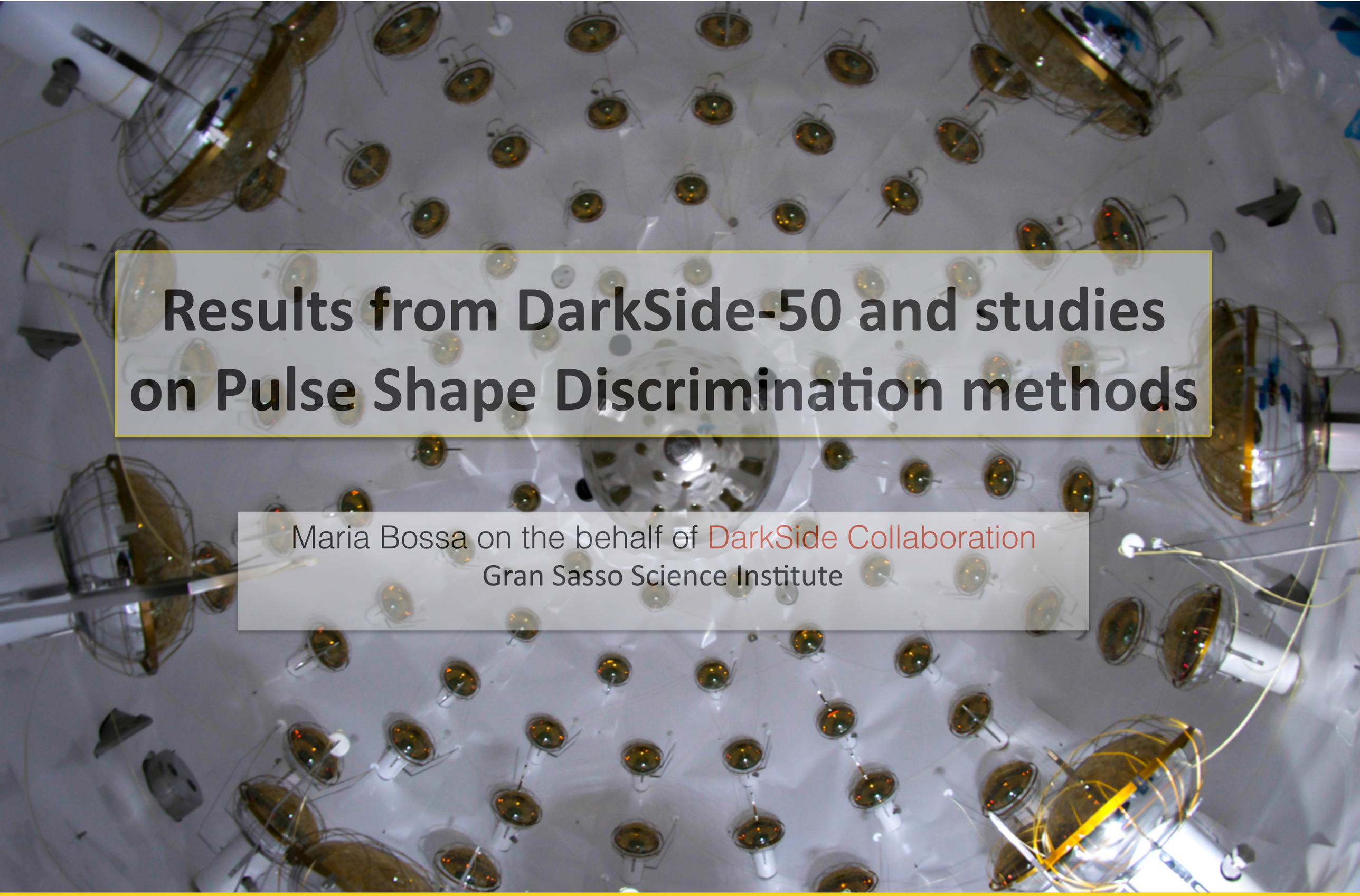


Results from DarkSide-50 and studies on Pulse Shape Discrimination methods

Maria Bossa on the behalf of DarkSide Collaboration
Gran Sasso Science Institute

Dark Matter 2016: From the smallest to the largest scales.

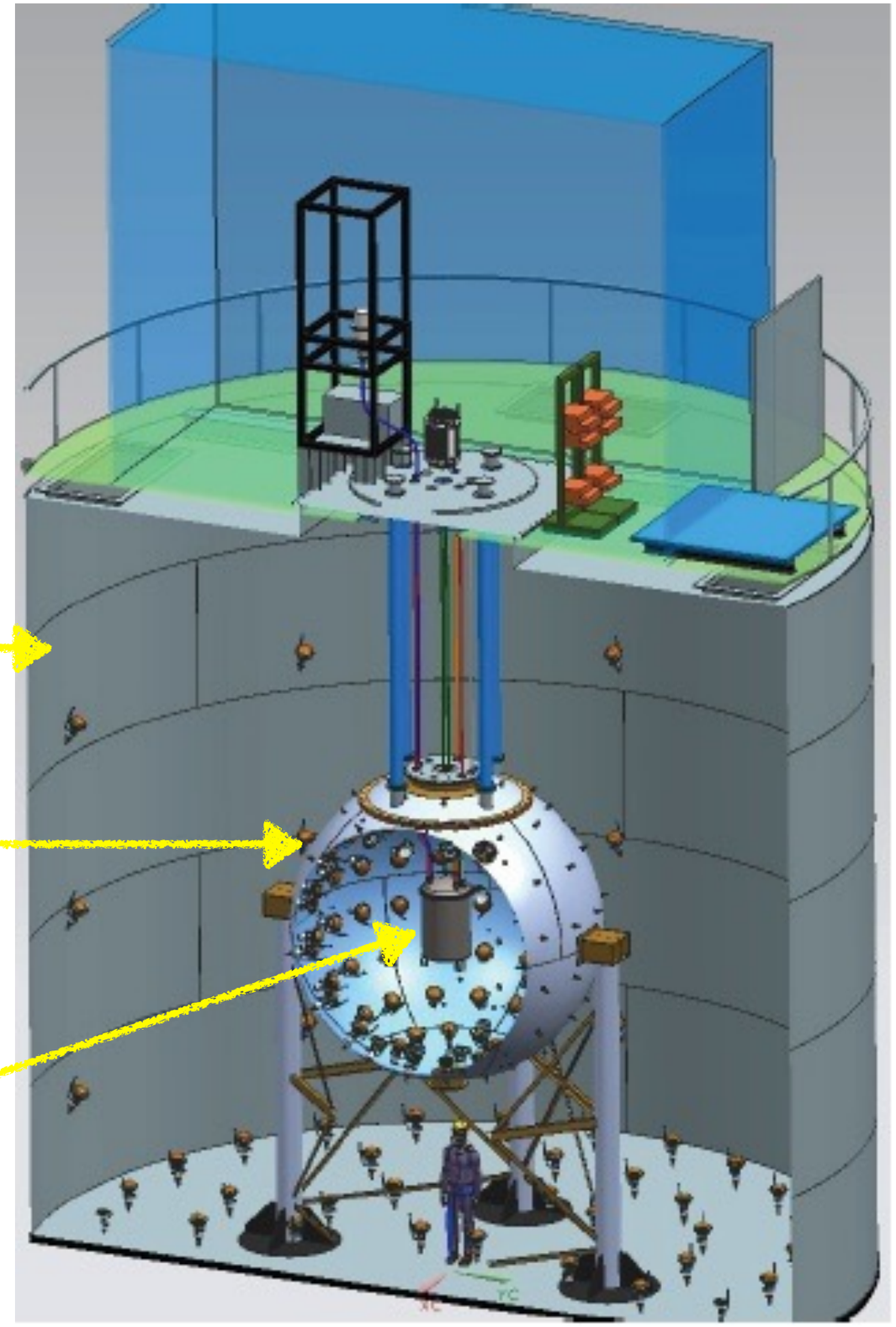
Outline

- The DarKSide experiment;
- Dark matter results
- Future of DS.

DarKSide-50 Experiment

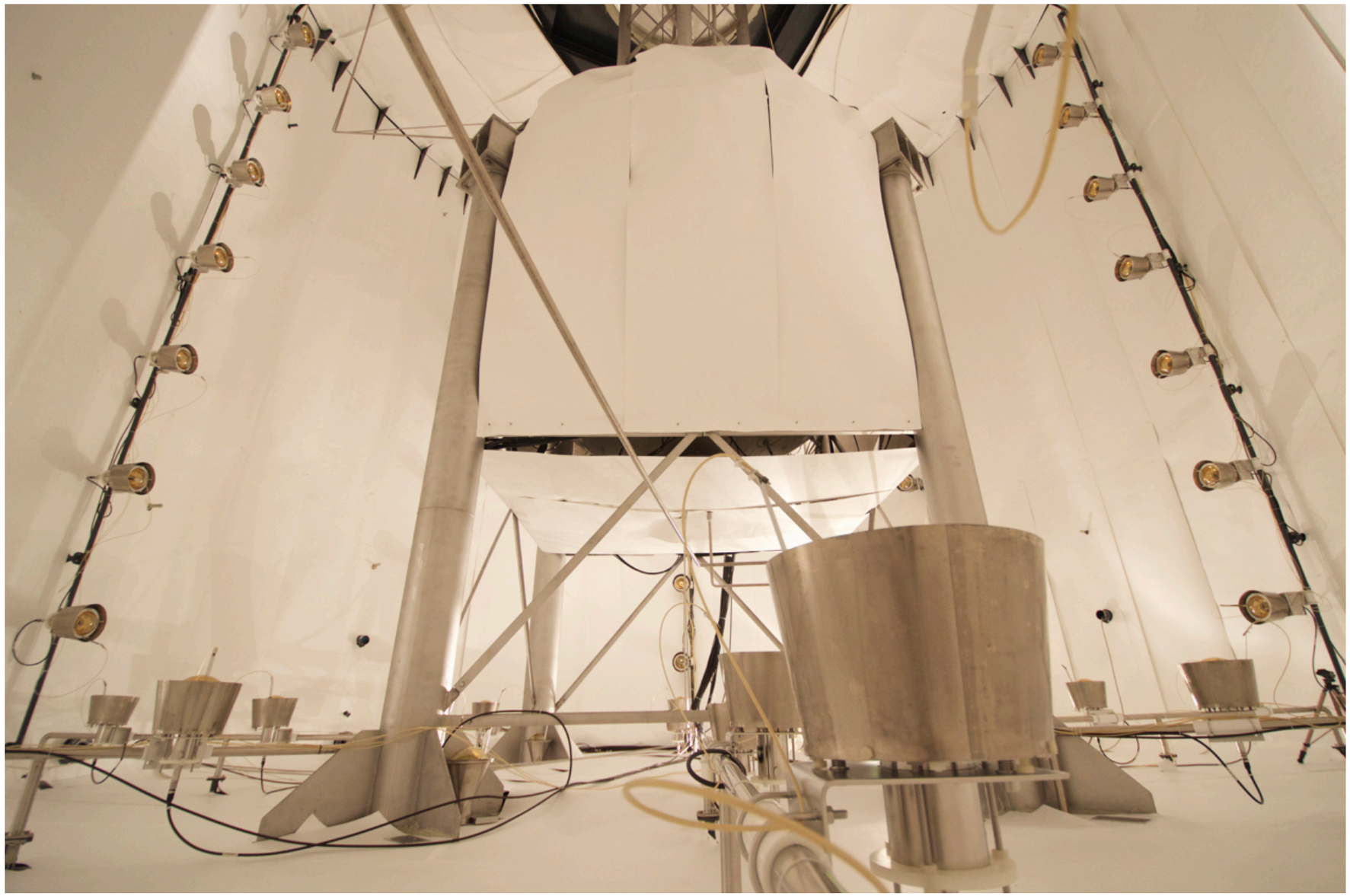
Three nested detectors:

- A Water Tank filled with 1000 tonne of pure water as **Muon veto**
- A Stainless-Steel Sphere filled with pseudocumene and trimethylborate (TMB) as **Neutron veto**
- A **TPC** filled with 50 kg of Ar



Cosmic Ray Veto

The water tank is filled with 1000 tonne of pure water and instrumented with 80 PMTs



Neutron Veto

The stainless steel sphere of 4 m diameter is filled with 30 t of boron-loaded scintillator and instrumented with 110 PMTs

Veto efficiency

Neutron capture processes:

$$^{10}\mathrm{B} + n \rightarrow \alpha(1775\ \mathrm{keV}) + {}^{7}\mathrm{Li} \quad (\mathrm{BR}:\ 6.4\%)$$

T=2.2 μs $$^{10}\mathrm{B} + n \rightarrow \alpha(1471\ \mathrm{keV}) + {}^{7}\mathrm{Li}^{*} \quad (\mathrm{BR}:\ 93.6\%)$$

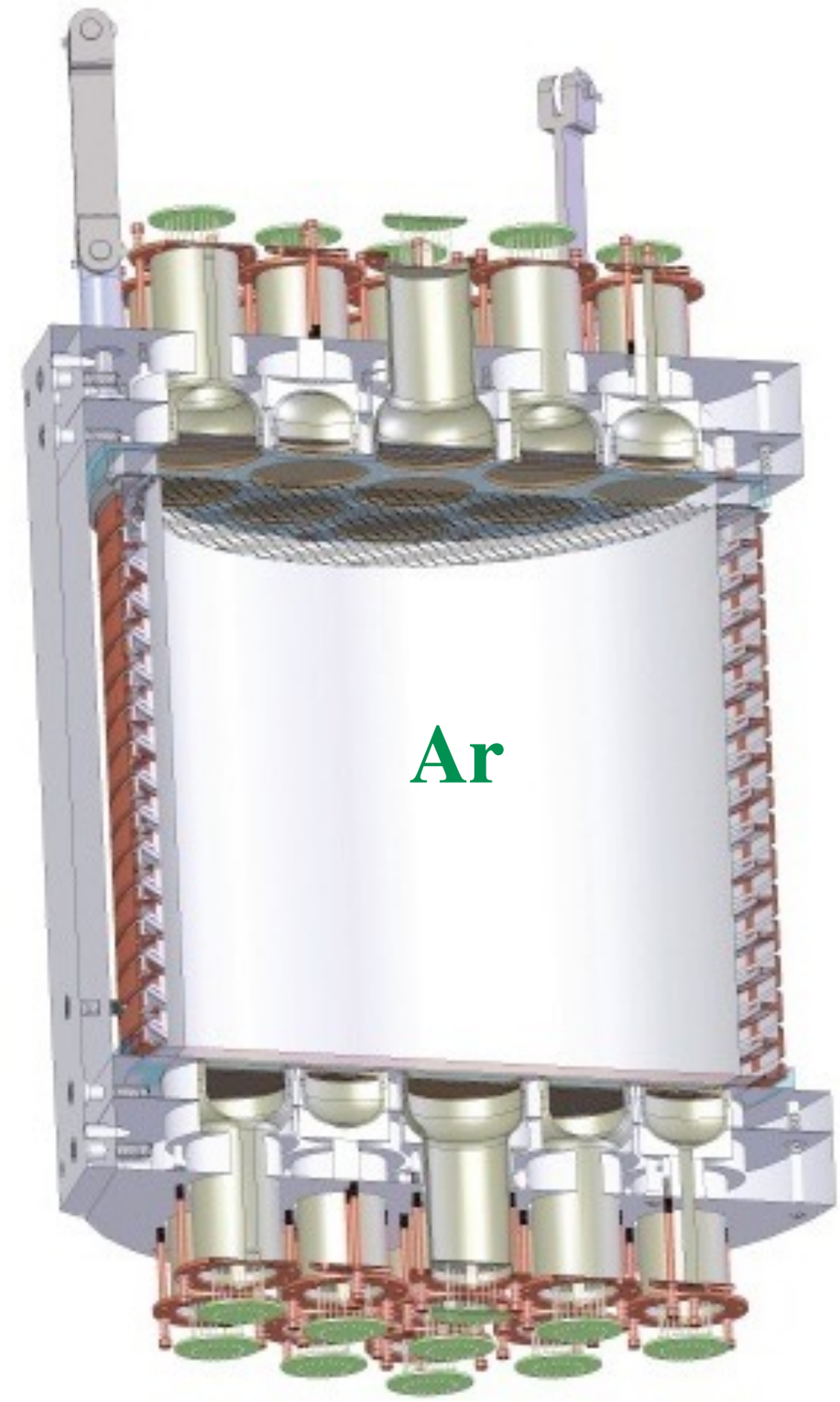
$$^{7}\mathrm{Li}^{*} \rightarrow {}^{7}\mathrm{Li} + \gamma(478\ \mathrm{keV}). \longrightarrow$$ **250 PE**

From AmBe data and MC simulations, we estimate a detection **efficiency** of **> 99.1%** for radiogenic neutrons when using the neutron capture signals only. This estimate is a lower limit since the calculation neglects the **neutron thermalization** signal from the scintillator.The main detection inefficiency is due to the fraction of the neutron captures on ^{1}H in which the 2.2 MeV deexcitation γ ray is fully absorbed in inert materials rather than in the scintillator.

arXiv: 1606.03316

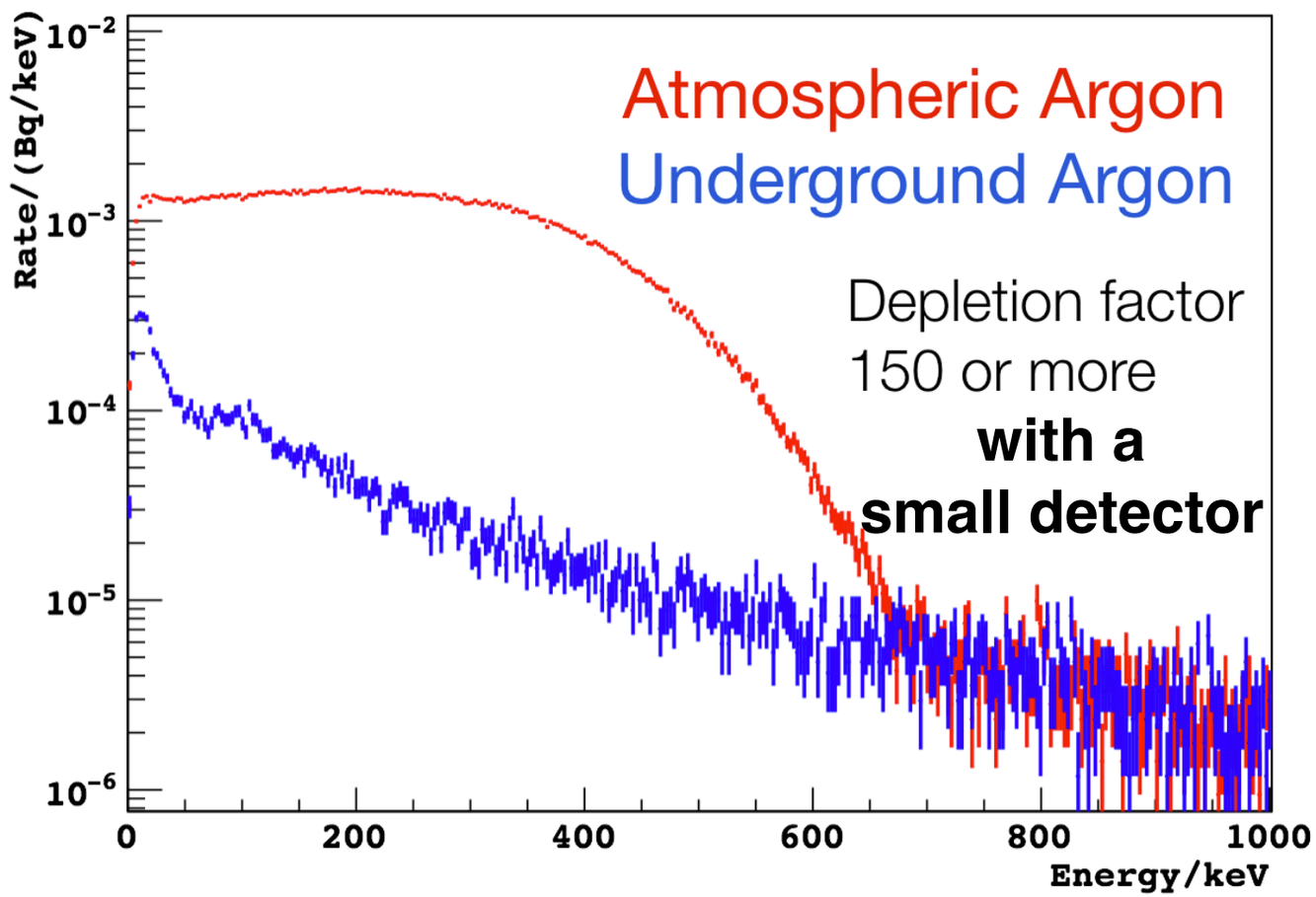
The Time Projection Chamber

- Filled with 50 kg of Underground Argon (UAr) low in ^{39}Ar and instrumented with 38 PMTs
- 36 cm height, 36 cm diameter
- High reflectivity Teflon walls
- Inner surfaces coated with wavelength shifter (**T**etra**P**henyl **B**utadiene)



Underground Argon

- Intrinsic ^{39}Ar radioactivity in **atmospheric argon** is the primary background for argon-based detectors
- ^{39}Ar activity sets the dark matter detection threshold at low energies (where pulse shape discrimination is ineffective)



Underground Argon

Plant at Colorado

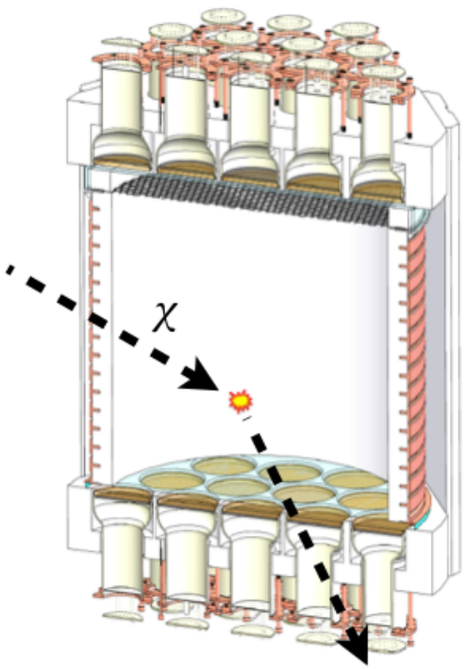
Extraction at Colorado (CO_2 Well)

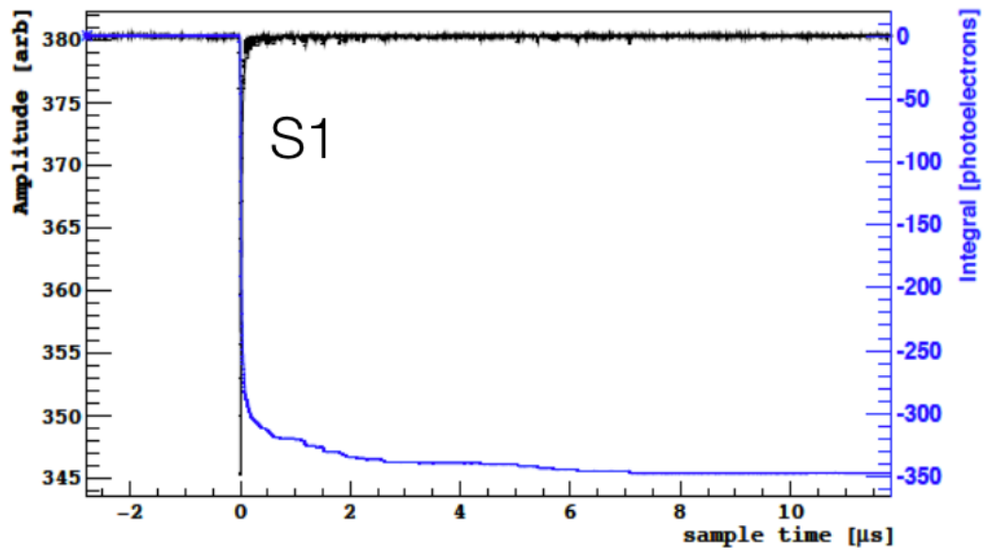
Extract a crude argon gas mixture (Ar, N_2,and He)

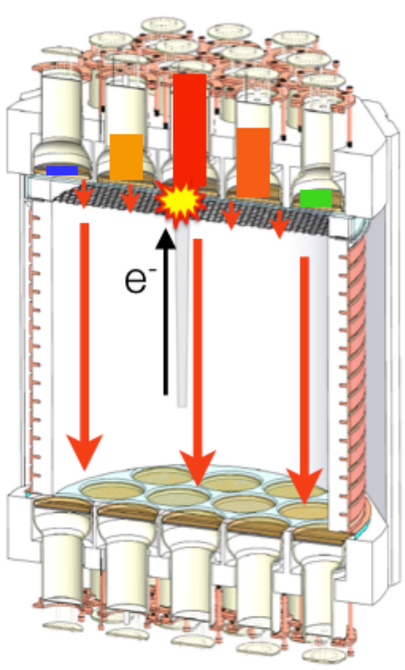
Distillation Column at Fermilab

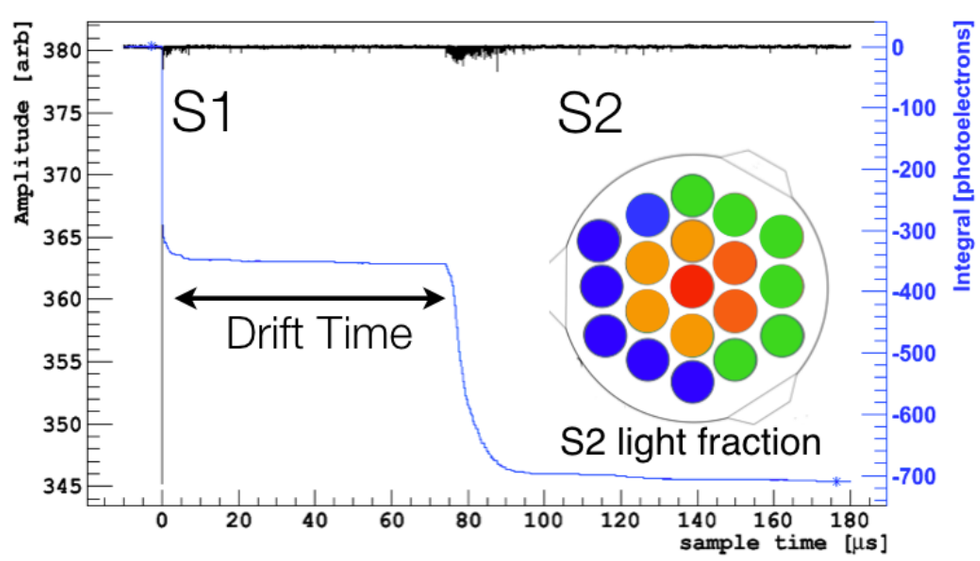
Shipped to LNGS

The Time Projection Chamber





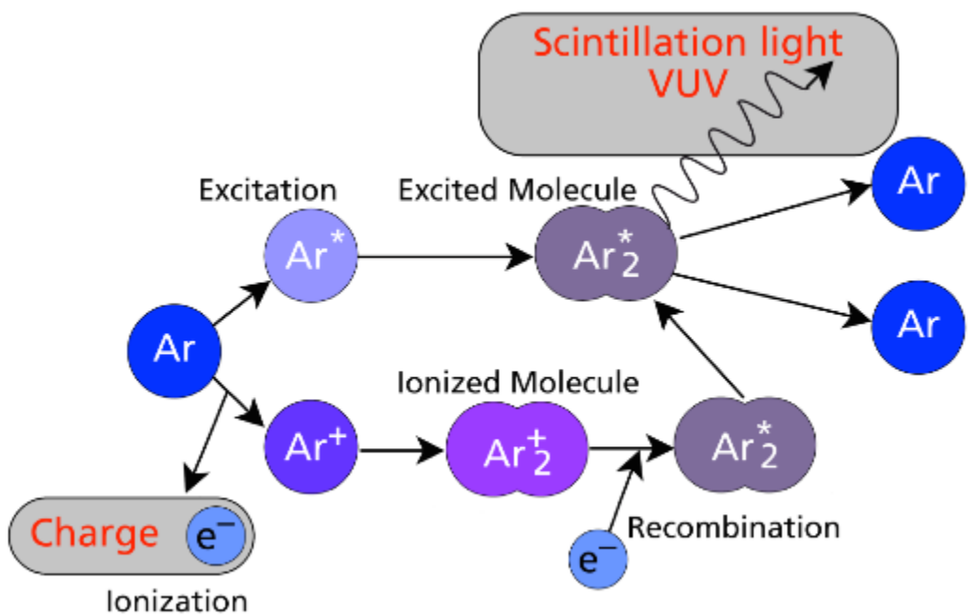




- Nuclear Recoil **excites** and **ionizes** the liquid argon, producing **scintillation** light (S1) that is detected by the photomultipliers
- The electrons are extracted into the gas region, where they induce **electroluminescence** (S2)
- The time between the S1 and S2 signals gives the vertical position.
- x-y position of events are reconstructed from fraction of S2 in each PMT.

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

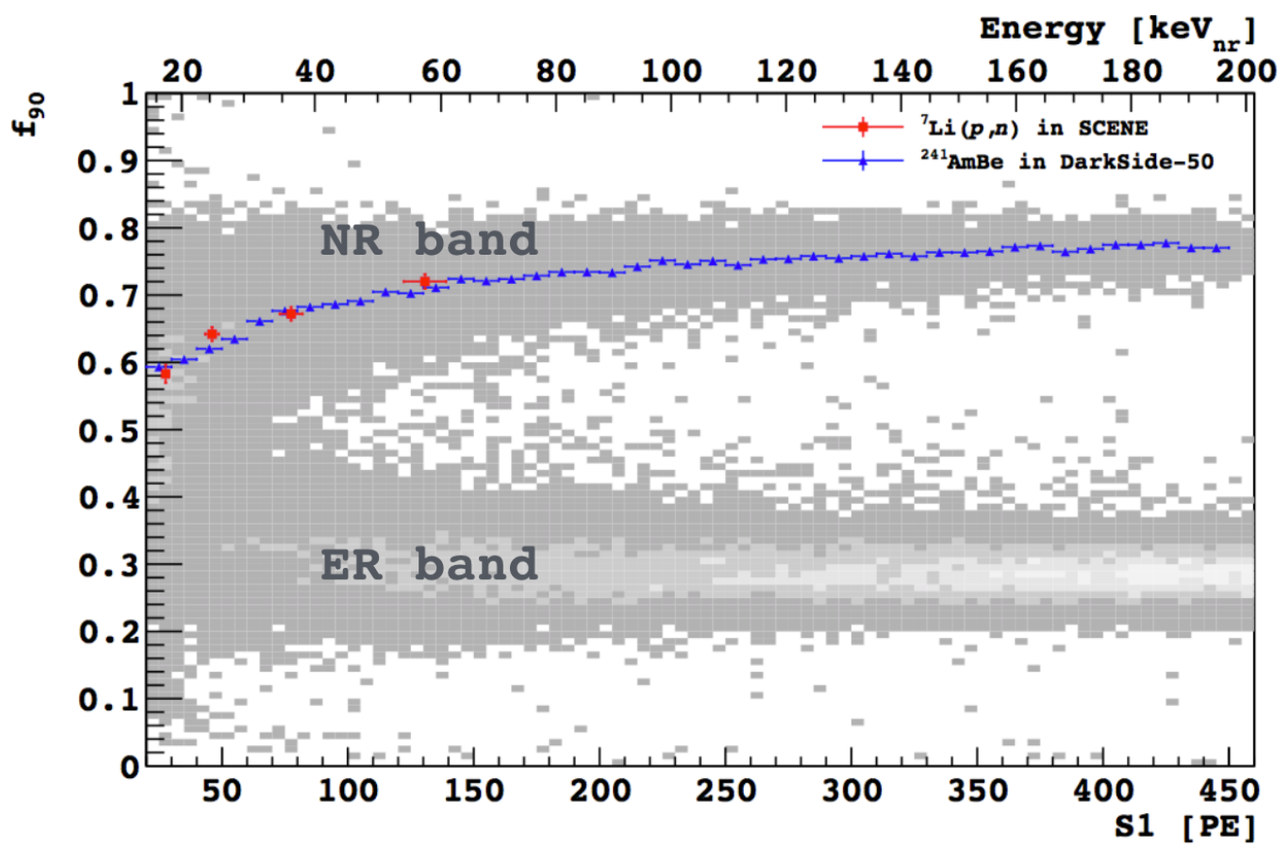
PSD parameter: **F90** defined as the ratio between the light detected in the first 90 ns and the total signal

$$F_{90} = \frac{\int_0^{90\,ns} dt\, f(t)}{\int_0^{\infty} dt\, f(t)} = \begin{cases} 0.3 \text{ ER} \\ 0.7 \text{ NR} \end{cases}$$

Calibration Campaign

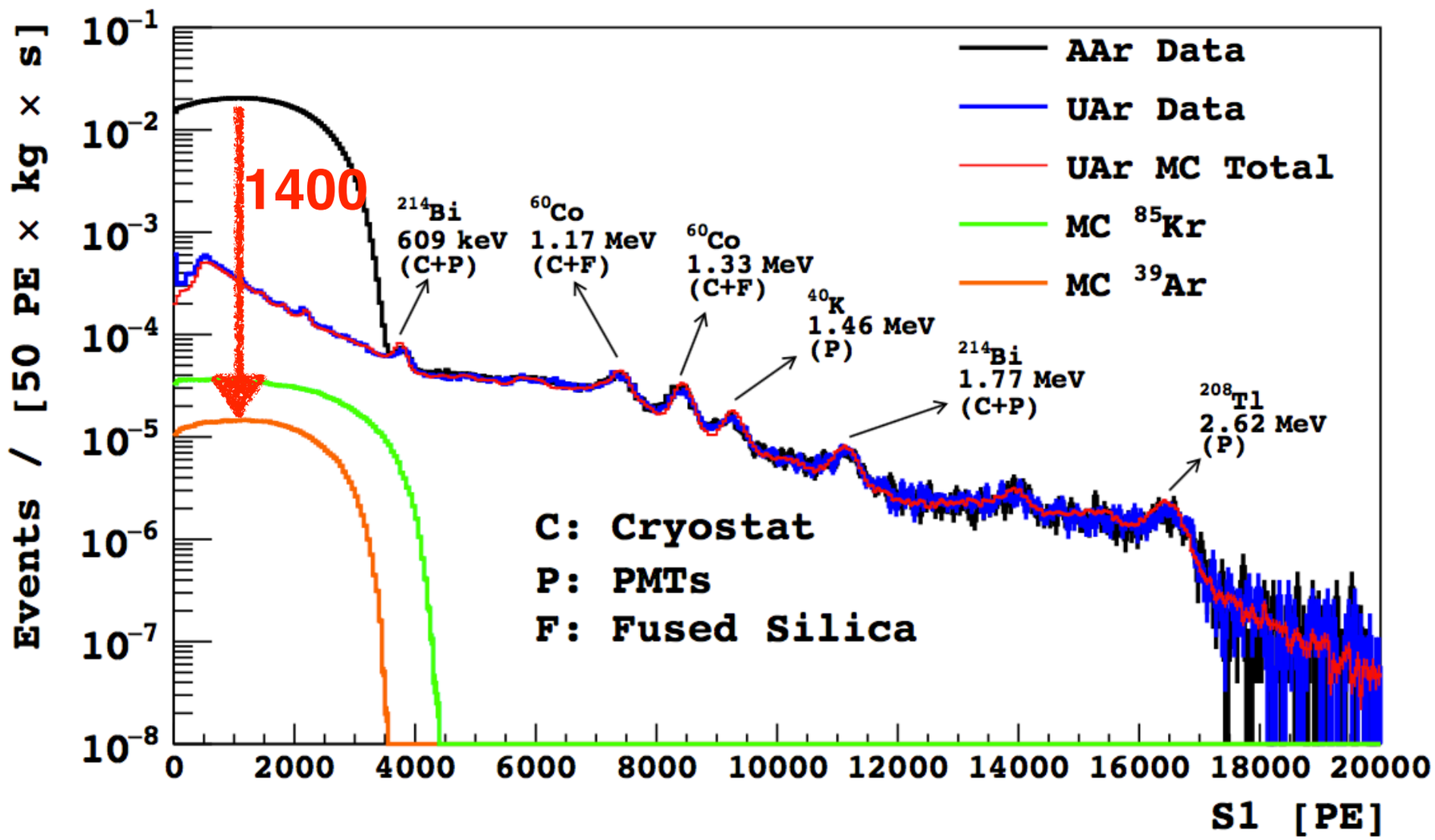
Aim: calibrate both the **TPC** and the **neutron veto**.

- **Gamma Sources:** ^{57}Co (122 keV), ^{133}Ba (356 keV), ^{137}Cs (663 keV)
- **Neutron Sources**: AmBe



UAr Results

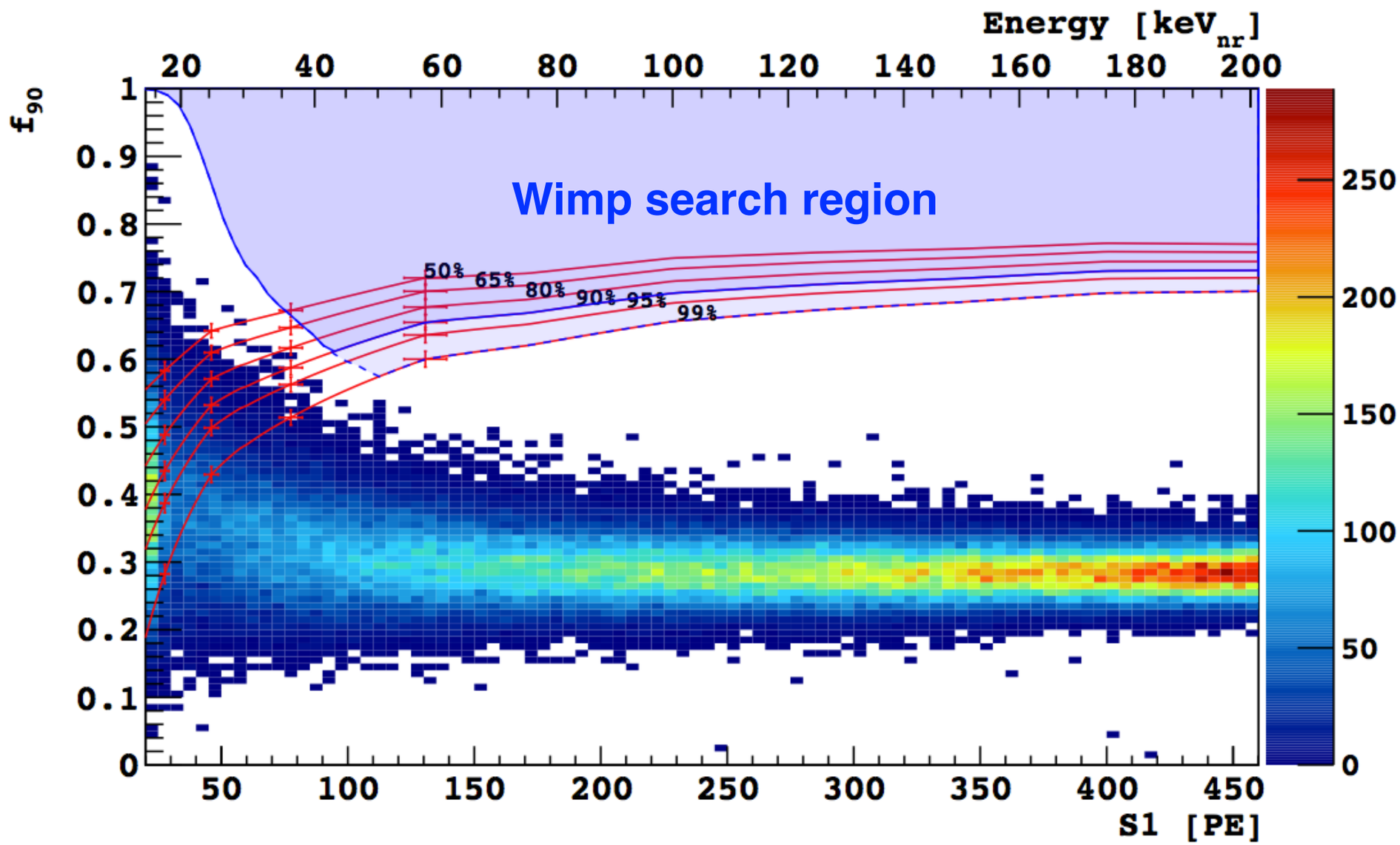
Comparison of the measured **field off** spectra for the UAr and AAr targets



^{85}Kr unexpected—> natural fission underground, which produces Kr in deep underground water reservoirs at specific activities similar to those of ^{39}Ar

UAr Results

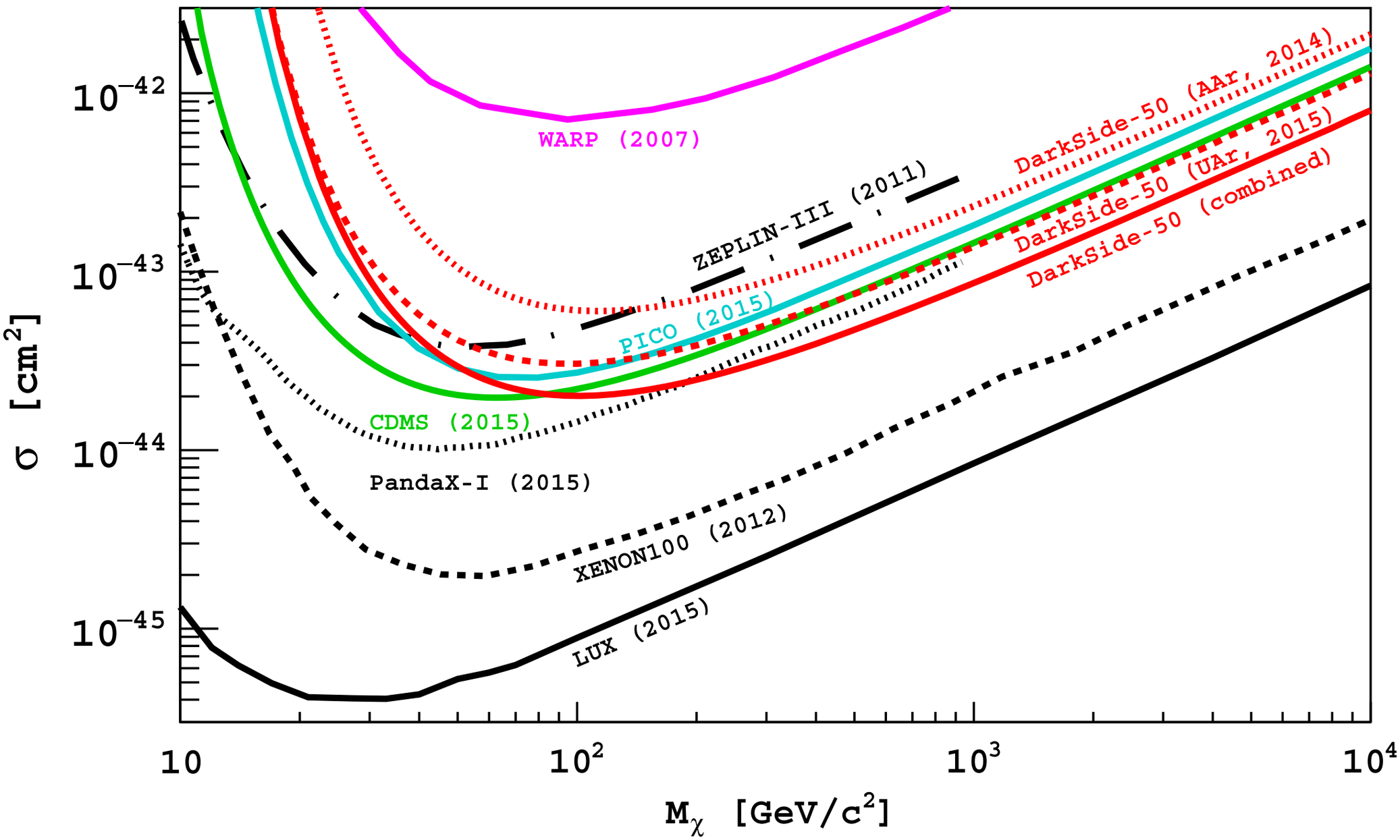
No background events in nuclear recoil (WIMP) region!



71 live days after all cuts: single-hit interactions in the TPC, no energy deposition in the veto.

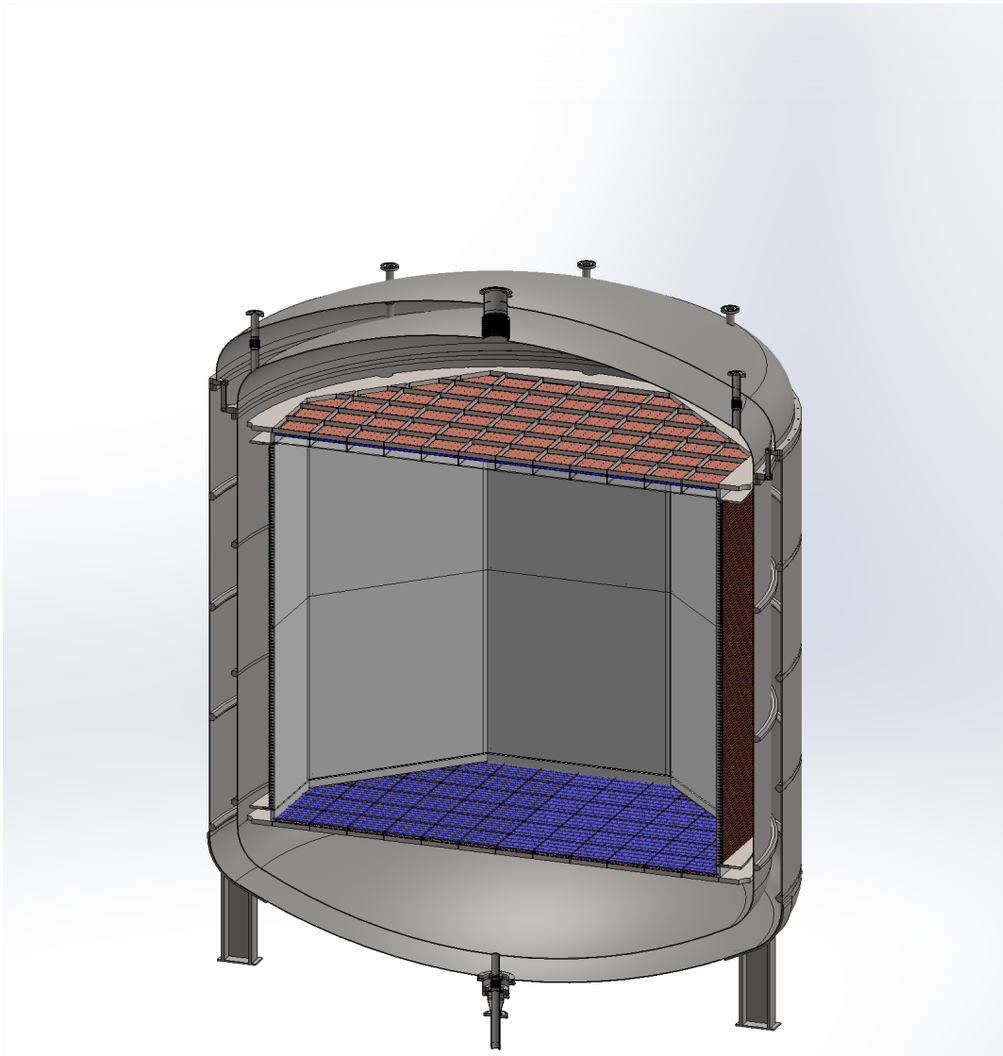
Phys. Rev. D 93 081101, 2016

Exclusion Plot



Upper limit of **3,1 x 10^{-44} cm^2** for a WIMP mass of **100 GeV/c^2**. Combining the result of AAr we obtain an upper limit of **2.0 x 10^{-44} cm^2** for a WIMP mass of **100 GeV/c^2**

Multi-ton scale



DS-20k

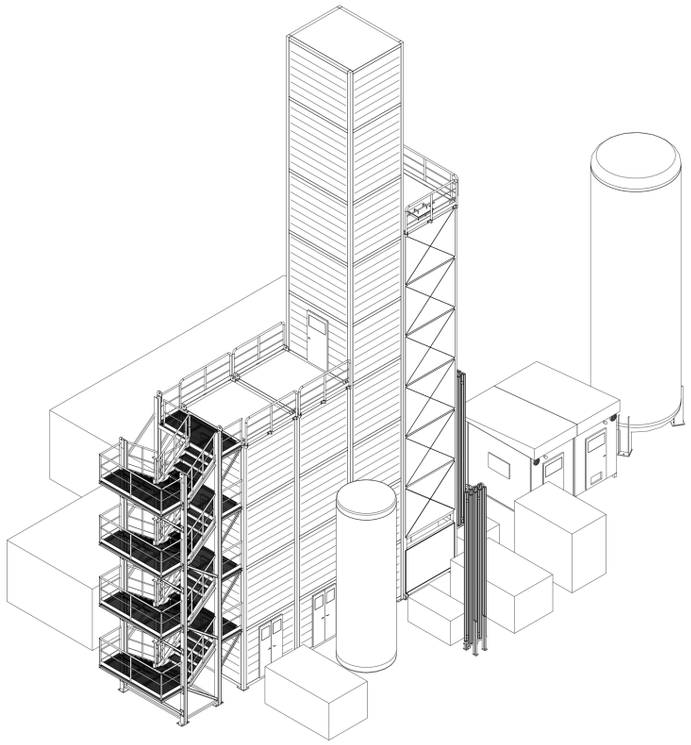
Requirements:

- Veto system;
- Radiopure **SiPm** and ultra-clean titanium for the TPC
- Underground Argon

Multi-ton scale

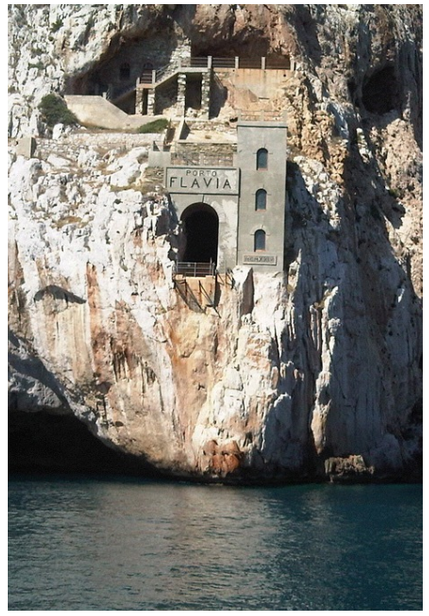
Urania (Underground Argon):

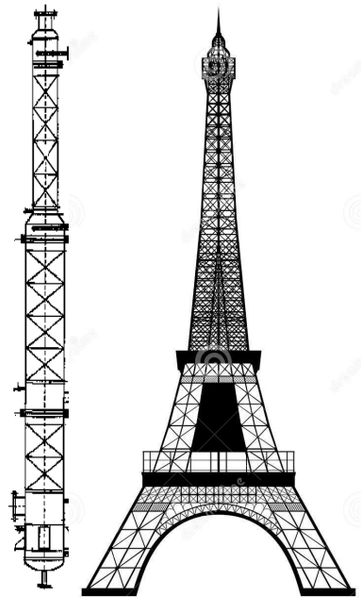
- New argon extraction plant in Cortez, CO, to reach capacity of **100 kg/day** of Underground Argon



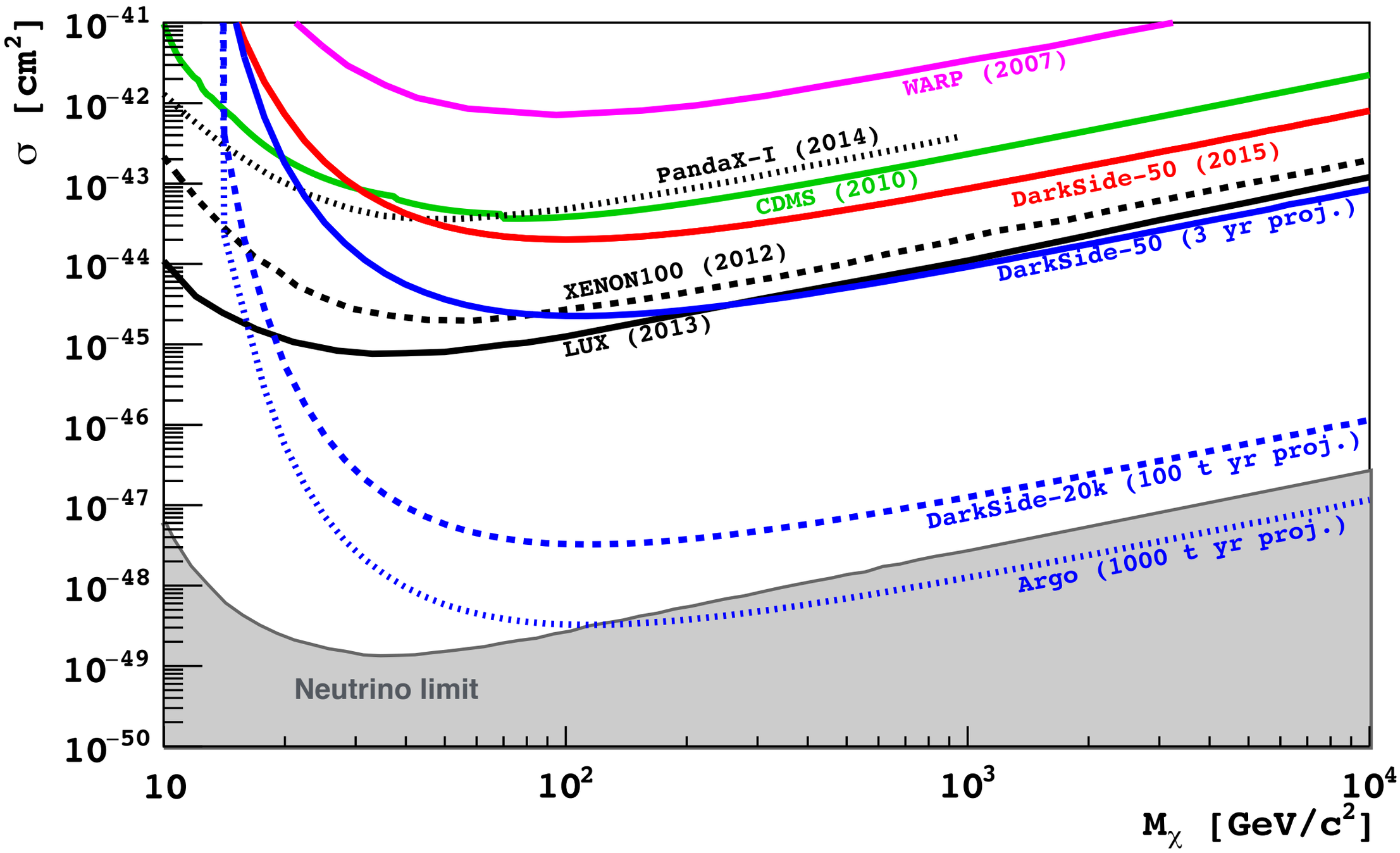
Aria (UAr Purification):

- 350 meters high column in the Seruci mine in Sardinia, Italy, for high-volume chemical and isotopic purification of Underground Argon





Expected sensitivity



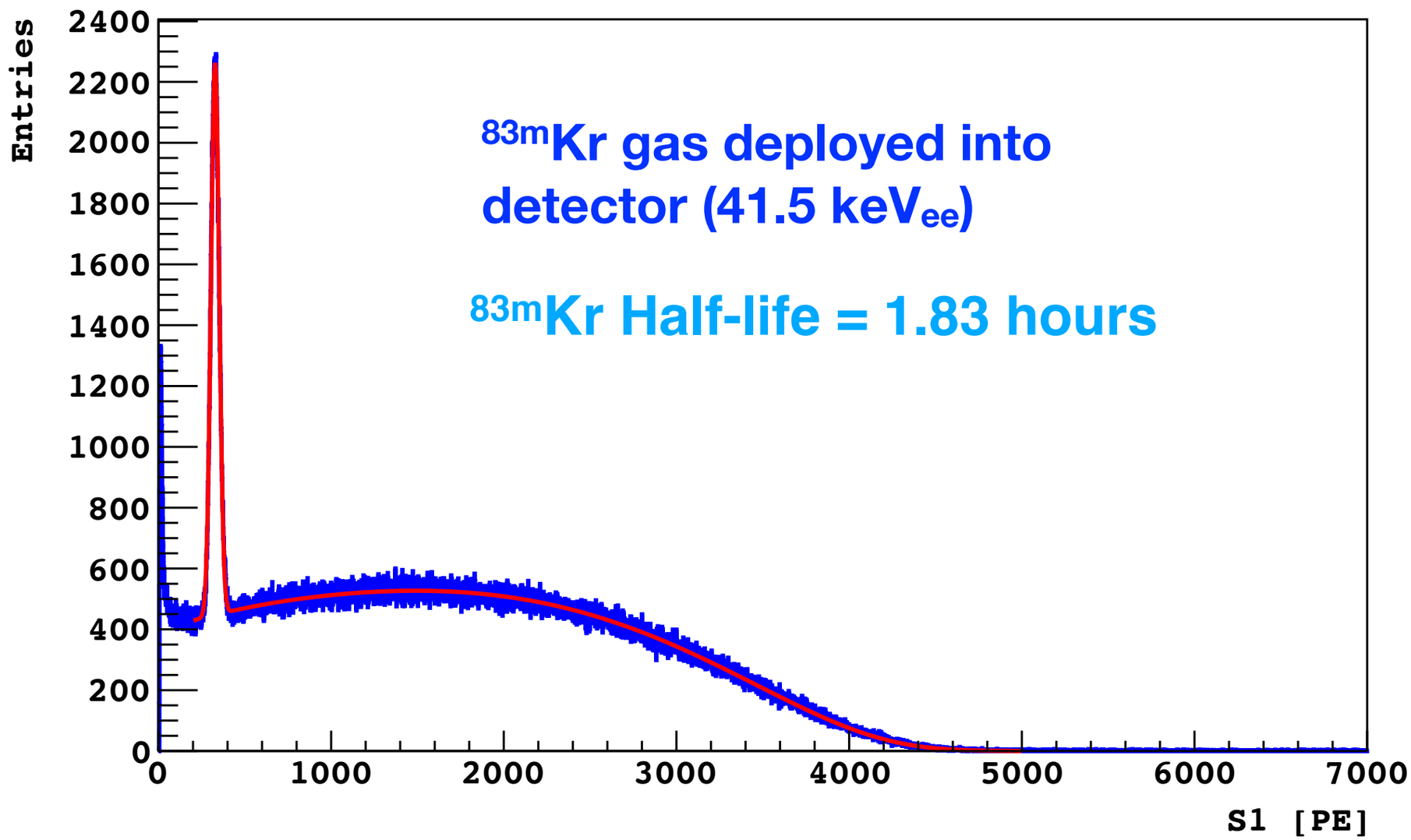
Summary

- DarkSide-50 performed the first ever WIMP dark matter search with **UAr**.
- DarkSide-50 has **the strongest** WIMP limit among Ar target experiments.
- Efficiency of the Neutron Veto is **>99.1%** with only the **capture signals** and is expected to be **more** with additional **thermalization signals.**
- Low level of 39Ar allows extension of DarkSide program to ton-scale detector
- Future detectors are planned and active R&D's are underway.

Thank you for your attention

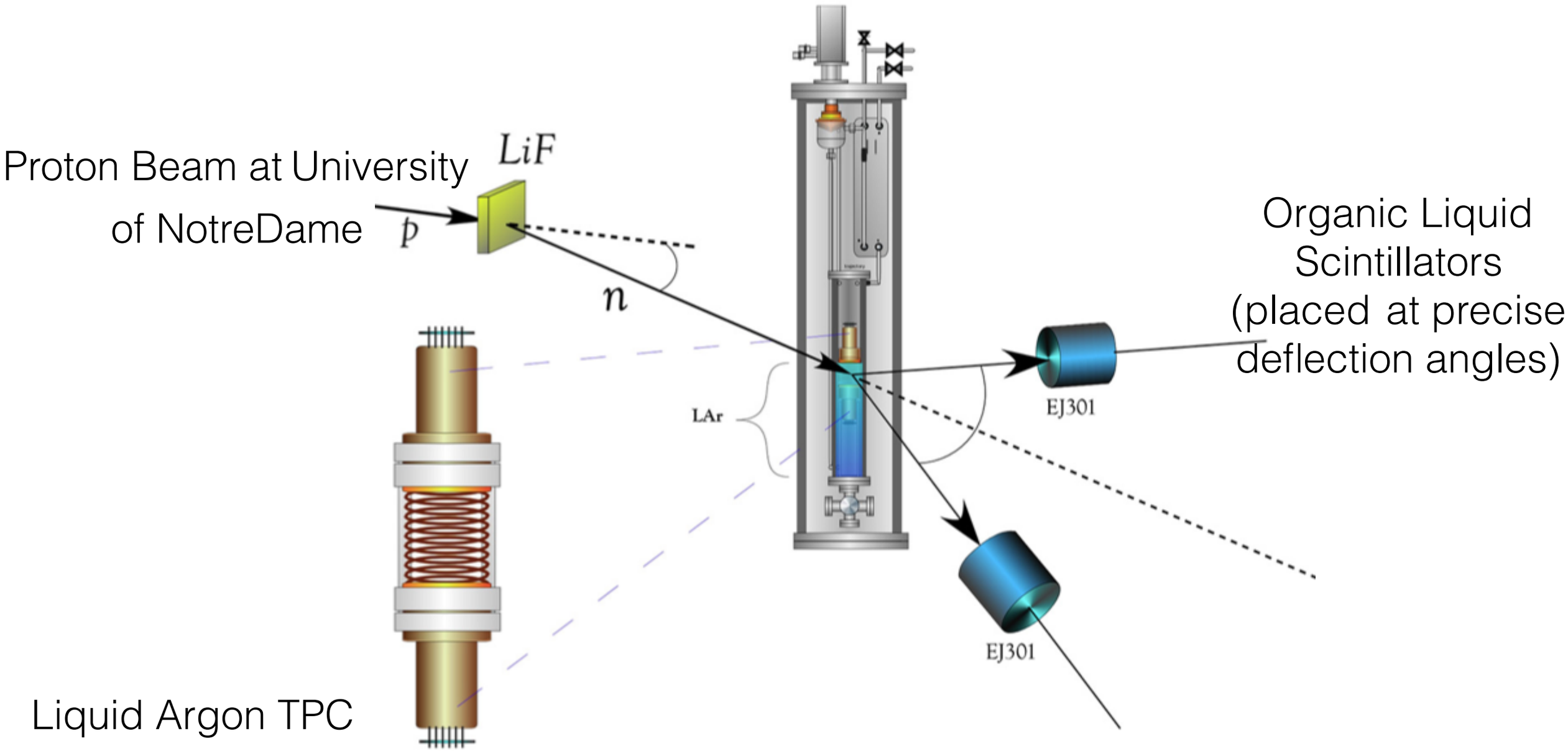
Backup slides

Light yield measurement



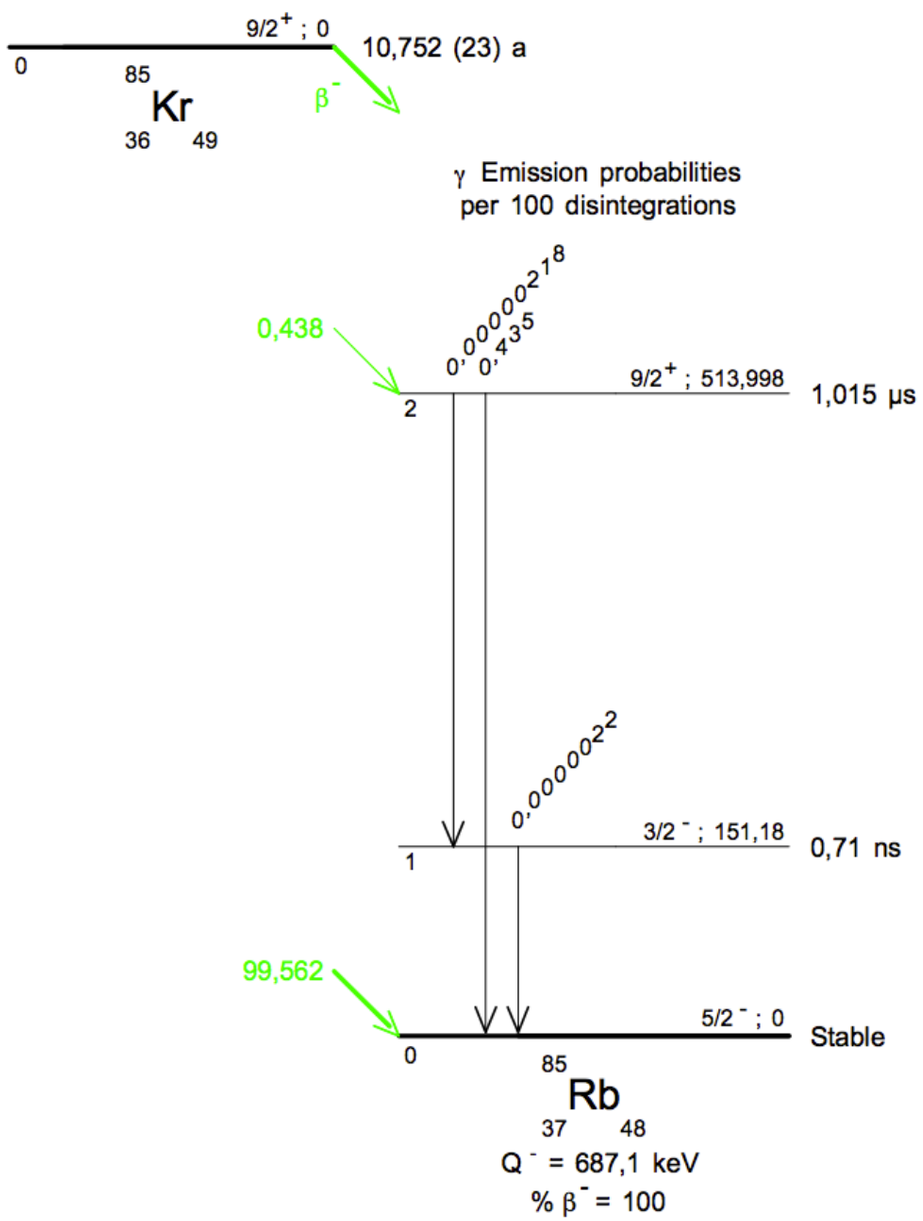
LIGHT YIELD: **8.1 ± 0.2** PE/keV$_{ee}$ at **zero field**

SCENE
(Scintillation Efficiency of Nuclear Recoils in Noble



^{7}Li(p, n)^{7}Be reaction produces low energy monoenergetic neutrons
TOF measurement between target, LAr and organic scintillators allows clean identification of elastic neutron interactions of known energy

Identification of ^{85}Kr



β-γ coincidence. Mean lifetime = 1,46 μs

Results: 33.1± 0.9 events/d in agreement with spectral fit: 35.3±2.2 events/d