Large-Area RPCs for Muography

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HIDRONAV TECHNOLOGIES

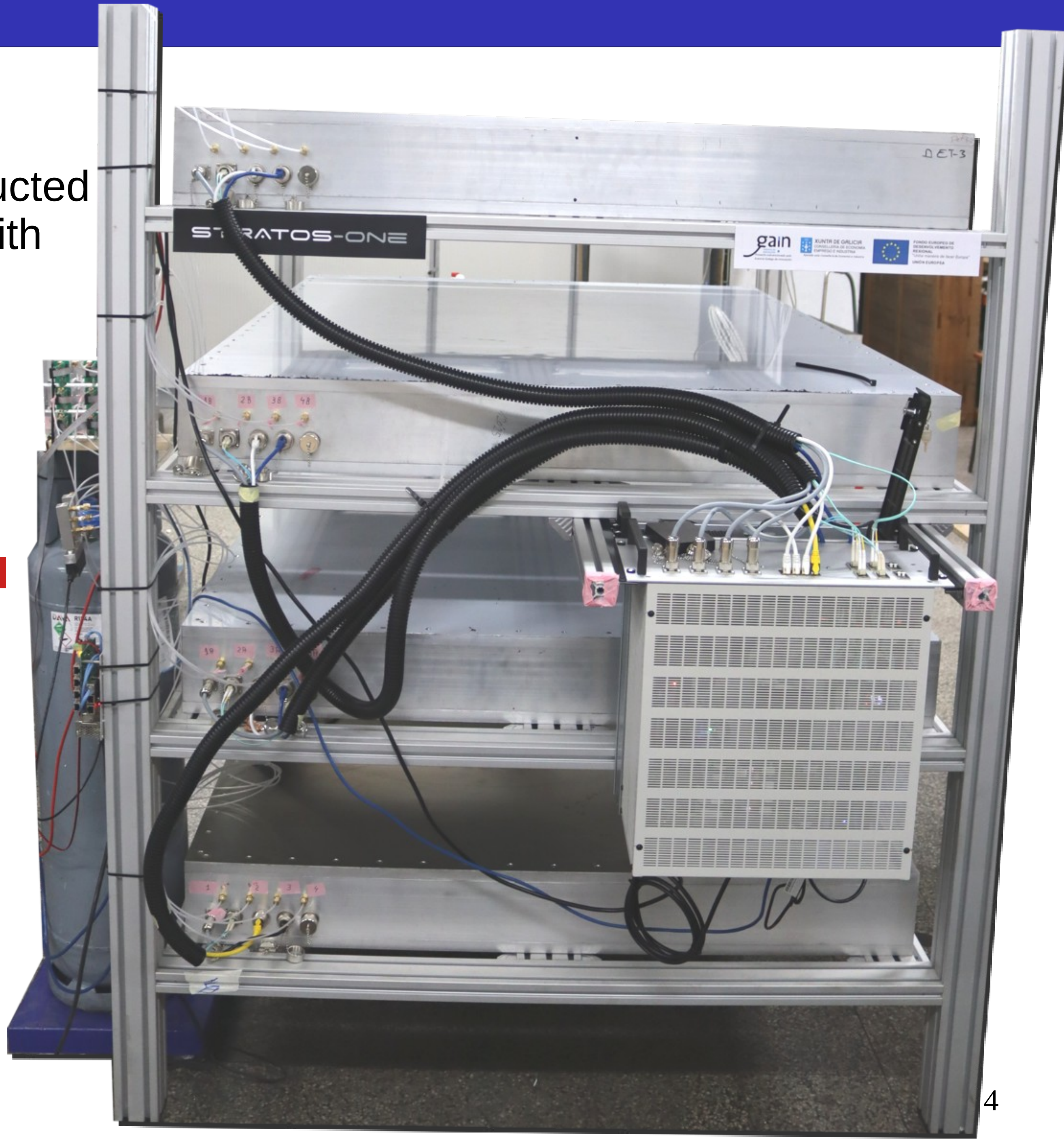
Overview

1. **STRATOS Detector**
2. **Low Gas Flow Operation**
3. **Scattering Muography**
4. **Conclusion**

STRATOS Detector – Overview

Cosmic-Ray telescope constructed at *LIP Coimbra* in partnership with the Spanish company *Hidronav*

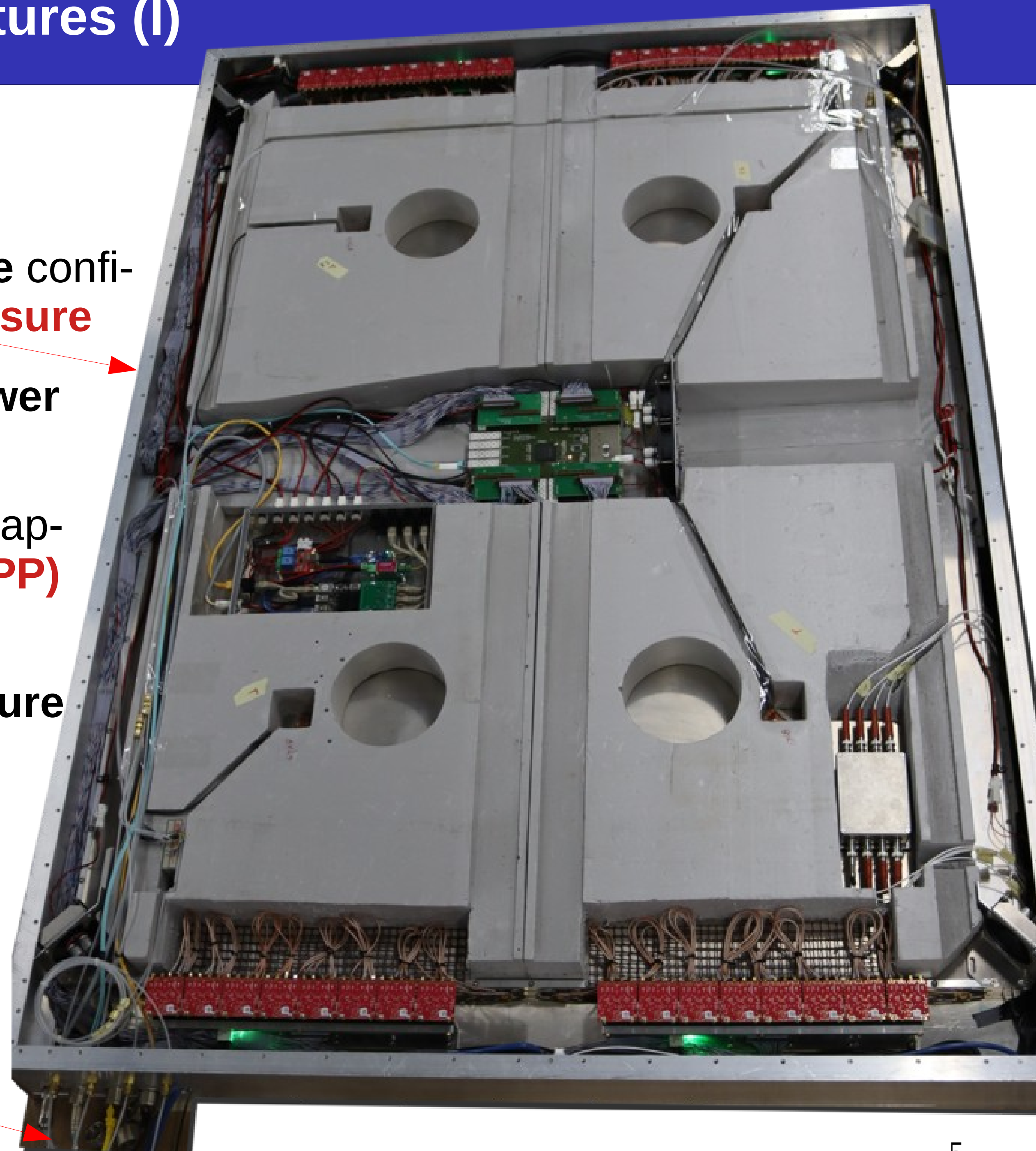
- equipped with **4 RPCs**
- active area: **2 m²** per plane
- designed to work in **industrial environments** (EMI, environmental changes)
- operated at **very low gas flow**



STRATOS Detector – Features (I)

Specific design, e.g.:

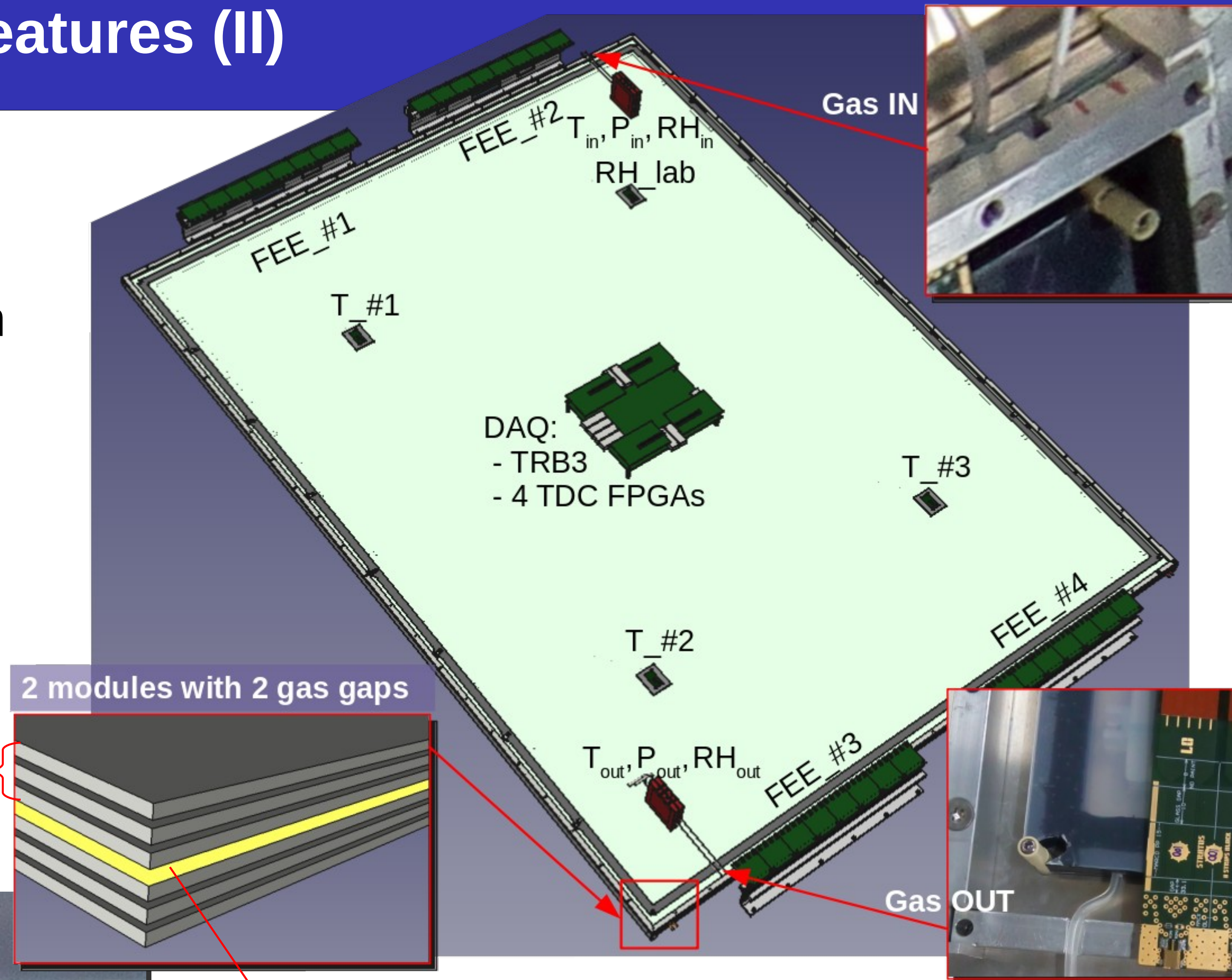
- **Instrumentation & RPC module** confined in external **aluminum enclosure**
  - ➔ external connections: **gas**, **power** and **communication**
- **active volume** of each RPC encapsulated in tight **polypropylene (PP) box** + internal **aluminum box**:
  - ➔ provides good barrier to **moisture** and **atmospheric gases**
  - ➔ allows stable operation at low gas flux (**~1 cm³/min/m²**)

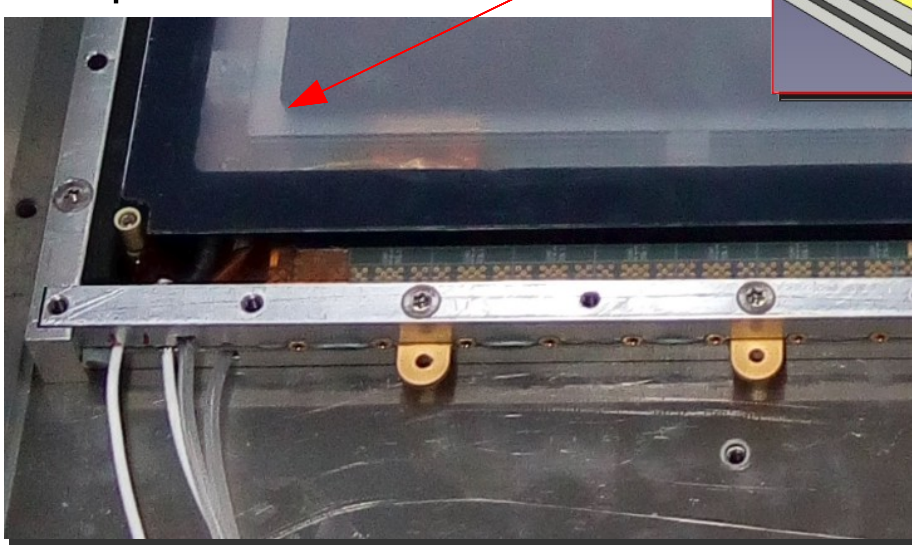


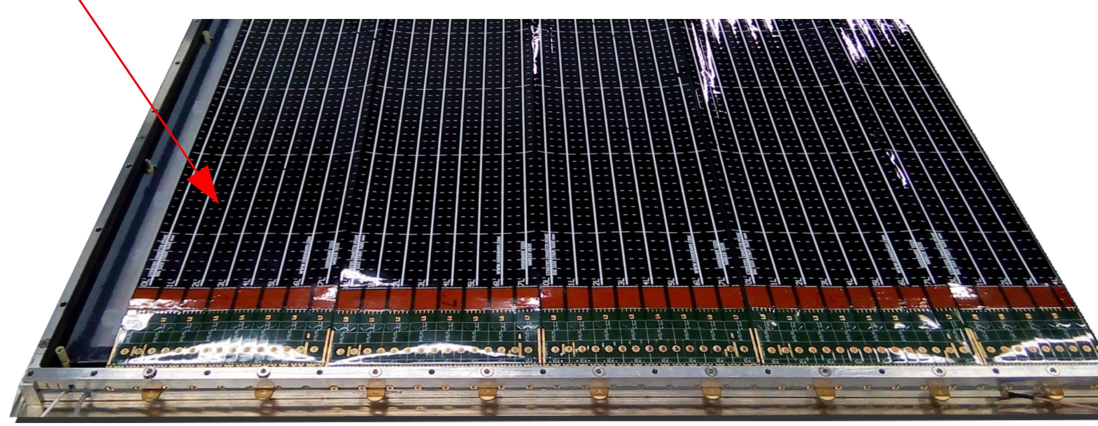
gas (R-134a), power (48V) & communication (slow control+data, trigger, LAN)

STRATOS Detector – Features (II)

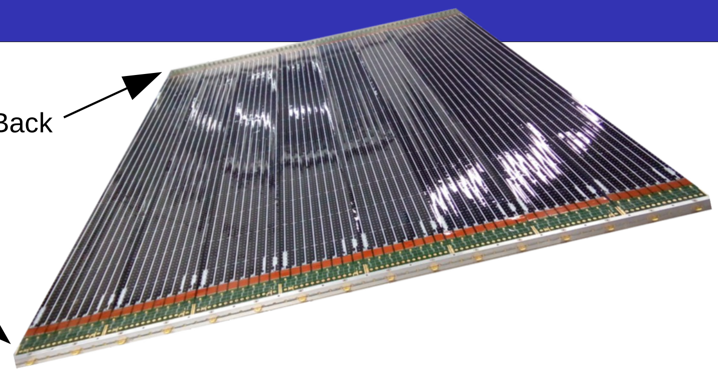
- active area: **1.2 x 1.6 m²**
- multi-gap RPC:
  - **two modules** (one on each side of the pick-up strips)
  - **two gas gaps** each, 1 mm wide
  - glass 2 mm thick
    - $\rho \approx 4\times10^{12}\ \Omega.\mathrm{cm}$ (25 ºC)
- **64 readout strips**
  - 1.55 cm wide
  - pitch of 1.85 cm







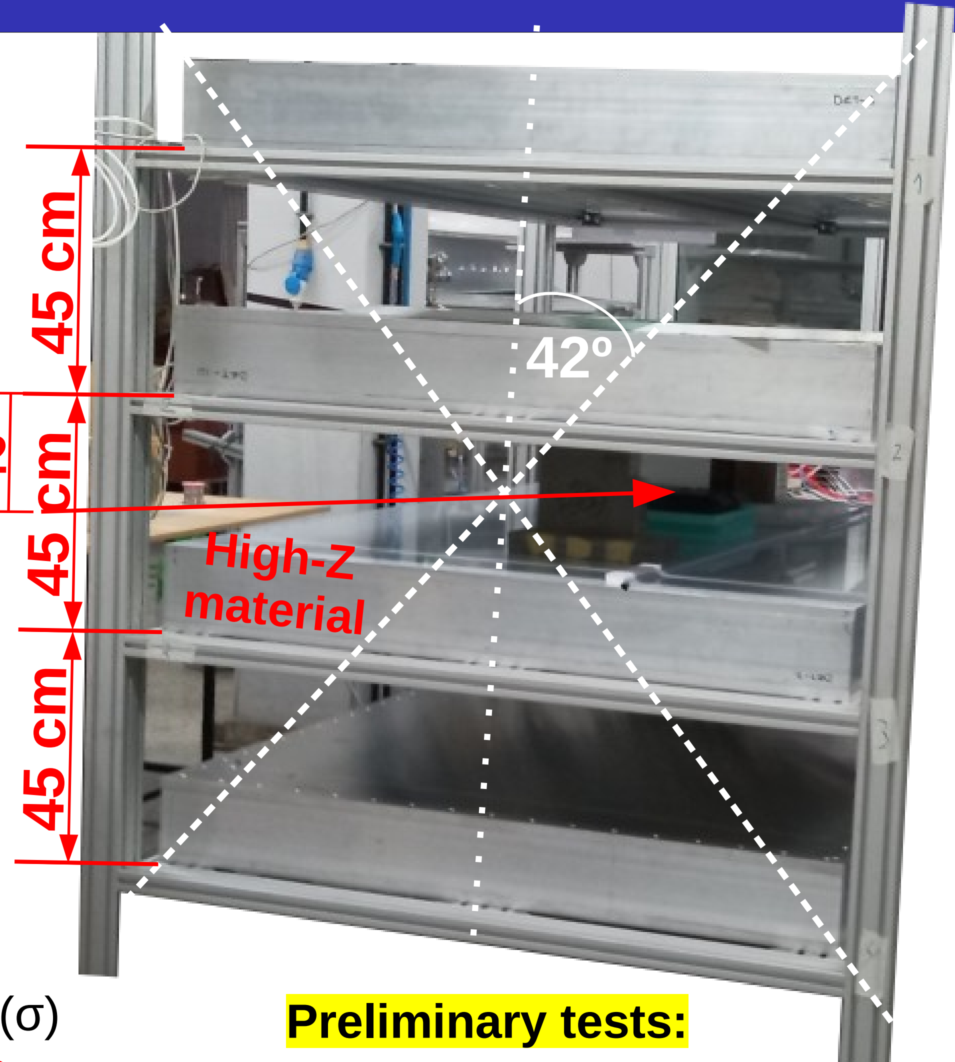
STRATOS Detector – Specifications



For each event:

- time: $(T_F+T_B)/2$
- charge: $(Q_F+Q_B)/2$
- 2D position:
  - ➔ $(T_F-T_B)/2$ (along the strips, Y)
  - ➔ $Q_{highest}$ (transversal to strips, X)

Time resolution	350 ps
Spatial resolution	x: 0.85 cm (σ), y: 1.6 cm (σ)
Angular resolution*	θ_x: 2.2º (σ), θ_y: 4.0º (σ)
Angular acceptance	x: 42º, y: 50º
Efficiency**	>98%



Preliminary tests:

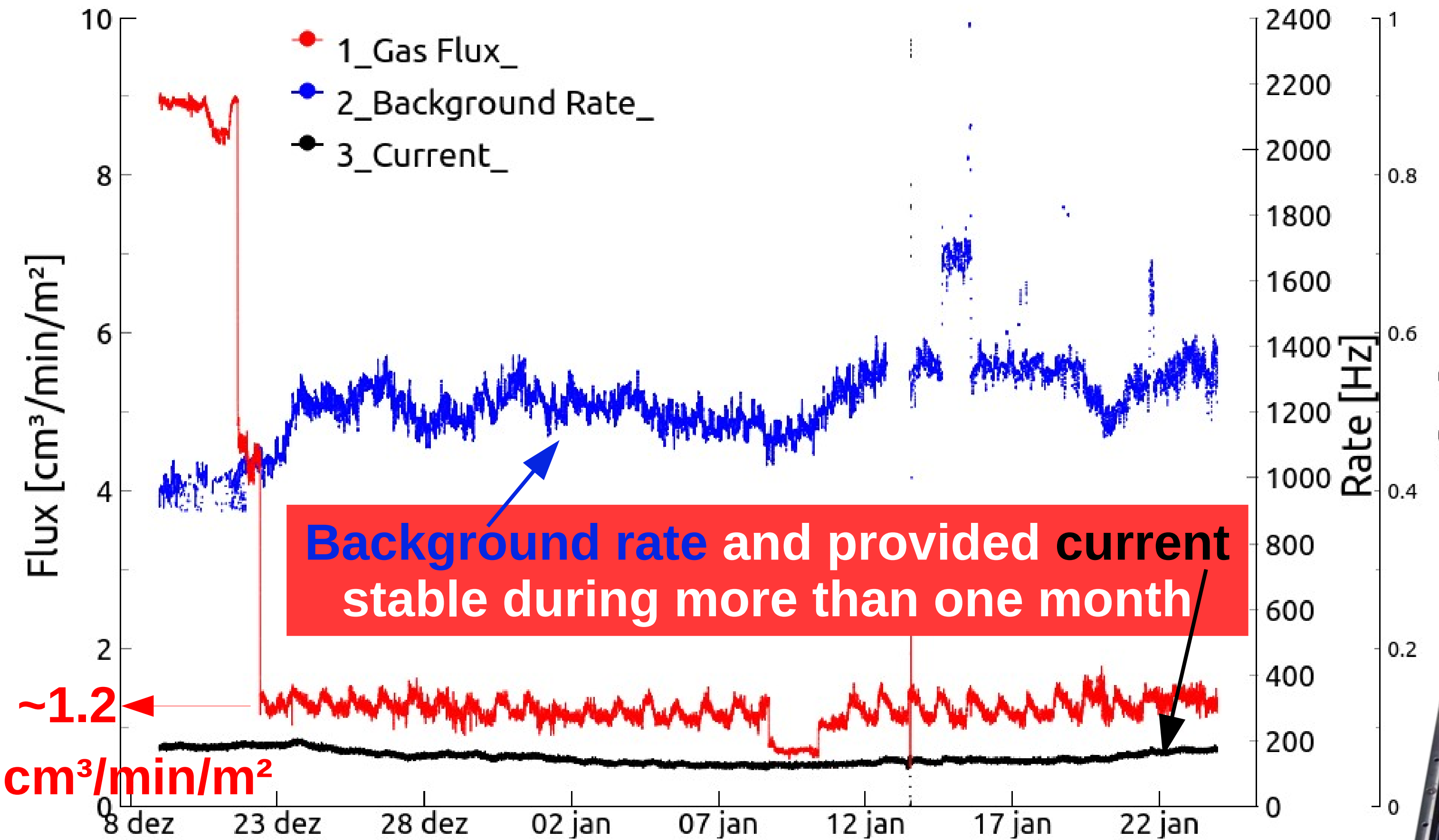
scattering muography (high-Z materials)

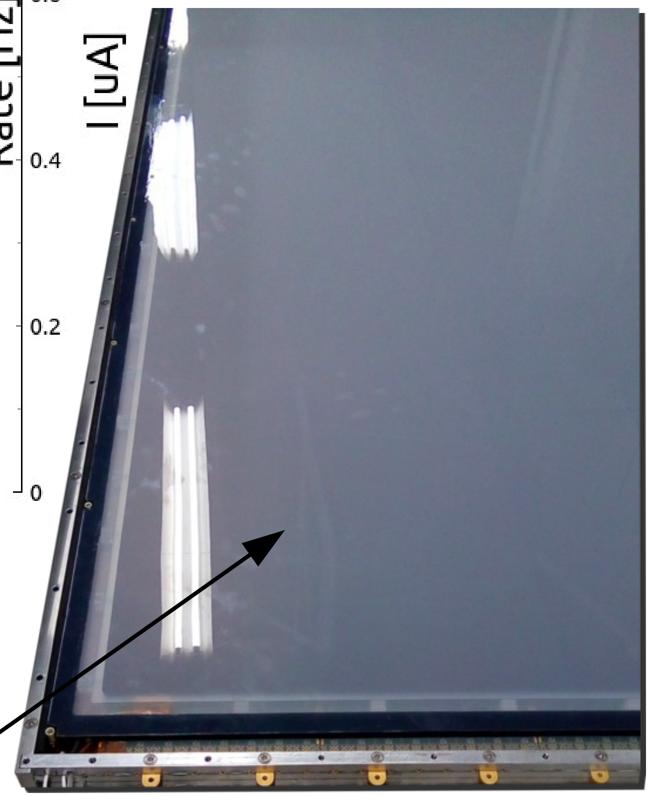
max. distance between RPCs: 45 cm

* $\theta_{x,y} = \tan^{-1}[x,y/(L/2)]$

** Reduced electric Field: 235 Td

Low Gas Flow Operation – One month at very low gas flow

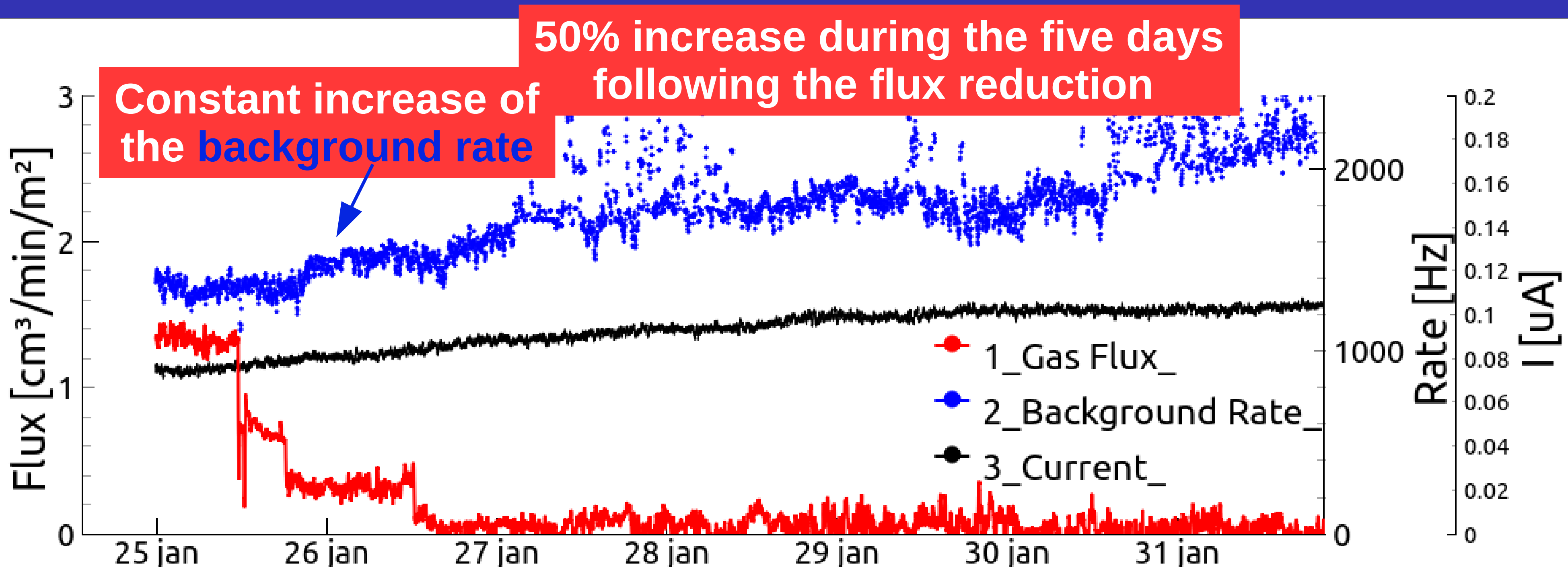




One-month operation in stable conditions:

- **Gas flux** slightly above **1 cm³/min/m²**
- **one volume exchange** each **~2.5 days**
- background rate & current remained **stable**
  - choice of **polypropylene** for the enclosure of the **sensitive volume** resulted in a **high sealing performance against external contaminants**
  - **Improvement with respect to previous setups** -> acrylic & polycarbonate (lid)

Low Gas Flow Operation – 5 days @ residual flow



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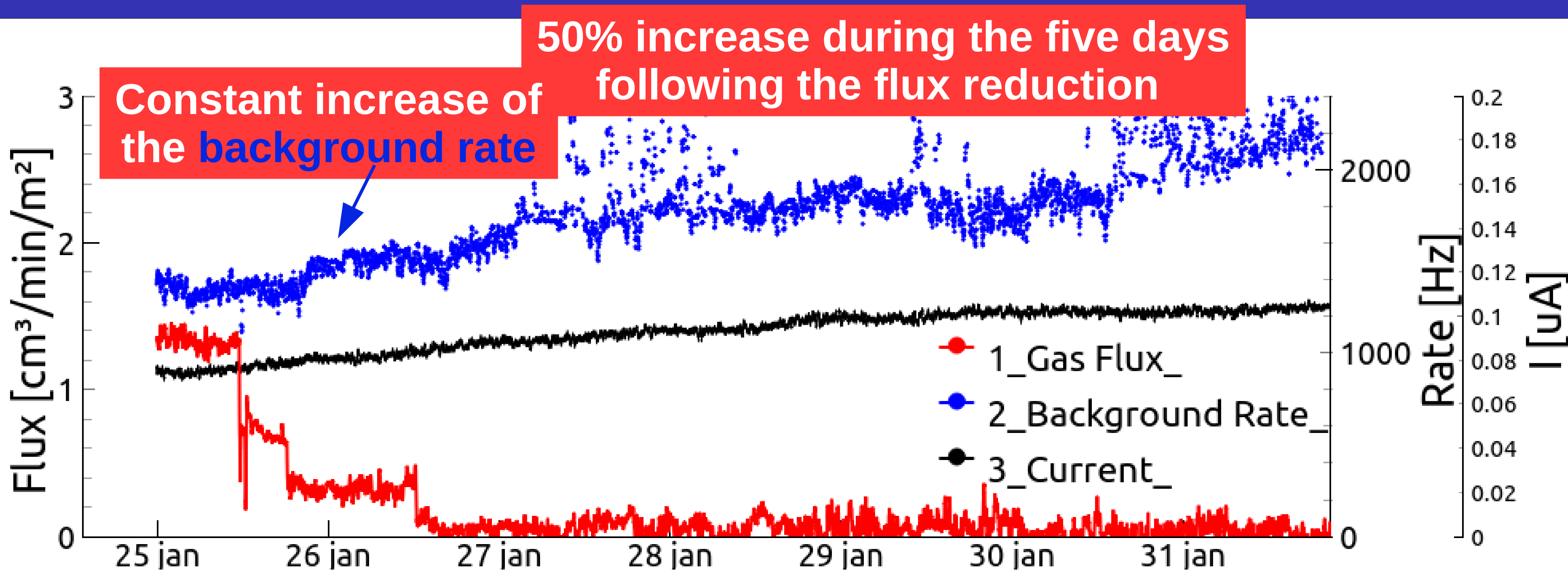
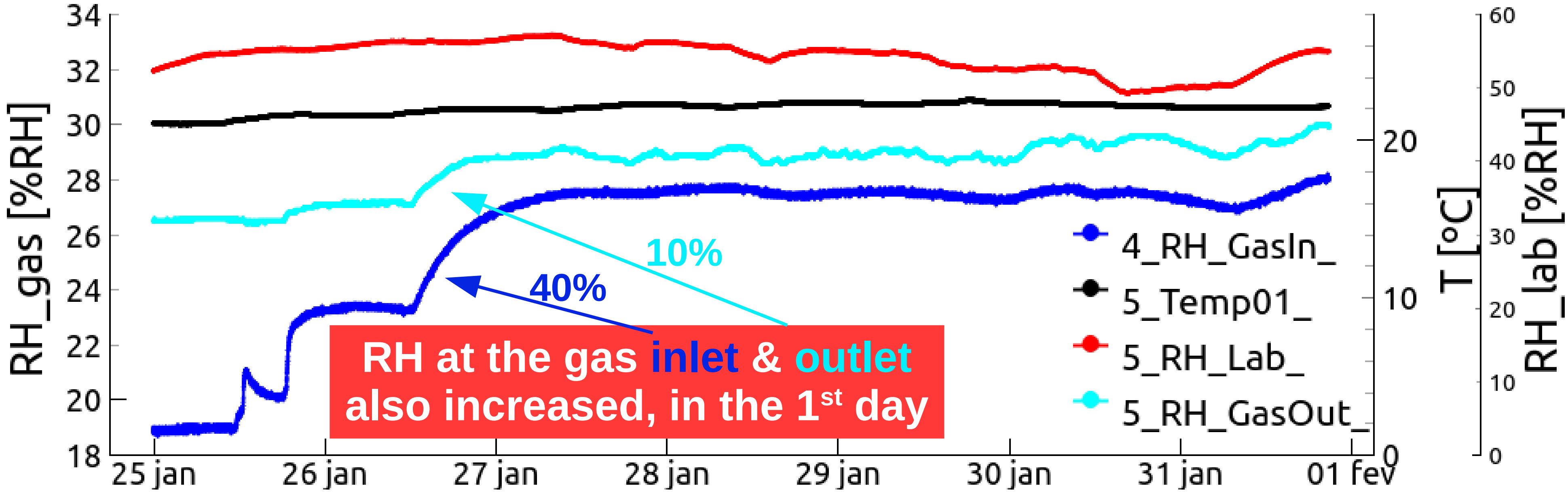
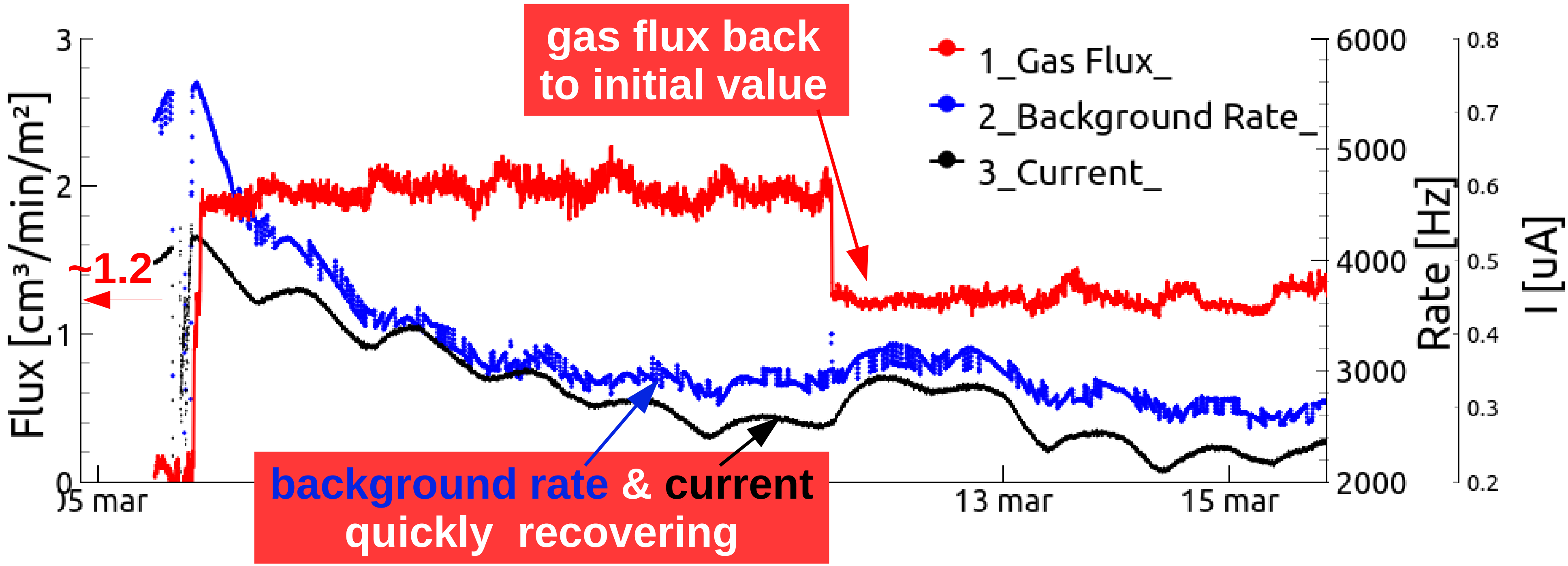




Low Gas Flow Operation – Re-establishment of gas flow



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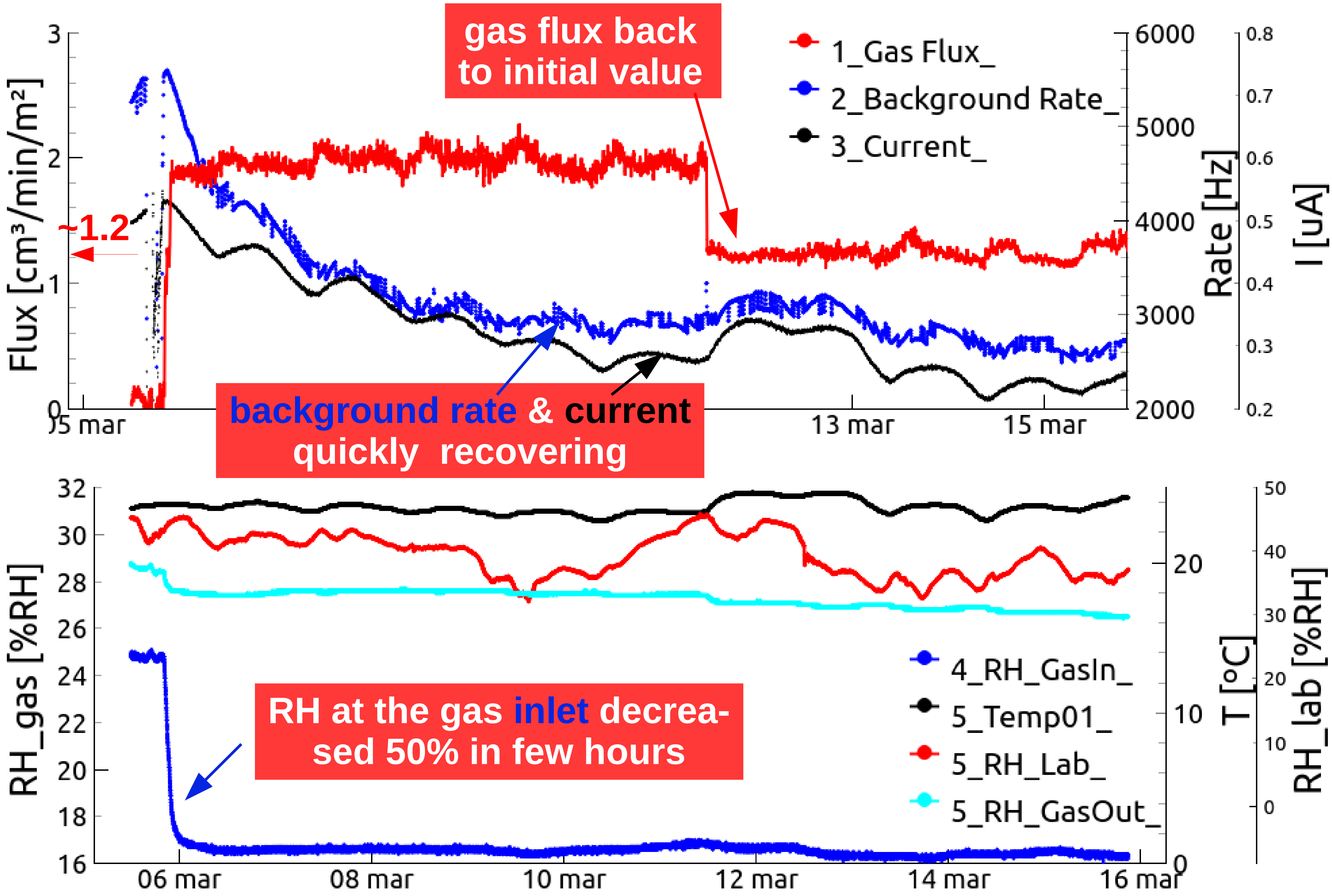

Low Gas Flow Operation – Summary (I)

- **@ low gas flow (~1cm³/min/m²)**
  - ➔ stable operation during one month (rates & currents constant)
- **@ residual flow**:
  - ➔ rate & current increased instantaneous and constantly (~50% in five days)
  - ➔ RH at the gas inlet & outlet increased 40% and 10% in the 1st day, respectively
- **Restoring low gas flow**:
  - ➔ rate & current quickly recovered (decreasing a factor of 2 in few days)
  - ➔ RH of the gas at the inlet side decreased 50% in few hours
  - ➔ RH of the gas at the outlet side decreased only few percent

Low Gas Flow Operation – Summary (I) & further analysis

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The whole RPC contributed to the increase of background rate and current during the residual flux period?

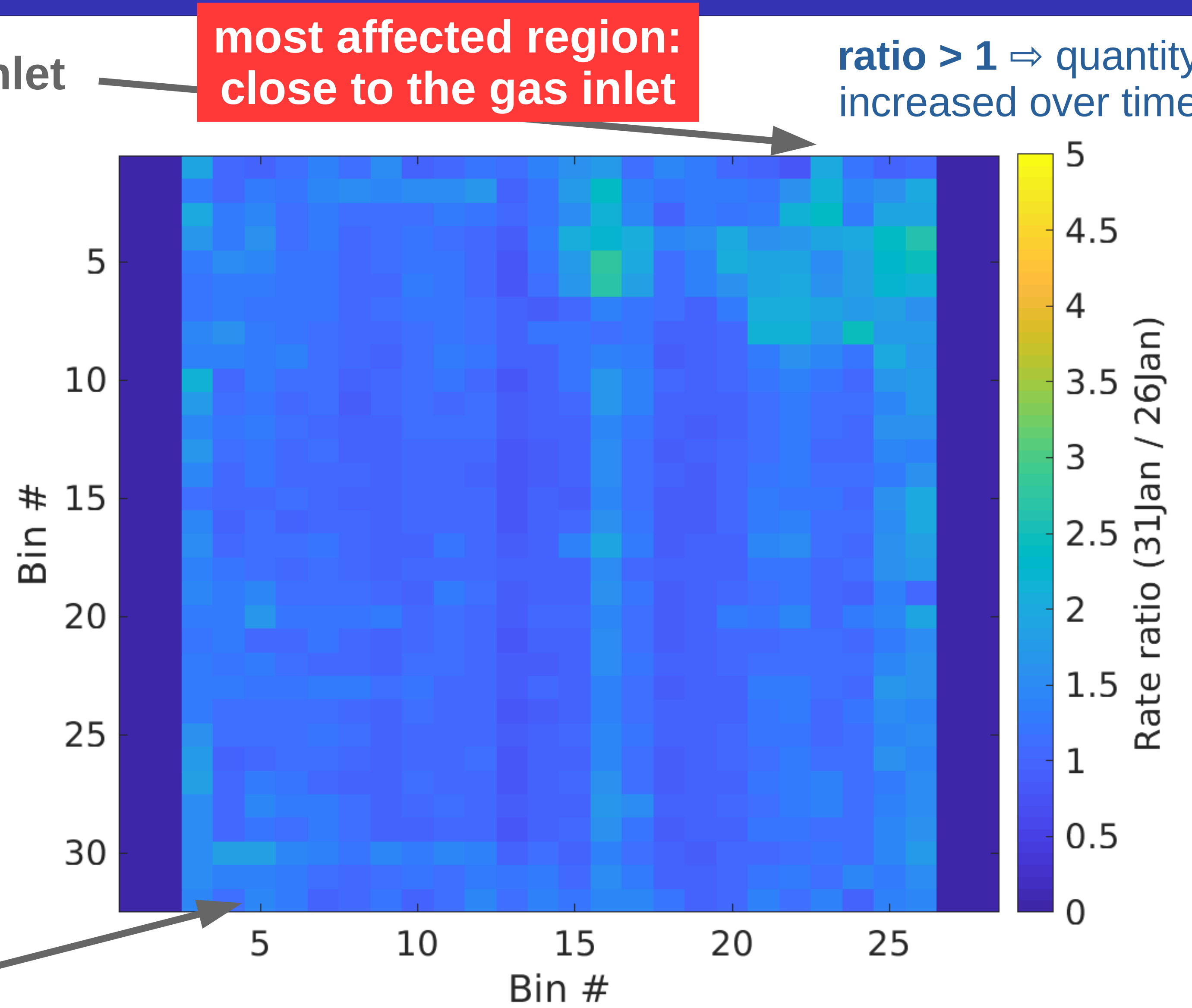
-> analysis @ residual flow:

(1) split the RPC sensitive area into **5x5 cm² bins** (32x24 bins)

(2) compute values per bin: (i) **background rate**, (ii) **deposited charge**

(3) evaluate **temporal and spatial evolution** of these quantities using **bin-wise division** between corresponding values **spaced out in time**

Low Gas Flow Operation – Bin-wise division_Background rate



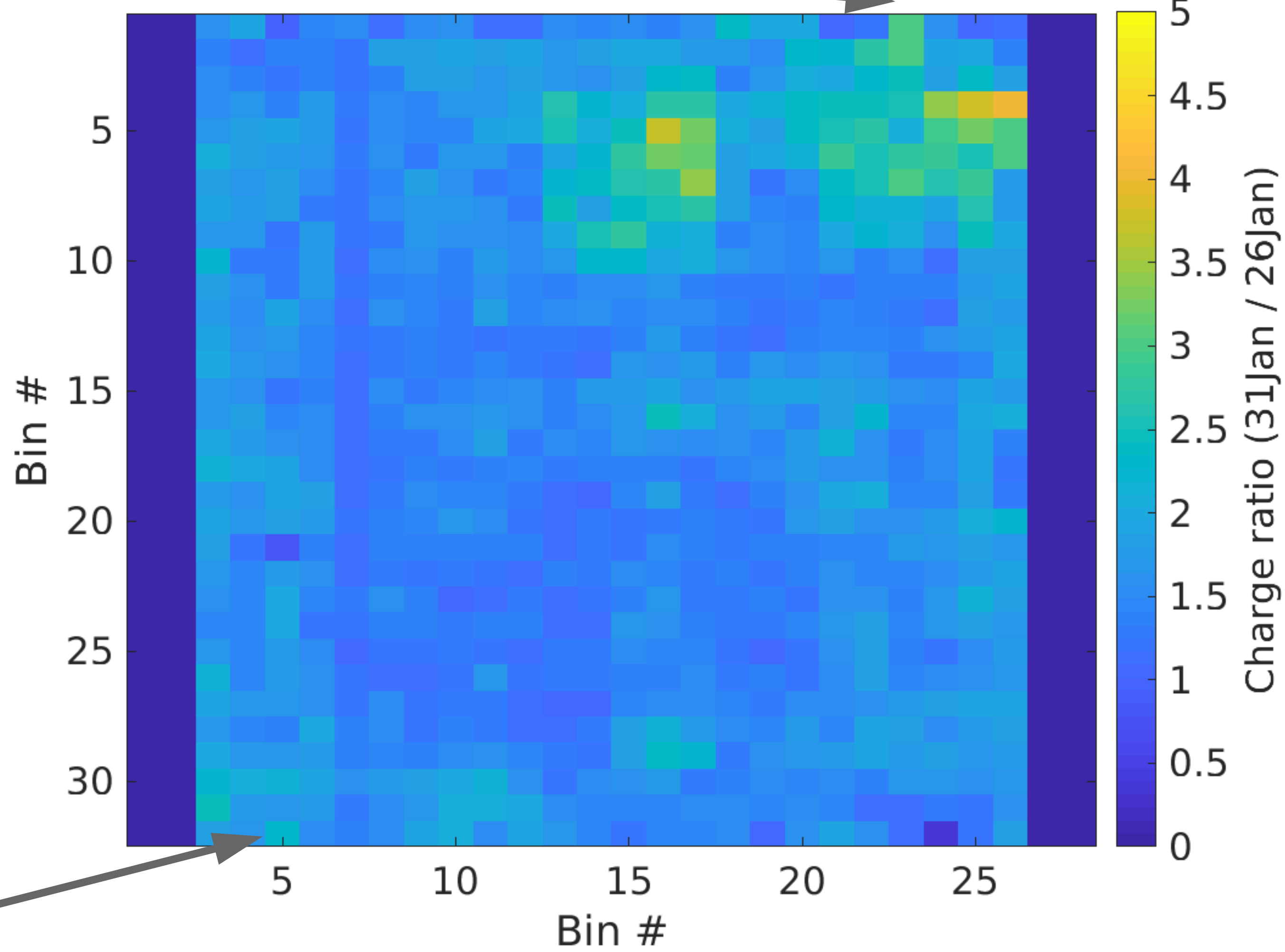
Bin-wise division of **background rate spaced 5 days apart** after the gas flow cut-off

Low Gas Flow Operation – Bin-wise division_Charge

Gas inlet

most affected region: close to the gas inlet

ratio > 1 ⇨ quantity increased over time



Gas outlet

Bin-wise division of **induced charge spaced 5 days apart** after the gas flow cut-off

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  - ➔ RH of the gas at the outlet side decreased only few percent

@ residual flow:

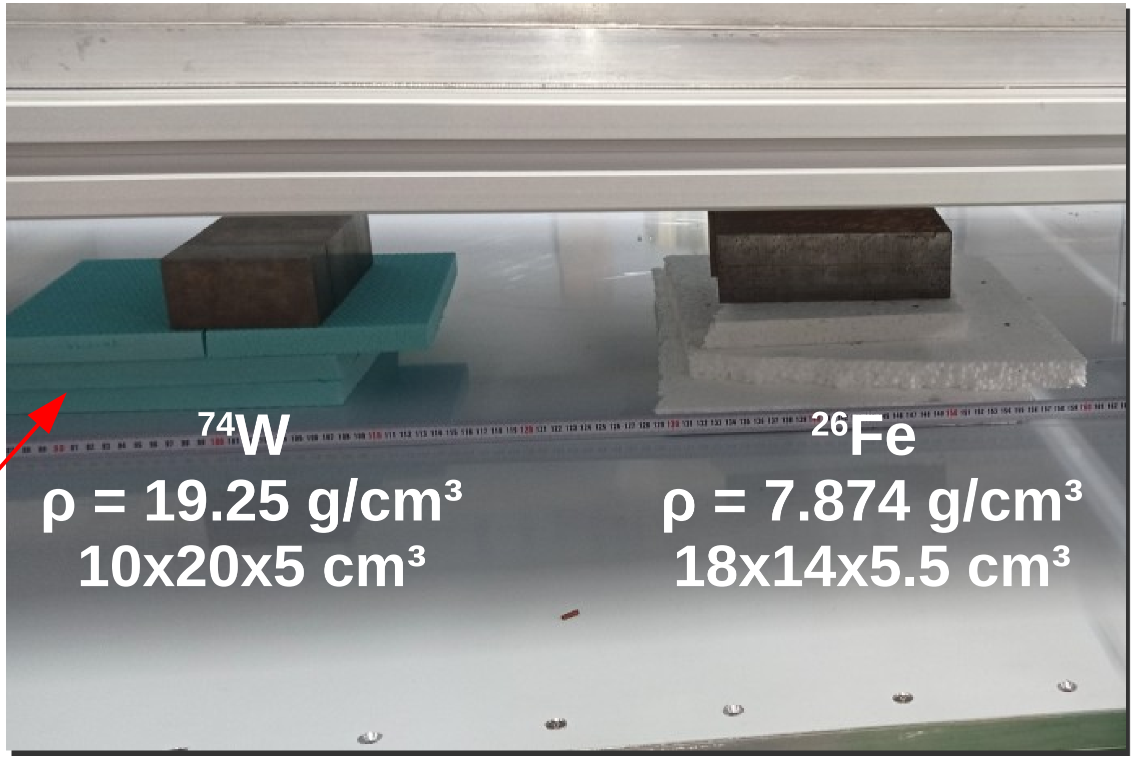
- **increase** of background rate & charge mainly circumscribed to the **gas inlet side**
- RH of the gas **entering the RPC** was also the most affected
- probably due to a lack of sealing at this measurement point
  - ➔ Inlet & outlet connections to be improved -> work in progress

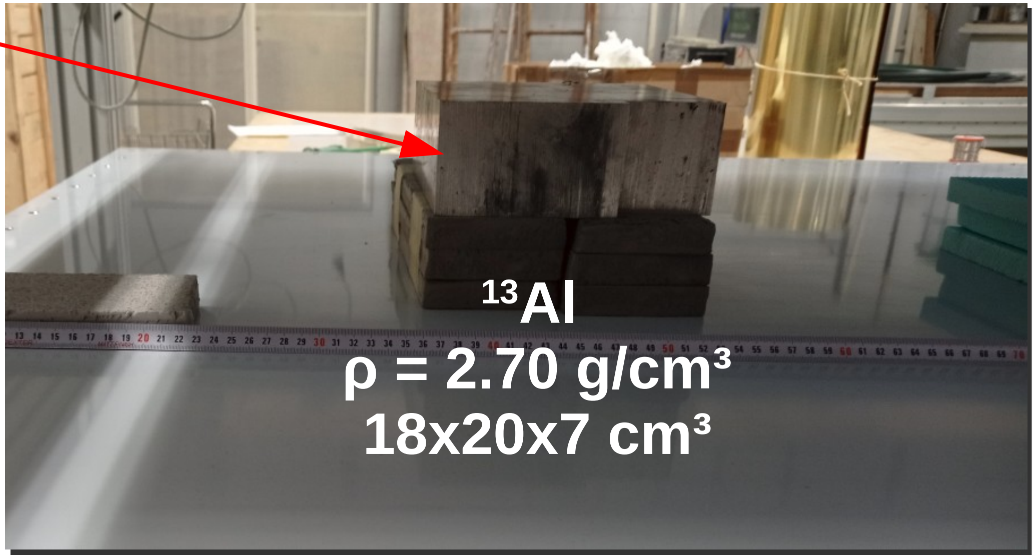
RPCs applied to Muography – Preliminary tests

Scattering muography

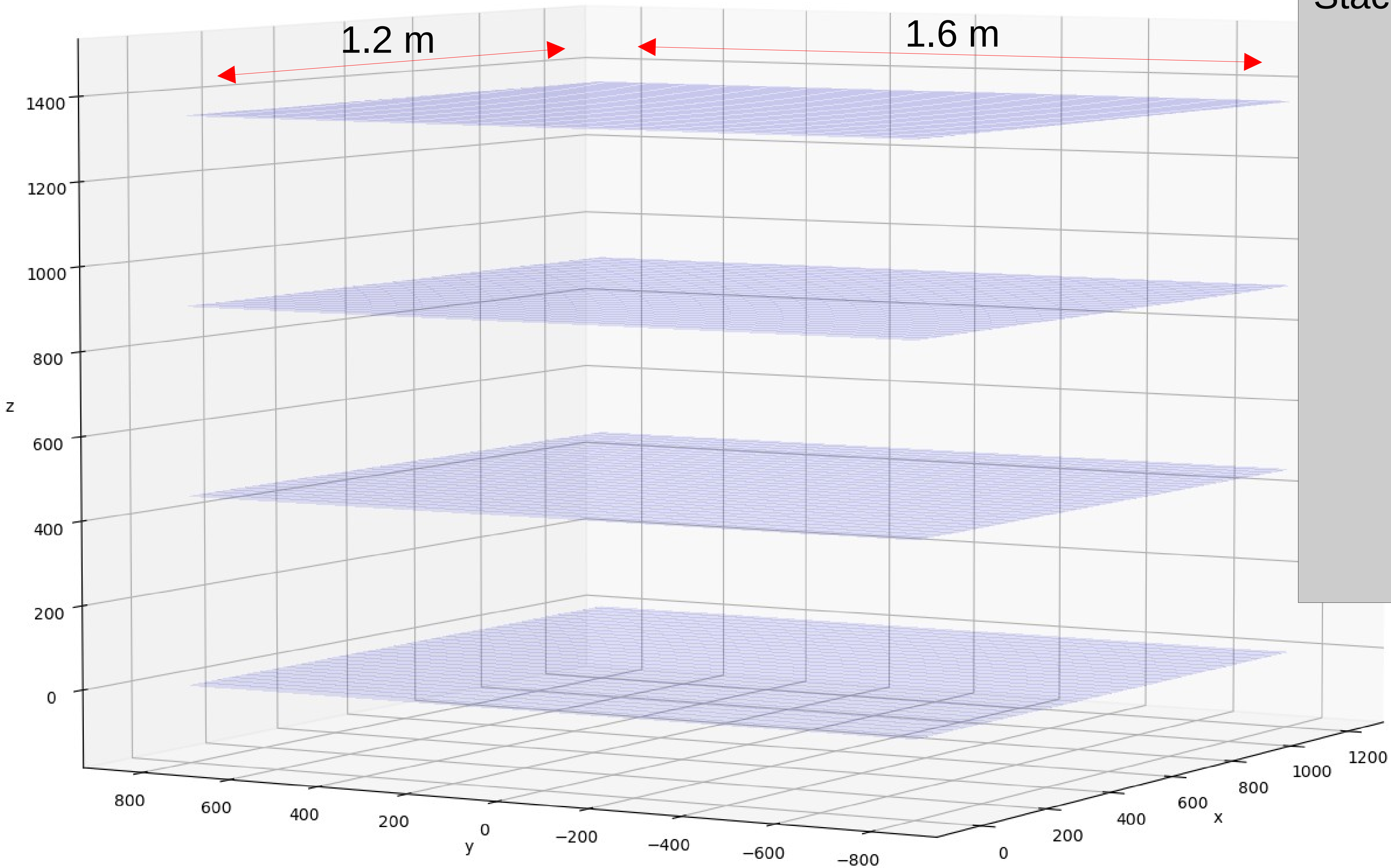
of several materials placed

at the center of the telescope



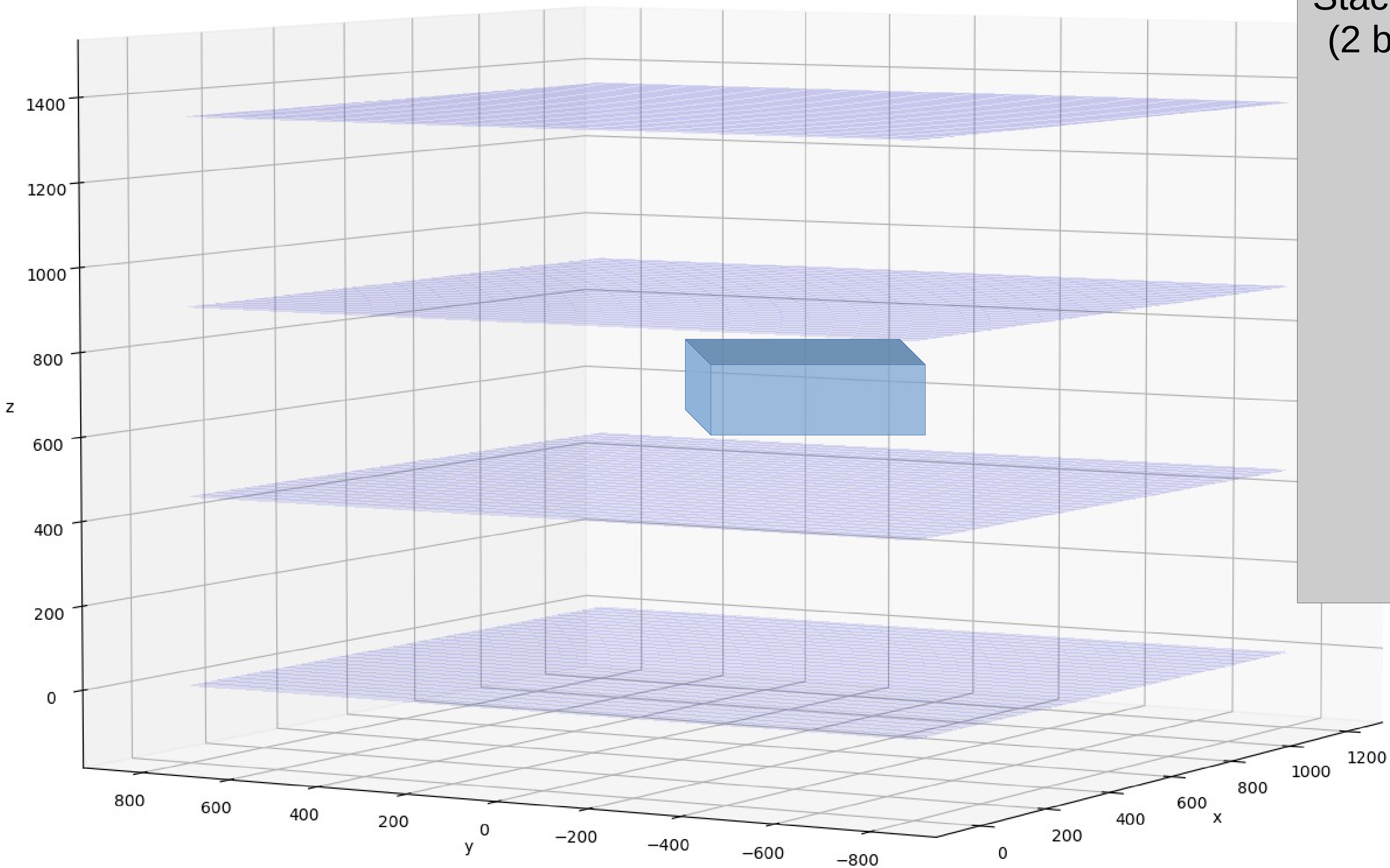


Scattering Muography – 4 planes



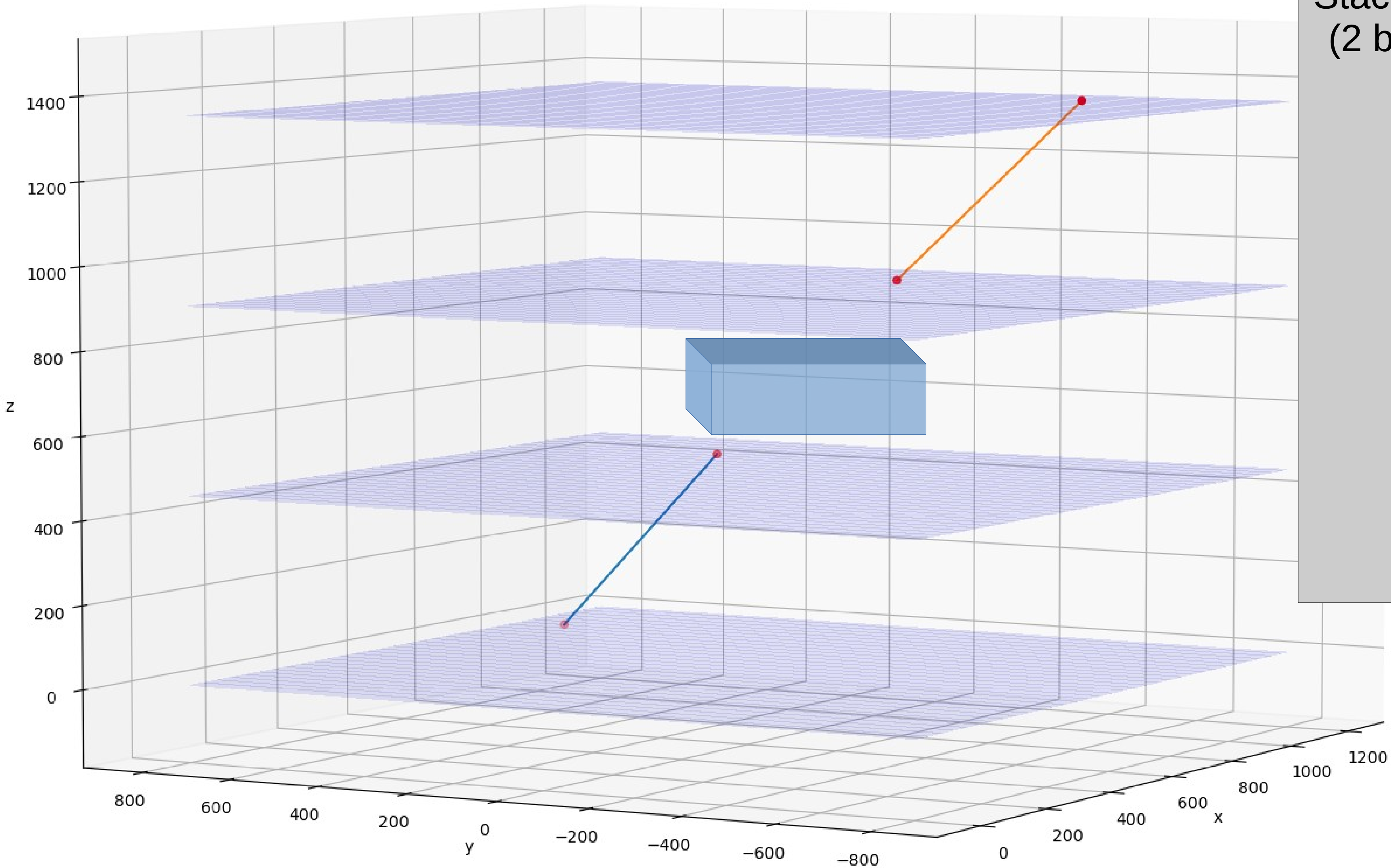
Stack of 4 detectors

Scattering Muography – 4 planes, target @ the center



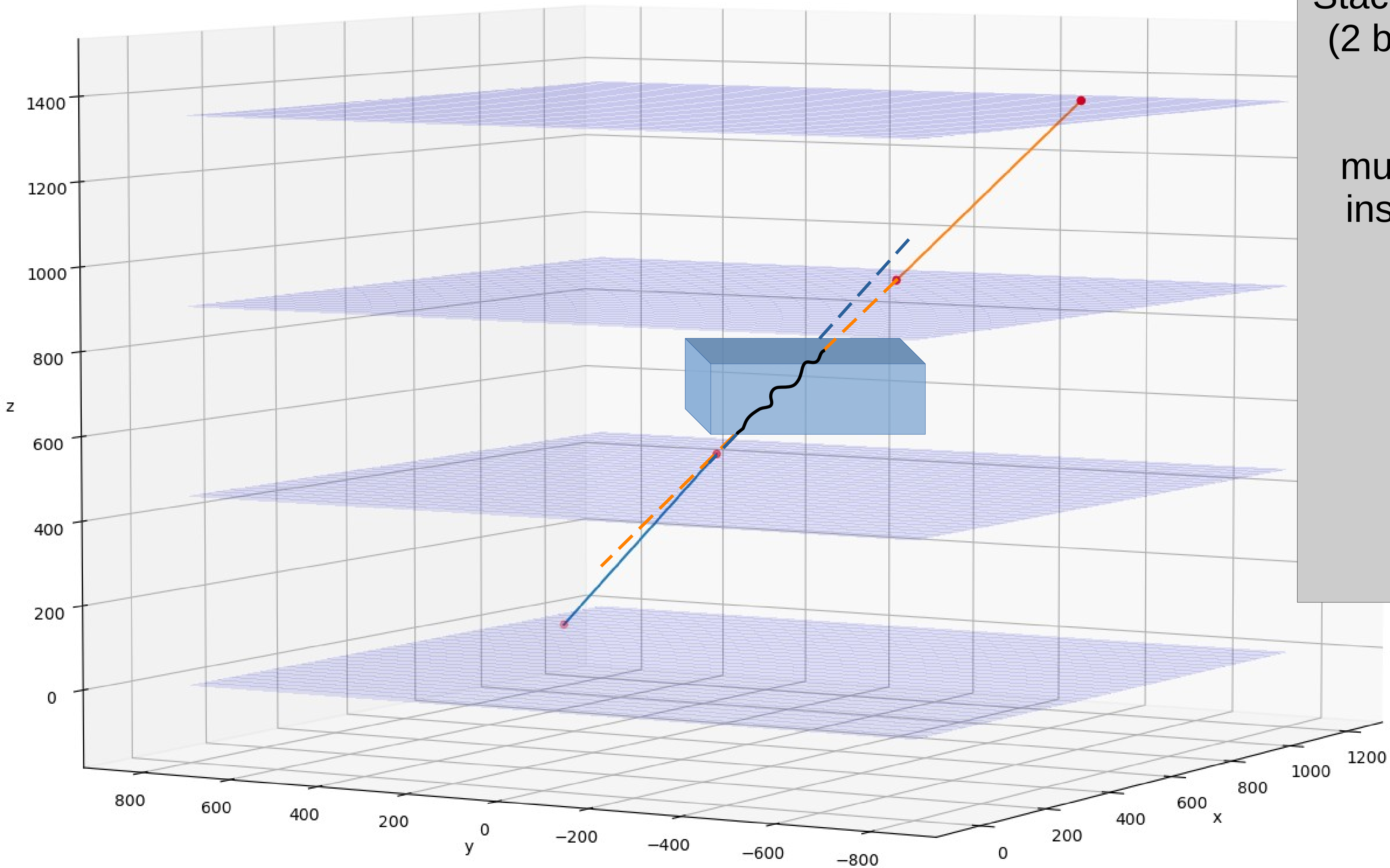
Stack of 4 detectors (2 before & 2 after the target)

Scattering Muography – Muon trajectories before & after target



Stack of 4 detectors (2 before & 2 after the target)

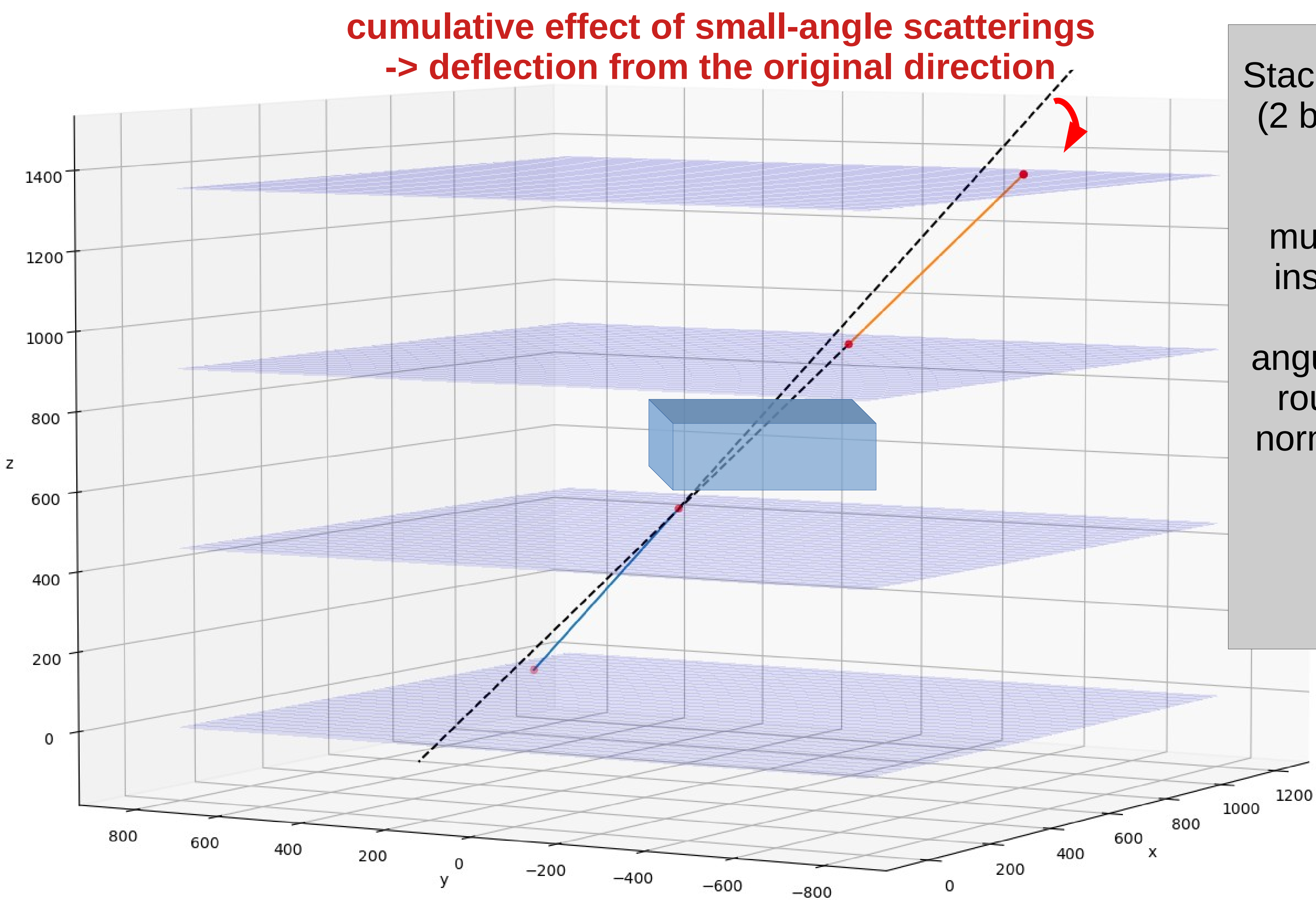
Scattering Muography – Small-angle scatterings (MCS)



Stack of 4 detectors (2 before & 2 after the target)

muons scattered inside the target

Scattering Muography – Angular deflection



Stack of 4 detectors (2 before & 2 after the target)

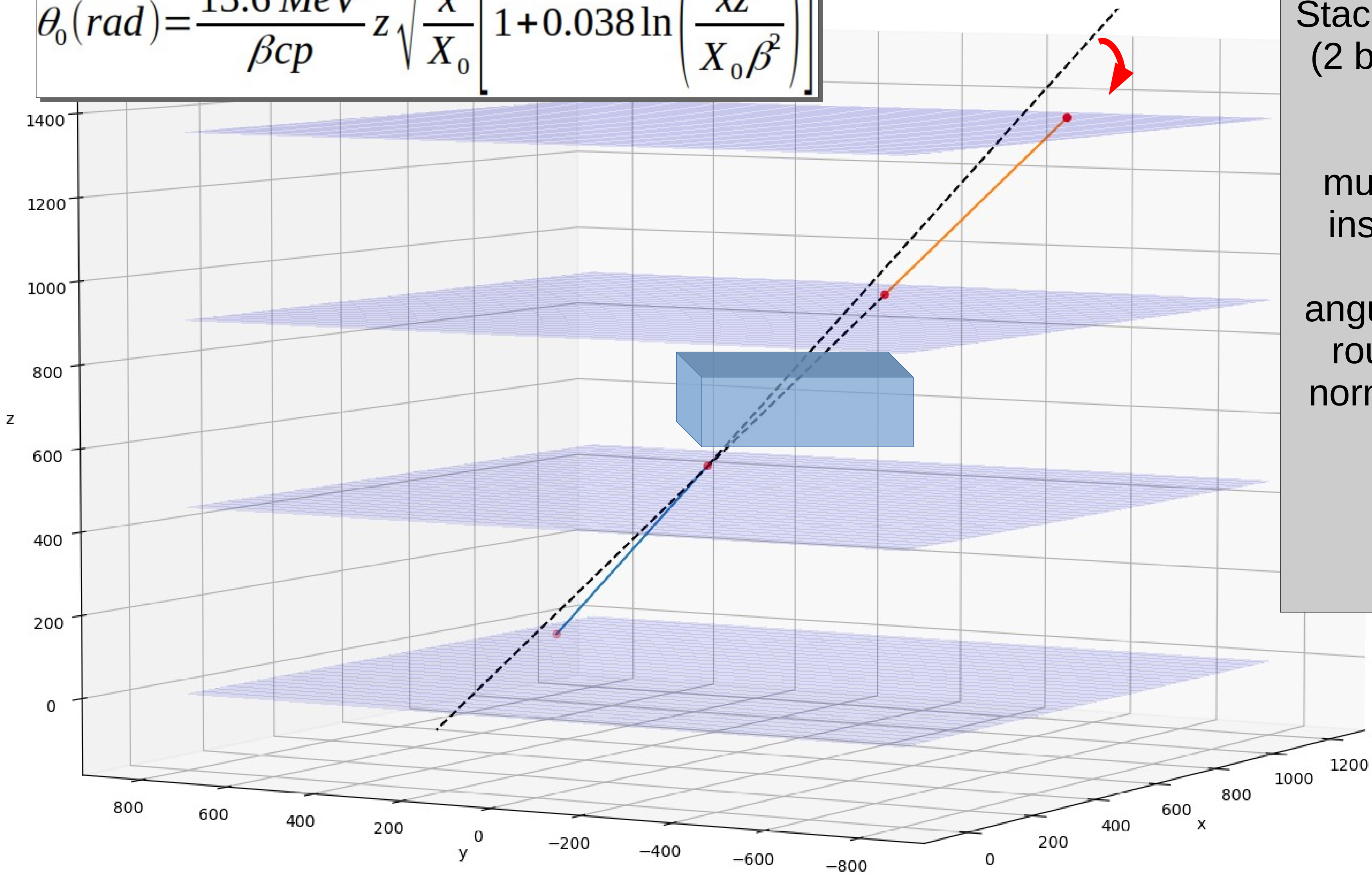
muons scattered inside the target

angular deflections roughly follow a normal distribution

Scattering Muography – Lynch & Dahl formula

rms width of the Gaussian approximation of the angular distribution

$$\theta_0(rad) = \frac{13.6\,MeV}{\beta c p} z \sqrt{\frac{x}{X_0}} \left[1 + 0.038 \ln\left(\frac{x z^2}{X_0 \beta^2} \right) \right]$$



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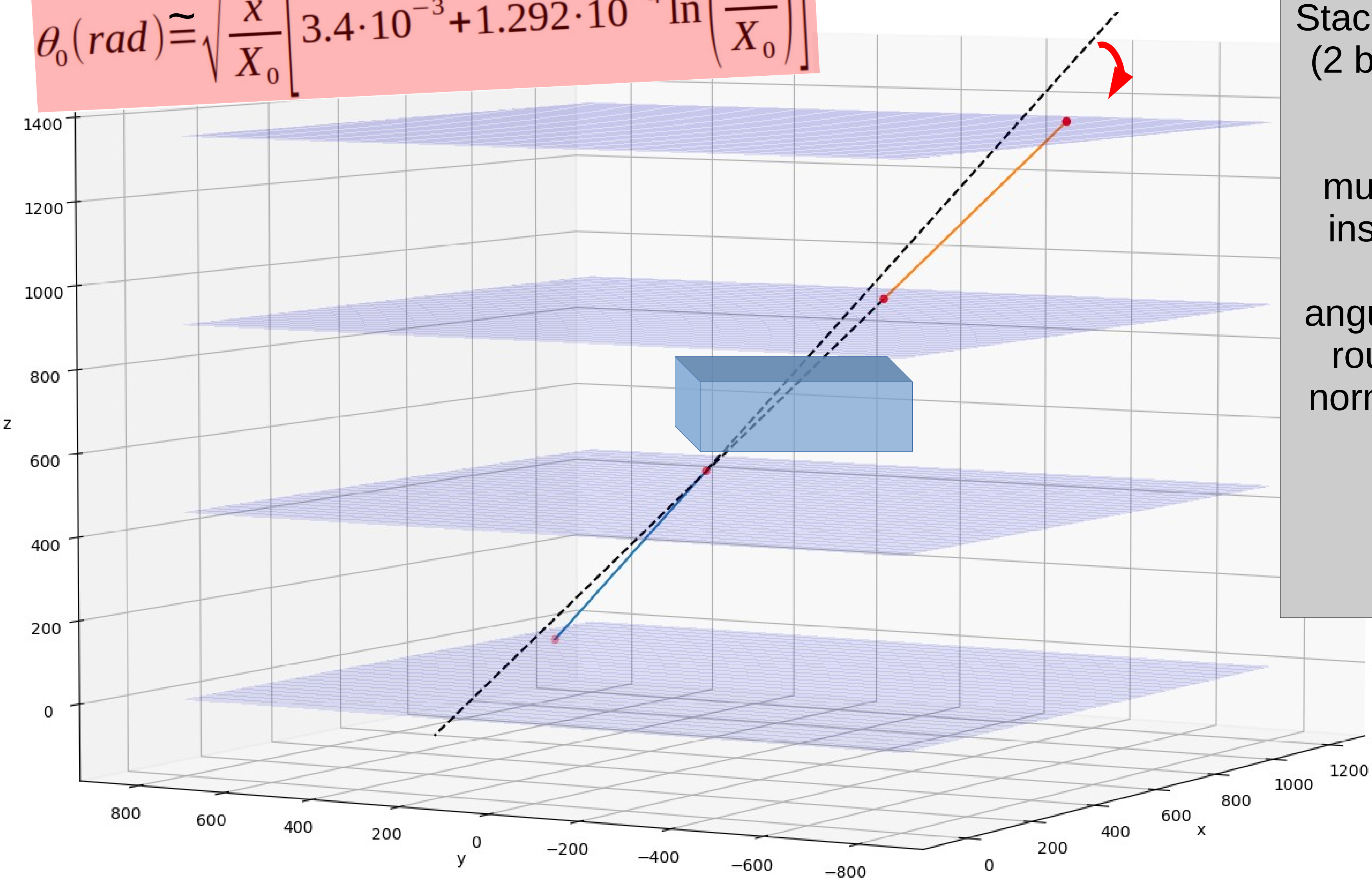
Scattering Muography – Lynch & Dahl formula -> 4 GeV muons

rms width of the Gaussian approximation of the angular distribution

$$\theta_0(rad) \cong \sqrt{\frac{x}{X_0}}\left[3.4\cdot10^{-3}+1.292\cdot10^{-4}\ln\left(\frac{x}{X_0}\right)\right]$$



Stack of 4 detectors (2 before & 2 after the target)

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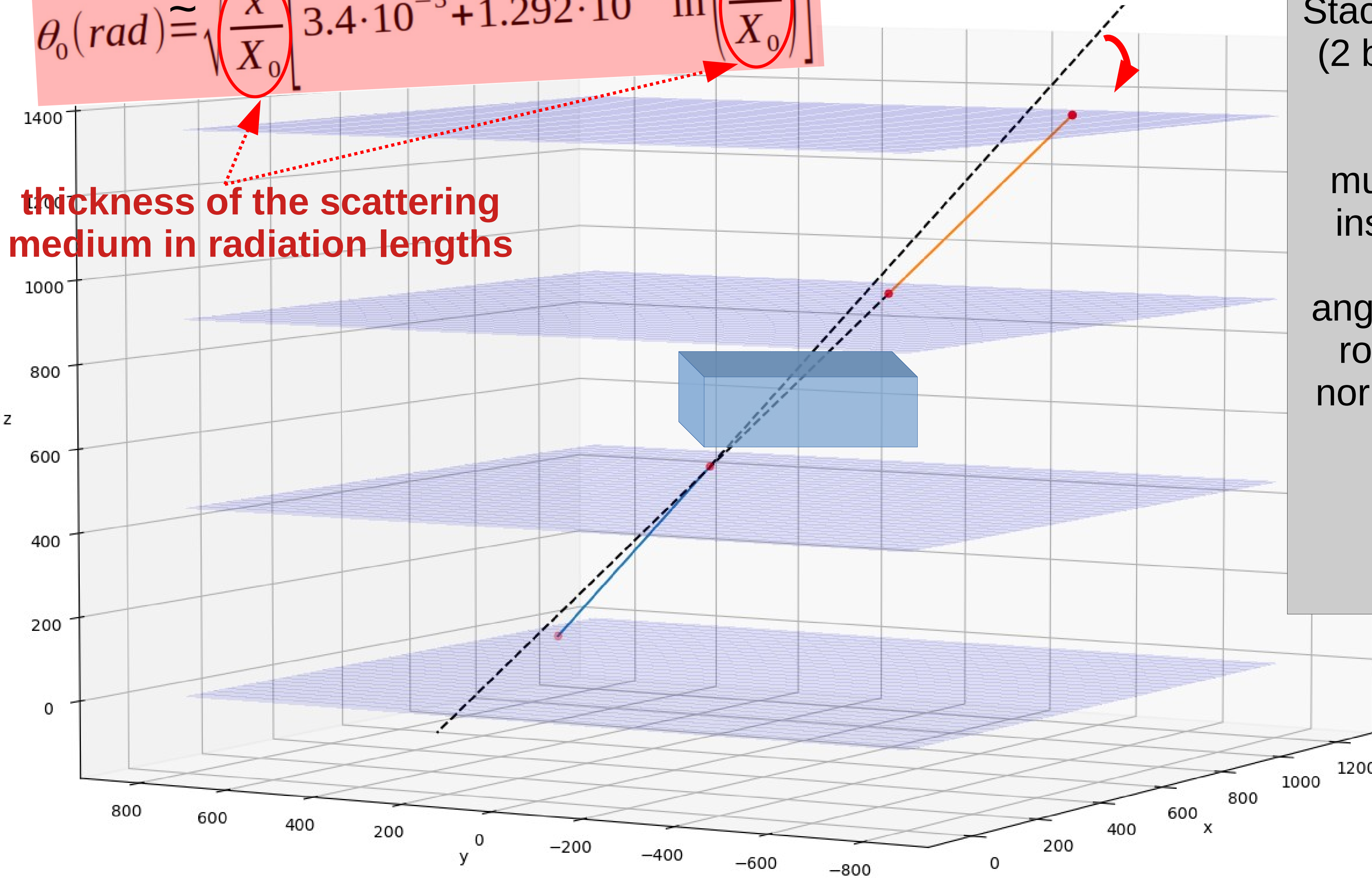
Scattering Muography – Lynch & Dahl formula -> 4 GeV muons

rms width of the Gaussian approximation of the angular distribution

$$\theta_0(rad) \simeq \sqrt{\frac{x}{X_0}}\left[3.4\cdot 10^{-3} + 1.292\cdot 10^{-4}\ln\left(\frac{x}{X_0}\right)\right]$$

thickness of the scattering medium in radiation lengths



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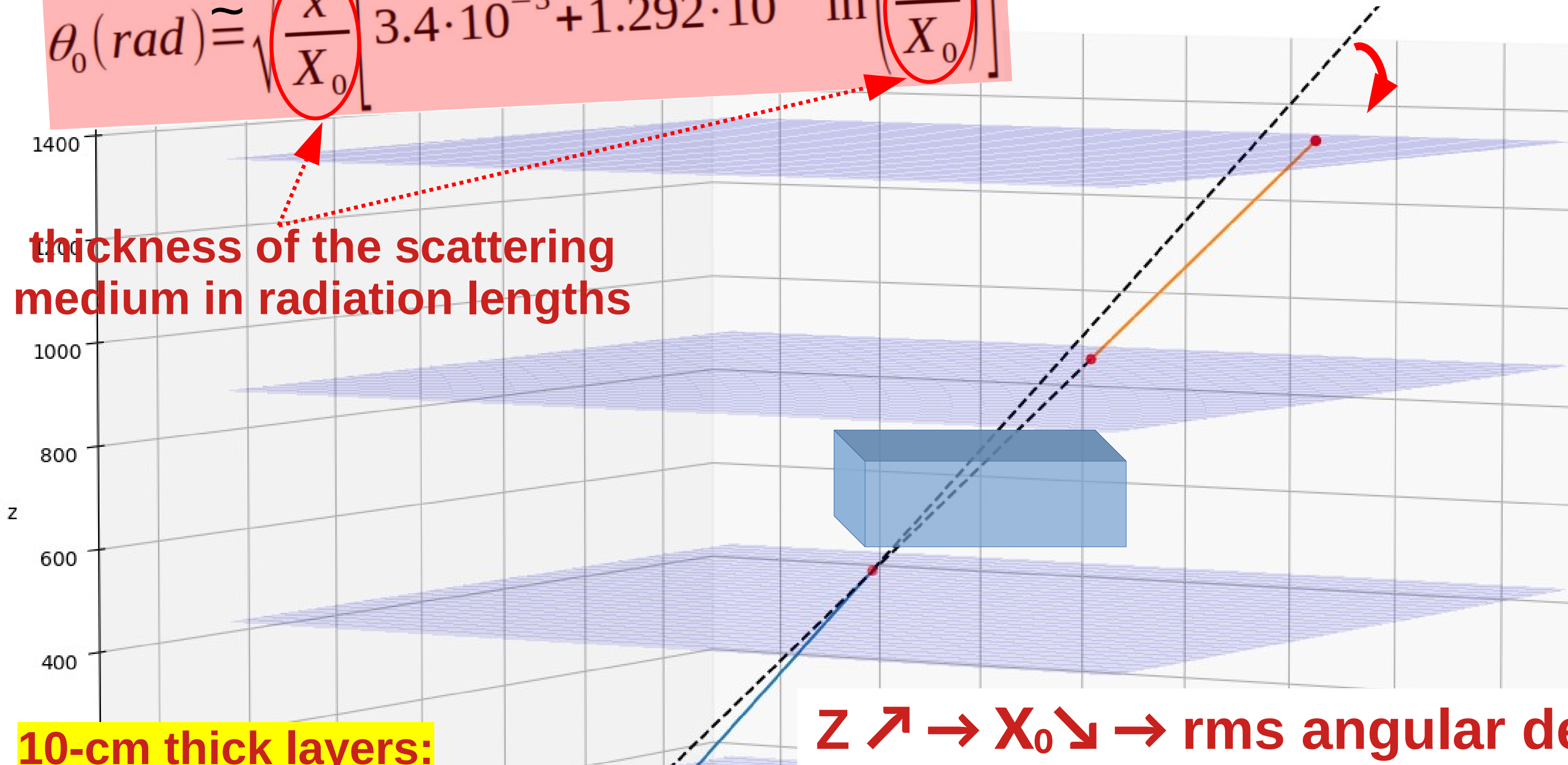


Stack of 4 detectors (2 before & 2 after the target)

muons scattered inside the target

angular deflections roughly follow a normal distribution

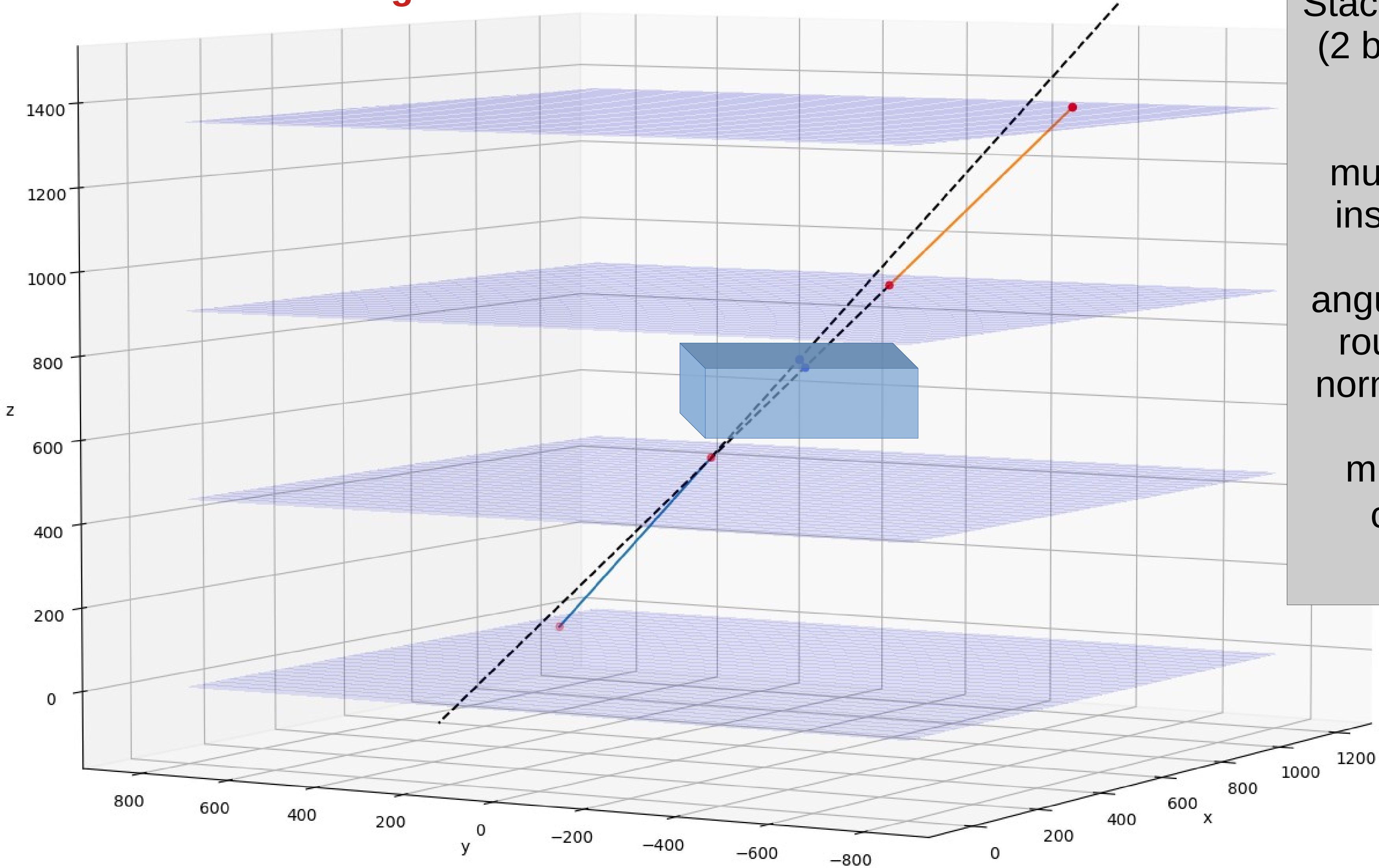
Z ↗ → X_0↘ → rms angular deflection ↗

10-cm thick layers:

Material	Z	X_0 [cm]	θ_0 (mrad)	θ_0 (deg)
Al	13	8.99	3.60	0.21
Fe	26	1.80	8.55	0.49
Ag	47	0.87	12.57	0.72
W	74	0.35	20.46	1.17
U	92	0.31	21.96	1.26

Scattering Muography – Point of Closest Approach (PoCA)

3D reconstruction technique to identify the location of high deflections



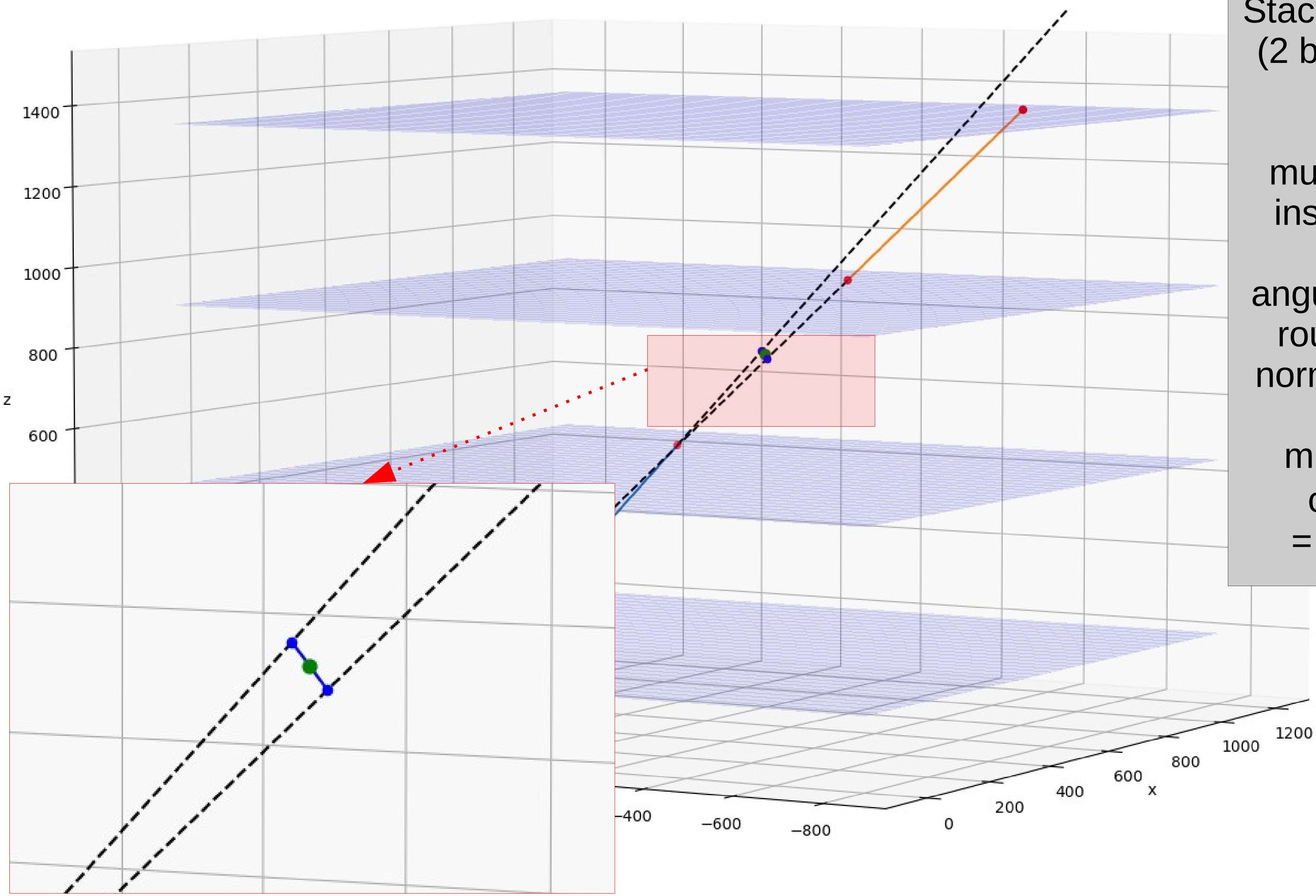
Stack of 4 detectors (2 before & 2 after the target)

muons scattered inside the target

angular deflections roughly follow a normal distribution

midpoint of the common ⊥

Scattering Muography – Point of Closest Approach (PoCA)



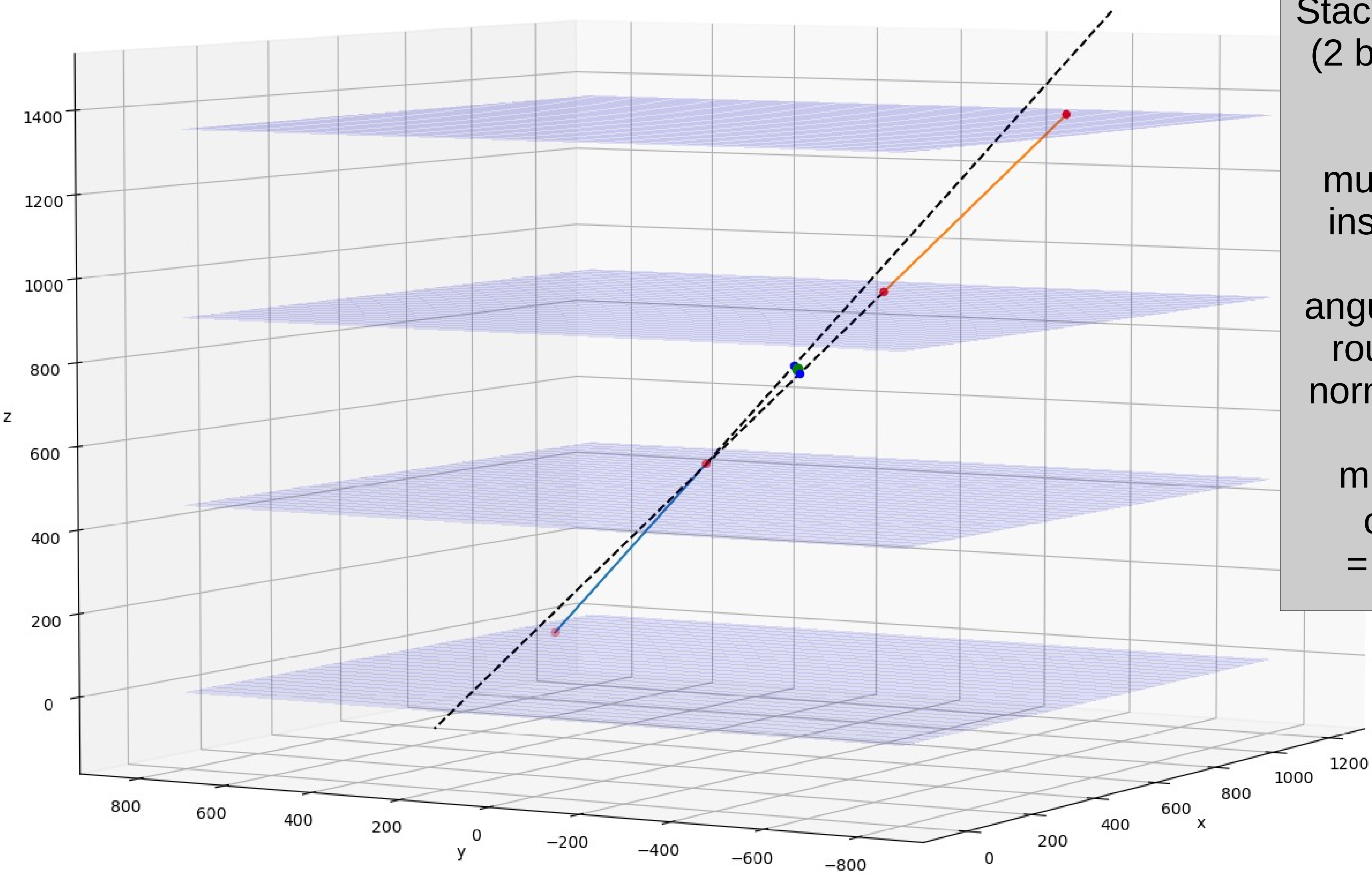
Stack of 4 detectors (2 before & 2 after the target)

muons scattered inside the target

angular deflections roughly follow a normal distribution

midpoint of the common ⊥ = PoCA point

Scattering Muography – 1 (real) event



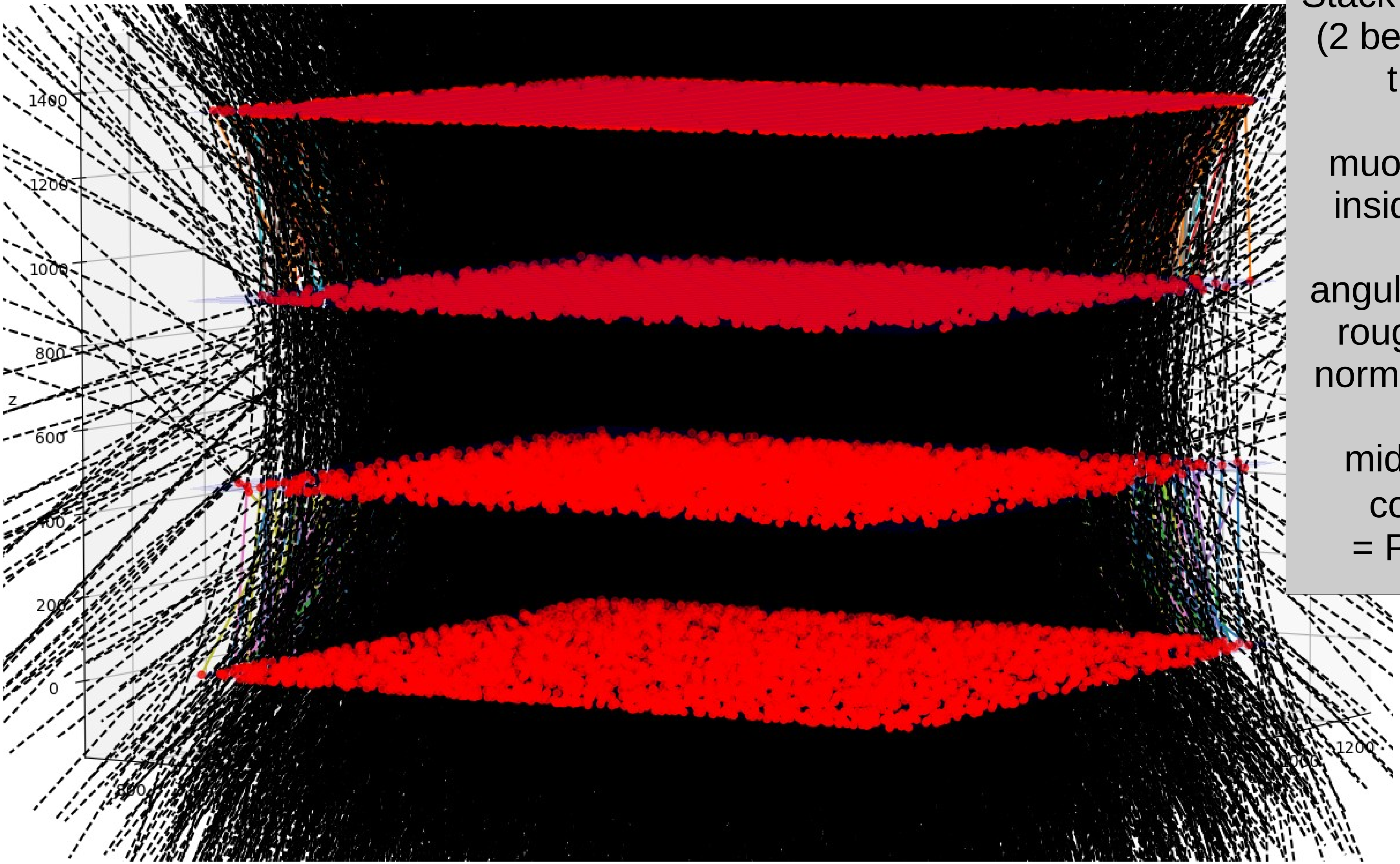
Stack of 4 detectors (2 before & 2 after the target)

muons scattered inside the target

angular deflections roughly follow a normal distribution

midpoint of the common ⊥ = PoCA point

Scattering Muography – 5k events (all deflections)



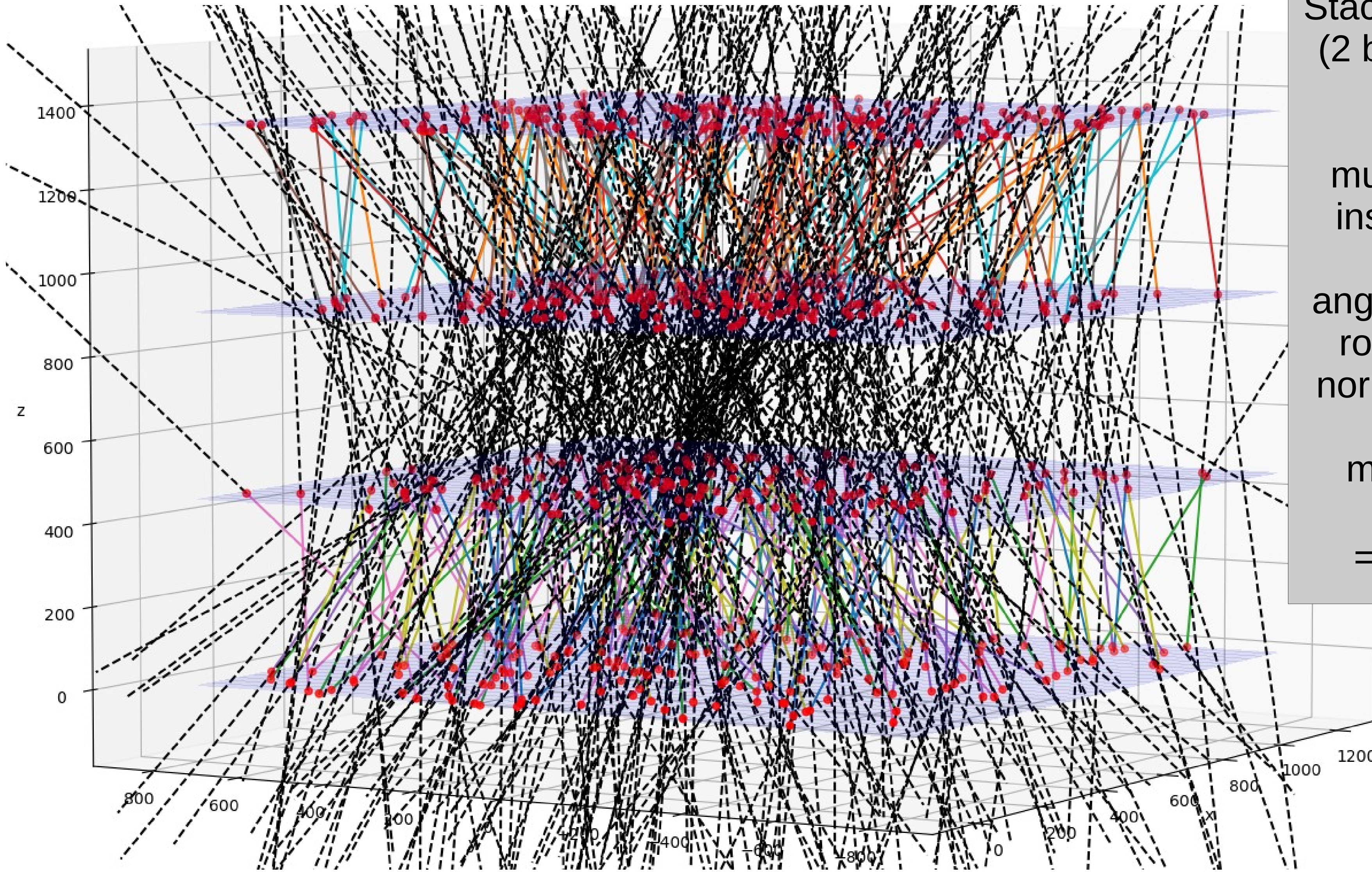
Stack of 4 detectors (2 before & 2 after the target)

muons scattered inside the target

angular deflections roughly follow a normal distribution

midpoint of the common ⊥ = PoCA point

Scattering Muography – 5k events (11º < θ < 21º)



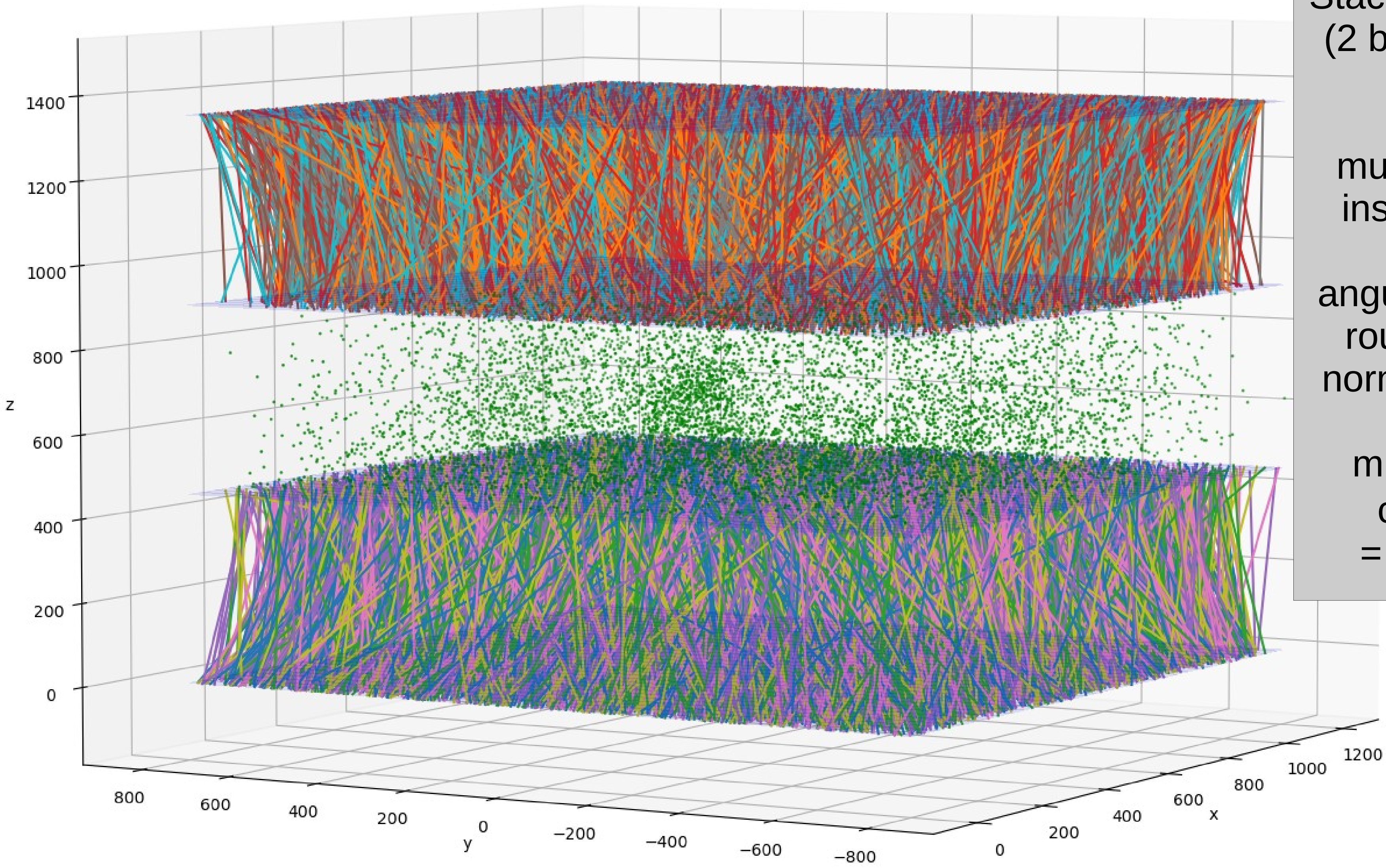
Stack of 4 detectors (2 before & 2 after the target)

muons scattered inside the target

angular deflections roughly follow a normal distribution

midpoint of the common ⊥ = PoCA point

Scattering Muography – 500k events (11º < θ < 21º)



Stack of 4 detectors (2 before & 2 after the target)

muons scattered inside the target

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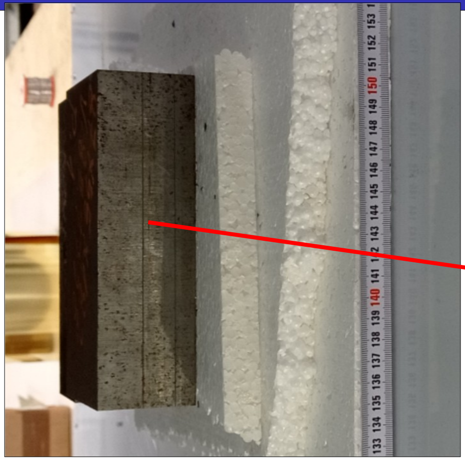
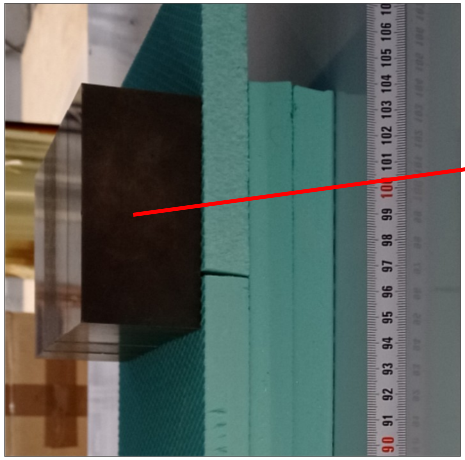
midpoint of the common ⊥ = PoCA point

Scattering Muography – Horizontal projection (bins: 7.5x4 cm²)

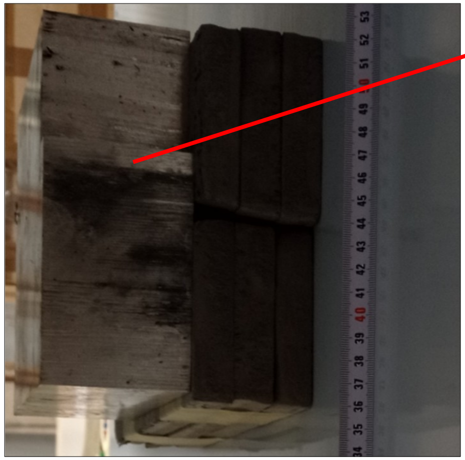
^{26}Fe
ρ = 7.874 g/cm³
18x14x5.5 cm³

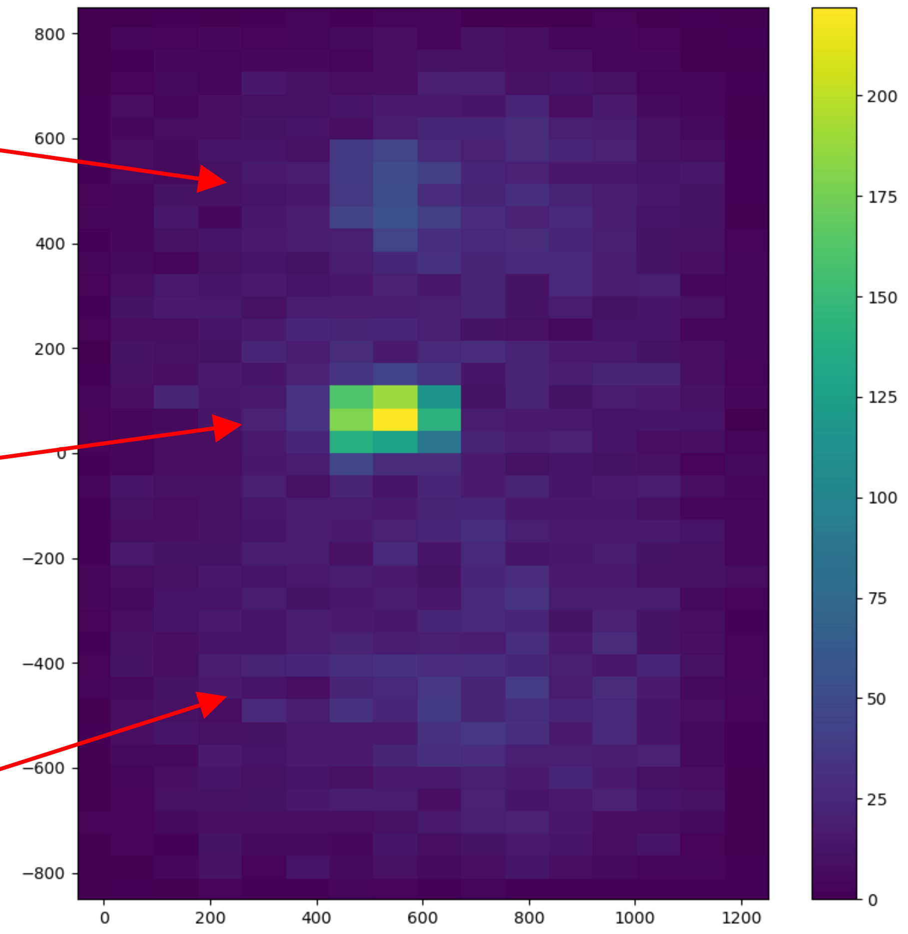


^{74}W
ρ = 19.25 g/cm³
10x20x5 cm³



^{13}Al
ρ = 2.70 g/cm³
18x20x7 cm³

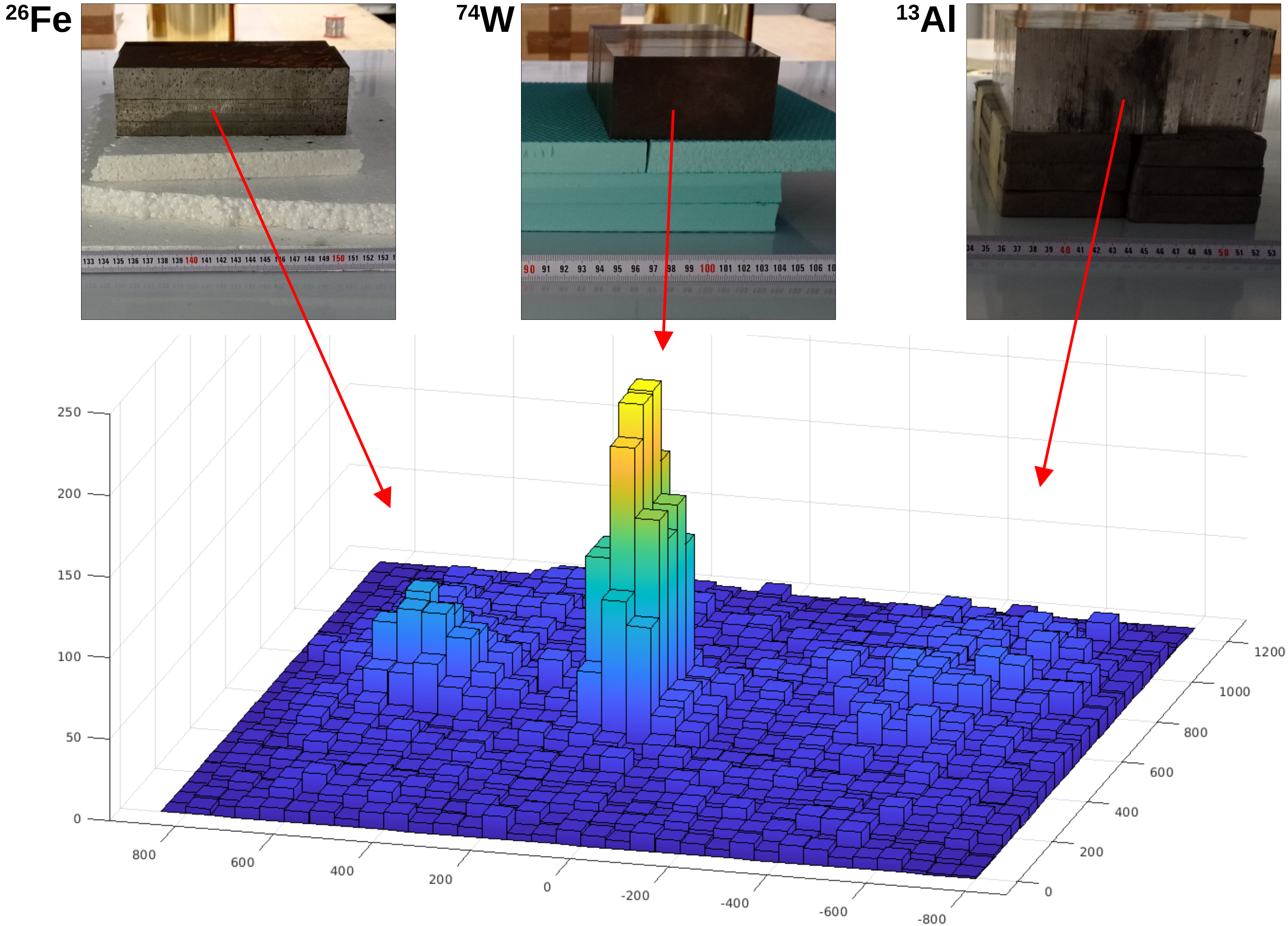




1.1M events (total) -> ~5 hours

11º < θ < 21º -> ~10k events

Scattering Muography – 3D, θ > 10º (bins: 5x5 cm²)



Conclusion

- Cosmic-Ray telescope with **4 RPCs** and active area of **2 m²** operated in stable conditions during more than **one month with low gas flow** (**~1 $cm^3/min/m^2$**)

- **Tight polypropylene box** used to encapsulate the **sensitive volume** provided
  - ➔ **high sealing performance to external contaminants**

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@ residual flow:

- background rate and induced charge **increased** mostly in the **gas inlet region**
  - ➔ **suggesting a lack of sealing at this measurement point**

- **Rapid recovery of stable operation** after **gas flow re-establishment**

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- **Rapid recovery of stable operation** after **gas flow re-establishment**

Preliminary tests for **scattering muography of High-Z materials**:

- even with a **low angular resolution** due to the short distance between RPCs (**only 45 cm apart**):
- materials detected with this configuration:

✅ Tungsten ✅ Iron ❌ Aluminum

Backup

Scattering Muography – 3D

10 minutes, with RPCs only 45 cm apart