Calibration simulation work at CPPM: Plan A vs Plan C

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

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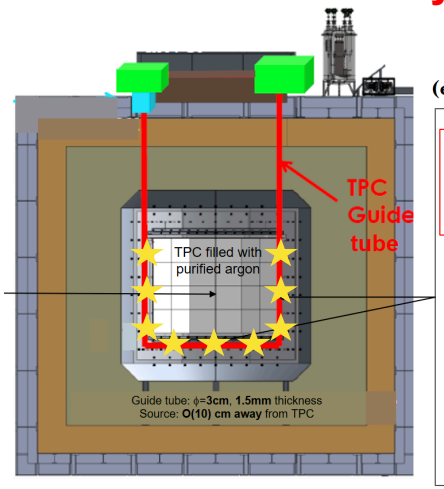
Last time presentation

❑ Presentation of my internship work : study of Plan A DarkSide-20k

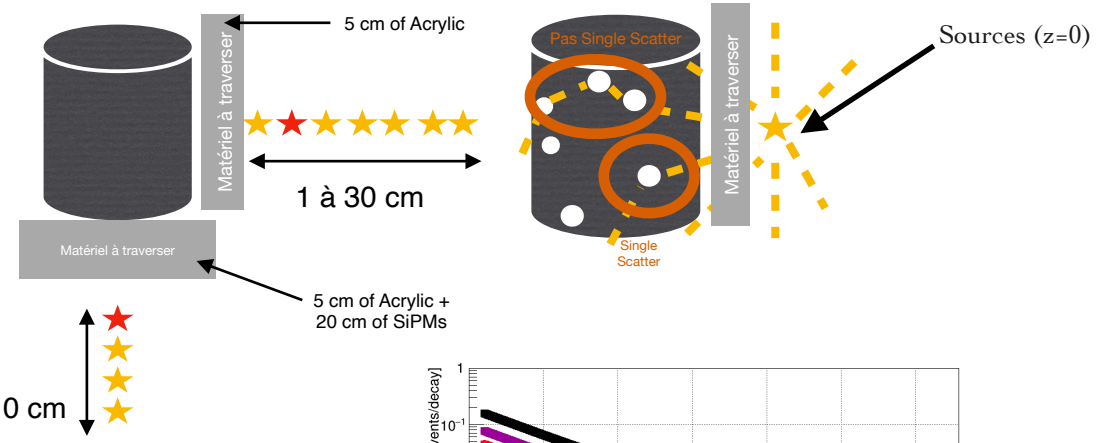


Guide tube sources (electron + nuclear recoil)

External gamma sources (^{60}Co, ^{137}Cs, ^{133}Ba, ...)
Precisely positioned, electron lifetime (bottom)
O(10) cm TPC penetration

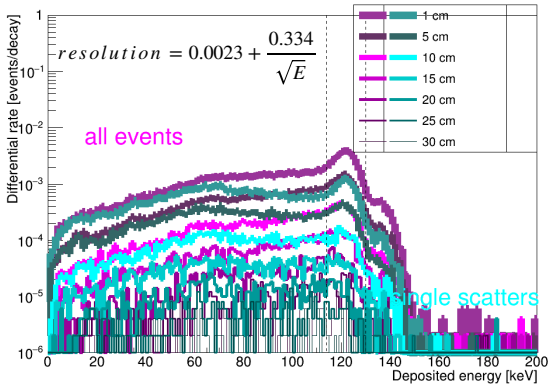
External neutron sources (AmBe, AmC)
Precisely positioned
Non monochromatic

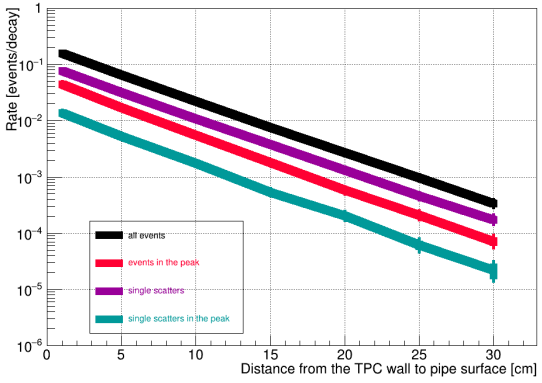
DD gun
Monochromatic neutrons
Recoil energy reconstruction



Simulation de la calibration sur le côté et sous la TPC

- Study of event rate inside the TPC
- Penetration of particles in plan A
- Time analysis





Towards plan C : compare it with plan A

- Study of event rates inside the TPC
- Possibilities to save some events
- Time analysis

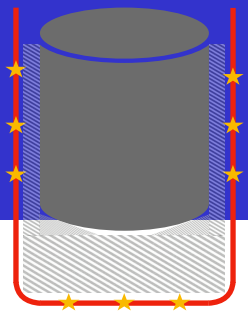
❑ Presentation of my internship work : mock up

Overview

- ➔ Geometry of the TPC in g4ds : Plan A vs Plan C
- ➔ Calibration with sources in the calibration tubes
  - ➔ Calibration with photons sources : Plan A vs Plan C
  - ➔ Calibration with neutrons sources : Plan A vs Plan C
  - ➔ Possible improvements for Plan C
  - ➔ Time estimation for the calibration programme

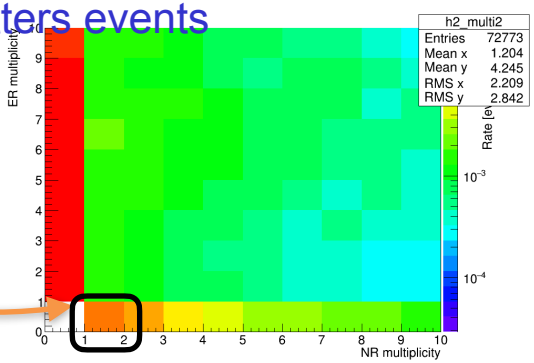
- ➔ Guide tube Activity (contamination coming from the pipes)
  - ➔ ER & NR
  - ➔ Stainless Steel and Titanium

Introduction



- **Goal:** estimate ER and NR rates using radioactive sources circulating in the guide tubes for plans A and C

- **Methodology**
  - Simulate 1 Mevents with g4ds with full-chain radioactive decays
  - Photon sources: Compute events/decays that are single scatters with an energy in the peaks
  - Neutron sources: Compute events/decays for pure NR single scatters events



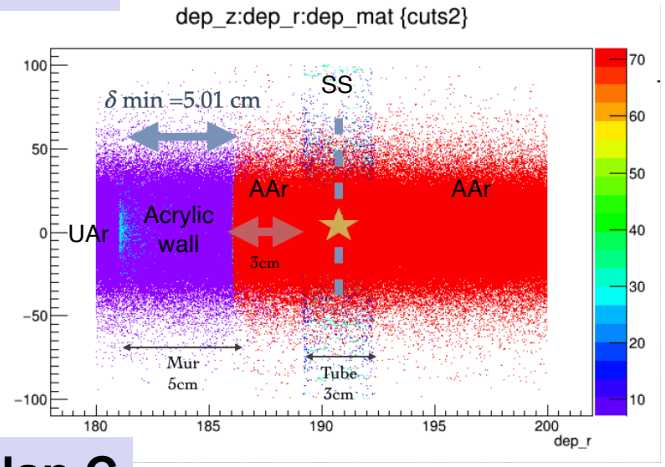
- **Started from Alex Kish work and code (see INT calibration note*)**
  - First : Reproduce his Plan A results assuming the tube are ArDM Stainless Steel (ϕ = 3.0 cm, wall thick. = 1.5 mm), 3 (1) cm from TPC wall aside (below)
  - Include Plan C .mac (Alex)

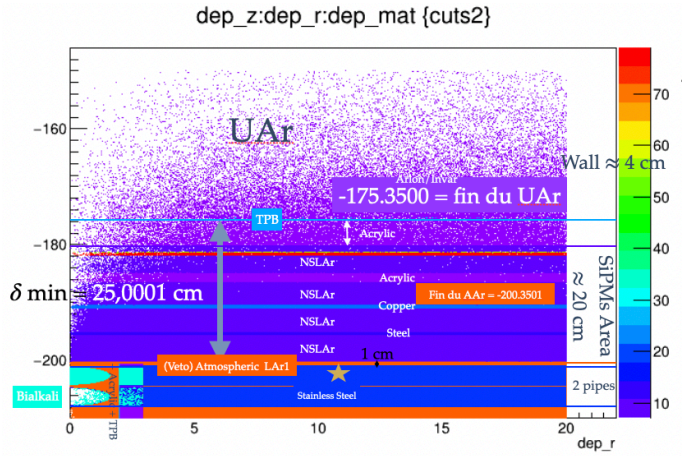
➔Produce results ER, NR for Plan C and compare with Plan A

* see docdb 4334

Geometry in g4ds

Plan A

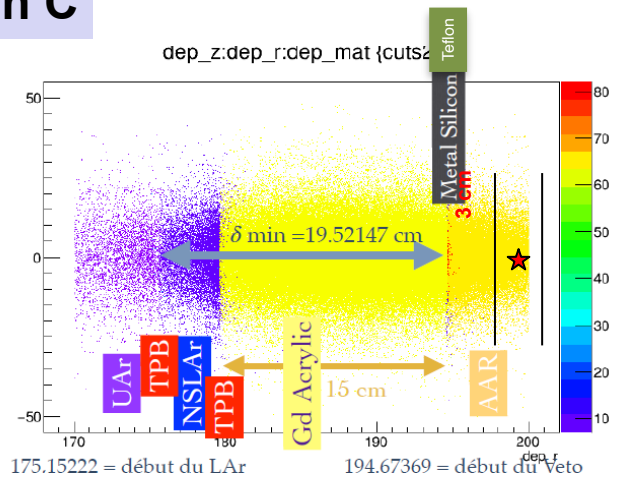


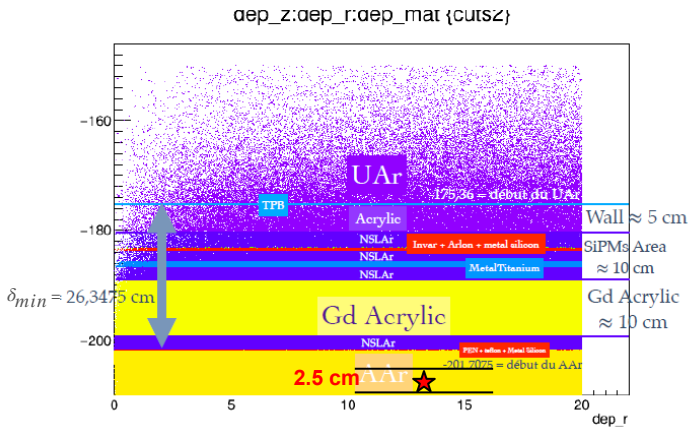


Side :
- d(Source–UAr) = **9.5 cm**
- Acry (5cm) + Ar (3cm)

Bottom :
- d(Source–UAr) = **27.5 cm**
- SiPM (20cm) + Acry (5cm) + Ar (1cm)

Plan C





Side :
- d(Source–UAr) = **24 cm**
- GdAcry(15cm) + Ar (7cm)

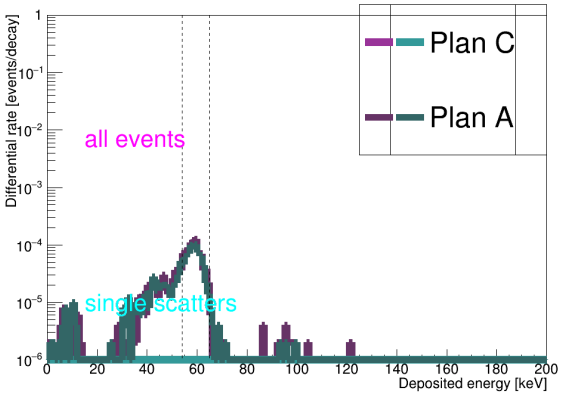
Bottom :
- d(Source–UAr) = **28.8 cm**
- SiPM(10cm) + Acry (5cm) + GdAcry (10cm) + Ar (1cm)

Side : Plan C implies an increased distance for the particles to reach the TPC (14.5 cm)
Bottom : Plan C does not change a lot (in distances) compared to plan A

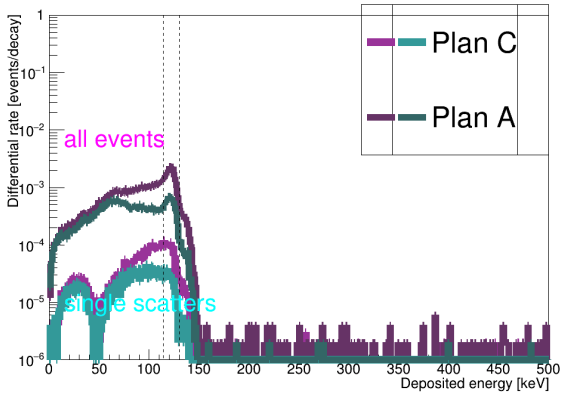
Photons sources (1/3)

- **Plan A and Plan C on the side (all events and single scatters) at z=0**

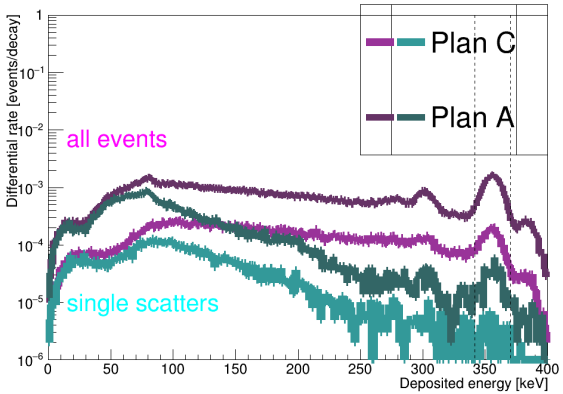
Am 241 — 59.5 keV



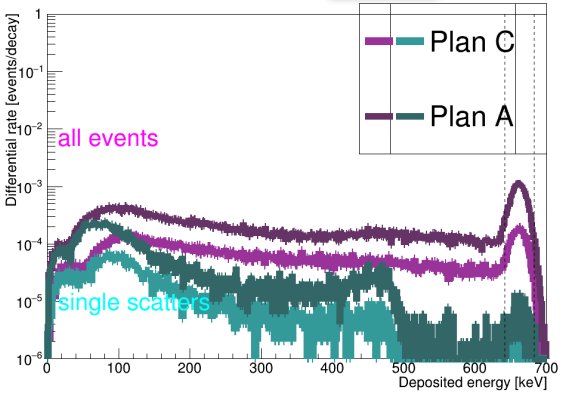
Co 57 — 122 keV



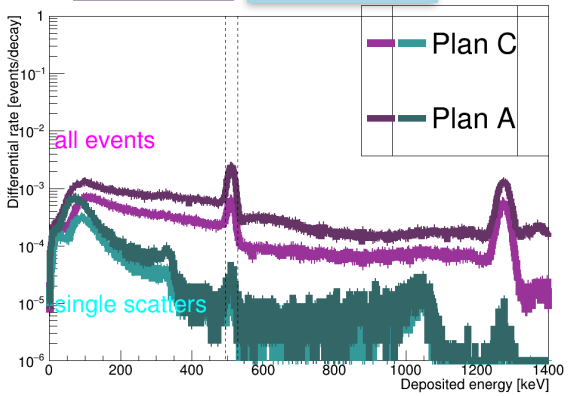
Ba 133 — 356 keV



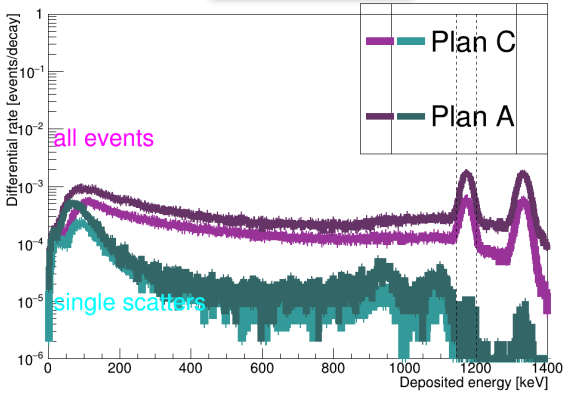
Cs 137 — 662 keV



Na 22 — 511 & 1274 keV



Co60 — 1173 & 1332 keV



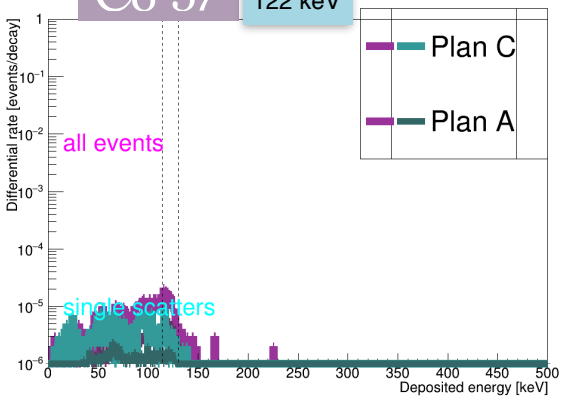
Photons sources (2/3)

- **Plan A and Plan C at the bottom (all events and single scatters)**

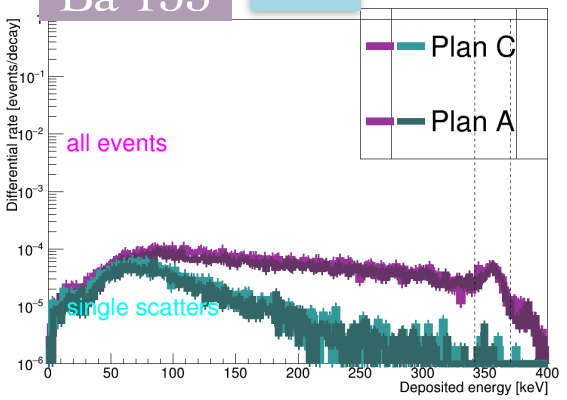
Am 241 — 59.5 keV

Too few events

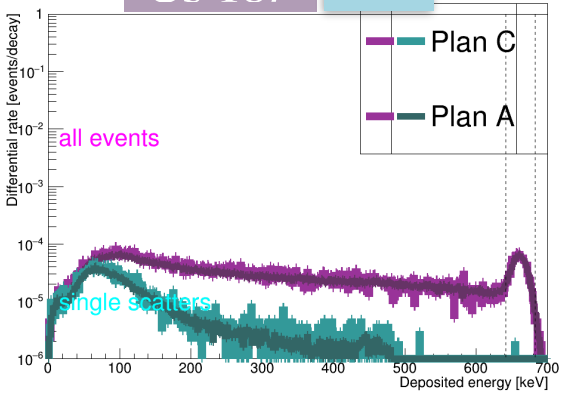
Co 57 — 122 keV



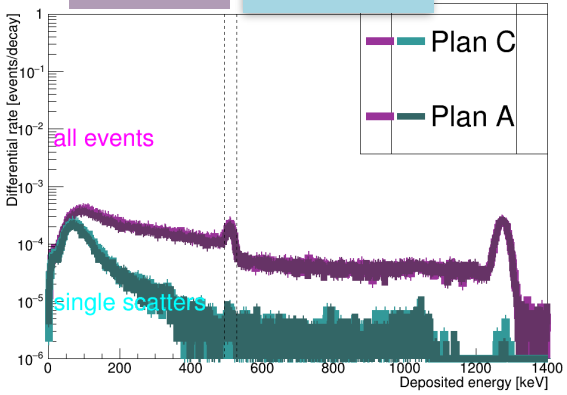
Ba 133 — 356 keV



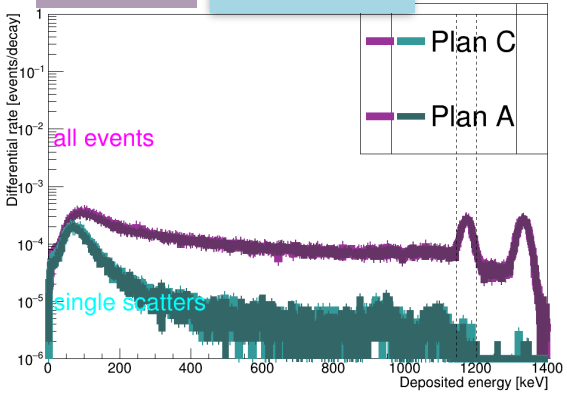
Cs 137 — 662 keV



Na 22 — 511 & 1274 keV



Co60 — 1173 & 1332 keV



Photons sources (3/3)

❑ **Plan A and PlanC : single scatters in the peak of energy**

Side (z=0)

(events /decay)	E (keV)	Plan A	Plan C	PlanC/PlanA
Am241	59.5	7.3×10^{-4}	2×10^{-6}	0.003
Co57	122	8.5×10^{-3}	4.1×10^{-4}	0.05
Ba133	356	7.5×10^{-4}	9×10^{-5}	0.1
Cs137	662	2×10^{-4}	3.5×10^{-5}	0.2
Na22	511, 1274	8.2×10^{-4}	3.5×10^{-4}	0.4
Co60	1173, 1332	2.6×10^{-4}	1.2×10^{-4}	0.5

Bottom

(events /decay)	E (keV)	Plan A	Plan C	PlanC/PlanA
Am241	59.5	NA	NA	NA
Co57	122	2×10^{-5}	5.3×10^{-5}	2.6
Ba133	356	2.2×10^{-5}	2.6×10^{-5}	1.2
Cs137	662	1.3×10^{-5}	1.1×10^{-5}	0.9
Na22	511, 1274	1.4×10^{-4}	1.3×10^{-4}	1.0
Co60	1173, 1332	4.1×10^{-5}	5×10^{-5}	1.2

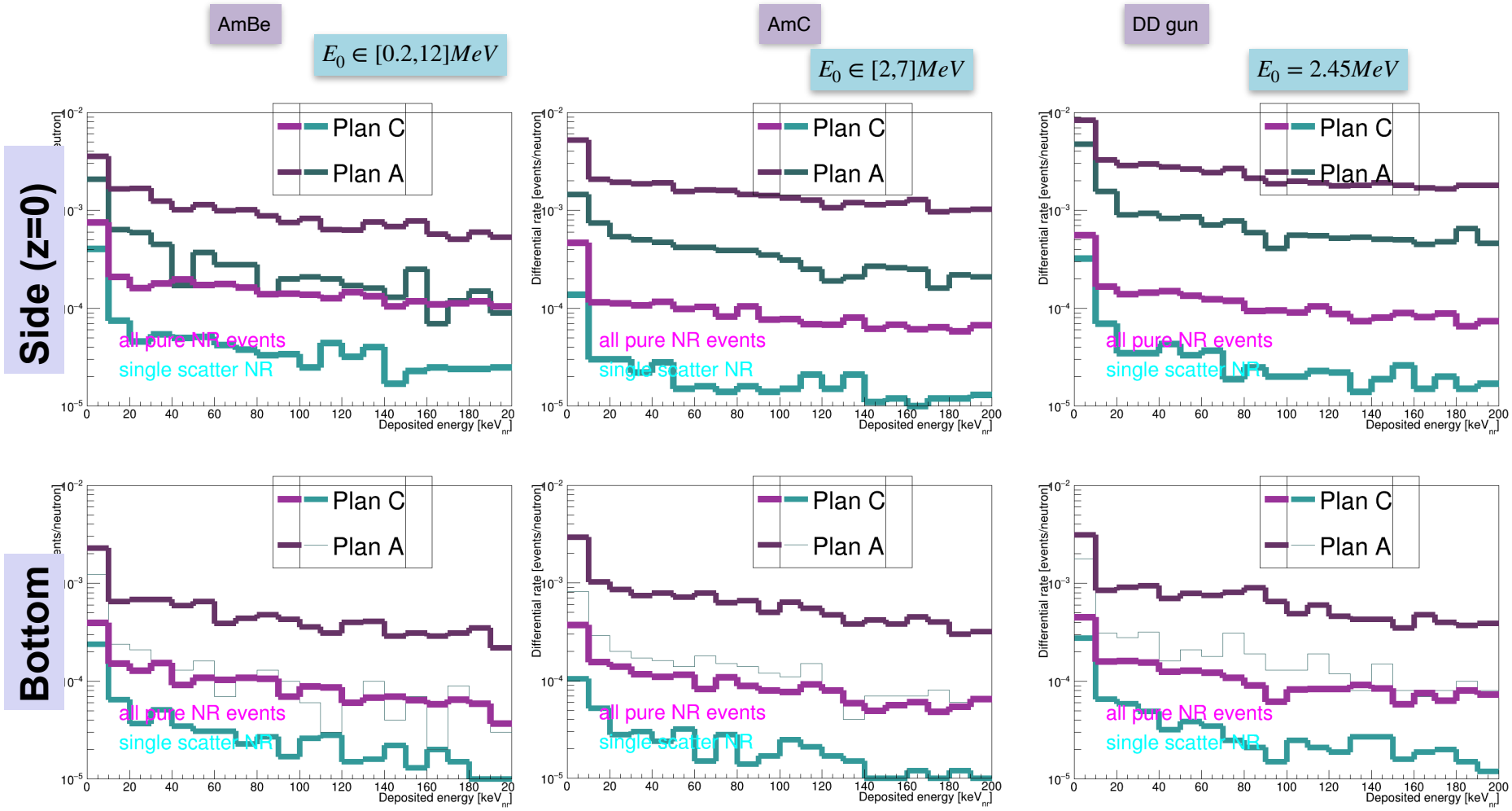
- Main impact : **300-2** times lower rates on 50-500 keV photons for PlanC – side wrt Plan A

→ Possible to compensate by higher activity sources ?

- No impact at the bottom (thanks to reduction of electronics material (cf slide 4))

Neutrons sources (1/2)

- **Plan A and PlanC (pure NR events and single scatters)**



Neutrons sources (2/2)

- **Plan A and PlanC : pure NR single scatter**

Side (z=0)

(events /decay)	Plan A	Plan C	PlanC/PlanA
AmBe	6.3×10^{-3}	1.1×10^{-3}	0.17
AmC	9.98×10^{-3}	6.4×10^{-4}	0.06
DD gun	1.5×10^{-2}	6.5×10^{-4}	0.04

Bottom

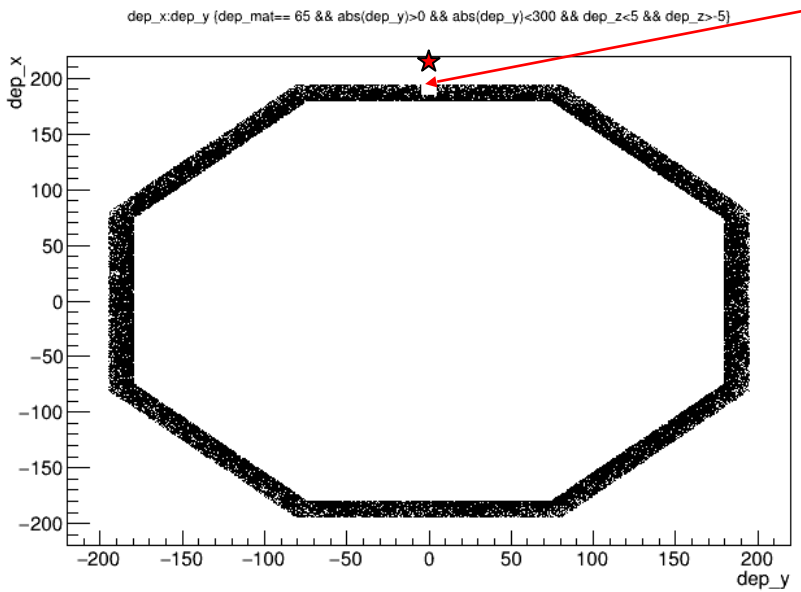
(events /decay)	Plan A	Plan C	PlanC/PlanA
AmBe	2.6×10^{-3}	6.5×10^{-4}	0.25
AmC	3.7×10^{-3}	6.1×10^{-4}	0.16
DD gun	3.8×10^{-3}	6.4×10^{-4}	0.17

- Main impact on AmC and DD gun (**~20** times lower rates) for PlanC – side wrt Plan A. Lower impact on AmBe (**7** time lower rates)
- Lower impact at the bottom (**7** and **4** lower rates, resp.)

→ Possible to compensate by higher activity sources ?

Window in the TPC wall

- Try to do a 10x10 cm2 window on the acrylic on the side (to mitigate the loss)



10cm x 10cm x 10cm window at z = 0

Results similar with what Victor showed in June collaboration meeting

❑ **Results :**

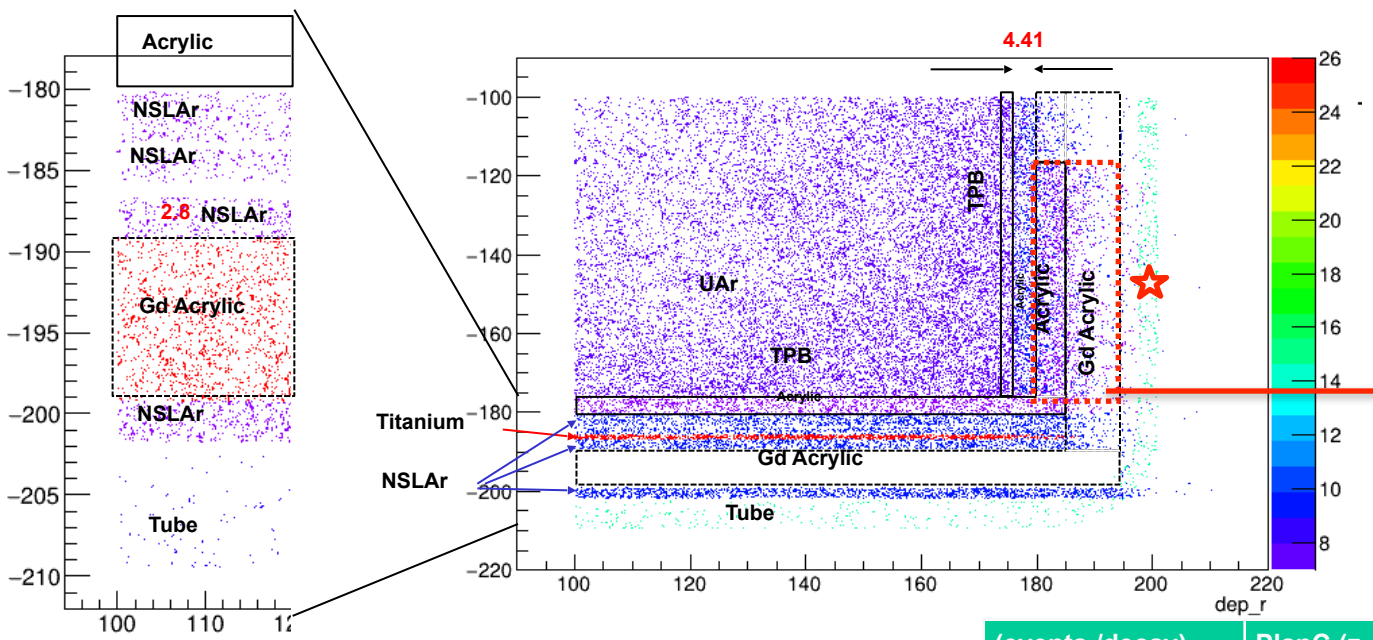
(events /decay)	PlanC (w/ out window)	PlanC (w/ window)	PlanC(with)/ PlanC(without)
DD gun 2.45 MeV	6.5×10^{-4}	1.1×10^{-3}	1.7
AmBe	1.1×10^{-3}	8.9×10^{-4}	0.8
AmC	6.4×10^{-4}	1.3×10^{-3}	2.0

Under investigation

- Doing this, we would increase the rate of events by a factor ~2

Neutrons sources at z = -150 cm

Plan C



Less Gd to cross in this area : might be an asset for calibration with neutrons

- At the bottom of the TPC, the material isn't exactly the same as at z = 0 -> less Gd

(events /decay)	PlanC (z = 0)	PlanC (z = -150)	PlanC(150) /PlanC(0)
DD gun 2.45 MeV	6.5×10^{-4}	1.2×10^{-3}	1.8
AmBe	1.1×10^{-3}	1.3×10^{-3}	1.2
AmC	6.4×10^{-4}	1.7×10^{-3}	2.7

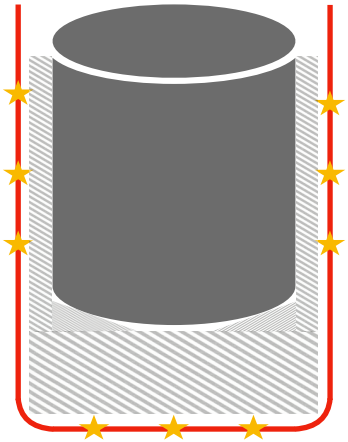
Under investigation

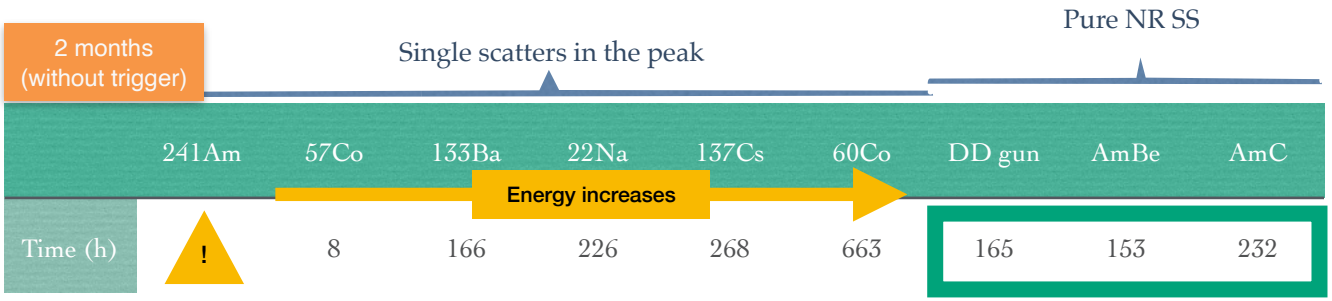
- Performing the calibration at z = -150 cm, we would increase the rate of events by a factor ~2

Time estimation

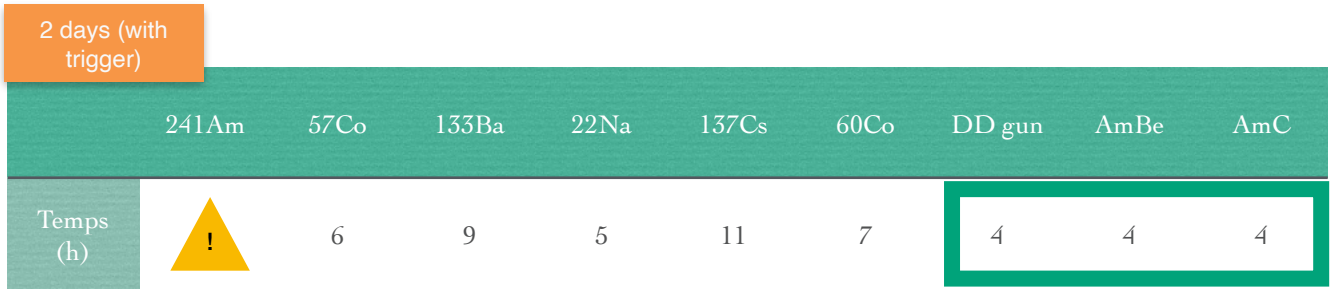
Plan C

- **Goal:** estimate the time needed to perform the calibration with 10k events per position
- **Assumptions :**
  - 2h of sources handling + 9 positions (6 on the side + 3 at the bottom)
  - The signal reconstruction system saturates at 100 Hz
  - Maximum source activity of 100 kBq if bandwidth lower than 100 Hz





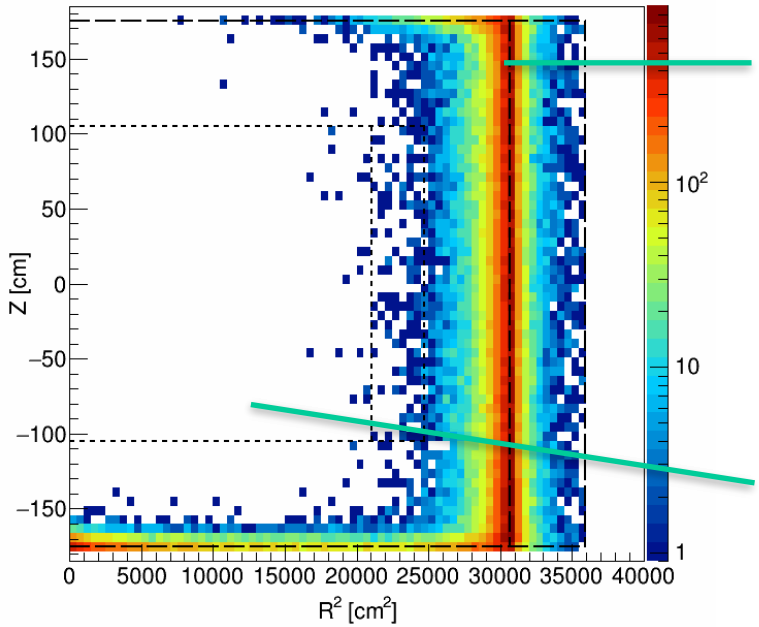
Assuming we do not have any online trigger system (to detect SS in the peak/pure NR SS)



With online trigger (detecting SS in the peak/pure NR SS)

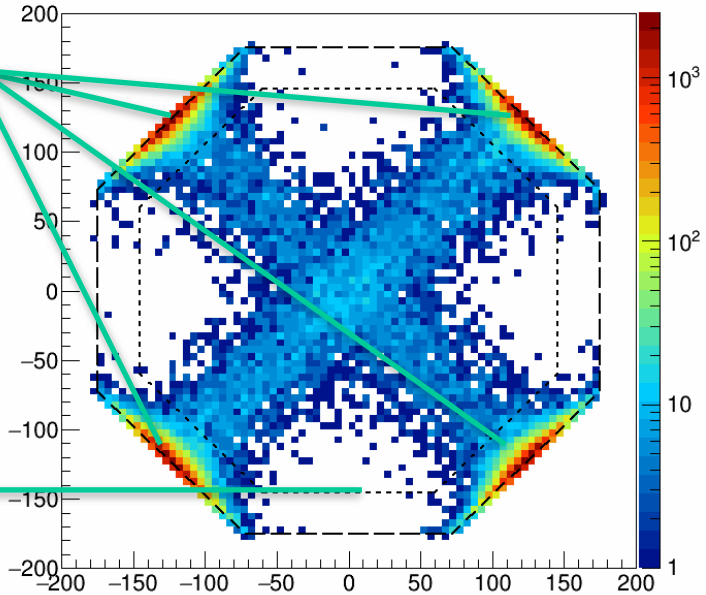
- Huge advantage (~30 x faster) to have an online trigger in the plan C (if we do not use any of the previous tricks)

Guide Tube Activity



(Radioactive) Pipes

Fiducial volume (dashed lines)



Guide Tube Activity

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

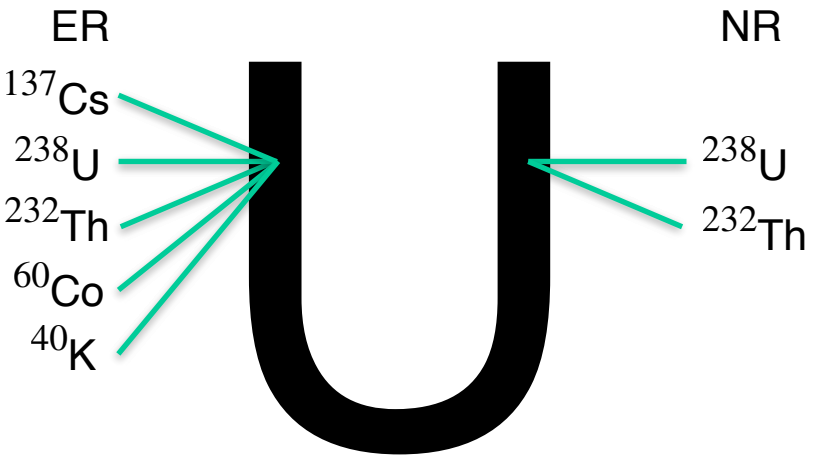
- **Methodology**
  - Simulate 10 Mevents with g4ds with full-chain radioactive decays (HP list for hadronic interactions)
  - Count number of events surviving cuts (if none, put a limit at <2.3 events)
    - ER background: single scatter in ROI (7.5<E<50 keVee) and fiducial volume (veto 70 cm in z, 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 (energies in inner and outer veto both < 800 keV for plan A; veto energy<200 keV for plan C)
  - Normalise to radioactive contamination of the material (from DS material group), mass of tubes (~30 kgs) and time exposure

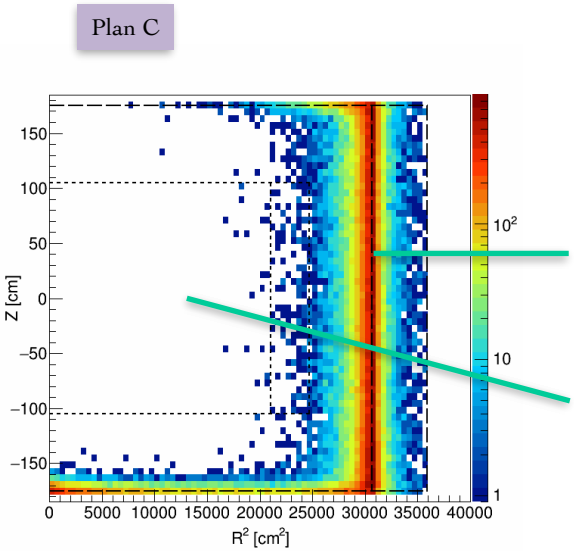
- **Started from Alex Kish work and code (see INT calibration note)**
  - First : Reproduce his Plan A results assuming the tubes are ArDM Stainless Steel (worst case scenario). Tubes: ϕ=3 cm, thick=1.5 mm, 3 (1) cm from TPC wall aside (below)
  - Include Plan C modeling of the guide tube in g4ds (Alex)

➔Produce results ER, NR for Plan C and compare with Plan A

Background induced by the tubes

- **Stainless Steel contamination :**





- **ER**

X-rays emitted during atomic relaxation of excited **Gd atom**

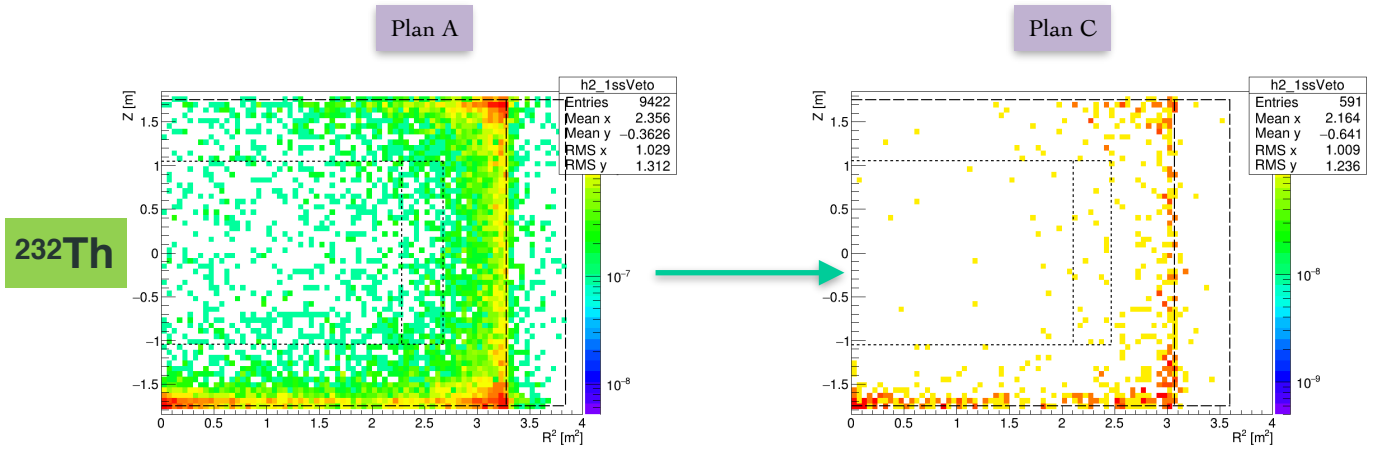
- This induces 10% to 70% more single scatter events at the ROI level in **plan C** wrt plan A
- However, none event survive the ROI + FV cut (Plans A & C)

Element	Contamination in SSArDM (worst case) (mBq/kg)	Events/year
137Cs	1.5	< 0.31
40K	6.4	< 1.34
60Co	13.0	< 2.73
238U	50.0	< 10.52
232Th	20.0	< 4.21

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

NR background

Presence of Gd implies a lower pure NR single scatter contamination in plan C



		Plan A		Plan C	
	n/year	Surviving events (/ 10^7)	NR bknd / 10 years (200 t.y)	Surviving events (/ 10^7)	NR bknd / 10 years (200 t.y)
^{232}Th	34.1	71	0.0024	4	0.0001
^{238}U	22.7	78	0.0018	4	0.0001

Normalisation using production rate of 1.8E-6 n/decay for ^{232}Th and 4.8E-7 for ^{238}U (from (alpha,n) reactions and spontaneous fission due to natural contamination in ^{232}Th and ^{238}U)

- Results for plan A in agreement with Alex Kish
- Results for plan C much lower than plan A (15 cm Gd)
- NR background negligible wrt foreseen budget of 0.1 events after 10 years (200 t.y), for the worst case of SS ArDM (Plans A & C)

→ And even more negligible for Ti tubes (see backup)

Conclusion

- **Calibrating with Plan C** implies a loss of gold-plated events (pure NR single scatters (neutrons) and ER SS (photons)) for the calibration
  - **Side** : 2 to 300 times lower rates in Plan C than in Plan A for photons
  - **Bottom** : ~same results for Plans A and C
  - 4 to 20 times lower rates in Plan C than in Plan A for neutrons
  - Possibilities to try saving some events :
    - Window at z = 0 in the TPC wall
    - Performing neutron calibration at z = -150.0 cm where the Gd wall is thiner

- **Contamination**
  - Our calibration system shouldn't pollute the TPC with events from decay of radioactive elements contaminating the pipe (with Stainless Steel or Titanium)
  - This contribution is negligible compared to the 0.1 events/10 years budget

Back up

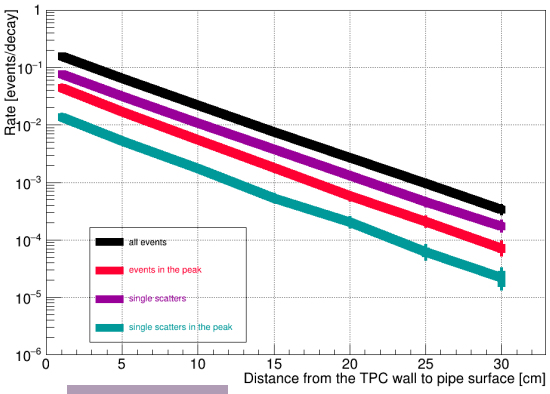
Rates vs distance : Plan A

Side

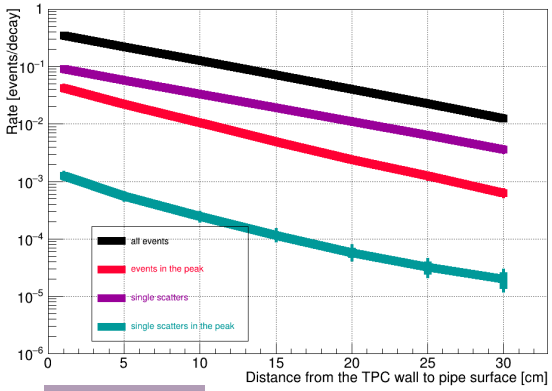
Am 241 59.5 keV

Too few events

Co 57 122 keV



Ba 133 356 keV



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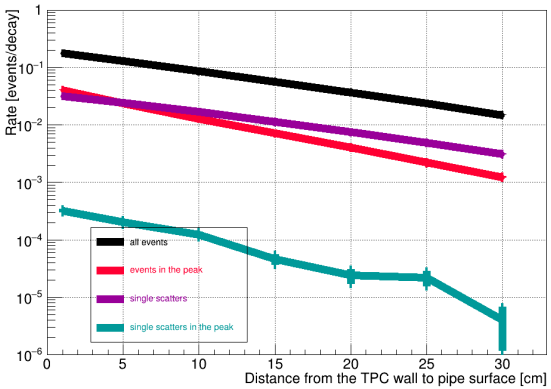
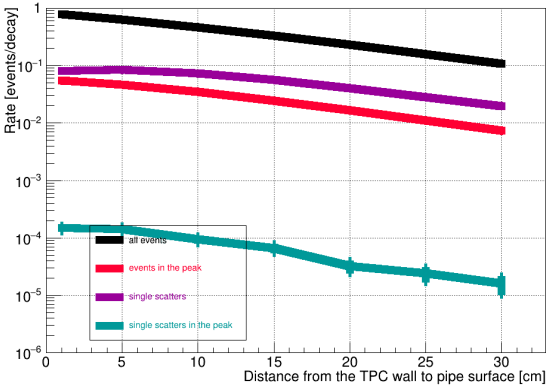
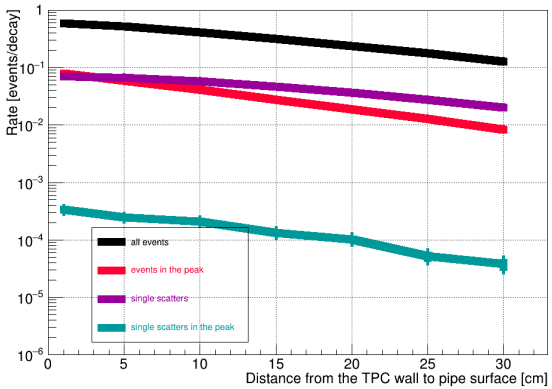


Na 22 511 & 1274 keV



Co60 1173 & 1332 keV



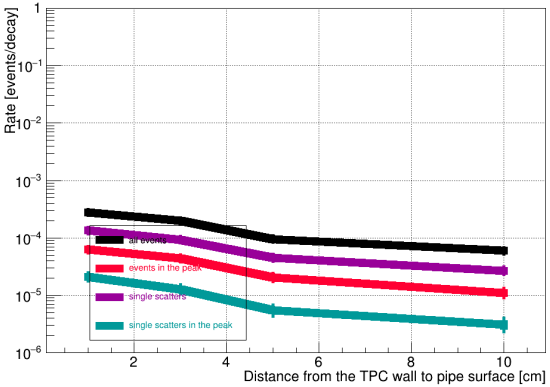
Rates vs distance : Plan A

Bottom

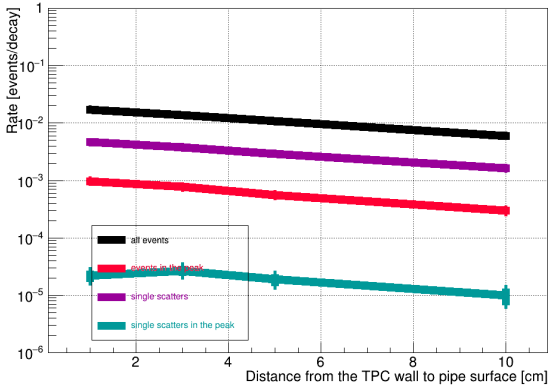
Am 241 — 59.5 keV

Too few events

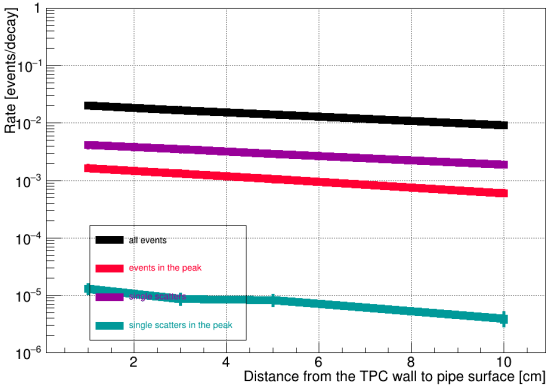
Co 57 — 122 keV



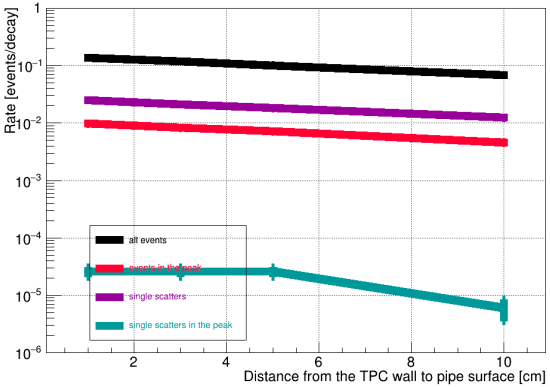
Ba 133 — 356 keV



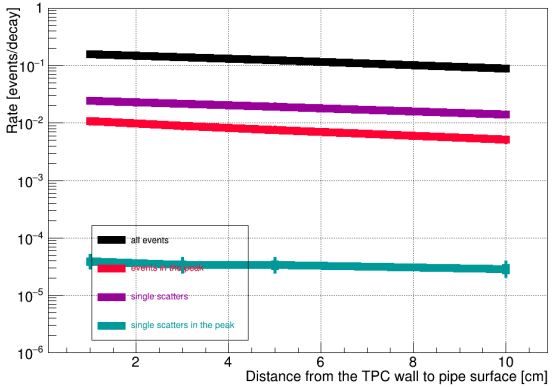
Cs 137 — 662 keV



Na 22 — 511 & 1274 keV



Co60 — 1173 & 1332 keV



Rates vs distance : Plan A

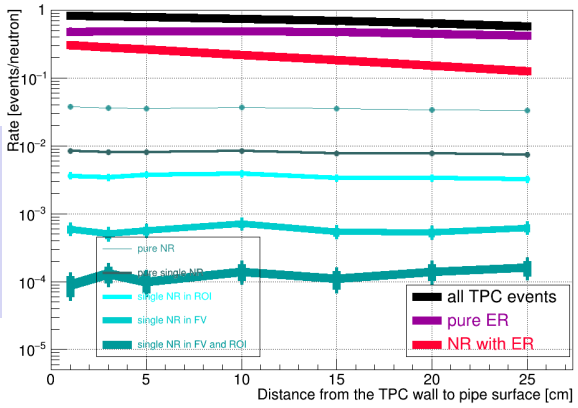
AmBe $E_0 \in [0.2,12] MeV$

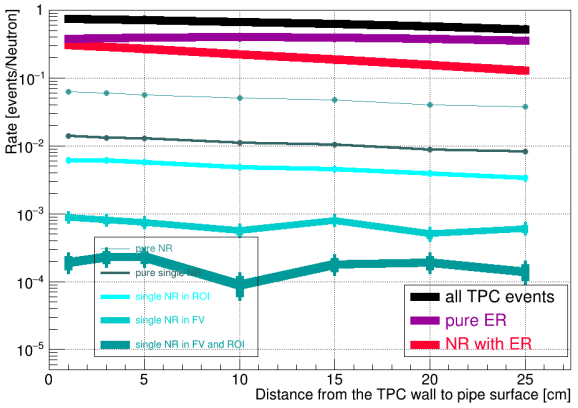
AmC $E_0 \in [2,7] MeV$

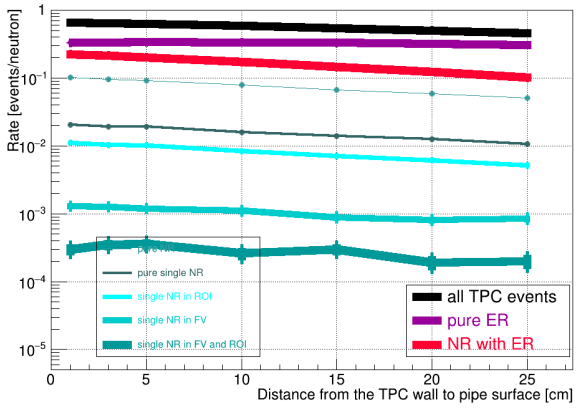
DD gun $E_0 = 2.45 MeV$

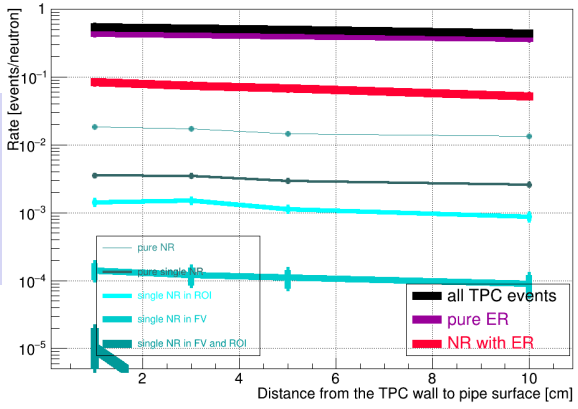
Side

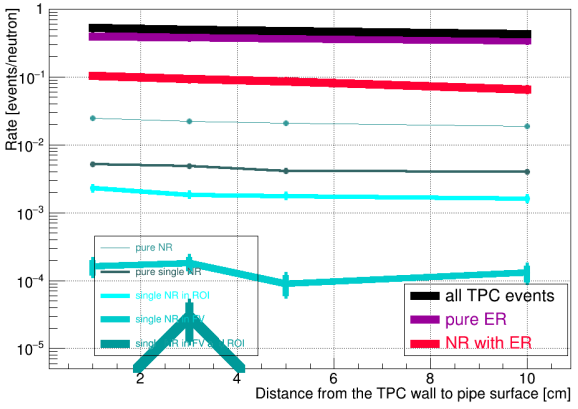
Bottom

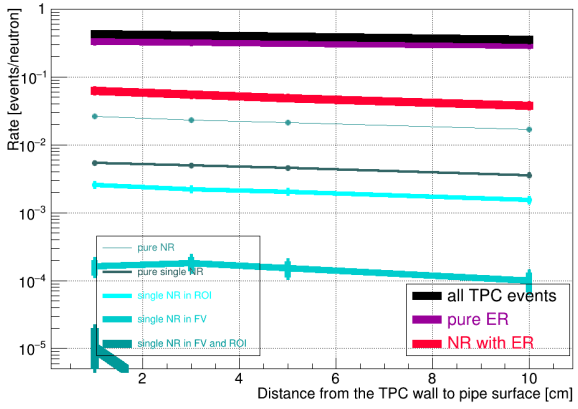




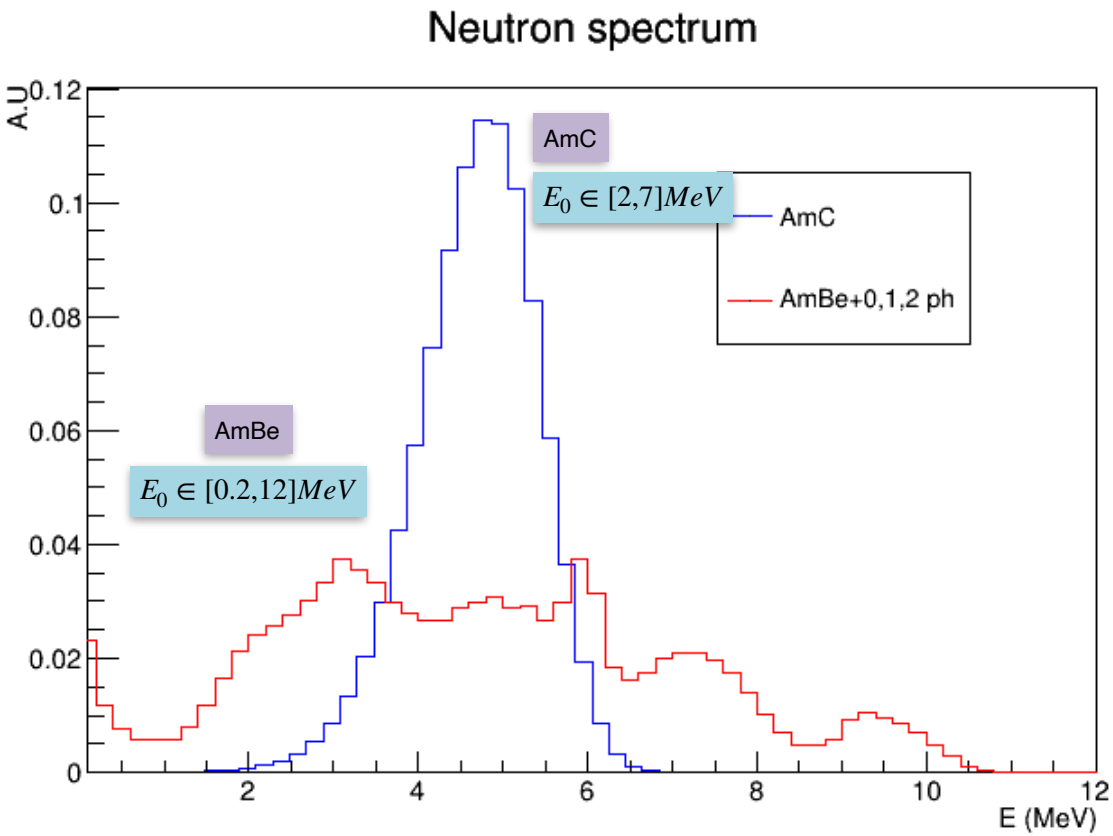








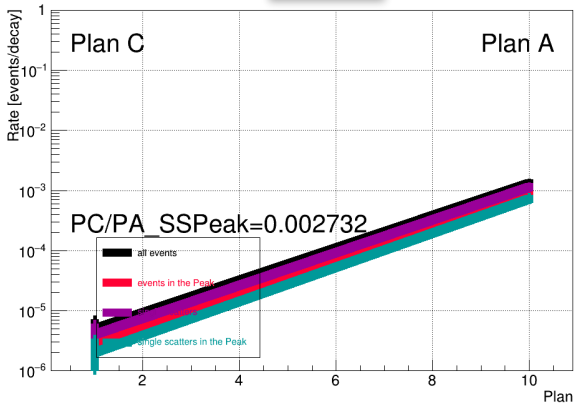
Energy spectrum of AmBe and AmC



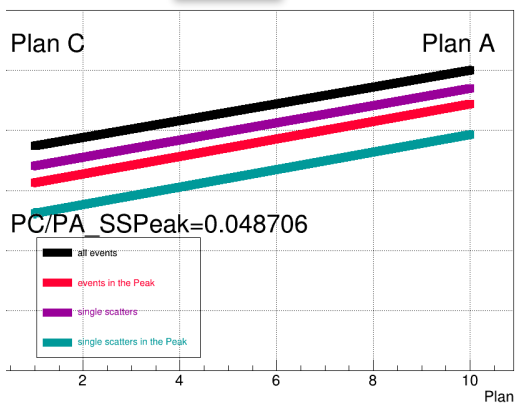
Rates : PlanA vs PlanC

Side

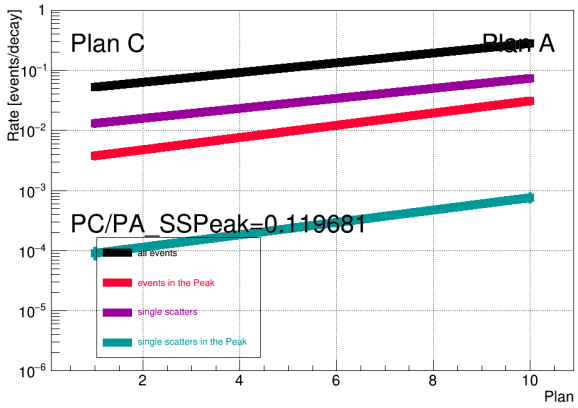
Am 241 59.5 keV



Co 57 122 keV

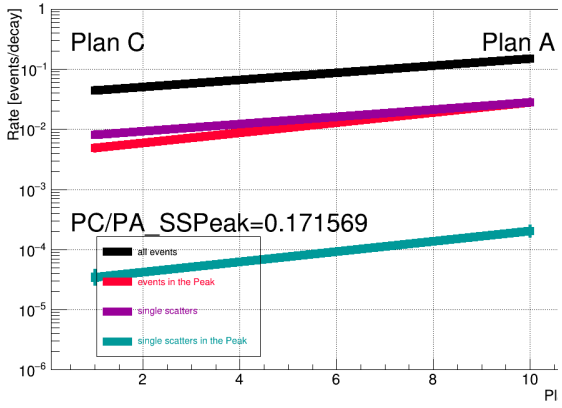


Ba 133 356 keV



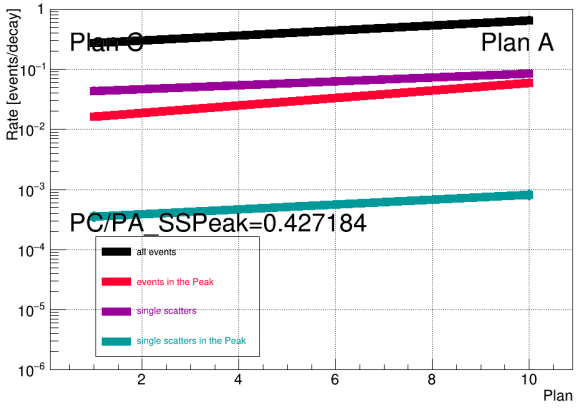
Cs 137 662 keV

Side



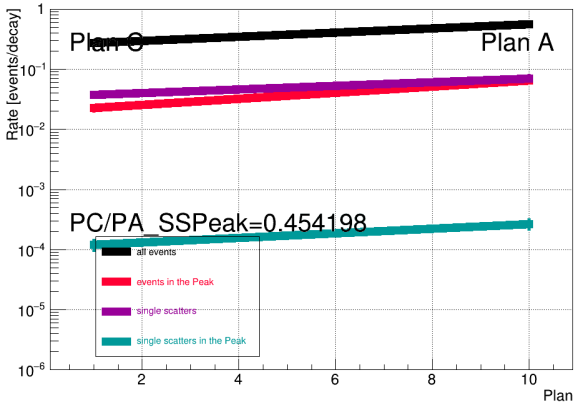
Na 22 511 & 1274 keV

Side



Co60 1173 & 1332 keV

Side



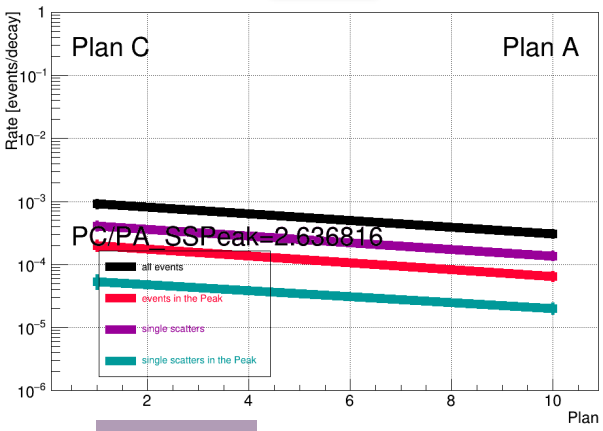
Rates : PlanA vs PlanC

Bottom

Am 241 — 59.5 keV

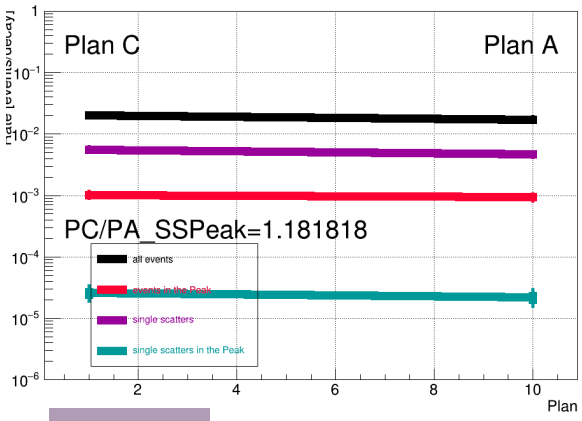
Too few events

Co 57 — 122 keV

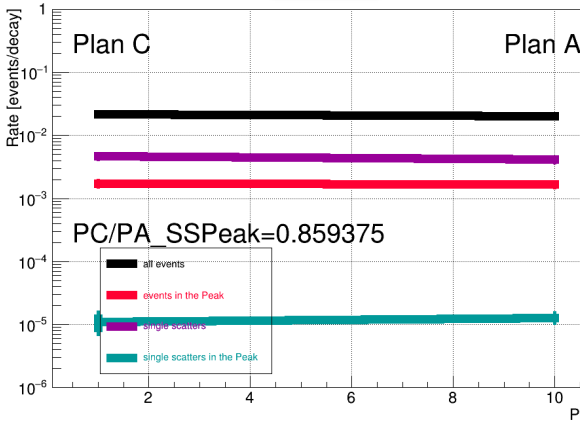


Ba 133 — 356 keV

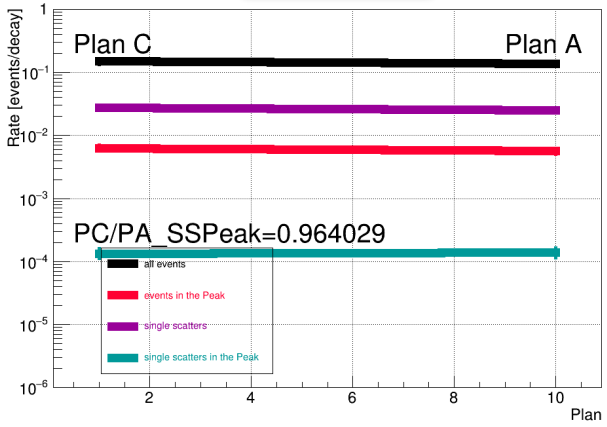
Bottom



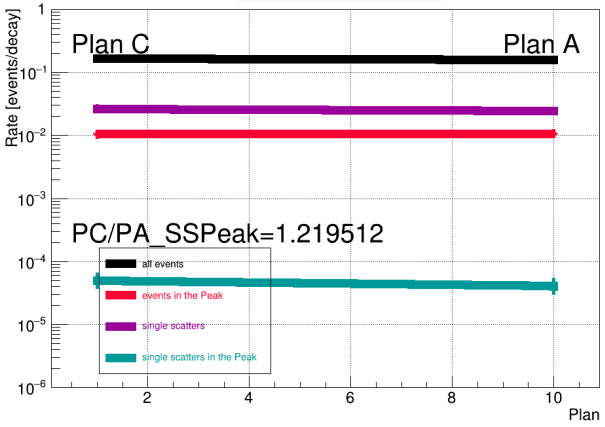
Cs 137 — 662 keV



Na 22 — 511 & 1274 keV



Co60 — 1173 & 1332 keV



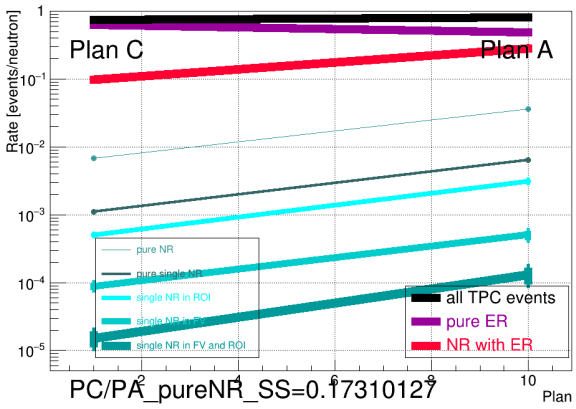
Rates : PlanA vs PlanC

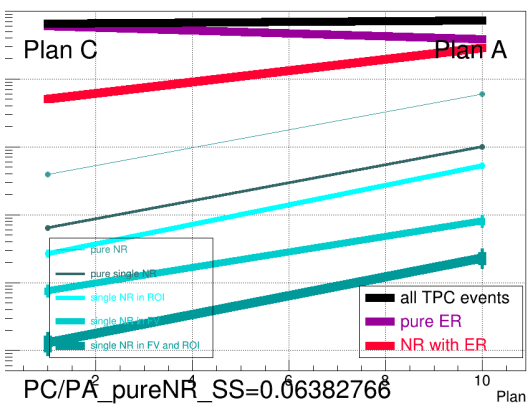
AmBe $E_0 \in [0.2,12] MeV$

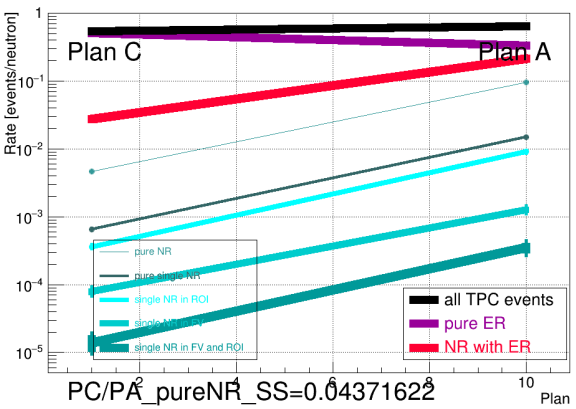
AmC $E_0 \in [2,7] MeV$

DD gun $E_0 = 2.45 MeV$

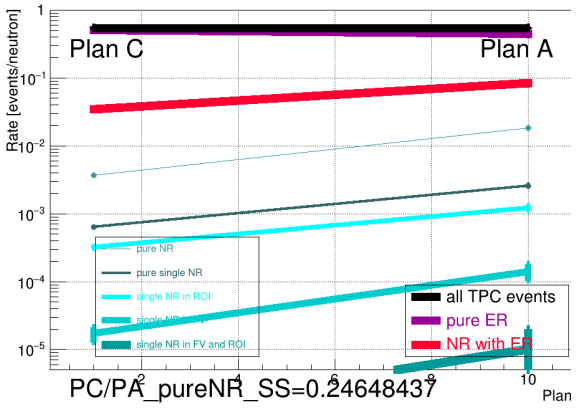
Side

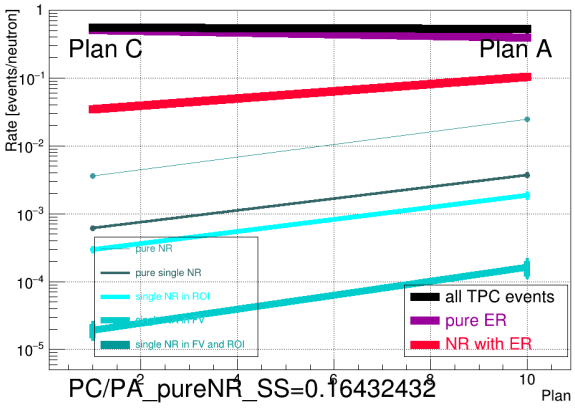


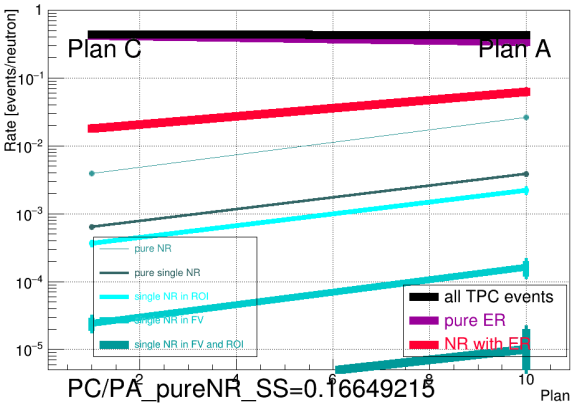




Bottom







Investigations

- **Neutrons at different energies**
  - **Idea** = trying to see the influence of the initial energy of the neutron on the rate of pure NR SS

(events /decay)	Plan A	Plan C	Plan C / Plan A
Neutron 1 MeV	1.2×10^{-2}	9×10^{-5}	7.5×10^{-3}
DD gun 2.45 MeV	1.5×10^{-2}	6.5×10^{-4}	4.3×10^{-2}
Neutron 5 MeV	1.0×10^{-2}	8.8×10^{-4}	8.8×10^{-2}
AmC ($E_0 \approx 5MeV$)	1.0×10^{-2}	6.4×10^{-4}	6×10^{-2}
Neutron 10 MeV	5.8×10^{-3}	1.0×10^{-3}	0.17
AmBe ($E_{0_{0G}} \approx 10MeV$)	6.3×10^{-3}	1.1×10^{-3}	0.17

Almost consistent

Consistent

- **Test** if the 20 cm of LAr separating the tube and the wall of the TPC at z = -150cm affects our previous result

(events /decay)	PlanC (z = -150)	PlanC (z = - 150 cm x,y + 20cm)
DD gun 2.45 MeV	1.2×10^{-3}	1.1×10^{-3}

Tiny impact

- **Test** if imposing 0 gamma gives a better result for AmBe on the side of the TPC

(events /decay)	Source all Plan C	0G Plan C	Source all Plan A	0G Plan A
AmBe	1.1×10^{-3}	1.4×10^{-3}	6.3×10^{-3}	7.0×10^{-3}

Investigations

- **AmBe** test if disabling gamma gives a better result for AmBe on the side of the TPC

(events /decay)	Source all Plan A	Disabling Plan A	Source all Plan C	Disabling Plan C
AmBe	6.3×10^{-3}	1×10^{-2}	1.1×10^{-3}	1.4×10^{-3}

- **AmBe vs neutrons at 10MeV** test about the window

(events /decay)	Plan C without	Plan C with
AmBe	6.6×10^{-4}	8.9×10^{-4}
Neutron 10 MeV	1.0×10^{-3}	1.4×10^{-3}

Time estimation : activity of the sources

Plan C

Pure NR SS

Single scatters in the peak

	241Am	57Co	133Ba	22Na	137Cs	60Co	DD gun	AmBe	AmC
Activity (side) kBq		18.15	1.9	0.36	2.24	0.37	0.19	0.14	0.15
Activity (bottom) kBq		100	4.95	0.67	4.61	0.6	0.23	0.18	0.18
Time (h)	!	8	166	226	268	663	165	153	232

Energy increases

Assuming we do not have any online trigger system (to detect SS in the peak/pure NR SS)

	241Am	57Co	133Ba	22Na	137Cs	60Co	DD gun	AmBe	AmC
Activity (side) kBq		100	100	100	100	100	21.7	14.8	25.6
Activity (bottom) kBq	100	100	100	100	100	100	26	27	28
Temps (h)	!	6	9	5	11	7	4	4	4

With online trigger (detecting SS in the peak/pure NR SS)

Materials

- Radioactive contamination (mBq/kg), as measured by DarkSide material WG

https://docs.google.com/spreadsheets/d/1ApsqO_sK92faNfSgIIBCDc9YR61MY6gGXnmdRxmuk3g/edit#gid=1436335937

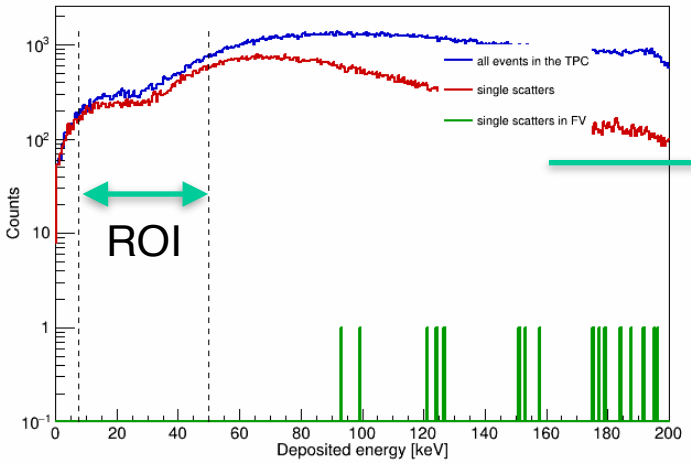
mBq/kg	^{232}Th	^{238}U	^{60}Co	^{40}K	^{137}Cs
SS	10	10			
SS ArDM	20	50	13	6.4	1.5
SS Proto structure	1.9	3.9	13	6.4	1.5
SS Proto cryostat	1.0	1.4	0.6	1.2	0.09
SS DS50	0.8	0.4	13	2.5	0.29
MSS0364 DUNE	3.9	49	11	15	0.8

Background induced by the tubes

- **ER (with resolution)**

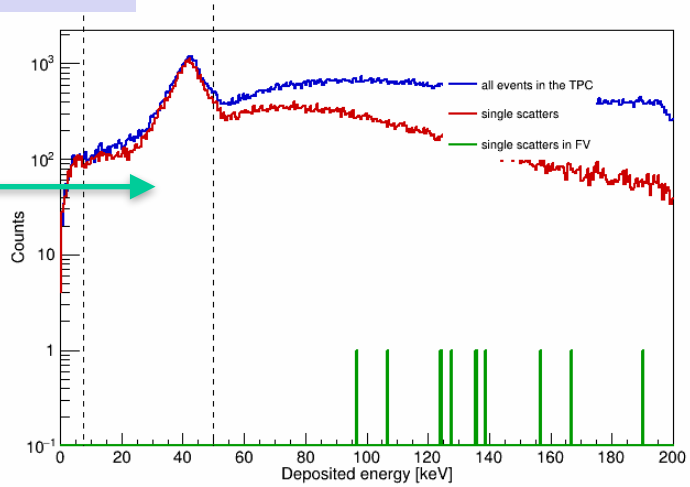
Plan A

^{137}Cs



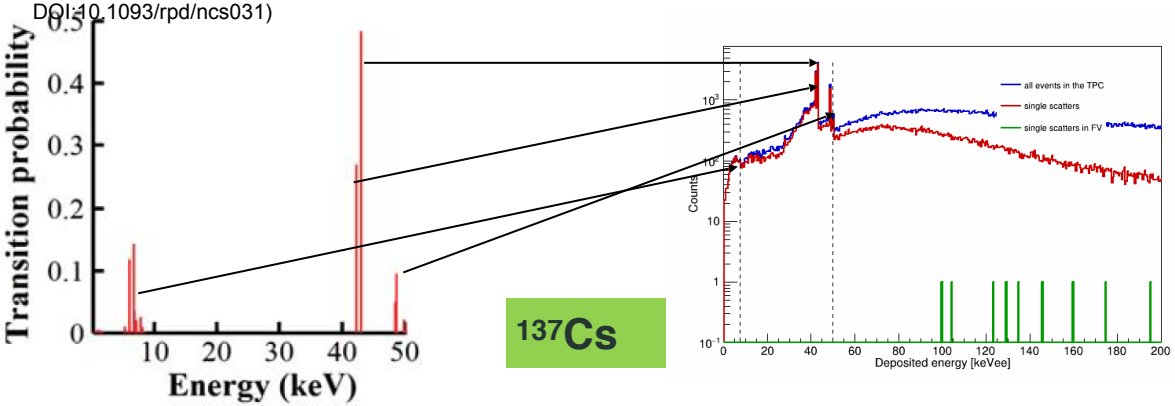
10 to 70% more events in plan C than in Plan A

Plan C



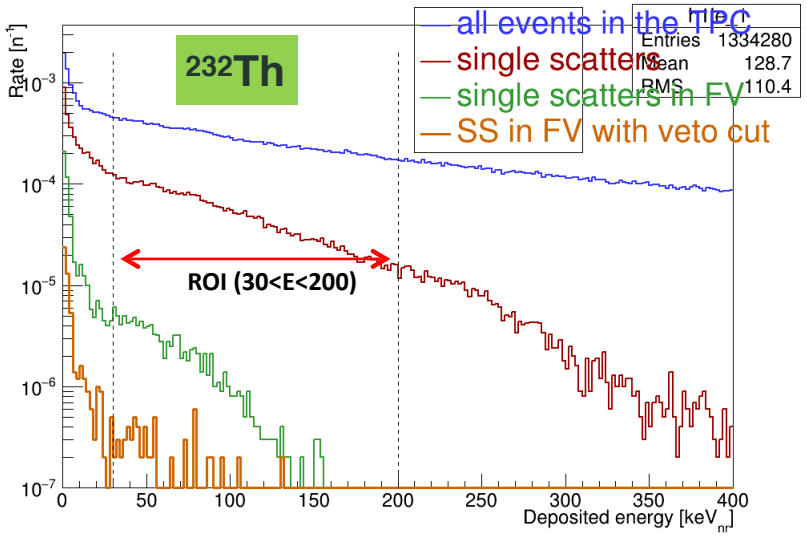
But none survives the ROI + FV cut

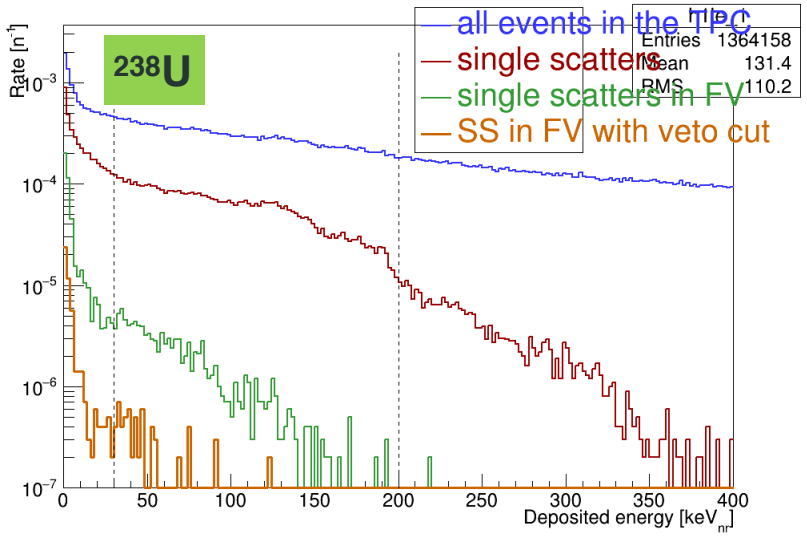
X-rays emited during atomic relaxation of excited Gd atom (Gamma-ray rejection, or detection, with gadolinium as a converter, P. Kandlakunta, DOI:10.1093/rpd/ncs031)



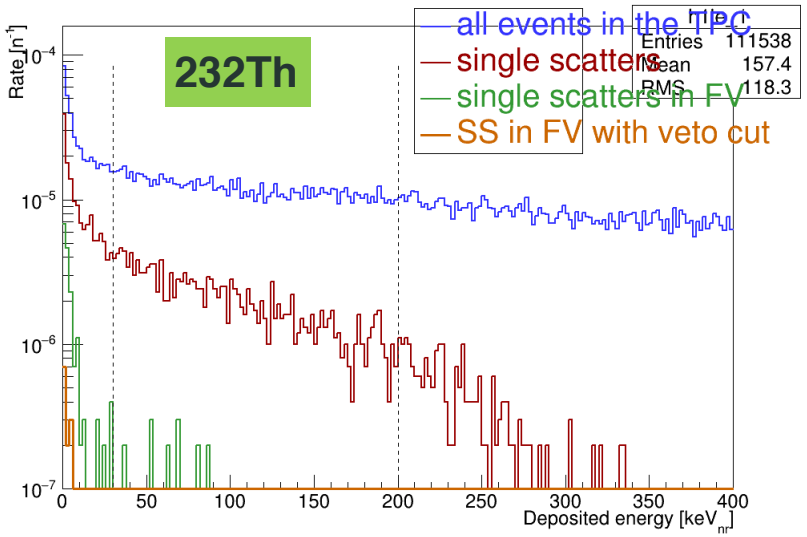
NR background

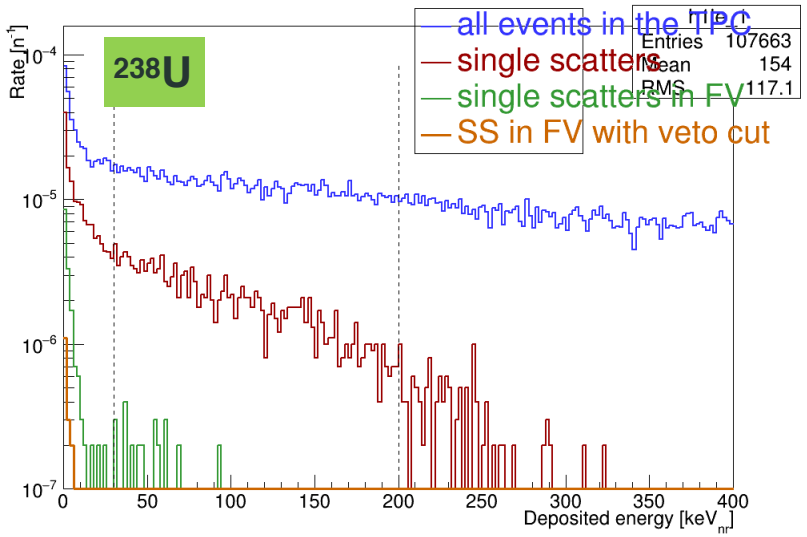
Plan A





Plan C





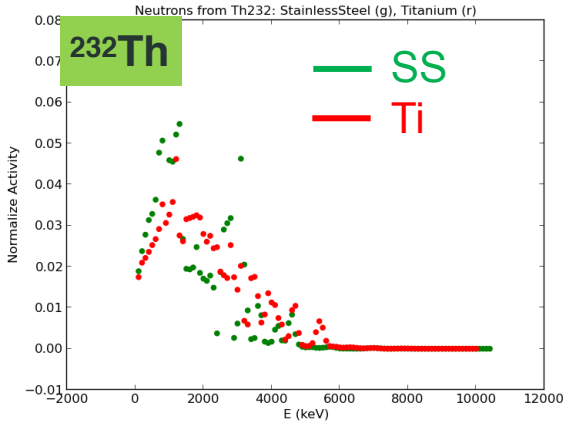
NR background Ti (1/2)

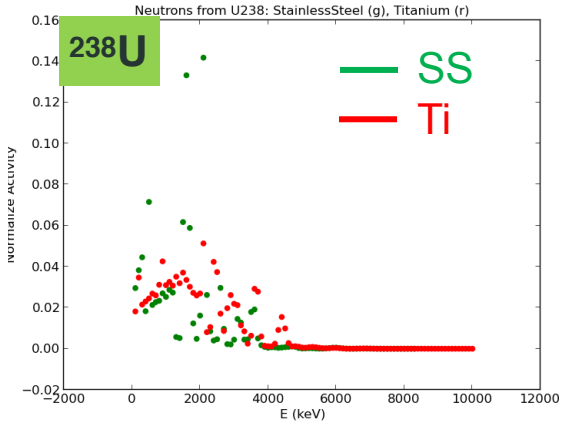
- **Titanium** possibility for plan C to have tube in Titanium. 4 changes:
  - Density → tube mass

	Density (g/cm3)	Tube mass (kg)
SS	7.7	30
Ti	4.5	17

  - Neutron spectra

(G4DS data library)





  - Number of neutrons / decay

n/decay	^{232}Th	^{238}U
SS	1.8E-6	4.8E-7
Ti	7.0E-6	2.8E-6

  - Radioactive contamination (mBq/kg)

mBq/kg	^{232}Th	^{238}U
SS ArDM	20	50
Ti	0.12	8

https://docs.google.com/spreadsheets/d/1ApsqO_sK92faNfSgIIBCDc9YR61MY6gGXnmdRxmuk3g/edit#gid=1436335937

NR background Ti (2/2)

- **Titanium** possibility for plan C to have tube in Titanium. Results:

	Plan C SS ArDM			Plan C Ti		
	n/year	Surviving events (/ 10^7)	NR bknd / 10 years (200 t.y)	n/year	Surviving events (/ 10^7)	NR bknd / 10 years (200 t.y)
^{232}Th	34.1	4	0.0001	0.45	5	<<0.0001
^{238}U	22.7	4	0.0001	12.1	7	0.0001

- For Ti tubes, even more negligible contribution wrt foreseen budget of 0.1 events after 10 years (200 t.y)