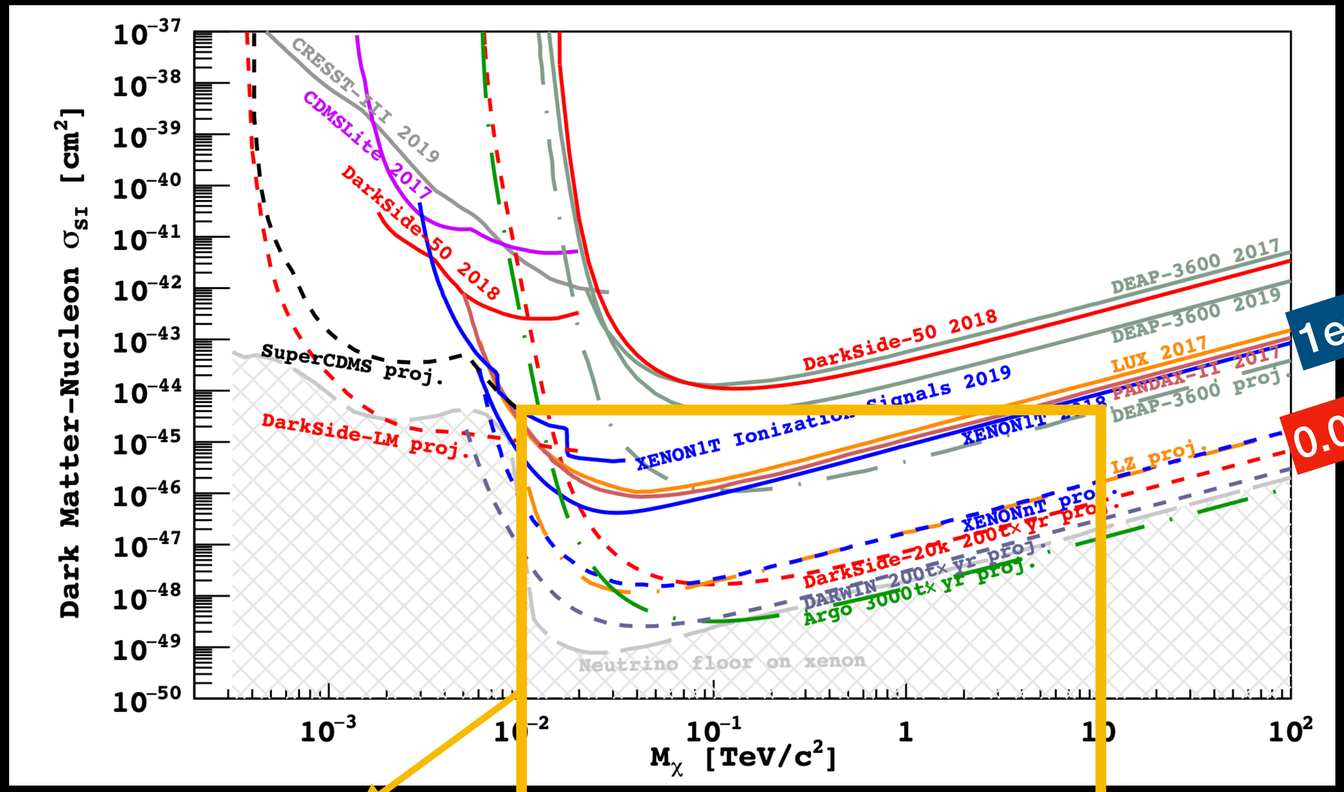
Direct search for Dark Matter with the DarkSide-20k experiment

Marie van Uffelen - PhD student - 10/02/2022 - IPhU days

PhD supervisors: Fabrice Hubaut (CPPM), Emmanuel Nezri (LAM)

WIMPs & DarkSide-20k



- Strong discovery potential in the 10GeV-10TeV range
- Next Argon experiment: DarkSide-20k
  - 200 t x year exposure
  - Argon **double phase TPC**

Technology providing the best limits at high WIMP mass

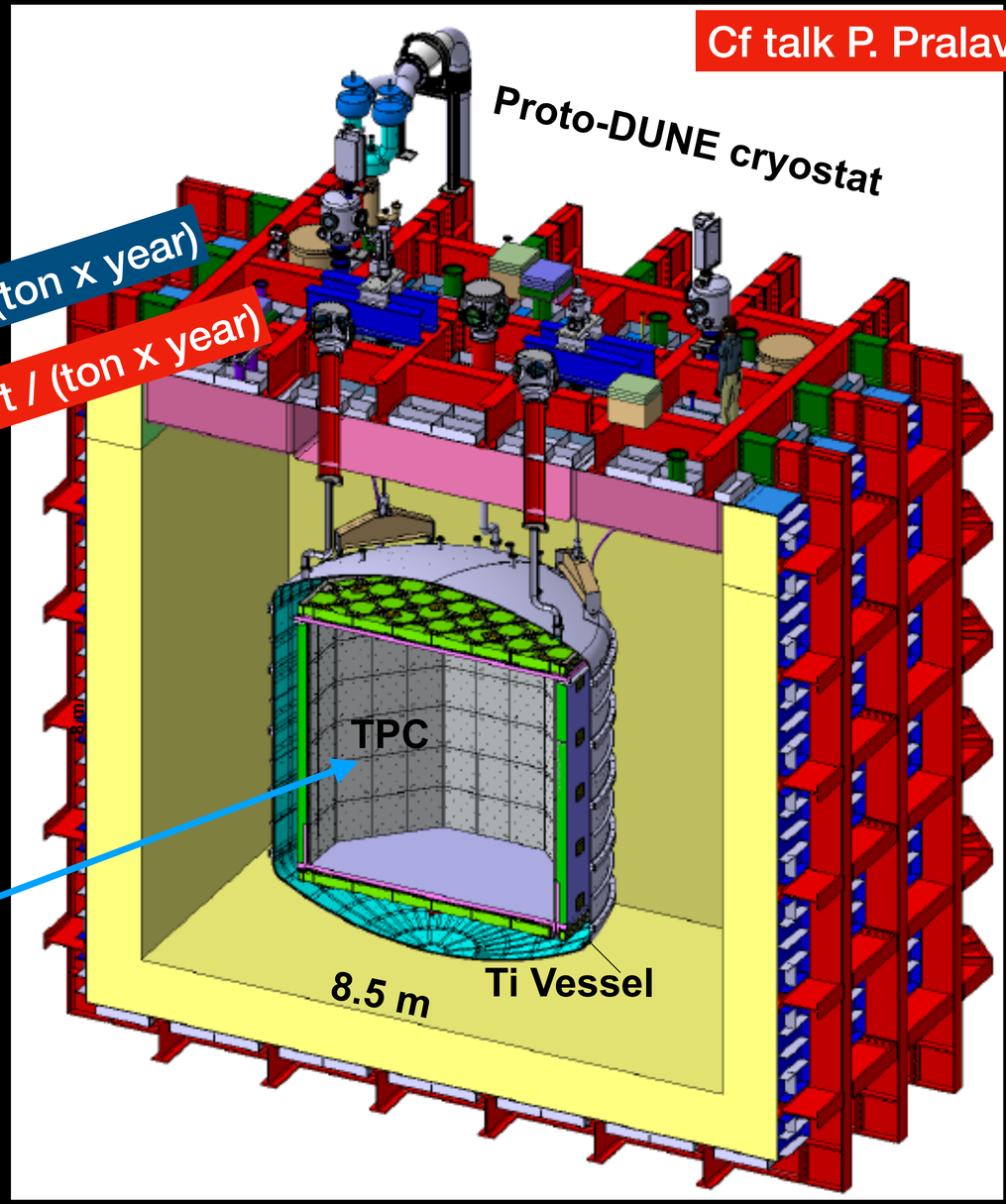
1evt / (ton x year)

0.01 evt / (ton x year)

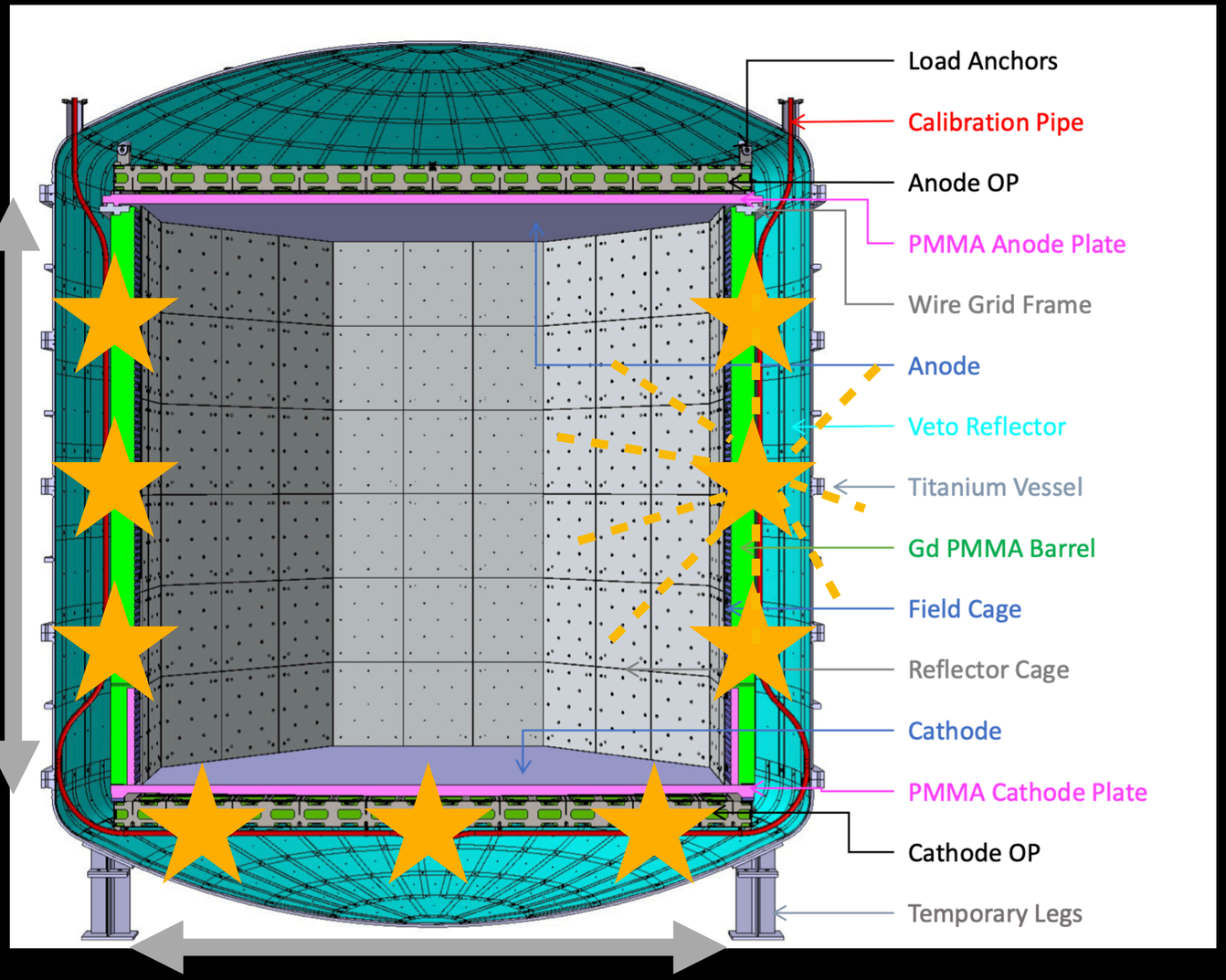
Will be the largest TPC ever built for dark matter search purpose

needs to be properly calibrated

Cf talk P. Pralavorio



The TPC calibration set up



- 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

Hardware work: mock up

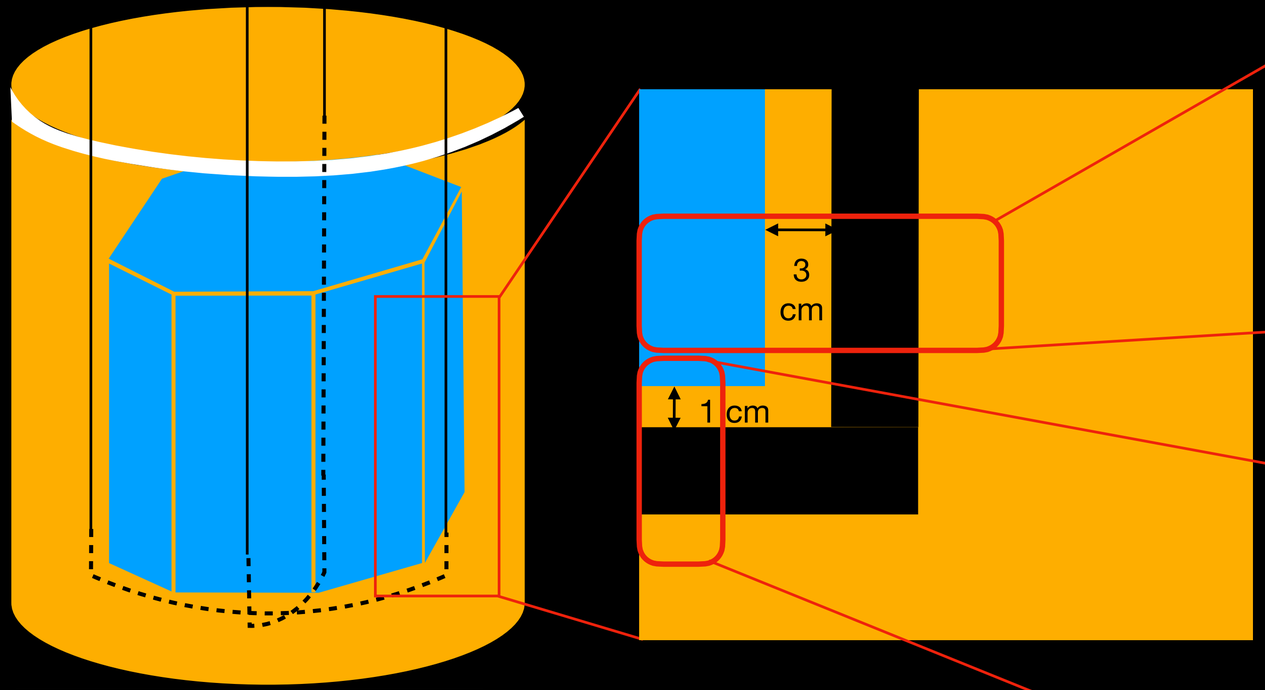
- Goal = check the feasibility of the calibration system: if sources don't get stuck in the pipes, test the motors system …
- Mock up = one U-shaped tube inserted inside a tank
- July 2021: the tank is thermally insulated -> tests at cold (LN_2)
- July test's goal = test the hermeticity of the tank, measure the volume of LN_2 needed to fill the tank, measure the constraints applied on the tubes when cooling down
- Since then, the motors have been added -> new interesting tests to come (2022)

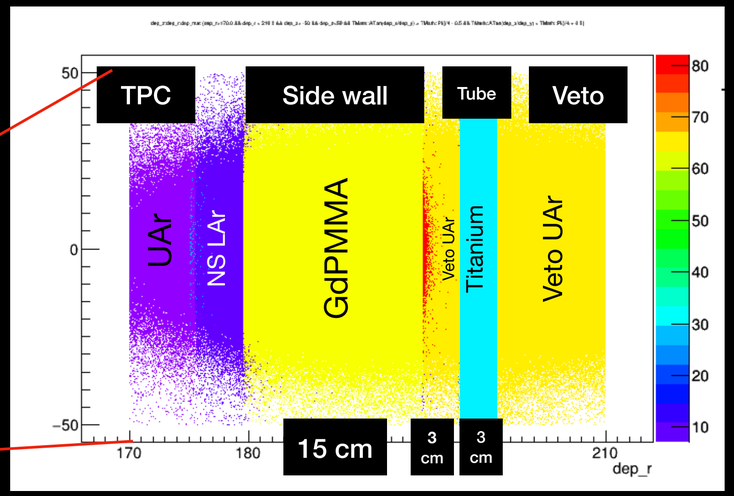
Work on this during my internship
See back-up for more details

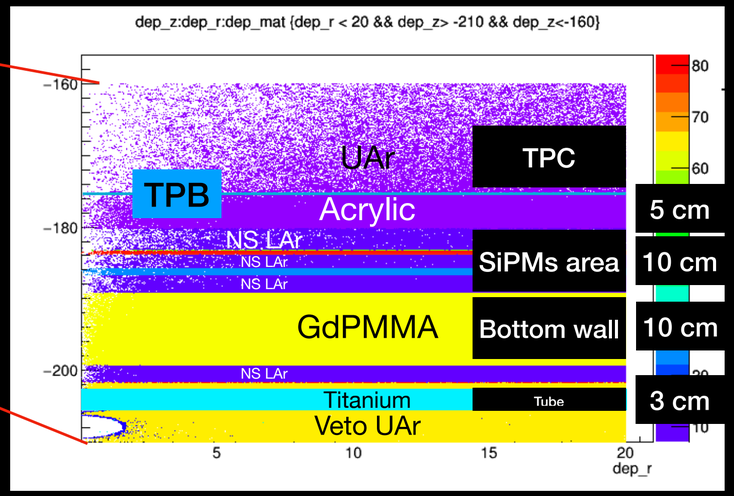
Financed by
Institut Physique de l'Univers
Aix*Marseille Université

The TPC calibration set up inside g4ds

- 2017: first DS20k design proposal
- 2019: new design of DS20k, complex veto, design called « plan A »
- Dec. 2021: **TDR froze the geometry of DS20k** -> redo all the simulations made for plan A

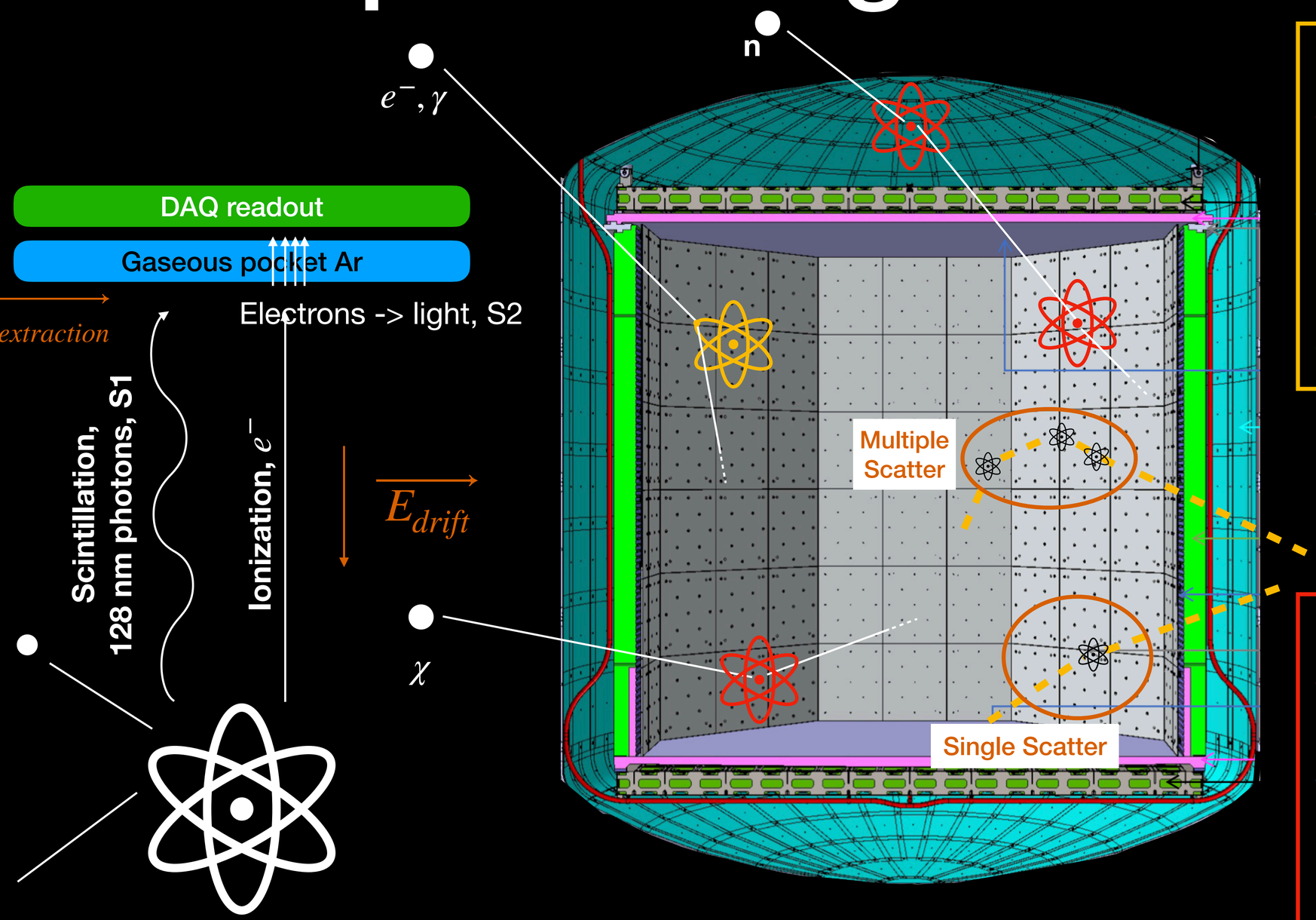






Geometry of the detector as it is implemented in g4ds, a GEANT4-based software applied for the DarkSide20k experiment

Expected signals in the TPC



ER signal

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

LAr => very good separation between both

NR signal

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

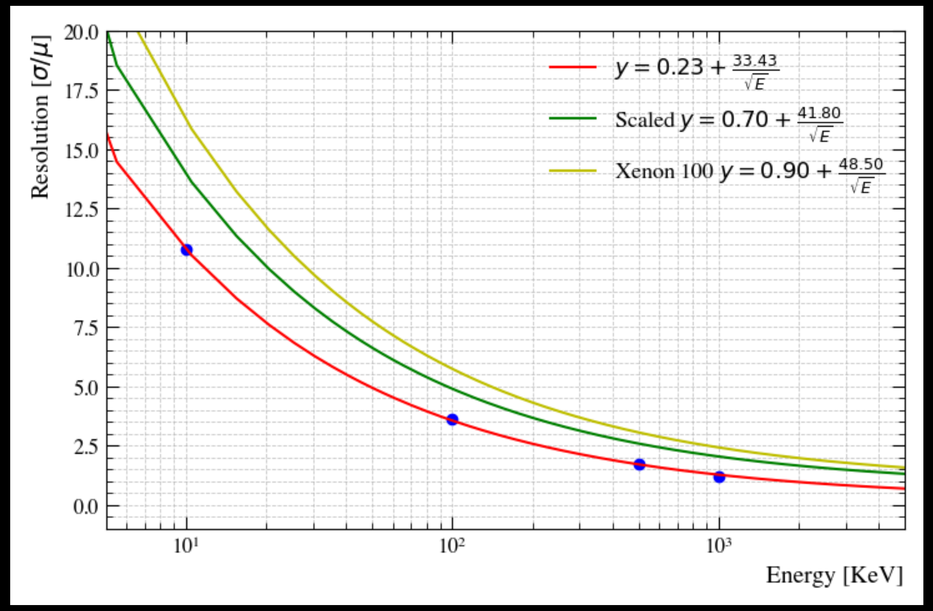
Simulation of the response to photon sources exposure (ER)

- 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

Takes all the physics of the detector into account



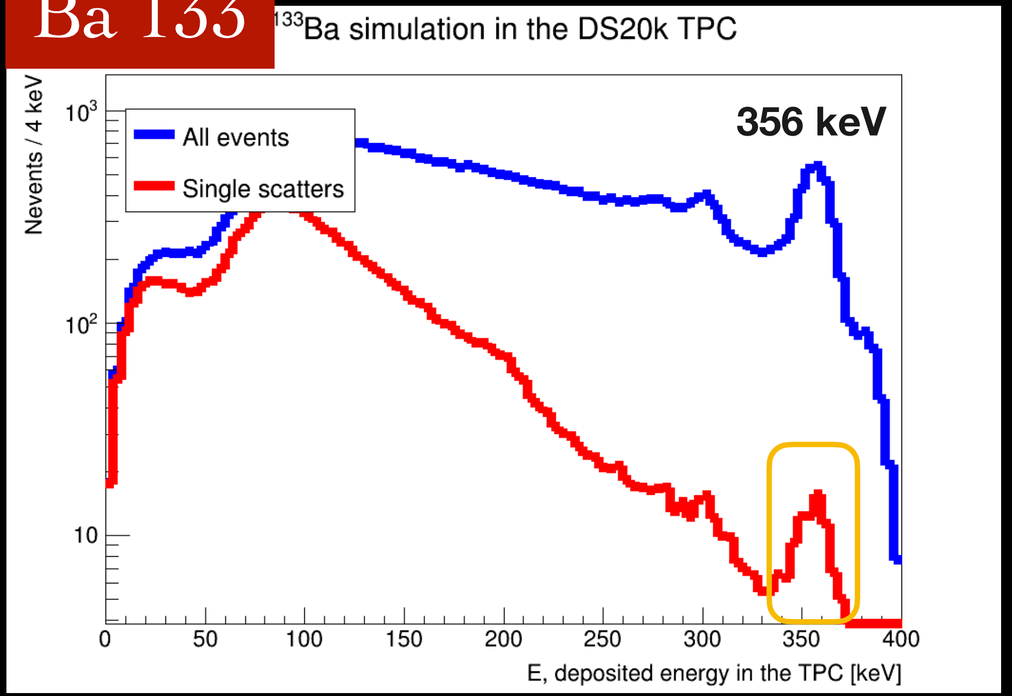
DS20k resolution = 0.0023 + 0.334/sqrt(E)

Spectrum normalized to 10 000 pure ER SS events

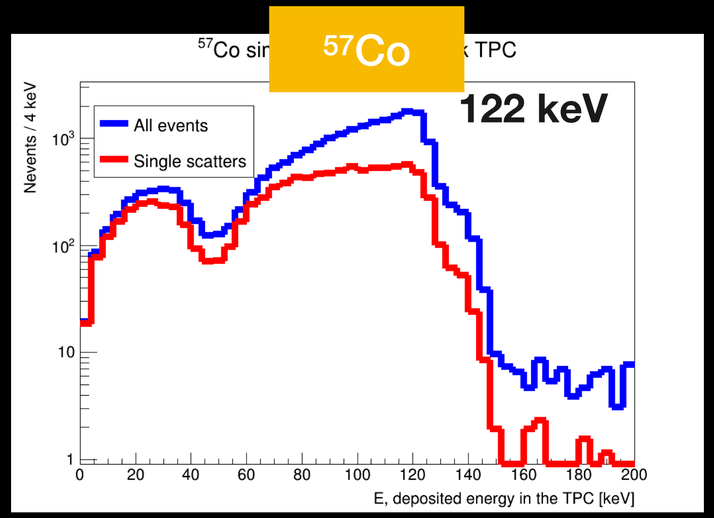
All events | Pure ER SS

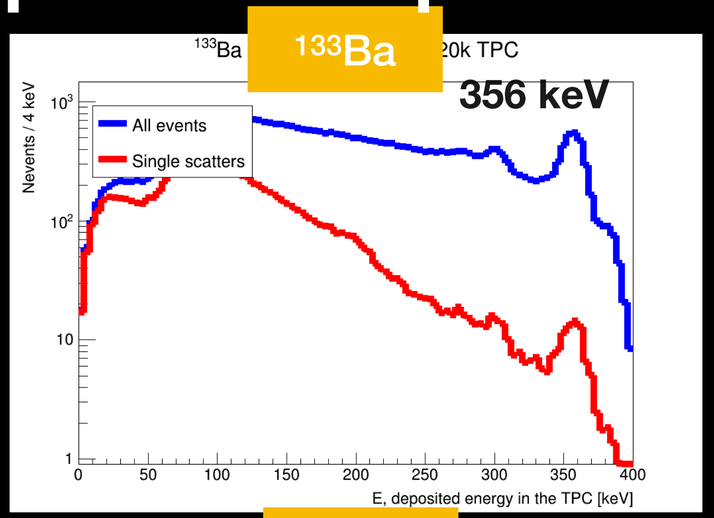
From these spectra: computation of the **rates of interesting events** inside the TPC per decay of the source located in the tubes

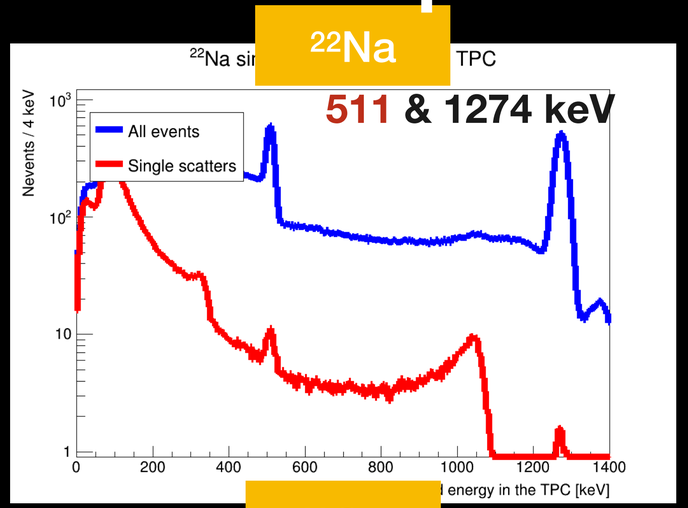
Ba 133

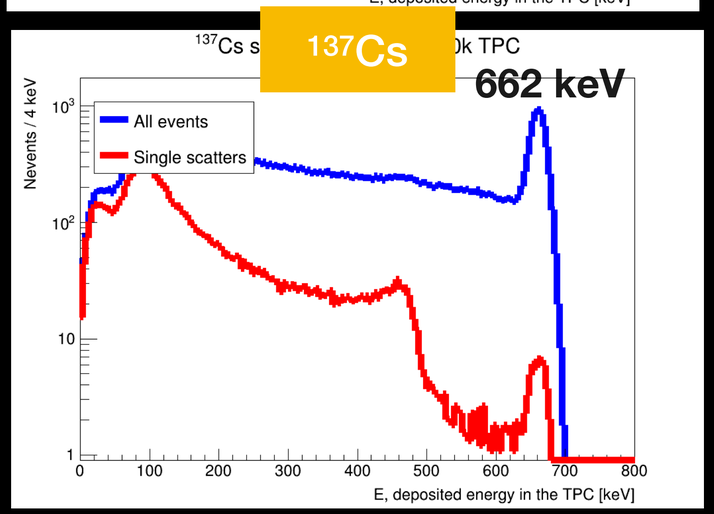


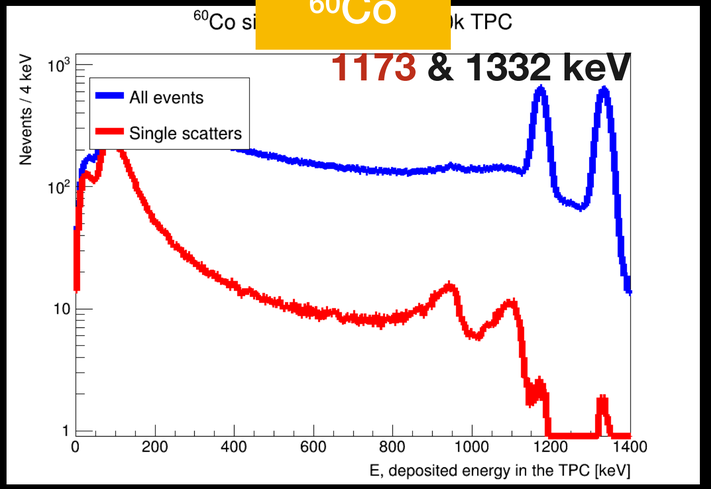
Simulation of the response to photon sources exposure











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

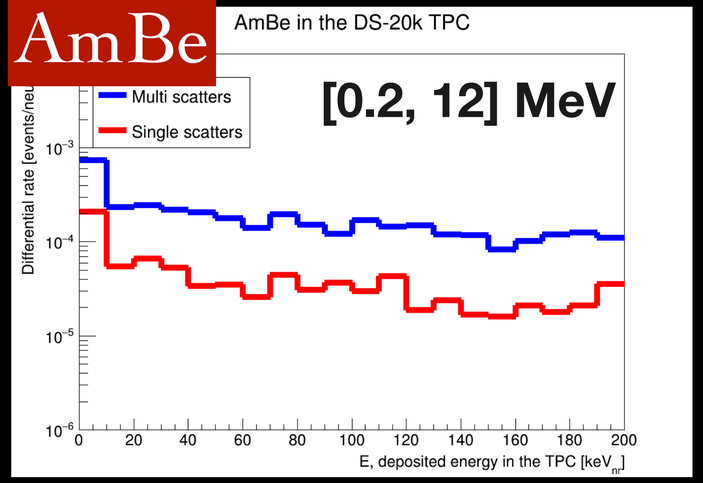
- Rates ∈ [1.2 e-5, 6.2 e-4] evts/ decay
- Asking for 1e3 pure ER SS in the photoelectric peak, it leads to ≈ 1 week of ER calibration

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

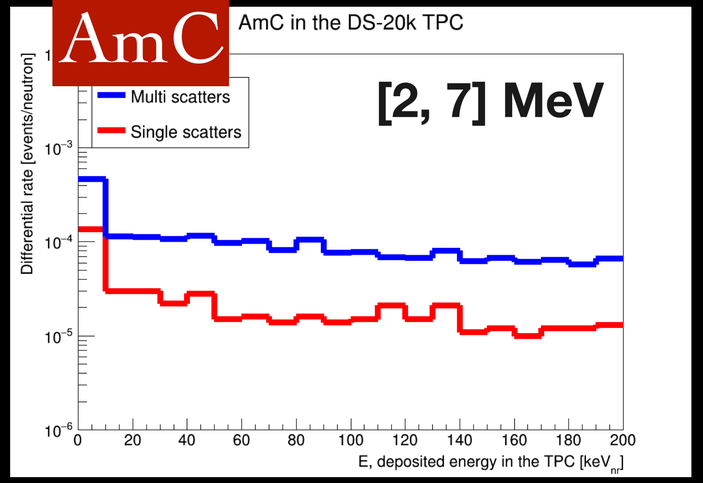
Simulation of the response to neutron sources exposure (NR)

- 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)

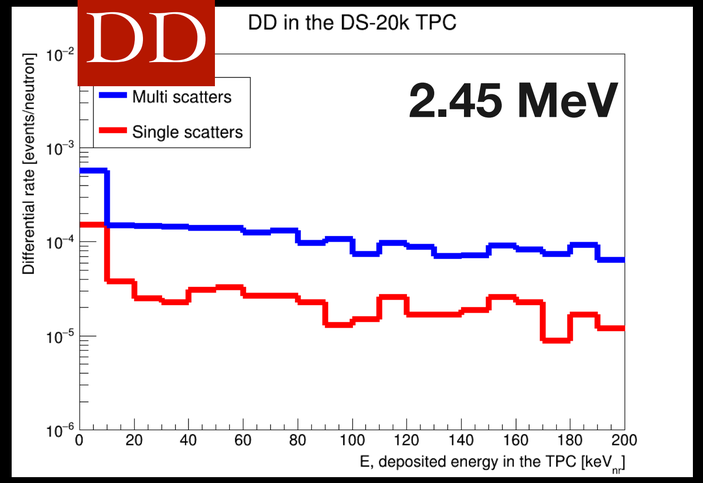
AmBe



AmC



DD



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

Some tricks could fasten the calibration

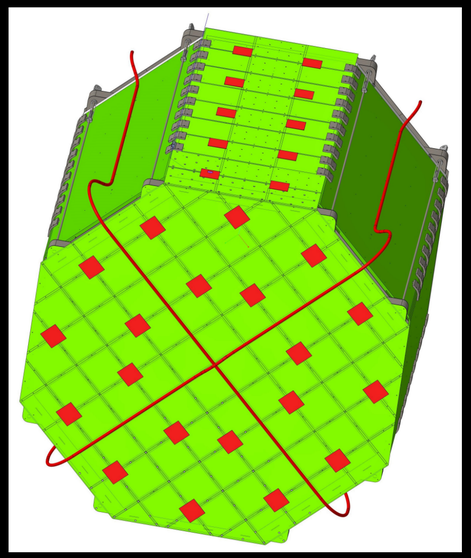
Crave a window in the wall

Perform the calibration where the Gd wall is thiner

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 thecase 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**

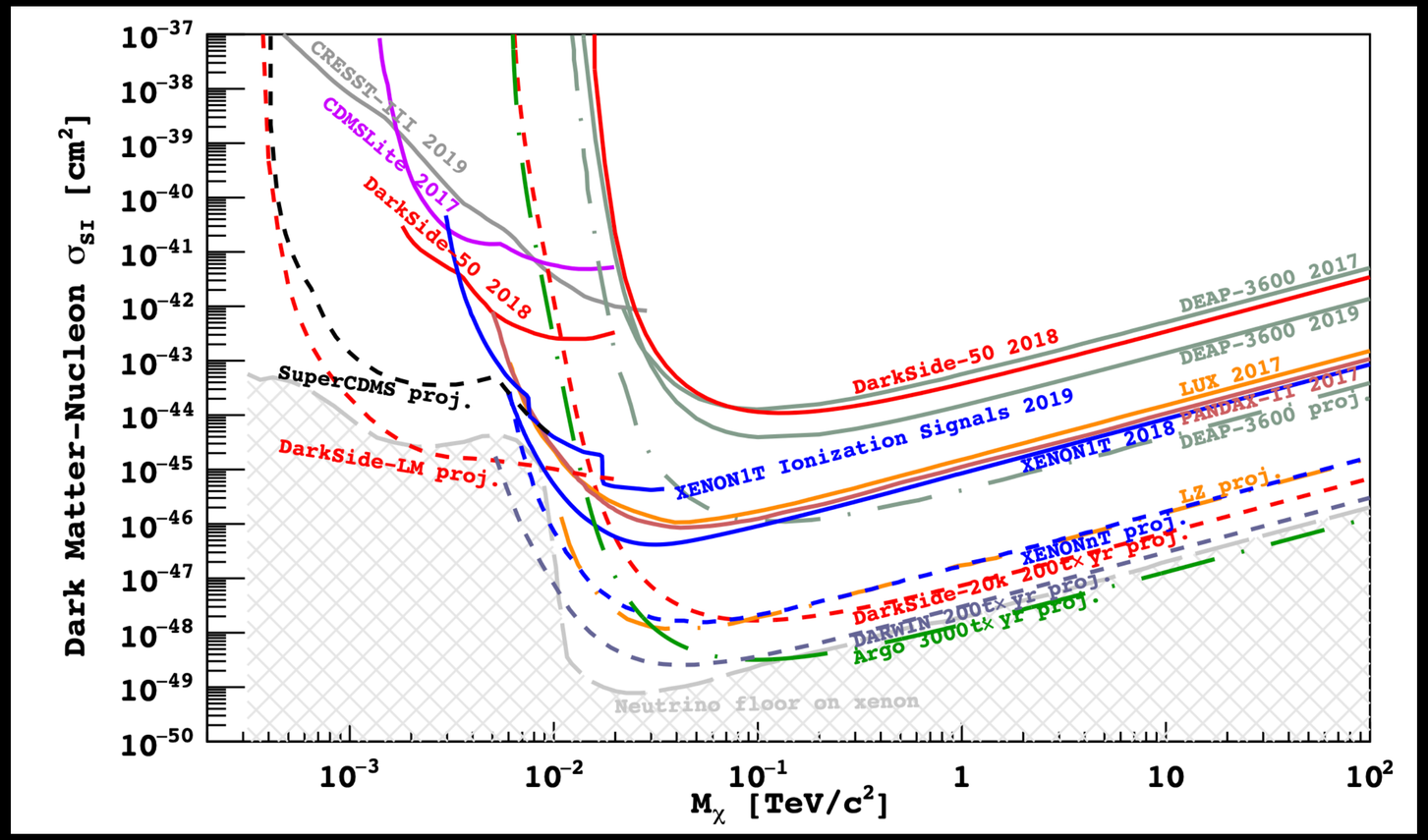
NR

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

ER

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

Current work: phenomenology



- $$\frac{dR}{dE_R} = \frac{\rho_0}{m_\chi m_N} \int_{v_{min}}^{v_{esc}} \frac{f(v)}{v} \frac{d\sigma}{dE_R} d\vec{v}$$

  HEP Astro Y-Axis X-Axis

- Parameters at stake : $v_0, v_c, v_{esc}, \rho_0$ & f(v)
- Changing these parameters will affect the exclusion limits
- Goal: assess astrophysical uncertainties on DS-20k exclusion limit

Current main admitted model

SHM = Standard Halo Model

- SHM: the velocity distribution is Maxwellian = $\frac{N}{2\pi v_0^2} exp\left(-\frac{3|\vec{v}|^2}{2v_0^2}\right)$

- SHM : $v_0 = 220\ ^{+50}_{-50} km/s$

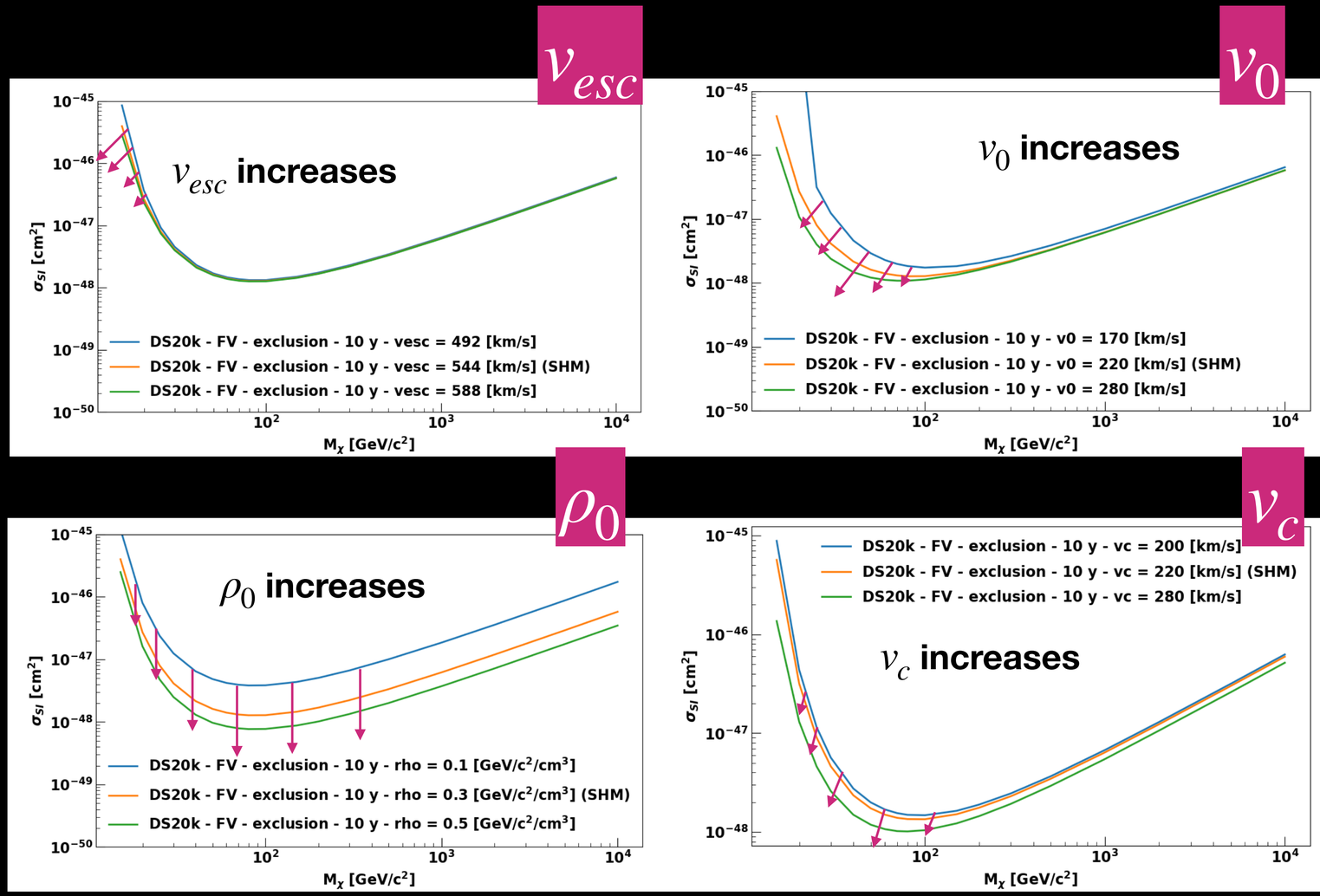
$v_c = 220\ ^{+60}_{-20} km/s$

$v_{esc} = 544\ ^{+54}_{-41} km/s$

$\rho_0 = 0.3\ ^{+0.2}_{-0.03} GeV/cm^3 = 8 \cdot 10^{-3} M_\odot/pc^{-3}$

! **Ranges of fiducial values**

- Goal: assess astrophysical uncertainties on DS-20k exclusion limit



Timeline

TPC calibration simulation
Phenomenology
Mock-up
Signal reconstruction

1st of October: start of the PhD

Institut Physique de l'Univers

Purchase of a computer

Present

Proto-0 runs & tests

End 2022

Proto-1 construction

End 2022

DS facilities visit at CERN

Institut Physique de l'Univers

Long test of calibration pipes at CERN

Beginning 2023

Internship

Simulations of the calibration in the previous geometry of DS20k

Hardware work on the mock up at CPPM:

- *Tests at room temperature and cold*
- *Strain deformation vs temperature + data analysis*

*Simulations of the calibration in the **frozen** geometry of DS20k*

- *TPC calibration strategy*
- *Minimization of the guide tube system impact on the other parts of DS20k*

Writing of an internal note presenting the simulation results

7 oral reports to the collaboration

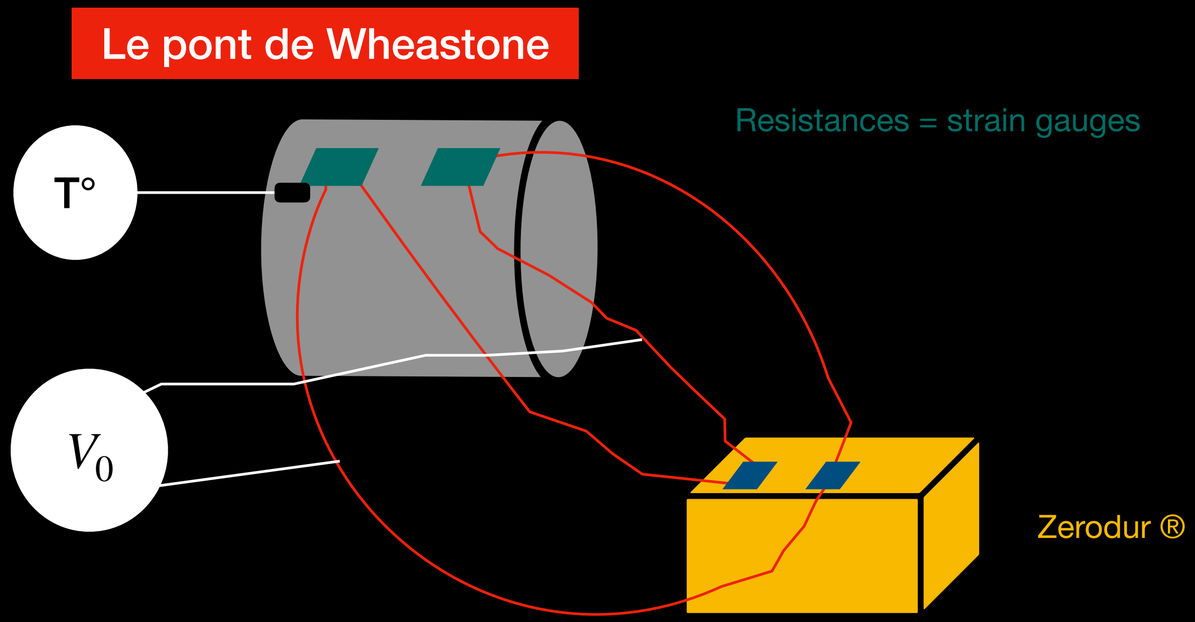
Astrophysical impact on the DS20k exclusion limits

Using AI to help signal reconstruction and optimize signal/background rejection

Back-up

Hardware work: mock up

- Mock up built at CPPM to check if the system is doable (cold resistance, circulation of rope inside the pipes, foresee the calibration time, motors monitoring precision …)
- U-shape tube, made with stainless steel
- Measure of strain vs temperature in order to study the lengthening of the pipe when cooling down
  - Room temperature
  - Heat
  - Cold tests (LN_2)

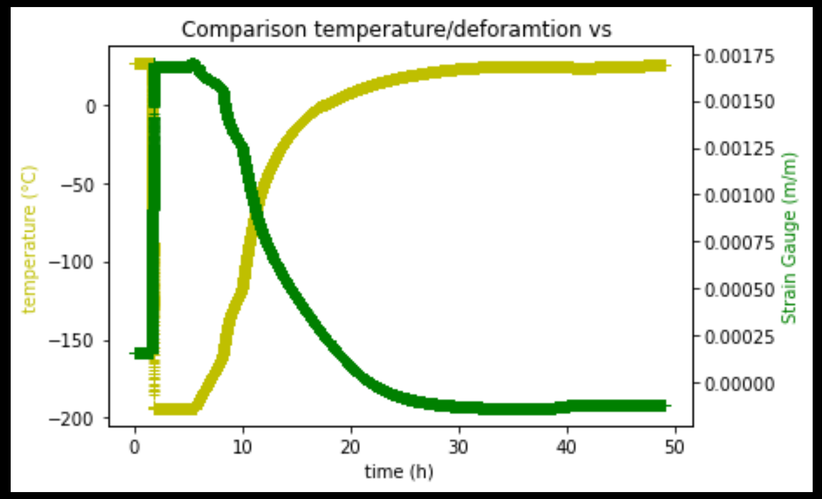


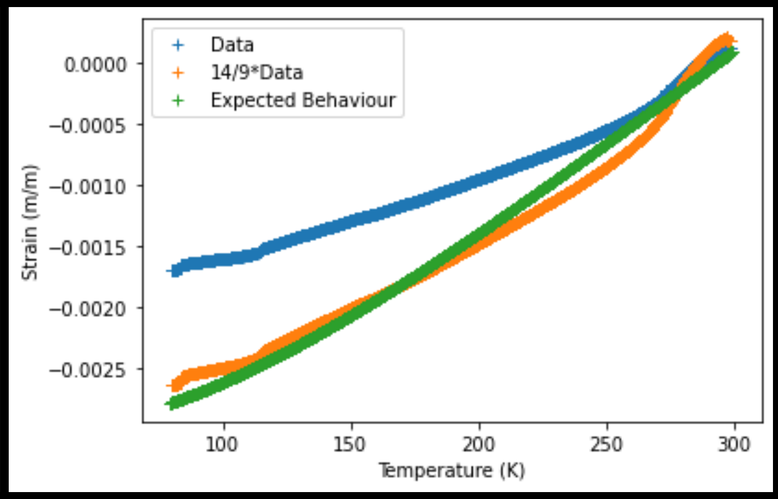
Expected behaviour: equation of the form:

$$y = a + bT^{+}cT^{2} + dT^{3} + eT^{4}$$ **if T >** T_{low}

Y = cste if T < T_{low}

$T_{low} = 23K$





Current design of the mock up

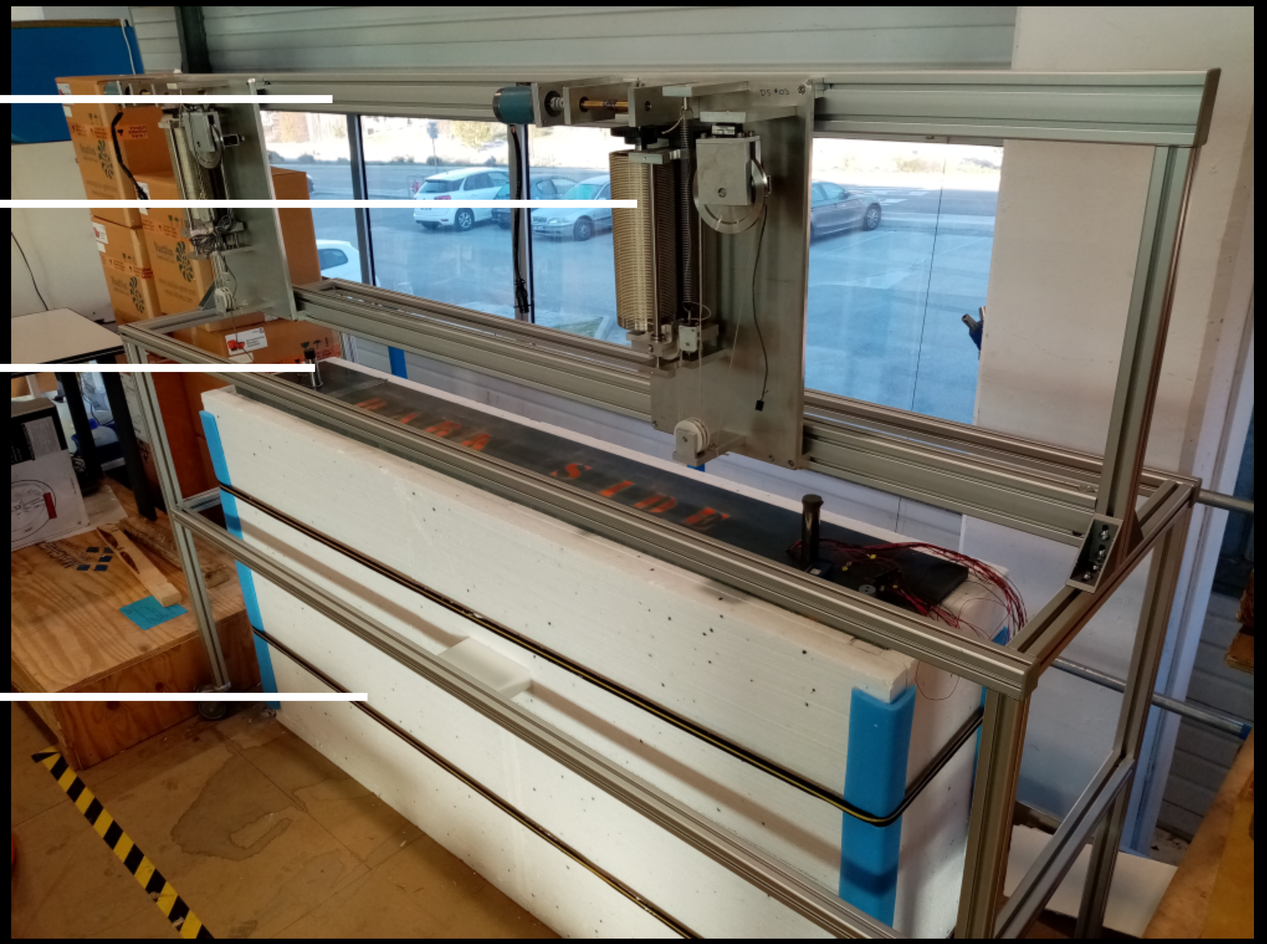
On the CPPM platform

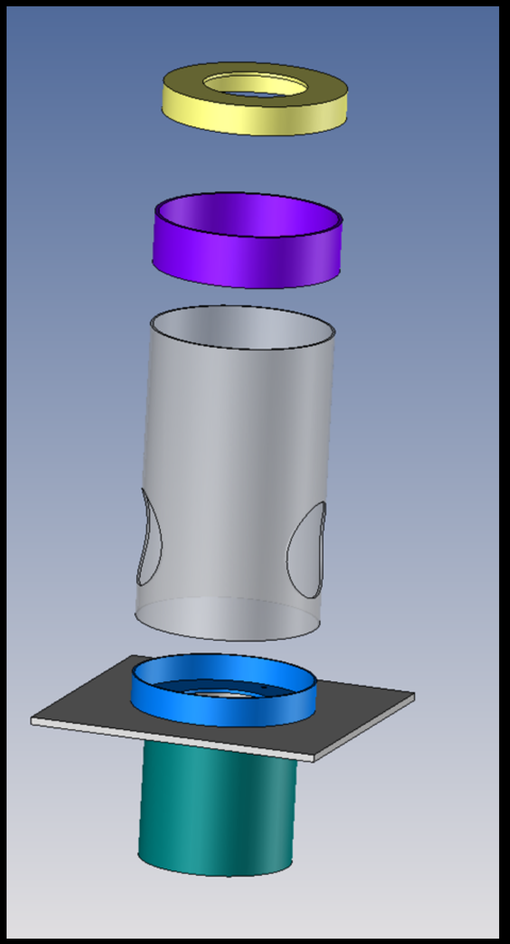
Structure holding the motors

Motors which will drive the rope

Stainless steel pipes
U-shaped inside the tank
(+ rope inside)

Insulated tank which will
contain LN_2





Glove box mockup

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Simulation of the response to neutron sources exposure (NR)

NR calibration = really at stake

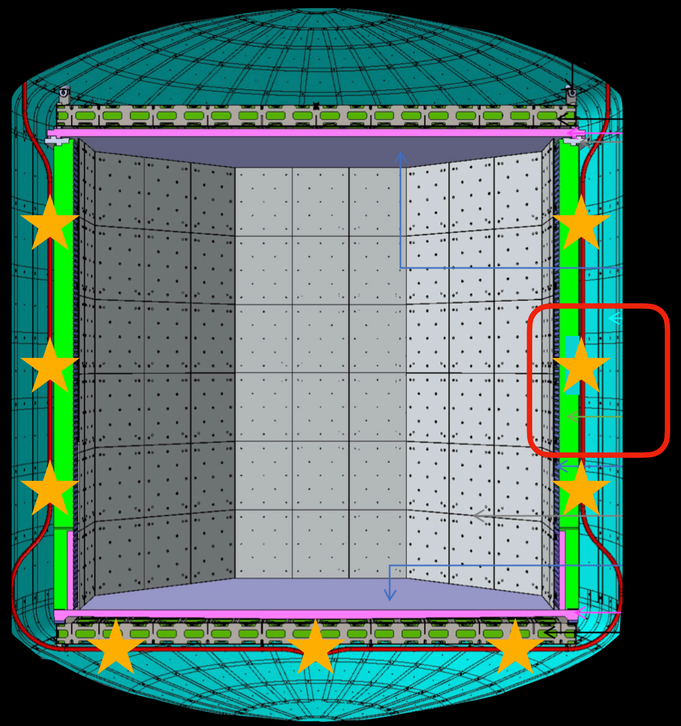
Gold plated events	AmBe	AmC	DD
Side	1.1 e-3	6.4 e-4	6.5 e-4
Bottom	6.5 e-4	6.1 e-4	6.4 e-4

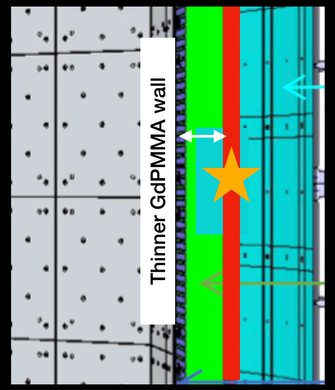
- Rates ≈ 1-6 e-4 evts/decay
- Asking for 1e4 pure NR SS, it leads to ≈ 1 month of NR calibration

Crave a window in the wall

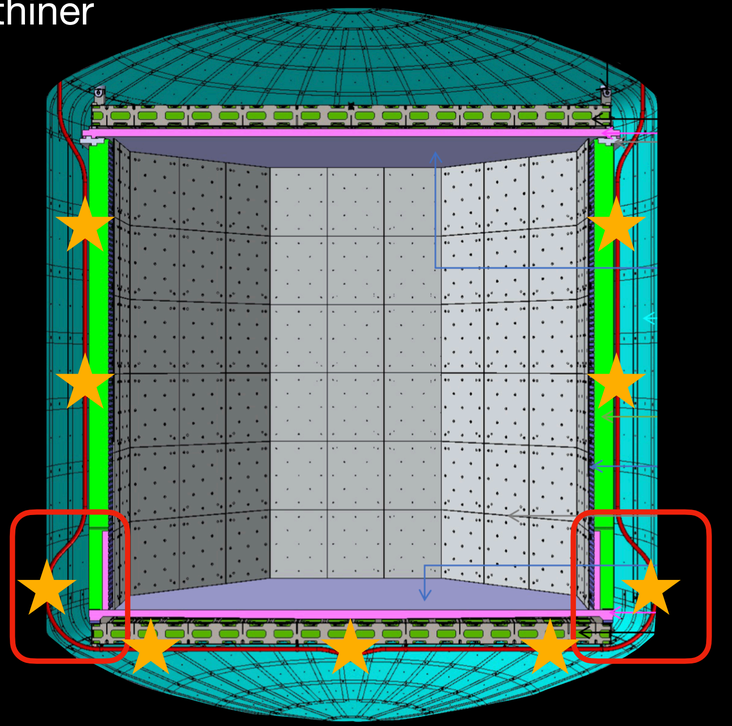
Some tricks could fasten the calibration

Perform the calibration where the Gd wall is thiner





Rates multiplied by ≈ 2



Here : Rates multiplied by ≈ 2

Current main admitted model

SHM

- SHM: the velocity distribution is Maxwellian = $\frac{N}{2\pi v_0^2} exp\left(-\frac{3|\vec{v}|^2}{2v_0^2}\right)$

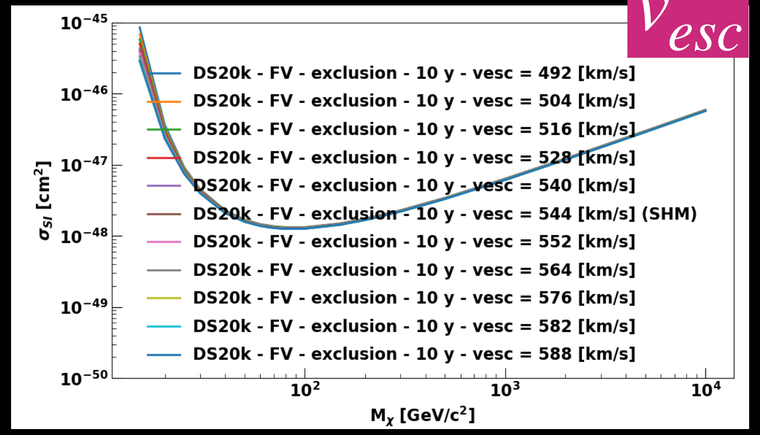
- $v_0 = 220^{+50}_{-50} km/s\,, \quad v_c = 220^{+60}_{-20} km/s$
  $v_{esc} = 544^{+54}_{-41} km/s$
  $\rho_0 = 0.3^{+0.2}_{-0.03} GeV/c^2/cm^3$

! More best-fit mean value ranges than uncertainties

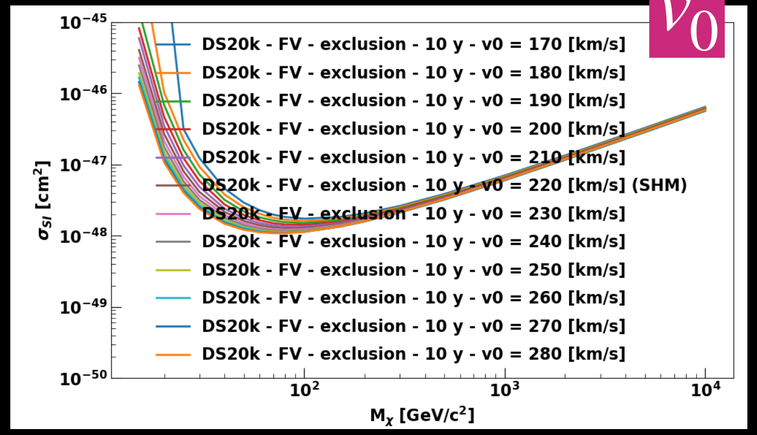
- Changing these parameters will affect the exclusion limits -> bandwidth

- Goal: find the exclusion limits with astrophysical parameter within their uncertainty and for different plausible velocity distributions

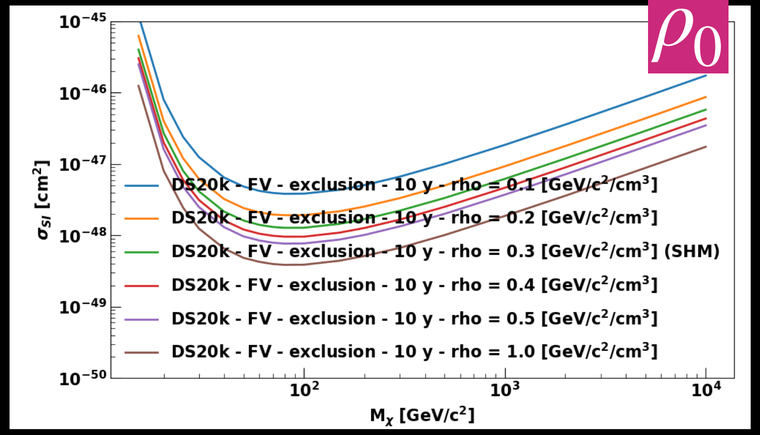
v_{esc}



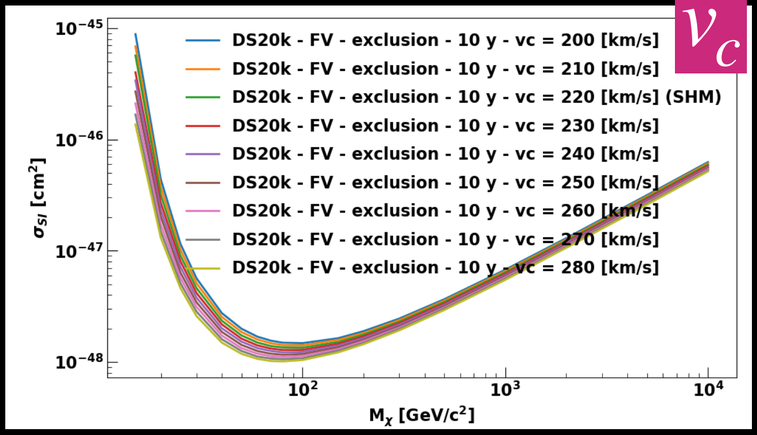
v_0



ρ_0



v_c



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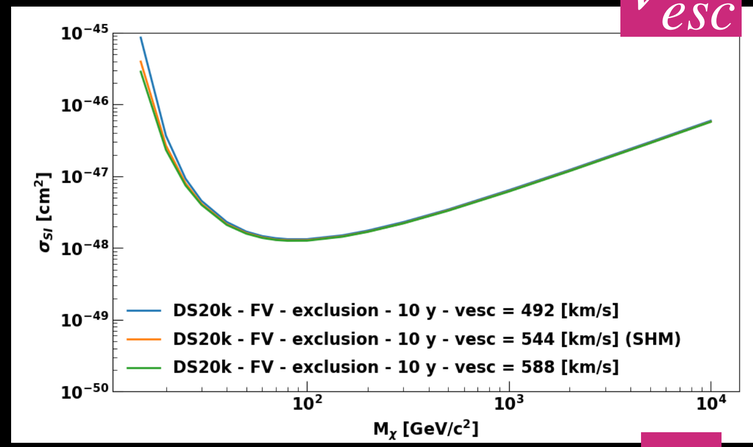
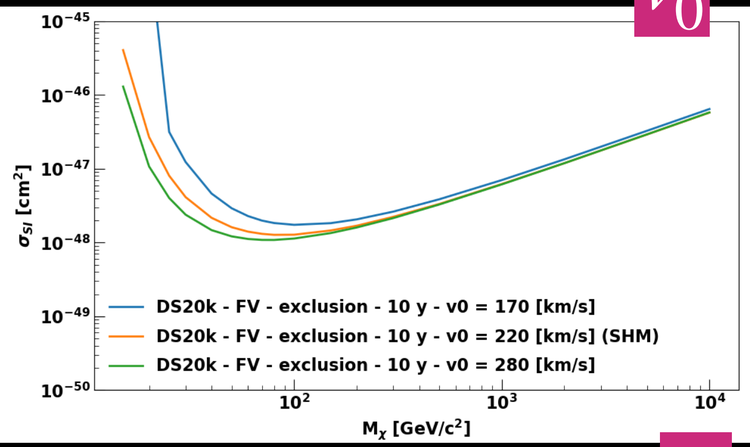
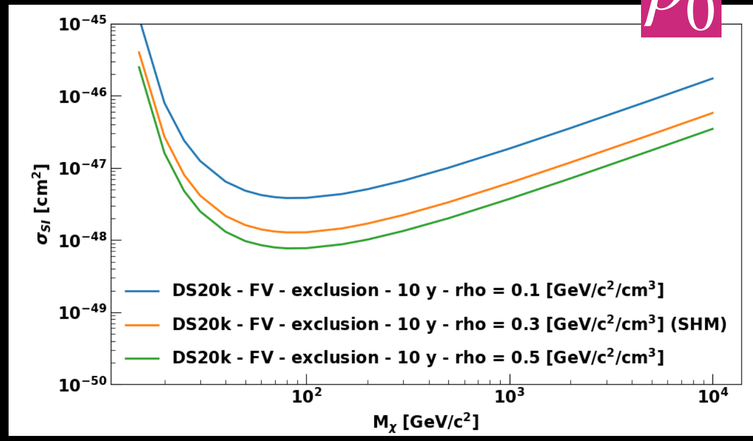
v_{esc}



v_0



ρ_0



v_c