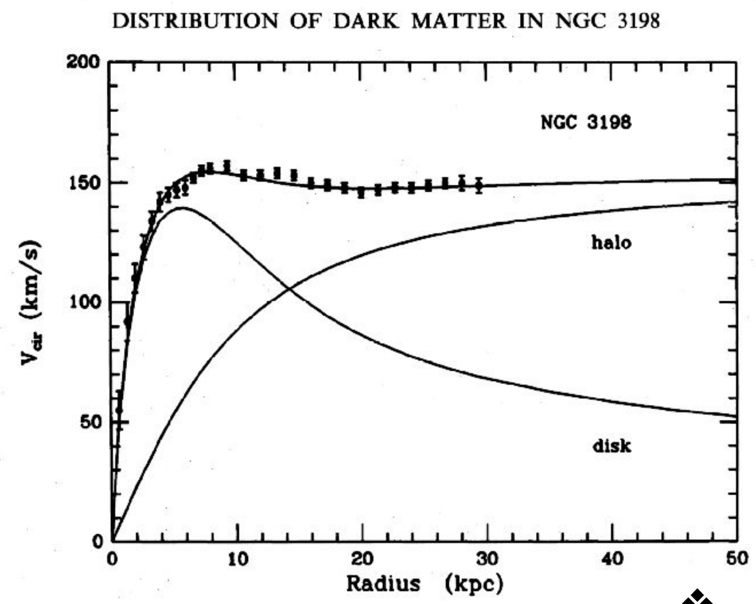
Search for dark matter with the DarkSide-50 experiment

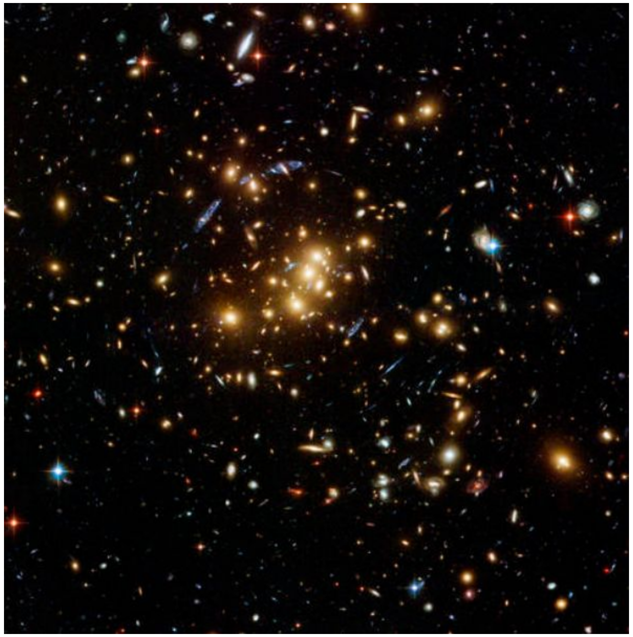
Giulia Tuci, *Università di Pisa & INFN-Pisa*
giulia.tuci@pi.infn.it

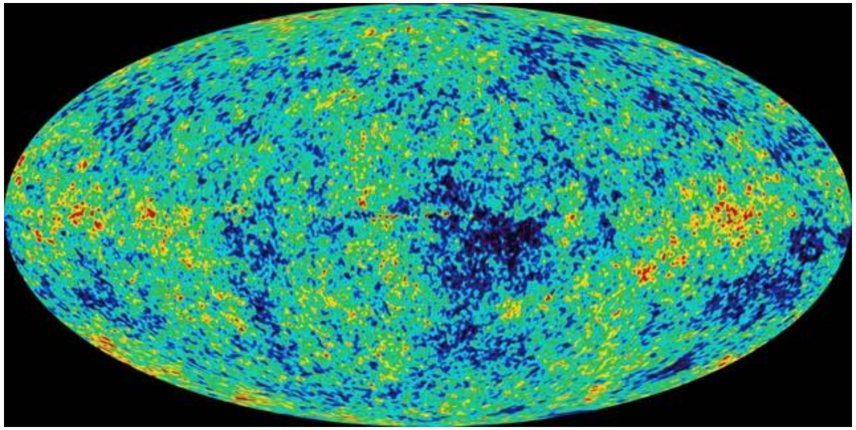
PhD Seminar- I year
Pisa, 22/10/2018

Evidence of dark matter



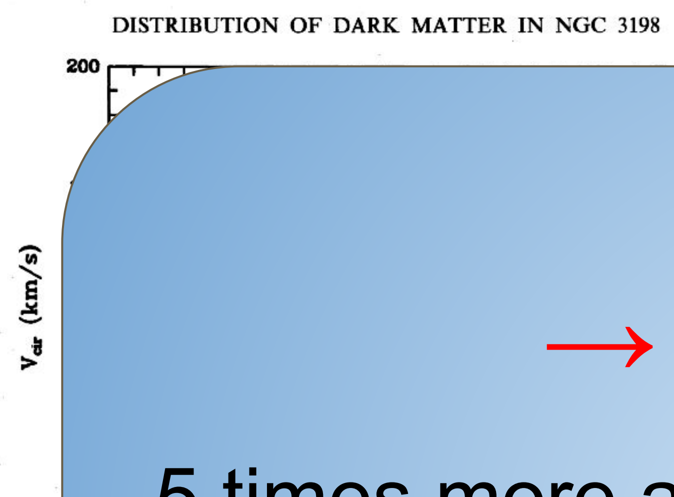
- ❖ Rotational curves of galaxies
- ❖ Gravitational lensing

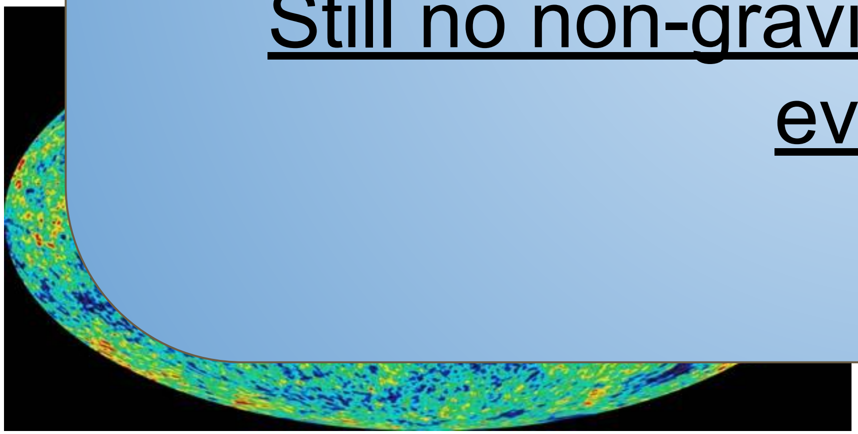


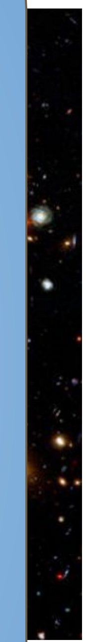


- ❖ Anisotropies in the CMB

Evidence of dark matter







→ Dark Matter

5 times more abundant than ordinary visible matter

<u>Still no non-gravitational experimental evidence</u>

Dark matter candidates

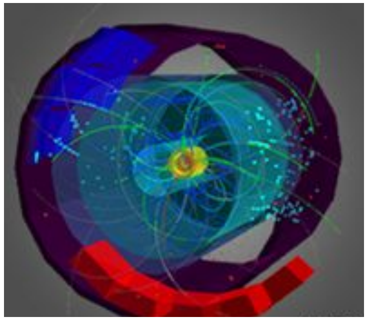
- **MACHOs** (baryonic dark matter): non-luminous celestial bodies such as neutron stars, black holes, brown dwarfs
- **Sterile neutrinos**: massive and right-handed counterpart of Standard Model neutrinos (only gravitational interaction)
- **Axions**: a light pseudoscalar particle introduced to solve the so-called strong CP problem
- **WIMPs**: hypothetical stable and neutral particles with a mass in the range of GeV/c^2 to several TeV/c^2 which interacts with ordinary matter at the weak scale or below

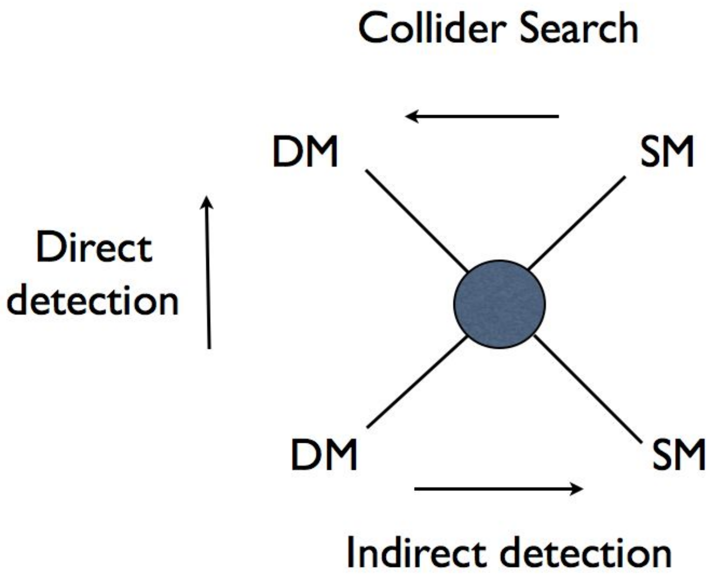
Dark matter candidates

- **MACHOs** (baryonic dark matter): non-luminous celestial bodies such as neutron stars, black holes, brown dwarfs
- **Sterile neutrinos**: massive and right-handed counterpart of Standard Model neutrinos (only gravitational interaction)
- **Axions**: a light pseudoscalar particle introdu ed to solve the so-called strong CP problem
- **WIMPs**: hypothetical stable and neutral particles with a mass in the range of GeV/c^2 to several TeV/c^2 which interacts with ordinary matter at the weak scale or below

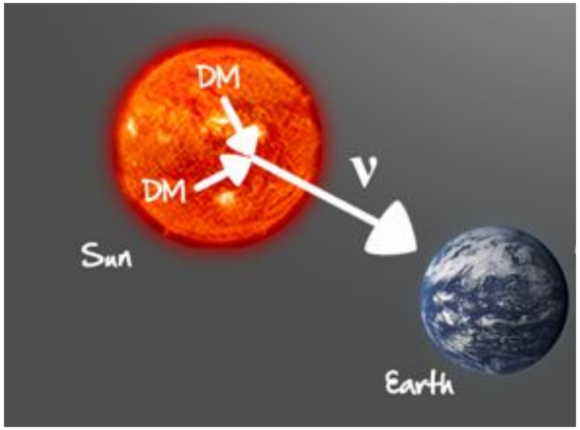
How to detect dark matter

❖ **Dark matter at colliders**

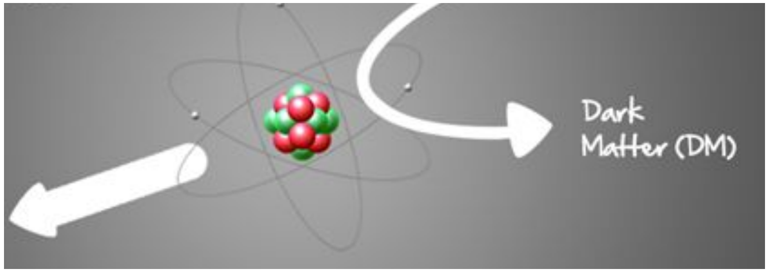




❖ **Indirect search**: annihilation of DM into SM particles

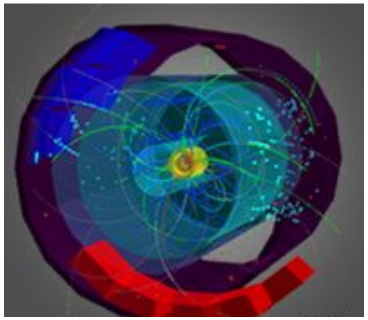


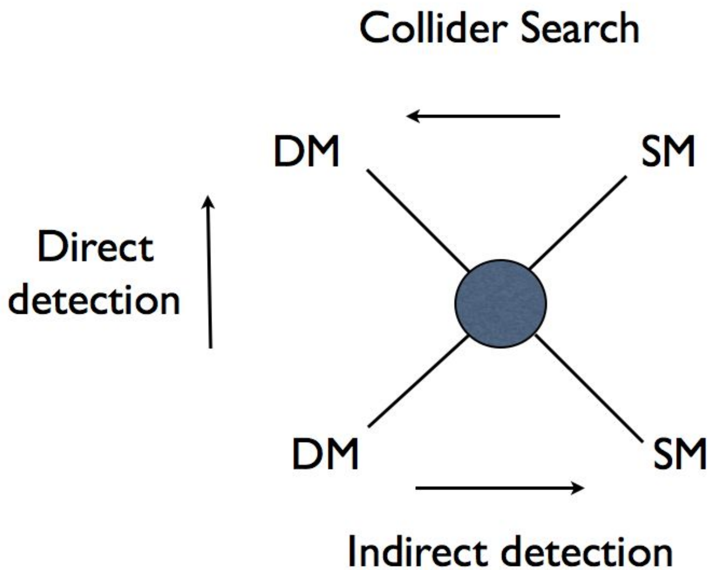
❖ **Direct search**: detecting nuclear recoil caused by the scattering with a DM candidate



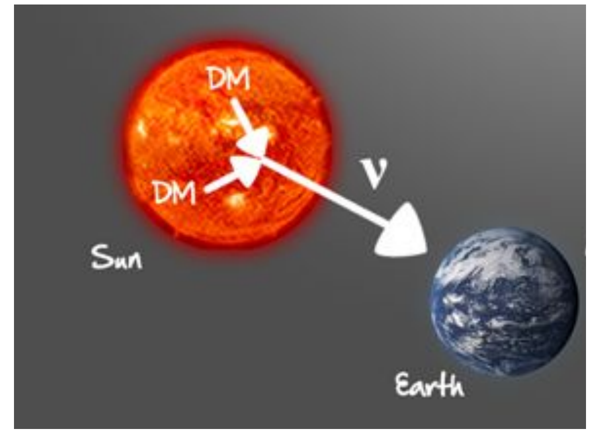
How to detect dark matter

- **Dark matter at colliders**

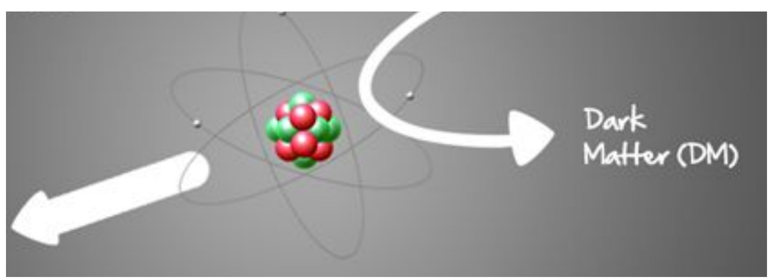




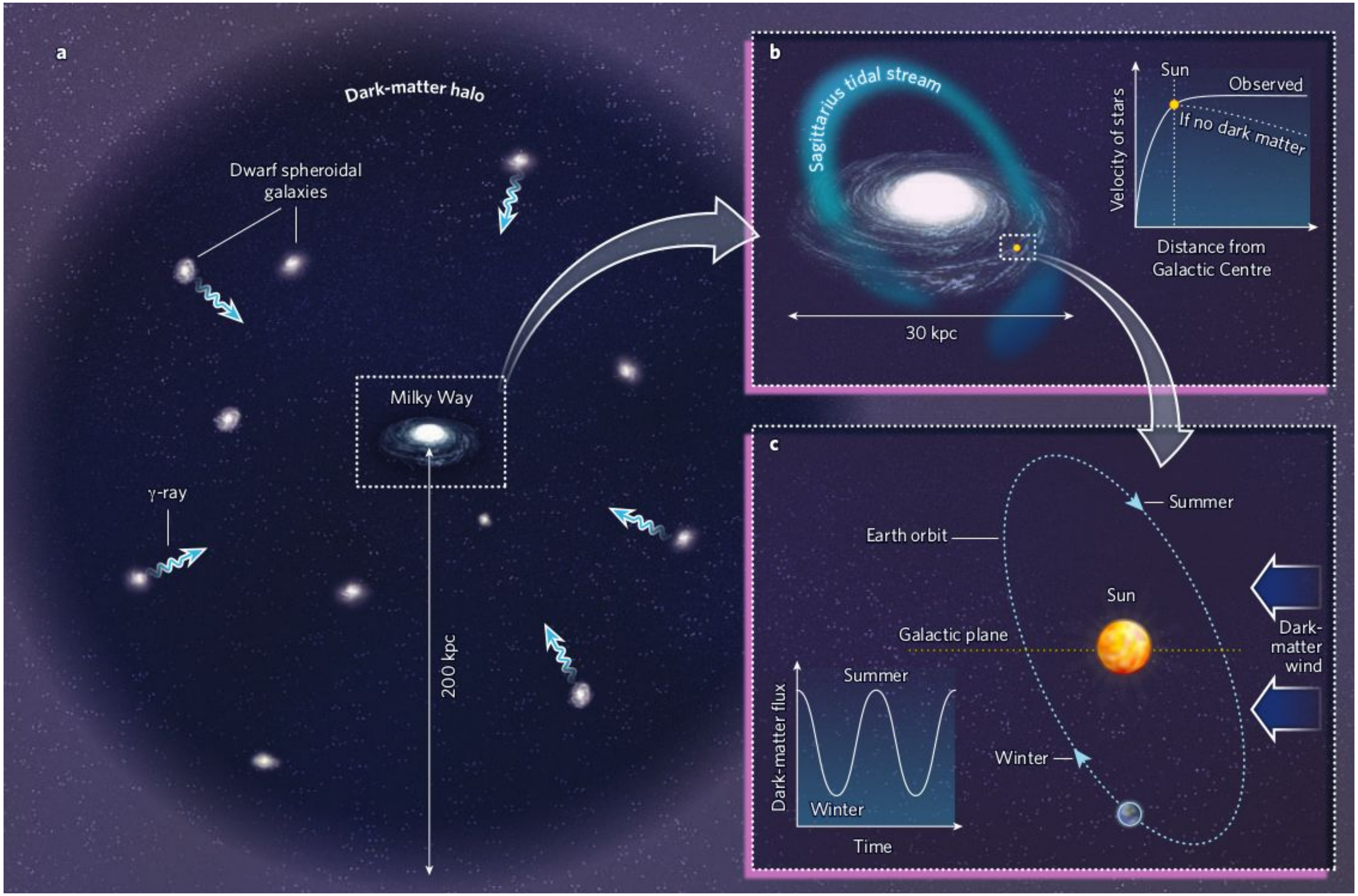
- **Indirect search**: annihilation of DM into SM particles



- **Direct search**: detecting nuclear recoil caused by the scattering with a DM candidate

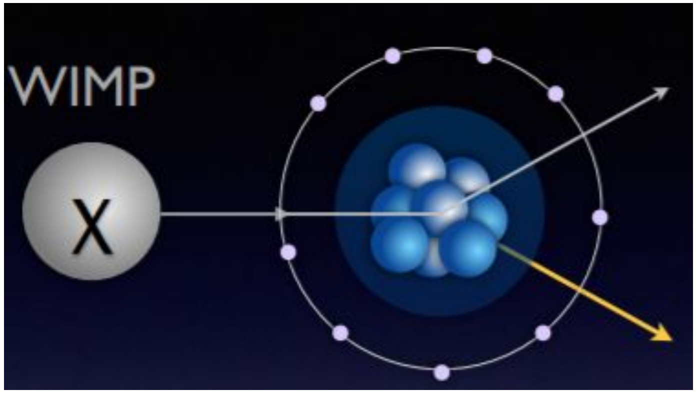


WIMPs direct detection



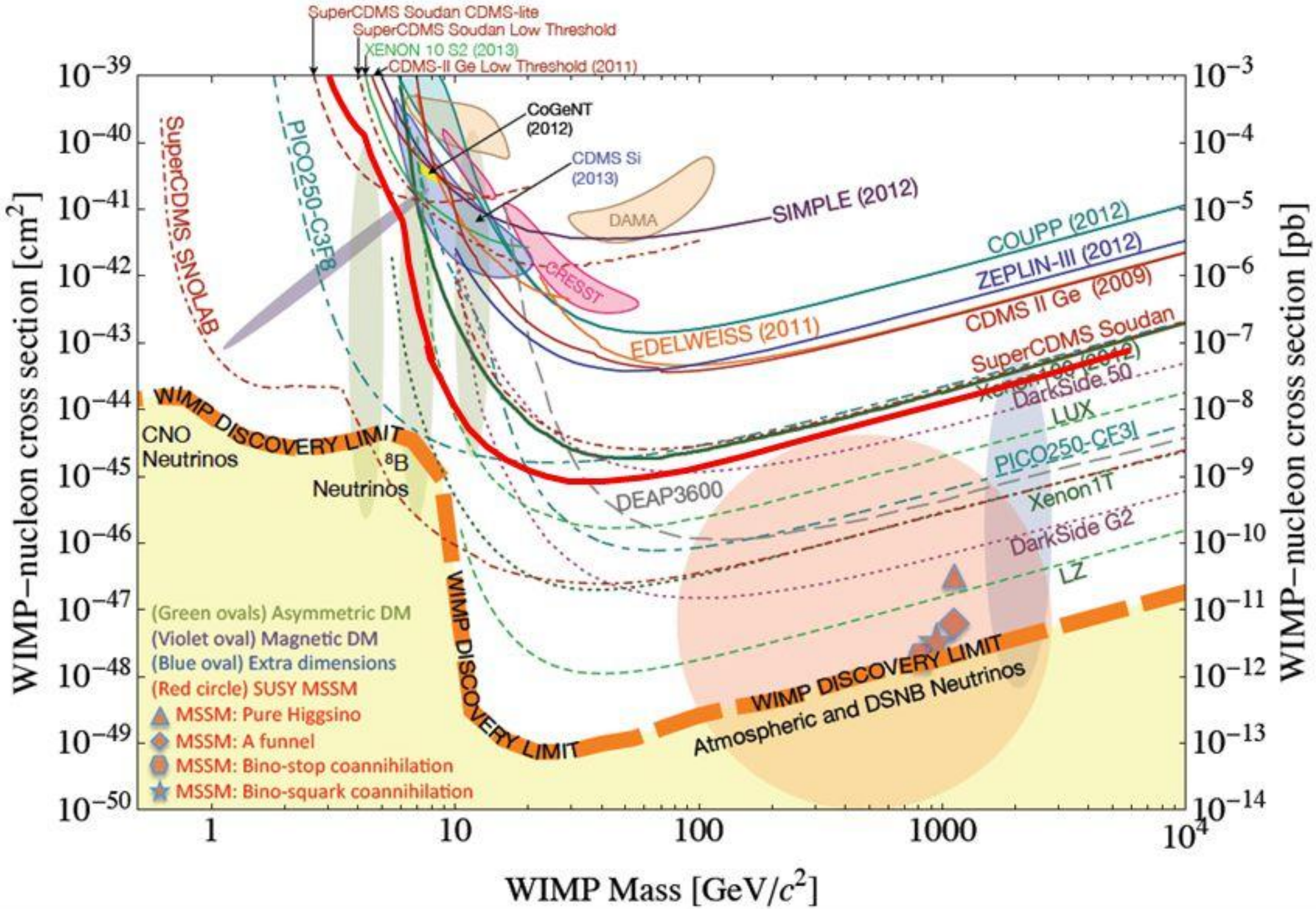
- $\chi\, N \rightarrow \chi\, N$ elastic scattering

WIMPs direct detection: some numbers



- $\beta \sim 10^{-3}$; if m_X~1/1000 GeV → Nuclear recoil energy ~1/100 keV
- $\rho_{DM} \sim 0.3$ GeV/(c^2cm^3) near the Solar System
- If $\sigma \sim 10^{-47}$ cm^2 → R ~ 1 event/tonne/year

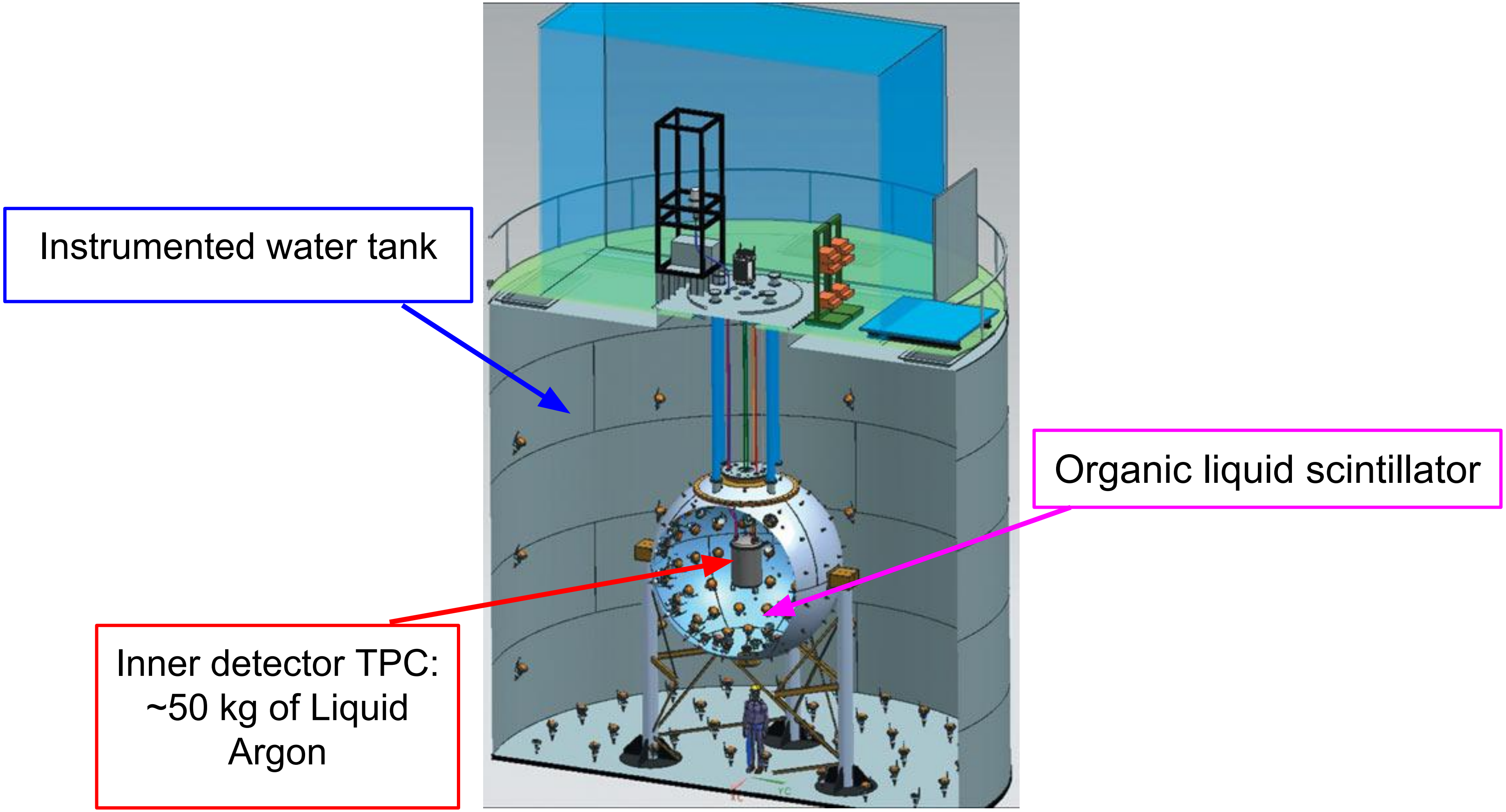
Status of direct WIMPs searches



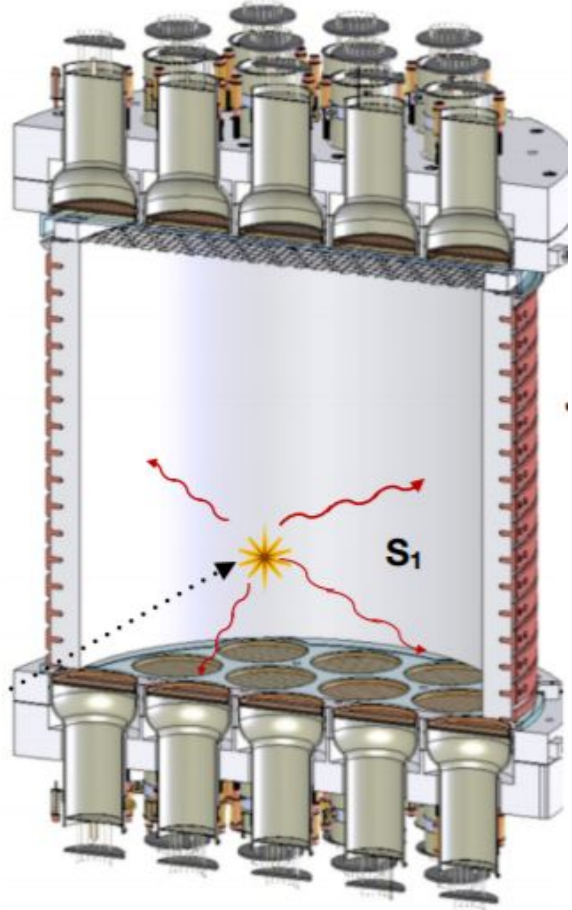
❖ **In this presentation**: results of 532 days of data taking with the DarkSide-50 experiment

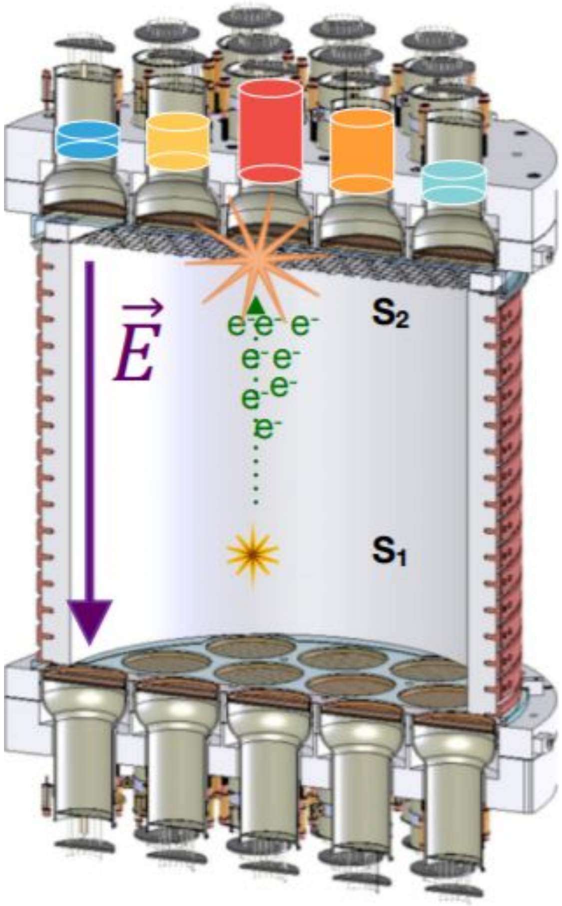
The DarkSide-50 experiment

- Dual-phase argon time-projection chamber operating at Laboratori Nazionali del Gran Sasso, depth 1400 m



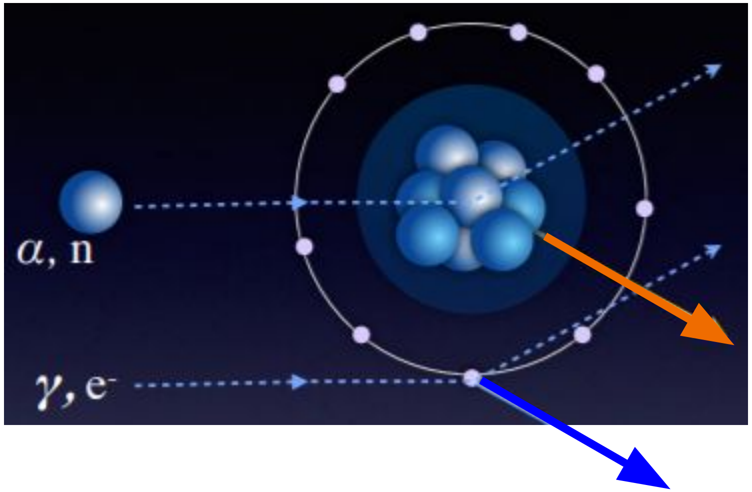
Detecting WIMPs





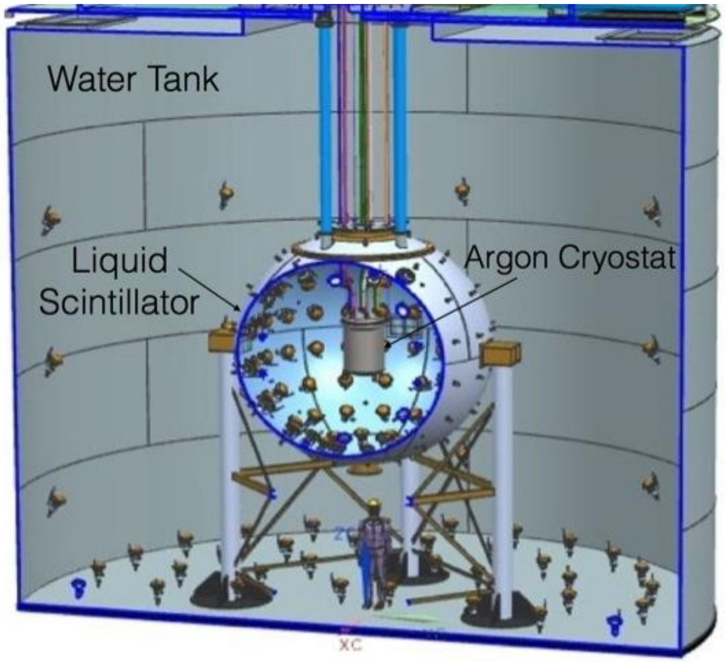
- $S_1 \rightarrow$ energy
- Time between S_1 and $S_2 \rightarrow$ z location
- $S_2 \rightarrow$ x and y coordinates

Background sources



- From natural radioactivity
  - $\gamma\, e^- \rightarrow \gamma\, e^-$
  - $nN \rightarrow nN$
  - $N \rightarrow N' + \alpha, \beta$
- **To discover DM full understanding of background and its suppression needed!**

Neutrons

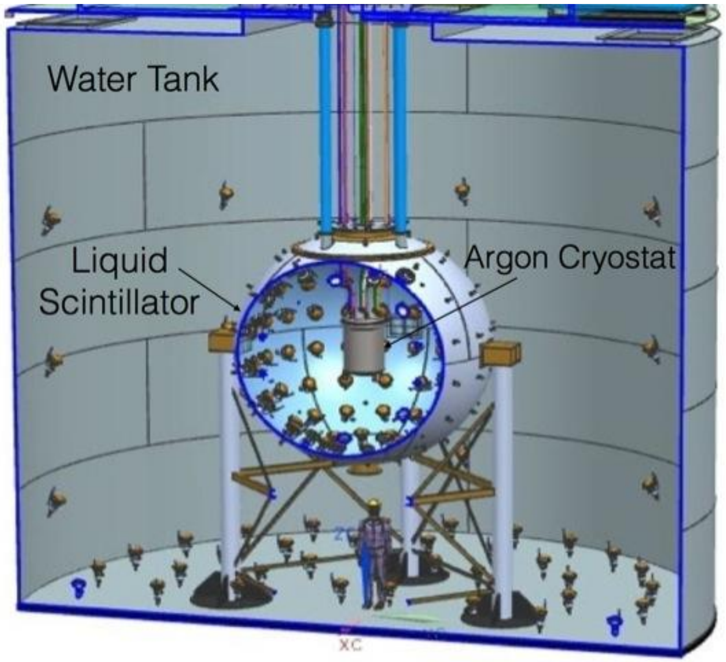


- From cosmic-ray muons and by trace radioactivity of detector
- Cosmogenic neutrons suppresses by Water Cherenkov Veto (WCV) and by Liquid Scintillator Veto (LSV)
- Radiogenic neutrons from spontaneous fission removed thanks to high efficiency LSV
- Neutrons very likely to interact multiple times with the detector

- After all the cuts, in the WIMP search data :
  - < 0.005 radiogenic neutrons expected
  - < 0.00034 cosmogenic neutrons expected

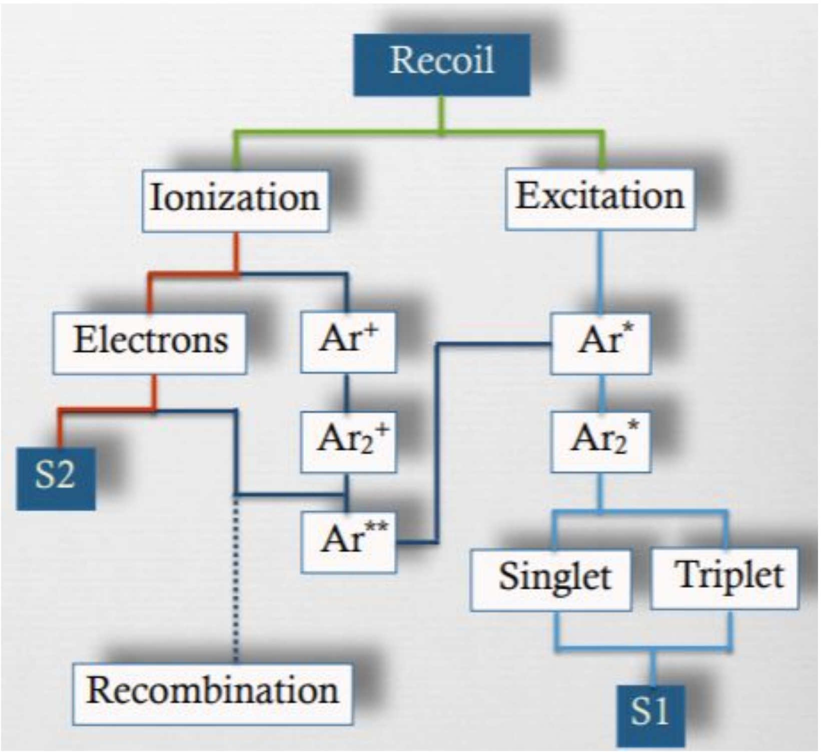
β and γ rays

- WCV and LSV efficient shielding against γ and β rays coming from outside the TPC
- ^{39}Ar reduced by a factor ~10^{-3} using UAr
- Compton scatter of γ-rays from the TPC and cryostat → dominant source of ER
- To discriminate, use of f_{90} parameter:
  - defined as the fraction of the primary scintillation light seen in the first 90 ns.
- 0.08 ± 0.04 events of ER after il cuts in the WIMP search region



Pulse shape discrimination

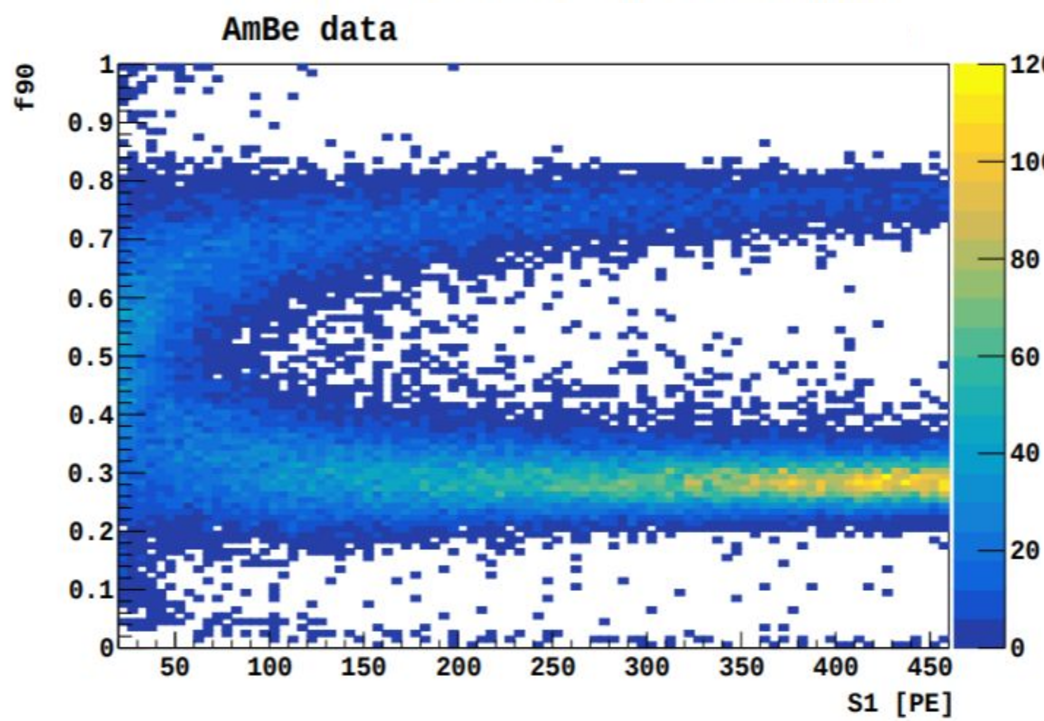
- ER and NR → different excitation of Ar



τ singlet ~ 7 ns
τ triplet ~ 1.3 μs

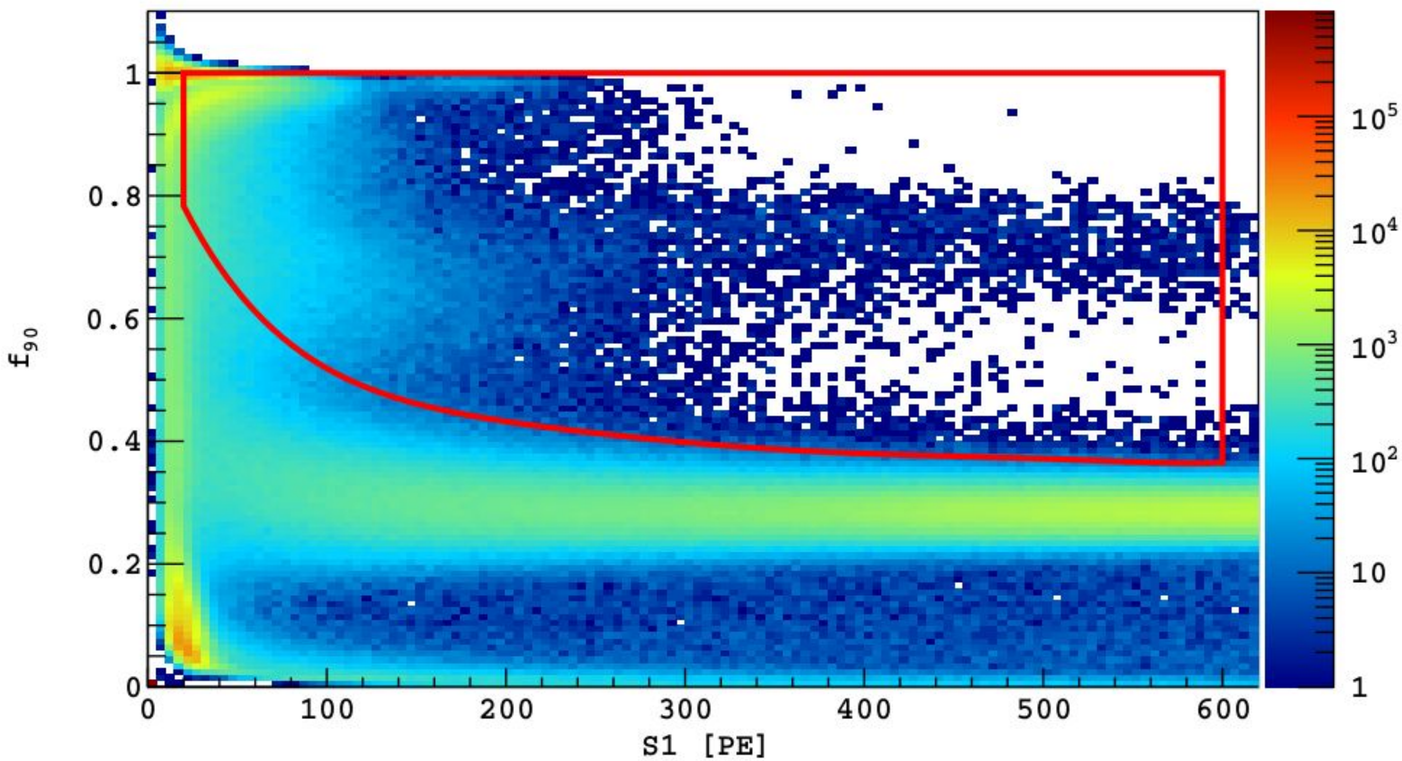
singlet/triplet → NR ~ 3
singlet/triplet → ER ~ 0.3

→ f_{90} ~0.3 for ER and 0.7 for NR

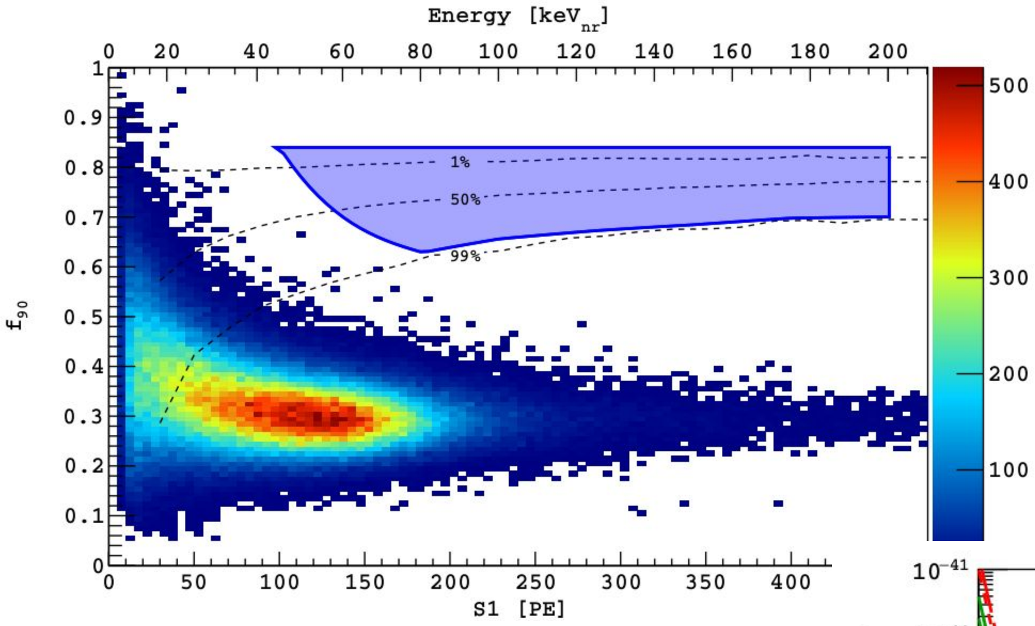


Blinding scheme

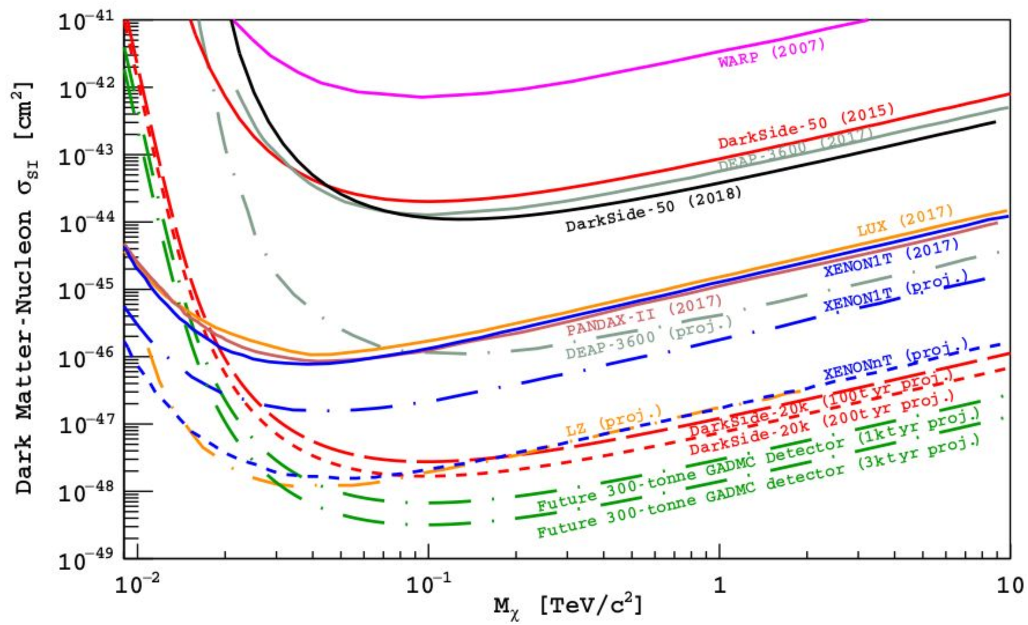
- Blind analysis f_{90}- S_1 plane
- Blinding box larger than any expected final WIMP search box
- Some blinded regions (outside WIMP search region) opened during the analysis to check background prediction



Final results



➡ No events observed in the DM search region



Black curve: upper limit on the cross section imposed with this analysis

($\sigma \sim 3.8 \times 10^{-44}$ cm^2 , $m_\chi = 1$TeV/c^2)

Conclusions

- DarkSide-50 succeeded in demonstrating the possibility to achieve “zero background” for dark matter discovery
- No signal detected
- Upgrade planned in 2022: DarkSide-20k → 20 tonne of Liquid Argon
- Projected sensitivity of 1×10^{-47} cm^2 for a 1 TeV/c^2 dark matter particle mass and an exposure of 100 tonne×yr

Backup slides

Why Liquid Argon?

Advantages

- ❖ High scintillation yield
- ❖ High ionisation yield
- ❖ Very powerful rejection capability for ER background
- ❖ Easily scalable to large masses
- ❖ Easy to purify

Disadvantages

- ❖ Cosmogenic radioactive ^{39}Ar
  - ➢ Atmospheric Argon (AAr) ~1Bq/kg, while Underground Argon (UAr) ~1mBq/kg
  - ➢ AAr cheap, UAr not
- ❖ Scintillation light at 128 nm → need wavelength shifters

TPC component activities

Source	Activity [Bq]	Source	Activity [Bq]
$^{232}Th_p$	0.277 ± 0.005	$^{232}Th_c$	0.19 ± 0.04
$^{40}K_p$	2.74 ± 0.06	$^{40}K_c$	$0.16^{+0.02}_{-0.05}$
$^{60}Co_p$	0.15 ± 0.02	$^{60}Co_c$	1.4 ± 0.1
$^{238}U_p^{low}$	0.84 ± 0.03	$^{238}U_c^{low}$	$0.378^{+0.04}_{-0.1}$
$^{238}U_p^{up}$	4.2 ± 0.6	$^{238}U_c^{up}$	$1.3^{+0.2}_{-0.6}$
$^{235}U_p$	0.19 ± 0.02	$^{235}U_c$	$0.045^{+0.007}_{-0.02}$
^{85}Kr	1.9 ± 0.1 mBq/kg	^{39}Ar	0.7 ± 0.1 mBq/kg

Expected rate

Escape velocity

DM velocity distribution in the laboratory frame

$$\frac{dR}{dE_R} = \frac{\rho_\chi}{m_\chi m_N} \int_{v_{min}}^{v_{esc}} v \tilde{f}(\mathbf{v}, t) \frac{d\sigma}{dE_R} \, d^3 v$$

Minimum velocity needed to cause a nucleus to recoil

Bullet cluster