FROM LHCb TO ENVIRONMENT MONITORING

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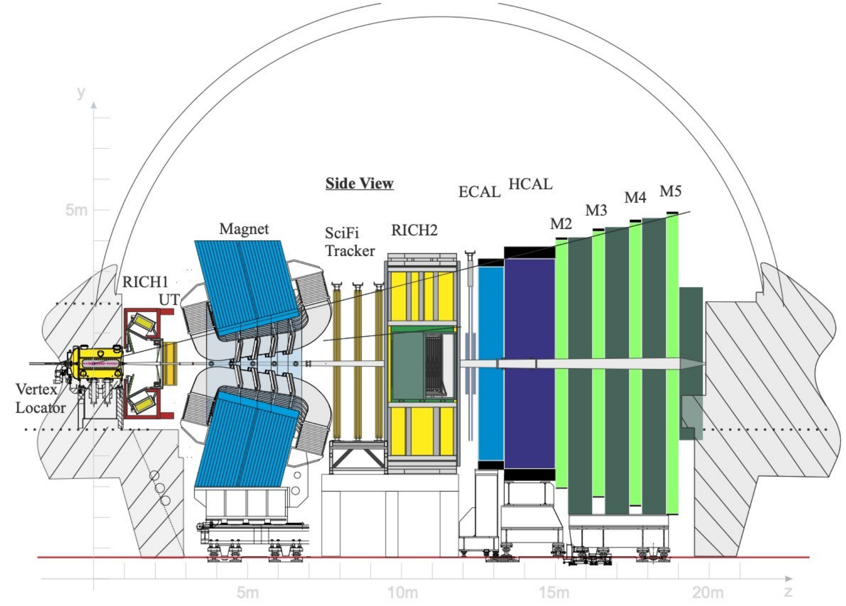
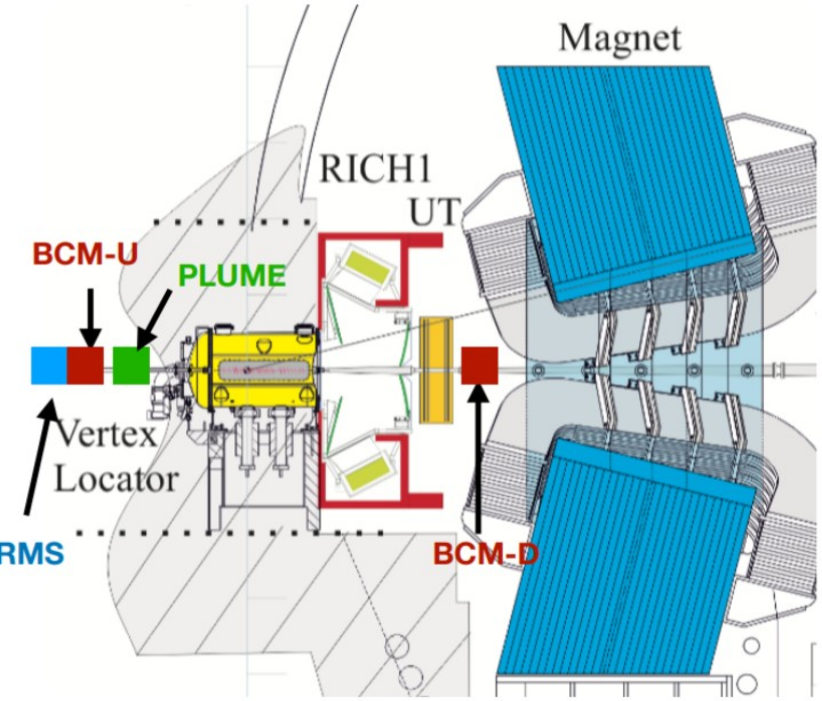




LHCb experiment

Nominal conditions in Run 3 (2022 - 2025):

- P-p collision energy $\sqrt{s_{NN}}$ = 13,6 TeV
- Increased instantaneous luminosity up to $2x10^{33}$ $cm^{-2}s^{-1}$
- Collider mode of operation and fixed (gas) target mode

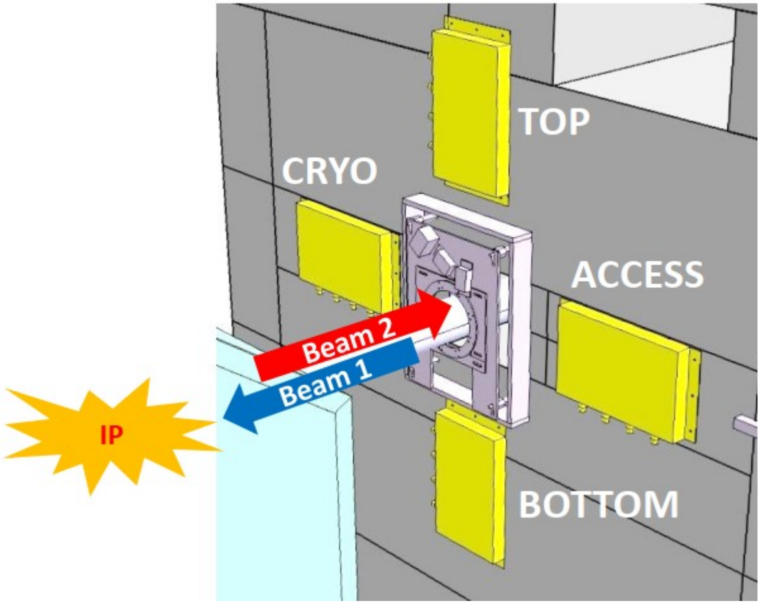
LHCb research program

- Flavor physics, in particular the physics of c- and b-quarks;
- CP parity violation in B and D meson decays
- Decays with flavor violation in the lepton sector
- Physics beyond the flavor sector (Electroweak, exotic decays, QCD, etc.)
- Search for New Physics beyond the Standard Model

To ensure safe and effective operation of the experiment, beam and background (B&B) monitoring systems have been developed:

- PLUME luminometer
- Beam condition monitoring system (BCM)
- **RMS-R3 luminosity and background monitoring system**

RMS-R3 as the B&B system monitor at LHCb



Goals:

- Instantaneous luminosity monitoring:

Nominal - 4×10^{32} $cm^{-2}\cdot s^{-1}$ -> linear up to 2×10^{33} $cm^{-2}\cdot s^{-1}$

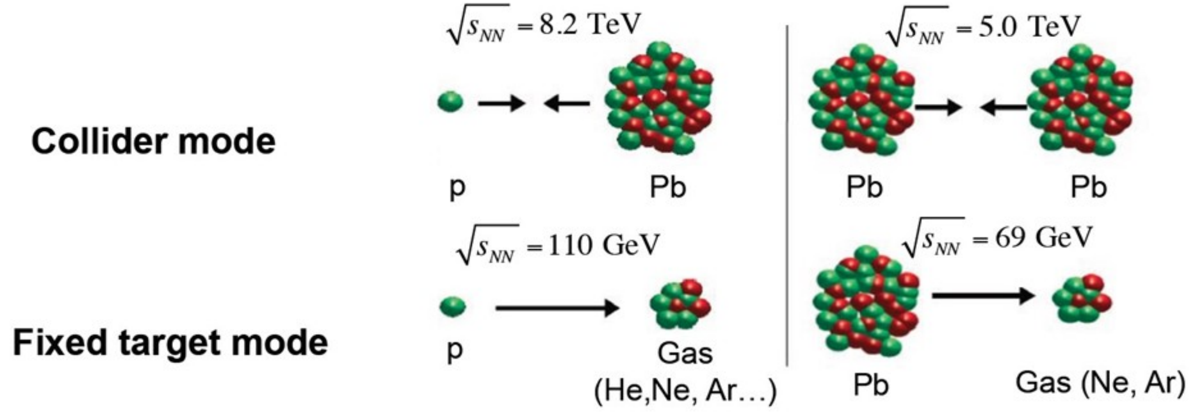
- Beams (Target) interaction region and background conditions monitoring

- **Construction:**

Metal Foil Detectors → 4 pairs symmetrically in horizontal and vertical plane around the beam pipe

- **Reading**:
- charge integrators, frequency counters
- LHCb Front-End board

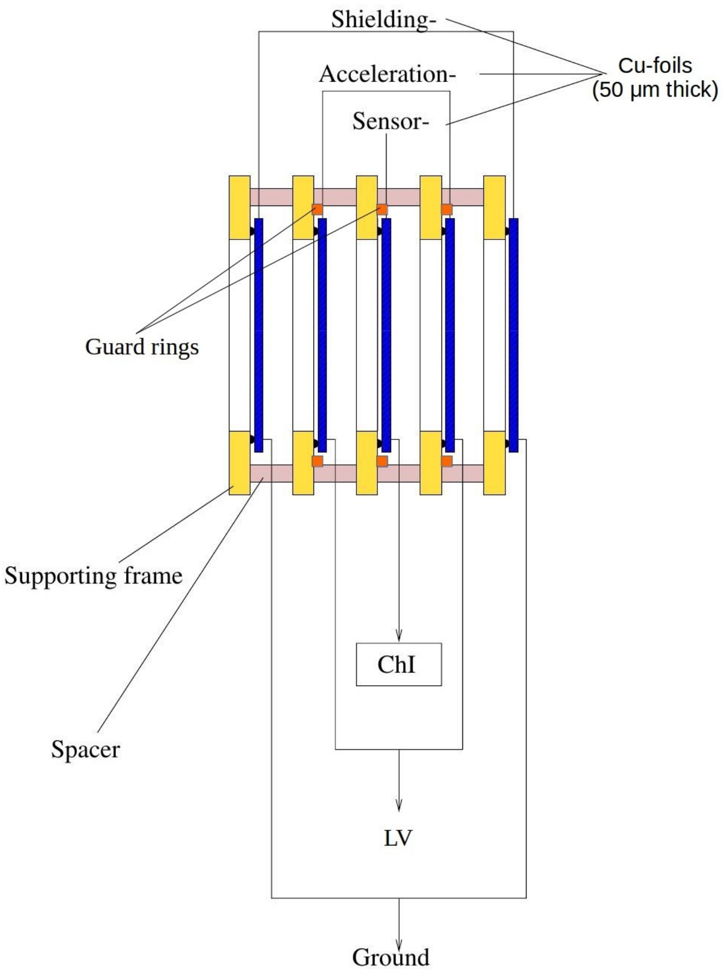
- **Data monitoring:**
- Continuous display on the LHCb control panel
- Remote access to data through the LHCb framework



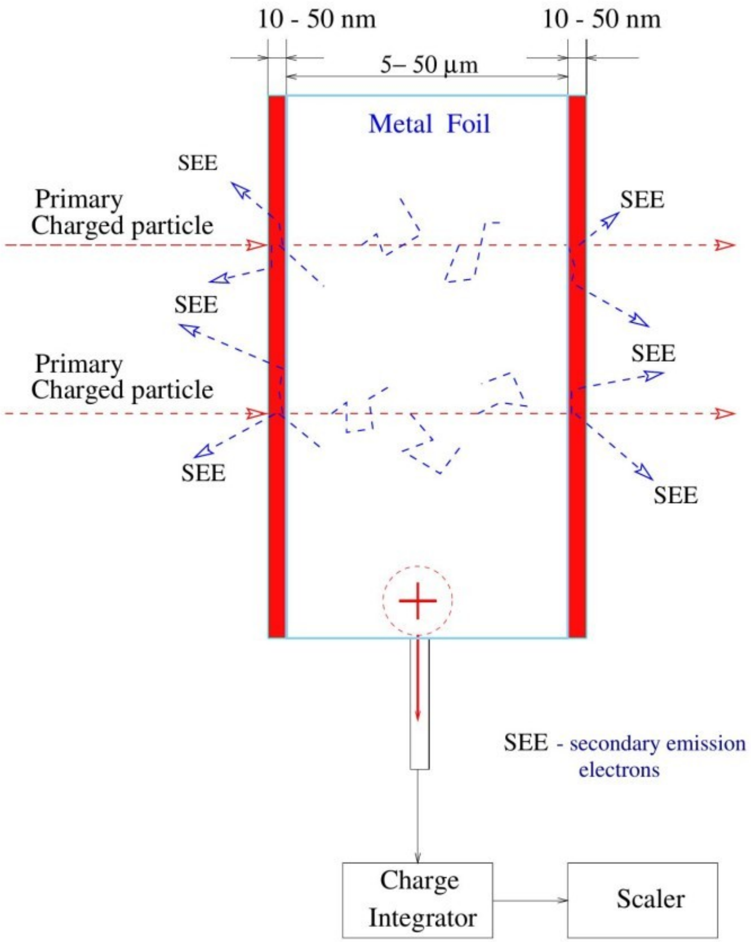
Key features:

- **Radiation hard** (~1 GGy) MFD sensors respond to
MIPs flux by secondary electron emission
→ positive charge in a Foil isintegrated
- **charge-to-frequency conversion**, - **digital output**
- **Large dynamic range** (10^3-10^9 MIPs/s → **linear response** up to 2 MHz
- **Stable response** → ~ 1 % during Run 3
- **Low** operational **voltage** (24 V)

Beam and background system RMS-R3



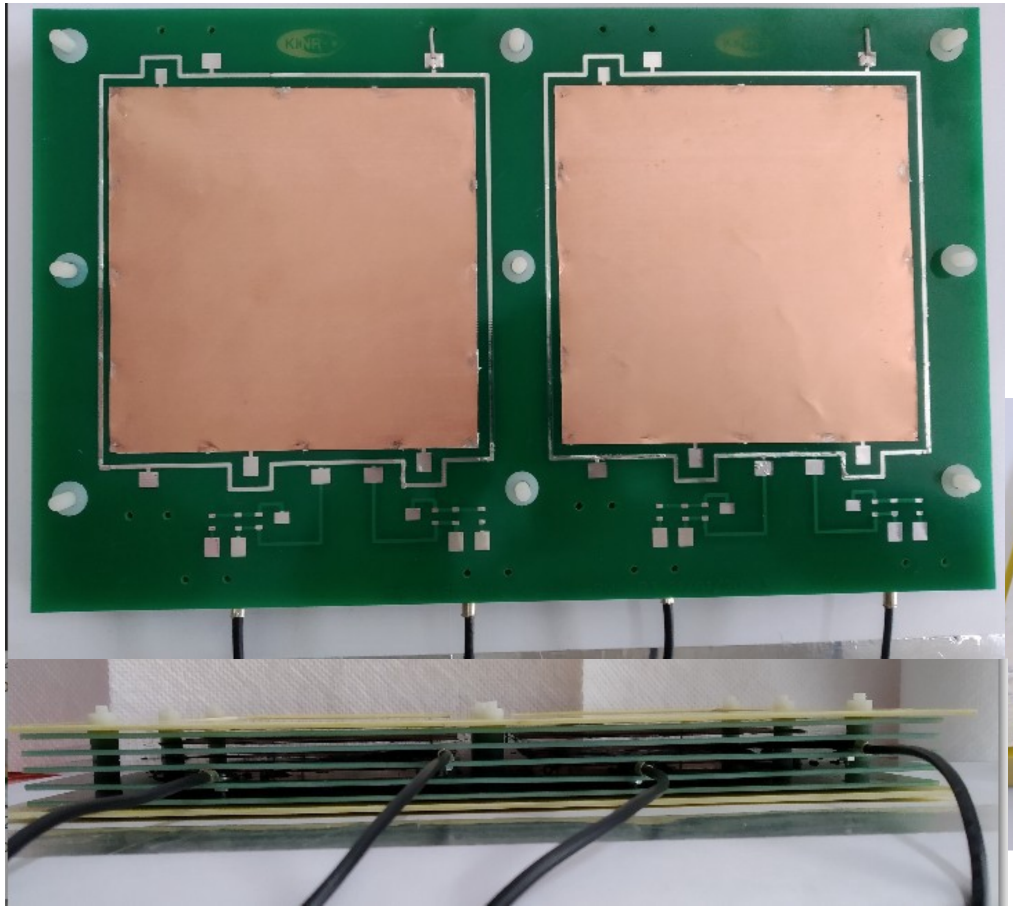
RMS-R3 sensor schematic



Schematic of the physical phenomenon of EEE on the surface of foil sensors

- The RMS-R3 is based on the metal foil detector (MFD) technology, an original development of the Institute for Nuclear Research of the National Academy of Sciences of Ukraine.
- Fluxes of bombarding charged particles cause secondary electron emission (SE) from the near-surface layer of the sensor metal foil (10-50 nm)
- The positive charge arising in the insulated metal foil (sensor) is integrated by a sensitive charge integrator
- The input analog signal is converted proportionally by the charge integrator to the output frequency, which is measured by frequency counters based on STM32F4-Discovery microcontroller boards

Design of the RMS-R3 touch module

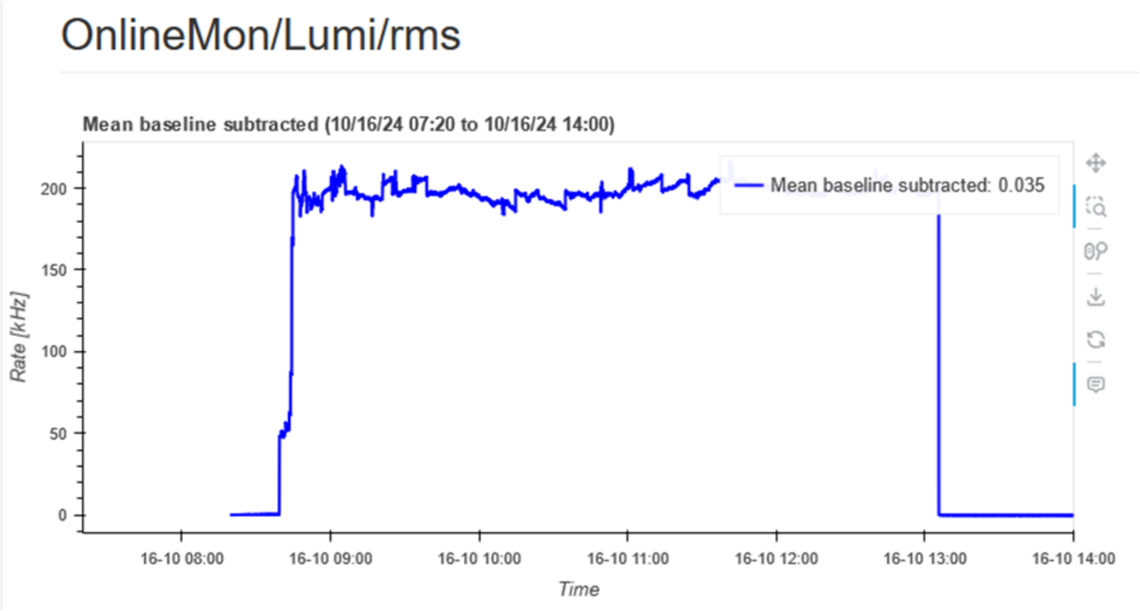


- The module contains 2 sensors 9×9 cm^2
- 5 panels made of **printed circuit board** (**PCB**)
- Sensors: copper foils 50 microns
- Special protective rings for sensors (guard ring technology)
- Protective input RC low-pass filters (resistance 1 MΩ, two capacitors 1 μF and 10 pF)

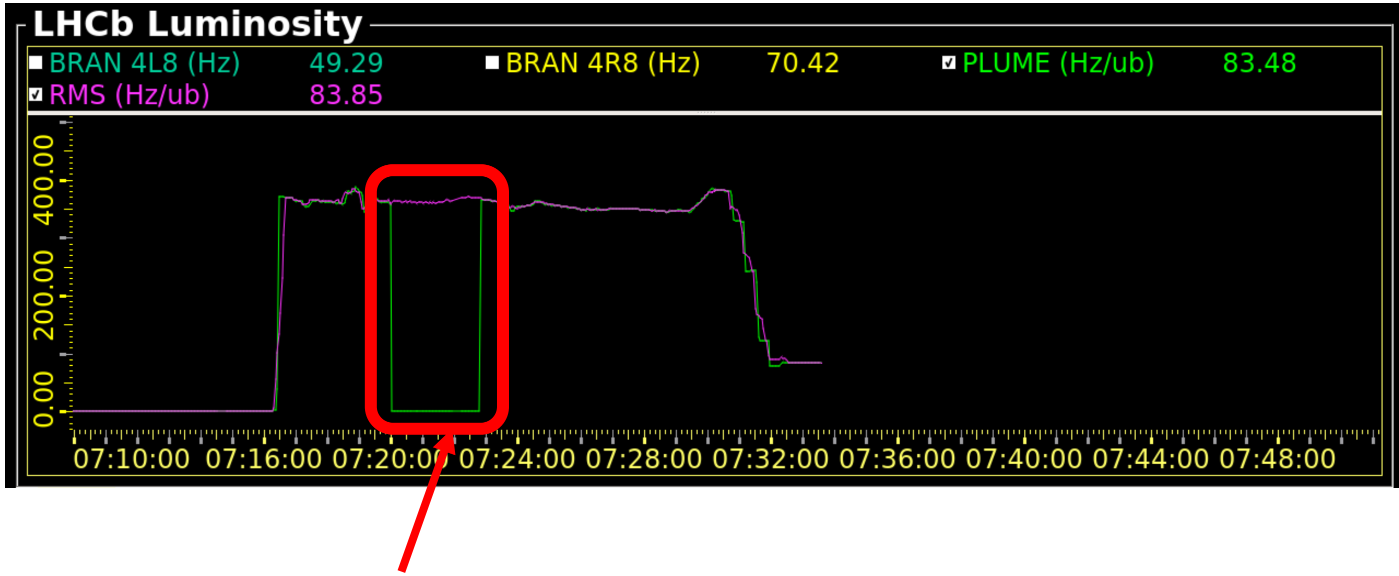
- The module body, made of fiberglass, is covered with aluminum foil and grounded
- Straight cable connector, BNC type

RMS-R3 as an additional luminosity counter

- Currently, LHCb provides instantaneous luminosity for LHC -> beams are adjusted -> target luminosity is being reached
- PLUME is the main luminosity counter
- RMS-R3 - backup luminosity counter

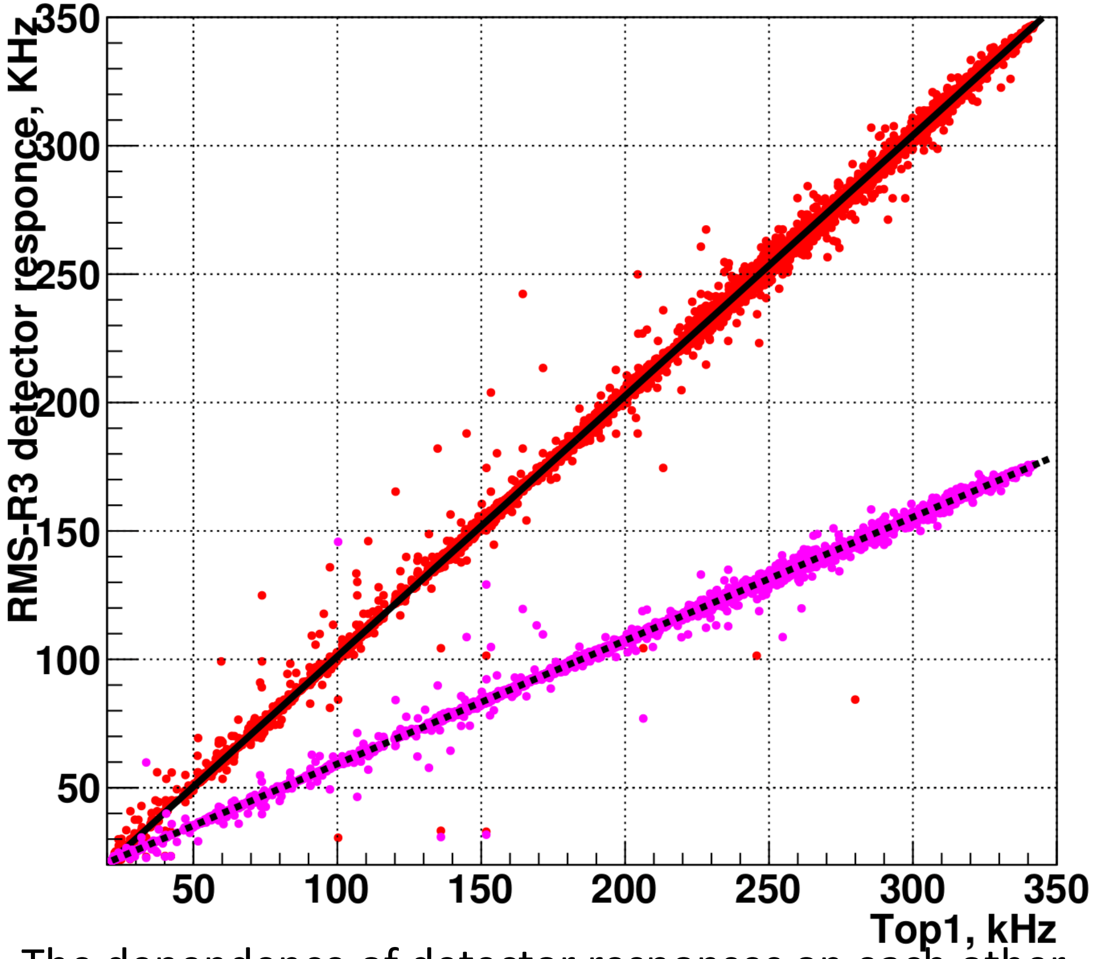


RMS-R3 luminosity in MONET

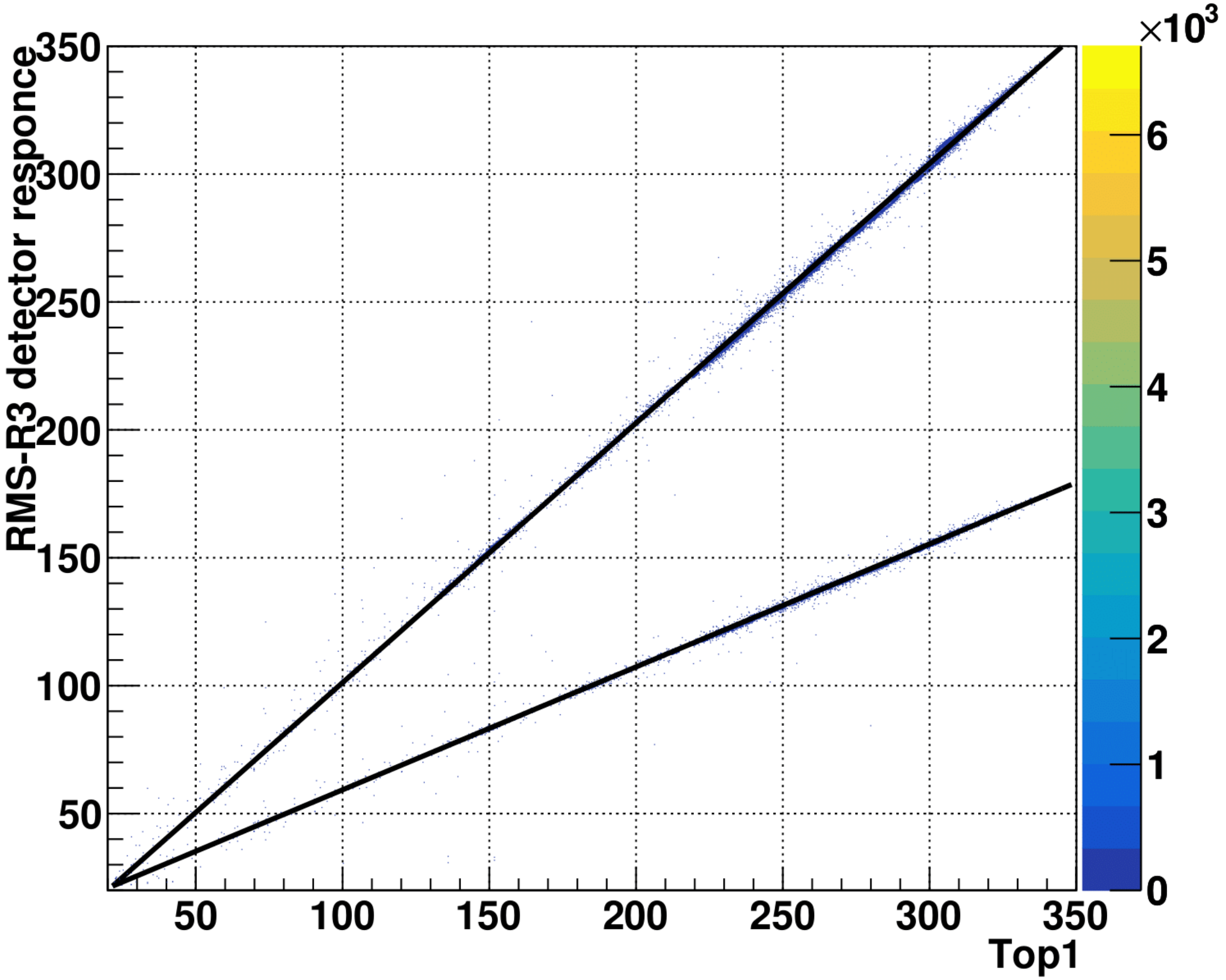


RMS-R3 used as a backup online luminosity meter

Linearity of RMS-R3 detectors. Dependence of Top 2 and Bottom 1 on Top1

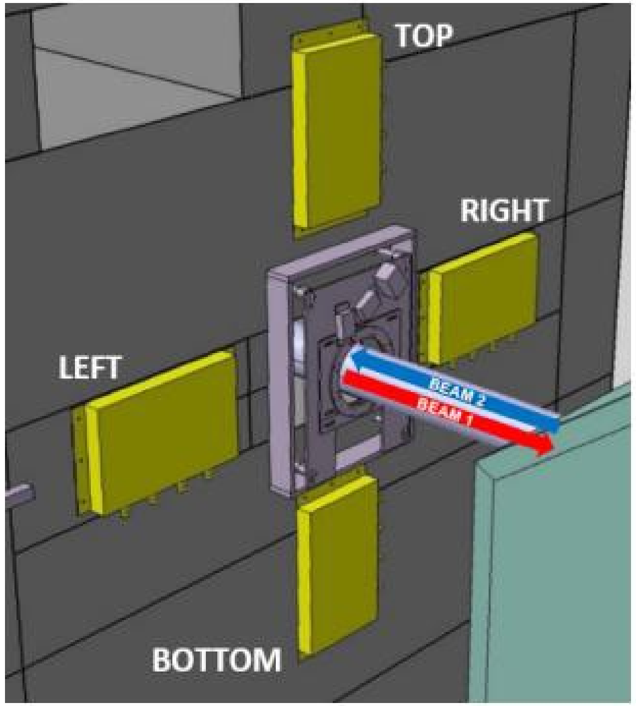


The dependence of detector responses on each other demonstrates the linearity of the system. The results are given without baseline subtraction.



Statistical dependence of detector responses on each other. Maximum number of coincidences in the centre of loci

Theory of asymmetries method

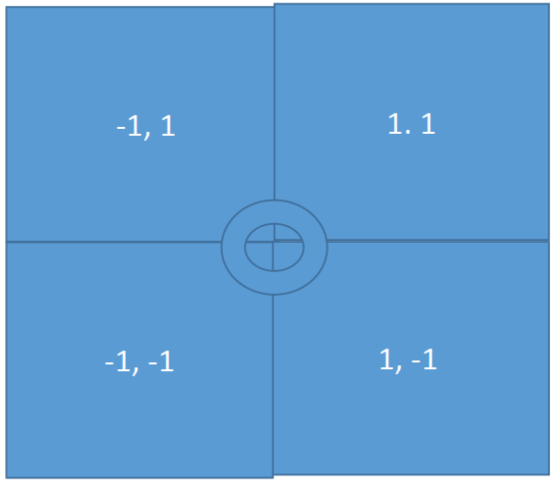


$$A_{ij} = (R_i - R_j) / (R_i + R_j),$$

where Ri and Rj are the response frequencies of sensors i and j corresponding to the LEFT - RIGHT or UP - DOWN pairs

Full cross section

azimuth angle aperture



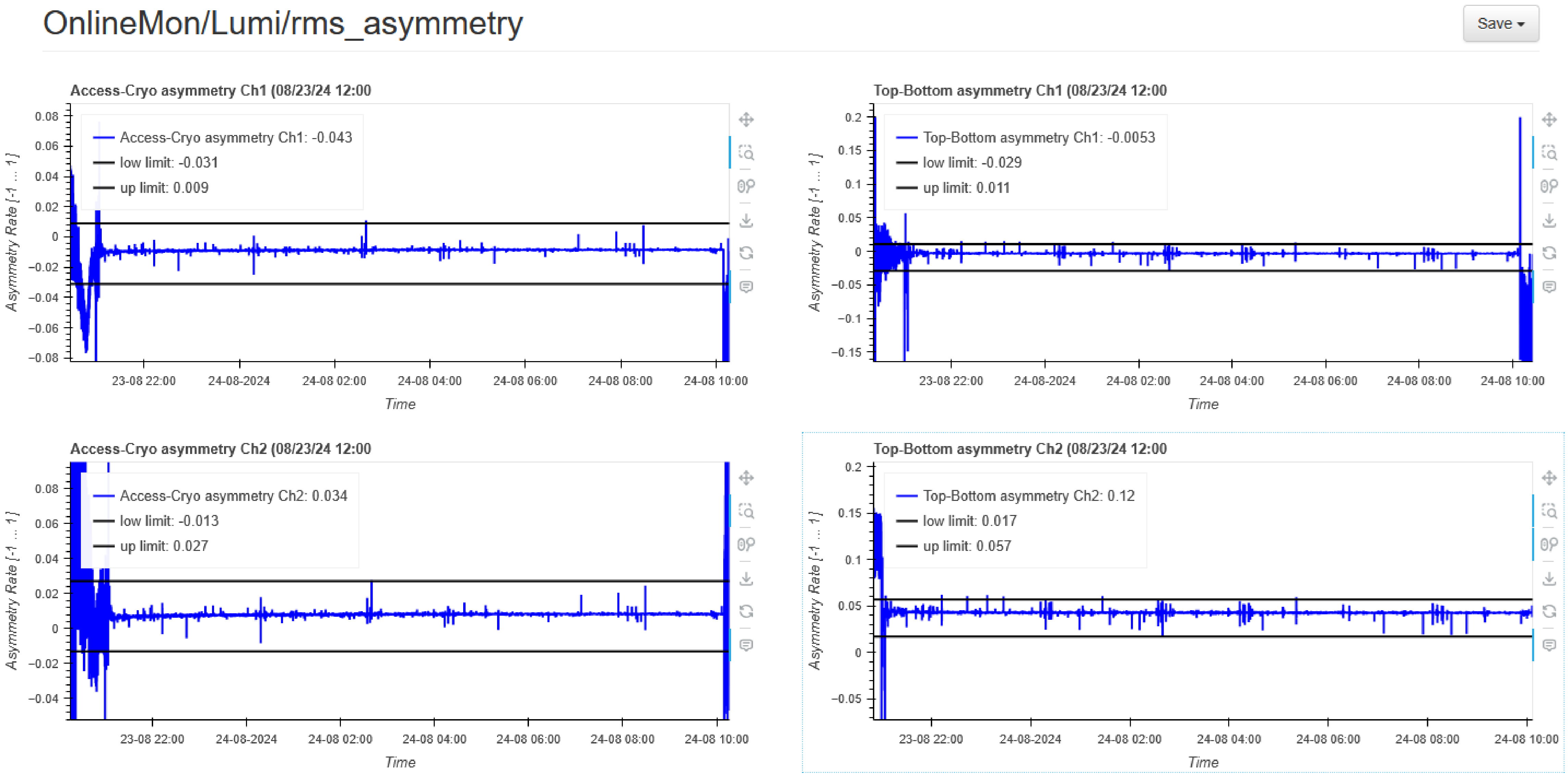
$$R = \int_{\vartheta_1}^{\vartheta_2} \int_{\varphi_1}^{\varphi_2} \frac{d^2\sigma}{d\vartheta d\varphi} \sin\vartheta \frac{dL}{dt} d\vartheta d\varphi$$

polar angle aperture

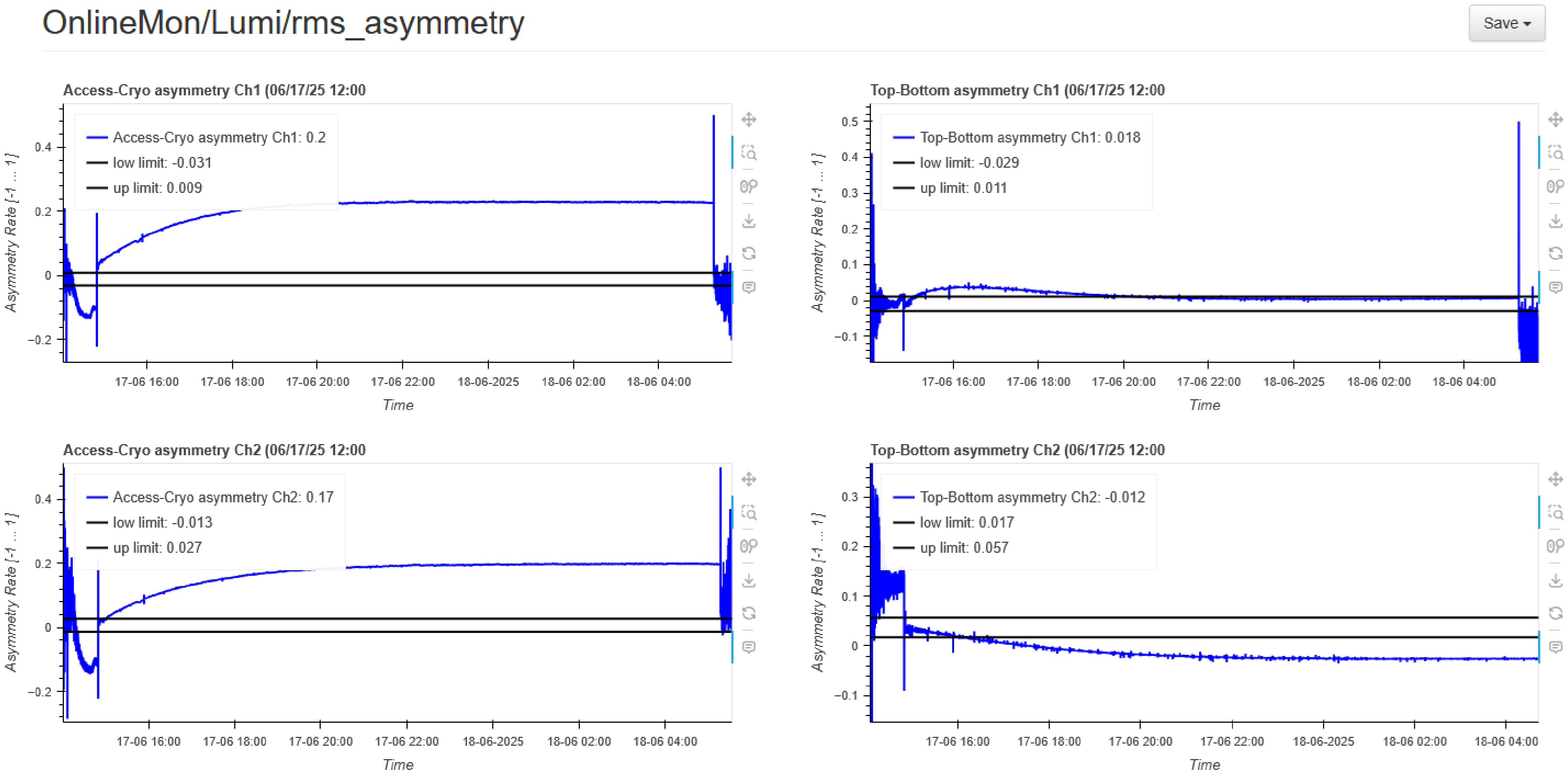
$\vartheta_1, \vartheta_2, \varphi_1, \varphi_2$ angles of RMS-R3 modules acceptance

The response of the RMS-R3 sensors depends directly on where the interaction occurred

Asymmetries in MONET (with allowed limits) in 2024



Asymmetries in MONET (with allowed limits) in 2025



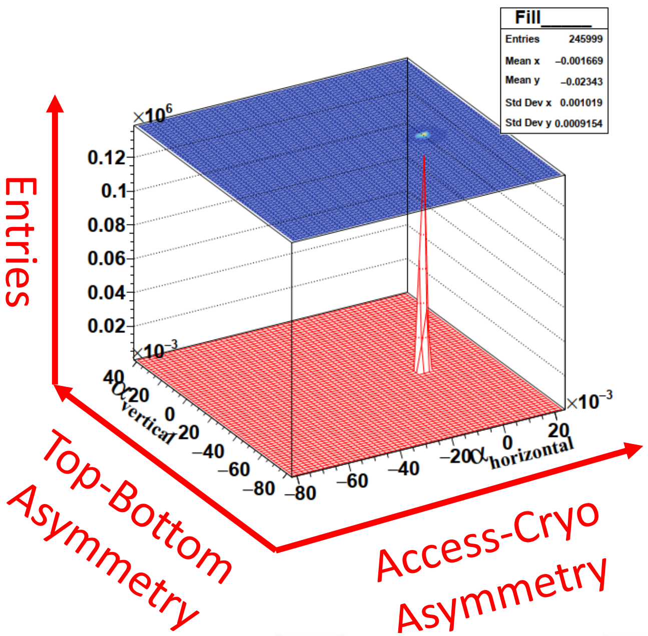
RMS-R3 asymmetries for different experimental conditions

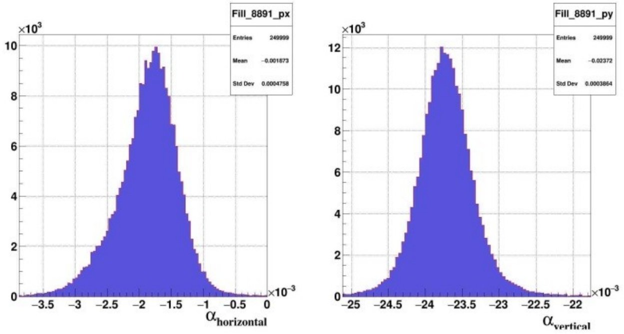
- RMS-R3 asymmetry is

$A_{ij} = (R_i - R_j) / (R_i + R_j)$,
where R_x is sensor response

- The 2D distribution of asymmetries is sensitive to the changing of the beam and background experimental conditions.
- The functional purpose of the RMS-R5 is to monitor the state of the beam and background, and to control LHCb radiation safety
- pp collisions for $\sqrt{s_{NN}}$ = 13,6 TeV for luminosity 2×10^{33} sm^{-2} a^{-1}
- PbPb collisions for $\sqrt{s_{NN}}$ = 5,36 TeV for luminosity up to 10^{28} sm^{-2} s^{-1}

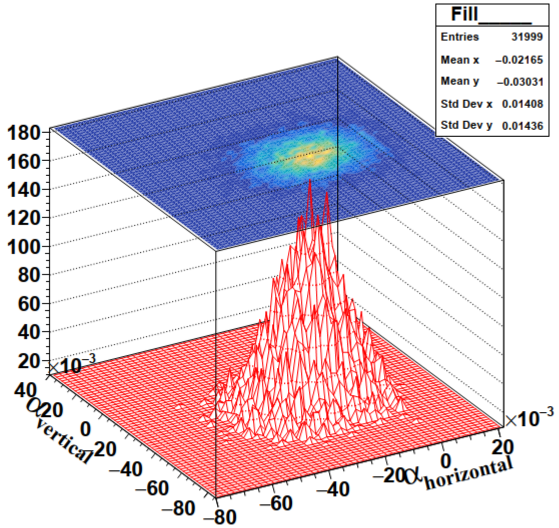
pp collisions

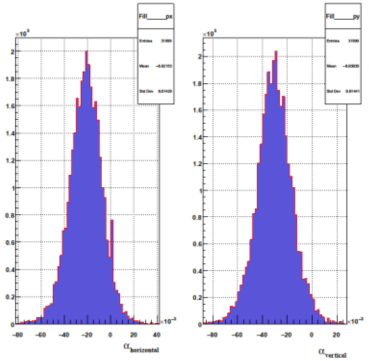




09.06.23 | Fill 8891 | μ ≈ 4
Locus coordinates ($-2*10^{-3}$; $-2*10^{-3}$)
Sigma ~ $0.43*10^{-3}$

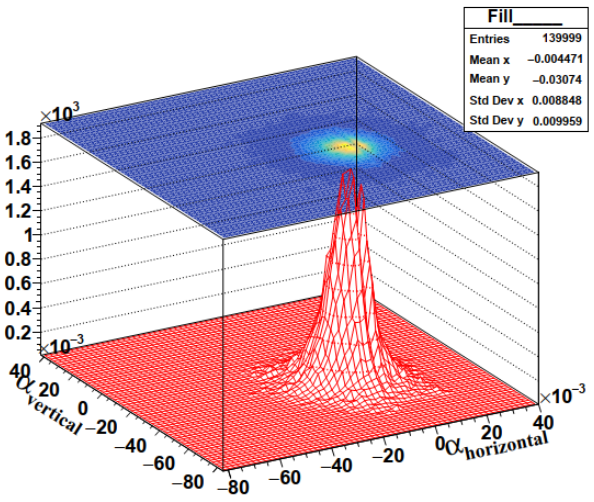
PbPb collisions

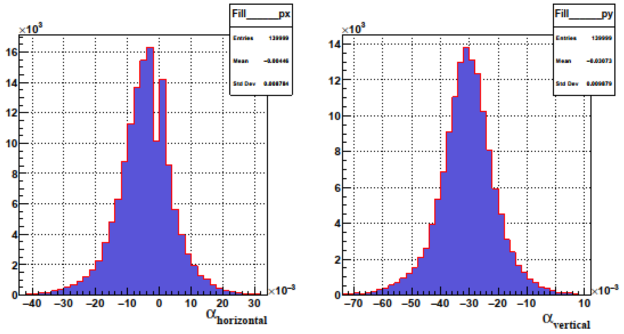




28.09.23 | Fill 9200
Locus coordinates ($-21*10^{-3}$; $-30*10^{-3}$)
Sigma ~ $14,4*10^{-3}$

PbPb + PbAr collisions



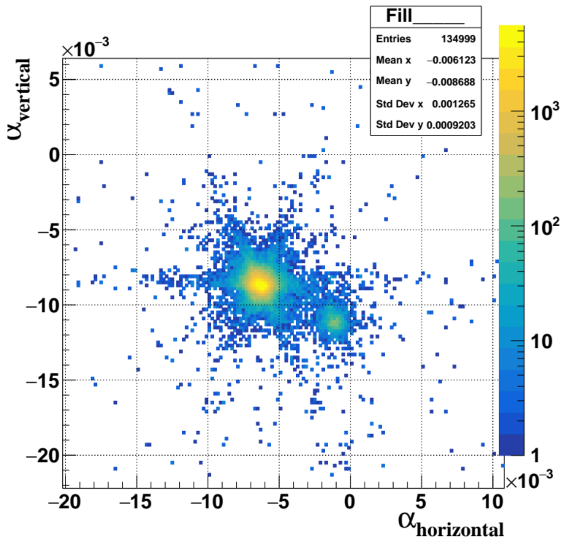


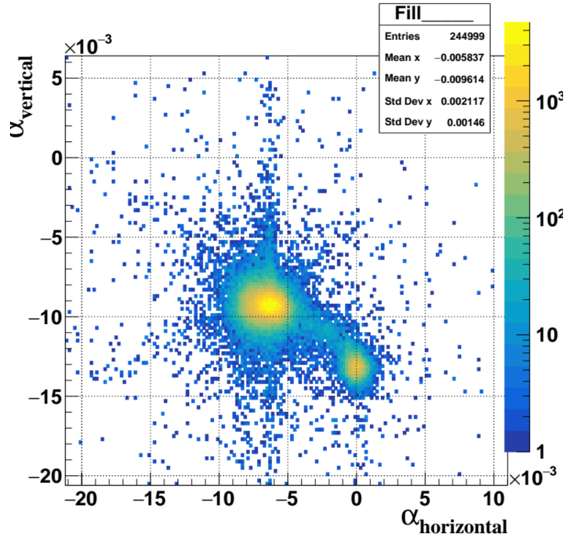
03.10.23 | Fill 9220
Ar injection a la SMOG
Locus coordinates ($-4*10^{-3}$; $-30*10^{-3}$)
Sigma ~ $9,3*10^{-3}$

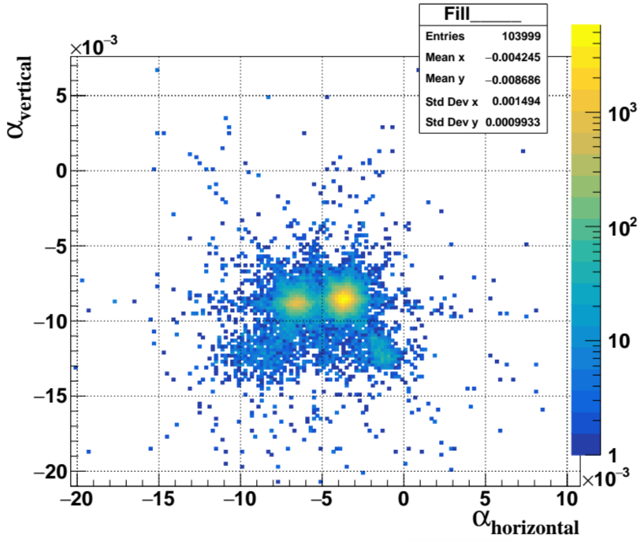
Asymmetries of pA for injections of different gases in the fixed target mode in 2024

H2 | He | Ne

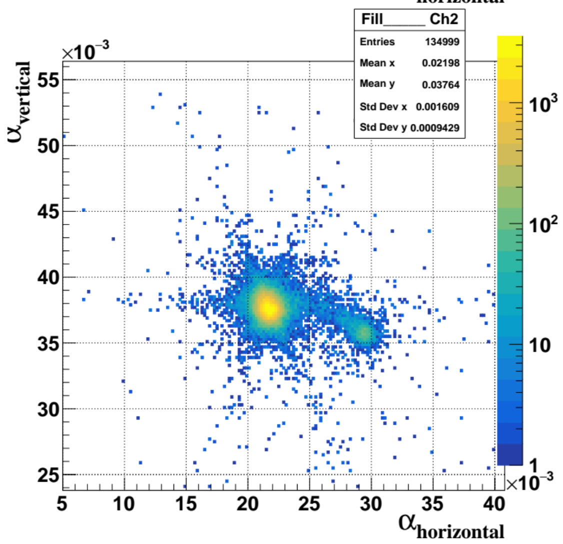
Ch1

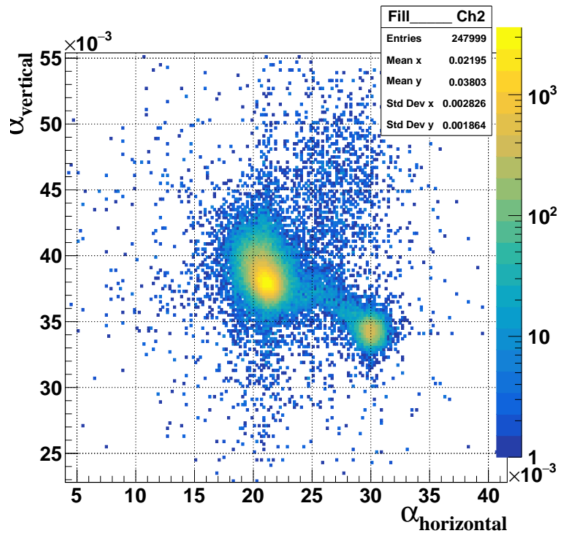


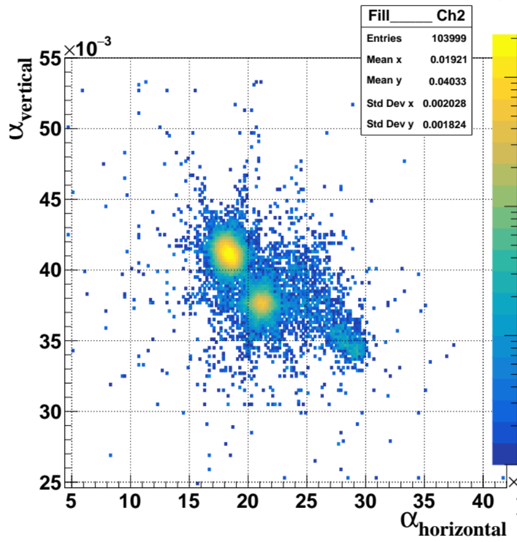




Ch2





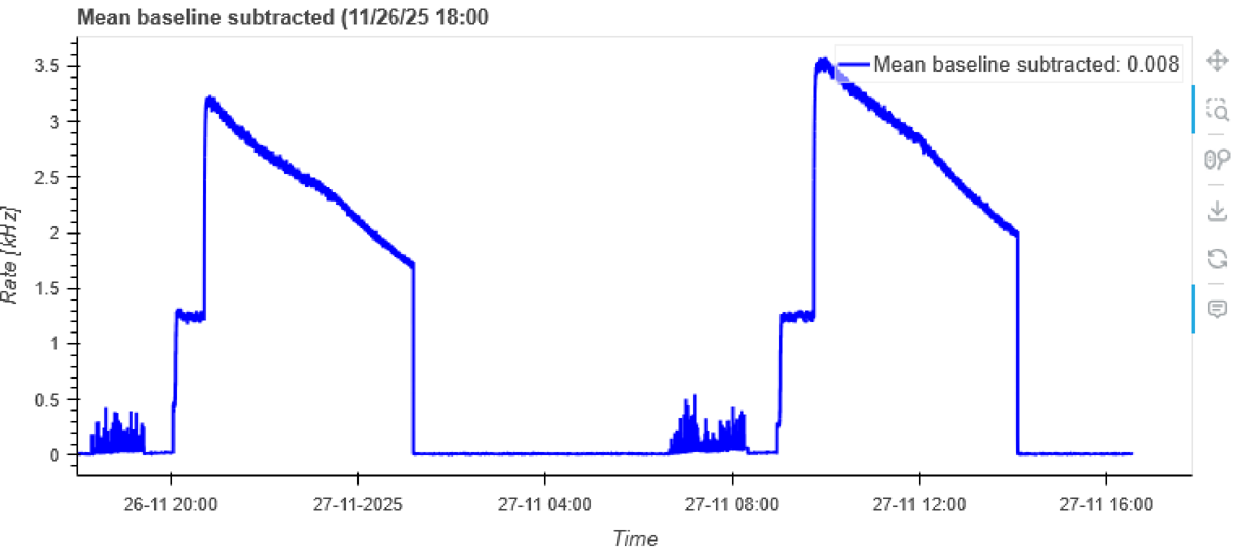


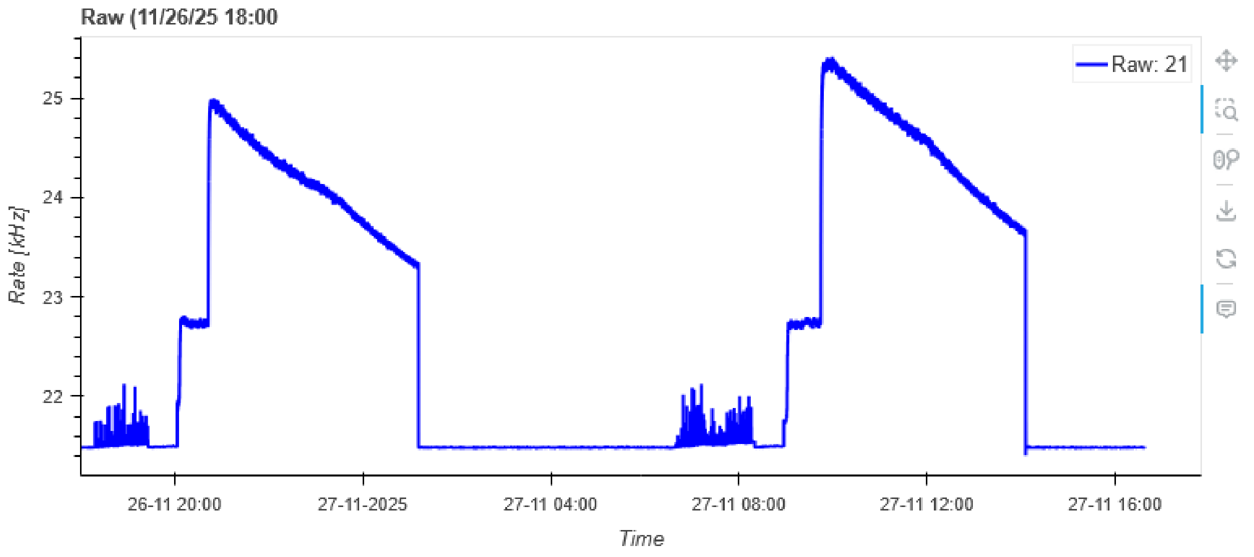
Not pp collisions in 2025

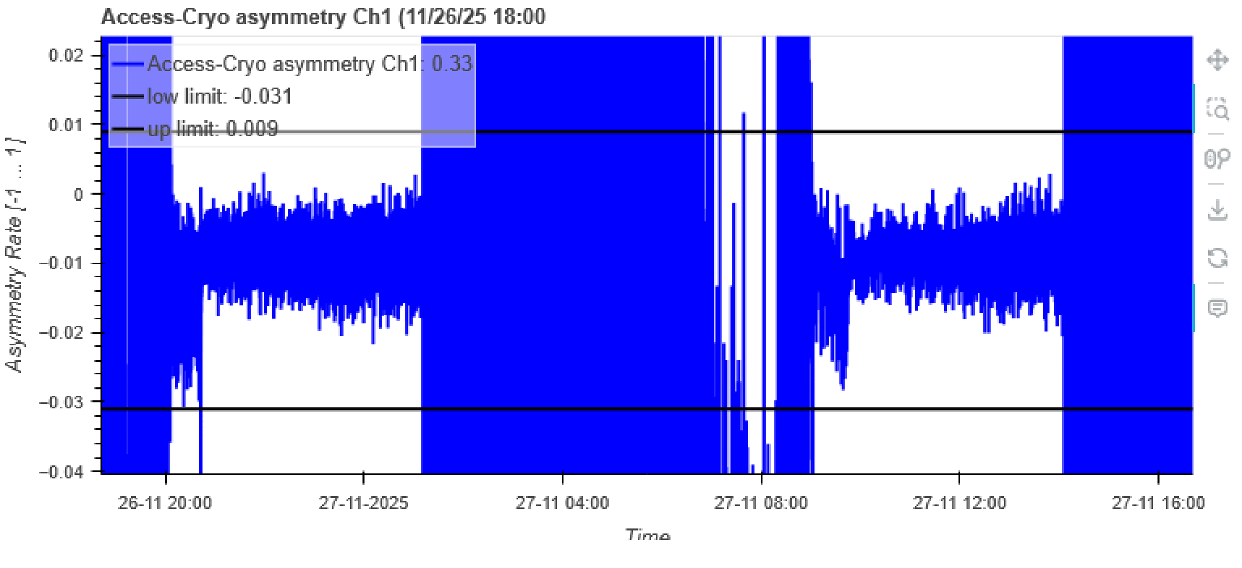
- pO & OO collisions (July 2025)
- NeNe (1 collison)
- AA (PbPb) November 2025
- 3 pO collisions (2 with Ar)
- 7 OO collisions (All with H2)
- 1 NeNe collision (With Ne gas SMOG2)
- For PbPb (total 23 collisons on 28 November):

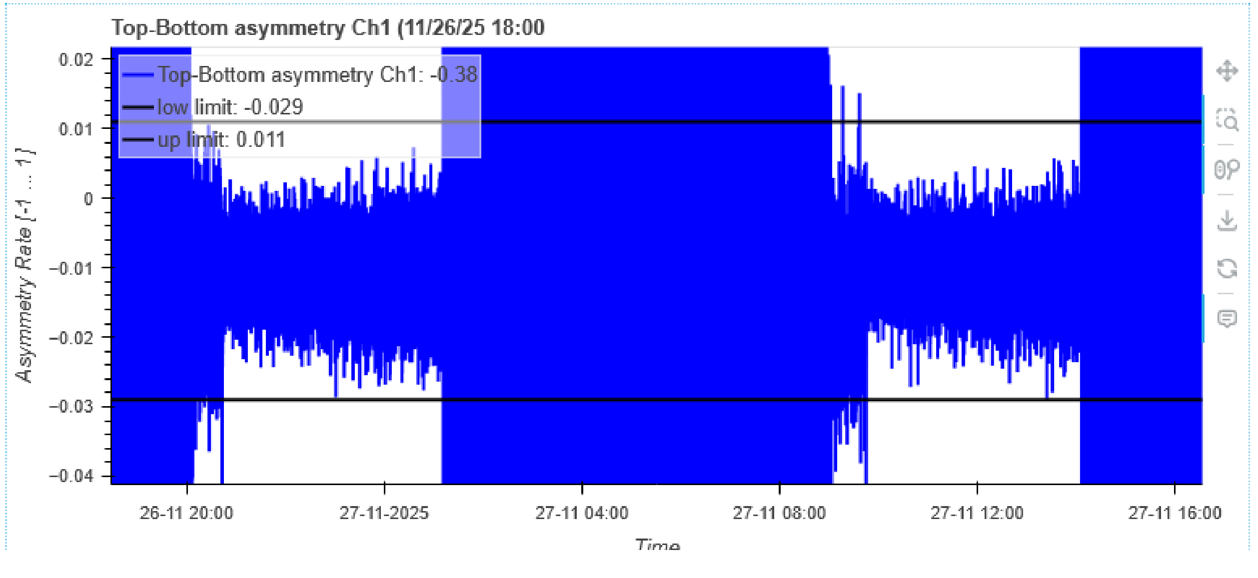
  With SMOG – 19 (11 with Ne, 7 with Ar, 1 with H2)

PbPb with Ne vs PbPb with Ar

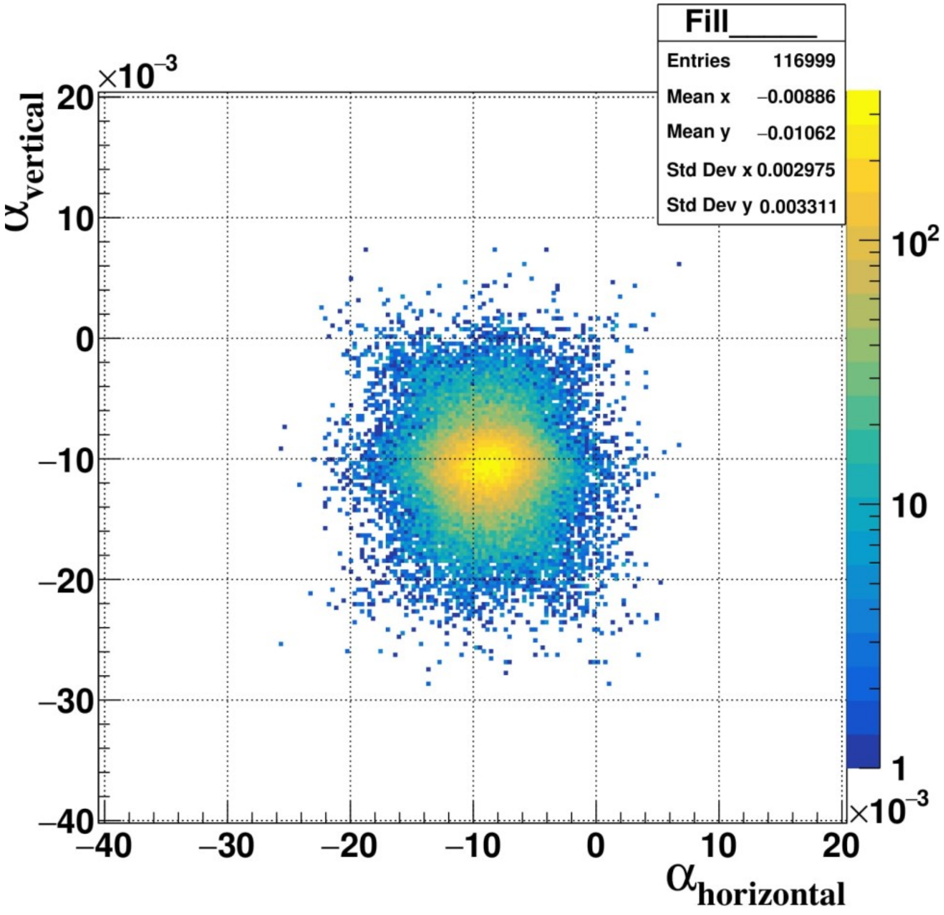


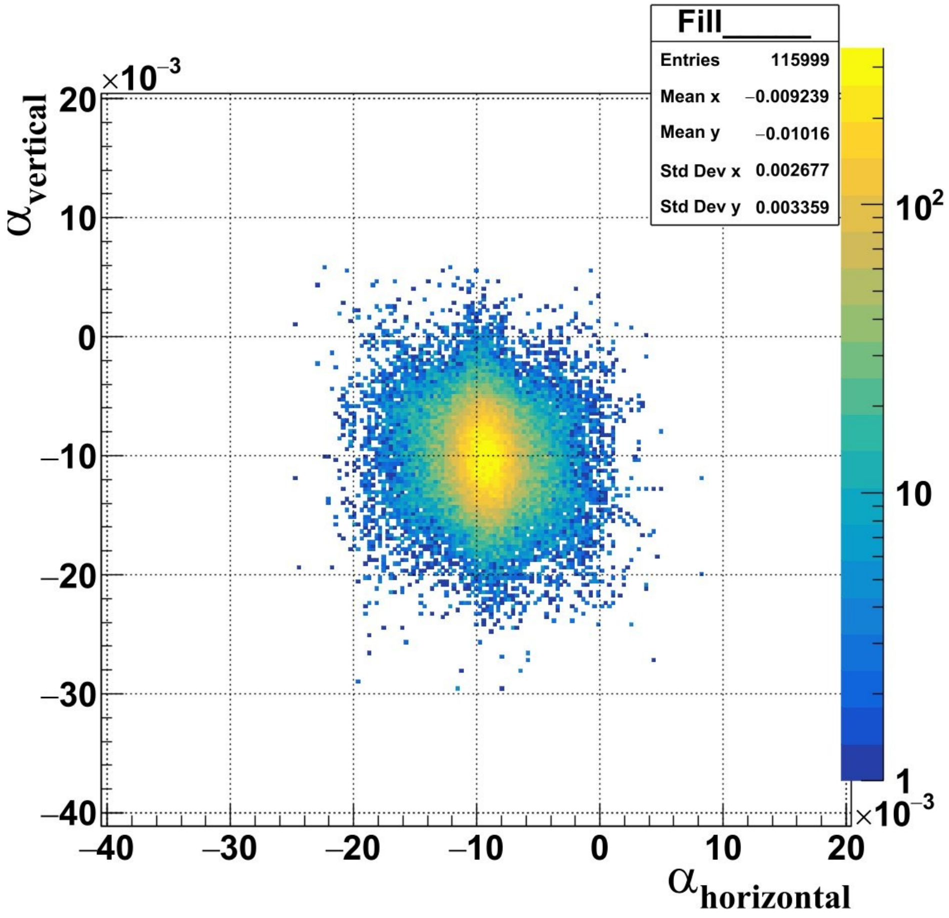




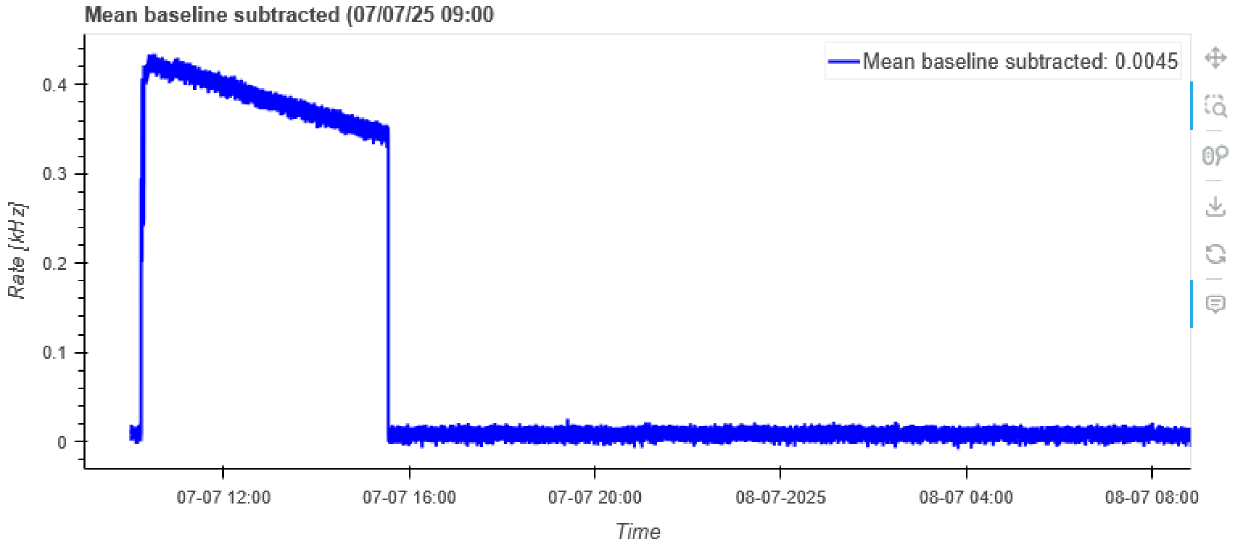


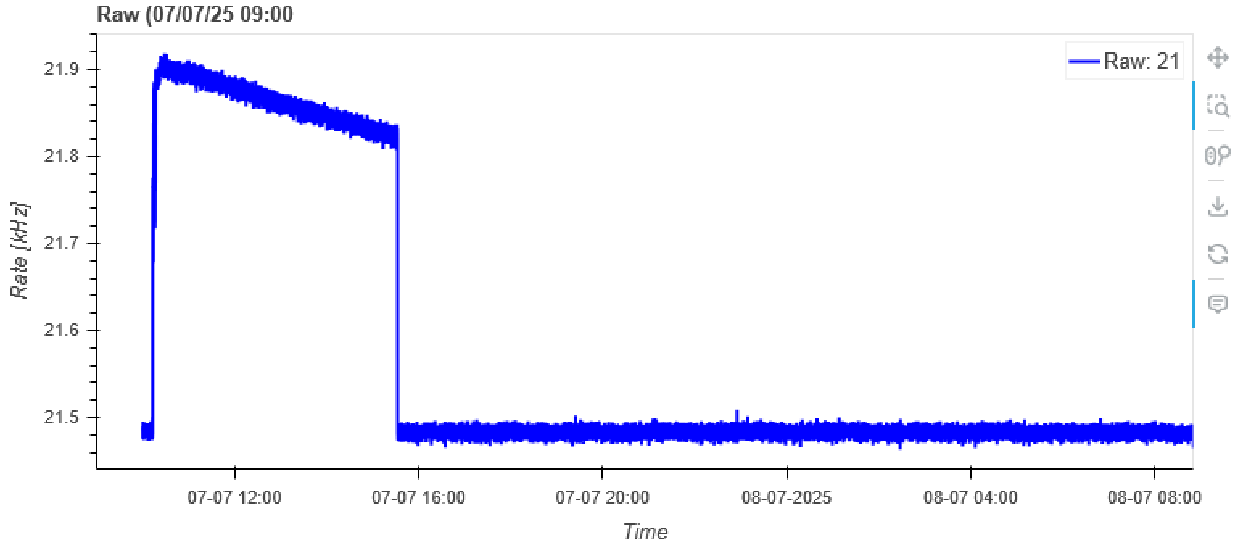
PbPb with Ne vs PbPb with Ar

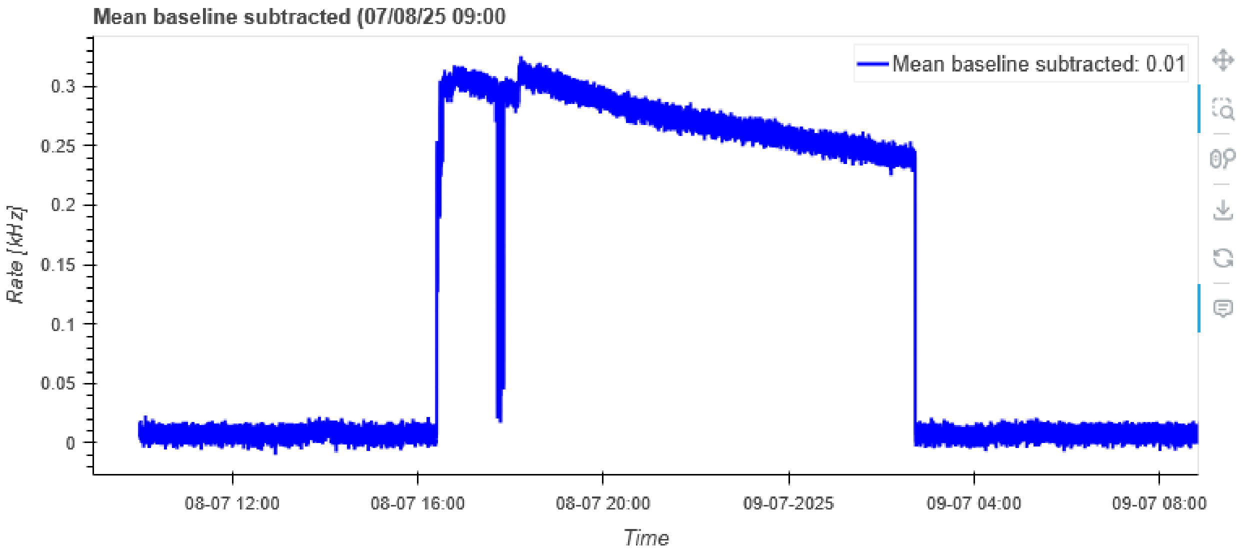


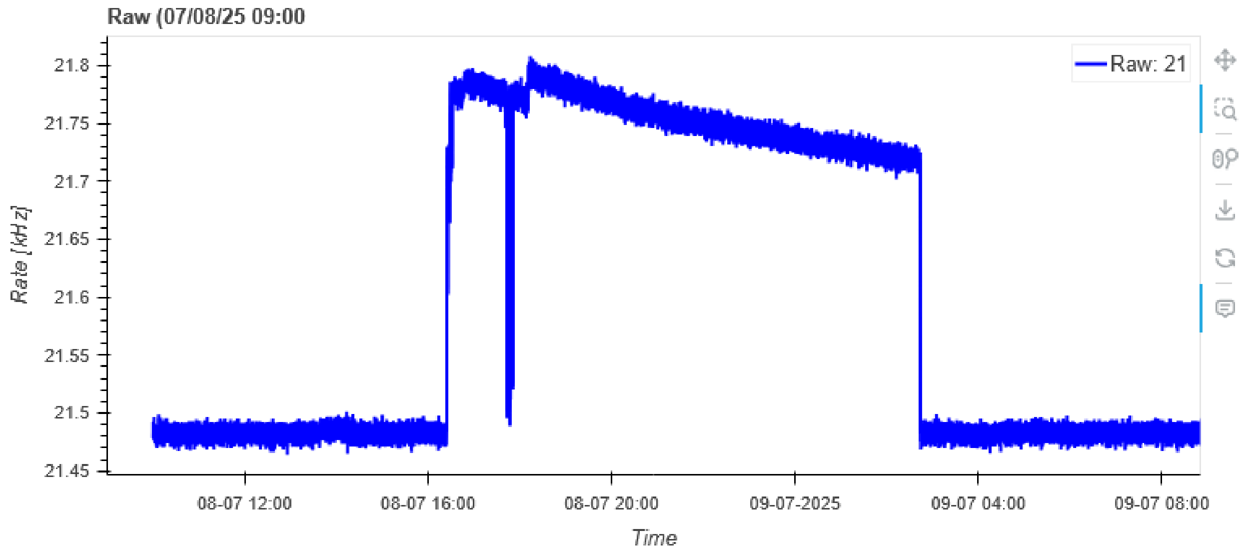


OO (H2 SMOG2) & NeNe (Ne)









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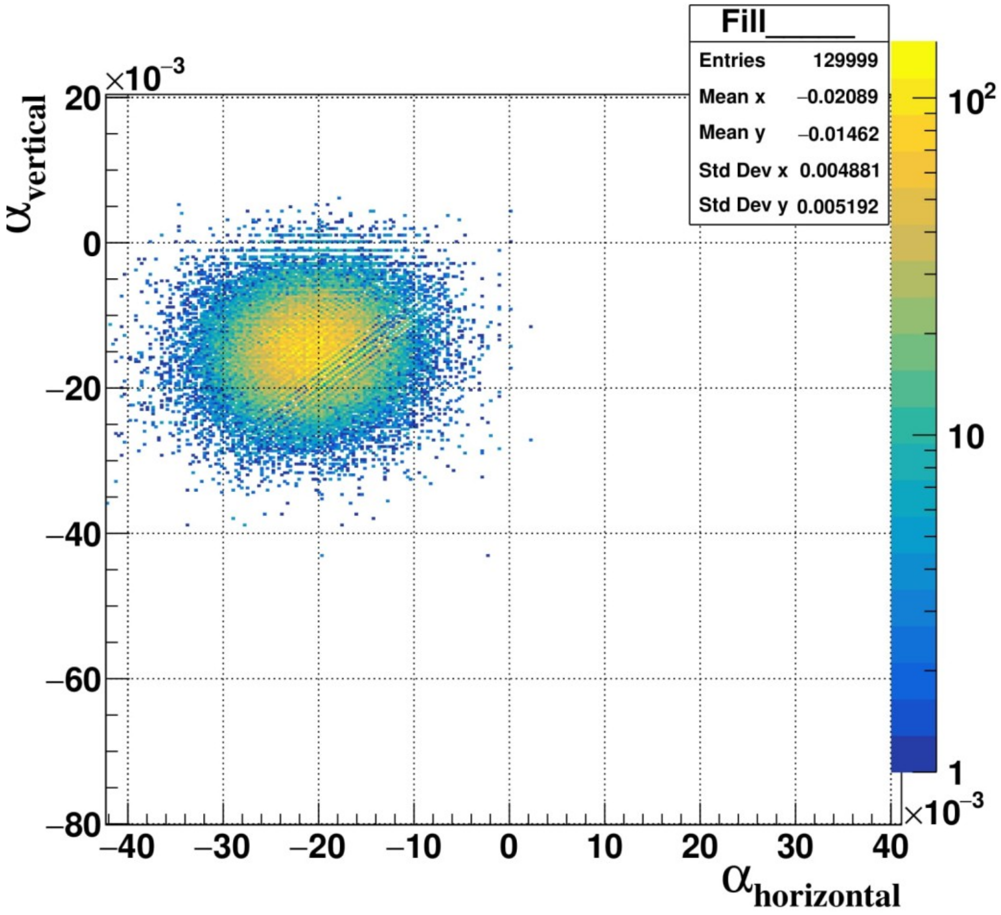
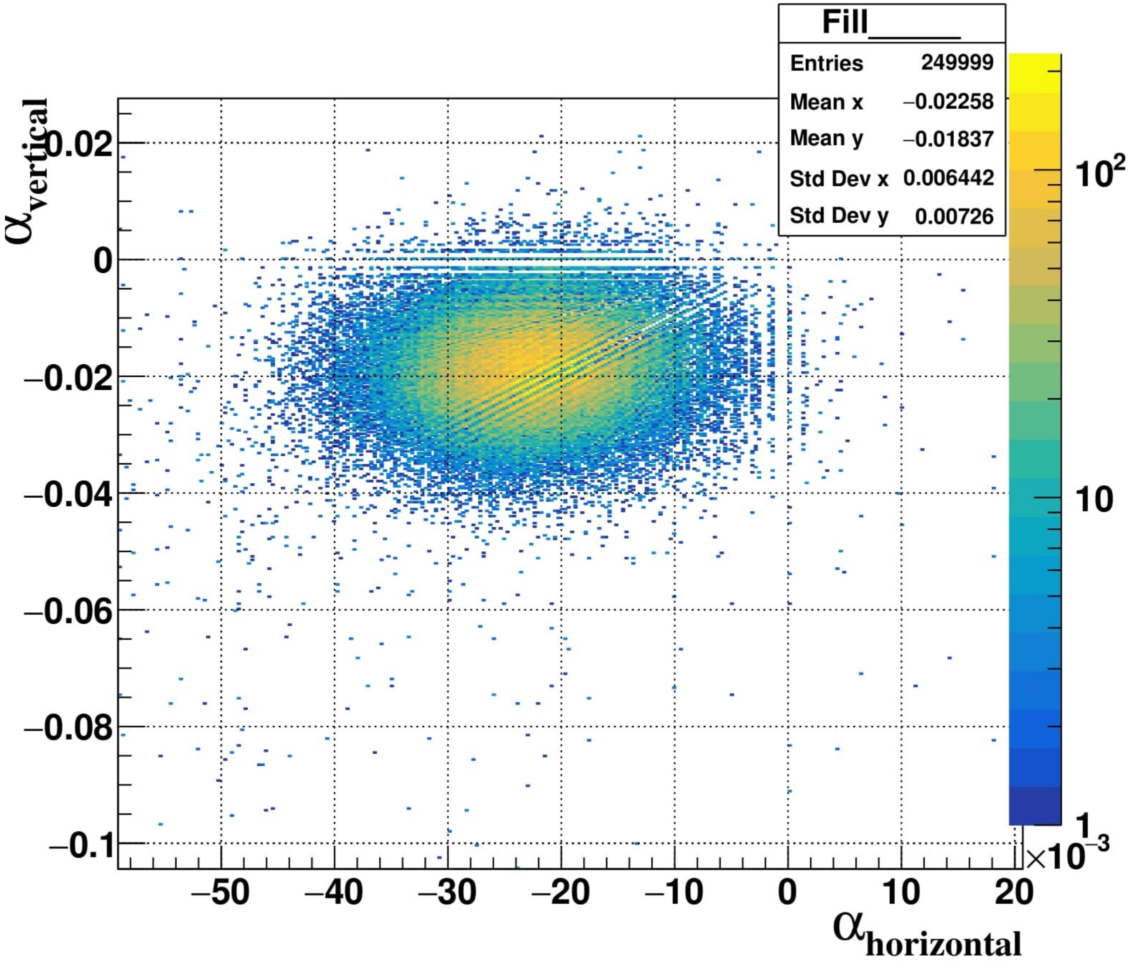
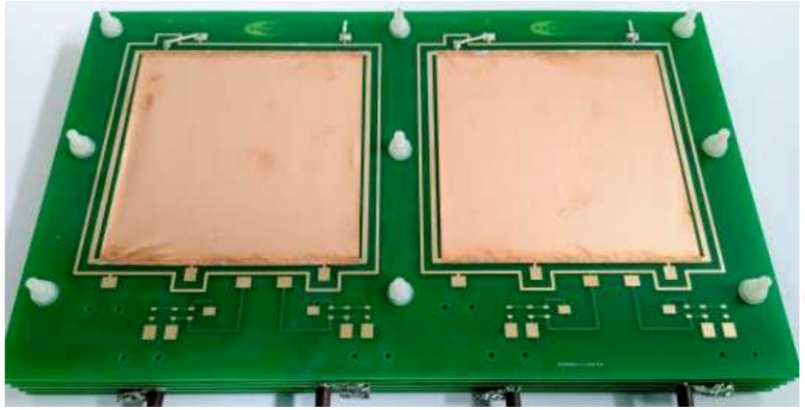


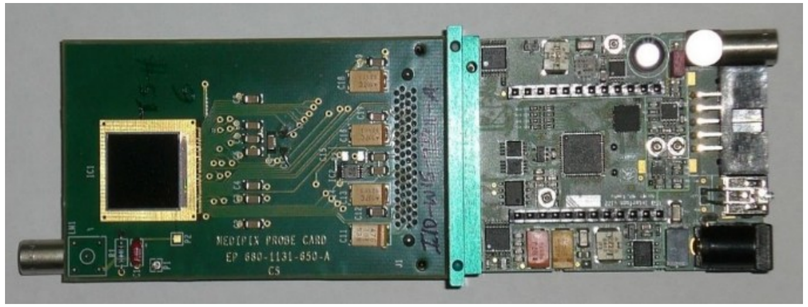


What’s next?

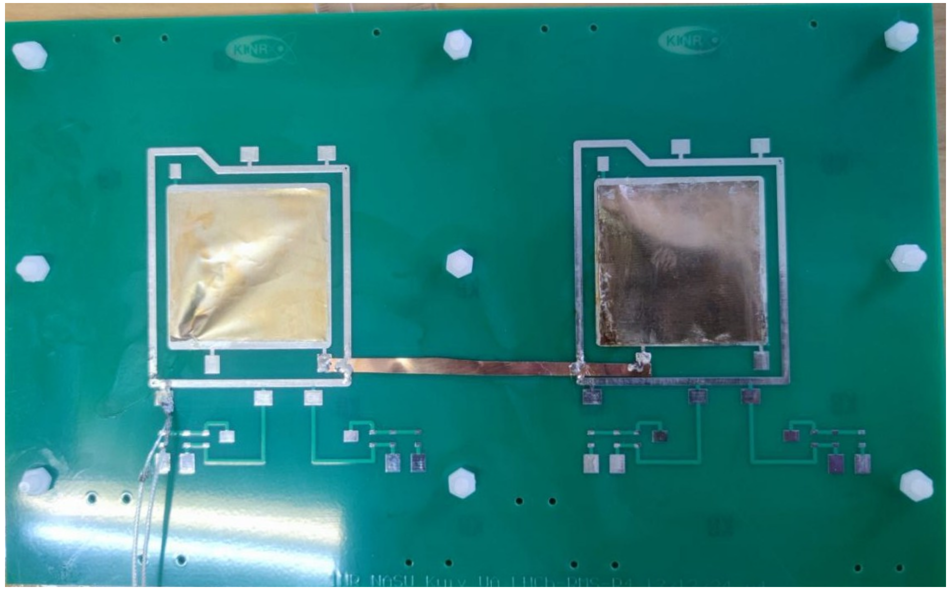
Next step is Mobile system for monitoring and displaying in real time the radiation situation in the environment and radiation therapy **(MSOR-E)**

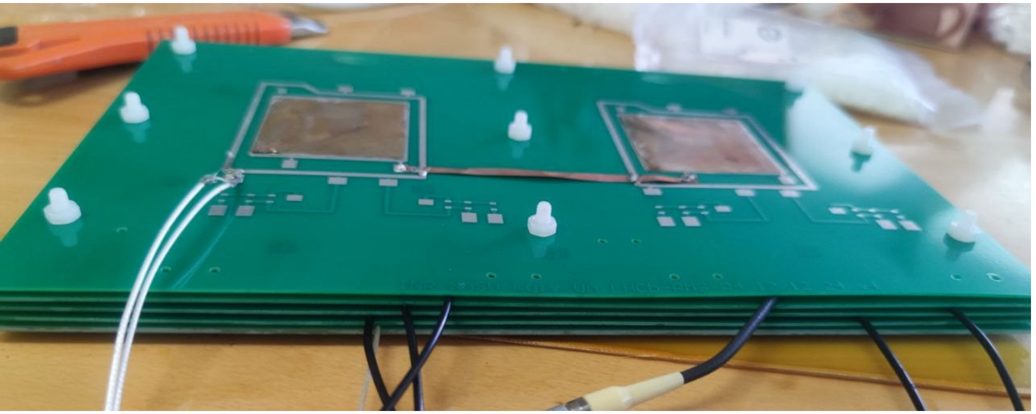
MFD (Mobile Fission Detector / MERMS)
•Utilizes the SEE phenomenon
•Based on the RMS-R3 LHCb work
•Used for detection of β and protons
Pixel Detectors
•Based on TimePix 2/3
•Detects all types of radiation (alpha, beta, gamma, neutrons)
•Determines particle type and energy
•Creates radiation distribution maps
Gas Discharge Detectors
•Detects gamma radiation
•Measures dose rate in the range of 0.1–999 μSv/h
Additional Detectors
•BME280: Pressure, Temperature, Humidity
•Compact scintillator





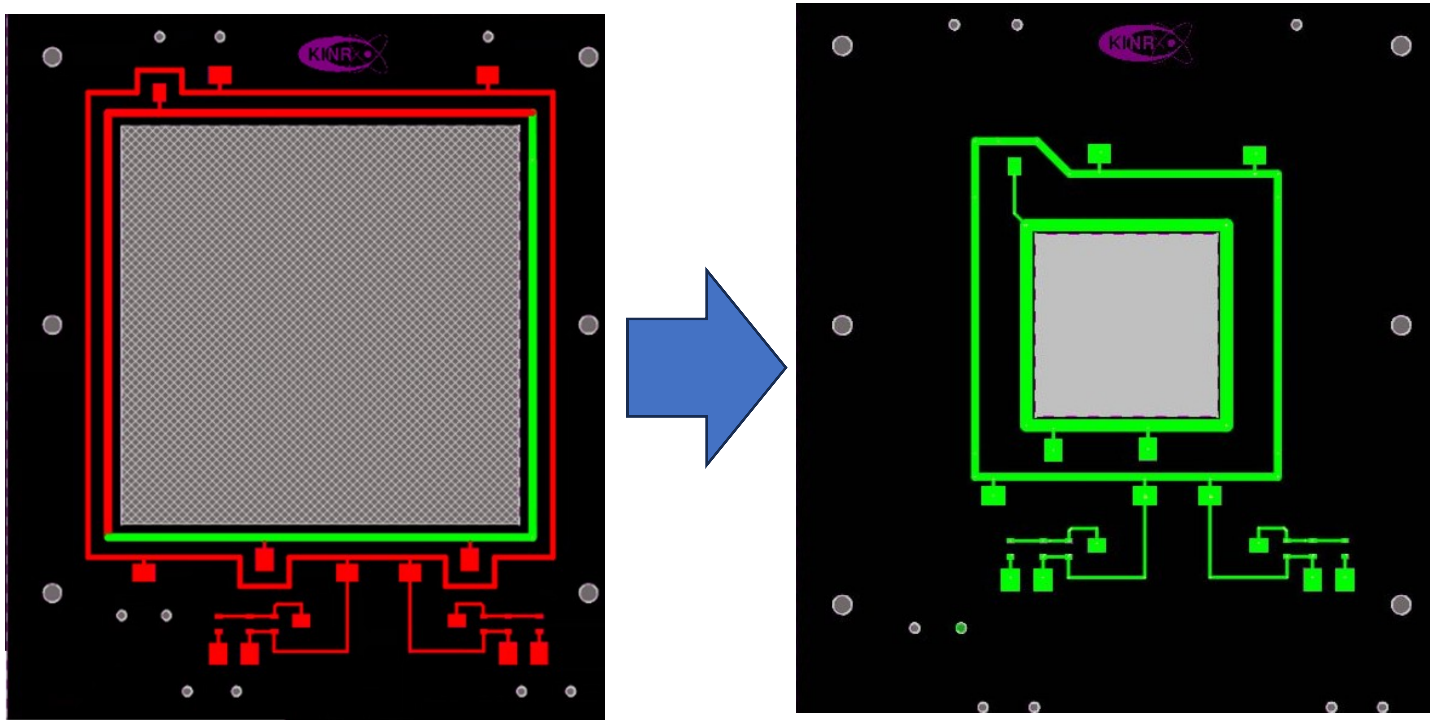
Prototypes of MFD modules for a mobile monitoring system



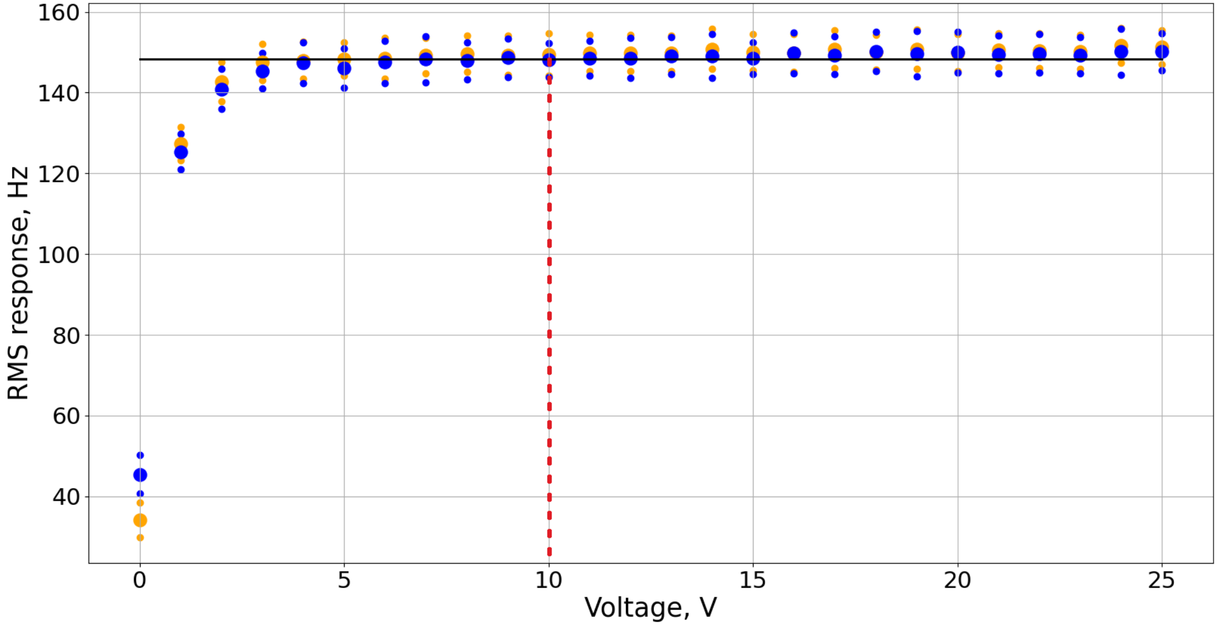


New RMS sensor design:

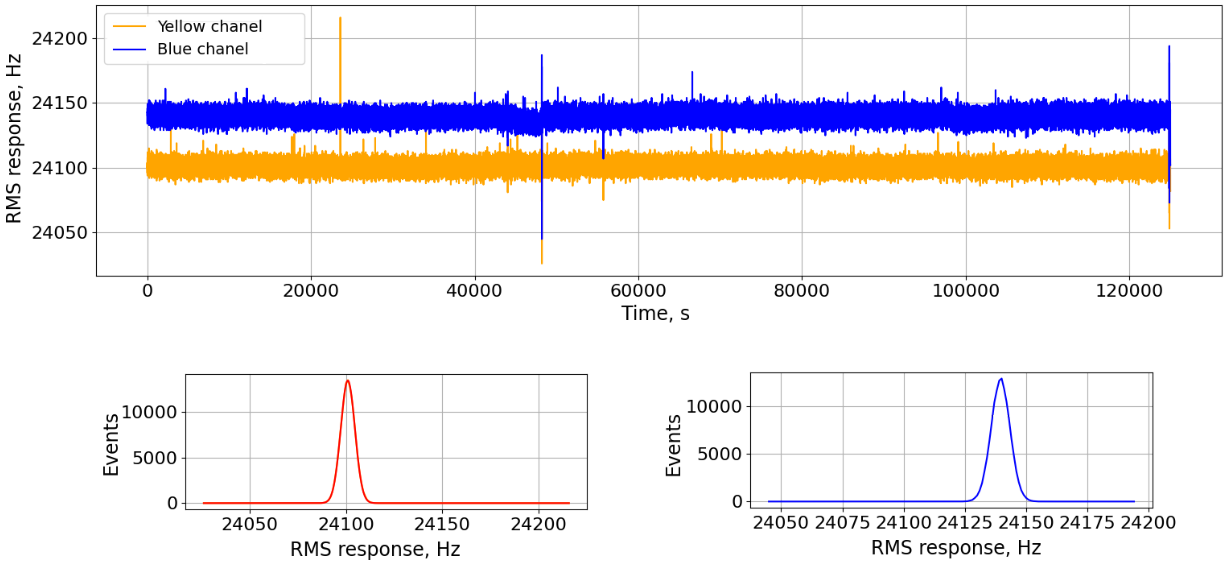
- reduced sensor area to 25 cm^2
- using of gold foils for hanging and efficiency of SEE
- using of ‘rough’ charge integrators 1Hz ~ 10 fA



Testing prototypes on calibration current

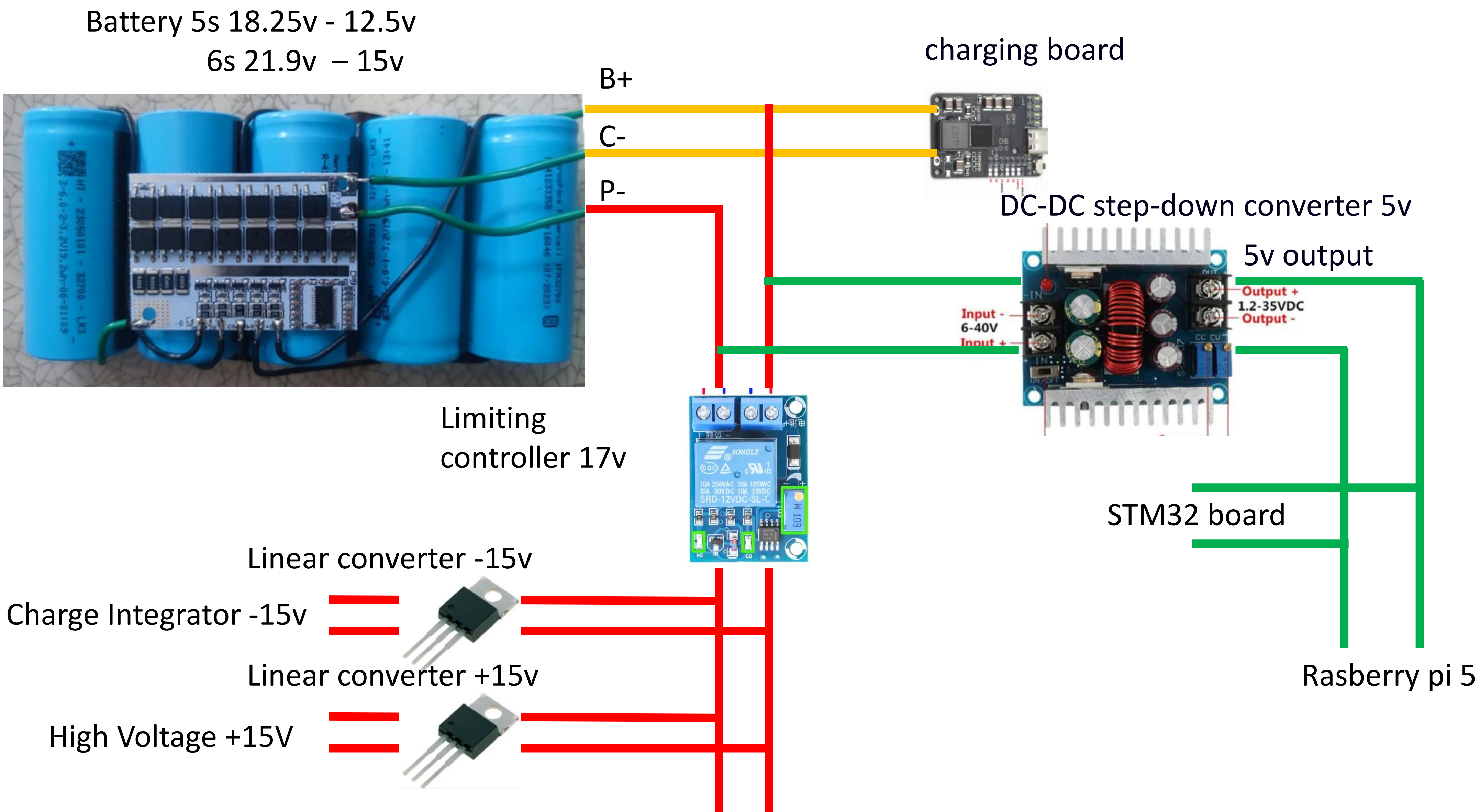


Dependence of the response of the prototype module for MSM on the supplied voltage. It has been determined that the optimal minimum voltage is ~10V.

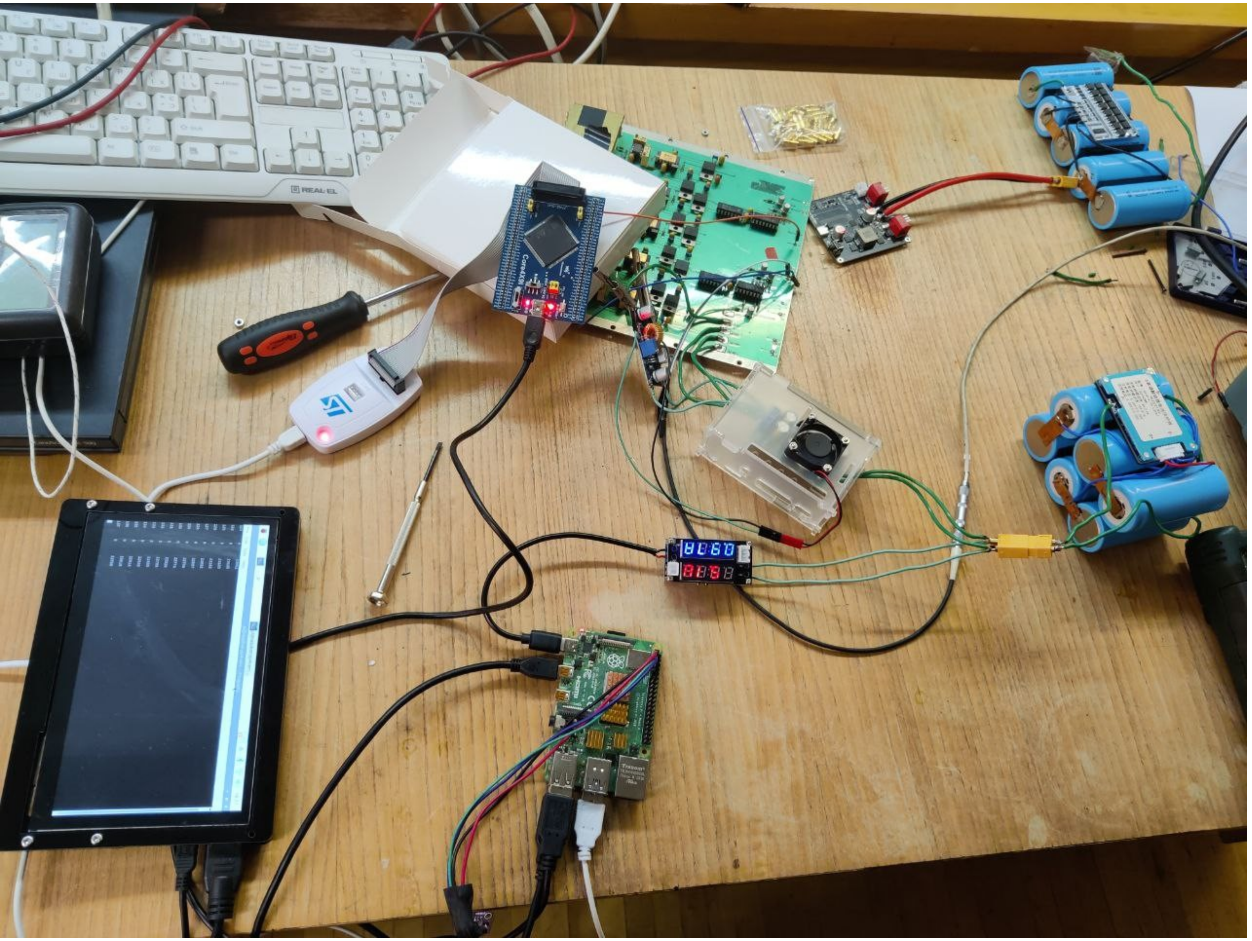


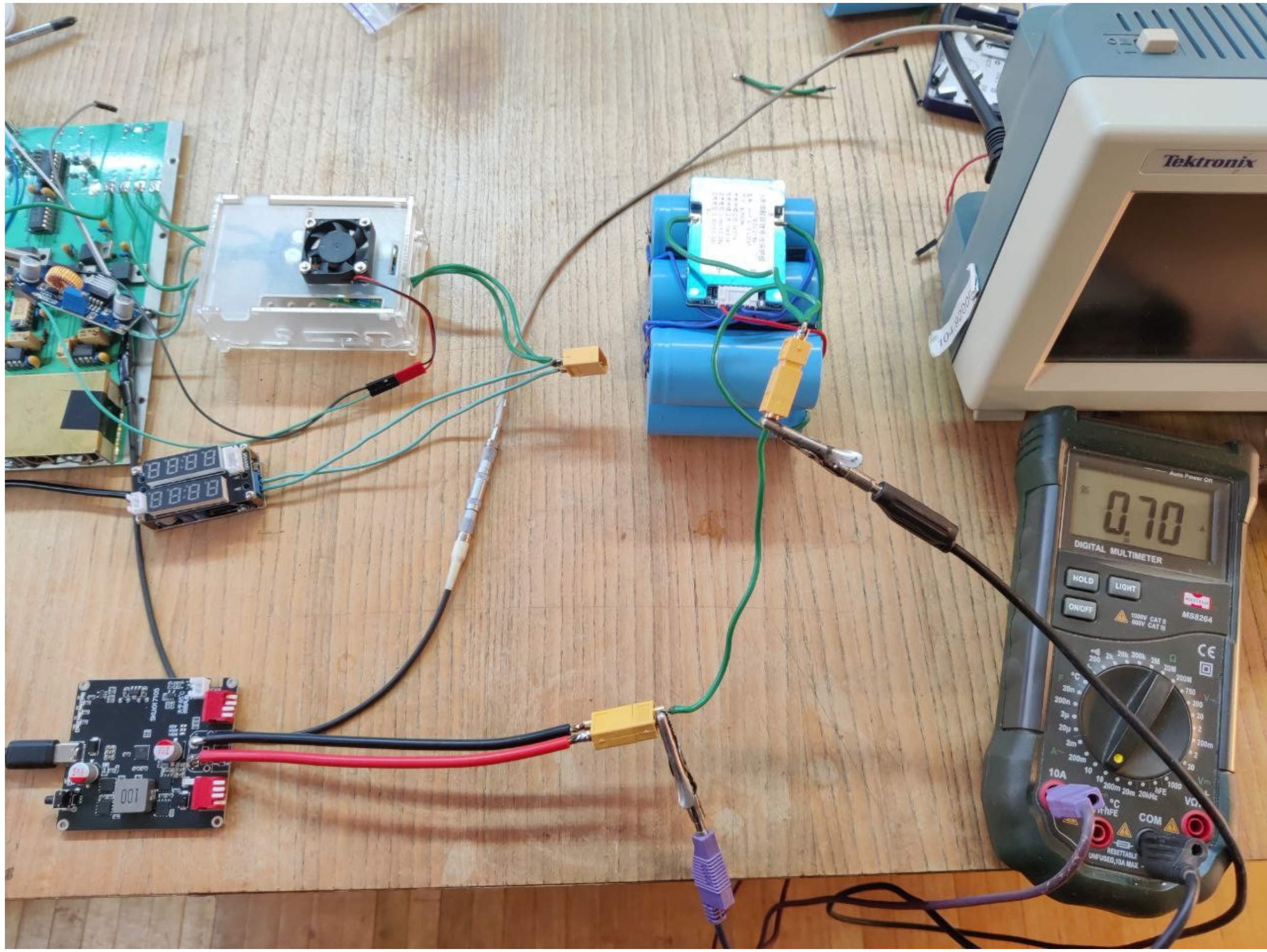
Baseline (calibration current testing) from the charge integrator. The projections are smooth and Gaussian-like.

Power supply system



Mobile monitoring system (prototype)





Conclusions

1. Four years (2022-2025) of RMS-R3 successful operation at LHCb experiment as:
- Secondary luminosity counter
- Experiment conditions monitoring system
- Real-time control of interaction region position
- Independent system integrated into LHCb control structure

2. Experience and technology from RMS-R3 successfully adapted to develop mobile system MSOR-E for real-time environmental radiation monitoring.
System combines complementary detection technologies:
- TimePix (2/3) for particle identification, energy measurement, and radiation distribution mapping
- Gas discharge detectors for gamma dose rate (0.1-999 μSv/h)
- Environmental sensors (BME280: pressure, temperature, humidity)
- Compact scintillator
- Suitable for environmental monitoring, emergency response, and potential radiotherapy applications

Modular architecture allows system expansion and adaptation to various monitoring scenarios.

Acknowledgments

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Part of the work was carried out within the framework of the NASU grant 03/405 ‘Mobile system for monitoring and displaying in real time the radiation situation in the environment and radiation therapy’. This project received funding as part of grants to research laboratories/groups of young scientists of the National Academy of Sciences of Ukraine to conduct research in priority areas of science and technology development for 2025-2026.

Bonus slides

RMS-R3: electronics

Sensitive charge integrators

Universal ADC, developed by the SNR NASU

- Charge-frequency conversion: the input current is converted into a sequence of output pulses with a proportional frequency
- Sensitivity : 10 fA - 1 Hz
- Input current range : 10 fA - 20 nA
- Excellent linearity : ± 0,02% at 2 MHz
- Radiation resistance : ~ 3 kRad

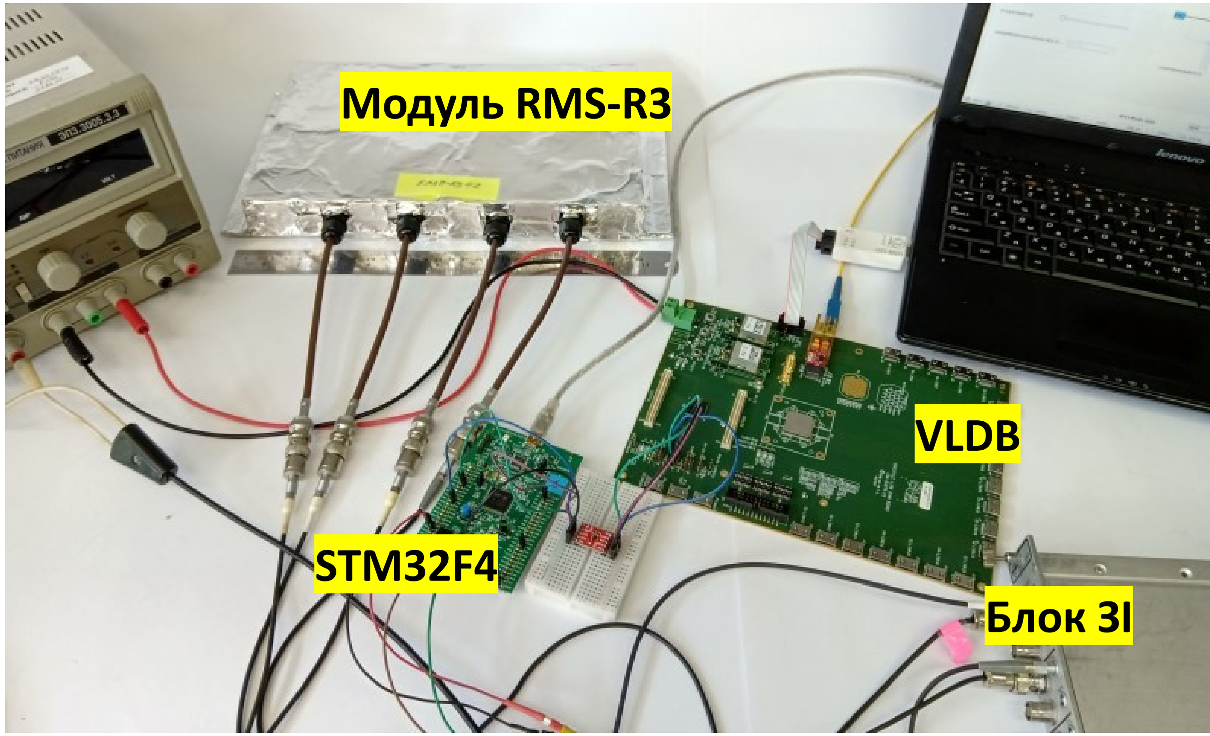
Frequency counters

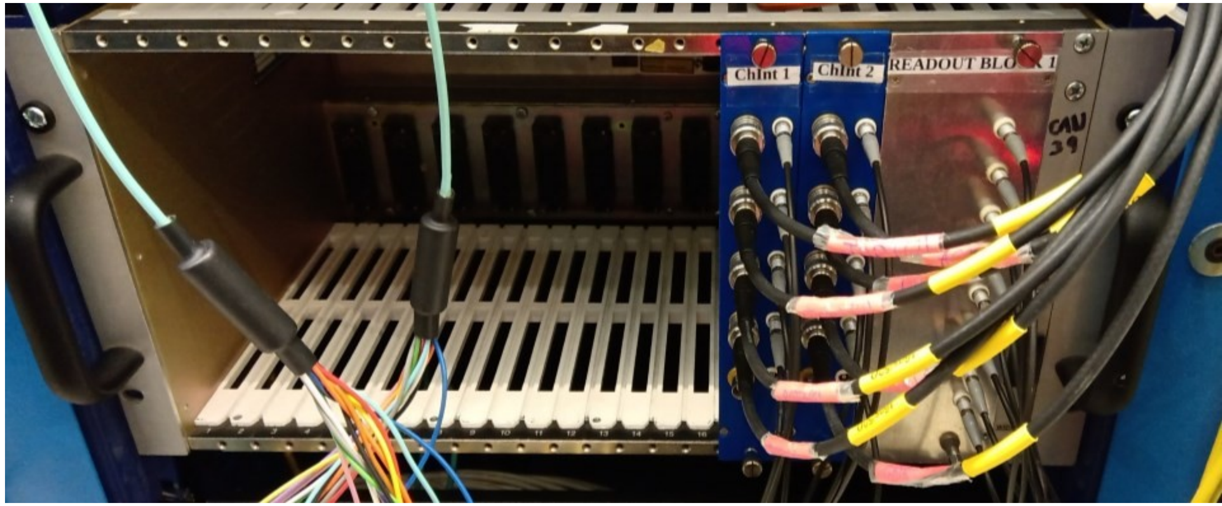
Based on the STM32F4DISCOVERY development board (developed by STMicroelectronics)

- Two 32-bit programmable timers (counters)
- I2C interface for communication with the VLDB board

Universal communication board VLDB

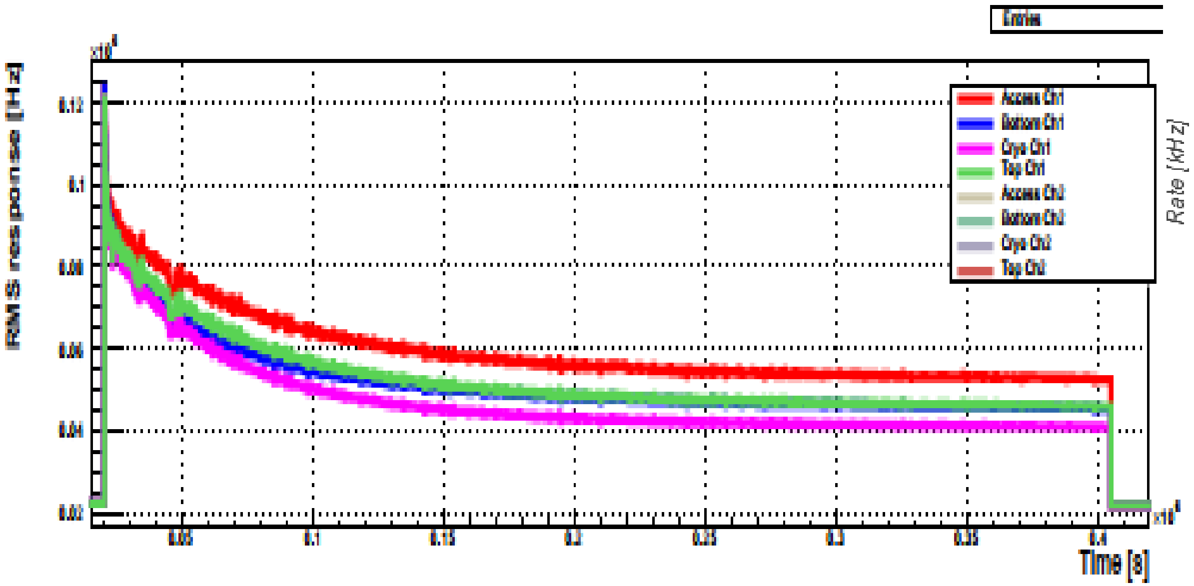
- Versatile Link Demonstrator Board (VLDB) (Developed by the group CERN ESE)
- Board for operation in a radiation-resistant optical communication ecosystem
- 4,8 Gbit/s, data transition b/w FE and BE
- Radiation resistance up to 400 Mrad

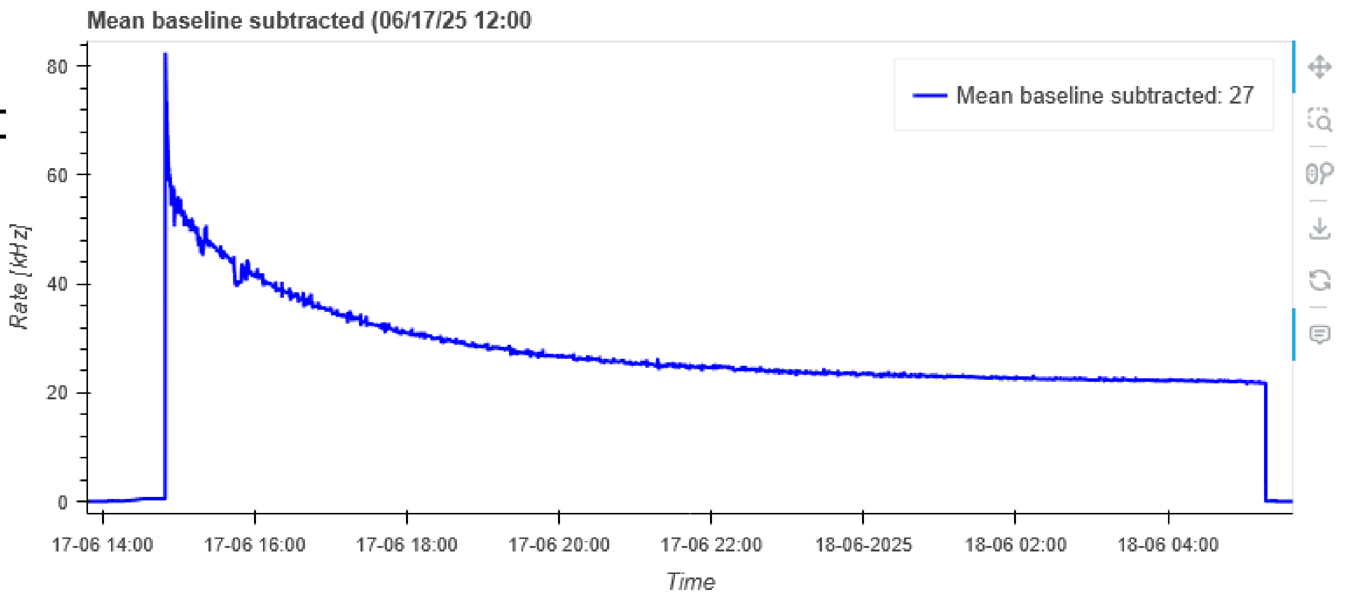


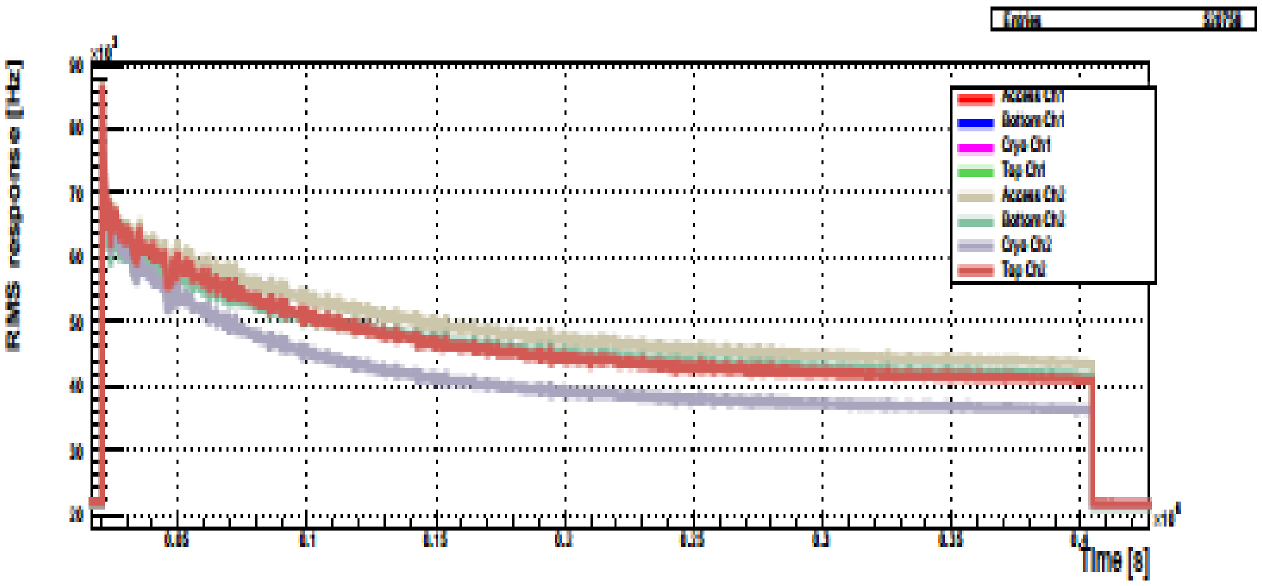


R. Lesma et al., JINST 12 C02020 (2017)

Pp in 2025 (fill 10731)

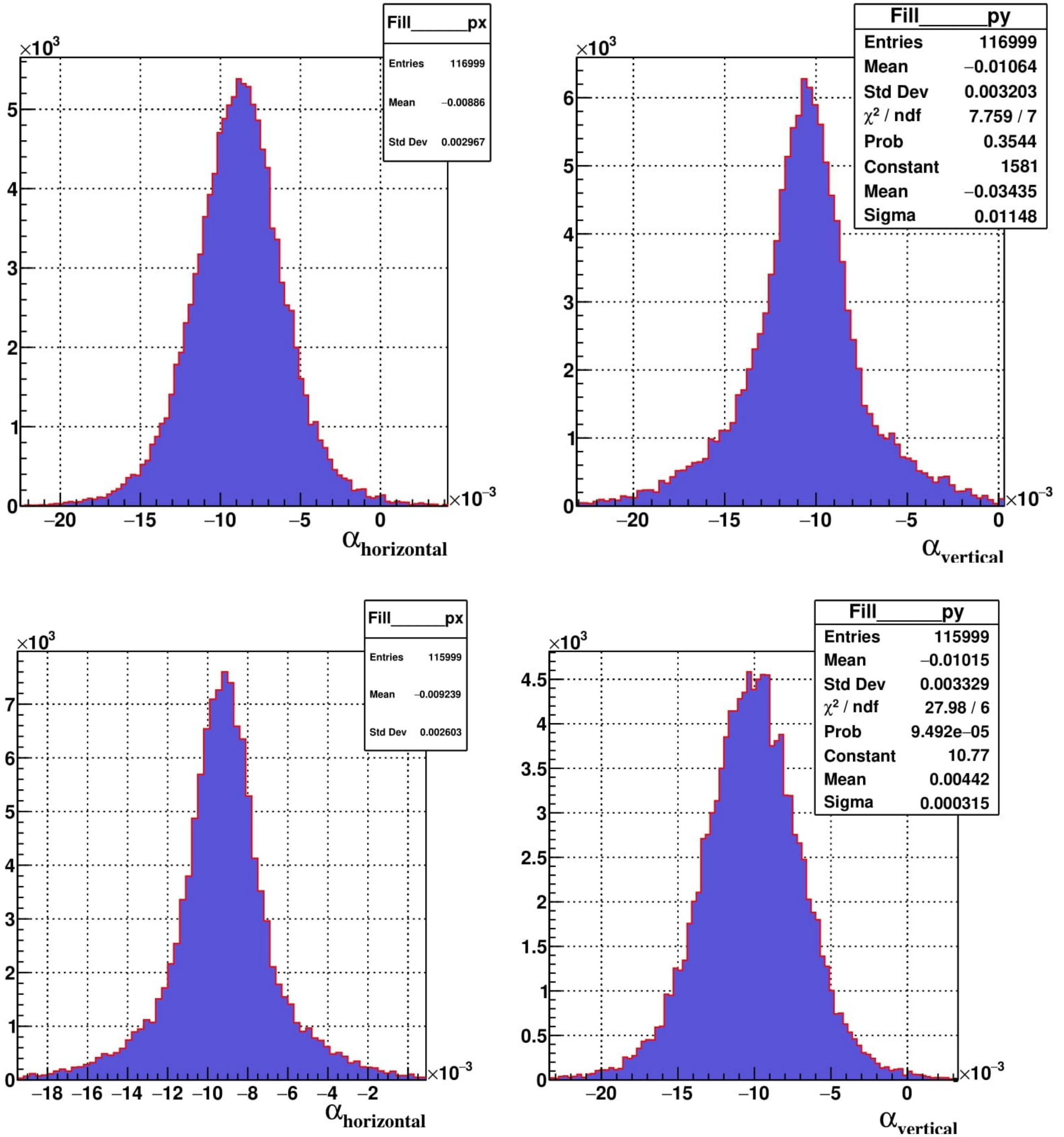




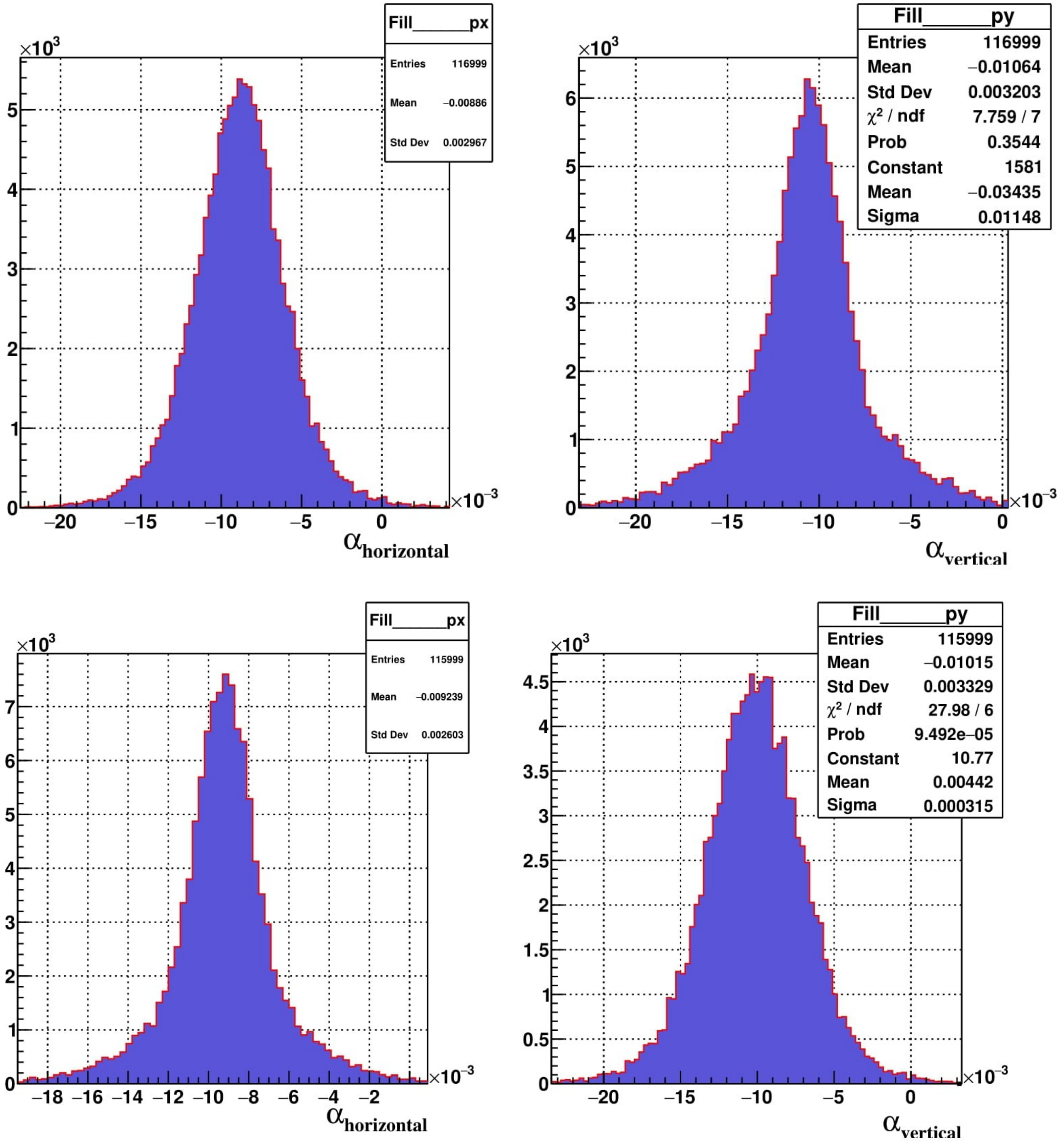


This form is very similar to PbPb collisions, where beam deflection was presented. Although, now the asymmetries are not localized around a single point, but behave much more irregularly with very large deviation of centroids from previous fills asymmetries.

PbPb with Ne vs PbPb with Ar



PbPb with Ne vs PbPb with Ar



OO (H2 SMOG2) & NeNe (Ne)