Beam halo monitor – coronagraph study

Jan Pucek, D. Butti, G. Trad, E. Bravin, S. Burger, F. Roncarolo

HL-LHC collaboration week in Genoa, October 2024

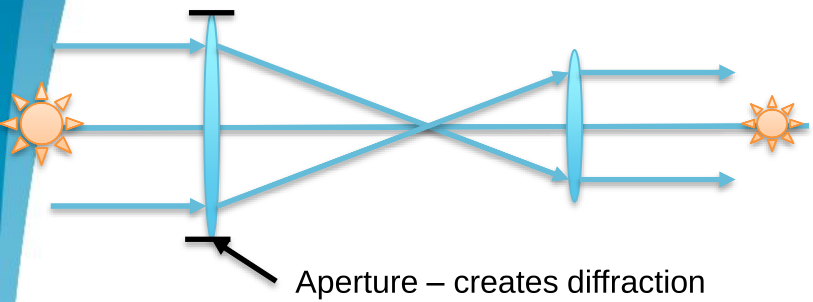
Outline

- Coronagraph – principle
- BSRH status
  - Current layout
  - Demonstration of modes
  - Important parameters
- First MD (May)
  - Results
- Second MD (September)
  - Preliminary results
- Conclusions + Outlook

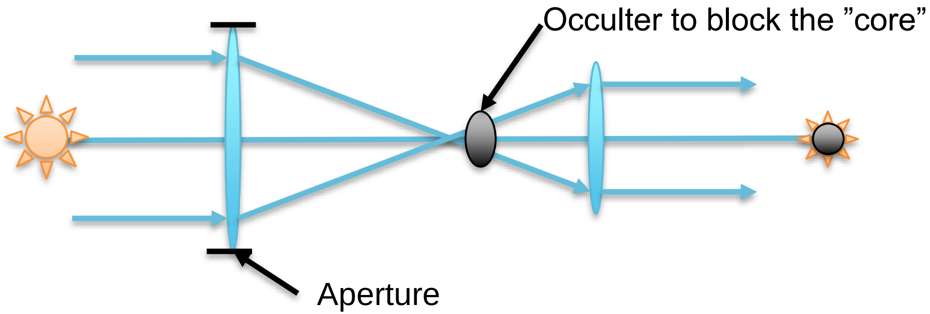
Coronagraph – principle

Coronagraph – principle

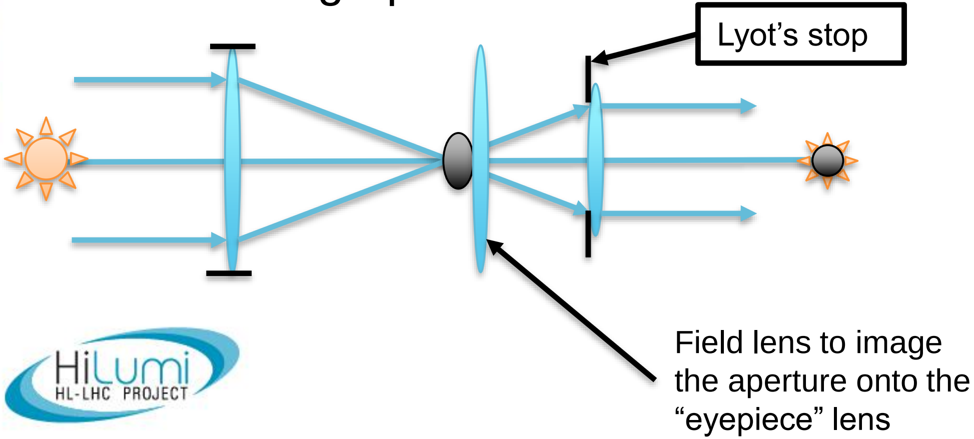
1. Telescope – two lenses



2. Telescope with occulter



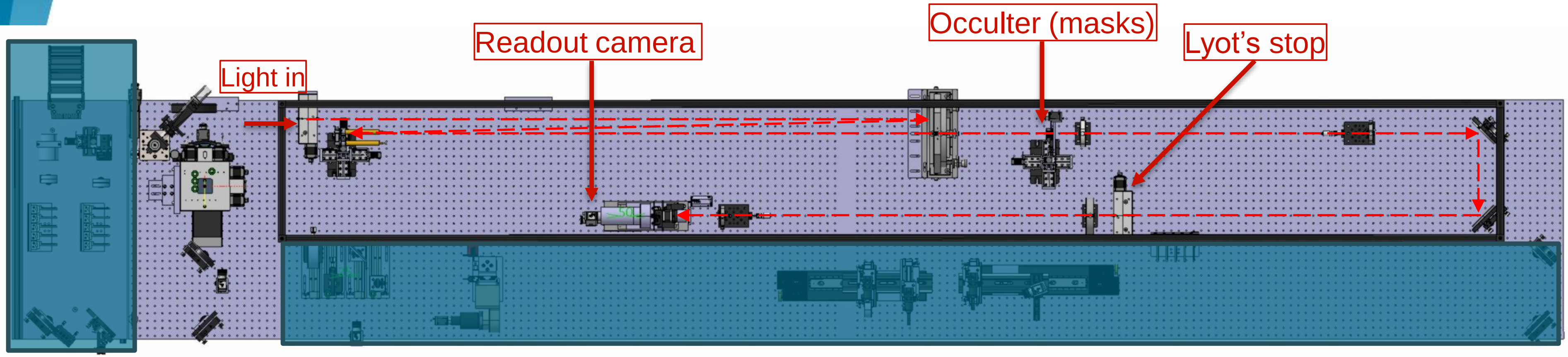
3. Coronagraph



1. Telescope provides an image of an object
2. In case of measuring low intensity tails, the occulter is not sufficient – diffraction created at the aperture will disturb the image
3. Coronagraph is an “enhanced” telescope that uses “field” lens to image the aperture on the Lyot’s stop – blocking the diffraction of the aperture

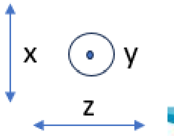
BSRH status

Current layout – Beam 2



Possible configurations:

1. Regular telescope – imaging the SR
2. Telescope with occulter – masking the core enables longer exposure time/gain
3. Coronagraph – diffraction from the beam mirror can be mitigated

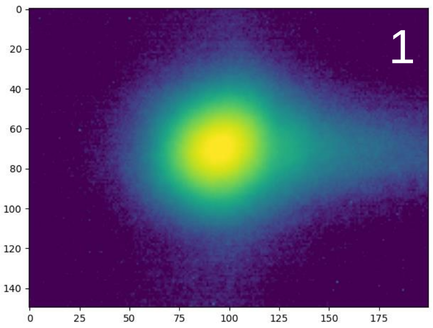


HL-LHC PROJECT

Demonstration of modes

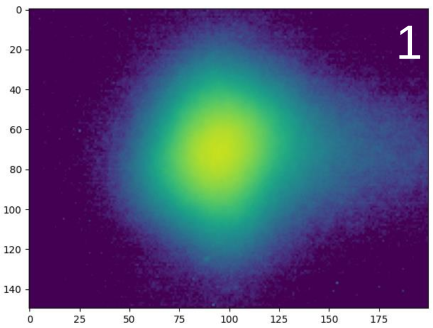
Possible configurations:

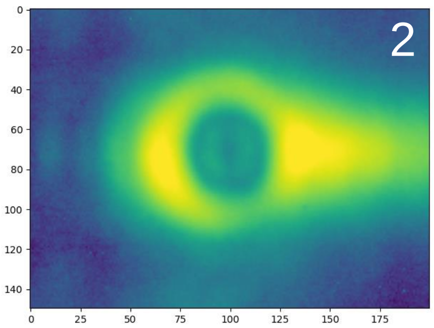
1. Regular telescope – imaging the SR
2. Telescope with occulter – masking the core enables longer exposure time/gain
3. Coronagraph – diffraction from the beam mirror can be mitigated

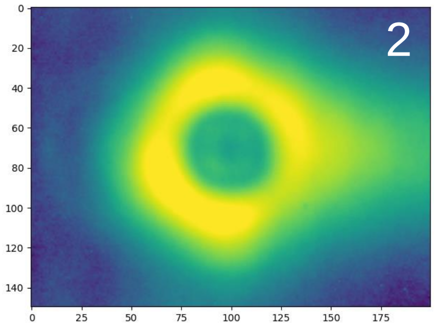


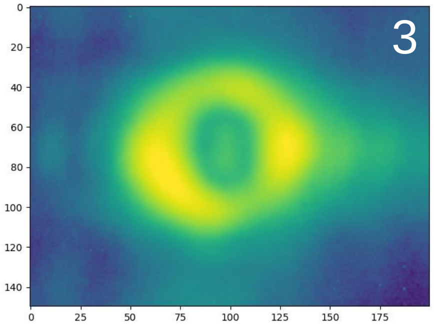
Low ε

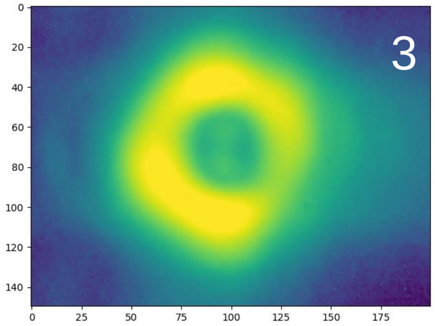
High ε







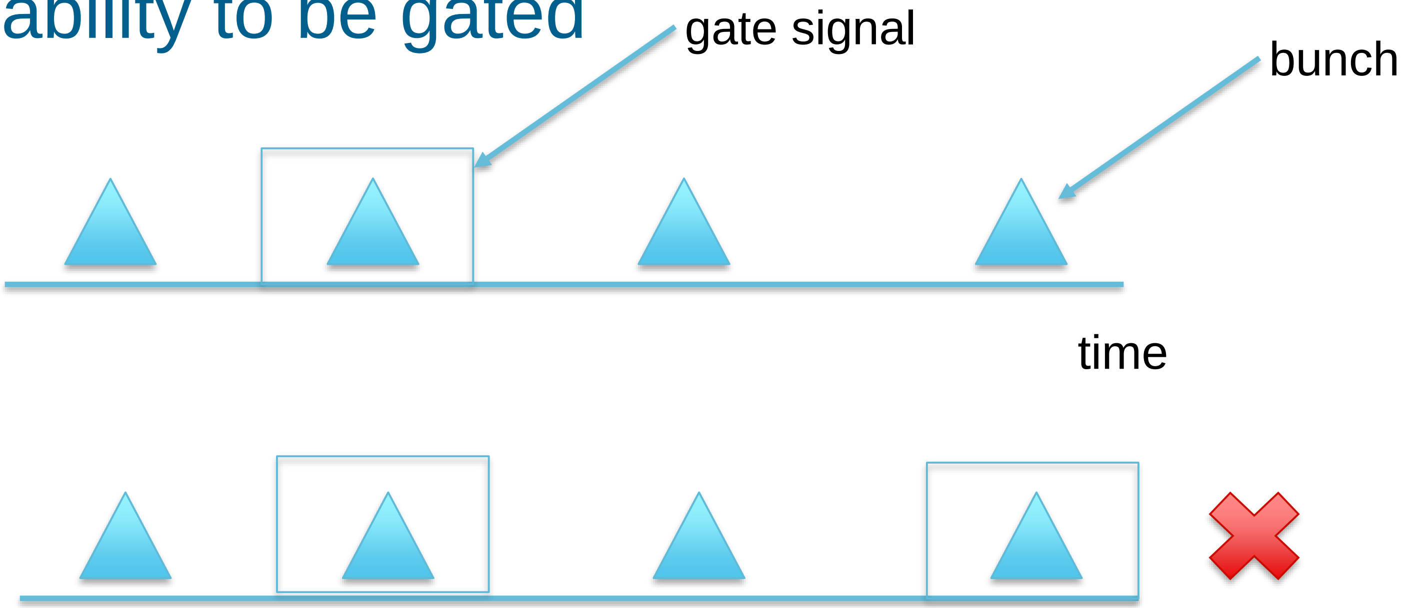




Z-axis in log scale

“Gating”

- The camera coupled to the intensifier has the ability to be gated



Important parameters (prepare, carry out, analyze MD)

- Wire scanners BWS:
  - ß$_y$ = 418.23m
  - ß$_x$ = 185.15m
- Coronagraph BSRH:
  - ß$_y$ = 366.63m
  - ß$_x$ = 193.8m
- Primary collimators TCP (V):
  - ß$_y$ = 71.49m
  - ß$_x$ = 148.43m

For ε_N = 2.5um rad

- σ_y = 386 um
- σ_x = 257 um

- σ_y = 362 um
- σ_x = 263 um

- σ_y = 160 um
- σ_x = 230 um

First MD (May)

Analysis and Results

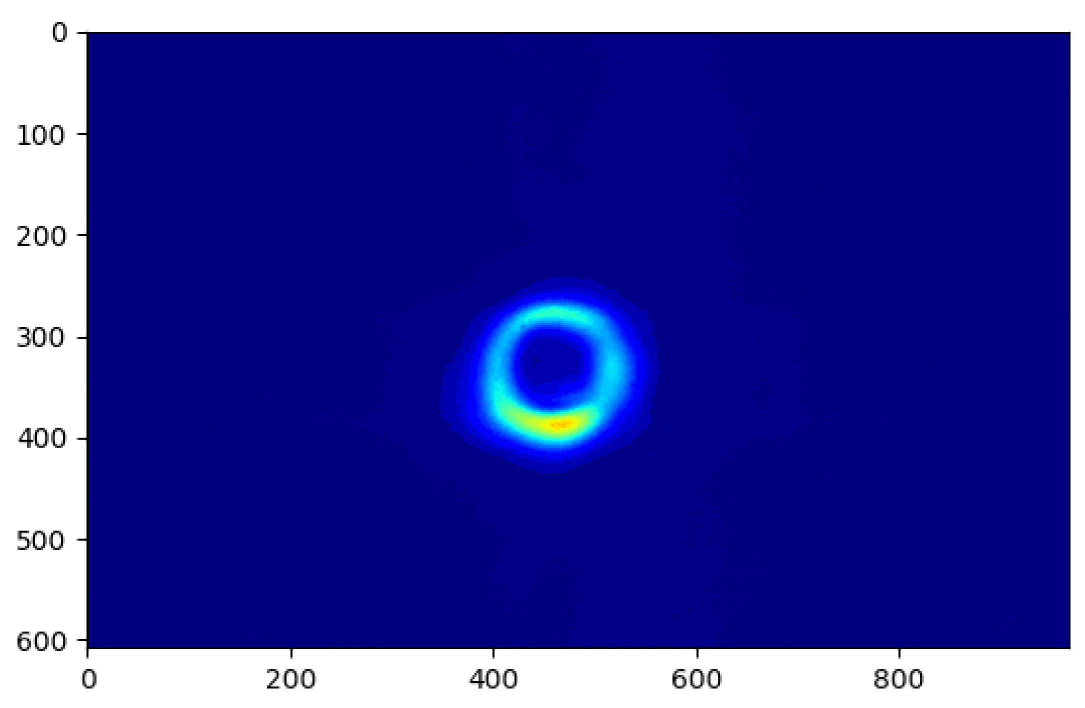
MD overview

- Procedure:
  - Injection: Nominal, 5x Pilot, Nominal, 5x Pilot at ε = 2.5 um (nominal HL-LHC)
  - Scrape the beam to 3σ, blow up pilots to artificially create Halo
  - Measure the distributions with BWS and BSRH (while testing different instrument settings)

→ Changing the beam and the instrument + few machine related problems, gave us direction for 2nd MD

→ Saved over 12 000 datapoints, only ~2000 in steady condition (1 blow-up scan in V plane)

BSRH – data video



Important to notice: Unstable position of the distribution→ changing the integration limits of the HALO
Our suspition is that it was caused due to coherent beam centroid oscillations induced by the ADT

Analysis procedure

- **BWS**
  1. Fit data with a Gaussian distribution (obtain the center of the distribution)
  2. Calculate the integration limits
  3. Normalize the data by the FBCT measurement
  4. Integrate the data to obtain the charge in the halo region

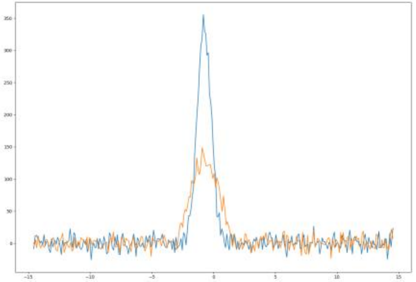
- **BSRH**
  1. Create projections from the 2D image
  2. Fit the projections outside the mask with a Gaussian distribution (obtain the center of the distribution)
  3. Calculate the integration limits
  4. Normalize the data with the charge-to-count scaling factor (w_q)
  5. Integrate the data to obtain the charge in the halo region

HiLumi HL-LHC PROJECT

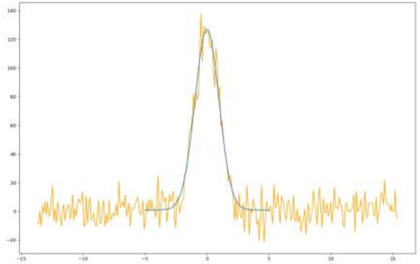
Illustration of the analysis procedure

- BWS

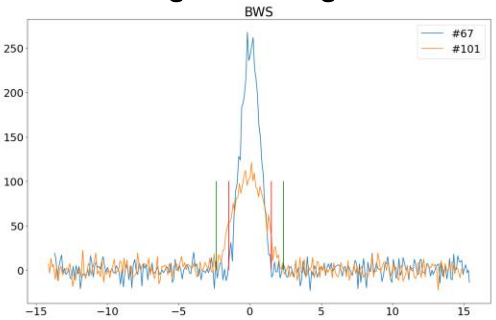
Raw data



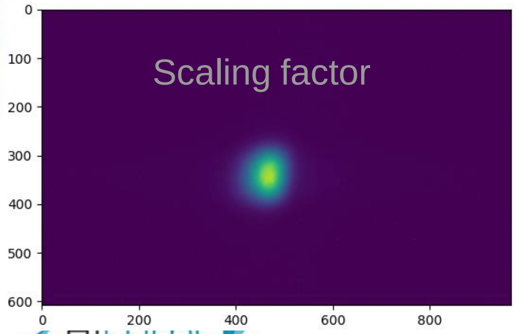
Gaussian Fit



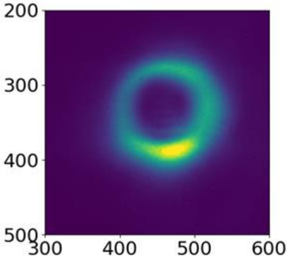
Integration region



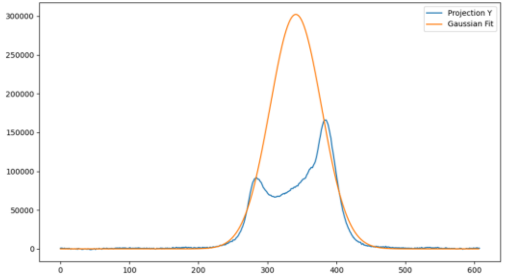
- BSRH



Raw data

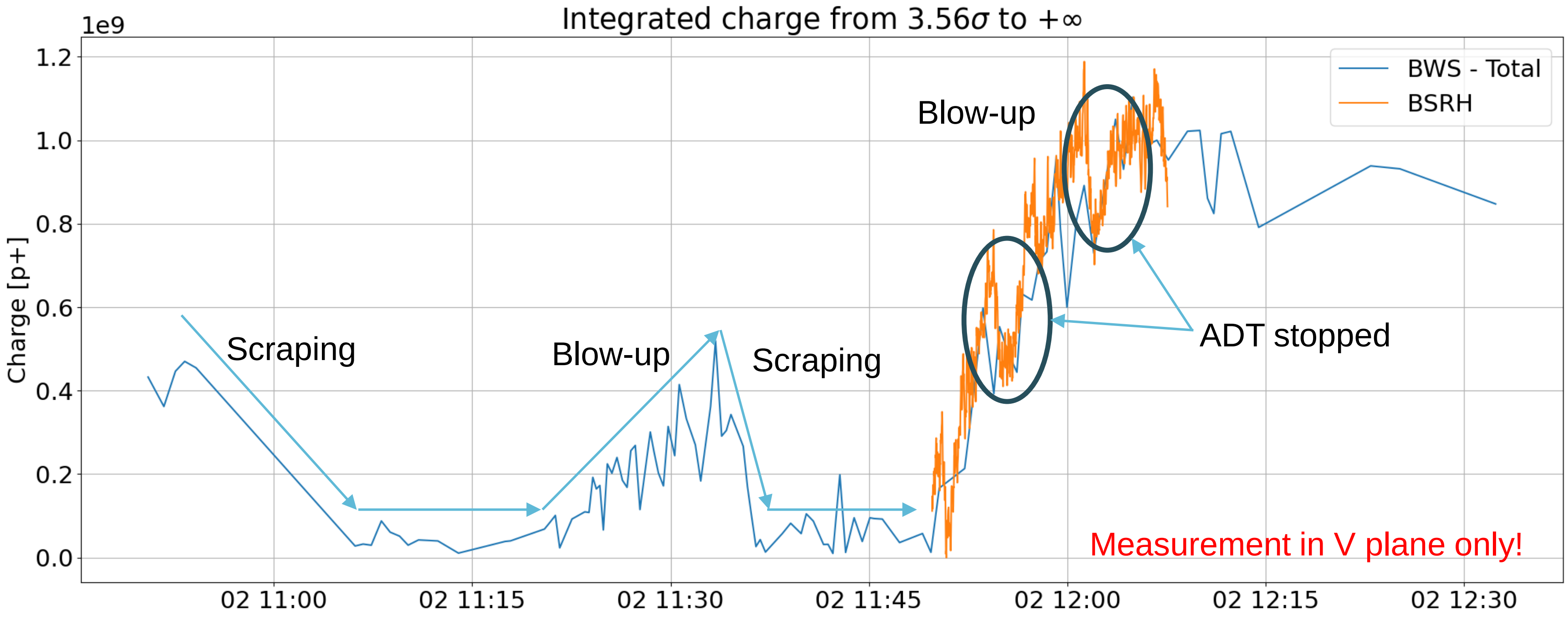


Projection + Fit



Integration region → Charge in halo

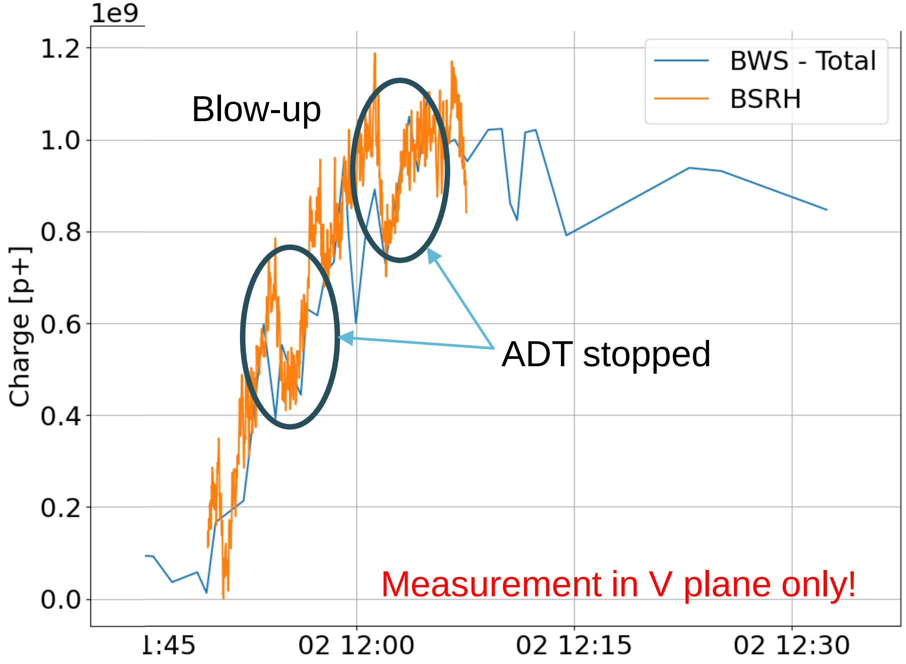
Results – summary plot



Another MD was dedicated to verify the performance with respect to the functional specifications + increase the resolution of the BWS

Results

1. BWS – raw data to charge scaling done at beginning (with FBCT),kept constant
   + no bg substraction
2. BSRH – charge scaling done once at beginning without occulter,then kept constant
   + bg substraction = last point of scraping used as 0
3. The two instruments agree in absolute and relative measurement (total charge outside $3.5\sigma_r$), one division on the graph = 2e8 p^+



Second MD

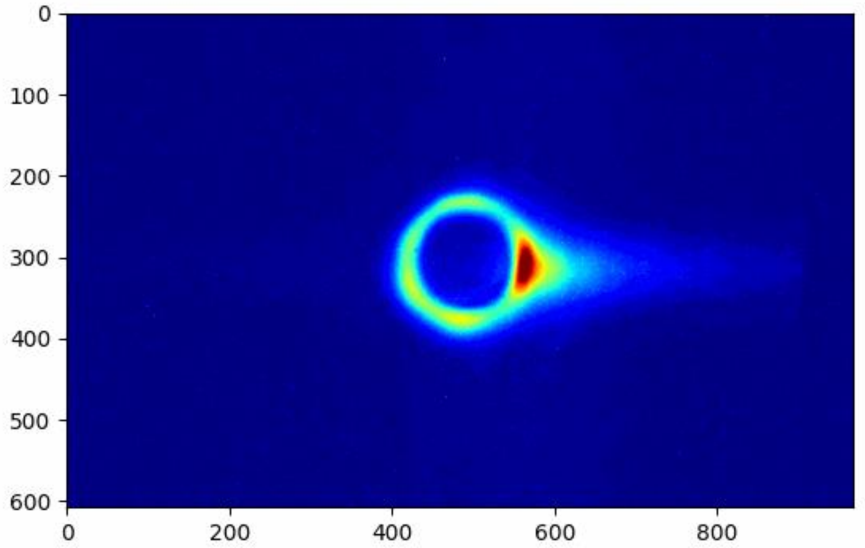
Overview

Preliminary results

MD overview

- Procedure:
  - Injection: 20x Pilots (ε = 2.5 um rad), 4x Pilot (high ε), 4x Pilot (low ε)
    Measure the PSF and magnification of the BSRH, increase the PMT gain of the BWS
  - Scrape the beam (to obtain the background light yield), blowup individual pilots to provide limits of the charge resolution in the region from 4.7 to 6.7 σ
  - Acquired 17 000 measurements, with at least 2 scans per plane, ~12 000 measurements to be analysed!
- Analysis:
  - The same analysis performed as with the previously acquired data

BSRH - video



More stable?
High octupole settings and different chromaticity

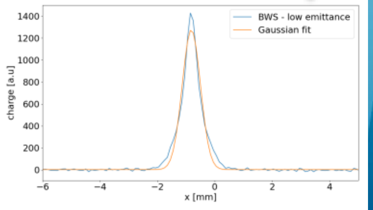
Preliminary results

- Setup (alignment, occulter change etc.) of the BSRH was fast+easy, used experience from 1st MD
- Measured magnification and PSF (under the assumption of profiles being Gaussian) ← Low emittance ones are not Gaussian (from BWS)

- In H: magnification = 0.589 (pixel size= 19.9 um/px), σ_{PSF} = **438 um**
- In V: magnification = 0.514 (pixel size = 22.8 um/px), σ_{PSF} = **453 um**

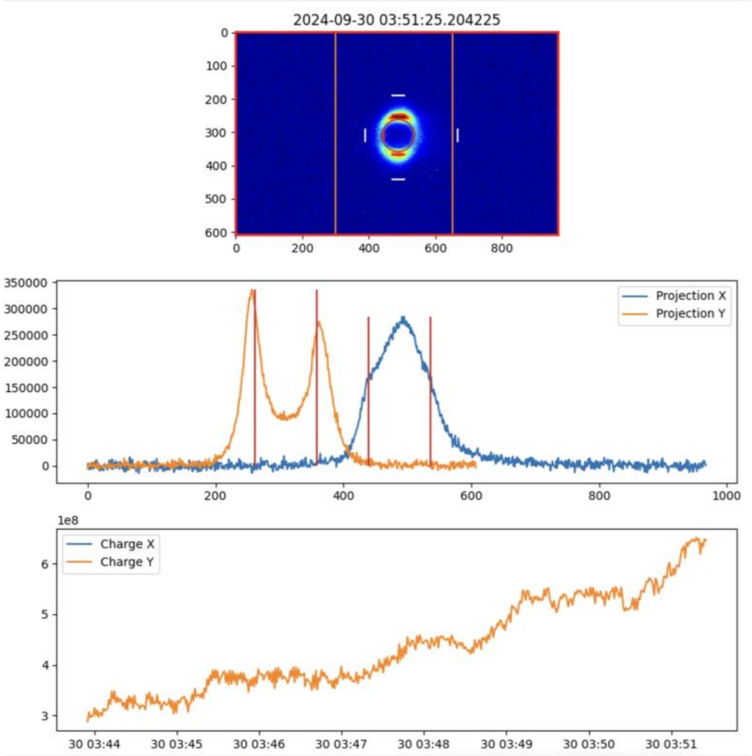
} From target measured ~350 um

- Measured charge scaling
  - This seems to be problematic – changes with the gate length, for $n_b > 5$: $w_q = 44.5$ p^+/count
  - Currently under discussion with the manufacturer of the image intensifier

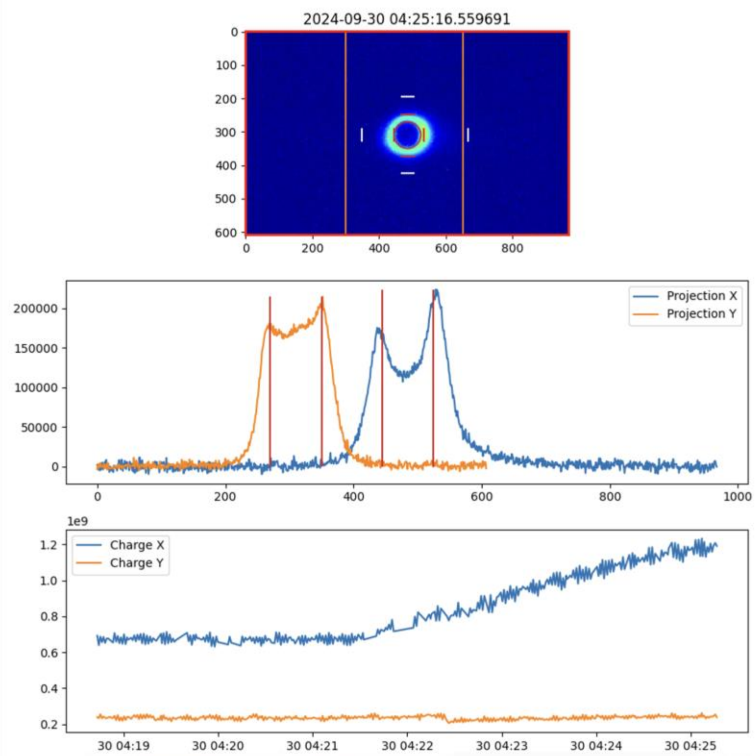


Preliminary results

Single pilot blowup in V



Single pilot blowup in H



BSRH results must be compared to BWS and FBCT → in progress

Two MDs in short

- After a challenging first MD data analysis, we identified that:
  - Correcting for beam position oscillations to consistently determine beam halo boundaries
  - Calibrating BSRH raw images vs FBCT

are two essential ingredients to prove agreement between BWS and BSRH

- During second MD a real-time analysis of each scan gave inputs for the following ones
  - Complete analysis ongoing

HiLumi HL-LHC PROJECT

Conclusions

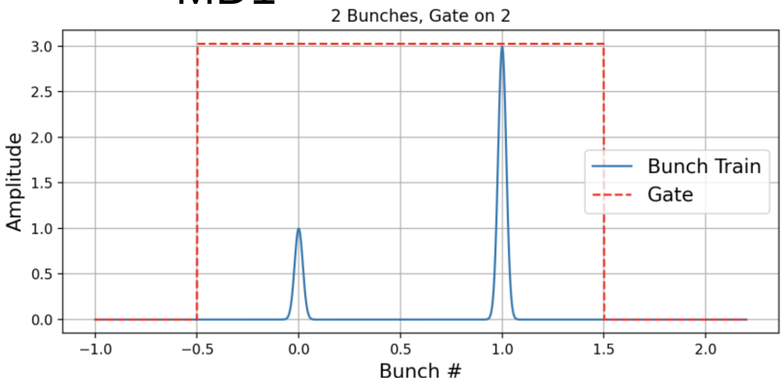
- Same trend measured with BWS and BSRH – agreement within ≈1e9
  - Issue: Assess BG without scrapping
- The image intensifier is the limitting piece of equipment (by design, additional gating problems in case the system is made operational)
- Coronagraph is complex – could the measurement be performed using occulted BSRT?
- Next steps:
  - Analyse all the data from the second MD
  - Study the gains in case of second SR extraction line
  - Provide a solution to the intensity problem
  - Review of Beam Halo Monitor (provide decision on used technology)

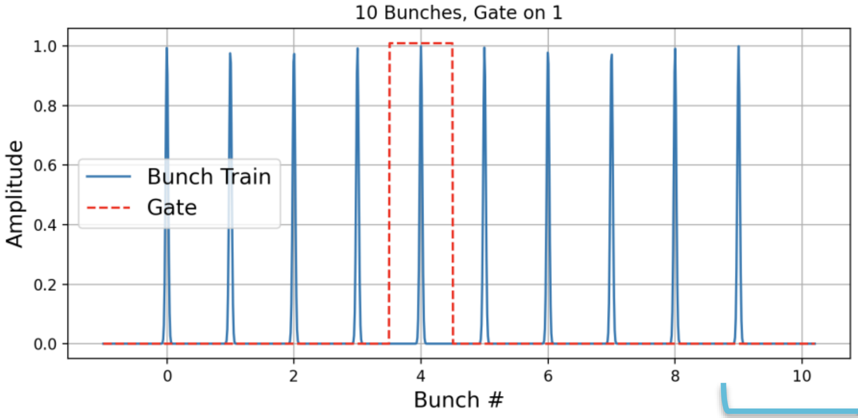
Thank you for your attention

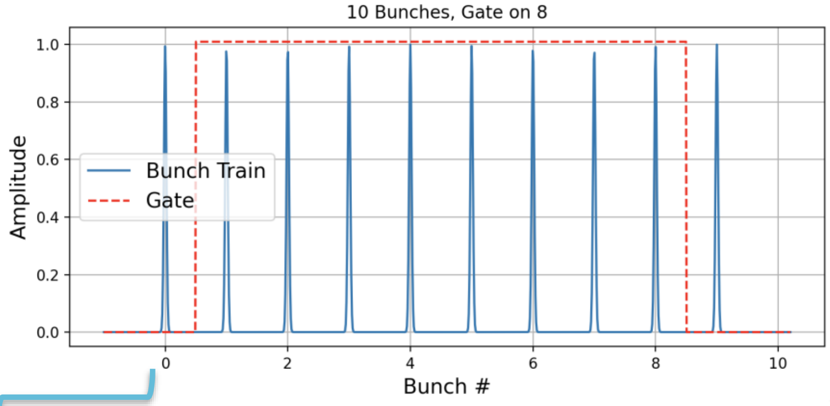
Backup

Gating example

MD1

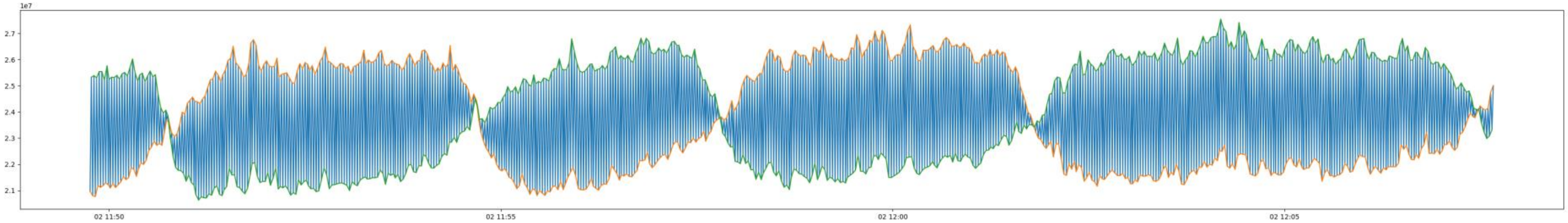






MD2

BSRH intensity problem



±10% intensity oscillation due to finite capacitance of the intensifier – only possibility is to calculate the moving average (or provide different engineering solution)