Sensitivity of liquid argon dark matter search experiments to core-collapse supernova neutrinos

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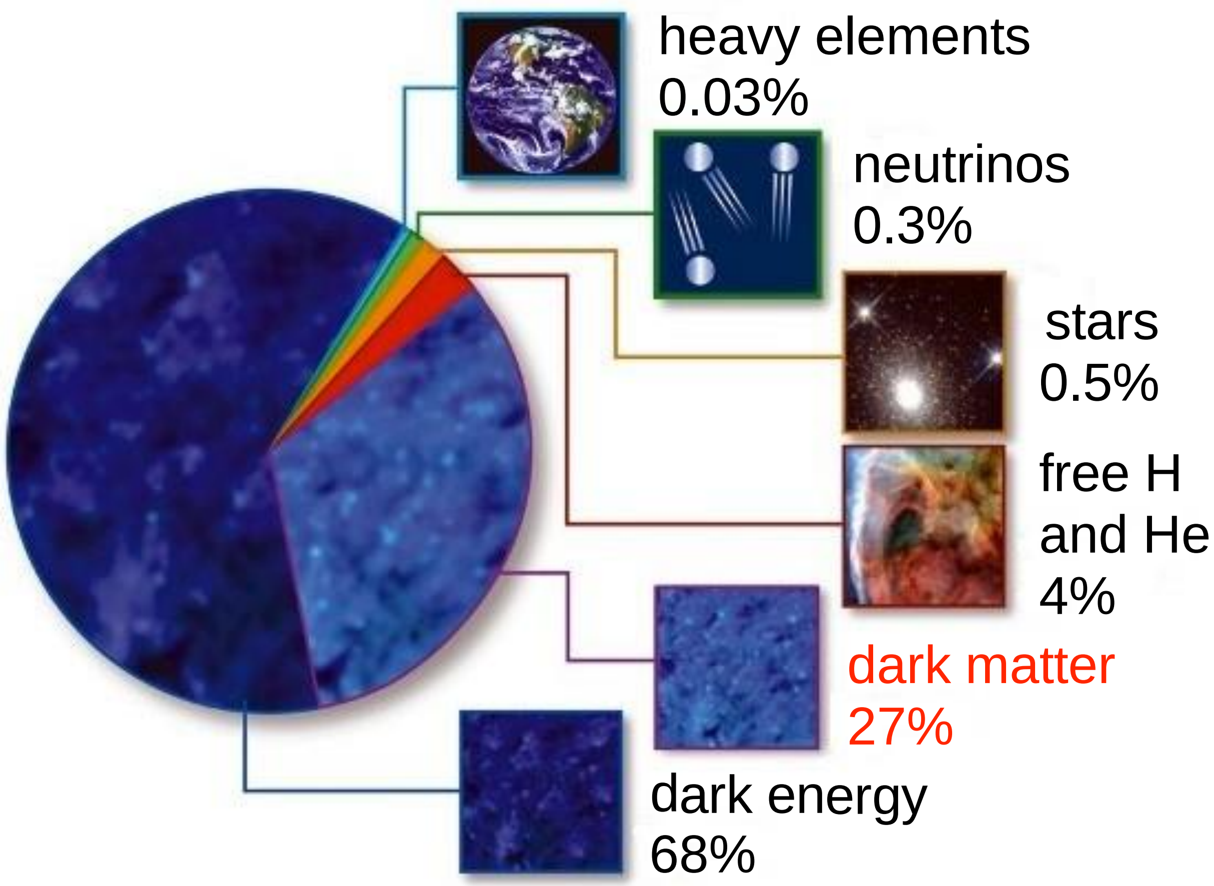
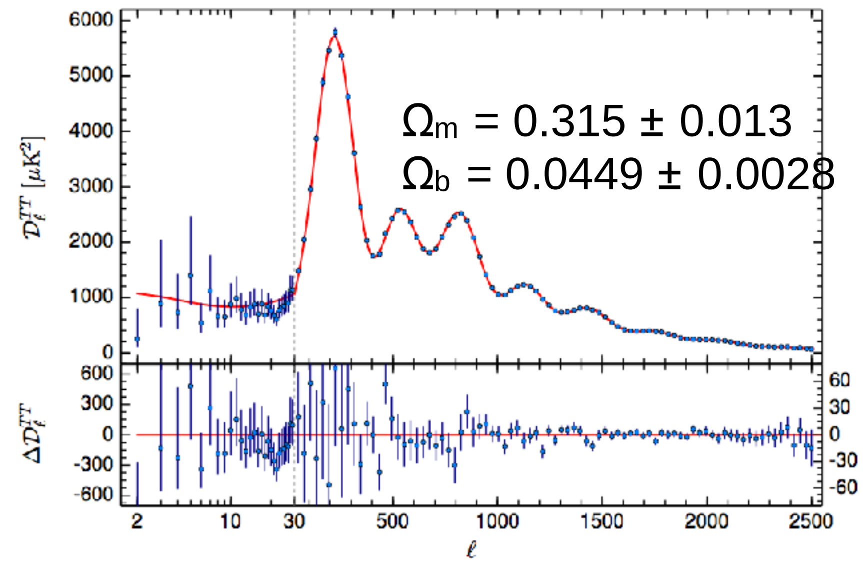
on behalf of DarkSide collaboration

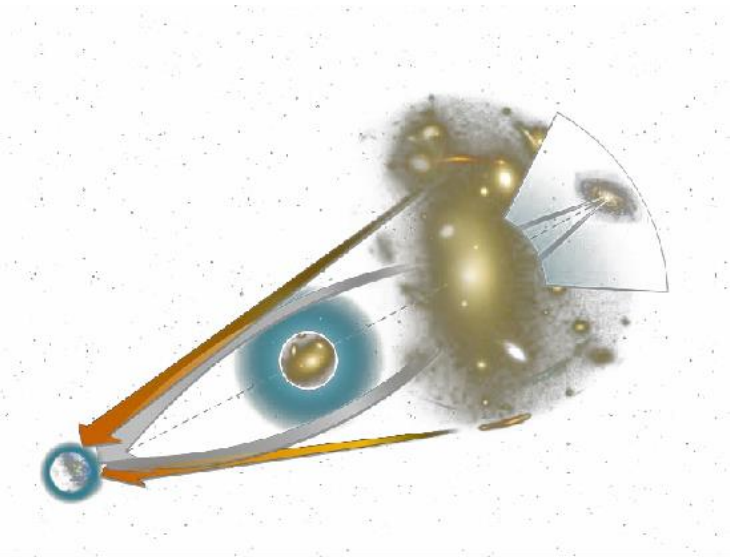
NUCLEUS–2021, 21 September, 2021, St.Petersburg, Russia

Dark Matter from Astrophysical Observations

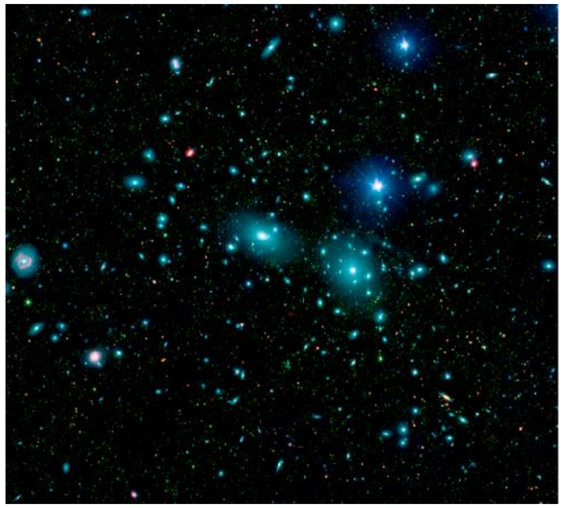




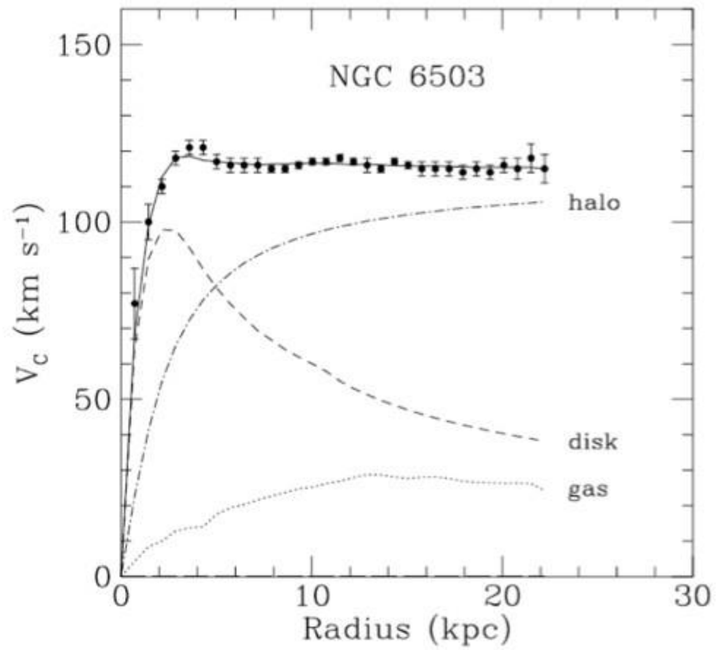
Temperature spectrum of Cosmic Microwave Background



Gravitational lensing

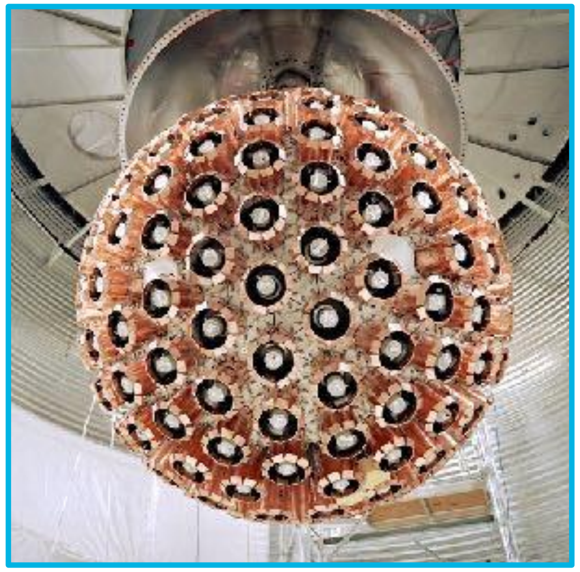


Redshift / velocity dispersion measurements in galaxy clusters



Rotation curves of stars and gas in galaxies

Global Argon Dark Matter Collaboration

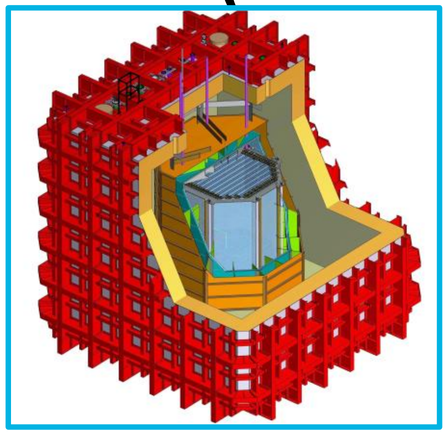


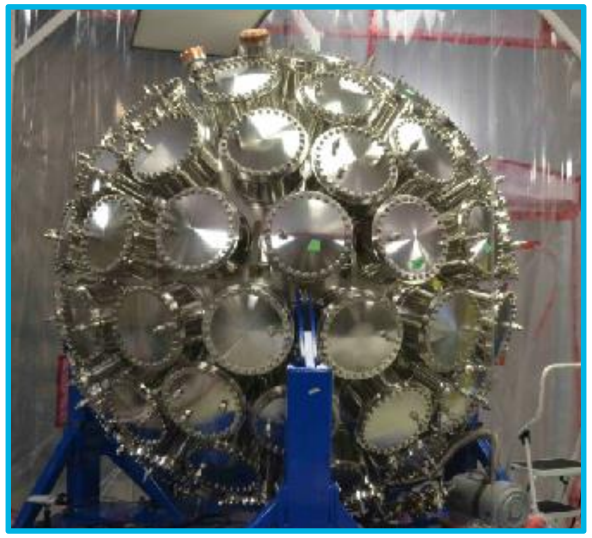
DEAP-3600

More than 400 scientists from past and present argon-based experiments in a single international argon collaboration: **GADMC**

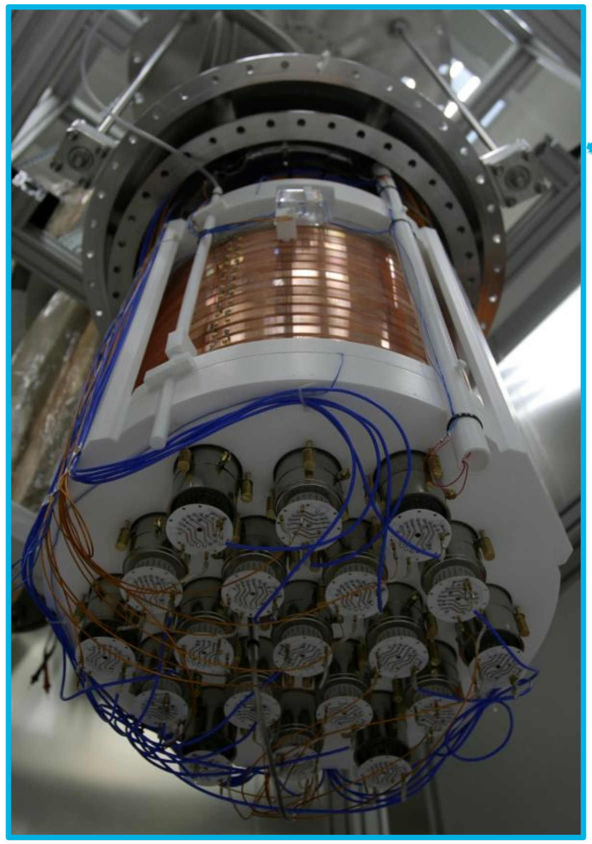
A sequential, two-steps program:

DarkSide-20k (20 tonne fiducial)

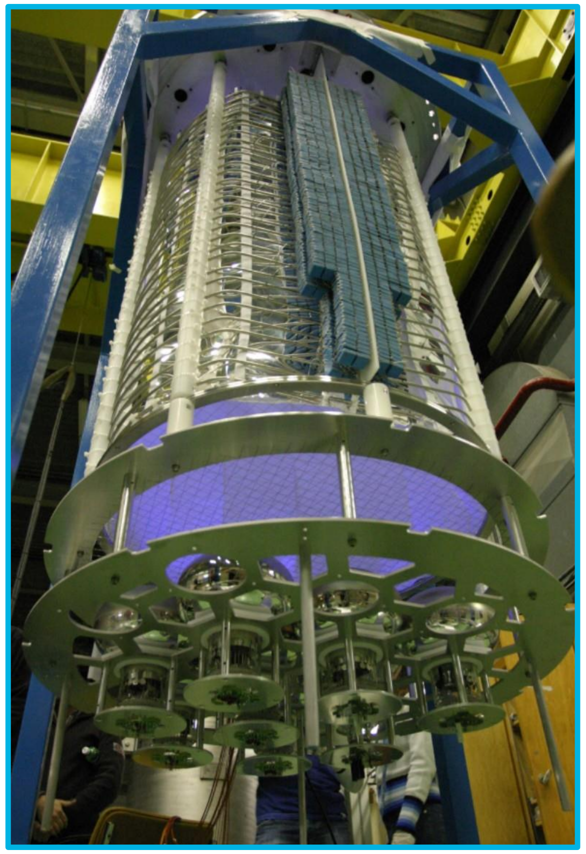




MiniCLEAN



DarkSide-50



ArDM

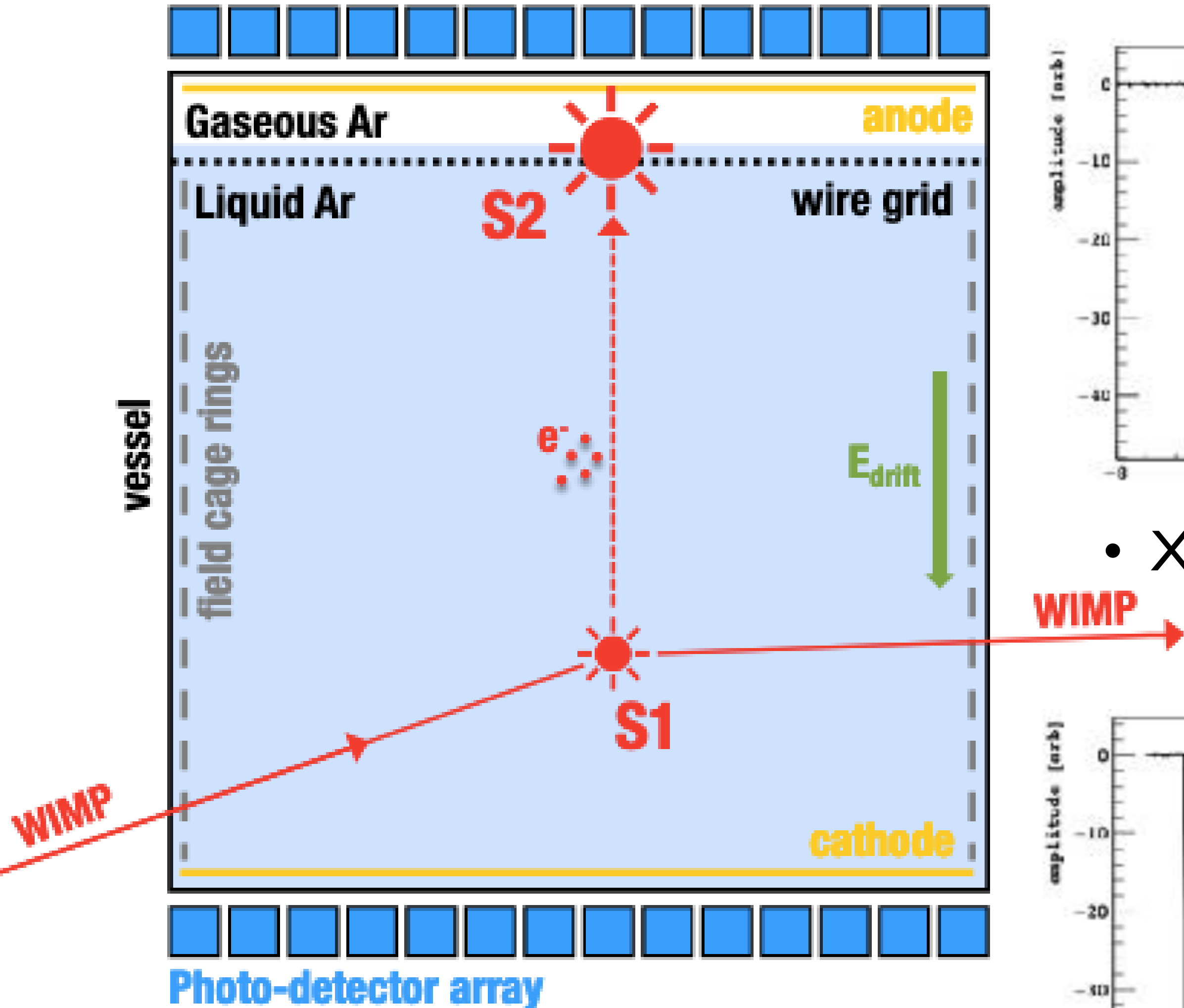
Argo (3,000 tonne fiducial)

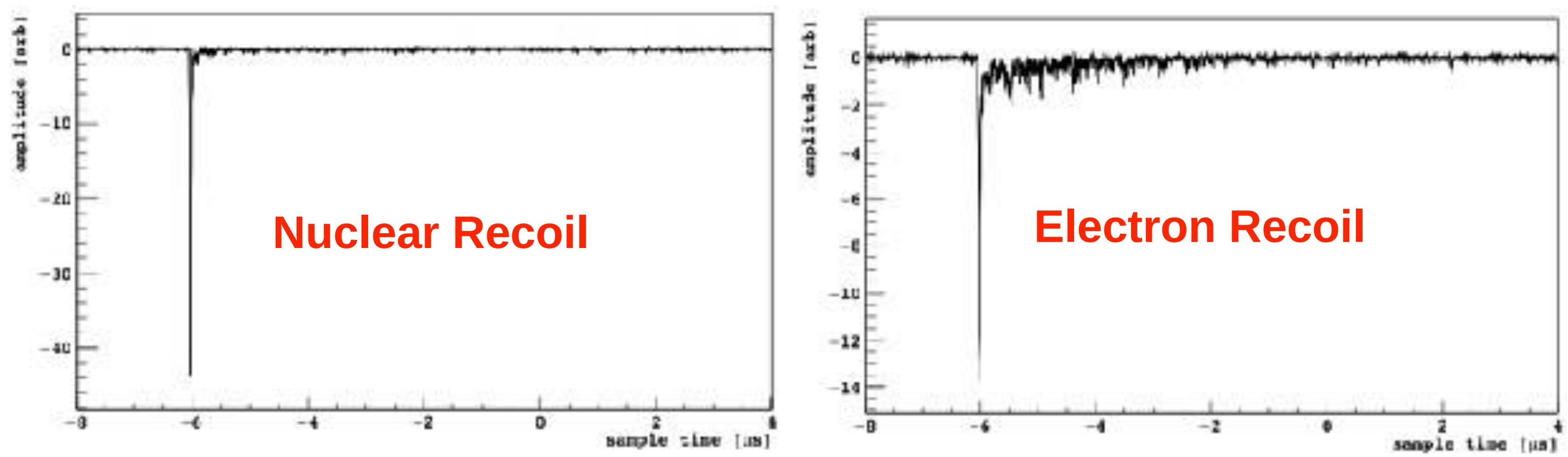
The goal: explore heavy dark matter to the neutrino floor and beyond with extremely low instrumental background

Direct dark matter detection

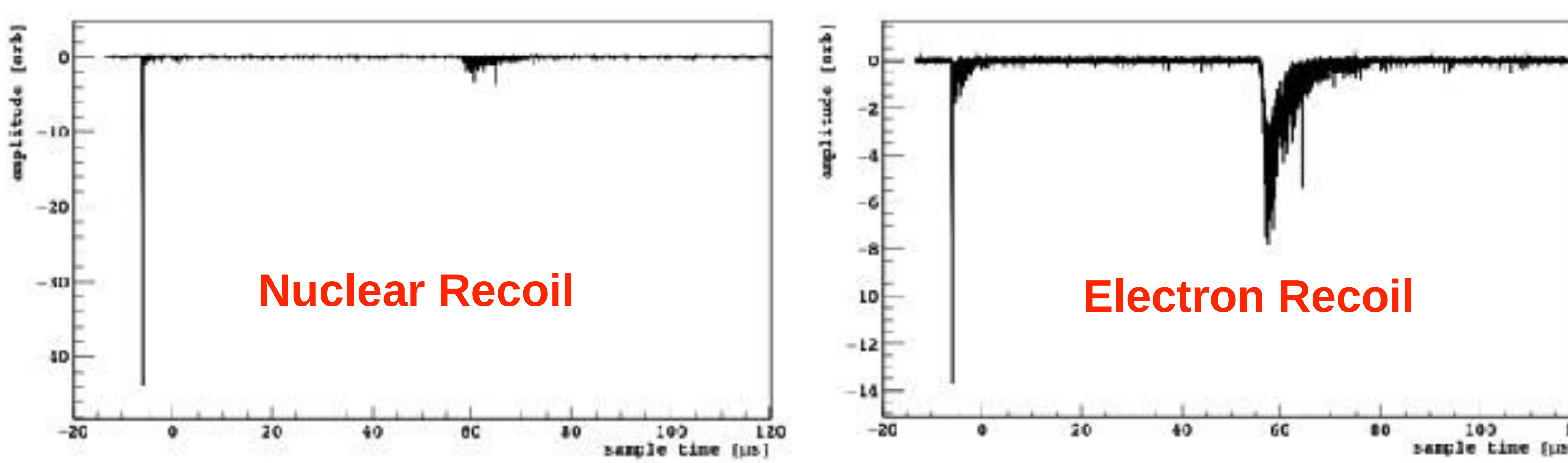
One of the well-known candidates for dark matter - WIMP, Weakly Interacting Massive Particle, M ~ [GeV-TeV], e.g. from supersymmetry: neutralino, lightest superpartner with R-parity conservation

Dual-phase time-projection chamber (TPC)





- X-Y position is determined by the top PMTs (*SiPM*) array with S2.



- Z position from drift time.

Two types of analyses for WIMP search

S1+S2

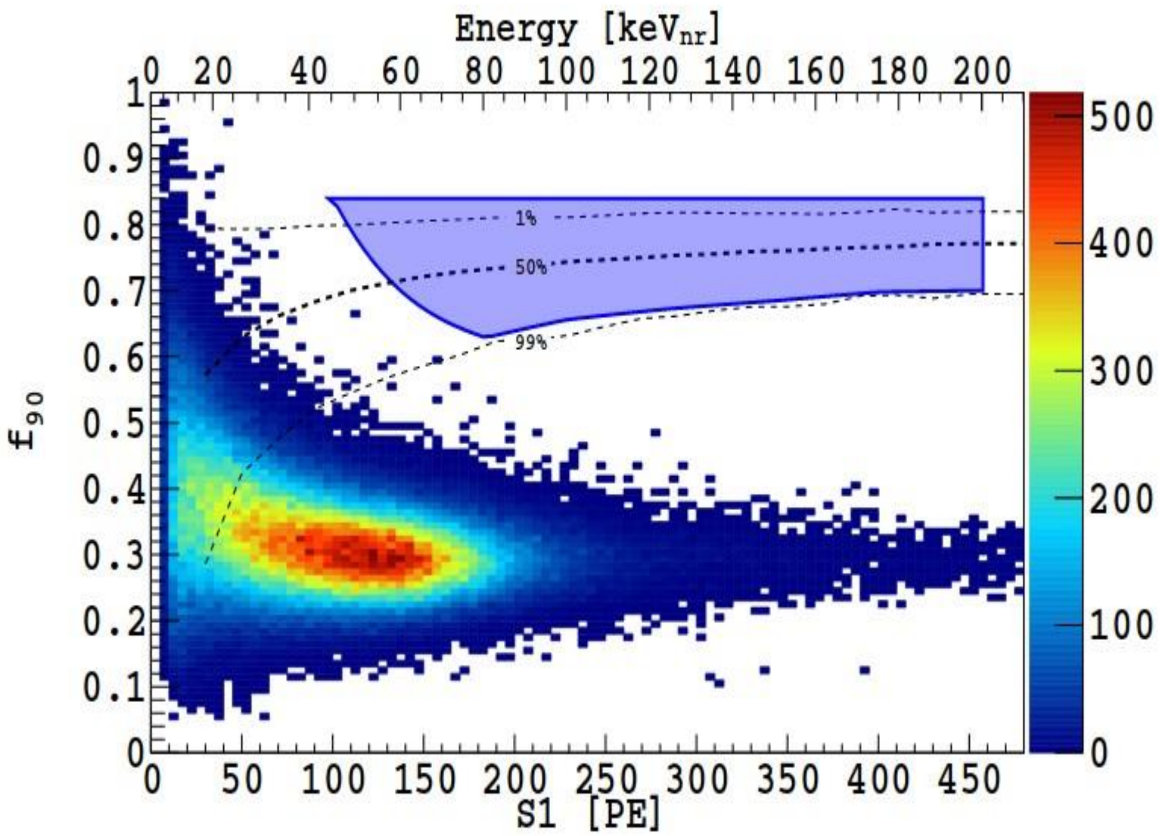
<u>Search for 2 signals from nuclear recoil</u>

WIMP mass range > 20 GeV/c^2

Pulse Shape Discrimination

Background free analysis (< 0.1 events)

Energy diapason 45-200 keV_{nr}



Phys.Rev. D98 (2018) no.10, 102006

S2-only

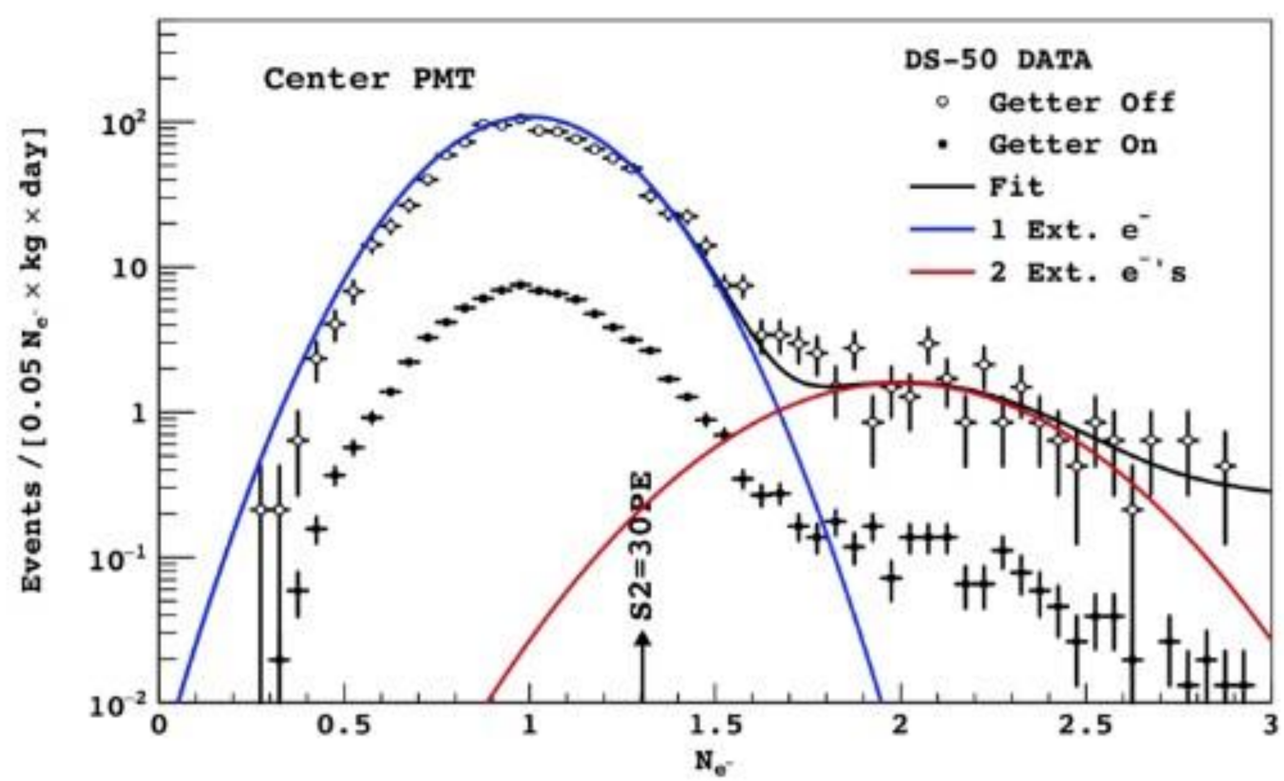
<u>Search for low energy nuclear recoil signals</u>

WIMP mass range 1.8-20 GeV/c^2

Full signal acceptance at 0.1 keV_{ee}

Energy threshold 0.6 keV_{nr}

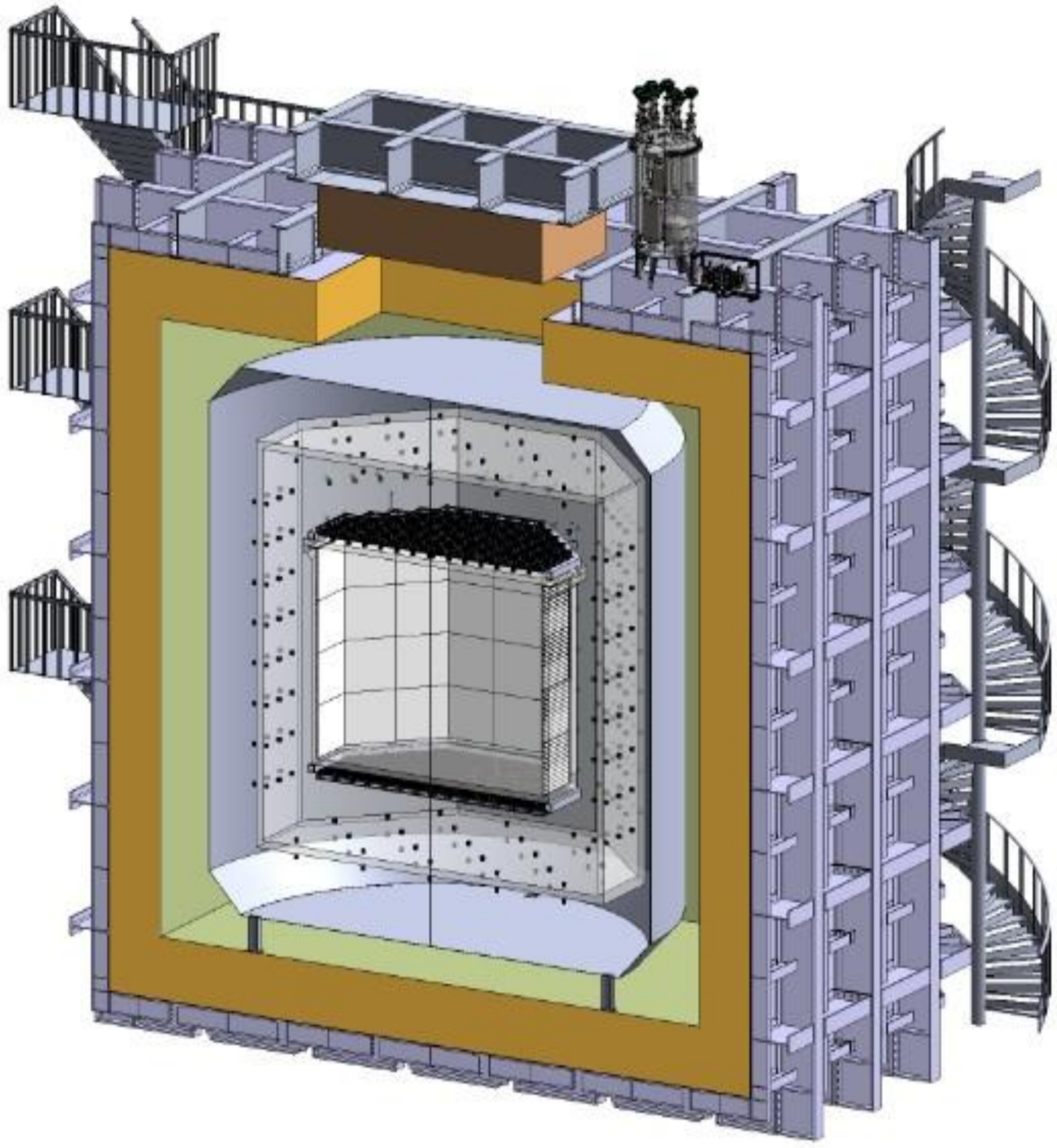
Best DM exclusion limit for 1.8–6 GeV/c^2 WIMP



Single-electron background from impurities

Phys.Rev.Lett. 121 (2018) no.8, 081307

DarkSide20K and ARGO projects



DarkSide20K

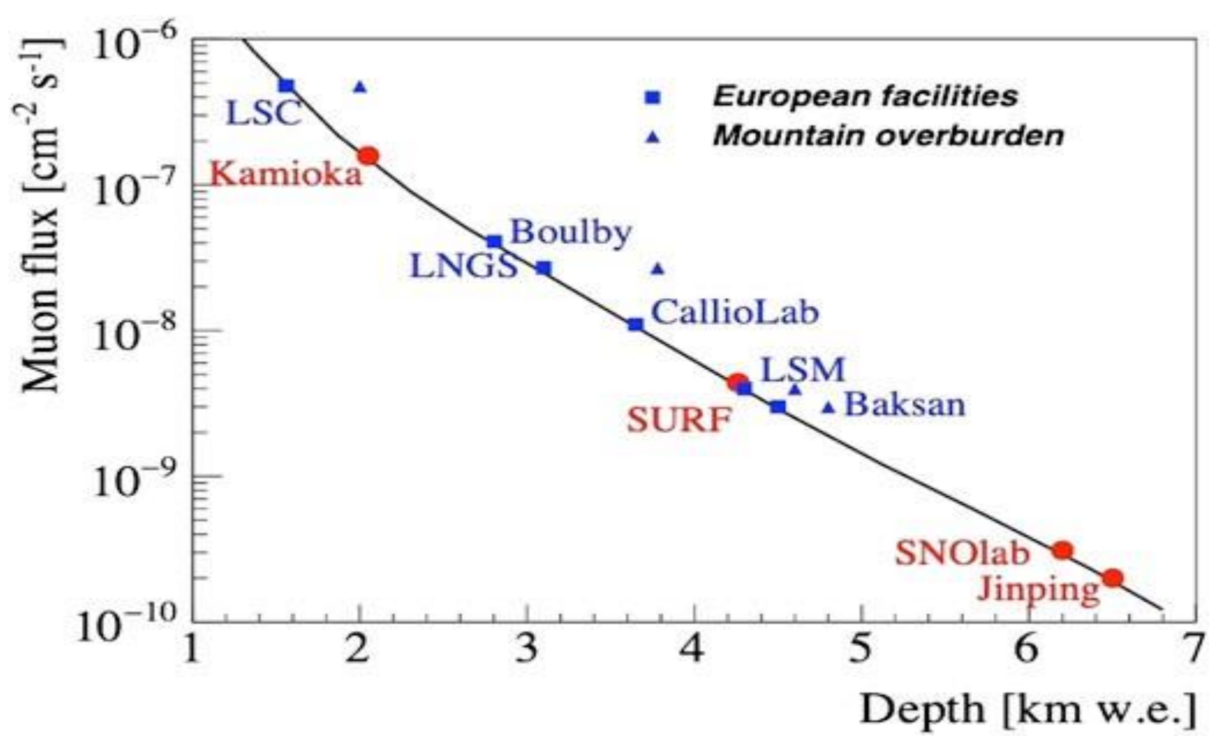
DarkSideS20K design:

Ultra pure acrylic vessel TPC filled with **51 ton** of low-radioactivity Argon (UAr)
14 m^2 + 14 m^2 of SiPM array
Outer active veto of atmospheric Ar (300 ton), with a layer of acrylic loaded with Gd
3.800 m.w.e, in Hall C of LNGS

ARGO design:

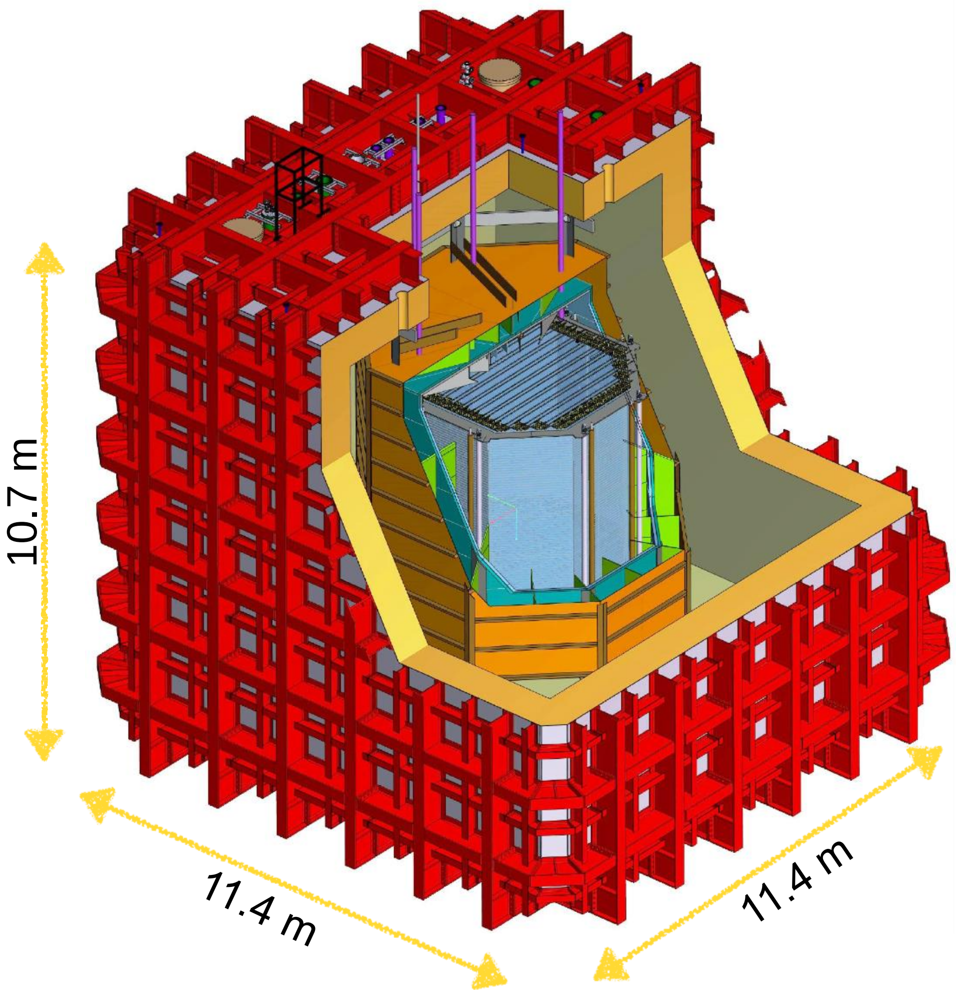
- TPC filled with **360 ton of UAr**
- Same shields of DS20K

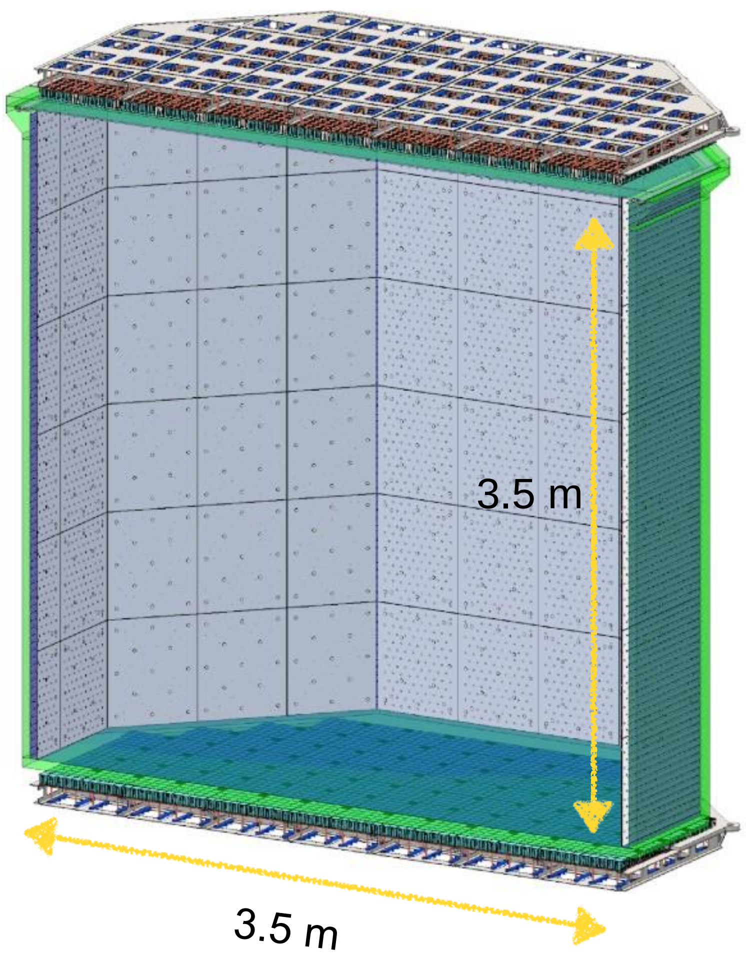
6.000 m.w.e., at SNOLab

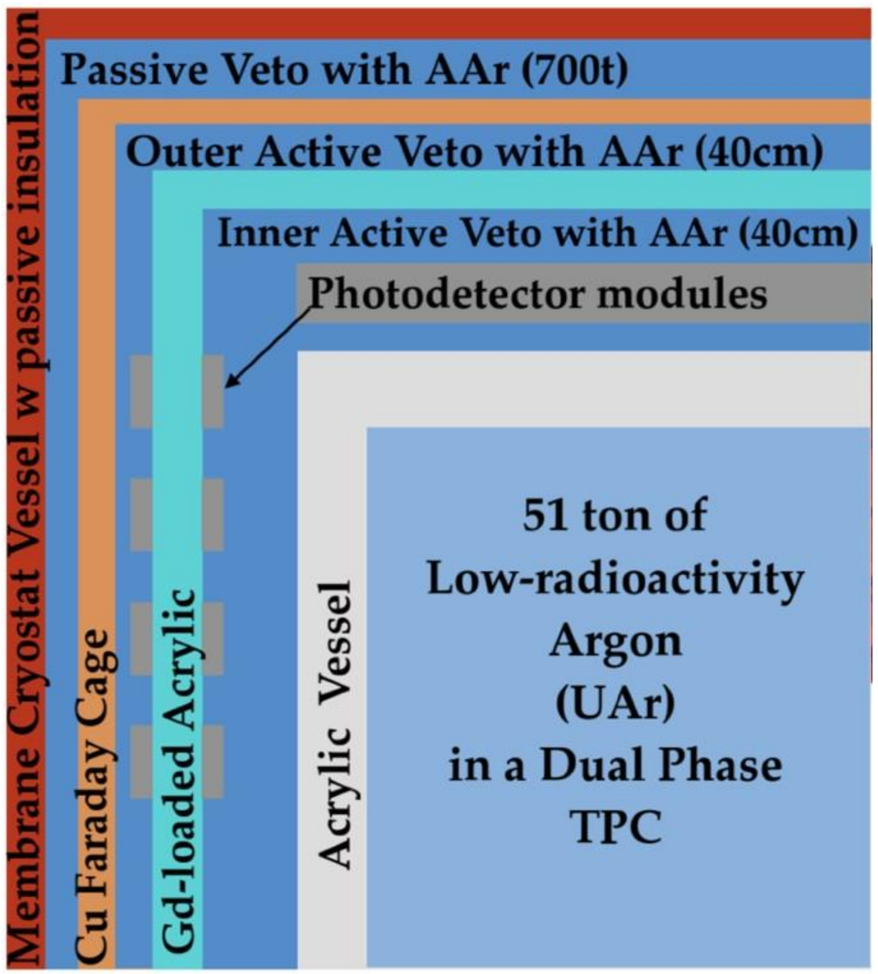


DarkSide20k construction

- Proto DUNE type membrane cryostat with passive insulation.
- Copper Faraday cage,
- Gd-loaded acrylic shell as a neutron Veto,
- Sealed ultra pure acrylic vessel as TPC filled with 51 ton of low-radioactivity Argon (UAr) views from top and bottom by 14 m^2 + 14 m^2 of SiPM array.



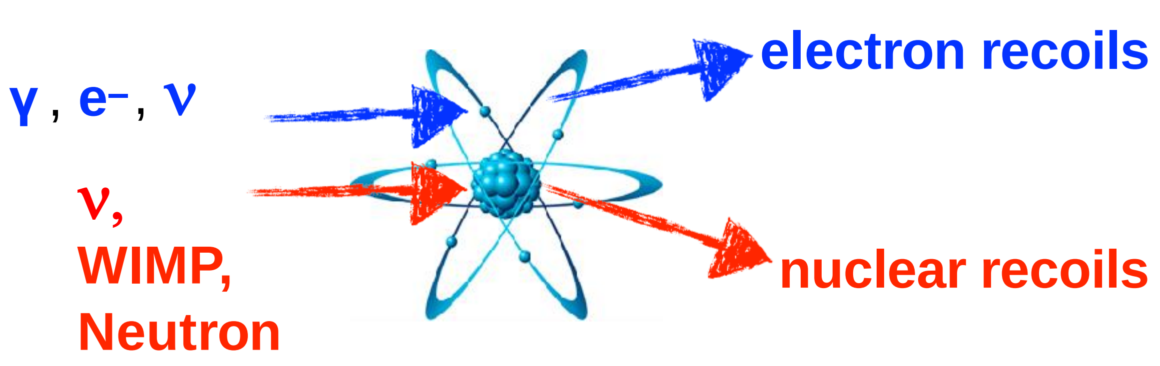


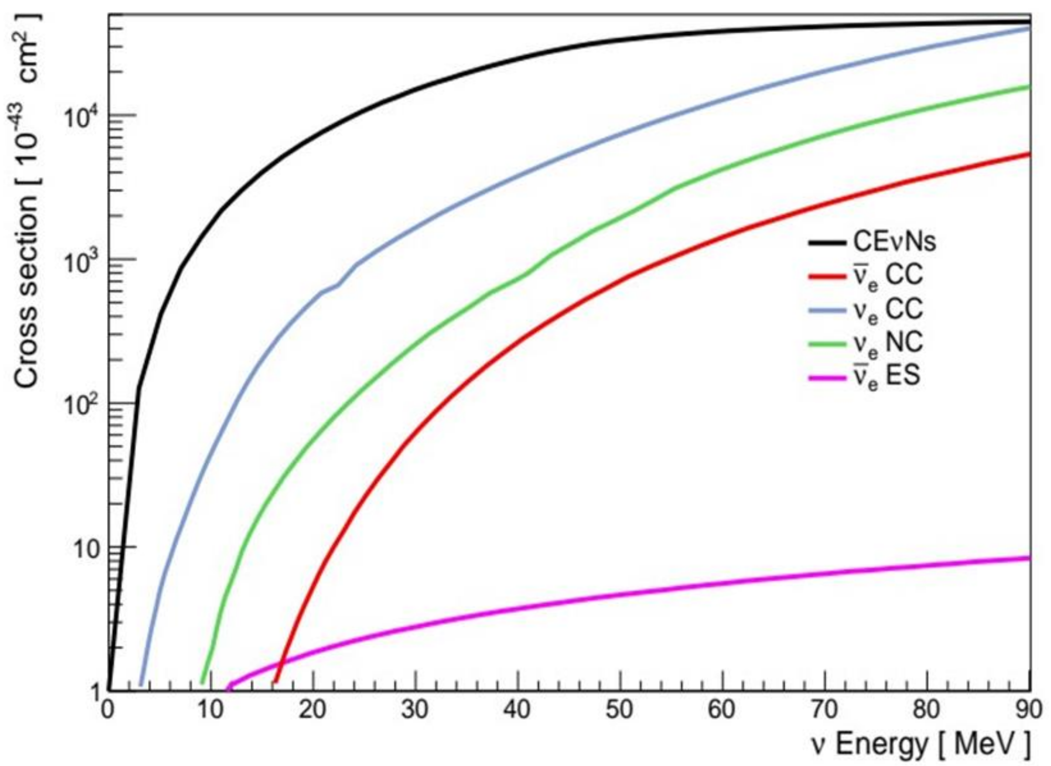


Neutrino Detection from Core-Collapse Supernova in DS20K and ARGO vs Coherent Elastic ν-Nucleus Scattering (CEνNS)

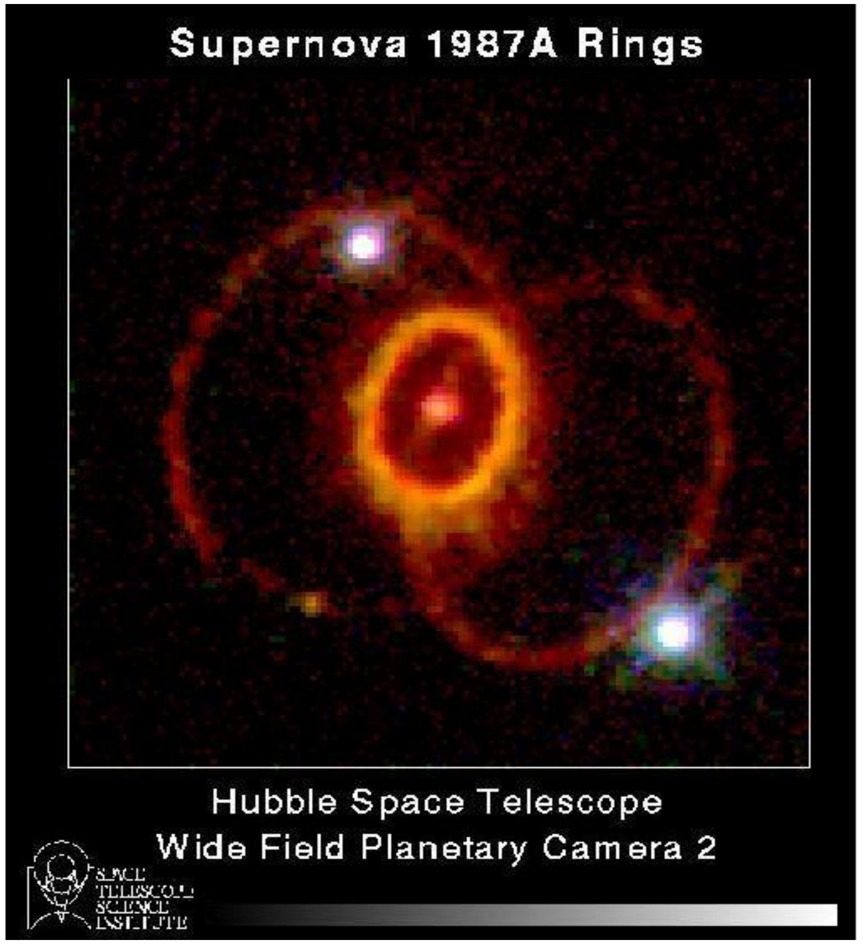
Journal of Cosmology and Astroparticle Physics, 03, 2021, 043

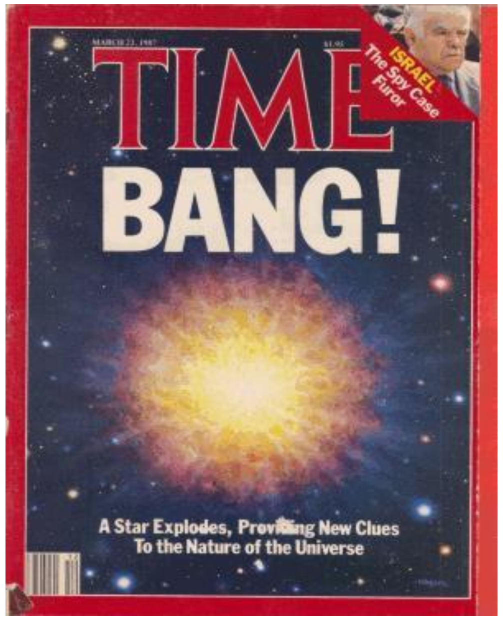
- CEvNS channel has the high cross-section, roughly 50 times larger than that of charge current interaction [at 10 MeV (compensates for the relatively small target masses of DarkSide-20k and Argo)
- CEvNS is equally sensitive to all neutrino flavours and therefore allows to measure the unoscillated SN neutrino flux.
- CEvNS could potentially provide a measurement of the neutrino mass hierarchy in combination with the other experiments



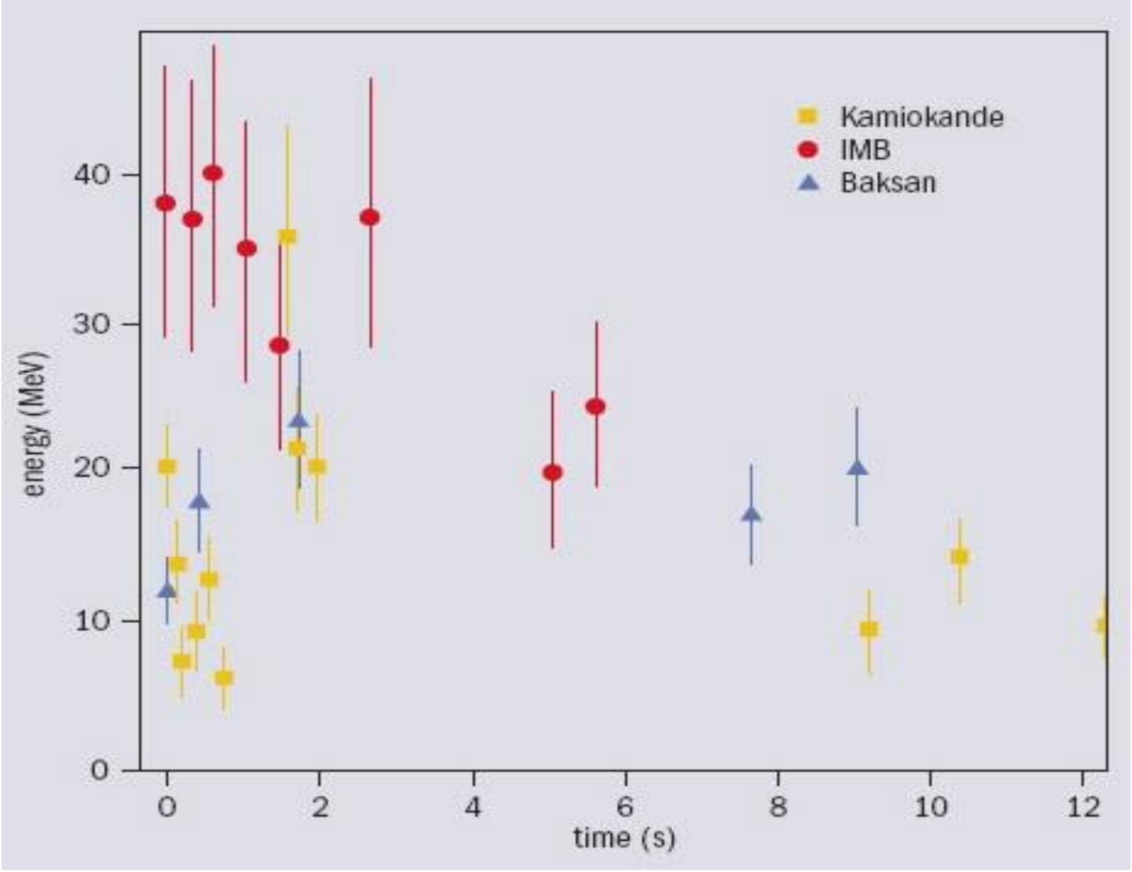


Core-collapse Supernova and Neutrinos

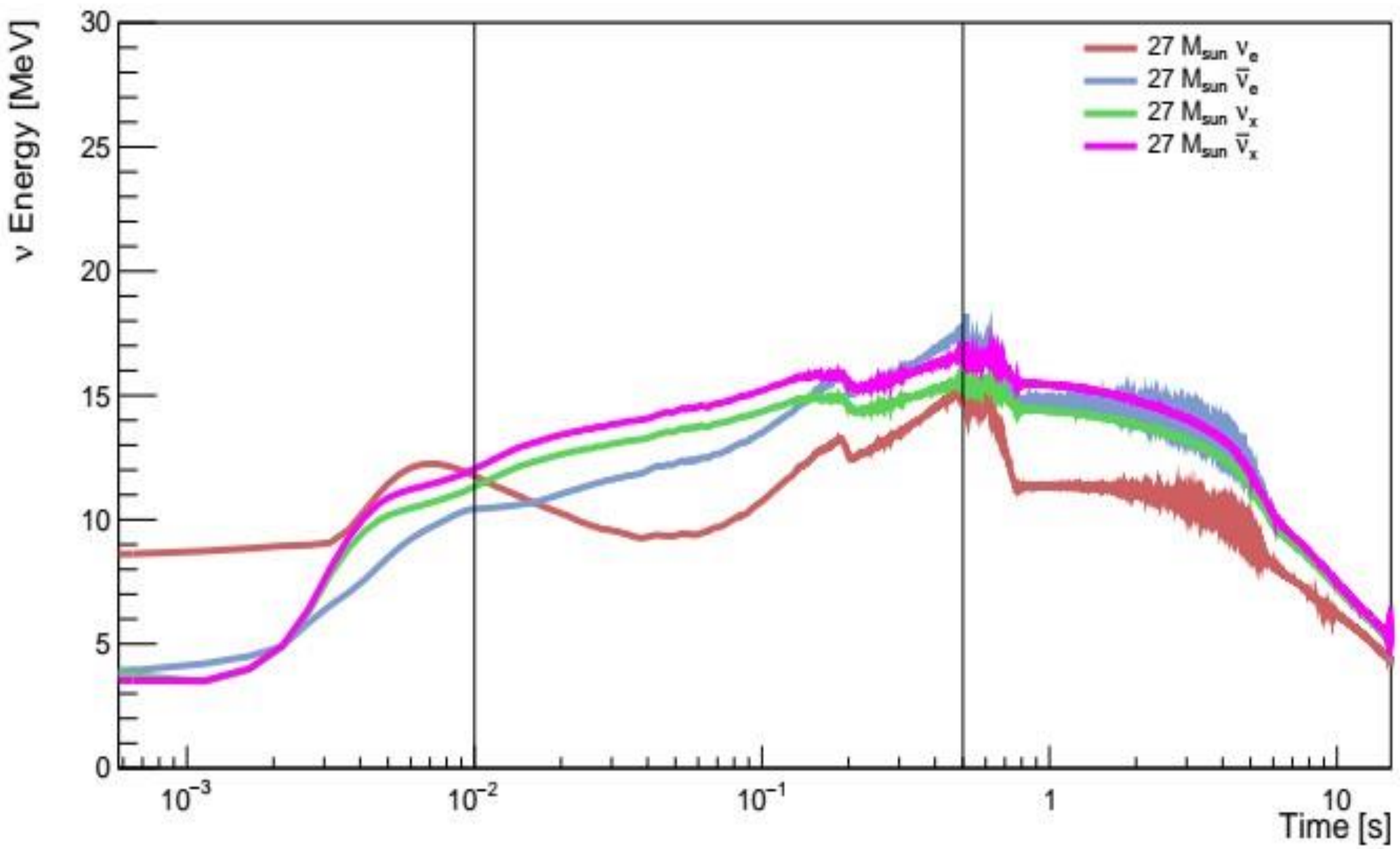




Only one observation of neutrinos from SN 1987A , 50 kpc, in the Large Magellanic Cloud



Core-collapse Supernova and Neutrinos



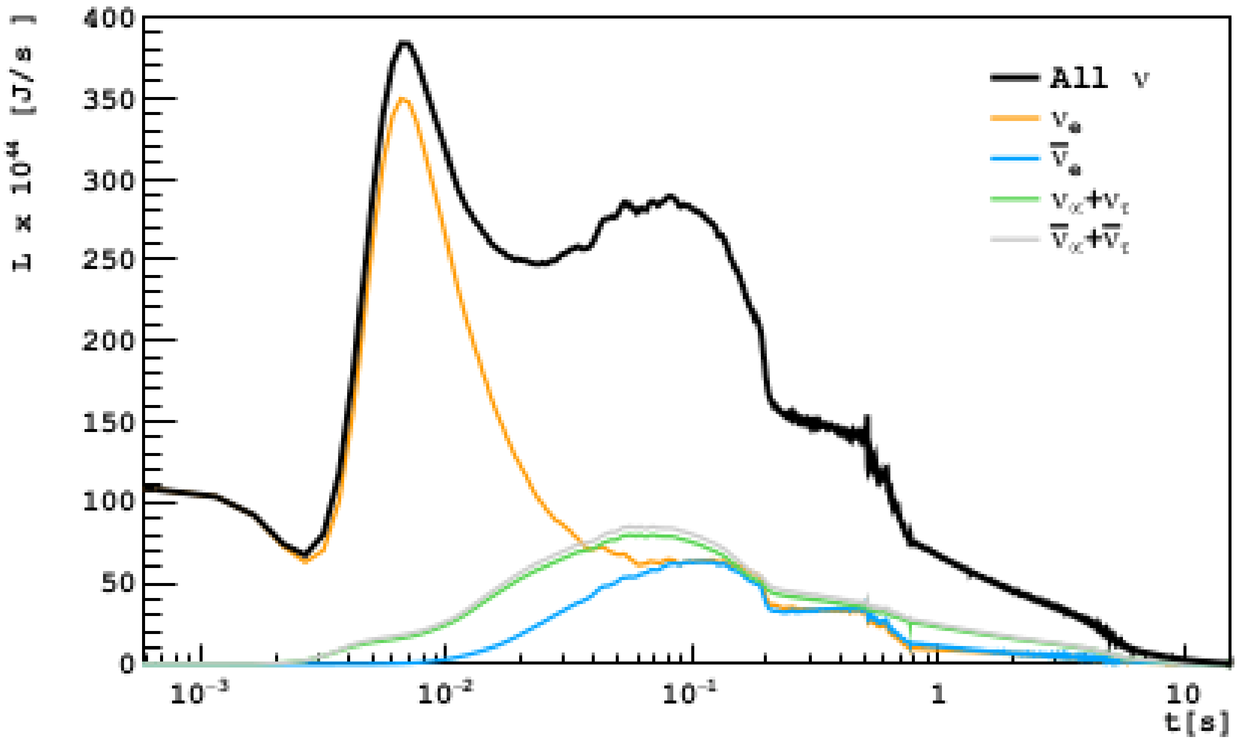
Four phases:

- Infall (~ 10 ms)
- **Neutronization (~50 ms)**
- Accretion (~1 s)
- Cooling (~9 s)

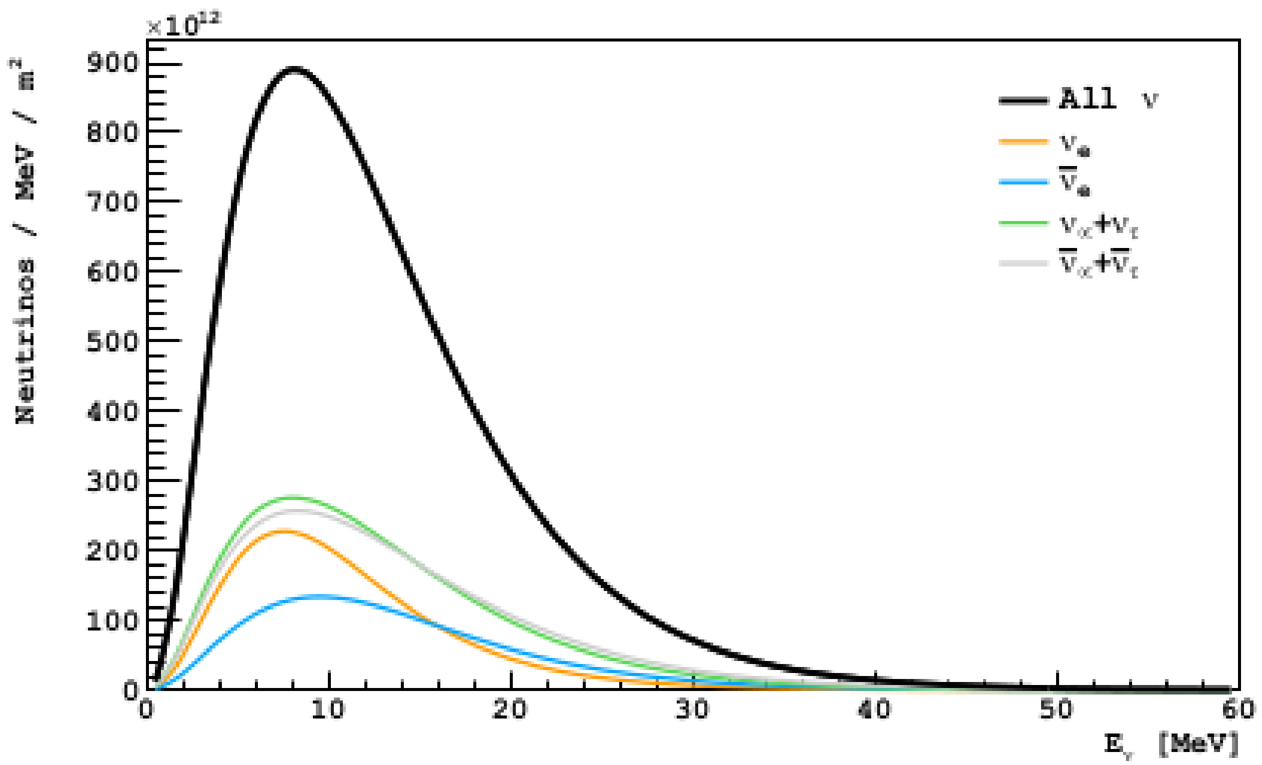
Time evolutions of neutrino mean energy from a core-collapse 27M SN for the different neutrino species, using Garching group 1-d simulations

- Core-collapse supernovae are violent explosions of very massive stars at the end of their lives, triggered by the gravitational collapse of the stellar cores .
- The characteristic energy emitted by a core-collapse SN is $\sim 10^{53}$ erg, which corresponds to the gravitational binding energy of a 1.4 M_{Sun} core that collapses into a neutron star.
- 99% of energy is emitted as neutrinos, ~1% goes into the kinetic energy associated with the external layers of the progenitor that are ejected at ~10,000 km/s, and only 0.01% is radiated at UV, optical and near-infrared wavelengths.
- Neutrinos are the ideal “messengers” for investigating the final stages of stellar evolution, even when the SN is not accessible to optical and radio telescopes

Core-collapse Supernova and Neutrinos



Time evolutions of neutrino luminosity from a core-collapse 27 M_{Sun} SN for the different neutrino species, using Garching group 1-d simulations



Energy spectrum from a core-collapse 27 M_{Sun} SN for the different neutrino species, using Garching group 1-d simulations

Total emitted neutrino flux on the Earth surface:

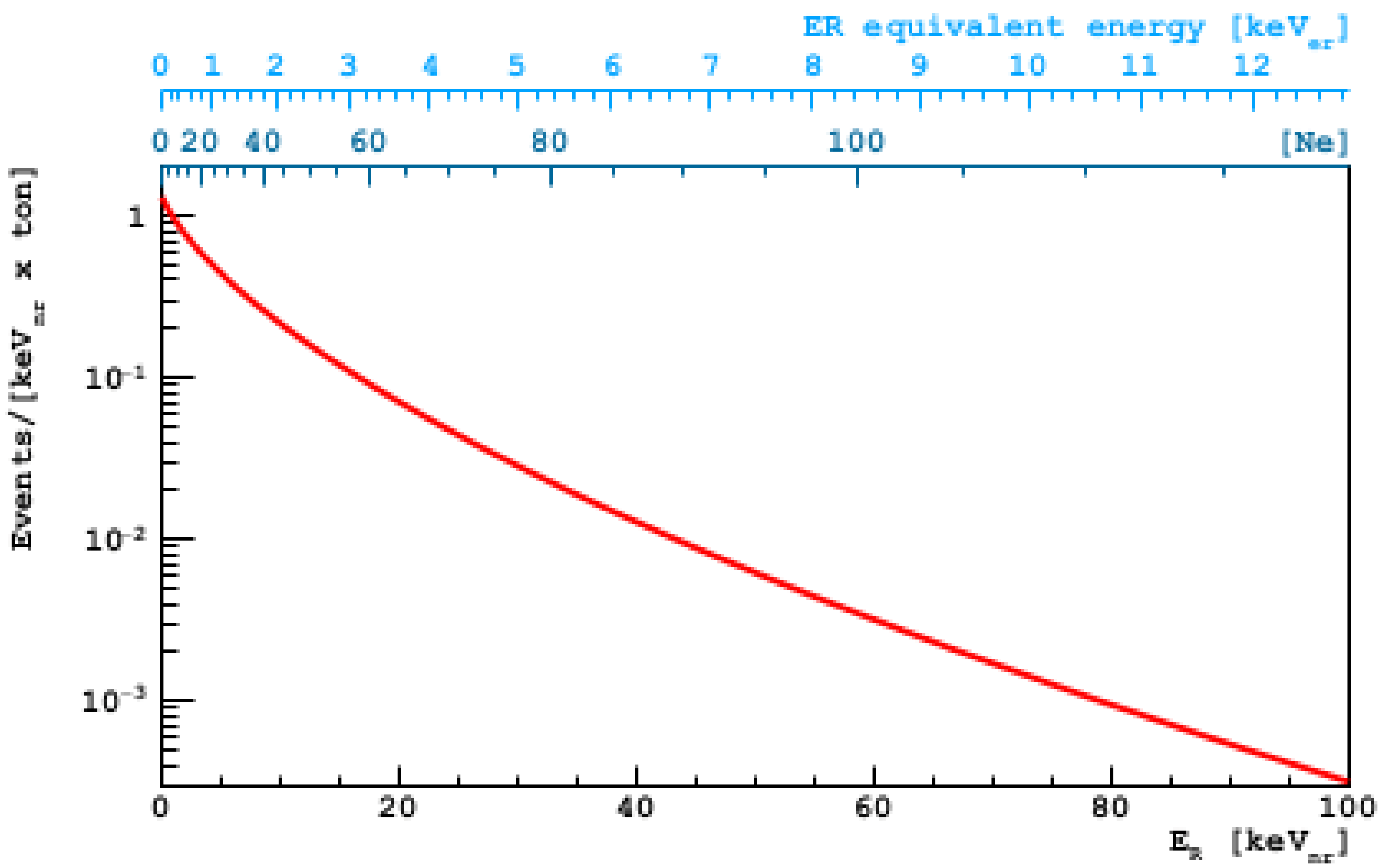
7.9 x 10^{15} ν/m^2 from 11 M_{Sun} SN

13.7 x 10^{15} ν/m^2 from 27 M_{Sun} SN

Supernova Signal in Liquid Argon TPC

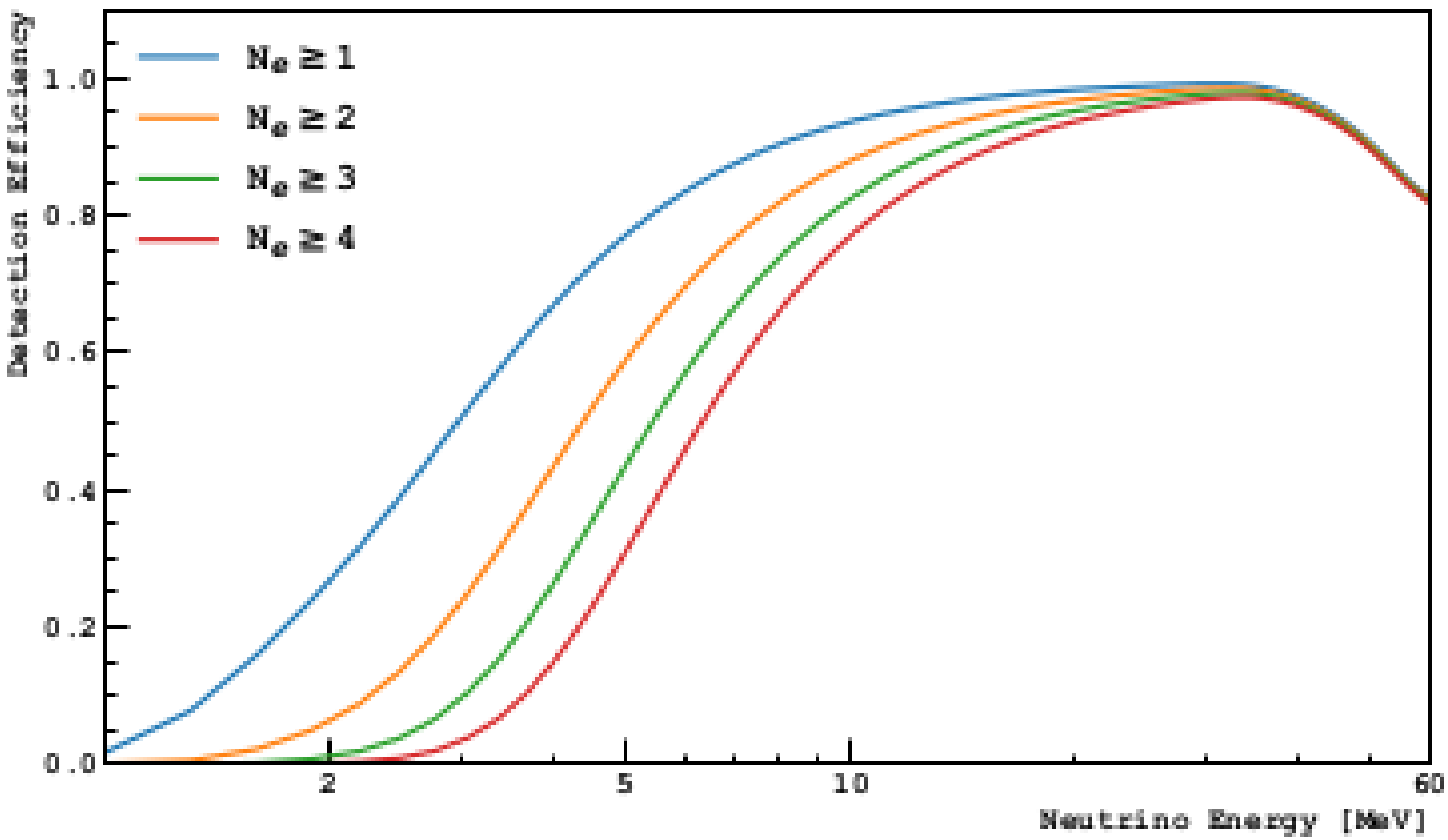
$$\mathrm{d}\sigma(E_\nu, E_r) = \frac{G_F^2}{4\pi} Q_W^2 m \left(1 - \frac{m E_r}{2E_\nu^2}\right) F^2(q)\,\mathrm{d}E_r,$$

where GF is the Fermi coupling constant, QW the weak charge of argon nucleus, and m the argon nucleus mass. F(q) is the Helm form factor, parametrized with the Lewin-Smith approach, as a function of the momentum transfer q=p/2mE



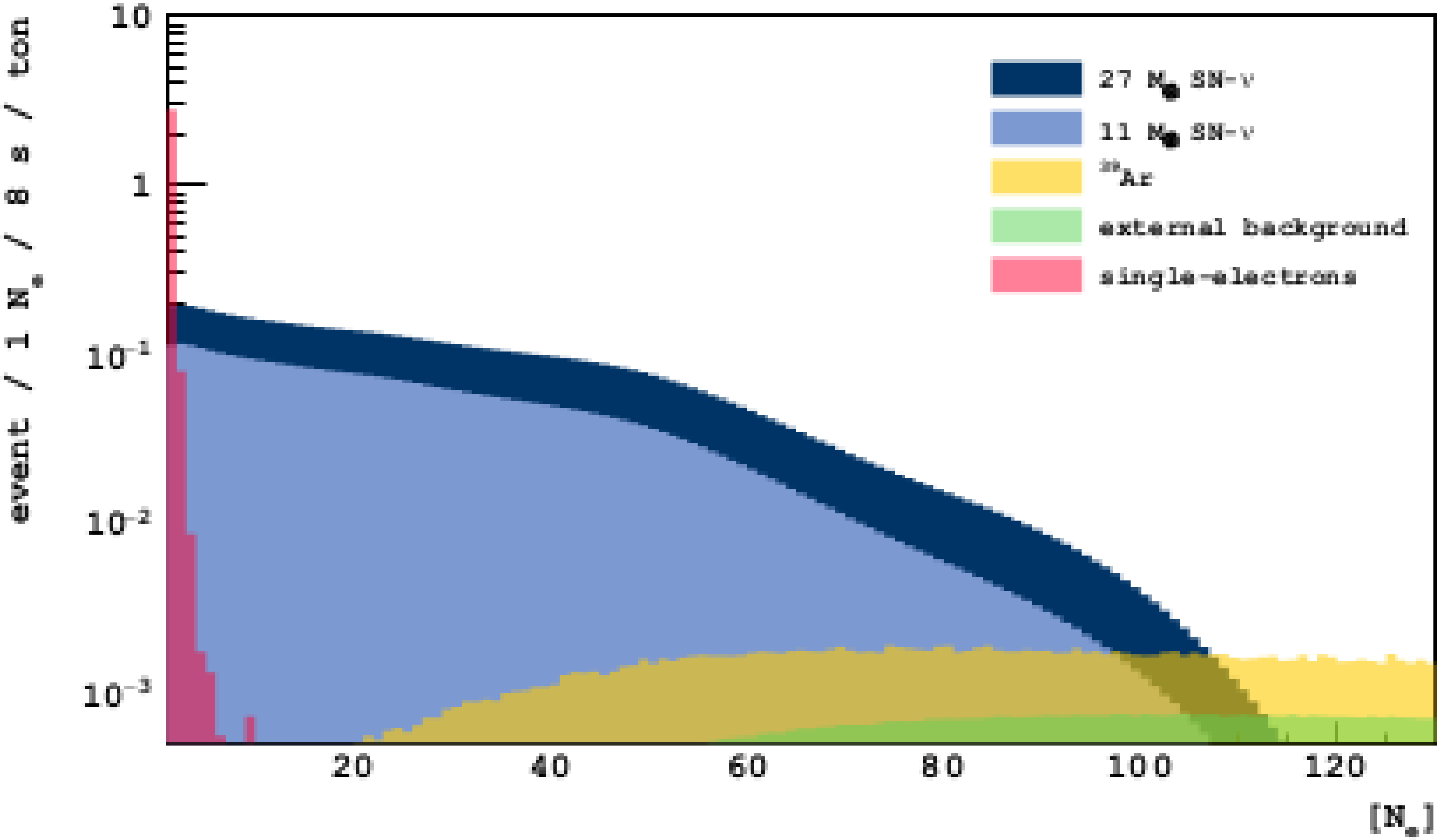
Nuclear recoil energy spectrum from neutrino interactions in LAr via CEνNS from a core-collapse 27 M_{Sun} supernova at 10 kpc

Detection efficiency of Supernova neutrinos in Liquid Argon TPC



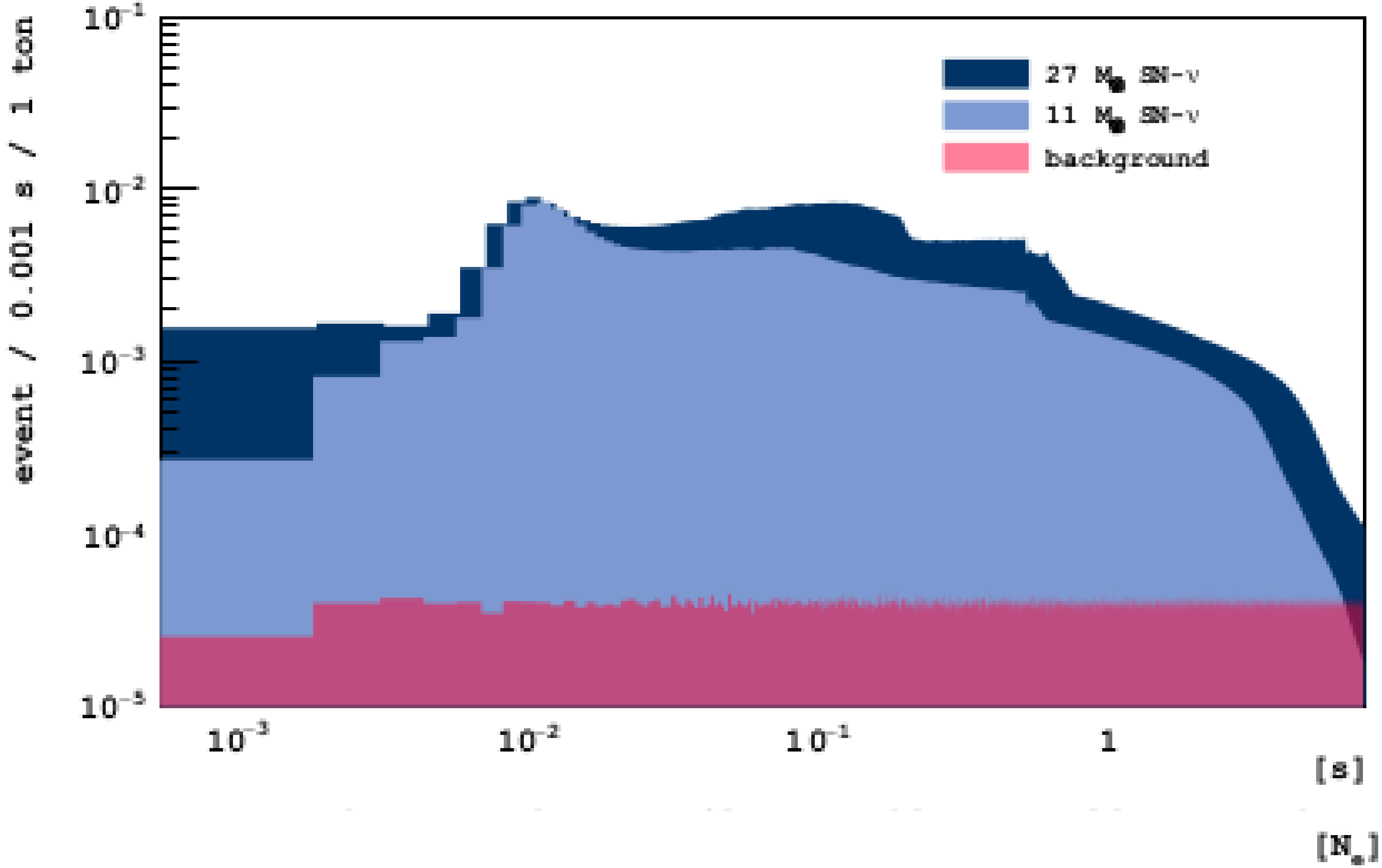
Neutrino detection efficiency via CEνNS as a function of neutrino energy, for different N_{e^-} thresholds and below 100 N_{e^-}

Supernova Signal in Liquid Argon TPC



Energy spectrum in number of ionization electrons (N_e) per unit of mass of neutrinos from 11- M_{Sun} and 27- M_{Sun} SN and background from single electron events, 39Ar decays and external background from SiPMs.

SuperNova Signal in Liquid Argon TPC



Time evolution of signal and all background components (external background as expected in Argo) by selecting events in the [3,100] N_e energy range.

Supernova neutrino rates in Darkside20k and Argo detectors

	DarkSide-20k	Argo
11-M_{Sun} SN-vs	181.4	1396.6
27-M_{Sun} SN-vs	336.5	2591.6
39Ar	4.3	33.8
external background	1.8	8.8
single-electrons	0.7	5.1

Event statistics expected in DarkSide-20k and Argo from 11- M_{Sun} and 27- M_{Sun} SN at 10 kpc and from single-electron and ^{39}Ar background components, within the [3, 100] *Ne*− energy window and in 8 s from the beginning of the burst.

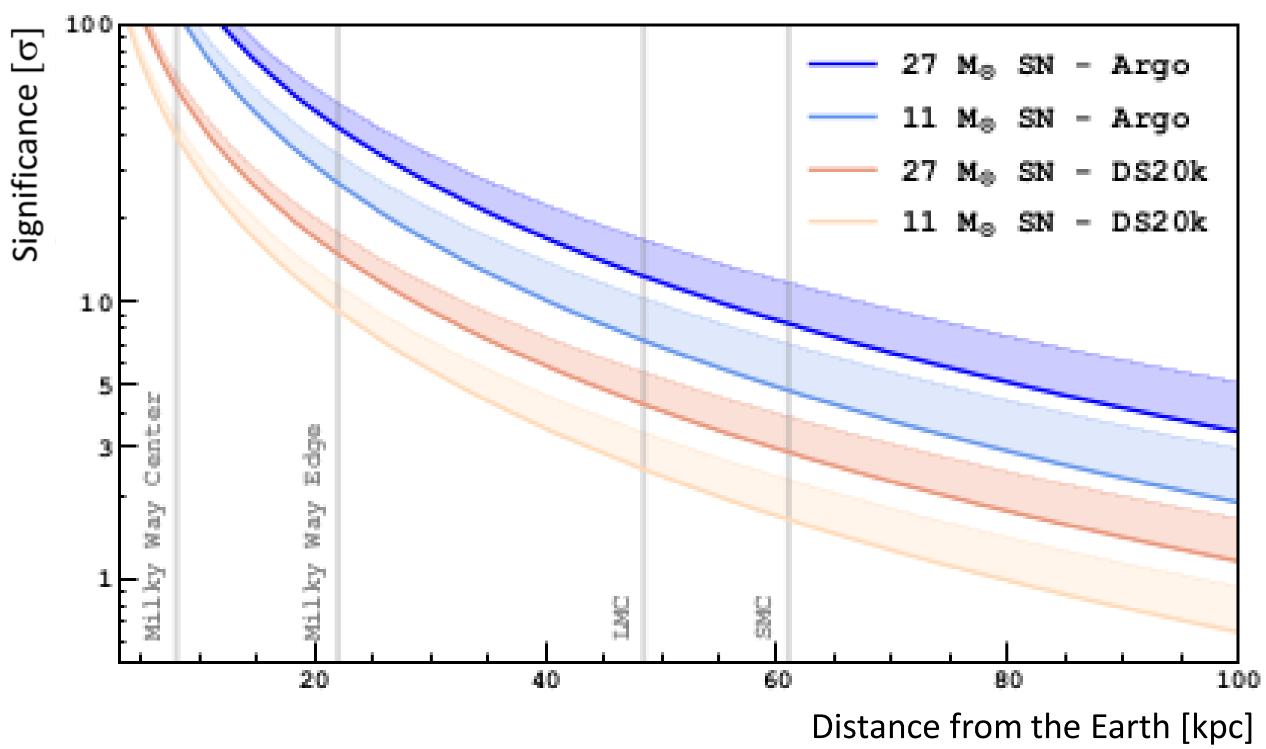
SN phase	11-M_{Sun} SN			27-M_{Sun} SN		
	SN-ν [1/t]	S/B		SN-ν [1/t]	S/B	
		DS20k	Argo		DS20k	Argo
Burst	0.08	212	231	0.09	243	264
Accretion	1.83	105	114	3.30	190	207
Cooling	1.96	16	17	3.76	30	33

Number of events per unit of mass expected in GADMC TPCs from 11-M_{Sun} and 27-M_{Sun} SN at 10 kpc and signal-to-background ratio, accounting for single-electron, external background, and ^{39}Ar rates, within the [3, 100] *Ne*− energy window.

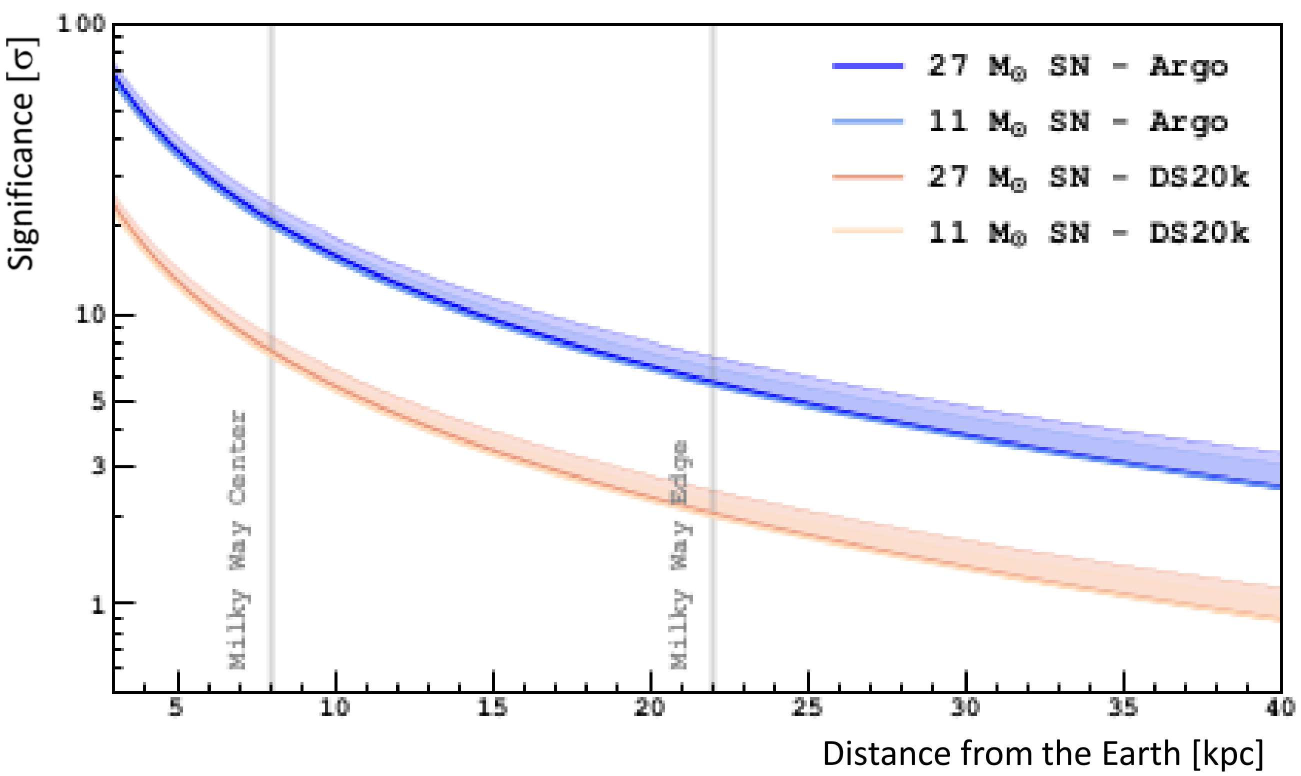
Sensitivity to Supernova Neutrinos

Experiment with negligible background uncertainty and Poisson statistics.

All Supernova



Only neutronization burst



DarkSide-20k and Argo significance to 11- M_{Sun} and 27- M_{Sun} SN (left) and to its neutronization burst only (right), as a function of the distance, assuming the standard background hypothesis (solid line) and (band) lower contamination of ^{39}Ar up to a factor of 10 less. Vertical lines represent the distance from the Earth of the Milky Way center and farthest edge, and of Large (LMC) and Small (SMC) Magellanic Clouds.

Conclusion

- DarkSide-20k and Argo (50 t and 360 t), respectively, can detect neutrinos from SN burst via CENS channel.

- LAr TPCs achieve good accuracies in the reconstruction of average and integrated SN-emitted neutrino energies. Time evolution of the SN burst can be investigated with 1.1 ms and 1.6 ms resolutions for DarkSide-20k and Argo, respectively.

- DarkSide-20k can explore 11- M_{Sun} and larger SN up to the Milky Way edge, and Argo up to the Small Magellanic Cloud. Both DarkSide-20k and Argo detectors are also sensitive to neutrinos from the 11- M_{Sun} neutronization burst up to the Milky Way center and edge, respectively.

- The flavour-blind measurement from DarkSide-20k and Argo could be combined with the flavour-sensitive measurements of other neutrino detectors to provide input into the triangulation of the positions of SN, to be carried out by the SuperNova Early Warning System 2.0 (SNEWS2.0)

Thank you for your attention