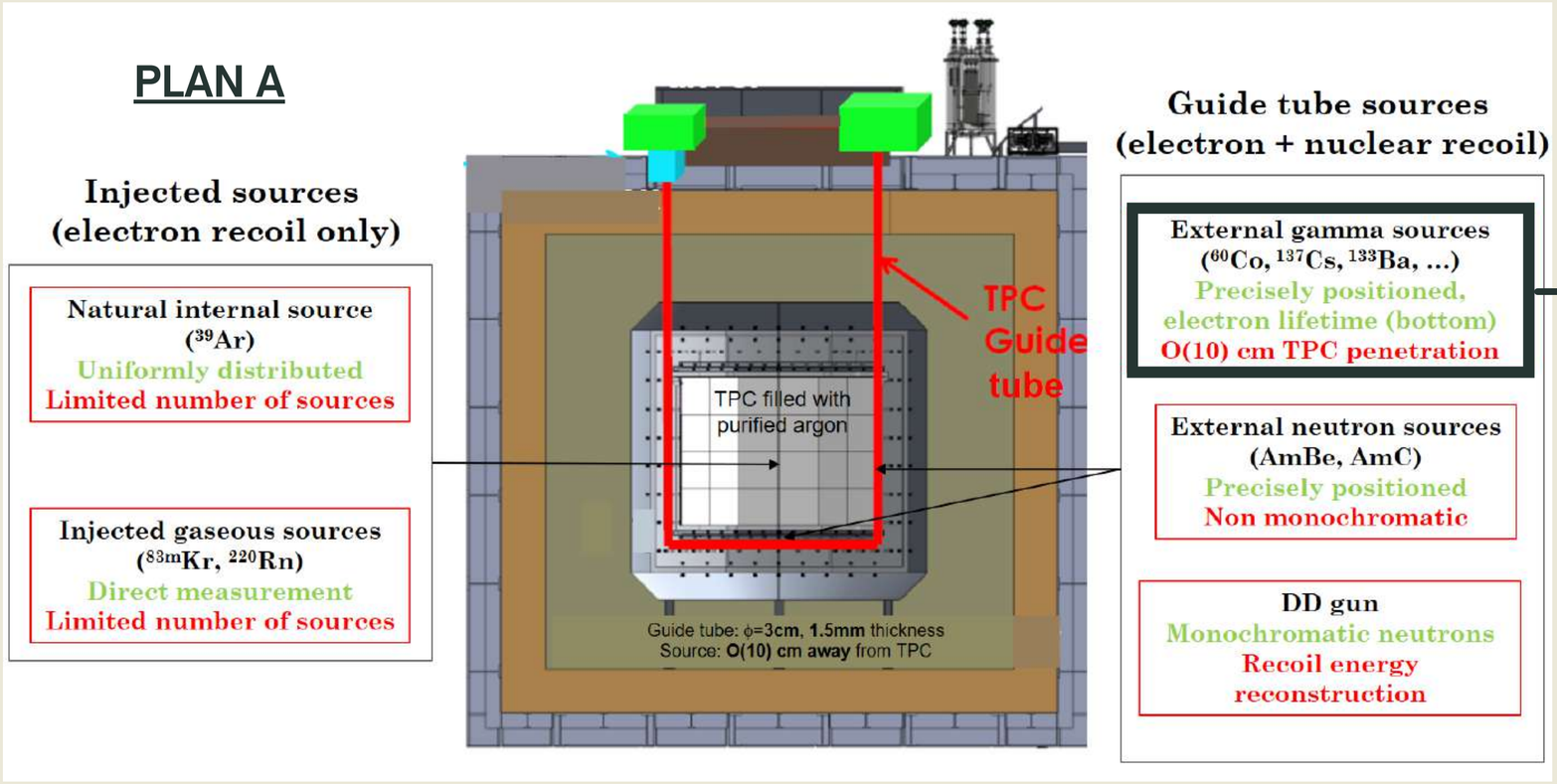
Théo Abounnasr--Martins, summer student

RAPPORT D'ACTIVITÉS 12/07/2021

GUIDE TUBE CALIBRATION DARKSIDE20K



Before calibrating the detector with sources in the guide tube, it is necessary to estimate the **background rate of events generated in the TPC by the tube** material in itself

FOCUS ON ELECTRONIC RECOIL

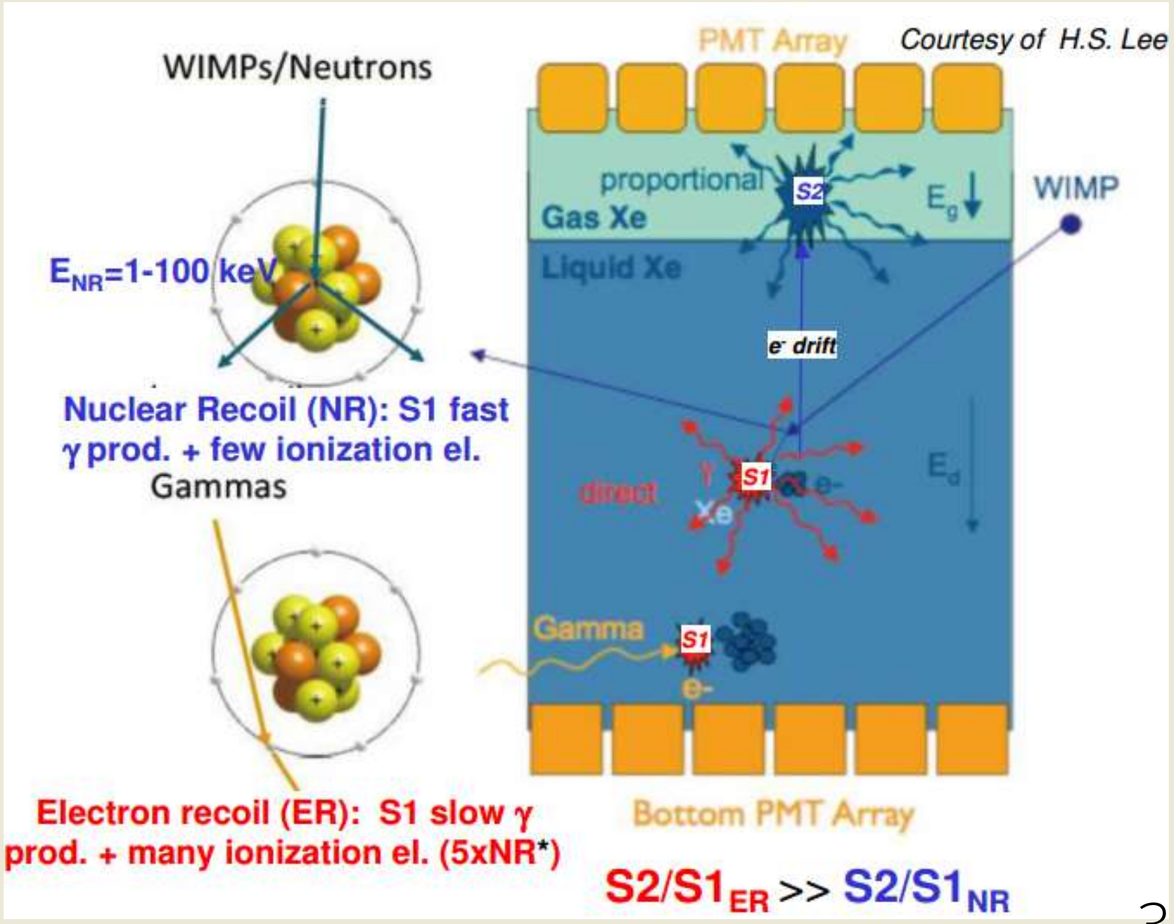
There are two kind of events :

- Nuclear Recoil events
  - Particle scatters on nucleus (if WIMP : through unknown process)
  - Fast but small ɣ production, few e-
  - nucleus-nucleus and WIMP/nucleus interactions *apriori* undistinguishable from

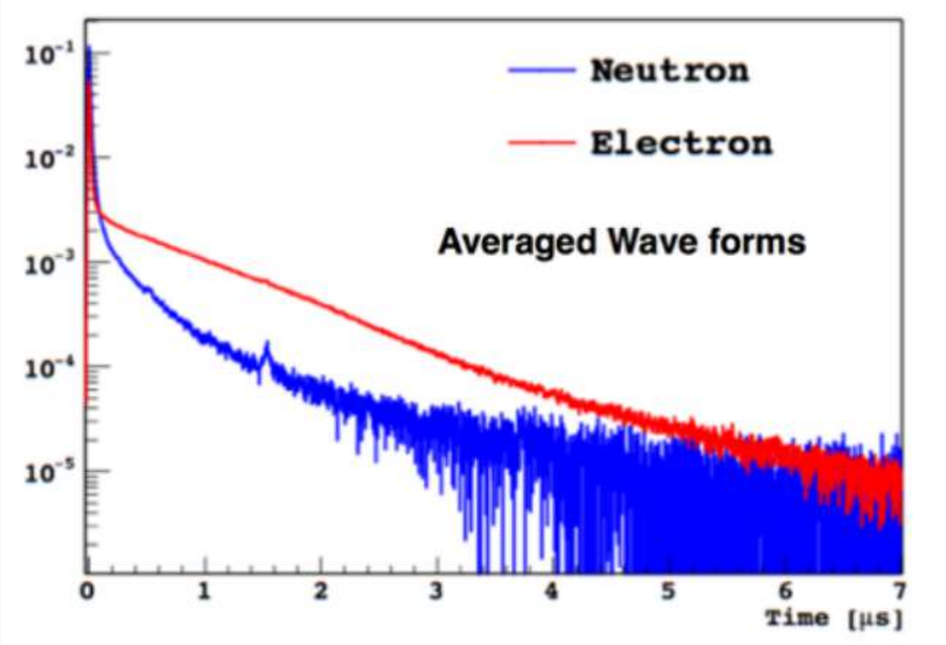
    ---> Events discriminated with veto outside of TPC

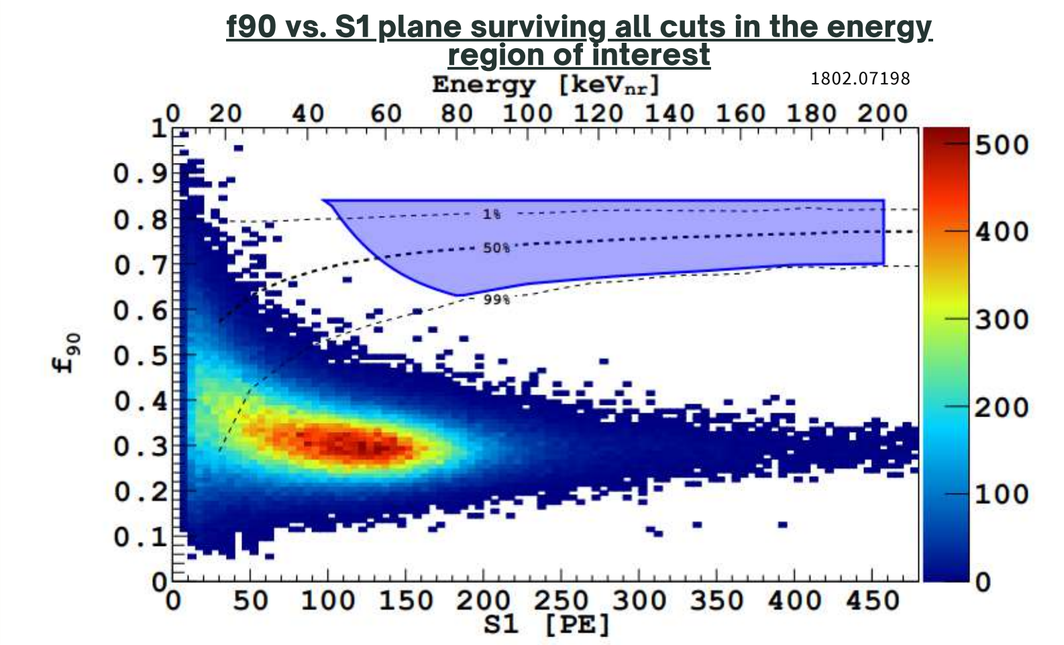
- **Electronic Recoil events**
  - ɣ scatters on electronic orbitals
  - Many but slow ɣ production, many e-
  - Distinguishable to an extent through Pulse Shape Discrimination (PSD) method

We will focus on the **electronic recoil events** generated in the TPC by radioactive elements of the tube



PULSE SHAPE DISCRIMINATION (PSD)





→ **PSD with error $\varepsilon=10^{-8}$**

ER* BACKGROUND RATES

I

A

Estimate decay rates from radioactive elements of the tube

B

Find the number of events in the TPC volume through GEANT4DS simulation of the tube for each radioactive source

C

Apply various cuts to estimate the number of remaining events in a given fiducial volume

*ER : ELECTRONIC RECOIL

I

A - DECAY RATE

RADIOACTIVE COMPONENTS

Propreties of radioactive elements in SSArDM (The Lund/LBNL Nuclear Data Search)

Element	Halflife (years)	Activity (Bq/mg)	Proportion in SSArDM (ng/kg)	Contamination in SSArDM (mBq/kg)
^{137}Cs	30.18	3.20e+09	4.69e-10	1.50
^{40}K	1.28e+09	2.59e+02	0.02	6.40
^{60}Co	5.27	4.18e+10	3.11e-10	13.00
^{238}U	4.47e+09	12.44	4.01	50.00
^{232}Th	1.40e+10	4.06	4.92	20.00

I

A - DECAY RATE

DECAY PER YEAR ESTIMATION

$$Rate = Activity \times M(tubes)$$

Number of decay / time

$(Time \times Mass)^{-1}$

Mass

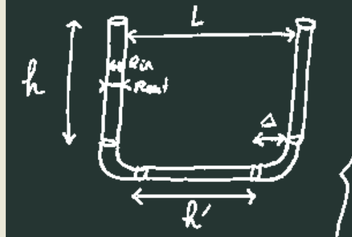
I

A - DECAY RATE

DECAY PER YEAR ESTIMATION

TUBE MASS

Masse tube



$\rho_{ss} \approx 8000\ kg/m^3$ (20°C)

$R_{in} = 3,2\ cm = 3,2 \times 10^{-2}\ m$

$R_{out} = R_{in} + e$, $e = 1,5\ mm$

$= 3,35\ cm$

$h = 3,5\ m$

$h' \approx h$

$L = 4,01\ m$

$\Delta = \frac{L - h'}{2}$ ou $\Delta^* = \Delta + R_{out}$

• 1 tube de longueur h :

$V_{1\,tube} = \pi h (R_{out}^2 - R_{in}^2)$

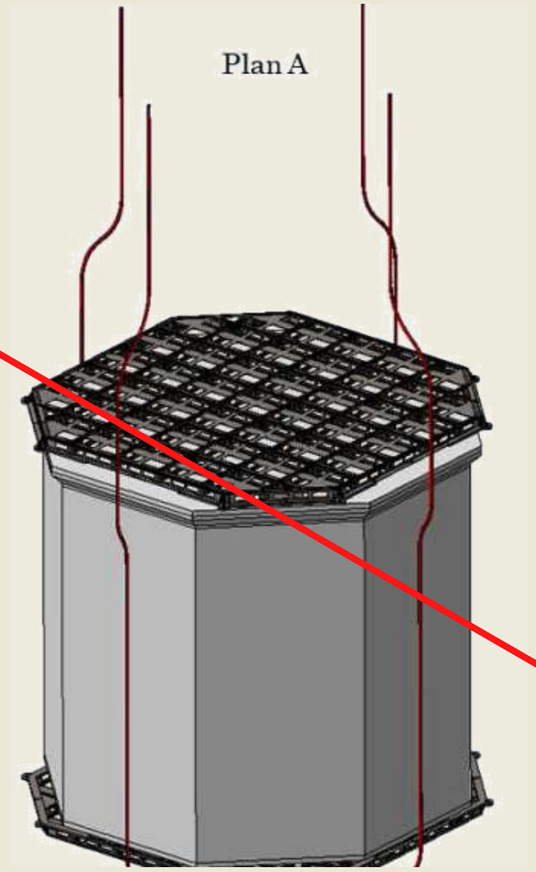
• 1 coude ≡ 1 demi cercle de rayon Δ^* :

$\frac{1}{4}$ de périmètre de longueur : $2\frac{\pi\Delta^*}{4}$ $\Rightarrow$ $V_{coude} = \frac{\pi\Delta^*}{2} \times \pi (R_{out}^2 - R_{in}^2)$

$\Rightarrow M_{tot} = (3V_{1\,tube} + 2V_{coude}) \times \rho_{ss}$

$= \rho_{ss}\, \pi (R_{out}^2 - R_{in}^2) \left(h\left(3 - \frac{\pi}{2}\right) + \frac{\pi L}{2} \right)$

AN : $M_{tot} \approx 28\ kg$



2 tubes en U

M(tubes) = 56 kg

I

A - DECAY RATE

DECAY PER YEAR ESTIMATION

TUBE MASS

Gantry pipe mass

$\rho_{SS} = 7,7\ g/cm^3$

$h_1 = 4202,5\ mm$

$h_2 = 4222,0\ mm$

$h_{horizontal} = 3374,52$

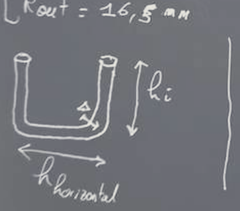
pipe $\varnothing_{out} = 30\ mm$

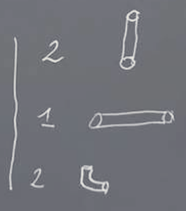
pipe bending radius = 200 mm "Δ"

$e = 15\ mm$

$R_{in} = 15\ mm$

$R_{out} = 16,5\ mm$





Volume cylindre tube $= \pi (R_{out}^2 - R_{in}^2) h$

Volume tous $\frac{1}{2} \pi^2 \Delta (R_{out}^2 - R_{in}^2)$

=> for $\rho = 7,7\ kg/cm^3$

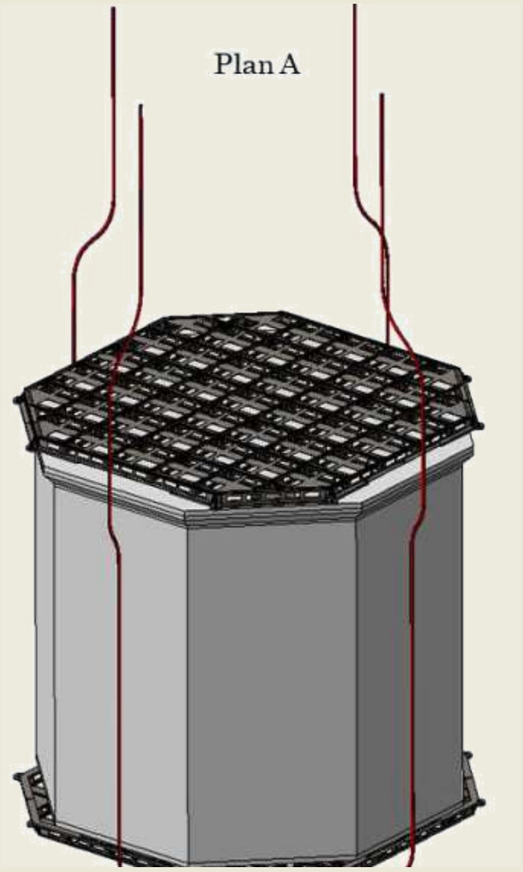
$m(U_1) = 13,9\ kg$

$m(U_2) = 14,29\ kg$

=) for $\rho = 8,0\ g/cm^3$

$m(U_1) = 14,3\ kg$

$m(U_2) = 14,8\ kg$



2 tubes en U
with rho=8.0 g/cm3

M(tubes) = 29.0 kg

I

A - DECAY RATE

DECAY PER YEAR ESTIMATION

ACTIVITY

STAINLESS STEEL ACTIVITY

Sample identifier	Radioactive contamination [mBq/kg]				
	^{232}Th	^{238}U	^{60}Co	^{40}K	^{137}Cs
SS	10	10	–	–	–
SS ArDM	20	50	13	6.4	1.5

Exemple ^{137}Cs

Activity = 0.0015 Bq/kg

Rate= 0.0015 Bq/kg x 29 kg = 0.044 decay/s

= 1.4×10^{6} decay/y

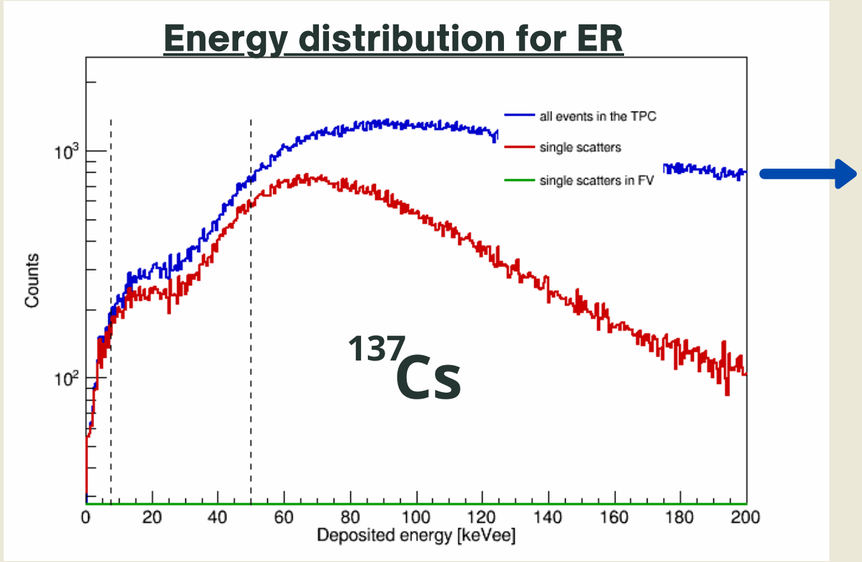
NUMBER OF SURVIVING EVENTS

$$\text{Surviving Events Rate} = \frac{\text{Events in Volume}}{\text{Total of events simulated}} \times \text{Rate}$$

10^7 events simulated

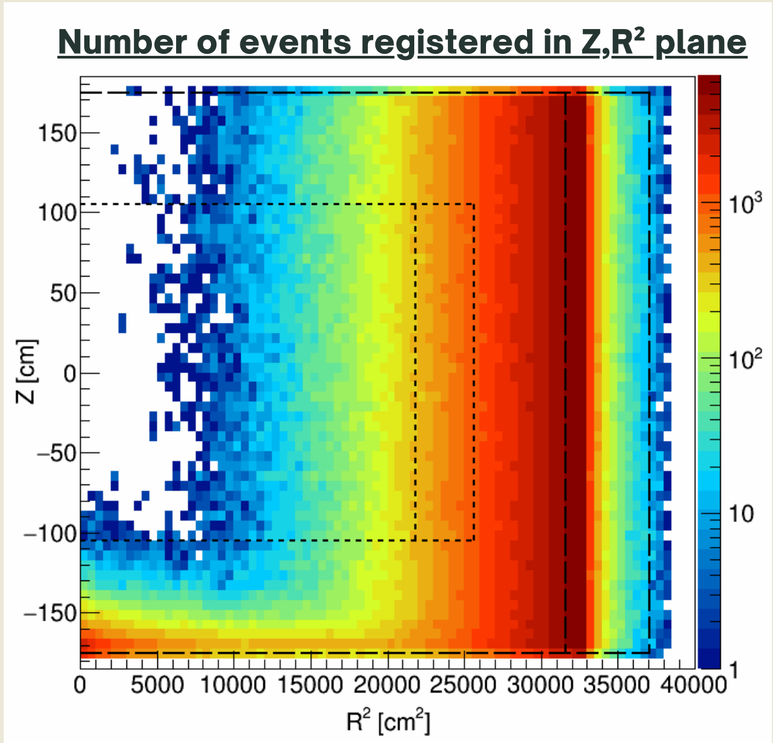
I

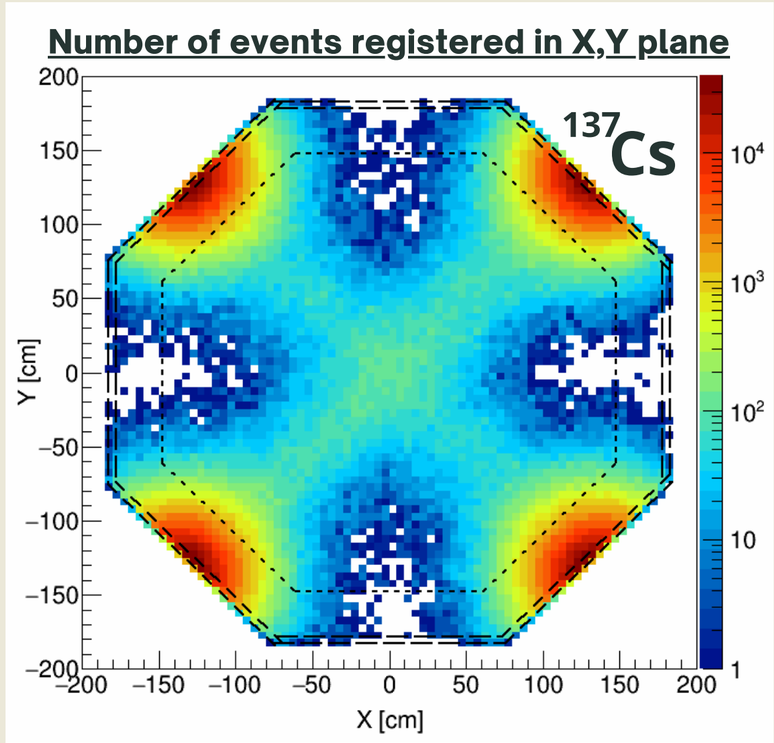
B - SIMULATION



150 224 LE events in TPC

ALL ER
at LE ∈ [0,200 keV]





I

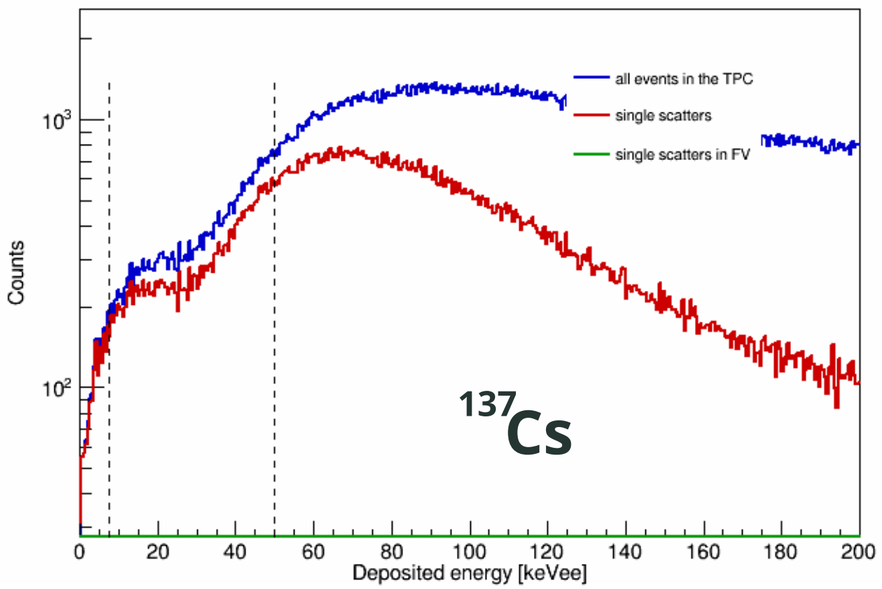
B - SIMULATION

Taking detector response into account

$$Res(E)=0.0023 + 0.334/\sqrt{E}$$

~~$Res(E)=0.009 + 0.485/\sqrt{E}$~~

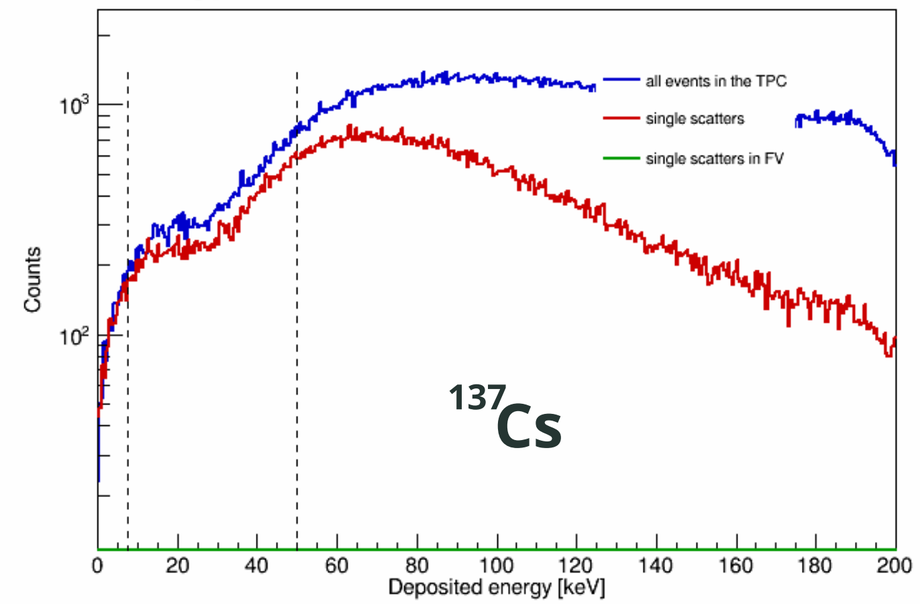
Energy distribution for ER before resolution



+28 LE events

+117 ROI events

Energy distribution for ER with resolution



33234 ROI events in TPC

150 224 LE events in TPC

33347 ROI events in TPC

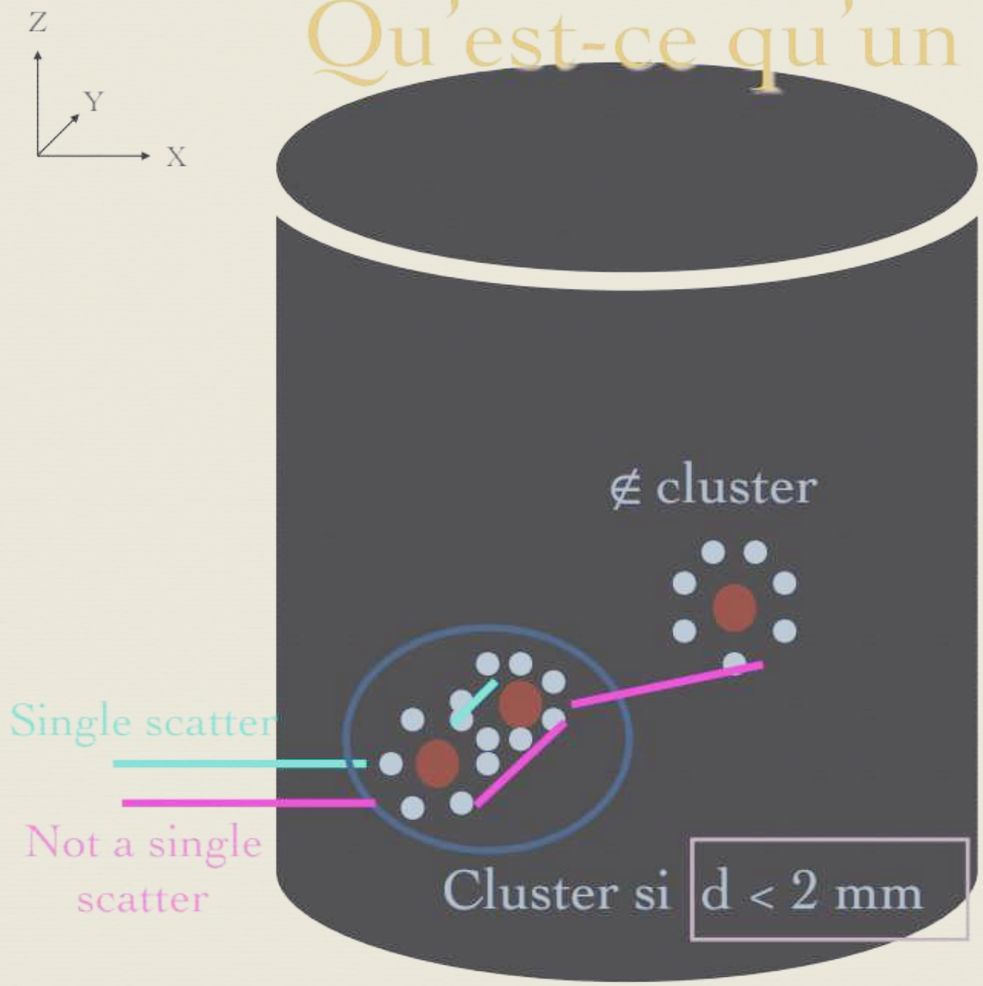
150 352 LE events in TPC

I

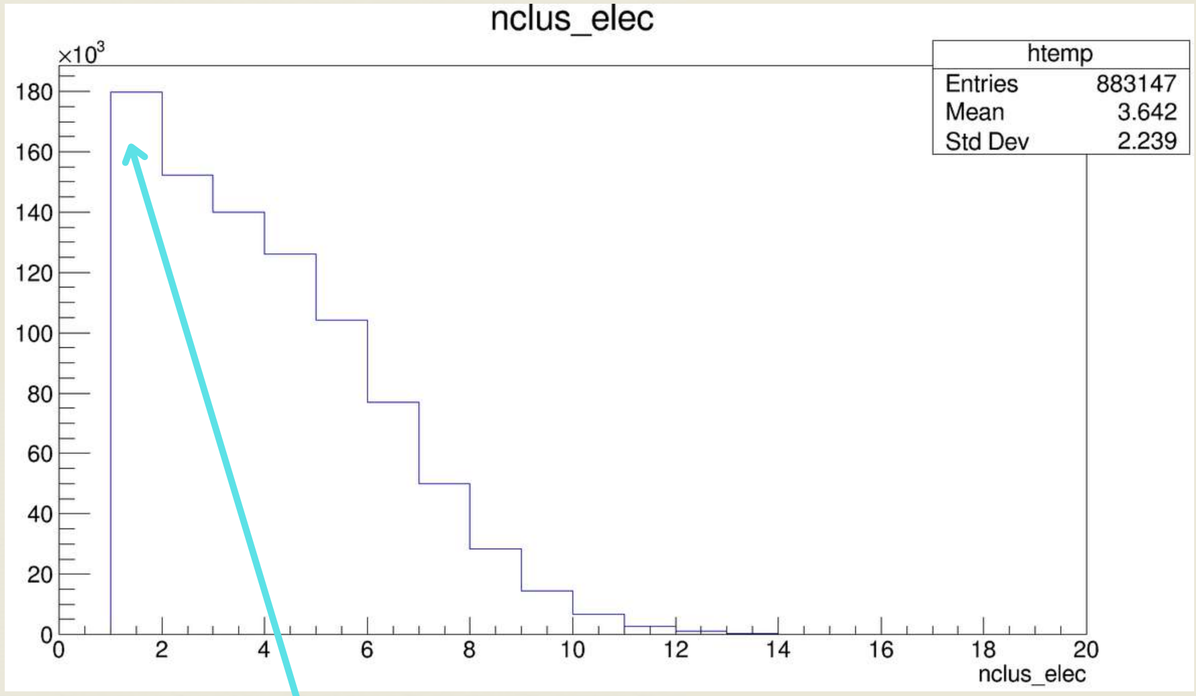
C - CUTS

Exclude non-single scatter events

Qu'est-ce qu'un single scatter ?



Vient de la résolution lors de la reconstruction en z

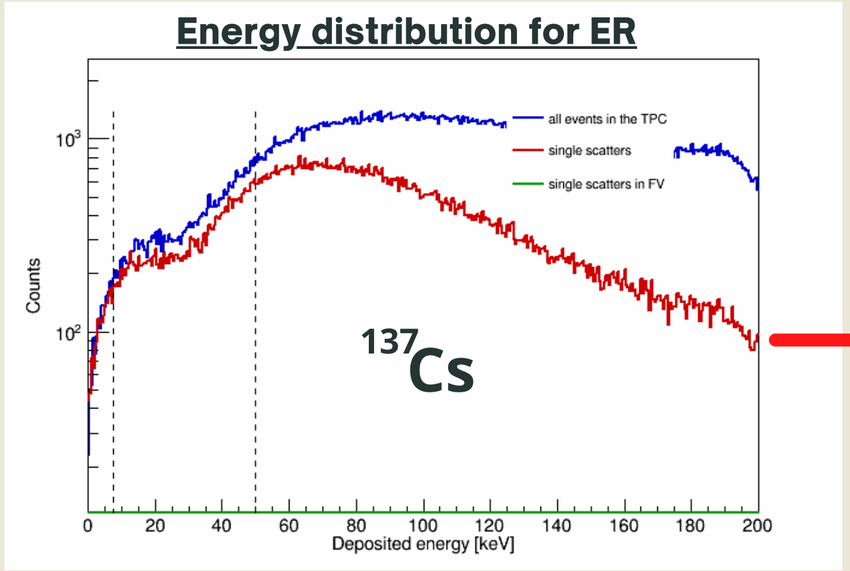


Single scatter

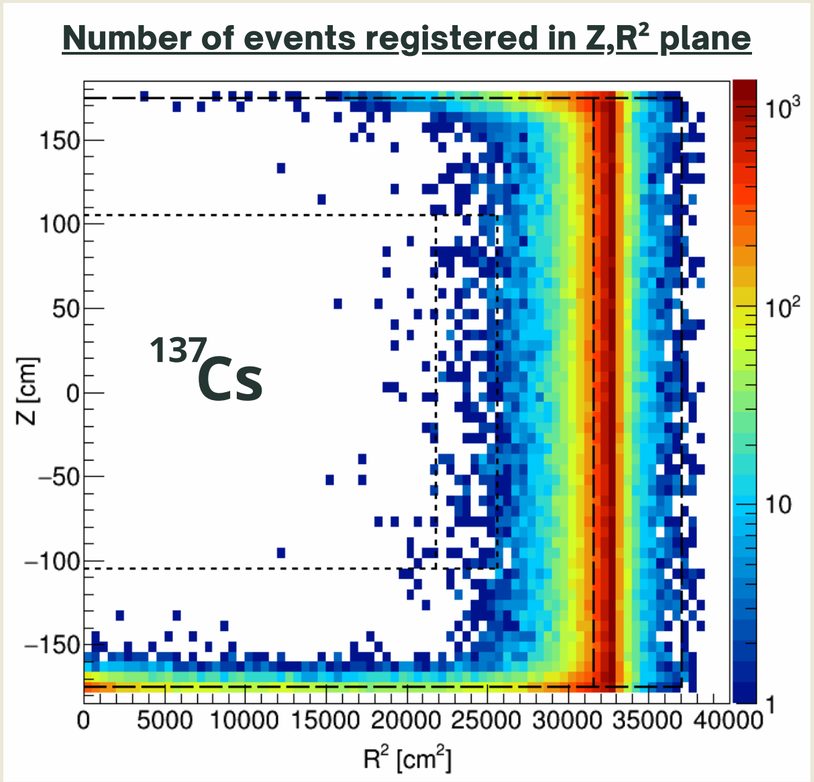
?

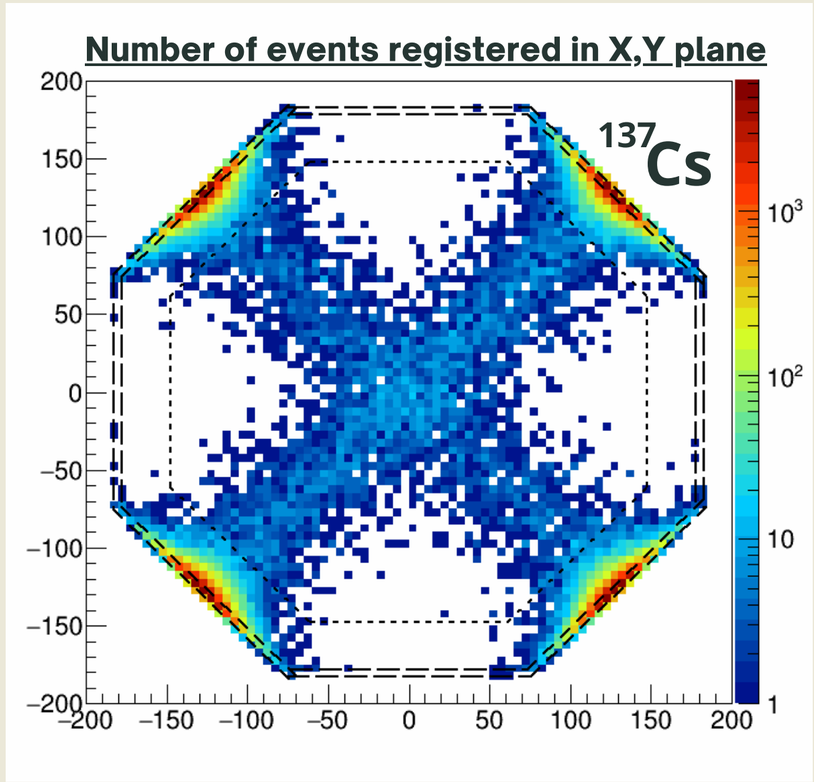
I

C - CUTS



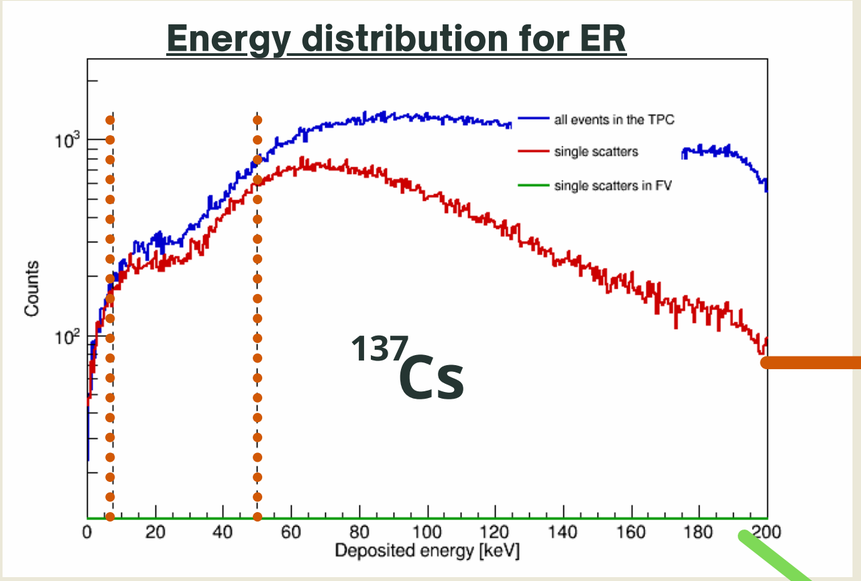
94702 LE SS in the TPC





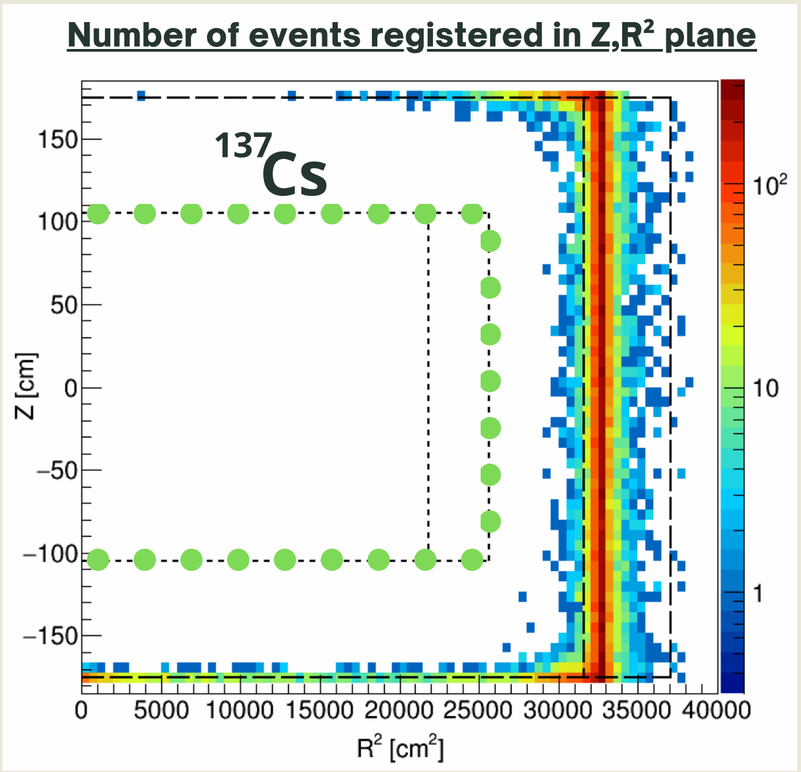
ONLY SINGLE SCATTERS (SS) at LE ∈ [0,200 keV]

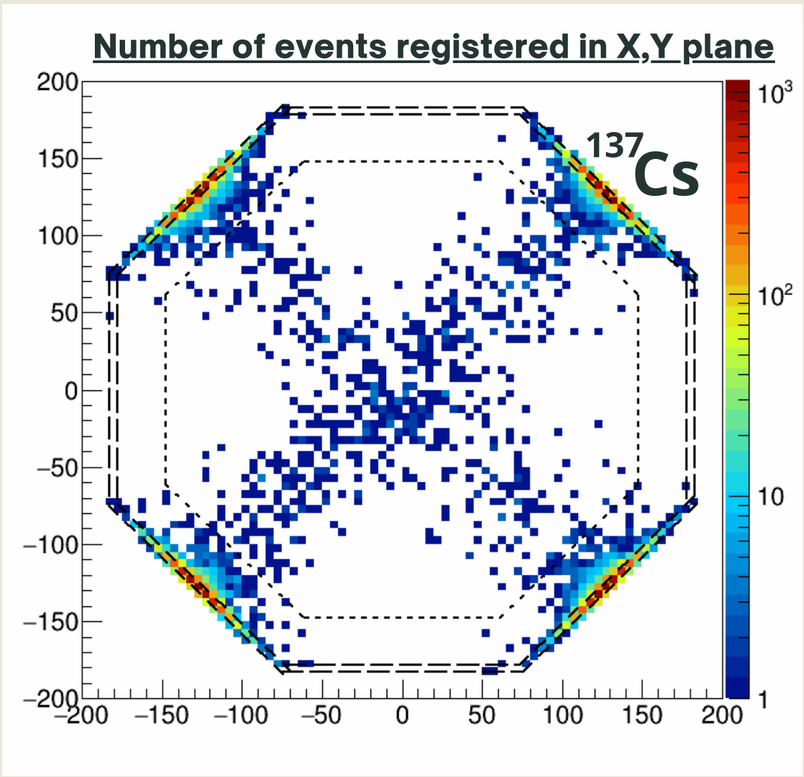
C - CUTS



ONLY SINGLE SCATTERS (SS) IN ROI

26478 SS at ROI

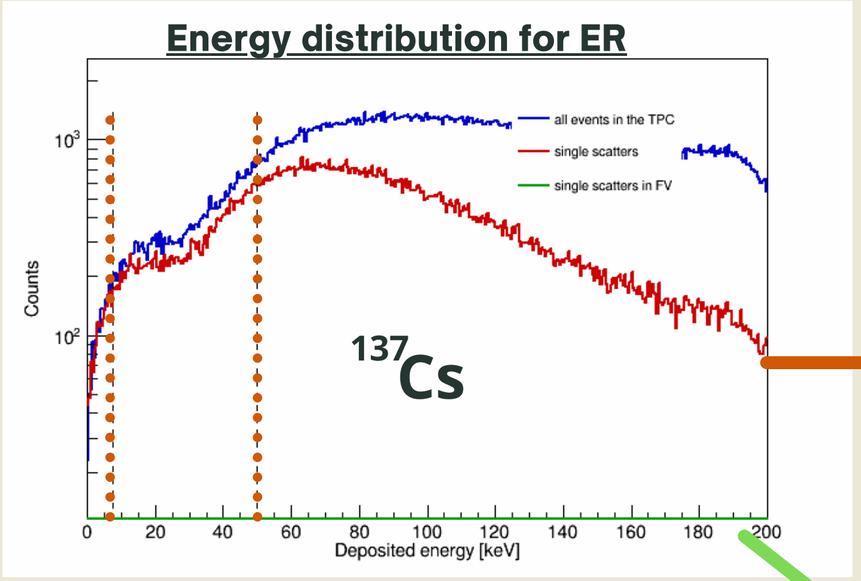




0 SS in FV (ROI)

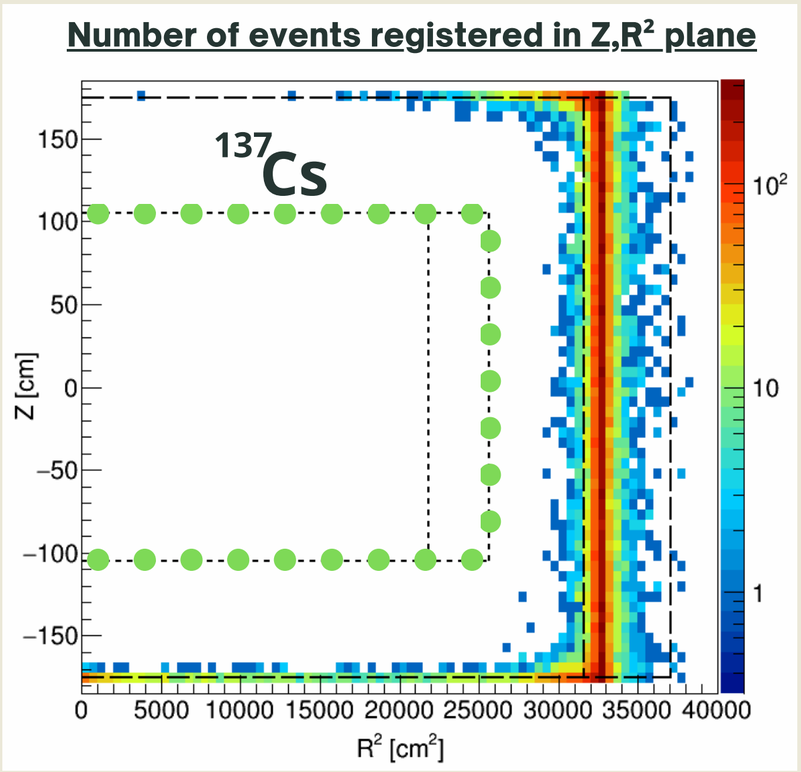
SINGLE SCATTERS IN ROI INSIDE FV

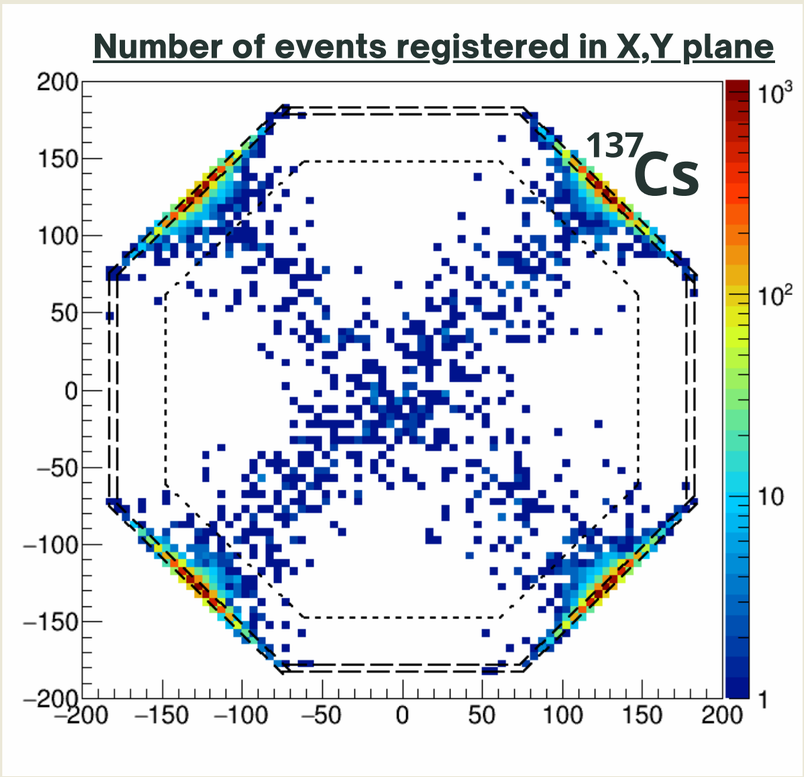
C - CUTS



ONLY SINGLE SCATTERS (SS) IN ROI

26478 SS at ROI





0 SS in FV (ROI)

SINGLE SCATTERS IN ROI INSIDE FV

I

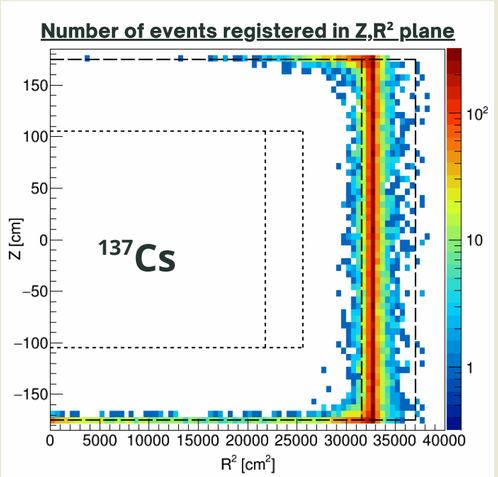
ER BACKGROUND RATES

DECAY PER YEAR ESTIMATION

ACTIVITY

STAINLESS STEEL ACTIVITY

Sample identifier	Radioactive contamination [mBq/kg]				
	^{232}Th	^{238}U	^{60}Co	^{40}K	^{137}Cs
SS	10	10	–	–	–
SS ArDM	20	50	13	6.4	1.5



→ **< 2.3 events**

Statistical margin

Exemple ^{137}Cs

Activity = 0.0015 Bq/kg

Rate = 0.0015 Bq/kg x 29kg = 0.044 decay/s

= 1.4×10^{6} decay/y

$$\text{Surviving Events Rate} < \frac{2.3 \text{ events}}{10^{7} \text{ events}} \; 1.4 \times 10^{6} \text{ decay/y}$$

=

0.31 events/y

PSD : x 10^{-8}

ER BACKGROUND RATES

Background event rates for 56kg of stainless steel, 1e7 events simulated

Element	Contamination (mBq/kg)	Decay/s	decay/y	events sim FV	events/y	events/y PSD
^{137}Cs	1.5	0.08	2.65e+06	<2.30	<0.60	<0.00
^{40}K	6.4	0.35	1.13e+07	<2.30	<2.59	<0.00
^{60}Co	13.0	0.72	2.30e+07	<2.30	<5.28	<0.00
^{238}U	50.0	2.80	8.83e+07	<2.30	<20.30	<0.00
^{232}Th	20.0	1.12	3.53e+07	<2.30	<8.12	<0.00

Predicted background rate [events/year]				
^{232}Th	^{238}U	^{60}Co	^{40}K	^{137}Cs
<1.6	<2.4	–	–	–
<4.4	<12.2	<1.1	<0.5	<0.1

A. Kish's results for 25 kg tube, and statistical margin of 1 (instead of 2.3)

ER BACKGROUND RATES

Background event rates for 29kg of ArDM stainless steel, 1e7 events simulated

Element	Contamination (mBq/kg)	Decay/s	decay/y	events sim FV	events/y	events/y PSD
^{137}Cs	1.5	0.04	1.37e+06	<2.30	<0.31	<0.00
^{40}K	6.4	0.18	5.86e+06	<2.30	<1.34	<0.00
^{60}Co	13.0	0.37	1.19e+07	<2.30	<2.73	<0.00
^{238}U	50.0	1.45	4.58e+07	<2.30	<10.52	<0.00
^{232}Th	20.0	0.58	1.83e+07	<2.30	<4.21	<0.00

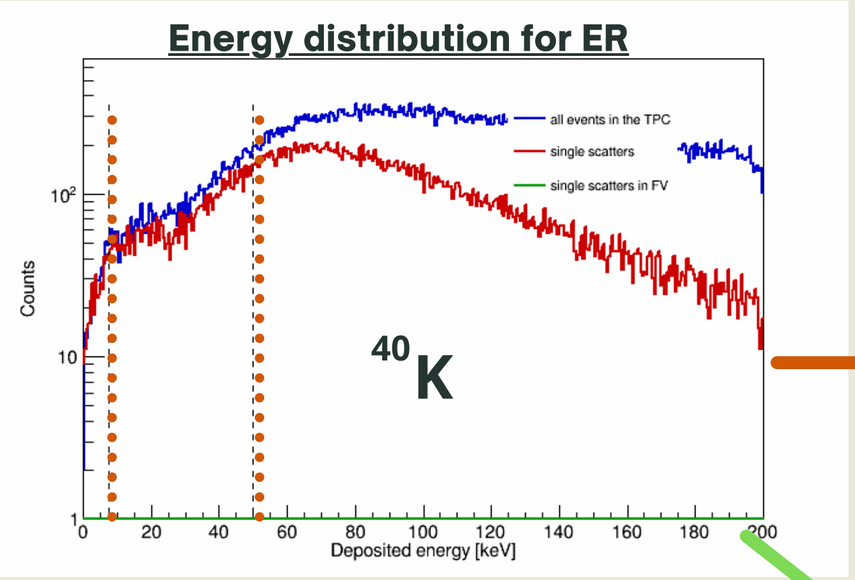
Predicted background rate [events/year]				
^{232}Th	^{238}U	^{60}Co	^{40}K	^{137}Cs
<1.6	<2.4	–	–	–
<4.4	<12.2	<1.1	<0.5	<0.1

A. Kish's results for 25 kg tube, and statistical margin of 1 (instead of 2.3)

OTHER SOURCES

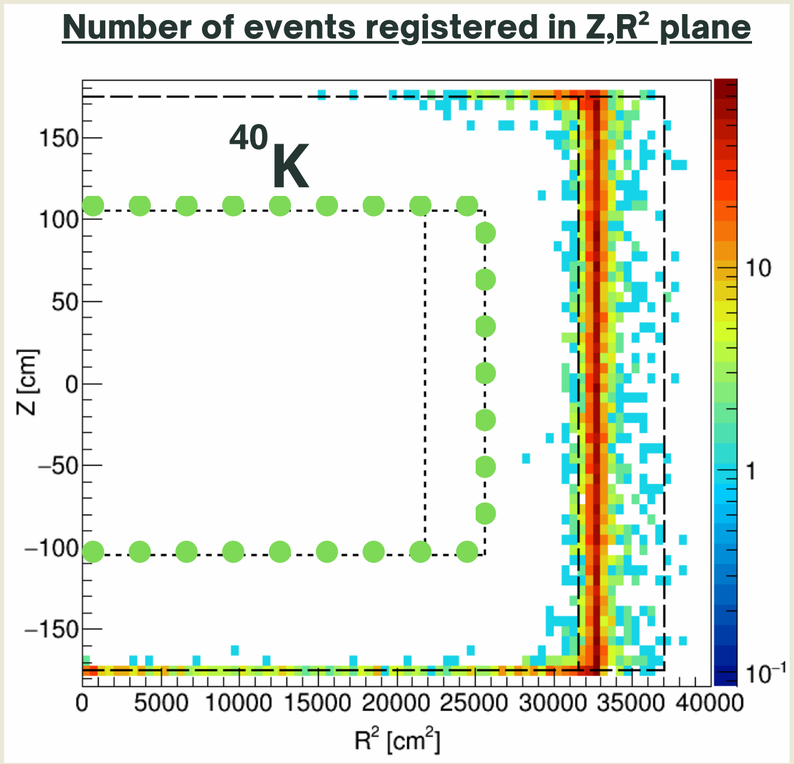
I

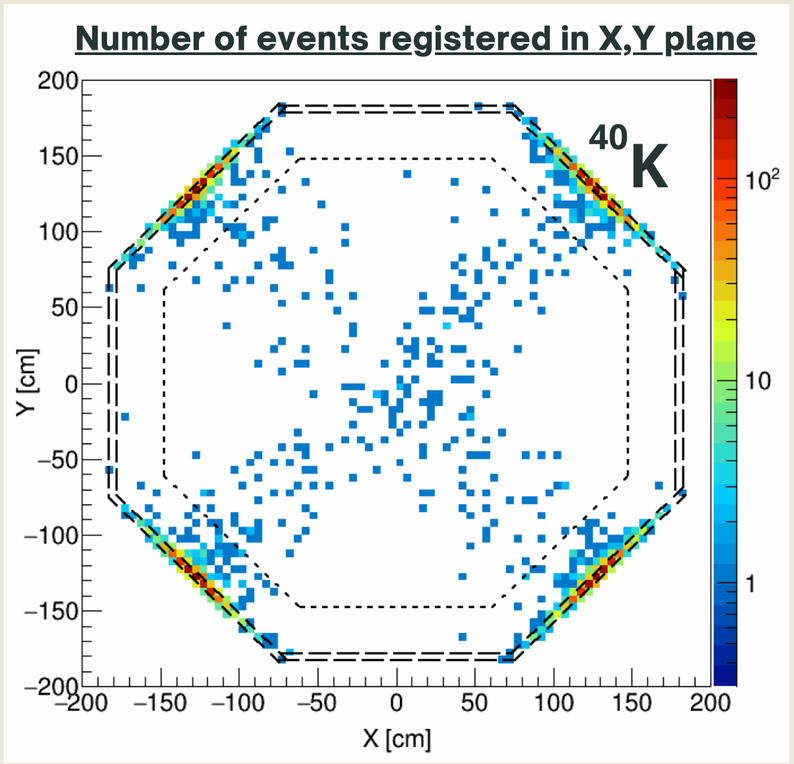
POTASSIUM



ONLY SINGLE SCATTERS (SS) IN ROI

6557 SS at ROI



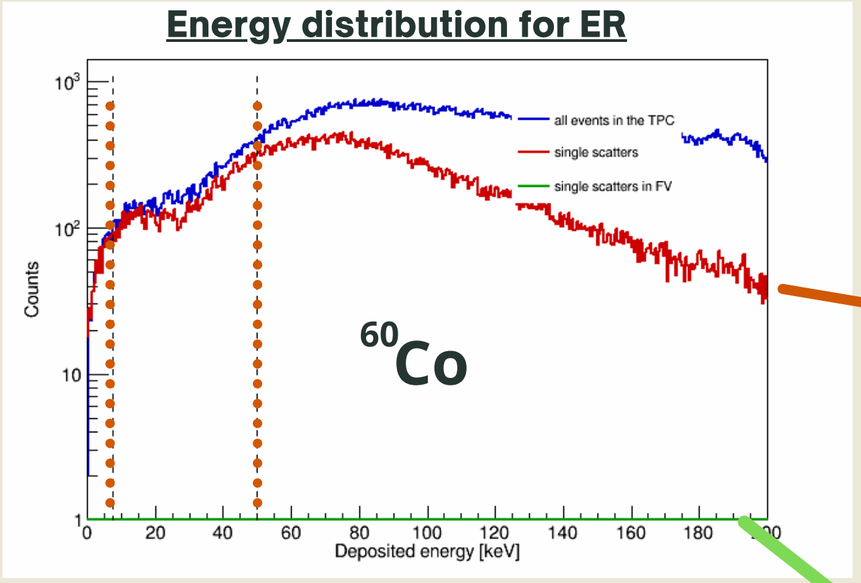


0 SS in FV (ROI)

SINGLE SCATTERS IN ROI INSIDE FV

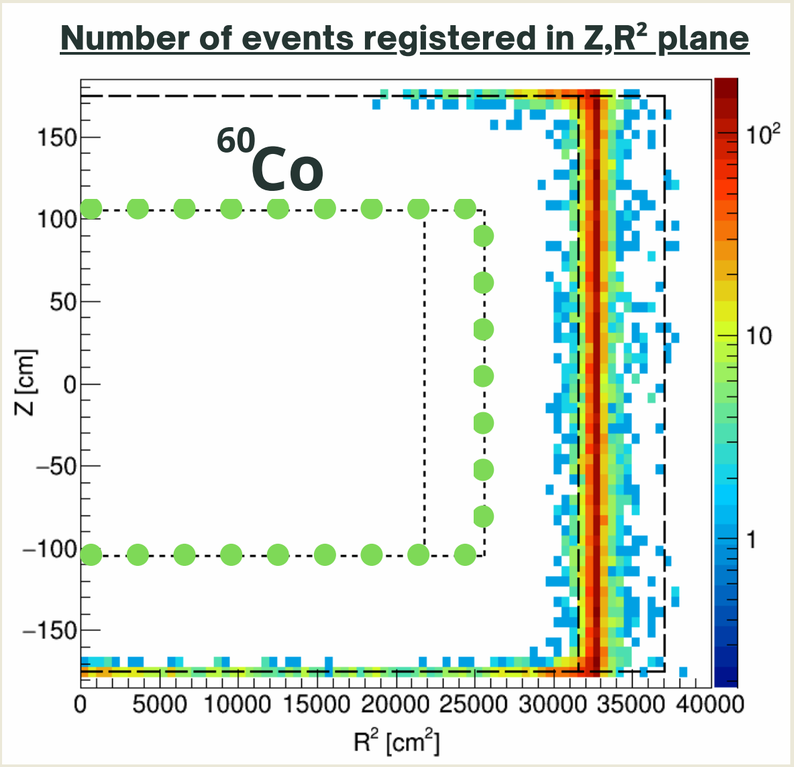
I

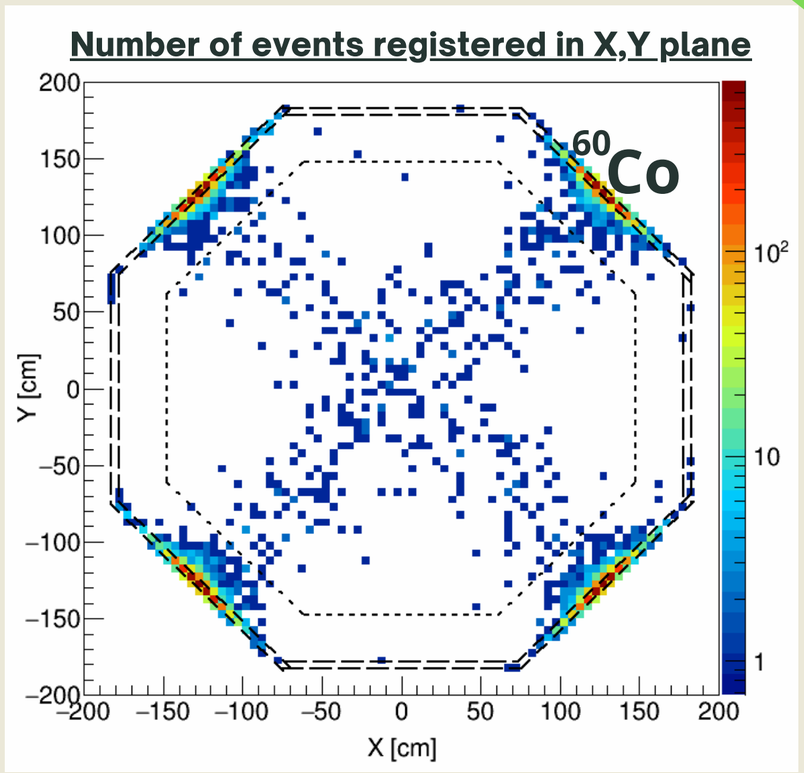
COBALT



ONLY SINGLE SCATTERS (SS) IN ROI

68564 SS at ROI



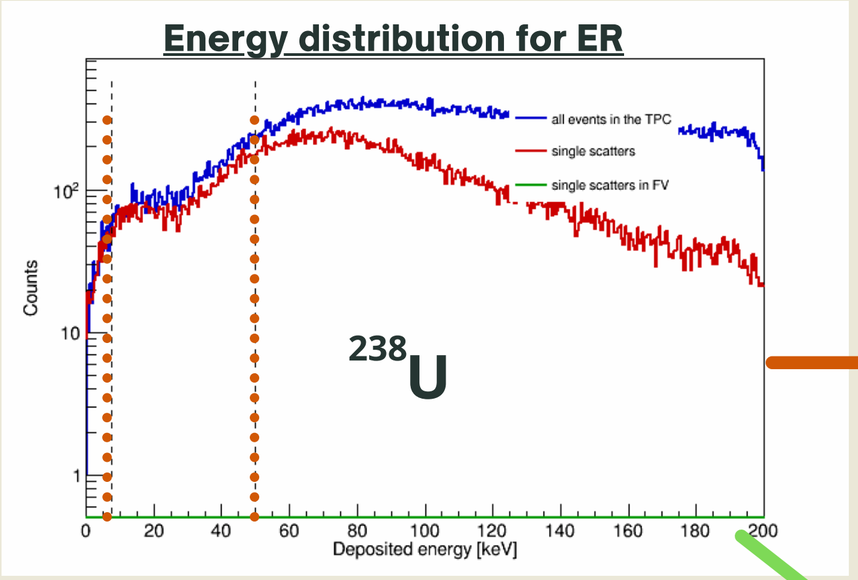


0 SS in FV (ROI)

SINGLE SCATTERS IN ROI INSIDE FV

I

URANIUM

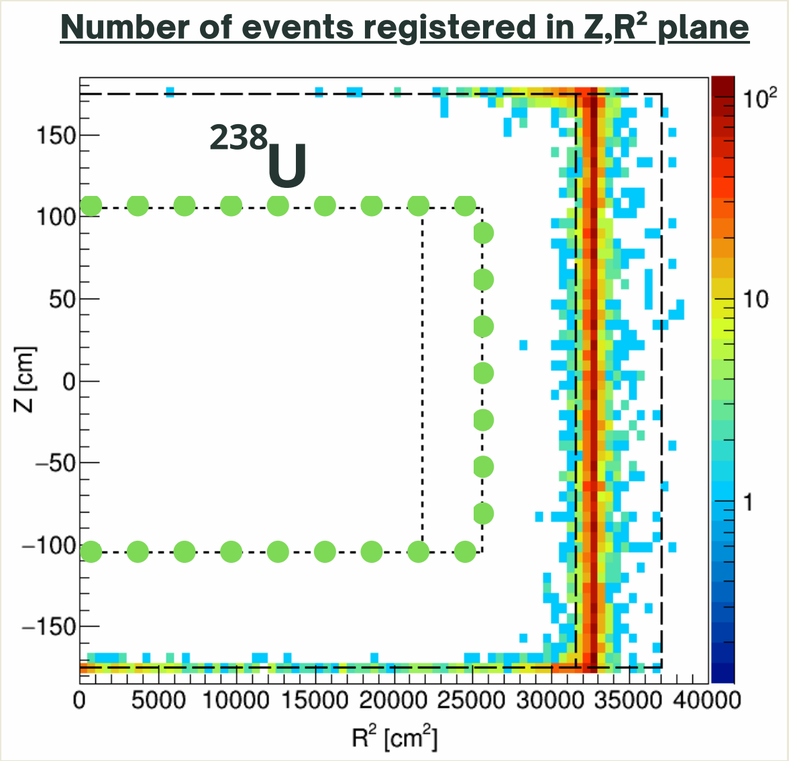


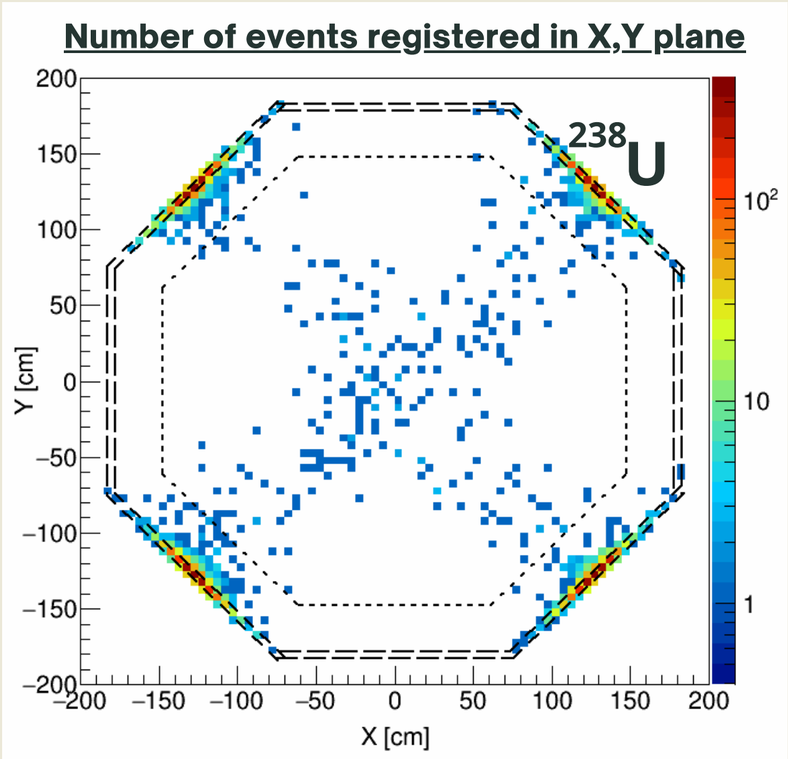
ONLY SINGLE SCATTERS (SS) IN ROI

8046 SS at ROI

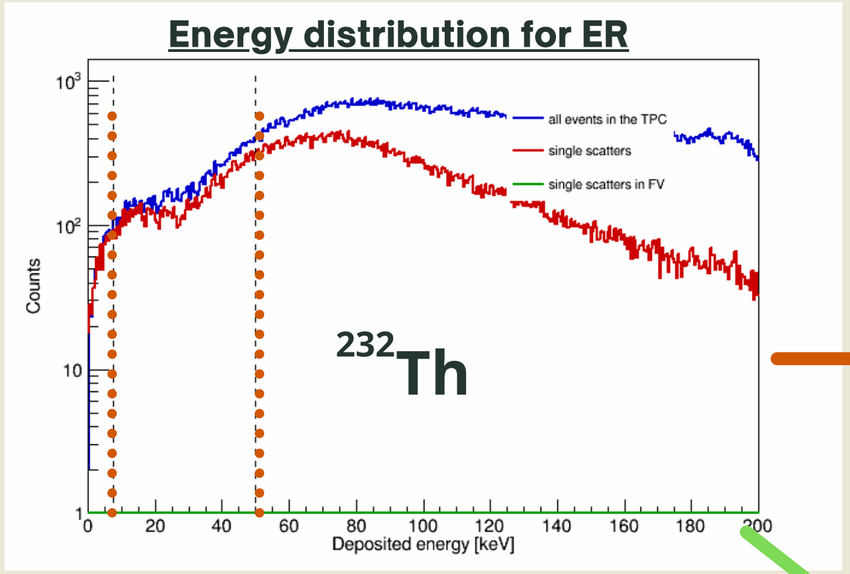
0 SS in FV (ROI)

SINGLE SCATTERS IN ROI INSIDE FV



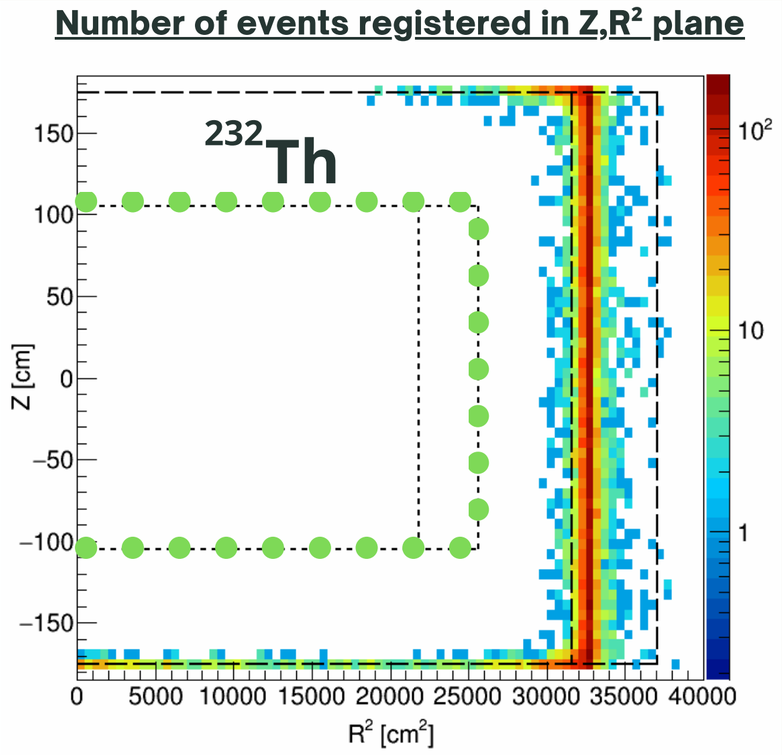


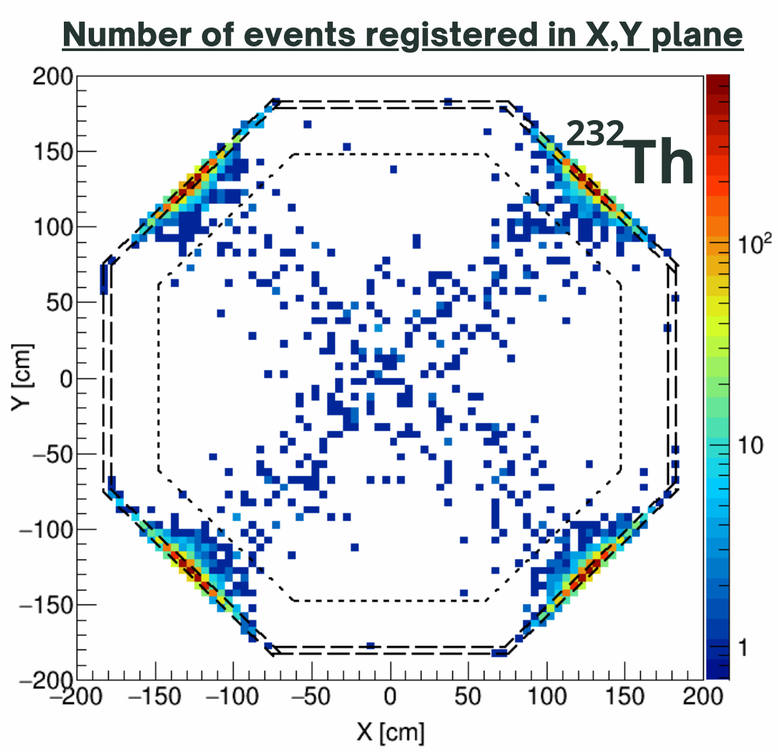
THORIUM



ONLY SINGLE SCATTERS (SS) IN ROI

13833 SS at ROI





0 SS in FV (ROI)

SINGLE SCATTERS IN ROI INSIDE FV

NR* BACKGROUND RATES

A

Estimate decay rates from radioactive elements of the tube

B

Find the number of events in the TPC volume through GEANT4DS simulation of the tube for each radioactive source

C

Apply various cuts to estimate the number of remaining events in a given fiducial volume

*NR : NUCLEAR RECOIL

II

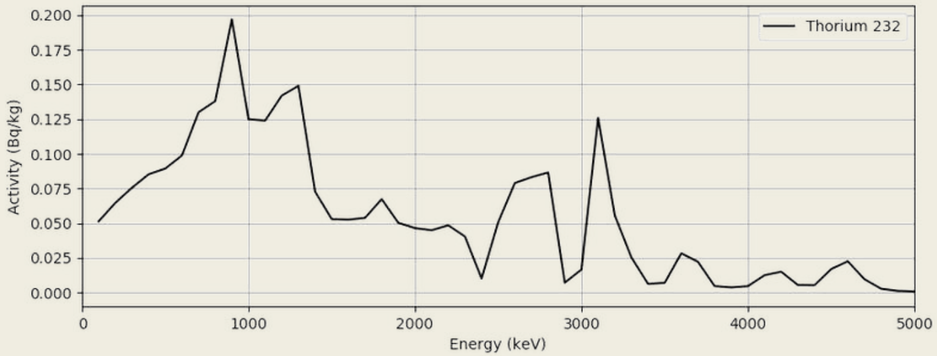
A - DECAY RATE

NEUTRON SOURCES

In underground experiments looking for rare events such as WIMPs interaction, some background events may be caused by neutrons single-scatter interactions. Those are expected to be indistinguishable from the events of interest.

Nuclear yield **from (α, n) reactions** depends on the alpha energy, cross-section of the reaction and alpha energy loss in a sainless steel. The rate has to take into account all the decay chain.

Spontaneous fission contribution is only significant for U238



$$^{238}_{92}\mathrm{U} \xrightarrow[4{,}468\times10^{9}\ \mathrm{a}]{\alpha} {}^{234}_{90}\mathrm{Th} \xrightarrow[24{,}1\ \mathrm{j}]{\beta^-} {}^{234\mathrm{m}}_{91}\mathrm{Pa} \begin{cases} \xrightarrow{0{,}16\%} {}^{234}_{91}Pa \xrightarrow[6{,}7\ h]{\beta^-} \\ \xrightarrow[1{,}17\ min]{99{,}84\%\beta^-} \end{cases} {}^{234}_{92}\mathrm{U} \xrightarrow[2{,}445\times10^{5}\ \mathrm{a}]{\alpha} {}^{230}_{90}\mathrm{Th} \xrightarrow[7{,}7\times10^{4}\ \mathrm{a}]{\alpha} {}^{226}_{88}\mathrm{Ra} \xrightarrow[1600\ \mathrm{a}]{\alpha} {}^{222}_{86}\mathrm{Rn}$$

1.8 x 10^{-6} neutrons/decay

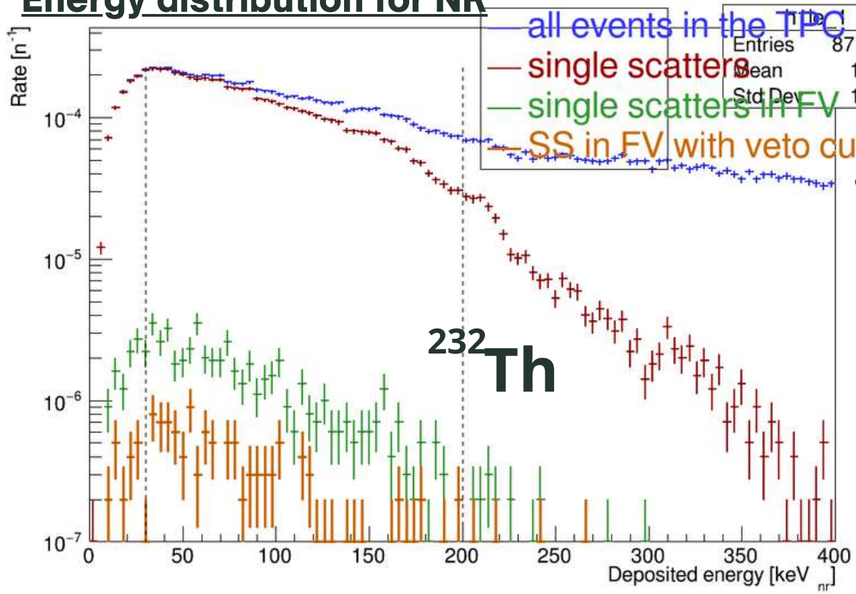
$$^{232}_{90}\mathrm{Th} \xrightarrow[1{,}41\times10^{10}\ \mathrm{ans}]{\alpha} {}^{228}_{88}\mathrm{Ra} \xrightarrow[5{,}75\ \mathrm{ans}]{\beta^-} {}^{228}_{89}\mathrm{Ac} \xrightarrow[6{,}13\ \mathrm{h}]{\beta^-} {}^{228}_{90}\mathrm{Th} \xrightarrow[1{,}91\ \mathrm{ans}]{\alpha} {}^{224}_{88}\mathrm{Ra} \xrightarrow[3{,}62\ \mathrm{jours}]{\alpha} {}^{220}_{86}\mathrm{Rn} \xrightarrow[55{,}6\ \mathrm{s}]{\alpha} {}^{216}_{84}\mathrm{Po} \xrightarrow[146\ \mathrm{ms}]{\alpha} {}^{212}_{82}\mathrm{Pb}$$

4.8 x 10^{-7} neutrons/decay

II

B - SIMULATION

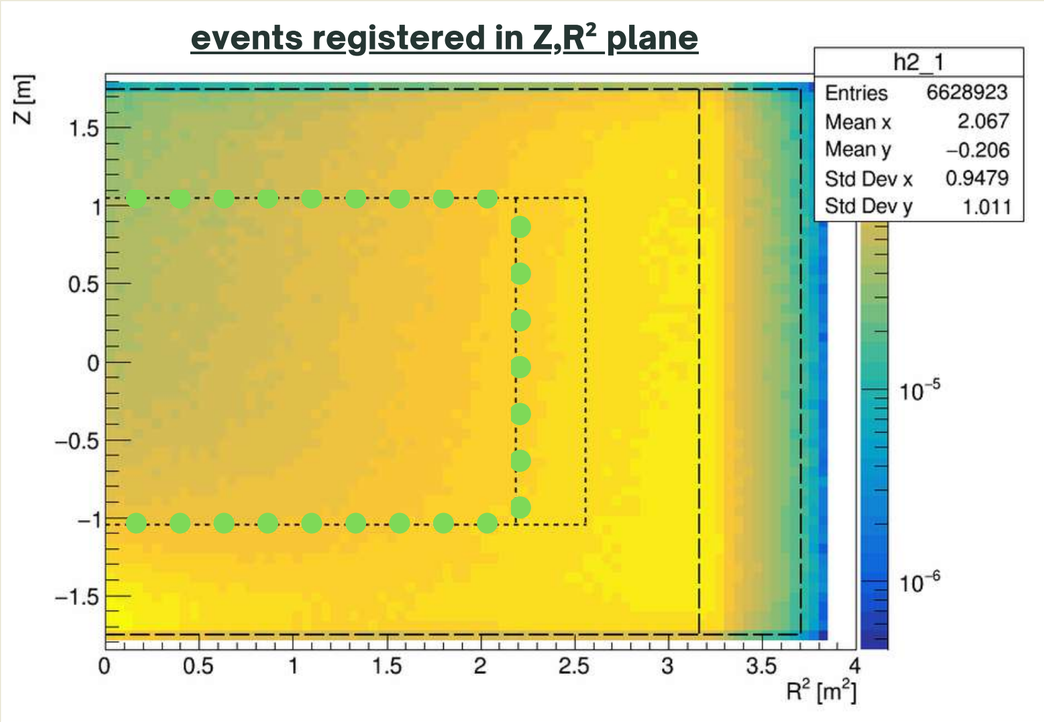
Energy distribution for NR



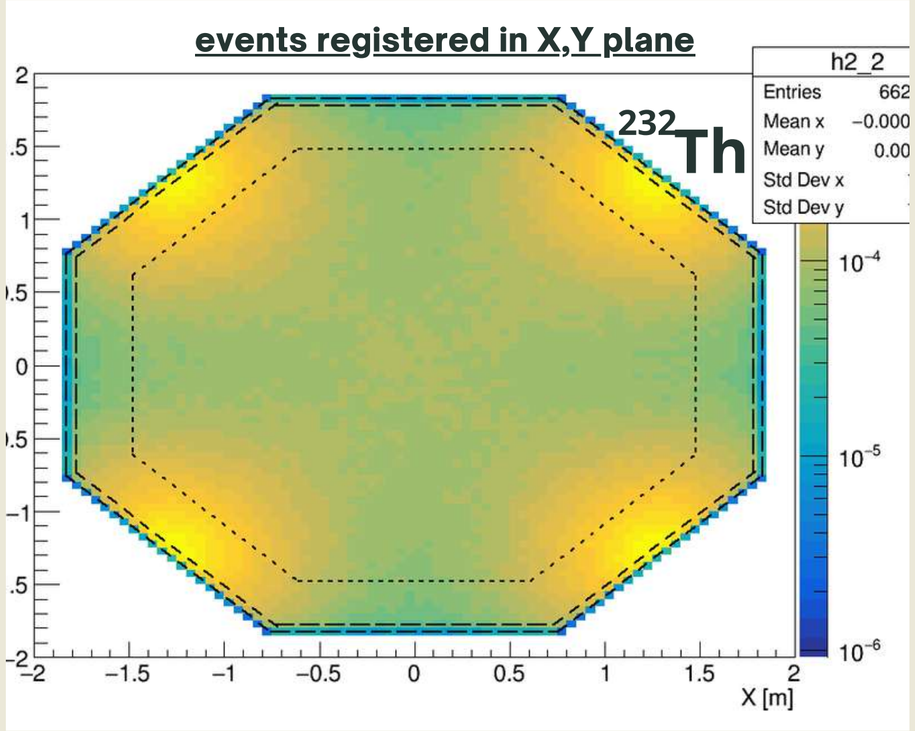
64174 ROI events in TPC

ALL NR
at ROI ∈ [30,200 keVee]

events registered in Z,R² plane



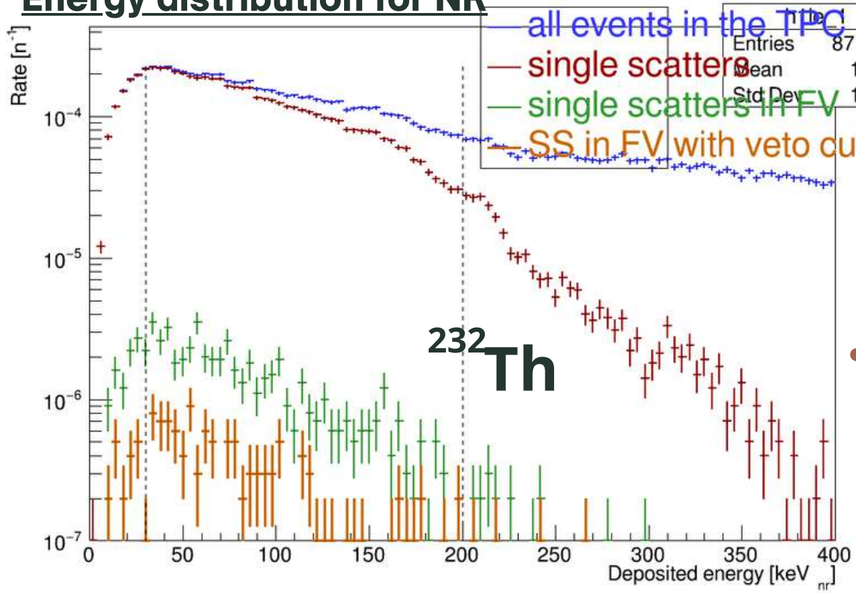
events registered in X,Y plane



II

C - CUTS

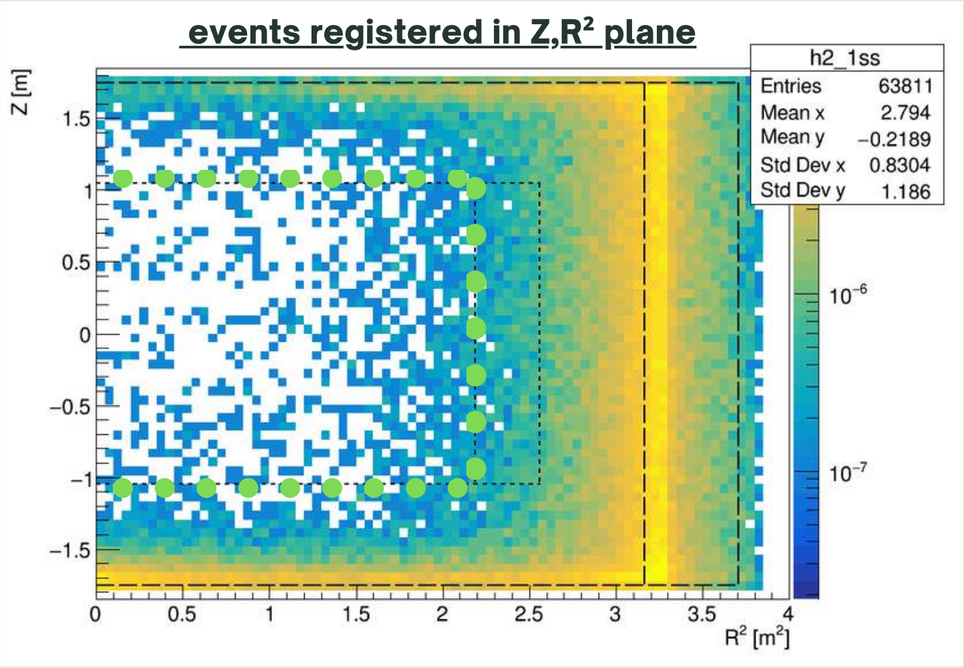
Energy distribution for NR



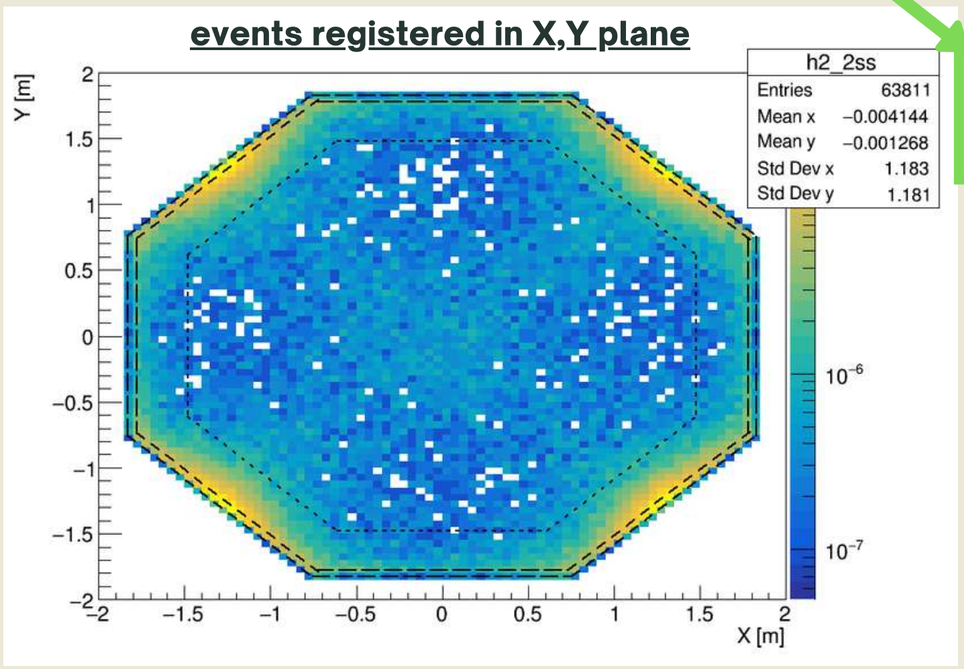
ONLY SINGLE SCATTERS (SS) IN ROI

53470 SS at ROI

events registered in Z,R² plane



events registered in X,Y plane



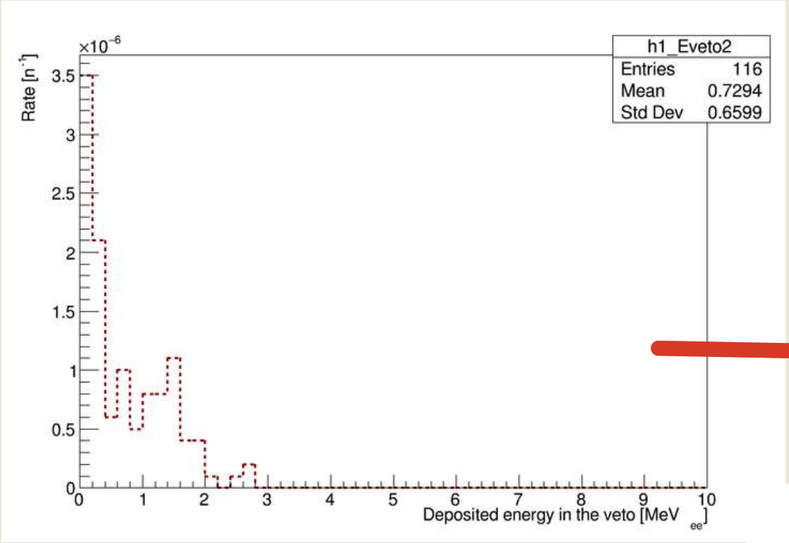
567 SS in FV (ROI)

SINGLE SCATTERS IN ROI INSIDE FV

II

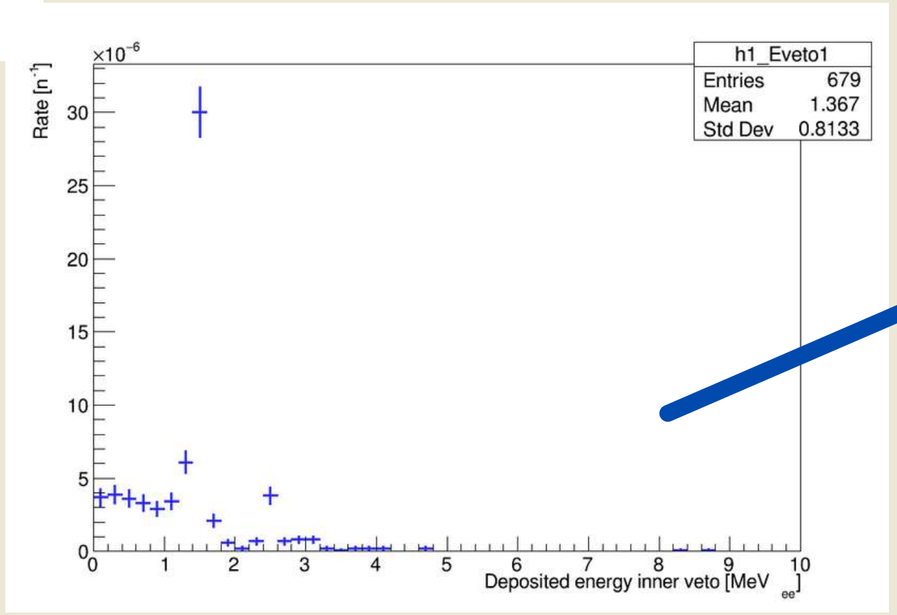
C - CUTS

DISCRIMINATION OF EVENTS BY VETO COINCIDENCE

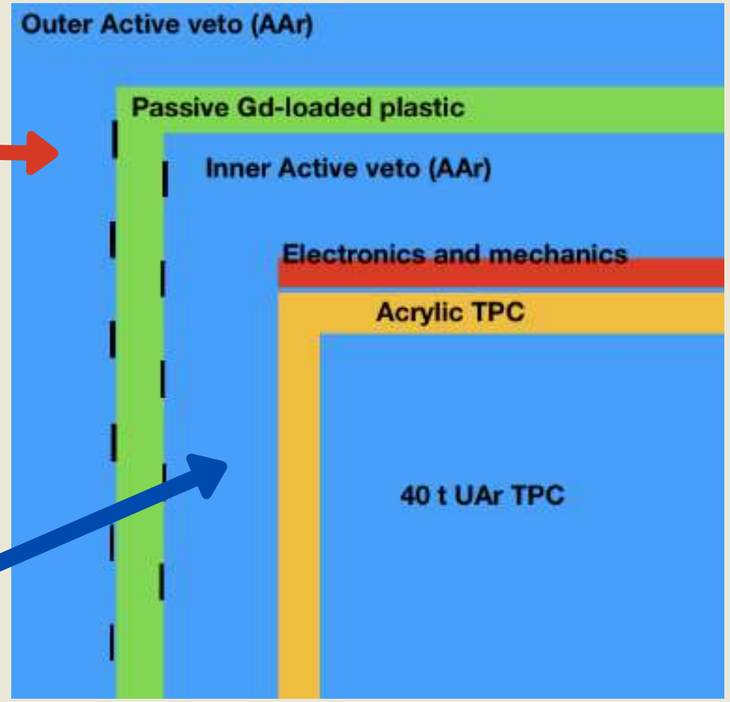


Energy distribution rates for veto2

Energy distribution rates for veto1



PLAN A



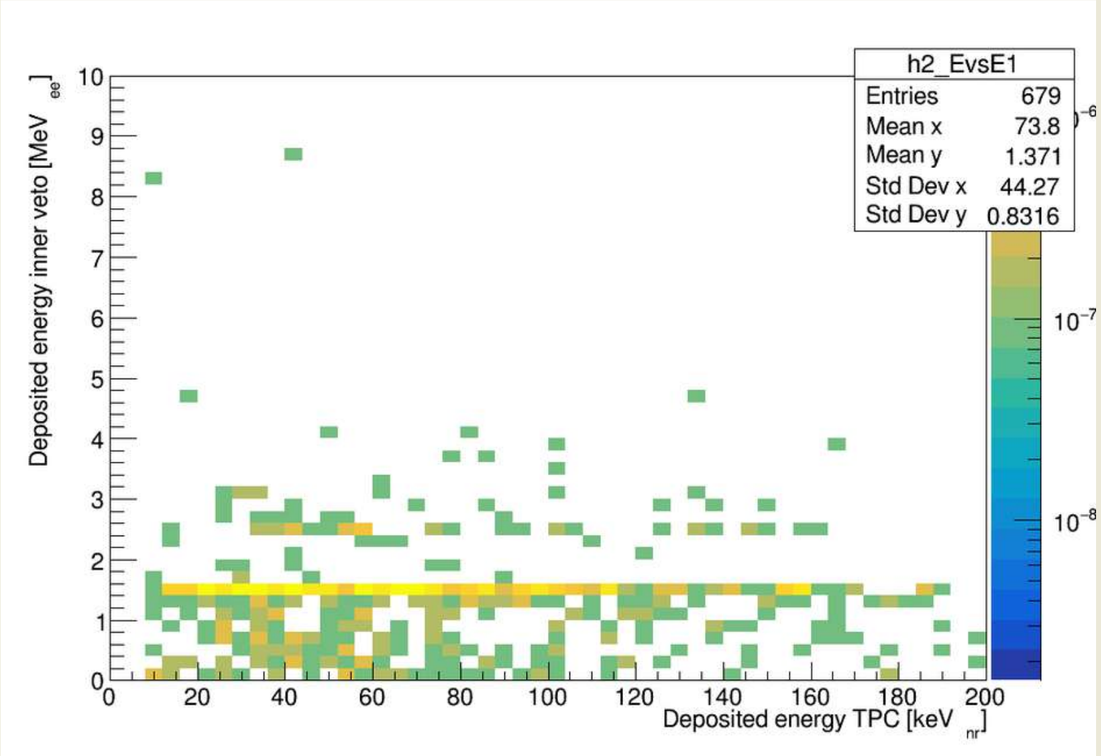
http://deap3600.ca/darkside-20k/

II

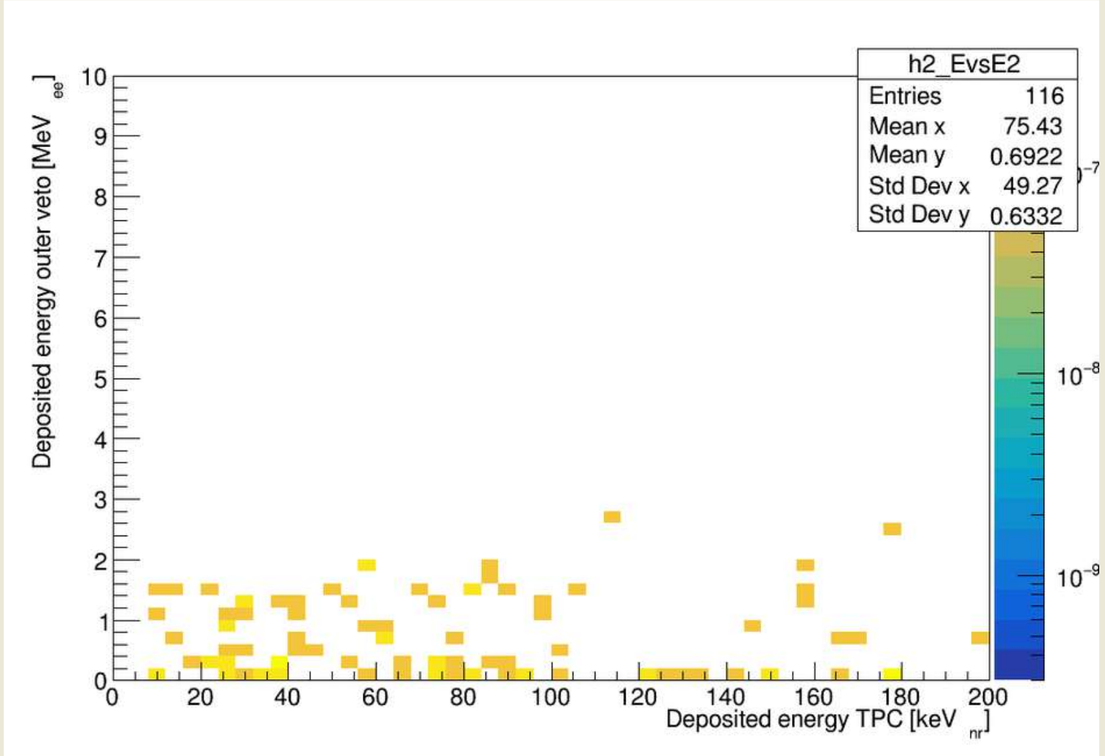
C - CUTS

VETO ENERGY COINCIDENCE

Inner veto



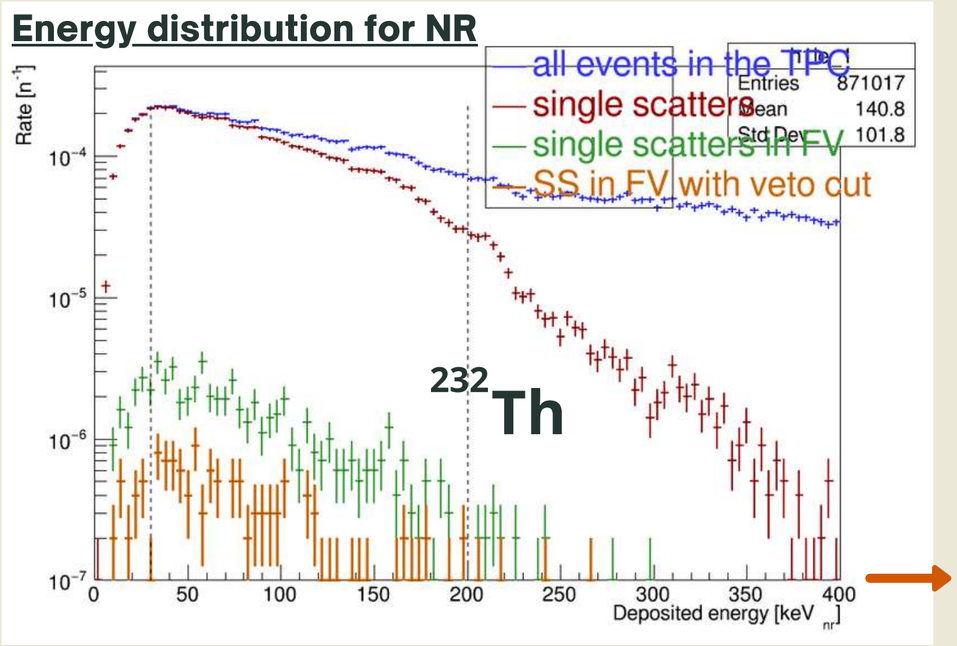
Outer veto



II

C - CUTS

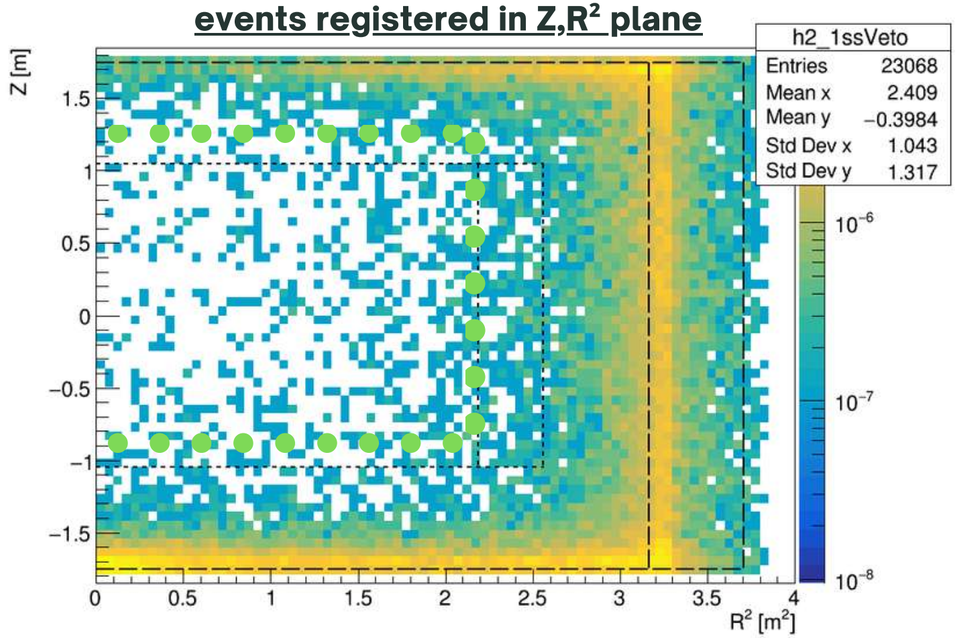
Energy distribution for NR



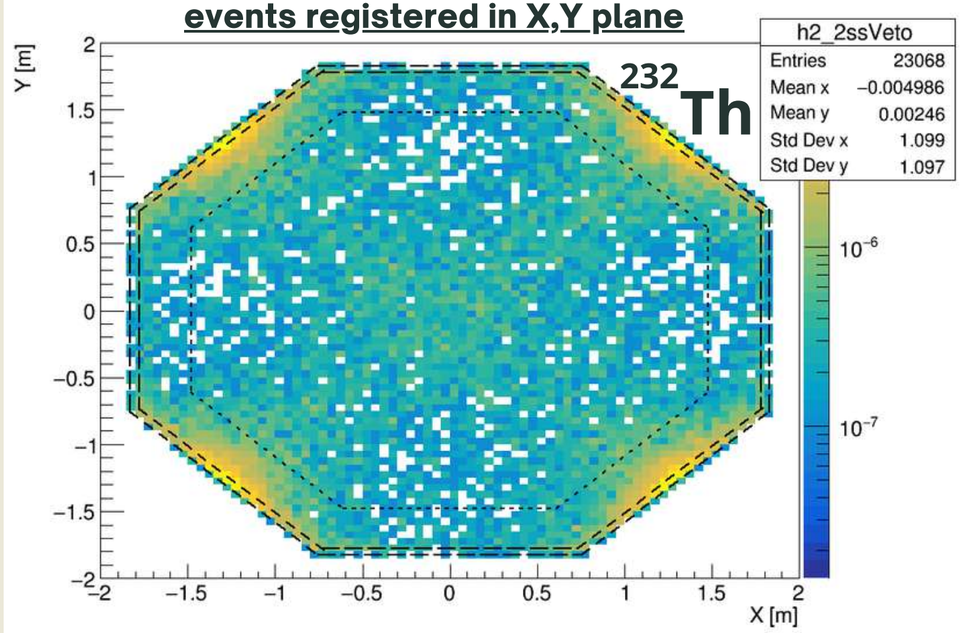
SINGLE SCATTERS
IN ROI
INSIDE FV
NOT TRACED IN VETO

113 SS ROI events in TPC with veto cut

events registered in Z,R² plane



events registered in X,Y plane

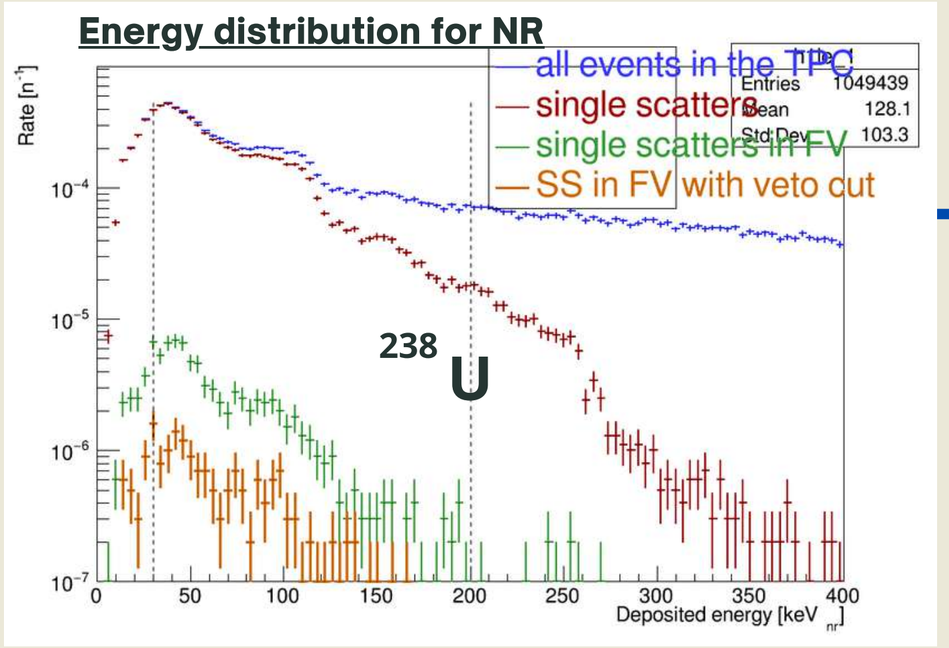


OTHER SOURCES

II

B - SIMULATION

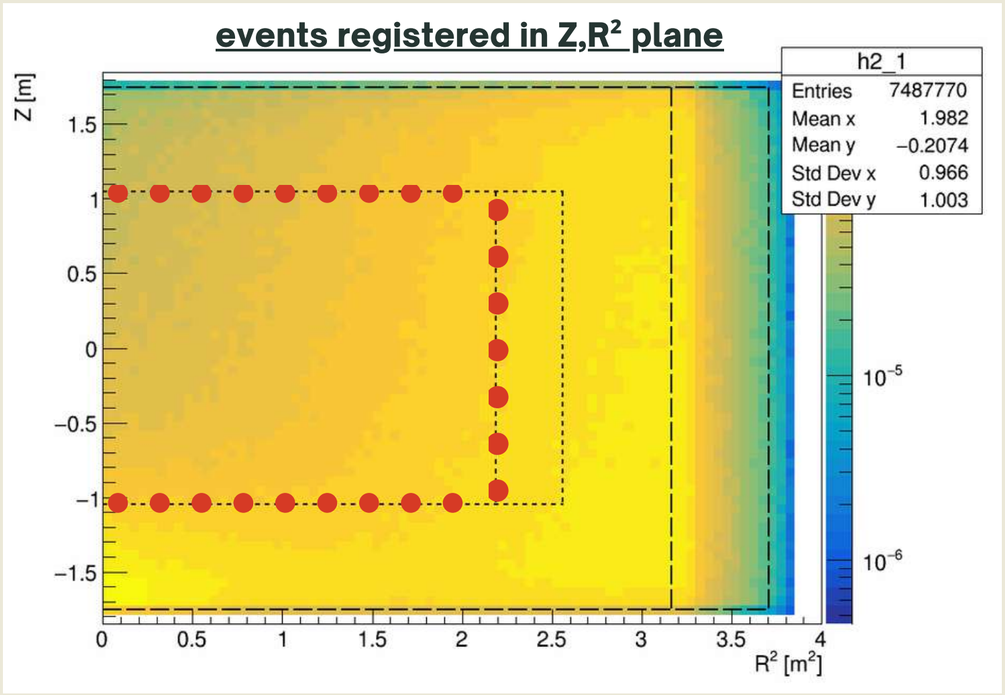
Energy distribution for NR



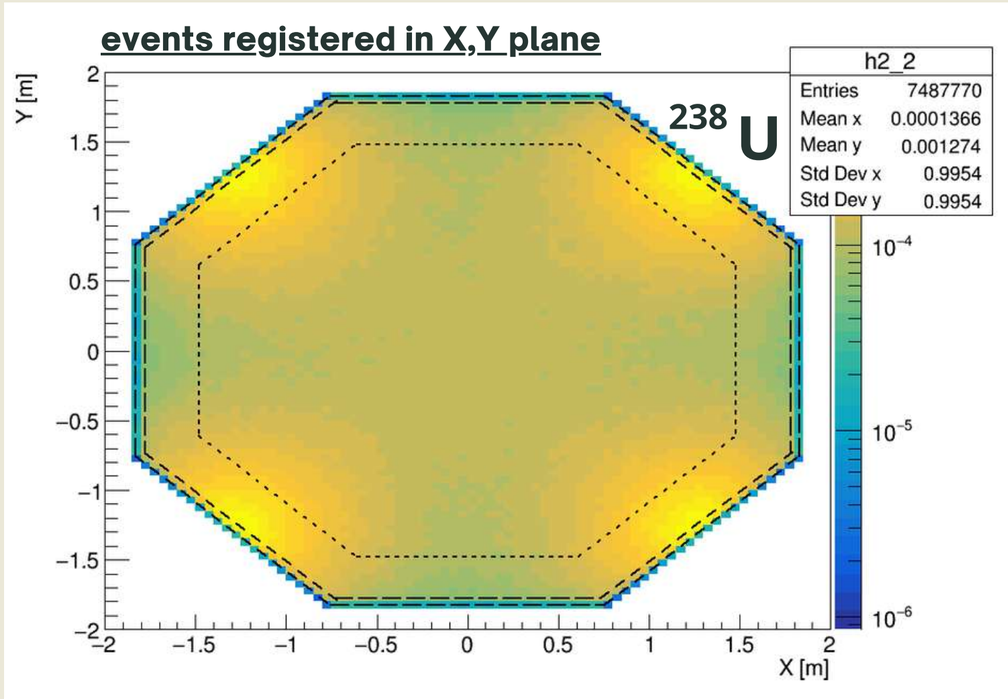
79816 ROI events in TPC

ALL NR
at ROI ∈ [30,200 keVee]

events registered in Z,R² plane

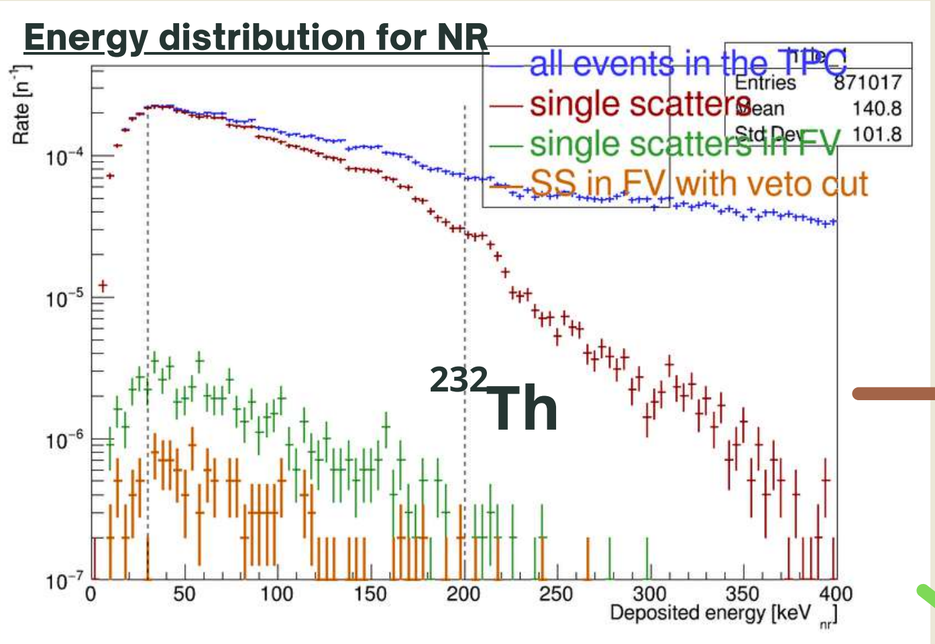


events registered in X,Y plane



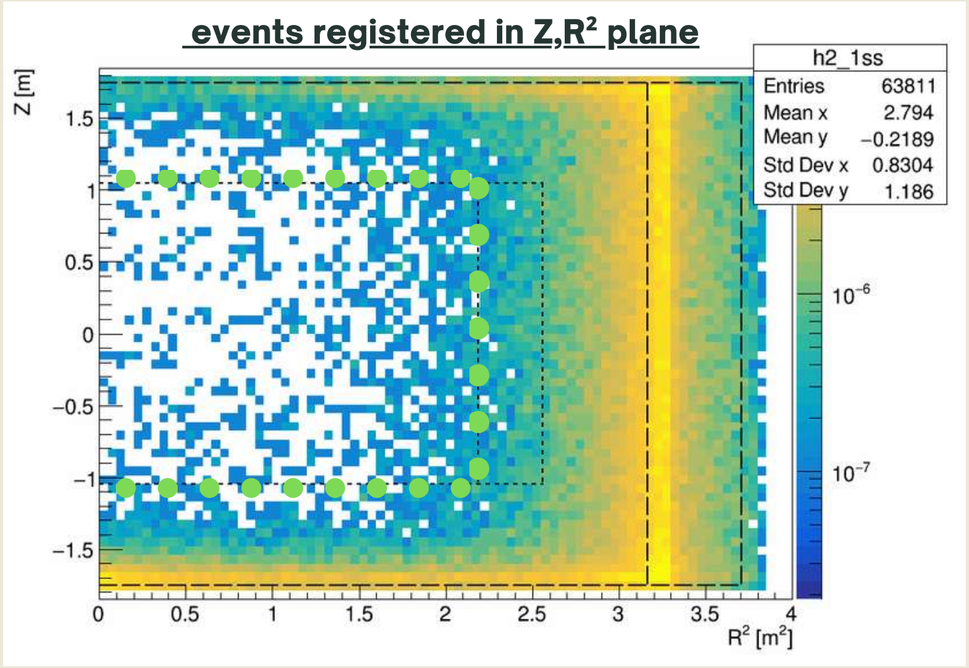
II

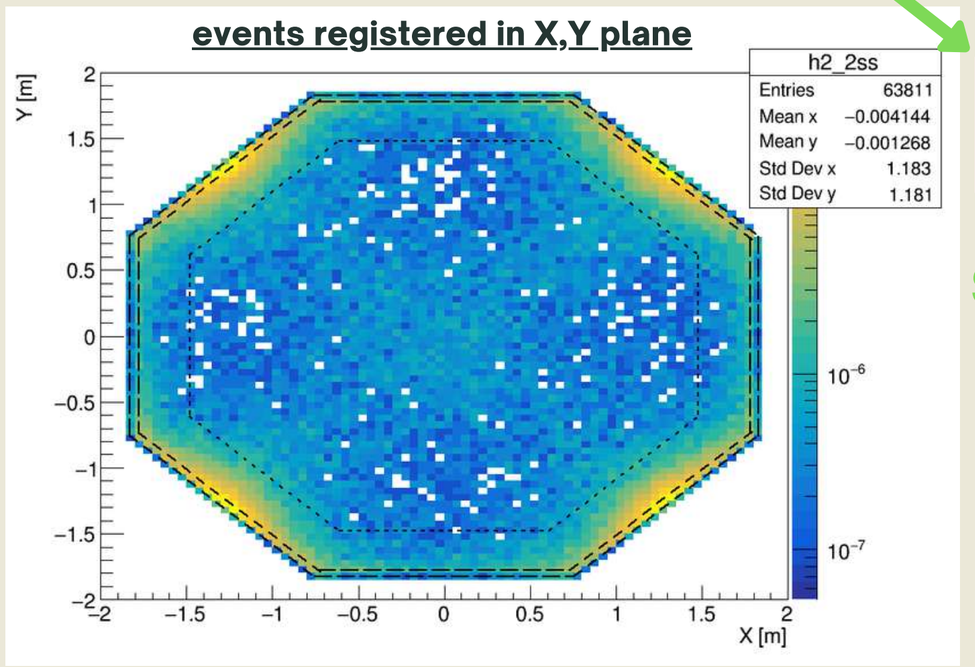
C - CUTS



ONLY SINGLE SCATTERS (SS) IN ROI

64957 SS at ROI





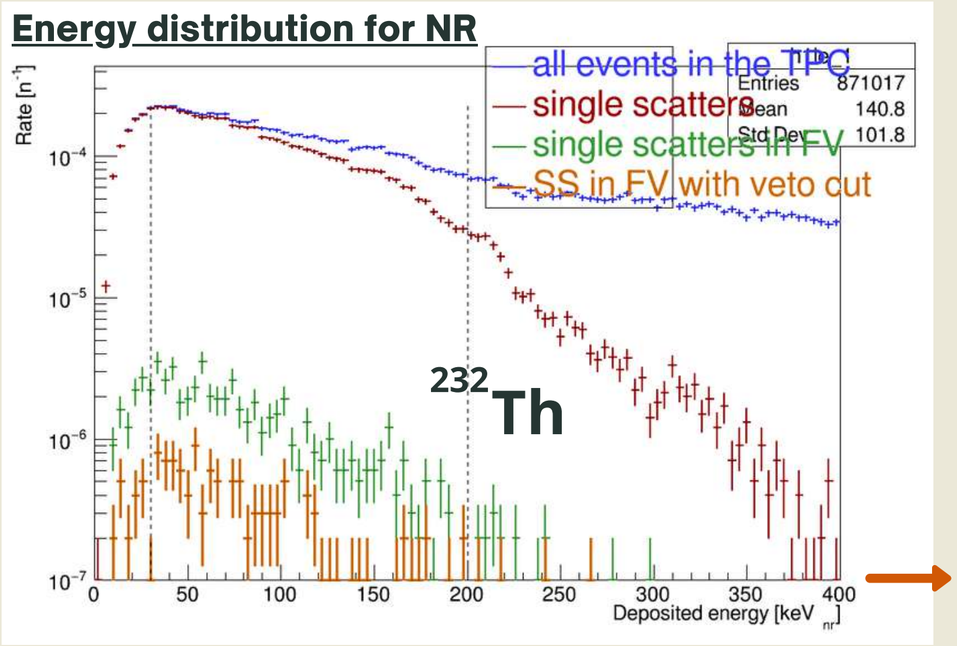
848 SS in FV (ROI)

SINGLE SCATTERS IN ROI INSIDE FV

II

C - CUTS

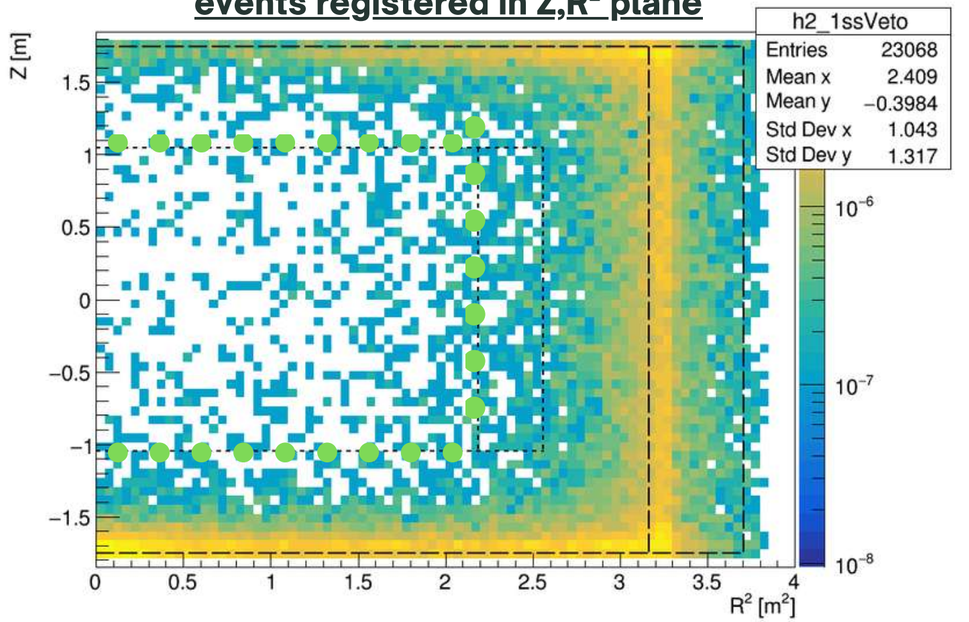
Energy distribution for NR



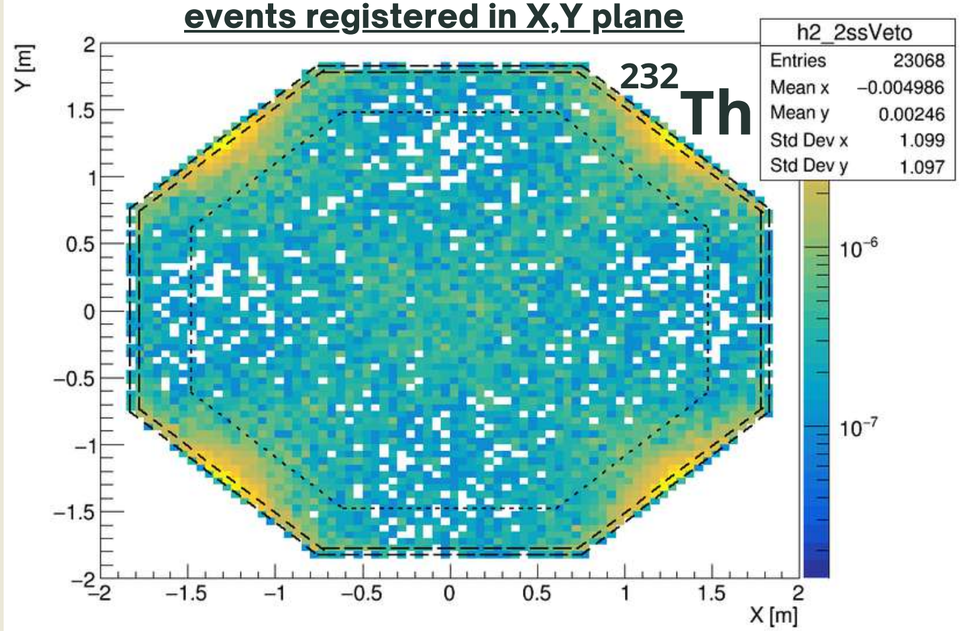
SINGLE SCATTERS
IN ROI
INSIDE FV
NOT TRACED IN VETO

164 SS ROI events with veto cut in FV

events registered in Z,R² plane



events registered in X,Y plane



NR BACKGROUND RATES

Background event rates for 29kg of ArDM stainless steel, 1e7 events simulated

Element	Contamination (mBq/kg)	Decay/s	decay/20y	neutrons/20y	events sim FV	surviving neutrons/20y	Contrib for 0.21 events in 200 t y
^{238}U	50	1.45	9.16e+08	4.39e+02	<164.00	<0.00	3.43
^{232}Th	20	0.58	3.66e+08	6.59e+02	<133.00	<0.00	4.17

Background event rates for 29kg of stainless steel, 1e7 events simulated

Element	Contamination (mBq/kg)	Decay/s	decay/20y	neutrons/20y	events sim FV	surviving neutrons/20y	Contrib for 0.21 events in 200 t y
^{238}U	10	0.29	1.83e+08	8.79e+01	<164.00	<0.00	0.68
^{232}Th	10	0.29	1.83e+08	3.30e+02	<133.00	<0.00	2.08

Background event rates for 25kg of stainless steel, 1e7 events simulated. 89 events for each (ITS A TEST)

Element	Contamination (mBq/kg)	Decay/s	decay/20y	neutrons/20y	events sim FV	surviving neutrons/20y	Contrib for 0.21 events in 200 t y
^{238}U	10	0.25	1.58e+08	7.57e+01	<89.00	<0.00	0.32
^{232}Th	10	0.25	1.58e+08	2.84e+02	<89.00	<0.00	1.20

VERIFICATION POUR PASCAL

NR BACKGROUND RATES

Sample identifier	Budget I (0.21 events in 200ty)	
	^{232}Th	^{238}U
SS	0.9	0.2
SS ArDM	1.9	0.9