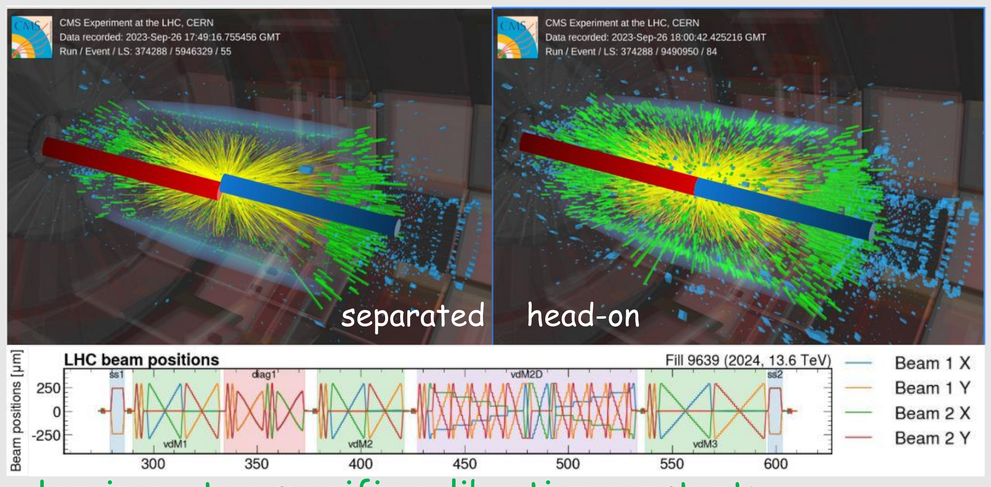
Novelties of measuring the XY factorization bias for precision luminosity determination

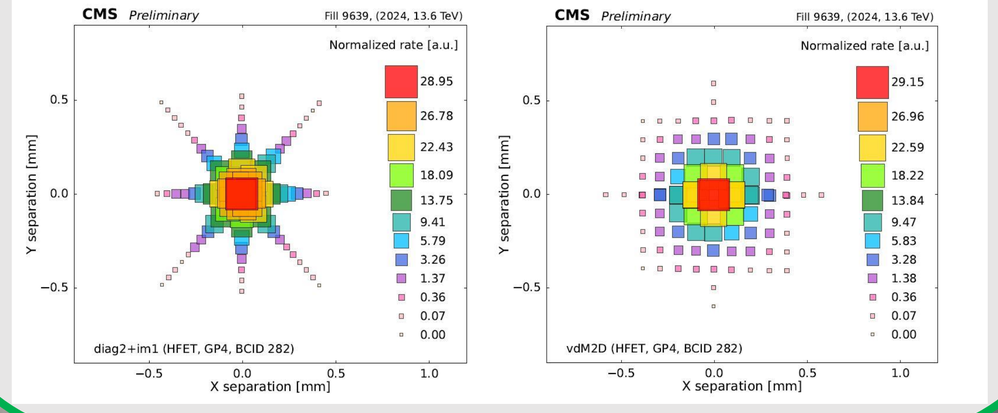
Anna Fehérkuti
Eötvös Loránd University, HUN-REN Wigner RCP

1) Precision luminosity at CMS: the vdM scan

- High-precision physics results: dominant contribution to their uncertainty from luminosity → accuracy matters
- Scanning the (proton density within) bunches by separating them in the transverse directions:

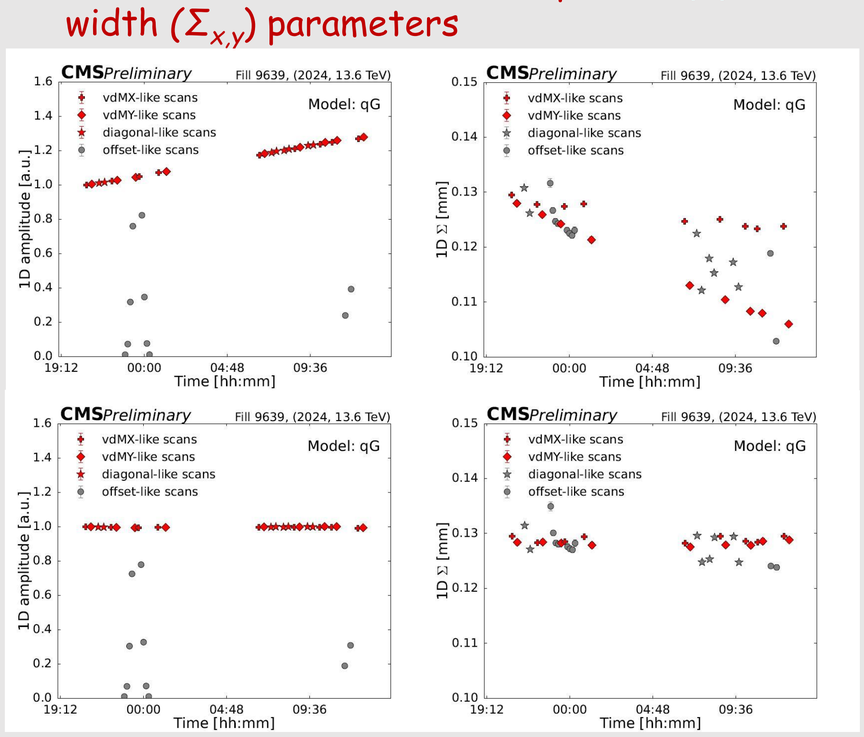


- Luminometer-specific calibration constant:
  $\sigma_{vis} = \int\int(\rho_1 \cdot \rho_2)(x,y)\,dx\,dy \approx 2 \cdot \max(\rho_1 \cdot \rho_2) \cdot \Sigma_x \Sigma_y = 2 \cdot R \cdot \Sigma_x \Sigma_y$
- Check this approximation, correct for bias
  → new, fine-grained scans:



2) Time evolution of the beams

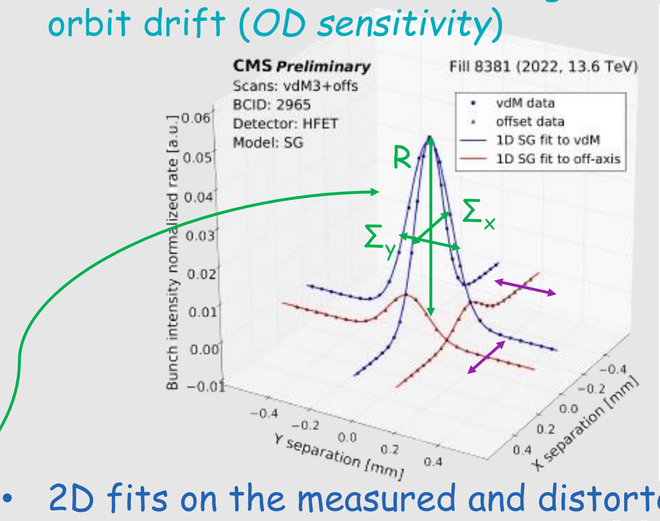
- 1D fits with (generalized Gaussian-type) vdM fit model
- Time evolution tracked on amplitude (R) and width ($\Sigma_{x,y}$) parameters

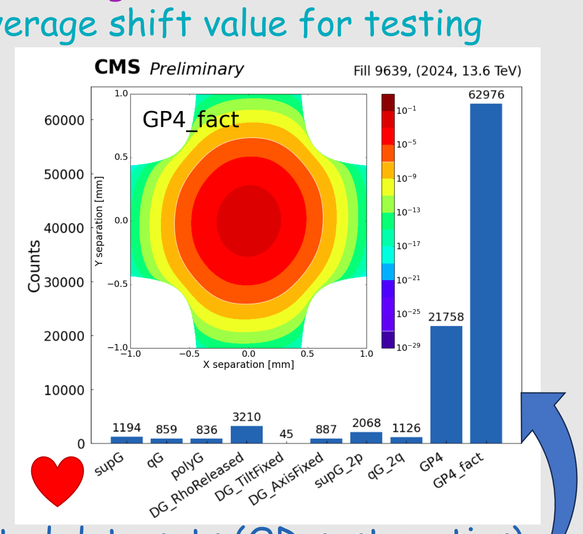


- Correction applied per bunch crossing (*BCID*) to all scans → input data for later steps

3) Handling the data in 2D: rate matching of paired scans, 2D fits, simulation of vdM scans on toy 2D shapes

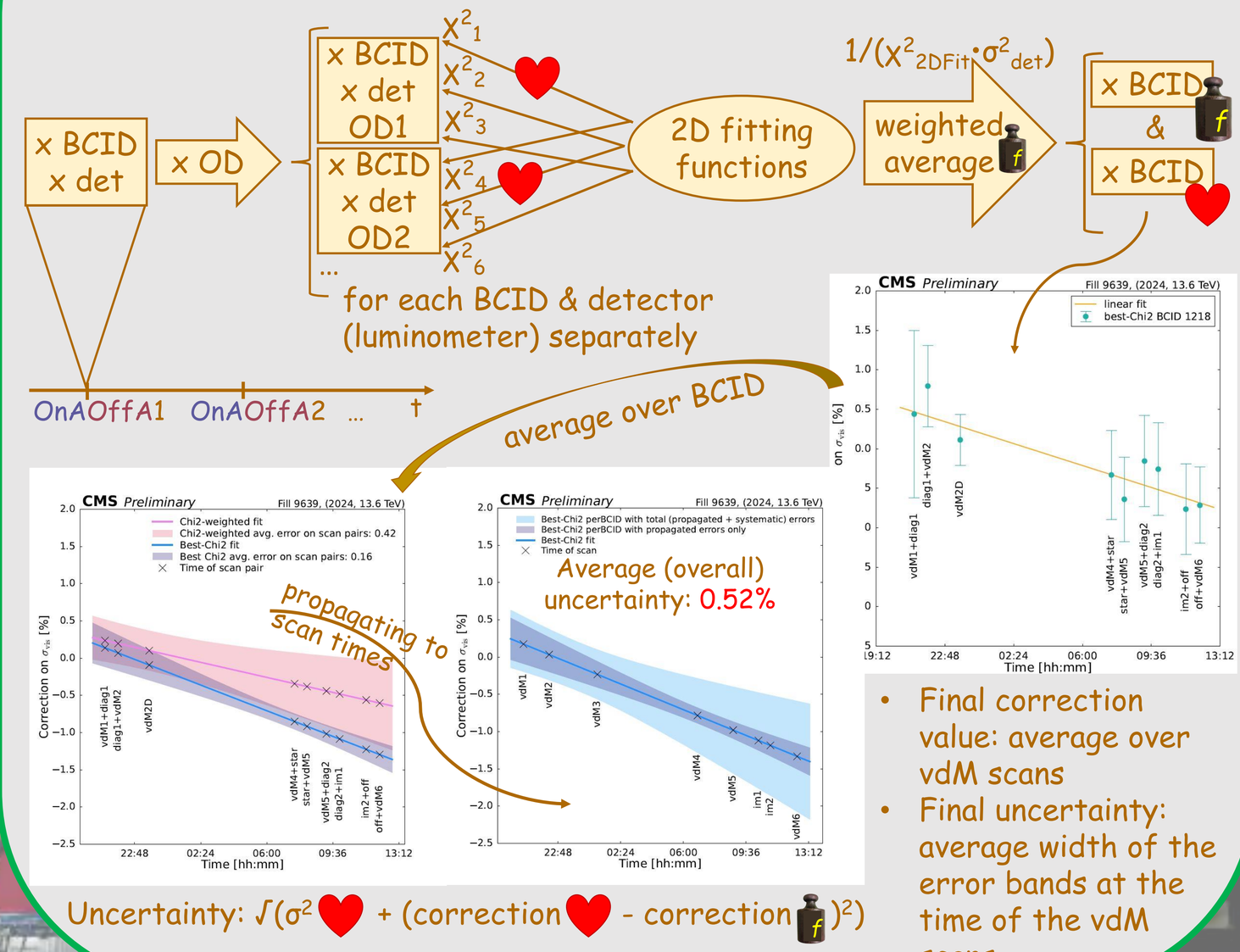
- Pairing on-axis with off-axis scans (→ *OnAOffA scan pairs*)
- Rate matching at intersections (by shifting off-axis scans) to ensure smooth surface for 2D fit → get average shift value for testing orbit drift (*OD sensitivity*)





- 2D fits on the measured and distorted data sets (OD systematics)
  → choose the best fitting model ❤ for each case
  - New fitting models to describe „square-like" shapes
- Vary 2D fit parameters according to their covariance matrix
  → get randomized 2D shapes
- Perform „hypothetical" scans on these toy data
- Compare σ_{vis} from the simulated vdM (product) with the exact one
  → get the factorization correction

4) Calculating per-BCID results for vdM-like scans



Uncertainty: $\sqrt{(\sigma^2}$ ❤ + (correction ❤ - correction f)^2)

- Final correction value: average over vdM scans
- Final uncertainty: average width of the error bands at the time of the vdM scans

5) References and Acknowledgement

[1] *The CMS Collaboration*, Precision luminosity measurement in proton-proton collisions at $\sqrt{s}$=13 TeV in 2015 and 2016 at CMS, *Eur. Phys. J. C*, (2021), **81**, 800
[2] *The CMS Collaboration*, Measurement of the integrated luminosity with the CMS proton-proton dataset at 13.6 TeV recorded in 2024, (2025), CMS DP-2025/
[3] *The CMS Collaboration*, Luminosity measurement in proton-proton collisions at 13.6 TeV in 2022 at CMS, (2022), LUM-22-001
[4] *A. Fehérkuti, P. Major, G. Pásztor*, XY factorization bias in luminosity measurements, *International Journal of Modern Physics A*, (2025), **40**, 09, 2444005

This work was partially supported by the National Research, Development and Innovation Office – NKFIH, K 143460 and K 146914, 2025-1.1.5-NEMZ_KI-2025-00004 and TKP2021-NKTA-64 grants.

25th Zimányi School Winter Workshop on Heavy Ion Physics
1-5 December, 2025.
Budapest