Calibration of a direct search for dark matter detector: the TPC of DarkSide 20k

JRJC 2022

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DARKSIDE

Institut
Physique de
l'Univers
Aix*Marseille Université

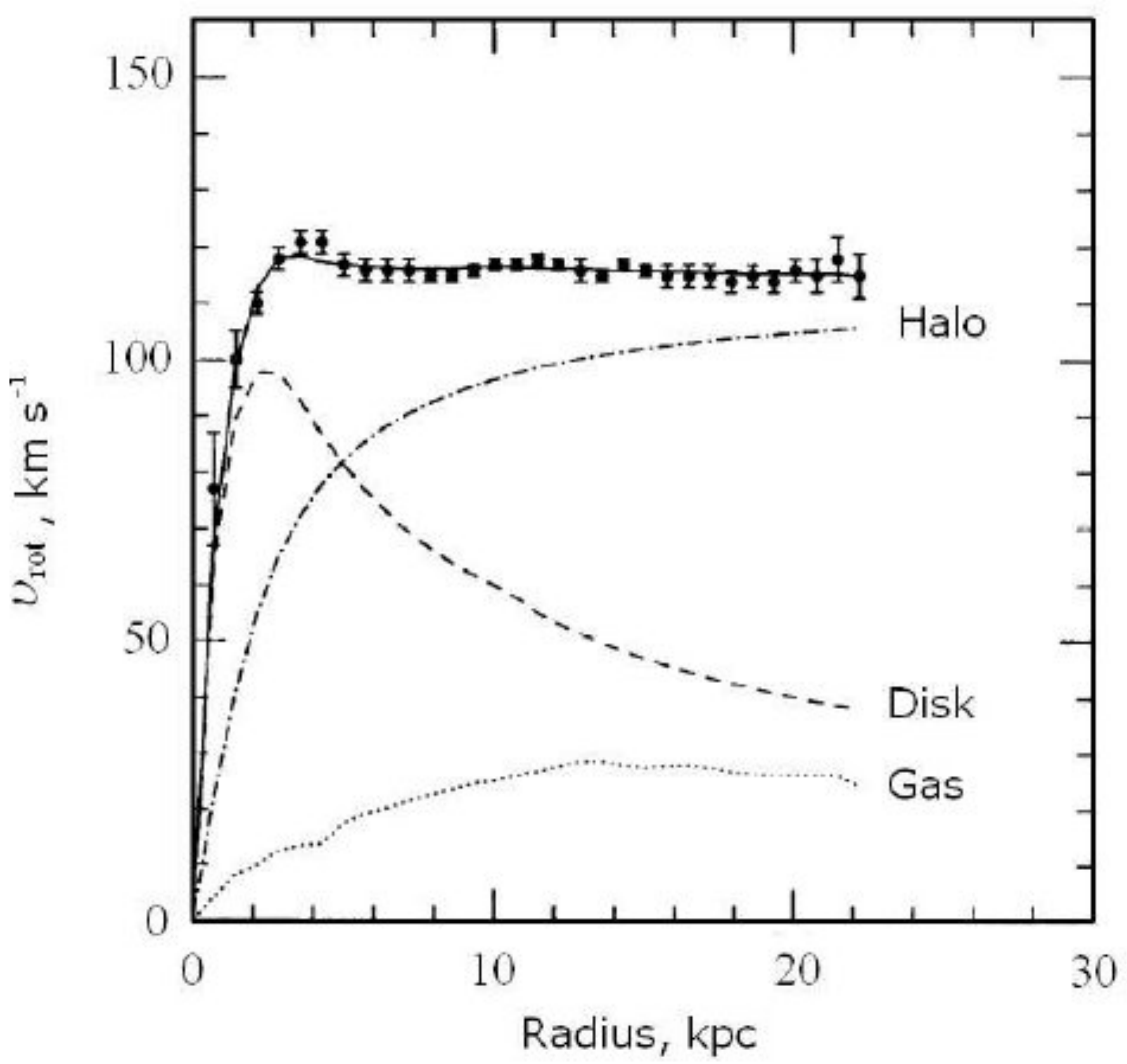
LAM
LABORATOIRE D'ASTROPHYSIQUE
DE MARSEILLE

CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE
CPPM

Dark matter ?

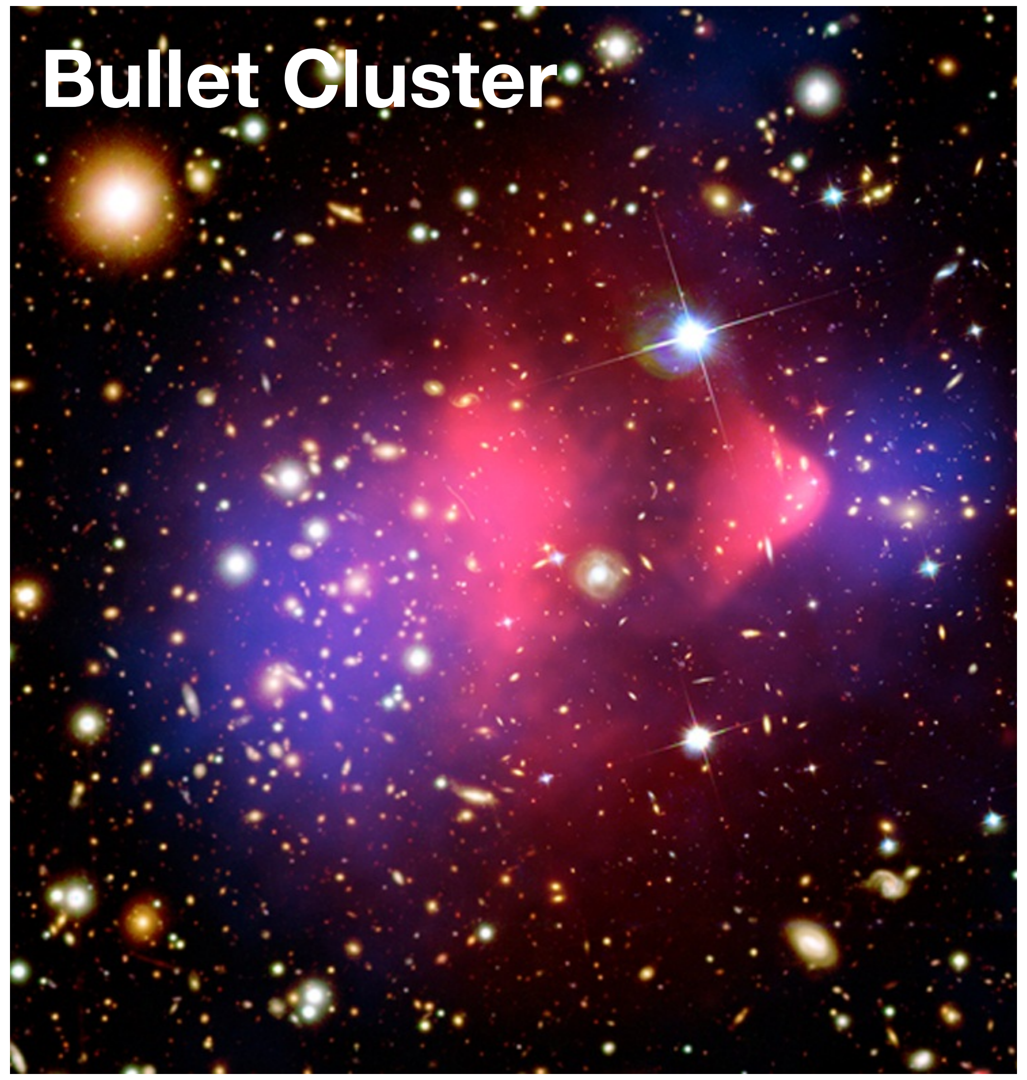
Many hints at different scales

Galaxies



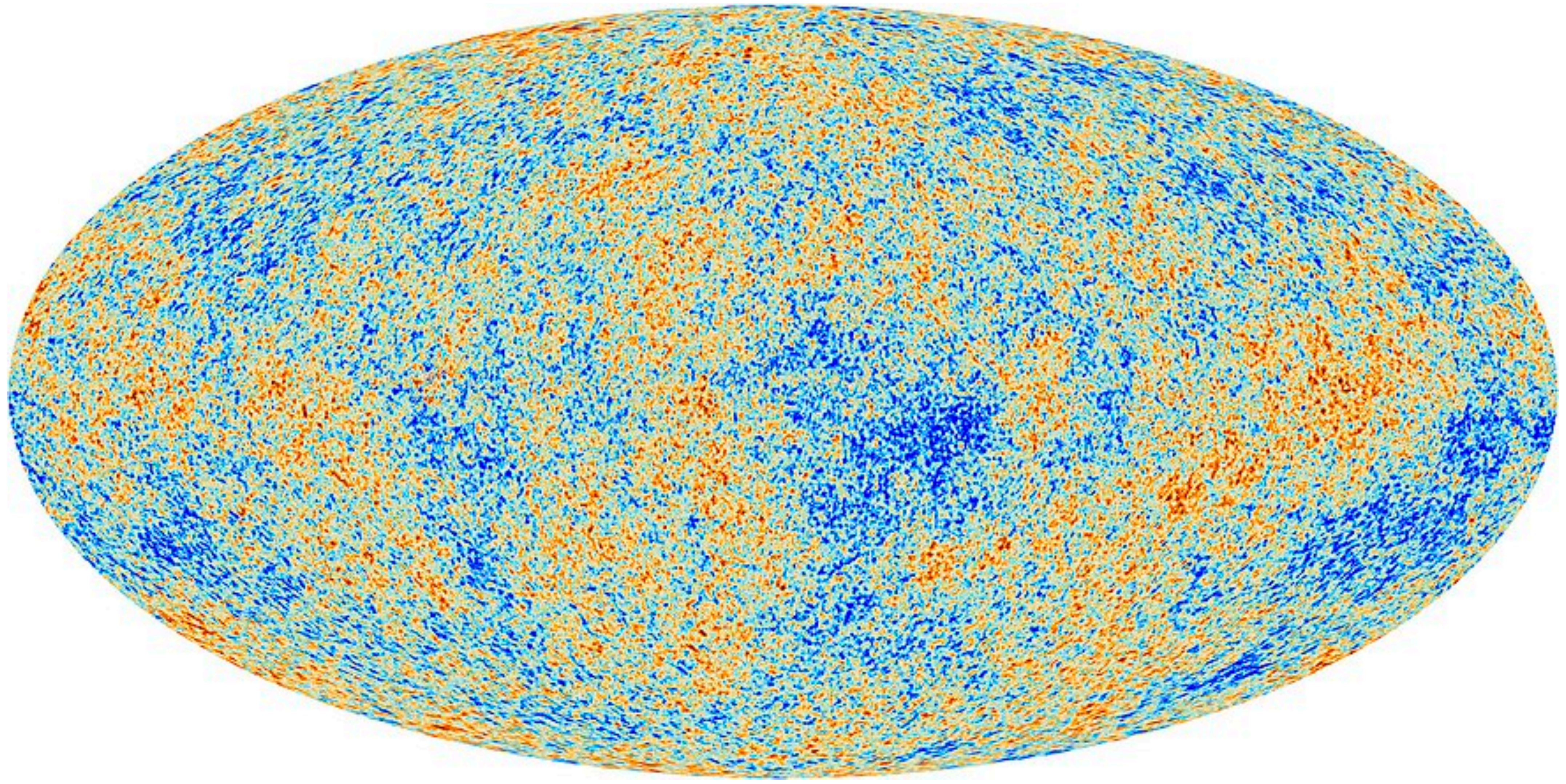
Measured rotation curves of galaxies fit the expectations only if we include a DM component in the galaxy

Collision of galaxy clusters



Collision of galaxy clusters measured only thanks to photons vs measured by gravitational lensing
-> different repartition of mass + DM is collision-less

Cosmology



CMB (here measured by Planck) - anisotropies explanation includes a dark matter component

➡ **Missing mass in the Universe**
Standard model does not provide particle candidate for dark matter

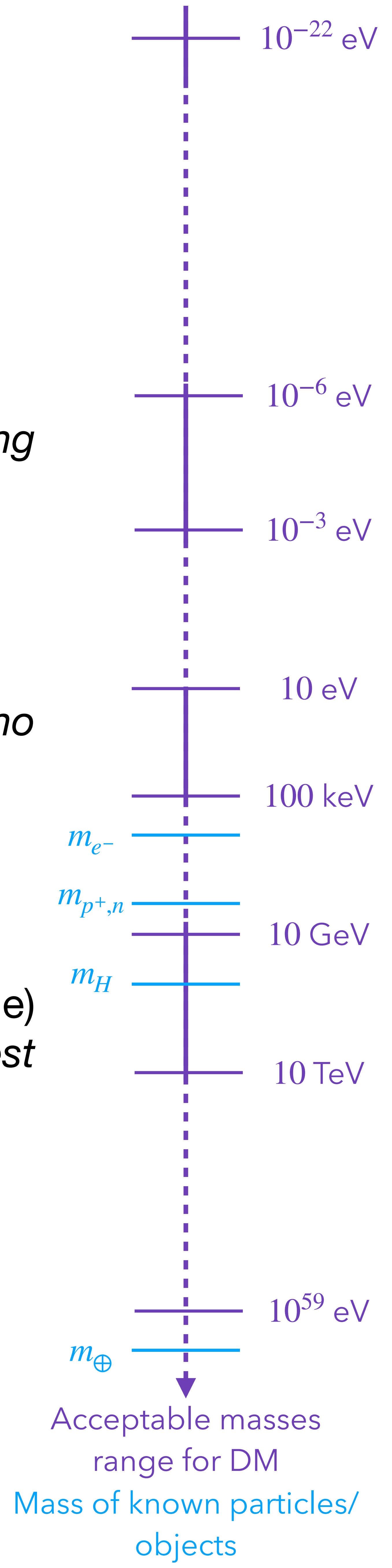
Dark matter ?

Properties of dark matter

- Massive
- Do not (directly) interact with photons
- Long lived (or at least one of them)
- Cold (non relativistic)

Dark matter candidates

- Axion *(driven by CP non-violation in the strong interaction (BSM))*
- Sterile neutrino *(something to do with neutrino oscillations)*
- WIMP (Weakly Interactive Massive Particle) *(introduced by cosmology and SUSY's lightest neutralino fits requirements)*
- Primordial Black Holes *(cosmology driven)*



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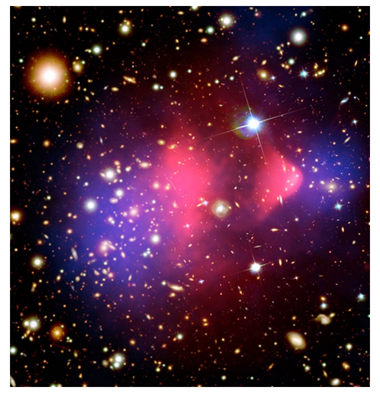

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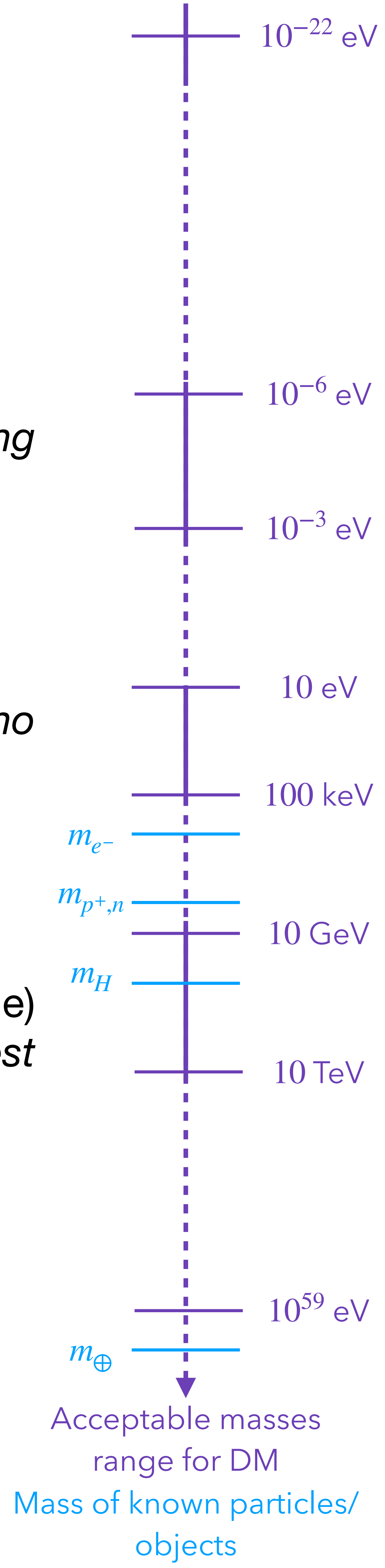

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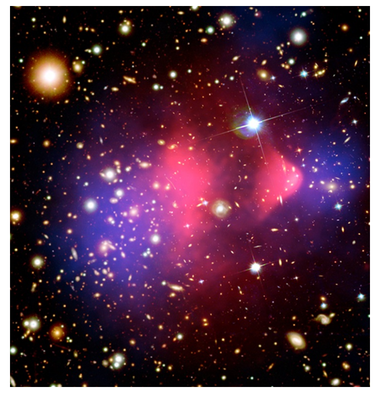

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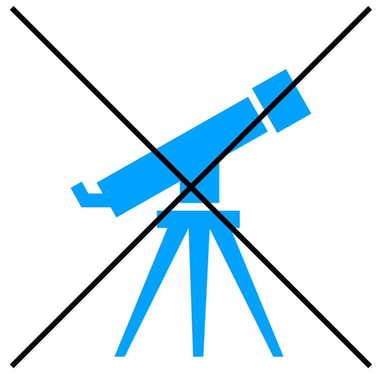

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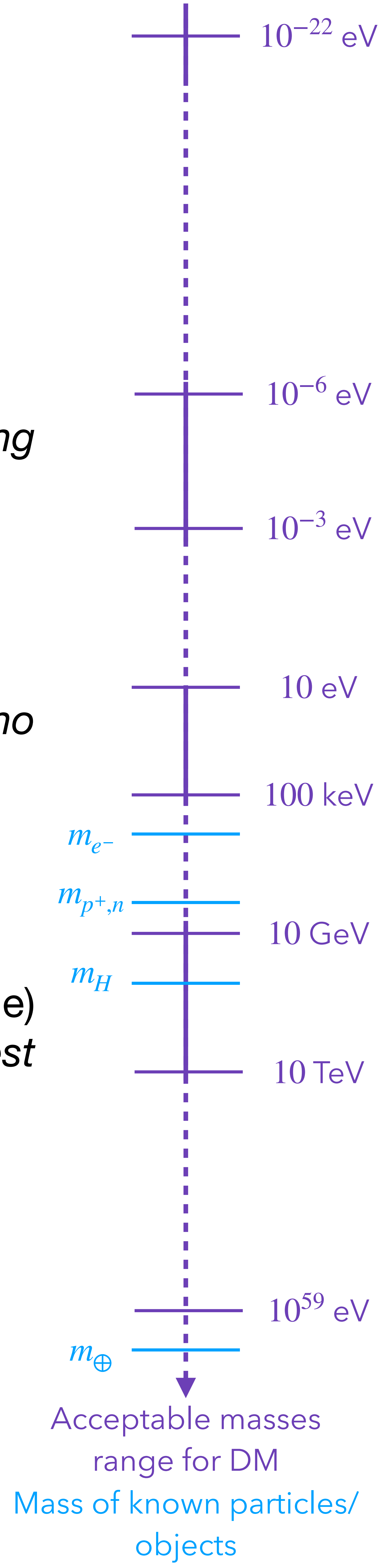

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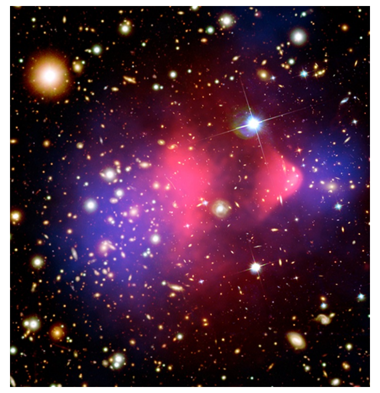

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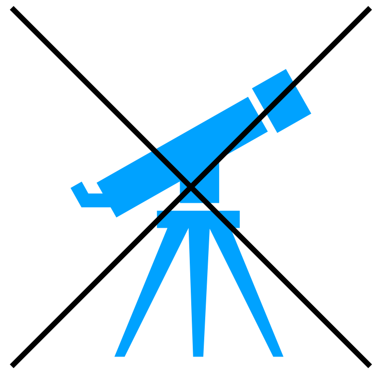

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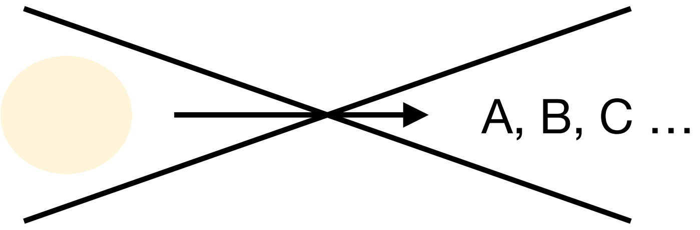

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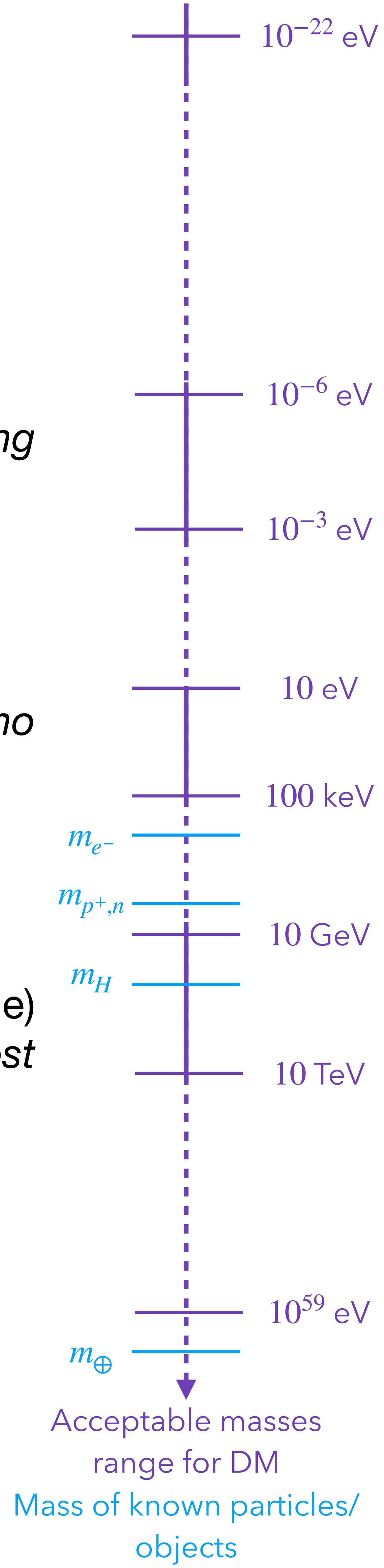

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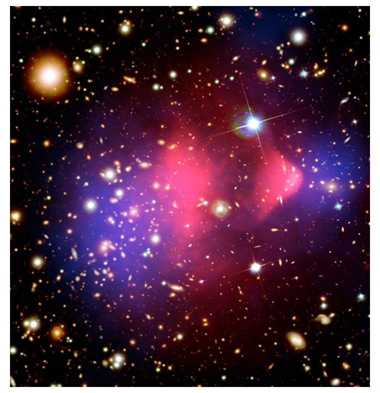

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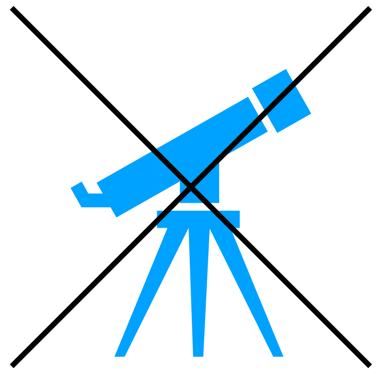

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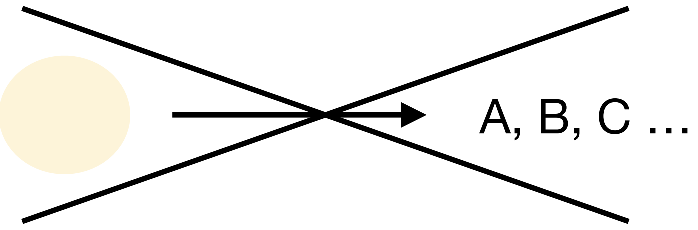

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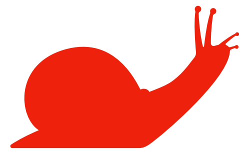

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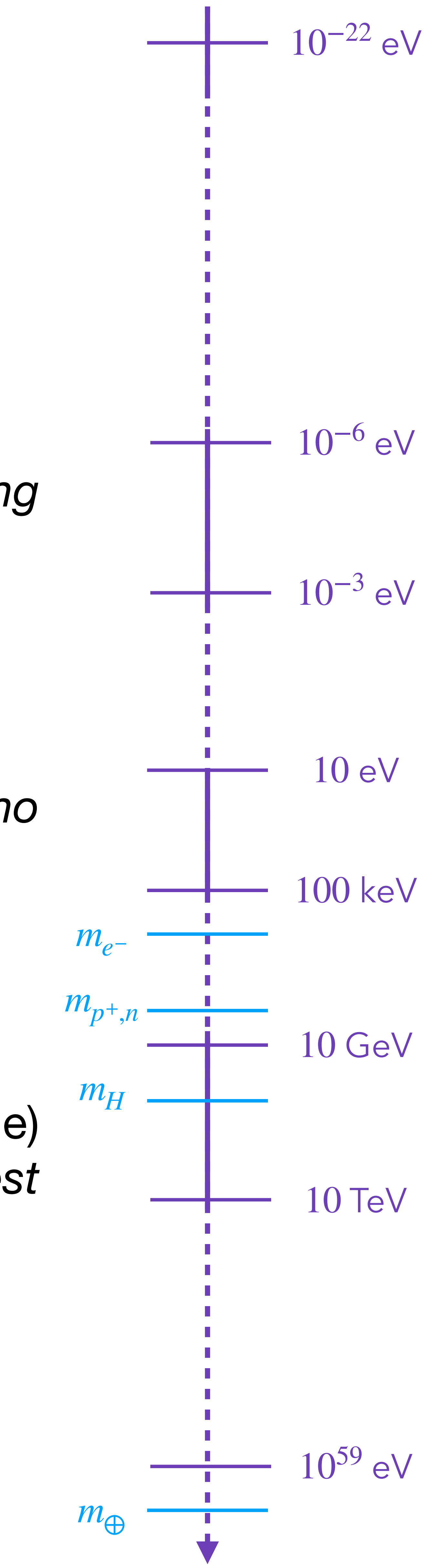

Acceptable masses range for DM
Mass of known particles/objects

Dark matter ?

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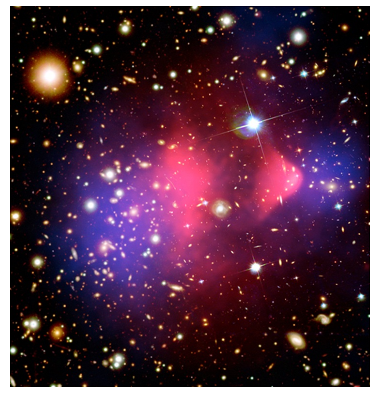

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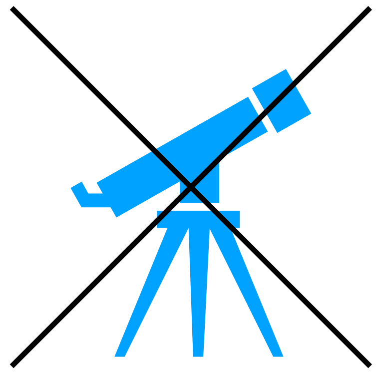

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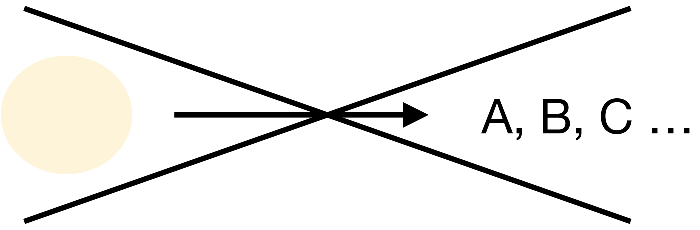

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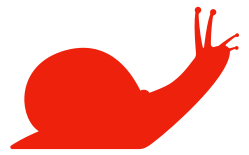

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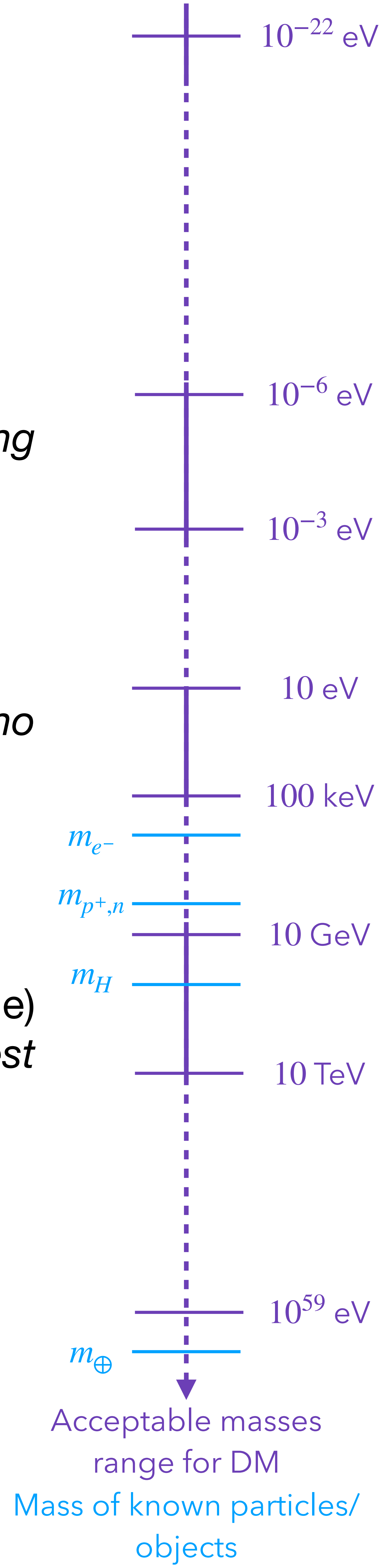
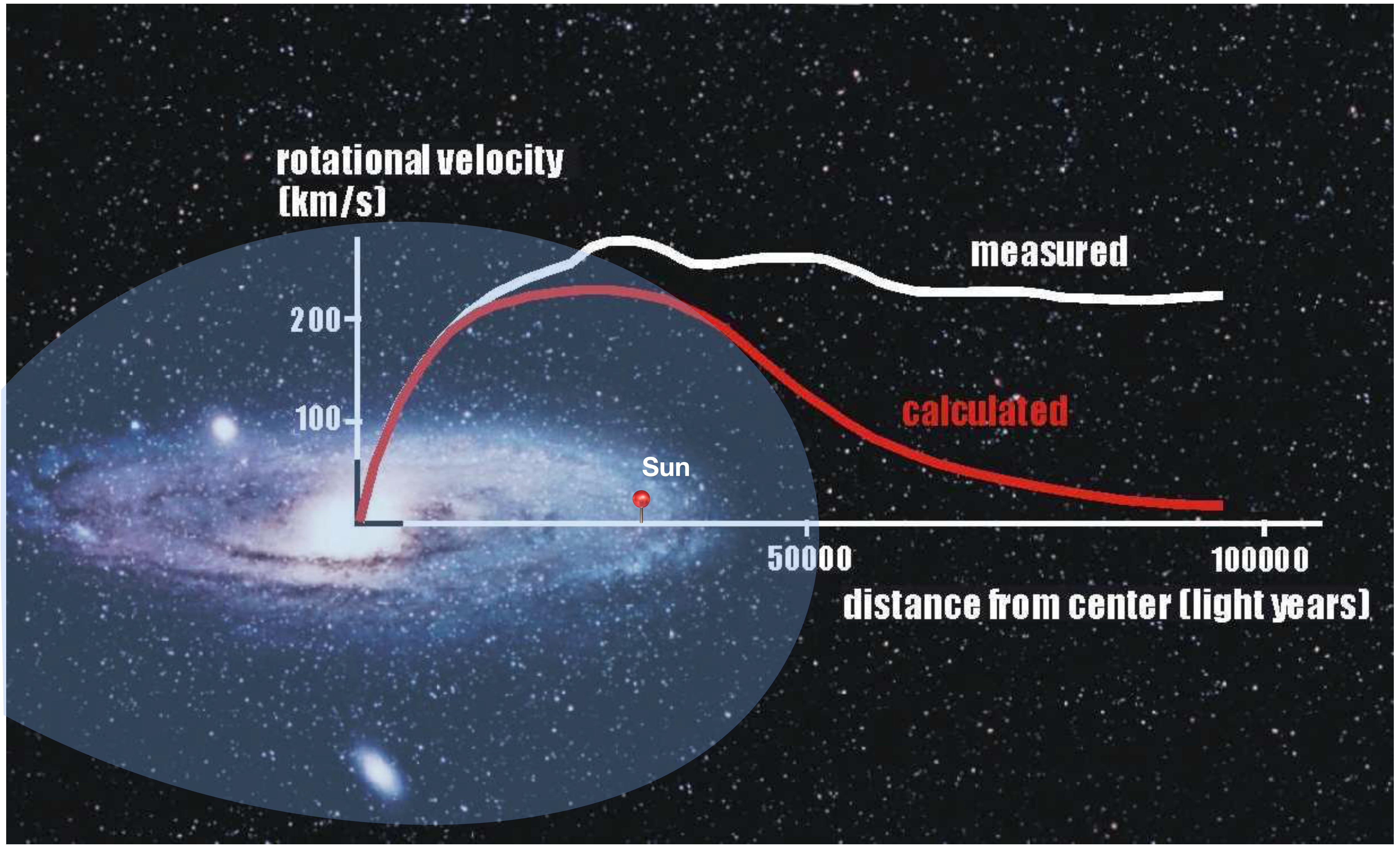
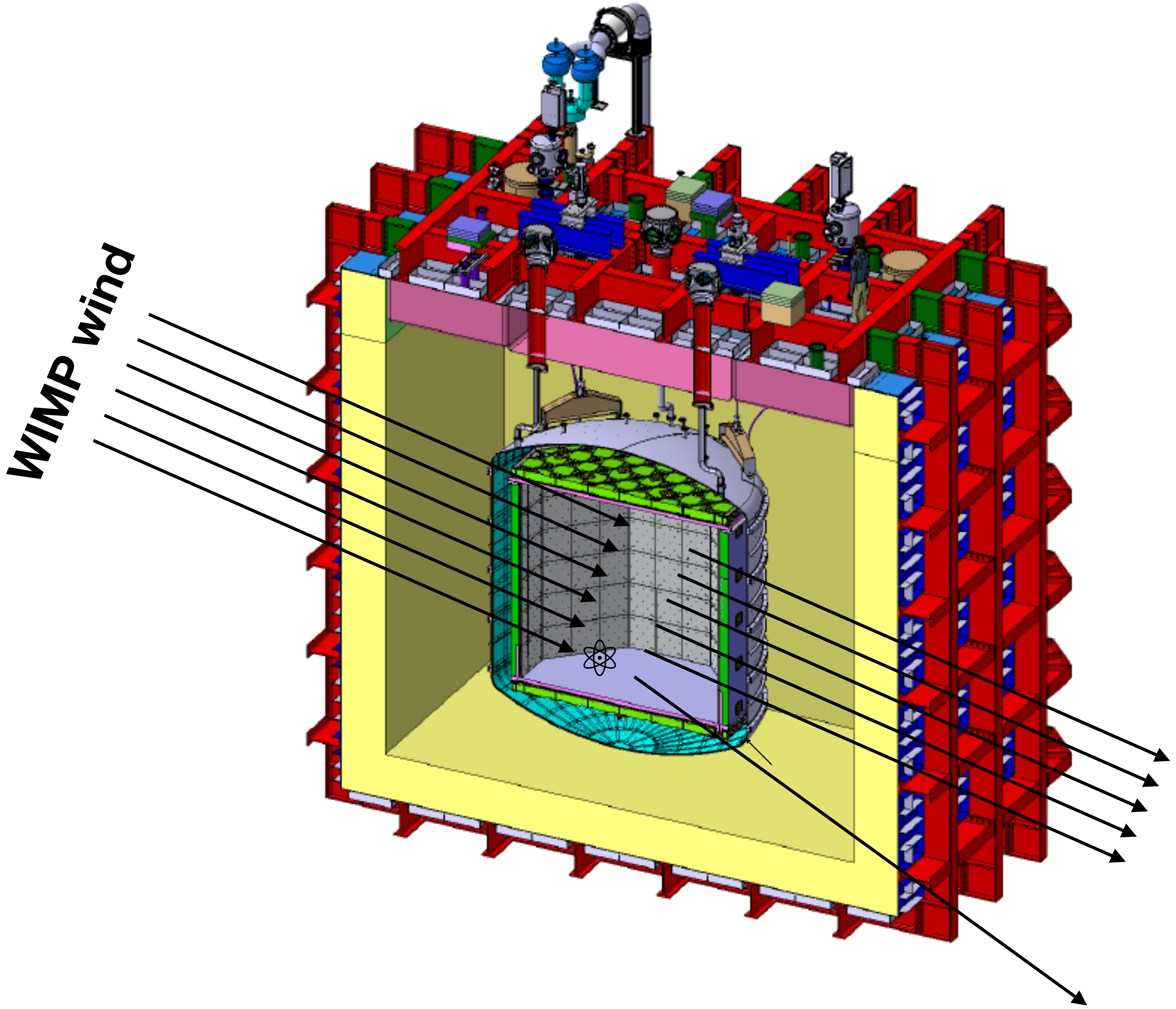


Dark matter halo





How to search for WIMPs ?

Searching for WIMPs

Create huge detectors

As the WIMPs are expected to have a very small interaction probability with ordinary matter, experiments should build very large (or dense) experiments in order to increase the detection probability

Shield the detector from background

In order not to miss an event being over crowded by background events. Dark matter direct searches are located deep underground

Know the detection limits of the experiment

In case on non detection, one cannot claim the non existence of dark matter, just its non existence in a certain phase space

The exclusion limits of an experiment are computed using a simple model of the Milky Way dark matter's halo

Understand the remaining background

It comes from natural radioactivity of the detector

The most dangerous background comes from heavy particles (neutrons)

Discriminate background and signal

Use detectors that are able to discriminate backgrounds and signal. E.g. : as we expect WIMPs to be heavy, they are supposed to interact with the nucleus of the material of the detector while most background interact with cloud electrons

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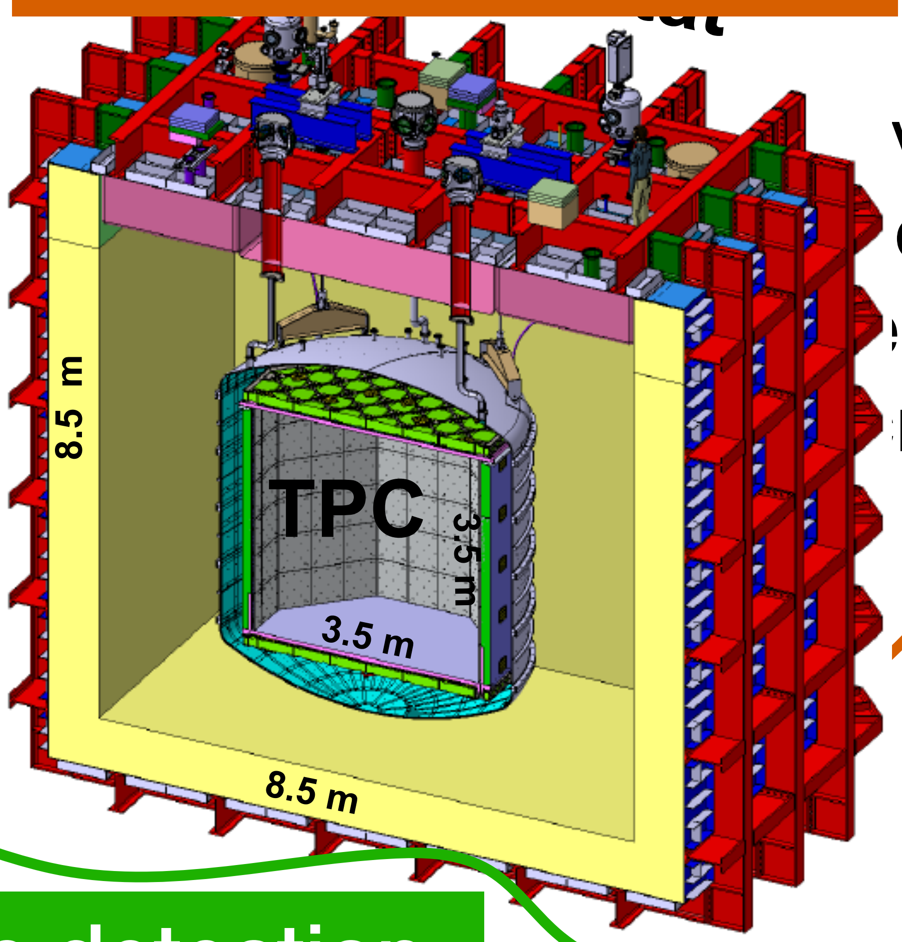

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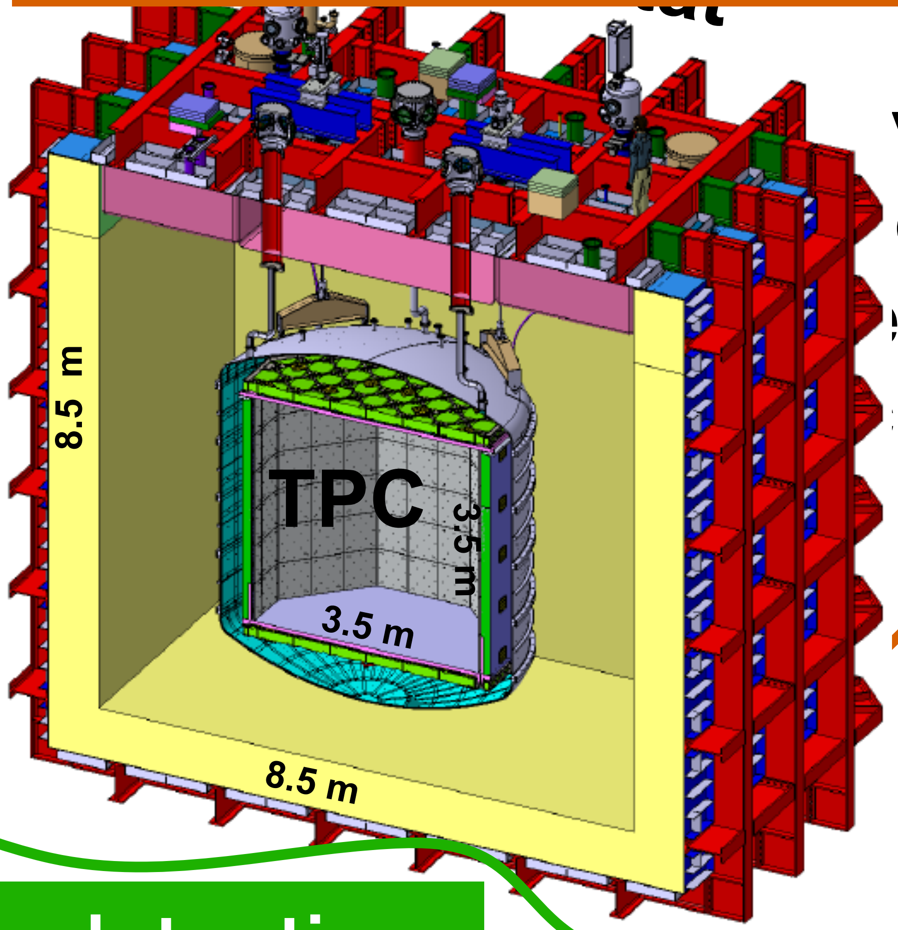

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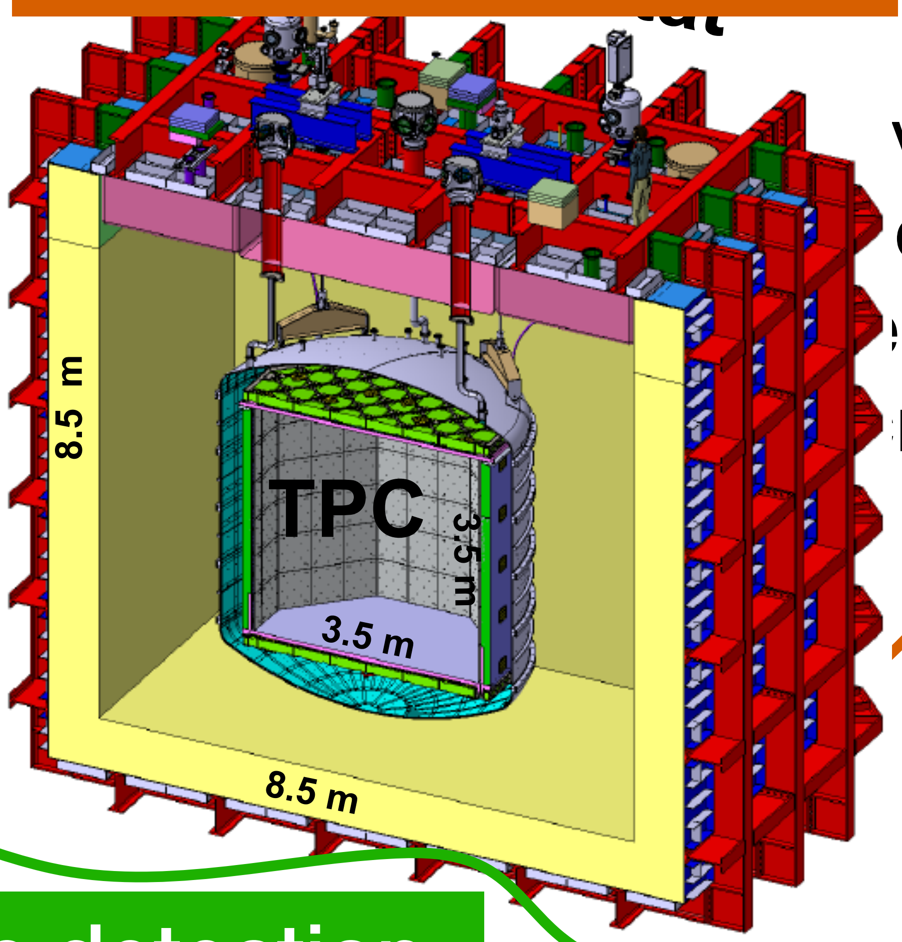

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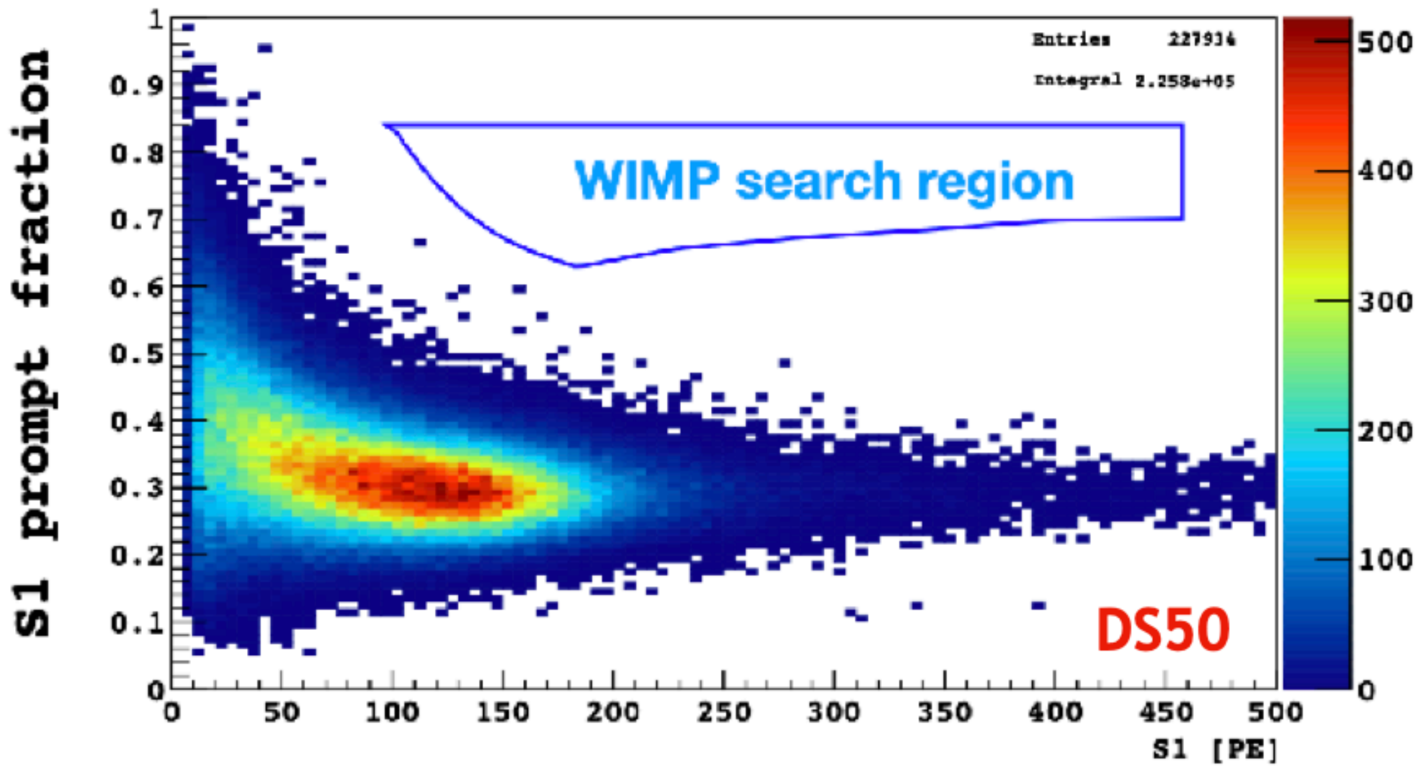

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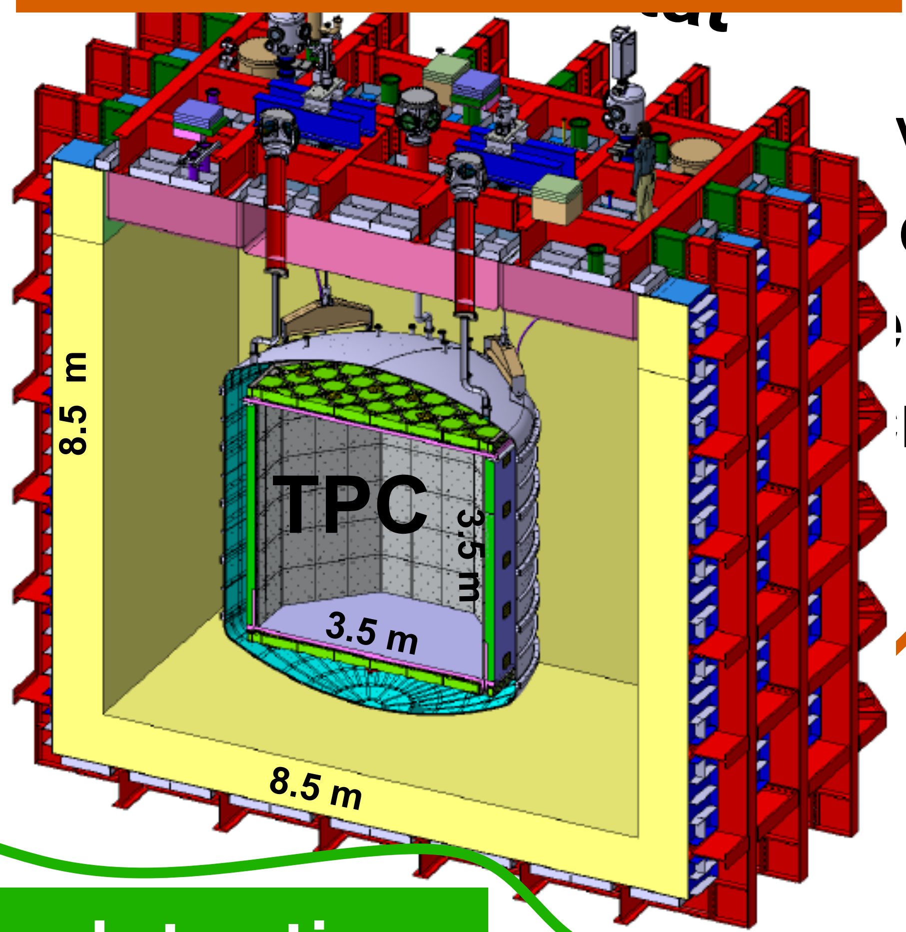

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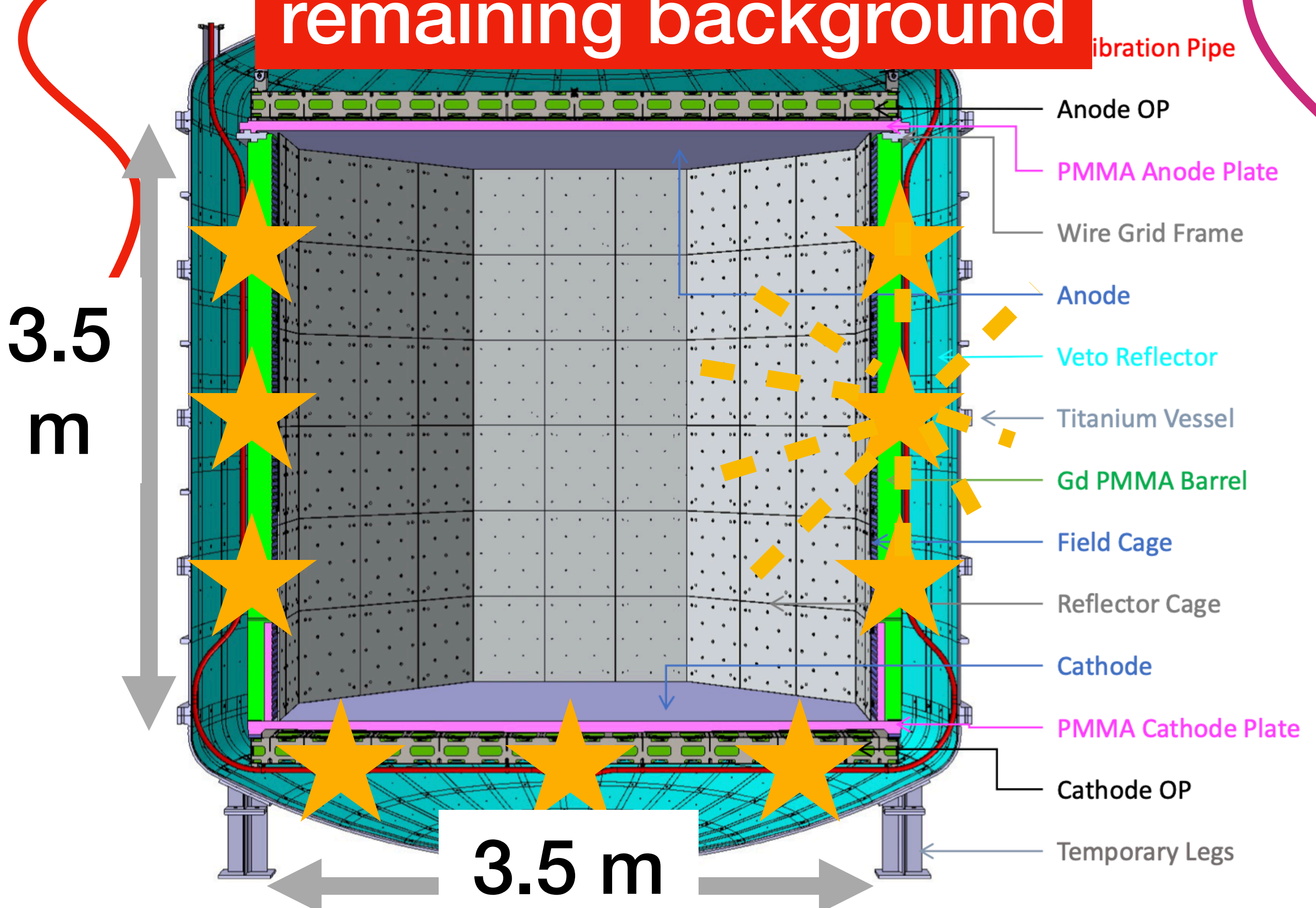

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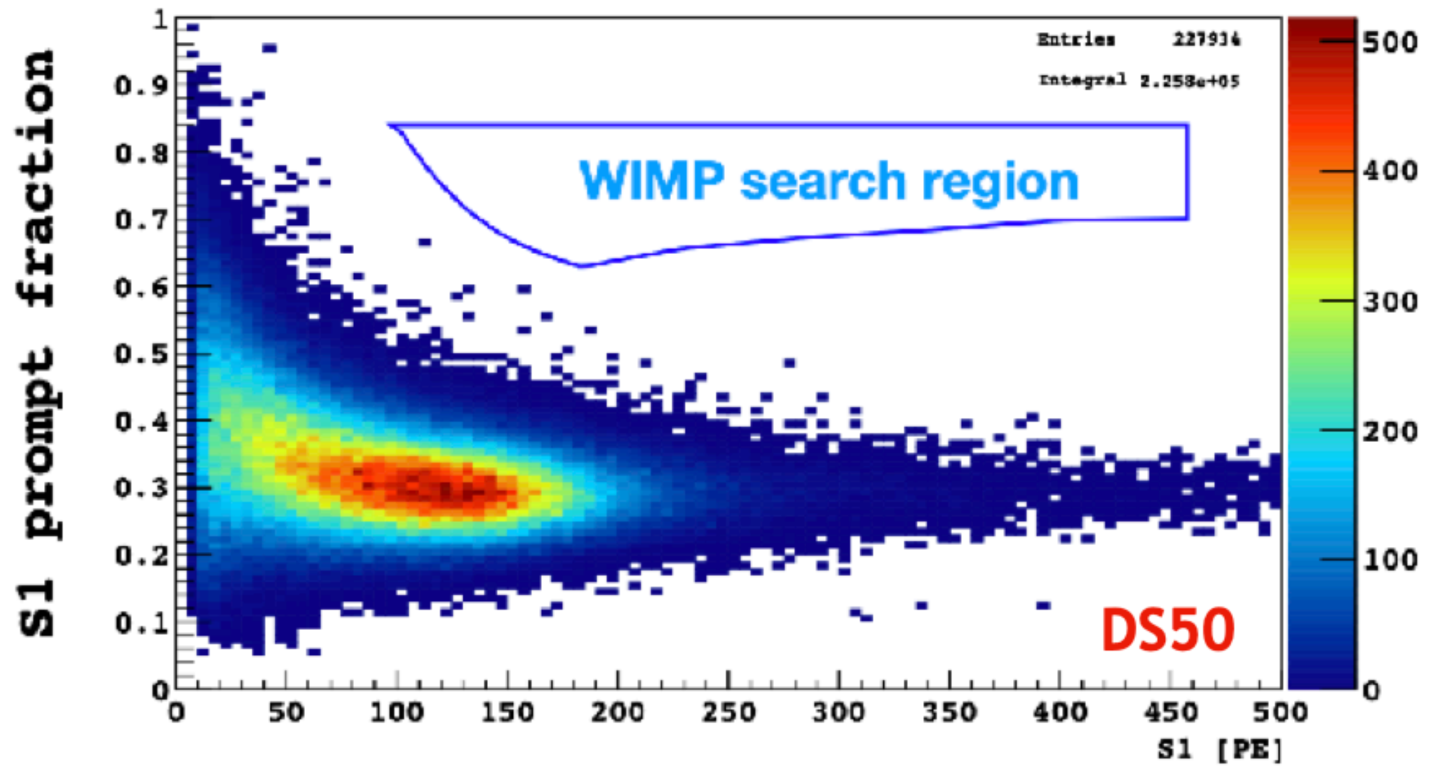

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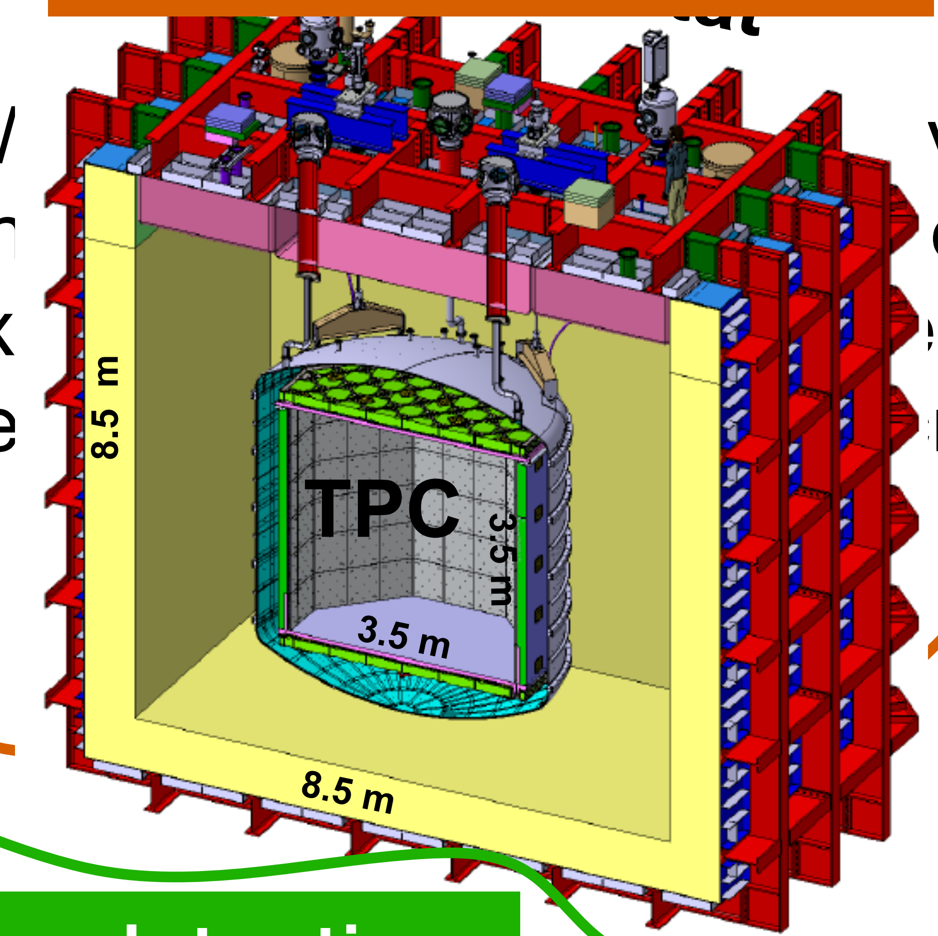

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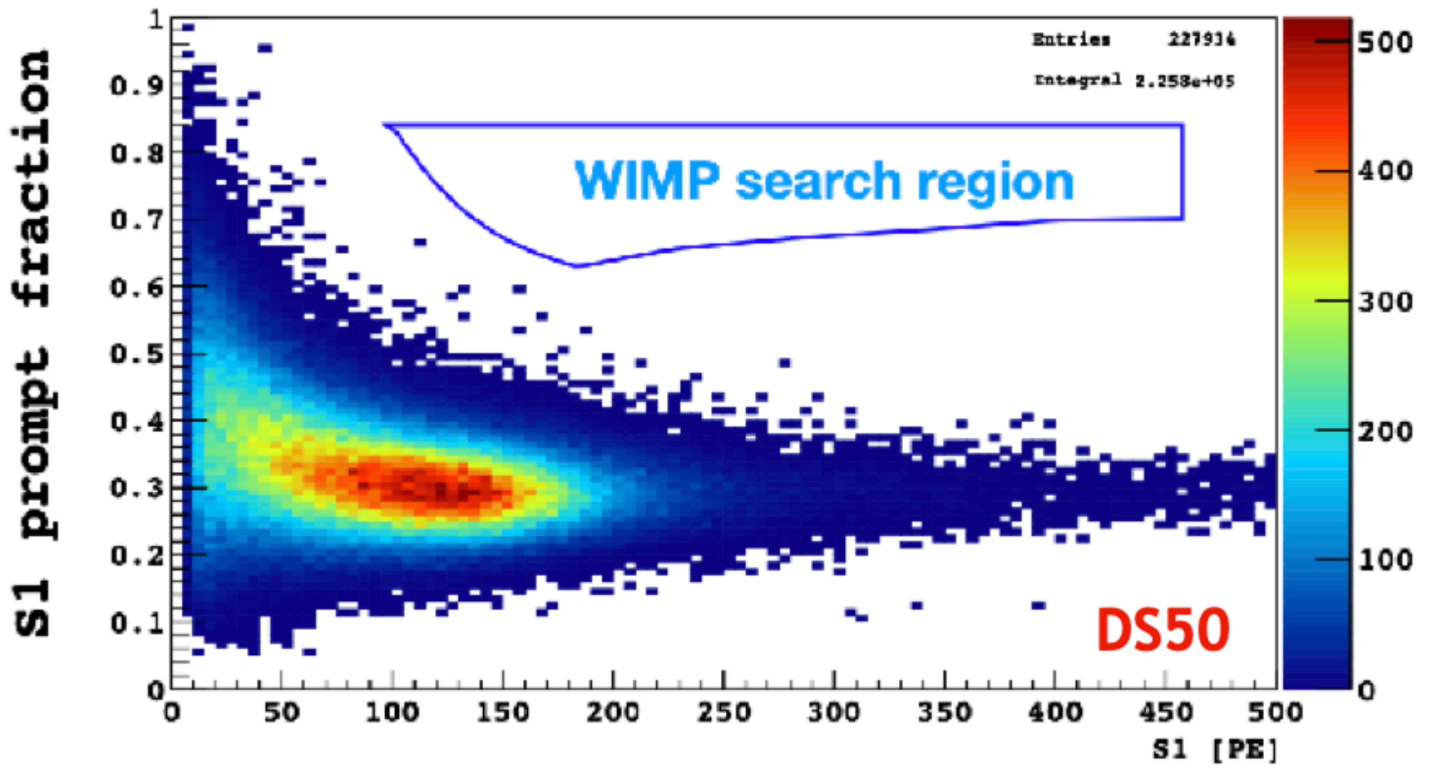

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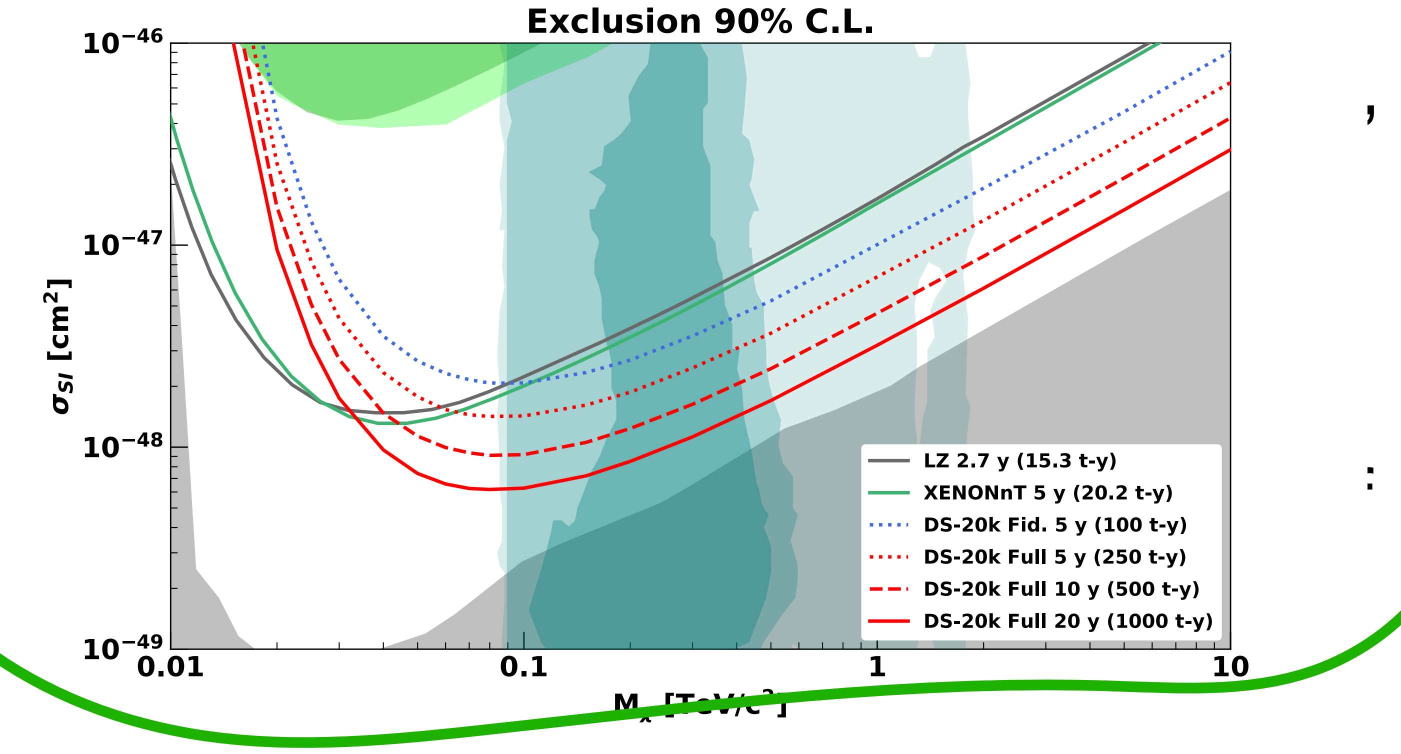

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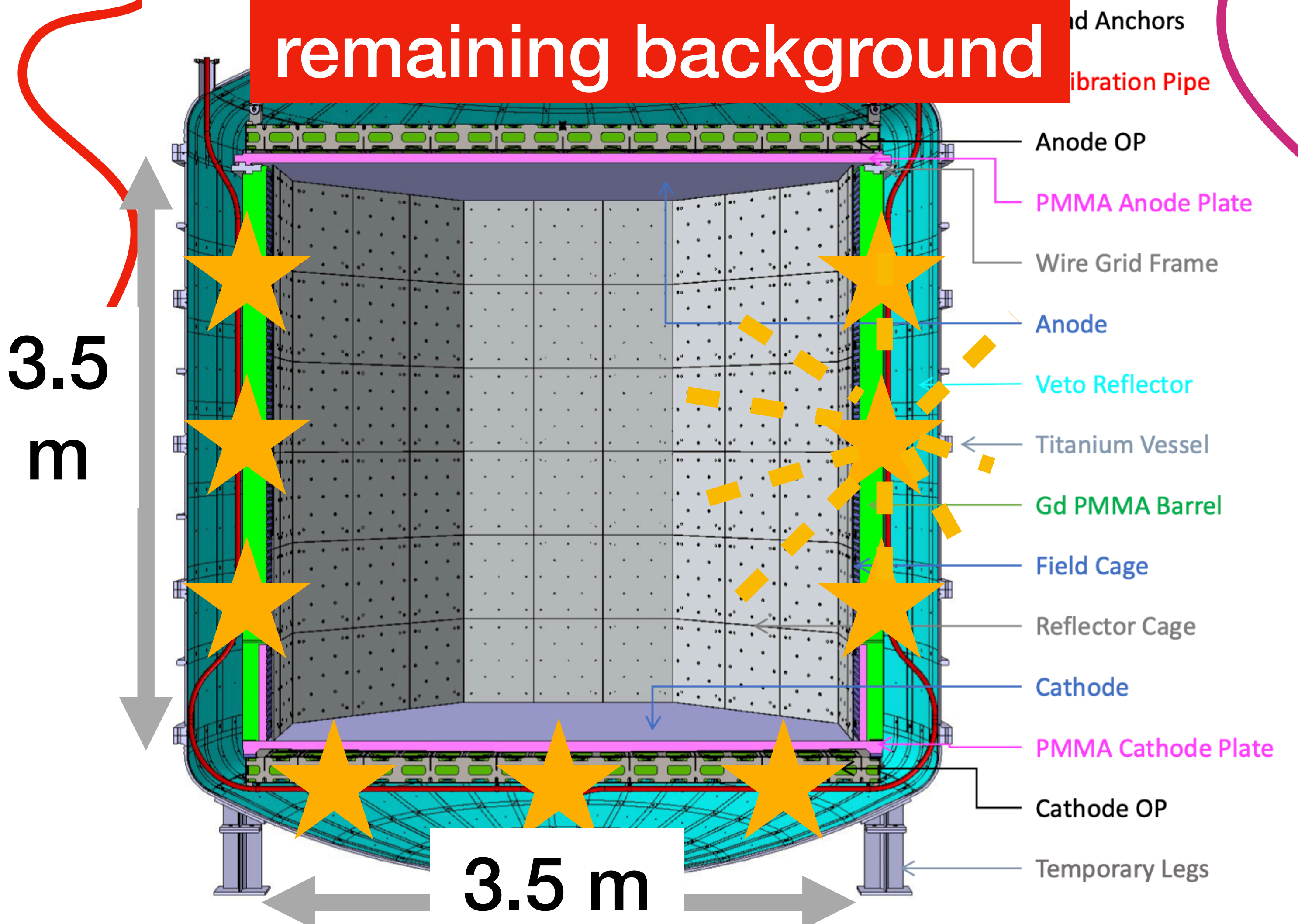
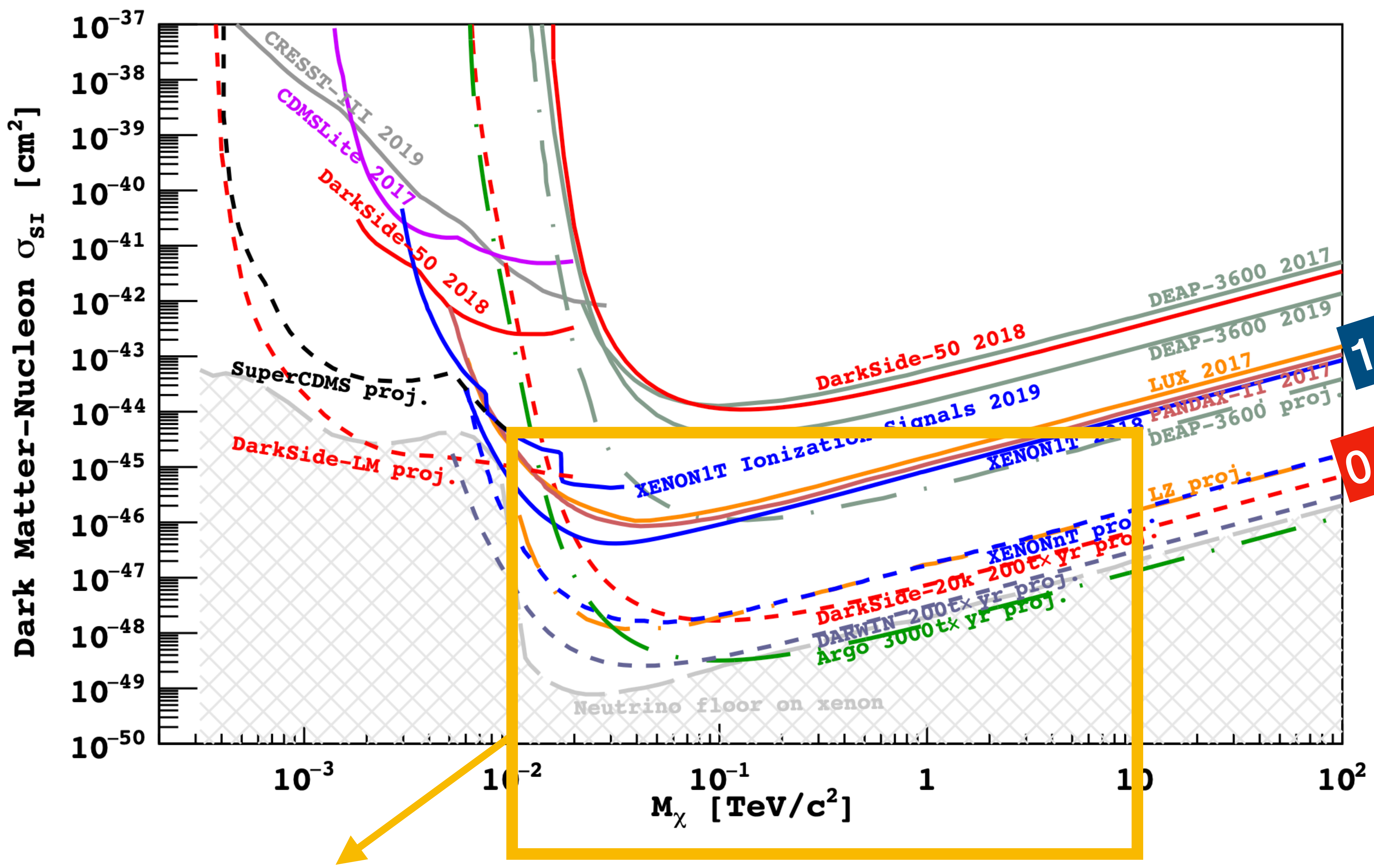
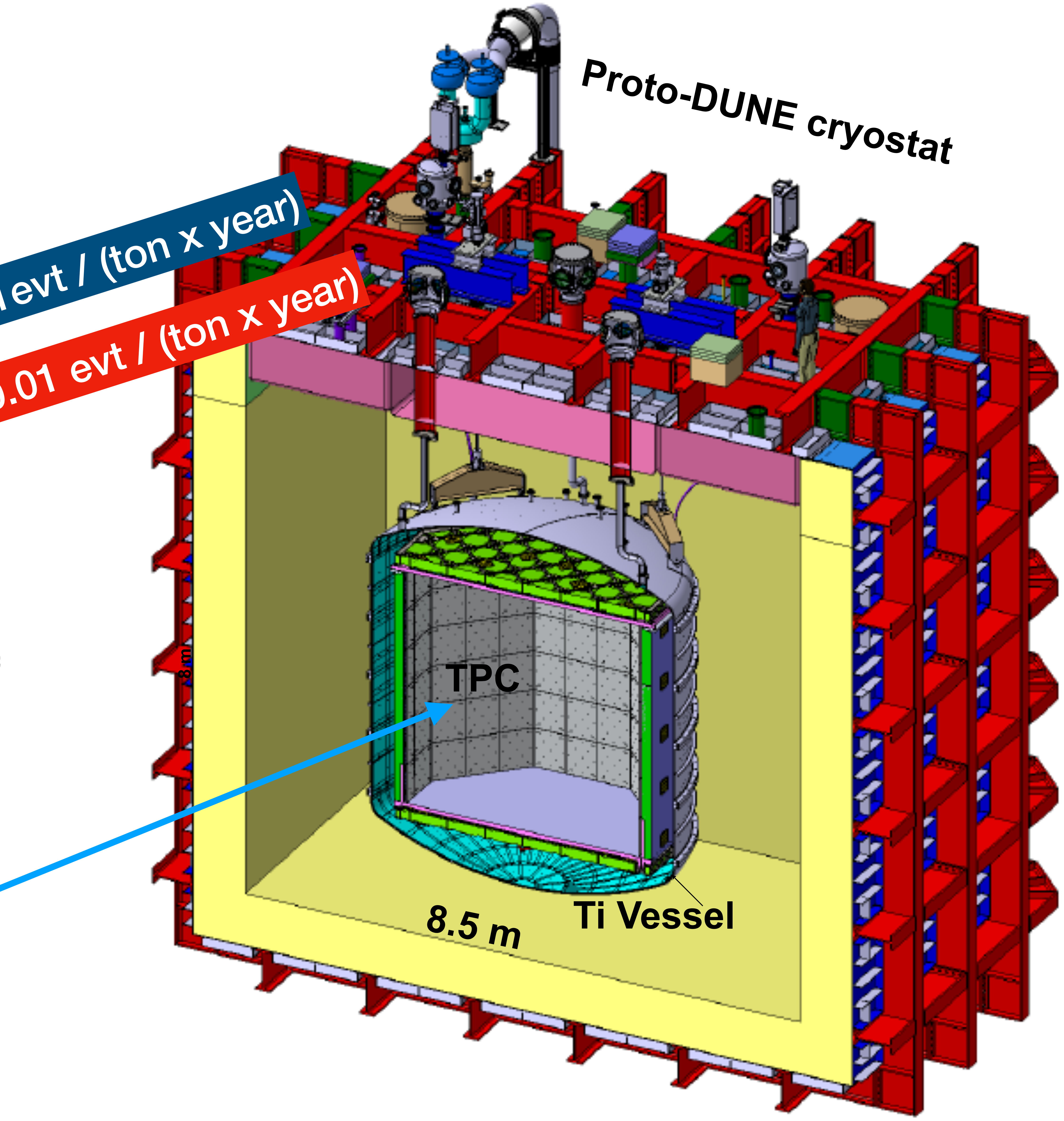


DarkSide-20k





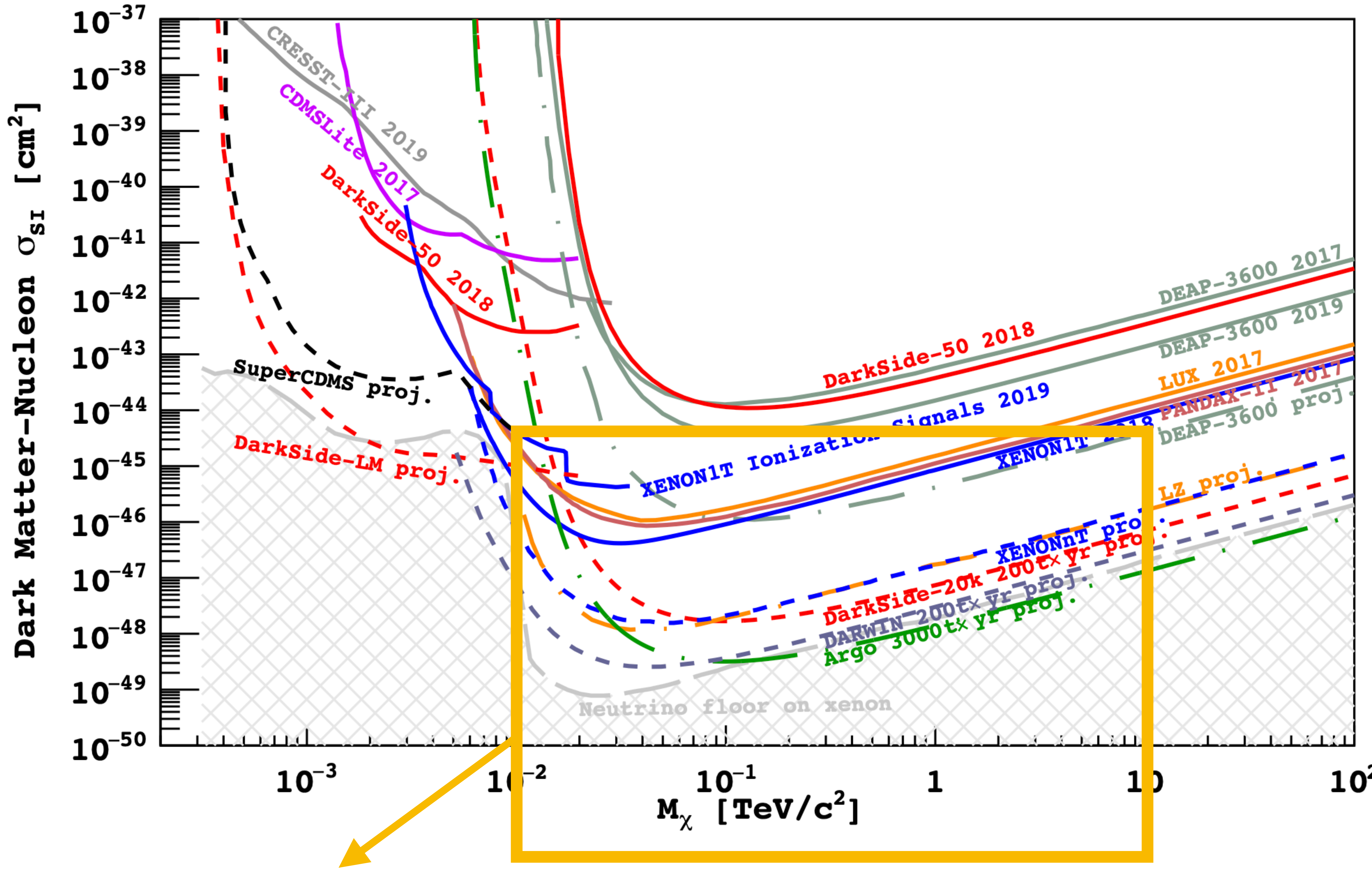
- Strong discovery potential in the 10GeV-10TeV range

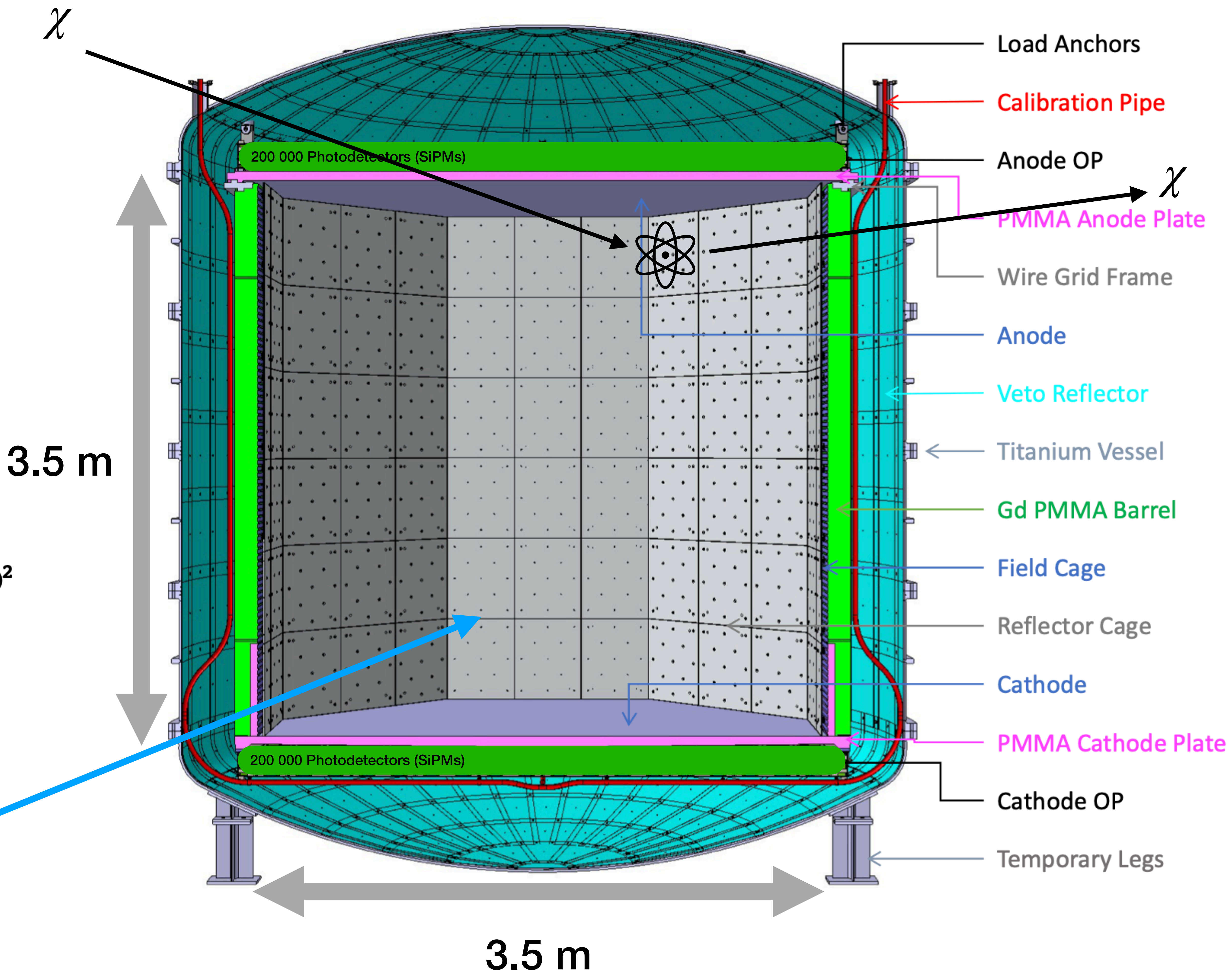
- Next Argon experiment: DarkSide-20k
  - 200 t x year exposure
  - Argon double phase TPC

Will be the largest TPC ever built for dark matter search purpose

Technology providing the best limits at high WIMP mass

DarkSide-20k





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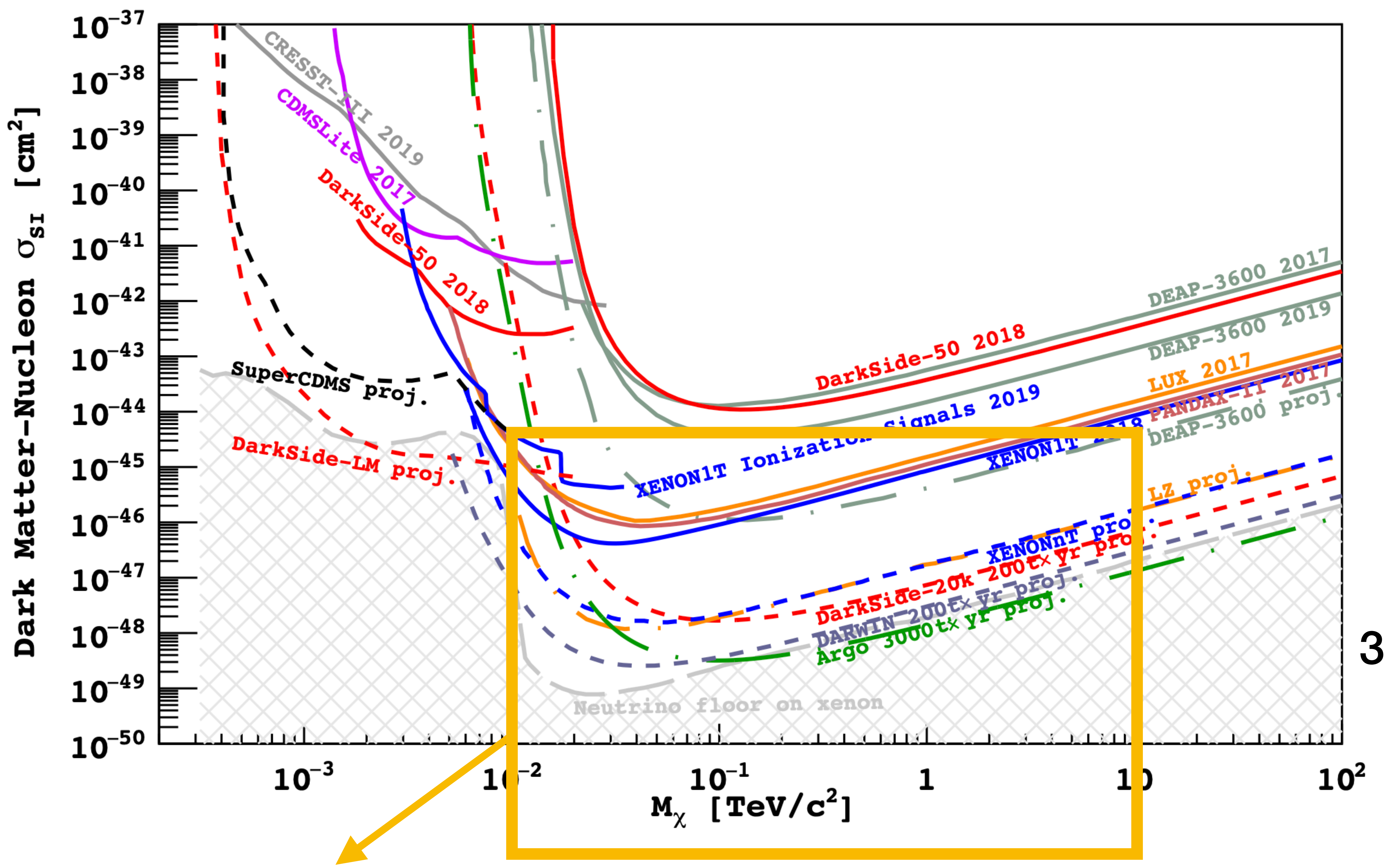

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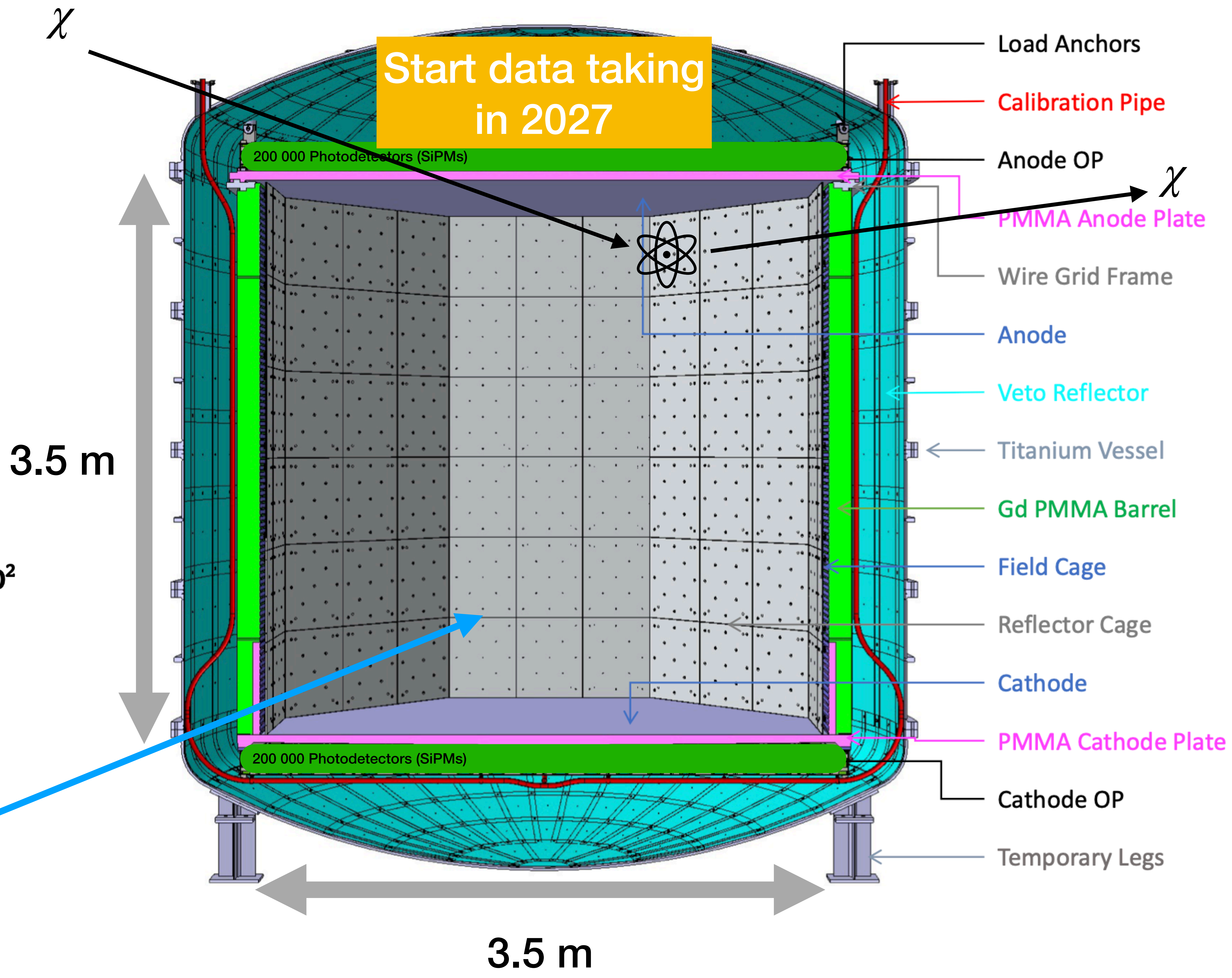
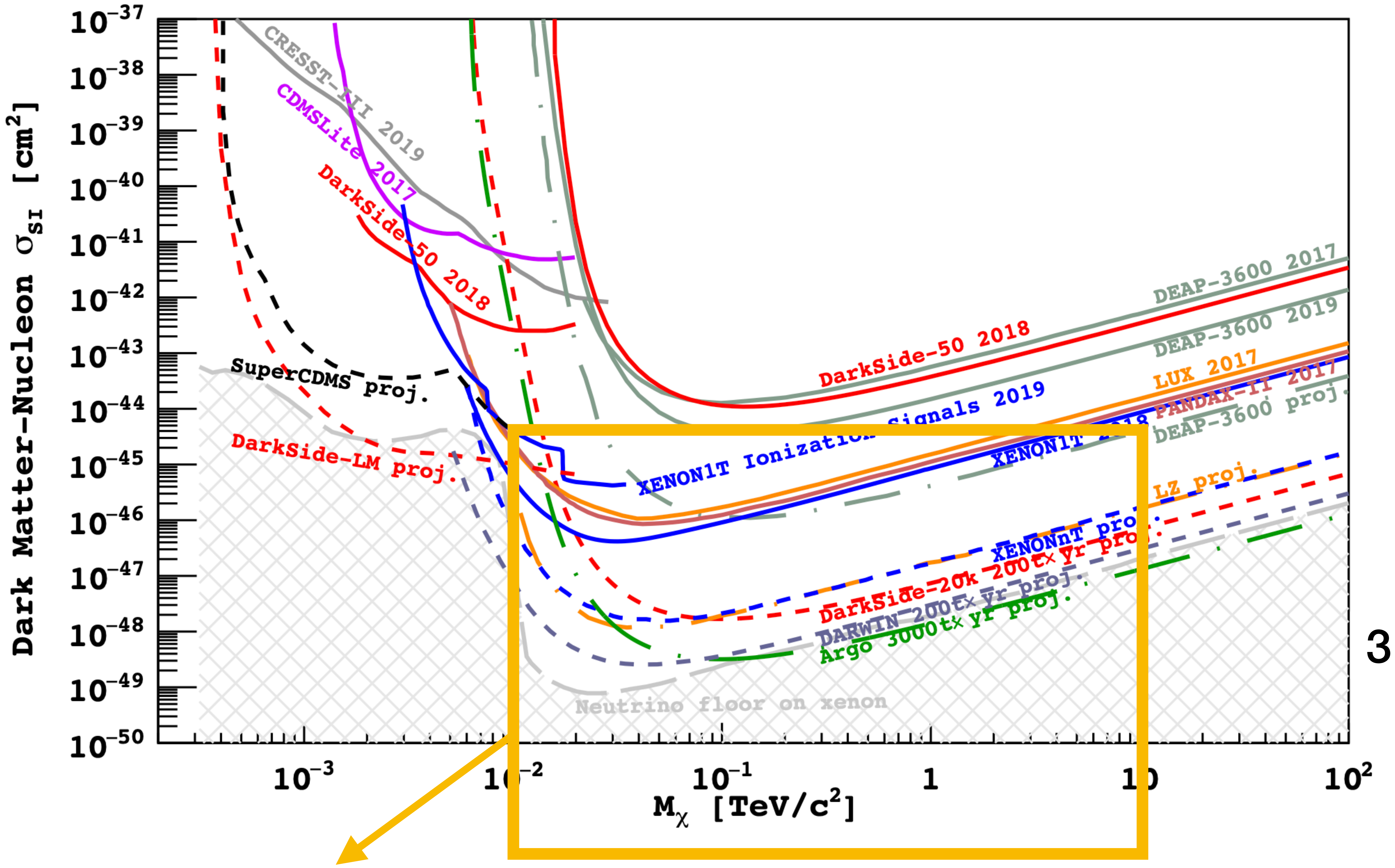
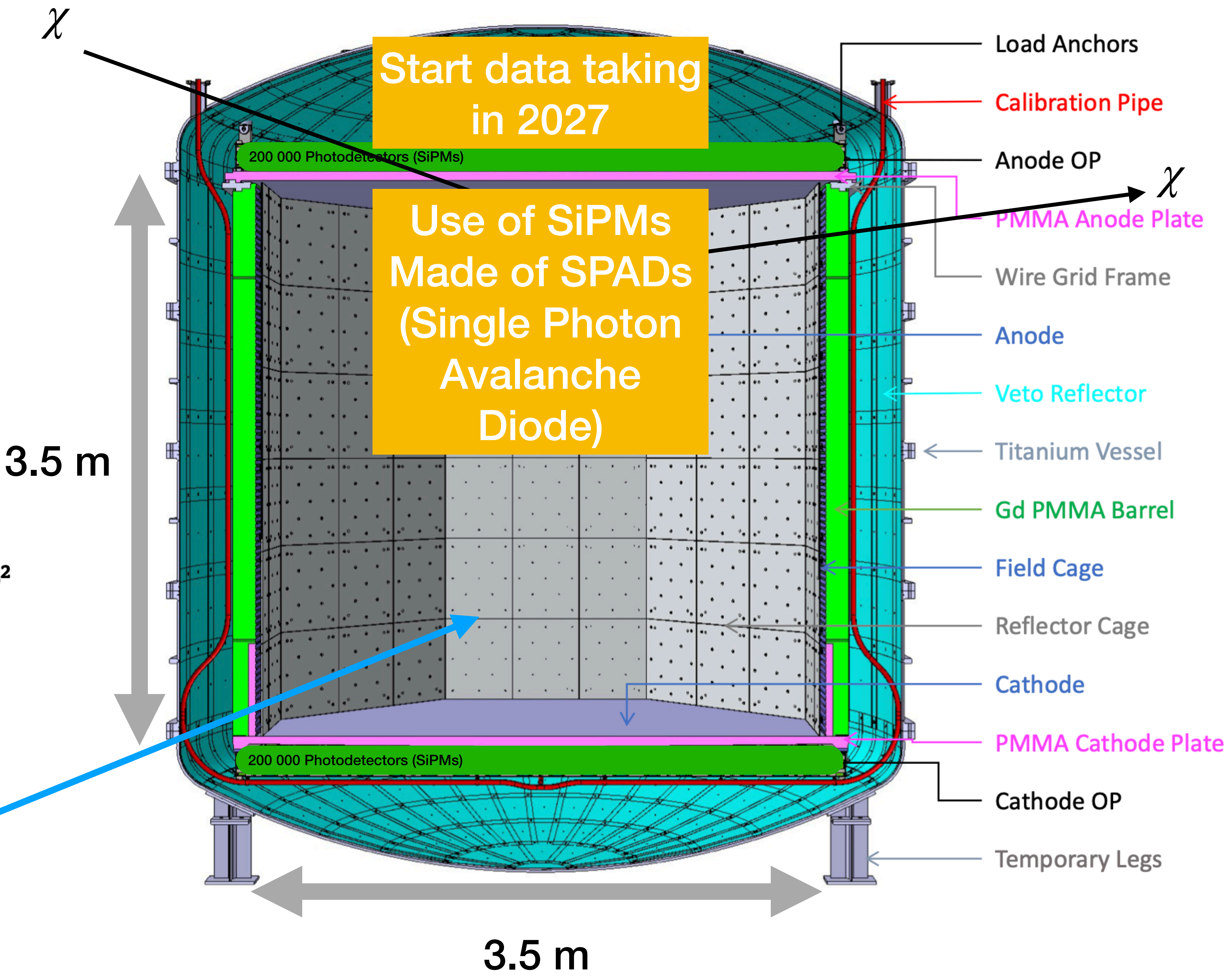

Start data taking in 2027

DarkSide-20k





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Use of SiPMs Made of SPADs (Single Photon Avalanche Diode)

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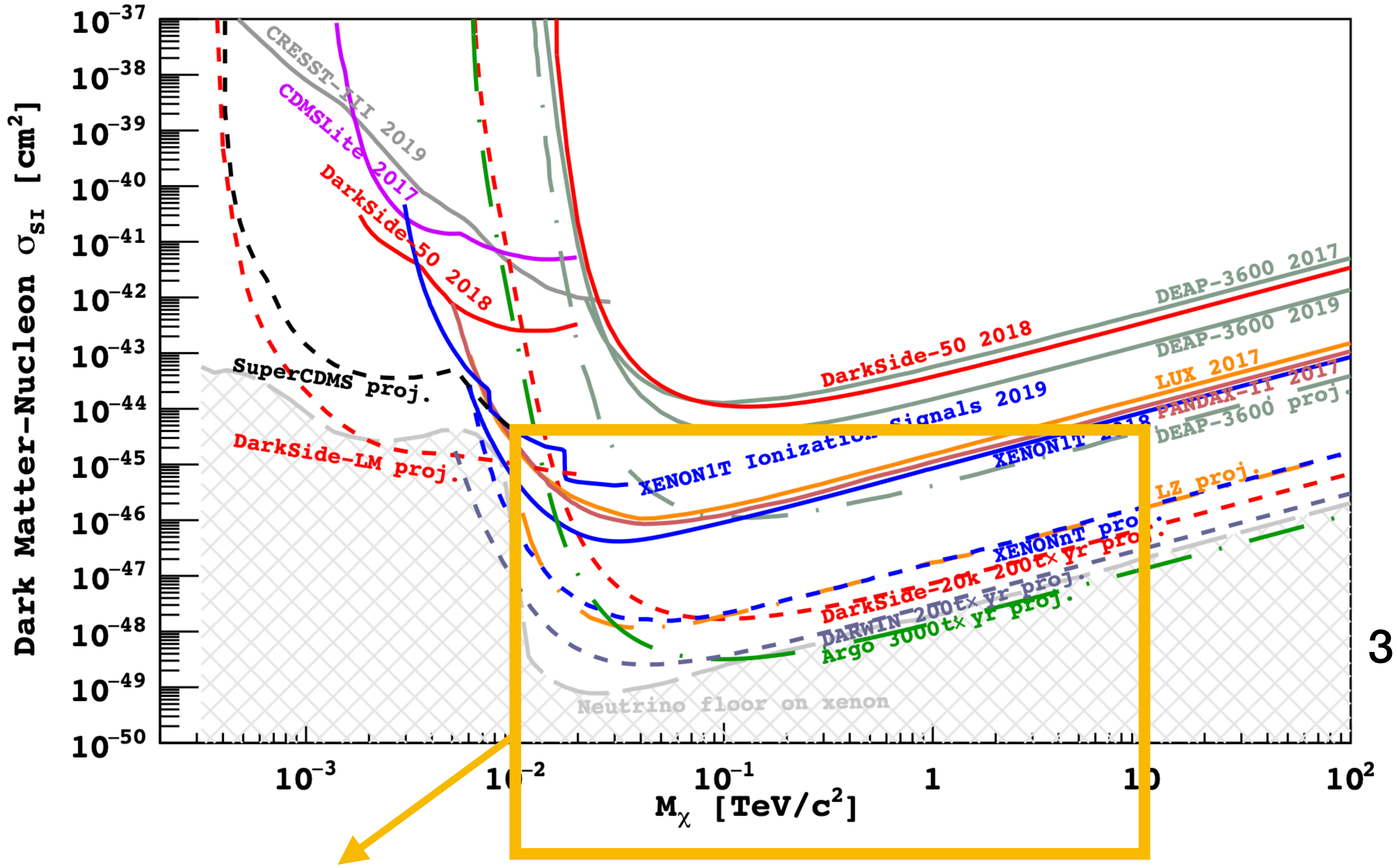

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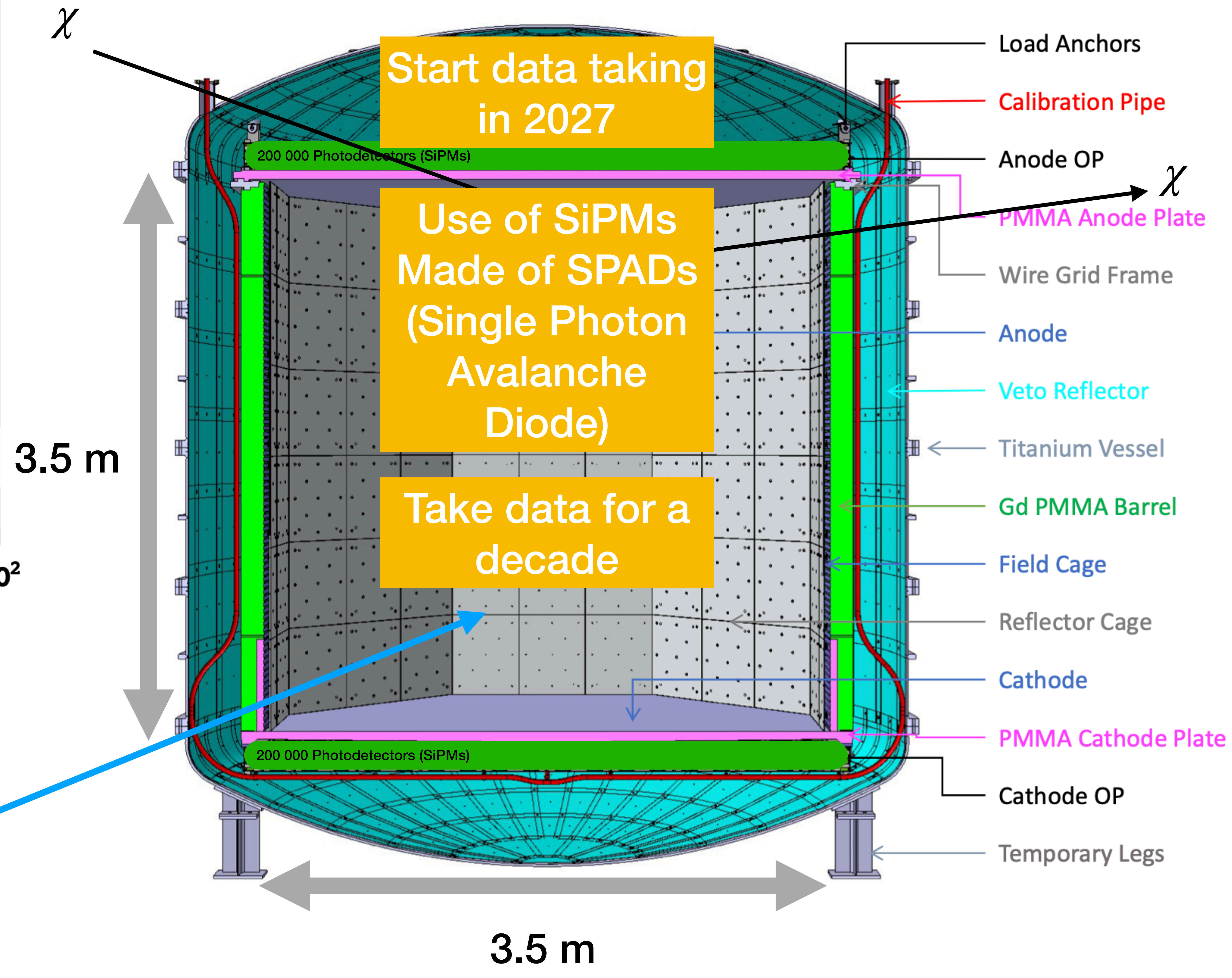

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Use of SiPMs Made of SPADs (Single Photon Avalanche Diode)

Take data for a decade

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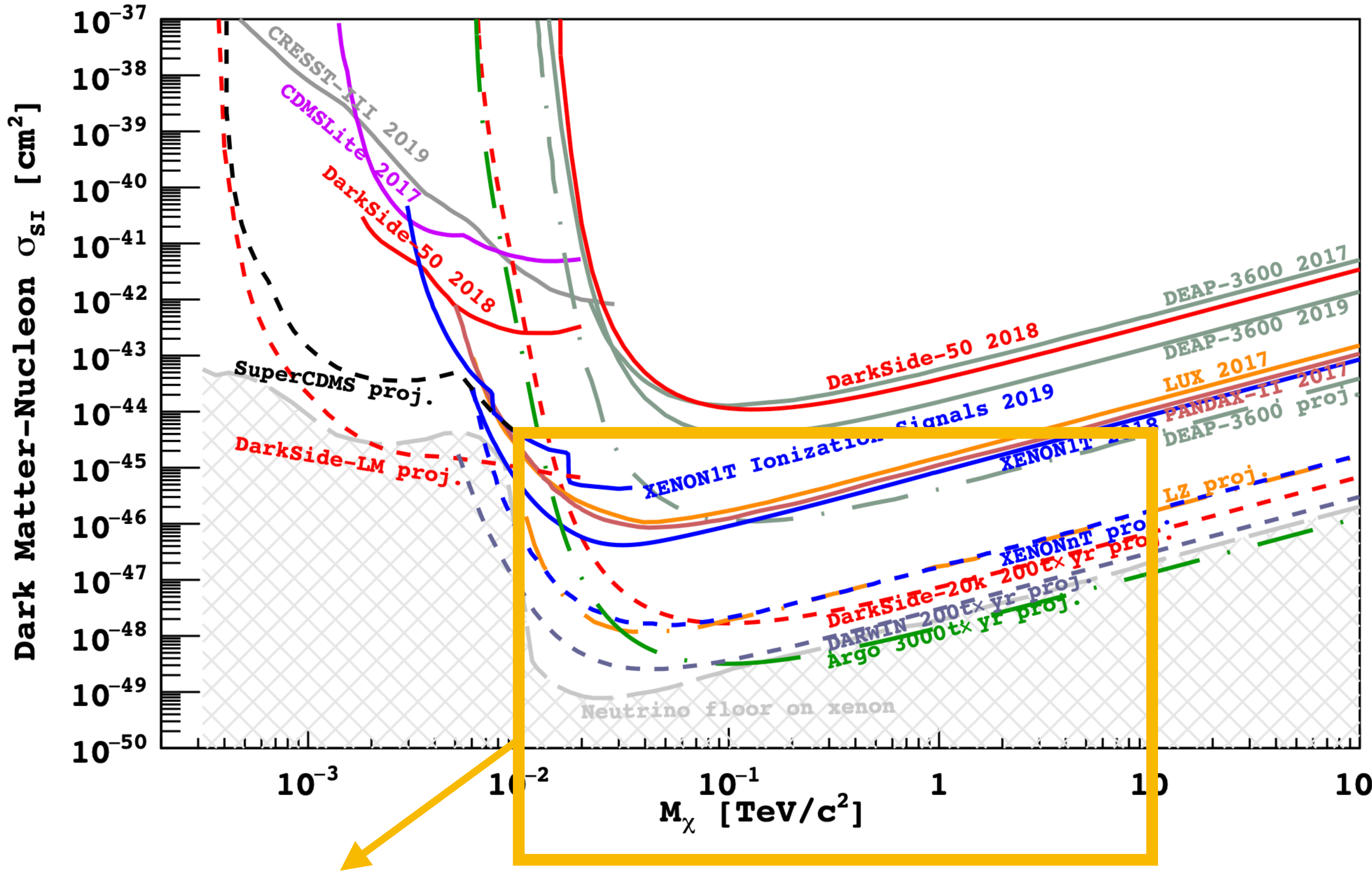

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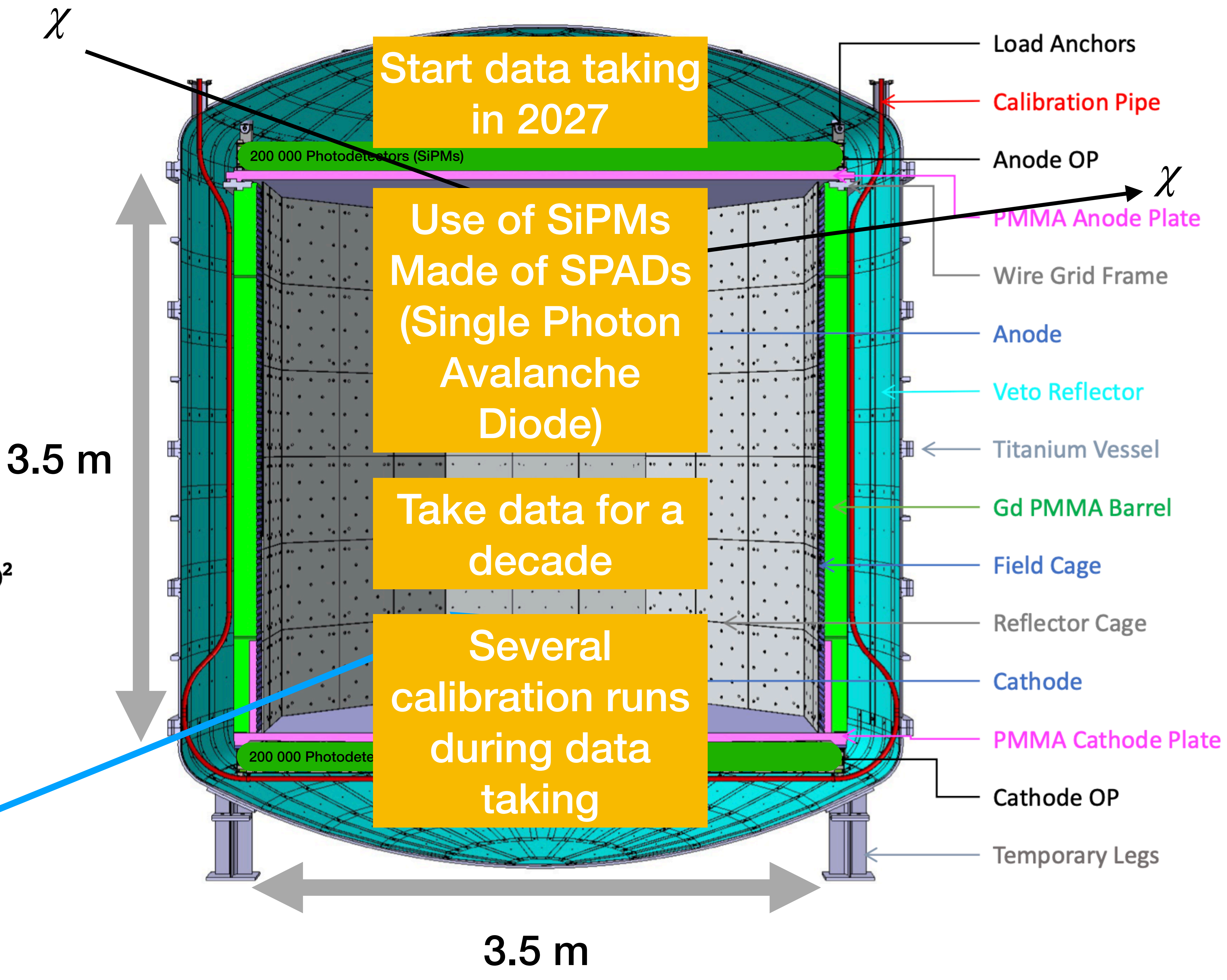

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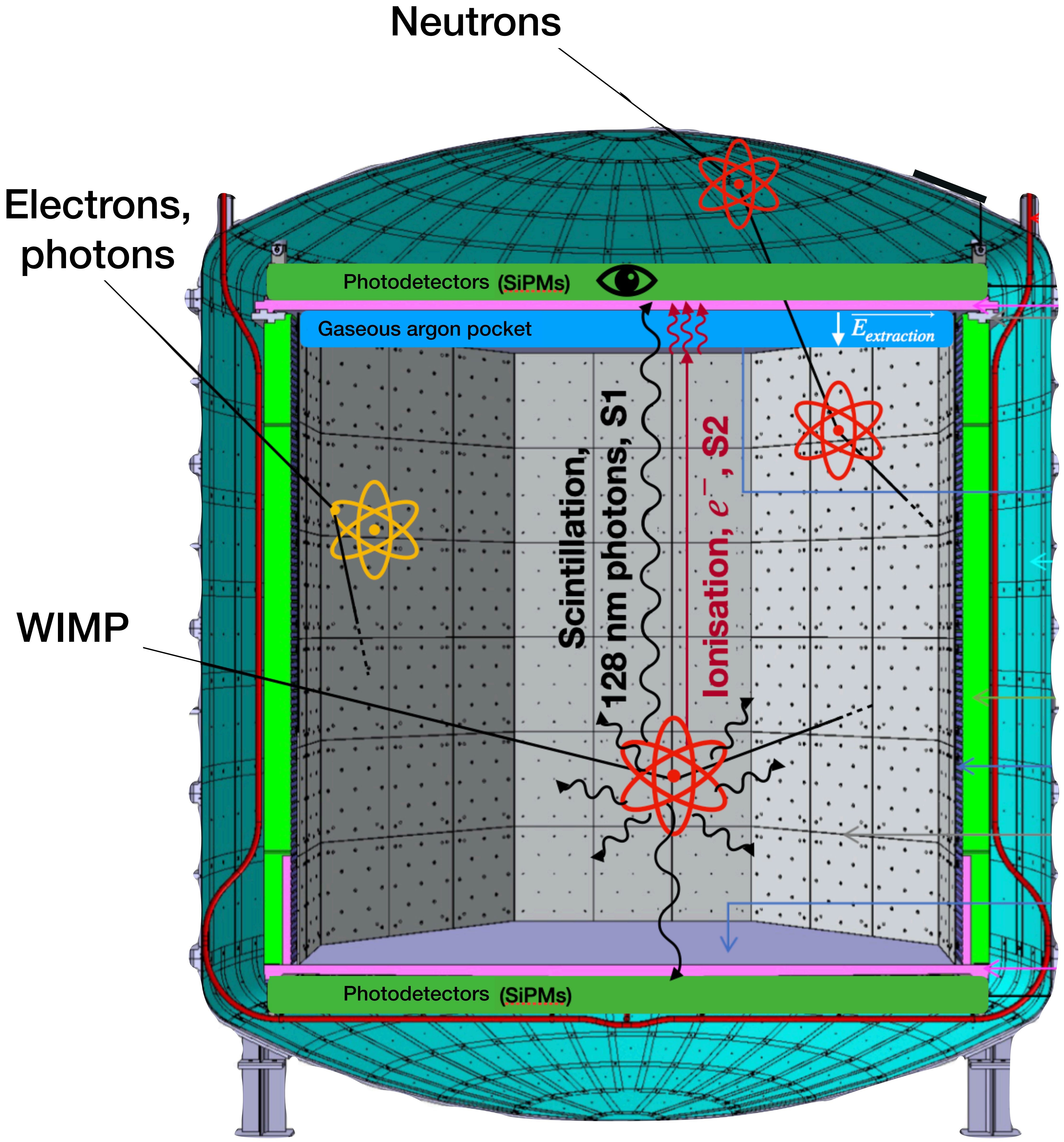
Several calibration runs during data taking

Expected signals in the TPC



ER event

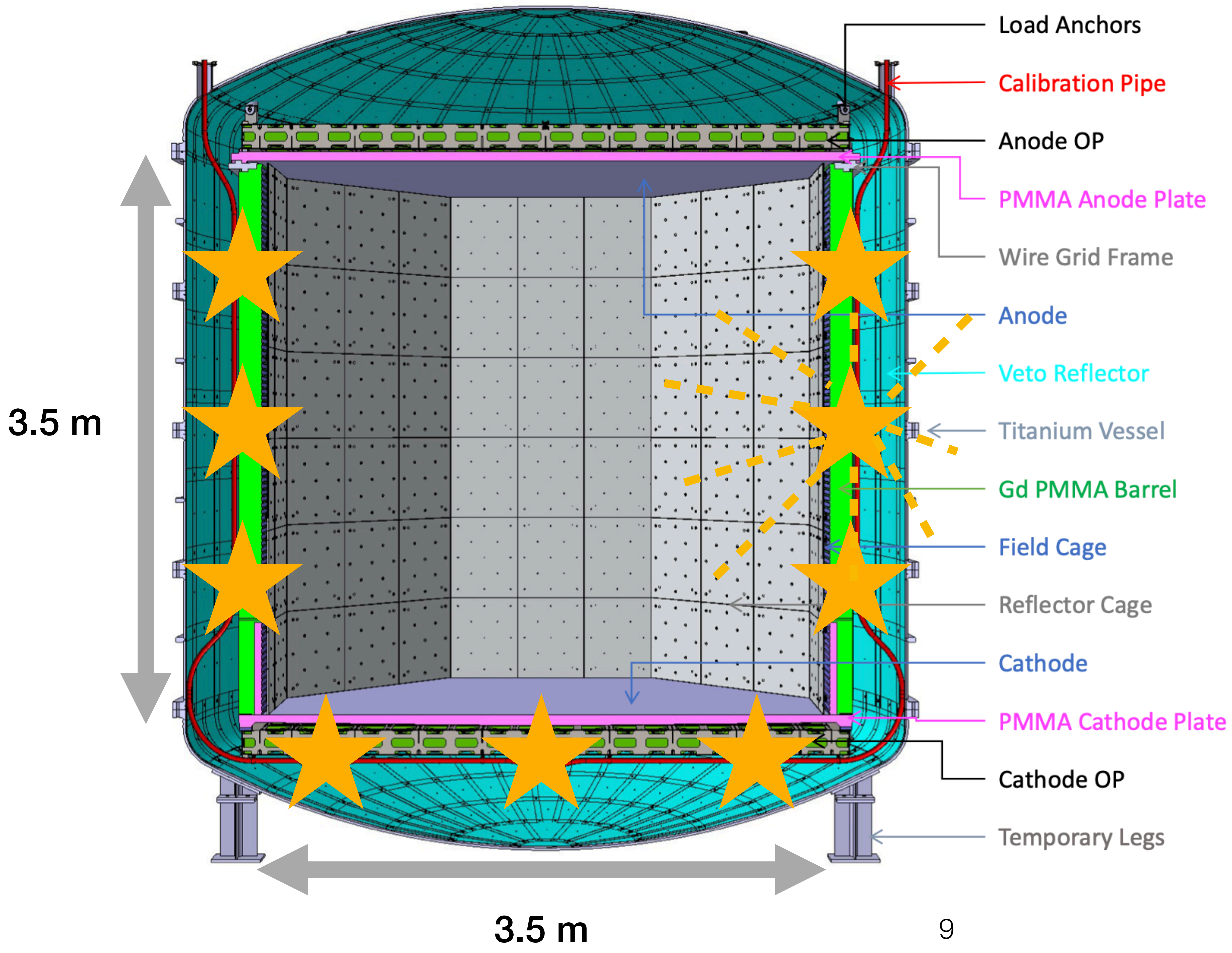
- **Electronic recoil**
- **Comes from electrons and photons (residual background)**
- **Slow S1 / high yield of S2**

LAr => very good separation between both

NR event

- **Nuclear recoil**
- **Comes from neutrons (residual background) and WIMPs (signal)**
- **Fast S1 / few S2**

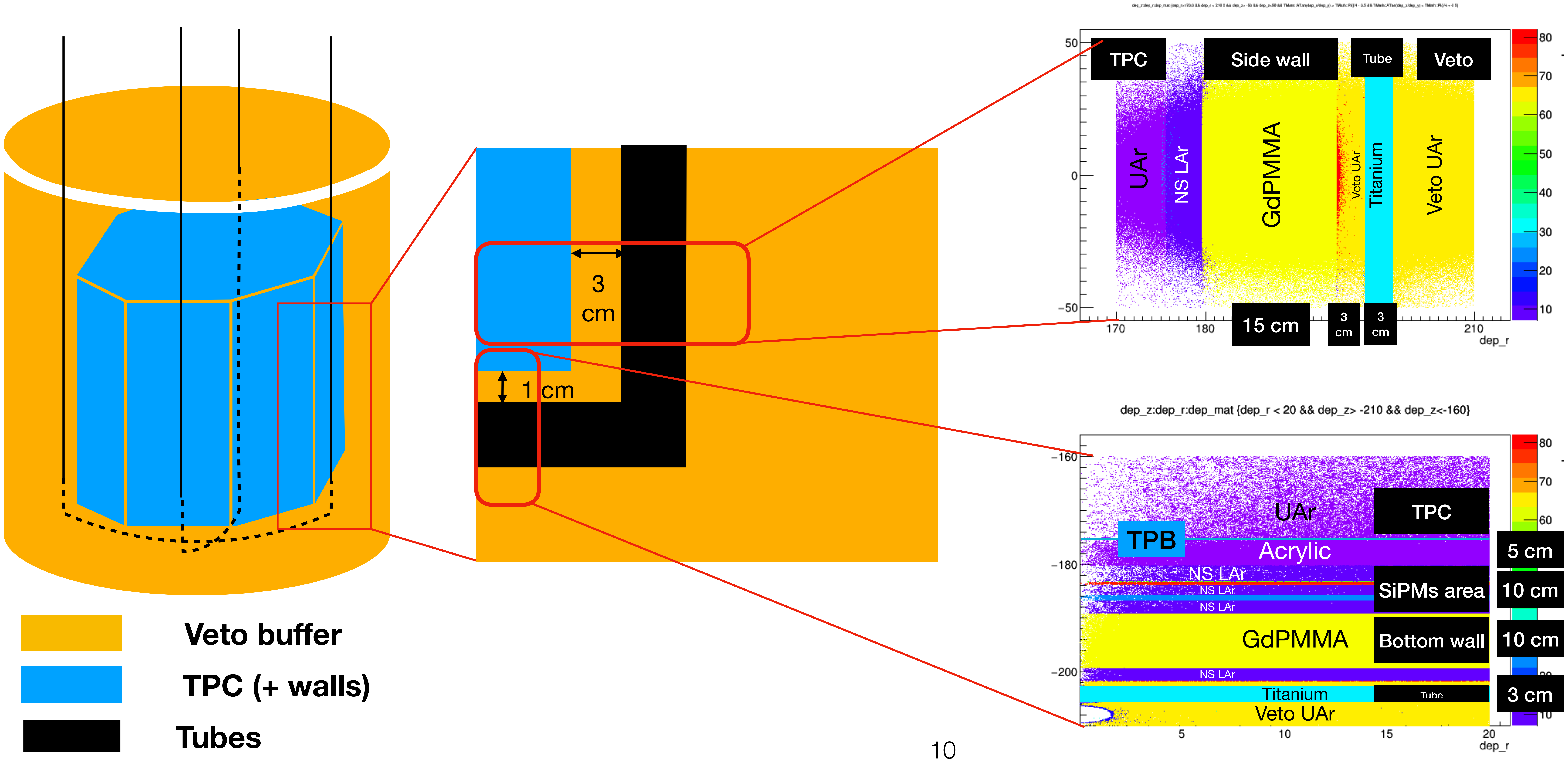
The TPC calibration



- Goal: position precisely (≈ cm precision level) photons and neutrons sources around the TPC -> achievable precision will be checked thanks to the mockup
- Photons and neutrons sources will be of different energy to calibrate the DS20k TPC response

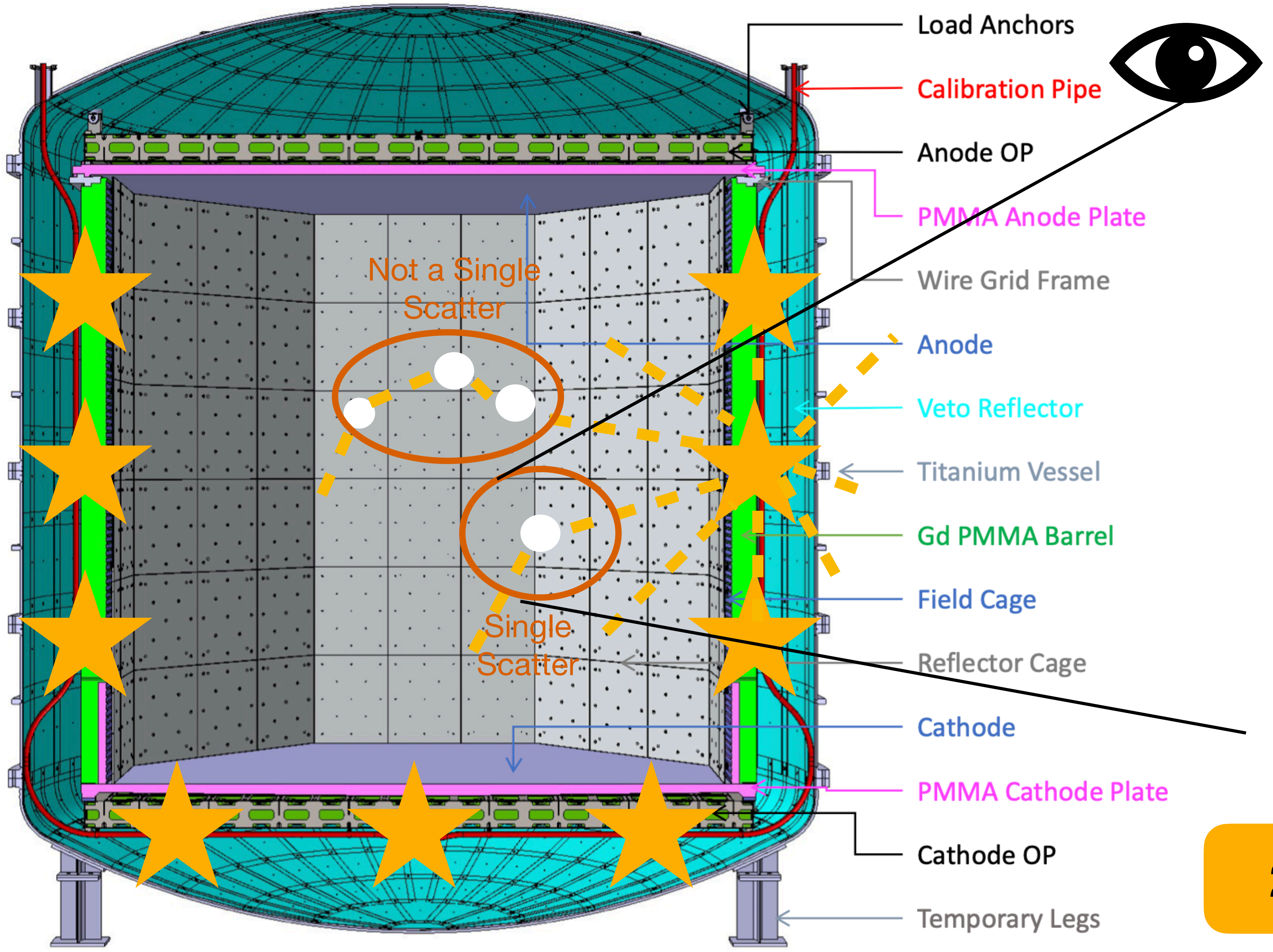
The TPC calibration set up design inside g4ds

- Dec. 2021: **TDR froze the geometry of DS20k** -> final simulations of the calibration



Geometry of the detector as it is implemented in g4ds, a GEANT4-based software applied for the DarkSide20k experiment

Stakes coming with the calibration

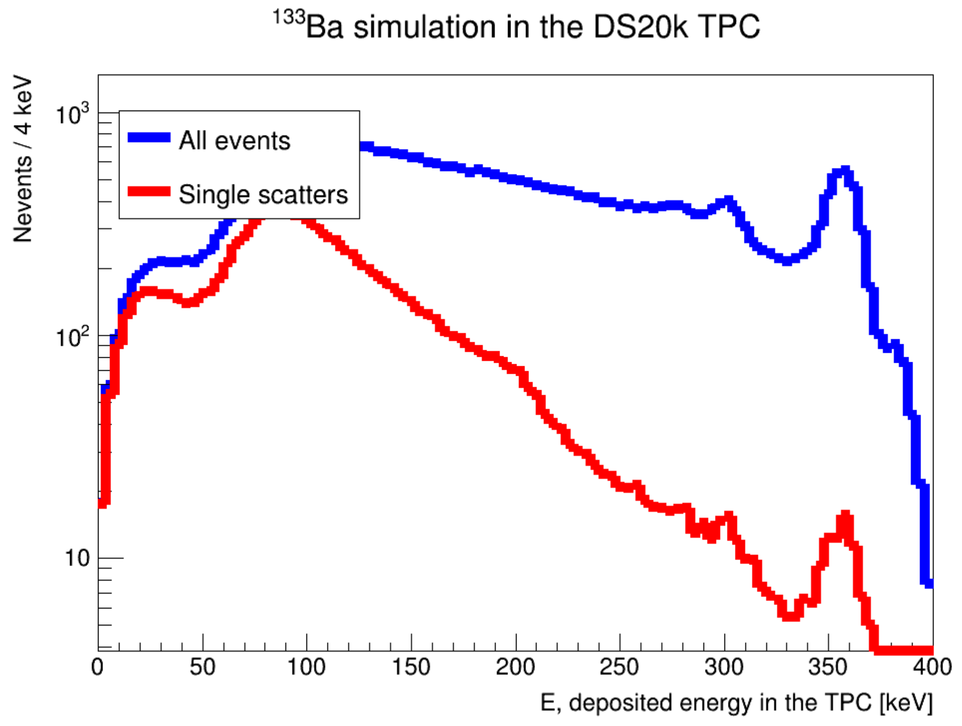


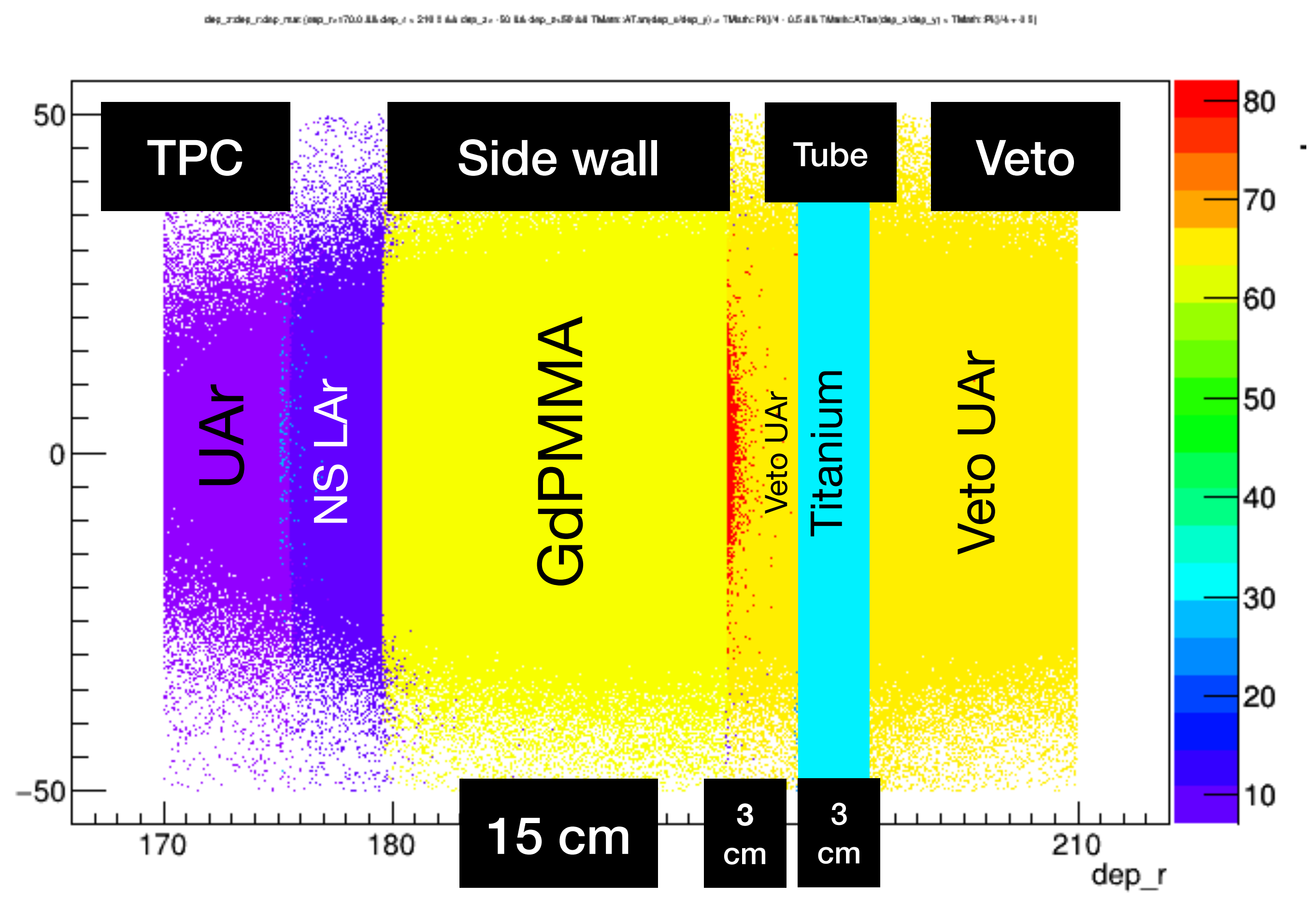
1

Make the TPC calibration as efficient as possible

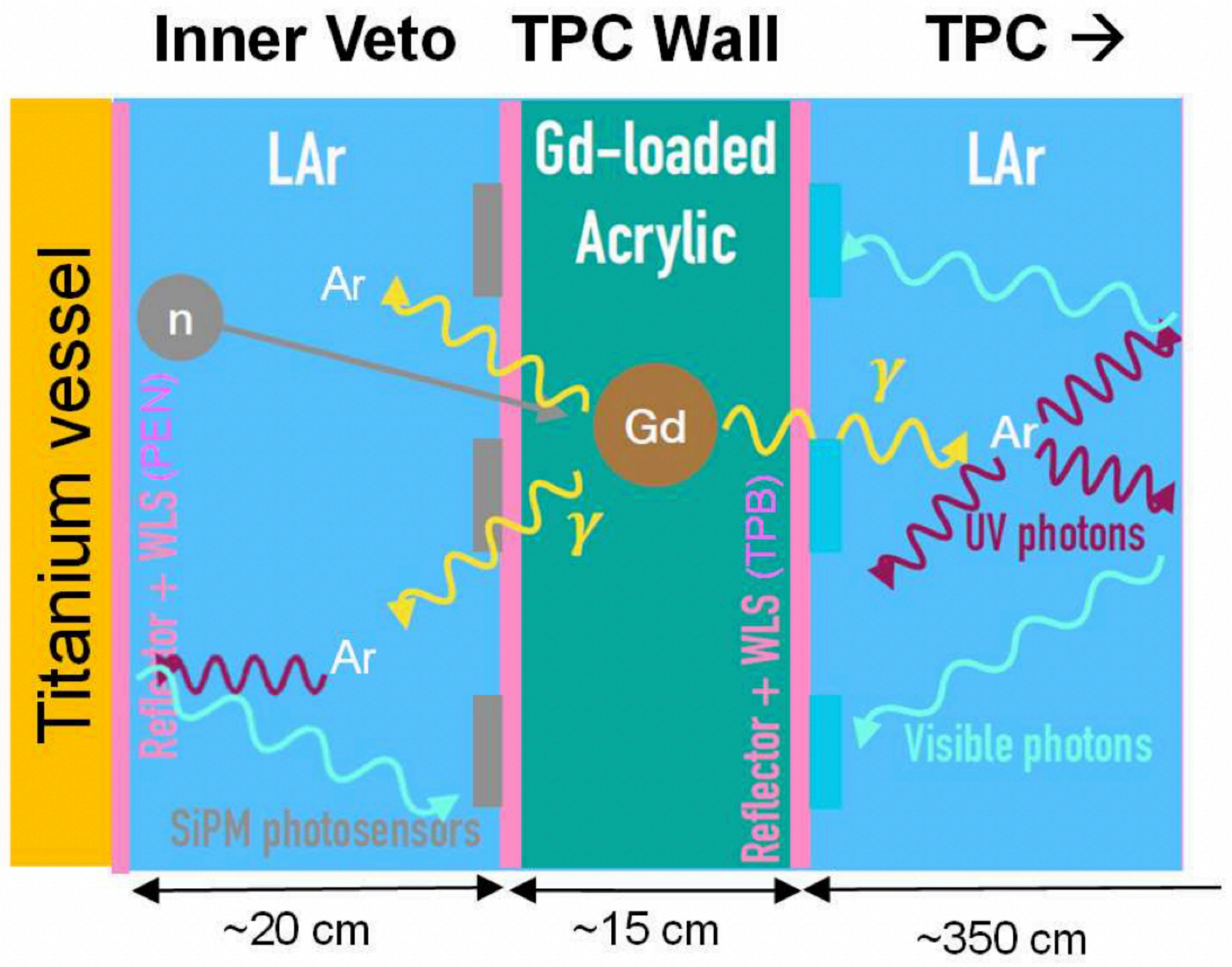
Play with the hypothesis to reach an affordable time for the calibration runs

Find the best way to calibrate





Gd-loaded PMMA :
-> Make difficult having a WIMP-like NR event (NR single scatter without γ accompanying)



2

Tubes dived inside the veto buffer

Impact (to minimize) on the light collection efficiency of the veto buffer

3

Tubes close to the TPC: background induced ?

How much background is induced because of the tubes ? Is it negligible ?

Simulation work

- Prepare at best the calibration thanks to simulations
- What needs to be calibrated ?
    - ER signal: mainly background
    - NR signal: can be residual background (from neutrons) or actual WIMP signal

Both need to be carefully calibrated

Pure ER Single Scatters ((+) carrying the initial photons energy)

Pure NR Single Scatters

- Simulations made thanks to a GEANT4-based software applied to DS20k geometry: g4ds
- Geometry of the detector implemented inside -> it simulates the interaction between calibration particles and the detector
    - Estimation of the rates of events in the TPC following photons and neutrons exposure

Simulation of the response to photon sources exposure (ER)

- ER : expected to be mainly background (photons, electrons)

- g4ds : Use of five monochromatic sources of photons: ^{57}Co, ^{133}Ba, ^{22}Na, ^{137}Cs, ^{60}Co

  From 122 to 1173 keV

- Most important signal to reconstruct for the calibration: **pure ER single scatters**

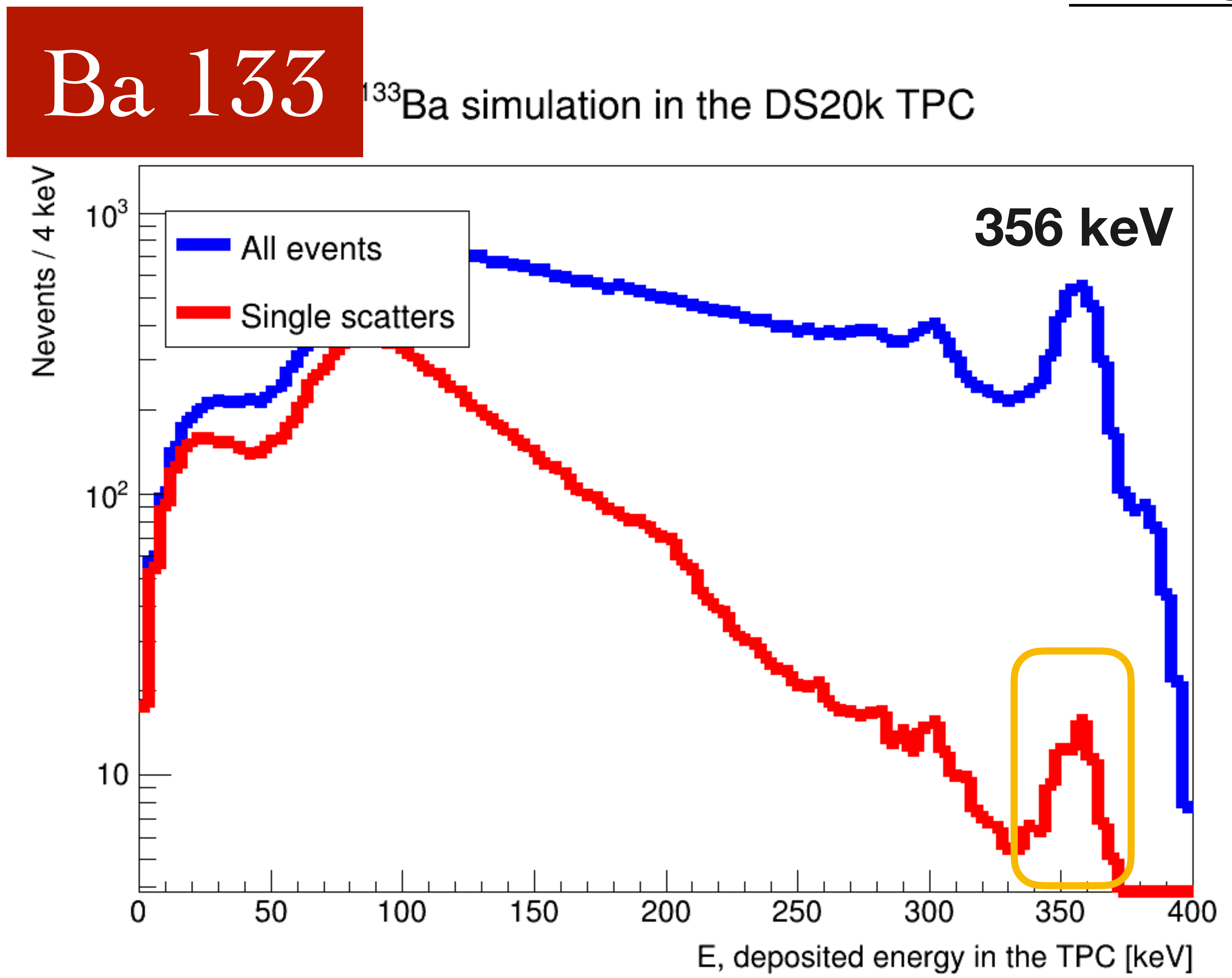
WIMPs' signature

Smeared by DS20k resolution (taking into account all the physics of the detector)

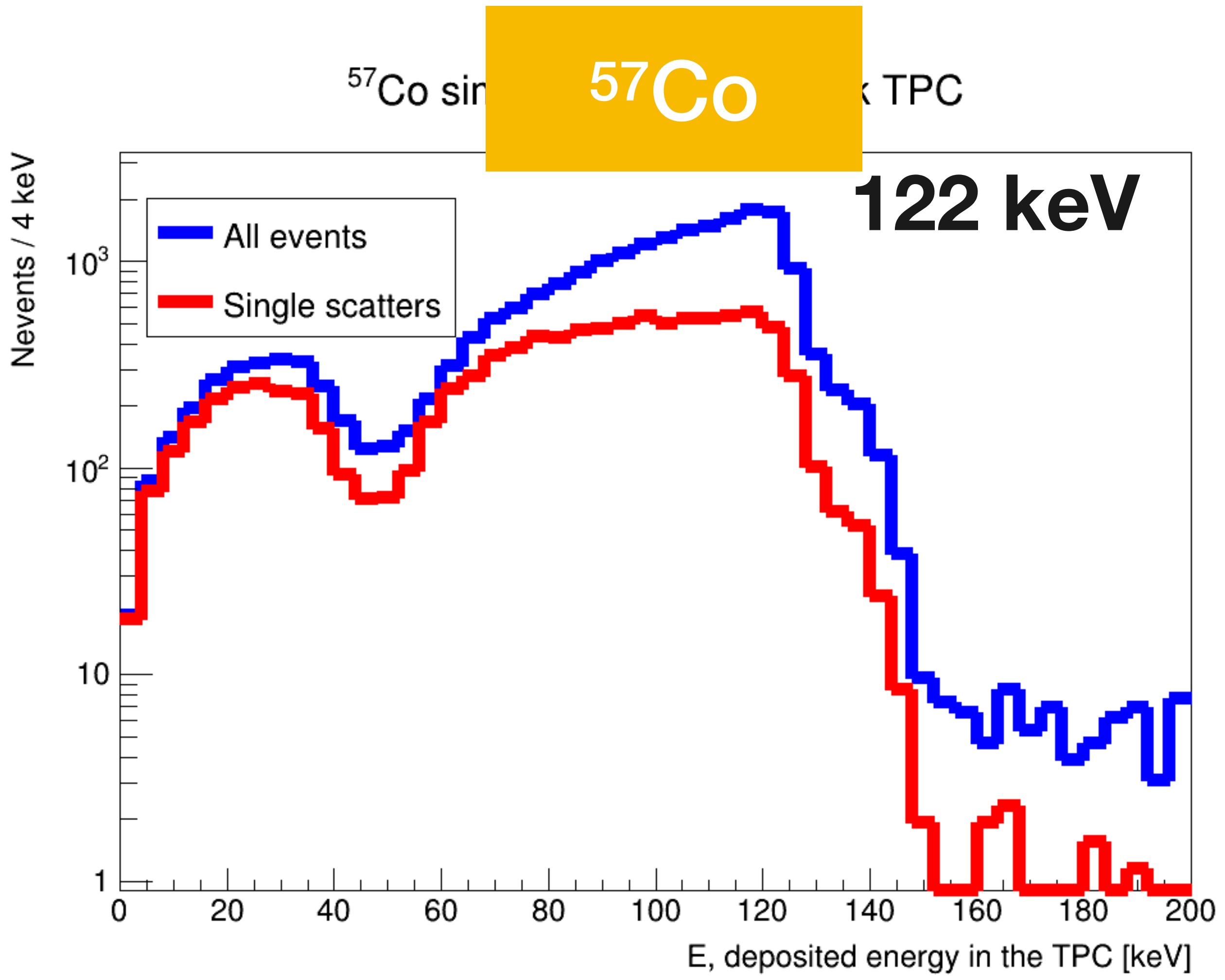
Spectrum normalized to 10 000 pure ER SS events

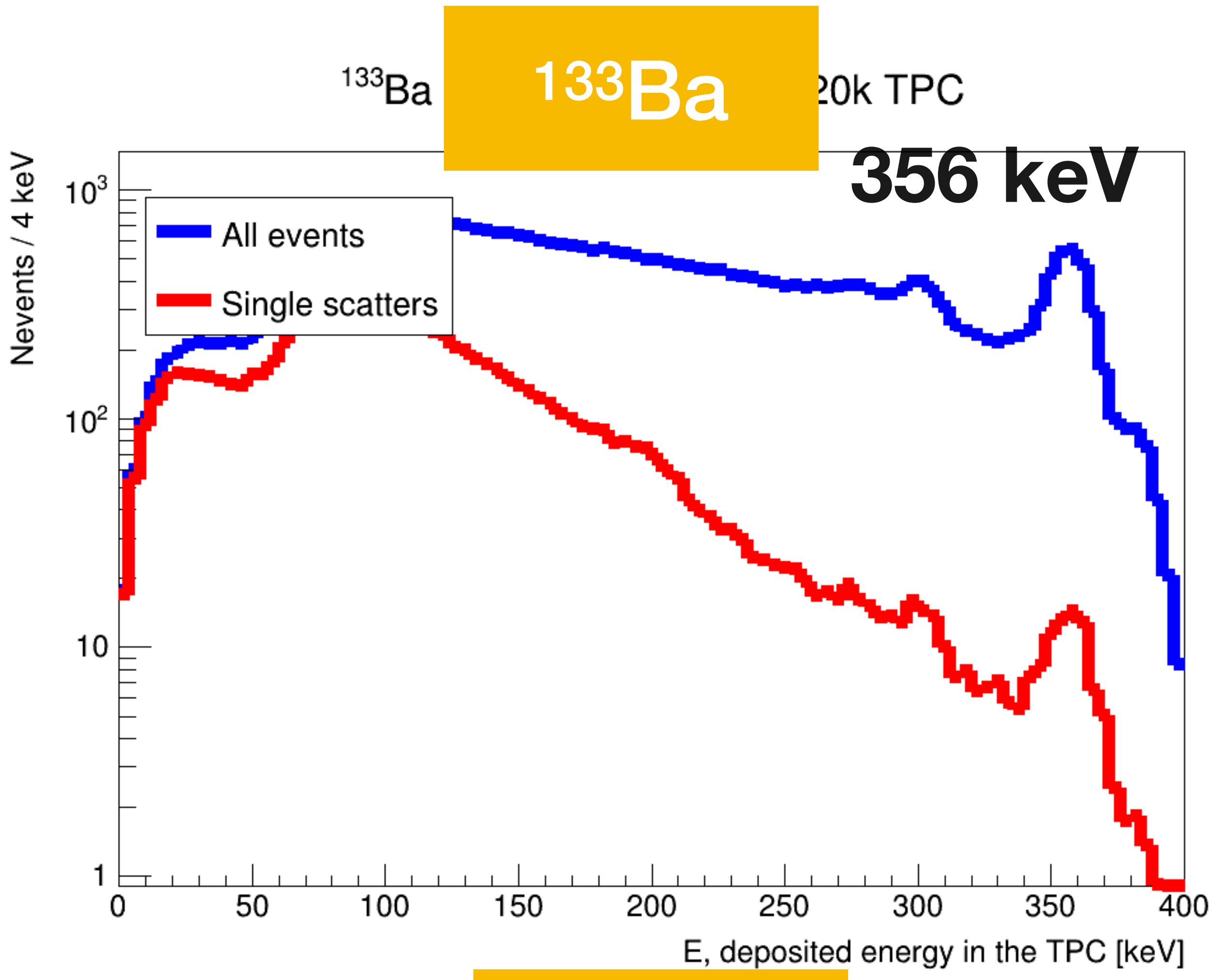
All events | Pure ER SS

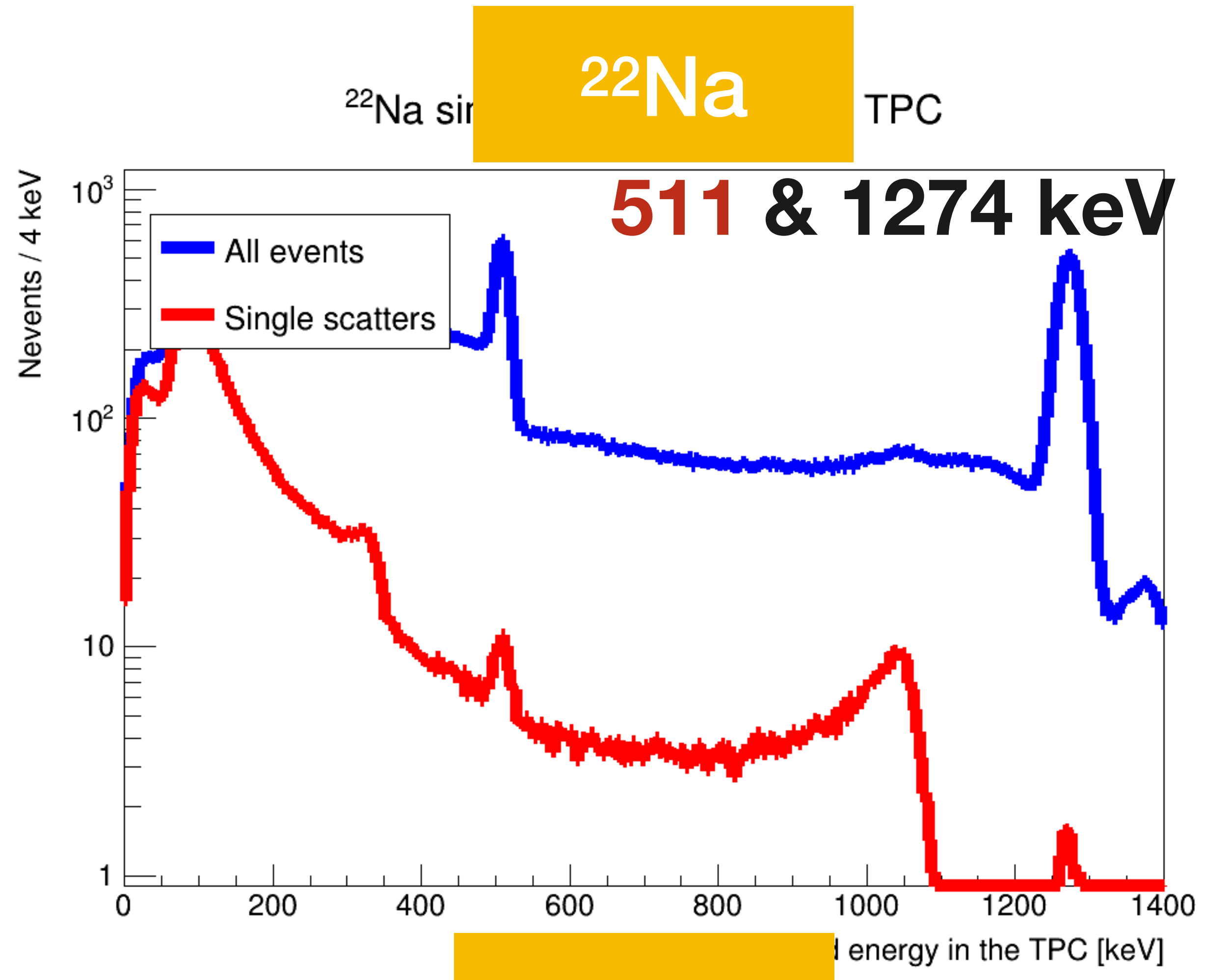
From these spectra: computation of the **rates of interesting events** inside the TPC per decay of the source located in the tubes



Simulation of the response to photon sources exposure

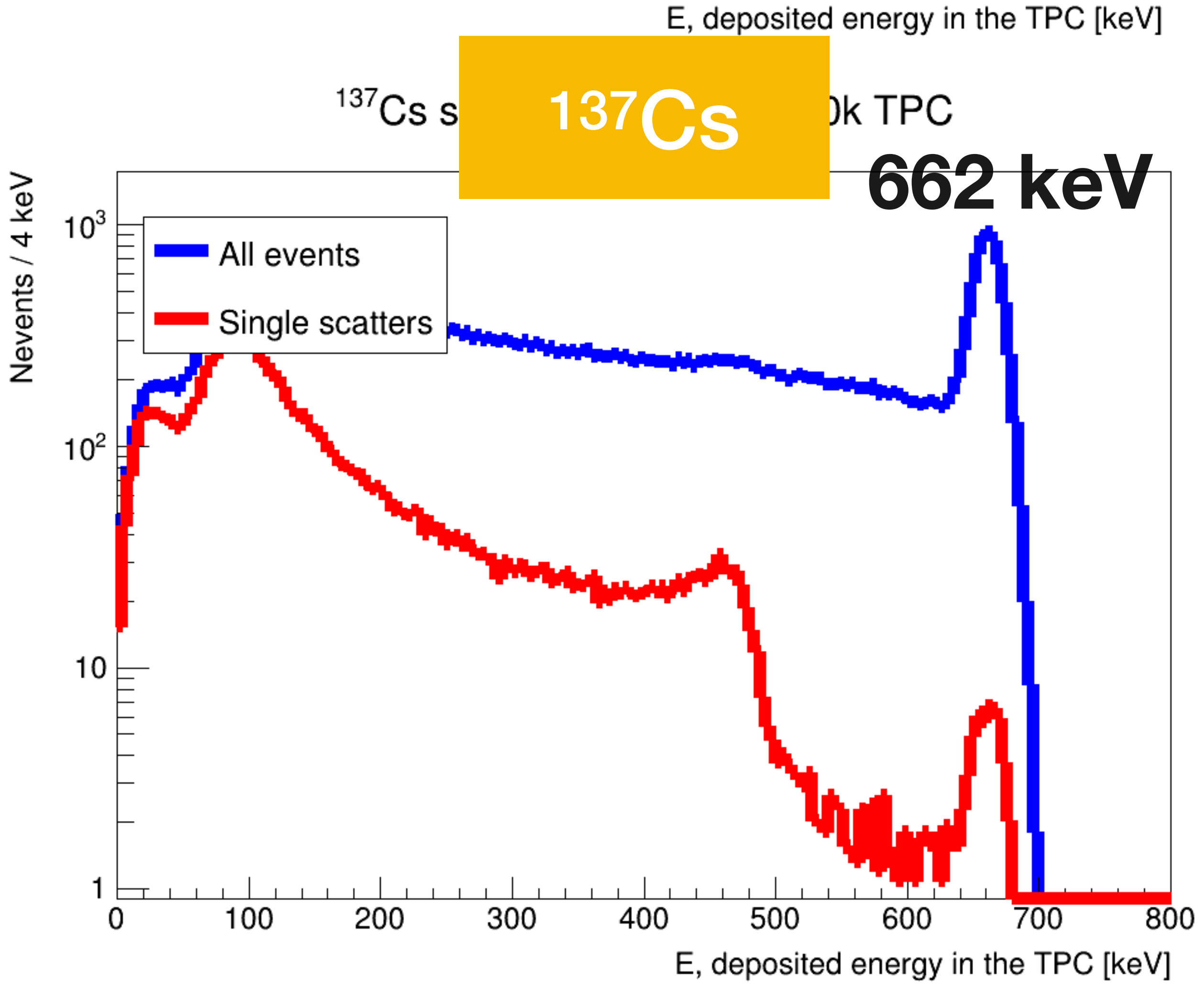


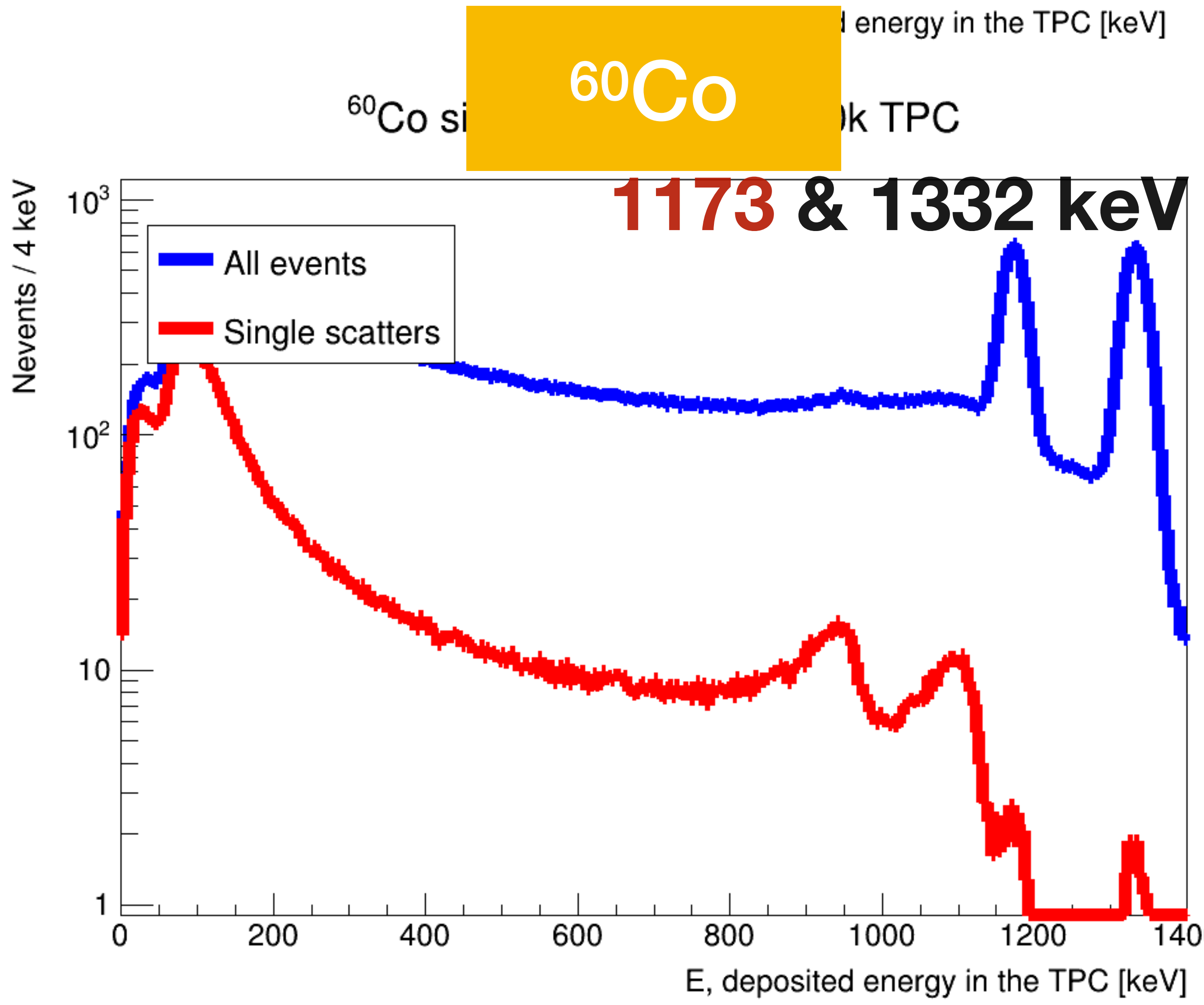




From these spectra: computation of the **rates of interesting events** inside the TPC per decay of the source located in the tubes

- Rates $\in$ [1.2 e-5, 6.2 e-4] evts/decay
- Asking for 1e3 pure ER SS in the photoelectric peak, it leads to ≈ 1 week of ER calibration





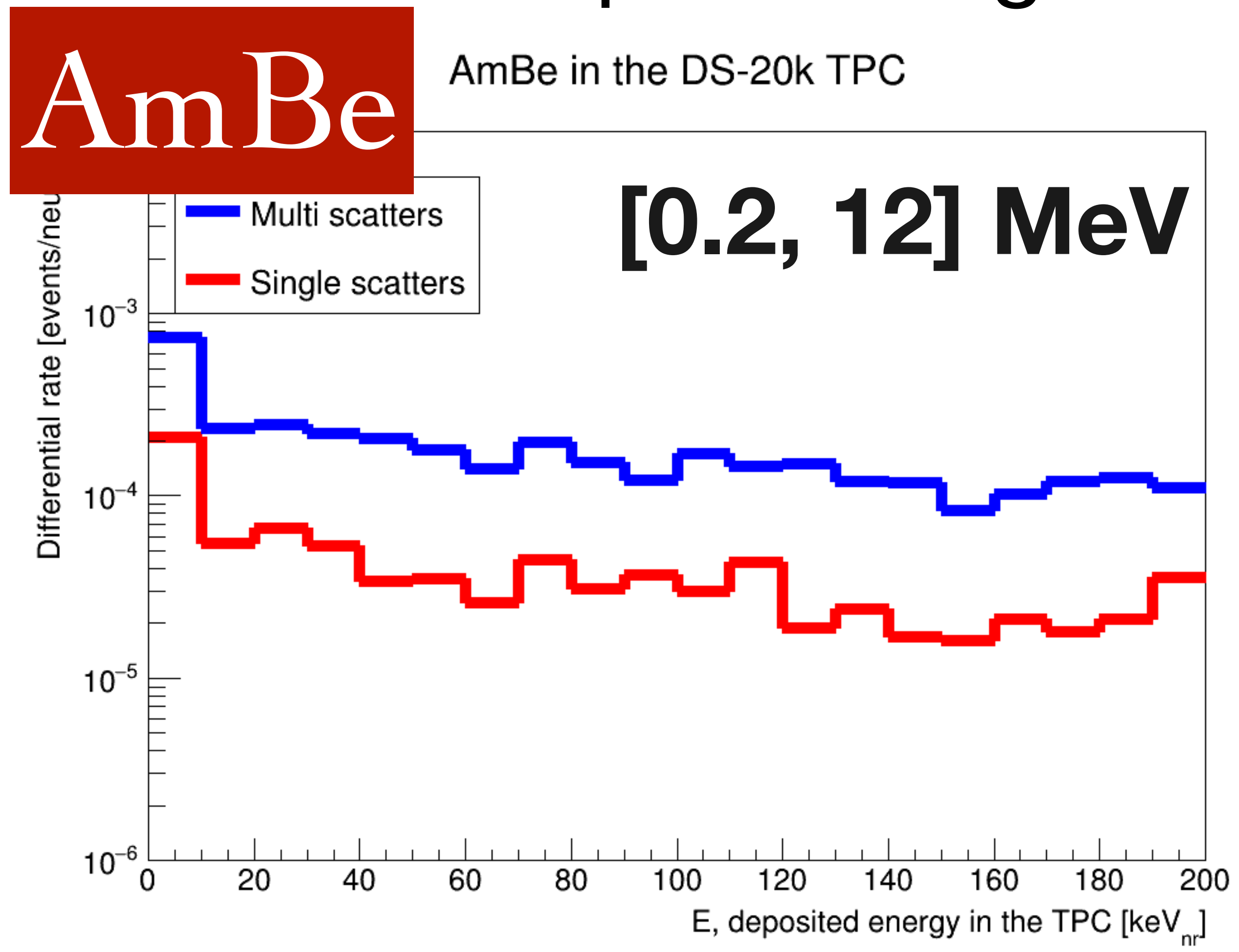
Interesting events	^{57}Co	^{133}Ba	^{22}Na	^{137}Cs	^{60}Co
Side	6.2 e-4	1.1 e-4	3.7 e-4	4.0 e-5	1.0 e-4
Bottom	8.4 e-5	2.6 e-5	1.6 e-4	1.2 e-5	5.2 e-5

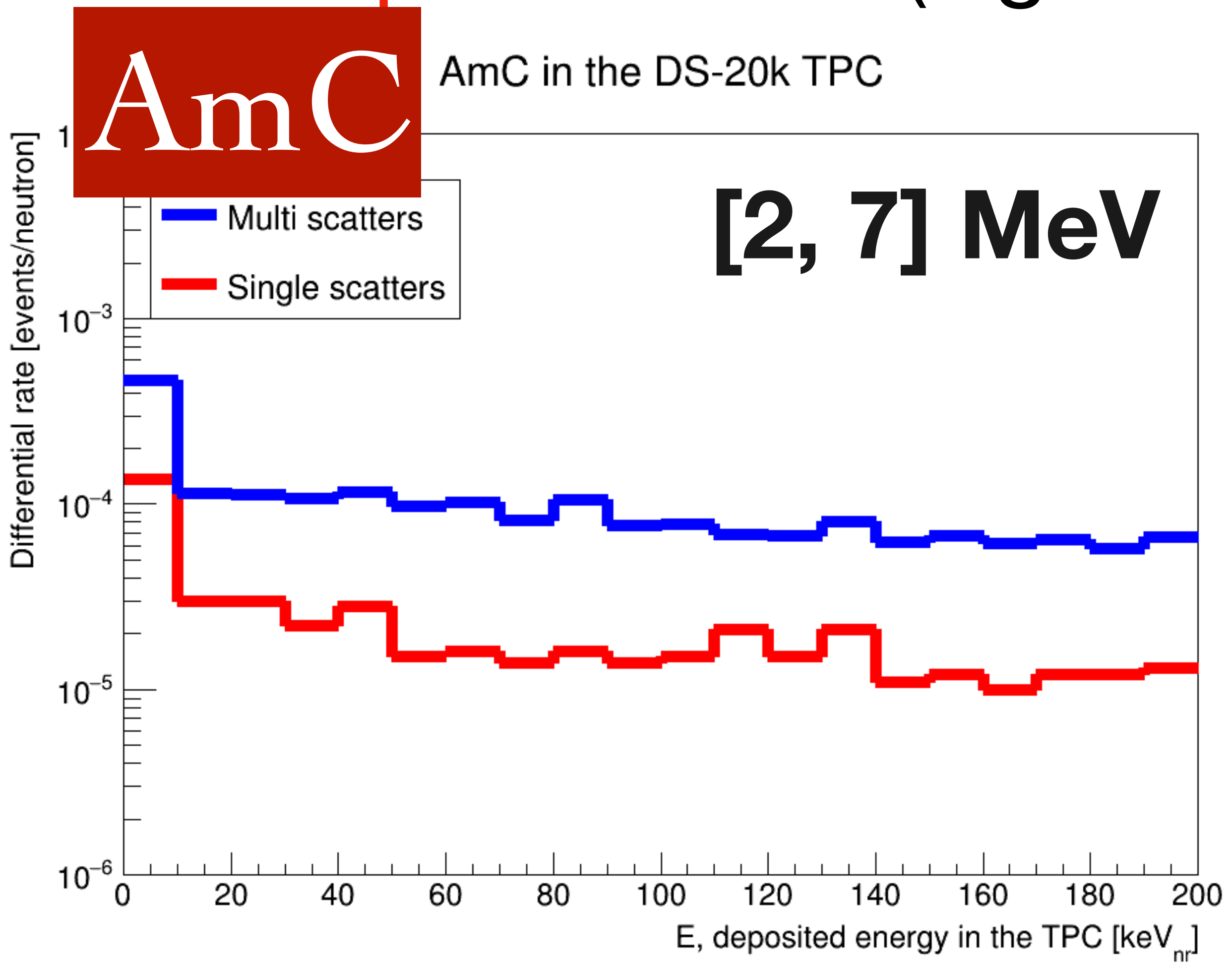
Simulation of the response to neutron sources exposure (NR)

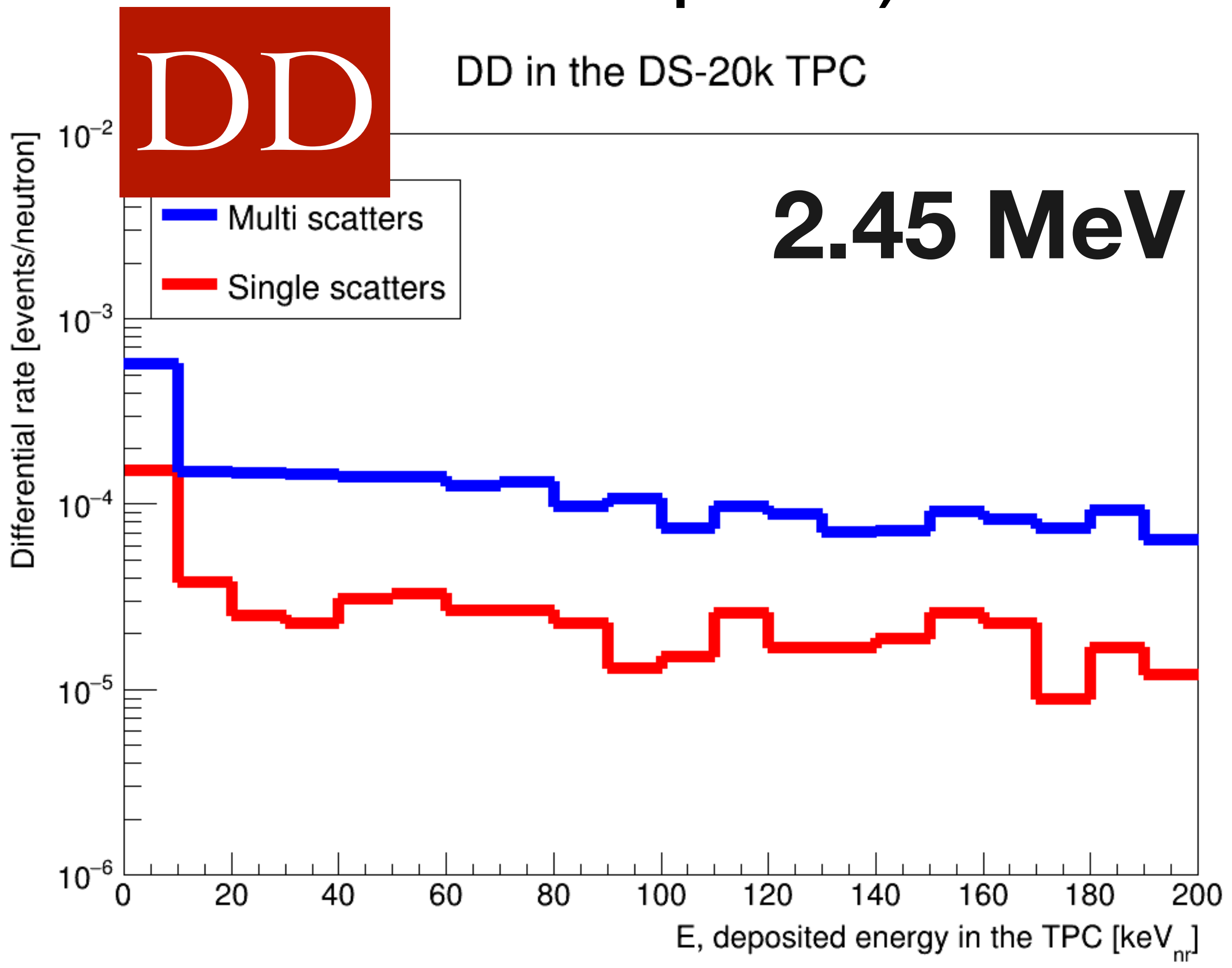
- NR : can be background (neutrons) or signal (WIMPs) **NR calibration = really at stake**

- g4ds : use of three radioactive sources of neutrons: AmBe, AmC, DD gun (monochromatic source of 2.45 MeV neutrons)

- Most important signal to calibrate = pure NR SS (signal that WIMP should deposit)







All events

Pure NR SS

Gold plated events	AmBe	AmC	DD
Side	1.1 e-3	6.4 e-4	6.5 e-4
Bottom	6.5 e-4	6.1 e-4	6.4 e-4

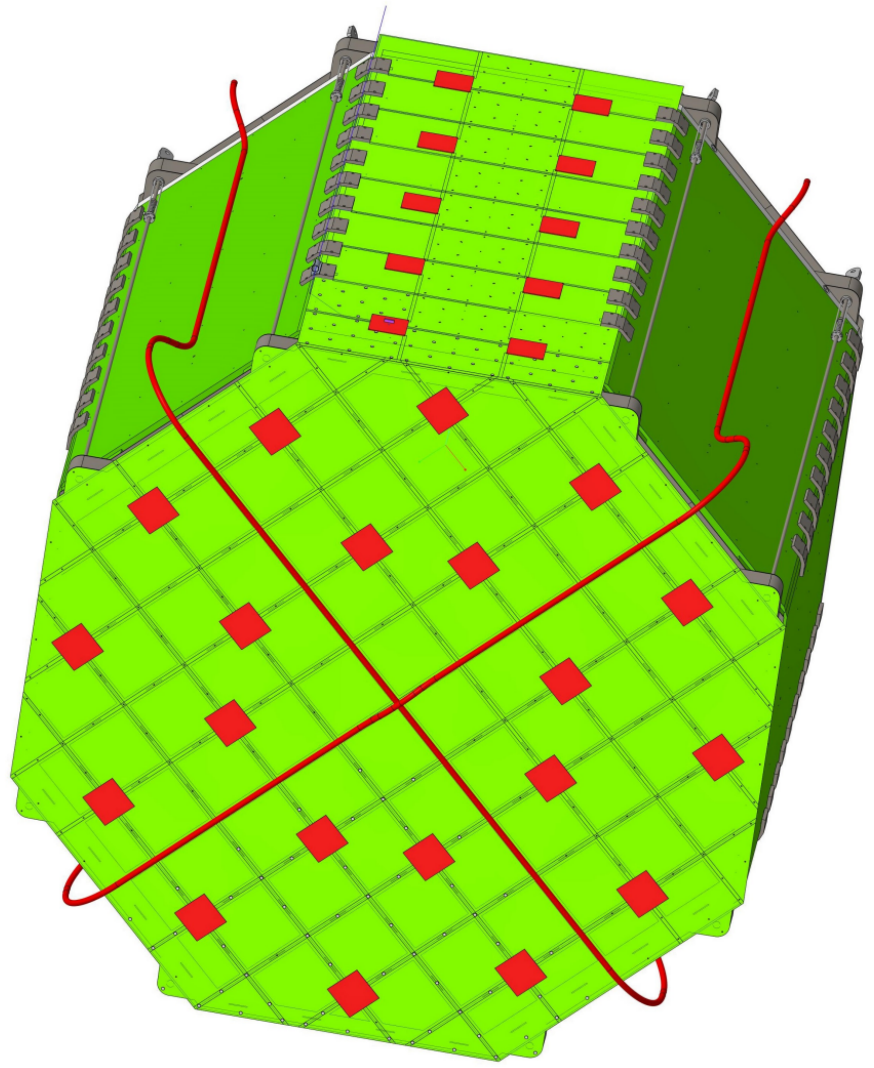
- Rates ≈ 1-6 e-4 evts/decay

- Asking for 1e4 pure NR SS, it leads to ≈ 1 month of NR calibration

Impact of the tubes on the detector

The preparation of the TPC calibration was the main goal of the simulation work. Yet, as the presence of the pipes can have a negative impact on the rest of the detector, simulations were performed in order to check how much impact the tubes have

Veto's Light Collection Efficiency (LCE)



- Tubes can absorb the light emitted by the argon when scintillating: this could lower the veto LCE
- Simulations were performed in order to test different optical boundaries so as to minimize the loss of LCE
- Best solution = **reflector-wrapped** titanium tubes : 4% LCE, 1% loss compared with the case without pipes

Veto and TPC background induced by titanium

^{238}U ^{235}U ^{232}Th ^{40}K ^{46}Sc

- **DS20k background budget = 0.1 events/10years**

NR

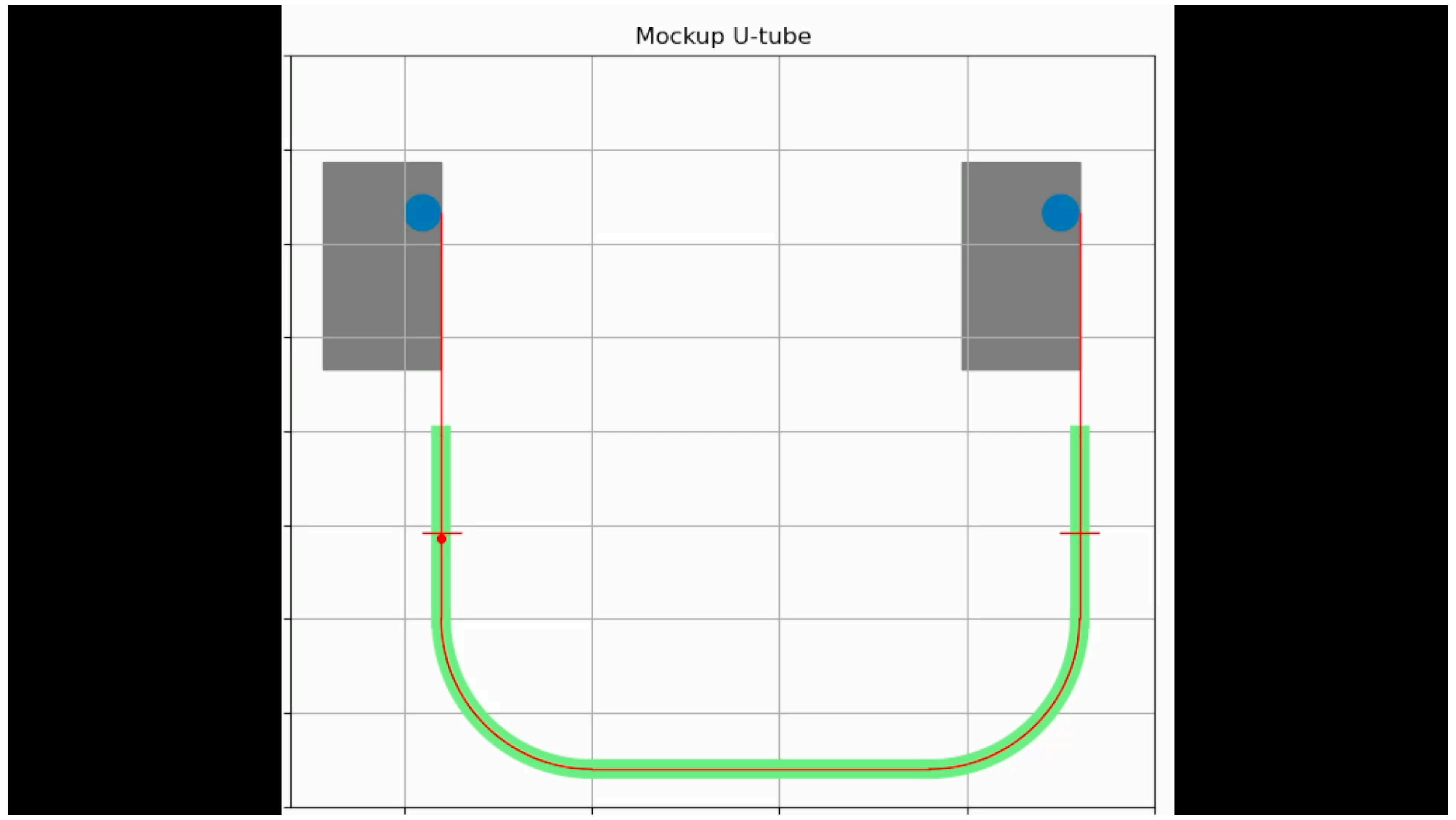
- Represents less than 0.01% of the budget : fully negligible

ER

- S1/S2 ratio + PSD: will be fully negligible

Ongoing tests at CPPM: the mock up of the calibration system

- Goal = check the feasibility of the calibration system: if sources don't get stuck in the pipes, test the motors system etc
- Mock up = one U-shaped tube inserted inside a tank
- Sept. 2022: the tank is thermally insulated and the mock up is complete -> tests at cold (LN_2, -196°C)
- Tests: the motors systems drive a fake source inside the U-shaped tube while being at cold in order to mimic the experimental conditions of DarkSide-20k
    - Measure: tension of the rope, position of the source + monitoring of the whole system
    - The tension increased after decreasing the temperature without blocking the source



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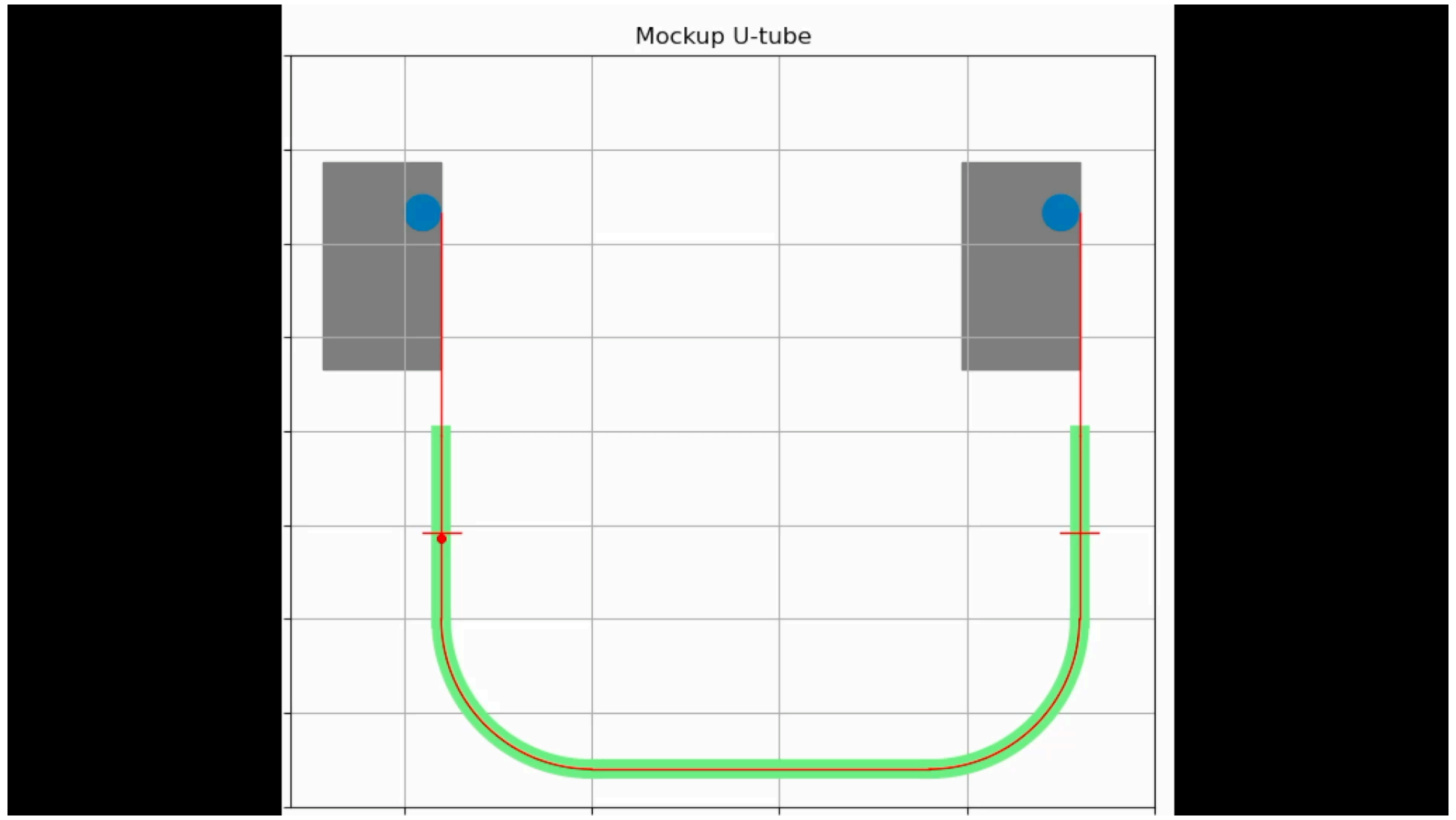


Conclusions

- The calibration is possible even considering the constraints of the detector
- ER calibration : 1 week / NR calibration : 1 month
- The calibration system do not induce too much background in the detector nor impacts consequently the efficiency of the veto buffer (in which the tubes are dived)
- Current tests : mock up of the calibration system, at cold

Perspectives

Searching for WIMPs

FUTURE COMMITMENTS

Create huge detectors

As the WIMPs are expected to have a very small interaction probability with ordinary matter, experiments should build very large (or dense) experiments in order to increase the detection probability

Shield the detector from background

In order not to miss an event being over crowded by background events. Dark matter direct searches are located deep underground

Know the detection limits of the experiment

In case on non detection, one cannot claim the non existence of dark matter, just its non existence in a certain phase space

The exclusion limits of an experiment are computed using a simple model of the Milky Way dark matter's halo

Understand the remaining background

It comes from natural radioactivity of the detector

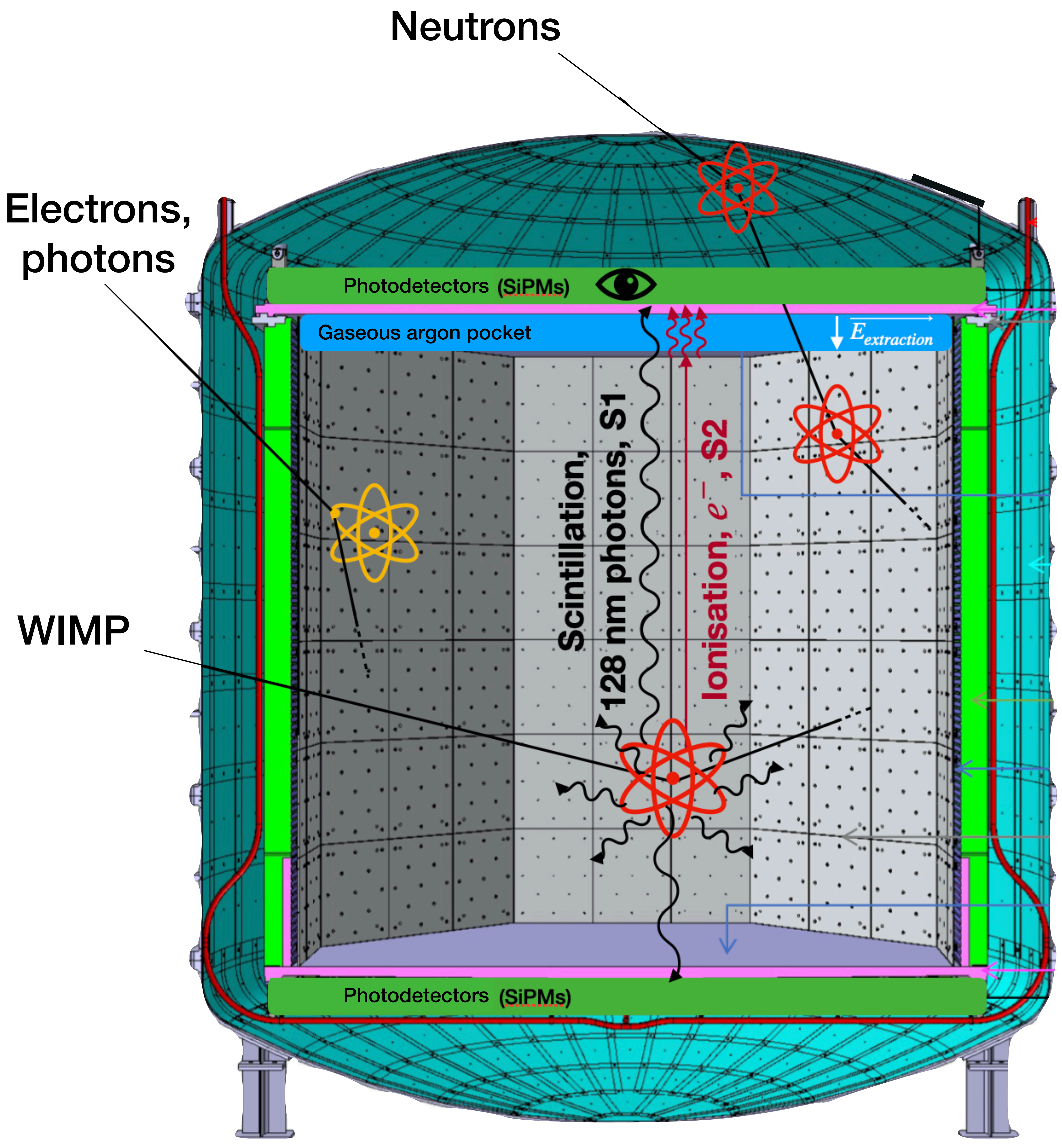
The most dangerous background comes from heavy particles (neutrons)

Discriminate background and signal

Use detectors that are able to discriminate backgrounds and signal. E.g. : as we expect WIMPs to be heavy, they are supposed to interact with the nucleus of the material of the detector while most background interact with cloud electrons

Back-up

Signals in a double phase TPC



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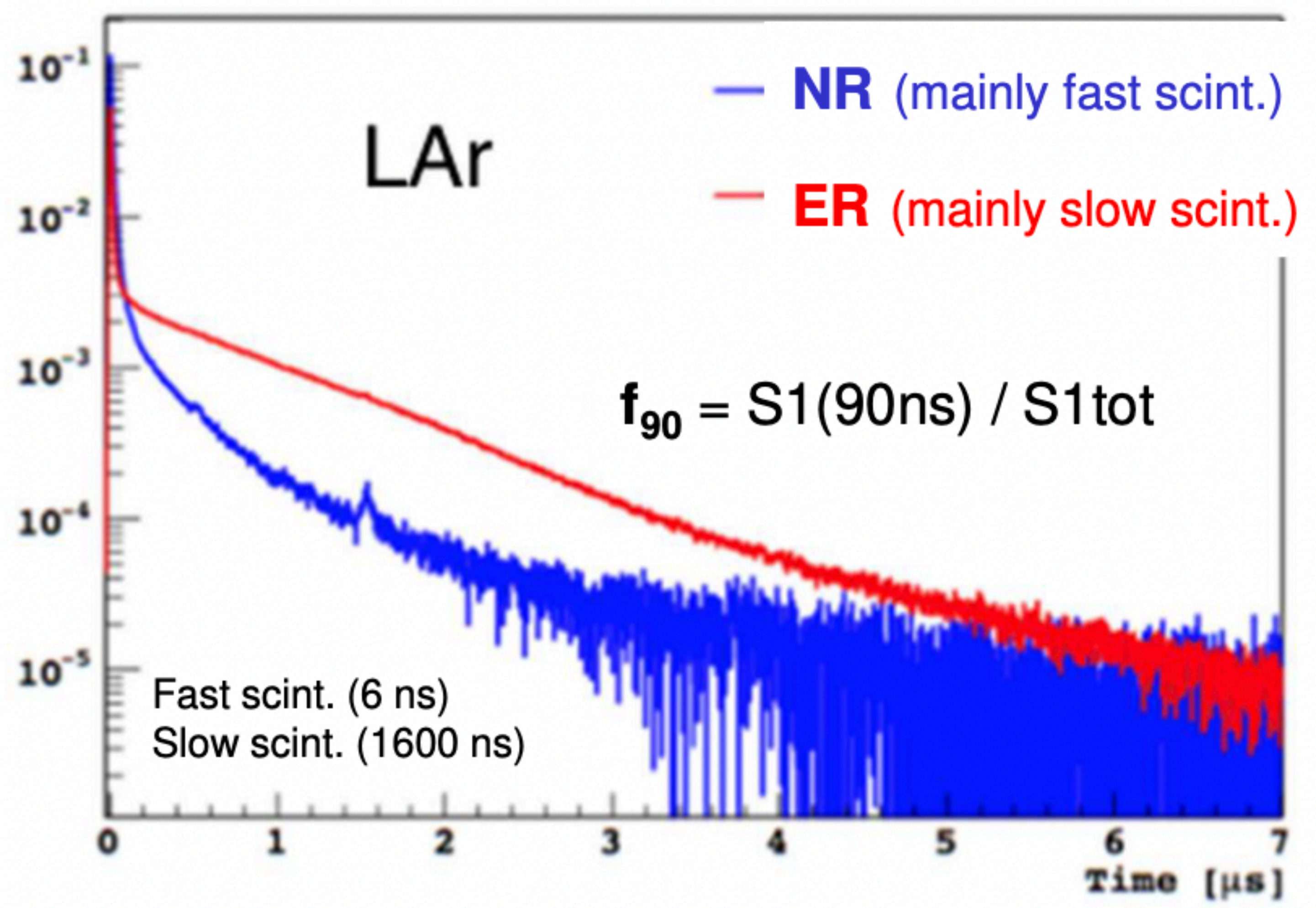
S1 Pulse Shape Discrimination (R_{ER}>10^8)*



* PSD measurement by DEAP-3600 in PRD 100 (2019) 022004

Example with DarkSide 50