MARIE VAN UFFELEN - PHD THESIS DEFENSE - THURSDAY, THE 26TH OF SEPTEMBER 2024

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

Direct search for dark matter with the DarkSide-20k experiment

DARKSIDE

amU Aix Marseille Université

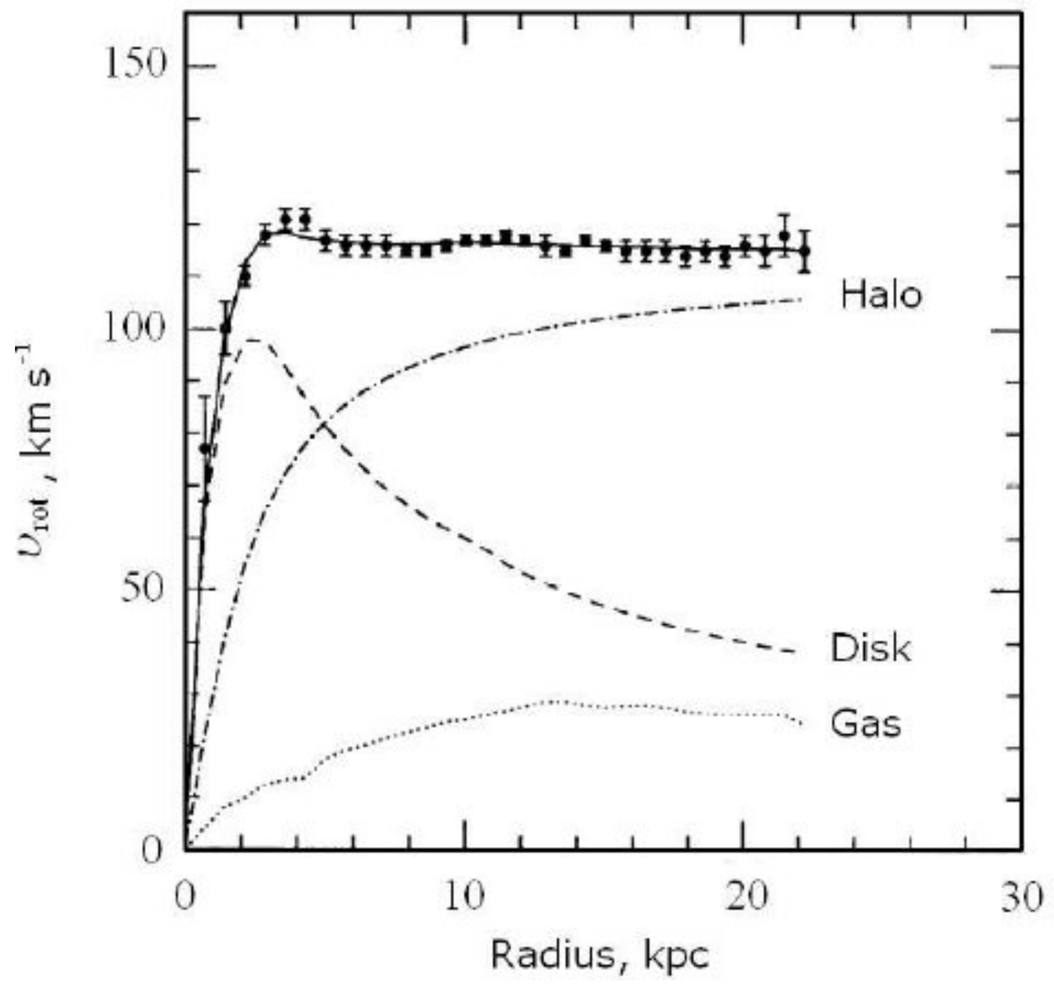
Institut Physique de l'Univers Aix Marseille Université

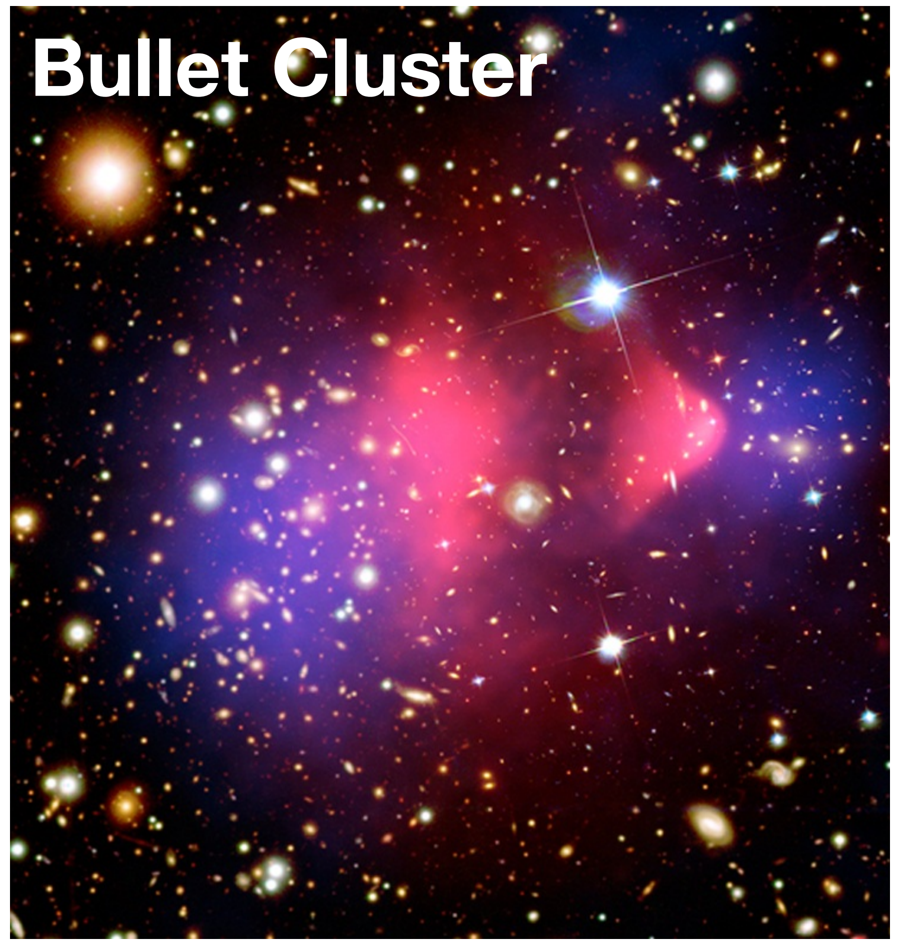
LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

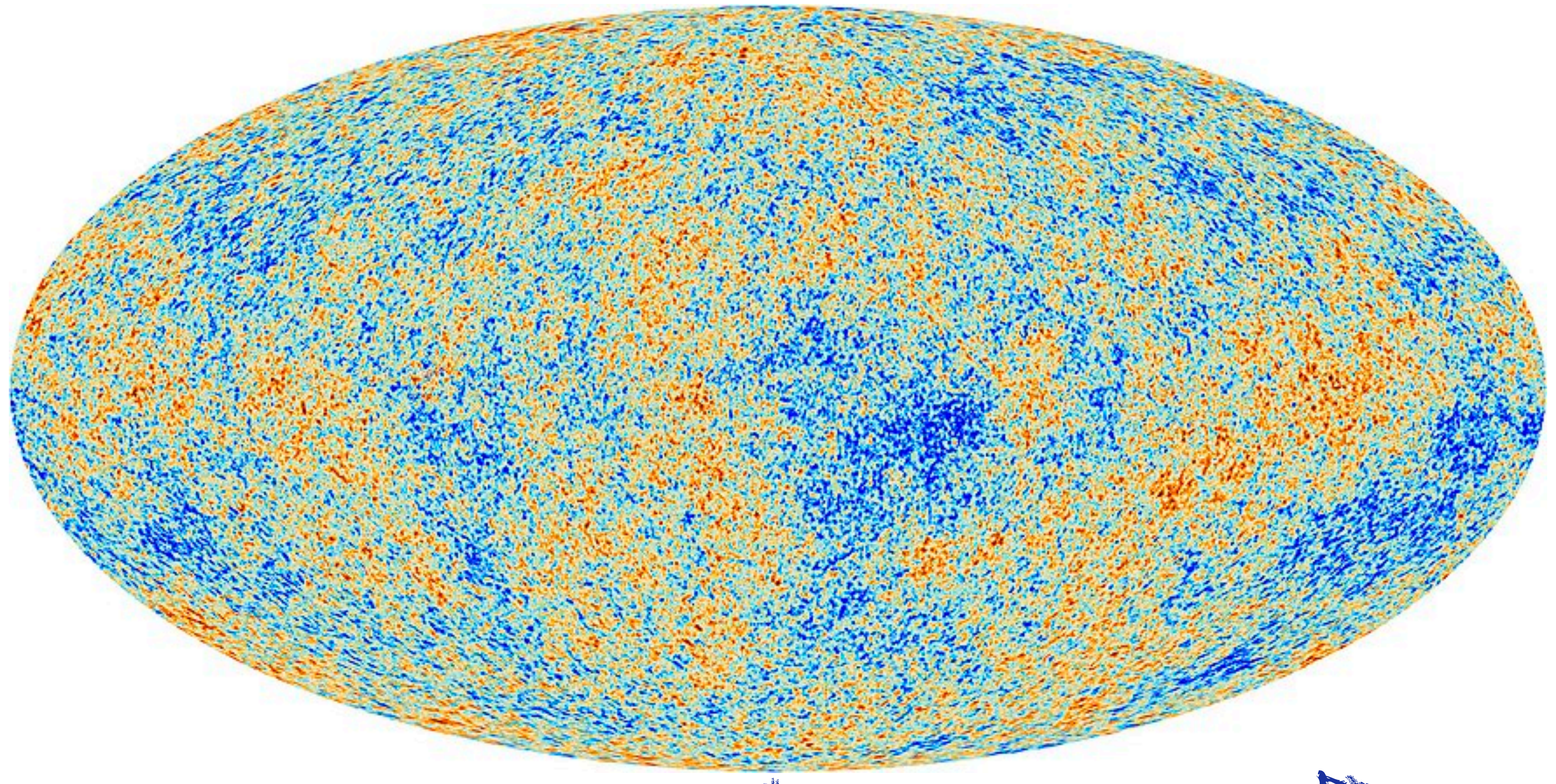
CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE CPPM

The puzzle of dark matter

90 years of evidence from gravitational effects at all scales







Galaxy scale

~ 100 kpc

- 1932: Oort (stars motion in the Milky Way)
- 1939: Babcock (Andromeda)
- 1970s: N-body simulations
- 1970: Rubin and Ford (Andromeda)

Clusters of galaxy scale

~ Mpc

- 1933: Zwicky (virial mass from galaxies velocity dispersion)
- 2000s: collision of the Bullet cluster of galaxies observed with X-rays and gravitational lensing

CMB and large scale structures

> Gpc

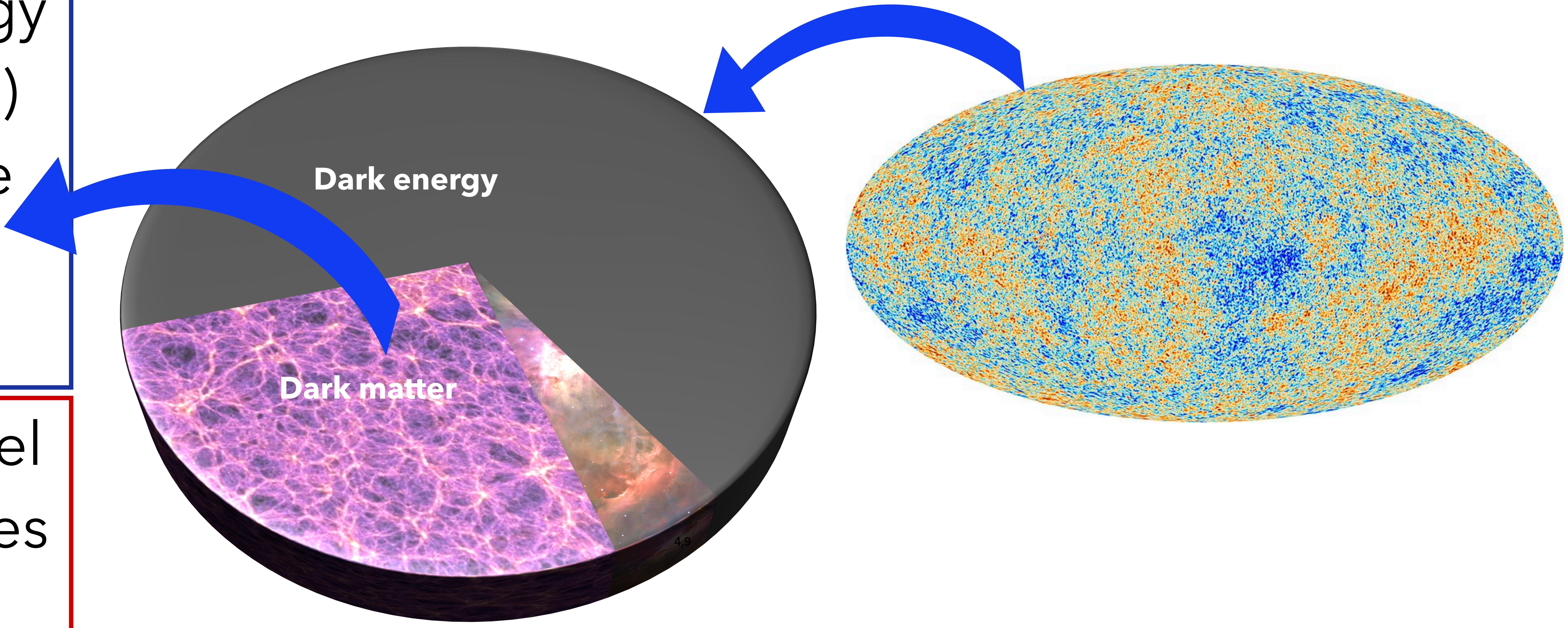
- > 1990s: COBE, WMAP and PLANCK CMB missions → CMB power spectrum
- 1970s: Cosmological simulations
- Hierarchical scenarios of structure formation need collisionless matter

The puzzle of dark matter

90 years of evidence from gravitational effects at all scales

~**27%** of energy (**85%** of mass) content of the Universe is unknown

Standard model of particles does not provide a viable dark matter (DM) candidate



Dark matter candidates

Minimal DM properties

- Massive
- Neutral regarding electromagnetic and strong interactions
- Collisionless fluid
- Stable or long lived
- Cold enough

"**W**eakly **I**nteracting **M**assive **P**article"

- Motivated by both beyond standard model particle physics (e.g. SUSY) and Λ_{CDM}
- WIMP miracle: a ~100 GeV particle naturally emerges from cosmology with right abundance

Axion

Sterile ν

🫶 **WIMP** 🫶

Primordial Black Hole

DM mass

10^{-22} **eV**

10^{-12} **eV**

10^{-2} **eV**

keV

GeV

Electroweak scale

100 TeV

O(10 $M_{\odot}$)

Heisenberg uncertainty principle (boson DM)

Ultra-light DM

Light DM

Direct search for galactic dark matter

DM halo
- ➡ 3D
- ➡ size > Milky Way

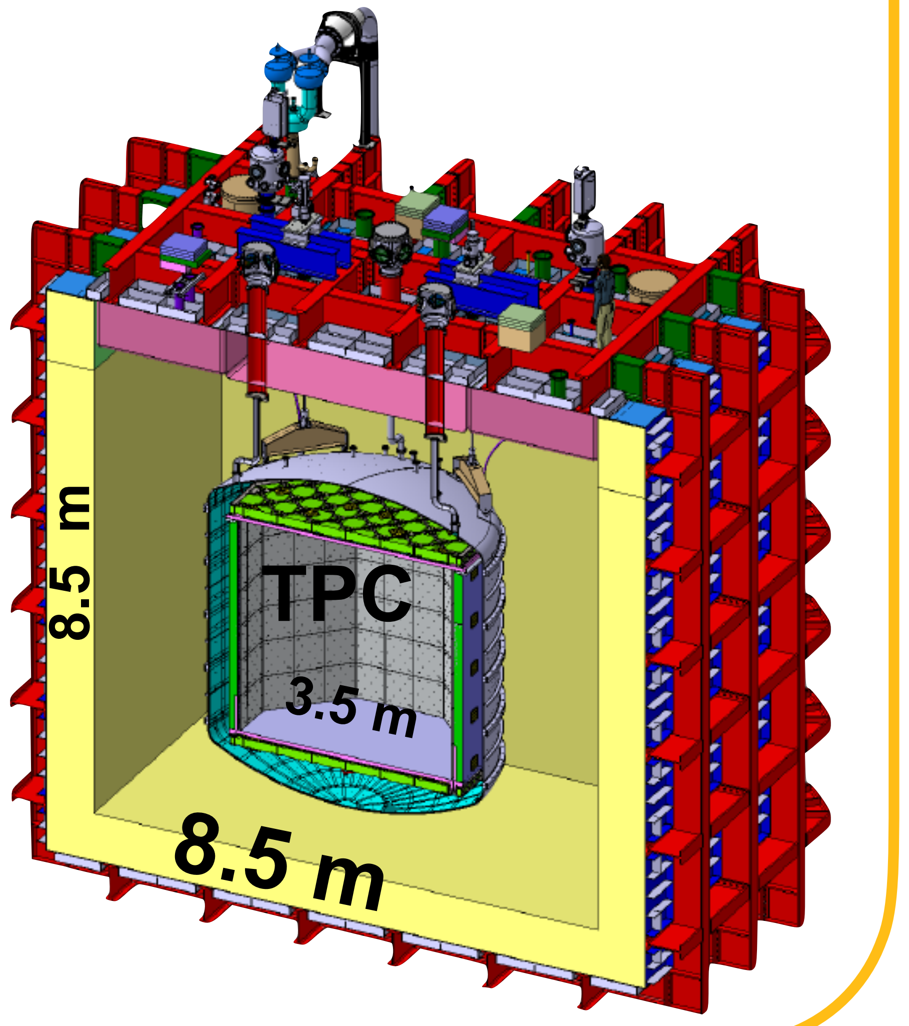
Direct search for galactic dark matter

How to search for WIMPs ?

Create scalable detectors

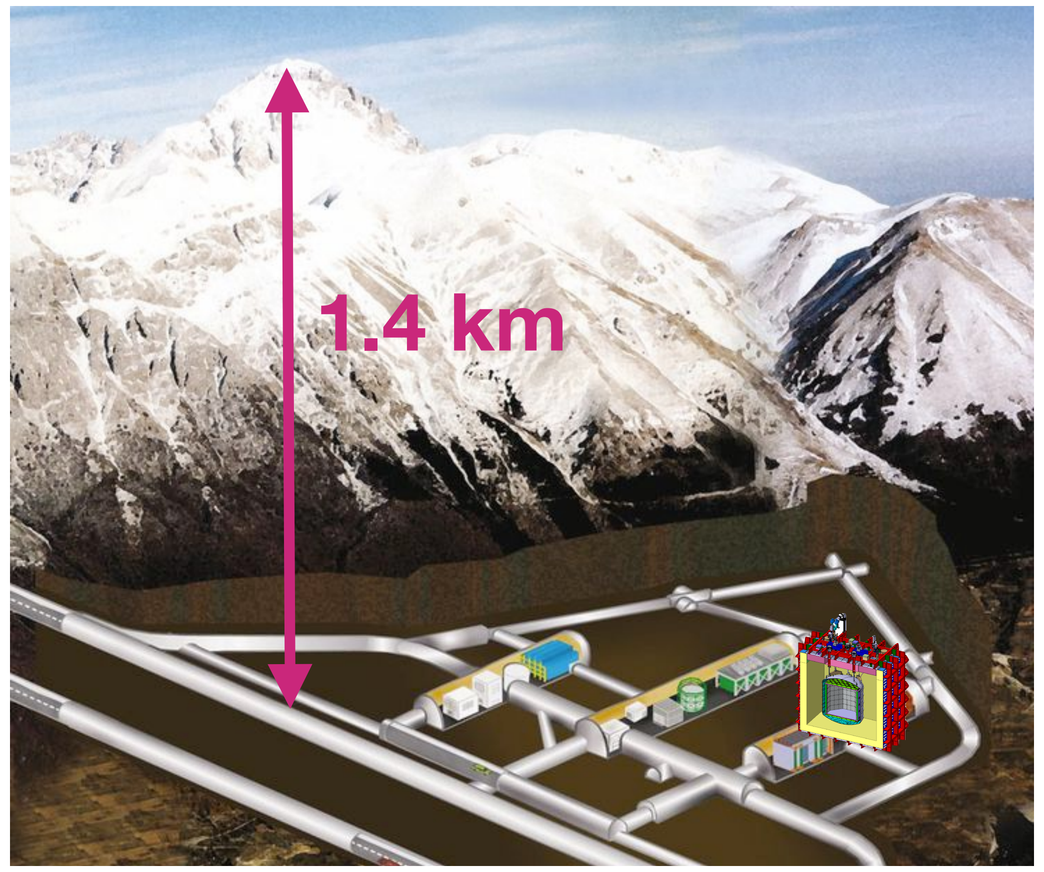
DarkSide-20k : 20t of argon at liquid phase in fiducial volume (650t in total)

Largest TPC ever built for DM search purposes



Shield the detector from background

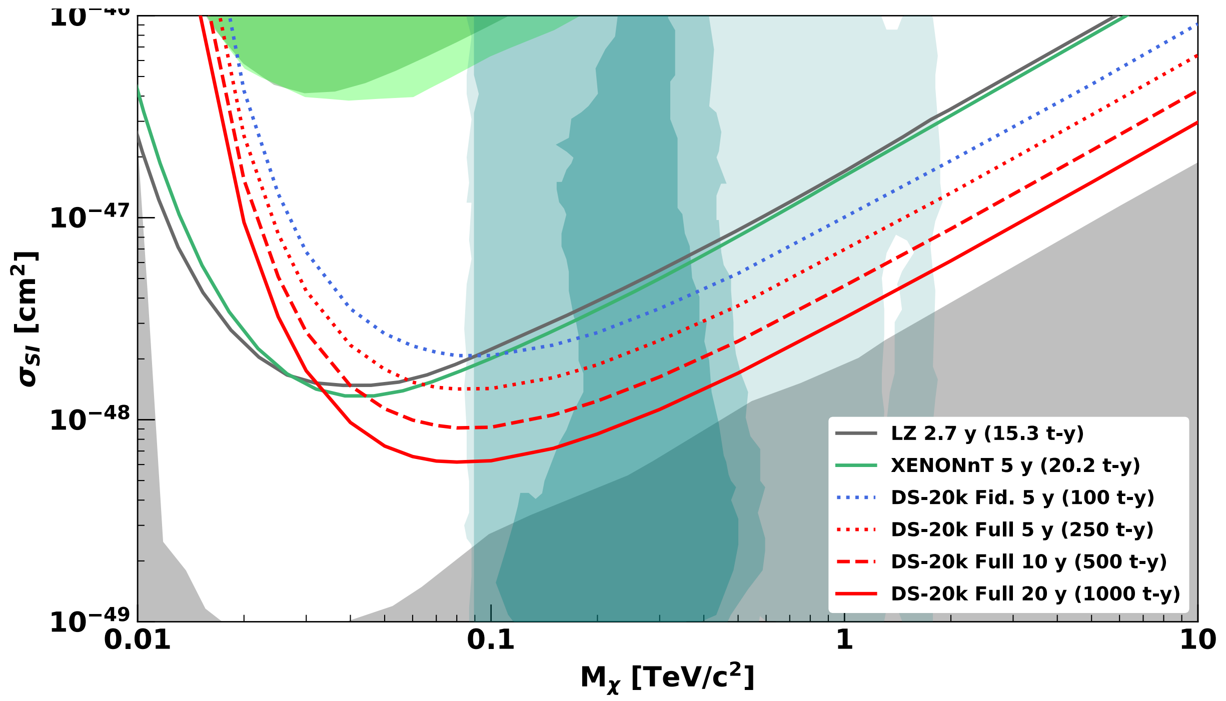
DarkSide-20k : located at the Gran Sasso Laboratory (Italy) under 1.4km of rock to shield from cosmic rays



Searching for WIMPs

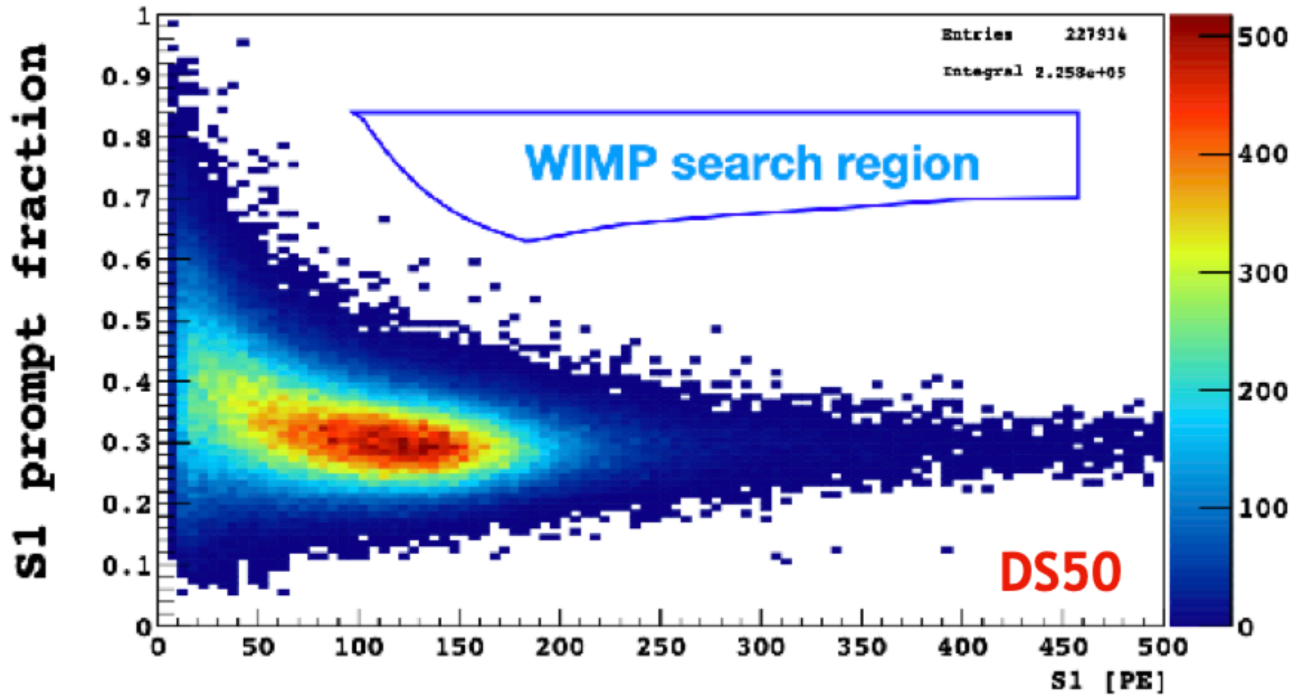
Compute the sensitivity of the experiment

Depends on the DM halo modelling



Understand and discriminate backgrounds and signal

Argon: extremely powerful discrimination between backgrounds and signal

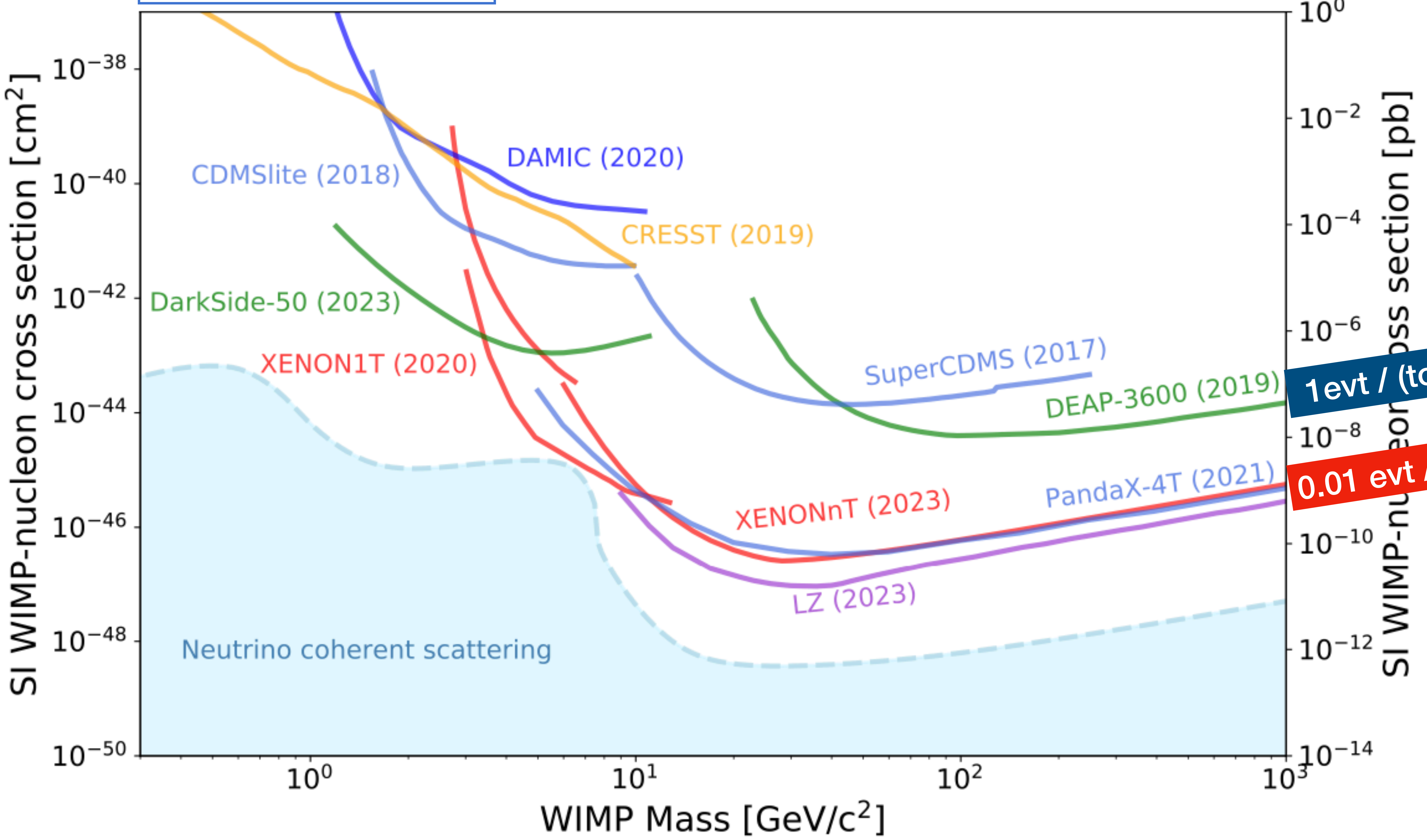


Background budget (after cuts): 0.1 event / 10y

WIMP direct detection: where do we stand ?

State of the art of direct search for WIMP dark matter

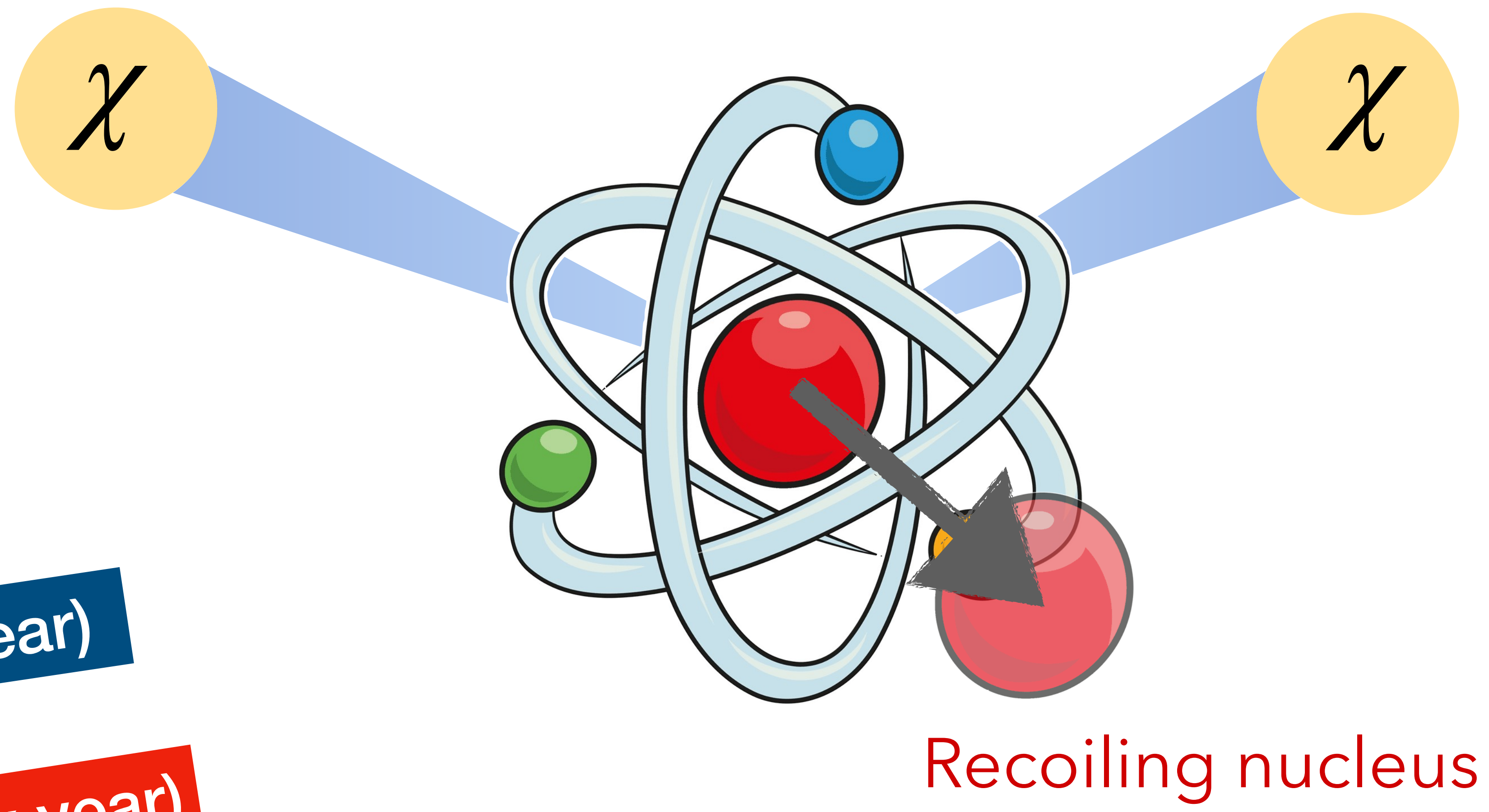
From PDG 2023



1evt / (ton x year)

0.01 evt / (ton x year)

Signal - Nuclear recoil



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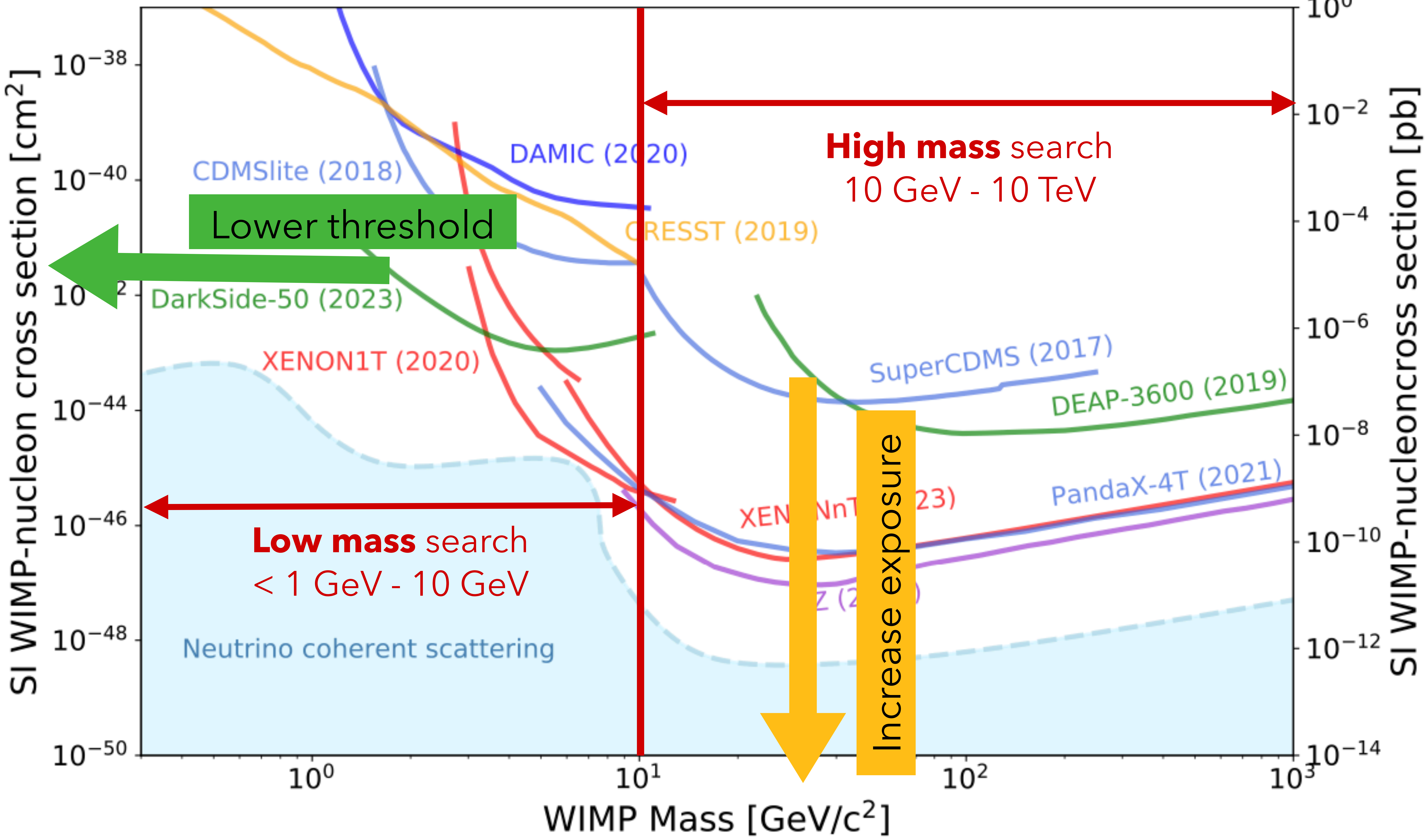

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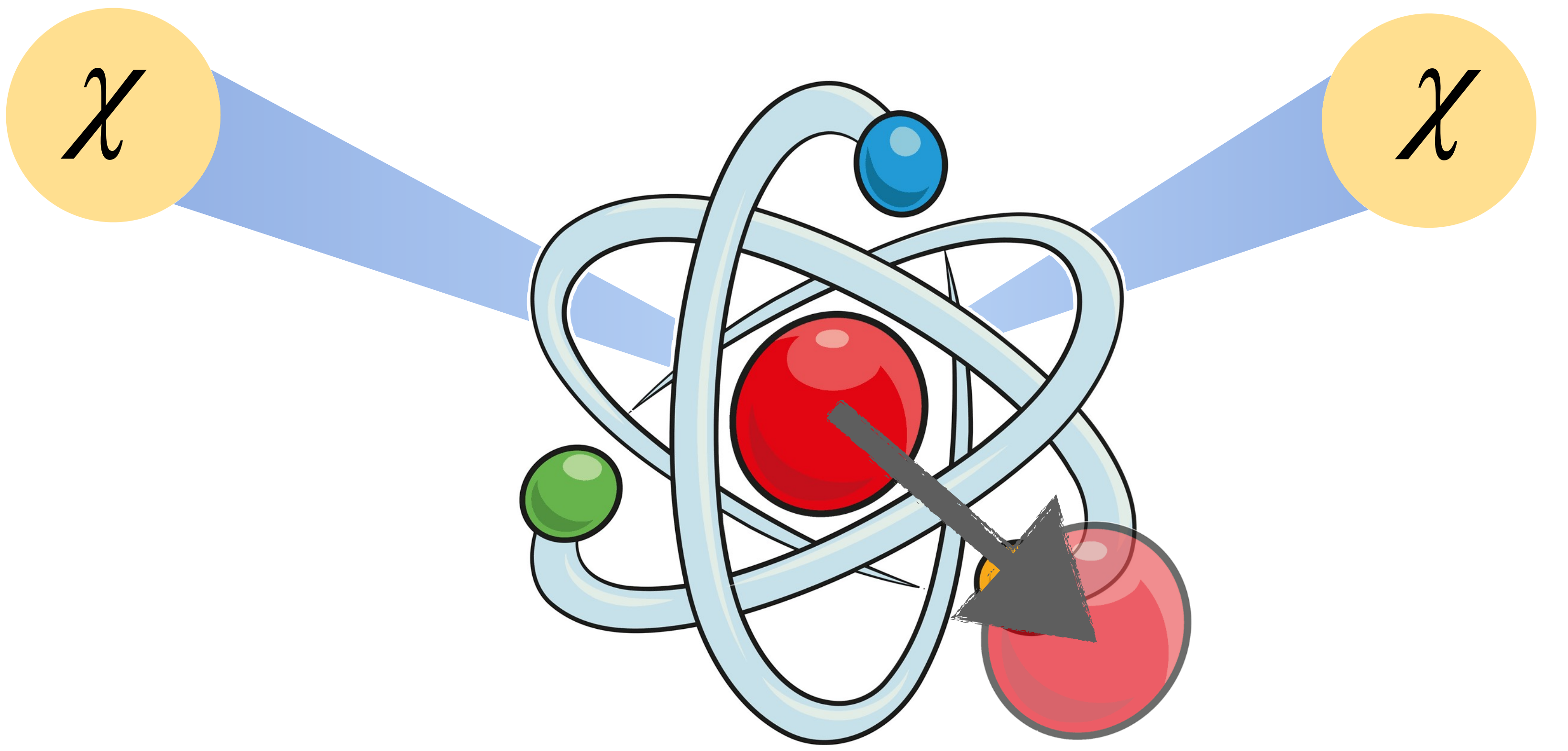

Recoiling nucleus

WIMP direct detection: where do we stand ?

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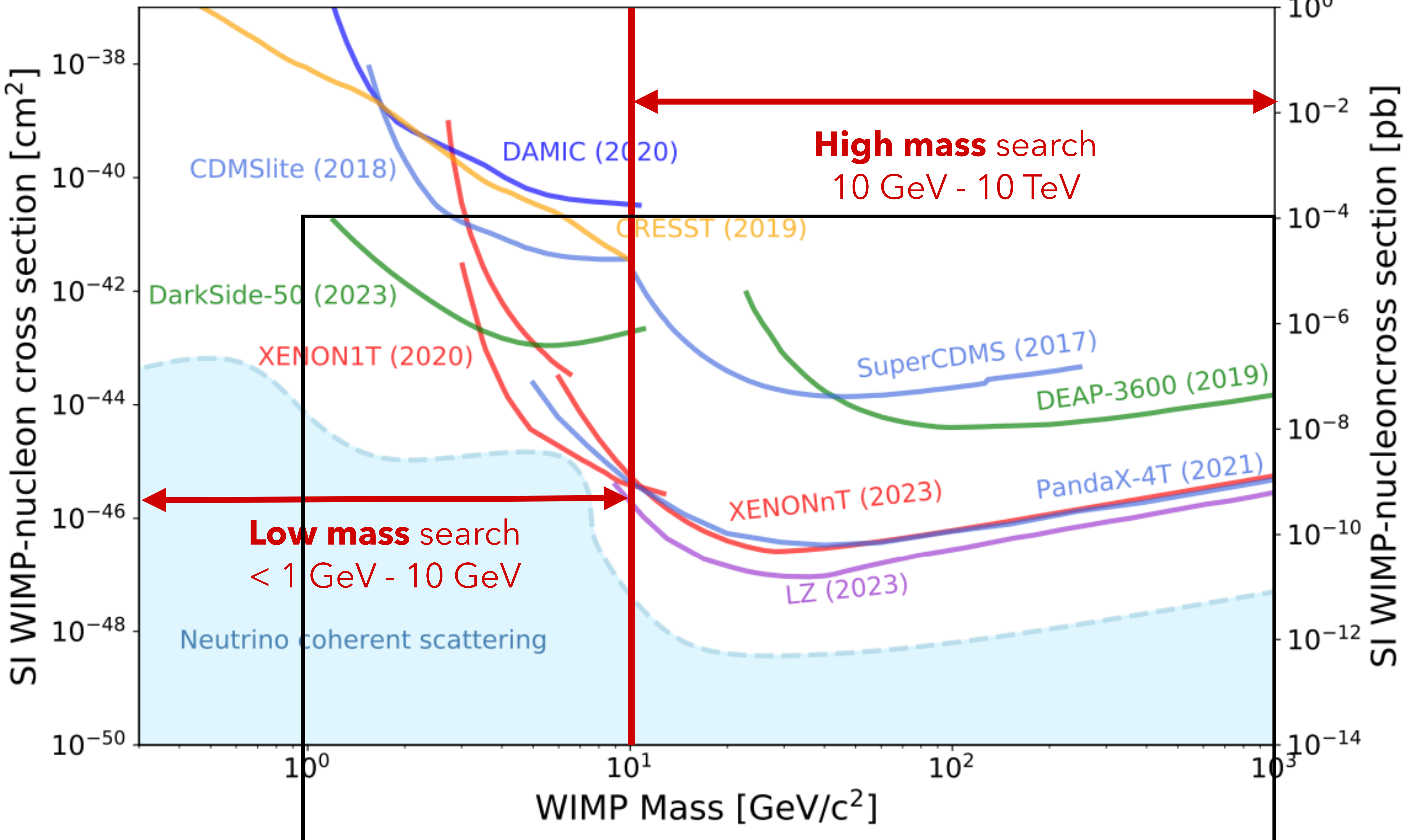
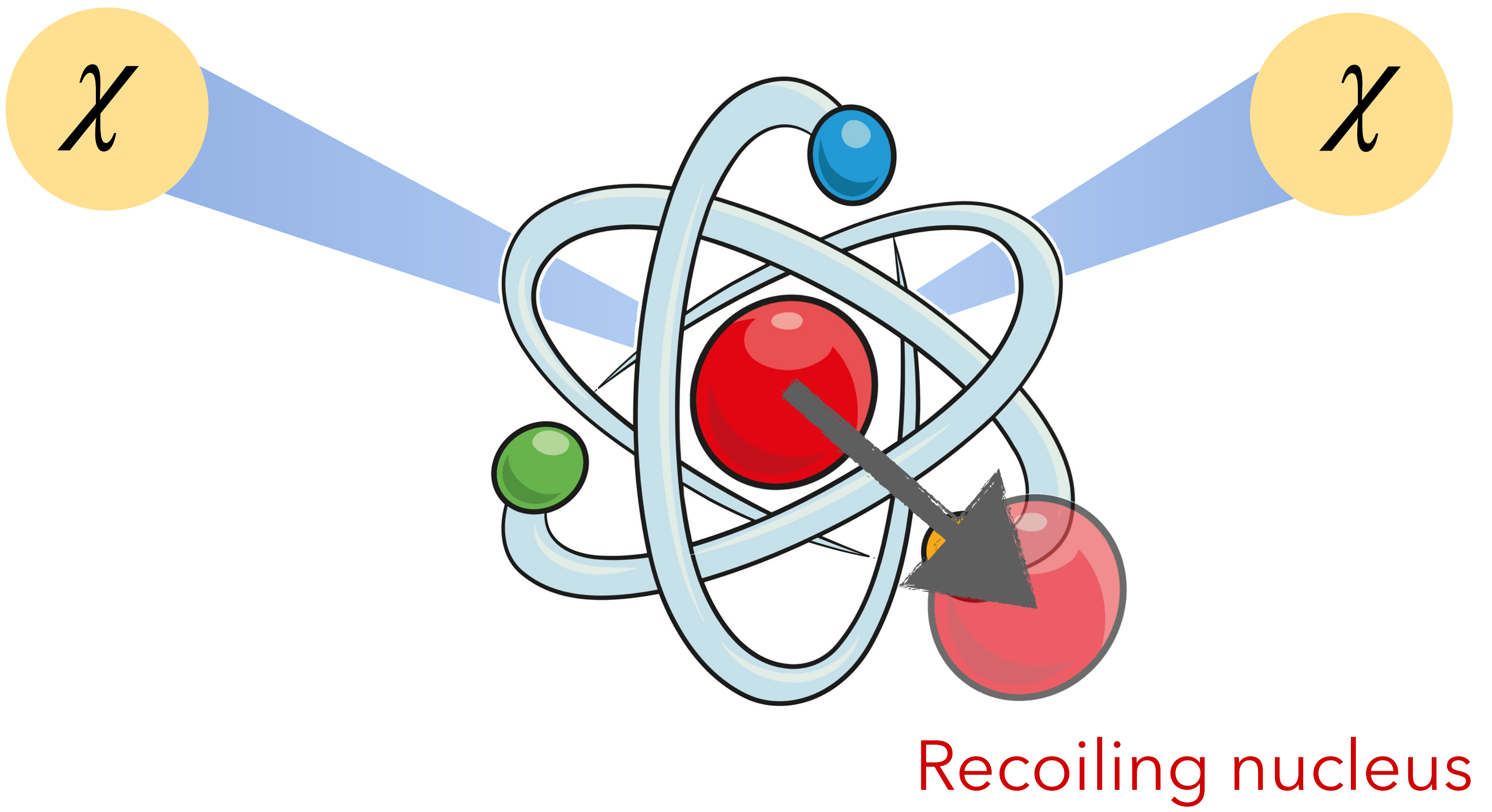


High mass search
10 GeV - 10 TeV

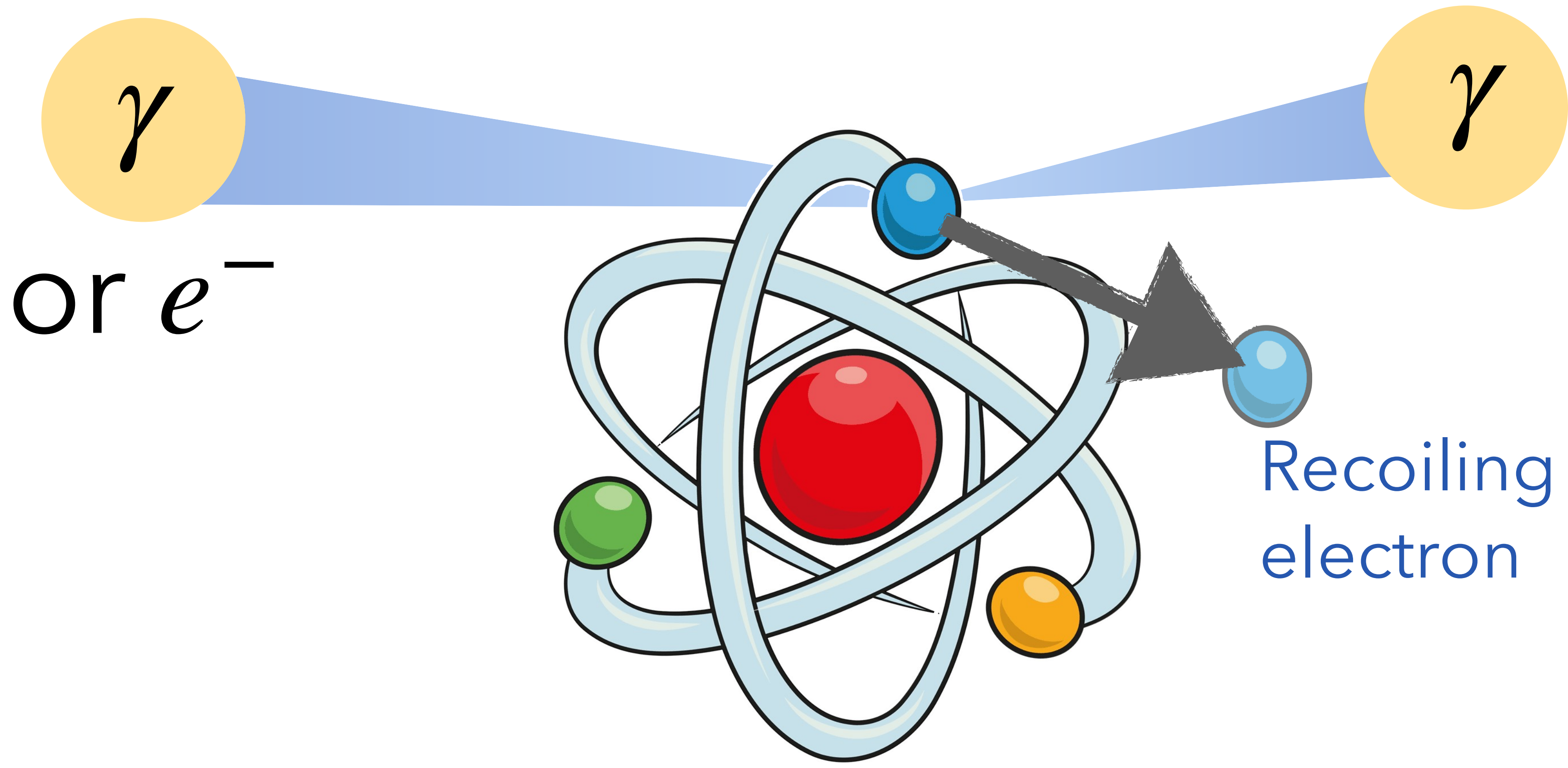
Low mass search
< 1 GeV - 10 GeV

WIMP search dominated by dual phase TPCs in 1 GeV - 1 TeV

Signal - Nuclear recoil

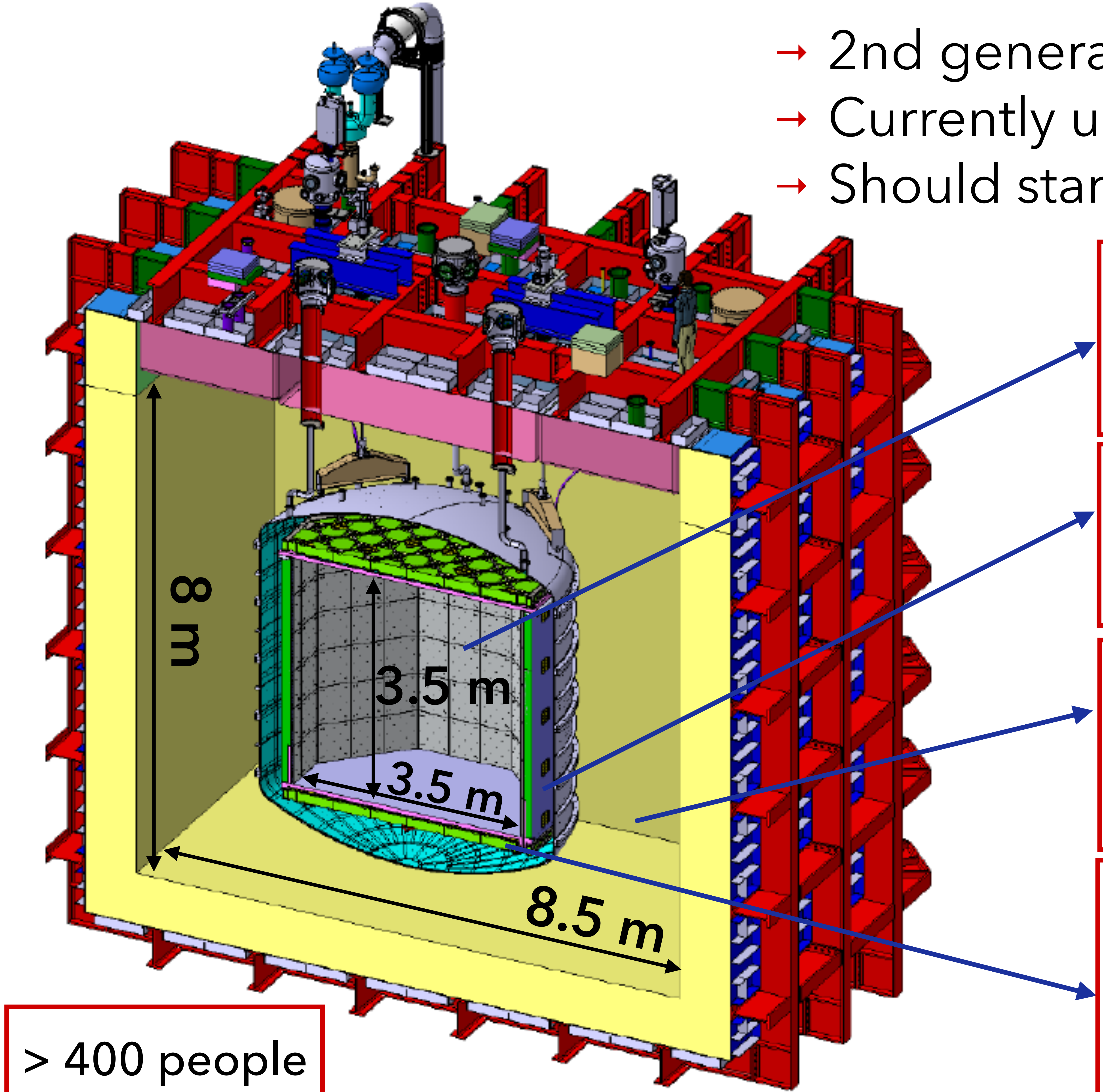


Backgrounds - Electron recoil



The DarkSide-20k experiment

- → 2nd generation experiment
- → Currently under construction
- → Should start data taking in 2027



TPC: 50 t
Underground argon
(UAr)

Inner veto
(neutron veto): 32 t
UAr

Outer veto
(muon veto): 650 t
Atmospheric argon

TPC photo-electronics
2x10.5 m² SiPMs
arrays
2112 readout channels

> 400 people

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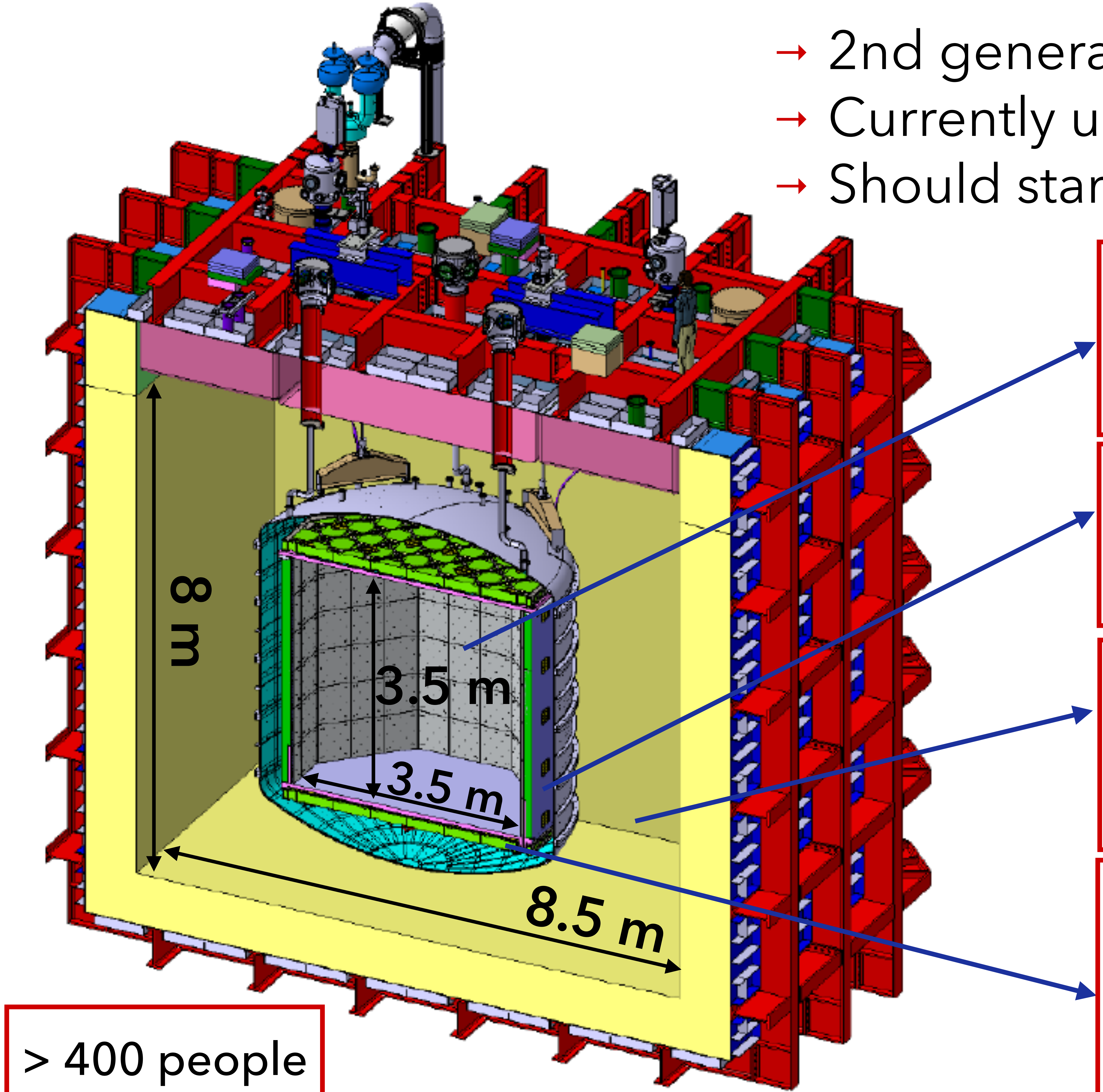

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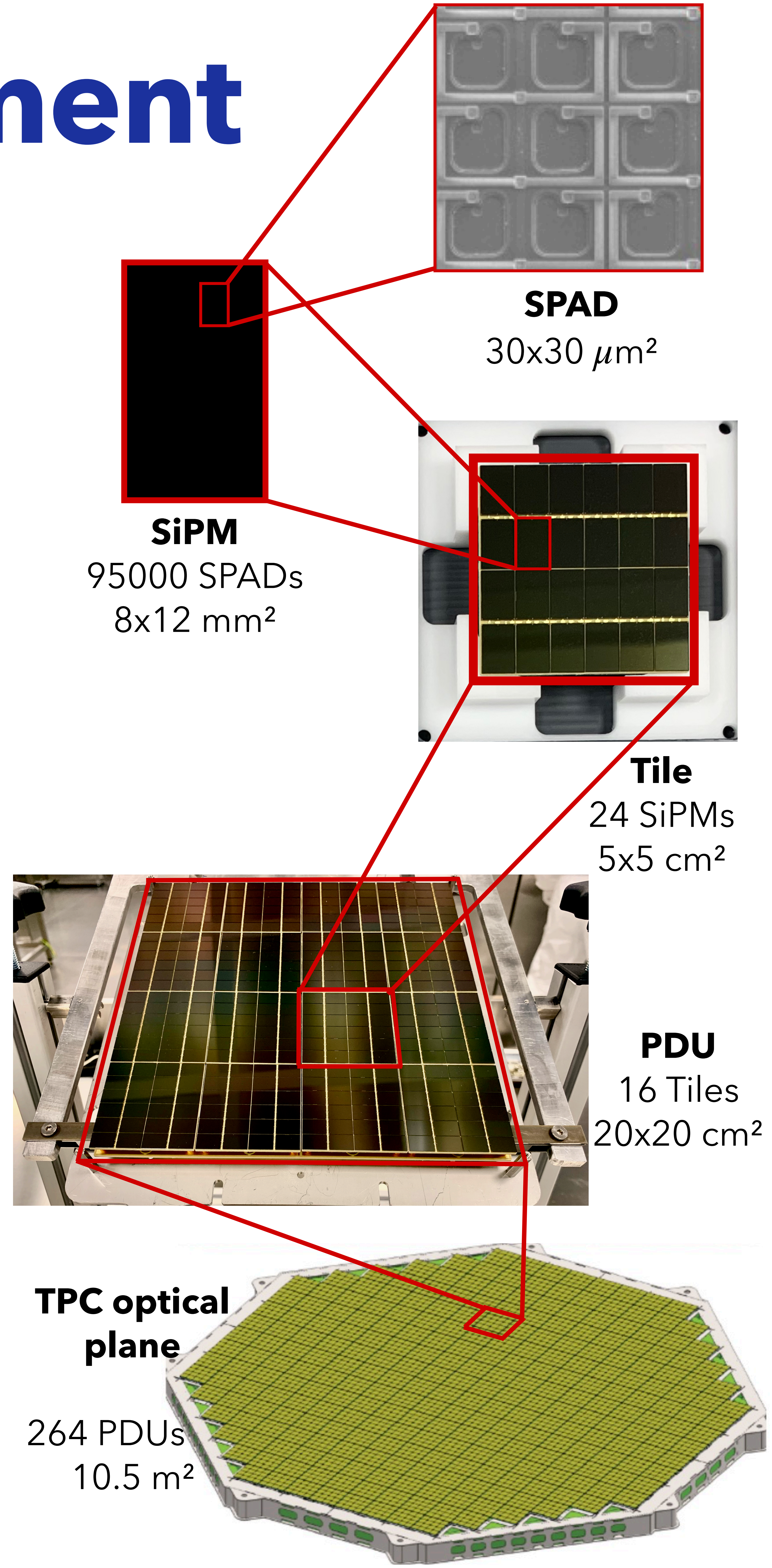


SPAD
30x30 μm^2

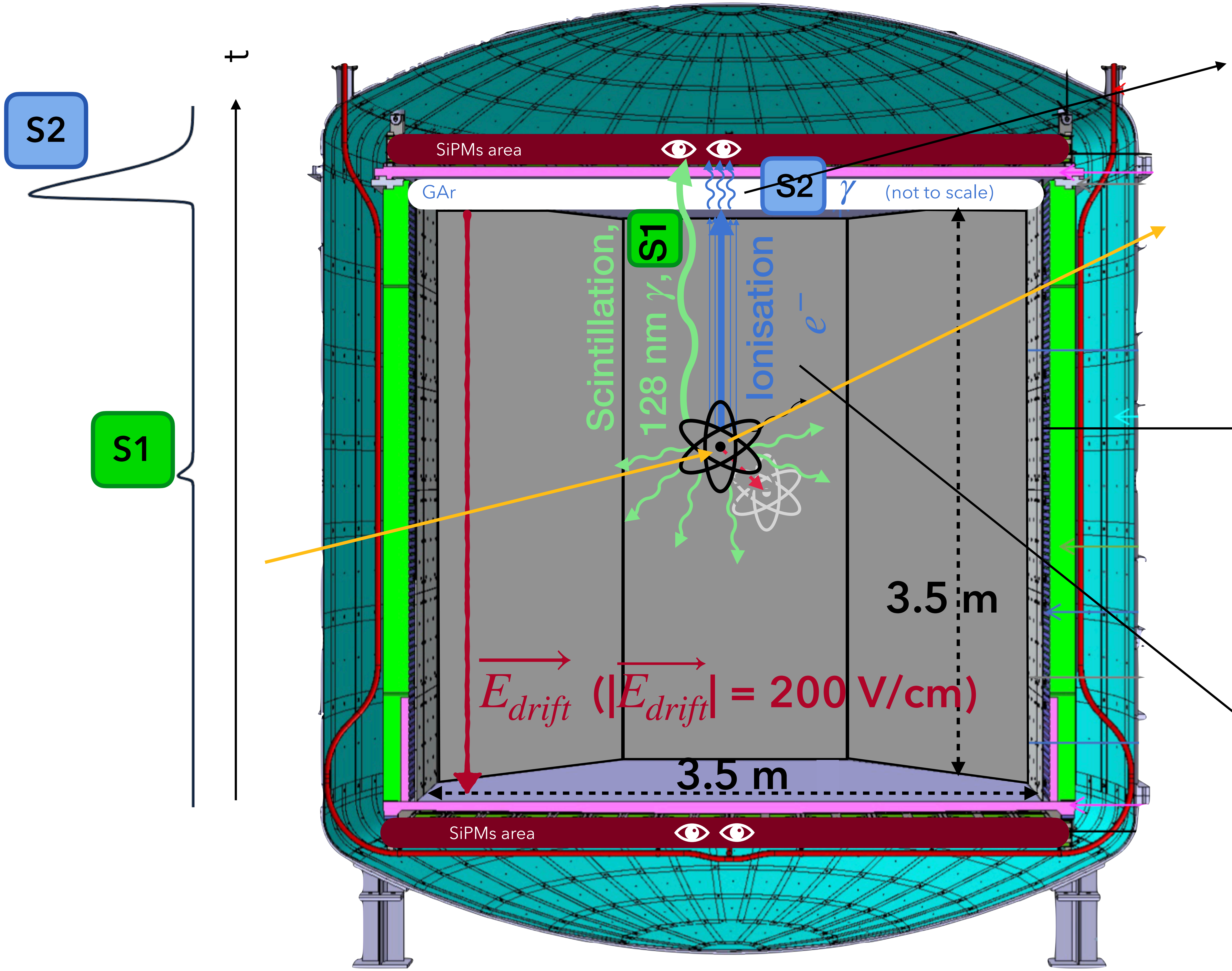
SiPM
95000 SPADs
8x12 mm^2

Tile
24 SiPMs
5x5 cm^2

PDU
16 Tiles
20x20 cm^2

TPC optical plane
264 PDUs
10.5 m^2

The DarkSide-20k experiment



Electroluminescence light yield ≈ 25 photo-e^-/e^-

Wave-length shifters on the walls

Scintillation light : λ = 128 nm → **shifted to λ = 420 nm**

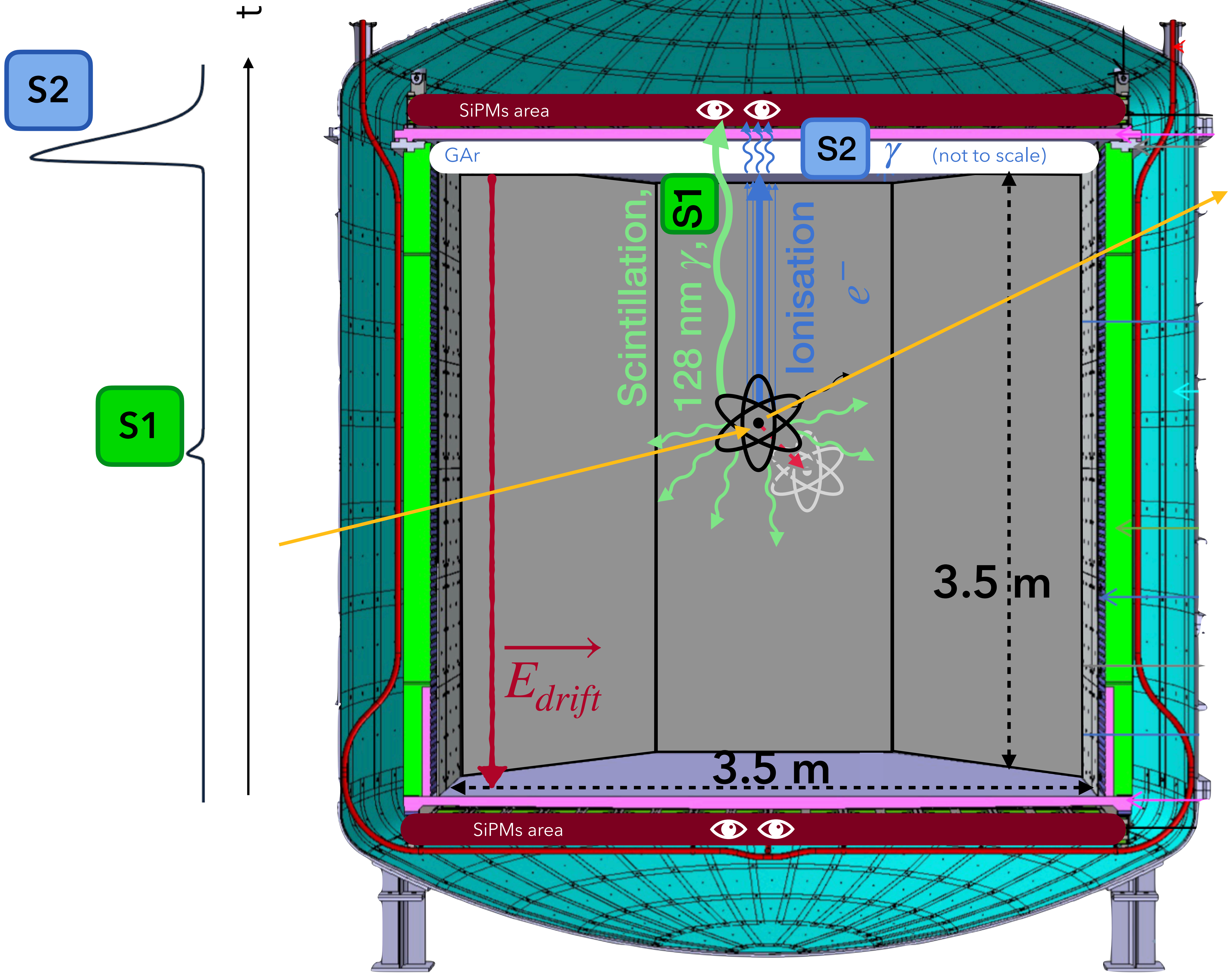
SiPMs efficiency at (λ = 128 nm) ≈ 0 %

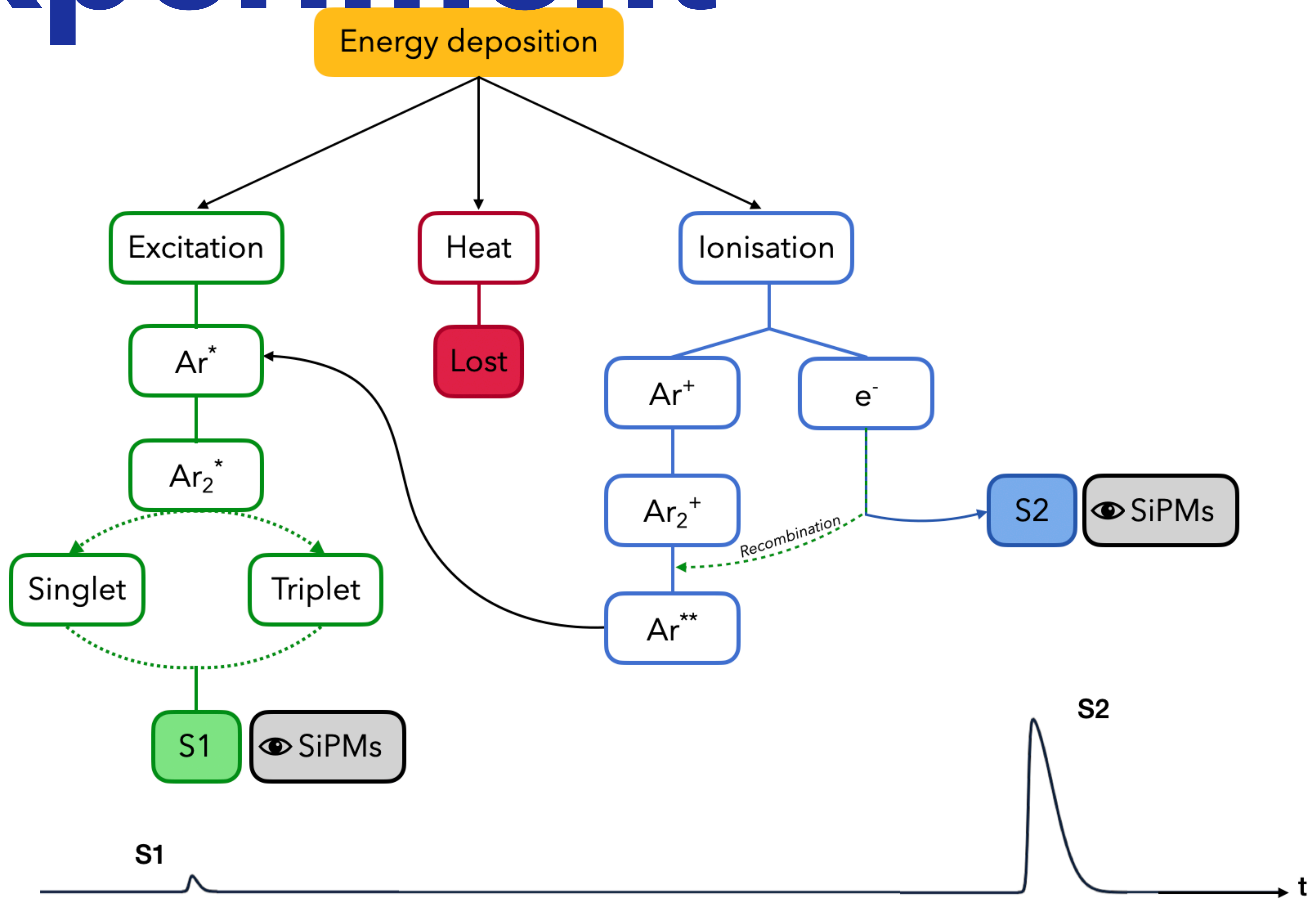
SiPMs efficiency at (λ = 420 nm) **> 40 %**

Maximum drift time = 3.7 ms

Electron lifetime = 15.8 ms

The DarkSide-20k experiment



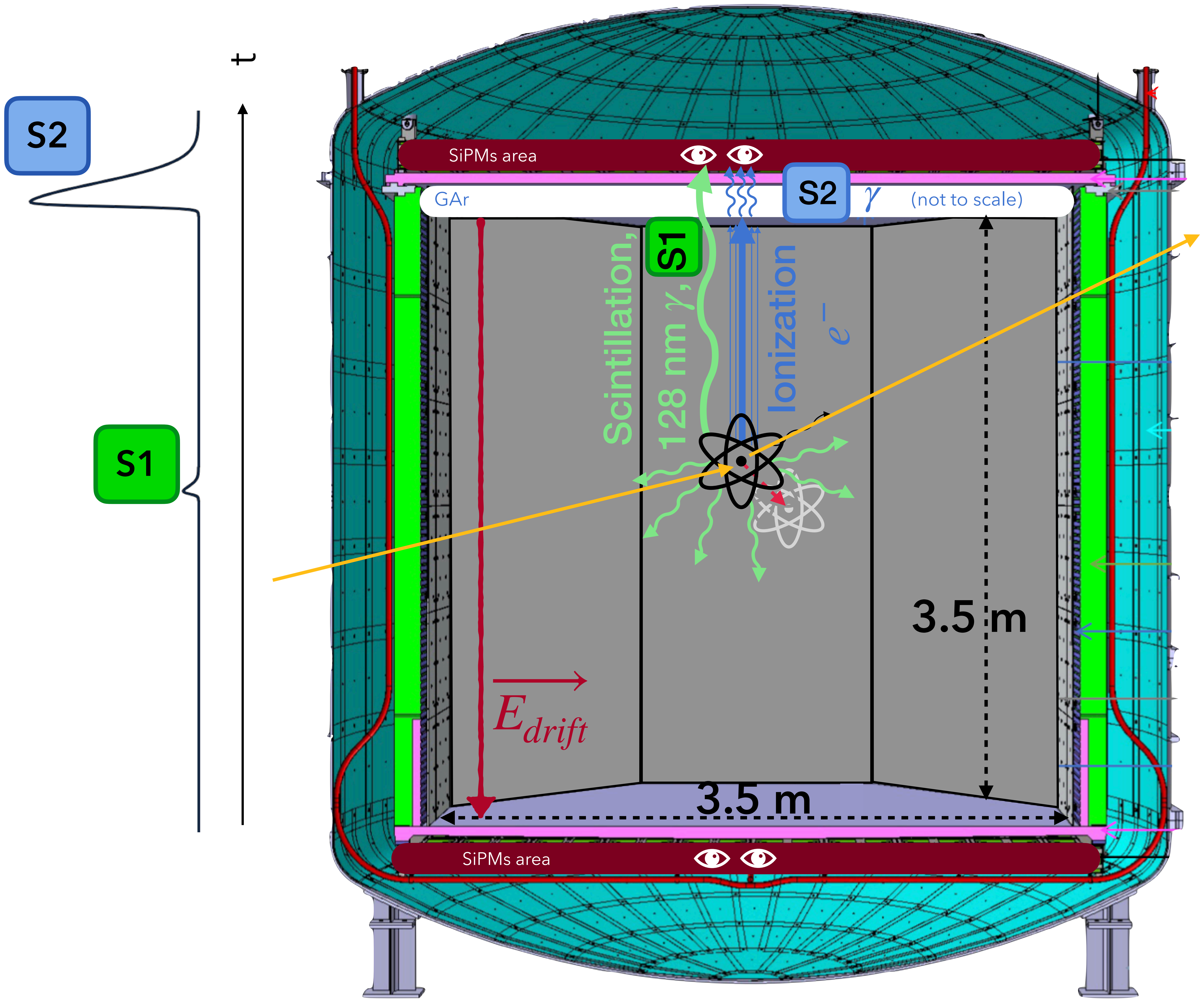


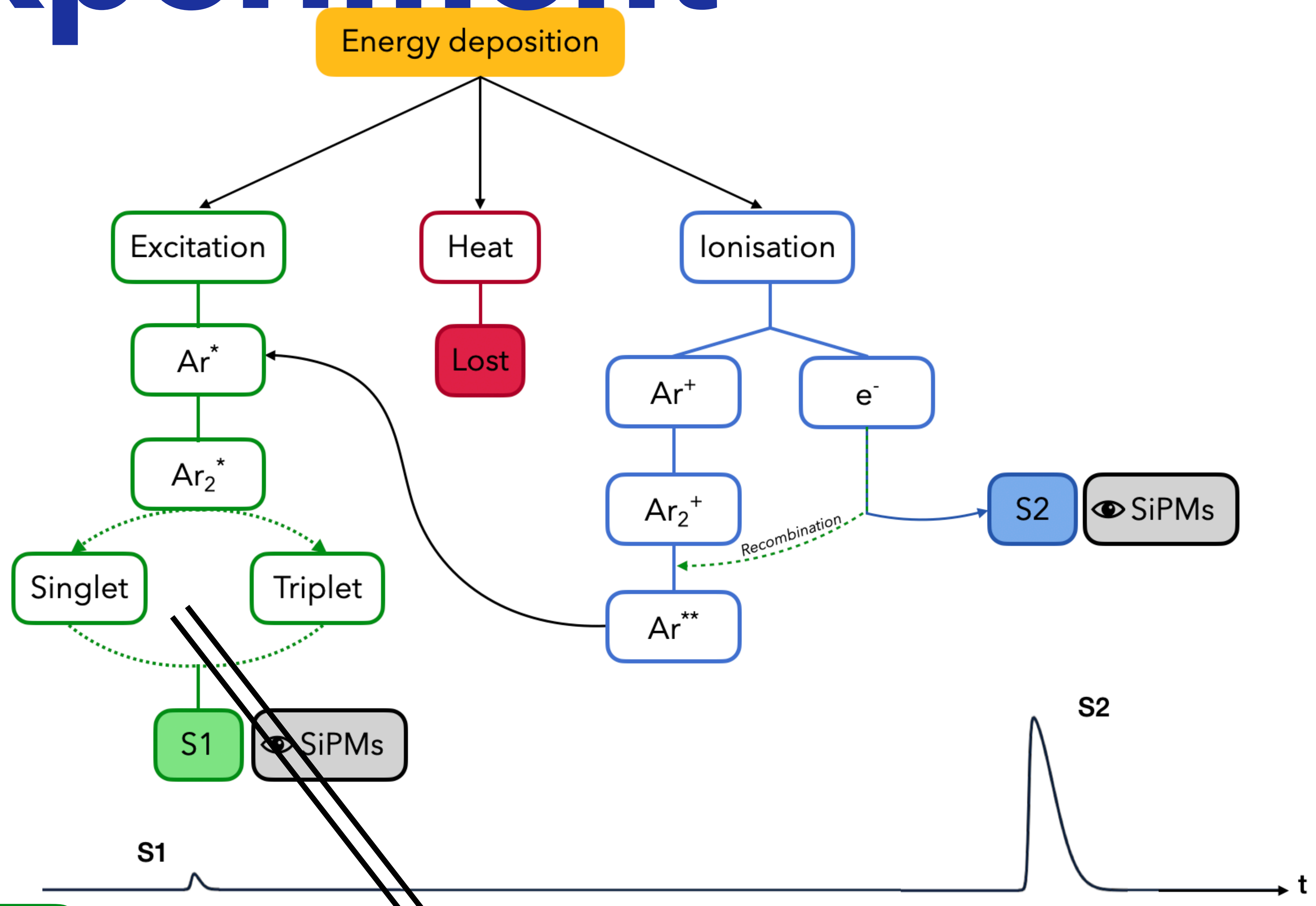
S1

scintillation signal (prompt)

S2 ionisation signal (delayed)

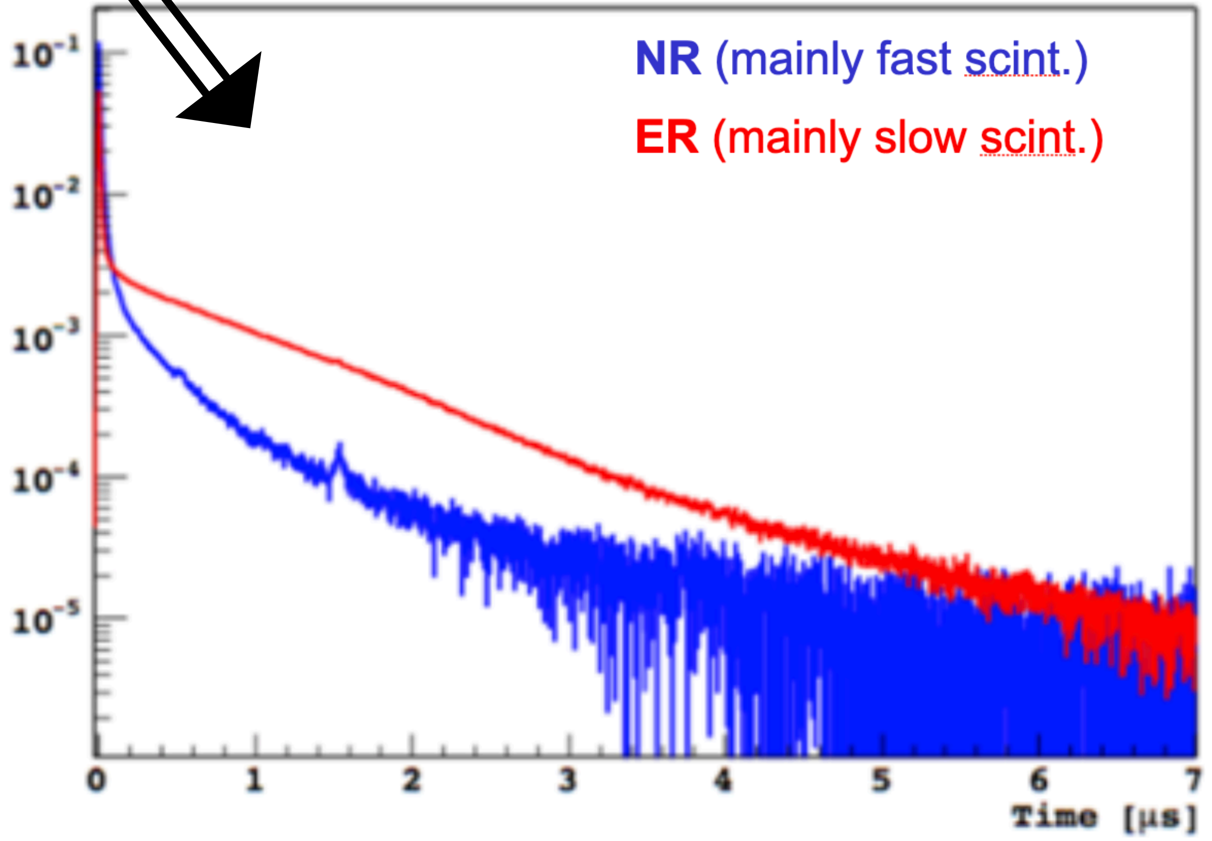
The DarkSide-20k experiment





S1 scintillation signal (prompt)

S2 ionization signal (delayed)



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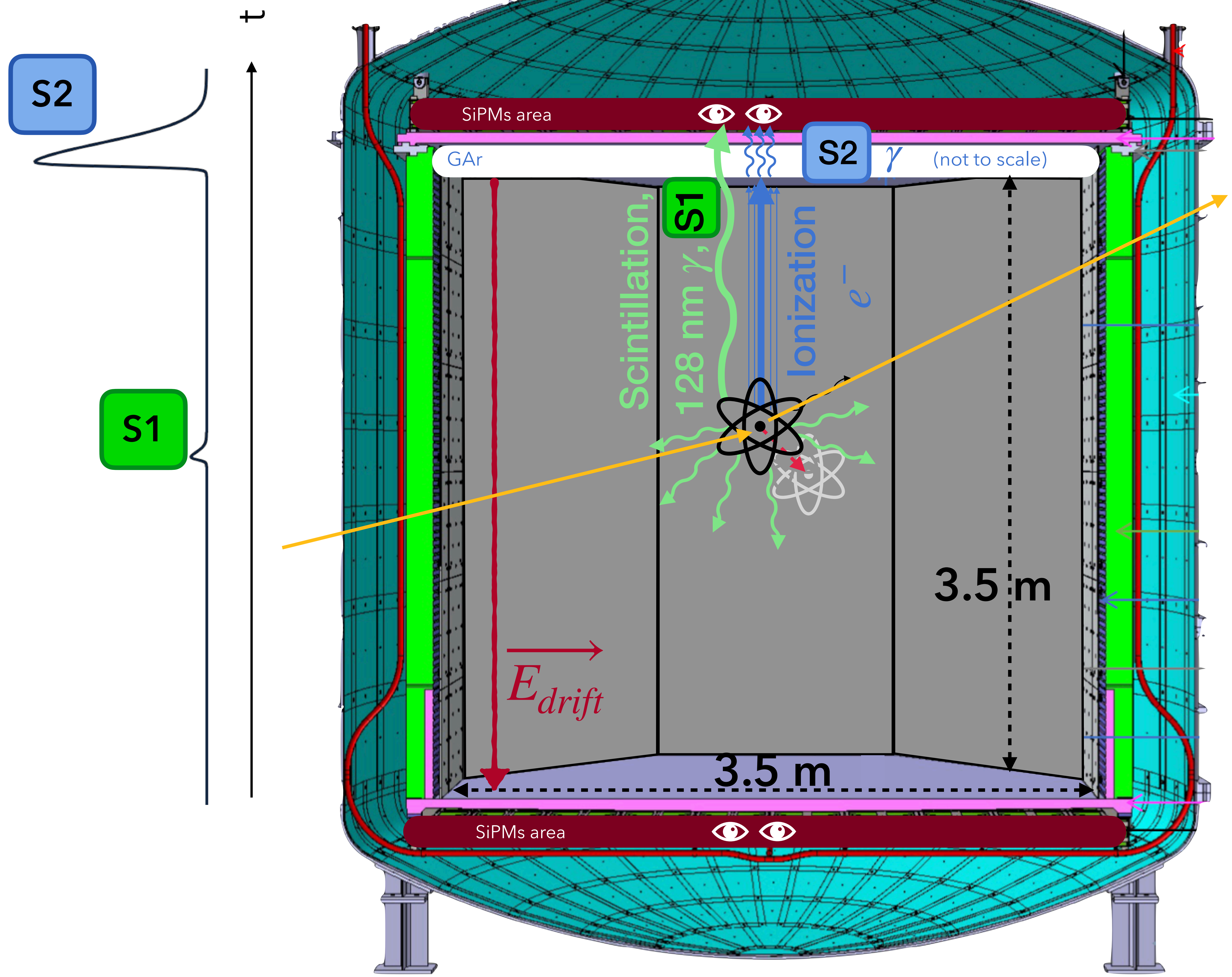
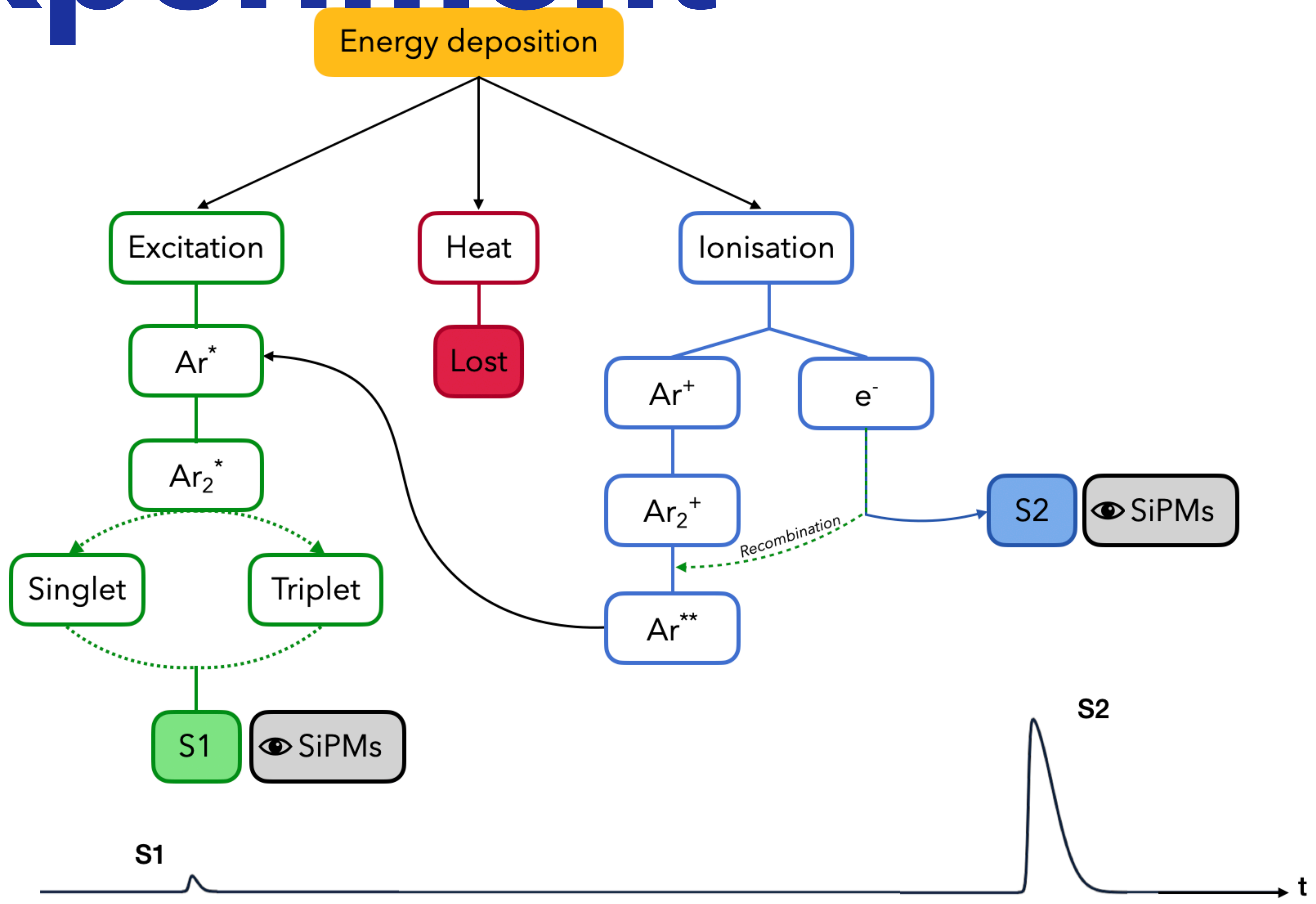




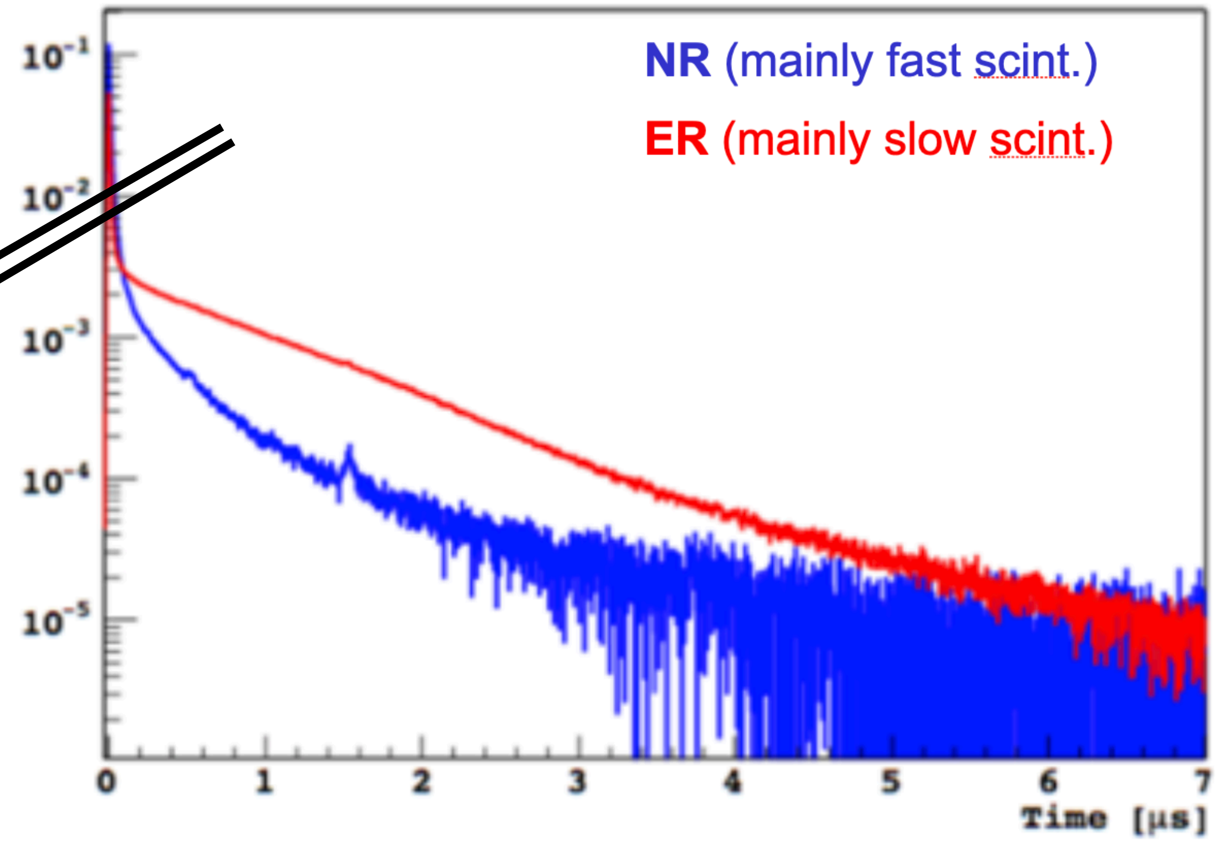
S1 scintillation signal (prompt)

S2 ionization signal (delayed)

Pulse Shape Discrimination

O(10⁸) signal-background (bkg) discrimination power

Bkg-free experiment

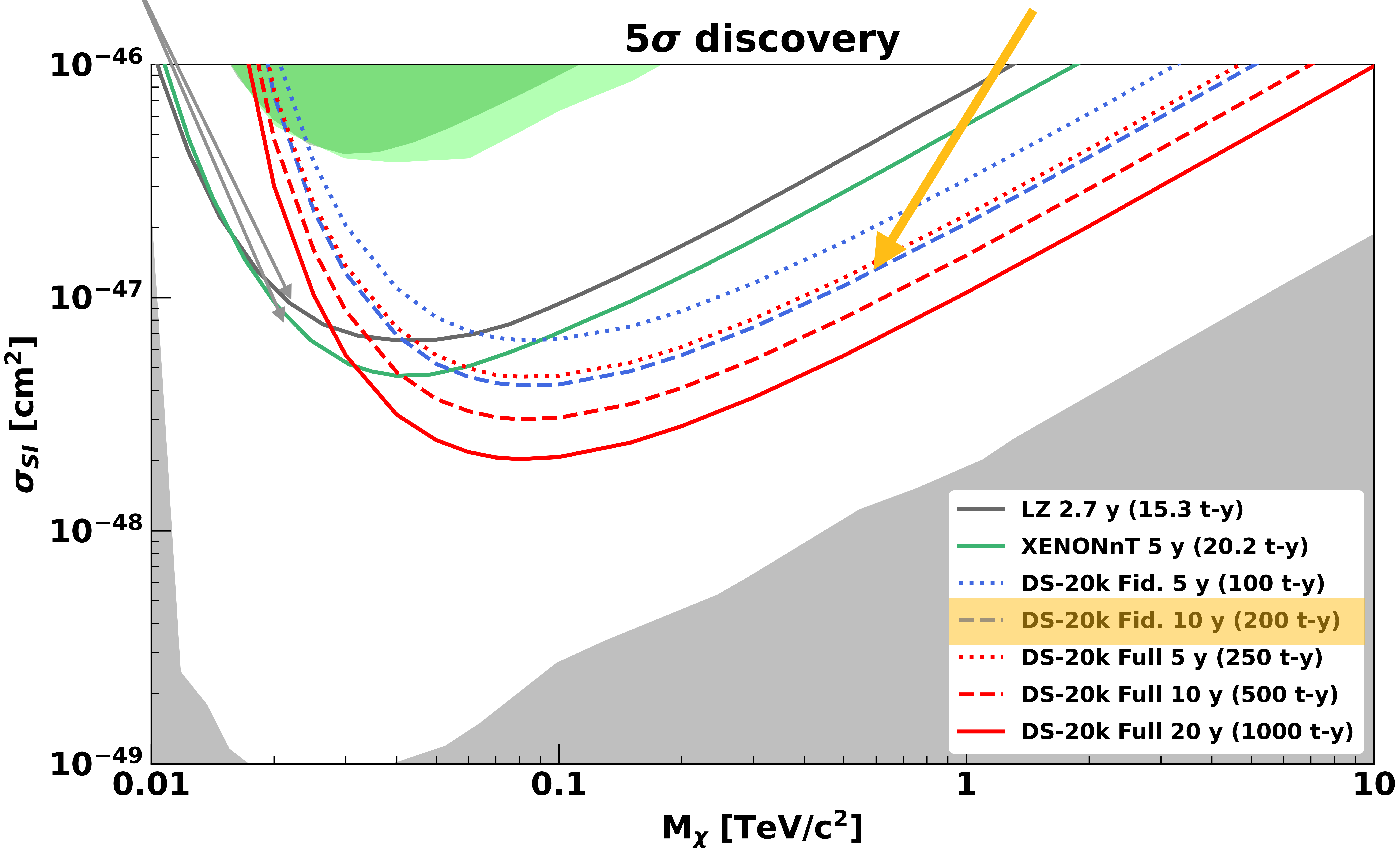


DarkSide-20k sensitivity

Xenon - based experiments

DS-20k sensitivity for different exposure assumptions

Nominal exposure: 200 t.y



DS-20k claimed sensitivity (discovery potential) to high mass WIMPs as shown in its Technical Design Report

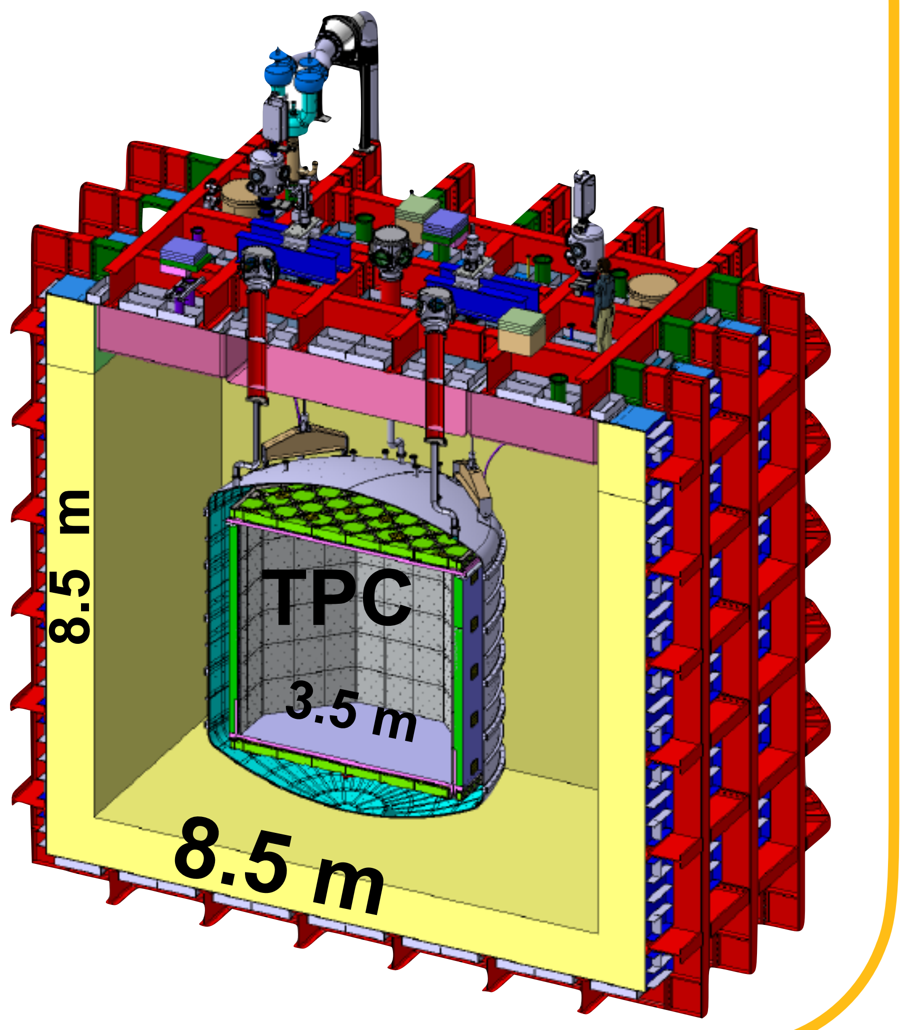
Benefits from background-free search

How to search for WIMPs ?

Create scalable detectors

DarkSide-20k : 20t of argon at liquid phase in fiducial volume (700t in total)

Largest TPC ever built for DM search purposes



Shield the detector from background

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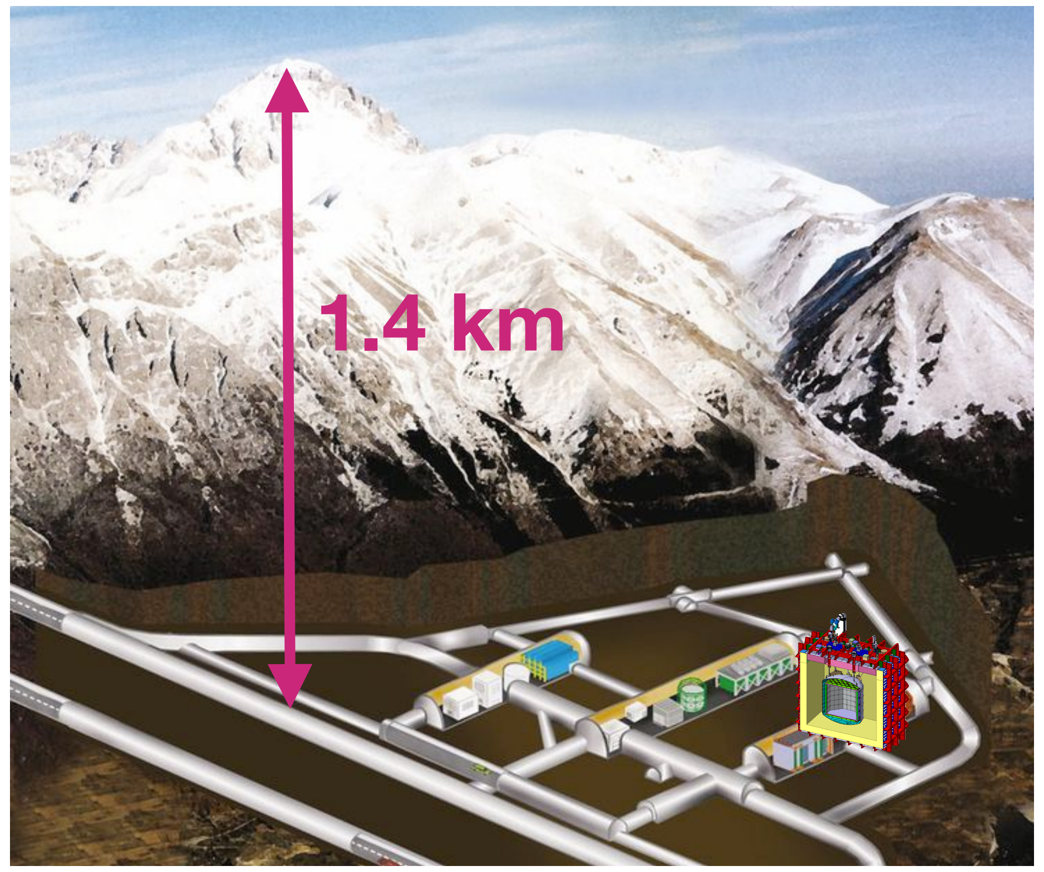


Searching for WIMPs

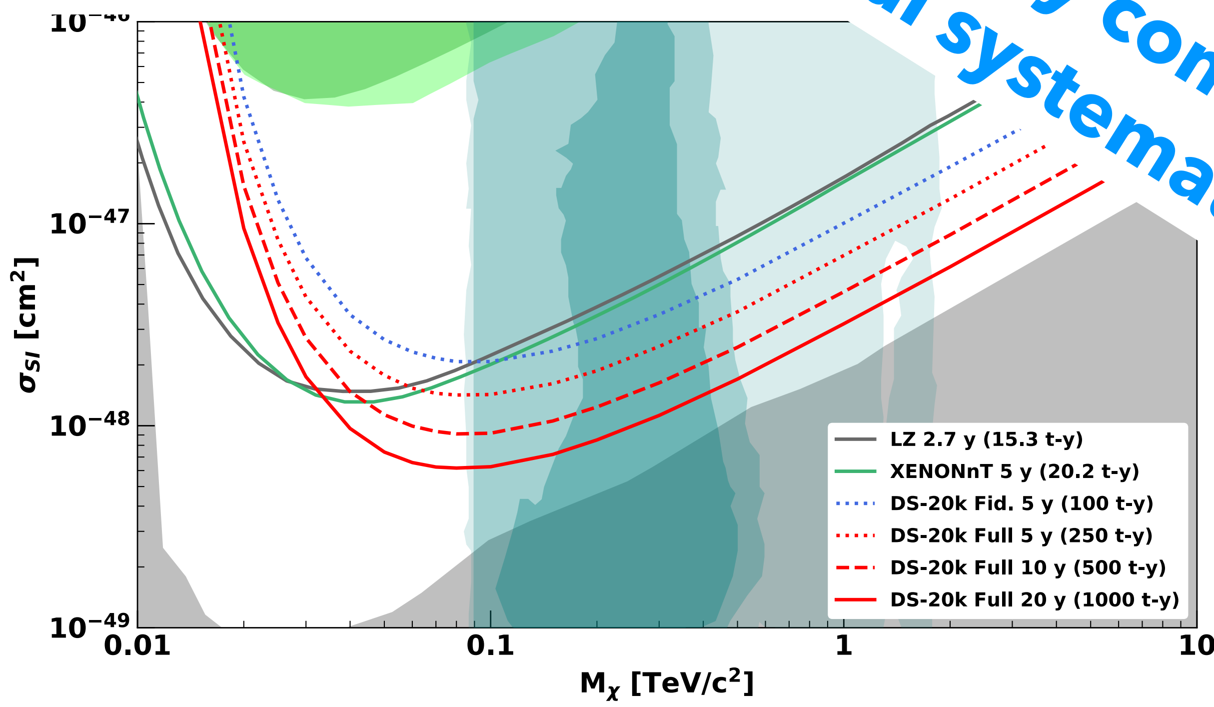
My contributions to the experiment

Sensitivity computation and signal systematics studies

Calibration of DS20k

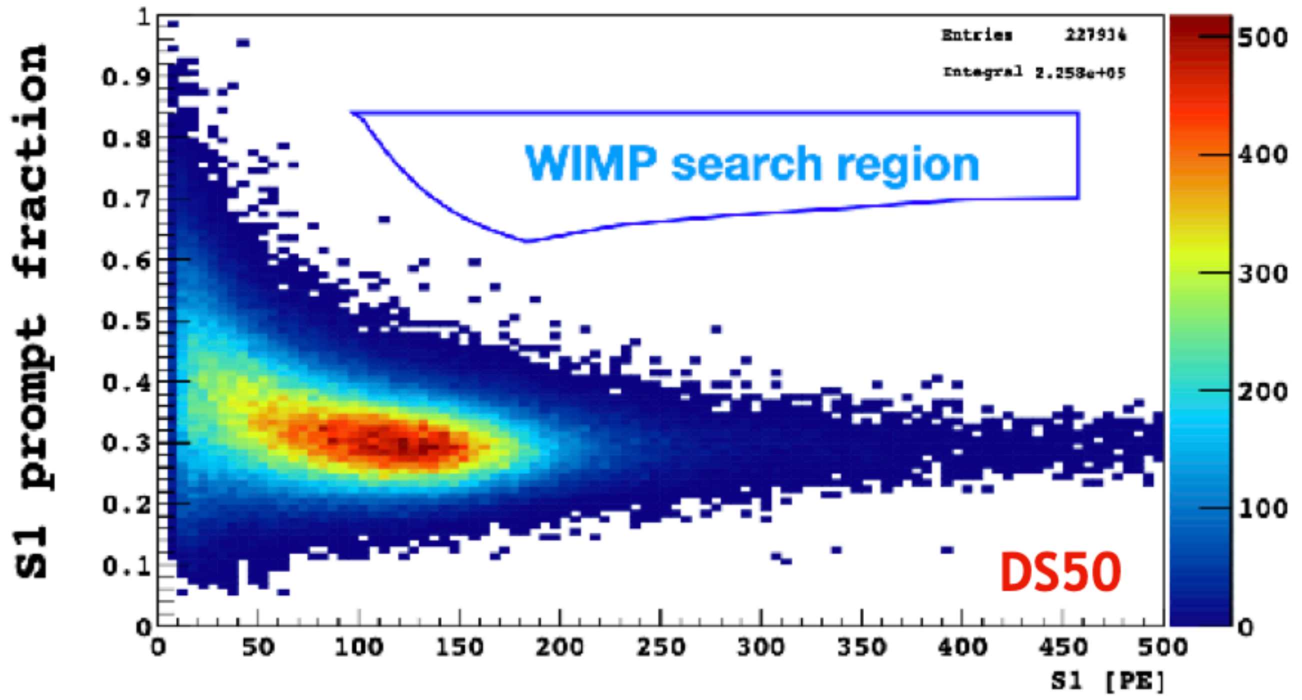
Compute the sensitivity of the experin

Depends on the DM halo m



Understand and discriminate backgrounds and signal

Argon: e nely powe dis nation veen ackgrounds and signal



Background budget (after cuts): 0.1 event / 10y

DarkSide-20k TPC calibration

How to and related challenges

CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE
CPPM

CPPM contribution to detector construction

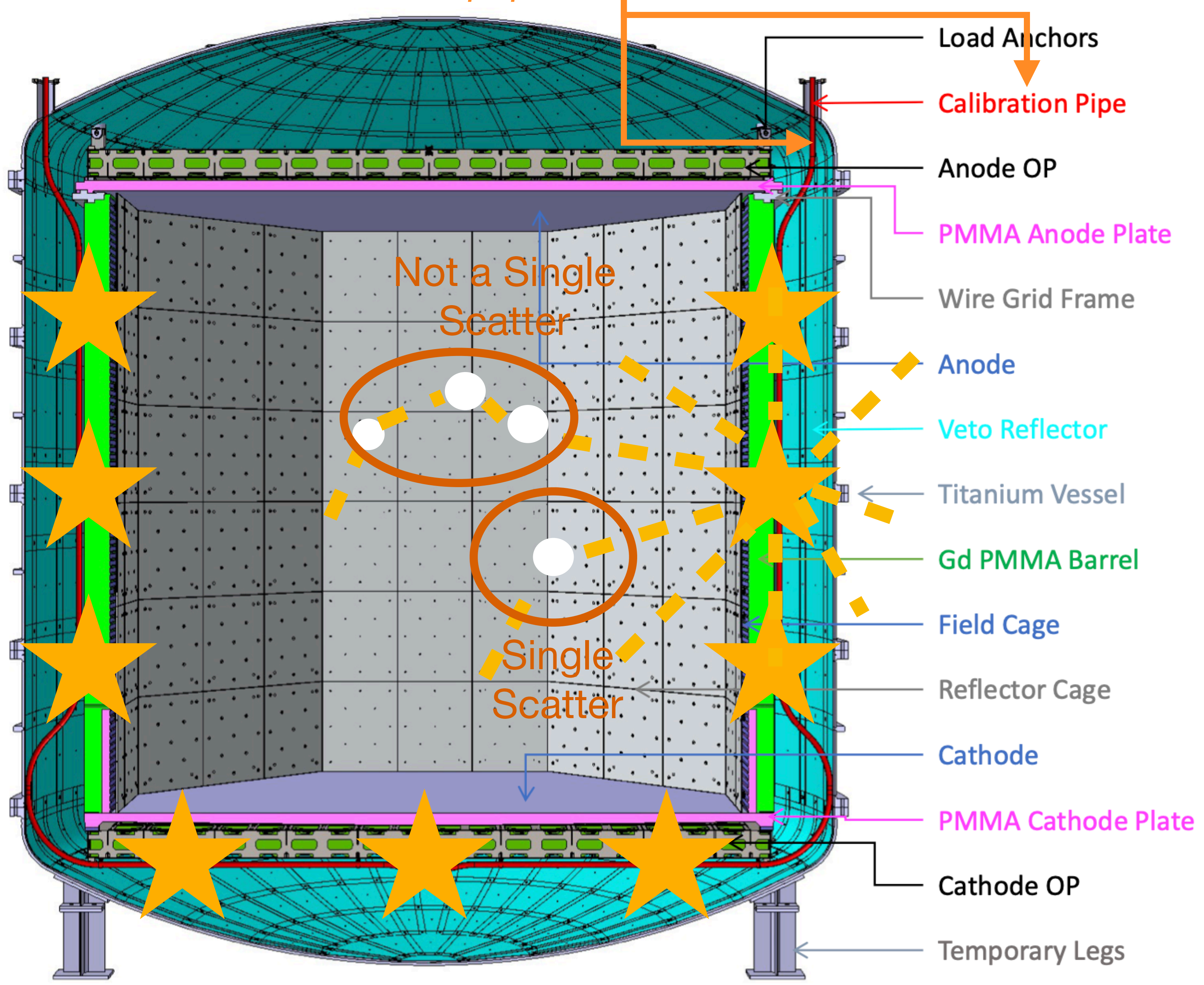
Goals of the calibration

- Calibrate energy deposits of NR signal and ER background
- Study the linearity of the detector response
- Study its spatial uniformity
- Study its time stability

Diffuse sources
ER uniform calibration
^{83m}Kr | ^{220}Rn | ^{39}Ar
Only background characterization
No position resolution & linearity

External sources
ER + NR calibration
^{57}Co | ^{133}Ba | ^{22}Na | ^{137}Cs | ^{60}Co
AmLi | AmC | AmBe

Circulated in calibration pipes



DarkSide-20k TPC calibration

How to and related challenges

contribution to detector construction

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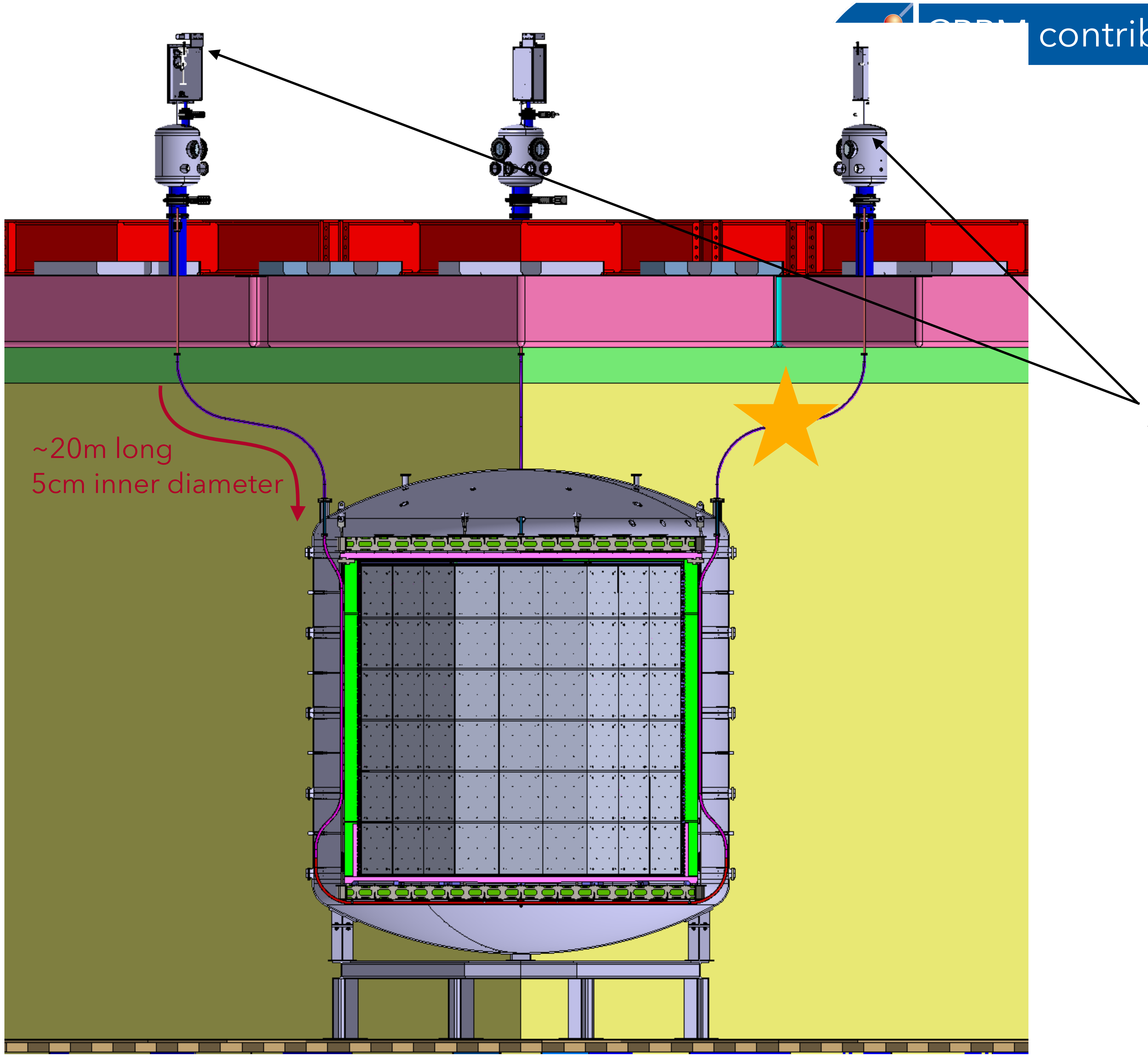

~20m long
5cm inner diameter

Synchronous motorized systems to drive the source in the tube

DarkSide-20k TPC calibration

How to and related challenges

Goals of the calibration

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Challenges of the calibration

- Largest TPC ever built for DM search purposes
- Narrow and cryogenic environment

Diffuse sources

ER uniform calibration

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Only background characterization
No position resolution & linearity

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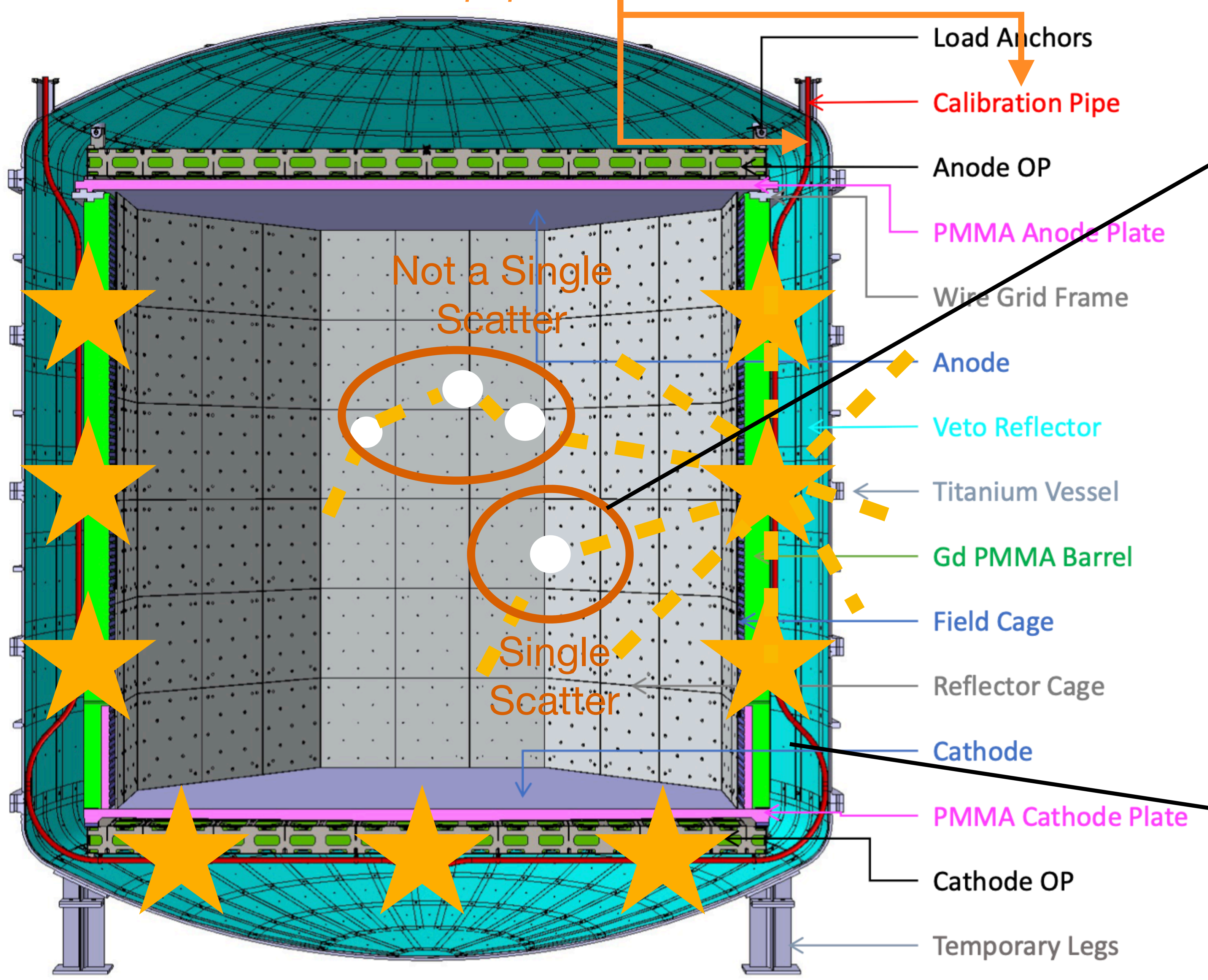


CPPM contribution to detector construction

1 **Make the TPC calibration as efficient as possible**

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

2 **Tubes dived inside the veto buffer**

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

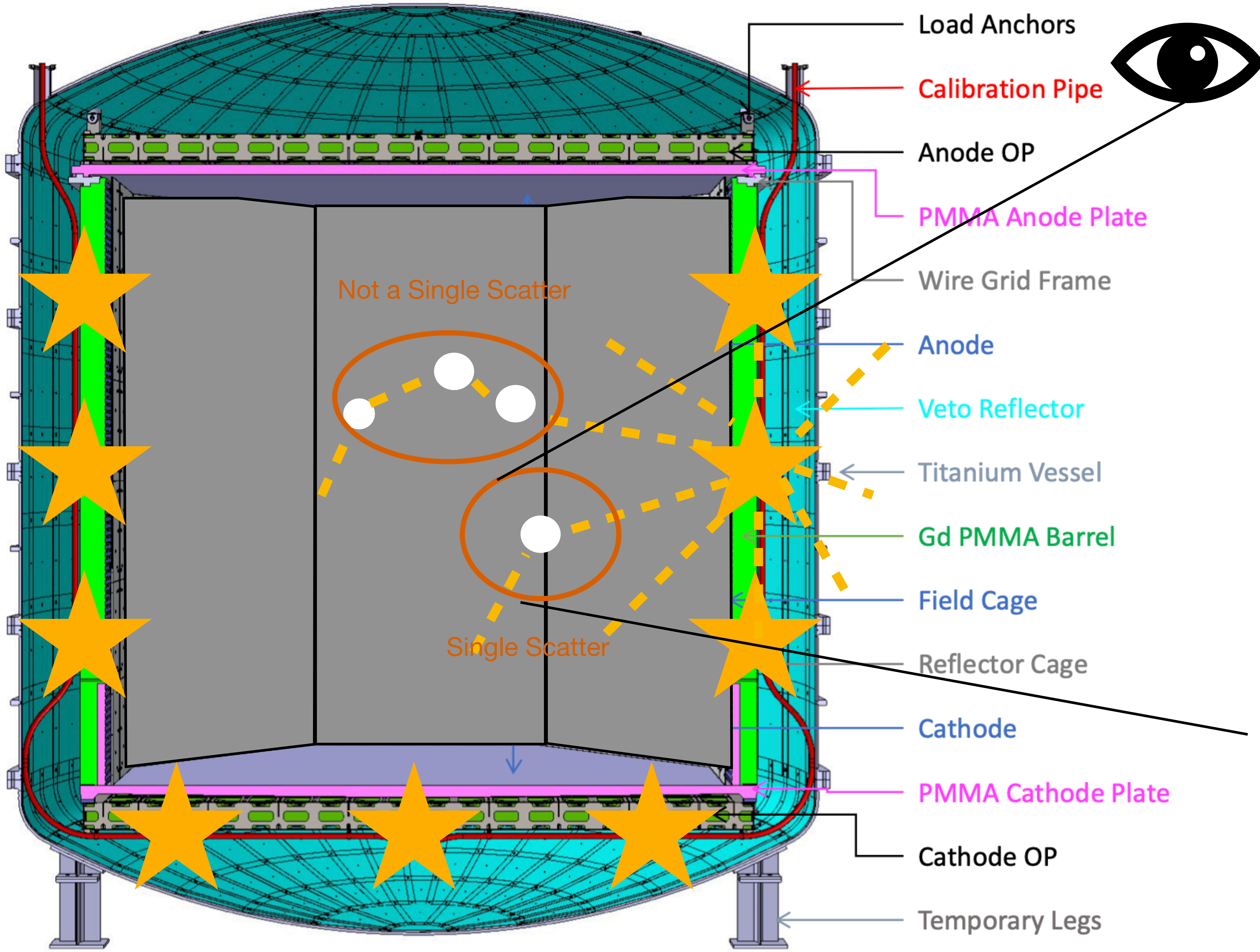
3 **Tubes close to the TPC: background induced ?**

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

DarkSide-20k TPC calibration

Simulation of the calibration

- Signal - like (neutron emitters) or background - like (photon emitters) sources
- Simulate energy spectra in the TPC from the exposure of a radioactive source
  - GEANT4-based software
  - Source positioned on the side or at the bottom of the TPC (in the tube)
- Selection of interesting events (single scatters = WIMP-like)



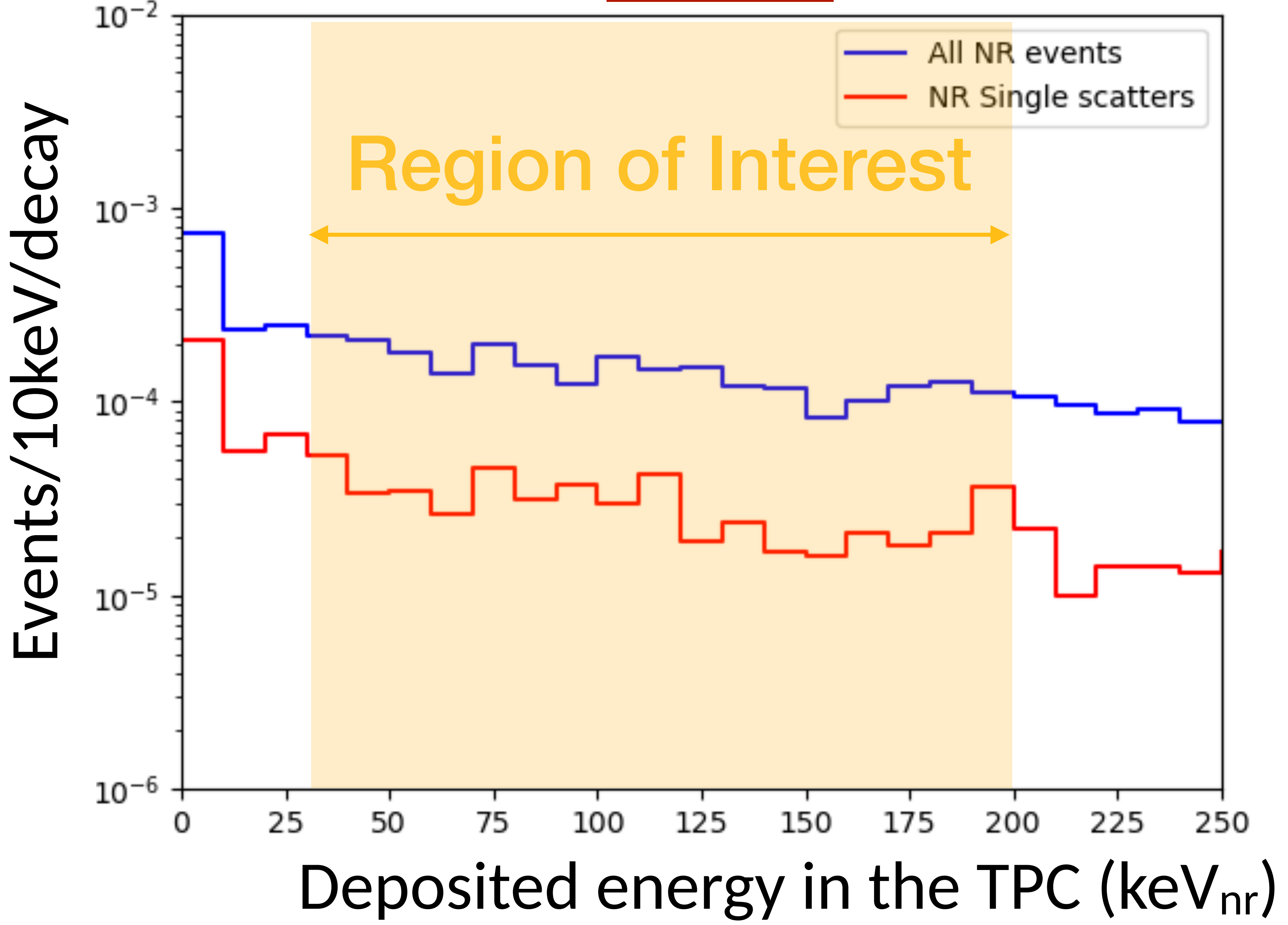
DarkSide-20k TPC calibration

Simulation of the calibration

NR calibration (signal-like)

	AmBe	AmC
E (MeV)	[0.2, 12]	[2, 7]

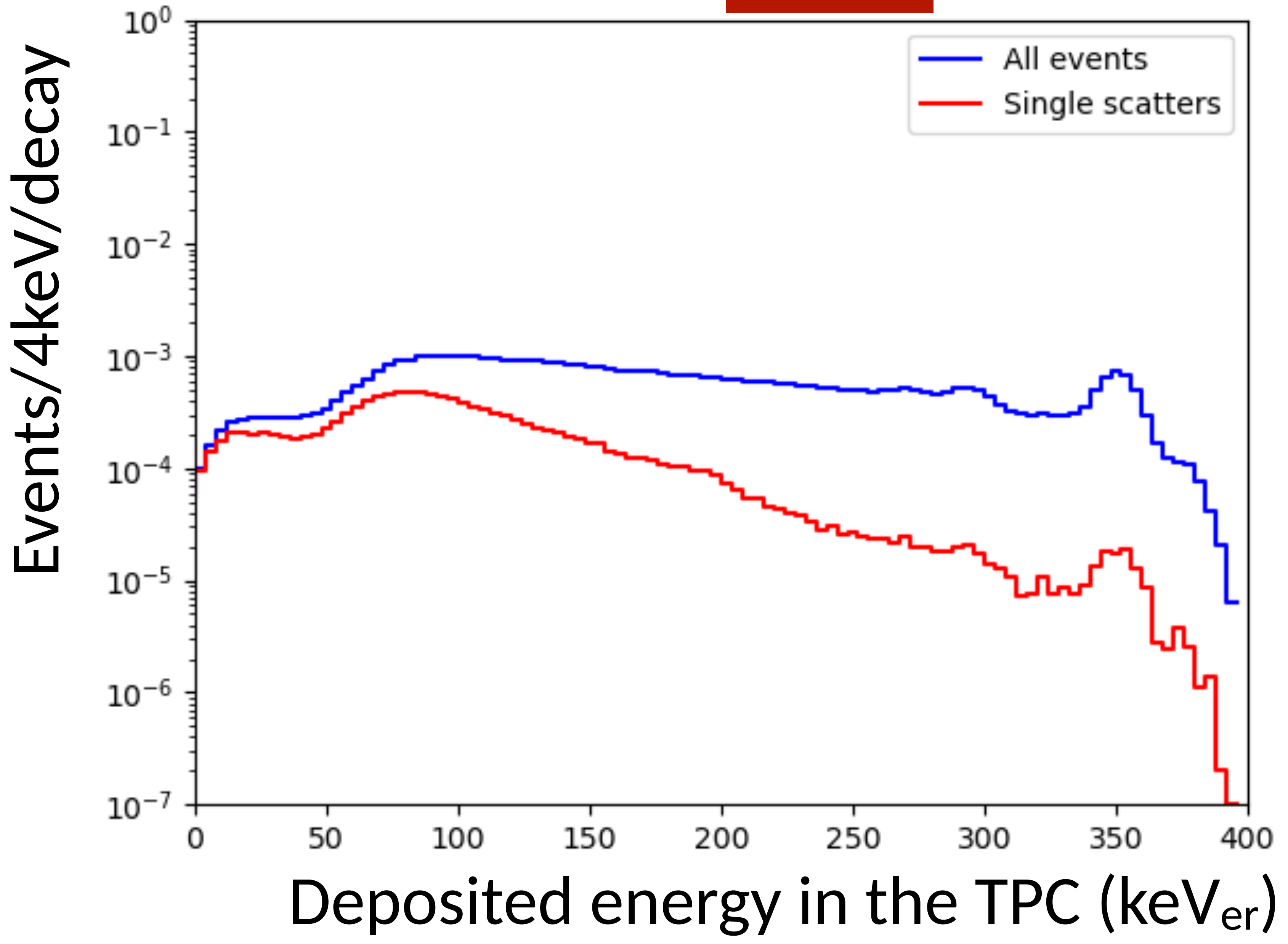
AmBe [0.2, 12] MeV

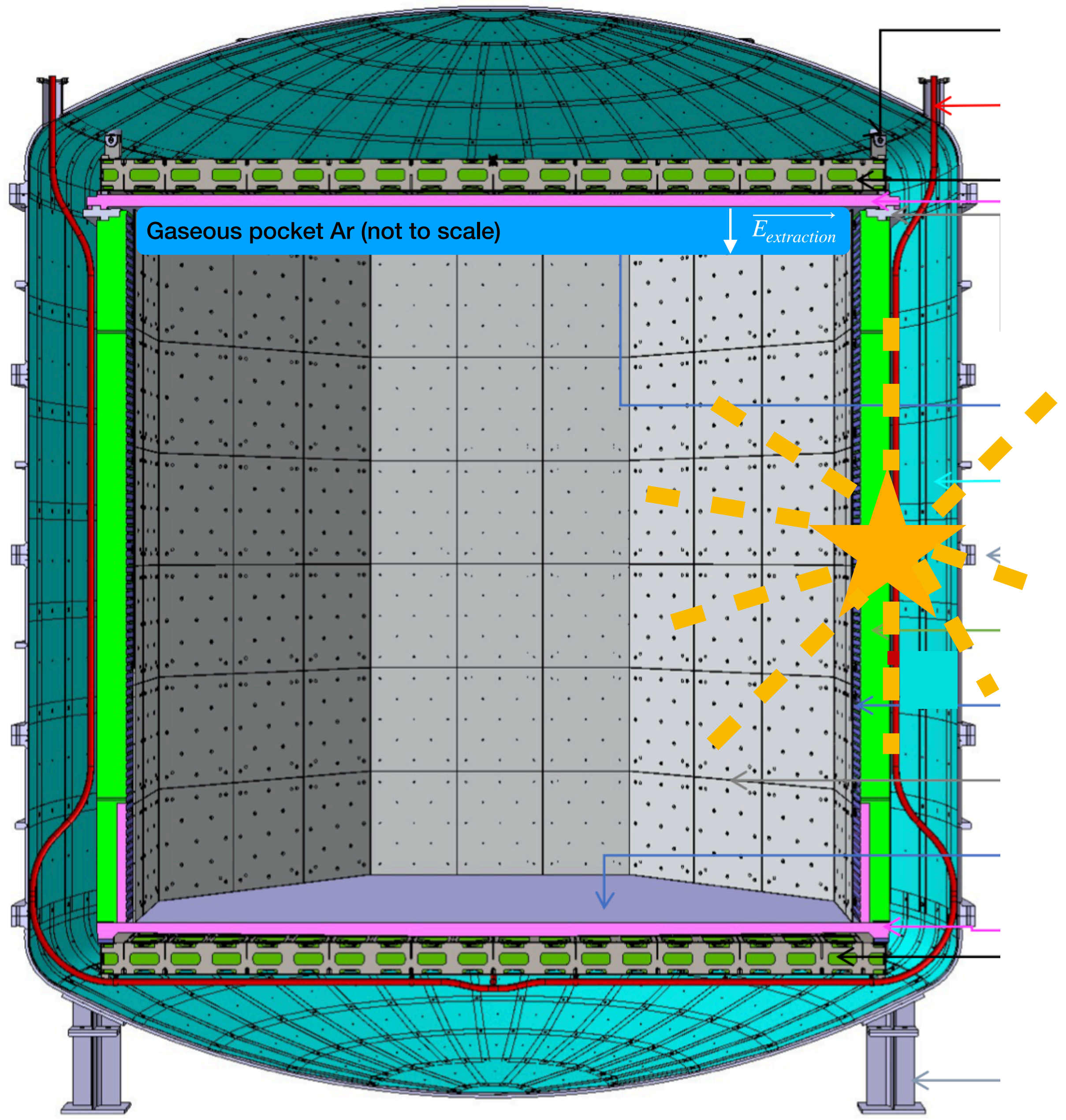


ER calibration (background-like)

	^{57}Co	^{133}Ba	^{22}Na	^{22}Na	^{137}Cs	^{60}Co	^{60}Co
E (keV)	122	356	511	1274	662	1173	1322

^{133}Ba 356 keV





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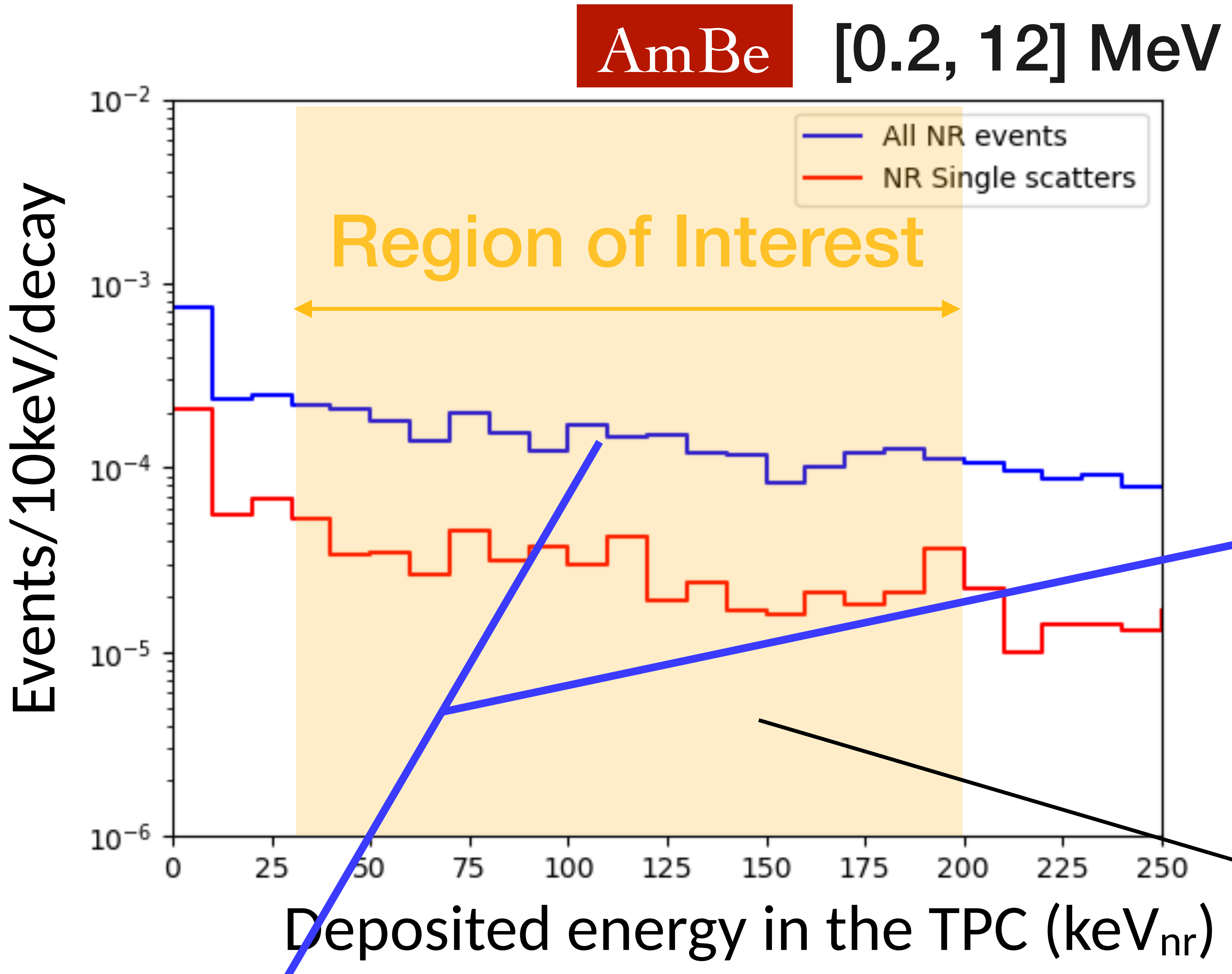
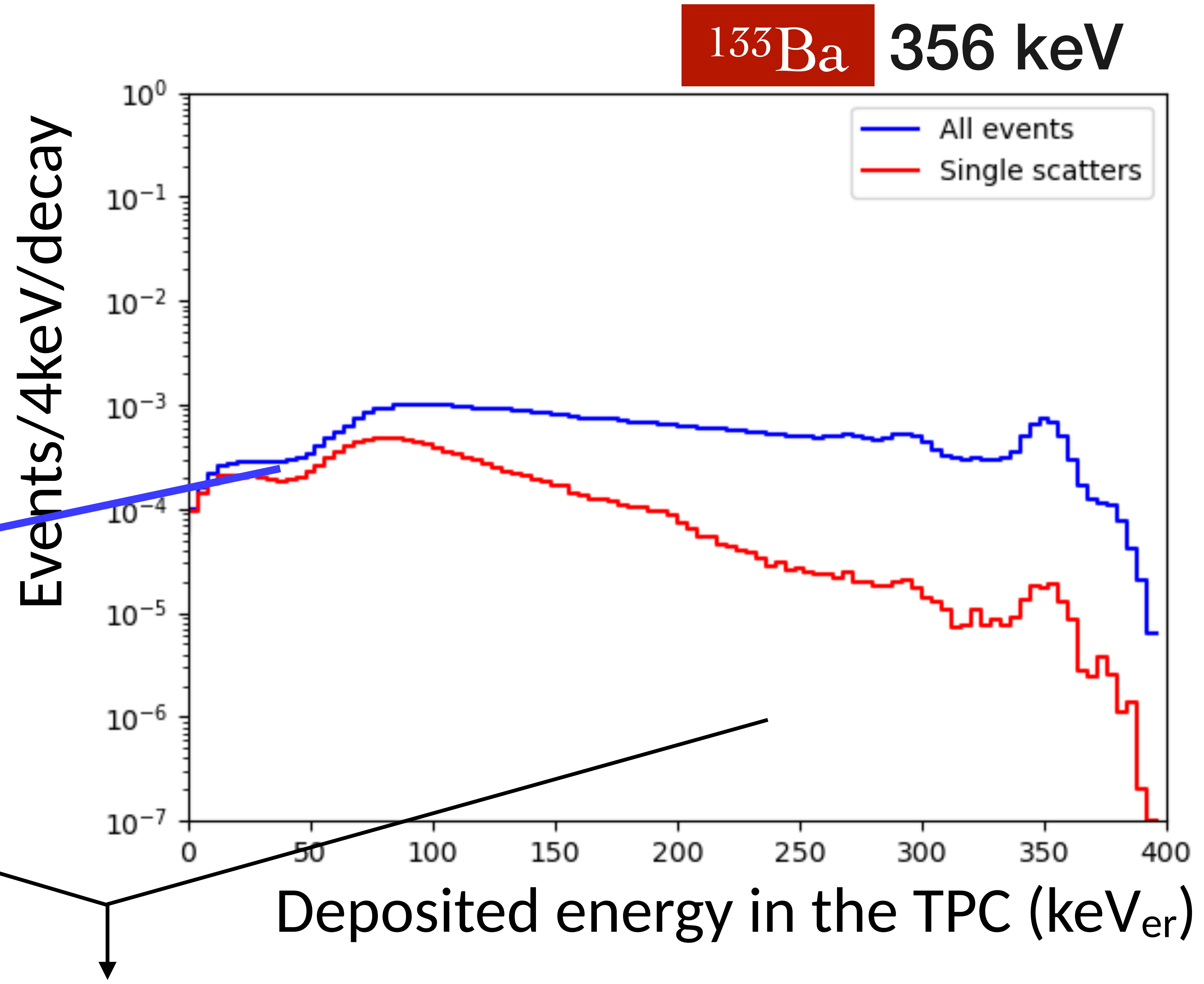
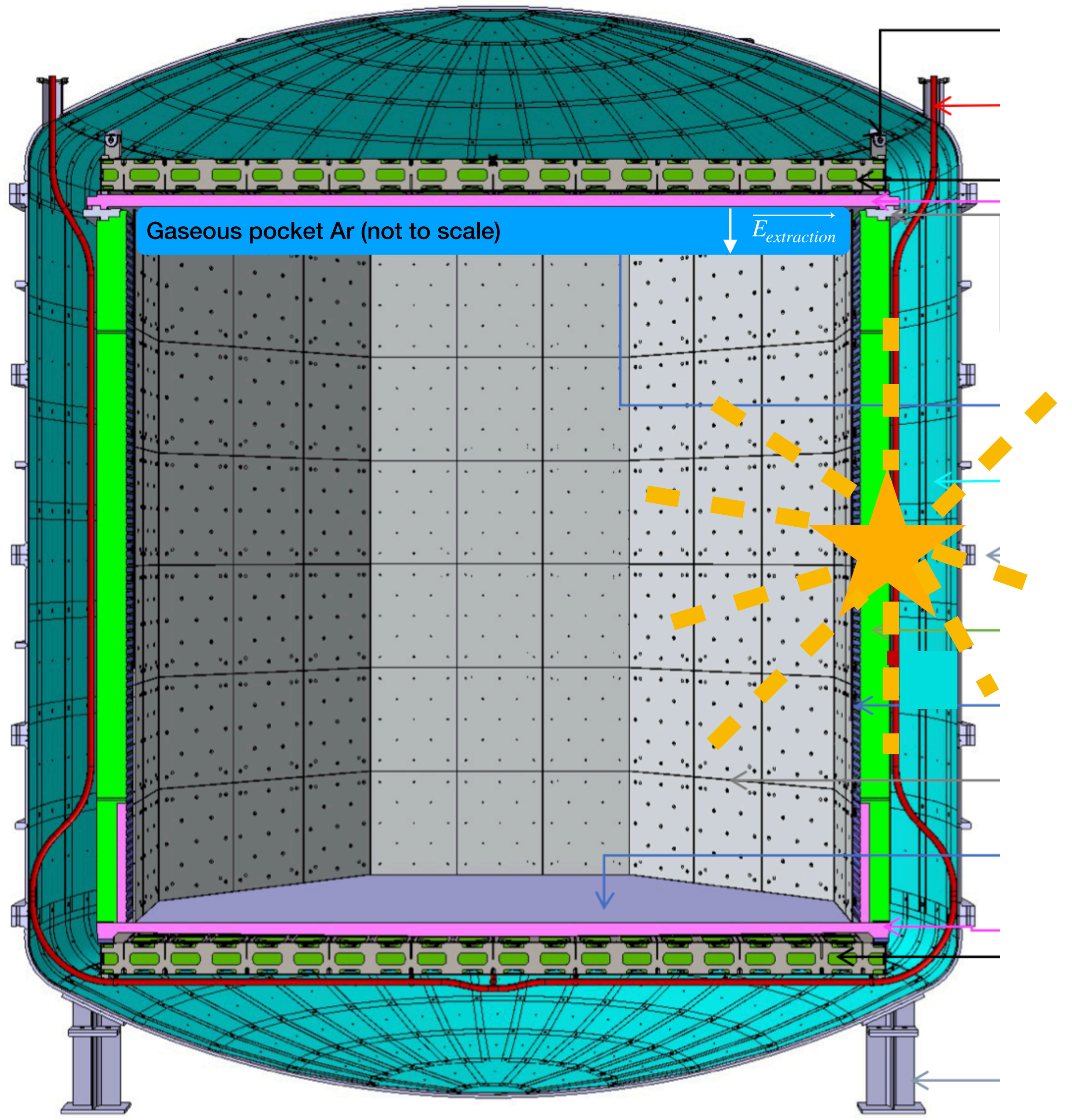






Rates of "all events" permit to optimise the sources activity to take into account the DAQ limitations

Computation of rates of events/decay
+
Assumptions on the detector and calibration runs (verified with the mock ups at CERN and CPPM)

Estimate of the time needed to perform the calibration program

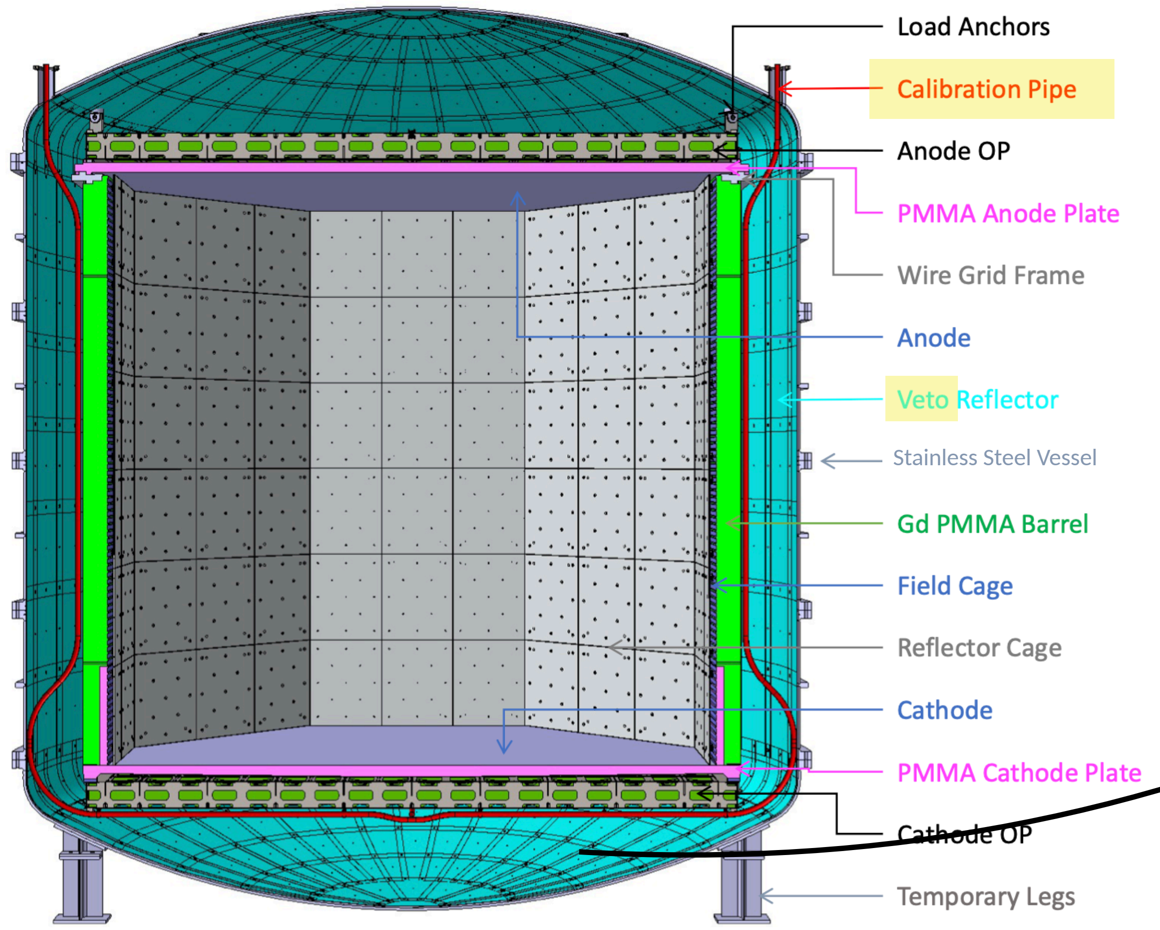
With 9 positions of calibration

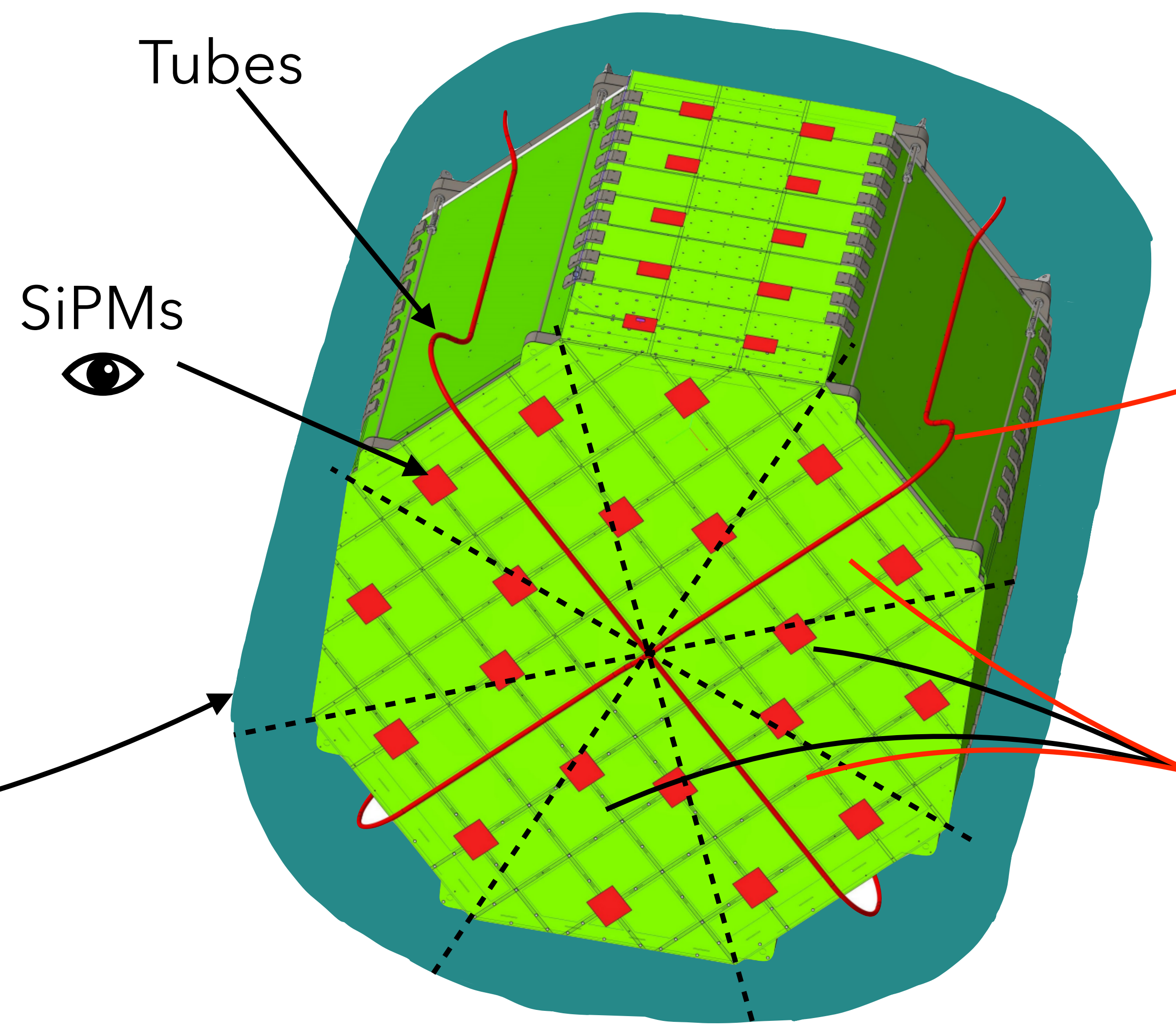
NR calibration (with neutrons) : 15 days

ER calibration (with photons) : 1 day to 1 week

DarkSide-20k TPC calibration

Adverse impact on the veto's light collection efficiency





Tubes can absorb the light emitted by the argon when scintillating: this could lower the veto light collection efficiency (LCE)

Impact estimated thanks to dedicated optical simulations in the veto

Asymmetry between octants up to 0.3 %

LCE	**Relative loss of LCE (%)**
Full veto buffer (3D)	0.9
Octants with pipes	1.1

Errors on these numbers are < 1e-2
(Gaussian statistical errors)

With **reflector-wrapped** stainless steel tubes

= Best solution after different **tests of optical boundaries**

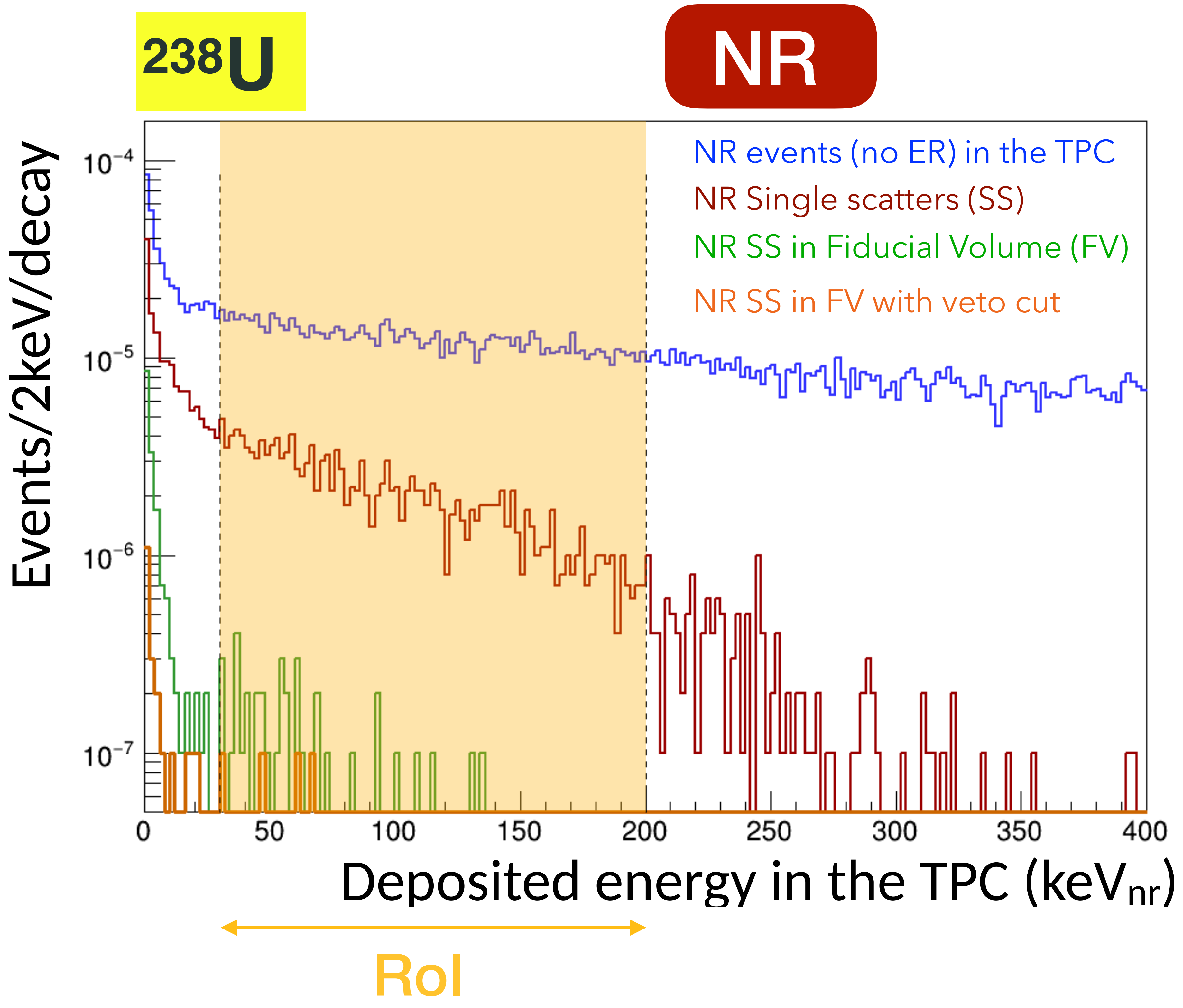
DarkSide-20k TPC calibration

Background contribution

Very low background experiment & stainless steel tubes => control radio-purity

	^{238}U up	^{238}U mid	^{238}U low	^{232}Th	^{235}U	^{40}K	^{60}Co	^{137}Cs
Activity (mBq/kg)	1	0.72	1	0.83	0.046	0.49	3.1	0.86
Neutron yield (n/decay)	1.1e-9	4.8e-7	1.1e-9	1.8e-6	3.7e-7			

From (α, n) reactions due to natural contamination in ^{232}Th and ^{238}U and spontaneous fission of ^{238}U



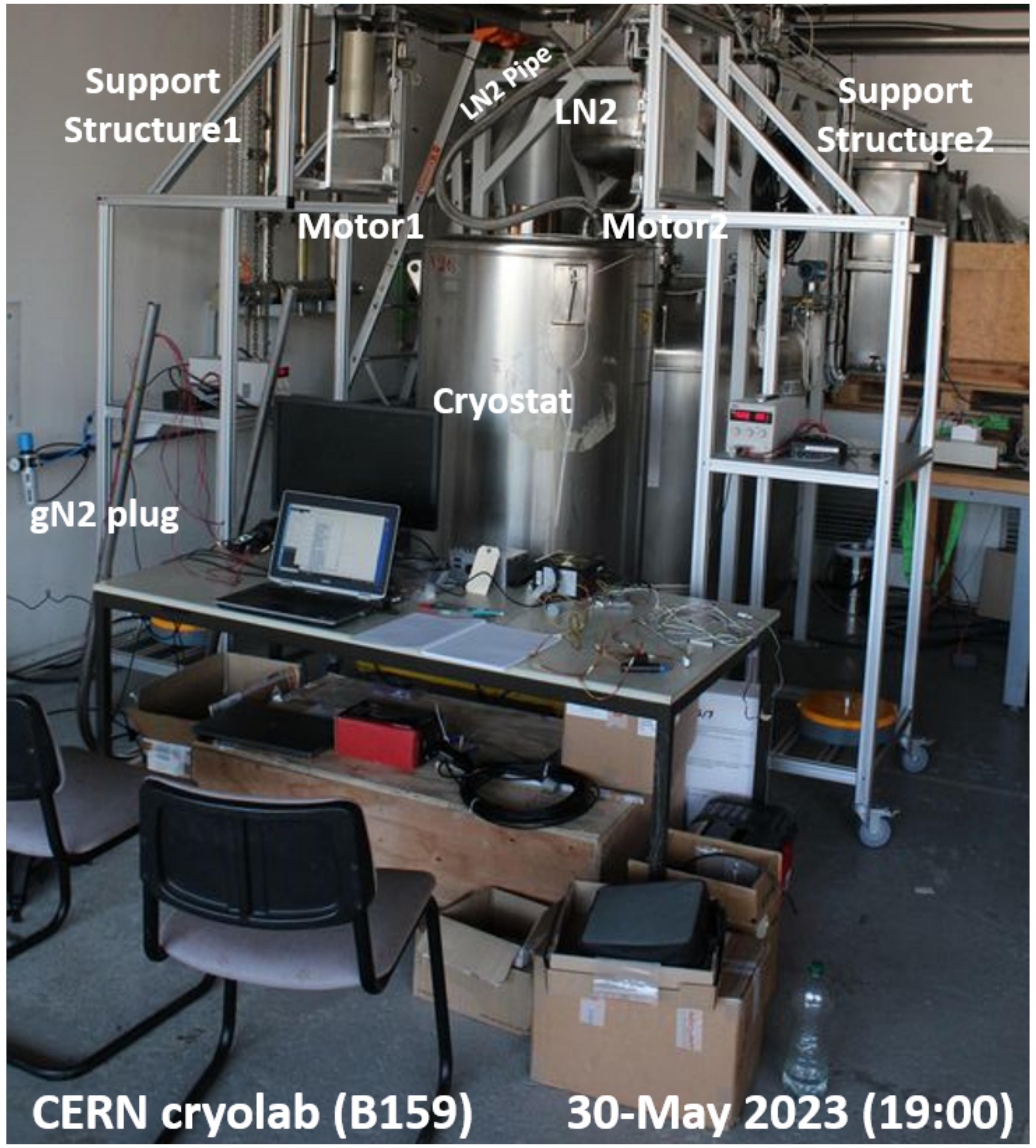
	^{238}U up	^{238}U mid	^{238}U low	^{232}Th	^{235}U
NR bkg / 10 years (200 t.y.)	4.0e-9	1.3e-6	4.0e-9	5.7e-6	6.0e-8

- NR background from pipes represents < 0.01% of DS20k budget: **fully negligible**
- Same study for ER : **ER background also negligible + S1/S2 ratio and PSD (= argon asset)**

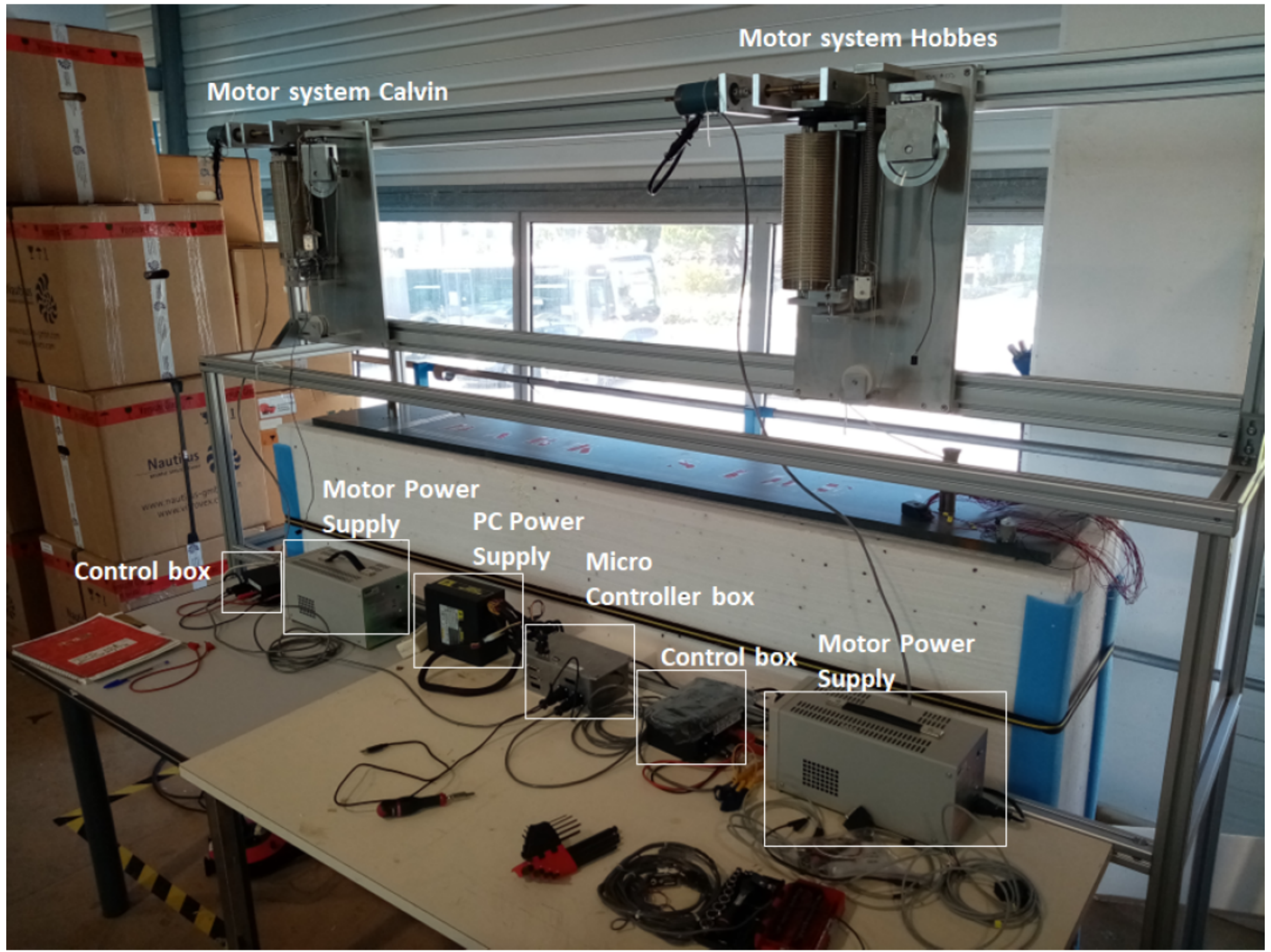
DarkSide-20k TPC calibration

Feasibility tests at CPPM and CERN

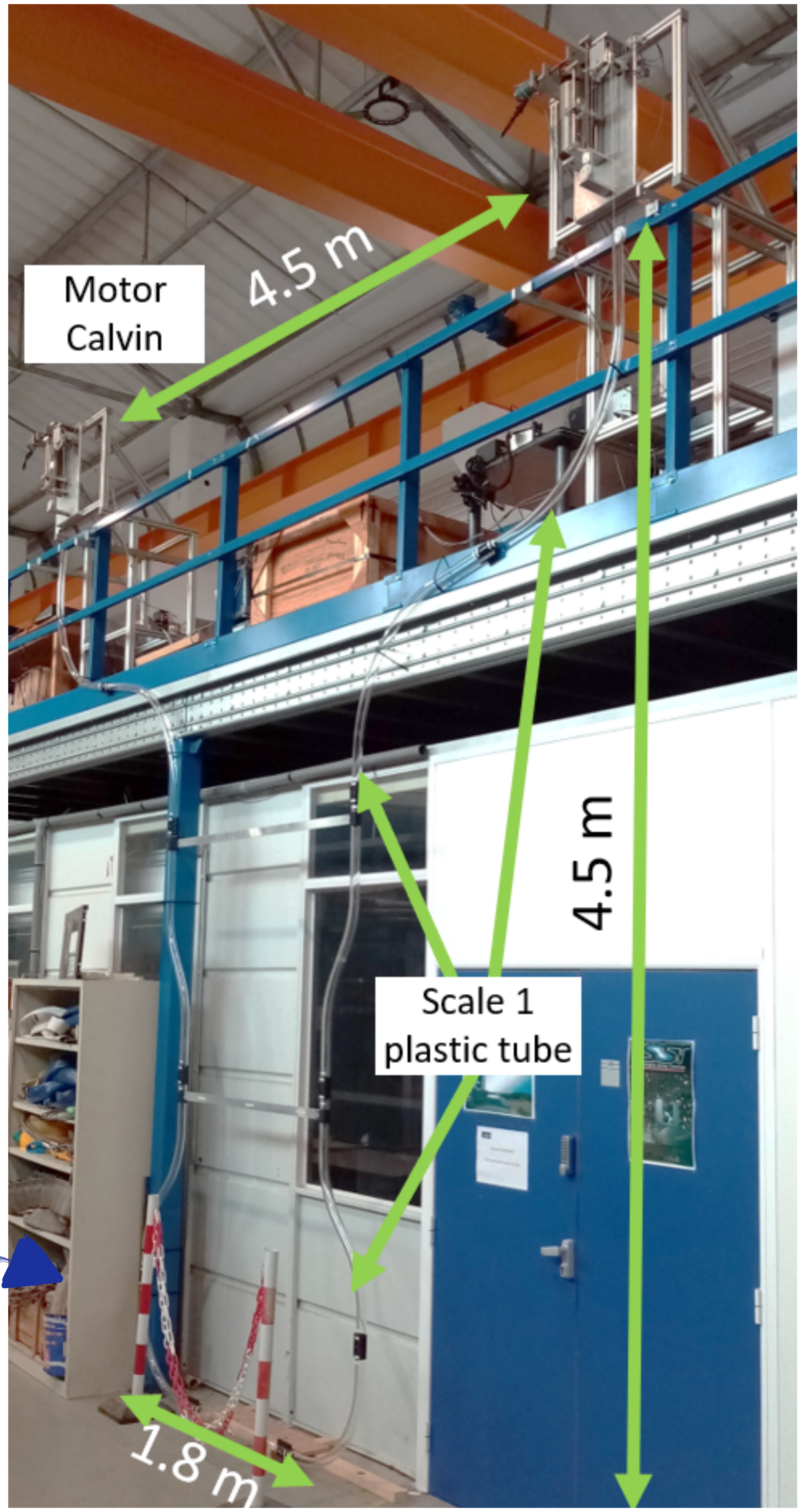
CERN



CPPM



CPPM



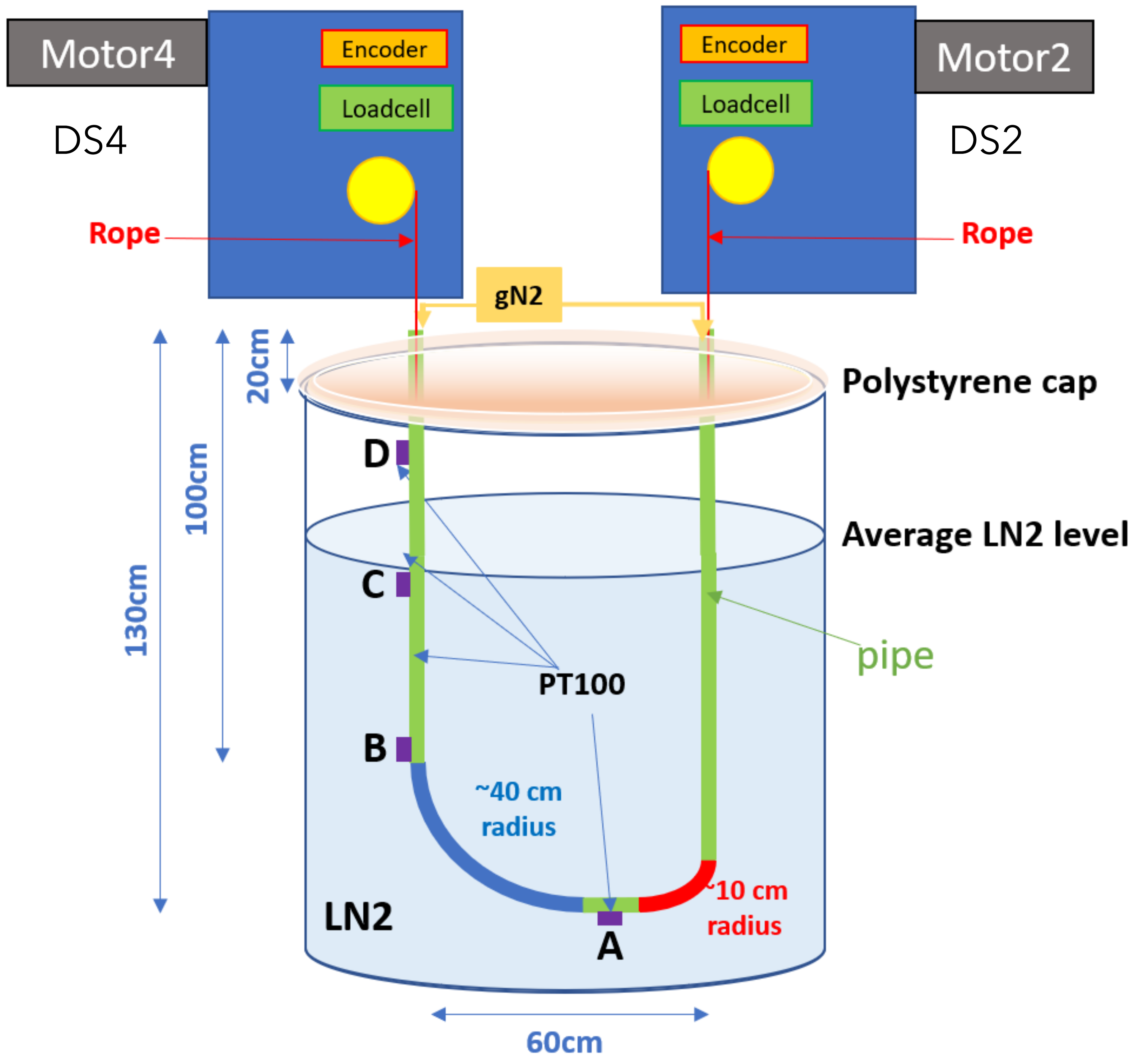
Cryogenic mock-ups

Scale-1 mock-up

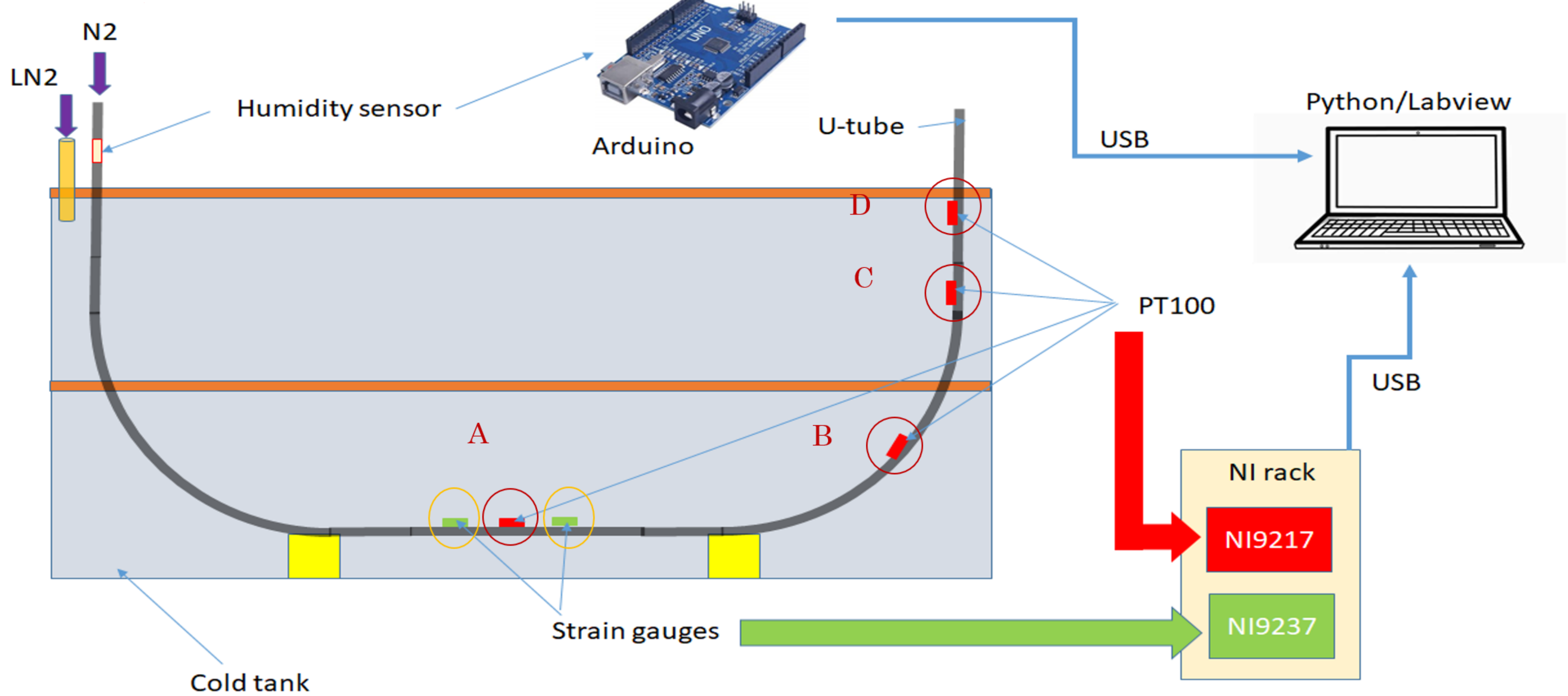
DarkSide-20k TPC calibration

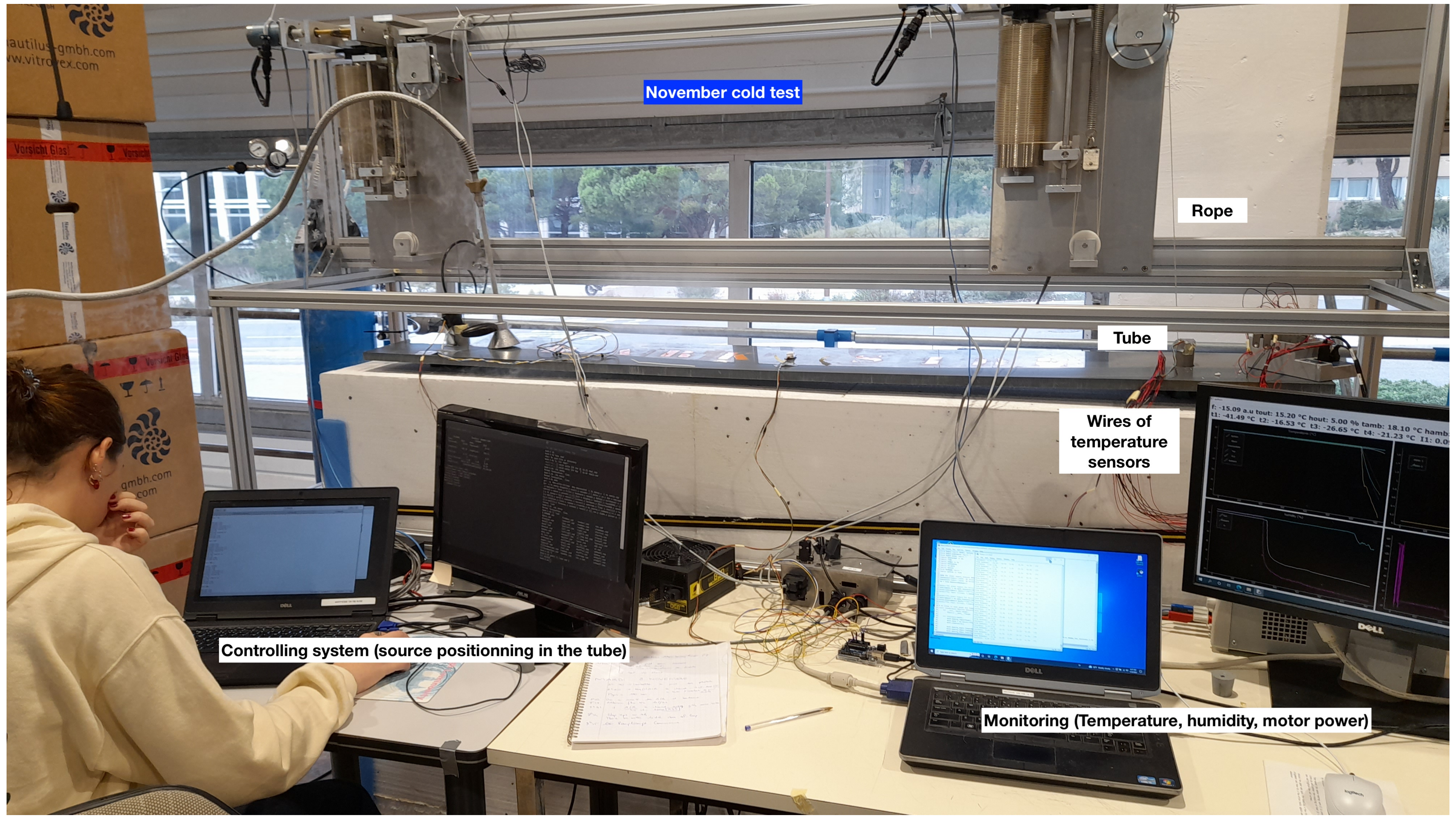
Feasibility tests at CPPM and CERN

CERN



CPPM





Measure the warm to cold tension ratio

Test the robustness of the motorised systems

Test extreme cryogenic conditions

Test the stability of the system's behaviour

- + Apprehend the system and source management
- + Develop the monitoring

DarkSide-20k TPC calibration

Feasibility tests at CPPM and CERN

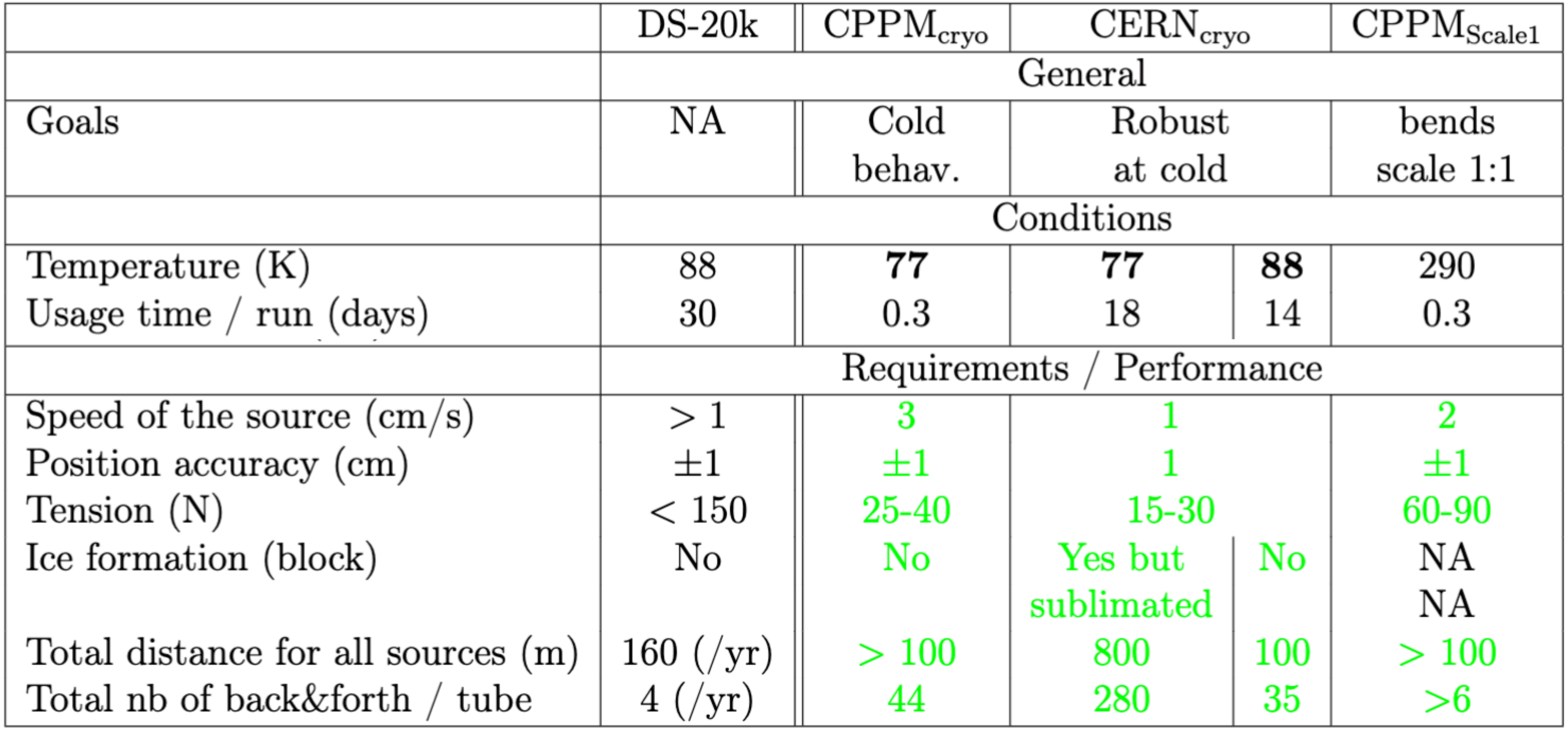
📍 **CERN (LN$_2$ temperature)**

→ Stability of the pattern of the tension to apply on the ropes to move a pseudo source

→ Robustness of the system (travelled distance is equivalent of 4 calibration runs)

DarkSide-20k TPC calibration

Feasibility tests at CPPM and CERN



	DS-20k	CPPM$_{cryo}$	CERN$_{cryo}$		CPPM$_{Scale1}$
	General				
Goals	NA	Cold behav.	Robust at cold		bends scale 1:1
	Conditions				
Temperature (K)	88	**77**	**77**	**88**	290
Usage time / run (days)	30	0.3	18	14	0.3
	Requirements / Performance				
Speed of the source (cm/s)	> 1	3	1		2
Position accuracy (cm)	±1	±1	1		±1
Tension (N)	< 150	25-40	15-30		60-90
Ice formation (block)	No	No	Yes but sublimated	No	NA
					NA
Total distance for all sources (m)	160 (/yr)	> 100	800	100	> 100
Total nb of back&forth / tube	4 (/yr)	44	280	35	>6

Take home messages

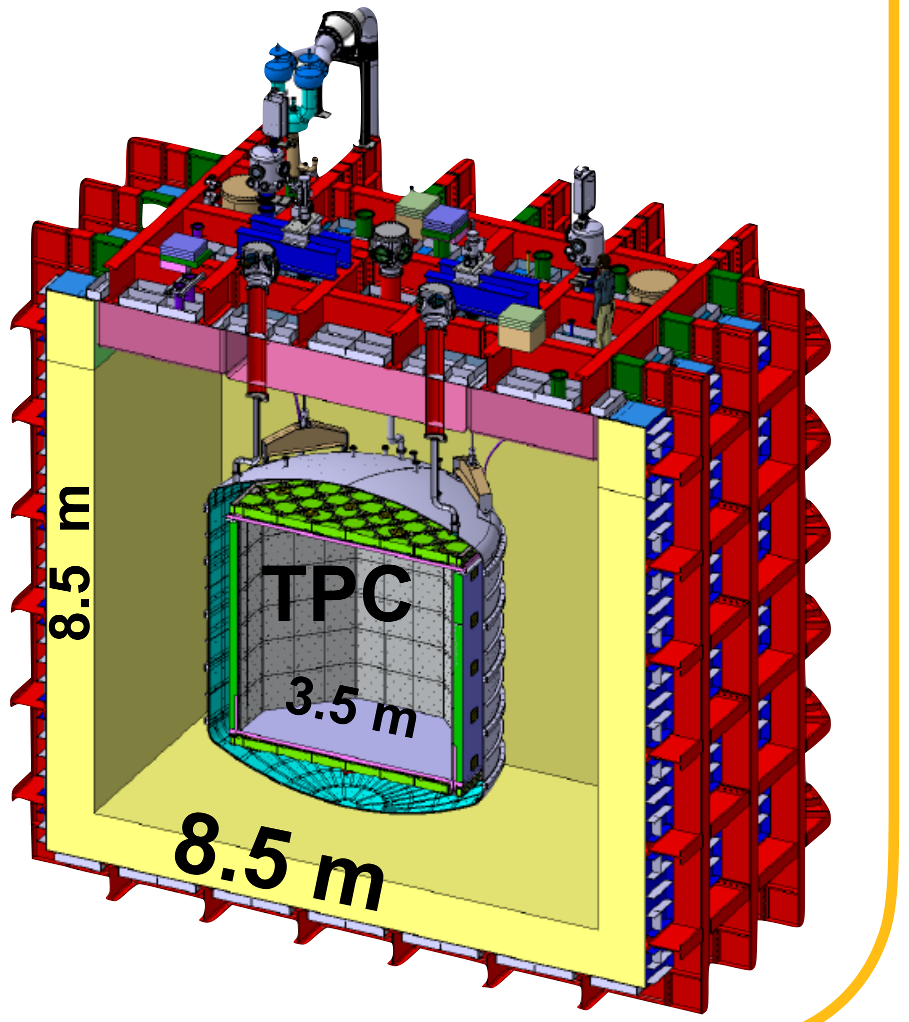
- **First simulations** of the external calibration system
- Simulations **drove/helped some design choices** for the calibration system
  - Activities of the sources
  - Choice of the sources
  - Optical boundary for the tubes
  - Diameter of the tube
- Simulation studies presented at the **57th Rencontres de Moriond - EW** (2023)
- Simulation and hardware works prove the feasibility of the calibration
- The calibration studies permitted the system to **pass the Final Design Review** and to be validated by an independent external INFN committee
- Now entering **Production Readiness Review** stage

How to search for WIMPs ?

Create scalable detectors

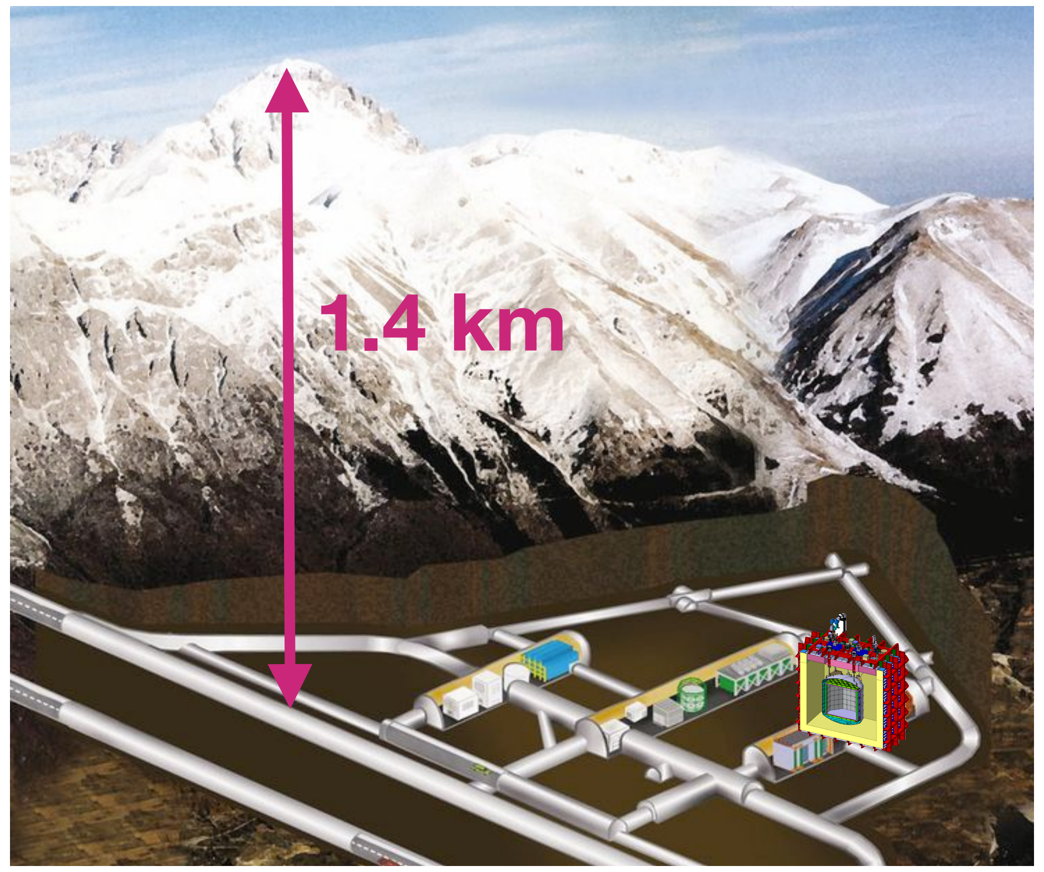
DarkSide-20k : 20t of argon at liquid phase in fiducial volume (700t in total)

Largest TPC ever built for DM search purposes



Shield the detector from background

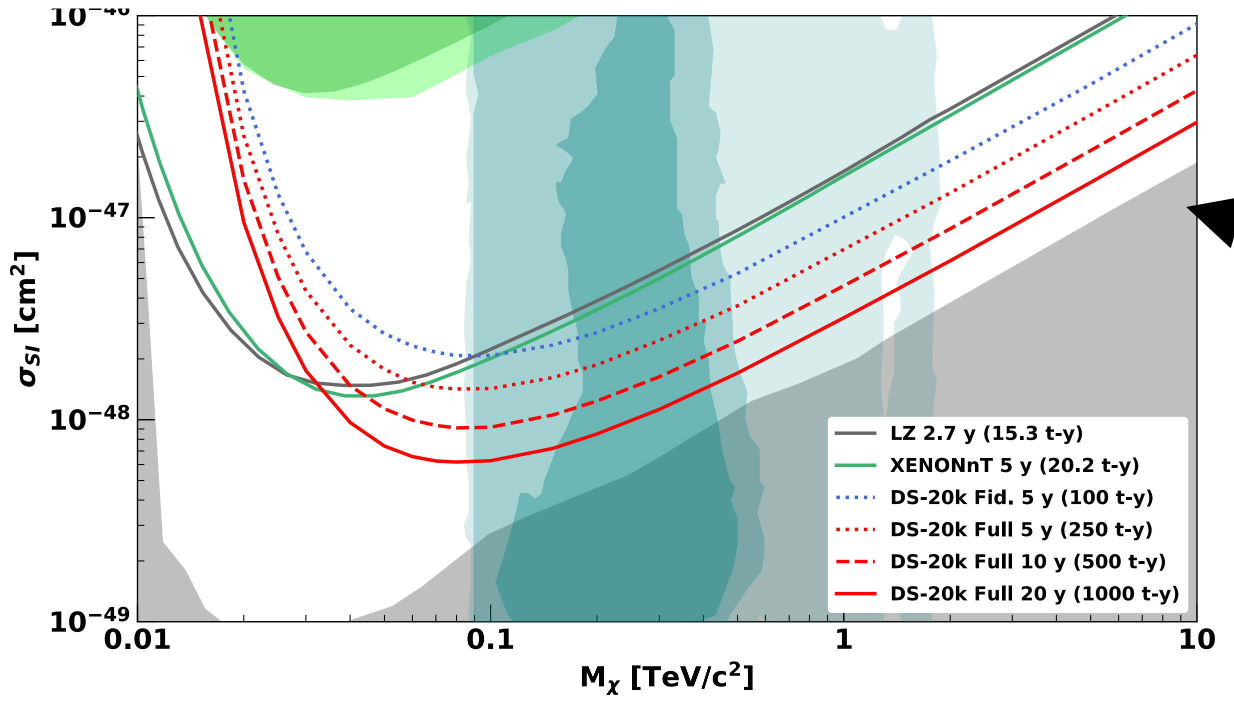
DarkSide-20k : located at the Gran Sasso Laboratory (Italy) under 1.4km of rock to shield from cosmic rays



Searching for WIMPs

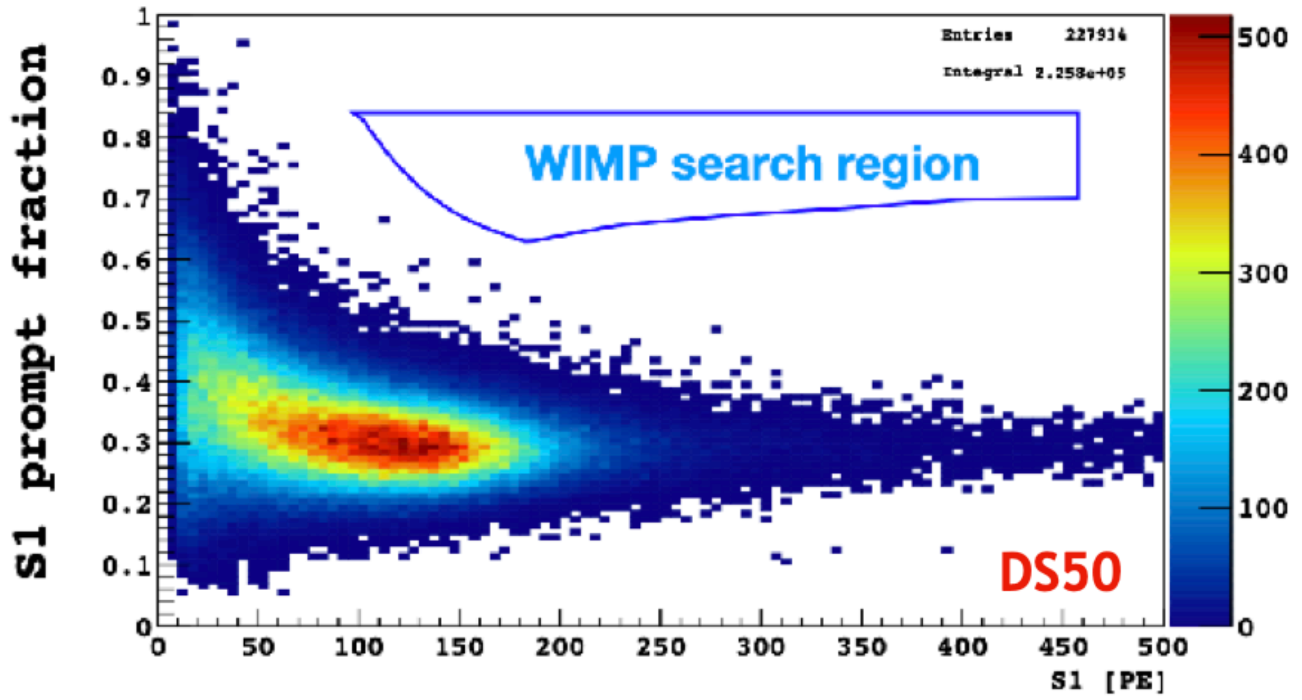
Compute the sensitivity of the experiment

Depends on the DM halo modelling



Understand and discriminate backgrounds and signal

Argon: extremely powerful discrimination between backgrounds and signal

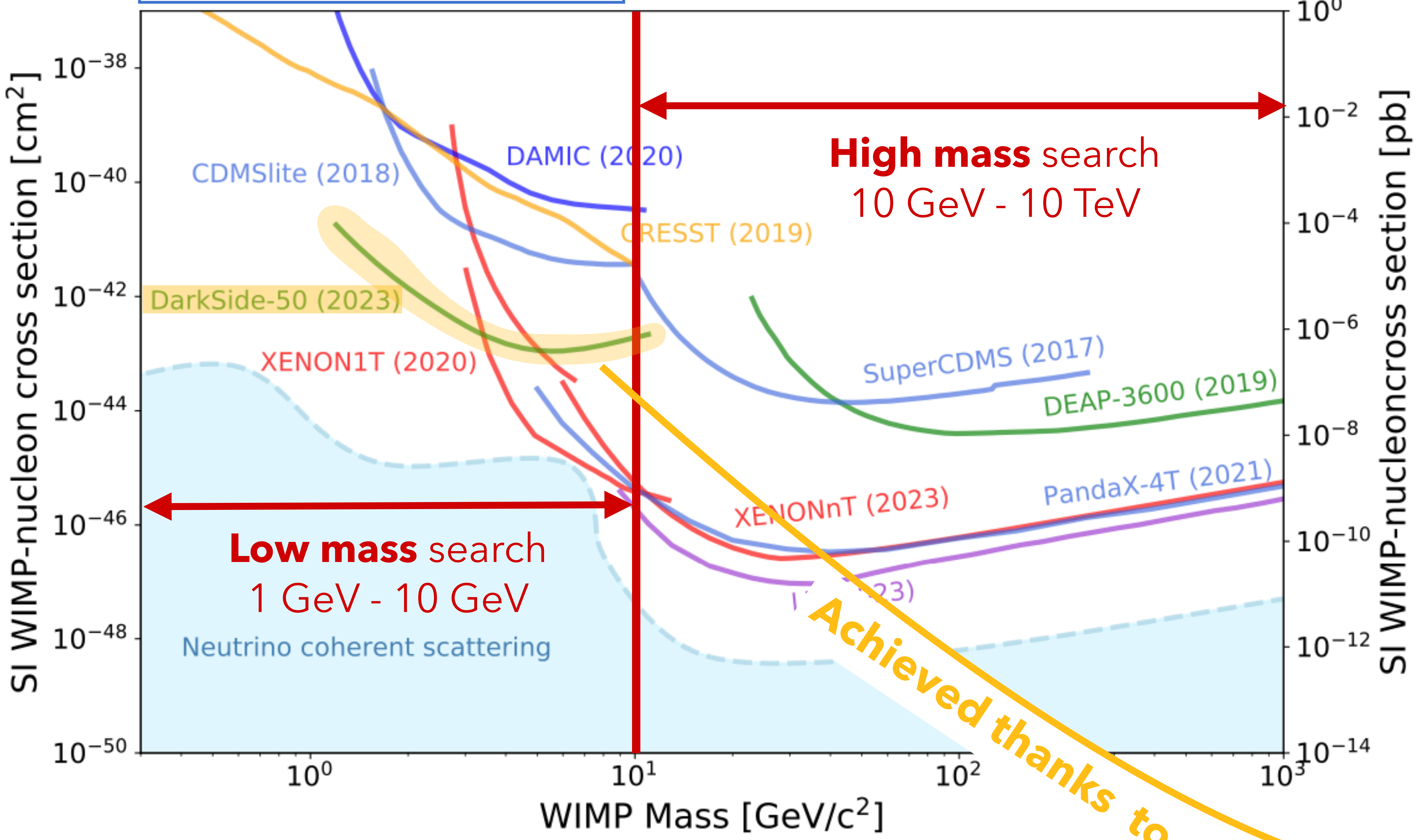


Background budget (after cuts): 0.1 event / 10y

DarkSide-50 legacy

Low mass WIMPs search

From PDG 2023



High mass search
10 GeV - 10 TeV

Low mass search
1 GeV - 10 GeV

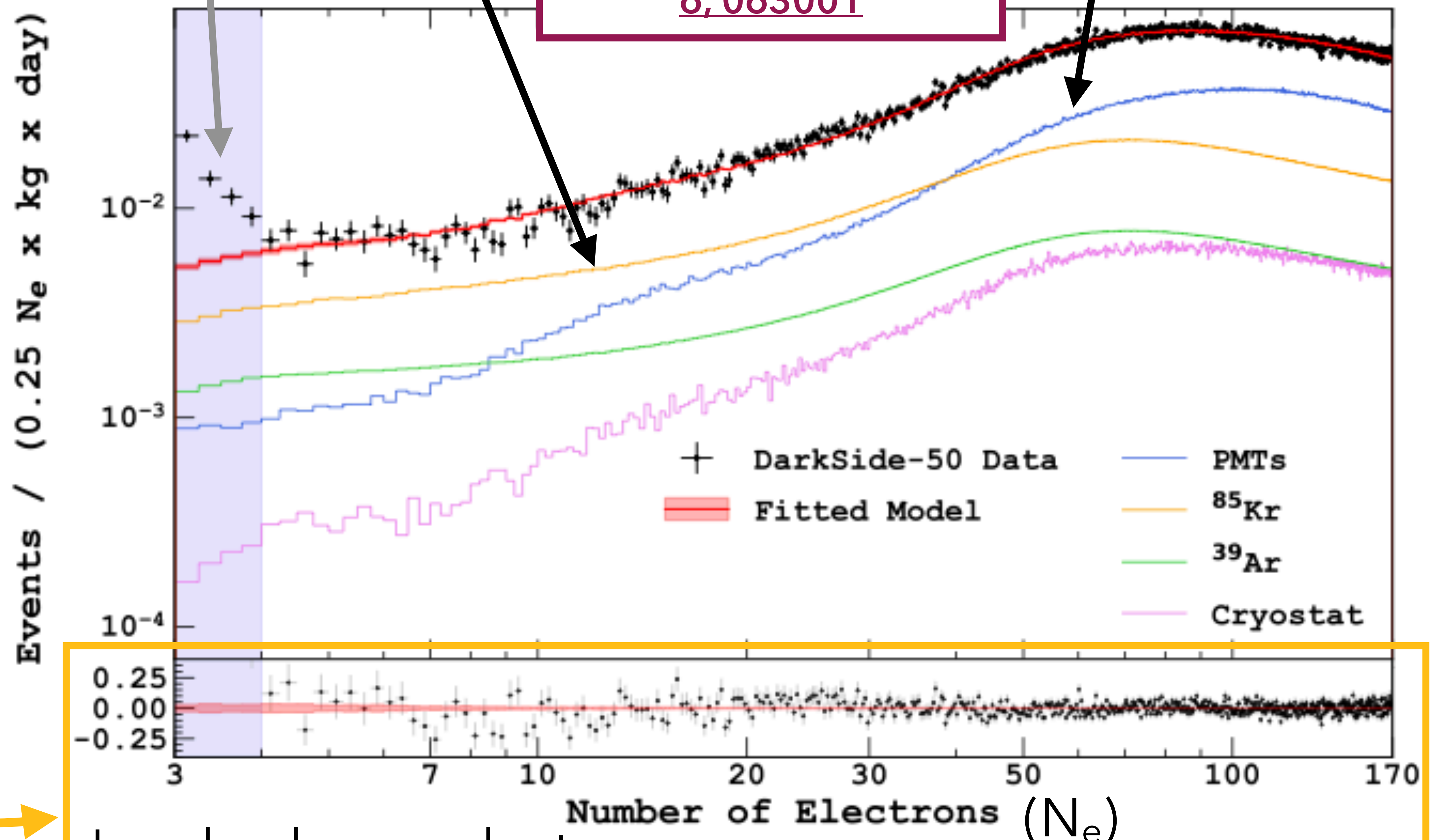
Achieved thanks to

Spurious electrons

Dominated by ^{85}Kr at low N_e

Dominated by PMTs at high N_e

Phys.Rev.D 107 (2023) 6, 063001



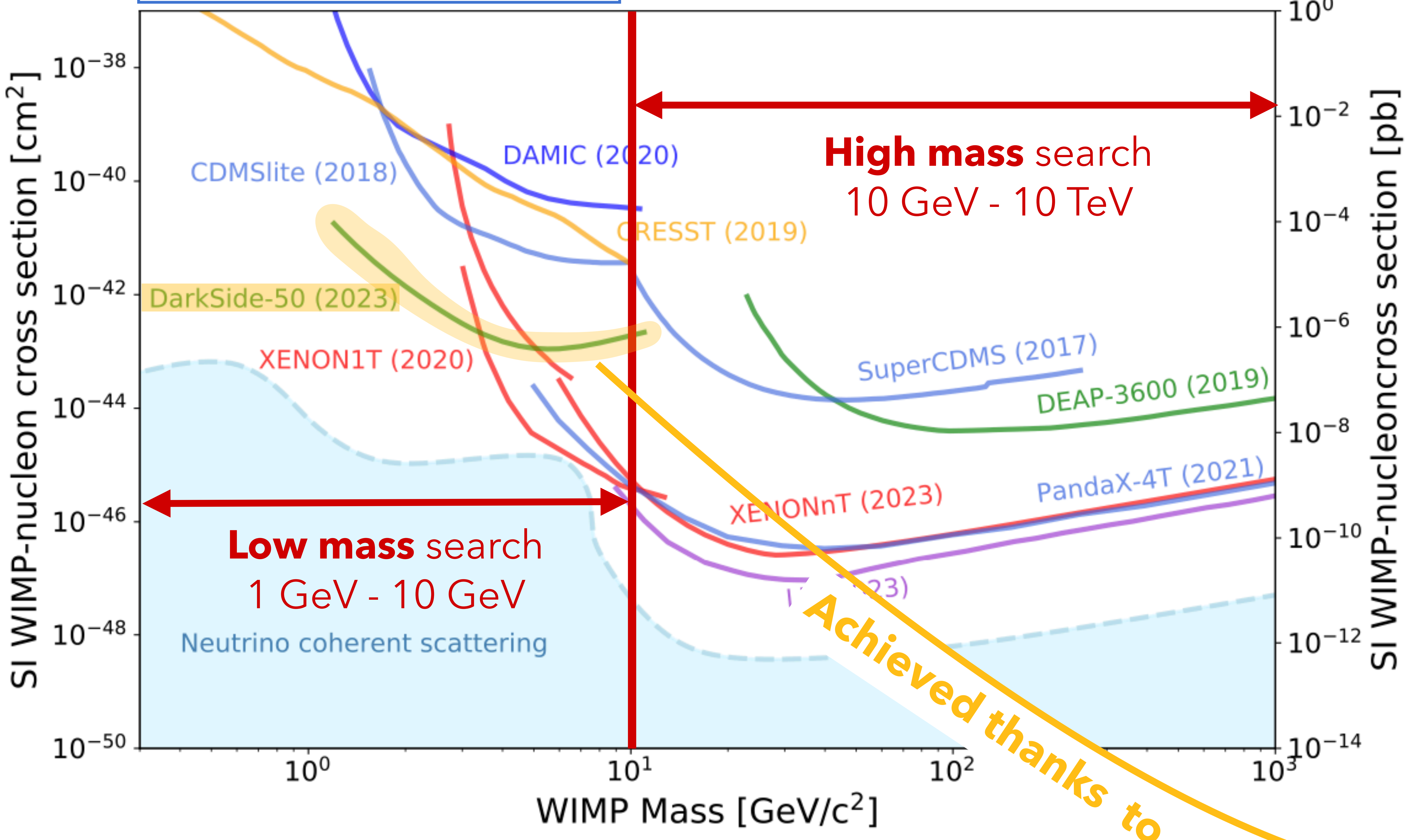
Low background rate

Excellent background modelling above 4 N_e

DarkSide-50 legacy

Low mass WIMPs search

From PDG 2023



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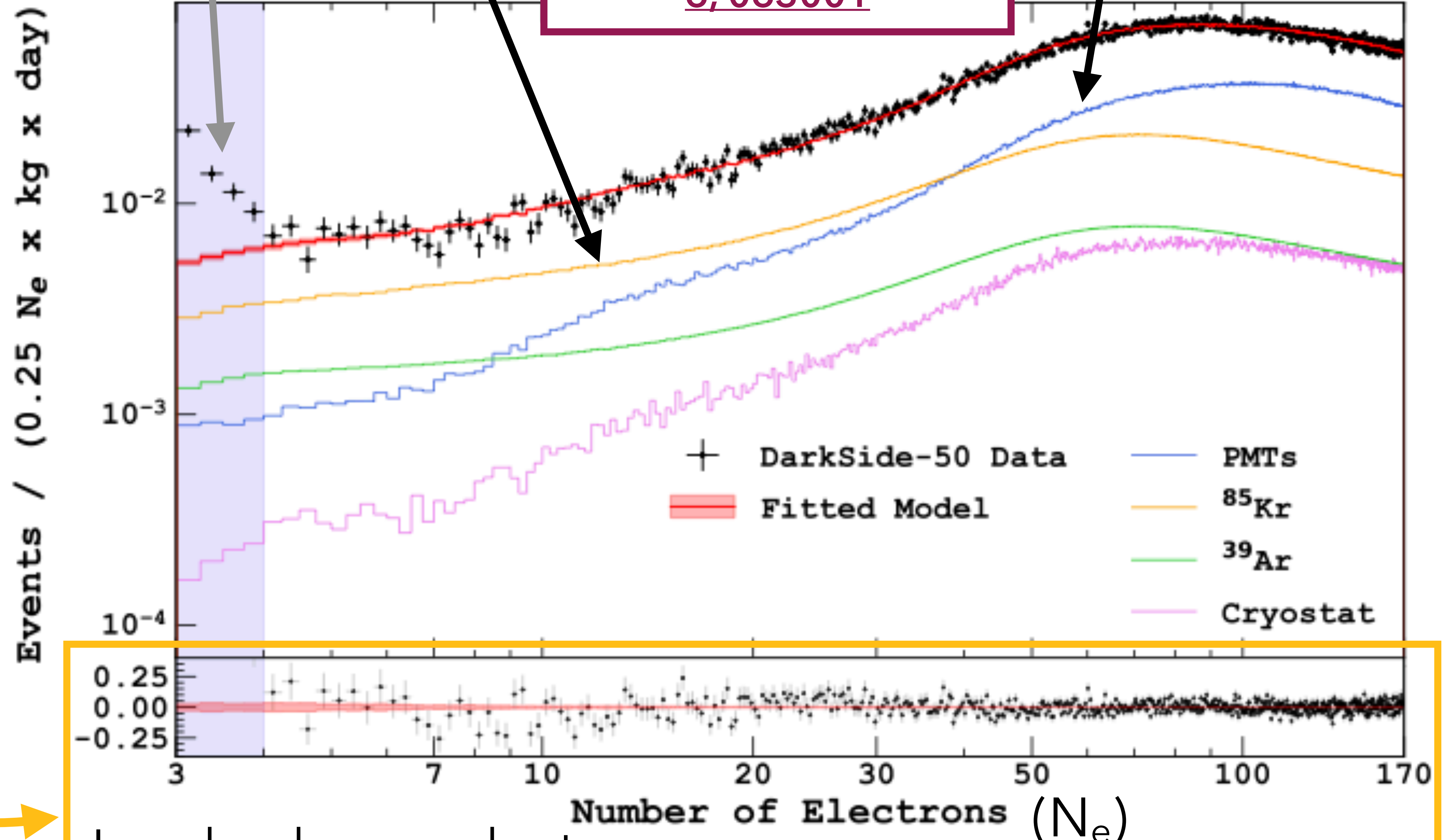


Low background rate

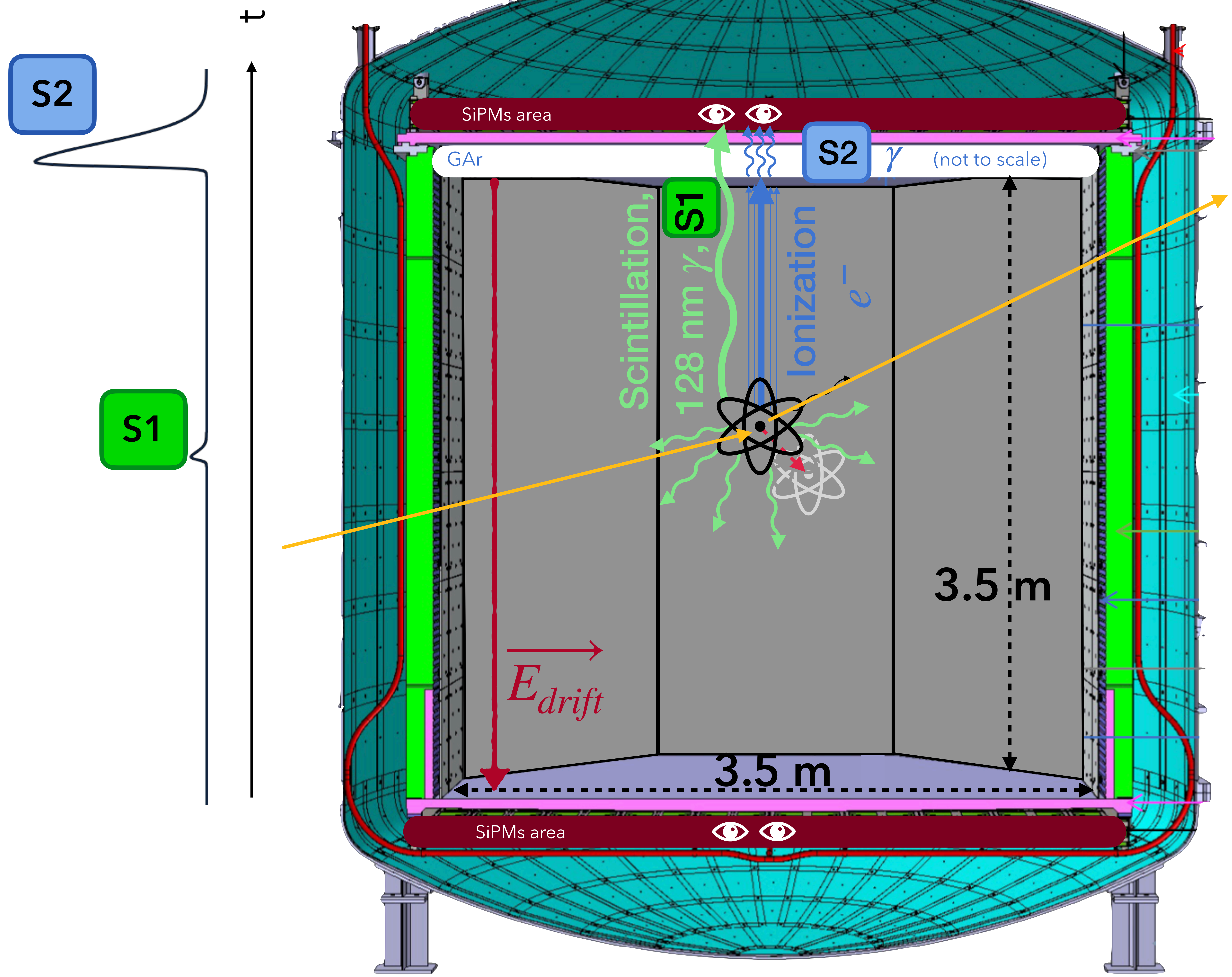
Excellent background modelling above 4 N_e

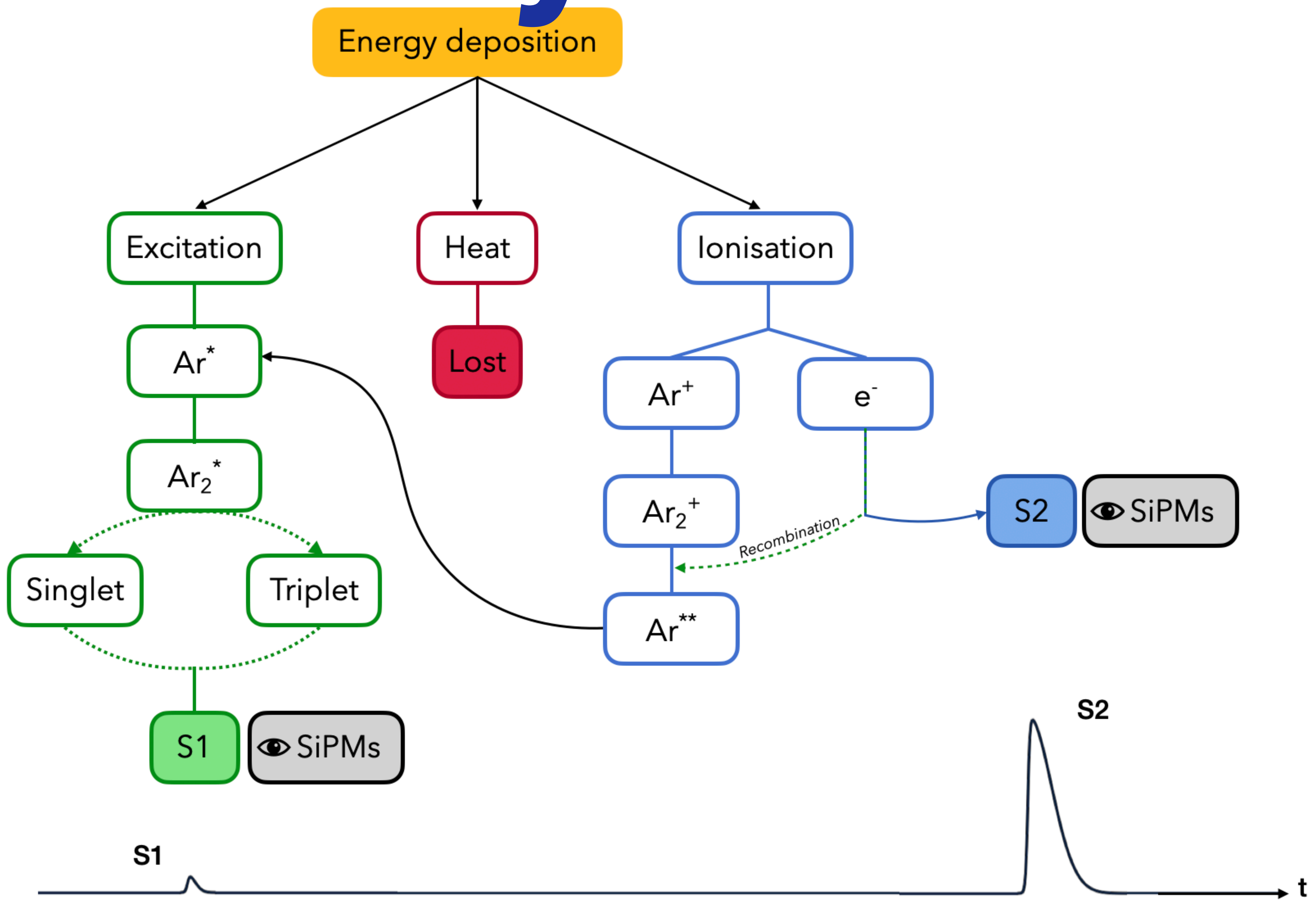
DarkSide-20k:

- 1,000 times larger detection volume than DarkSide-50
- UAr extraction with URANIA –> expect reduced ^{85}Kr
- SiPMs: better radio-purity than PMTs

Scientific opportunity for DS-20k

DarkSide-20k low mass analysis





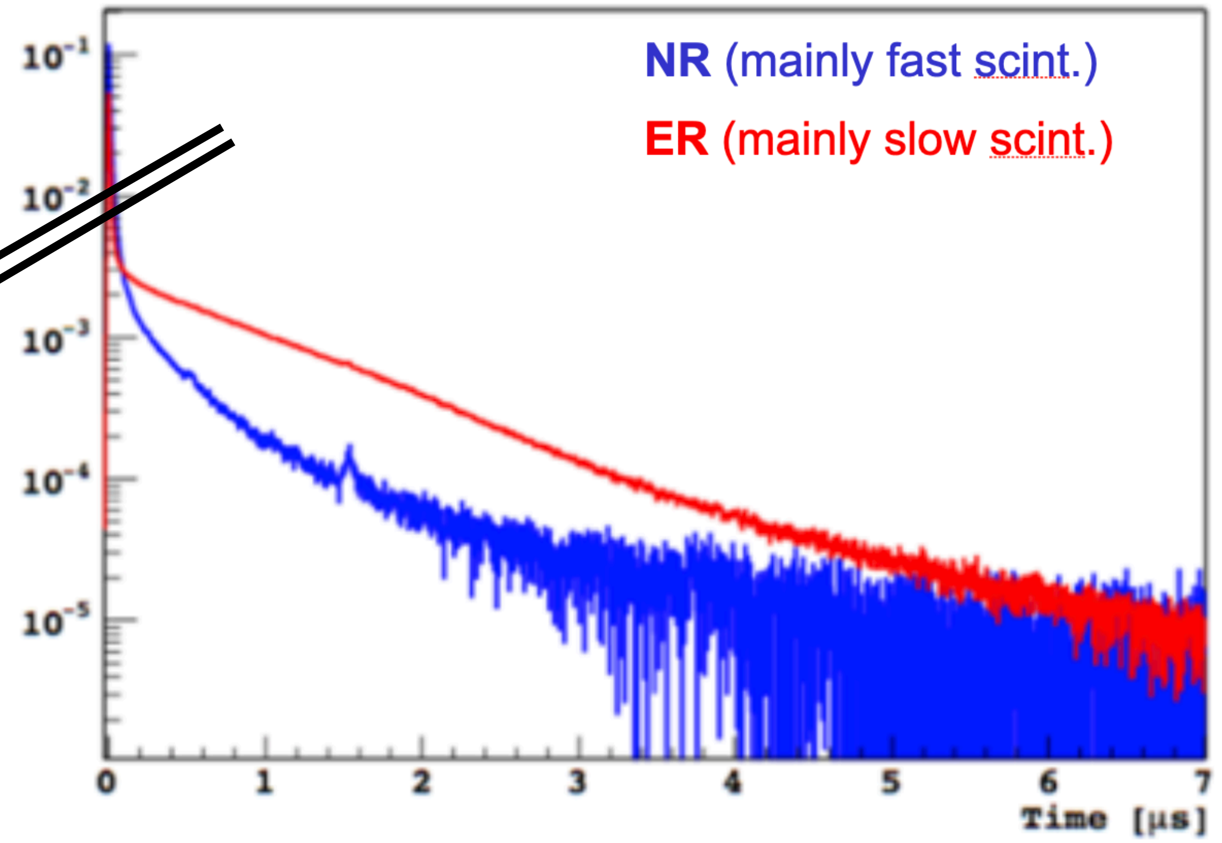
S1 scintillation signal (prompt)

S2 ionization signal (delayed)

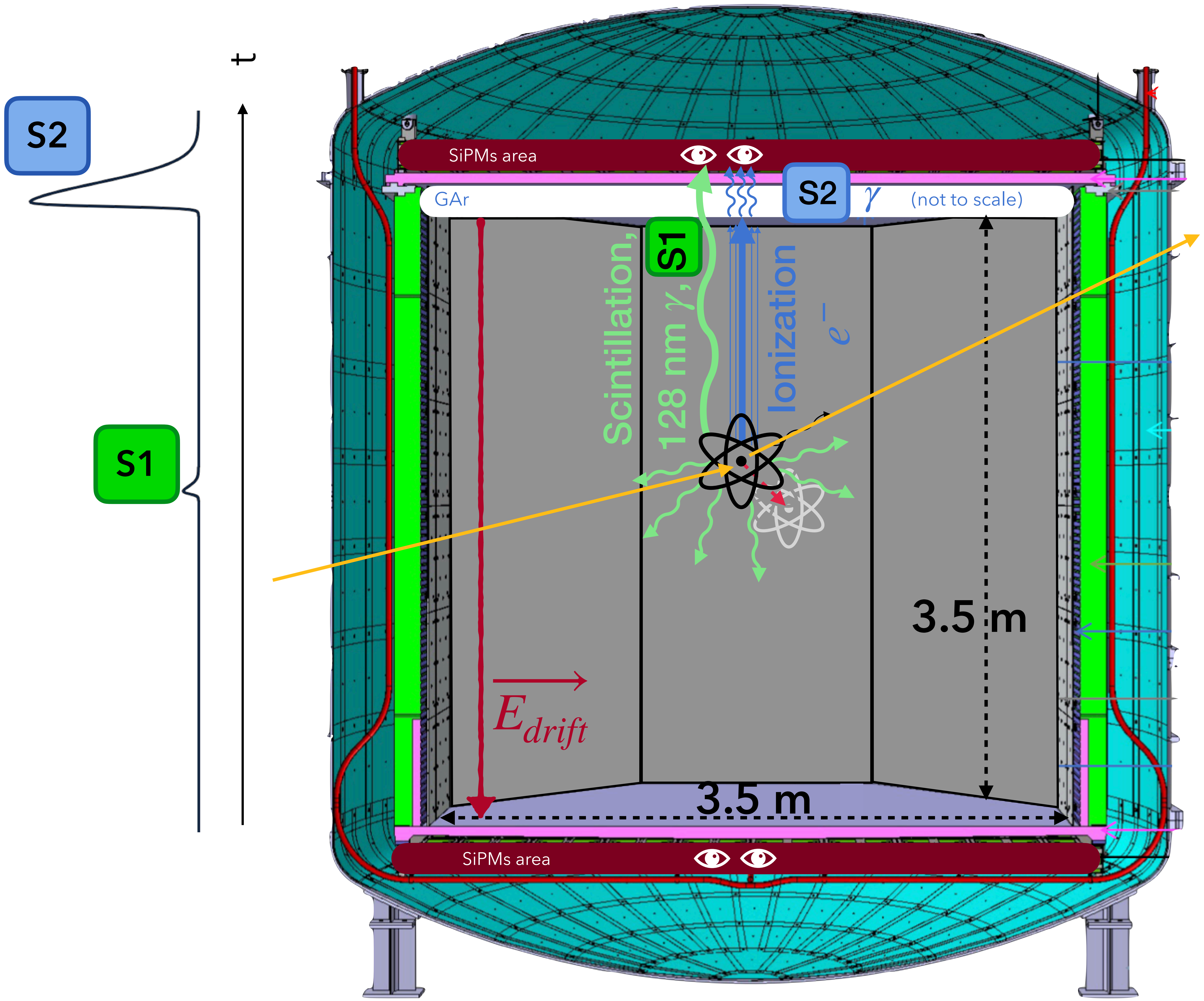
Pulse Shape Discrimination

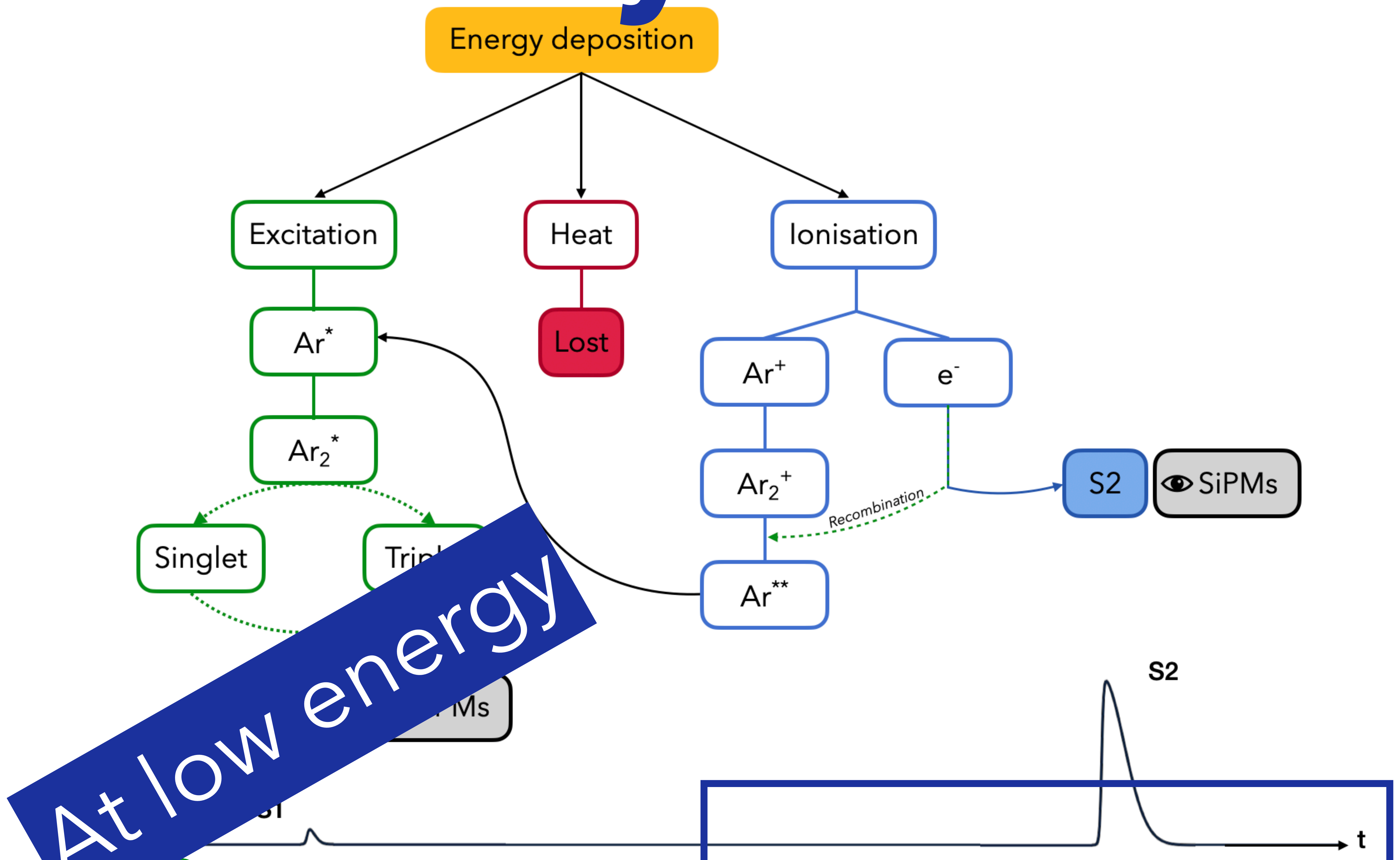
$10^7 - 10^9$ signal-background (bkg) discrimination power

Bkg-free experiment



DarkSide-20k low mass analysis





At low energy

~~S1 scintillation signal (prompt)~~

~~**Pulse Shape Discrimination**~~

~~$10^8 – 10^9$ signal-background (bkg) discrimination power~~
~~Bkg-free experiment~~

S2 ionization signal (delayed)
Only information

☑ Sub-keV threshold to extract S2

☒ (ER) bkg-dominated analysis

DarkSide-20k low mass analysis

Pile up

- Expect 80 Hz from β, X and γ backgrounds
- **Select isolated S2**, with other S2 occurring at times greater than one maximum drift time (3.7 ms)

51% of effective livetime

Fiducialisation

- **Radial**: 30 cm fiducialisation from the walls
- Drift direction: no fiducialisation

69% of signal acceptance

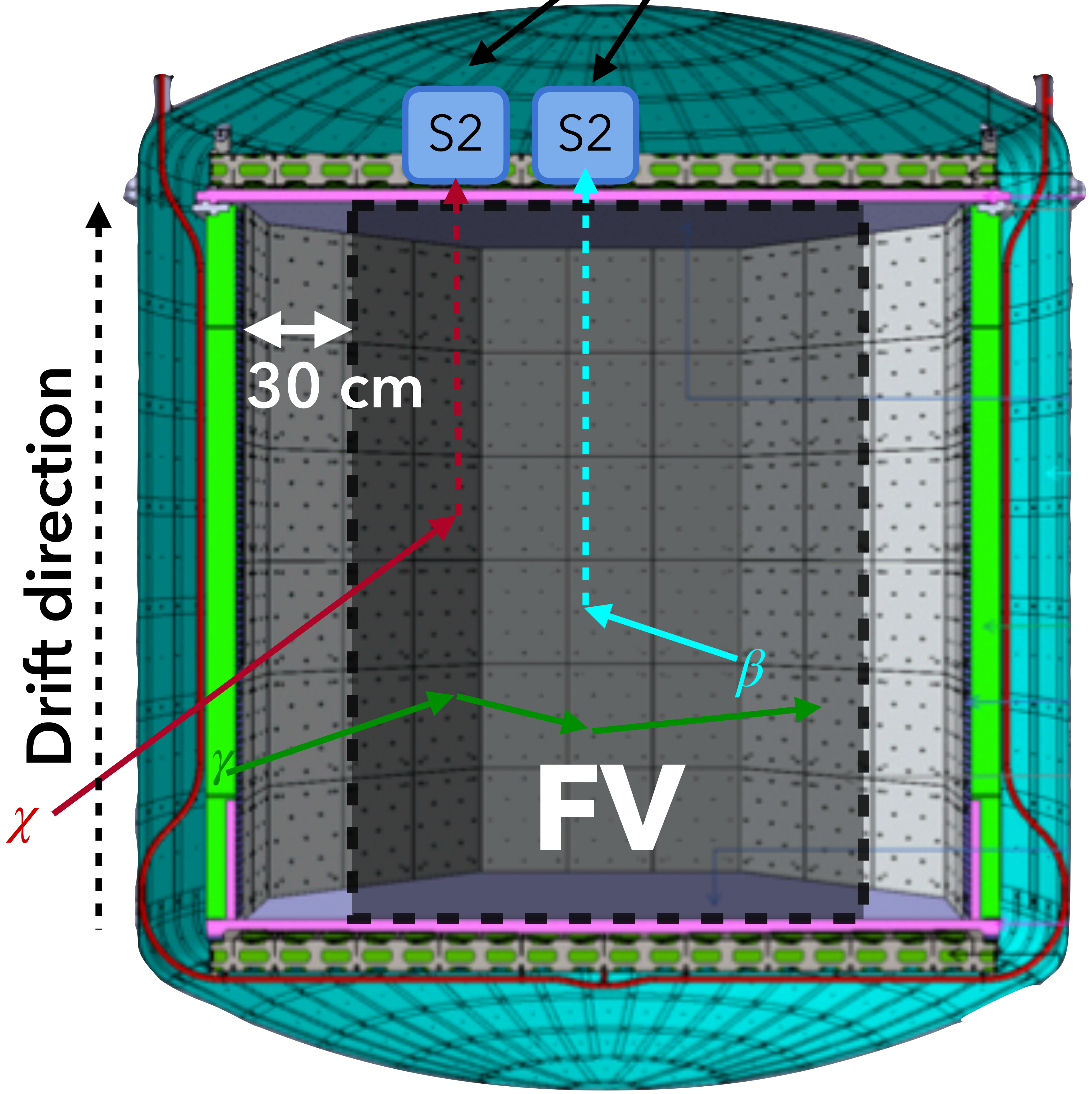
TPC:
49.7 t UAr

x 0.51

x 0.69

Exposure = **17.4 ton.year**
for 1 year of data taking

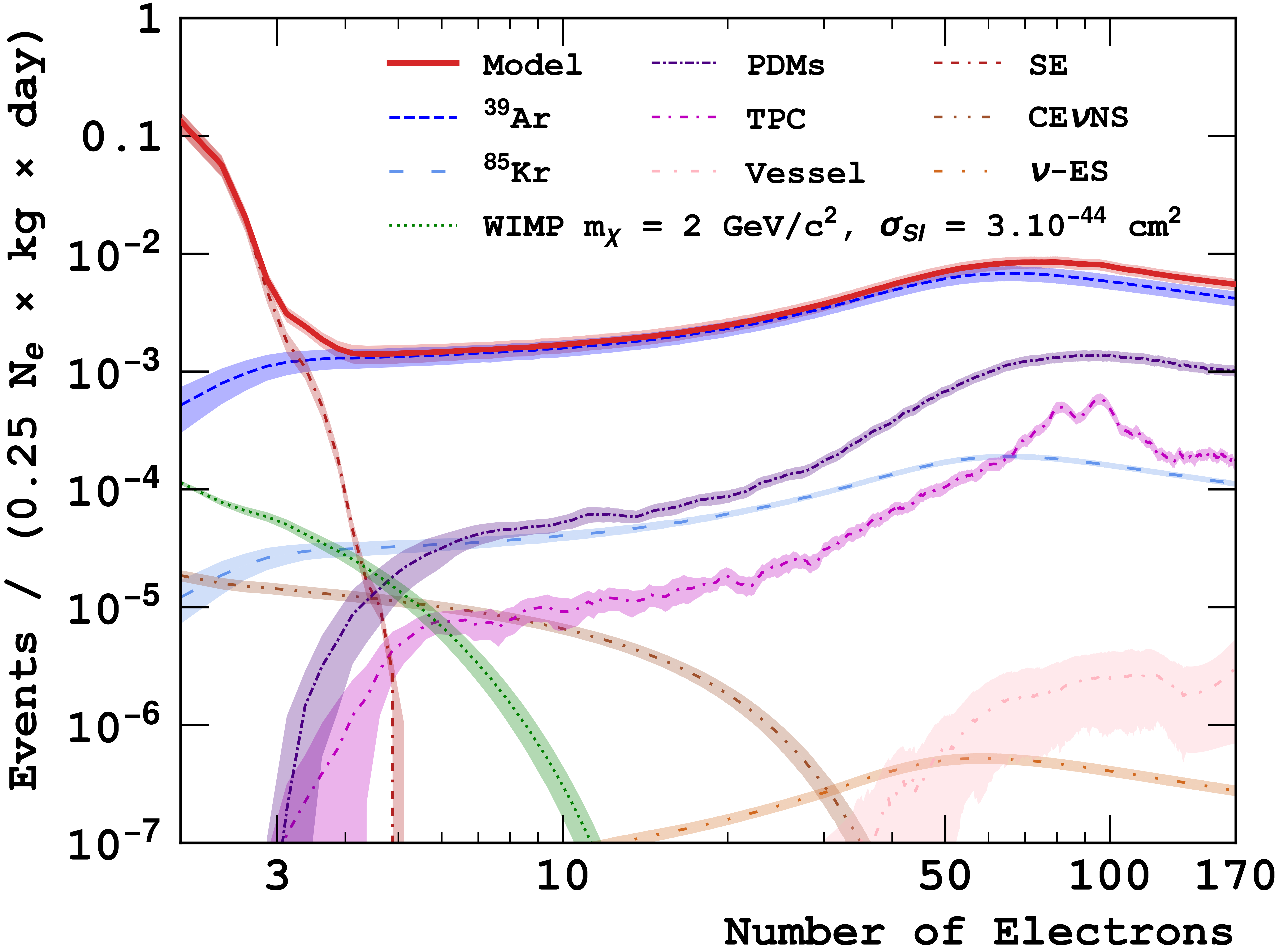
May arrive close in time and look like a multiple scatter



DS-20k inner detector

DarkSide-20k low mass background model

- Eight background components
- Five categories



DarkSide-20k low mass background model

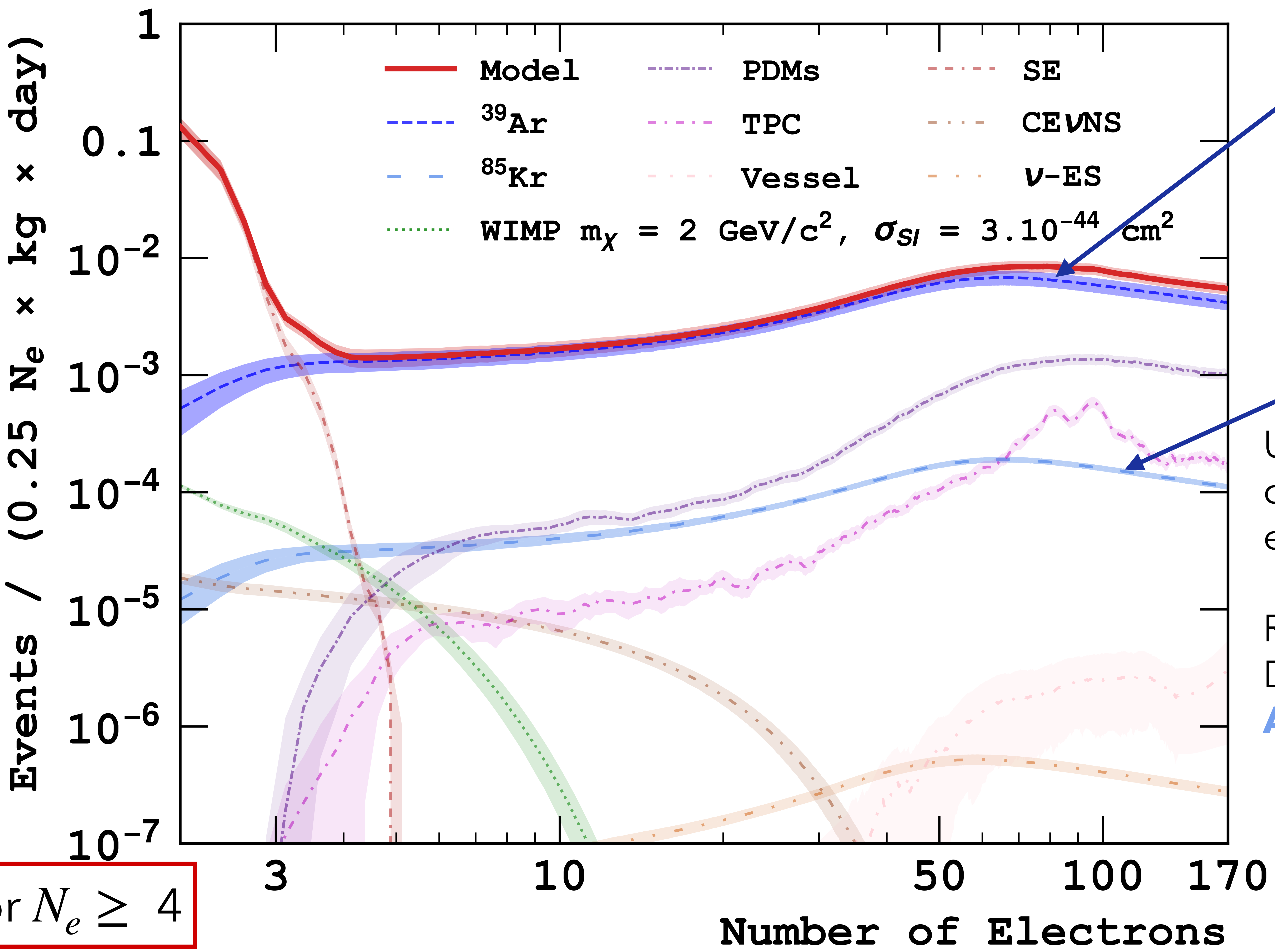
- Uniformly distributed in the fiducial volume
- Include recent calculations of β-decay energy spectra

[Phys.Rev.A 90 (2014) 012501](#)

[Phys.Rev.C 102 (2020) 065501](#)

- Include shape systematics (atomic exchanges, screening effect, Q-value)

LAr intrinsic backgrounds (β decays)



^{39}Ar dominant for $N_e \geq 4$

^{39}Ar

Same activity as DS-50 (same UAr mine)

A(^{39}Ar) = 0.73 mBq/kg

^{85}Kr

Urania (Colorado, USA): dedicated facility for extraction

Reduced ^{85}Kr activity wrt DS-50

A(^{85}Kr) = 1.9 10^{-2} mBq/kg

DarkSide-20k low mass background model

- Simulated with a GEANT-4 based simulation tool
- ≈ 2.5x reduced bkg contamination per surface area wrt DS-50

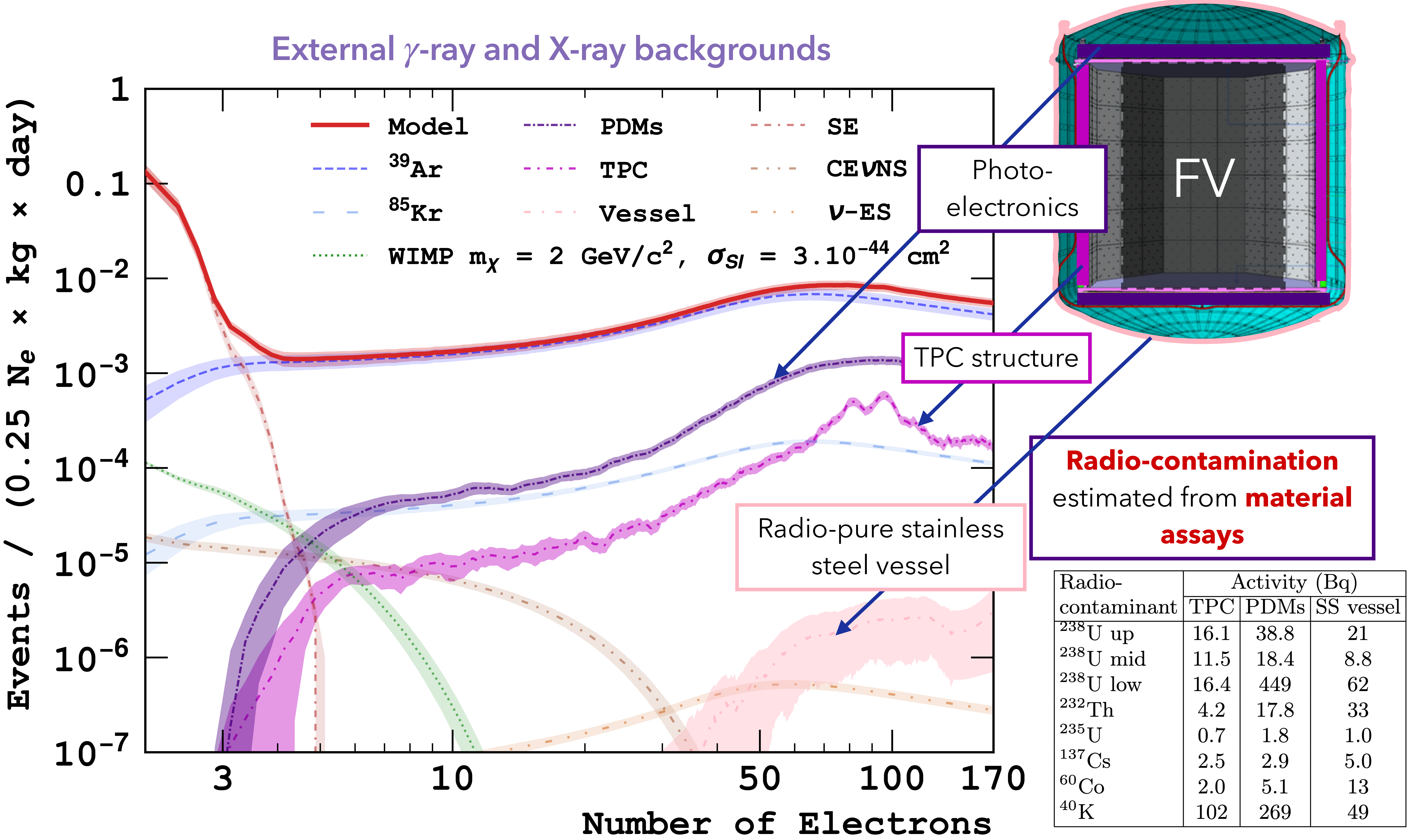


Photo-electronics

TPC structure

Radio-pure stainless steel vessel

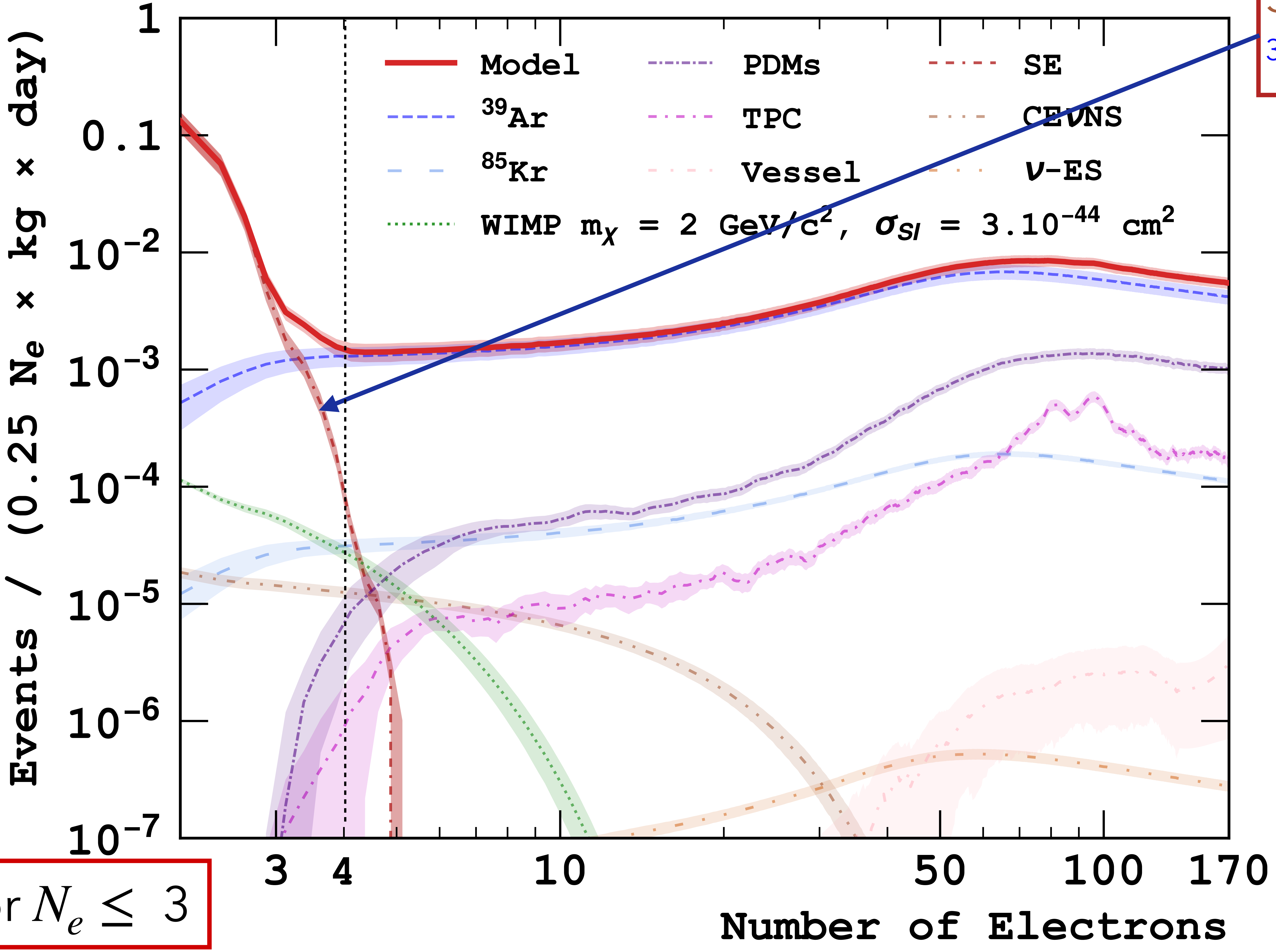
Radio-contamination estimated from **material assays**

Radio-contaminant	Activity (Bq)		
	TPC	PDMs	SS vessel
^{238}U up	16.1	38.8	21
^{238}U mid	11.5	18.4	8.8
^{238}U low	16.4	449	62
^{232}Th	4.2	17.8	33
^{235}U	0.7	1.8	1.0
^{137}Cs	2.5	2.9	5.0
^{60}Co	2.0	5.1	13
^{40}K	102	269	49

DarkSide-20k low mass background model

- Observed in DS-50 (and xenon-based dual phase TPCs)
- Origin might be trapped electrons by impurities and released later
- For DS20k: **Extrapolation from DS-50 data**

Spurious electron (SE) background



SE 18x lower than ^{39}Ar at N_e = 4

SE dominant for $N_e \leq 3$

2 fit scenarii:

- **Conservative** (almost indep. of SE modelling): Fit from N_e = 4 (DS-50 strategy)
- **Ultimate**: Fit from N_e = 2 assuming good control of rate and spectral shape of SE in DS-20k

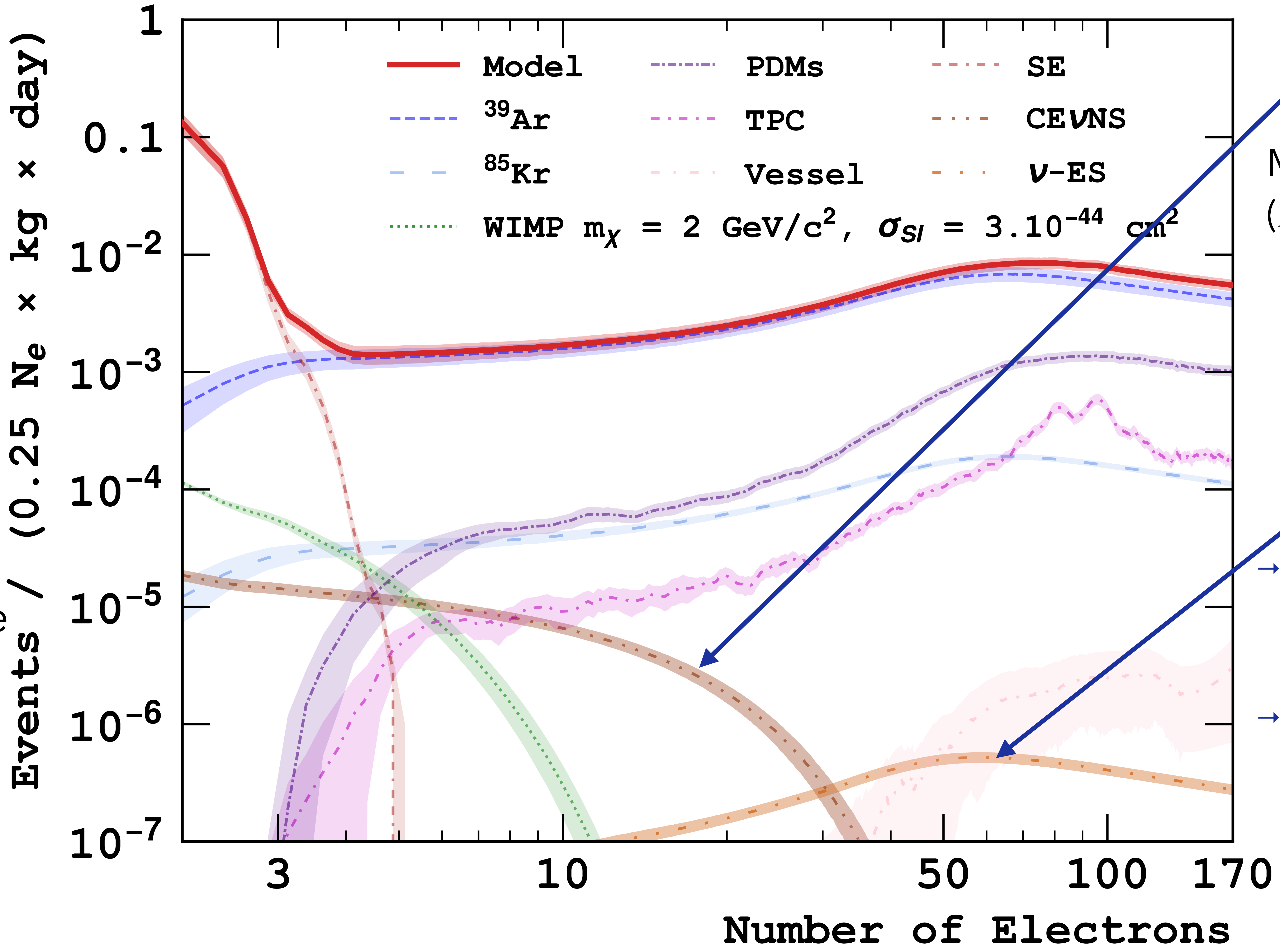
DarkSide-20k low mass background model

- Mostly from solar neutrinos (^{7}Be, ^{15}O, pep, ^{8}B, hep)
- Include radiative corrections in CEνNS

  JHEP 05, 271
- Include accurate parametrisation of the nucleus structure

  Phys.Rev.D 102 (2020) 015030

Neutrino backgrounds



CEνNS

Mainly from solar ^{8}B ν ($E_{dep} < 10$ keV$_{nr}$)

ν-ES

- → Mainly from pp (+ ^{7}Be) ν ($E_{dep} < 20$ keV$_{er}$)
- → Dominates over CEνNS at $N_e \gtrsim 30$

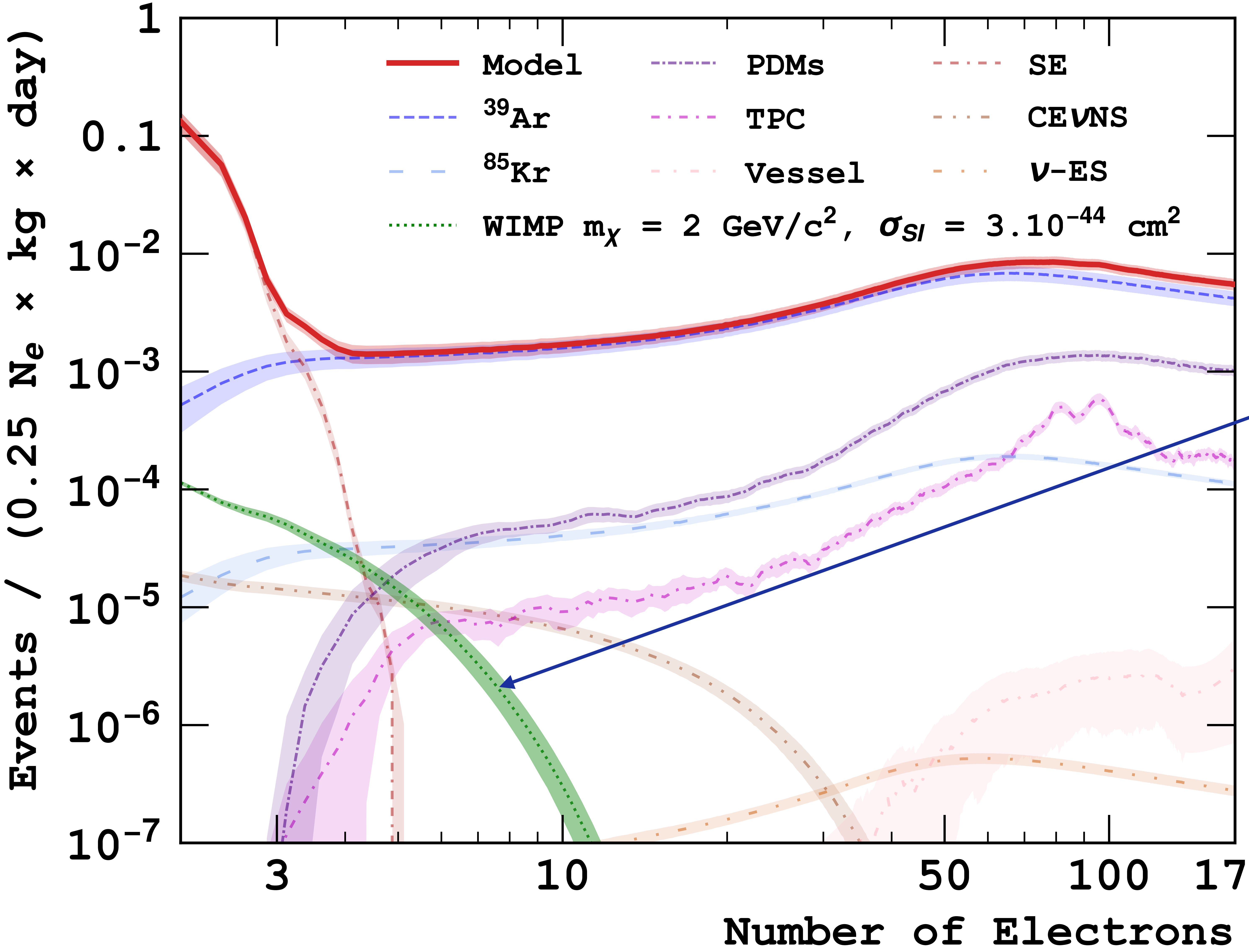
Signal model

- Assuming Standard Halo Model and recommended conventions

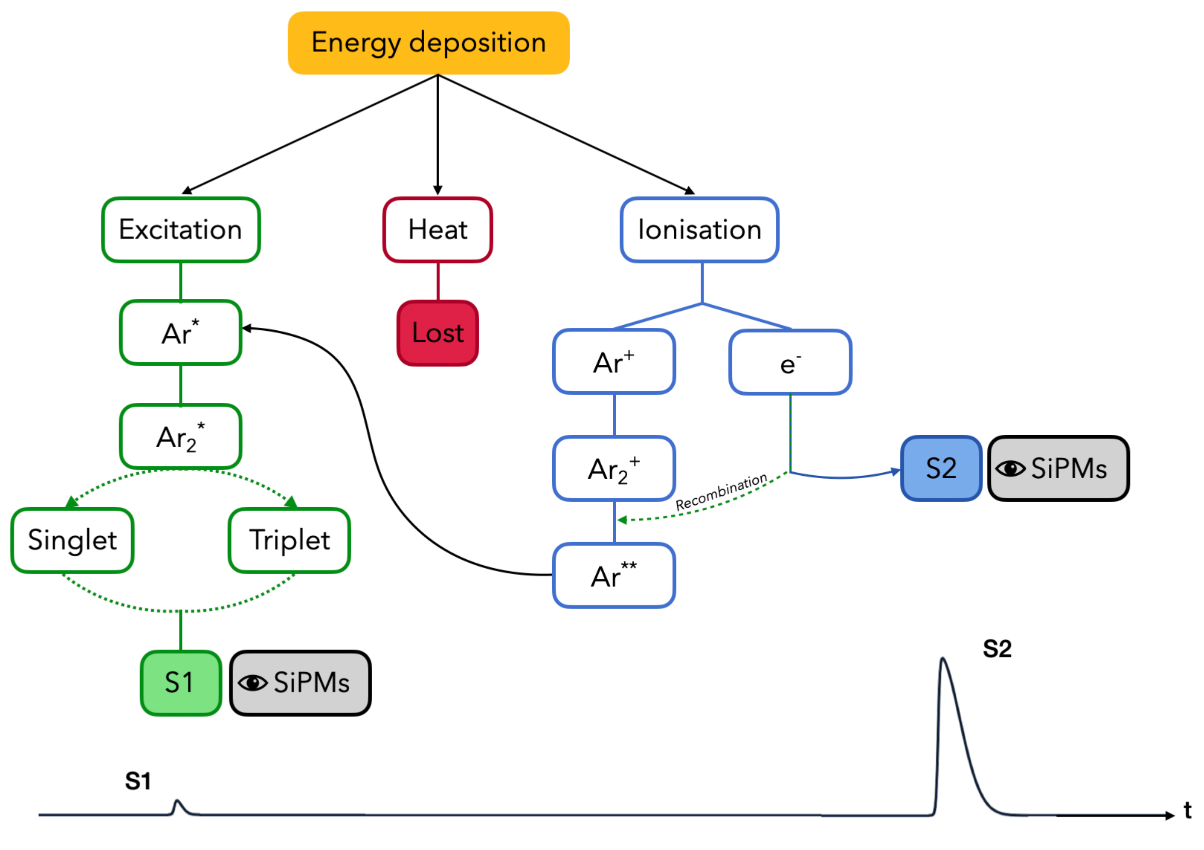
Eur. Phys. J. C 81 (2021), p. 907

- Localised at low N_e

WIMP (pure NR part)



Two ^{40}Ar response models for NR



QF

Assuming **binomial fluctuations** in the fraction of quanta doing quenching

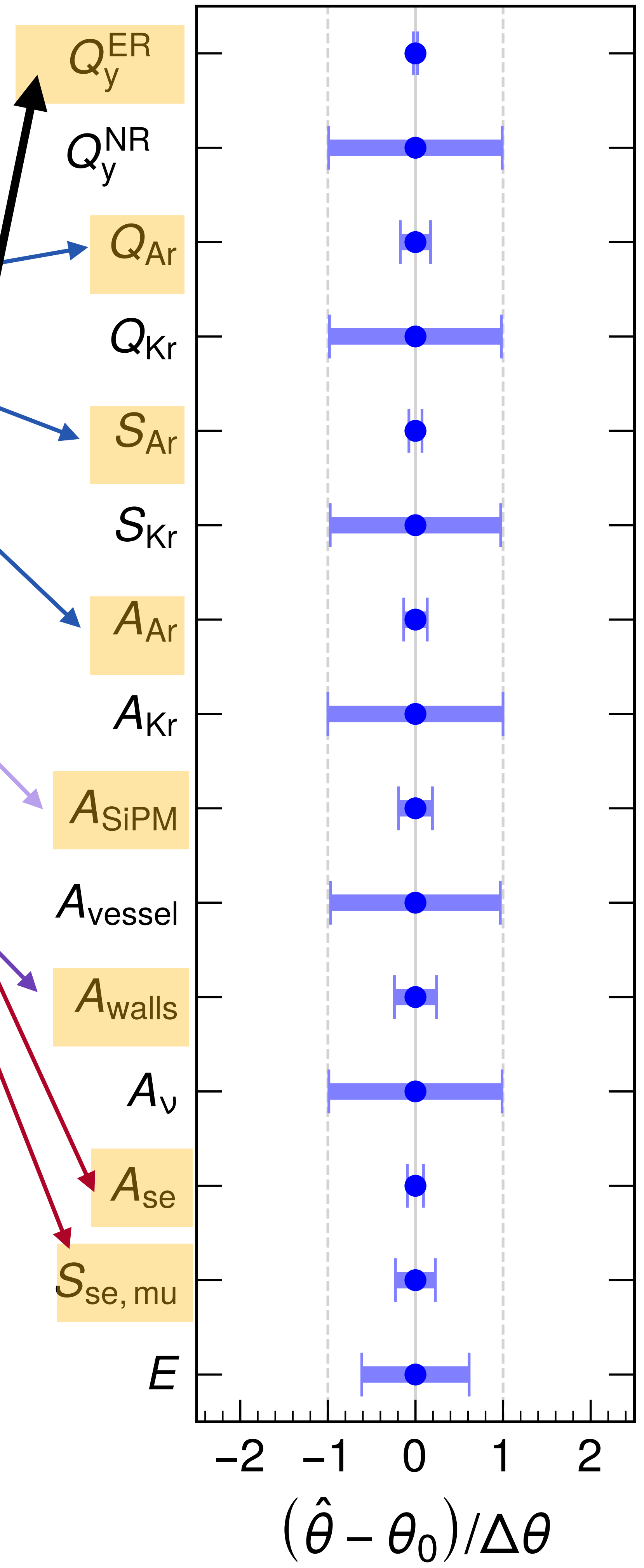
NQ

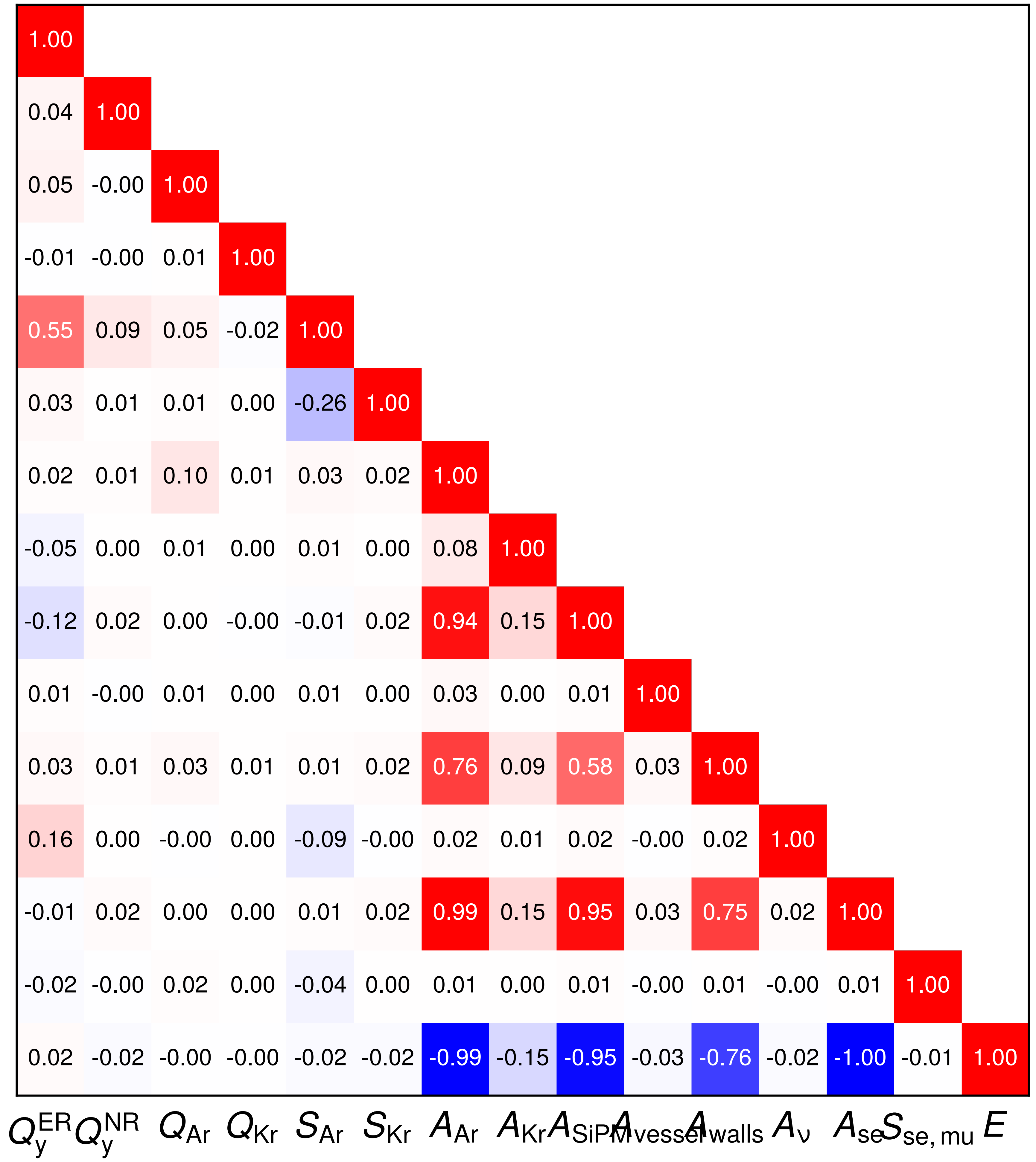
Assuming no fluctuations

Systematic uncertainties

Main bkg components and ER ionization yield → Dominant systematic uncertainties & constrained by the profile likelihood fit

	Source uncertainty	Affected components
Amplitude	5% on the exposure	All
	15% on ^{39}Ar activity	^{39}Ar
	15% on ^{85}Kr activity	^{85}Kr
	20% on SE normalization	SE
	10% on activity from PDMs	PDMs
	10% on activity from the vessel	Vessel
	10% on activity from the TPC	TPC
	10% on neutrinos normalization	Neutrinos
Shape	atomic exchange and screening	^{39}Ar
	atomic exchange and screening	^{85}Kr
	1% on the ^{39}Ar-decay Q-value	^{39}Ar
	0.4% on the ^{85}Kr-decay Q-value	^{85}Kr
	SE modelling	SE
	ER ionization response	All backgrounds but CEνNS, SE
	NR ionization response	WIMP, CEνNS





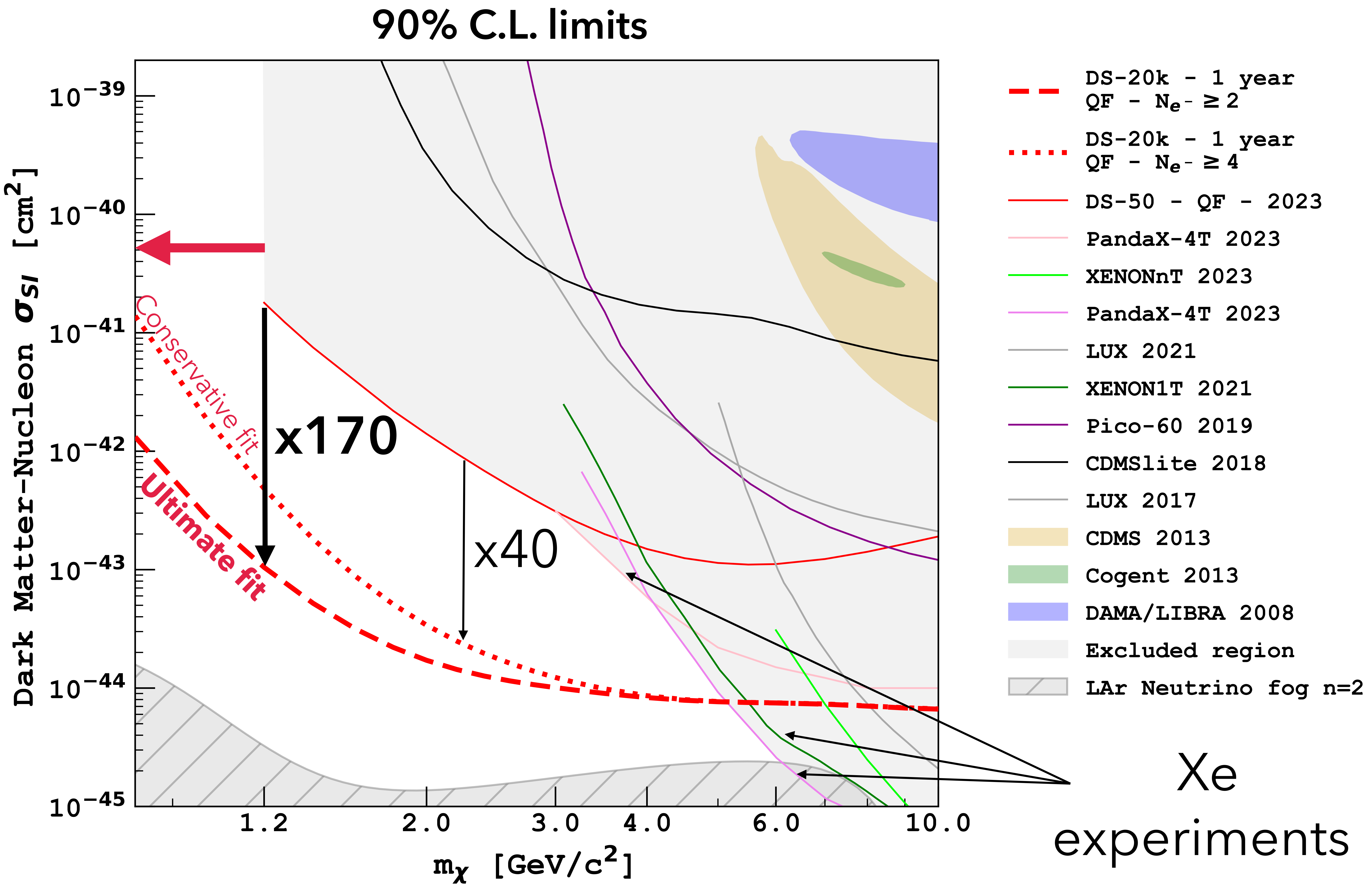
Q_y^{ER}	Q_y^{NR}	Q_{Ar}	Q_{Kr}	S_{Ar}	S_{Kr}	A_{Ar}	A_{Kr}	A_{SiPM}	A_{vessel}	A_{walls}	A_{ν}	A_{se}	$S_{se, mu}$	E
1.00														
0.04	1.00													
0.05	-0.00	1.00												
-0.01	-0.00	0.01	1.00											
0.55	0.09	0.05	-0.02	1.00										
0.03	0.01	0.01	0.00	-0.26	1.00									
0.02	0.01	0.10	0.01	0.03	0.02	1.00								
-0.05	0.00	0.01	0.00	0.01	0.00	0.08	1.00							
-0.12	0.02	0.00	-0.00	-0.01	0.02	0.94	0.15	1.00						
0.01	-0.00	0.01	0.00	0.01	0.00	0.03	0.00	0.01	1.00					
0.03	0.01	0.03	0.01	0.01	0.02	0.76	0.09	0.58	0.03	1.00				
0.16	0.00	-0.00	0.00	-0.09	-0.00	0.02	0.01	0.02	-0.00	0.02	1.00			
-0.01	0.02	0.00	0.00	0.01	0.02	0.99	0.15	0.95	0.03	0.75	0.02	1.00		
-0.02	-0.00	0.02	0.00	-0.04	0.00	0.01	0.00	0.01	-0.00	0.01	-0.00	0.01	1.00	
0.02	-0.02	-0.00	-0.00	-0.02	-0.02	-0.99	-0.15	-0.95	-0.03	-0.76	-0.02	-1.00	-0.01	1.00

DarkSide-20k sensitivity to low mass WIMPs

Assuming 1 year of data taking

- **More than one order of magnitude** of uncharted theory parameter space will be probed
- Stable against detector model assumptions

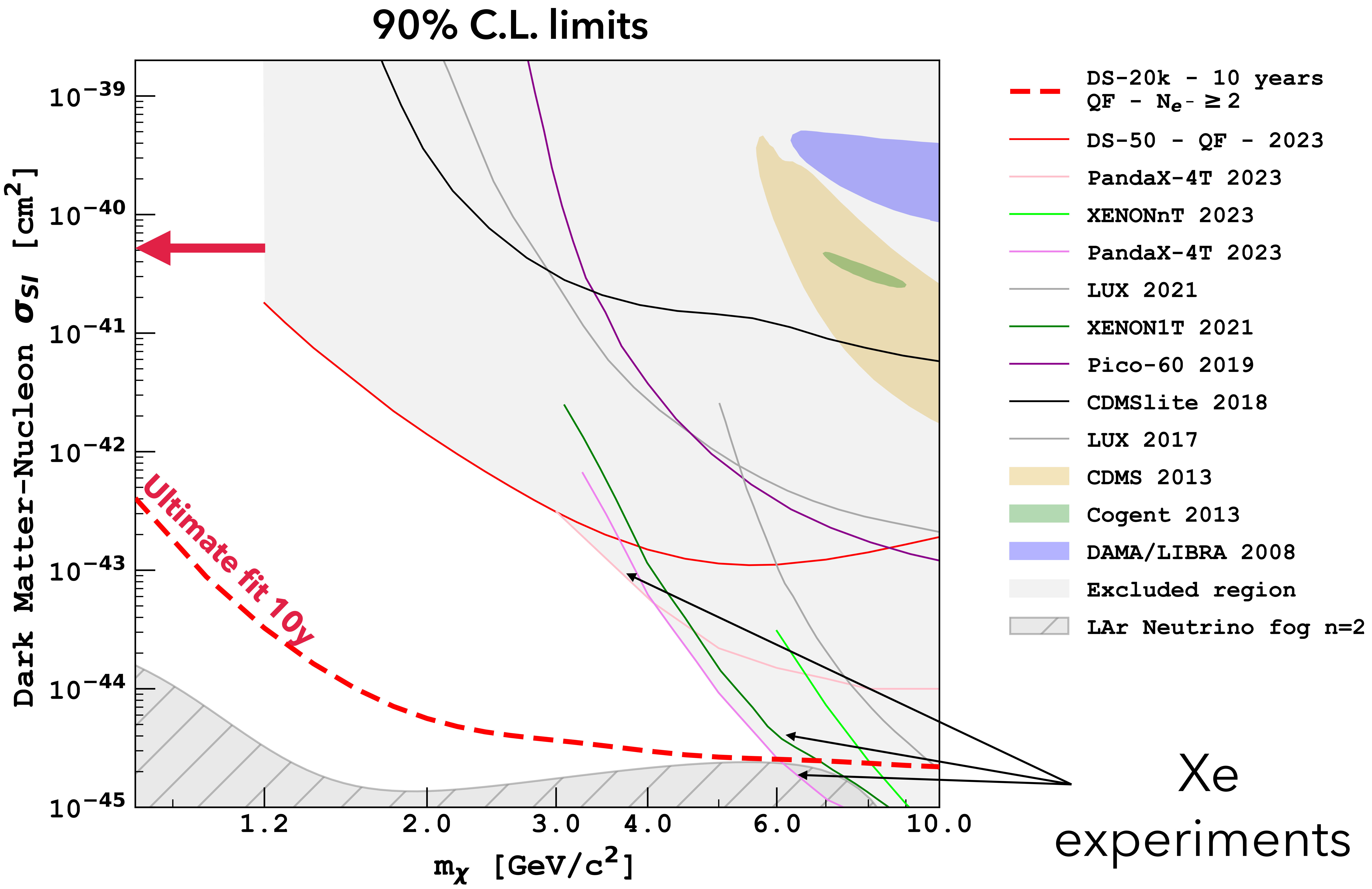
DarkSide-20k will lead the low mass WIMP search below $m_\chi \approx 5$ GeV/c^2 after only one year of data collection


90% C.L. limits

DarkSide-20k sensitivity to low mass WIMPs

Assuming 10 years of data taking

→ **Scales with $\sqrt{\text{exposure}}$**



Xe experiments

DarkSide-20k will reach the neutrino fog around $m_\chi \approx 5$ GeV/c^2 after 10 years of data collection

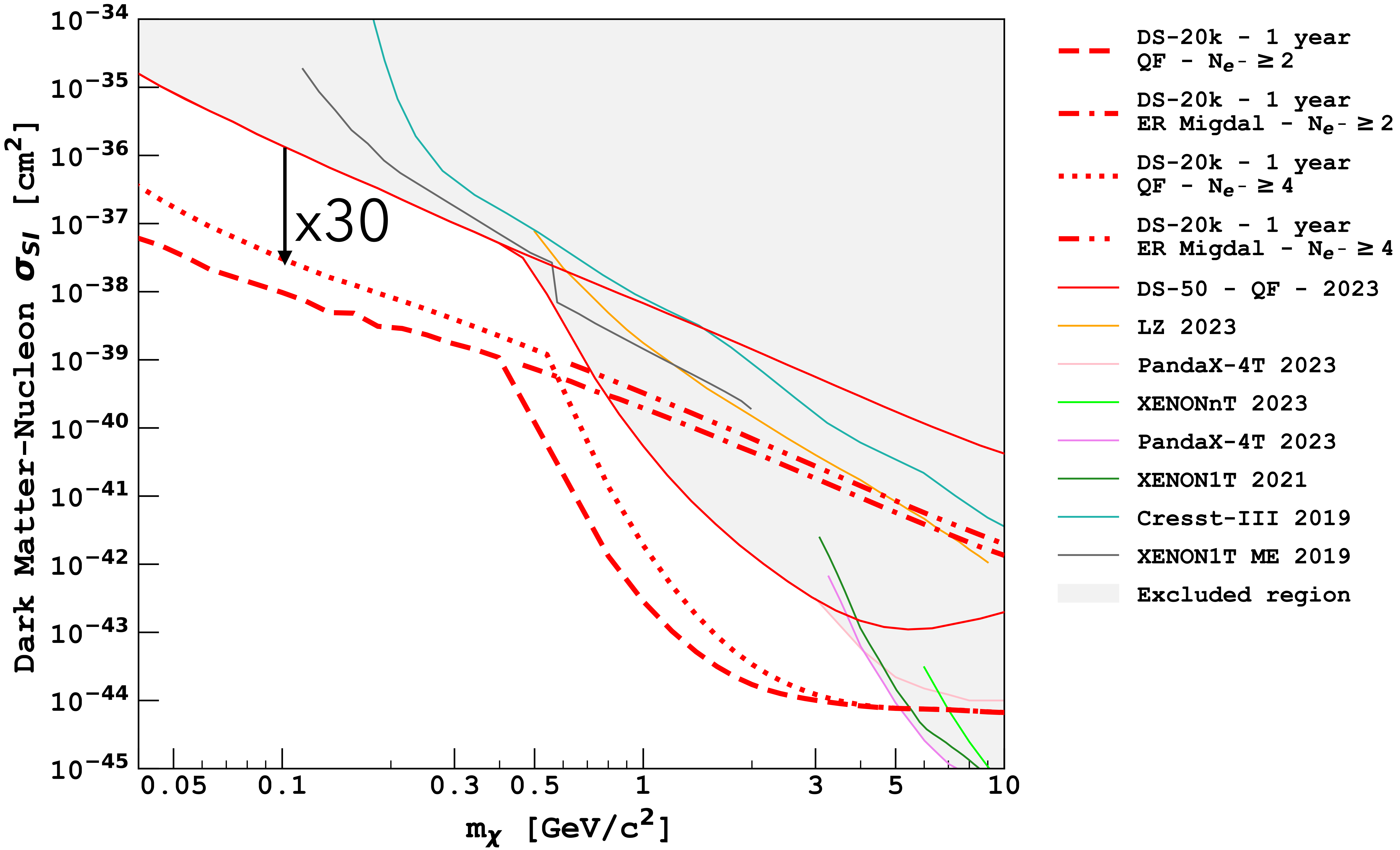
Including Migdal effect

Assuming 1 year of data taking

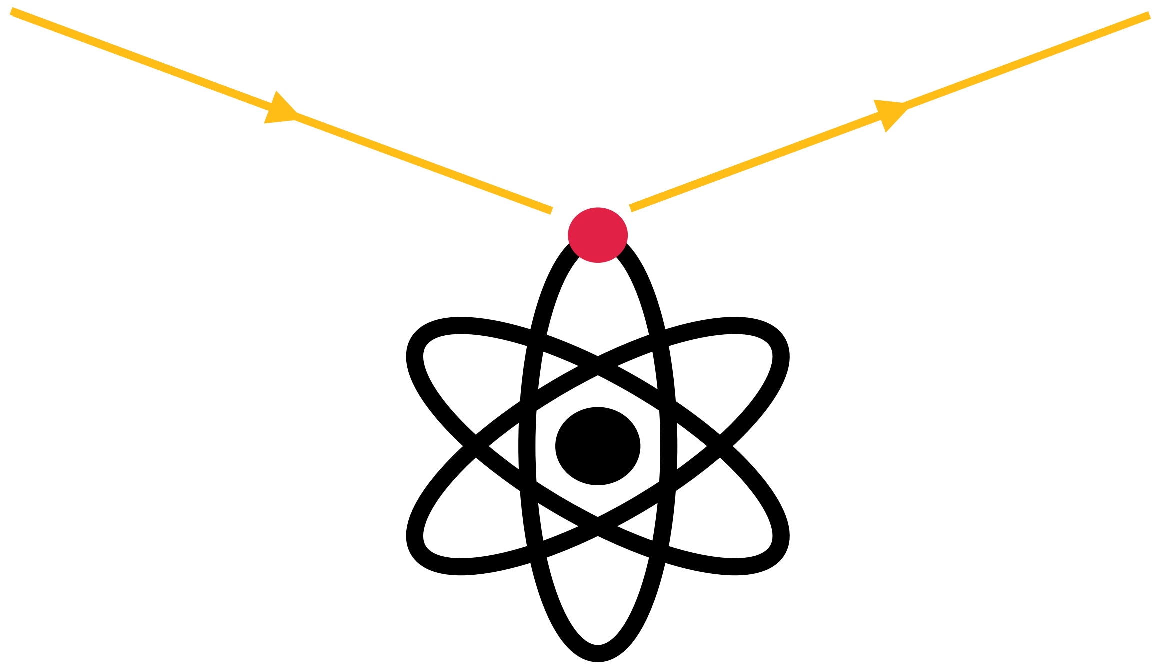
- Migdal effect = possible atomic effect
- Electron released in NR
  - Lower the detection threshold

→ **With Migdal effect:** best limits from 40 MeV/c² to 5 GeV/c²

→ Expect **> 1 order of magnitude improvement** wrt to current experiments in **1y** only



Light dark matter (LDM)

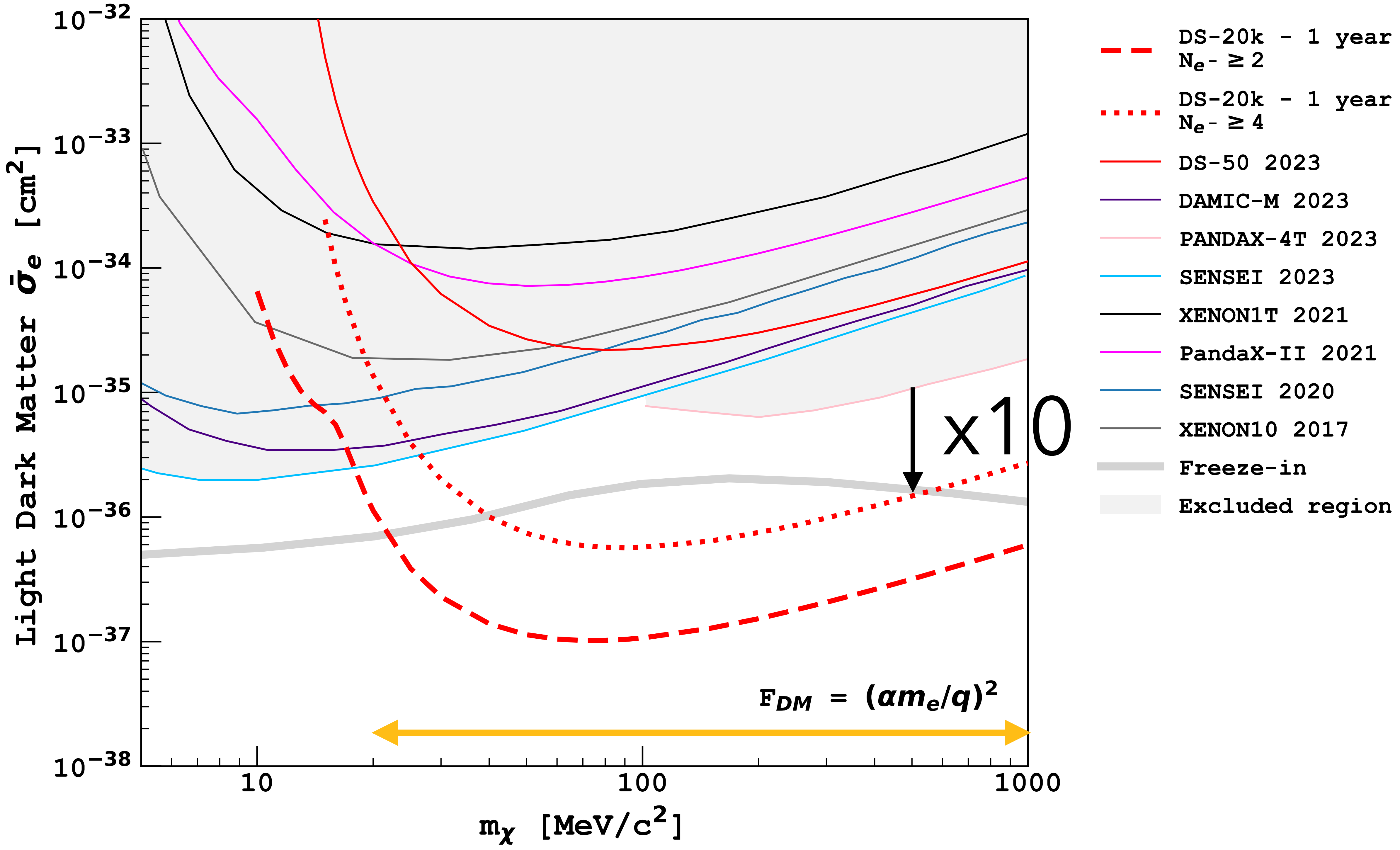


- Elastic scatter of Light Dark Matter (LDM) off bound electrons
- LDM = Sub GeV fermion or scalar boson
- Mediator can be light ($\rightarrow F \sim 1/q^2$) or heavy ($\rightarrow F \sim 1$)

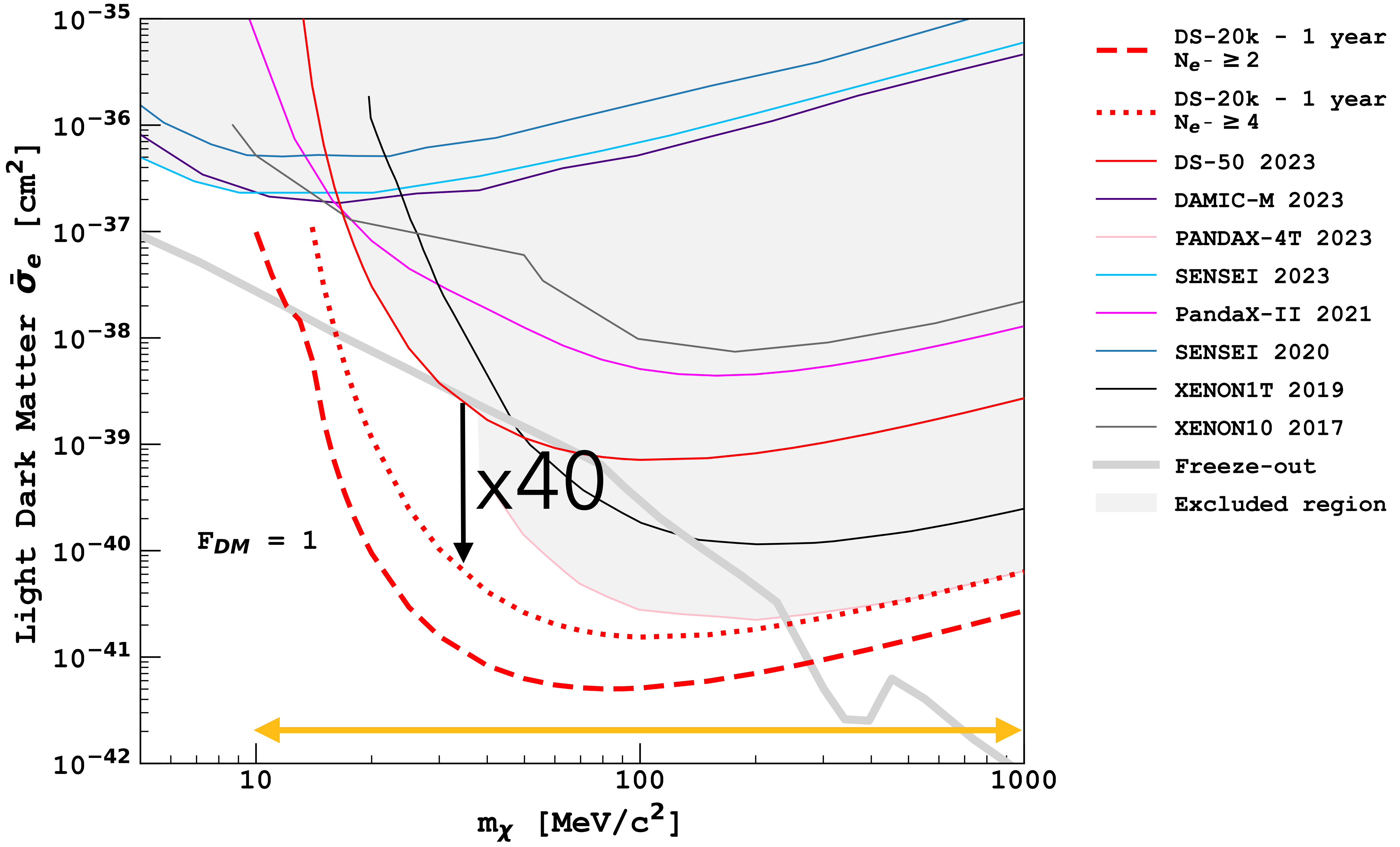
Expect **> 1 order of magnitude improvement** wrt to current experiments in **1y** only

Assuming 1 year of data taking

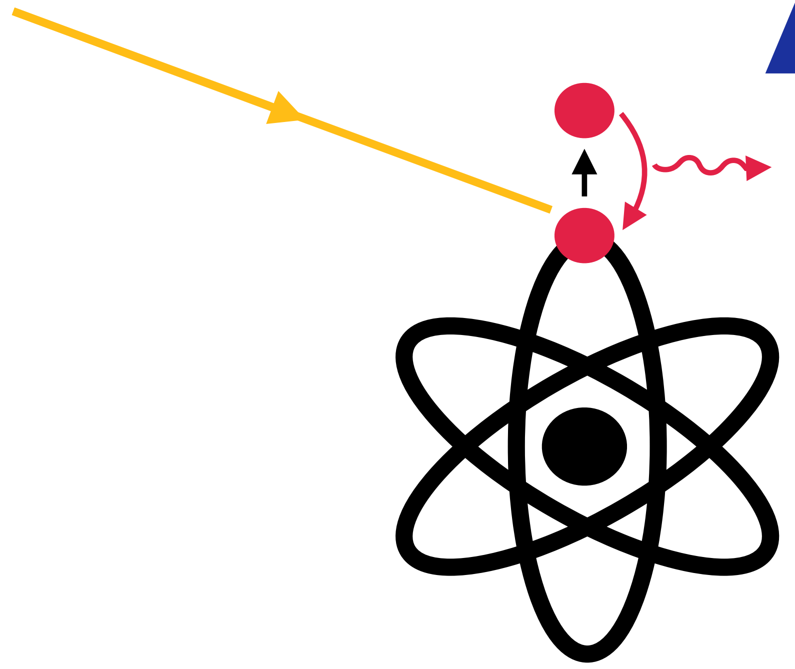
90% C.L. limits



90% C.L. limits



ALP and dark photon (DP)



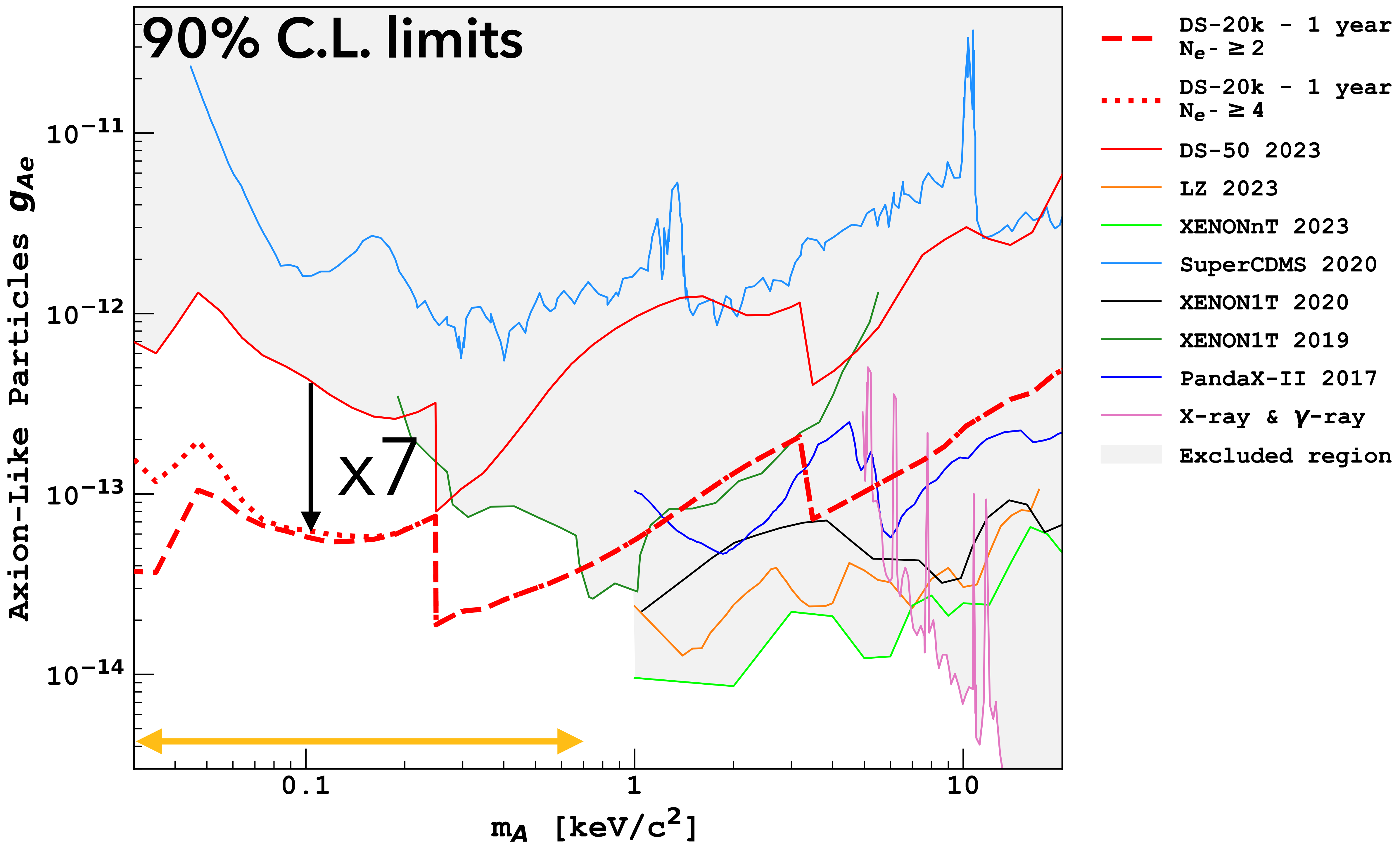
Absorption of ALP/DP by bound electrons → mono-energetic signal

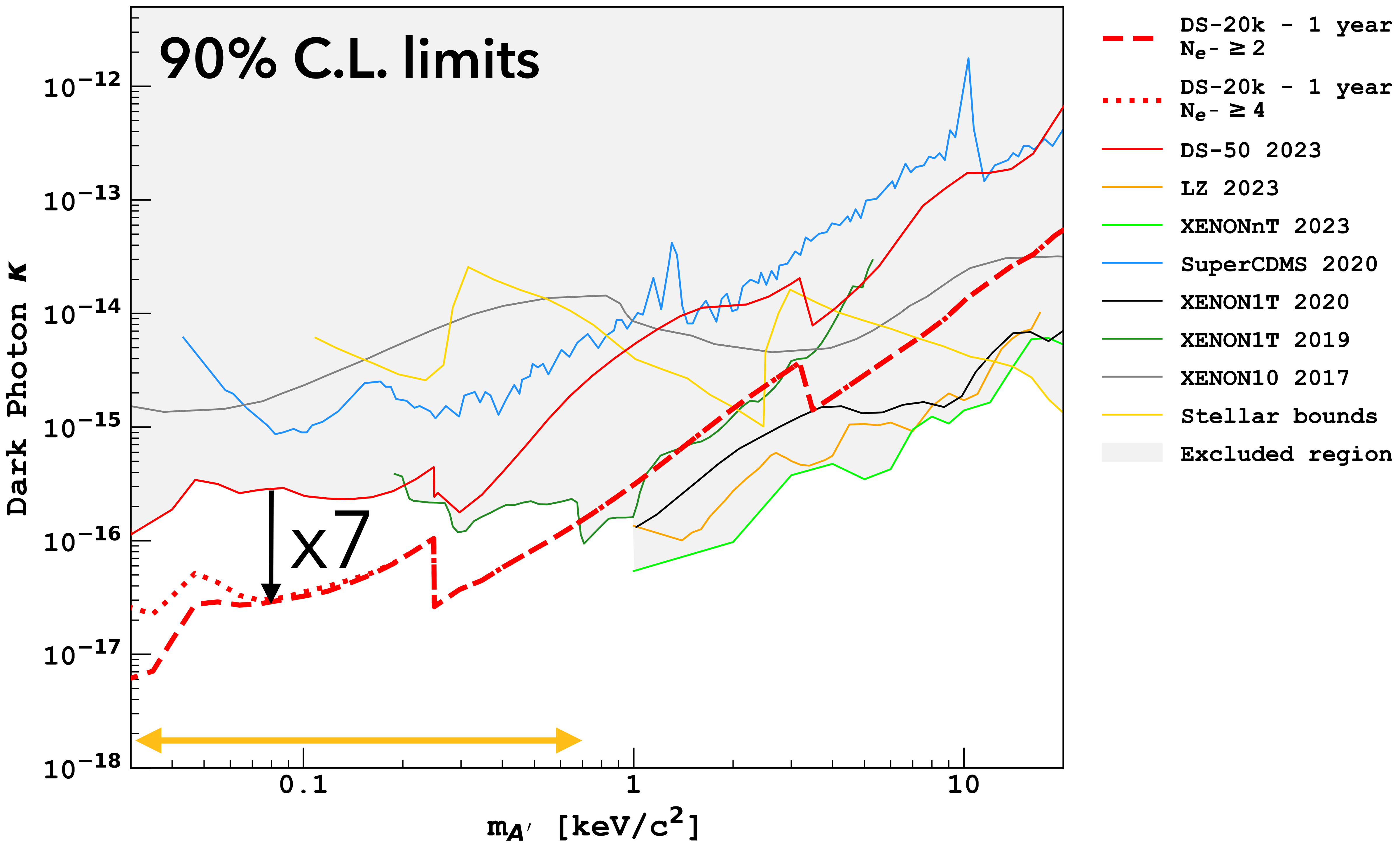
- ALP = pseudo scalar particle
- Coupling ALP - electrons → g_{Ae}

- DP = vector boson particle
- Kinetic mixing between DP and SM photons → strength κ

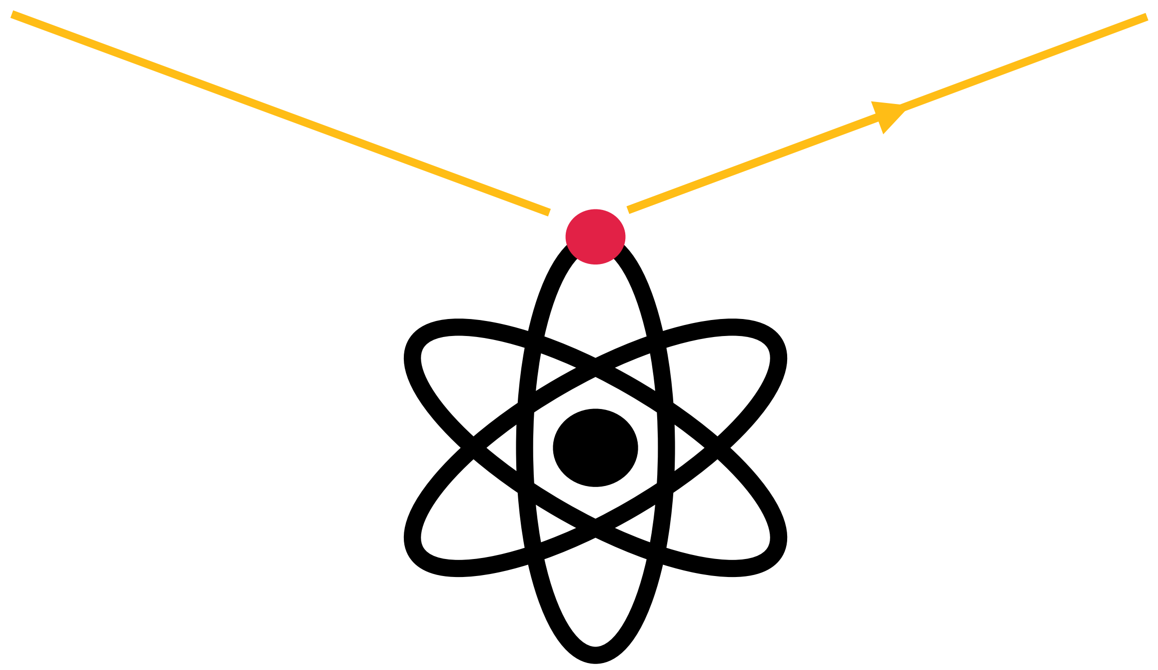
Expect ≈**5x improvement** wrt to current experiments in **1y** only

Assuming 1 year of data taking



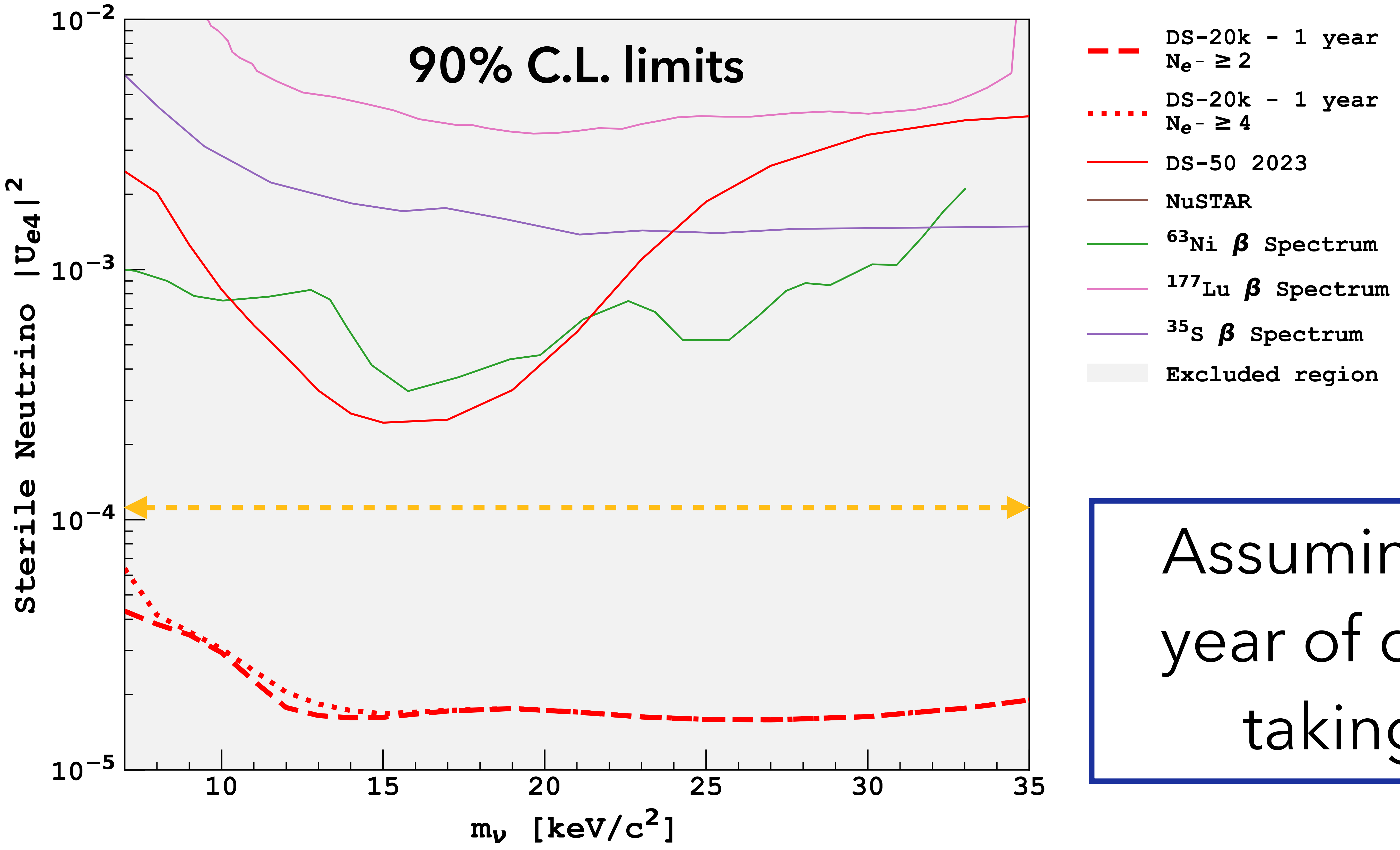


Sterile neutrino ν_s



- Inelastic scatter of sterile ν_s off bound electrons
- Possible mixing with active neutrinos → PMNS-like matrix element $|U_{e4}|^2$

Best direct limits (1 year) but phase space already rejected by NuSTAR indirect measurements

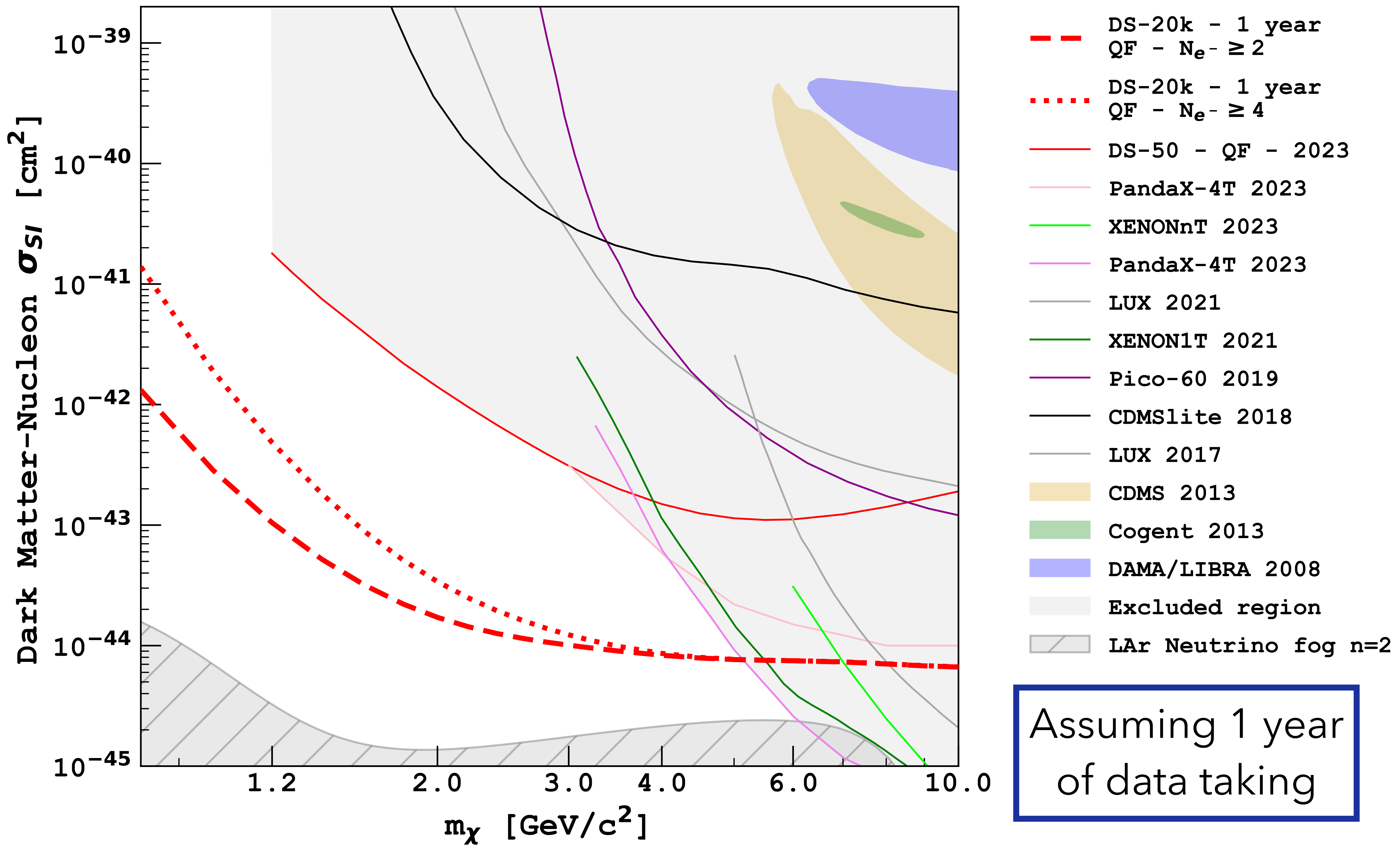


Assuming 1 year of data taking

Take home messages

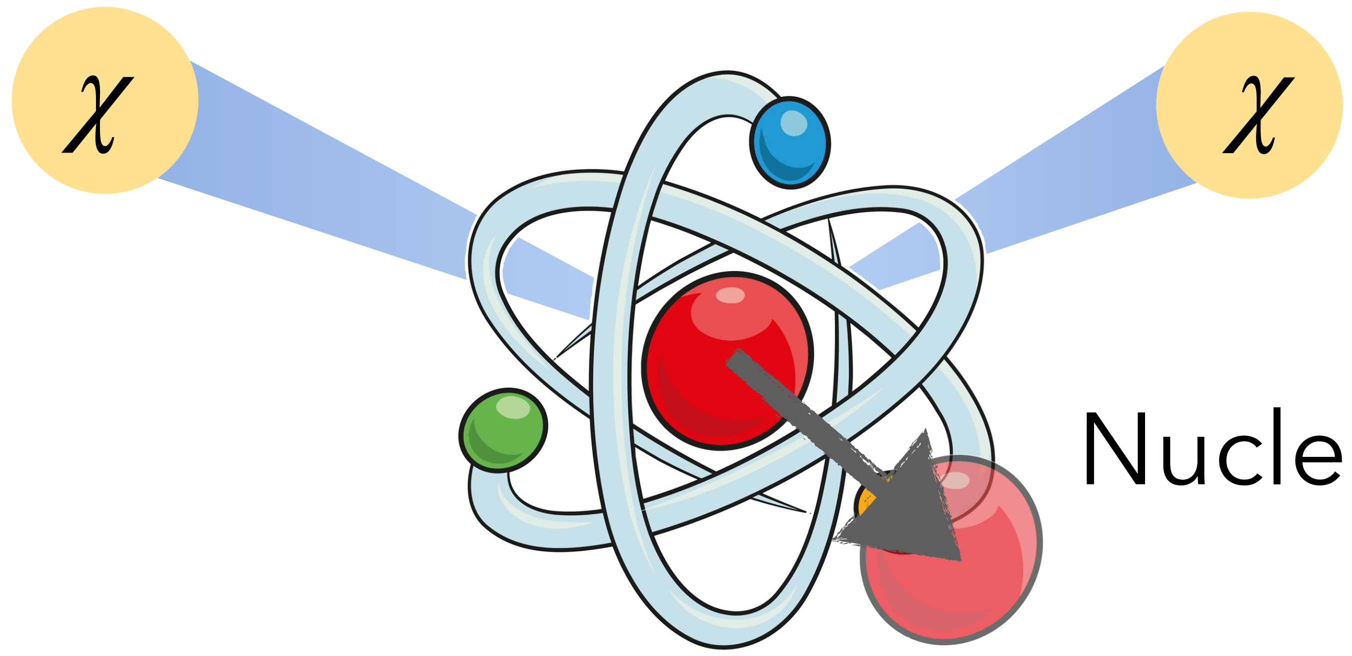
- First assessment of **DarkSide-20k sensitivity to low mass dark matter particles**
- Further strengthens the physics reach of DS-20k
- Expect to probe > 1 order to magnitude of un-charted theory parameter space **within 1 year only** for a **variety of dark matter particles**
- Presented at the **Identification of Dark Matter** (IDM) conference
- **Submitted for publication**

90% C.L. limits



Assuming 1 year of data taking

+ Studies assessing the influence of **backgrounds level / detector effects / exposure / systematics / signal modelling** on the limit



Signal rate

$$\frac{dR}{dE_r} = \frac{\sigma_{SI}}{2\mu^2 m_\chi} M_{tot} \cdot T \cdot A^2 \cdot |F(E_r)|^2 \cdot \rho_0 \cdot \eta(v_{min})$$

Physics

$\sigma_{SI} \rightarrow$ WIMP-nucleon cross section

$\mu \rightarrow$ WIMP-nucleus reduced mass

$m_\chi \rightarrow$ WIMP mass

Target material

$M_{tot} \rightarrow$ Detector fiducial mass

$T \rightarrow$ Detector running time

$A \rightarrow$ Target material atomic mass number

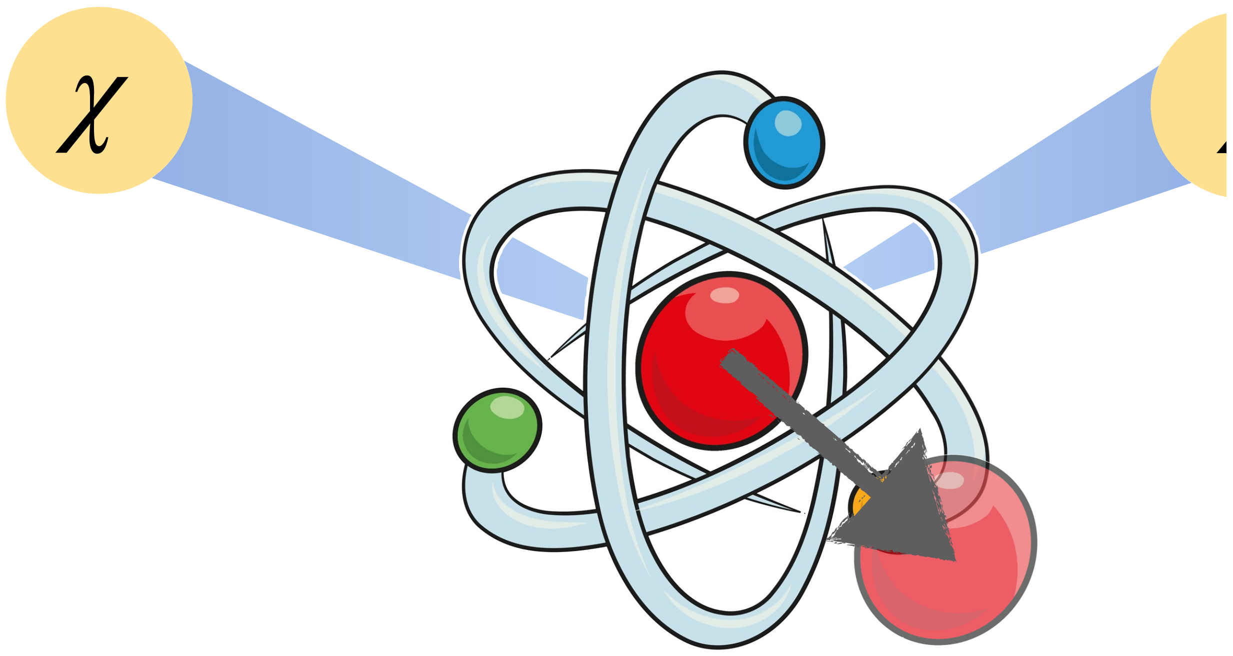
$F(E_r) \rightarrow$ Nuclear form factor

Astrophysics (galactic DM halo modelling)

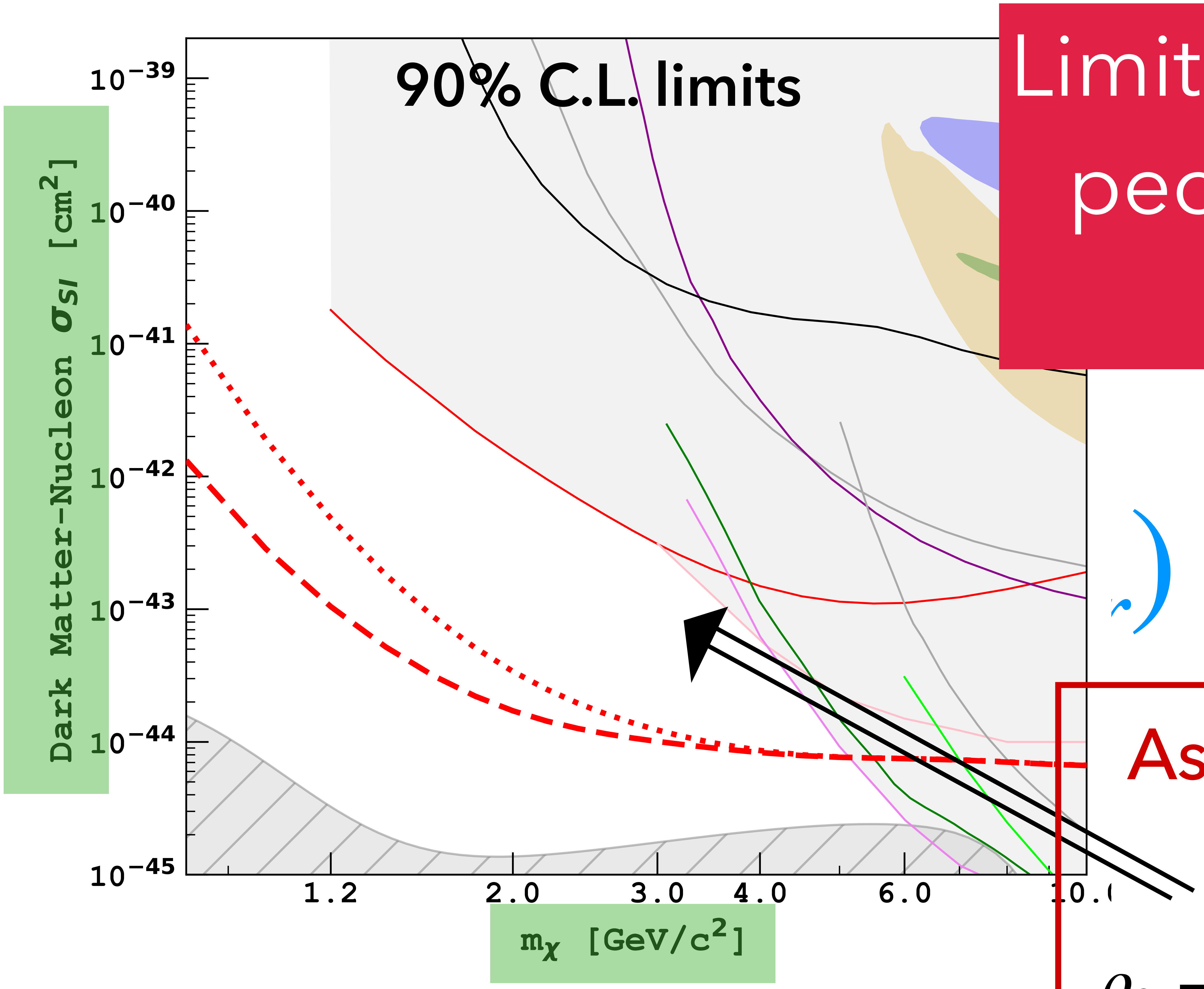
$\rho_0 \rightarrow$ Local DM mass density (set to $\rho_0 = 0.3$ GeV/cm^3/c^2)

$\eta(v_{min}) \rightarrow$ Mean inverse speed of DM $\left(\eta(v_{min}) = \int_{v_{min}} \frac{f(v)}{v} dv\right)$

$v_{min} \rightarrow$ Minimal velocity needed to have a recoil of energy E_r



$$\frac{dR}{dE_r} = \frac{\sigma_{SI}}{2\mu^2 m_\chi}$$



Limits are computed in a peculiar astrophysical framework

$$)|^2 \cdot \rho_0 \cdot \eta(v_{min})$$

Physics

σ_{SI} → WIMP-nucleon cross section

μ → WIMP-nucleus reduced mass

m_χ → WIMP mass

T → Detector running time

A → Target material atomic mass number

$F(E_r)$ → Nuclear form factor

Astrophysics (galactic DM halo modelling)

ρ_0 → Local DM mass density (set to ρ_0 = 0.3 GeV/cm^3/c^2)

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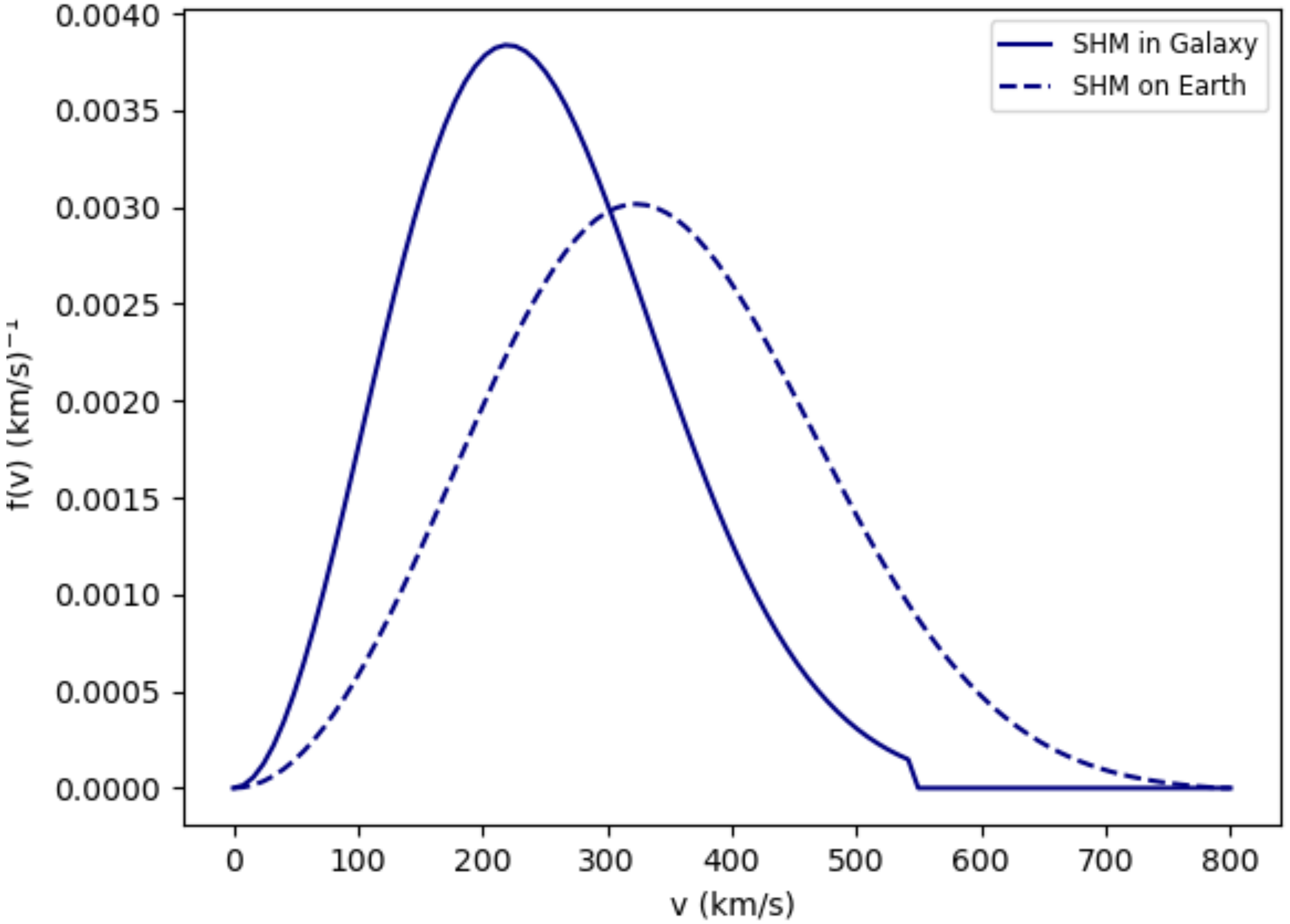
v_{min} → Minimal velocity needed to have a recoil of energy E_r

Galactic dark matter halo

Standard Halo Model (SHM)

A velocity distribution

SHM: Maxwellian velocity distribution



Four astrophysical parameters

$\rho_0 \rightarrow$ Local DM mass density
Set to ρ_0 = 0.3 GeV/cm^3/c^2

$v_{esc} \rightarrow$ Escape velocity at the position of the Sun
Set to v_{esc} = 544 km/s

$v_0 \rightarrow$ Most probable velocity at the position of the Sun
Set to v_0 = 238 km/s

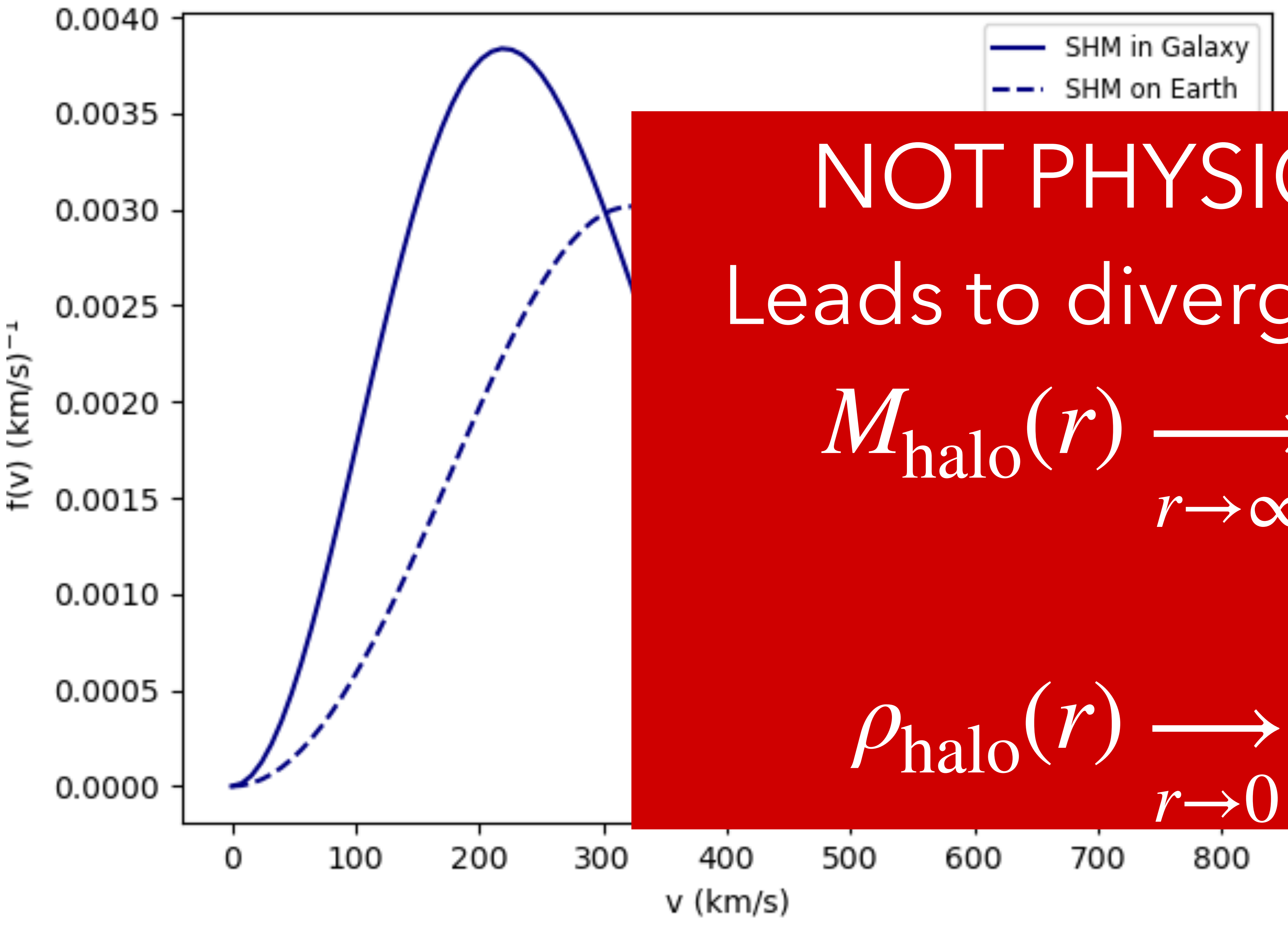
$v_c \rightarrow$ Circular velocity at the position of the Sun
Set to v_c = 238 km/s

Galactic dark matter halo

Standard Halo Model (SHM)

A velocity distribution

SHM: Maxwellian velocity distribution



NOT PHYSICAL

Leads to divergences

$$M_{\text{halo}}(r) \xrightarrow[r\to\infty]{} \infty$$

$$\rho_{\text{halo}}(r) \xrightarrow[r\to 0]{} \infty$$

Four astrophysical parameters

$\rho_0 \rightarrow$ Local DM mass density
Set to ρ_0 = 0.3 GeV/cm^3/c^2

$v_{esc} \rightarrow$ Escape velo
Set to v_{esc} =

$v_0 \rightarrow$ Most proba
Set to v_0 = 2

$v_c \rightarrow$ Circular vel
Set to v_c = 2

Parameters set independently (to their best fit values) while they depend on the chosen halo and on one another

Galactic dark matter halo systematics

Theoretical event rate :

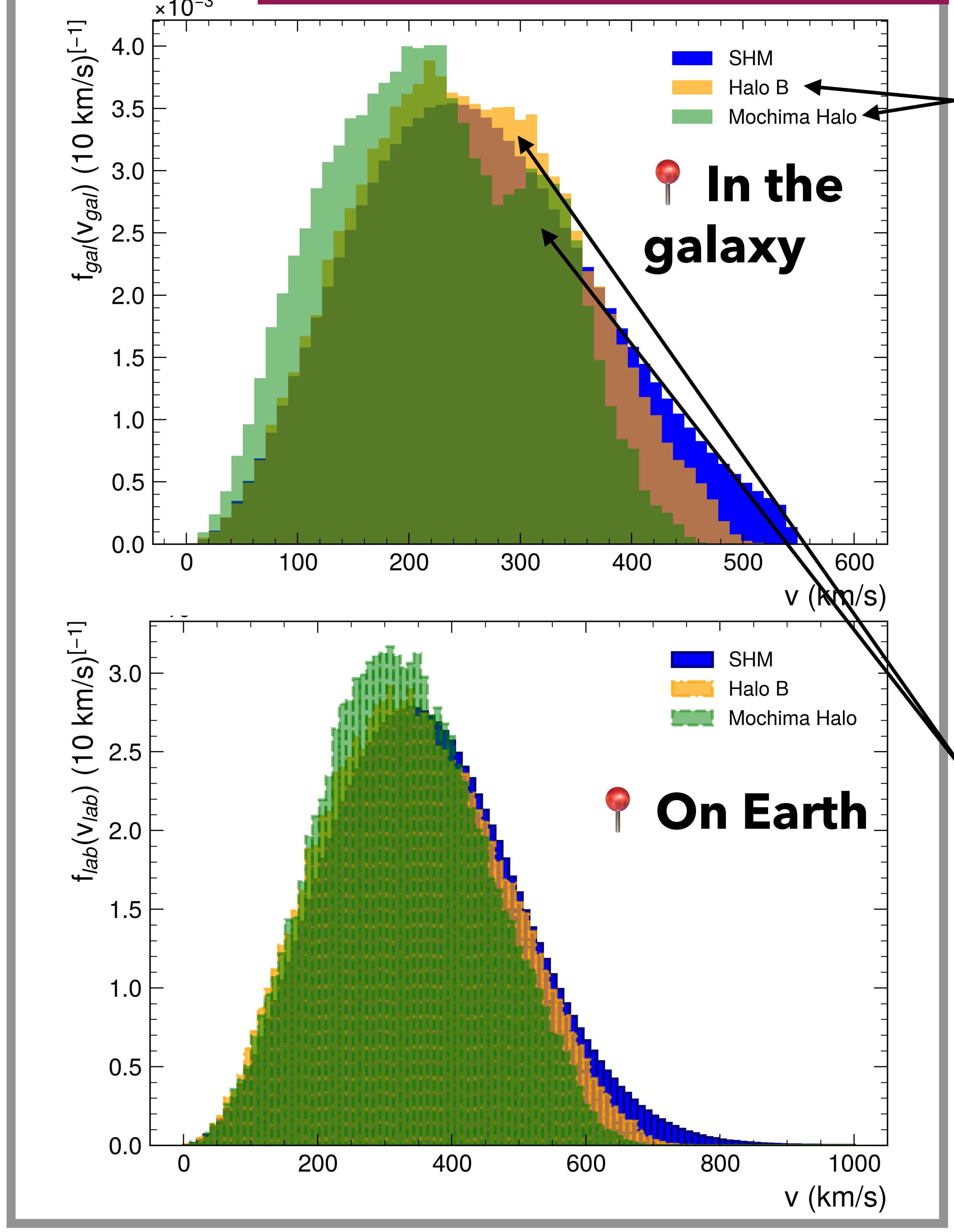
$$\frac{dR}{dE} = \frac{\rho_0}{m_\chi m_A}\int_{v>v_{min}}^{v_{max}} \frac{d\sigma}{dE}\, v\, f(\vec{v})\, d^3\vec{v}$$

SHM → Maxwellian velocity distribution

Astrophysical parameters

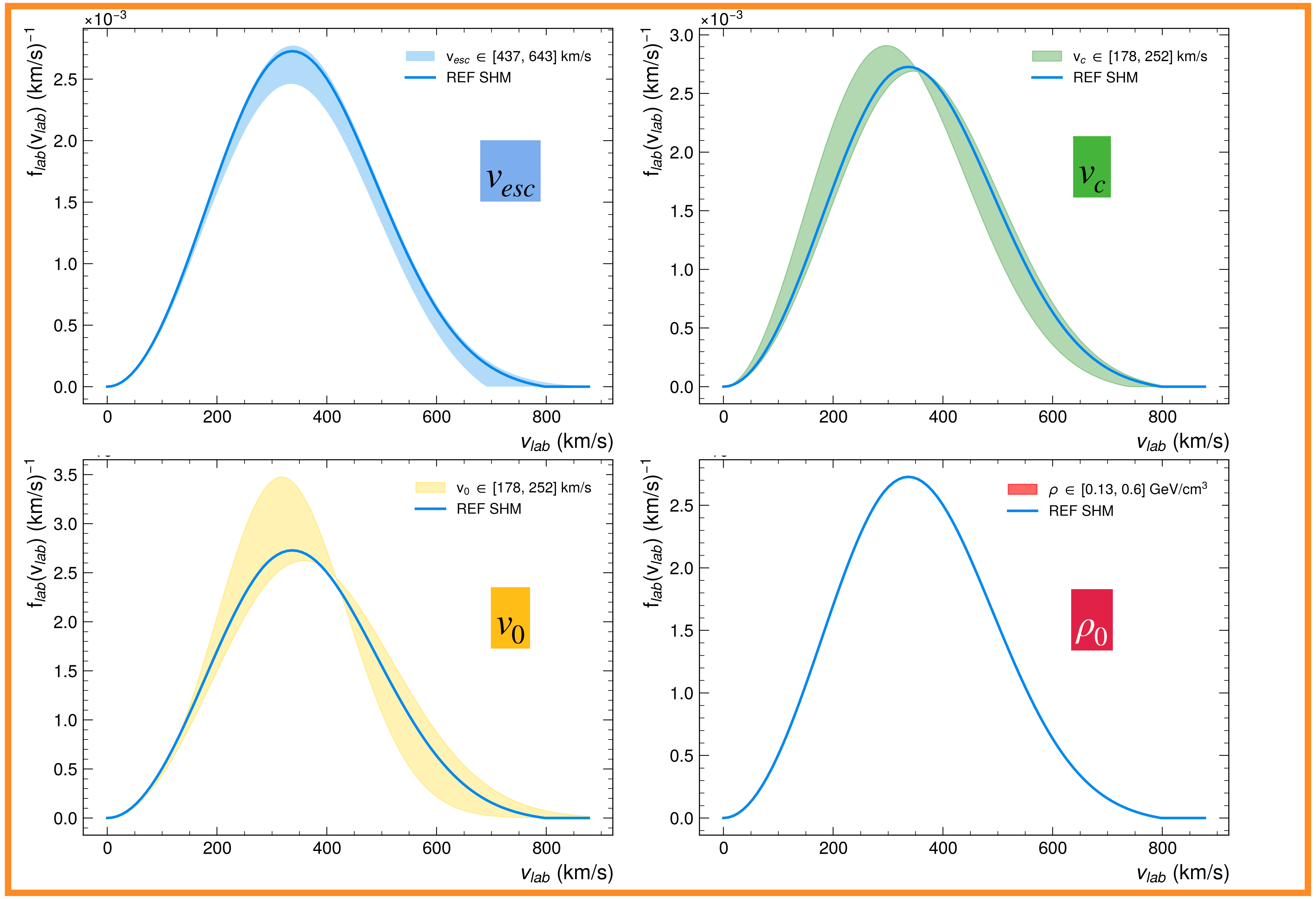
- $v_{max} = v_{esc} + v_{Earth}$, v_{esc}=544 km/s
- $v_c = v_0 = 238$ km/s
- ρ_0 = 0.3 GeV/cm^3

Mon. Not. Roy. Astron. Soc. 447 (2015)



DM haloes of Milky-Way-like galaxies derived from **DM+baryon cosmological simulations**

Bumps resulting from non - linearities in the history of the halo formation



On Earth

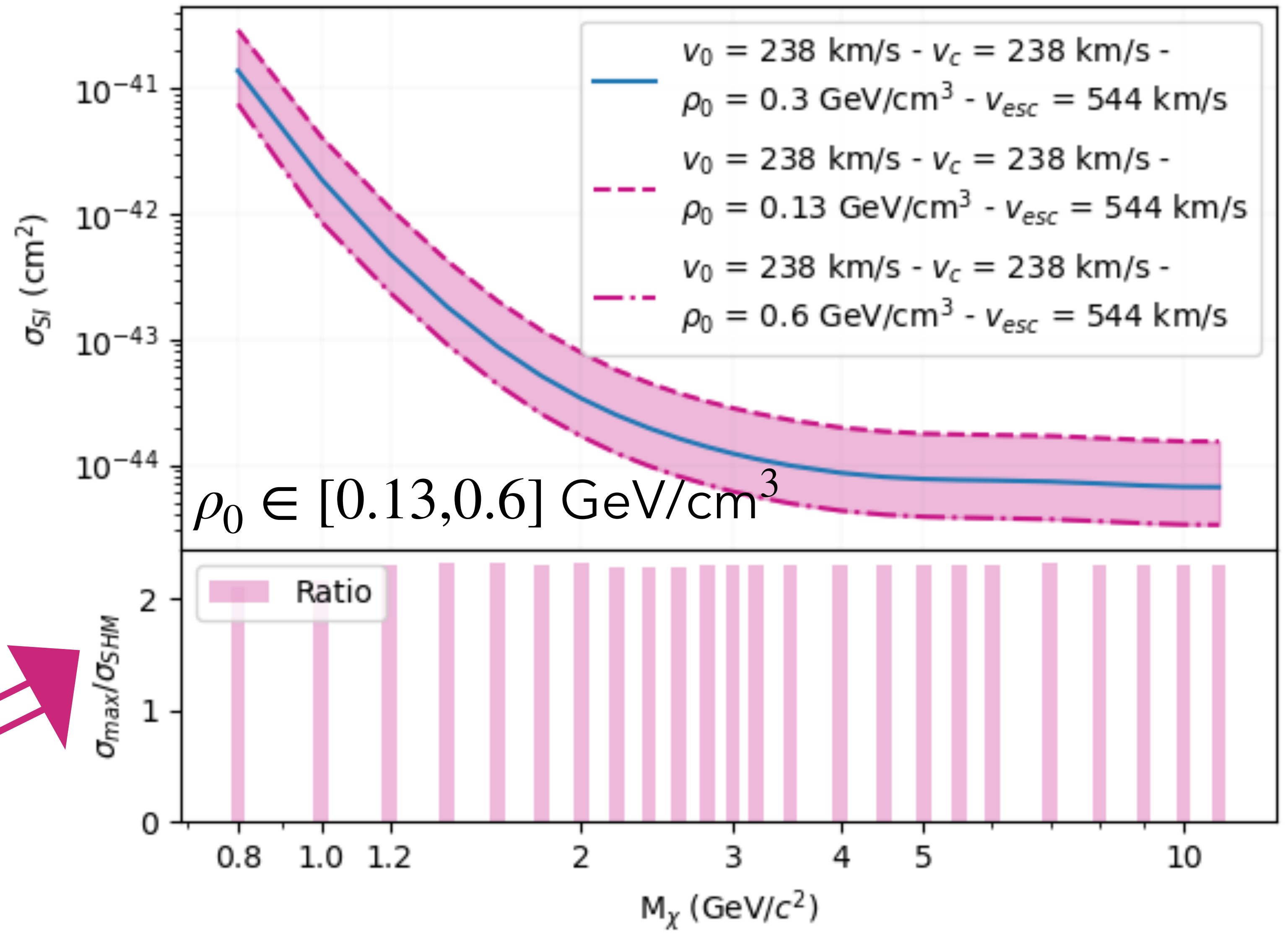
Systematics from DM halo uncertainty: LM case

- Theoretical event rate :

$$\frac{dR}{dE} = \frac{\rho_0}{m_\chi m_A}\int_{v>v_{min}}^{v_{max}} \frac{d\sigma}{dE}\, v\, f(\vec{v})\; d^3\vec{v}$$

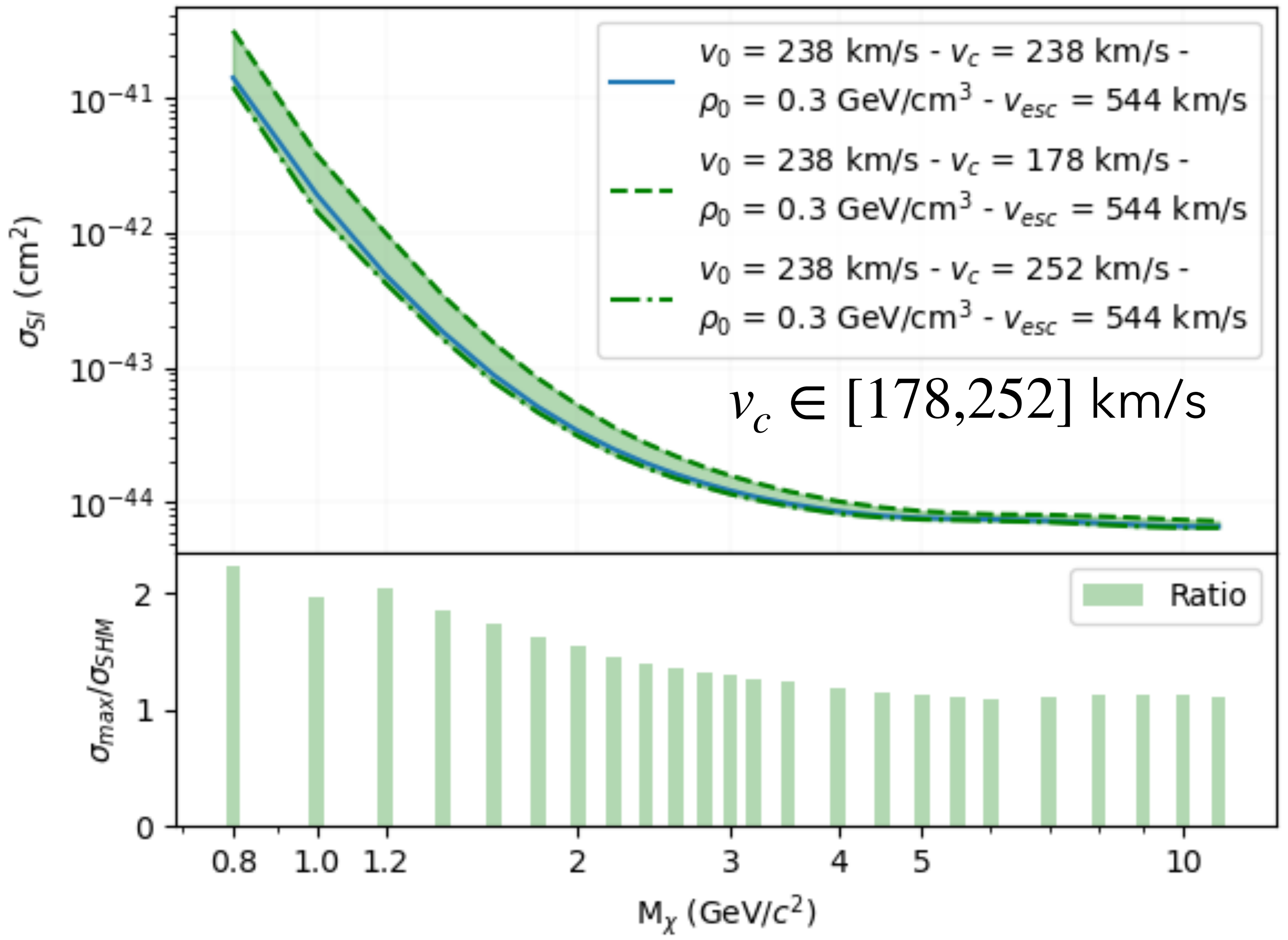
ρ_0 scales linearly with the event rate
$\Rightarrow$ linear effect on the sensitivity

Vary ρ_0



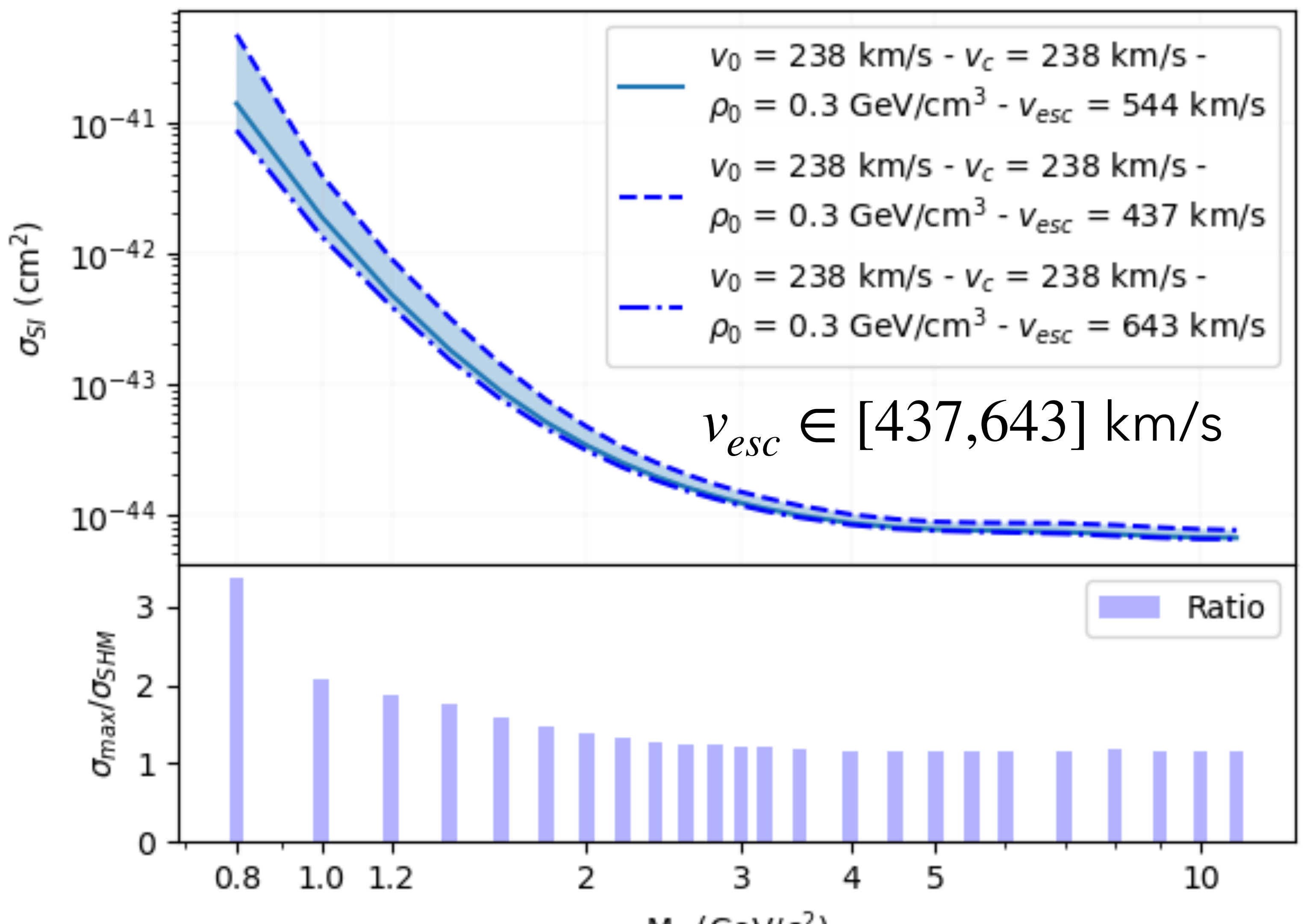
$\rho_0 \in [0.13,0.6]$ GeV/cm^3

Vary v_c



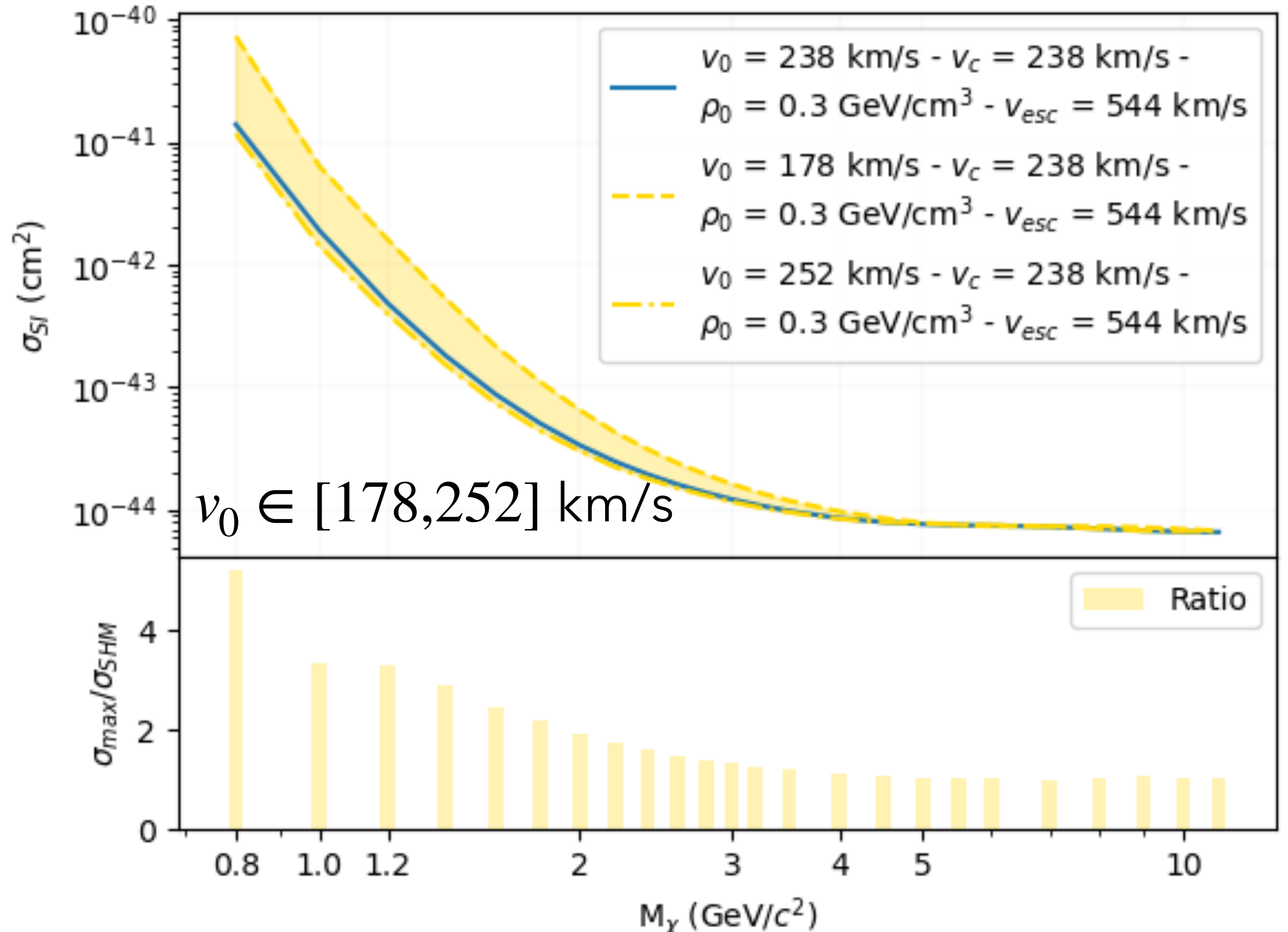
$v_c \in [178,252]$ km/s

Vary v_{esc}



$v_{esc} \in [437,643]$ km/s

Vary v_0



$v_0 \in [178,252]$ km/s

Systematics from DM halo uncertainty: LM case

- Theoretical event rate :

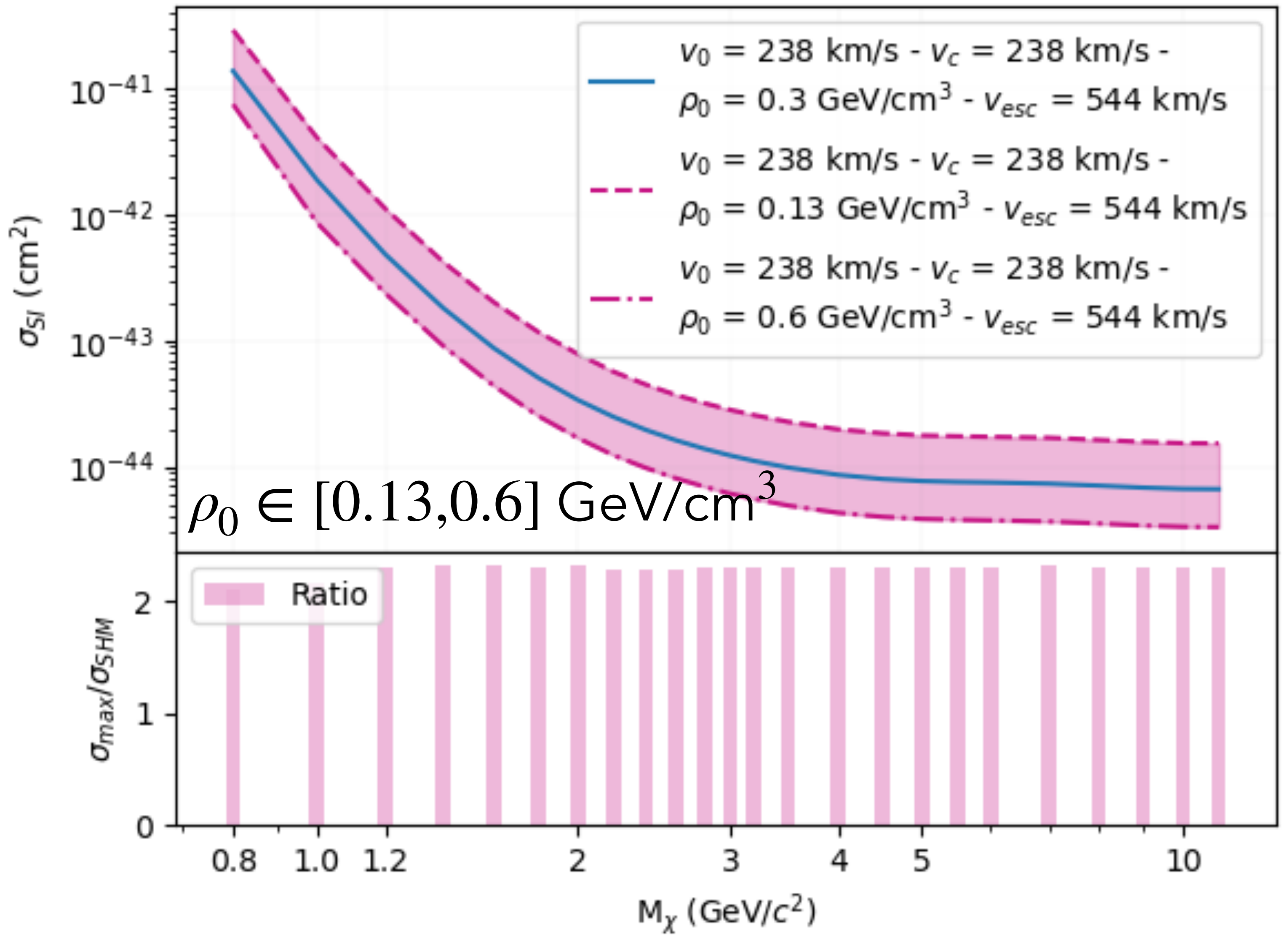
$$\frac{dR}{dE} = \frac{\rho_0}{m_\chi m_A} \int_{v>v_{min}}^{v_{max}} \frac{d\sigma}{dE} v \, f(\vec{v}) \, d^3\vec{v}$$

v_{esc} parametrises the tail of the velocity distribution (VPDF)
⇒ effect at low mass on the sensitivity

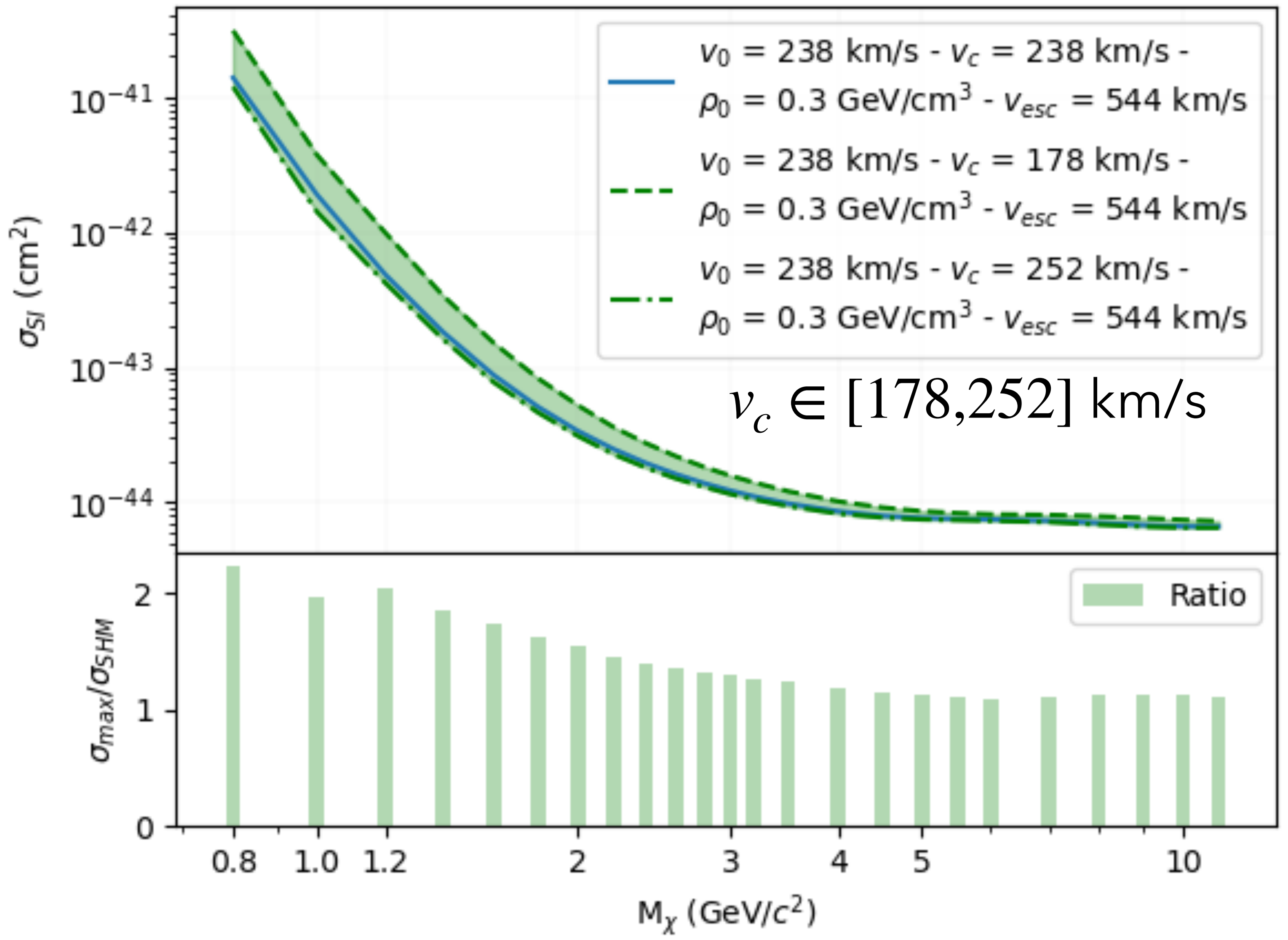
$$v_{min}(E_{th}, m_\chi, M) = v_{esc} + v_c + v_\odot$$

Minimal velocity needed by a WIMP of mass $m_\chi \propto \frac{1}{m_\chi}$ (at low mass)

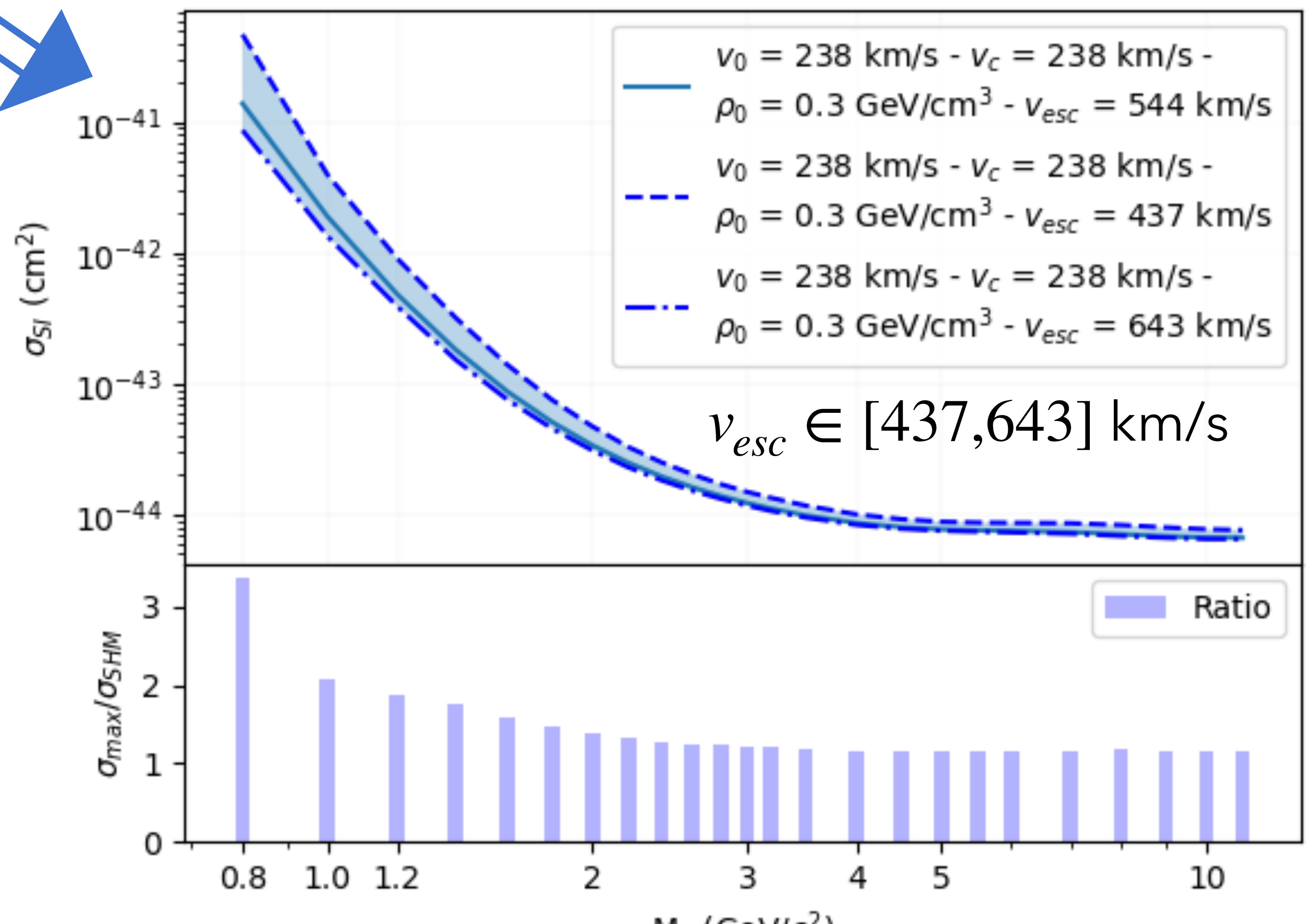
Vary ρ_0



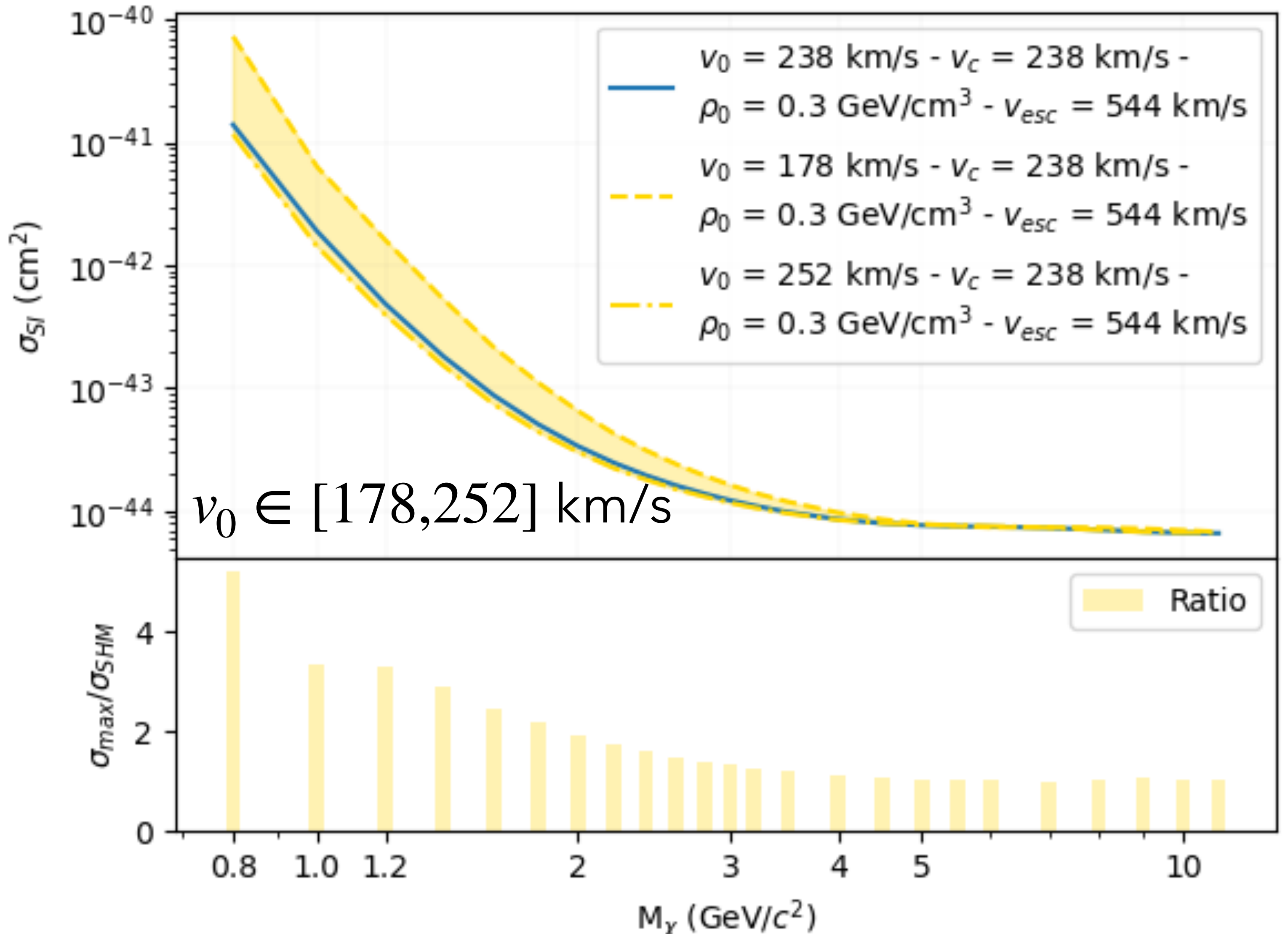
Vary v_c



Vary v_{esc}



Vary v_0



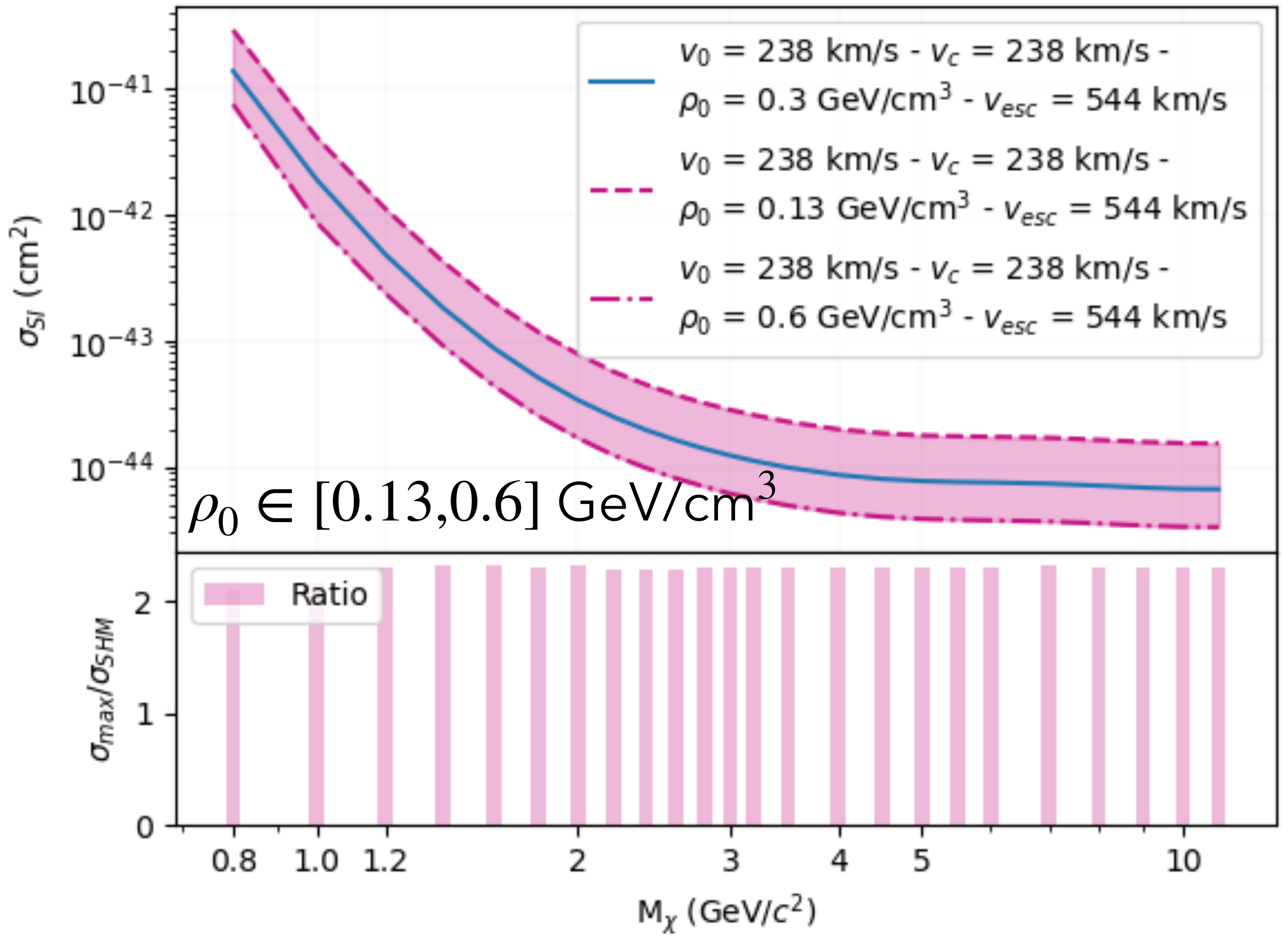
Systematics from DM halo uncertainty: LM case

- Theoretical event rate :

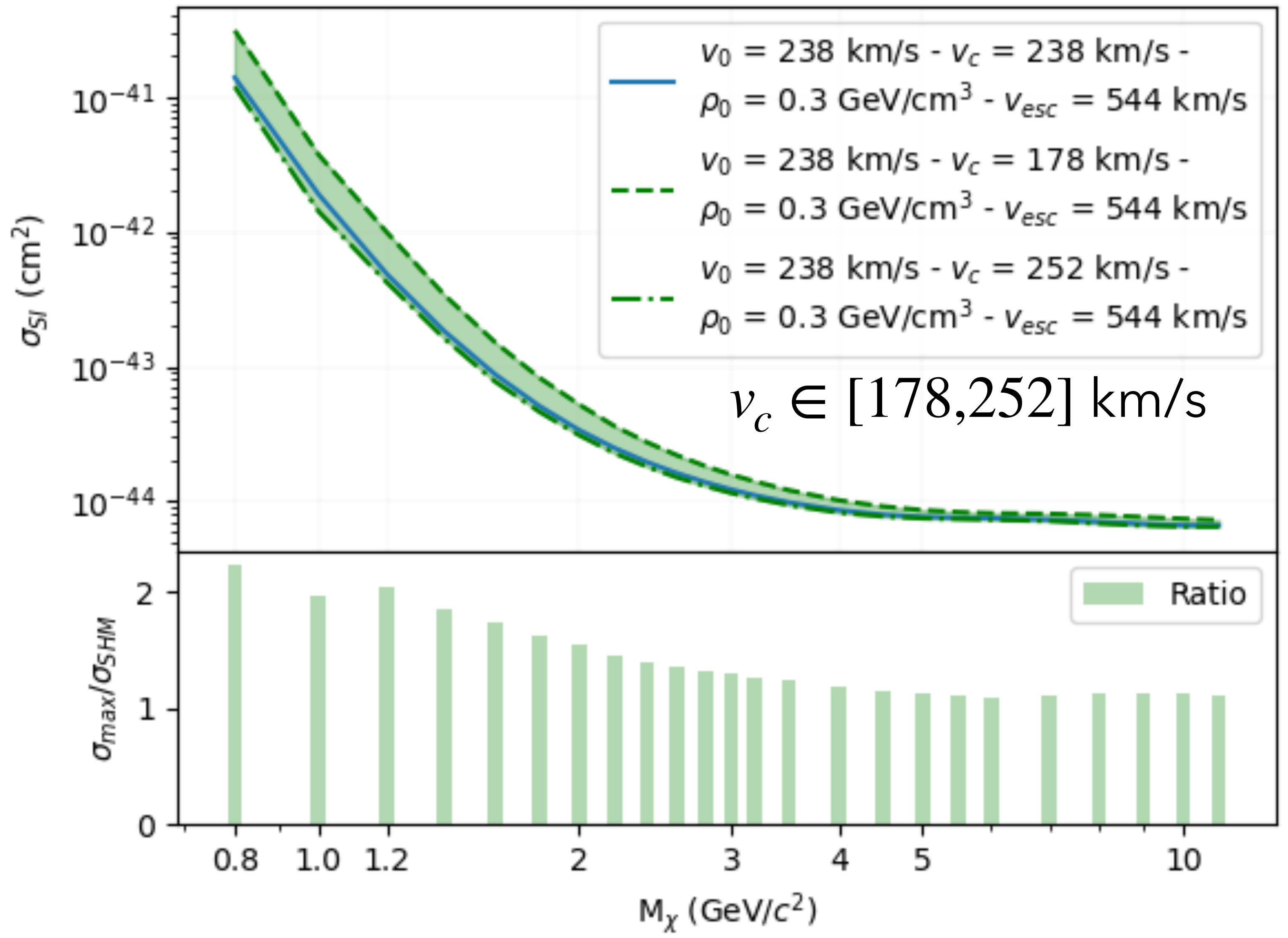
$$\frac{dR}{dE} = \frac{\rho_0}{m_\chi m_A}\int_{v>v_{min}}^{v_{max}} \frac{d\sigma}{dE}\, v\, f(\vec{v})\; d^3\vec{v}$$

v_0 parametrises the tail of the VPDF (as it is a velocity dispersion) ⇒ effect at low masses on the sensitivity

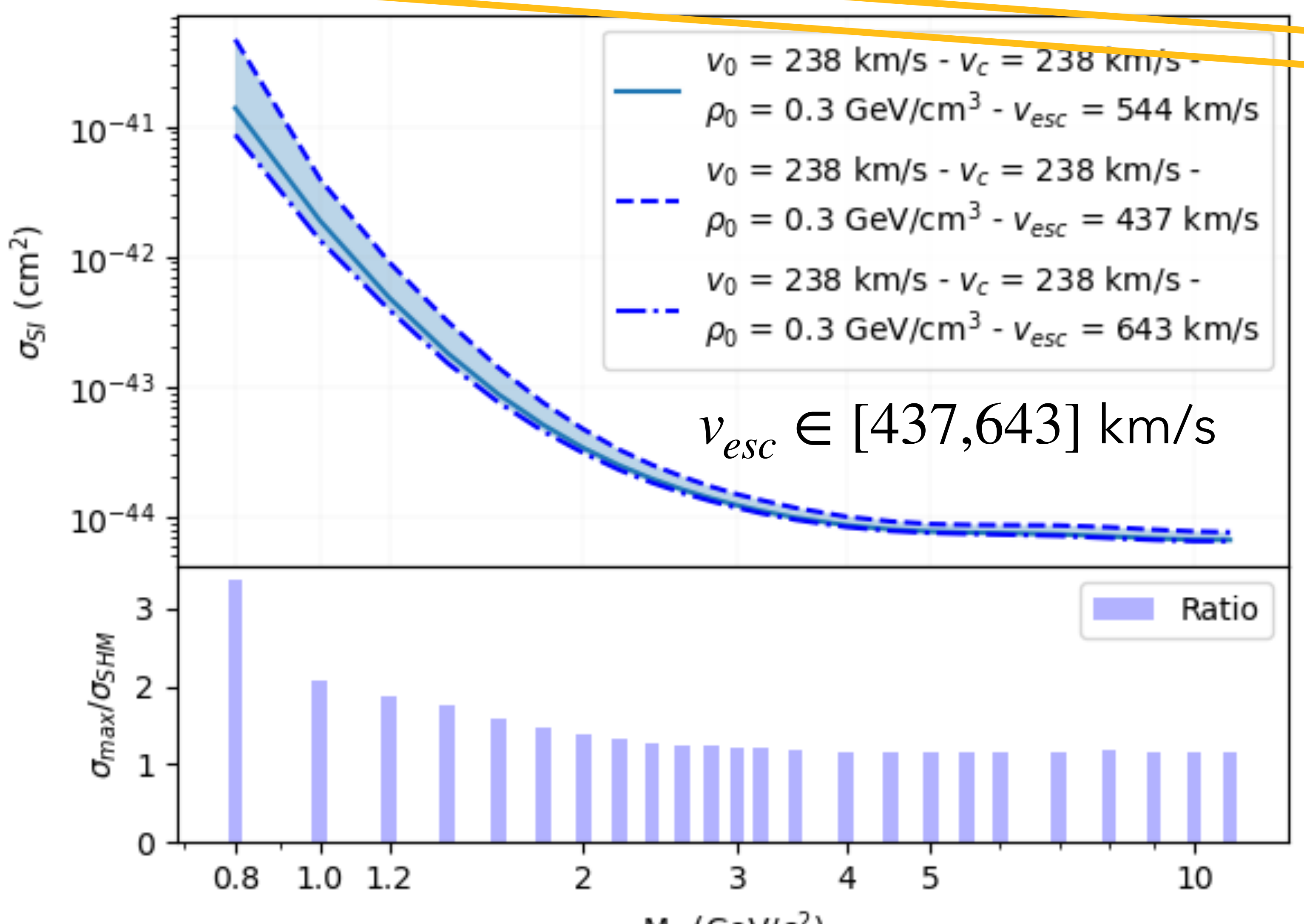
Vary ρ_0



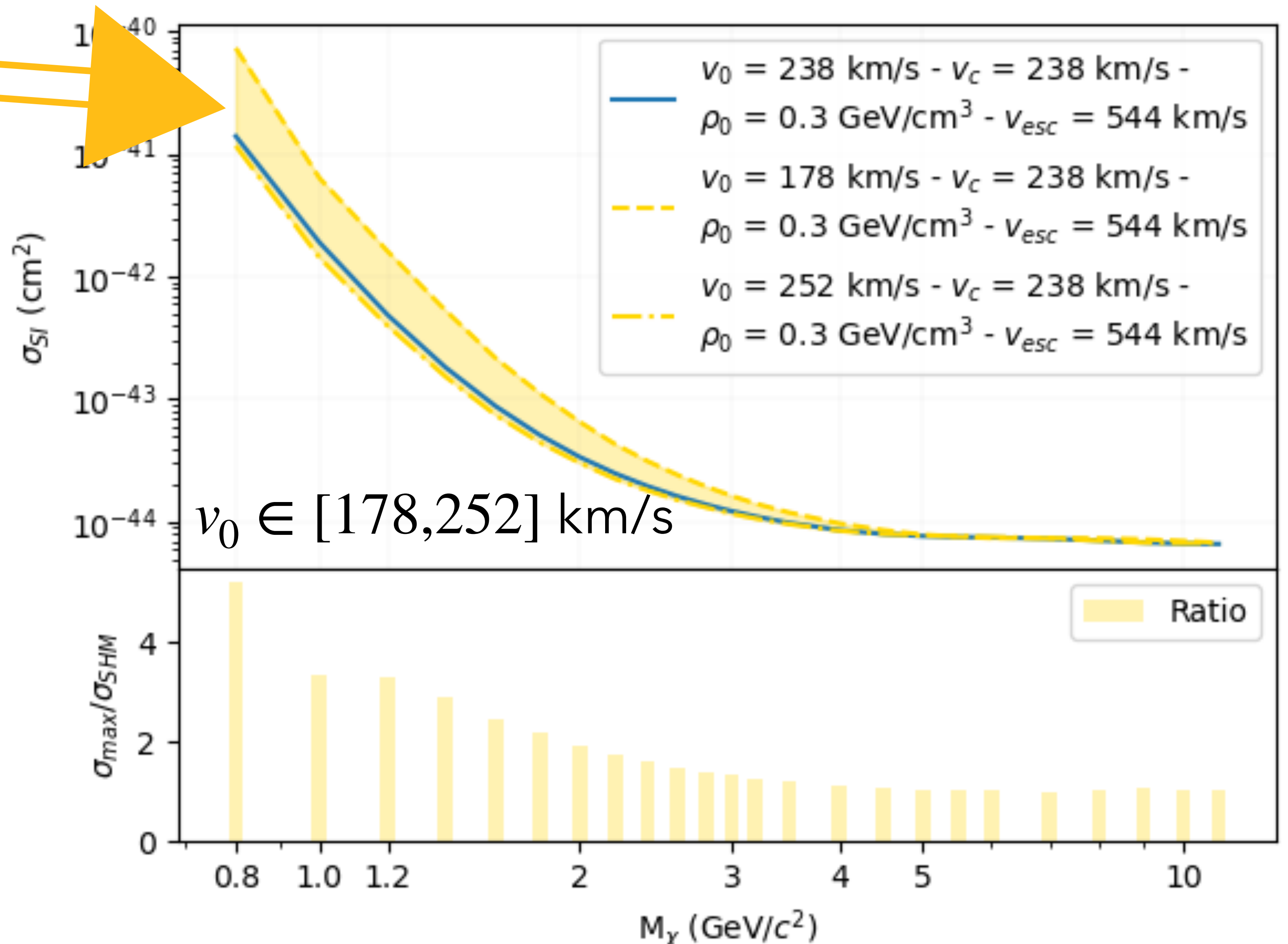
Vary v_c



Vary v_{esc}



Vary v_0



Systematics from DM halo uncertainty: LM case

- Theoretical event rate :

$$\frac{dR}{dE} = \frac{\rho_0}{m_\chi m_A}\int_{v>v_{min}}^{v_{max}} \frac{d\sigma}{dE}\, v\, f(\vec{v})\, d^3\vec{v}$$

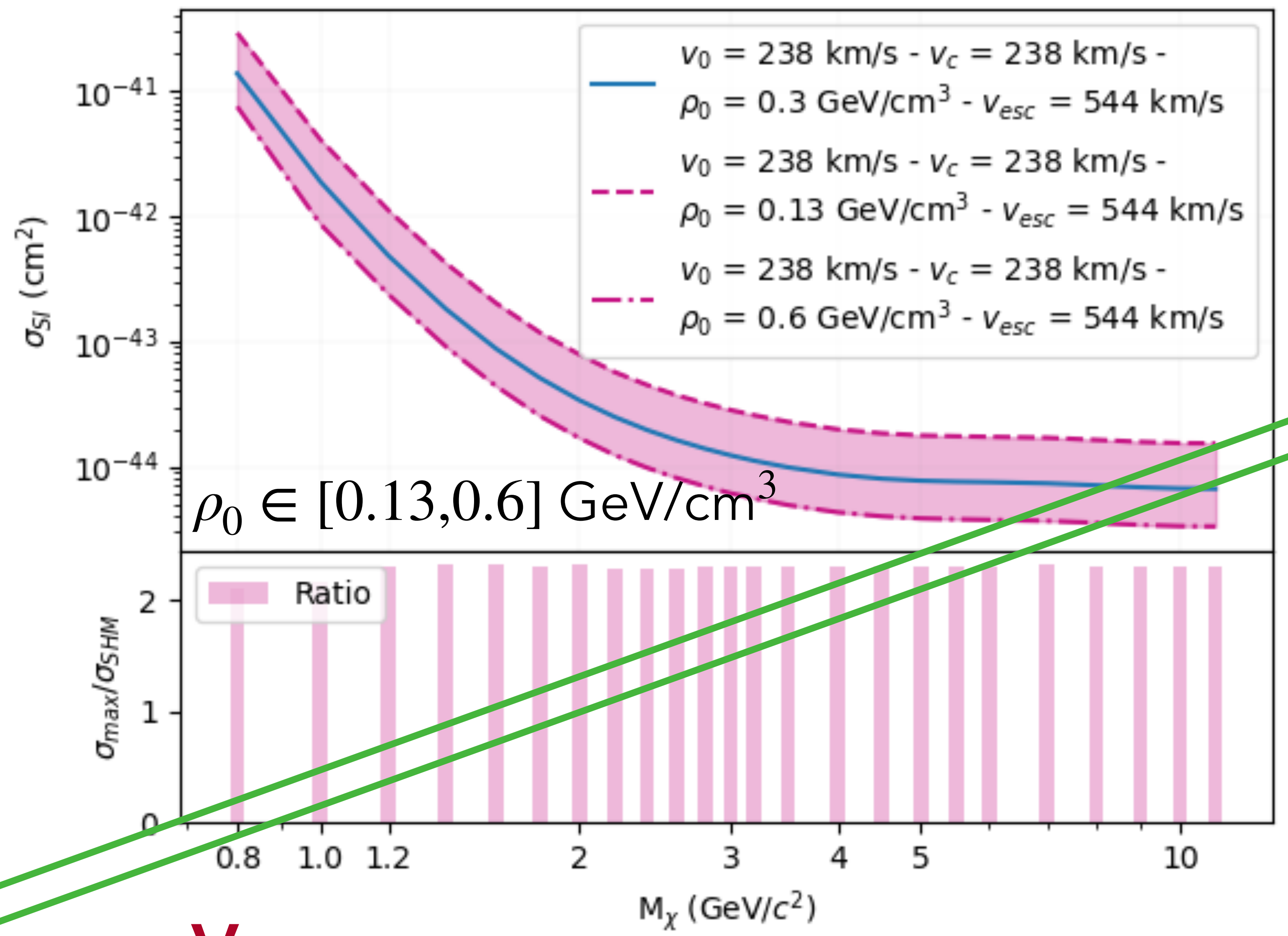
v_c parametrises the tail of the VPDF and the change of frame
⇒ effect at all (but mostly low) masses on the sensitivity

$$\overrightarrow{v_{\chi/\oplus}} = \overrightarrow{v_{\chi/gal}} - \overrightarrow{v_{\oplus}}(t) \longleftarrow v_c \text{ in } \overrightarrow{v_{\oplus}}(t)$$

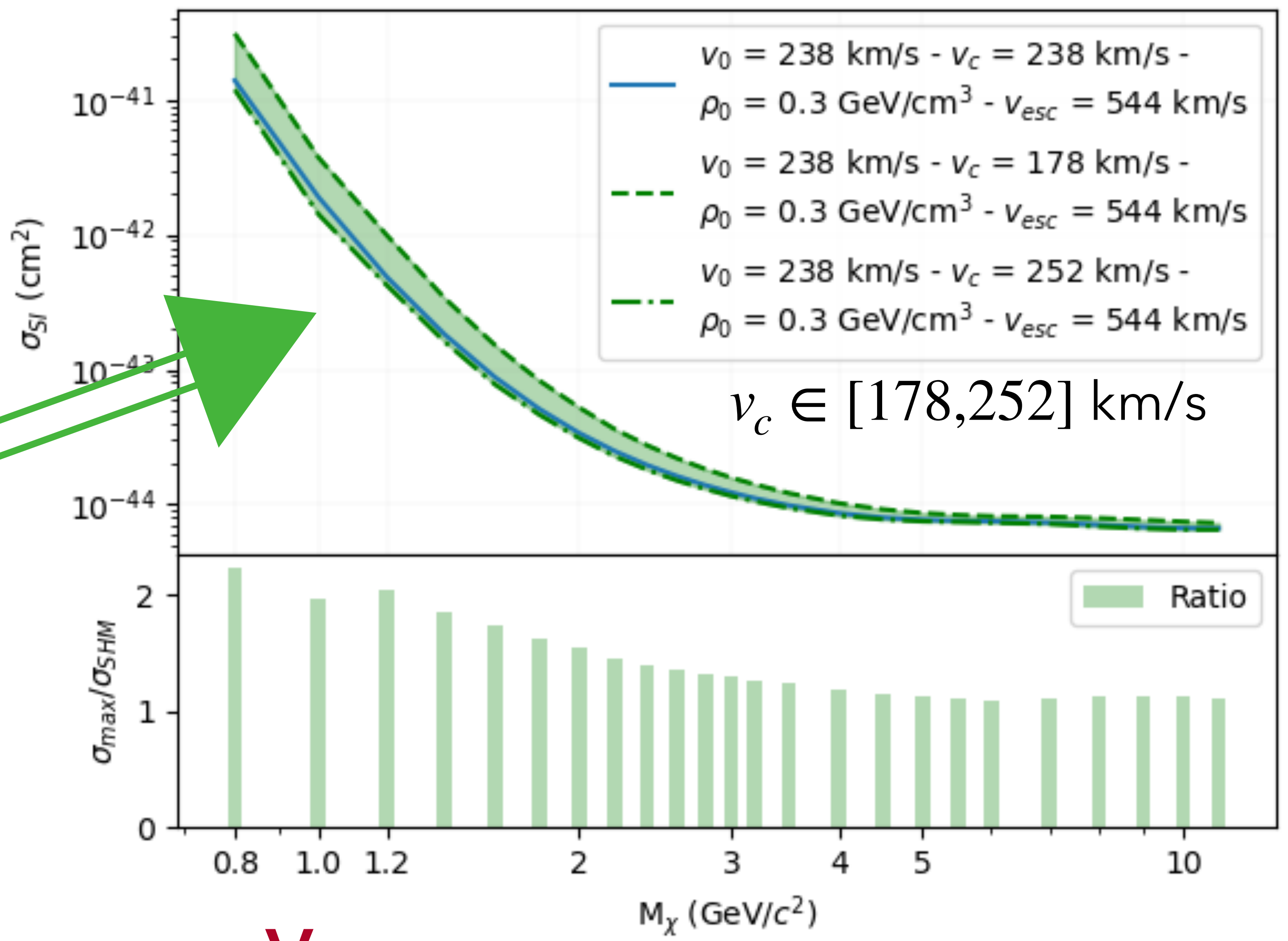
$$v_{min}(E_{th}, m_\chi, M) = v_{esc} + v_c + v_\odot$$

Minimal velocity needed by a WIMP of mass $m_\chi \propto \frac{1}{m_\chi}$ (at low mass)

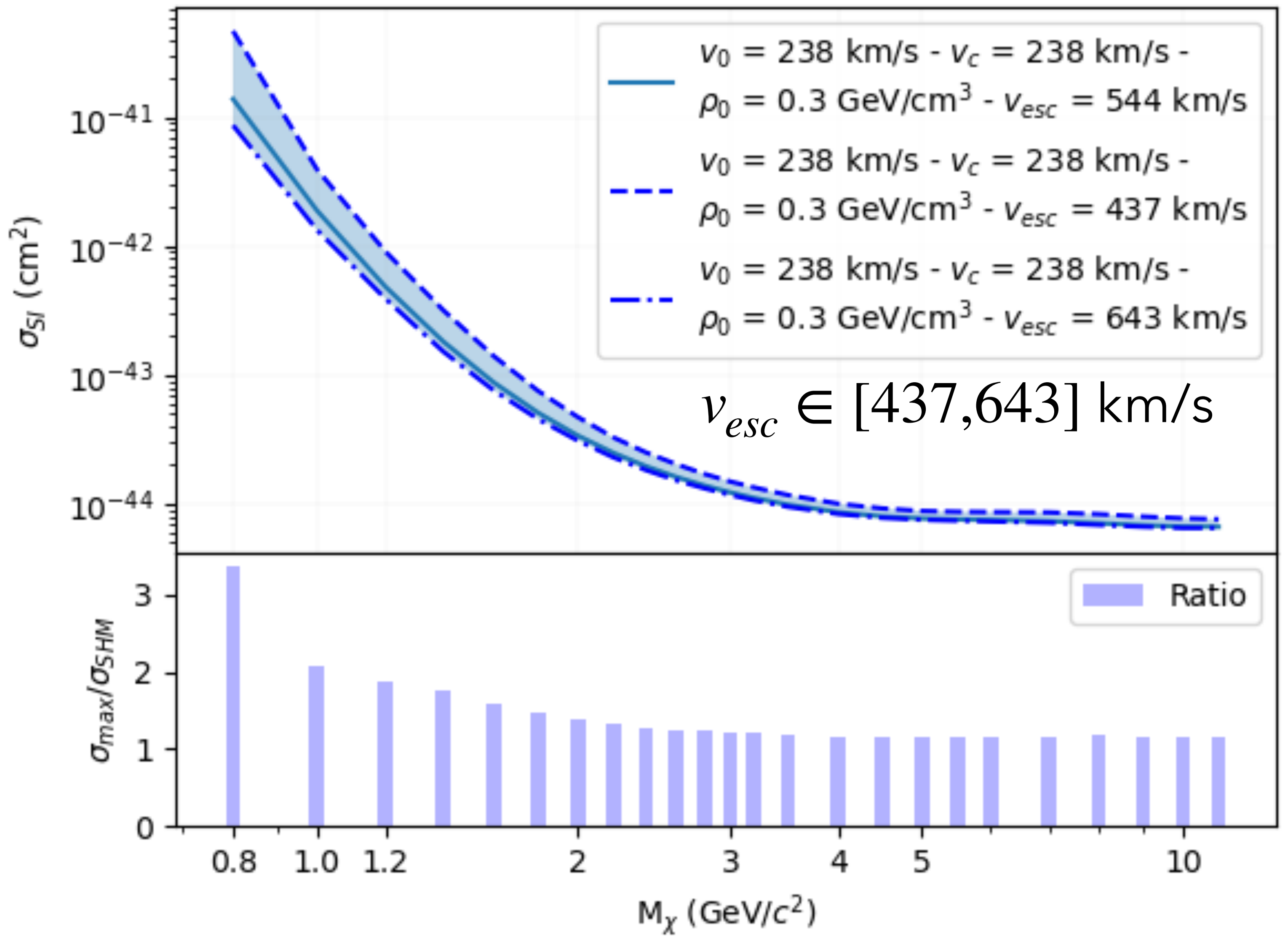
Vary ρ_0



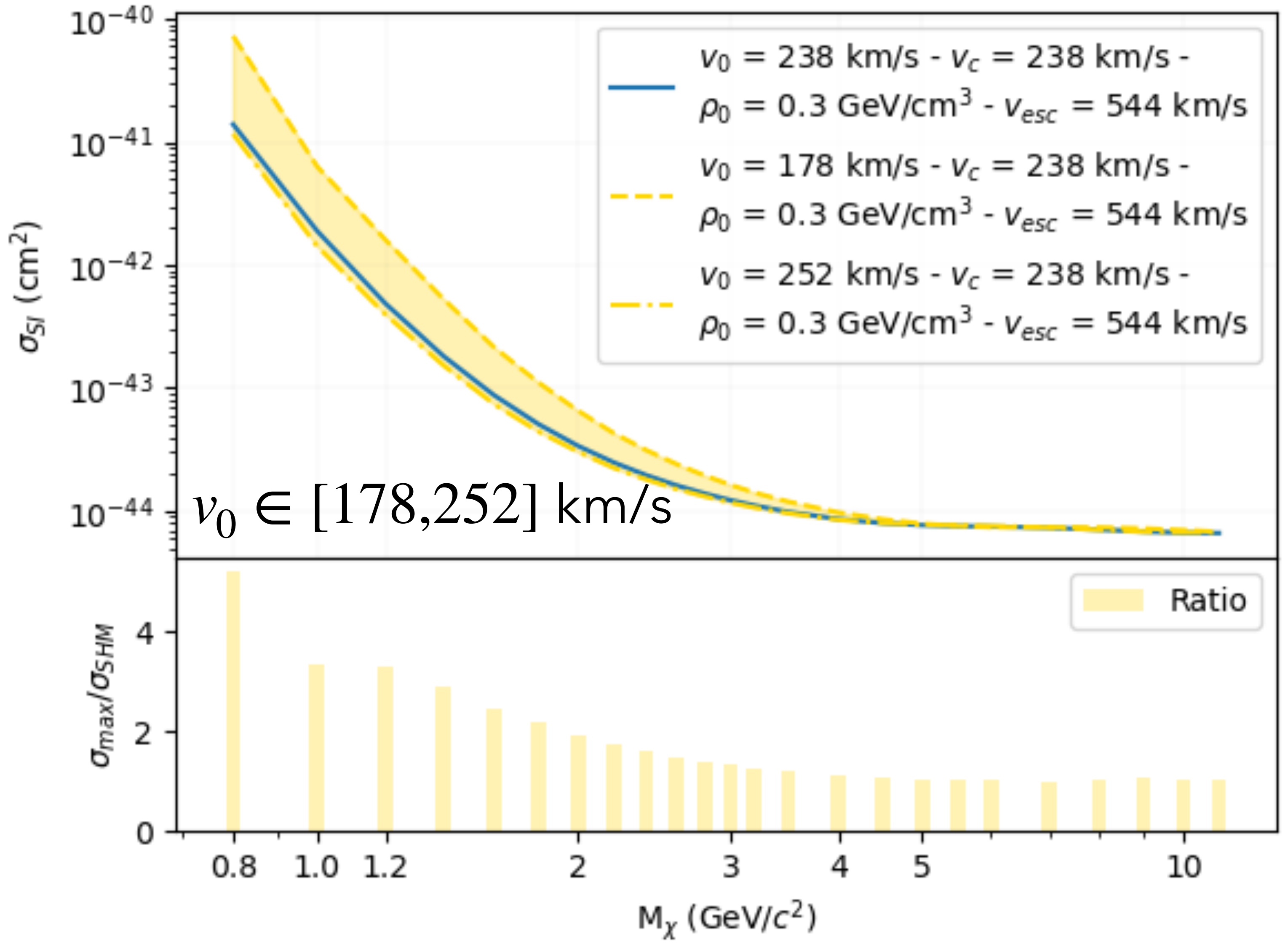
Vary v_c



Vary v_{esc}



Vary v_0



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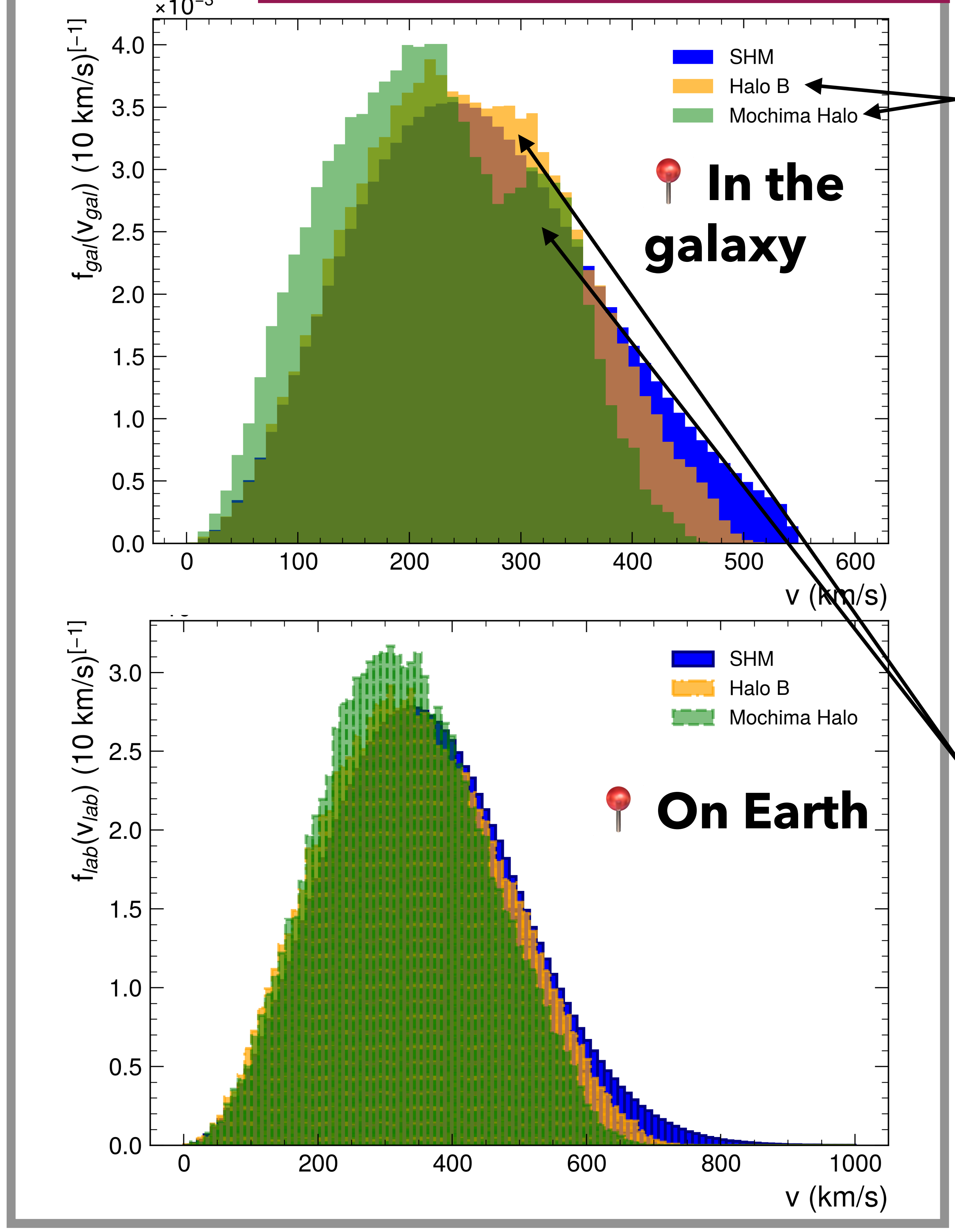
Mon. Not. Roy. Astron. Soc. 447 (2015)



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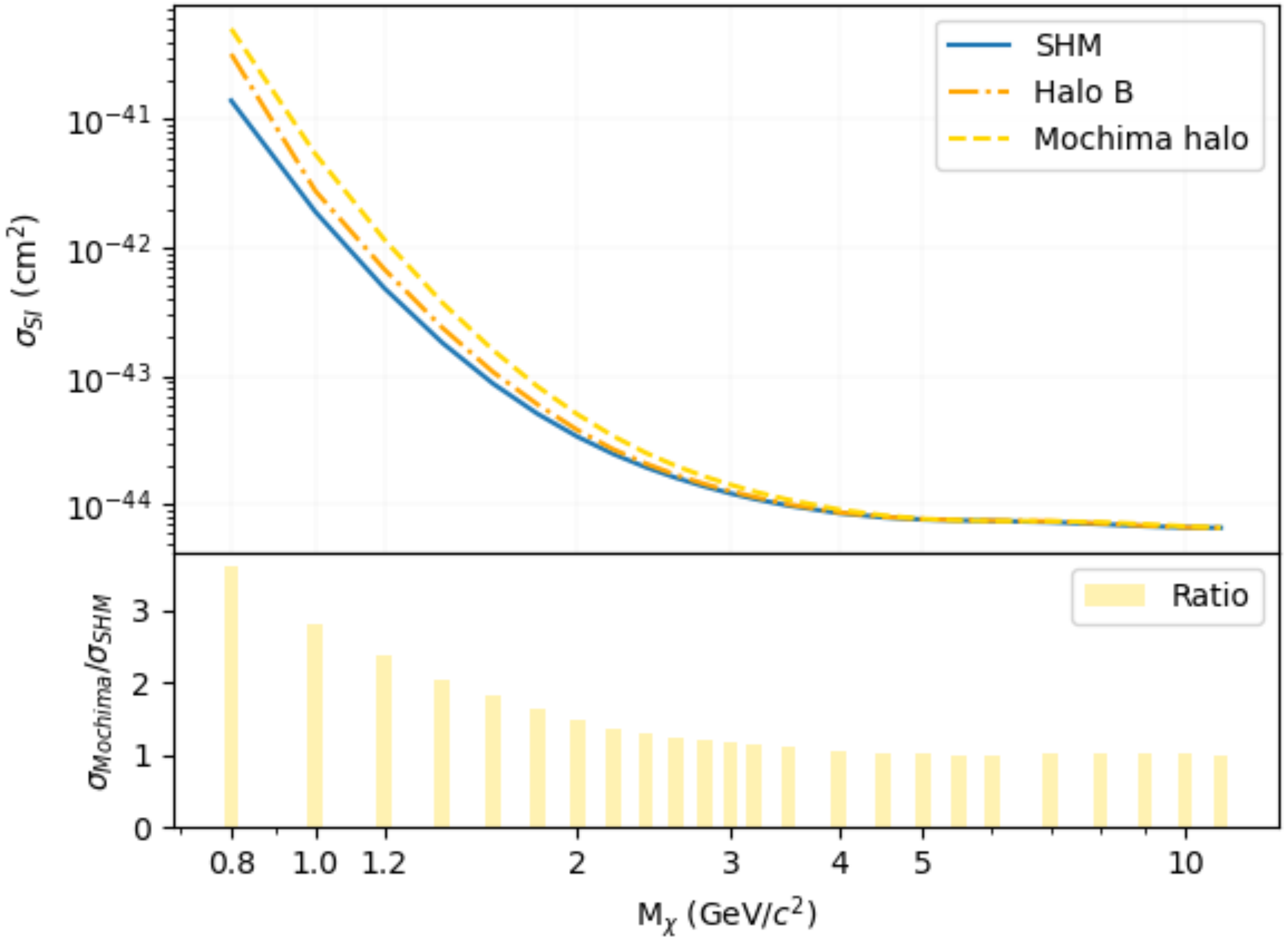
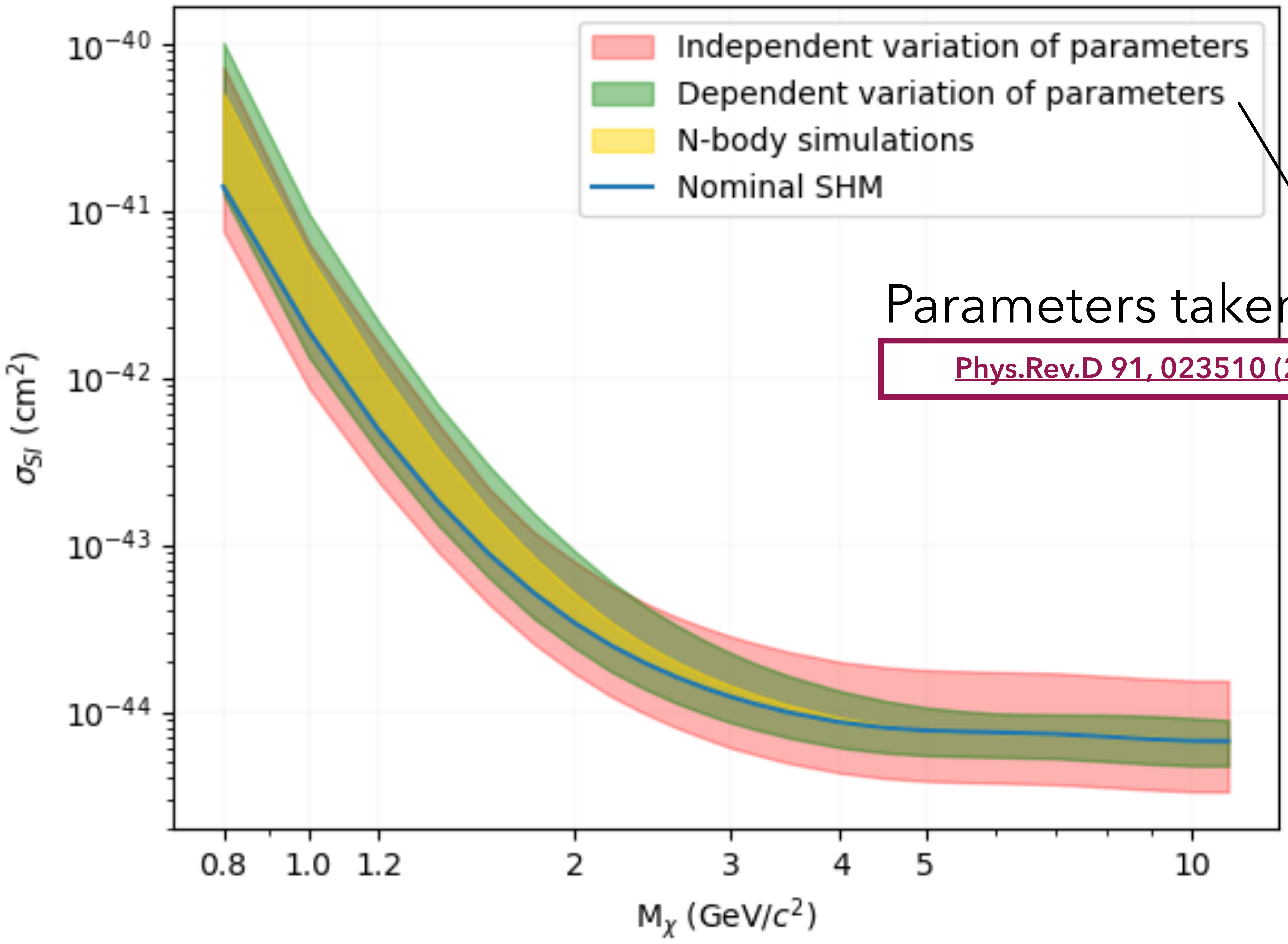


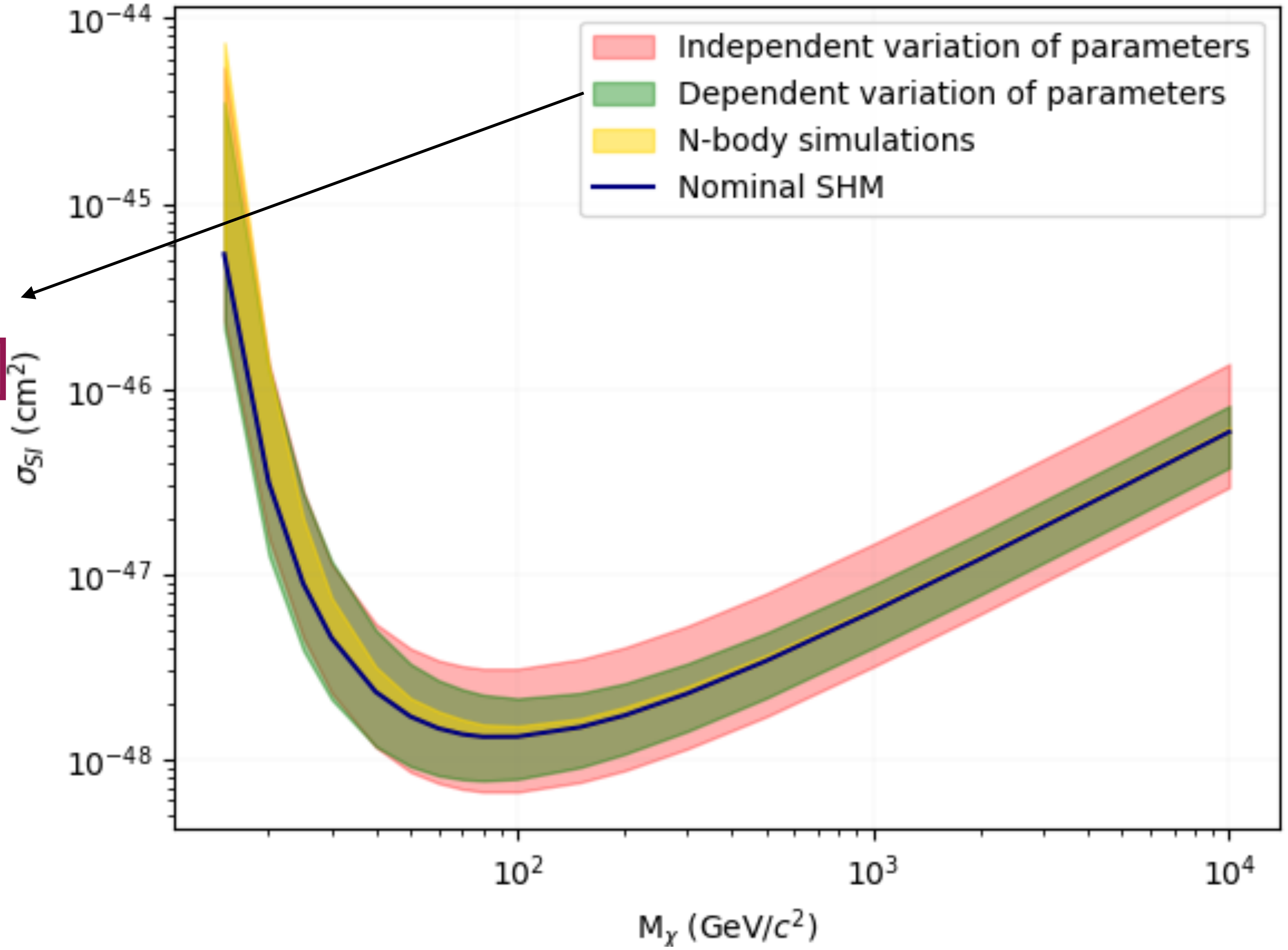
SHM = least conservative model
With SHM, up to 3.6x (at 800 MeV) better sensitivity

Systematics from DM halo uncertainty

All effects at low mass



All effects at high mass



Parameters taken from

Phys.Rev.D 91, 023510 (2015)

Same overall behaviour at low and high mass

Conclusions

I took part in the preparation of DarkSide-20k before commissioning

Detector

- First simulations of the TPC calibration
- Calibration feasibility tests with mock ups

Contribution 1

Contribution 2

Physics potential

- First assessment of DarkSide-20k sensitivity to light dark matter particles
  - **Paper submitted** to Nature Communications
- Brings a new front-row scientific opportunity to DarkSide-20k

Contribution 3

Phenomenology

- Estimate of the impact of the galactic dark matter halo uncertainties on the sensitivities of DS-20k

Conclusions

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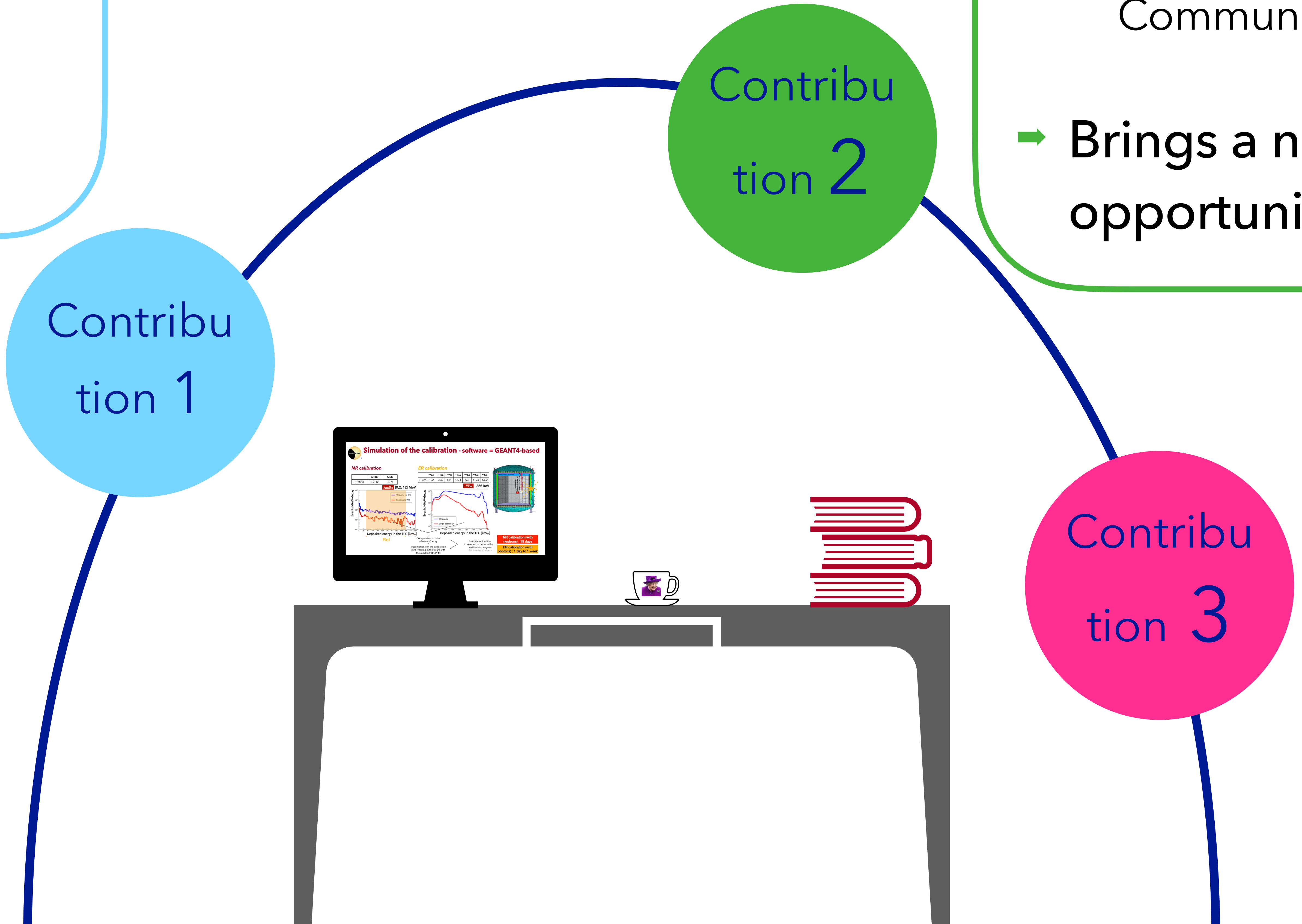
What's next?

- Construction and commissioning
- Calibration
- High quality data collection



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What's next?

- Construction and commissioning
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Phenomenology

- Estimate of the impact of the galactic dark matter halo uncertainties on the sensitivities of DS-20k

Thank you for your attention

Back-up slides

DS-20k

Calibration Simus

Calibration Tests

Low mass

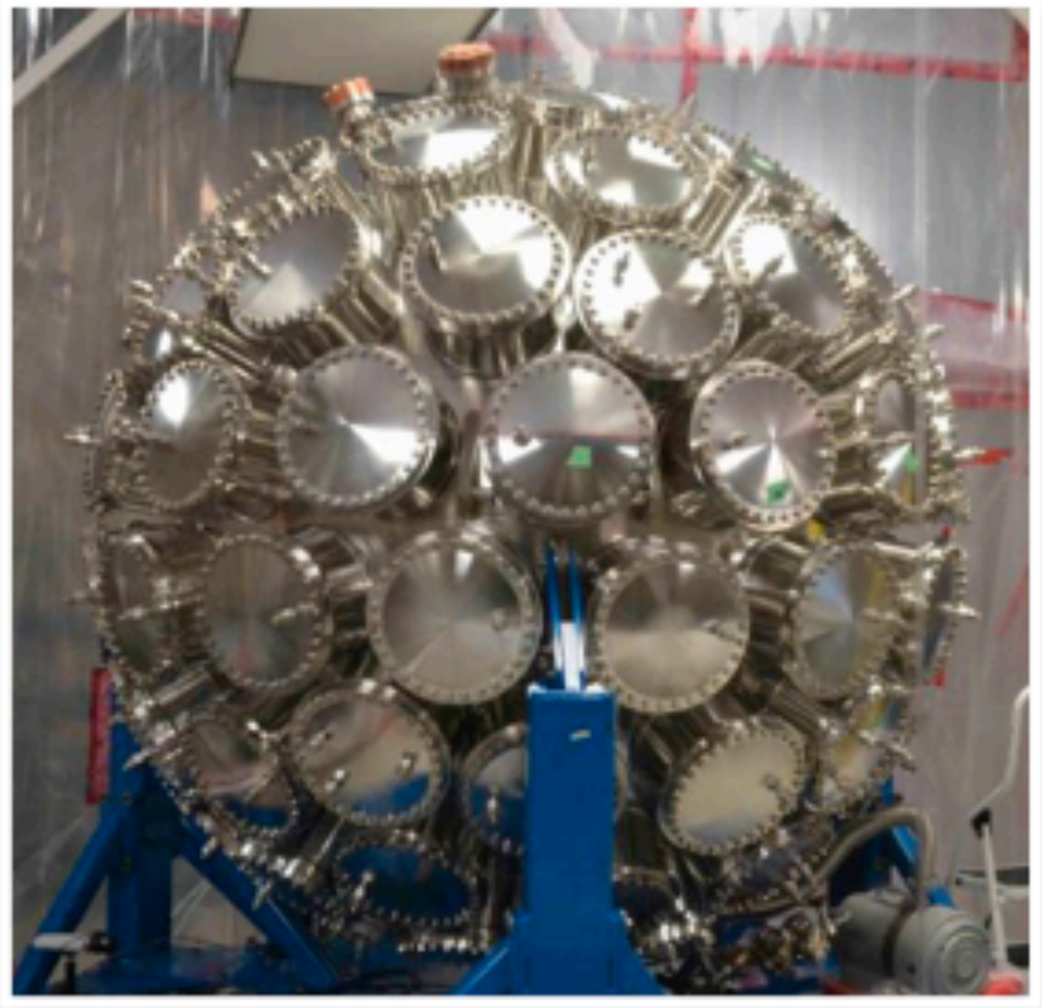
Signal systematics

Back to
back-up wrap

The DarkSide programme

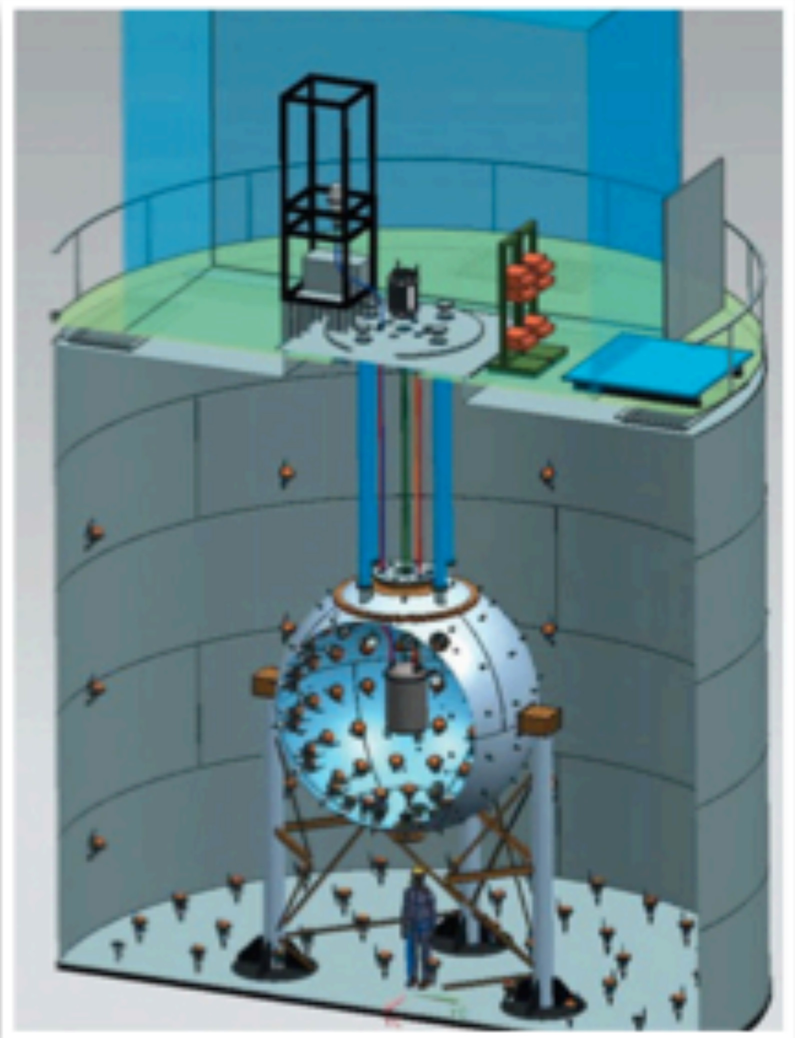
Back up

GADMC



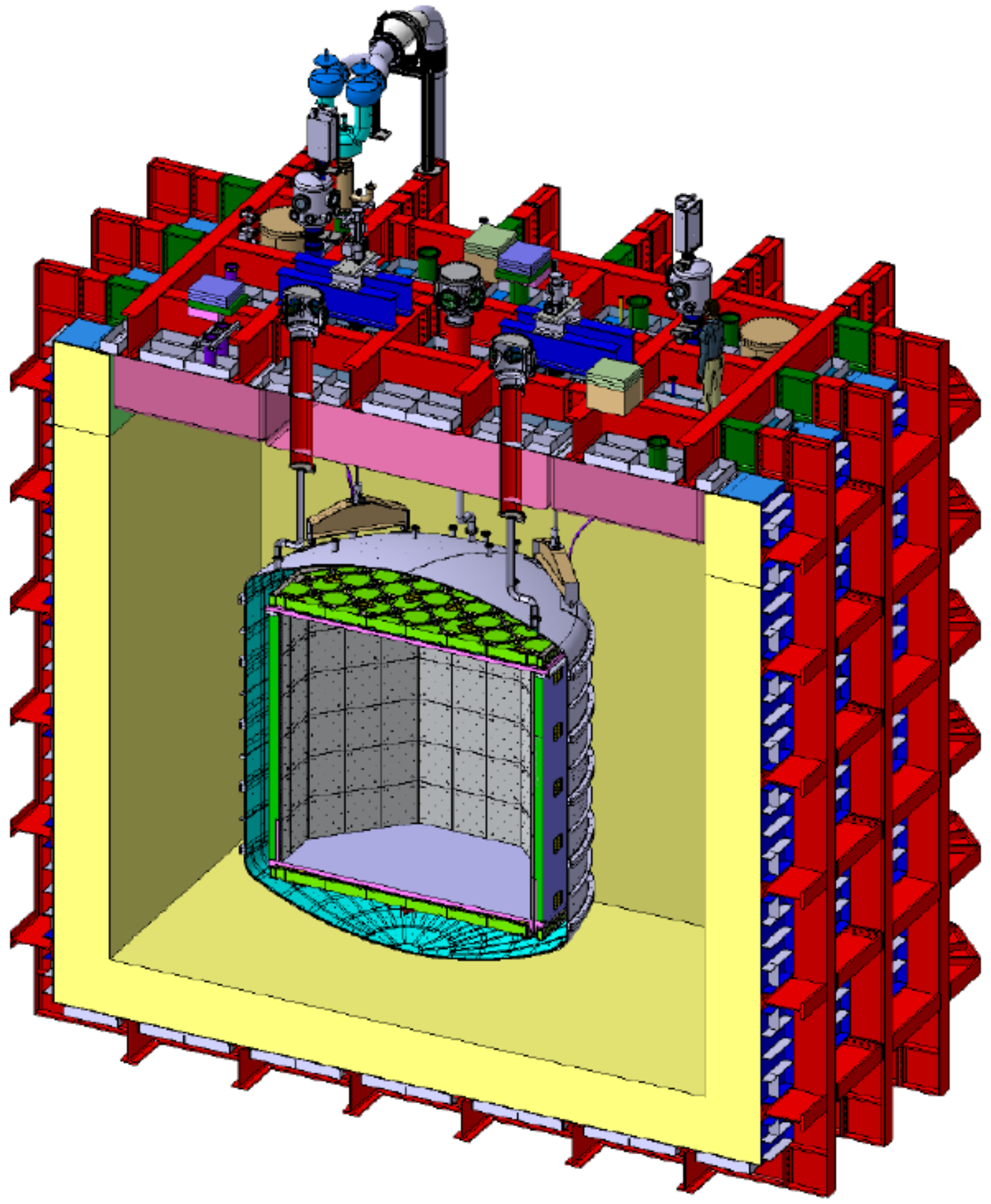
MiniCLEAN @Snolab

- Combined expertise from 4 LAr experiments
- Over 400 collaborators from 100 different institutes



DarkSide-50 @LNGS

DEAP @Snolab



ArDM @Canfranc

DarkSide programme

Back up

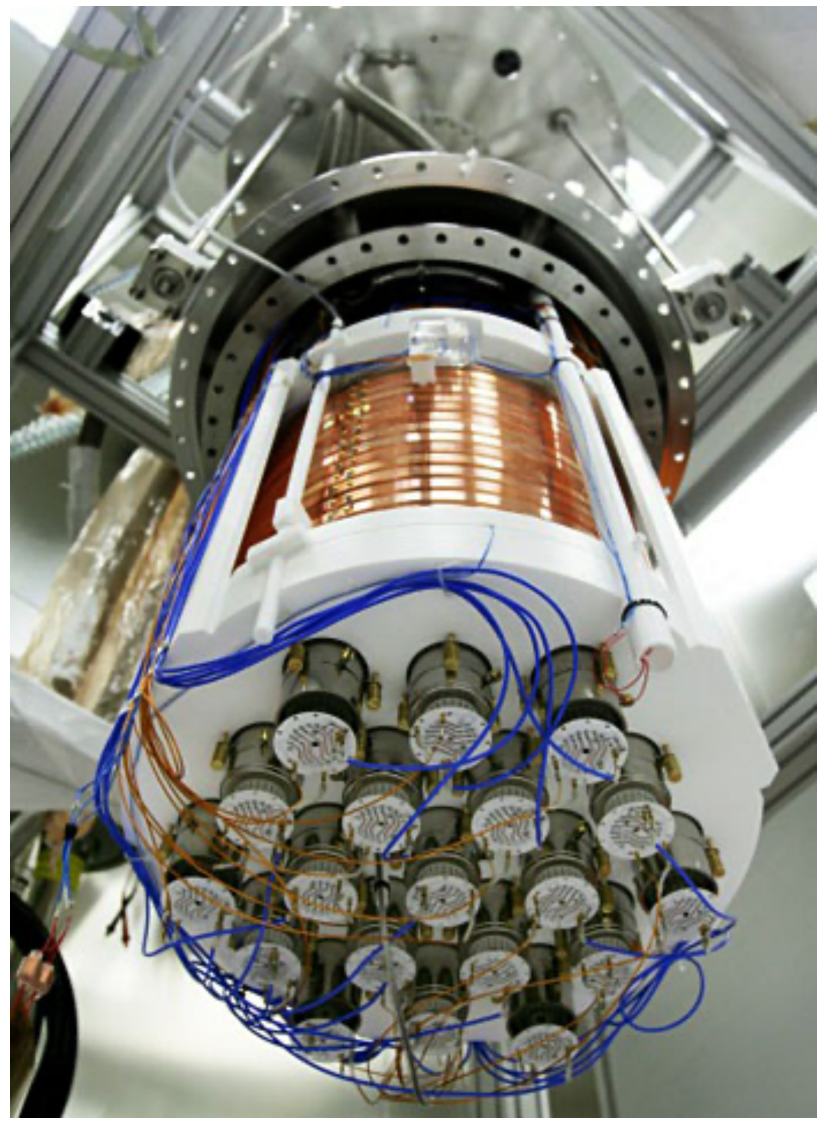
2011-2012

DarkSide-10

- Prototype with ~10kg of atmospheric argon
- No dark matter search goal

2013-2021

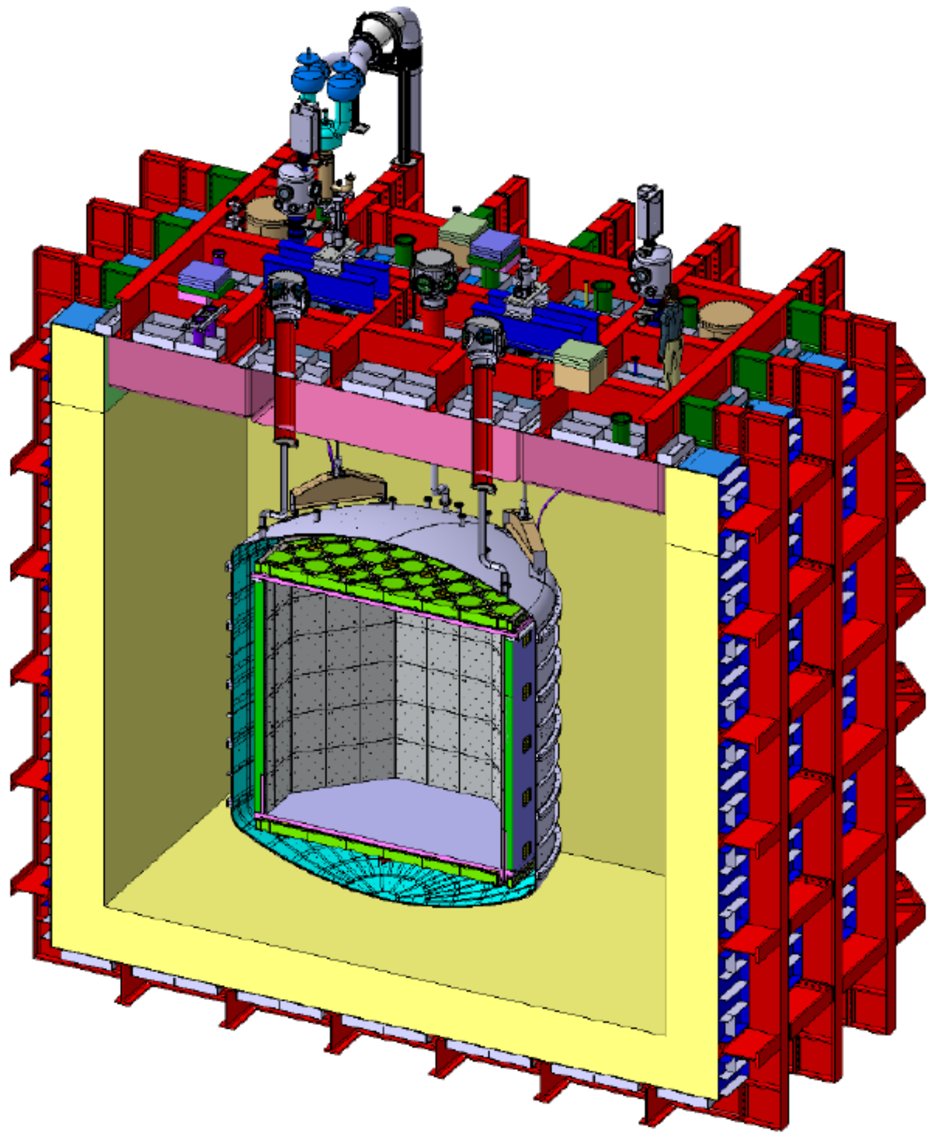
DarkSide-50



- ~50kg UAr for the 2nd run
- (12 306 ± 184)kg.day exposure
- Best limit at low WIMP mass in [1.2, 3.6]GeV
- Best limits for other LDM candidates

2027-2037

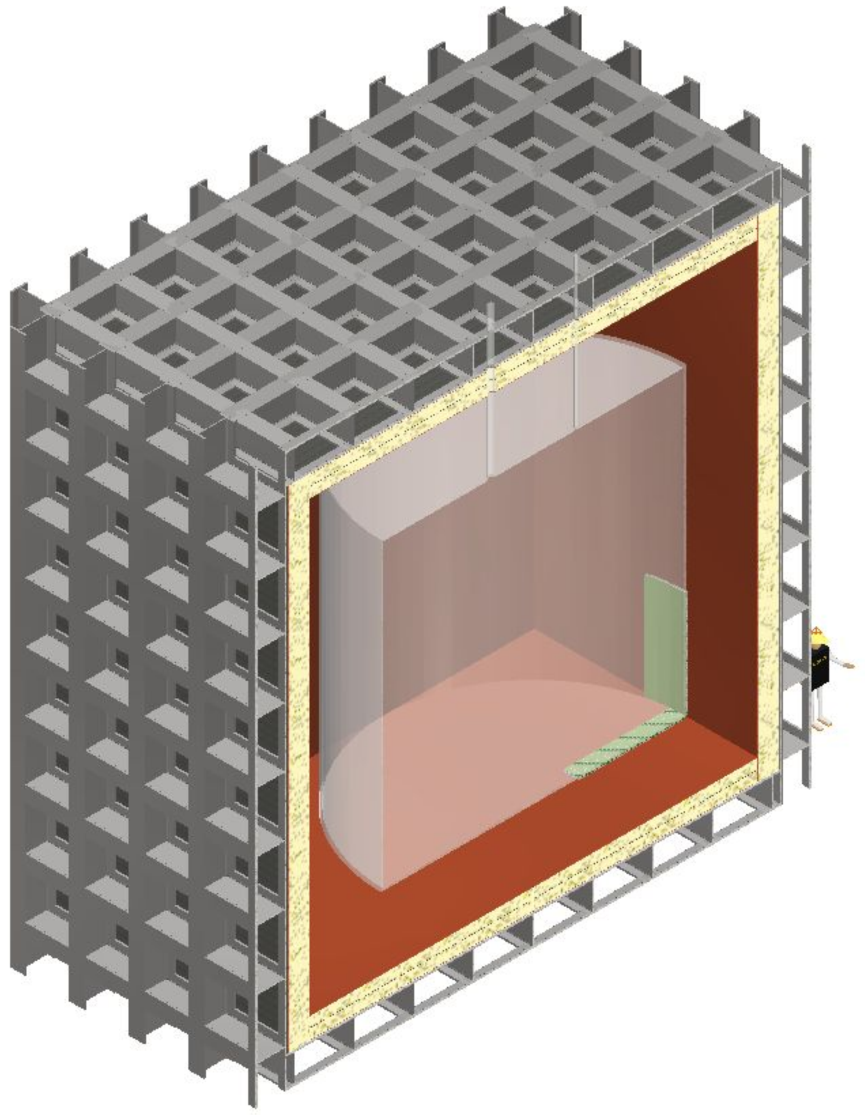
DarkSide-20k



- ~50t UAr in the TPC
- 32t UAr in the neutron veto / 650t Aar in the muon veto
- Novel photosensor technology
- Nominal exposure = 200 t.yr

> 2030s

ARGO

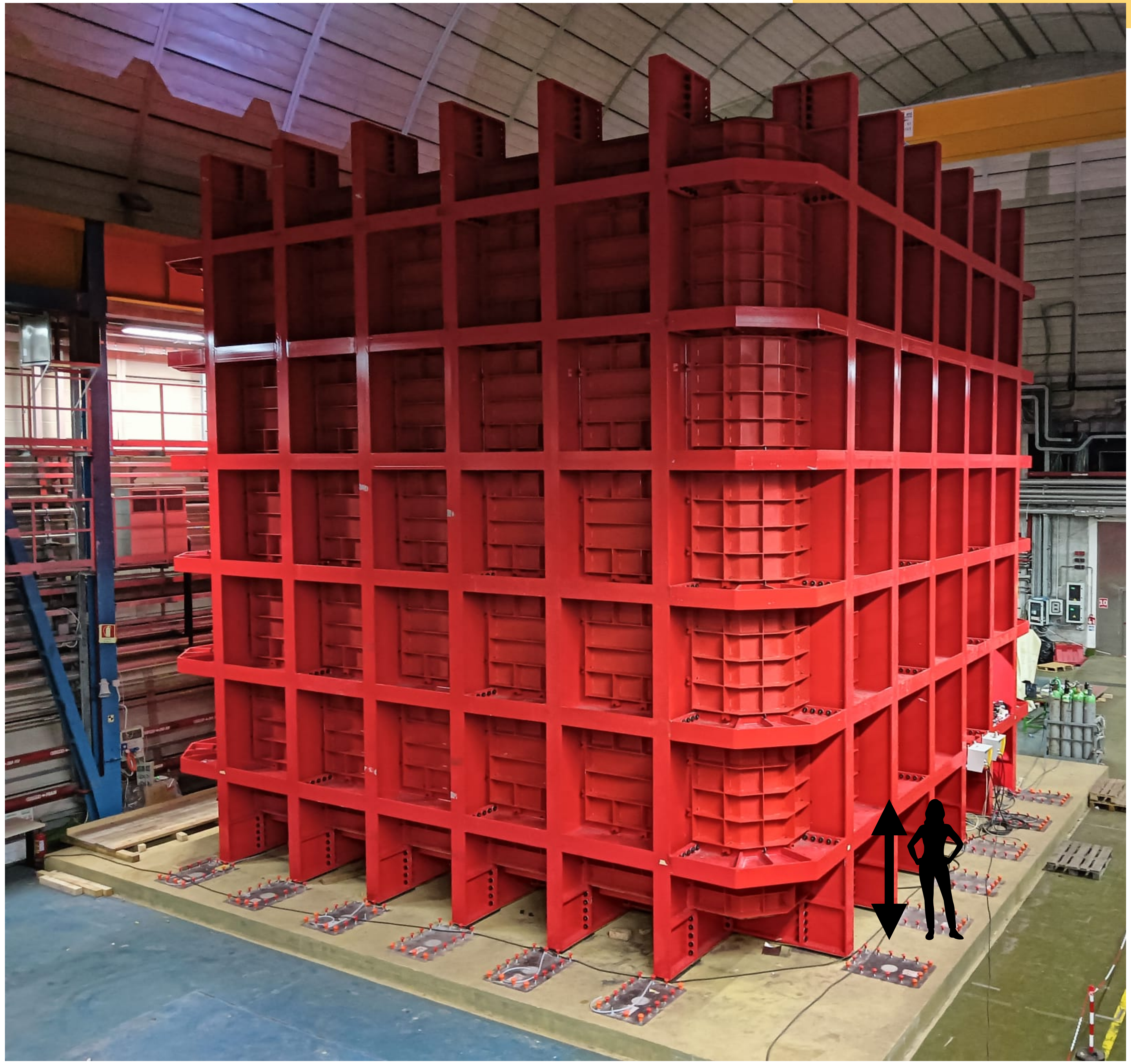


- Ultimate Ar detector
- Nominal exposure = 3000 t.yr
- Will be designed to reach the neutrino fog at high mass

The DarkSide-20k experiment

📍 LNGS (Hall-C)

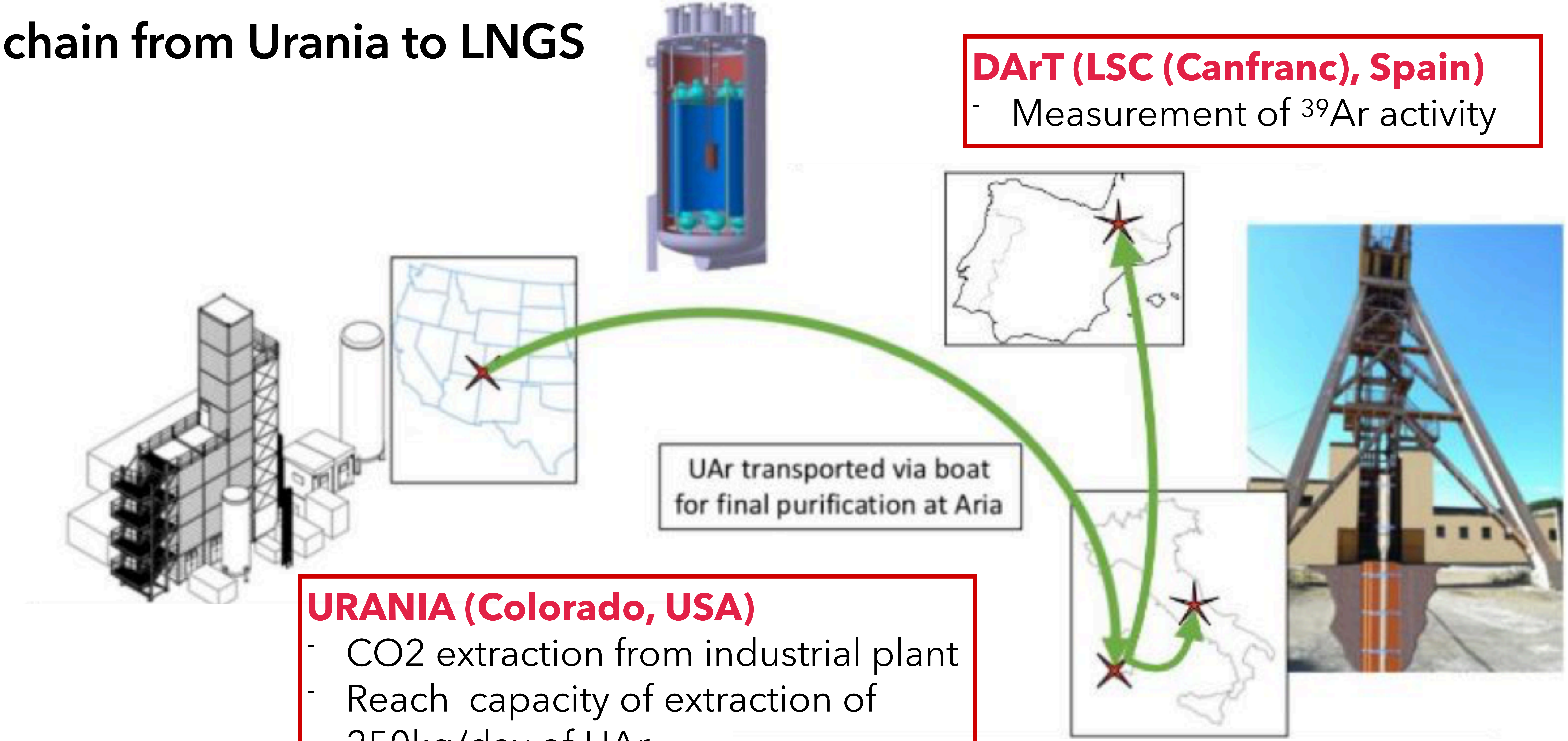
→ Currently under construction



DarkSide-20k and ^{39}Ar

- Most abundant source of argon: atmosphere
- Ar isotopes: ^{40}Ar (stable) and ^{39}Ar (β^- emitter)
- Atmospheric ^{40}Ar is cosmogenically activated by cosmic rays: ~1Bq/kg in AAr
- ^{40}Ar present in underground wells (1400x depleted in ^{39}Ar) of CO_2 in Colorado, USA –> **used for DS50 and DS20k**

UAr chain from Urania to LNGS



DArT (LSC (Canfranc), Spain)

- Measurement of ^{39}Ar activity

URANIA (Colorado, USA)

- CO2 extraction from industrial plant
- Reach capacity of extraction of 250kg/day of UAr
- 99.99% pure at exit

ARIA (Sardinia, Italy)

- ~350m high cryogenic distillation column
- 1 t/day chemical separation rate
- Nitrogen and Argon runs with prototype: ✅

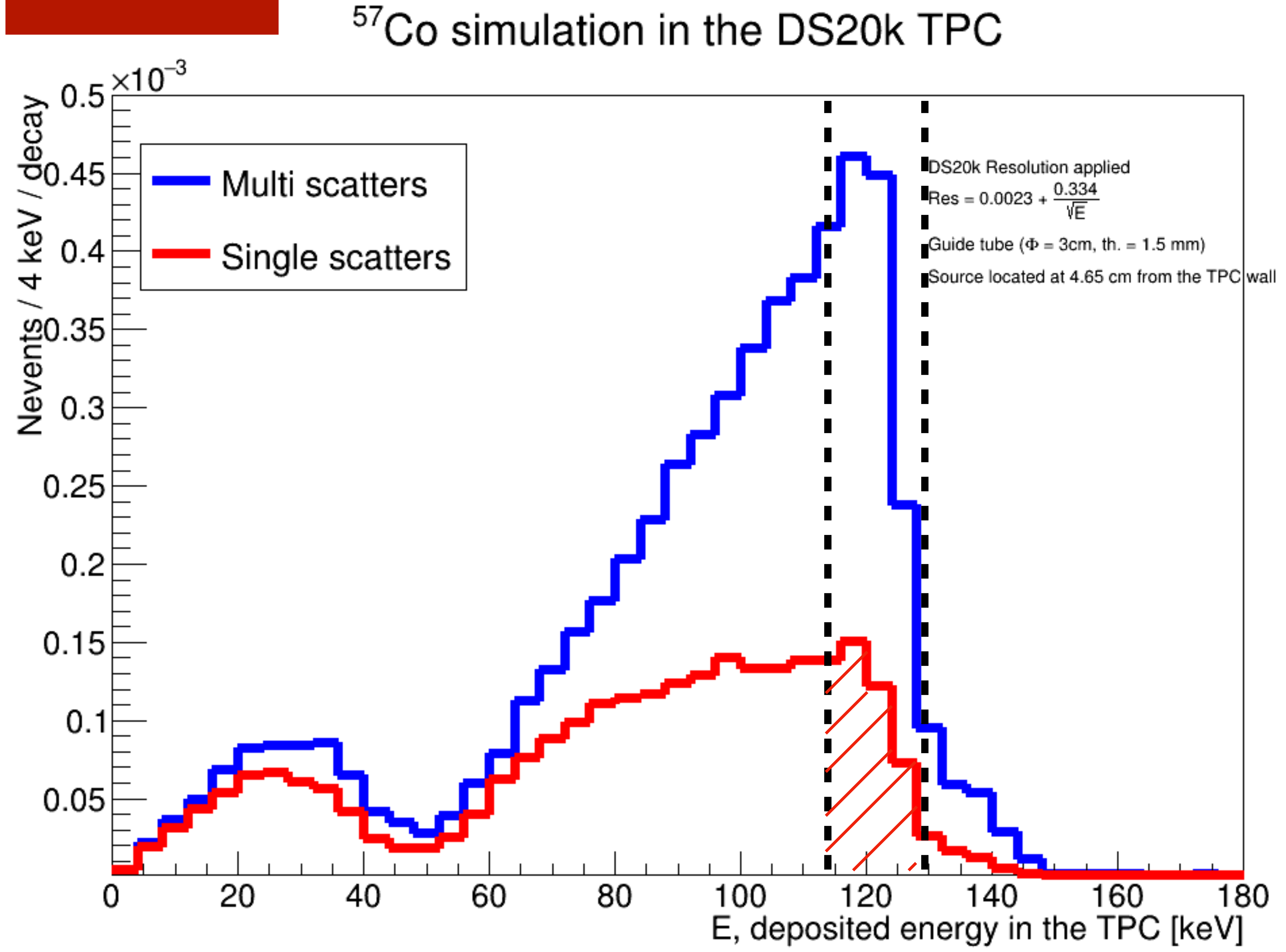
Back to
back-up wrap

Simulation of the TPC calibration

Calibration strategy - Time estimation - Computation

- **Time computation:** Take into account the ratio of ”all events” over gold plated events

Co57



- **First: let’s compute the time needed to reach 10 000 calibration points:**
  - **If the activity of the source doesn’t saturate at 100 kBq:**

$$Time^{10^4pts}_{A<100kBq} = \frac{Nb-points}{DAQ-frequency} = \frac{10^4pts}{100hz} = 100\text{ s}$$

  - **If the activity of the source does saturate at 100 kBq, then the time has to be normalized by the rate of ”all” events that saturate the DAQ:**

$$Time^{10^4pts}_{A=100kBq} = \frac{Nb-points}{Rate-of-all-events} \cdot \frac{1}{Activity} = \frac{10^4pts}{8.8 \cdot 10^{-4}events/decay}\frac{1}{100 \cdot 10^3Bq}$$

=114 s

- **Second: Multiply this time to the ratio of the rate of all the events occurring in the TPC over the rate of GP events:** $Time^{1position} = Time^{10^4pts} \cdot \frac{Rate-of-all-events}{Rate-of-GP}$

ex of 57Co (side) : $Time^{1position} = 100s \cdot \frac{5.7 \cdot 10^{-3}}{6.2 \cdot 10^{-4}}$ = 919 s = 0.25h

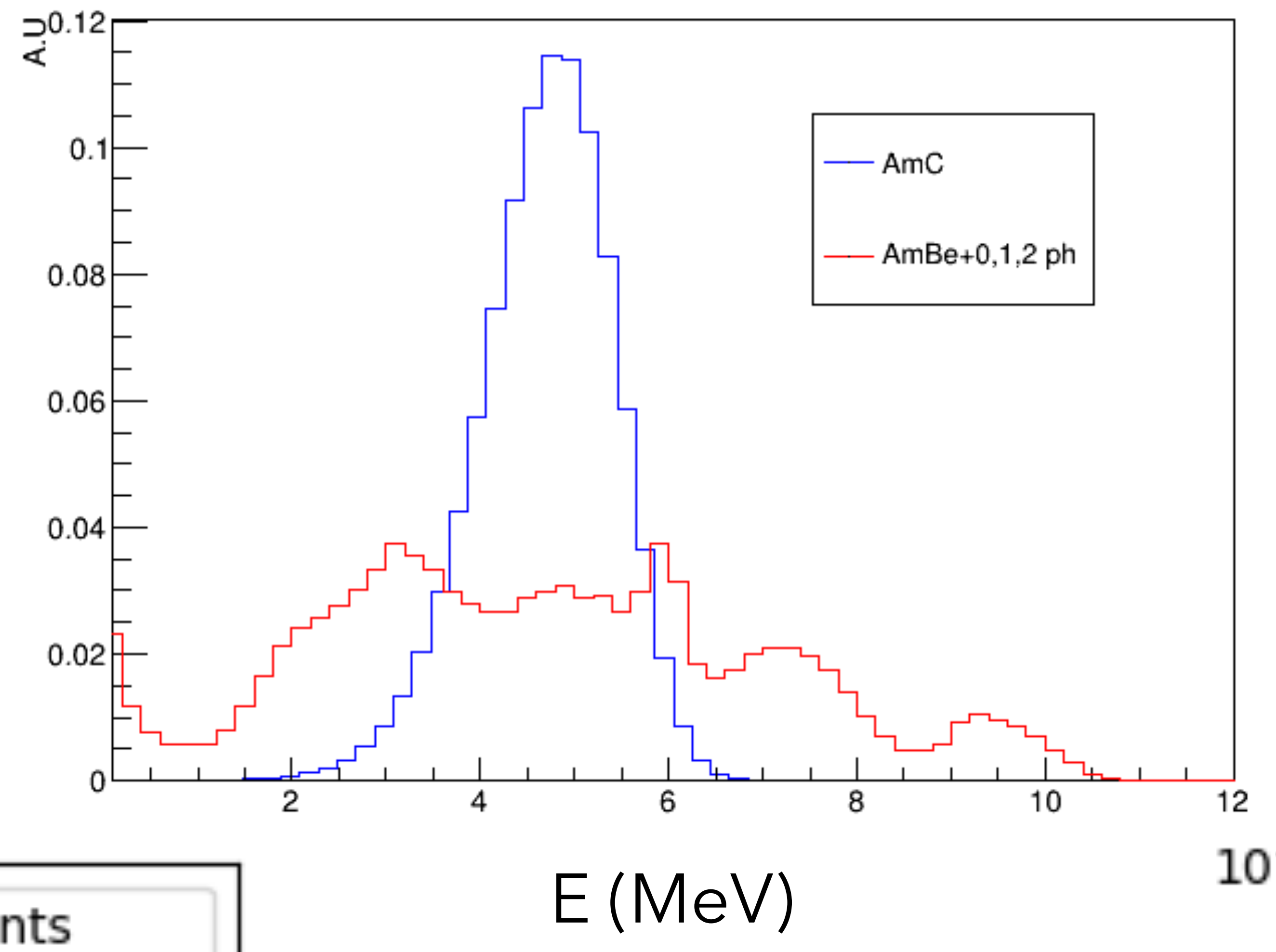
- **To finish : The time needed for one source is the sum of the handling time and the time needed on the side * 6 positions and the time needed at the bottom * 3 positions:** $Time^{source} = 6 * Time^{1position}_{side} + 3 * Time^{1position}_{bottom}$

ex of 57Co: $Time^{57Co} = 3.67 + 6 * 0.38 + 3 * 0.52 = 7.5h = 0.3day$

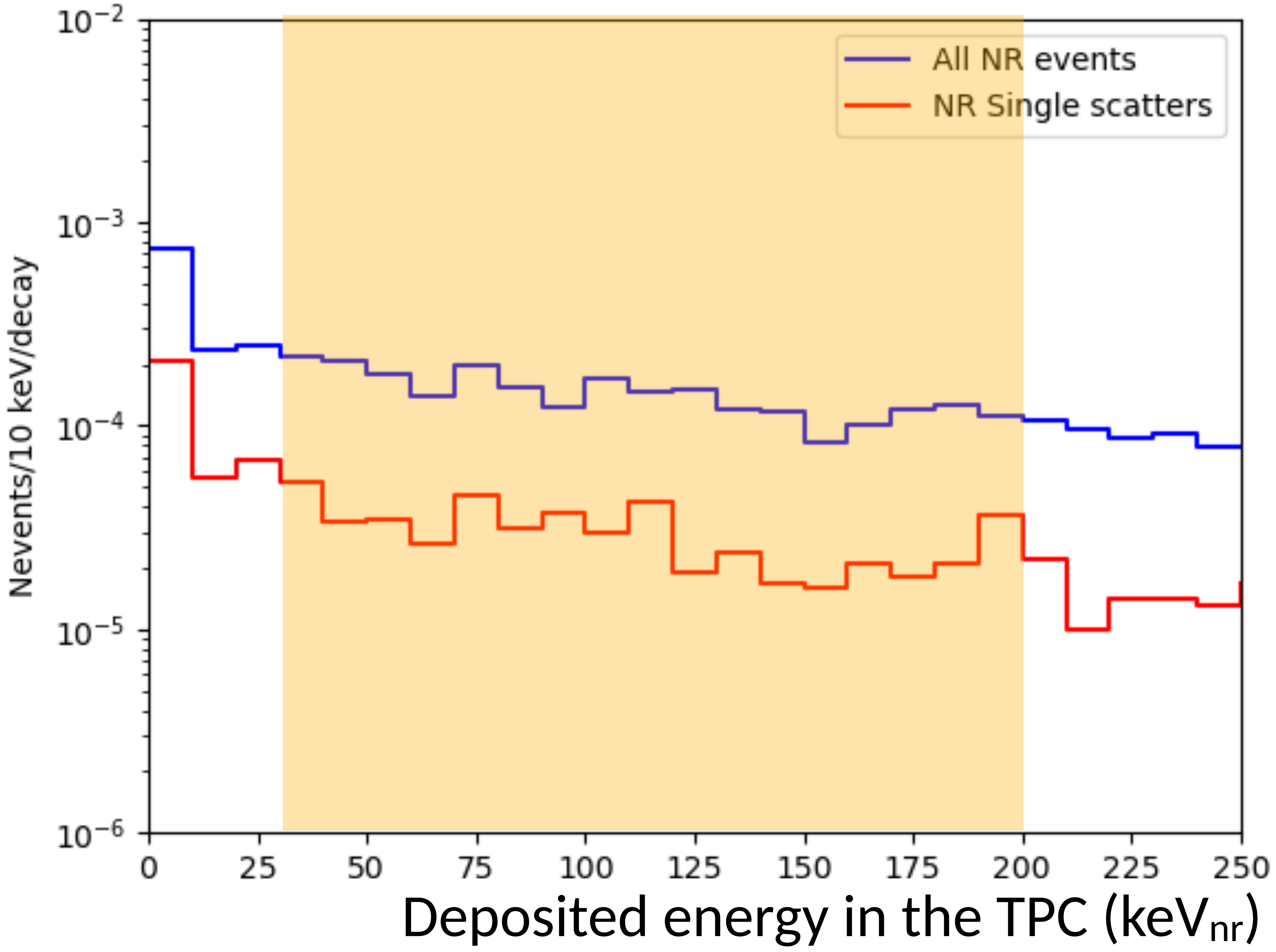
Back up

Simulation of the calibration - all NR sources spectra

Back up

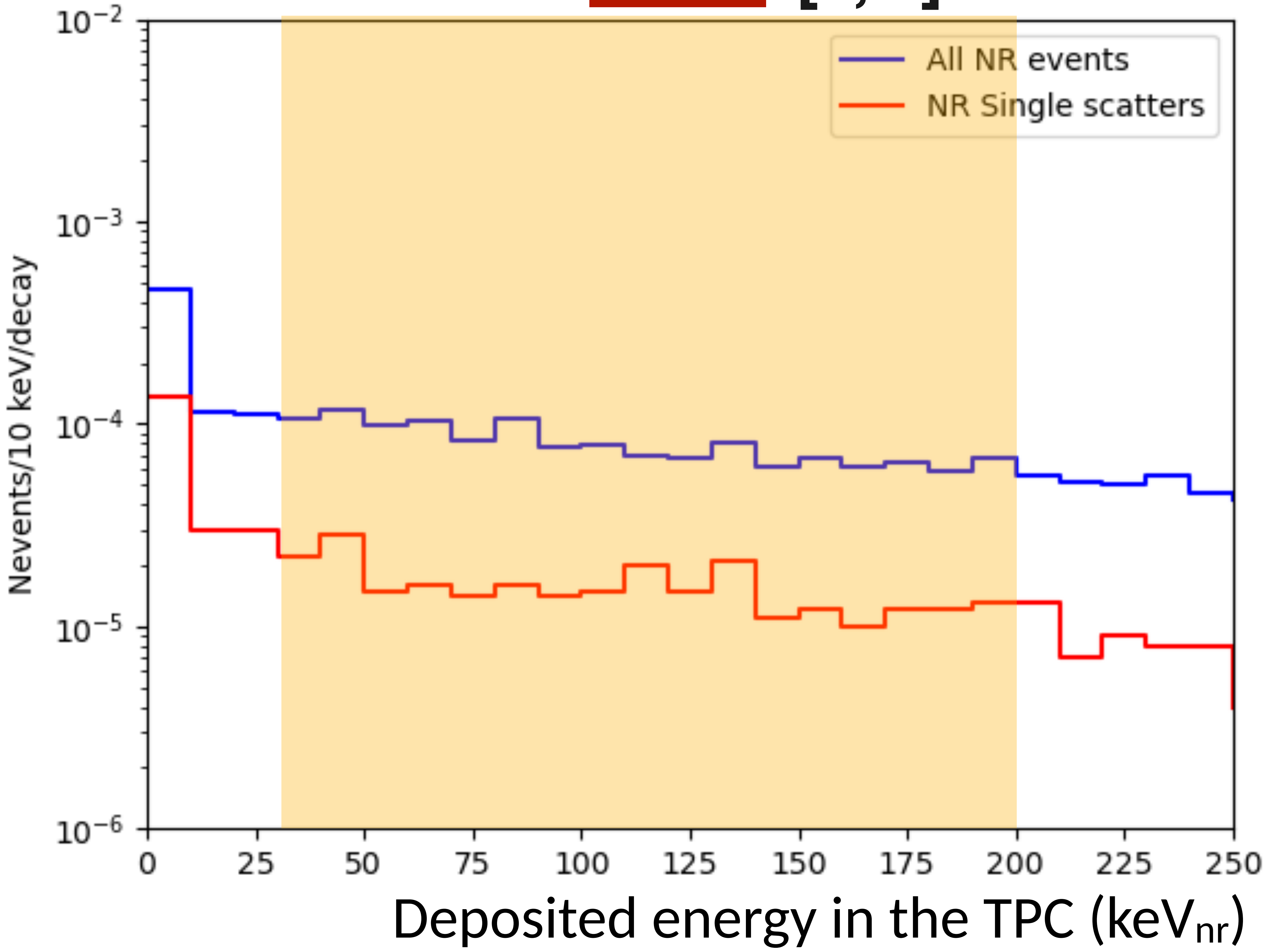


AmBe [0.2, 12] MeV



RoI

AmC [2, 7] MeV



RoI

Neutron sources - time estimation

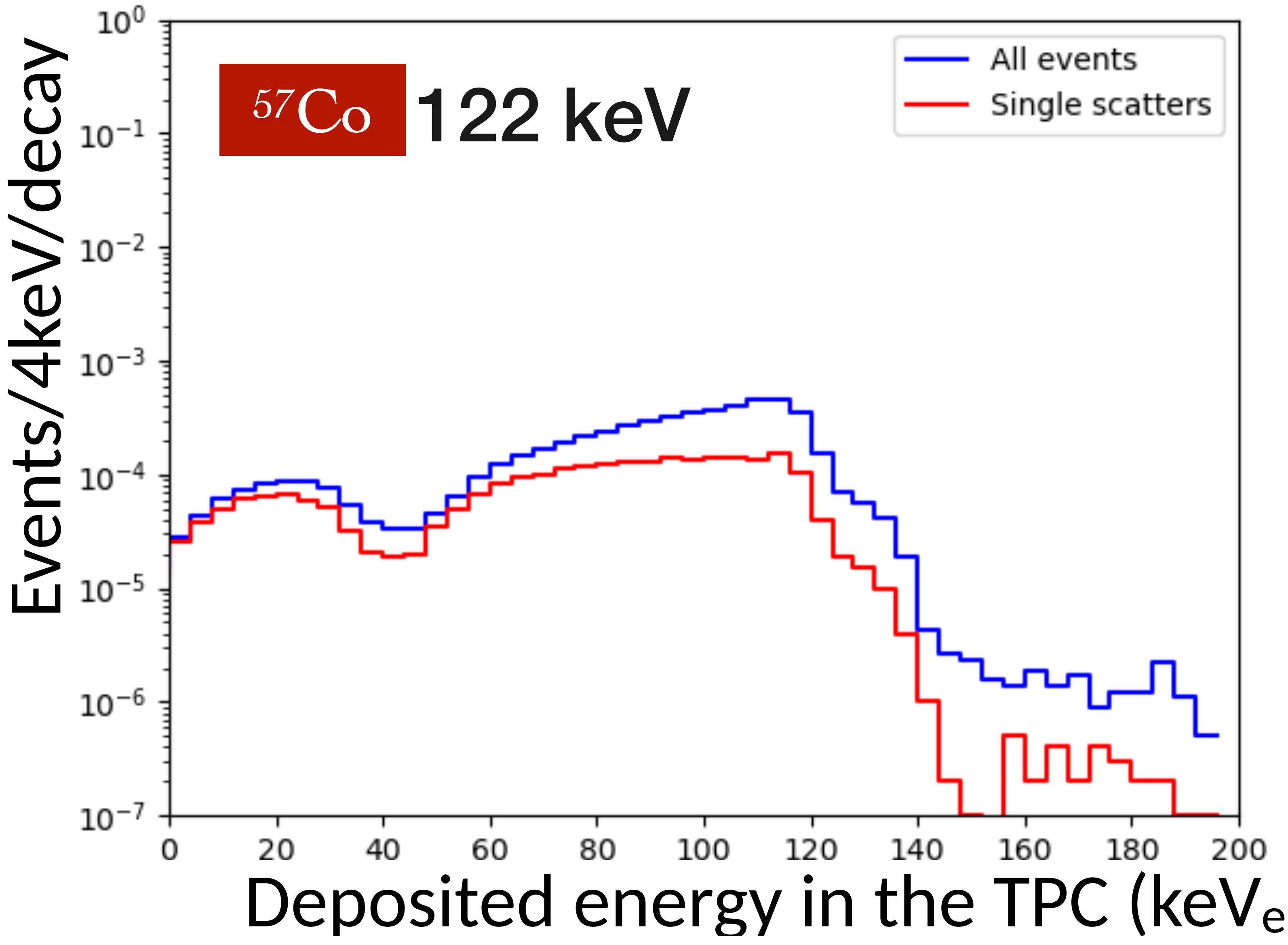
NR calibration - 10 000 Pure NR single scatters - Side (1e6 simulated events)

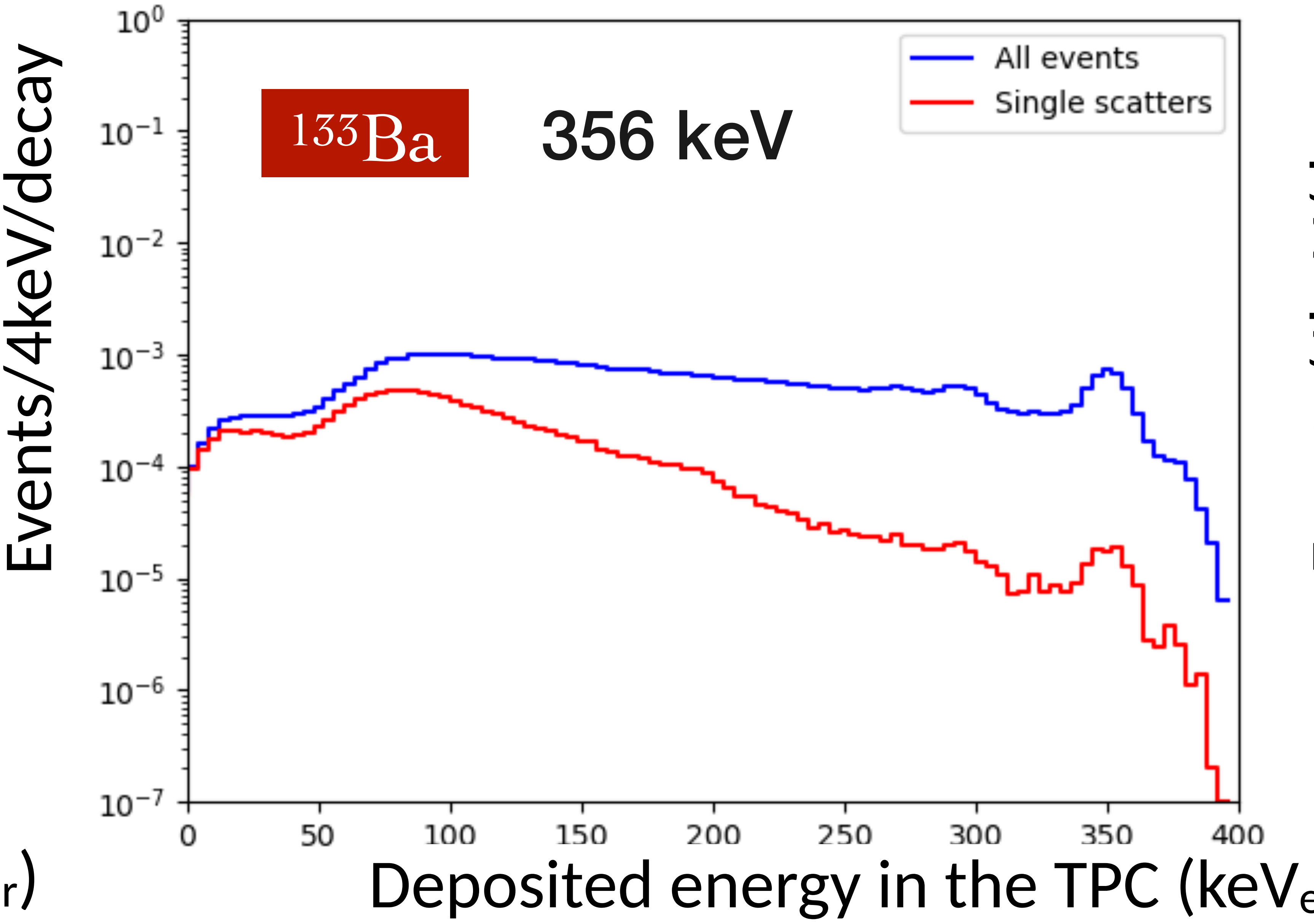
18 days

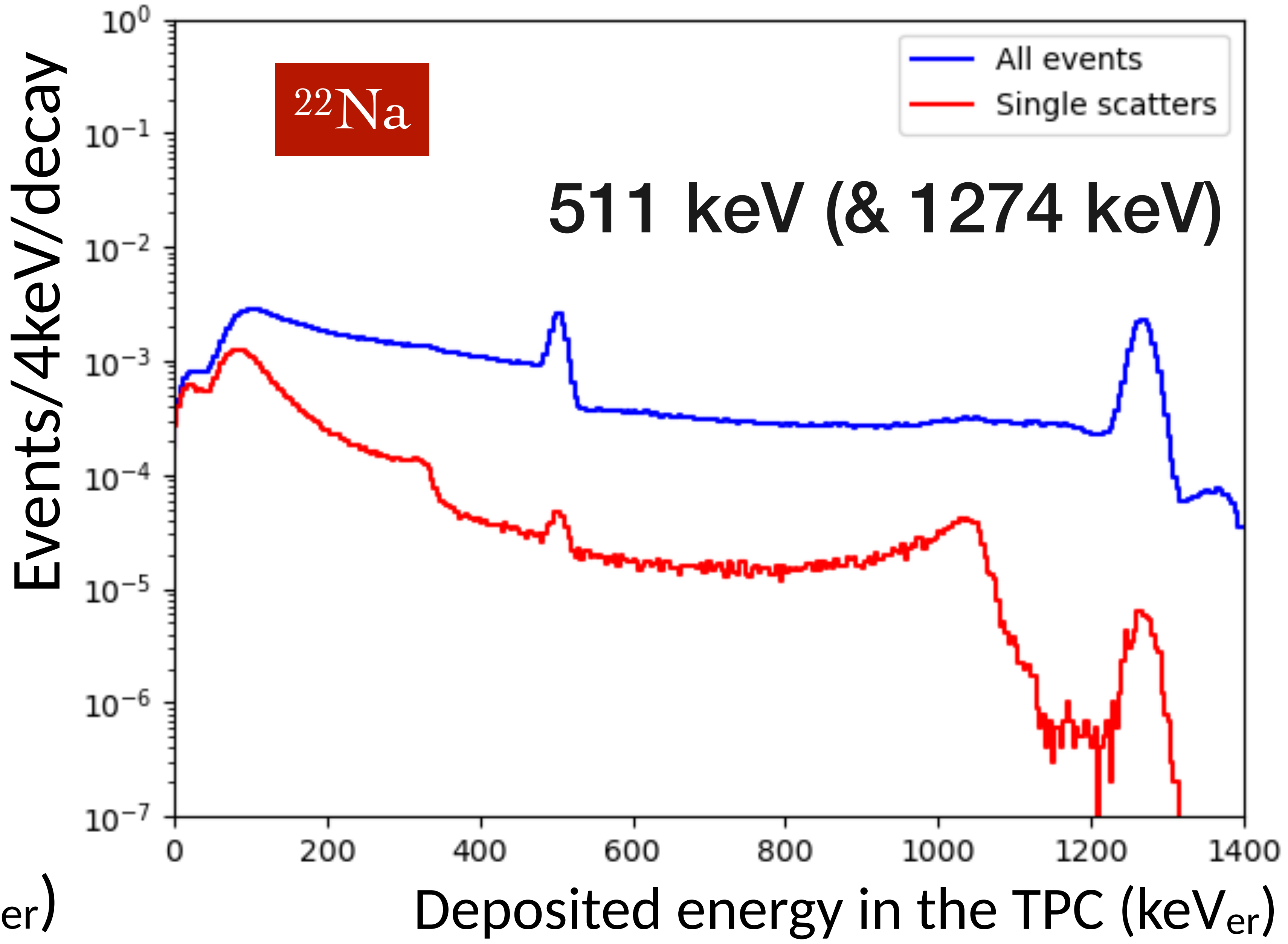
	AmBe	AmC
Time per position (side) (h)	19	28
Time per position (bottom) (h)	23	25
Total time (day)	8	10

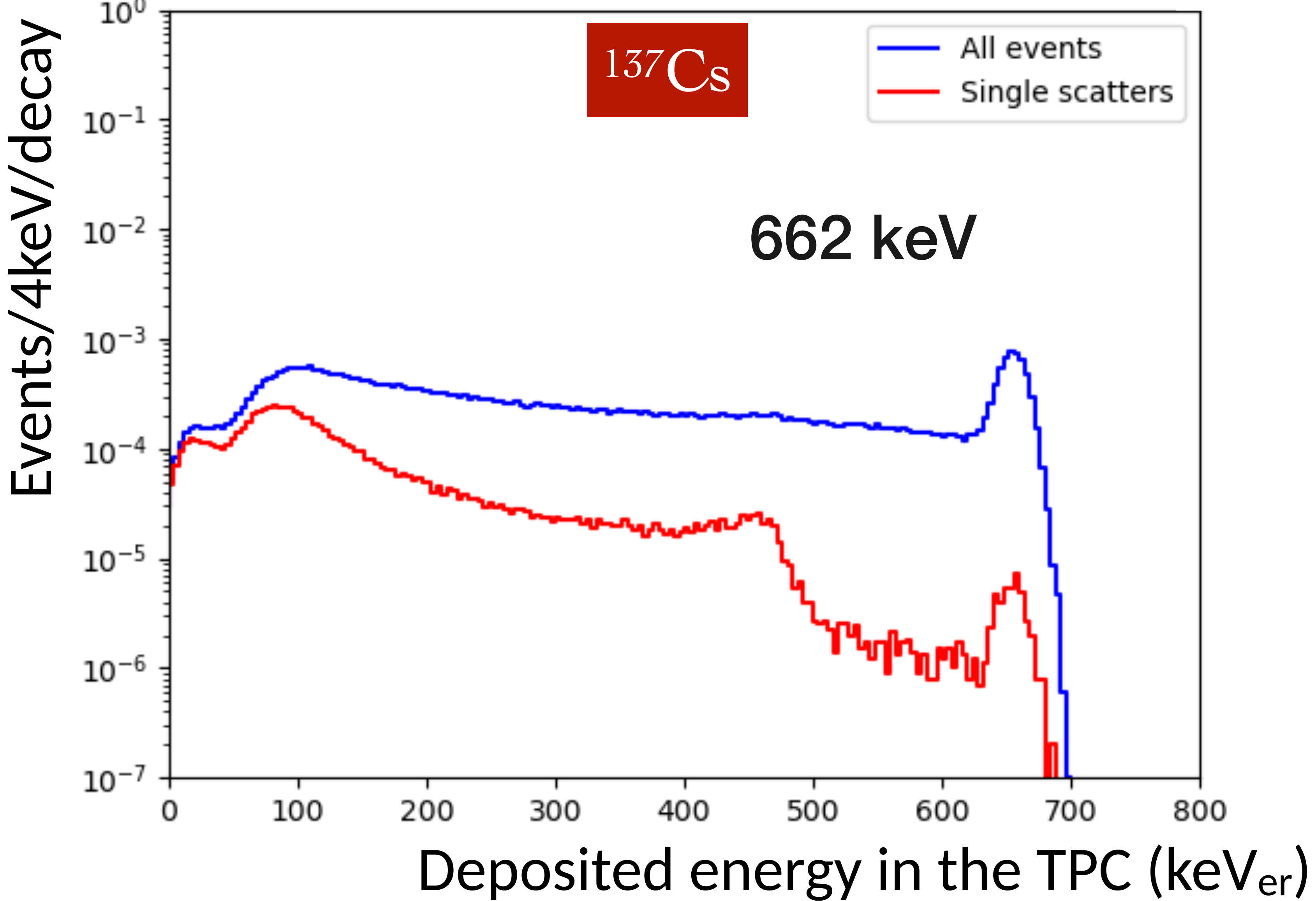
Back up

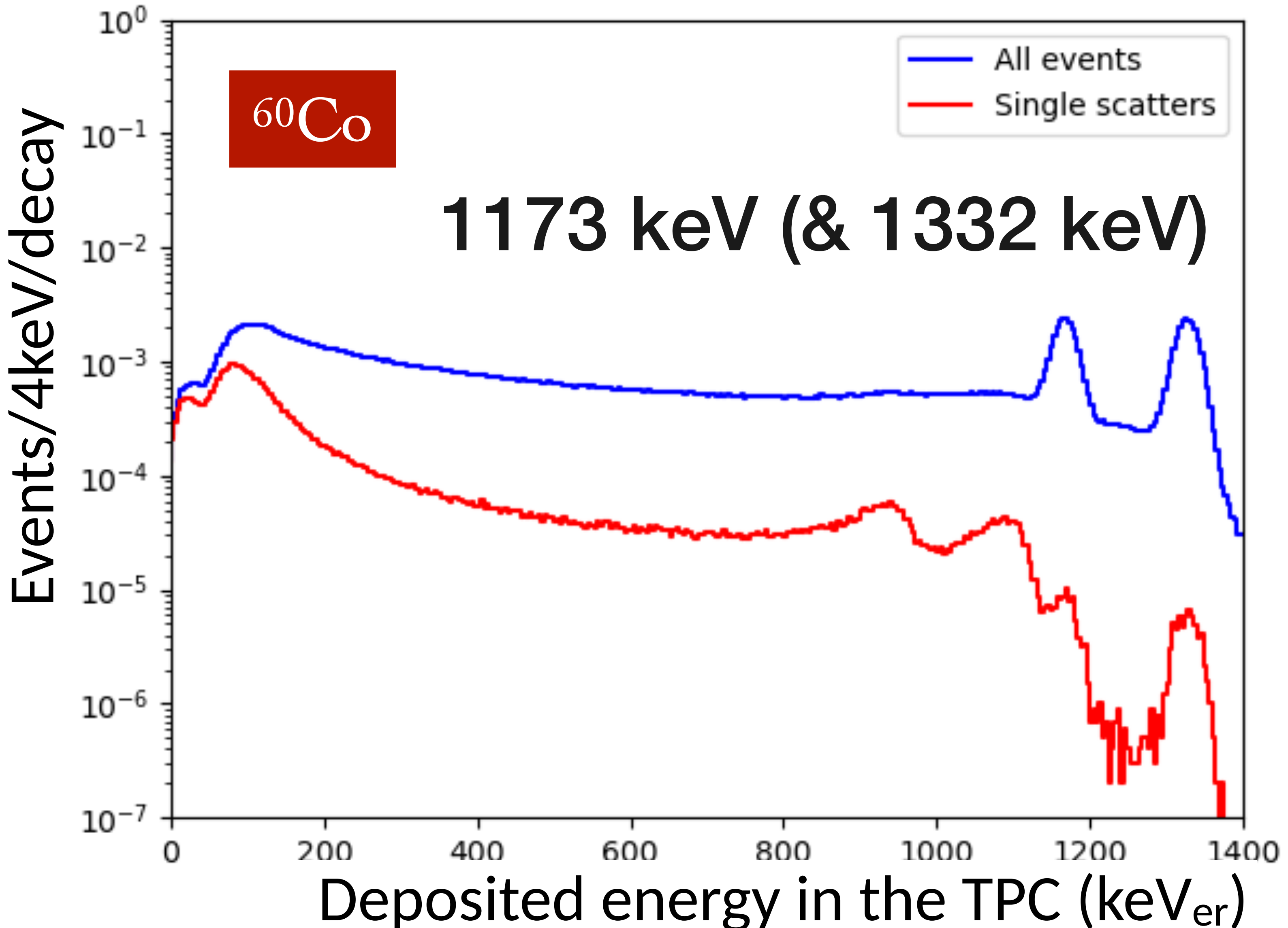
Simulation of the calibration - all ER sources spectra











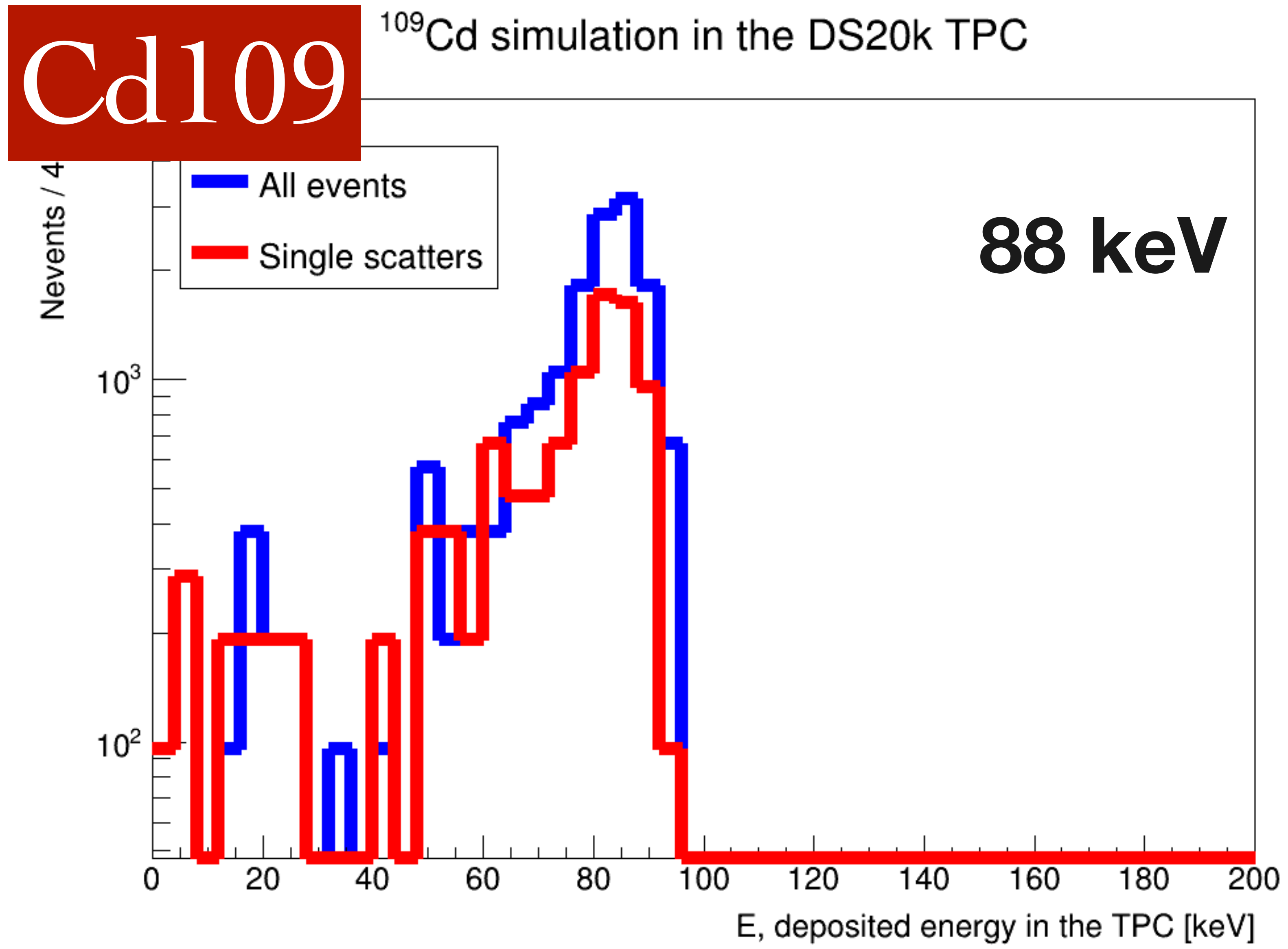
Back up

Spectra normalized to 10 000 pure ER SS events

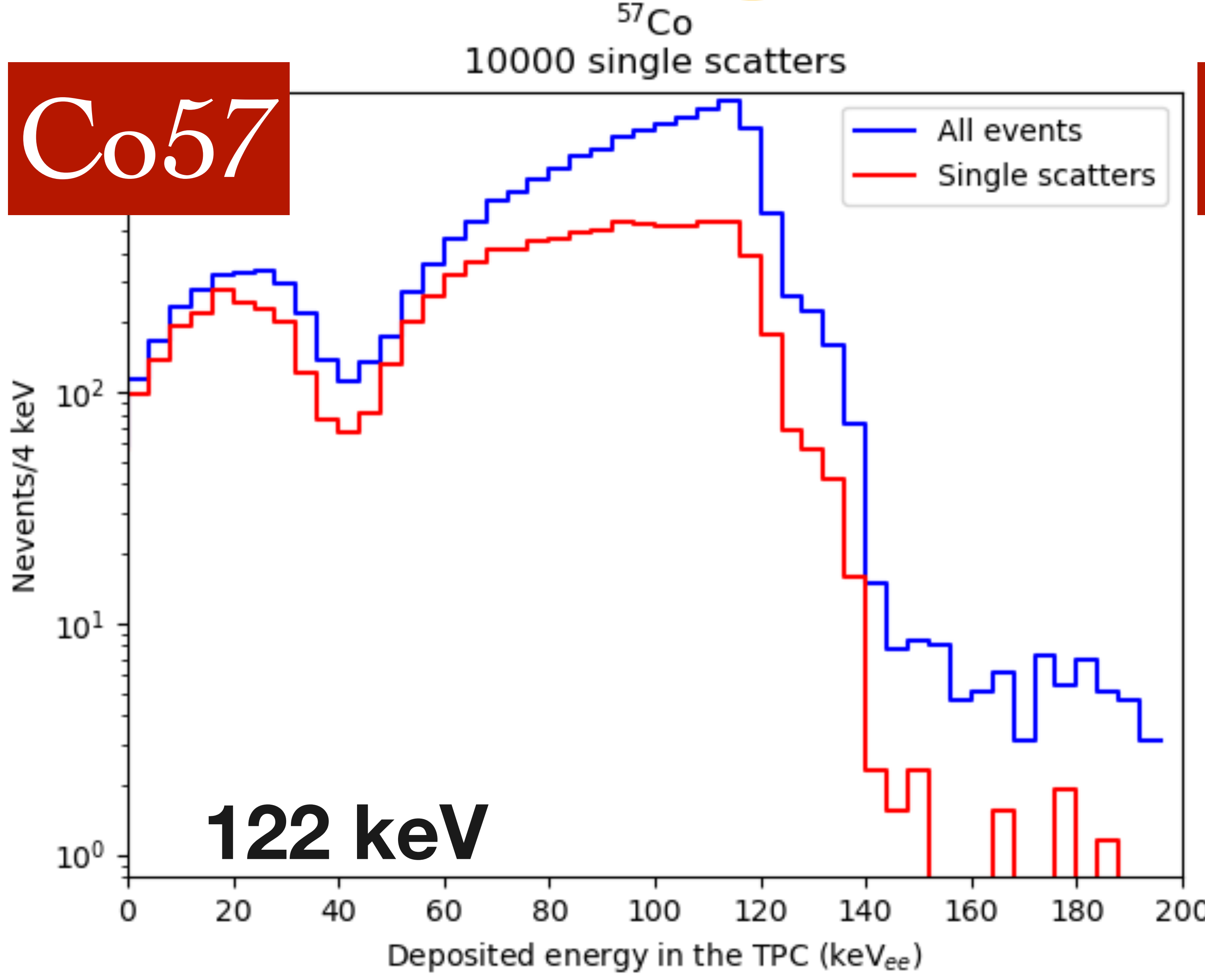
Back up

DS20k resolution = 0.0023 + 0.334/sqrt(E)

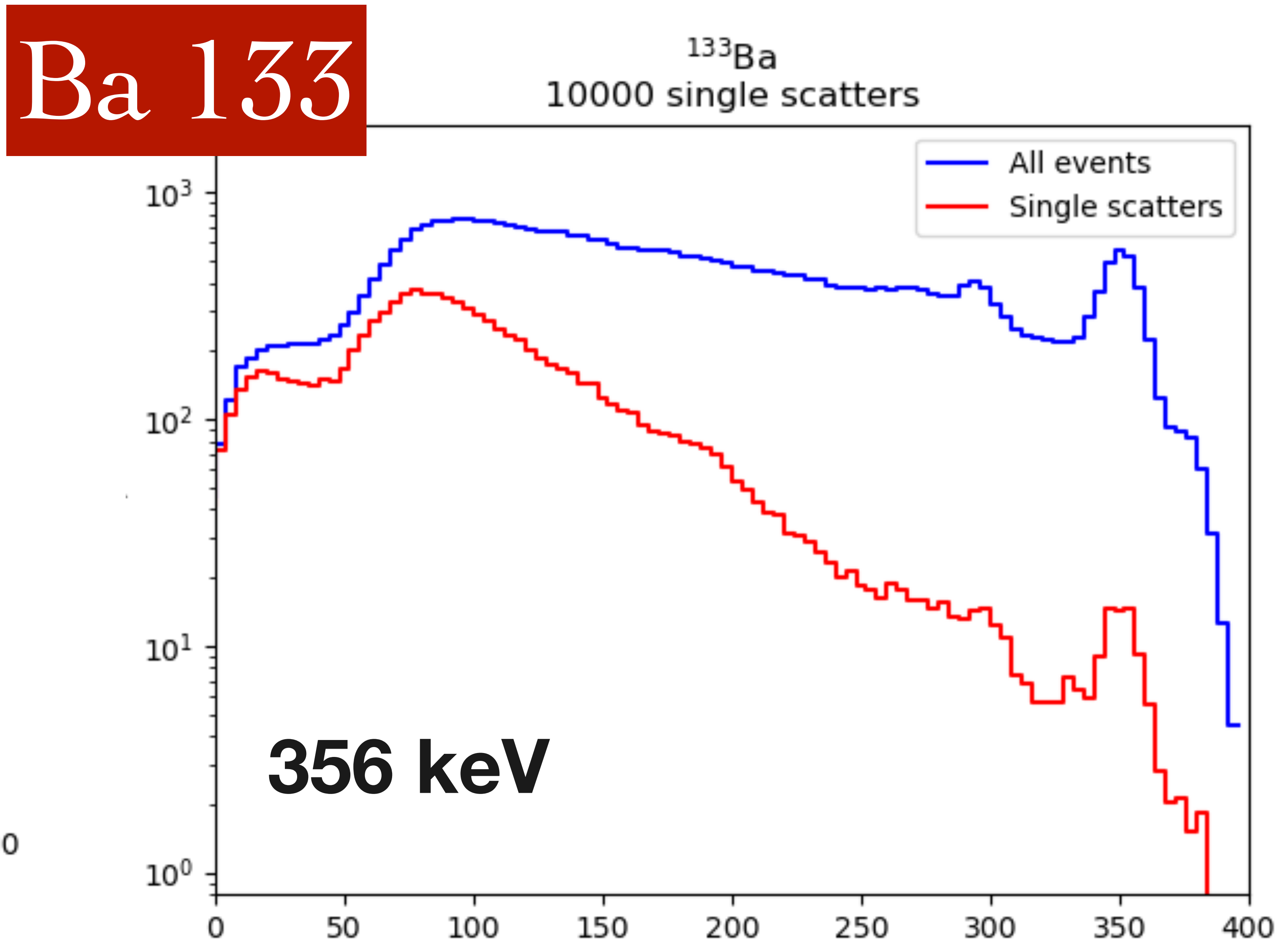
Photon sources - Side


Cd109

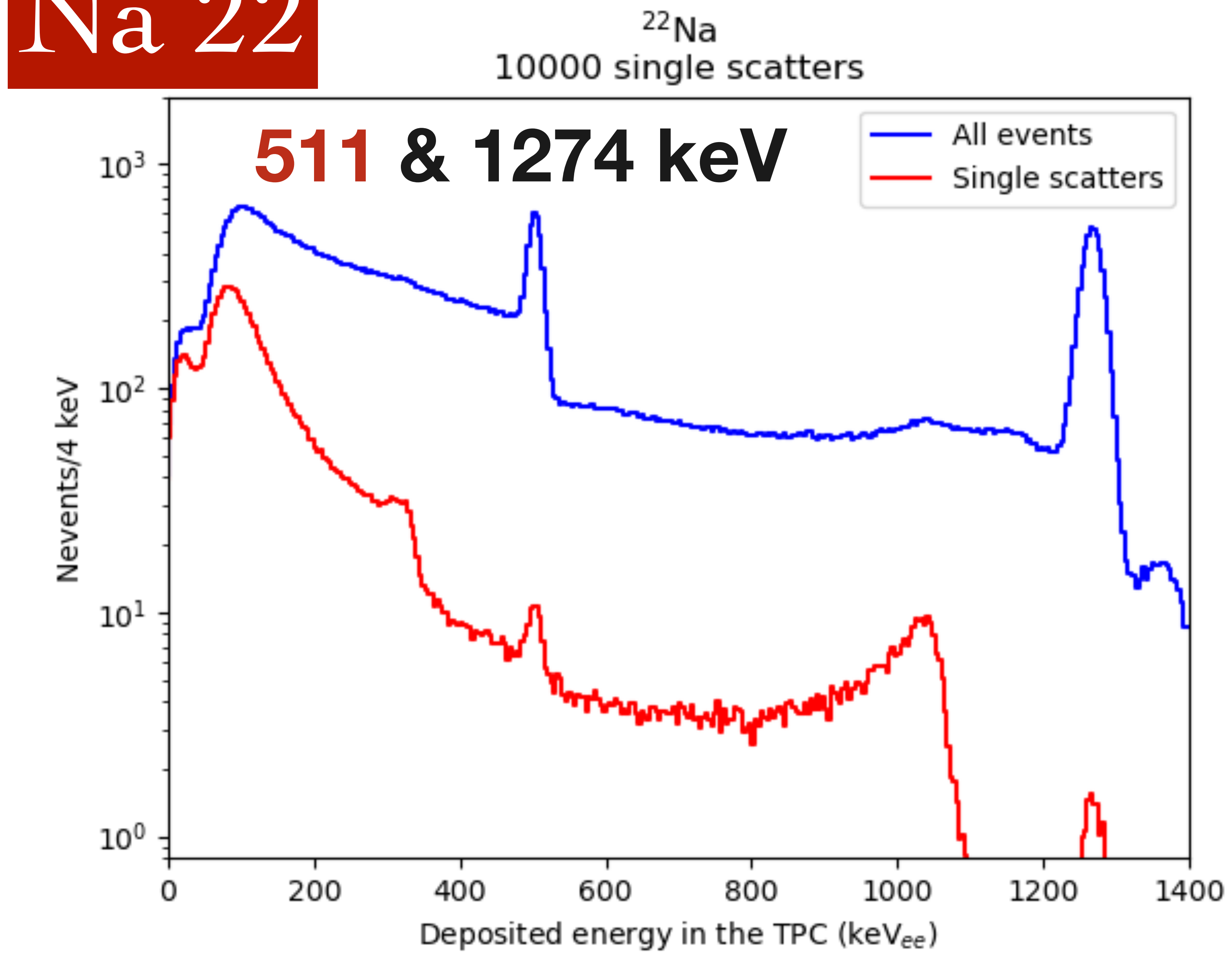
88 keV


Co57

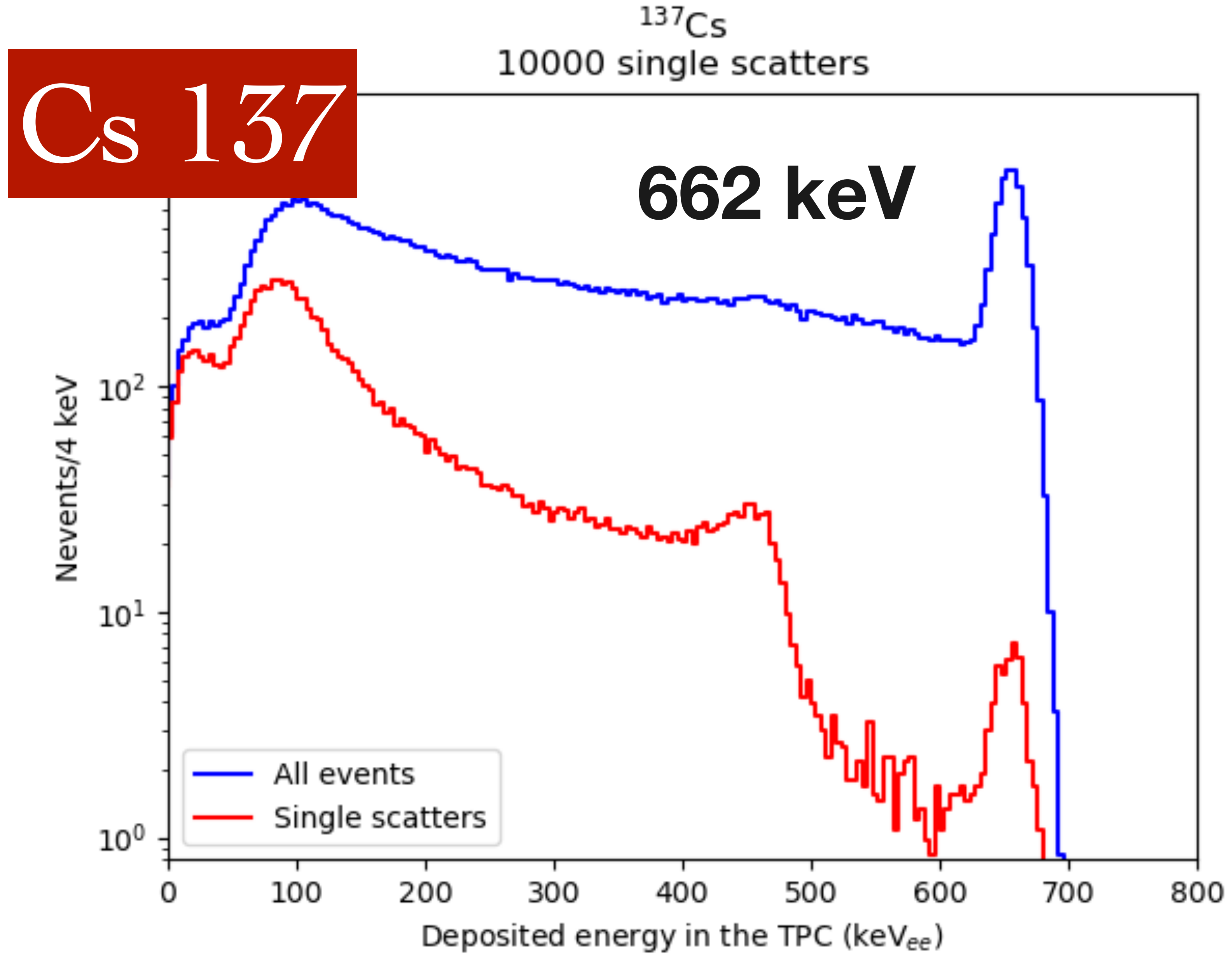
122 keV


Ba 133

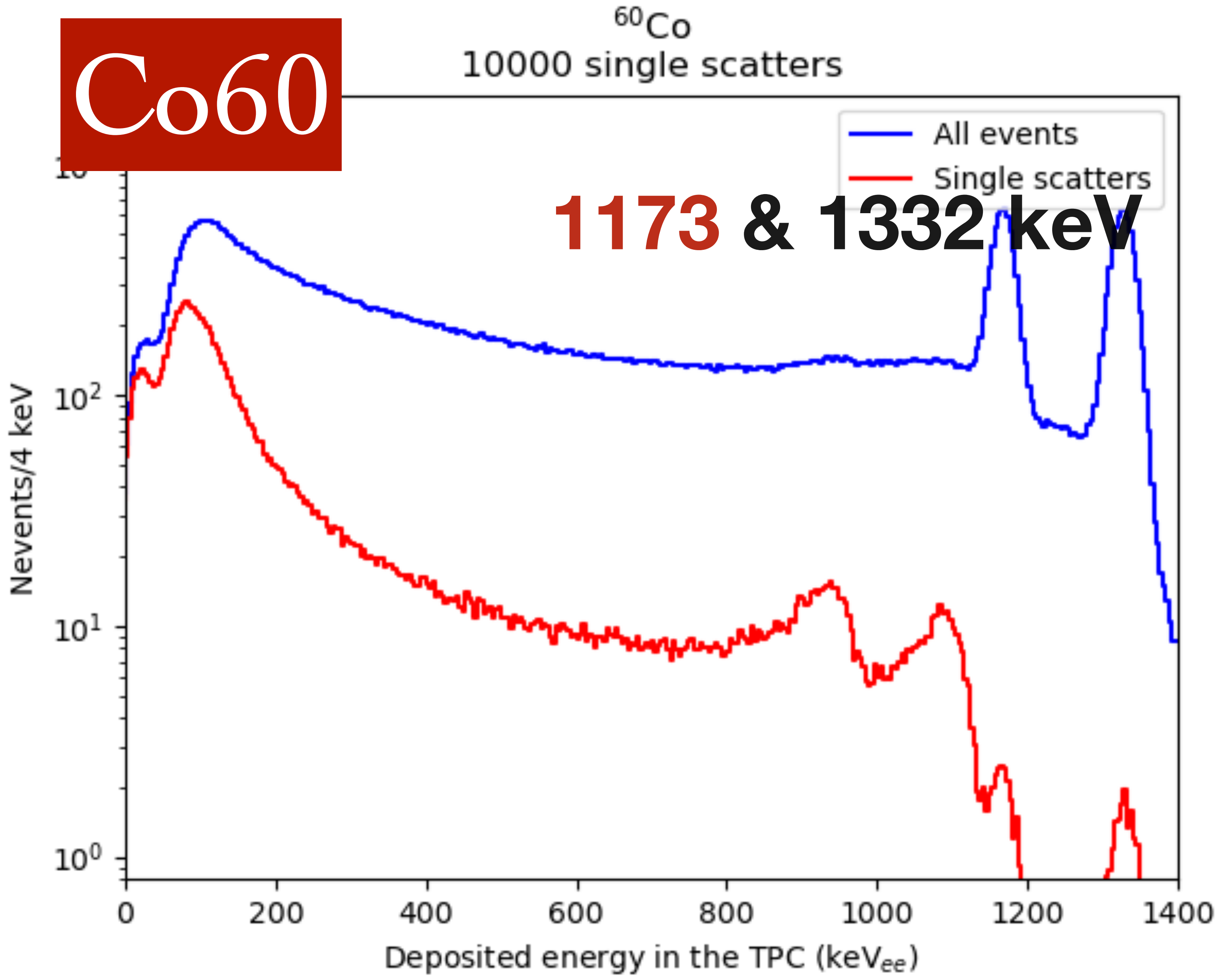
356 keV


Na 22

511 & 1274 keV


Cs 137

662 keV


Co60

1173 & 1332 keV

Calibration strategy - Time estimation ER

1000 single scatters in the peak

6.3 days

	57Co	133Ba	22Na	137Cs	60Co
Time per position (side) (h)	2.5E-2	1.4	2.1	3.1	7.3
Time per position (bottom) (h)	3.4E-2	2.2	2.5	4.7	9.1
Total time (day)	1.6E-1	7.8E-1	9.8E-1	1.5	3.1

10 000 single scatters

1 day

	57Co	133Ba	22Na	137Cs	60Co
Time per position (side) (min)	3.7	6.6	10.8	9	12.6
Time per position (bottom) (min)	3.8	5.9	9	7.8	10.8
Total time (h)	4.2	4.6	5.2	5.0	5.4

Additional ideas: maybe interesting to

- Use the Compton edge to calibrate at high energy (instead of the photo-electric peak)
- Have S1-only events to have a faster calibration having a greater DAQ frequency

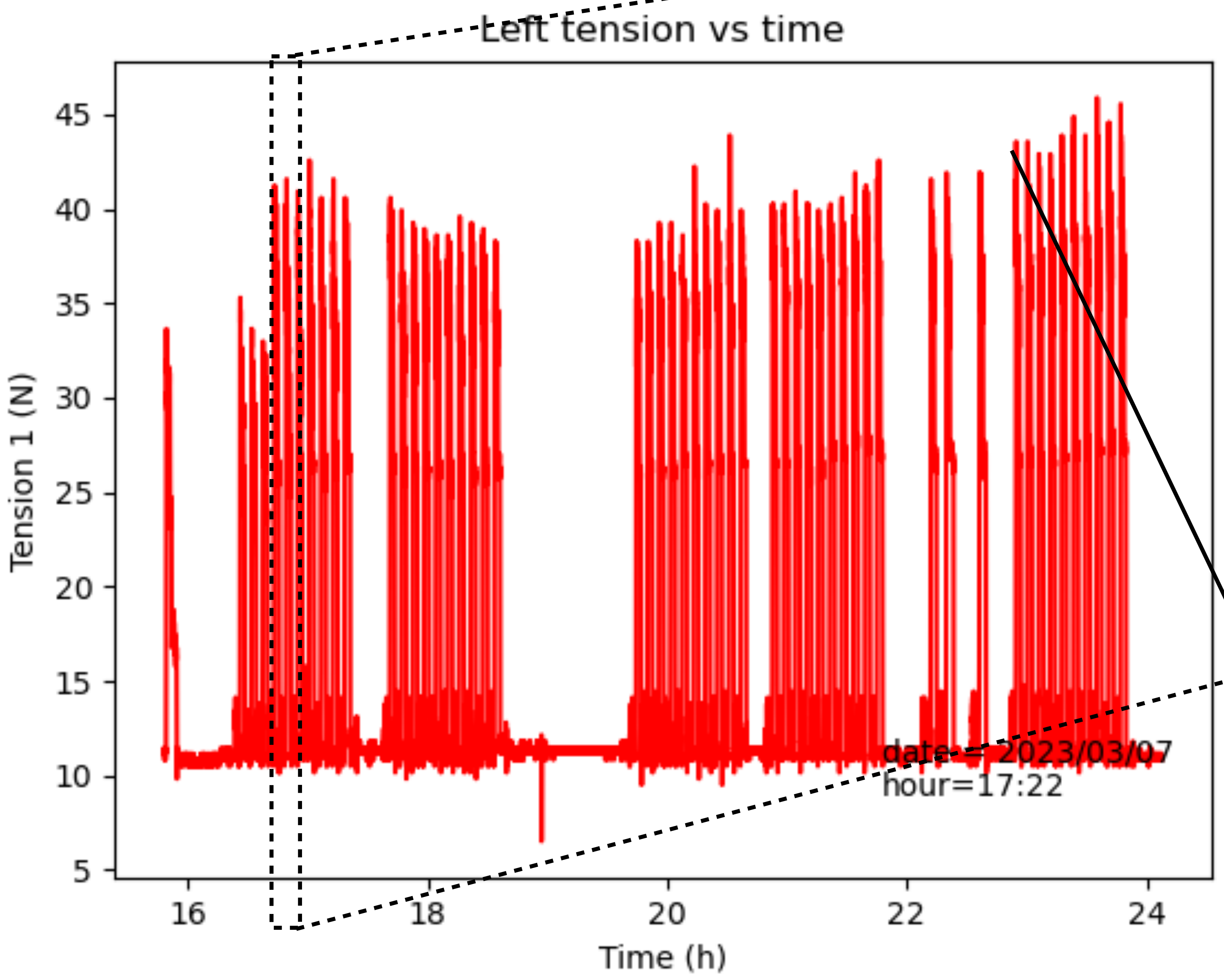
Back up

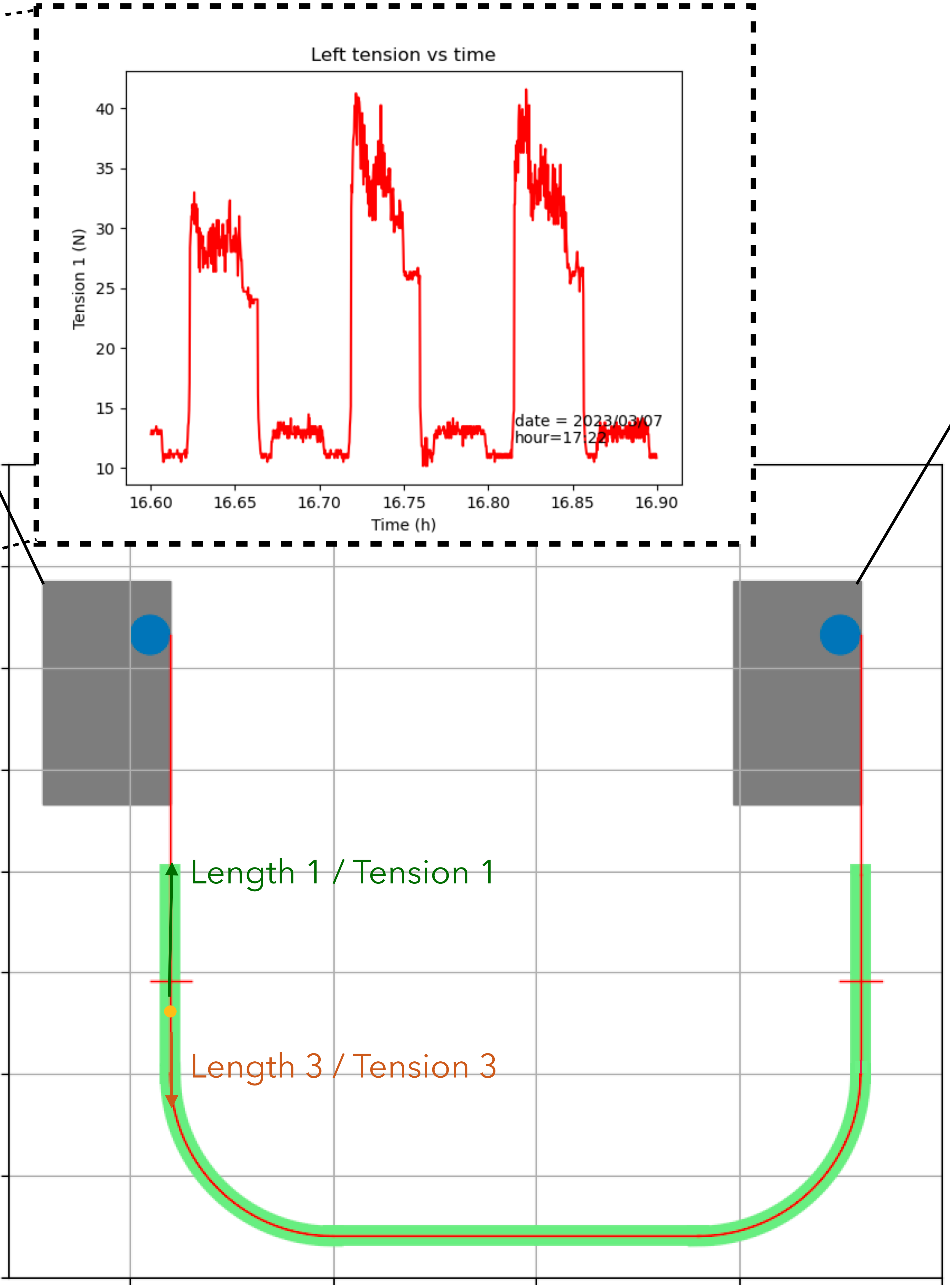
Back to
back-up wrap

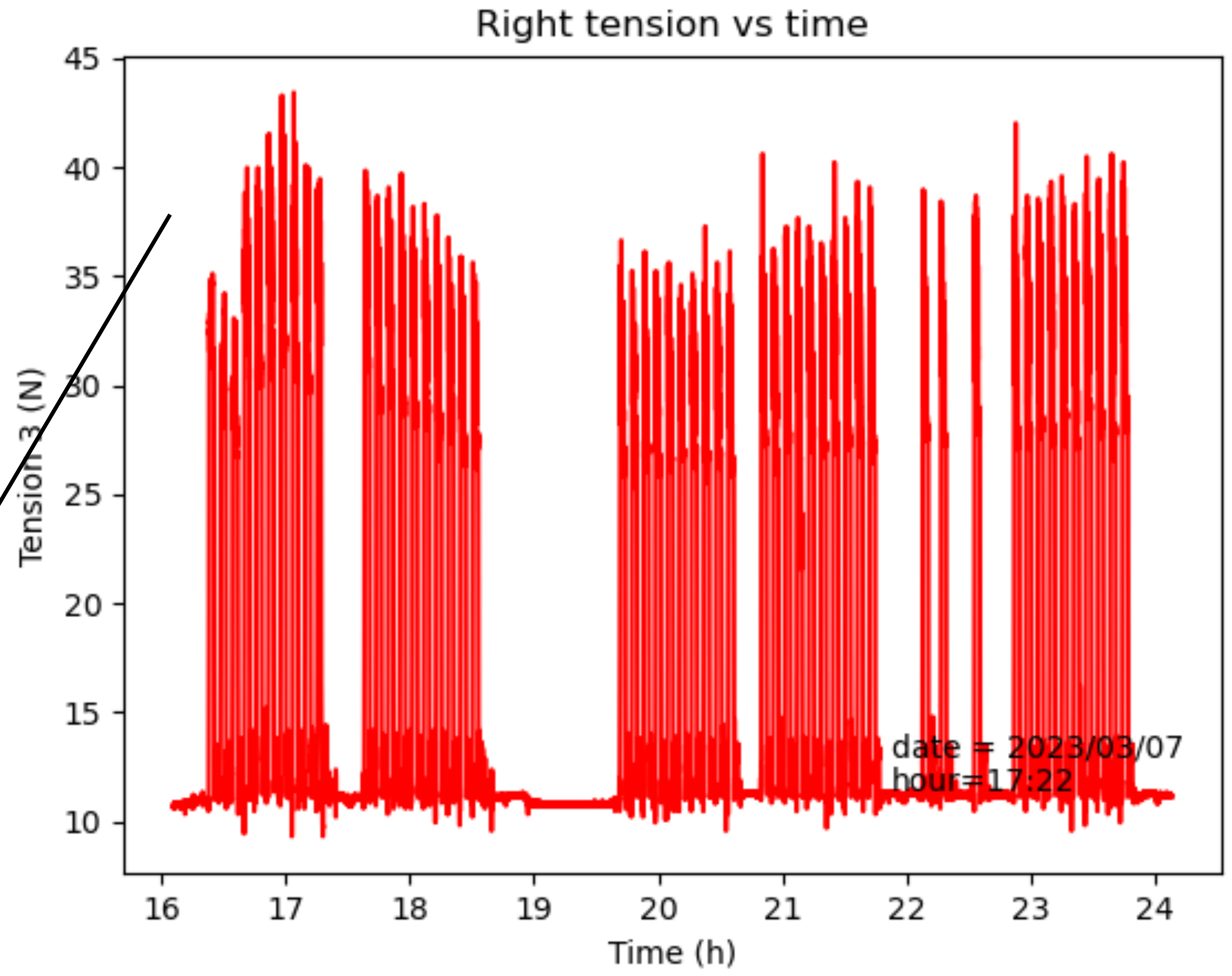
Hardware tests of the calibration

Cryogenic tests at CPPM

Back up





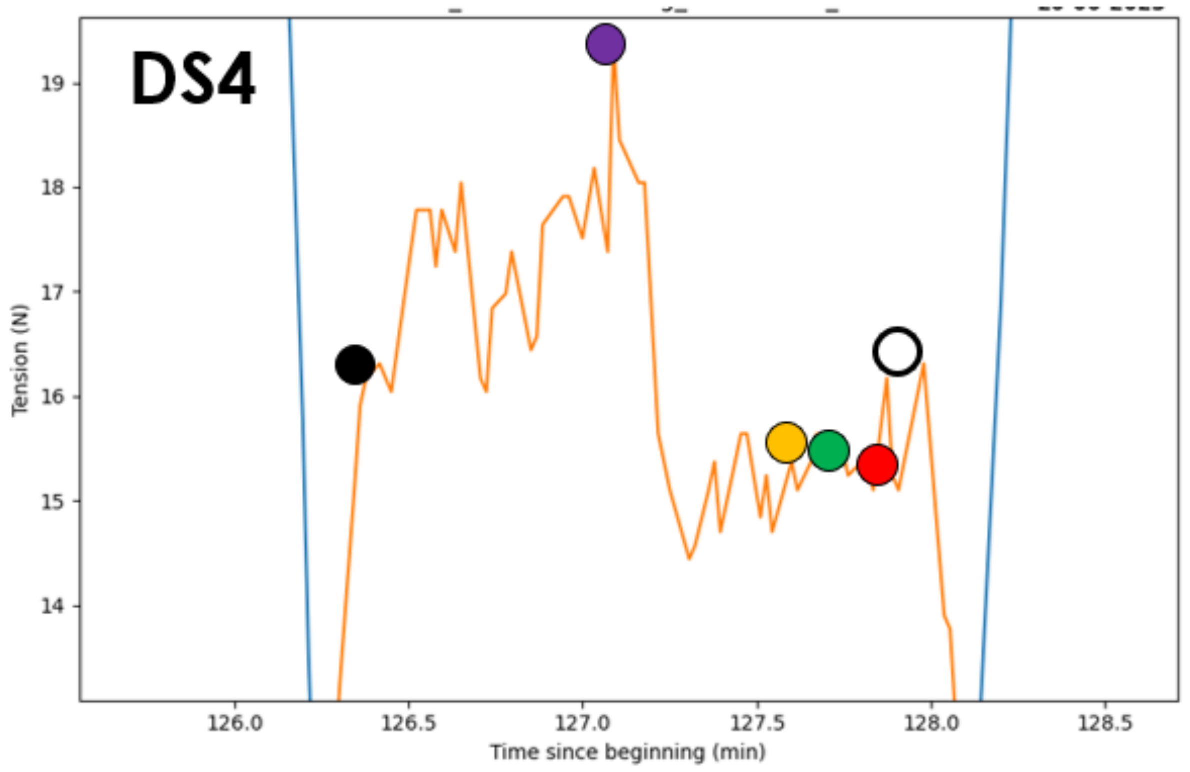


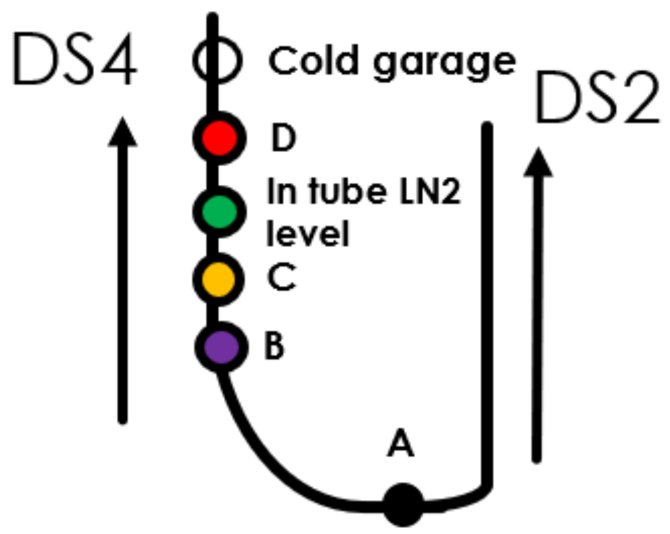
- ➡ Stable tension pattern during the tests of ~12h
- ➡ Tension of the puller motor around 30N (with peaks at ~40N)

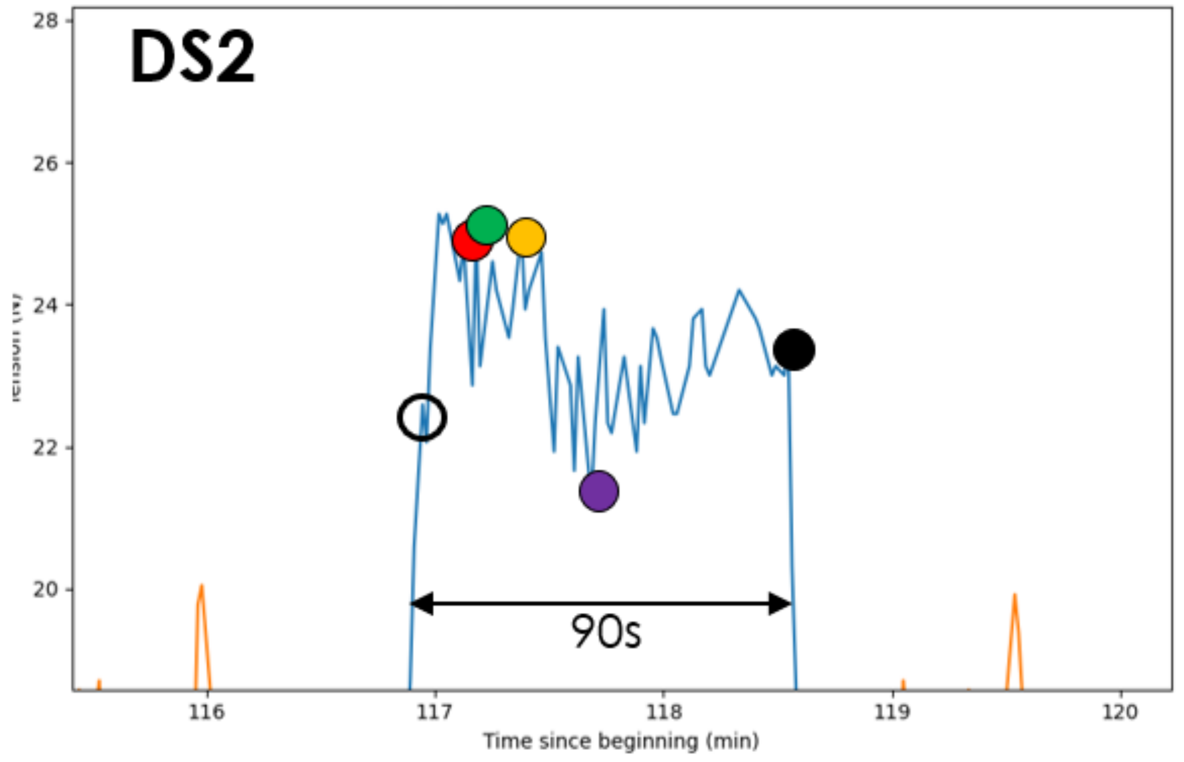
- ➡ With the mock up at CPPM, we can test the system at cold for ≈ 8h
- ➡ The behavior of the motorised systems is reproducible

Back up

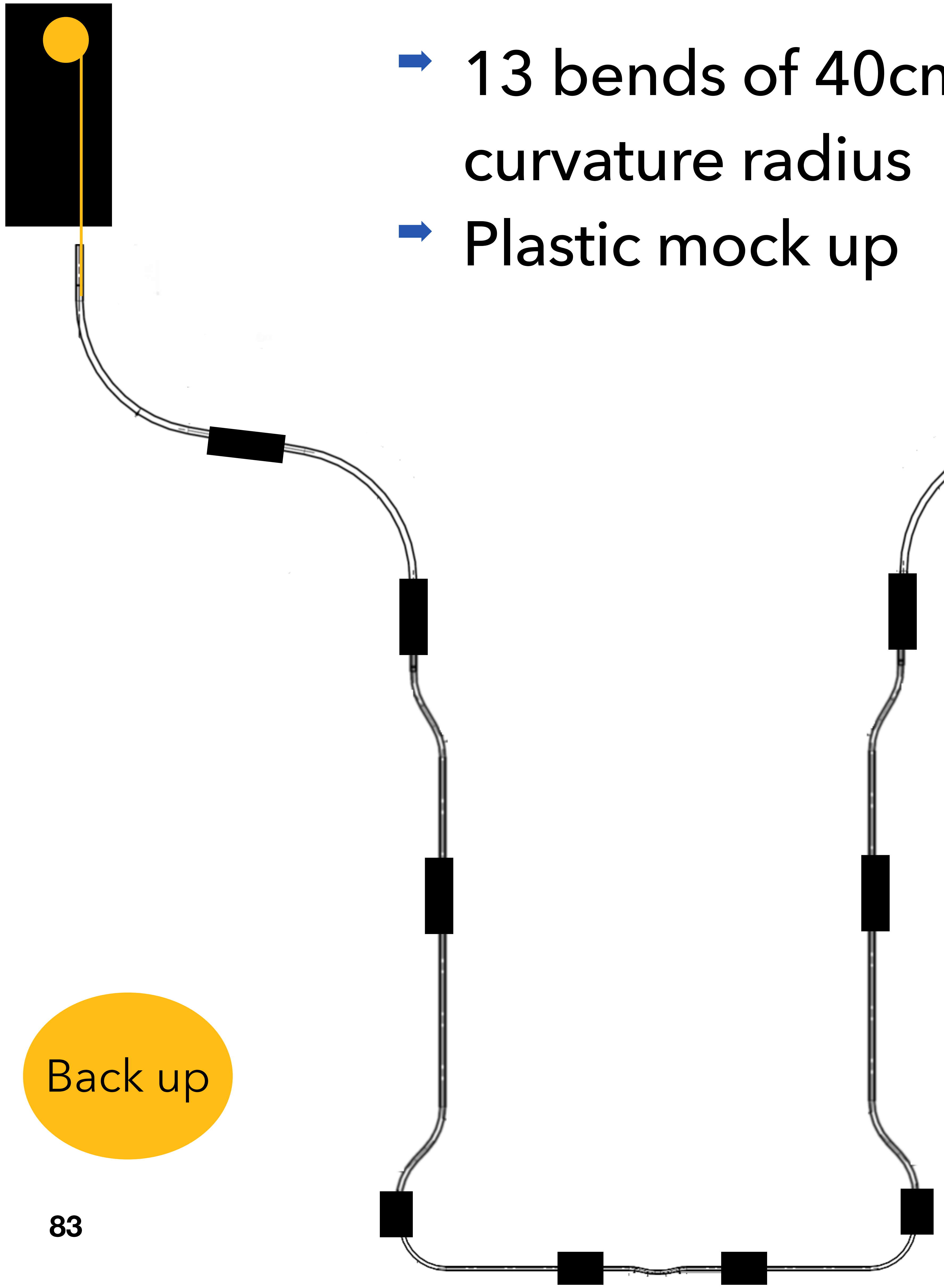
Cryogenic tests at CERN





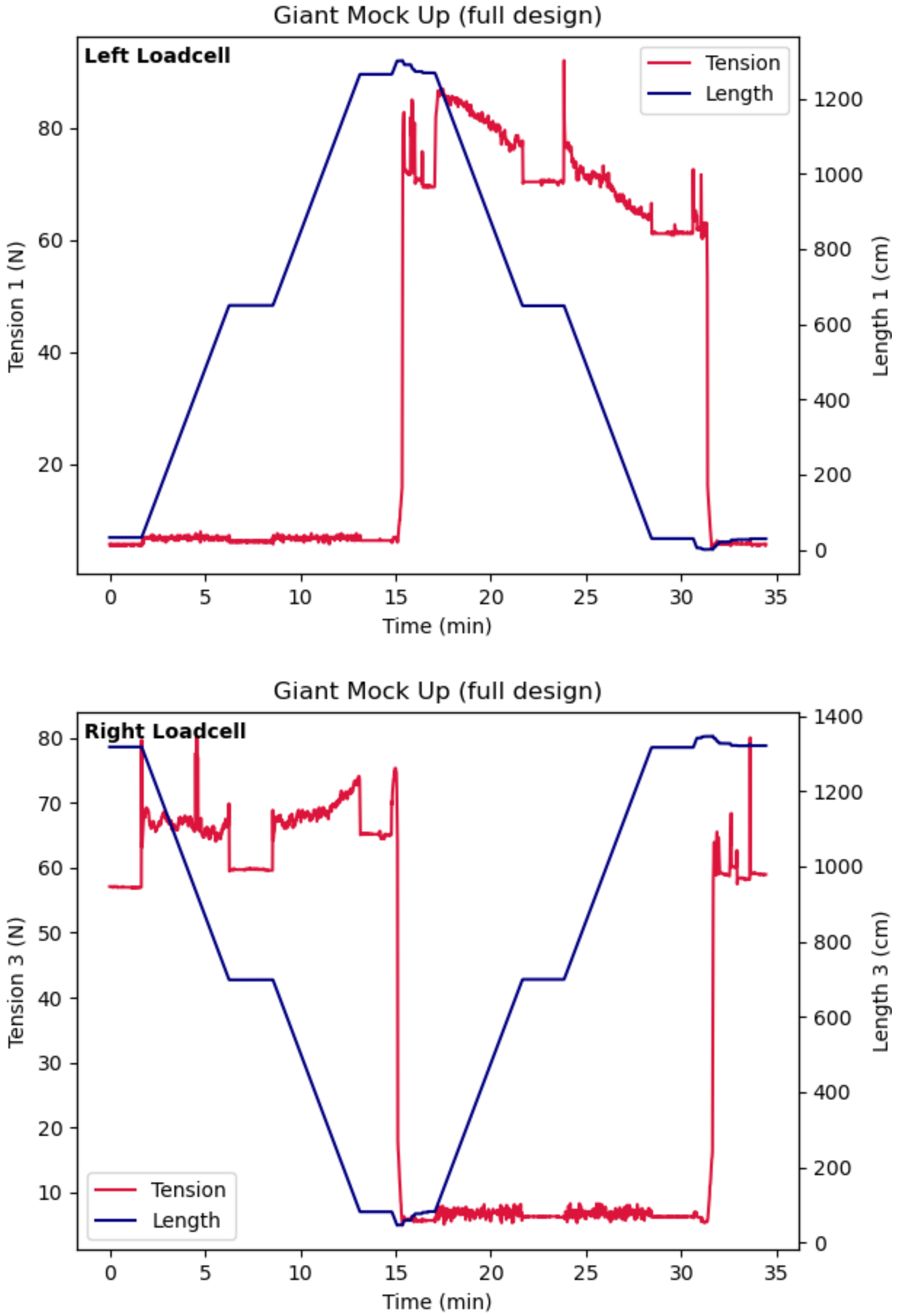


Scale-1 tests at CPPM



- 13 bends of 40cm curvature radius
- Plastic mock up

- Tension of the pulling motor in [65, 75]N range
- Chaotic/fluctuating behavior of the tension (allocated to the use of plastic, see next slide)
- Not the same pattern for DS1 and DS3 BUT DS1 always has the same pattern travels after travels (same for DS3)

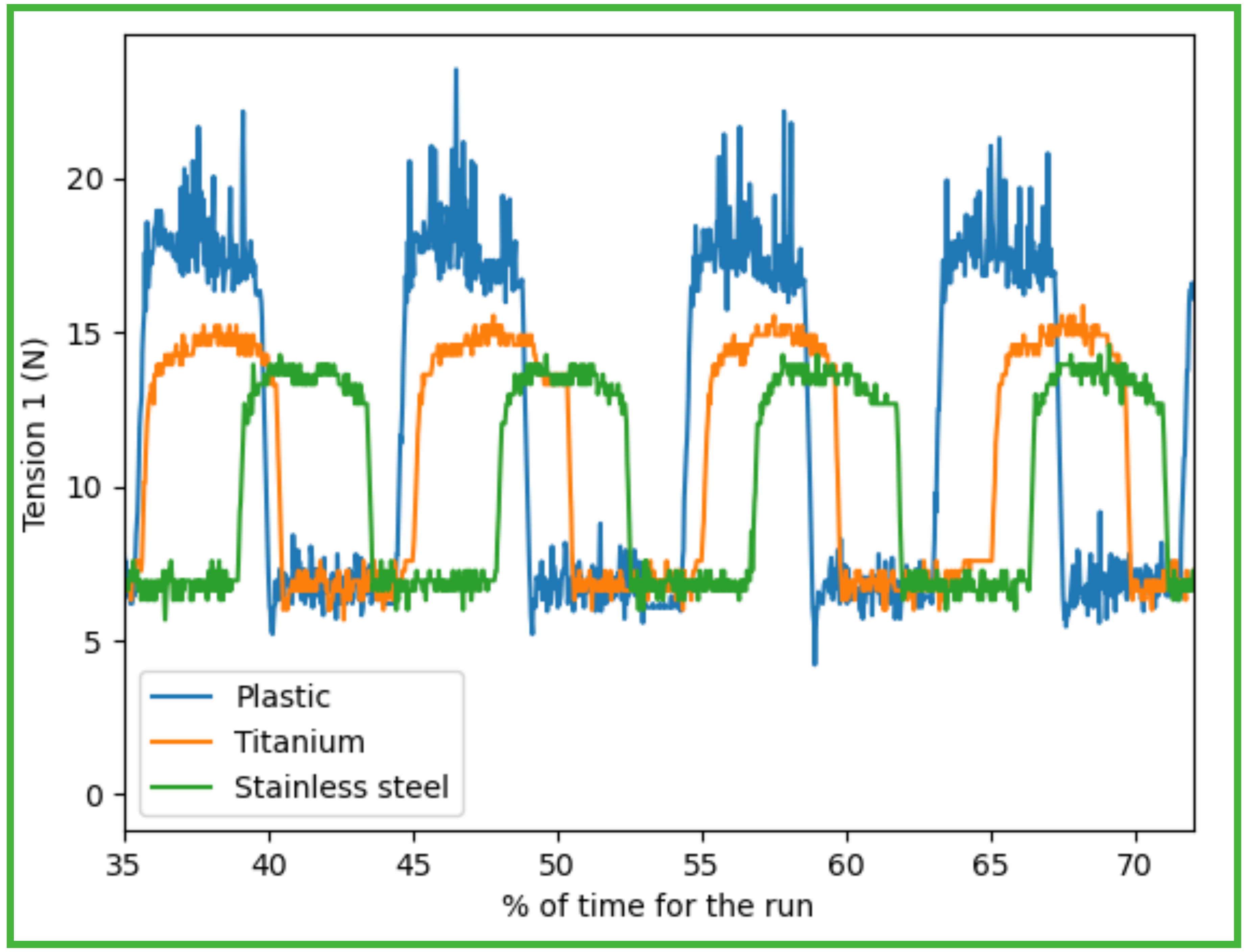


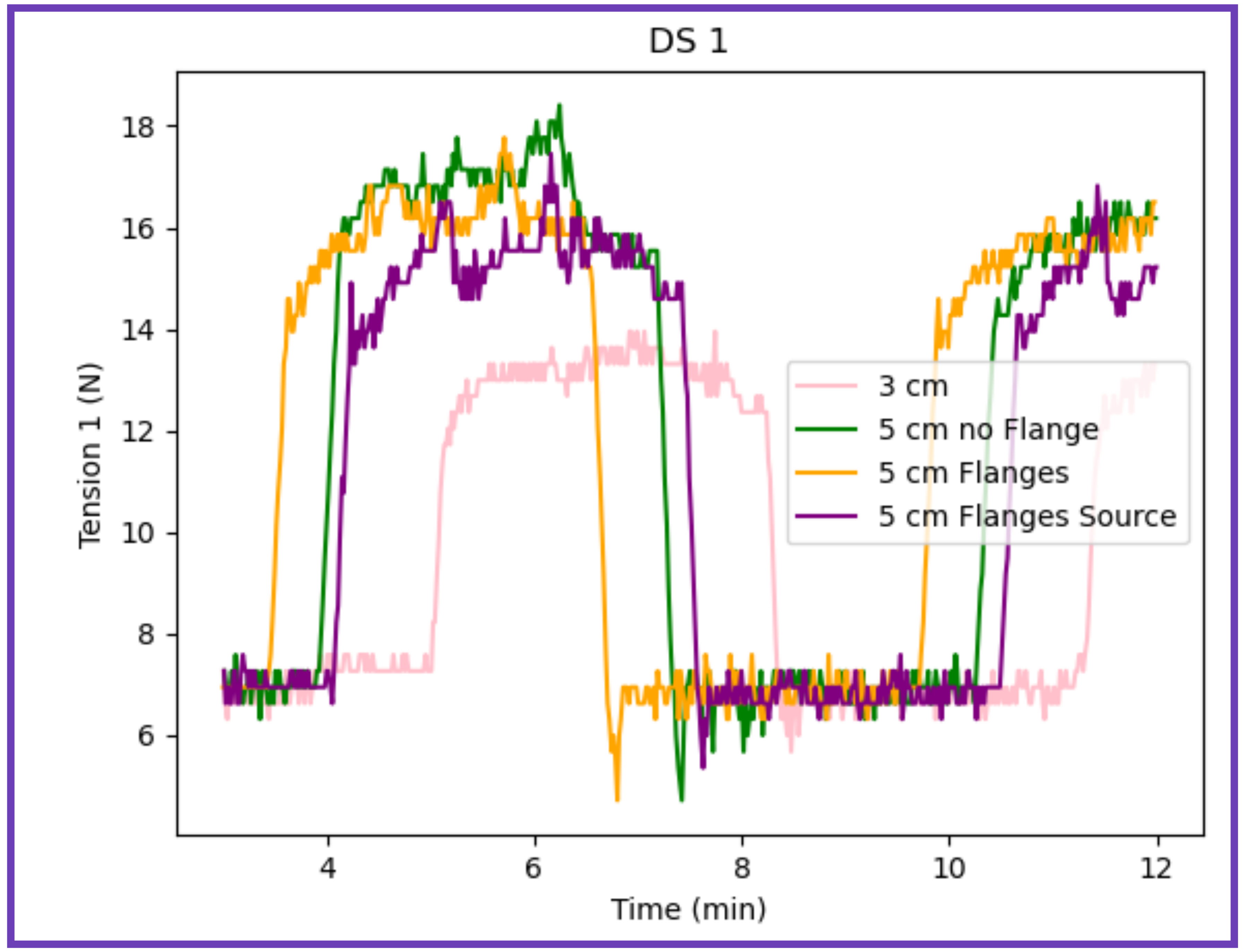
Back up

Small tests at CPPM

Back up

- Each small design change impacting the calibration system is systematically tested (at warm)
- Among these tests:
  - Tube's material: changed from titanium to stainless steel (and comparison with plastic to extrapolate giant mock-up runs to cryogenic scale 1 final system)
  - Tube's inner diameter: increased from 3 cm to 5 cm
  - Total tube = small tubes assembled with flanges –> impact of the flange on the tension

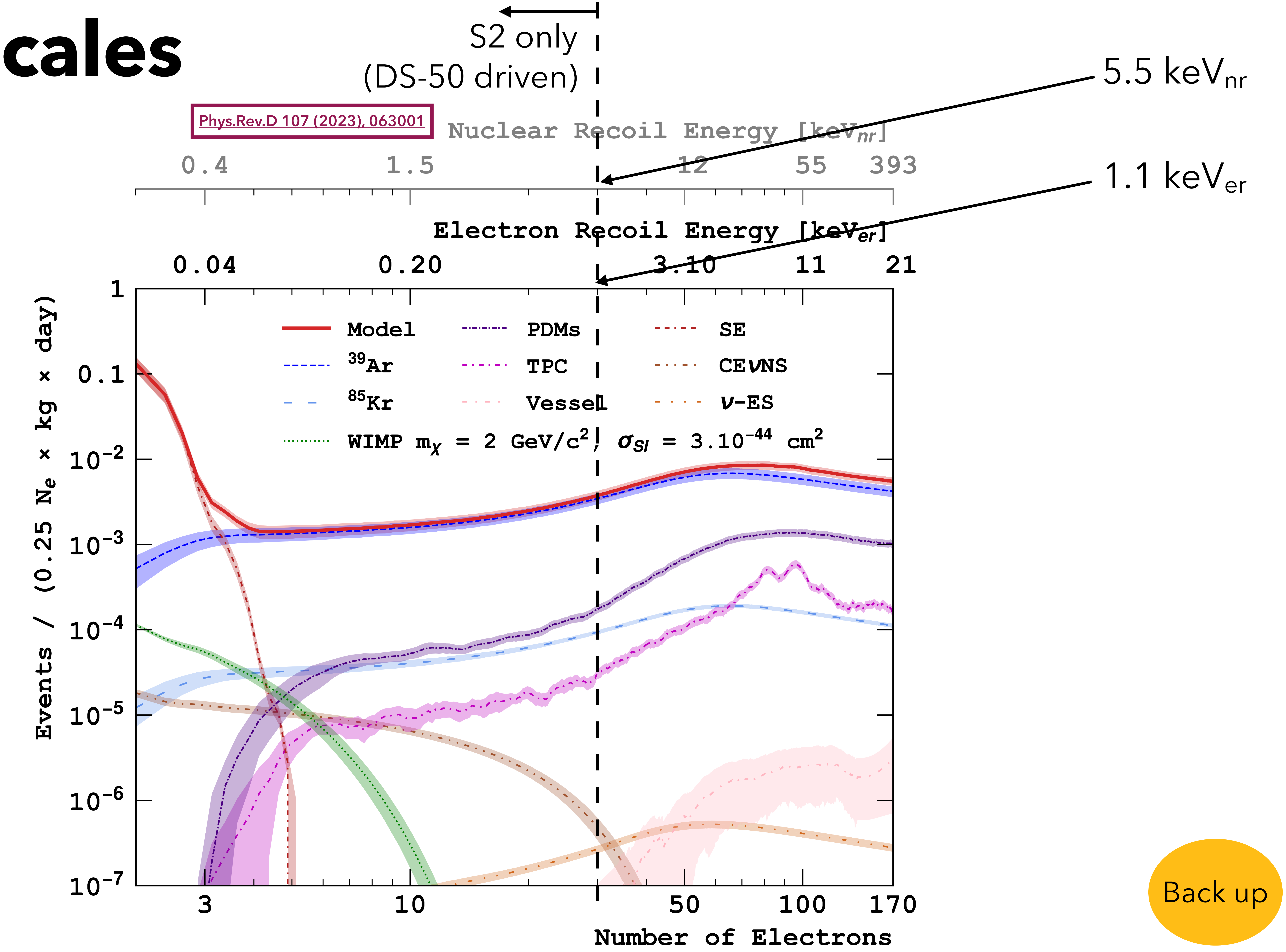




Back to
back-up wrap

Low mass analysis

Energy scales

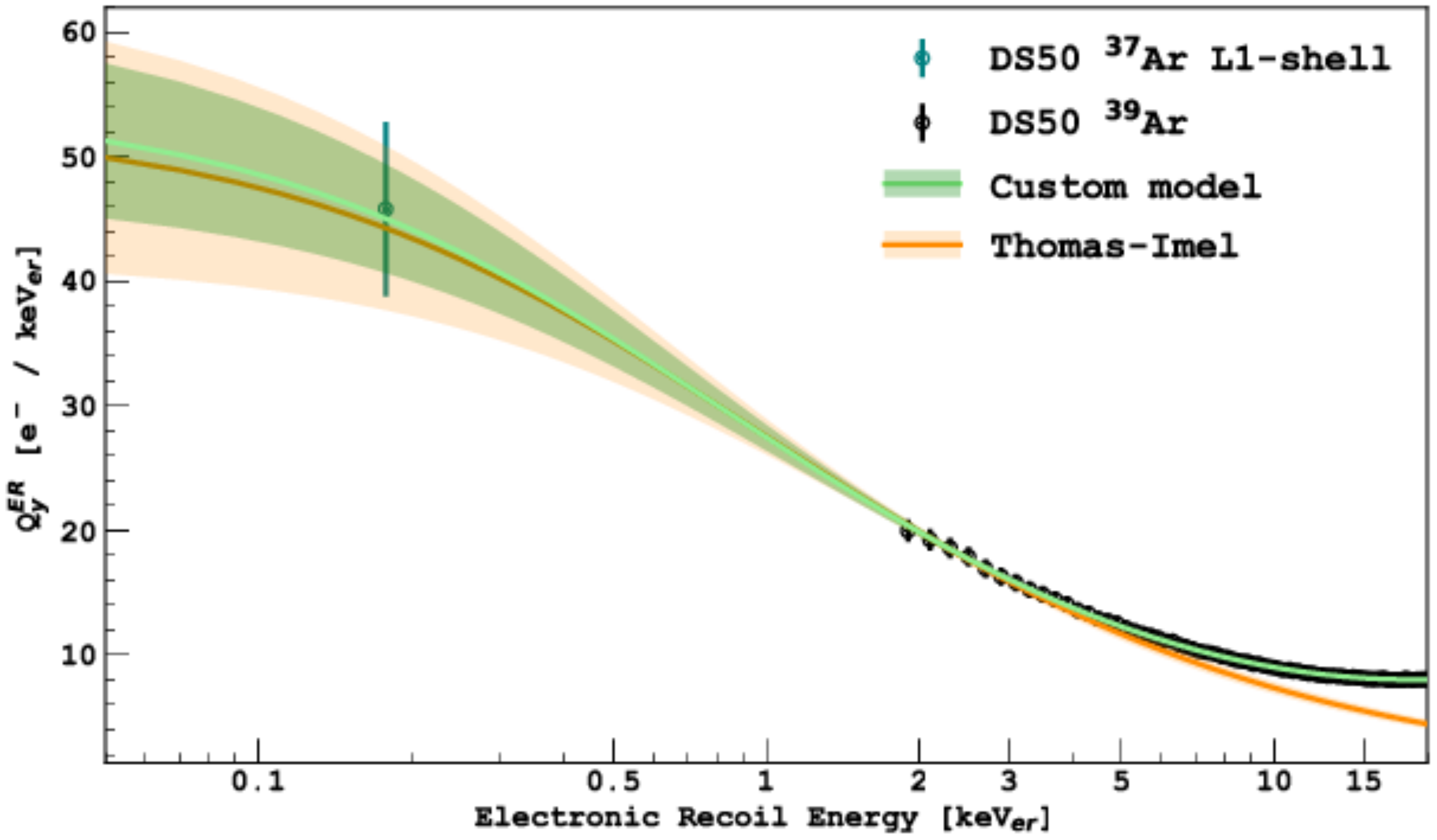


Back up

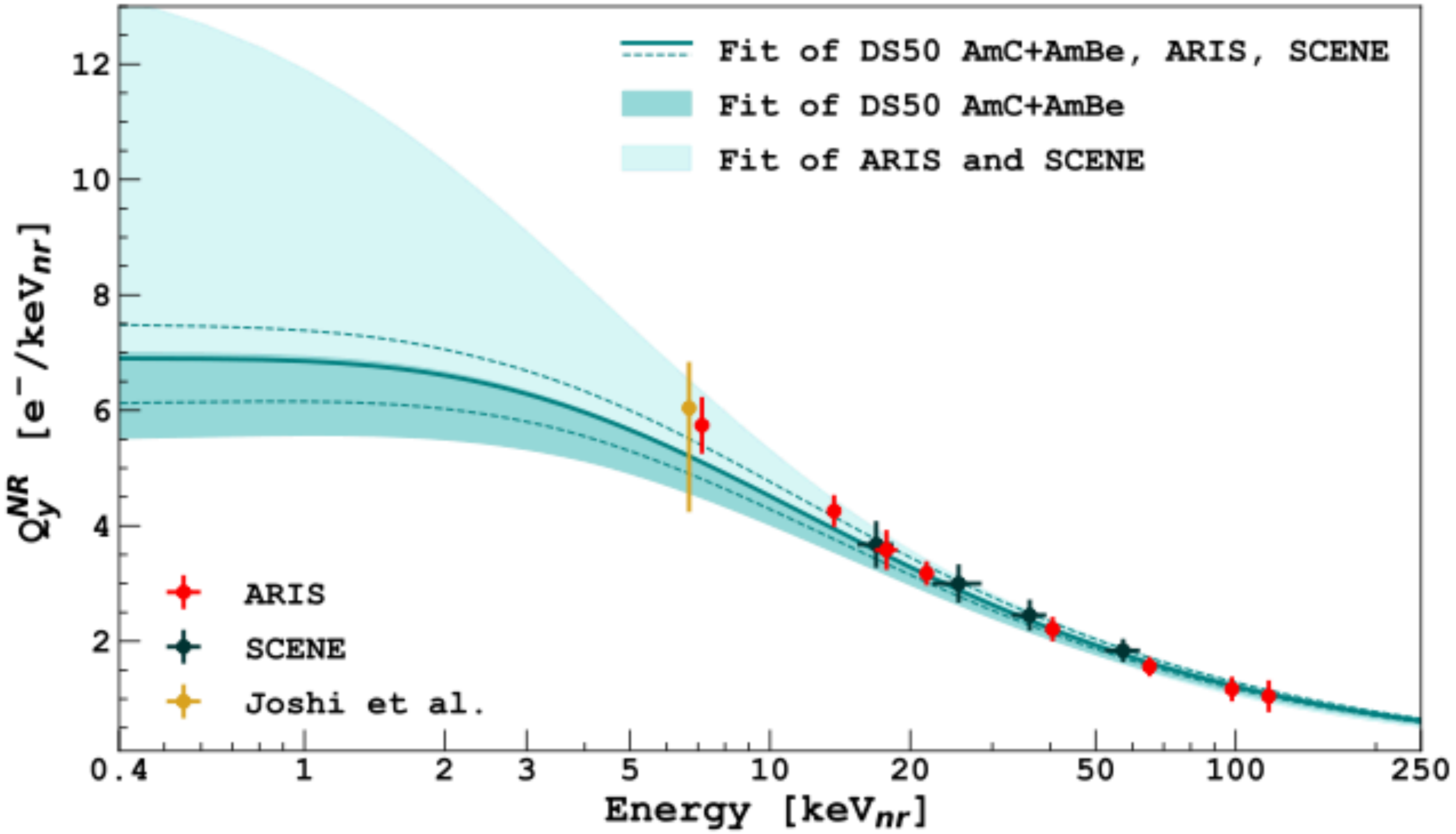
LAr response model

DarkSide-50 calibration

ER ionization yield



NR ionization yield



Phys.Rev.D 104 (2021), 082005

Back up

Back up

LAr response model

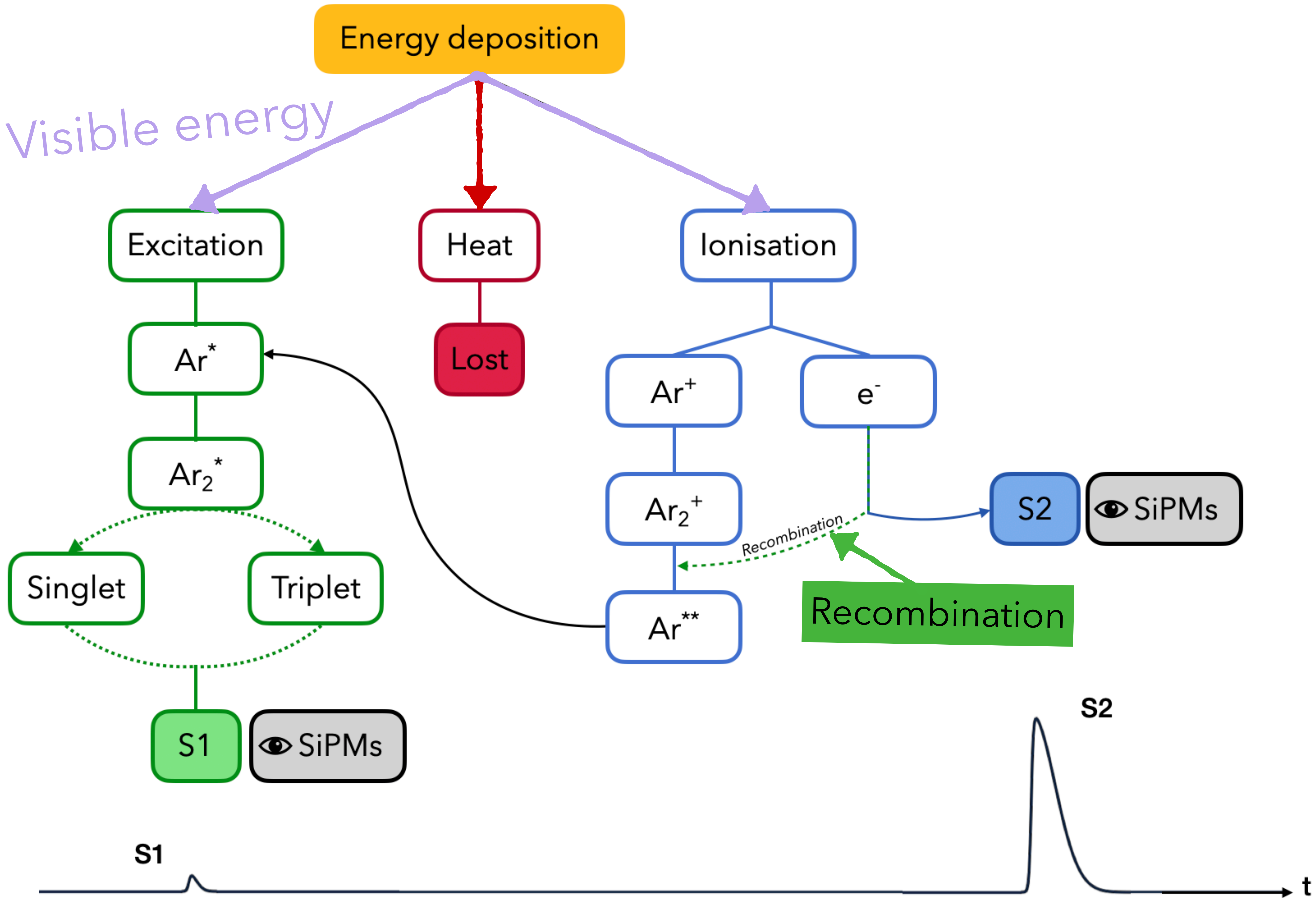
Quenching fluctuations -> no theoretical predictions

NQ model:

Visible energy fixed to its average value. Not physical but conservative.

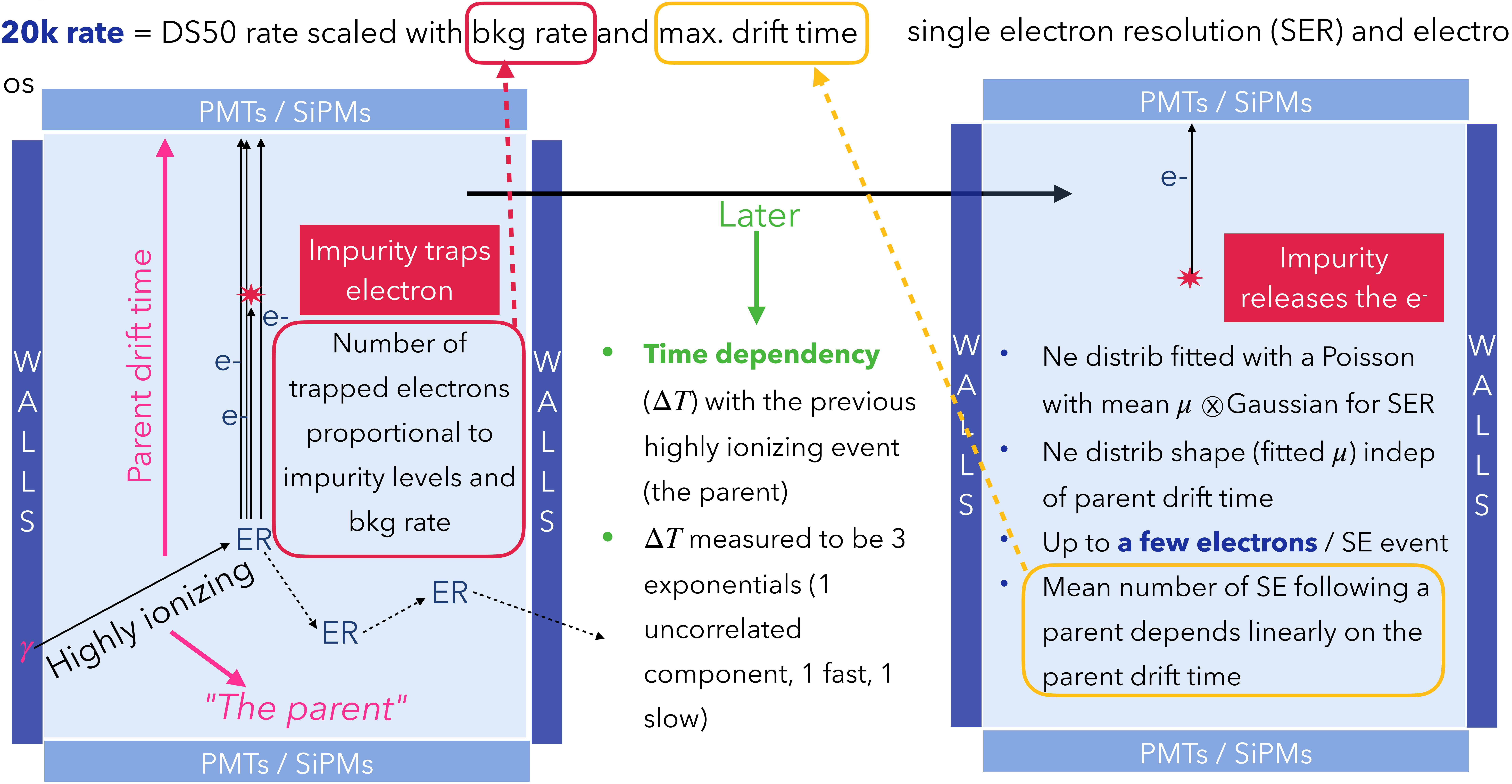
QF model:

binomial quenching fluctuations between detectable and undetectable energy : ensures that the number of produced quanta does not exceed the maximum possible one
+ other fluctuations in recombination process
(nb of electron-ion pair that recombine) and repartition between excitation and ionization quanta



Spurious electron background

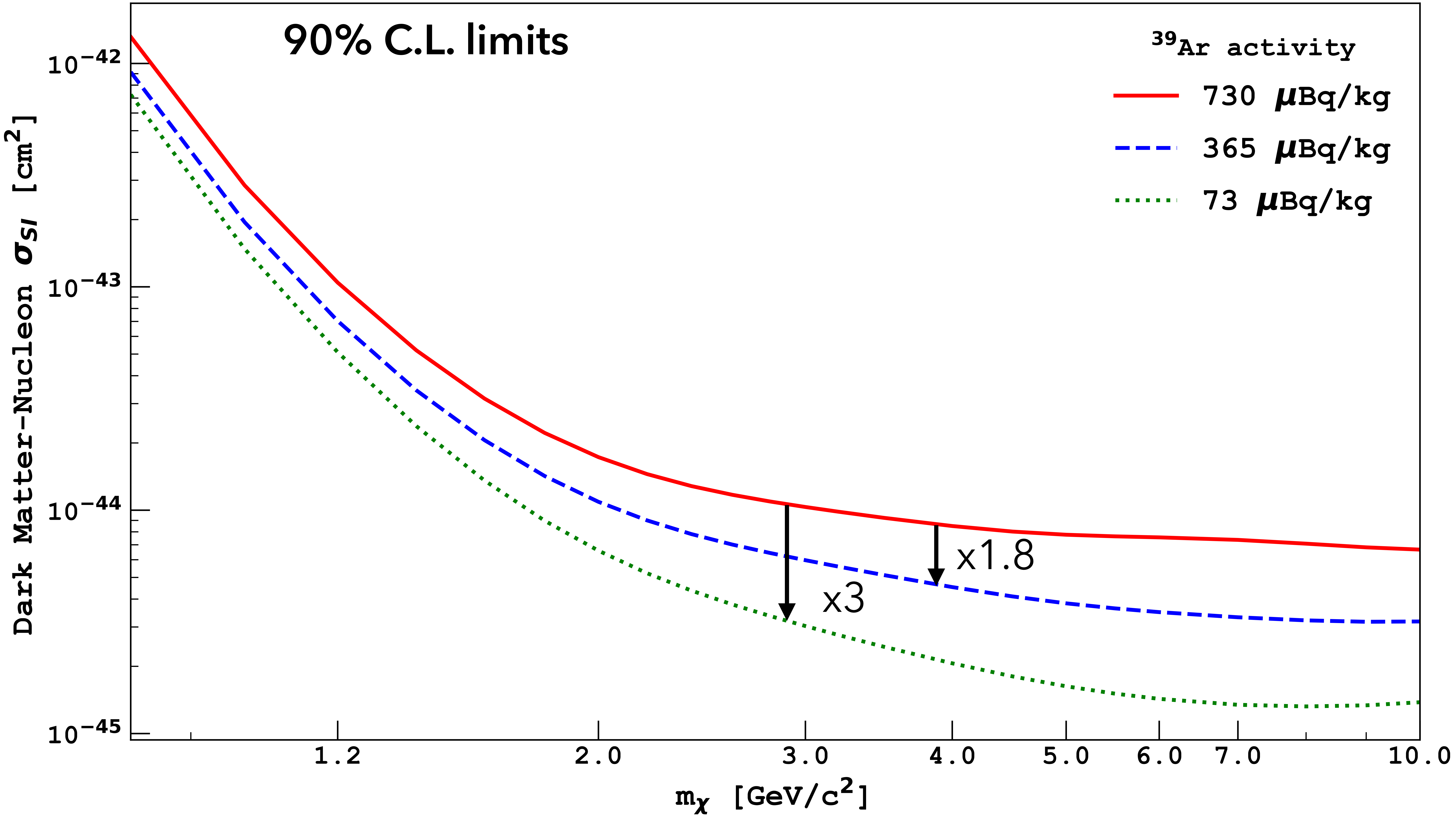
- **Extrapolated** from DarkSide-50 data
- **DS20k rate** = DS50 rate scaled with bkg rate and max. drift time ratios
- **DS20k shape (in Ne):** takes into account expected single electron resolution (SER) and electron lifetime



- **Time dependency** (ΔT) with the previous highly ionizing event (the parent)
- ΔT measured to be 3 exponentials (1 uncorrelated component, 1 fast, 1 slow)

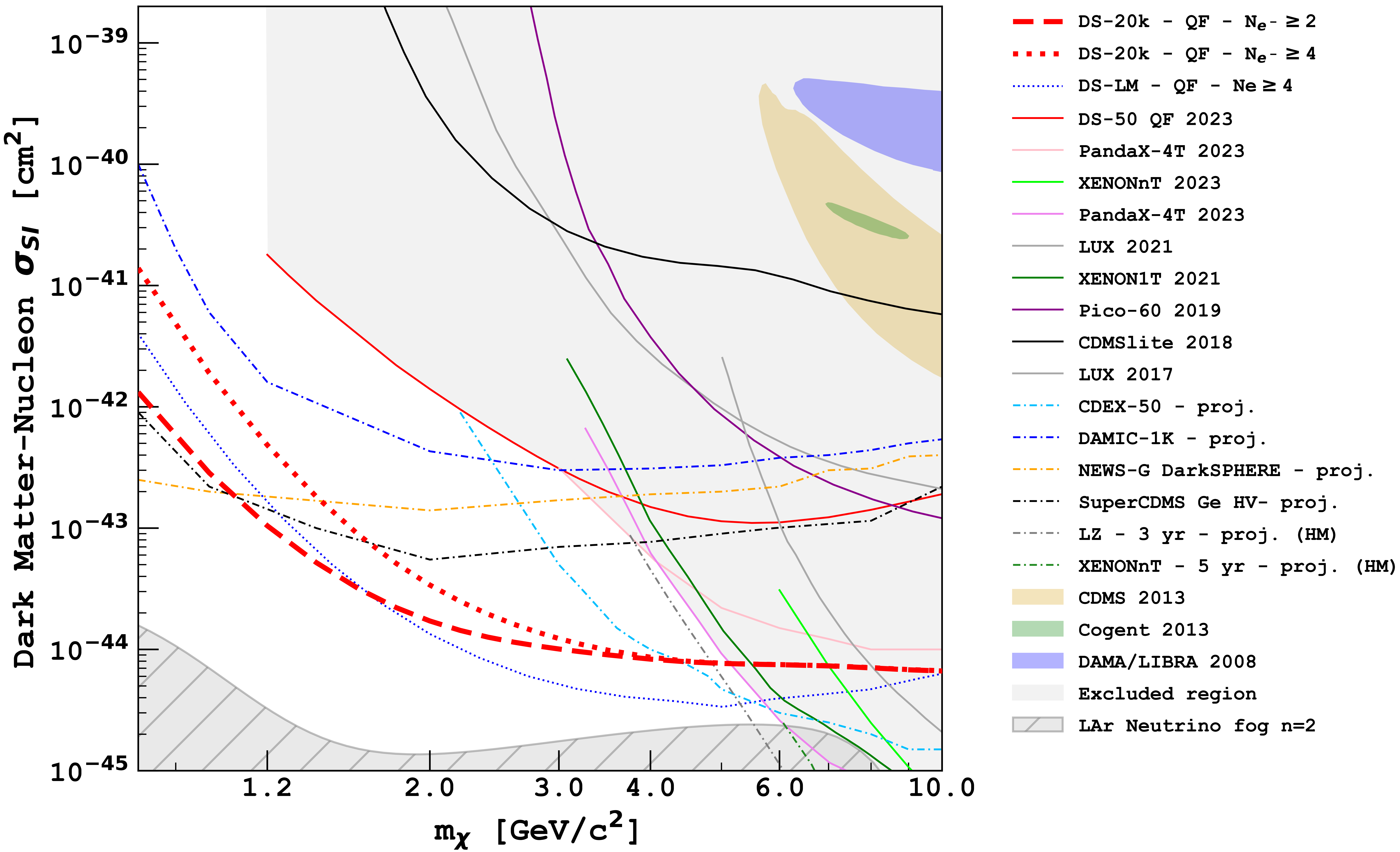
- Ne distrib fitted with a Poisson with mean μ $\otimes$Gaussian for SER
- Ne distrib shape (fitted μ) indep of parent drift time
- Up to **a few electrons** / SE event
- Mean number of SE following a parent depends linearly on the parent drift time

Sensitivity vs argon level



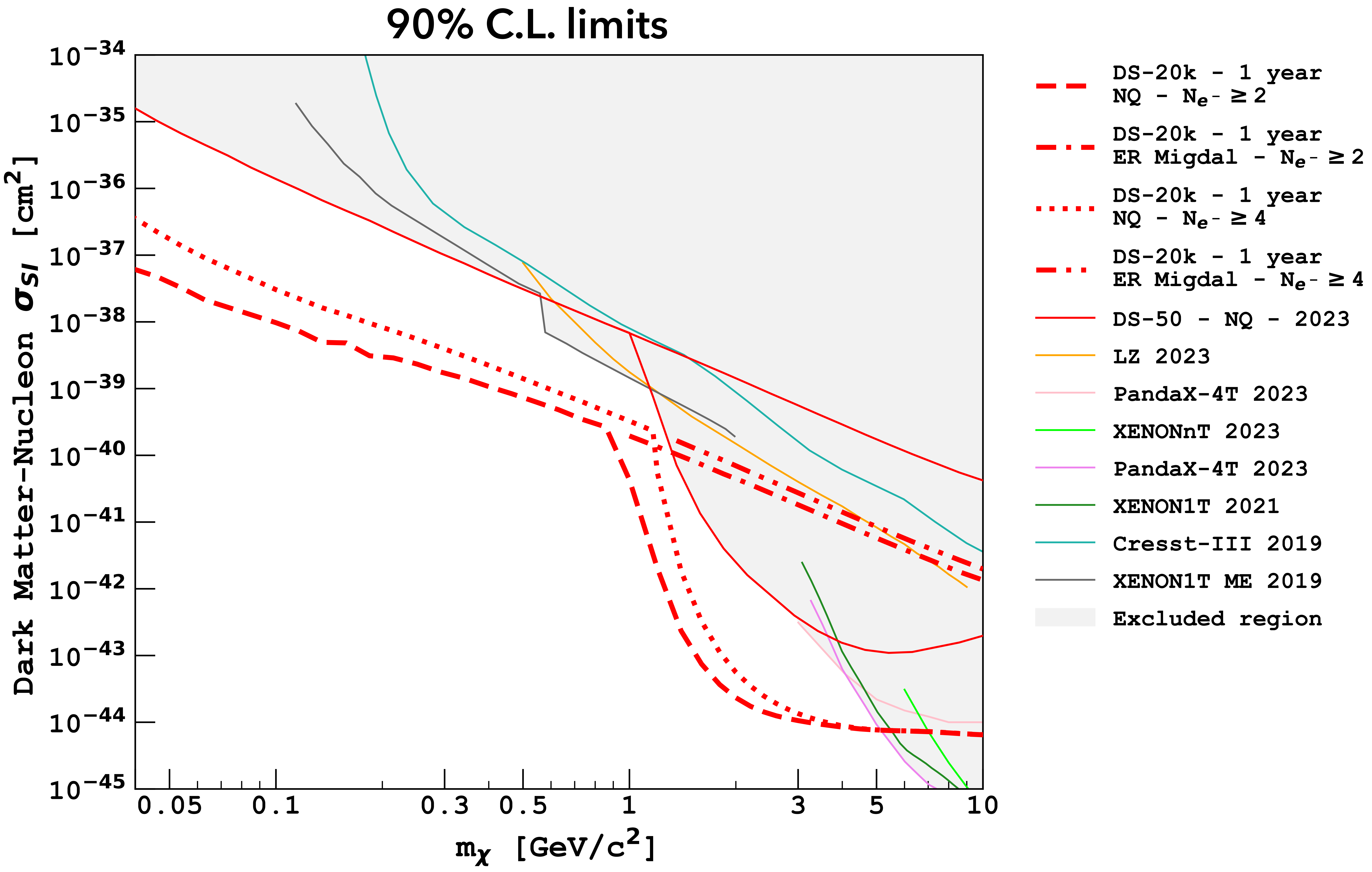
Back up

DarkSide-20k and other prospective experiments



Back up

No quenching fluctuations in NR



LM - Other signal models

Back up

Rates

e- in a given orbital (n, l)

LDM:

$$\frac{dR}{d\ln E_{er}} = N_T \frac{\rho_{DM}}{m_\chi} \times \frac{\boxed{\bar{\sigma}_e}}{8\mu_{\chi e}^2} \times \sum_{nl} \int |f_{ion}^{nl}(k', q)|^2 |F_{DM}(q)|^2 \eta(v_{min}) q dq$$

ALPs:

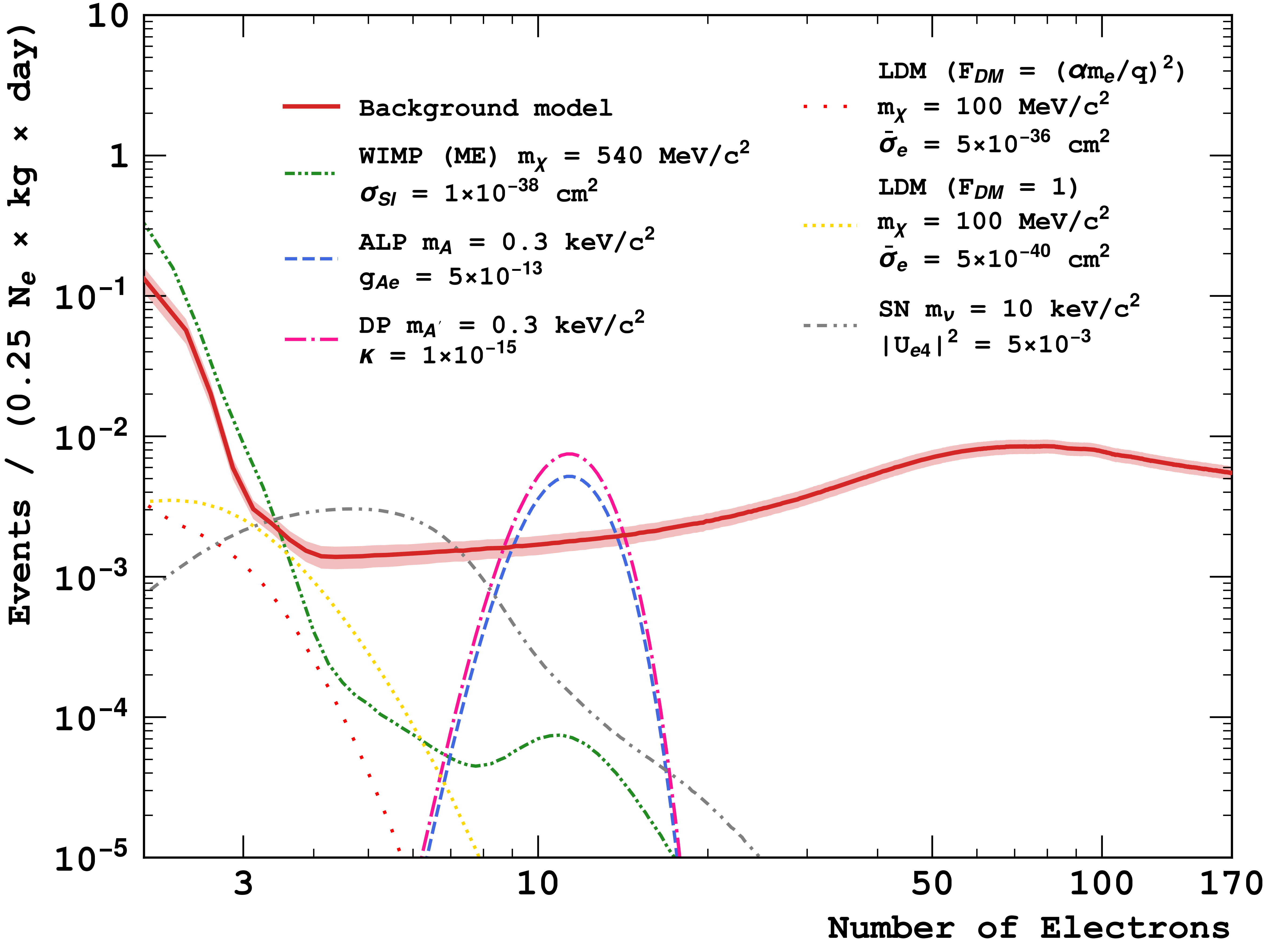
$$R = N_T \frac{\rho_{DM}}{m_A} \times \frac{3 m_A^2 \boxed{g_{Ae}^2}}{16\pi\alpha m_e^2} \sigma_{pe}(m_A c^2) c$$

DP:

$$R = N_T \frac{\rho_{DM}}{m_{A'}} \times \boxed{\kappa^2} \sigma_{pe}(m_{A'} c^2) c$$

Sterile neutrinos:

$$\frac{dR}{dE_{er}} = N_T \frac{\rho_{DM}}{m_\nu} \times \sum_{nl} 2(2l+1) \int \frac{d\sigma_{nl}}{dE_{er}} \left(v, m_\nu, \boxed{|U_{e4}|^2} \right) f(v)\ v\ dv$$



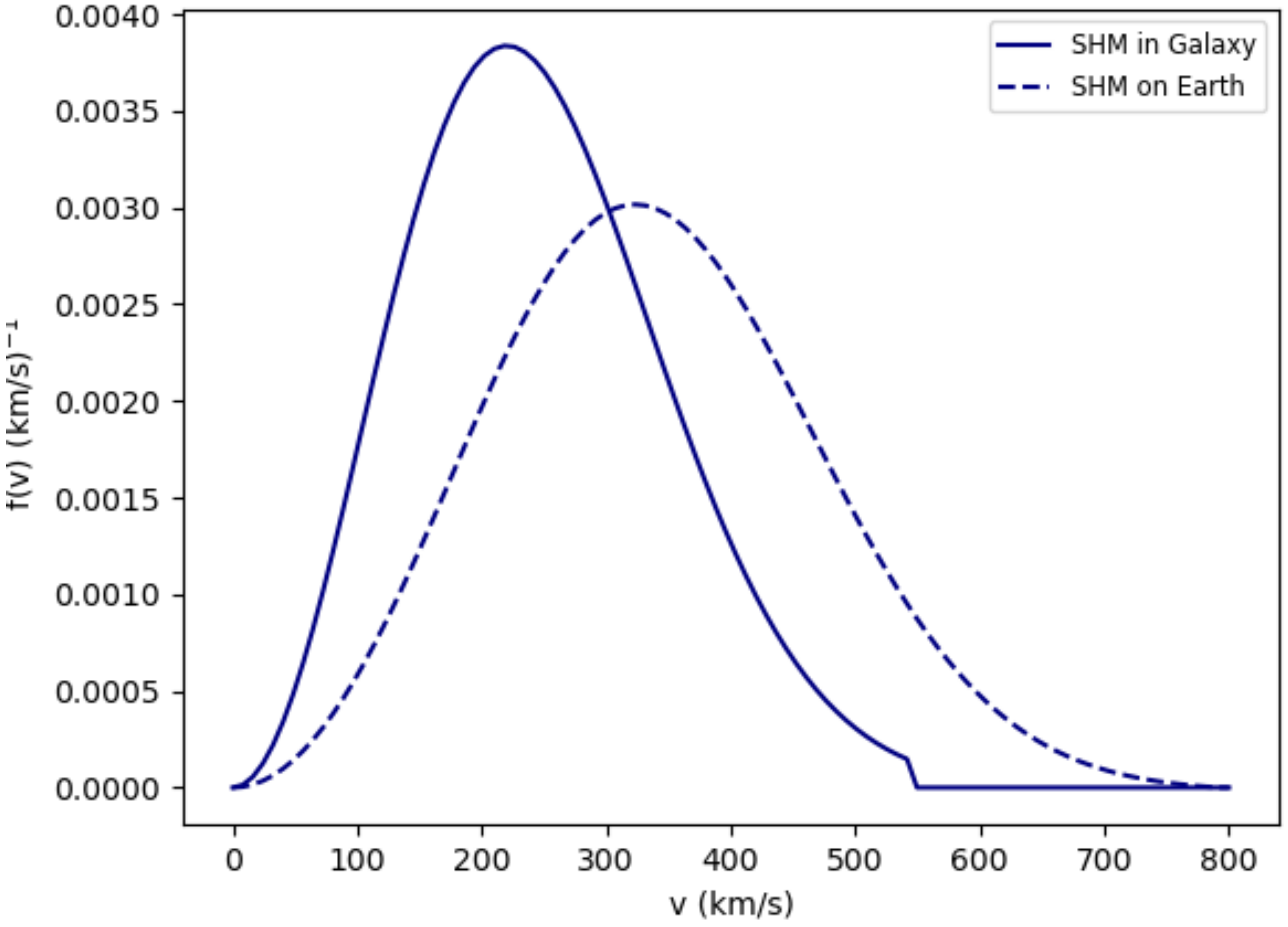
Back to back-up wrap

Systematics uncertainties from the modelling of the galactic DM halo

The standard halo model (SHM)

Back up

Velocity probability distribution function (VPDF)



- The SHM intends to describe a isotropic isothermal spherically symmetric halo
- Each velocity component v_x, v_y, v_z follows a gaussian distribution centered on 0 with width v_0
- $f_{gal}(\vec{v}) = f_{gal}(v_x) \times f_{gal}(v_y) \times f_{gal}(v_z)$
- Pb: with width v_0, $f_{gal}(\vec{v})$ allows for $\vec{v}$ such as $|\vec{v}| = \mathrm{v} > \mathrm{v}_{esc}$
    - Manually force the VPDF to be null at $\mathrm{v} \geq \mathrm{v}_{esc}$

$$\Downarrow$$

$$f_{gal}(\mathrm{v}) = \begin{cases} \dfrac{1}{N_{esc}} \cdot \mathrm{v}^2 \cdot e^{-\frac{\mathrm{v}^2}{\mathrm{v}_0^2}} & \text{if } \mathrm{v} < \mathrm{v}_{esc} \\ 0 & \text{if } \mathrm{v} \geq \mathrm{v}_{esc} \end{cases}$$

Correlation of astrophysical parameters

Back up

For a spherically symmetric system

- $\rho(r) \propto \frac{v_0(r)^2}{r^2}$ $\rho(r)$ and $v_0(r)$ correlated
- $f_{MB}(\vec{v}, r) = \frac{1}{K} e^{-\frac{m\vec{v}^2}{2k_BT}} e^{-\frac{m\Phi(r)}{k_BT}}$ & $\rho(r) = \int d^3\vec{v} f_{gal}(\vec{v}, r)$
- $\rho(r) = \int d^3\vec{v}\, \frac{1}{K} e^{-\frac{m\vec{v}^2}{2k_BT}} e^{-\frac{m\Phi(r)}{k_BT}}$ $\rho(r)$ and $\Phi(r)$ correlated
- $v_{esc}(r) = \sqrt{2(\Phi(r_{max}) - \Phi(r))}$ $v_{esc}(r)$ and $\Phi(r)$ correlated

→ $\rho(r)$ and $v_{esc}(r)$ correlated

- $|\vec{a}(r)| = \frac{v_c(r)^2}{r} = -\frac{m|\vec{\nabla}\Phi|}{m} \Rightarrow v_c(r) = \sqrt{r\frac{d\Phi}{dr}(r)} = \sqrt{\frac{\mathcal{G}M_{int}(r)}{r}}$

and $M_{int}(r) = \int_0^r \rho(r')d^3\vec{r'} \Rightarrow v_c = \left(\frac{\mathcal{G}\int_0^r \rho(r')d^3\vec{r'}}{r}\right)^{1/2}$ v_c(r) and $\rho(r)$ correlated

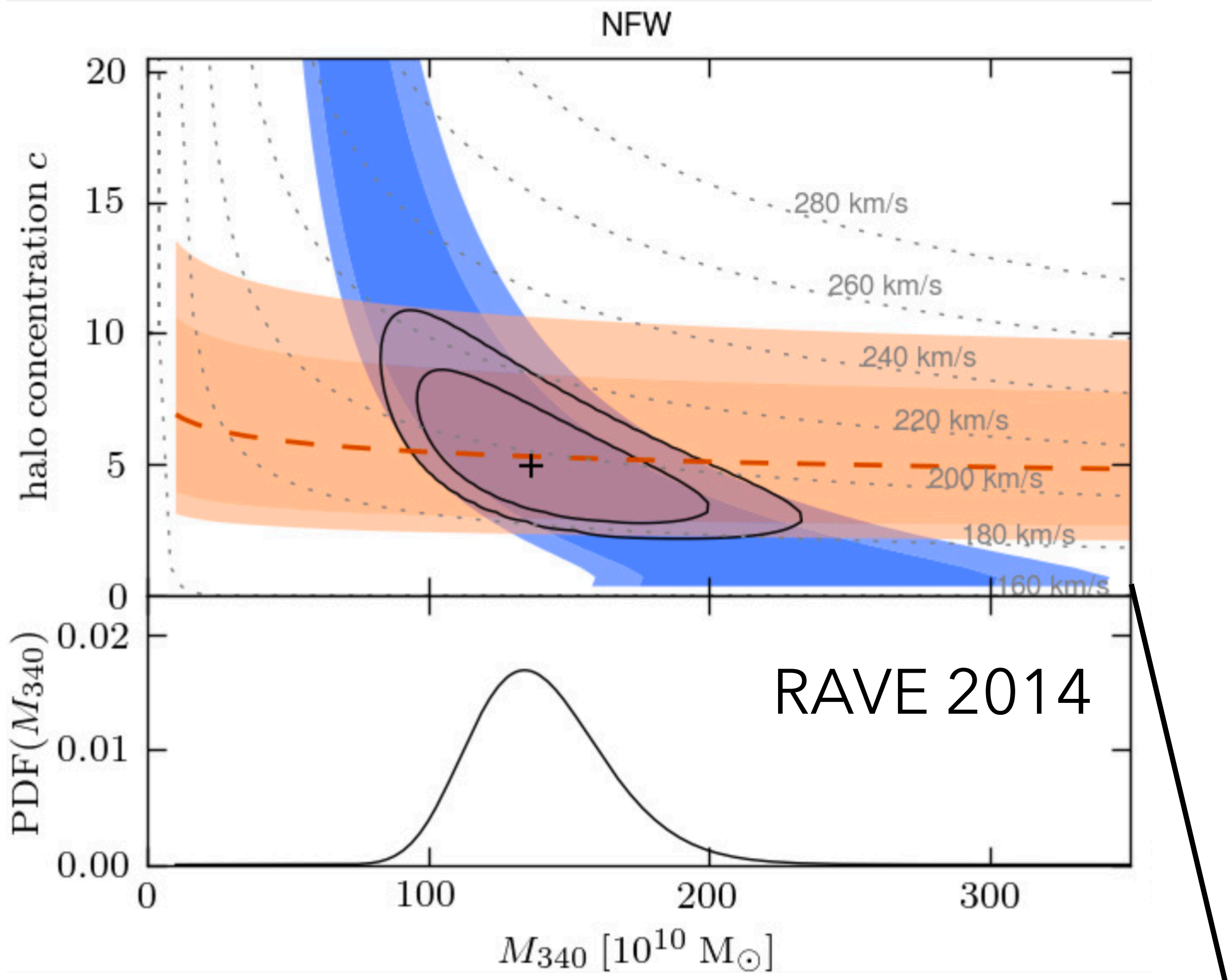
$\phi(r)$: gravitational potential

r_{max}: the radius at which the gravitational potential isn't determined by the central halo anymore

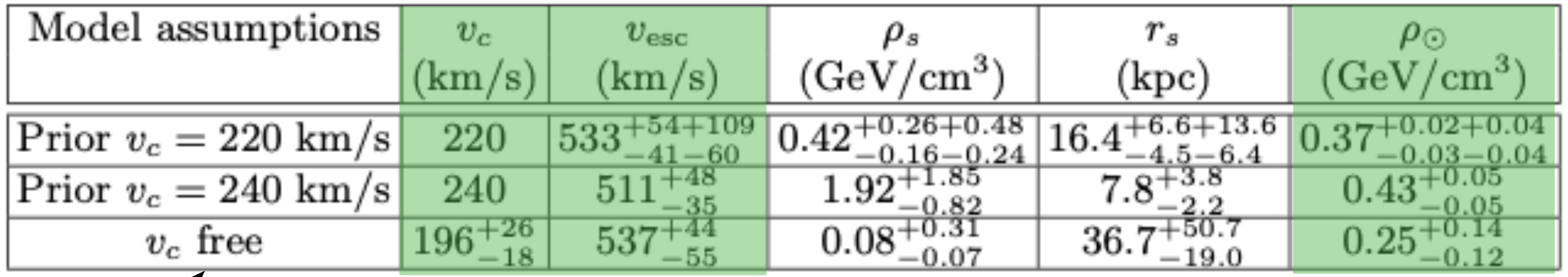
➡ Astro param depend on one another AND on the prior for the halo

Coherent sets of astrophysical parameters

From Lavalle & Magni



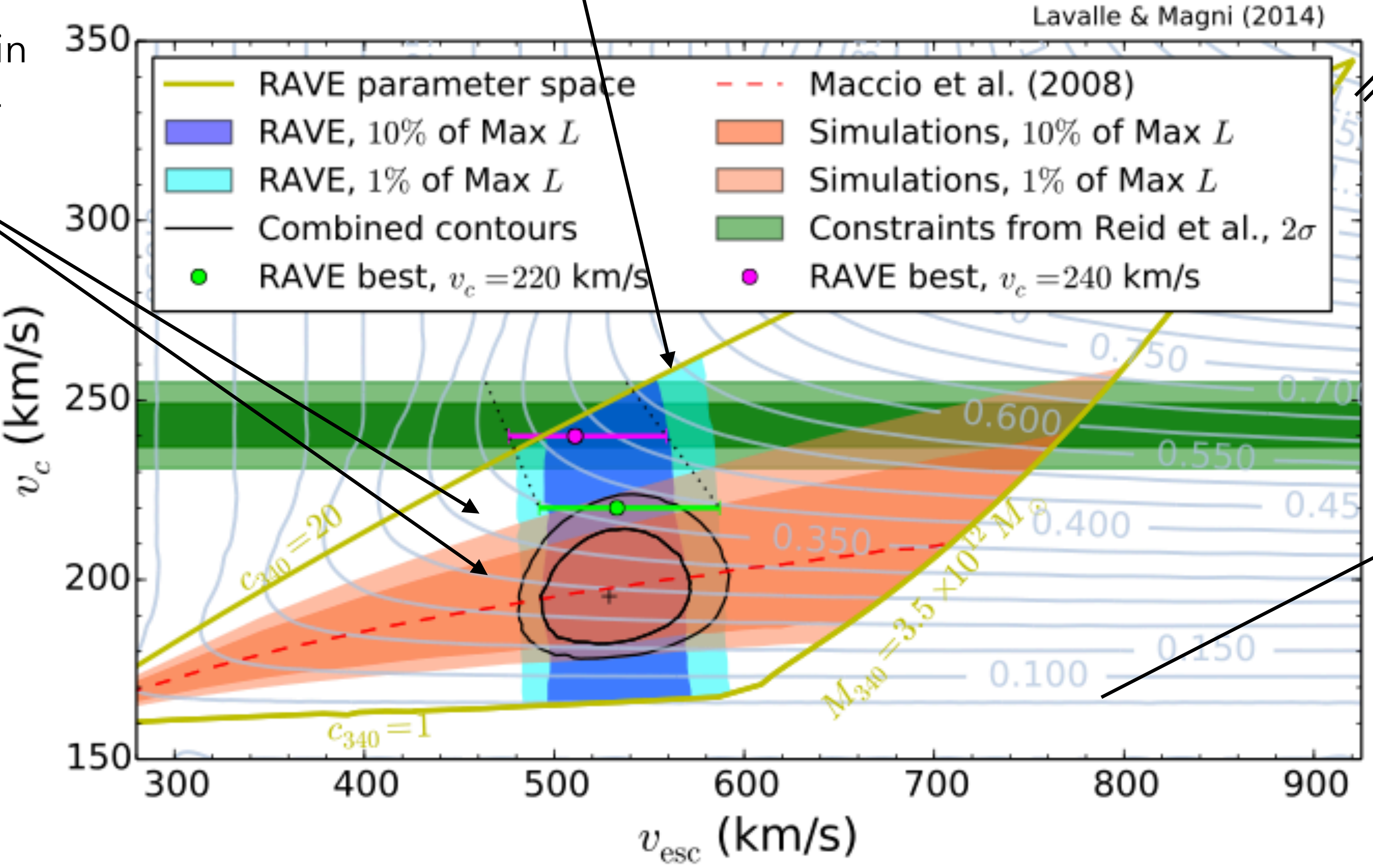
Parameters of green band slide 43



Model assumptions	v_c (km/s)	$v_{\rm esc}$ (km/s)	ρ_s (GeV/cm^3)	r_s (kpc)	$\rho_\odot$ (GeV/cm^3)
Prior $v_c = 220$ km/s	220	$533^{+54+109}_{-41-60}$	$0.42^{+0.26+0.48}_{-0.16-0.24}$	$16.4^{+6.6+13.6}_{-4.5-6.4}$	$0.37^{+0.02+0.04}_{-0.03-0.04}$
Prior $v_c = 240$ km/s	240	511^{+48}_{-35}	$1.92^{+1.85}_{-0.82}$	$7.8^{+3.8}_{-2.2}$	$0.43^{+0.05}_{-0.05}$
v_c free	196^{+26}_{-18}	537^{+44}_{-55}	$0.08^{+0.31}_{-0.07}$	$36.7^{+50.7}_{-19.0}$	$0.25^{+0.14}_{-0.12}$

Prior on v_c in RAVE 2014

Phys.Rev.D 91, 023510 (2015)



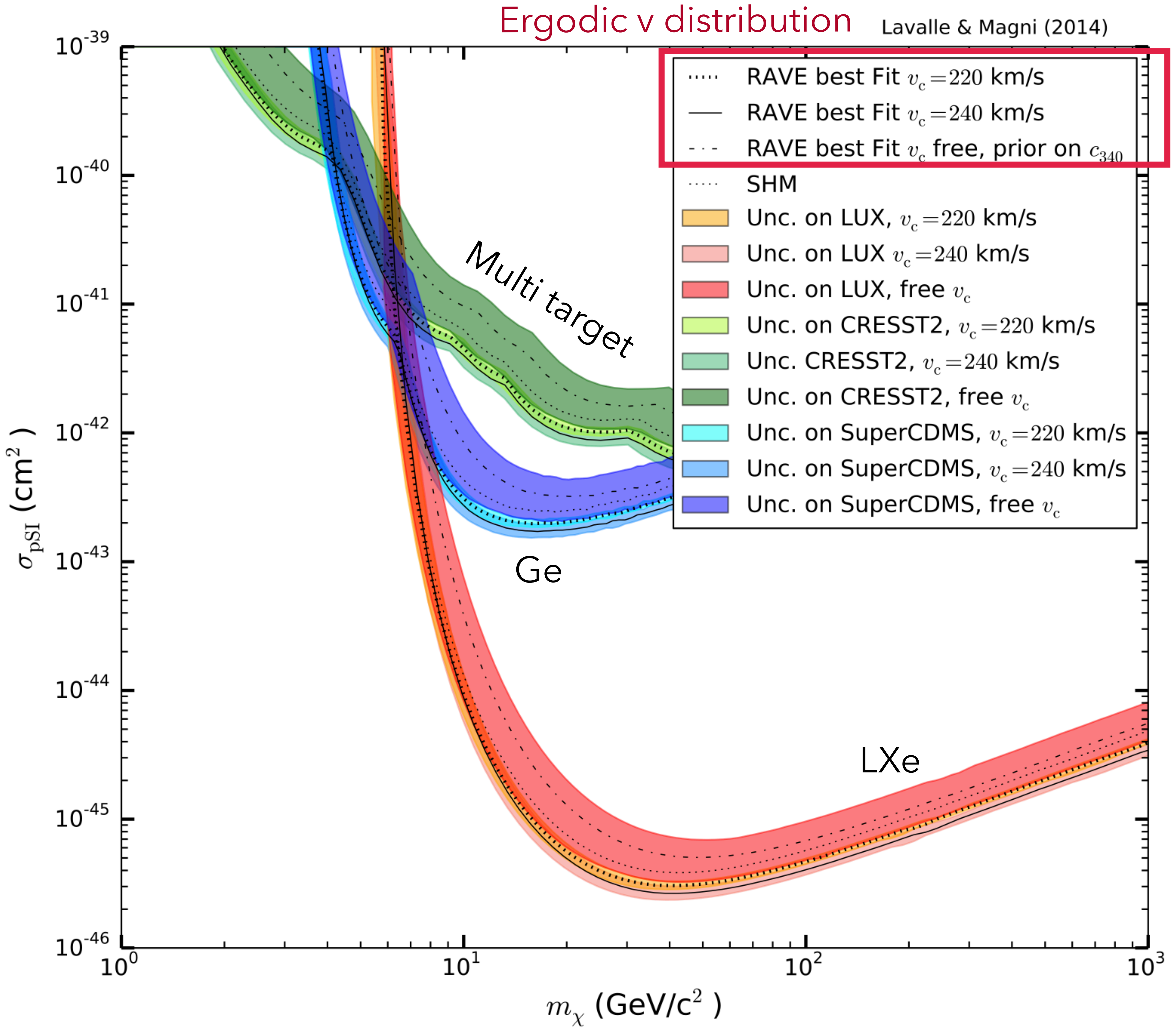
iso-DM density curves

FIG. 1: P14 likelihood results converted in the plane $v_{\rm esc}$-v_c. See text for details.

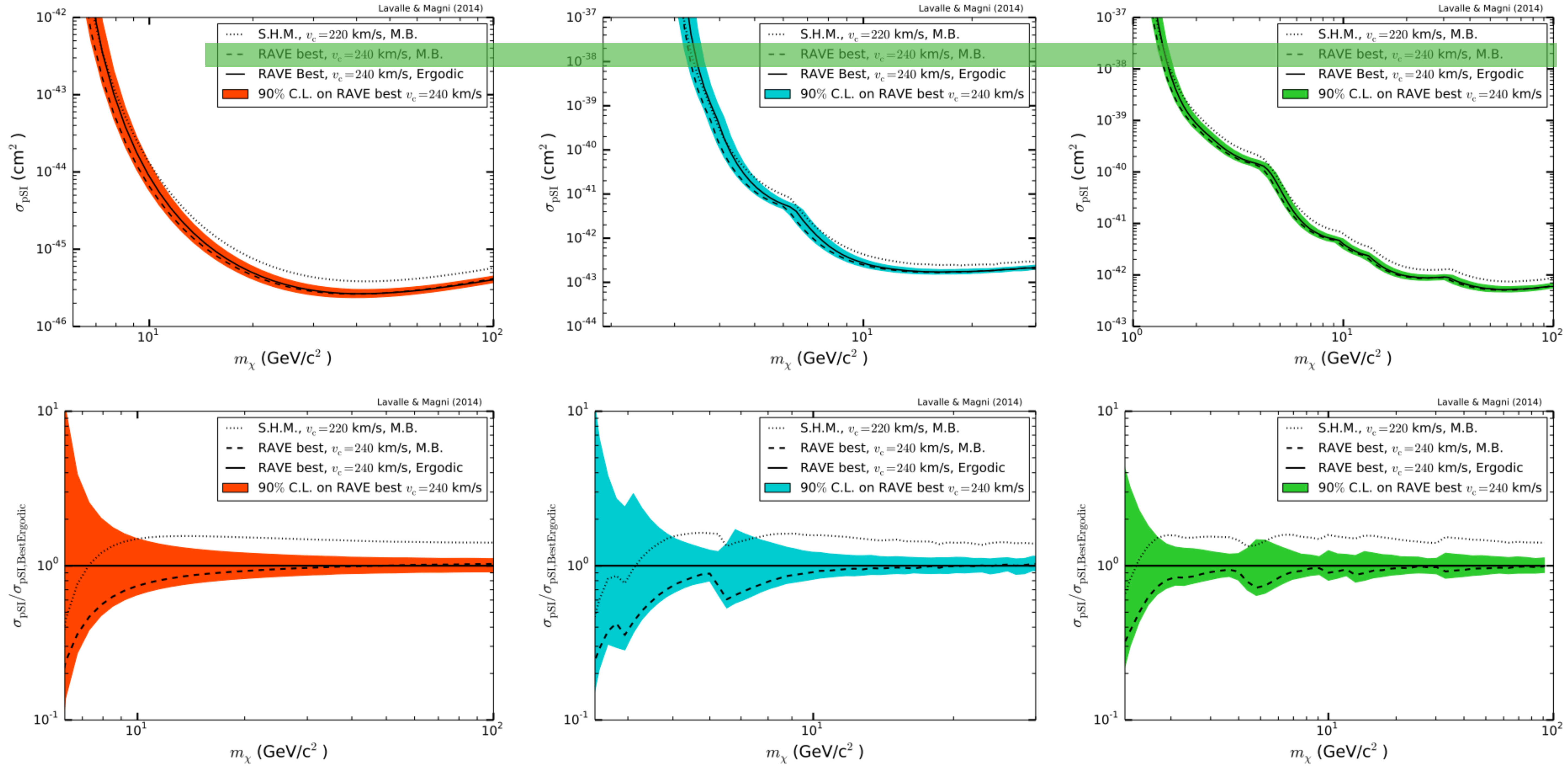
- ➡ v_c-free case includes a prior on the concentration parameter which affects the (low) result
- ➡ Beyond consistent sets: ergodic f(v) instead of Maxwell-Boltzmann (MB) for spherically symmetric systems

Coherent sets of astrophysical parameters

From Lavalle & Magni



Equivalent of green band slide 43



- ➡ SHM is the most conservative model (wrt ergodic and MB + RAVE best set vc = 240km/s) to use on the limit for most masses
- ➡ Beyond this: relax the prior on the concentration

Simulated dark matter halos

Back up

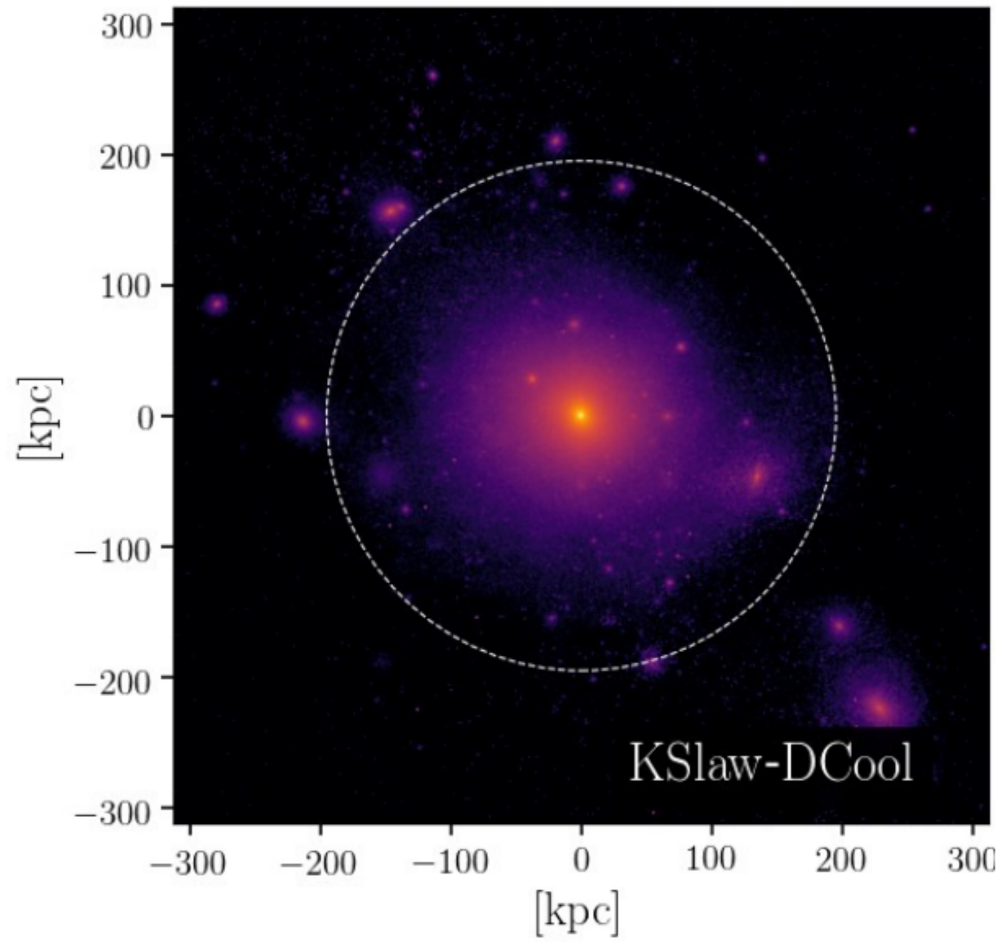
Cosmological simulations

Model gravitational interactions across time with a set of initial conditions (that are optimized)

The resolution of the simulation is increased in the Lagrangian volume after the first round of simulation

Mon. Not. Roy. Astron. Soc. 447 (2015)

Mochima



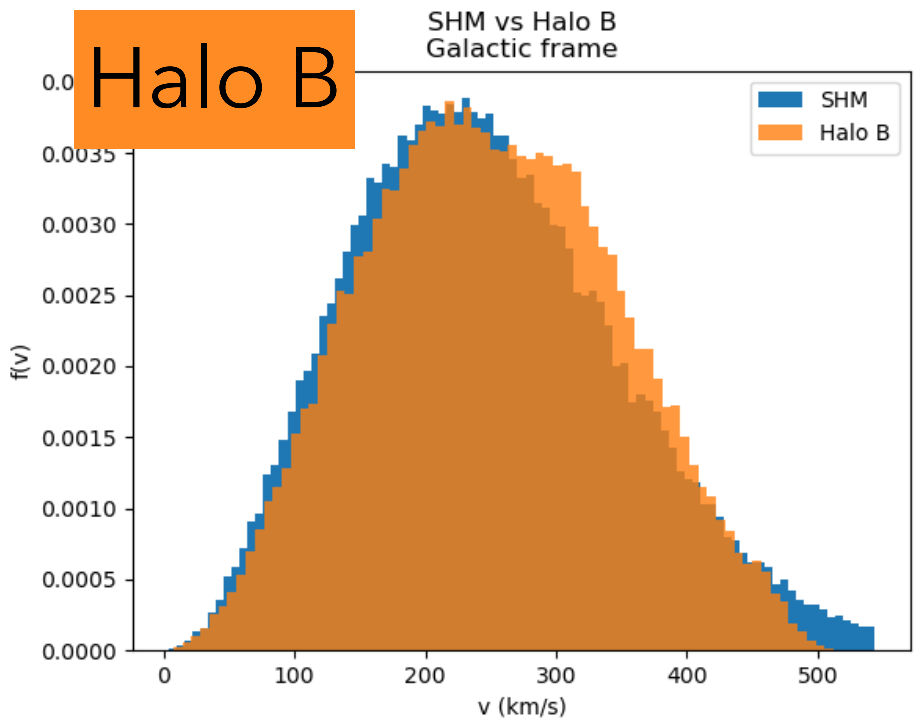
Result

Mass distribution

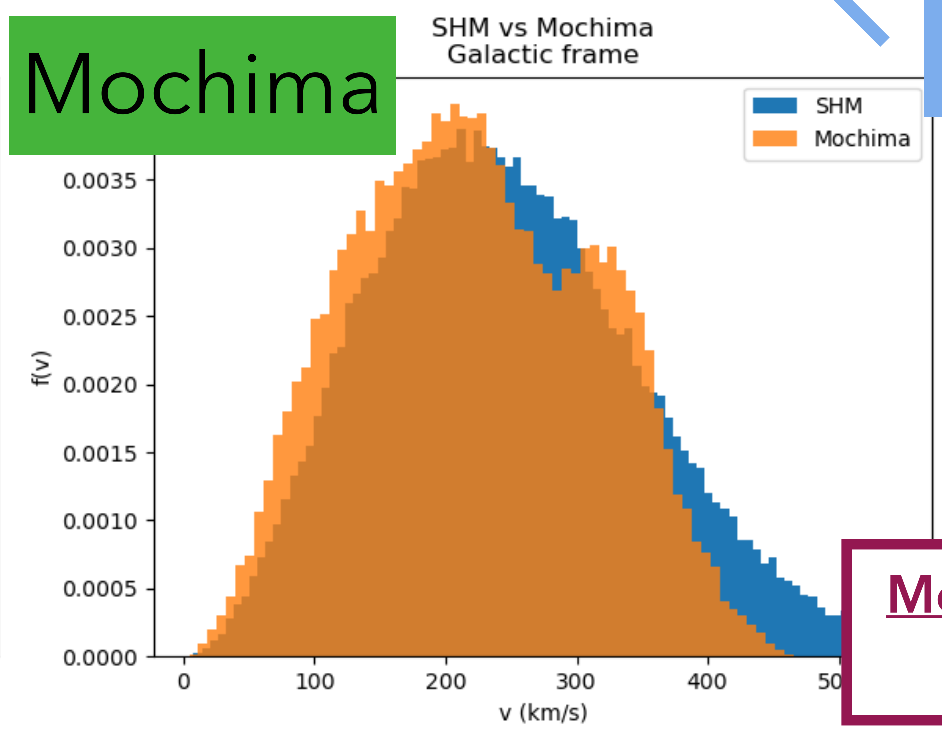
Velocity distribution

$v_{x,gal}, v_{y,gal}, v_{z,gal}$ in the galactic frame

Halo B



Mochima



Mon. Not. Roy. Astron. Soc. 501 (2021)

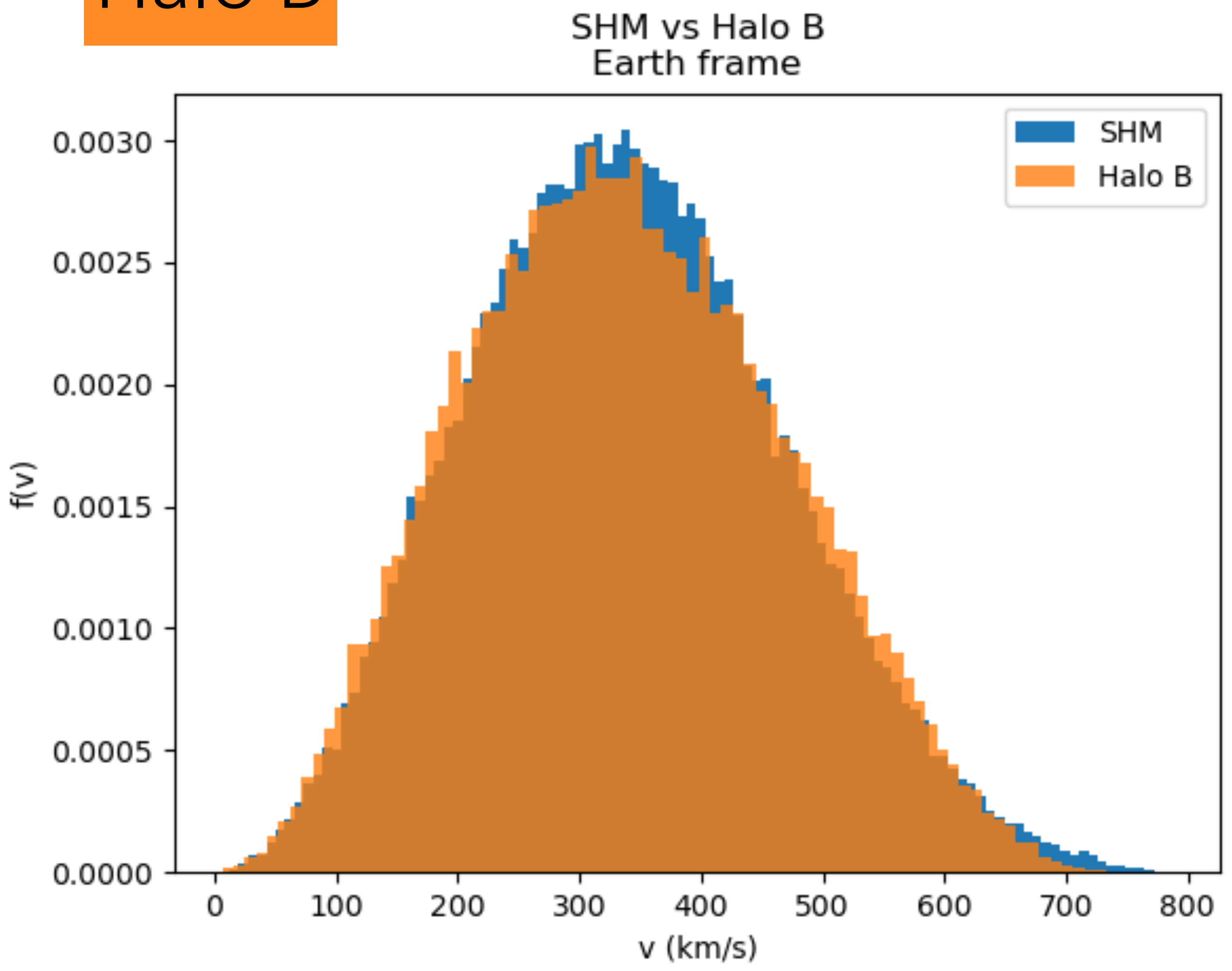
Change of frame

Galactic to Earth frame :

$$v_{i,lab} = v_{i,gal} - v_{i,\oplus}(t)$$

$$i = x, y, z$$

Halo B



Mochima