

# Study of radon background in SuperNEMO

02/06/2026 IRN, IJCLAB

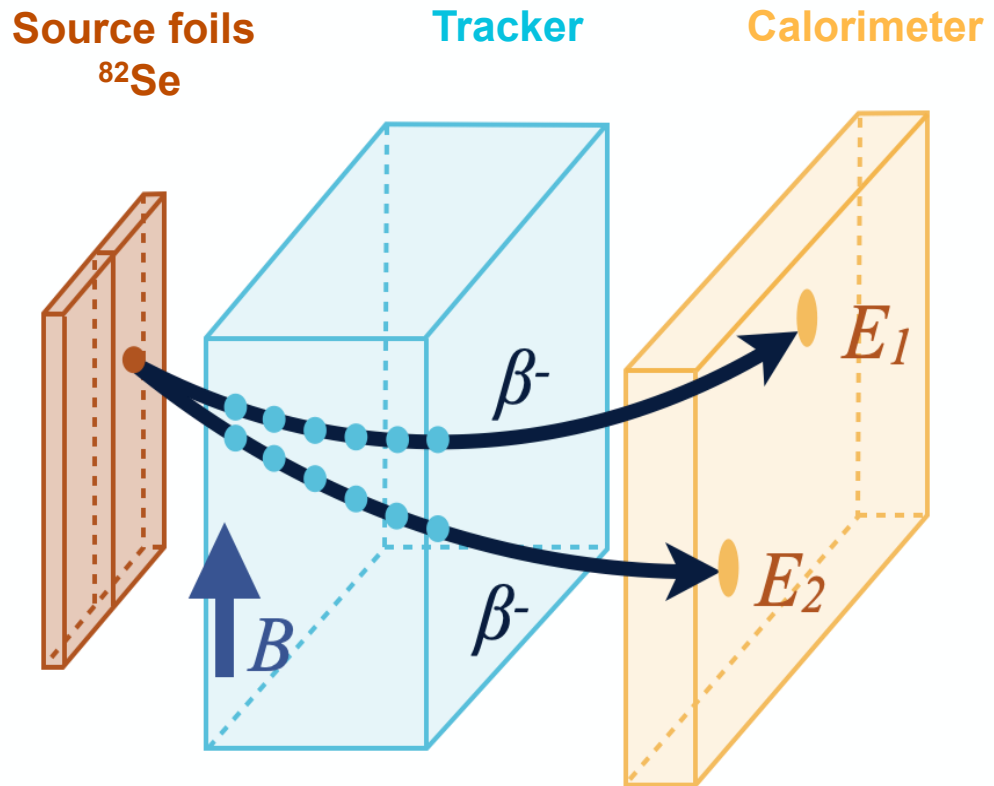
Antoine Lahaie, LP2IB



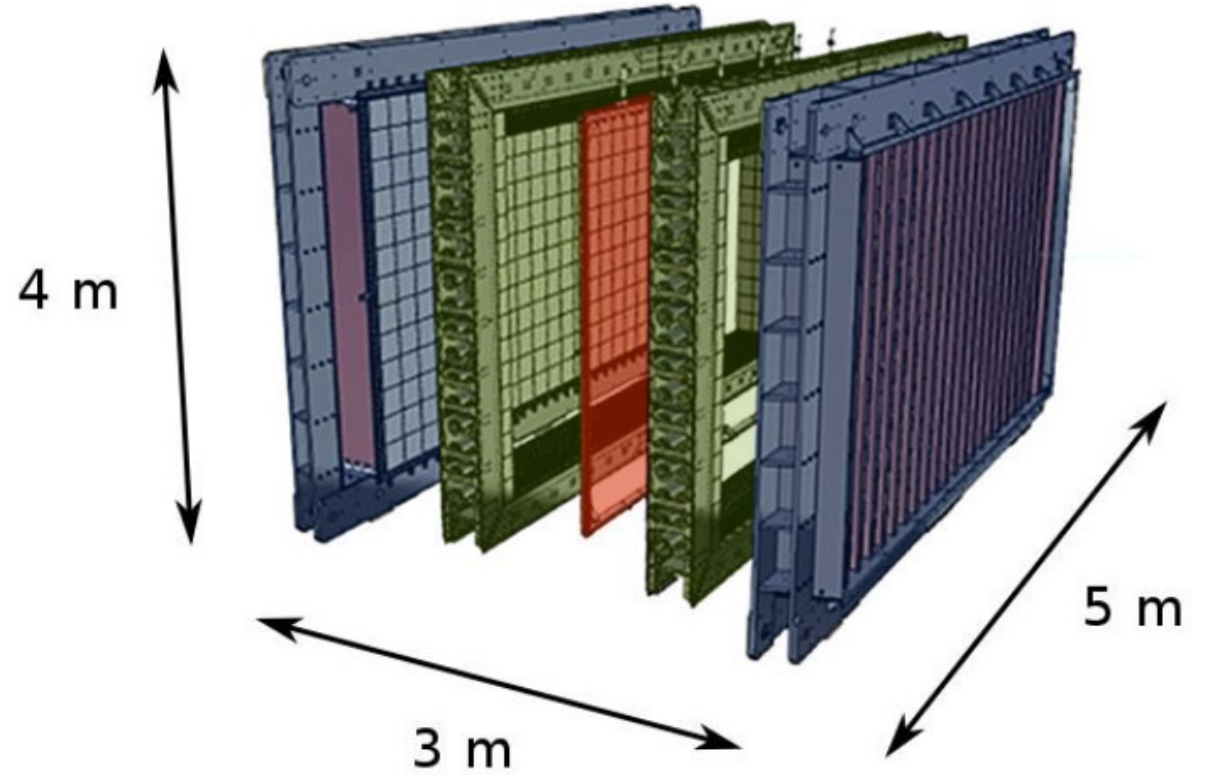
# SuperNEMO experiment

Demonstrator of unique technology for  $\beta\beta 0\nu$  reaserch

Tracker-calorimetry technology



SuperNEMO demonstrator



# Source foils $^{82}\text{Se}$

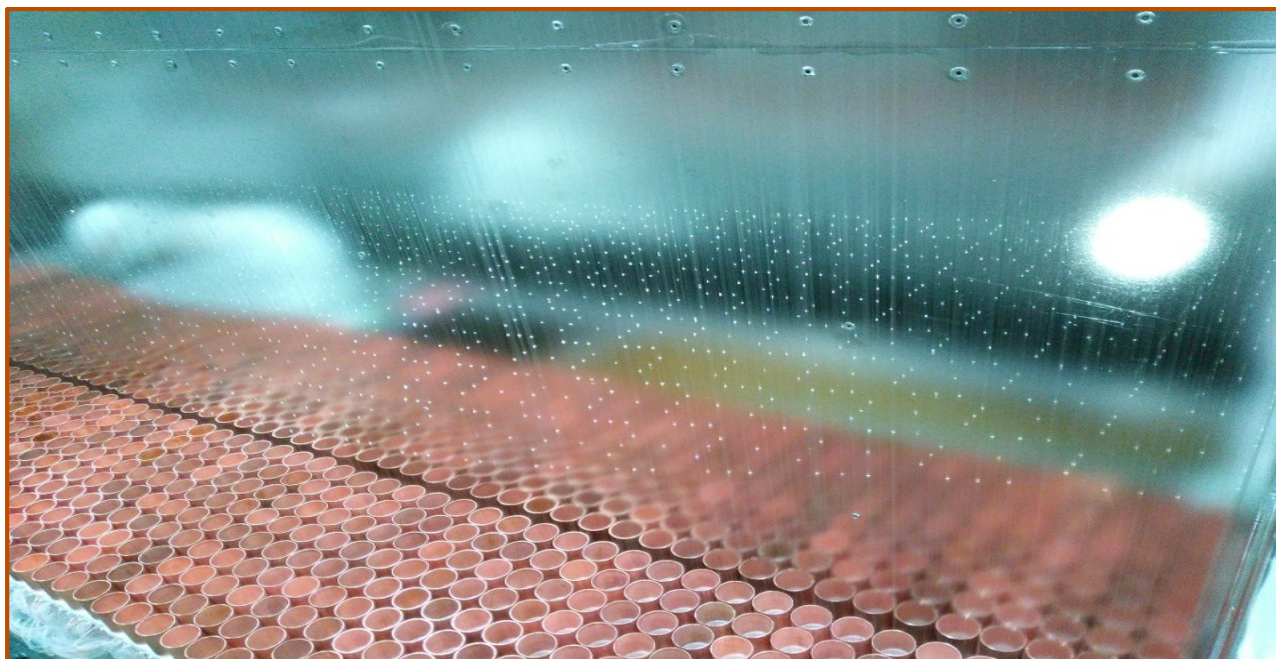
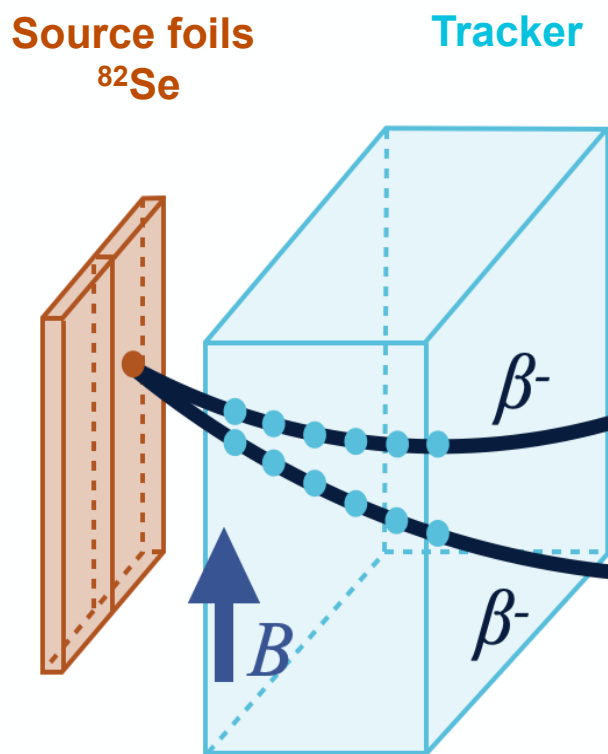
- 34 foils of  $^{82}\text{Se}$   $\sim 300 \mu\text{m}$  thick (6.11kg of  $^{82}\text{Se}$ )
- High energy decay  $Q_{\beta\beta} = 2.998 \text{ MeV}$
- $T_{1/2}^{2\nu\beta\beta} = 8.69 \cdot 10^{19} \text{ years [1]}$

Source foil  
 $^{82}\text{Se}$



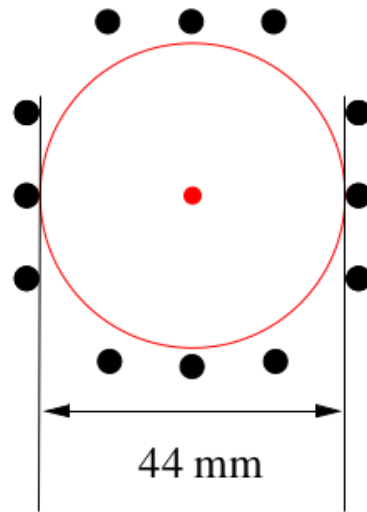
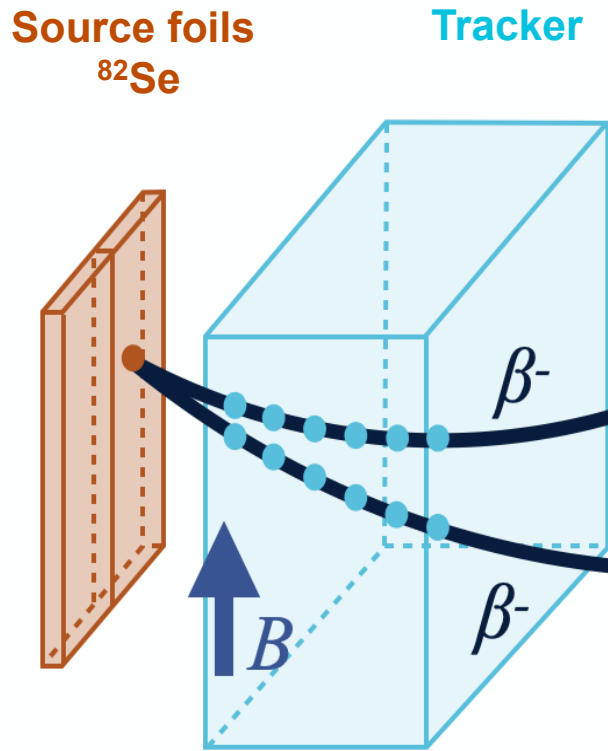
[1] CUPID-0, *Phys. Rev. Lett.* 131, (2023) 222501

Tracker : aims to reconstruct charged particle trajectory

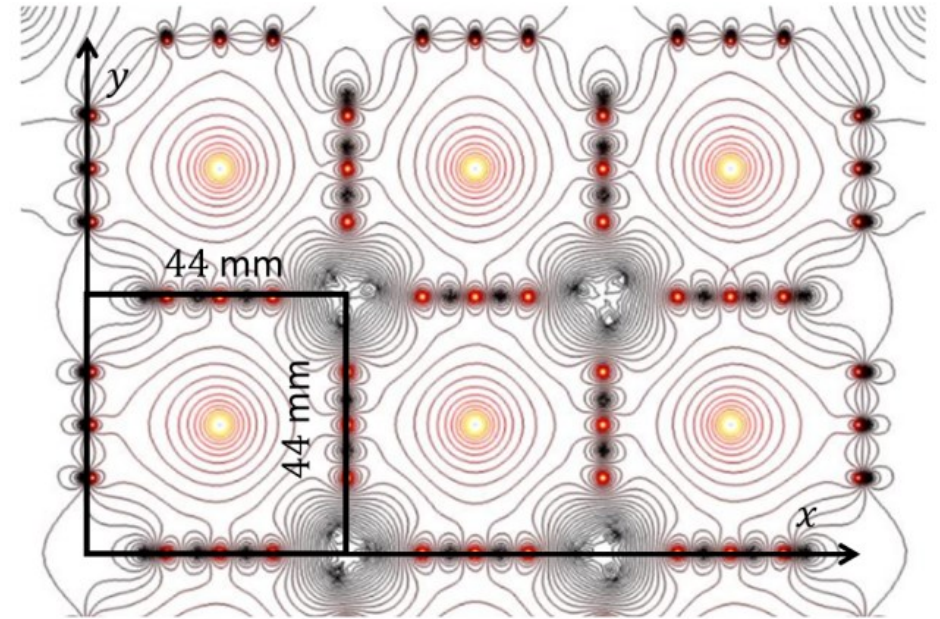


- 2034 Geiger cells (97.2 % working)
- Tracker gas : He (95%) + Ethanol (4%) + Ar (1%)

Tracker : aims to reconstruct charged particle trajectory

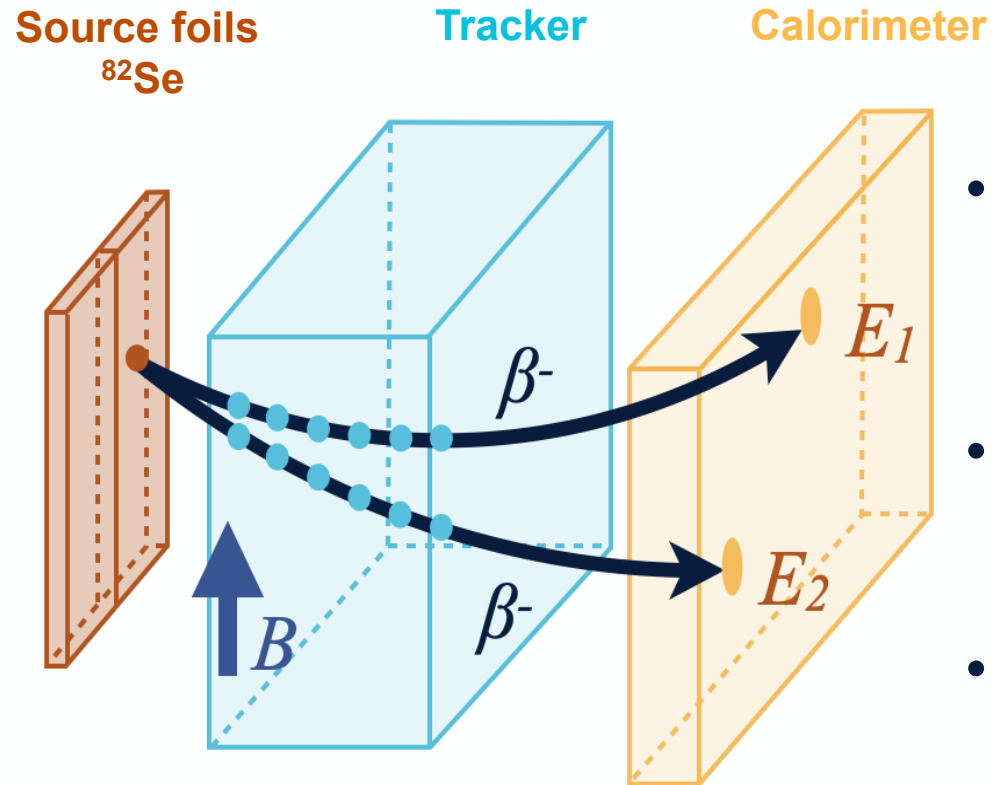


Sketch of a Geiger cell



Electric field of Geiger cells

## Measurements of individual electron energy & Time Of Flight (TOF)

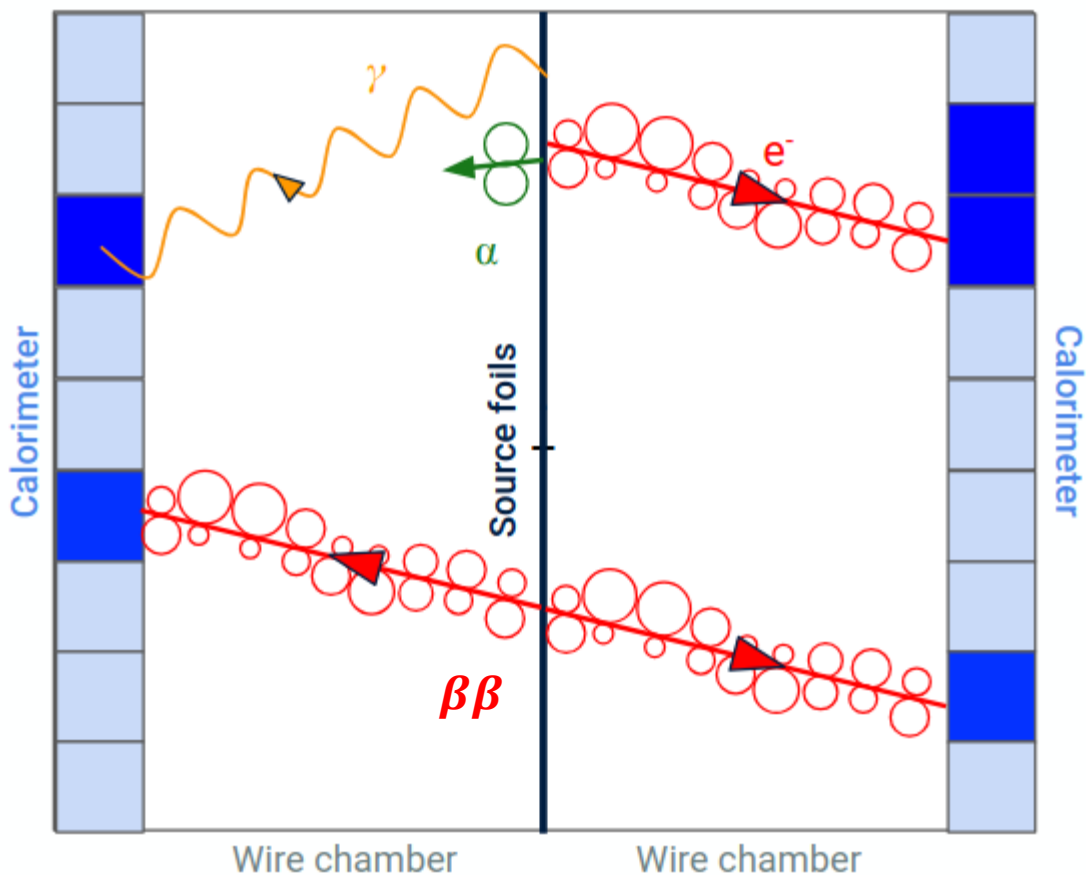


- 712 Optical Module (OM)  
Scintillator + photomultiplier 8'' or 5''  
FWHM  $\sim 12\%$  ( $e^-$  @ 1 MeV)
- Good time resolution  
 $\sigma \sim 250$  ps ( $e^-$  @ 1 MeV)
- 97.4 % OMs working



Module optique 8''

# Event topology reconstruction

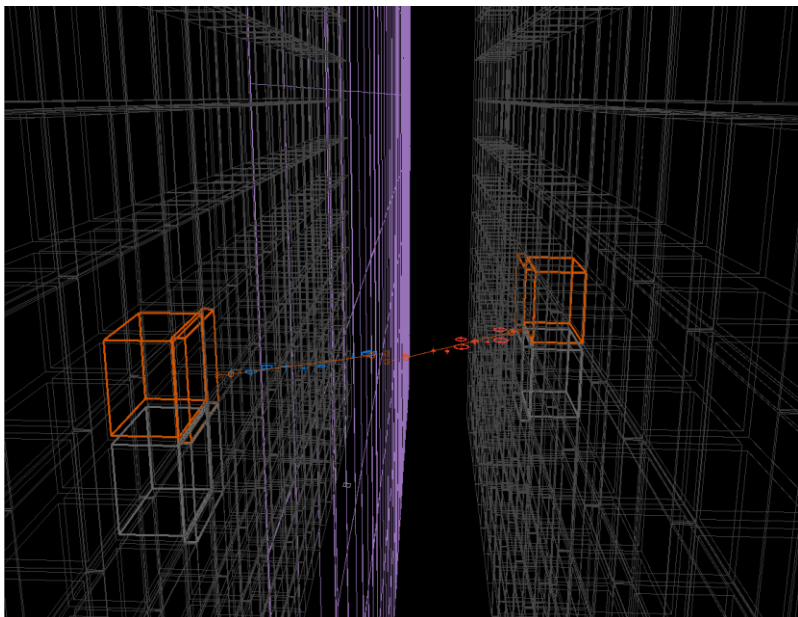


- Full reconstruction of  $\beta\beta$  event topology
- Research for physics mechanisms of  $\beta\beta 0\nu$
- **Electron** : Track with associated OM
- **Alpha** : Short track without associated OM
- **Gamma** : OM without associated track

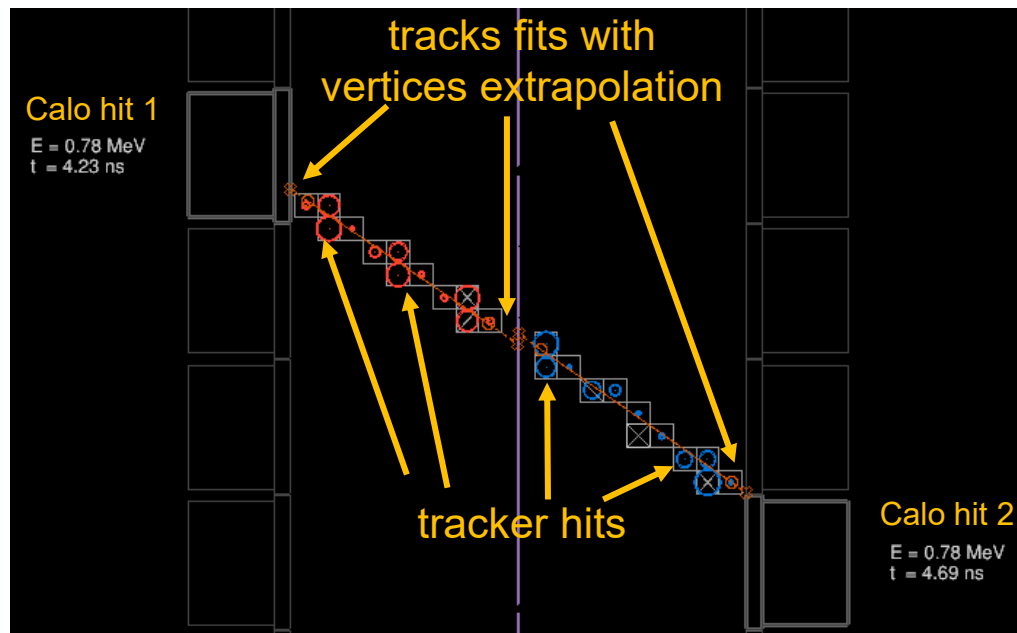
## Start of data Taking : 10 April 2025

At Laboratoire Souterrain de Modane (LSM)

First event with 2 electrons : first  $\beta\beta$  candidate !



Side view

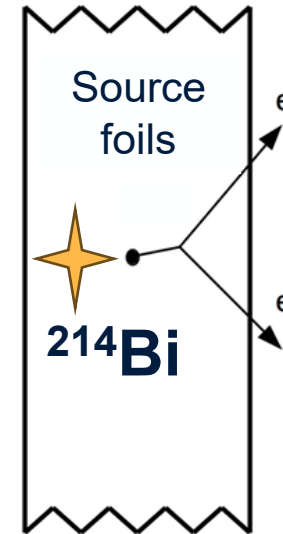
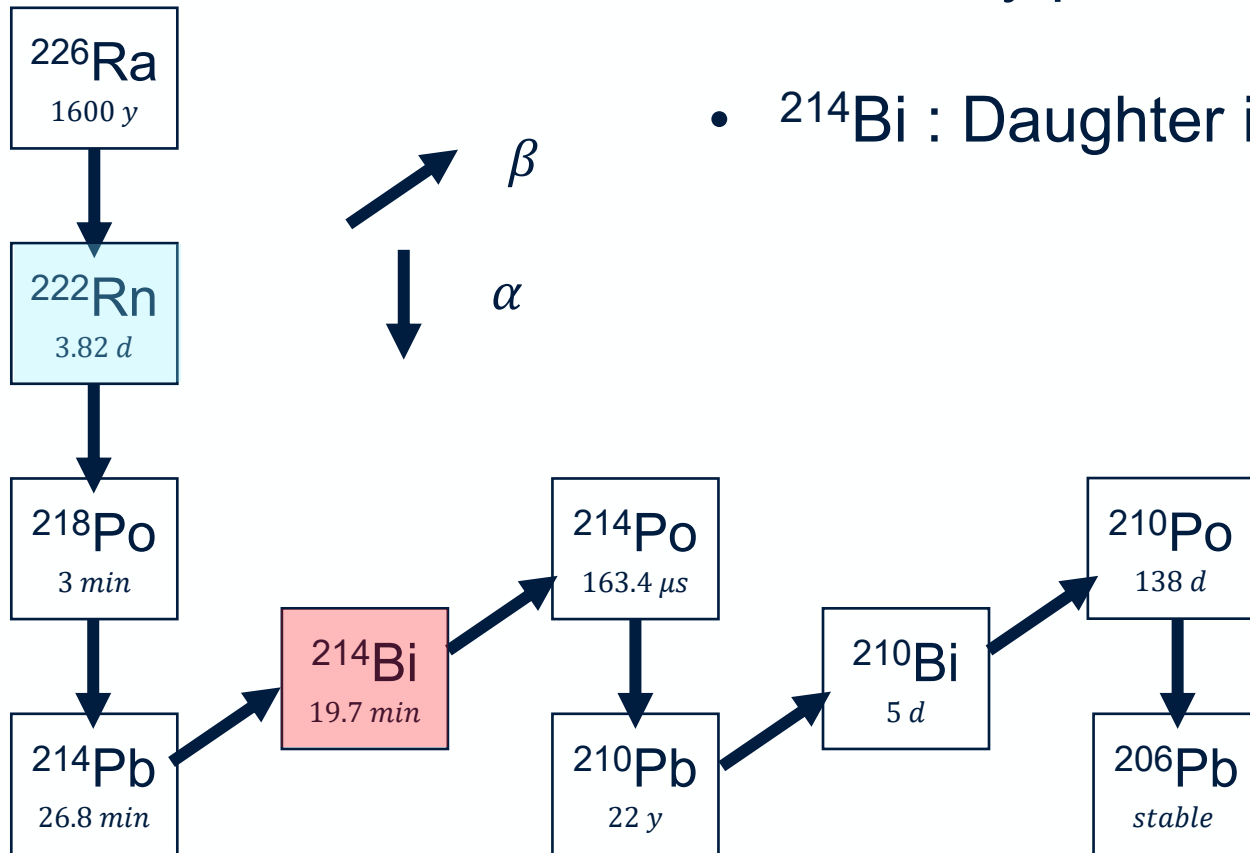


Top view

328.93 days of data

# Radon as background : $\beta\beta 2\nu$ & $\beta\beta 0\nu$

- Naturally present in environment ( $^{238}\text{U}$  chain decay)
- $^{214}\text{Bi}$  : Daughter isotope of Rn  $\rightarrow Q_{\beta^-} = 3.269 \text{ MeV}$



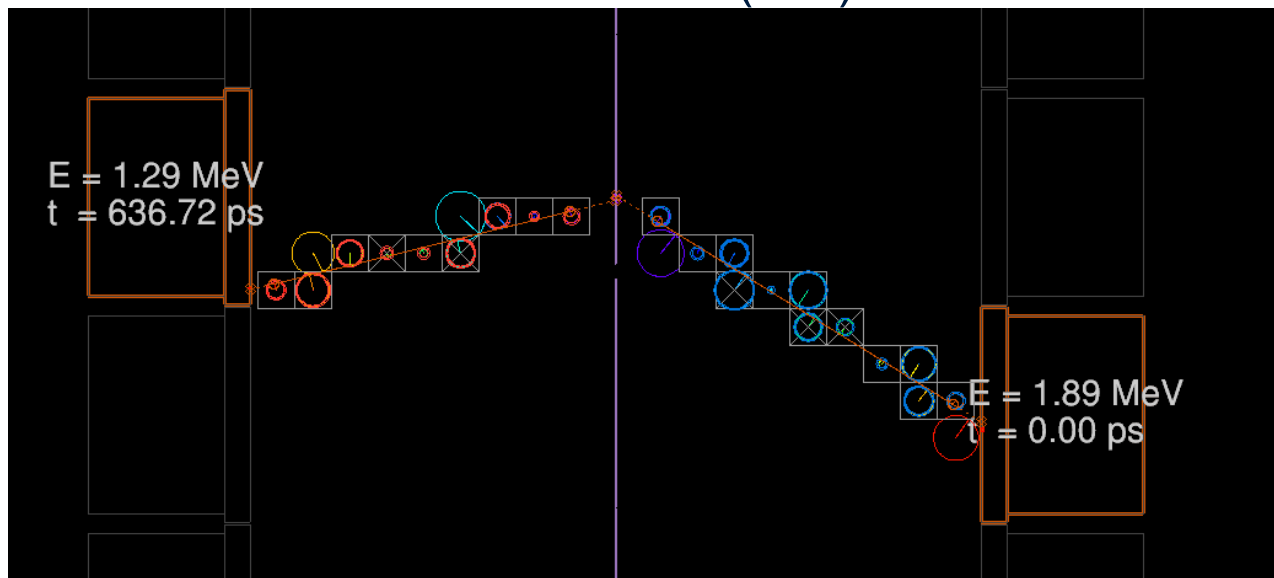
$\beta$  particle emitted from  $^{214}\text{Bi}$  in or on source foils can create 2 electrons and mimic  $\beta\beta 0\nu$  event

$\beta$  decay  
&  
Moller scattering

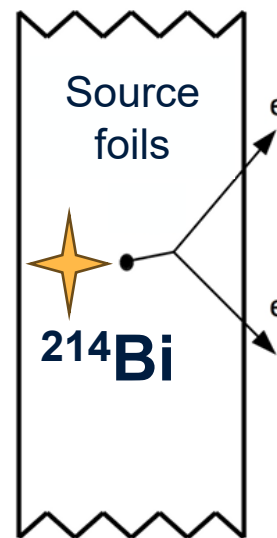
# Radon as background : $\beta\beta 2\nu$ & $\beta\beta 0\nu$

- Naturally present in environment ( $^{238}\text{U}$  chain decay)
- $^{214}\text{Bi}$  : Daughter isotope of Rn  $\rightarrow Q_{\beta^-} = 3.269 \text{ MeV}$

Top view of 2 electrons produced by  $^{214}\text{Bi}$  decay from source foil bulk (MC)



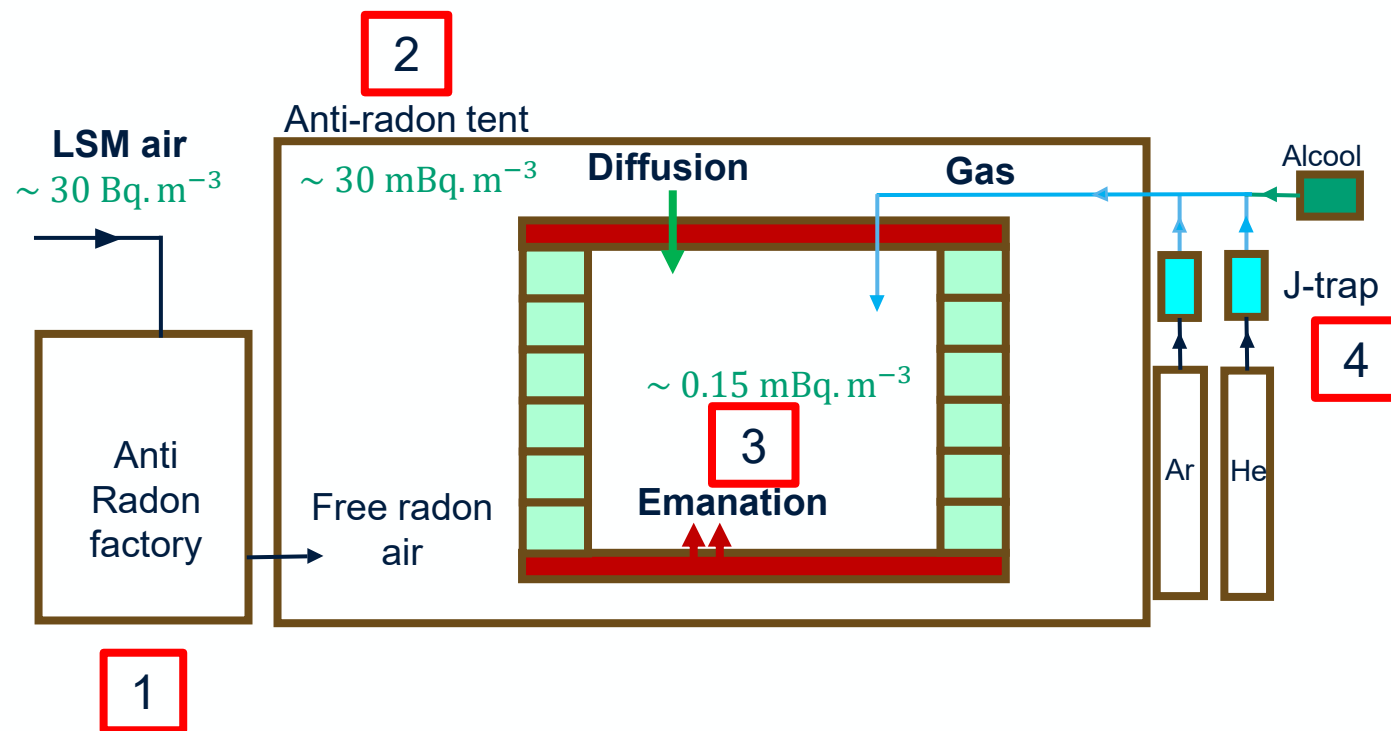
$$\sum_i E_i > 3 \text{ MeV}$$



$\beta$  particle emitted from  $^{214}\text{Bi}$  in or on source foils can create 2 electrons and mimic  $\beta\beta 0\nu$  event

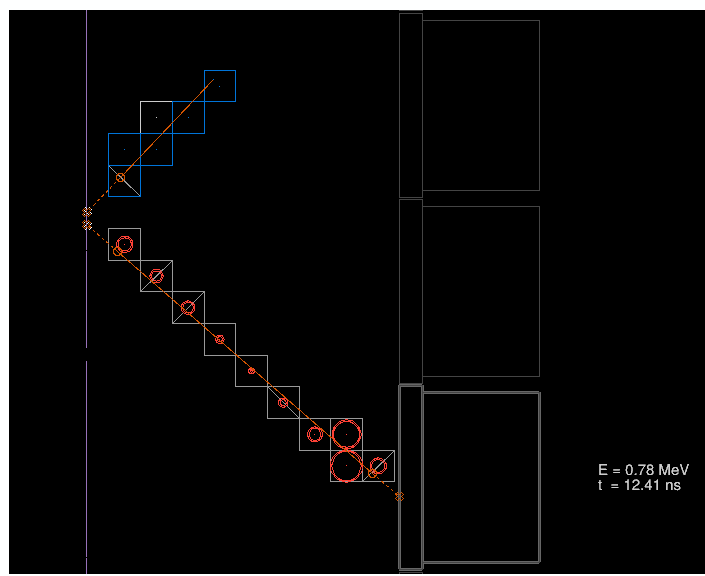
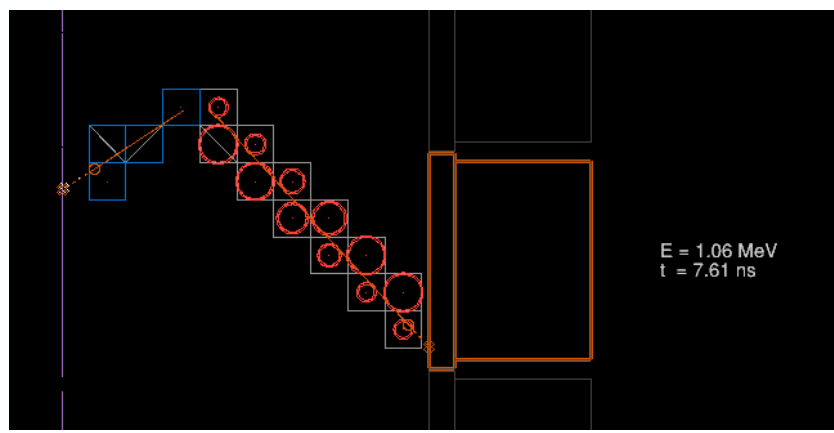
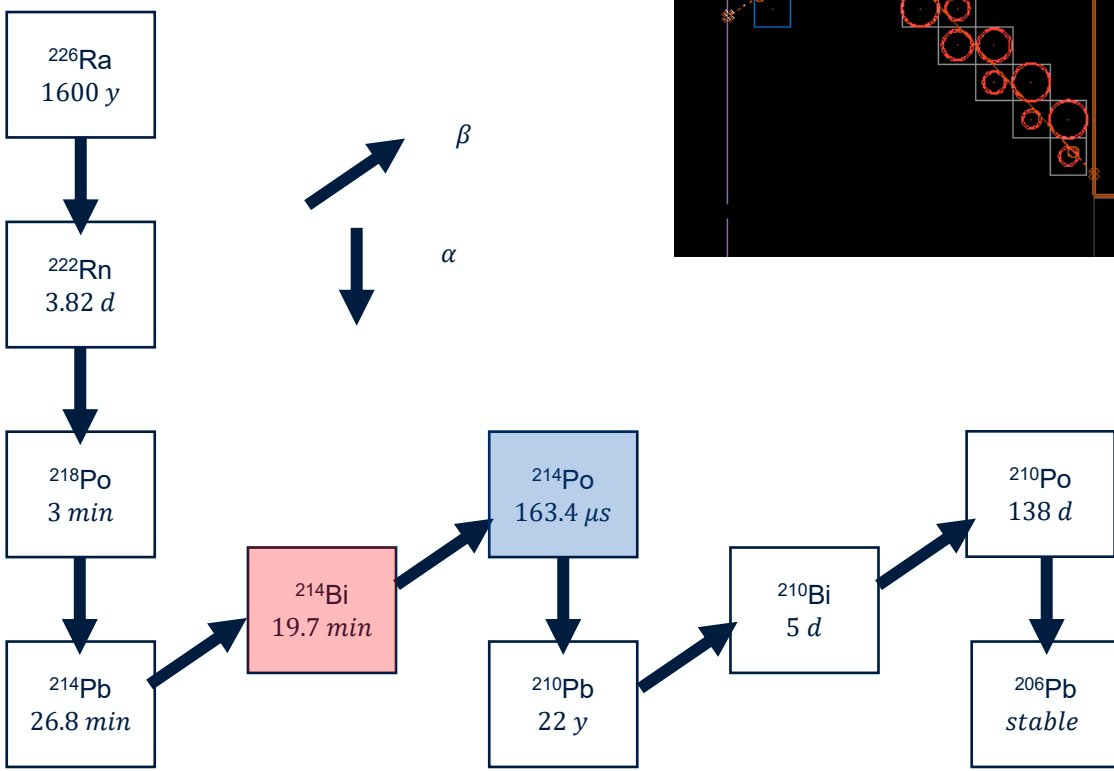
$\beta$  decay  
&  
Moller scattering

# Anti radon strategy



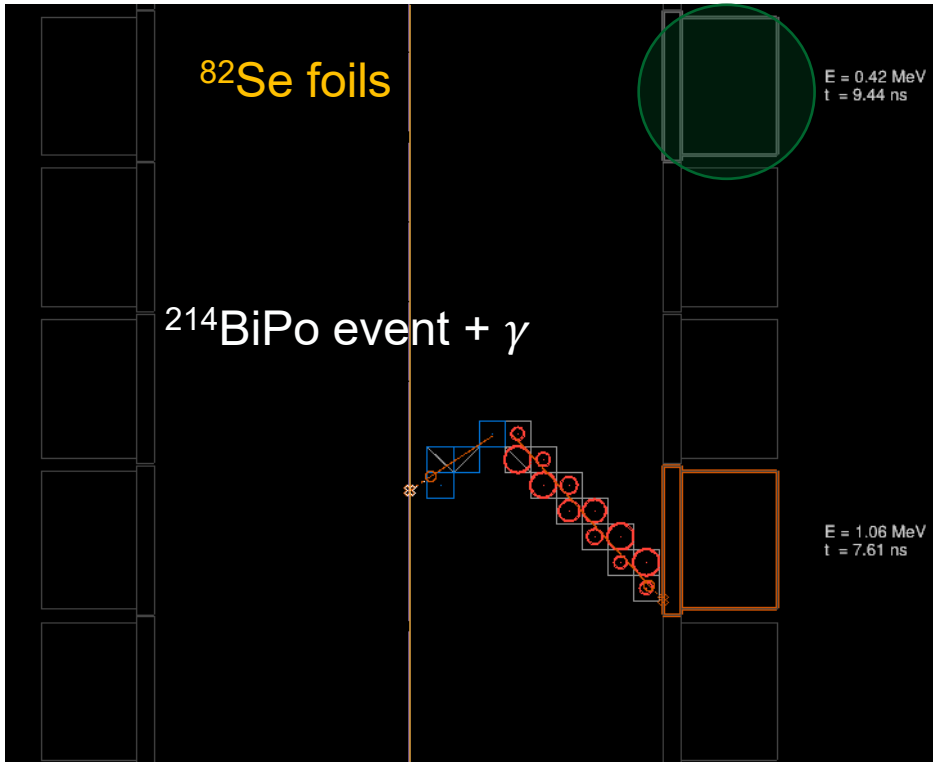
- **Diffusion** of Rn from the laboratory towards the tracker → 1 2
- **Rn emanation in the tracker:**  
→ Material screening 3
- **Rn contamination of gas** → 4

# BiPo selection



- Searching for **1 electron** and **1 delayed alpha** from source foils or Tracker

## BiPo event

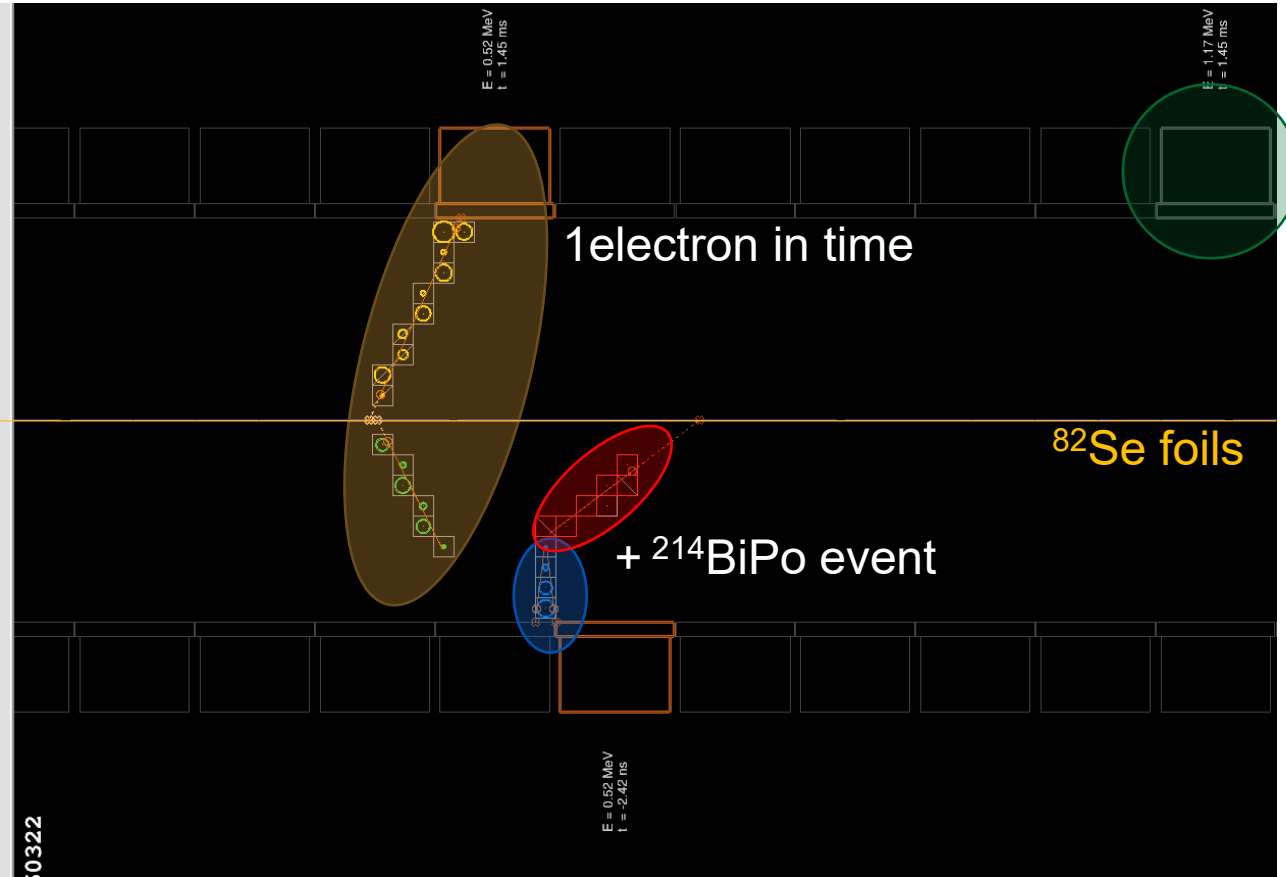


Top view

- 1  $e^-$  in the tracker
- 1 short track (alpha)
- 1 gamma in time with  $e^-$

# BiPo selection

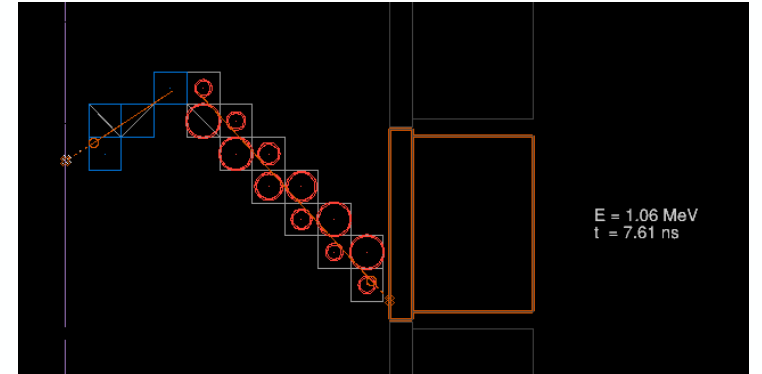
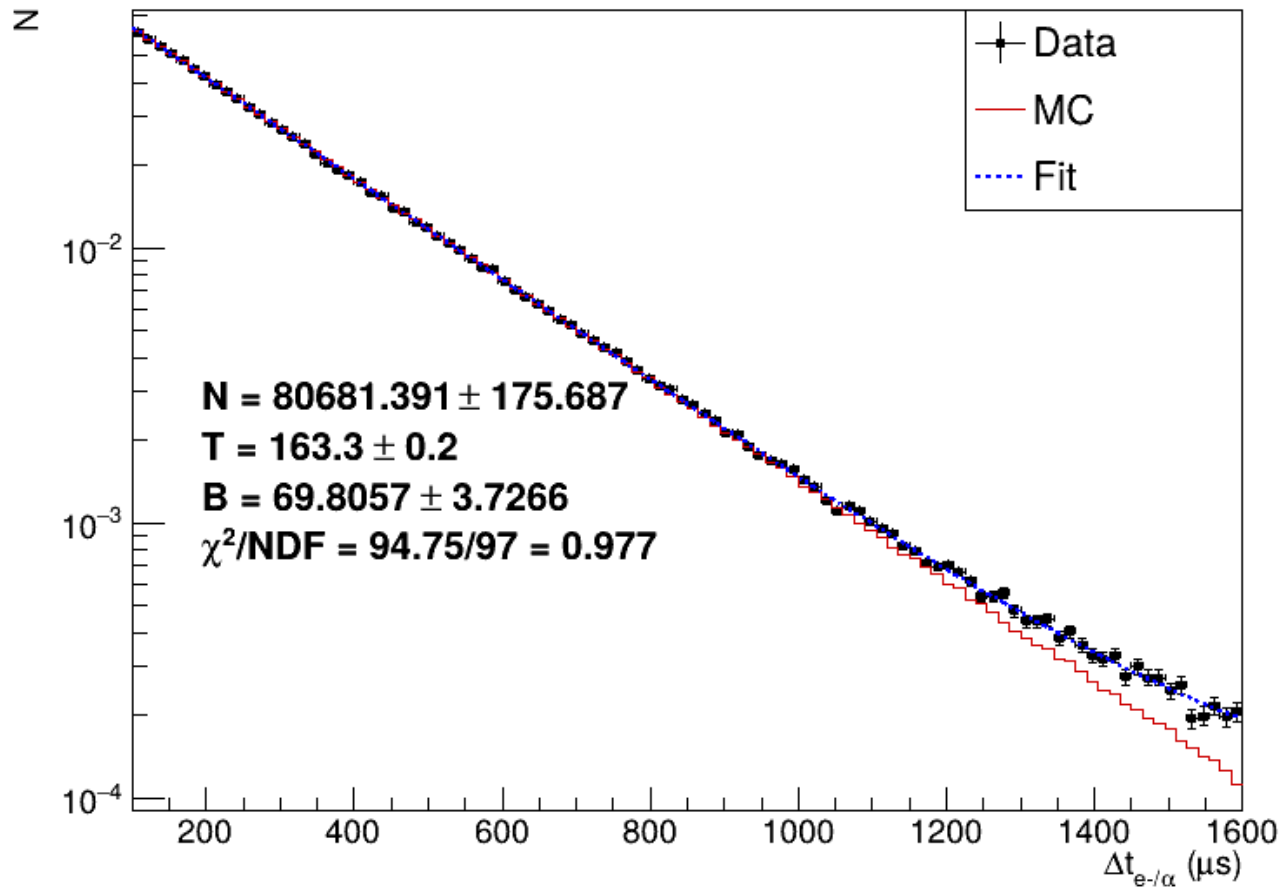
## BiPo event + random particles



- 1  $e^-$  crossing the source foils
- 1  $e^-$  in the tracker
- 1 short track (alpha)
- 1 gamma

# $\Delta t_{e/\alpha}$ time delay between $e^-$ & $\alpha$

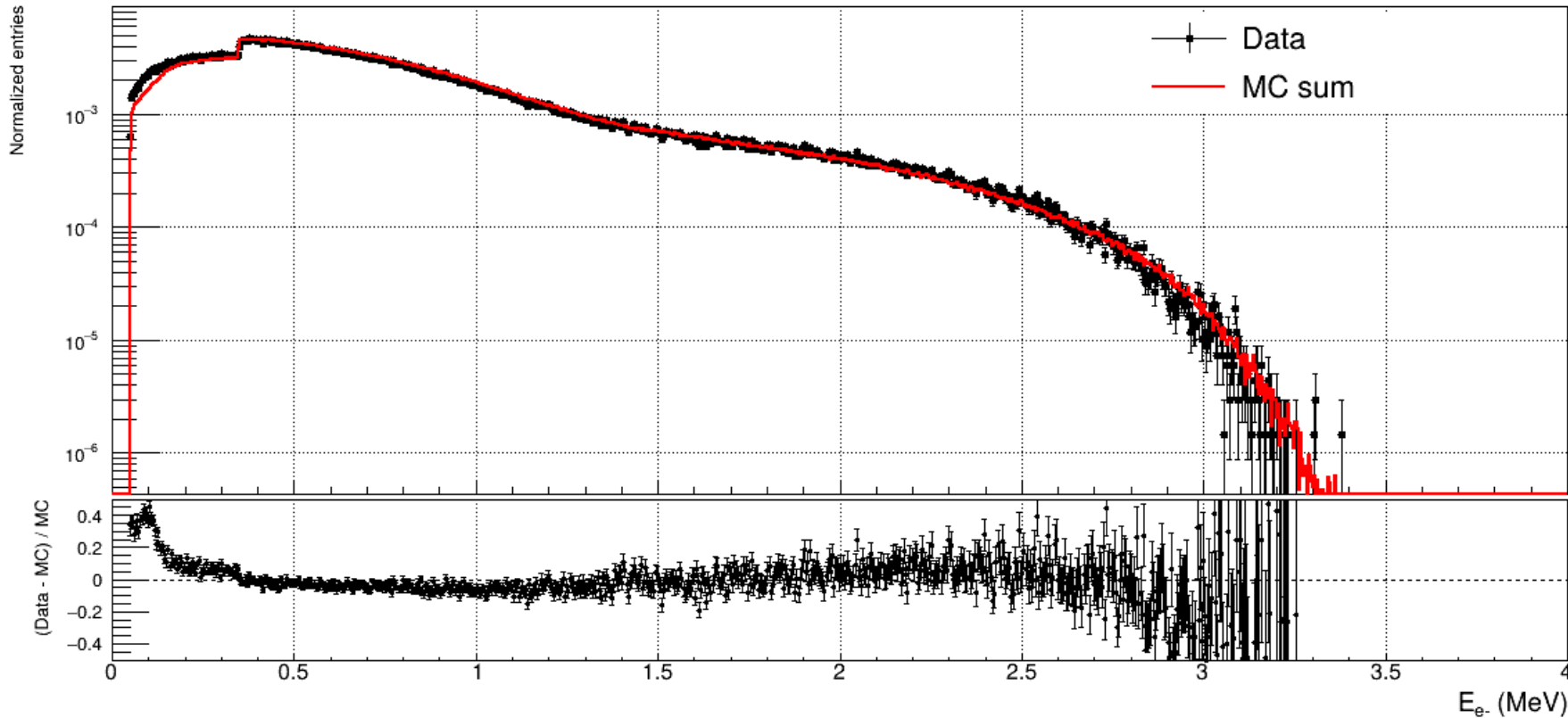
Time delay between  $e^-$  from  $^{214}\text{Bi}$  &  $\alpha$  from  $^{214}\text{Po}$



- Half file of  $^{214}\text{Po}$ :  **$163.3 \pm 0.2 \mu\text{s}$**   
fully consistent ( $163.4 \mu\text{s}$  expected [2])
- ➔ Good channel analysis to measure radon activity

# Electron energy spectra from $^{214}\text{Bi}$

## $^{214}\text{Bi}$ electron energy spectra

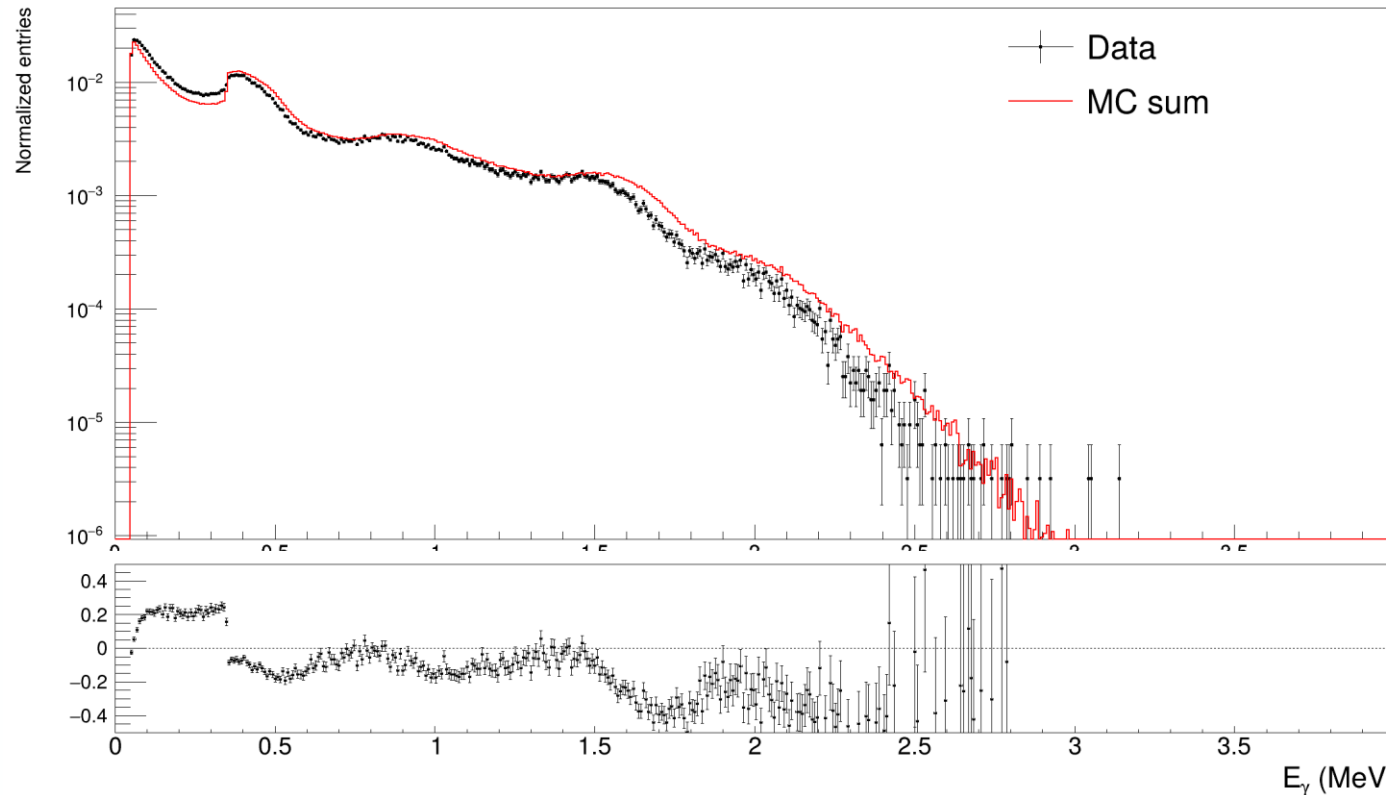


154.97 days

- Preliminary energy calibration (only weekly  $^{207}\text{Bi}$  data; daily LED calibrations not used)
- Good agreement between data & MC

## $^{214}\text{Bi}$ gamma energy spectra

Energy spectra

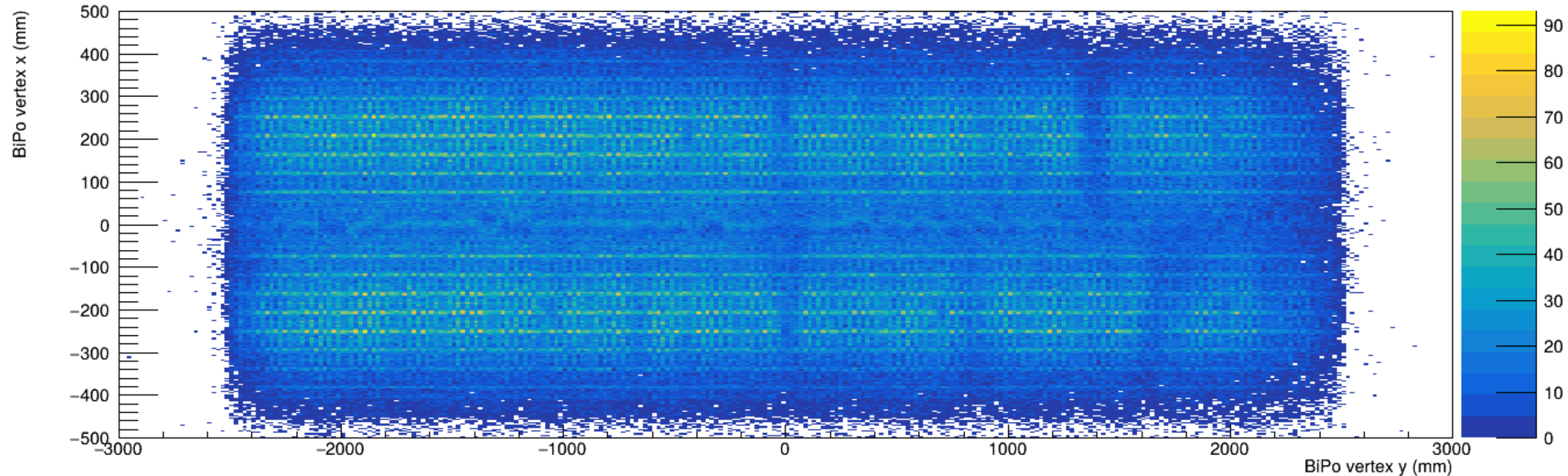


154.97 days

- Preliminary energy calibration (only weekly  $^{207}\text{Bi}$  data; daily LED calibrations not used)
- Bad agreement between data & MC → electron calibration used !

# BiPo vertex distribution in SuperNEMO

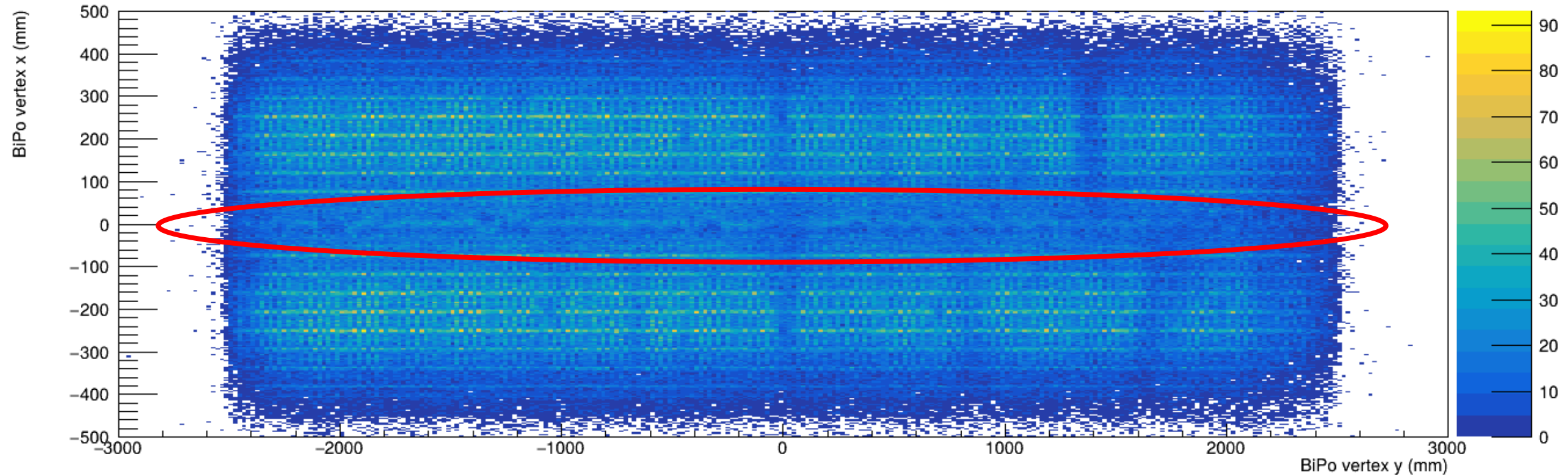
Top View of BiPo vertex (Data)



**Small left-right asymmetric distribution**  
probably due to asymmetric helium flushing inside the tracker

# BiPo vertex distribution in SuperNEMO

Top View of BiPo vertex (Data)

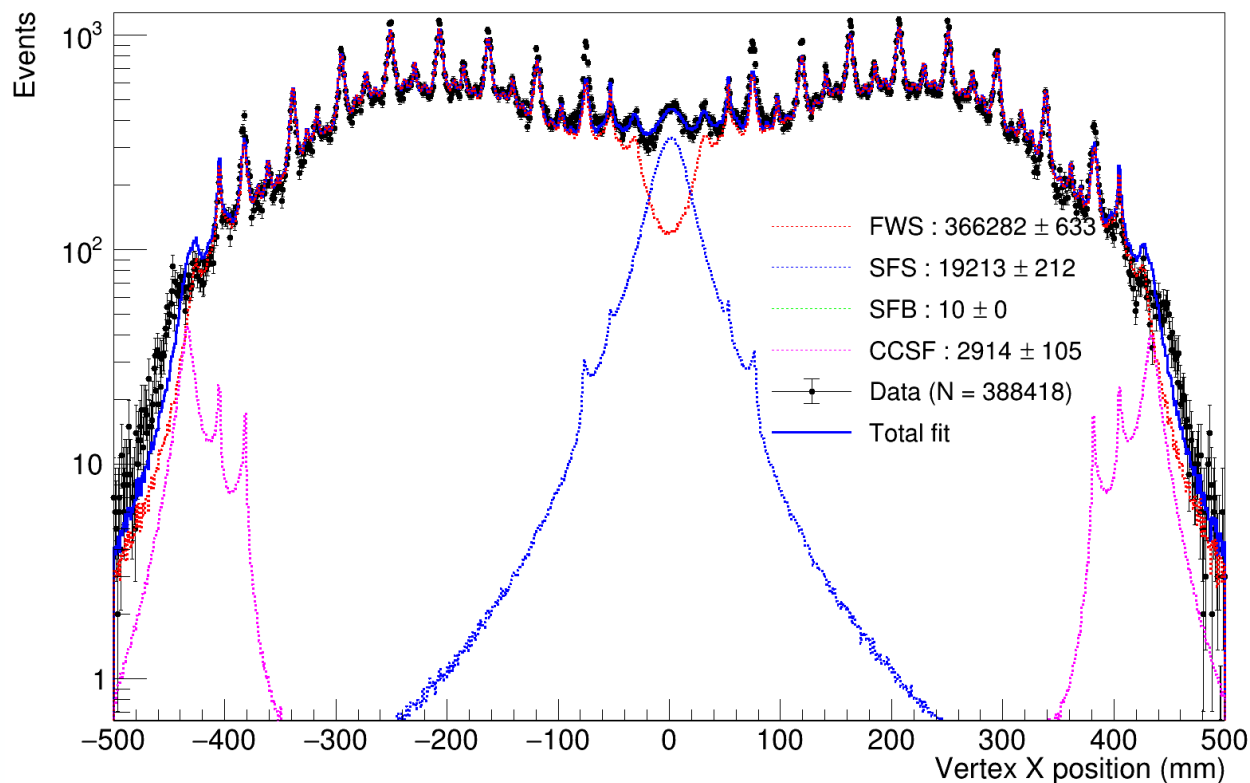


**We can see the source foils of  $^{82}\text{Se}$  !**

**Due to Radon daughter isotopes deposited on source foils surfaces**

# BiPo vertex contribution

BiPo vertex projection on X axis – Comparisons with different vertex simulations



$$\chi^2 / ndf = 3.92$$

Simulations:

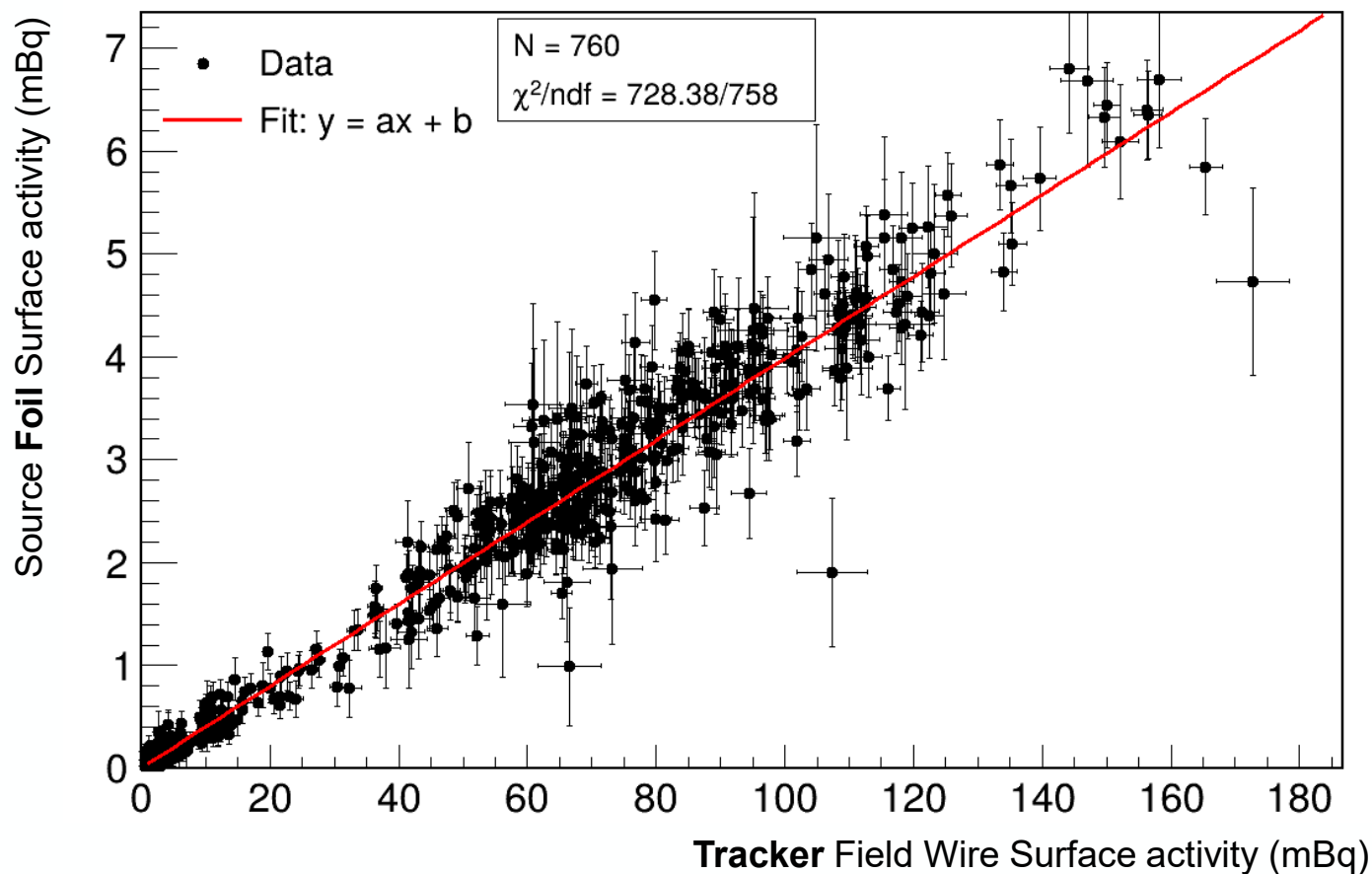
- Field Wire Surface: FWS
- Source Foil Surface  $^{82}\text{Se}$  : SFS
- Source Foil Bulk  $^{82}\text{Se}$  : SFB
- OMs surfaces : CCSF

→ Few events from source foils (in dashed blue)

$$R = \frac{N_{SFS}}{N_{tot}} = 5.25 \pm 0.06 \%$$

# BiPo vertex contribution

## Radon activity dependency as function of Vertex



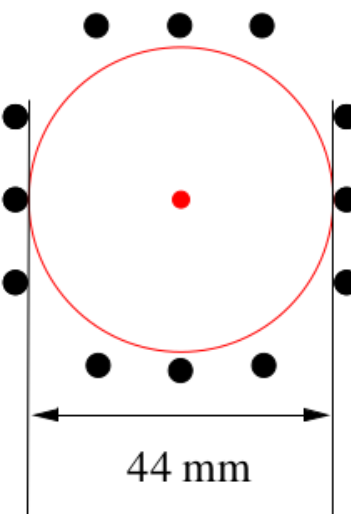
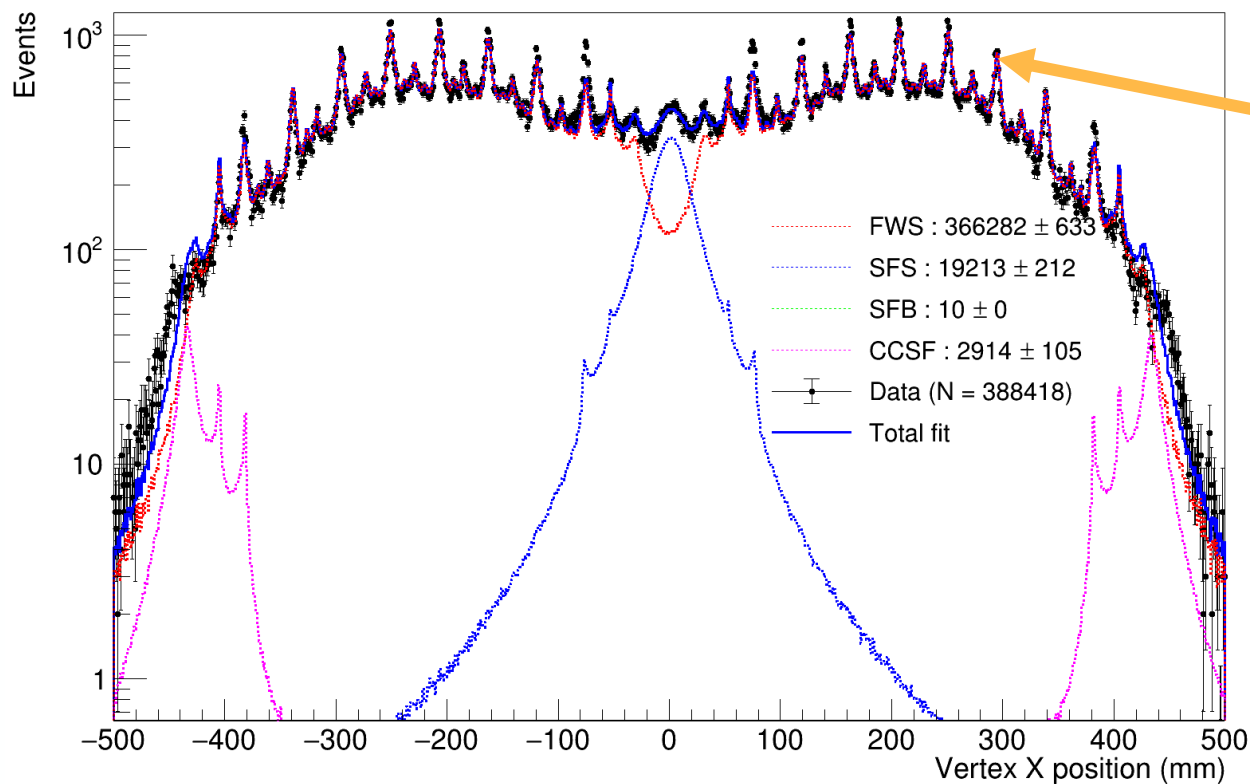
Linear relation between Rn activity from **field wires** and **source foils surfaces**

$$b = 6.3 \pm 3.1 \mu Bq$$

➔ Small contribution from internal contaminations

# BiPo vertex contribution

BiPo vertex projection on X axis – Comparisons with different vertex simulations

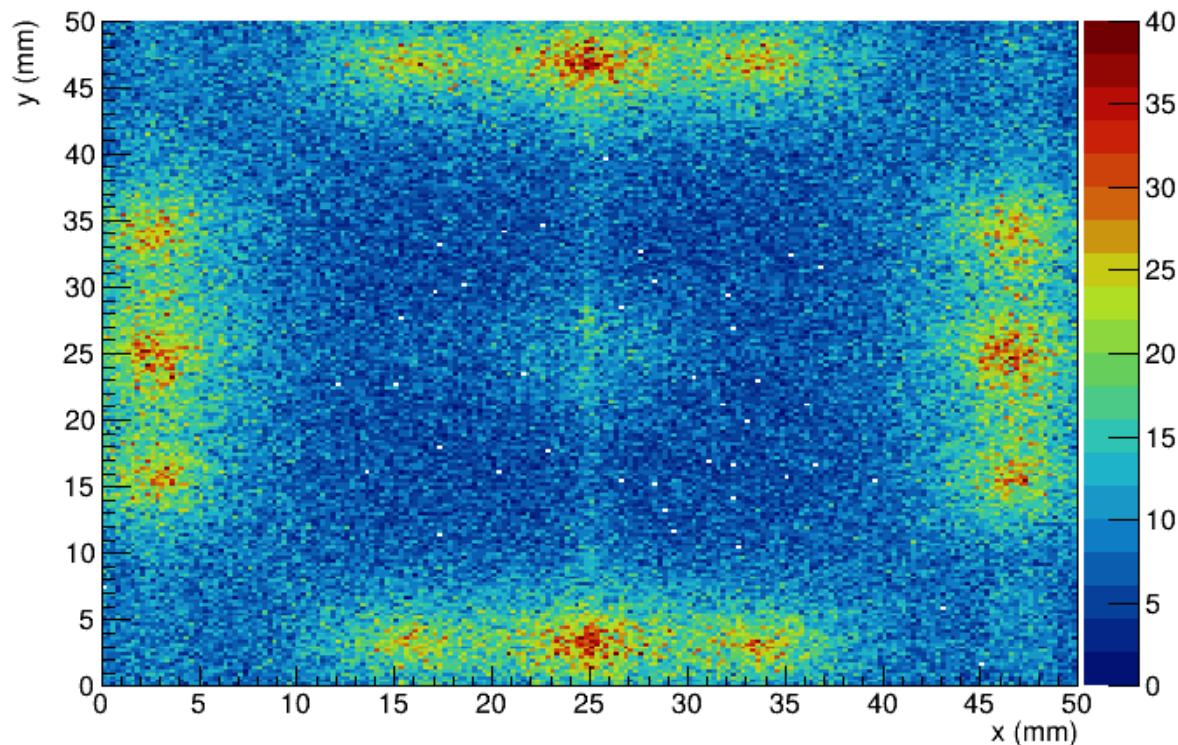


Geiger cell geometry

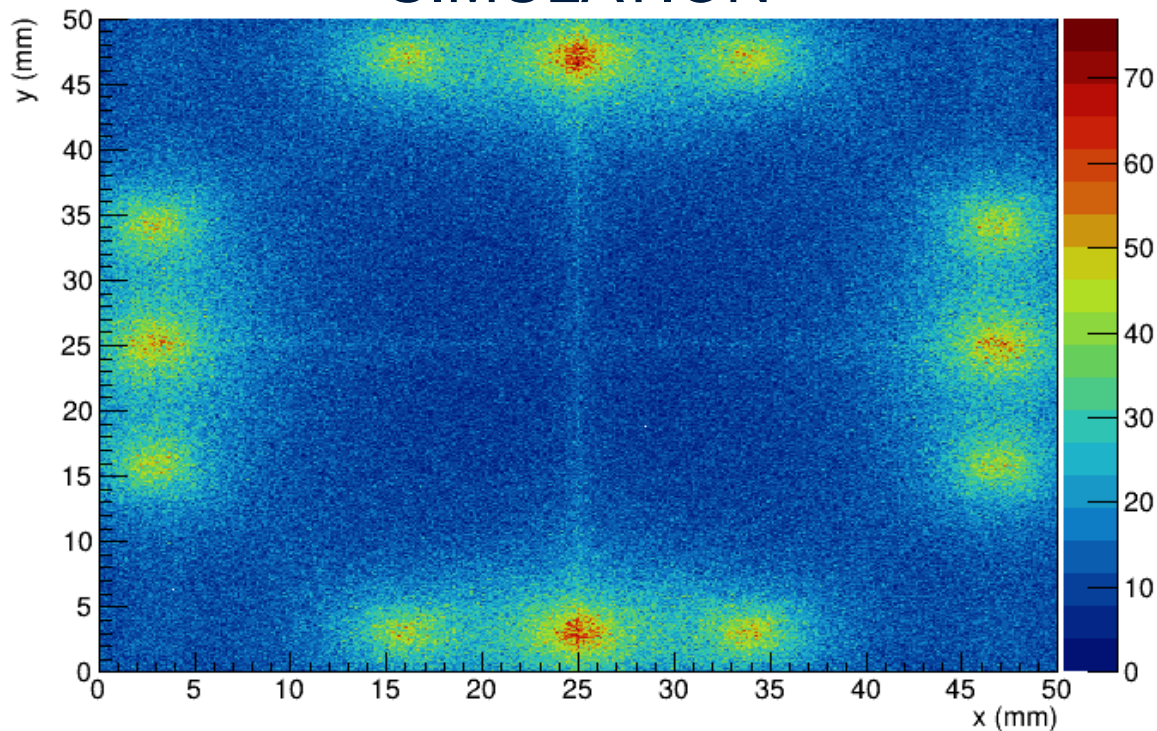
# BiPo vertex: Geiger cell

All BiPo vertex in the tracker merged in on cell geometry

DATA

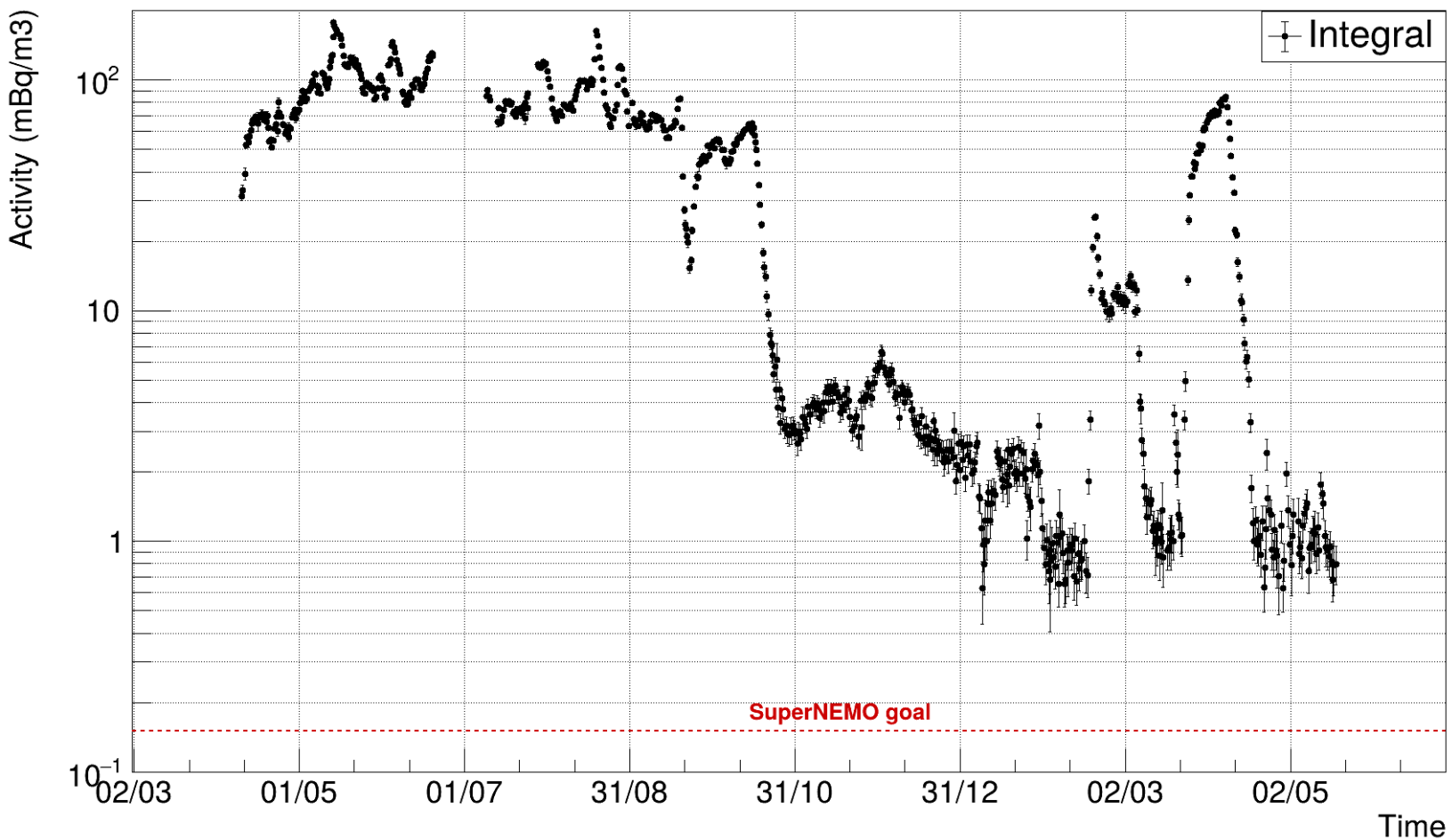


SIMULATION

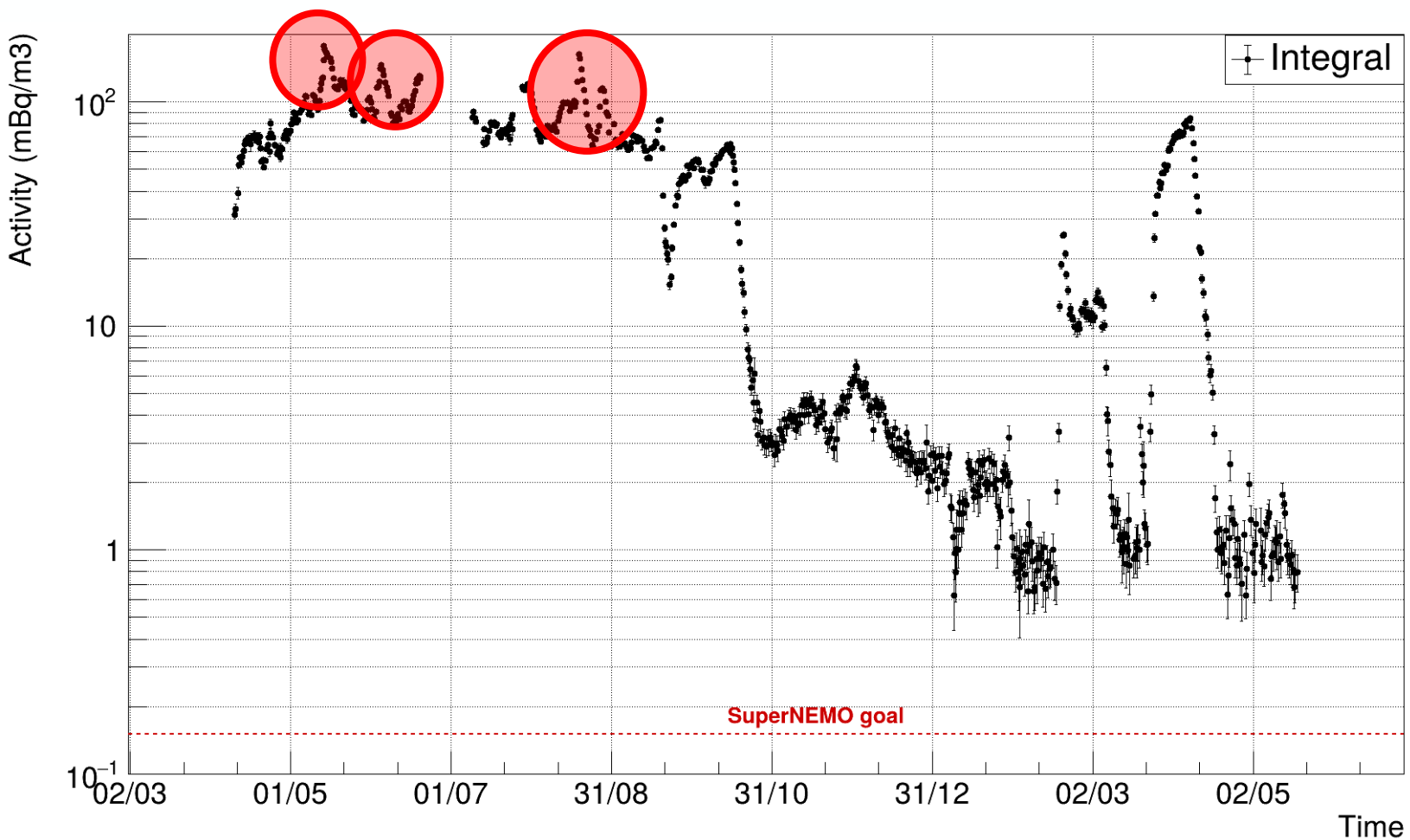


Proof that BiPo come from field wires surfaces

# Radon activity inside the tracker:

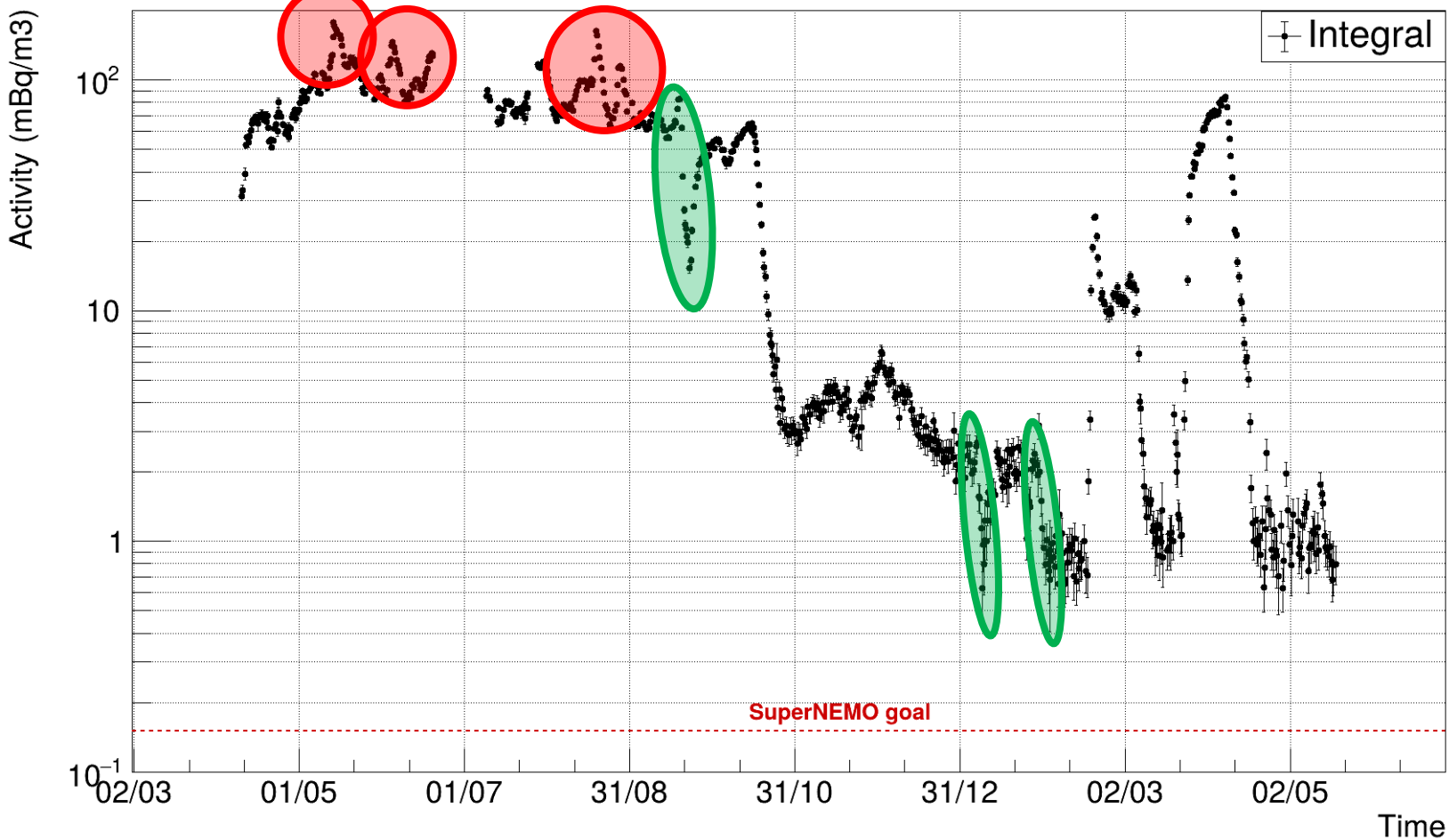


# Radon activity inside the tracker:



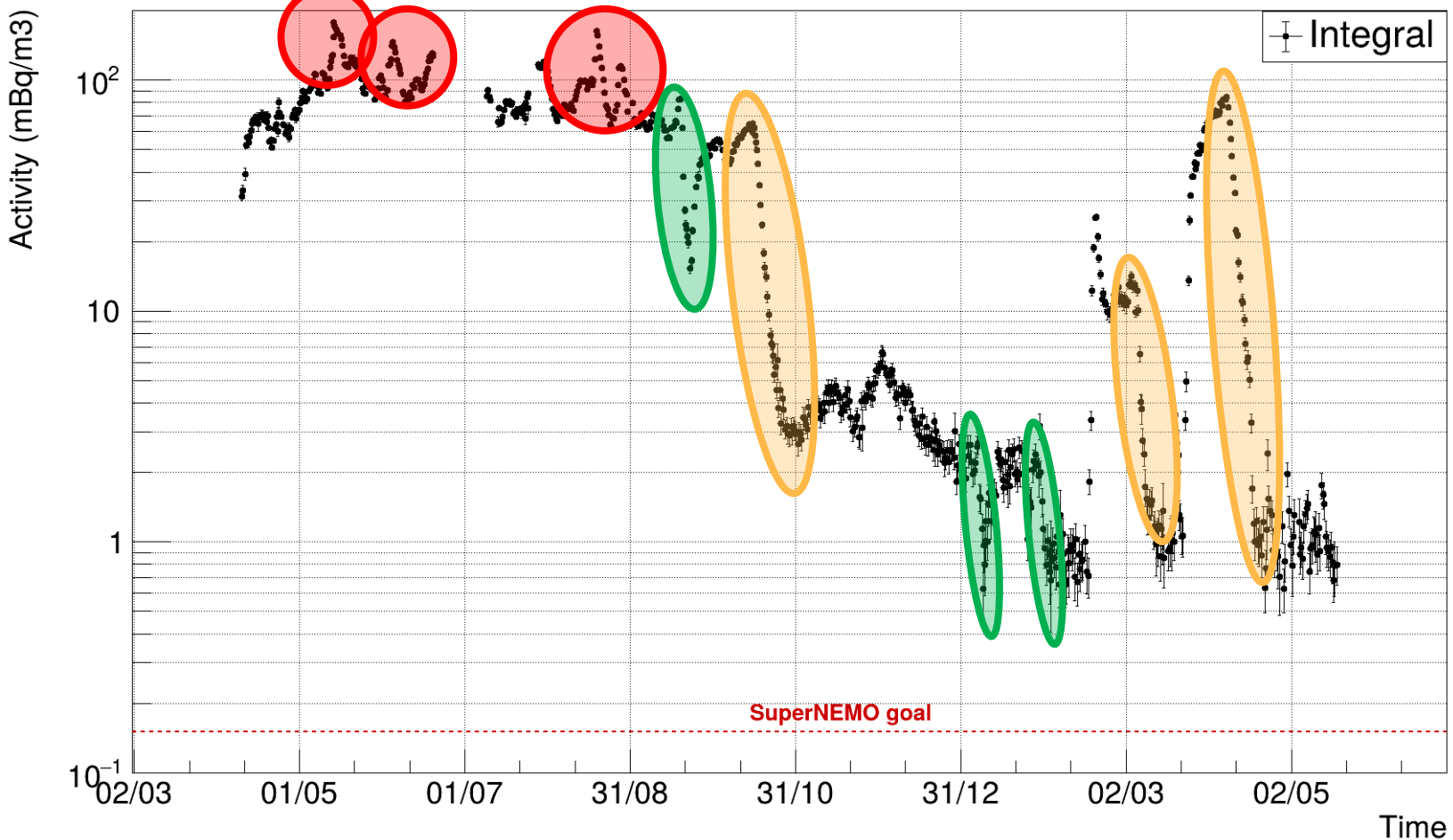
- Tracker became in underpressure due to ventilation test in the tunnel

# Radon activity inside the tracker:



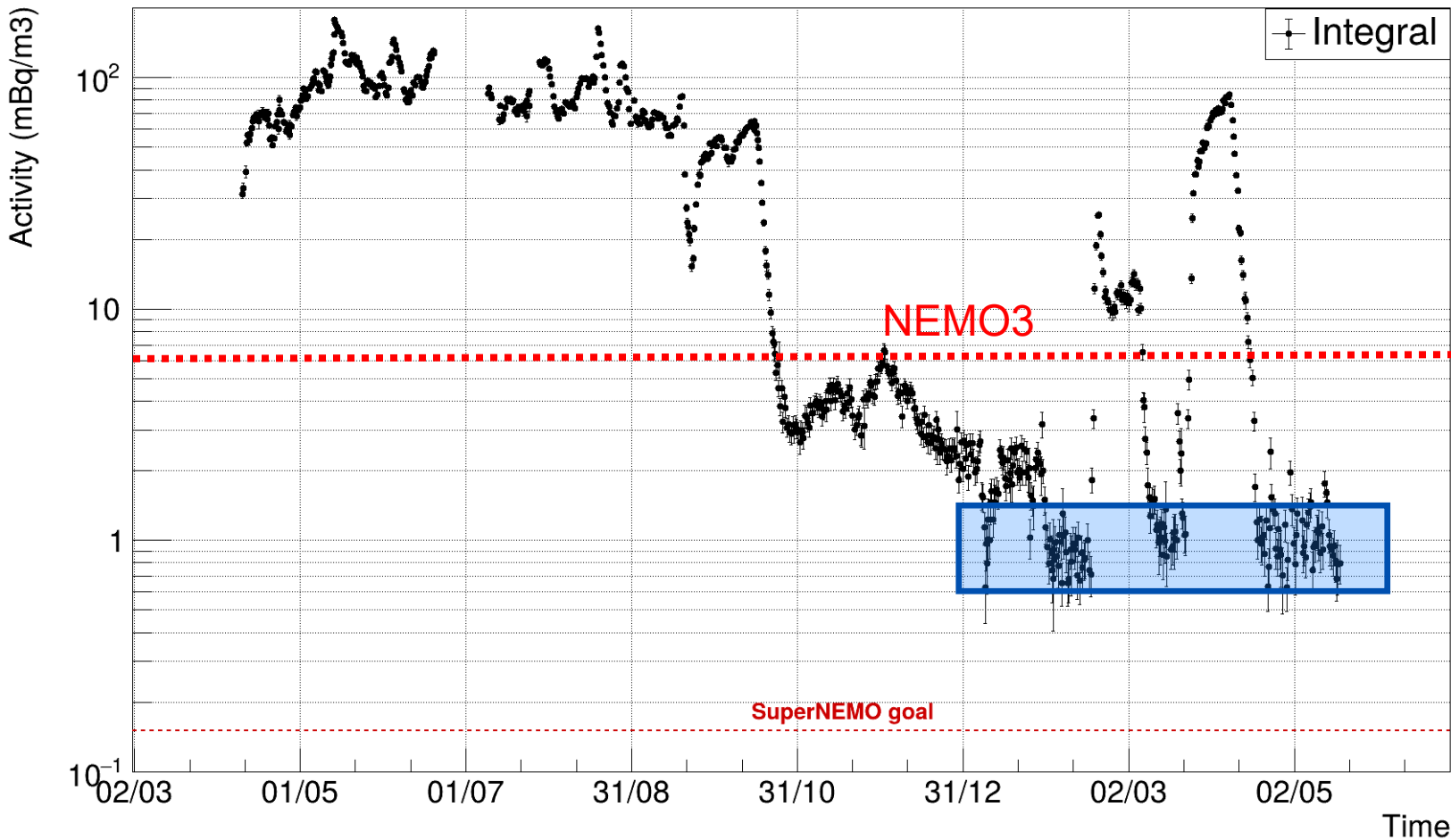
- Tracker became in underpressure due to ventilation test in the tunnel
- He flux set at 10L/min instead of 3L/min

# Radon activity inside the tracker:



- Tracker became in underpressure due to ventilation test in the tunnel
- He flux set at 10L/min instead of 3L/min
- Anti Radon Factory (ARF) switched on & restarted after issues

# Radon activity inside the tracker:



Best radon level at 0.6 mBq/m<sup>3</sup>  
(with high He flux)

10 x better than NEMO3 !

65.3 days below 2 mBq/m<sup>3</sup>

1 mBq.m<sup>-3</sup> → 70 BiPo  
detected over 1130 BiPo per  
day!

- Measurement of radon background in SuperNEMO possible by looking on BiPo topology event
- Best radon activity :  $0.6 \text{ mBq. m}^{-3}$  → 10 times better than NEMO3!
- Some low background data acquisition periods (65.3 days below  $2 \text{ mBq/m}^3$ )
- For similar He flushing, anti Radon radon facility improved the Rn background by a factor  $\sim 24$
- BiPo vertex location is under study. Better anti-Rn facility stability will help to study the remaining radiological contaminations of the source foils

Thank you !

# Radon evolution in SuperNEMO / ARF

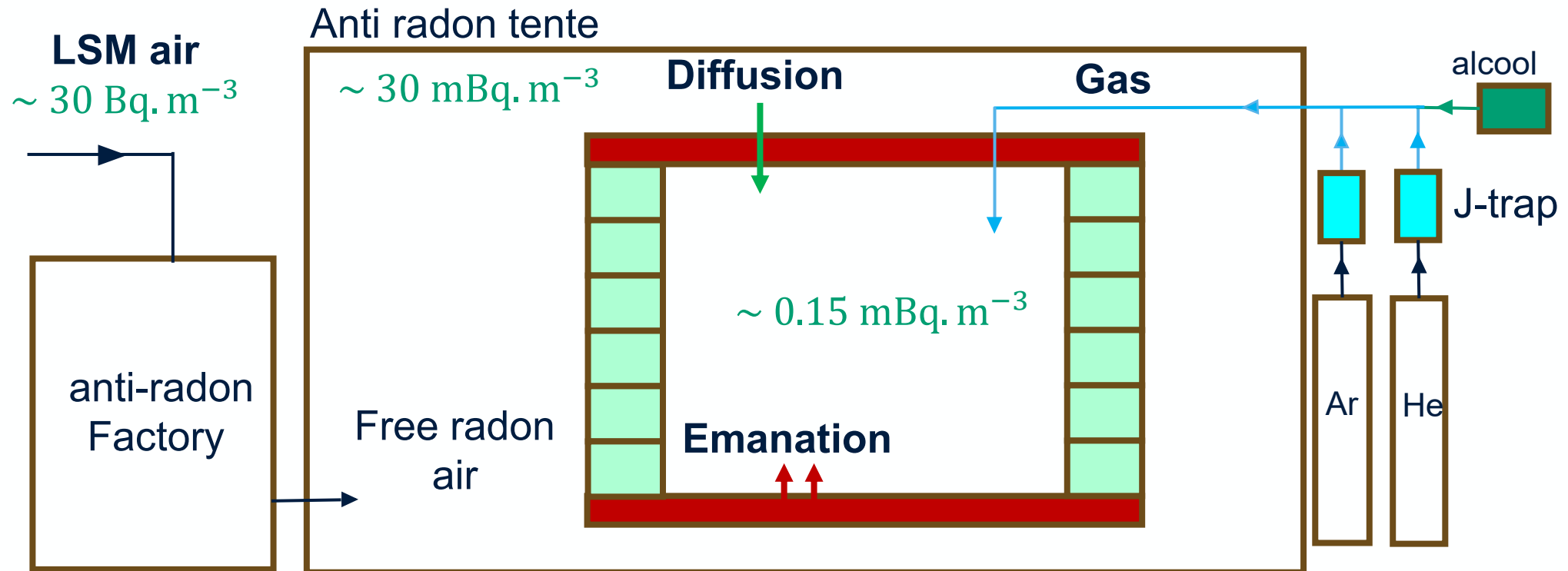
Total time data acquisition : 354,1 days

75,9 days :  $A_{Rn} < 2 \text{ mBq} \cdot \text{m}^{-3}$



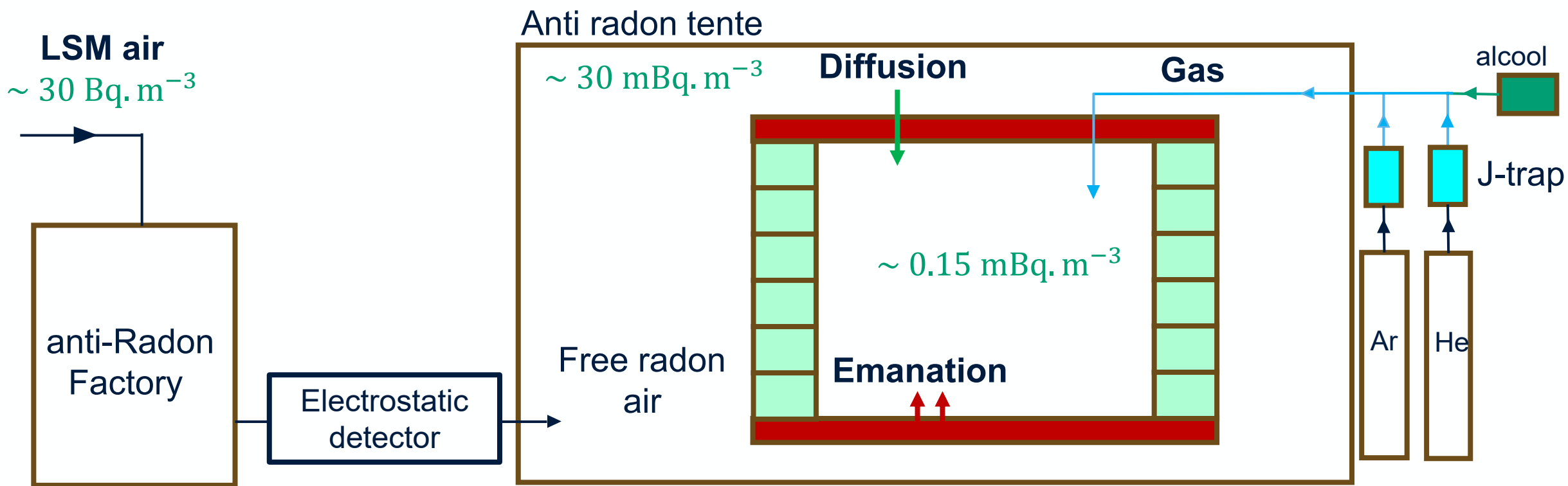
# Anti-Radon strategy on SuperNEMO:

- Need to prevent Radon from external contamination

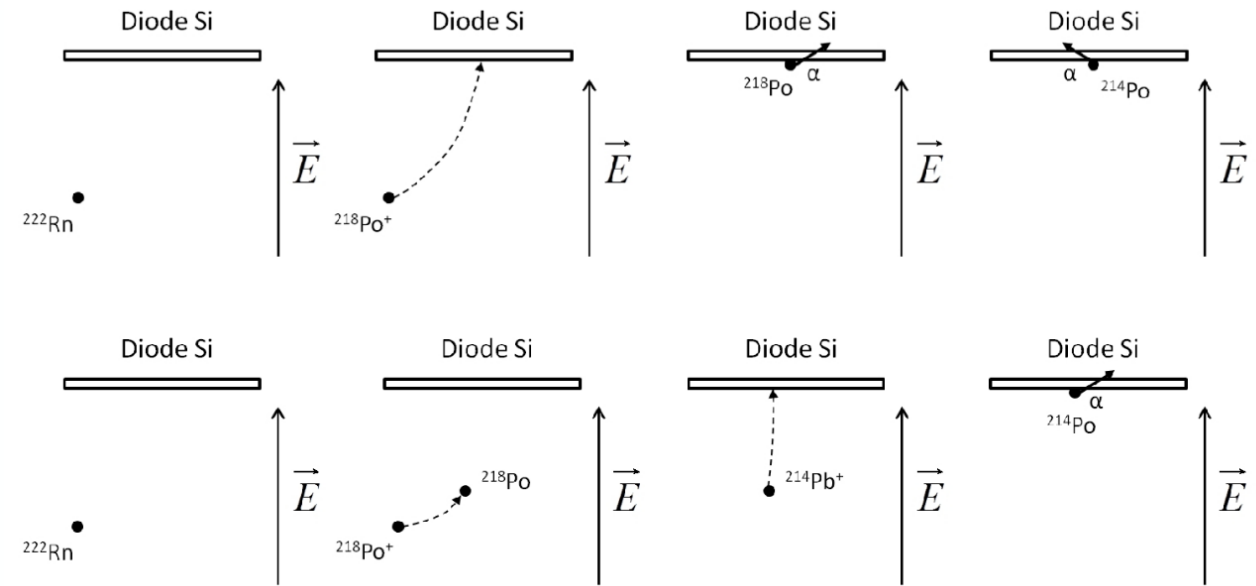
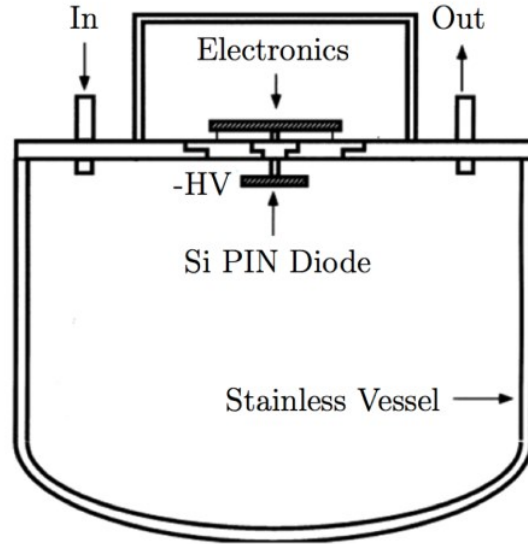
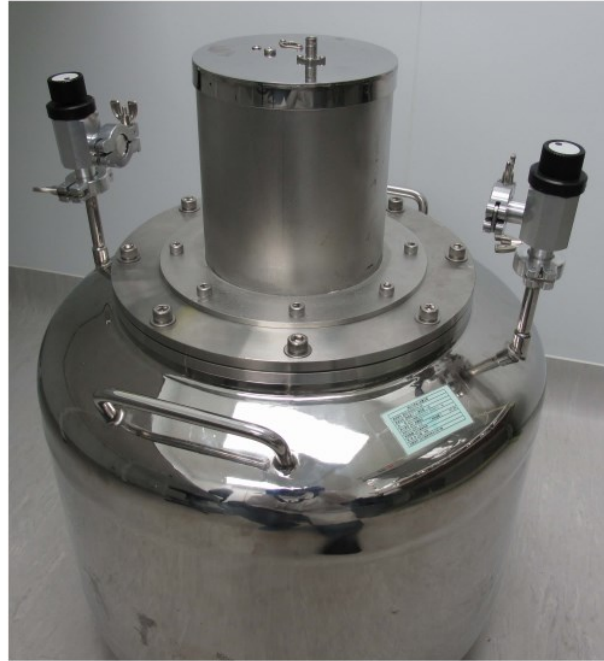


# Radon Survey strategy :

- We can monitor output quality from Anti-Radon Factory (ARF)

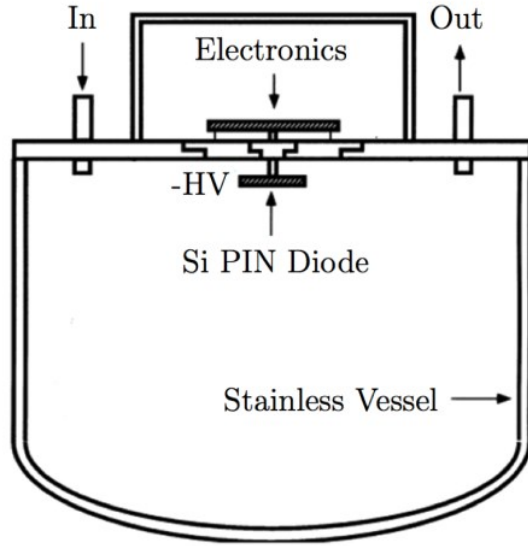
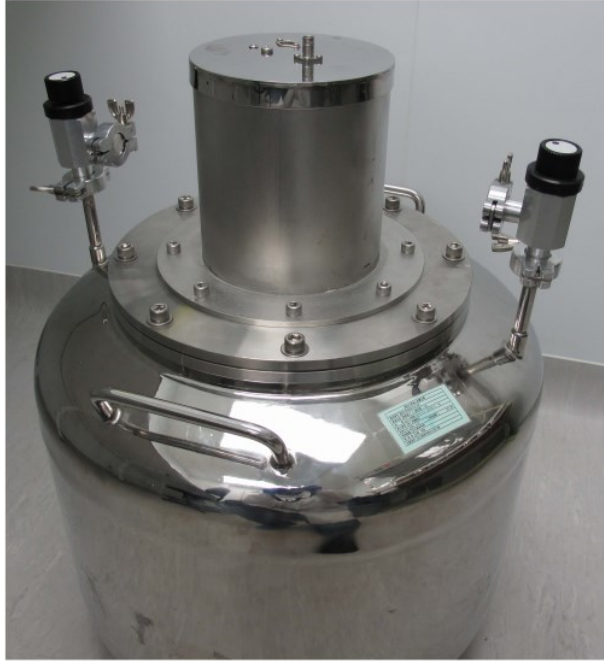


# Radon Survey strategy : ARF

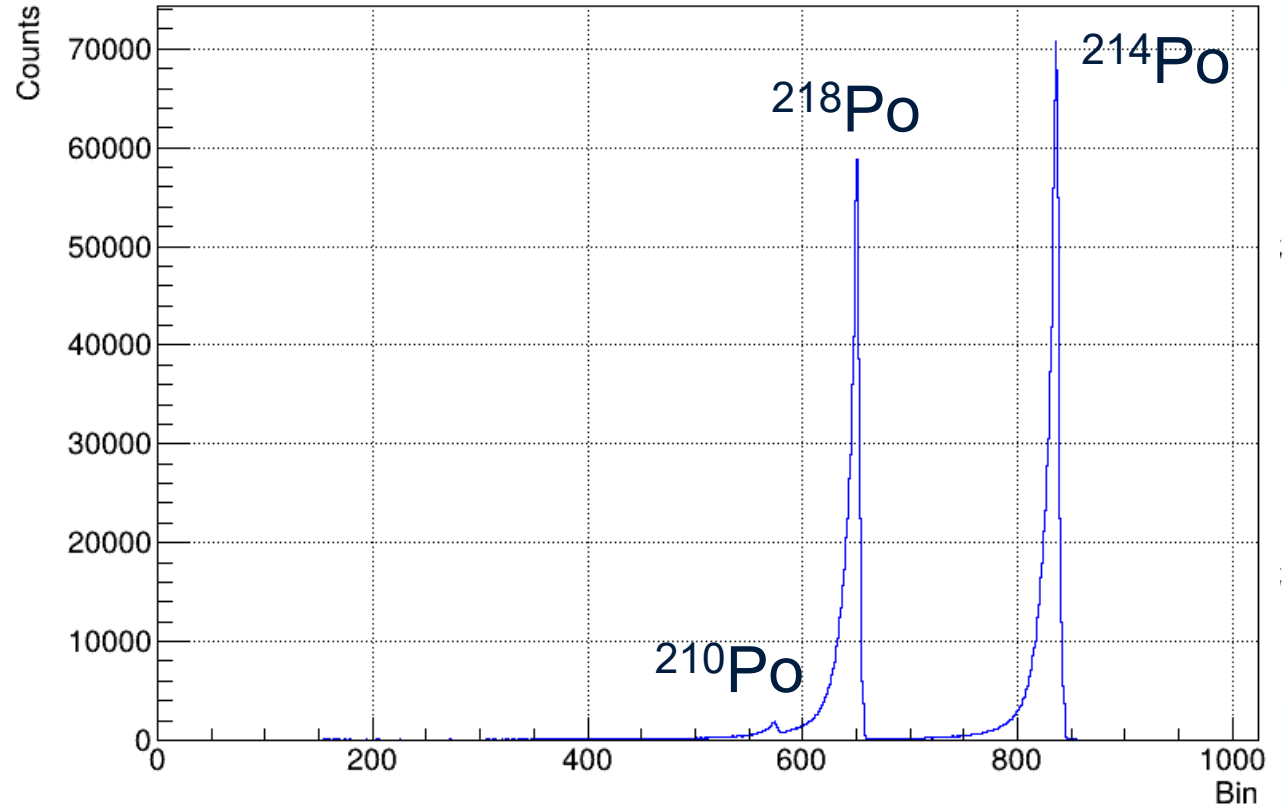


Electrostatic detector  $\epsilon \approx 0.16$  in dry air

# Radon Survey strategy : ARF



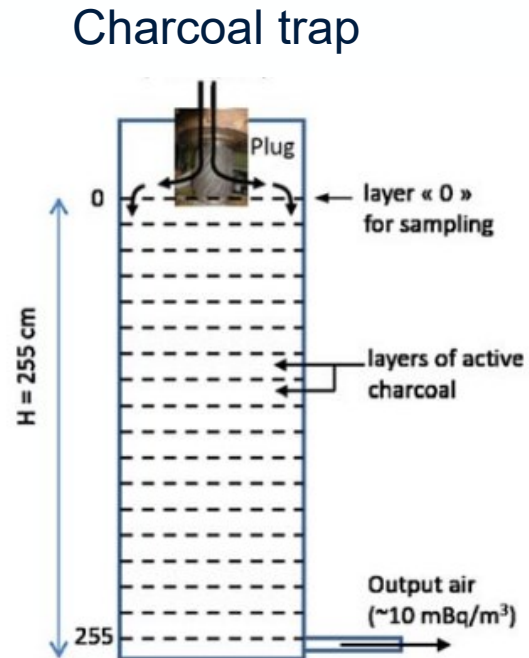
Electrostatic detector  $\epsilon \approx 0.16$  in dry air



# Anti radon factory

## Anti radon factory\* : Trapping radon with charcoal

\* Developed by LSM

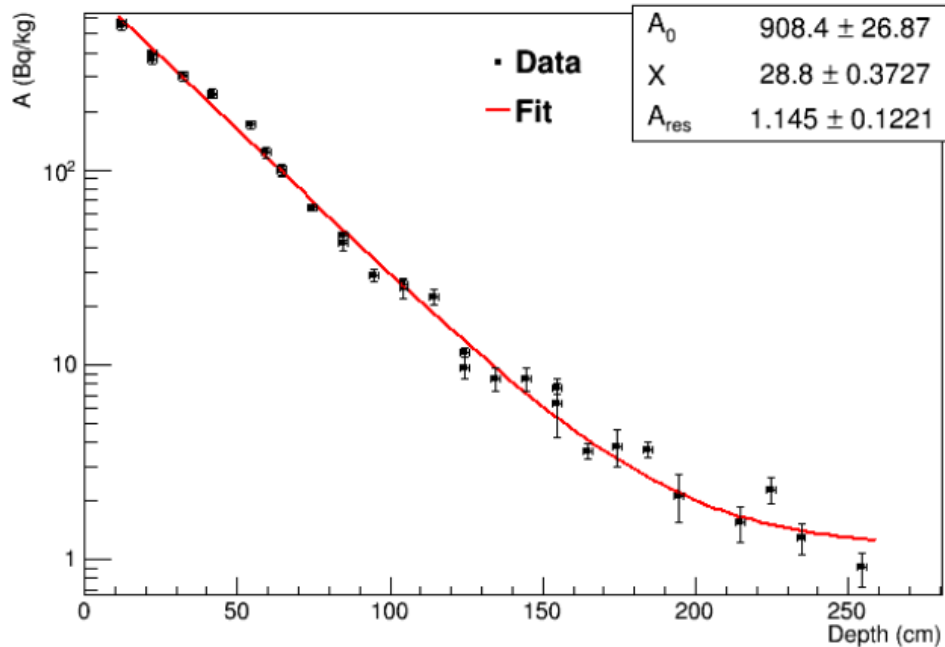


- Radon activity decreased by a factor 3000 :  $30 \text{ Bq} \cdot \text{m}^{-3} \rightarrow 10 \text{ mBq} \cdot \text{m}^{-3}$
- Radon free air flux used by SuperNEMO:  $150 \text{ m}^3 \cdot \text{h}^{-1}$

*J. Phys. G: Nucl. Part. Phys.* **46** (2019) 115105

## Anti radon factory\* : Trapping radon with charcoal

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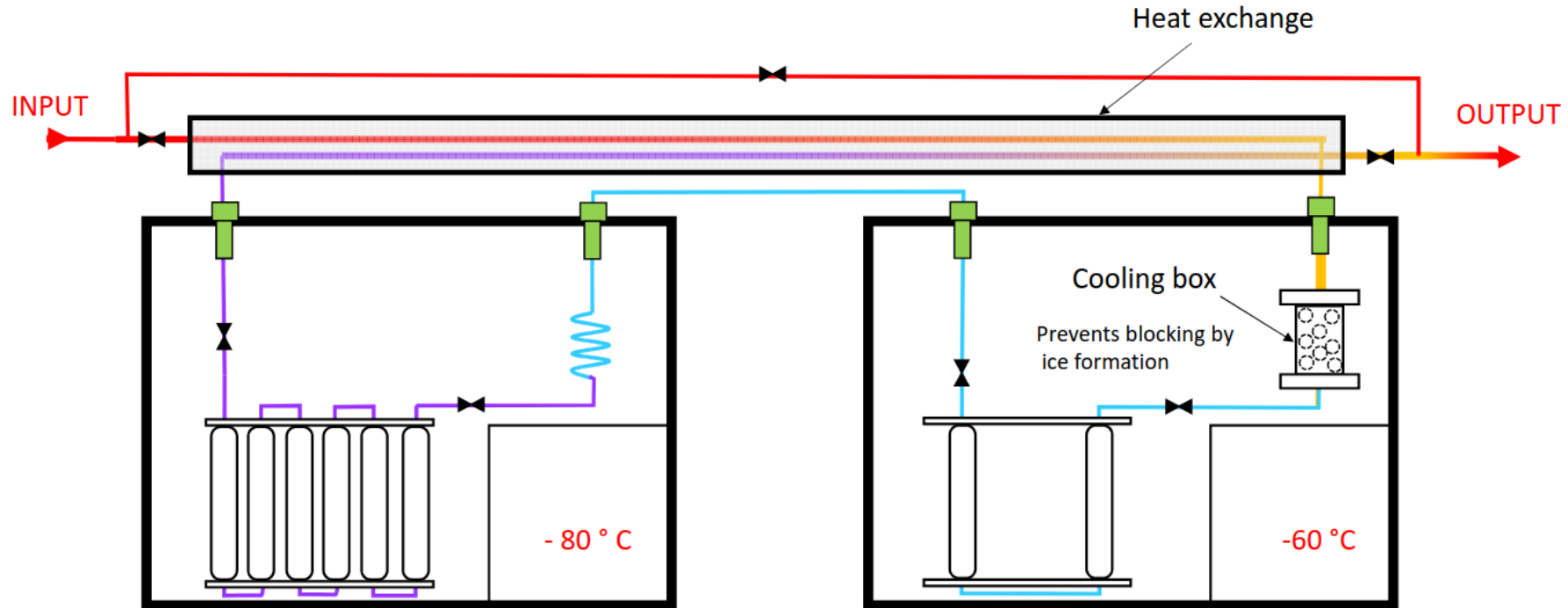


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# Gas purification « J-Trap »

## Gaz purification system in SuperNEMO : J-Trap

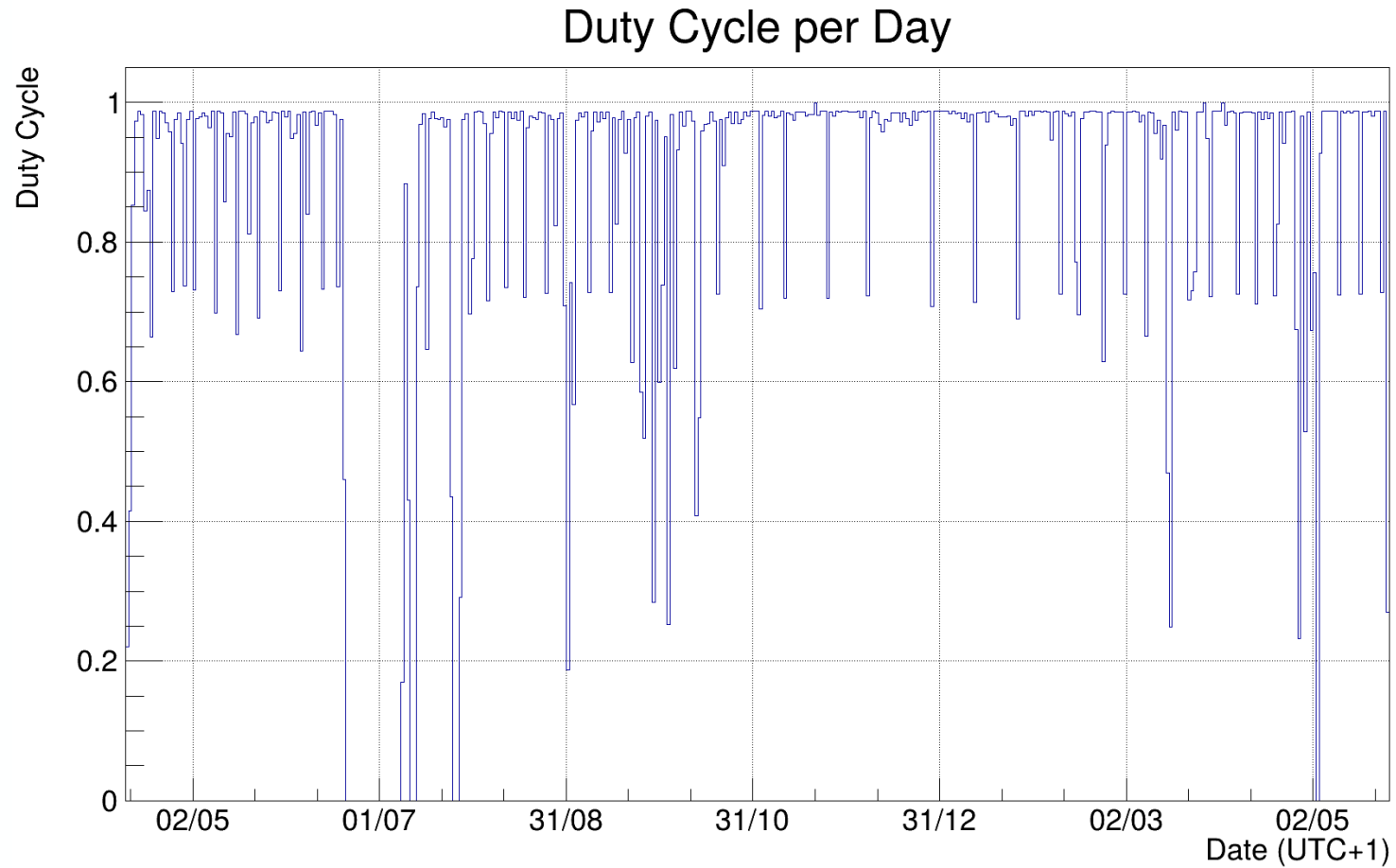


- 6 small column  $500 \text{ cm}^3$  (1,5 kg charcoal)
- Radon absorption

- 2 column  $500 \text{ cm}^3$  (250g charcoal)
- Cooling, Water absorption

# Duty cycle

Mean duty cycle without calibration periods : 97,9 % !



# PTD extraction module

- Falaise Skeleton module → Reading PTD information from TrackFit
- 3 types of particles saved :
  1. **Gammas** (OMs hit without tracks) → Few ambiguities to corrects
  2. **Electrons**
    - i. Electron on one side of the tracker
    - ii. Electron crossing the source foil (needed for  $\beta^-$  background studies)
  3. **Undefined particle ("UND")** : → Few ambiguities to corrects
    - Short reconstructed track without associated OMs

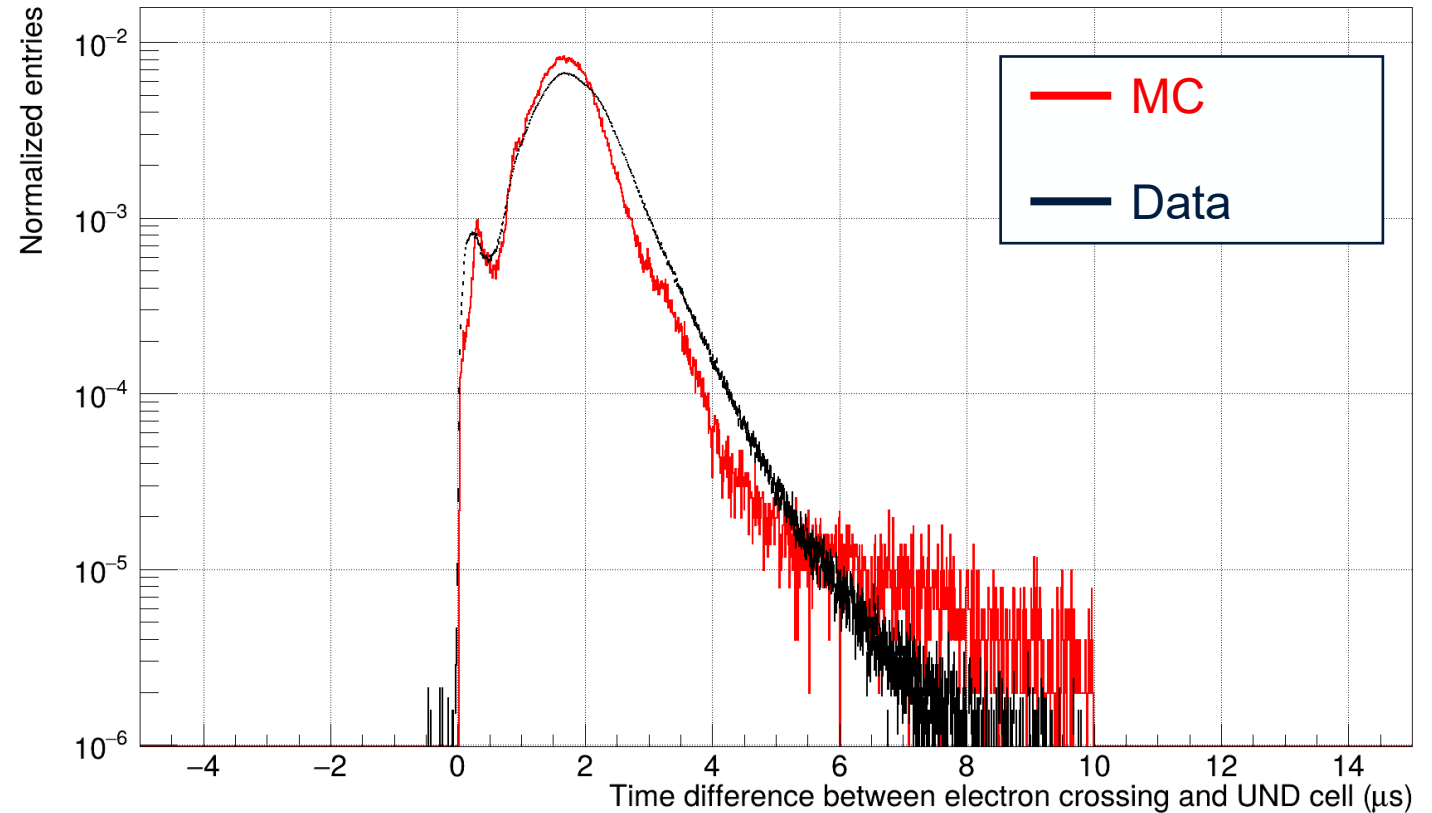
# Electron crossing source foil at low $\Delta t$

$\Delta t_{UND/e^-}$  cut

Mean time difference with  
OM of UND cells merged  
with electron

Cut applied :

$$-0.5 \mu s \leq \Delta t_{UND/e^-} \leq 10 \mu s$$



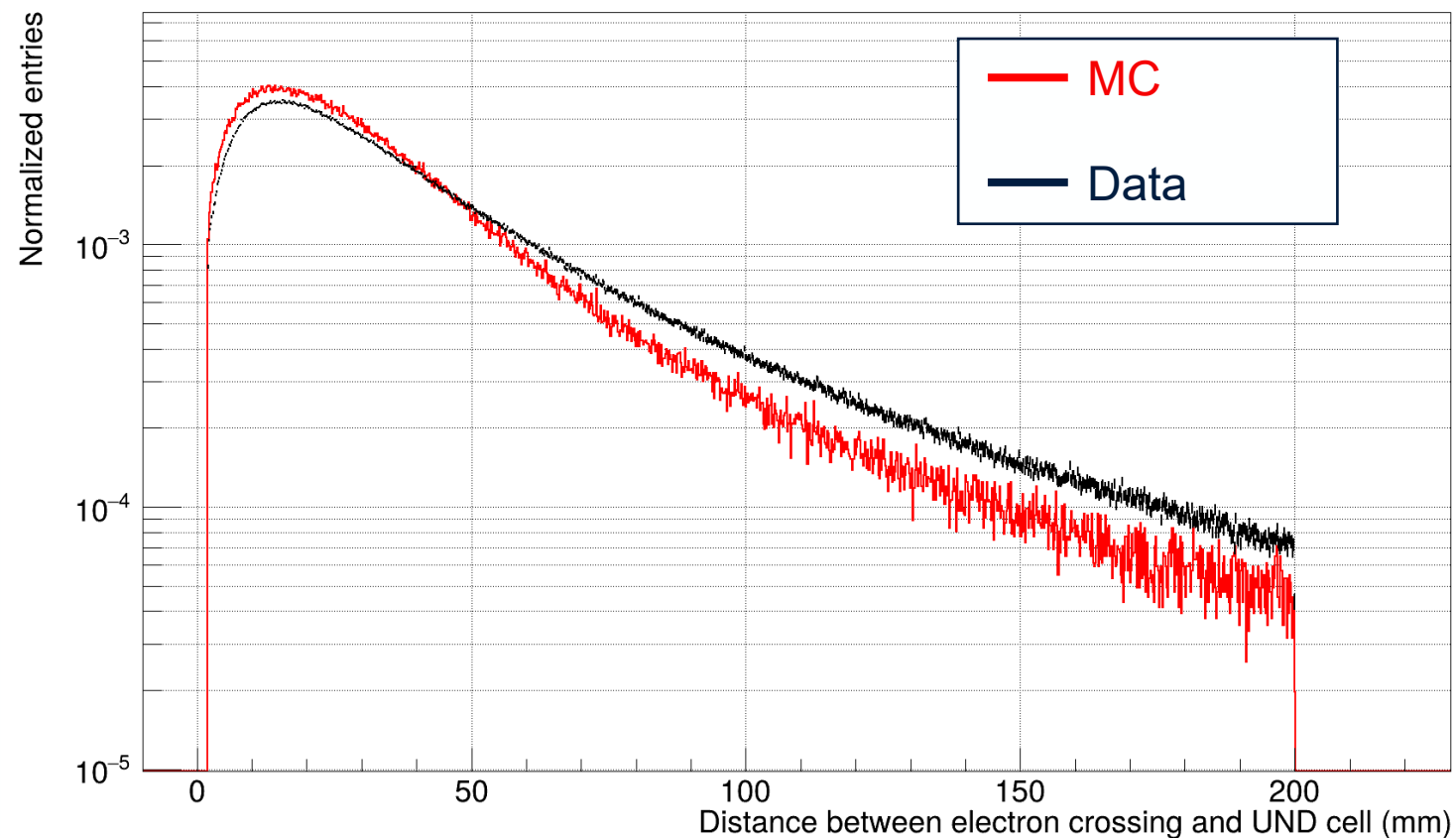
# Electron crossing source foil: vertex

## $\Delta r_{e^-/UND}$ cut

Vertex distance measured in the plane of the source foils

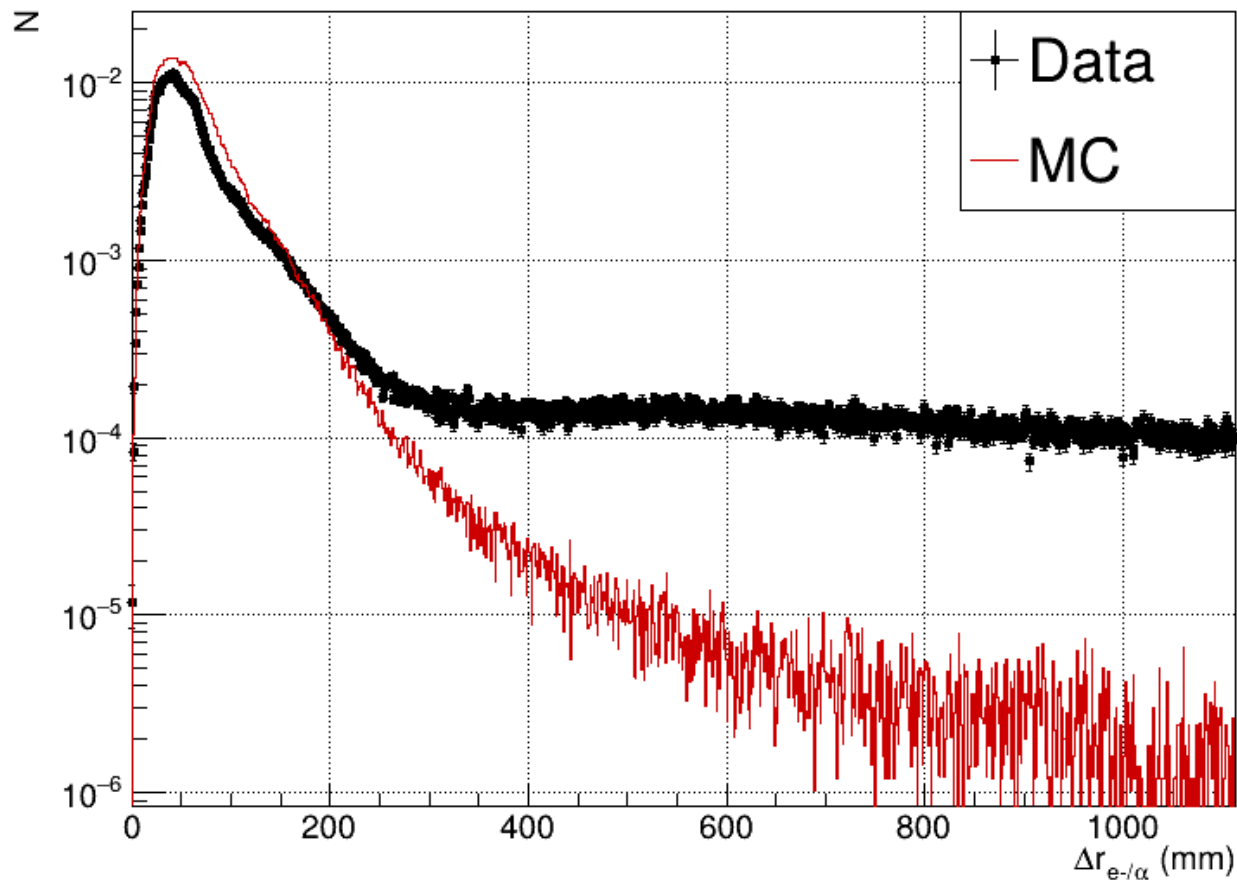
Selection Cut applied :

$$\Delta r_{e^-/UND} \leq 200 \text{ mm}$$



# BiPo selection : vertex distance $e^-/\alpha$

vertex distance between,  $e^-/\alpha$

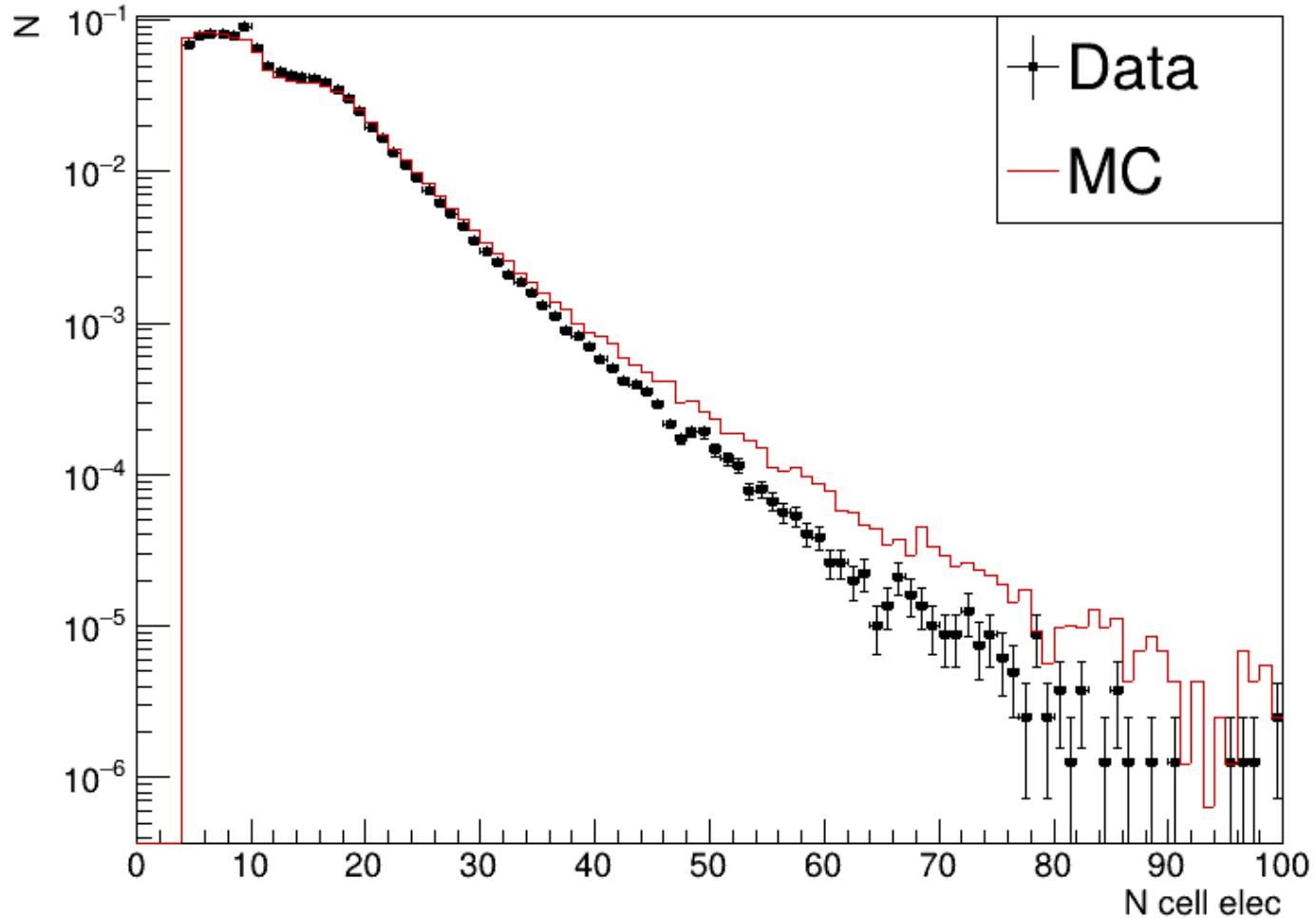


Cut set :  $\Delta r_{e^-/\alpha} \leq 200 \text{ mm}$

97.55 % of MC event with  $\Delta r_{e^-/\alpha} \leq 200 \text{ mm}$

# BiPo selection $N_{\text{cell e}}$

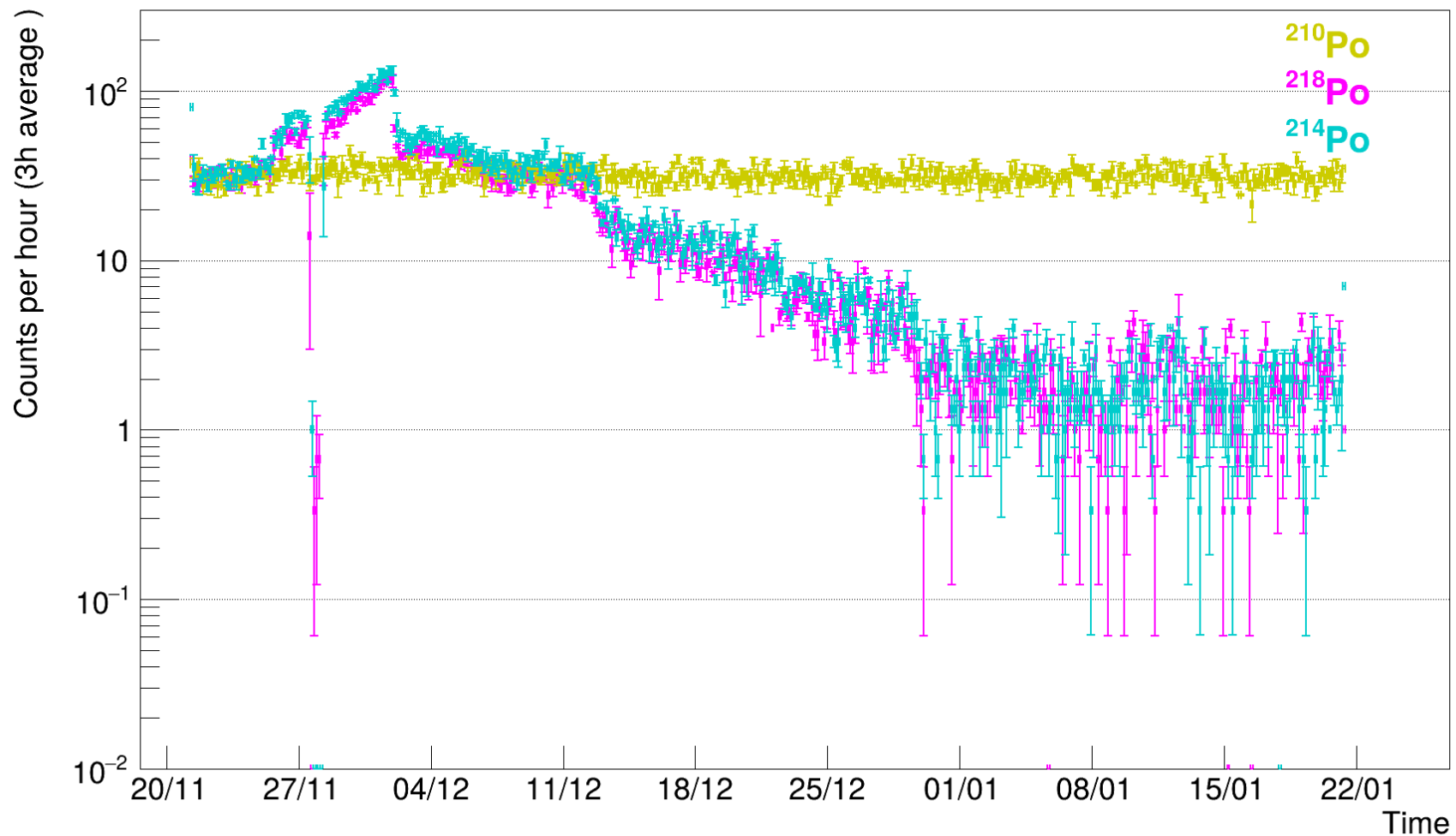
nb cell elec



- General good agreement between Data and MC

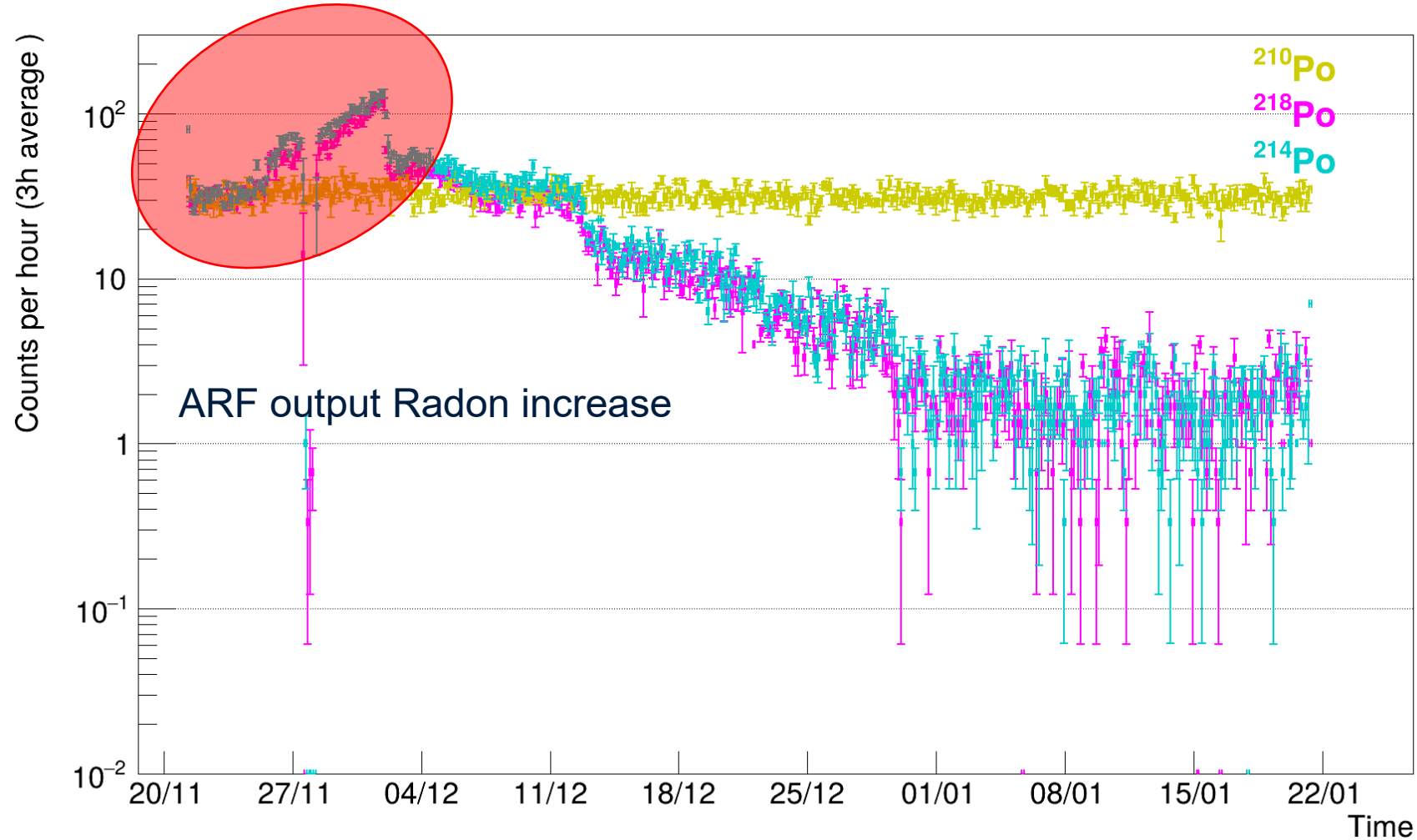
# Radon Survey strategy : ARF

ARF



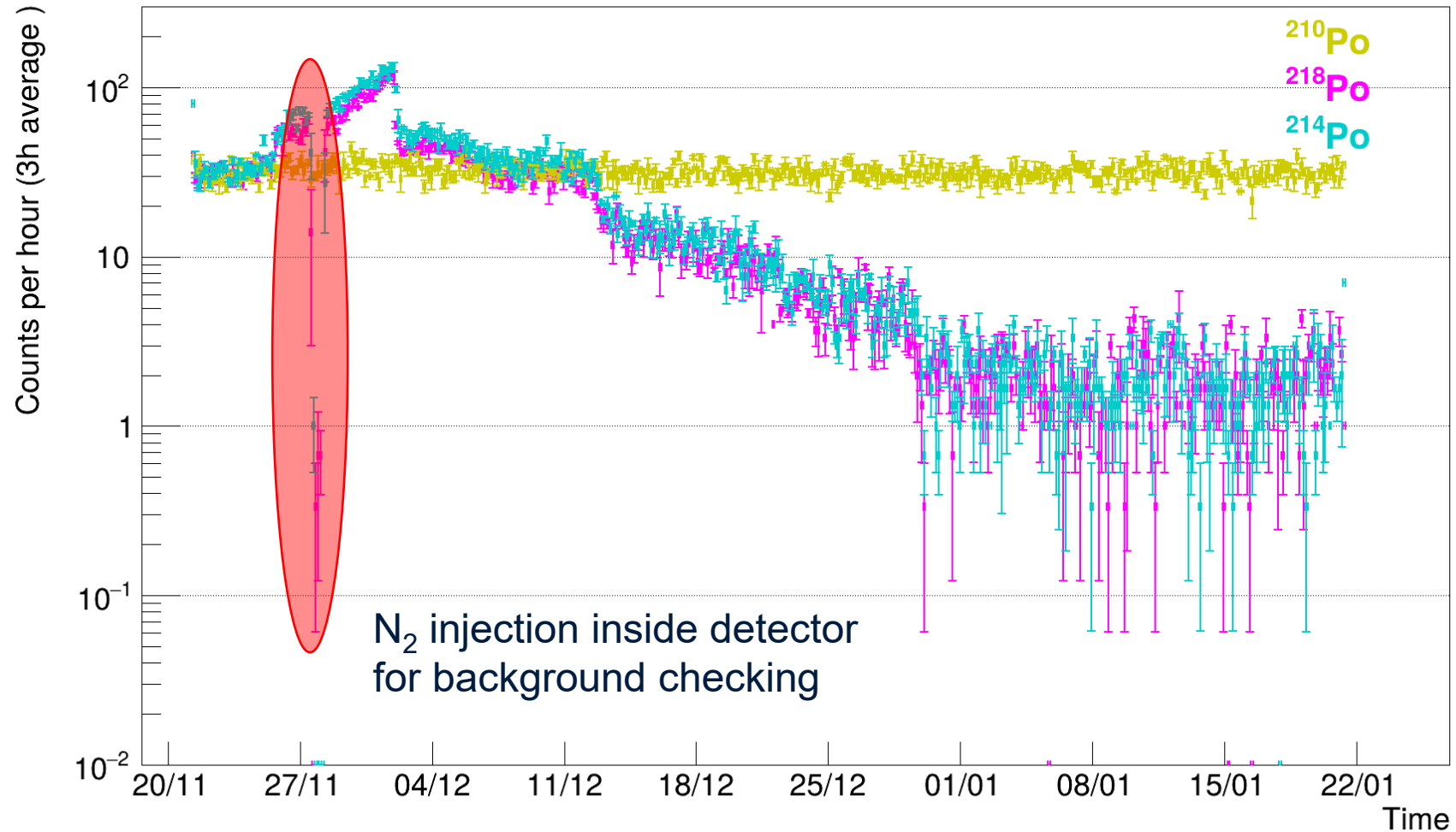
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ARF



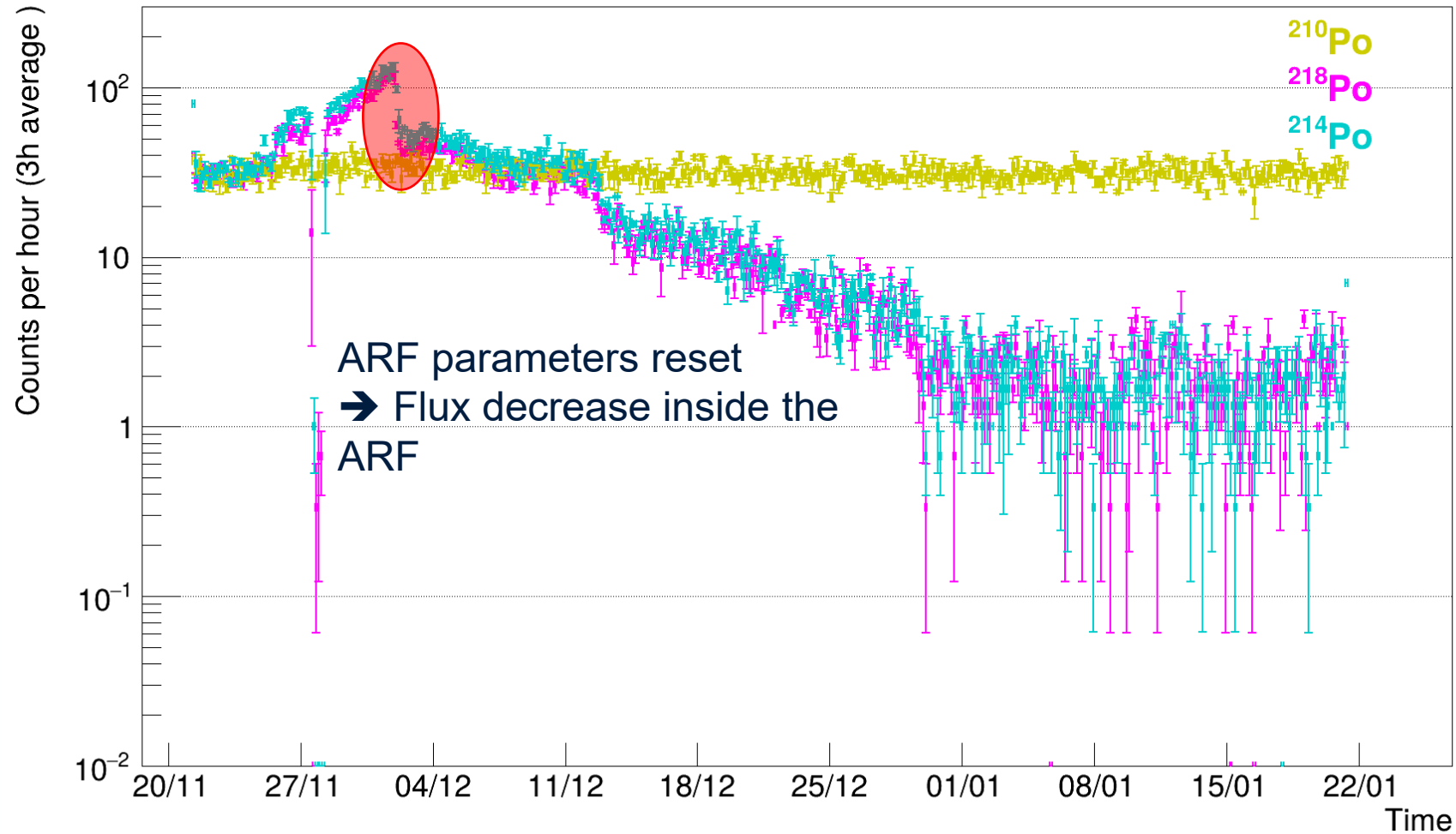
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ARF



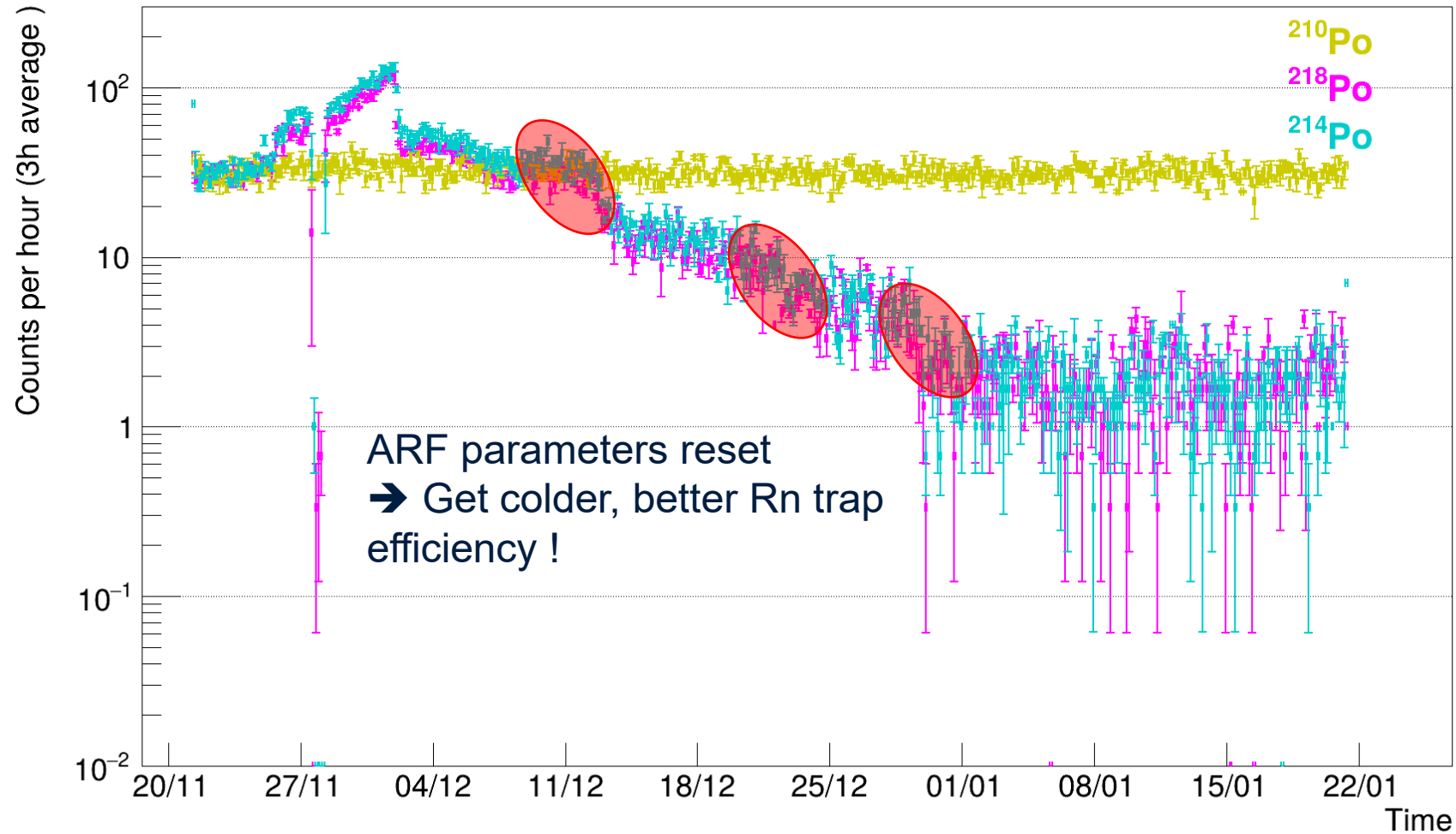
# Radon Survey strategy : ARF

## ARF



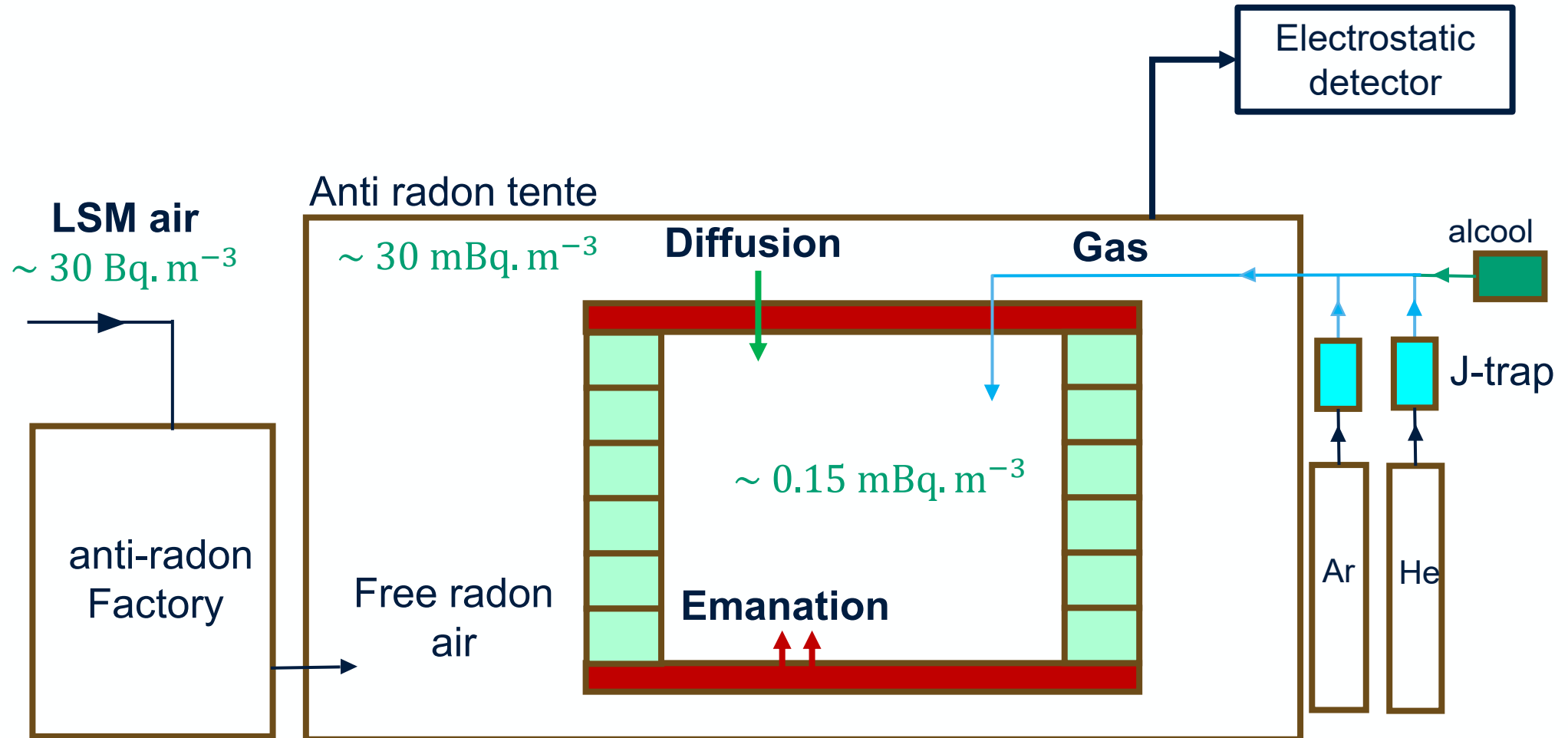
# Radon Survey strategy : ARF

## ARF

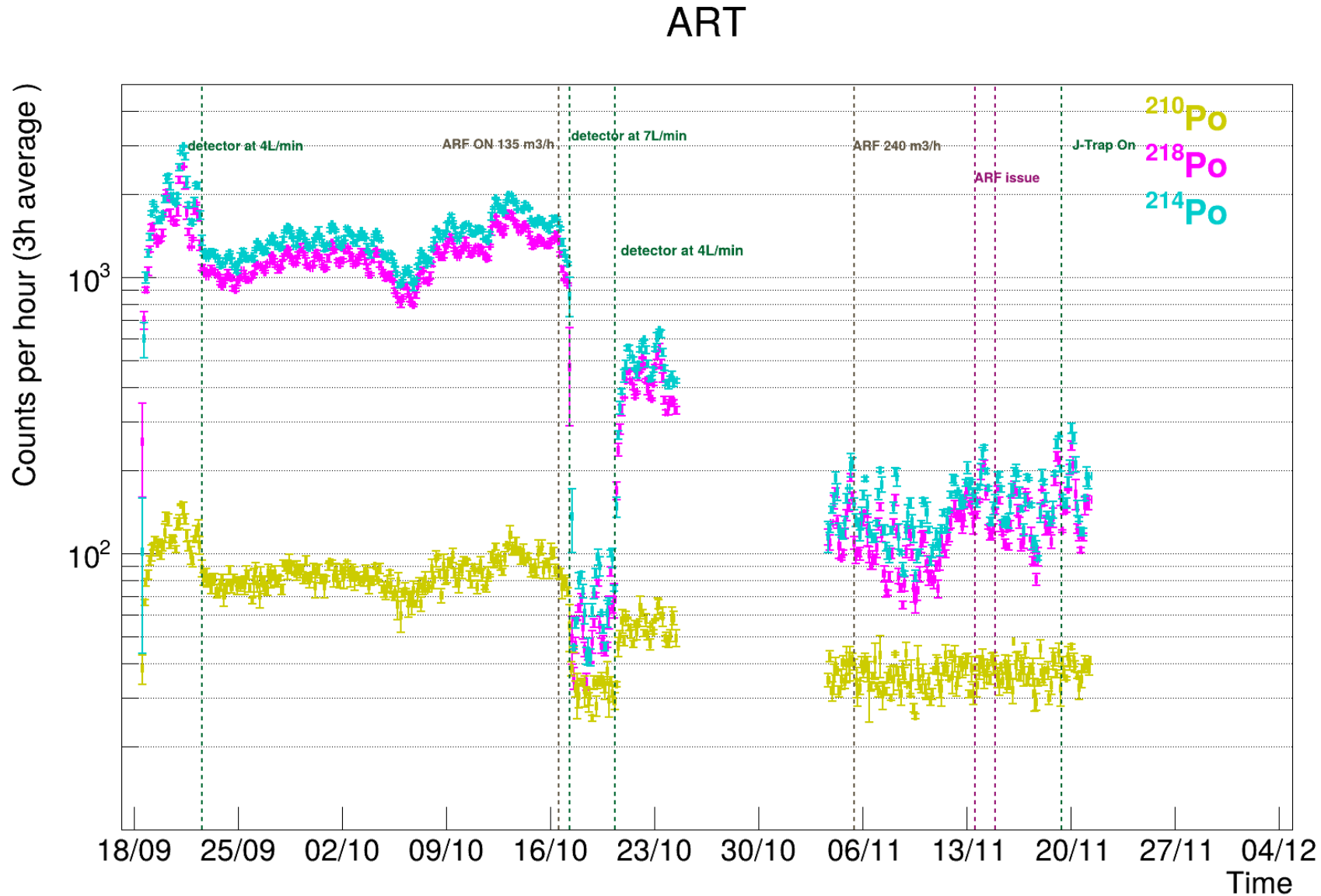


# Radon Survey strategy : ART

- We can monitor air output from Anti-Radon Tent (ART)

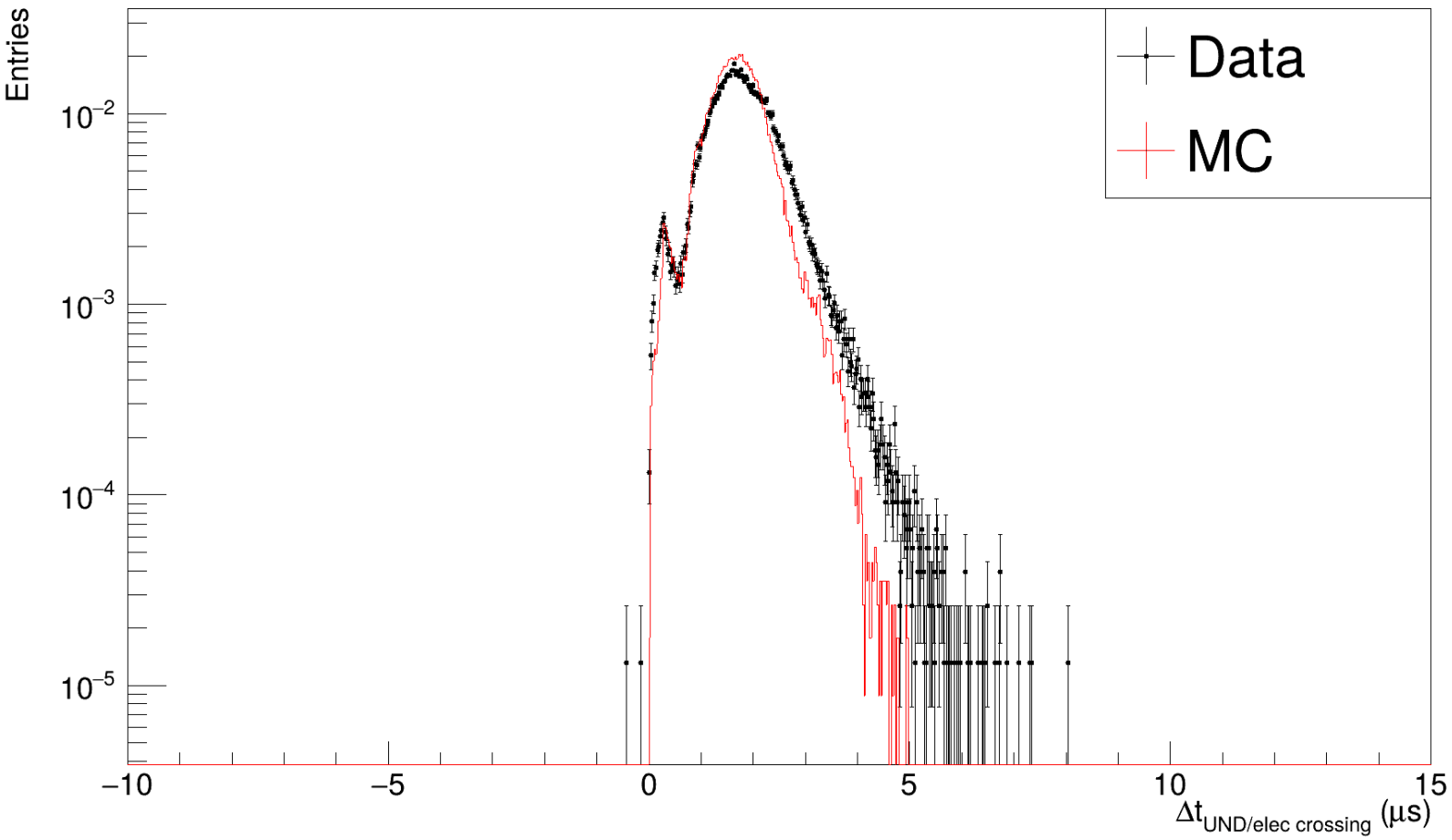


# Radon Survey strategy : ART



- Radon leaks inside electrostatic detector !
- ARF issue, not enough efficient due too high air temperature at the output

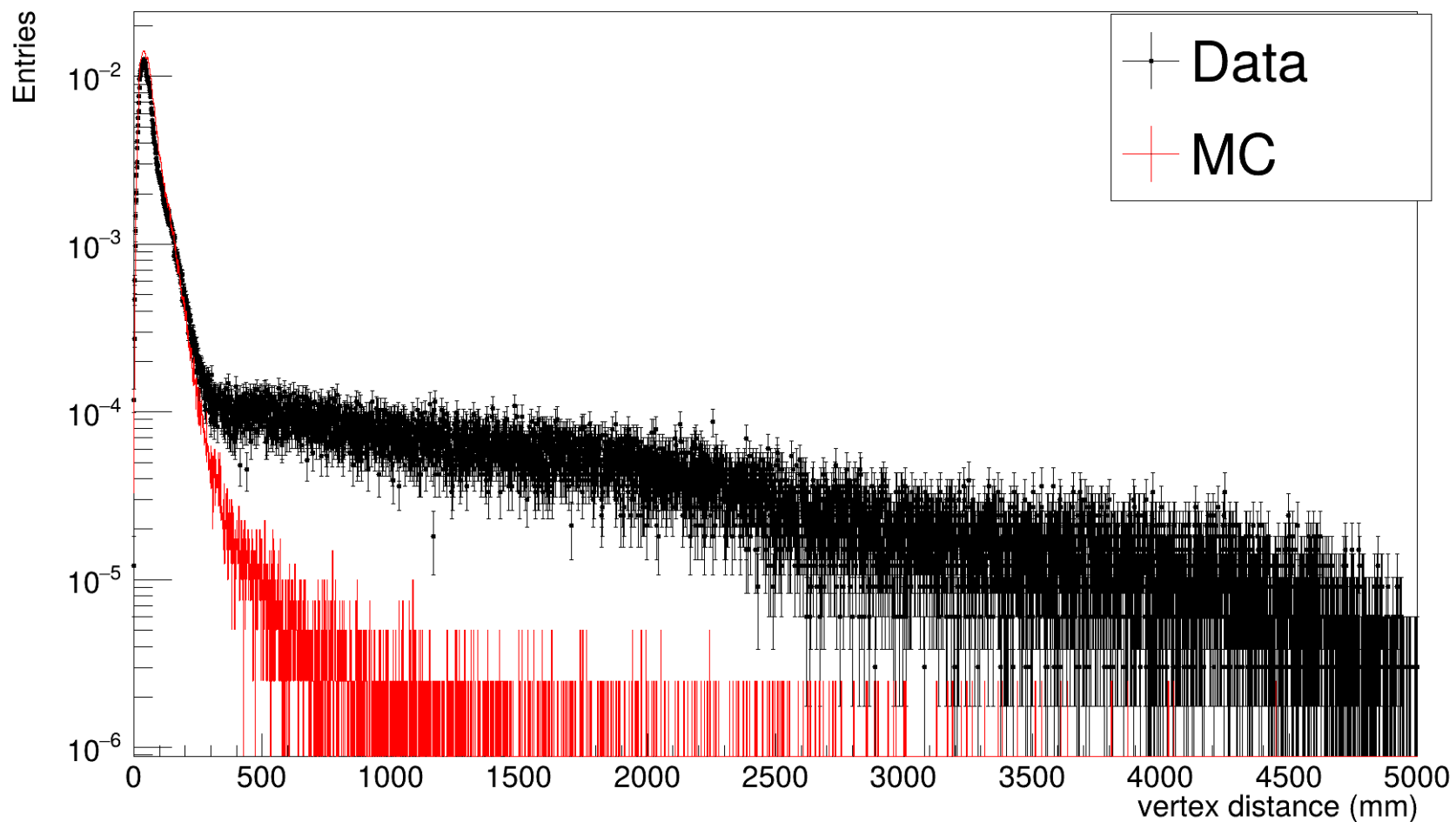
# Distribution of $\Delta t_{UND}/e^-$ from real BiPo



- Better agreement between MC/Data from BiPo event (electron crossing the SF)

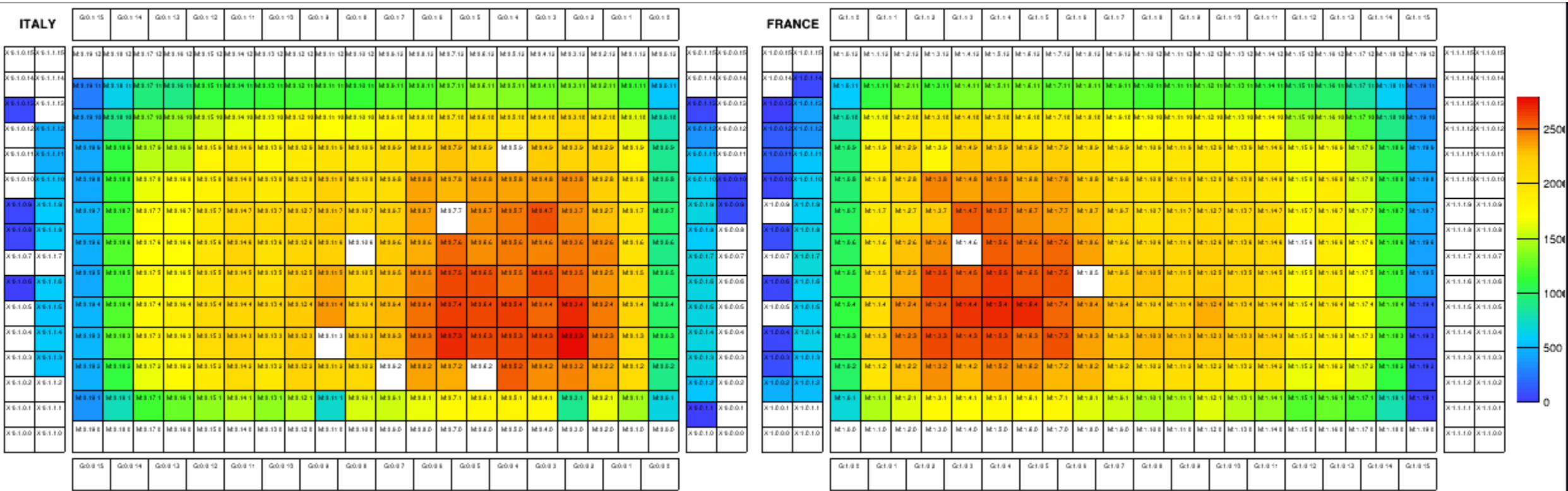
# BiPo selection : vertex distance $e^-/\alpha$

vertex distance between  $e^-/\alpha$  for phase 2b

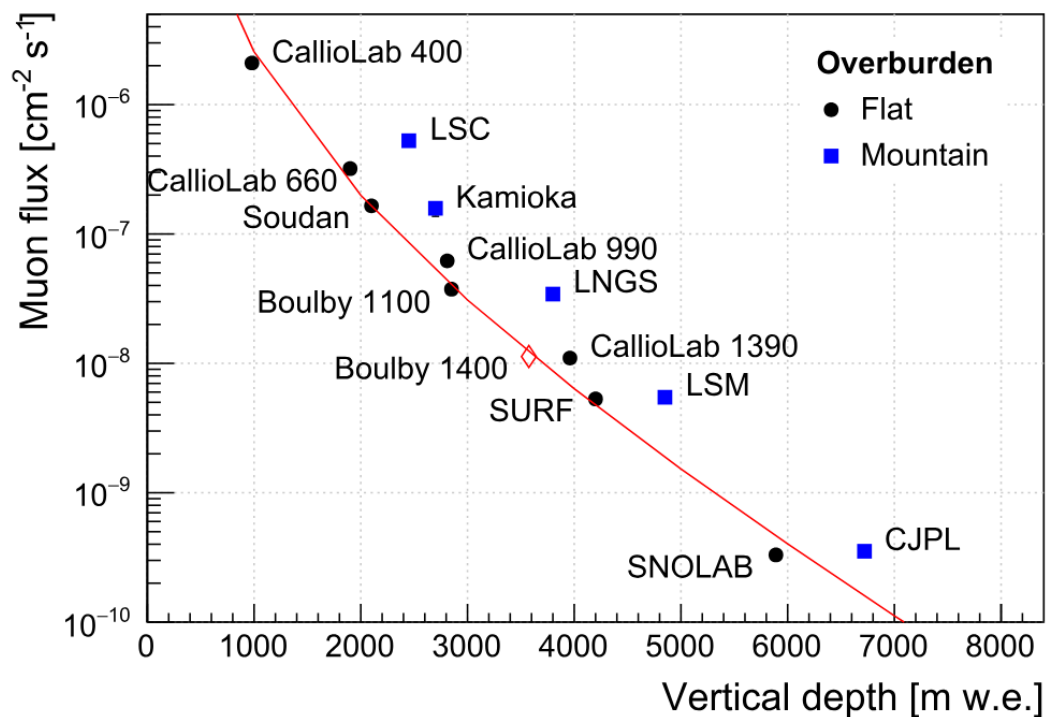


All range before cut

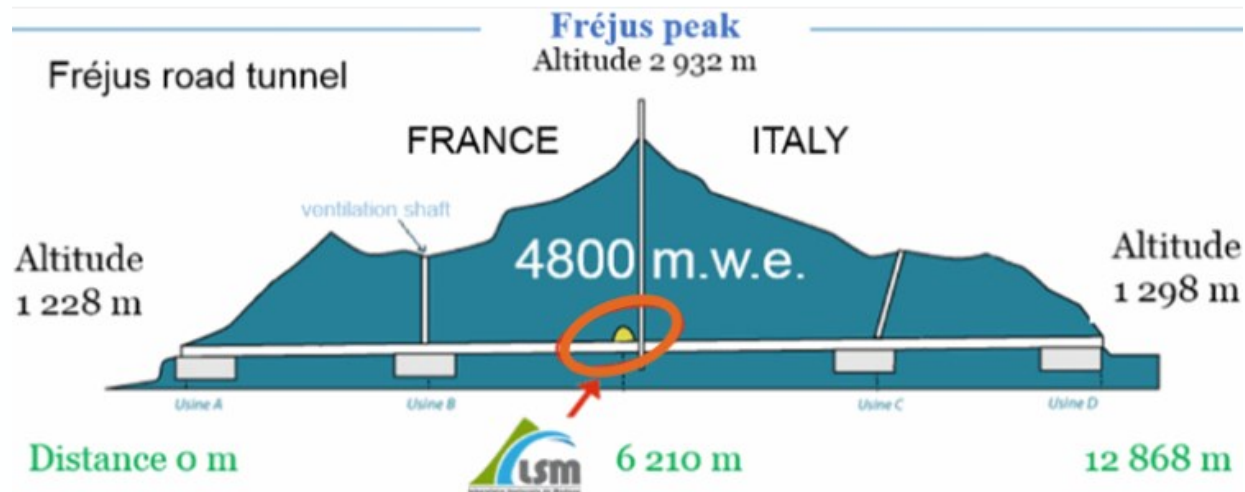
# OMs map



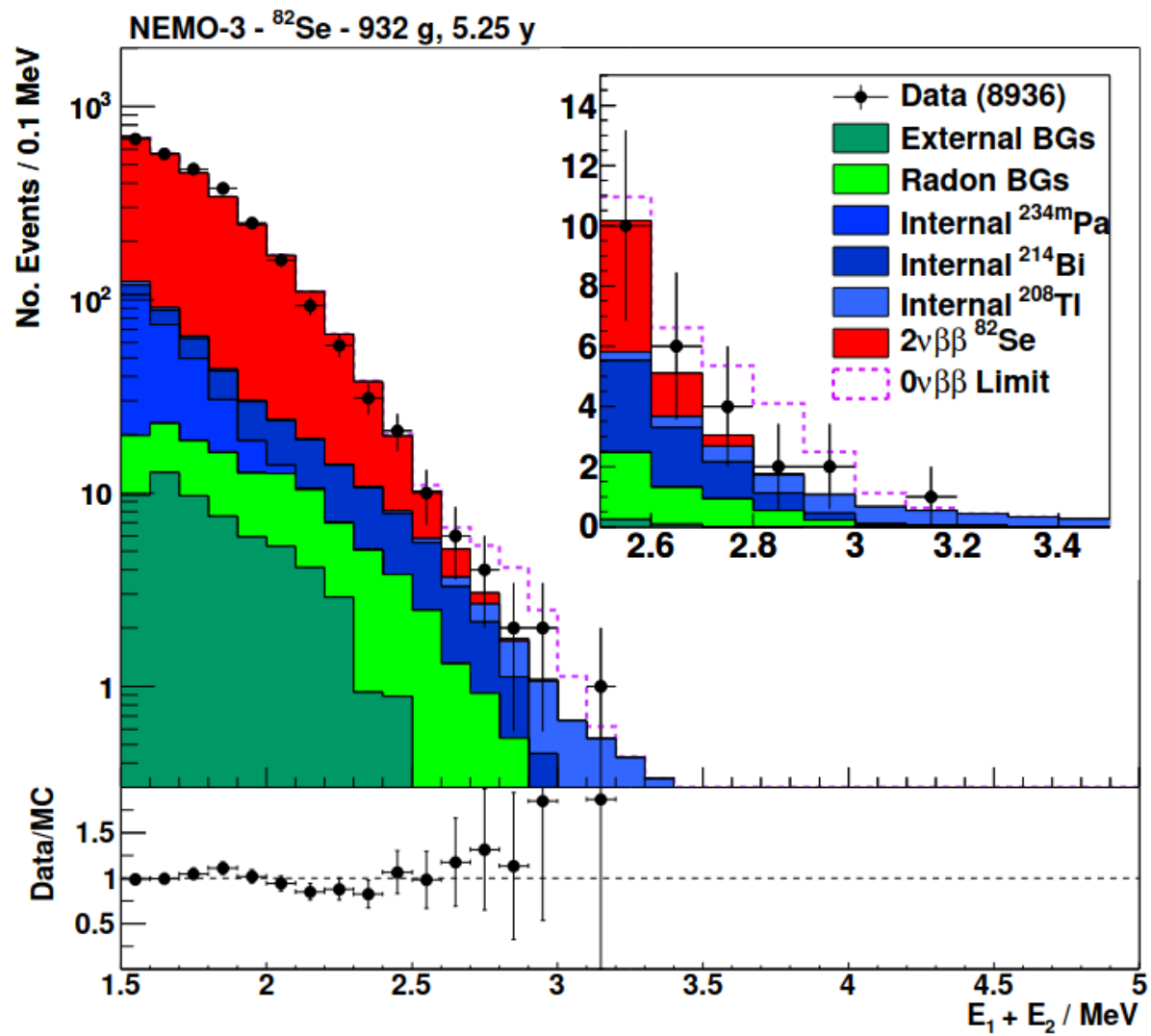
# Muons backgrounds



## Laboratoire Souterrain de Modane (LSM)



Muon flux reduced by a factor  $10^6$

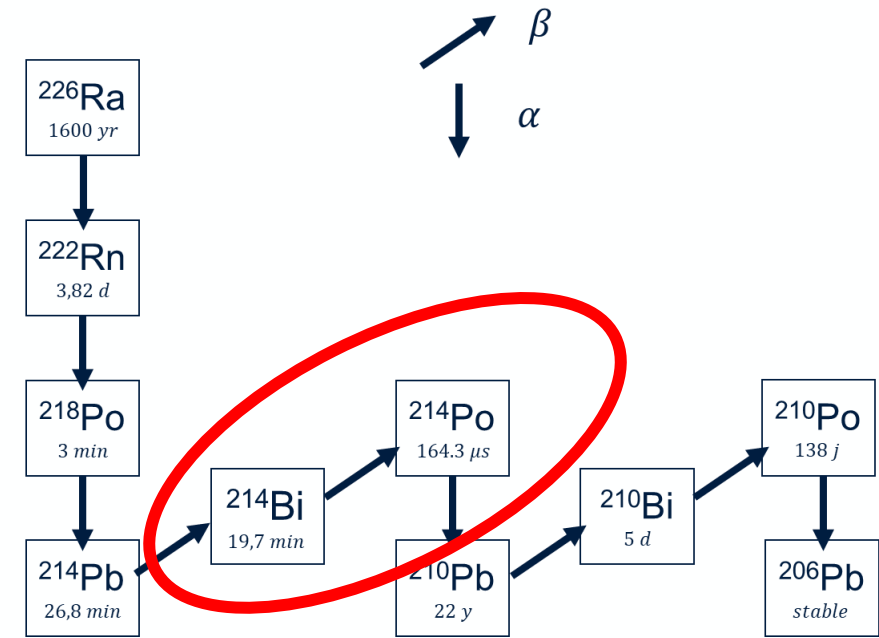
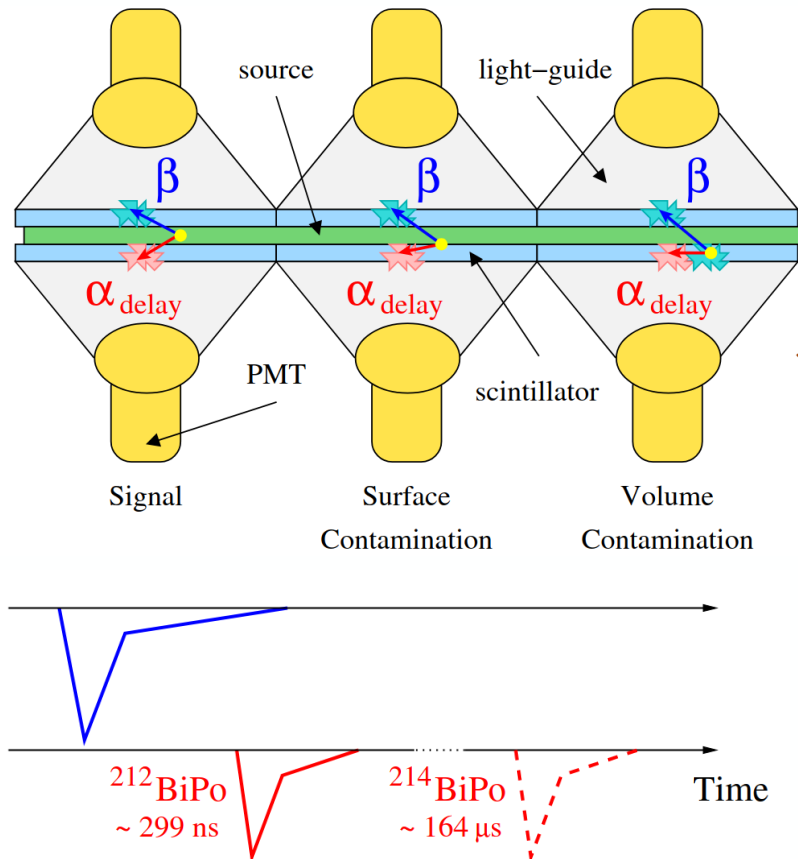


NEMO3 : Radon background contribution in the ROI

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# $^{214}\text{Bi}$ measurements in source foils

Measurements of radiopurity in source foils using “BiPo” detector



$$A(^{214}\text{Bi}) < 300 \mu\text{Bq} \cdot \text{kg}^{-1} \text{ (90\% CL)}$$