Background induced in the TPC by the calibration guide tube system

Material Meeting - 23 November 2021

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My work for the DS collaboration

- PhD student (2021-> 2024) under the supervision of Fabrice Hubaut (CPPM, Marseille, France)

- Current commitment on TPC calibration with guide tubes:

Presentation to the DS calibration working group

  - Hardware work on the guide tube system mock-up
    - → Data analysis
    - → Mostly first tests at room T° and at cold
  - Simulation of the TPC calibration with plan C configuration
    - → Energy spectra - photons and neutrons
    - → Rates of interesting events
  - Derivation of a TPC calibration strategy
    - → TPC calibration points' position optimisation
    - → Time estimation

➡ Simulation of the background (ER, NR) induced in the TPC by the calibration guide tube system

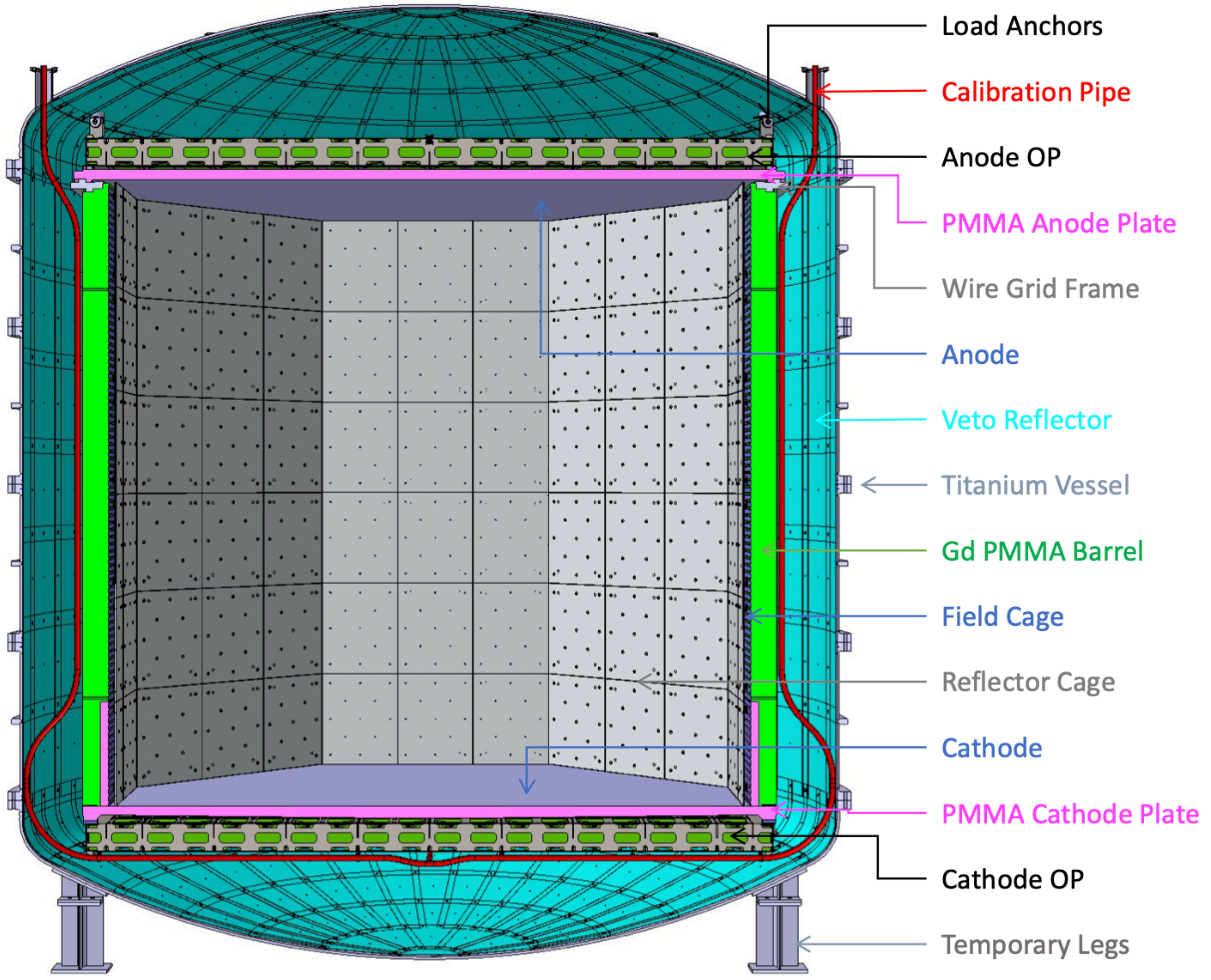
The calibration guide tube system

Fig from [TDR]

- System that enables the circulation of calibration radioactive sources around the TPC during the calibration runs

- The sources will be removed during the WIMP search data taking

- Tubes have a ø = 3 cm, are 1.5 mm thick and made with titanium (17 kg)



Background induced by tubes

Tubes made with titanium

- **Goal:** estimate ER and NR background induced in the TPC by radioactive contamination in calibration pipes

- **Methodology**
  - Simulate 10 Mevents (for each radio contaminant) with g4ds with full-chain radioactive decays (HP list for hadronic interactions)
  - Count number of events surviving cuts (if none, put a limit at <2.3 events)
    - ER background: single scatter in ROI (7.5 < E < 50 keVee) and fiducial volume (veto 70 cm in z, 30 cm in r)
    - NR background: single scatter in ROI (30 < E < 200 keVnr), fiducial volume (veto 70 cm in z, 30 cm in r) and veto (veto energy<200 keV for plan C)
  - Normalise to radioactive contamination of the titanium (from DS material group), mass of tubes (~17 kg for a density of 4.5 g/cm^3) and time exposure

- **Started from Alex Kish work and code (see INT calibration note)**
  - First : Reproduce his Plan A results assuming the tubes are ArDM Stainless Steel (which is the worst case scenario). Tubes: ø=3 cm, thick=1.5 mm, 3 (1) cm from TPC wall aside (below)
  - Include Plan C modeling of the guide tube in g4ds (Alex)
  - Produce results ER, NR for Plan C

Titanium contamination

Activity (mBq/kg) and radiogenic neutron yield per decay, as measured by DarkSide material WG

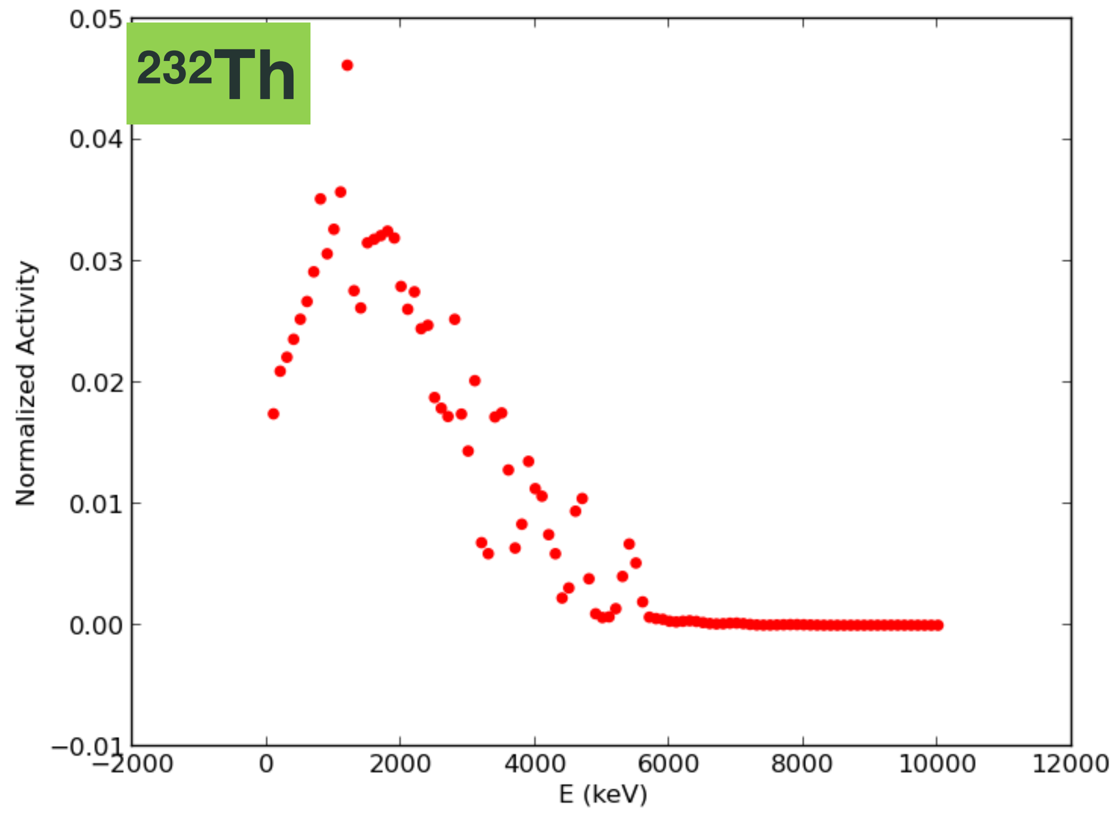
Source: TDR in preparation

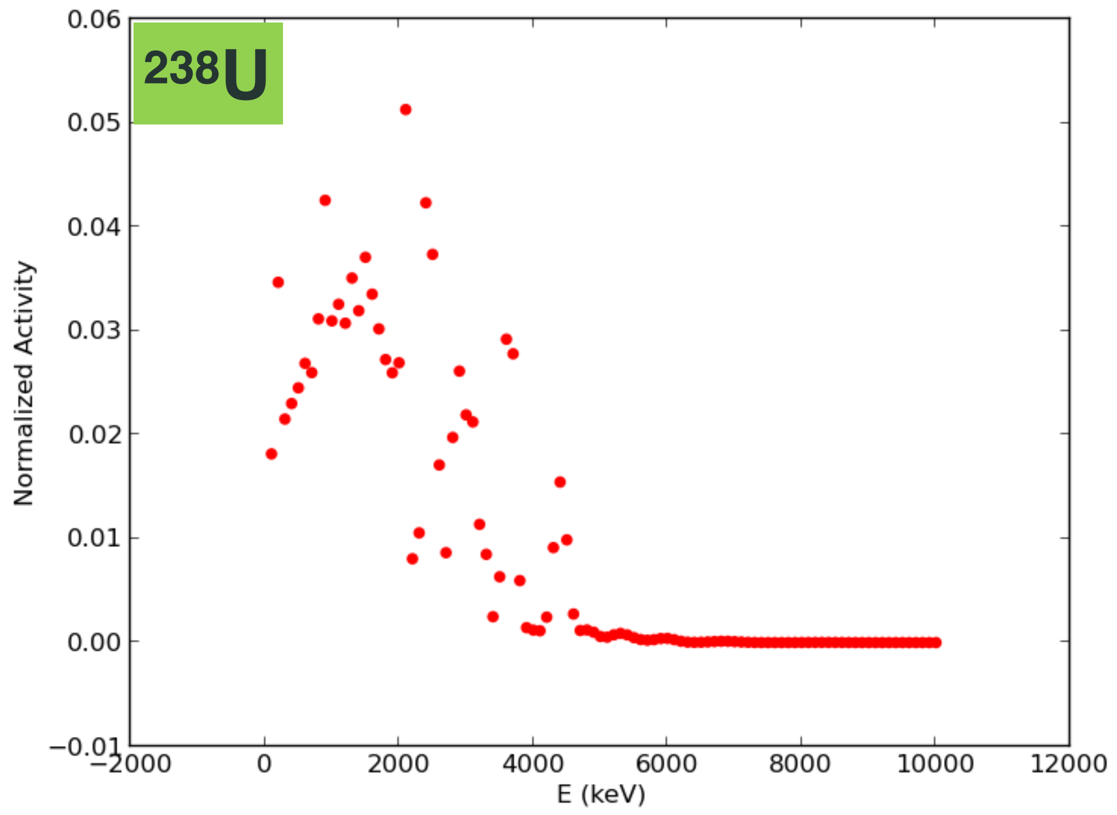
	^{238}U up	^{238}U mid	^{238}U low	^{232}Th	^{235}U	^{40}K	^{46}Sc
Activity (mBq/kg)	8	0.12	80	0.12	0.37	0.6	3.1
Neutron yield (n/decay)	4.9E-9	2.6E-6	1.6E-8	6.5E-6	2.6E-6	No	No

(from (alpha,n) reactions due to natural contamination in ^{232}Th, ^{238}U and ^{235}U and spontaneous fission of ^{238}U)

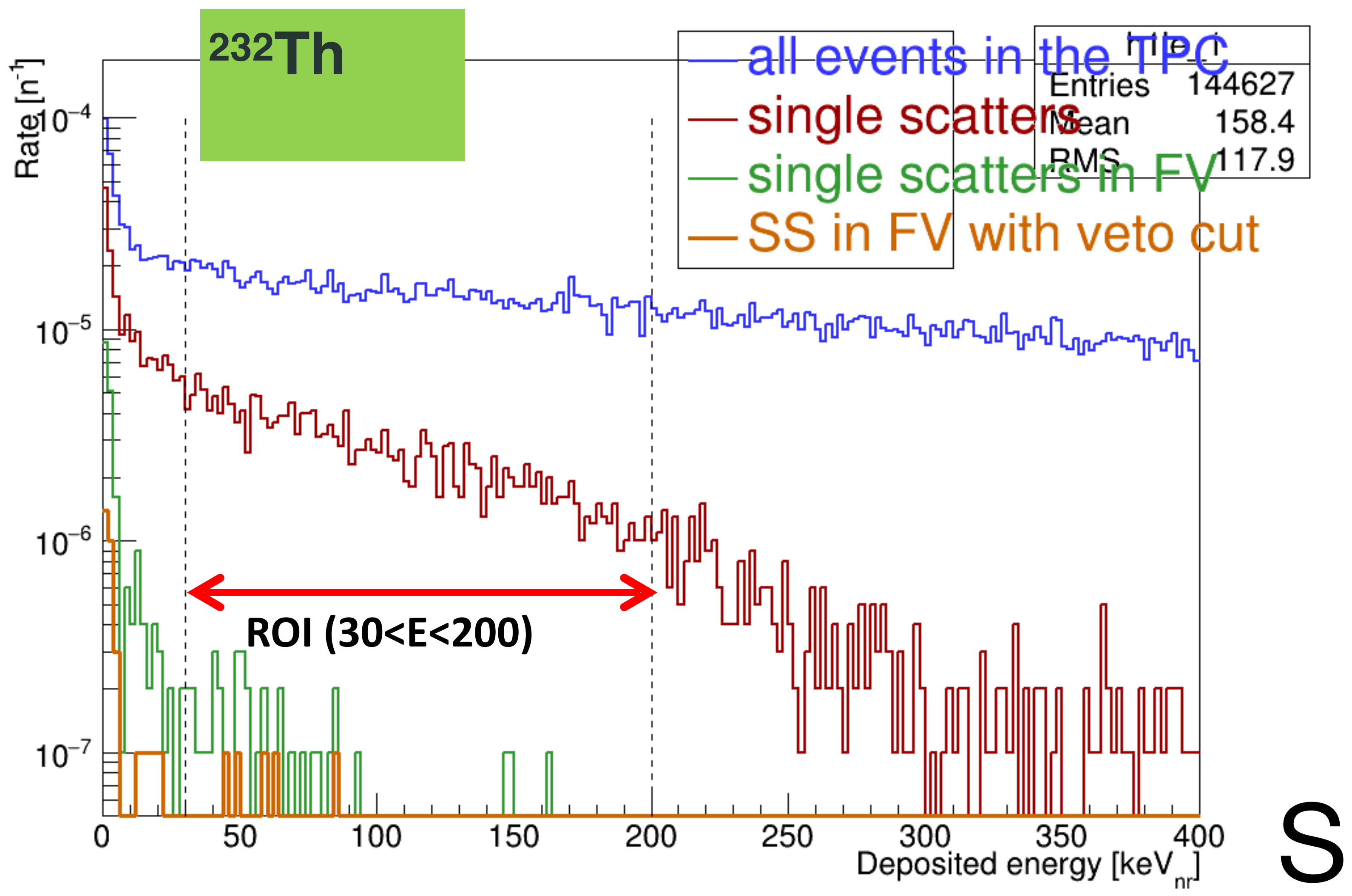
Neutron spectra are coded for U (Th) in /g4ds/data/physics/U238(Th232)Titanium.dat

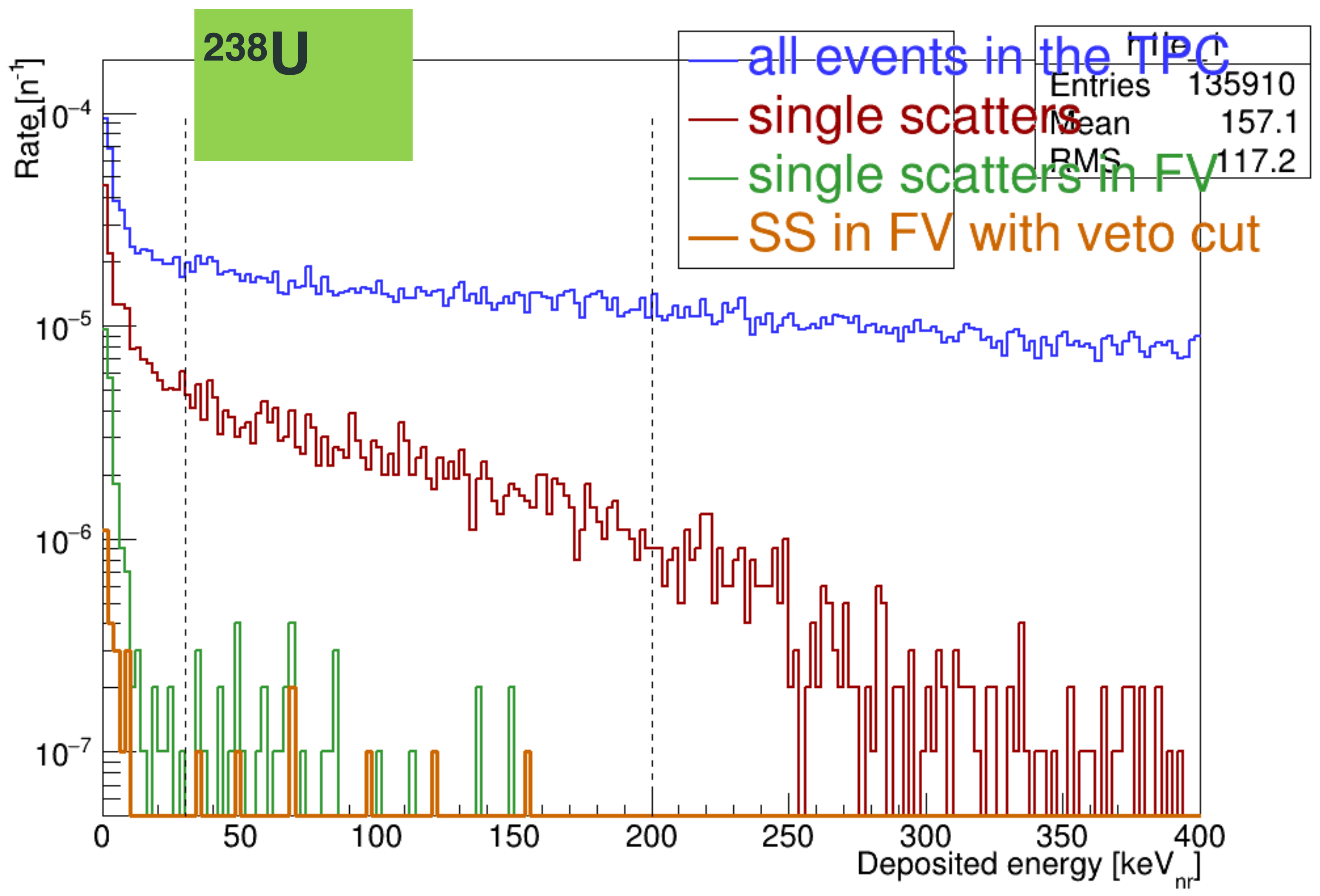
Spectrum for U235 not available in /g4ds/data/physics??



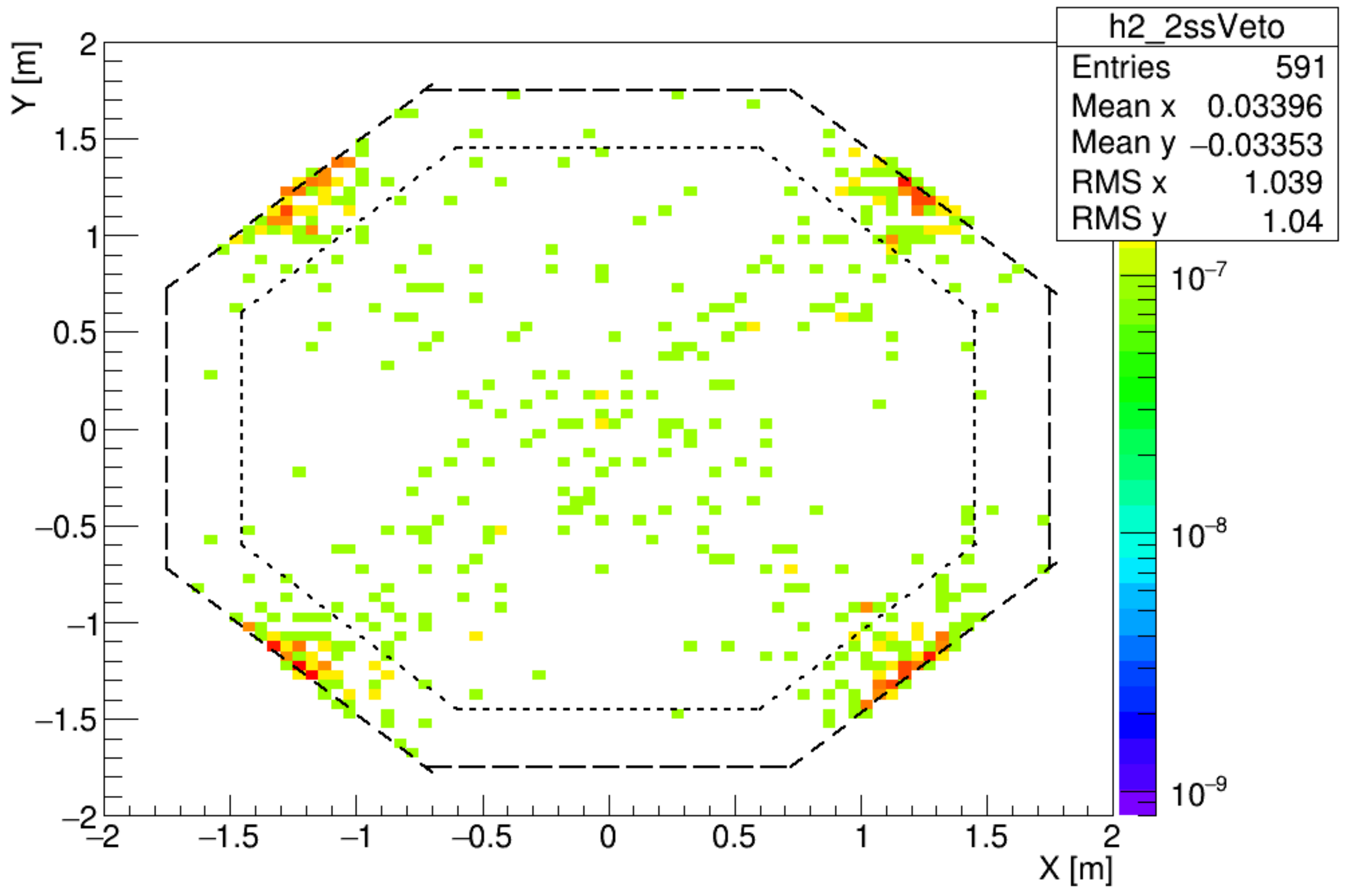


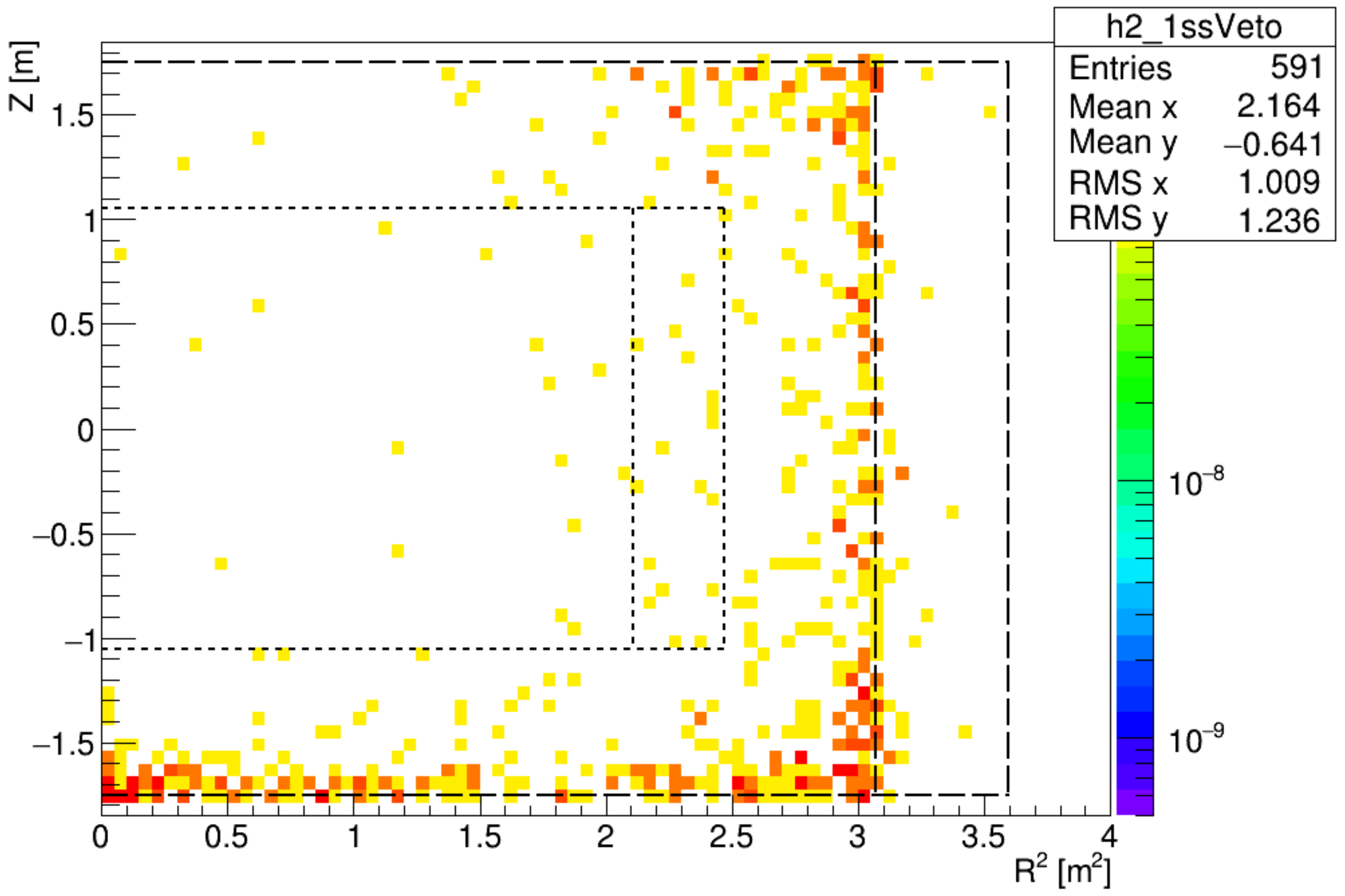
NR background (1/2)





Spatial distributions of SS events after veto cut for ^{232}Th





NR background (2/2)

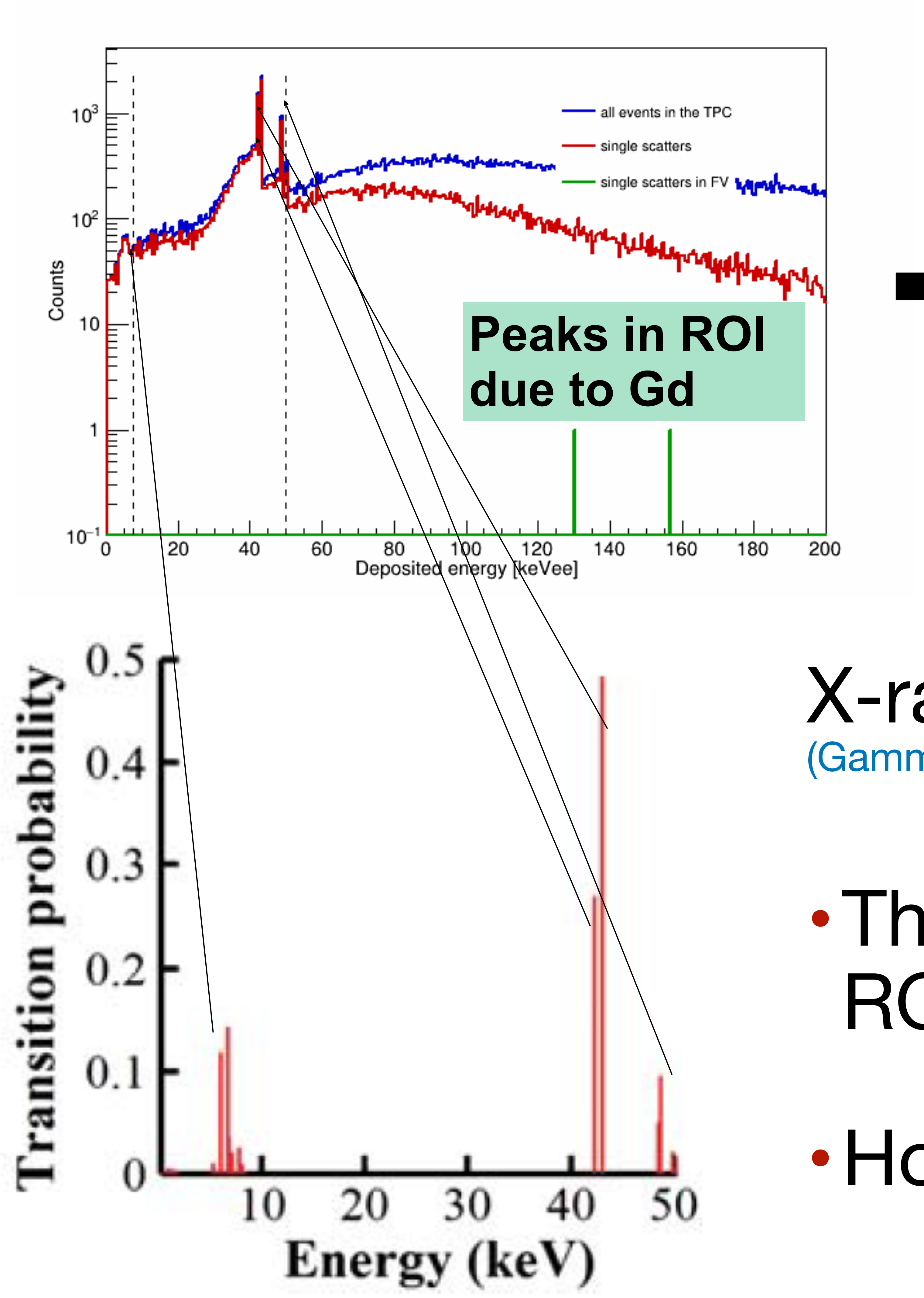
Final computation

	^{238}U up	^{238}U mid	^{238}U low	^{232}Th
Activity (mBq/kg)	8	0.12	80	0.12
Neutron yield (n/decay)	4.9E-9	2.6E-6	1.6E-8	6.5E-6
Neutron/year for 17 kg	0.02	0.17	0.69	0.42
Surviving events ($/10^7$)	7	7	7	5
NR bknd / 10 years (200 t.y)	1E-07	1E-06	5E-06	2E-06

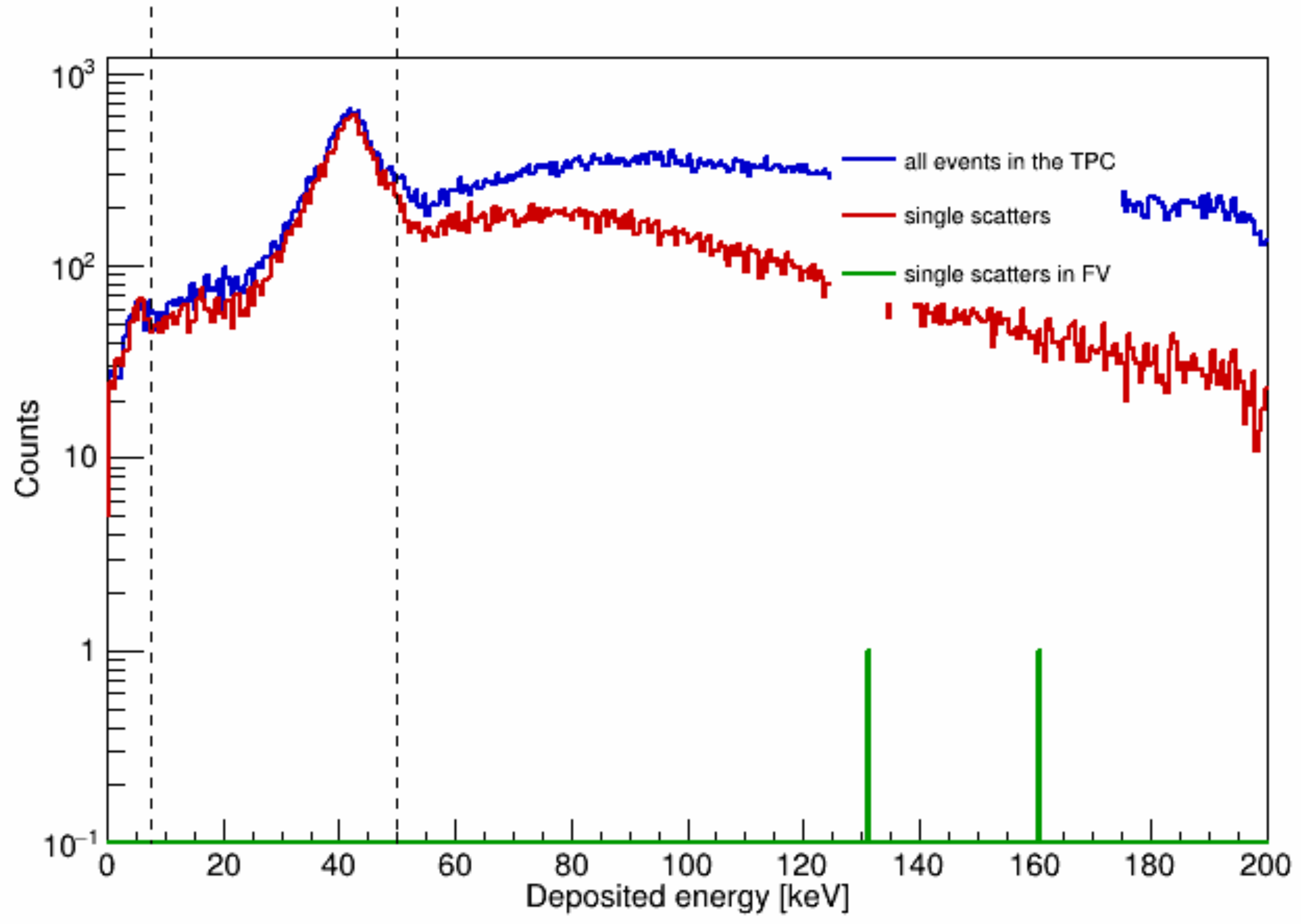
- Negligible (<1 E-5 events) wrt foreseen budget of 0.1 events after 10 years (200 t.y) = <0.01%
- Fully compatible with TDR results (980 kg of Ti -> 1 E-3 events)

ER background (1/3)

Gd impact - example of ^{238}U



Res(E)=0.0023 + 0.334/√E



X-rays emitted during atomic relaxation of excited Gd atom

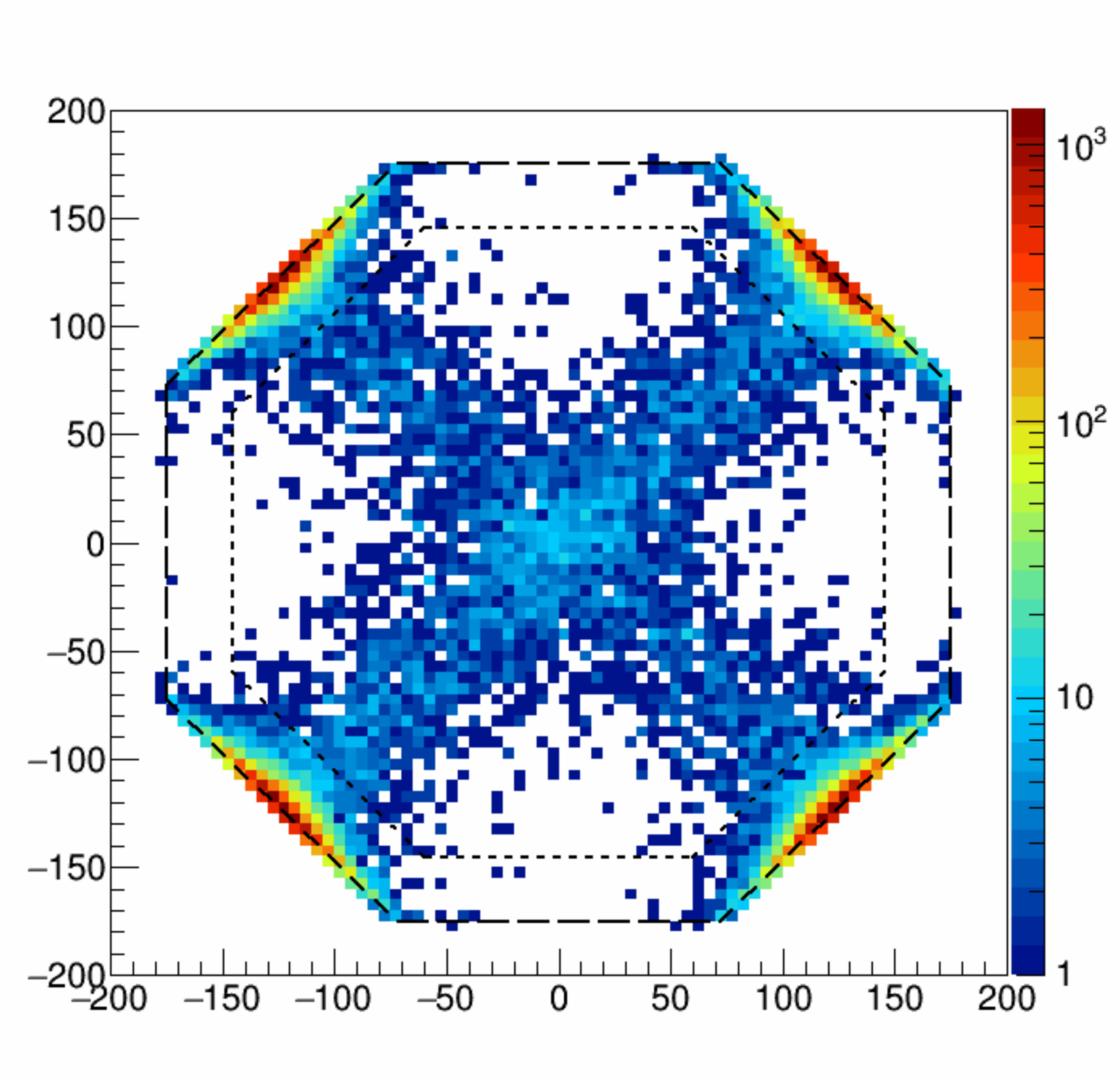
(Gamma-ray rejection, or detection, with gadolinium as a converter, P. Kandlakunta, DOI:10.1093/rpd/ncs031)

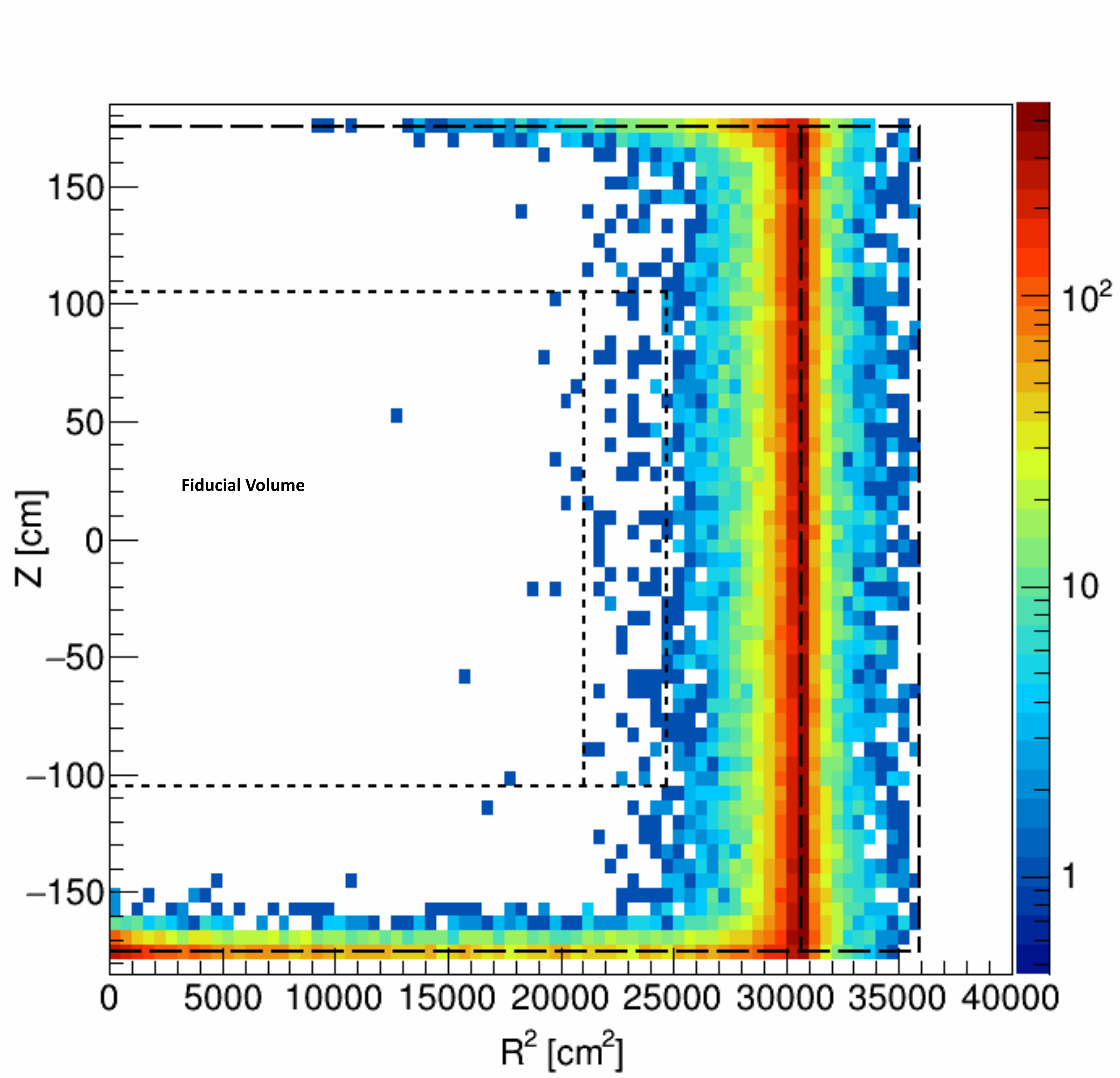
- This induces 10% to 70% more single scatter events at the ROI level in plan C wrt plan A
- However, none event survive the FV cut

ER background (2/3)

Events distribution - example of ^{238}U

- Spatial distributions of Single Scatter events (no ROI requirement)





- No event left in fiducial volume after ROI requirement.

ER background (3/3)

Final computation

- No event left in fiducial volume after ROI requirement.

	^{238}U up	^{238}U mid	^{238}U low	^{232}Th	^{235}U	^{40}K	^{46}Sc
Activity (mBq/kg)	8	0.12	80	0.12	0.37	0.6	3.1

x 17 kg

x 3.1 10^7 s/y

x 2.3 events/10^7 (no events after cuts)

	^{238}U up	^{238}U mid	^{238}U low	^{232}Th	^{235}U	^{40}K	^{46}Sc
Events/y	<1.0	<0.02	<10	<0.02	<0.05	<0.07	<0.4

- This is before S2/S1 and PSD requirements (10^7-10^8 rejection) → ER background fully negligible!

Conclusion

- Background induced by the calibration guide tubes is negligible (<< budget of 0.1 events per 10 years) for both ER and NR sources of background
    - Results compatible with those in the TDR
- Yet, to be exhaustive, we still need to perform the NR background study coming from ^{235}U, but the spectrum is not available yet in /g4ds/data/physics (see slide 4)

Back up

Results quoted in the TDR

NR bckgd in the TPC (vessel) / NR bckgd in the TPC (tubes)

Material or detector component	Mass [kg]	^{238}U upper Activity [mBq/kg] Yield [n/decay]	^{238}U middle Activity [mBq/kg] Yield [n/decay]	^{238}U lower Activity [mBq/kg] Yield [n/decay]	^{232}Th Activity [mBq/kg] Yield [n/decay]	^{235}U Activity [mBq/kg] Yield [n/decay]	Number of neutrons $[200\,\mathrm{t\,yr}]^{-1}$	Efficiency of cuts	Neutrons after cuts $[200\,\mathrm{t\,yr}]^{-1}$	Bkg fraction [%]
TPC									$\mathbf{9.2 \times 10^{-3}}$	**9.2**
Ultrapure acrylic	1978.0	3.7×10^{-3} 8.5×10^{-8}	1.2 5.5×10^{-7}	1.2 5.5×10^{-8}	2.4×10^{-3} 8.8×10^{-7}	1.7×10^{-4} 9.0×10^{-7}	4.5×10^{2}	5.8×10^{-6}	2.6×10^{-3}	2.6
Acrylic	2142.15	2.5×10^{-1} 8.5×10^{-8}	1.2 5.5×10^{-7}	1.2 5.5×10^{-8}	2.4×10^{-1} 8.8×10^{-7}	1.1×10^{-2} 9.0×10^{-7}	6.6×10^{2}	6.7×10^{-7} 5.8×10^{-6}	8.0×10^{-4}	0.8
Gd oxide	47.8	6.2 2.7×10^{-8}	2.7 1.2×10^{-7}	2.7×10^{1} 1.5×10^{-8}	2.3 1.9×10^{-7}	2.9×10^{-1} 2.1×10^{-7}	2.1×10^{1}	6.7×10^{-7}	1.4×10^{-5}	1.4×10^{-2}
Gd-acrylic	47.8	6.2 8.2×10^{-8}	2.7 5.5×10^{-7}	2.7×10^{1} 5.5×10^{-8}	2.3 8.7×10^{-7}	2.9×10^{-1} 8.8×10^{-7}	8.6×10^{1}	6.7×10^{-7}	5.8×10^{-5}	5.8×10^{-2}
Titanium	980.0	8.0 4.9×10^{-9}	1.2×10^{-1} 2.6×10^{-6}	8.0×10^{1} 1.6×10^{-8}	1.2×10^{-1} 6.5×10^{-6}	3.7×10^{-1} 2.6×10^{-6}	1.05×10^{3}	6.7×10^{-7} 5.8×10^{-6}	9.9×10^{-4}	0.99
Sulfactant IGEPAL Co-520	47.8	1.2×10^{-1} 8.0×10^{-8}	1.20 5.5×10^{-7}	1.20×10^{1} 5.5×10^{-8}	4.1×10^{-2} 8.8×10^{-7}	5.5×10^{-3} 8.8×10^{-7}	2.1×10^{1}	6.7×10^{-7}	1.4×10^{-5}	1.4×10^{-2}
Stainless steel for the TPC	1055.0	4.0×10^{-1} 3.9×10^{-10}	4.0×10^{-1} 5.8×10^{-7}	4.0×10^{-1} 9.25×10^{-10}	8.0×10^{-1} 2.0×10^{-6}	1.8×10^{-2} 4.6×10^{-7}	6.2×10^{2}	5.8×10^{-6}	3.6×10^{-3}	3.6
Shaping rings copper parts	1.7×10^{-1}	3.3×10^{-1} 0.0	1.6 3.8×10^{-8}	1.6×10^{1} 0.0	1.0×10^{-2} 3.1×10^{-7}	1.5×10^{-2} 1.8×10^{-8}	3.4×10^{-3}	5.8×10^{-6}	2.0×10^{-8}	2.0×10^{-5}
Shaping rings resistors	7.1×10^{-3}	3.7×10^{3} 3.6×10^{-7}	7.0×10^{3} 4.2×10^{-6}	8.2×10^{3} 3.1×10^{-7}	9.7×10^{2} 7.1×10^{-6}	$7.1 \times 10^{+2}$ 6.3×10^{-6}	1.0×10^{2}	5.8×10^{-6}	5.8×10^{-4}	0.58
Shaping rings resistors solder	4.9×10^{-3}	2.8×10^{1} 2.5×10^{-9}	7.2×10^{2} 2.1×10^{-7}	7.2×10^{2} 4.7×10^{-9}	2.8×10^{1} 4.2×10^{-7}	1.3 2.8×10^{-7}	2.6×10^{-1}	5.8×10^{-6}	1.5×10^{-6}	1.5×10^{-3}
PCB substrate Arlon 55NT	6.6×10^{-2}	53.0 7.9×10^{-8}	53.0 9.6×10^{-7}	128.0 5.3×10^{-8}	70.0 1.6×10^{-6}	2.4 1.3×10^{-6}	3.7	5.8×10^{-6}	2.1×10^{-5}	2.1×10^{-2}

TABLE XXII. Simulated radiogenic neutron rates from the detector materials over the full 200 t yr fiducial volume exposure.

Optical plane structures		Tubes
$= \frac{1e3}{1e3} = 1n \cdot kg^{-1}$	/	$1n \cdot kg^{-1}$
$\approx 7 \cdot 10^{-7}$	/	$\approx 7 \cdot 10^{-7}$
$\approx 1 \cdot 10^{-3}$	/	$\approx 1 \cdot 10^{-5}$
For 10^3 kg (Ti)		For 10 kg (Ti)
		↓
		$\approx 1 \cdot 10^{-3}$
		For 10^3 kg