LUMINOSITY, BEAM AND BACKGROUND CONTROL SYSTEM RMS-R3 in the LHCb EXPERIMENT

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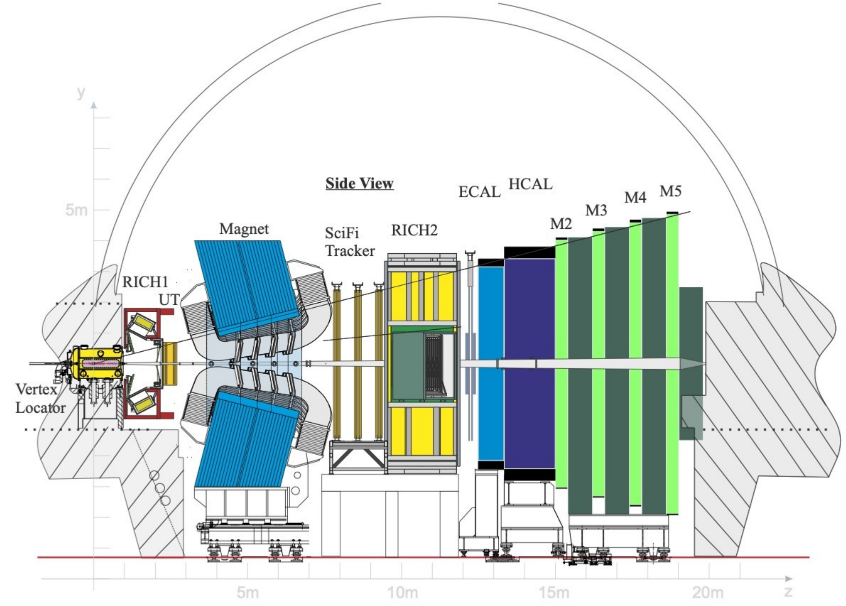
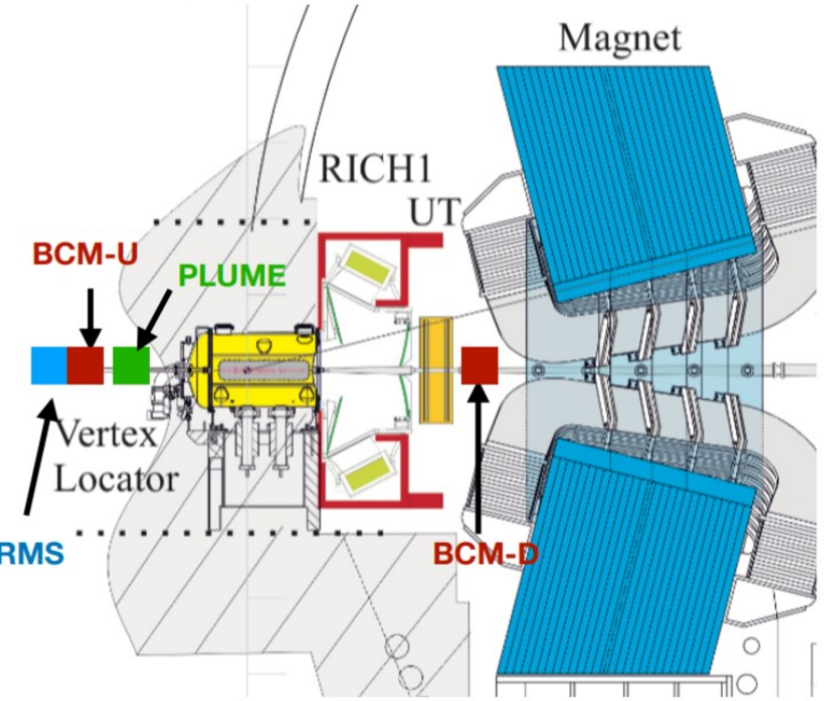




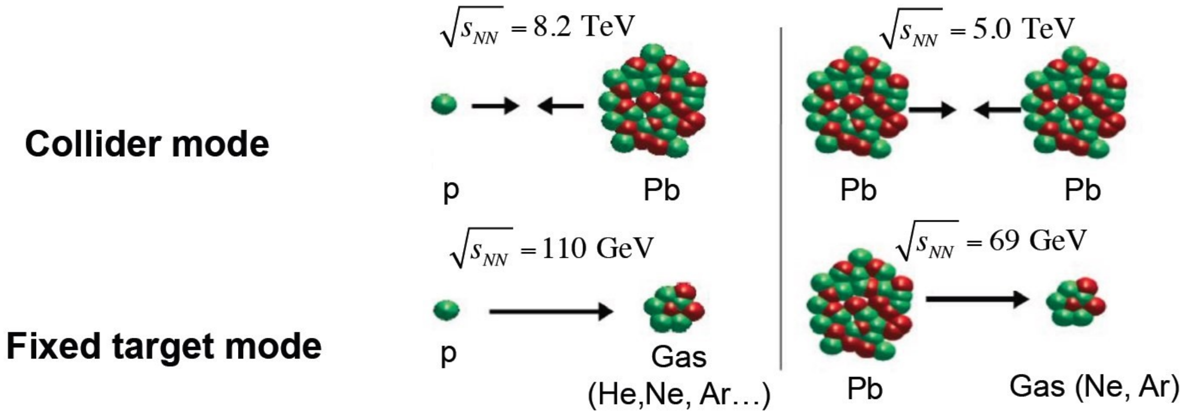
LHCb experiment

Nominal conditions in Run 3 (2022 - 2025):

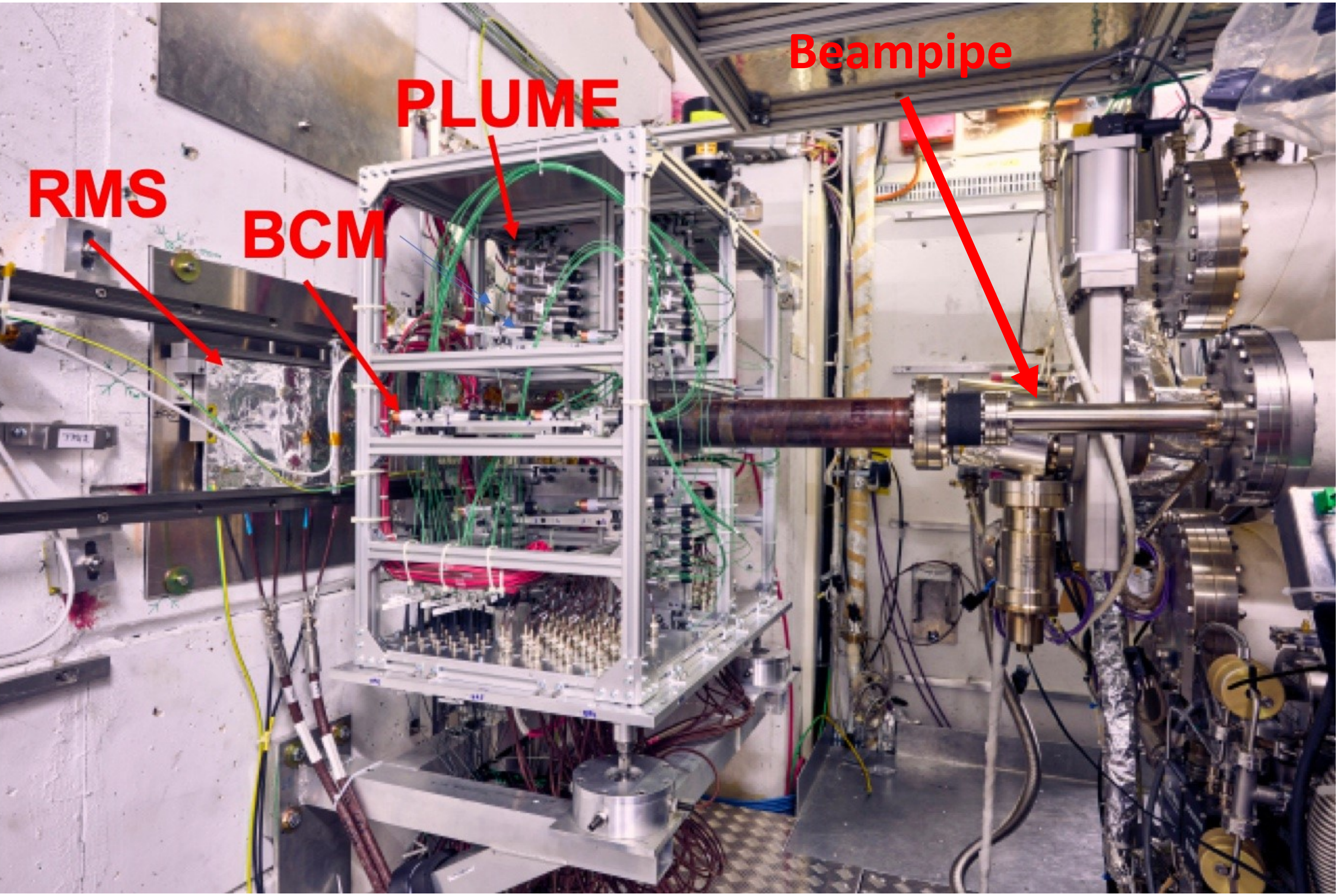
- P-p collision energy √s_{NN} = 13,6 TeV
- Increased instantaneous luminosity up to 2x10^{33} $cm^{-2}s^{-1}$
- Collider mode of operation and fixed (gas) target mode

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



Beam and background monitoring systems



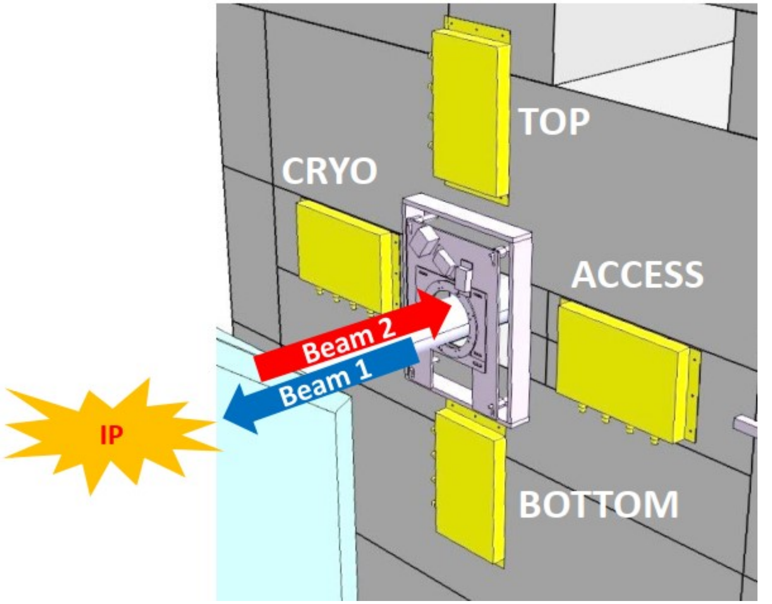
Beam and background monitoring systems .
Taken from LHCb collaboration. LHCb Upgrade I

Beam and background monitoring systems (B&B) were created to ensure safe and efficient experimentation:

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

- Luminosity and background beam conditions monitoring is essential to optimize collisions, reduce systematic uncertainties, and ensure safe detector operation by quickly detecting anomalous beam conditions that could harm the experiment.

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

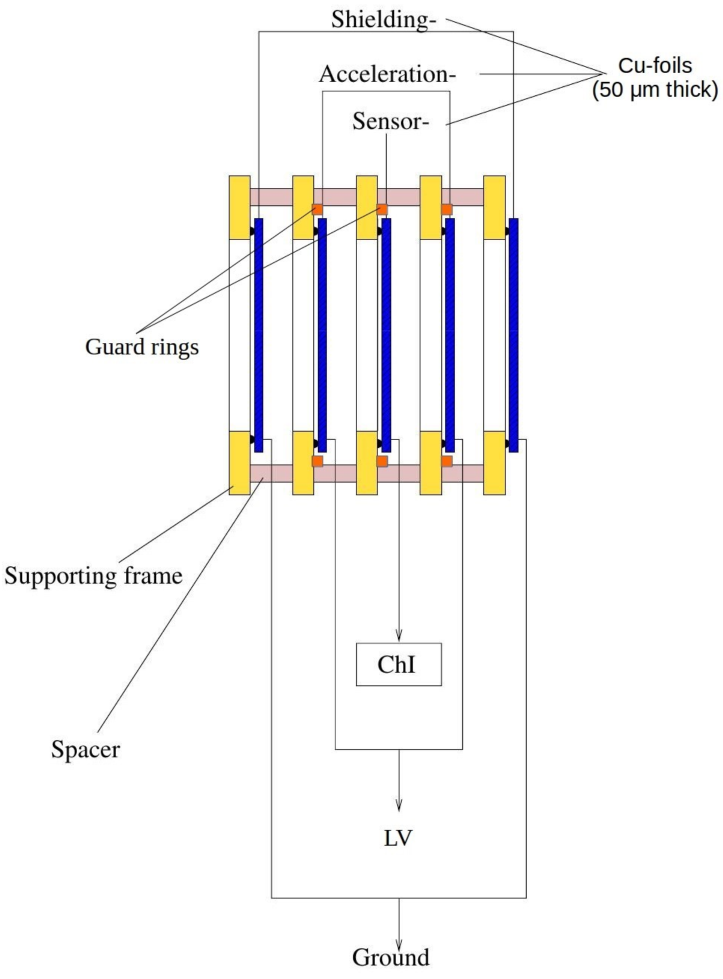
• **charge-to-frequency conversion**, - **digital output**

• **Large dynamic range** (10^3-10^9 MIPs/s → **linear response** up to 2 MHz

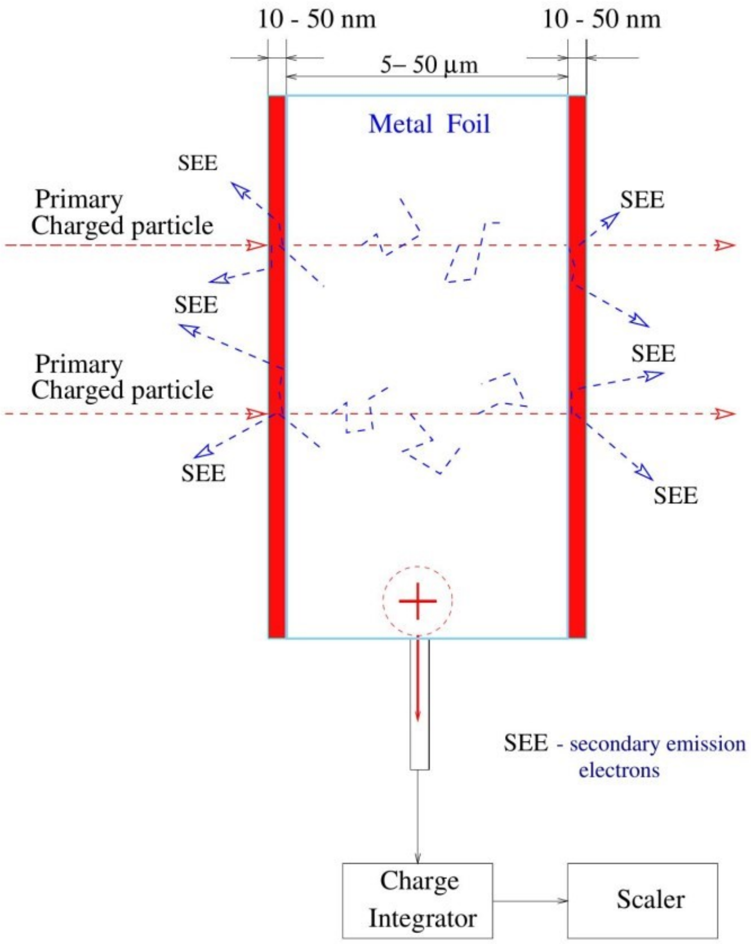
• **Stable response →** ~ 1 % during Run 3

• **Low** operational **voltage** (24 V)

Beam and background system RMS-R3



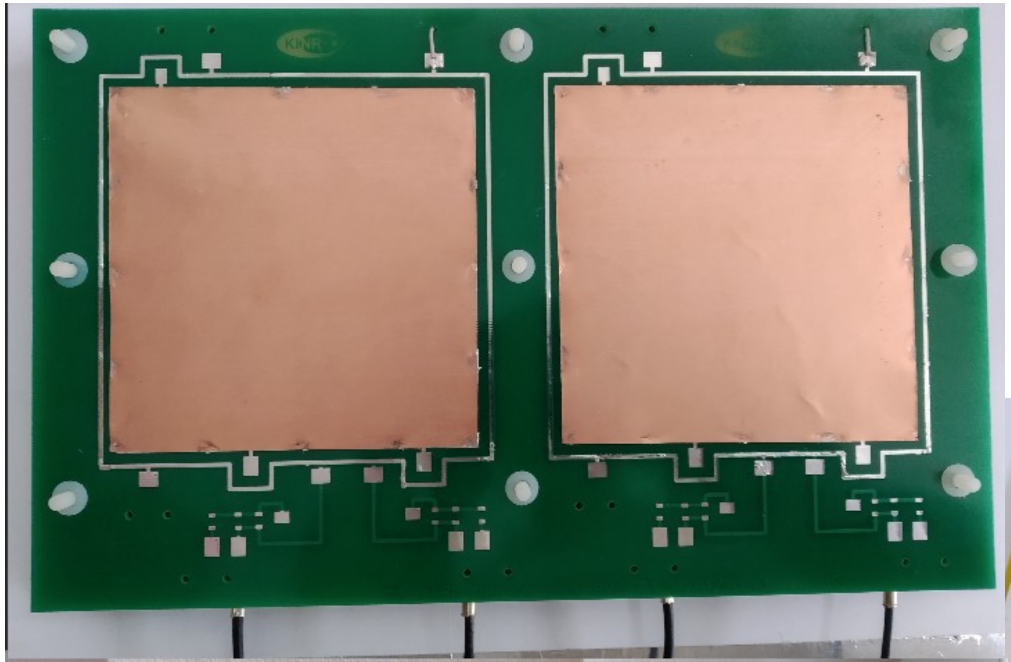
RMS-R3 sensor schematic

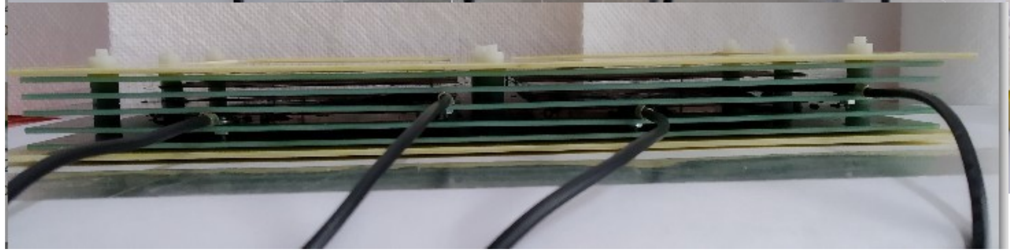


Schematic of the physical phenomenon of EEE on the surface of foil sensors

- 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: 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

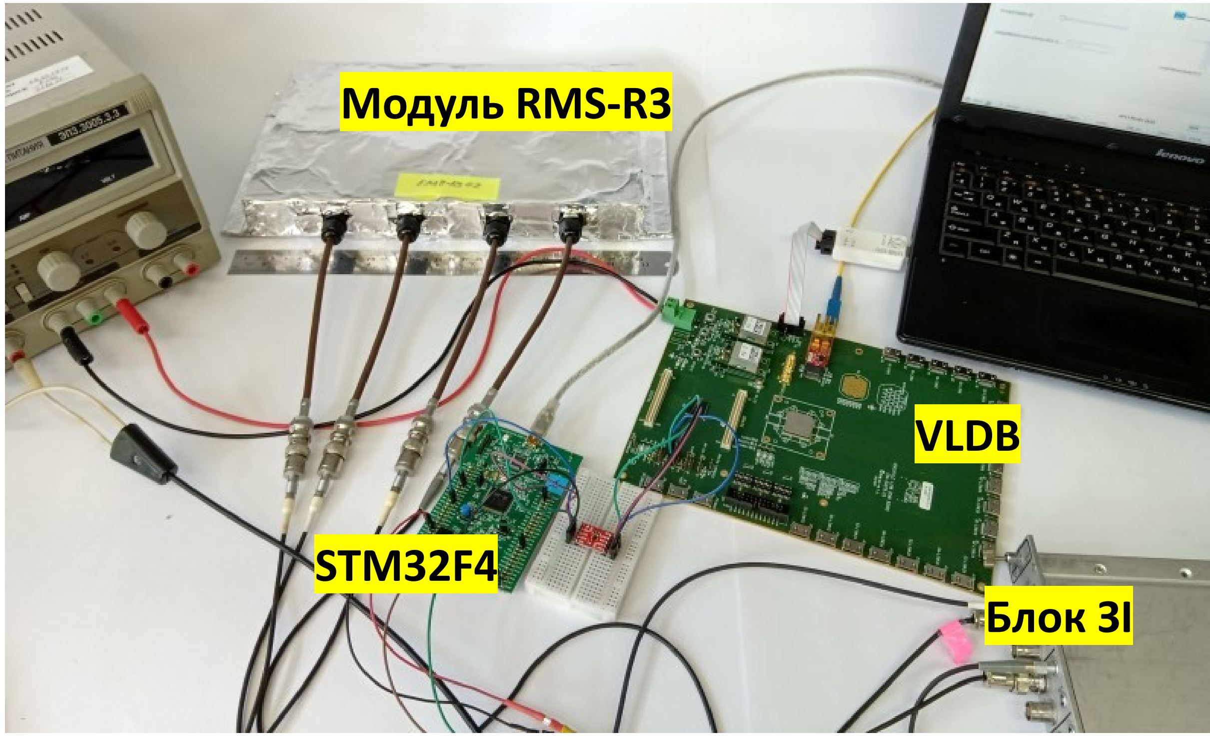
Frequency counters

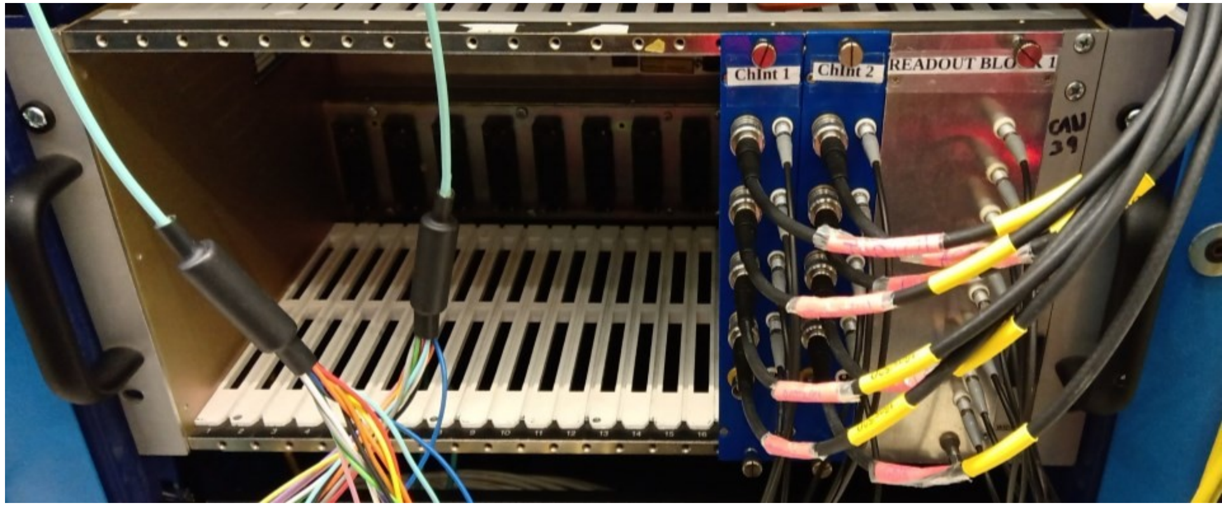
Based on the STM32F4DISCOVERY development board (developed by STMicroelectronics)

- 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

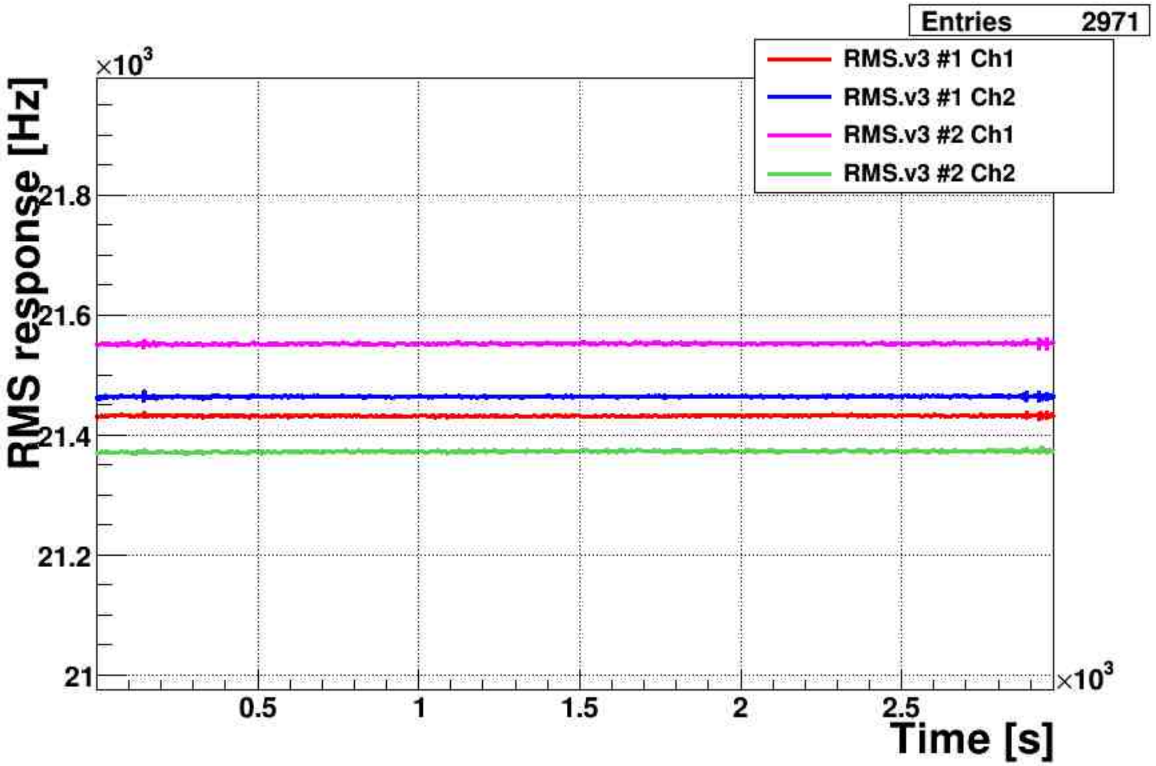




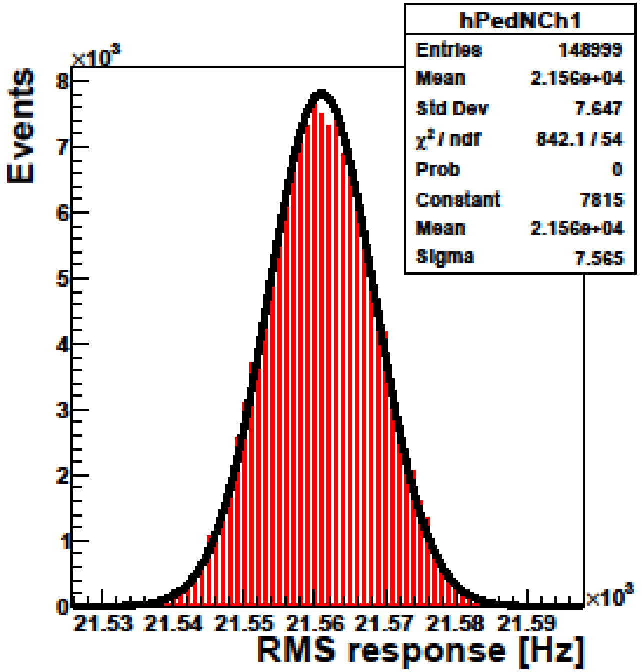
R. Lesma et al., JINST 12 C02020 (2017)

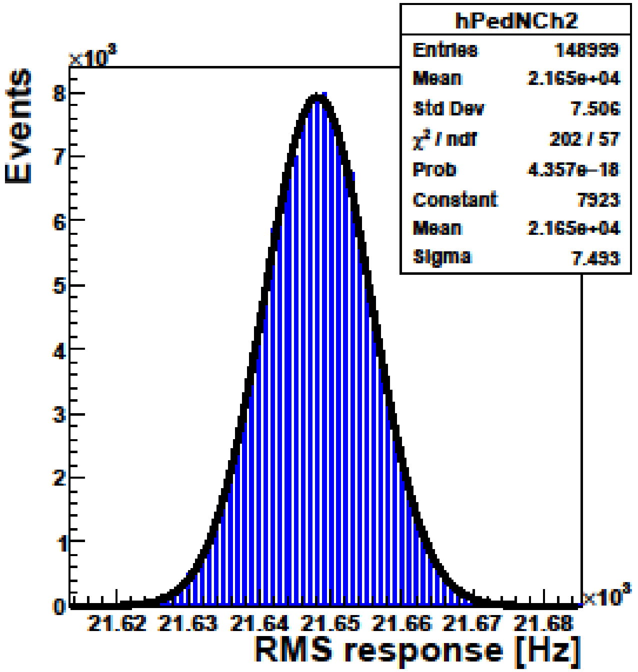
RMS-R3 response to calibrated current (baselines)

- Control measurements were carried out for 21 days
- Sensitive charge integrators were used (1 Hz corresponds to 1 fA)
- The LHCb experiment uses charge integrators with the following parameters:1 Hz corresponds to 10 fA



Відгук сенсорів RMS-R3 при вимірюванні базових ліній





Projections of RMS-R3 baselines in the LHCb experiment. RMS deviation from 7.5 Hz to 10 Hz -> high stability, noise < 0.1%

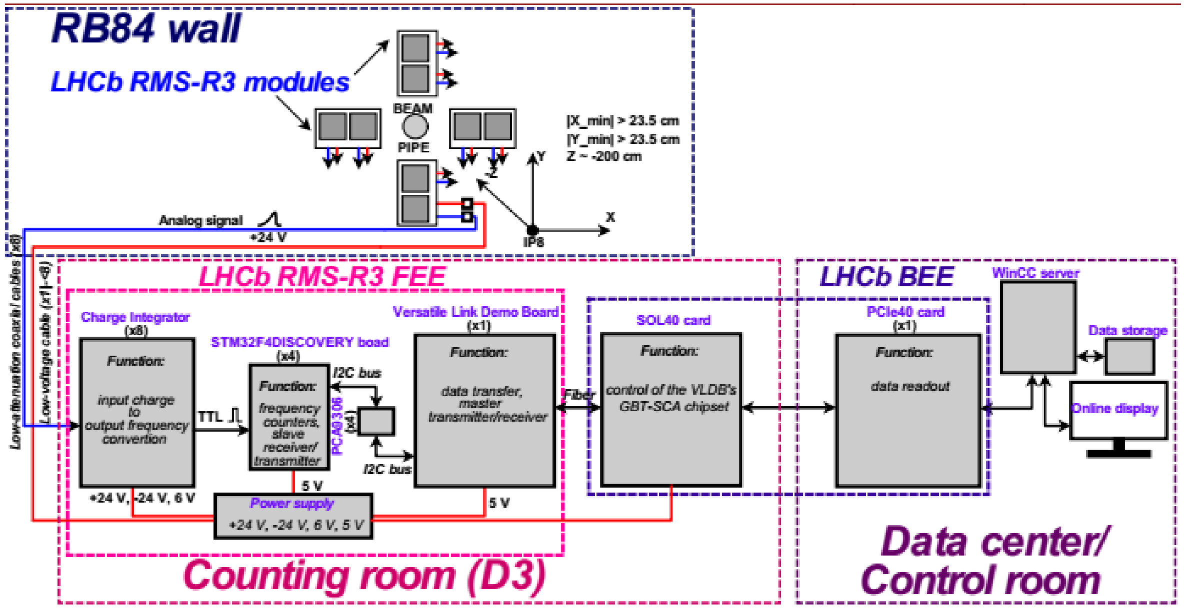
RMS-R3 functional structure and features for Beam and Background Monitoring at LHCb

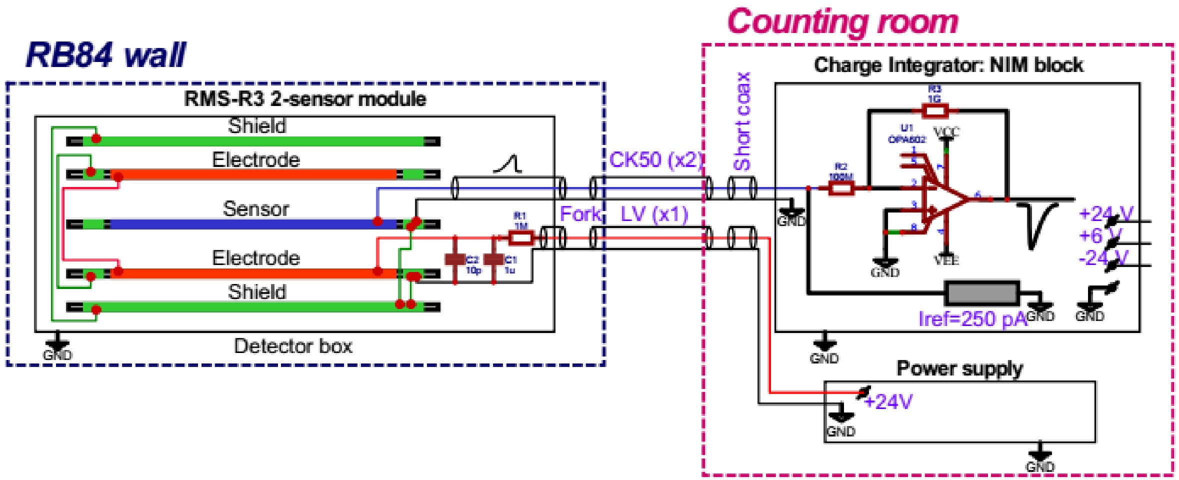
Precision geometry layout
around the beam pipe at 2.2 m from IP8:
4 pairs of the MFD detectors

- Top-Bottom and Left-Right pairs of detectors measure asymmetries of their response to particle fluxes

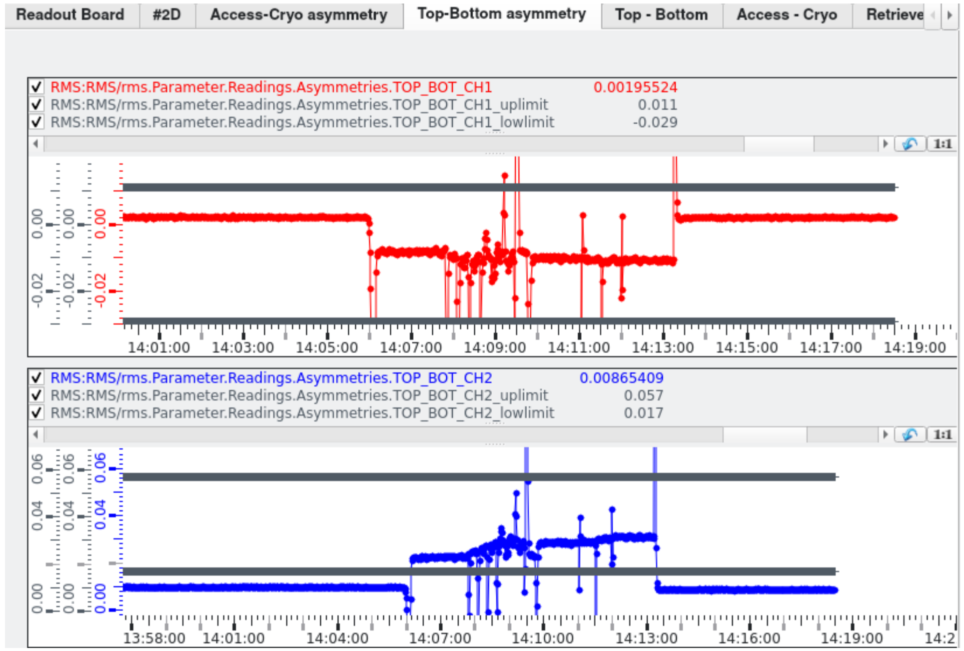
- Any change of asymmetries – on-line indication and message to the shift crue about the change of the conditions of the experiment

- Perfect measurement of luminosity:
- pp collisions at $2{\times}10^{33}$ sm^{-2} a^{-1} (linear up to 10 times higher)
- PbPb collisions from 10^{28} sm^{-2} s^{-1}





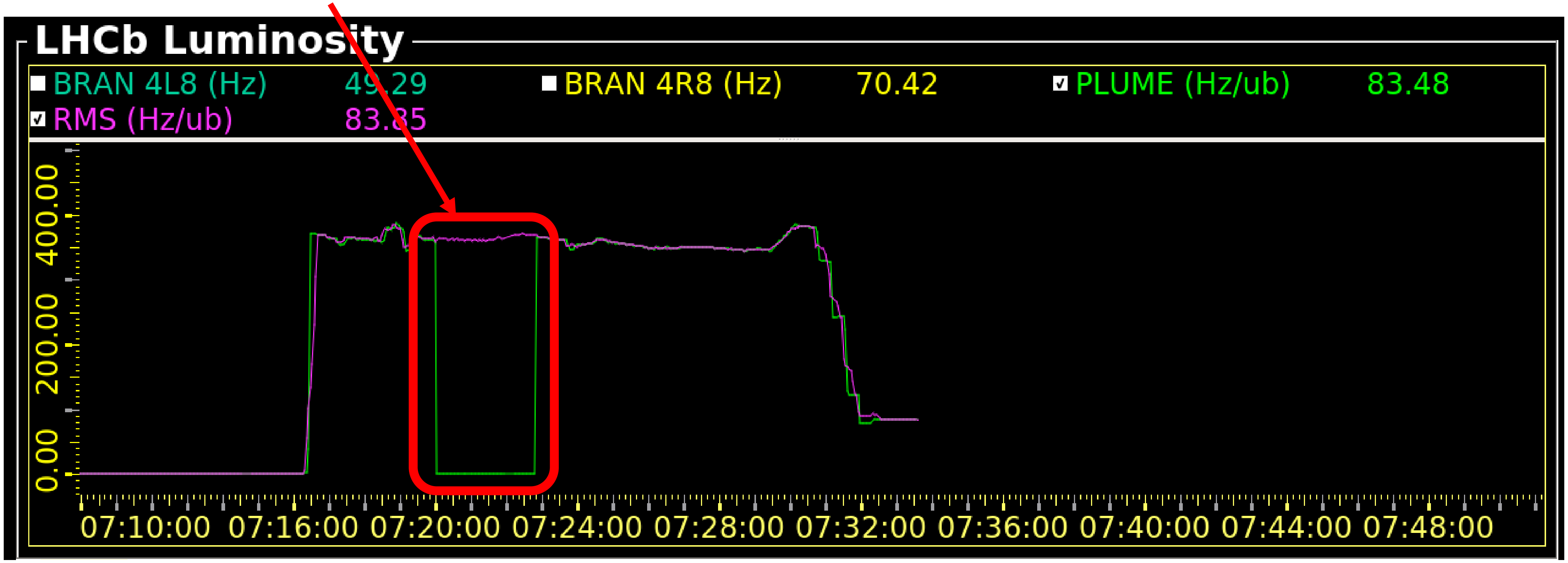
RMS-R3 data on the beam and background monitoring panel



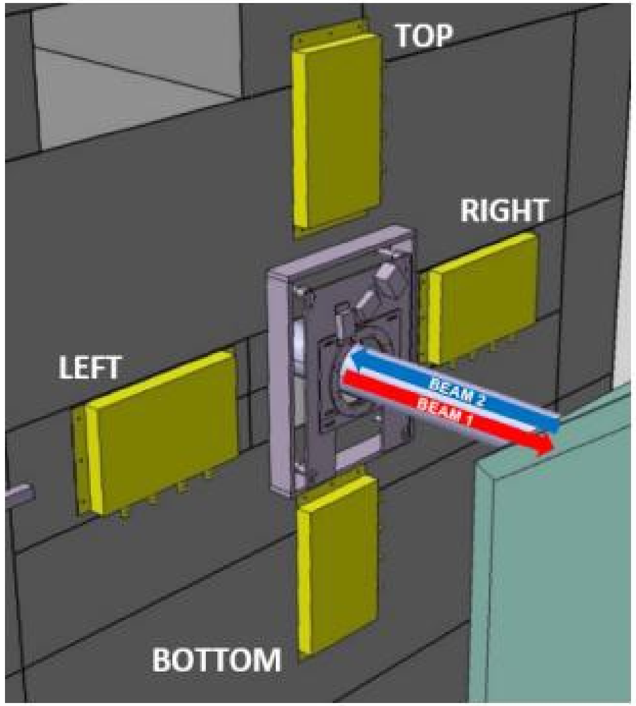
RMS-R3 as an additional luminosity counter

- 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 used as a backup online luminosity meter



Theory of asymmetries method

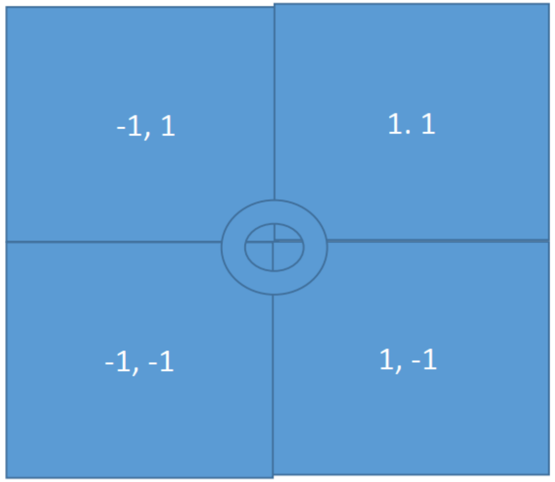


$$A_{ij} = (R_i - R_j) / (R_i + R_j),$$

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



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

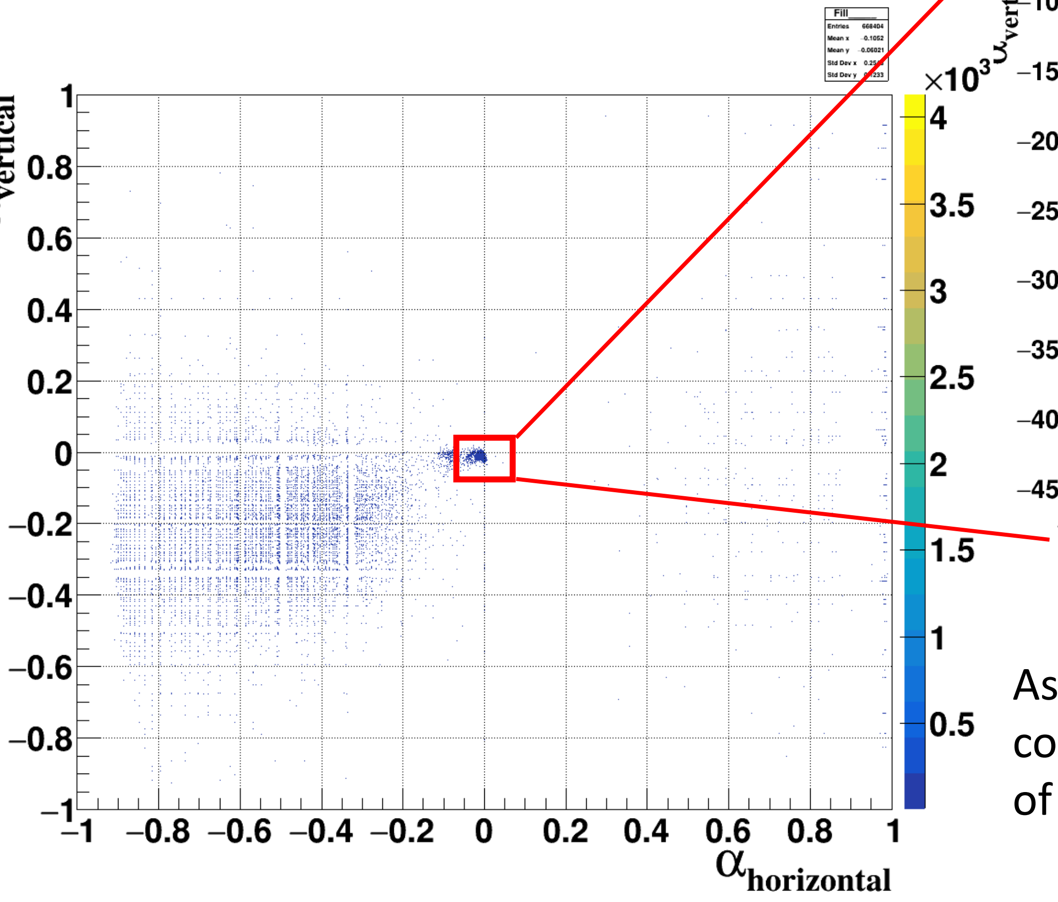
polar angle aperture

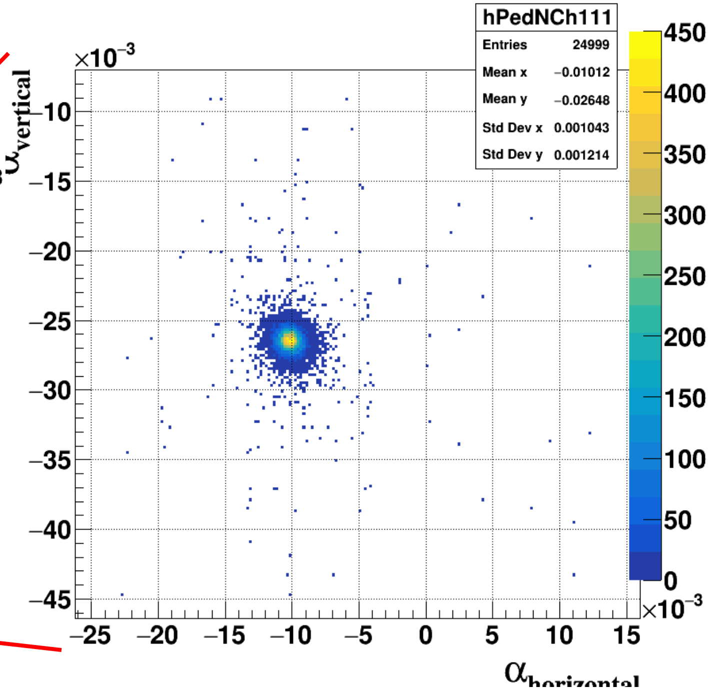
$\vartheta_1, \vartheta_2, \varphi_1, \varphi_2$ angles of RMS-R3 modules acceptance

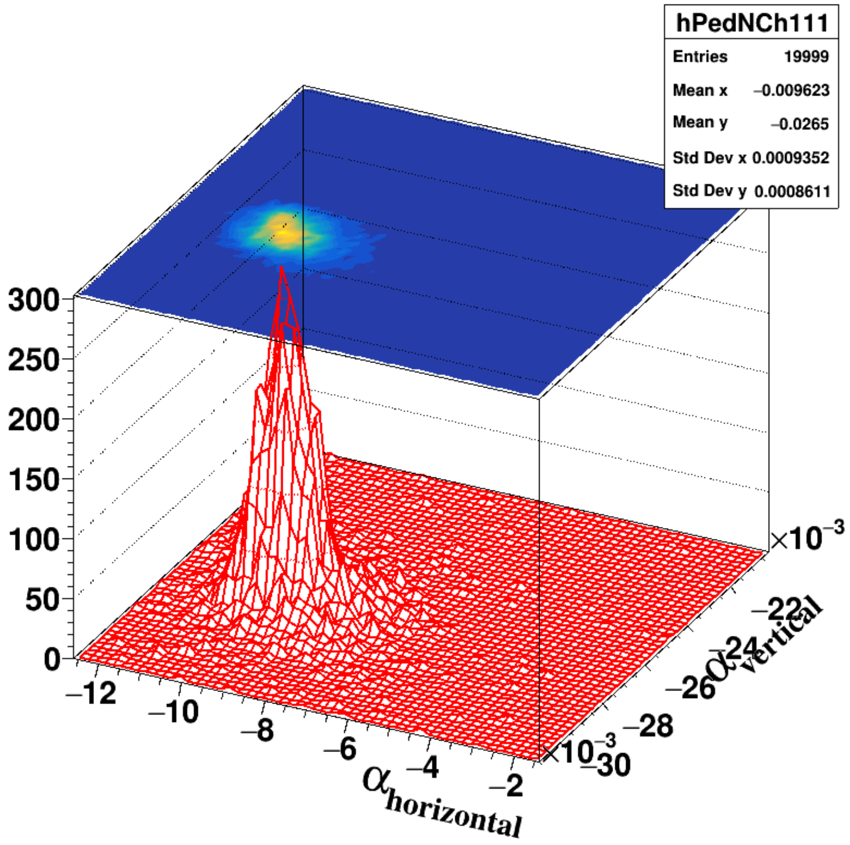
The response of the RMS-R3 sensors depends directly on where the interaction occurred

Scale of asymmetries in the response of RMS-R3 sensors

The value of the RMS-R3 asymmetry scale in the illustrations presented here is increased by a factor of 1000. That is, on the plane of asymmetries from -1 to 1, the "diameters" of the loci are ~ 5-20 * 10^{-3} .







Asymmetries for proton-proton collisions under normal conditions of the experiment (stable beams)

RMS-R3 asymmetries for different experimental conditions

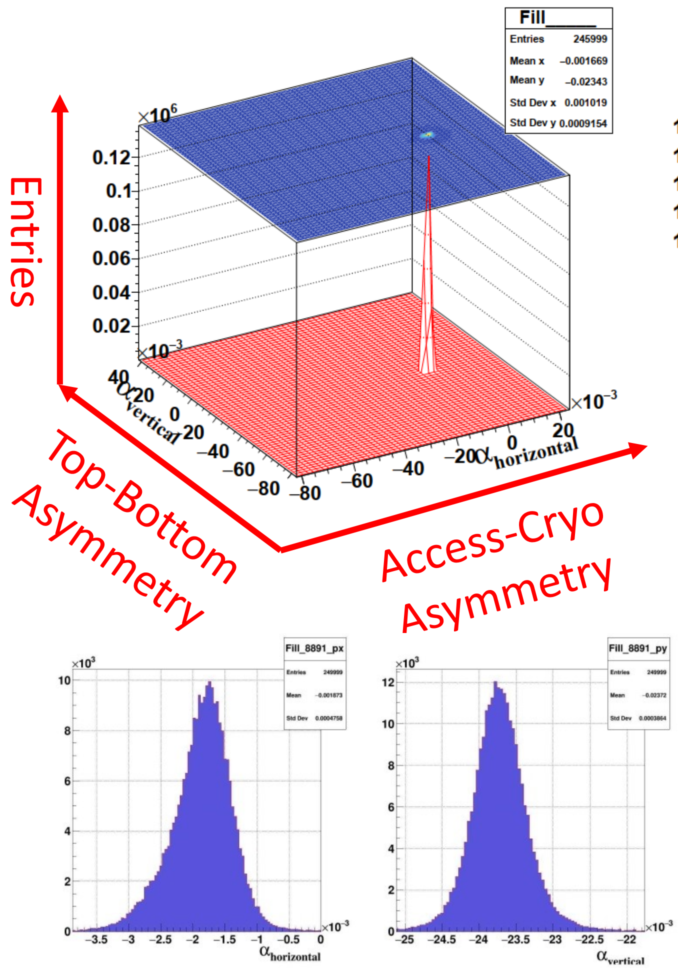
- RMS-R3 asymmetry is

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

where R_x is sensor response

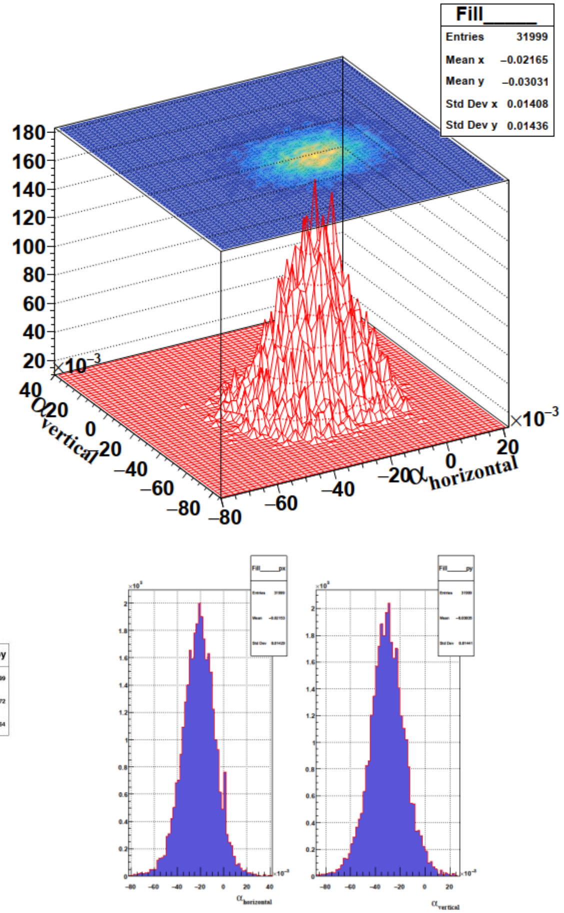
- The 2D distribution of asymmetries is sensitive to the changing of the beam and background experimental conditions.
- The functional purpose of the RMS-R5 is to monitor the state of the beam and background, and to control LHCb radiation safety
- pp collisions for $\sqrt{s_{NN}}$ = 13,6 TeV for luminosity 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



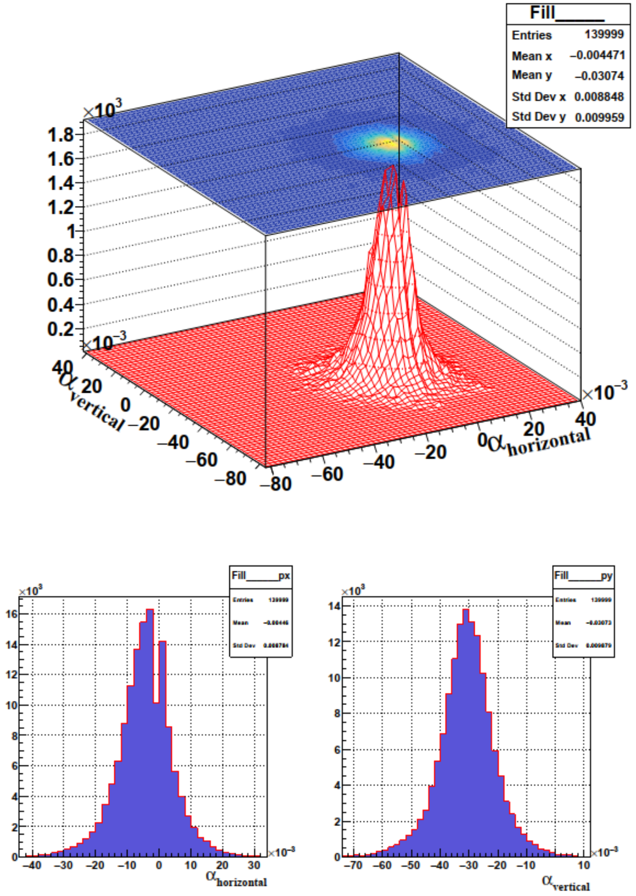
09.06.23 | Fill 8891 | μ ≈ 4
Locus coordinates ($-2*10^{-3}$; $-2*10^{-3}$)
Sigma ~ $0.43*10^{-3}$

PbPb collisions



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

PbPb + PbAr collisions

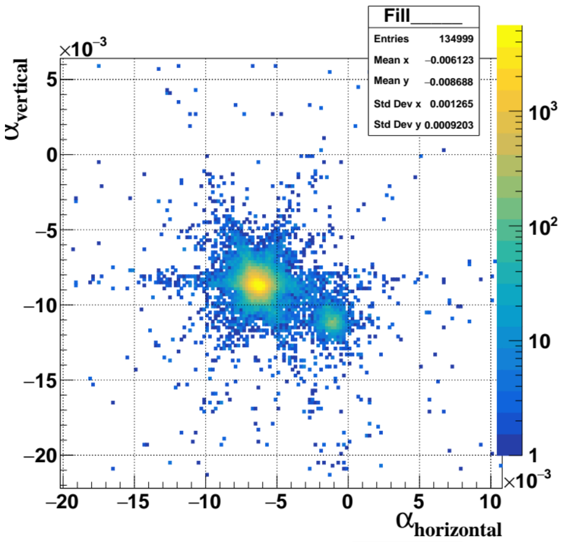


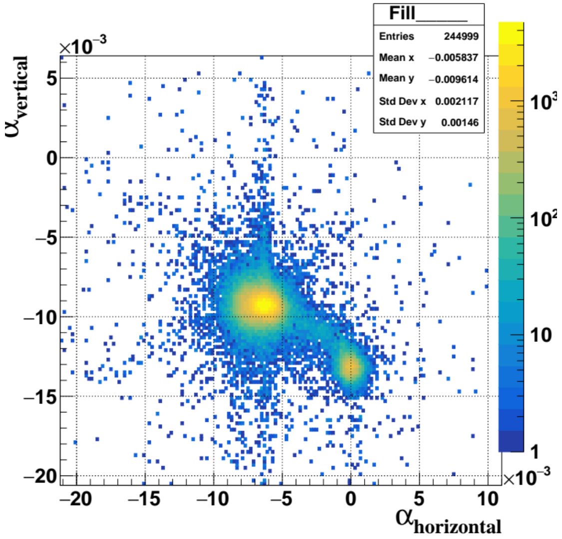
03.10.23 | Fill 9220
Ar injection a la SMOG
Locus coordinates ($-4*10^{-3}$; $-30*10^{-3}$)
Sigma ~ $9,3*10^{-3}$

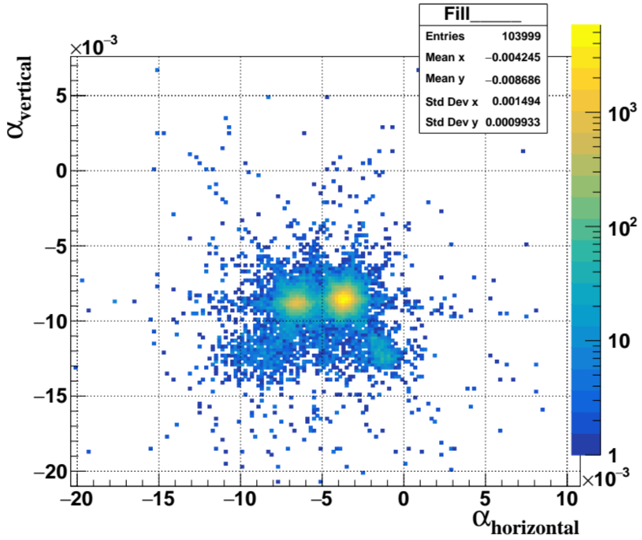
Asymmetries of pA for injections of different gases in the fixed target mode in 2024

H2 | He | Ne

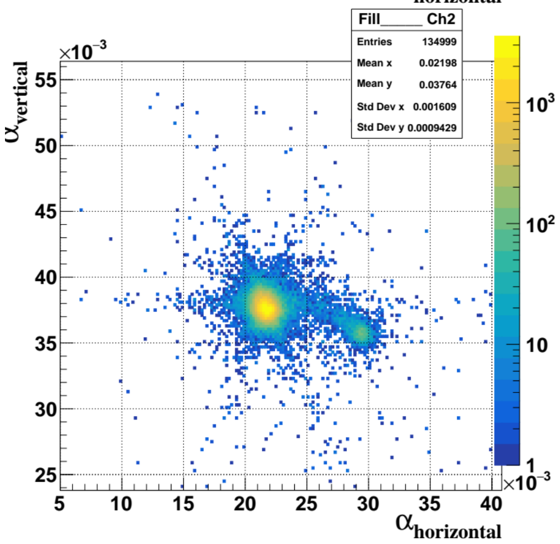
Ch1

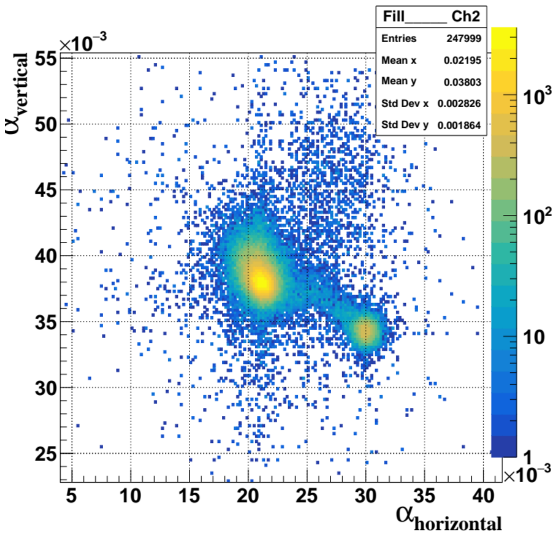


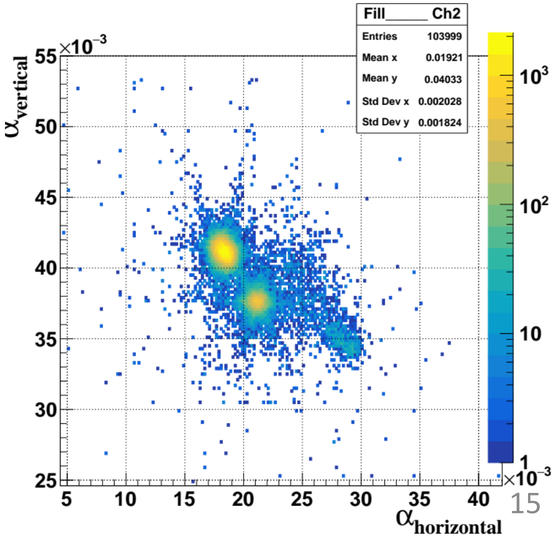


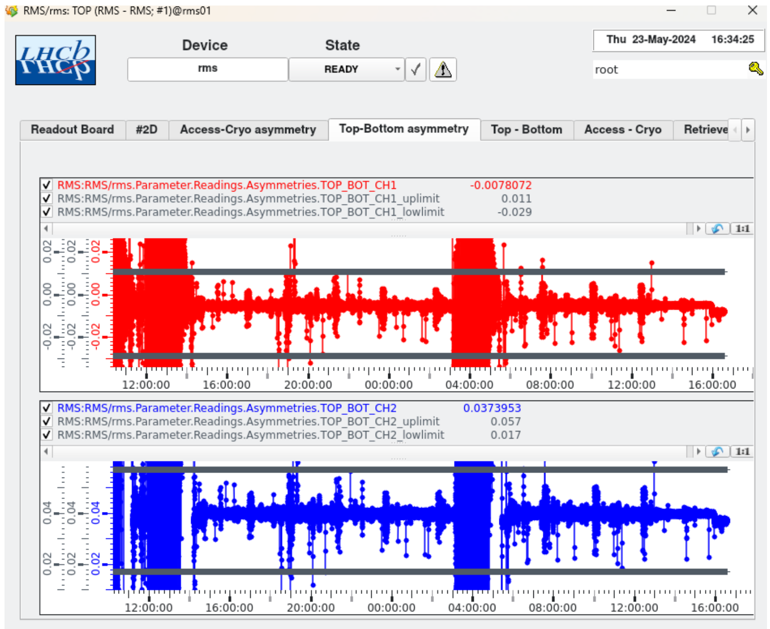


Ch2

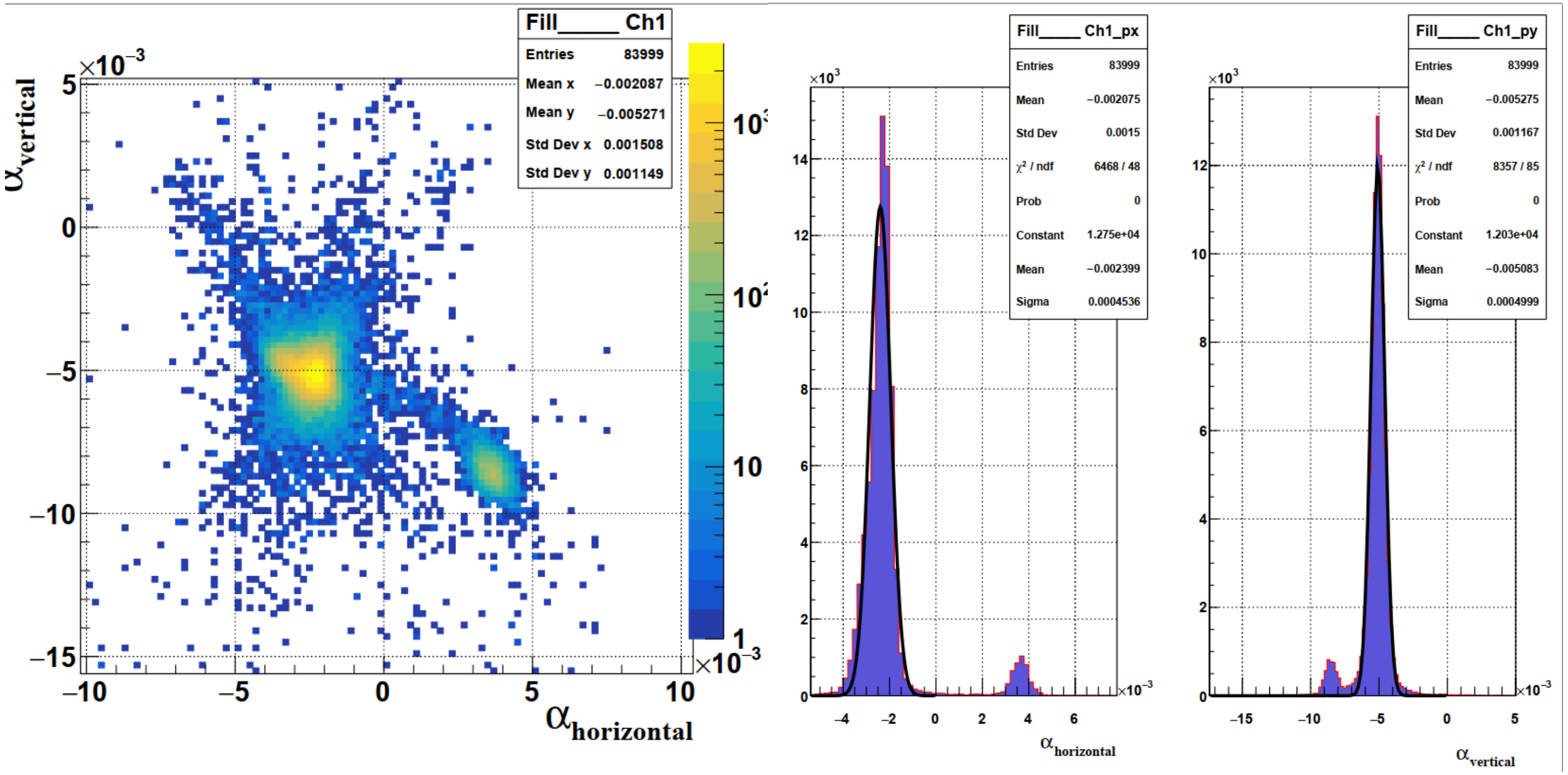








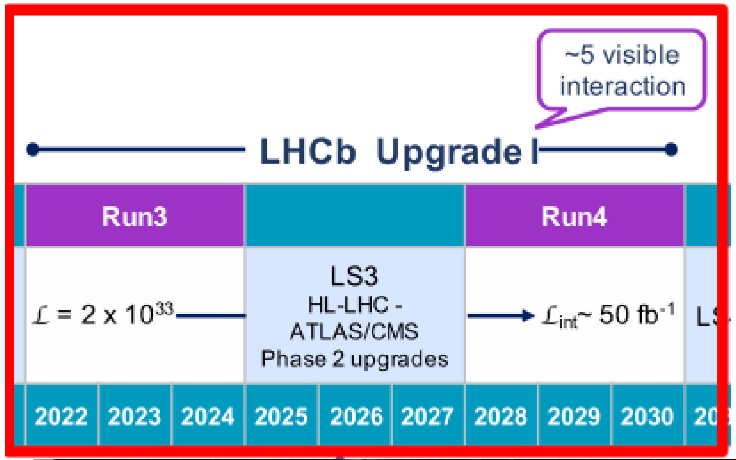
Displaying asymmetries. WinCC software package

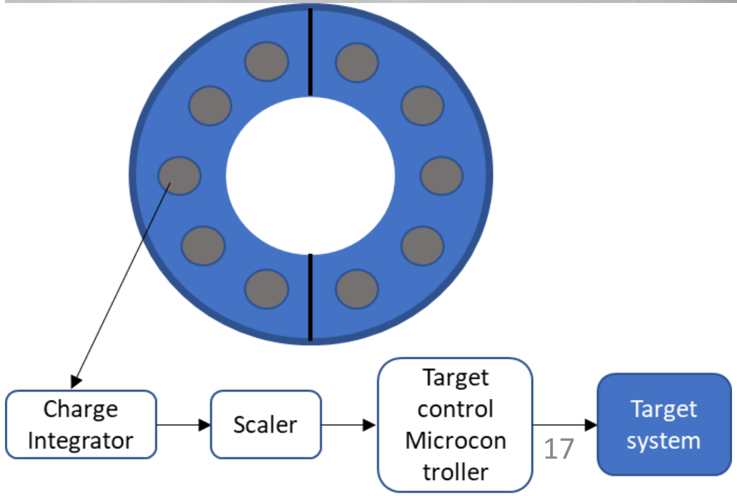


Standard deviation for the horizontal component of the asymmetries ~ 4.5 * 10^{-4} units, for the vertical component of the asymmetries ~ 5 * 10^{-4} units

RMS-R3. Prospects.

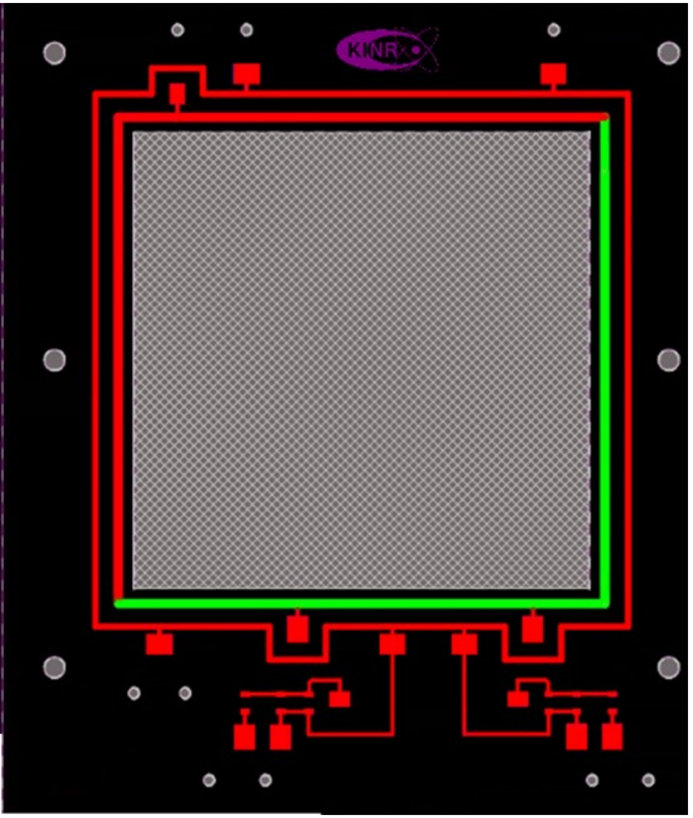
- RUN4 will start in 2028, Run5 in 2033 -> New luminance and background system RMS-R4 and RMS-R5
- Development of a mobile system for monitoring and displaying in real time the radiation situation in the environment and for radiation therapy, based on Compact RMS with the use of additional silicon sensors, pressure, temperature, and humidity sensors.
- Development of a system for controlling luminance and background in the CBM experiment (GSI, FAIR) - MS-CBM-R1.

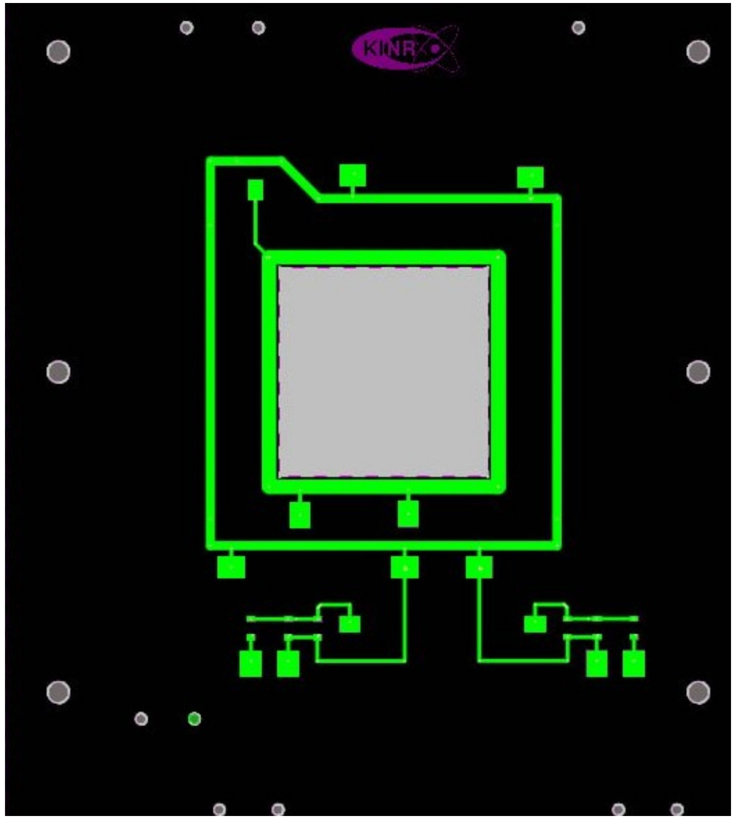




Rms-R5 design

- New RMS-R5 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
- Monte Carlo simulation for Run 5 -> new location of sensors relative to the beam axis
- Soon: 2D asymmetries for MONET
- New tool for data managers and shift leaders in Control Room





Summary

- RMS-R3, as a system for monitoring the luminosity and background of the LHCb experiment, implemented using metal foil detector technology, is successfully operating in the third series of physical measurements at CERN.
- The RMS-R3 provides real-time measurements of the LHCb instantaneous luminosity and control of the experiment conditions, including control of the position of the interaction region.
- RMS-R3 is independent in the LHCb control system, and its data on the experimental conditions and their reproducibility are integrated into the LHCb structure and displayed online.
- Using RMS-R3 data it is possible to distinguish different experimental conditions.
- In the future, we plan to develop RMS-R4/RMS-R5 (improved RMS-R3) for LHCb RUN4, RUN5, develop MS-CBM-R1, and develop compact radiation monitoring systems for applied purposes (Compact RMS).

Acknowledgments

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- Частина роботи виконана в рамках діяльності в Міжнародній асоційованій лабораторії LIA IDEATE з частковою фінансовою підтримкою в рамках проєкту УНТЦ P9903 та цільової програми наукових досліджень НАН України 1230 “Фундаментальні дослідження з фізики високих енергій та ядерної фізики (міжнародна співпраця)”

ДЯКУЮ ЗА УВАГУ