Monitoring rain rate with proximal gamma-ray spectroscopy

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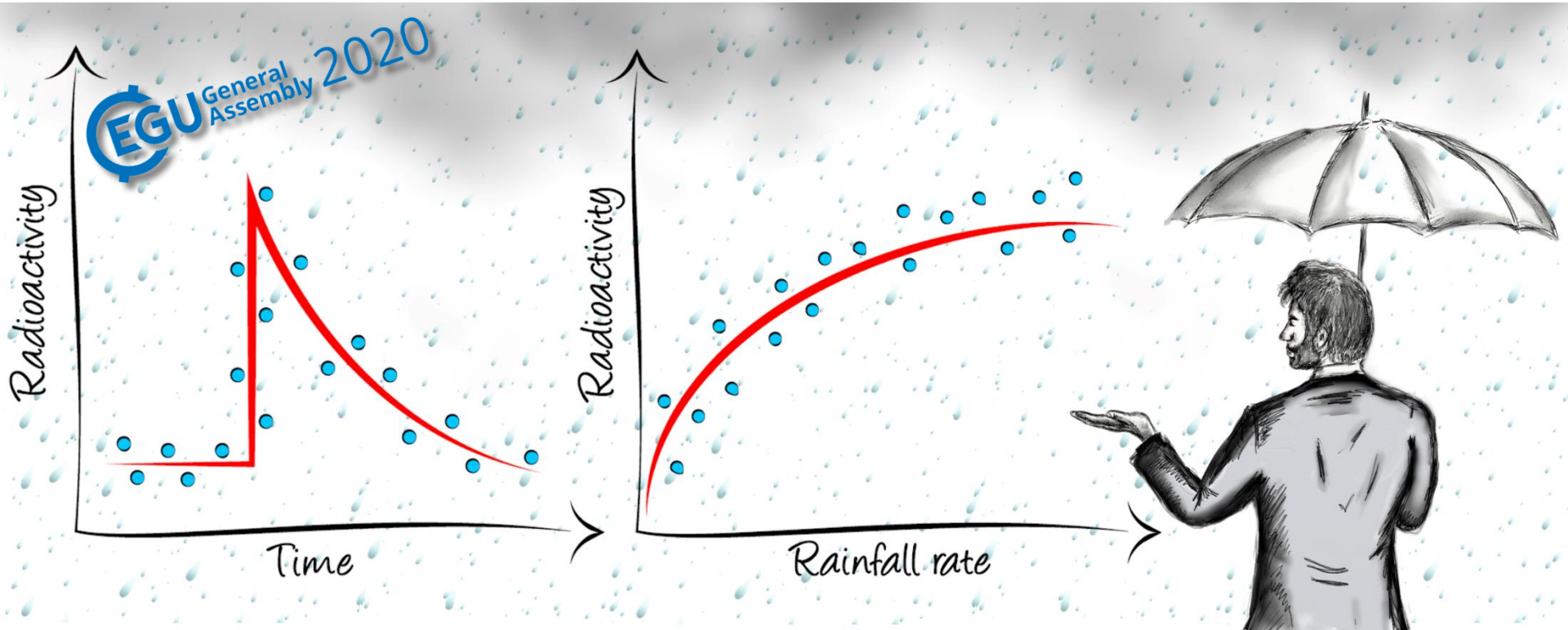
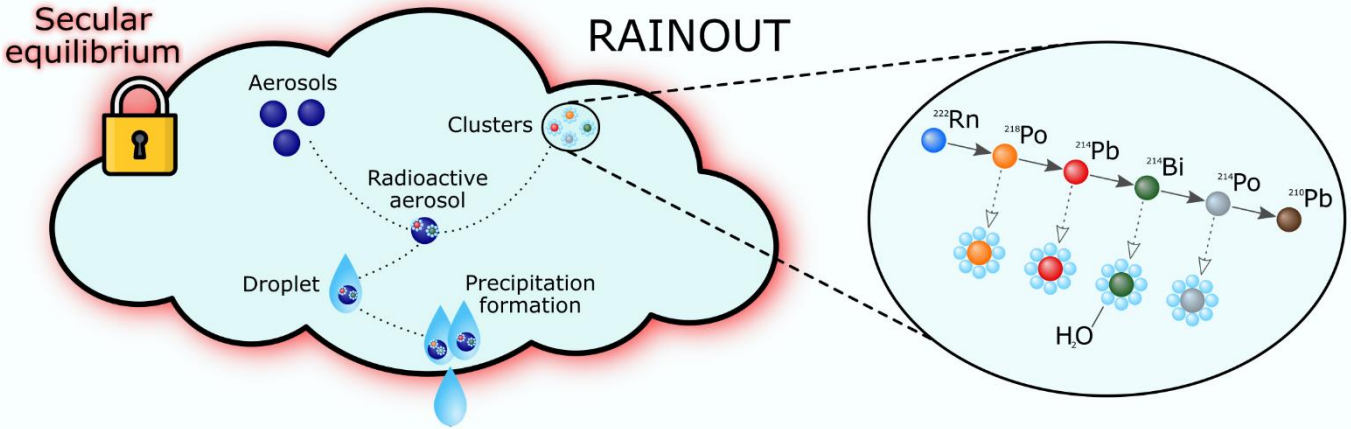
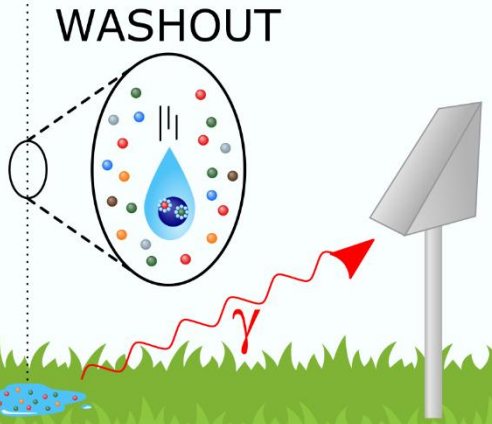


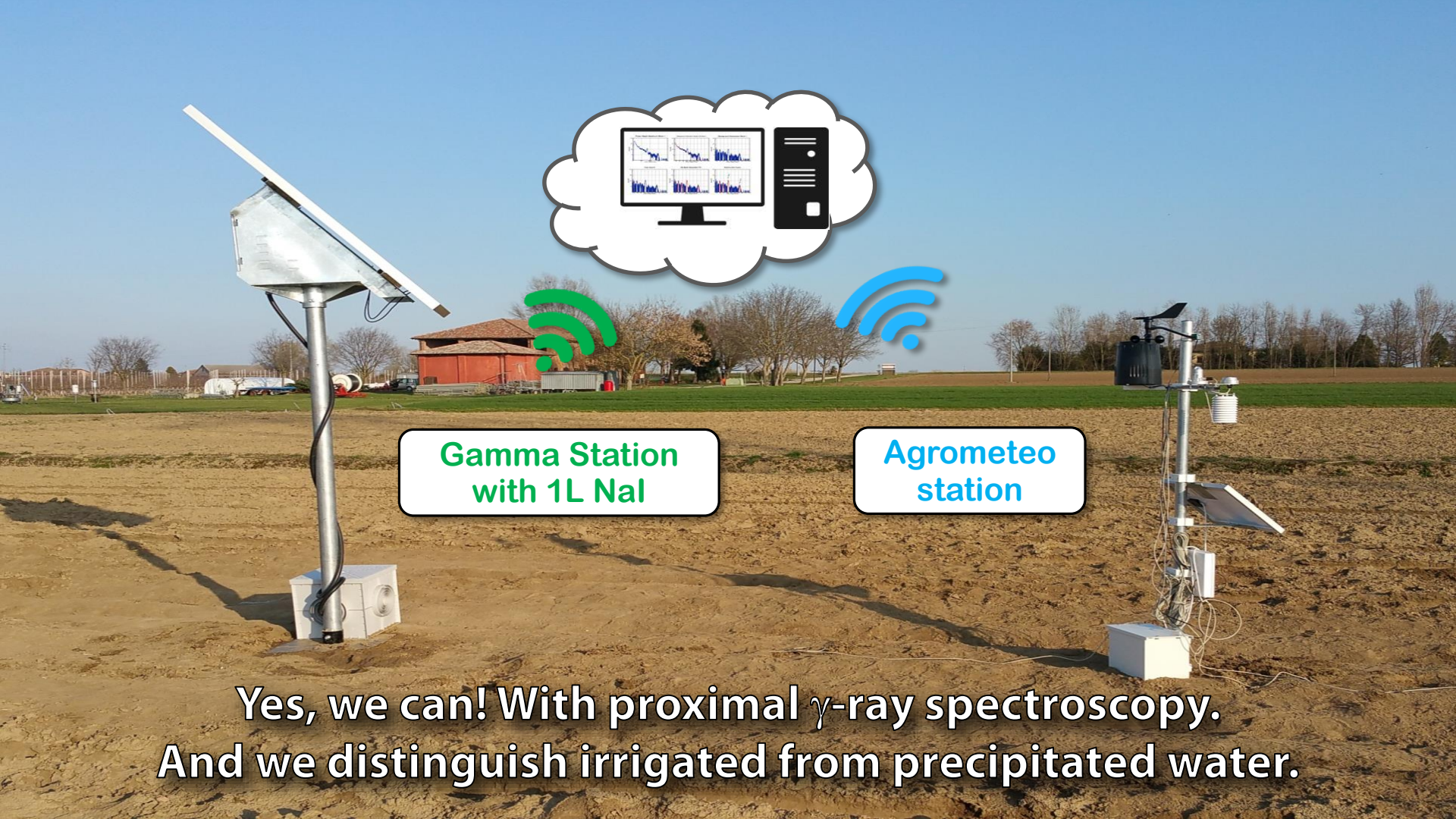
Radon is in the air…



… and it's singing in the rain!

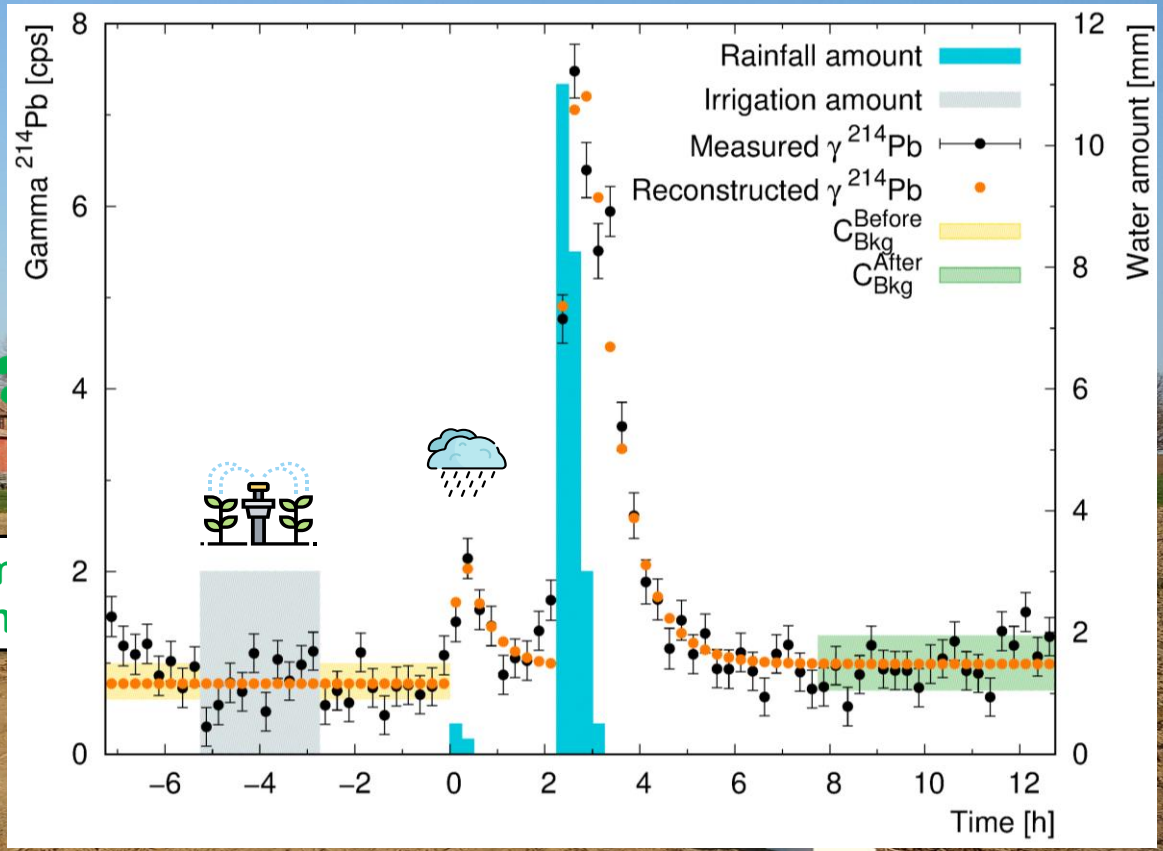


So, can we measure the rain rate by hearing its voice?



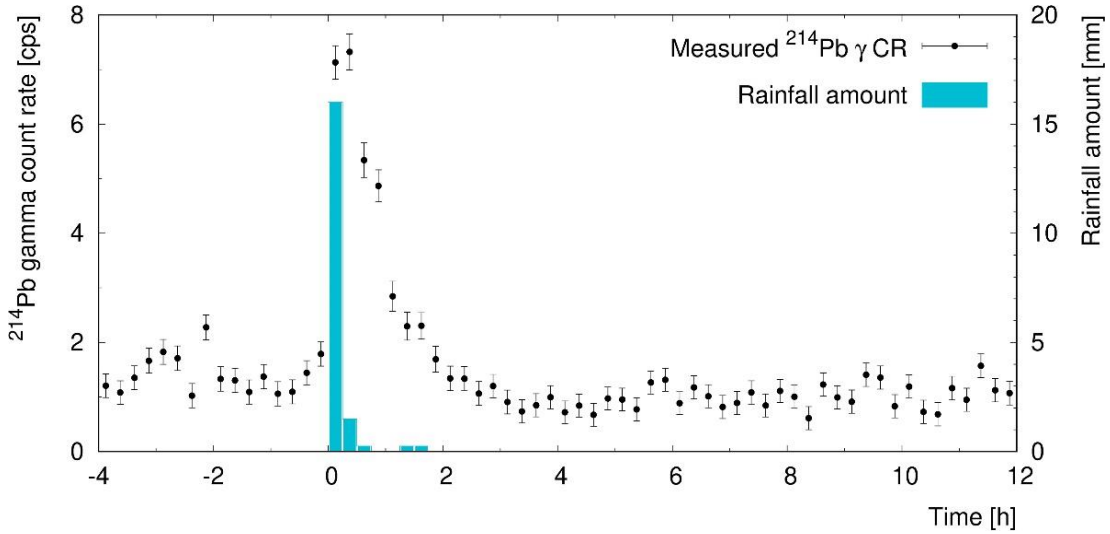
Yes, we can! With proximal γ-ray spectroscopy.
And we distinguish irrigated from precipitated water.

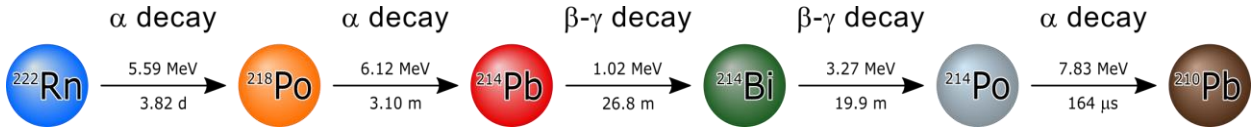
Gamm
with



Yes, we can! With proximal γ-ray spectroscopy.
And we distinguish irrigated from precipitated water.

During and after a **rainfall event** an **increase** of the gamma activity at **ground level** is observed in the energy windows of ^{214}Pb and ^{214}Bi. In such energy regions the net Count Rate (CR) can be enhanced, during a precipitation, **more than four times** with respect to that measured in absence of rain.

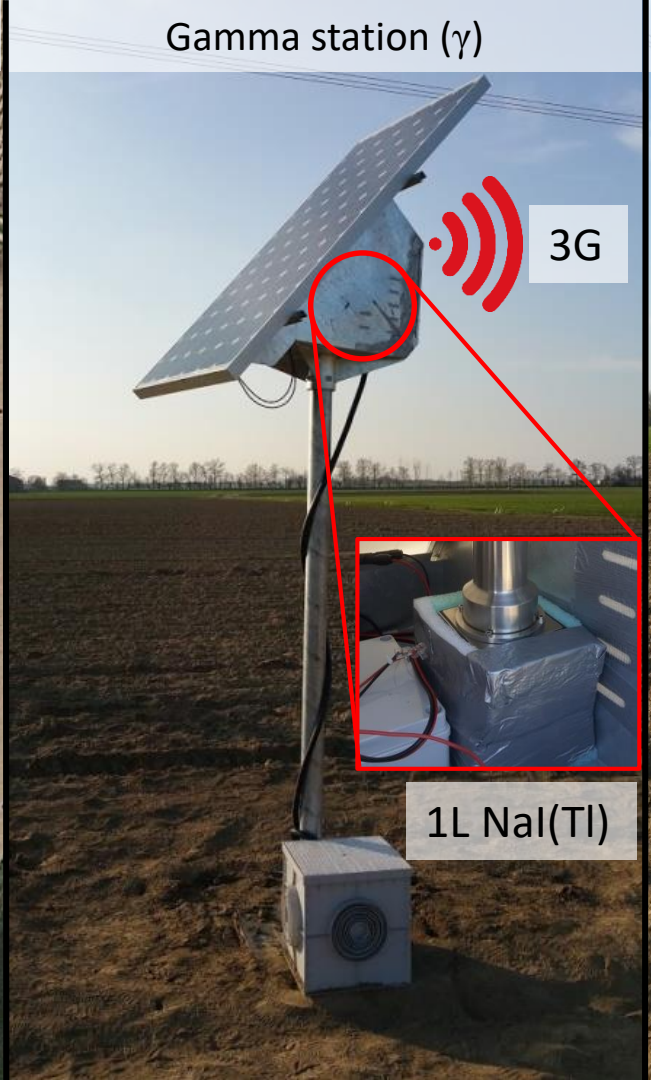


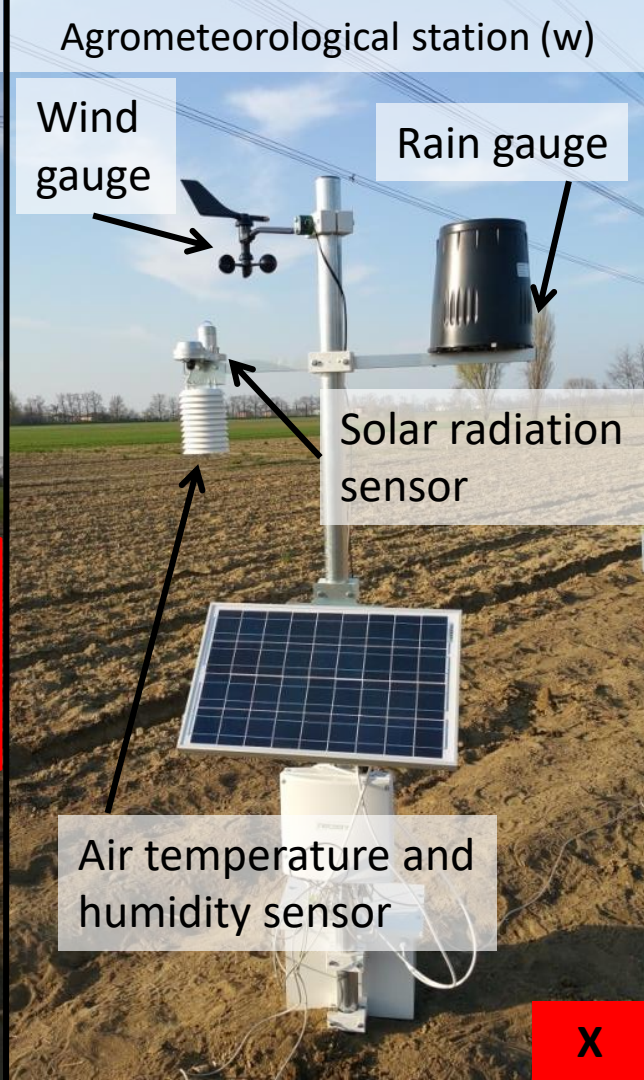


- The enhancement in activity is induced by the atmospheric **^{214}Pb** and **^{214}Bi**, gamma emitters **daughters of ^{222}Rn**.
- These radon daughters fall from the clouds **to the ground with a precipitation**, leading to an increase in the activity beyond the terrestrial background.
- Such an activity augmentation is measurable using **gamma-ray spectroscopy** techniques.
- The present work takes into account the activity of **^{214}Pb** (E_γ = 351 keV, half-life = 26.8 min), being the first ^{222}Rn daughter to undergo gamma decay.

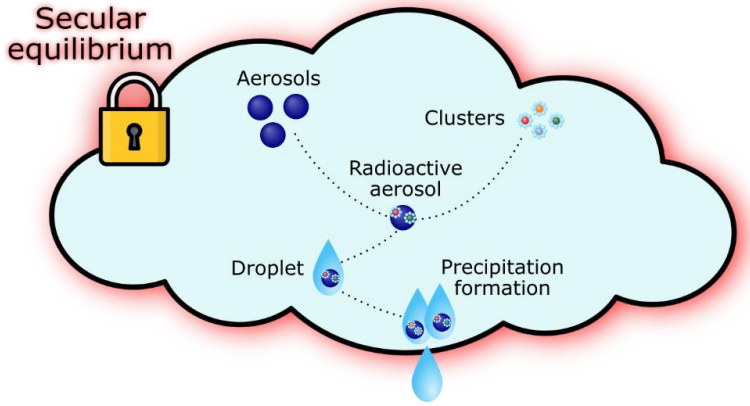
- To study the rain-induced gamma activity, a gamma-ray spectroscopy experiment was performed at an **agricultural test field** in Emilia-Romagna (Italy).
- 2 categories of data were acquired:
  1) **environmental gamma spectra** and
  2) **meteorological data**, including fallen millimeters of rain. The data have been time aligned and merged in a single database having a **15 minutes temporal resolution**.
- In the 7-month data acquisition period (4th April – 2nd November 2017) **12 different rain episodes** have been chosen (ranging from 45 min to 3.5 h in duration and from 3.8 mm to 23.5 mm in precipitation amount).


Experimental site
40 m
108 m
γ
W
N


Gamma station (γ)
3G
1L NaI(Tl)


Agrometeorological station (w)
Wind gauge
Rain gauge
Solar radiation sensor
Air temperature and humidity sensor

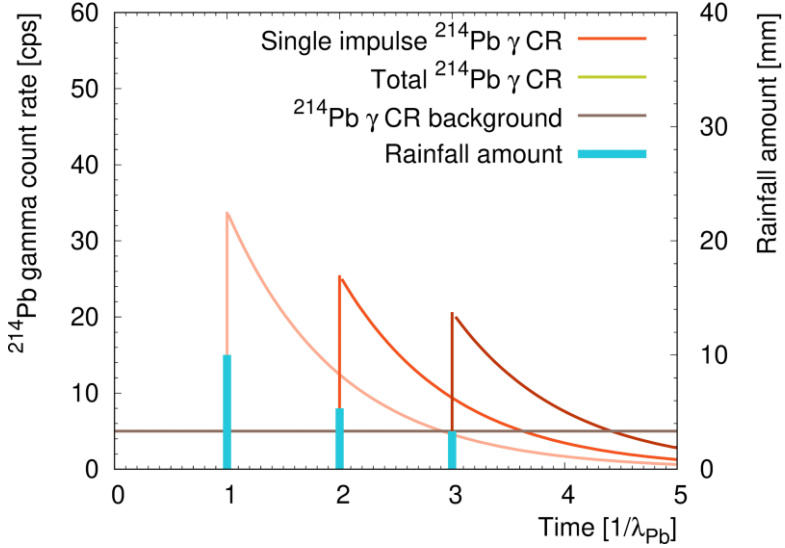
- ^{222}Rn daughters, in secular equilibrium with ^{222}Rn in the cloud, react very fast with air vapors and aggregate in "**clusters**", i.e. agglomerations of polar molecules (e.g. H_2O) around the atoms of the radon daughters.



- The clusters attach themselves to air **aerosol particles** via electrostatic forces, forming a "radioactive aerosol".
- In the clouds, aerosol particles stick to droplets, which grow until they fall to the ground.

An analytical model is needed to fit the experimental Count Rate (CR).

$$A(t) = \int_{t_0}^{t} D(\tau) \cdot e^{-\lambda_{Pb}(t-\tau)} d\tau + Bg(t)$$



- ***A(t)*** [cps]: expected ^{214}Pb gamma count rate as function of time;
- ***t_0*** [s]: rain start time;
- ***D(t)*** [cps/s]: instantaneous increase to the CR due to the impulse of rain in time *t*; it depends on the rain rate;
- ***Bg(t)*** [cps]: CR not due to the precipitation; in first approximation it is constant.

Introduction

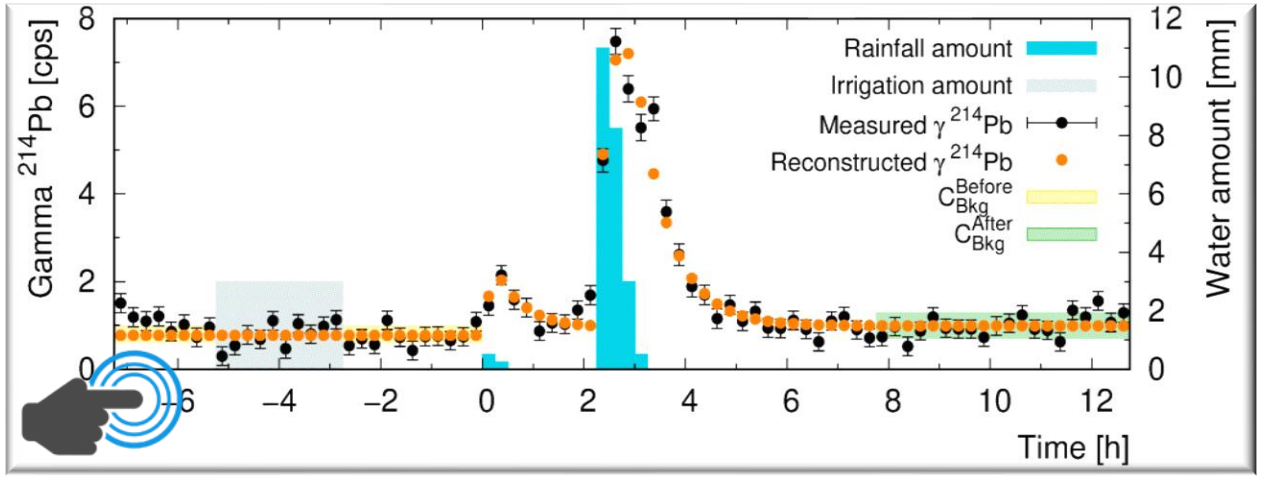
Experiment

Physical model

Analytical model

Results

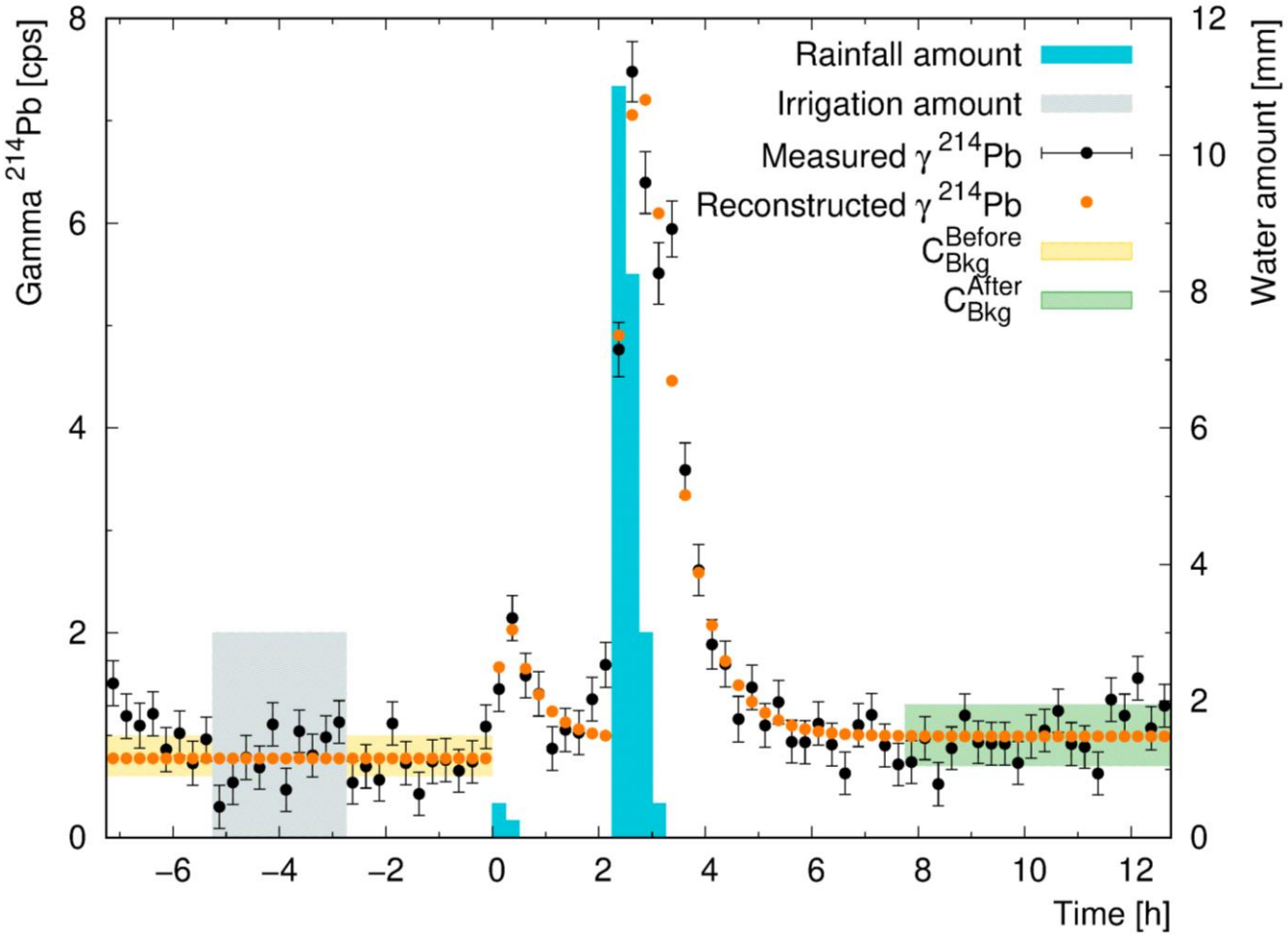
Applications



- Irrigation water is not charged with ^{222}Rn daughters nuclei.
- When it doesn't rain, the fit function approaches the constant environmental background.

Experimental data fit

- Irrigation events do not cause changes in the ^{214}Pb count rate.
- The reconstructed ^{214}Pb count rate well reproduces the temporal evolution of the ^{214}Pb count rate over the entire duration of a rainfall event.
- The method developed for the time-series reconstruction of the ^{214}Pb count rate works strikingly well, considering also that experimental measurements are performed in situ and can be affected by changing environmental conditions.



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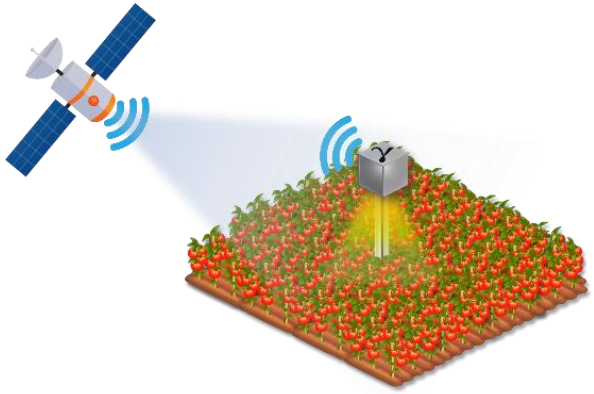


Satellite ground-truthing

Gamma spectroscopy can be applied when **field scale measurements** are needed as ground calibration for **satellite estimation** of **soil water content**. Results shown in the present study suggest an improvement related to the distinction of irrigated and precipitated water.

Gamma spectroscopy measurements

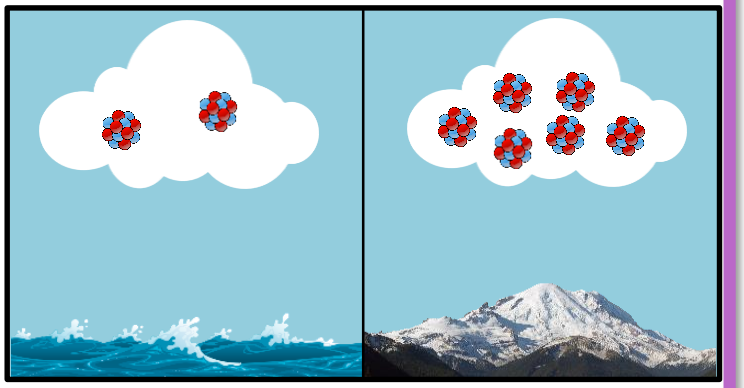
Having a quantitative knowledge of the rain-induced gamma activity can help in refining the spectral analysis and reconstruction of **in-situ** and **airborne gamma-ray spectroscopy measurements**

Homeland security

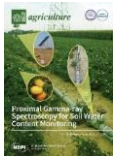
In fields such as homeland security and monitoring of nuclear facilities the understanding of **rain-induced gamma activity** is fundamental in **reducing false positive alarms** of over-threshold activities due to precipitations.

Meteorology

A synergy with meteorology and climatology can arise in **air masses tracing** studies. Indeed, clouds with **marine** or **continental origin** are typically characterized by a **^{222}Rn concentration below** or **above average**, respectively.



For more information…



Modelling Soil Water Content in a Tomato Field: Proximal Gamma Ray Spectroscopy and Soil–Crop System Models

Strati V., Albéri M., Anconelli S., Baldoncini M., Bittelli M., Bottardi C., Chiarelli E., Fabbri B., Guidi V., Raptis K.G.C., Solimando D., Tomei F., Villani G. and Mantovani F. Agriculture, 8(4), 60 (2018)

Biomass water content effect on soil moisture assessment via proximal gamma-ray spectroscopy

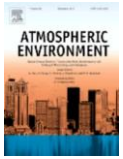
Baldoncini M., M. Albéri, C. Bottardi, E. Chiarelli, K. G. C. Raptis, V. Strati, and F. Mantovani. Geoderma, 335, 69-77 (2019)

Investigating the potentialities of Monte Carlo simulation for assessing soil water content via proximal gamma-ray spectroscopy

Baldoncini, M., M. Albéri, C. Bottardi, E. Chiarelli, K. G. C. Raptis, V. Strati, and F. Mantovani
Journal of Environmental Radioactivity, 192, 105-116 (2018)

Soil moisture as a potential variable for tracking and quantifying irrigation: a case study with proximal gamma-ray spectroscopy data.

Filippucci, P., A. Tarpanelli, C. Massari, A. Serafini, V. Strati, M. Alberi, K. G. C. Raptis, F. Mantovani and L. Brocca (2020).
Advances in Water Resources 136, 2020



Rain rate and radon daughters' activity.
Bottardi, C., M., Baldoncini, M. Albéri, E. Chiarelli, M. Montuschi, K. G. C. Raptis, A. Serafini, V. Strati, and F. Mantovani
Advances in Water Resources, *In press*

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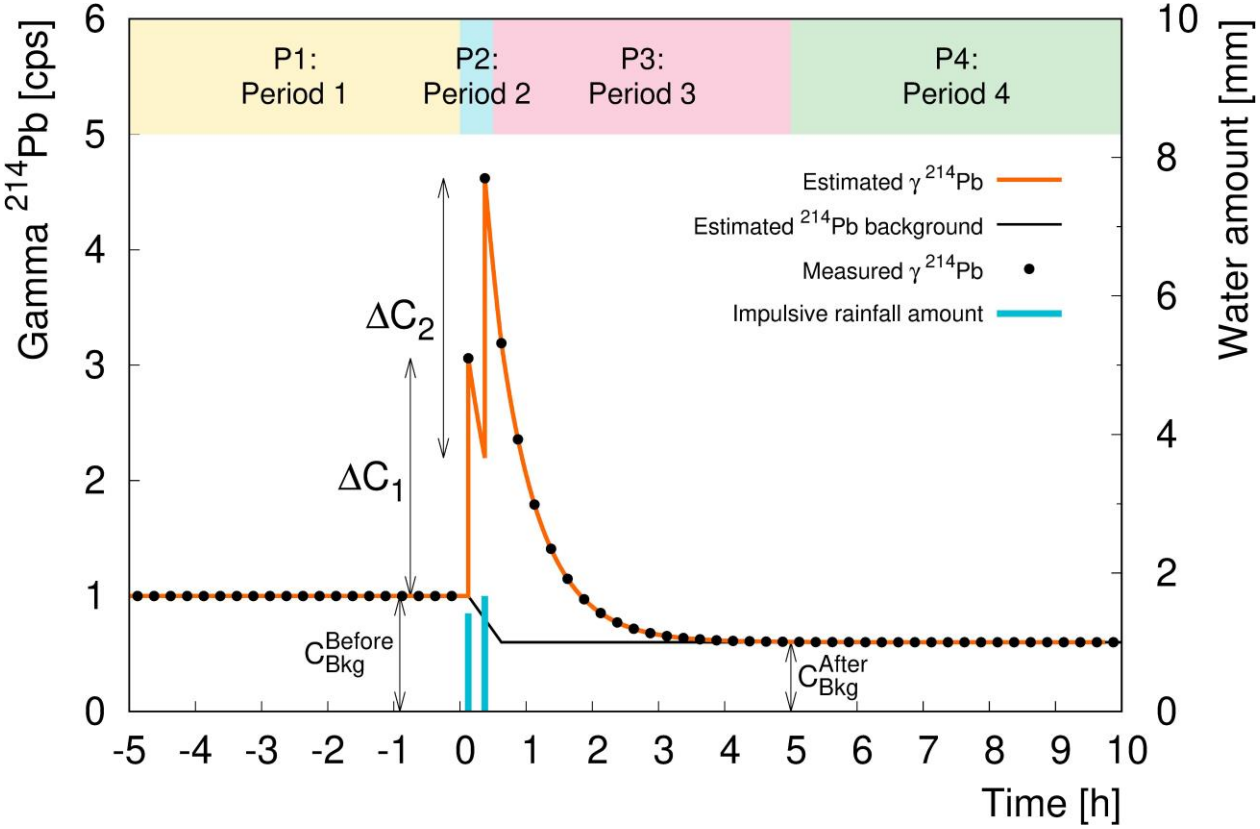
BACK-UP SLIDES

Example of a rain episode

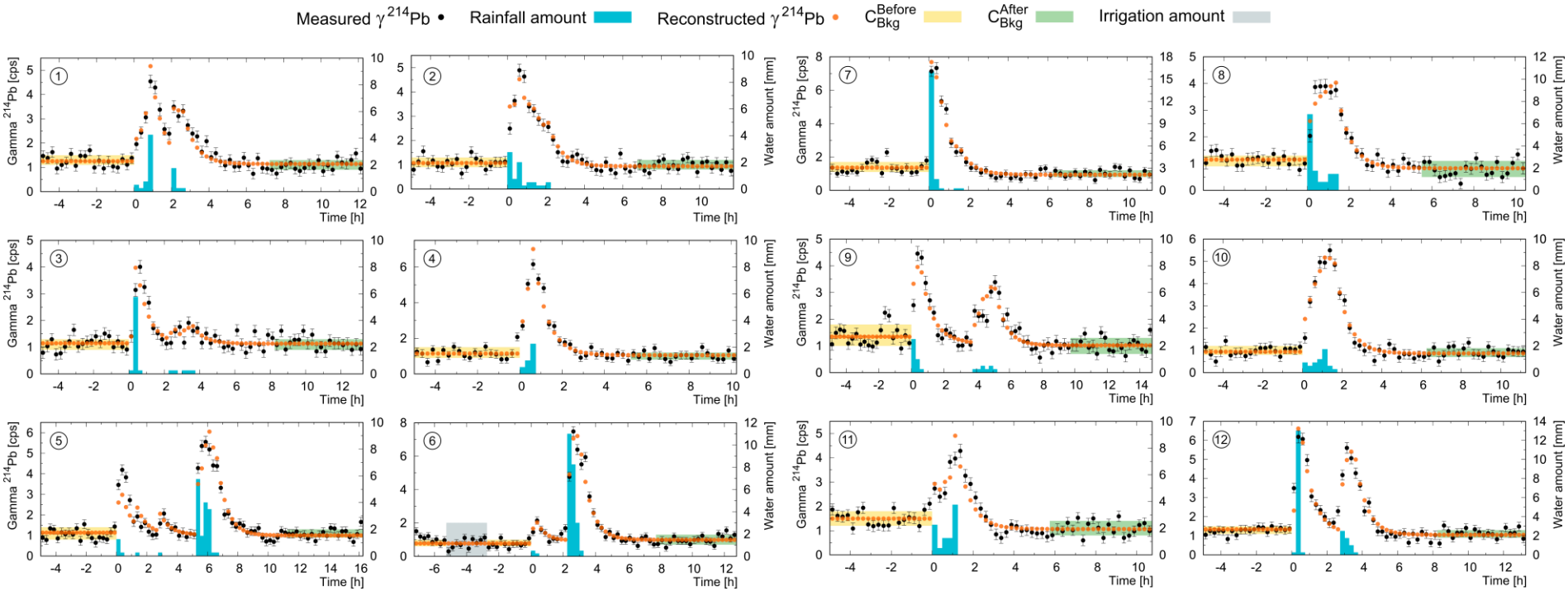
4 Periods in the fit range:

- P1: covers the 5 h before the beginning of the rainfall;
- P2 starts and ends respectively at the first and last temporal bins for which a non-zero rainfall amount is measured. Note that this Period can include more rain bins separated by no rainfall time intervals shorter than 9.5 h;
- P3 follows the end of P2 for a duration of 4.5 h, corresponding to ~10 ^{214}Pb half-lives;
- P4 covers the 5 h after the end of P3.

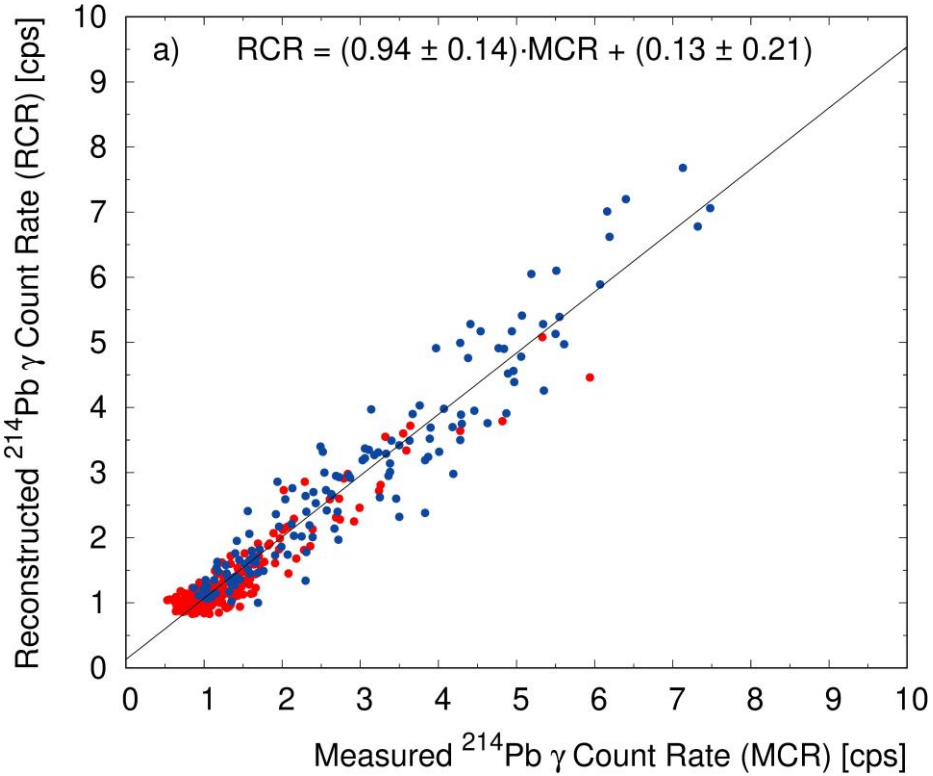
ΔC_i is the ^{214}Pb count rate increase due to the i-th impulse of rain.



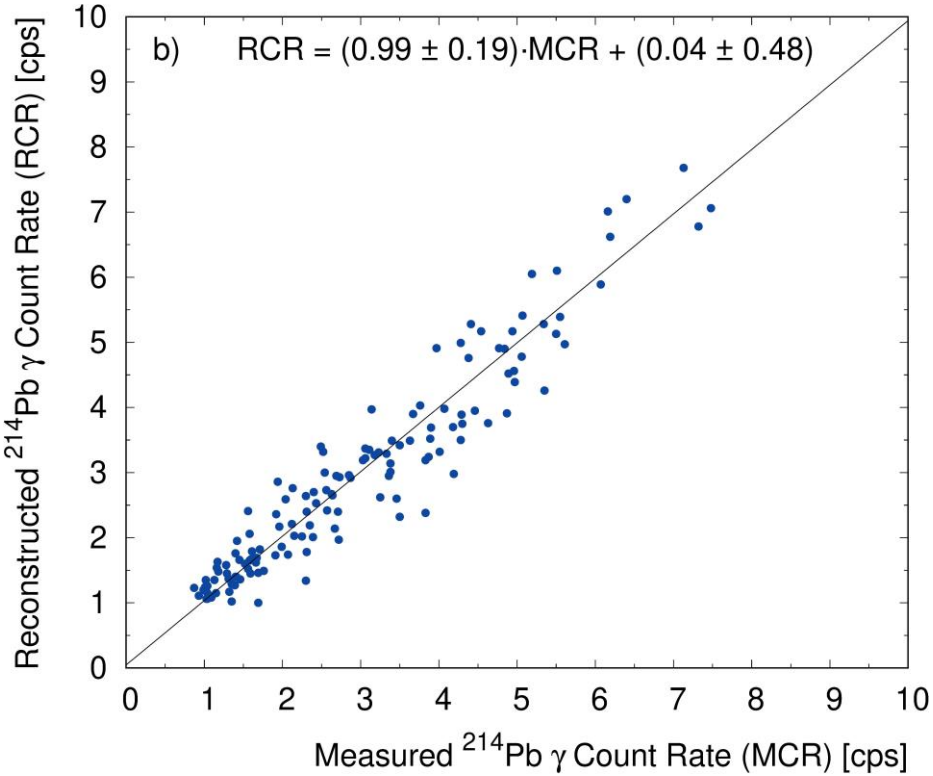
Analysis of the 12 rain episodes



Reliability of the episodes reconstruction



355 points from P2 and P3



139 points from P2

Gamma increase in function of the rain rate

$$\Delta C = \Delta T \cdot A \cdot R^d$$

- $A\left[\frac{cps}{mm^d}h^{1-d}\right]$ is a proportionality factor that depends from the response of the 1L NaI(Tl) detector installed in the Gamma station and from in-cloud ^{222}Rn concentration.
- d is a factor accounting for a non-linear dependance between the number of ^{214}Pb nuclei in a raindrop and the rainfall rate R.

We analysed 82 temporal bins in P2 (characterized by non-zero rainfall amount). The fit of ΔC as a function of the rain rate R permits to calculate the best values of A and d.