Radio-purity needs for DM direct search:

the DarkSide-50 experience and DarkSide-20k future plans and R&Ds

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for the **DARKSIDE Roma group:**

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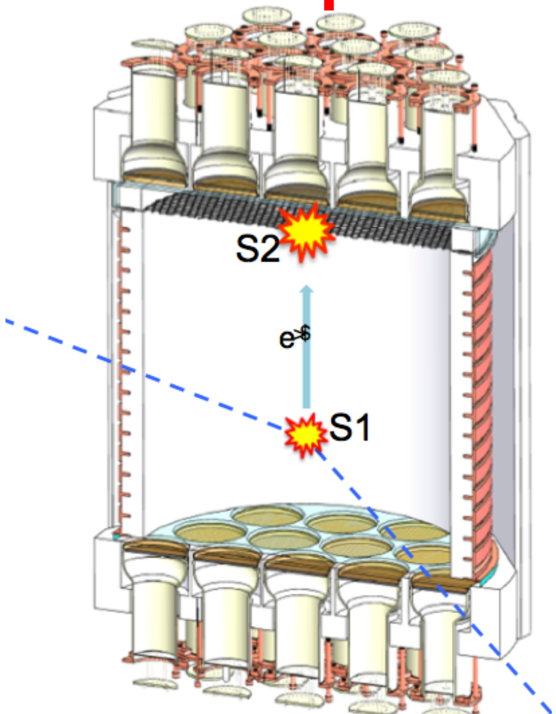
Outline

- DM direct search with LAr TPC detector, main features concerning radio-purity constraints
- The DarkSide-50 experience
- R&D and plans toward DarkSide-20k, impact on new overall detector design
- Focus on radio-purity R&D activities @ Roma1

Dual phase Time Projection Chamber



1 - Nuclear Recoil excites and ionize **Liquid Ar** producing scintillation **light** S1 detected by top and bottom photosensors

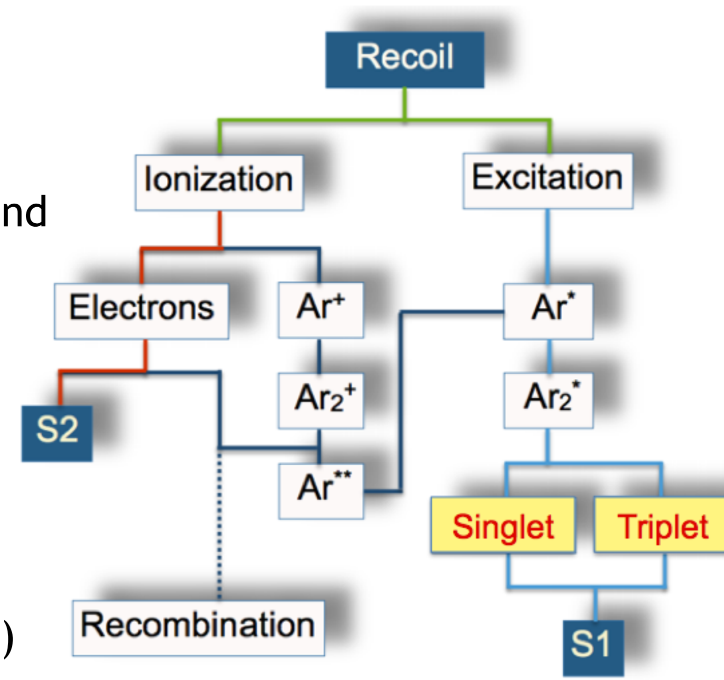
2 - ionization **electrons** are drifted to the **Ar gas** pocket region were they induce a second **delayed scintillation** light S2 signal

- **Time difference** between S1 and S2 gives **vertical position** while fraction of S2 in each photo-sensor gives x-y position.

Recoil can be with electrons (**ER**) or nuclei (**NR**). Ionization and direct excitation of Ar* to form Ar_2* dimer that emits light.

Dimer excitons Ar_2* emits light in singlet or triplets.
Different singlet/triplet fractions for ER and NR (NR ~70% singlet, ER ~70% triplet) diff. exc. mechanism.
Ar ions can recombine and form excited Ar** states.

Also, NR ion.+thermic energy loss → **NR quenching** (less S2)

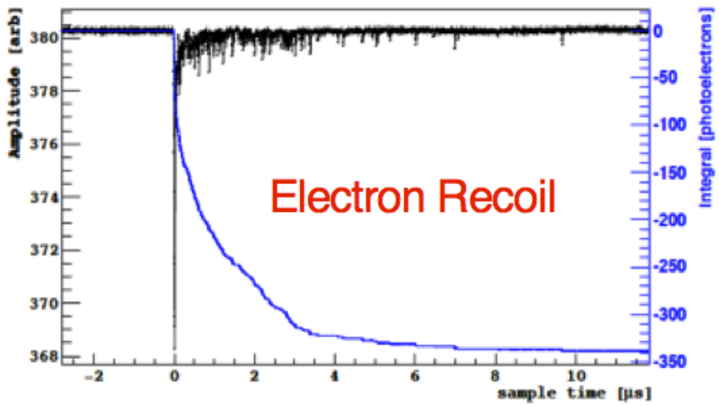


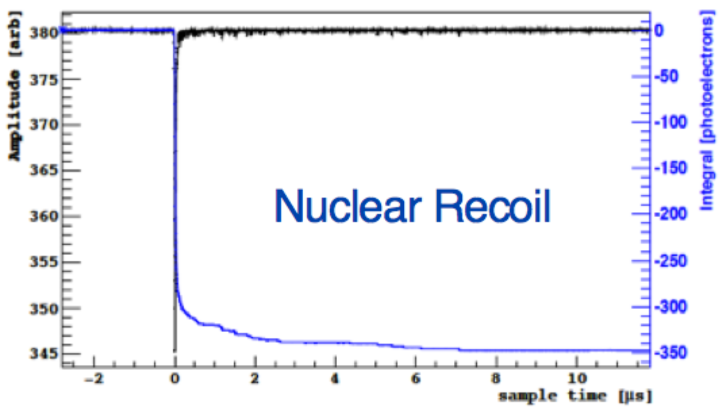
LAr Pulse Shape Discrimination

Electron and nuclear recoils produce different excitation densities in the argon, leading to different **ratios of singlet and triplet excitation states**

τ singlet ~ 7 ns

τ triplet ~ 1500 ns

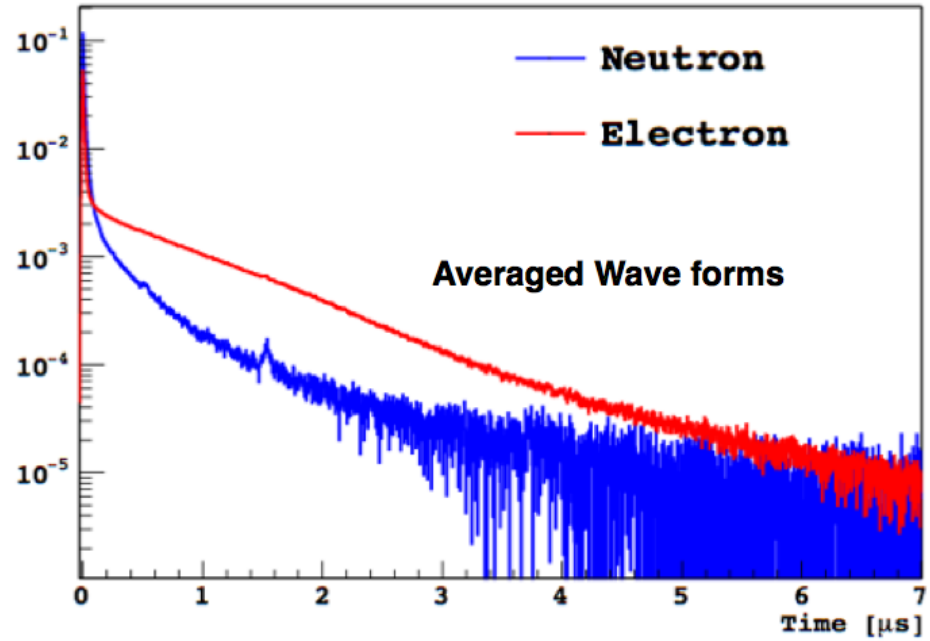




PSD parameter

F90: Ratio of detected light in the first 90 ns, compared to the total signal

~ Fraction of singlet states



ER rejection measured by: DS-50 is >10^7 and DEAP-3600 is ~ 10^9

Dual phase TPC Electron Recoil rejection

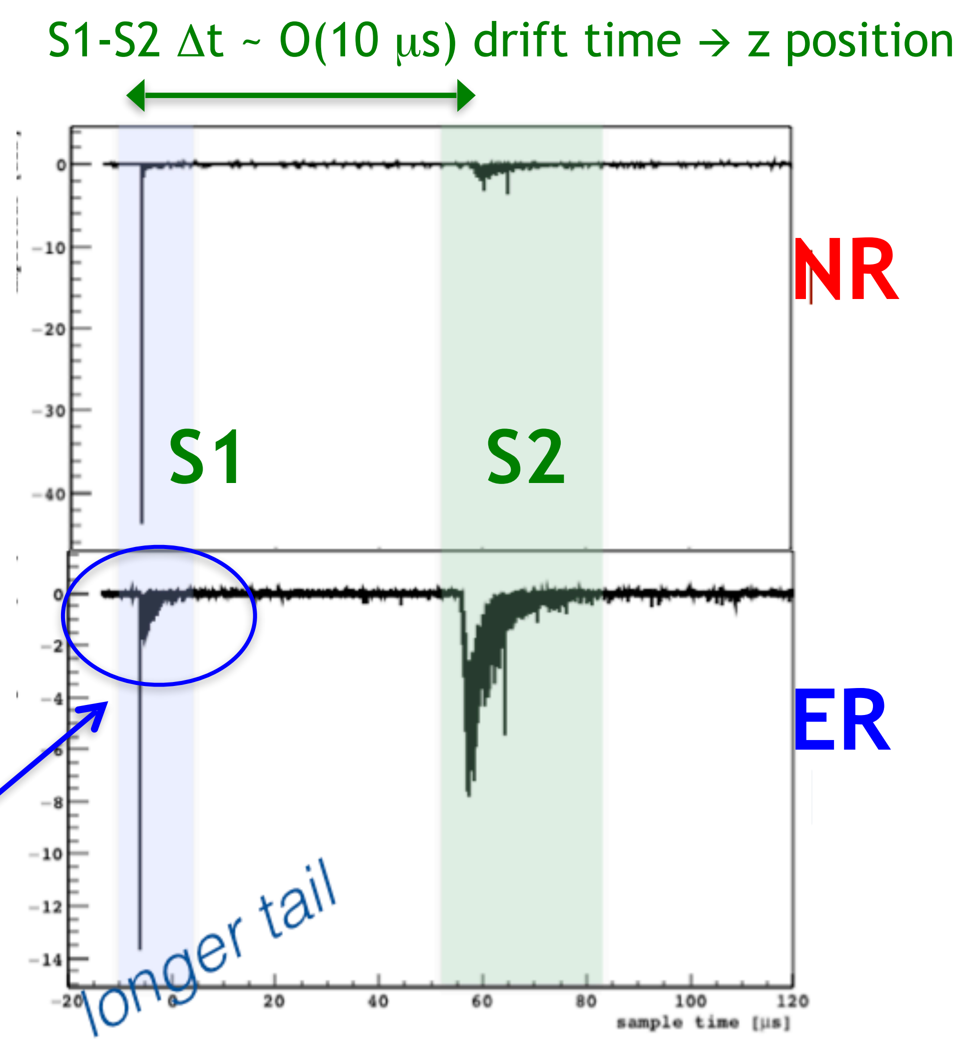
Due to Nuclear quenching, ionization signal and hence **S2** scintillation, is less intense for NR than for ER

→ separation power in **S2/S1**

gives an **ER** rejection factor of 200-300

Typically used in Xenon experiment (same in Argon) as only ER vs NR discriminant.

But, unique to Argon : **Pulse Shape Discrimination (PSD)** due to longer tails in ER S1 signal.

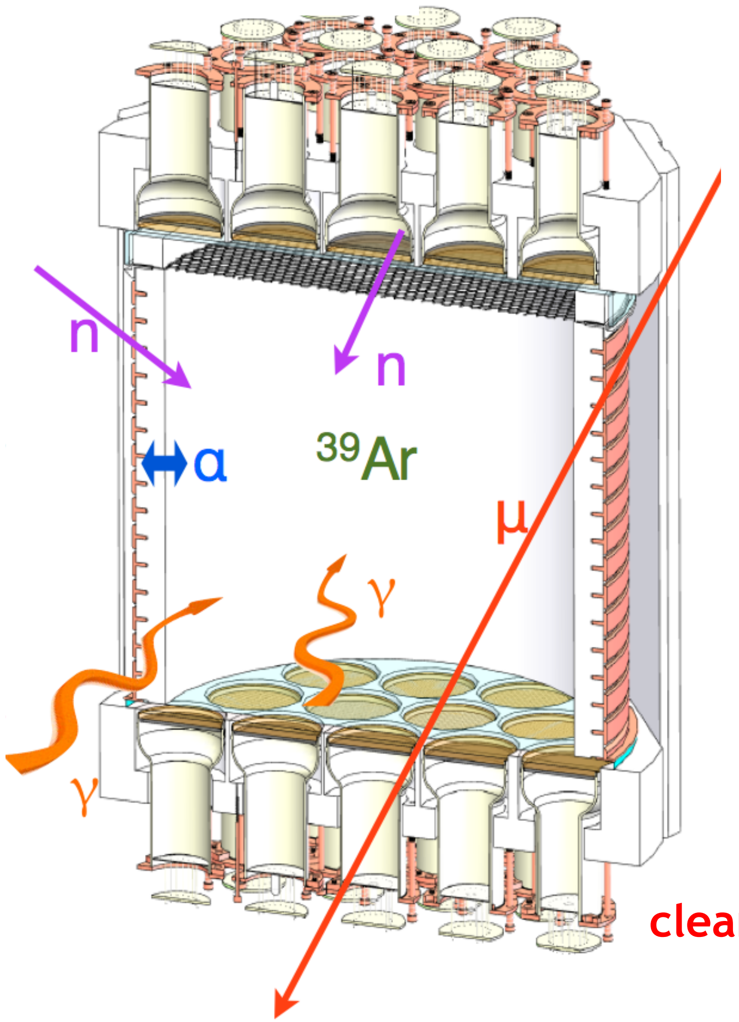


Xenon only have this discrimination power for ER rejection … see Post Scriptum

LAr TPC DM search backgrounds :

DM signal extremely rare and consists in ~10 keV energy deposit in the detector leading to ~10 photons detected. Backgrounds divided in two classes, **NR** and **ER** :

Signal Rate:
- 100 GeV, 10^{-45} cm^2 WIMP ~10^{-4}evt/kg/day



Nuclear recoils:
- μ ~10^{-4}evt/kg/day
- Radiogenic n ~$6\cdot10^{-4}$ evt/kg/day → *<u>Detector material</u> purity: U and Th decay chains, mostly (α, n) neutrons.*
- α ~10 evt/m^2/day → *<u>Surface events:</u> fiducial x-y cut and radon suppression filter*

Electron recoils:
- ^{39}Ar ~$9\cdot10^{4}$ evt/kg/day → *<u>Inner volume events:</u> → PSD + ARGON DEPLETION programs URANIA & ARIA (also Cherenkov bck.→cuts)*
- γ ~$1\cdot10^{2}$ evt/kg/day

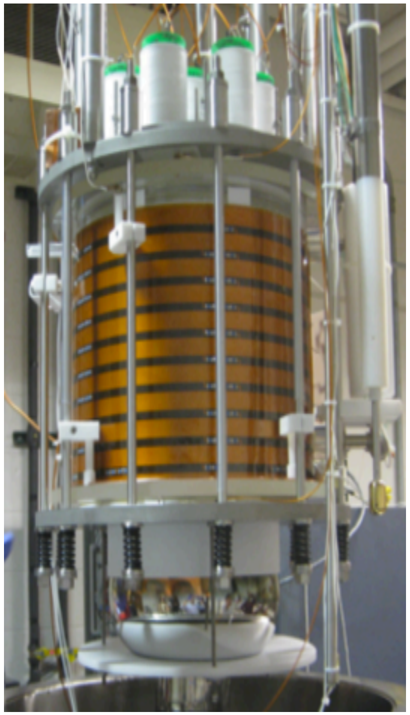
And also, solar and atmospheric:
- ν - electron scattering → *<u>reducible ER:</u> with PSD*
- coherent ν - nucleus scattering → *<u>irreducible NR</u>*

<u>KEYS</u> :
clean materials, active veto shieldings and Depleted Ar

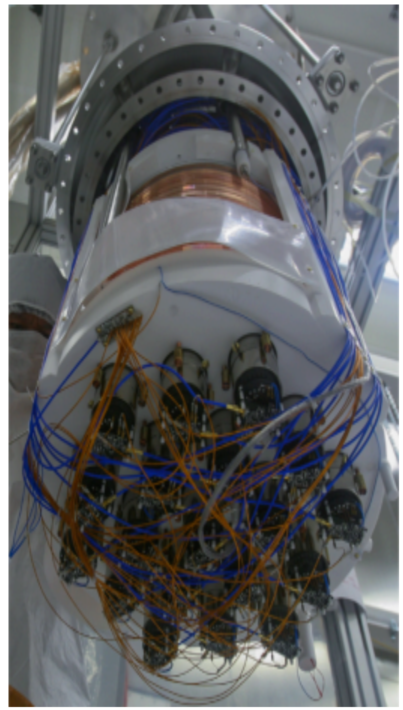
The DarkSide staged program

2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 … →

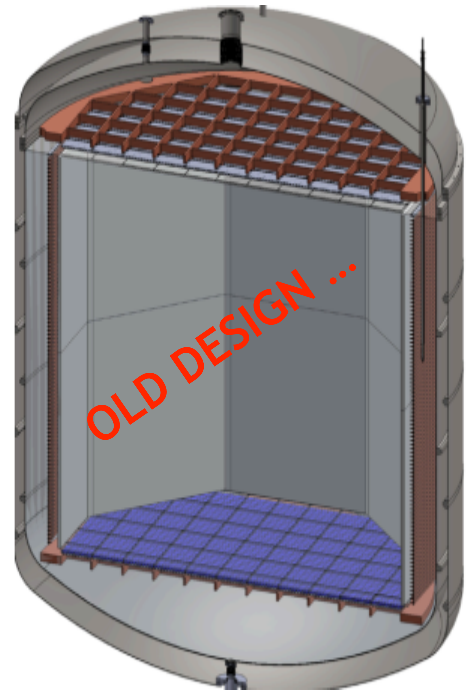
Past Present Future



DarkSide-10 (10kg)
Technical prototype
No Dark Matter goal



DarkSide-50 (50kg)
Sensitivity to WIMP-nucleon cross section 10^{-44} cm^2 for a WIMP mass of 100 GeV/c^2



…→*300t*

DarkSide-20k (20t)
Sensitivity to WIMP-nucleon cross section 10^{-48} cm^2 (10^{-47} cm^2) for a WIMP mass of 100 GeV/c^2 (1 TeV/)

DarkSide-20k Tech. Proposal, baseline design :

Baseline design :
(arXiv:1707.08145)

- 30 ton total, **20 ton** fiducial UAr

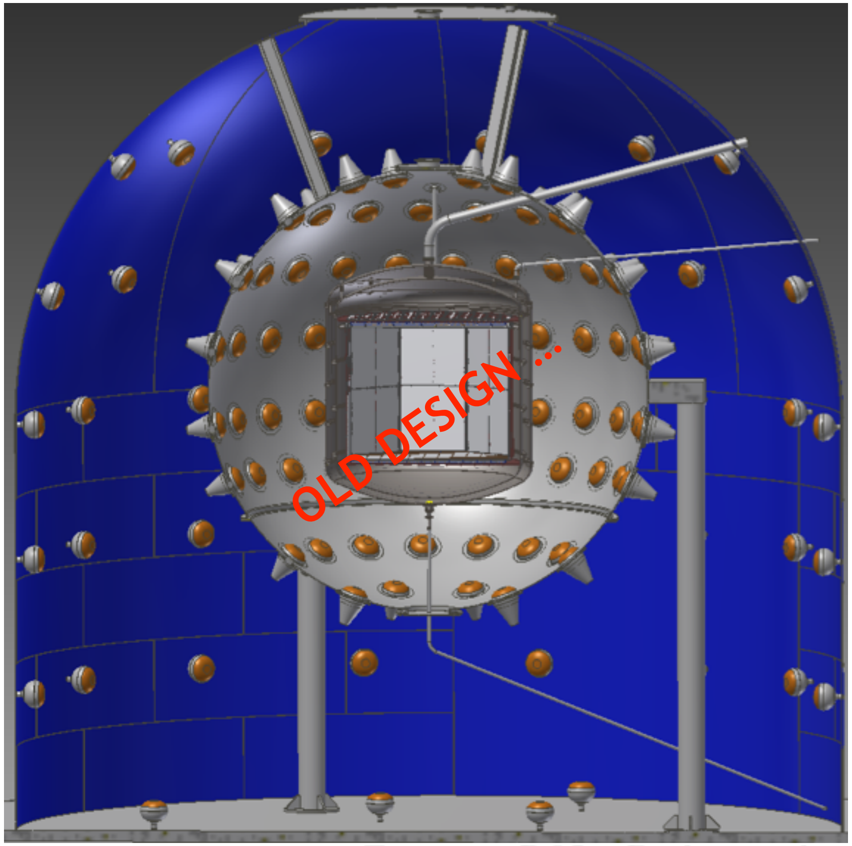
- Liquid Argon target extraction and purification from underground (**URANIA**, US) and ^{39}Ar depletion with cryogenic distillation (**ARIA**, Sardinia)

- 15m^2 of **cryogenics SiPM photosensors** (low radioactivity, increased LY) - assembly and test at Nuova Officina Assergi - NOA

- high efficiency LS **active neutron veto**
- 15m diameter water tank muon veto

- ER background from residual ^{39}Ar
- SS/Ti cryostat and PTFE largest sources of (α, n) Nuclear Recoils backgrounds

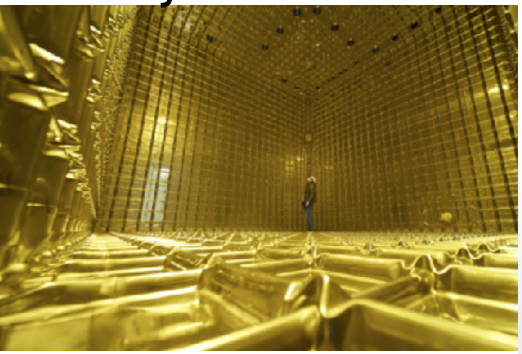
→ a 100 ton yr background free exposure :



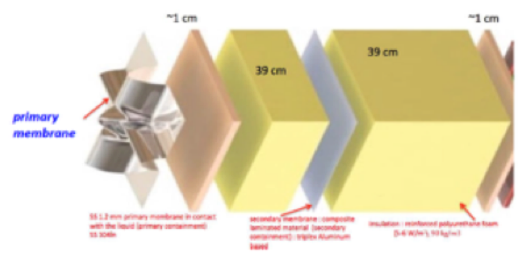
Background	Events in ROI $[100\,\mathrm{t\,yr}]^{-1}$	Background $[100\,\mathrm{t\,yr}]^{-1}$
Internal β/γ's	1.8×10^8	0.06
Internal NRs	negligible	negligible
e^--ν_{pp} scatters	2.0×10^4	negligible
External β/γ's	10^7	<0.05
External NRs	<81	<0.15
Cosmogenic β/γ's	3×10^5	≪0.01
Cosmogenic NRs	–	<0.1
ν-Induced NR	1.6	–

DarkSide-20k, design evolution :

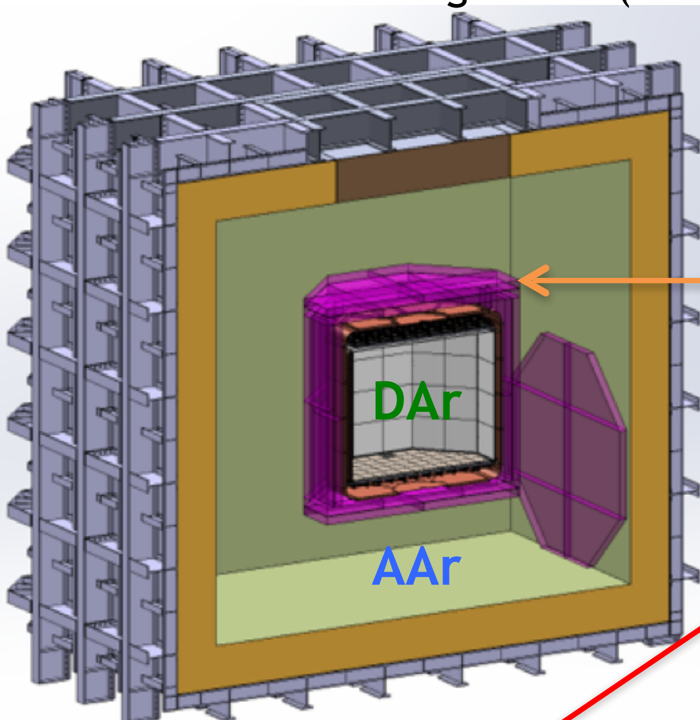
- a **ProtoDUNE** like large cryostat (8x8x8 m3 inner dim.) filled with750t **AAr**, also as shielding
- Much simpler design and concept : allows for **fully radio-pure materials close to TPC**
- **Fully scalable** to future modular and/or larger size (300 tons)

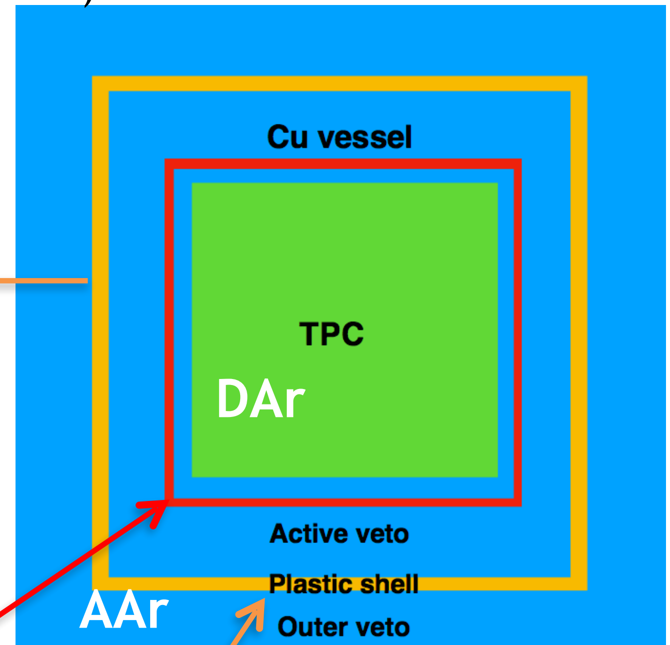


LNG technology : firm GTT



Internal : polyurethane ~78 cm, 90 kg/m^3, heat input ~6.5 W/m^2





Radio pure **Copper/Titanium Vessel** separation between outer AAr and inner TPC **Depleted Ar**.

Plastic Scintillator Veto, (solid) with Boron, Gadolinium or Lithium doping for neutron capture. R&D on going

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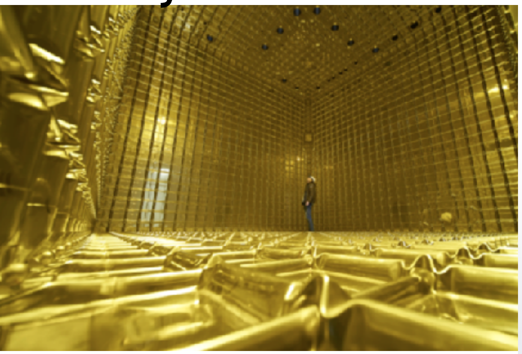

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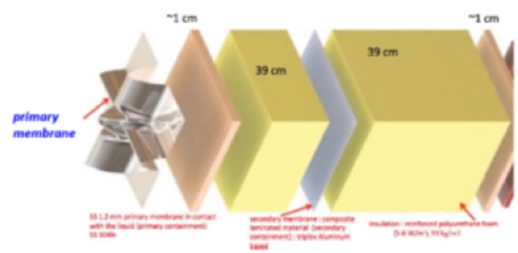

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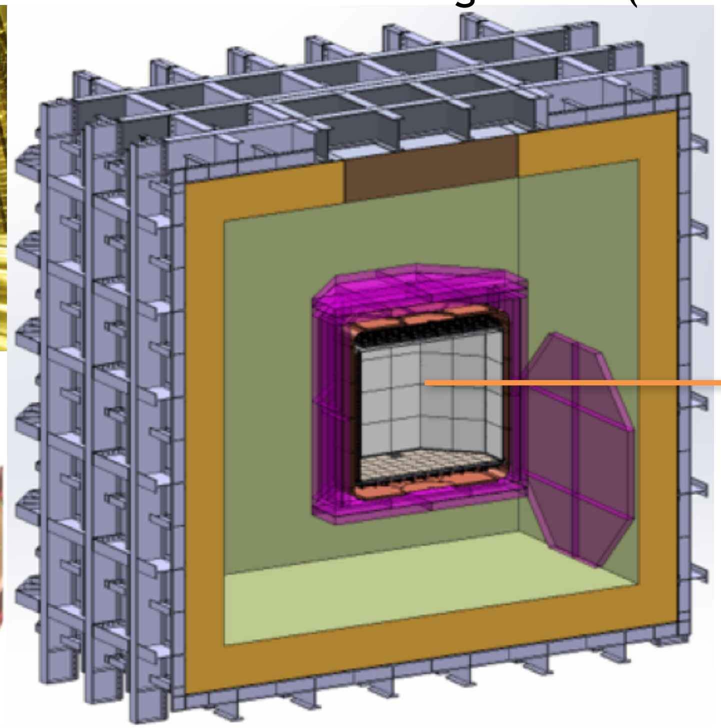
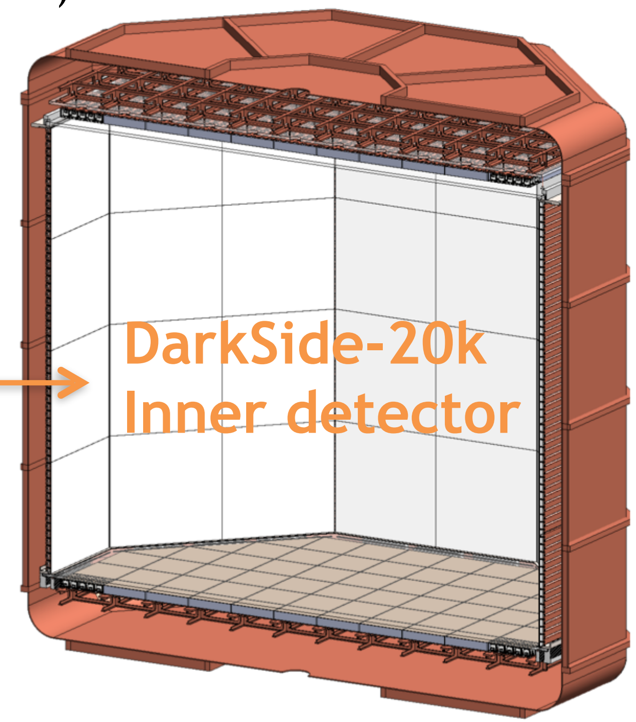




DarkSide-20k Inner detector : Vessel + Depleted LAr TPC

- Ultra radio pure Copper/Titanium Vessel removes higher source of ***n*** background
- TPC reflector change from PTFE to Acrylic + 3M foils, will reduce significantly Cherenkov and ***n*** backgrounds
- **Increase fiducial mass** 20t→**30t**, TPC self ***n*** veto, release eff. PS veto →**larger exposure !**

Radio-purity key points for DarkSide-20k

Given the following important inputs for DarkSide-20k LAr TPC:

- **Argon impurities** in 39Ar and 85Kr will be at a negligible level (Underground Ar)
- **ER rejection** measured to be 10^7 to 10^9 or greater —> residual gamma and beta are a minor concern
- **New overall detector design** concept (ProtoDUNE cryostat AAr bath) —> most of non radio-pure materials are in the outer structure, intrinsically allows the use of radio-pure items close to TPC, radio purity requirements become more stringent …
- **Neutron background** still "the" key point for zero-background DM searches with LAr TPC —> active neutron veto needed and should not be major source of neutrons itself. Liquid scintillator option now excluded for LNGS security and safety new constraints.

The key radio-purity points for DarkSide-20k materials are hence:

- Depleted Argon procurement and handling
- TPC Vessel, baseline material OFC HC Copper, UHP Titanium R&D
- New active neutron veto : solid plastic scintillator vs solid moderator + Argon
- SiPMs substrates: Arlon vs others (Si, …)
- … and 2nd order items: connectors, fibres, cables … (not treated today)
- Radon free assembly conditions and Radon traps needs remains.

Depleted Ar from underground source

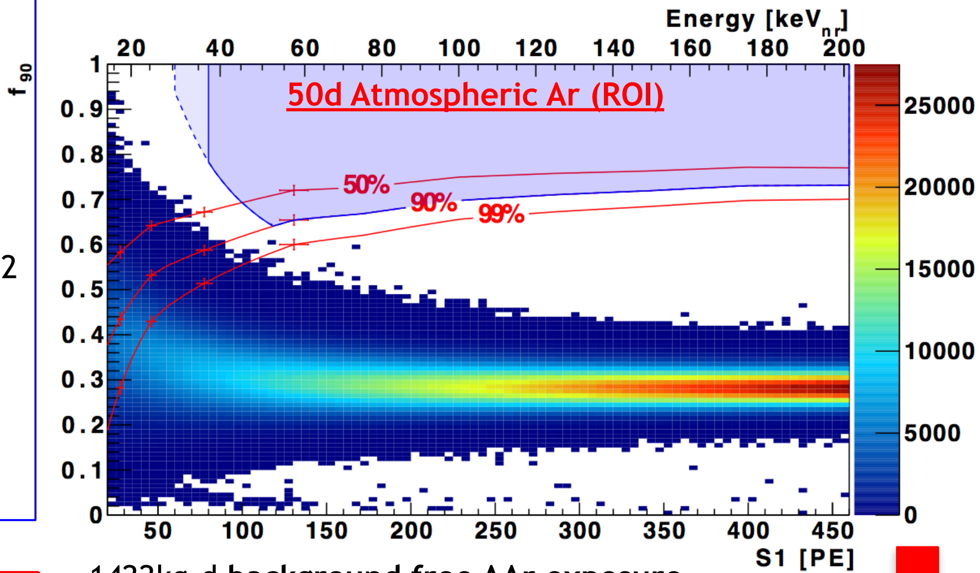
^{40}Ar from ^{40}K decay underground
^{39}Ar cosmogenic ^{40}Ar(n,2n)^{39}Ar in atmosphere

→ ^{39}Ar β emitter (565 keV) with 269y $T_{1/2}$
Atmospheric Ar act. 1Bq/kg from ^{39}Ar

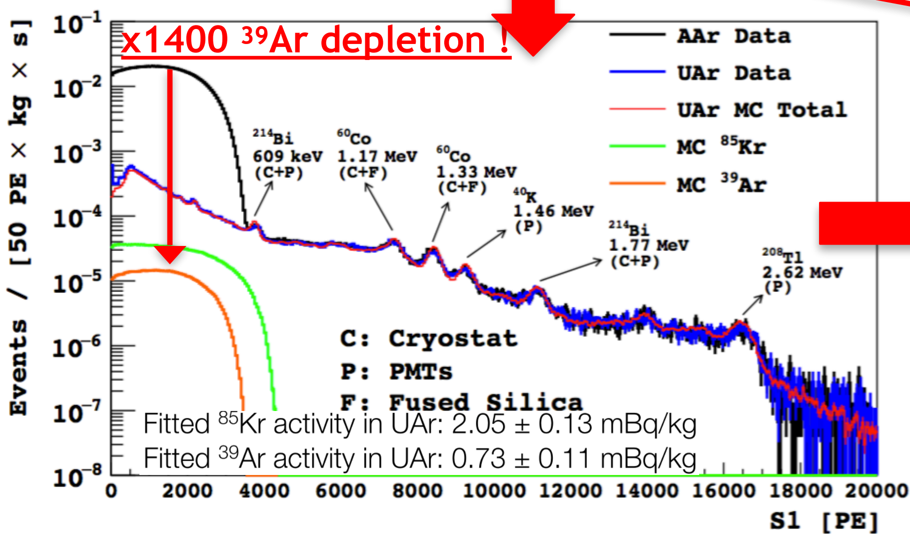
→ expect UAr depleted in ^{39}Ar
→ extract Ar from **underground source**

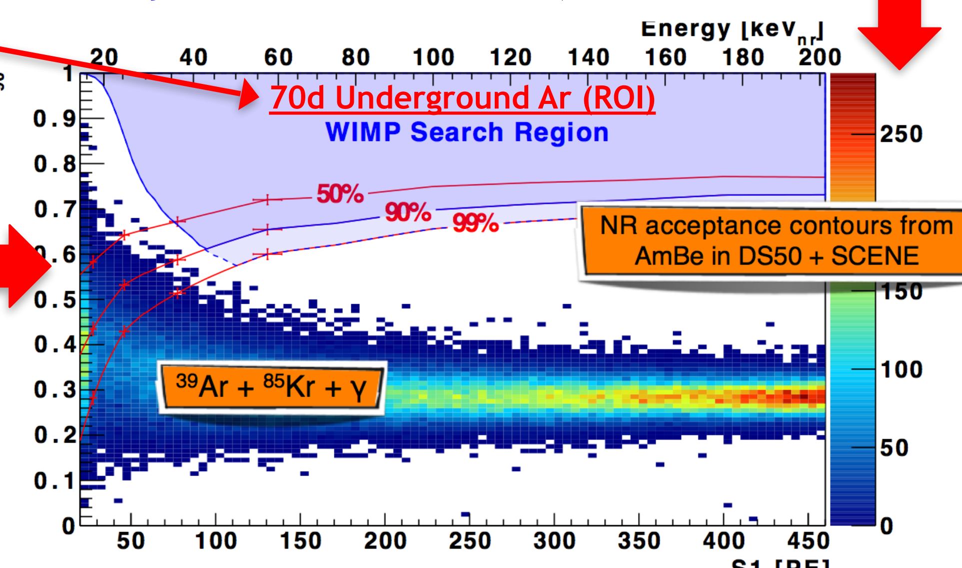
→ in **2015**: fill of DS-50 with Underground Argon

arXiv:1510.00702v1 [astro-ph.CO] 2 Oct 2015



1422kg-d **background free AAr exposure**
ER rejection with PSD >1.6x10^7 (stat. limited estimate

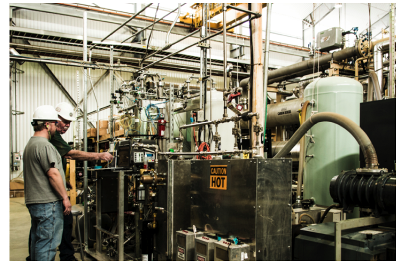




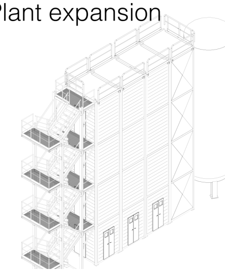
AAr + Uar → **background free** demonstrated for exposure **>5.5 t yr** → Scaling to multi-ton LAr

Underground/Depleted Ar : URANIA & ARIA projects

- **URANIA**:
  - Replacement of the Ar extraction plant in Colorado to reach capacity of 100 kg/day of UAr
  - Cost: 3.2M€
    - MIUR/INFN Progetto Premiale 2013 (2.3M€)
    - NSF + other US sources (0.9M€)
    - discussion with CERN towards the possibile commissioning and test at the Neutrino Platform
- **ARIA**:
  - 350 m tall distillation column in the Seruci mine in Sardinia for chemical and isotopic purification of UAr
  - Exploits finite vapor pressure difference between 39Ar/40Ar (39Ar reduction factor of 10 per pass at the rate of 100 kg/day)
  - Protocollo di Intesa between INFN and Regione Sardegna
  - Cost: 12.5M€
    - INFN (4M€)
    - NSF + other US sources (1.3M€)
    - CARBOSULCIS (4.5M€)
    - Regione Autonoma Sardegna (2.7M€)

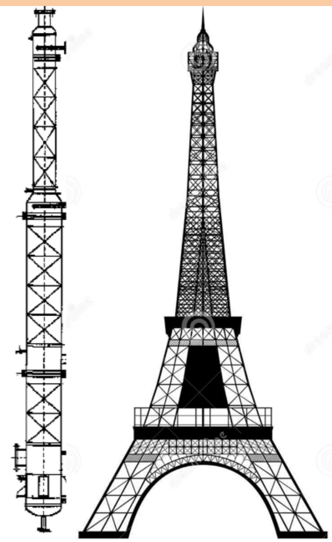


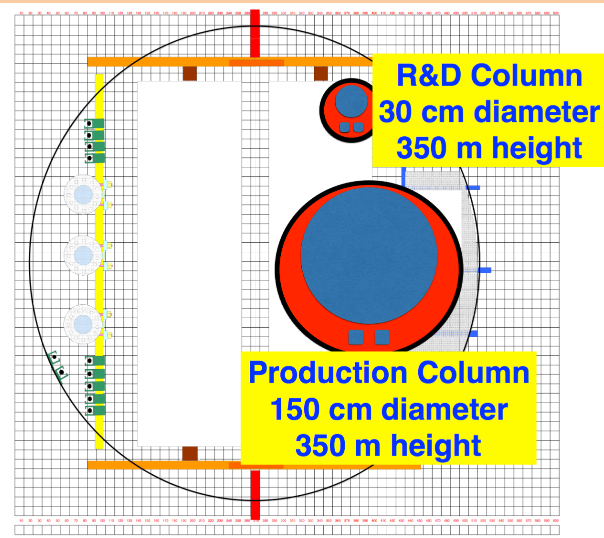
Plant expansion



extraction of UAr with activity (measured by DS-50) of (0.73±0.11)x10^{-3}Bq/kg

—> evidence for impurities coming from He line upstream. It will be placed downstream of URANIA



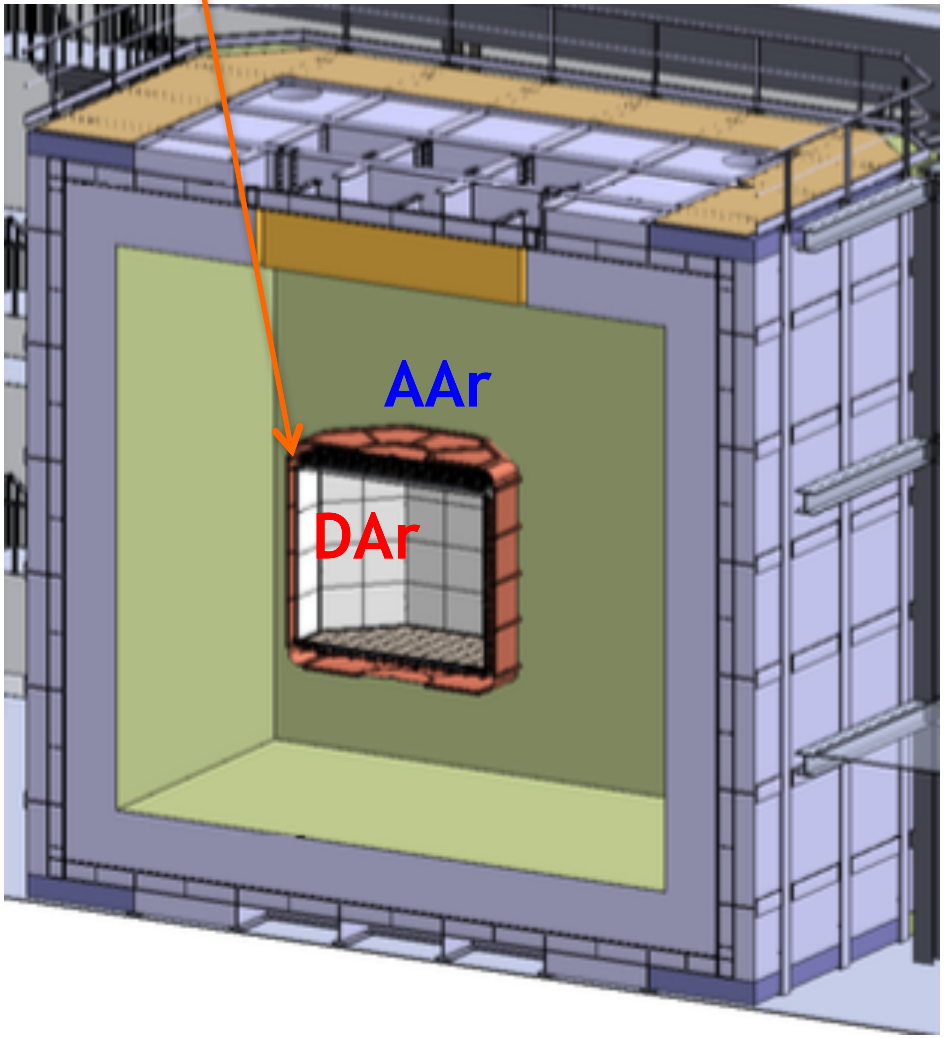


Seruci I —>removal of chemical impurities at 1t of Ar/day; also of ^{85}Kr with factor 1000 per pass

10kg/day isotopic distillation for ^{39}Ar —>rate too low for DS-20k

Seruci II —>150kg/day for ^{39}Ar : 30t —> 200d

Copper Vessel new DS-20K baseline design FEA analysis results

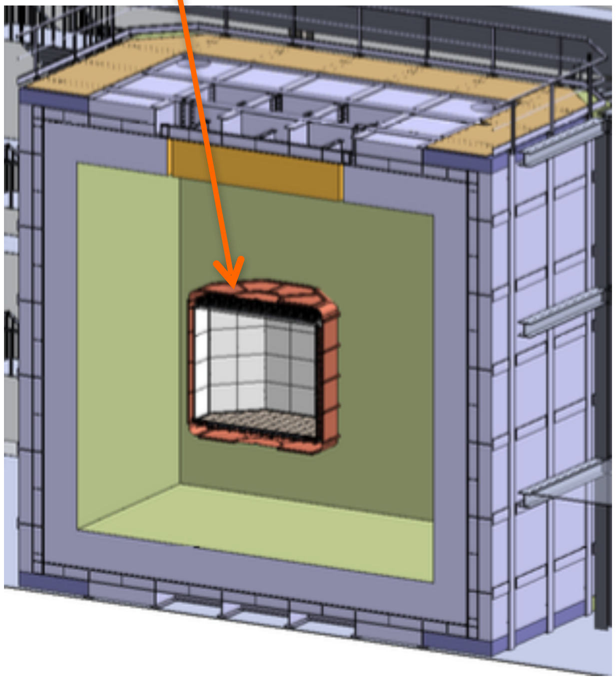


New veto strategy: TPC vessel

- In the frame of new veto design for DarkSide-20k a **new TPC Vessel** should separate DAr from surrounding AAr bath.

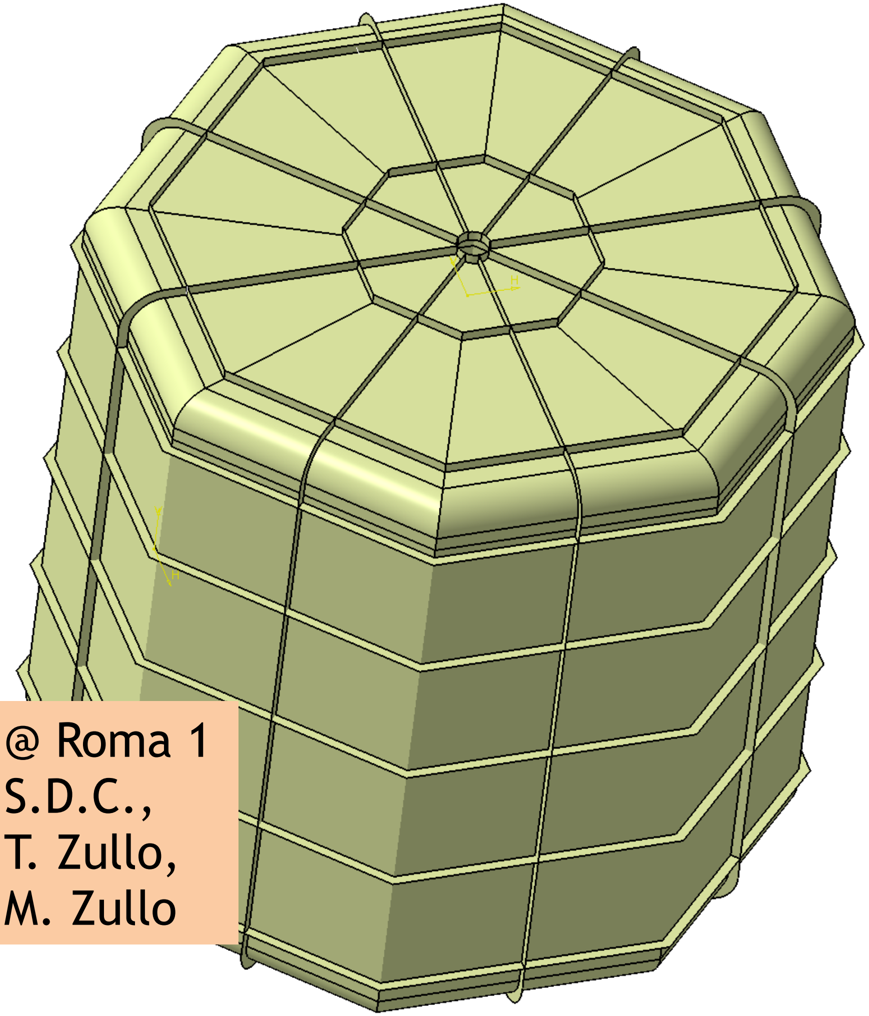
- Replaces the need of an thermic insulated SS/Ti two-vessels cryostat.

- Pros:
  - can use **intrinsically radio-pure materials** (**Cu**, Fibers, plastics…) or **Titanium**
  - no need for strong mechanical properties (internal/external pressures balancing)
  - not any more a true "cryostat" (the whole system is in LAr bath)



- Caveats :
  - Copper has poor mechanical properties and high weight/cost
  - Should decouple mechanically this vessel from TPC hanging: foresee a flange connecting directly roof hanging and TPC hangings.
  - Should be hermetic (no AAr / DAr leaks), attention to weldings

Design baseline: Copper & Titanium versions



@ Roma 1
S.D.C.,
T. Zullo,
M. Zullo

Optimization still ongoing, can further reduce mass by 10-20% with alleged bar designs, reinforcement geometry …

Designs adapted for both materials, passing buckling/deformation analysis thresholds :

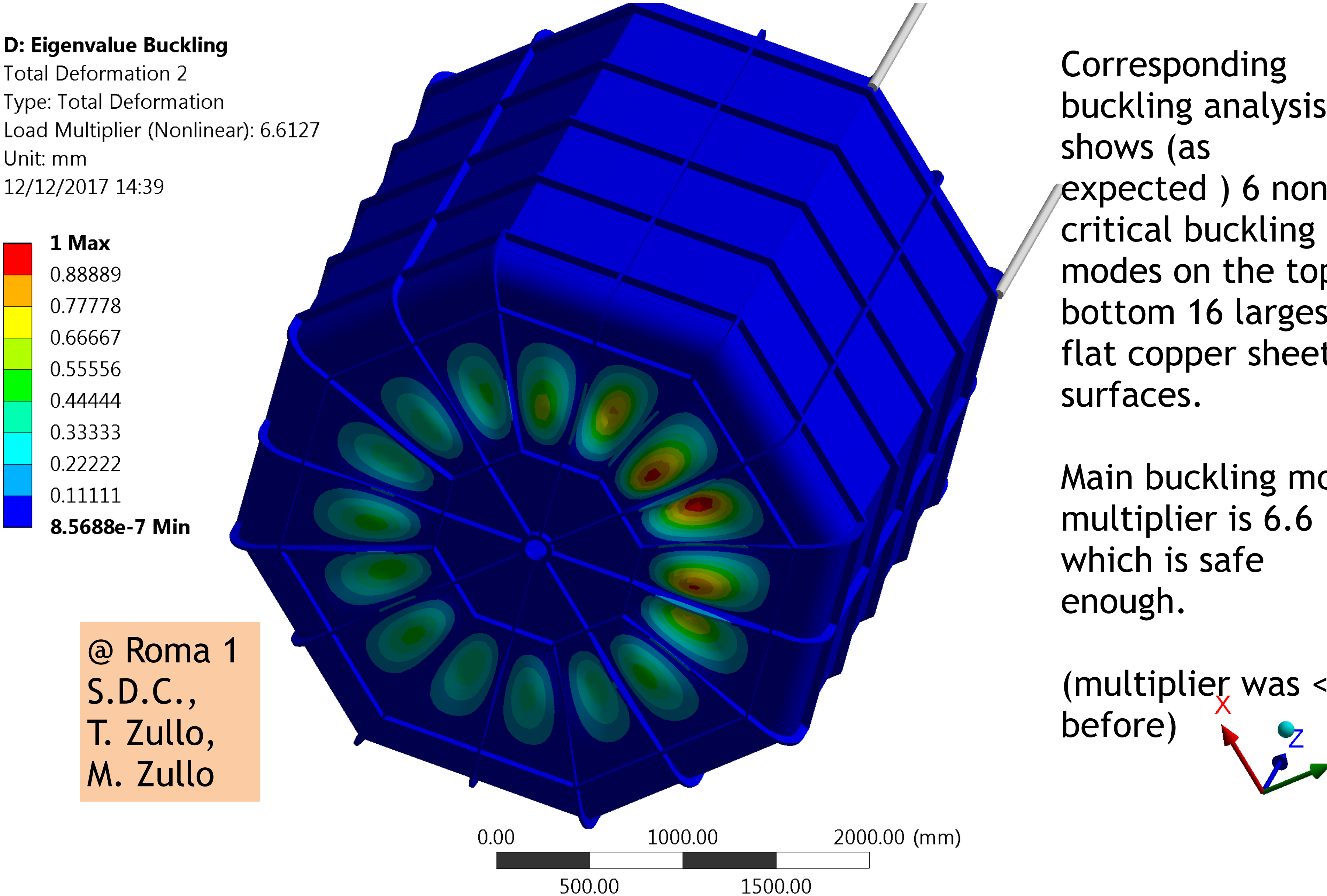
Copper version :

- **5mm** thick sheets for both top/bottom plates and lateral walls
- reinforcement bars/rings/ribs : 5cm x **2cm**
- Total mass : ~ **4 tons**

Titanium version :

- **2mm** thick sheets for lateral walls and 5mm thick top/bottom
- reinforcement bars/rings/ribs : 5cm x **1cm**
- Total mass : ~ **1 ton** ➔ relax constrains on radio-purity

Copper Vessel FEA @ 87K / 2psi overpressure



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Corresponding buckling analysis shows (as expected) 6 non critical buckling modes on the top/ bottom 16 largest flat copper sheet surfaces.

Main buckling mode multiplier is 6.6 which is safe enough.

(multiplier was < 1 before)

Industrial partnership for DS-20k Copper Vessel

walter tosto

In dettaglio la fornitura comprende le seguenti voci:

- Gestione progetto;
- Disegni e studi di fabbricazione, in accordo ai codici applicabili;
- L'approvvigionamento dei materiali e dei componenti necessari alla costruzione, nonché attività di "expediting" nei riguardi dei subfornitori;
- Qualifica dei processi di fabbricazione (saldatura, formatura, controlli non distruttivi, ecc.);
- Fabbricazione del vessel in officina con relative certificazioni, ispezioni e collaudi;
- Accoppiamento dei componenti del vessel con saldatura a fascio elettronico (Electron Beam Welding);
- Flange e connessioni di servizio in accordo ai disegni di riferimento;
- Le prove, i controlli ed i collaudi in officina;
- Golfari di sollevamento;
- Targa dati;
- Imballaggio per la spedizione via camion;
- Produzione della documentazione tecnica in accordo al par. 6.0;
- Garanzia meccanica.

La presente offerta comprende la fornitura dei seguenti componenti:

- **N°1 TPC Copper Vessel**

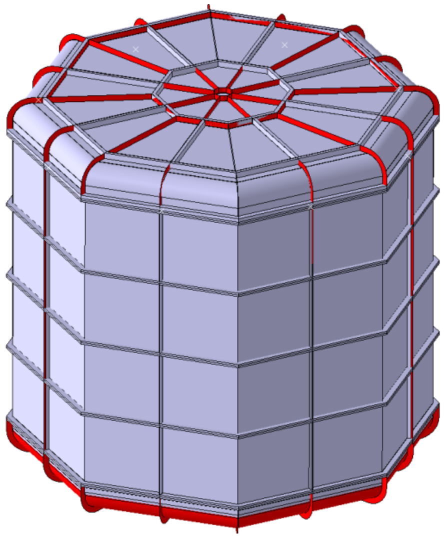


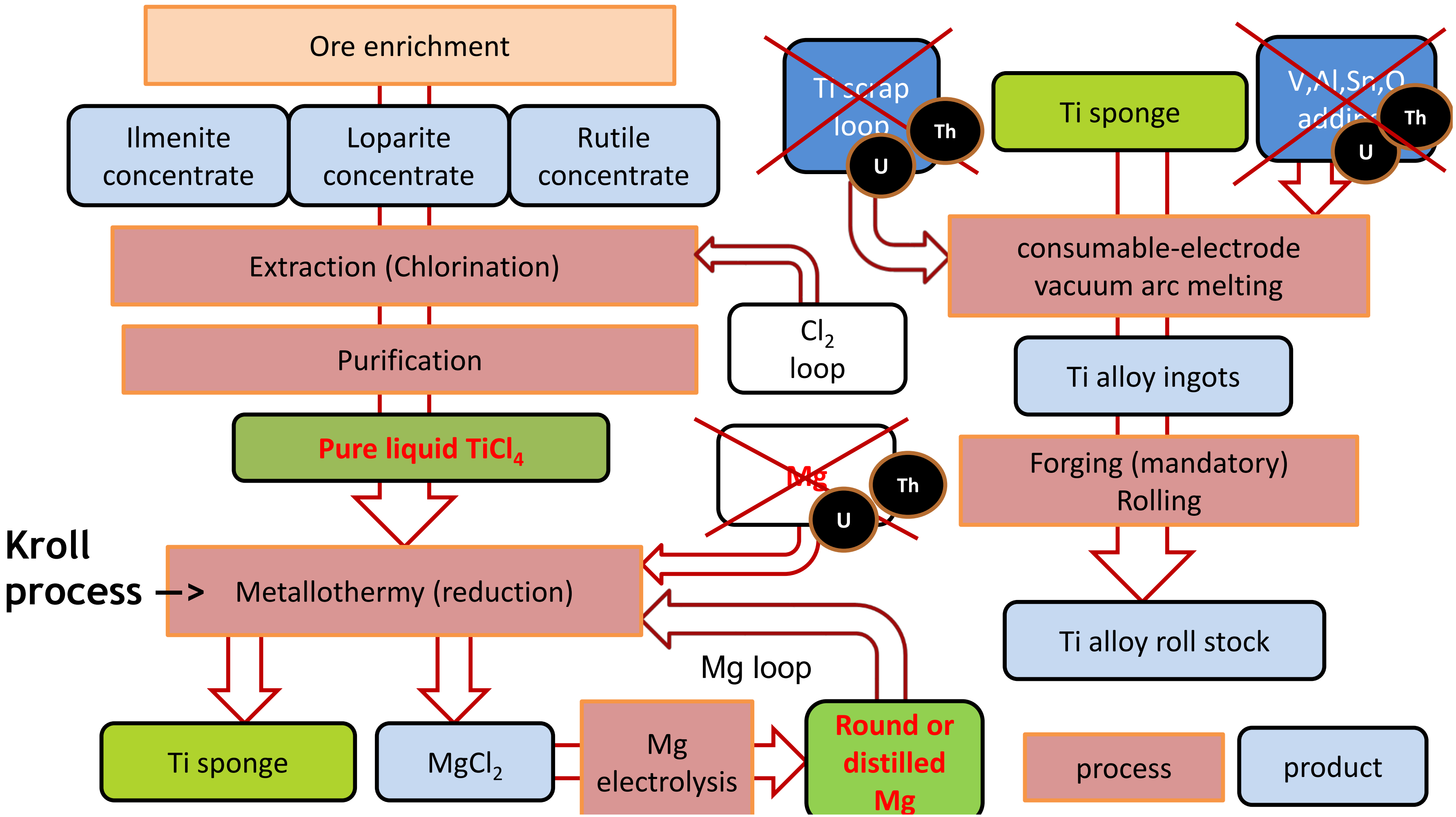
Fig.1 – Vista 3D del TPC vessel

EB welding is crucial to minimize mechanical properties degradation at the welding heating zones (down to few ten's of microns) and to avoid additional material in welding and corresponding recontamination source. *(see CUORE exp.)*

Ultra-High-Purity Titanium R&D

A. Chepurnov (Moscow U.), S.D.C. (Roma1), I. Nikulin (Belgorod) U.

Pure Ti alloy has excellent mec. properties. Potential UHP from production process



Industrial scale R&D and publication in progress. Good preliminary results

UHP Titanium R&D samples

Mechanical and U/Th properties

Материал	HV (hardness)	$\sigma_{0,2}$, Mpa (conventional yield limit)	$\sigma_в$, Mpa (tensile strength)		
Industrial materials					
AISI 304		210	510		
VT1-00 / GRADE 1	**110-140**	**250-380**	**300-450**		
AISI 316	180-250	250-450	450-800		
VT1-0 / GRADE 4	120-160	300-420	400-450		
VT16 (Al, V)	170-400	600-1000	1000-1500		
Ingots/sheet from pure Ti-sponge				U, ppb	Th, ppb
Original ingot from pure Ti-sponge	140 std.dev 30	150	220	<0.003	< 0.05
Sample №2	160 std.dev 53	410	565	0.83	0.67
Sample №3	**165 std.dev 10**	**420**	**590**	**<0.003**	**< 0.05**
Sample №4	155 std.dev 15	250	390	0.16	0.14
Sample №5	160 std.dev 45	280	400	<0.003	0.017
Sample №6	150 std.dev 8	415	575	1.11	1.25

~30 micro Bq/Kg in U!

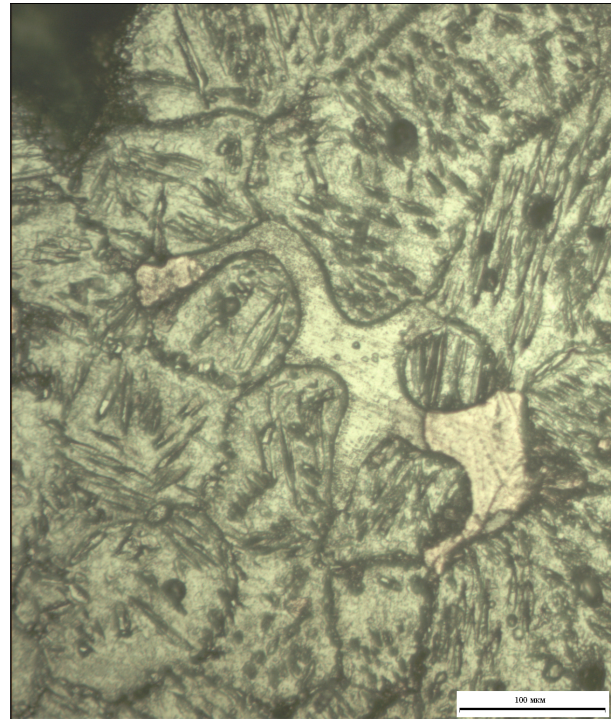
REMEMBER THE GOAL: U < 0,10 ppb ~ 1 mBq/kg
Th < 0,25 ppb ~ 1 mBq/kg

Potential :
obtain radio-purities comparable with Copper

and also Ti-Cu alloy R&D in Russia :

A. Chepurnov (Moscow U.), S.D.C. (Roma1), I. Nikulin (Belgorod) U.

80-20 Ti-Cu alloy with very good mechanical properties and good uniformity produced in Russia



There is literature on **Cu-Ti alloys (90-10 for ex.)** with excellent mechanical properties which could allow light and ultra radio pure structures close to the DarkSide-20k TPC:

"High-strength age hardening copper-titanium alloys: redivivus" W.A.Soffa, D.E.Laughlin
https://www.sciencedirect.com/science/article/pii/S007964250300029X

DarkSide-20k prototype SS cryostat

- Testing the full scale components intended for use in DarkSide-20k

  O(1m) linear dimensions to validate mechanics and SiPM photosensors

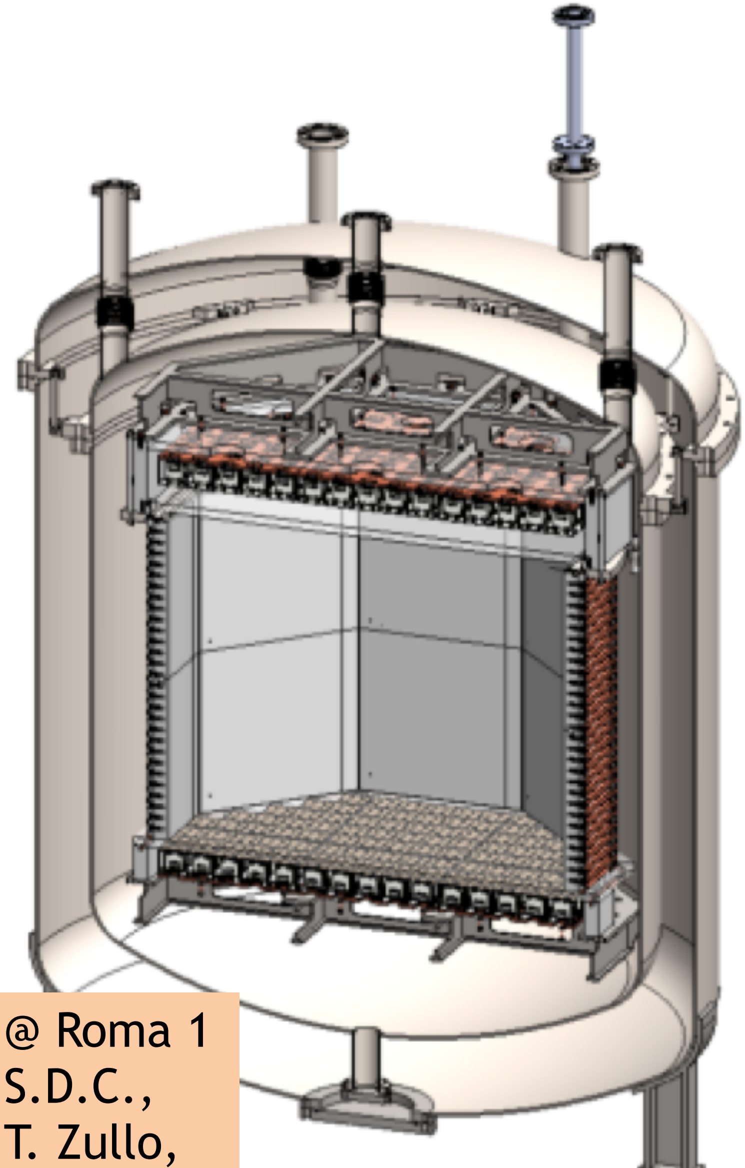
  ton scale to test full size DarkSide-20 cryo system

  TPC assembly and integration test

  - All the components of the prototype designed and built in the different institutions of the DarkSide Collaboration
  - Is currently under construction, to be assembled and tested **at CERN starting 2018** and later at LNGS

    eventually more at Cern facilities until mid-2019 (agreement)

    proposal to run the test underground at LNGS approved by the collaboration in June 2017



@ Roma 1
S.D.C.,
T. Zullo,
M. Zullo

SS procurement: Nironit Steel radio-assay

==

sample: steel Nironit, 1.4301, AB1849282, 5 mm plates, Xenon
(restarted on 28-FEB-2018 after general blackout)
weight: 7.7466 kg
live time: 1941933 s
detector: GeMPI2

radionuclide concentrations:

Th-232:			
Ra-228:	(1.0 +- 0.1) mBq/kg	<==>	(2.4 +- 0.3) E-10 g/g
Th-228:	(0.56 +- 0.08) mBq/kg	<==>	(1.4 +- 0.2) E-10 g/g
U-238:			
Ra-226	(1.36 +- 0.11) mBq/kg	<==>	(1.10 +- 0.09) E-10 g/g
Th-234	< 23 mBq/kg	<==>	< 1.9 E-9 g/g
Pa-234m	< 7.3 mBq/kg	<==>	< 5.9 E-10 g/g
U-235:	< 0.43 mBq/kg	<==>	< 7.6 E-10 g/g
K-40:	(1.2 +- 0.3) mBq/kg	<==>	(4 +- 1) E-8 g/g
Cs-137:	< 0.092 mBq/kg		
Co-60:	(0.60 +- 0.06) mBq/kg	@ start 28-FEB-2018	

Mn-54:	(0.58 +- 0.08) mBq/kg	@ start 28-FEB-2018
Co—58:	(0.21 +- 0.05) mBq/kg	@ start 28-FEB-2018
Co—56:	< 0.11 mBq/kg	@ start 28-FEB-2018
Co-57:	(1.0 +- 0.2) mBq/kg	@ start 28-FEB-2018
Sc-46:	(0.11 +- 0.03) mBq/kg	@ start 28-FEB-2018
V-48:	(0.19 +- 0.04) mBq/kg	@ start 28-FEB-2018
Cr-51:	(2.1 +- 0.6) mBq/kg	@ start 28-FEB-2018

upper limits with k=1.645,
uncertainties are given with k=1 (approx. 68% CL);

Ra-228 from Ac-228;
Th-228 from Pb-212 & Bi-212 & Tl-208;
Ra-226 from Pb-214 & Bi-214;
U-235 from U-235 & Ra-226/Pb-214/Bi-214;

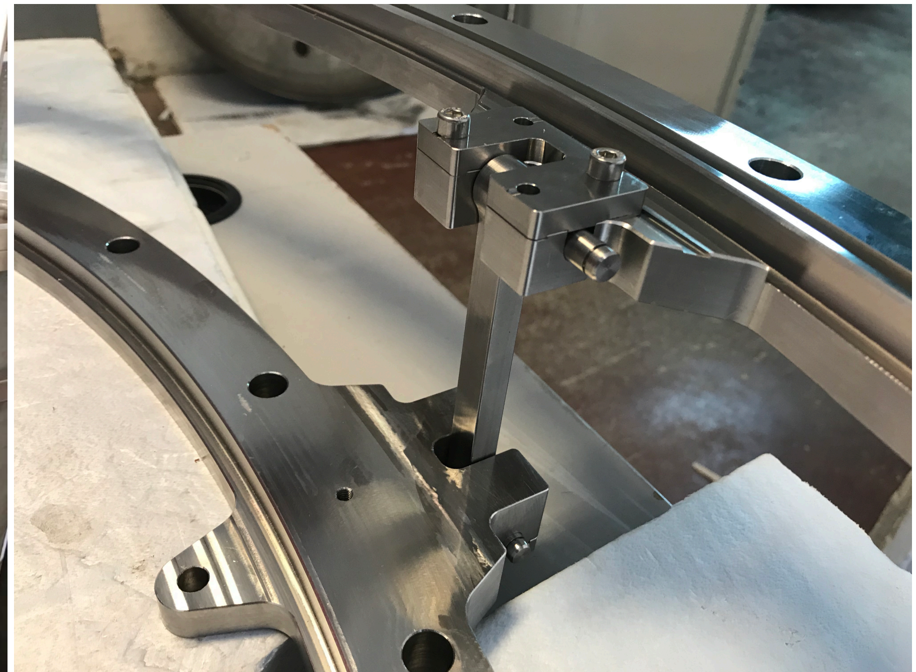
==

Very radio pure SS procured at NIRONIT (Germany) same heat/number as for Xenon-nT new cryostat. In pipeline for Mass Spectroscopy to fix 235U/238U/

We do have a remaining stock of ~1ton in form of 5mm thick sheets

@ Roma 1
S.D.C.,
T. Zullo,
M. Zullo

Prototype Cryostat construction on going



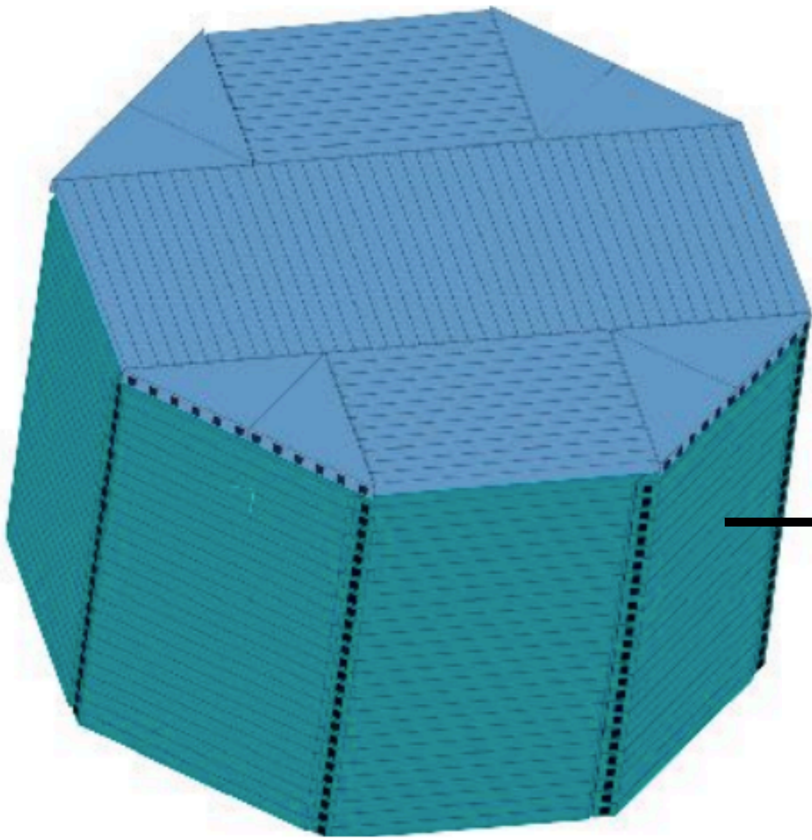
Active neutron Veto design R&D

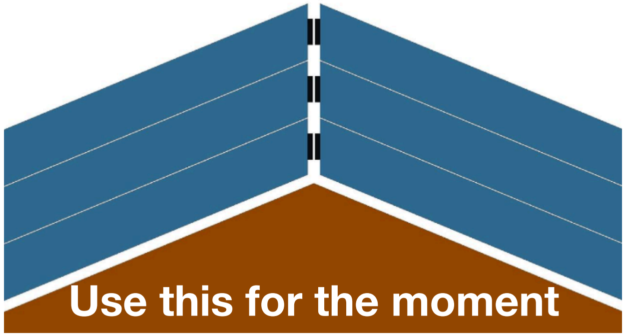
3 layers of bars (10x10 cm^2) cross section.

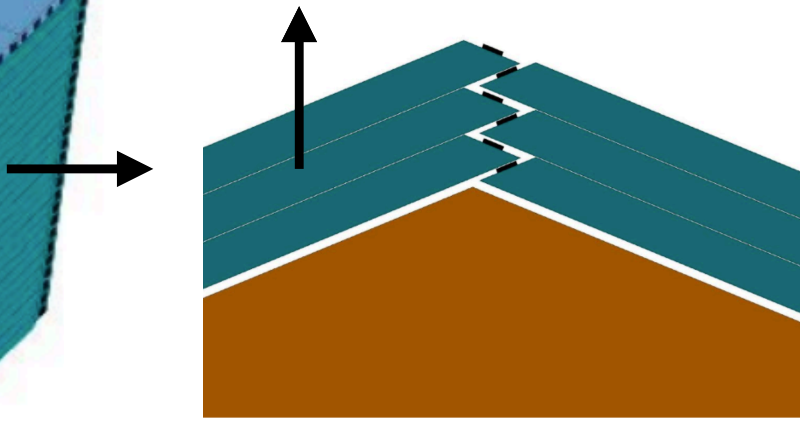
Coating with 50 us of GdOxide

“Compact” geometry: bars are almost touching the Cu vessel (a few cm of LAr in between).

Baseline design : Plastic scintillator bars coated with Gd reflector foils







Active neutron Veto: radio-purity

Material	Volume [m³]	Density [g/cm³]	Weight [t]
UAr Active	**28.48**	**1.4**	**39.87**
UAr Passive	**15.4**	**1.4**	**21.56**
PS	25.5	1.2	**30.60**
Cu Vessel	0.71	8.96	**6.36**
Cu Parts	0.27	8.96	**2.42**
Acrylic	0.65	1.2	**0.78**
Steel Structure	0.08	8.3	**0.66**
SiPM	0.021	2.33	**0.05**
Teflon	0.0156	2.16	**0.03**

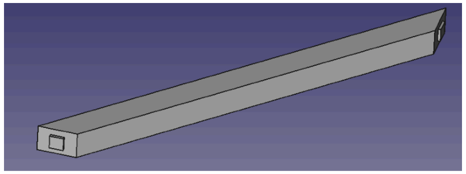
<-- relevant PS moderator mass

Radio-purity issue crucial: **alpha-n** & fission neutrons from U and Th chains

dirty PS (30 mBq/kg U, 10 mBq/kg Th and 30 tons)

Option for PS bars + SiPMs (ex. BC408)

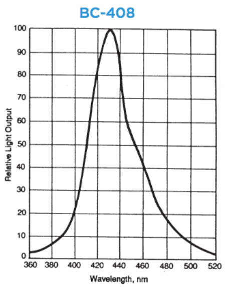
186 cm is maximal length



One bar geometry. Simple parallelepiped **10x10x190 cm³**

Optical properties of St Gbain BC408

98% reflective reflector all around.



Scintillation Properties	
Light Output, %Anthracene	64
Rise Time, ns	0.9
Decay Time (ns)	2.1
Pulse Width, FWHM, ns	~2.5
Wavelength of Max. Emission, nm	425
Light Attenuation Length, cm*	210
Bulk Light Attenuation Length, cm	380

~ 10 photons / keV

very fast

two values, in principle should use bulk

*The typical 1/e attenuation length of a 1x20x200cm cast sheet with edges polished as measured with a bialkali photomultiplier tube coupled to one end.

One SiPM (5x5 cm²) at each end. PDE 40%

Alternative option under study:

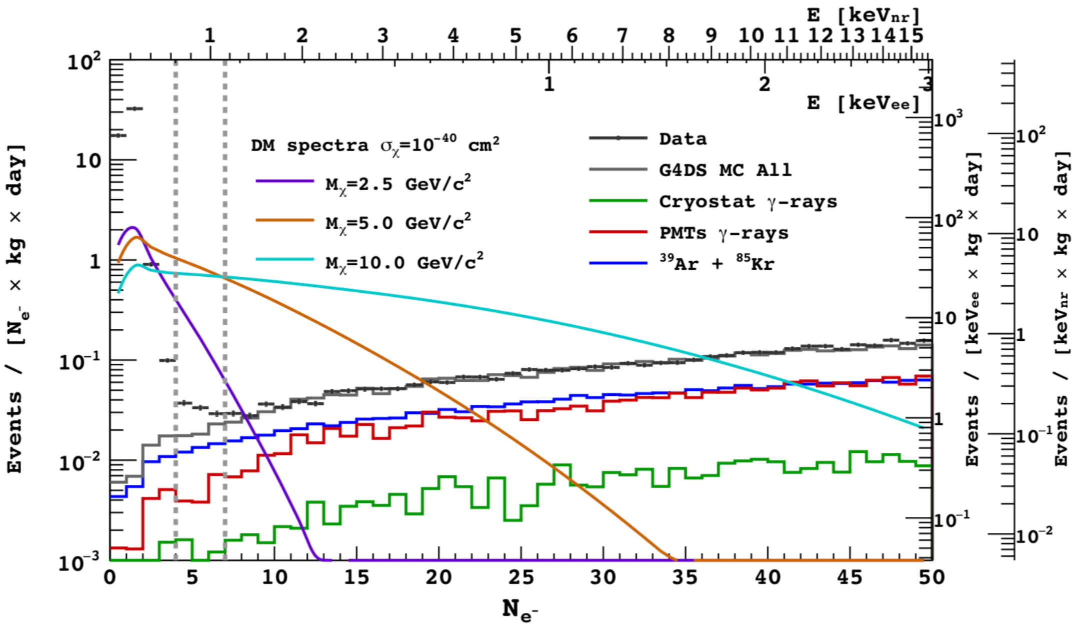
- Use radio-pure plastic as moderator only material
- Keep Gd foils for neutron capture
- But use AAr bath (for free) as capture gamma detection material
- Pros : get rid of Scintillator (hard to procure radio-pure)

DS-50 PMTs and Cryostat radioactivity

TABLE I. TPC component activities, estimated by fitting $^{232}\mathrm{Th}_{\mathrm{PMT}}$, $^{238}\mathrm{U}^{\mathrm{lower}}_{\mathrm{PMT}}$, $^{40}\mathrm{K}_{\mathrm{PMT}}$, and $^{60}\mathrm{Co}_{\mathrm{PMT}}$ in sequence, followed by $^{235}\mathrm{U}_{\mathrm{PMT}}$, $^{238}\mathrm{U}^{\mathrm{upper}}_{\mathrm{PMT}}$ while $^{85}\mathrm{Kr}$ and $^{39}\mathrm{Ar}$ are fixed at their measured rates as reported in [15]. Cryostat activities ($_{\mathrm{c}}$) are summed across all cryostat locations, and fixed at their respective measured rates from assays. PMT activities ($_{\mathrm{p}}$) are summed across all PMT locations, and across all 38 tubes.

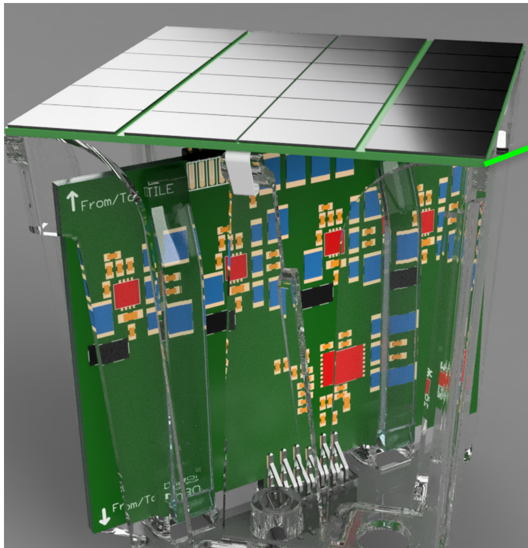
Source	Activity [Bq]	Source	Activity [Bq]
$^{232}\mathrm{Th}_{\mathrm{p}}$	0.277 ± 0.005	$^{232}\mathrm{Th}_{\mathrm{c}}$	0.19 ± 0.04
$^{40}\mathrm{K}_{\mathrm{p}}$	2.74 ± 0.06	$^{40}\mathrm{K}_{\mathrm{c}}$	$0.16^{+0.02}_{-0.05}$
$^{60}\mathrm{Co}_{\mathrm{p}}$	0.15 ± 0.02	$^{60}\mathrm{Co}_{\mathrm{c}}$	1.4 ± 0.1
$^{238}\mathrm{U}^{\mathrm{low}}_{\mathrm{p}}$	0.84 ± 0.03	$^{238}\mathrm{U}^{\mathrm{low}}_{\mathrm{c}}$	$0.378^{+0.04}_{-0.1}$
$^{238}\mathrm{U}^{\mathrm{up}}_{\mathrm{p}}$	4.2 ± 0.6	$^{238}\mathrm{U}^{\mathrm{up}}_{\mathrm{c}}$	$1.3^{+0.2}_{-0.6}$
$^{235}\mathrm{U}_{\mathrm{p}}$	0.19 ± 0.02	$^{235}\mathrm{U}_{\mathrm{c}}$	$0.045^{+0.007}_{-0.02}$
$^{85}\mathrm{Kr}$	1.9 ± 0.1 mBq/kg	$^{39}\mathrm{Ar}$	0.7 ± 0.1 mBq/kg

… and example of impact on physics,
DS-50 low mass DM search result :



The choice of SiPMs for photo-detection is crucial for DarkSide-20k physics program
SiPMs per se are at micro Bq/kg level and small total mass wrt PMT … but … —>

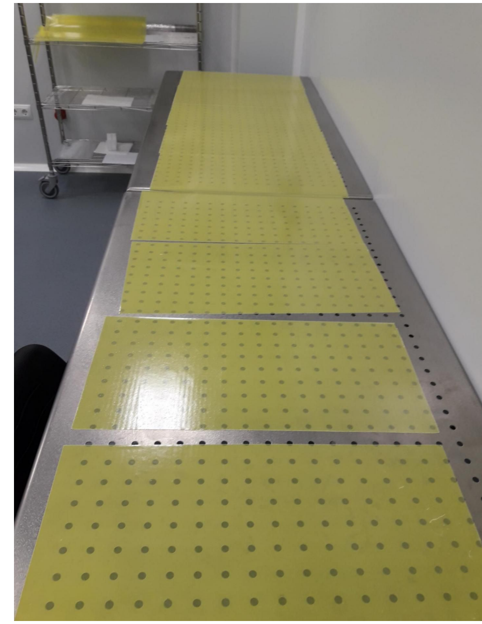
SiPMs PCB substrates contribution in DS-20k PDMs:



Photon Detection Module

Arlon PCB substrate foils samples under Radon emanation on large surface facility and direct 210Po alpha counting screenings

Also investigate alternatives (Pyralux, Si,…)



Radio-purity assay:

	mg	/PDM	238U uBq/PDM	232Th uBq/PDM		Material	238U yield	232Th yield	n 238U /5 yr	n 232Th /5 yr
PPS capacitors	307	29	14,95	3,07			0,00E+00	0,00E+00	0,00E+00	0,00E+00
PEN capacitors	20	2	0,01	0,004			0,00E+00	0,00E+00	0,00E+00	0,00E+00
Si capacitors	2,52	6	0,05	0,19		Si	2,20E-06	3,45E-06	9,03E-02	5,38E-01
Resistors	40,8	51	3,26	0,67	ohmite?		0,00E+00	0,00E+00	0,00E+00	0,00E+00
Chips	74,4	4	6,32	0,89			0,00E+00	0,00E+00	0,00E+00	0,00E+00
Connectors	263	3	2,7	2,9	plastic?	Acrylic?	1,22E-06	1,38E-06	2,70E+00	3,28E+00
Solder	400	1	2,25	2,11			0,00E+00	0,00E+00	0,00E+00	0,00E+00
PCB	5000	1	9,75	0,55	Arlon	Arlon	2,44E-06	2,37E-06	1,95E+01	1,07E+00
PEN cap	40	4	0,02	0,01			0,00E+00	0,00E+00	0,00E+00	0,00E+00
Divider	96	48	3,26	0,67			0,00E+00	0,00E+00	0,00E+00	0,00E+00
Connectors	178	2	2	2,05		Acrylic?	1,22E-06	1,38E-06	2,00E+00	2,32E+00
Clips	182	4	4,01	3,28			0,00E+00	0,00E+00	0,00E+00	0,00E+00
Solder	200	1	1,12	1,06			0,00E+00	0,00E+00	0,00E+00	0,00E+00
PCB	6000	1	11,7	0,66	Arlon	Arlon	2,44E-06	2,37E-06	4,69E+00	2,57E-01
			Tot 238U / PDM	Tot 232 Th /PDM					TOTAL / 5 yr	
			61,4	18,114					36,47	

Ongoing DS-20k neutron budget estimates:

Physics driven goal for 0-back search : **<0,1 neutron** in total 5 years exposure of 100 ton yr

Inner TPC detector

TPC side and Vessel			
			After
Description of position	combined eff0	neutrons in 5 years	all cuts:
Reflector	0.0001711	4.18E+00	7.15E-04
Vessel	0.0001093	6.77E+00	7.40E-04
TPC side	0.0001711	1.70E+02	2.90E-02
TOTAL		**1.81E+02**	**3.05E-02**

Already complains with budget

Outer Neutron active Veto

Plastic Scintillator			After
Description of position	combined eff0	neutrons in 5 years	all cuts:
Dirty Plastic	**1.30E-05**	**1.85E+05**	**2.41E+00**
Clean Plastic	**1.30E-05**	**1.85E+03**	**2.41E-02**

Steel structure			
Description of position	combined eff0	neutrons in 5 years	
Dirty Plastic	**1.27E-04**	**3.71E+02**	**4.71E-02**

Now investigate pure plastic moderator and gamma detection in cryostat AAr

SiPMs PCB substrates options:

SiPM planes: all Pyralux, Arlon tile

SiPM tiles	0.0002106	1.99E+03	4.20E-01
Front end board	0.0002106	1.67E+02	3.51E-02
Mother board	0.0002106	1.35E+00	2.85E-04
Finger board	0.0002106	1.75E+01	3.68E-03
Steering module	0.0002106	6.31E+01	1.33E-02
Optical module	0.0002106	1.74E+01	3.66E-03
	0.0002106		0.00E+00
TPC Top/Bottom	0.0002106	3.71E+02	7.81E-02
TOTAL		**2.26E+03**	**5.54E-01**

After all cuts

All Si + integrated electronics (except/with HV)

SiPM tiles	0.0002106	1.00E+00	2.11E-04
Front end board	0.0002106	1.00E+00	2.11E-04
Mother board	0.0002106	1.00E+00	2.11E-04
Finger board	0.0002106	1.00E+00	2.11E-04
Steering module	0.0002106	1.00E+00	2.11E-04
Optical module	0.0002106	1.00E+00	2.11E-04
	TODO		0.00E+00
TOTAL		**6.00E+00**	**1.26E-03**

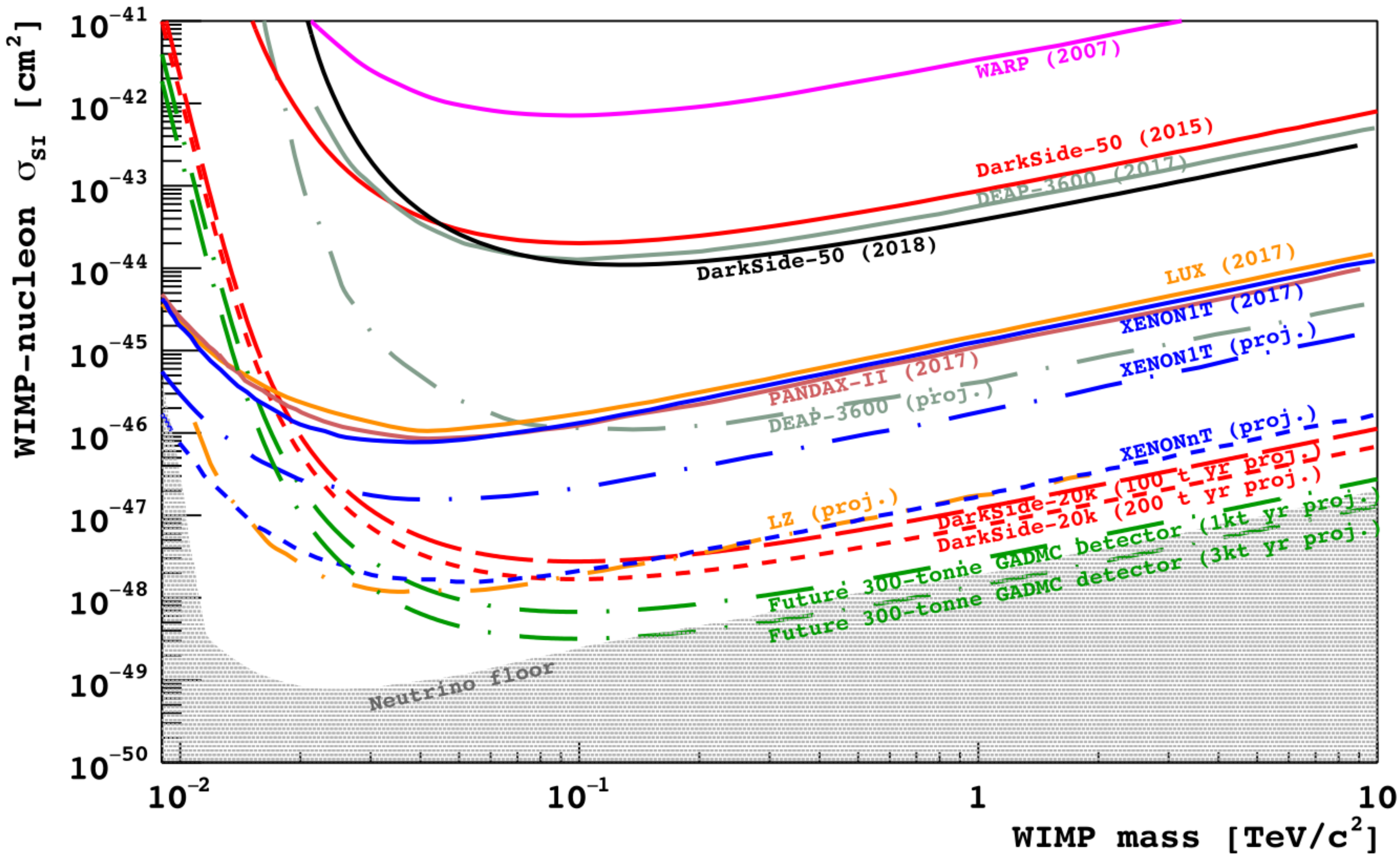
After all cuts

Current SiPMs substrate option at limit. R&D and radio assay on-going

Caveat: large simulation uncertainties for alpha-n/2n… x-sec on light nuclei (O and C). DS-50 measured less neutrons than what was predicted by simulation physics tables …

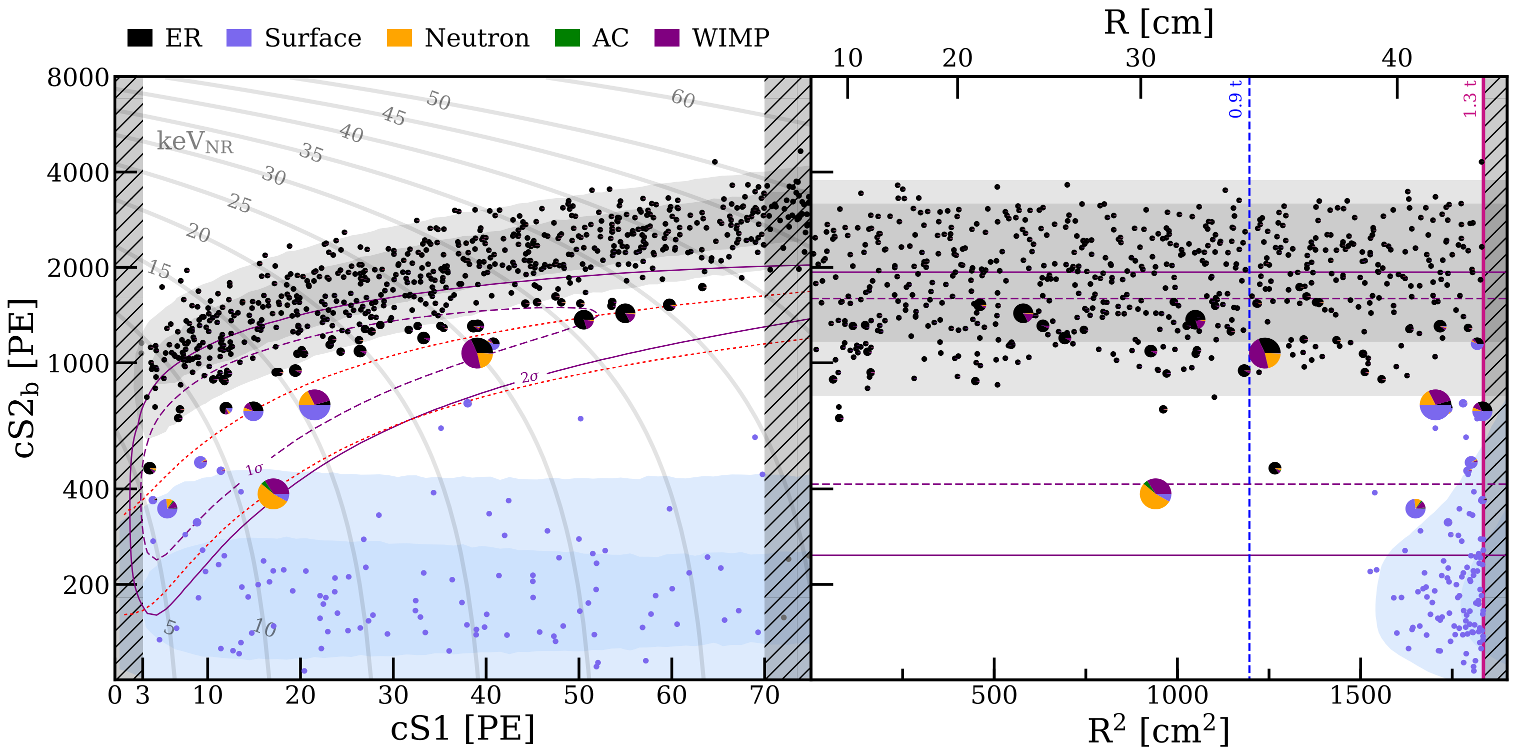
DarkSide-20k and GADMC physics reach

… with zero instrumental background (<0.1 neutron in total exposure)



—> Radio-purity issue and R&D is crucial. Roma 1 group is part of the effort

P.S.: on Xenon-1T new not so pure result



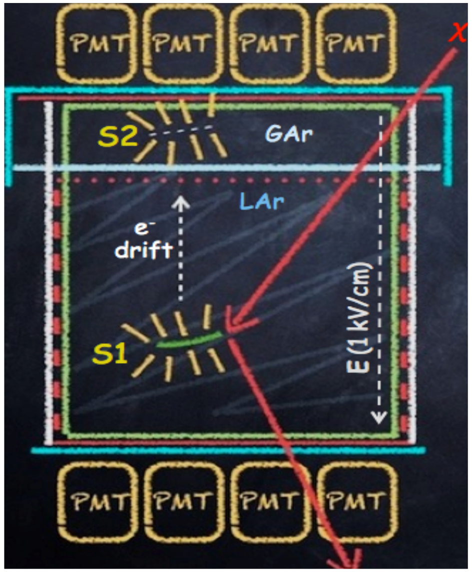
Mass	1.3 t	1.3 t	0.9 t	0.65 t
($cS1$, $cS2_b$)	Full	Reference	Reference	Reference
ER	627±18	1.62±0.30	1.12±0.21	0.60±0.13
neutron	1.43±0.66	0.77±0.35	0.41±0.19	0.14±0.07
CEνNS	0.05±0.01	0.03±0.01	0.02	0.01
AC	$0.47^{+0.27}_{-0.00}$	$0.10^{+0.06}_{-0.00}$	$0.06^{+0.03}_{-0.00}$	$0.04^{+0.02}_{-0.00}$
Surface	106±8	4.84±0.40	0.02	0.01
Total BG	735±20	7.36±0.61	1.62±0.28	0.80±0.14
$\mathrm{WIMP}_{\text{best-fit}}$	3.56	1.70	1.16	0.83
Data	739	14	2	2

ER recoil leakage in SR starts hurting sensitivity. Difficult to have solid estimate. Dominated by 214Bi beta from Radon dissolved in the whole volume (fiducialisation not effective)

- Excess dominated by 1 neutron(wimp) candidate in SR, and No active veto …

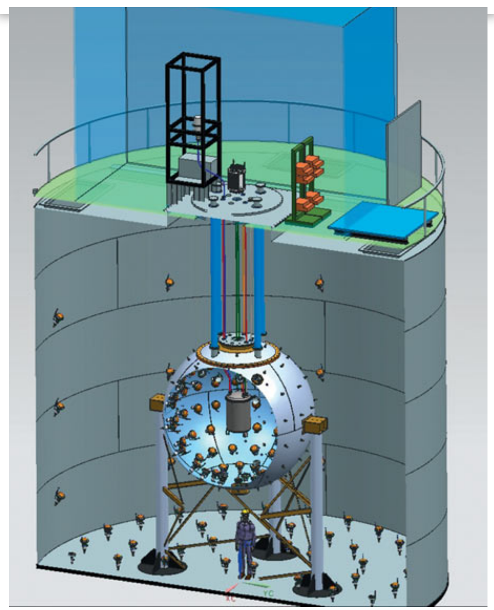
BACKUP

DarkSide-50 LAr TPC and vetoes



DarkSide-50 in LNGS hall C :

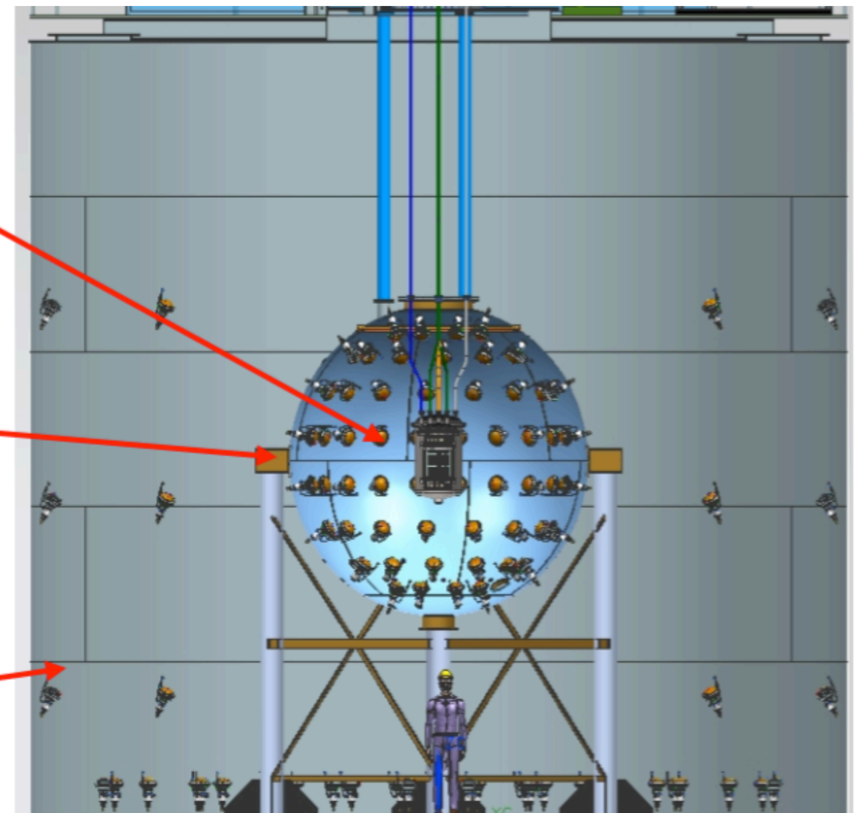
- 50 kg LAr active mass
- 19 PMTs top / 19 PMTs bottom cryogenic (LT bi-alkali photocathodes)
- Active neutron veto with borate-scintillator
- Data taking since 2014 until ~2018



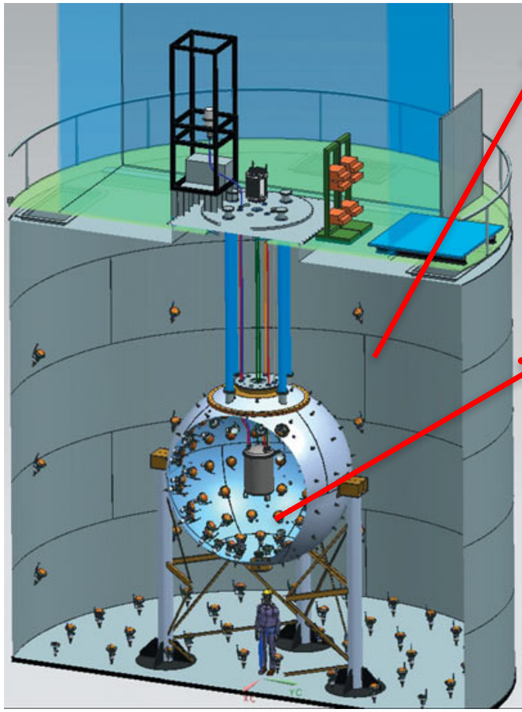
Liquid Argon TPC
153 kg ^{39}Ar-Depleted
Underground Argon
Target

4 m Diameter
30 Tonnes
Liquid Scintillator
Neutron Veto

10 m Height
11 m Diameter
1,000 Tonnes
Water Cherenkov
Muon Veto



Neutron background active veto



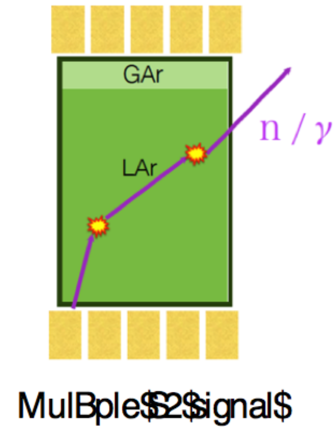
Water Tank

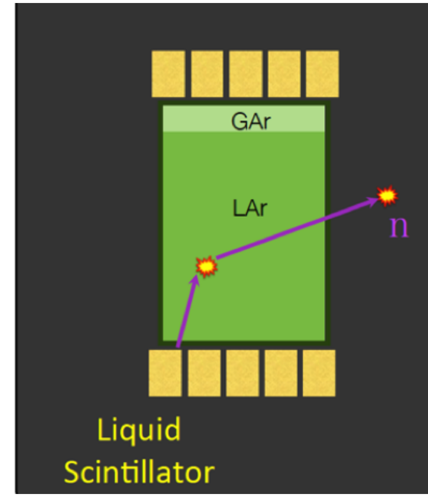
- 11 m diameter x 10 m high
- 80 PMTs
- Active muon veto
  - tag cosmogenic neutrons
- Passive neutron and γ shielding

Liquid Scintillator Veto

- 4 m diameter sphere
- Boron-loaded: PC + TMB
- 110 8" PMTs
- Active neutron veto
  - tag neutrons in TPC
  - in situ measurement of neutron BG
- Passive neutron and γ shielding

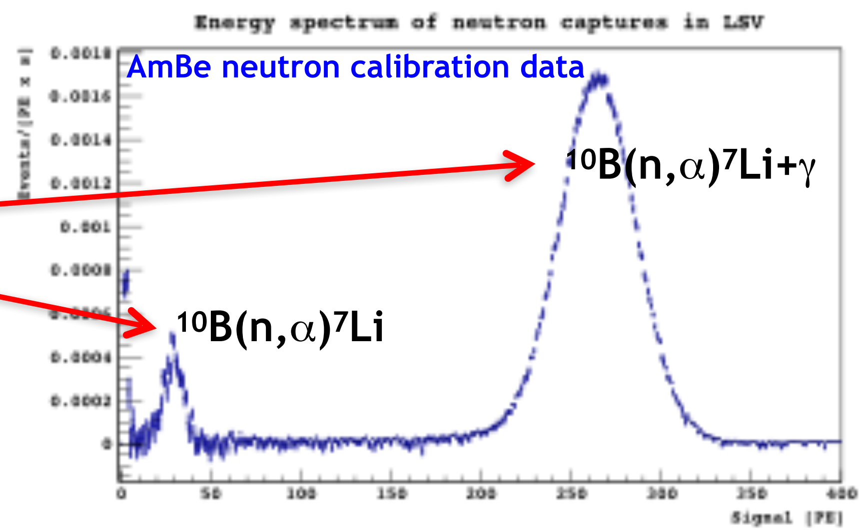
Neutron mean free path 1-10 cm, can be tagged with multiple hits in TPC and in LSV :





Observe neutron capture on ^{10}B through :

- 93.6%: $^{10}\mathrm{B} + \mathrm{n} \Rightarrow {}^{7}\mathrm{Li}^{*} + \alpha$
  $^{7}\mathrm{Li}^{*} \Rightarrow {}^{7}Li + \gamma$ (478 keV)
- 6.4%: $^{10}\mathrm{B} + \mathrm{n} \Rightarrow {}^{7}\mathrm{Li}$ (1015 keV) + α (1775 keV)
  α (1775 keV) equivalent to 50–60 keVee



>99.1% efficiency to veto neutrons with capture signals. **Ex. :** in current DS-50 data <0.02 n predicted after veto
and total of 2 +- 2 tagged events.

DarkSide-50 detector performances

S1 and S2 Yields:

- S1 Yield ~7.9 pe/keV at null field
- S1 Yield **~7.0 pe/keV** at 200 V/cm at 41 keV_{ee}
- Light collection efficiency ~ 16%
- Ionization Work Function ~ 23.4 eV
- S2 yield **~23 pe / e^-**

Electron lifetime > 10 ms

Maximum drift time: 376 μs at 200 V/cm

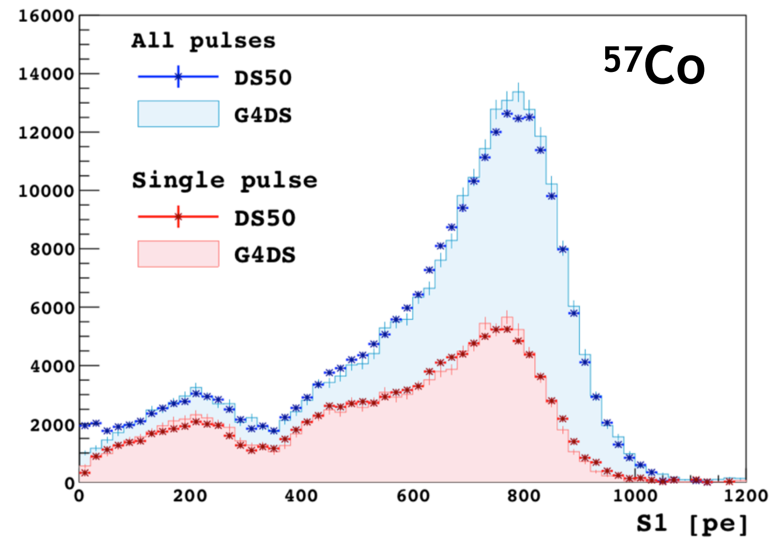
Drift velocity: 0.93 mm /μs

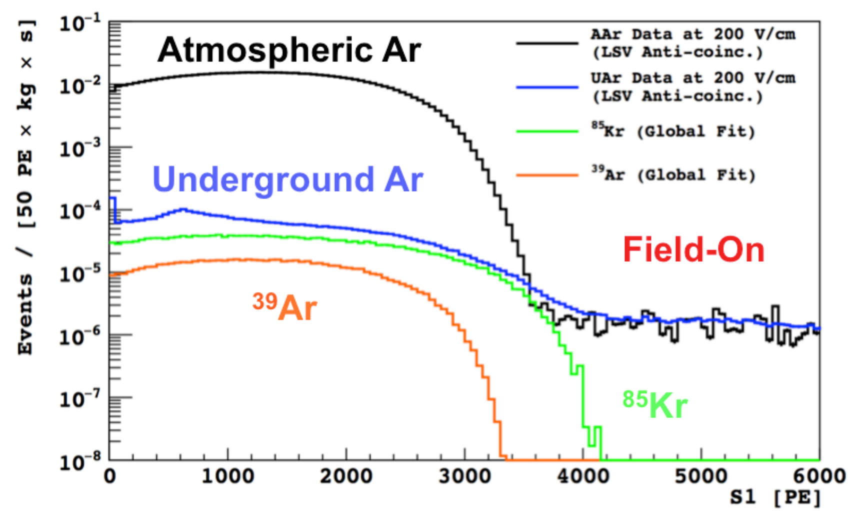
Position reconstruction:

- Resolution in Z **~1 mm**
- Resolution in XY **<1 cm**

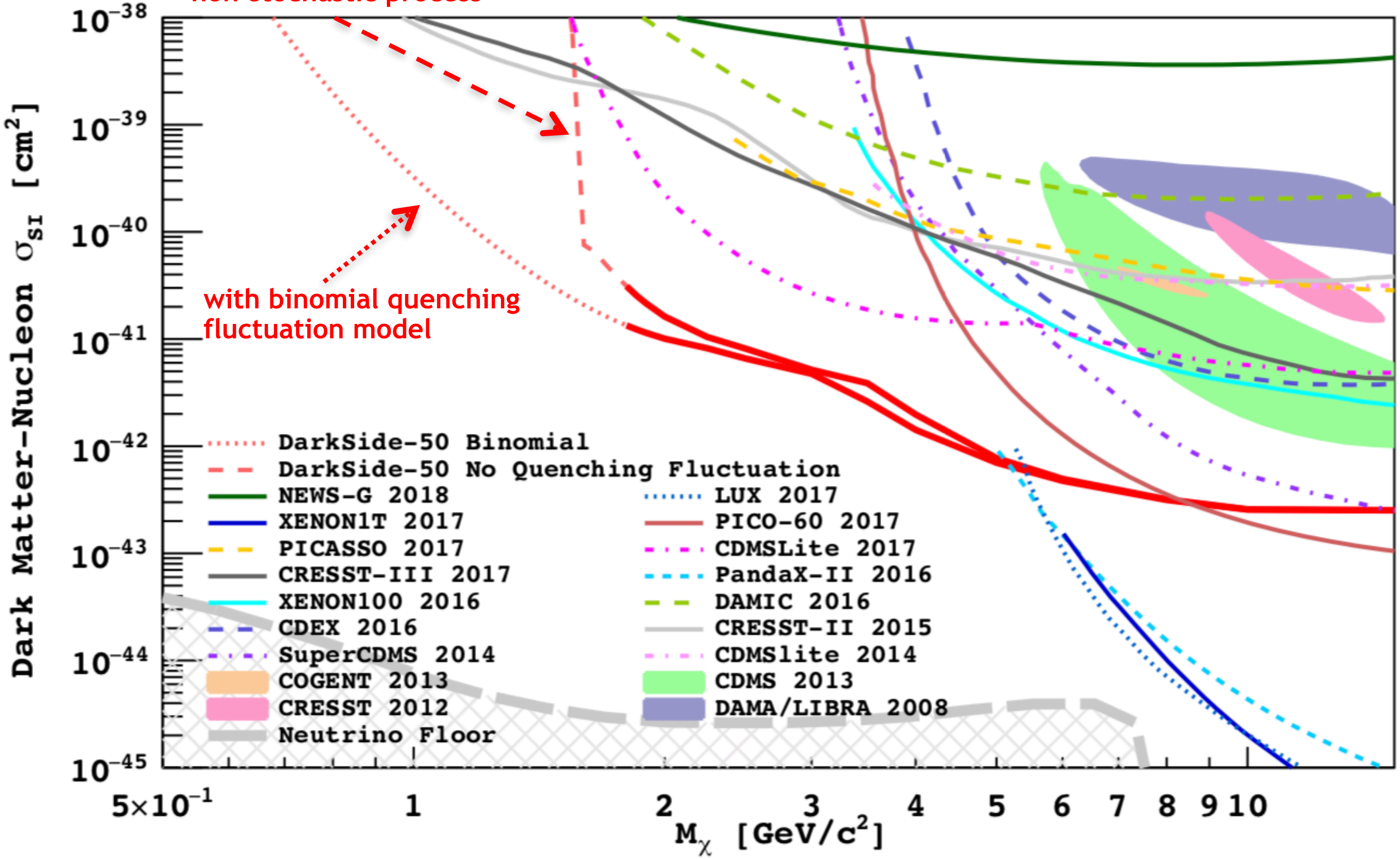
^{39}**Ar depletion factor** in UAr ~**1400** (~0.7 mBq/kg)

Full characterization of the detector response with **Monte Carlo** (JINST 12 (2017) P10015)





Low Mass DM 90% C.L. exclusion limit result :



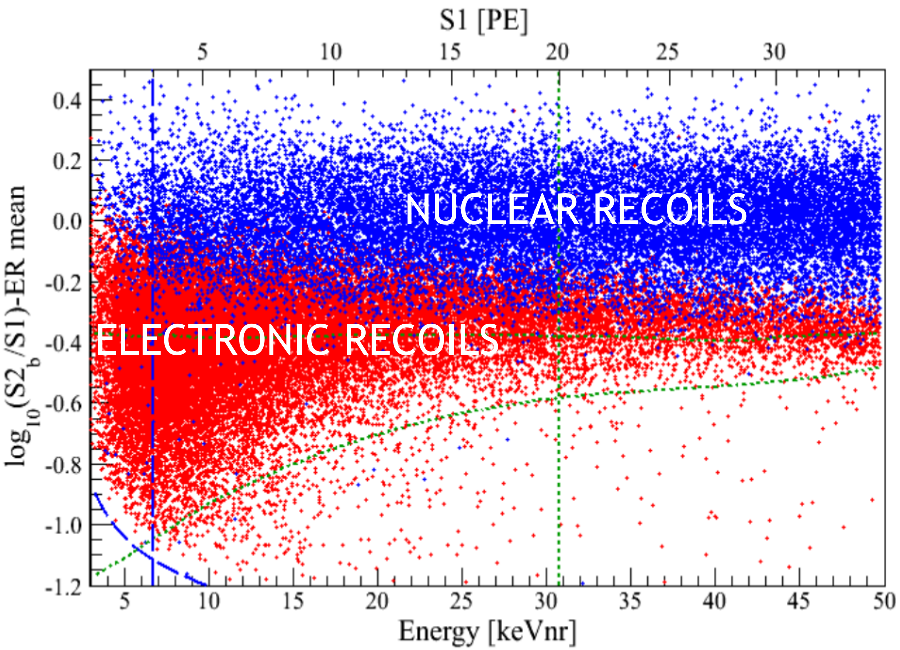
- **Profile Likelihood Method** for $N_e>4$ and $N_e>7$ thresholds shown respectively for **$M\chi$ < 3.5 GeV** and **$M\chi$ > 3.5 GeV**
- **Uncertainties** for both WIMP signals (NR ionization yield, single electron yields) and BG spectrum (rates, ER ioniz. yield)

Due to lack of knowledge about fluctuation at very low recoil energy, two cases :

- **Binomial fluctuation** for NR energy quenching, ionization, and recombination processes.
- **No Fluctuation** for NR energy quenching process. Corresponding to apply hard cut off in quenched energy ~0.6 keV_{nr}

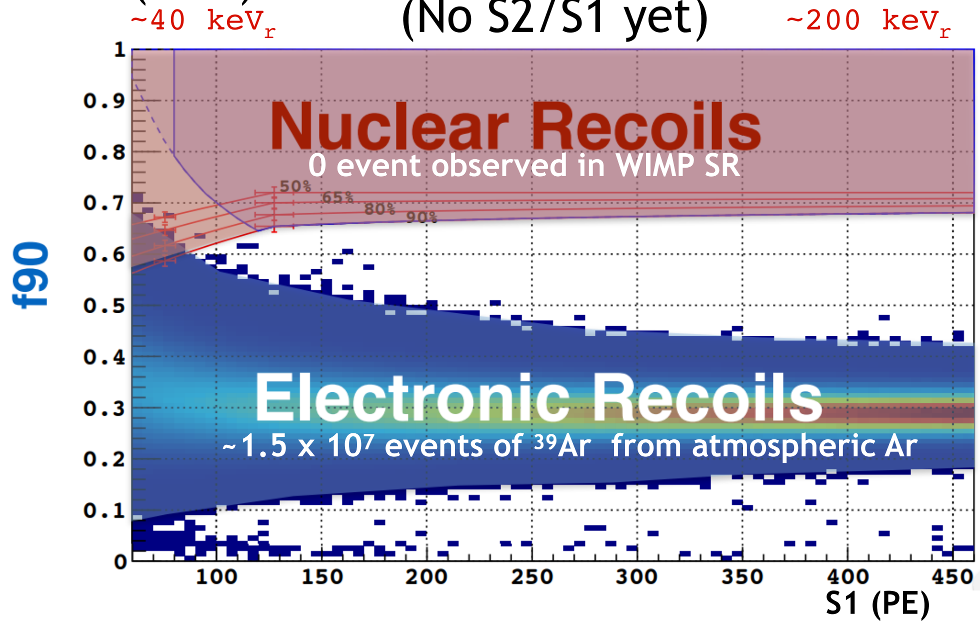
Noble liquids DM targets : Xenon vs Argon

XENON:
S2/S1 Discrimination



ARGON:
S1 Pulse Shape Discrimination (PSD)

(No S2/S1 yet)



In **XENON** With the separation achieved by XENON100, it is found that a **99.5% Electronic Recoil discrimination** corresponds to a **50% acceptance of Nuclear Recoil events**, while 99.75% ER discrimination gives 40% Nuclear Recoil acceptance.

ARGON has a fast component with a 7 ns decay time, or a slower component with 1.6 μs decay time depending on the nature of incident particle. **ER rejection in 10^7 - 10^9 range** with **NR acceptance > 90%**
→ Virtually "BACKGROUND FREE" analysis :
(<0.1 instrumental bck. events in the exposure)

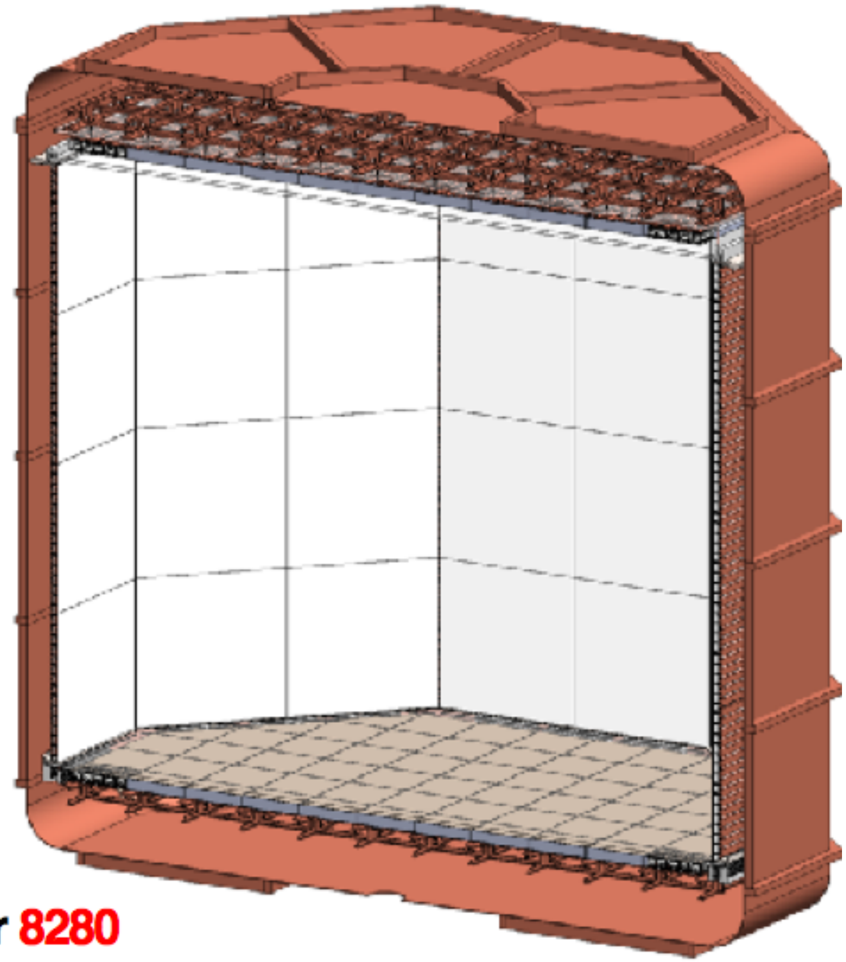
Scaling fiducial mass / TPC size :

Natural Size based on PDM Mother board arrangements:

Total (ton),	active (ton),	Fiducial
33.9	22.9	20.4
(5210)	67.6%	60.2%
35.3,	23.9,	21.4
(5680)	67.7%	60.6%
43.7,	30.2,	27.3
(6930)	69.1%	62.5%
53.0,	37.3,	33.9
(8280)	70.0%	64.0%

drift length of 262.8 cm
Lateral radius scaled by ½ of motherboard (12.5 cm)
TPC parts volume (~1.75 ton argon)

Octagonal TPC Copper Vessel (to be updated)



# of readout channels: 5210, 5680, 6930, or 8280

DarkSide-20k background free strategy

ER backgrounds :

^{39}**Ar** : expect 1.8x10^{8} events in ROI with UAr (based on) → improve PSD to 10^{9} (possible) higher LY (*SiPMs*) and/or further depletion factor DAr/UAr O(10) from ARIA (OK if Seruci2 financed)

^{222}**Rn:** if <2μBq/kg (like DS-50) would be 100k events in ROI but will be less due to larger volume/surface

^{85}**Kr:** is x3 ^{39}Ar activity in DS-50 → ARIA ^{85}Kr depletion x1000 ok

ν**-electron** scattering : 20k events in ROI → negligible after PSD

Material radioactivity : subleading after ^{39}Ar → *radiopure SiPMs and ultra clean Titanium cryostat*

NR backgrounds :

cosmogenic neutrons (μ induced): negligible after WCD and LS veto.

Material radioactivity : total events in 100 t yr < 0.1 after veto → *radiopure SiPMs and ultra clean Titanium cryostat*

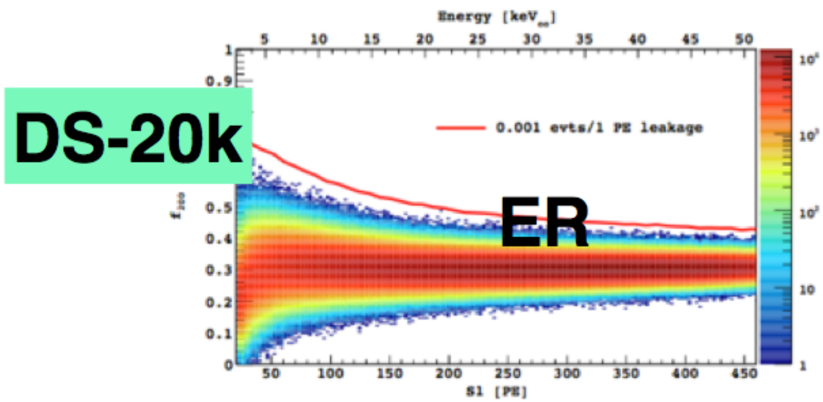
ν**-N CNNS** scattering : 1.6 events in 100 t yr → irreducible

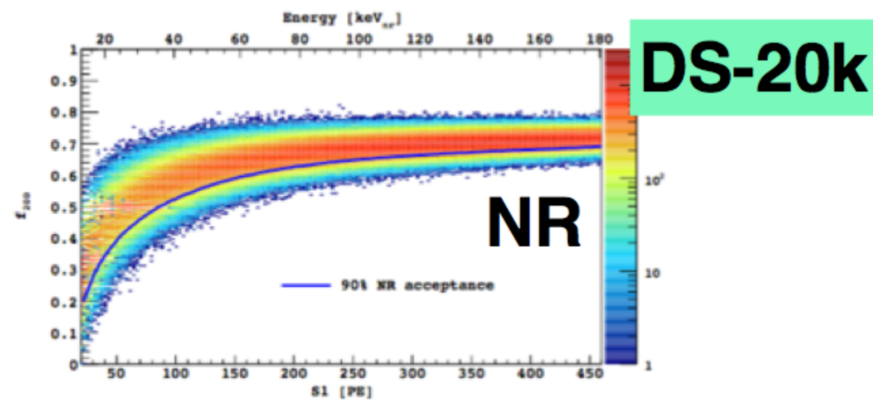
DS-20K Material radioactivity

Material	Mass [kg]	^{238}U [mBq/kg]	^{232}Th [mBq/kg]	^{60}Co [mBq/kg]	^{40}K [mBq/kg]
Steel Cryostat	5577	2.4 0.4 ± 0.2	0.8 ± 0.3	13 ± 1	<0.03
Ti Cryostat	1400	4.9 ± 1.2 <0.37	<0.8	–	<1.6
UHP Ti → Ultra High Purity Ti could perform even					
DAr (active)	23 000	–	–	–	–
Copper Parts	2795	<0.06	<0.02	–	0.12
PTFE Parts	1445	<0.07	<0.004	–	0.10 ± 0.04
Fused Silica Parts	189	0.008	0.01	–	–
SiPMs	11	<0.025	<0.003	–	–
Sapphire Tiles Substrate	69	<0.30	0.12 ± 0.03	–	<0.21

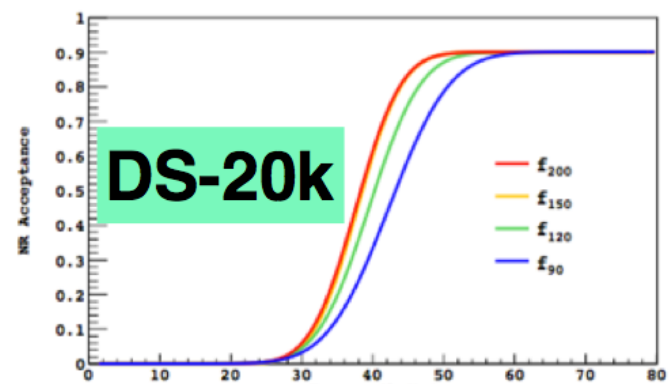
PSD in DarkSide-20k

Analytical model of f_{200} fitted to GEANT4 simulated events (few 10^6's). The simulation was tuned, to DS-50 data and to measured DS-20k readout characteristics, including SiPM PDE, noise rate and cross-talk





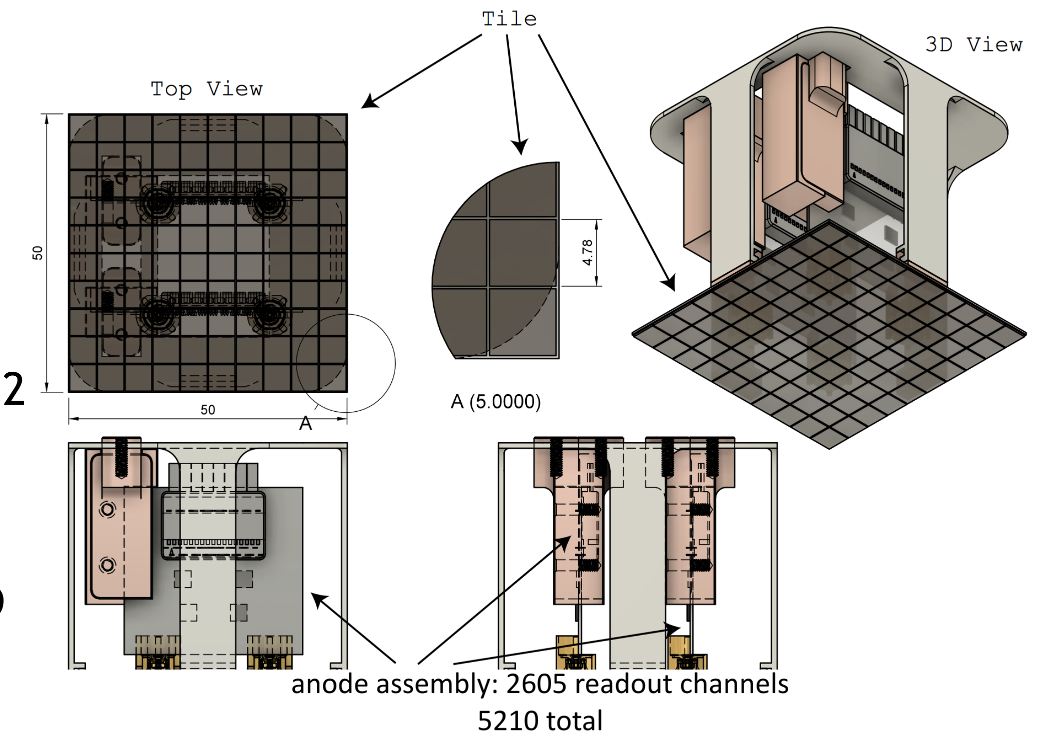
Suppression of ^{39}Ar by >3x10^9
i.e.<0.1 events of ^{39}Ar in 100 t yr
with threshold of 35keV$_{NR}$



DarkSide-20K SiPMs photosensors

SiPMs advantages vs cryogenic PMTs :

- compact and lower radioactivity (Si)
- Photo Detection Efficiency larger than 40% at 420 nm (PDE is 35% for PMTs)
- Very high filling factor: >90% (65% for PMTs)
- Dark Count Rate lower than 0.1Hz/mm2
- → Light Yield increase by 50%



SiPMs at LAr temperature R&D carried on by FBK for DarkSide-20K based on NUV-HD SiPMs. Tests of detector modules before large scale production on-going

Will cover ~14m^2 (top and bottom of TPC) with ~5000 channels of 5x5cm^2 SiPMs tiles.

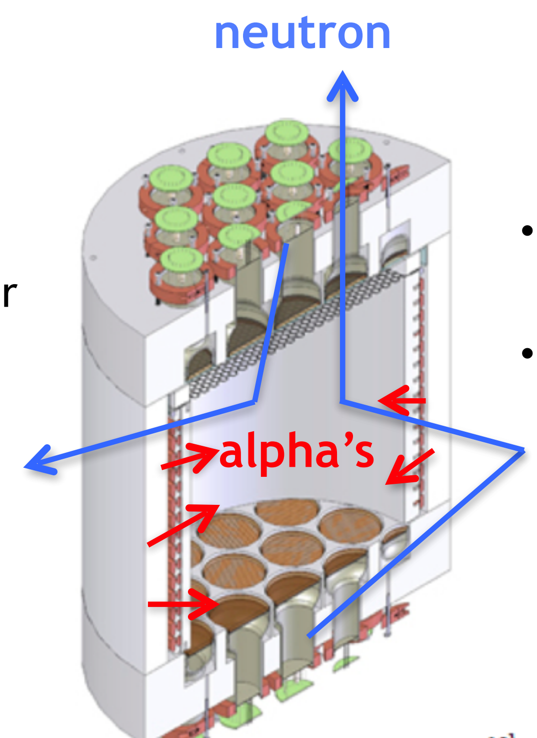
Also crucial: photoelectronics preamps/FEB and signal extraction and acquisition
Roma1 group responsibilities in Trigger/DAQ design: TPC DAQ boards (FPGA based) M.Rescigno
and software trigger system (CPU based) HLST S. Giagu/A. Messina

Nuclear recoil backgrounds

Neutrons

Background rejection:

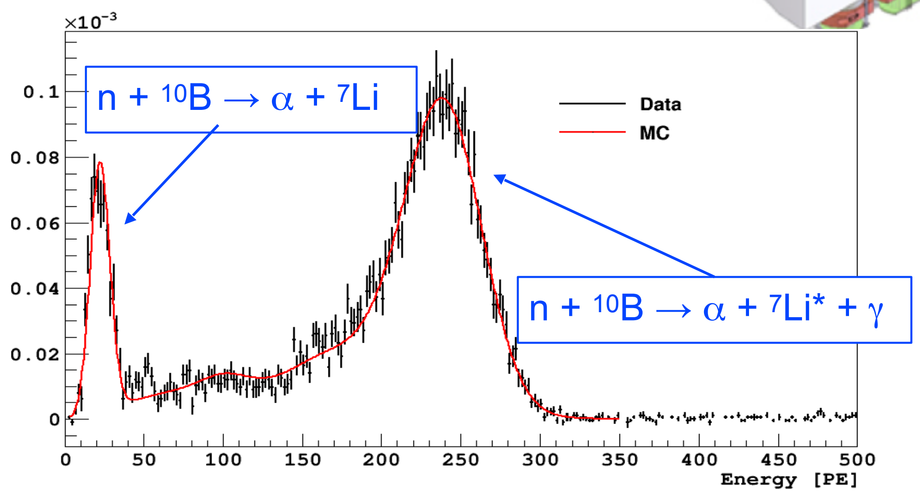
- TPC: multi-scatter
- LS Veto: efficiency from Am-C for TPC single-NR: **0.9964±0.0004**
- Water Cherenkov Veto for cosmogenics
- Neutrons in data are counted.

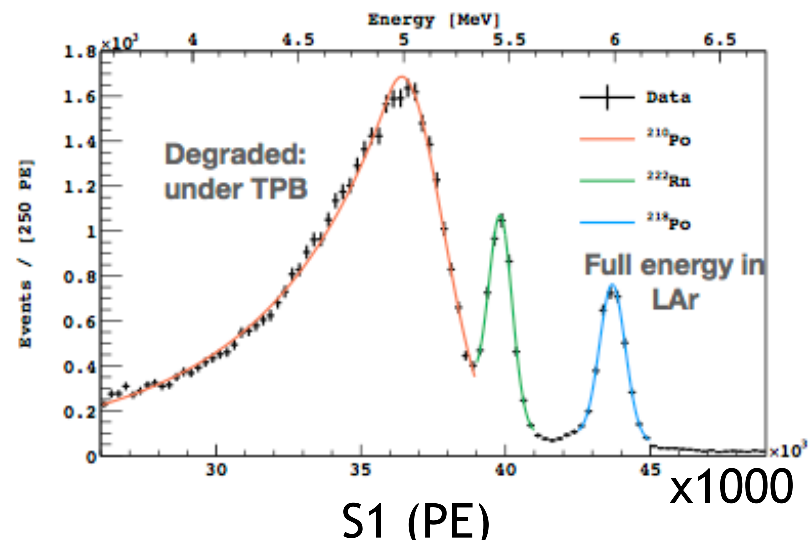


Alpha's

Background rejection:

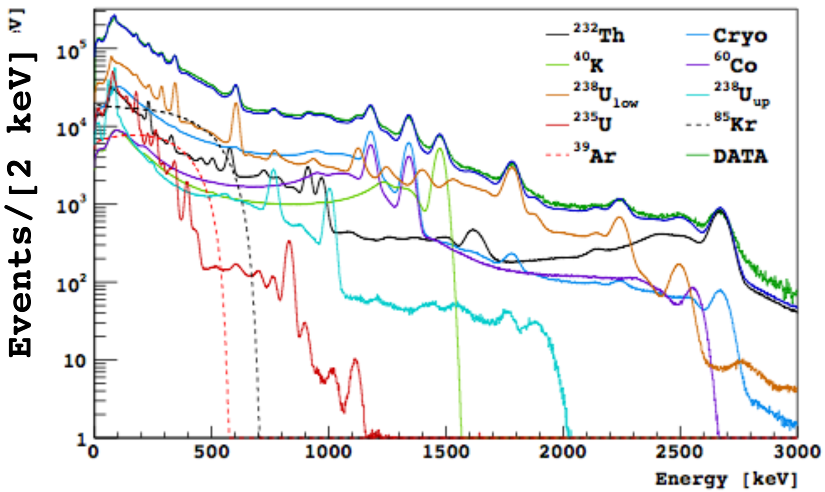
- Very high S1, small fraction at low energies (cut at S1<460 PE)
- Self-vetoing in DS-50!
    - Small or no S2
    - Long scintillation tail from TPB fluorescence



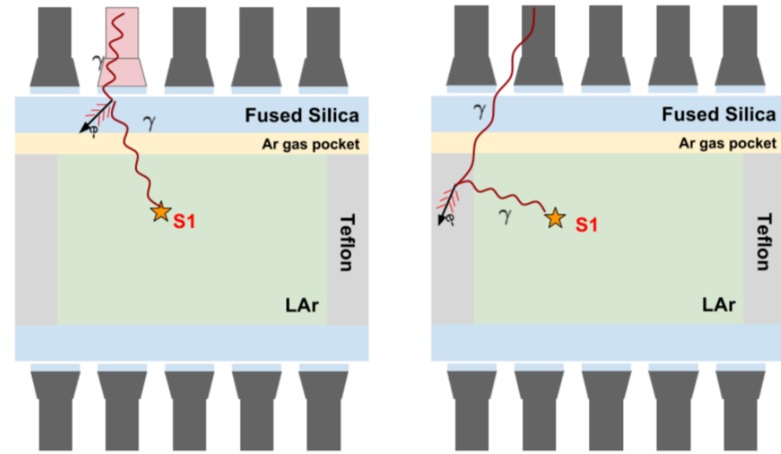


Electron recoils backgrounds

Internal ^{39}Ar and ^{85}Kr + external gammas



S1 + Cherenkov



Fused Silica Cherenkov BG

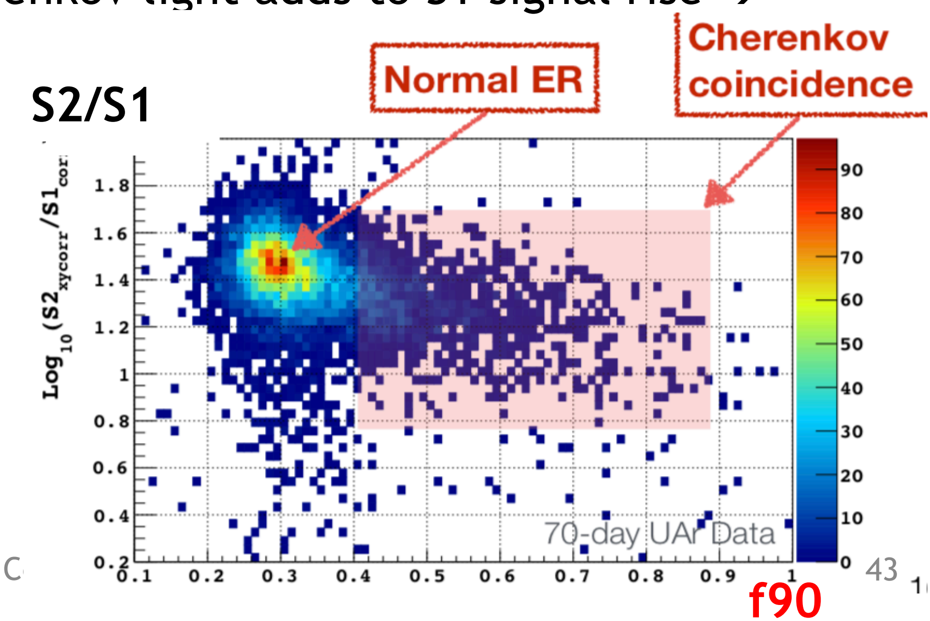
Teflon Cherenkov BG

→ γ-ray multiple Compton scatters in LAr and in nearby Cherenkov radiator (Fused Silica PMT window or PTFE) : prompt Cherenkov light adds to S1 signal rise → large f90

ER Background rejection:

- Underground Ar
- S1 fraction in max PMT
- PSD: f_{90} = S1 fraction in first 90 ns

Design cuts to reduce ER to : < 0.08 event of Total background



DS-20K keys/URANIA

- CO_2 wells in SW Colorado (near Cortez)
- Contains ~500 ppm Argon

- Procurement of underground argon at the Cortez(Co) site from Kinder Morgan wells will be expanded
- Support by 2013 MIUR **Progetto Premiale Urania** (€2.3M) will provide a plant capable of extracting 100 kg/day of UAr

- Air Products started operation of its helium extraction plant in June 2015
  - ➢ will provide ~20% of the production for the US National Helium Reservoir in Amarillo, TX
- Will exploit a slip-stream from the helium plant, the new Argon plant will be designed and built by Polaris SRL.