



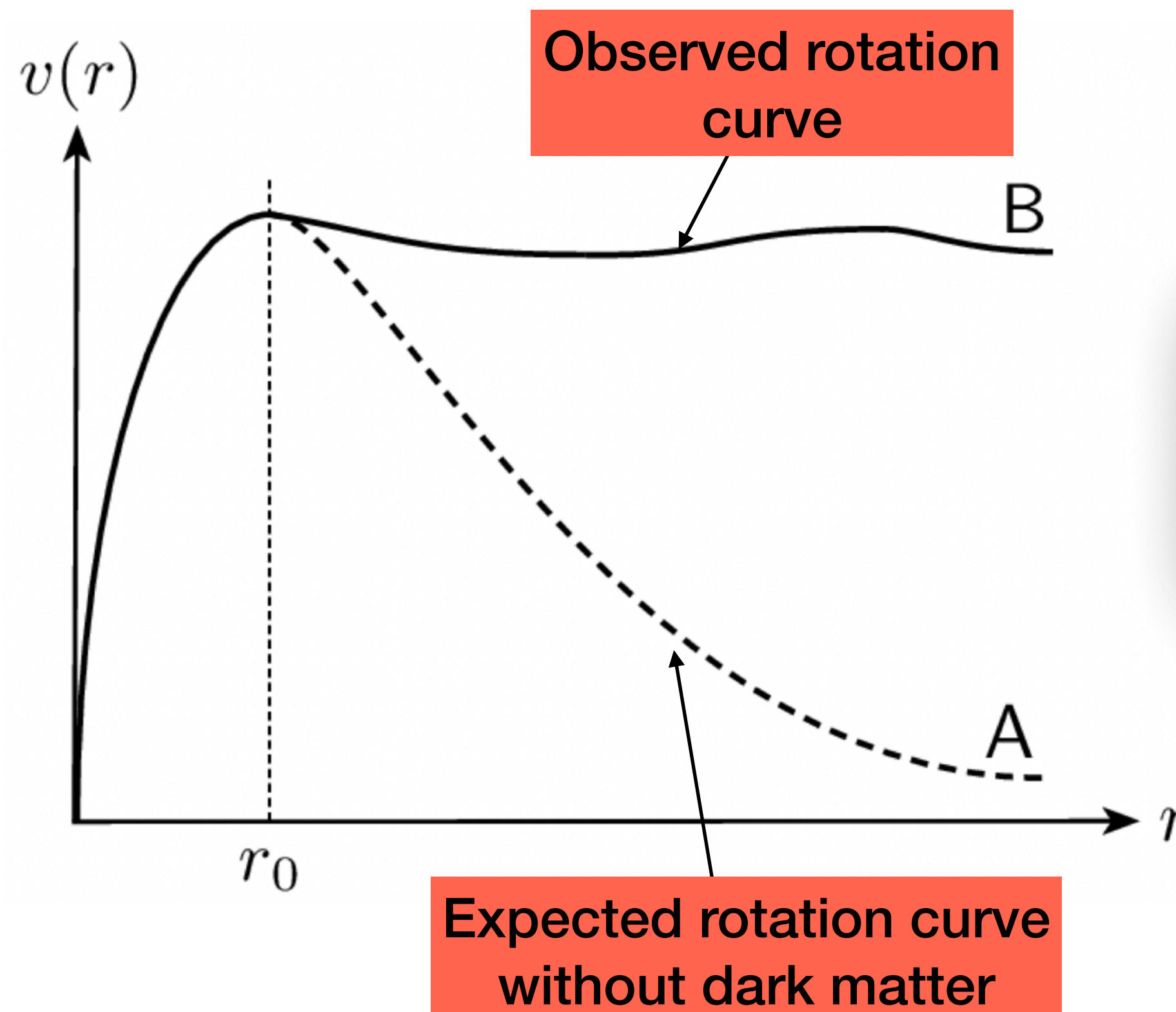
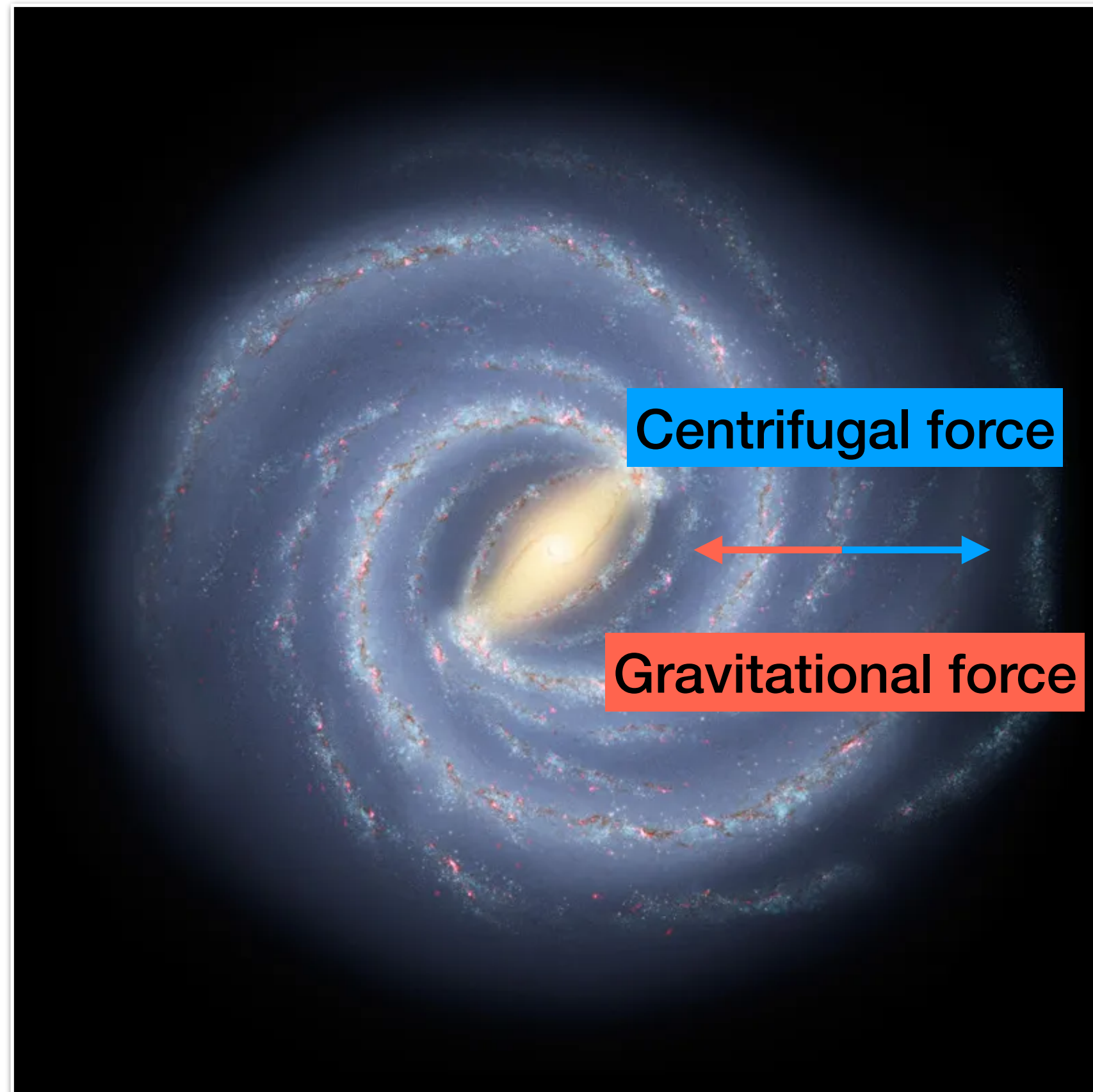
# DarkSide-20k

**Dark Matter Detection in Liquid Argon Dual Phase TPC**

*Timothée Hessel, on behalf of the DarkSide-20k collaboration*

# Evidences of dark matter

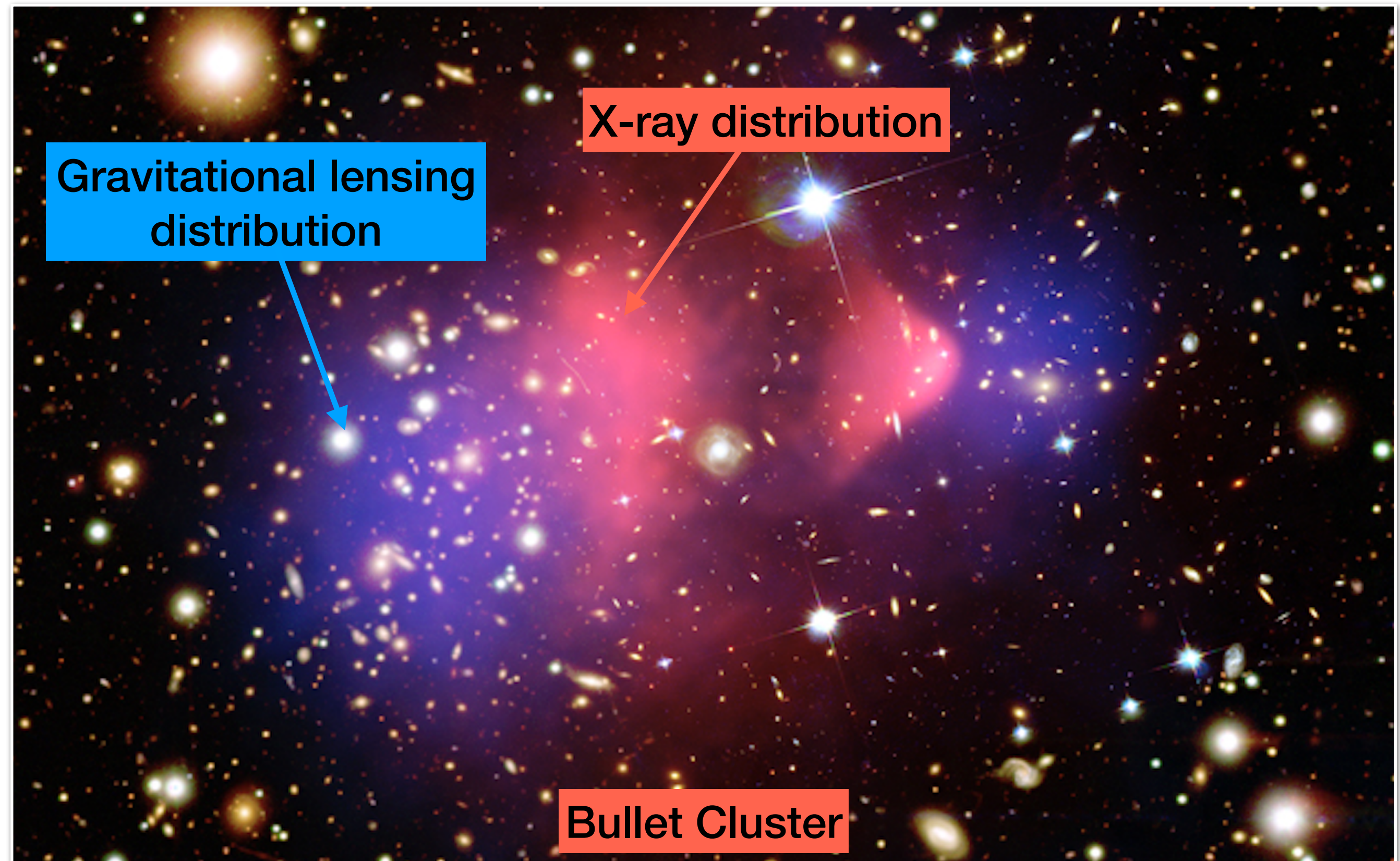
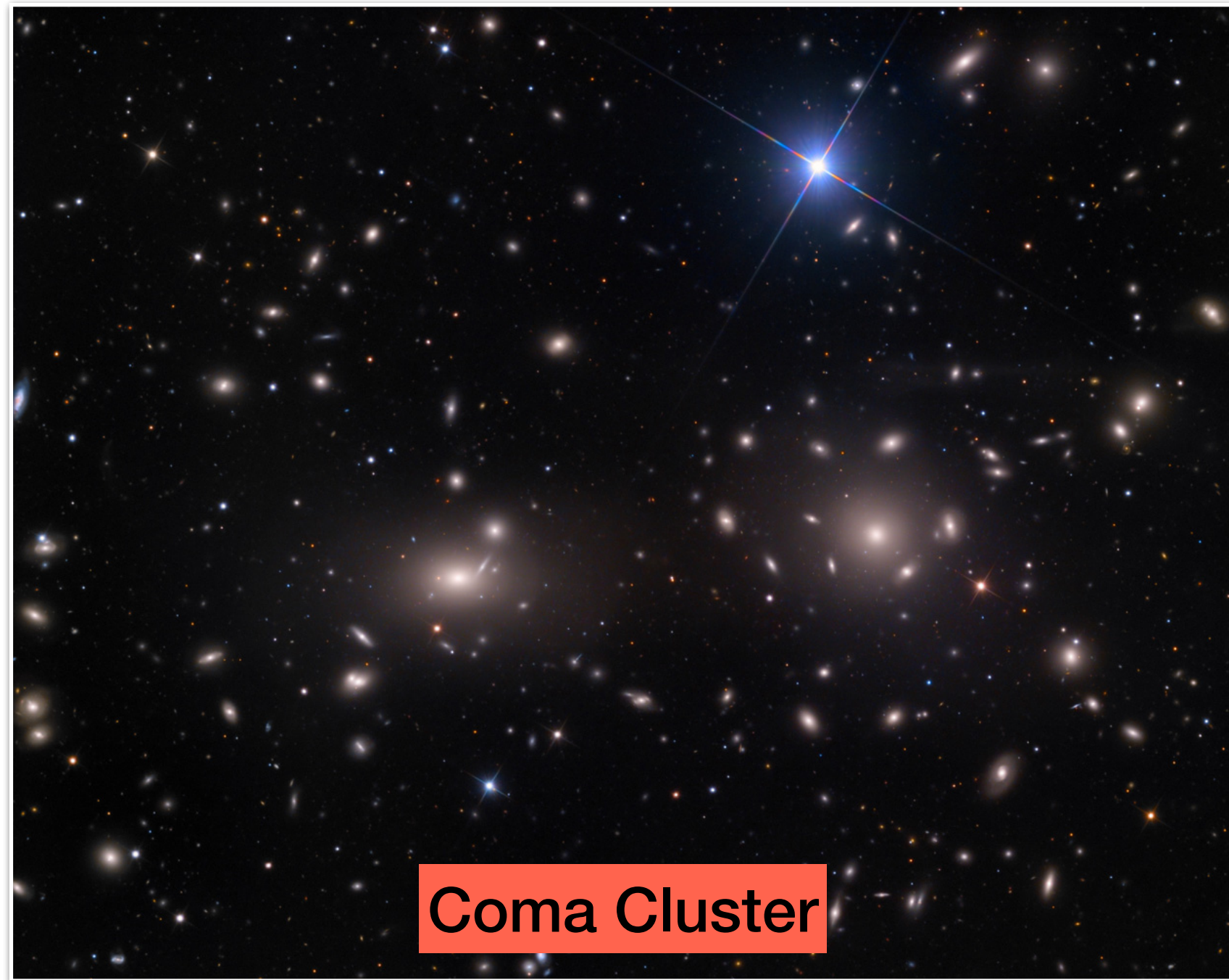
## Galaxy rotation curves



- ▶ Extra *invisible* matter.
- ▶ Contributing for ~80% of the galaxy mass.

# Evidences of dark matter

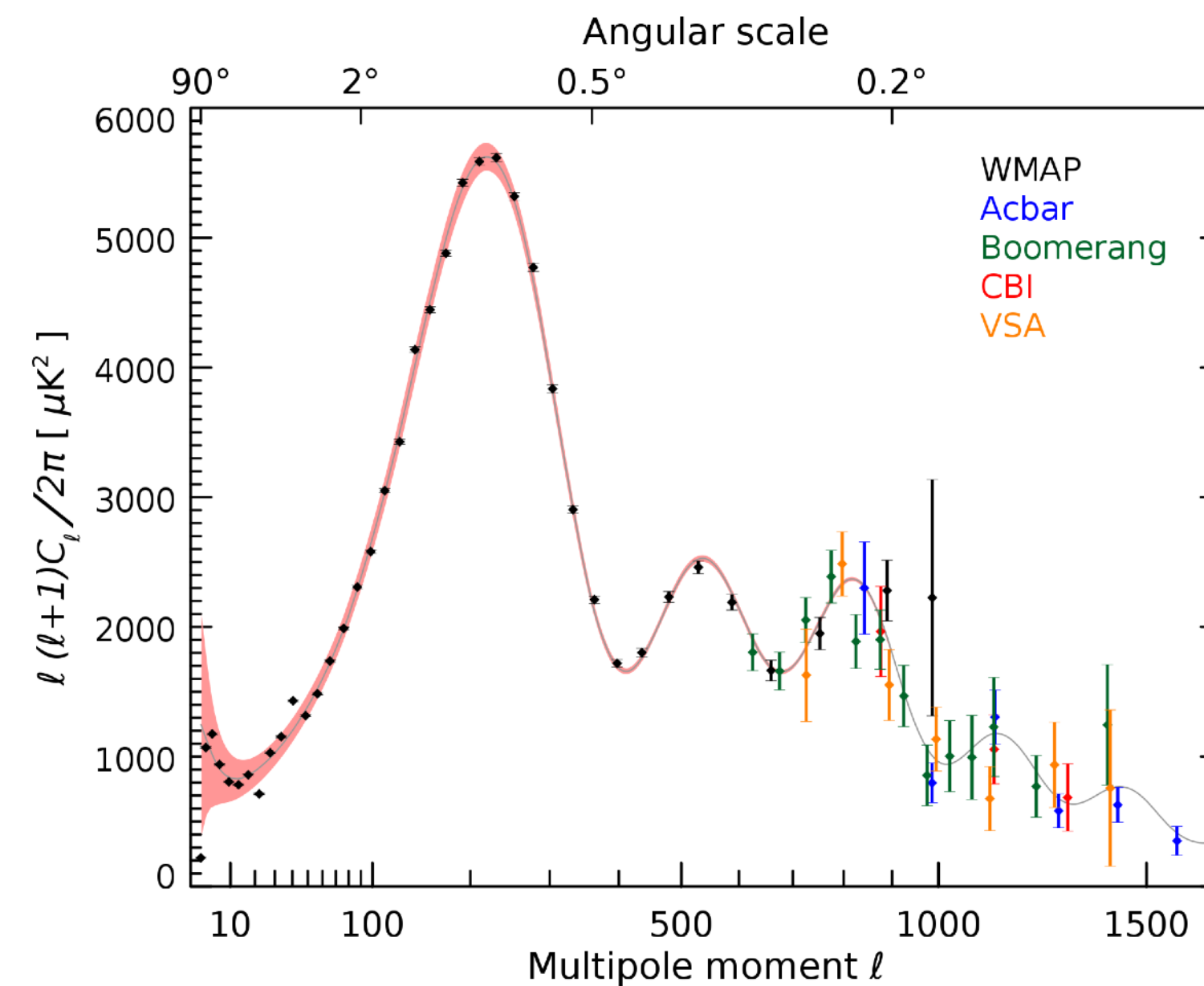
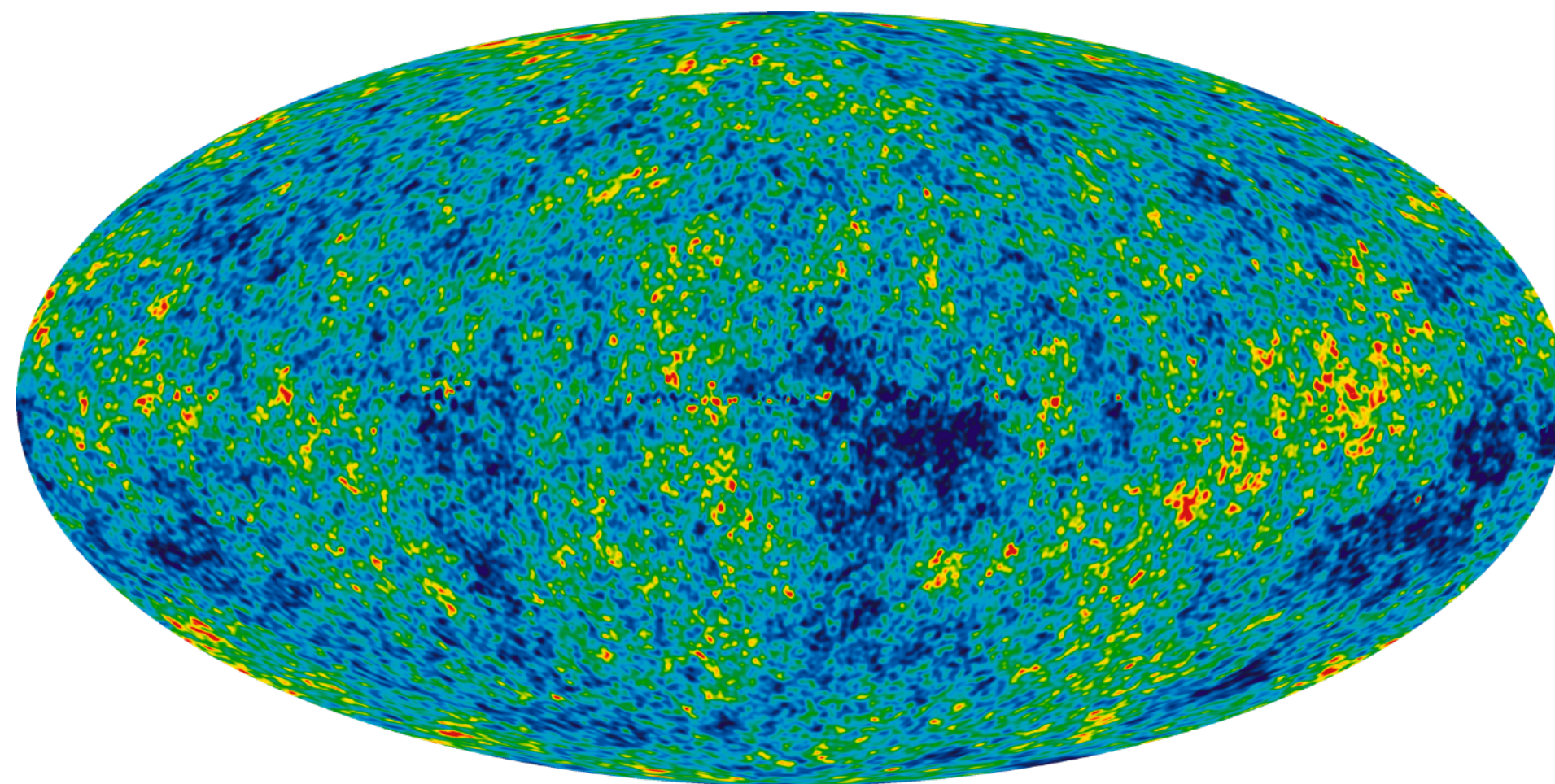
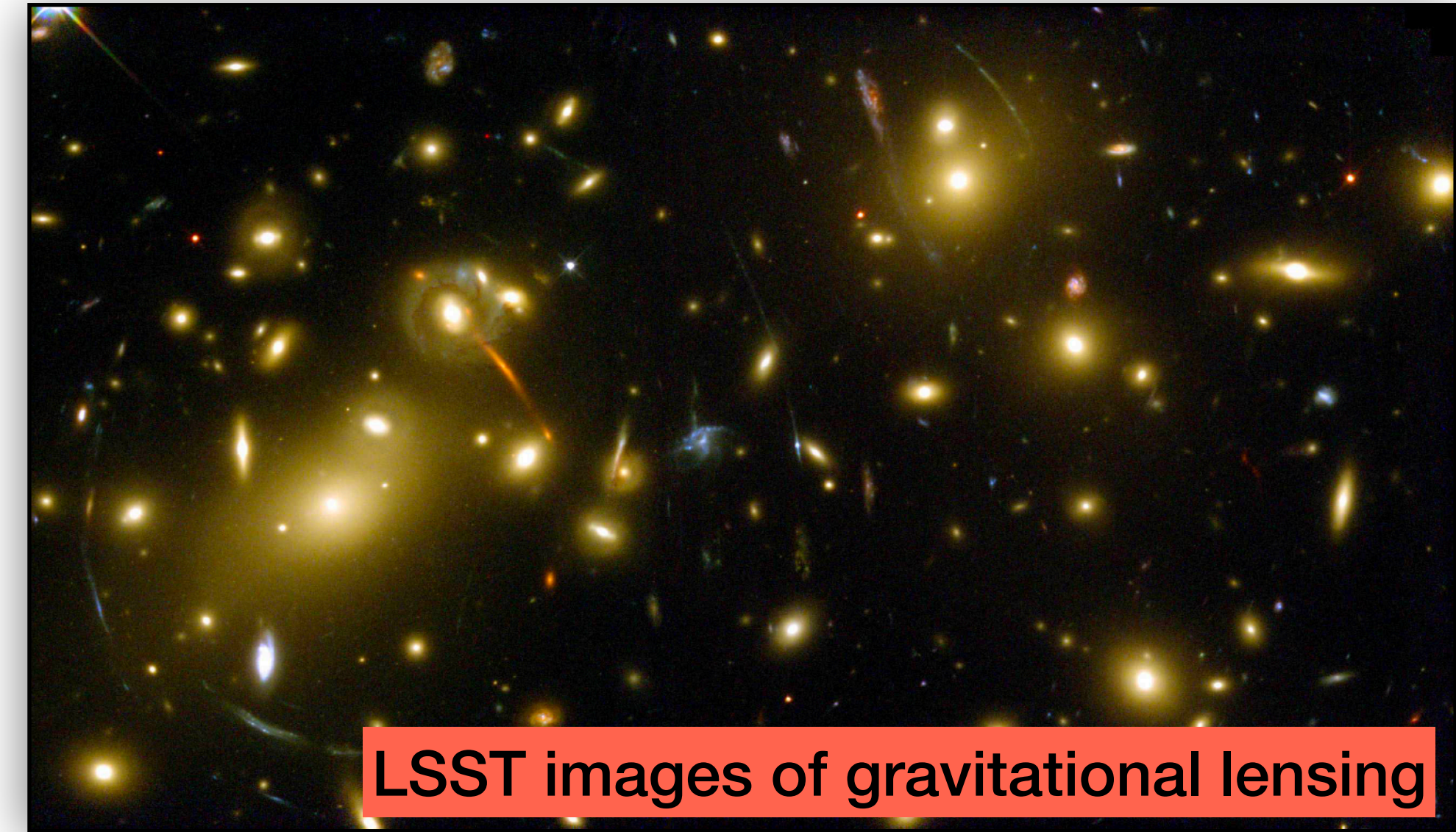
## Galaxy clusters



# Evidences of dark matter

## In cosmology

- ▶ Galaxy rotation curves and cluster dynamics
- ▶ Gravitational lensing
- ▶ CMB anisotropies ( $\Lambda$ CDM cosmology model)



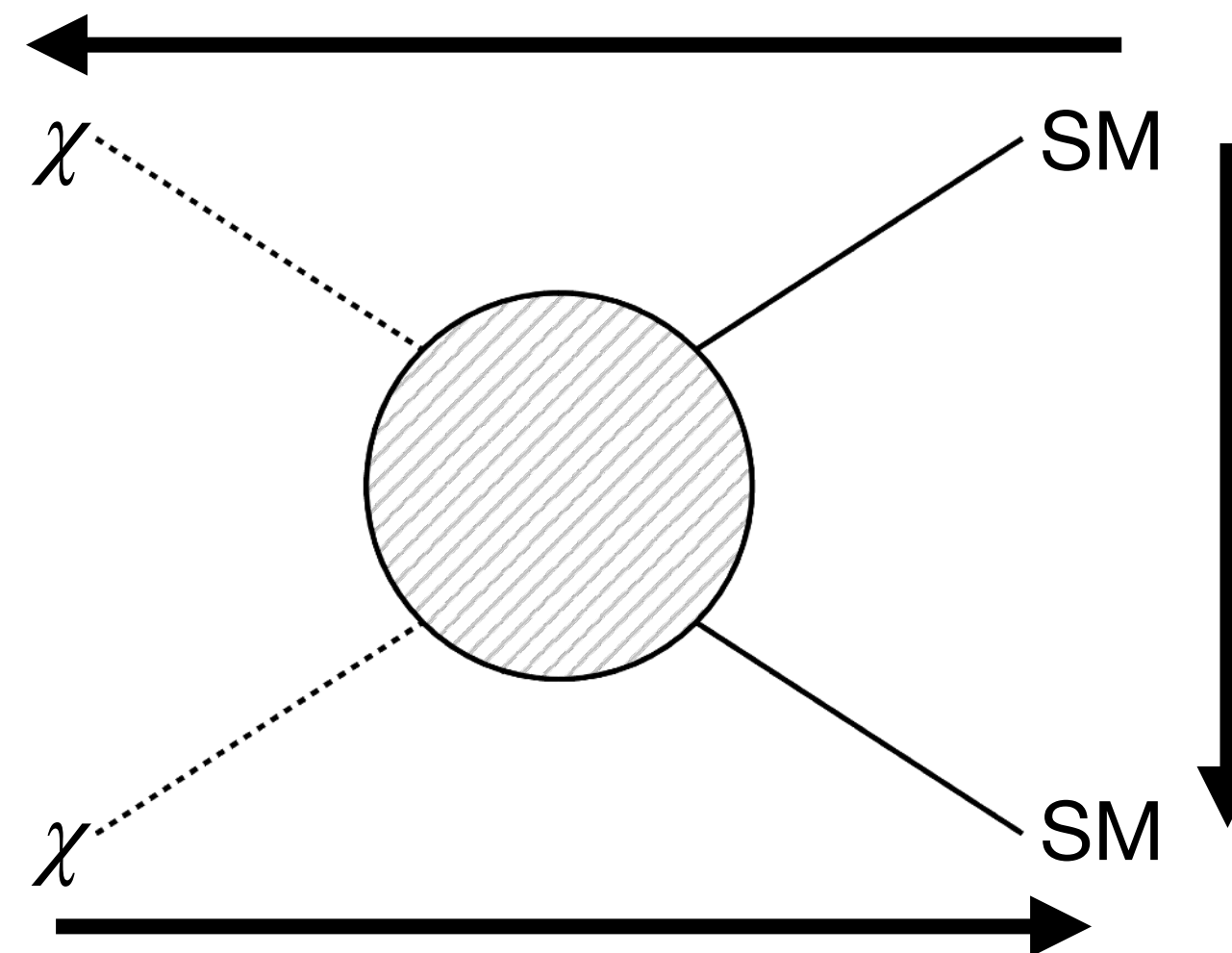
# Dark matter searches

## WIMP paradigm

- ▶ **Weakly interacting** (no electromagnetic or strong interaction) - Some interaction required for thermal equilibrium in early universe
- ▶ **Massive** (Cold Dark Matter)
- ▶ **Stable**

**Production:** search in collider -

Strongly model dependent



**Annihilation:** indirect search -

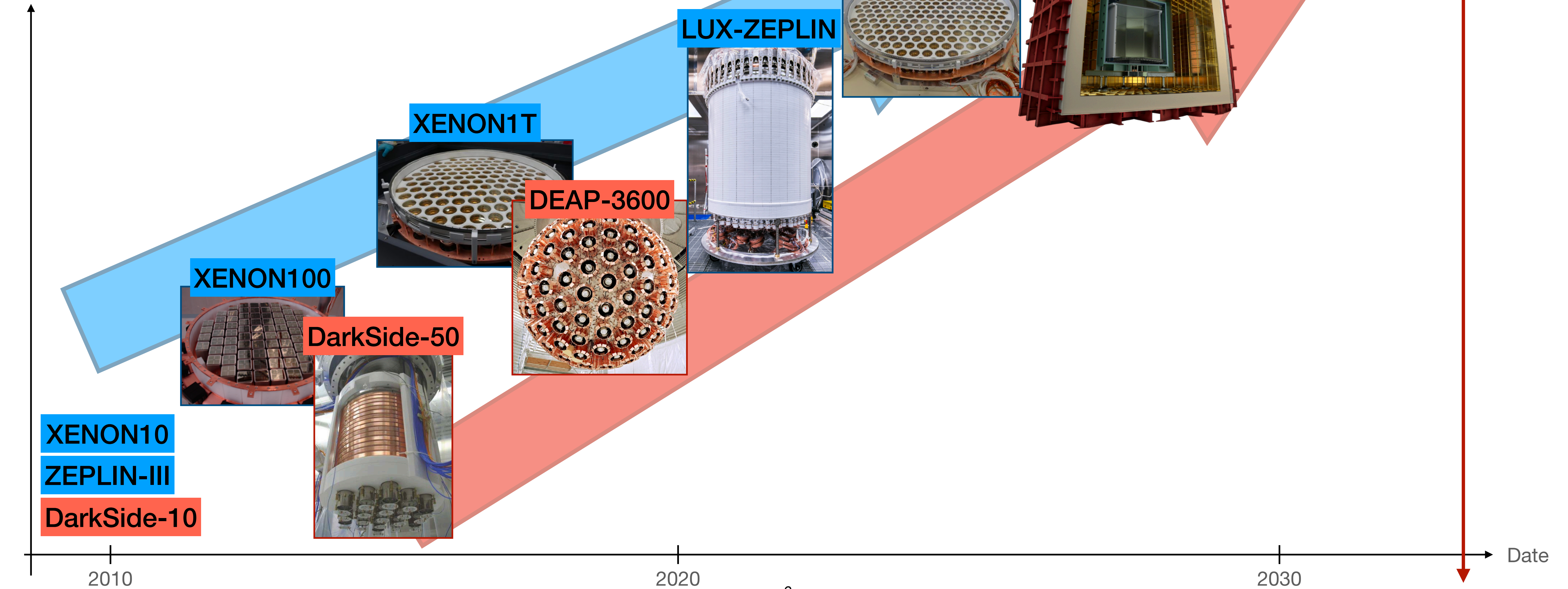
Complex background

**Collision:** direct search - Model independent, controlled background

# Direct dark matter search experiments

With noble liquids

Mass

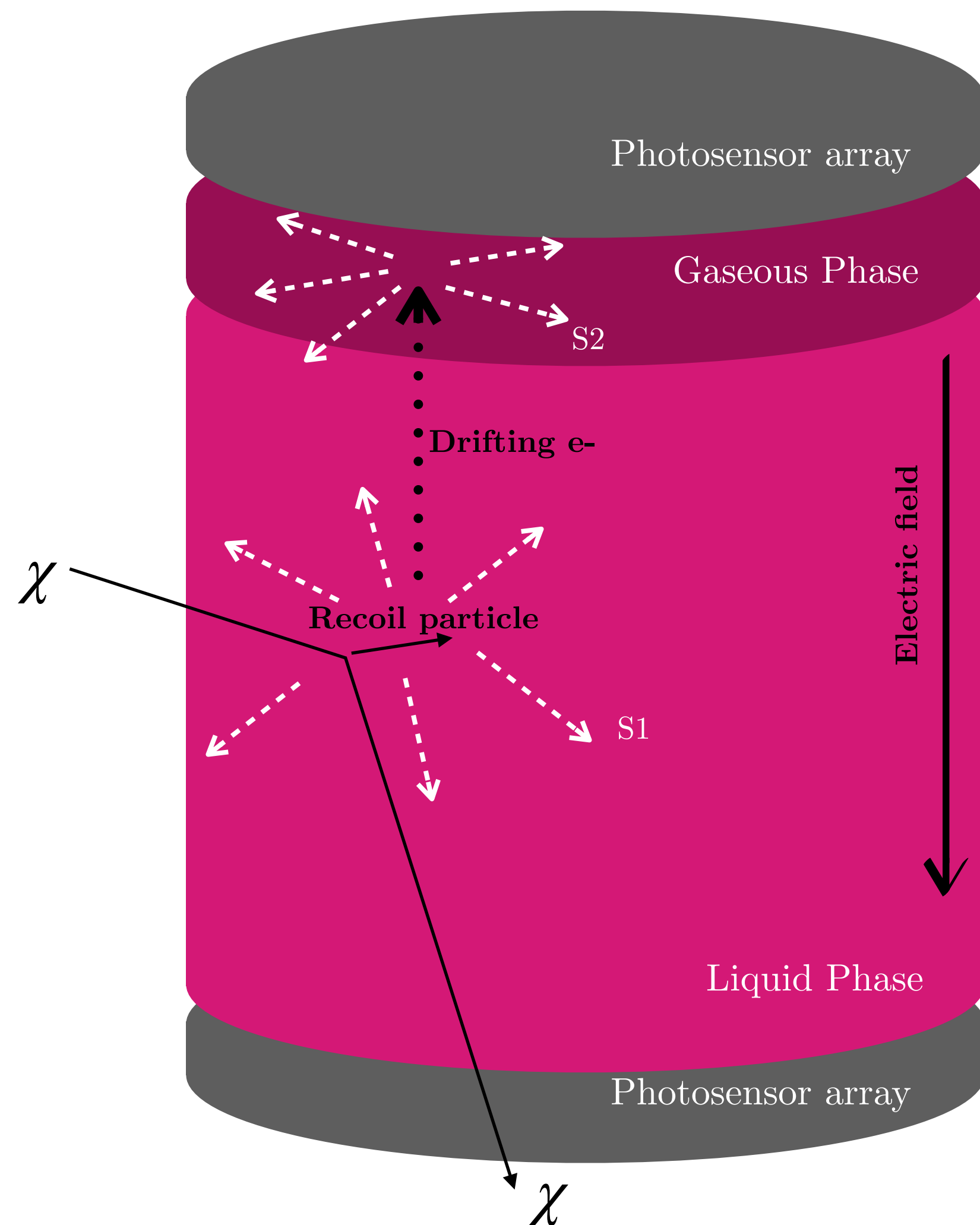


Cross-section sensitivity

Date

# Dual Phase Time Projection Chamber

## Working principle



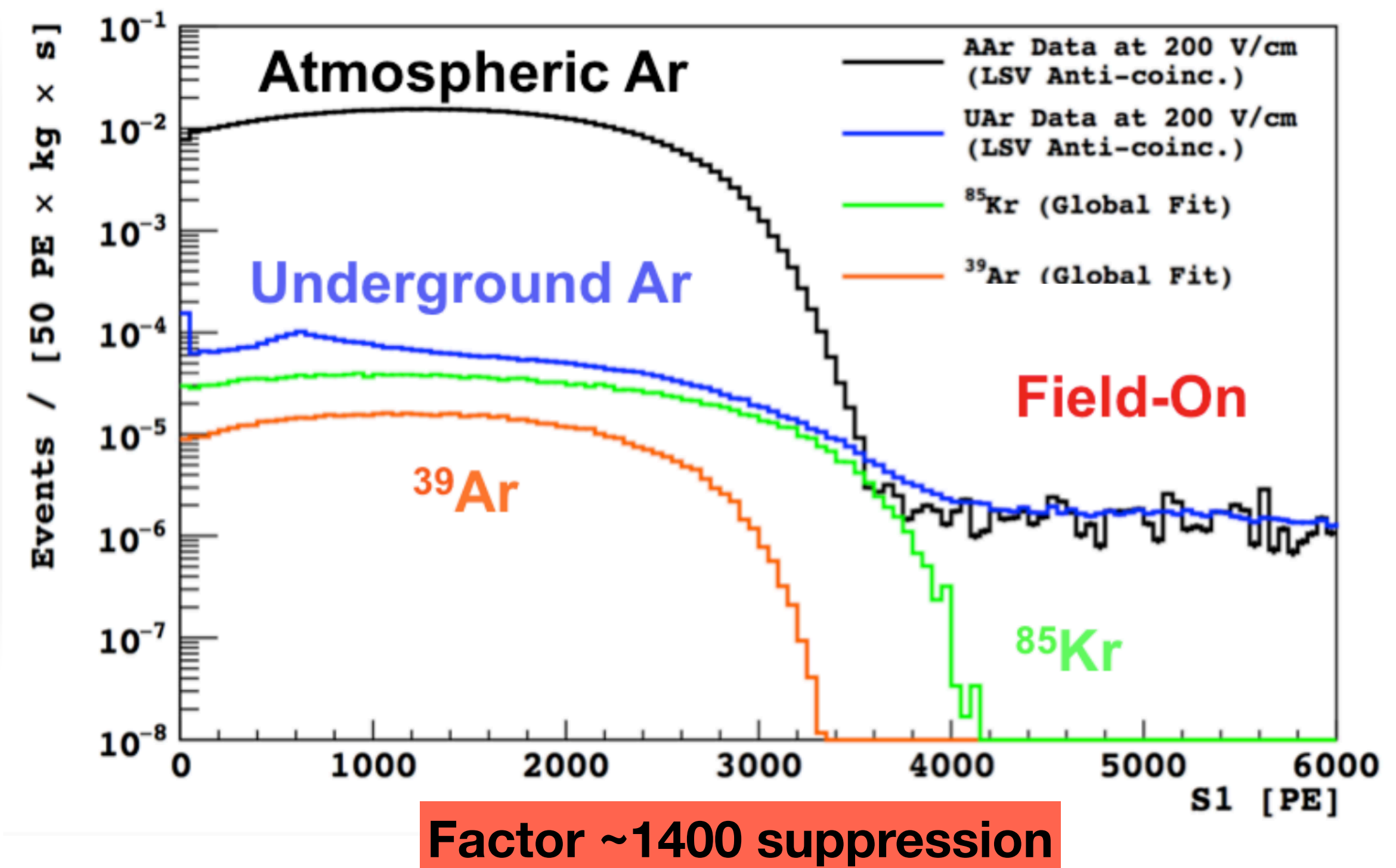
- ▶ Interacting particle induces **ER** or **NR**
- ▶ The recoil produces **scintillation (S1)** and ionization
- ▶ Ionization electrons are drifted and produce **electro-luminescence in the gas pocket (S2)**
- ▶ S1 and S2 lights are seen by **photosensor arrays** on top and bottom

# $^{39}\text{Ar}$ $\beta$ -emitter contamination

## Natural depletion in underground argon

$^{39}\text{Ar}$  produced in atmosphere by spallation of cosmic rays.

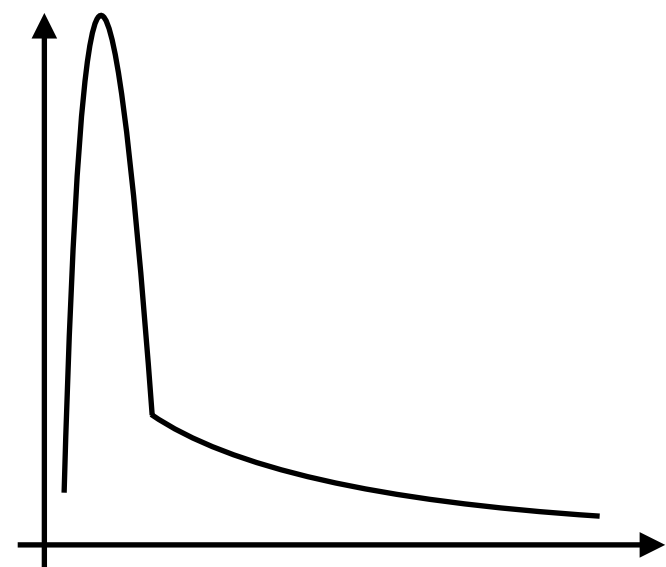
- ▶ **Underground argon** is naturally depleted.
- ▶ Extraction wells for large production.
- ▶ Urania facility in Colorado for extraction and purification (99.99% purity).



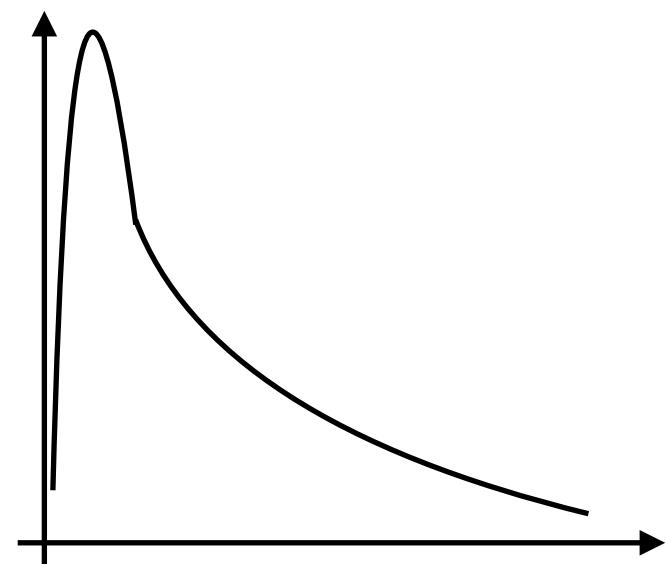


# Why liquid argon?

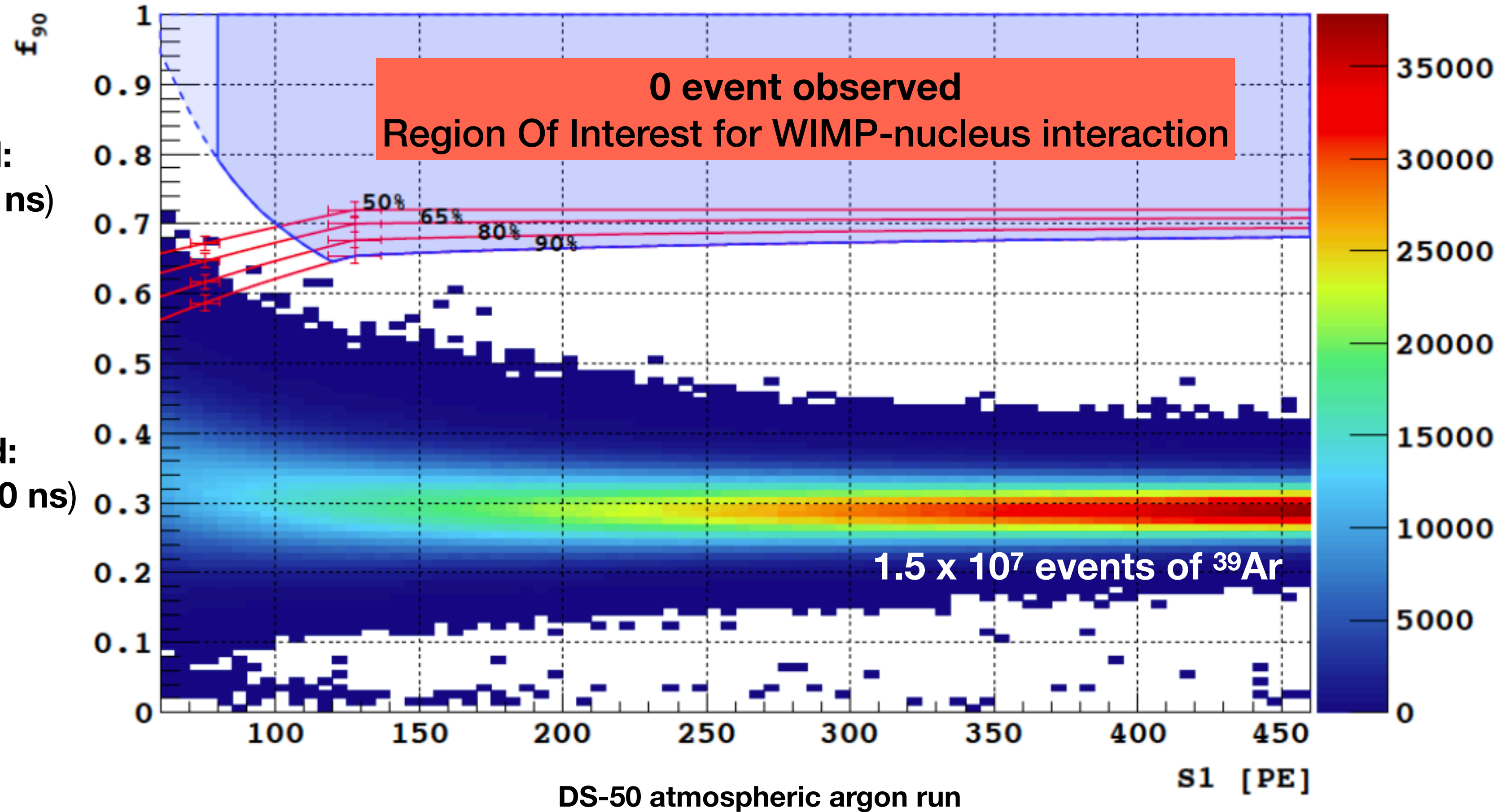
## Pulse shape discrimination



**Nuclear recoil band:**  
mostly singlet states (6 ns)



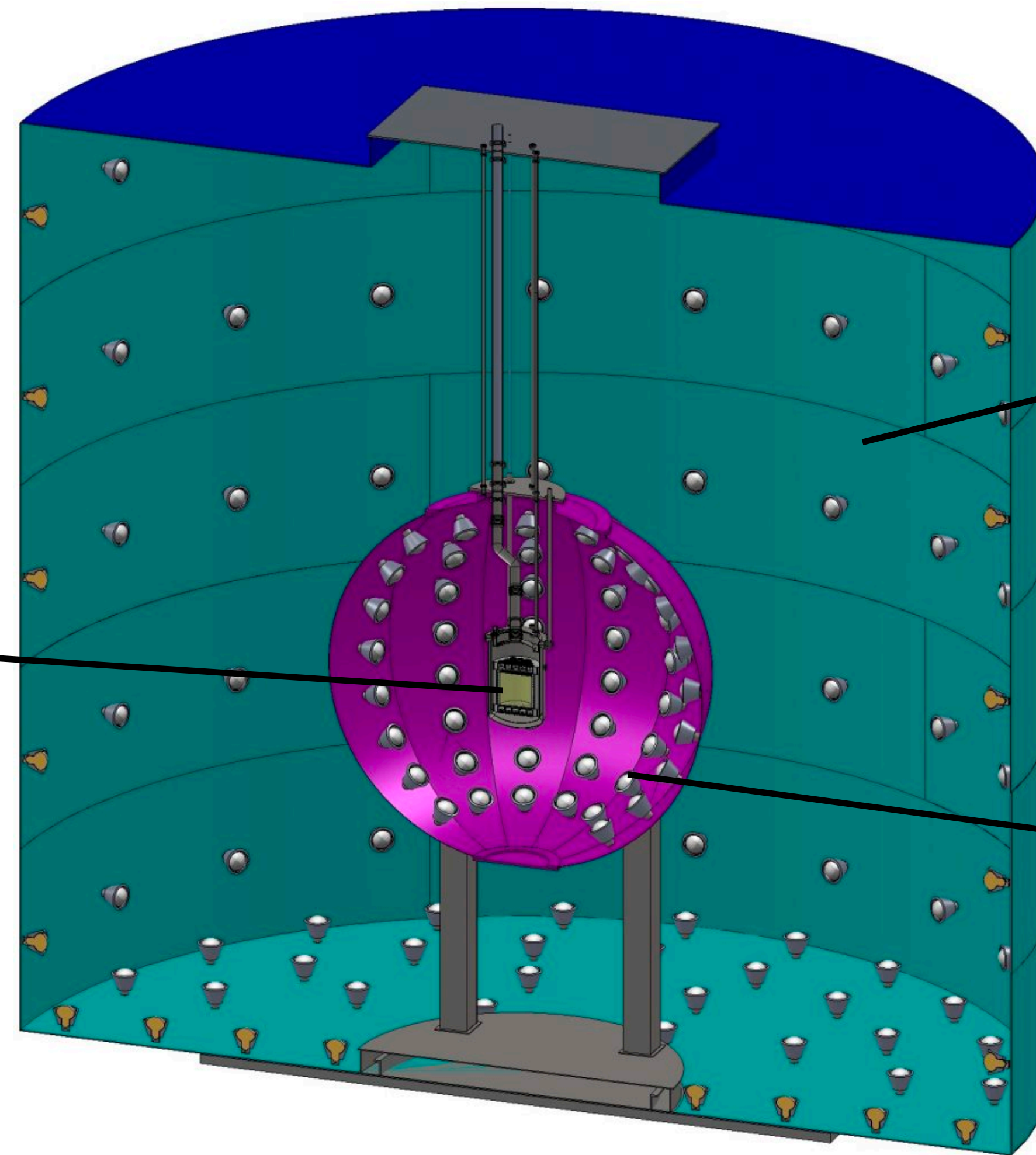
**Electron recoil band:**  
mostly triplet states (1600 ns)



# DarkSide-50

A first successful milestone

- Dual Phase Time Projection Chamber**
- 46.6 kg of UAr
  - 1 cm thick gas pocket
  - 2x19 Photo-Multiplier Tubes



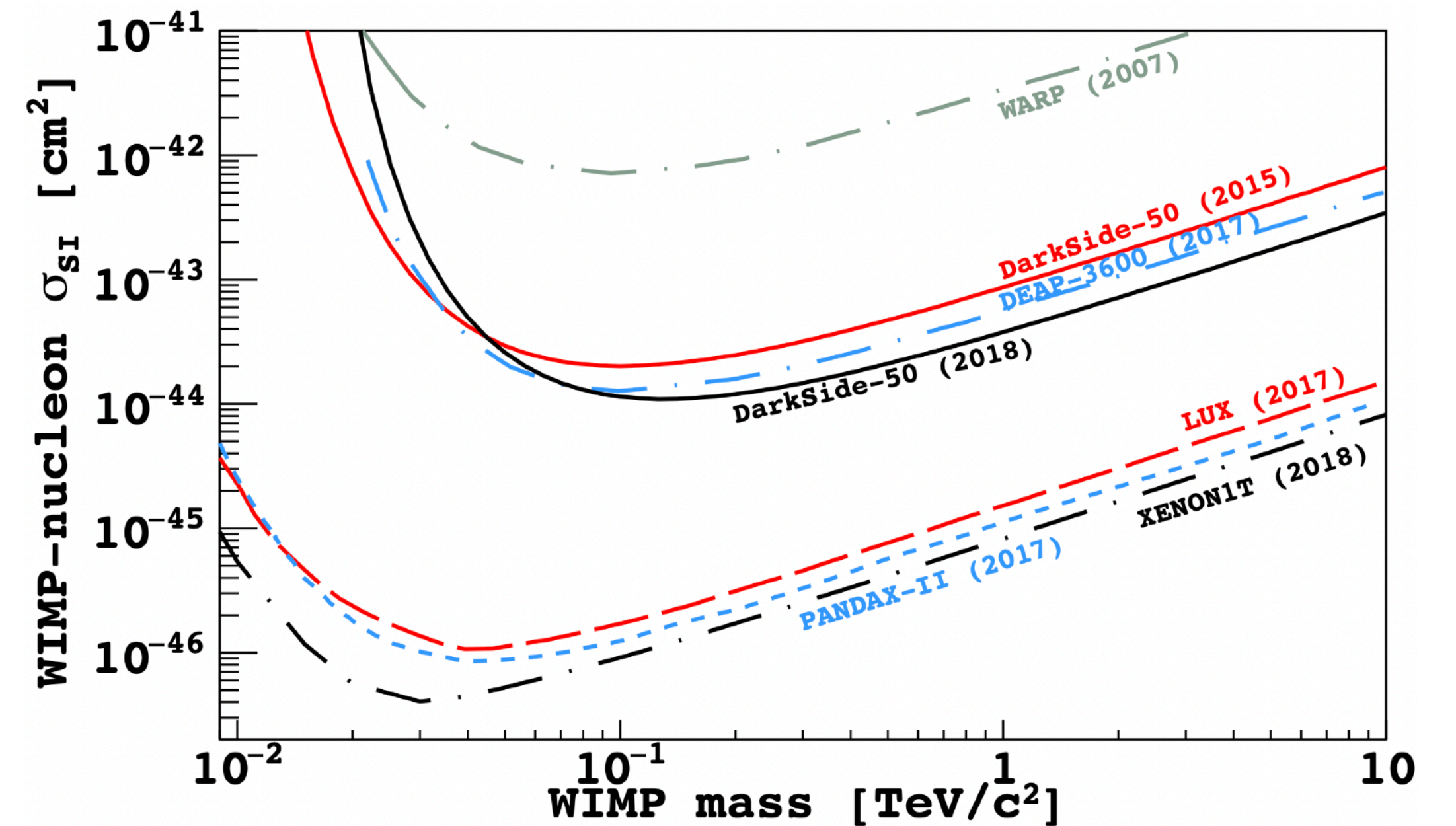
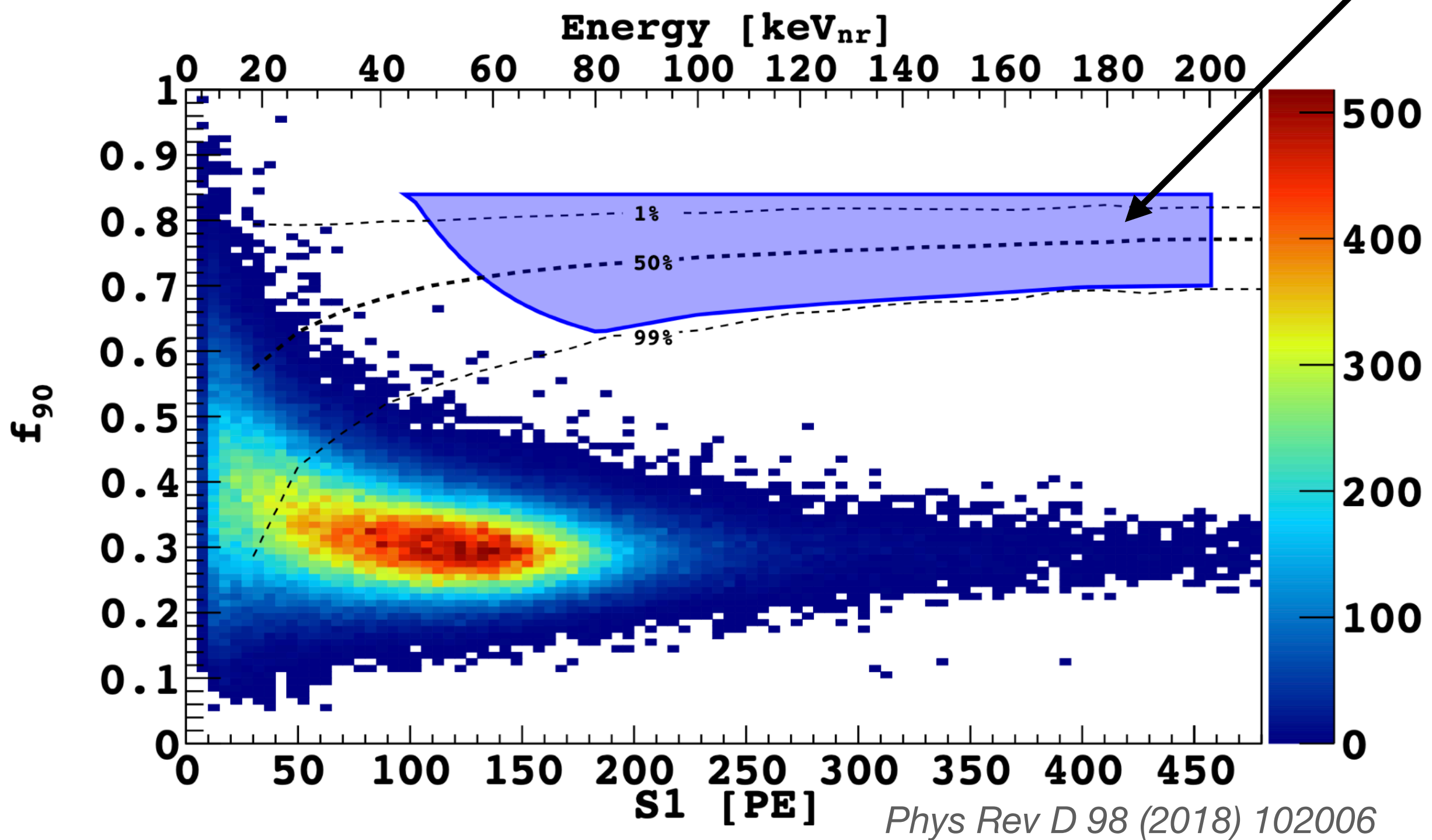
- Water Cerenkov veto**
- Neutron shielding and  $\mu$  detection
  - 1000 tonnes of purified water

- Liquid scintillator veto**
- Neutron and  $\gamma$  tagging
  - 30-tonnes of boron-loaded scintillator

# Results after 532 days exposure

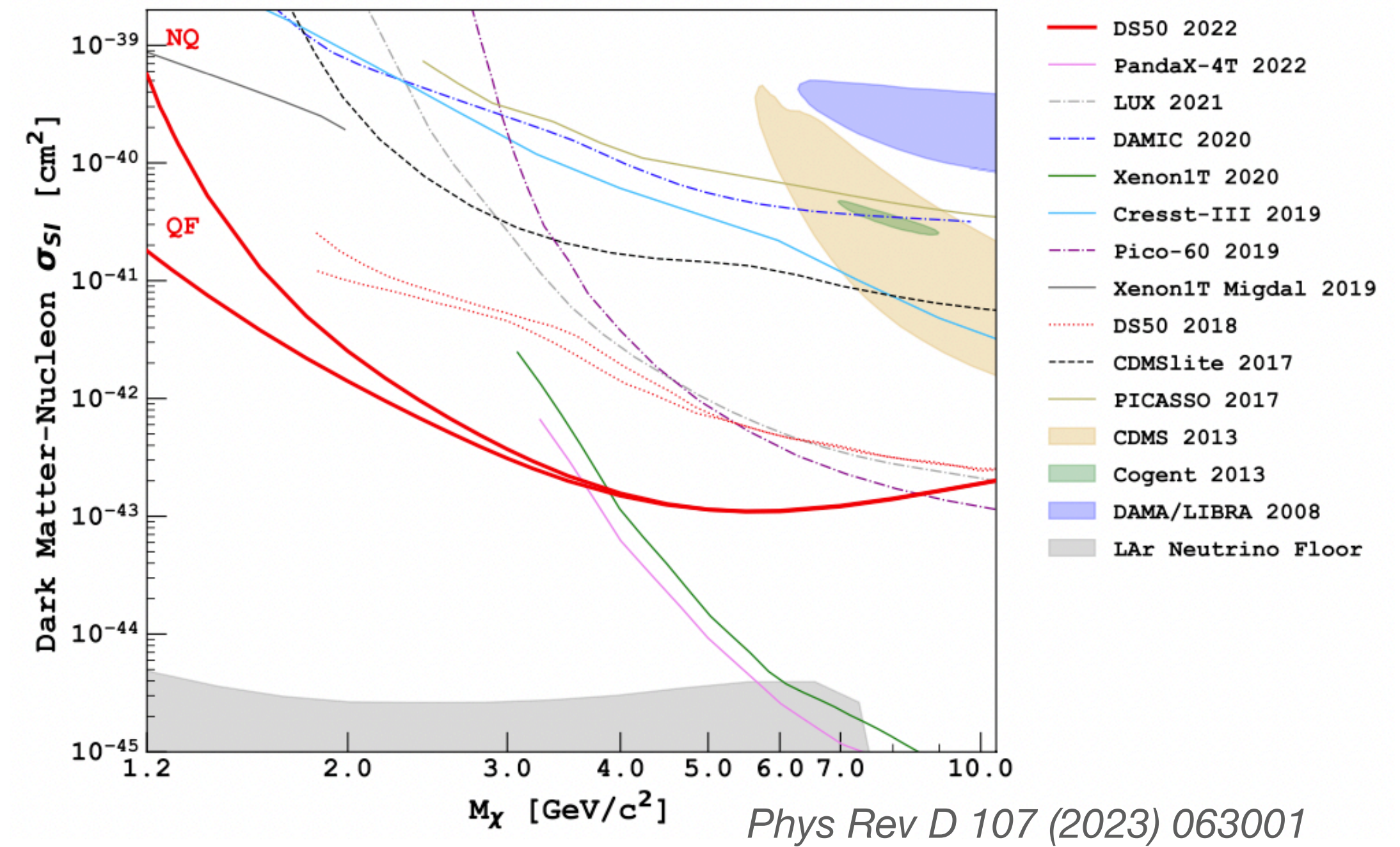
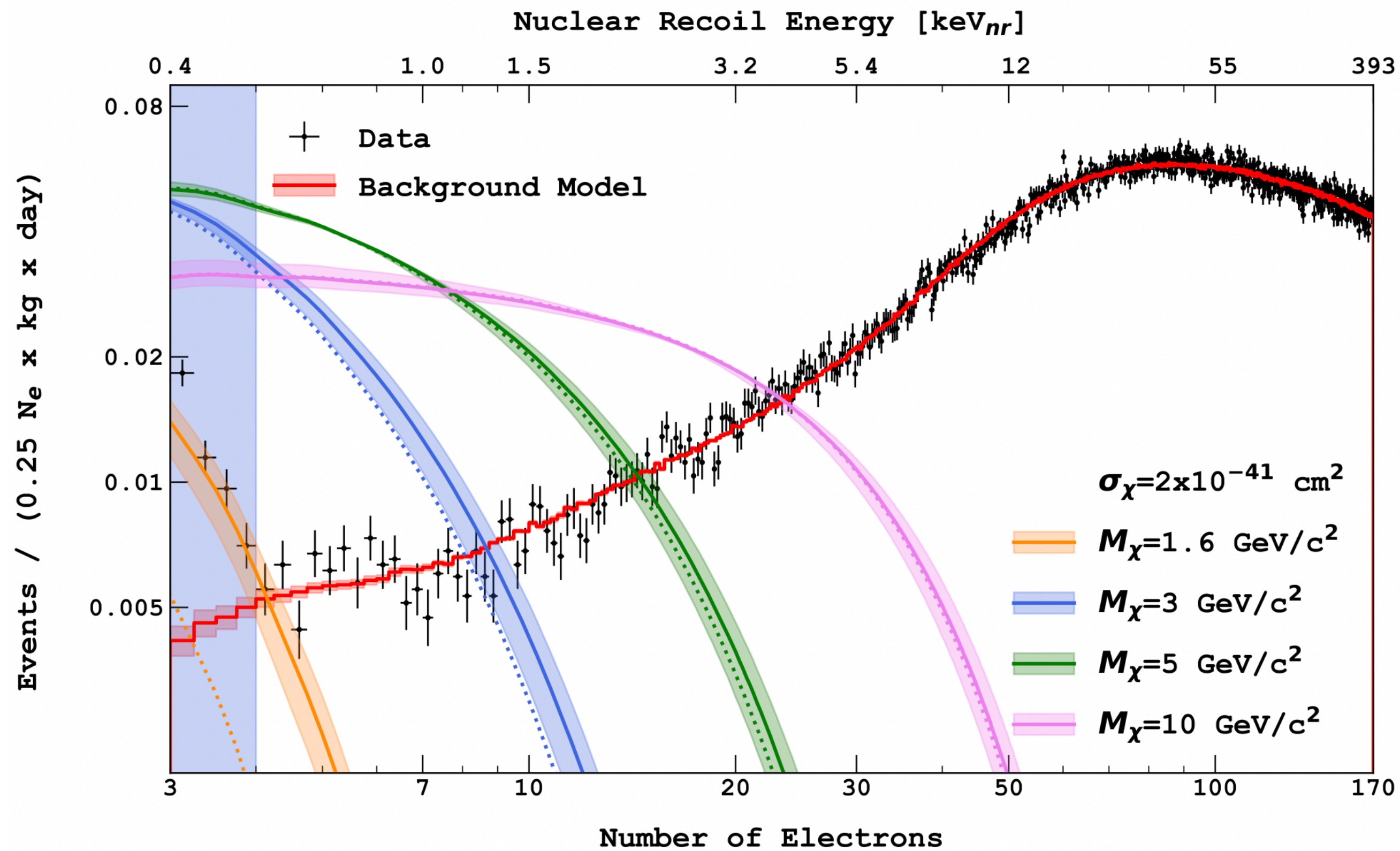
## Standard analysis

Empty ROI after all selection cuts  
Exclusion limit down to  $\sim 10^{-44}$   $\text{cm}^2$  at high mass (100  $\text{GeV}/c^2$ )



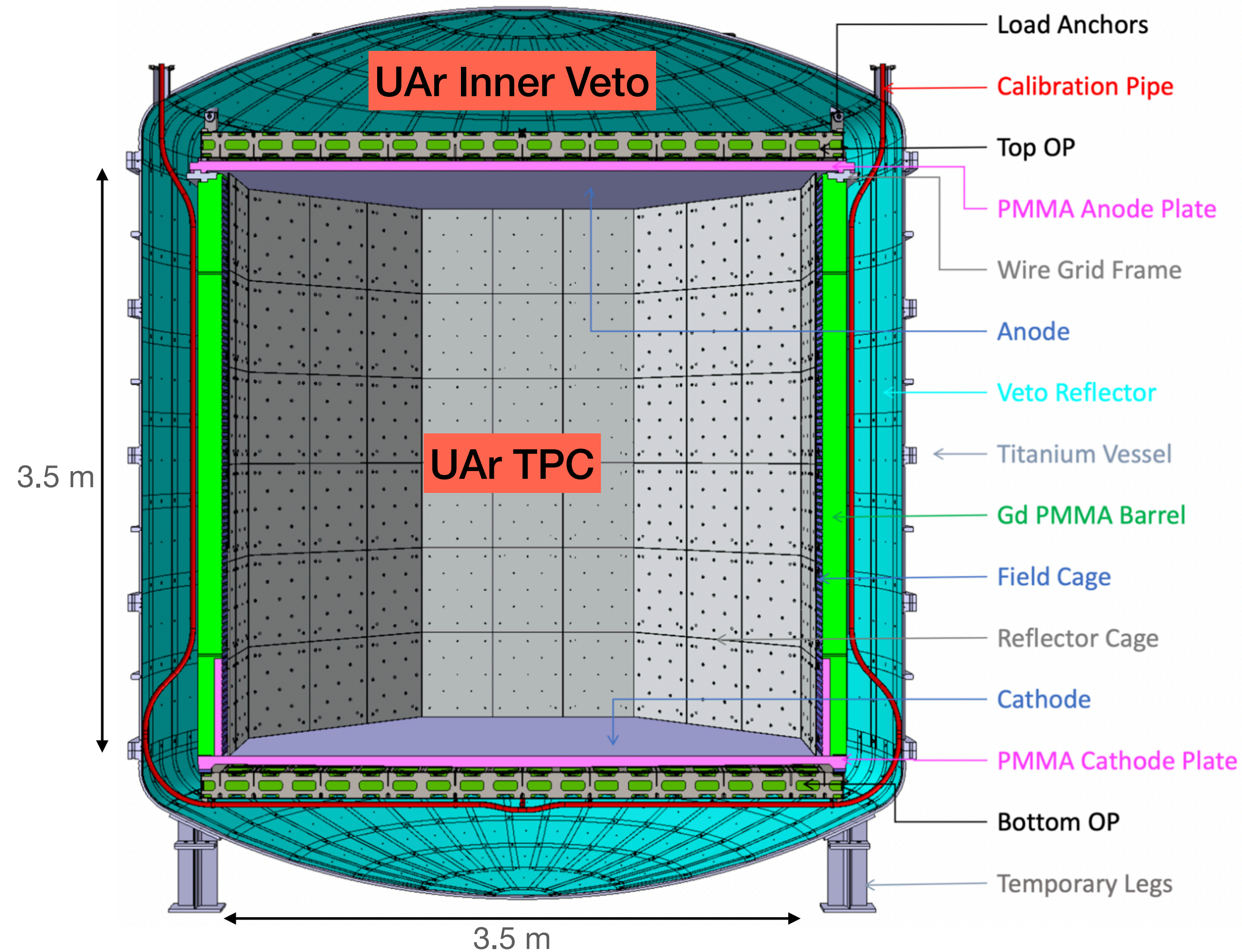
# Results after 532 days exposure

## Low mass analysis using ionization channel only



# Moving on to DarkSide-20k

## Down to the neutrino floor

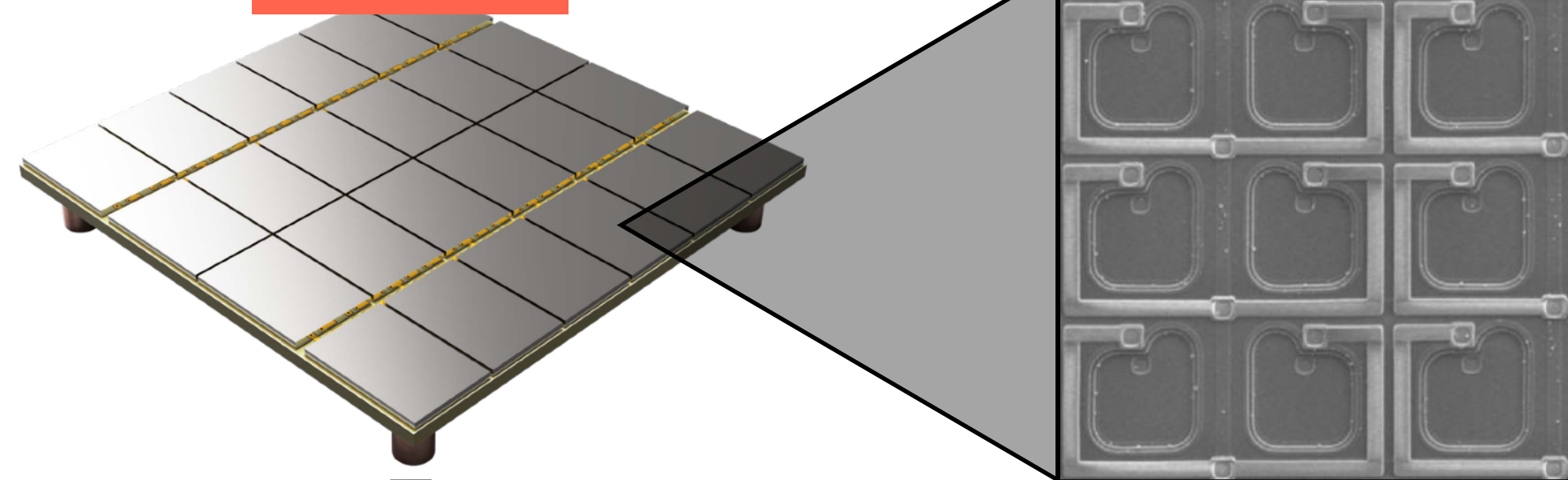


- **Larger volume:** 1 day of DS-20k has the same exposure as DS-50 full data taking.
- **TPC:** 50 tons of UAr, 20 tons fiducial.
- **Inner veto:** 32 tons of UAr.
- **SiPMs** instead of PMTs: better radio-purity.

# DS-20k photo-detection

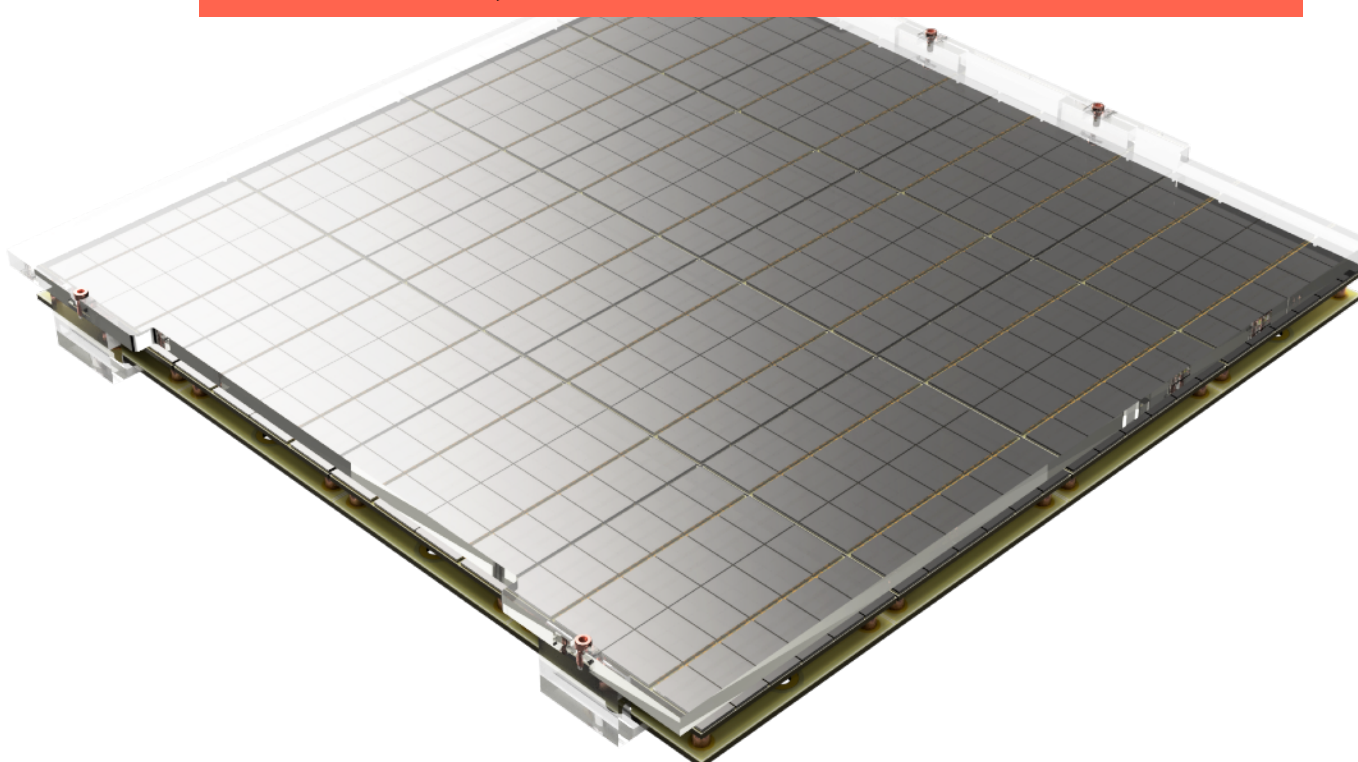
In TPC and inner veto

Tile  
24 SiPMs

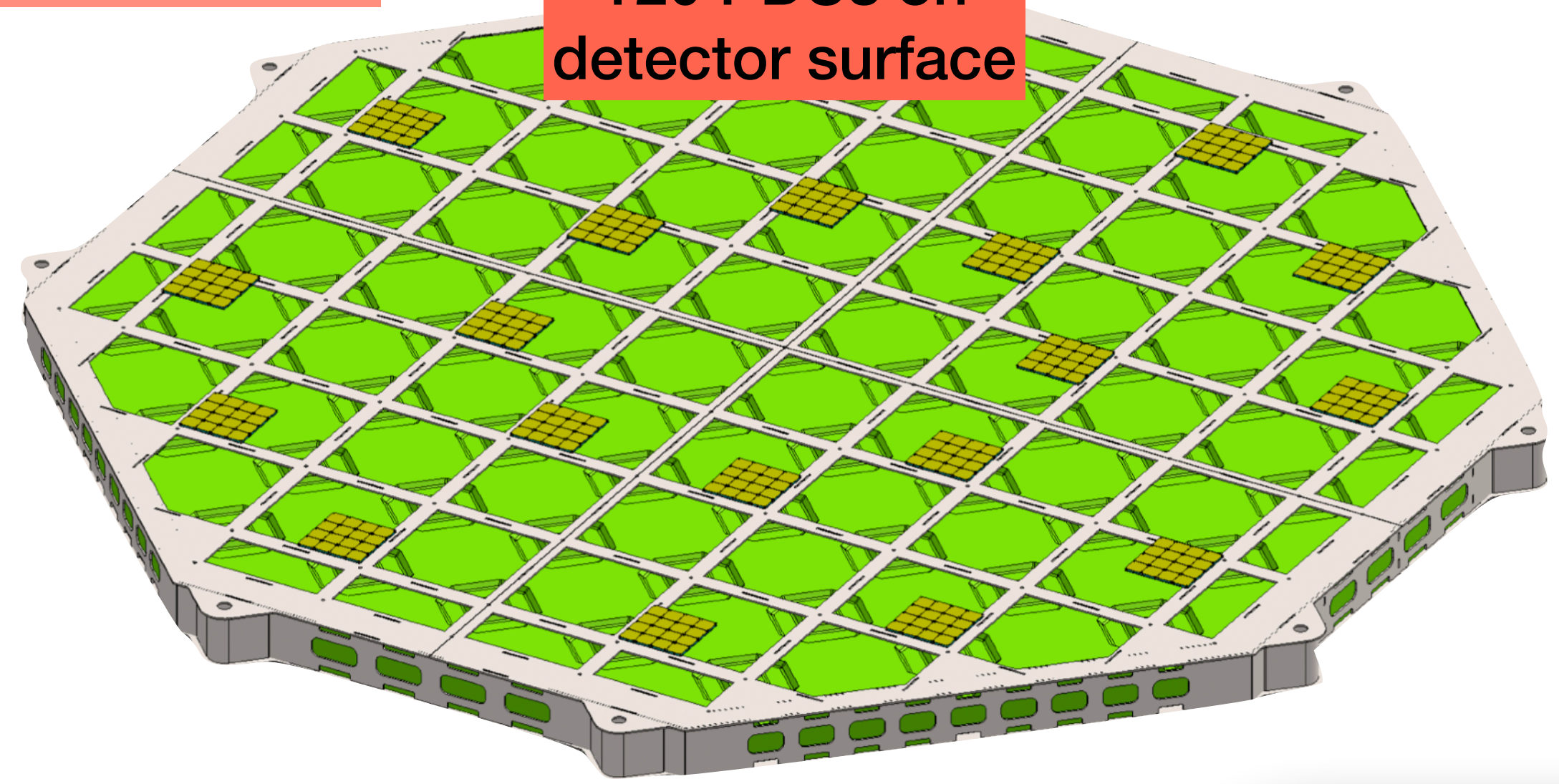


30  $\mu\text{m}$

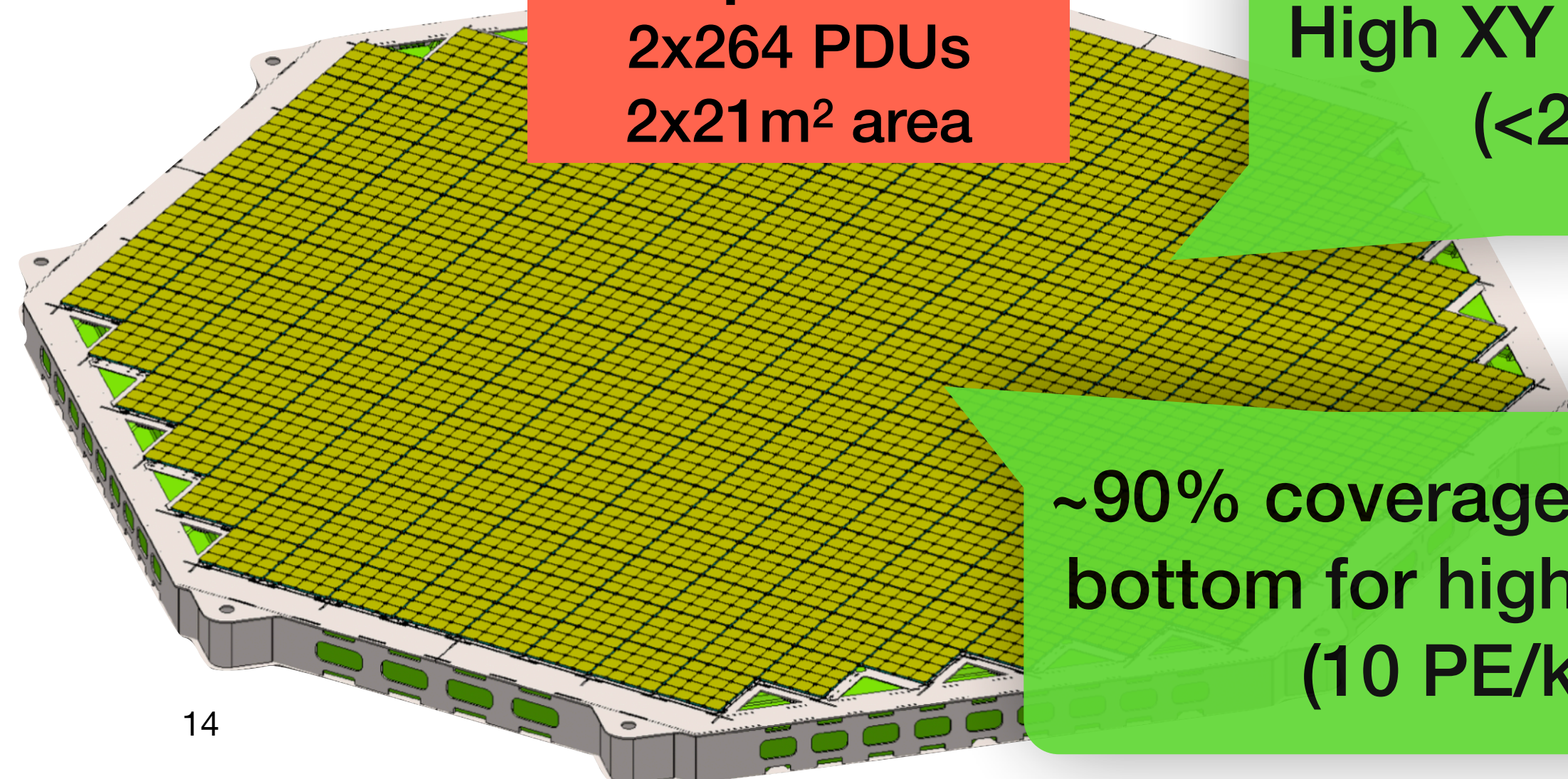
Photo-Detection Unit  
16 tiles, 4 readout channels



Inner veto  
120 PDUs on  
detector surface



TPC Optical Plane  
2x264 PDUs  
2x21 m<sup>2</sup> area

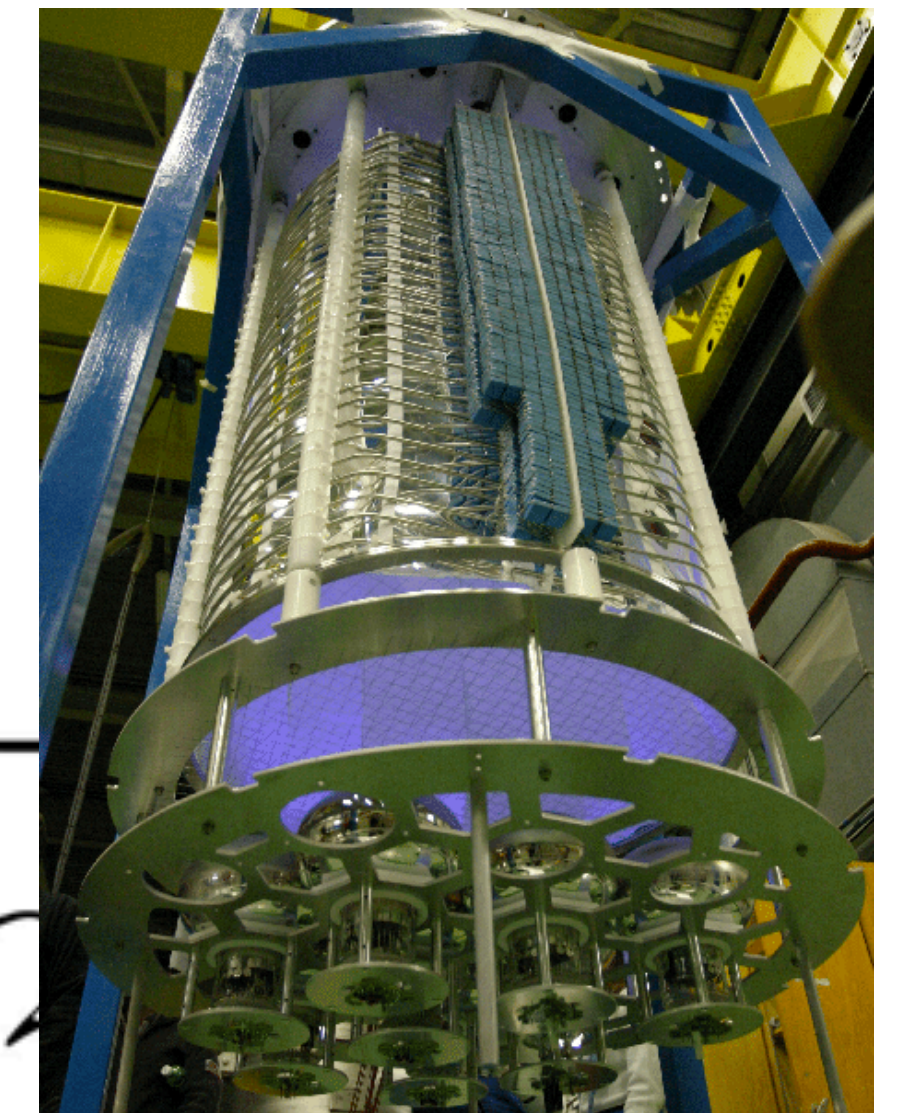
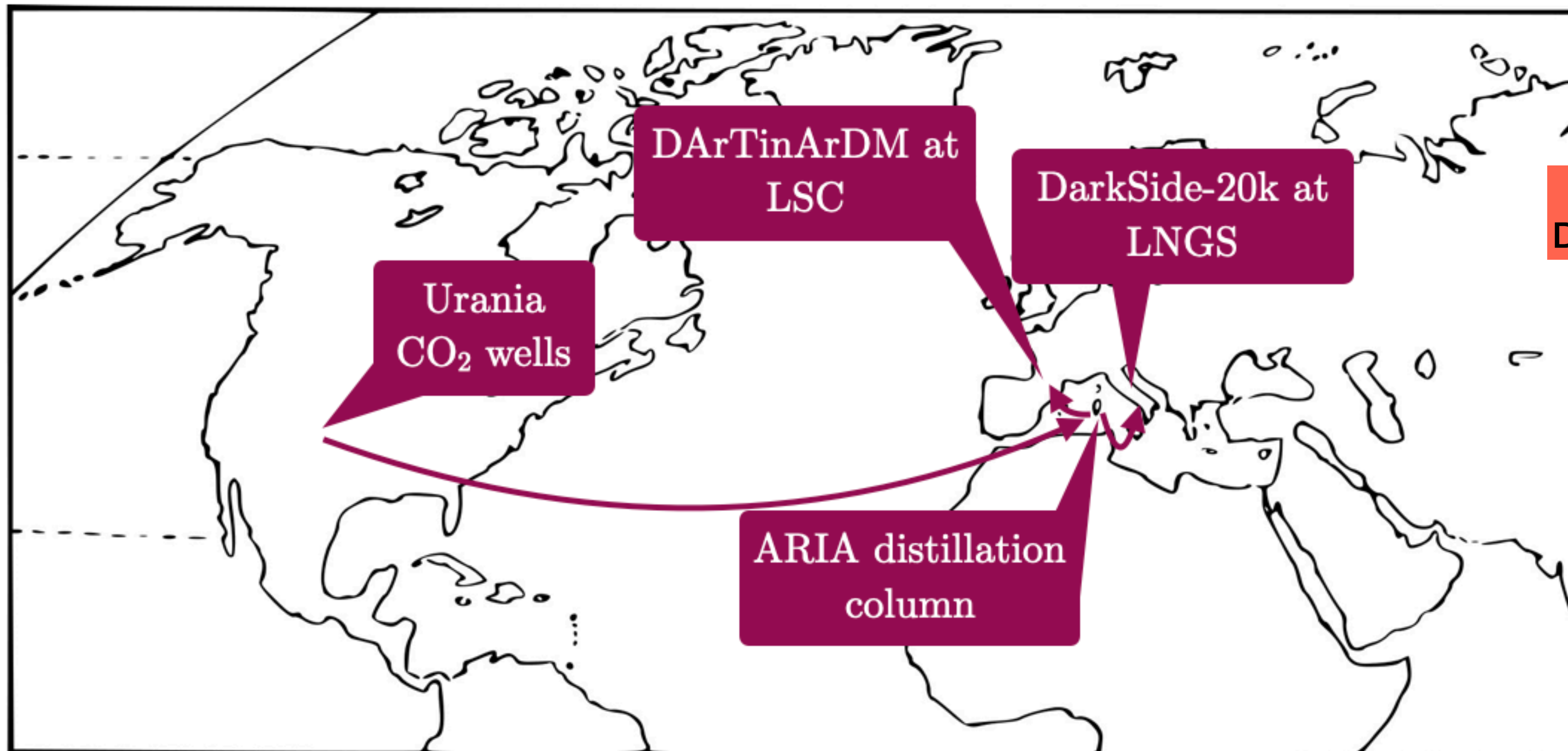


High XY resolution  
( $<2$  cm)

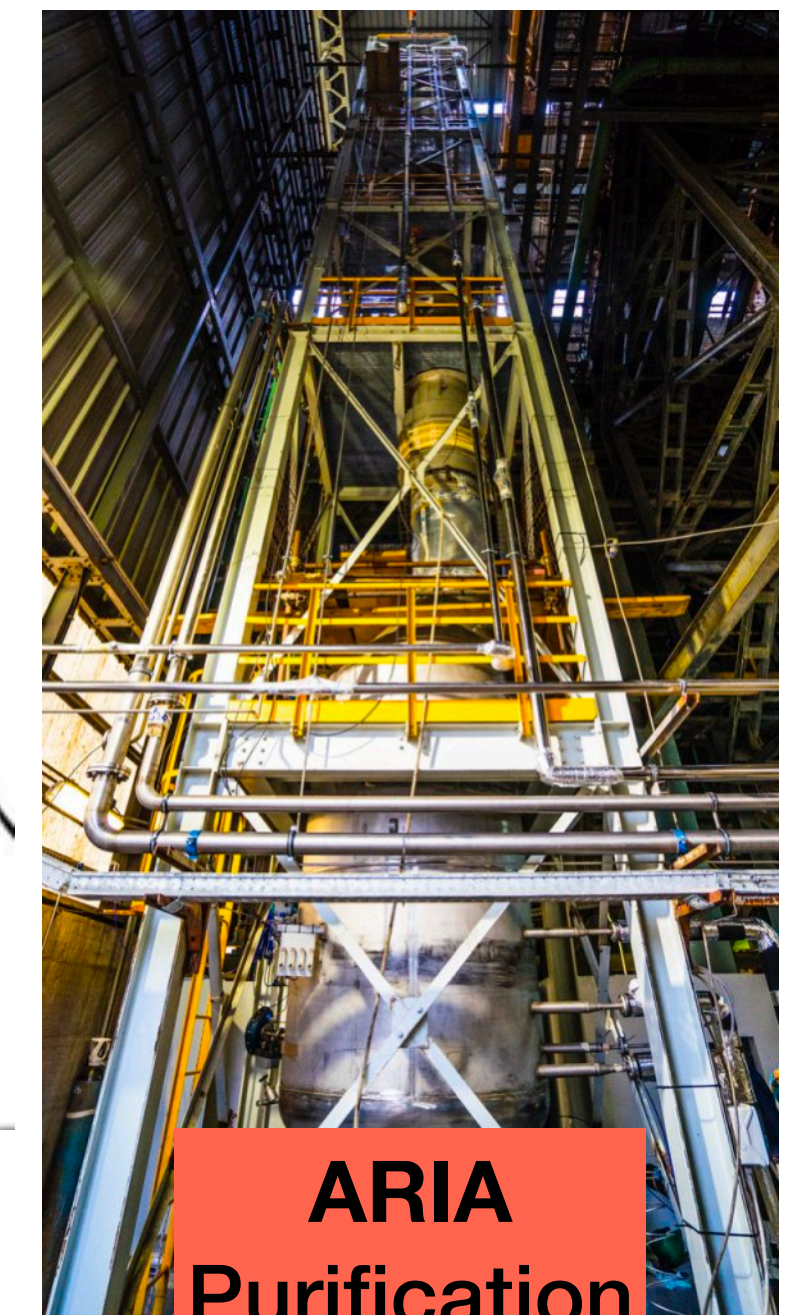
~90% coverage of top and  
bottom for high light yield  
(10 PE/keV)

# Argon 39 depletion

From the extraction to Gran Sasso



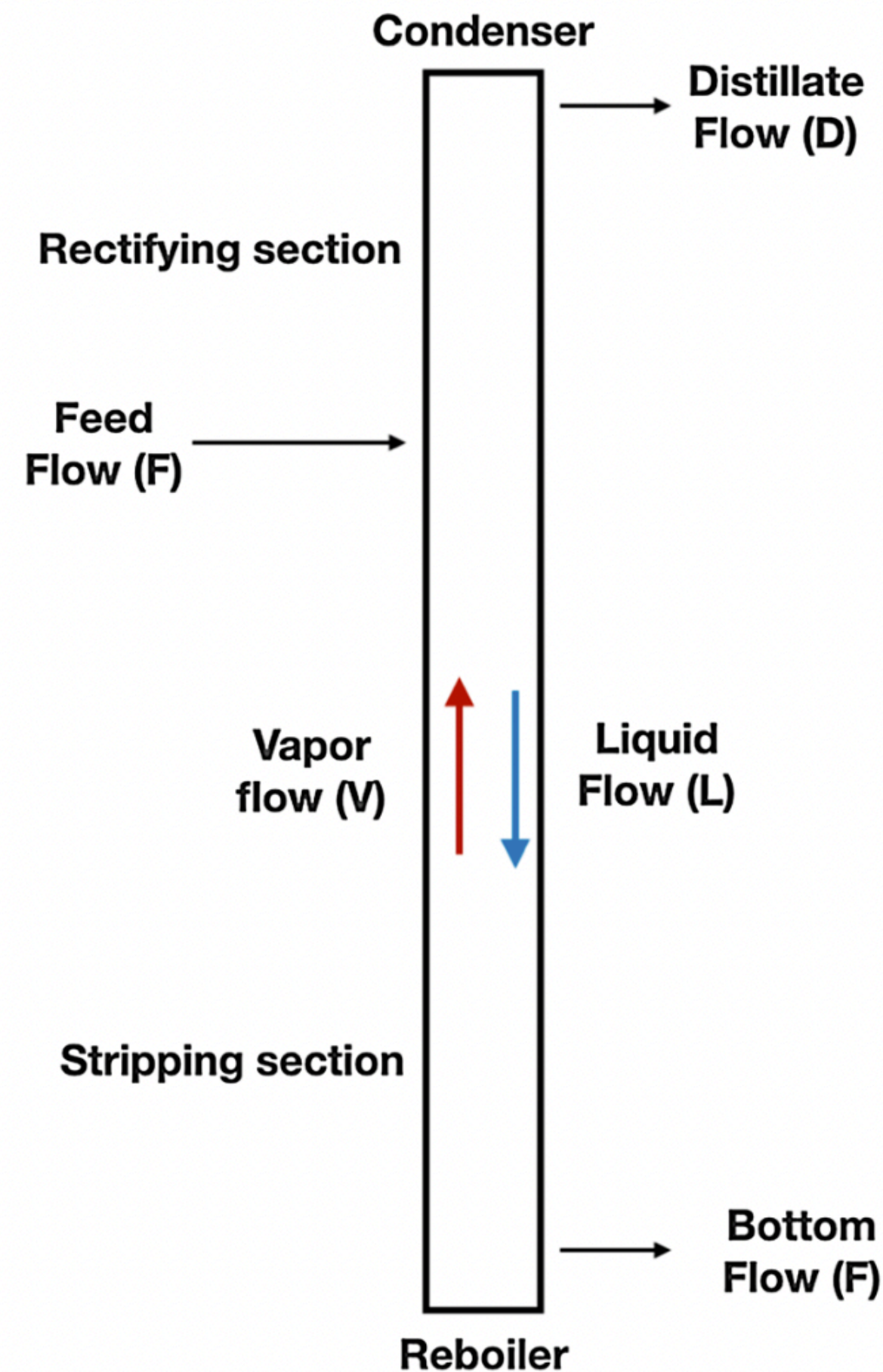
**DArTinArDM**  
Depletion measurement



**ARIA**  
Purification

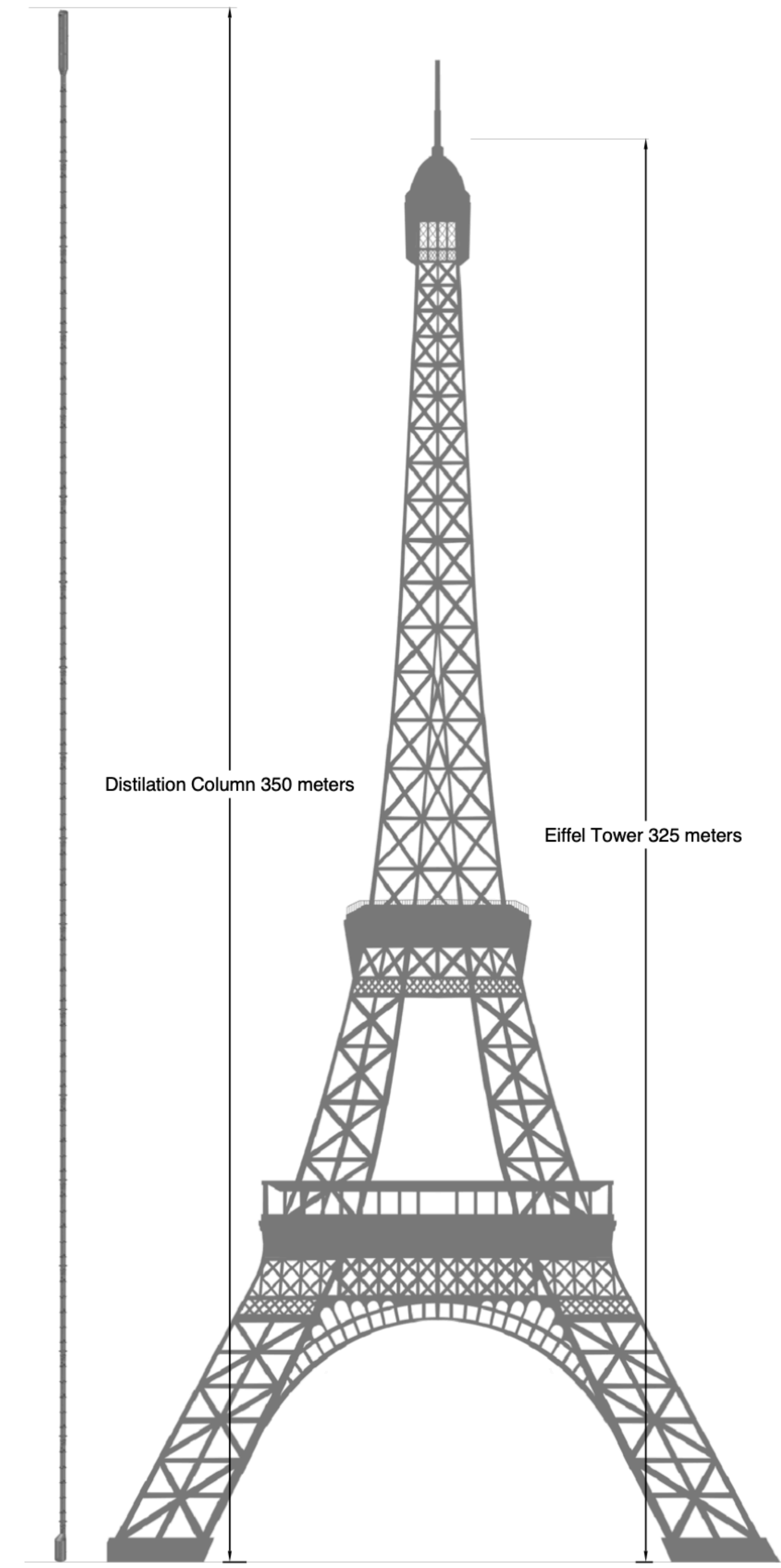
# ARIA distillation column

For purification and  $^{39}\text{Ar}$ - $^{40}\text{Ar}$  separation



The highest distillation column in the world, currently under assembly:

- ▶ Chemical purification rate: **1t/day**
- ▶ Argon purity to **ppt ( $10^{-12}$ )**
- ▶ Relative volatility of  $^{39}\text{Ar}$  with respect to  $^{40}\text{Ar}$ : 1.0015
- ▶ Isotope purification rate: O(10) kg/day (not needed to reach DS20k sensitivity)

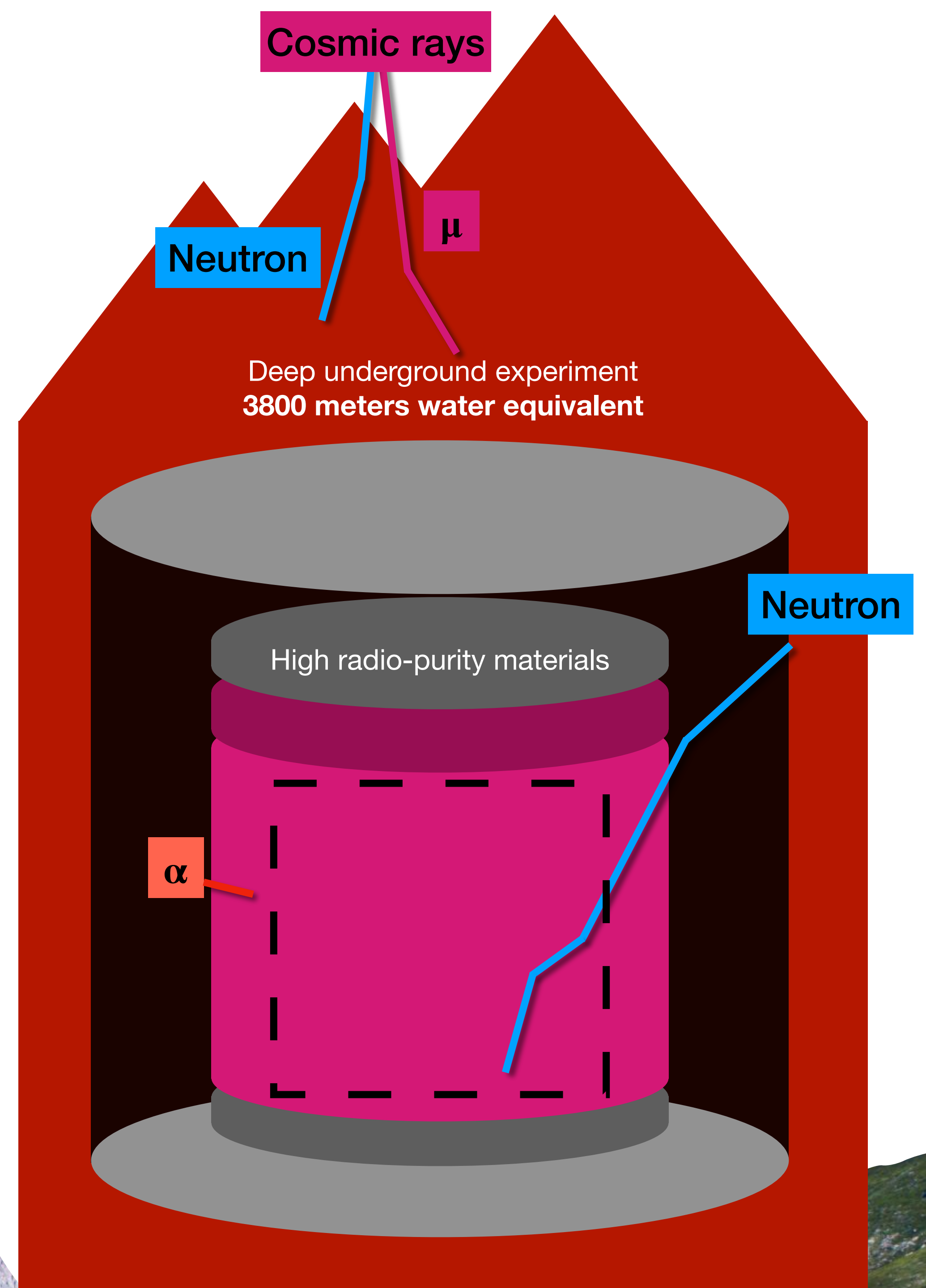




# Background

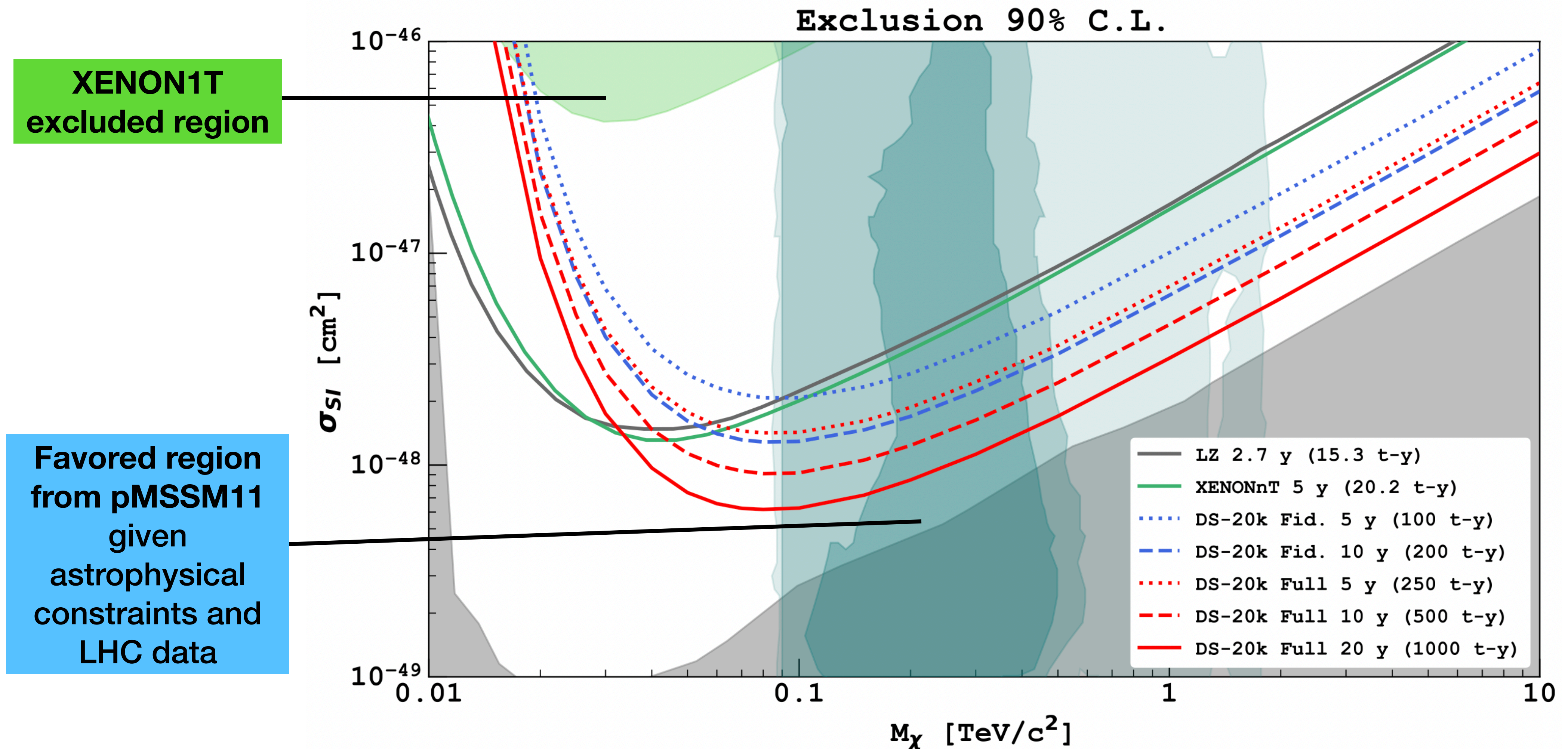
## Mitigation and rejection

- ▶ LNGS underground laboratory at Gran Sasso.
- ▶ Anti-coincidence with **veto**s.
- ▶ Rejecting **multiple scattering** events.
- ▶ **Fiducialisation** to reject materials radioactivity.



# DS-20k expected limits

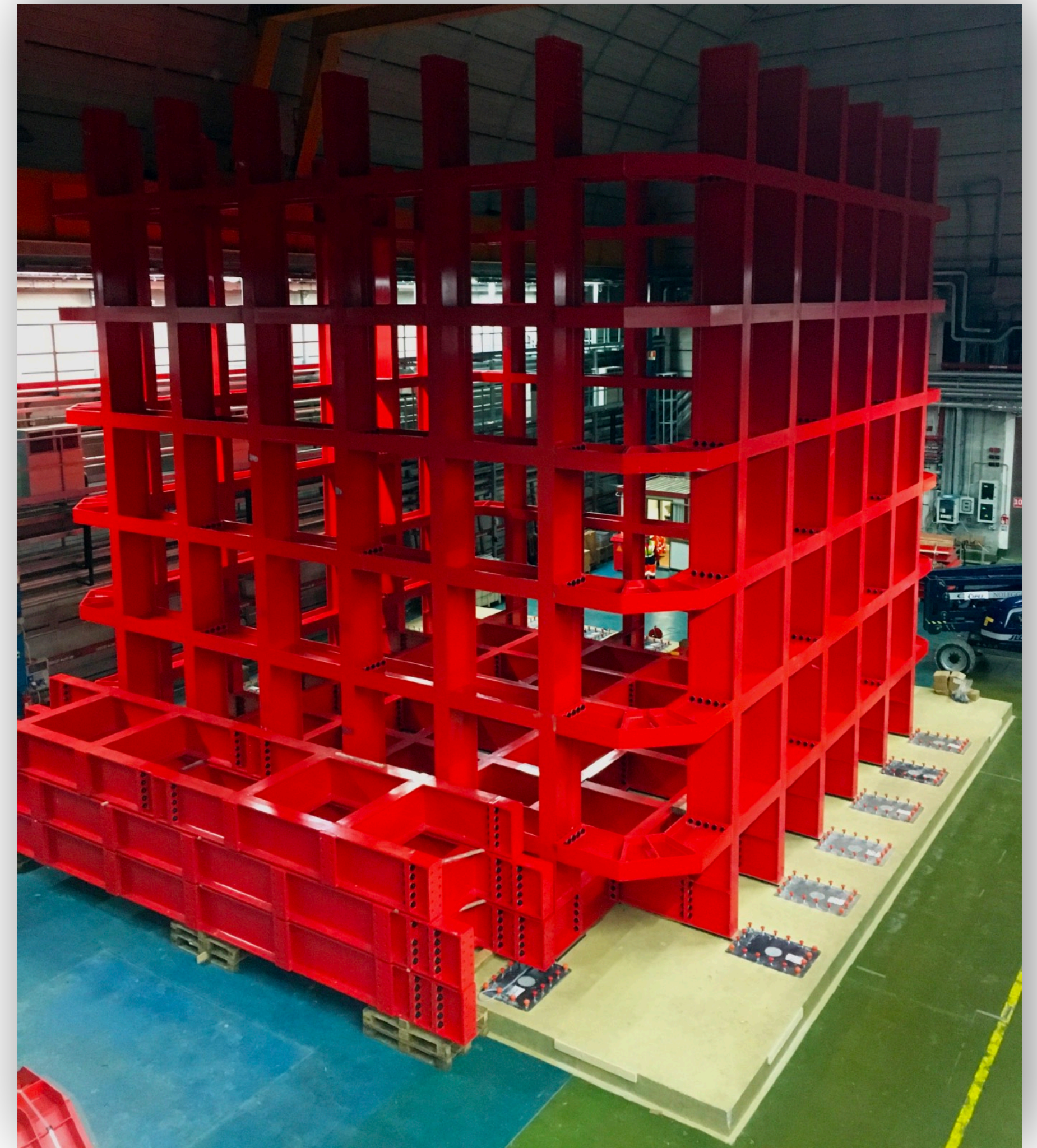
High discovery potential for the next direct search generation



# Conclusion

## Unprecedented physics reach

- ▶ **Construction started** (infrastructures and photo-electronics).
- ▶ Data taking starting in 2026.
- ▶ Other physics case (super-nova neutrino alarm)

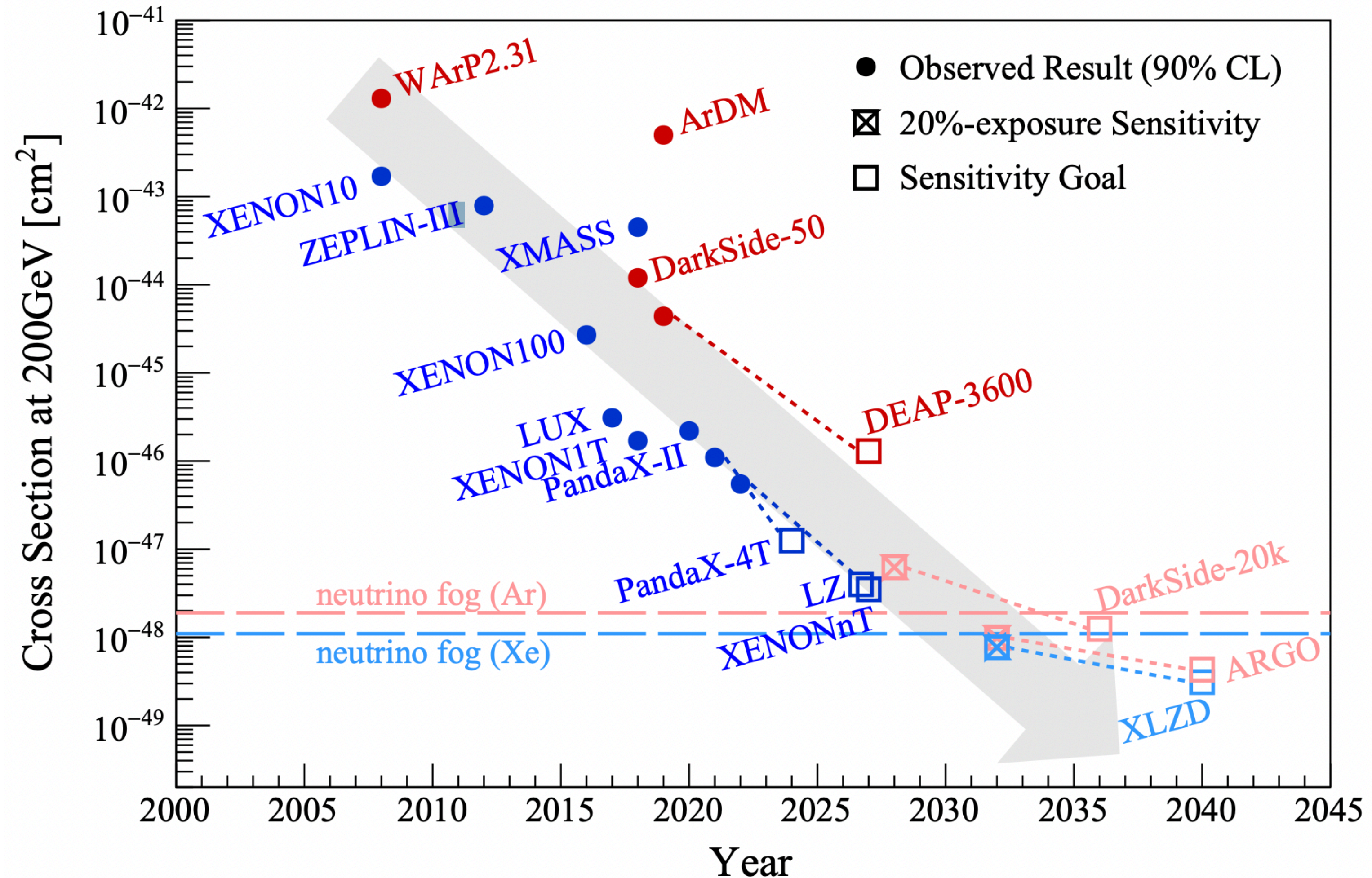


Thank you for your attention

**Backup slides**

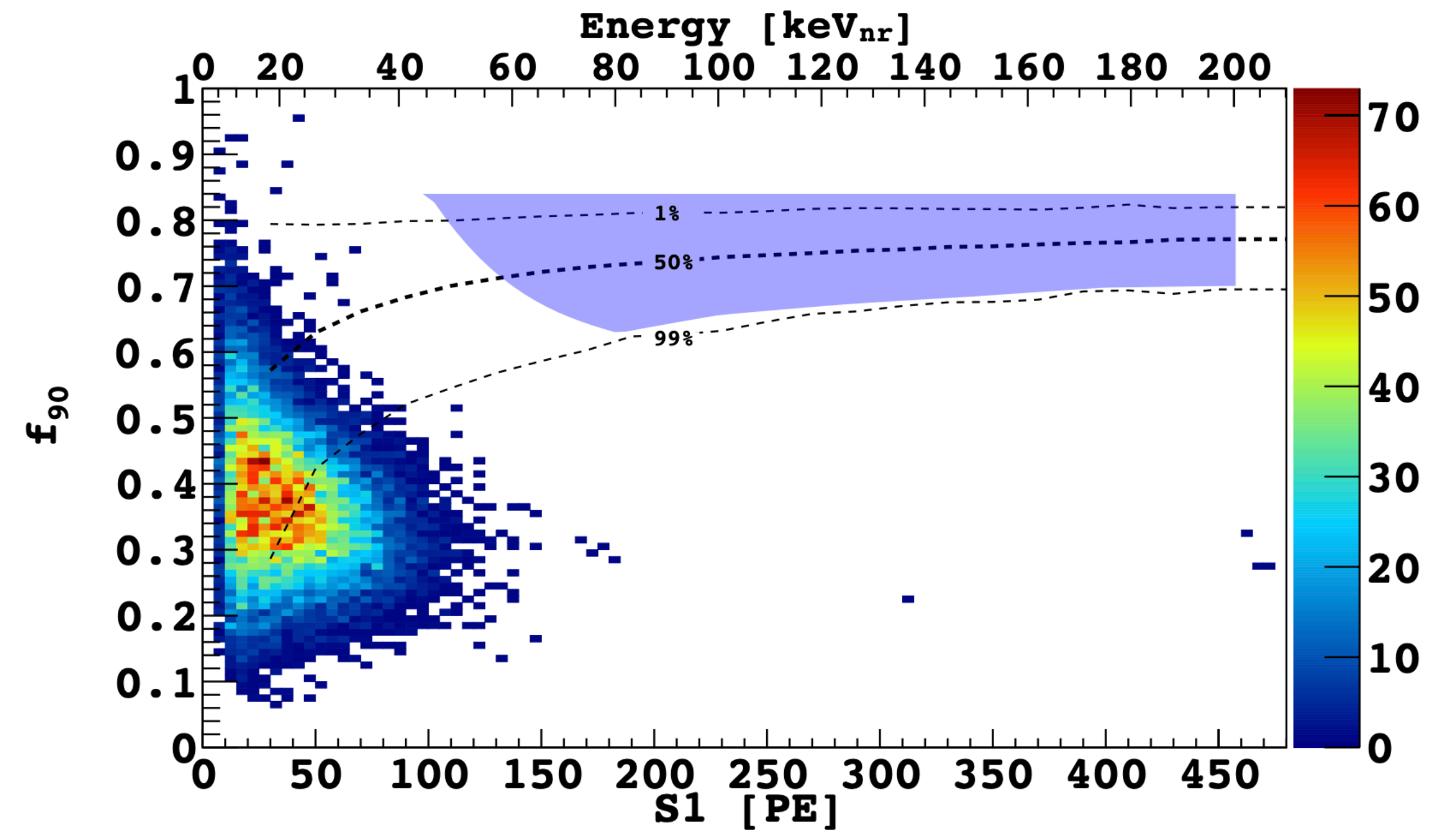
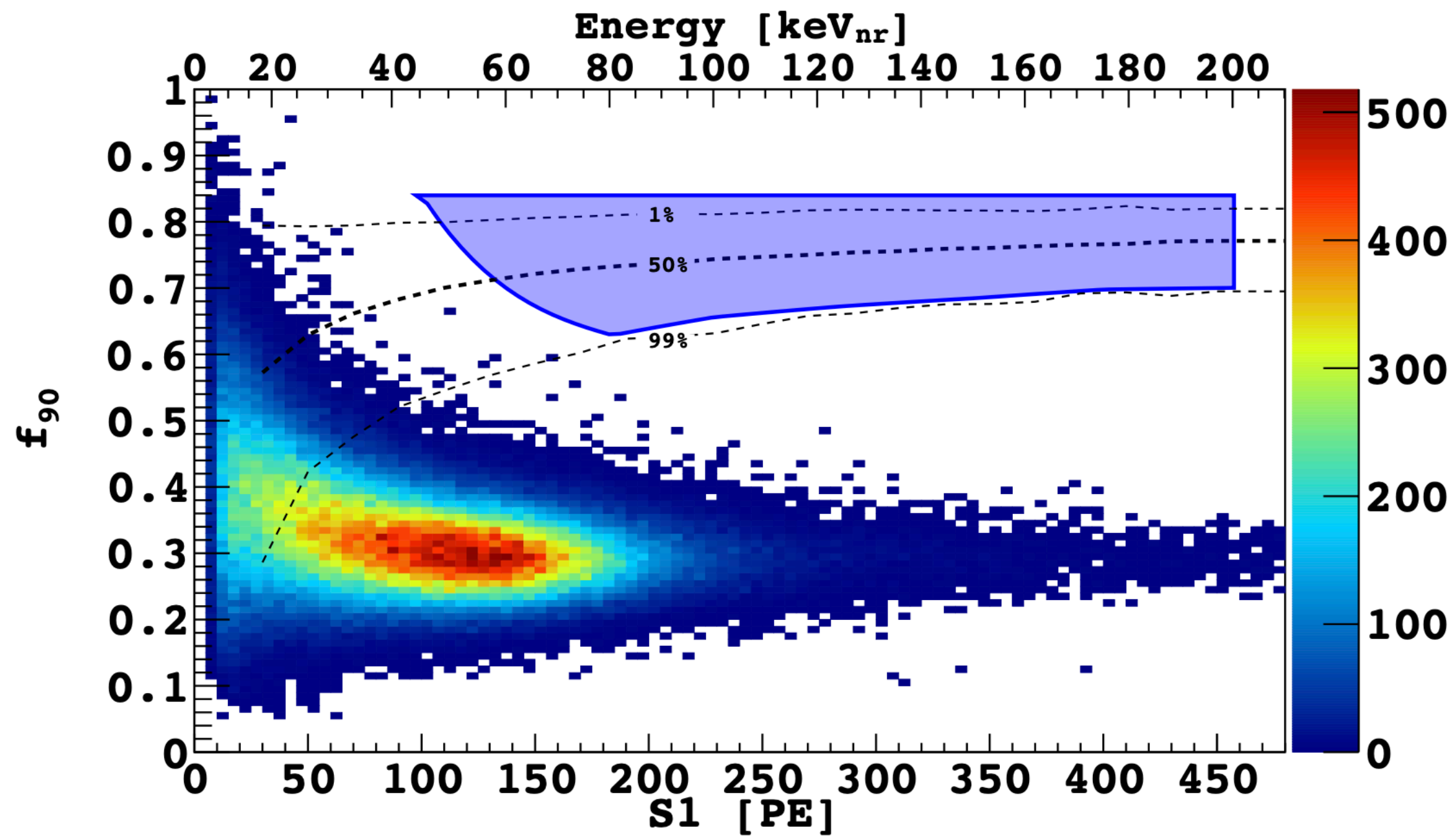
# WIMP-nucleon sensitivity

## With noble liquids experiments



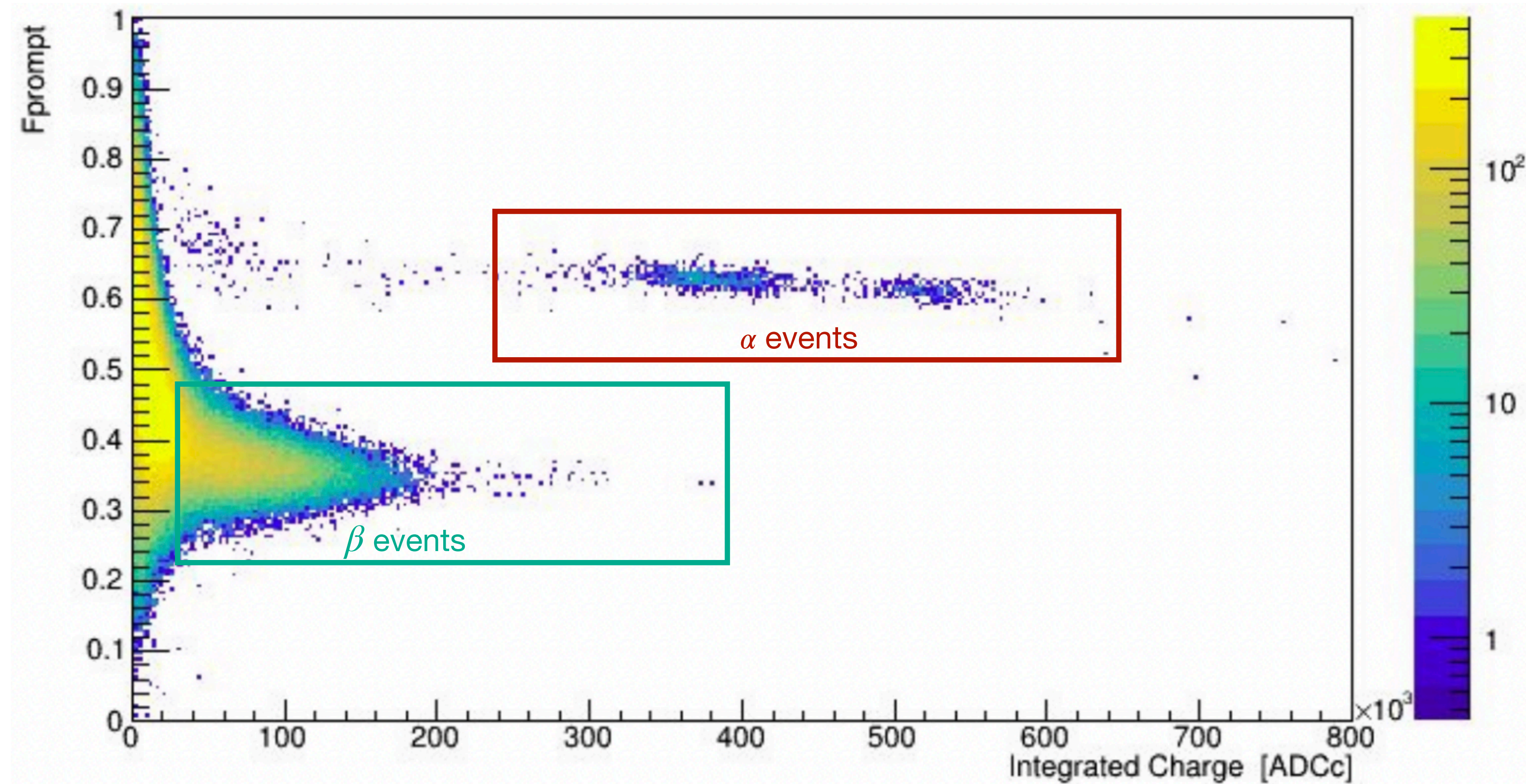
# High mass search in DS-50

Before and after analysis cuts



# DArT (Depleted Argon Test)

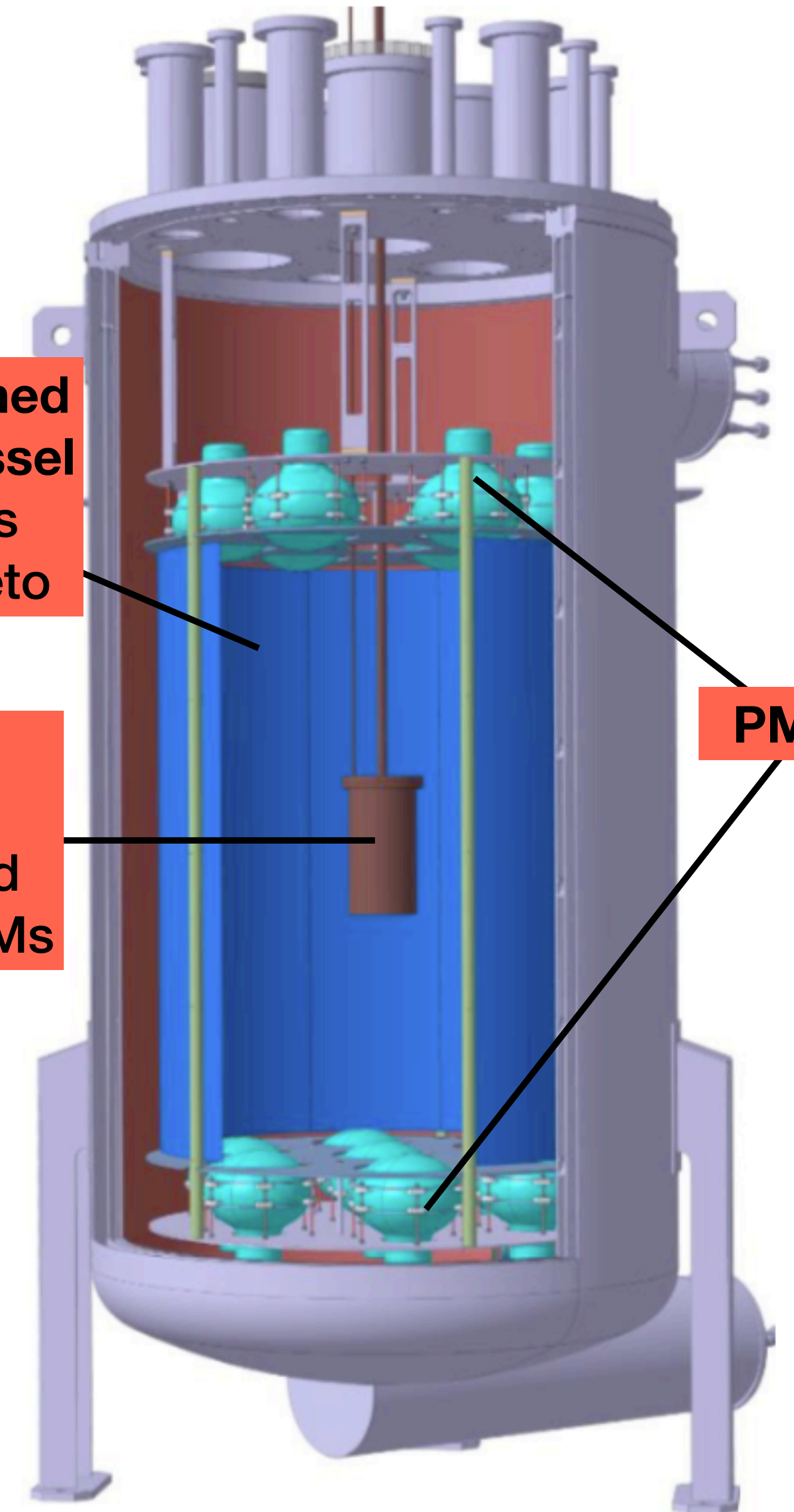
Measurement of  $^{39}\text{Ar}$  depletion factor



Refurbished ArDM vessel  
Used as active veto

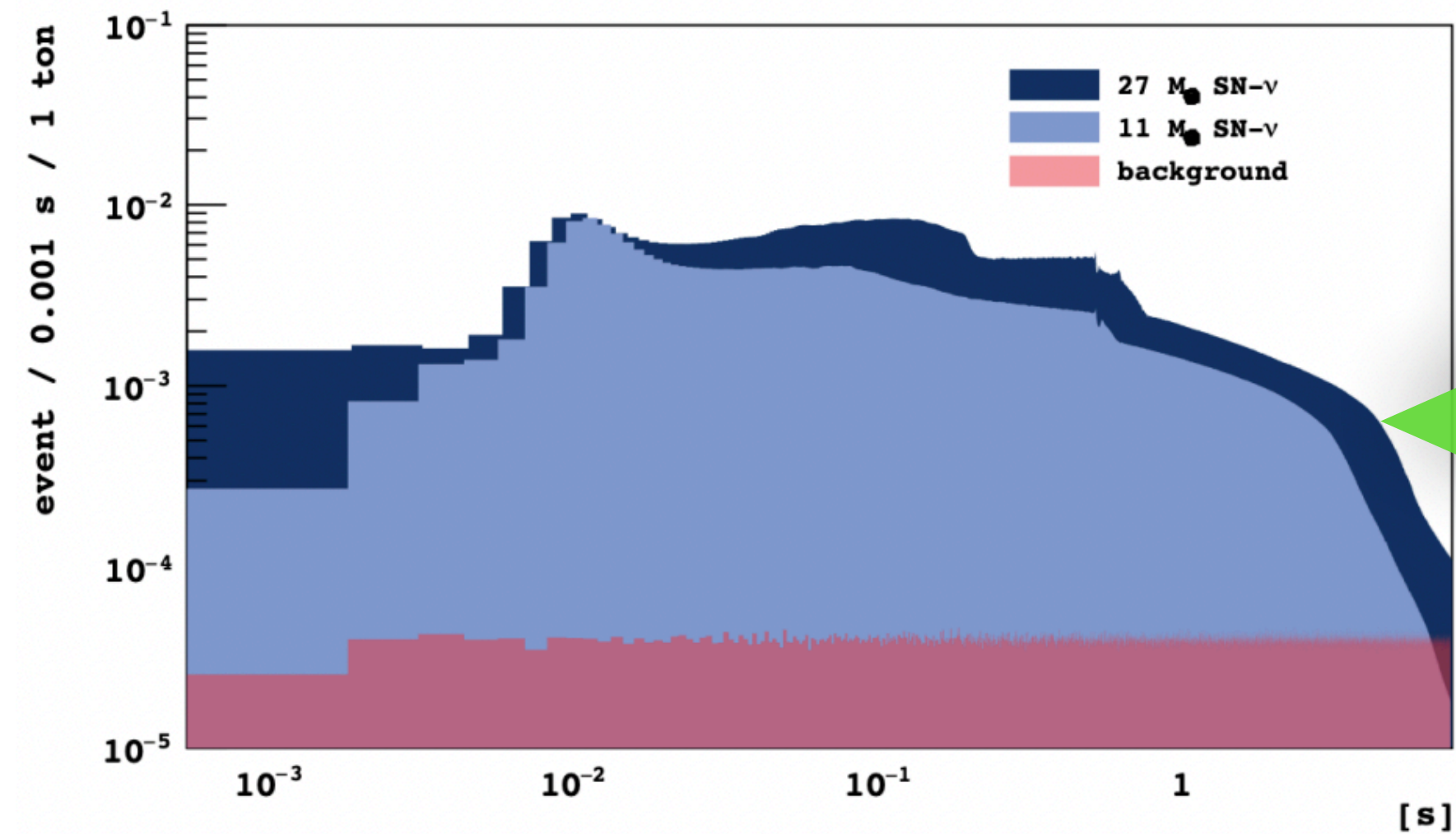
DArT vessel  
Equipped with SiPMs

PMTs

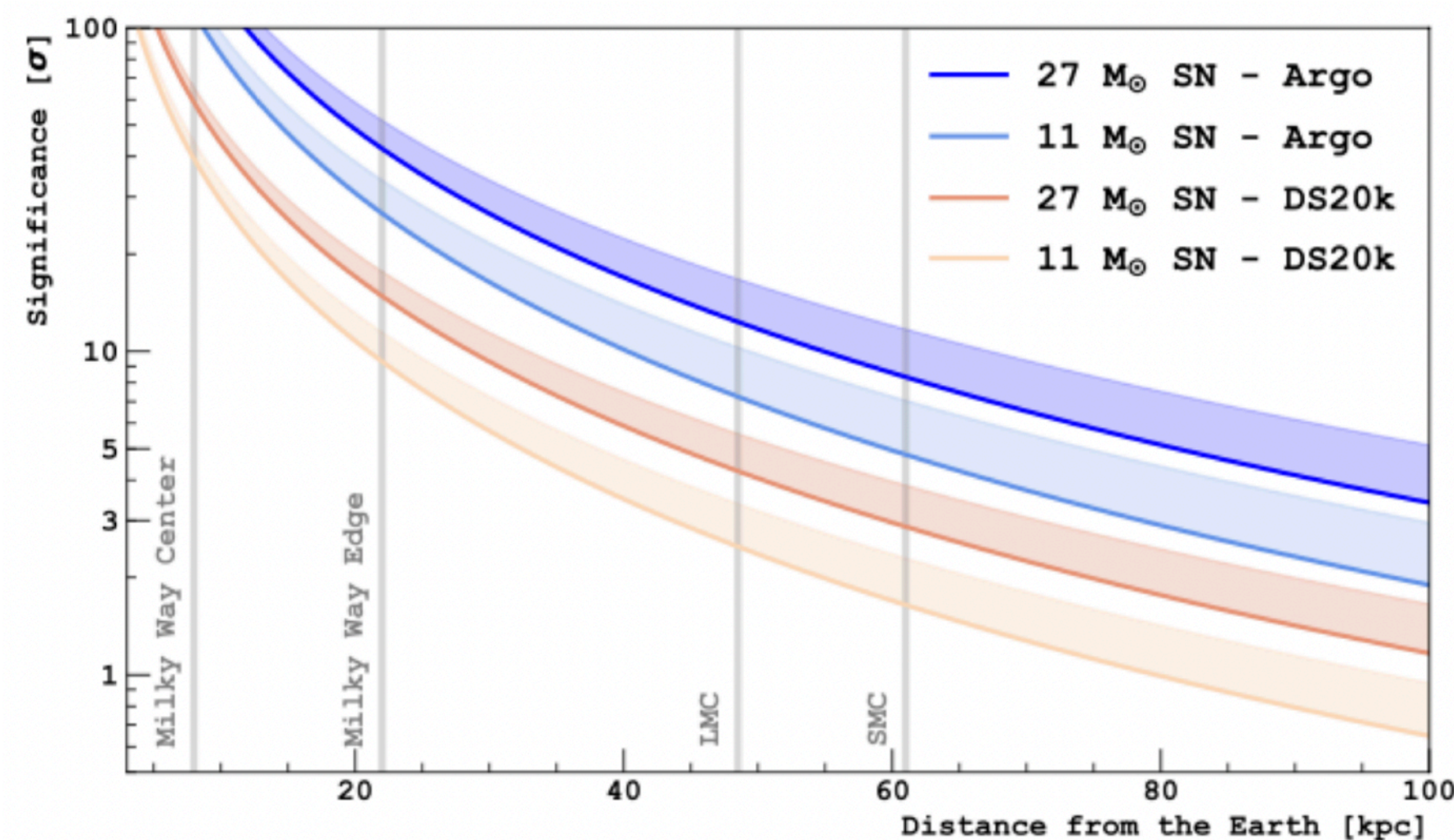


# Supernova detection in DS-20k

## Neutrinos interacting via $CE\nu NS$



27  $M_{\odot}$  at 10 kpc:  
350 events expected in  $\sim 10$  s



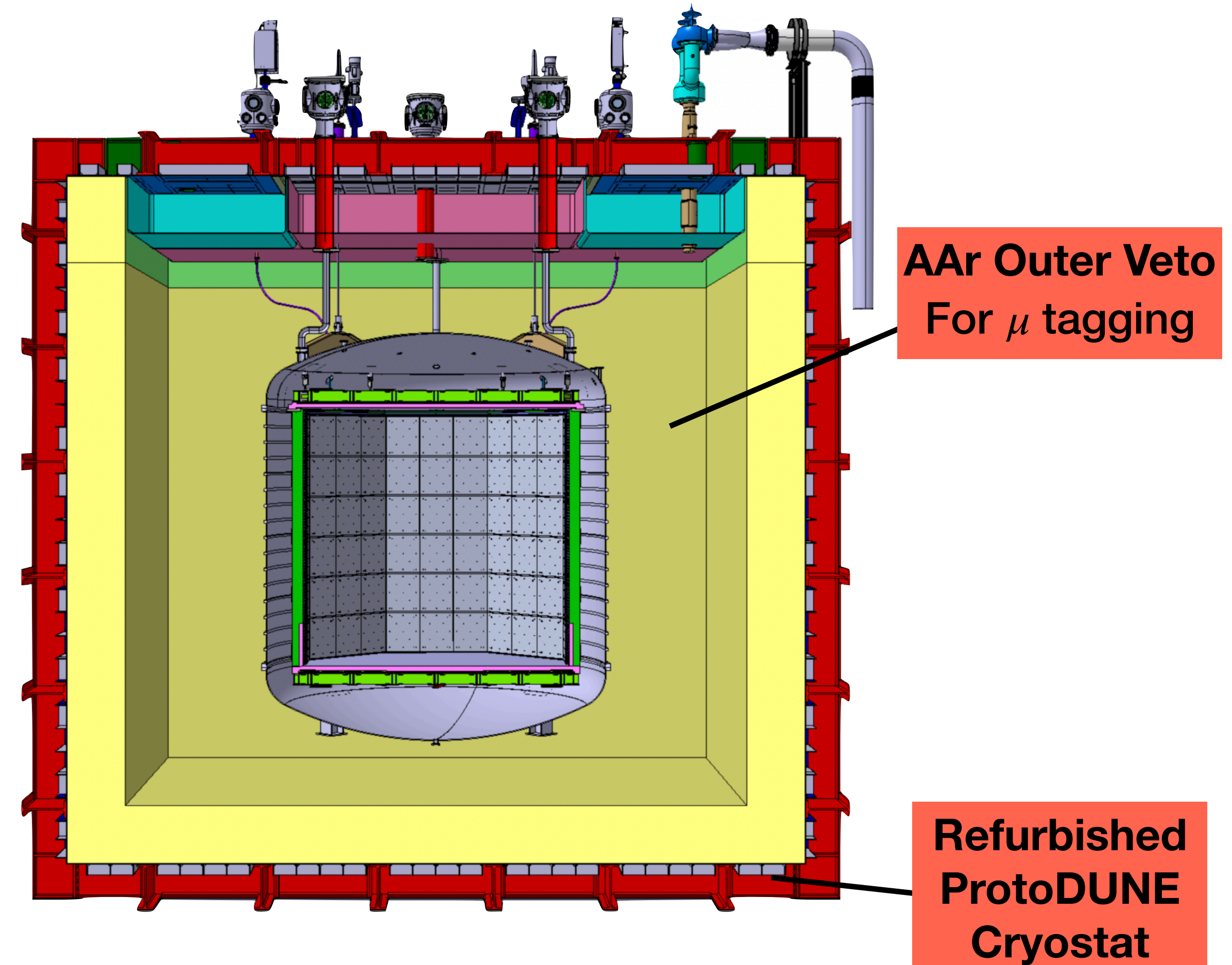
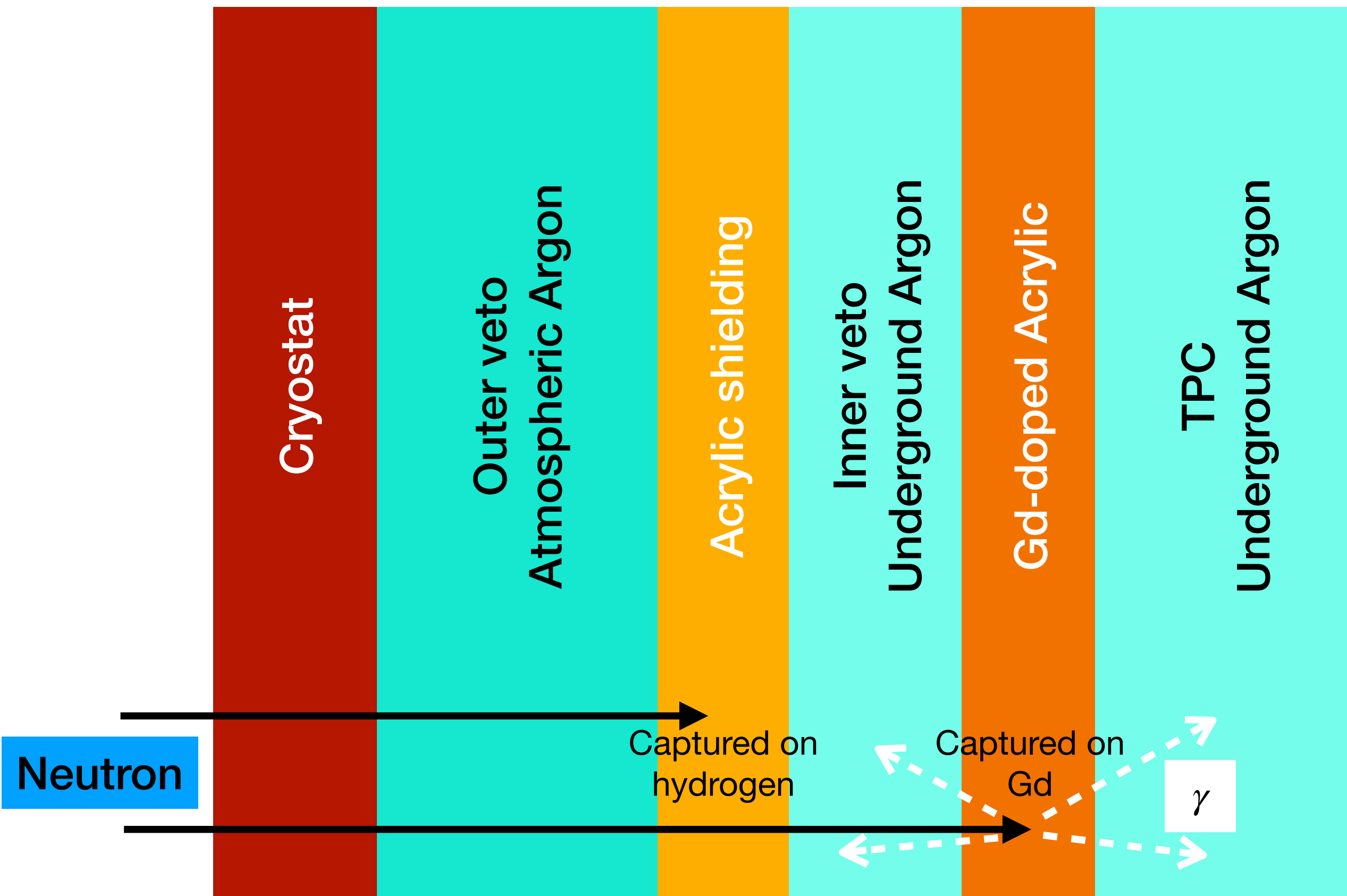
During a core collapse supernova, 99% of the energy is emitted through neutrinos ( $\sim 10^{53}$  erg):

- ▶  **$CE\nu NS$  signature:** low energy (S2 only) nuclear recoil.
- ▶ DS-20k **alarm system** for supernova observation?



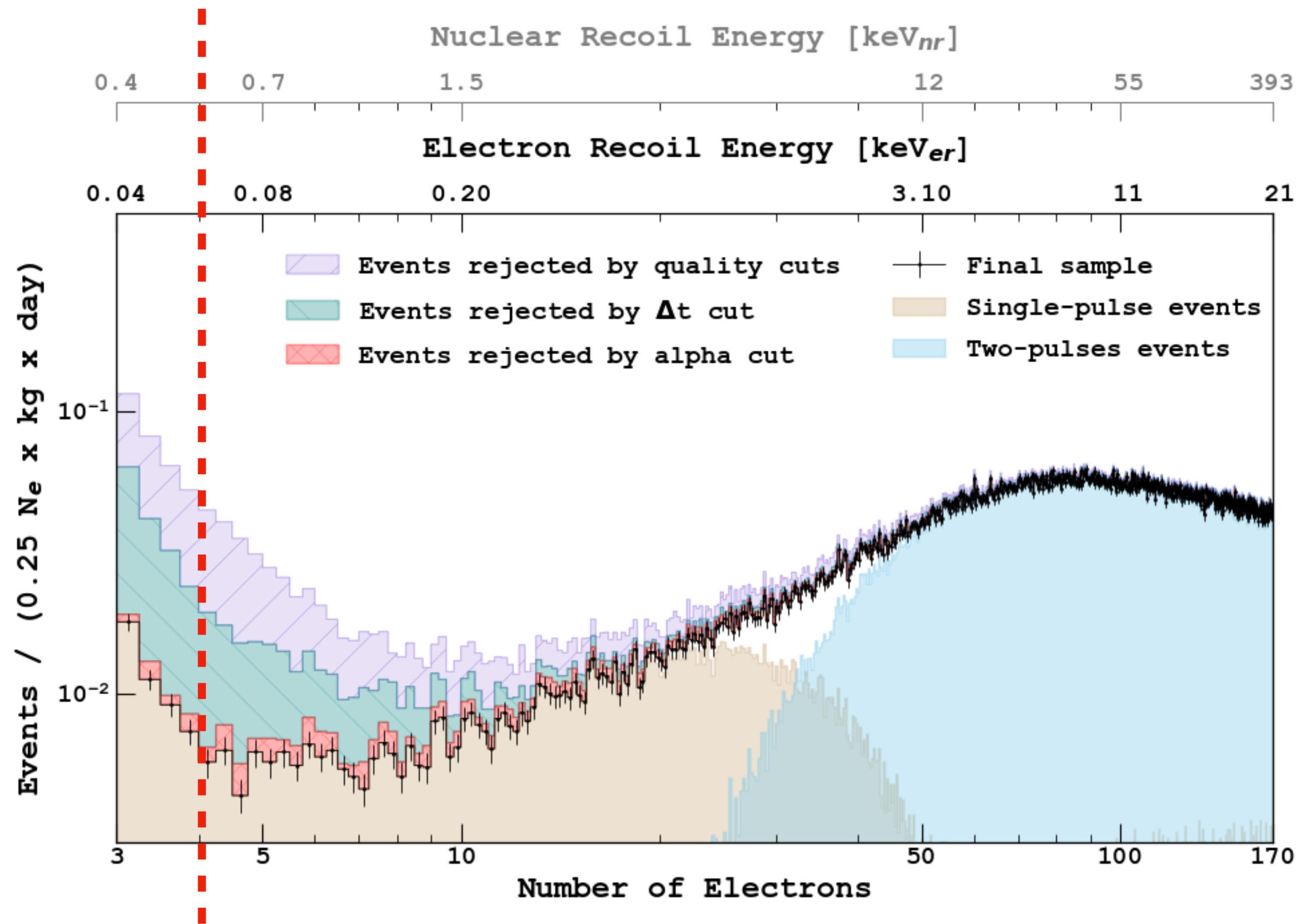
# Outer veto and neutron shielding

With Gd-doped acrylic



# Low mass search in DS-50

## Before and after analysis cuts



Analysis threshold

Improved light dark matter limits from 2018 analysis thanks to:

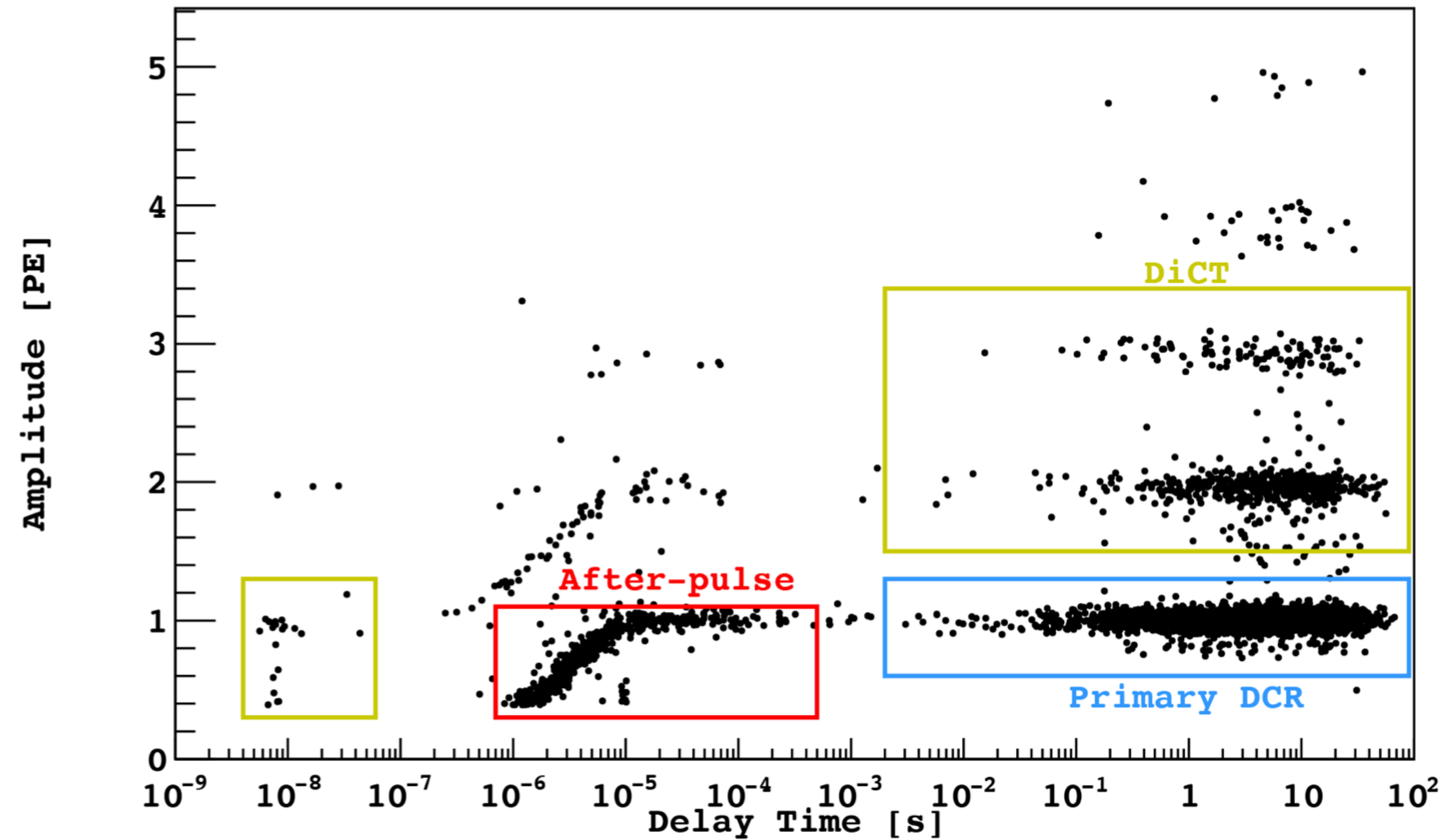
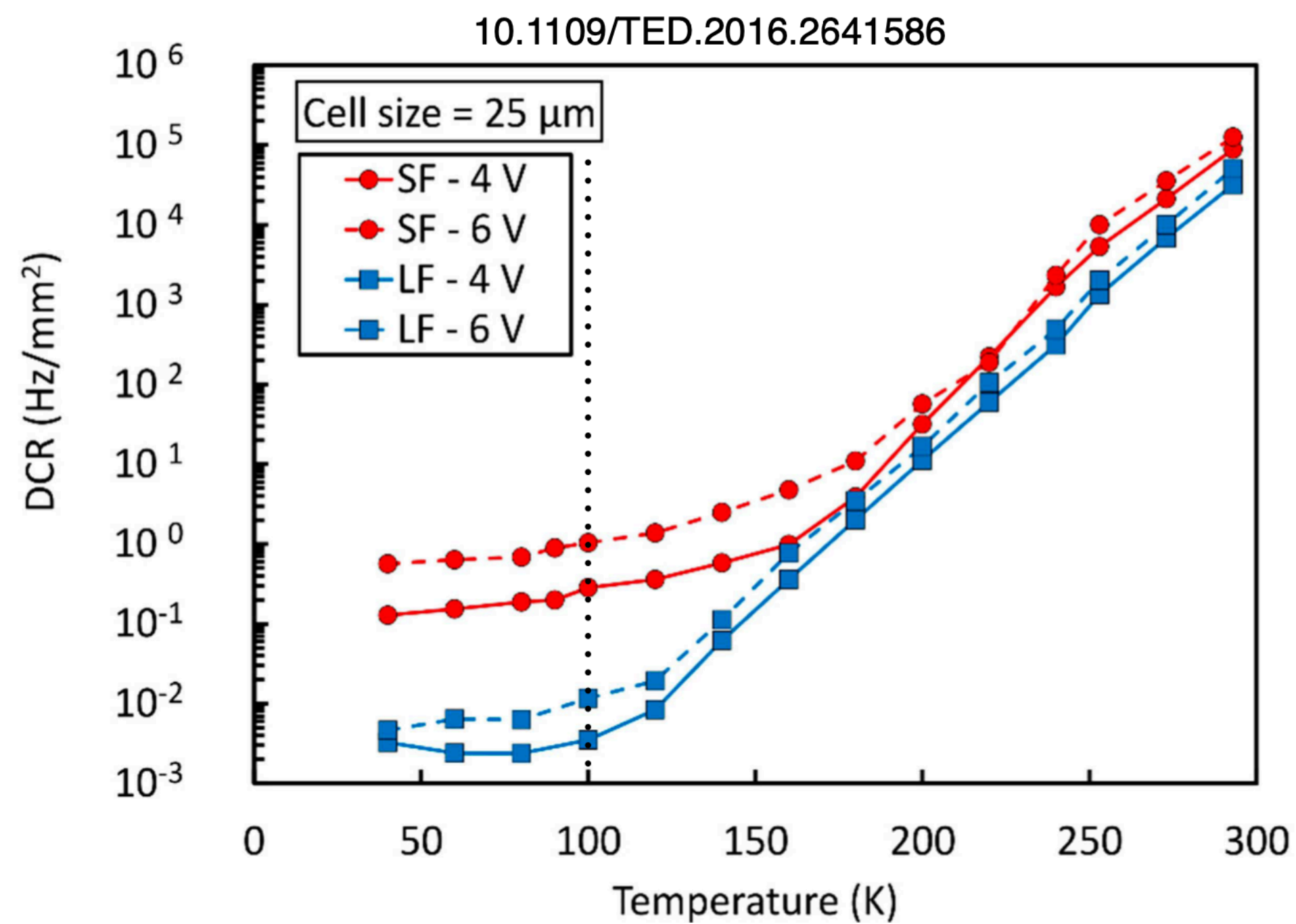
- ▶ **Calibration** of ionization response to ERs and NRs down to  $<1$  keV
- ▶ Extended **exposure**
- ▶ Better **data selection**

Best SI WIMP-nucleon limits down to  $1.2 \text{ GeV}/c^2$  ( $40 \text{ MeV}/c^2$ ) WIMP mass without (with) Migdal effect.

Improved limits on **WIMP-electron** interactions, galactic ALPs, dark photons, and sterile neutrinos.

# SiPM characterisation

## Noise measurements



# Hit finder algorithm

## Matched filtering

- ▶ Convolute waveform with a **reversed template** of the single photo-electron response.
- ▶ Subtract **moving average**.
- ▶ Apply **time-over-threshold**.

