DarkSide

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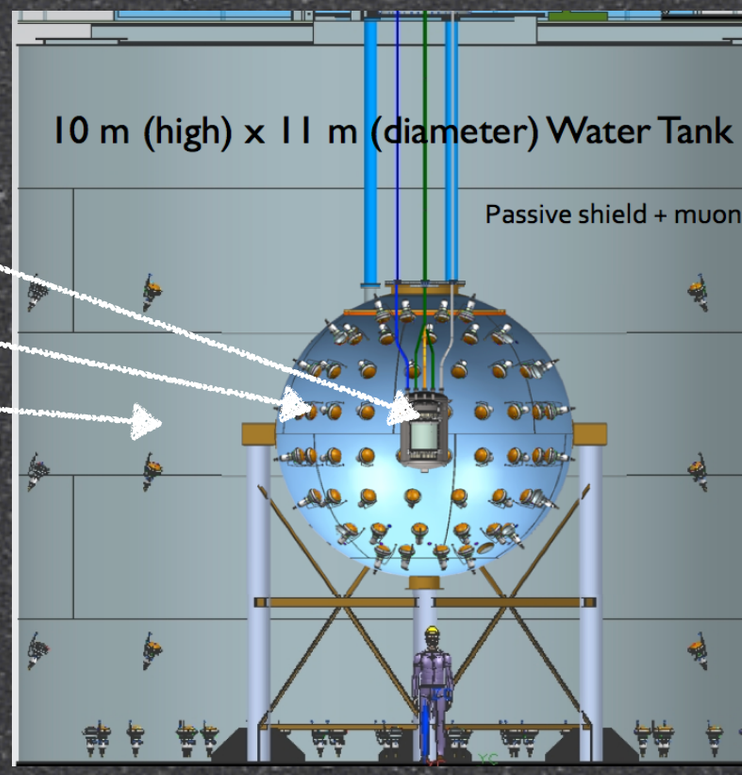
Journée Matiére Sombre - APC 01/01/2016

The DarkSide project

- Dual phase Liquid Argon TPC to search for Dark Matter
- DarkSide-50 (2013-2018)
  - Nested detectors: 50 kg Liquid Argon TPC
    Boron-loaded Liquid Scintillator Veto
    Water Cherenkov Veto
  - First use of underground argon (depleted of ^{39}Ar)
  - Demonstrate pulse shape discrimination (>10^7)
- DarkSide-20k (2020-2026)
  - 30 ton (20 ton FV) depleted Liquid Argon TPC
  - Designed to be background-free at 100 t yr exposure
  - Similar system of vetoes as DS-50, use of SiPM
- ARGO (2025-2035)
  - 300 ton (200 ton FV)
  - Search for WIMPs up to the neutrino floor
  - Solar neutrino physics



DarkSide Collaboration

- Large international collaboration (43 institutes, 277 signatures for the DS-20k proposal)
- Entire Liquid Argon community for DM searches to join this project → no competition with Liquid Argon for DS-20k
- Part of the collaboration works on external calibration experiments, using neutron beams to study the response of LAr to Nuclear Recoils
  - SCENE in the US (2014)
  - ARIS experiment at IPNO (2016)
  - Future experiments including directionality (ReD, ARIS-2)

IN2P3 DarkSide groups

DS-50 analyses
3 papers in preparation
(G4DS Monte Carlo,
f90 (PSD) model,
DS-50 background budget)

DS 1ton prototype

NR calibration
experiments and
directionality
ARIS (done)
ARIS-2
ReD

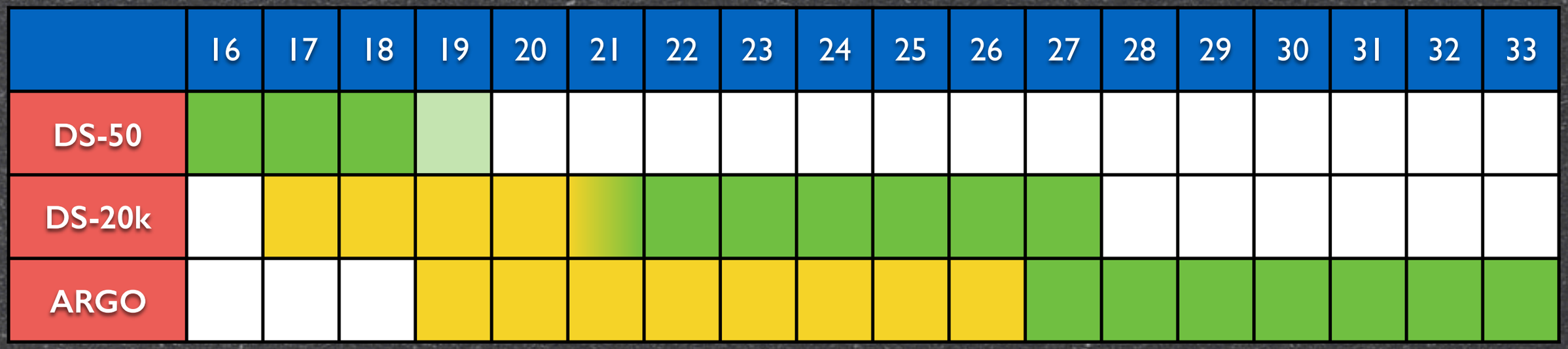
APC+LPNHE
Developers of the Monte Carlo simulation

DS-20k optimization
(do we need vetoes to
be background-free? yes!
DS-20k sensitivity
and discovery potential,
solar neutrinos, …)

ARIA
(depletion factor needed
for DS-20K and ARGO)

- French groups in DS have leading roles in physics analyses
- Leaders of the DS MC simulation
- External calibration with neutrons beam

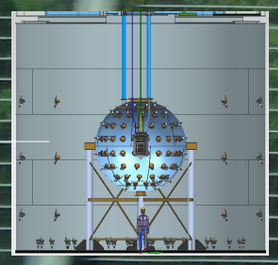
Timescale



- DarkSide-50 (37 kg FM) will take data at LNGS until 2018
- DarkSide-20k (20 ton FM) will start data taking at LNGS in 2021
  - Expect approval from INFN and NSF in April 2017
  - A 1-ton scale prototype will be built starting next year to test the technologies needed for DS-20k
- ARGO will follow DS-20k (200 ton FM)

What is DarkSide-50?

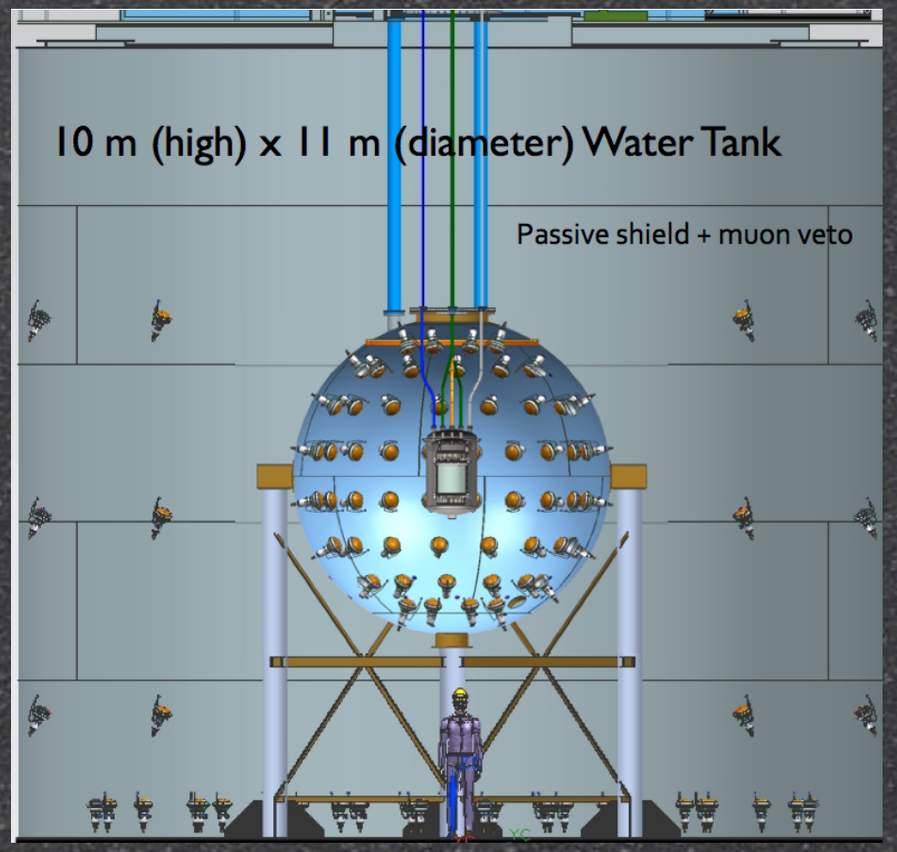
a two phase liquid argon (LAr) detector,
within a neutron veto,
within a muon veto,
under a mountain



… and all because of backgrounds

DarkSide-50

- Experiment installed at LNGS
- Double phase TPC with 50 kg of LAr
- Vetoes system: Liquid Scintillator and Water Cherenkov
- 2 data releases published
  - **Atmospheric Ar campaign (52 days)**
    Phys.Lett.B.743(456)
  - **Underground Ar campaign (71 days)**
    Phys. Rev. D 93, 081101 (2016)



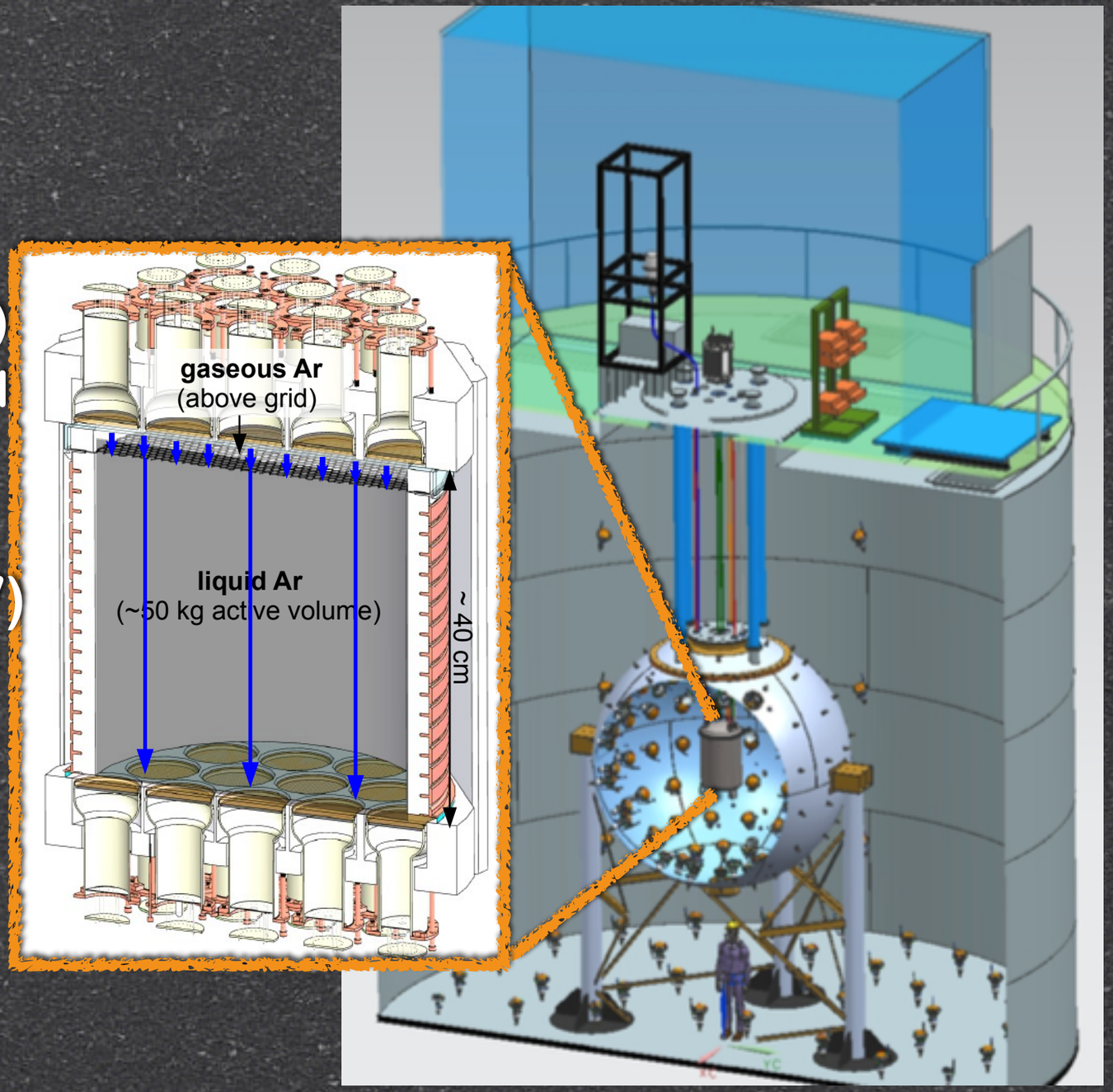
Background reduction
Depleted Underground Argon
Low background materials
Active Shields

Background identification
Pulse Shape Discrimination
S1/S2 discrimination
Measure neutron flux in borate scintillator

Demonstrate the potential of the technology for multi ton background-free detector

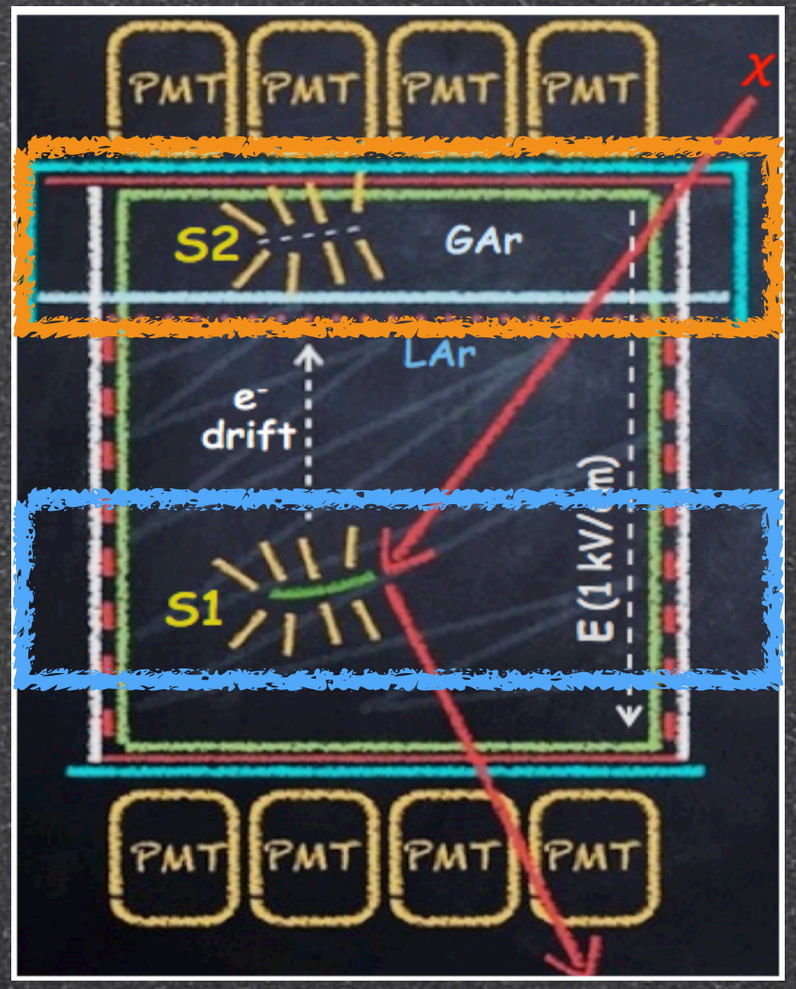
DarkSide-50 detector design

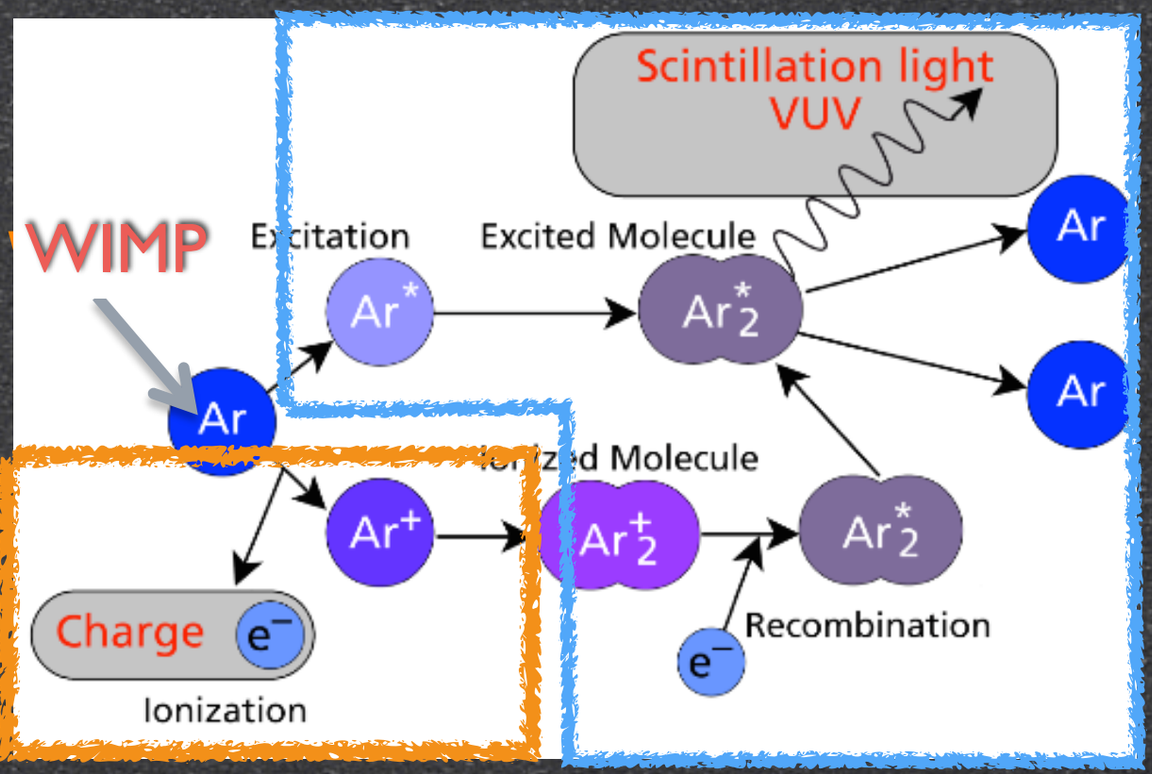
- **Liquid Argon TPC**
  - 36 cm x 18 cm radius
  - 50 kg (36.9 fiducial)
  - 38 PMTs
  - Uniform electric field (200 V/cm)
  - 1 cm gas pocket, extraction field (2.8 kV/cm)
  - Reflectors and TPB coating
- **Liquid Scintillator Veto (LSV)**
  - 30 tons, 2m radius
  - LS (1:1 TMB+PC)
  - 110 PMTs
- **Water Cherenkov (WCD)**
  - 1 kton water, 5.5m radius
  - 80 PMTs



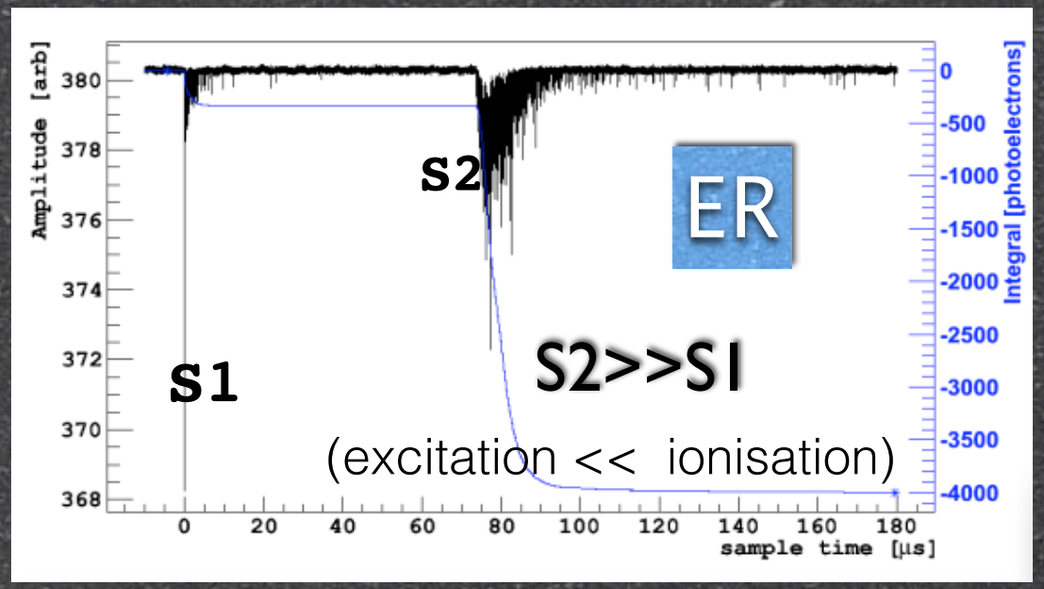
Ionization and excitation

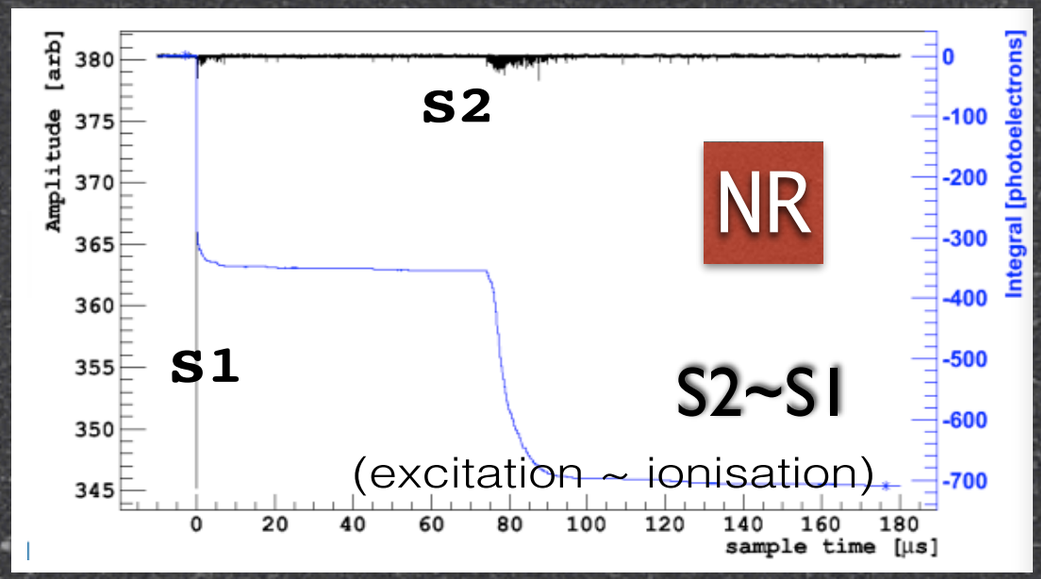
- WIMPs scatter on LAr → primary photons (S1) + electrons drifting to the GAr region where they are accelerated and emit light through electroluminescence (S2)
- S1/S2 ratio allow to distinguish electron recoils from nuclear recoils with a rejection power of ~10^2-10^3



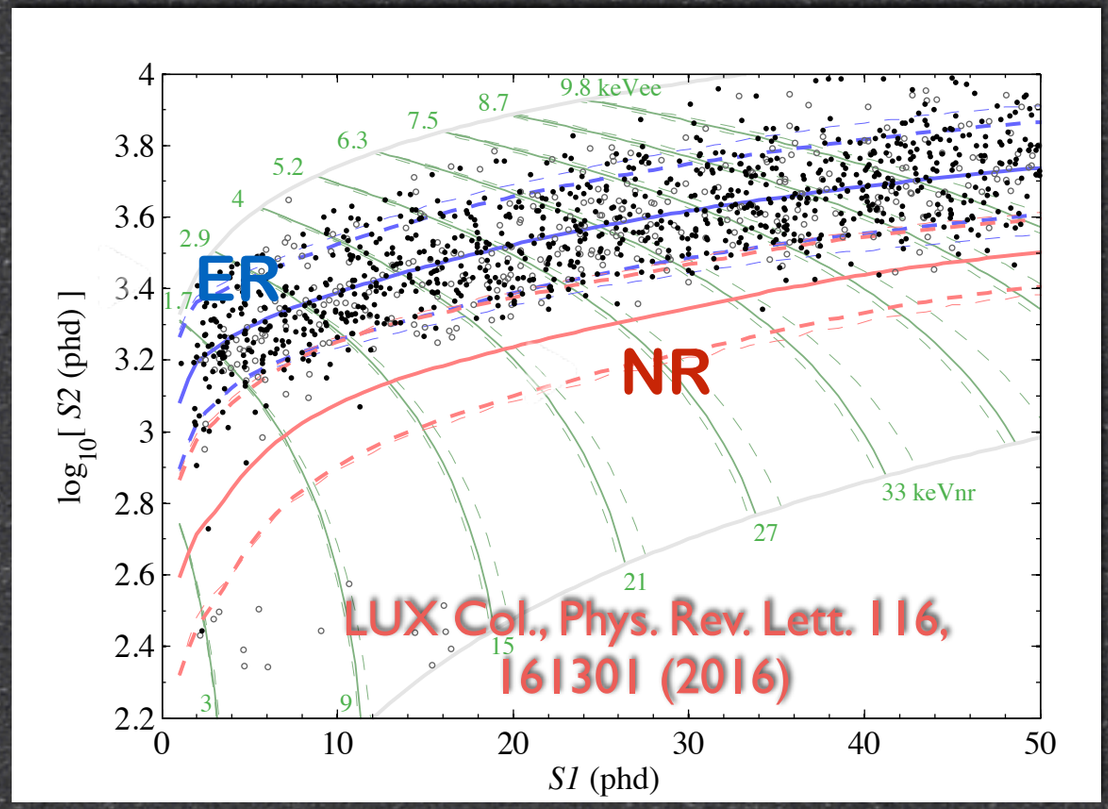


S1/S2

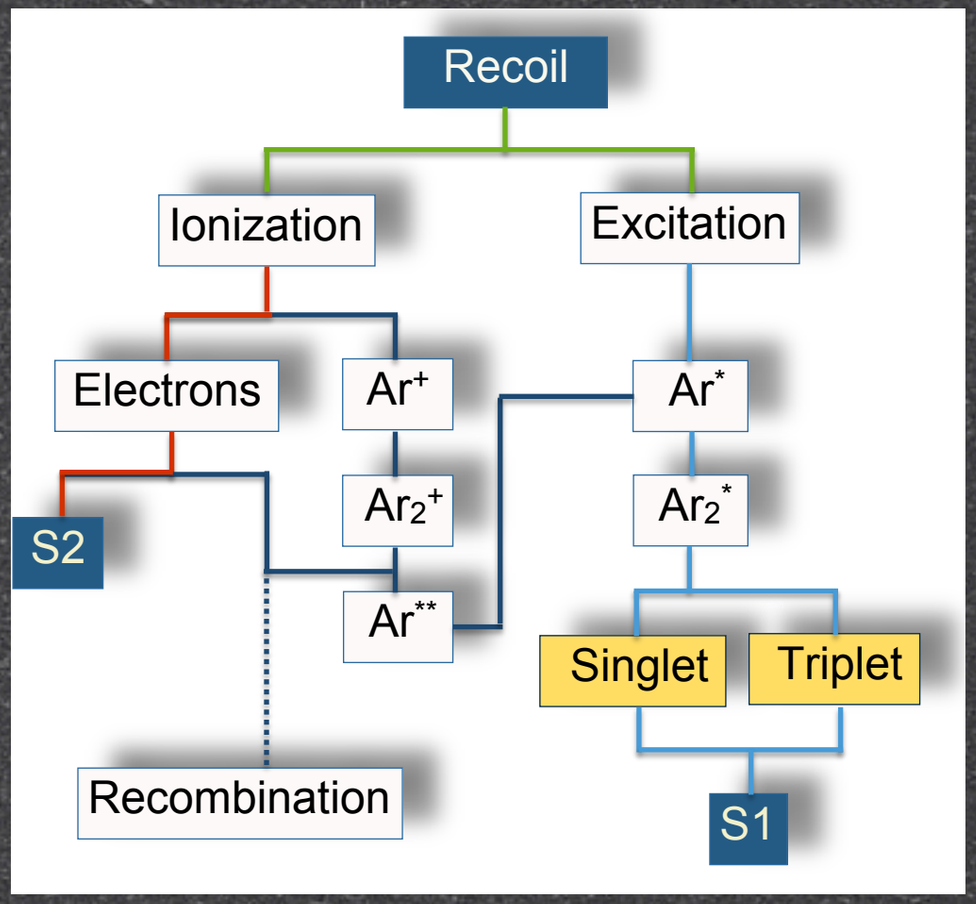




- Exploit different fractions of energy going to excitation (S1) and ionization (S2)
- Allow to distinguish ER from NR with a discrimination power of 10^2-10^3
- Technique available for dual phases noble liquids detector (Xe or Ar)



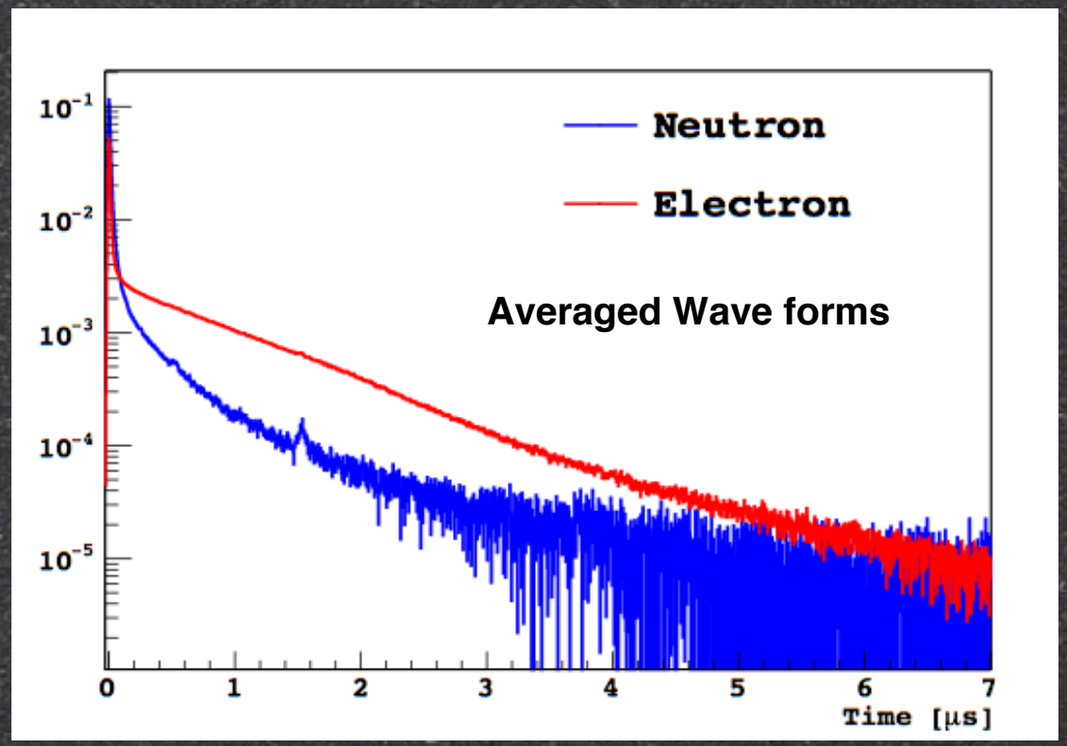
Pulse Shape Discrimination in LAr



	LAr	LXe
Singlet	~7 ns	4 ns
Triplet	~1600 ns	22 ns

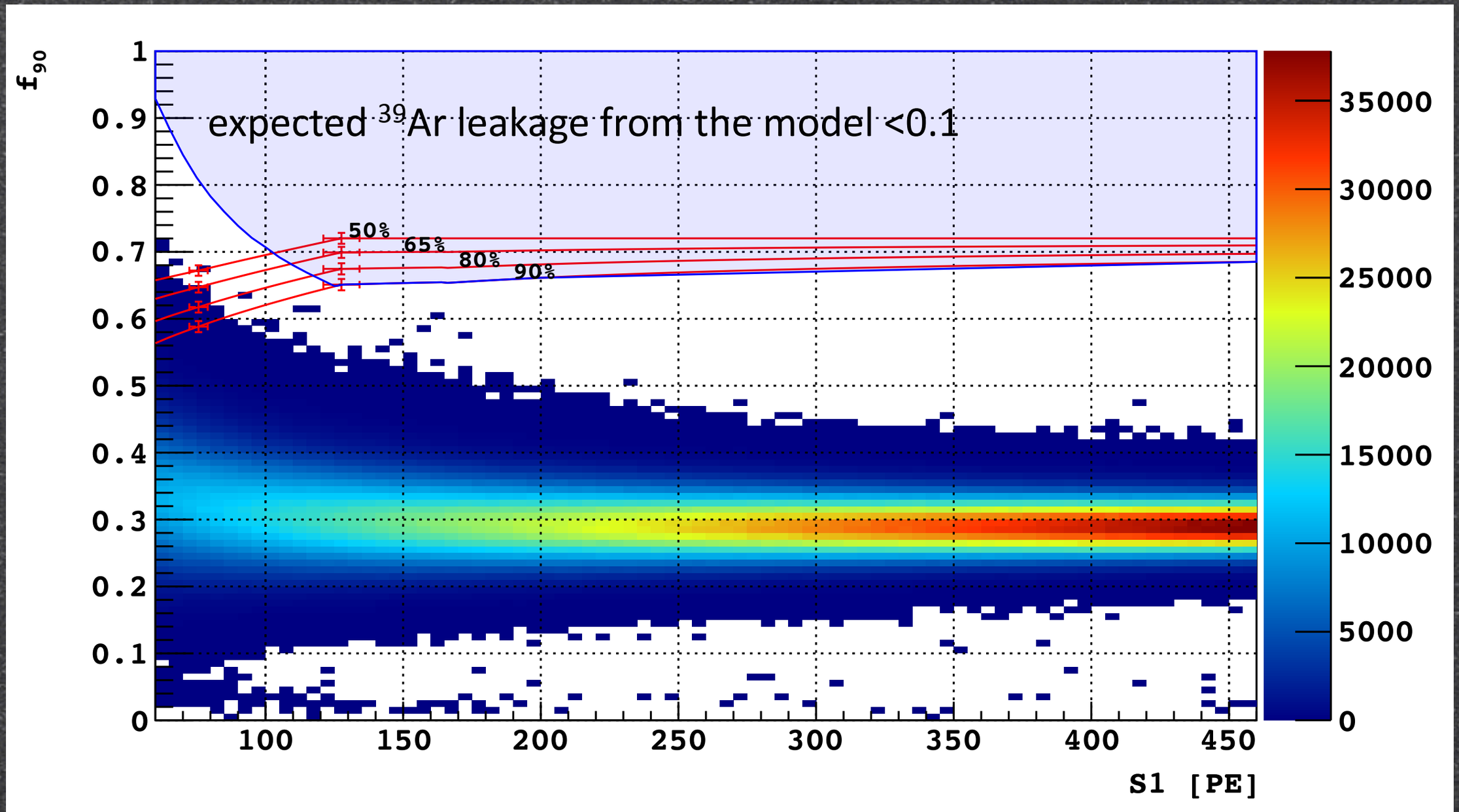
	Singlet	Triplet
Time Constant	7 ns	1600 ns
ER population	33%	67%
NR population	75%	25%

- Discrimination power depends on the Light Yield
- For DS-50 we use f_{90}=Q(0-90 ns)/ Q(all) and a discrimination power larger than 10^7 has been demonstrated



Atmospheric Argon results

- 50 days of data taking
- 1.5×10^7 single scatter events in the ROI (dominated by ^{39}Ar)
- None of them enter the WIMP search region



Underground Argon

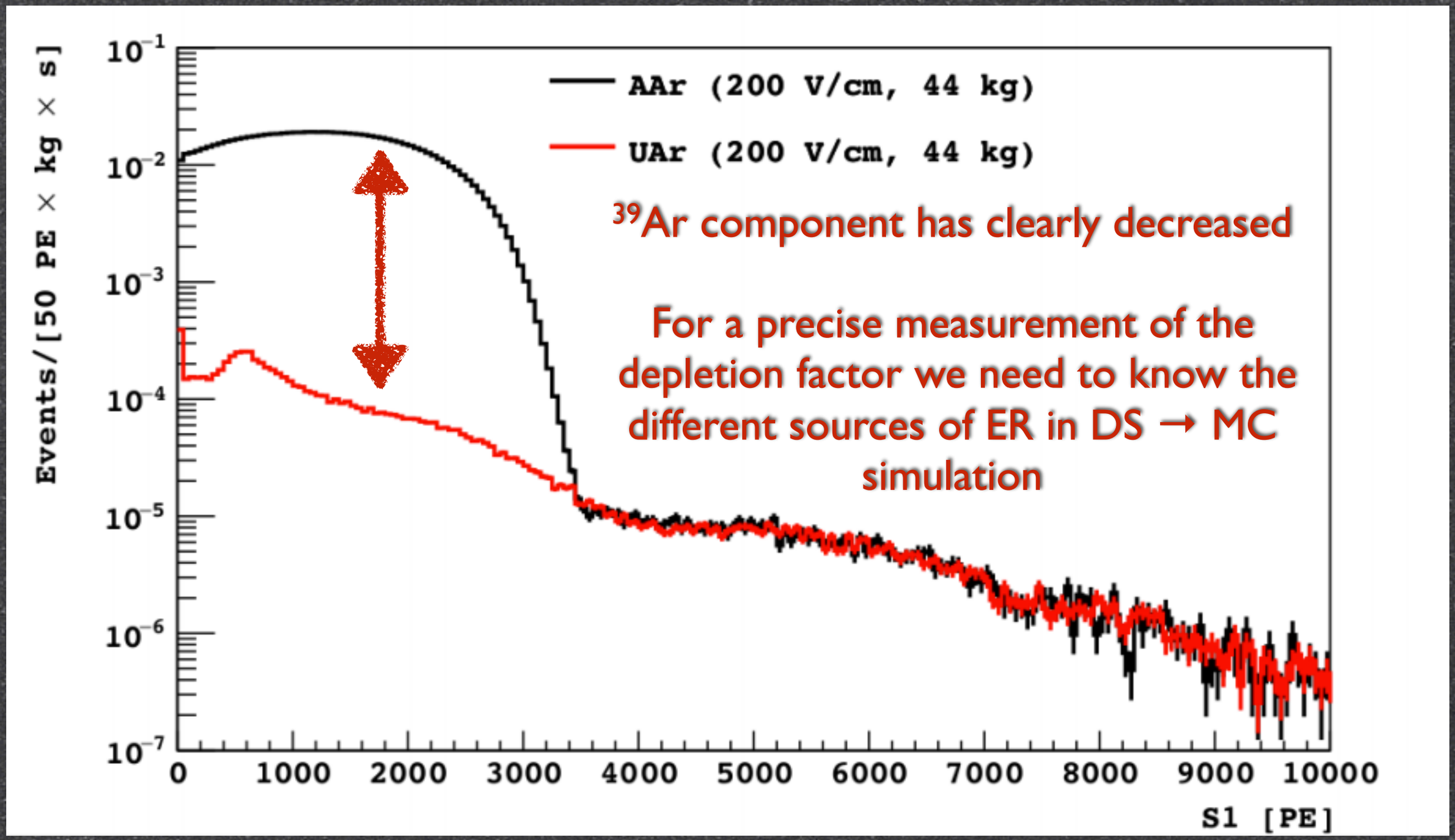
- Atmospheric Argon contains cosmogenic contamination from ^{39}Ar due to activation from cosmic rays
- β-decay with a rate of ~1 Hz/kg in Atmospheric Argon
- Half-life of ^{39}Ar is 270 years
- Solution: use underground argon naturally depleted of ^{39}Ar
- DS-50: 150 kg of UAr extracted from a mine in Colorado, purified at FNAL and shipped to LNGS


Extraction in Colorado


Purification at FNAL

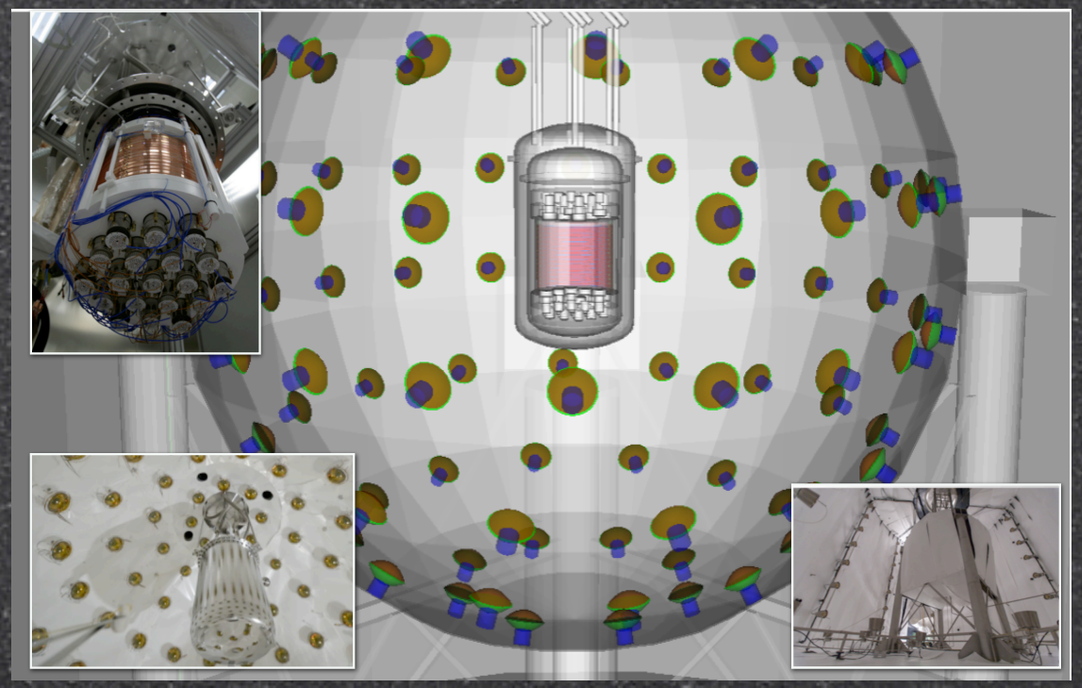

Shipping to LNGS

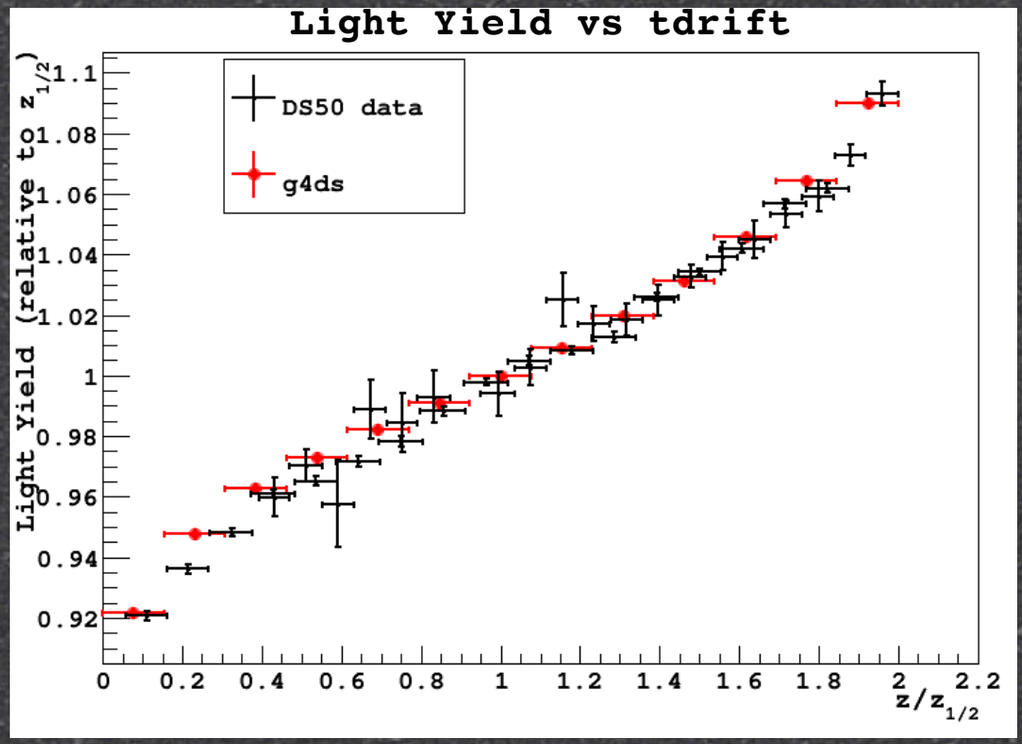
Underground Argon run

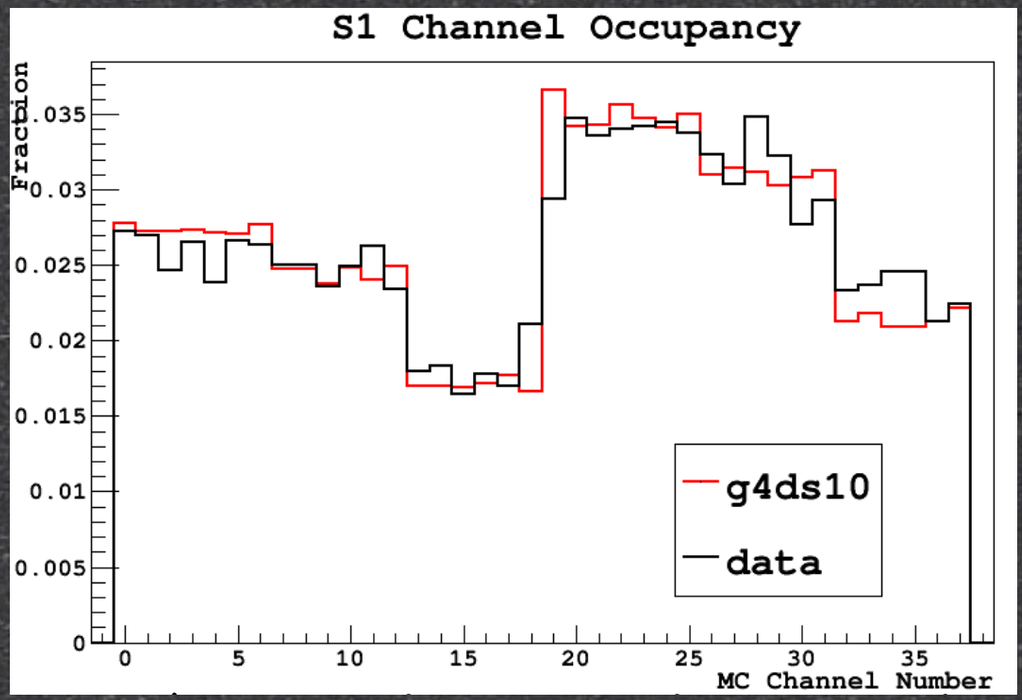


DS MC simulation: G4DS

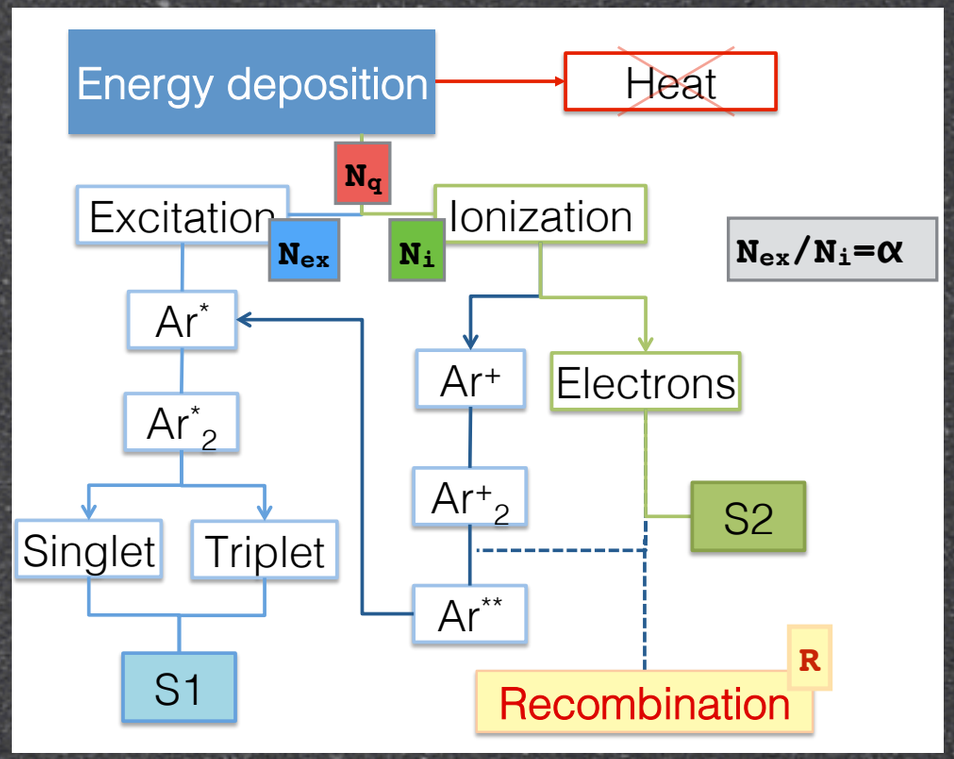
- The MC simulation of DS has been written by French groups
- **GEANT4 MC simulation** including all the geometries of the DS program (DS-50, DS-20k, DS-1ton, ARIS, ReD…)
- Optical tuning based on DS-50 data
- Fundamental tool for the analysis of DS-50 data and the design of DS-20k





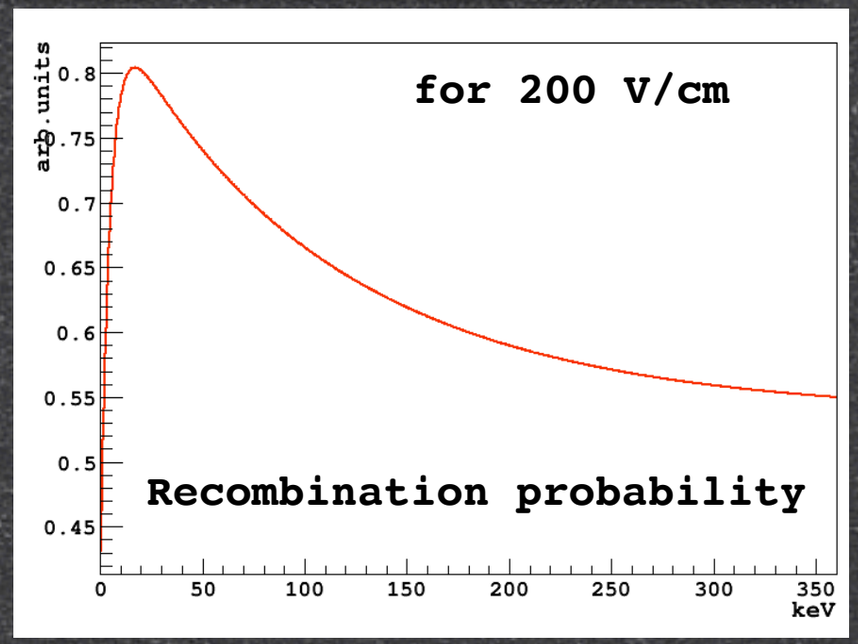


The PARIS model

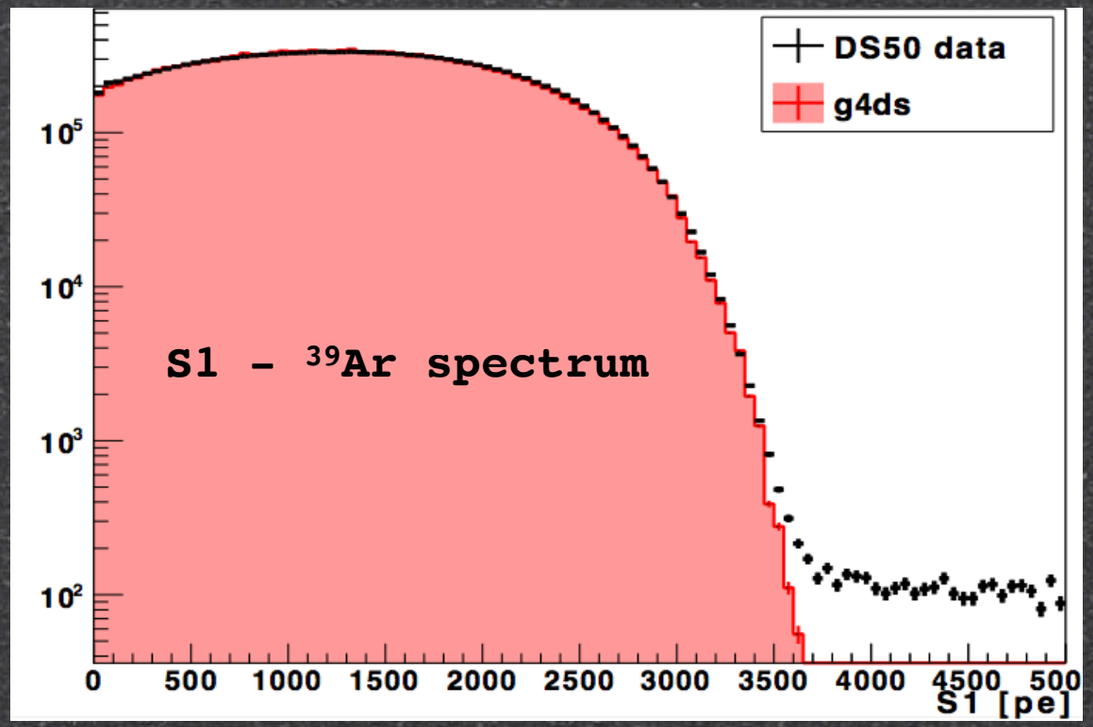


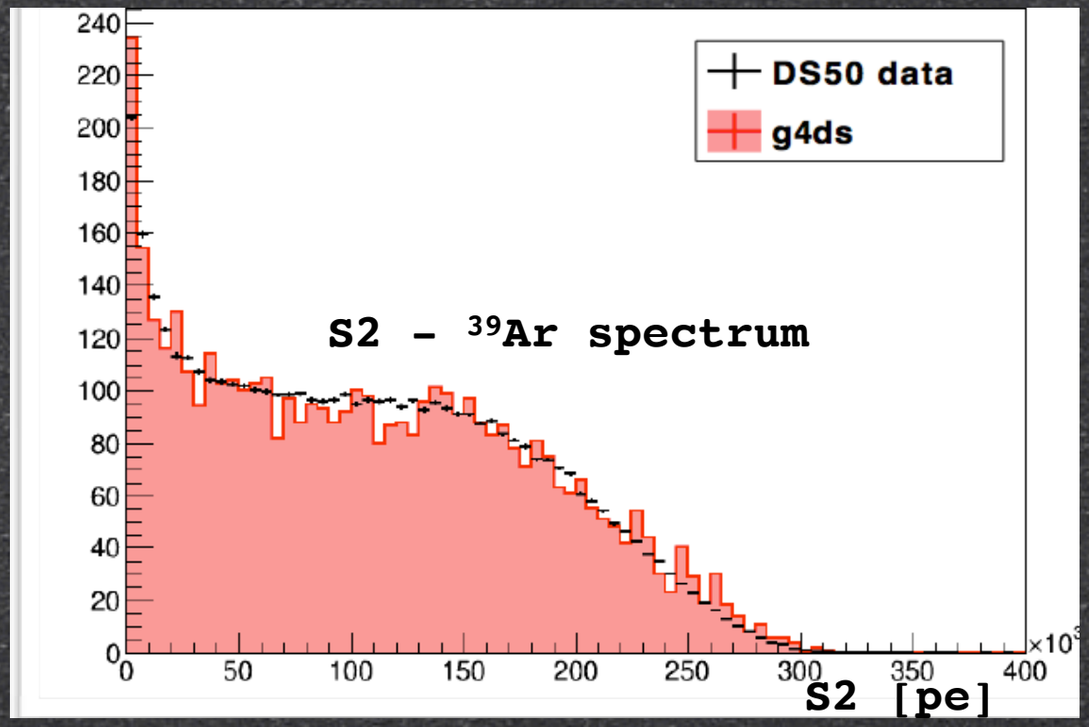
$$N_q = E / W$$
$$N_i = N_q / (1+\alpha)$$
$$N_{ex} = N_q - N_i$$

$$N_q^{S1} = N_{ex} + RN_i$$
$$N_q^{S2} = N_i(1 - R)$$



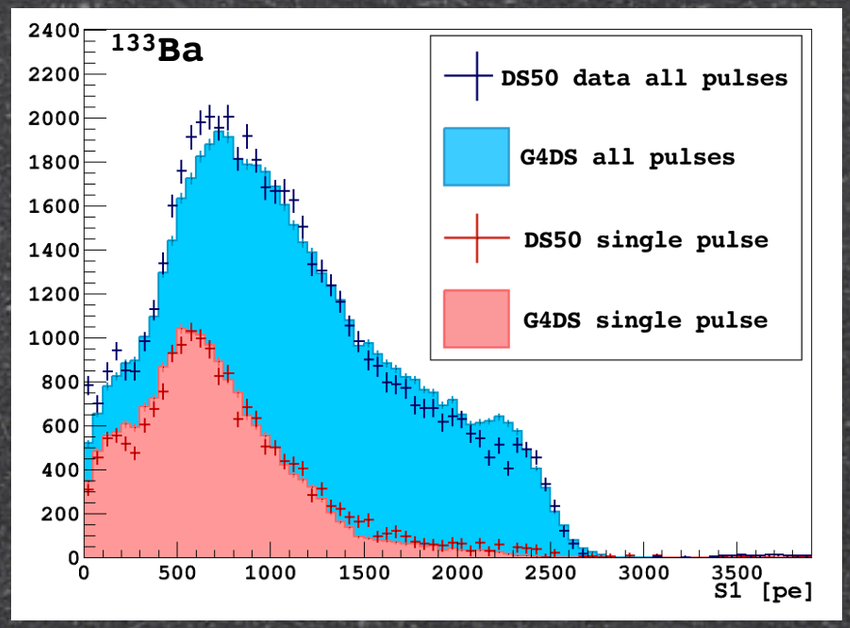
Model R as a function of the recoil energy and the drift field

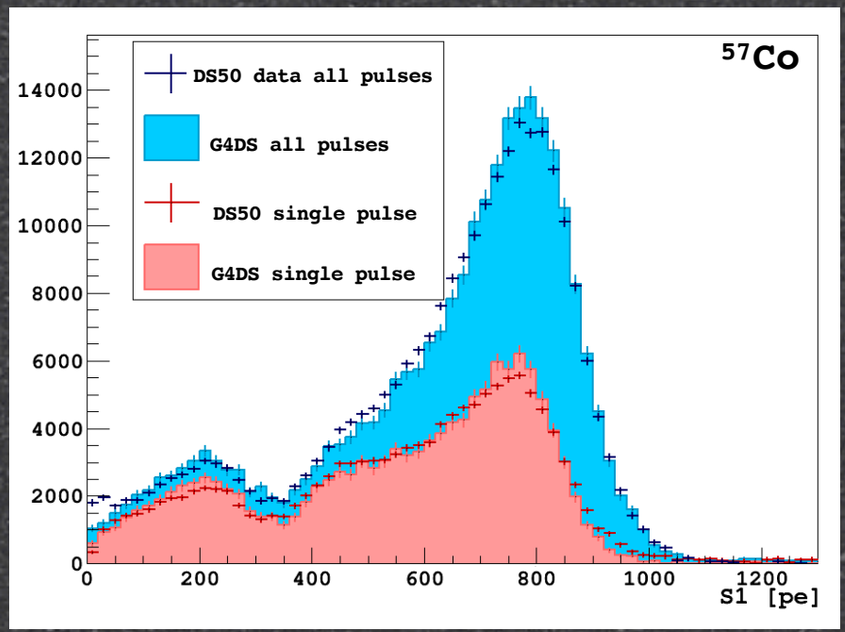


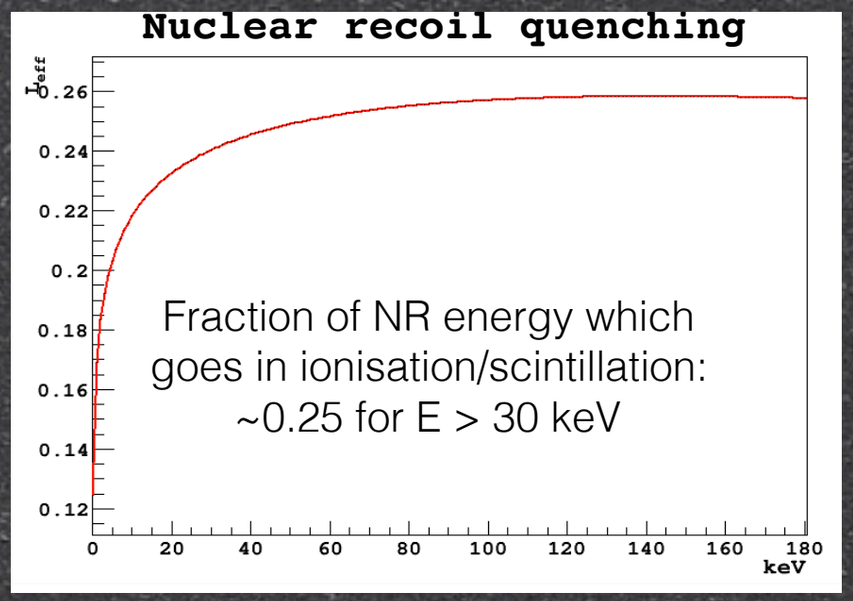


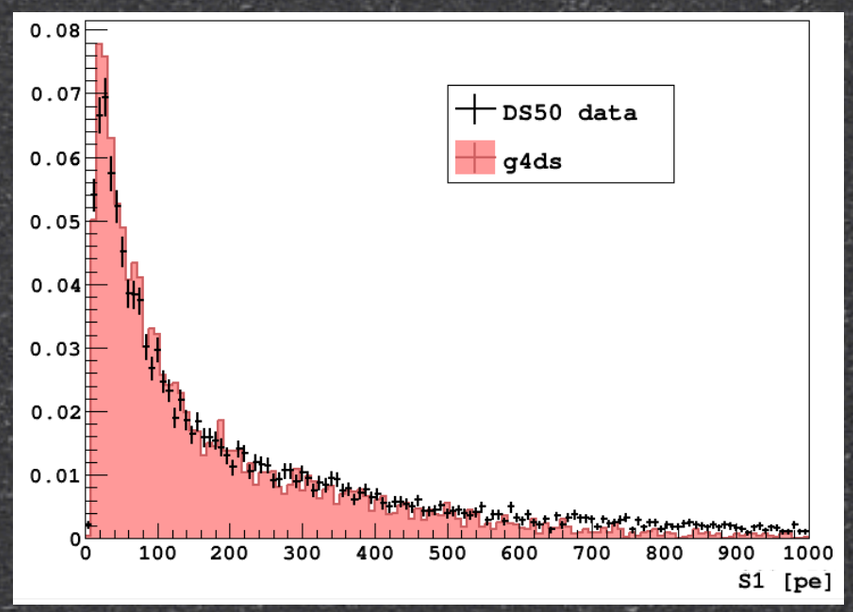
ER and NR calibration

External ER calibrations sources (Ba and Co) deployed in DS-50
Excellent data/MC agreement





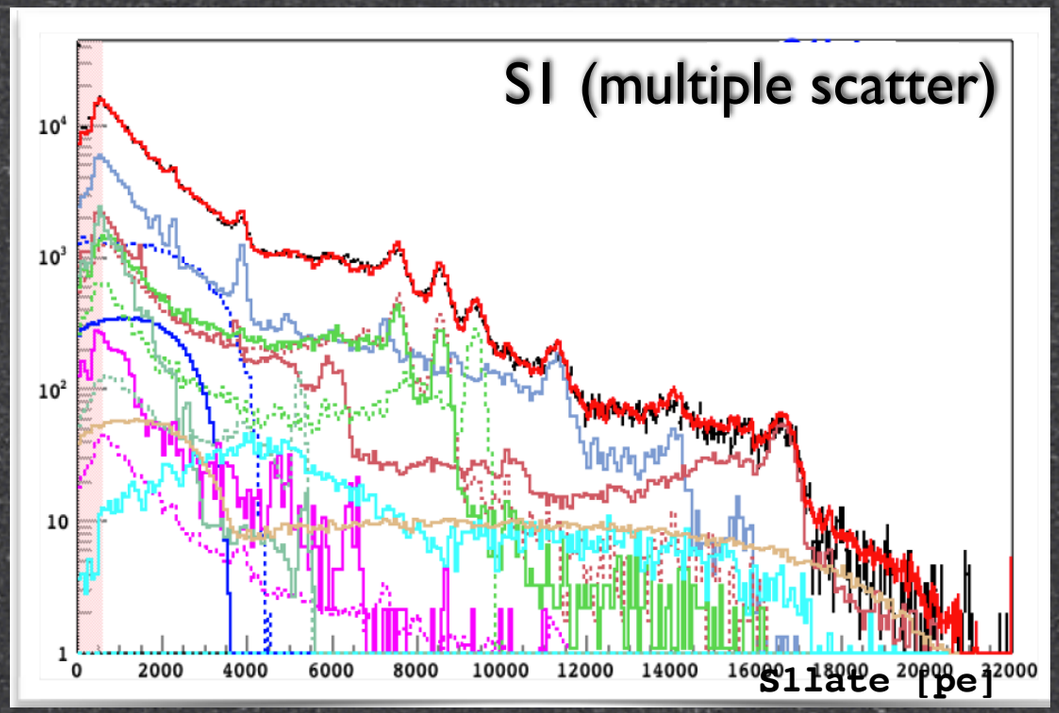


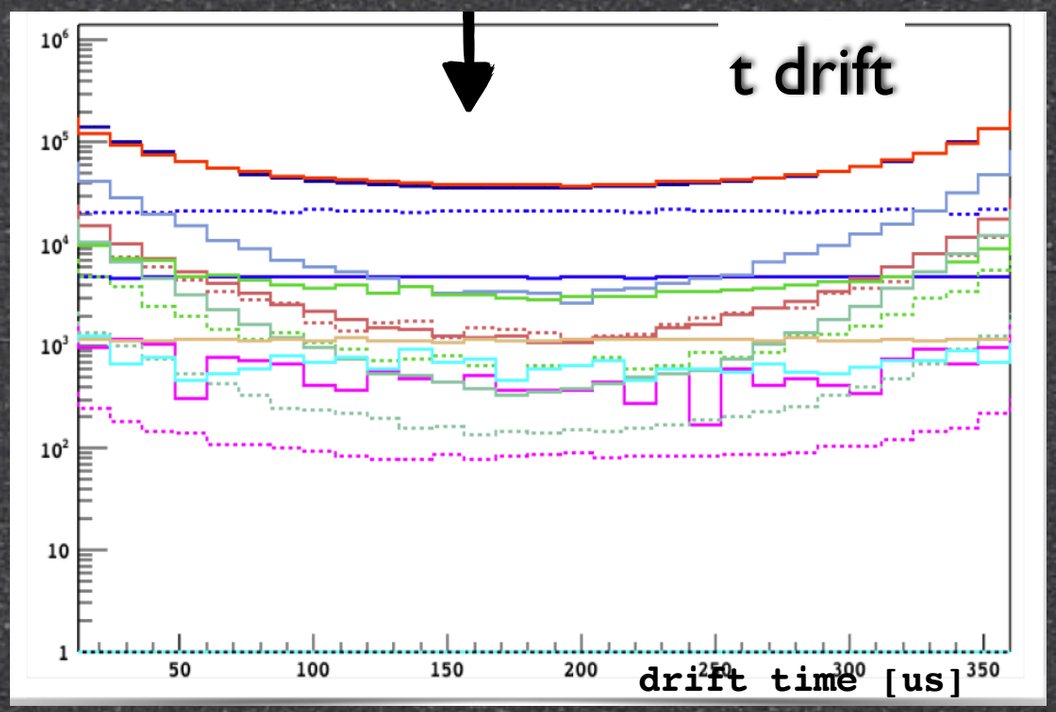


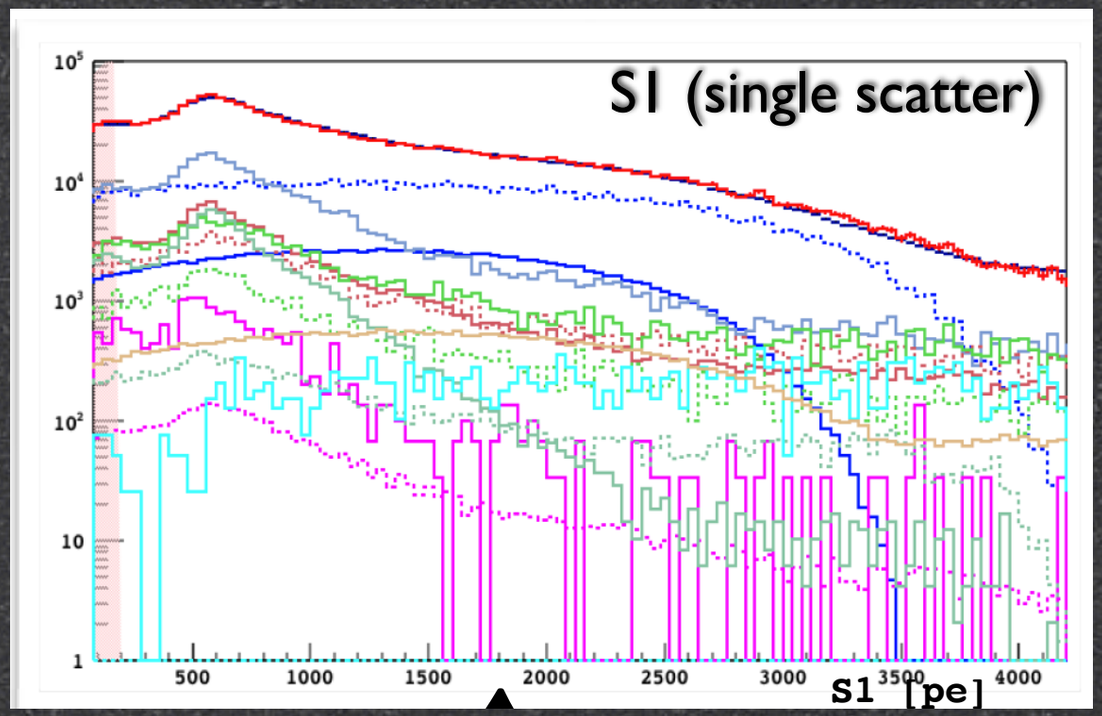
External NR calibrations sources (AmBe) deployed in DS-50
Excellent data/MC agreement

3D fit to extract ^{39}Ar component

- Done by French groups with MC
- Include the shape of the backgrounds from the different sources (Cryo, PMTs, etc)
- Fit the multiple scatter and single scatter spectra and the t_{drift} distribution



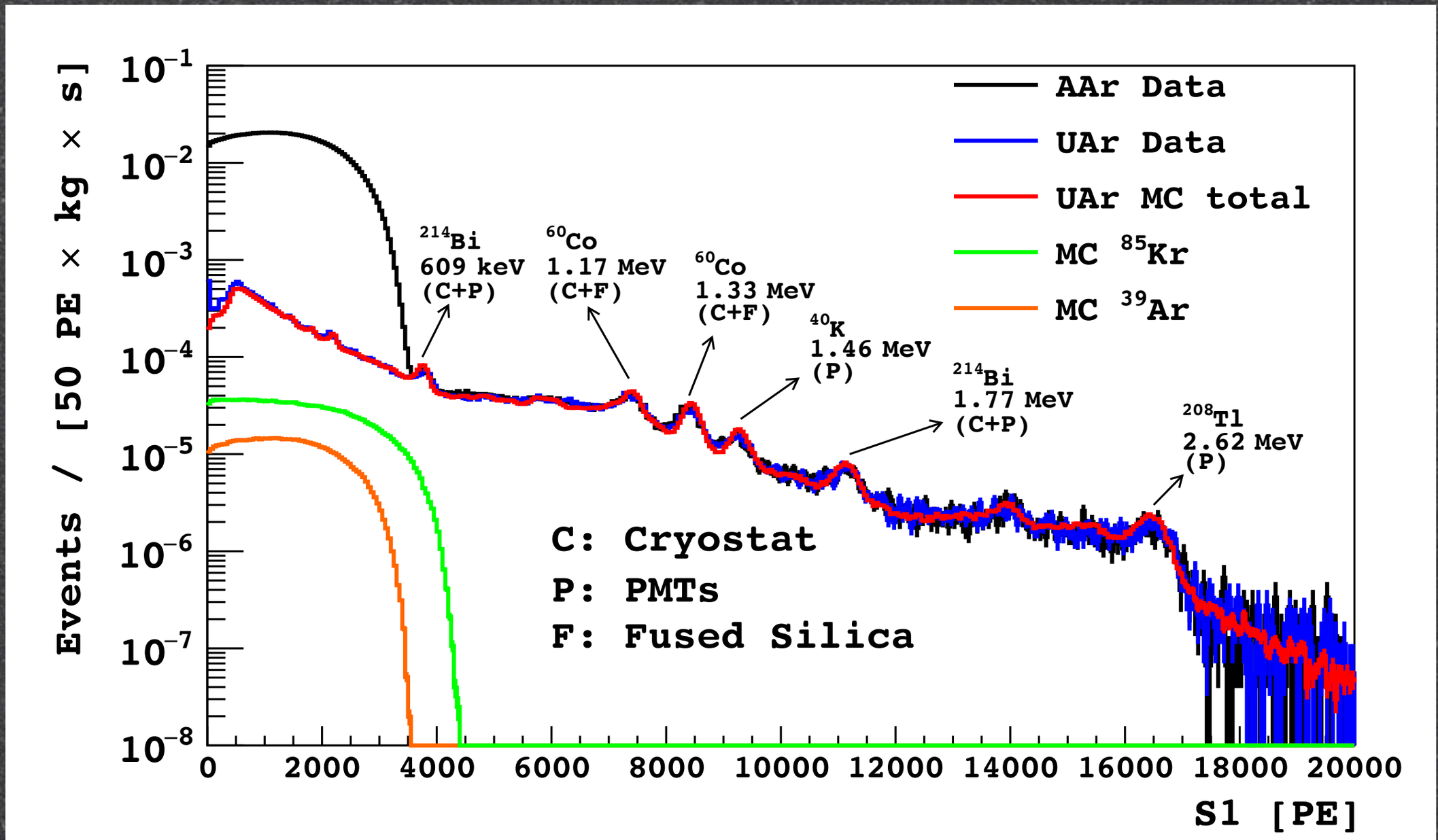




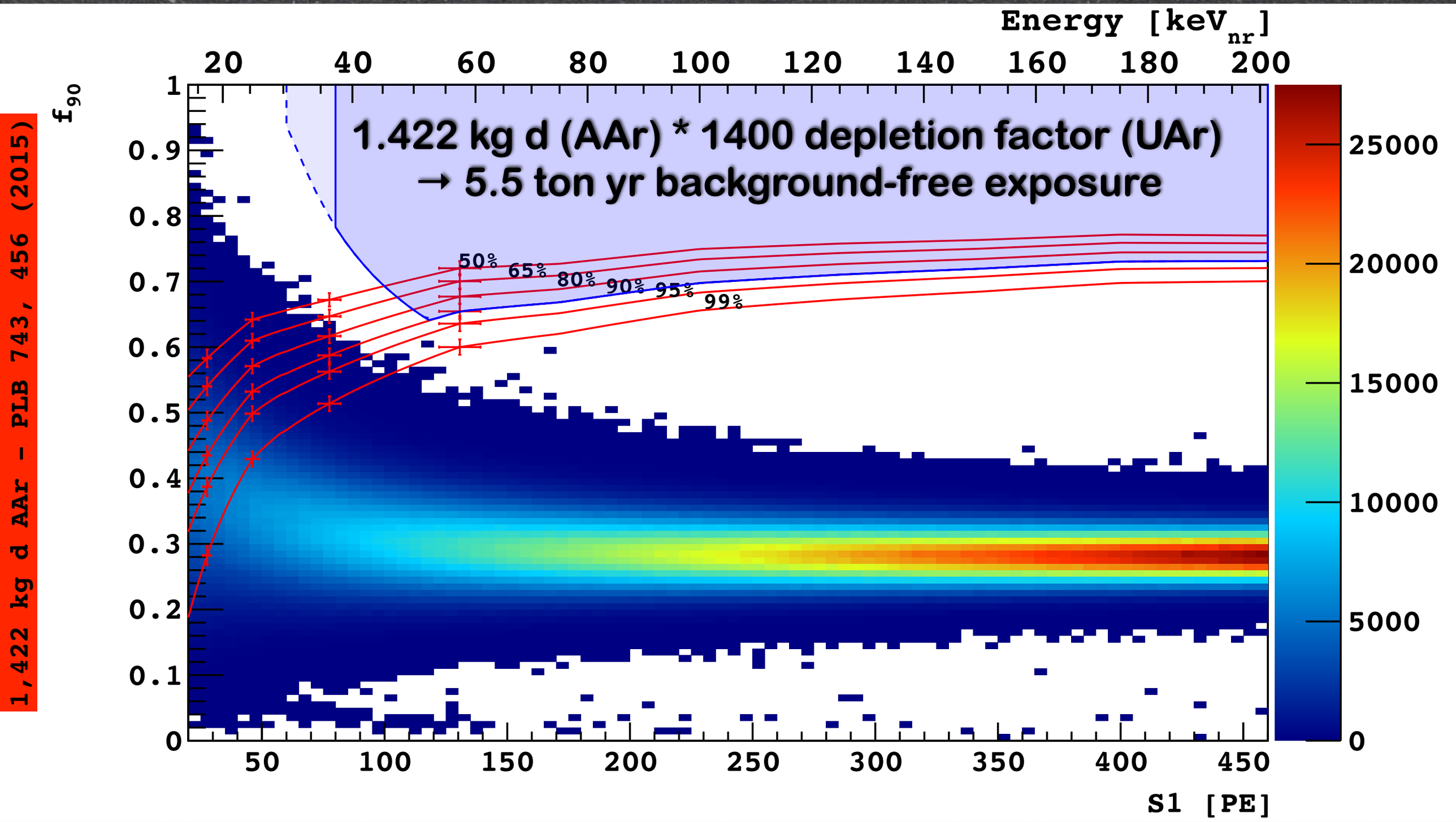
^{39}Ar depletion factor

^{39}Ar = 0.71±0.05 mBq/kg → depletion factor of 1400±200 (previous upper limit was >100)

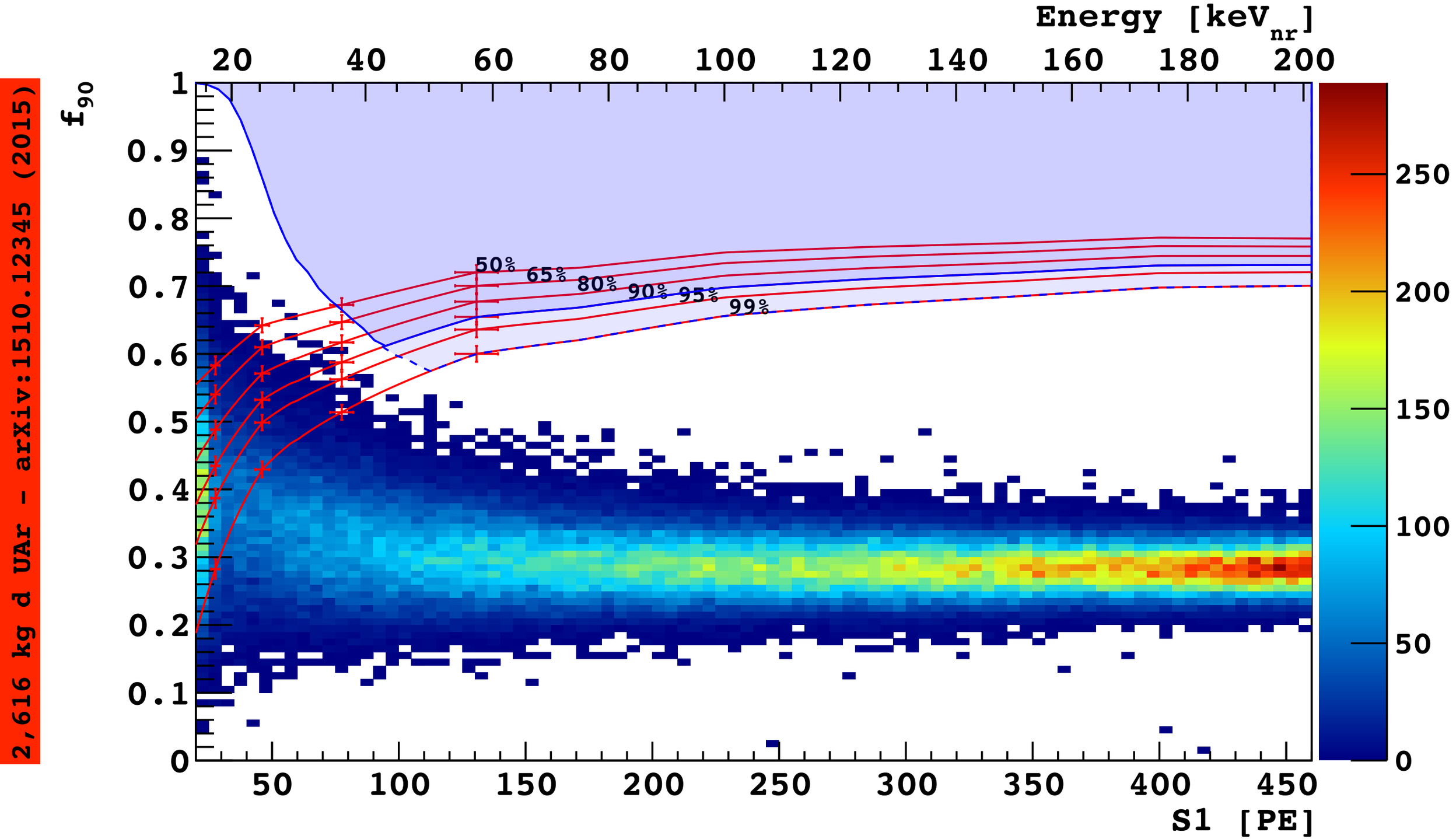
Discovery of the ^{85}Kr component ~ 2 mBq/kg (later confirmed by coincidence search)



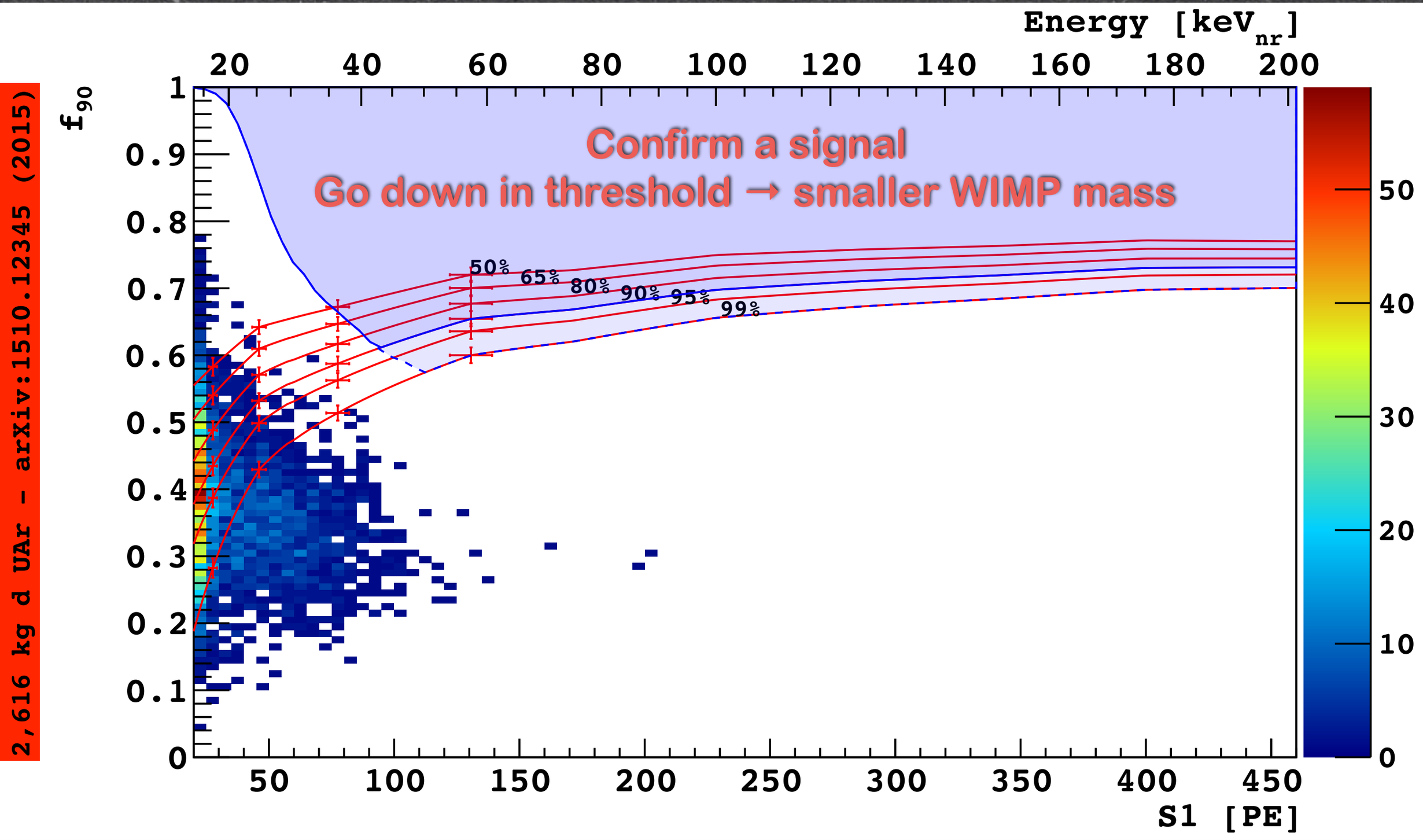
Background-free 52 days exp (AAr)



Background-free 70 days exp (UAr)



70 day exp (UAr) + S1/S2 cut



DarkSide-20k

- Dual phase TPC → from 50 kg to 30 ton (20 ton FV)
- TPC light readout with **SiPM**
  - **Better light yield** (>10 pe/keV)
  - Cleaner than PMTs and lower mass (**much lower neutron background**)
- Active vetoes (LS and WT) similar as DS-50
- **Depleted Argon**: extract large quantities of UAr in Colorado (**URANIA**) and further purify it with a distillation column (**ARIA**) already partially funded
- **Scientific goal: 100 ton yr background-free exposure**

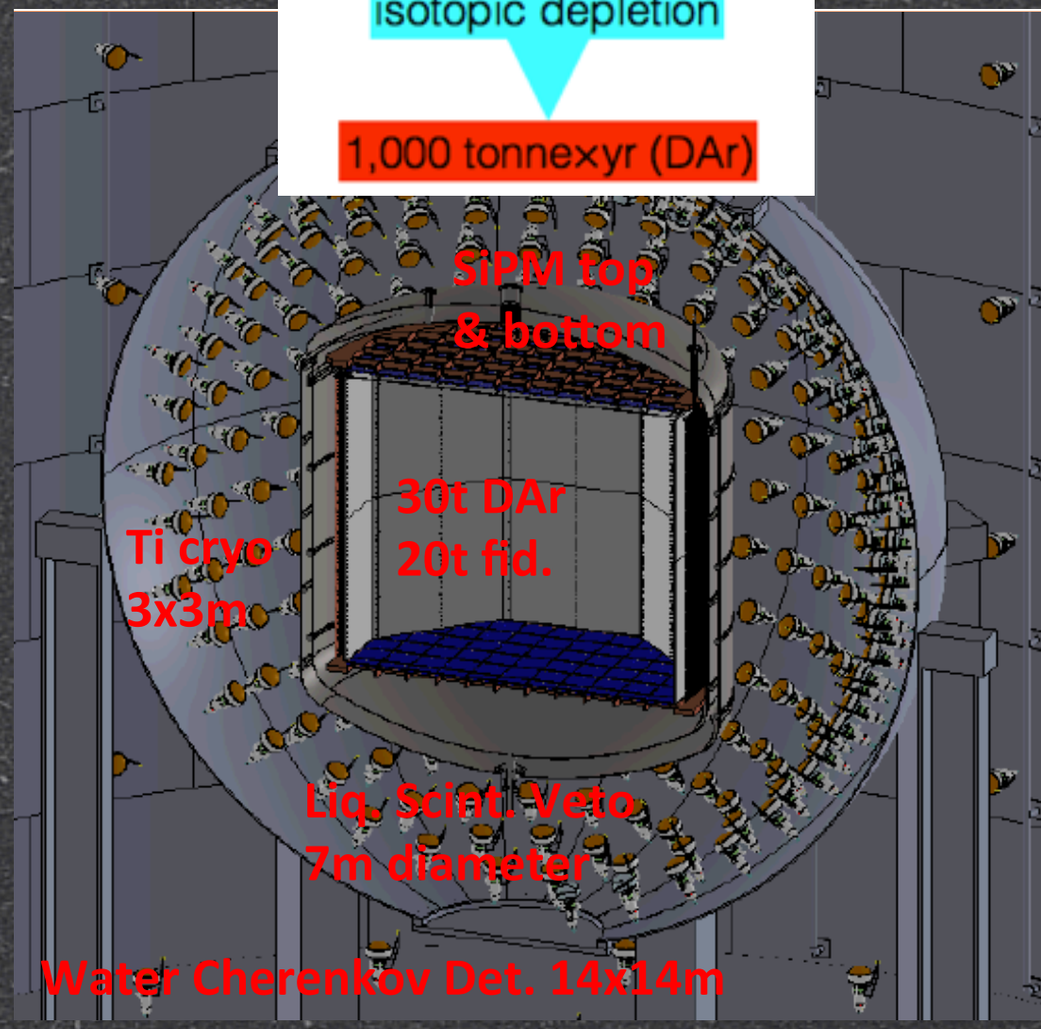
16M ^{39}Ar events
1,422 kg×day (@AAr)

÷1400 39Ar depletion
AAr/UAr

16M ^{39}Ar events
5.5 tonnexyr (UAr)

higher light yield
additional active
isotopic depletion

1,000 tonnexyr (DAr)



Yellow Book

The DarkSide-20k Yellow Book

Technical Proposal/Pre-Technical Design Report

September 5th, 2016

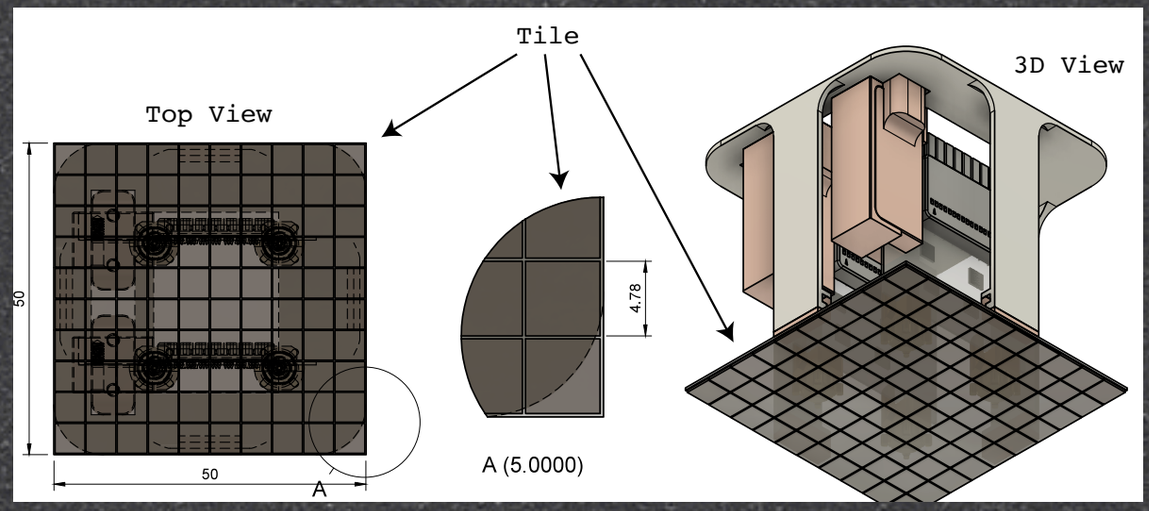
43 institutes
277 signatures

Submitted to the LNGS Scientific Committee and to INFN/NSF

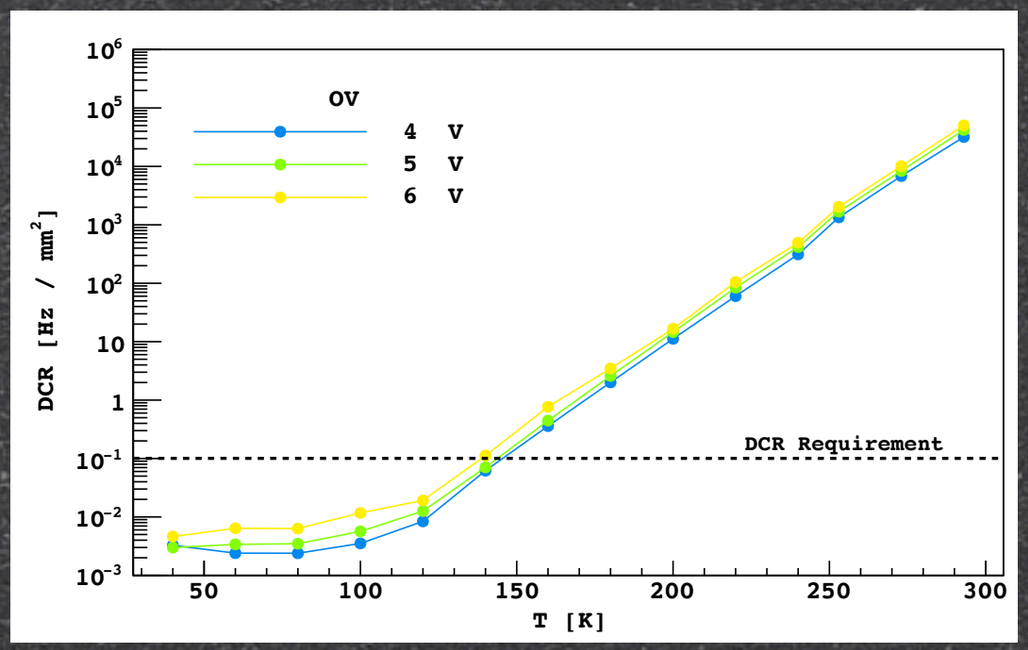
Joint review started
→ expect approval by April 2017

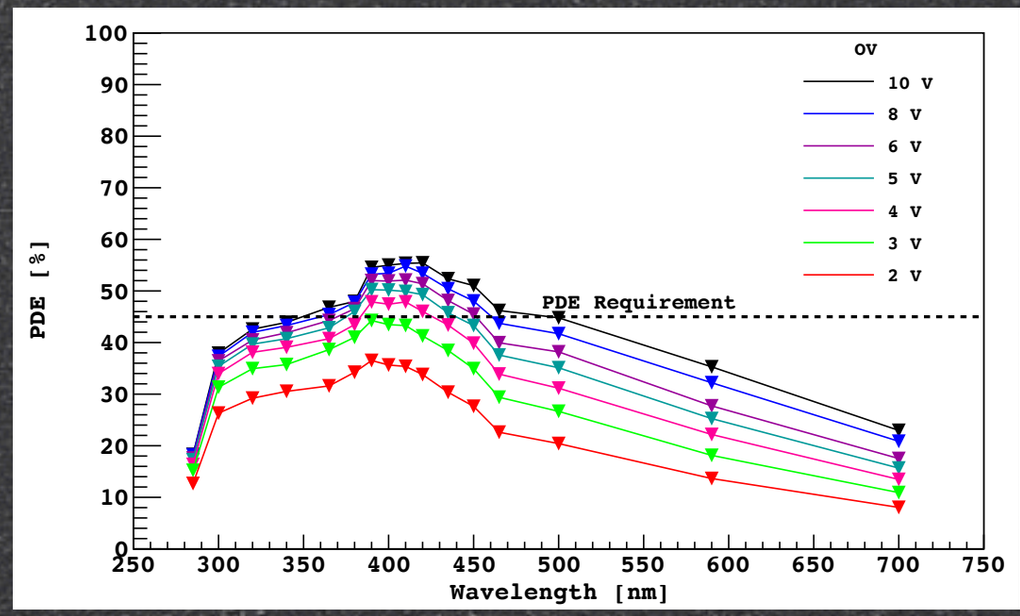
SiPM R&D

- The other big challenge of DS-20k is to instrument a large area of detector with SiPM (total active surface of ~15 m^2)
- A lot of R&D is on-going mainly driven by LNGS and FBK



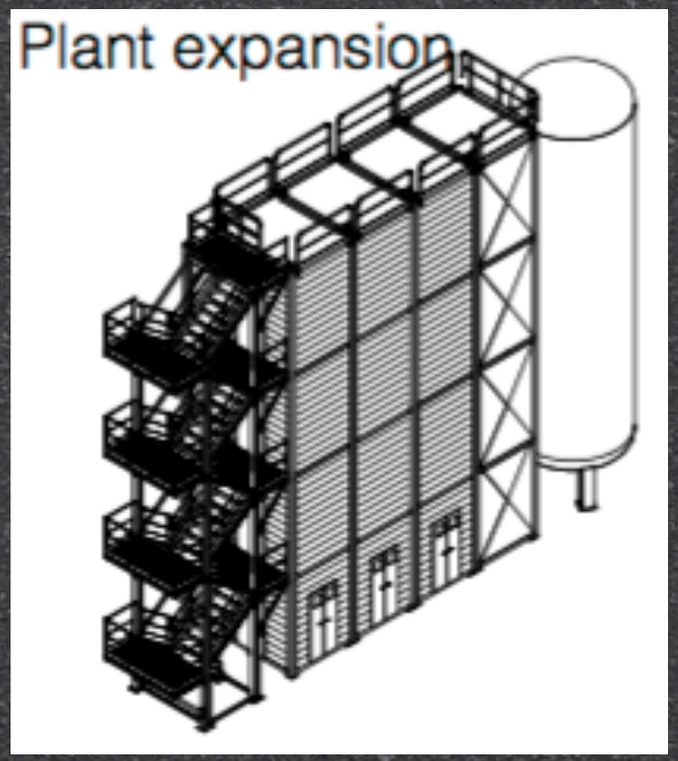
- Already reach goal for Dark Count rate and photon-detection efficiency

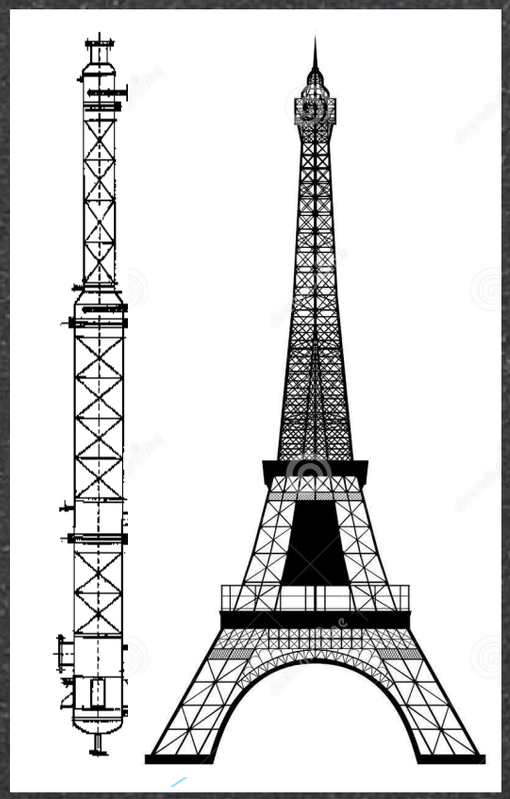




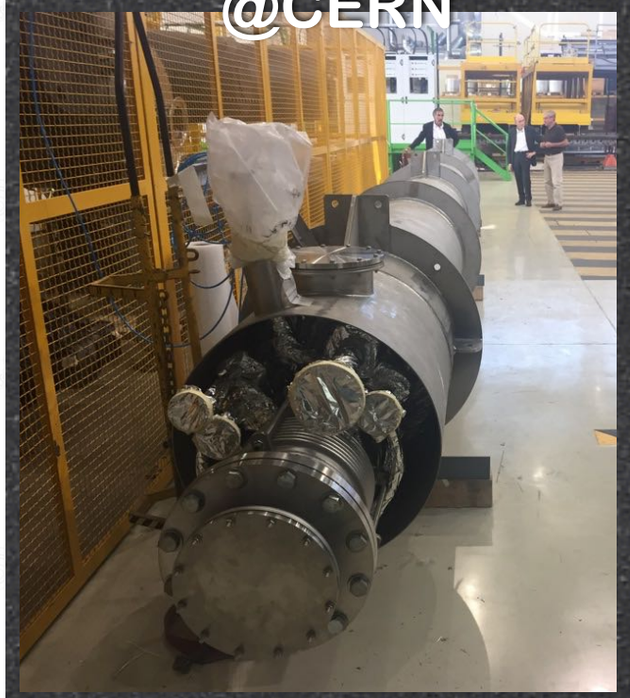
Underground Argon procurement

- **URANIA**: plant expansion to extract **100 kg/day** of UAr in Colorado
- **ARIA**: ~300 m distillation column to be installed at Seruci (Sardinia) to remove ^{85}Kr from Ar (easy) and to further reduce the residual ^{39}Ar component (→ factor of 10 per pass)
- These programs have already been funded



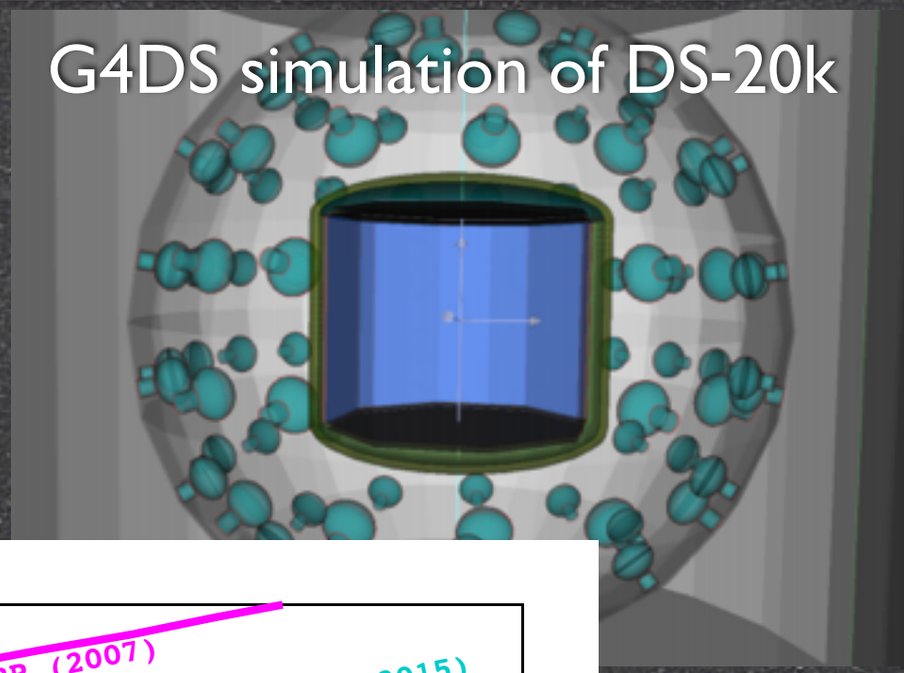


First ARIA module @CERN

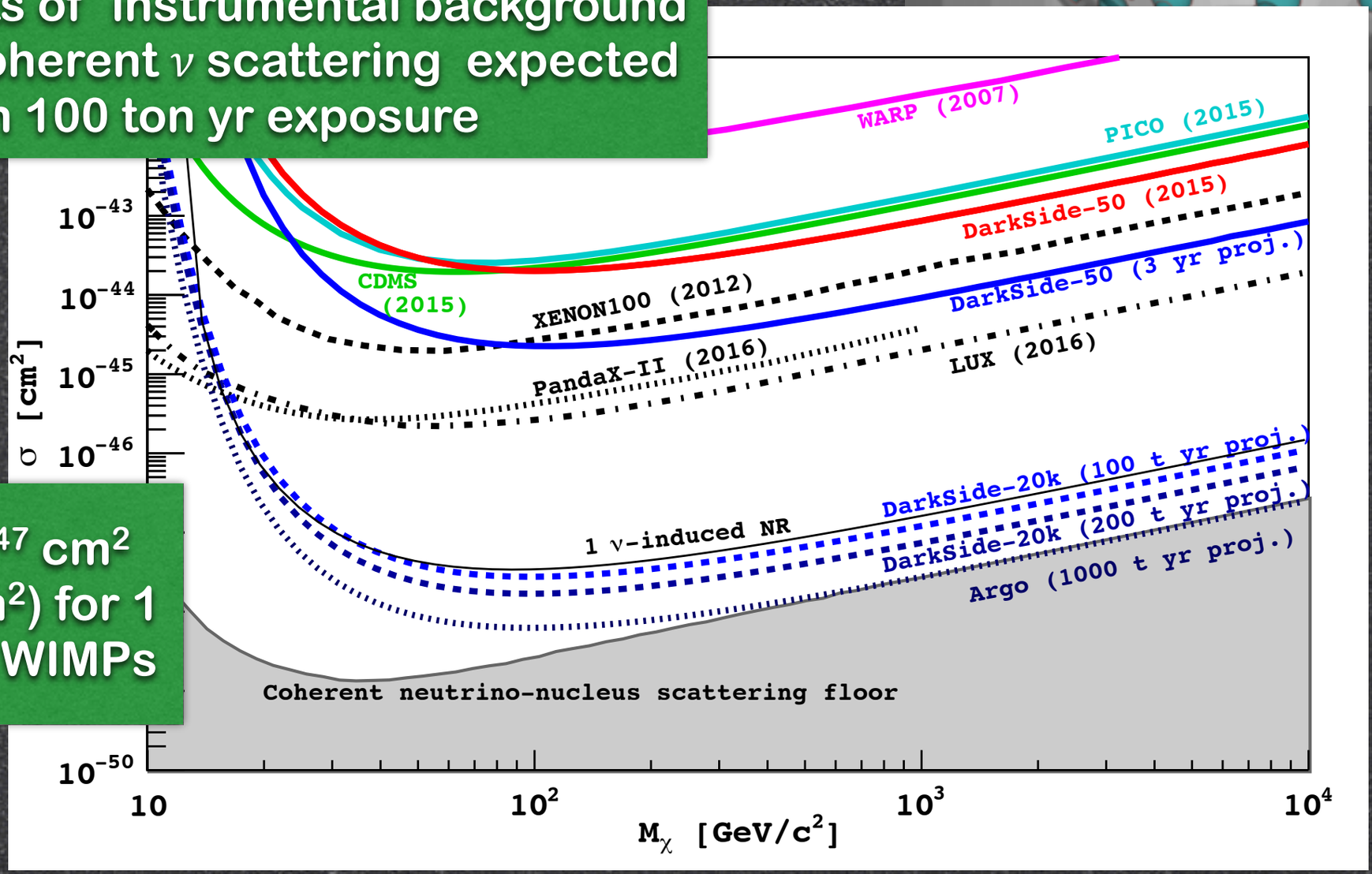


DarkSide-20k physics goal

- UAR + PSD → background-free (from ER) for an exposure of 100 ton yr
- Need also to be background-free from neutrons → Liquid Scintillator veto



<0.1 events of instrumental background and 1.6 coherent ν scattering expected in 100 ton yr exposure



σ_{SI}~1.2x10^{-47} cm^2 (1.1x10^{-46} cm^2) for 1 TeV(10 TeV) WIMPs

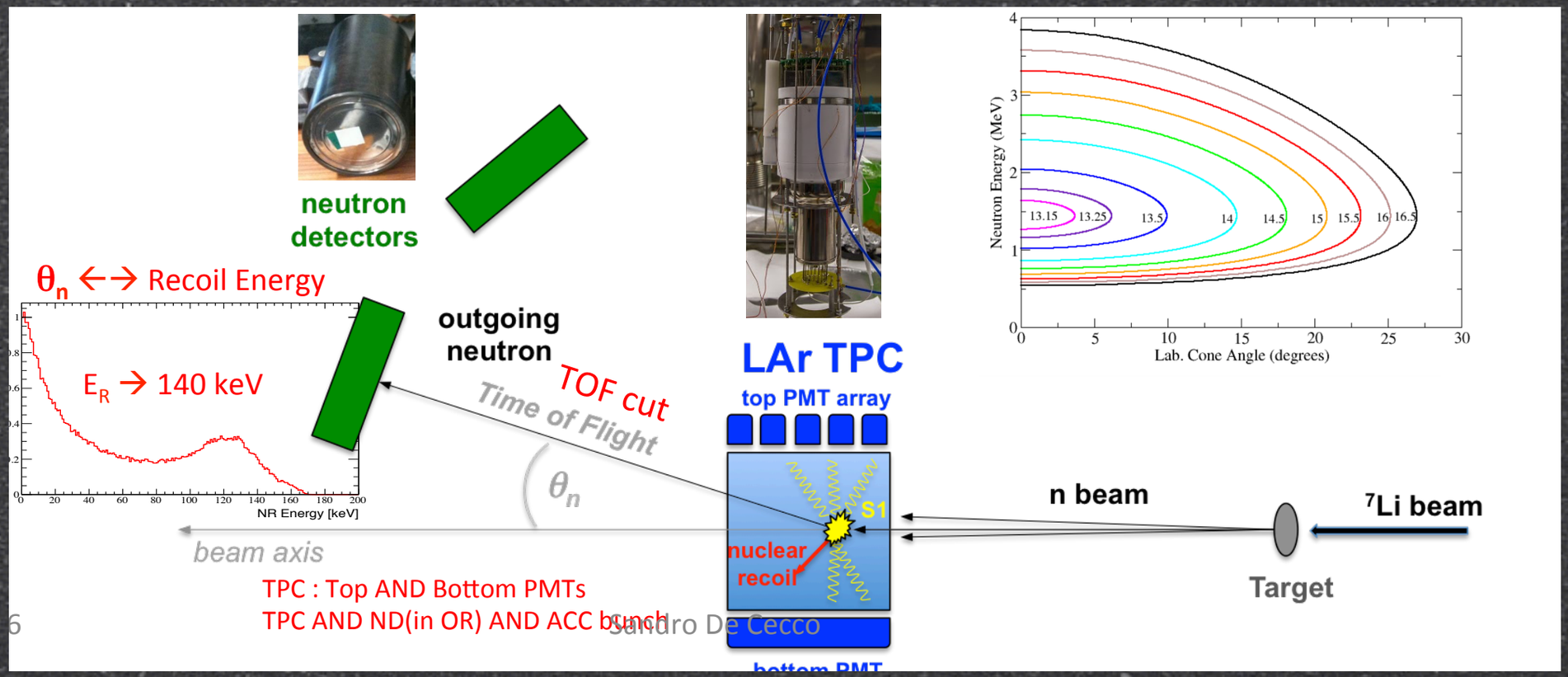
ARIS experiment

- Experiment performed at IPNO using the LICORNE beam
- Use a small dual phase TPC built at UCLA
- Installation of the detector on the LICORNE beam line in September 2016
- **Data taking with the neutron beam October 3-14**
- Analysis of the data is on-going

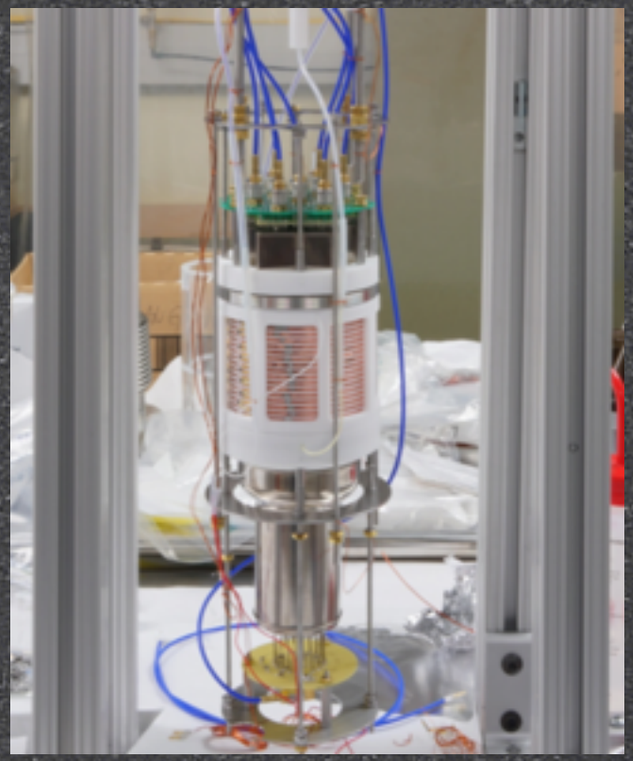
What is ARIS

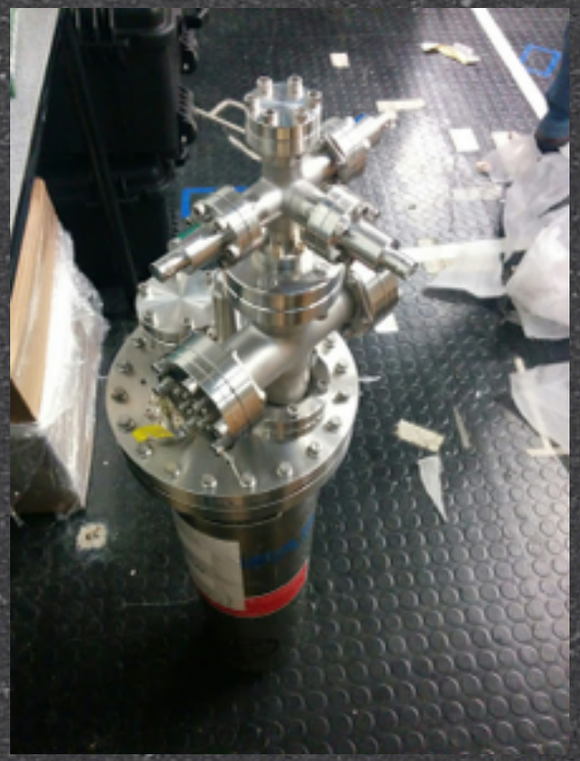
- Expose te TPC on the highly collimated neutron beam
  - Neutrons with mean energy of 1.44 MeV, beam opening angle of ~6 degrees → thanks to the neutron production through inverse kinematics
- Neutrons scatter in the TPC and are observed with EDEN detectors at different angles (i.e. different recoil energies)

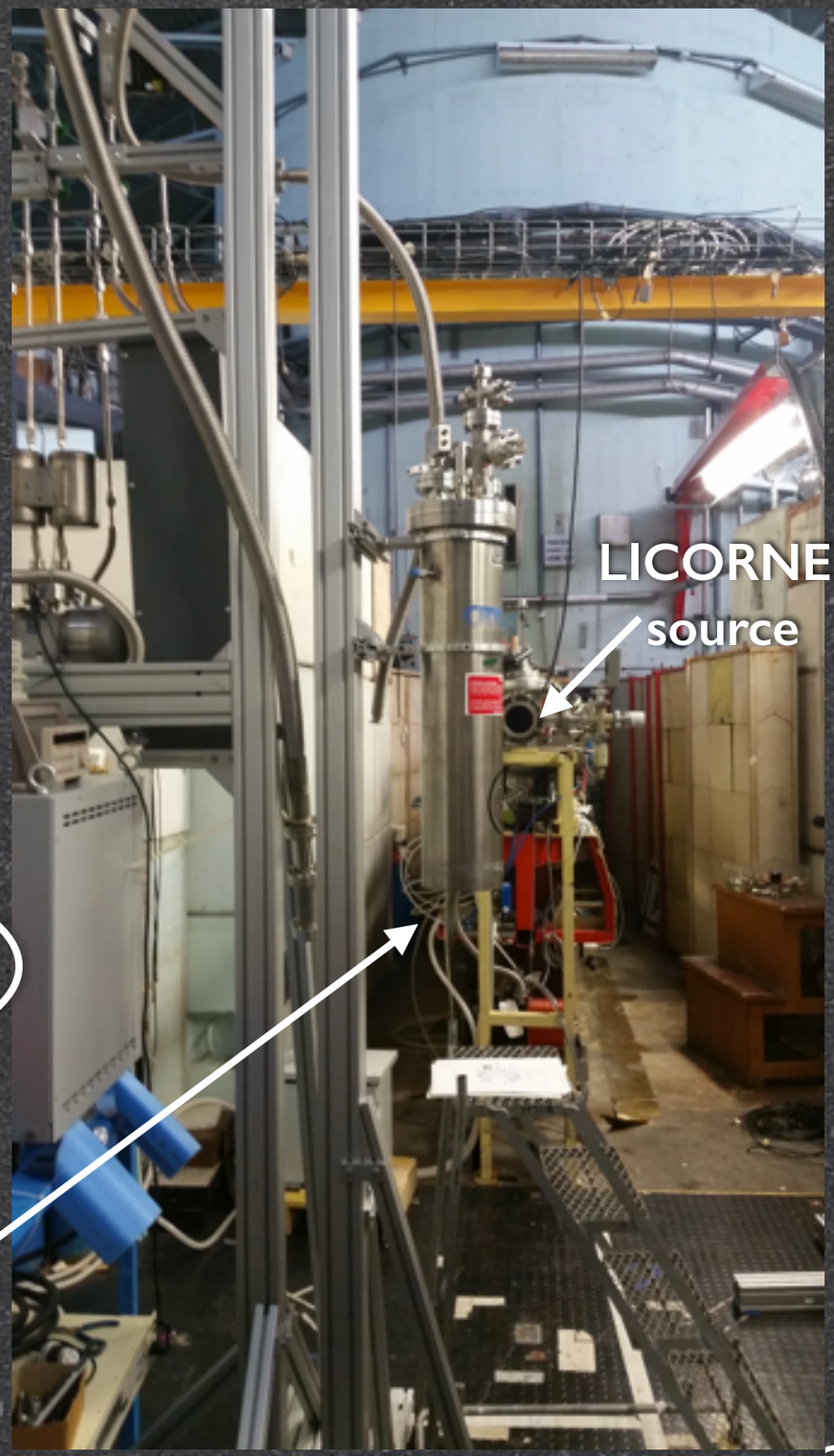
- Goal: characterize LAr response for scintillation, ionization and PSD as function of the recoil energy

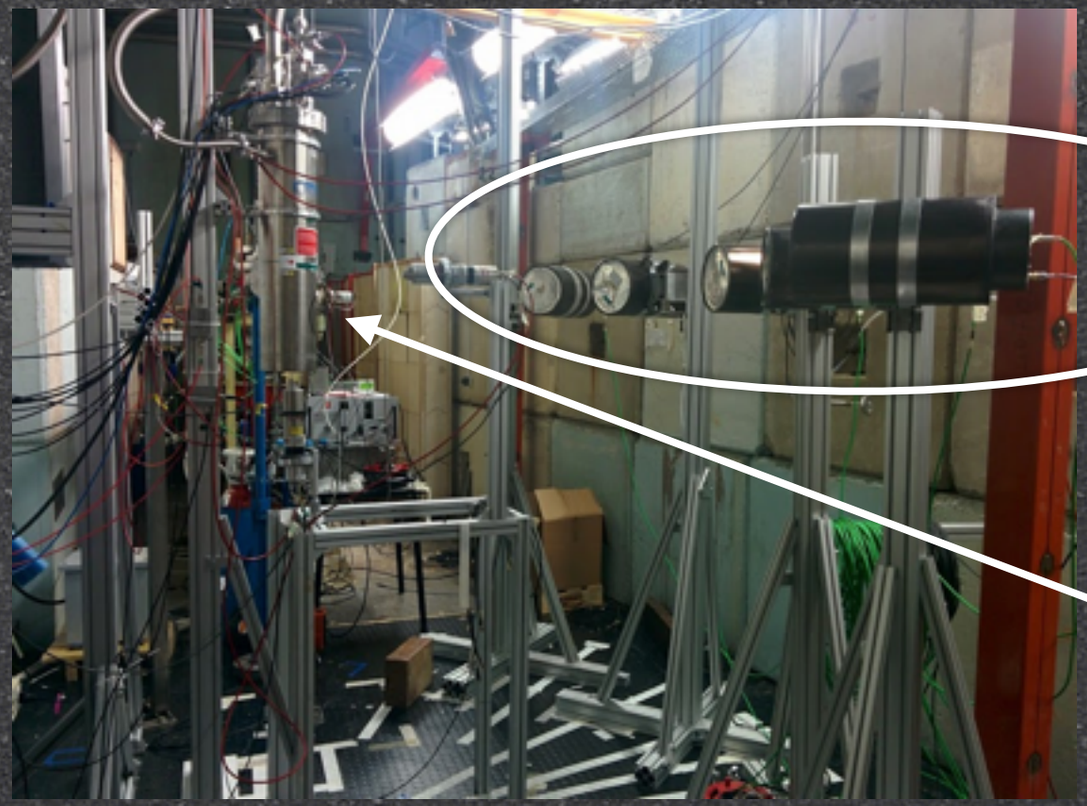


Experimental setup





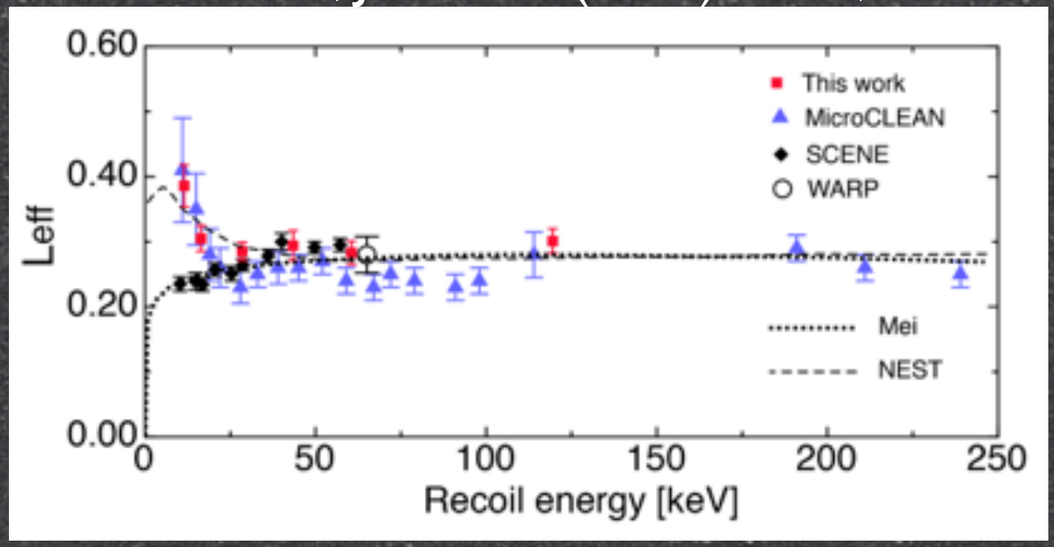


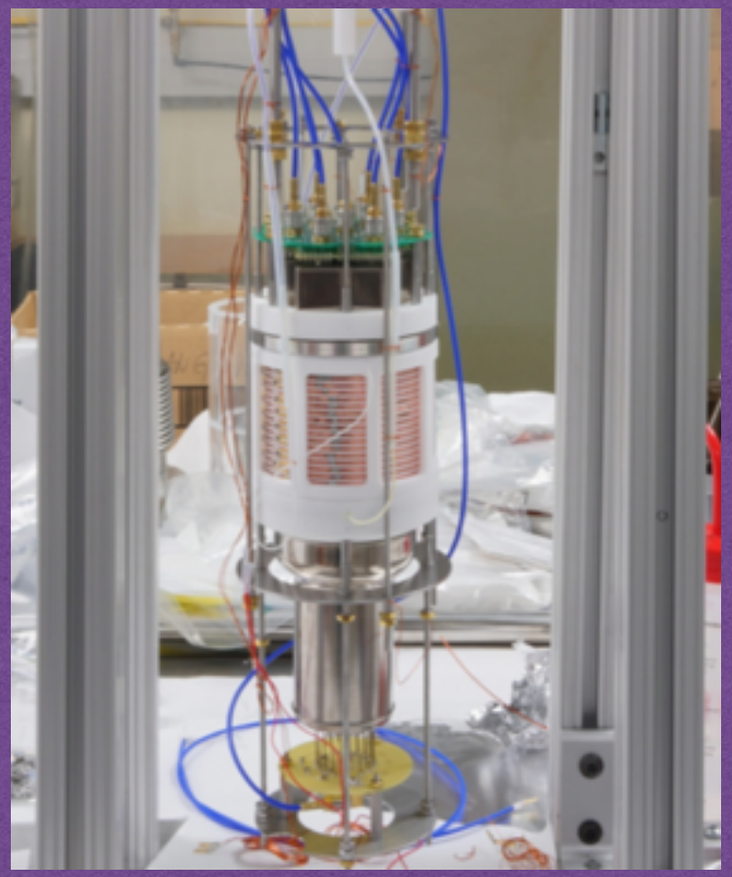


ARIS experimental setup

- We used 8 EDEN neutron detectors (energy from 7 keV to 120 keV)
- Beam energy as small as possible to maximize collimation
- 5 different electric fields in the TPC (from 0 to 500 V/cm)

W. Creus et al, JINST 10 (2015) no.08, P08002

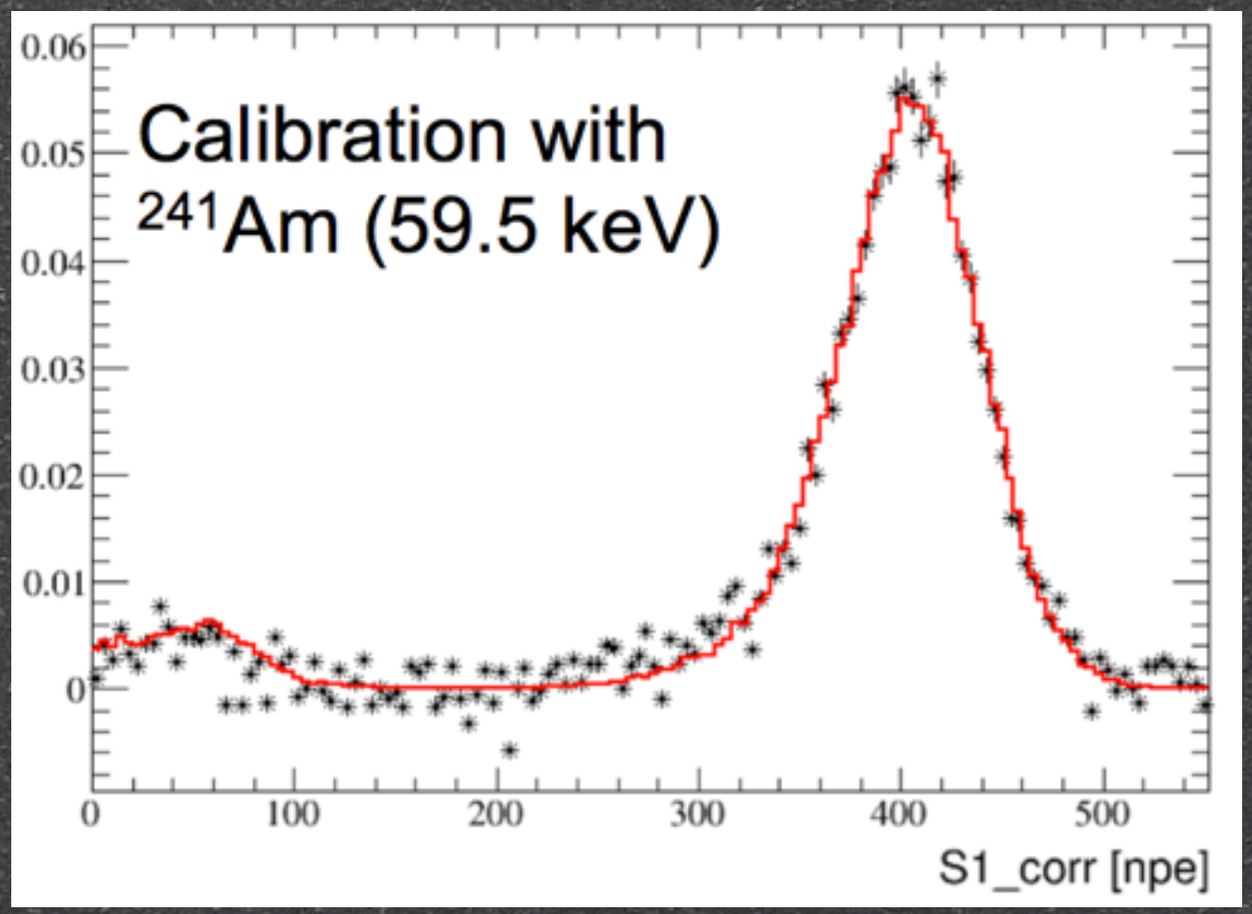




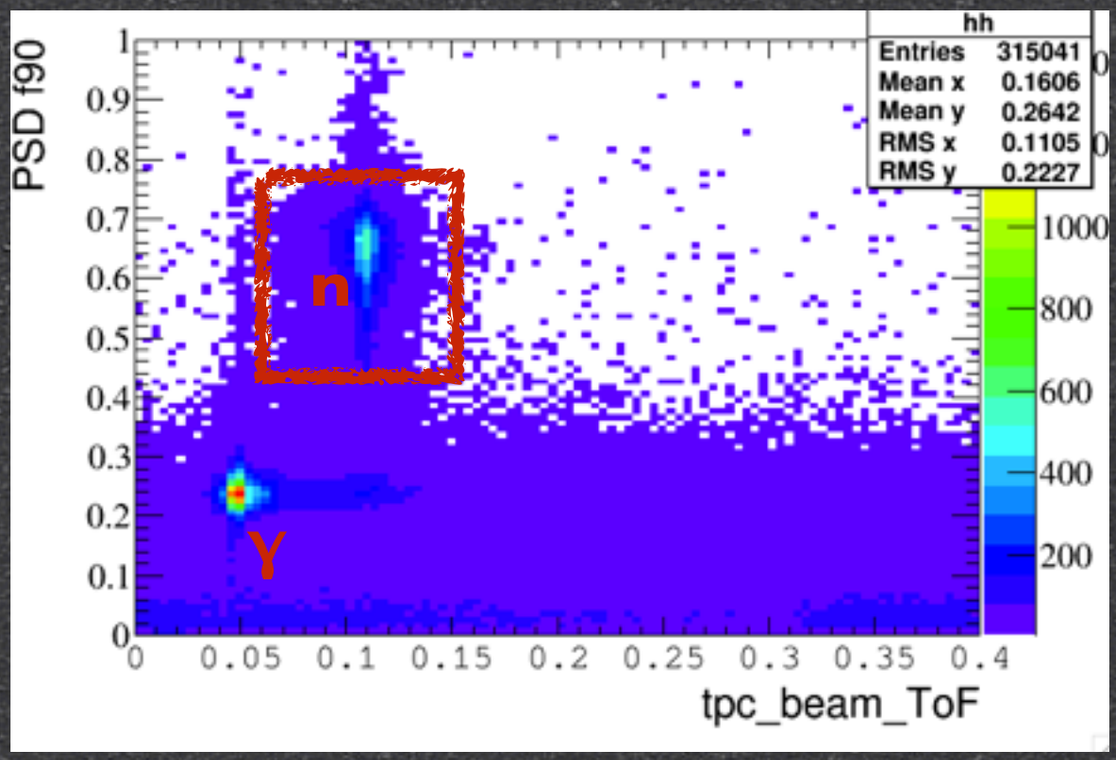
- Pulsed neutron beam
- TPC instrumented with 8 PMTs
  - 7 1-inch PMTs on the top
  - 1 3-inch PMT on the bottom
- EDEN neutron detectors for:
  - TOF
  - n/γ PSD
- Triple coincidence between beam, TPC and ND was requested

ARIS first results

^{241}Am 60 keV γ peak
LY~7 pe/keV



TPC/Beam TOF vs f90



Importance of IPNO beam

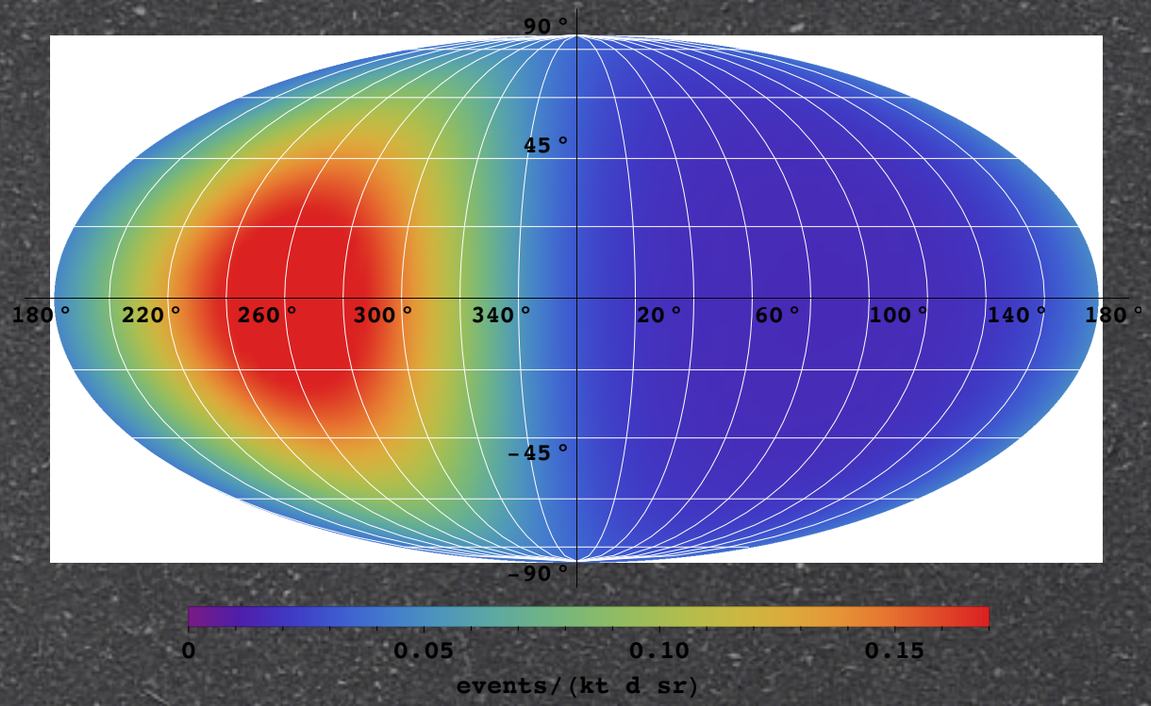
- **LICORNE** is a directional neutron source at the Tandem accelerator at IPNO
- ^{7}Li is accelerated to 13-17 MeV and neutrons are produced through the reaction p(^{7}Li,n)^{7}Be
  - **High fluxes of neutrons** (up to 10^{8} n/s/sr)
  - **Highly collimated** (from ~2 to ~25 degrees depending on the Li energy)
- This is a unique facility that can be exploited to characterize TPC response for low energy nuclear recoils
- The success of ARIS experiment demonstrated that this facility can be used for the DS external calibration program
- In-kind contribution that IN2P3 can offer to DarkSide

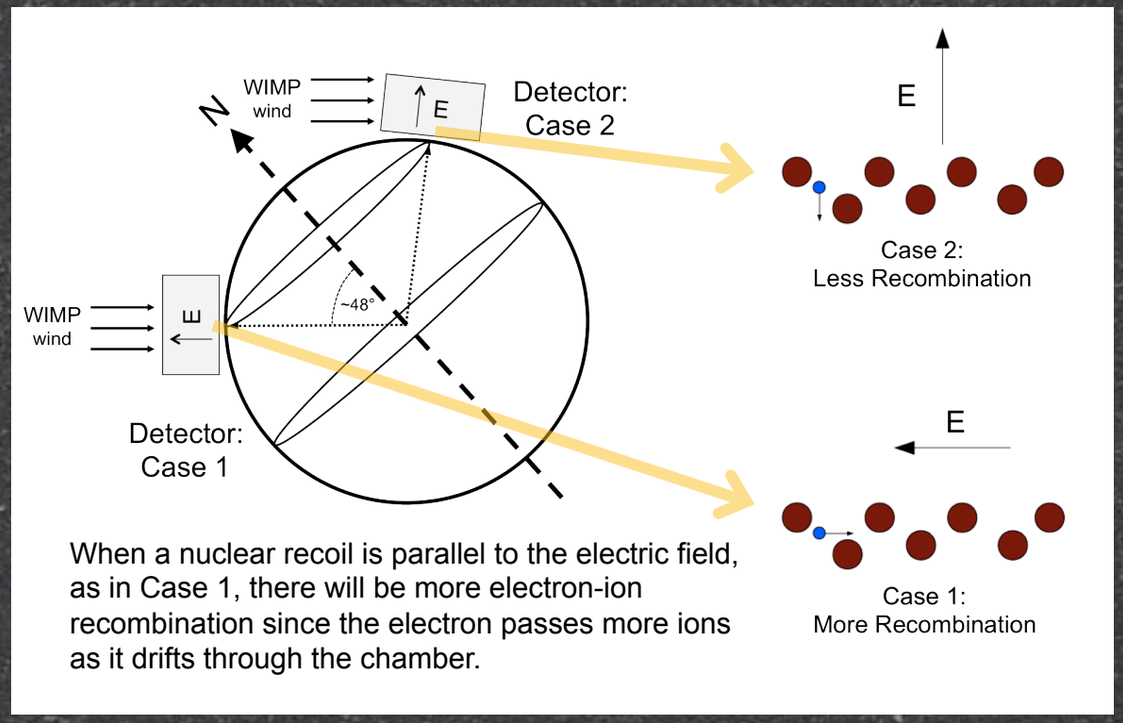
External calibration program

- The DarkSide collaboration is involved in an **external calibration program** for the characterization of the LAr response to low energy to NR
- SCENE experiment @ Notre Dame → isotropic neutron beam
- **ARIS** experiment @ IPNO → highly collimated and mono-energetic neutron beam
- Next: **ReD**: an experiment to sense directionality in LAR

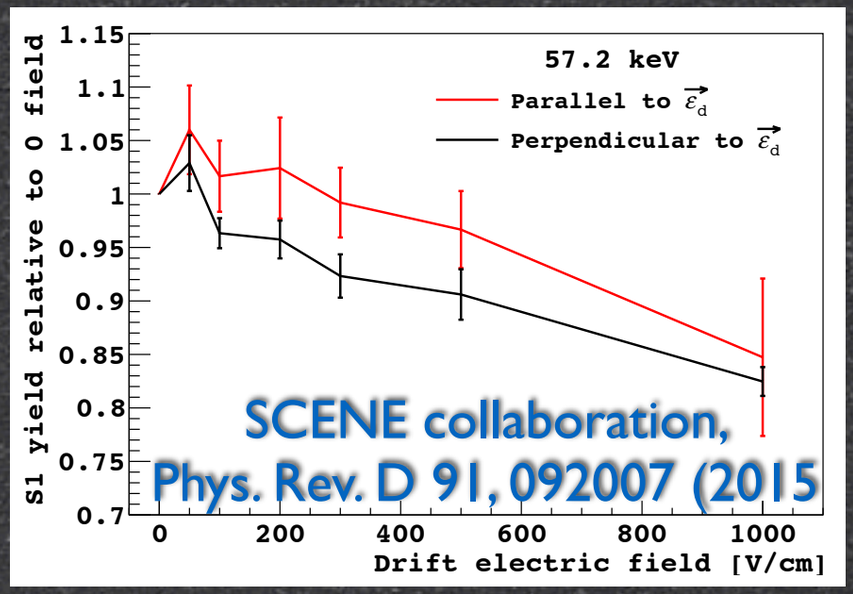
- **TPC** built at Naples, **instrumented with SiPM** (2 5x5cm arrays on top and bottom)
- Minimize materials out from LAr active region to maximize neutrons single scatter in LAr
- **Expose it to a neutron beam**
  - **LICORNE@IPNO** is a perfect candidate

Directionality



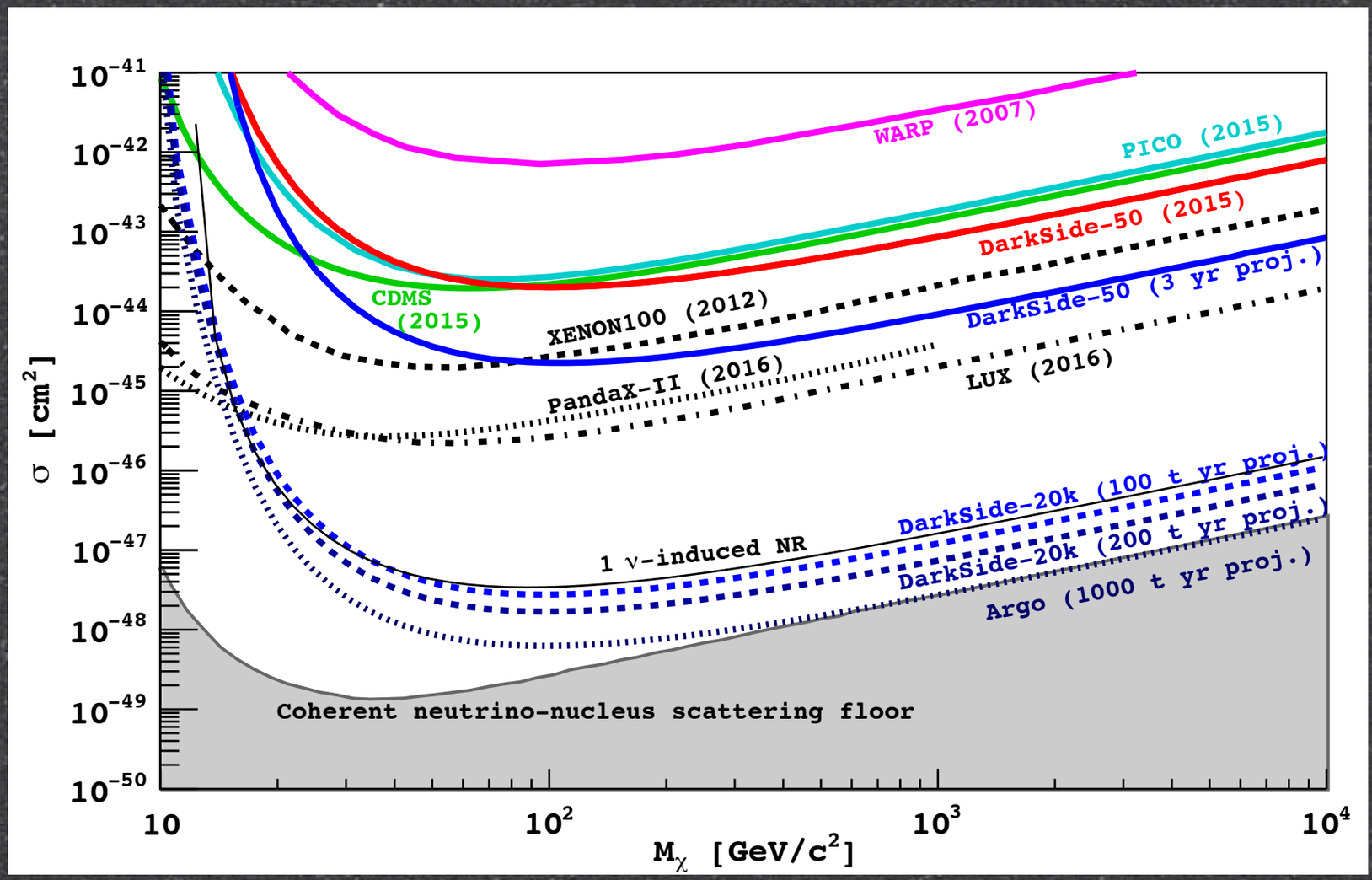


- Columnar recombination: more S1 and less S2 if track parallel to electric field
- Exploit the preferred direction of WIMPs with respect to isotropic ν and n backgrounds
- Might allow to go beyond the neutrino floor
- Some hints from SCENE but need more precise measurements on neutron beams with dedicated setup (ReD at IPNO)



ARGO

- DarkSide-20k will be followed by ARGO (Argon Observatory)
- 300 ton Dual Phase TPC to be operational in 2026
- Search for WIMPs through the neutrino floor
- Do solar neutrinos physics

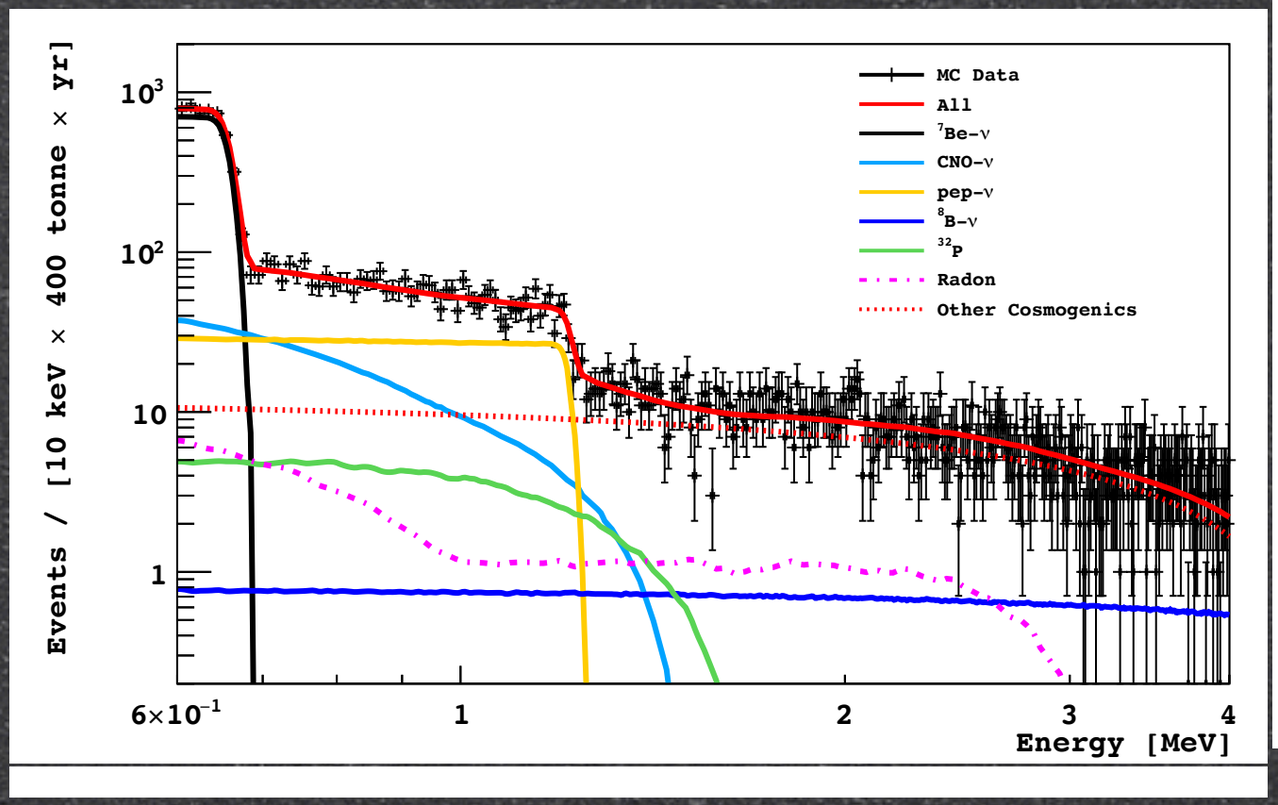


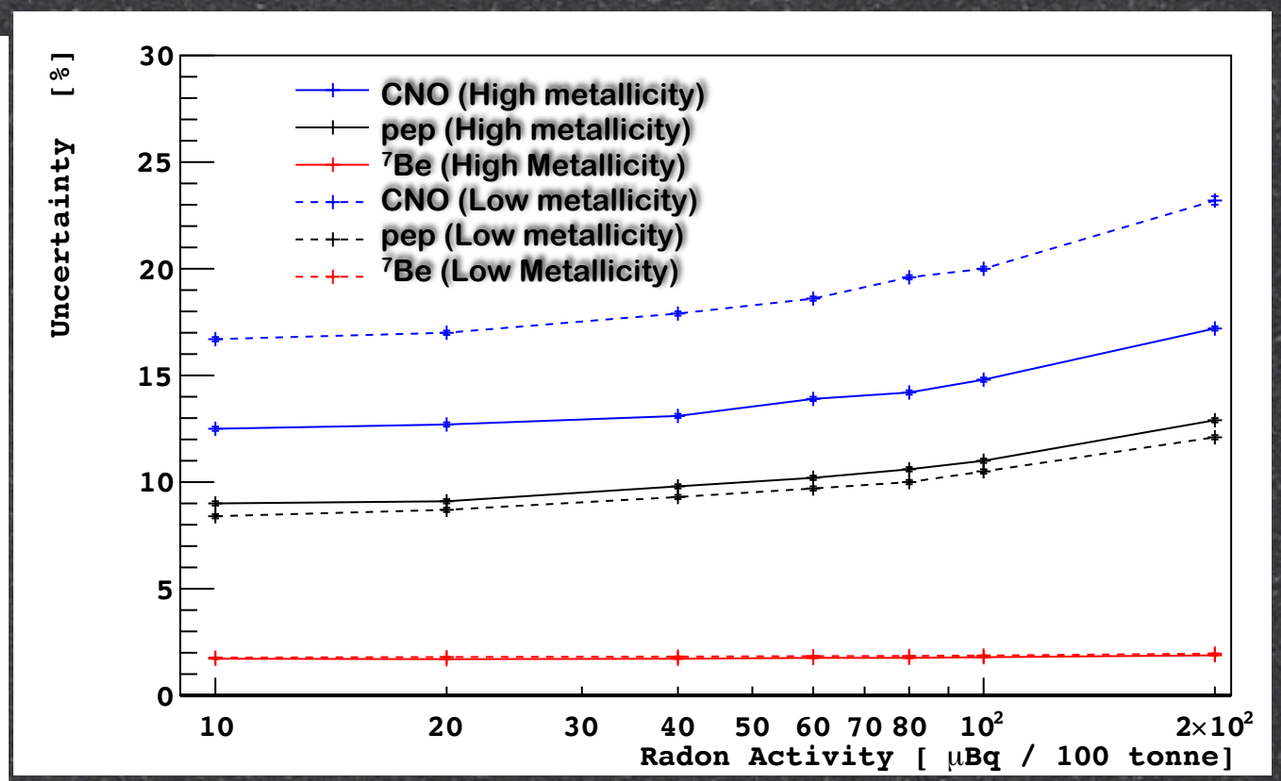
Solar neutrinos with ARGO

D. Franco et al, JCAP08(2016)017

- Excellent scintillator 40 photons/keV
- Easy to purify, high intrinsic radio-purity wrt organic liquid scintillators
- Hundreds of ton of mass
- Exceptional PSD

400 ton yr exposure:
First observation of
CNO neutrinos
measure ^{7}Be-ν (~2%),
pep-ν (~10%)





Conclusions

- DarkSide has a 20 years physics program built on the success of DarkSide-50
  - Excellent PSD of LAr, establish the use of UAr for DM searches
  - Already proved a background-free exposure equivalent to 5.5 ton yr
- We have submitted a pre-TDR to INFN and NSF to propose Darkside-20k@LNGS
  - Largest DM collaboration (unify the entire Argon community)
  - Background-free exposure of 100 ton yr → limit on σ_{SI}~1.2×10^{-47} cm^2 (1.1×10^{-46} cm^2) for 1 TeV(10 TeV) WIMPs
  - Expect approval from INFN and NSF in April 2017
- French groups have a leading role in the physics of DarkSide
  - Analyses of DS-50
  - Design optimization of DS-20k
- The ARIS experiment demonstrate the availability in France of LICORNE@IPNO as a unique facility for the DS external calibration program that will be performed in the next years