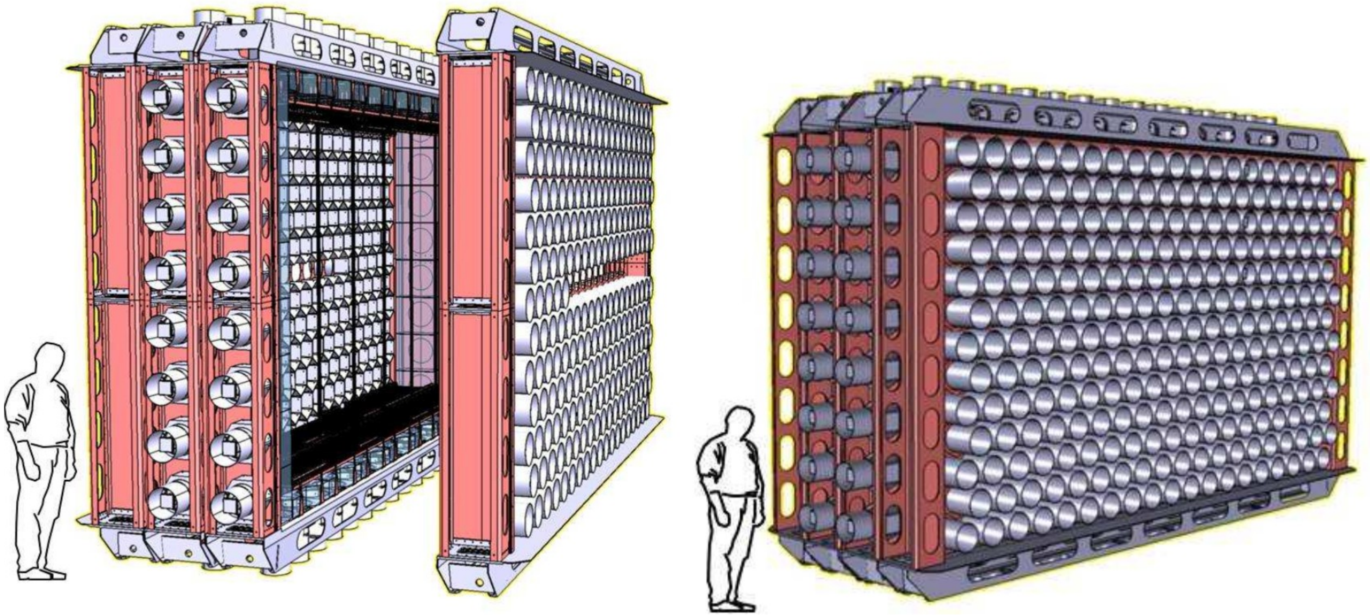
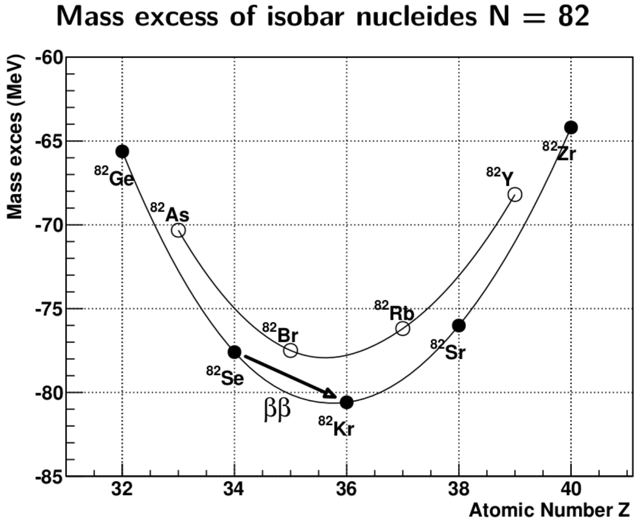
Radon emanation studies in the SuperNEMO double beta decay experiment

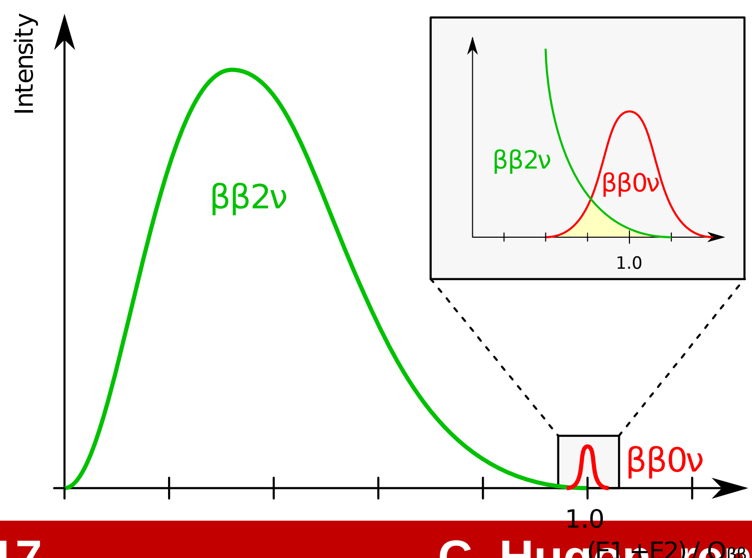


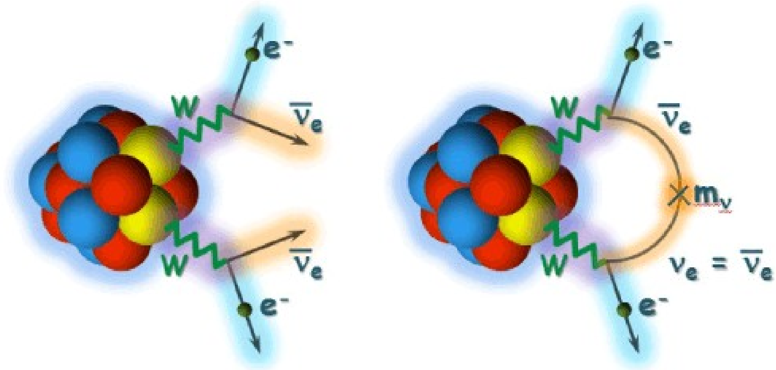
Hugon Christophe on behalf of the SuperNEMO collaboration

The double beta decay



For some isotopes as the ^{82}Se only the ββ decay is allowed





Gives an access to 3 fundamental informations

- Neutrino nature (Dirac or Majorana)
- Effective mass ν_{ee}
- Neutrino mass hierarchy

The both decays have a different energy spectrum

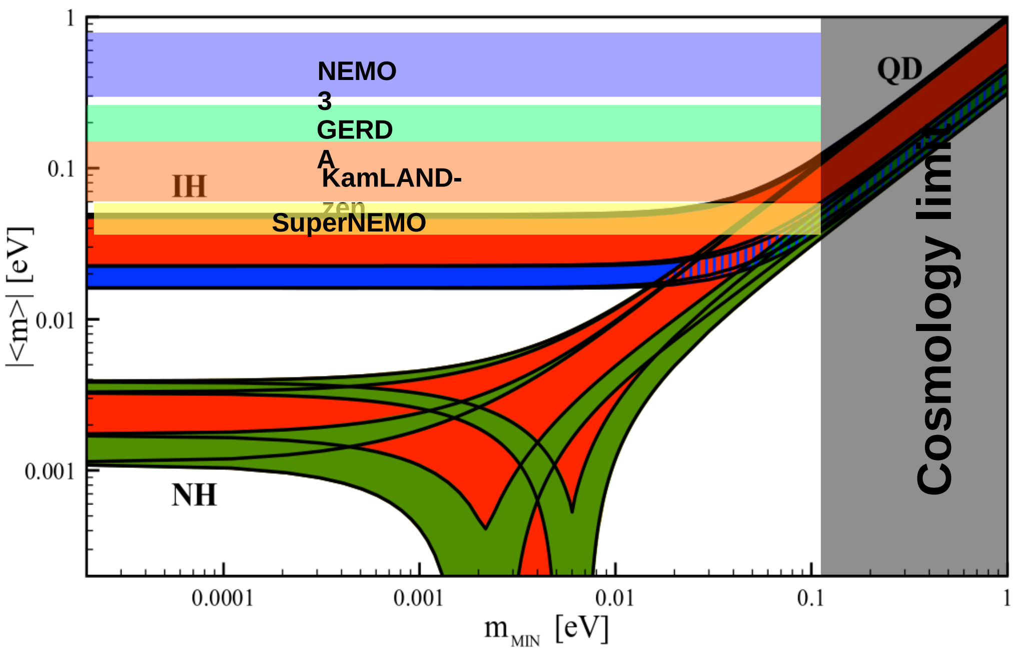
$$T^{1/2}(2\beta 0\nu) \propto \frac{1}{|M|^2 |m_{\beta\beta}|^2}$$

The Double beta decay and the mass hierarchy

$$(T_{1/2}^{0\nu})^{-1} = G_{0\nu}(Q_{\beta\beta}, Z)|M_{0\nu}|^2\langle m_{\beta\beta}\rangle^2$$

$$\langle m_{\beta\beta}\rangle \equiv |\sum_k m_k U_{ek}^2|$$

$$m_{\nu_e} = \left(\sum_i |V_{ei}^2|\ m_i^2\right)^{1/2}$$



The measurement of the double beta decay lifetime and the PMNS angle values gives an access to the hierarchy:

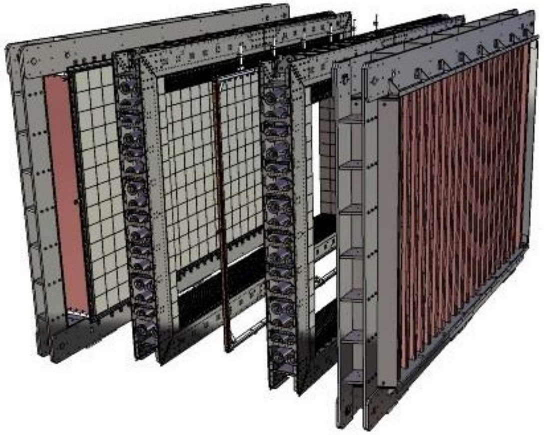
- NH: $<m_{ee}>$ = [4;0] meV
- IH: $<m_{ee}>$ = [60;15] meV & $m_{\nu e}$ ~ 40 meV

Nemo3 ^{100}Mo result: 300-900 meV

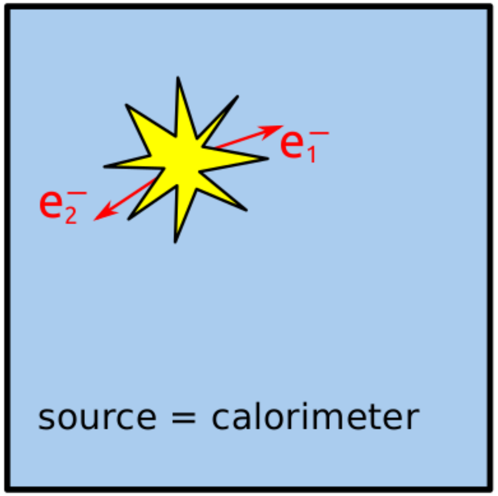
SuperNEMO goal: 50-100 meV

The tracko-calo technology
From NEMO-3 to SuperNEMO

NEMO-3 (2003 - 2011)



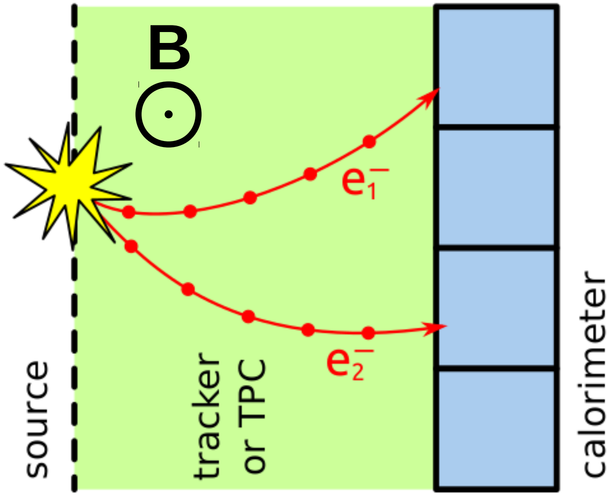
SuperNEMO démonstrateur (≥ 2016)



→ GERDA, KamLAND-Zen, CUORE, ...

The tracko calo technology
- Has a lower efficiency
- Poor energy resolution (8%@1MeV for SuperNEMO)

But
- It has a good electron recognition and ββ kinematics
- It can identify other particles (α,γ,β^+,β^-)
- It can be multi-sources
- Background identification an rejection
- Multi-channel study ββ0ν, ββ2ν, ββ*, ...

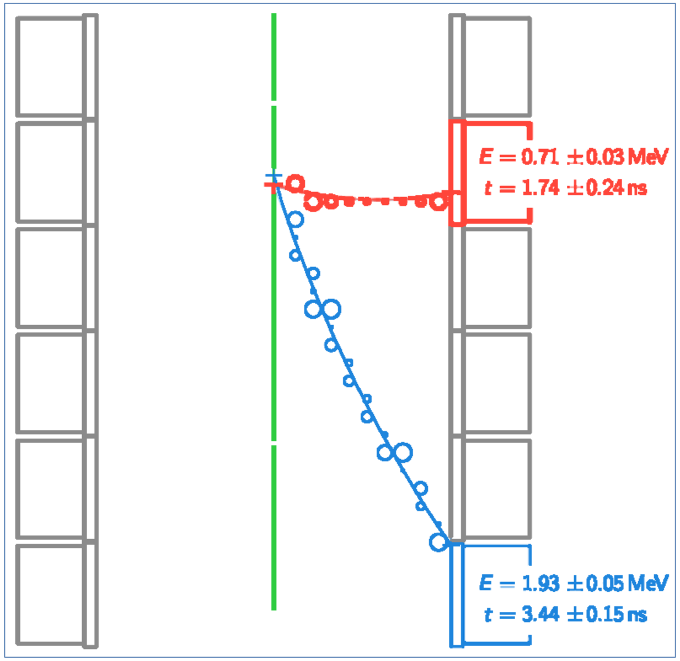


→ EXO, NEMO-3, SuperNEMO

Sources

- Source
  - 7 kg of ^{82}Se ⇄ 17.5 kg.yr
  - $T_{1/2}(2\nu\beta\beta) = 10.3 \pm 0.3$ (stat) $\pm$ 0.7 (syst) 10^{19} y
  - $Q_{\beta\beta}$ = 2,966 MeV

SuperNEMO tracker



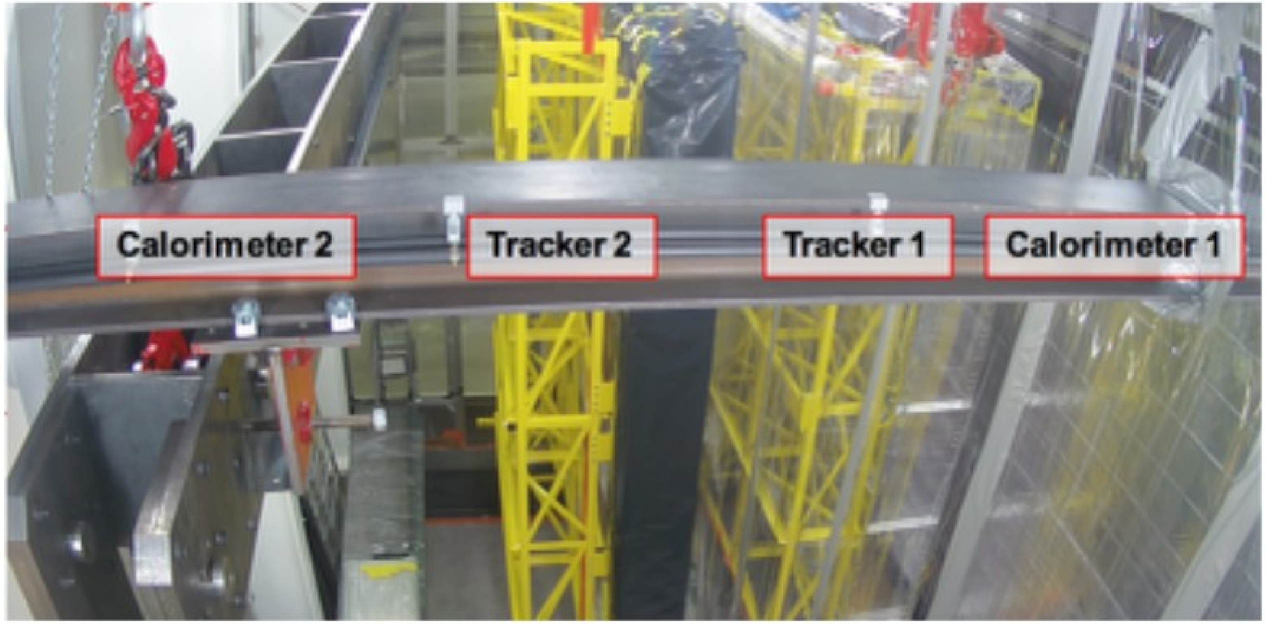
- 2034 wires in Geiger mode in each module (~45 km of wires)
- Ultra pure material (copper, steel, duracon, HPGe tested)
- 3d track reconstruction

Calorimeter walls

- Calorimeter
  - 520 x 8” PM + 192 x 5” PM coupled with polystyrene scintillators
  - Energy resolution: 8% FWHM @ 1 MeV
  - Time resolution: σ = 400 ps @ 1MeV

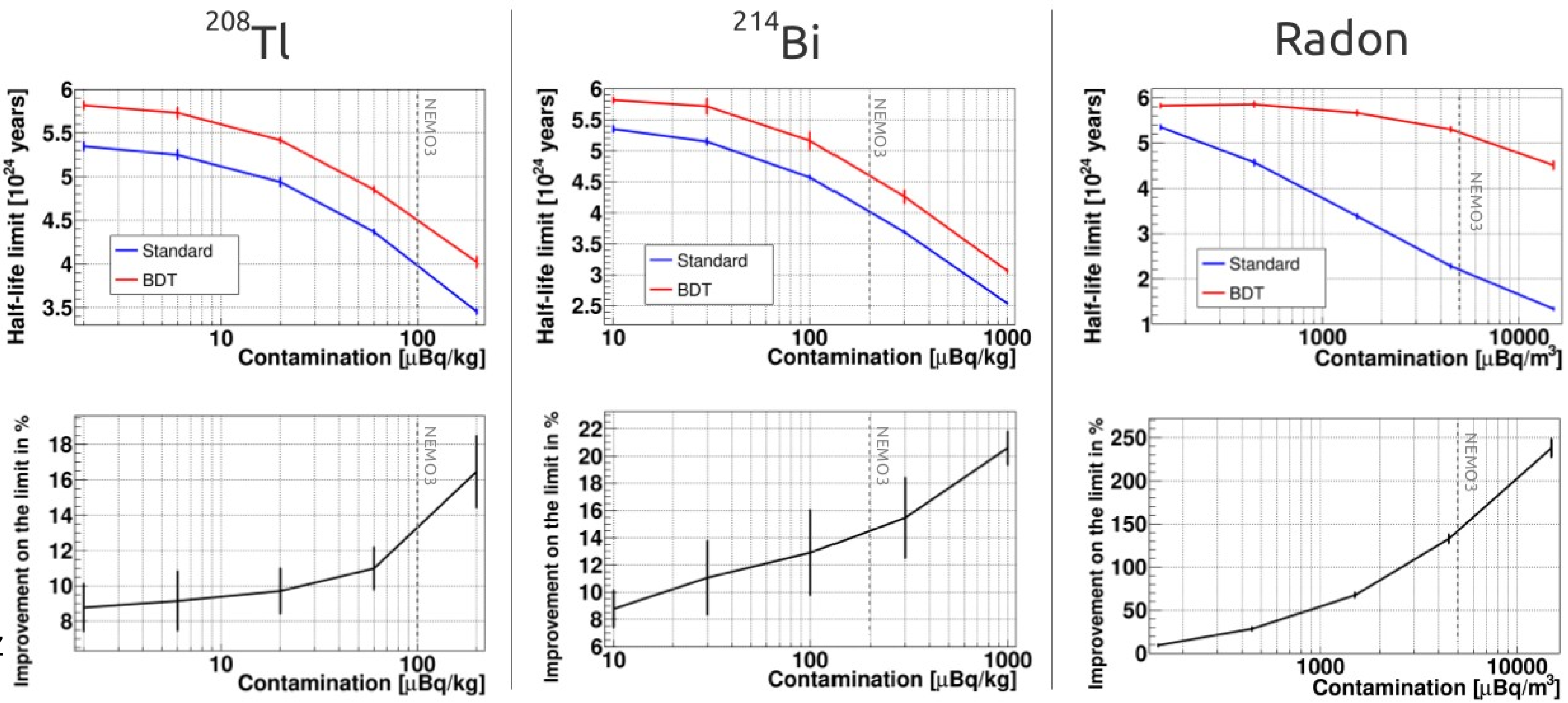
SuperNEMO demonstrator status

- Calorimeter on site, under commissioning
- Source foils radiopurity test ongoing at Canfranc (BiPo detector)
- The demonstrator data taking will start by the end of 2017



SuperNEMO demonstrator sensitivity

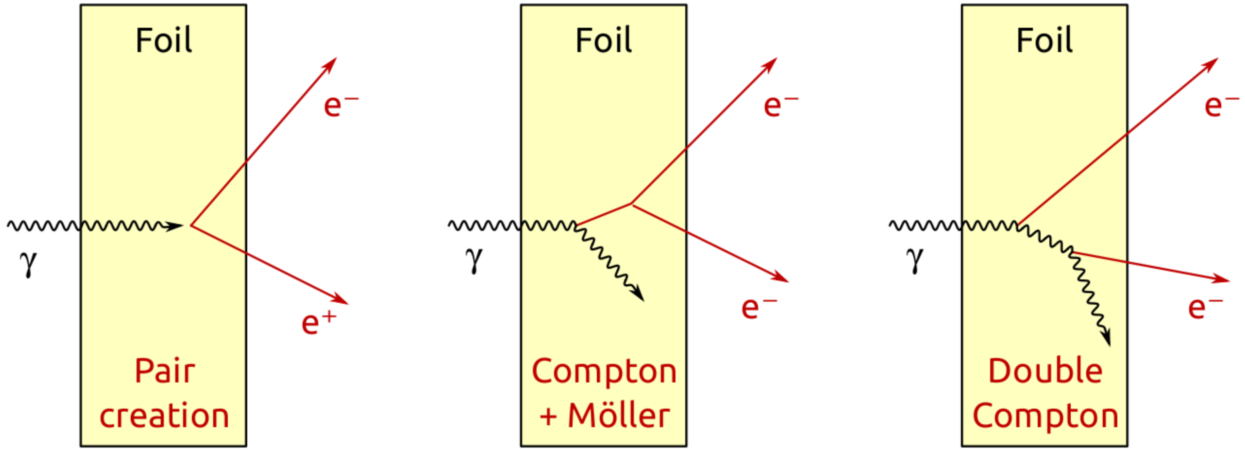
- Train BDTs to discriminate signal events from background events
- Radiopurity requirements : A(208 Tl) = 2 µBq/kg, A(214 Bi) = 10 µBq/kg
- and A(Radon) = 150 µBq/m3
- Half-life limit as a function of the background contamination levels :



Steven calvez
Moriond 2017

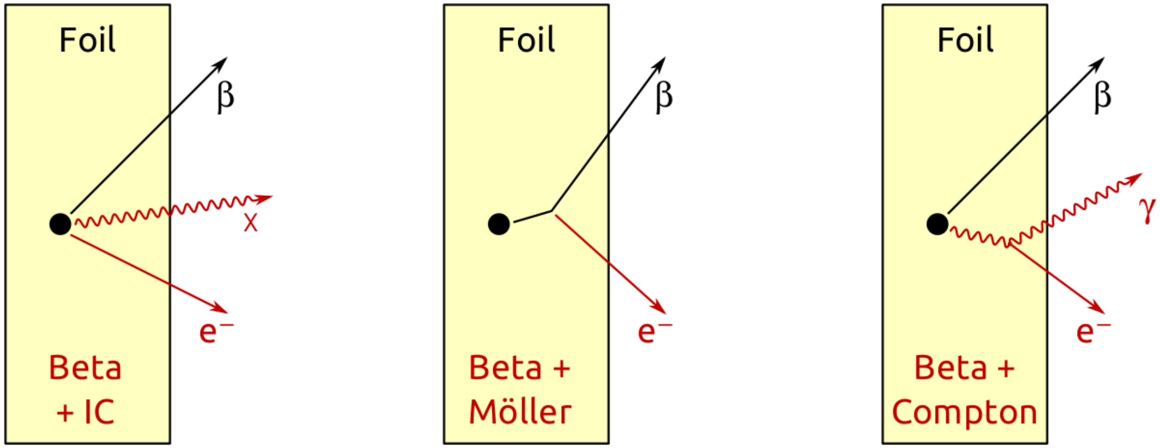
The background noise

- External γ, if not tagged
  - Origin : detector radioactivity, neutrons and cosmics
  - Efficient shielding of SuperNEMO (steel and water) and E < 2.6 MeV ⇒ background for ββ2ν
- Internal contamination in β emitter with $Q_\beta \geq Q_{\beta\beta} \sim 3$ MeV
  - ^{214}Bi in ^{238}U chain (Q_β = 3.3 MeV)
  - ^{208}Tl in ^{232}Th chain (Q_β = 4.9 MeV)
- Radon inside tracking detector
  - decay then deposit of daughter on wire and foil surfaces
  - feed internal contamination in ^{214}Bi



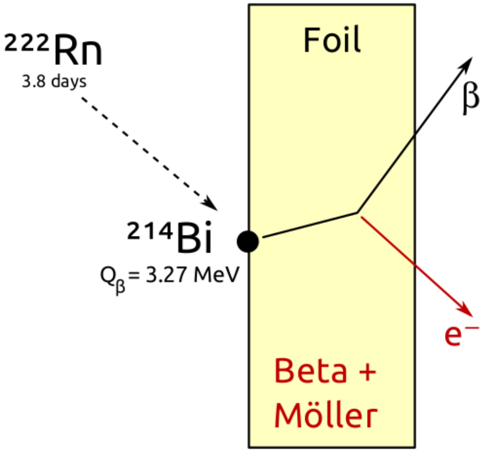
The background noise

- External γ, if not tagged
  - Origin : detector radioactivity, neutrons and cosmics
  - Efficient shielding of SuperNEMO (steel and water) and E < 2.6 MeV ⇒ background for ββ2ν
- Internal contamination in β emitter with $Q_\beta \geq Q_{\beta\beta} \sim 3$ MeV
  - ^{214}Bi in ^{238}U chain (Q_β = 3.3 MeV)
  - ^{208}Tl in ^{232}Th chain (Q_β = 4.9 MeV)
- Radon inside tracking detector
  - decay then deposit of daughter on wire and foil surfaces
  - feed internal contamination in ^{214}Bi



The background noise

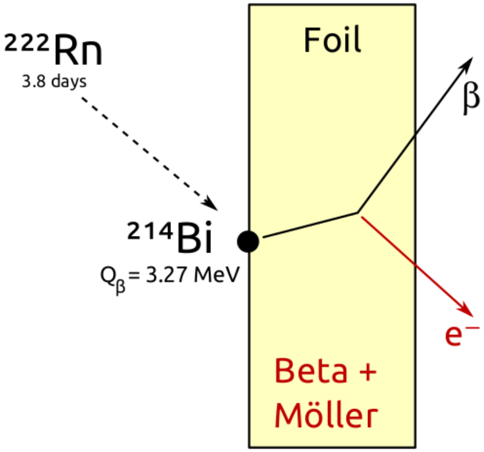
- External γ, if not tagged
  - Origin : detector radioactivity, neutrons and cosmics
  - Efficient shielding of SuperNEMO (steel and water) and E < 2.6 MeV ⇒ background for ββ2ν
- Internal contamination in β emitter with $Q_\beta \geq Q_{\beta\beta} \sim 3$ MeV
  - ^{214}Bi in ^{238}U chain (Q_β = 3.3 MeV)
  - ^{208}Tl in ^{232}Th chain (Q_β = 4.9 MeV)
- Radon inside tracking detector
  - decay then deposit of daughter on wire and foil surfaces
  - feed internal contamination in ^{214}Bi



The background noise

- **External γ, if not tagged**
  - Origin : detector radioactivity, neutrons and cosmics
  - Efficient shielding of SuperNEMO (steel and water) and E < 2.6 MeV
    ⇒ background for ββ2ν
- Internal contamination in β emitter with $Q_\beta \geq Q_{\beta\beta} \sim 3$ MeV
  - ^{214}Bi in ^{238}U chain (Q_β = 3.3 MeV)
  - ^{208}Tl in ^{232}Th chain (Q_β = 4.9 MeV)
- **Radon inside tracking detector**
  - **decay then deposit of daughter on wire and foil surfaces**
  - **feed internal contamination in ^{214}Bi**

Under construction demonstrator
- **7 kg of ^{82}Se**
- **BG 10^{-4} evt/keV/kg/y**
- **$|m_{\beta\beta}|$ < 0.2-0.4 eV in 2,5 years**

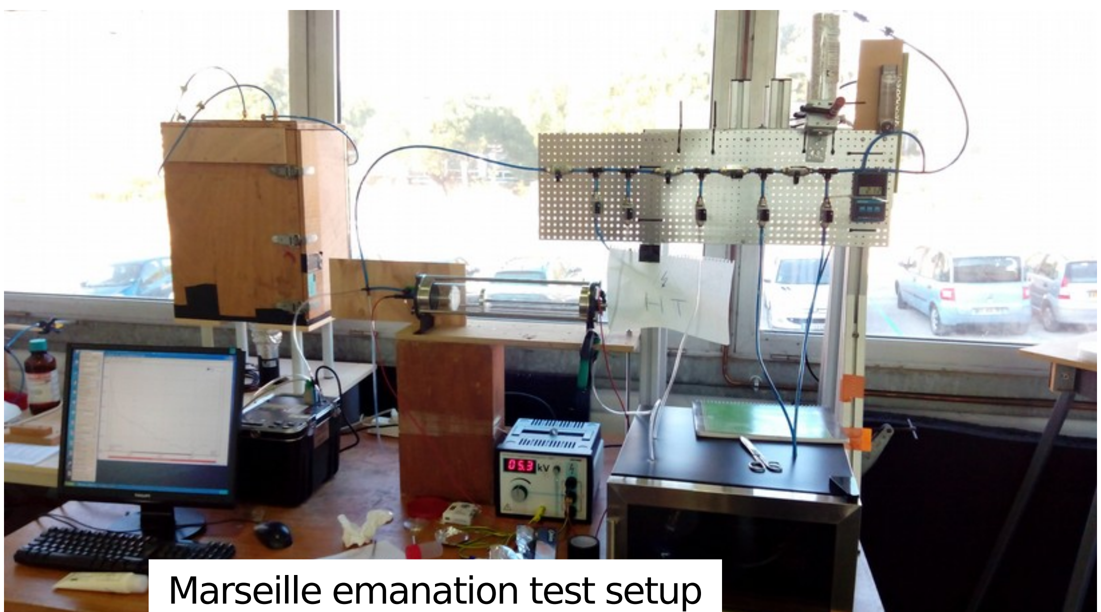


^{222}Rn is a major BG
The 150µBq/m^3 goal is hard to reach, but also to control: Radon contamination measurements

The radon measurements among the SuperNEMO collaboration

- CENBG Bordeaux
- UCL London
- IEAP CTU Prague
- **CPPM Marseille**


Bordeaux emanation setup

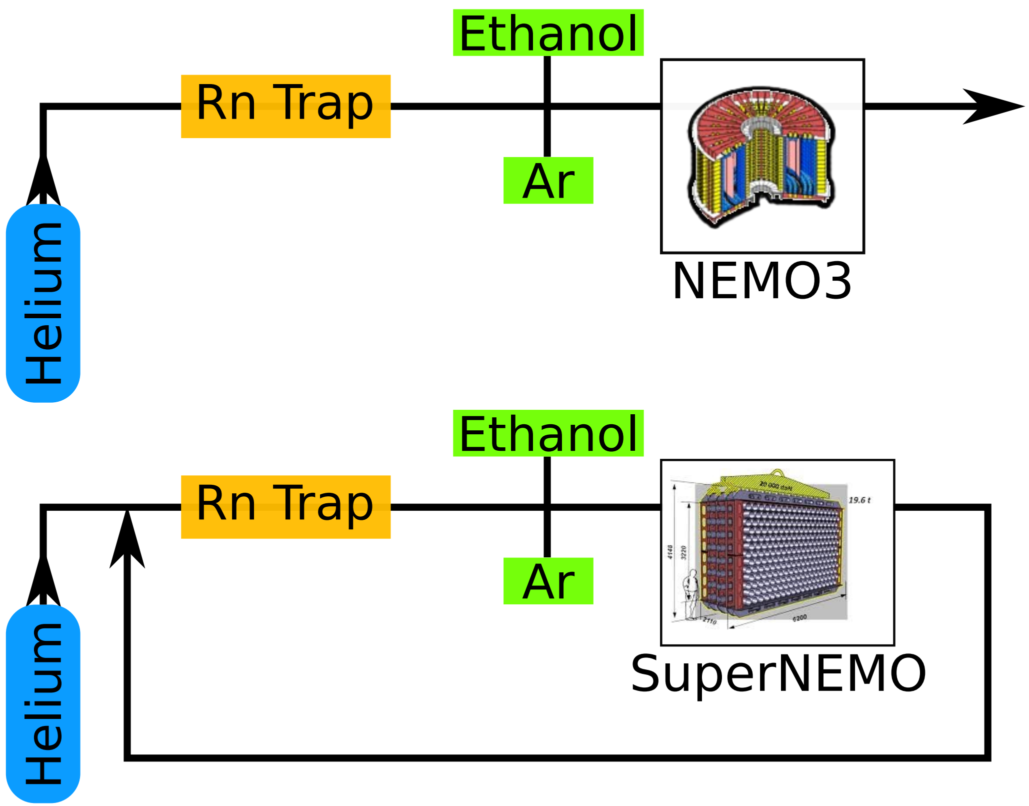

Marseille emanation test setup


London concentration line

R&D on low background studies in the SuperNEMO CPPM group

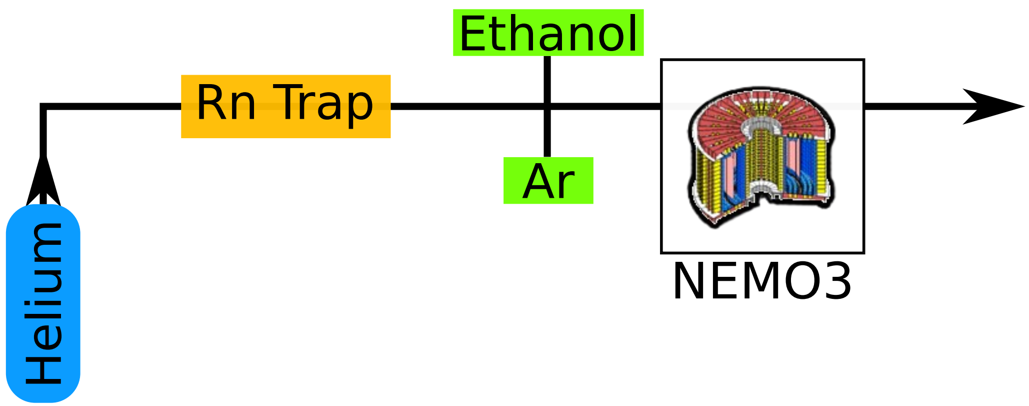
- Proportional spherical detector for continuous survey of radon rate in SuperNEMO gas
- Charcoal radon trap testing for the SuperNEMO gas purification
- **Radon transportation in the SuperNEMO gas studies**
- **Radon Emanation of material depending on the gas nature (helium, humidity, ethanol...)**

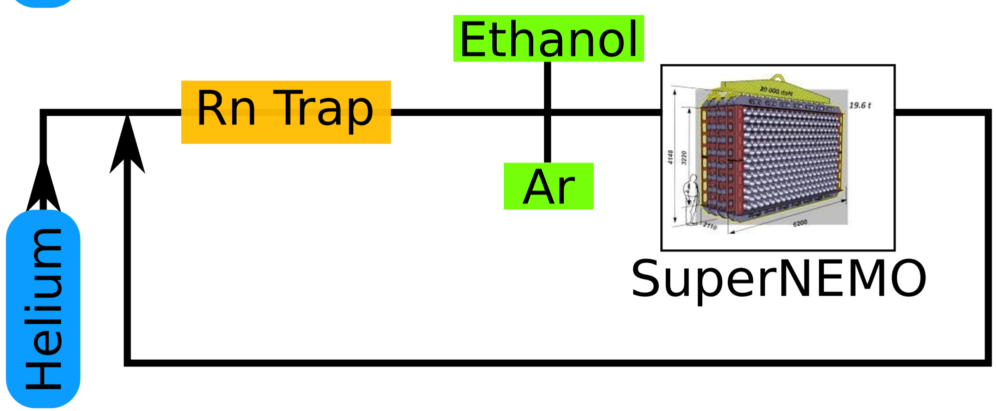
The radon transportation in the detector



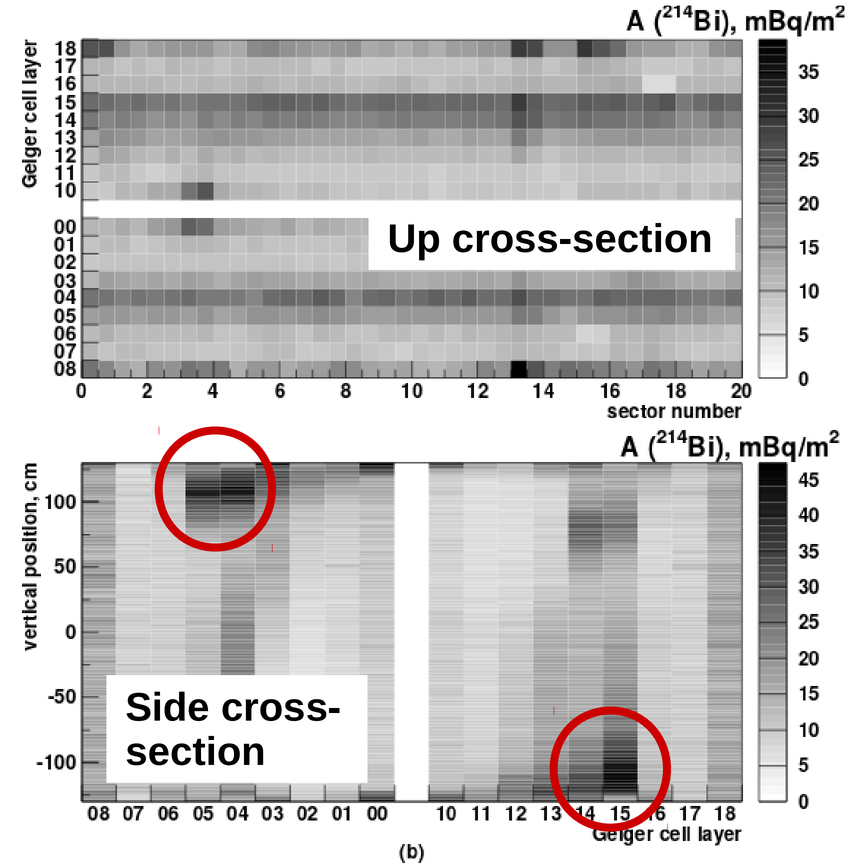
- Principle:
  - Continuous purified gas flushing in the detector wire chamber
  - Order of magnitude 1 m^3/h
  - ^{222}Rn goal for superNEMO 150 $\mu Bq/m^3$
  - Gas recycling system for SuperNEMO

The radon transportation in the detector





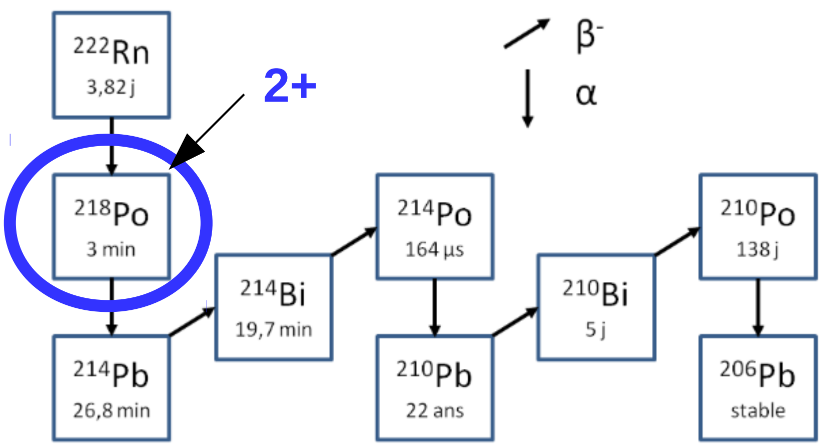
Radon hot spots in NEMO3 wire chamber



A better knowledge of the radon distribution in the detector would improve the total sensitivity

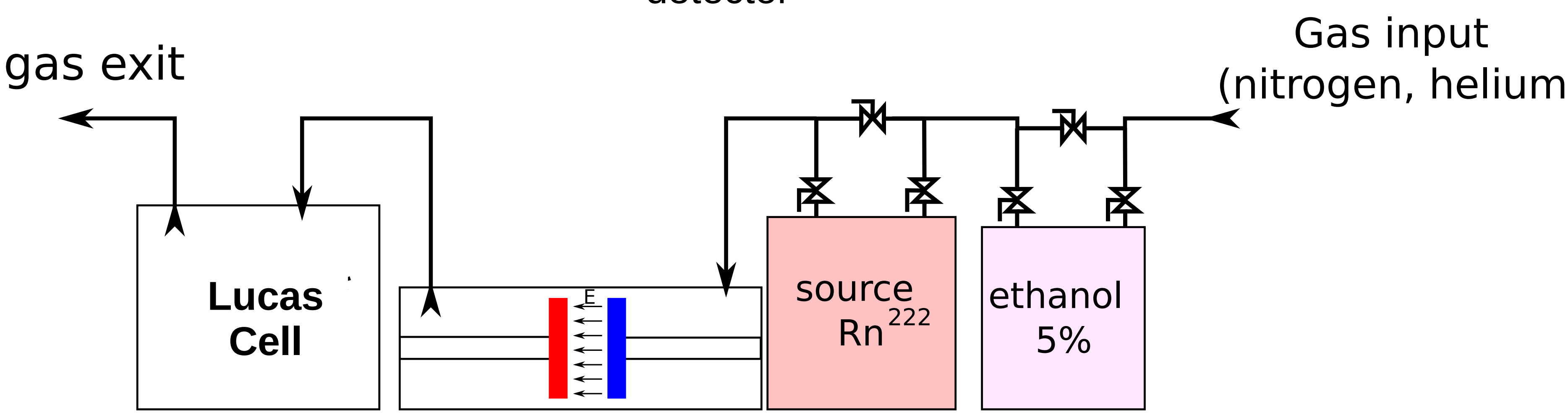
⇒ Fluid mechanics, electrostatic and neutralization/decays simulation to estimate the radon transportation in the wire chamber

The experimental setup of radon transportation measurements

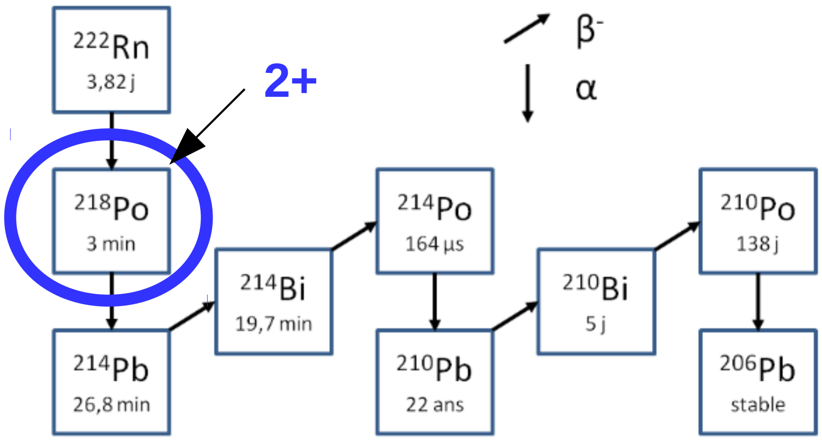


- Objective: Estimation of deposit of $^{218}Po^{2+}$ in the SuperNEMO chamber the wire → simulation FEM and experimental measurements
- Simpler setup for calibration/validation of simulation and measurements
- Measurement of ethanol role transportation/**neutralization**

- kBq/m^3 of radon in the input gas
- 1 kV/cm between electrodes
- The deposit on the anode is measured with an Ge detector

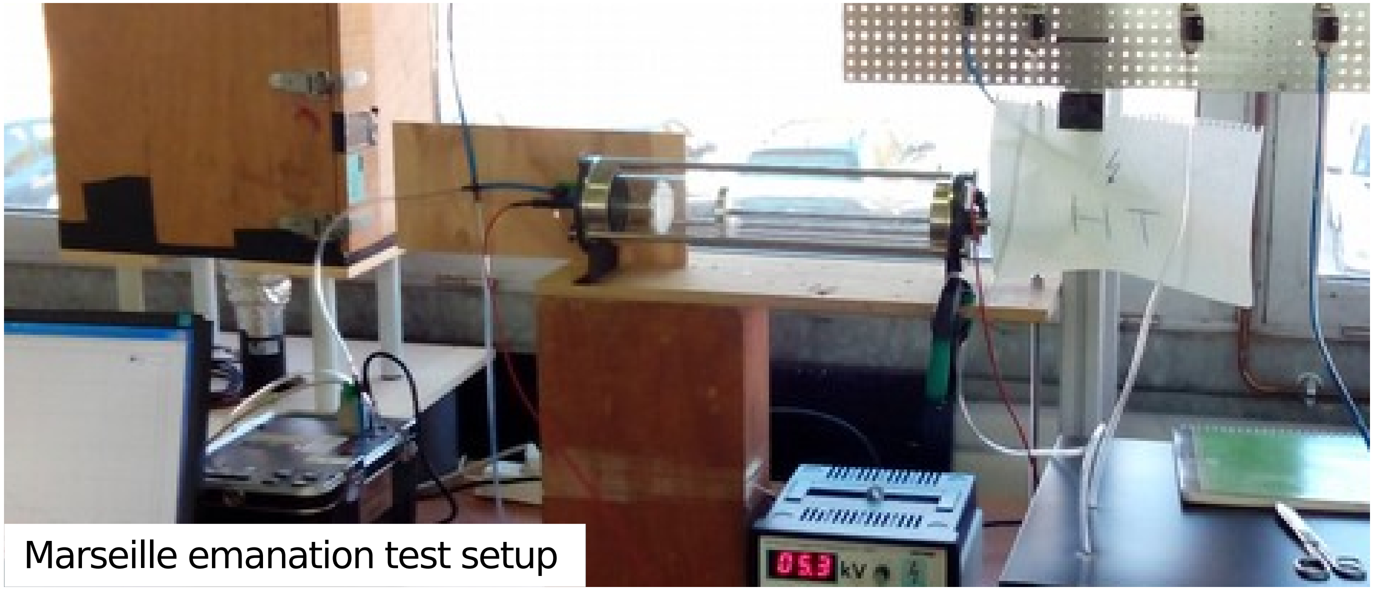


The experimental setup of radon transportation measurements



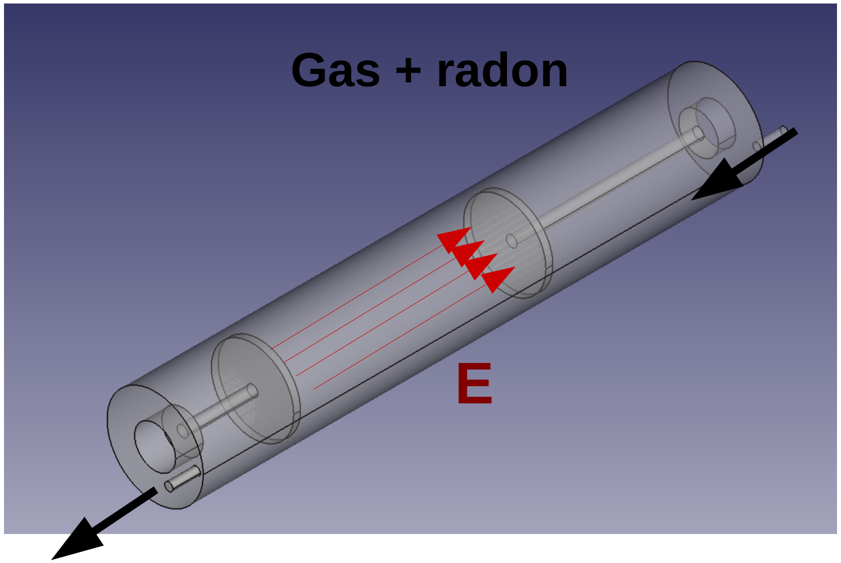
- Objective: Estimation of deposit of $^{218}Po^{2+}$ in the SuperNEMO chamber the wire → simulation FEM and experimental measurements
- Simpler setup for calibration/validation of simulation and measurements
- Measurement of ethanol role transportation/**neutralization**

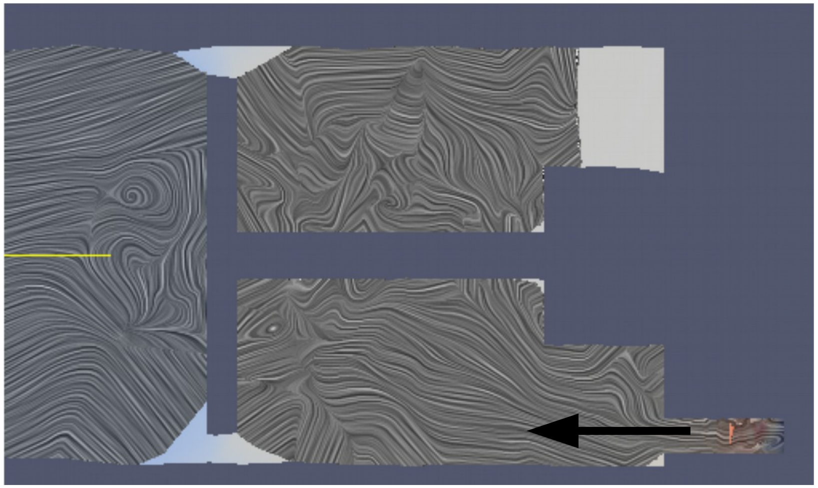
- kBq/m³ of radon in the input gas
- 1 kV/cm between electrodes
- The deposit on the anode is measured with an Ge detector

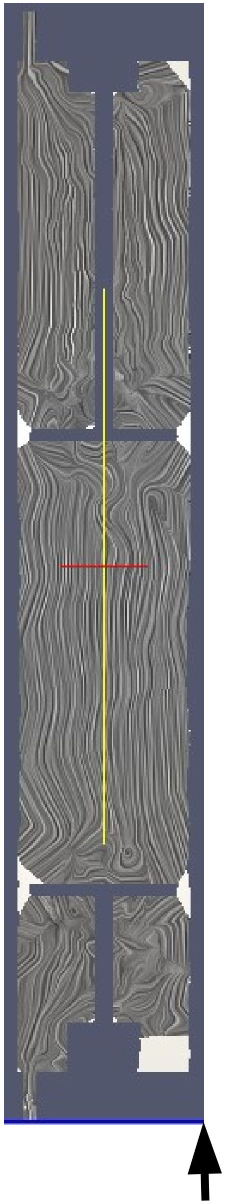


Marseille emanation test setup

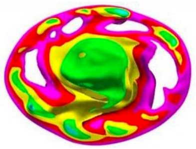
The fluid mechanics simulation







- Finite Element Method: ElmerFEM
  - Electrostatic
  - Fluid Mechanics
  - Time dependence

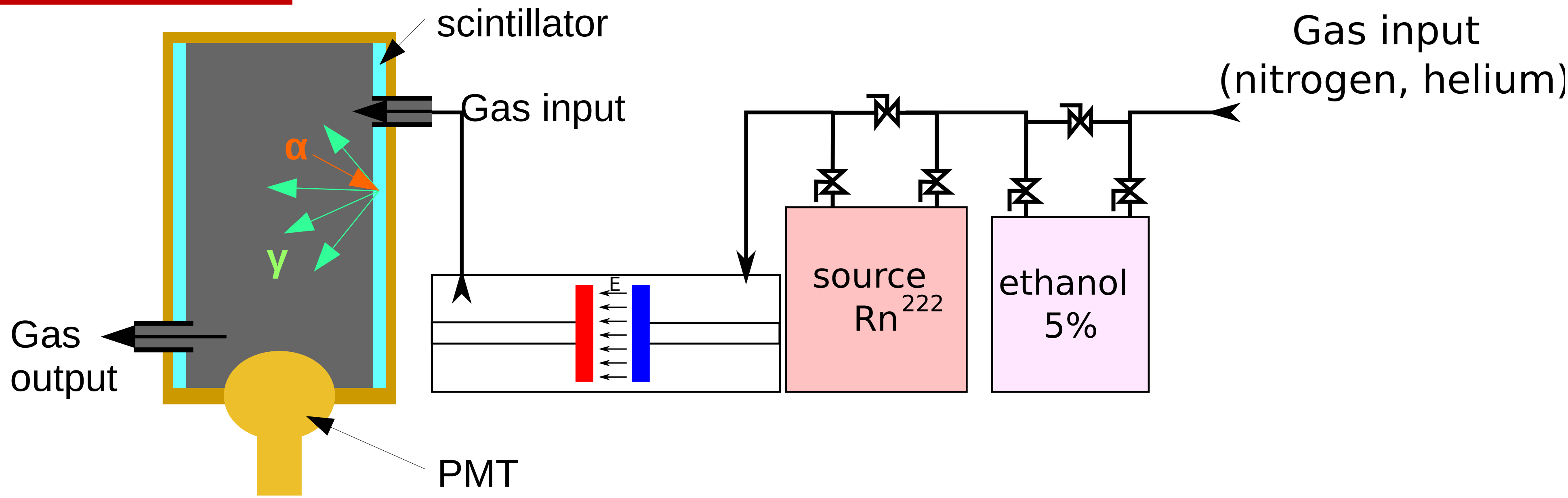


- Custom step-by-step simulation
  - Taking elmer data as input
  - Transportation of radon/polonium in in the flux
  - Decays/neutralization based on the half-life time
- Experimental measurement and simulation done with 0% and 4% of ethanol in the gas.
- Once validated and calibrated, it will be applied to the SuperNEMO volume

The first results and by-product

- **The first results showed an discordance between the experimental data and simulation! (roughly 2 times experimental excess in the 4% ethanol case)**
- Hypothesis:
  - There's a known humidity effect that increase the emanation rate (IJSR, ISSN (Online): 2319-706)
  - The radon emanation from the source material is also dependent to the rate of ethanol in the gas?
- Inverting the source and ethanol in the circuit suppressed this effect
- **By-product measurement: emanation rate of the source with and without ethanol in the gas**

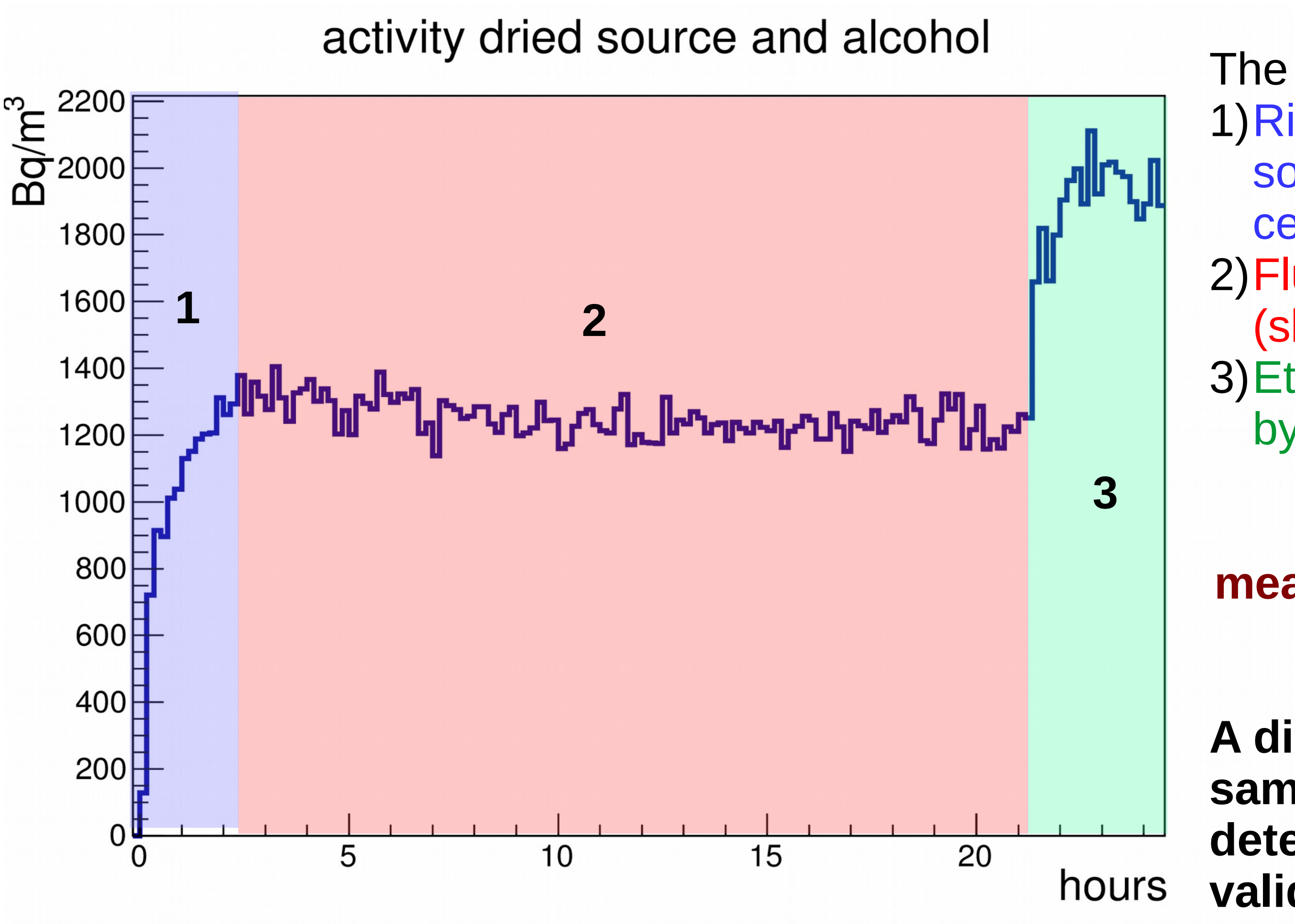
Measurment of the radon emanation with of ethanol exposure



- The common radon detector is based on the detection of $^{218}Po^{2+}$ thanks to a electrostatic collection of alpha-emitters.
- The presence of alcohol **neutralize the $^{218}Po^{2+}$** and make the measurements unreliable.

A Lucas cell has been used instead.

Measurement with "dried" source then exposed to ethanol



The measurement has 3 zones:

1) Rising until the equilibrium of the source activity and the Lucas cell volume
2) Flushing with dry nitrogen: stable (slow decrease)
3) Ethanol (4%): activity multiplied by **~2**

The source emanation measurements showed increase mean of 1,7!

A different setup based on sample injection and germanium detector indirect measurement validated this result at 3σ.

There is a strong dependence on ethanol rate and source emanation
The radio-purity should be measured taking this effect in account

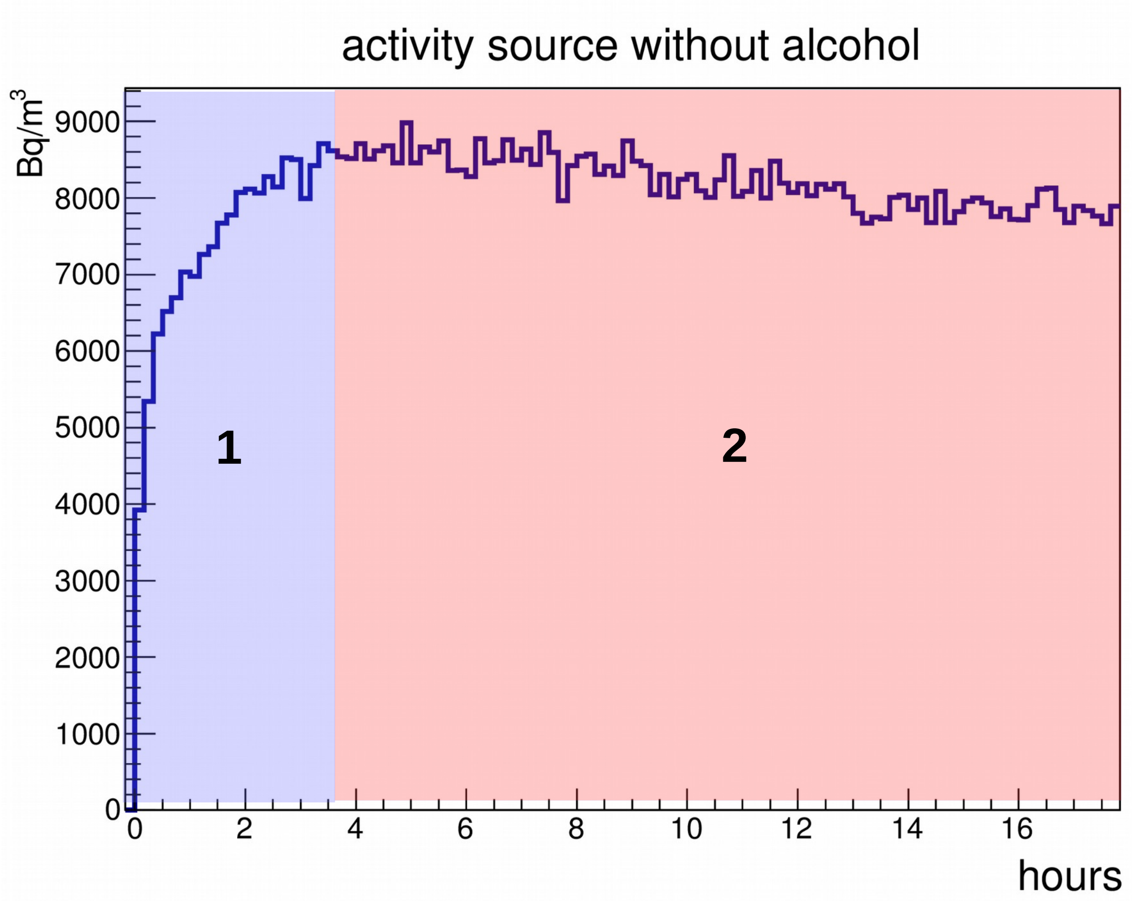
Summary, conclusions and perspectives

- SuperNEMO detector
  - Tracko-calo technology validated by NEMO3, used by SuperNEMO
  - The demonstrator commissioning started, the data taking should start by the end of the year
  - Demonstrator sensitivity $T_{1/2}^{0\nu} \sim 10^{24}$ years
  - 20 Modules final detector sensitivity $T_{1/2}^{0\nu} \sim 10^{26}$ years

- Radon measurement R&D
  - Expertises from the NEMO3 experiment (emanation chambers, gas circulation etc.)
  - New innovative approaches (transportation) for a better understanding of radon contamination in very low background experiments
  - Evidences for material emanation in function of the nature of gas (ethanol rate)
    - Essential for very low background experiment!
    - The material radio-purity measurements have to be done in the experimental gas
    - Additional measurement under going (humidity, helium, nitrogen etc...)

backup

Results with source, no alcohol



The source has been directly used, from ambient air (and “normal” humidity)

The flushing gas is dried nitrogen, at 10 l/h

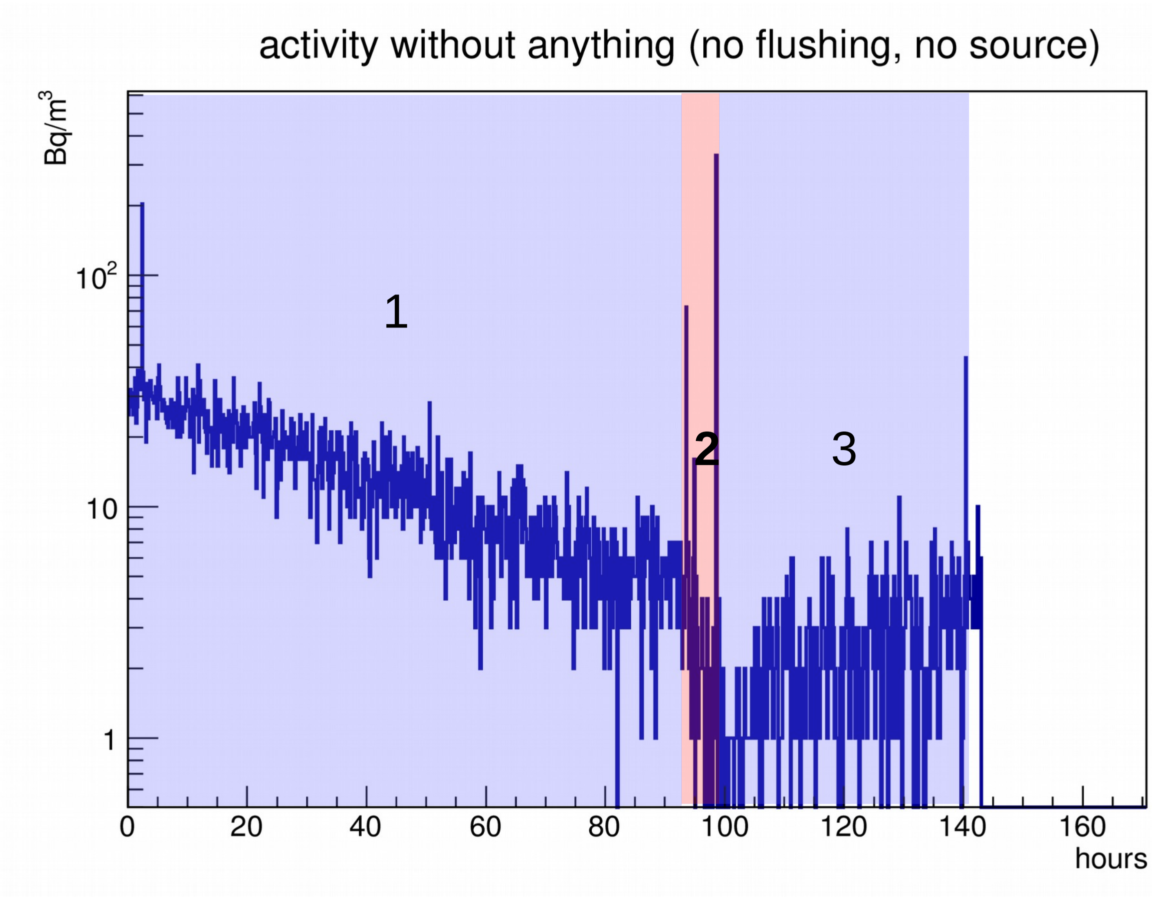
The preparatory measurement has been done for 17 hours. 2 zones are observed:

1) Flushing period: the radon come to equilibrium between the source and the Lucas cell,
2) The “stable” zone

The measurement seems stable and reliable

The slow decreasing will be explained later.

Test of the Lucas cell stability and alcohol sensitivity



To test the Lucas cell (PMT gain fluctuations, noise fluctuations) the Lucas was left without gas flushing, with and without alcohol injection:

1) No flushing, we see the decreasing of the ^{222}Rn decay rate (3.8 days) from the previous measurement
2) ~5 hours of 5% alcohol nitrogen flushing
3) No flushing (the alcohol remains inside the cell)

No counting rate fluctuations
No alcohol impact

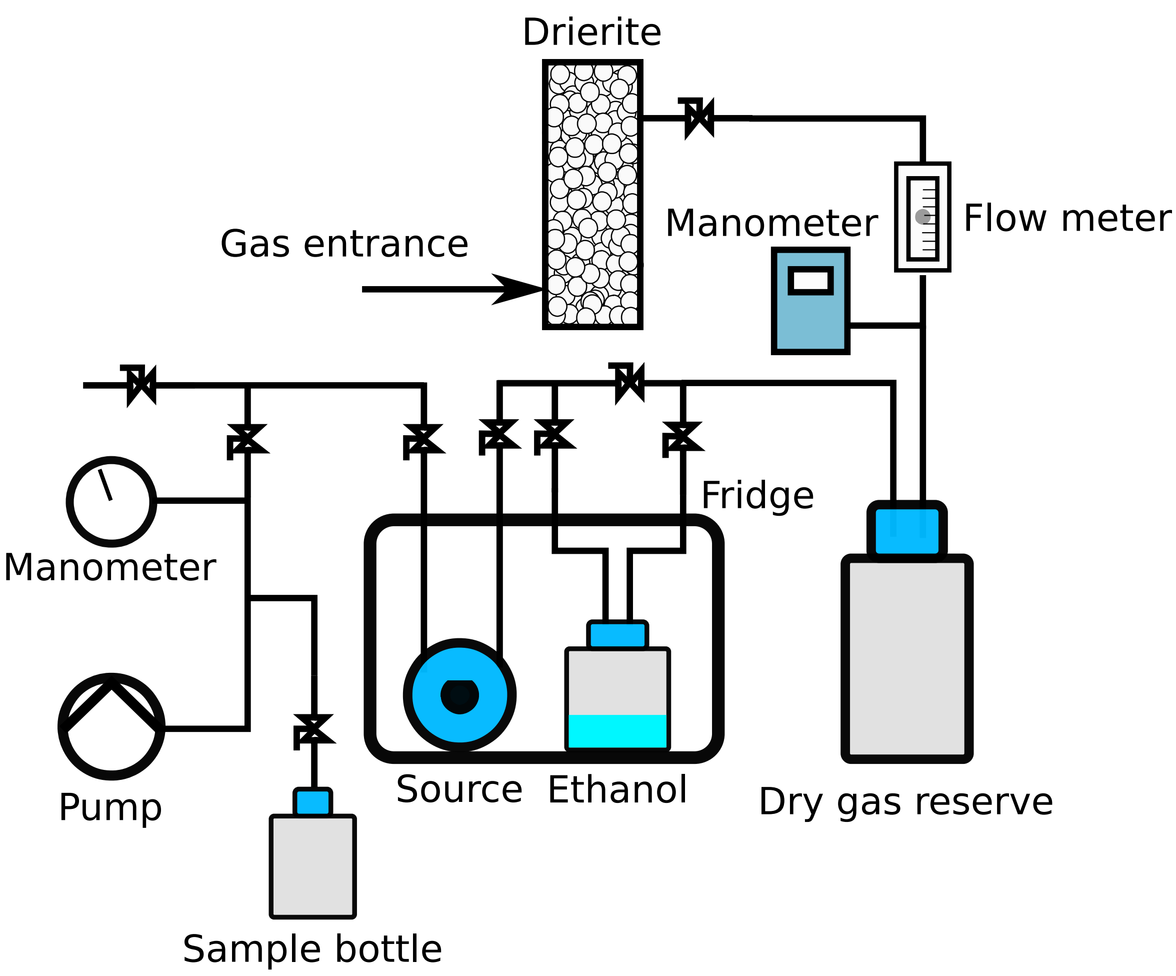
A word about the source and its preparation

- We have two kinds of source
  - Rocks
    - Centimeter sized
    - Porous ?
    - The recipient contains smaller rocks (mm) and dust
  - Clock hands
    - Millimeter sized
    - Less porous than rock?
- The drying out process has been automatized
  - At 150°
  - The recipient is emptied and fill back each minutes during 15 min cycles
  - A cycle each 30 min during a full night
- We are thinking to do it with the tested gas (now using ambient air)

Why a different setup

- To have a detector that is not exposed to the gas mixture (totally independent to the ethanol/humidity rates)
- To cross check the result with another way to measure it
- Idea:
  - Injection in a small bottle of source gas
  - Measurements done thanks to a germanium detector (^{214}Bi 609 keV gamma rays)

Summary of the new setup



- The setup is mostly the same:
  - The source is exposed to the gas during one hour
  - The sample bottle is under vacuum (50 mbar)
  - The vans are open such a way that the sample bottle fill itself with the gas from the source
  - Then the bottle is closed and placed in a germanium detector to measure the gas activity

The result is given in “hit”, the interesting point is to get a relative result with and without ethanol

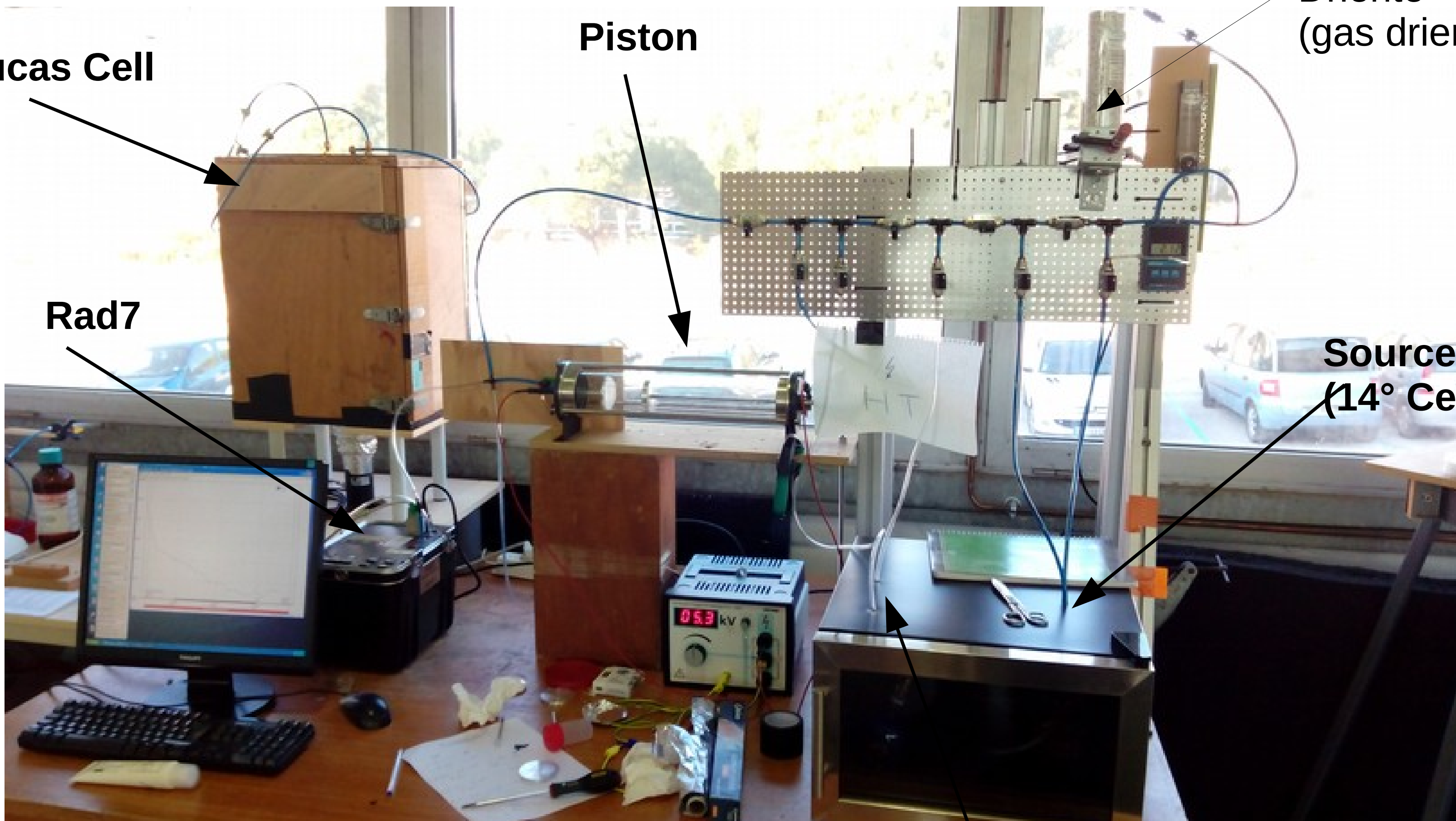
Summary of the first results and remarks

	Dried out source	5% ethanol + source	Totals, difference & sigma total
Nb Measurements	32	15	Total: 47
609 keV γ hits mean	359	578	Difference: 219
Errors	+/-52	+/-51	+/-73

- The measurements gave a relative difference of **~1.6 at 3σ** between dried out and ethanol exposed sources
- This setup much harder to manage (complex protocole) so it has bigger systematics errors
- Even if during the measurement protocol weakness has been identified, few measurement has been excluded (only them with clearly identified errors)

It validates previous measurements at 3σ
Need to reach 5σ?

What it looks like?



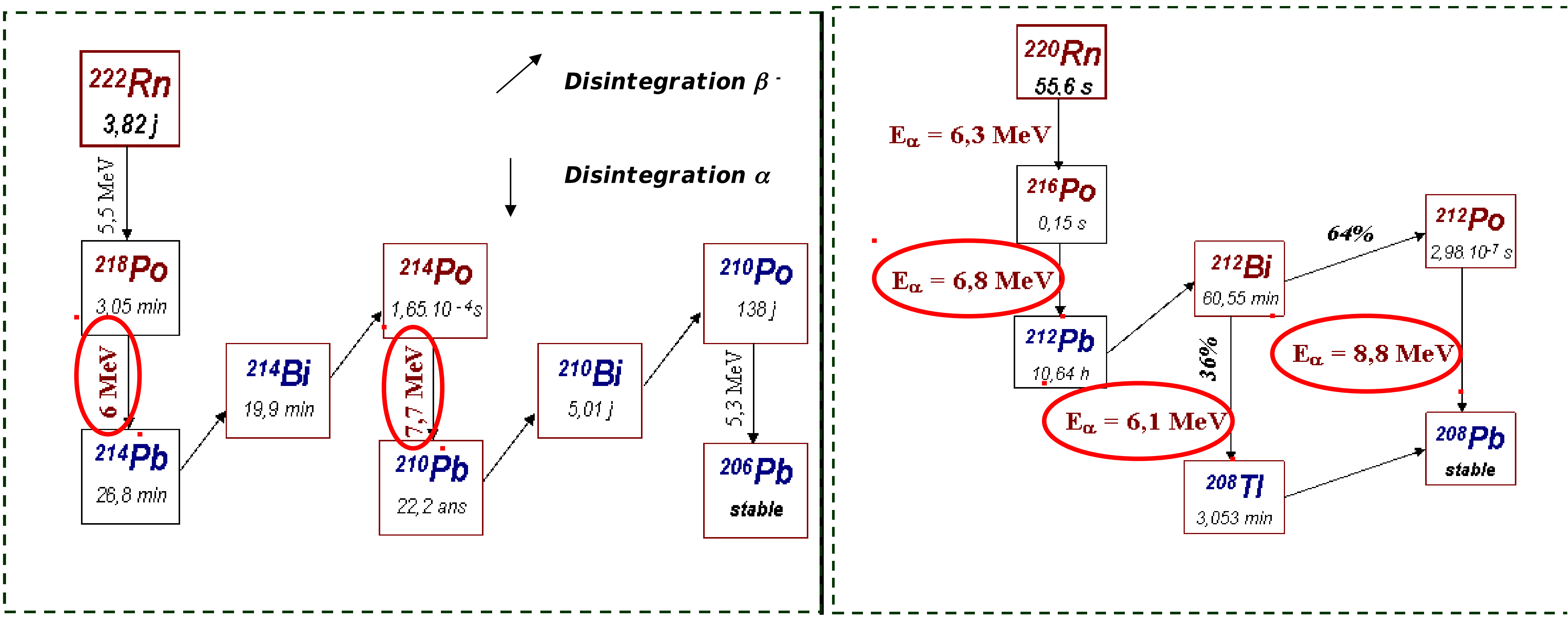
Radon and thoron decay chains

Radon

(Chain of l'^{238}U)

Thoron

(Chain of ^{232}Th)

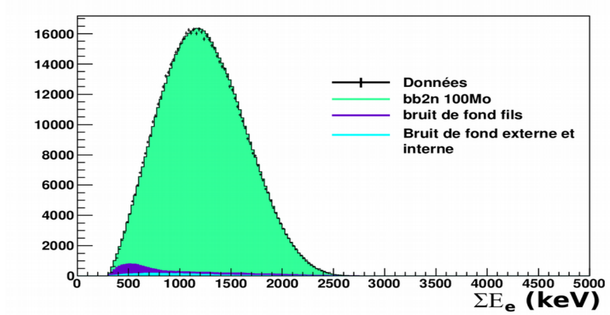


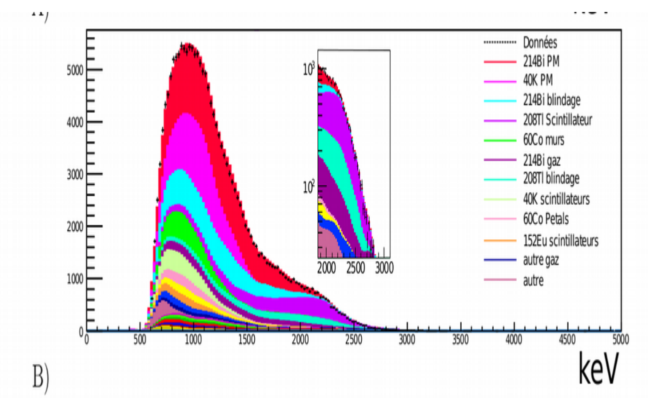
- Remarks :

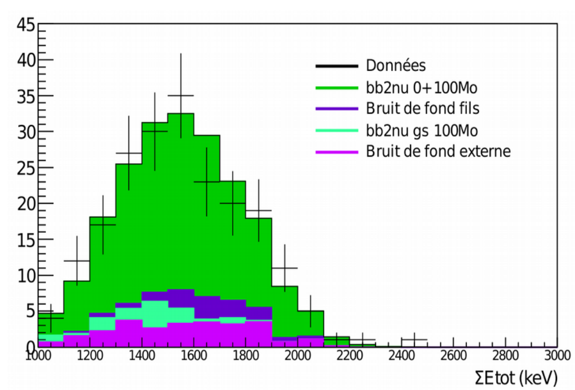
- The two decay chains are identical in the chemical point of view
- The main difference comes from the periods : 56 seconds for the thoron
  3.8 days for the radon

reconstruction

The reconstruction of the events and NEMO3 spectrums

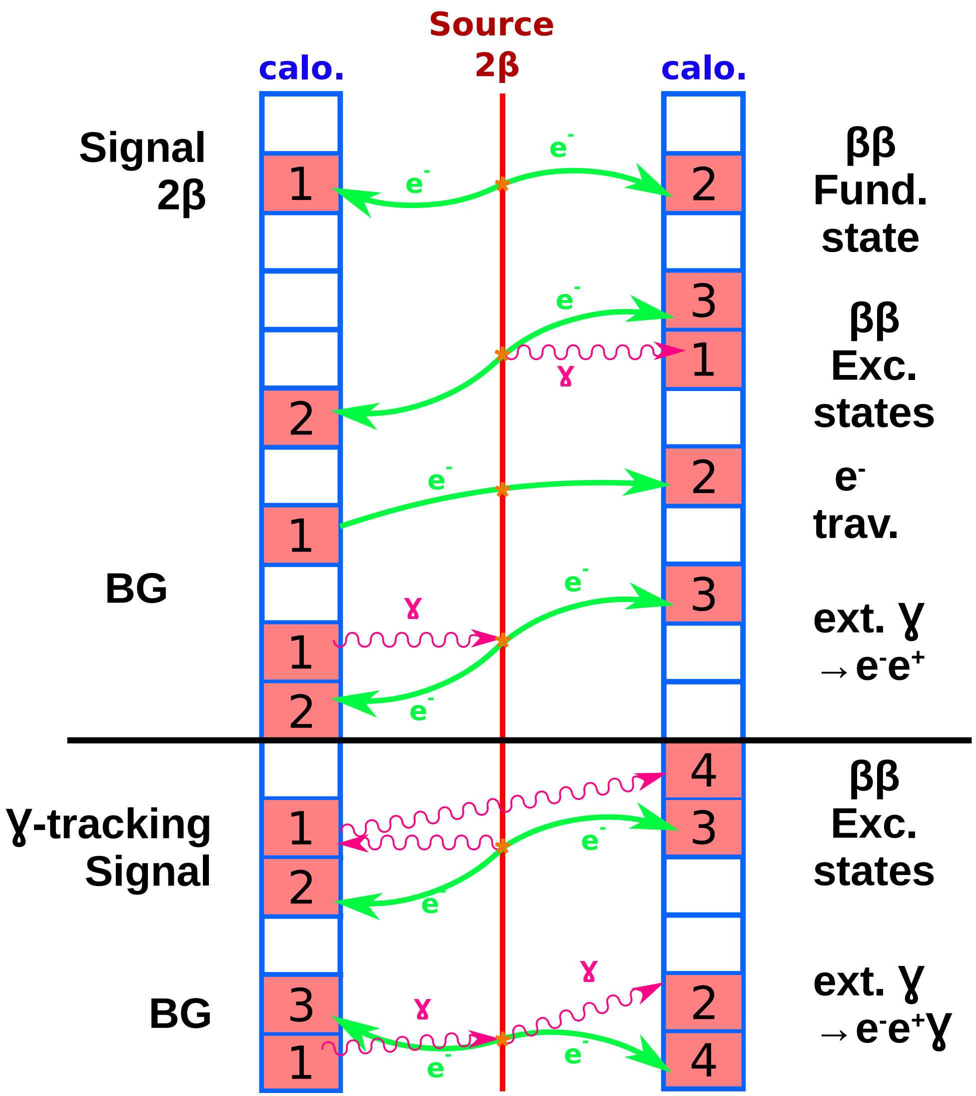




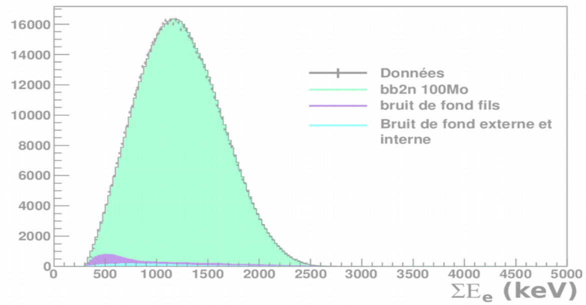


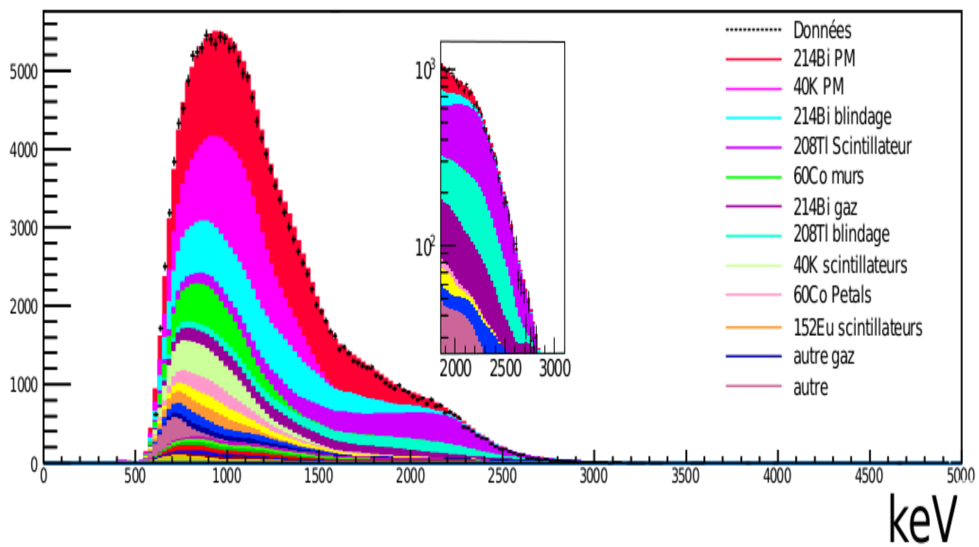
Event reconstruction

C. Hugon Ph.D (NAT++)

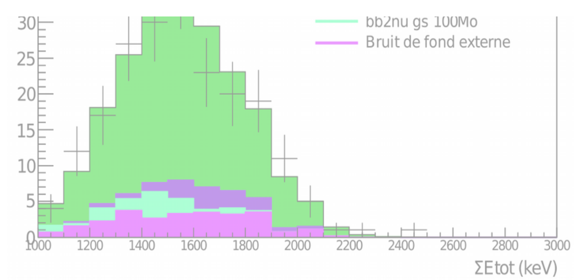


The reconstruction of the events and NEMO3 spectrums



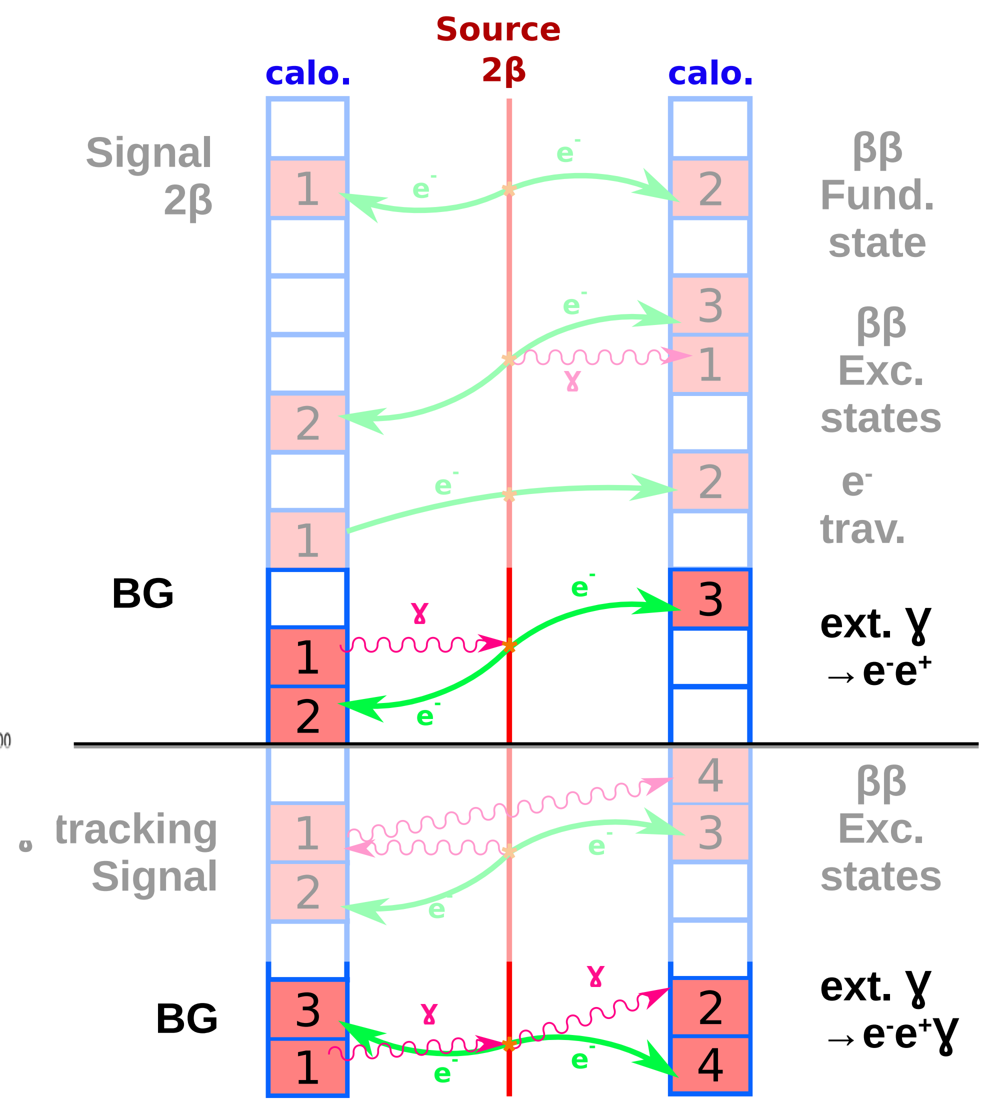


B)

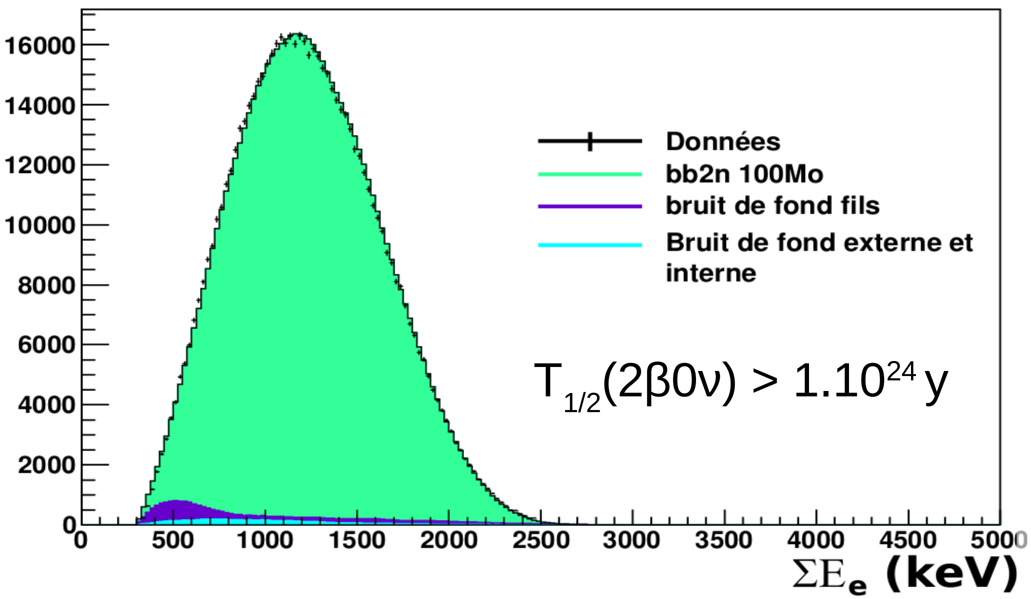


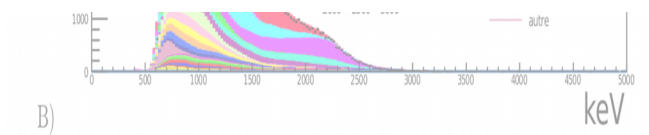
Event reconstruction

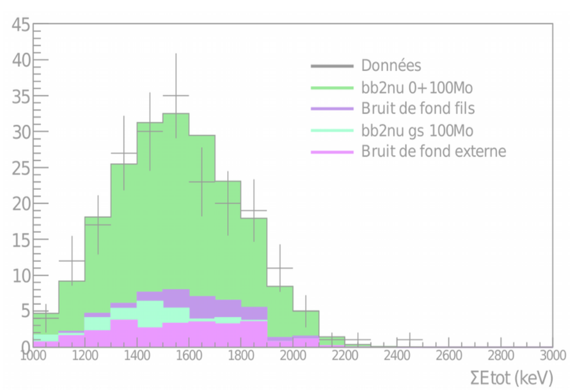
C. Hugon Ph.D (NAT++)



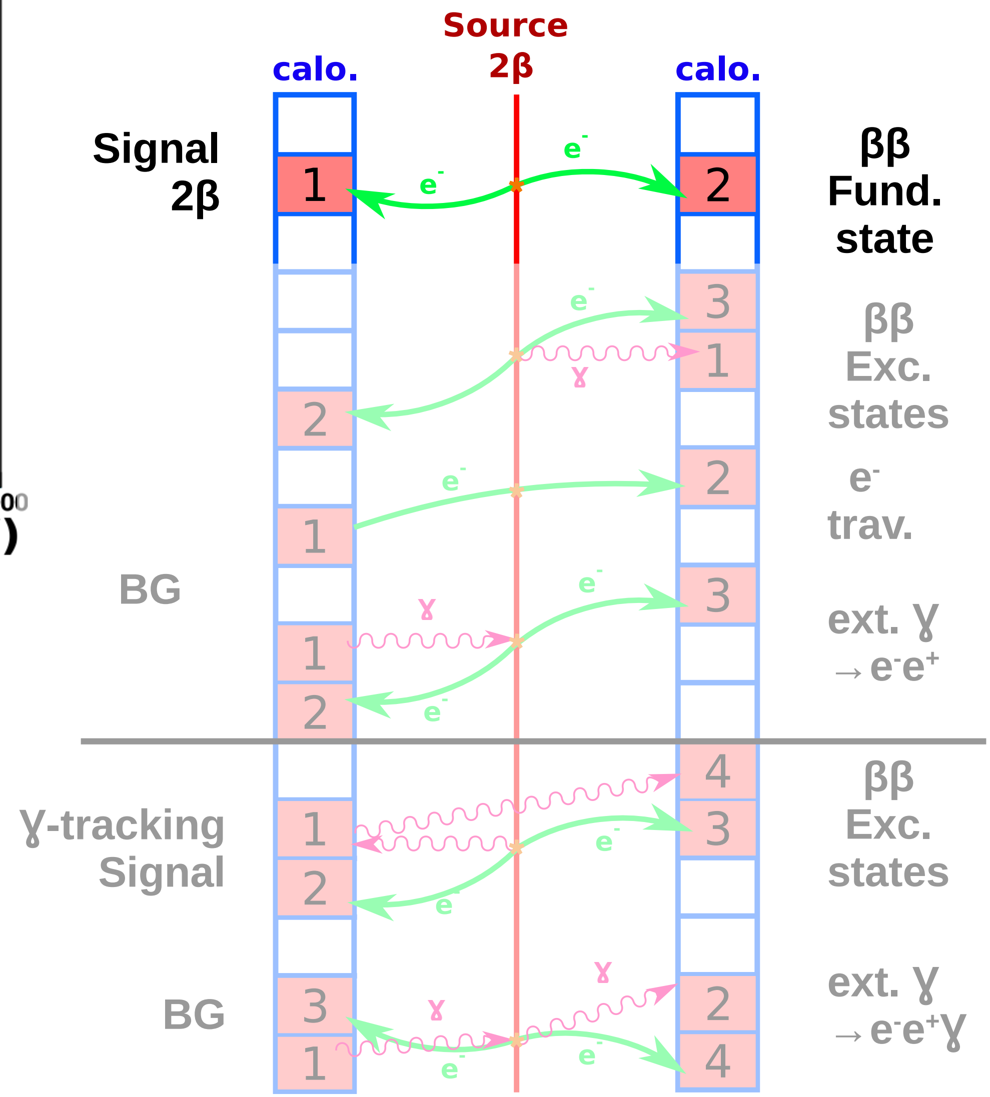
The reconstruction of the events and NEMO3 ^{100}Mo spectrums



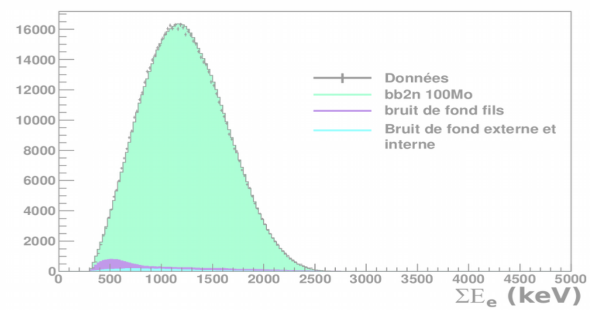


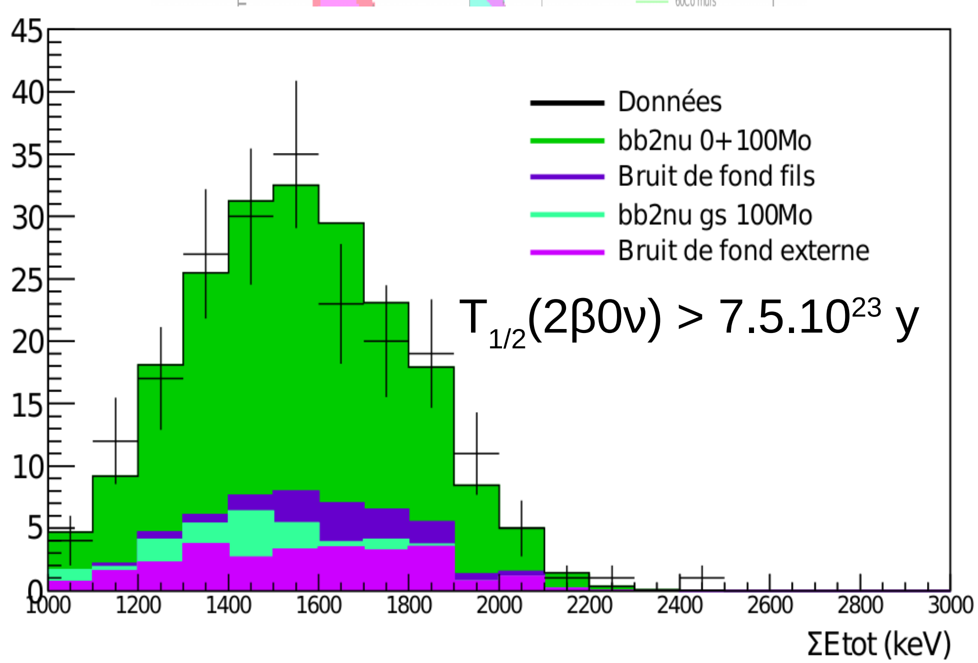


Event reconstruction
C. Hugon Ph.D (NAT++)

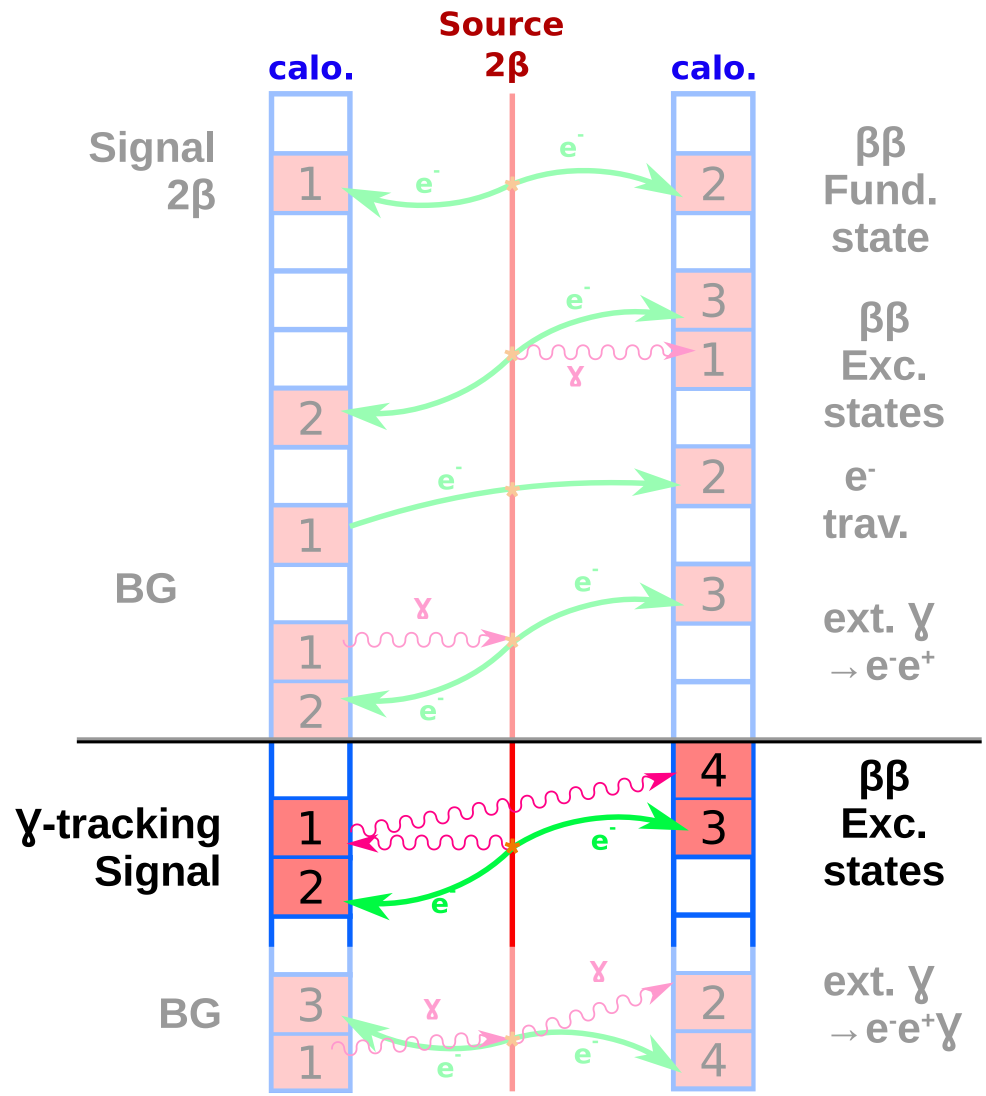


The reconstruction of the events and NEMO3 spectrums



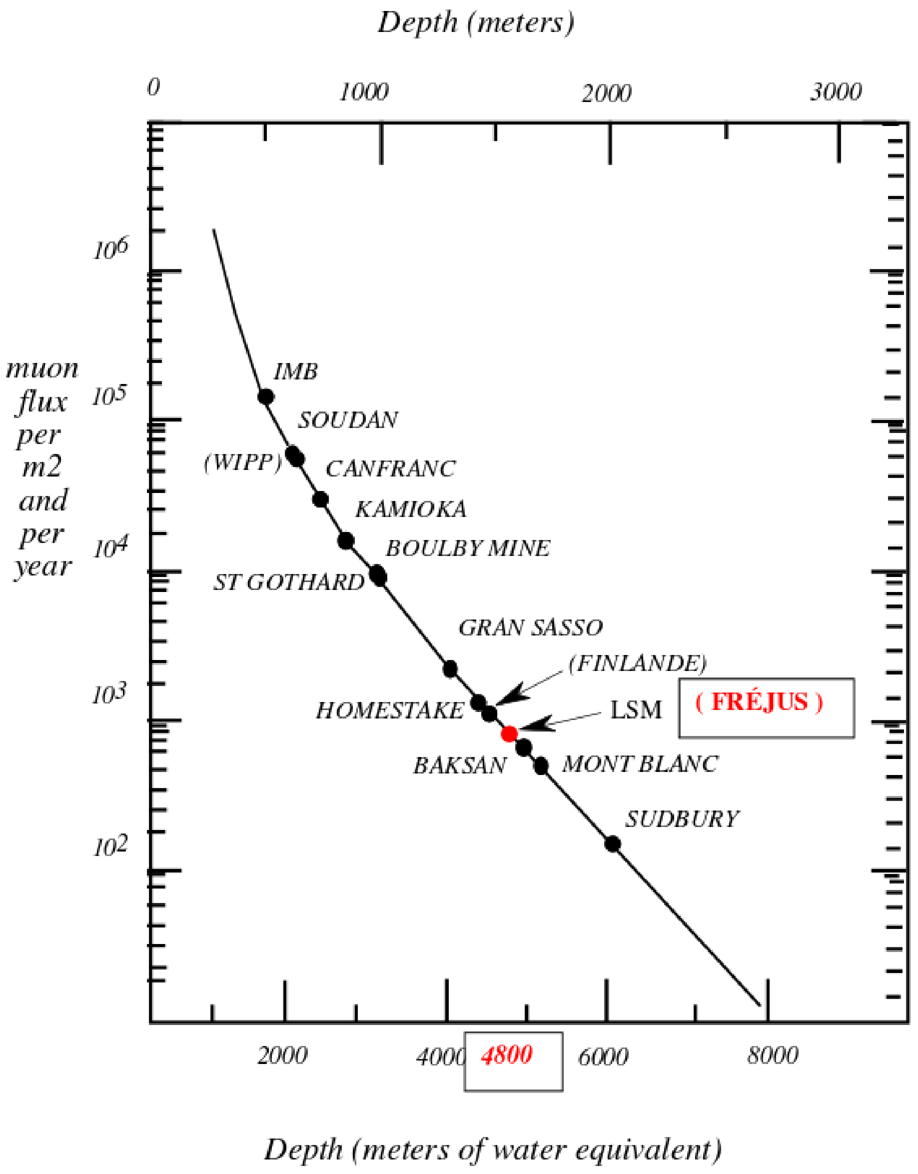


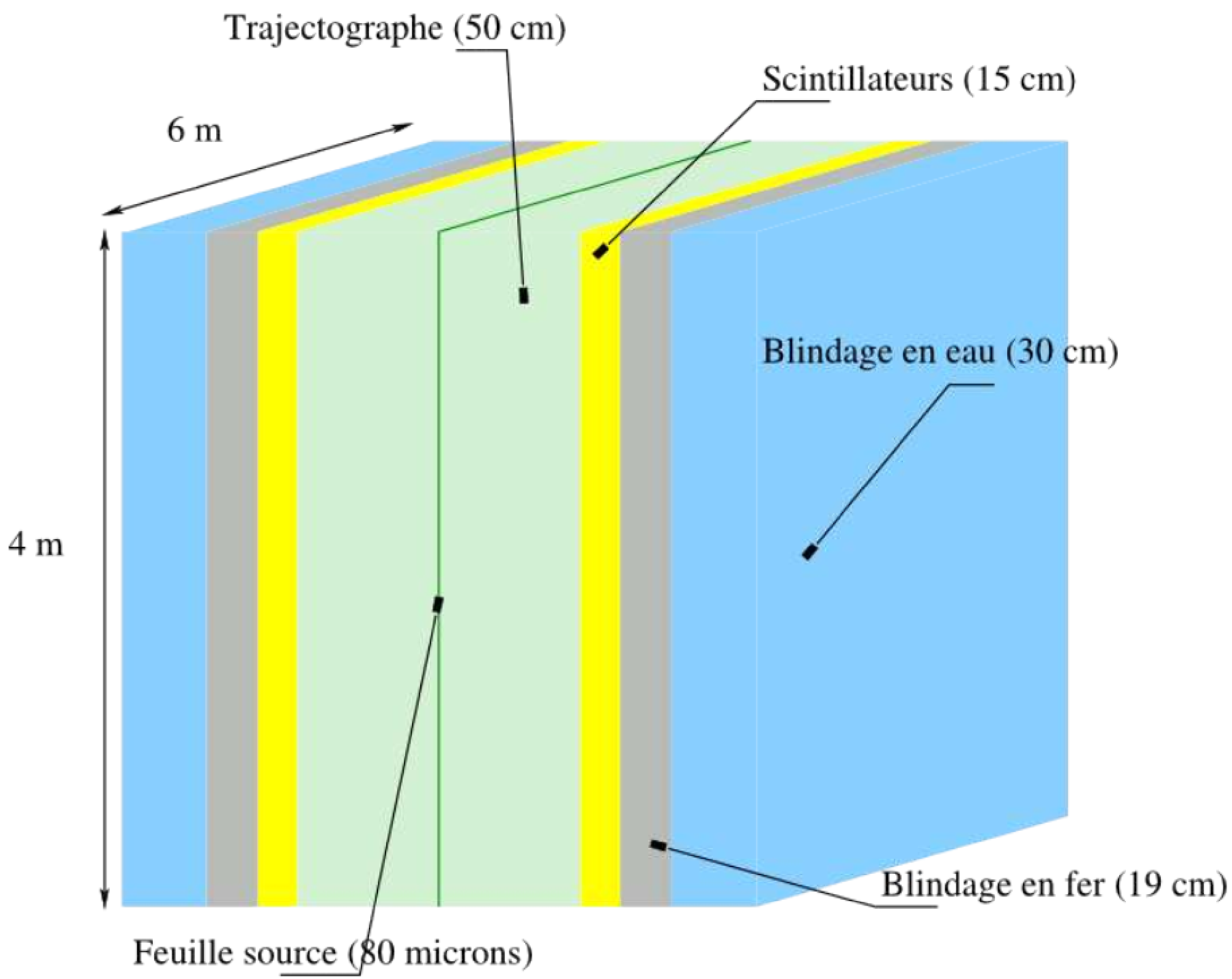
Event reconstruction



Muon flux per depth

Mwe ~ 2.5 – 3 x depth




Trajectographe (50 cm)
Scintillateurs (15 cm)
6 m
4 m
Blindage en eau (30 cm)
Blindage en fer (19 cm)
Feuille source (80 microns)