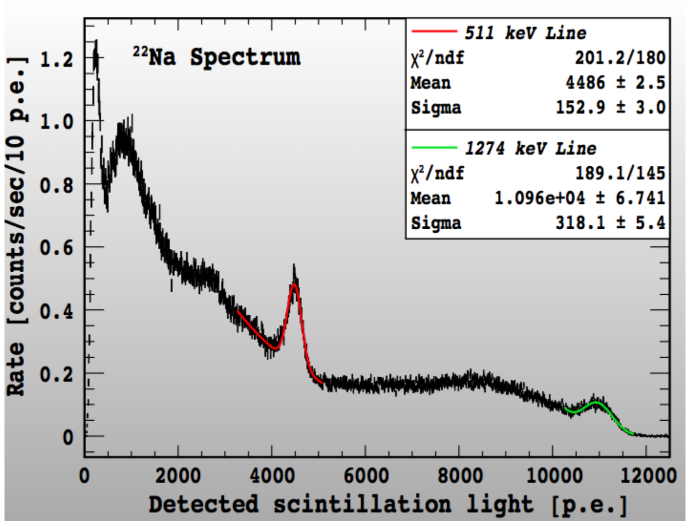
Rejection efficiencies:
- >99.5% against radiogenic neutron
- >95% cosmogenic neutrons



DarkSide-10

Two phase argon TPC prototype at Princeton:
- 10 kg active mass of Atmospheric LAr
- Passive water veto
- 7 top + 7 bottom R11065 HQE 3'' PMTs
- Electric field: Edrift = 1 kV/cm, Egas ~ 3 kV /cm
- 20 cm diamater, 20 cm height
- 2 cm gas gap

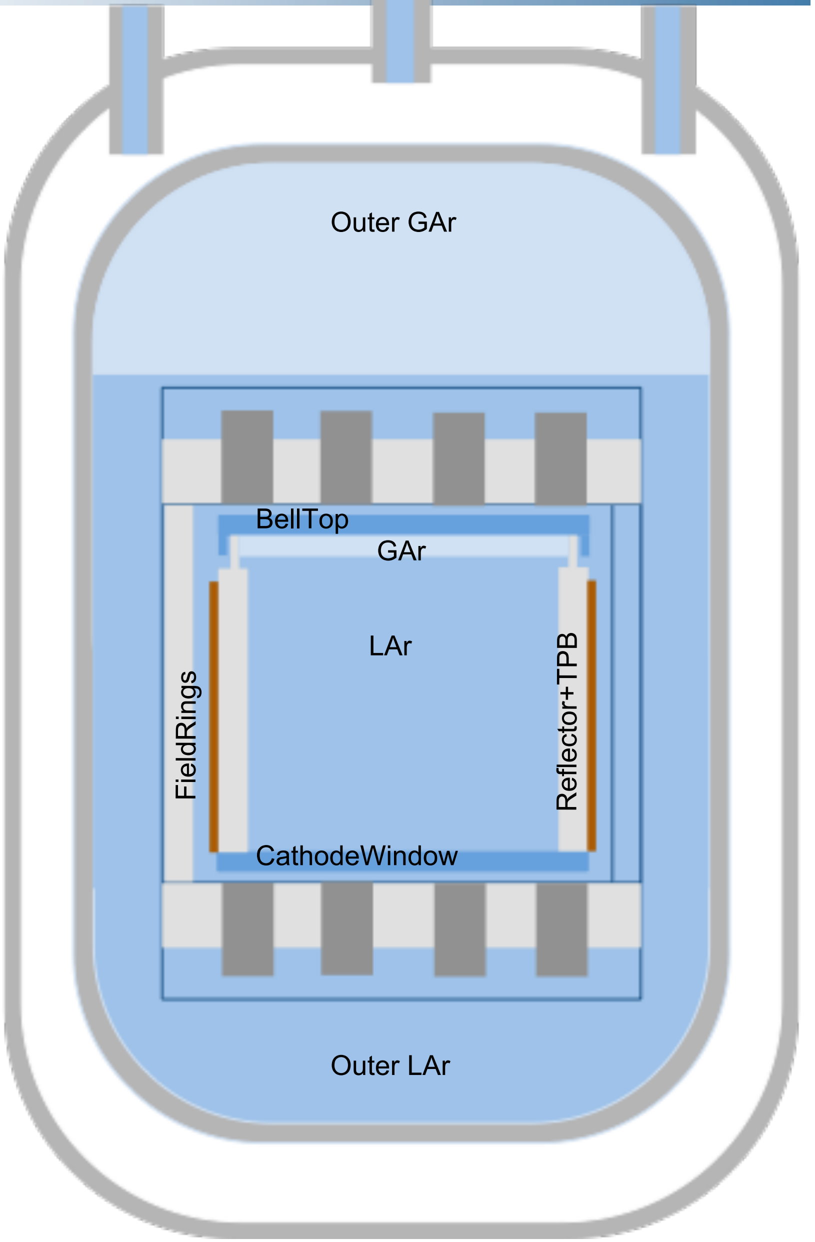
Goals:
- High LY: 8.78 ± 0.01 p.e./keVee @ null field
- Stable HHV at 36 kV
- Good discrimination
- Good purity
- Electric field settings



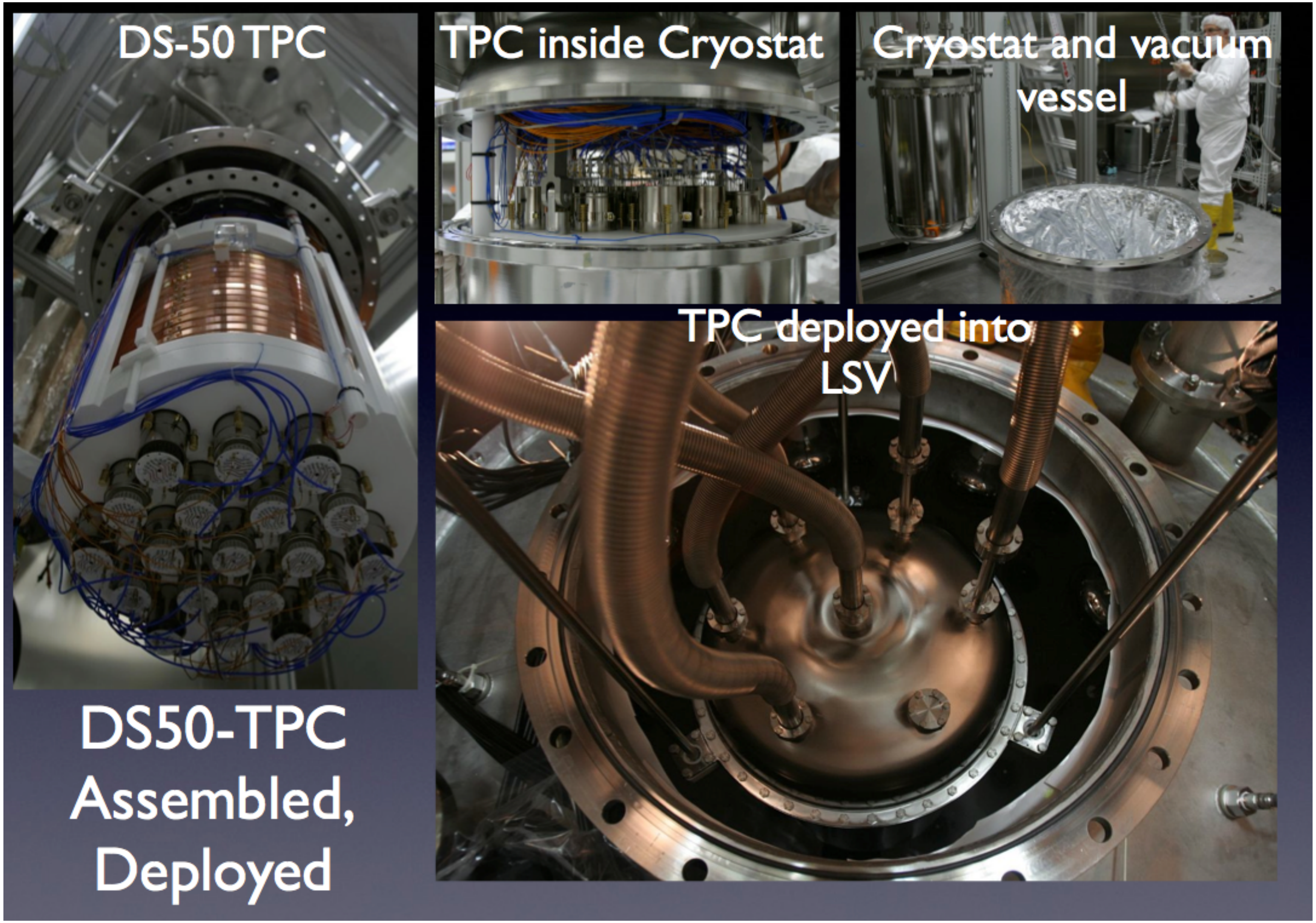
DarkSide-50

- 50 kg active mass of UAr
- 19 top + 19 bottom R11065 HQE 3’’ PMTs
- 36 cm height, 36 cm diameter
- Lateral walls covered by high reflectivity polycrystalline PTFE

- All inner surfaces coated with TPB
- Fused silica diving bell (top) and windows (bottom) in front of the PMT arrays, coated with ITO



DarkSide-50


DS-50 TPC
TPC inside Cryostat
Cryostat and vacuum vessel
TPC deployed into LSV
DS50-TPC Assembled, Deployed

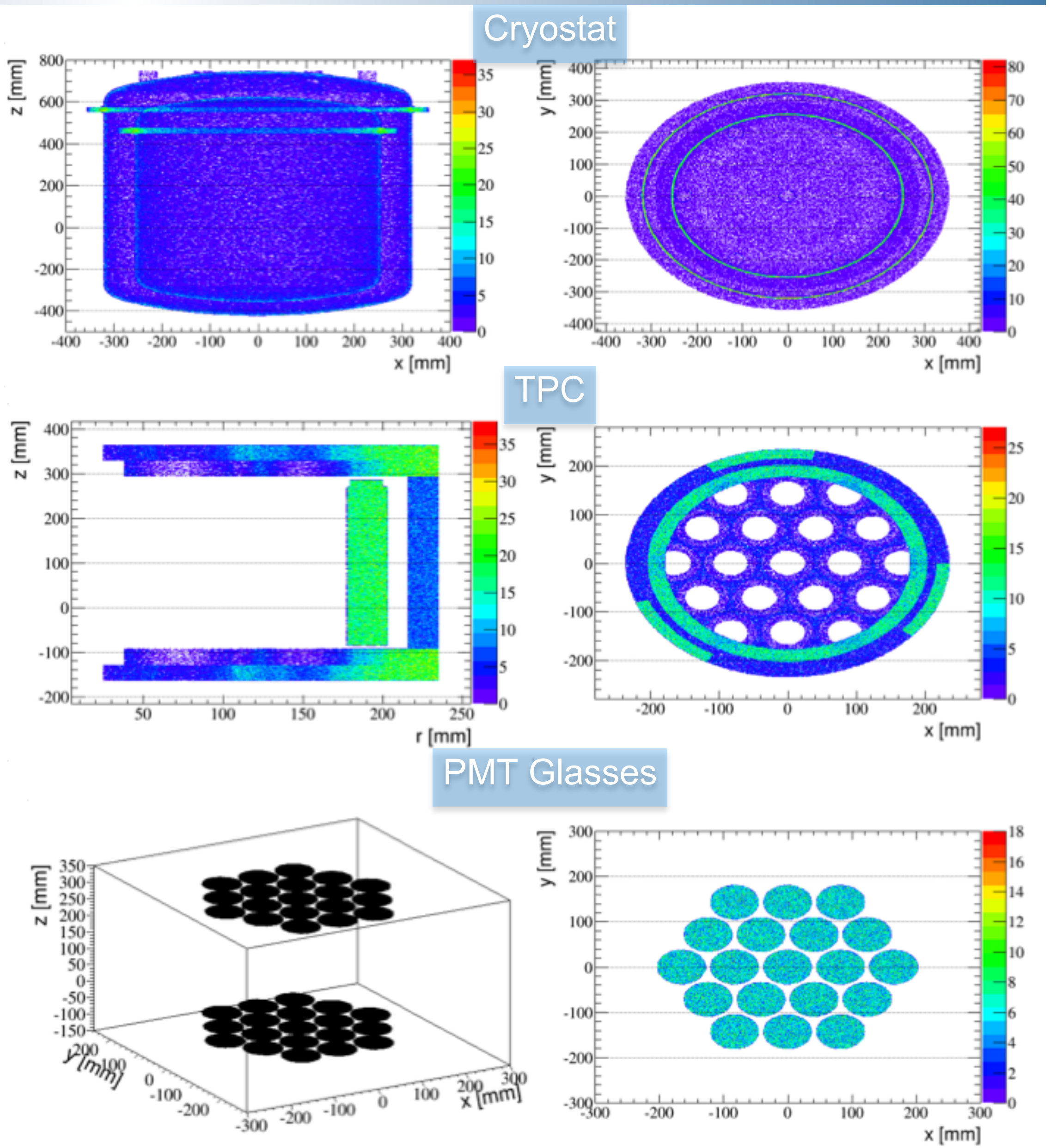
DarkSide-50

The DarkSide MonteCarlo

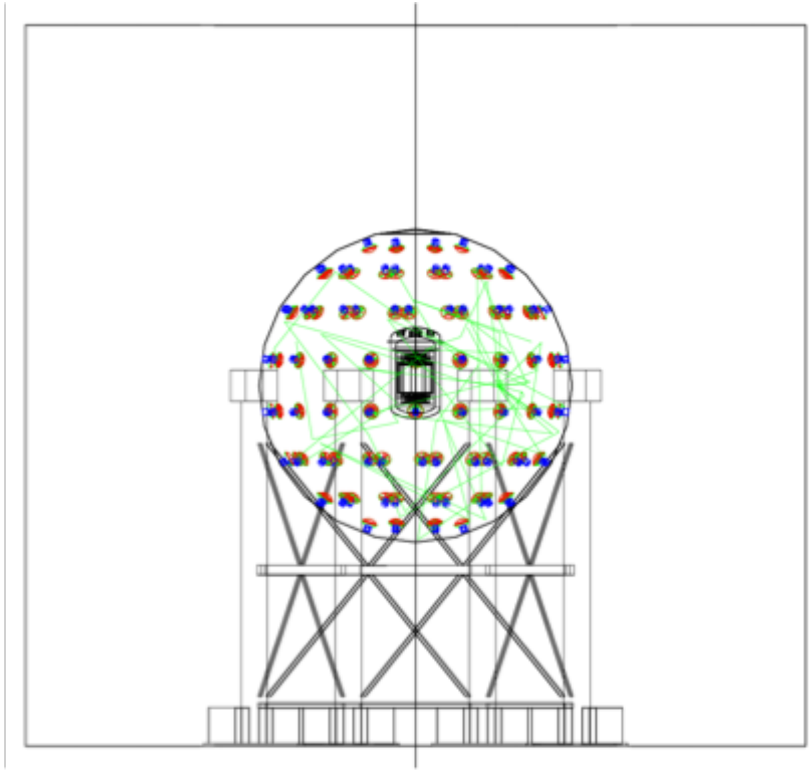
Developed at APC-IPHC

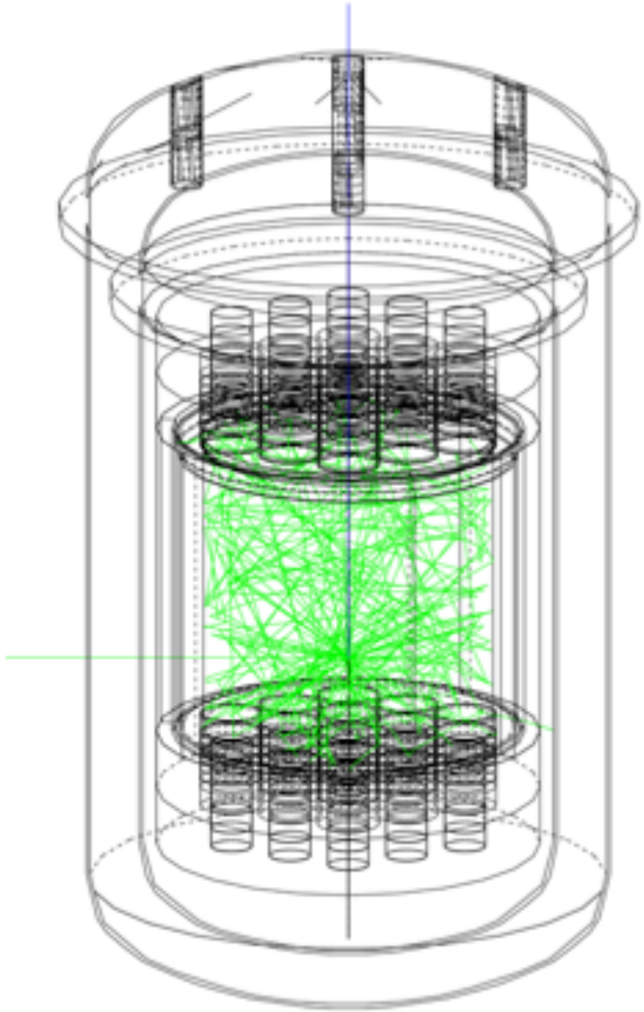
Full geometry description of:
- DarkSide-10
- DarkSide-50
- Multiple DarkSide-G2 designs
- Neutron Veto
- Muon Veto

Single photon tracking
Full description of the optical properties
Several generators
Two energy response model



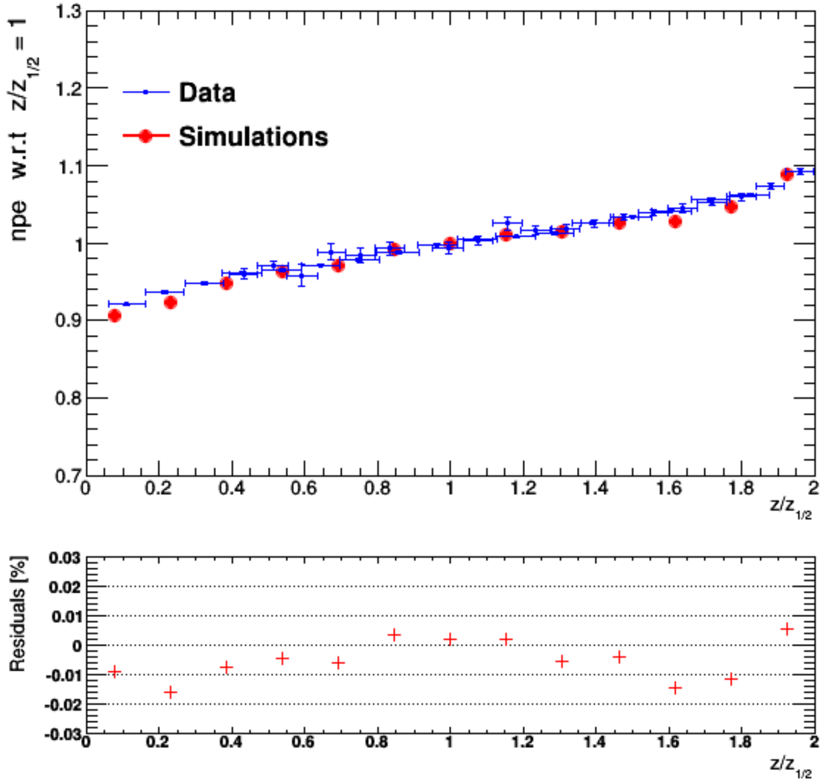
G4DS Single Photon Tracking

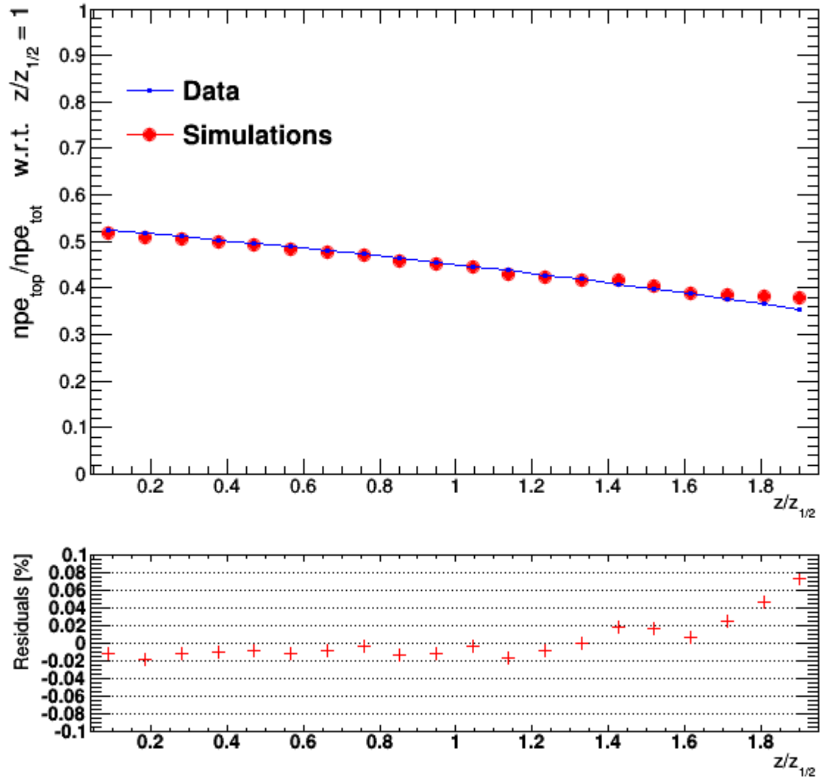




DarkSide-50 Optical Tuning

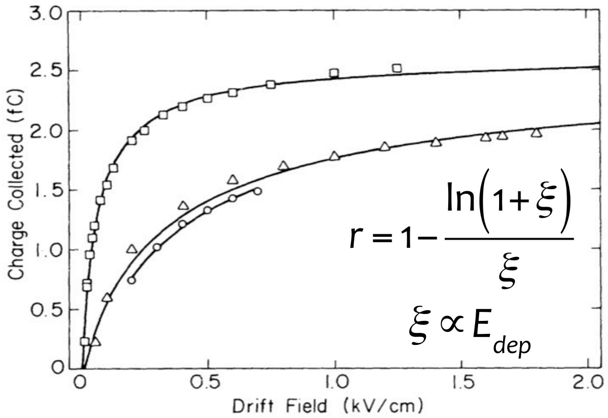
Tuning of the main 36 optical parameters





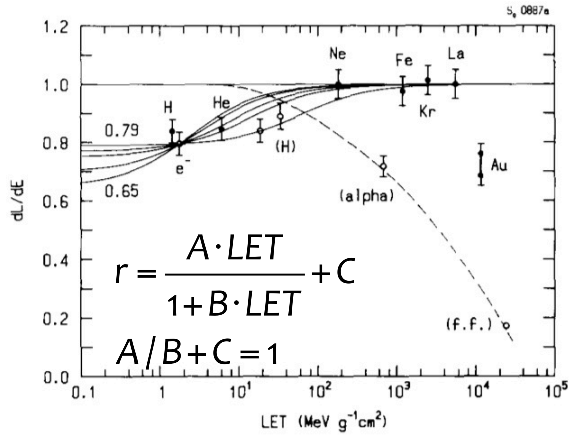
Few percent accuracy

The LAr Low Energy Response

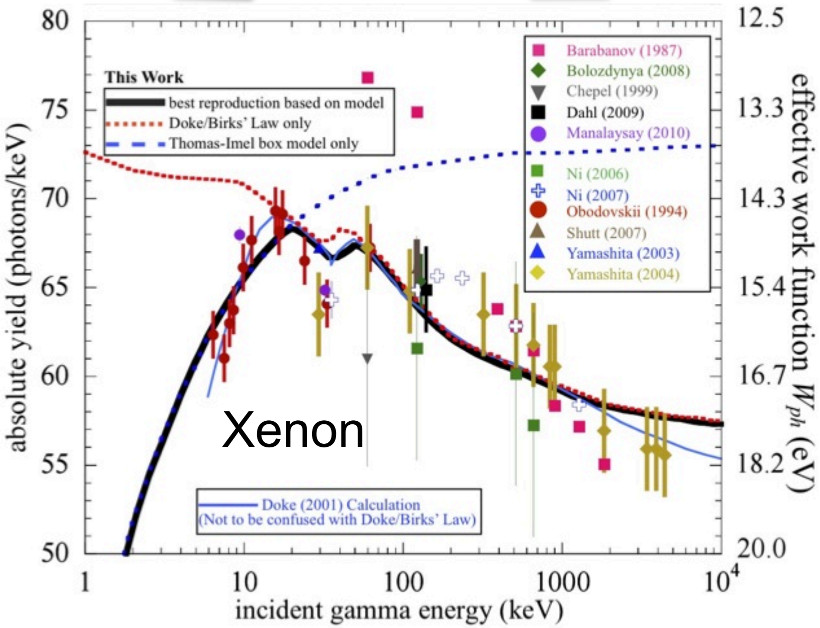


Thomas-Imel Model

Models of Recombination Probability

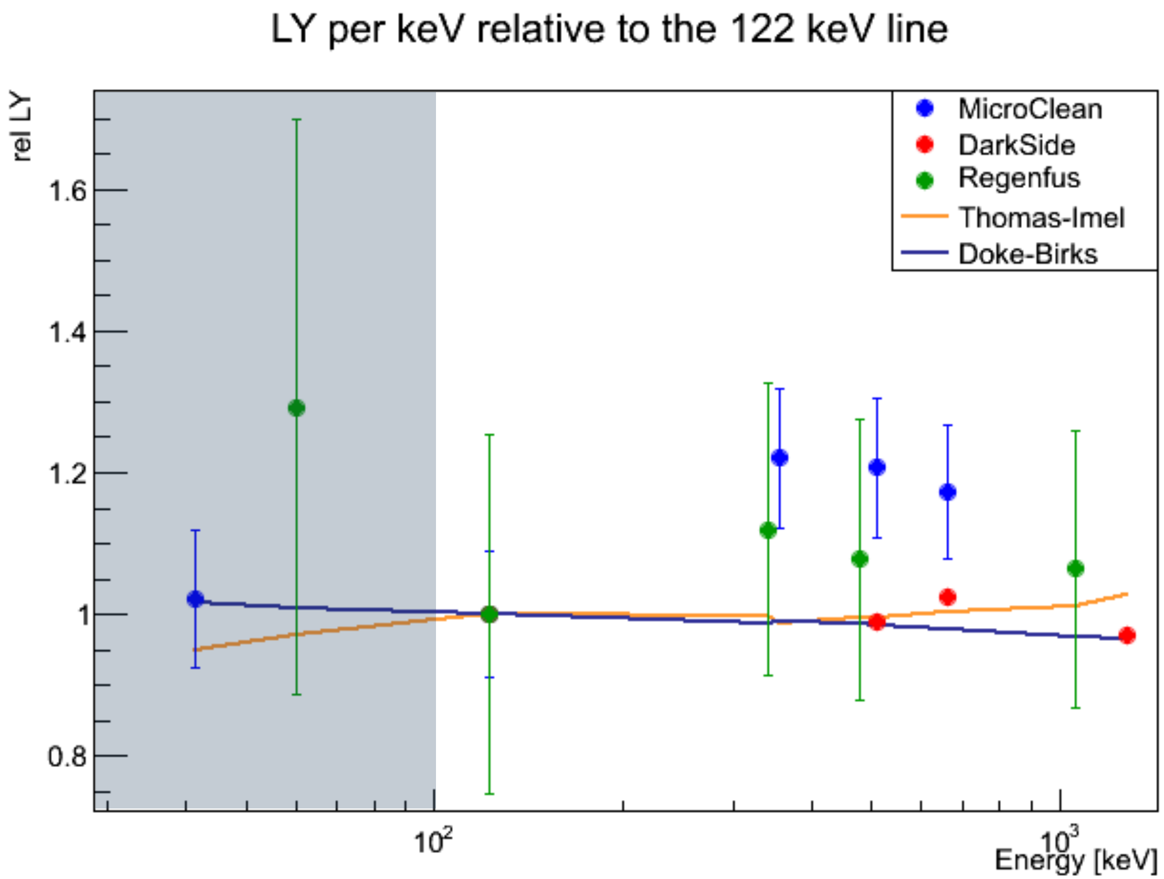


Doke-Birks Model



NEST

Scintillation Models in LAr



MicroClean: PRC81, 045803 (2010)
DarkSide: arXiv:1204.6218v2
Regenfus: arXiv:1203.0849v1

Electron Drift Lifetime

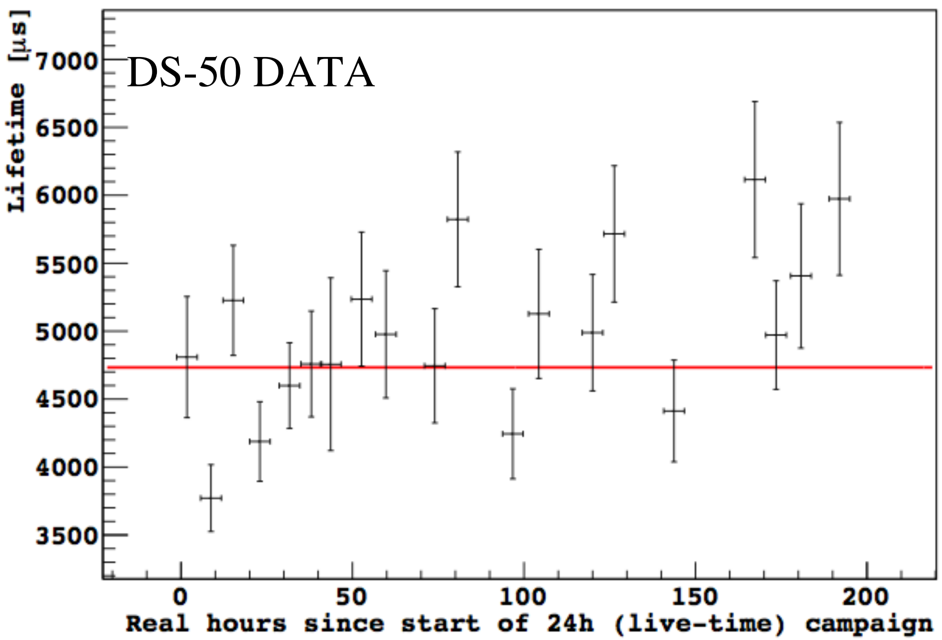
Achieved drift lifetime of

4733 +/- 90 μs

Maximum drift time of the TPC is ~370 μs at 200 V/cm drift field.

Demonstrates:

- high purity of argon
- Stable operation of electric fields

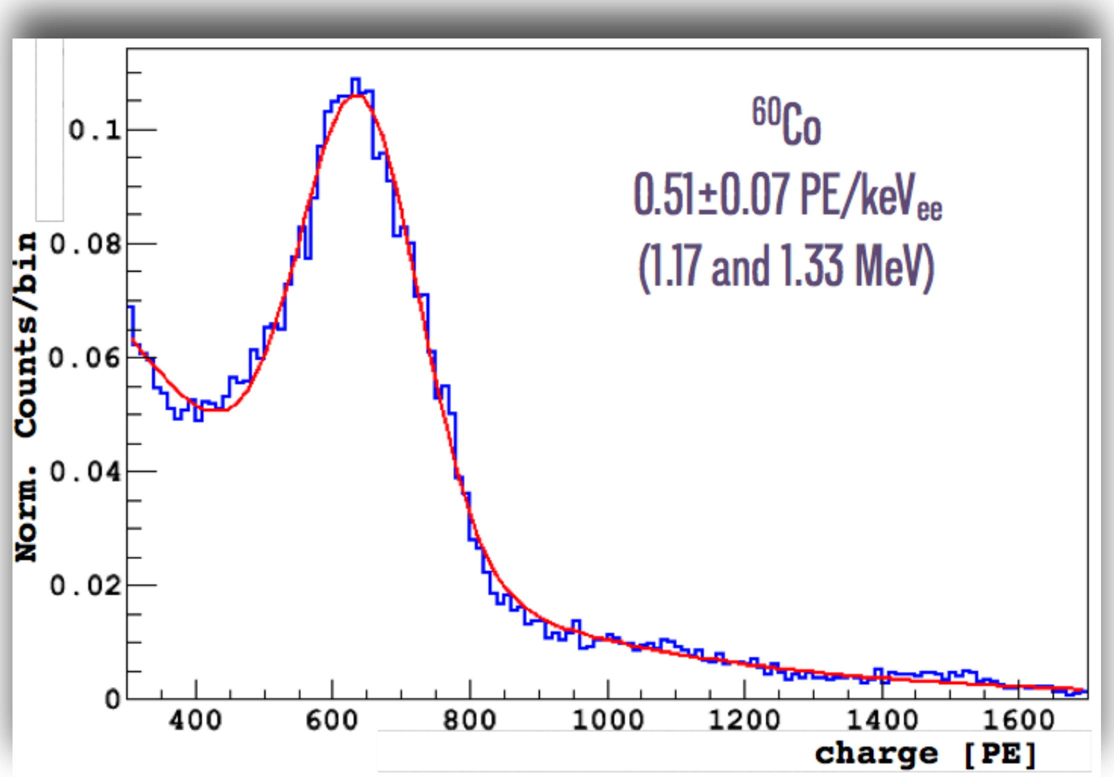


Outer Veto Commissioning

Light Yield:
liquid scintillator VETO LY of ~ 0.5 PE/keV$_{ee}$, satisfactory for VETO requirements.

Rate:
The background studies in the LS VETO evidenced a high rate due to 14C

- Identified 14C from TMB
- Identified and assayed a new batch of TMB with low 14C content
- TMB presently removed



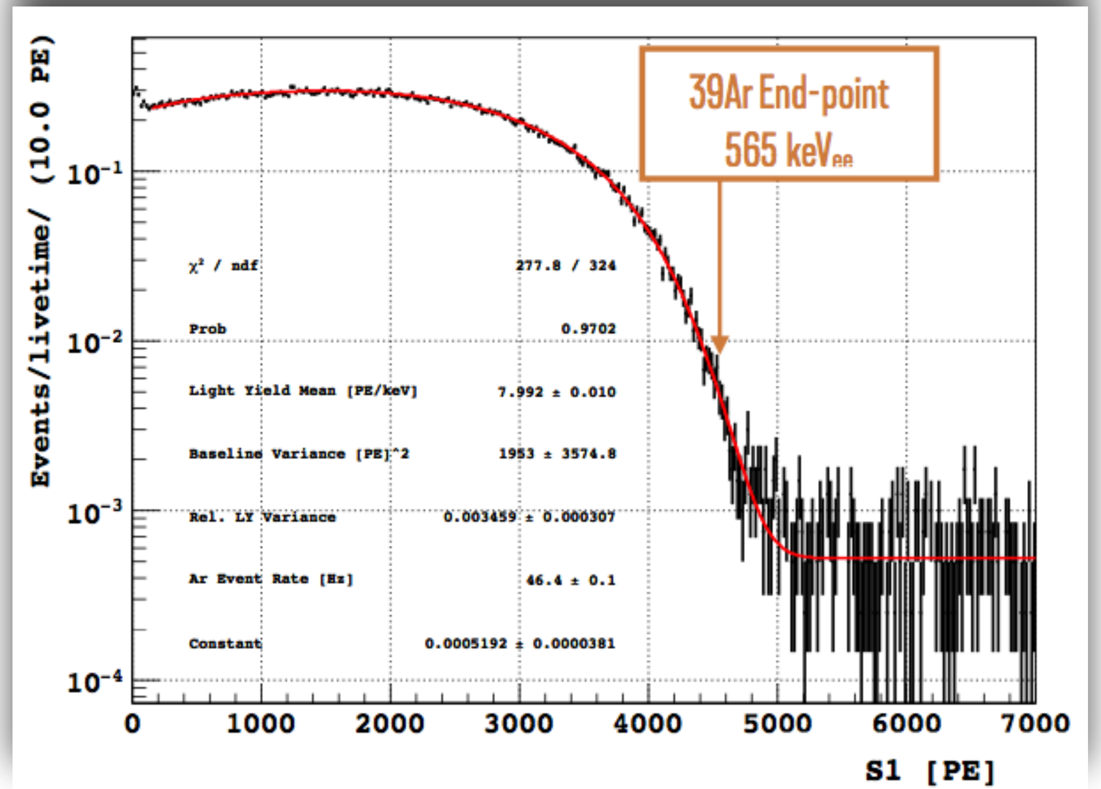
TPC: ER calibration @ null field

Light yield: critical parameter for argon detector exploiting PSD

Atmospheric LAr

39Ar rate: 46.4 Hz

Uniformly distributed in the volume



TPC: ER calibration @ null field

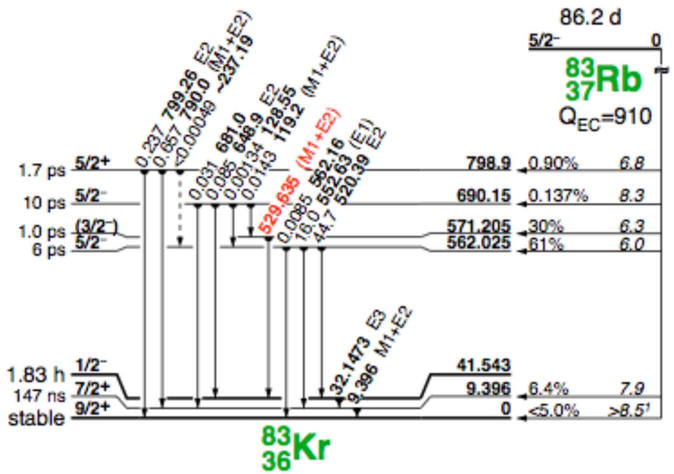
Light yield: critical parameter for argon detector exploiting PSD

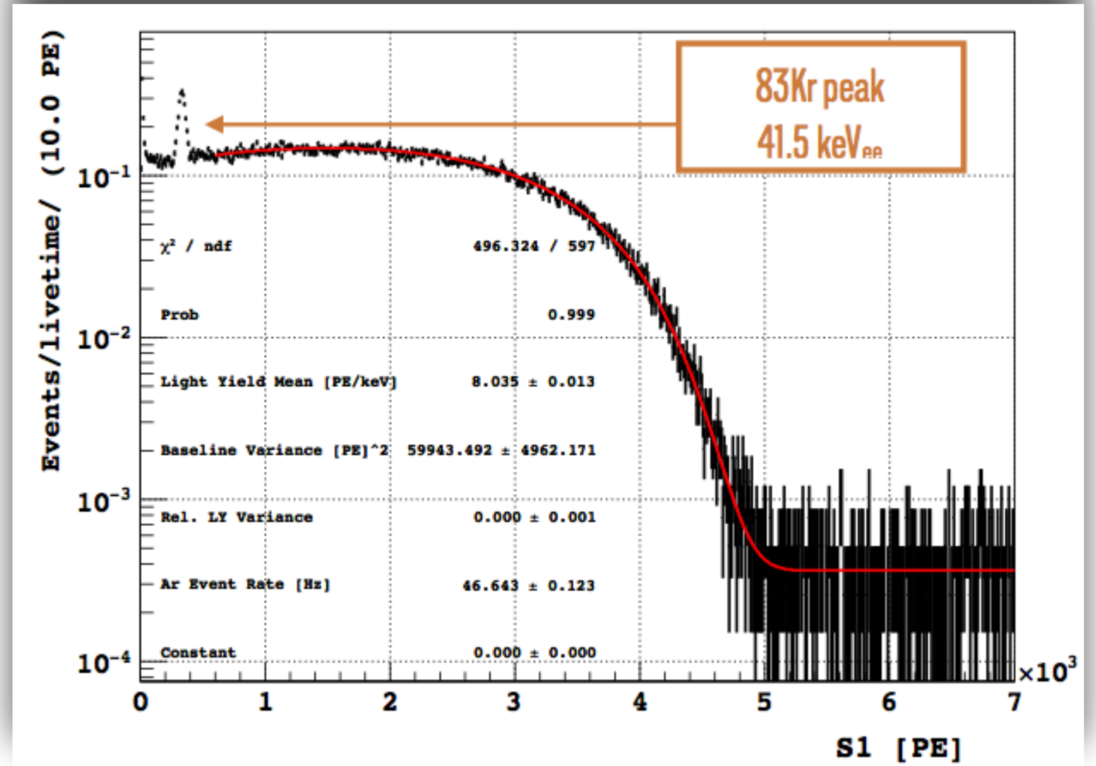
Injected gaseous ^{83m}Kr

Two sequential decays producing IC electron, gammas or x-ray (154 ns)

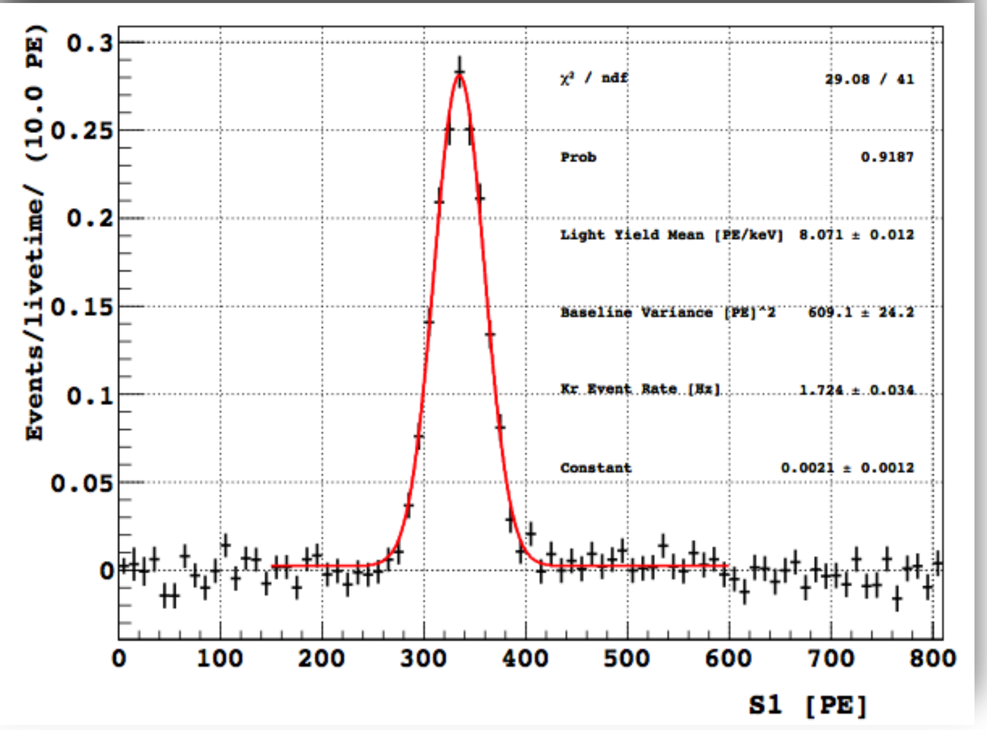
Total energy 41.5 keVee

Half-life: 1.83 hr



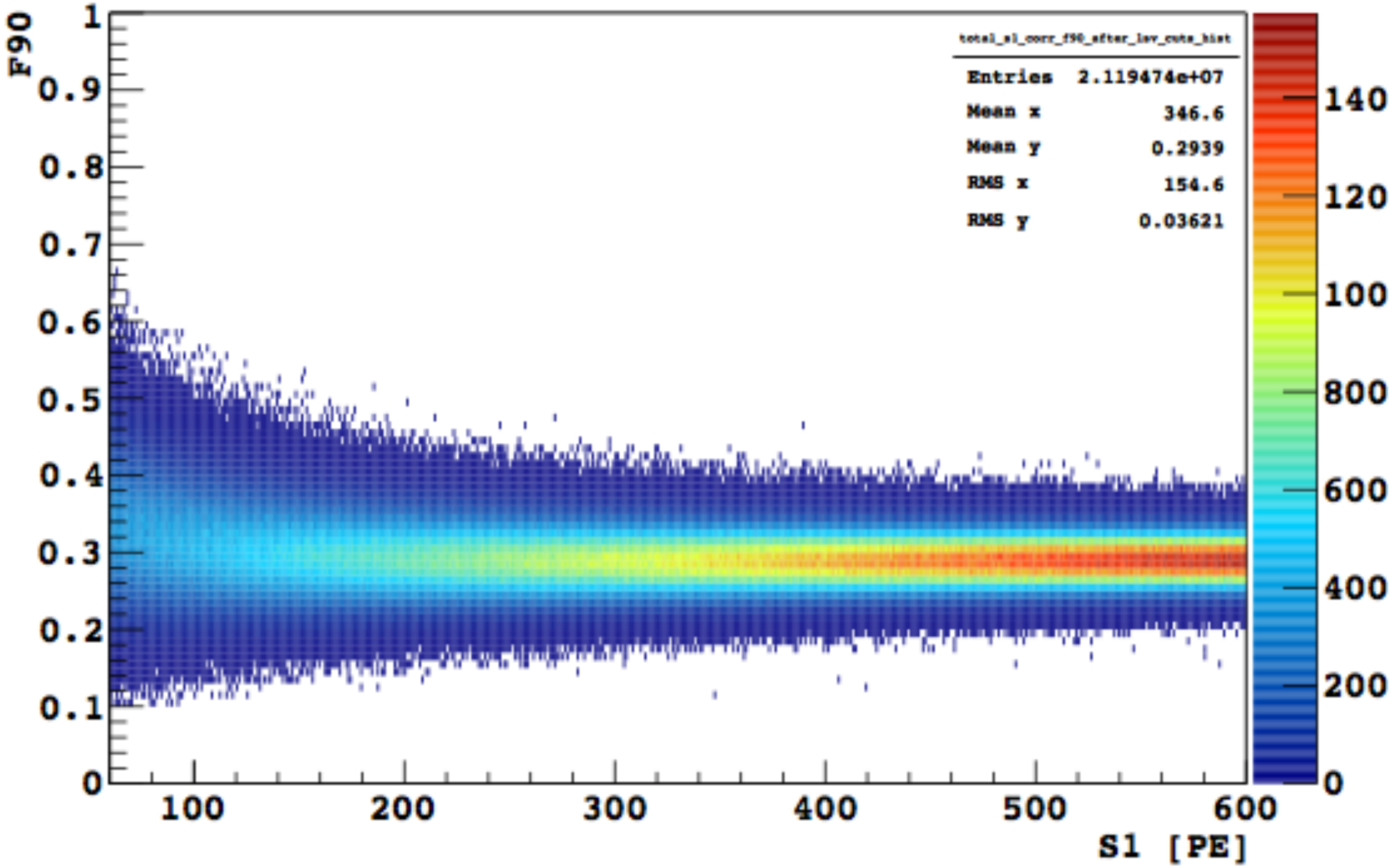


TPC: ER calibration @ null field



Average Light Yield: 8.040 ± 0.006 (stat) pe / keVee

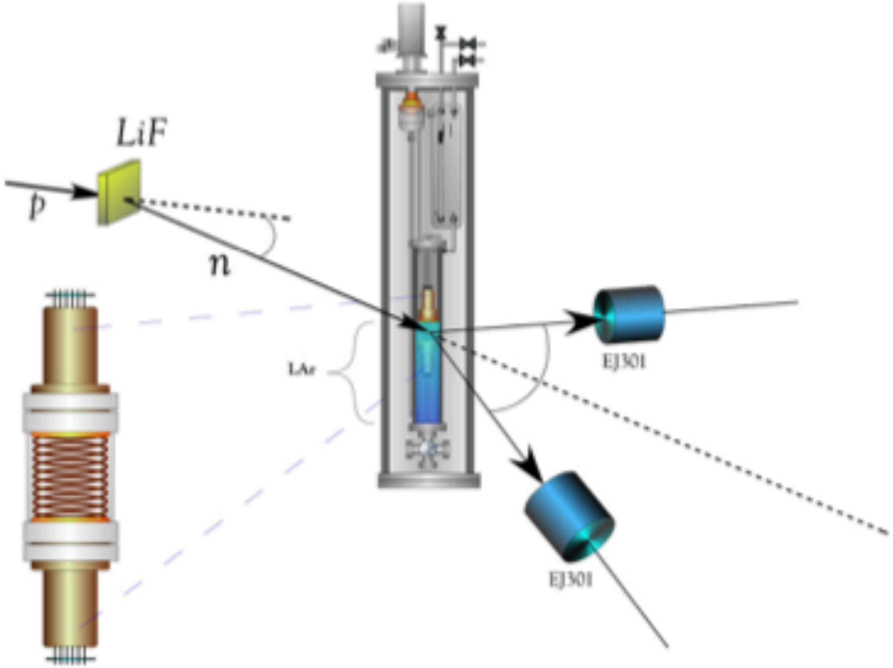
Background free exposure of 280 kg x day

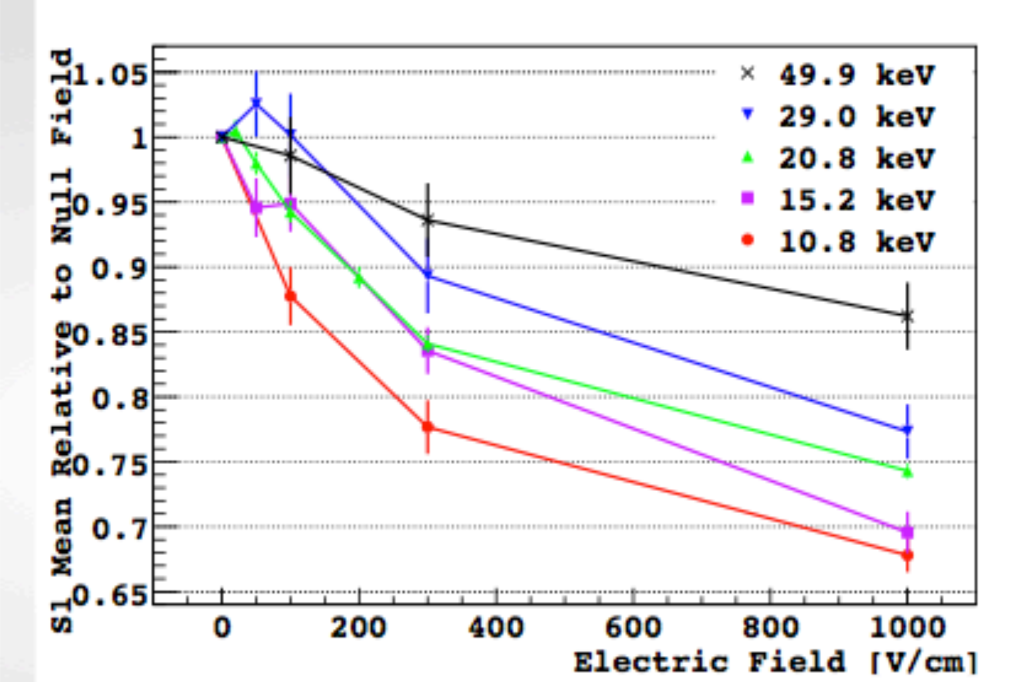


NR calibration @ 200 V/cm

SCENE

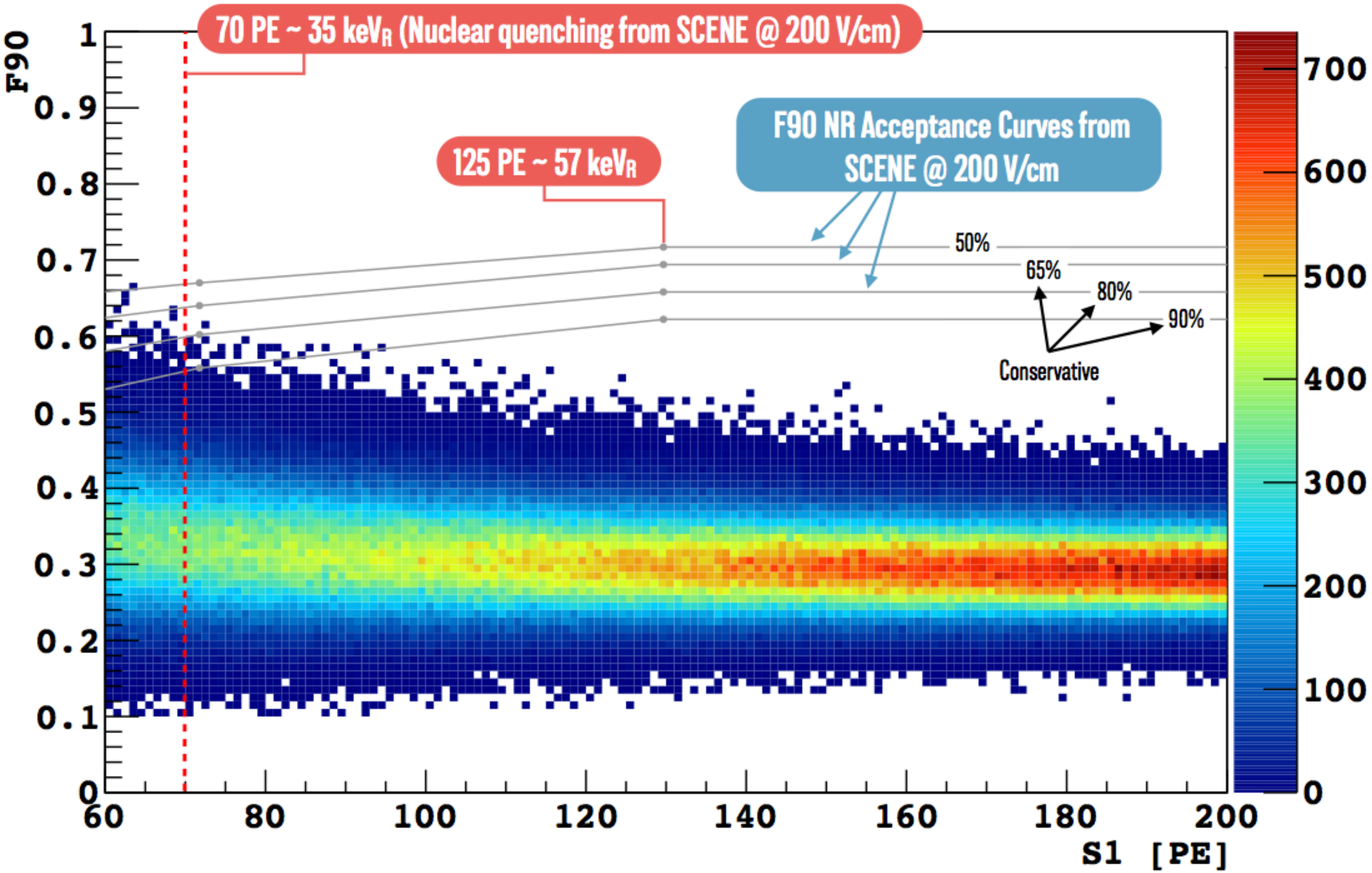
Scintillation Efficiency of Nuclear Recoils in Noble Elements



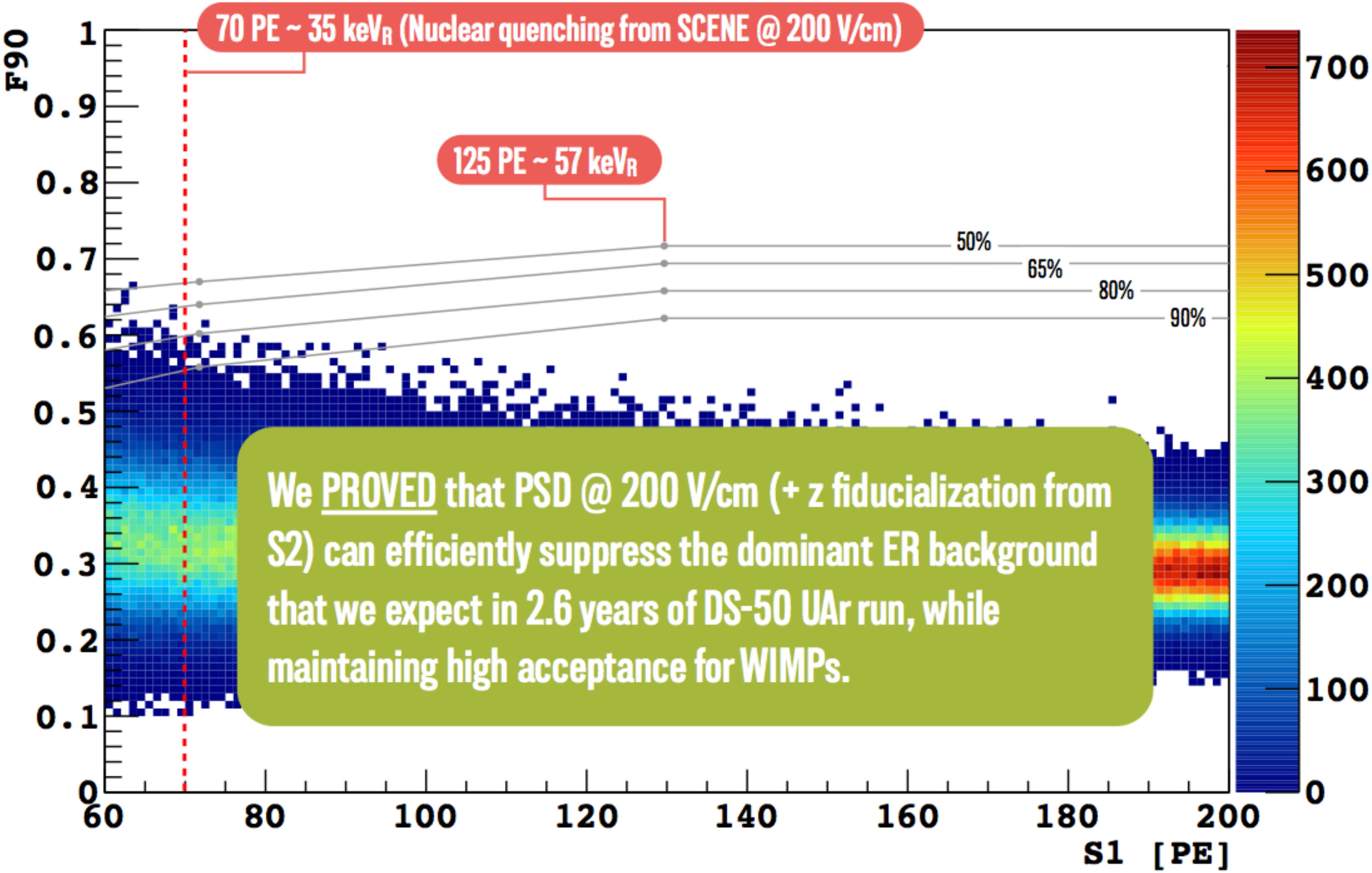


SCENE has collected extremely pure samples of single nuclear recoils in a small TPC resembling DS-50 TPC design. We opted to use SCENE data @ 200V/cm, which we have access to. We have extrapolated the quantities of interest to the present analysis and, equally important, the associated systematics.

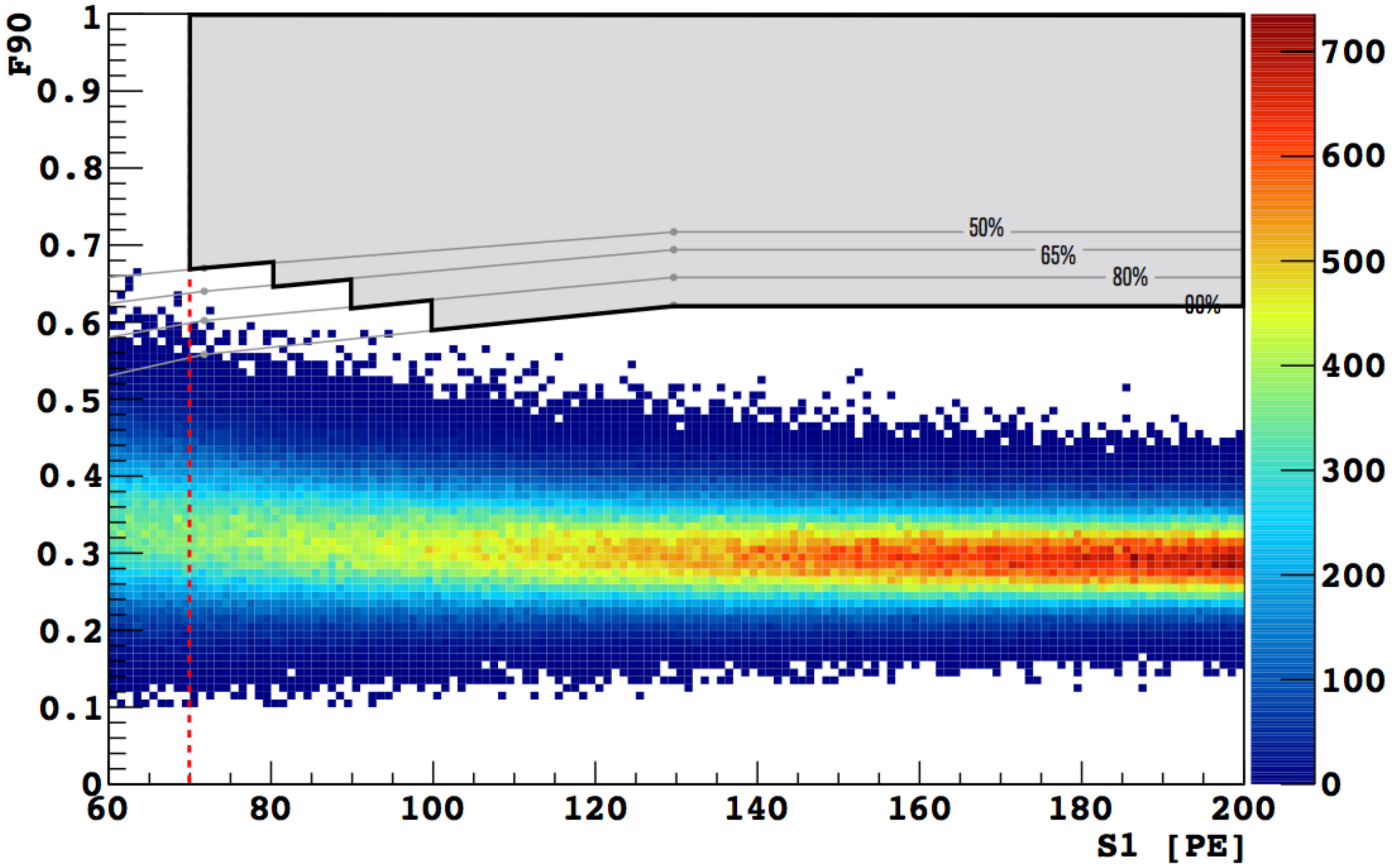
Background free exposure of 280 kg x day



Background free exposure of 280 kg x day



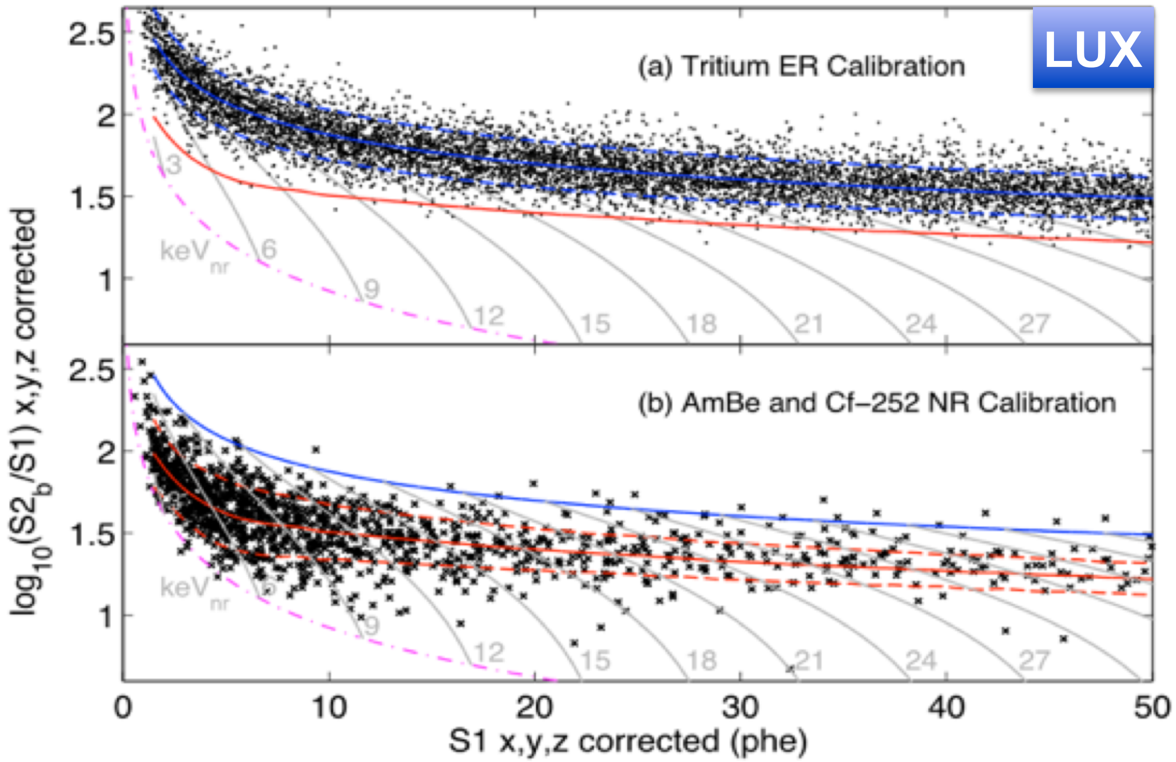
Background free exposure of 280 kg x day



To comparison: discrimination in Xe

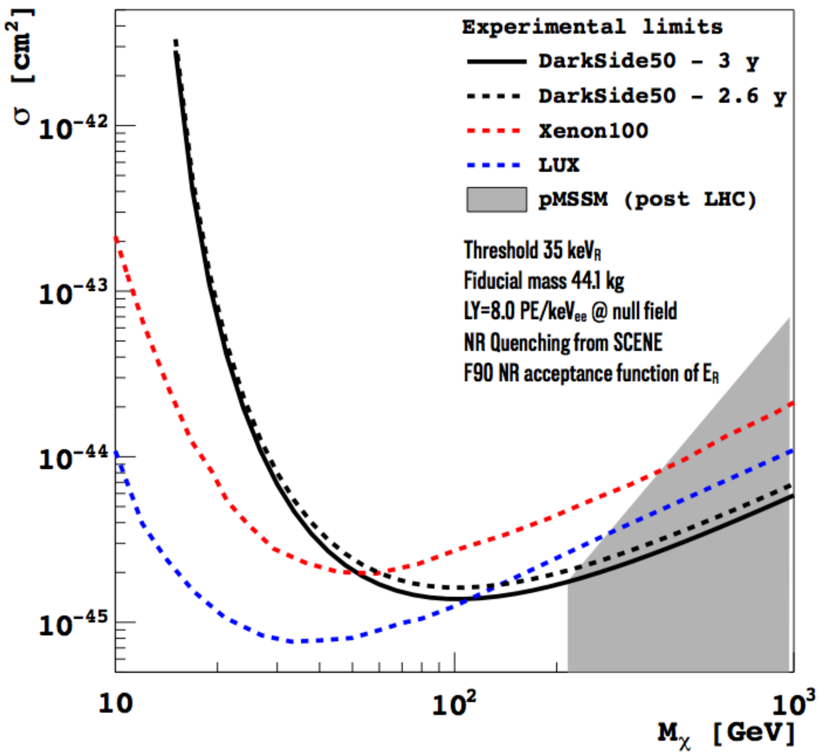
Electron Recoil and Nuclear Recoil Bands

Tritium provides very high statistics electron recoil calibration (200 events/phe)
Neutron calibration is consistent with NEST + simulations



Gray contours indicate constant energies using a S1-S2 combined energy scale

DS-50 projected sensitivity



Projected sensitivity evaluated assuming:

- the measured PSD performance;
- no rejection from S2/S1;
- fiducial volume along z axis-only;
- zero neutron-induced events;
- NR quenching and F90 acceptance curves from SCENE @ 200V/cm

Present systematics on NR Quenching and F90 NR acceptance curves responsible of ~10% variation of the projected sensitivity around 100 GeV/c^2.

DarkSide-G2

Scaled and improved inner detector, and cryogenic/purification systems.

Goal: **high light yield and radio/chemical-purity**

Radio-pure material selection ongoing

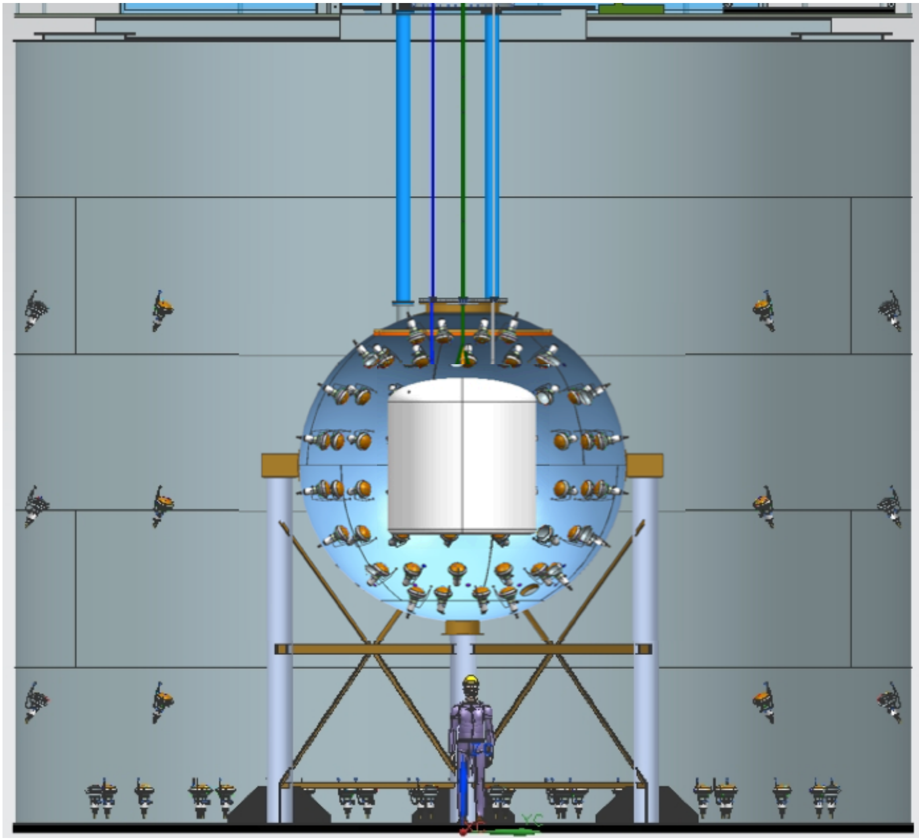
Stainless steel (cryostat, PMT support)

Copper field cage

PTFE for segmented reflective cylinder

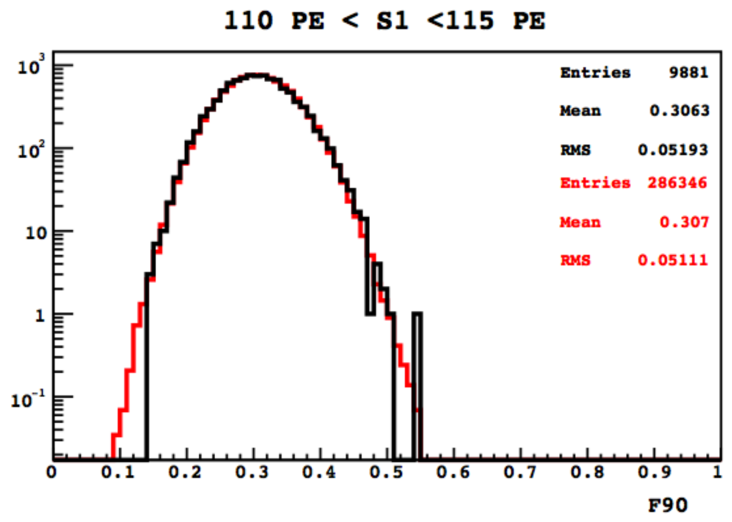
Fused silica for windows/diving bell

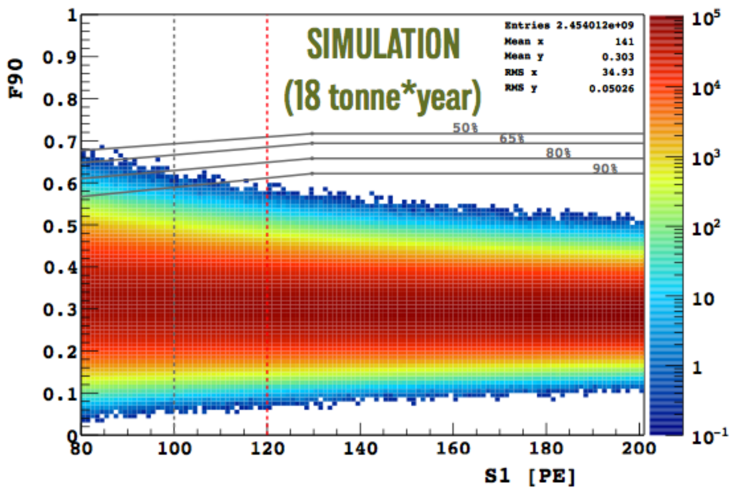
Wavelength shifter on reflective surfaces



PSD extrapolation in DS-G2

Model the statistical properties of the F90 discrimination parameter using statistical distributions of the underlying processes with parameters taken from data. The model accounts for macroscopic effects related to argon micro-physics, detector properties and reconstruction and noise effects.

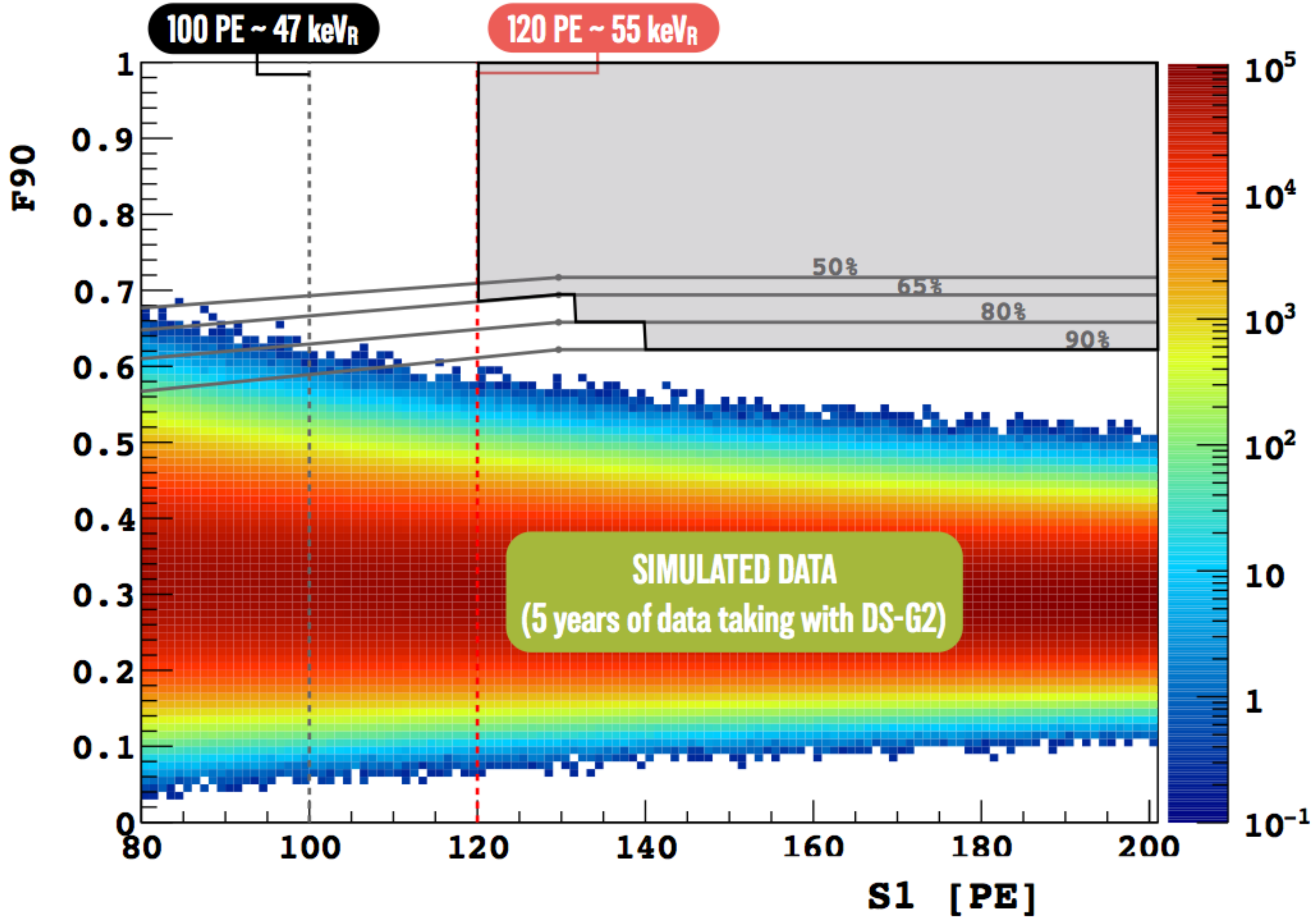




Excellent agreement through several orders of magnitude

Simulated F90 distribution for DS-G2 5 years run, assuming the ER background in the fiducial volume will be dominated by ^{39}Ar @ its present upper limit.

PSD extrapolation in DS-G2



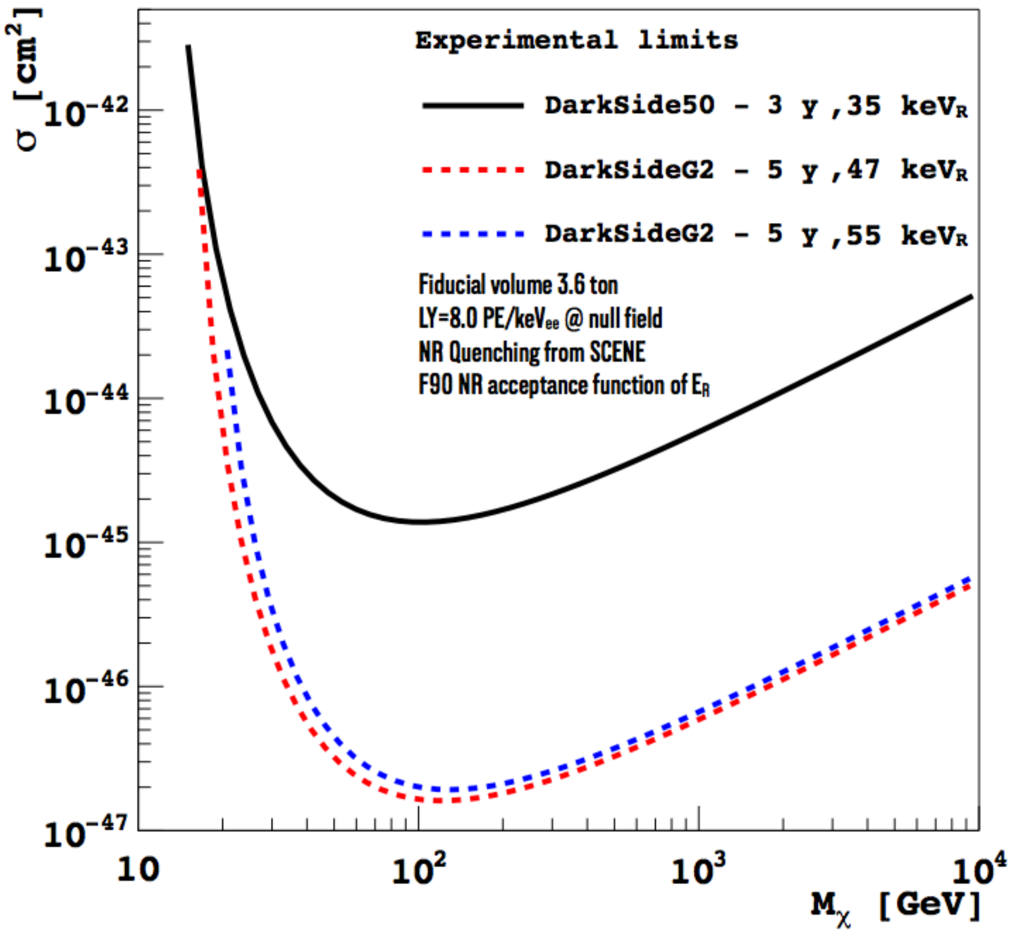
DS-G2 Sensitivity

Fiducial volume 3.6 ton

LY=8.0 PE/keV_{ee} @ null field

NR Quenching from SCENE

F90 NR acceptance function of E_R



Assuming:

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

Conclusions

DS-50 detector is running @ LNGS since Oct. 13:

- LAr TPC successfully commissioned
- Vetoes (designed to host DS-G2) successfully commissioned
- Scheduled to use Borexino distillation plant to separate PC from TMB and insert the new TMB with low 14C content

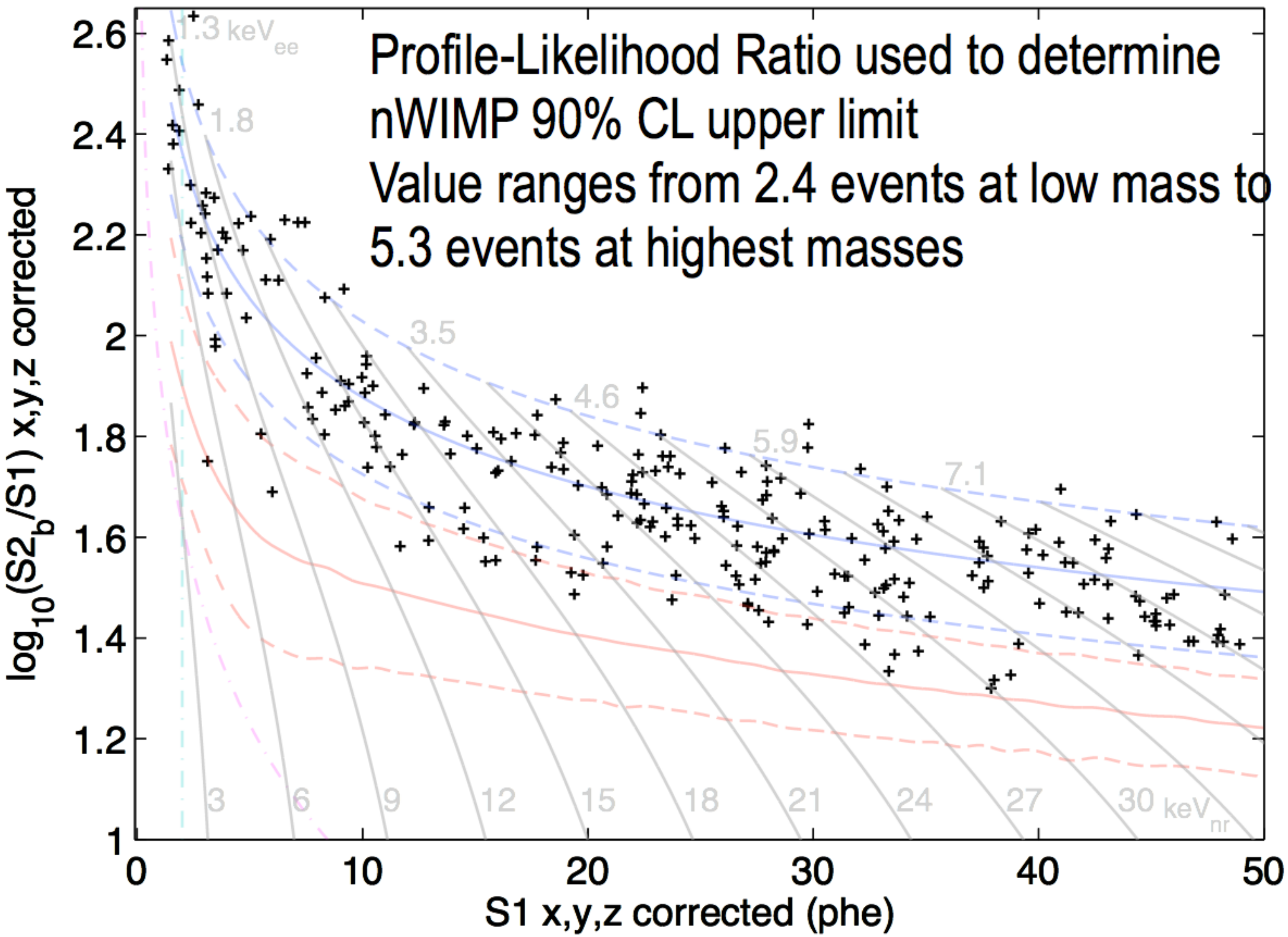
Demonstrated PSD performance needed to reject the expected background from ^{39}Ar (at the level of present upper limit) in 2.6 years of DS-50

Plan to calibrate DS-50 and to further study PSD until June when we will switch to UAr and to WIMP search mode

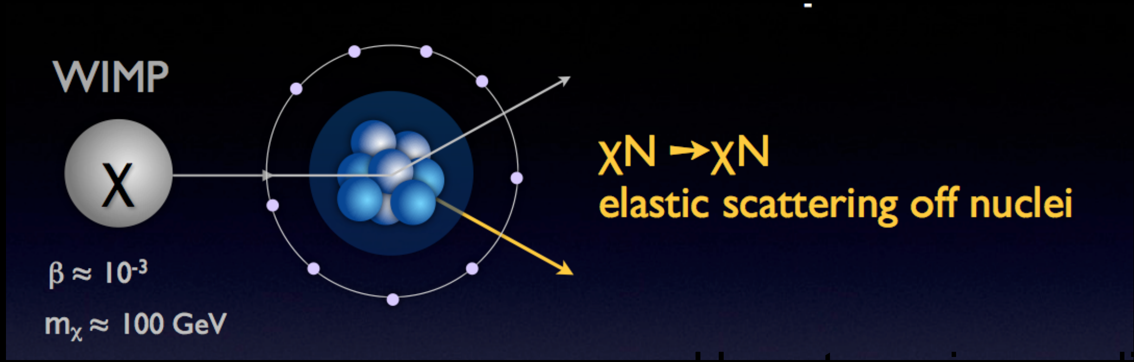
DS-50 results extrapolated conservatively to DS-G2 indicate the possibility of running for 5 years ^{39}Ar-free

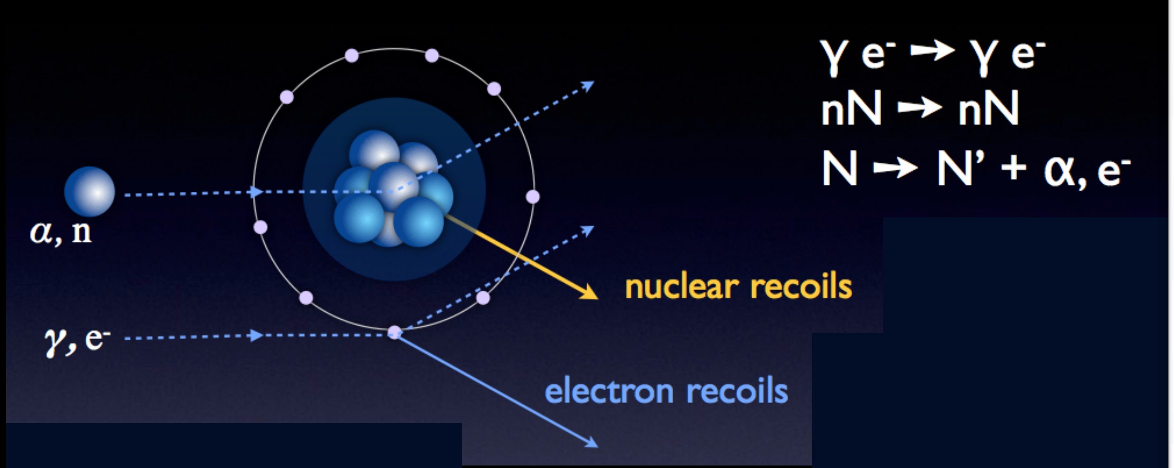
BackUp

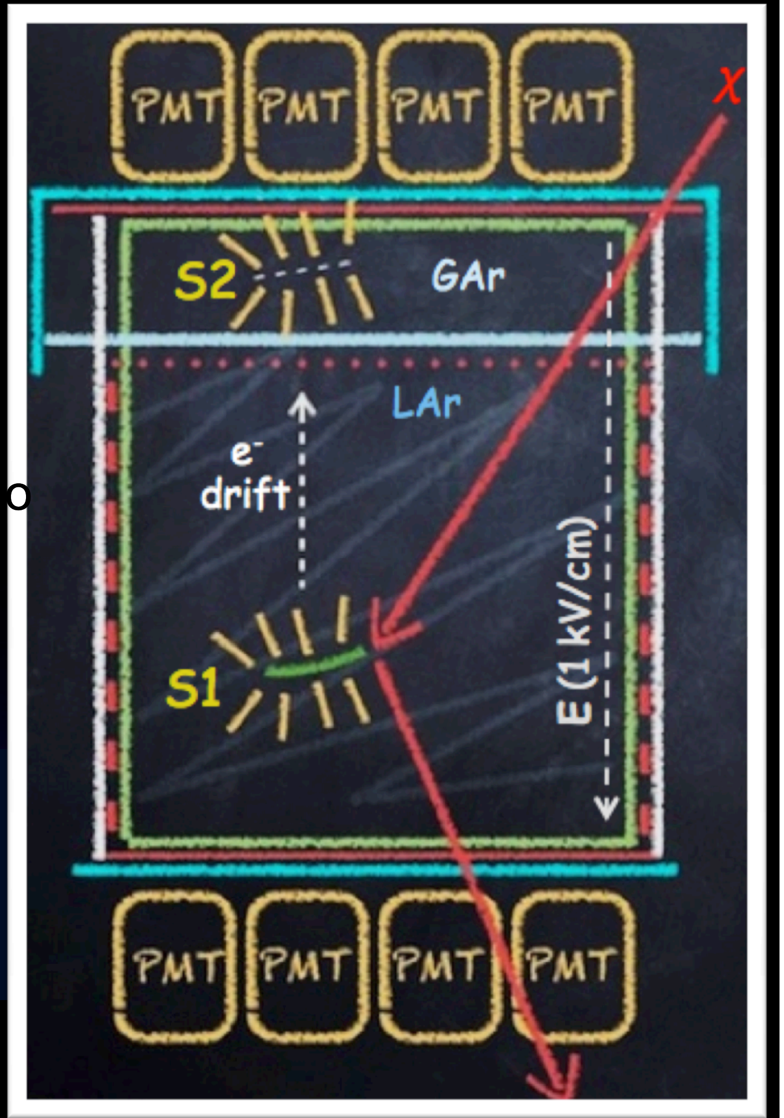
LUX WIMP Search, 85 live-days, 118 kg



Double Phase TPC







The WIMP Hunt