Luminosity with HF

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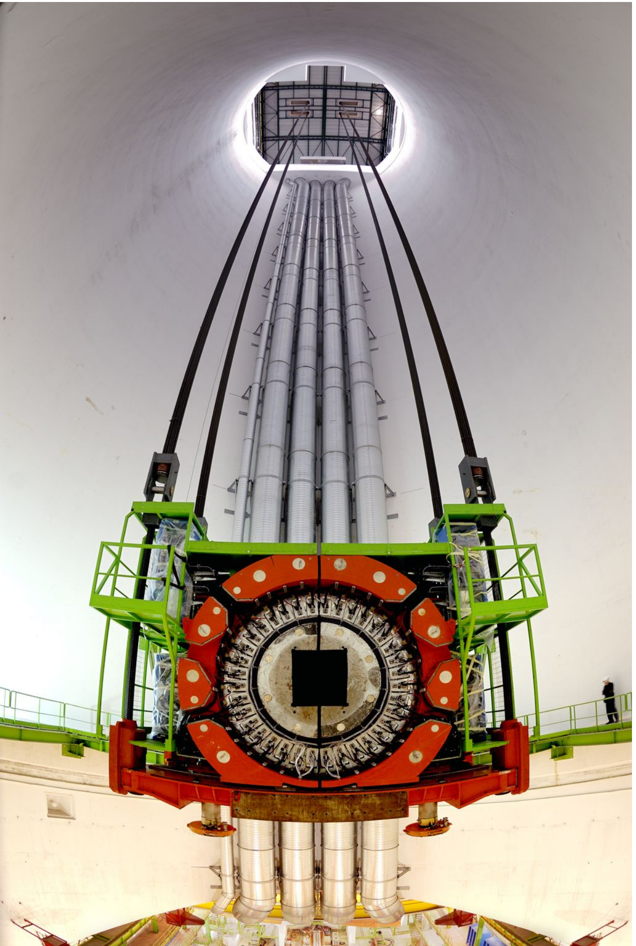
a.k.a.

✨ project == life ✨

BND School 2024 - Blankenberge

HFOC: Hadronic Forward Calorimeter Occupancy



The Hadronic Calorimeter is positioned in the forward direction, at ~11.2m, covering $3 < \eta < 5$.

The HFOC method measures the fraction of calorimeter channels with energy measurements above a certain threshold, to estimate the collision rate. This information is then used to determine the instantaneous luminosity by correlating the number of measured clusters with the number of proton-proton collisions.

Luminosity ingredients

$$\mathcal{L} = \frac{f n_b N_1 N_2}{2\pi \Sigma_x \Sigma_y}$$

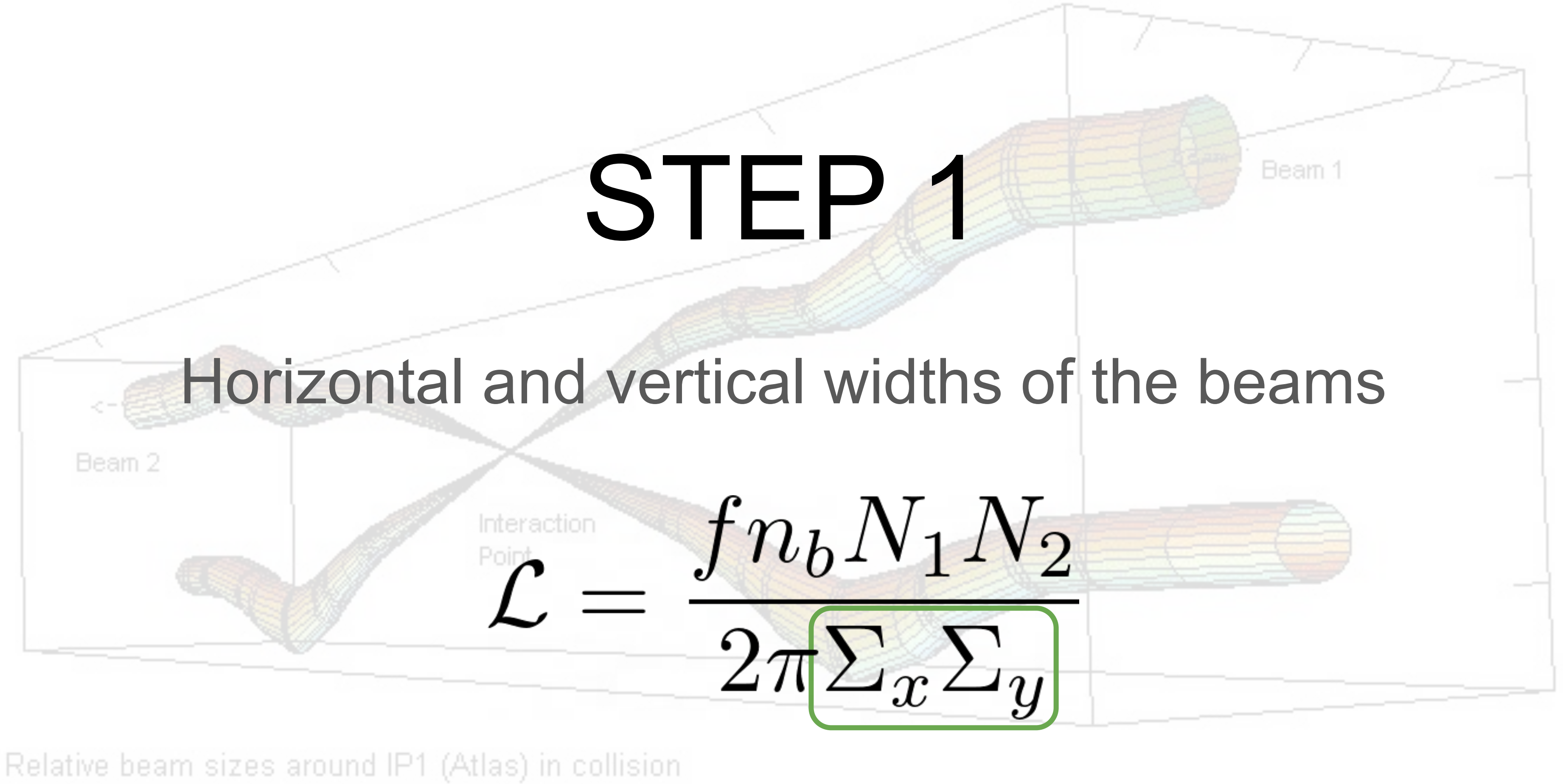
where

- $f = 11\,245\,\mathrm{Hz}$ is the LHC revolution frequency;
- n_b is the number of bunch crossings in the LHC that are filled with particles in both beams;
- N_1 and N_2 are the numbers of particles per bunch in beam 1 and beam 2,
- Σ_x and Σ_y are the widths obtained from the Gaussian fits to the x and y scan.

STEP 1

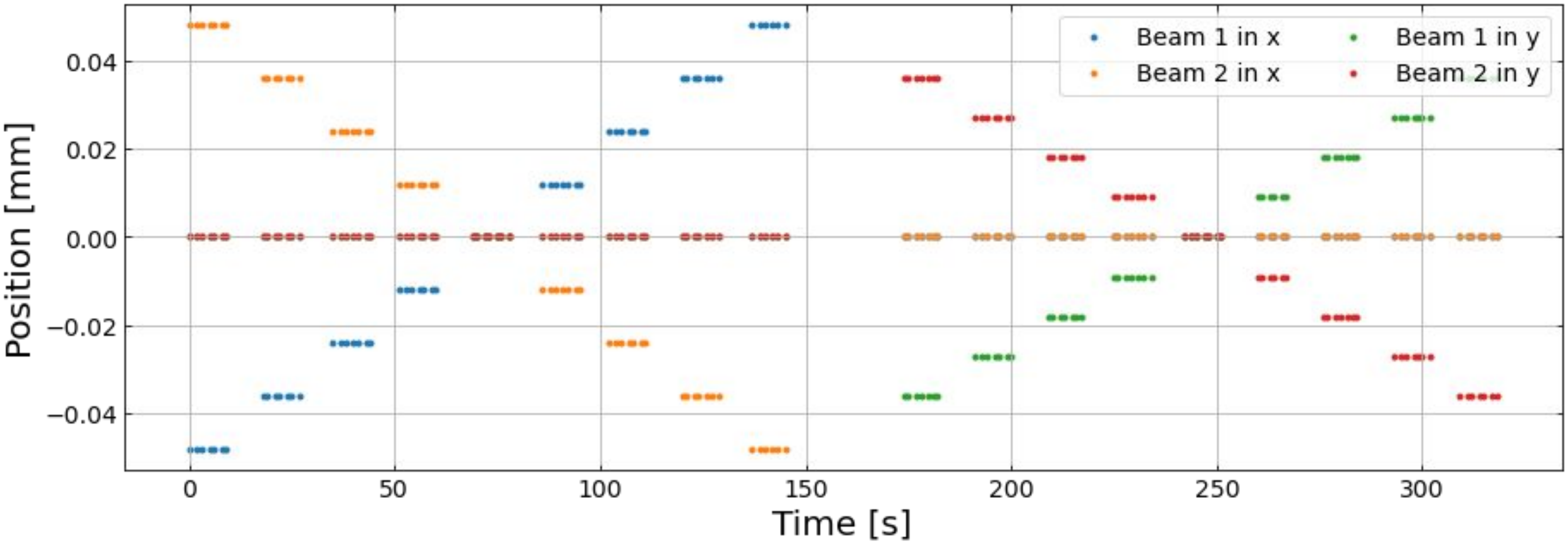
Horizontal and vertical widths of the beams

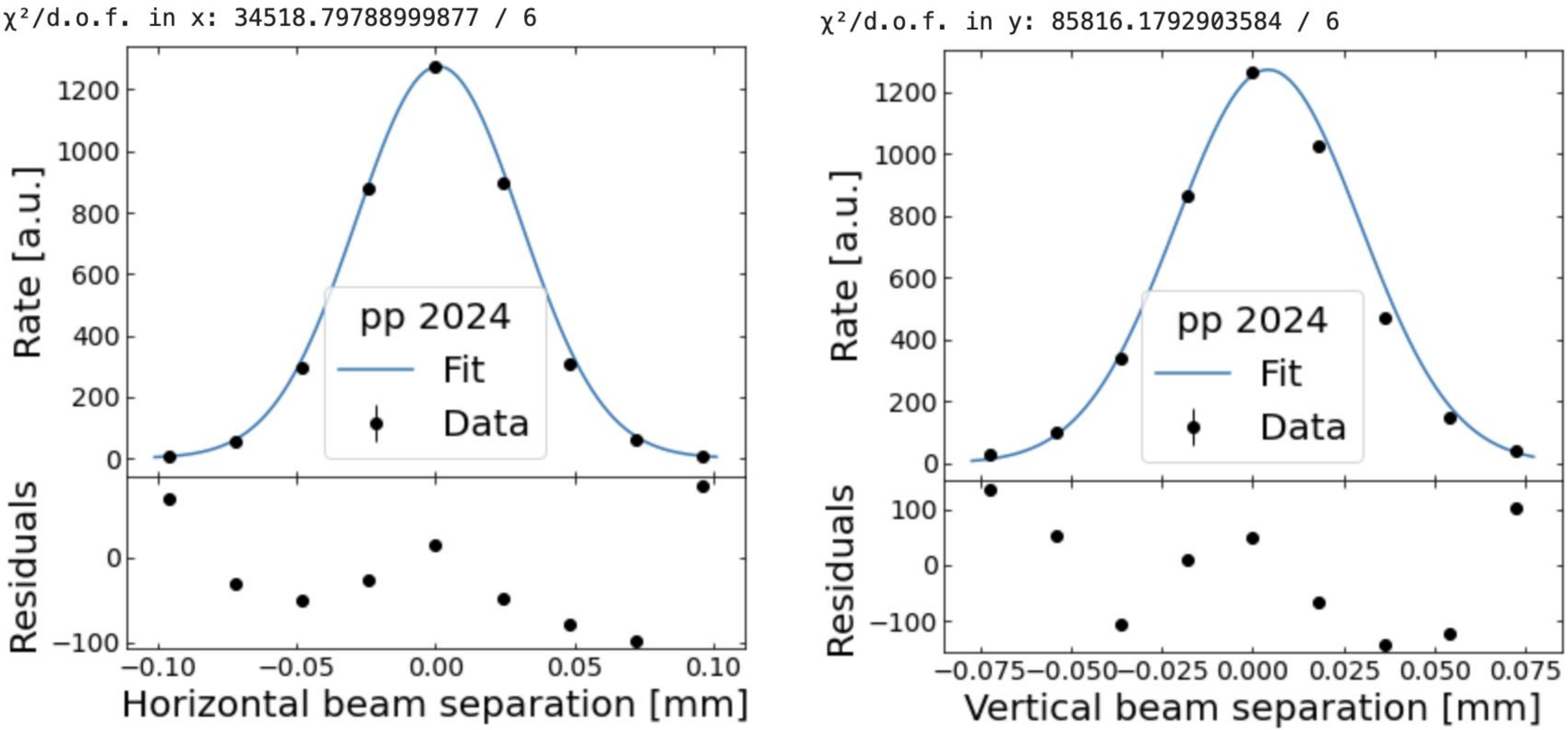
$$\mathcal{L} = \frac{f n_b N_1 N_2}{2\pi \Sigma_x \Sigma_y}$$



Van der Meer scan

The beam’s positions are first varied along the x-axis and then along the y-axis to measure how the collision rate changes, thereby determine the overlap of the beams for precise luminosity calibration.





The fitted width of the Gaussian gives us $\mathbf{\Sigma_x}$ and $\mathbf{\Sigma_y}$.

STEP 2

Number of bunch crossings

$$\mathcal{L} = \frac{f n_b N_1 N_2}{2\pi \Sigma_x \Sigma_y}$$

Easily calculated by checking out of all the 3564 bunch slots which ones have particles in both beams.

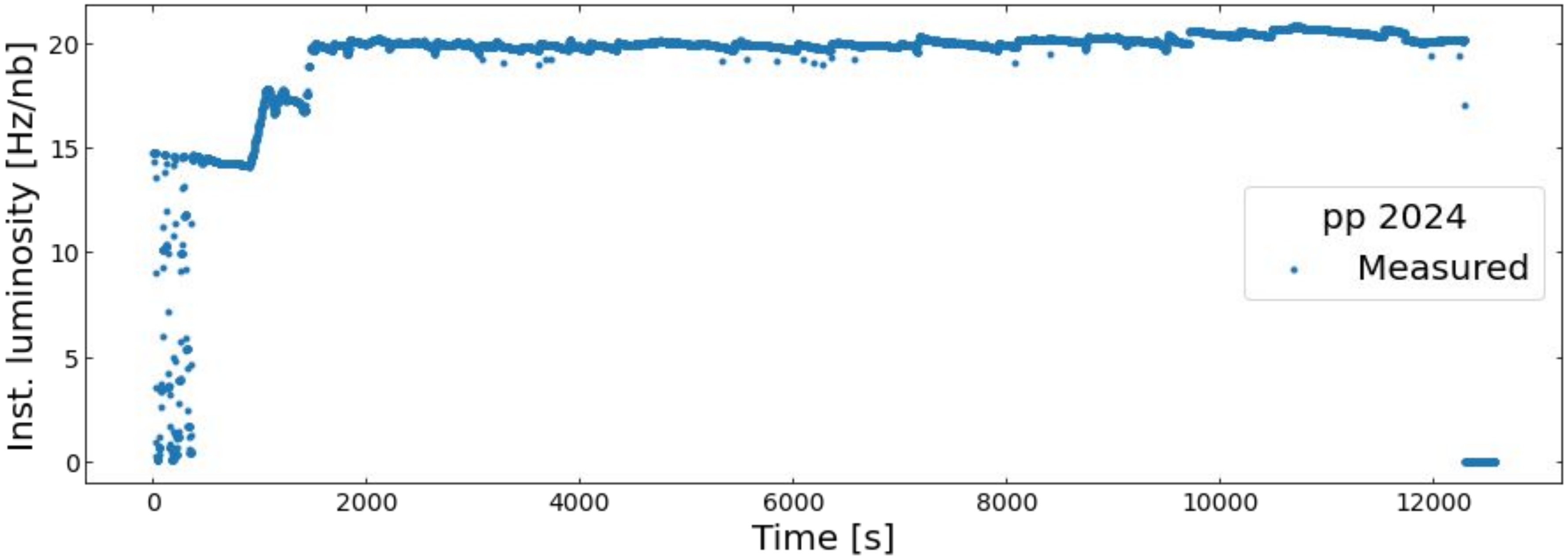
STEP 3

Number of particles per bunch per beam

$$\mathcal{L} = \frac{f n_b N_1 N_2}{2\pi \Sigma_x \Sigma_y}$$

Calculated as the number of particles divided by the number of bunches.

Instantaneous luminosity



Visible cross section

Once we calculated the head-on instantaneous luminosity, we calculate the visible cross section:

number of events per second = luminosity ($pb^{-1}s^{-1}$) x cross section (pb)

$$N_{coll} = \int \mathcal{L}\sigma_{vis}dt \Rightarrow \sigma_{vis} = \frac{N_{coll}}{t_{1meas} \cdot \mathcal{L}}$$

Where:

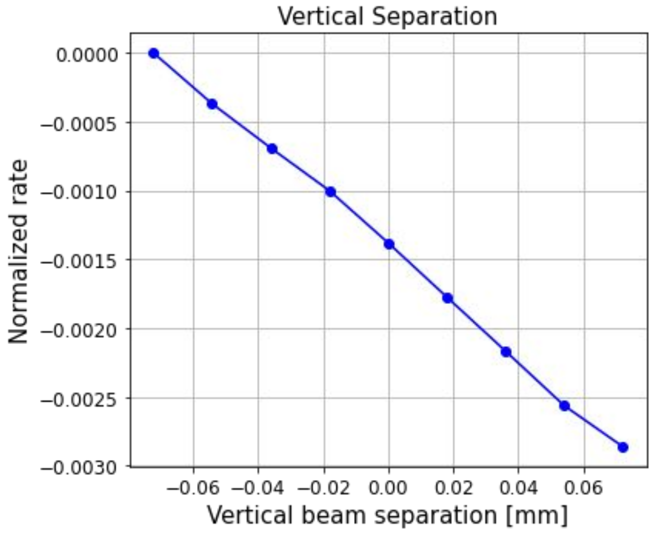
L is the instantaneous luminosity

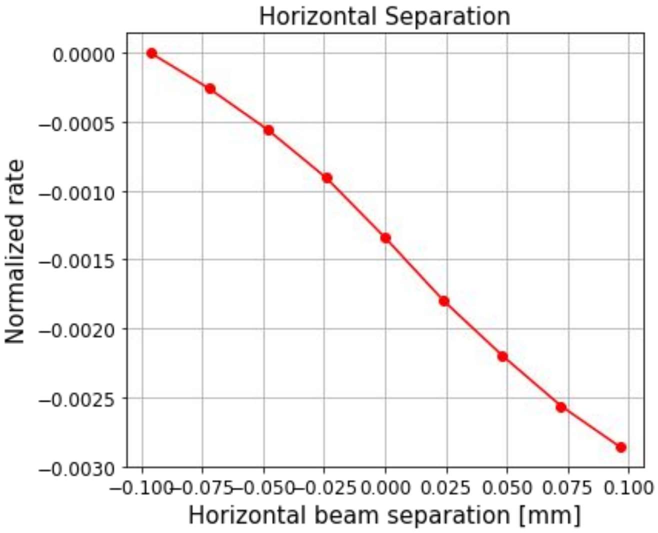
N_{coll} is a measurement of the number of collisions, calculated as the average rates during the VdM

t_{1meas} is the time interval of the stored measurements

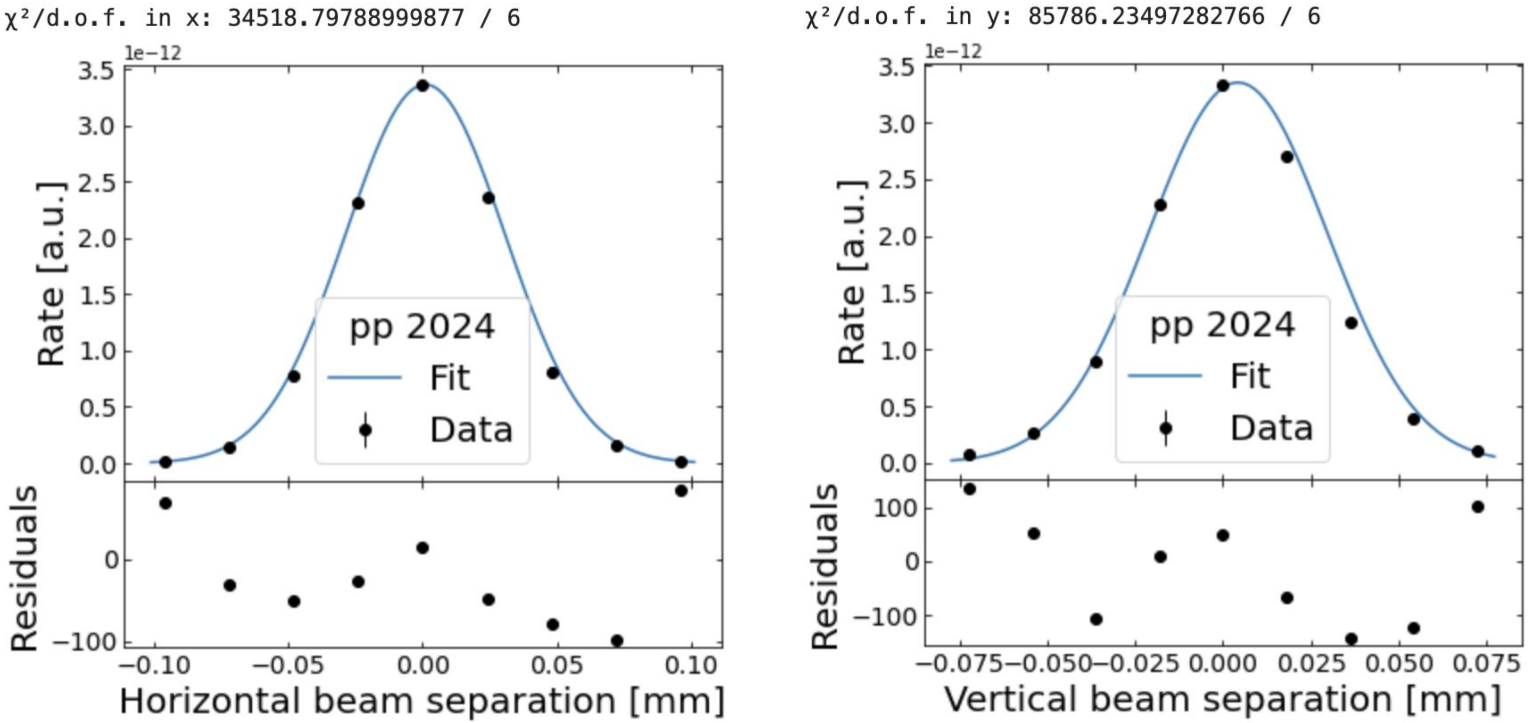
Task 1: including beam currents to the fit

We included beam currents in the fit to correct for changes in the number of protons per beam, which affects the interaction rate during the (m)VdM scan.
By normalizing the rate using the average number of protons in both beams, the fit quality improved by just 1%. This is consistent with expectations, as the normalization factor only varied by 0.3% throughout the scan.



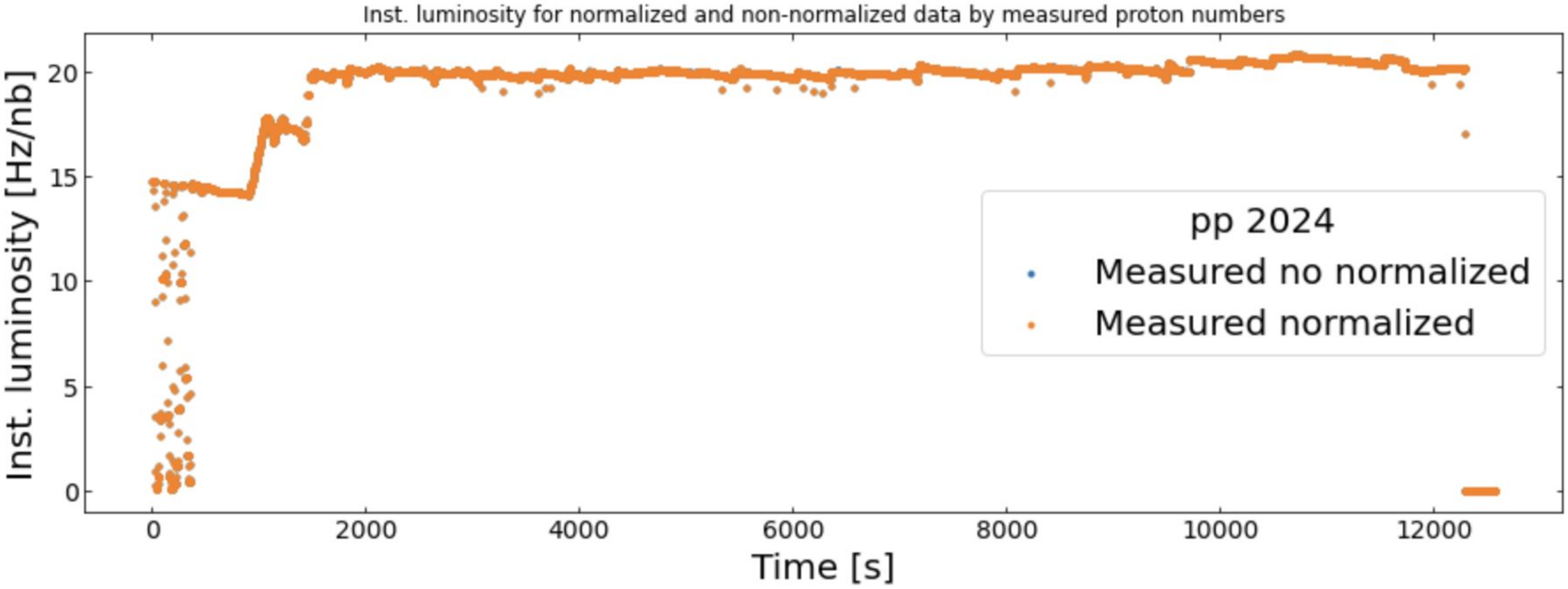


Normalized rates



The fitted width of the Gaussian gives us $\mathbf{\Sigma_x}$ and $\mathbf{\Sigma_y}$.

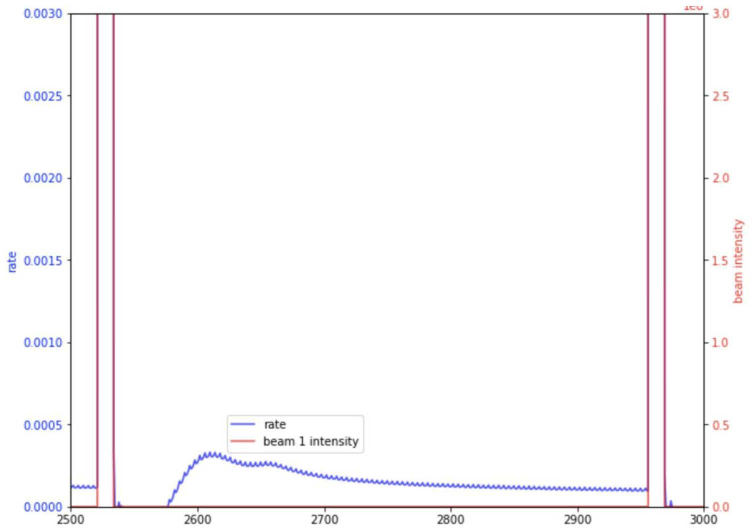
Instantaneous luminosity

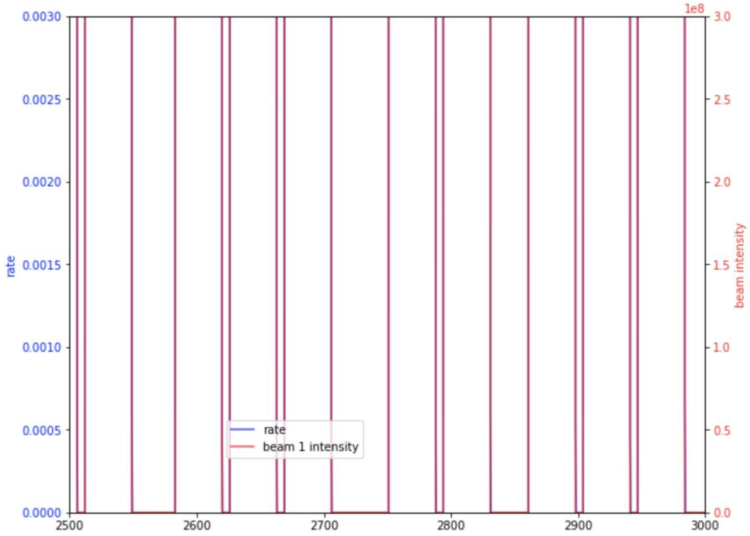


Integrated luminosity normalized: 236.7/pb

Integrated luminosity no normalized: 236.7/pb

Task 2: split in BxID



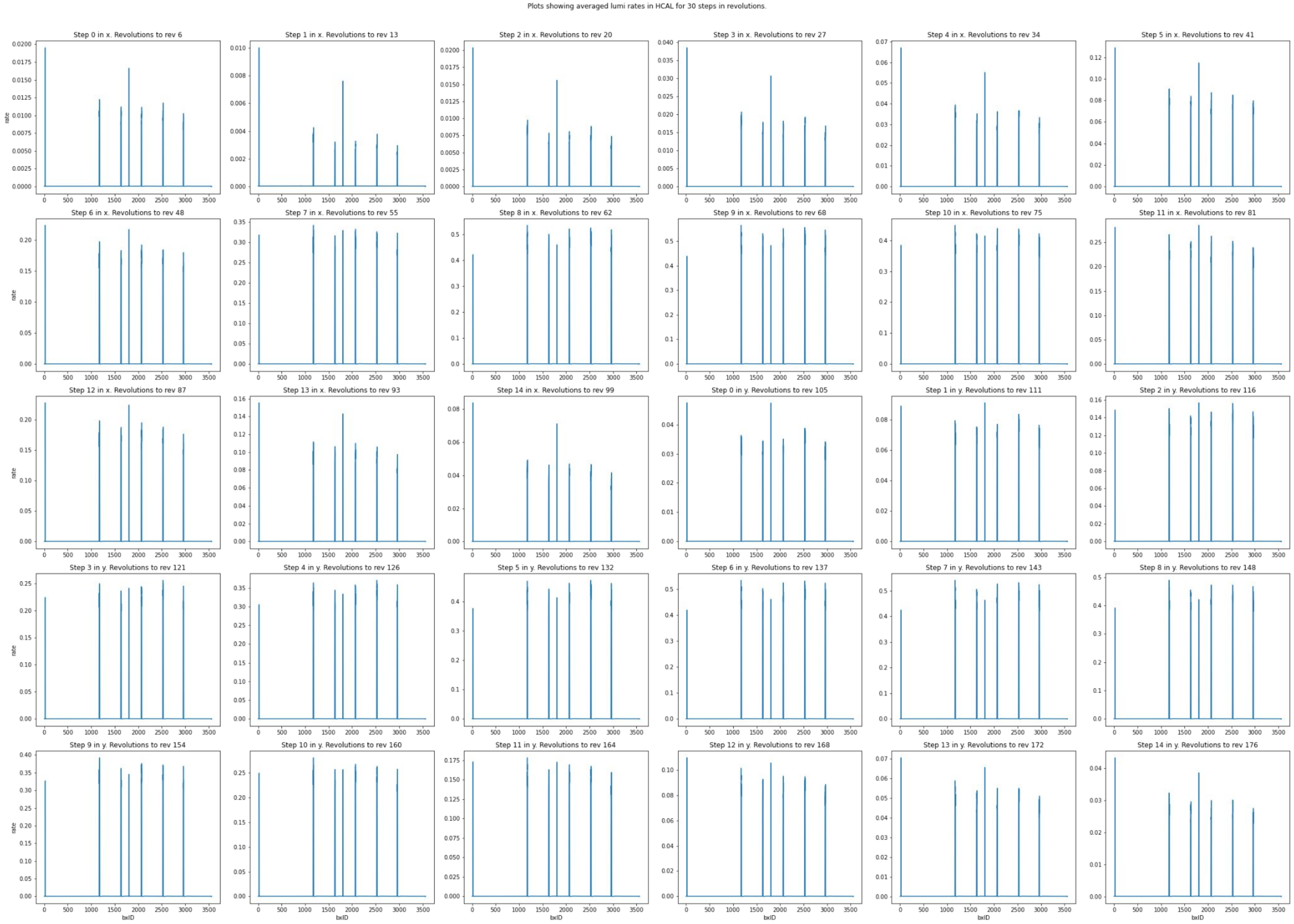


Beam induced effects can give backgrounds:

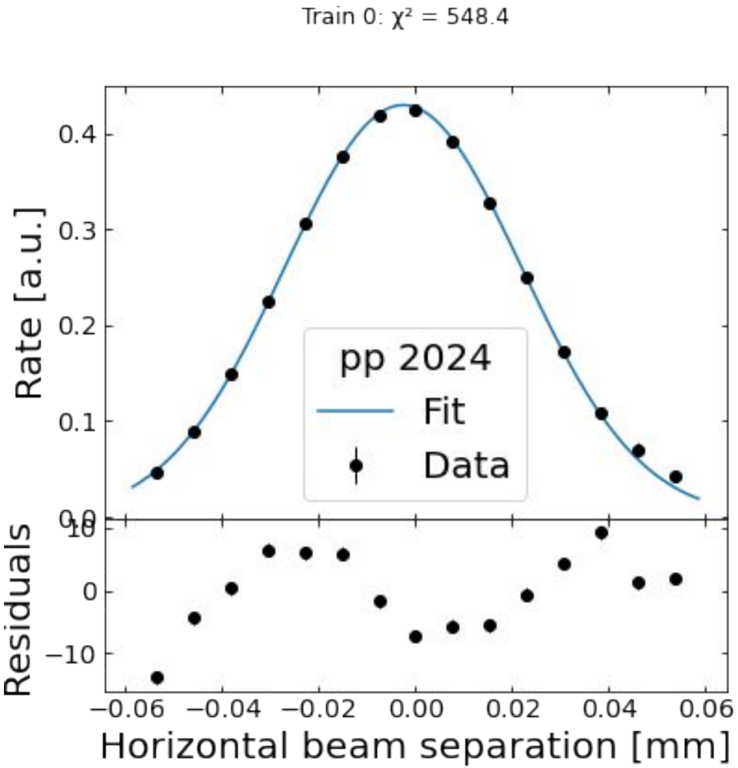
- Afterglow: activation of the detector which decays
- Slow particles (12m ~ 2 BxID)

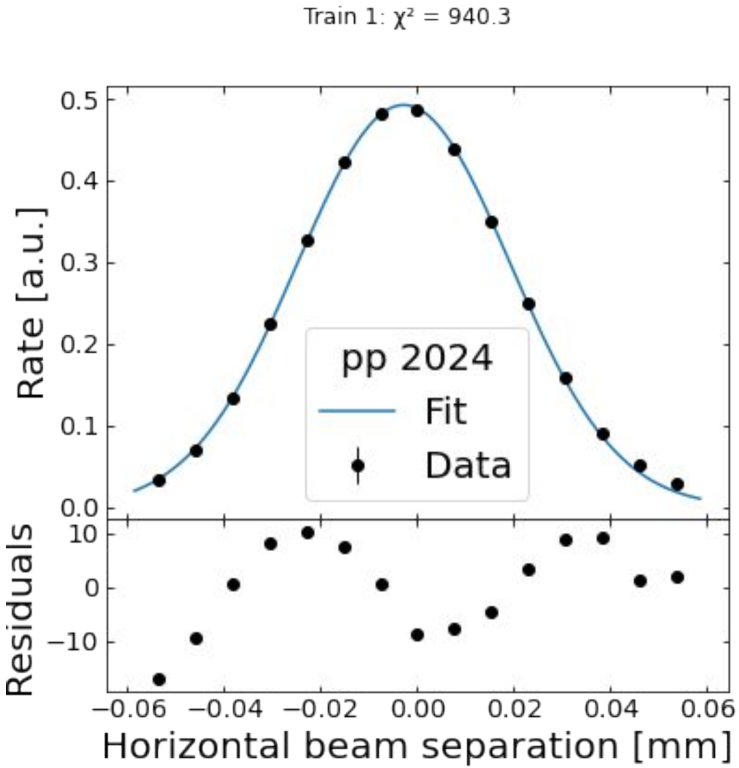
Let's look at older data:

- 7 trains
- 75 bunches
- Split by step

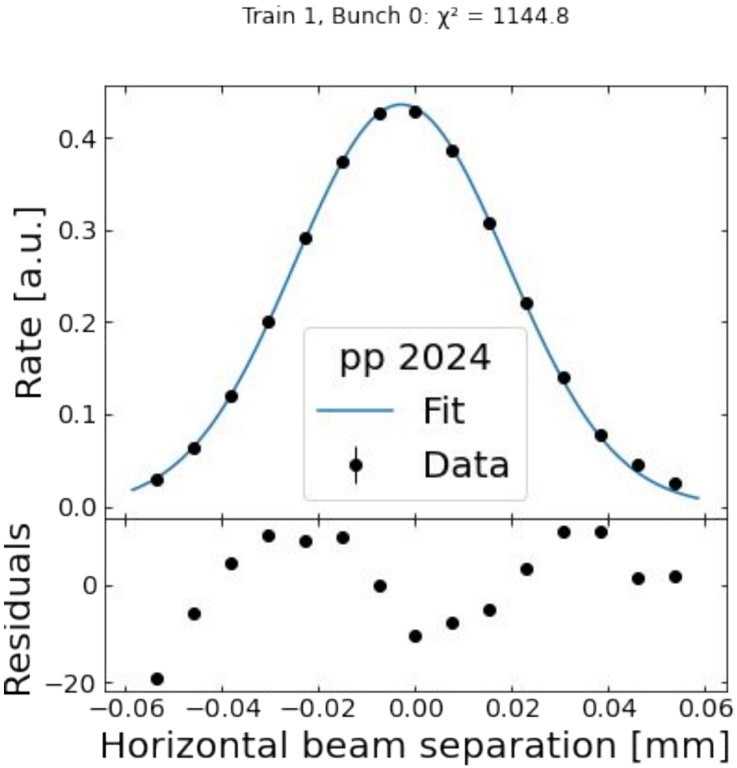


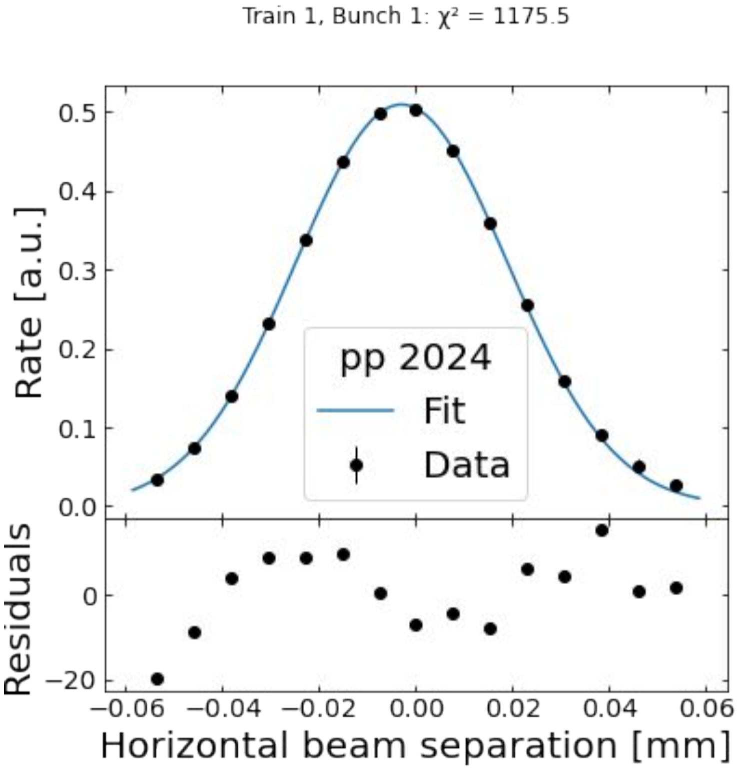
Fitting on train by train basis





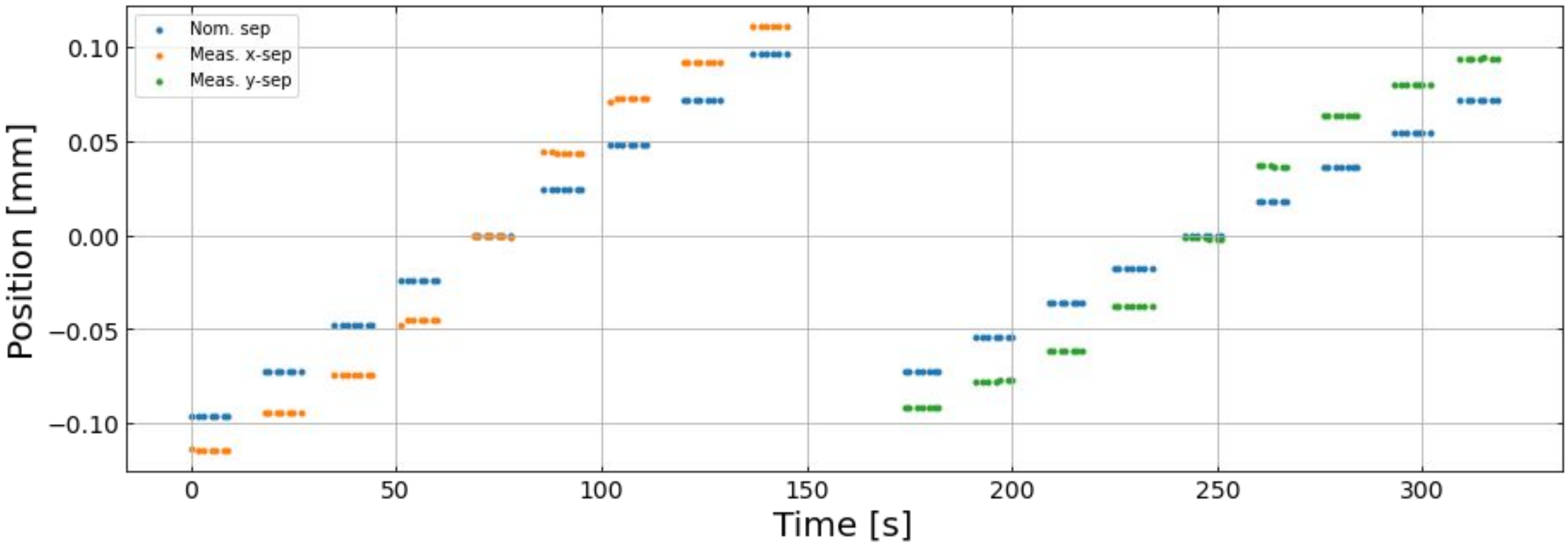
Comparing the first two bunches in train 1



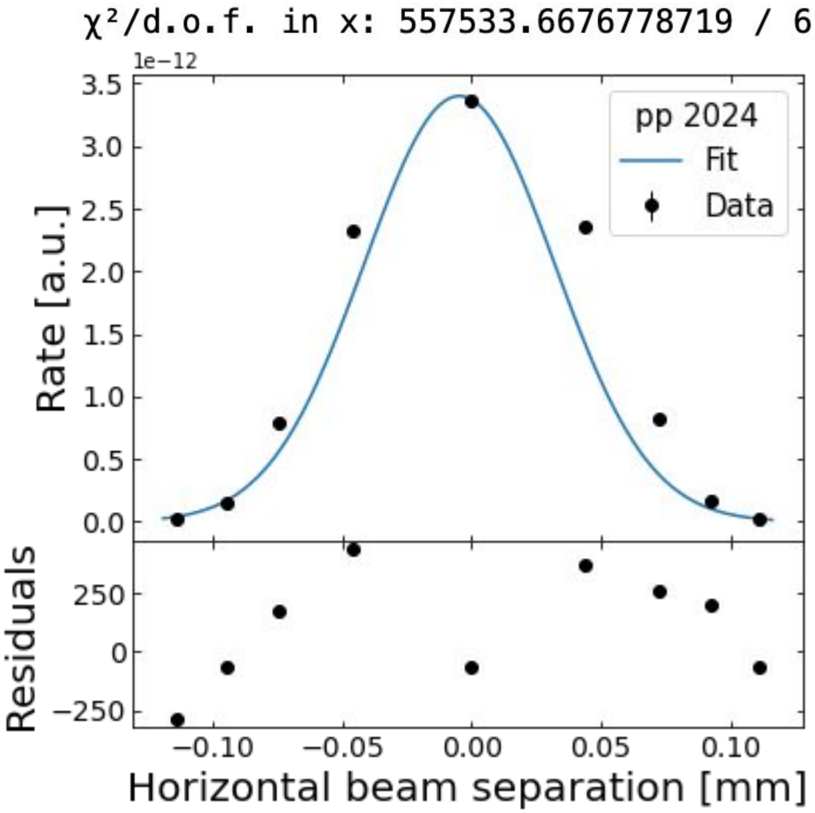


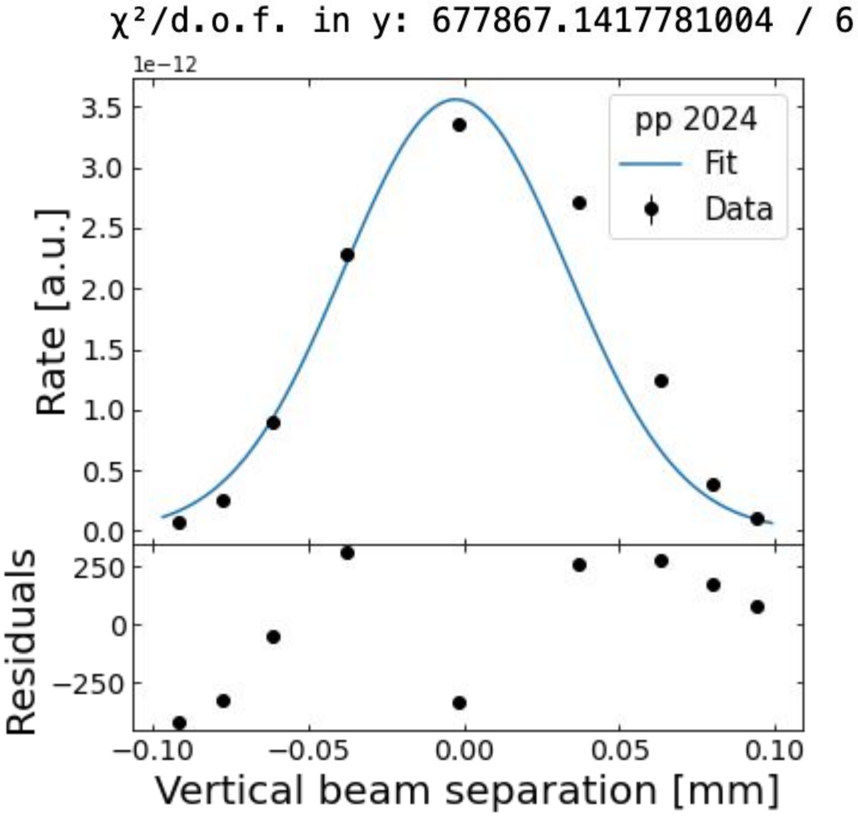
Task 3: using measured beam positions

Beam positions are measured by the DOROS beam position monitors, located on either side of the CMS detector. These monitors independently measure the transverse positions of the beams.



The fit quality is worse. Proper corrections are essential for improved accuracy in luminosity calibration.





Conclusions

An accurate luminosity is key when performing absolute measurements

When using a forward HCal:

- Beam decay shows sub-percent contributions
- Beamglow gives clear contribution → Corrected in recent data
- Clear deviation when using DOROS for the beam separation

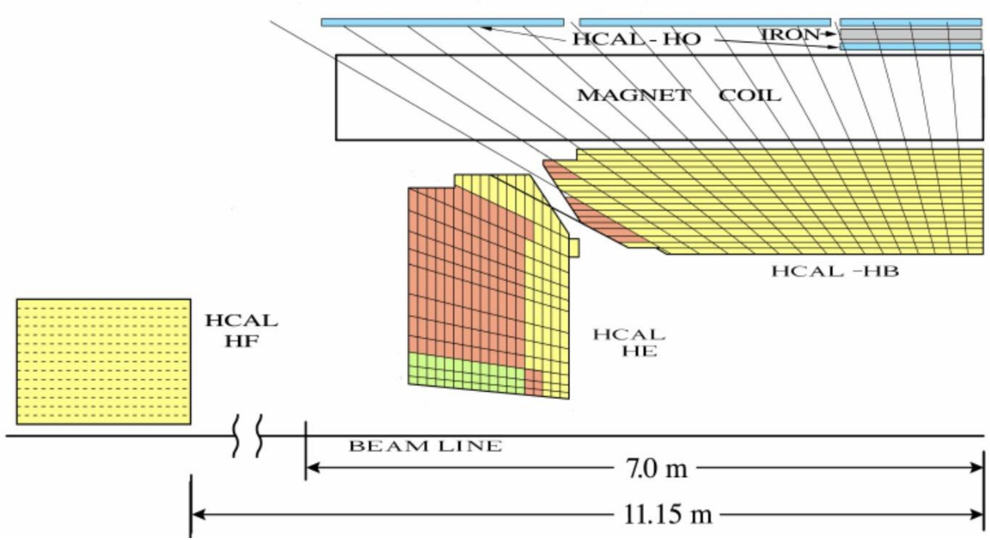
Backup

Hadronic Calorimeter

Positioned in the forward direction at around 11.2m covering $3 < \eta < 5$

Spa-cal based technology:

- Steel + quartz
- Fast signal and radiation hard



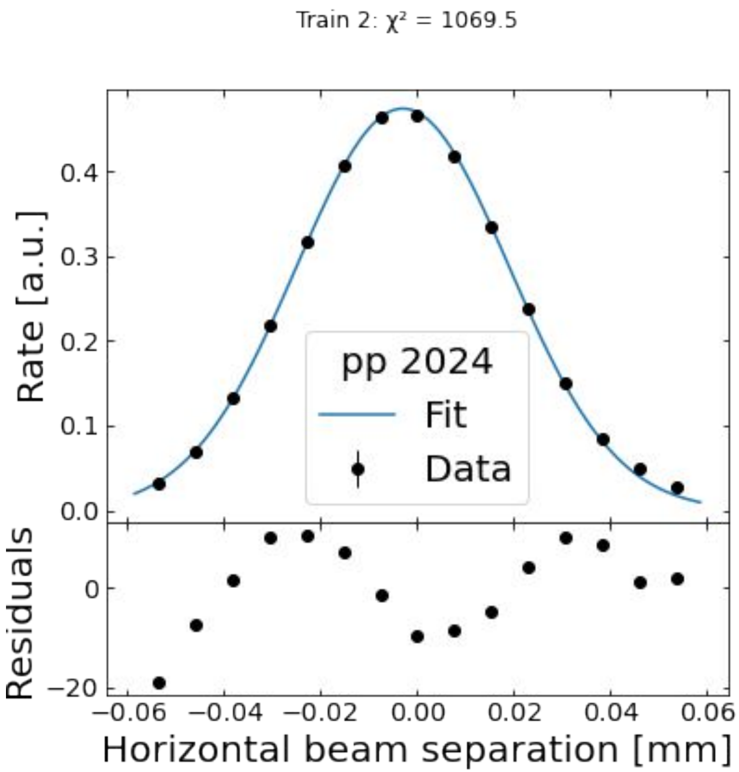
x-axis

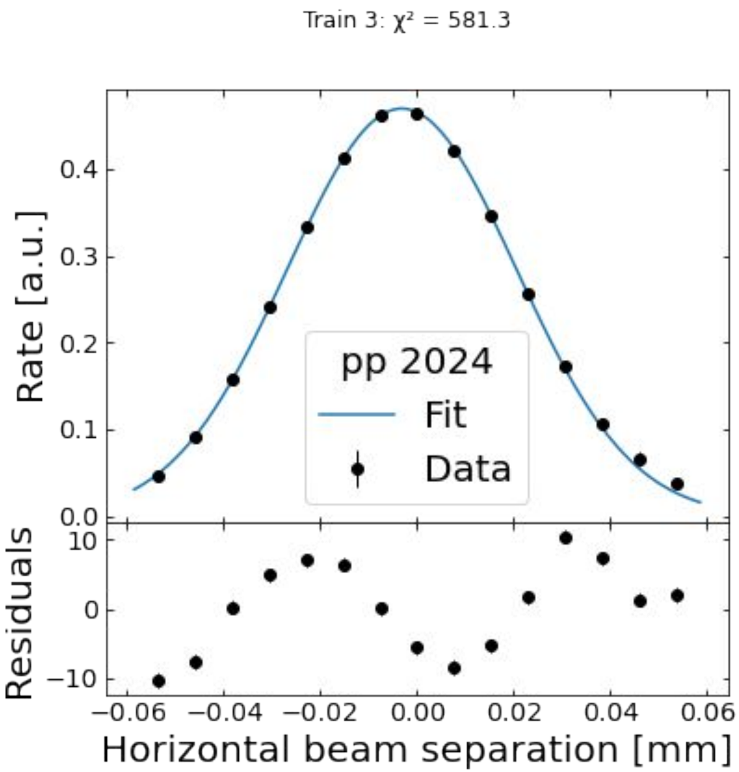
fill	No normalized χ^2/d.o.f. in x	Normalized χ^2/d.o.f. in x	Int. luminosity no normalized	Int. luminosity normalized
10012	34518.79788999877 / 6	34518.79788999877 / 6	236.7/pb	236.7/pb
10014	34276.72864382171 / 6	34276.72864382171 / 6	163.4/pb	163.4/pb
10056	22595.799183462455 / 6	22595.799183462455 / 6	884.9/pb	884.9/pb
9877	91001.67821348441 / 6	91001.67821348441 / 6	0.9/pb	0.9/pb

y-axis

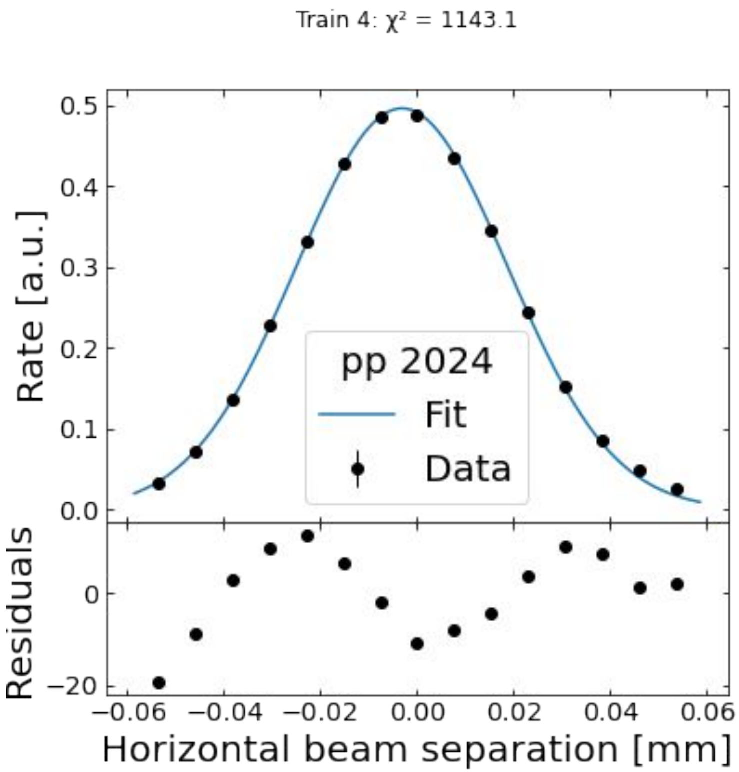
fill	No normalized χ^2/d.o.f. in y	Normalized χ^2/d.o.f. in y	Int. luminosity no normalized	Int. luminosity normalized
10012	85816.1792903584 / 6	85786.23497282766 / 6	236.7/pb	236.7/pb
10014	83824.05897390695 / 6	83814.70291925305 / 6	163.4/pb	163.4/pb
10056	65377.24355112927 / 6	65356.227503645954 / 6	884.9/pb	884.9/pb
9877	109564.26822149387 / 6	109556.44670980106 / 6	0.9/pb	0.9/pb

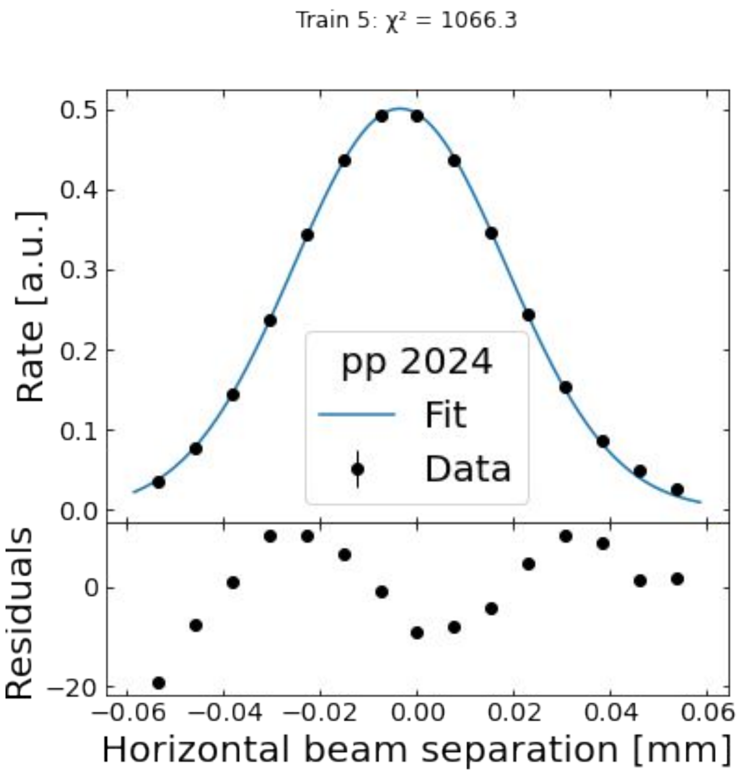
More averaged by train…





More averaged by train…





More averaged by train…

Train 6: χ² = 1049.1