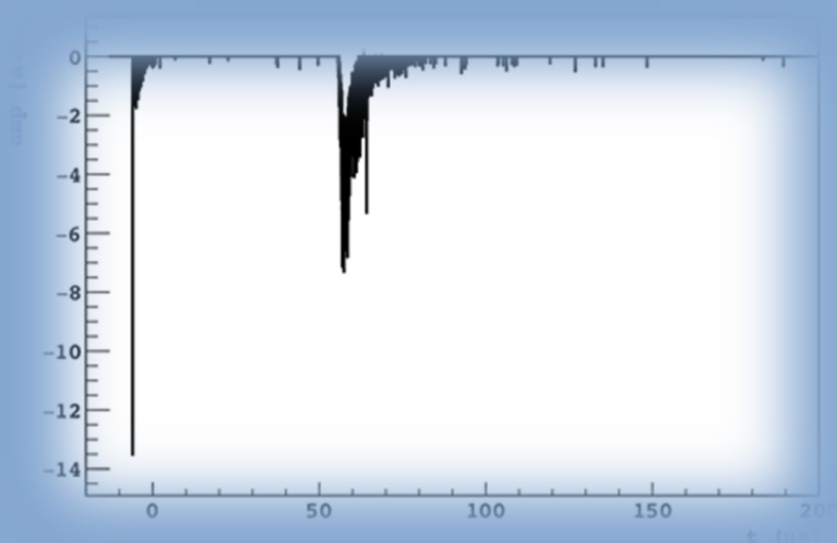
Argon dual-phase TPCs



Roberto Santorelli

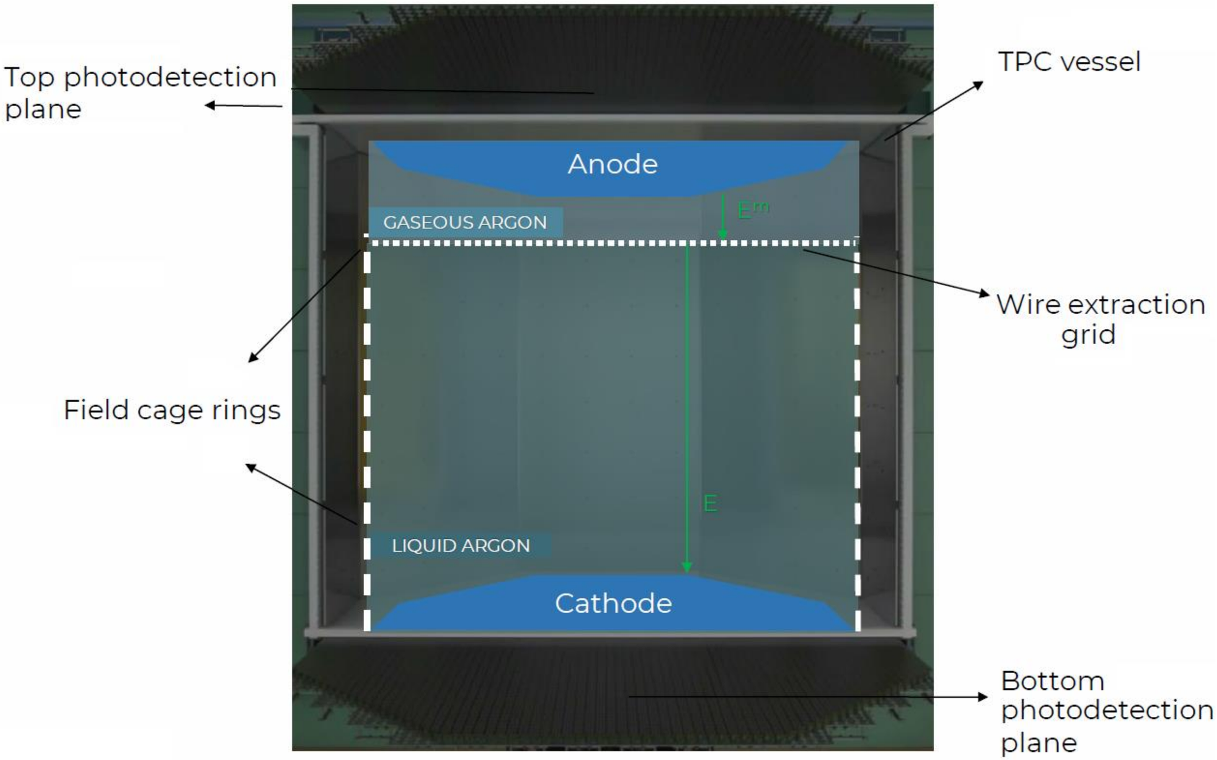
CIEMAT – Madrid

Topical workshop on New Horizons in TPCs – Santiago 06/Oct/2020

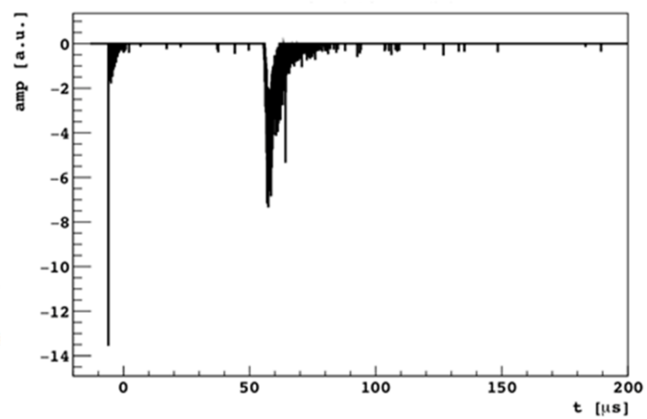
Outline

- Dual-phase Ar TPCs: recent achievements
- Technological breakthroughs
- The global Ar community
- Prospects
- Conclusions

LAr/GAr TPCs



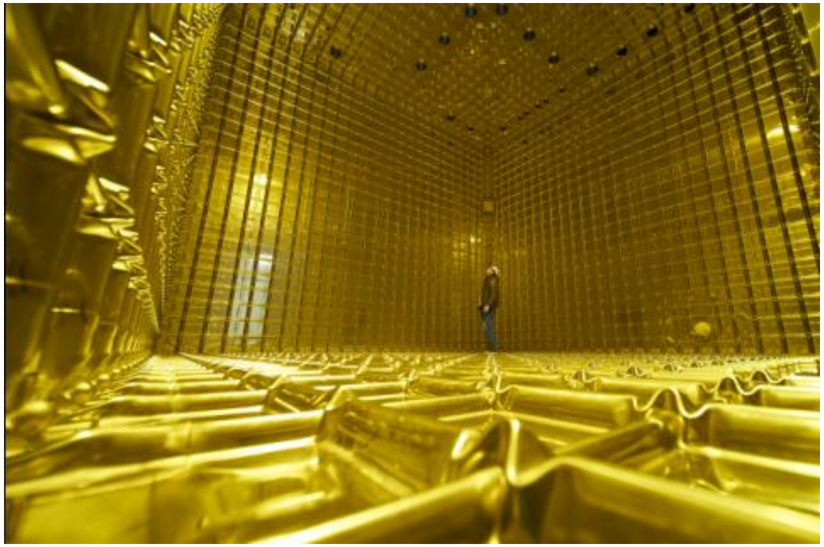
- Charge amplification/collection
  (larger signal/noise compared to SP)
- Electroluminescence
  (simple design, low threshold)

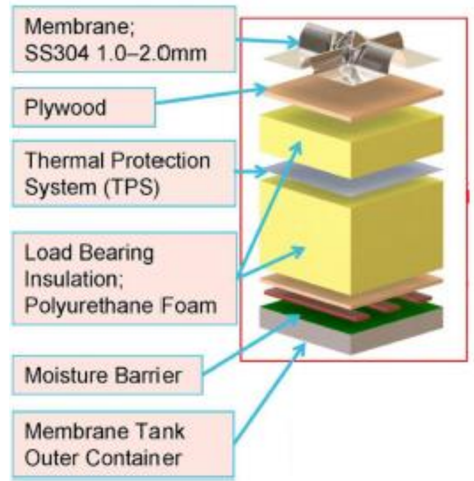


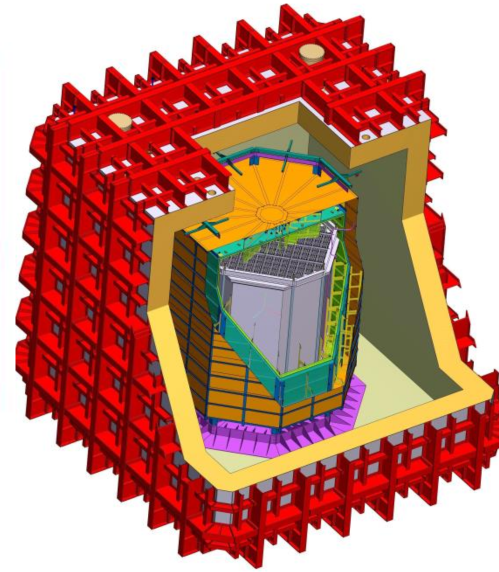
Frontiers

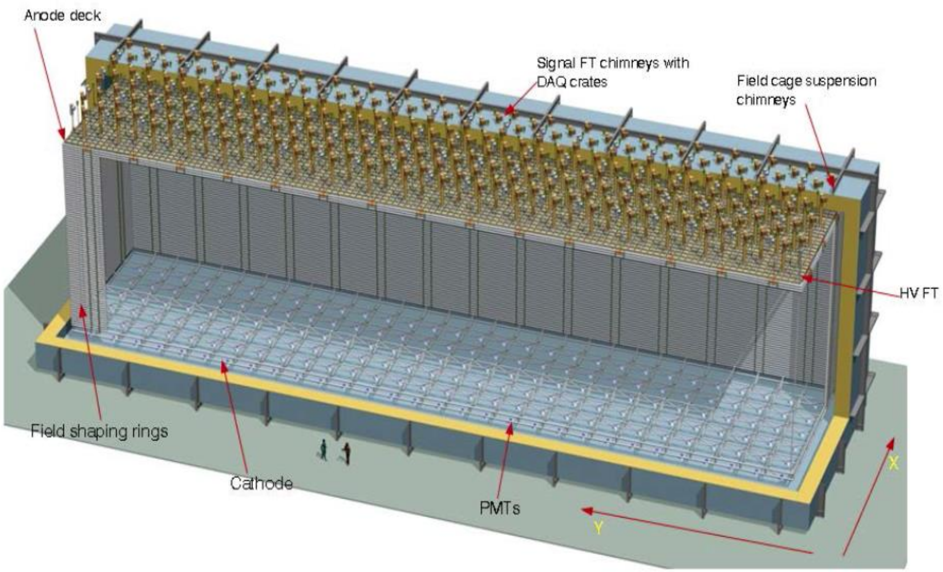
- Extreme large mass (>10kton) and long drift (> 10 m)
- Extreme purity and radiopurity
- HV
- Very low thresholds (~keV)
- New sensors…

Cryostat









- Active mass 12.096 kton
- Drift 12 m
- Nb. of channels 153600
- 80 CRP units
- 180 PMTs

Space charge

- Ions have drift velocity which is five/six orders of magnitude lower than v_e
- Without taking into account the liquid motion:

$\mu_i \sim 2 \cdot 10^{-4} cm^2 V^{-1} s^{-1}$ (T.H. Dey , T.J. Lewis , J. Phys. D: Appl. Phys. 1 (8) - 1968)

$\mu_i \sim 1.6 \cdot 10^{-3} cm^2 V^{-1} s^{-1}$ (M. Torti , Proceedings of the Fourth International Conference on New Frontiers in Physics - 2015)

At E_d=1 kV/cm, $v_i \sim 1.6 \cdot 10^{-5} mm/\mu s$ to be compared to $v_e \sim 2\ mm/\mu s$

- $v_i \ll v_e \Rightarrow \rho_i \gg \rho_e$ Depending on drift field, ionization rate, (+liquid motion ...etc)

<u>The electrons drift to the anode, the ions stay!</u>

<u>The electron drift in a positively charged volume (neutral target only when the field is off)</u>

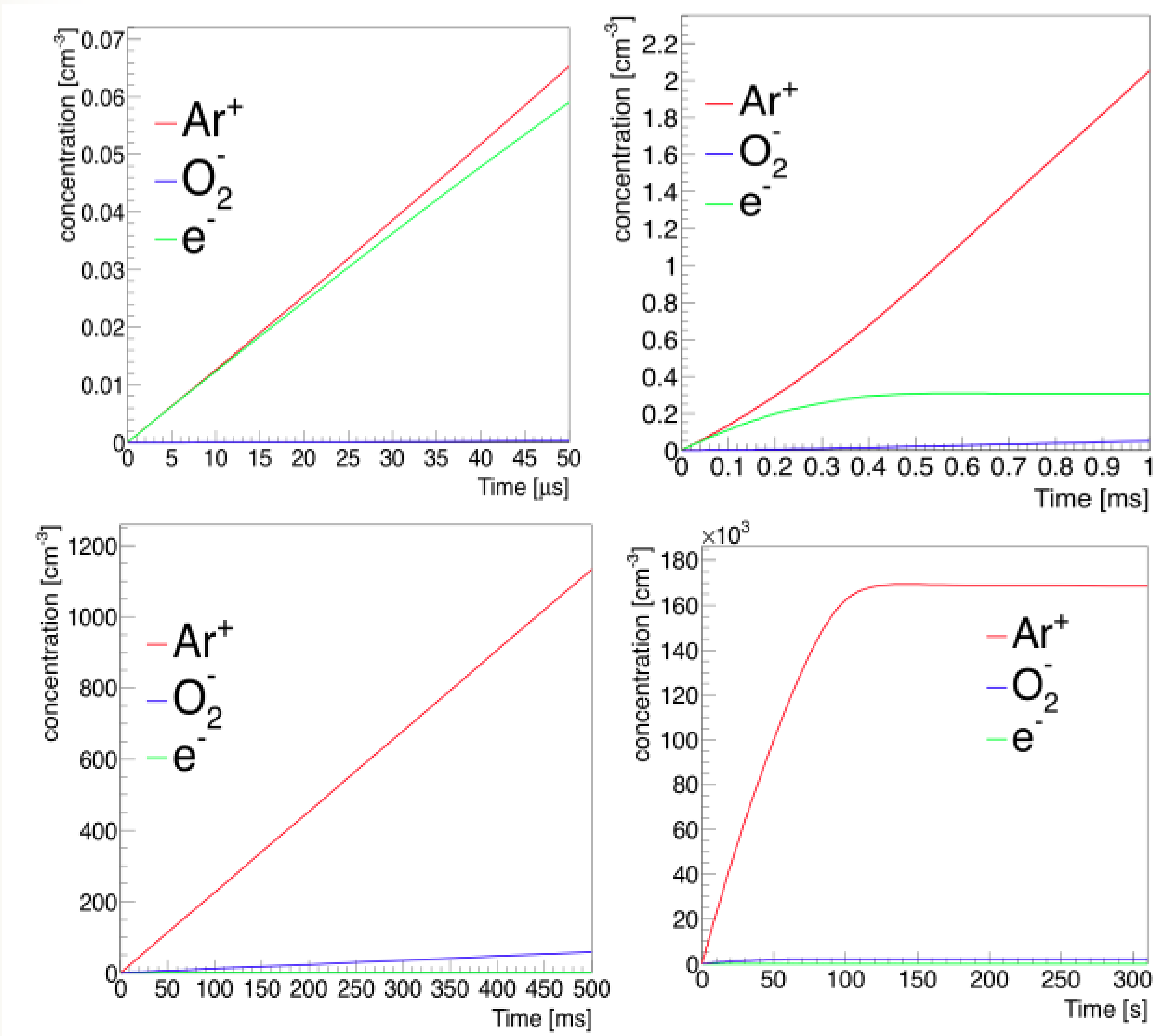
- ρ_i depends on:
  - Amount of ionization (event energy and rate)
  - Total drift length
  - Ion velocity (E_d and mobility)

Finite element analysis

COMSOL Multiphysics

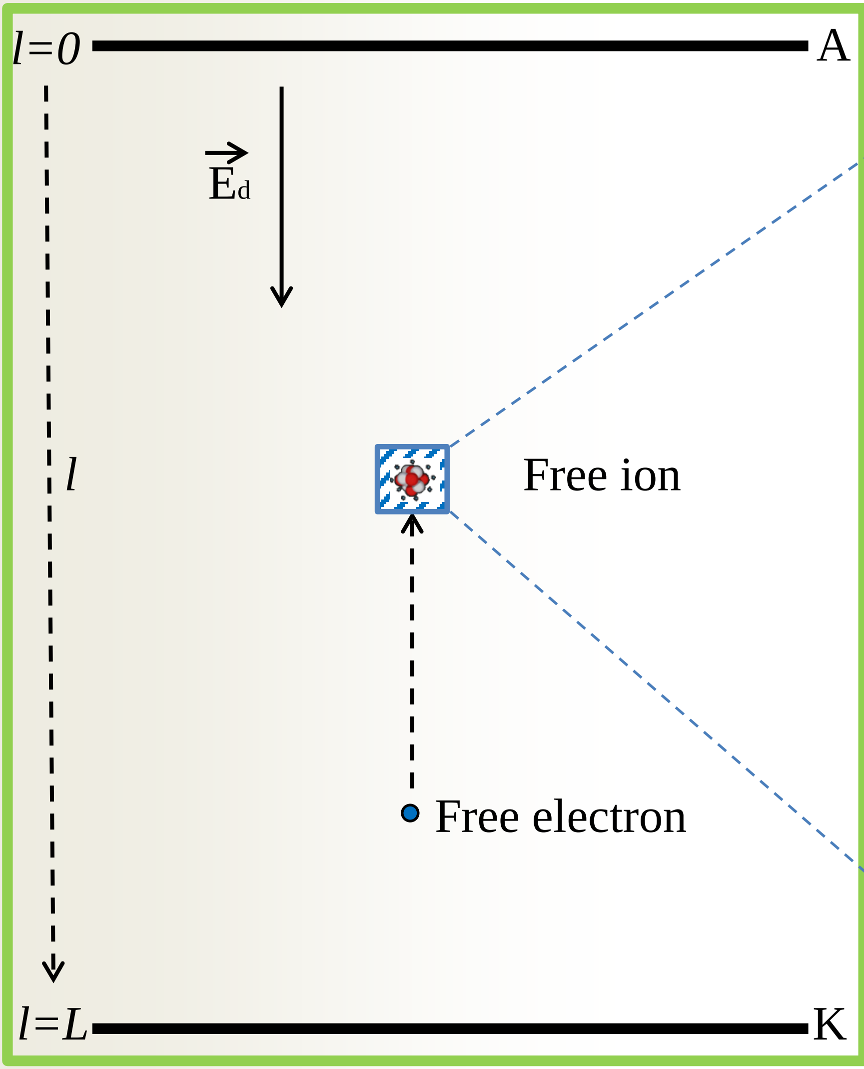
Electrostatics and *Transport of Diluted Species* modules

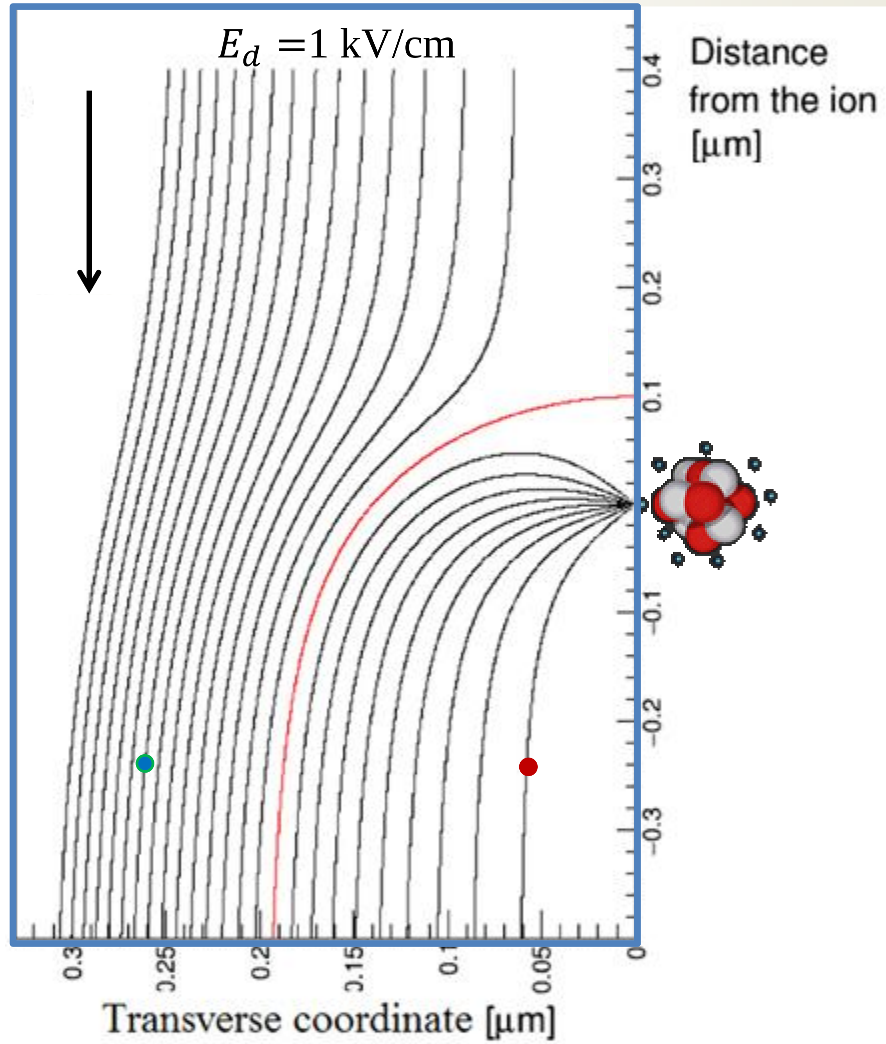
1 × 1 × 1 m3 box filled with liquid Argon, 100 kV between the top and the bottom surface.



JINST 13 (2018) no.04, C04015

Field distortion, "Secondary"recombination and volume light emission



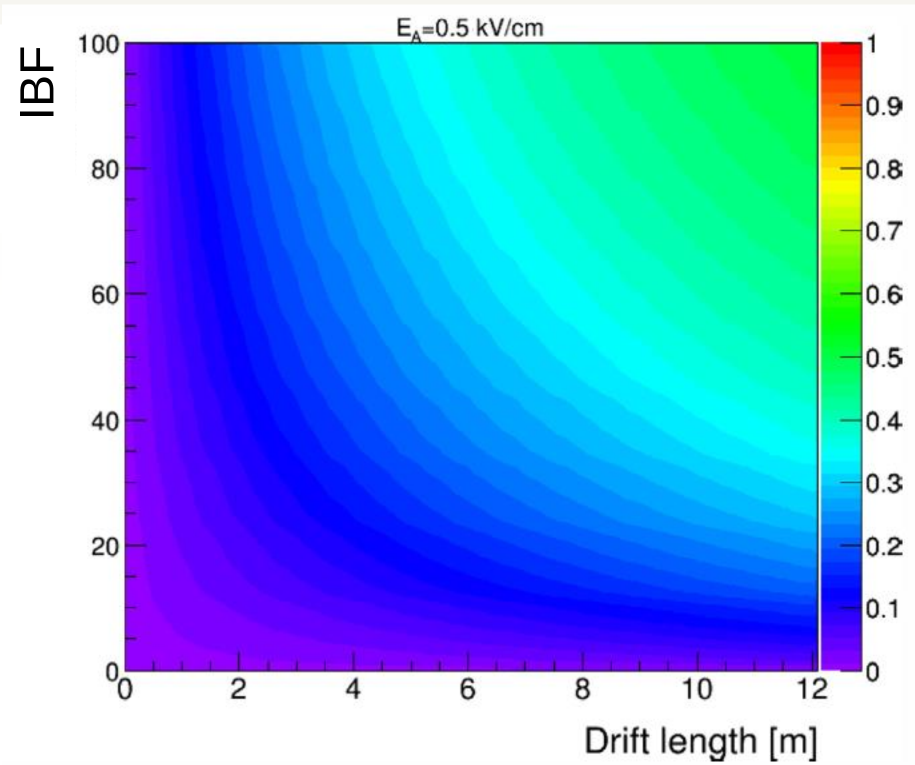


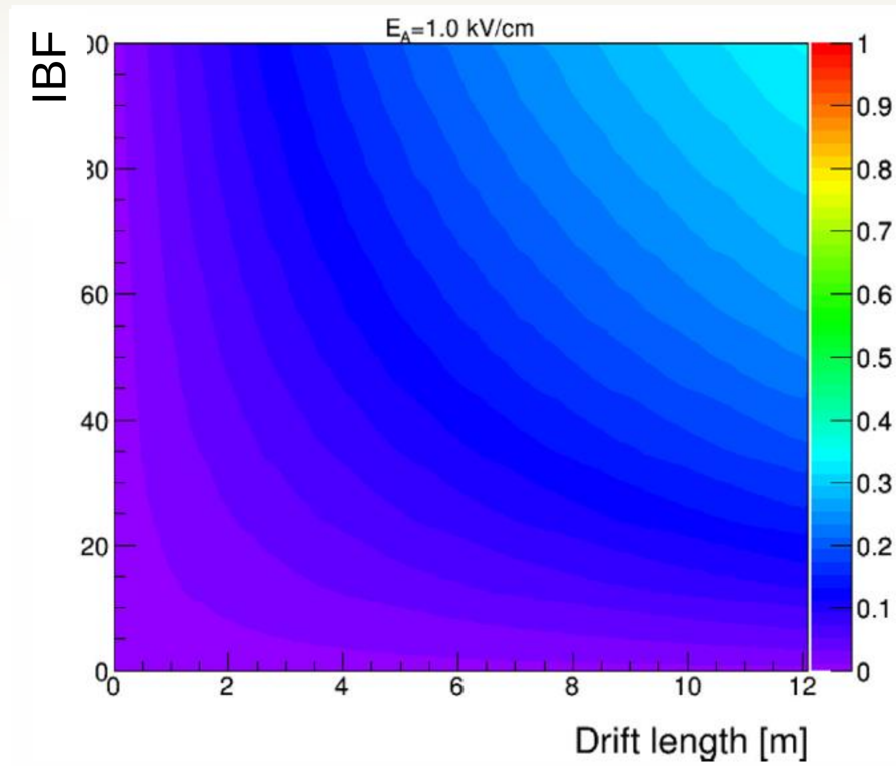
$S_{cs}\rightarrow$ transverse area (far enough) whose crossing field lines end on one ion (all the lines emerging from the ion cross that section)

$S_{cs}= 1.2 \cdot 10^{-7} mm^2$ with E_d=1 kV/cm

"Uncorrelated" Light production

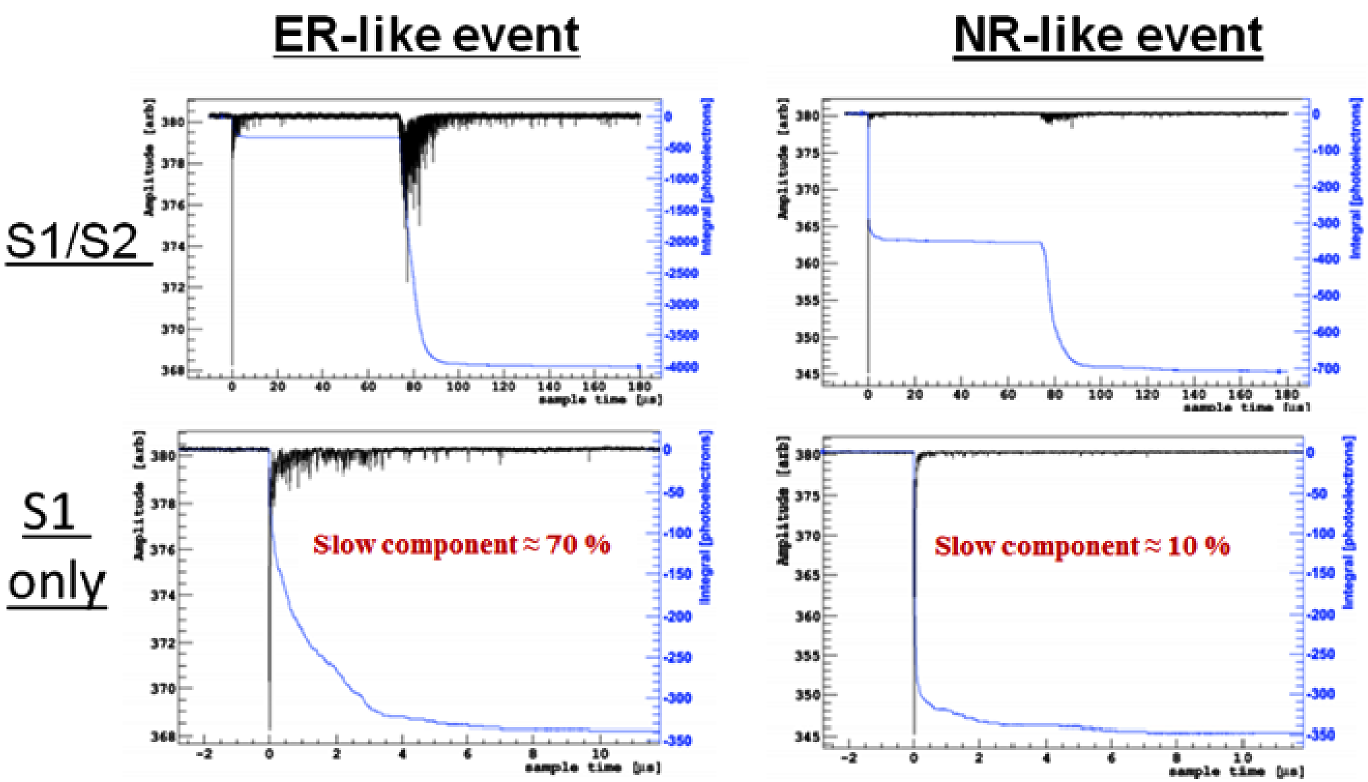
Underground case L=12 m





Astropart.Phys. 92 (2017) 11-20

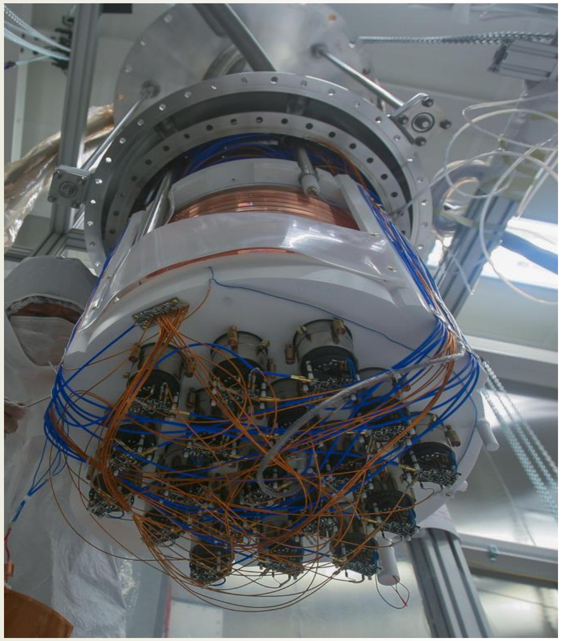
- Neutrino experiments using dual-phase technology have been proposed in recent years.
- This technology has been a standard for dark matter experiments for a couple of decades.

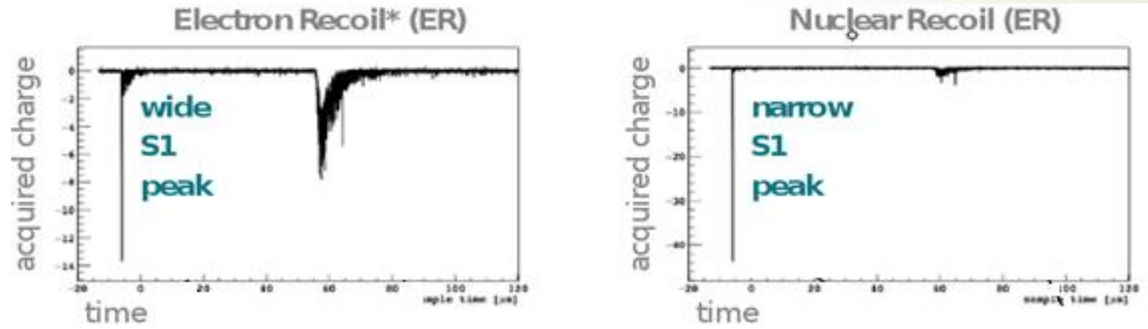


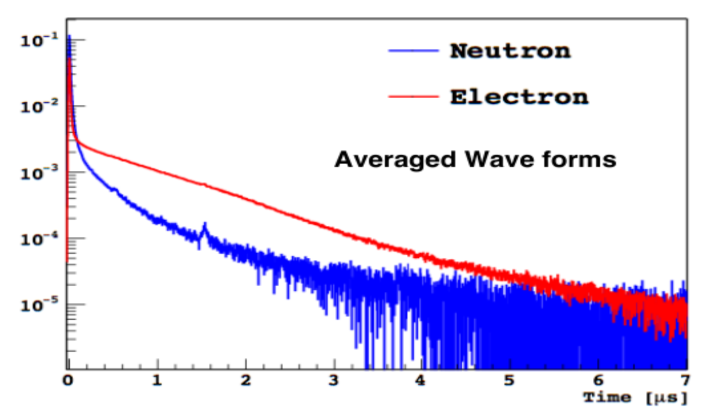
$$\left.\frac{S_2}{S_1}\right|_{ER} > \left.\frac{S_2}{S_1}\right|_{NR}$$

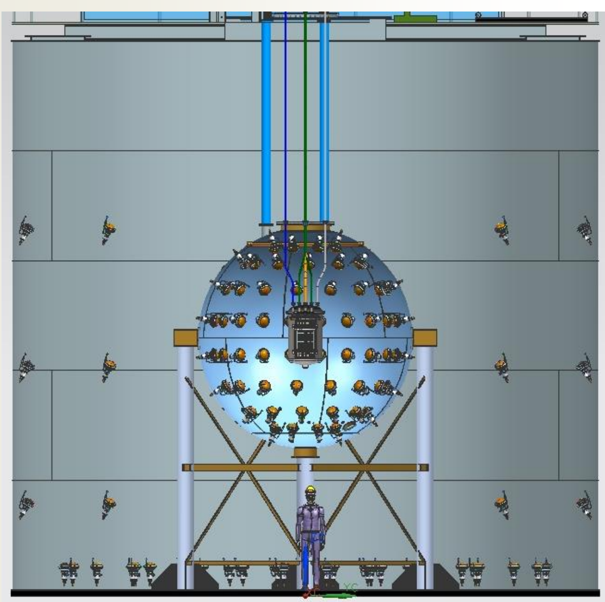
Due to an enhancement of the recombination process

DarkSide-50









- Ø 36.5 cm x 36.5 cm TPC
- 46.4 kg of Active LAr (150 kg of UAr)
- 38 3” Hamamatsu R11065 PMTs
- 4 m(d) sphere veto: 30 tonne boron loaded liquid scintillator (120 PMTs, eff > 99.8 %)
- 1 kt ultrapure water - Cherenkov Veto (80 PMTs, eff > 99.8 %)
- Installed @ LNGS (3400 m.w.e)

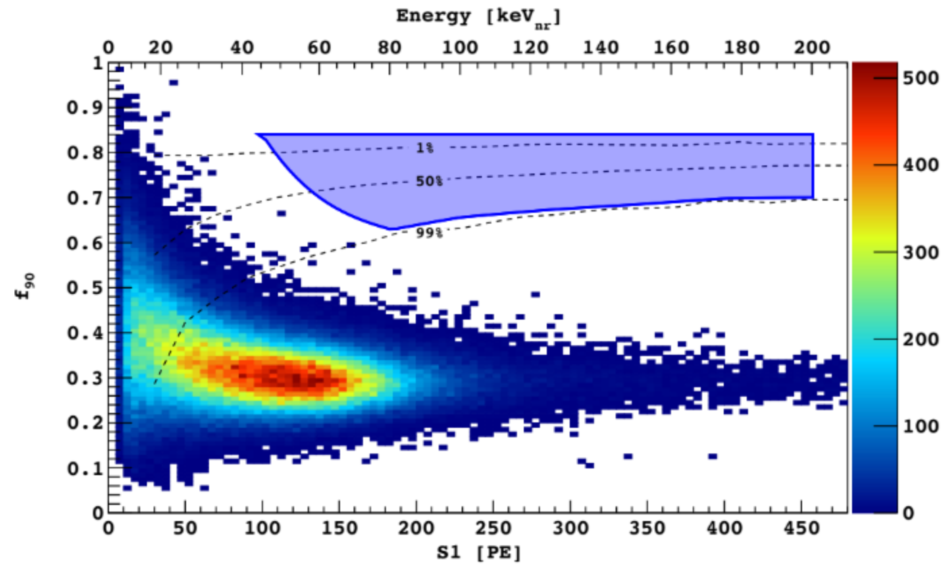
High WIMP mass search

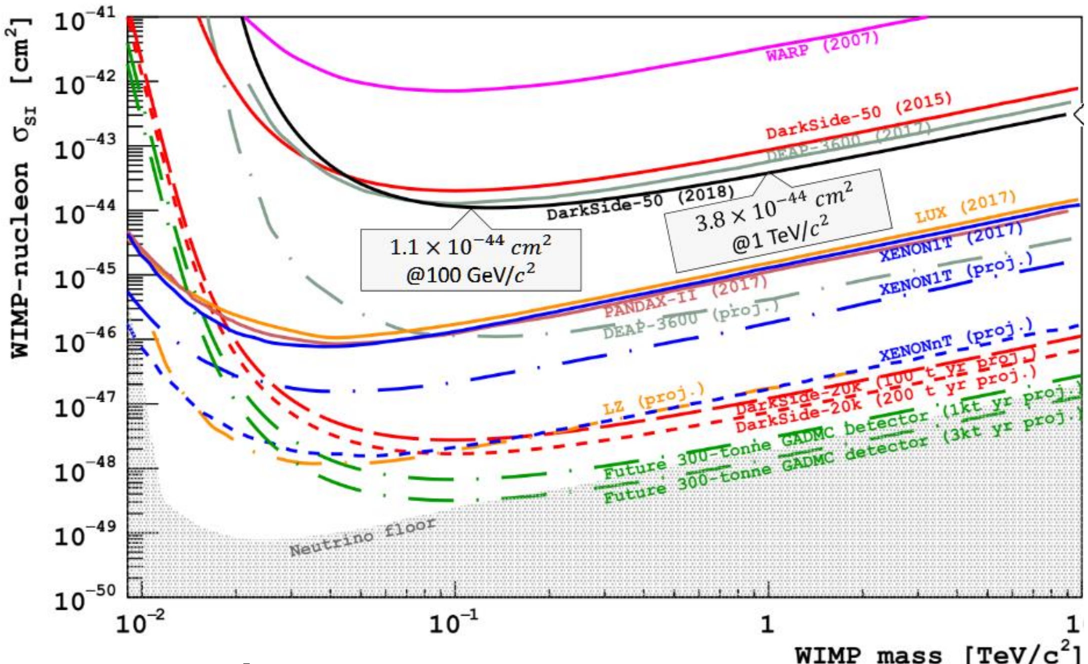
- (16 660±270) kg d exposure
- No WIMP-like event in the search box

→ 90% CL exclusion limit

1.1×10^{-44} cm^2 @ 100 GeV/c^2
3.8×10^{-44} cm^2 @ 1 TeV/c^2
3.4×10^{-43} cm^2 @ 10 TeV/c^2

(standard isothermal WIMP model)



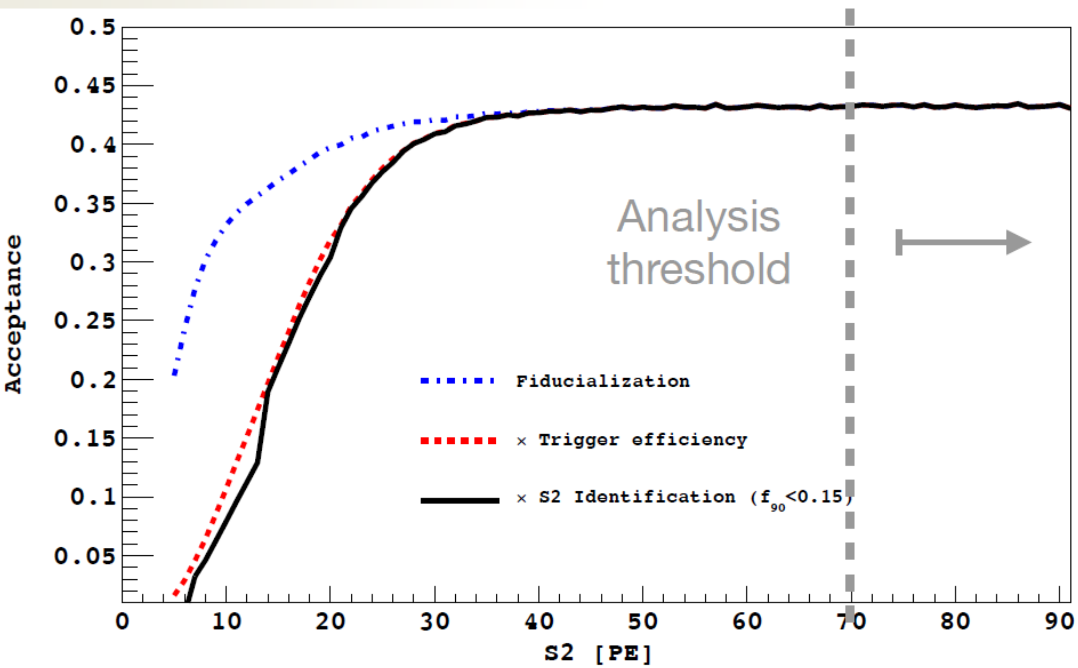


Phys. Rev. D 98, 102006

Type of bkg	Estimated evts passing the cut
Surface α	0.001
Cosmogenic n	<0.0003
Radiogenic n	<0.005
ER	0.008
Total	**0.09±0.04**

Low WIMP mass search (S2-only)

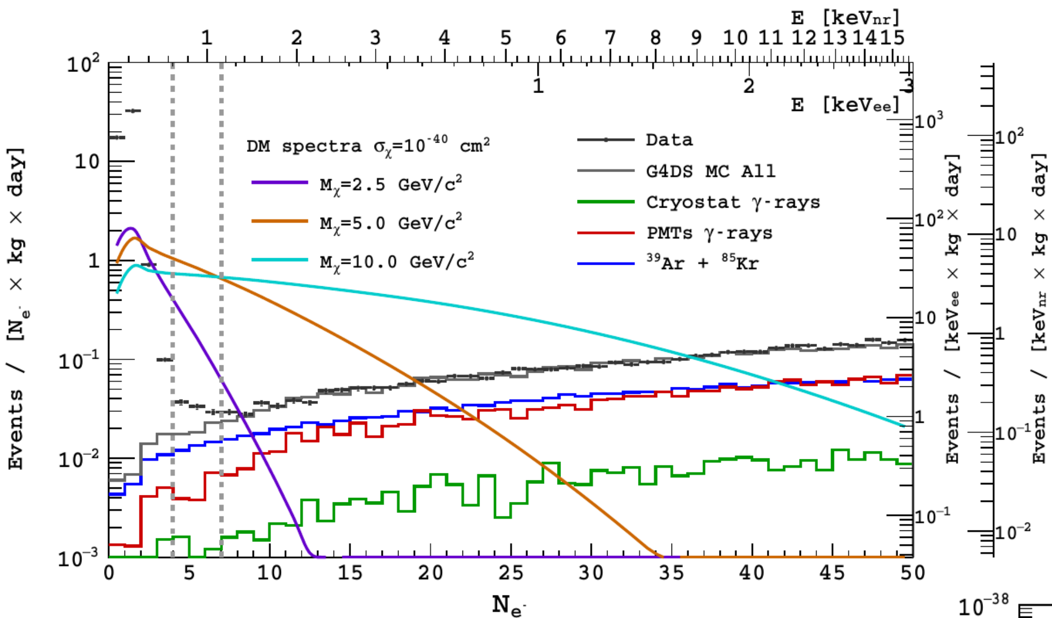
- Light WIMPs (~2 GeV) might produce low energy NR
- Other lighter DM candidates (~50 MeV) might induce low energy ER
- Low-energy interactions → S1 too small (E_{th} ~13keV_{nr})
- S2 charge signal sensitive to a single e^-
  Hardware trigger efficiency 100% above 30 PE
  E_{th}<0.6 keV_{nr} sensible to low mass WIMP
  S2 yield = 23 (1) PE/e^-,



Background:

- electrons captured 0.5 x 10^{-5} e^-/e^- ER
  Analysis threshold set to N_{e-}= 3
- Low E phenomena from the TPC walls (Fiducialization: volume under inner 7 PMTs)
- Large S1 with S2 in the ROI

Low WIMP mass: above 1.8 GeV



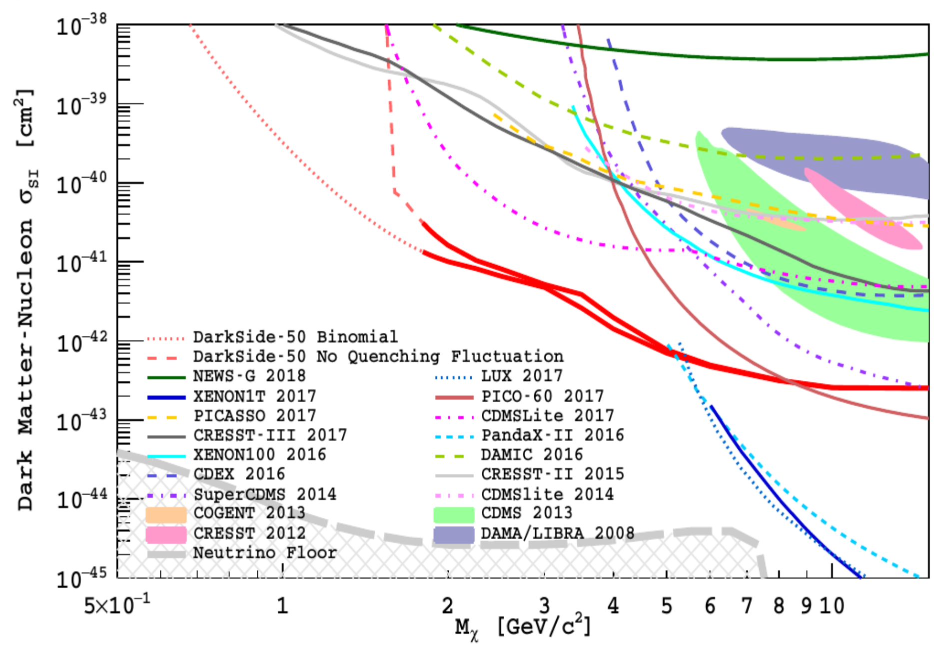
- ER energy scale: ^{37}Ar
- NR energy scale: AmBe and AmC

- At low energy excess of events (between N_{e-} = 4 and N_{e-} = 7)
- N_{e-} spectra expected for recoils induced by dark matter particles with 2.5, 5 and 10 GeV/c^2 for 10^{-40}cm^2 xsec

Fits performed using two thresholds N_{e-} = 7 (down to ~3 GeV) and N_{e-} = 4

Two models with and w/o fluctuations in the energy quenching (E_{th}=0.6 keV$_{nr}$)

Competitive results at M_χ > 1.8 GeV/c^2
Phys.Rev.Lett. 121 (2018)



LAr vs LXe: why LAr?

LXe:

- ✓ *Density*
- ✓ *~50% odd isotopes (^{129}Xe, ^{131}Xe) for spin dependent interactions*
- ✓ *No long-lived radioactive isotopes*

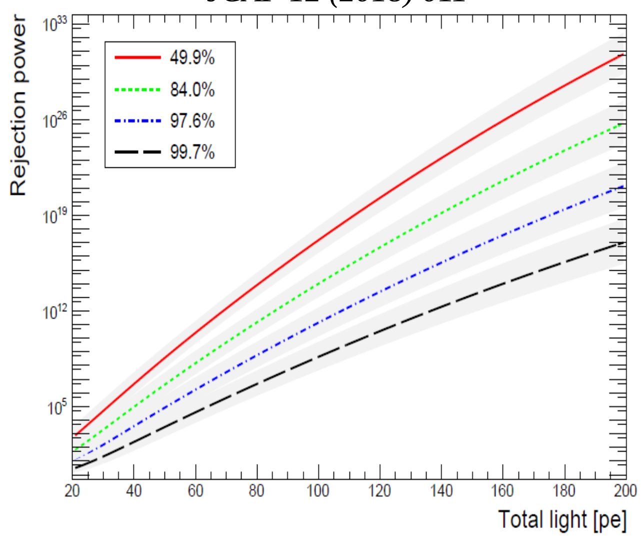
- ✗ *Price*
- ✗ *ER discrimination*

LAr:

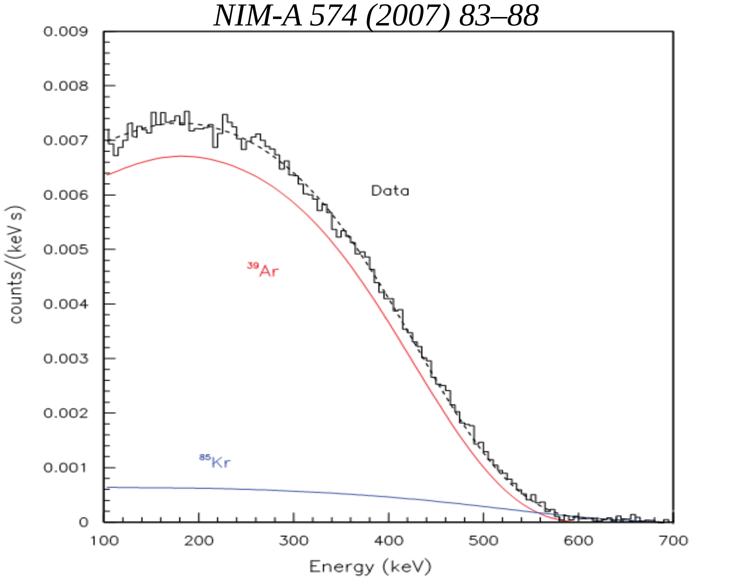
- ✓ *Available in large quantity*
- ✓ *ER background discrimination*

- ✗ *Radioactive isotopes*
  $^{39}Ar \rightarrow 1.01\ Bq/kg$

"Backgrounds and pulse shape discrimination in the ArDM liquid argon TPC"
JCAP 12 (2018) 011

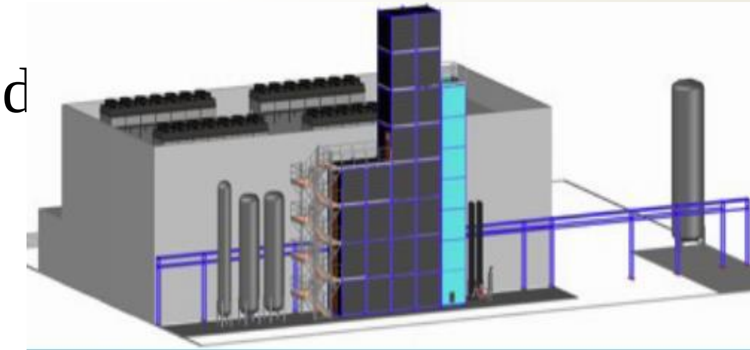


"Measurement of the specific activity of ar-39 in natural Argon"
NIM-A 574 (2007) 83–88

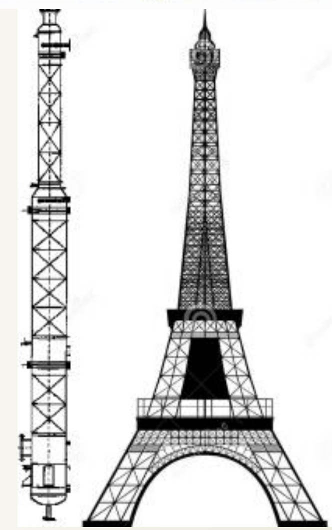


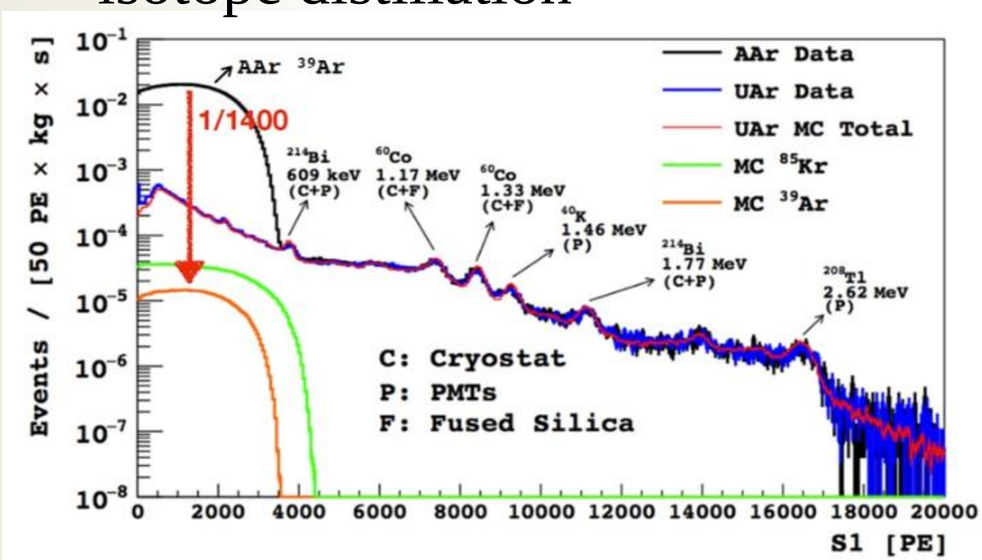
Technology breakthrough 1: radiopure Ar

- **URANIA** project:
  Procurement of 50 ton of UAr extracted from the CO_2 wells at Cortez mine, Colorado (~330 kg/d, 99.99% purity)
- **ARIA** project:
  - Seruci 1: chemical purification of the UAr by cryogenic distillation (reduction factor 1000 per pass, 1 t/d)
  - Seruci 2: Active Ar-39 depletion via isotope distillation



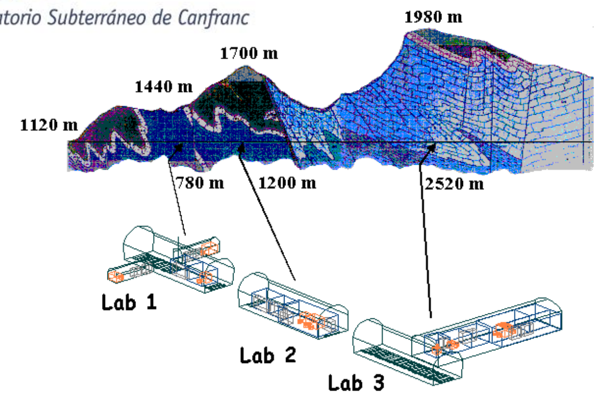
28 modules,
360 m in total

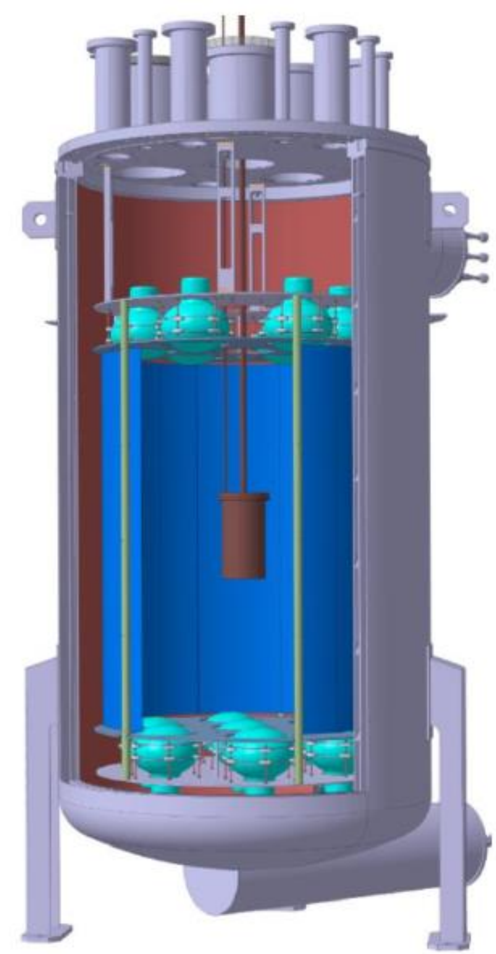




DART: Radiopure Ar measurement

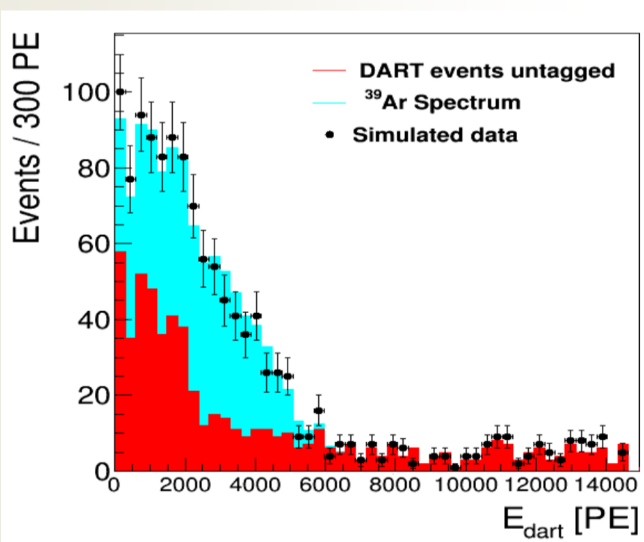
LSC
Laboratorio Subterráneo de Canfranc





- Main Lab under mount Tobazo
  - ~850 m rock
  - ~2500 mwe
  - 1400 m^2

- ArDM
  - 850 kg AAr to be used as active veto (E_{veto}= 10 keV)
  - RUN-I SP operations, DP planned



7% uncertainty in about a week of running
for 1400 DF

C.A. Aalseth, JINST 15 P02024 (2020)

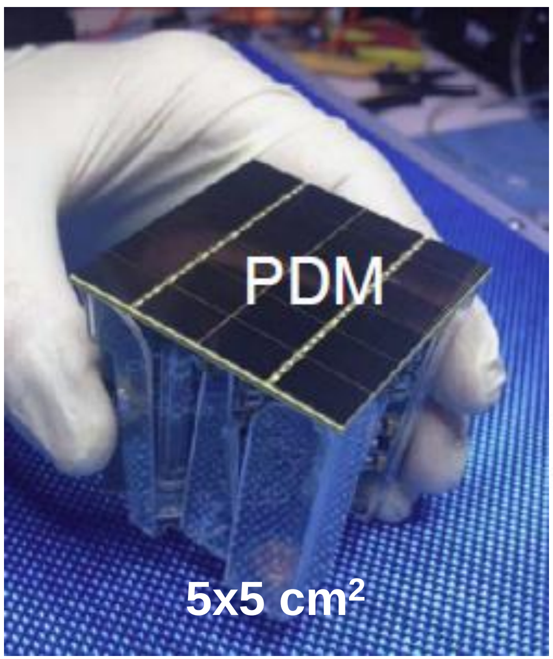
Technology breakthrough 2: radiopure cryogenic SiPM

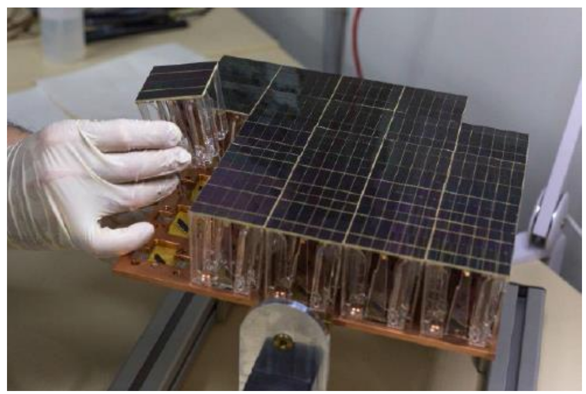
- **Radiopure** ~2 mBq/PDM dominated by the substrate(for SiPM and front-end)
- **High PDE (~ 50%), >90% fill factor**
- **Gain > 10^6**
- 0.1 Hz/mm^{2}dark count rate (87 K)
- Time resolution ~3 ns (sigma)
- Power consumption <100 μW/mm^2

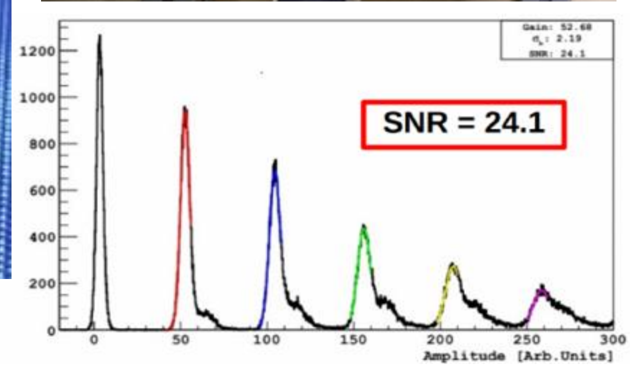
- 6 SiPMs → 1 r.o. channel
- 4 channels → one tile (PDM)
- 25 tiles → one Motherboard (PDU)

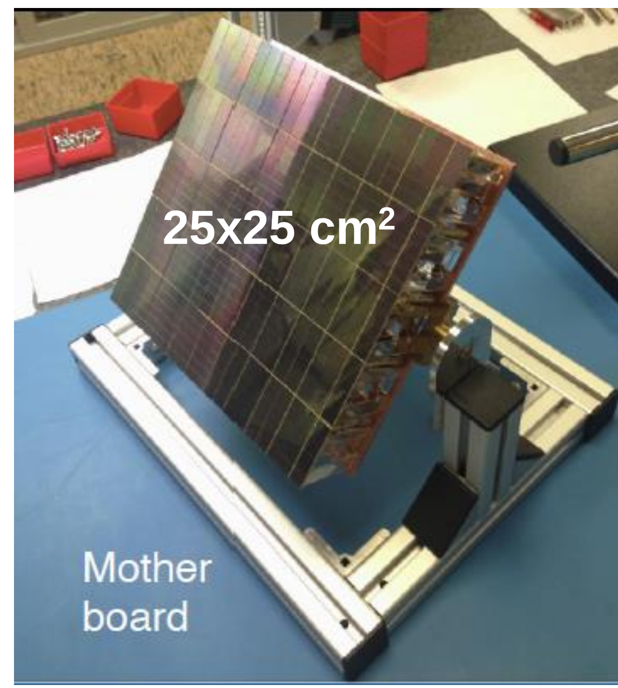
8280 PDMs (+3000 in the Veto)

21 m^2 SiPM, LY above 8 PE/keV
A packaging facility (NOA) at LNGS funded by INFN







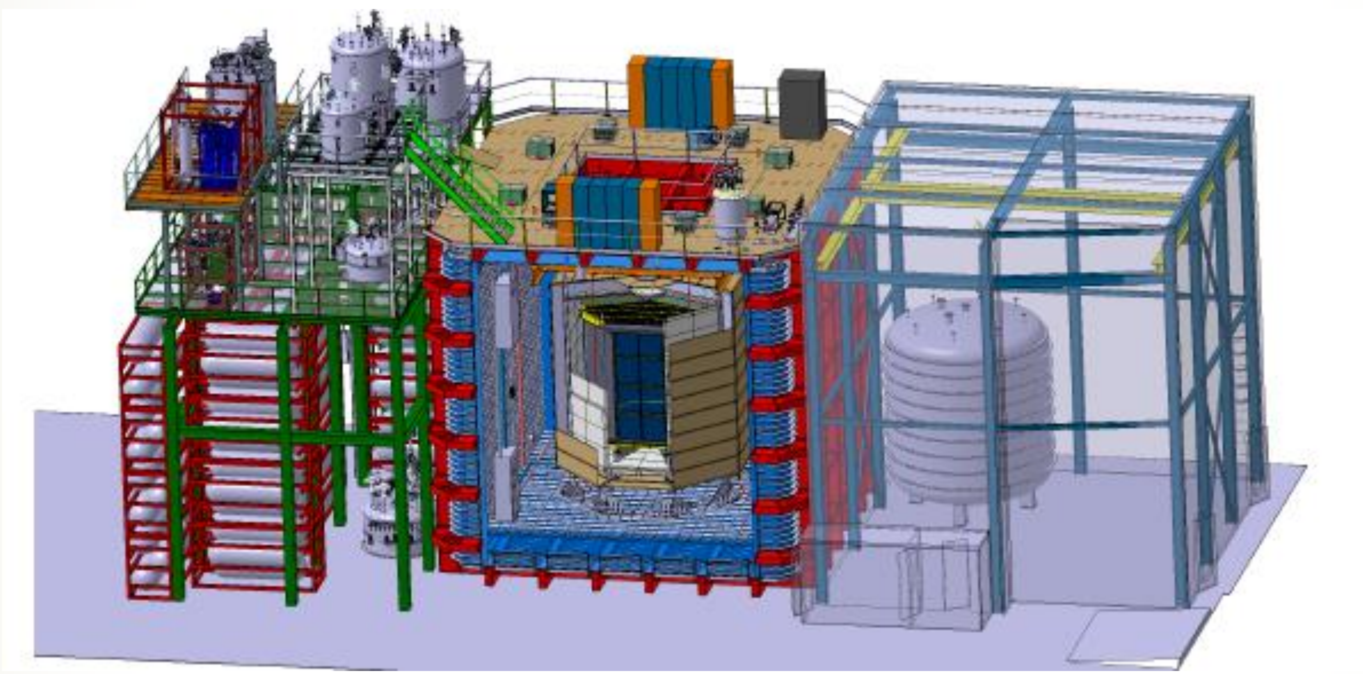


DarkSide-20k:Baseline design

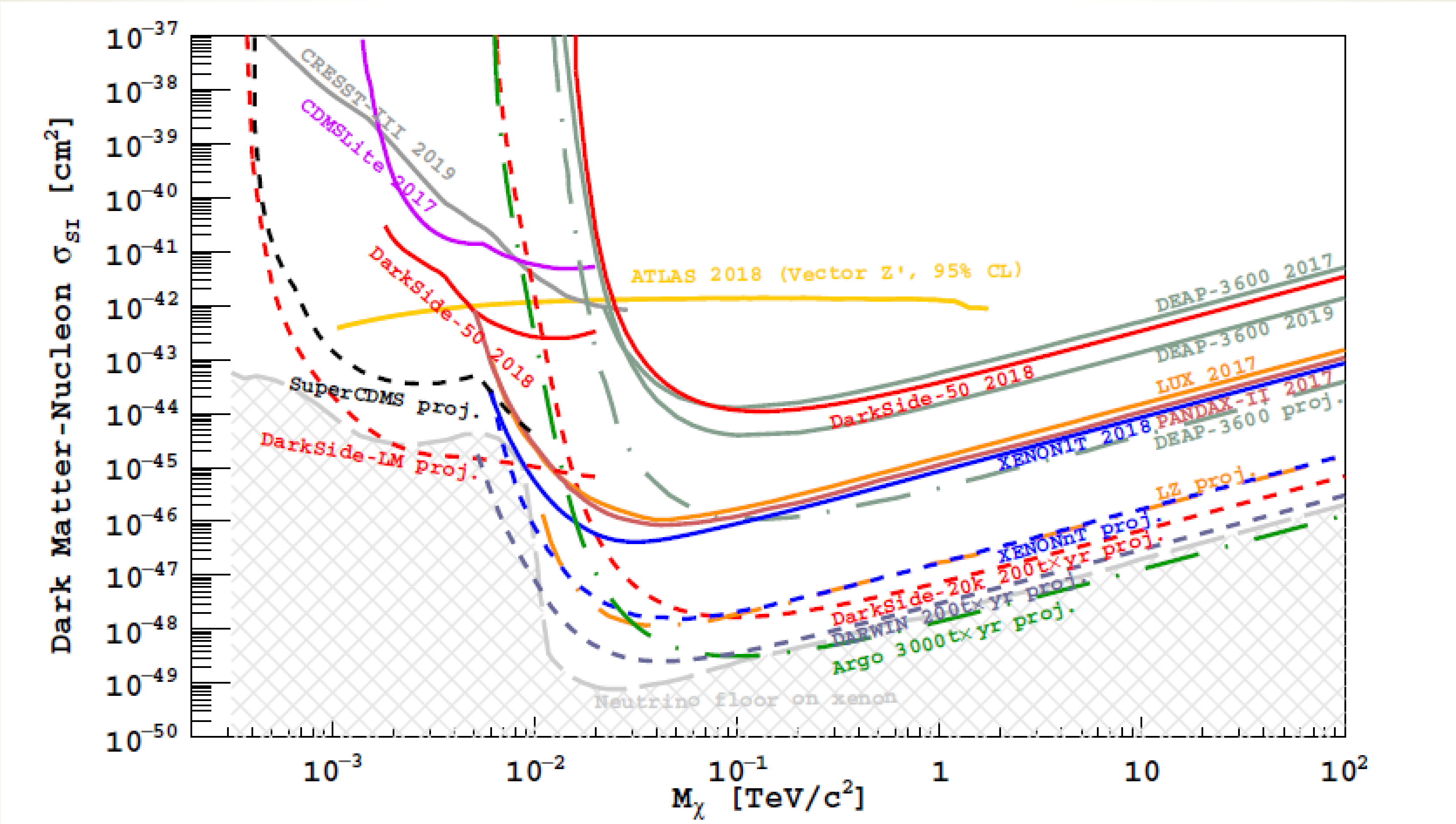
- ***GADMC***: New collaboration with groups from DS-50, ArDM and DEAP-3600.
- More than 70 institutions, 350 researchers, 12 countries (still growing)
- 200s ton×yr exposure with < 0.1 evt bkg
- ~50 ton low radiactivity Ar
- ~ 20 m^2 SiPM, LY above 8 PE/keV

- ProtoDune style large cryostat to provide shielding and active VETO
- Cubic volume, 8.5 m side (7.9 m int. height). 700 t AAr.
- Sensitivity ~10^{47} for 1 TeV/c^2 WIMP mass

➡Fully scalable design for future larger size detector (300 ton)



DarkSide-20k: Projected sensitivity

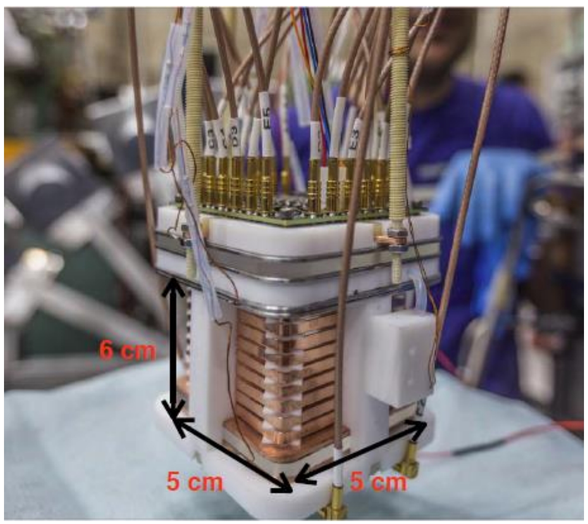


New studies: Recoil Directionality (ReD)

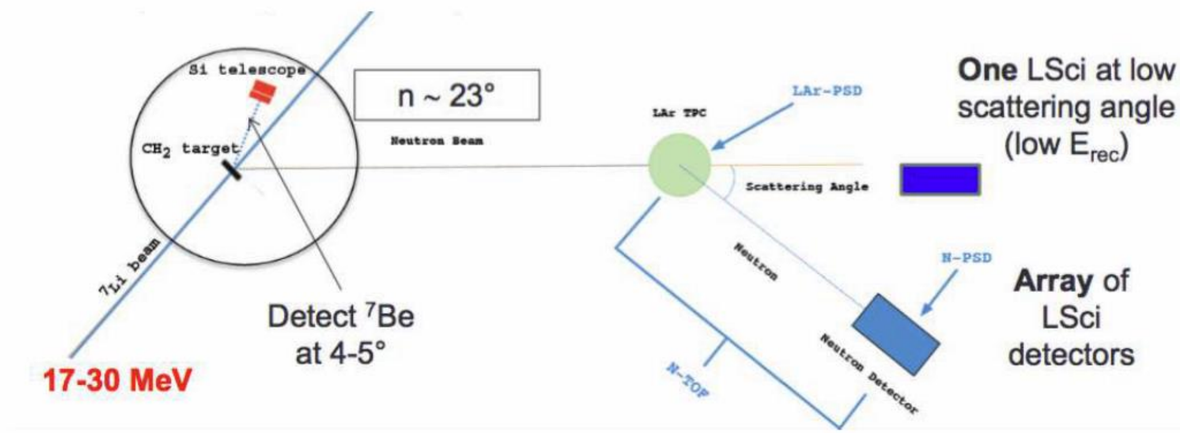
Goal: to sense recoil directionality in Liquid Argon

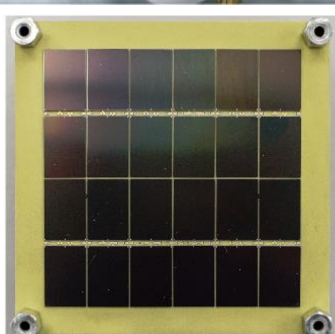
Strategy: Columnar recombination models suggest that the magnitude of the e^-/Ar^+ recombination depends on the angle between the field and the track direction.

ReD will try to demonstrate whether columnar recombination in a LAr TPC can provide directional DM detection



Neutron beam produced at INFN - LNS by the 15 MV Tandem via the p(^{7}Li,^{7}Be)n reaction





Recoil directionality might be the key for dark matter **discovery!**

Summary

- **Competitive results with Ar(DP)-TPCs**
  - High mass WIMPs
  - Low / Sub-GeV mass WIMPs

- **Exciting studies and technological developments on several fronts:** UAr, SiPMs, directionality…etc

- **PSD+ UAr+ SiPM+Radiopurity makes Ar a good candidate to lead the path towards the neutrino floor**

- **We are looking forward to the results of DP neutrino prototype**

Backup