TPC calibration: rates of events and time estimation

Presentation au DAQ Meeting - 7th of December, 2021

Huge thanks to A. Kish and V. Goicoechea for sharing their code !!

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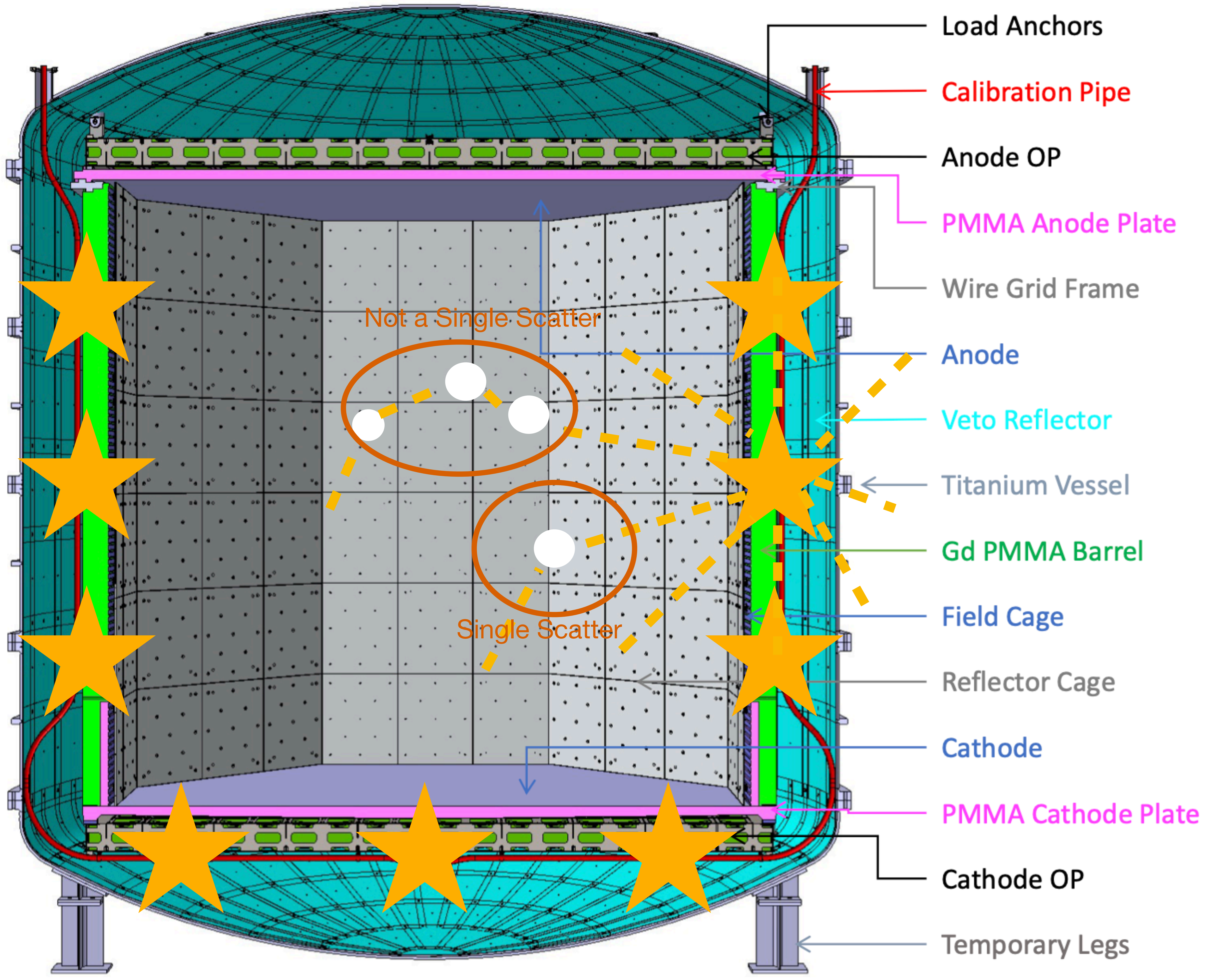
The calibration guide tube system

Fig from TDR

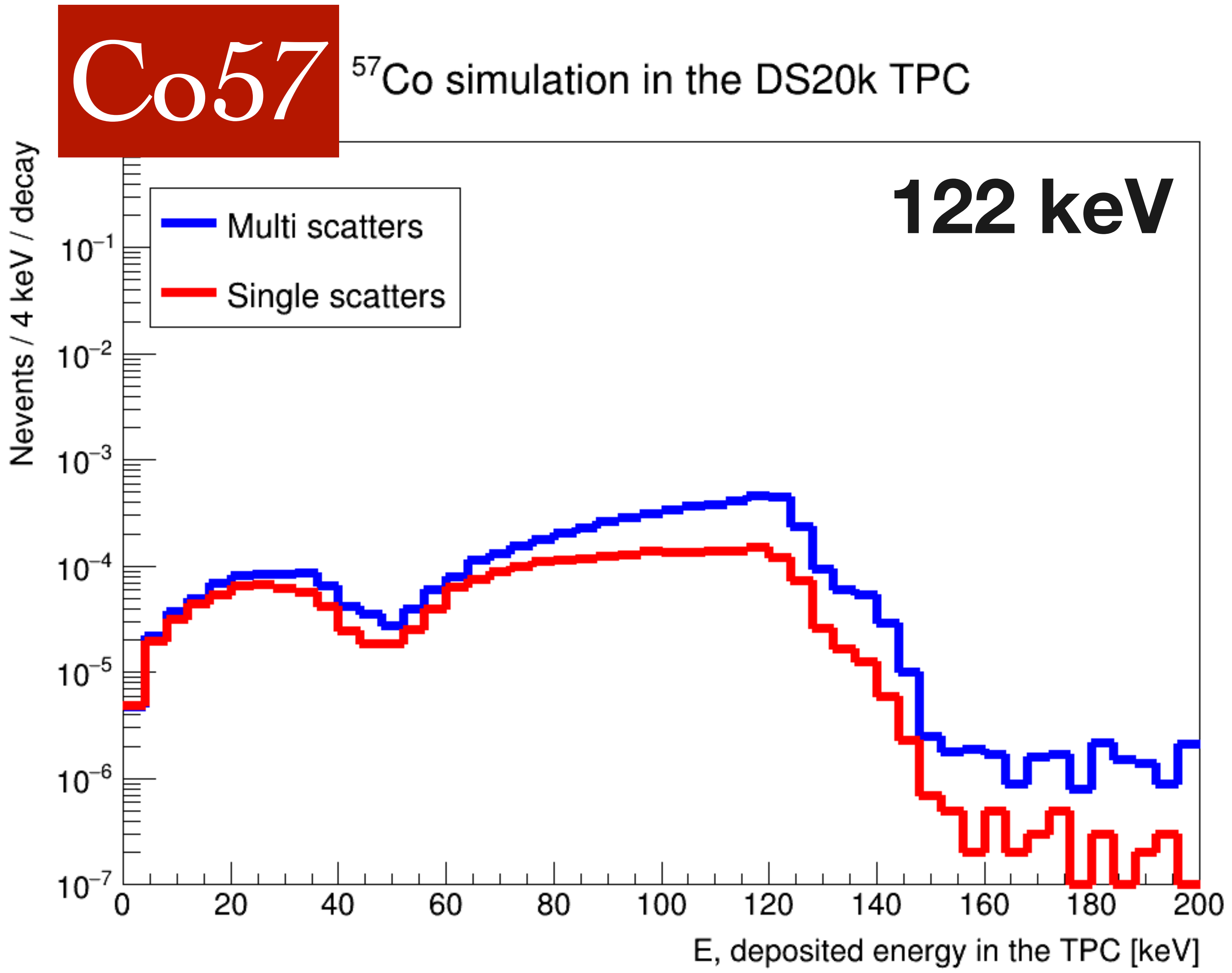
- System that enables the circulation of calibration radioactive sources around the TPC during the calibration runs
- Tubes: ø=3cm and th=1.5mm, 3cm (side), 1cm (bottom) from the TPC
- Computation of rates of events/decay of the source
- Calibration: we focus on:

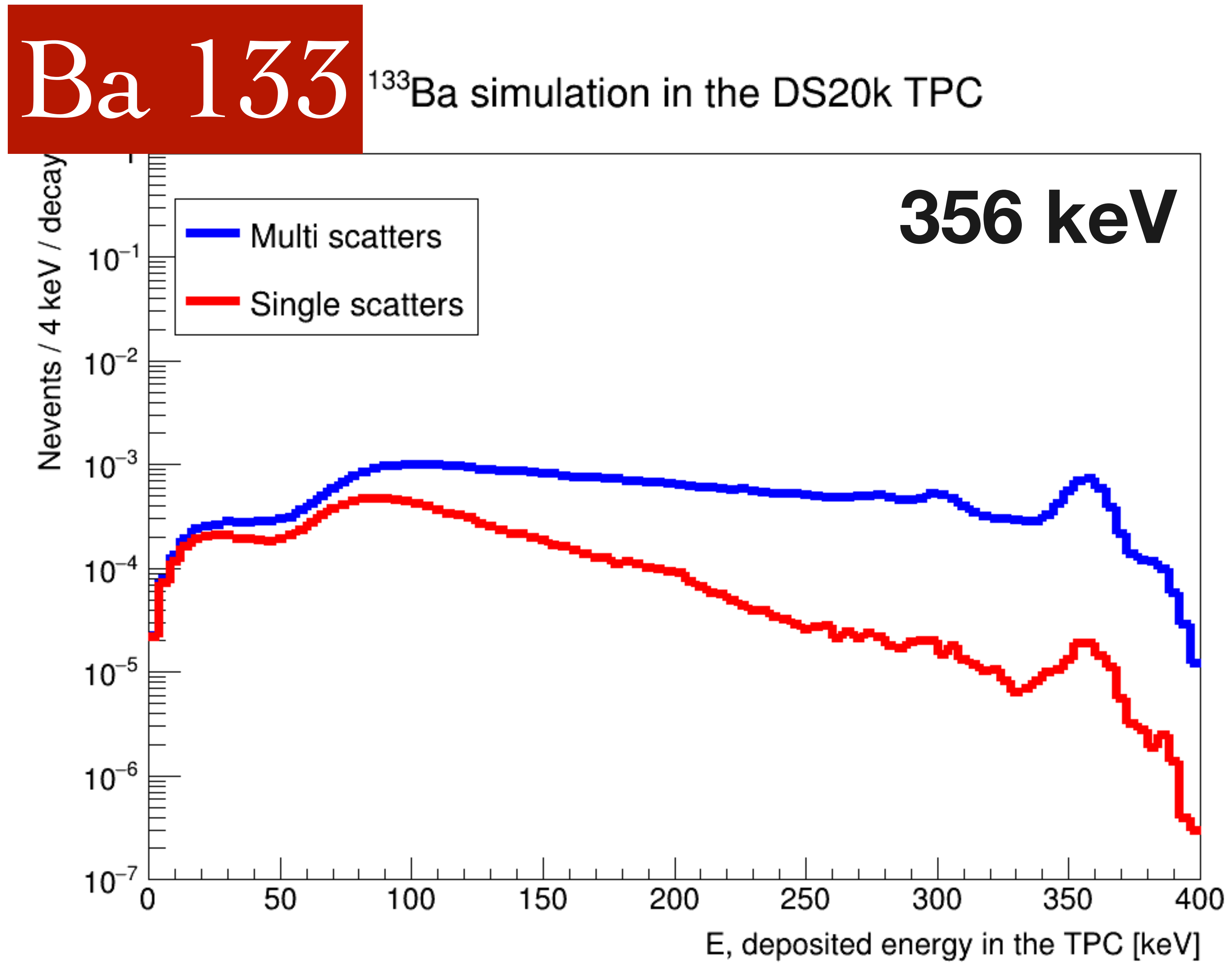
"Gold plated events"

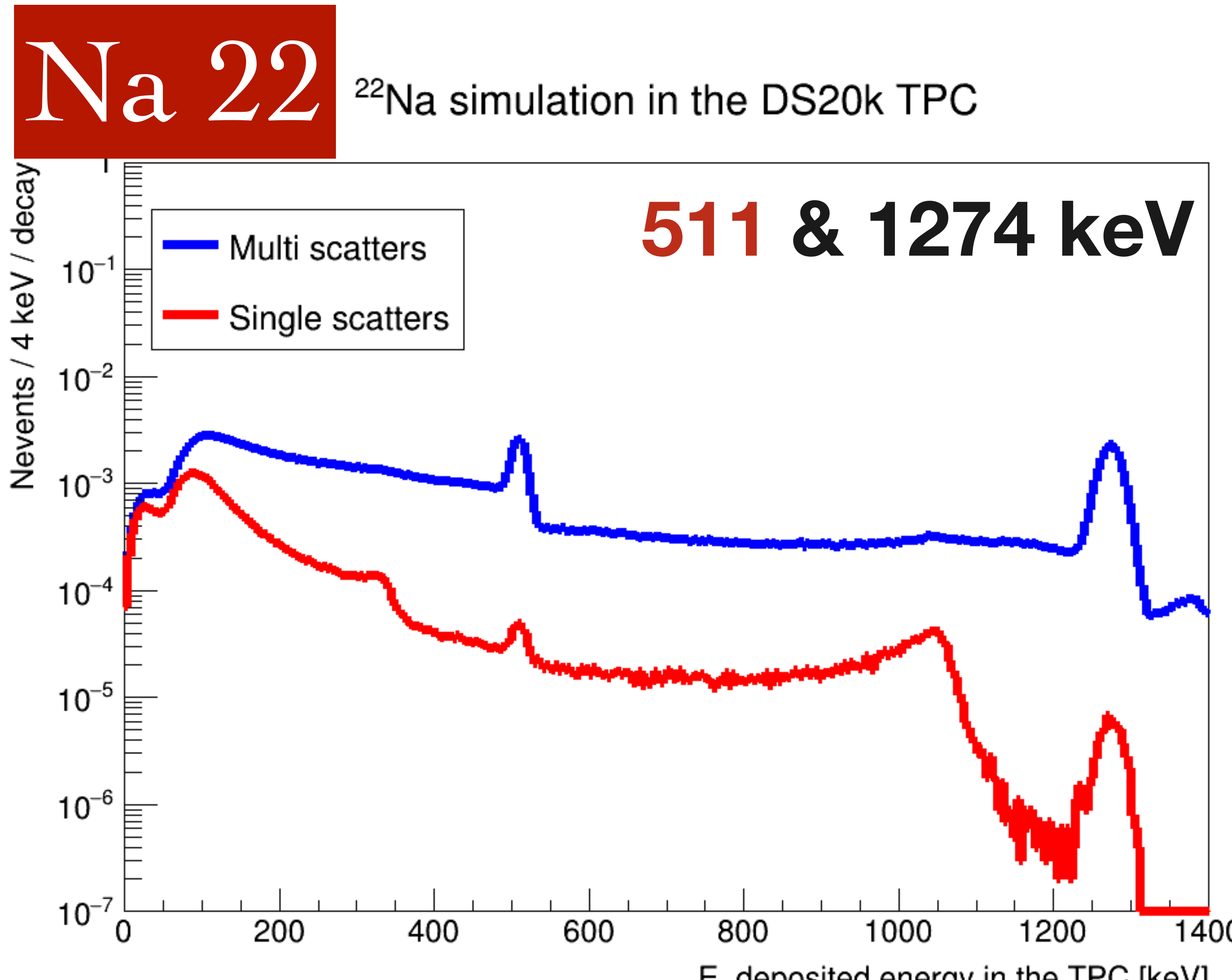
- NR: pure NR single scatters (SS)
- ER: single scatters (SS) with energy around the energy of the photon provided by the source

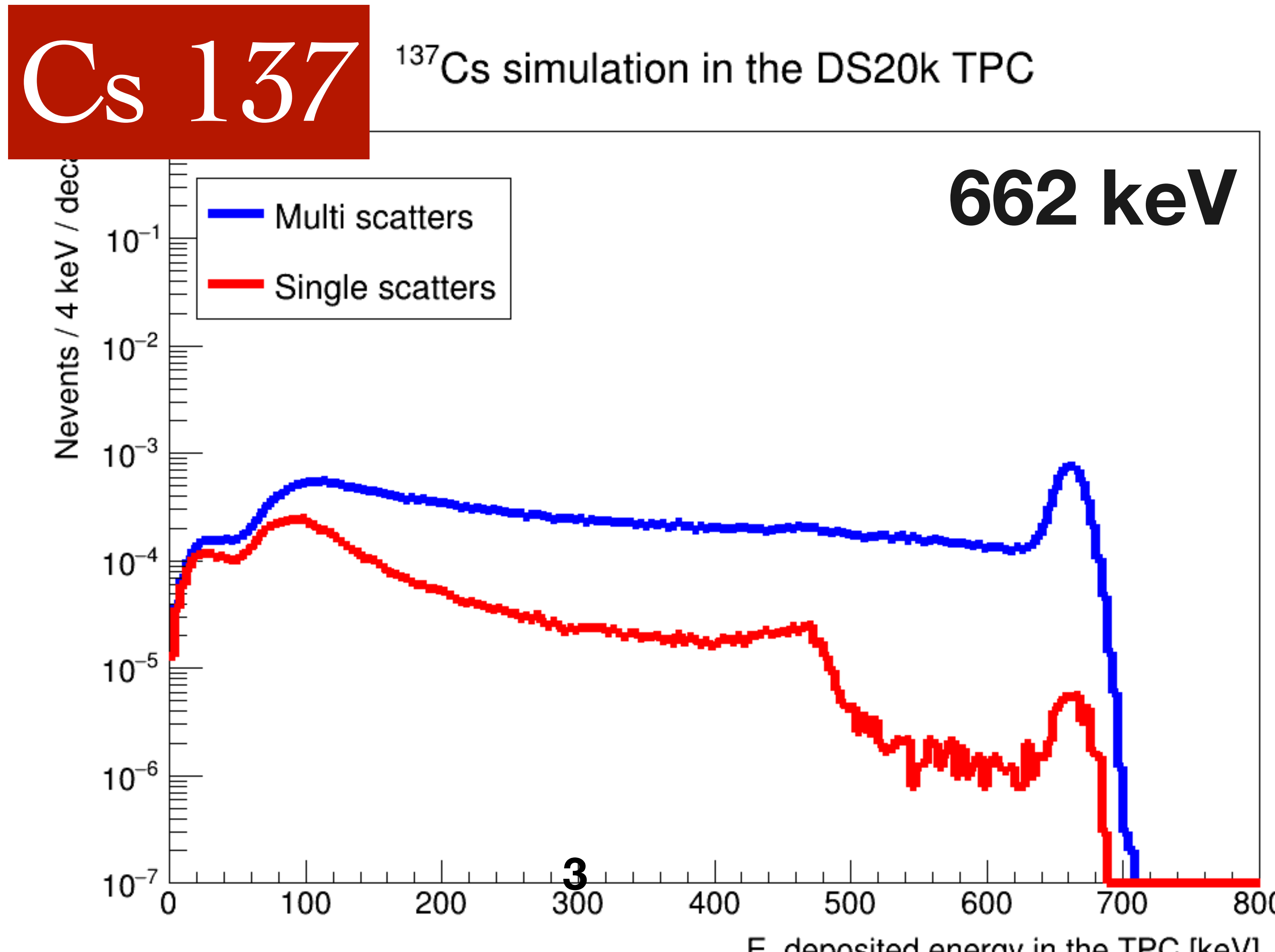


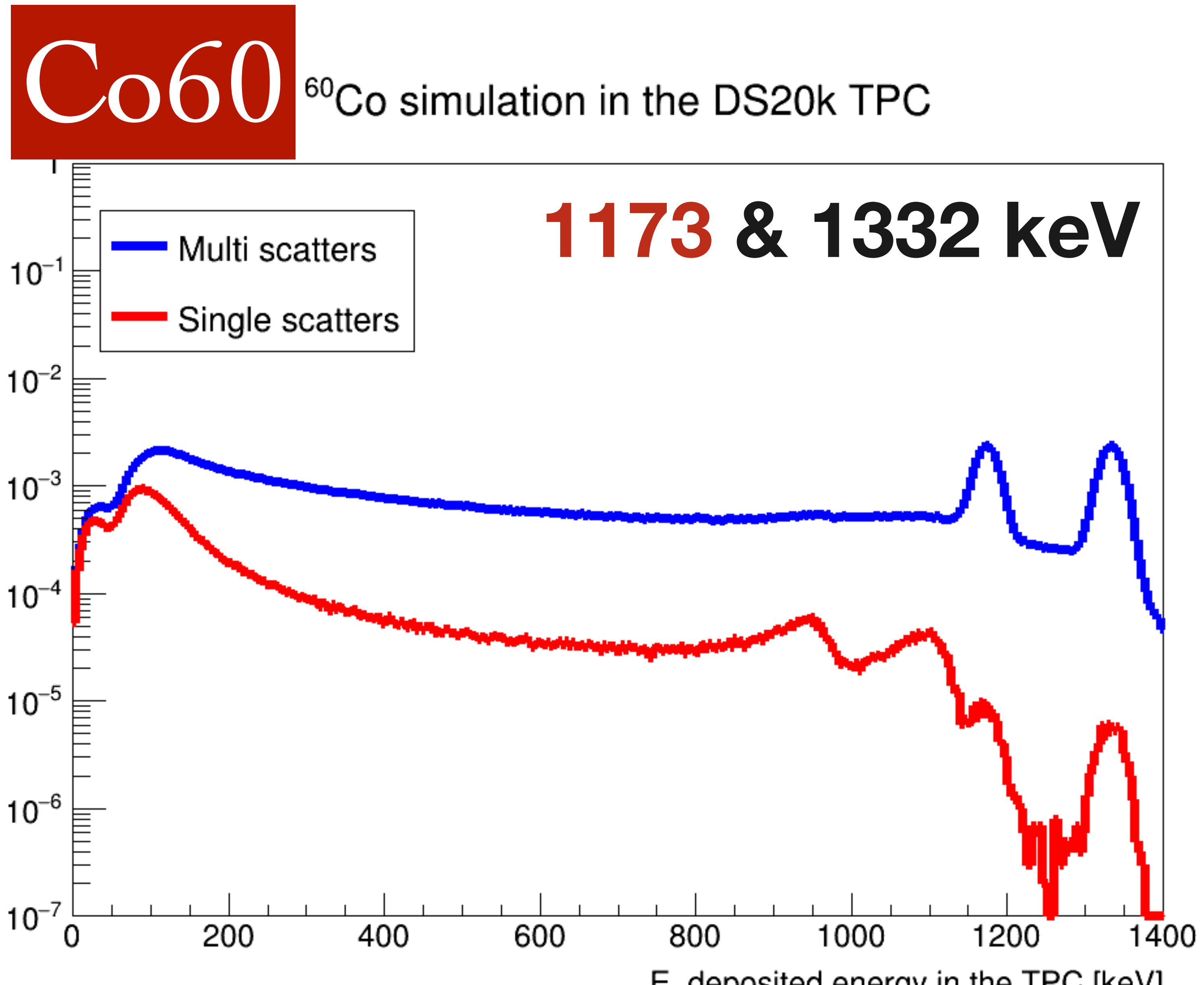
Photon sources - ER calibration (1e7 evt) - Side





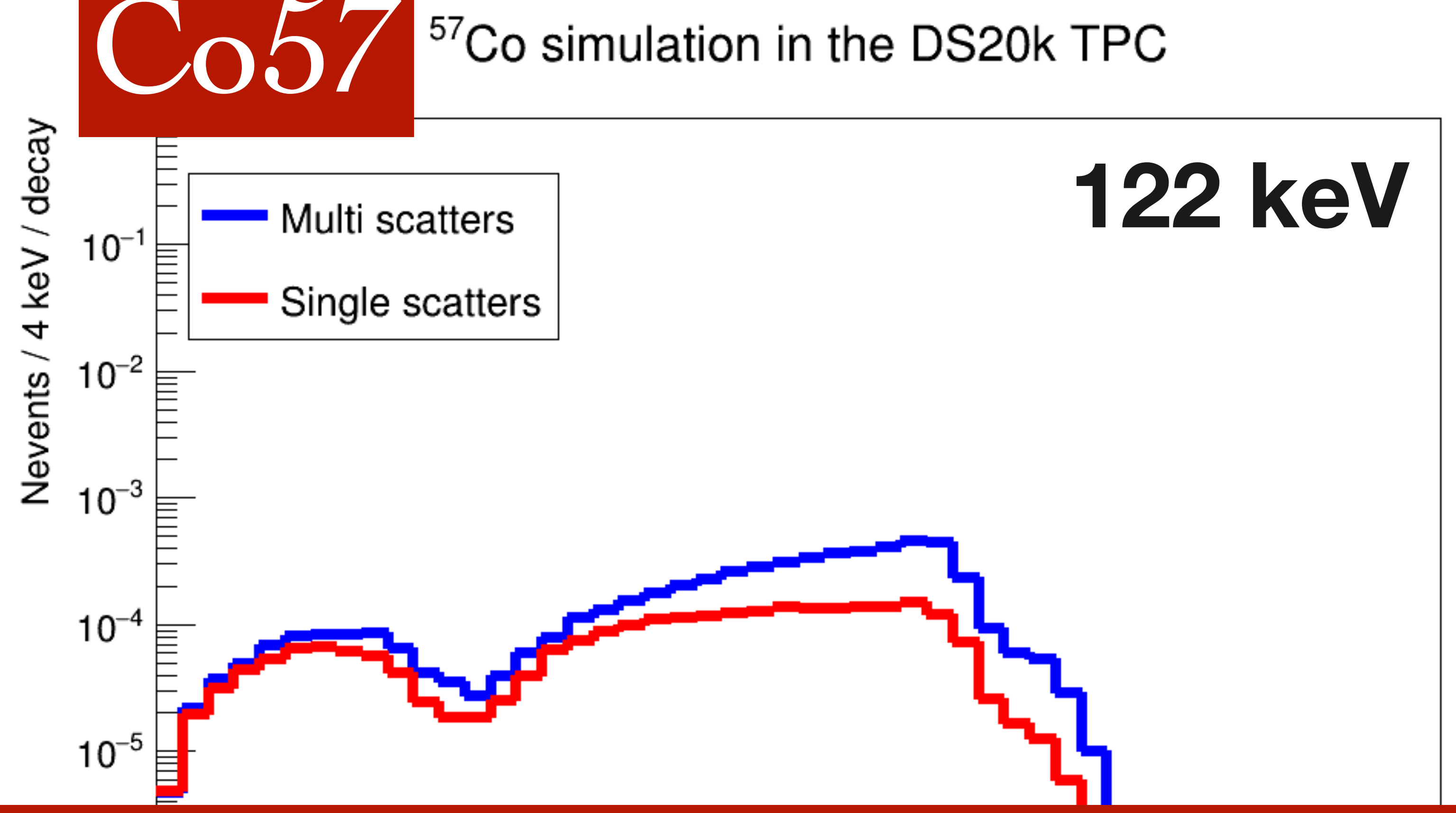




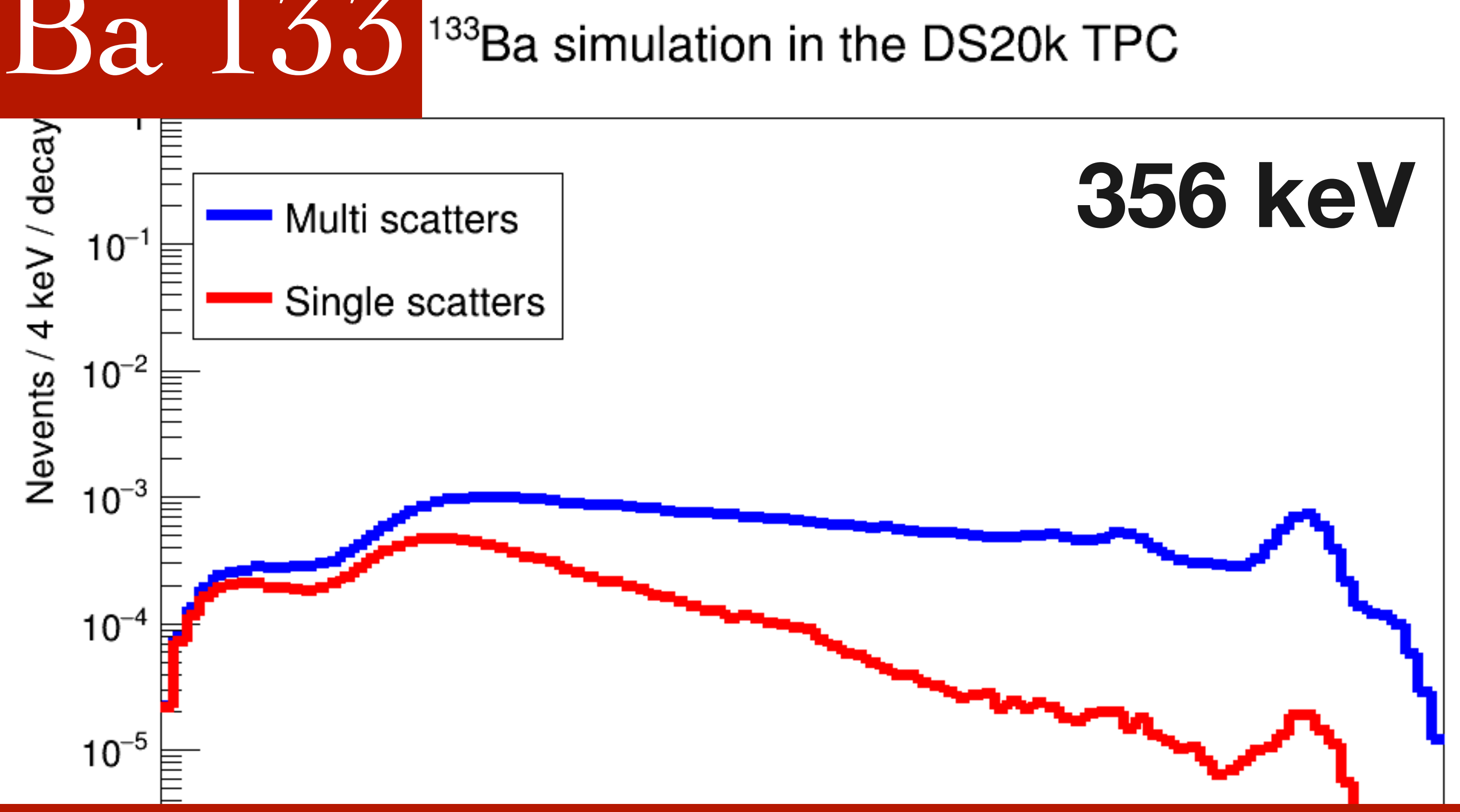


Photon sources - ER calibration (1e7 evt) - Side

Co57

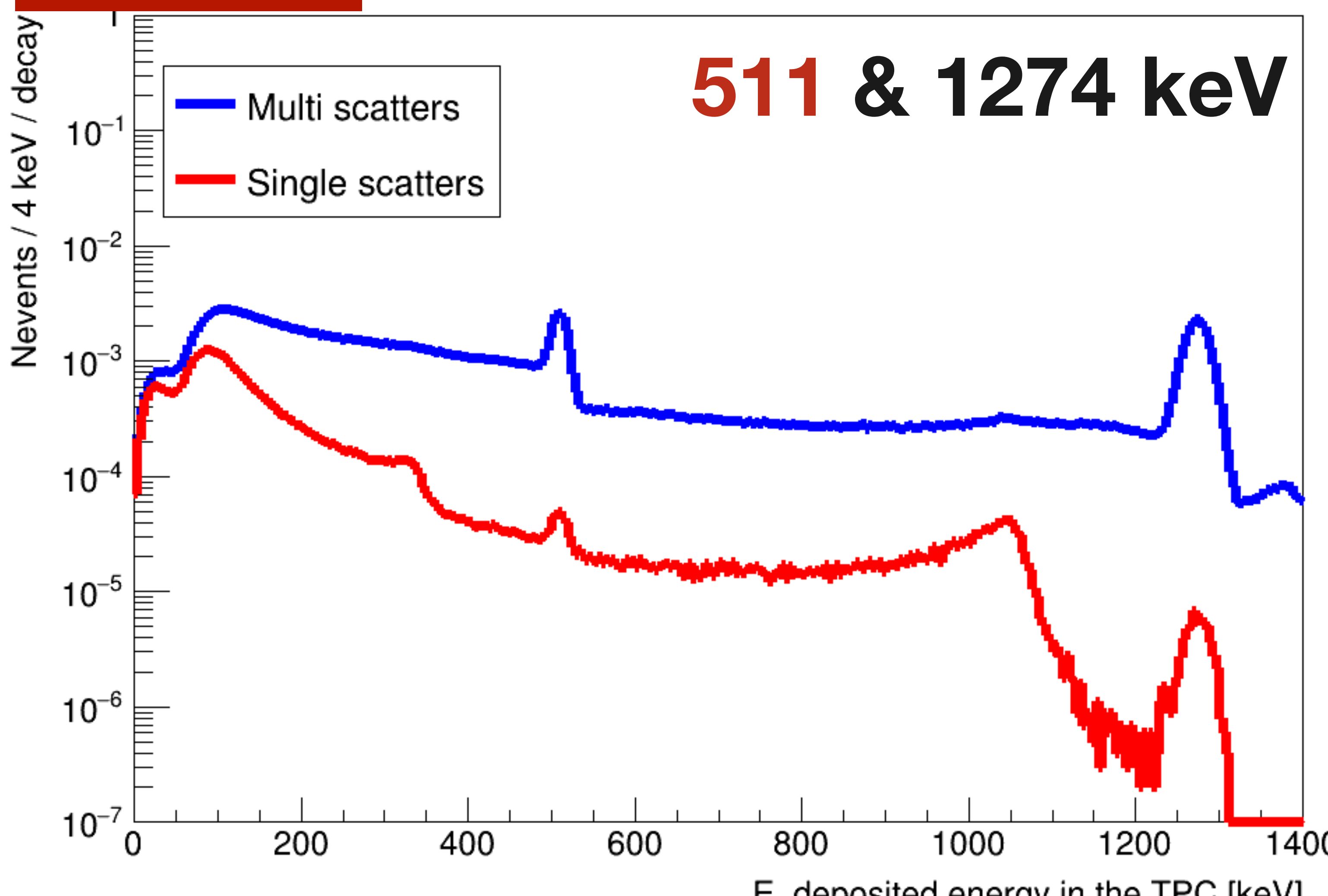


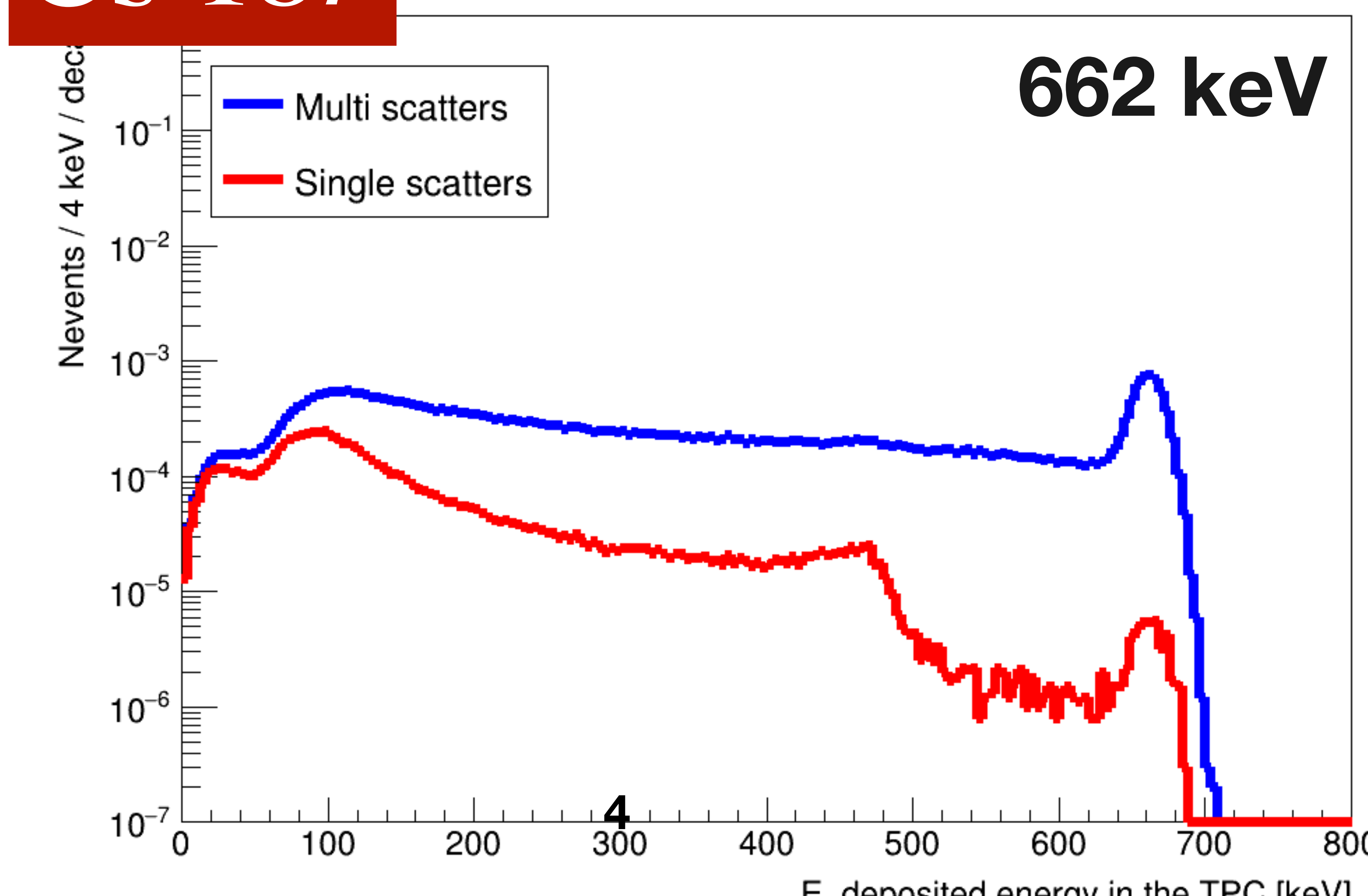
Ba 133

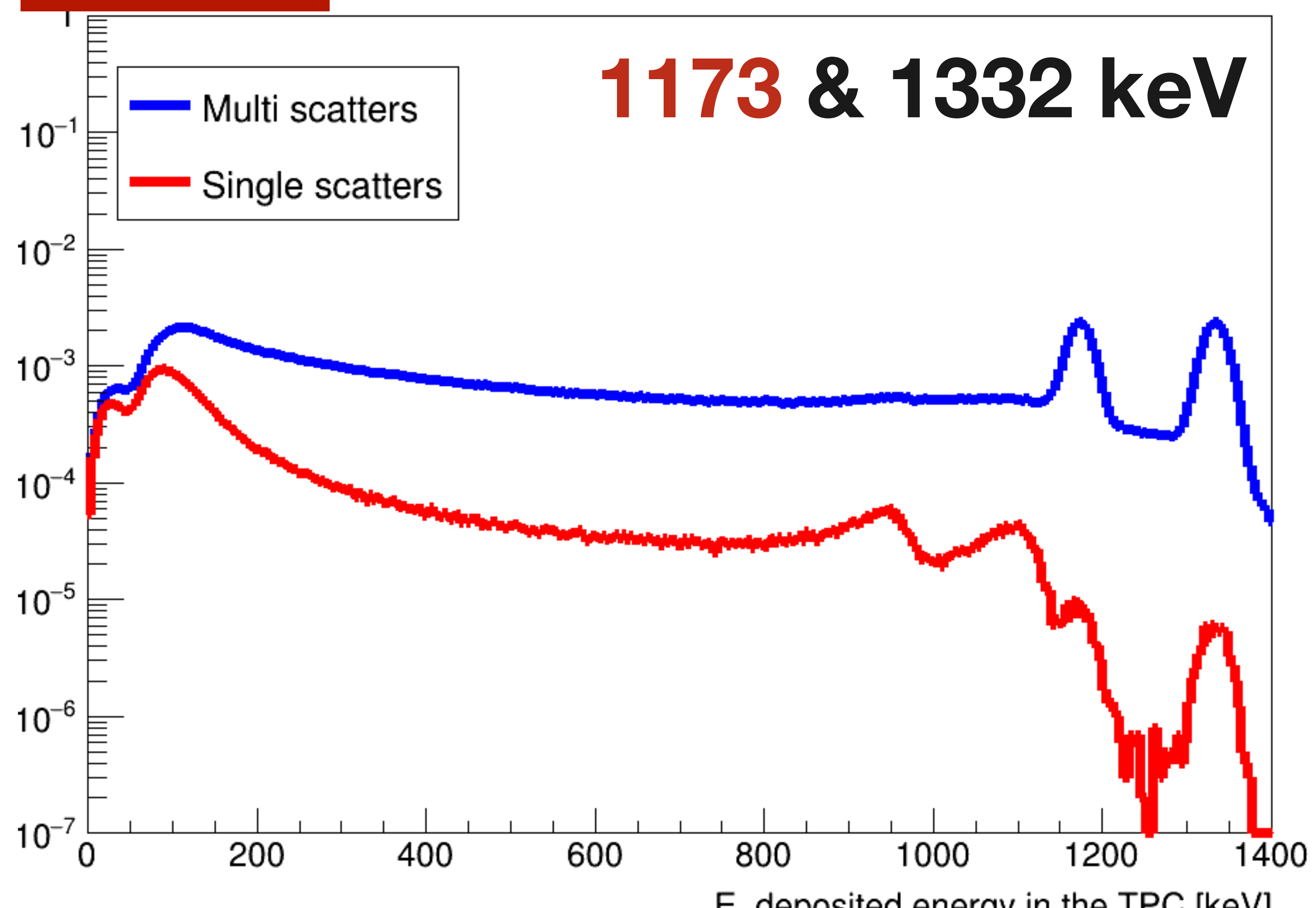


The spectra at the bottom of the TPC are essentially the same but with lower rates

Na 22







Neutron sources - NR calibration (1e6 evt) - Side

- **NR calibration:** particularly important. Should be able to have pure NR SS events in the Region Of Interest (ROI) for the WIMP search (30 < E < 200 keV_{nr}) and in the Fiducial Volume (FV) of DS20k (veto 70 cm in z and 30 cm in r)

Neutron sources - NR calibration (1e6 evt) - Side

The spectra at the bottom of the TPC are essentially the same

Rate of events

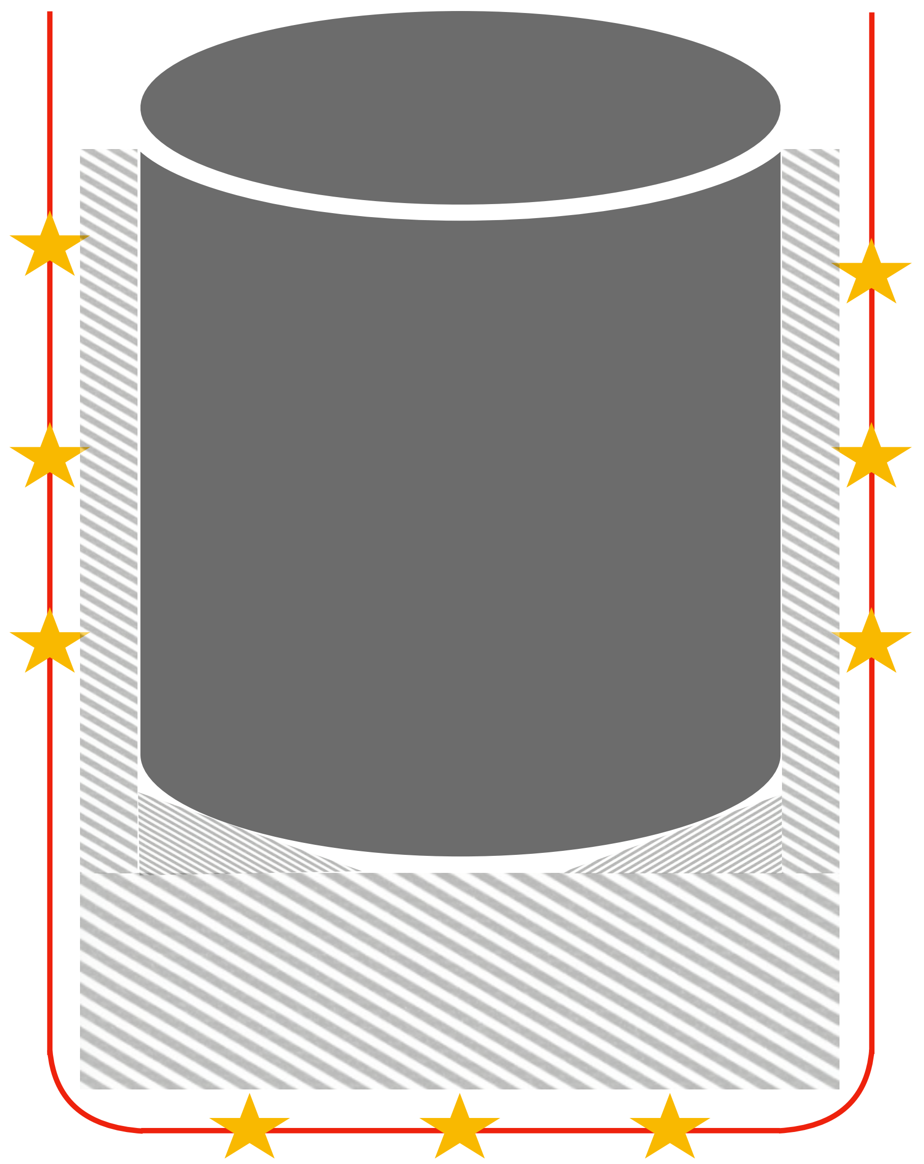
	Source	Energy	Rate plan C Side (all events)	Rate plan C Side (gold plated events)	(GoldPlated/ all)_{Side}	Rate plan C Bottom (all events)	Rate plan C Bottom (gold plated events)	(GoldPlated/ all)_{Bottom}
Photon sources	^{57}Co	122 keV	$5.7x10^{-3}$	$6.2x10^{-4}$	$1.1x10^{-1}$	$8.8x10^{-4}$	$8.4x10^{-5}$	$9.5x10^{-2}$
	^{133}Ba	356 keV	$5.4x10^{-2}$	$1.1x10^{-4}$	$2.0x10^{-3}$	$2.0x10^{-2}$	$2.6x10^{-5}$	$1.3x10^{-3}$
	^{22}Na	511 keV	$2.3x10^{-1}$	$3.7x10^{-4}$	$1.6x10^{-3}$	$1.4x10^{-1}$	$1.6x10^{-4}$	$1.1x10^{-3}$
	^{137}Cs	662 keV	$4.5x10^{-2}$	$4.0x10^{-5}$	$8.9x10^{-4}$	$2.2x10^{-2}$	$1.2x10^{-5}$	$5.5x10^{-4}$
	^{60}Co	1173 keV	$2.8x10^{-1}$	$1.0x10^{-4}$	$3.6x10^{-4}$	$1.7x10^{-1}$	$5.2x10^{-5}$	$3.1x10^{-4}$
Neutron sources	*AmBe*	[0.2, 12] MeV	$7.4x10^{-1}$	$1.1 x10^{-3}$	$1.5x10^{-3}$	$5.4x10^{-1}$	$6.5 x10^{-4}$	$1.2x10^{-3}$
	AmC	[2, 7] MeV	$6.5x10^{-1}$	$6.4 x10^{-4}$	$9.8x10^{-4}$	$5.5x10^{-1}$	$6.1 x10^{-4}$	$1.1x10^{-3}$
	DD	2.45 MeV	$5.3x10^{-1}$	$6.5 x10^{-4}$	$1.2x10^{-3}$	$4.4x10^{-1}$	$6.4 x10^{-4}$	$1.5x10^{-3}$

Rate of events - NR - Further investigation

Source	Initial neutron energy	Rate plan C Side	Rate plan C Bottom
AmBe	[0.2, 12] MeV	1.1 $\times 10^{-3}$	6.5 $\times 10^{-4}$
AmBe + ROI cut	[0.2, 12] MeV	$\frac{1}{2.3}$ * 1.1 $\times 10^{-3}$	$\frac{1}{2.0}$ * 6.5 $\times 10^{-4}$
AmBe + FV cut	[0.2, 12] MeV	$\frac{1}{9.9}$ * 1.1 $\times 10^{-3}$	$\frac{1}{30.7}$ * 6.5 $\times 10^{-4}$
AmC	[2, 7] MeV	6.4 $\times 10^{-4}$	6.1 $\times 10^{-4}$
AmC + Roi cut	[2, 7] MeV	$\frac{1}{2.4}$ * 6.4 $\times 10^{-4}$	$\frac{1}{2.1}$ * 6.1 $\times 10^{-4}$
AmC + FV cut	[2, 7] MeV	$\frac{1}{8.5}$ * 6.4 $\times 10^{-4}$	$\frac{1}{32}$ * 6.1 $\times 10^{-4}$
DD	2.45 MeV	6.5 $\times 10^{-4}$	6.4 $\times 10^{-4}$
DD + ROI cut	2.45 MeV	$\frac{1}{1.78}$ * 6.5 $\times 10^{-4}$	$\frac{1}{1.75}$ * 6.4 $\times 10^{-4}$
DD + FV cut	2.45 MeV	$\frac{1}{7.95}$ * 6.5 $\times 10^{-4}$	$\frac{1}{26.5}$ * 6.4 $\times 10^{-4}$

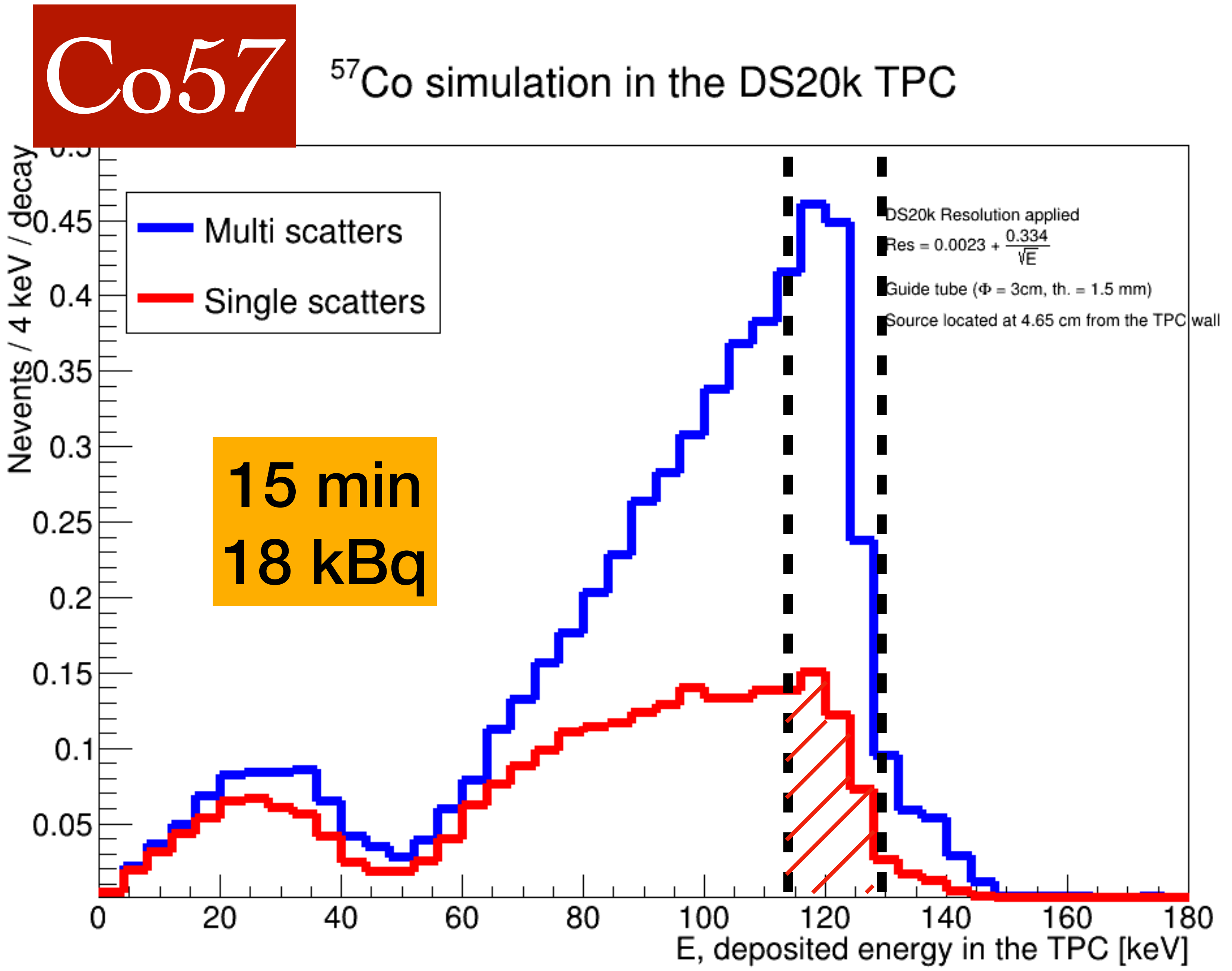
- ROI cut: Rates are reduced by a factor $\approx$ 2
- FV cut: Rates are reduced by a factor $\approx$ 8 on the side and ≈ 30 at the bottom

Calibration strategy - Time estimation



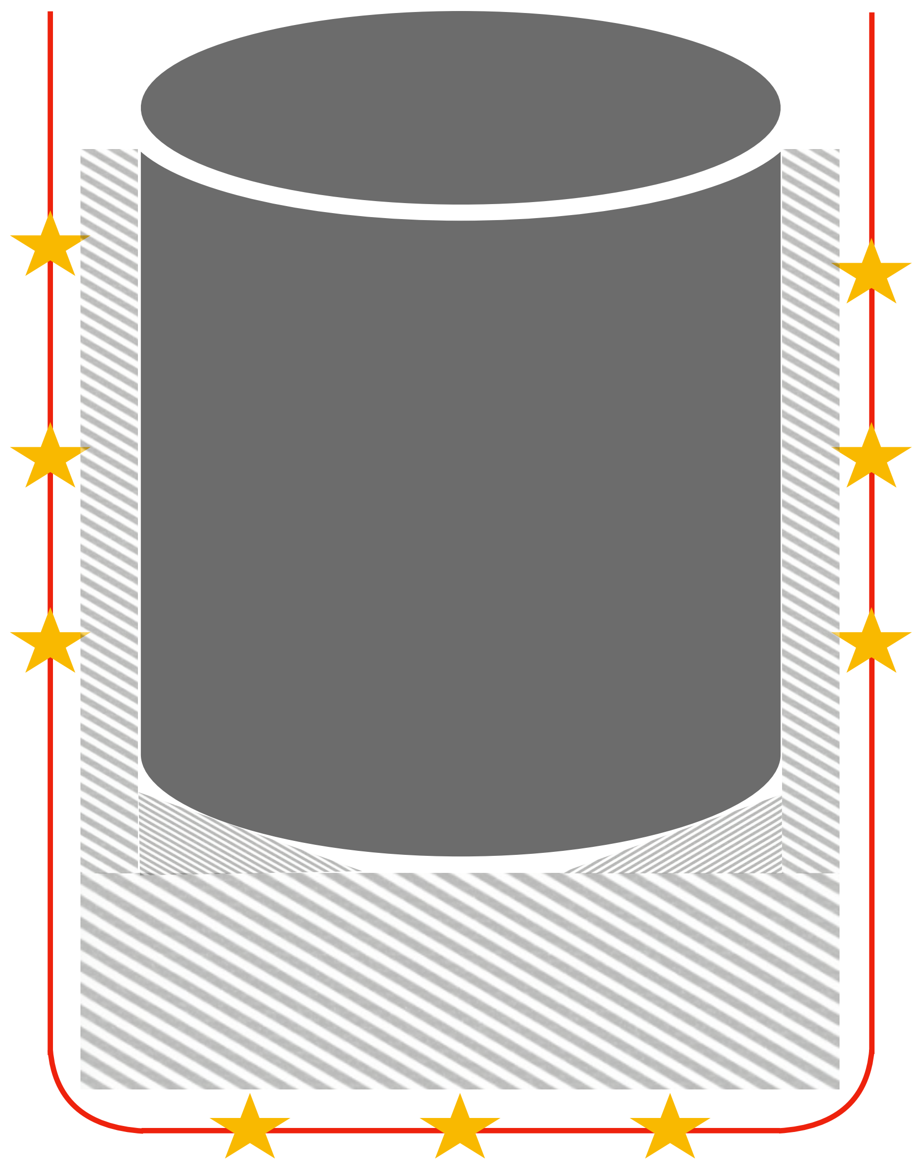
- **Goal:** Estimate the time needed to perform the calibration with 10k **gold plated events** per position (SS in the peak (ER) / pure NR SS (NR))

- Ex of 57Co: 10k gold plated evt = 10k SS in the peak (**red dashed** events)



- **Assumptions:**
  - 2h of source handling + 9 positions (3 on the sides + 3 bottom)
  - The DAQ saturates at 100 Hz (mostly saturated by **any of all events in the TPC**)
  - Maximum source activity of 100 kBq if bandwidth lower than 100 Hz
  - No hardware trigger

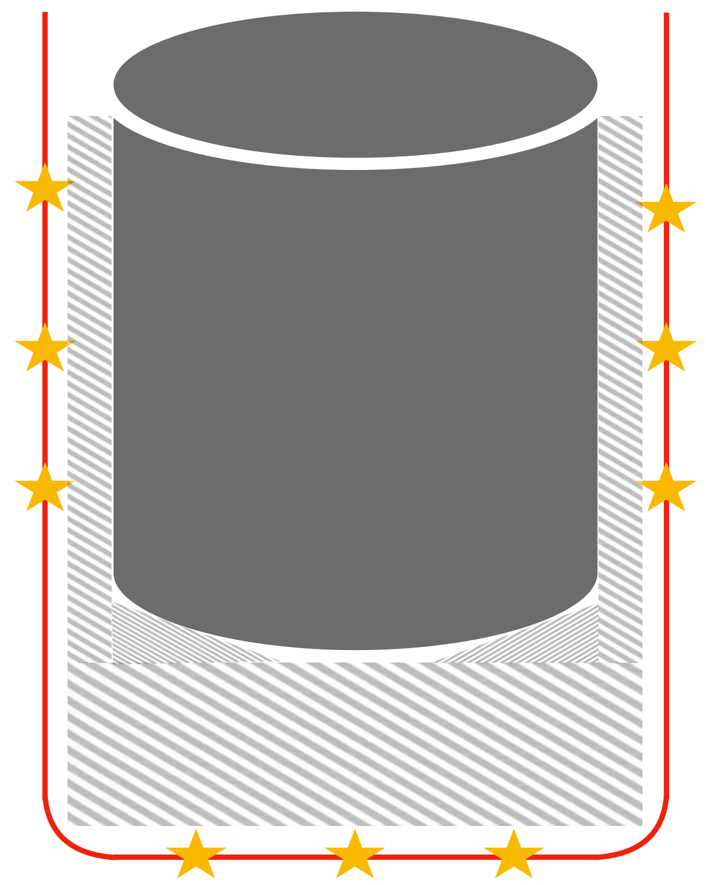
Calibration strategy - Time estimation



- **Final goal:** Estimate the time needed to perform the calibration with 10k gold plated events per position
- **Assumptions:**
    - 2h of source handling + 9 positions (3 on each side + 3 bottom)
    - The DAQ saturates at 100 Hz
    - No hardware trigger
    - Maximum source activity of 100 kBq if bandwidth lower than 100 Hz

Source	57Co	133Ba	22Na	137Cs	60Co	AmBe	AmC	DD
Activity Side (100 Hz) kBq	18	1.9	0.36	2.2	0.36	0.14	0.15	0.19
Activity Bottom (100 Hz) kBq	100	5	0.67	4.6	0.6	0.18	0.18	0.23

Calibration strategy - Time estimation



2.75 months (without trigger)*

	Single scatters in the peak					Pure NR SS		
	57Co	133Ba	22Na	137Cs	60Co	DD gun	AmBe	AmC
Time per position (side) (h)	0.25	14	17	31	77	23	19	28
Time per position (bottom) (h)	0.33	21	25	51	90	19	23	25
Total time (day)	0.26	6.3	7.5	14	31	8	8	10

Energy increases →

**Extreme opposite scenario: having a gold-plated events trigger would reduce the calibration time to 2 days*

Conclusion

- **Calibration with plan C:** Implies a loss of gold plated events w.r.t. plan A
    - Long (2.75 months) calibration duration without hardware trigger
- Ideas to increase the rates of events:
    - Window in the GdPMMA wall for neutrons ?
    - Use the Compton edge for photons ?
    - Dedicated calibration stream from the DAQ ?

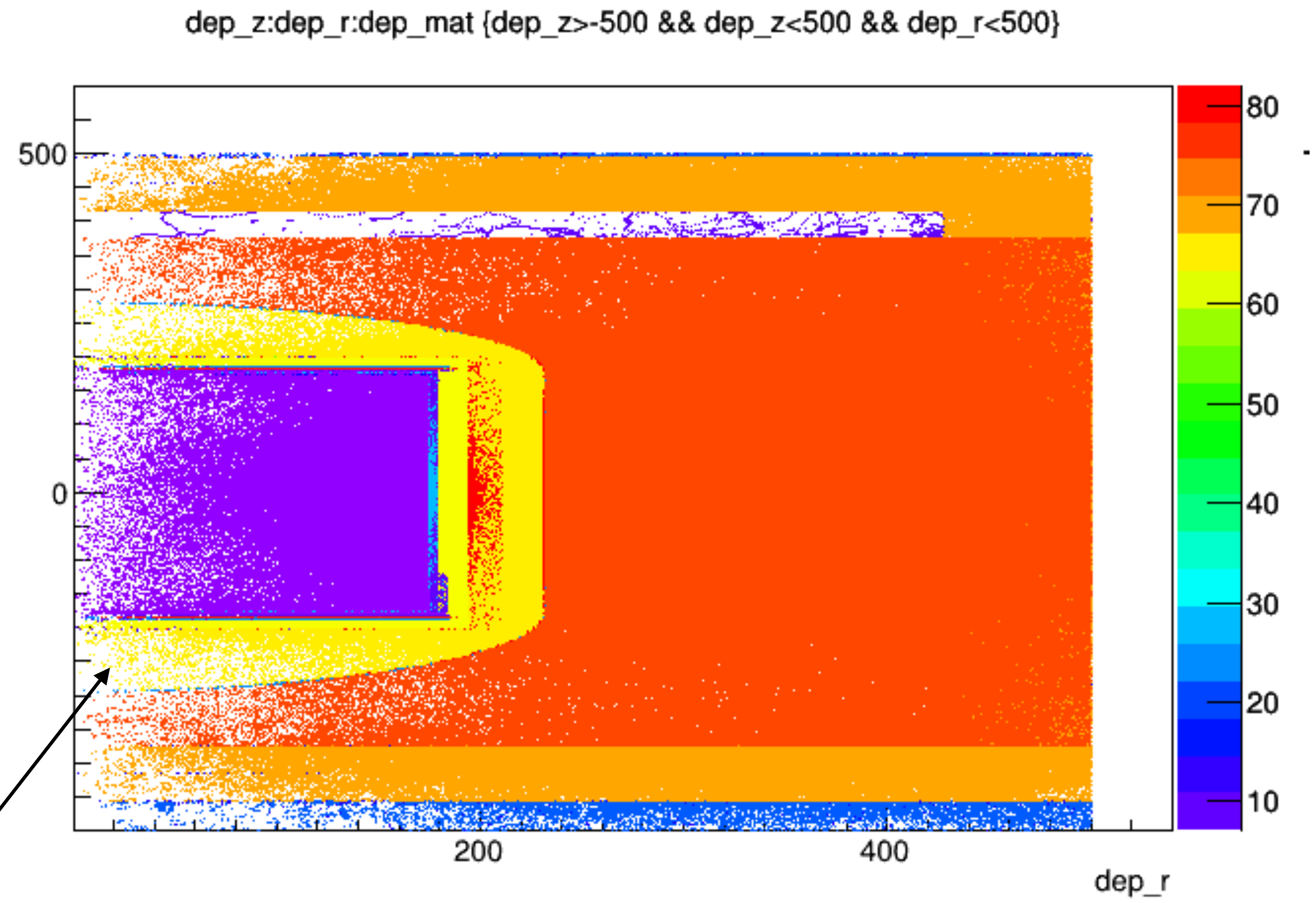
Light Collection Efficiency (LCE) in the veto buffer: impact of calibration tubes - plan C

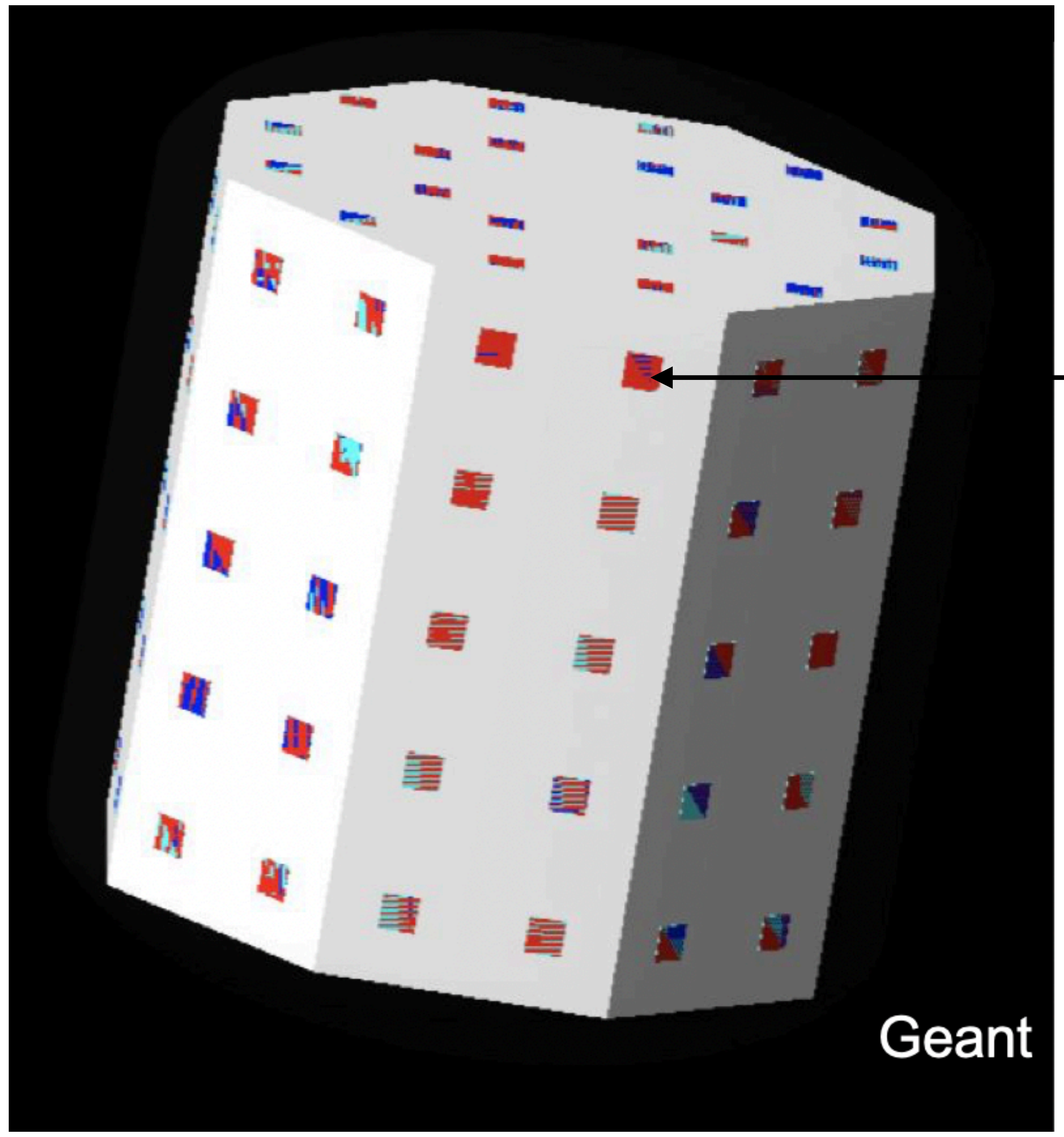
December 2021

Marie van Uffelen (PhD) & Fabrice Hubaut - CPPM

Methodology

- 200 jobs of 5 000 events = 1e6 events
- 1 event = 1000 photons (λ = 128 nm <=> E = 9.7 eV) generated isotropically and uniformly inside the veto buffer (VetoLAr2)
- Look at the number of photons seen by the SiPMs
    - Derive the efficiency of the system = detected PE/ simulated photons (1000)





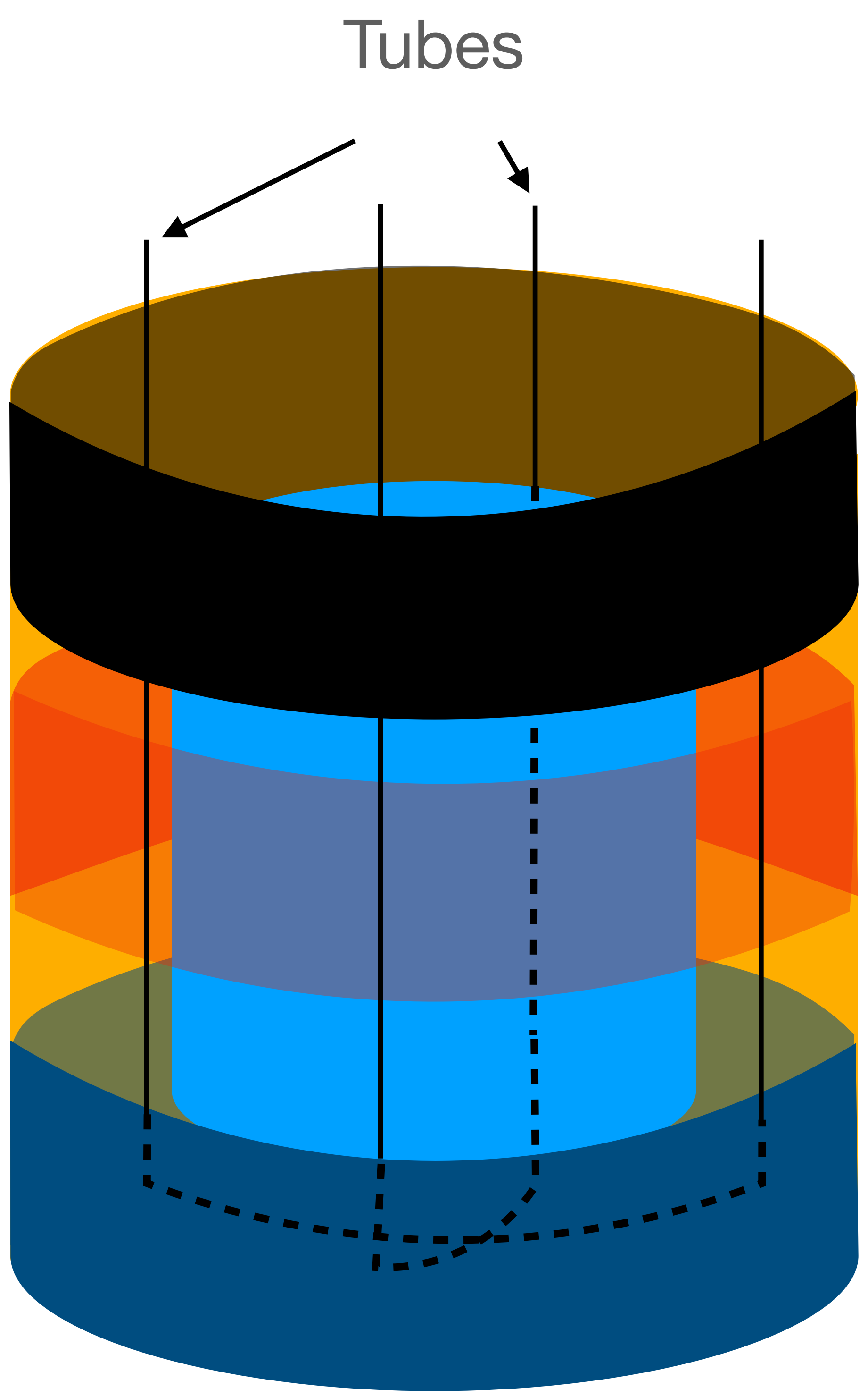
SiPMs are gathered in vPDU+ : veto Photo-Detection Units
- 20 on each octagonal face
- 10 on each vertical side

= 120 vPDU+ in total

Figure from M. Rossi (see link)

Code details

- g4ds: latest git version (from Oct 4) adding calibration tubes (to be submitted to git)
- Code returns plots and numbers about Light Collection Efficiency (LCE)
  - In the full veto buffer
  - In the octants where pipes are/are not

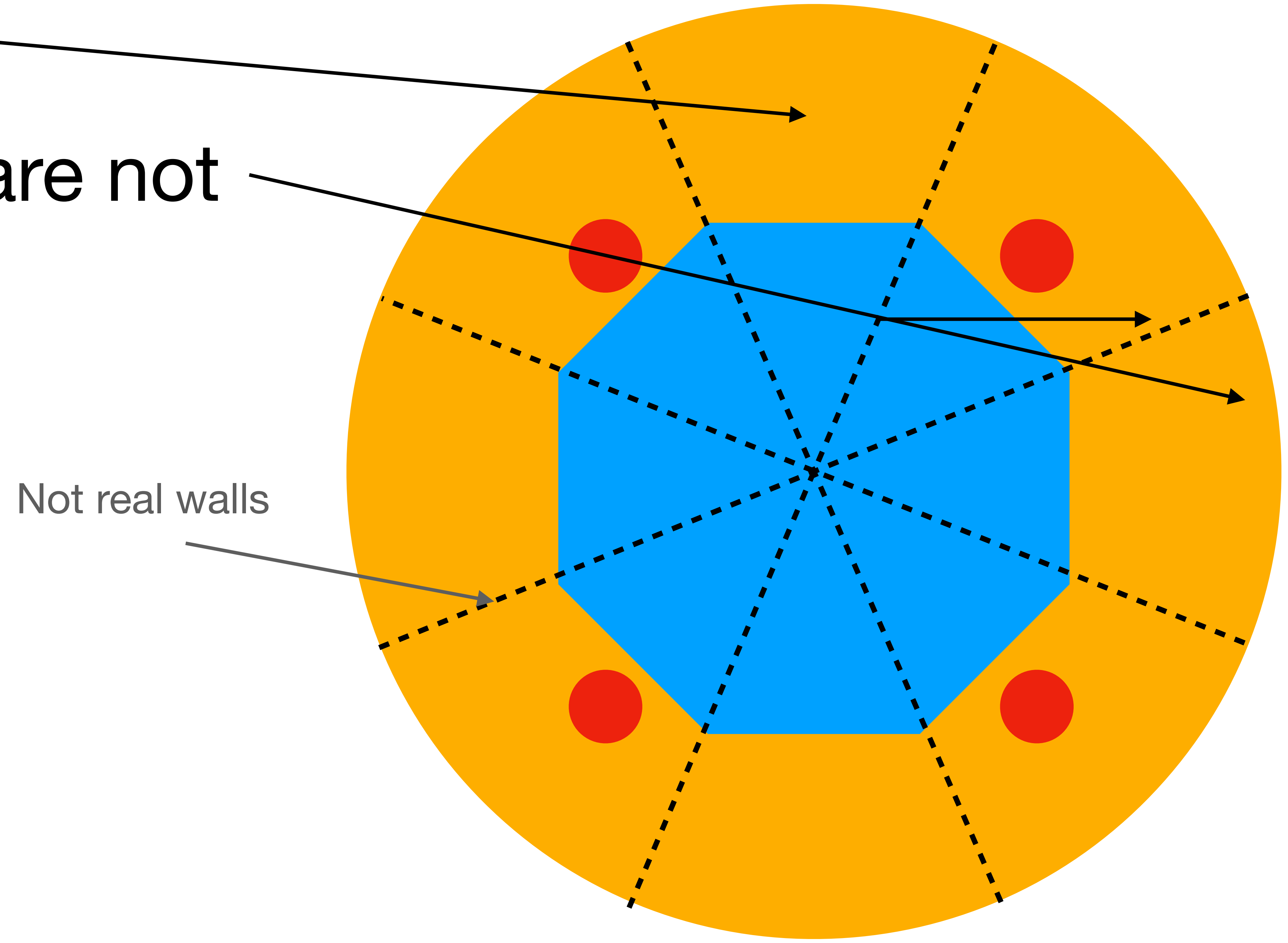


The "all" veto buffer corresponds to the whole volume of the veto, in all regions

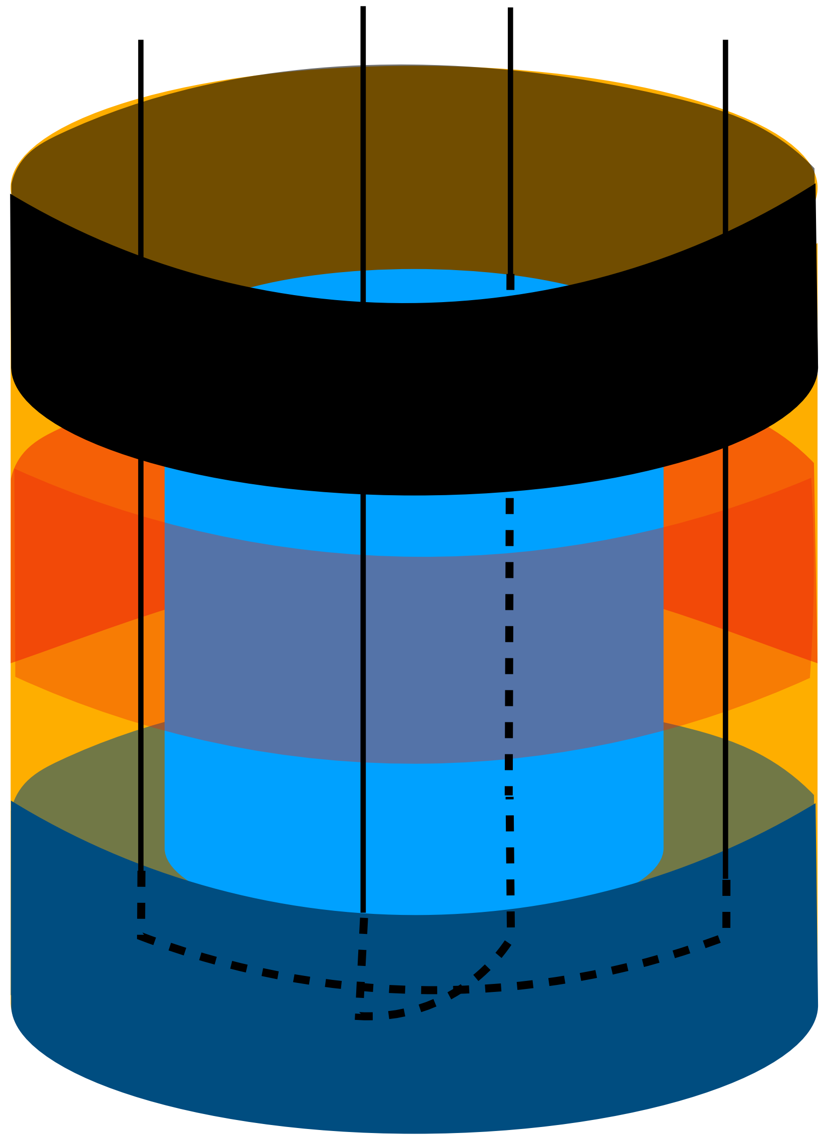
Top region of the veto buffer
Cut = "z > 200.4075"
(lower limit of the veto in the upper side)

Side region of the veto buffer
Cut = "z > -50 && z < 50"

Bottom region of the veto buffer
Cut = "z < -201.7050"
(Upper limit of the veto in the lower side)

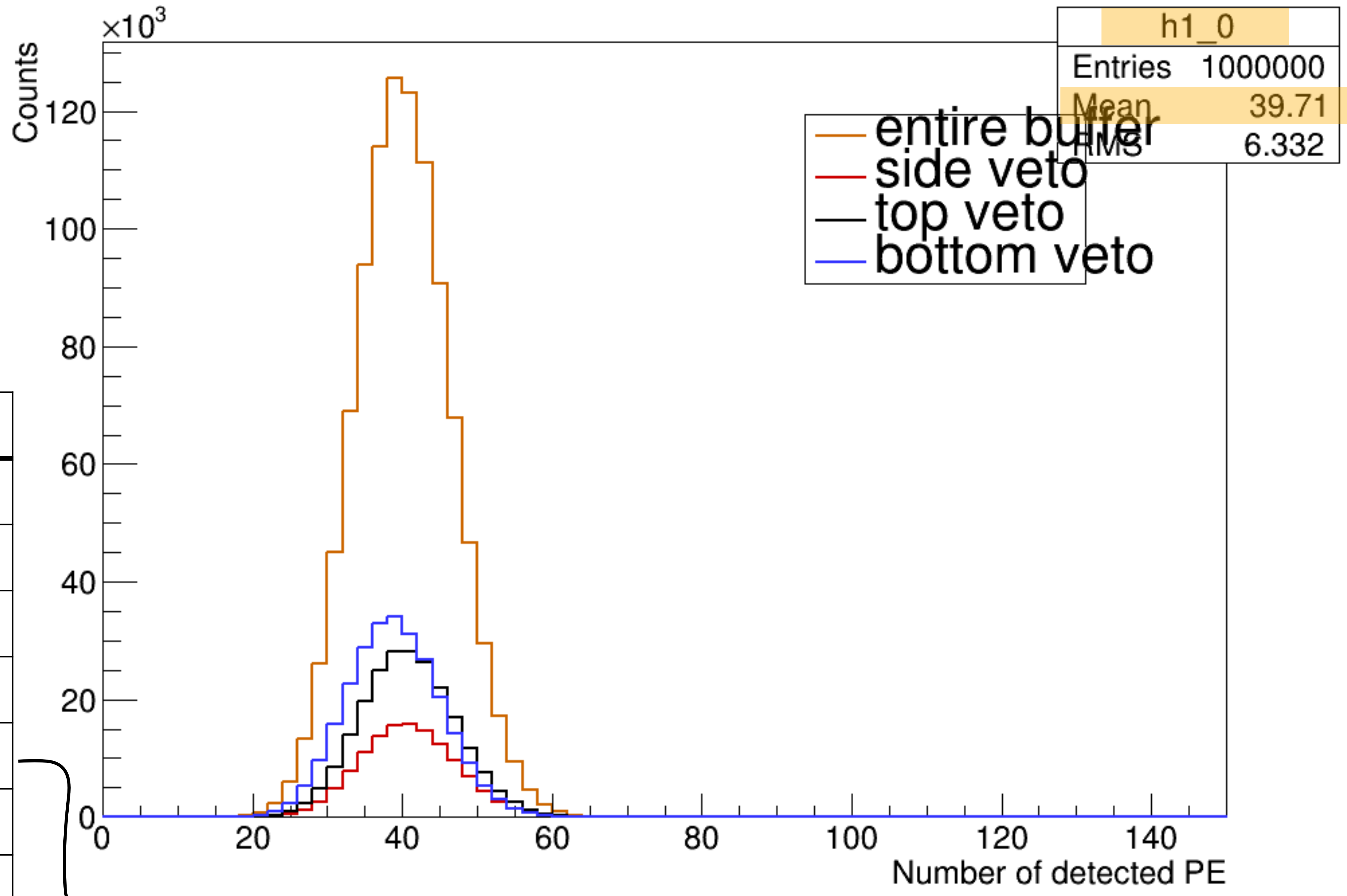


TPB coated (+reflector)



LCE	Full Veto Buffer (%):
> all =	3.97
> side =	4.04
> top =	4.03
> bot =	3.85
LCE	**Octants with Pipes (%):**
> all =	3.94
> side =	3.99
> top =	4.02
> bot =	3.83
LCE	**Octants without Pipes (%):**
> all =	4.00
> side =	4.08
> top =	4.04
> bot =	3.87

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

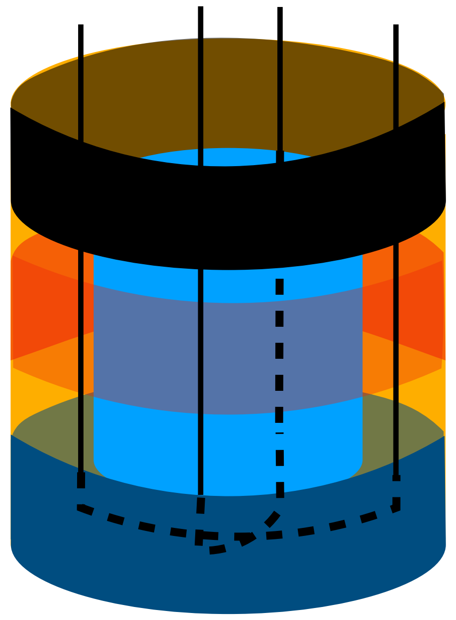


Asymmetry

	$\frac{LCE^{OctantsWithoutPipes} - LCE^{OctantsWithPipes}}{LCE^{OctantsWithoutPipes}}$
> all =	1.5 %
> side =	2.2 %
> top =	0.5 %
> bot =	1.0 %

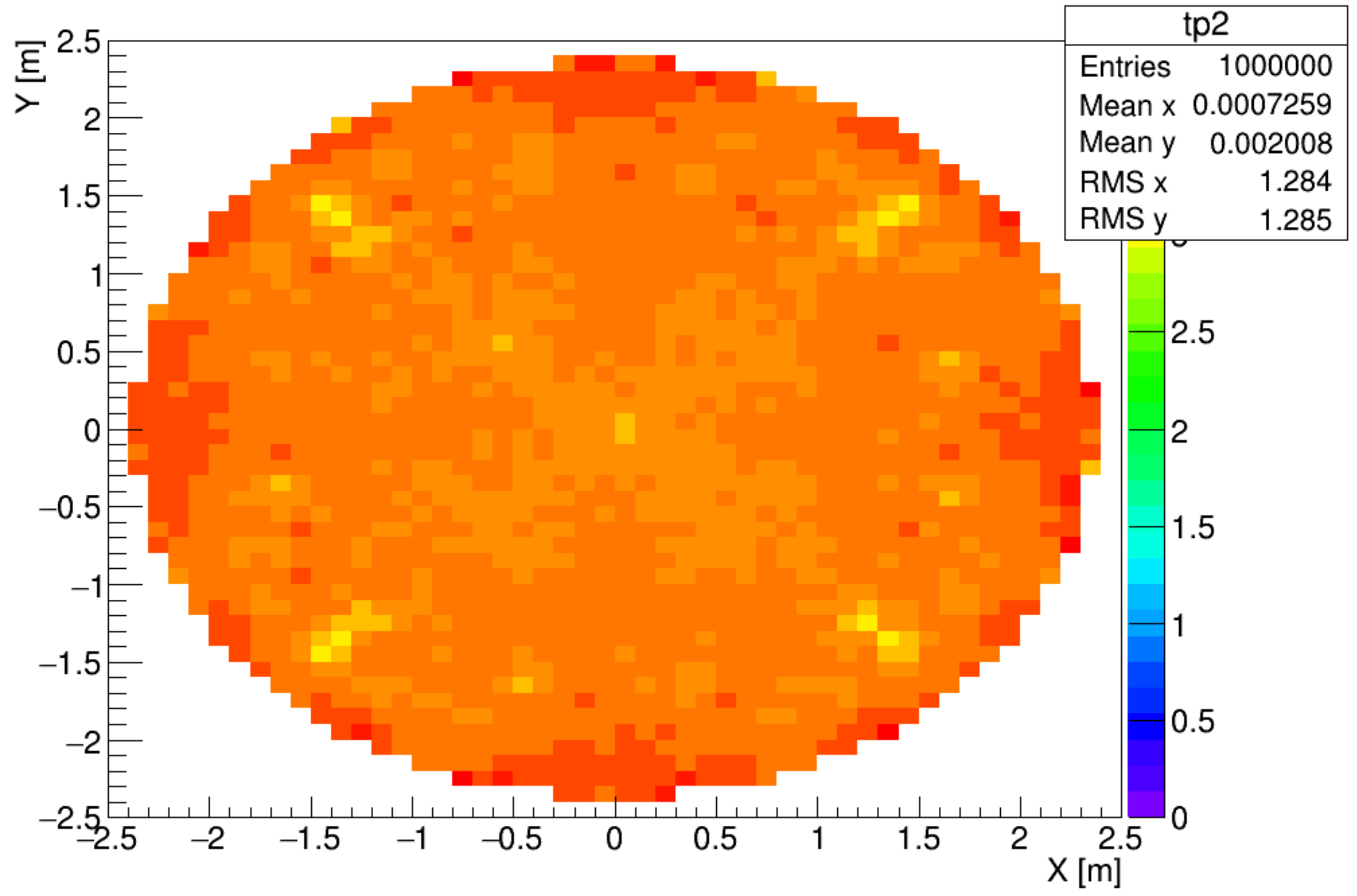
TPB coated (+ reflector)

XY cut-view of the number of photo-electrons



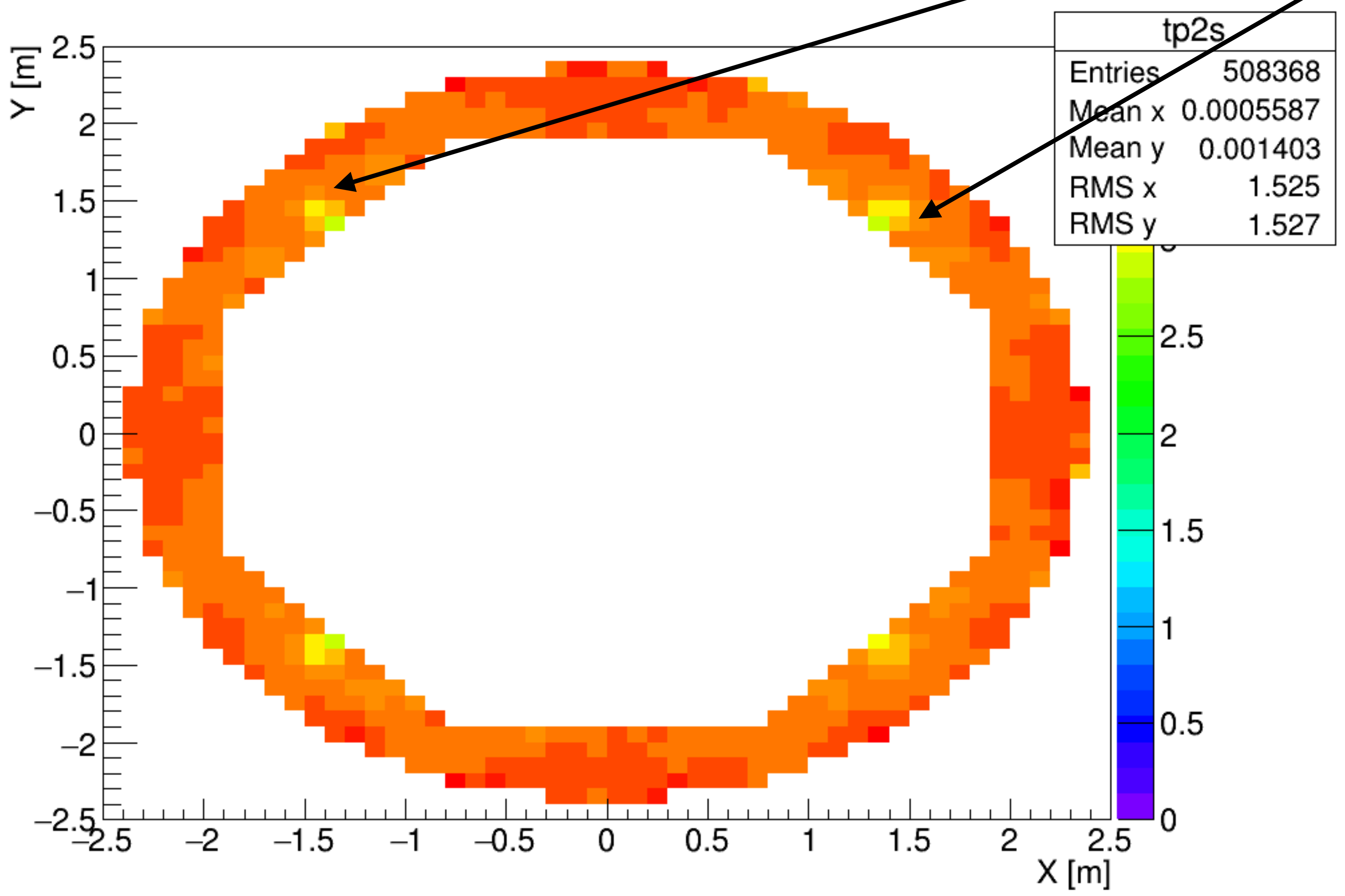
Presence of pipes are less but still seeable on Side (& Bottom) plots

All



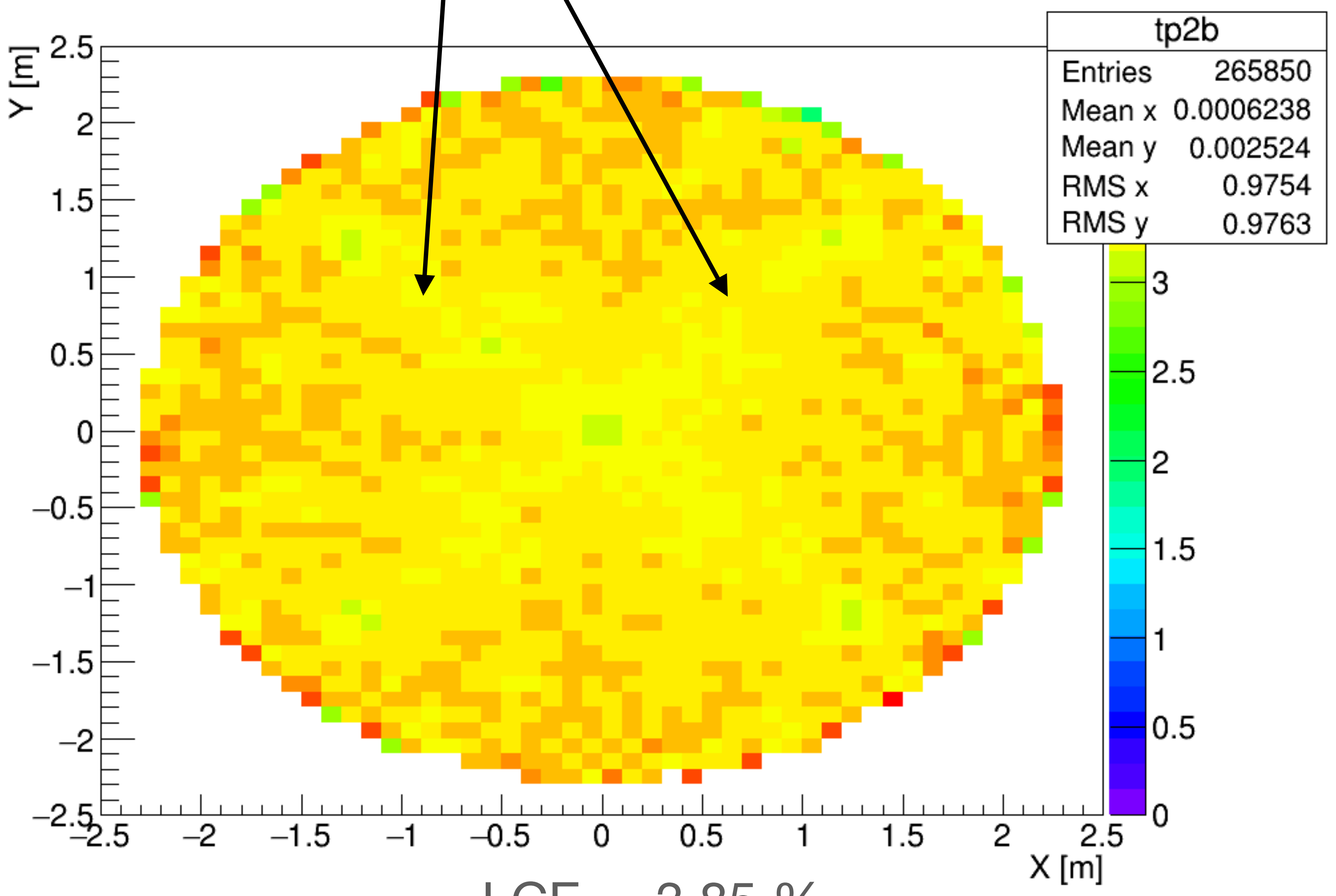
LCE = 3.97 %

Side



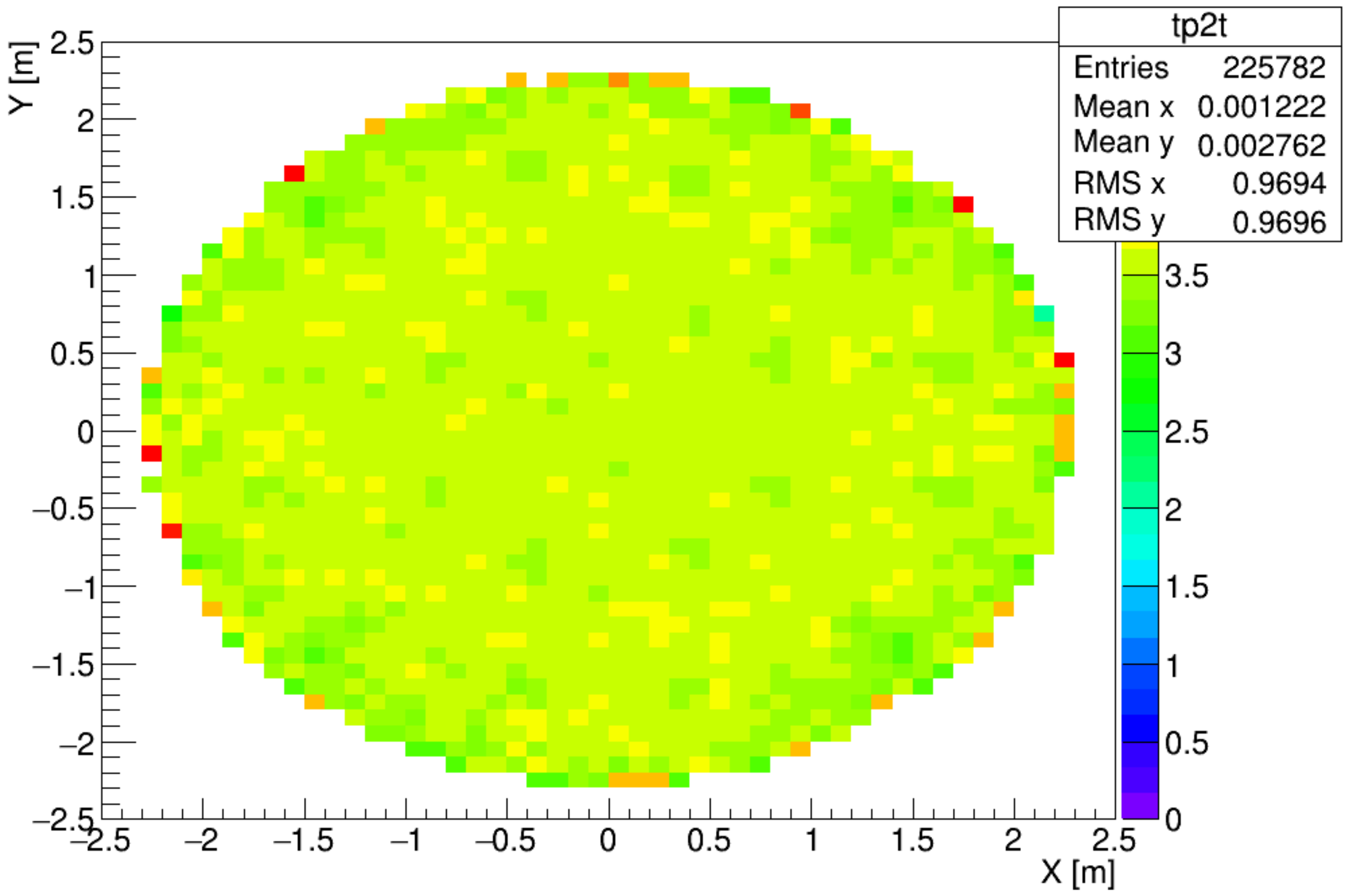
LCE = 4.04 %

Bottom



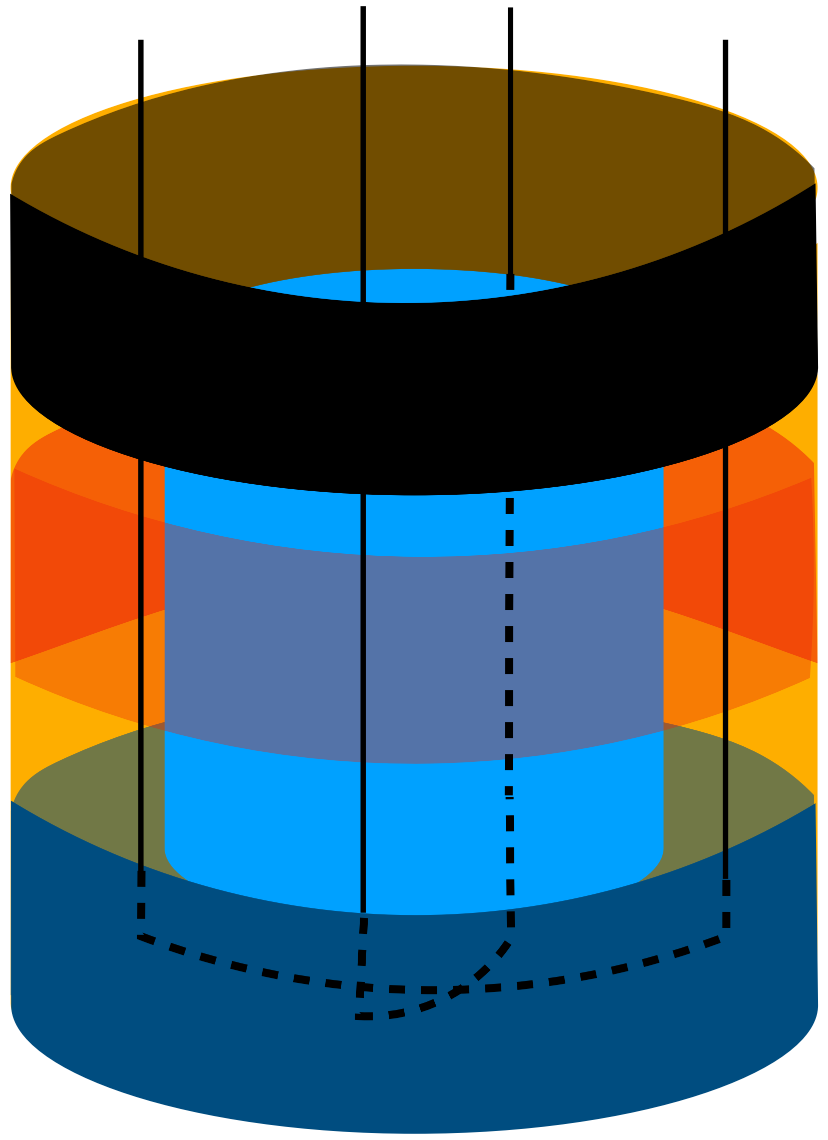
LCE = 3.85 %

Top



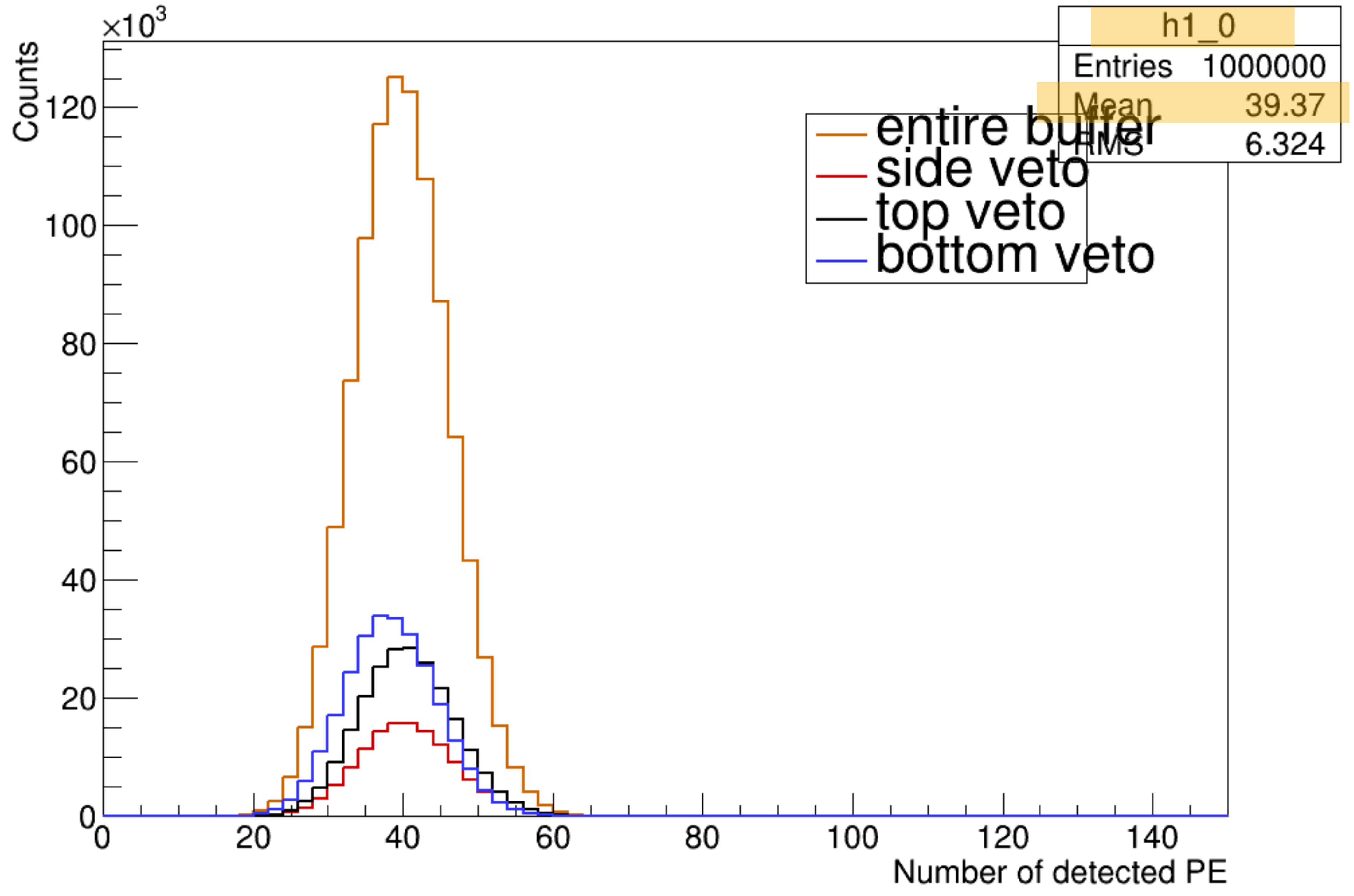
LCE = 4.03 %

PEN coated (+reflector)



LCE	Full Veto Buffer (%):
> all =	3.94
> side =	4.00
> top =	4.01
> bot =	3.80
LCE	**Octants with Pipes (%):**
> all =	3.90
> side =	3.95
> top =	4.01
> bot =	3.77
LCE	**Octants without Pipes (%):**
> all =	3.97
> side =	4.05
> top =	4.02
> bot =	3.83

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

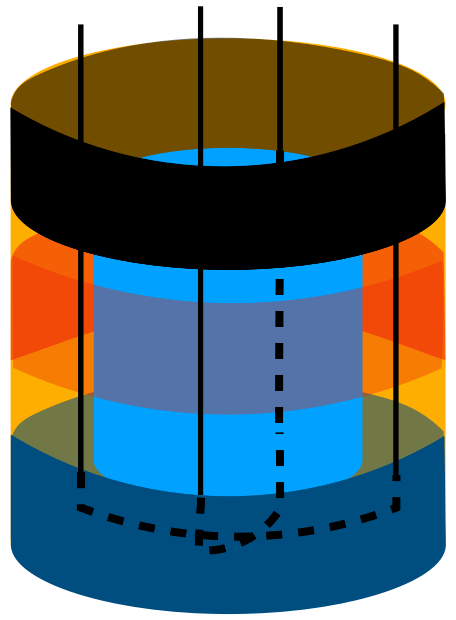


Asymmetry

	$\frac{LCE^{OctantsWithoutPipes} - LCE^{OctantsWithPipes}}{LCE^{OctantsWithoutPipes}}$
> all =	2 %
> side =	2 %
> top =	0.2%
> bot =	2 %

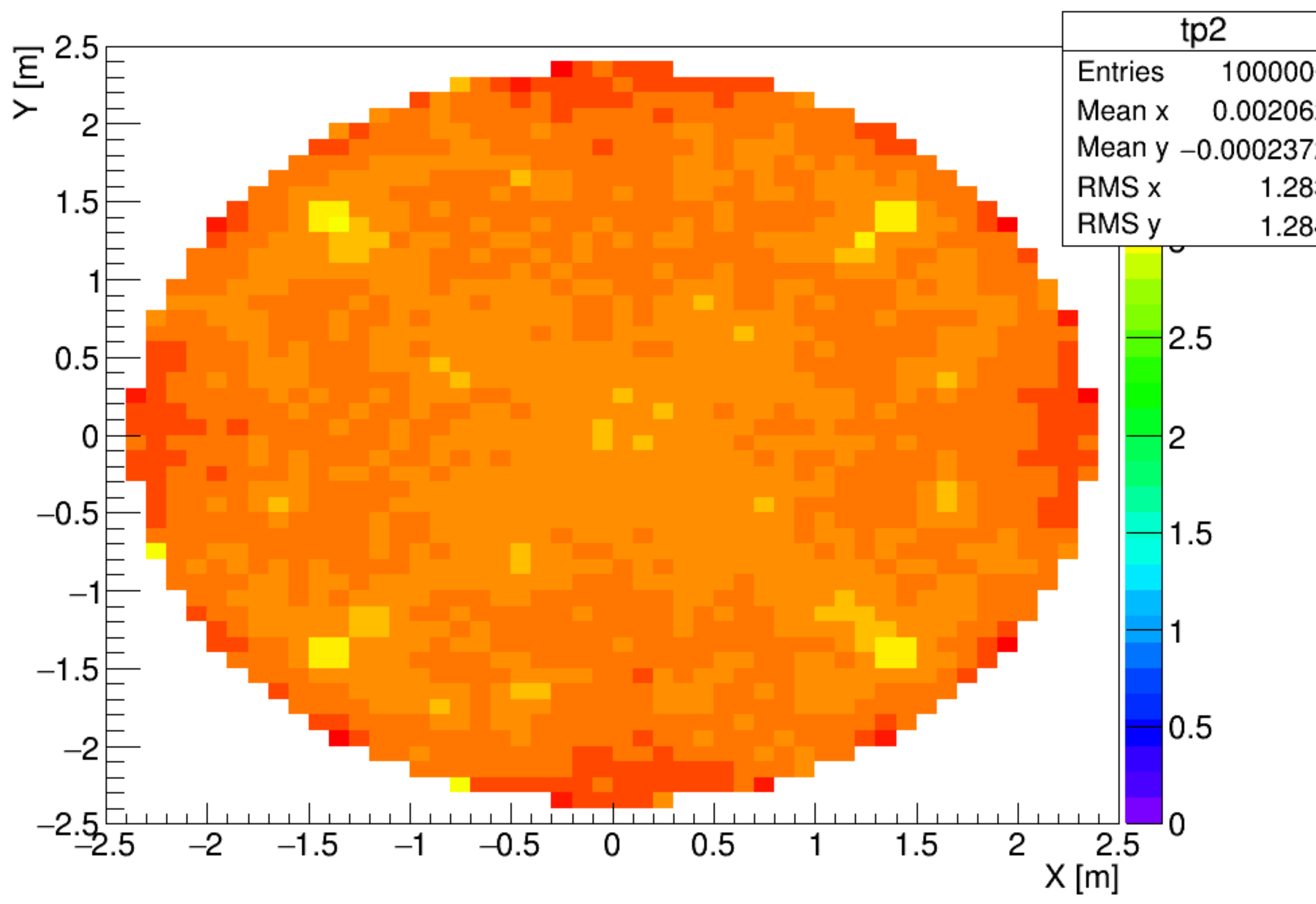
PEN coated (+reflector)

XY cut-view of the number of photo-electrons



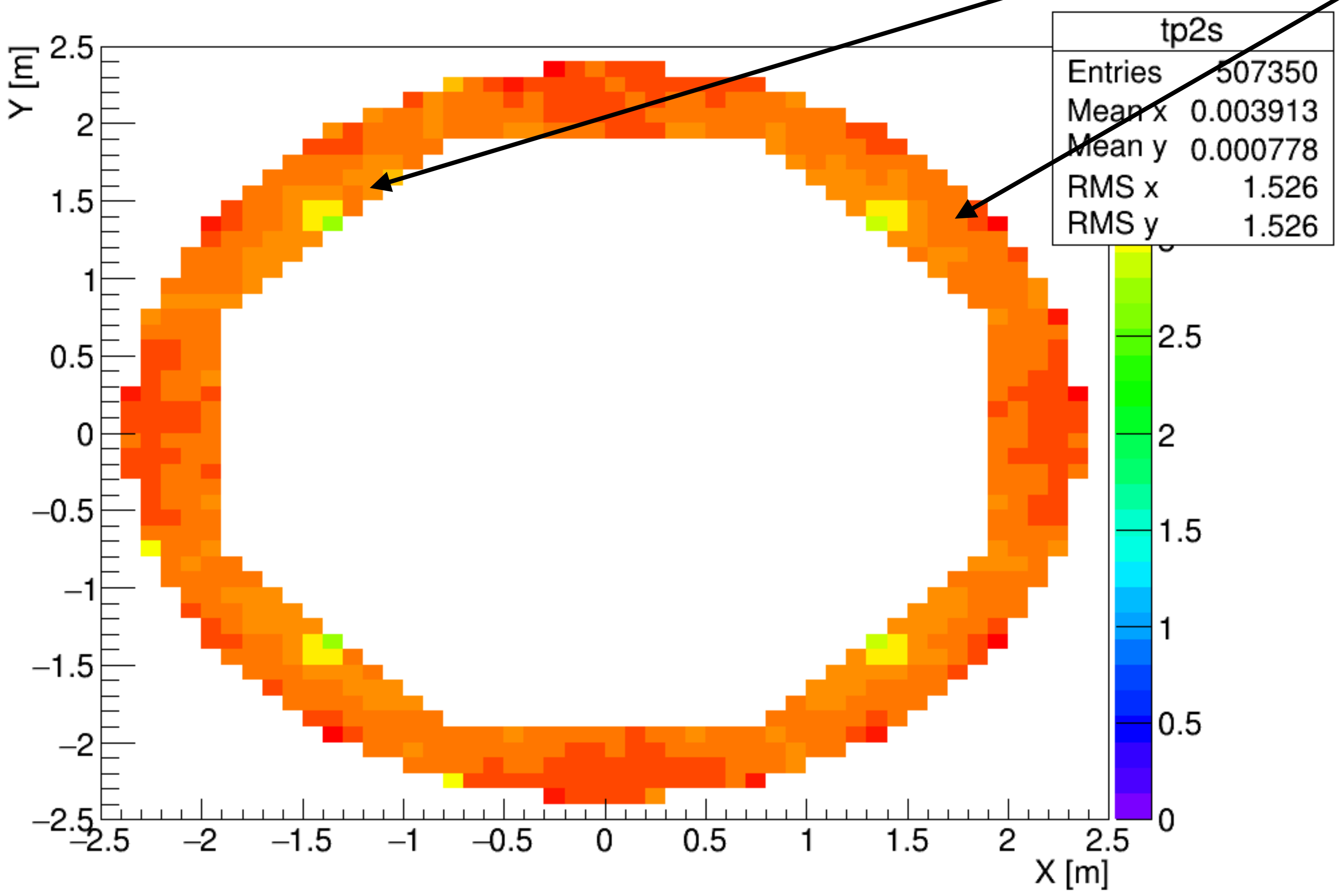
Presence of pipes are less but still seeable on Side (& Bottom) plots

All



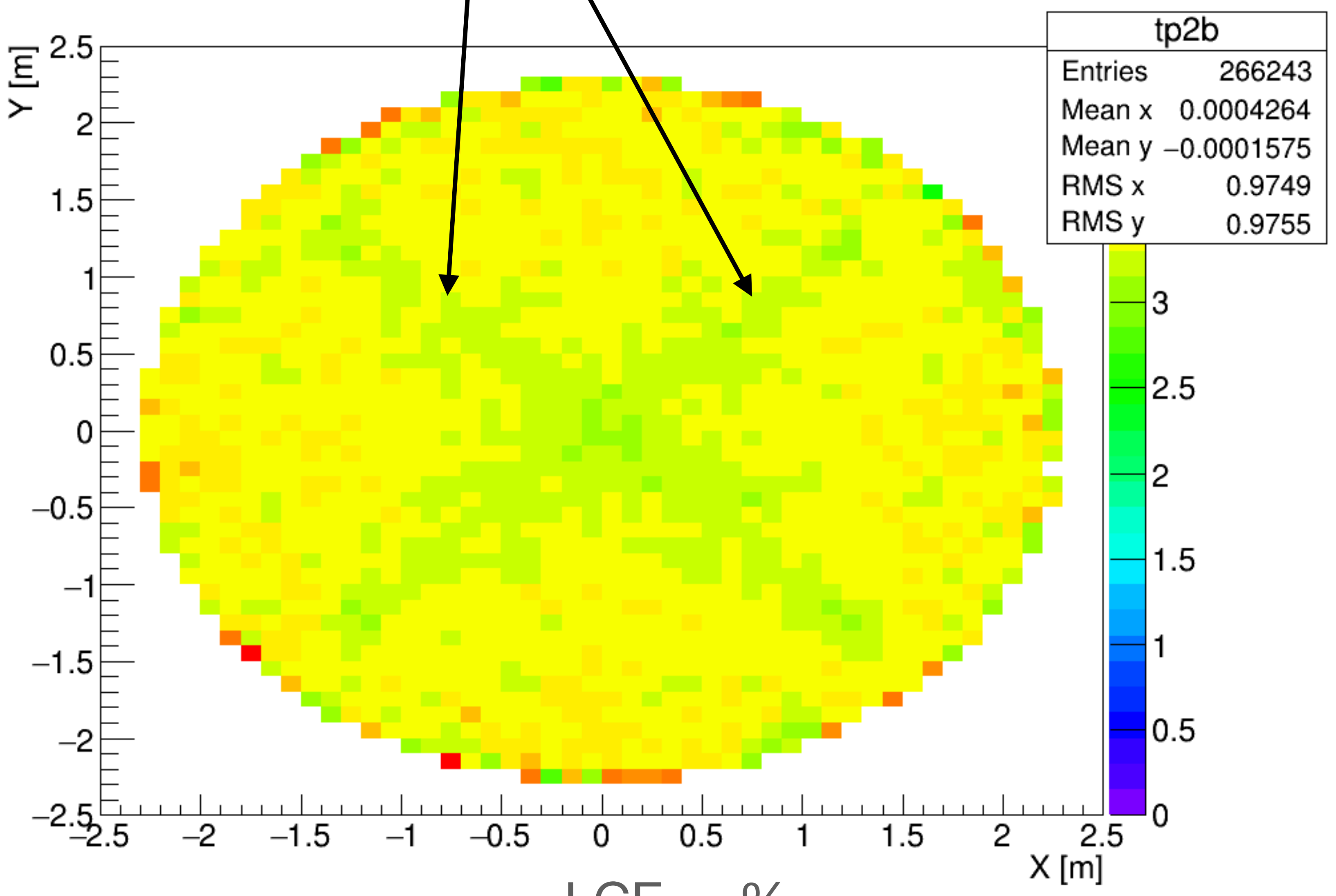
LCE = 3.97 %

Side



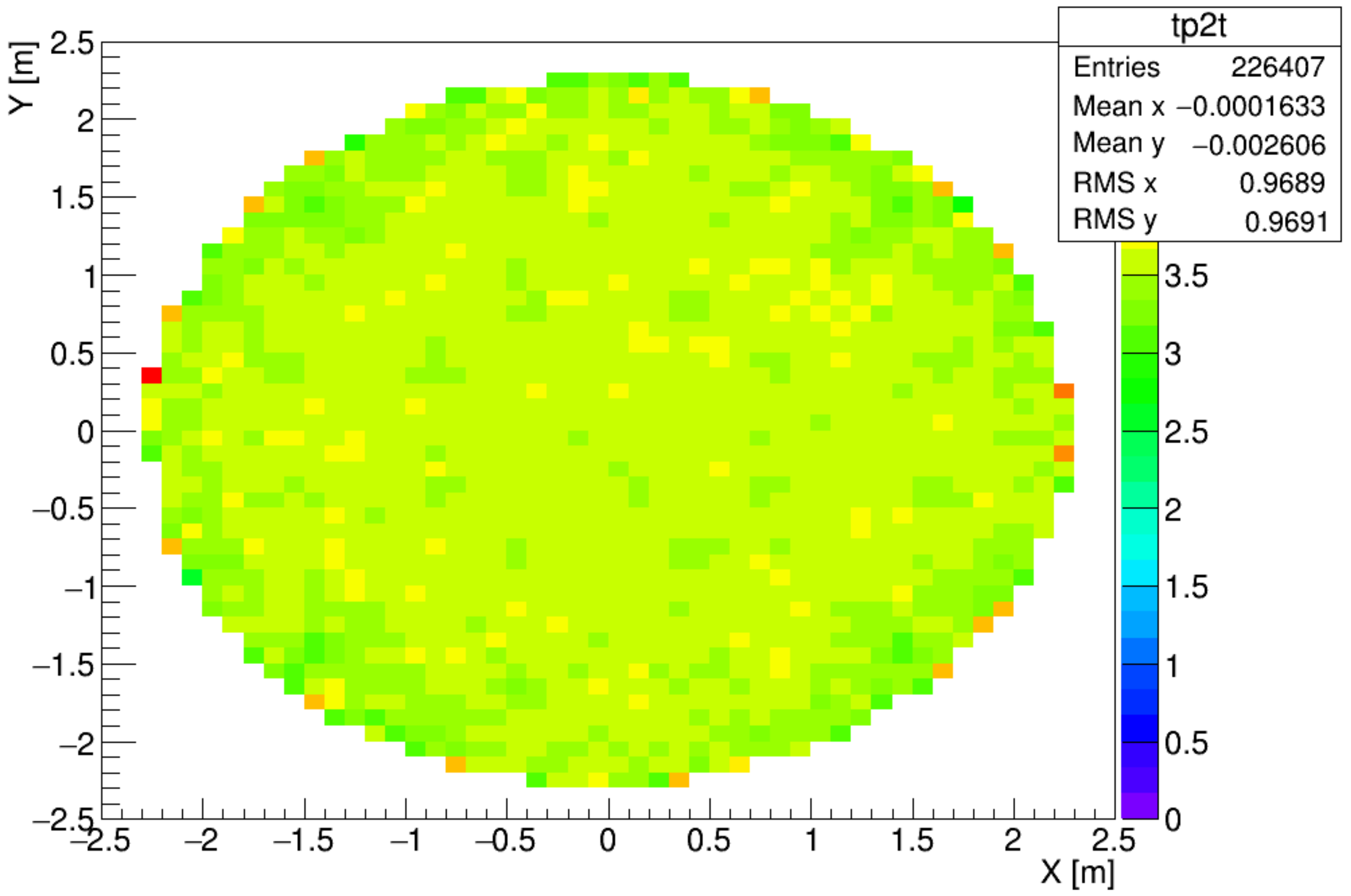
LCE = %

Bottom



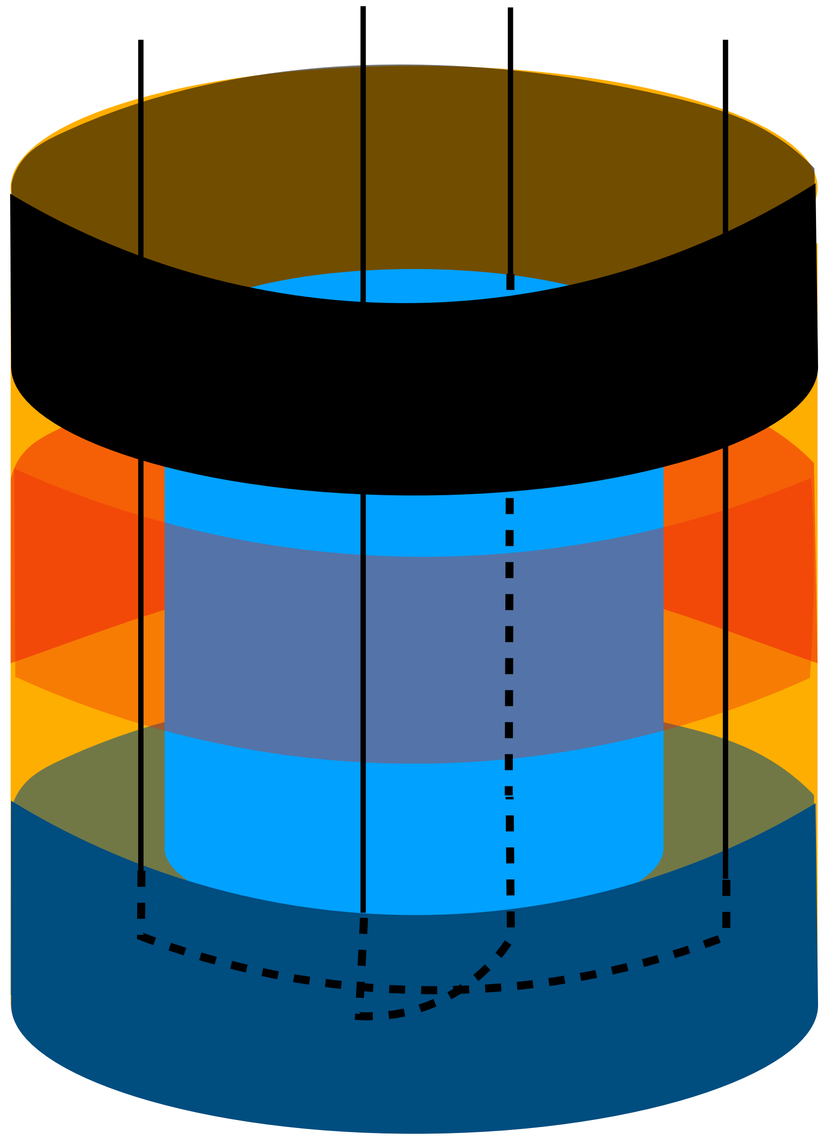
LCE = %

Top



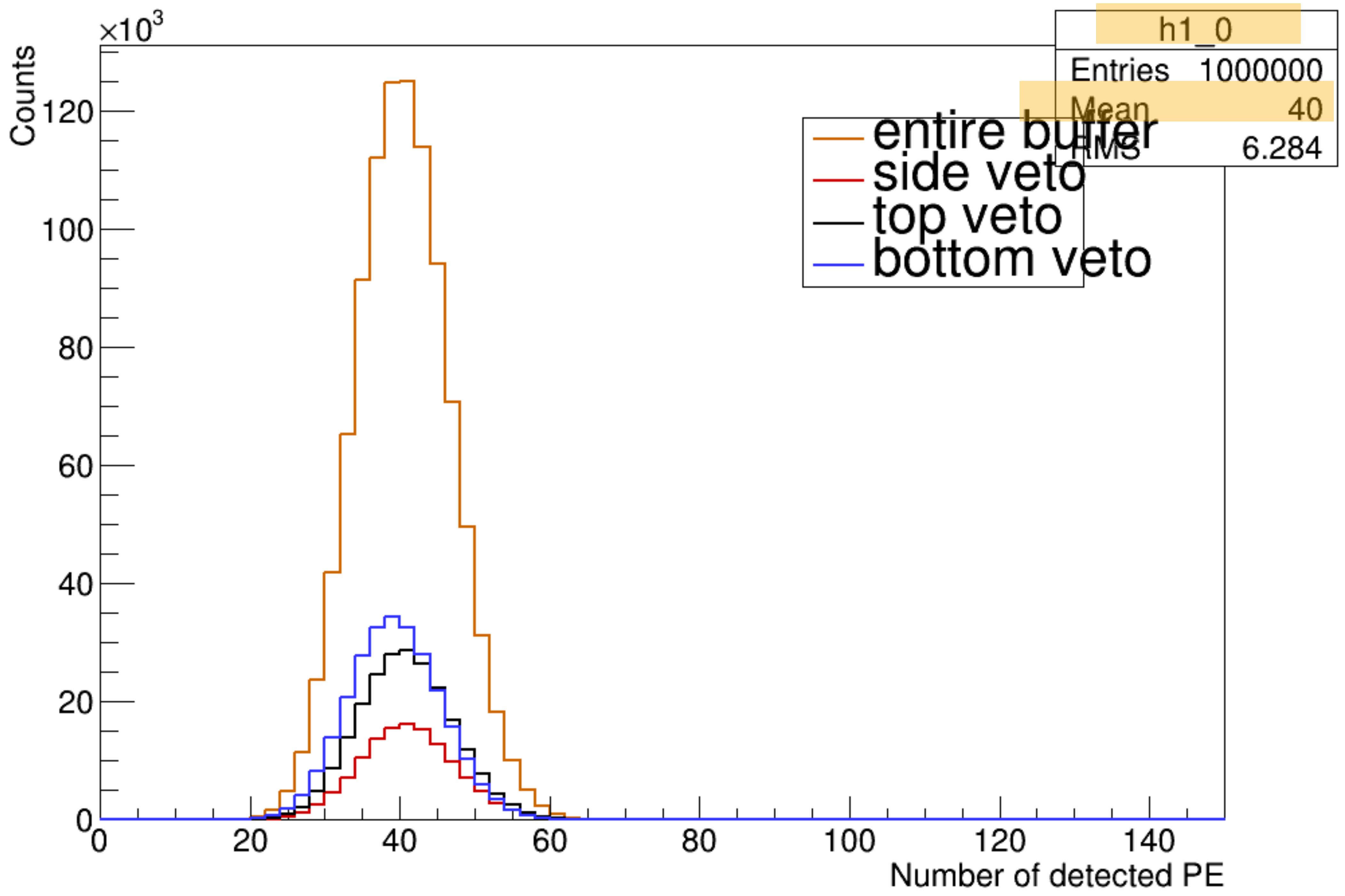
LCE = %

Reflector (ESR) alone



LCE	Full Veto Buffer (%):
> all =	4.00
> side =	4.06
> top =	4.03
> bot =	3.90
LCE	**Octants with Pipes (%):**
> all =	3.99
> side =	4.06
> top =	4.03
> bot =	3.89
LCE	**Octants without Pipes (%):**
> all =	4.01
> side =	4.07
> top =	4.04
> bot =	3.90

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



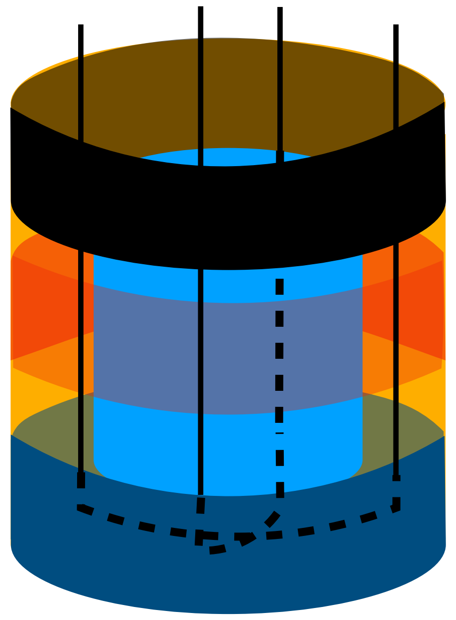
Asymmetry

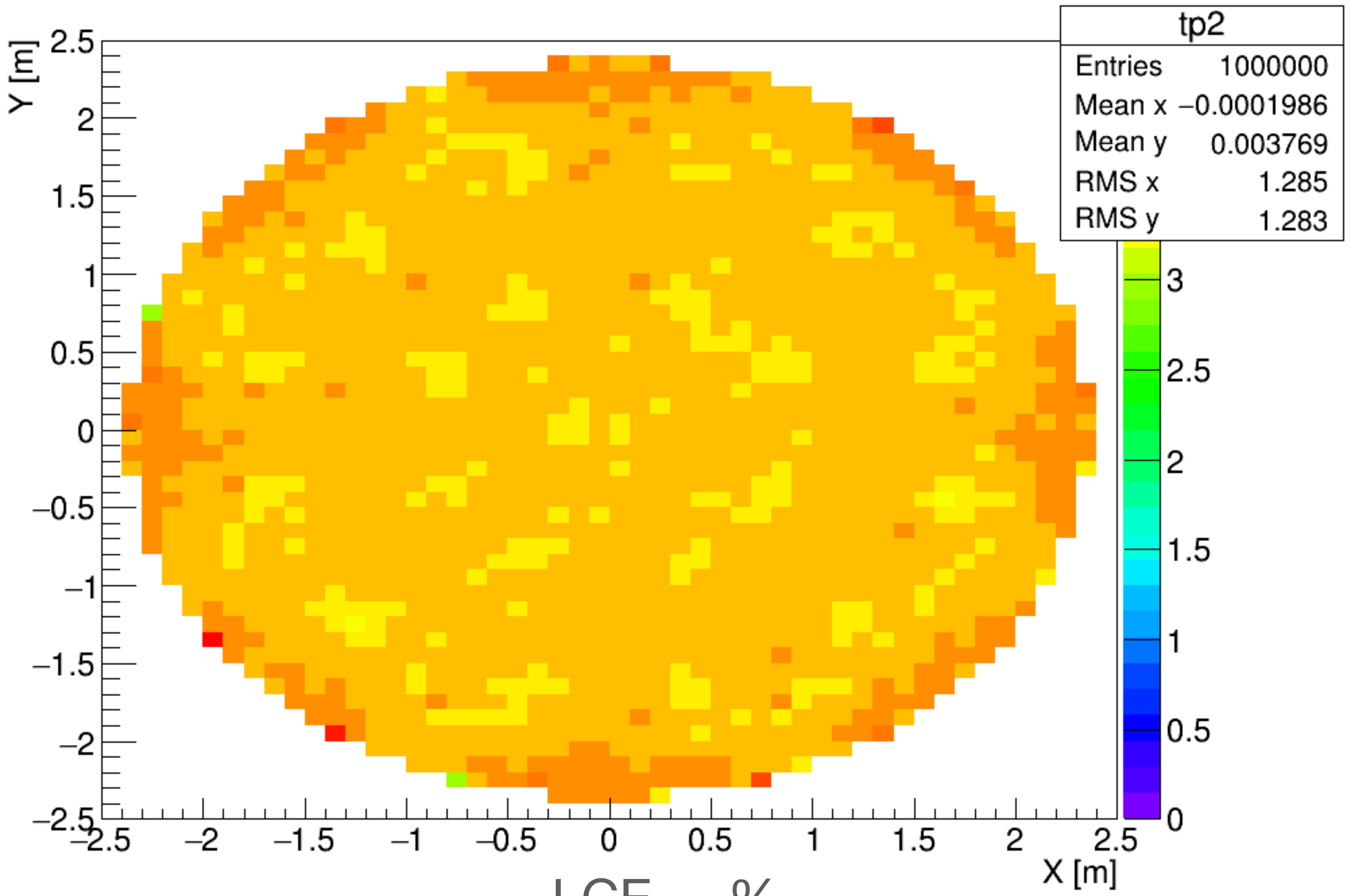
	$\frac{LCE^{OctantsWithoutPipes} - LCE^{OctantsWithPipes}}{LCE^{OctantsWithoutPipes}}$
> all =	0.5%
> side =	0.2%
> top =	0.2%
> bot =	0.3%

All

Reflector (ESR) alone

XY cut-view of the number of photo-electrons





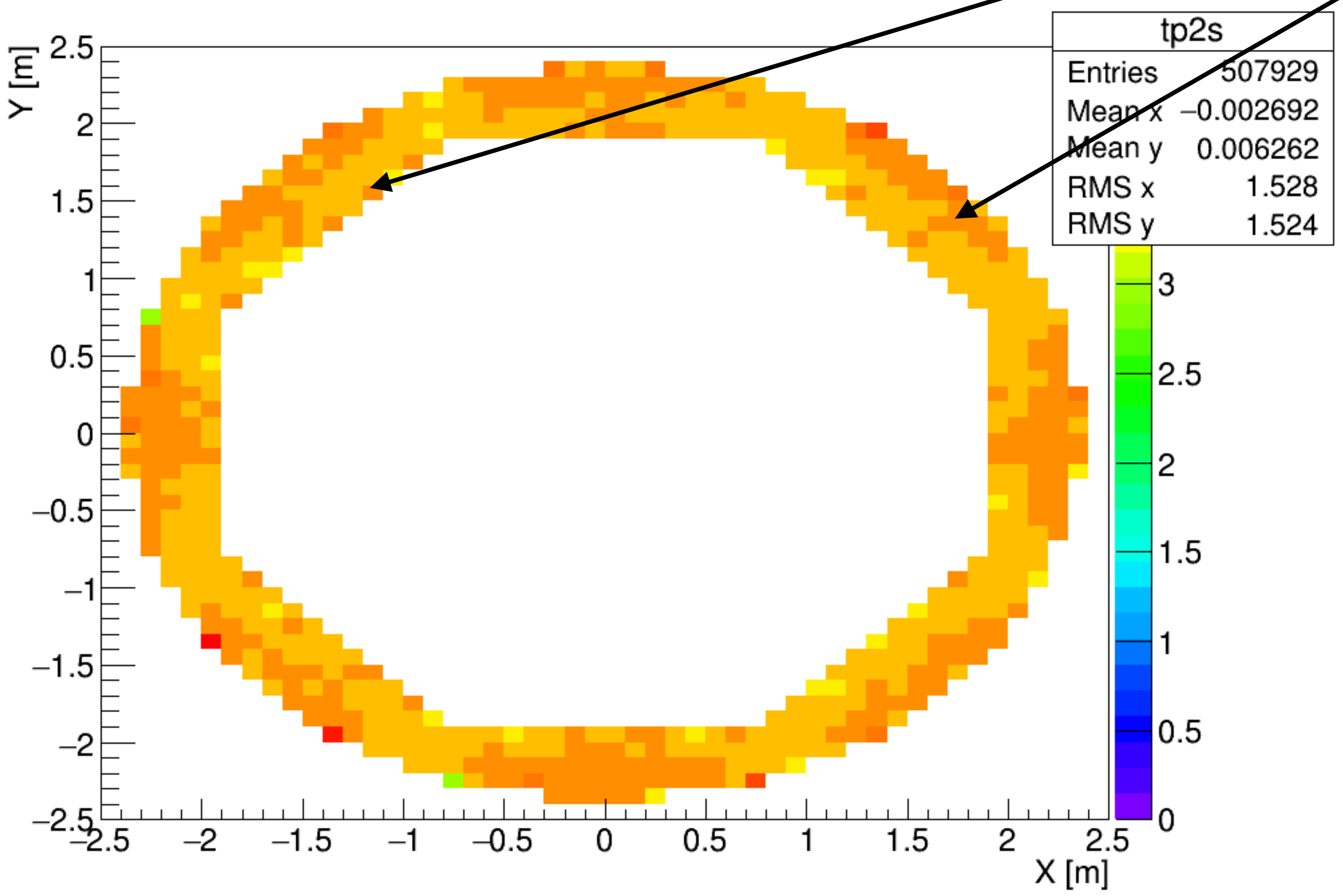
LCE = %

Presence of pipes are less but still seeable on Side (& Bottom) plots

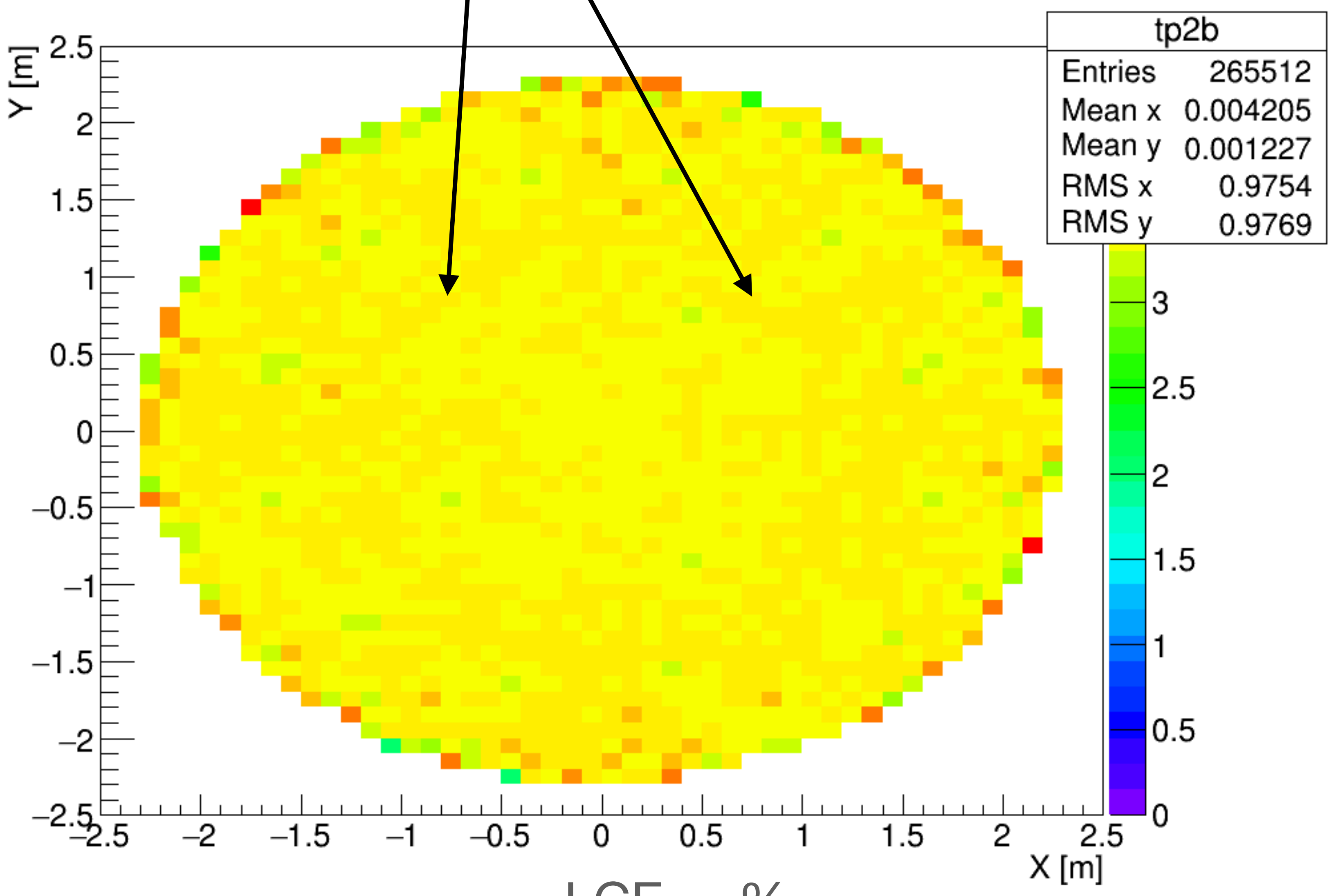
Side

Bottom

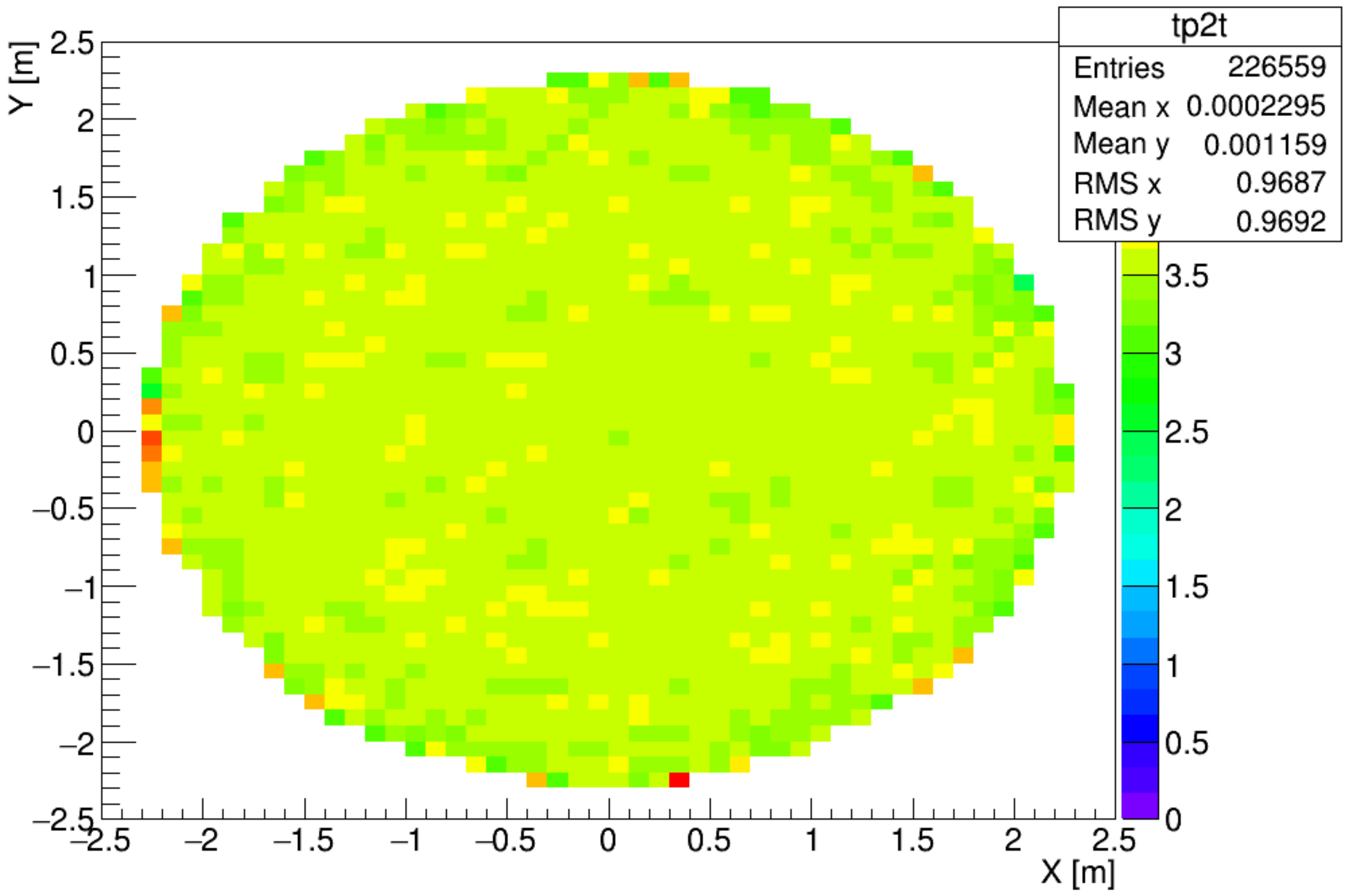
Top



LCE = %



LCE = %



LCE = %

Reference study of LCE

Study without pipes

- We studied the case where we do not have pipes inside the veto buffer in order to take it as our reference LCE (because pipes' coverage influences the octant where pipes are but also the ones where they are not)

Ref

LCE	Full Veto Buffer (%):
> all =	4.04
> side =	4.09
> top =	4.05
> bot =	3.97

Previous study (UT = untreated steel, EP= electropolished steel) (https://agenda.infn.it/event/29066/)

Relative loss of LCE

$\frac{\Delta LCE}{LCE}$	UT (%)	EP (%)	TPB (%)	PEN (%)	ESR (%)
> all =	9.4	7.9	1.7	2.5	0.99
> side =	9.0	7.6	1.2	2.2	0.73
> top =	4.9	4.0	0.5	0.99	0.49
> bot =	14	12	3.0	4.3	1.8

Computed as $\frac{LCE^{Full}_{without-pipes} - LCE^{Full}_{UT-EP-TPB-PEN-ESR}}{LCE^{Full}_{without-pipes}}$

Previous study (UT = untreated steel, EP= electropolished steel) (https://agenda.infn.it/event/29066/)

Relative loss of LCE in pipes octants

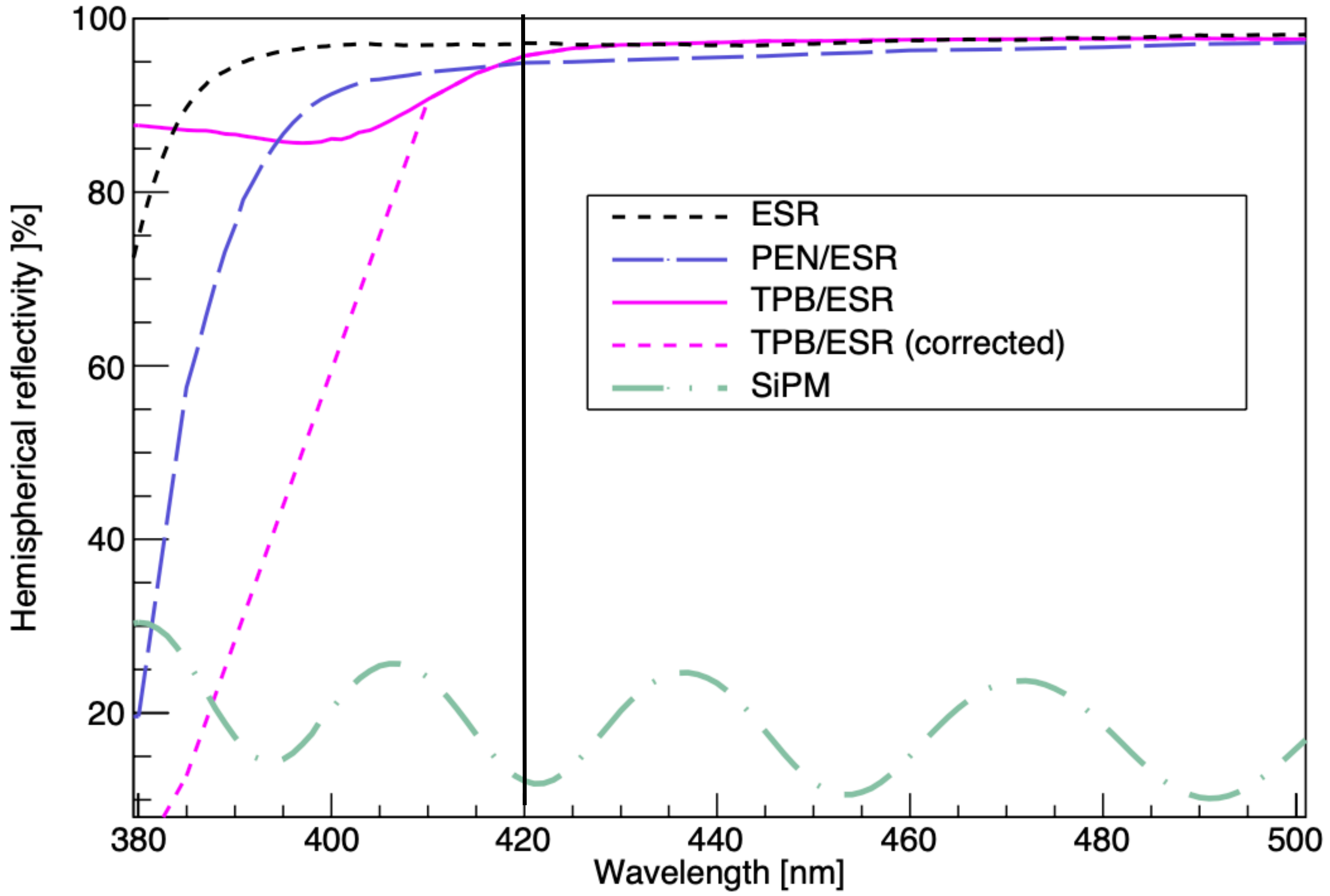
$\frac{\Delta LCE}{LCE}$	UT (%)	EP (%)	TPB (%)	PEN (%)	ESR (%)
> all =	11	9.2	2.5	3.5	1.2
> side =	12	10	2.4	3.4	0.73
> top =	5.2	4.2	0.7	0.99	0.49
> bot =	14	12	3.5	5.0	2.0

Computed as $\frac{LCE^{Pipes-octants}_{without-pipes} - LCE^{Pipes-octants}_{UT-EP-TPB-PEN-ESR}}{LCE^{Pipes-octants}_{without-pipes}}$

ESR, PEN and TPB reflectivities

Comparison of all surfaces

Expected at 420 nm:
Reflectivity: ESR > TPB > PEN



TDR Figure is equivalent to what is coded in g4ds

FIG. 42. Hemispherical reflectivity measured at 7° angle of incidence with a spectrophotometer equipped with an integrating sphere for: ESR, PEN air-coupled to ESR, TPB evaporated on ESR, TPB evaporated on ESR corrected for the spurious fluorescence component based on [49], and SiPMs (see legend).

Conclusion and perspectives

Previous study (https://agenda.infn.it/event/29066/)

- UT : The tubes do reduce the inclusive veto LCE by 9.4% and cause an asymmetry between octants up to 6.5%
- EP : The tubes do reduce the inclusive veto LCE by 7.9% and cause an asymmetry between octants up to 5.2%
- TPB: The tubes do reduce the inclusive veto LCE by 1.7% and cause an asymmetry between octants up to 2.2%
- PEN: The tubes do reduce the inclusive veto LCE by 2.5% and cause an asymmetry between octants up to 2%
- ESR: The tubes do reduce the inclusive veto LCE by 1% and cause an asymmetry between octants up to 0.5%

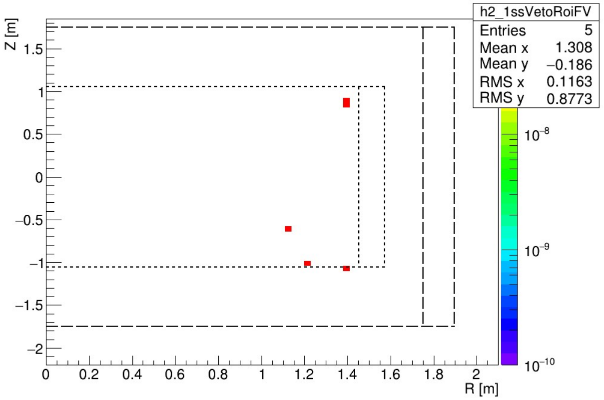
➡ The best solution looks to be ESR-only coated tubes

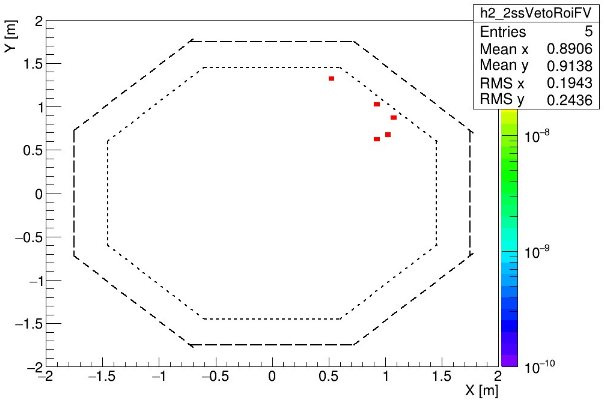
NR background

^{232}Th

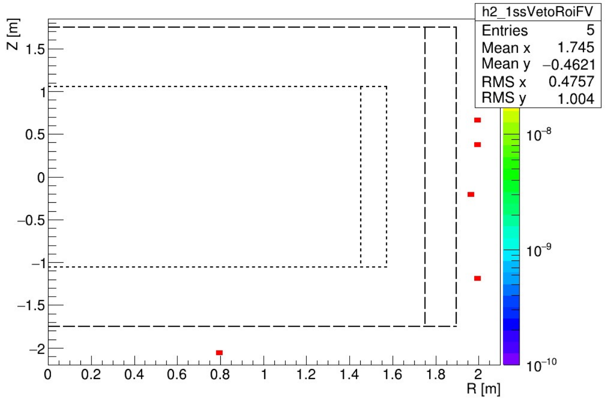
- Events after ROI cut and after FV cut

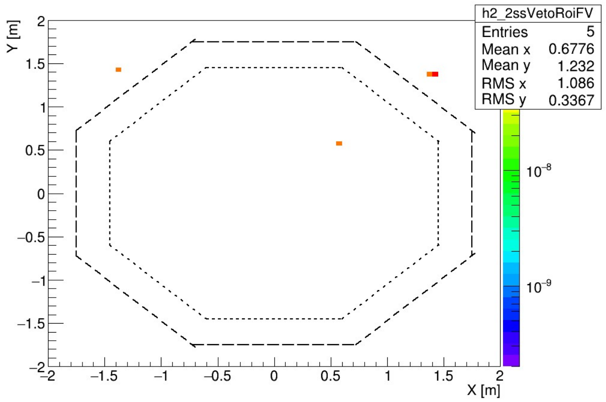
Location of energy deposit in TPC





Location of neutron emission



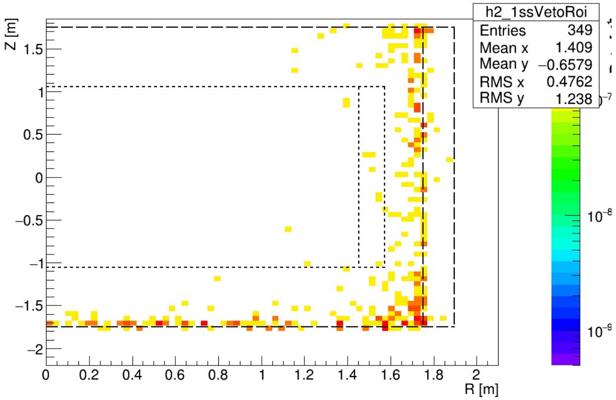


NR background

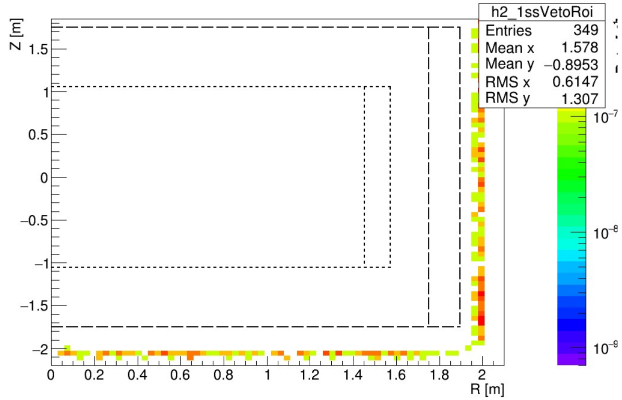
^{232}Th

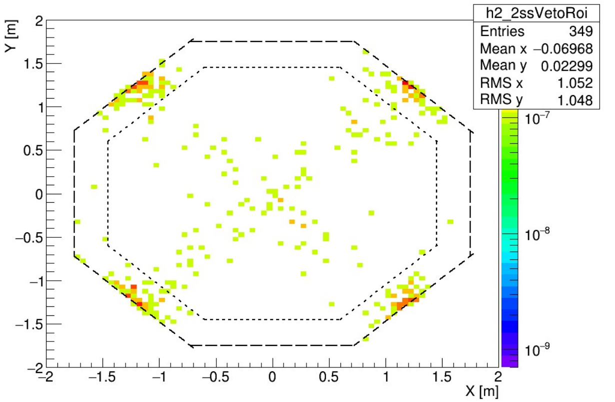
- Events after ROI cut but before FV cut

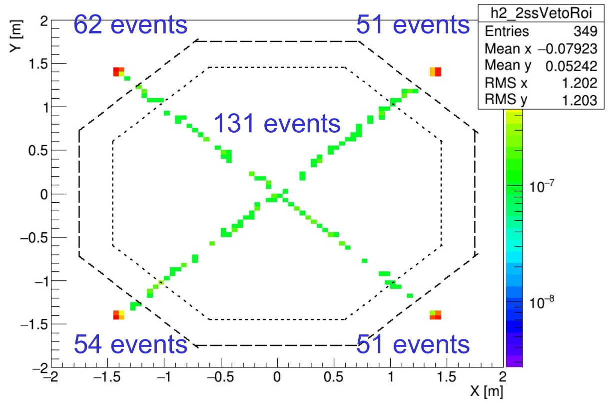
Location of energy deposit in TPC



Location of neutron emission







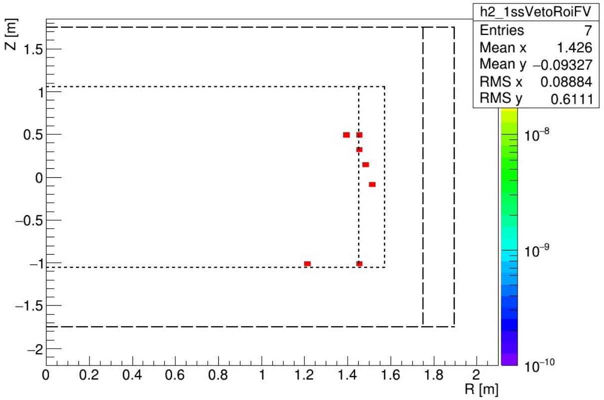
➢ No prefered position

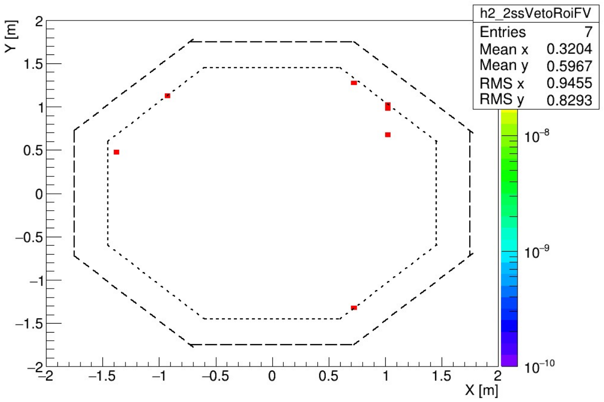
^{238}U

NR background

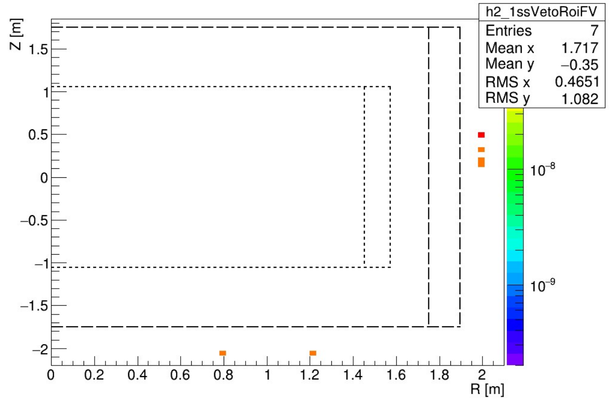
- Events after ROI cut and after FV cut

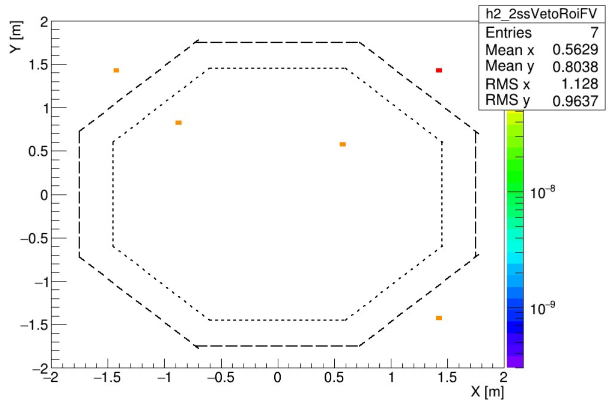
Location of energy deposit in TPC





Location of neutron emission



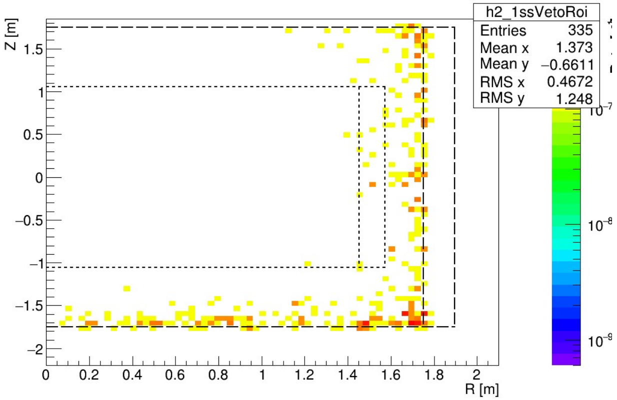


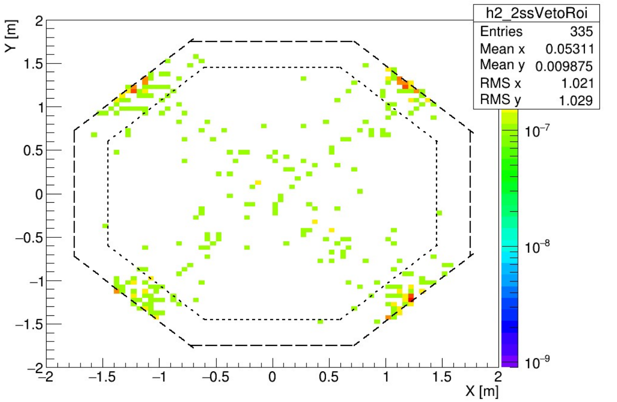
NR background

238U

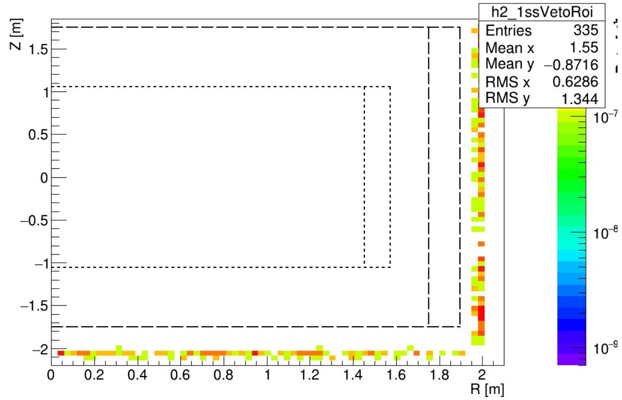
- Events after ROI cut but before FV cut

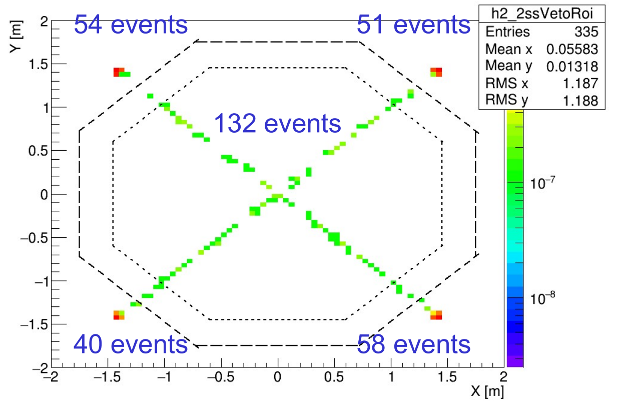
Location of energy deposit in TPC





Location of neutron emission





➤ No prefered position

ER background: rates

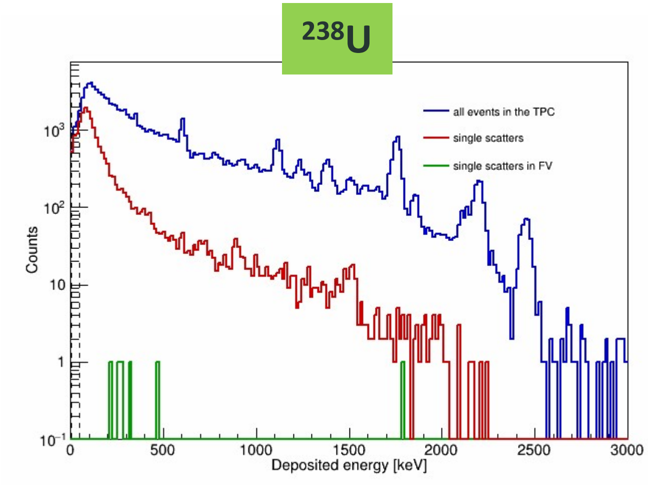
- Rates in the TPC and in the veto (all events with deposited energy >0 in TPC / veto)

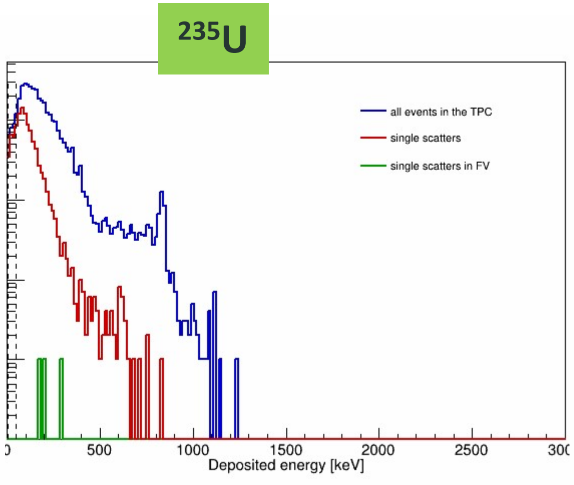
	^{238}U up	^{238}U mid	^{238}U low	^{232}Th	^{235}U	^{40}K	^{46}Sc
Activity for 17 kg Ti (mBq)	136	2.1	1360	2.1	6.2	10.2	53
Event depositing energy in TPC (%)	1.0	1.0	1.0	1.7	0.36	1.2	16.8
TPC rate (Hz)	0.001	<0.001	0.01	<0.001	<0.001	<0.001	0.009
Event depositing energy in veto (%)	11.8	11.8	11.8	18.8	18.9	14.4	97.4
Veto rate (Hz)	0.016	<0.001	0.16	<0.001	0.001	0.001	0.052

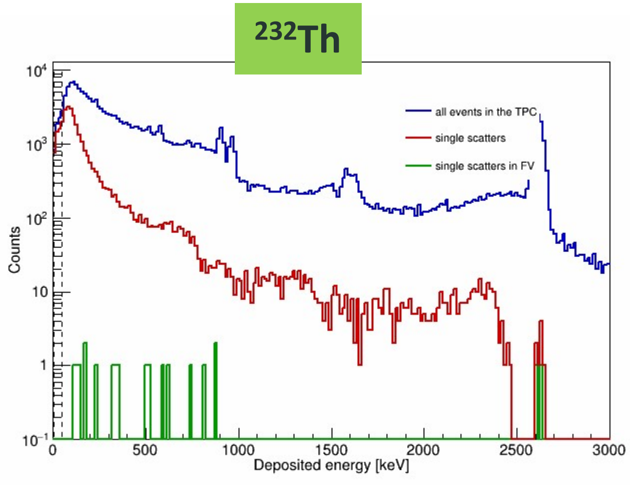
- TPC rate (~0.02 Hz) induced by the tubes fully negligible (TDR sum = 52 Hz)
- Veto rate (~0.2 Hz) induced by the tubes very small (TDR sum = 135 Hz)

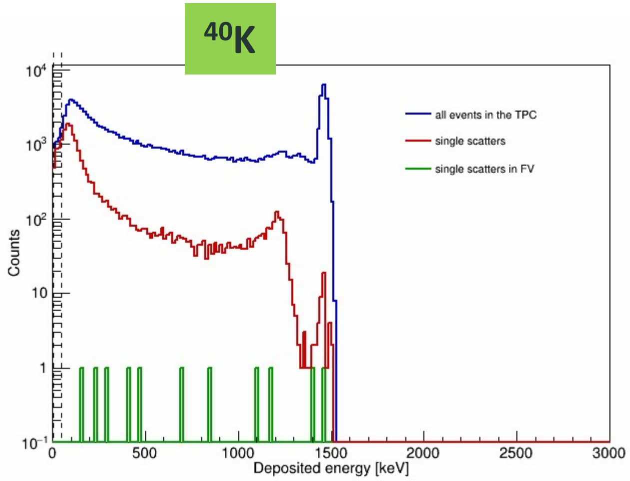
ER background: rates

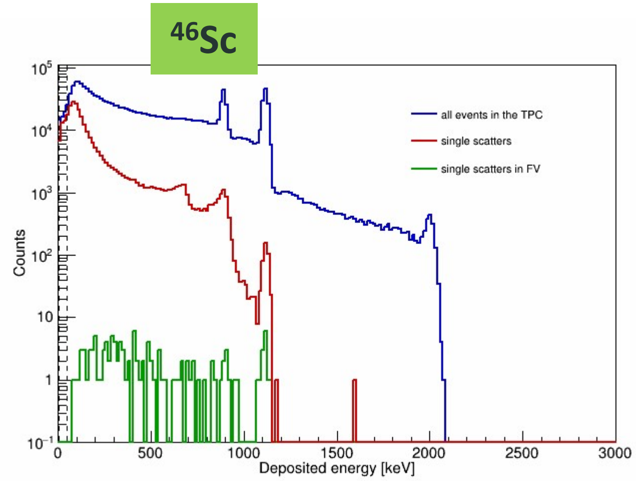
- Energy deposited in the TPC







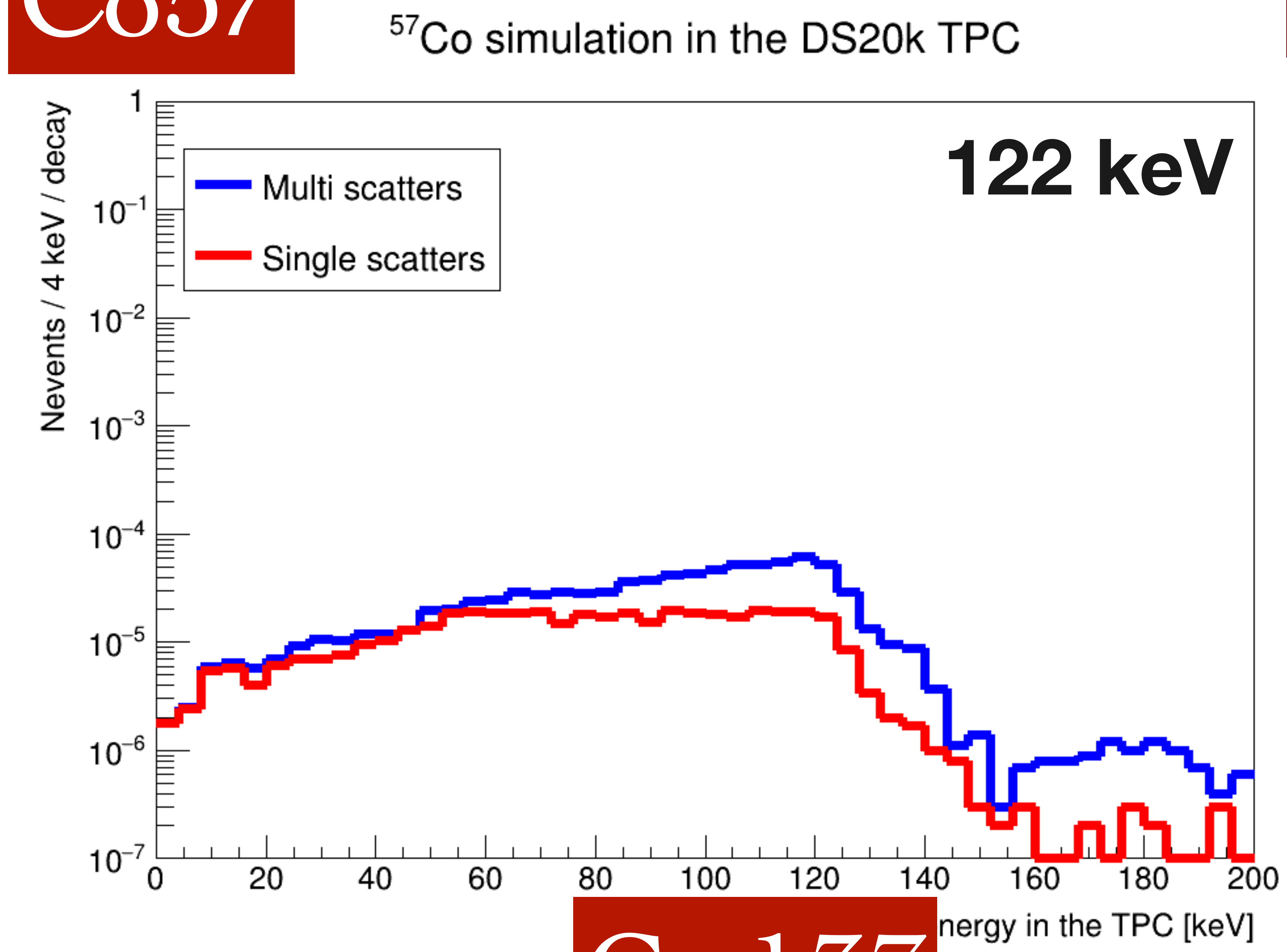




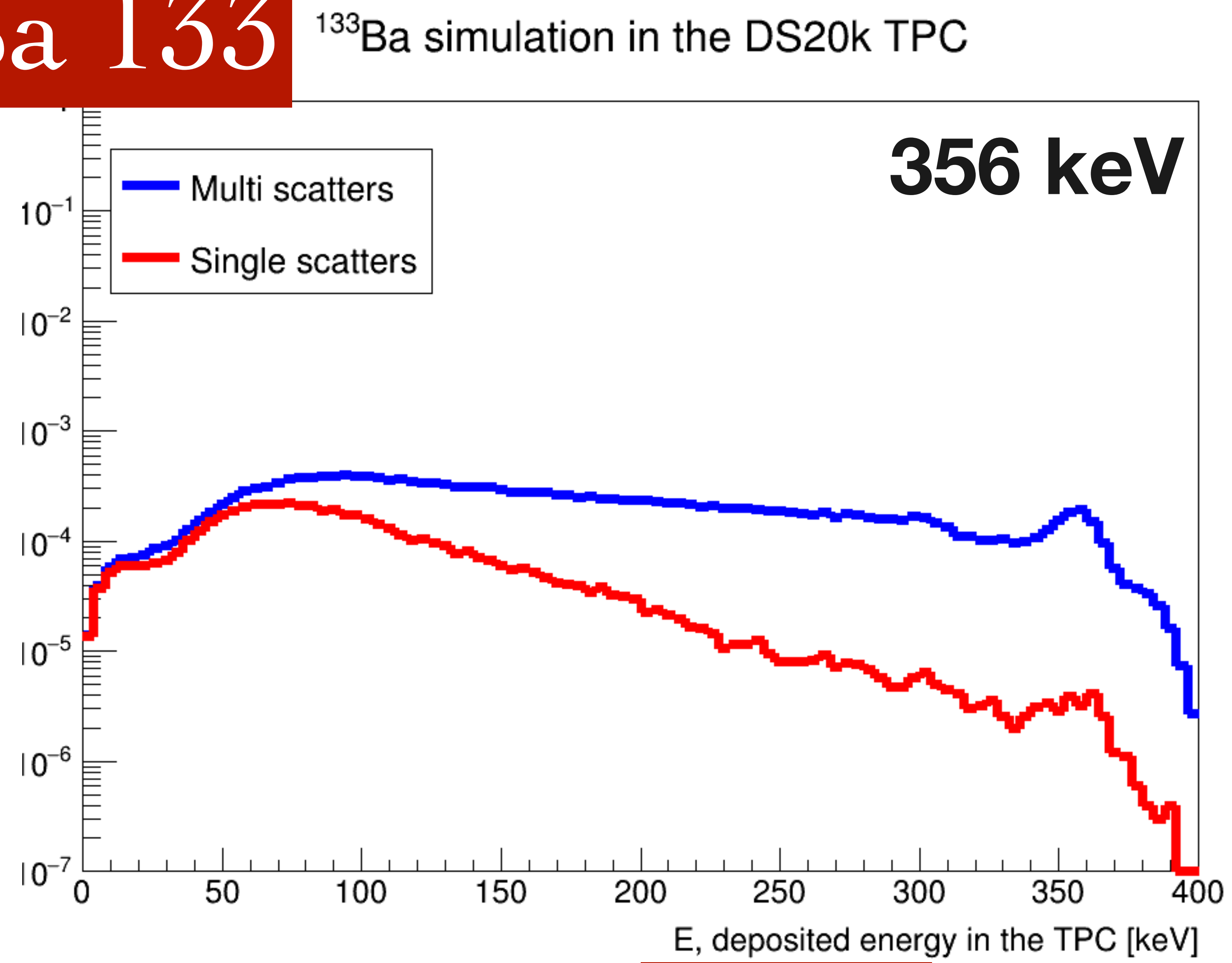
Back up

Photon sources - ER calibration - Bottom

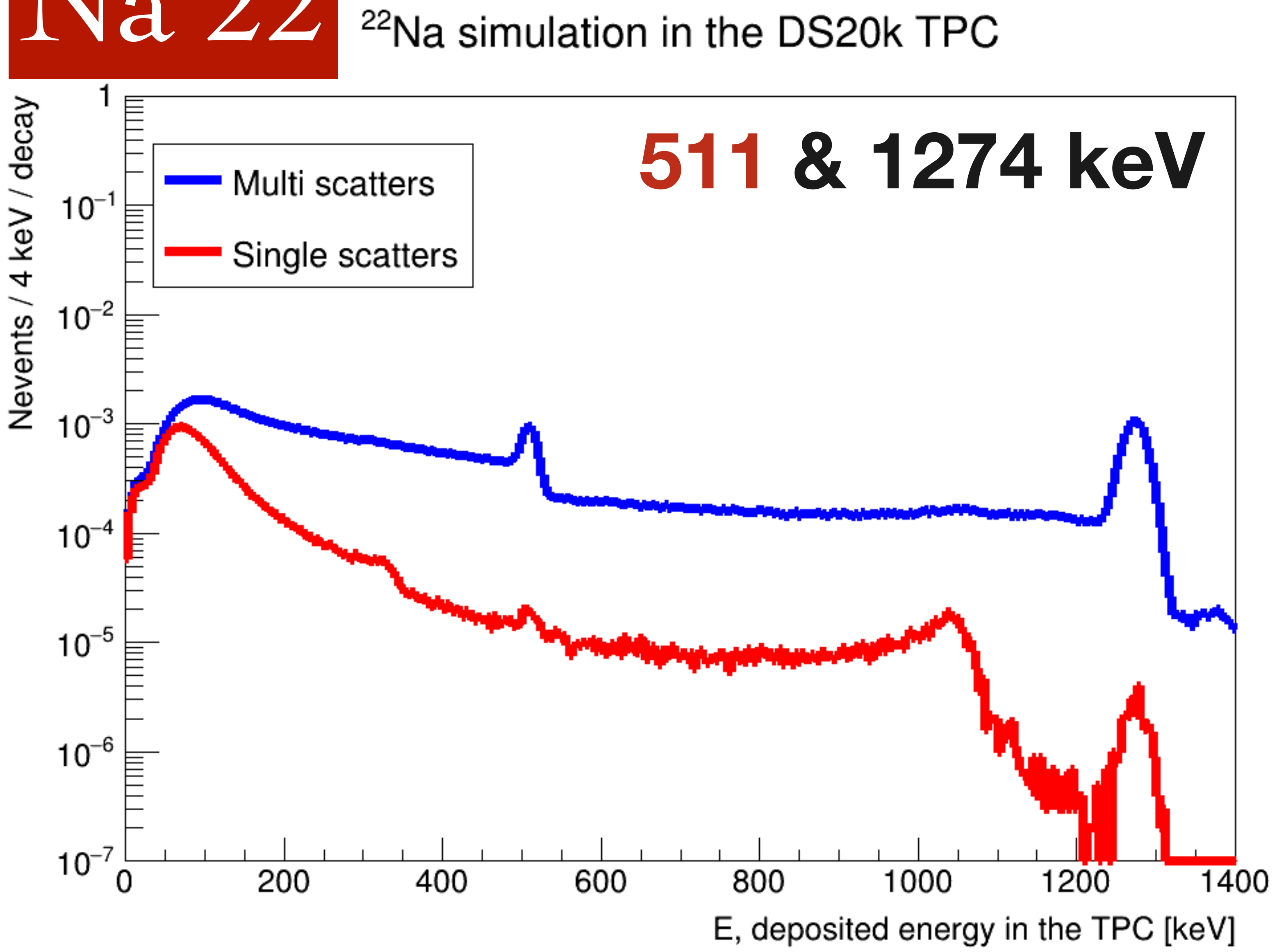
Co57



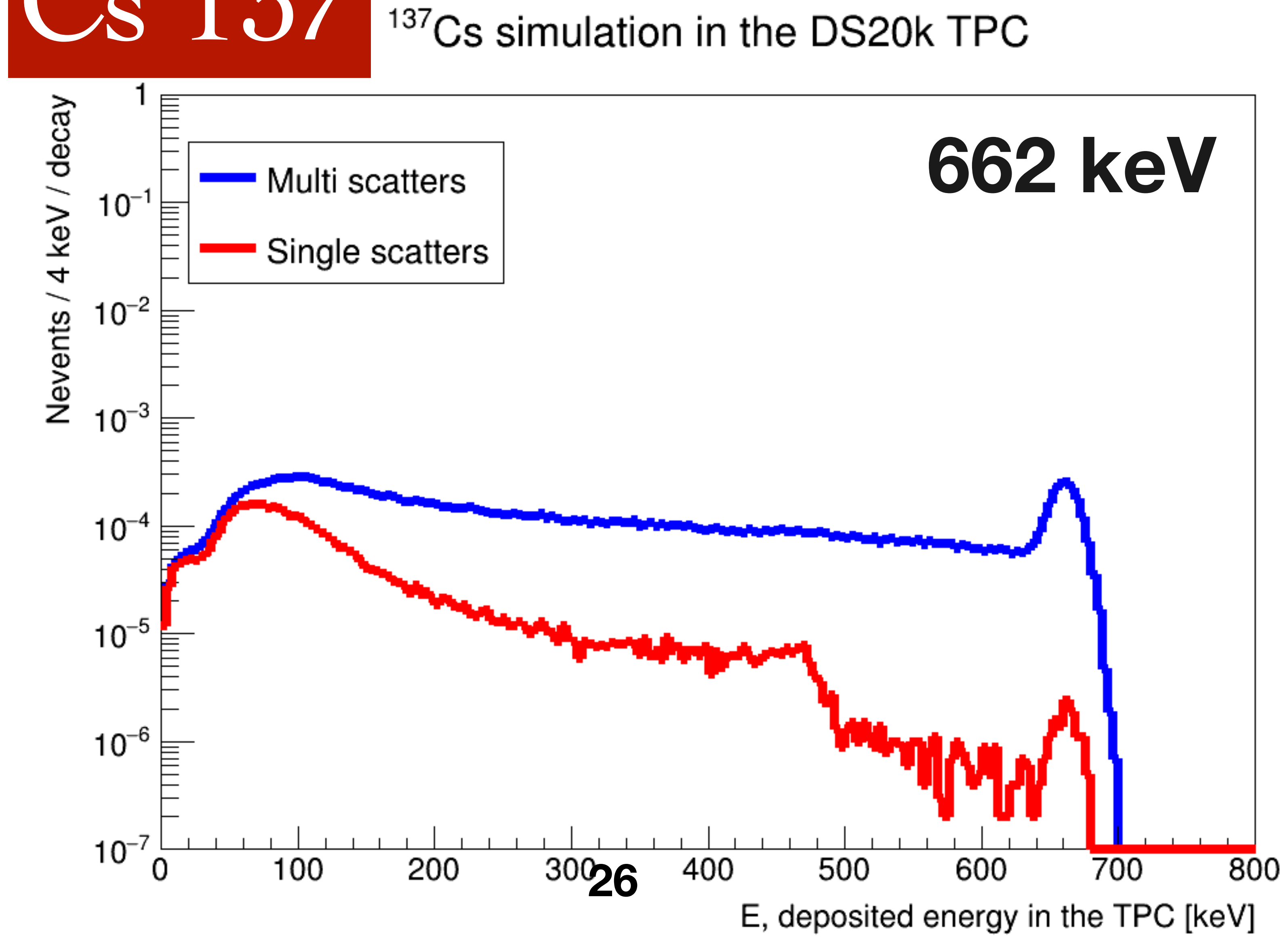
Ba 133



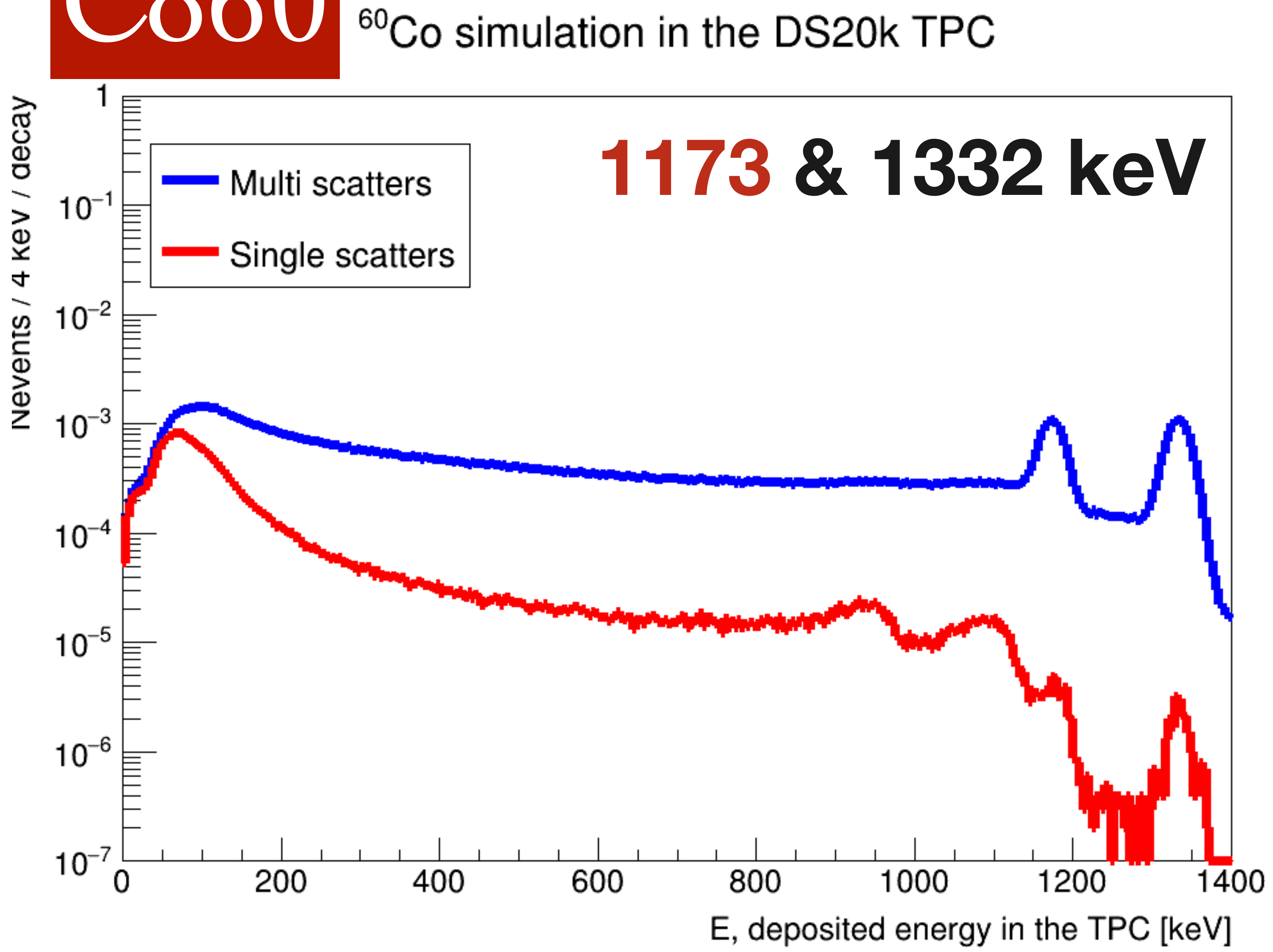
Na 22



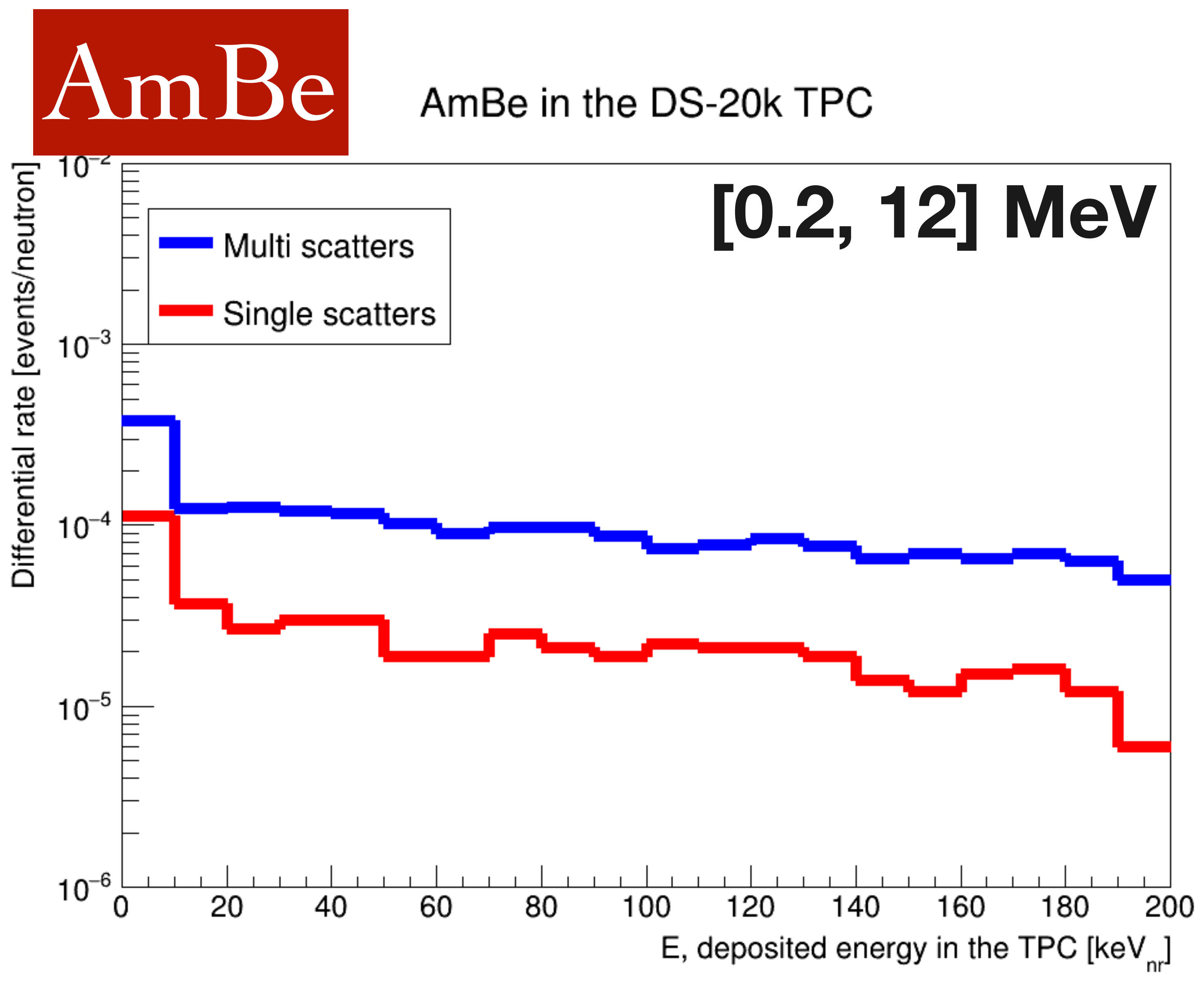
Cs 137

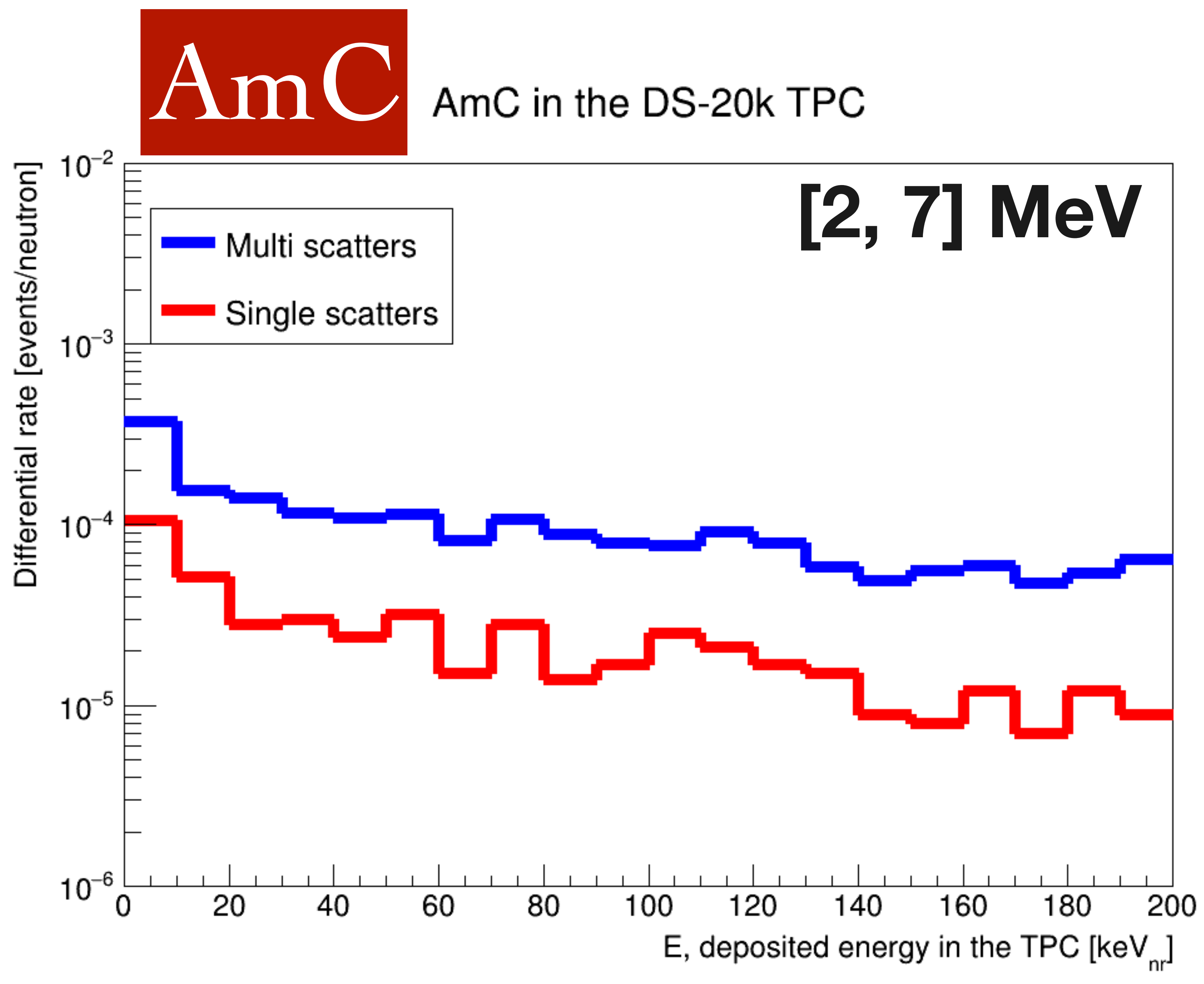


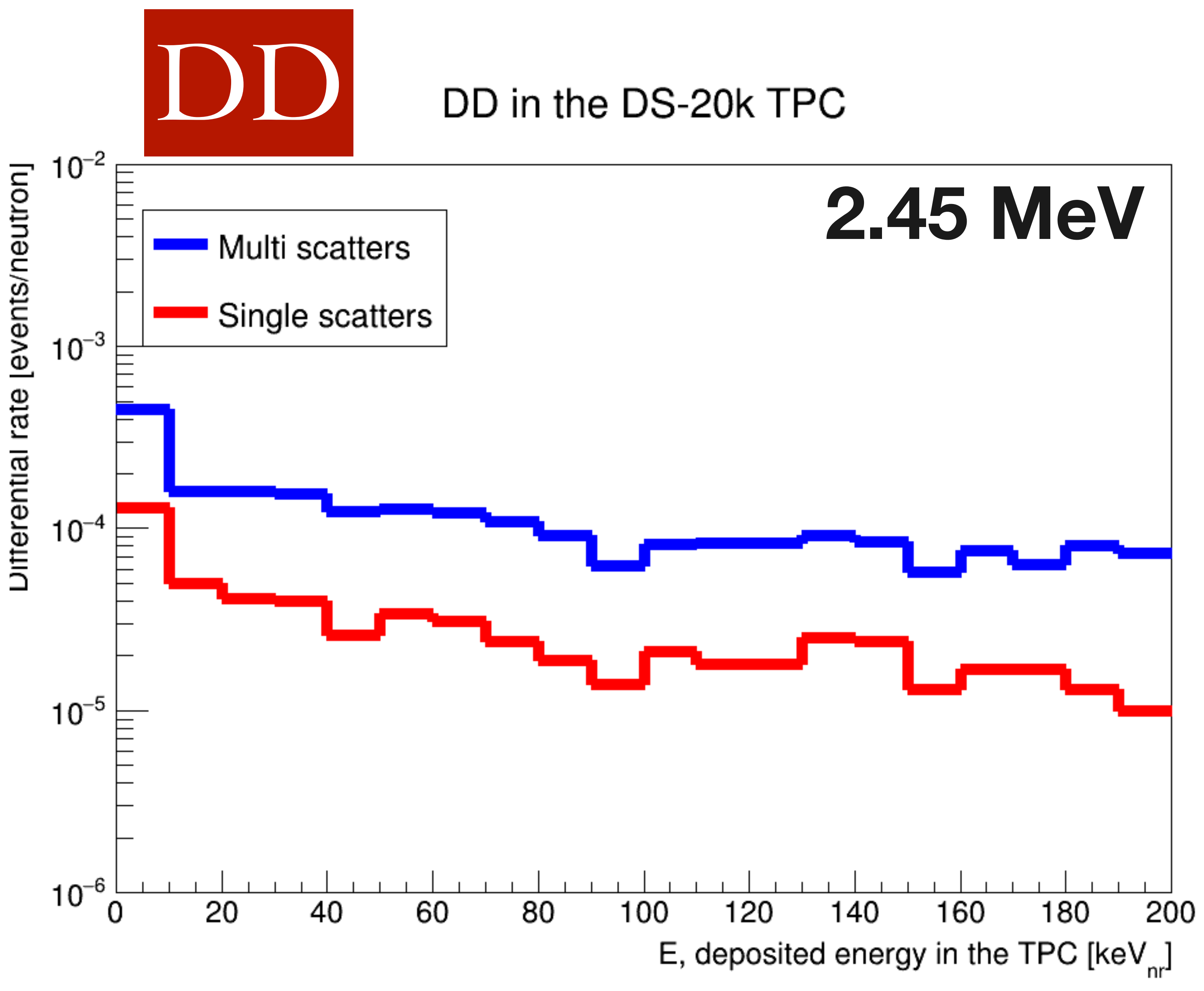
Co60



Neutron sources - NR calibration - Bottom

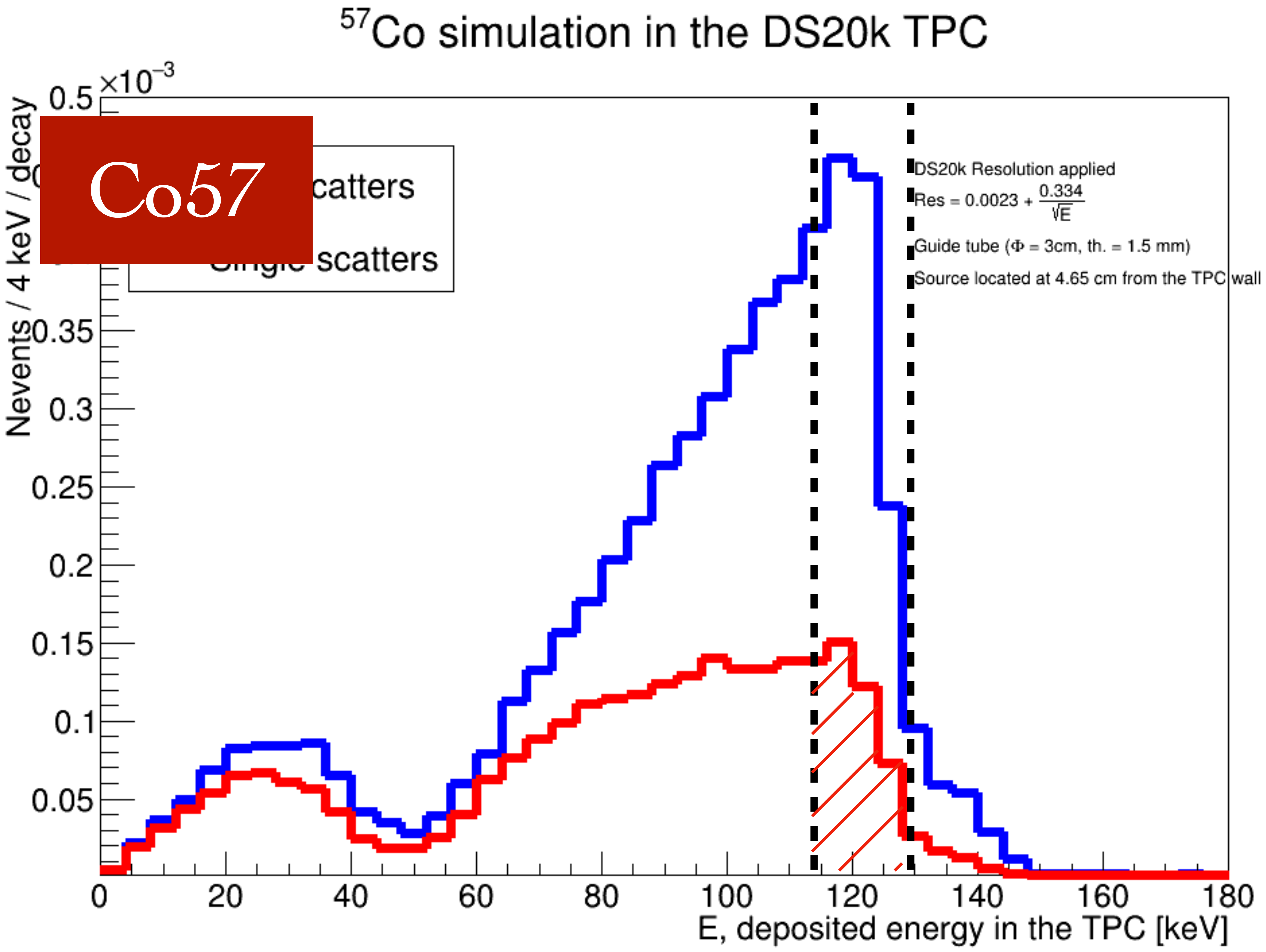






Calibration strategy - Time estimation - Computation

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



- **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:** $Time^{10^4 pts}_{A<100kBq} = \frac{Nb-points}{DAQ-frequency} = \frac{10^4 pts}{100hz} = 100$ 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:** $Time^{10^4 pts}_{A=100kBq} = \frac{Nb-points}{Rate-of-all-events} \cdot \frac{1}{Activity} = \frac{10^4 pts}{8.8 \cdot 10^{-4} events/decay} \frac{1}{100 \cdot 10^3 Bq} = 114s$
- **Second: Multiply this time to the ratio of the rate of all the events occurring in the TPC over the rate of GP events:** $Time^{1position} = Time^{10^4 pts} \cdot \frac{Rate-of-all-events}{Rate-of-GP}$

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