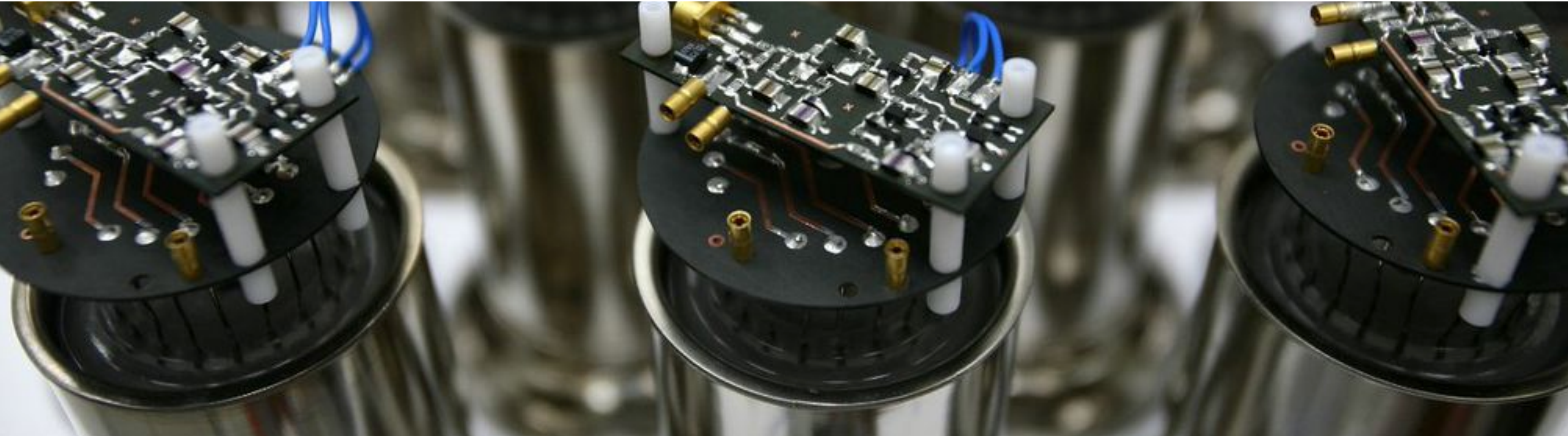


Status and perspectives of the DarkSide experiment at the LNGS

Paolo Agnes

University of Houston

for the **DarkSide** Collaboration

Les Rencontres de Physique de la Vallée d'Aoste

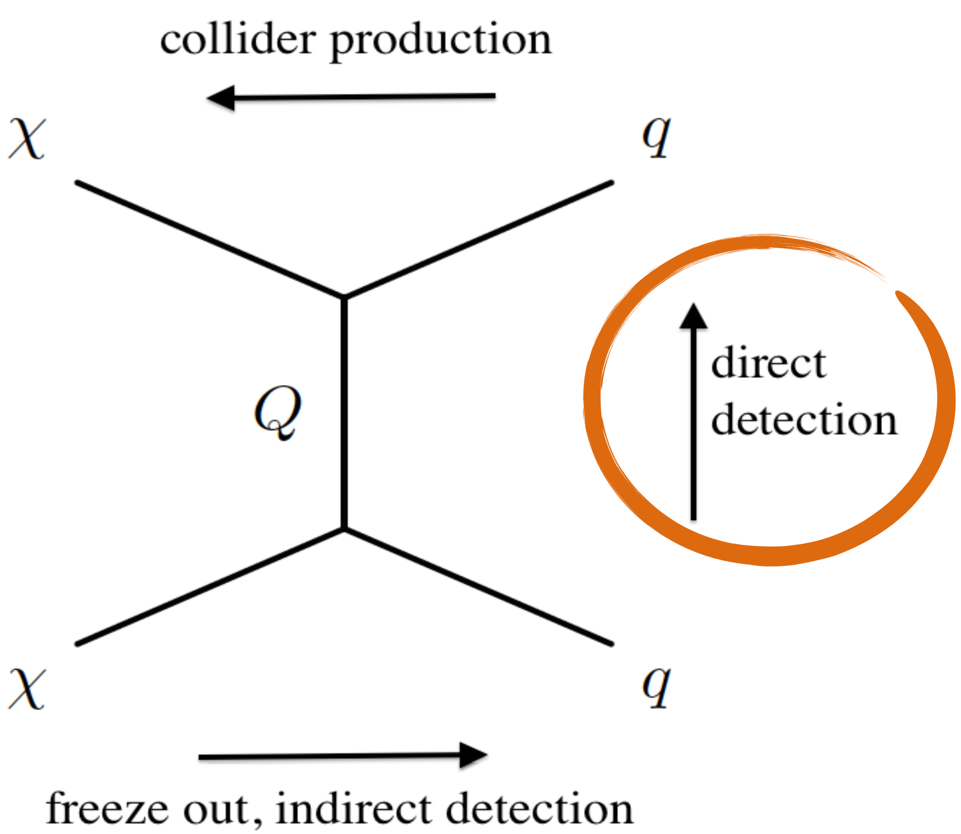
7 March 2017

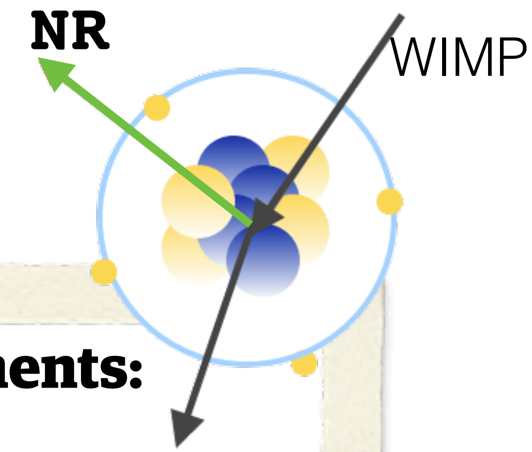
La Thuile

Direct detection of WIMPs

The WIMP properties:

- It is stable
- It interacts through gravitational force
- It is electrically neutral
- It does not interact strongly
- It should have preferential direction
- It may interact weakly





Detection requirements:

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

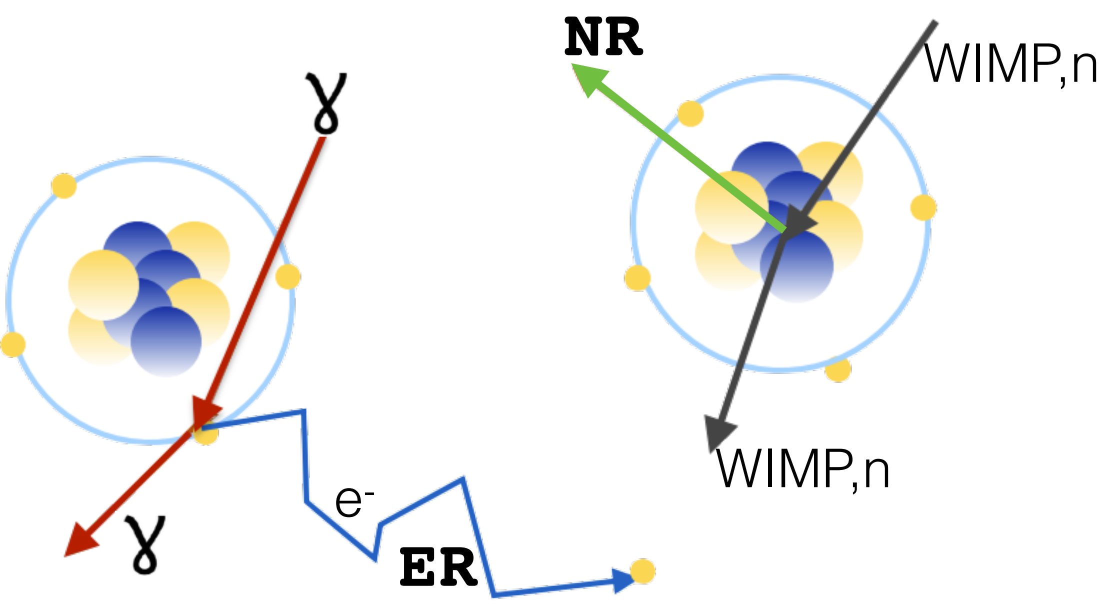
-Low energy thresholds
Low energy nuclear recoils (< 100 keV)

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

Direct Detection in Noble Liquids

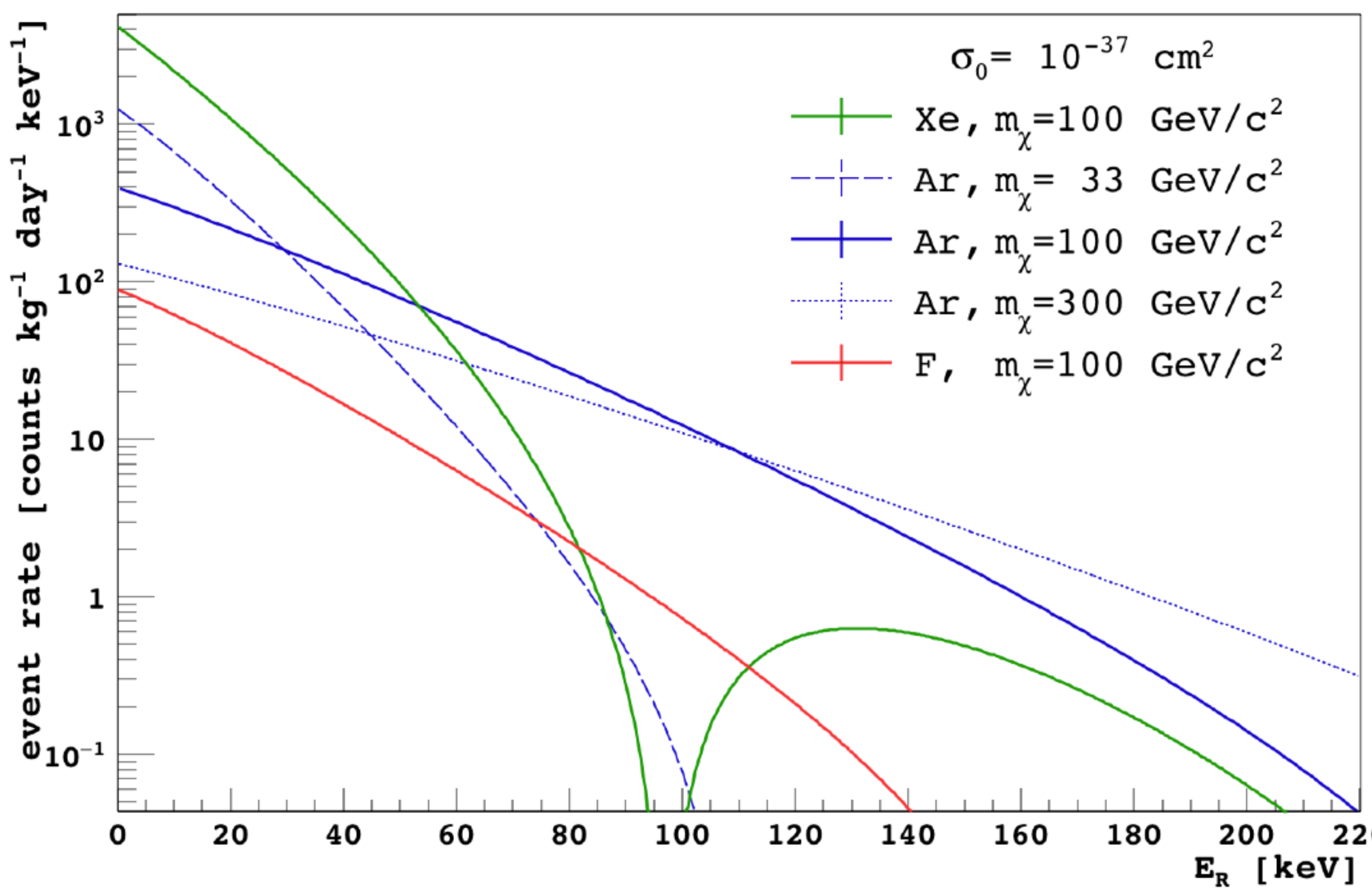
Dense and easy to **purify**

High **ionisation** yield (W ~ 10-20 eV)
High **scintillation** yield (> 50,000 photons/MeV)
Transparent to their own scintillation
High electron mobility and low electron diffusion
Discrimination electron/nuclear recoils (**ER/NR**)
with **ionisation/scintillation ratio**

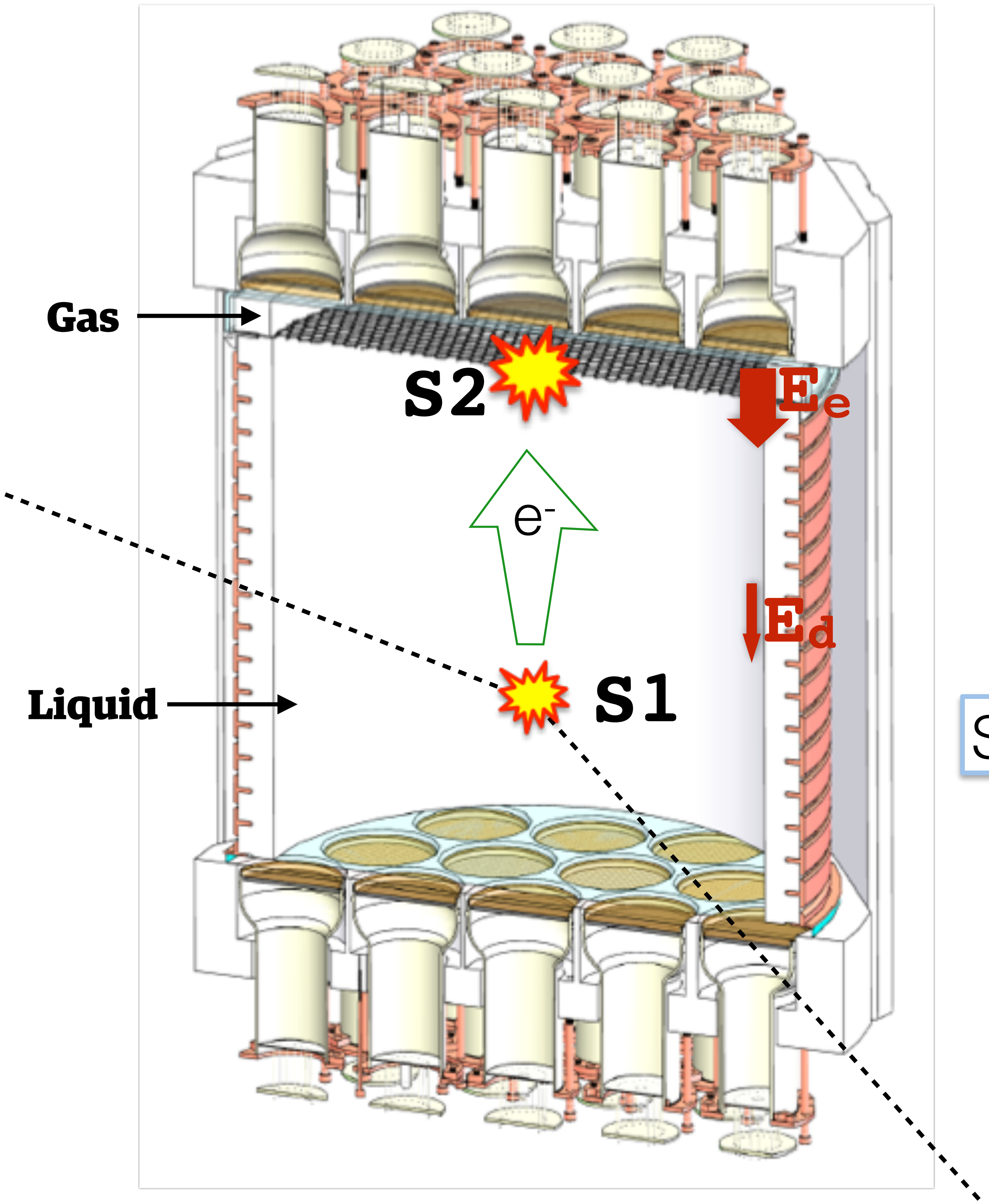


Liquid Xenon (LUX, XENON, PandaX)
Higher sensitivity to low masses at low thresh
More dense (self-shielded)
High intrinsic radio-purity

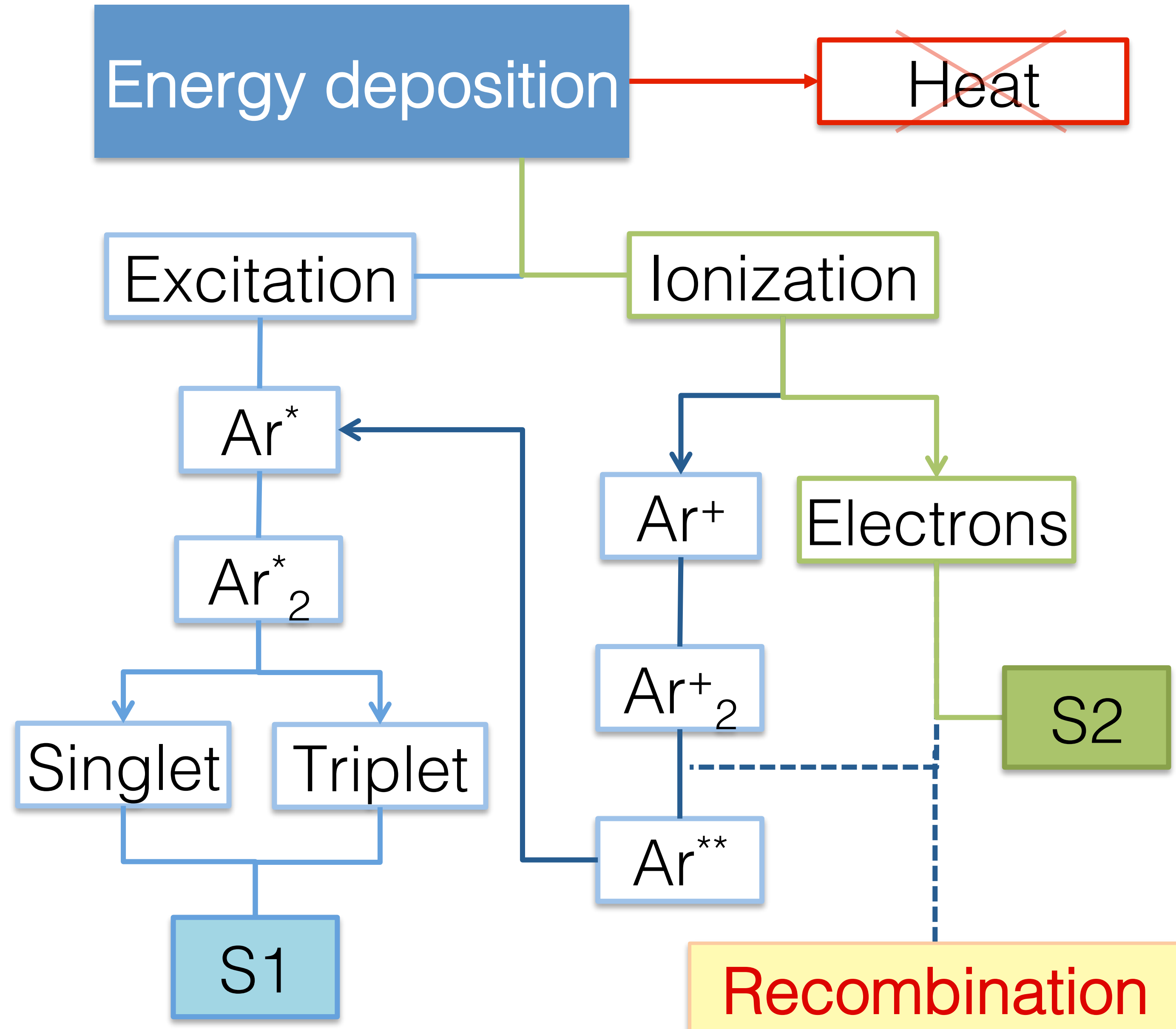
Liquid Argon (DarkSide, DEAP, ArDM)
Better ER discrimination:
ionisation/scintillation + **PSD**
Intrinsic contamination from ^{39}Ar
(it can be depleted)



Dual-phase TPC

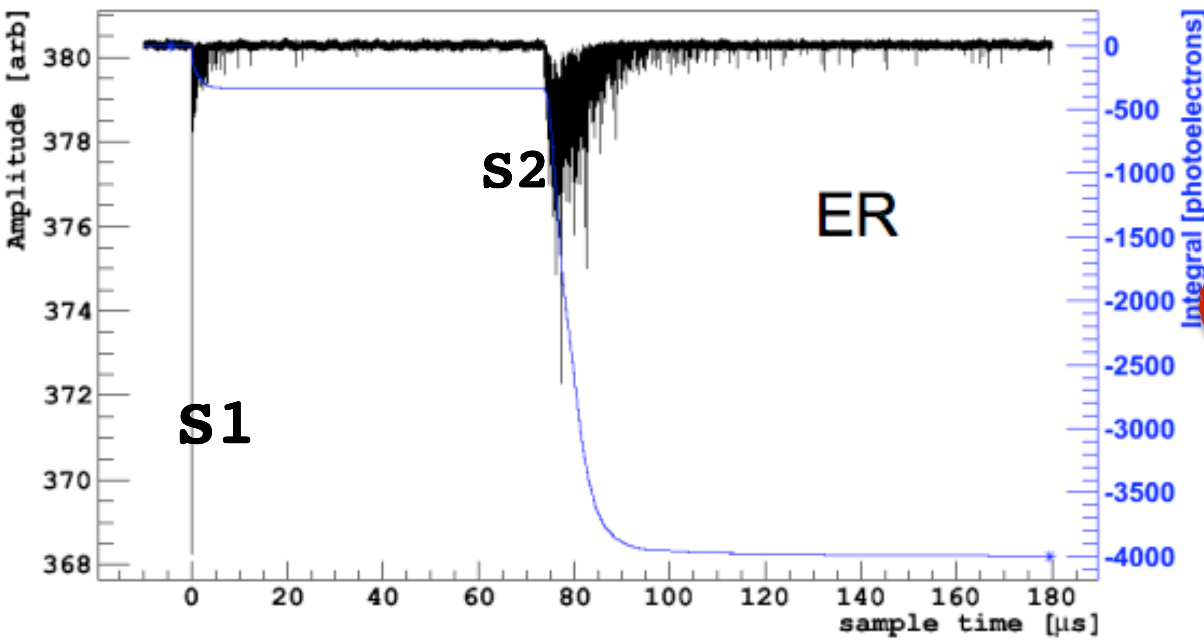


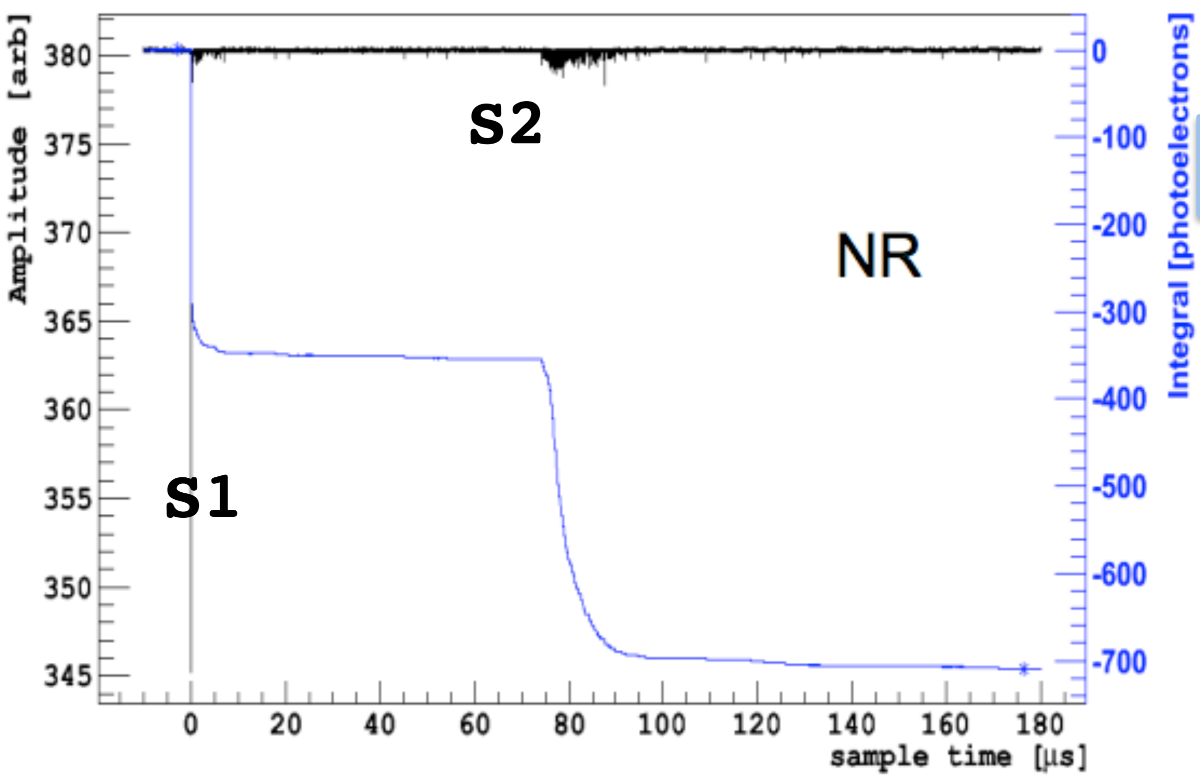
3D position reconstruction

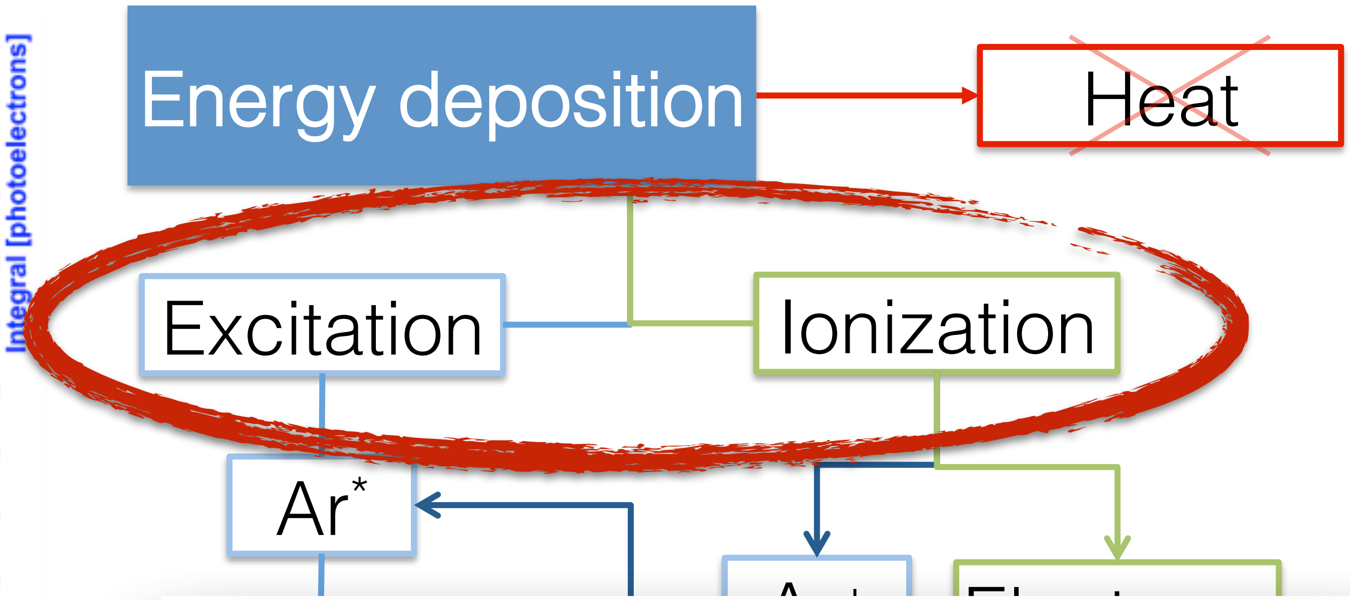


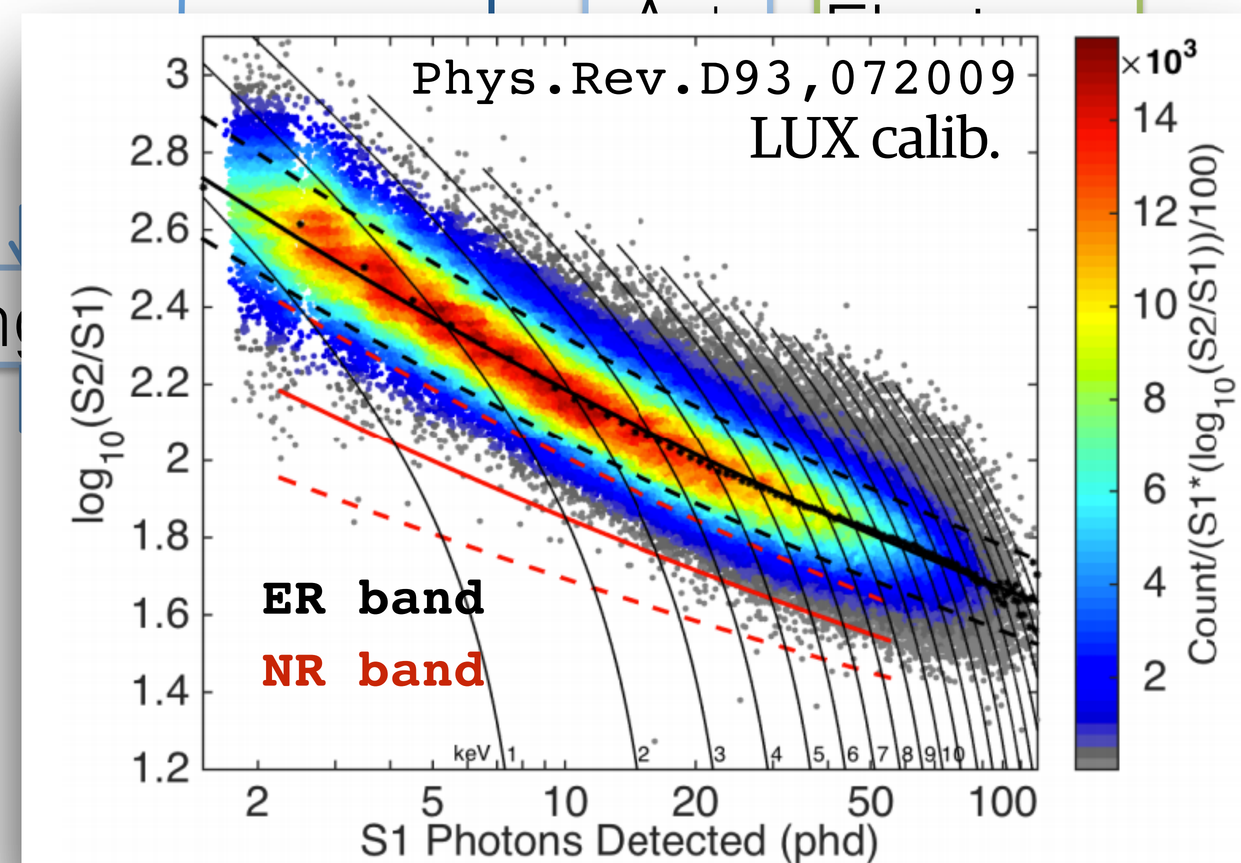
All the excitons produce **scintillation** (S1)
S2 proportional to number of **ionisation** e-
Recombined electron-ion pair contribute to S1

Ionization/Scintillation



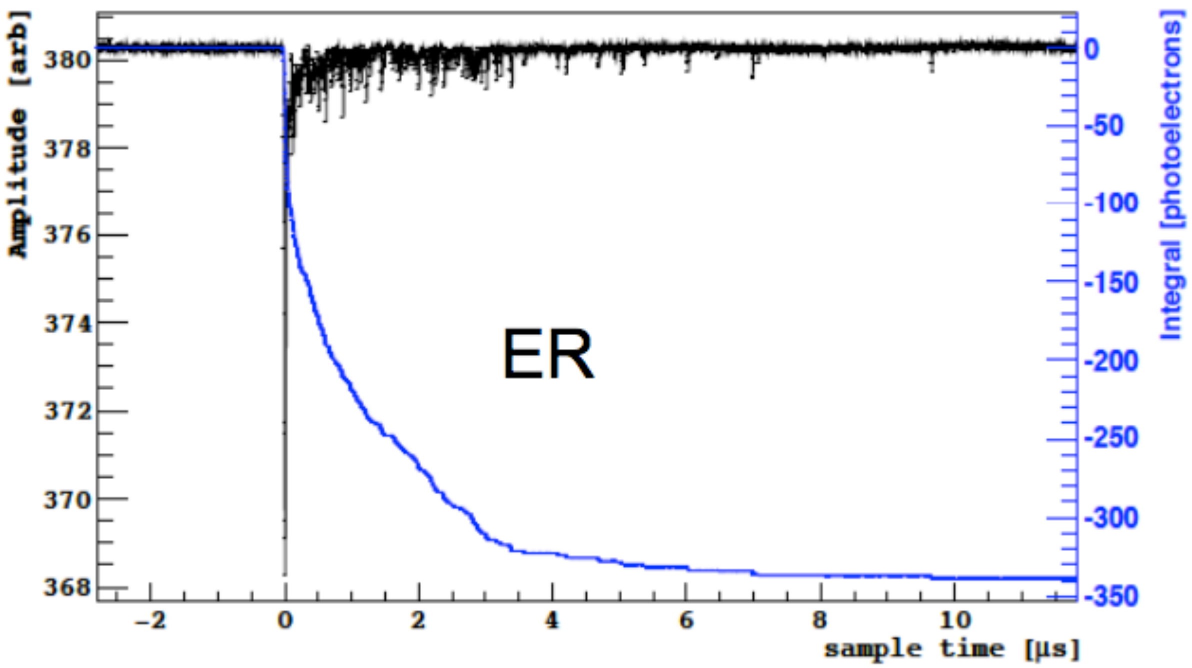


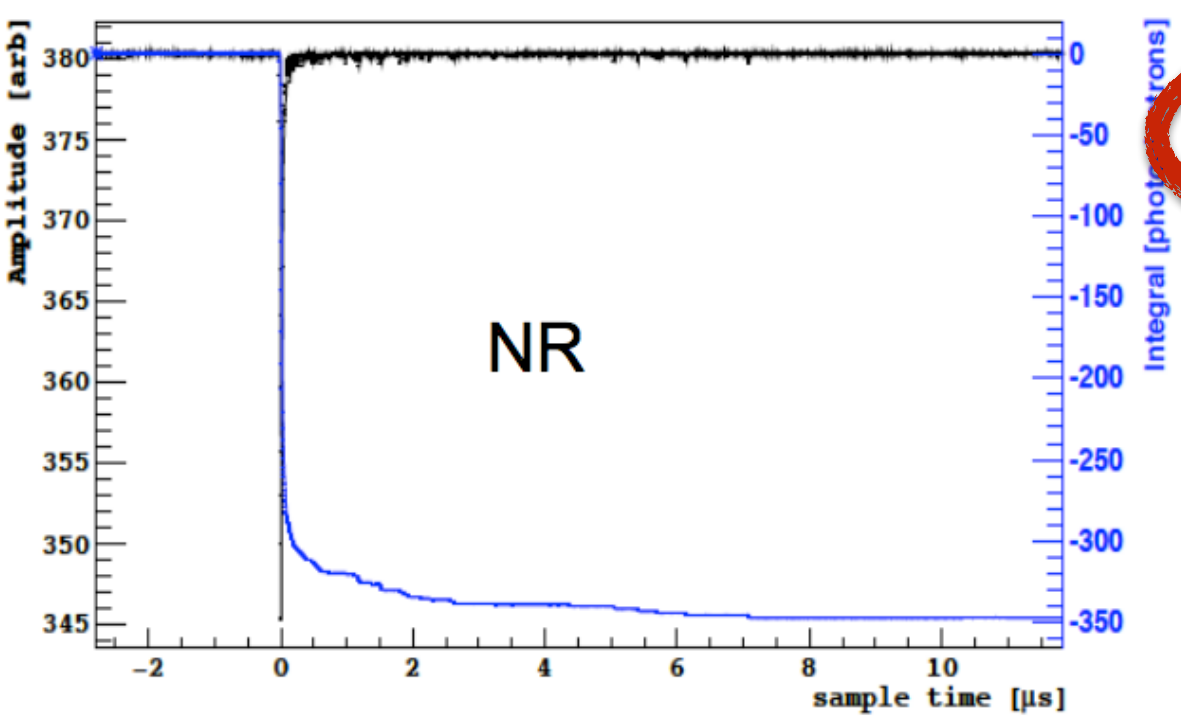


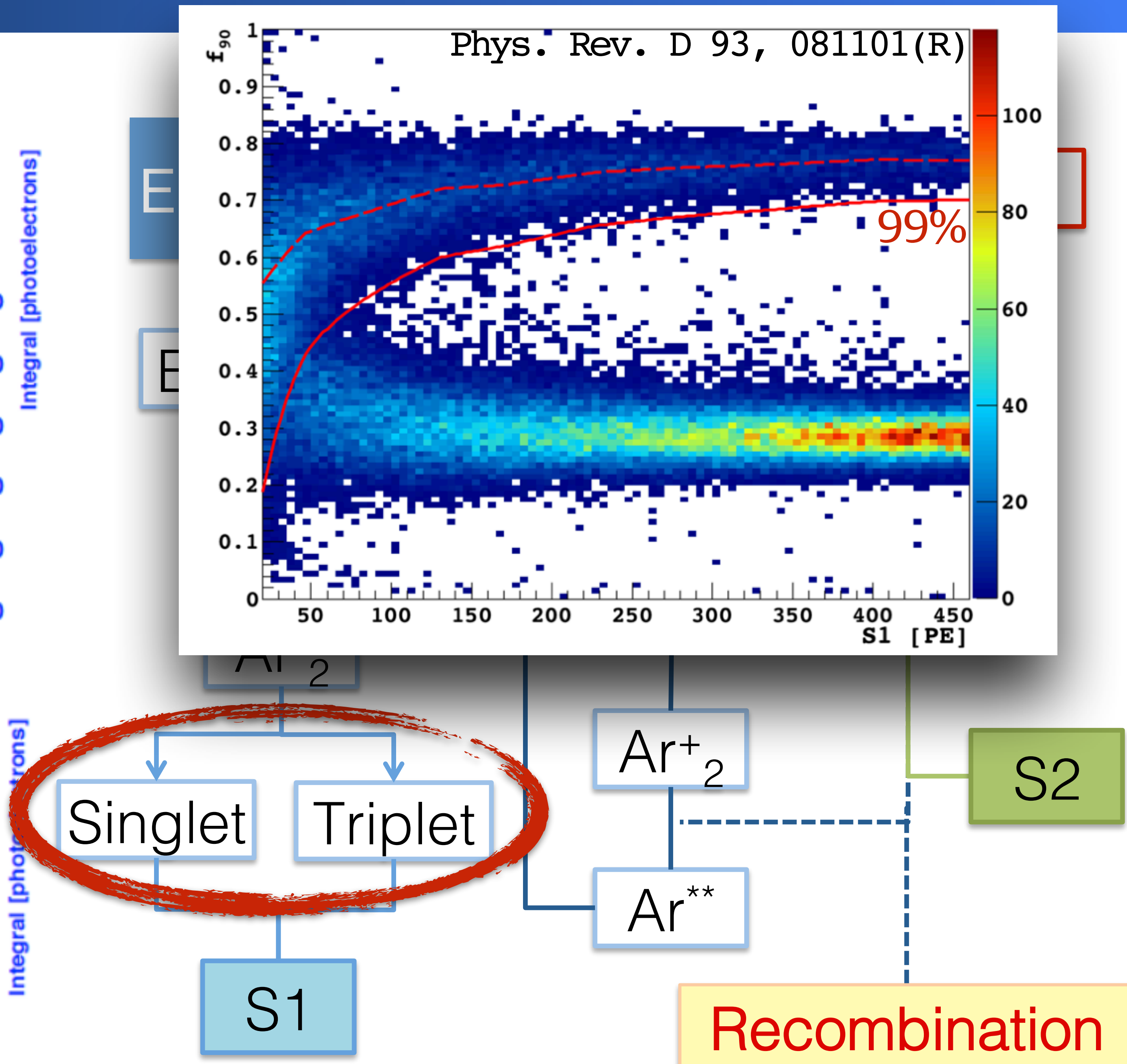


Discrimination power ~ 500 (LUX)

Pulse Shape Discrimination







ARGON: $t_{singlet} = 7$ ns $t_{triplet} = 1600$ ns

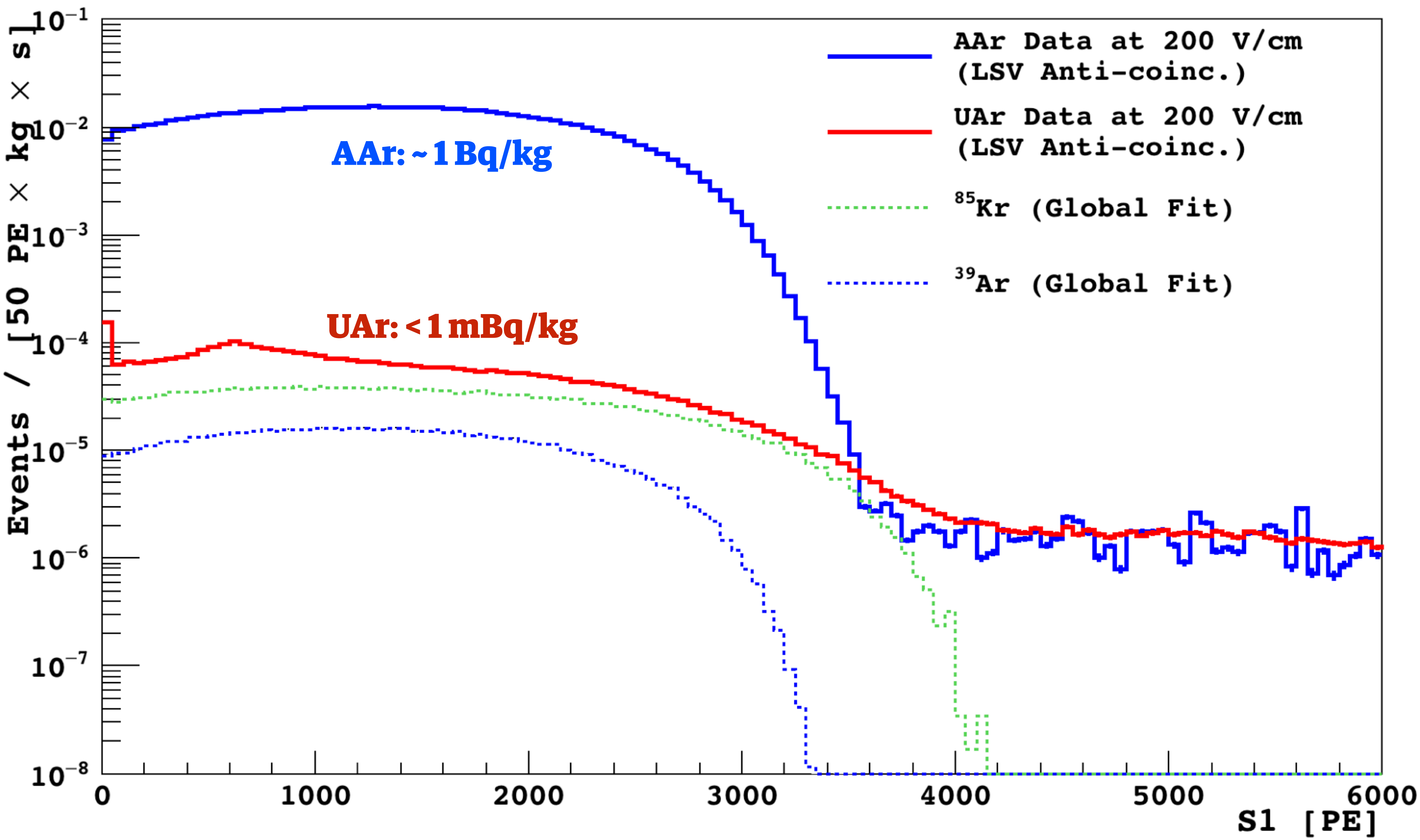
XENON: $t_{singlet} = 4$ ns $t_{triplet} = 22$ ns

PSD parameter: S1 fraction in first tens of ns of the signal

Exception discrimination (> 10^8) in Argon

Underground Argon

^{39}Ar, cosmic ray produced, first forbidden β decay: endpoint at 565 keV, $t_{1/2}$ = 269 years
Pile up in large TPC (drift time: acquisition window of the order of 1 ms)
~150 kg successfully extracted from a **CO_2 well in Colorado**, detector **filled in April 2015**



The DarkSide program

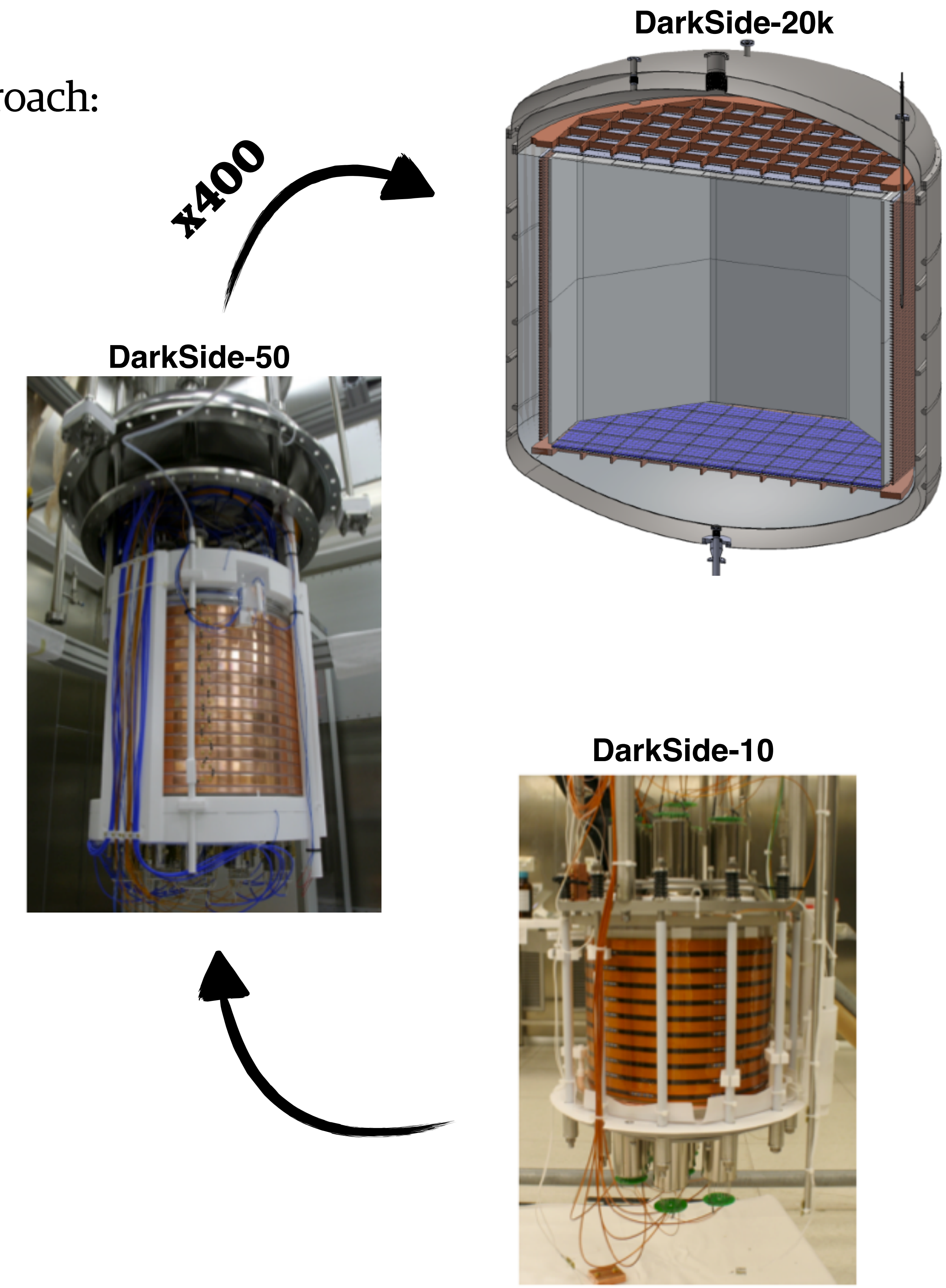
Dual phase liquid argon TPC, through a **staged** approach:

Main goal: a bg-free experiment
ER background: β's and γ's
NR background: neutrons

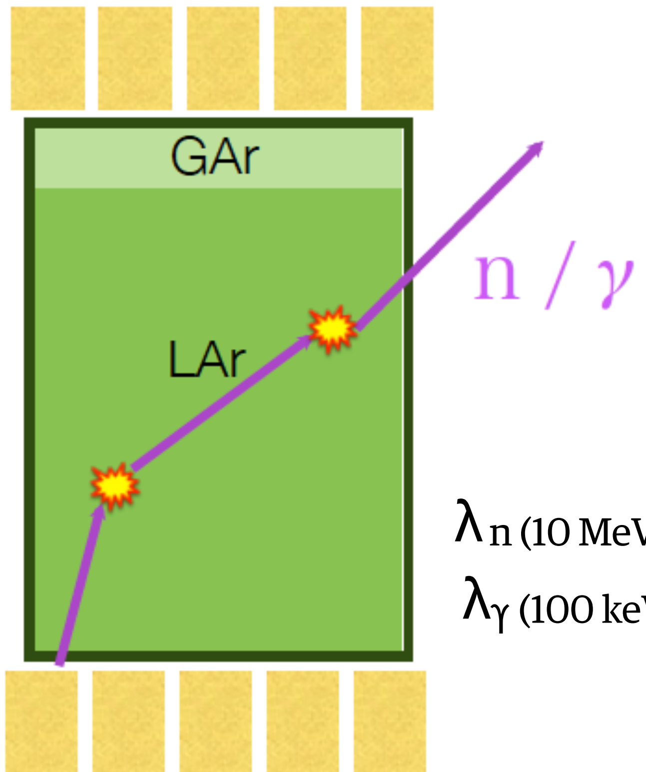
Background suppression
- Ultra-low background materials
- **Depleted Liquid Argon**
- Low background photo-detectors
- Low background material components

Background identification
- **Pulse Shape Discrimination** (PSD)
- Ionization/scintillation ratio
- Position reconstruction
  (surface events)
- **Multiple scatters within the TPC**

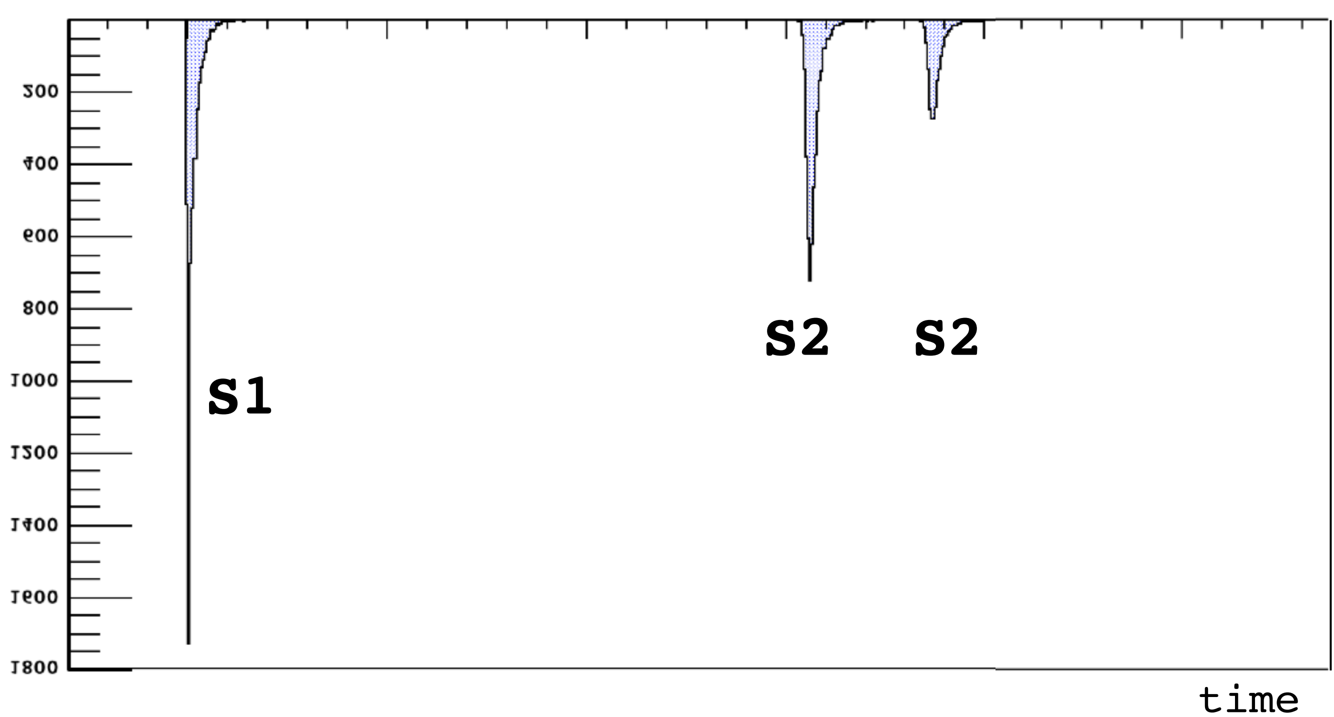
Active Shielding
- **Liquid Scintillator Veto** (LSV)
- Water Cherenkov against muons (WCD)



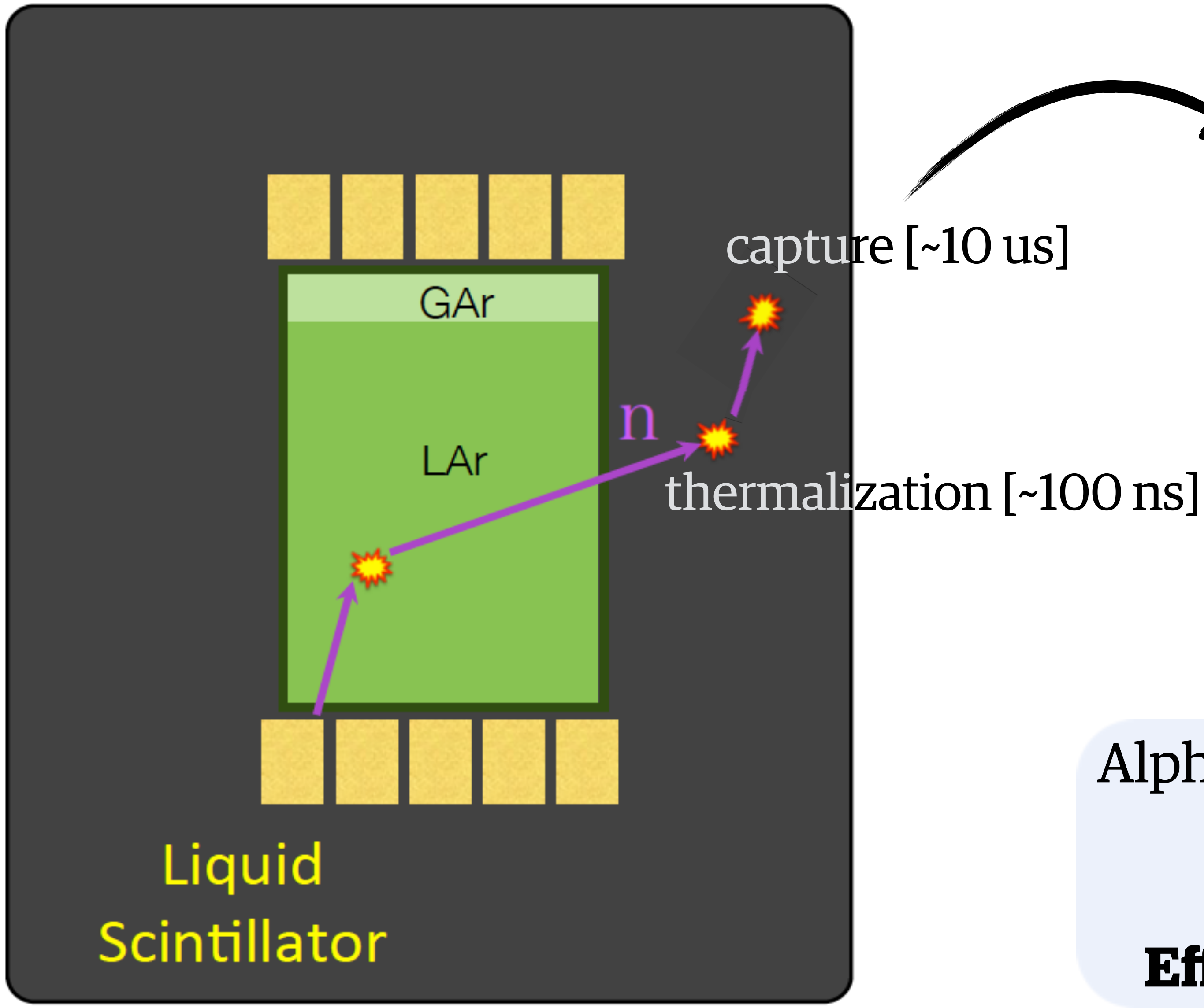
Multiple S2 signal

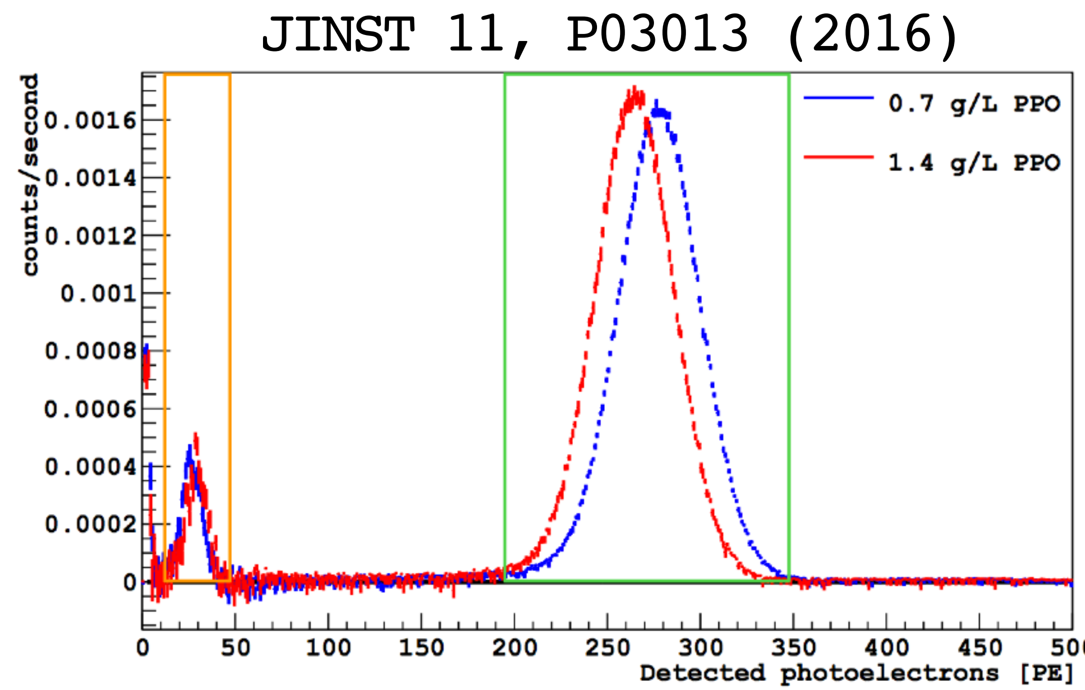


$\lambda_{n\,(10\ \mathrm{MeV})} \sim 15$ cm
$\lambda_{\gamma\,(100\ \mathrm{keV})} \sim 4$ cm



Background identification





Alphas are quenched down to few tens of keV.

Measured light yield: **0.520 pe/keV**
Efficiency (rad n) **> 99.1 %** (capture only)

Scintillator cocktail: PC +**10-50% TMB** + PPO (wls)
(Trimethylborane, $B(CH_3)_3$. [^{10}B] in natural B ~ 20%)

$$
{}^{10}\mathrm{B} + n \rightarrow \begin{cases} {}^{7}\mathrm{Li}\ (1015\ \mathrm{keV}) + \alpha\ (1775\ \mathrm{keV}) & (6.4\%) \\ {}^{7}\mathrm{Li}^{*} + \alpha\ (1471\ \mathrm{keV}), {}^{7}\mathrm{Li}^{*} \rightarrow {}^{7}\mathrm{Li}\ (839\ \mathrm{keV}) + \gamma\ (478\ \mathrm{keV}) & (93.6\%) \end{cases}
$$

The DarkSide-50 layout

At *Laboratori Nazionali del Gran Sasso* (LNGS), Italy

Liquid argon TPC

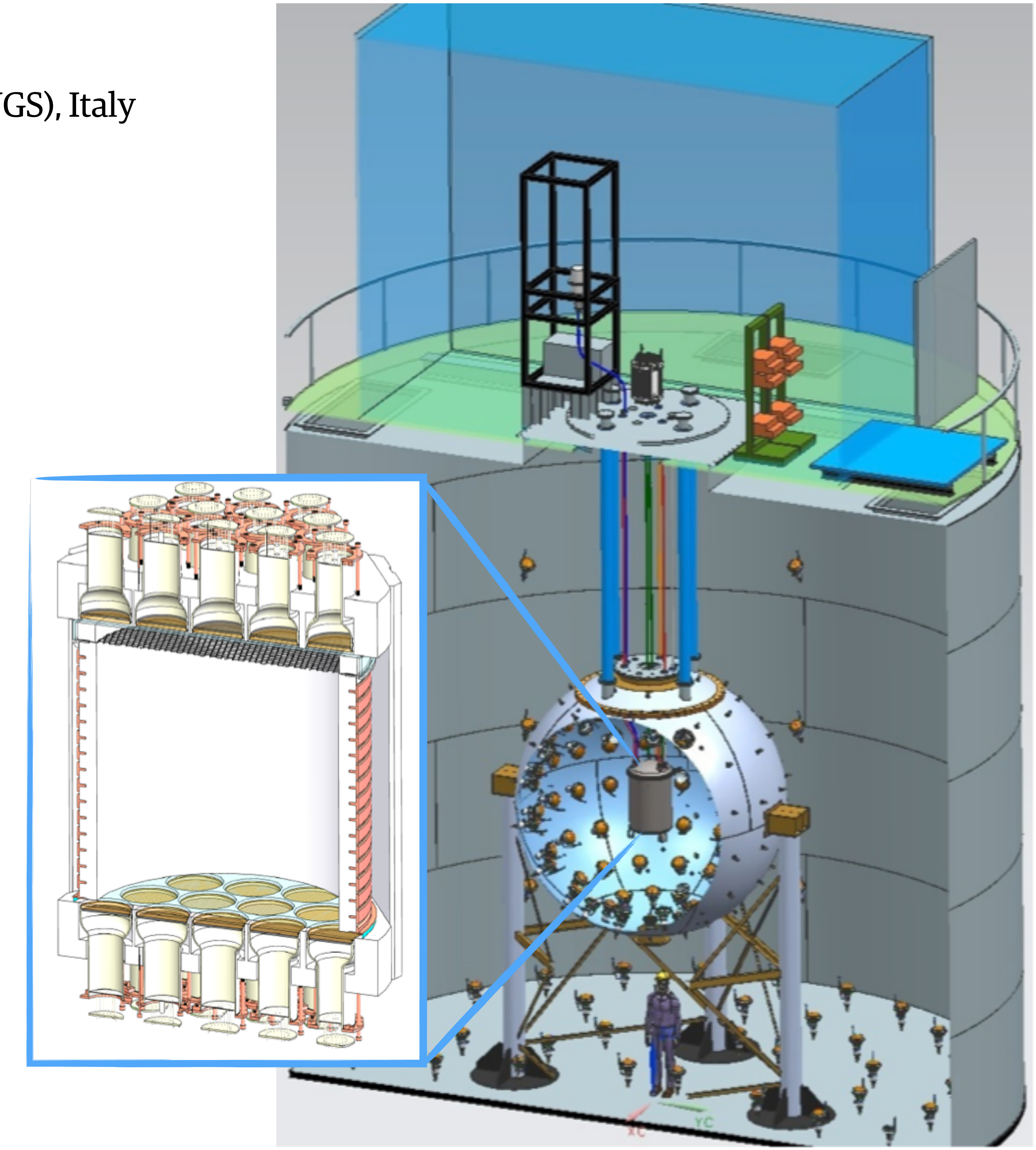
- 36 cm x 18 cm radius
- **50 kg LAr (36.9 kg fiducial mass)**
- **19 + 19 3" PMTs**
- Cold pre-amplifiers
- Uniform Electric Field (200 V/cm)
- ~ 1 cm Gas Pocket
- Extraction Electric Field (2.8 kV/cm)
- Reflectors and TPB coating

Liquid Scintillator Veto (LSV)

- 30 tons, 2 m radius
- Liquid Scintillator (1:1 TMB + PC)
- 110 PMTs (LY = 0.52 pe/keV)

Water Cherenkov Detector (WCD)

- 1 kt water, 5.5 m radius
- 80 PMTs



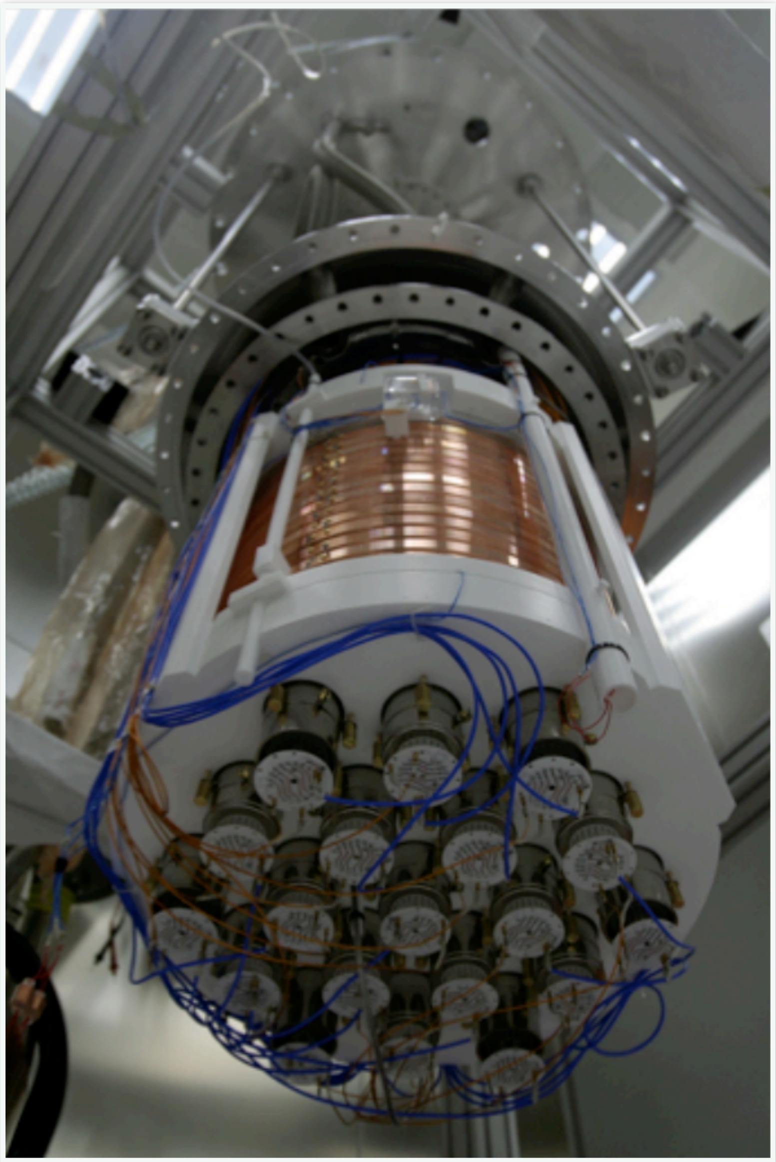
Operations and Stability

Data taking started	Oct 2013
Commissioning run end	June 2014
50 days of AAr dataset	Jul 2014 to Sept 2014
Filling with UAr	April 2015
70 days of UAr dataset	April 2015 to Jul 2015
1 yr lifetime collected	Jan 2017

Phys. Lett. B 743, 456 (2015)

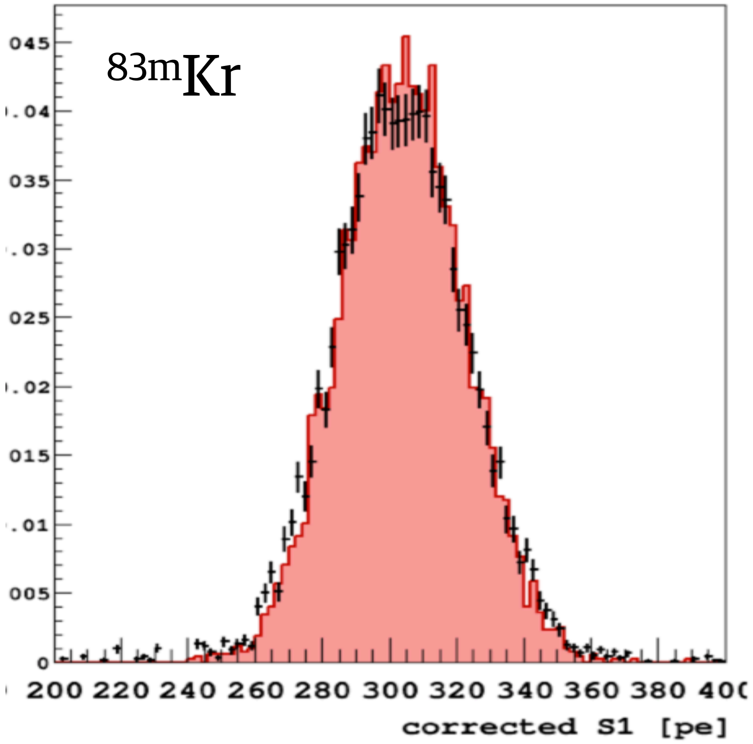
Phys. Rev. D 93, 081101(R)

Electron Lifetime: **> 5 ms**
Maximum drift time at nominal field: **375 μs**



Calibrations

CALIS (articulated arm for source insertion)
arXiv: 1611.02750



Internal ^{83m}Kr (41.5 keV)

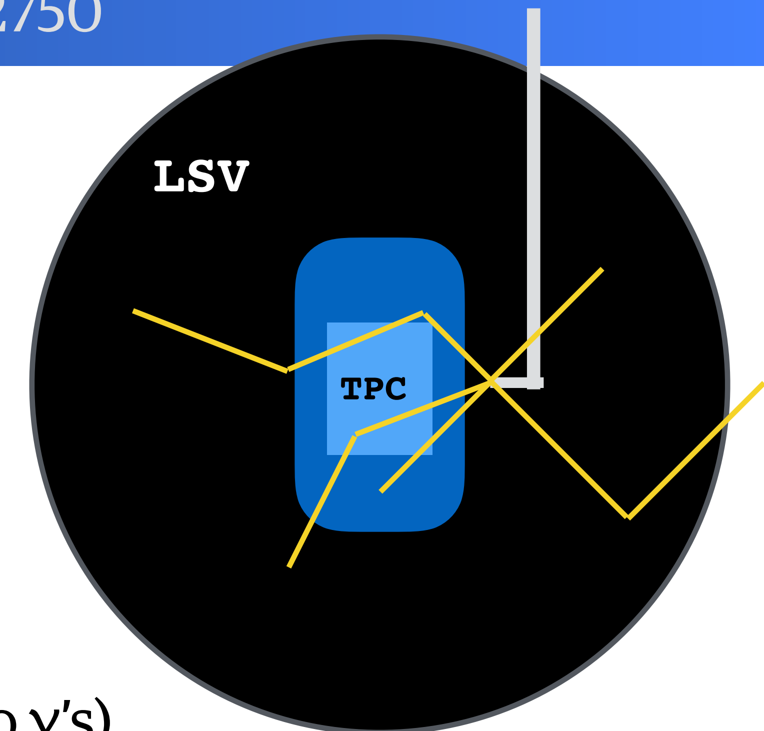
LY at null field: 8.1±0.2 pe/keV

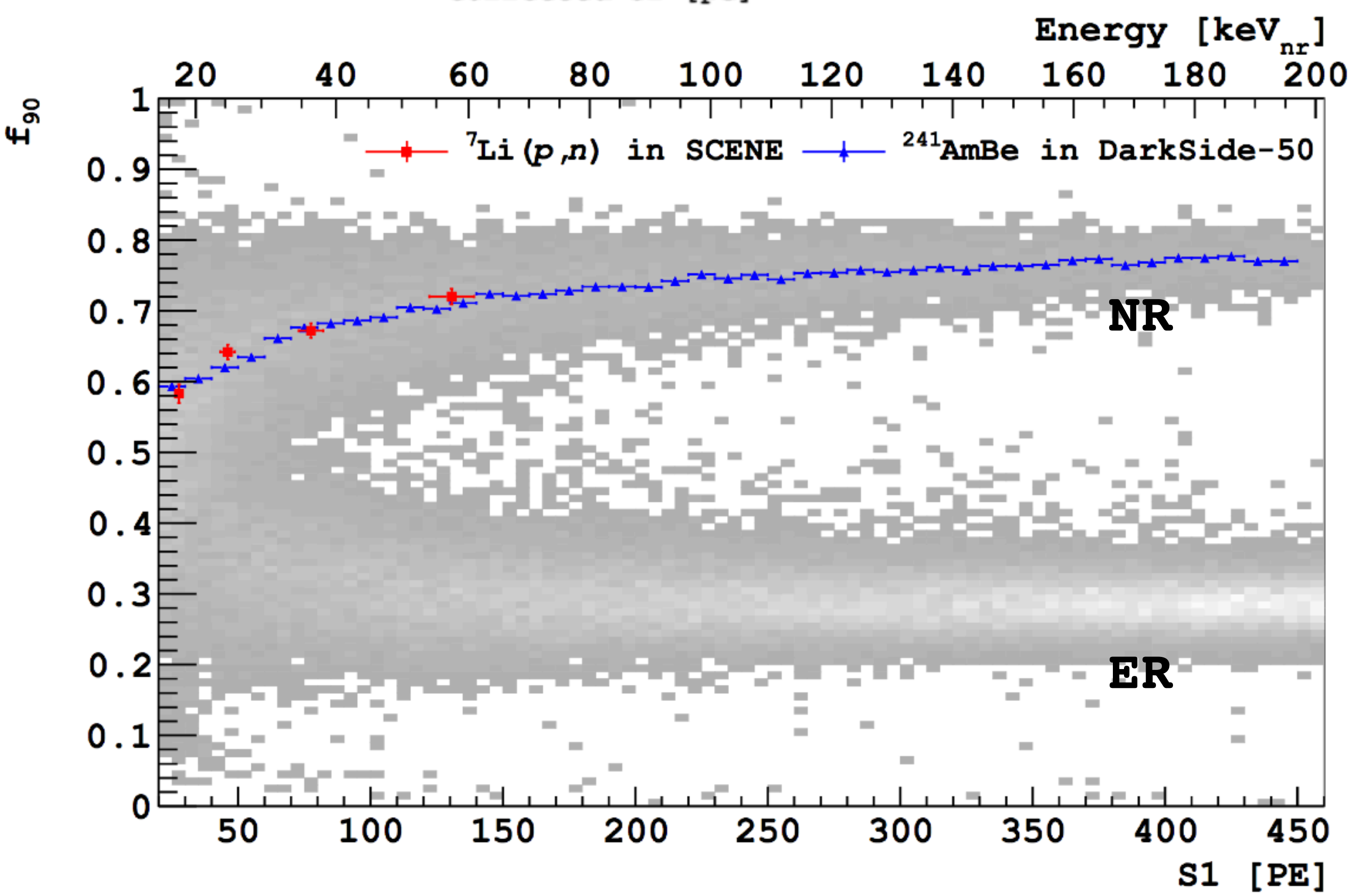
LY at 200 V/cm: 7.3 ± 0.1 pe/keV

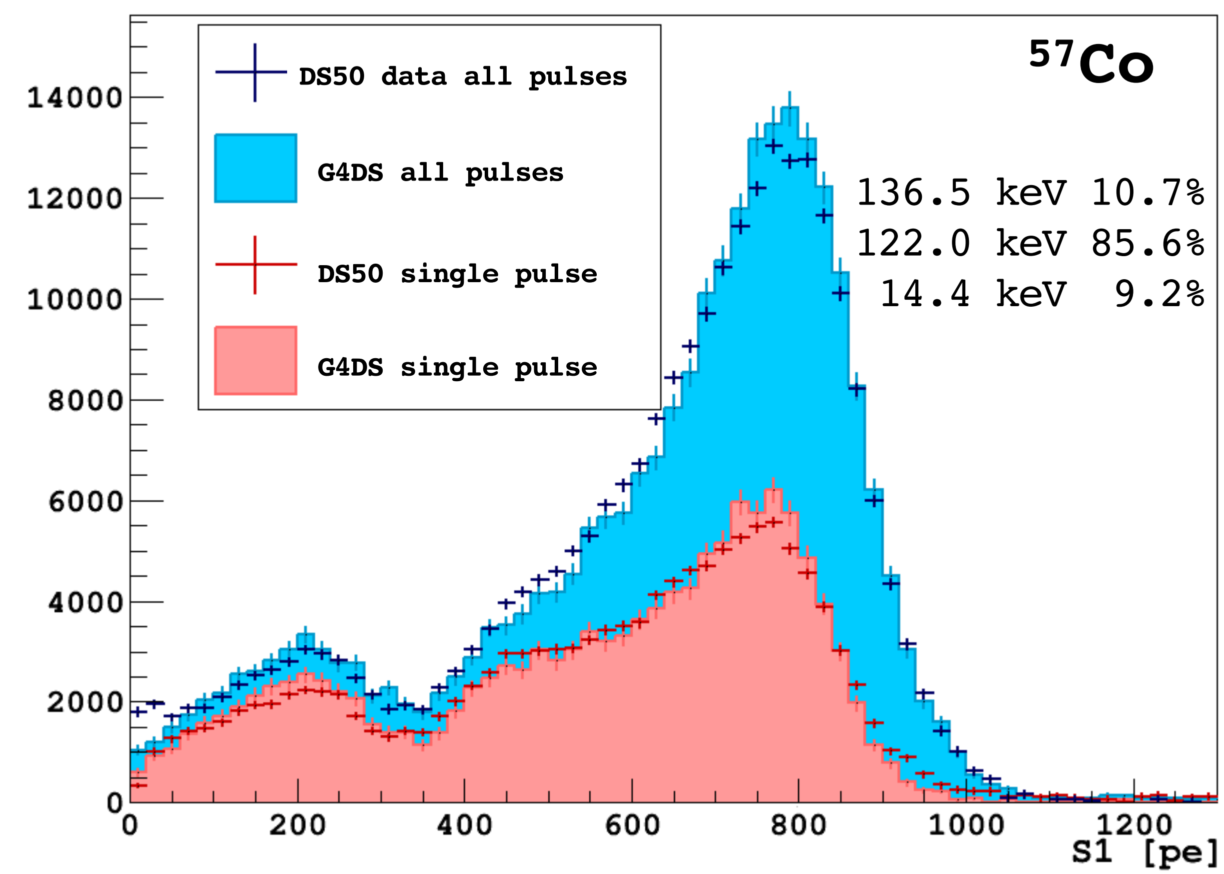
External

ER calibration: ^{57}Co, ^{133}Ba, ^{137}Cs

NR calibration: AmBe (with γ's), AmC (no γ's)







G4DS, the DarkSide Simulation

Geant-4 based simulation of detectors geometry, TPC response

Tuning of the **optics** (no energy assumption) at the %level

Calibration of the **energy scale (S1 and S2)**

- Effective parameterization of recombination probability of ions (E)

Pulse Shape Discrimination

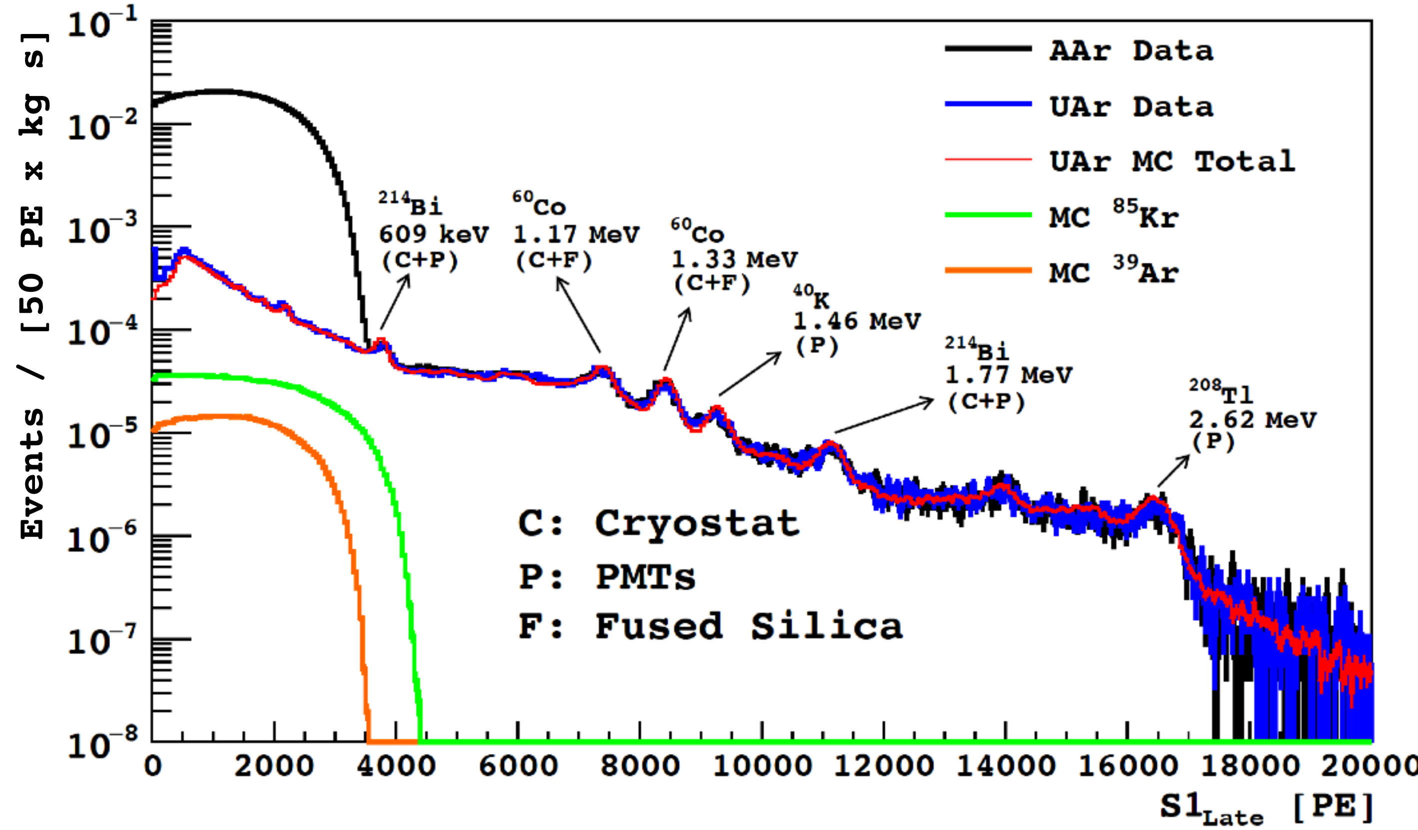
Simulation of the **vetoes**

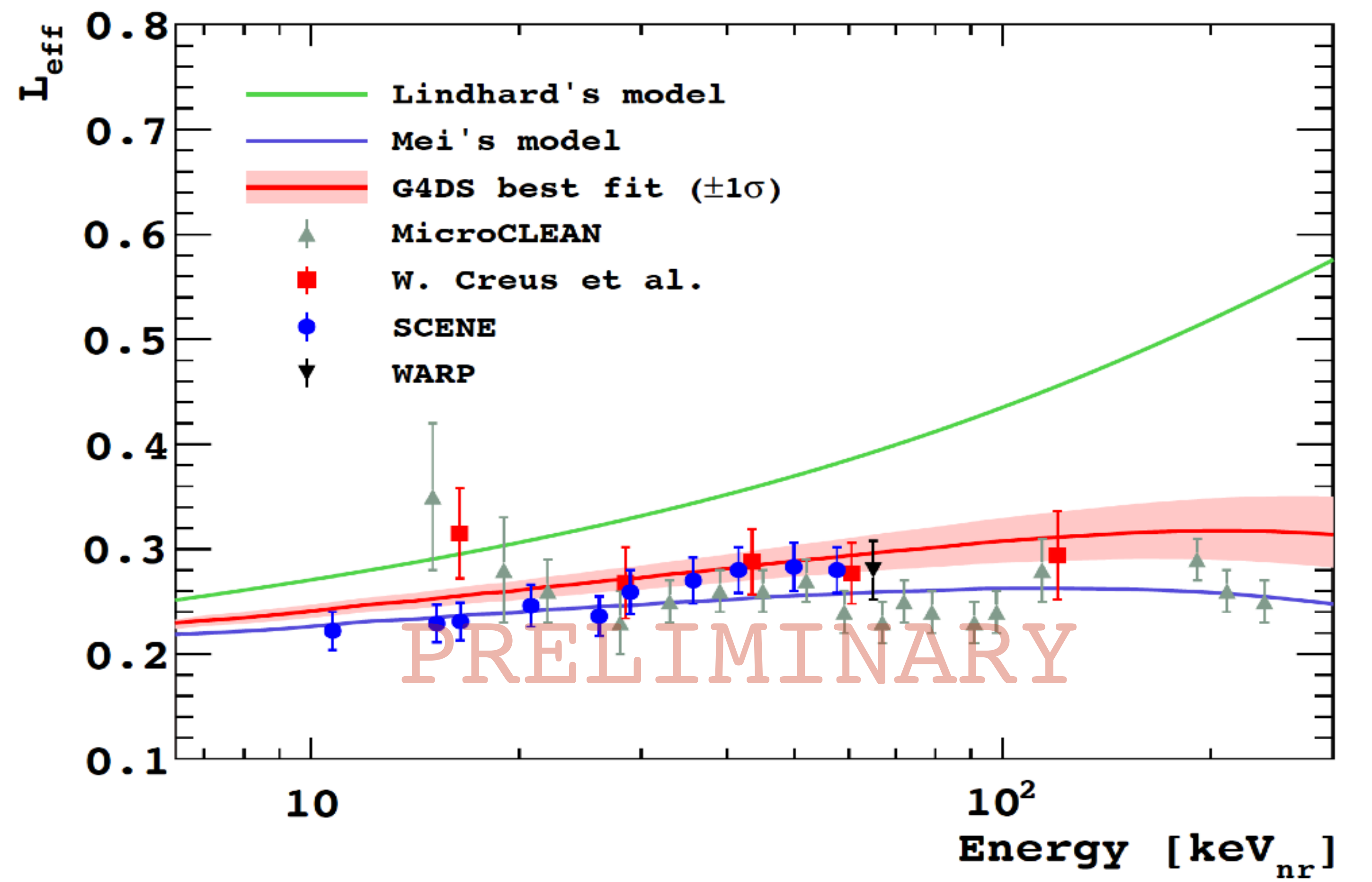
Some results:

Depletion factor (1400±200) and discovery of **^{85}Kr contamination** with spectral fit

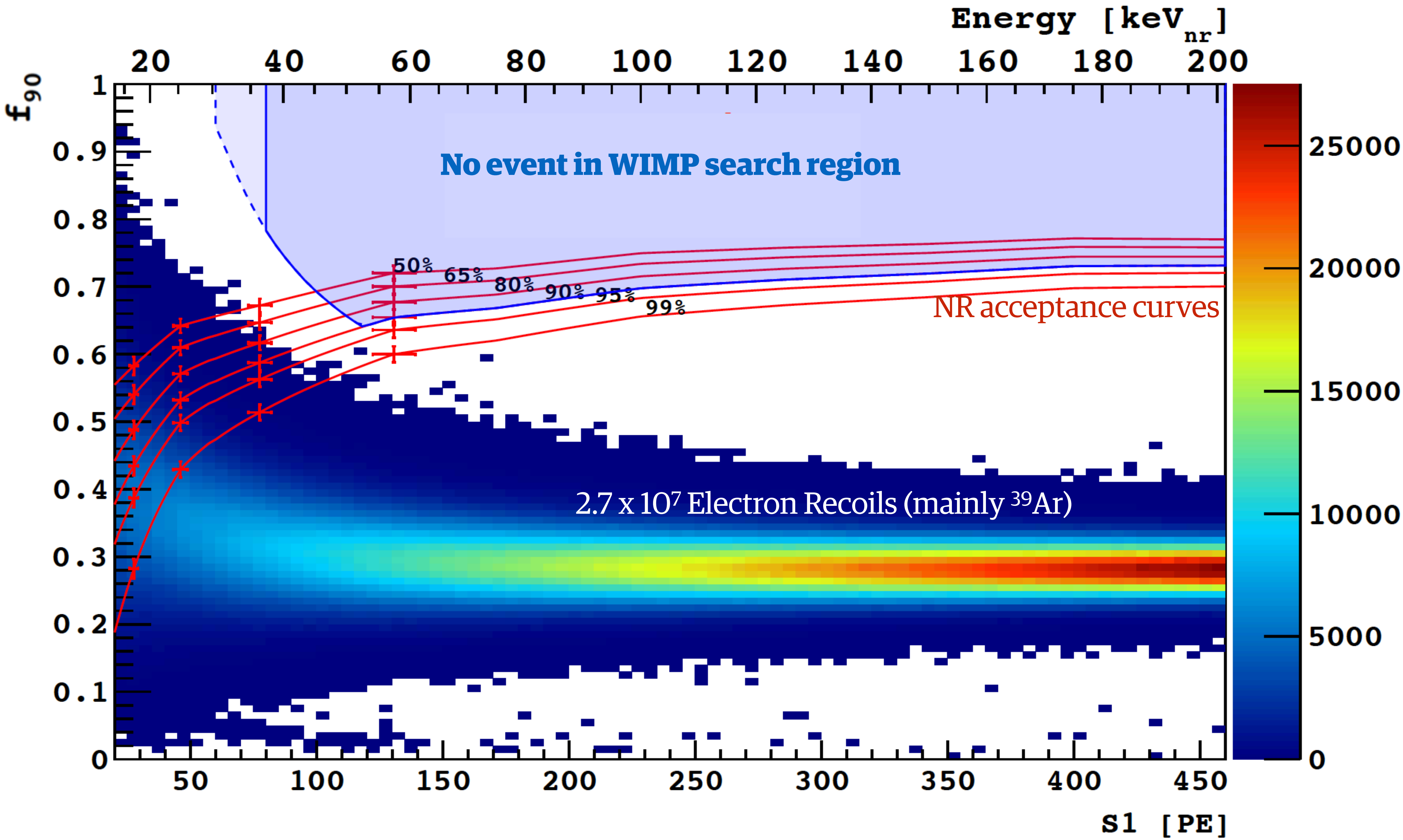
Quenching factor for NR with AmBe

Paper in preparation, soon ready!





A background free search

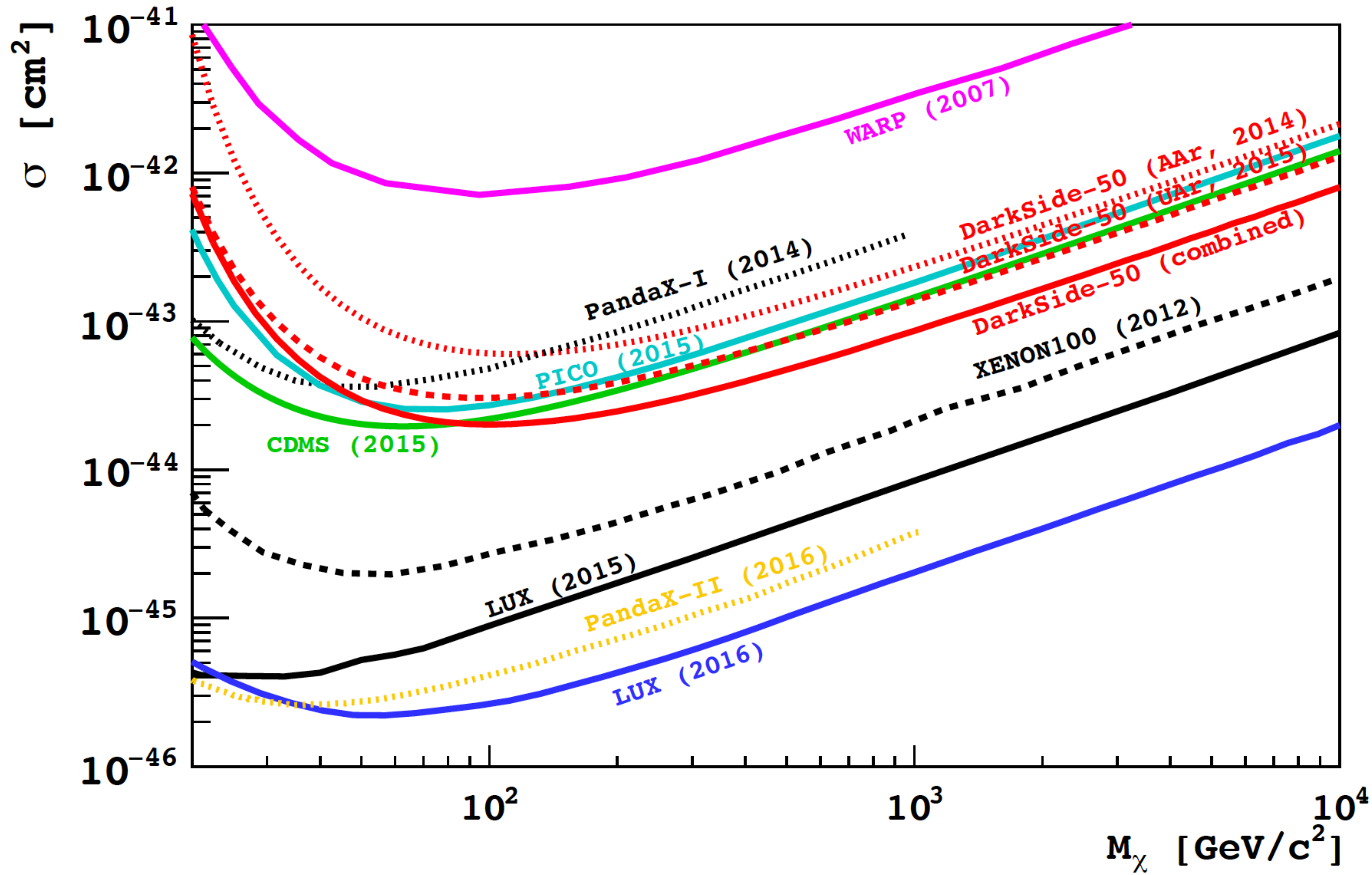


50 days lifetime with Atmospheric Argon fill.

Removed events with a **coincidence in the vetoes** (expected ~1). **Radial** and **S2/S1 cut NOT applied.**

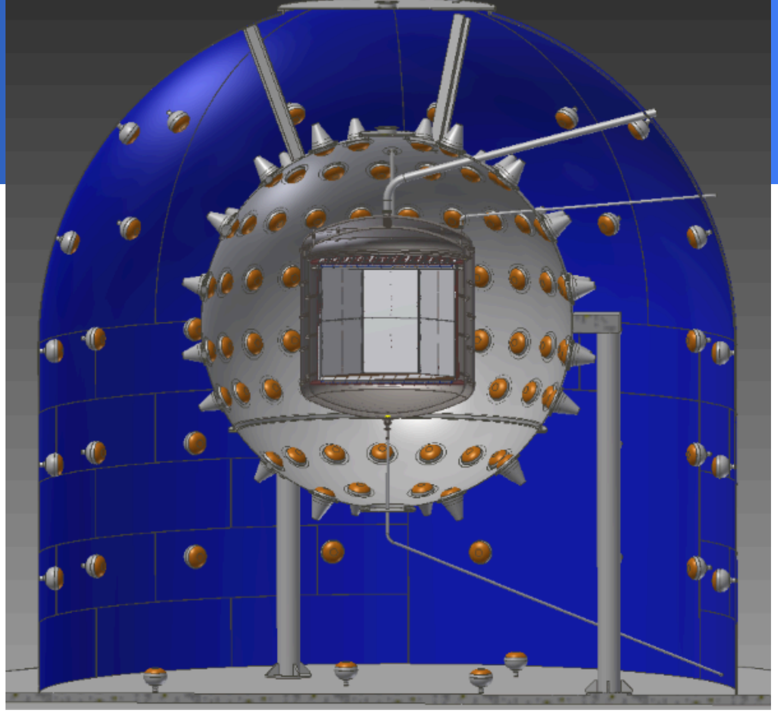
DS50 Exclusion

AAr: Phys. Lett. B 743, 456 (2015)
UAr: Phys. Rev. D 93, 081101(R) (2016)



Best limit to date obtained with a LAr target (50 + 70 days) combined exposure.
> 1 year lifetime statistics accumulated so far with UAr (**blind analysis** ongoing).

DarkSide-20k



Goals:

bg-free search with **exposure of 100 t.y** (possibly 200 t.y)

start taking data by 2021

Same detector concept:

Larger TPC (**20 t fiducial**)

Larger LSV (8m diameter)

Larger WT (14 m diameter)

x400 wrt DS50

High LY required

Different readout system

14 m^2 SiPM array (grouped)

Same need for low-background

Fiducialization

Radiopurity

UAr procurement

URANIA (Colorado) goal: 100 kg/day

x1400

ARIA (>300 m distillation column for even larger detector)

chemical purification

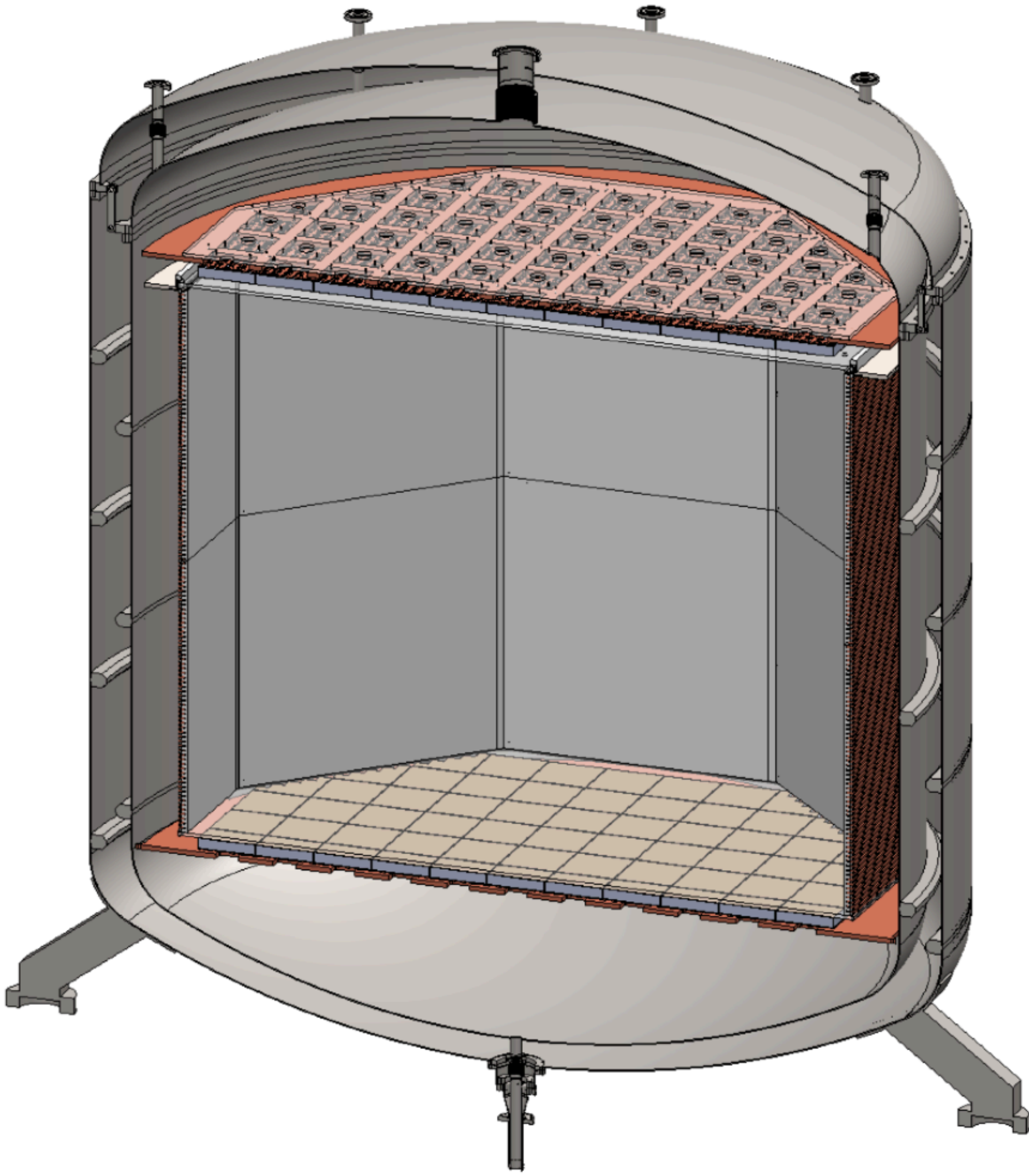
Intense calibration and prototyping

DSProto: 1 m^3 TPC to test SiPM

Neutron calibrations:

ARIS (pulsed neutron beam, single phase)

ReD (dual-phase TPC, directionality)



Photodetectors and Simulation

Proposed layout in DS20k

grouped in 5x5 cm^2 tiles (~5k channels)
readout currently being optimized:

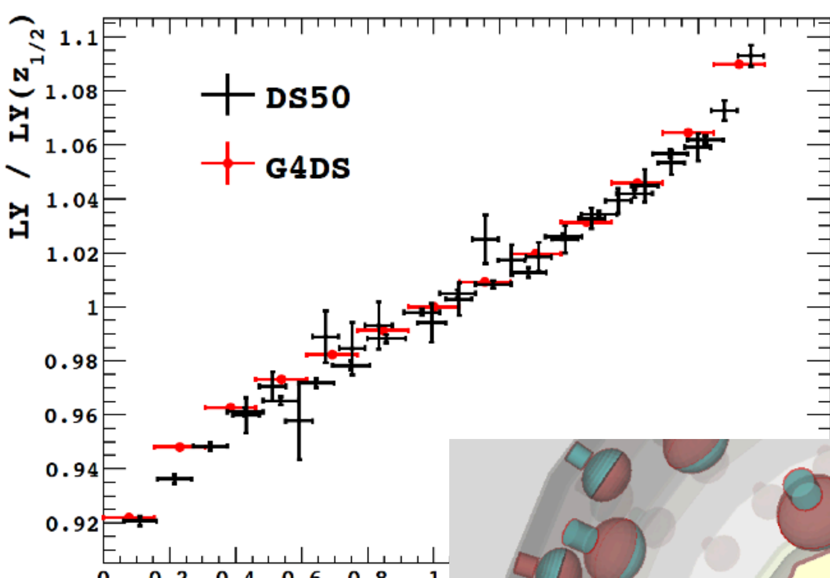
single pe regime for S1 (timing)
full charge integration for S2 (energy)

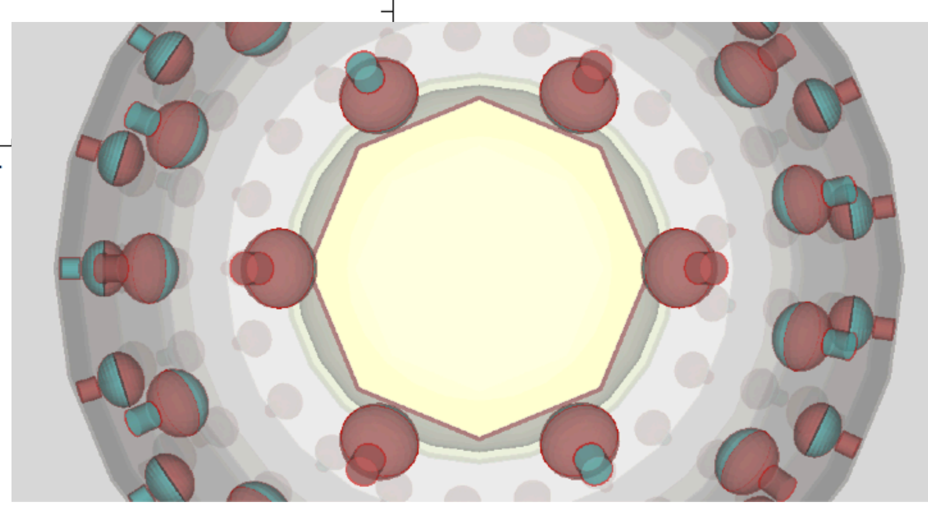
Requirements:
Low DCR (10^{-1} Hz/mm^2)
40% PDE (QE x Fill Factor)
Dynamic Range > 50 pe
Time resolution < 10 ns
Power < 250 mW /tile

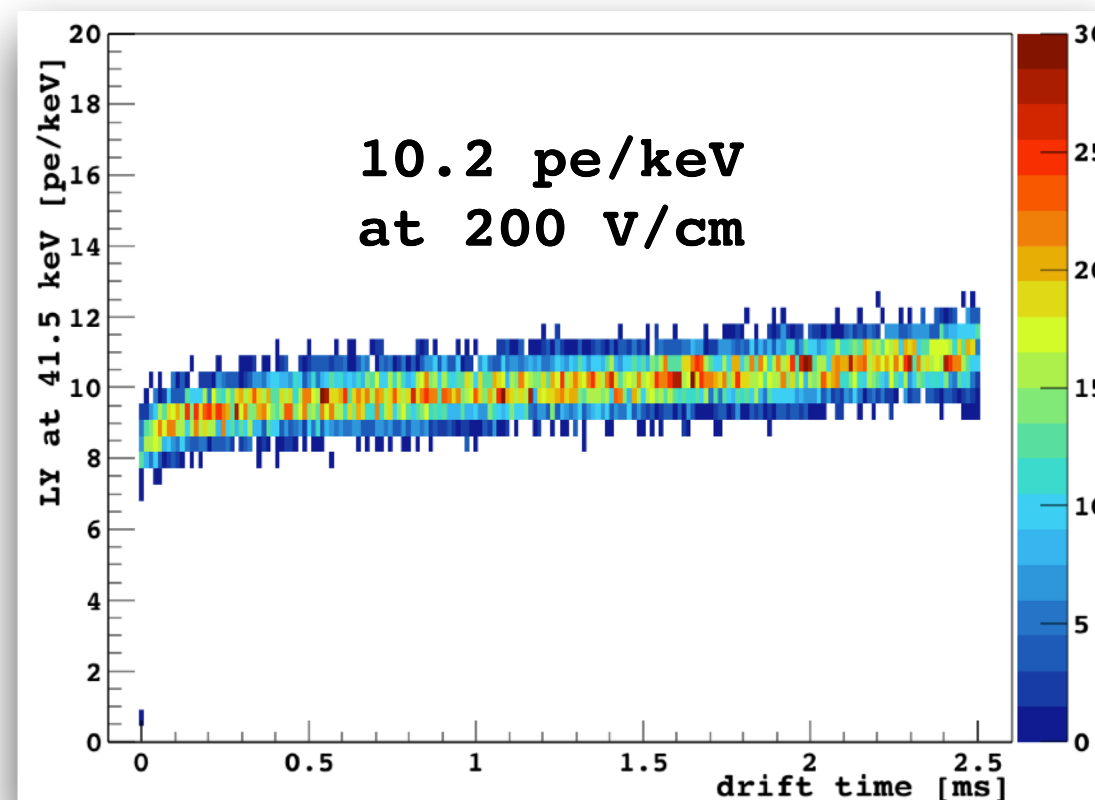
G4DS is tuned to reproduce **DS50 TPC response**

+ DS20k geometry

+ SiPM readout







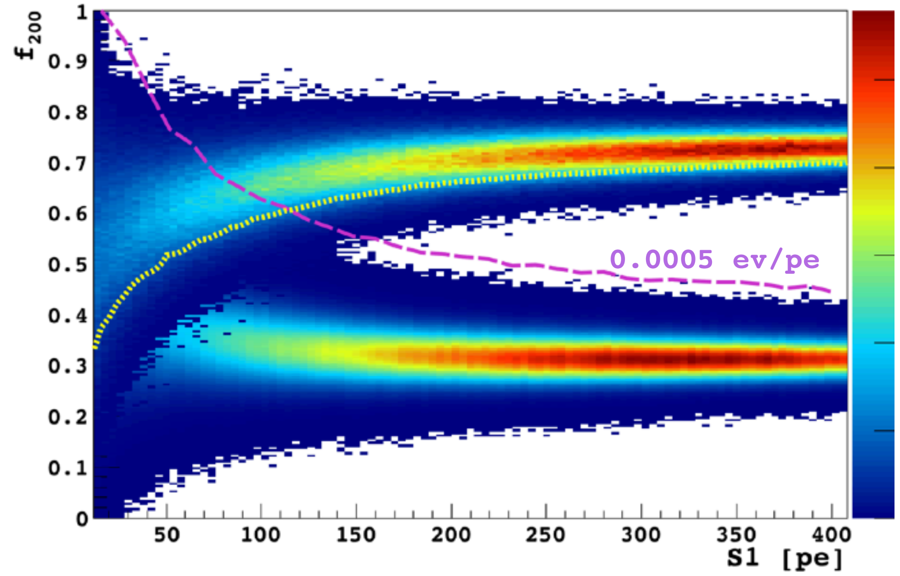
DarkSide-20k Projected Sensitivity

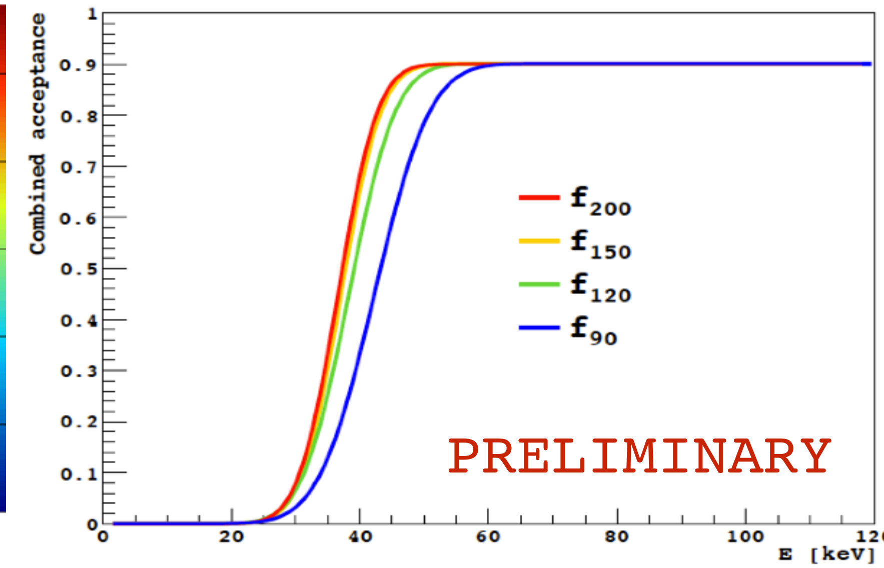
Simulation of several millions of events (ER and NR) to determine **the acceptance to WIMPs,** assuming NR + ER background < 0.1 events.

+ Nuclear recoil quenching from DS50

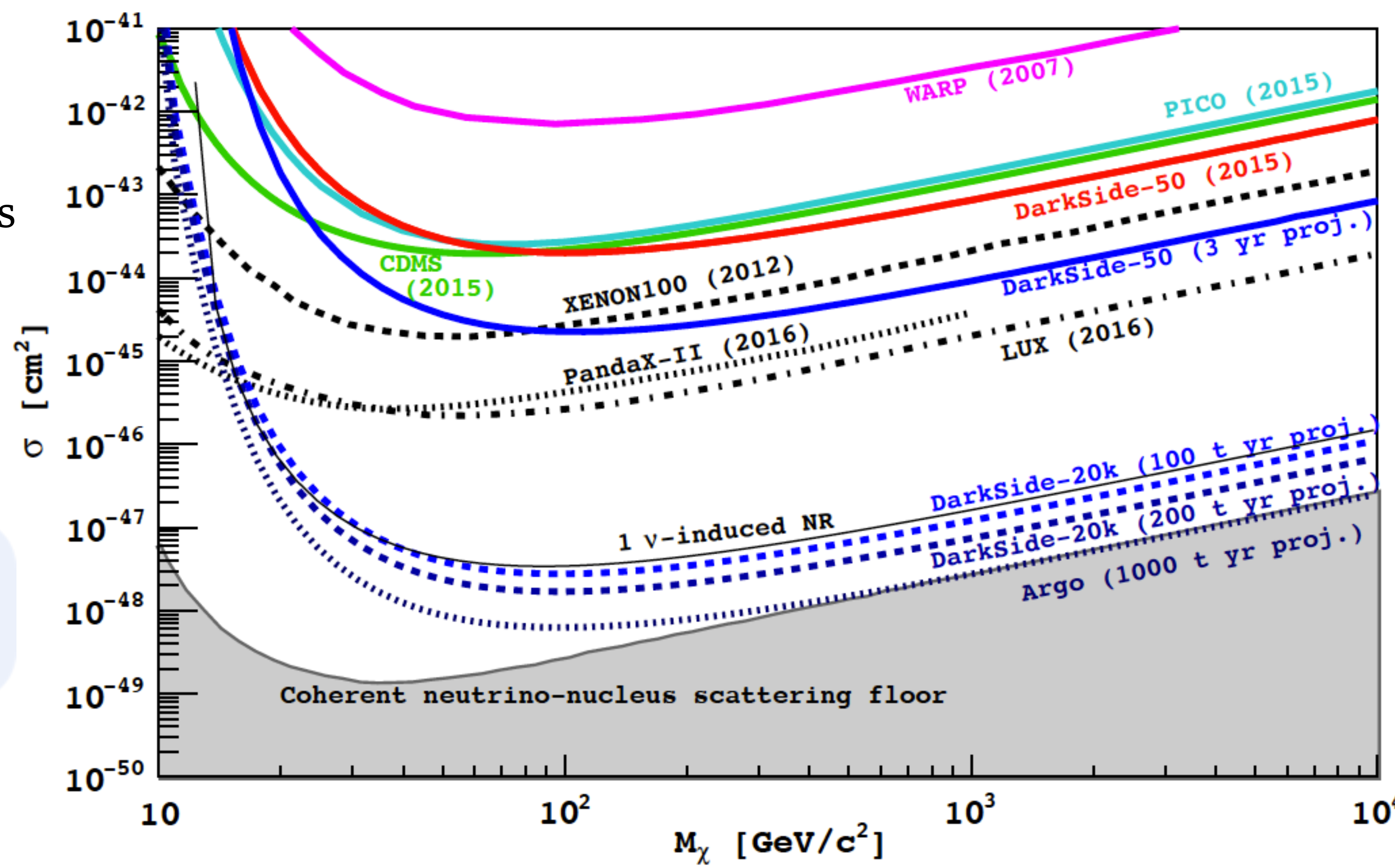
Optimization of PSD parameter for the best sensitivity.

Expected **>200x10⁶** events (1400 depletion) from ^{39}Ar only in [0,50] keV.
A simulation of the **full statistics** is ongoing.





1.6 CNNS events expected, likelihood approach in progress.



Conclusions

The DS50 experiment obtained the **most sensitive limit on the WIMP-nucleon cross section (bg-free) ever obtained with a liquid argon target.**

A (**blind**) data taking is currently ongoing and the accumulated lifetime now exceeds **one year (>13 000 kg.day)**

The DS50 results demonstrated

- the feasibility of a dual-phase LAr TPC
- the **exceptional rejection power** guaranteed by the **PSD**
- the **depletion factor** measured in UAr (**1400**) is large enough to build a >ton scale detector

Design studies for DS20k almost completed

- technological challenges (**SiPM** - **400x TPC scaling** - **UAr procurement**)
- **background level goal: < 0.1 evts** in the full exposure
- design exposure: **100 t.y**
- start with data taking by 2021

Backup

Backgrounds and Simulation

Background level goal: 0.1 evts in 100 t.y

Geant4 simulation of the DS20k geometry

- (alpha,n) neutrons
- γ's from detector components
- Internal ER
- Cosmogenics

WIMP-like events defined by:

- single scatter in FV
- 10 keV < Energy < 70 keV
- f90 compatible with NR
- No Energy in Vetoes

Background	Events in ROI $[100\,\mathrm{t\,yr}]^{-1}$	Background $[100\,\mathrm{t\,yr}]^{-1}$
Internal β/γ's	1.8×10^8	0.06
Internal NRs	negligible	negligible
e^--ν_{pp} scatters	2.0×10^4	negligible
External β/γ's	10^7	<0.05
External NRs	<154	<0.12
Cosmogenic β/γ's	3×10^5	$\ll 0.01$
Cosmogenic NRs	–	<0.1
ν-Induced NR	1.6	–

PRELIMINARY

Source	Neutrons produced in 5 yr years	Fraction passing TPC cuts	Fraction passing LSV cuts	Surviving n background in 100 t yr
Teflon reflector panels	<1717	0.015	0.0037	<0.095
Stainless steel cryostat	981	0.009	0.0029	0.026 ± 0.002
Total				<0.12

^{85}Kr

Unexpected contamination (no specific purification procedure put in place).

Two independent measurements: MC spectra fit and beta+gamma coincidence (0.04% BR)

-Decay: $^{85}Kr \rightarrow {}^{85m}Rb$

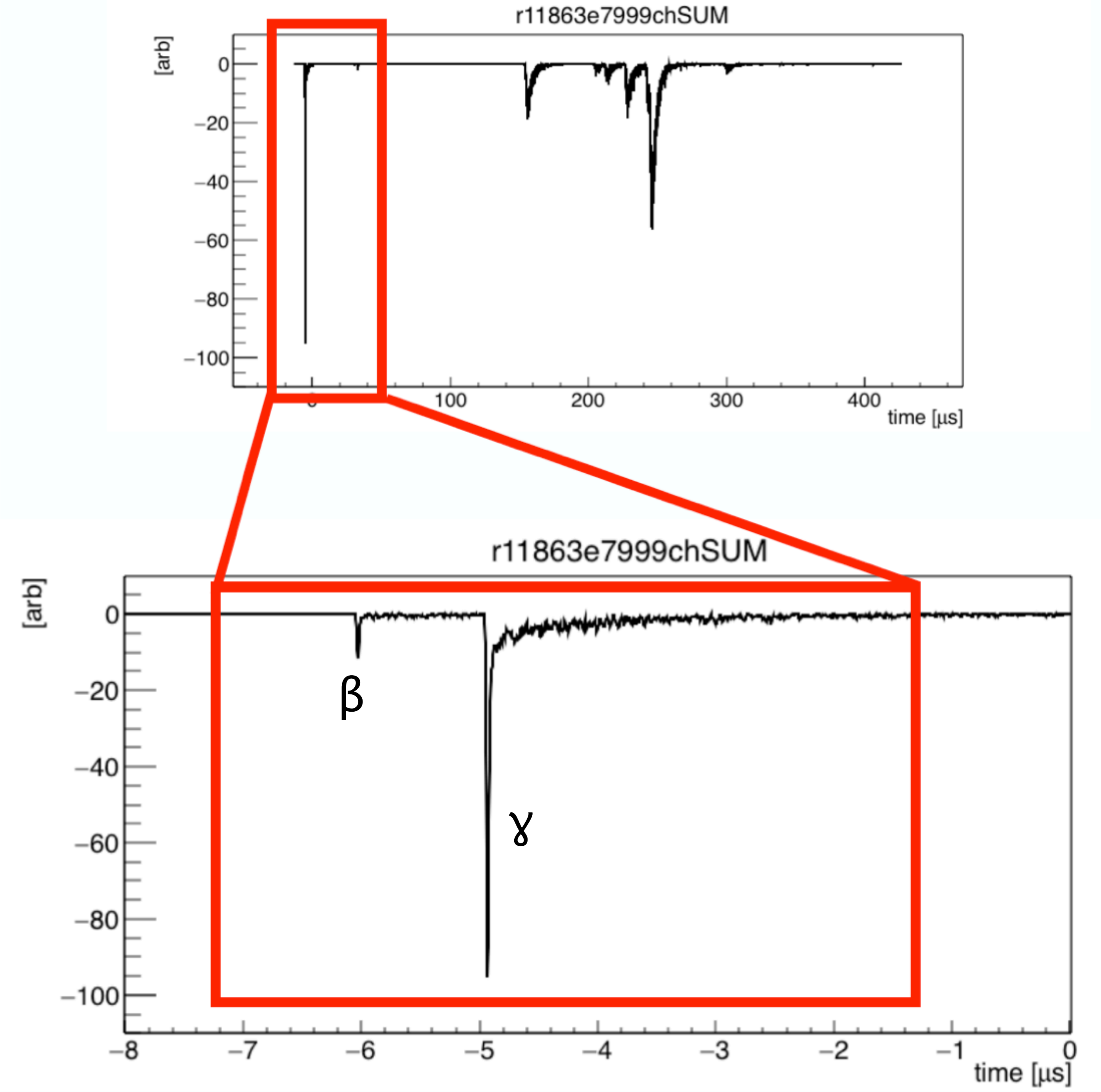
BR=0.4% ($\tau_{1/2}$~1 μs, E_γ~514 keV)

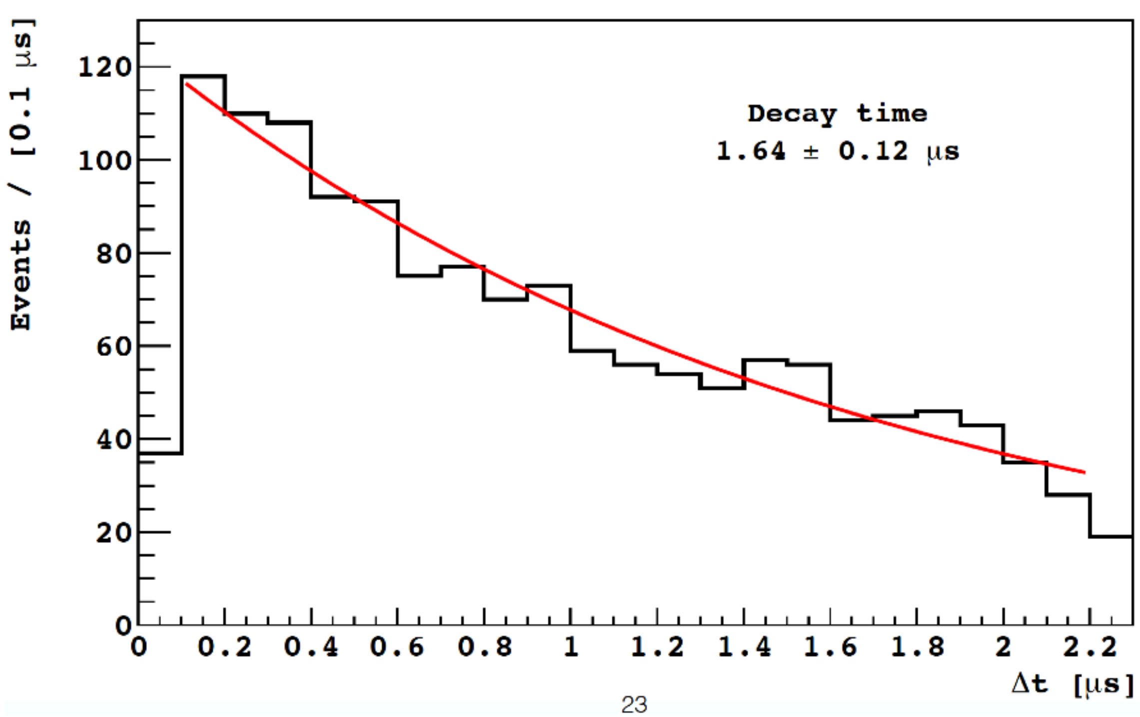
- Signature: 2 S1s (β+γ) in delayed

-Rate:

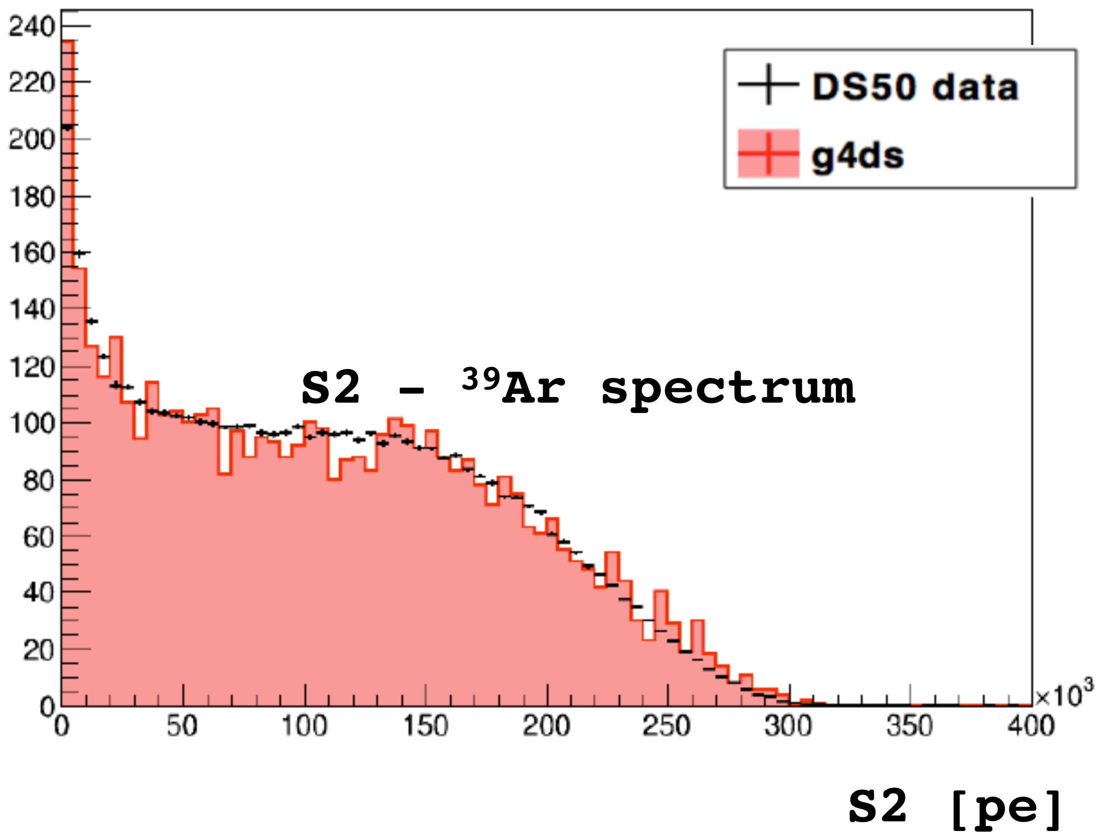
observed: 33.1 ± 0.9 events/d

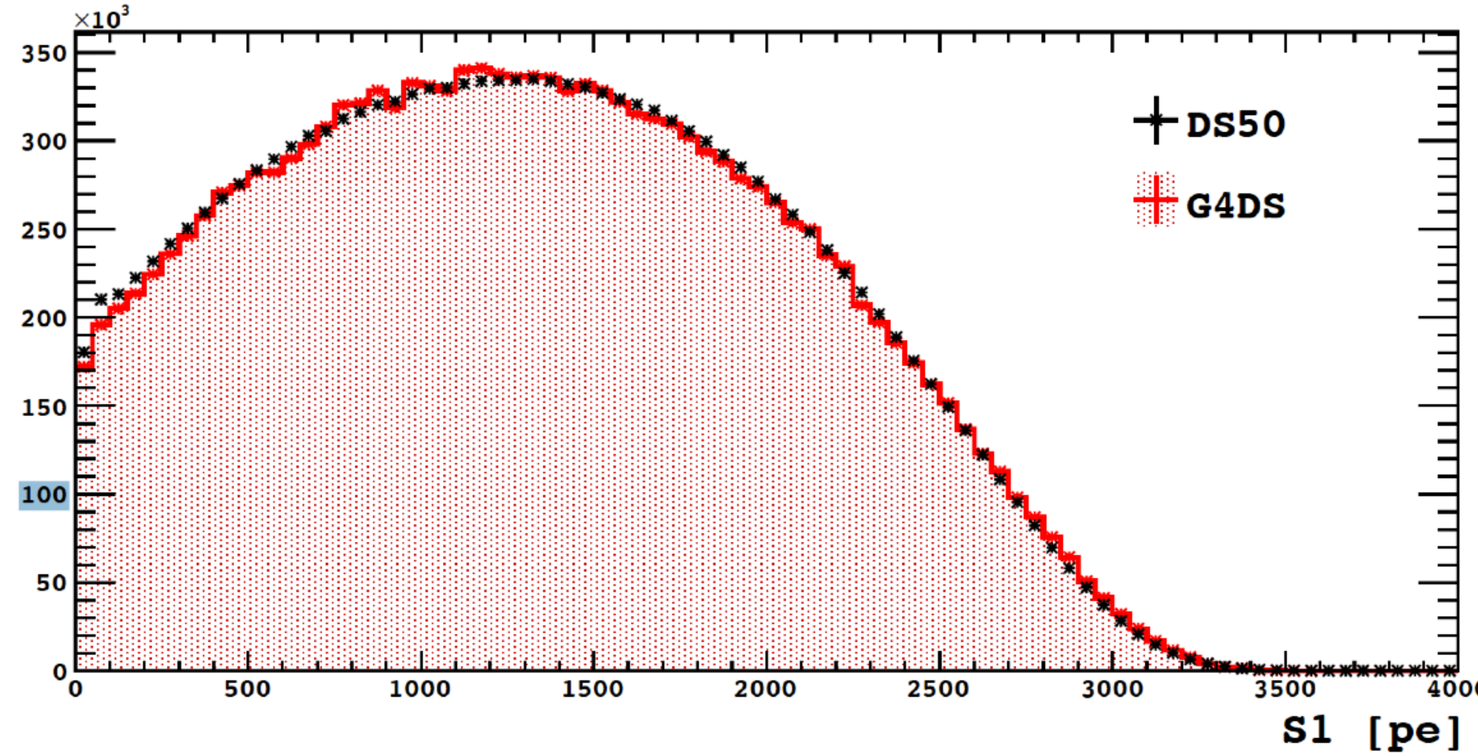
spectral fit: 35.3 ± 2.2 events/d

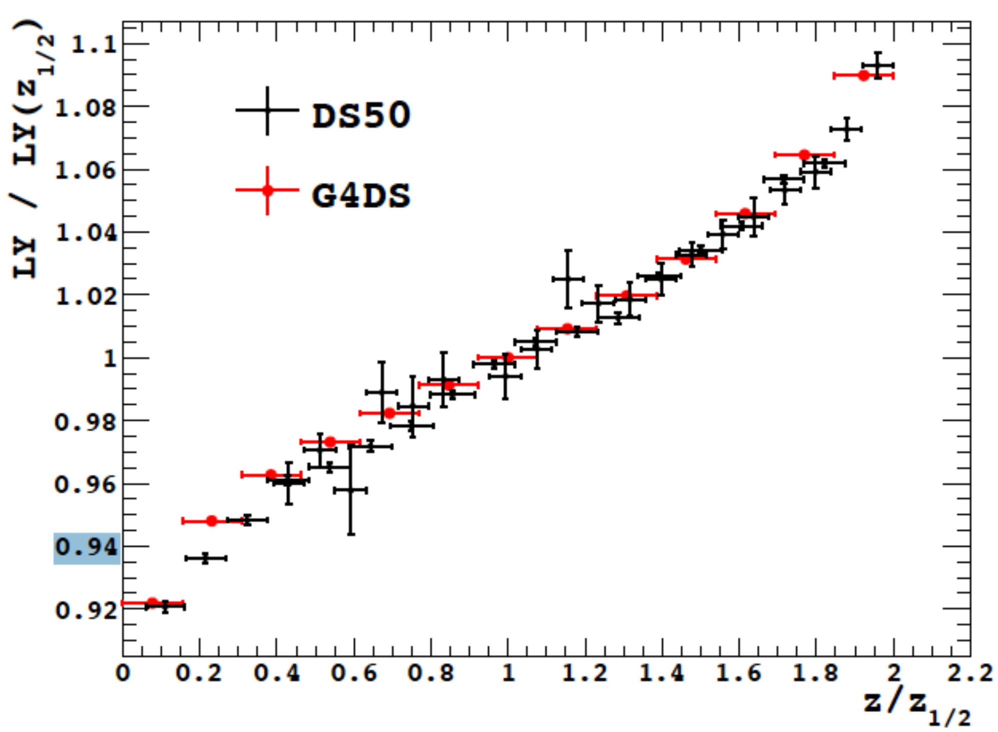


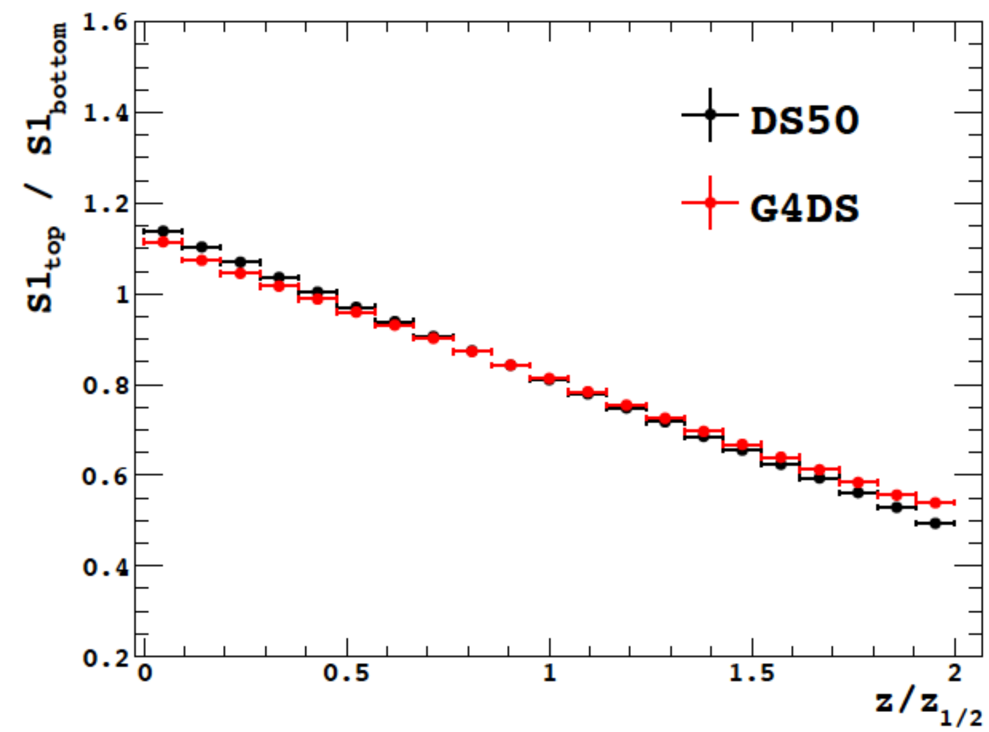


S1 and optics calibration in G4DS





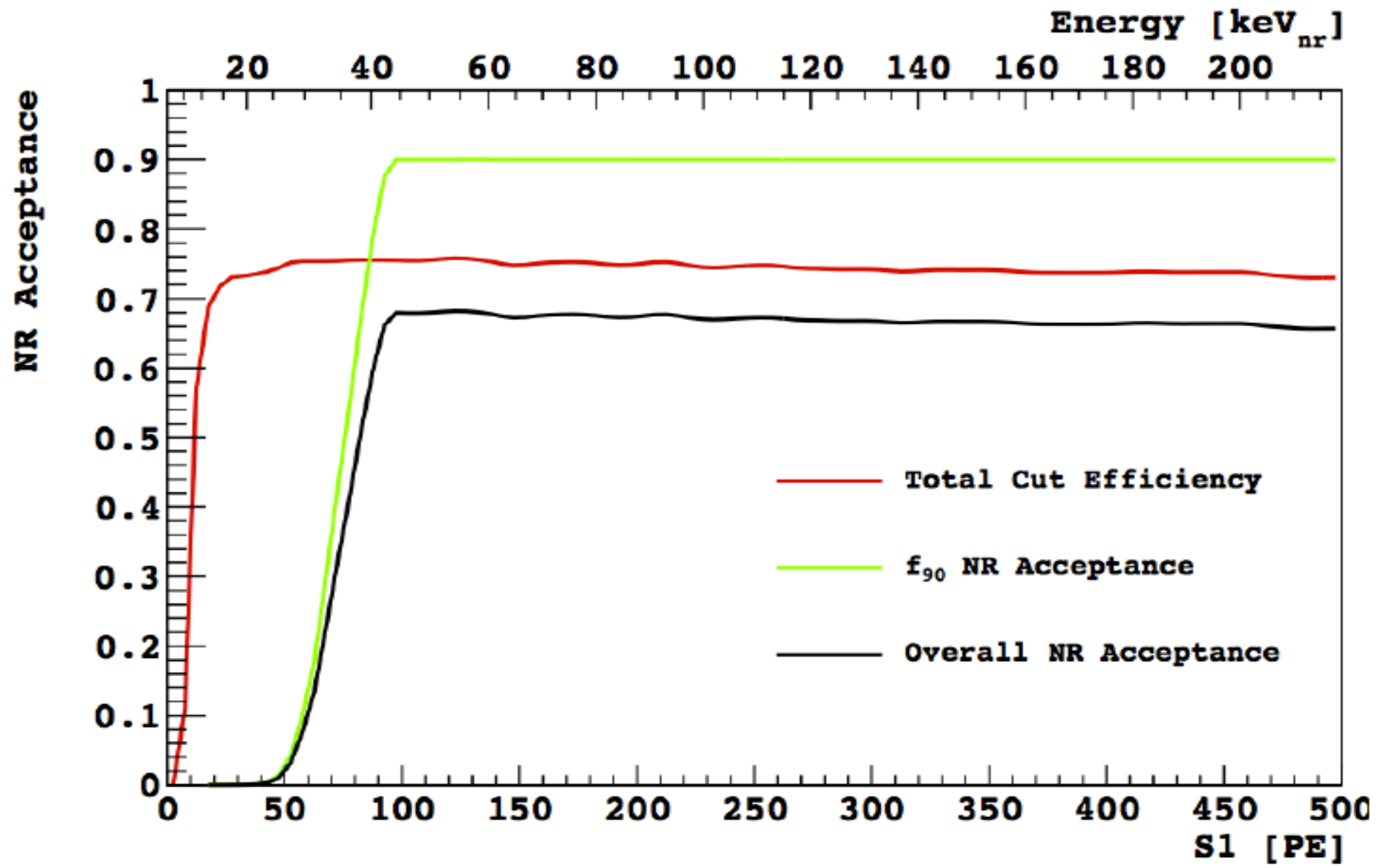




WIMPs acceptance in DS50

Cut	Acceptance
CUT 6: prompt LSV	0.95
CUT 7: delayed LSV and WCD	0.94
CUT 8: single scatters	$0.95^{+0.00}_{-0.01}$
CUT 9: first pulse time	$1.00^{+0.00}_{-0.01}$
CUT 10: no S1 saturation	1.00
CUT 11: max S1 fraction per PMT	0.99
CUT 12: S2 pulse shape	1.00
CUT 13: mimum S2	$0.99^{+0.01}_{-0.04}$
CUT 14: S1 range	1.00
Total	$0.82^{+0.01}_{-0.04}$

Tab. 2.4 Cuts acceptance for the AAr data-set. Errors are systematics, since the statistical error is negligible.



The UAr dataset