18th - 25th of March, 2023 - Rencontres de Moriond 2023 - EW session

The simulation of DarkSide-20k calibration

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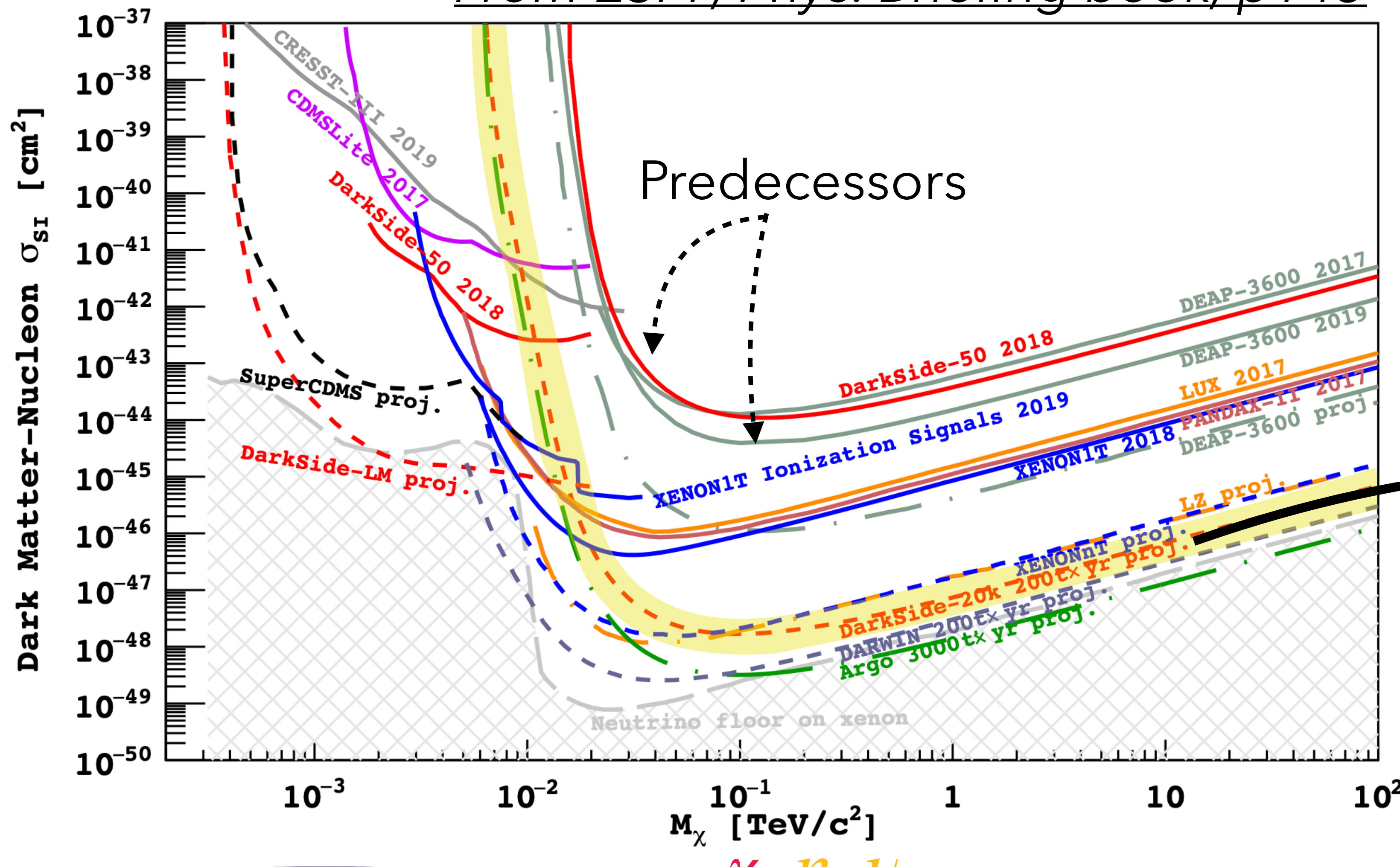
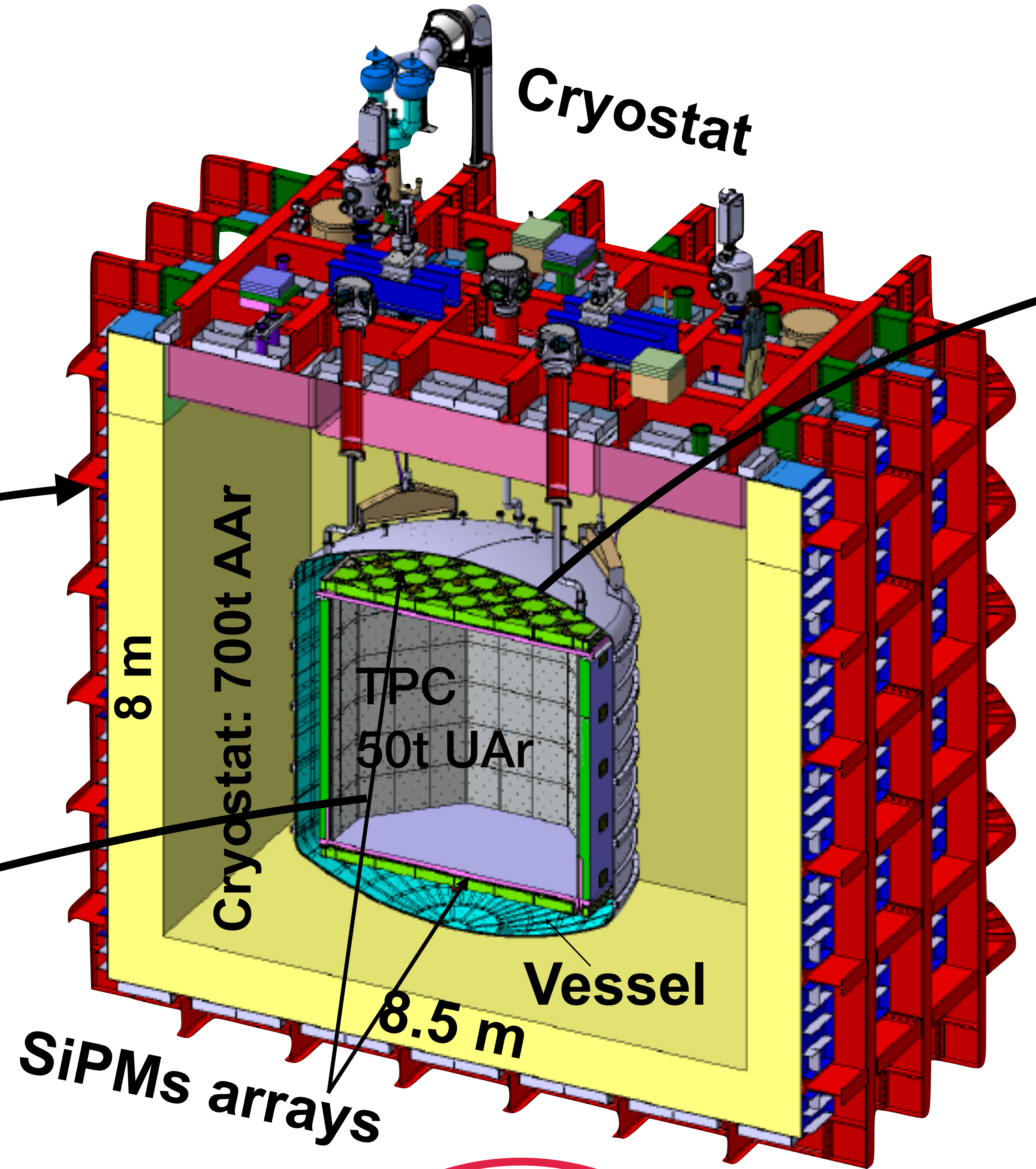
On behalf of the DarkSide-20k collaboration

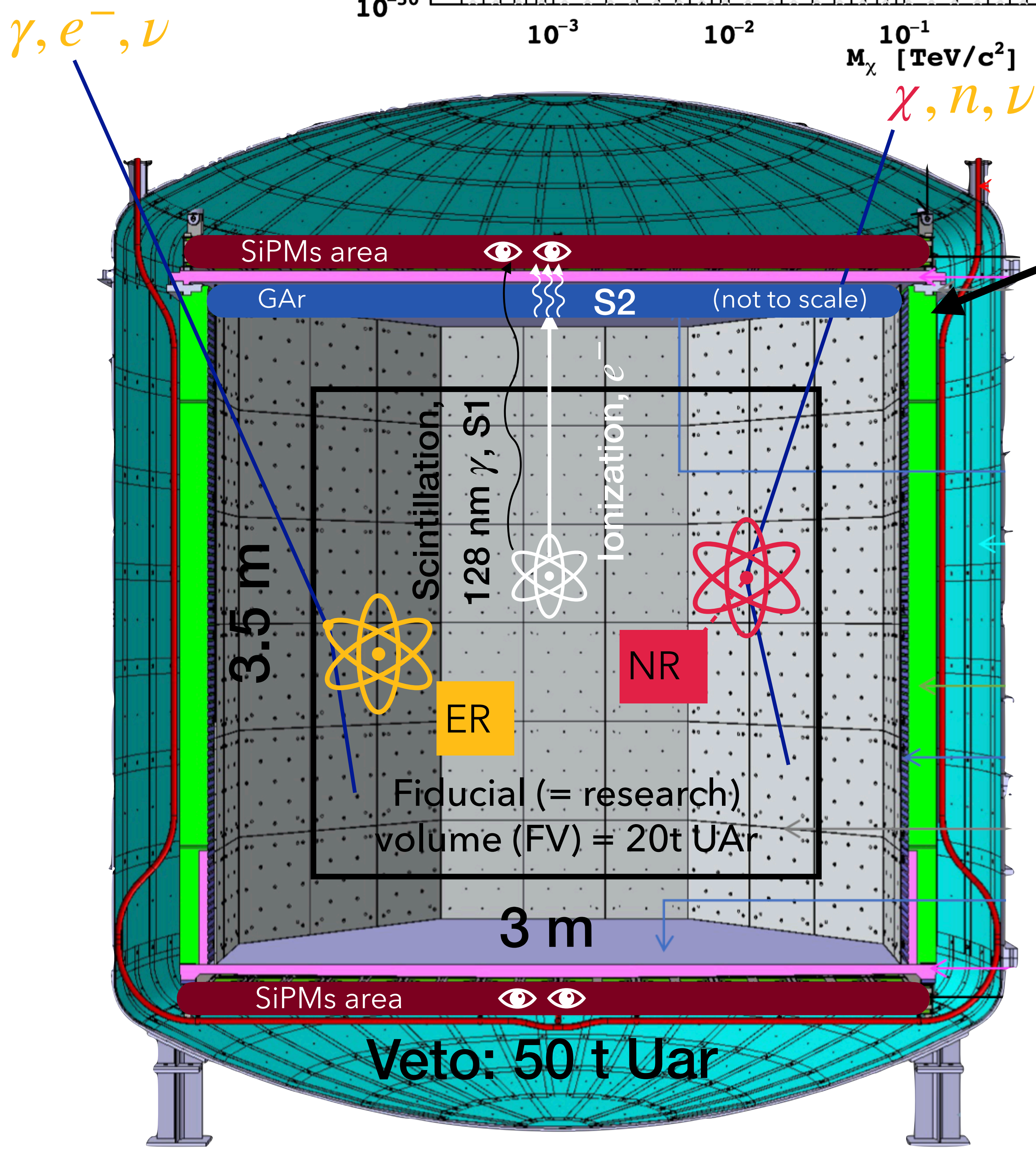
Thesis supervisor: Fabrice Hubaut (CPPM)

Direct search for WIMP dark matter with Darkside-20k

From ESPP, Phys. Briefing book, p145







Next generation experiment

- Start 2026 + 10 years of data taking
- Unique liquid argon experiment
- Double phase TPC technology
- Largest TPC ever built for DM search purpose
- Competitive at high WIMP mass (m_χ > 100 GeV)
- Competitive at low WIMP mass (m_χ < 5 GeV*)

*based on DS50 (2022) -> talk D. Franco

Signal characteristics

- Nuclear Recoil (NR)
- Single scatter (SS)
- Energy Region of Interest (RoI): $E \in [30 - 200]$ keV$_{nr}$

S1/S2 very different for ER and NR + argon : **Pulse Shape Discrimination** (PSD) => very good separation NR/ER

Background characteristics

- Photons & electrons (ER), neutrons (NR) from residual radioactivity
- Neutrinos (ER/NR)
- Multiple scatter & tagged by the veto
- DS20k budget = 0.1 NR events/10y (+3 neutrino events)

The calibration of DarkSide-20k

Design and stakes

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

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

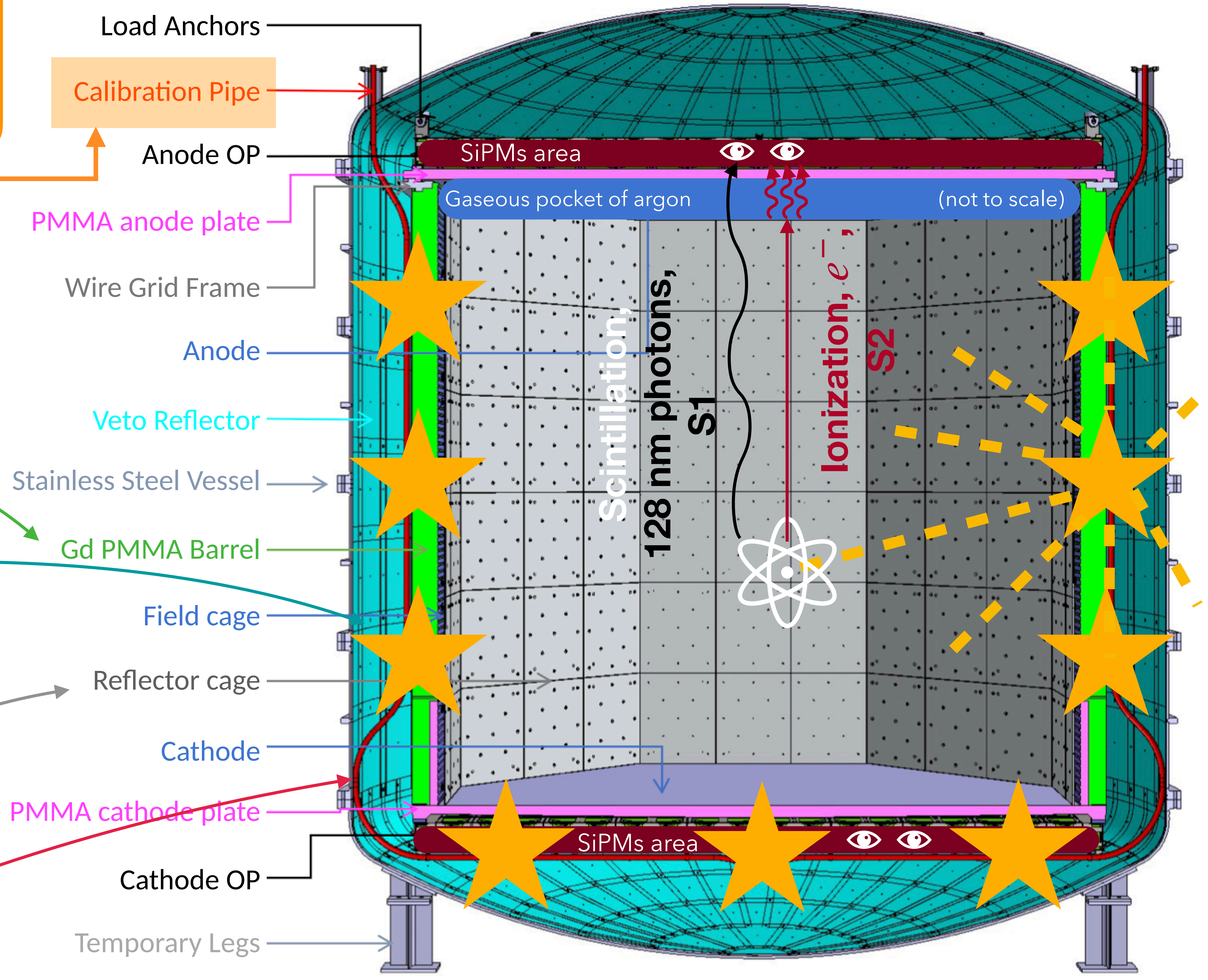
Circulated in calibration pipes

Simulations, with GEANT4-based software (g4ds)

Mock up tests

Potential issues

- The calibration is not efficient
- The pipes lower too much the Light Collection Efficiency in the veto buffer
- The material of the pipes induce too much background in the Inner detector
- The source circulation is difficult due to geometry or cold

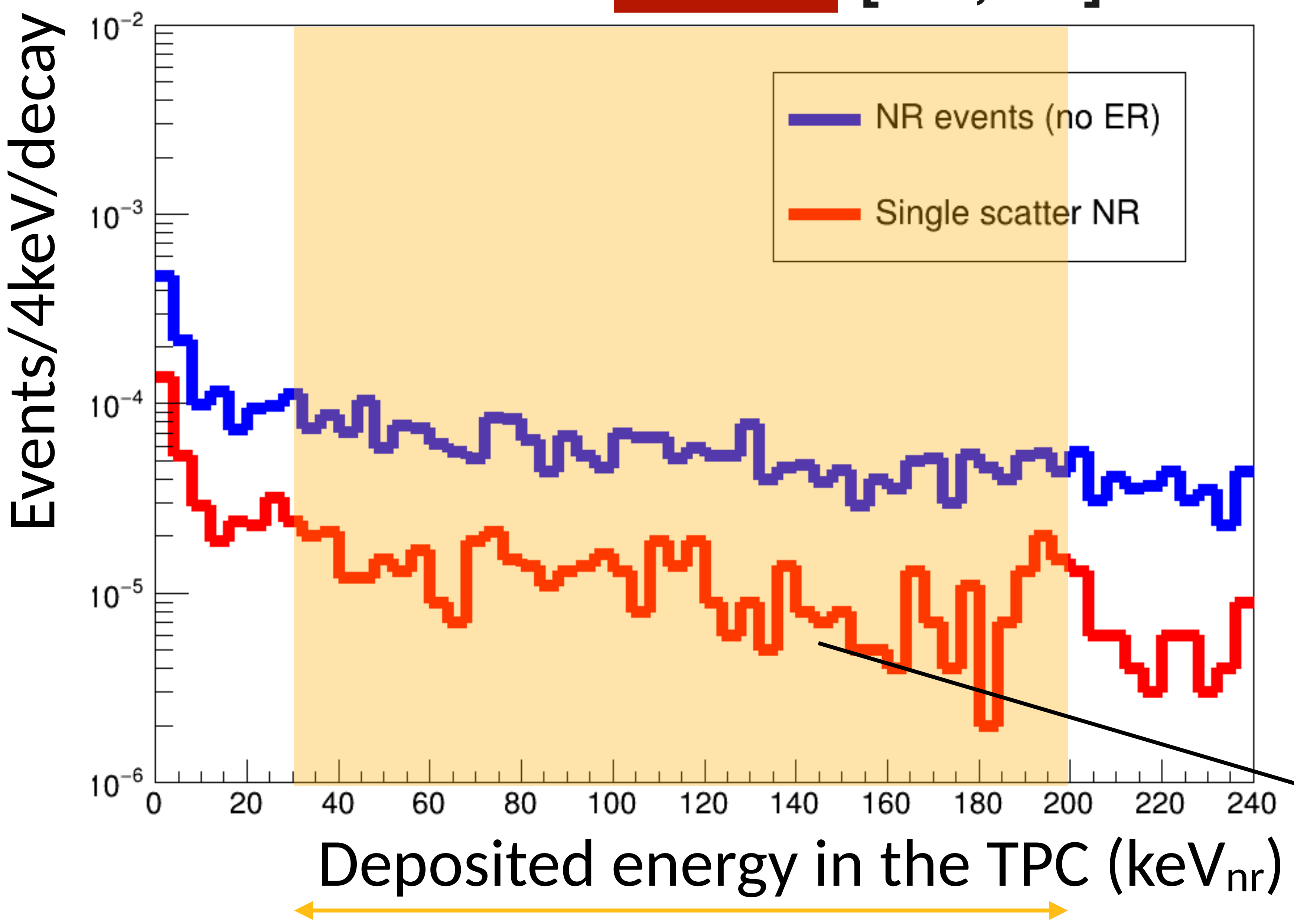


Simulation of the calibration - software = GEANT4-based

NR calibration

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

AmBe [0.2, 12] MeV

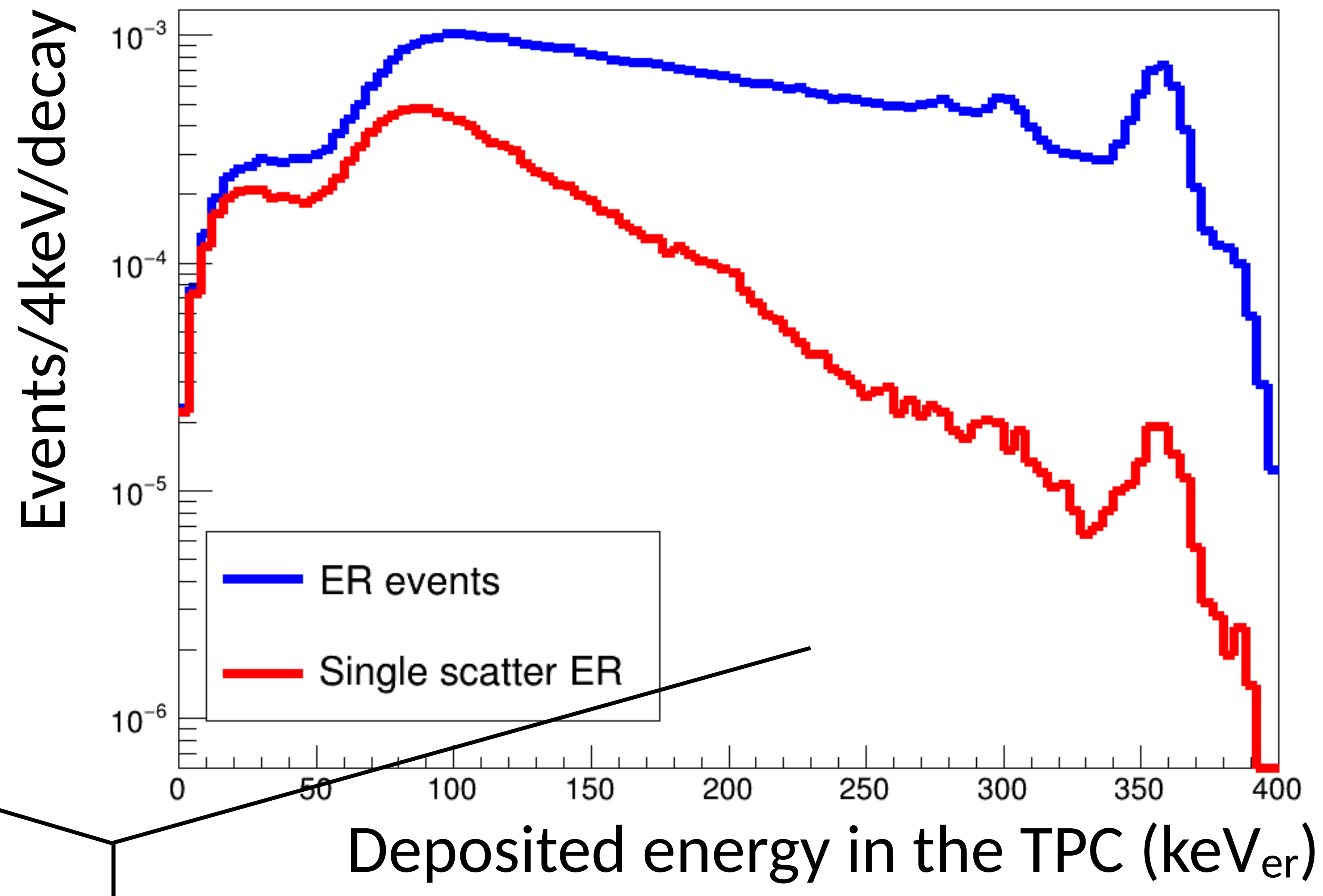


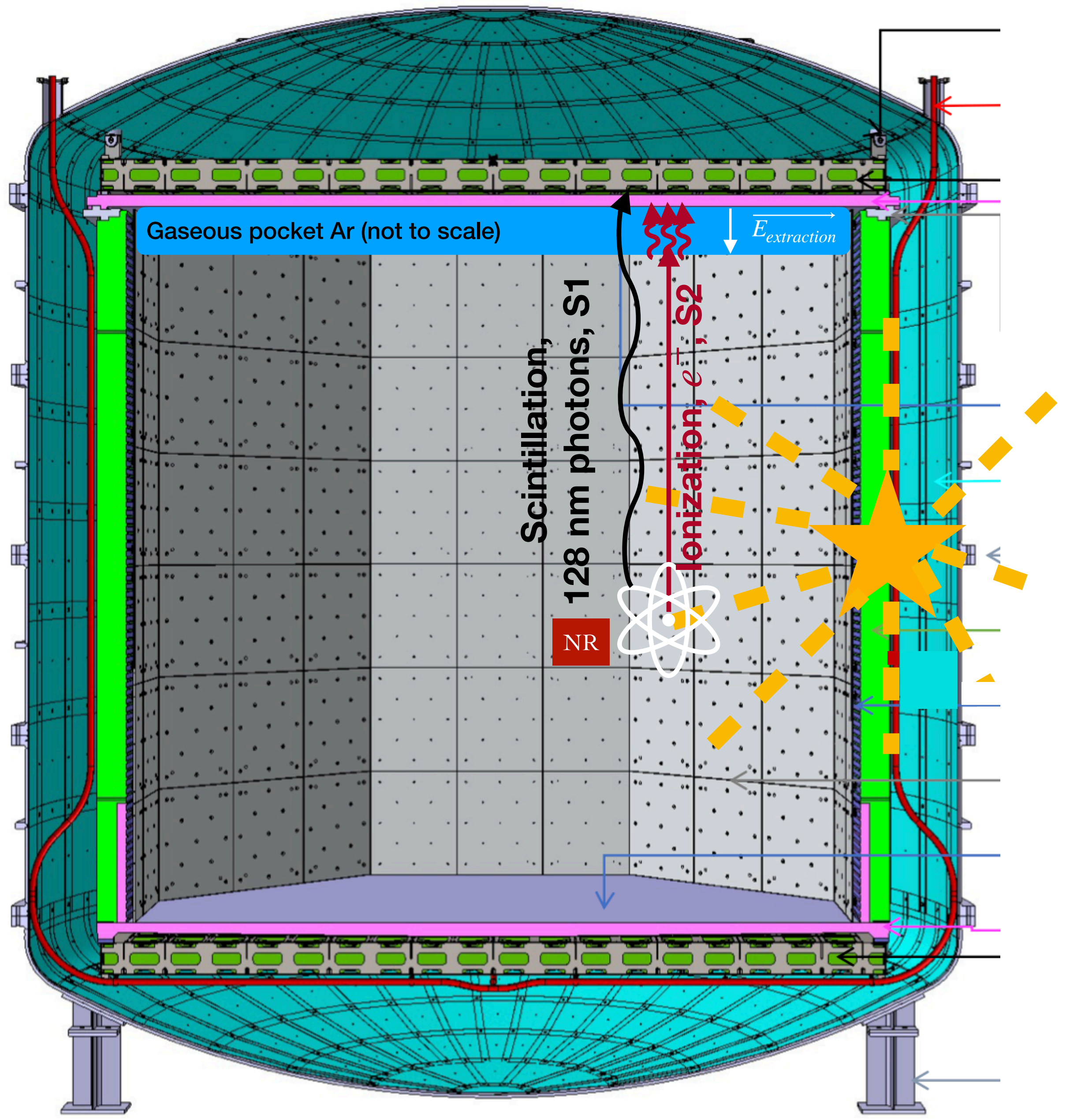
RoI

ER calibration

	^{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





Computation of rates of events/decay
+
Assumptions on the calibration runs (verified in the future with the mock up at CPPM)

→ Estimate of the time needed to perform the calibration program

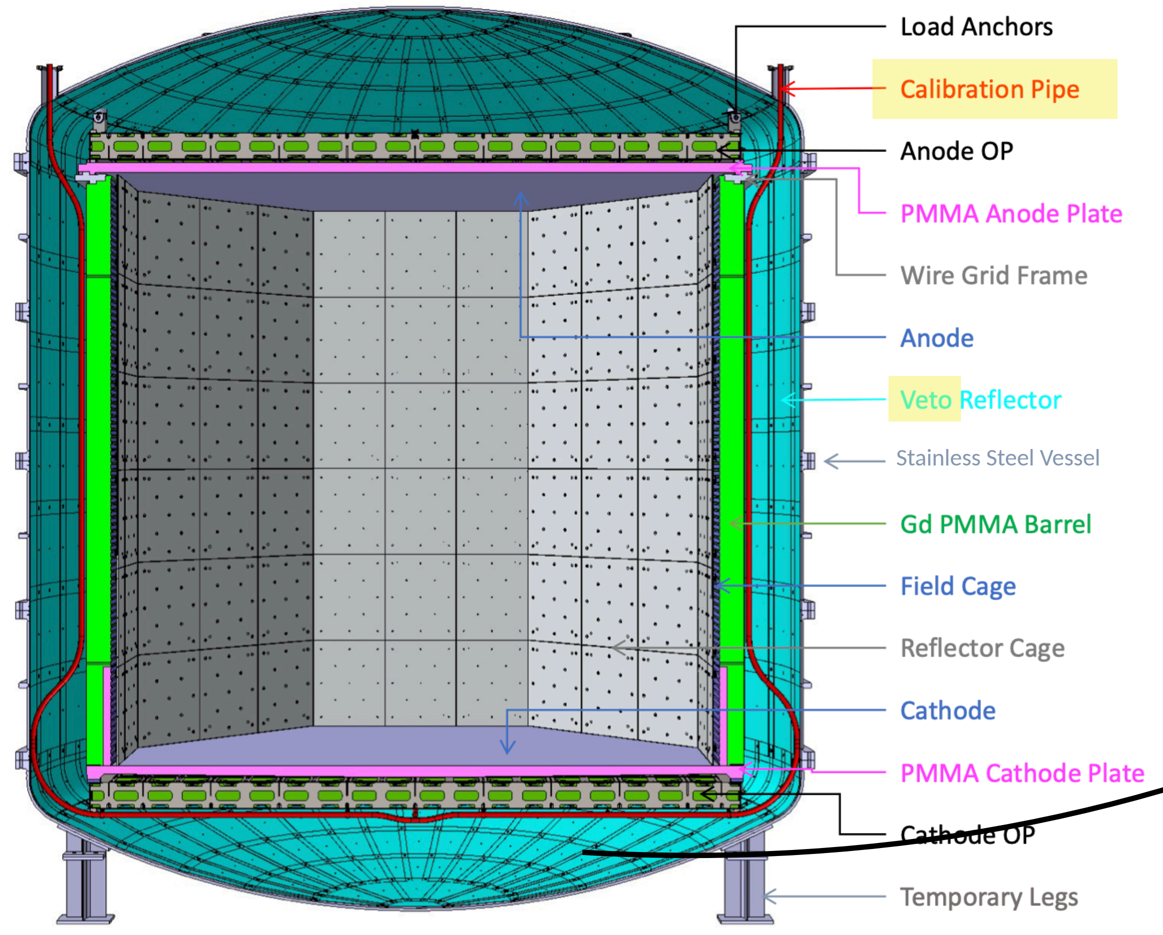
With 9 positions of calibration

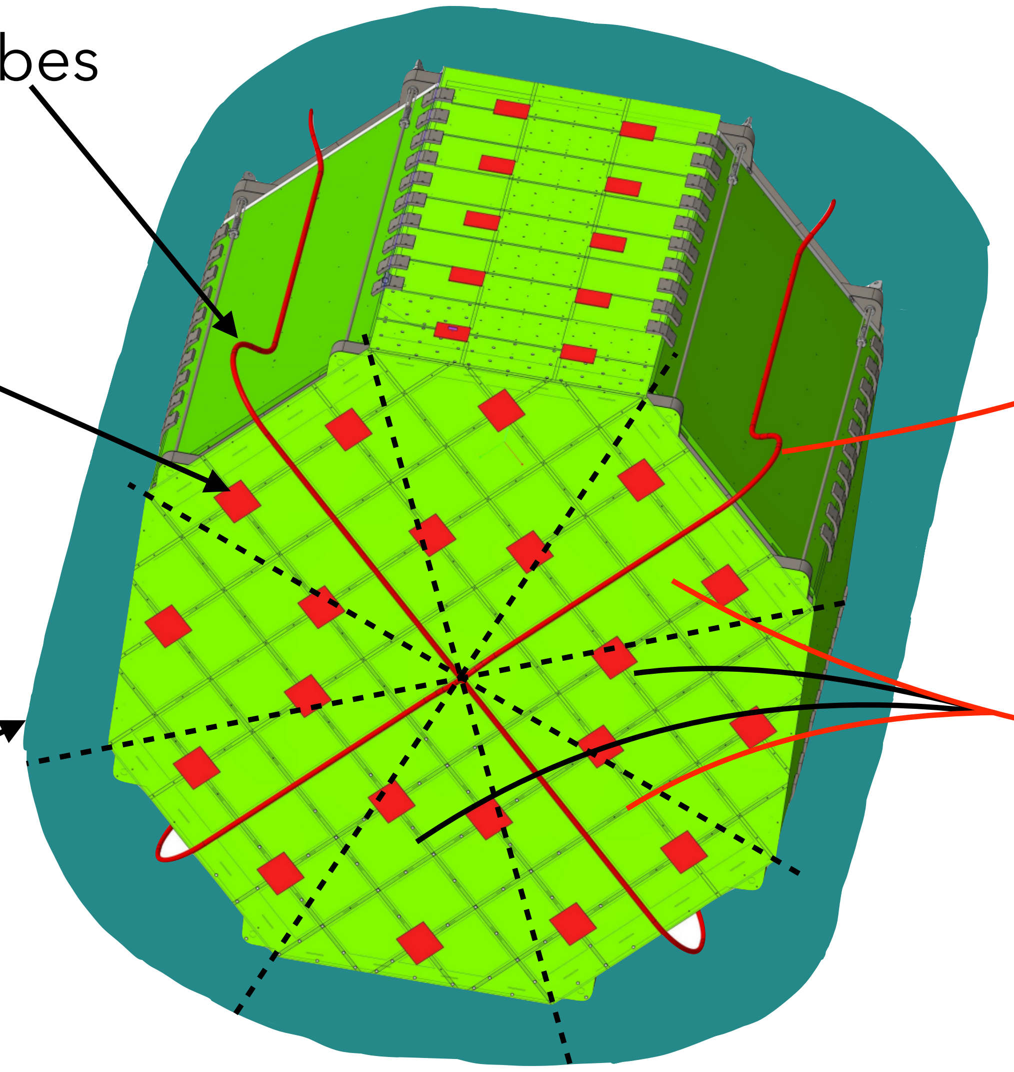
NR calibration (with neutrons) : 15 days

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

Impact of the tubes on the detector

Veto's Light Collection Efficiency (LCE)





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

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)

$$\frac{LCE^{Full}_{without-pipes} - LCE^{Full}_{ESR}}{LCE^{Full}_{without-pipes}}$$

$$\frac{LCE^{Pipes-octants}_{without-pipes} - LCE^{Pipes-octants}_{ESR}}{LCE^{Pipes-octants}_{without-pipes}}$$

With **reflector-wrapped** stainless steel tubes

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

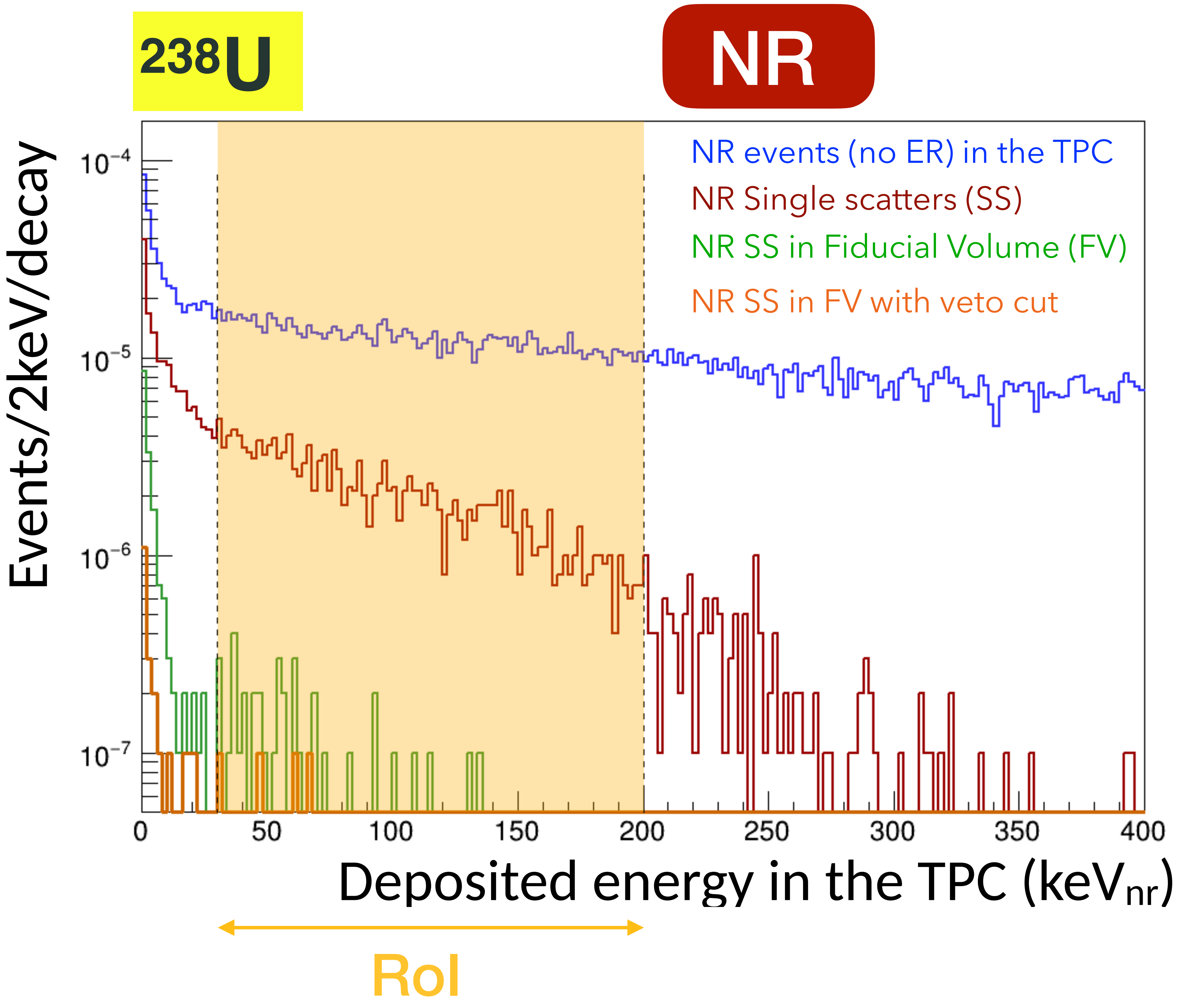
Impact of the tubes on the detector

Background induced in the veto and in the TPC

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



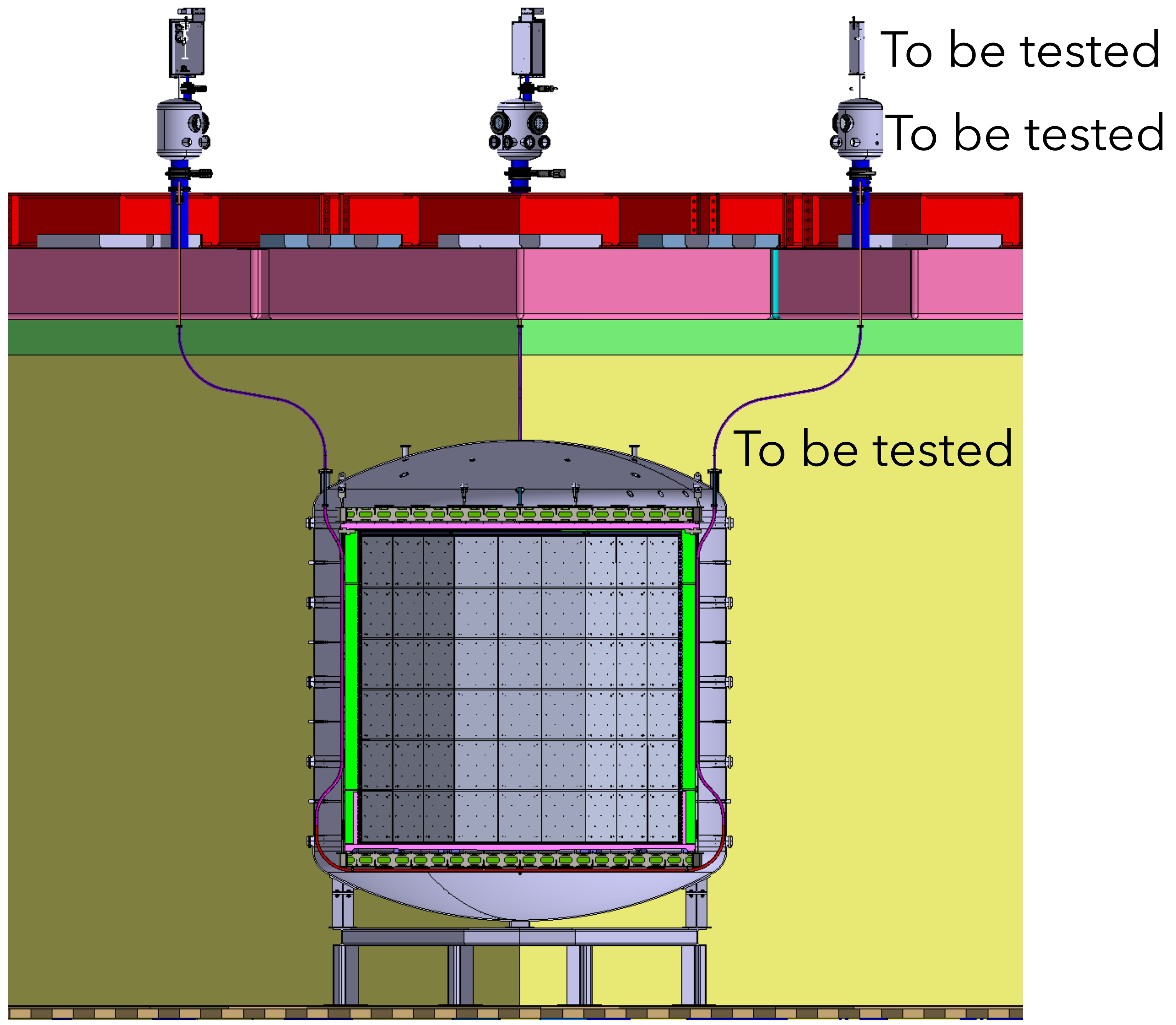
	^{238}U up	^{238}U mid	^{238}U low	^{232}Th	^{235}U
NR bknd / 10 years (200 t.y.)	4.0e-9	1.3e-6	4.0e-9	5.7e-6	6.0e-8

- 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)**

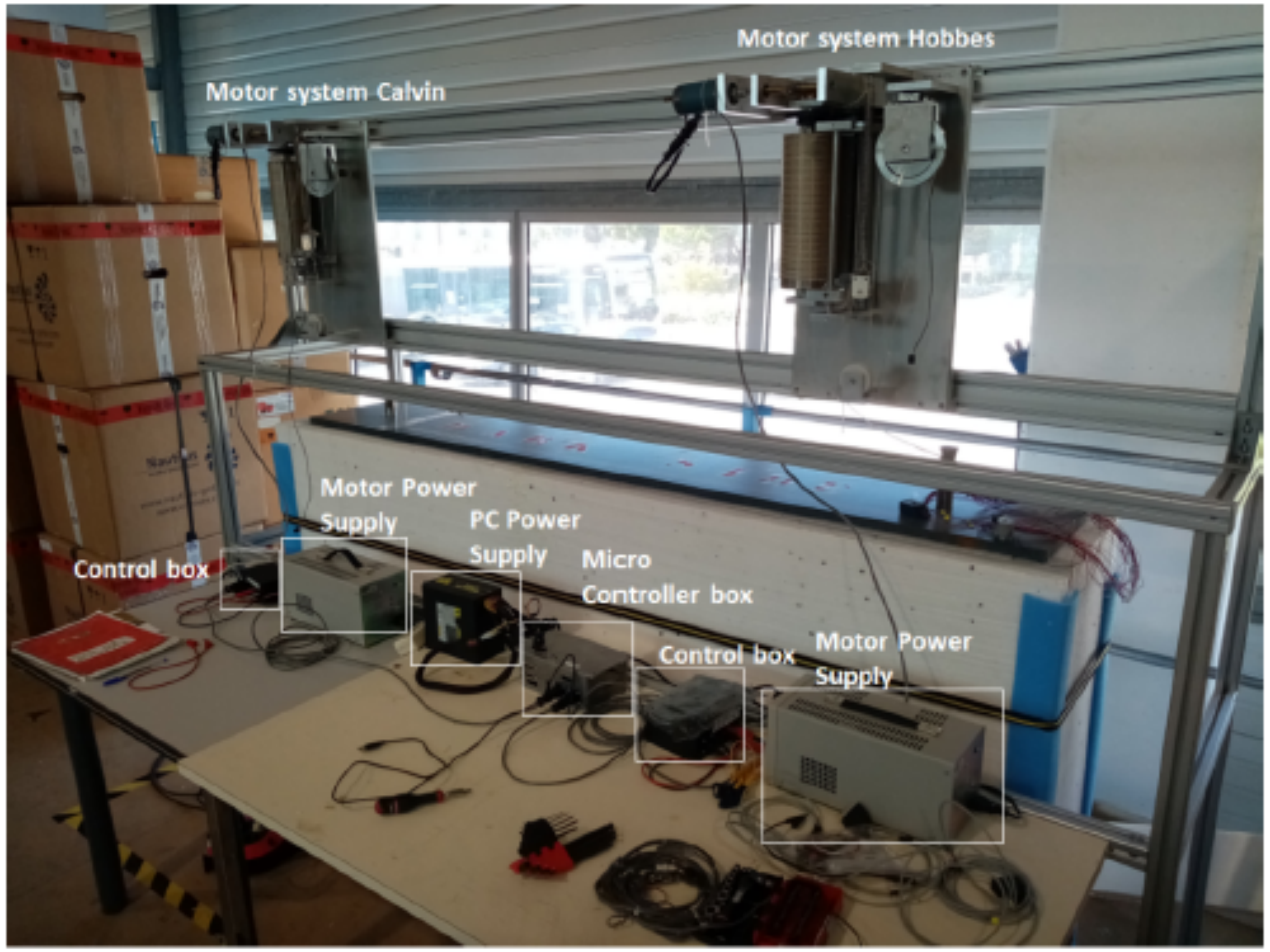
Conclusion and outlook

- Simulations allowed to optimize and validate the design of the calibration system

- In 2023, mock up to test the mechanical feasibility at cold

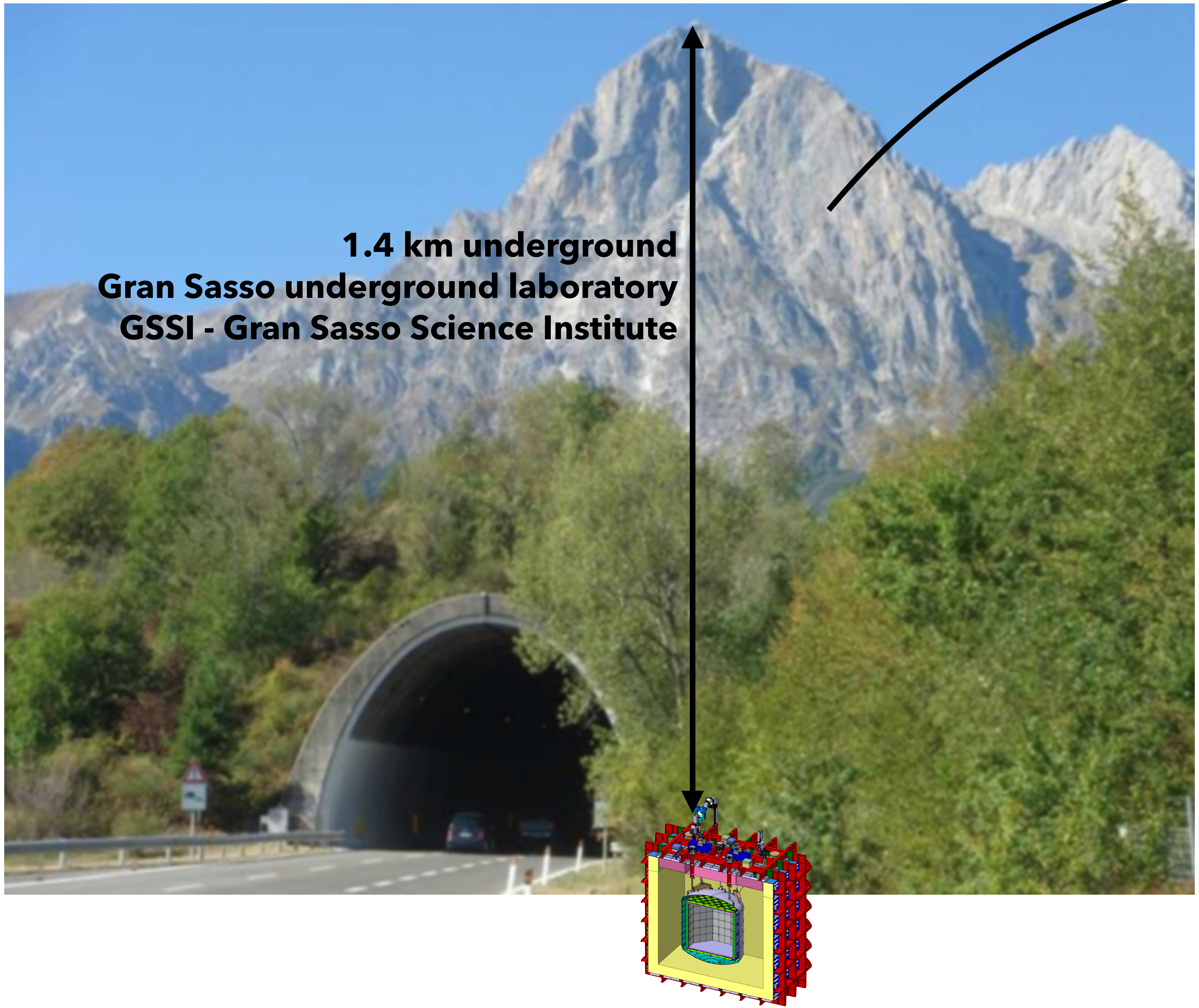


A mock up calibration system



Back up

Cosmic rays (μ) shielding



The inner detector
100t of UAr

+ purified

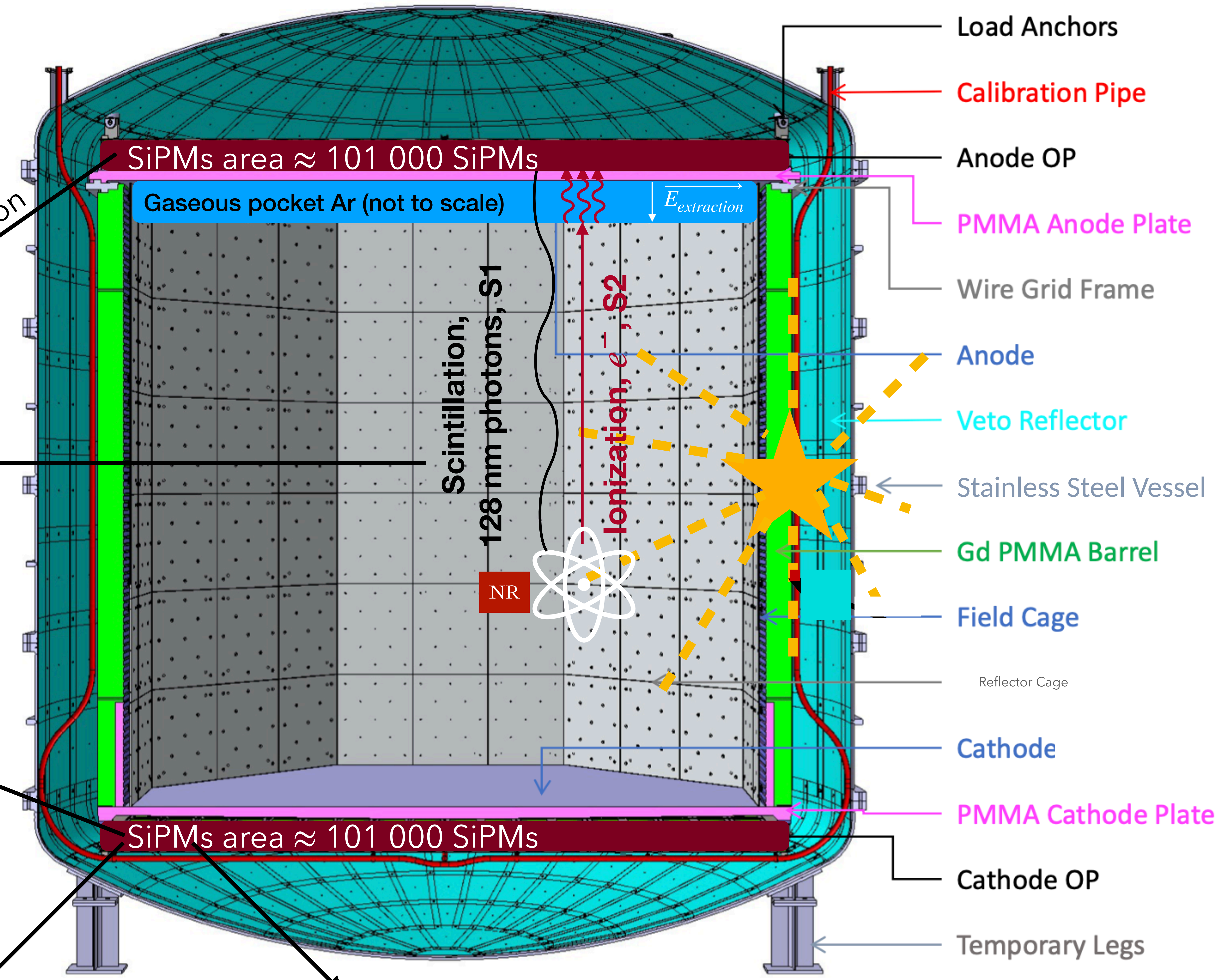
^{40}Ar depleted in ^{39}Ar*
Residual activity
of ^{39}Ar* : 0.73 mBq/kg (based on DS-50)

50 t TPC **50 t veto**

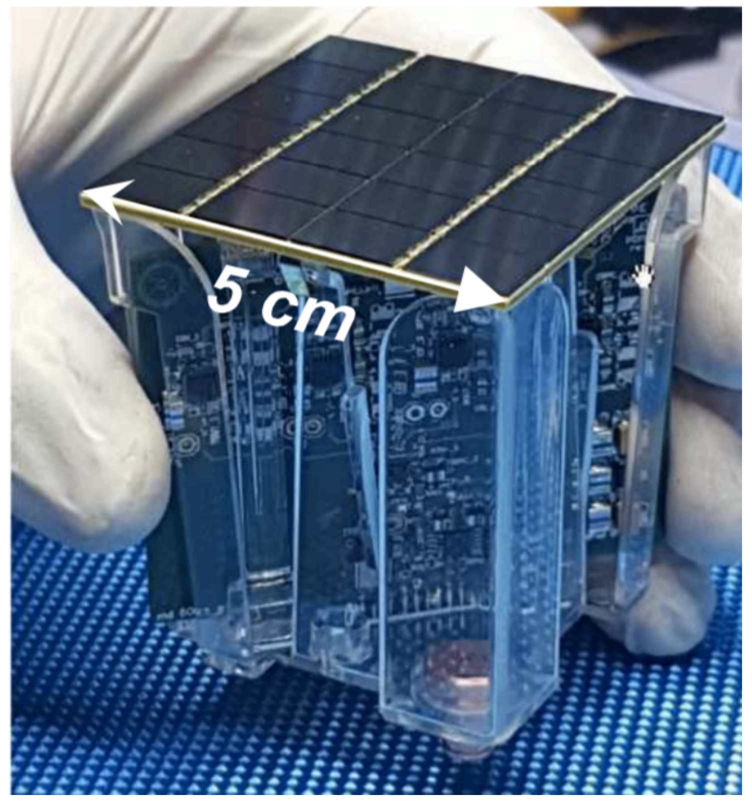
2D array -> x-y reconstruction

3D position reconstruction

Drift time -> z coord.



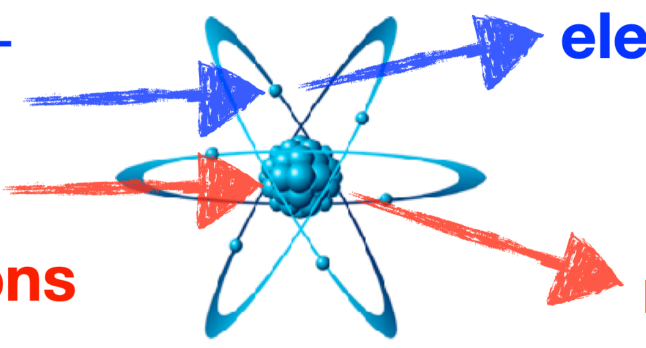
1 PDM = 6x4 SiPMs



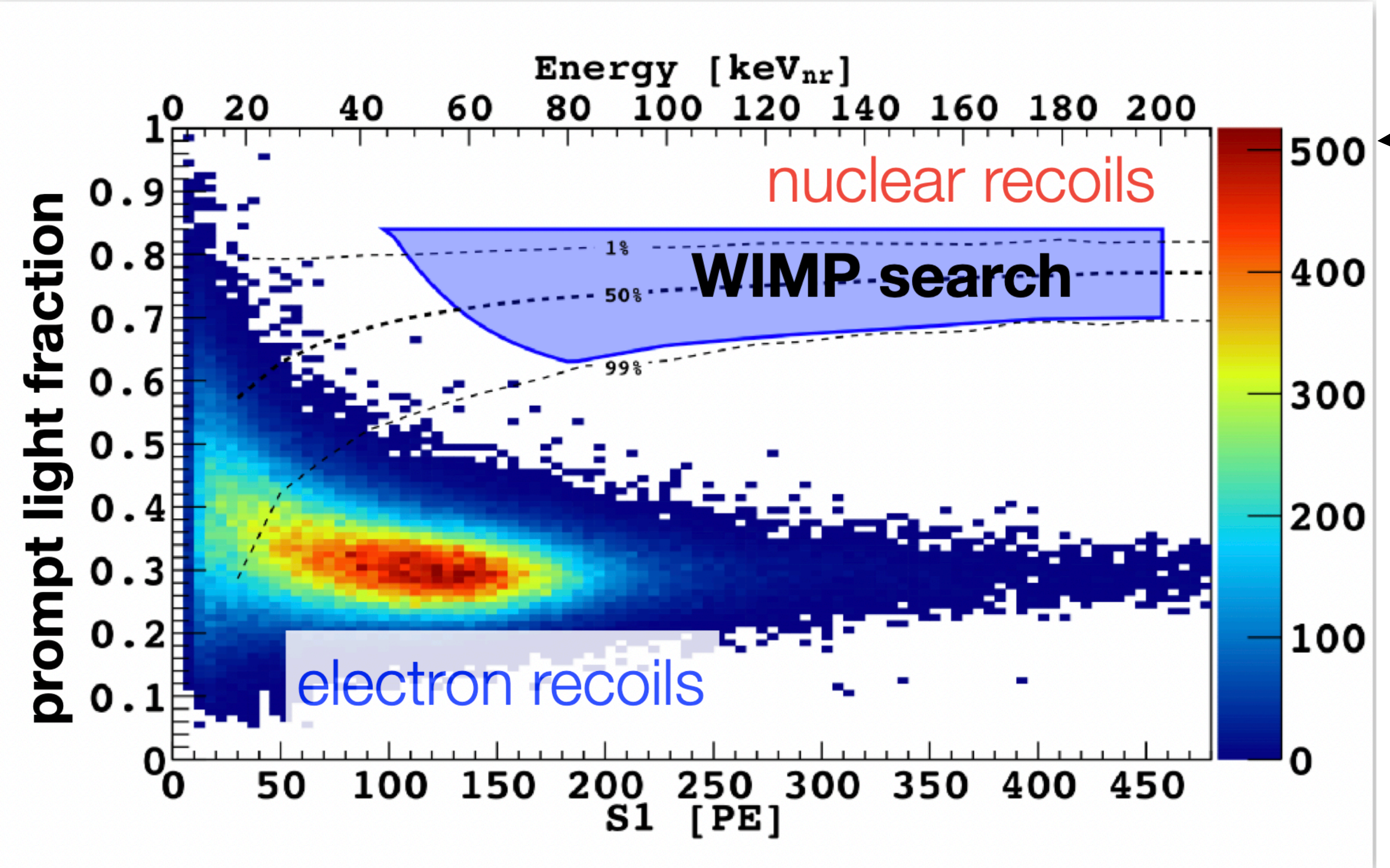
1 SiPM ≈ 95 000 SPADs
Single Photon Avalanche Diode

SiPM specifications: SNR > 8,
O(ns) time resolution, $\epsilon_{PD} > 40\%$

WIMP signal characteristics



LXe doesn't have this property to a measurable-enough magnitude



Allows an excellent signal/background rejection

Fast

Slow

NR : mostly fast // ER : both fast and slow

S1

LAr ✓✓✓

2 types of signals :
Ionisation and Scintillation

S2

Extraction with E_e

N_I → Ionisation → Electro-luminescence

Recombinaison

S2

E_0 → N_{Ex} → Scintillation

S1

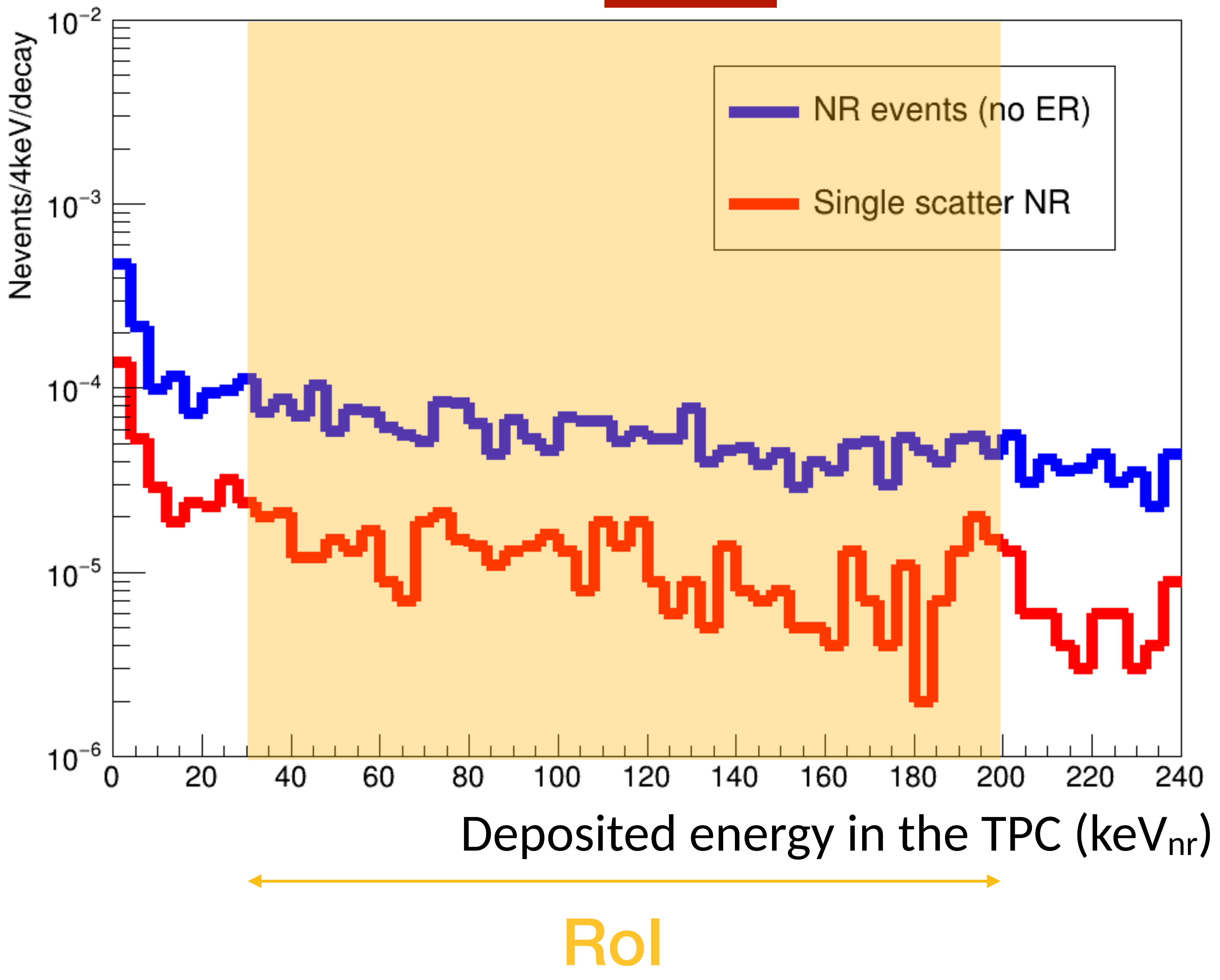
Heat

$$\frac{S2}{S1}_{ER(\gamma)} >> \frac{S2}{S1}_{NR(WIMP)}$$

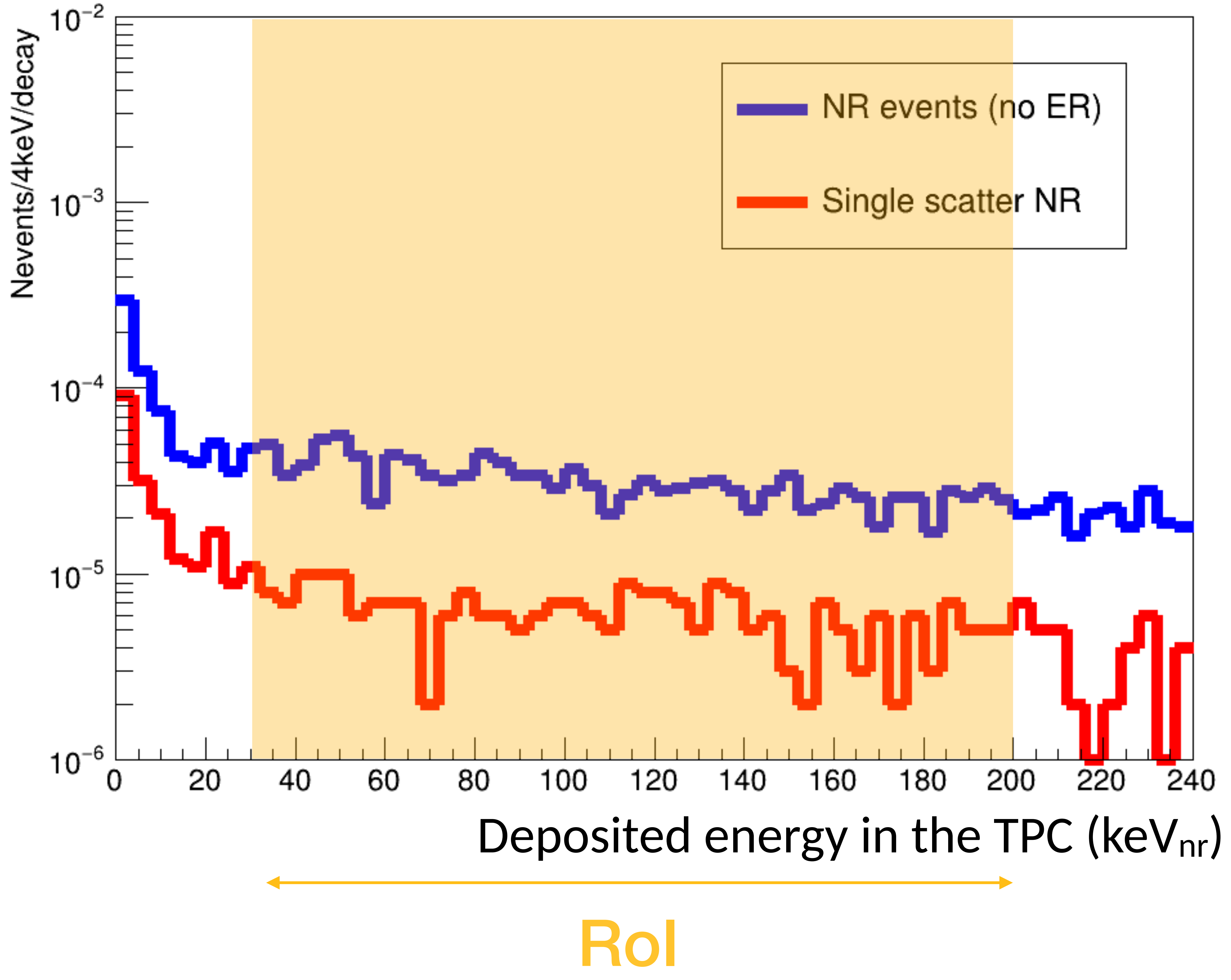
Simulation of the calibration - software = GEANT4-based

NR spectra

AmBe [0.2, 12] MeV



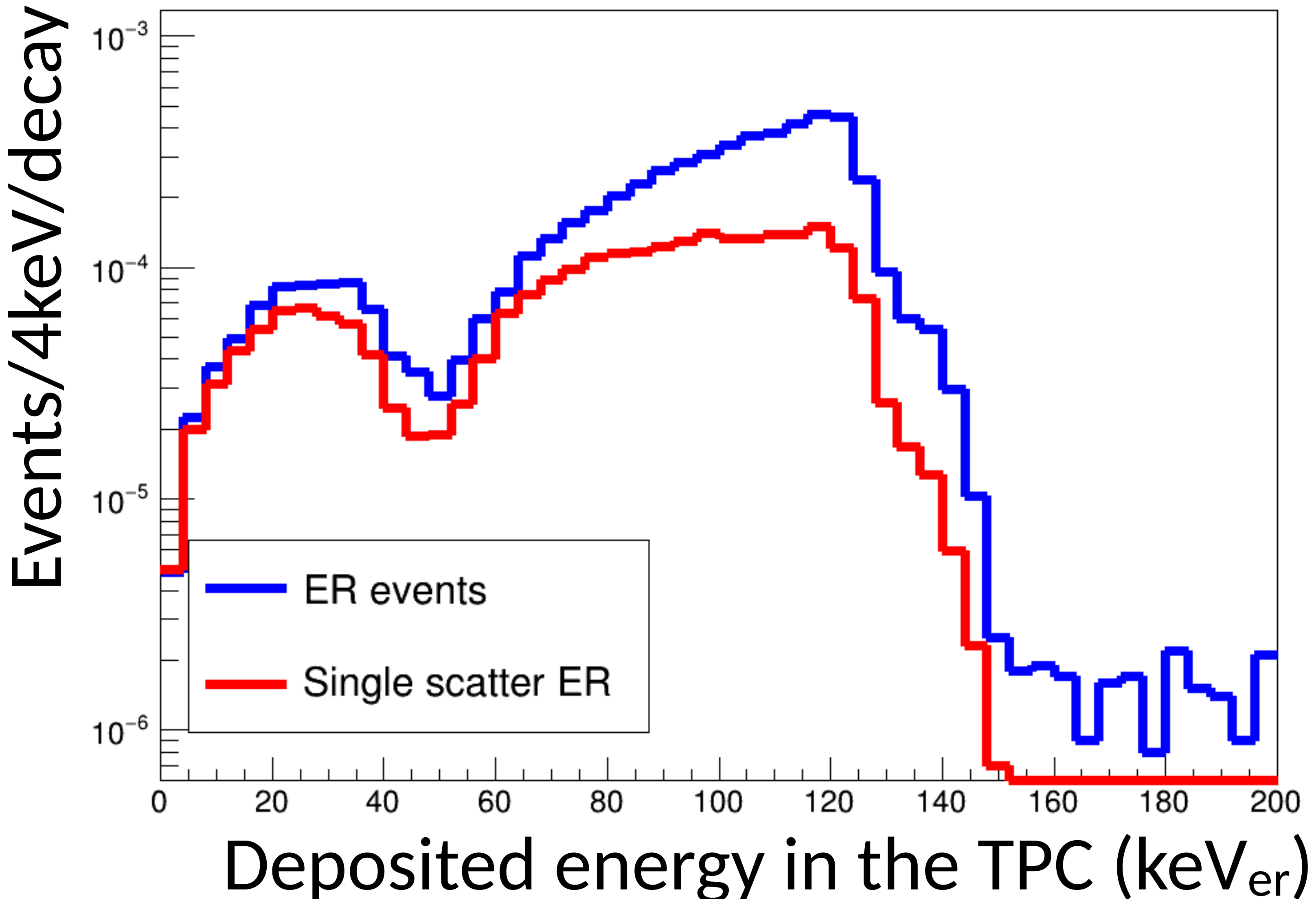
AmC [2, 7] MeV



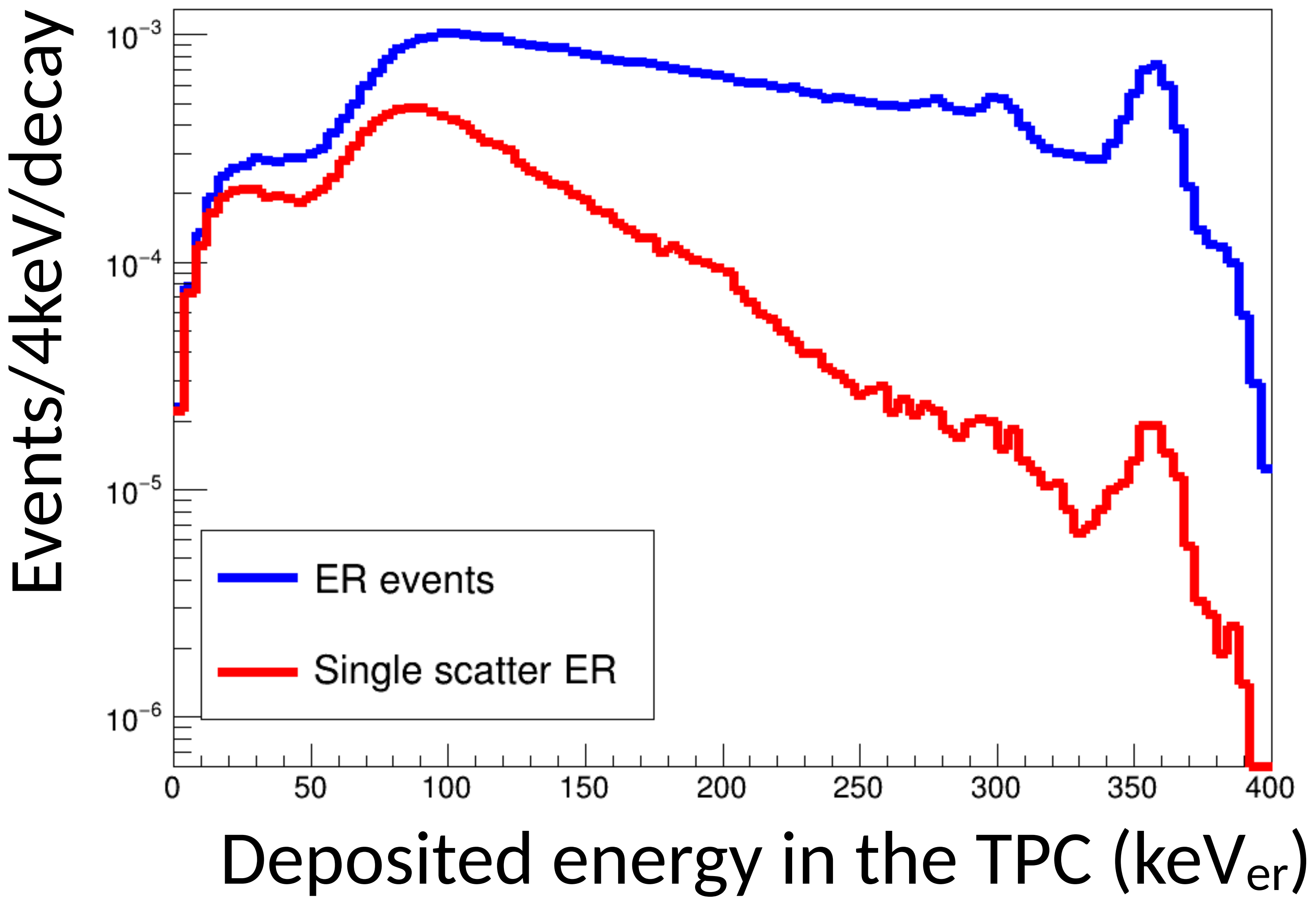
Simulation of the calibration - software = GEANT4-based

ER spectra

^{57}Co 122 keV



^{133}Ba 356 keV



^{22}Na 511 keV (& 1274 keV)