The DarkSide 20k Experiment

Tianyu Zhu on behalf of the DarkSide 20k collaboration

WIN 2023 July 7th, 2023

DARKSIDE

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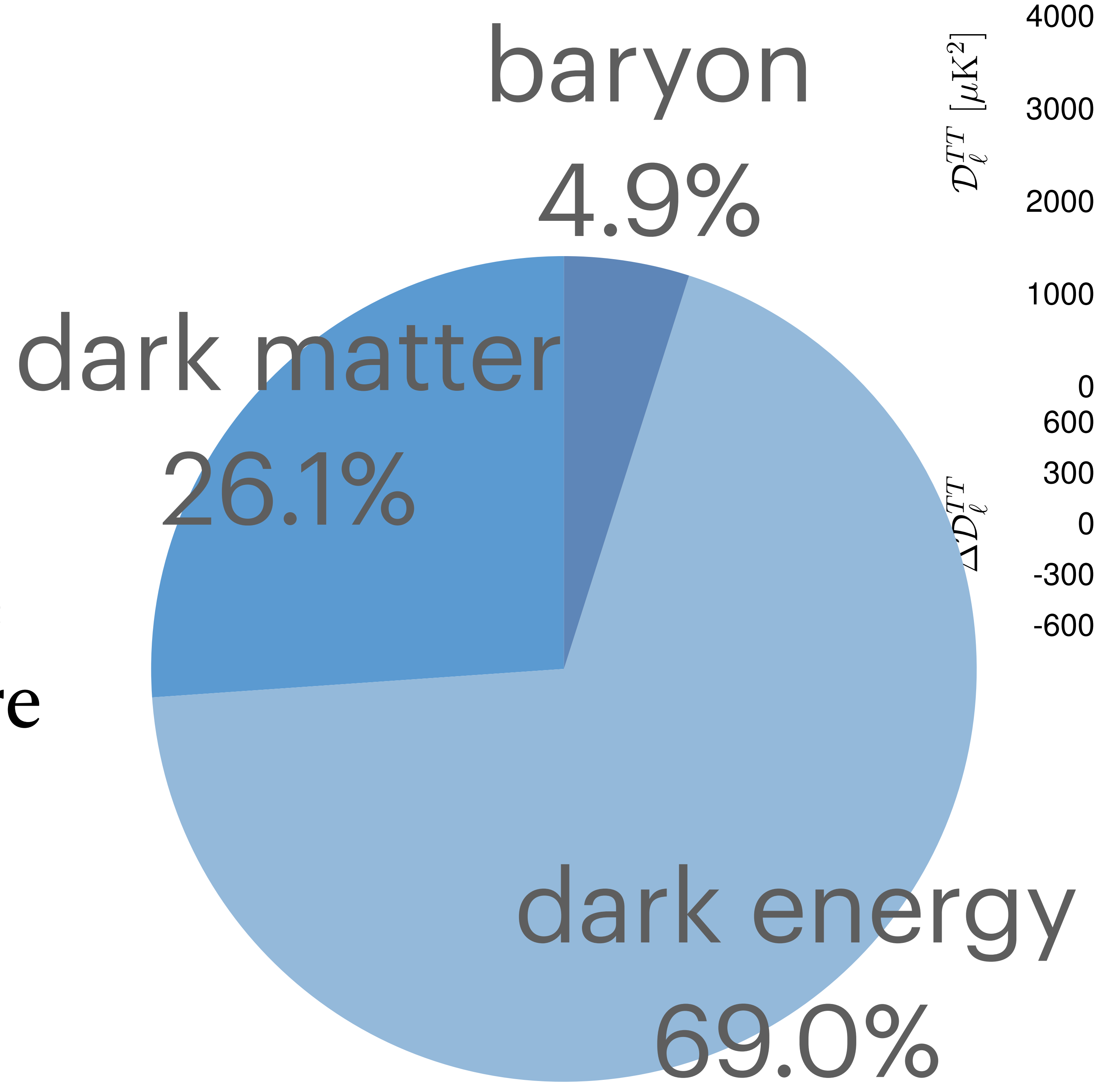
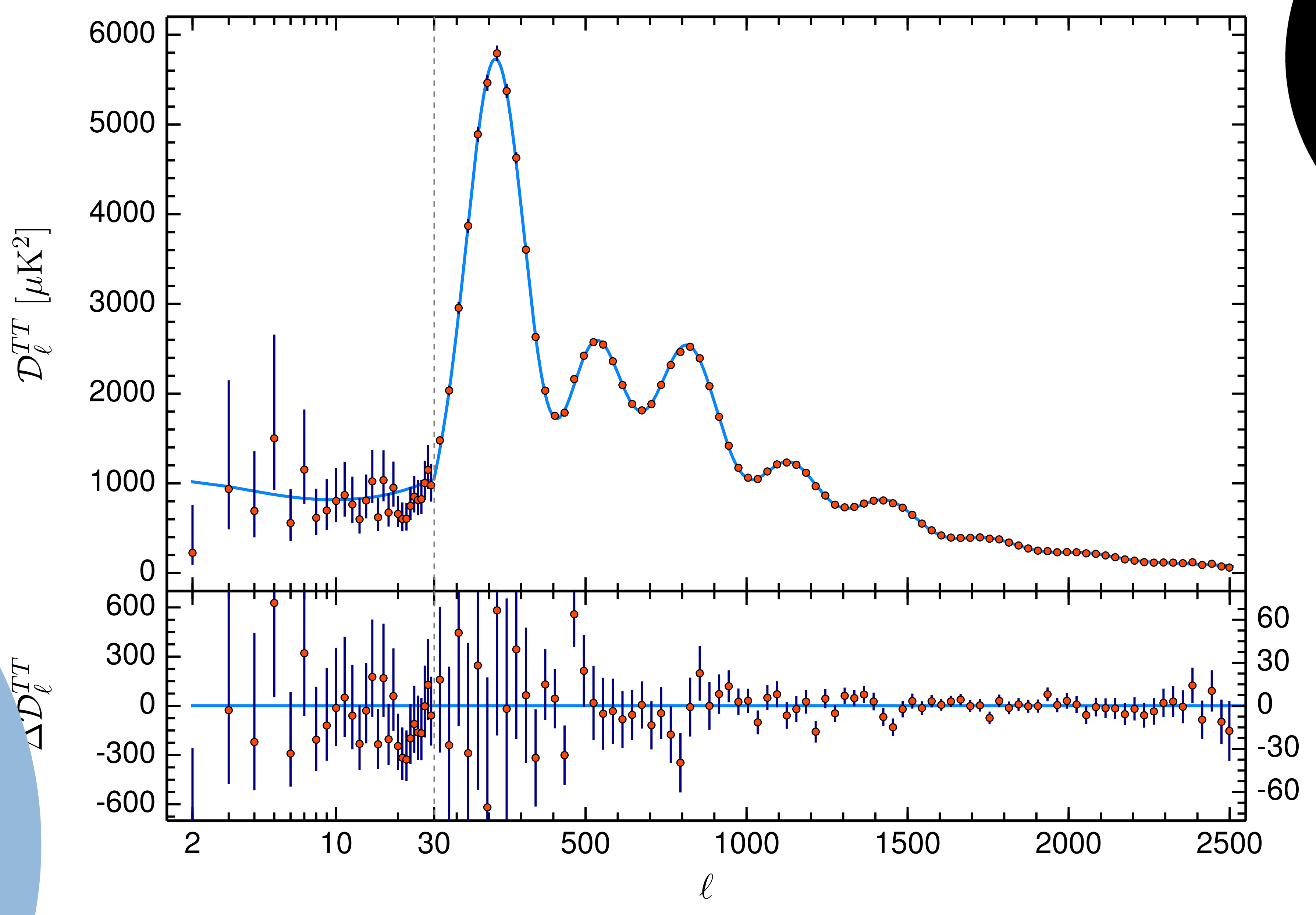
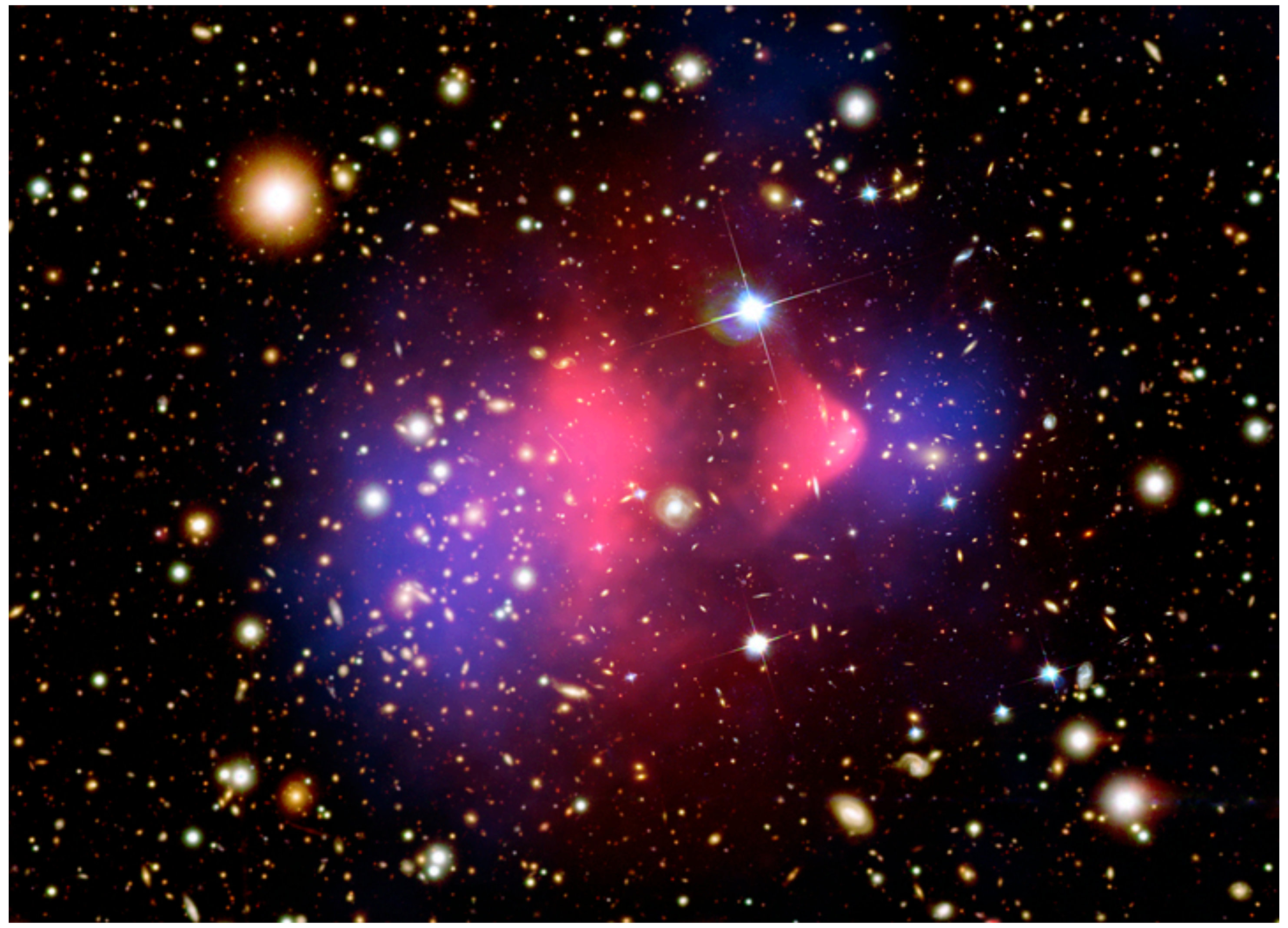
Evidence of Dark Matter

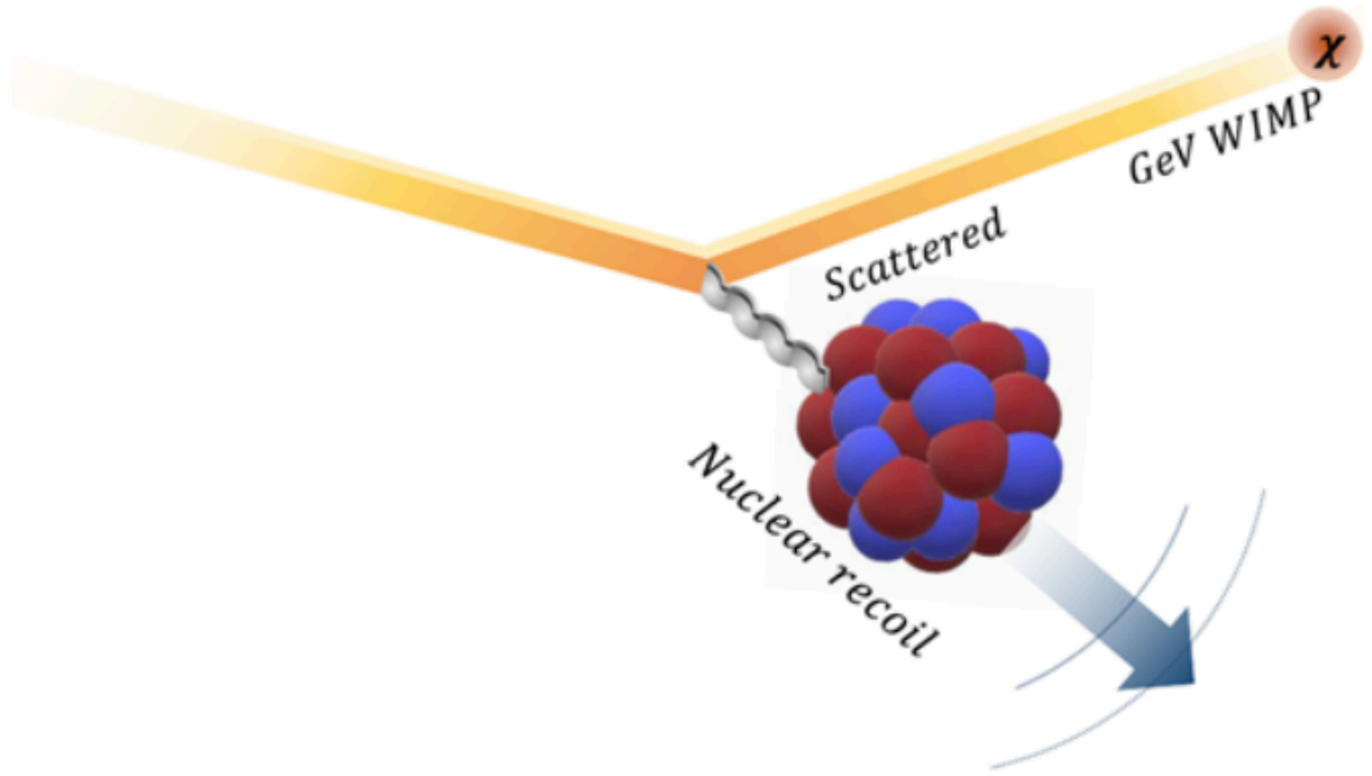
- From the relative height of the peaks in the cosmic microwave background (CMB) temperature anisotropy measurements the amount of baryon matter and dark matter can be estimated.







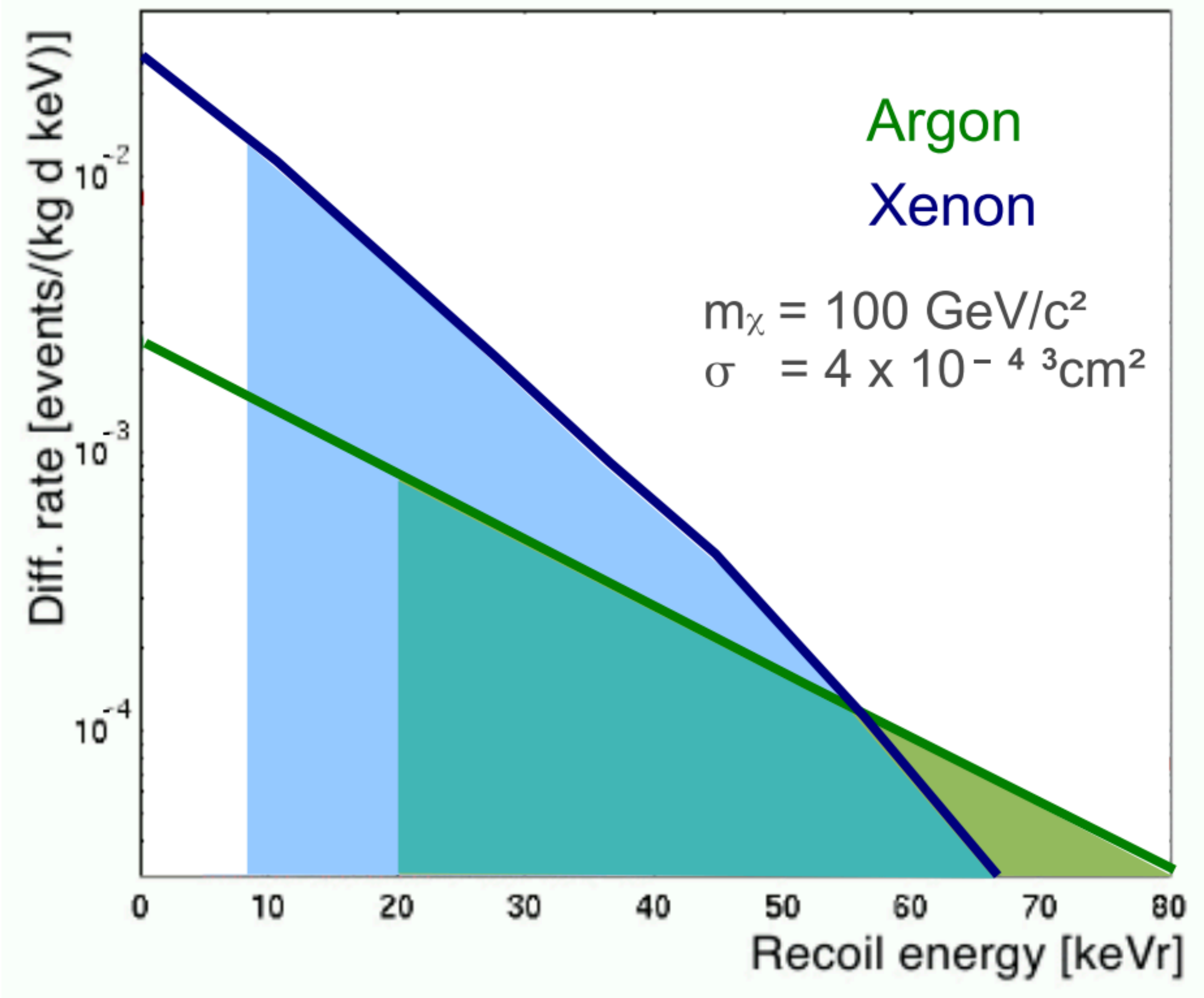
WIMPs Direct Detection With Liquid Nobel Gases



$$\frac{dR}{dE_r} = \frac{M_T}{2 m_W \mu_N^2} \times \boxed{\sigma_{Wn}} \times \frac{\mu_N^2}{\mu_p} A^2 \times \boxed{F^2(E_r)} \times \boxed{\rho_0 \times \int_{v_{min}}^{v_{max}} \frac{f(\vec{v})}{v} d^3 v}$$

Particle physics — Nuclear physics — Astrophysics

Rate dR/dE_R (events/keV/tonne/year)



By M. Schumann

Nuclear Recoil Energy E_R (keV)

Mw=50 GeV/c² and Mw=100 GeV/c²
Expect higher rate in LXe at low energies
but suppressed at higher energies
Not in the case of LAr

Nucleus and electron Recoil

- WIMPs, neutron,
- CEνNS
- N_{ex}/N_i ~ 1
- N_{fast}/N_{slow} ~ 1 for 10 keV visible energy

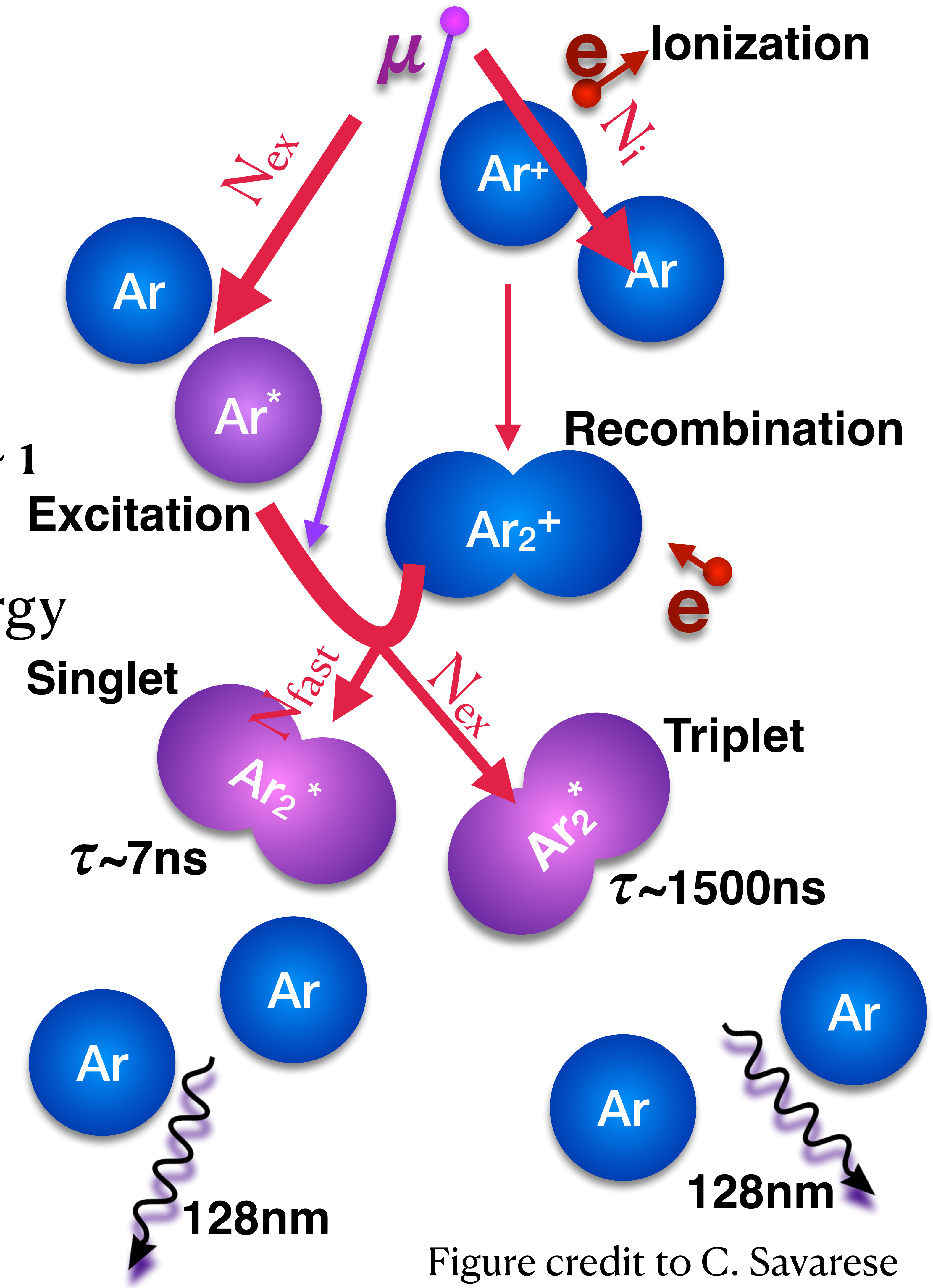


Figure credit to C. Savarese

- γ, β, and also low mass WIMPs, neutrinos
- N_{ex}/N_i ~ 0.21
- N_{fast}/N_{slow} ~ 0.4 for 10 keV visible energy

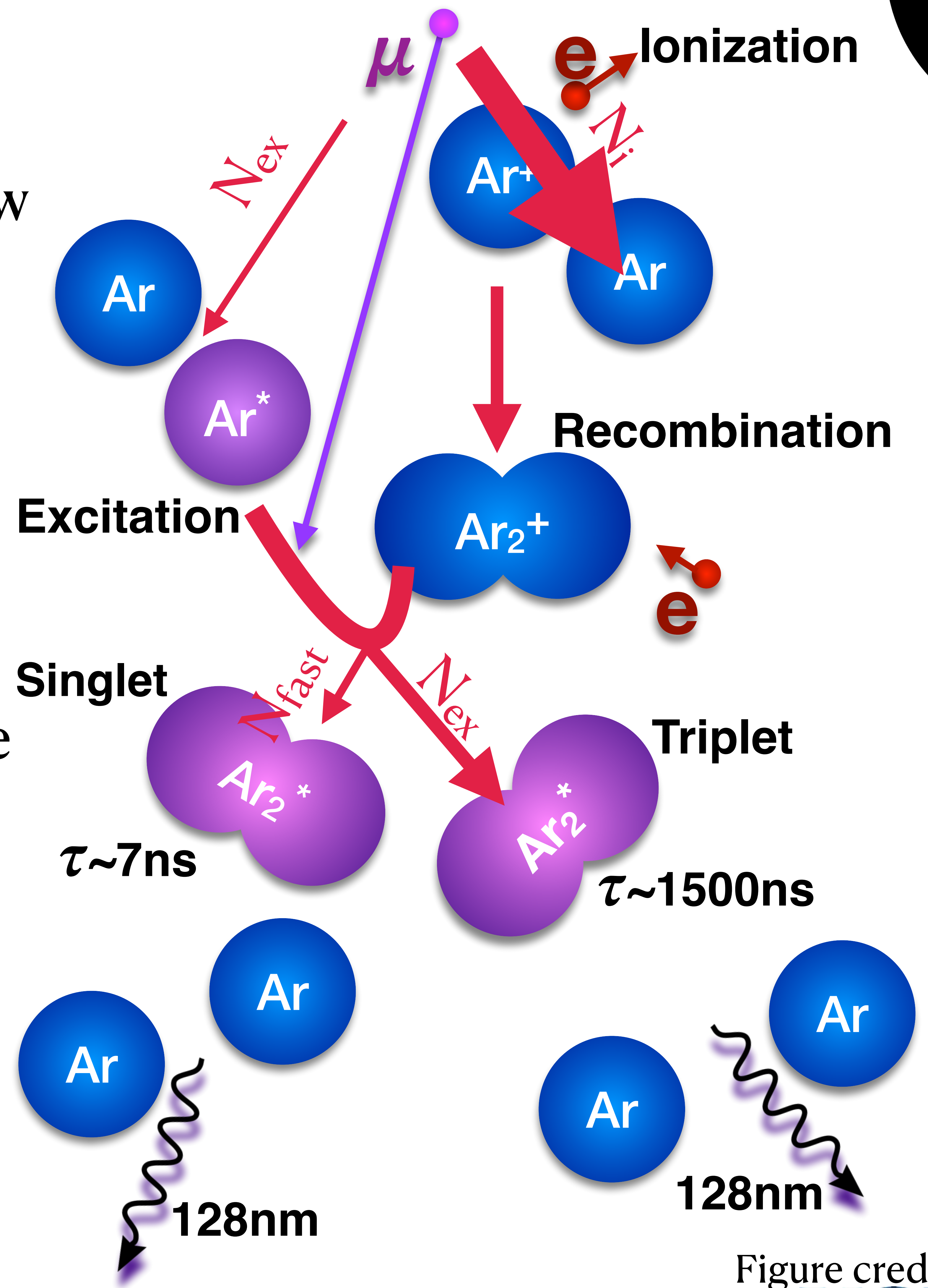
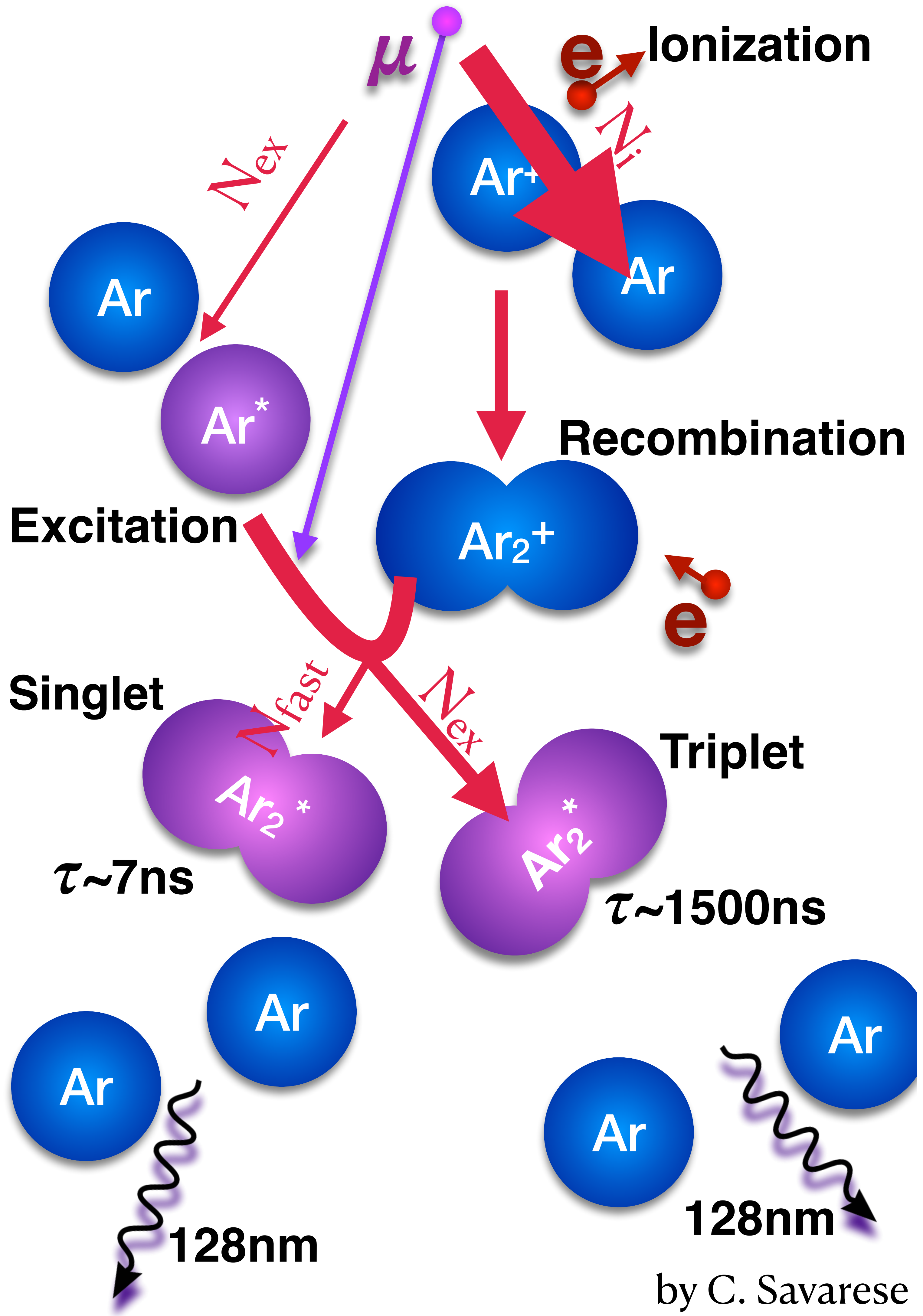


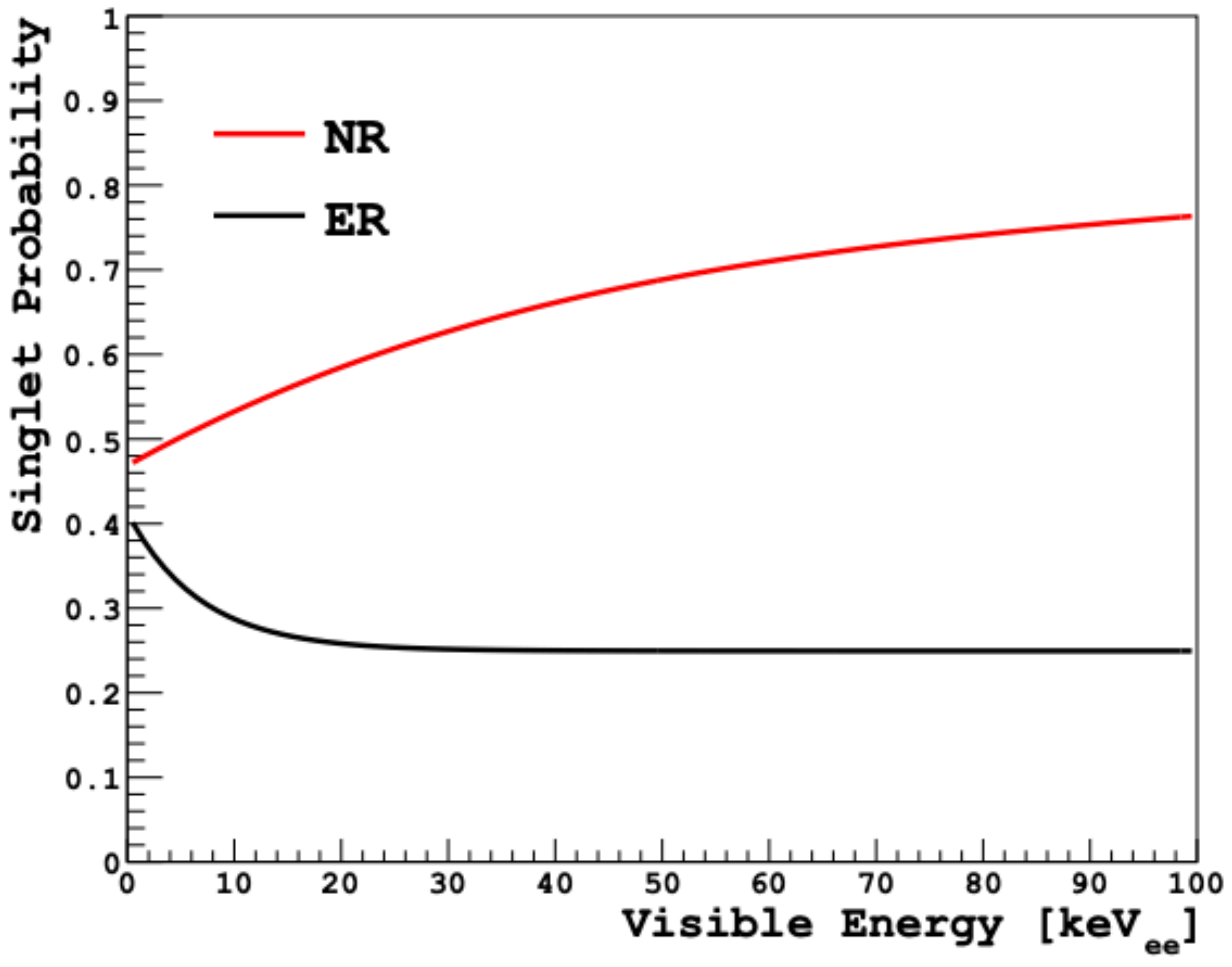
Figure credit to C. Savarese

JINST P12 10015 (2017)

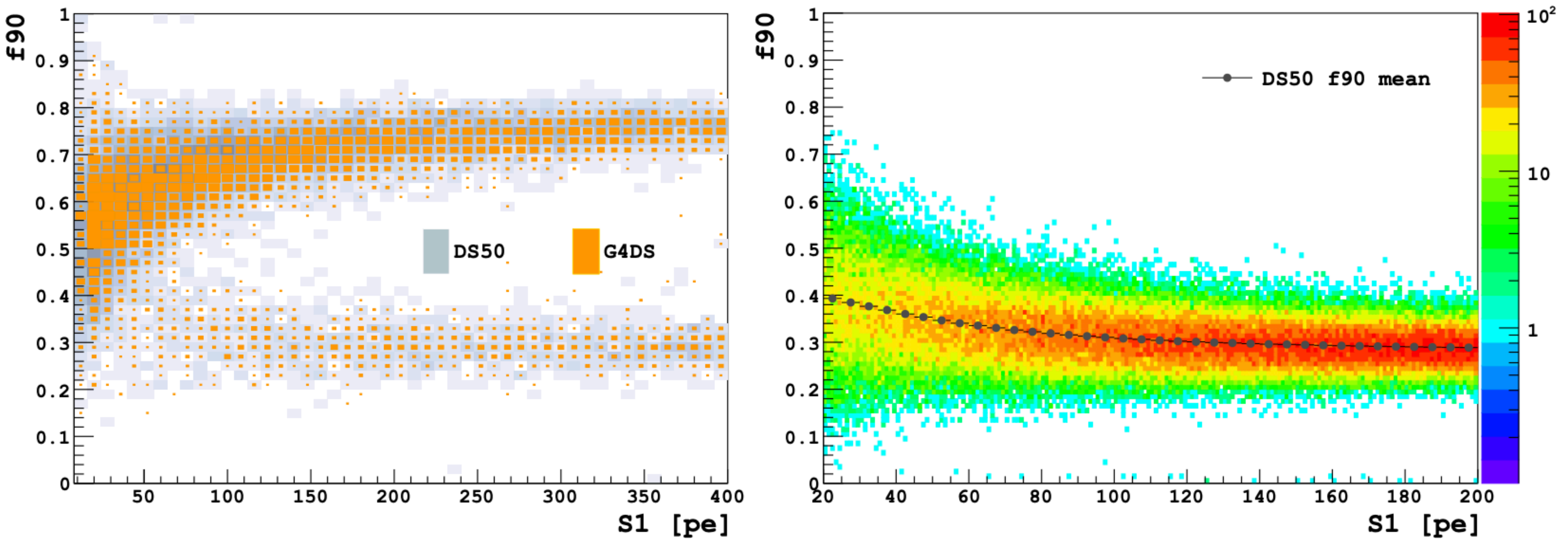
Nucleus and electron Recoil



by C. Savarese



$$f_{90} = \frac{\int_0^{90\,ns} S1\,(t)\,dt}{\int_0^{T} S1\,(t)\,dt}$$



PSD parameter data-MC comparison for AmBe neutron source (left) and Ar39 right

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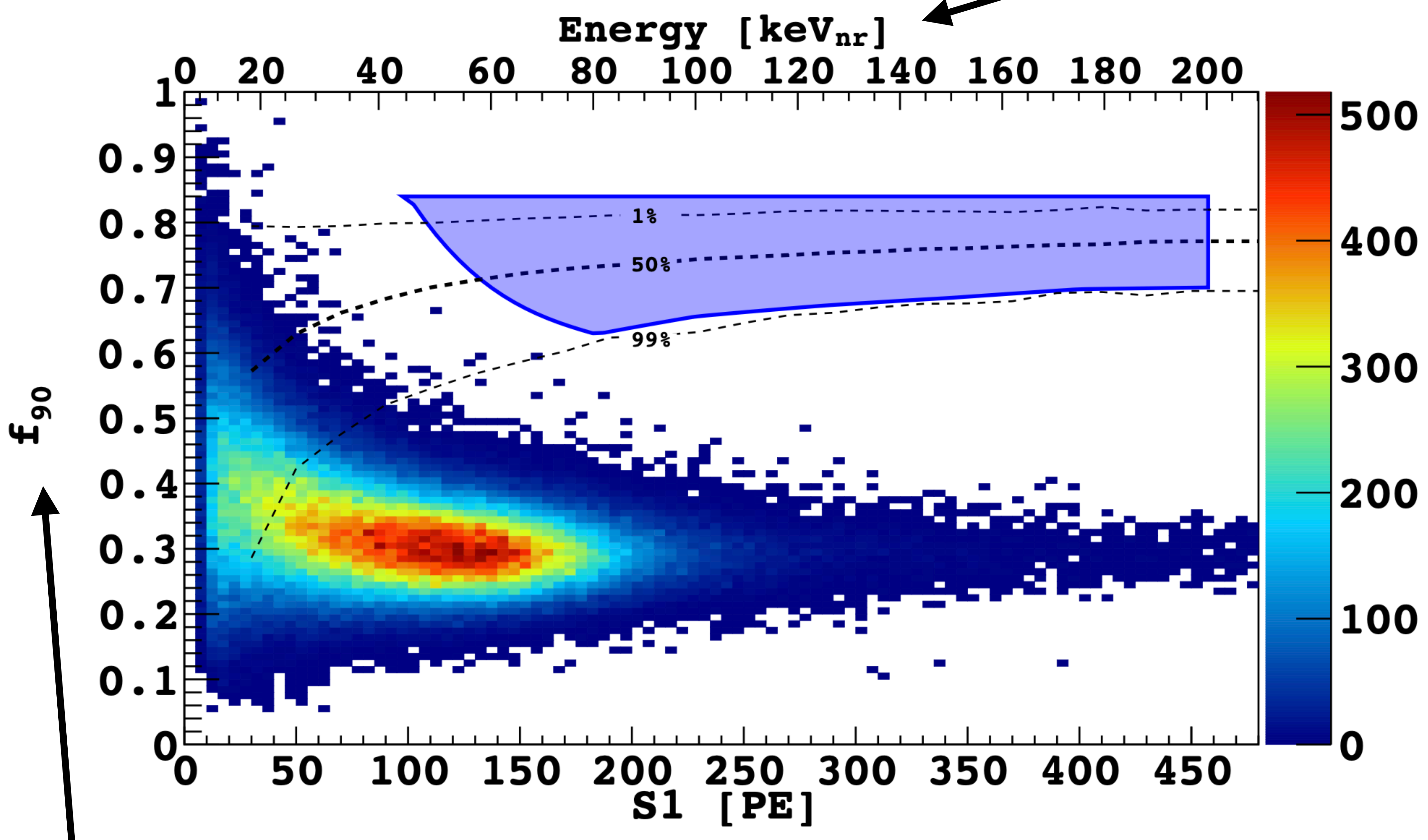
WIMPs Direct Detection with Pulse-shape Discrimination

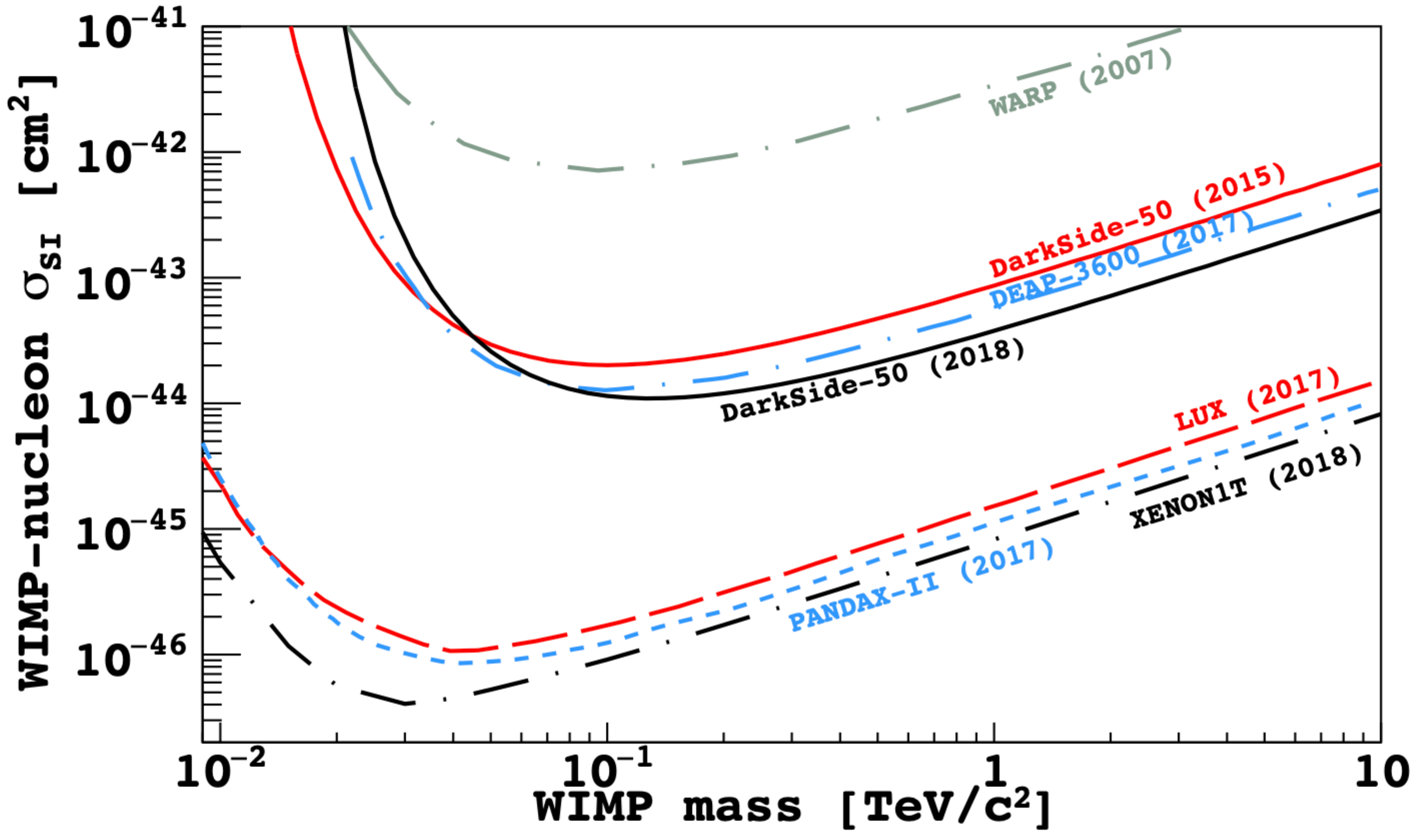
Inferred energy in NR



Number of PE seen in S1

$$f_{90} = \frac{\int_0^{90\,ns} S1\,(t)\,dt}{\int_0^{T} S1\,(t)\,dt}$$

No events in the ROI after selection cuts!



Phys. Rev. D .98.102006 (2018)

Exclusion limit down to 10^{-44} at high mass 100GeV/c^2

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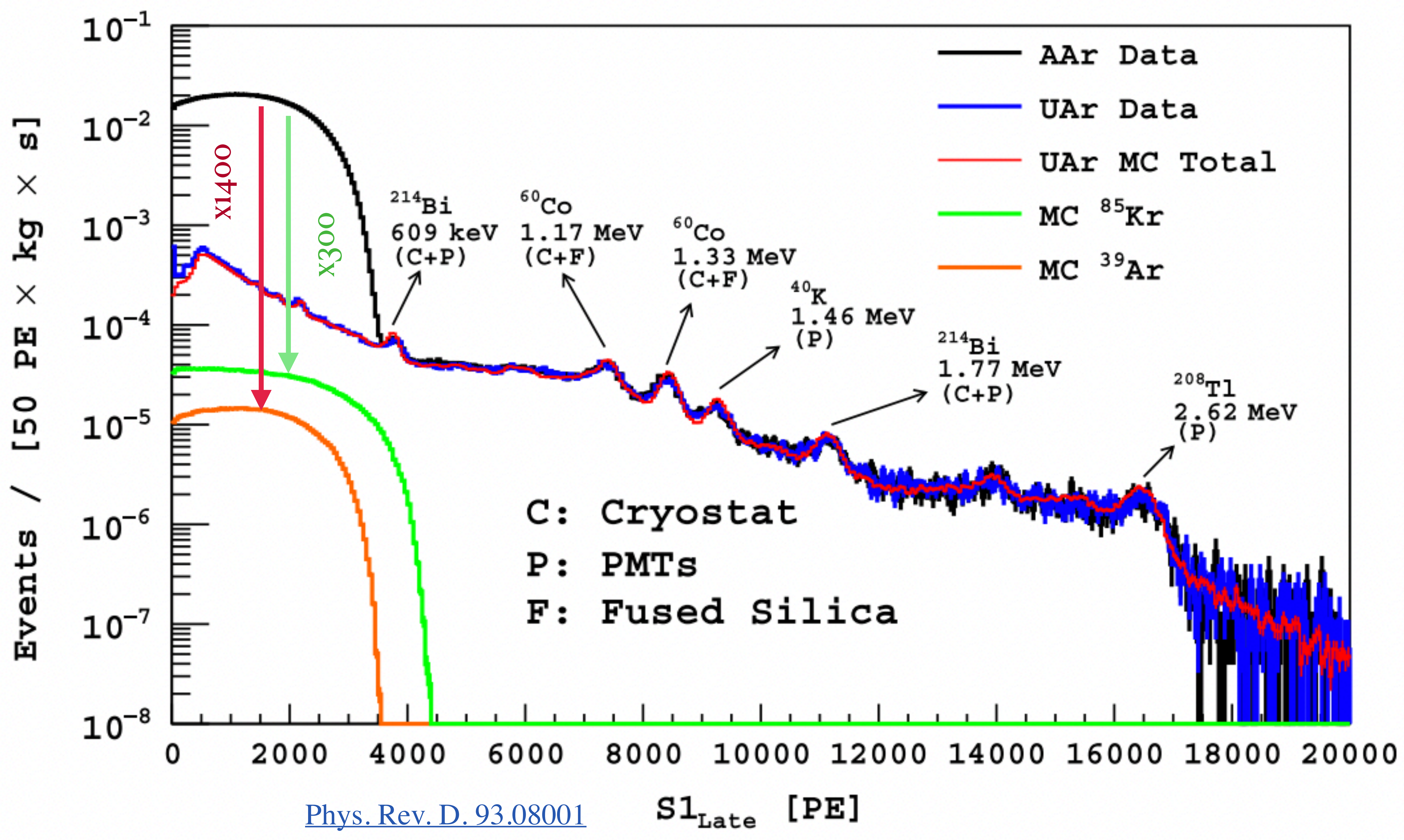
Underground Ar with Low ^{39}Ar Level



Phys. Rev. D. 93.08001

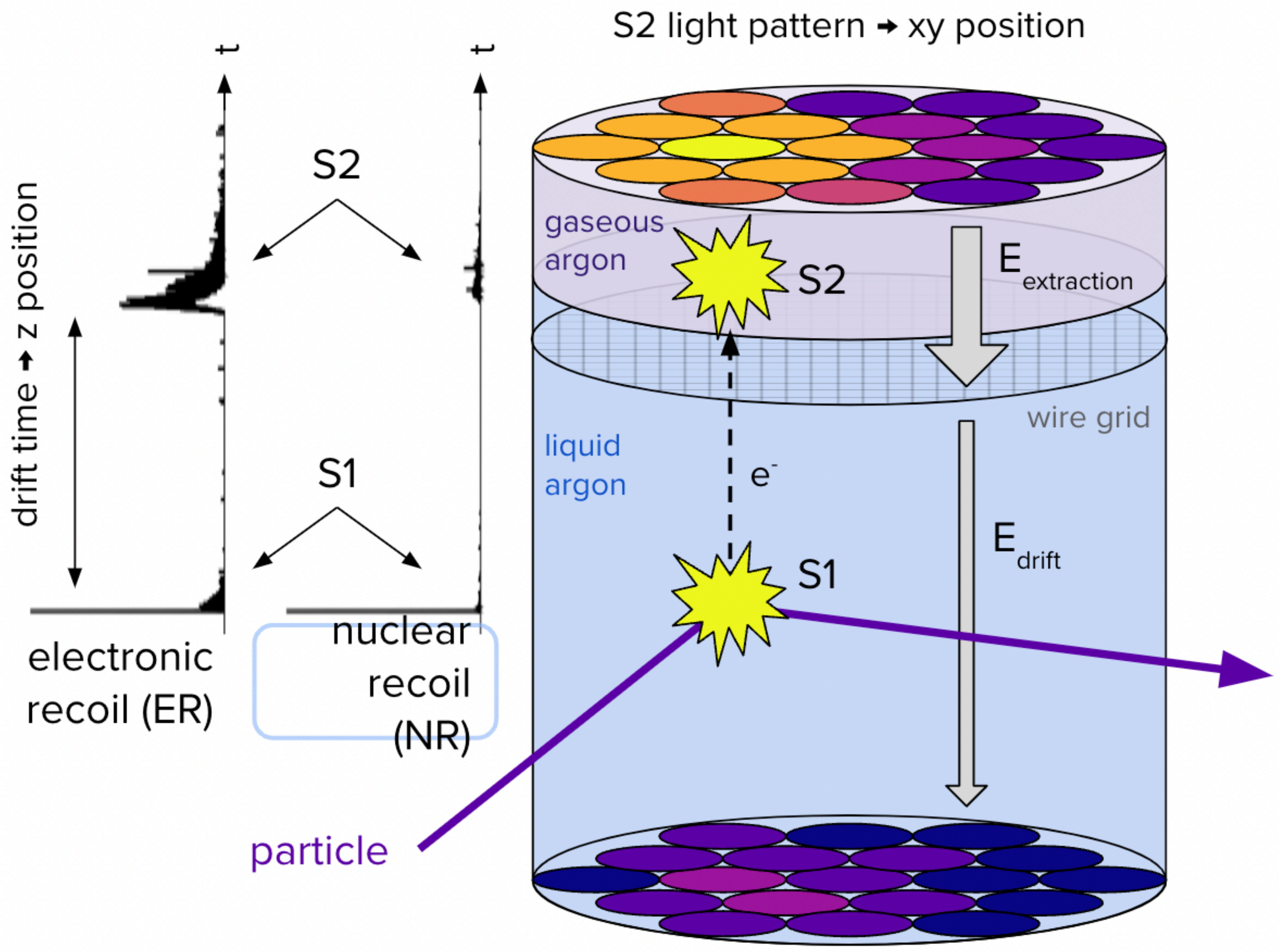
With respect to AAr:
> factor of **300** reduction of total radioactivity (^{39}Ar+^{85}Kr) in UAr
~ factor of **1400** reduction of ^{39}Ar activity

1000 mBq/kg

0.73± 0.11 mBq/kg

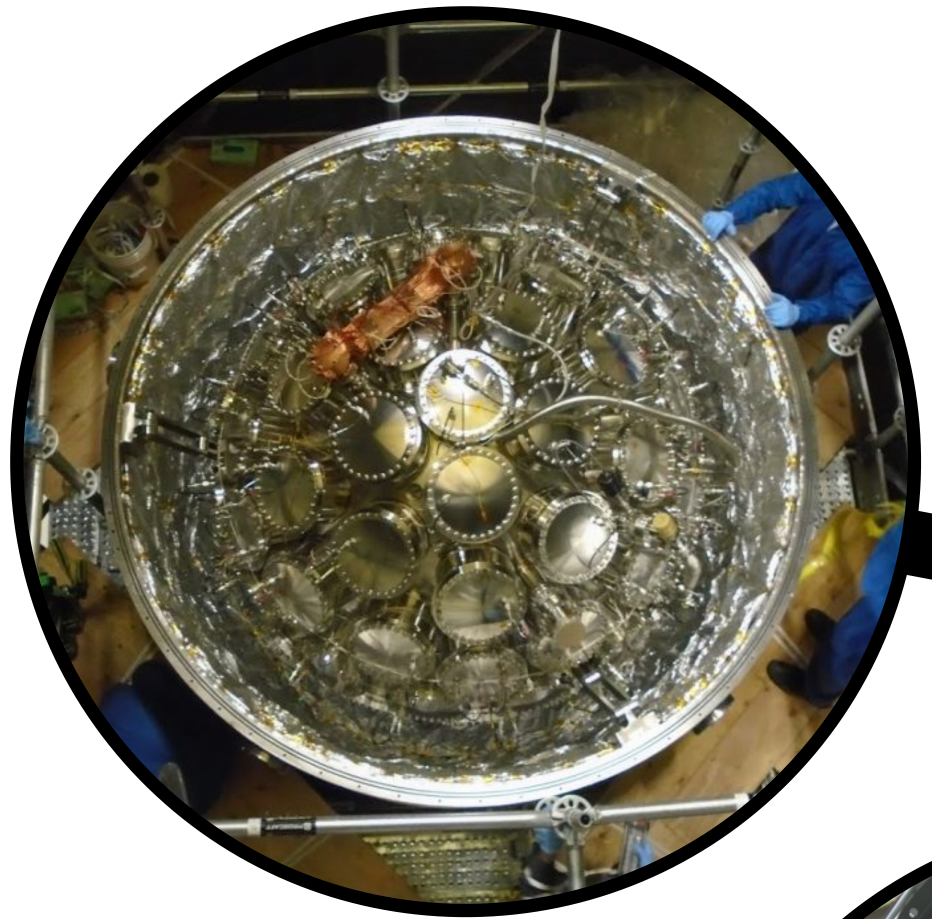
Dual Phase Time Projection Chamber

- Dual-phase liquid argon time projection chambers detect recoil energy transferred to both prompt scintillation (S1) and ionization (S2), thus providing excellent 3-D position reconstruction.
- Ionization electrons are drifted and produce secondary scintillation from electroluminescence in gas pocket.

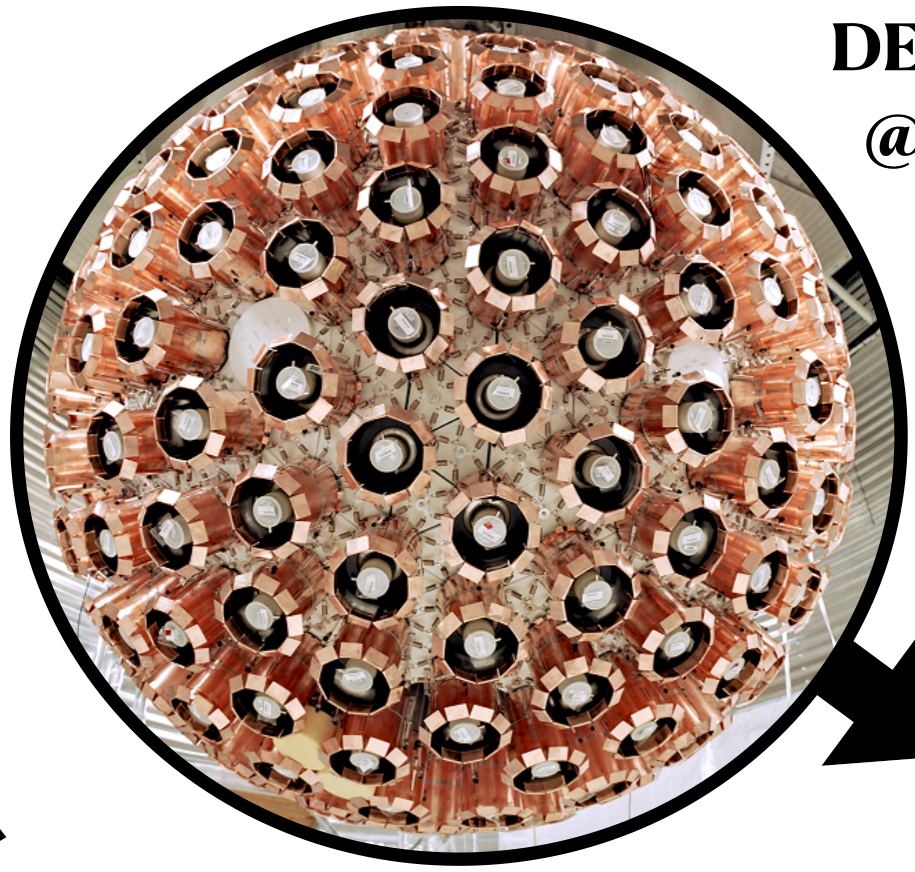


The Global Argon Dark Matter Collaboration

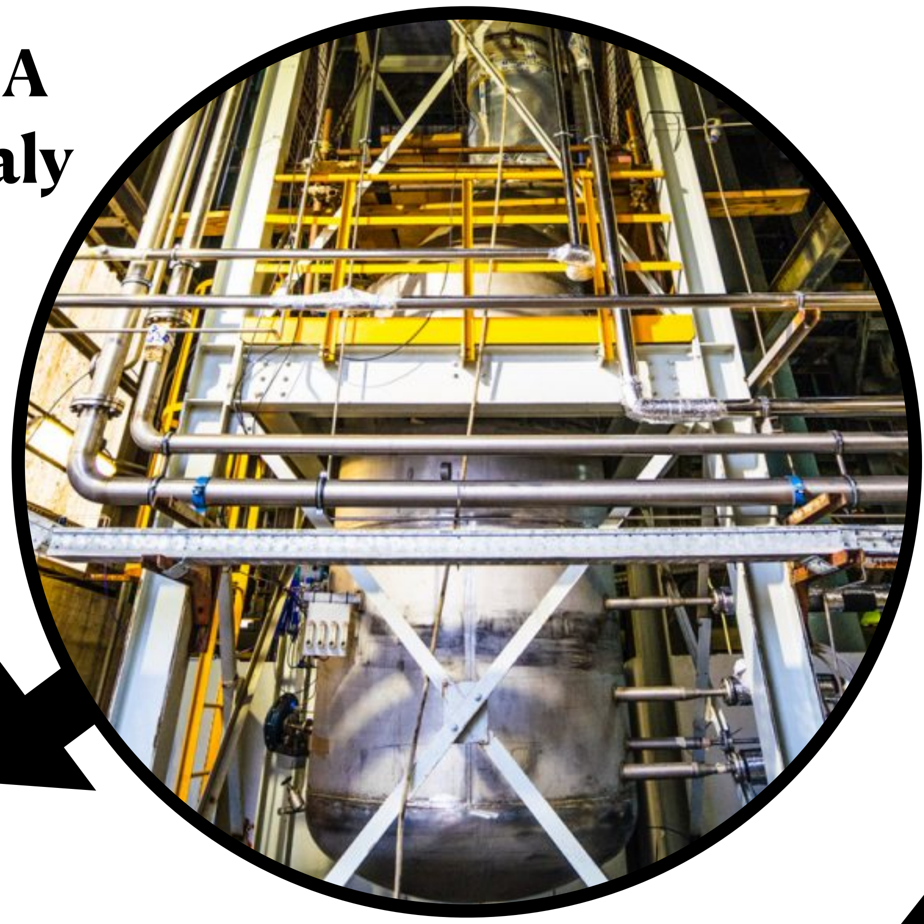
MiniCLEAN
@ Snolab



DEAP-3600
@ Snolab

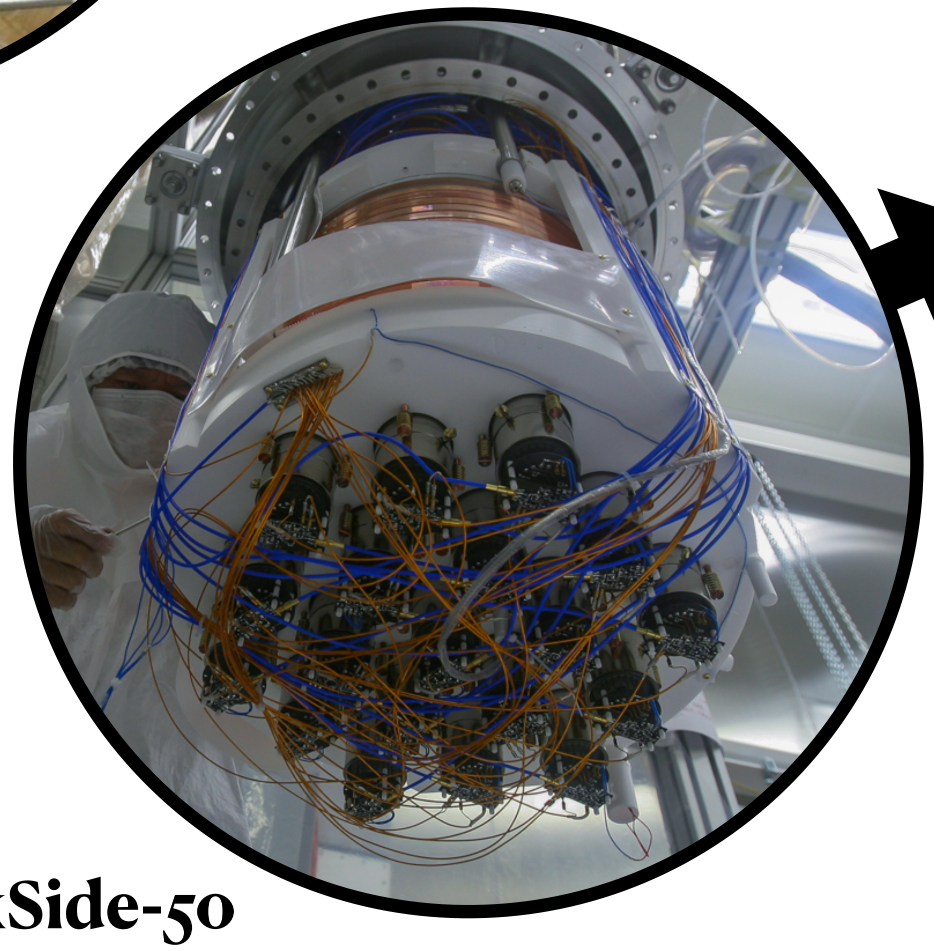


ARIA
@ Italy

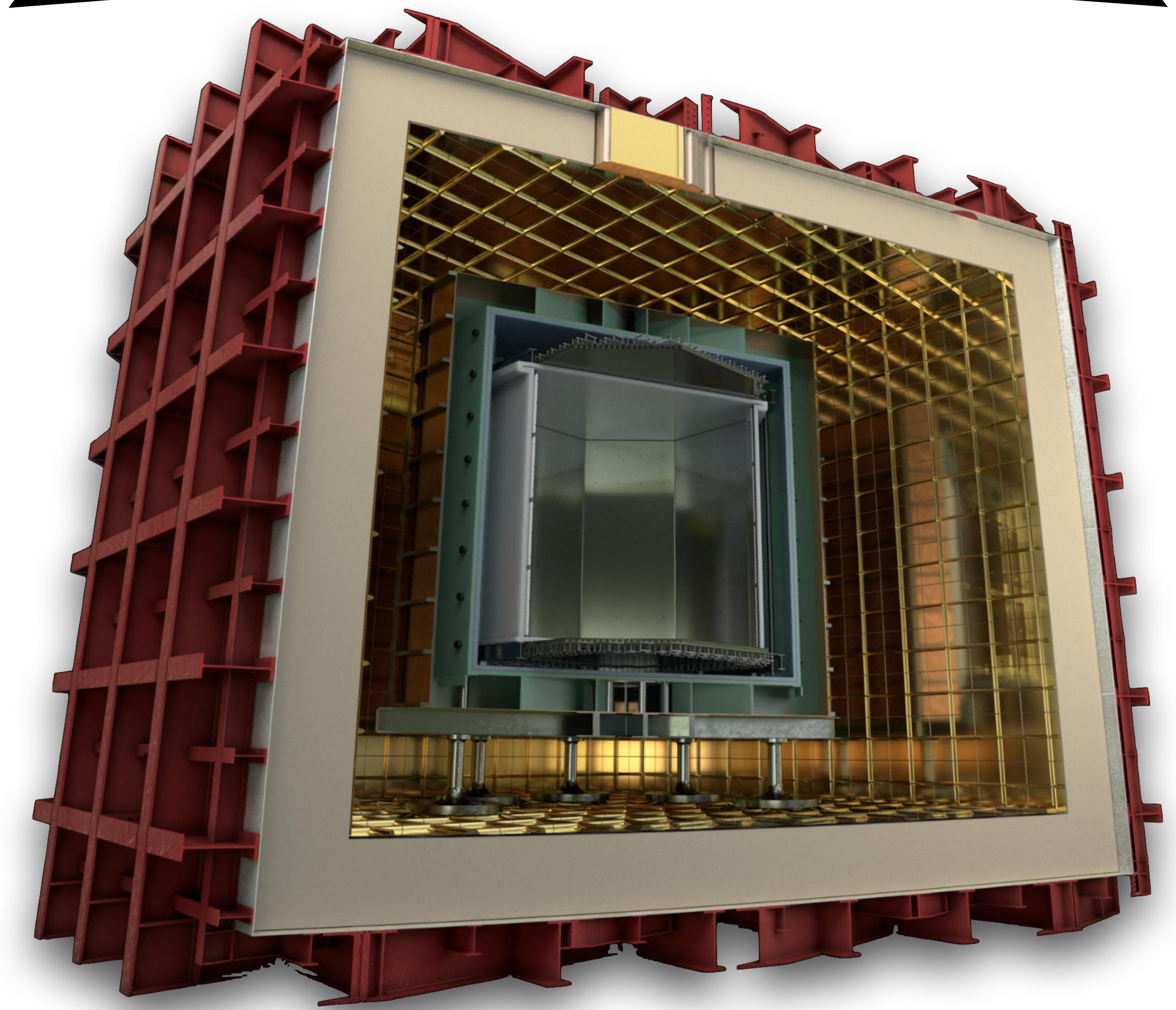


ArDM and DArT
@ Confranc

Urania CO_2 wells
@ USA

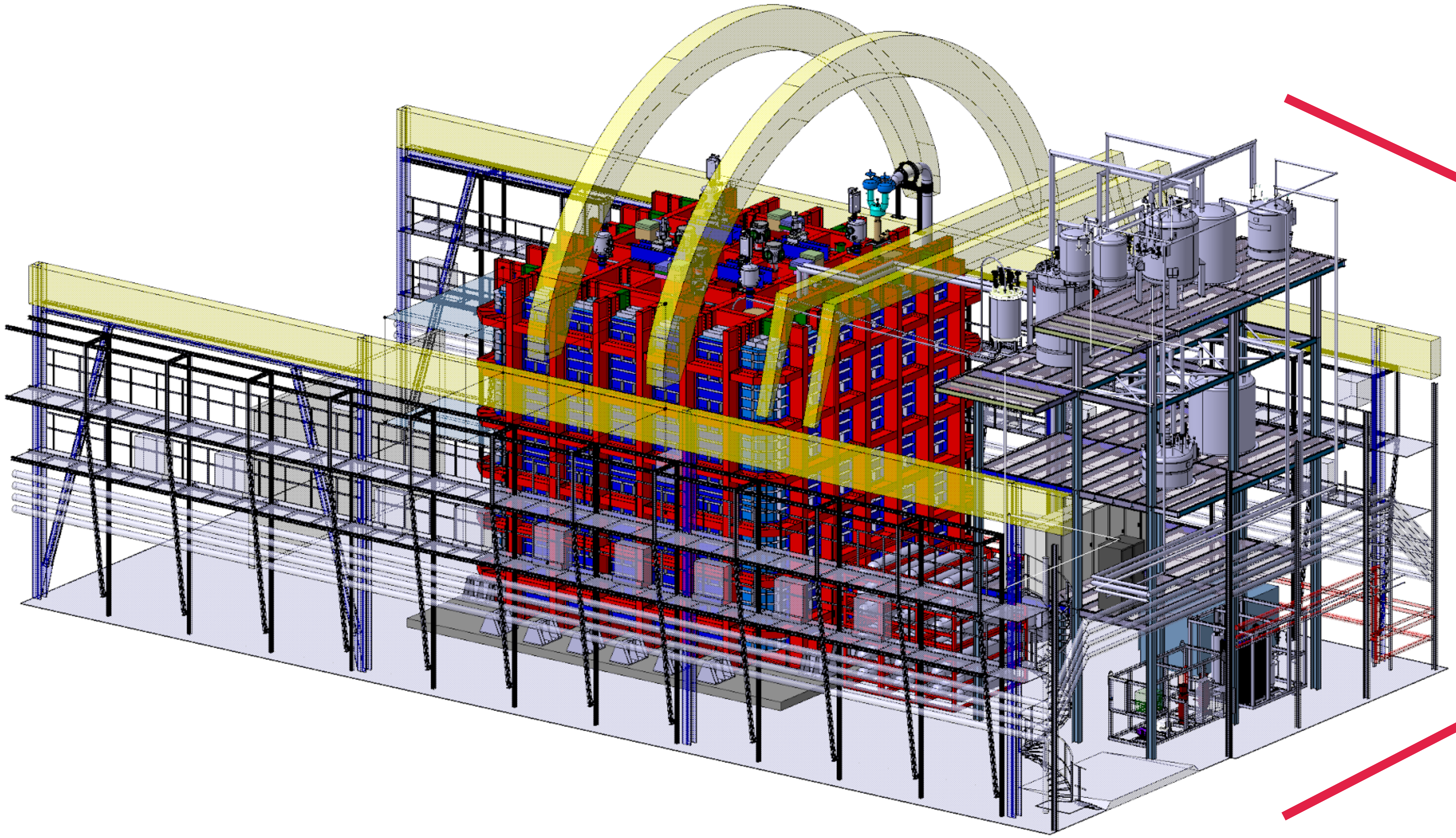


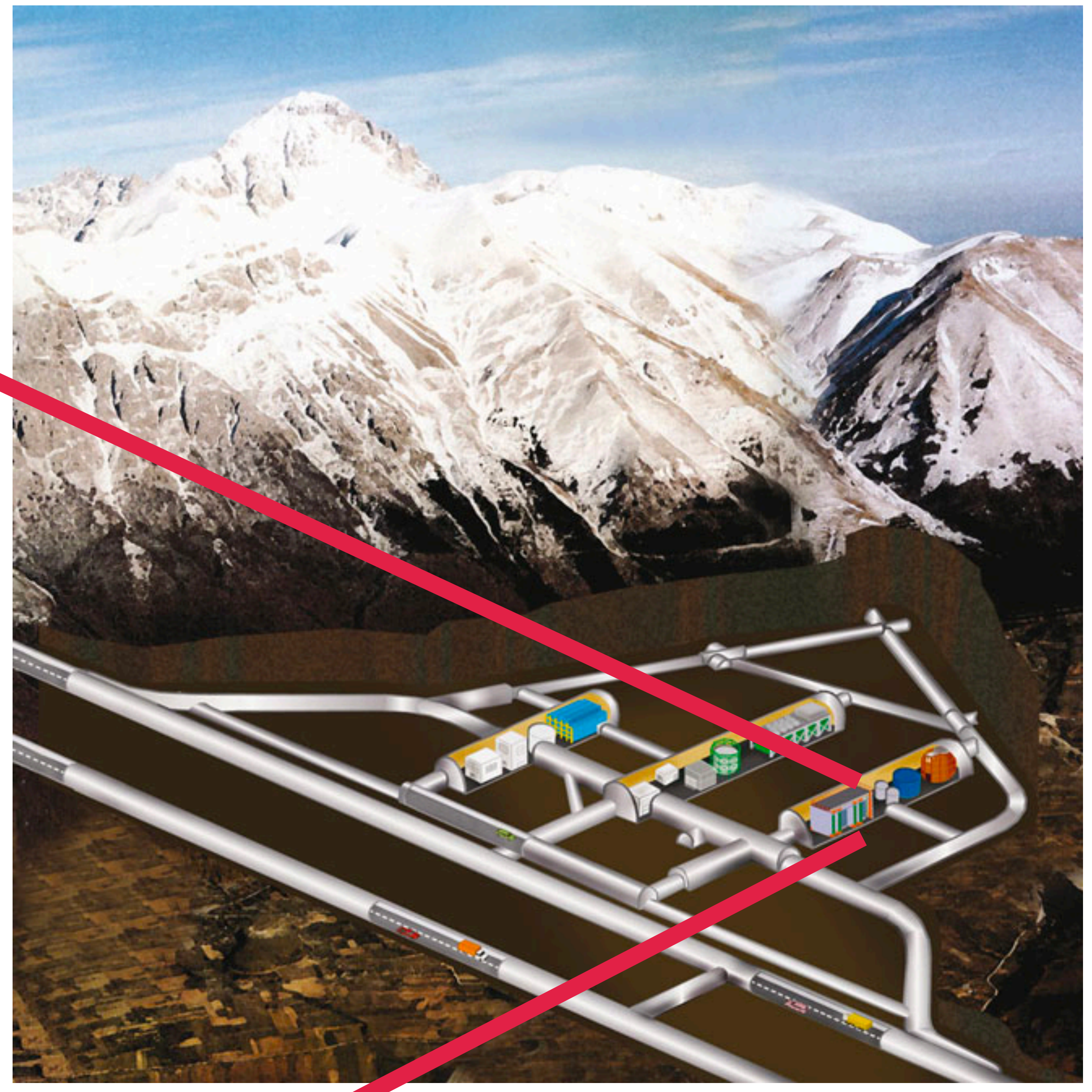
DarkSide-50
@ LNGS



DarkSide-20k
@ LNGS

The DarkSide-20k Experiment



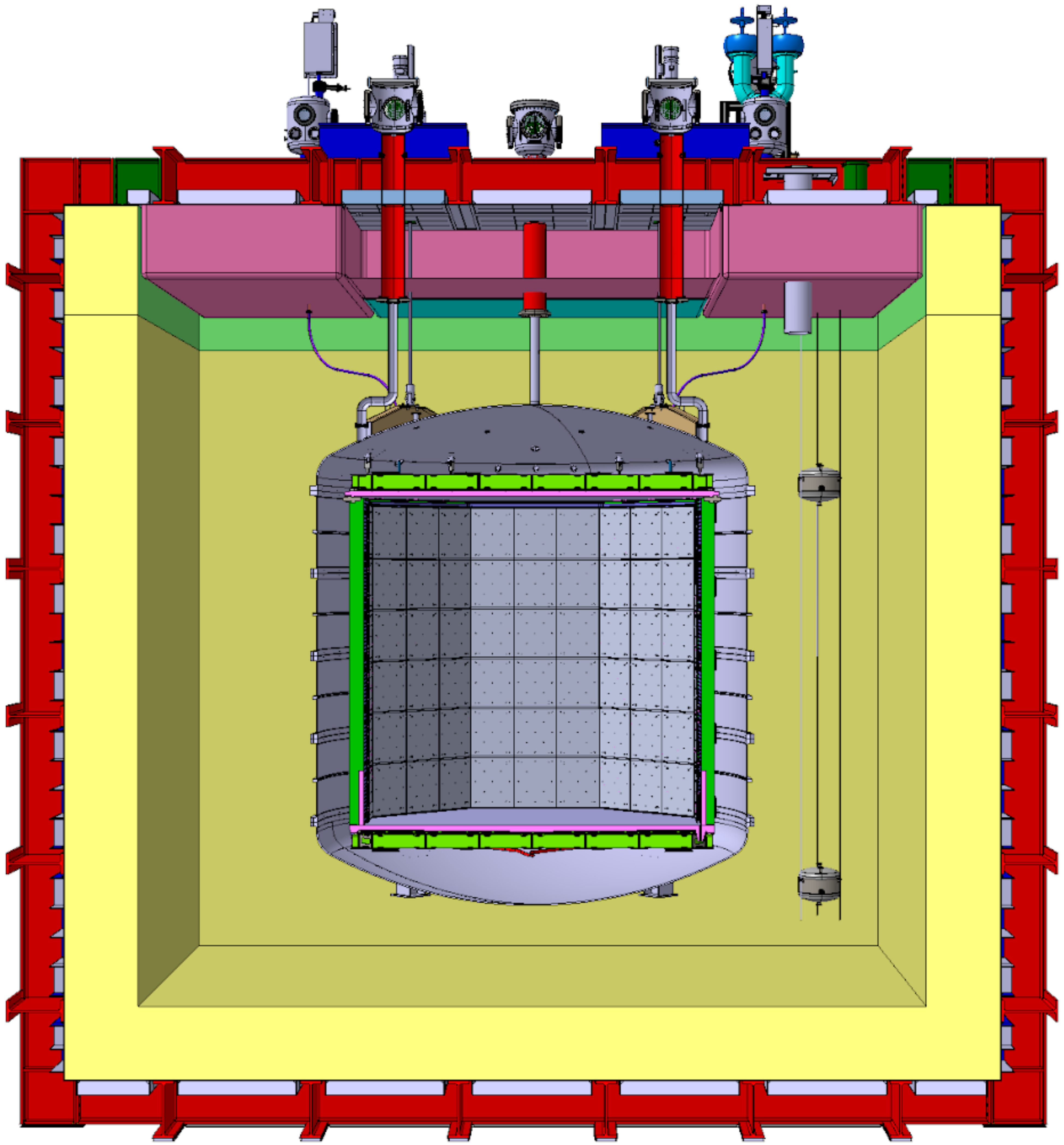


- Below ~1400m of rock (3400 m.w.e)
- Muon flux reduction factor ~10^6

The DarkSide-20k Experiment

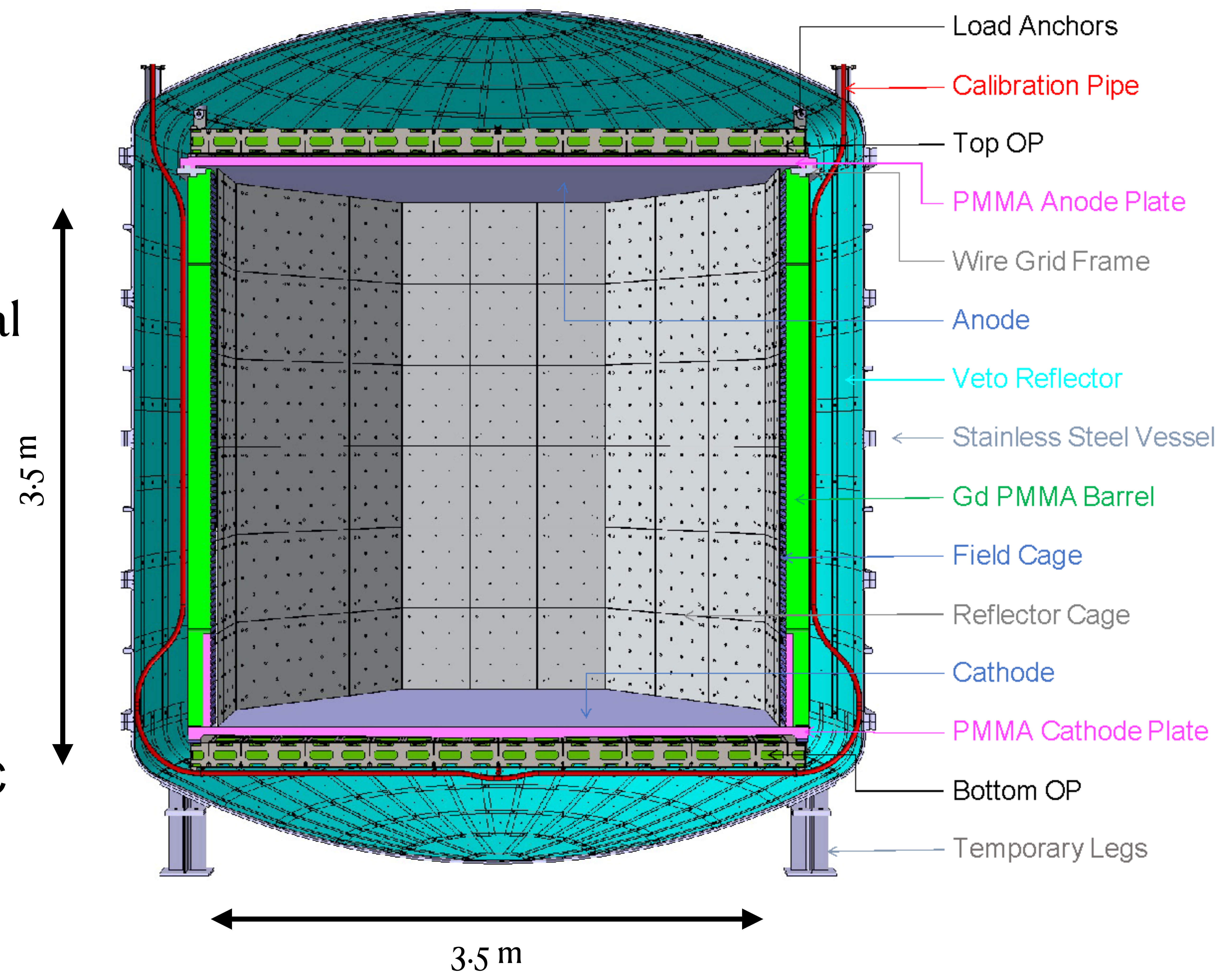
Nested detectors structure:

- ProtoDUNE-like cryostat ($8x8x8m^3$) - Muon veto
- SS vessel separating AAr from underground UAr.
- Integrated meutrons and γ veto
- WIMP detector: dual-phase TPC hosting 50tonnes of UAr

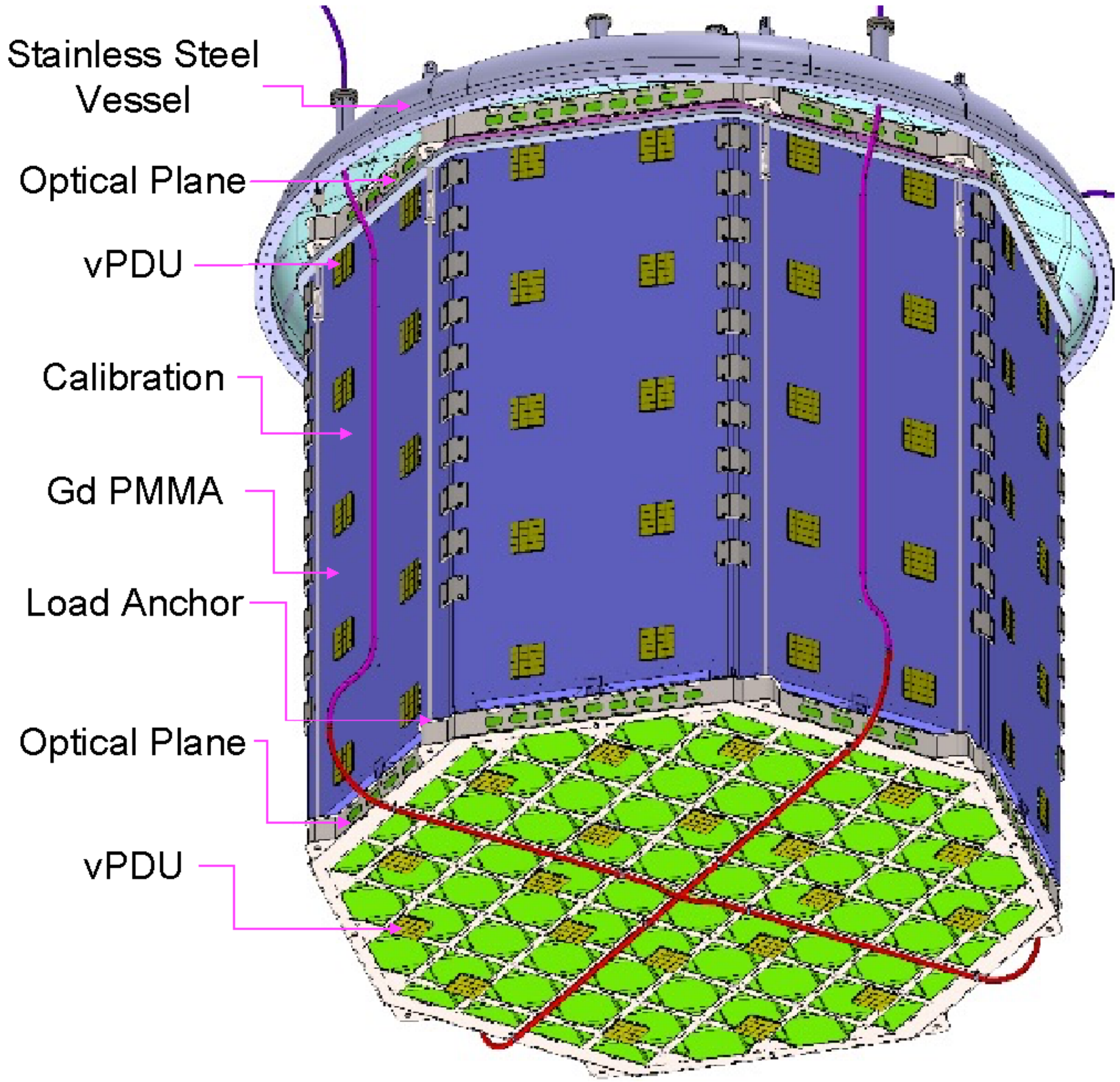


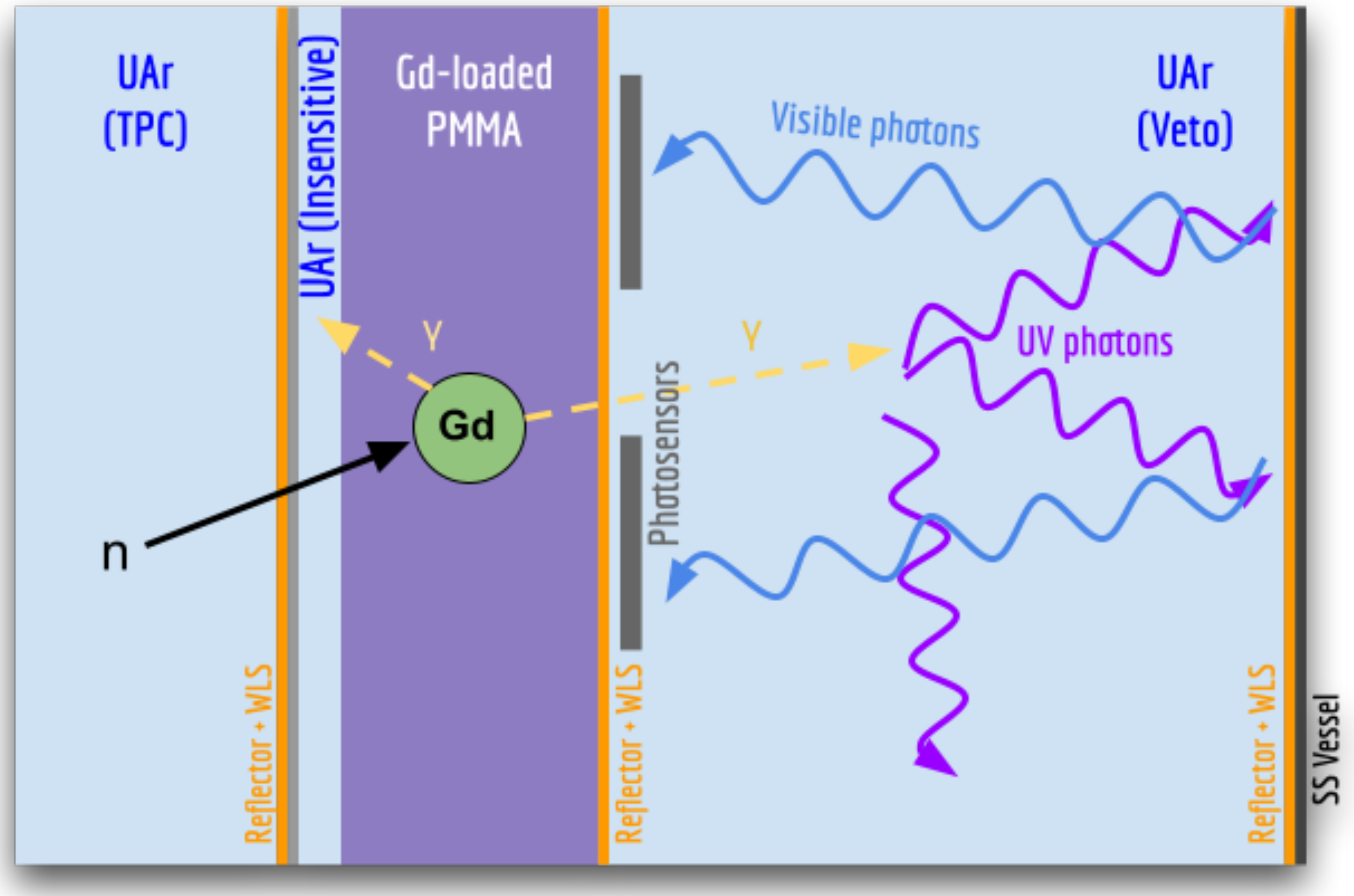
The DarkSide-20k Inner Detector

- TPC: 50 tonnes of UAr depleted in ^{39}Ar, 20 tons in fiducial volume.
- Active neutron veto integrated lateral TPC walls with Gd-loaded PMMA (acrylic)
- Reflector cage cover the TPC inner volume using TPB coated ESR foils
- Large SiPM based photo-detection covers the top and bottom of the TPC



Neutron Veto
with Gd-loaded PMMA



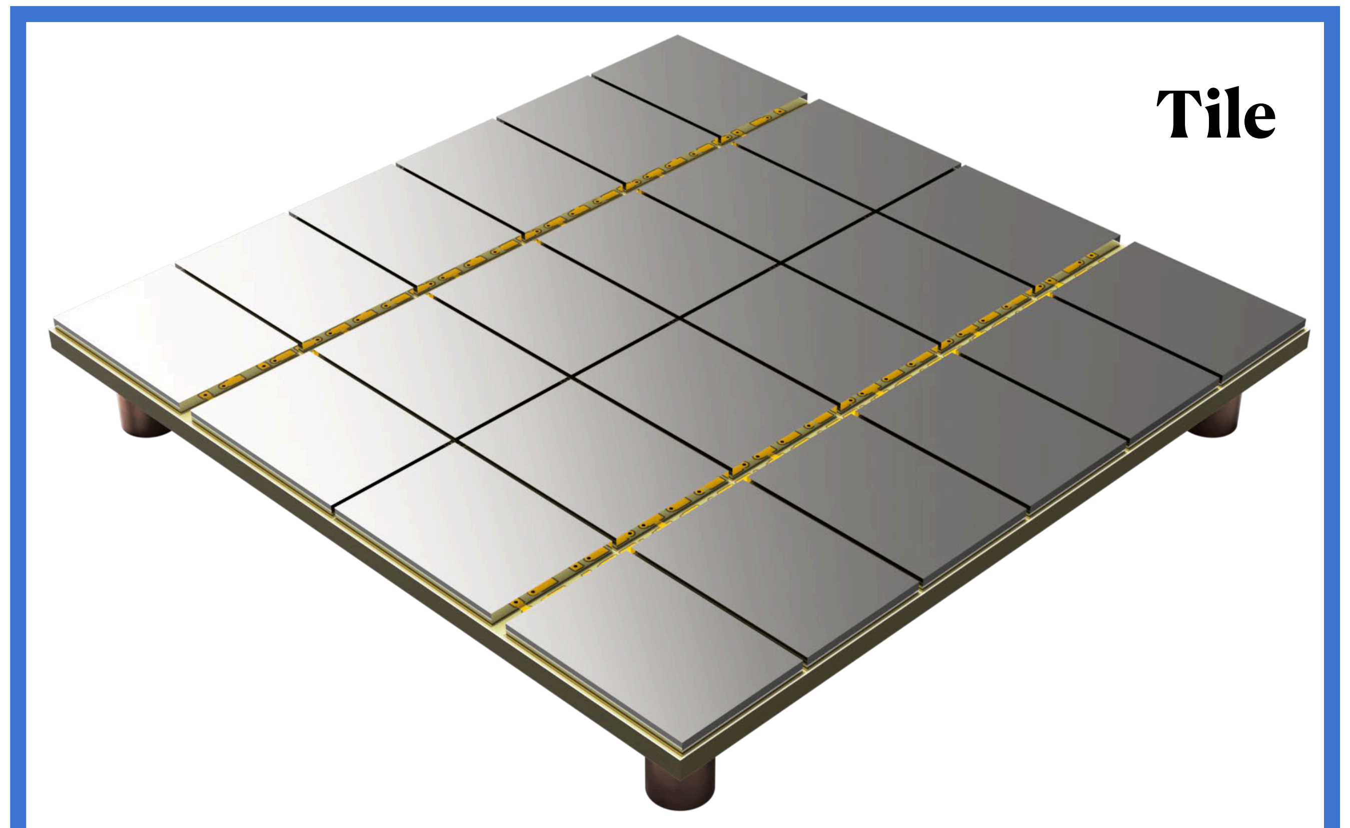


Neutrons are thermalize by collision with Hydrogen in PMMA and then captured on Gd.

Gd emits high energy γ ray cascade up to 8 MeV

Photo-detection with Large SiPM Arrays

Array of 24 SiPMs w/ signal pre-amplification



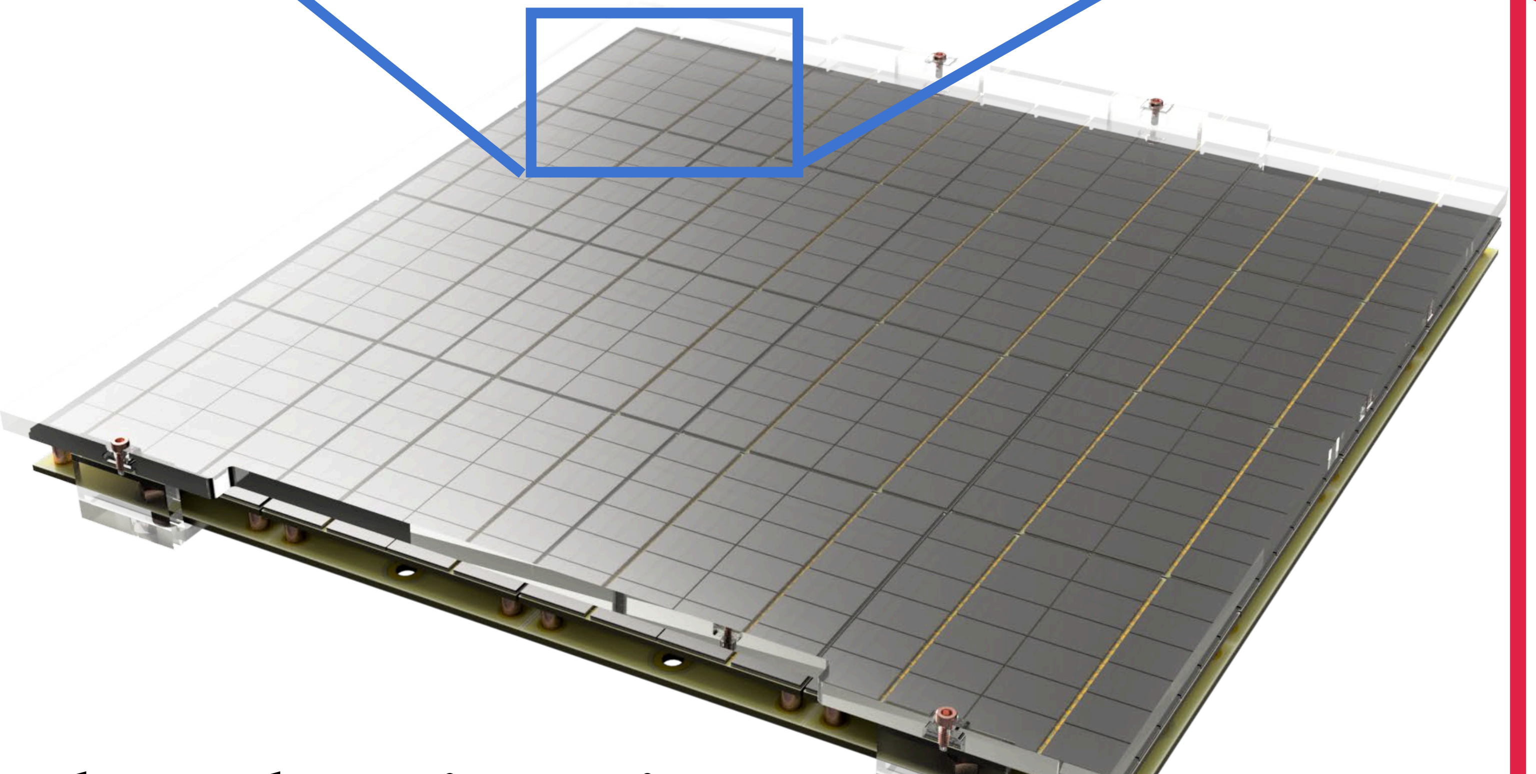
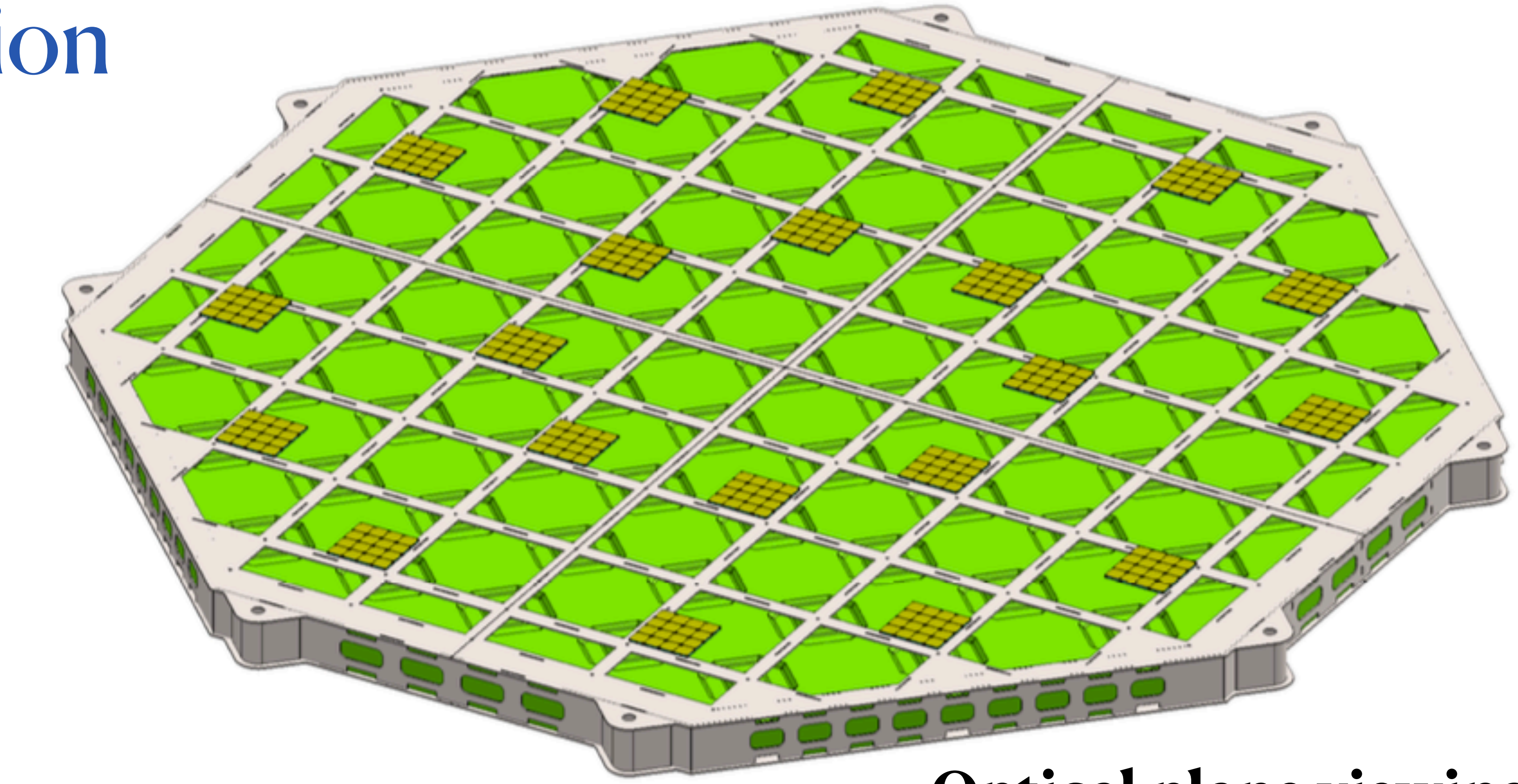
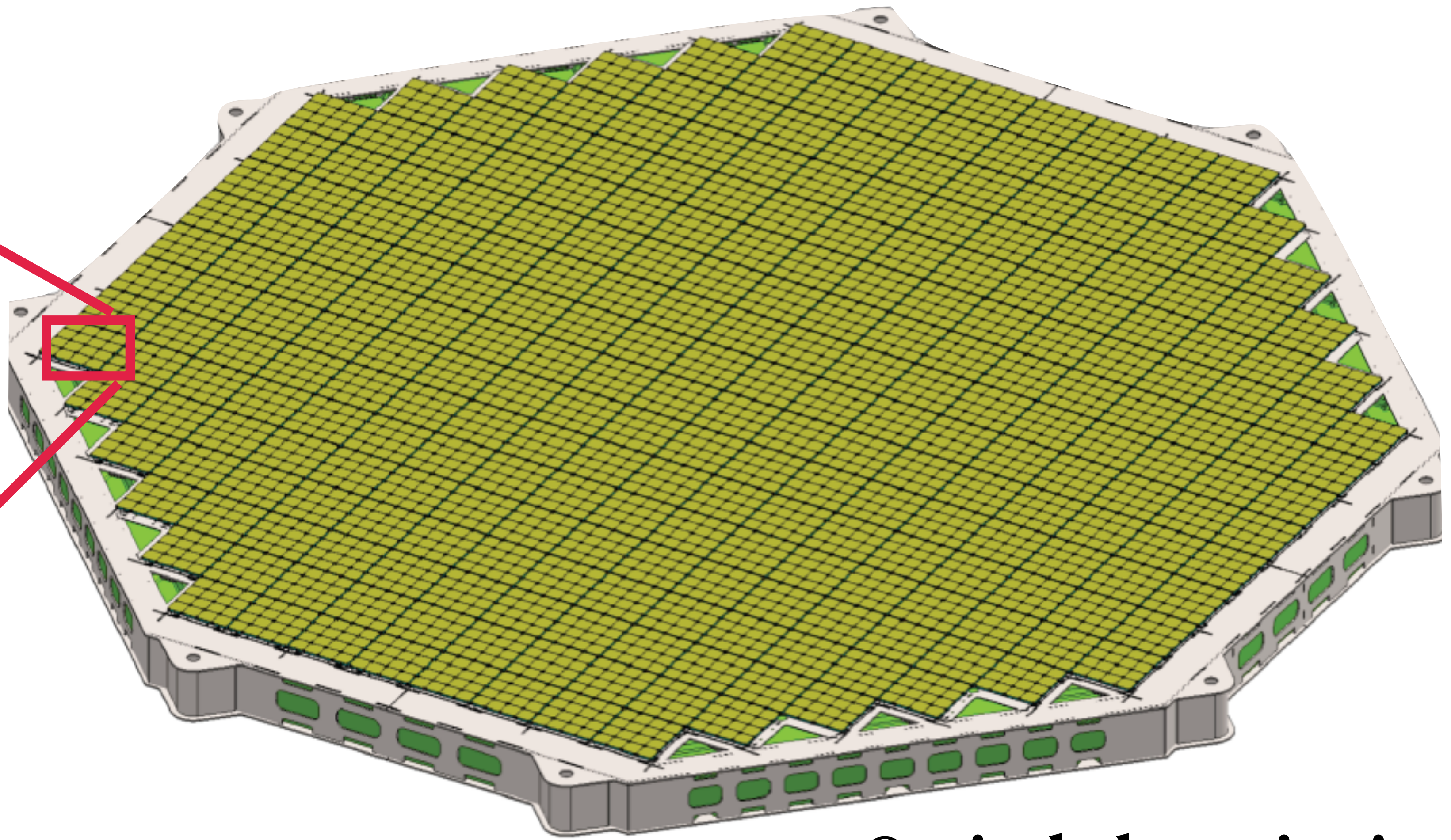


Photo-detection unit

16 tiles arranged in 4 readout channels



Optical plane viewing veto region

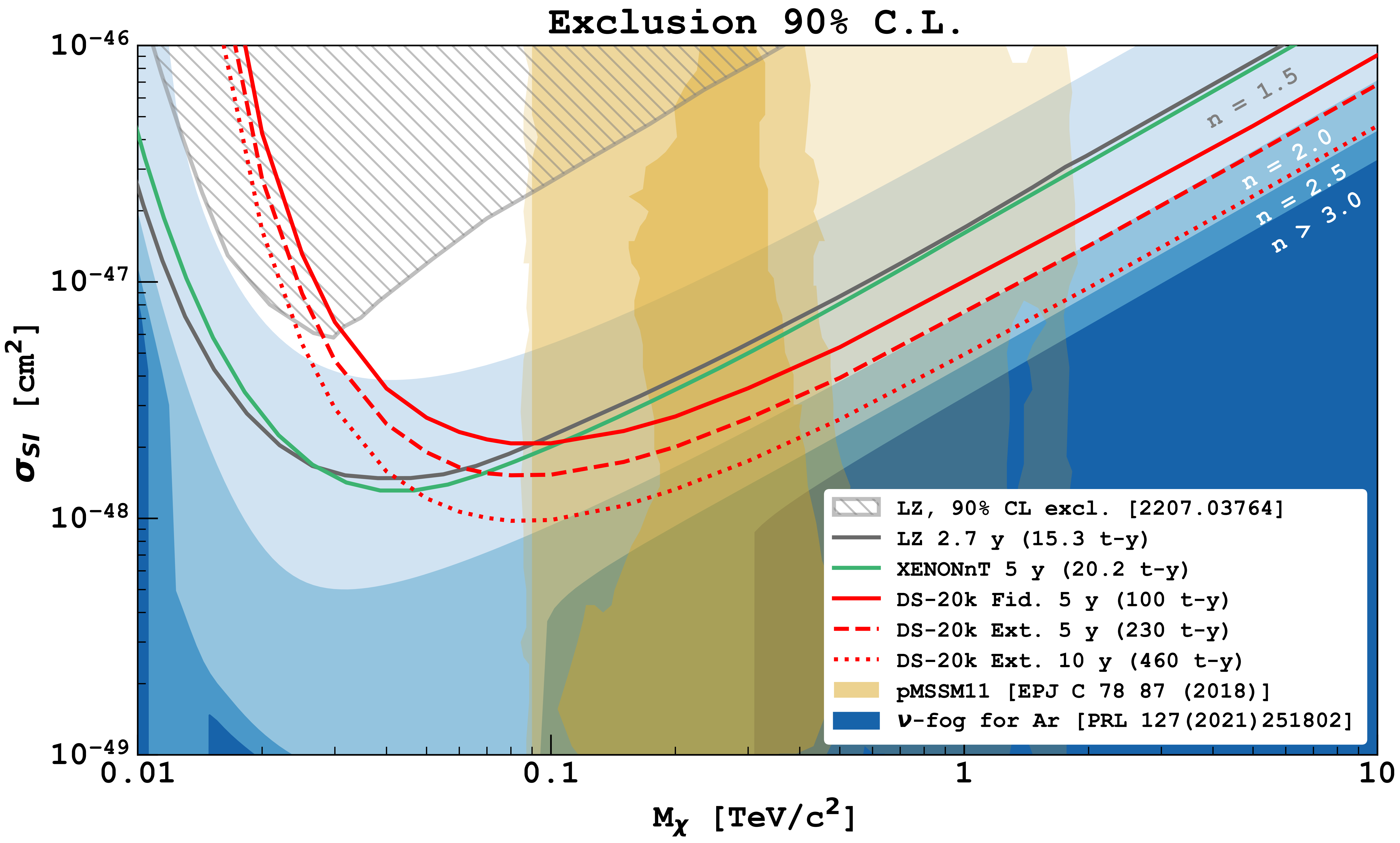


Optical plane viewing TPC

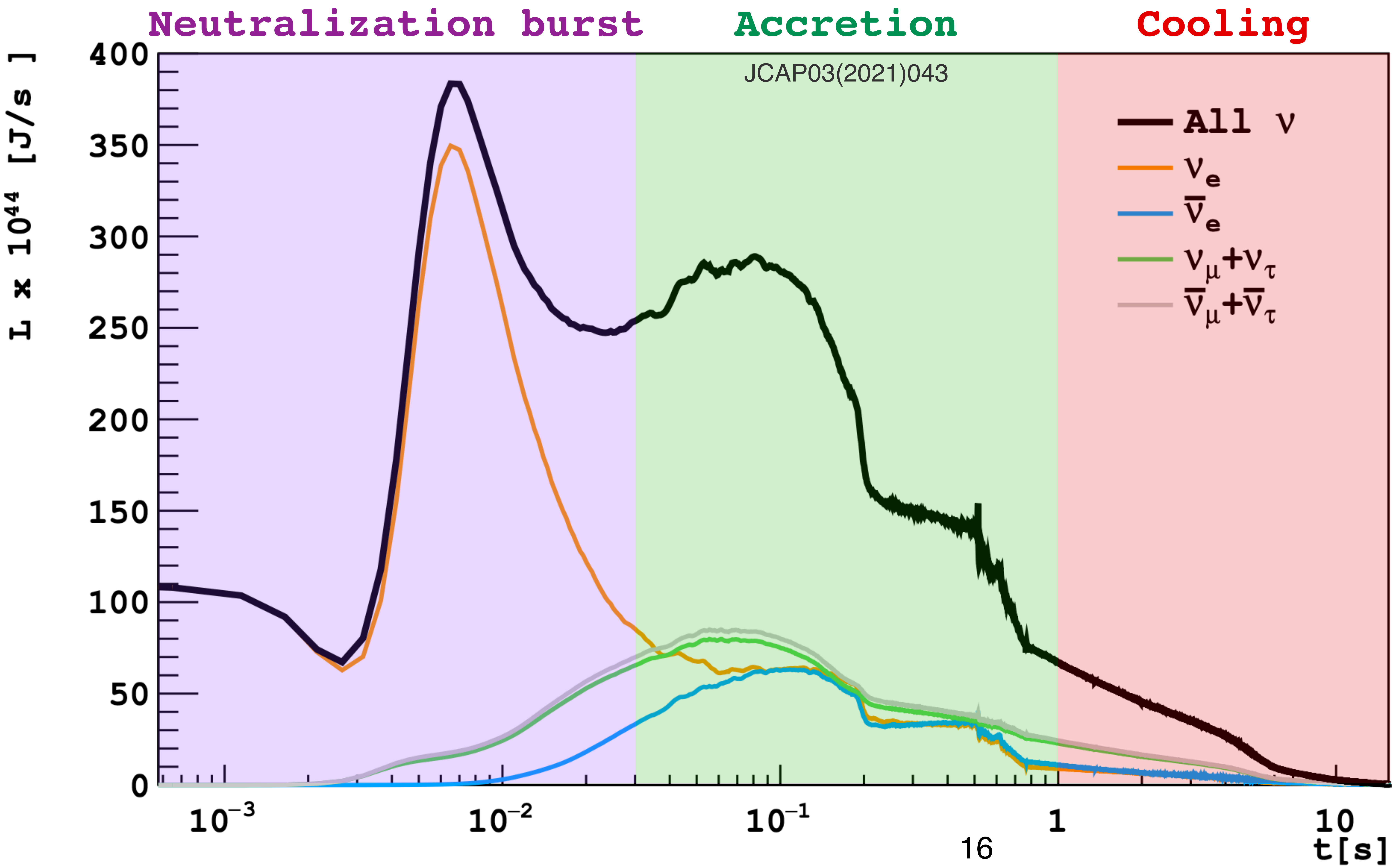
- 525 PDUs covers ~2x21m² top and bottom of the TPC
- 90% coverage for high light yield (10 PE/keV).
- 120 PDUs covers the inner veto

Sensitivity to WIMPs

- Projected 6.3×10^{-48} cm^2 sensitivity for DS-20k SI WIMP-nucleon cross-section with a nominal 20x10 t y exposure.
- Only 0.1 instrumental background events in 200 t yr
- Expected neutrinos: 3.2 events in 200 t yr
- Low mass WIMPs covered by Maxim Gromov



Sensitivity to CCSN Neutrinos via CEνNS Process

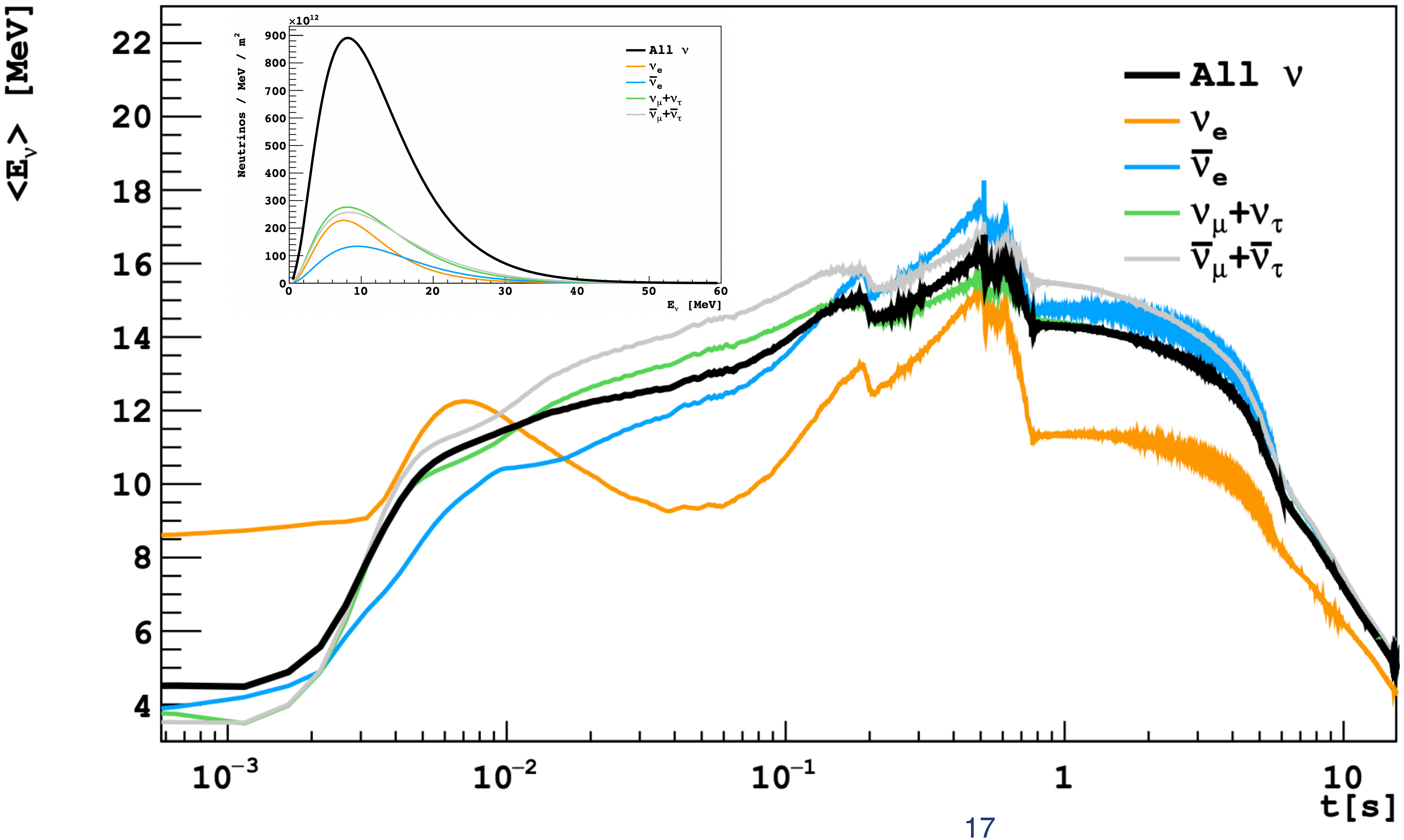


- Core Collapse Supernova go through three phases:
  1. neutronization burst (~30ms),
  2. accretion phase (~0.02-1s),
  3. cooling (~1-10s).

- Hydynamical spherically symmetric simulations by Garching group. Two progenitors are simulated: $11M_\odot$ and $27M_\odot$ (here shown) at 10kpc.

JCAP03(2021)043

Sensitivity to CCSN Neutrinos via CEνNS Process



- During a core collapse supernova, 99% of the energy is emitted through neutrinos (~10^{53} erg)
- Neutrinos recoil via CEνNS process are mostly observed as low-energy S2 only nuclear recoil signals.

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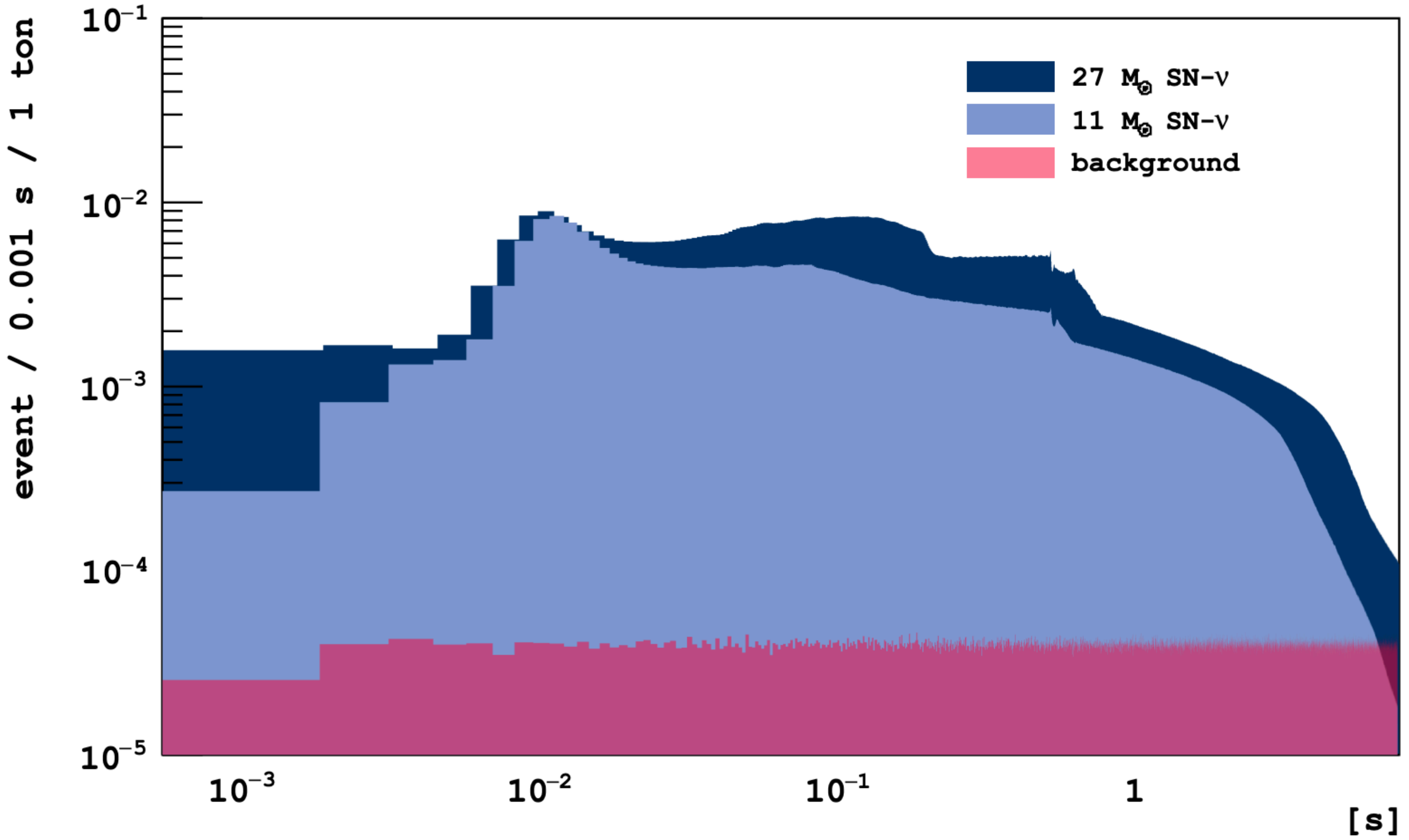
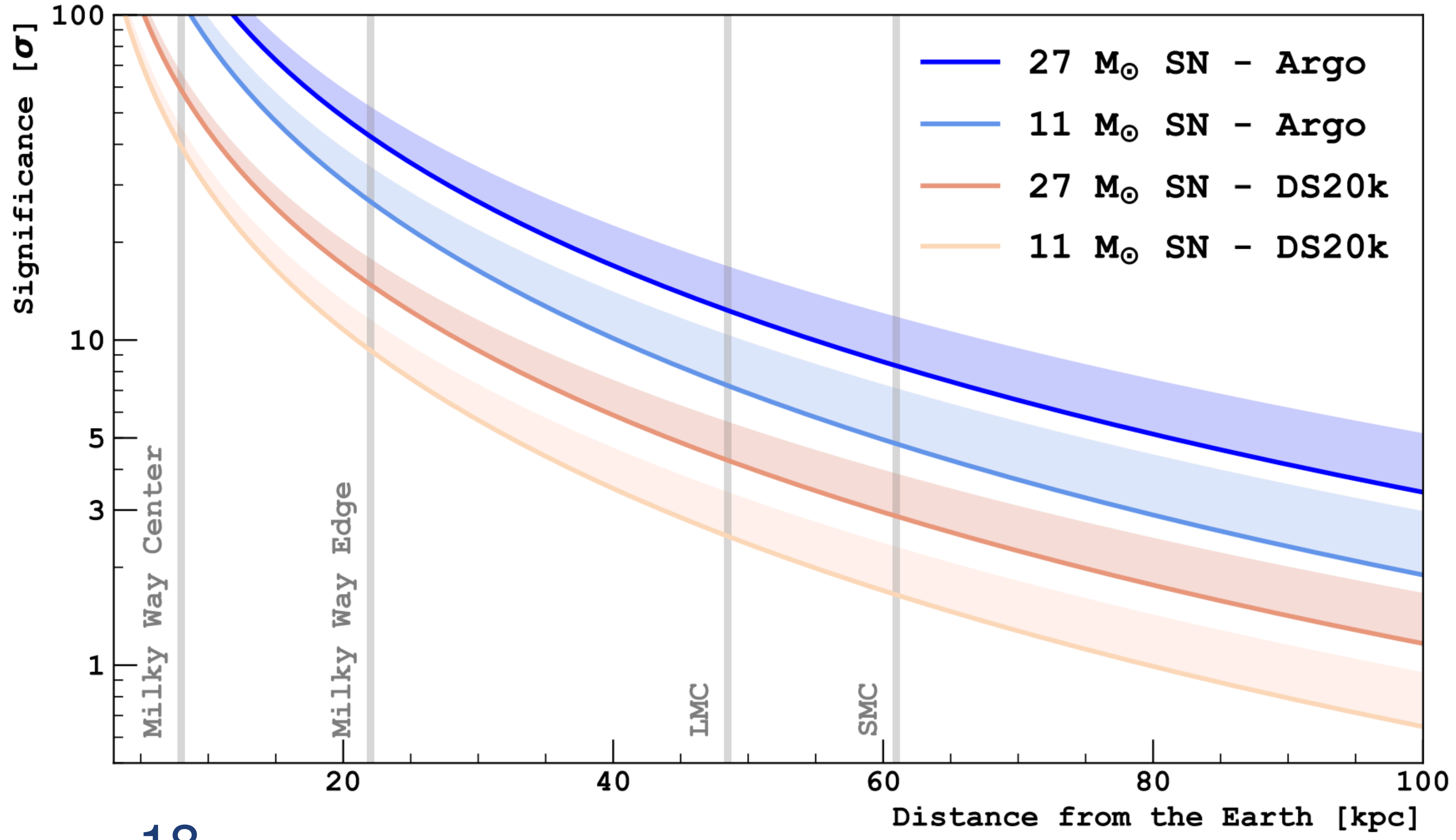
Sensitivity to CCSN Neutrinos via CEνNS Process

- During a core collapse supernova, 99% of the energy is emitted through neutrinos (~10^{53} erg)
- Neutrinos via CEνNS process are observed as low-energy S2 only nuclear recoil signals.
- Expected signal and background in 8s for a SN burst at a distance of 10 kpc

	DarkSide-20k	Argo
11-$M_\odot$ SN-νs	181.4	1396.6
27-$M_\odot$ SN-νs	336.5	2591.6
^{39}Ar	4.3	33.8
external background	1.8	8.8
single-electrons	0.7	5.1





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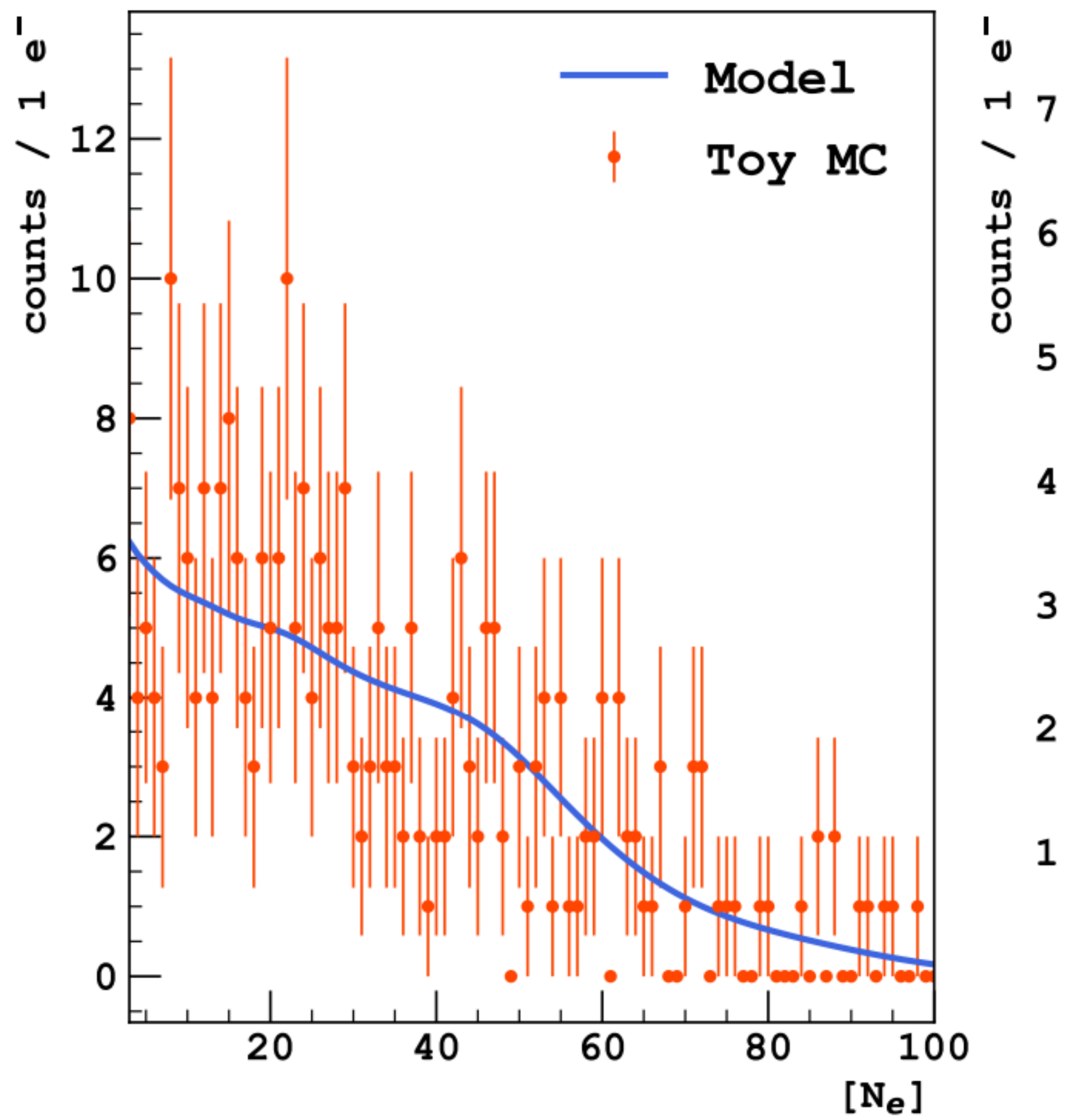
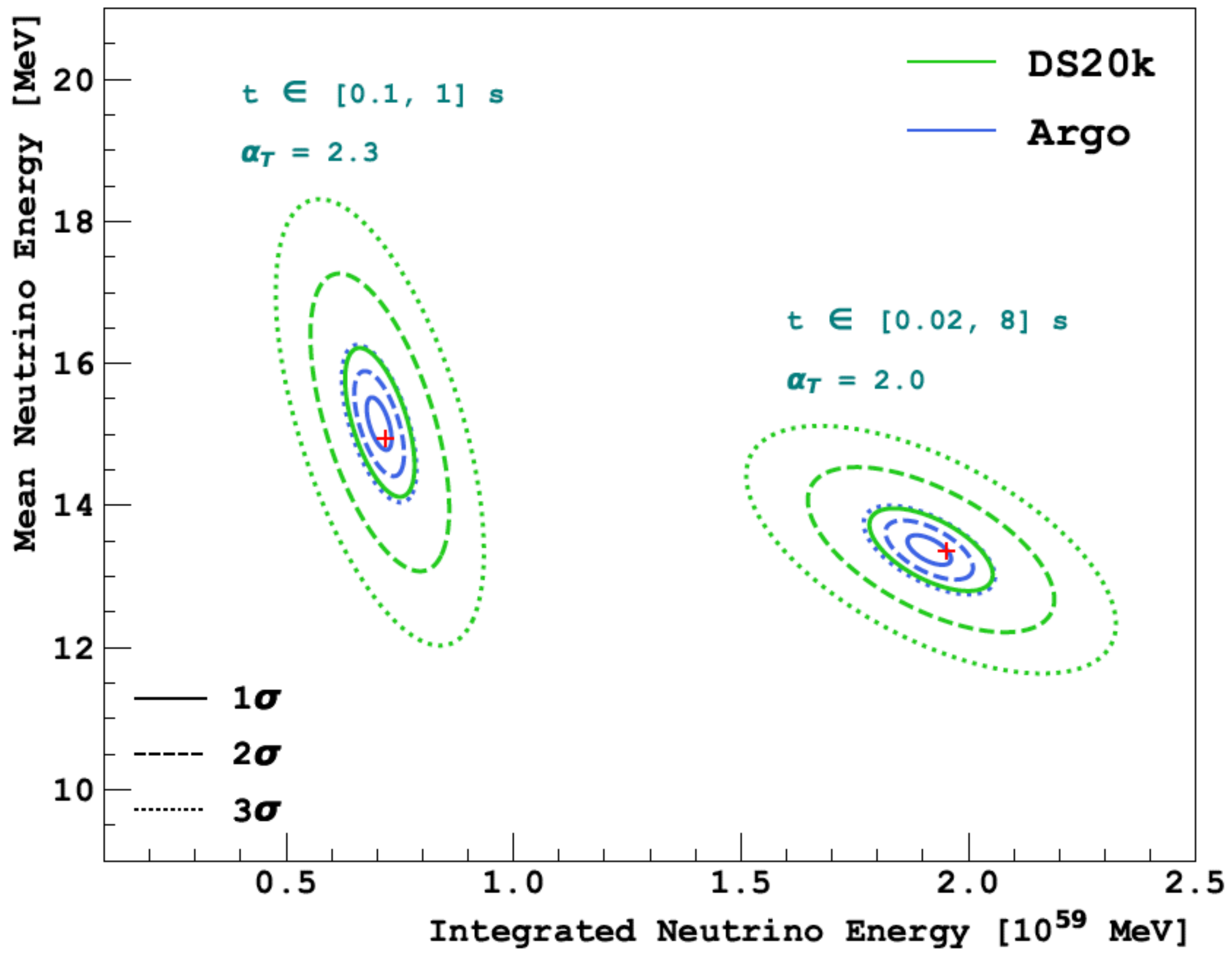
Counting CCSN Neutrinos via CEνNS Process



Toy MC signal in DS20k of $27M_{\odot}$ SN burst at 10 kpc from 0.02-8s.



- DS-20k and Argo energy and time resolution allow to reconstruct the mean and total energy of neutrinos from a SN burst. Spectra are fitted excluding the neutronization burst.

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- Total neutrino energy reconstruction at 3σ level with 11% (32%) accuracy in Argo (DS-20k).
- Mean neutrino energy reconstruction at 3σ level with 5% (13%) accuracy in Argo (DS-20k)

Thanks!

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Backups

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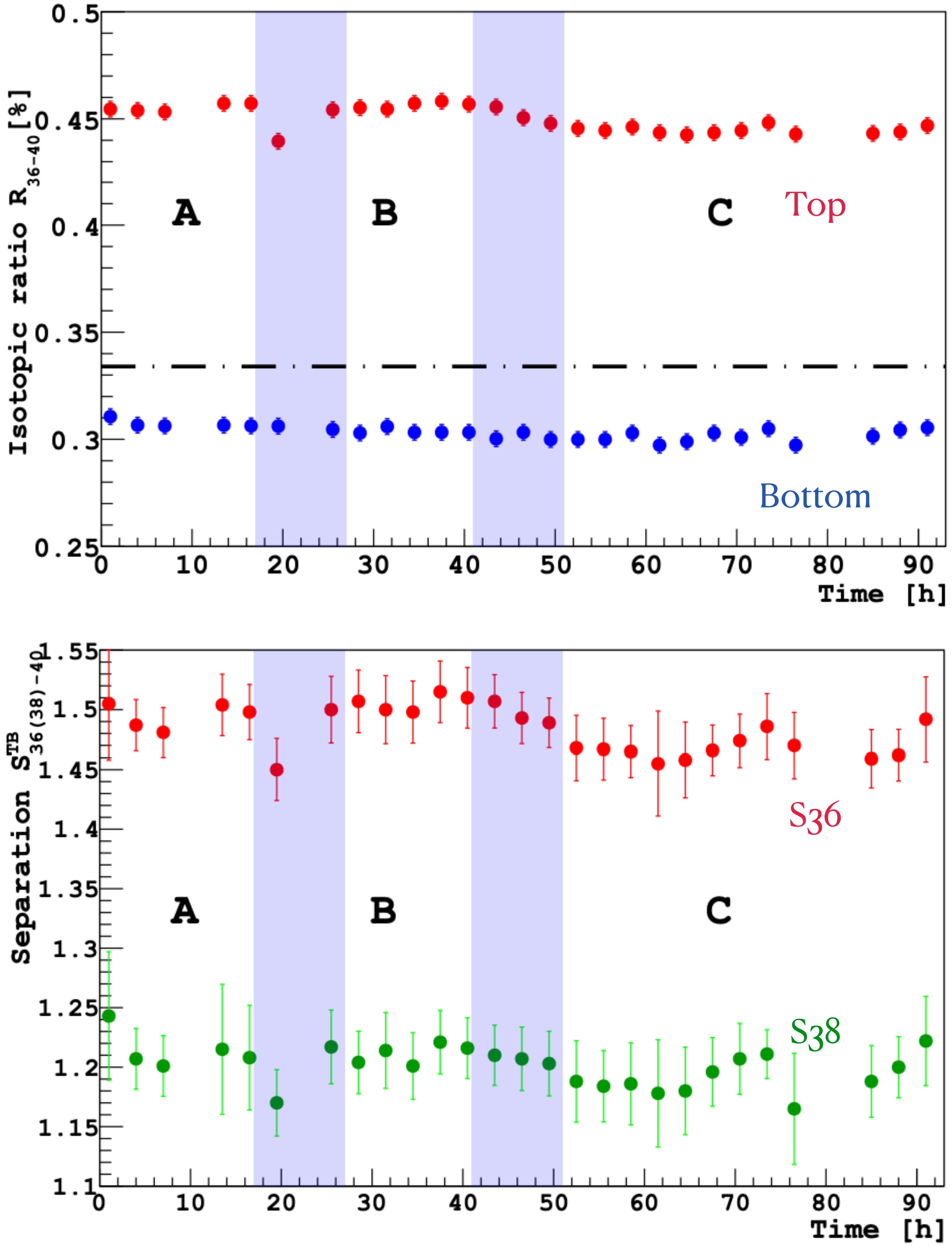
Aria

- A 350 m a 350 m cryogenic distillation column for isotopic separation.
- Measured isotropic separation in the prototype distillation plant in a 2021 run.
- To purify 120 tonne of UAr for DS-20k



epjc/s10052-023-11430-0(2023)

Underground Argon (UAr) Production

Production: Urania
Cortez, CO
Industrial scale extraction plant
Extraction rate: 250-330 kg/day
Production capability ≈ 120 t over two years
UAr purity: three-four nines

Production: Aria
Sardinia, Italy
Industrial scale extraction plant
350 m cryogenic distillation column
O(1 tonne)/day capability
UAr purity: > six nines
Ultimate goal: isotopic separation

DS-20k Experimental Project Summary Timeline