An overview of the GADMC and its neutrino physics program

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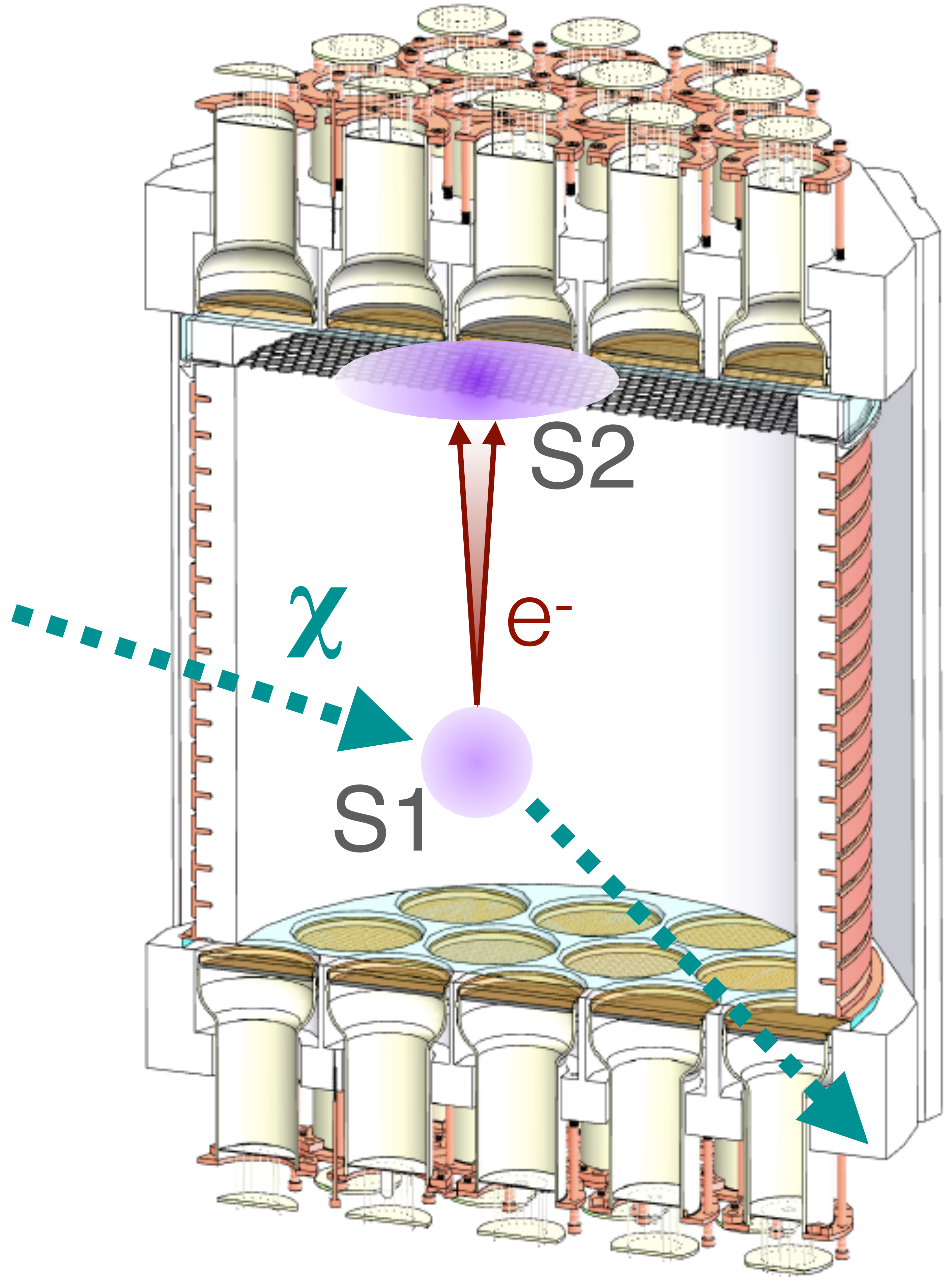
Magnificent CEνNS 2020

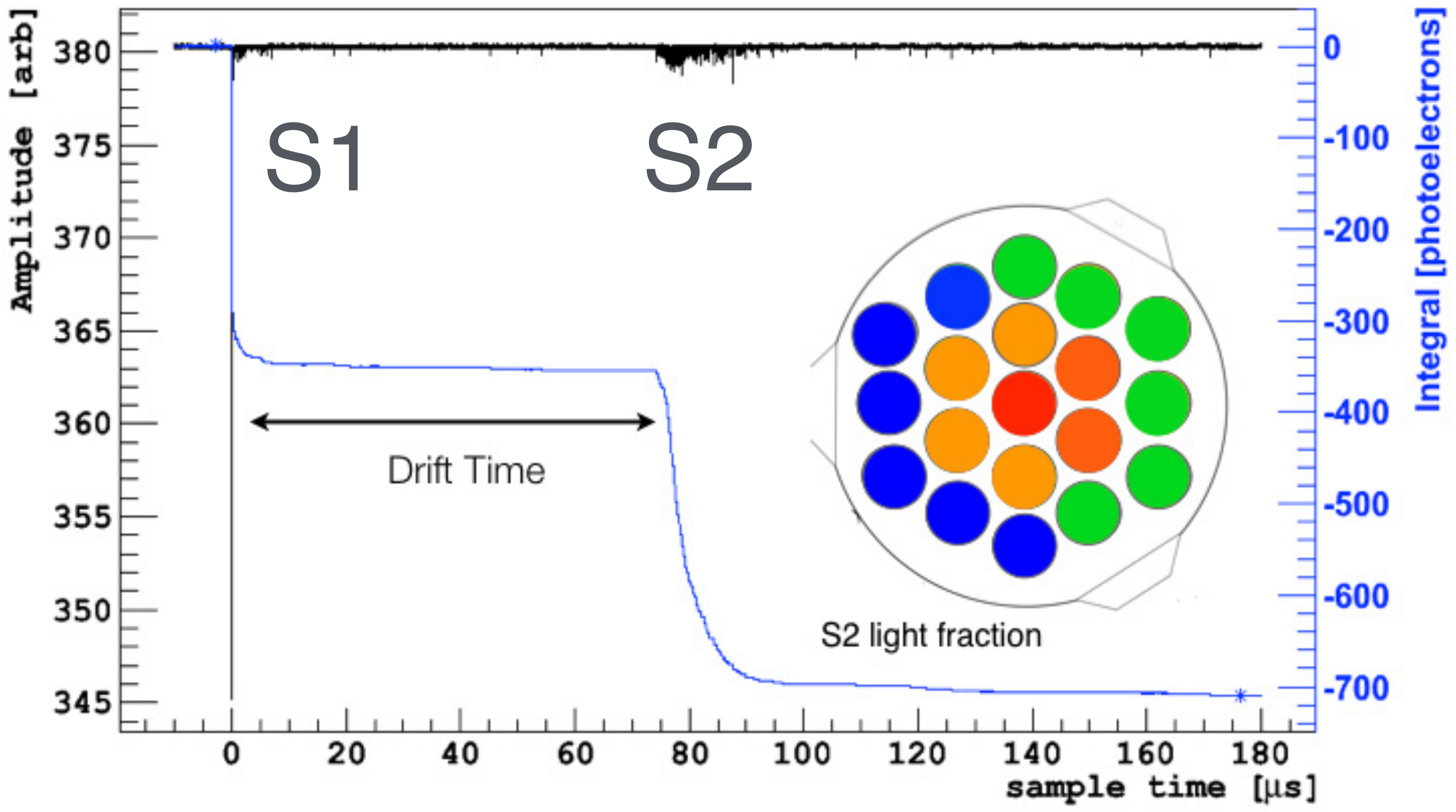
Cyberspace,11/18/2020

Dual-phase argon TPCs

DarkSide-50

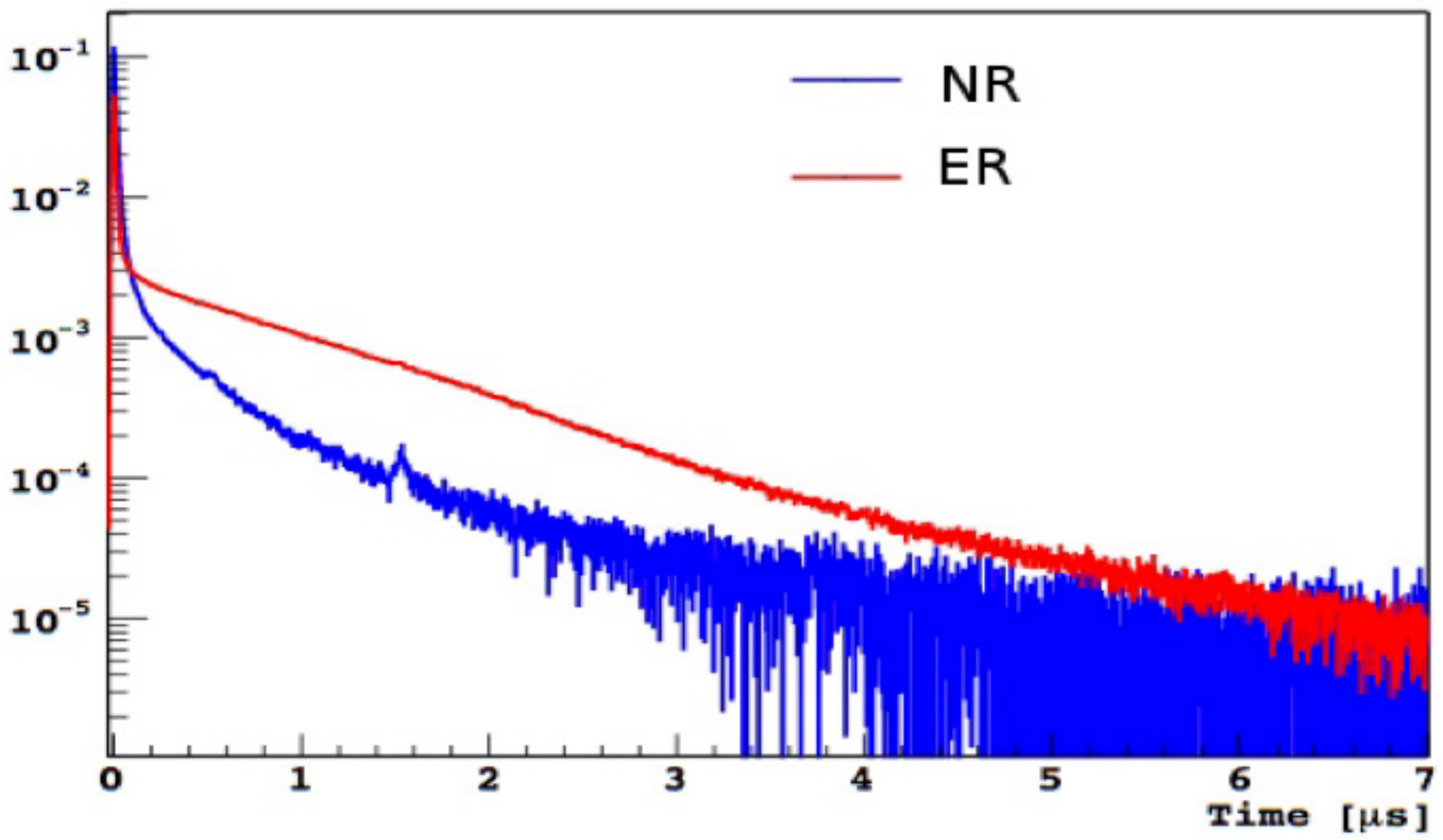


3D position reconstruction



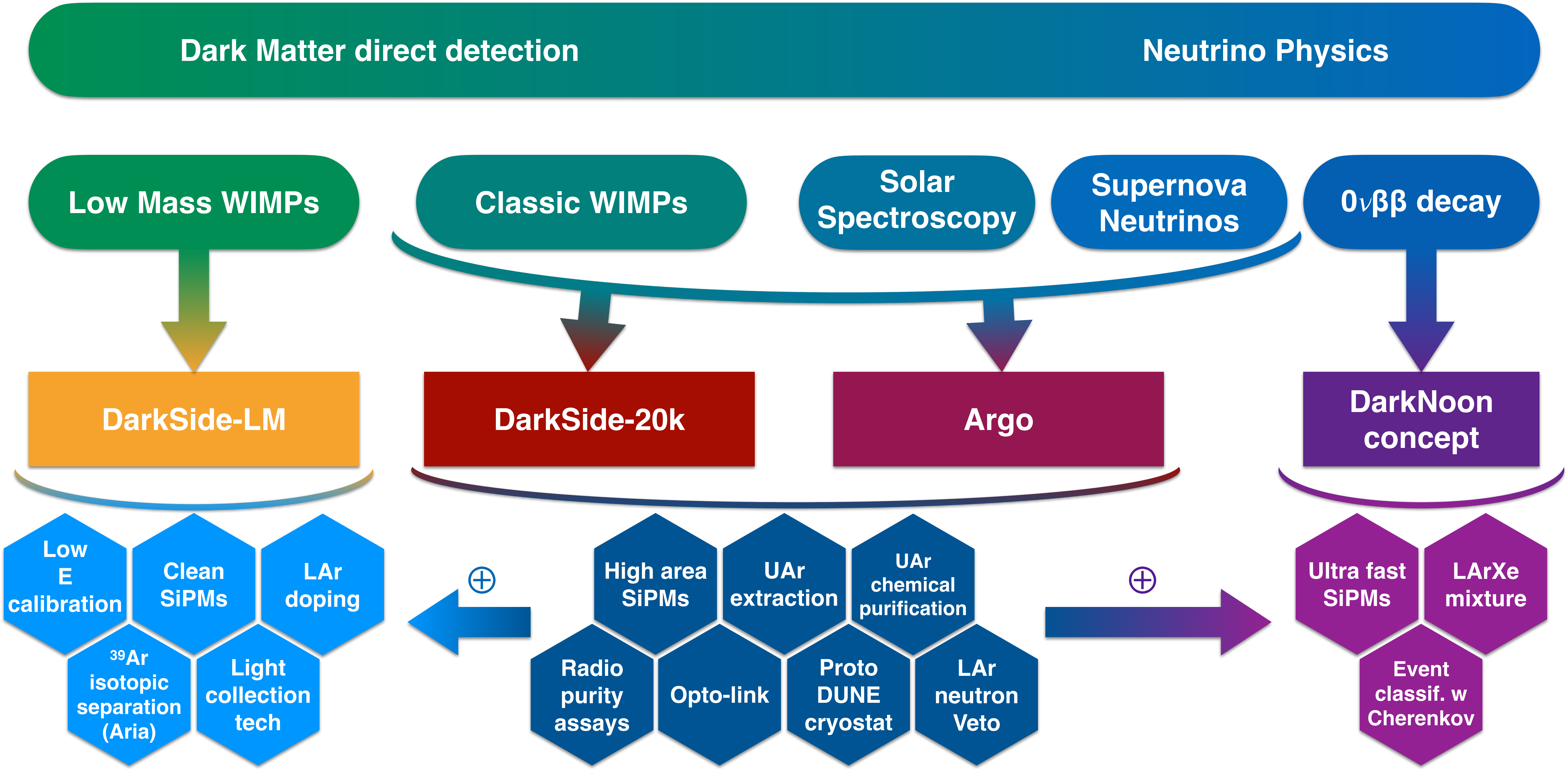
- Z from S1-S2 time difference
- XY from S2 light distribution
- Reliable fiducialization
- Multiple scattering rejection

ER rejection

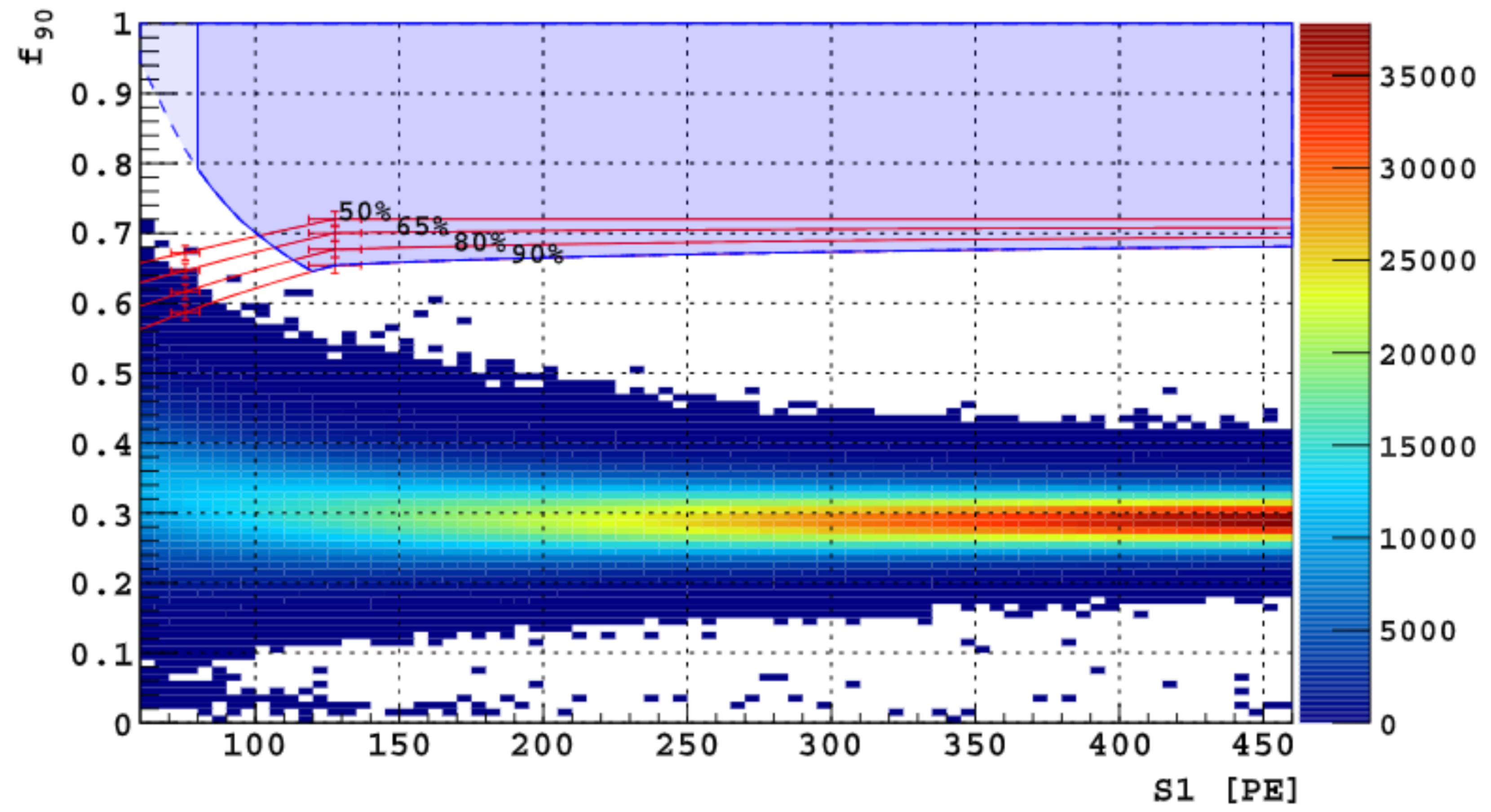


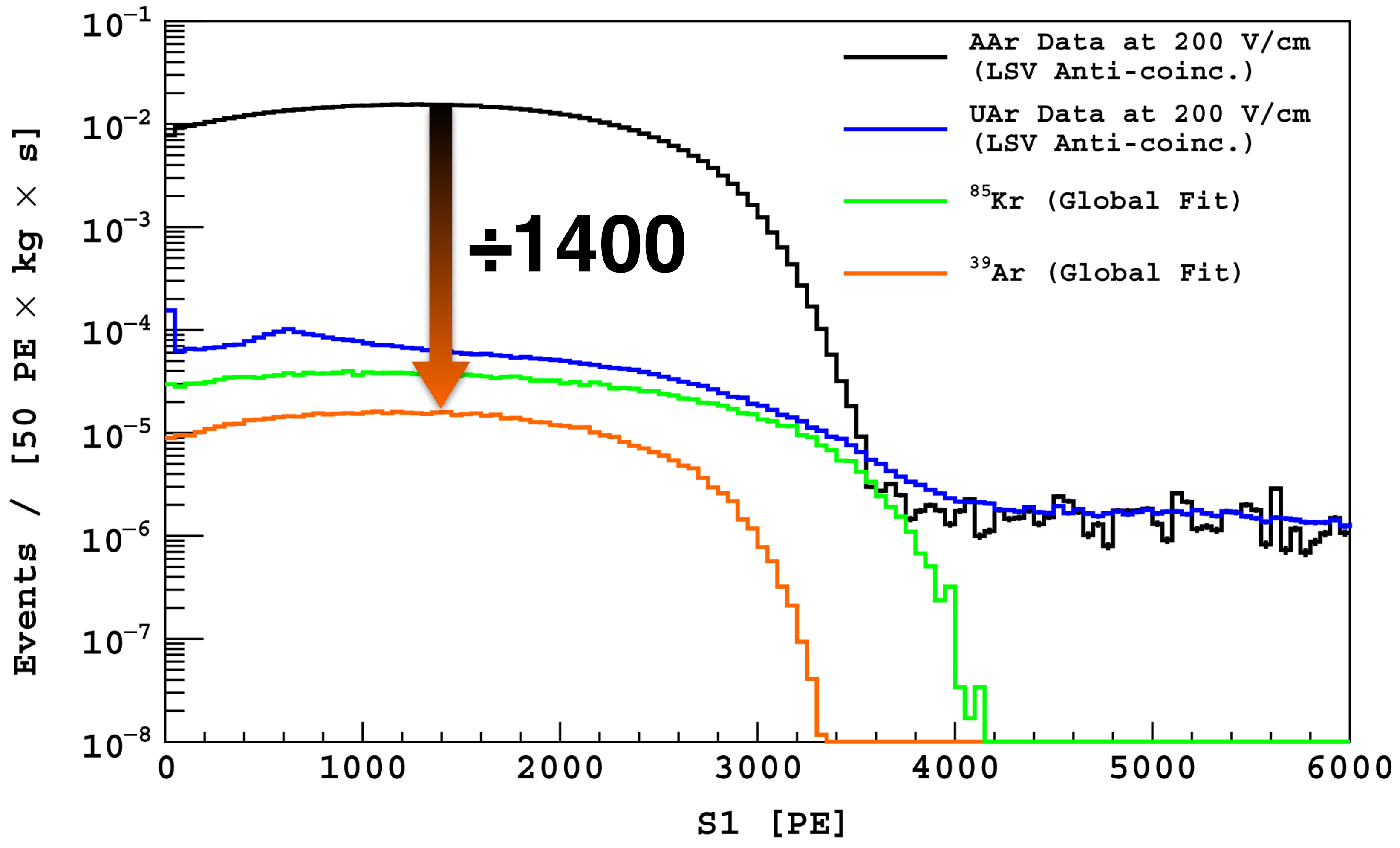
- S2/S1: 10^2 rejection factor
- PSD with S1 in LAr: f90 parameter
- ER rejection factor:
  DS-50 $>10^7$, DEAP $> 10^8$

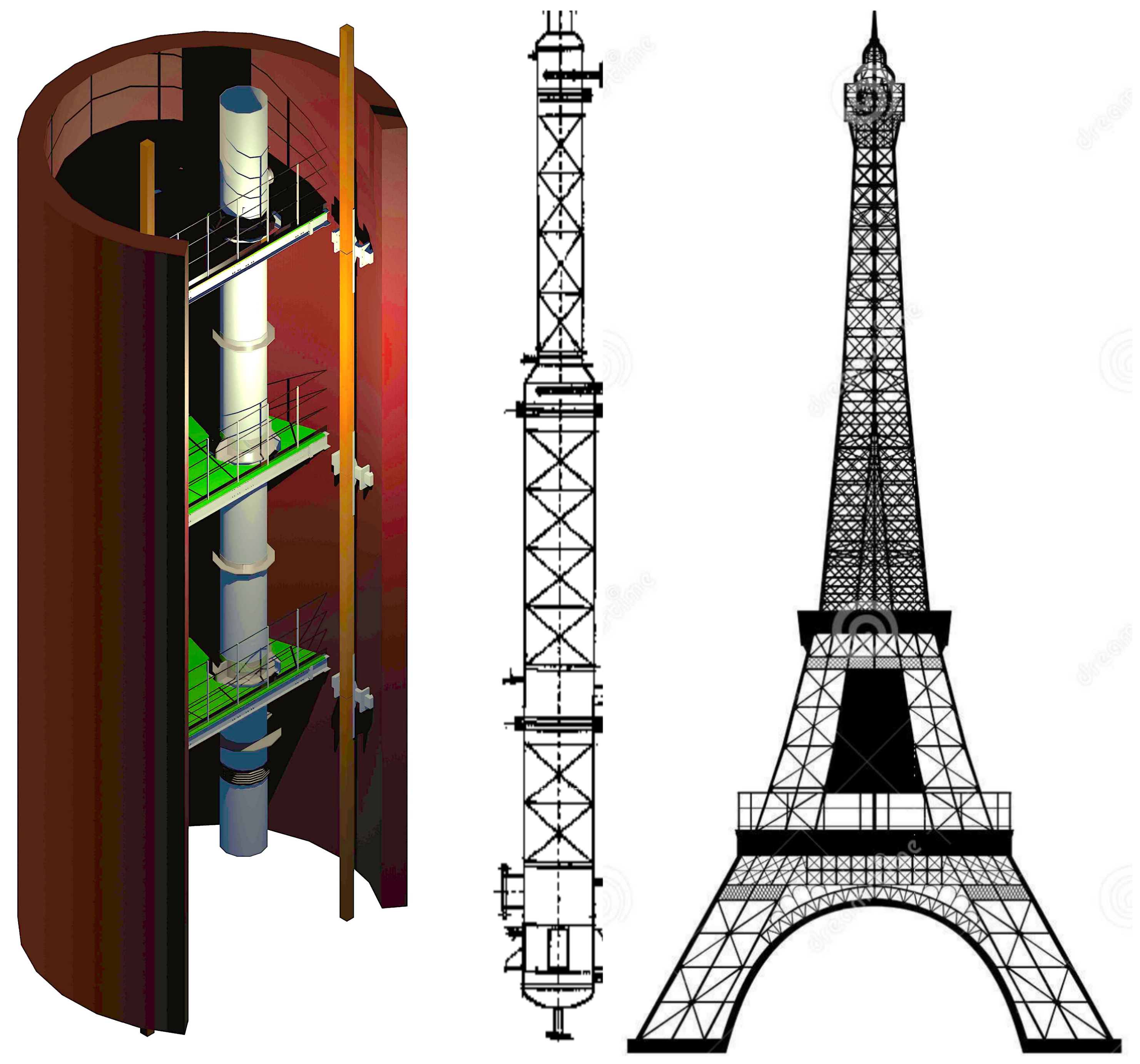
GADMC overview



The ^{39}Ar challenge







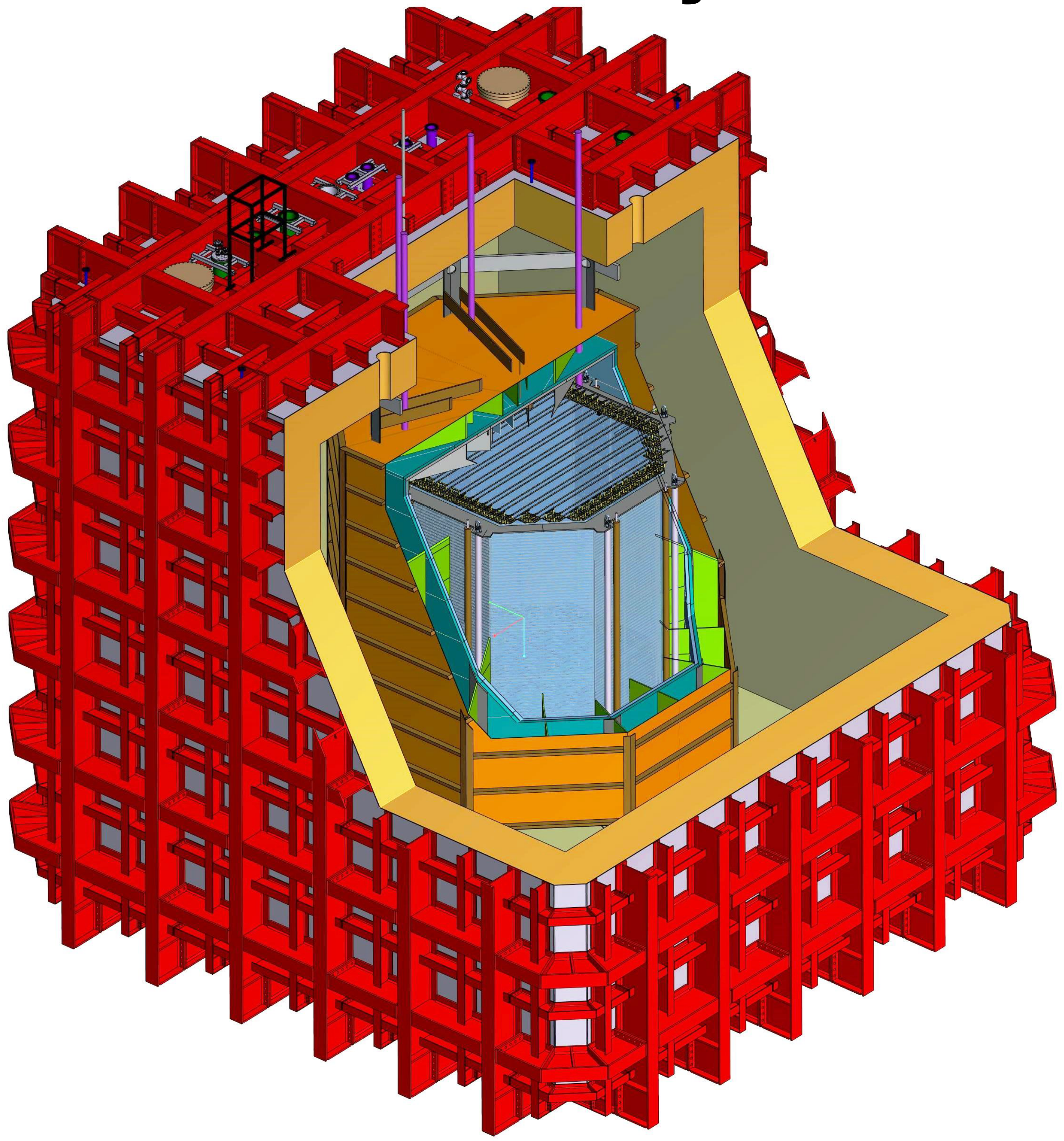
- ^{39}Ar is a cosmogenic isotope
- β-decay with 565 keV endpoint
- ~269y of half life
- ~1Bq/kg in atmospheric Ar
- Rejection with PSD, but pile-up!

- No activation in Ar from deep CO_2 wells
- Suppression factor ~1400 already demonstrated in DS-50
- Possibly higher depletion factor

- Extraction of 65t with “Urania”
- Cryogenic distillation for chemical purification with “Aria” column
- Possibility of isotopic distillation

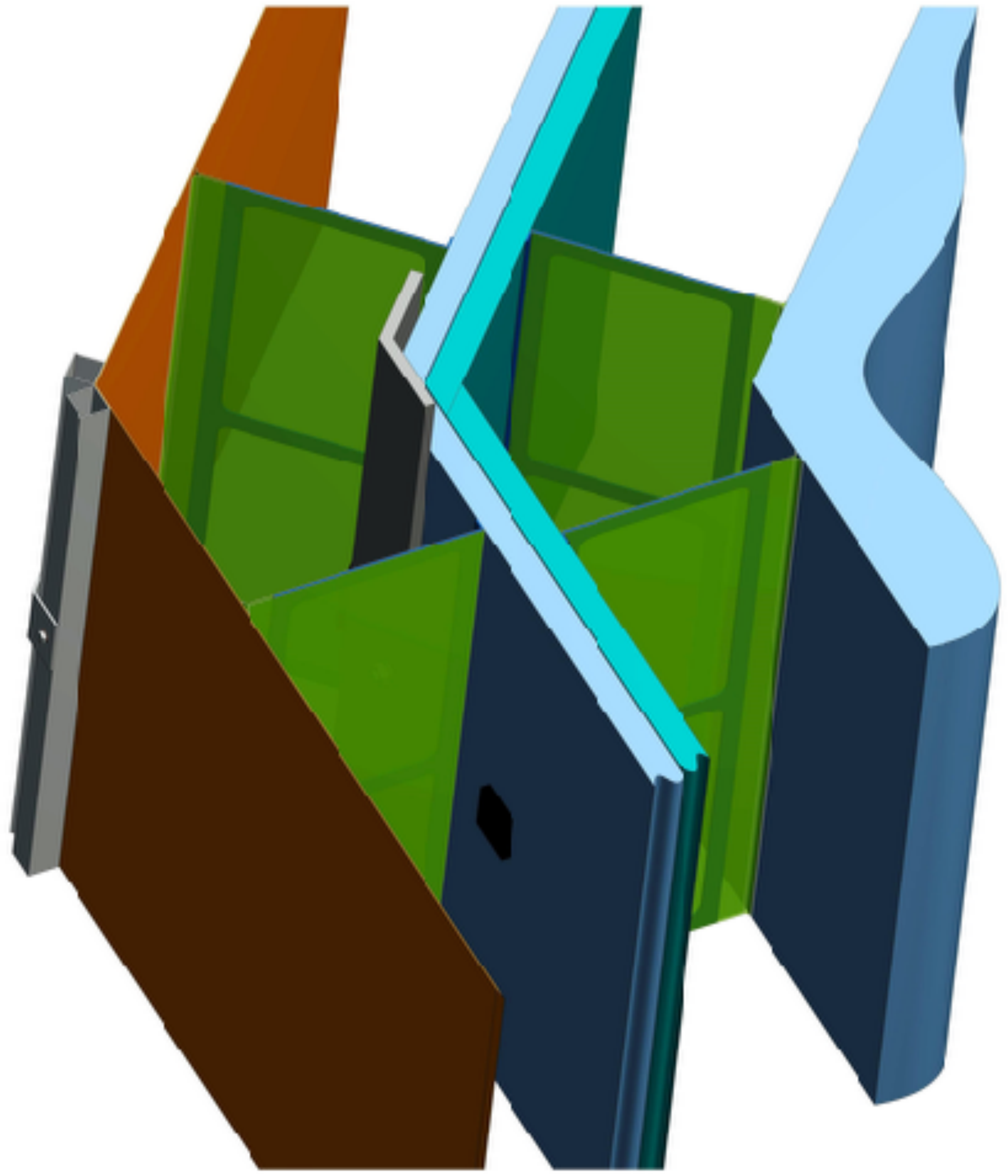
DS-20k new technologies

Membrane cryostat



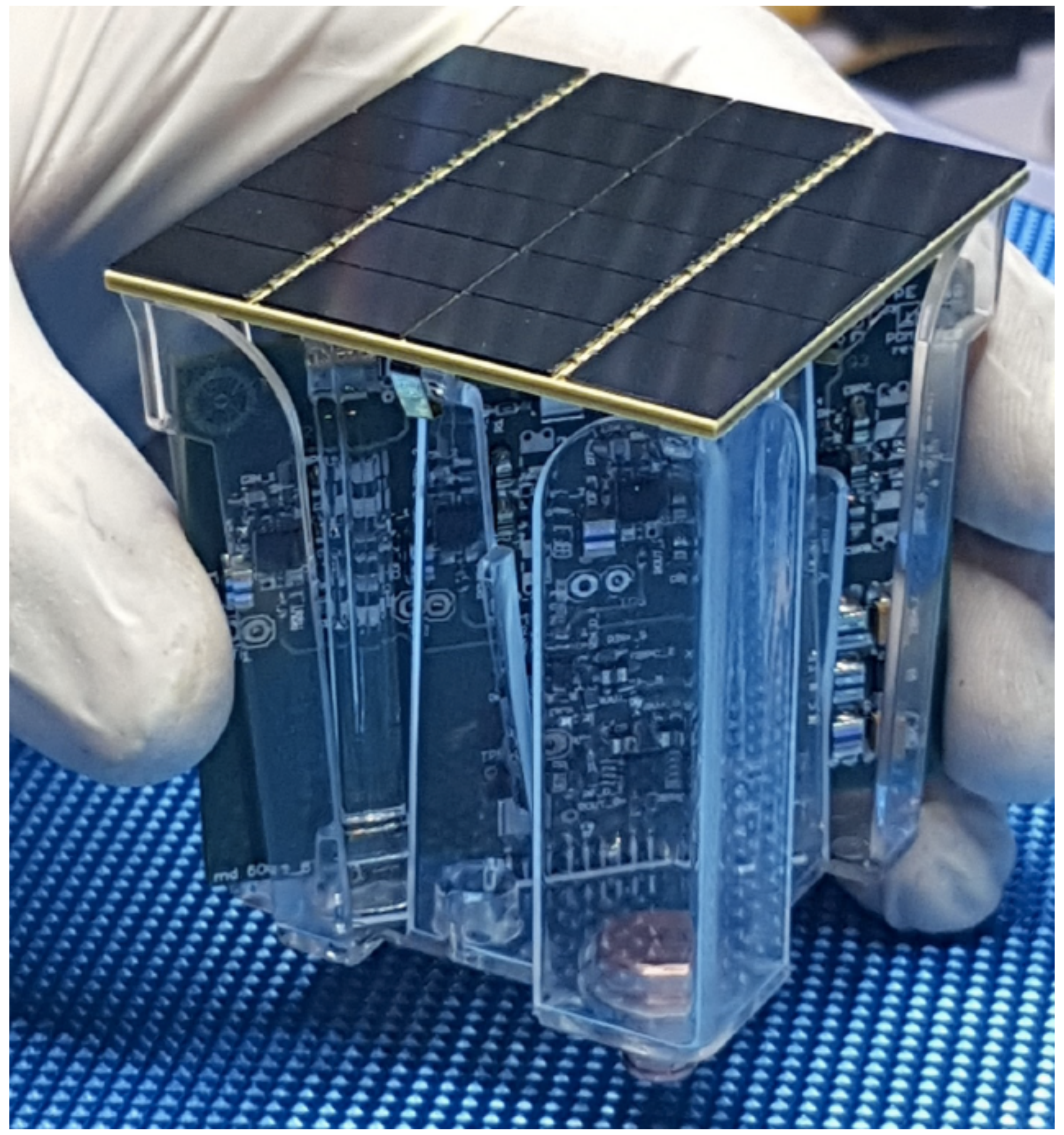
- Cryostat contribution to the bkg moved far from the TPC

Cryogenic neutron veto



- Neutron capture on Gadolinium
- Gd doped acrylic panels
- γ release energy in instrumented LAr buffers

Photodetectors

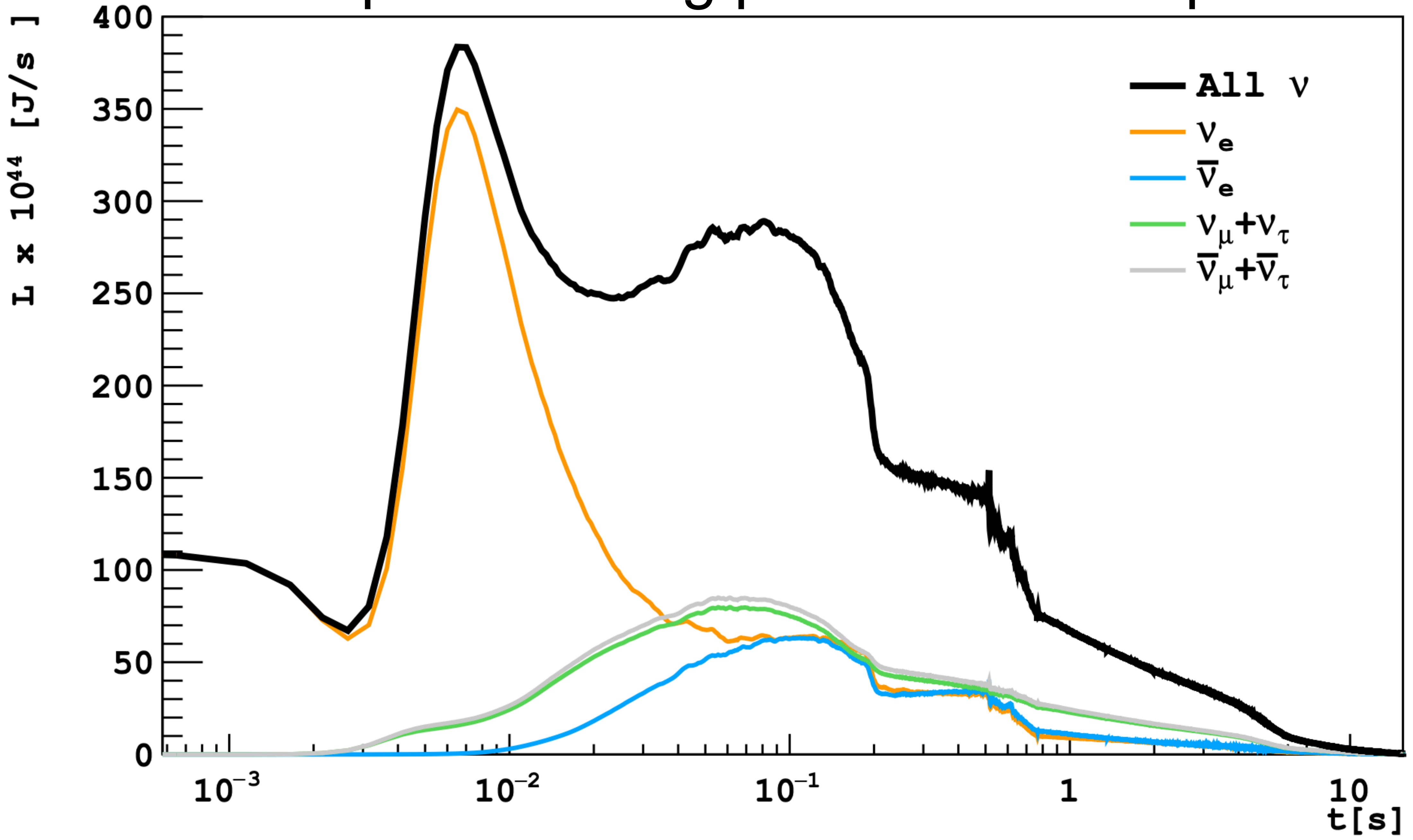


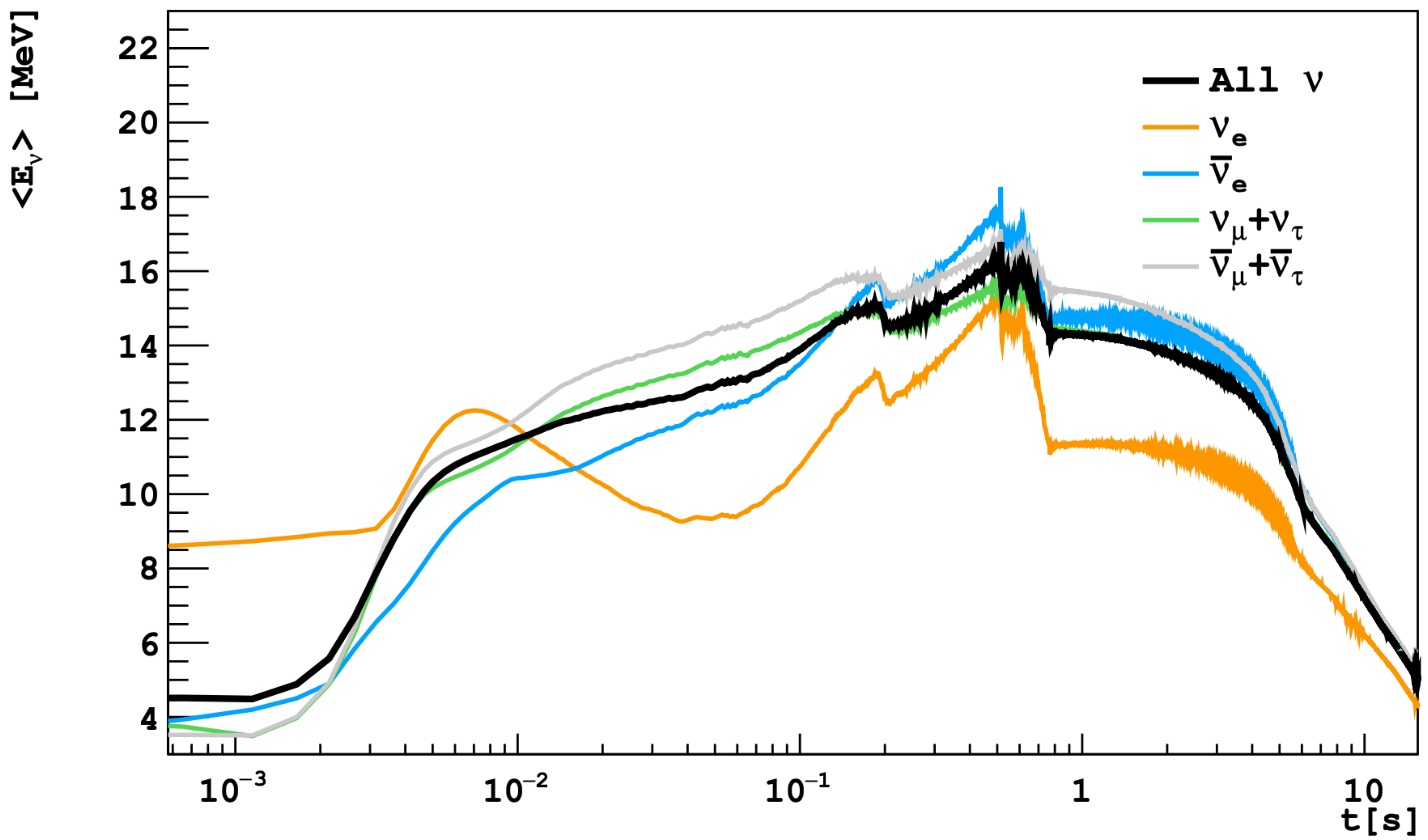
- New solid state photosensors
- Custom developed SiPMs
- High photo-detection efficiency @420nm

SuperNova neutrinos in DS-20k and Argo through CEνNS

SN neutrinos fluxes

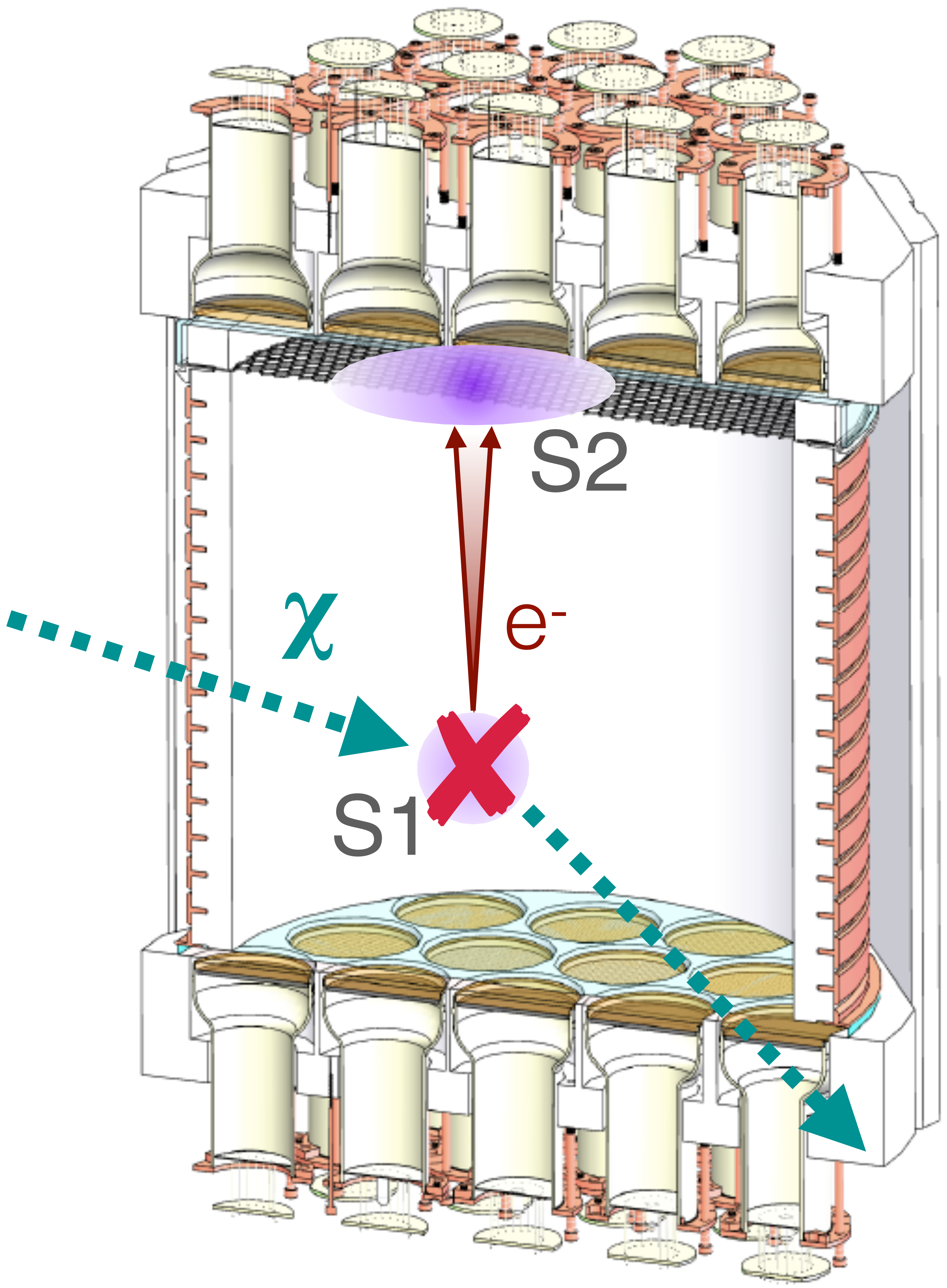
https://arxiv.org/pdf/2011.07819.pdf





- 99% of the total energy of a core collapse SN (~10^{53} erg) is emitted through the neutrino channel.
- SN phases: neutronization burst (~30ms), accretion phase (~0.2-0.8s), cooling (~10s)
- $\langle E_\nu \rangle$ maxes out in the first phases (15MeV) and drops to 5MeV after ~10s.
- Hydrodynamical spherically symmetric simulations by the Garching group. Star progenitor is $27M_\odot$ at 10kpc.

S2-only analysis



Lower the energy threshold ⇒ Look at the S2 only events

S2 >> S1 (23ph/e^- in DS50)

Pros:

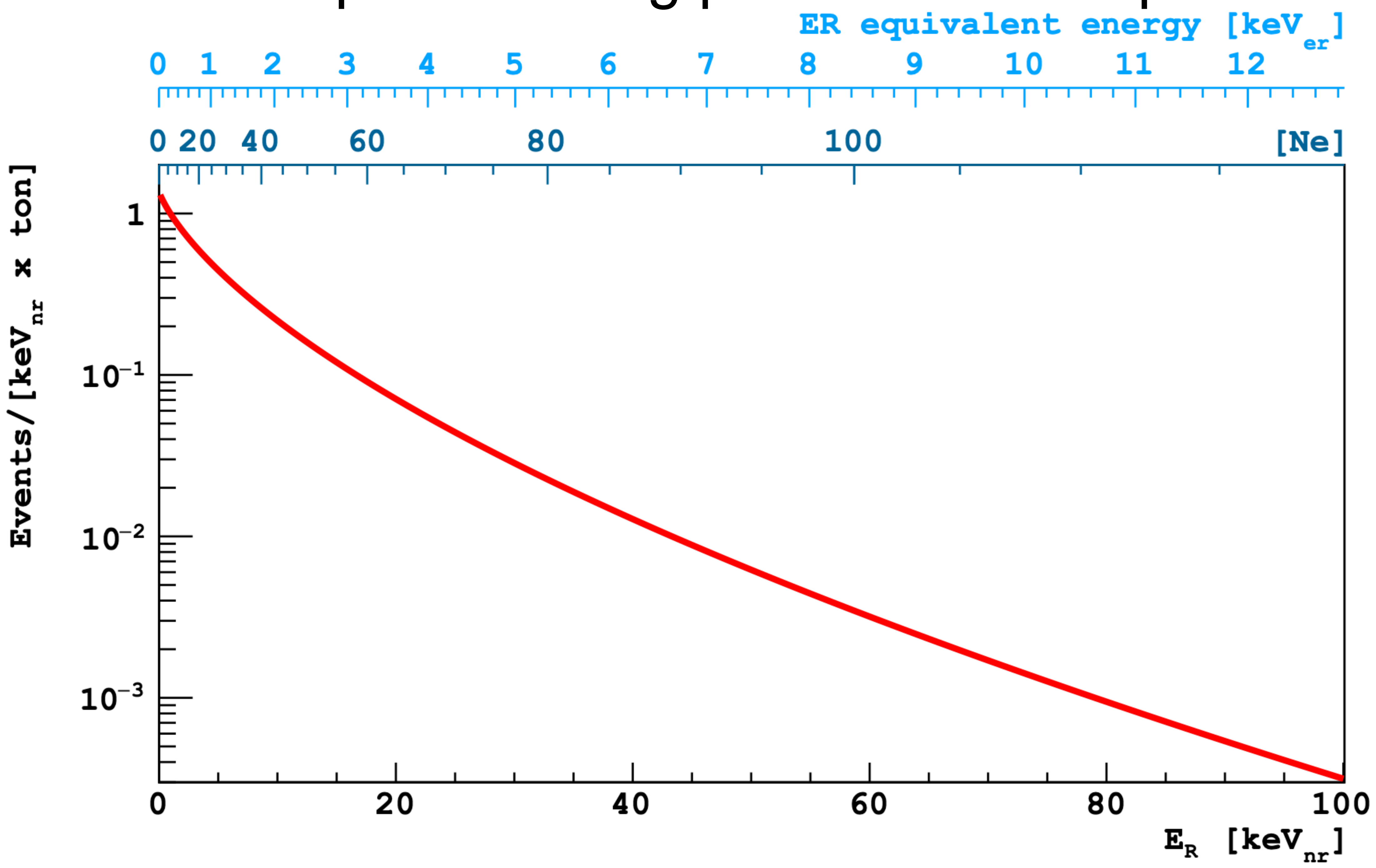
- Low energy threshold:
- 100% Trigger eff. > ~30PE

Cons: No S1

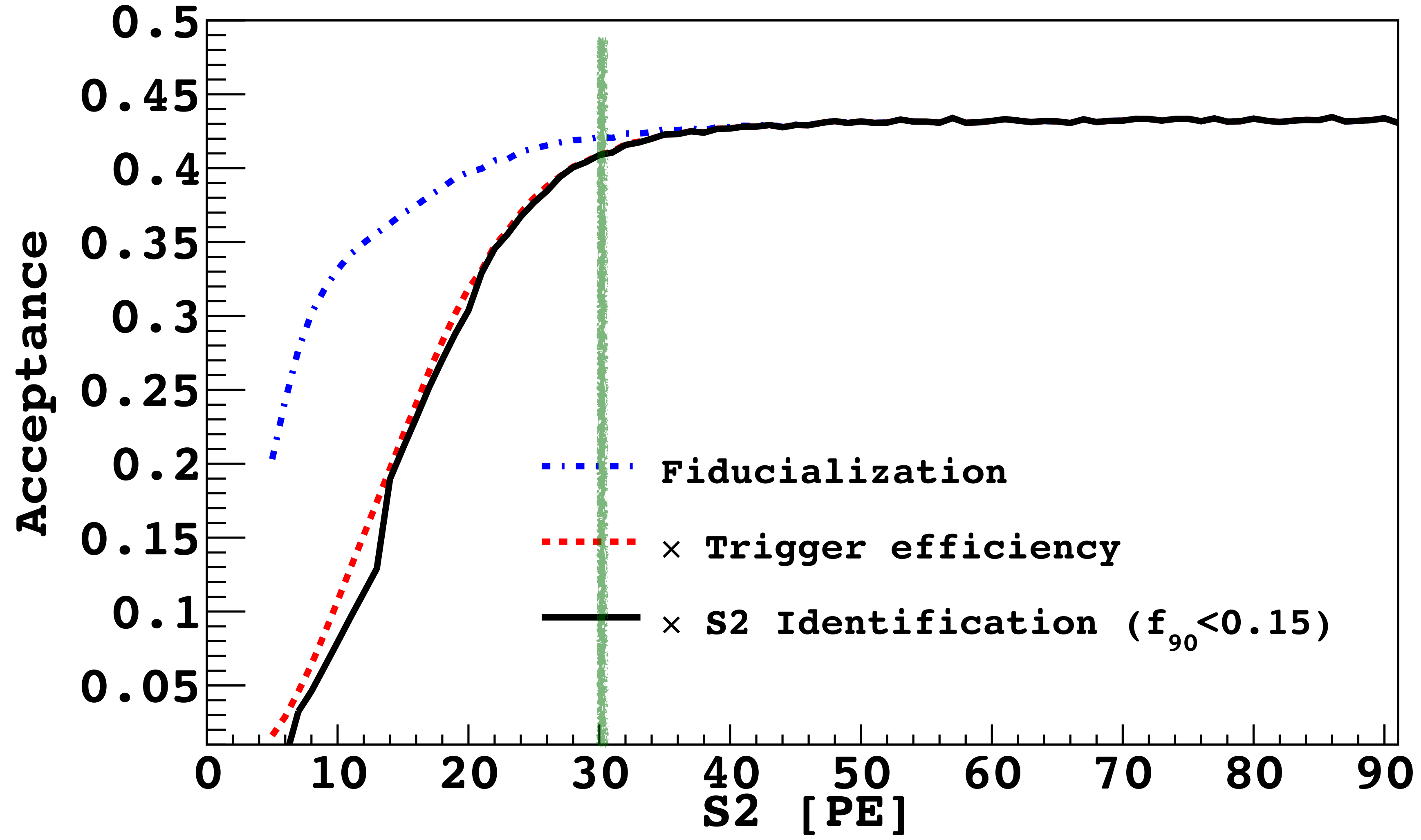
- No position reconstruction in z
- No PSD ⇒ No ER rejection
- Poor timing reconstruction, limited to the TPC drift time

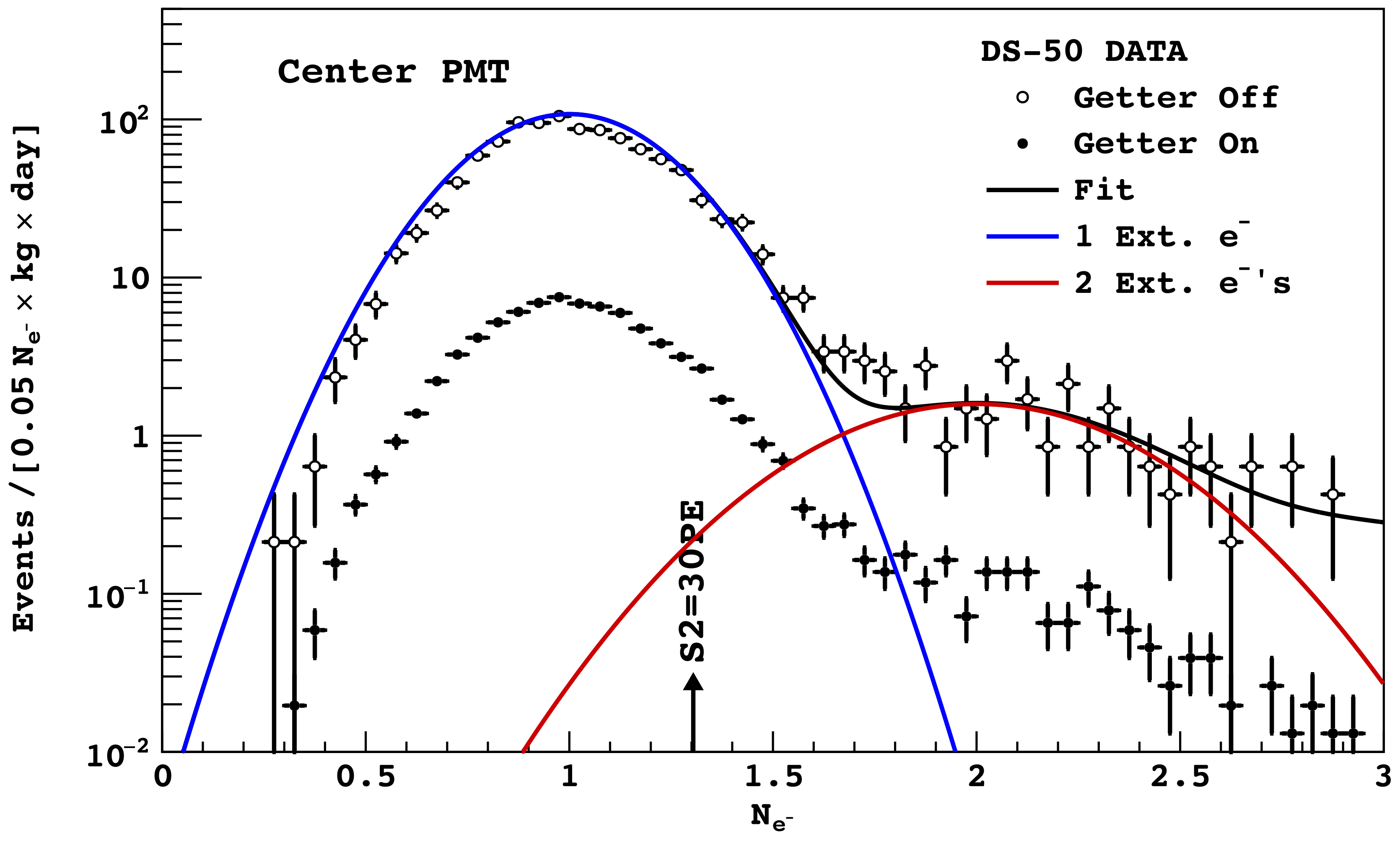
Detector response to CEνNS

https://arxiv.org/pdf/2011.07819.pdf



From DS50 low-mass analysis





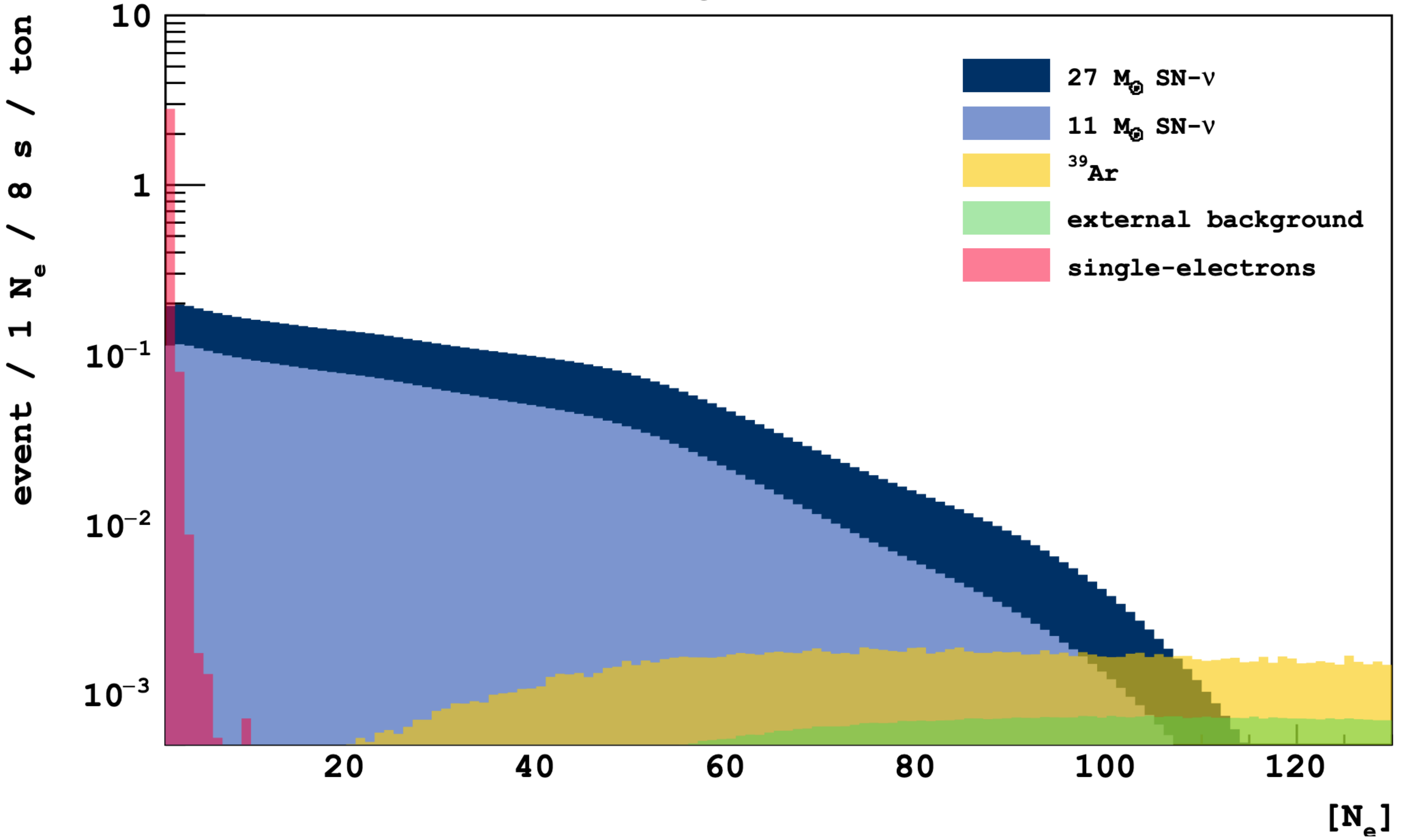
- Window of observation: up to 100keV$_{nr}$.
- 70% (50%) of the recoils is <10keV$_{nr}$ (5keV$_{nr}$).

- DS50 performance:
  - S2 identification: 100% >30PE
  - Trigger efficiency: ~100% >30-40PE
  - NR deposits detection is 100% >0.46keV$_{nr}$.

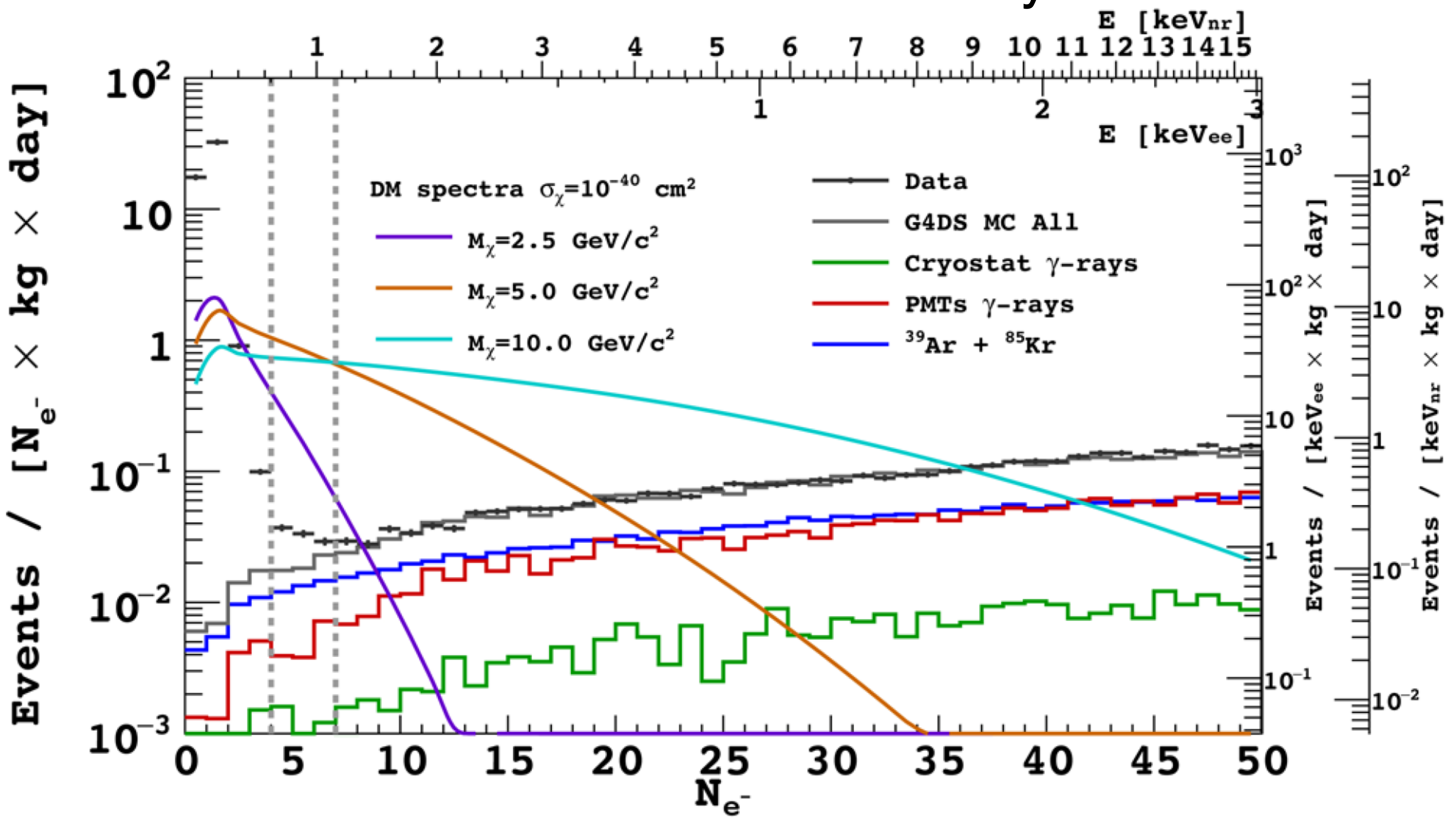
} 86% of SN CEνNS would be detected

Backgrounds

https://arxiv.org/pdf/2011.07819.pdf



From DS50 low-mass analysis



- **Internal background:** ^{39}Ar, dominant > 1keV$_{nr}$. Expected rate for N_e<100: 0.5Hz (DS20k) and 4.2Hz (Argo). ^{85}Kr will be removed by ARIA distillation column.
- **External background:** γ from SiPMs and cryostat. Expected rate for N_e<100: 0.3Hz (DS20k) and 1.3Hz (Argo). After fiducial cut: 0.2Hz (DS20k) and 1.1Hz (Argo).
- **Single electron background:** unknown origin, part due to impurities (observed time correlation with S2 events). Scaled rate from DS-50 for N_e>3: 1.8mHz/tonne, 0.085Hz (DS20k) and 0.65Hz (Argo).

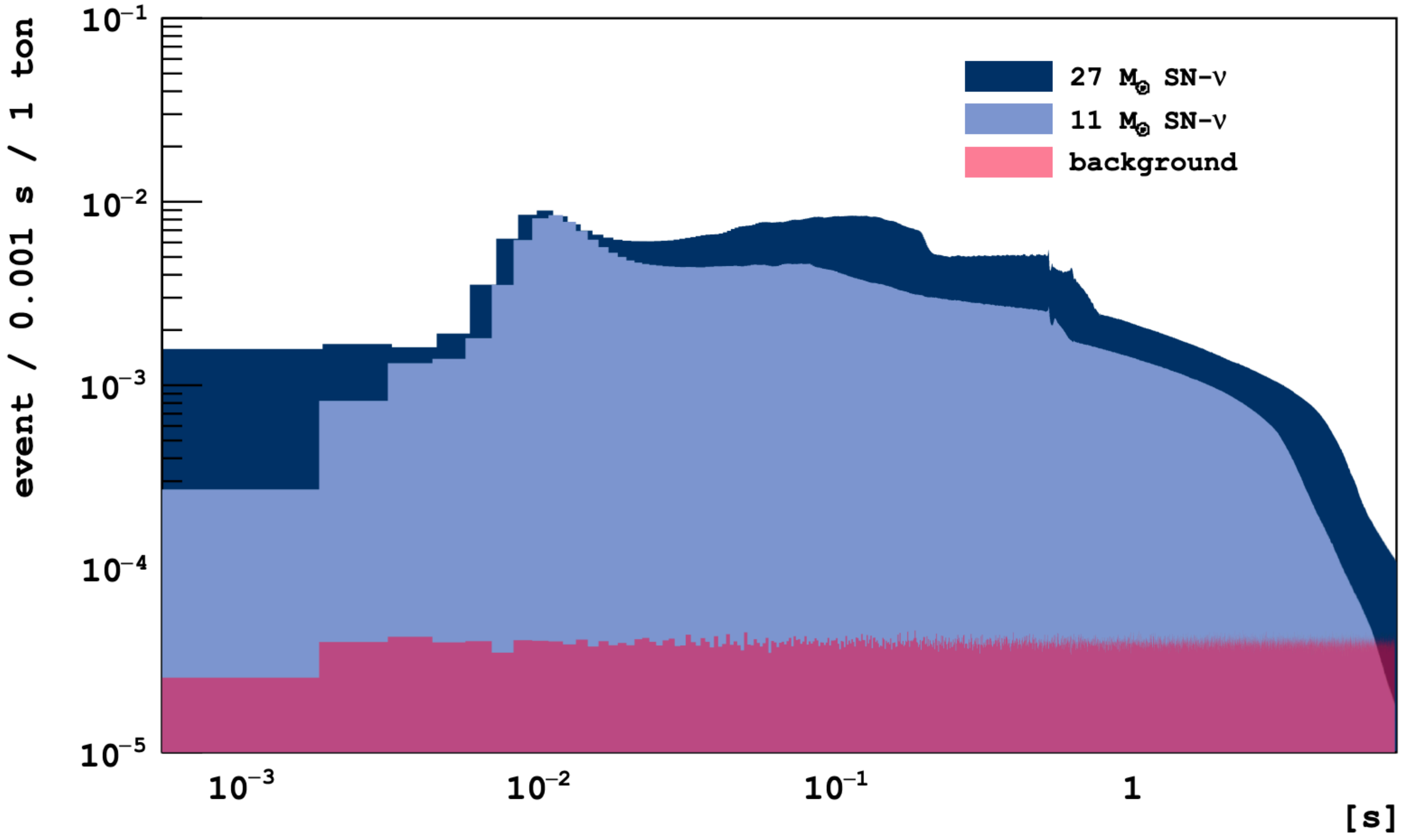
Sensitivity to SN bursts

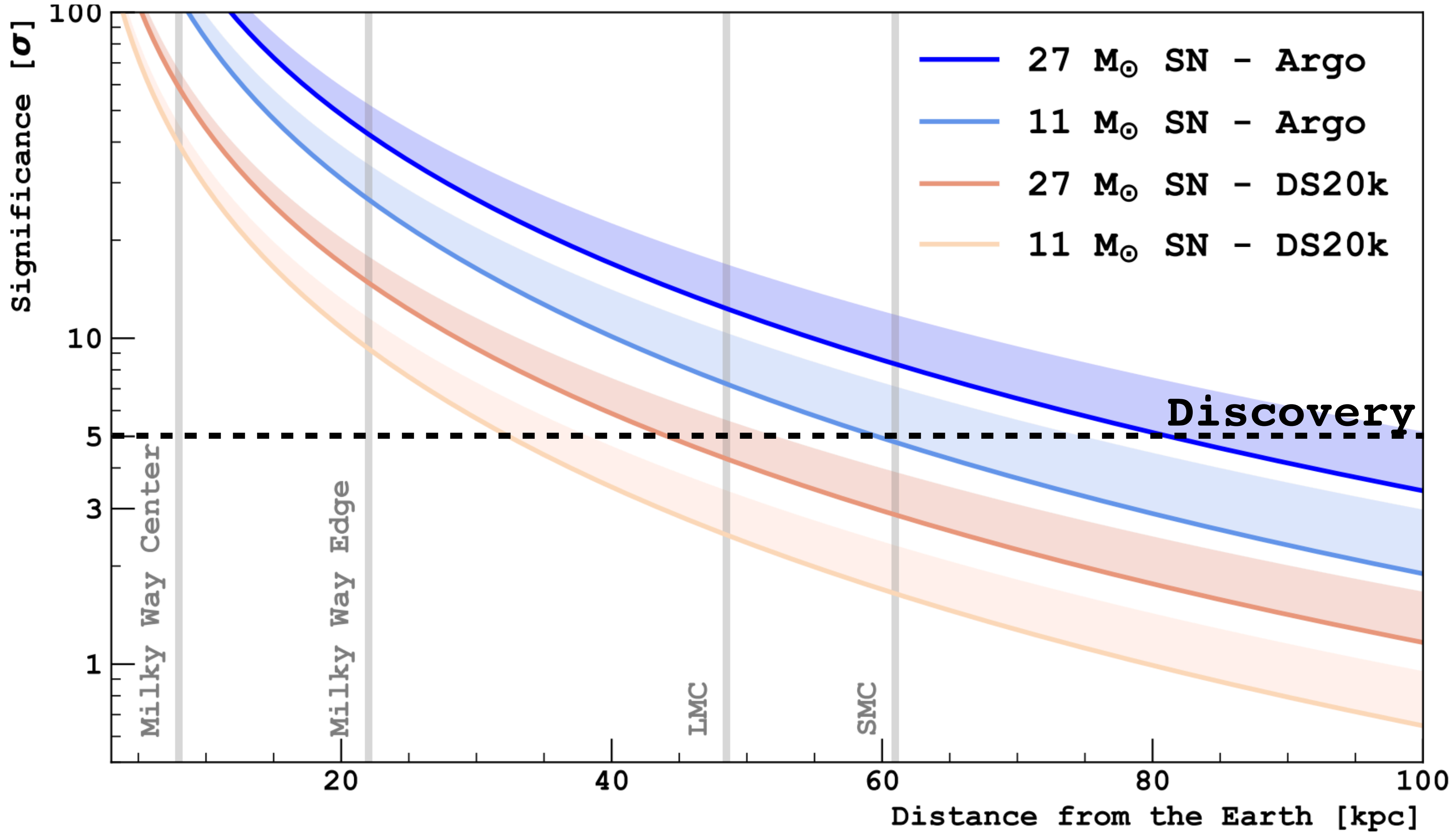
https://arxiv.org/pdf/2011.07819.pdf

Expected signal and background in 8s for a SN burst at a distance of 10kpc

	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

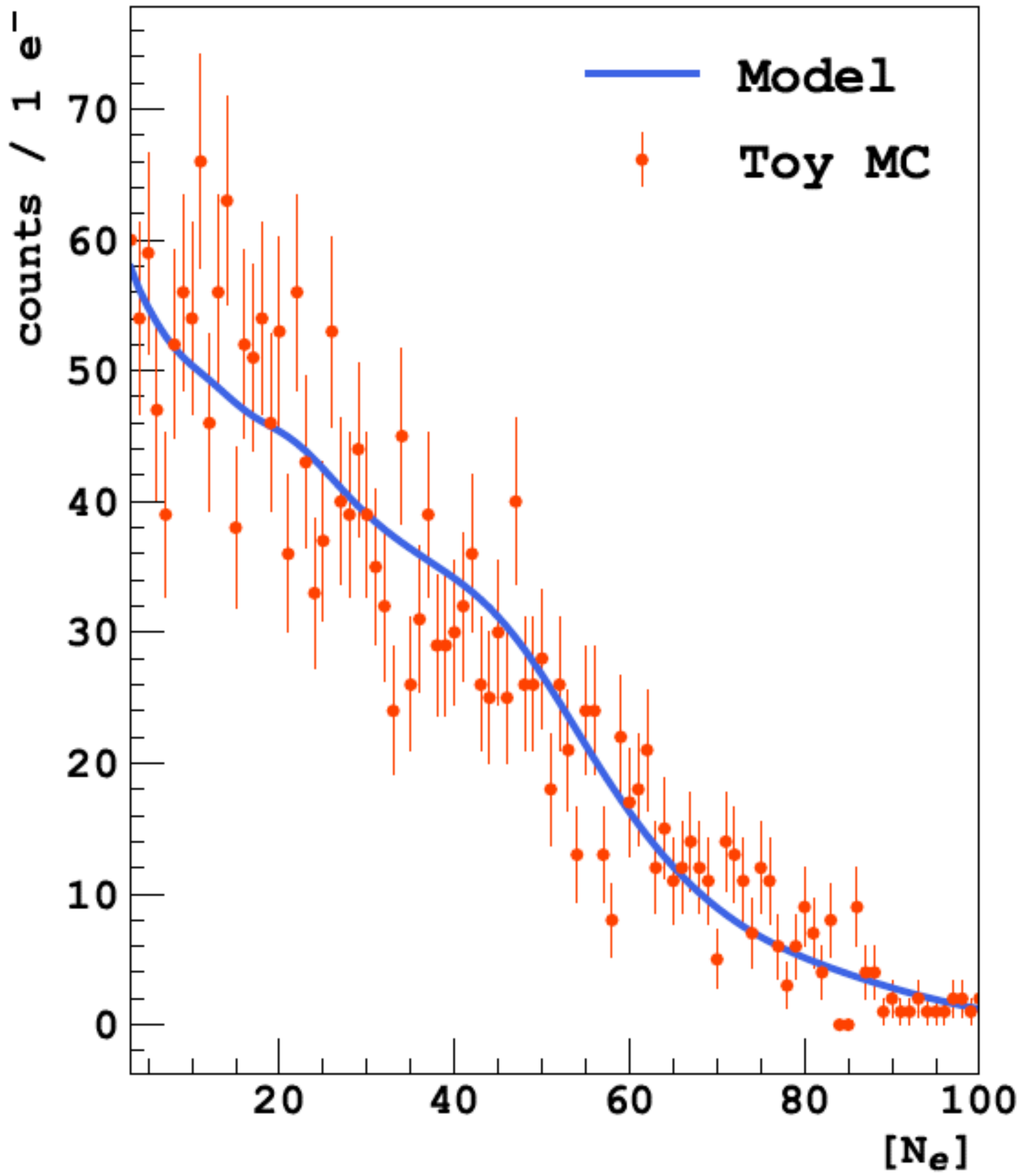
- SNR~10^2 during neutronization and accretion (1s). SNR~10 during cooling (>1s)
- Overall SNR~24(45) for 11$M_\odot$ (27$M_\odot$)
- Sensitivity >5**σ** up to the Milky Way edge for DS-20k and the Small Magellanic Cloud for Argo.

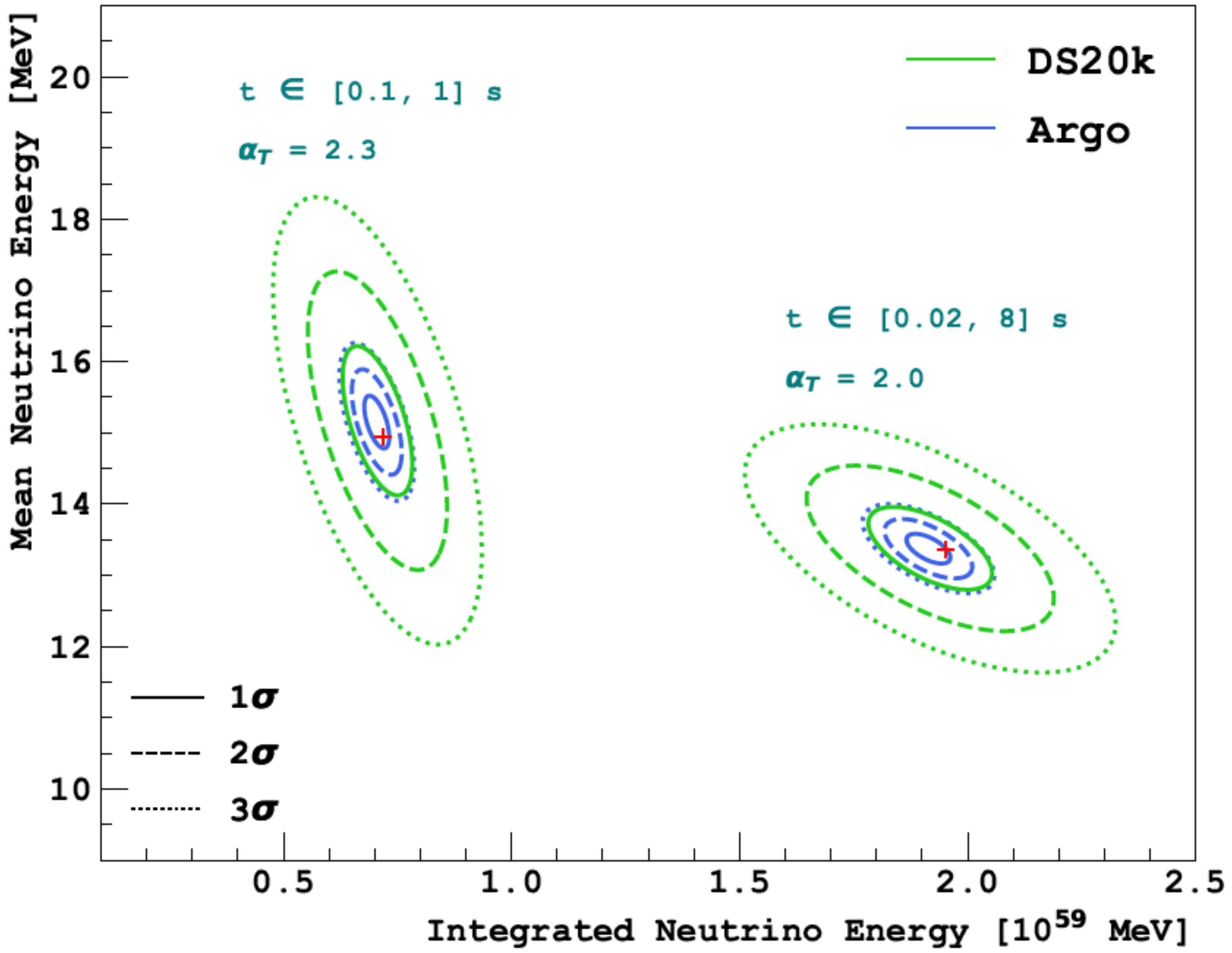




Not only a counting experiment

https://arxiv.org/pdf/2011.07819.pdf



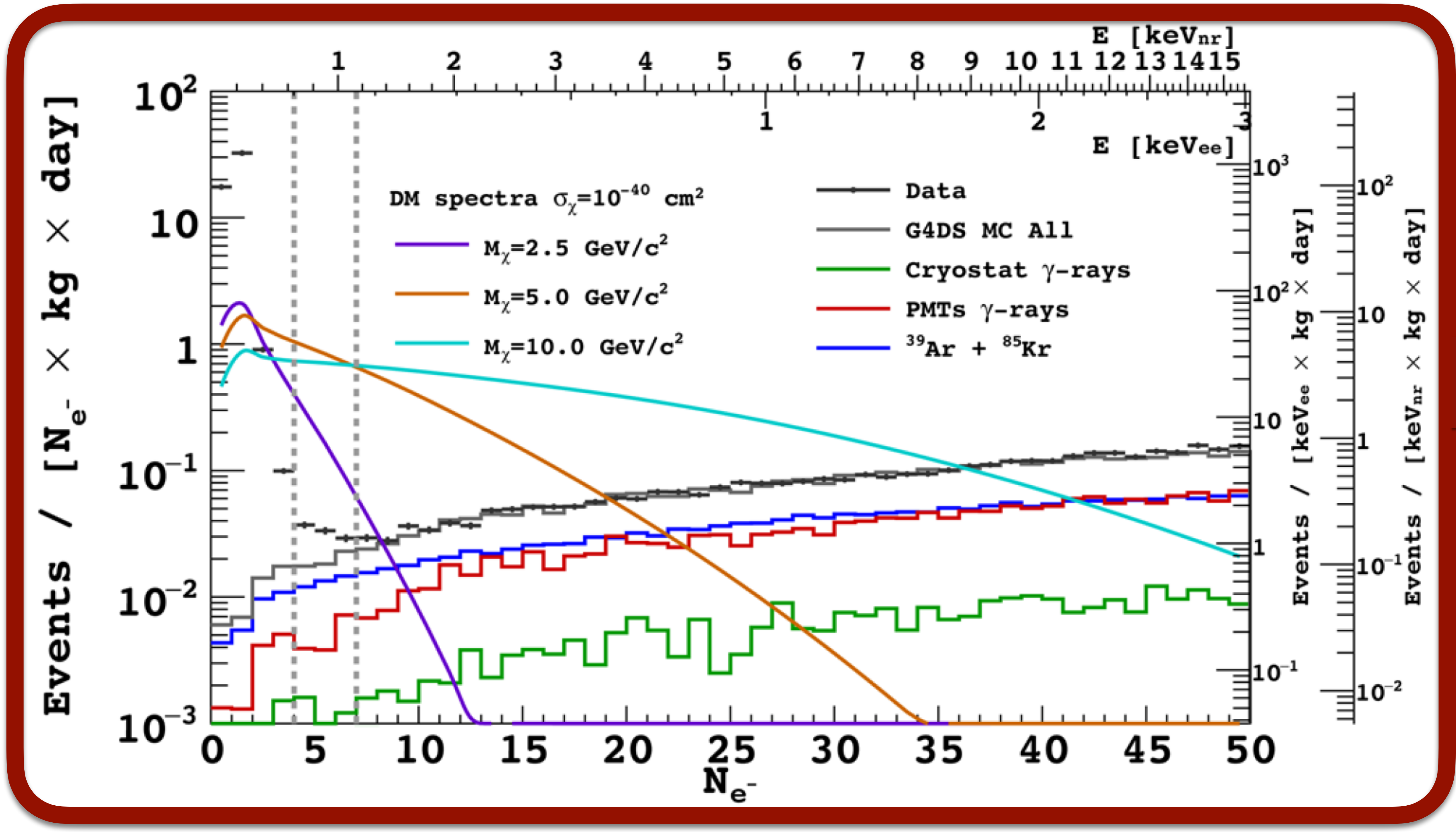


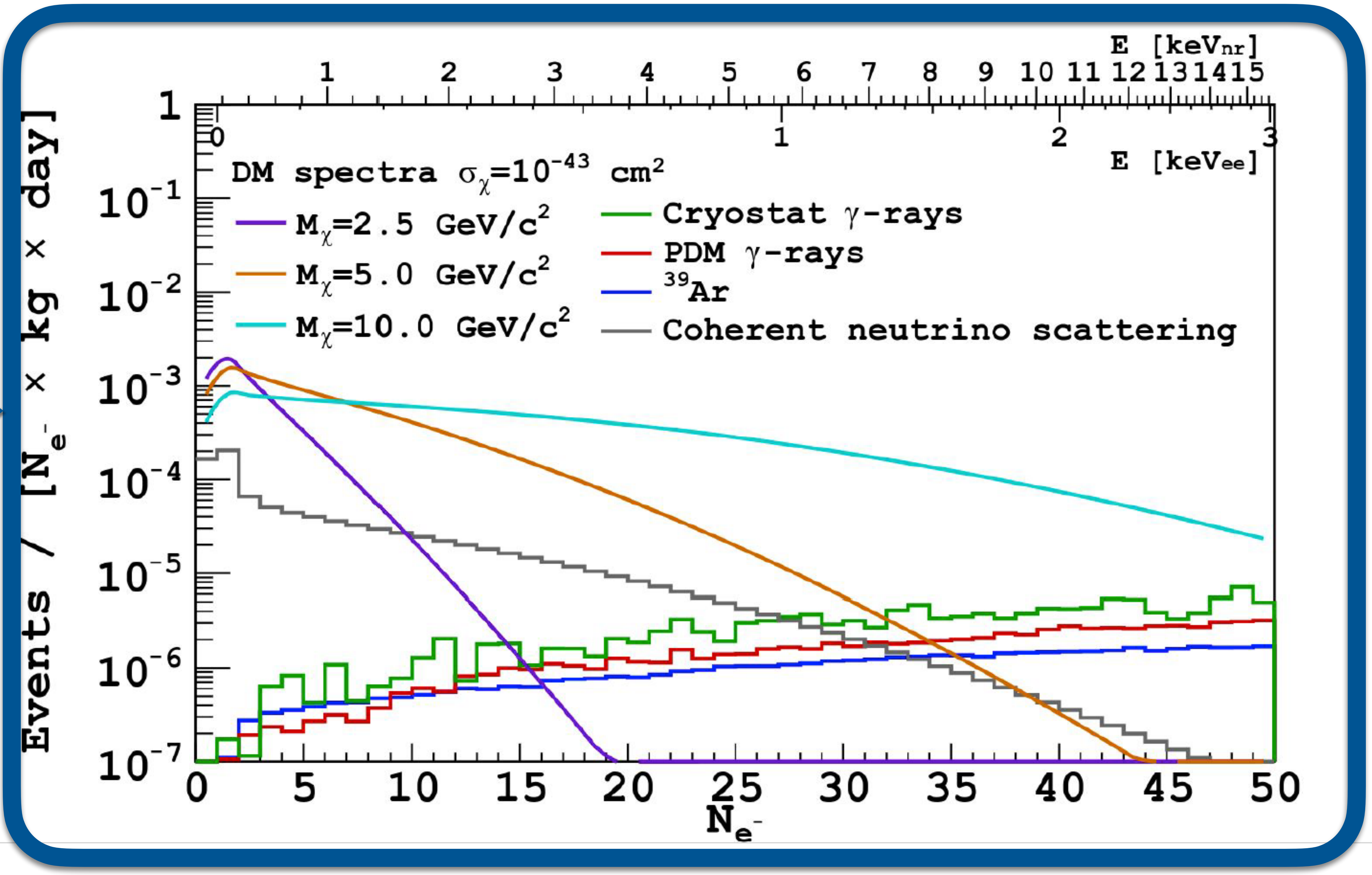
- DS-20k and Argo energy and time resolution allow to reconstruct the mean and total energy of neutrinos from a SN burst. Spectra are fitted excluding the neutronization burst.

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

DarkSide Low Mass

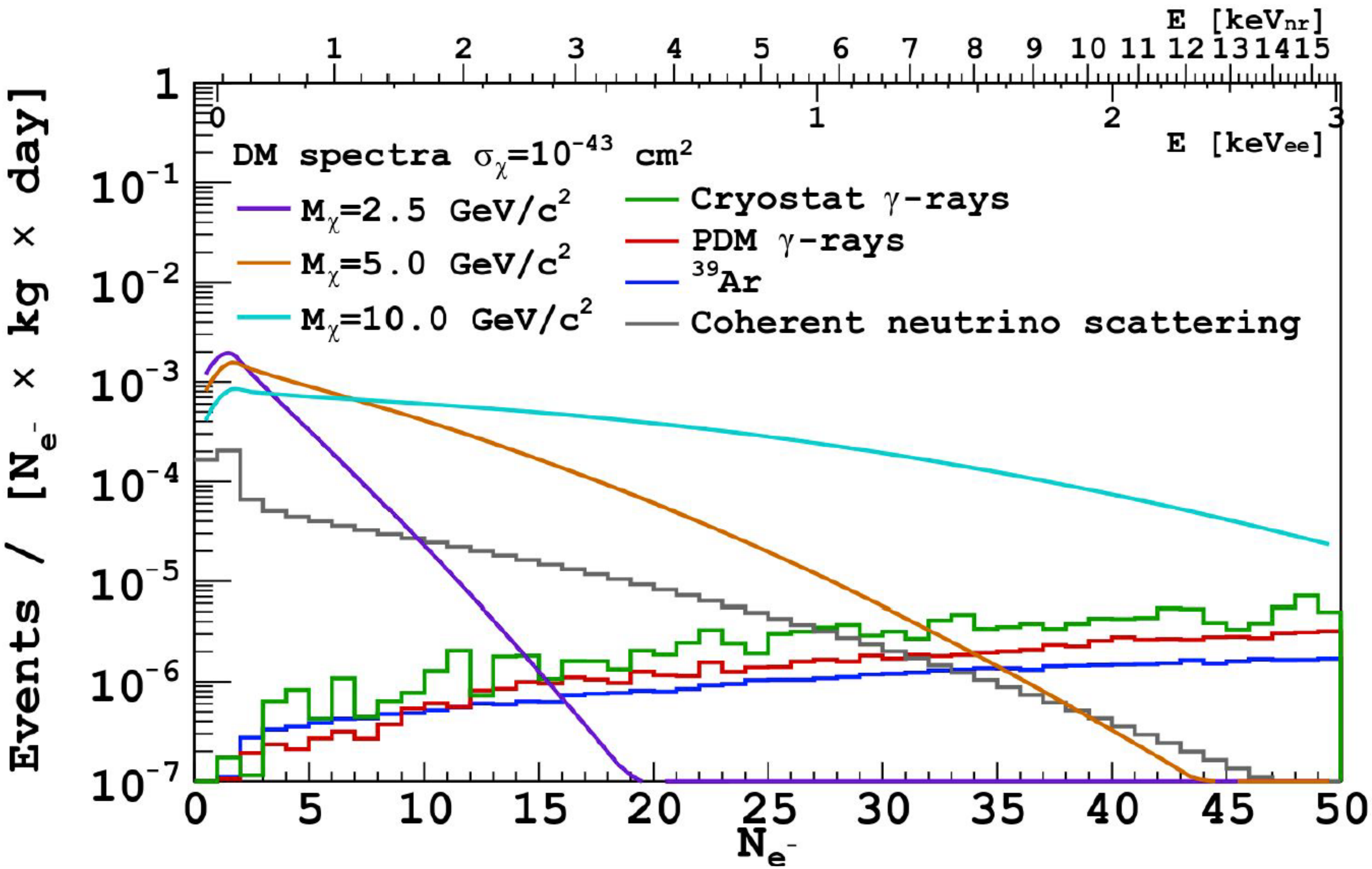
R&Ds: background reduction





- **Internal backgrounds (i.e. ^{39}Ar and ^{85}Kr):** isotopic distillation of UAr with Aria.
- **Cryostat:** ProtoDune membrane cryostat; a LAr-based gamma veto could be an option.
- **Light Detection:** drop coverage, use light collectors, develop radiopure cryogenic electronics and/or ASIC signal readout.
- **Single Electron background:** still to be fully understood. Instrumental for any noble liquid low threshold detector.

Neutrinos in DS-LM

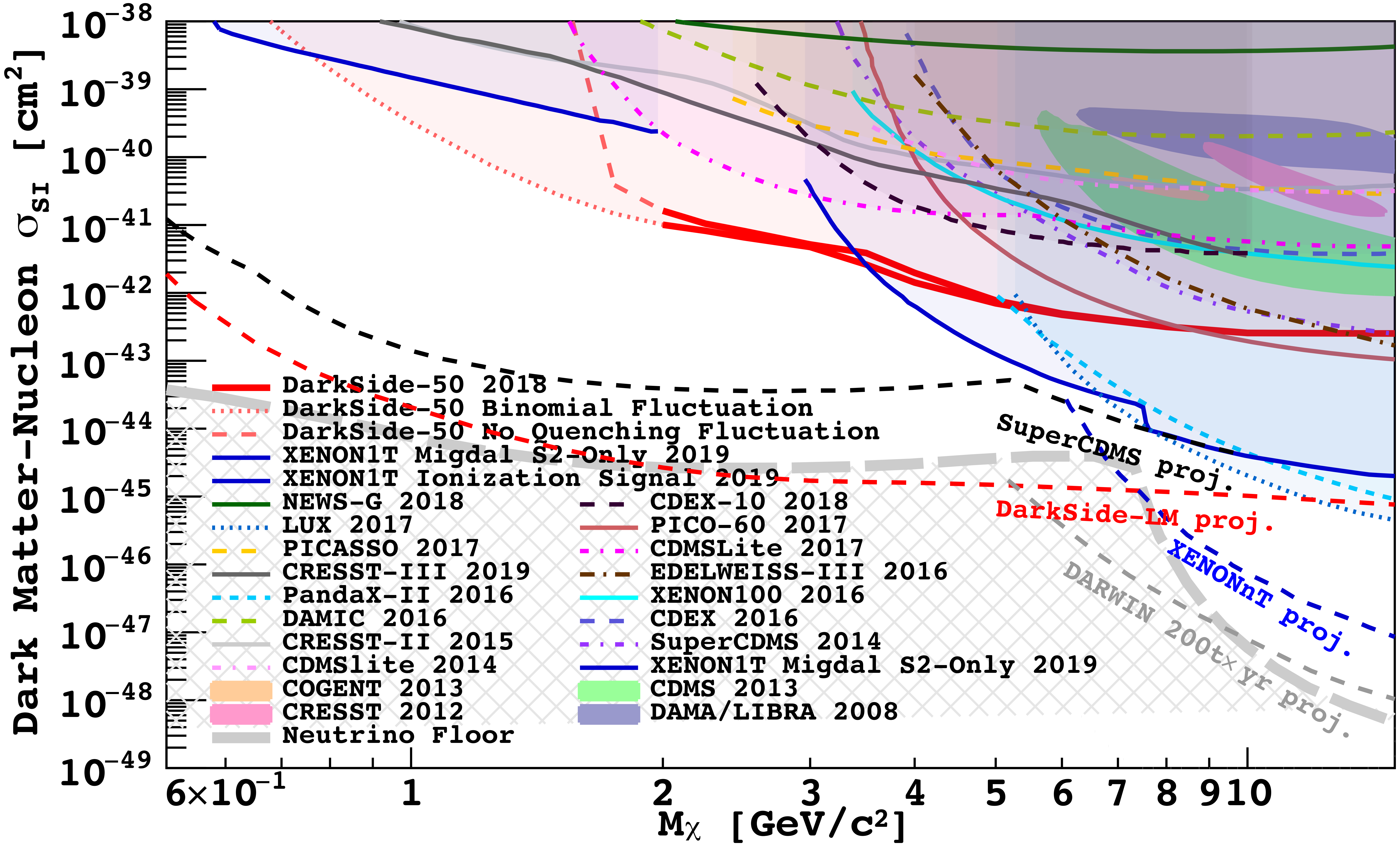


Thanks to E. Picciau for the numbers!

- At low energies neutrinos are a huge/major background
- ~178 evts of CEνNS
- ~48 evts of ν-e scattering
- Maybe good occasion to better constraint CEνNS cross-section

- WIMP spectra are very similar to CEνNS spectra
- No way around: that's the essence of the neutrino floor

Projected sensitivity



A lot of assumptions have to be made:

- ~1μBq ^{39}Ar, no ^{85}Kr
- 10^3 suppression of current γ Compton continuum
- $2e^-$ threshold
  ⇒ solve the SE rate puzzle
- 1 tonne x year exposure

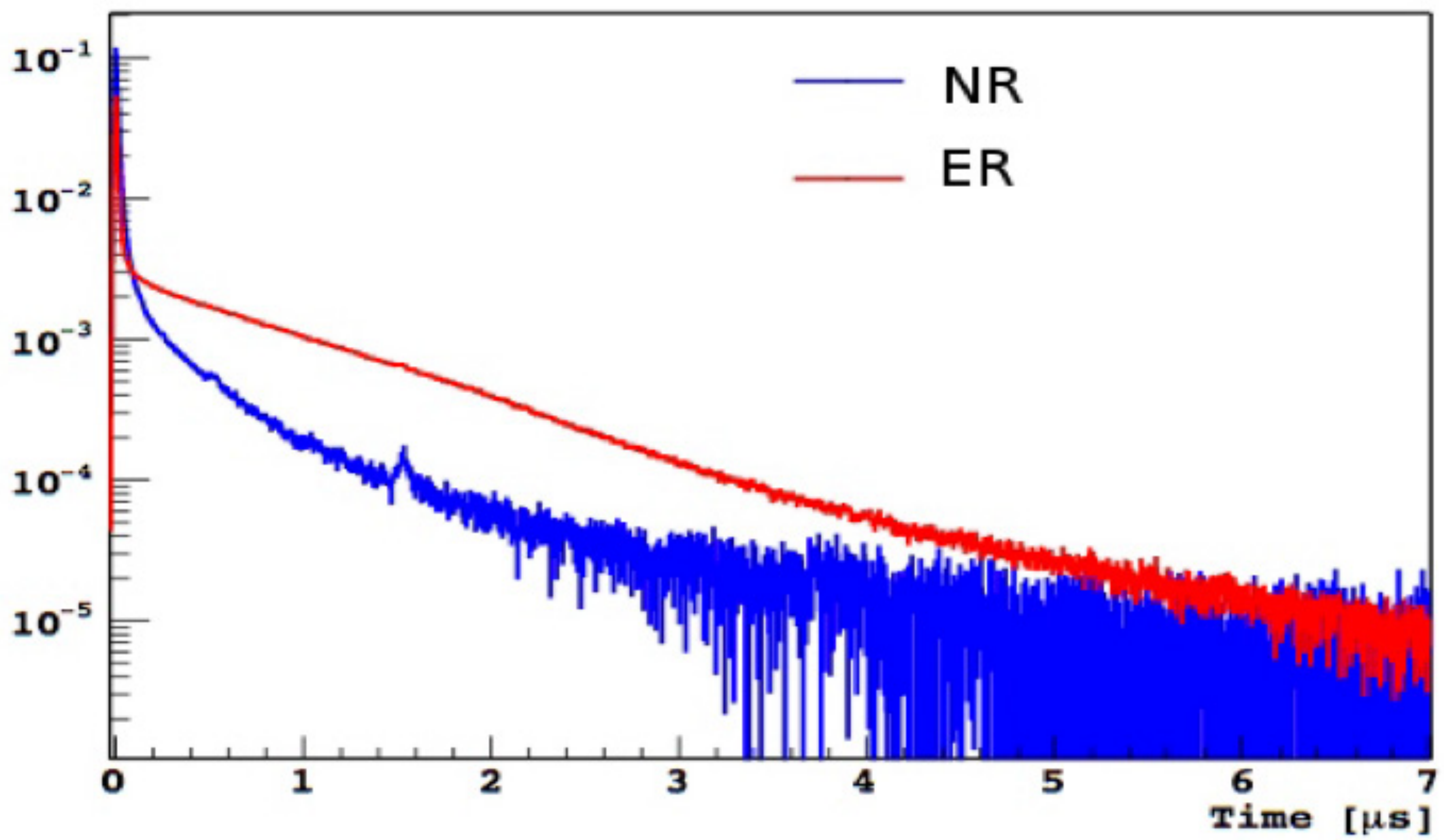
A lot of potential for interesting physics

Conclusions

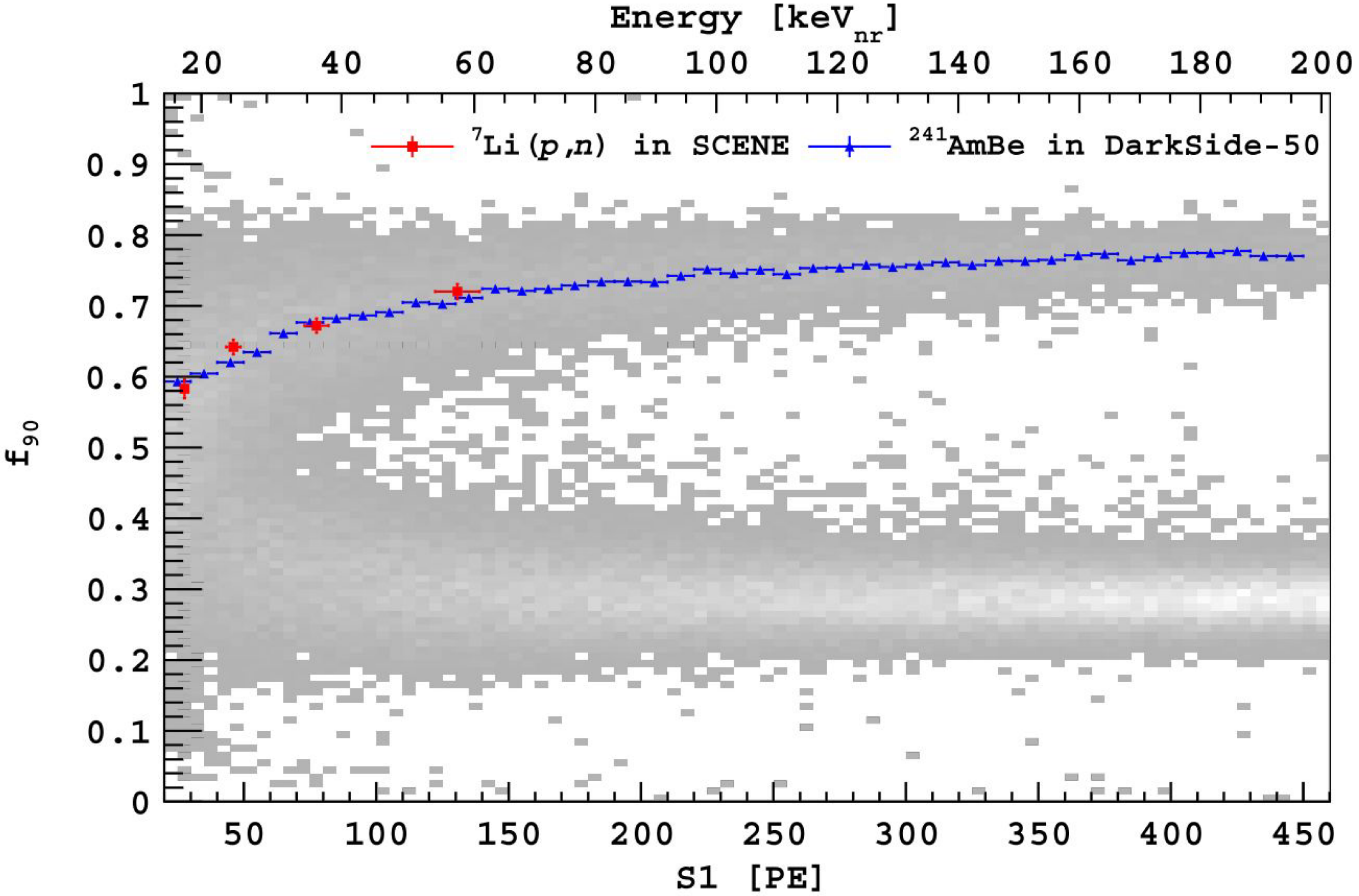
1. LAr G2 and G3 detectors face considerable technological challenges
2. R&D for DS20k is almost completed
3. Argon extracted from underground plays a crucial role for multi-tonne experiments
4. DS20k and Argo have the sensitivity to detect a SN neutrino burst to the edge of the Milky Way and beyond in the CEνNS channel.
5. DS20k and Argo will be able to constrain the average and total energy of neutrinos from a SN core collapse event.
6. LAr technology has a huge potential for the search in the LM range of WIMPs
7. DS-LM detector would be also a natural observatory for solar neutrino CEvNS
8. Still a lot to be understood before the deployment of such a detector

Thank you!

PSD in LAr



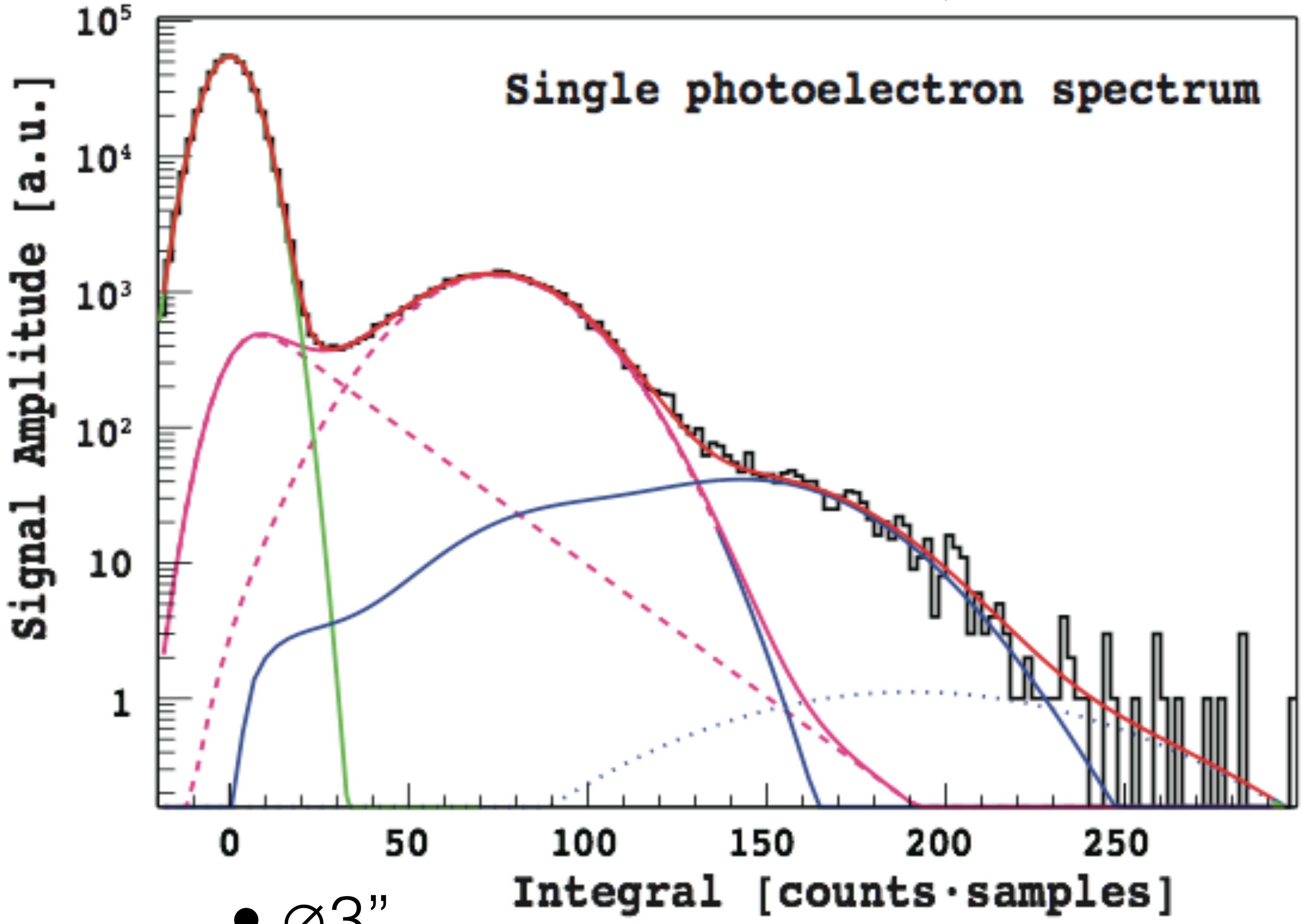
NR
ER
Time [μs]



Energy [keV$_{nr}$]
^{7}Li(p,n) in SCENE
^{241}AmBe in DarkSide-50
f_{90}
S1 [PE]

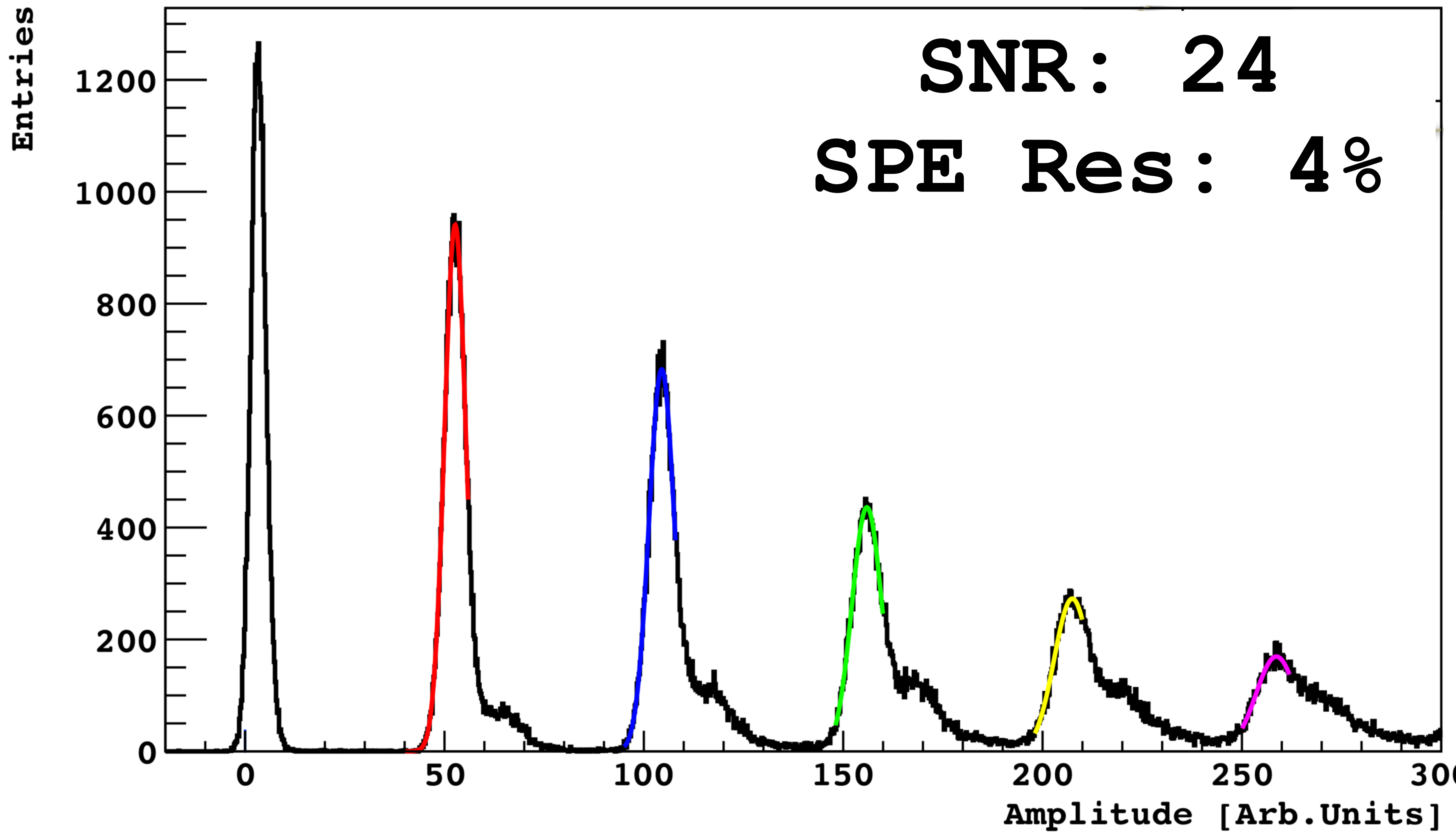
PMT vs SiPM

Hamamatsu 3” R11065, 35%QE



- ∅3”
- QE ~35%
- Noise Rate: negligible
- SNR~15, SPE Res~20%
- Time resolution ~ns

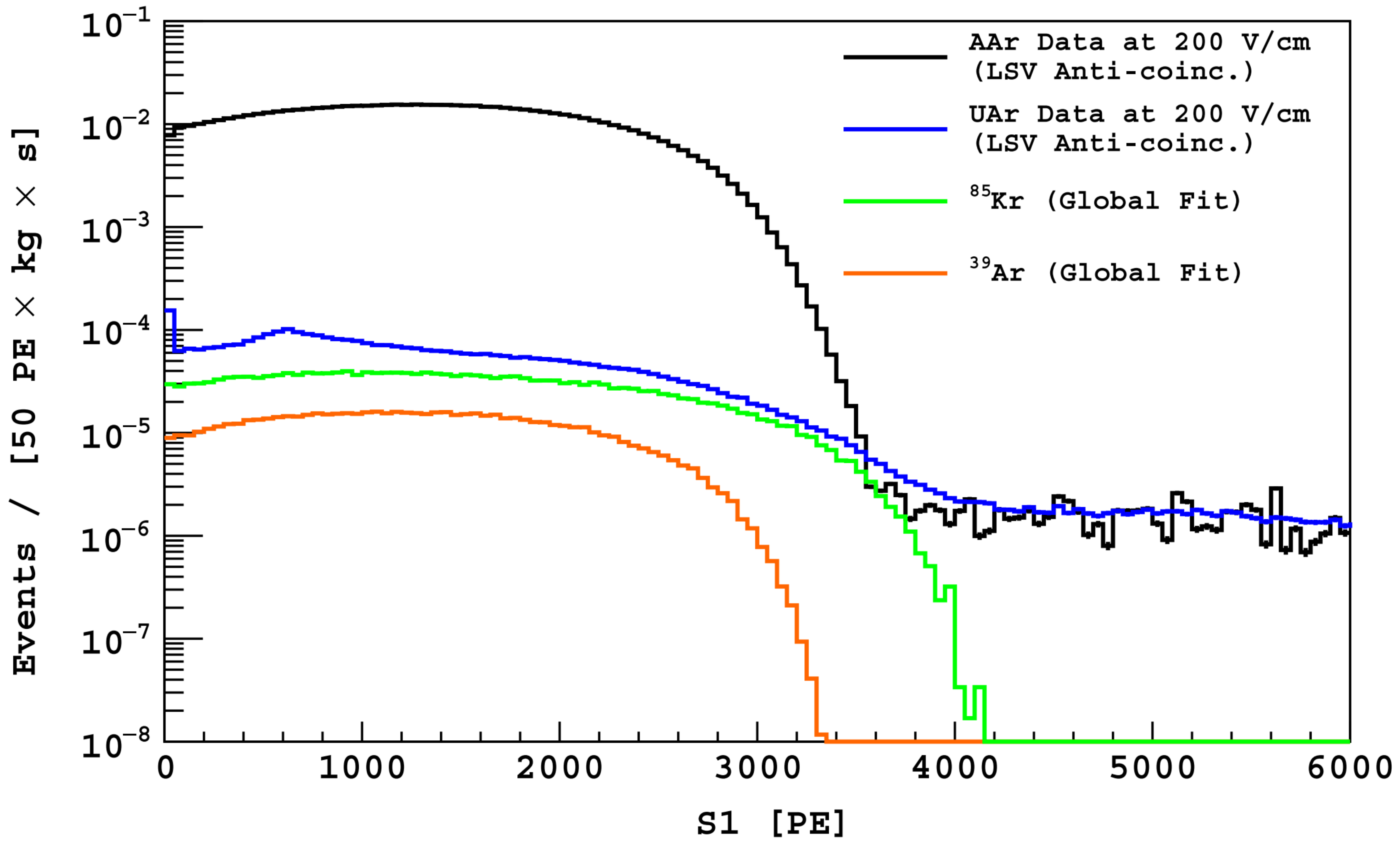
DS20k PDM 25cm², >40%PDE



- 25cm² per channel
- PDE > 40%
- DCR < 0.1cps, TCN < 60%
- SNR ~24, SPE Res~4%
- Time resolution ~3.5ns

Argon extraction and purification

^{39}Ar and UAr



- ^{39}Ar: cosmogenic isotope
- β-decay: Q = 565 keV and $\tau_{1/2}$~269y
- ~1Bq/kg in atmospheric Ar
- Rejection possible with PSD. Pile-up!
- No activation in deep CO_2 wells
- Suppression of ~1400 (DS-50)

Urania

- CO_2 well: Cortez (CO)
- Extraction plant: Urania
- Rate: ~330kg/d
- Purity: 99.9%
- Total foreseen mass: 60t
- Shipping by sea

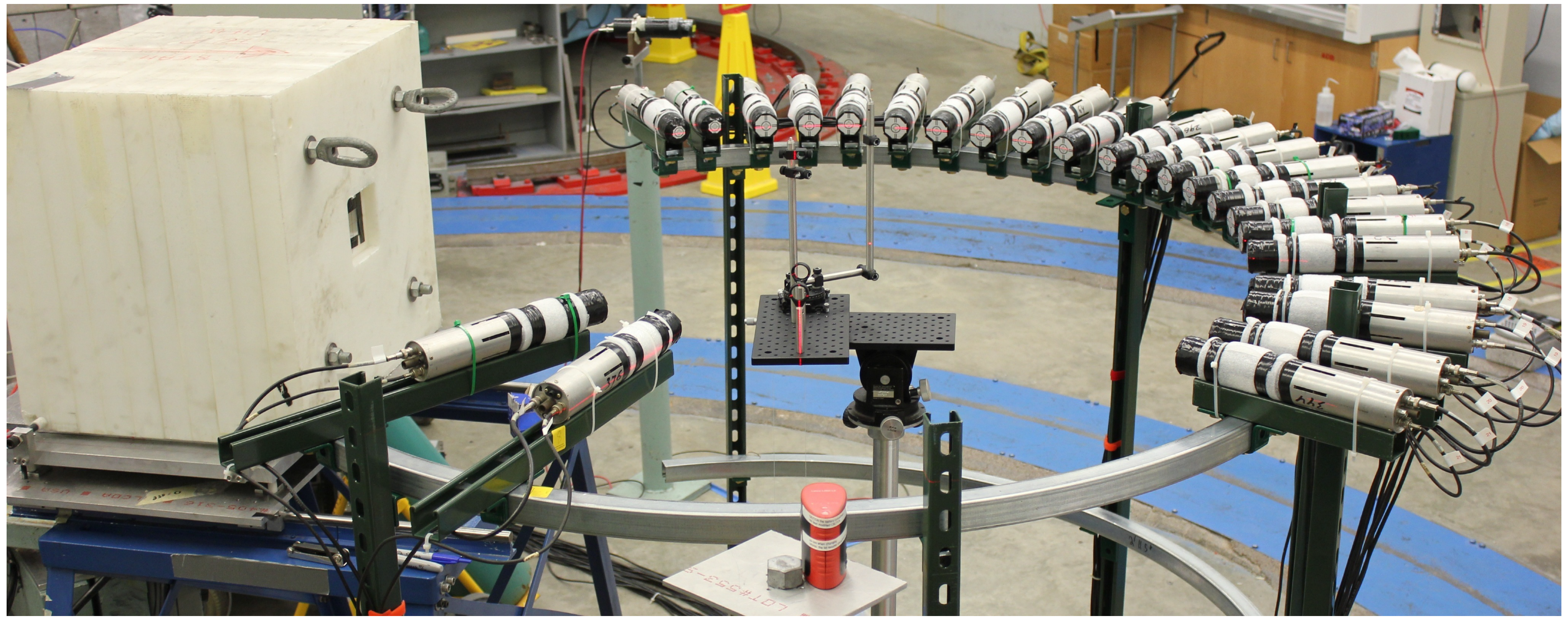
Aria

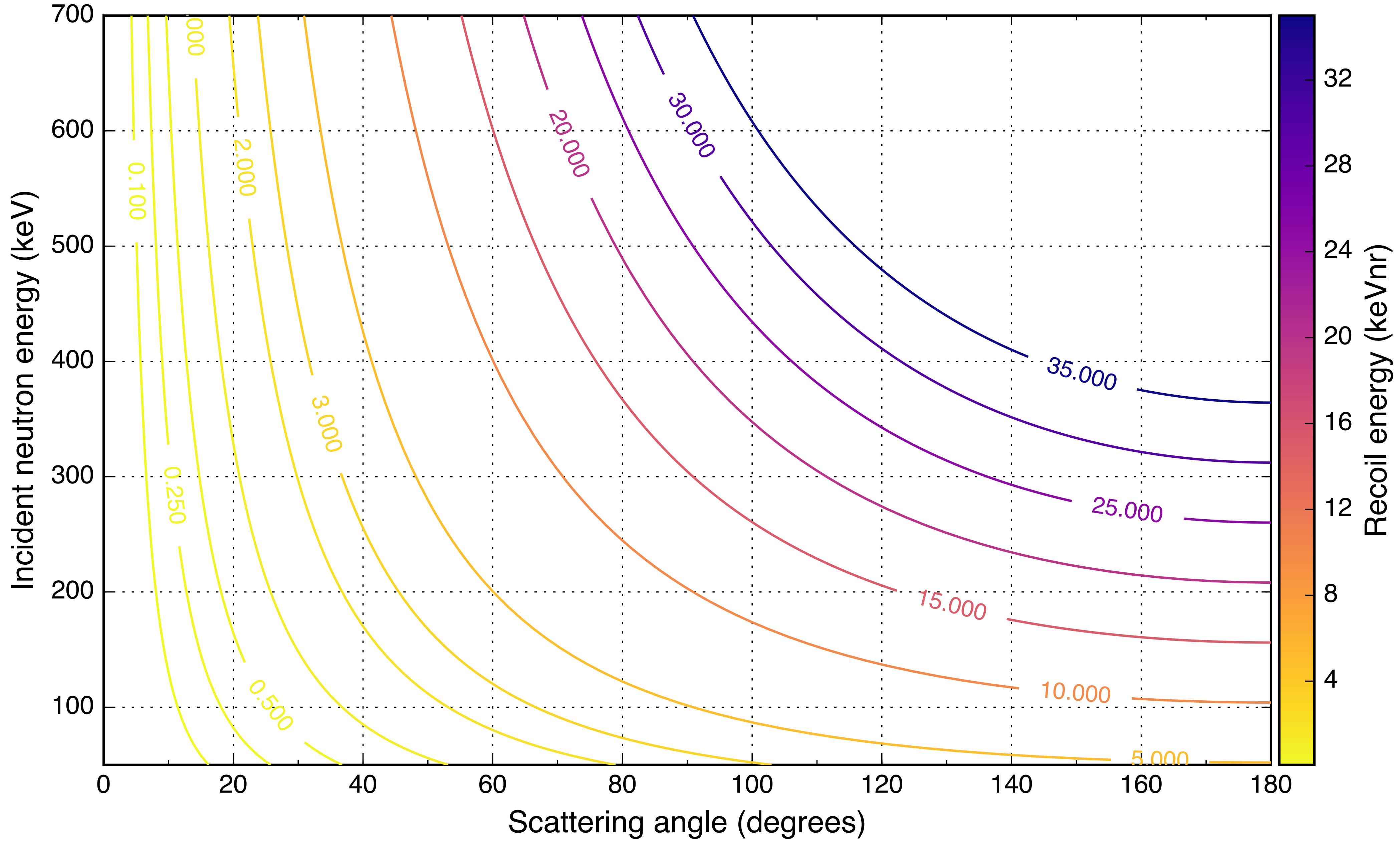
- Aria: chemical purification through cryogenic distillation
- 350m tall column in a mine shaft in Italy
- Purification rate: ~1t/d
- Possibility of isotopic separation (^{39}Ar/^{40}Ar) by difference in vapour pressure (10kg/d)

A key ingredient: Q_Y measurement

A Q_Y measurement at low energies is still needed

- We're hoping to do it at the TUNL facility
- Pulsed neutron beam
- Huge array of neutron backing detectors
- Flexible beam energy and repetition rate





- 2 beam energies: huge range 0.3-50 keV_{nr}
- Directly measure Q_Y with S2 pulses
- Measure S1 where possible
- Possibly run at more drift fields (0.2,0.5,1kV/cm)
- Small TPC to minimize multiple scattering
- Simulations and design are still embryonal