BSRH: Establishing performance at the LHC

Jan Pucek on behalf of BI-PM

HL-LHC collaboration week in Genoa, October 2024

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

HiLumi HL-LHC PROJECT

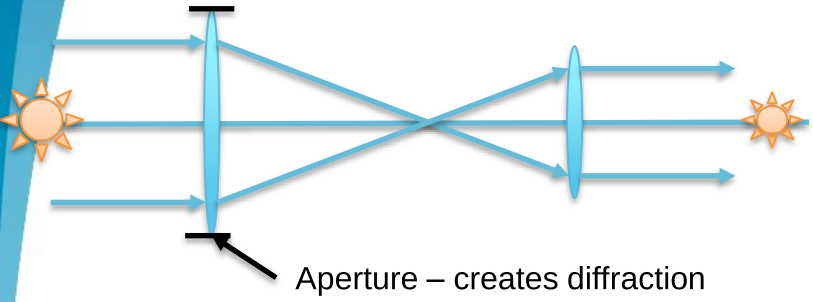
Outline

- Coronagraph – principle
- Calibration measurements
- Data analysis
- Performance overview
- System status
- Summary table

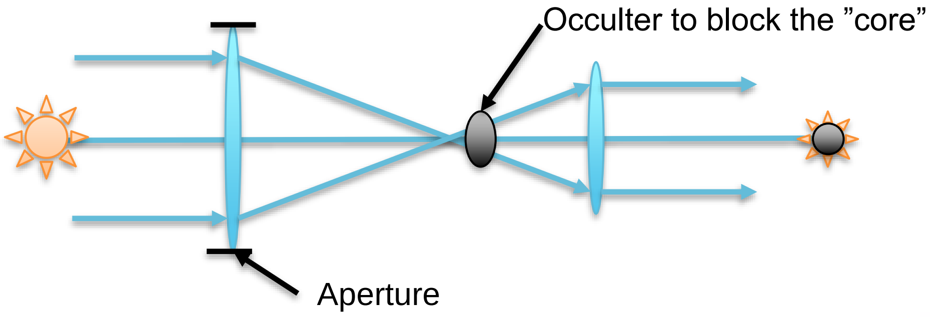
Coronagraph – principle

Coronagraph – principle

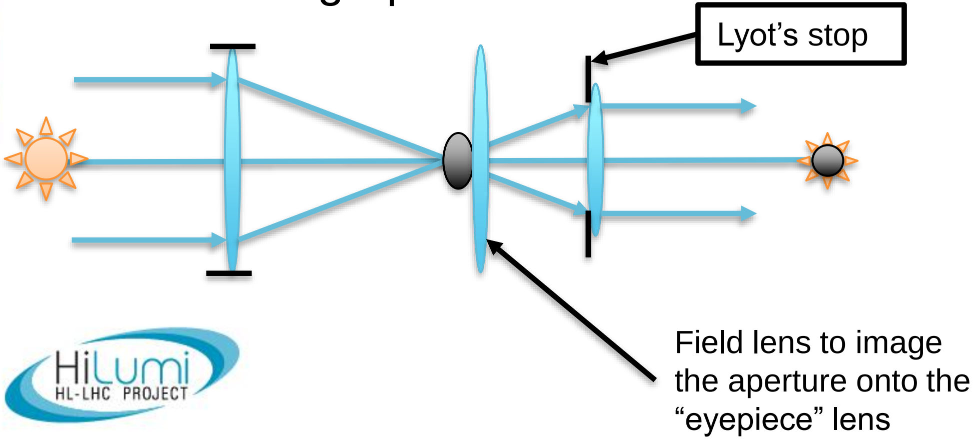
1. Telescope – two lenses



2. Telescope with occulter



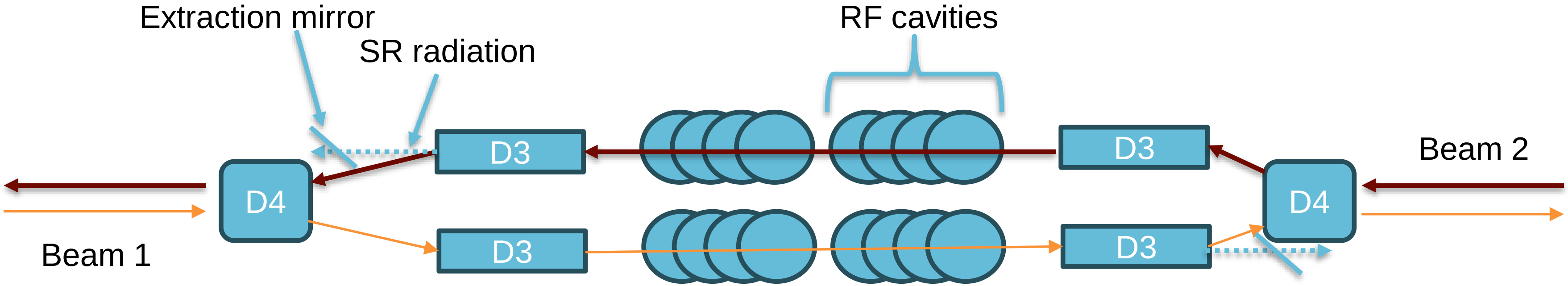
3. Coronagraph



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

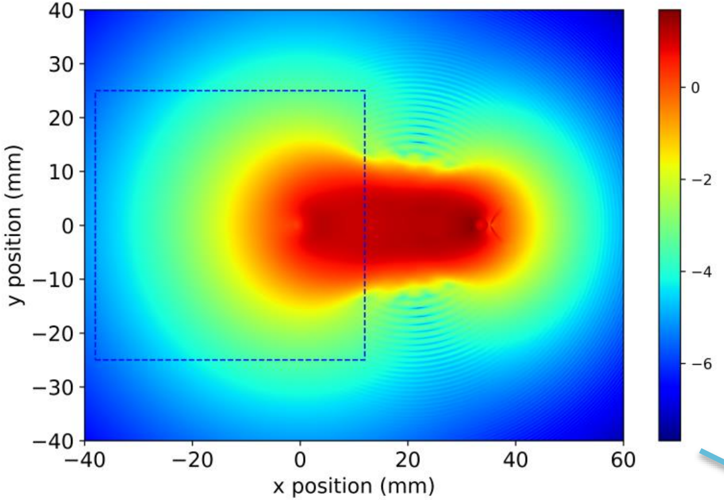
*not to scale

Introduction – the source



- Distance between D3 and BSRTM (extraction mirror) ≈ 21m
- Synchrotron radiation emitted in a narrow cone (due to Lorenz transformation) ≈ 140 μrad

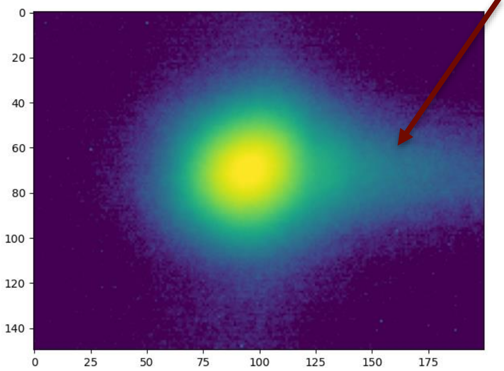
Introduction – the source



Simulation and figure produced by D. Butti

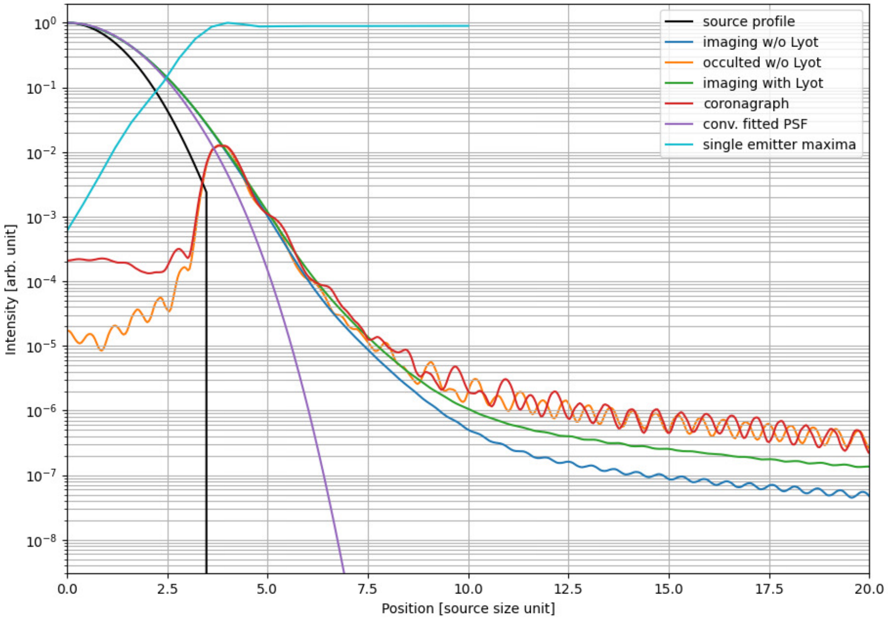
- Sharp edge of the extraction mirror within the light spot -> source of diffraction in horizontal plane

When imaged

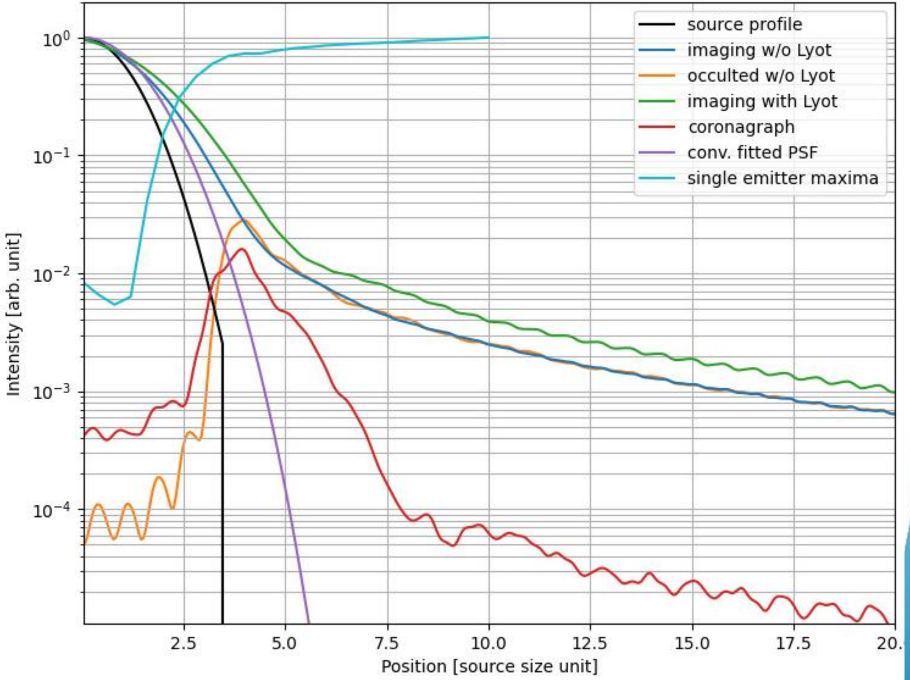


Concept of diffraction

Vertical plane



Horizontal plane



Measured profile ≠ True beam profile

Coronagraph can lower the diffraction contribution of the sharp mirror cut

Calibration measurements - imaging

Pixel size calibration:

- Bunches with 3 different emittances
- Comparing the BWS and the BSRH profiles in both planes independently

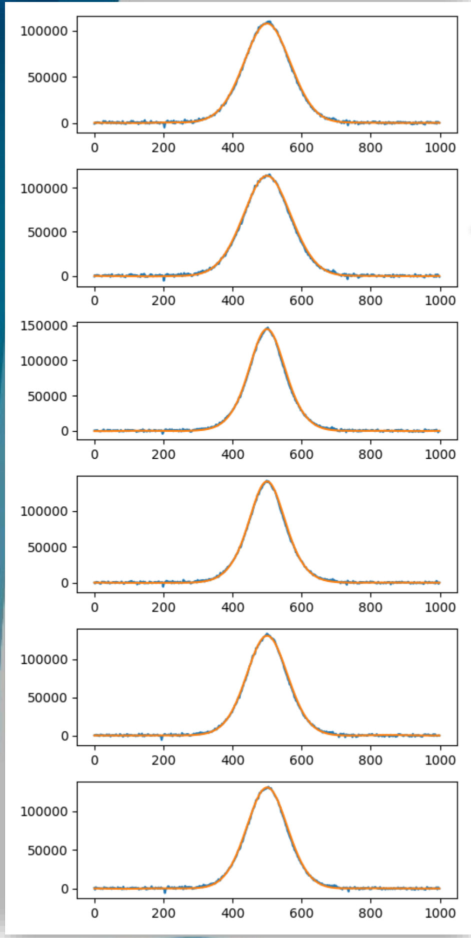
Charge scaling calibration:

- Requires the full measured profile from the BSRH and the corresponding FBCT measurement

$$FBCT(q) = A \, * BSRH(c)$$

Calibrating this factor

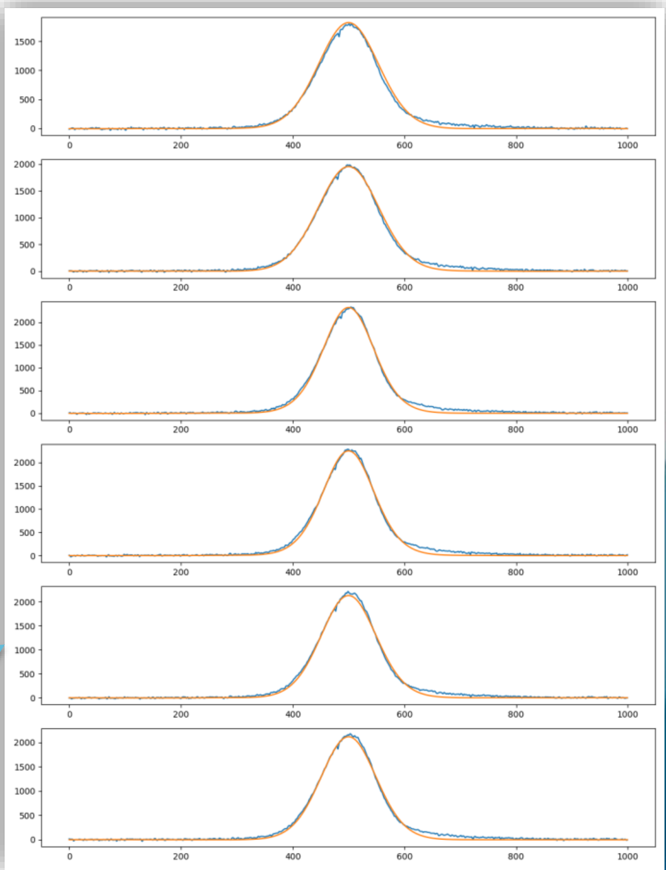
Calibration measurements



Results: **σ = (277 ± 8)μm**
m = (0.64 ± 0.006)
pixel size = (18.3 ± 0.2) μm/px

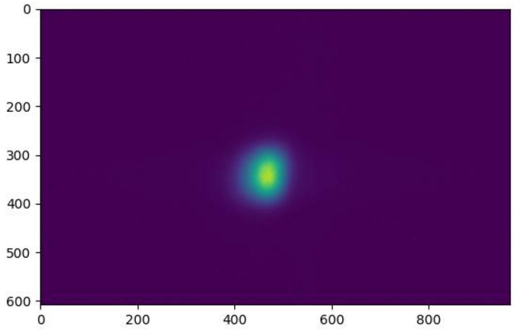
BWS ⊗ PSF
BSRH

- σ_y = 362 um
- σ_x = 263 um



Results (L-BFGS-B):**σ = (320 ± 30)μm**
m = (0.68 ± 0.03)
pixel size = (17.0 ± 0.8) μm/px

Calibration measurements

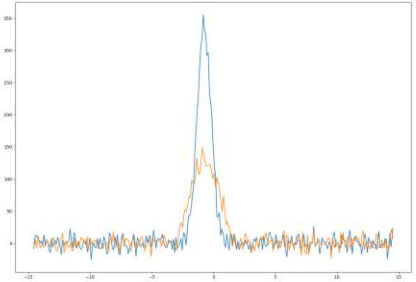


- The charge scaling factor = (42.7±1.7)p^+/count

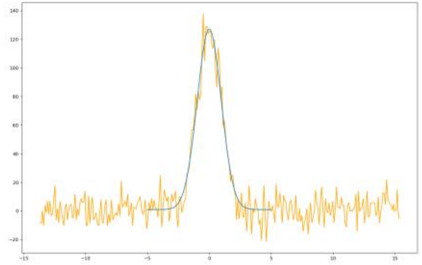
Illustration of the analysis procedure

- BWS

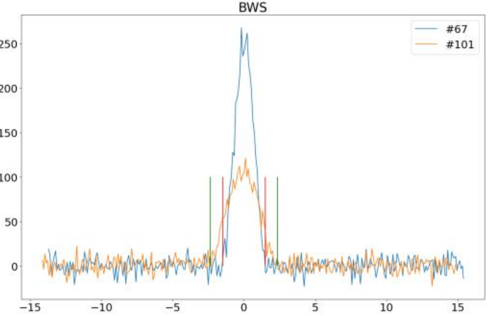
Raw data



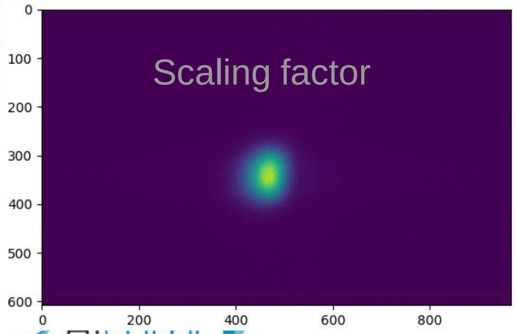
Gaussian Fit



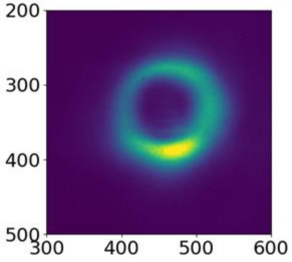
Integration region



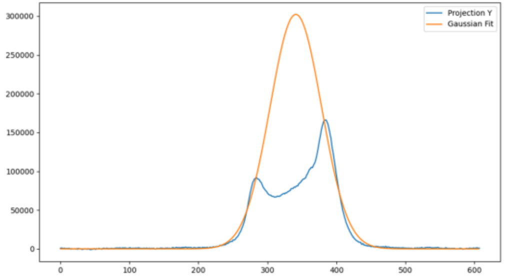
- BSRH



Raw data



Projection + Fit



Integration region → Charge in halo

Machine development session(s) - overview

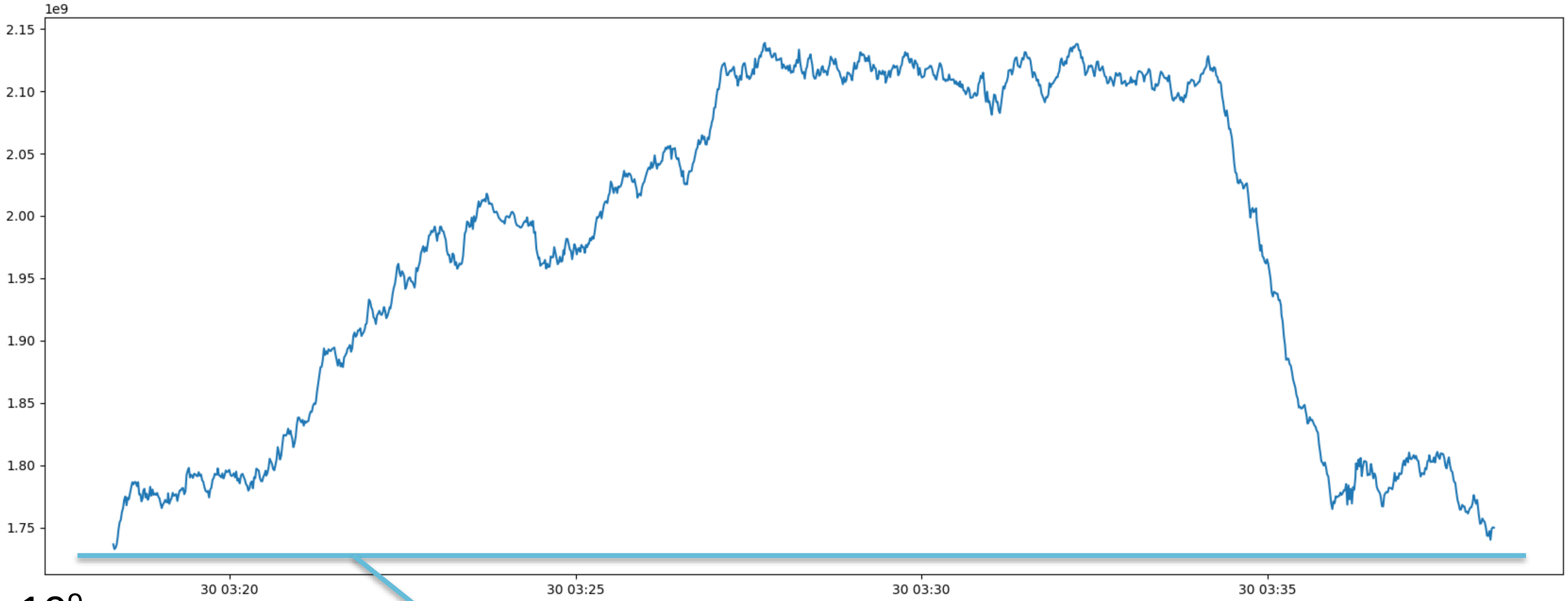
- **How to asses the performance of the instrument?**
- Scrape the beam to known size → beam halo = 0
- Blow up a bunch (ADT) to populate the halo region
- Measure charge in halo by two instruments (BWS, BSRH)

MD1:
- Nominals and pilots (- charge resolution of the BWS)
- Tried to measure changes in the profile

Lessons learnt →

MD4:
- Pilots only (+ charge resolution of the BWS)
- Online analysis ready

Data handling

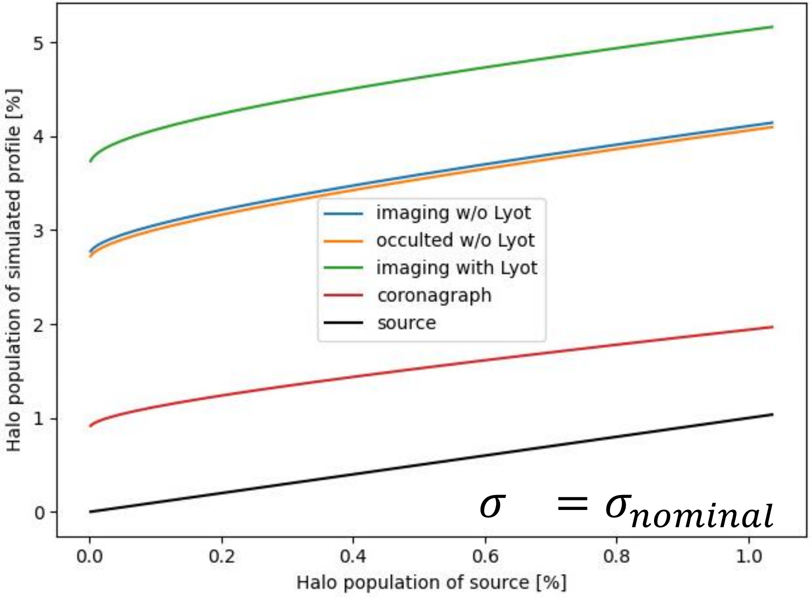


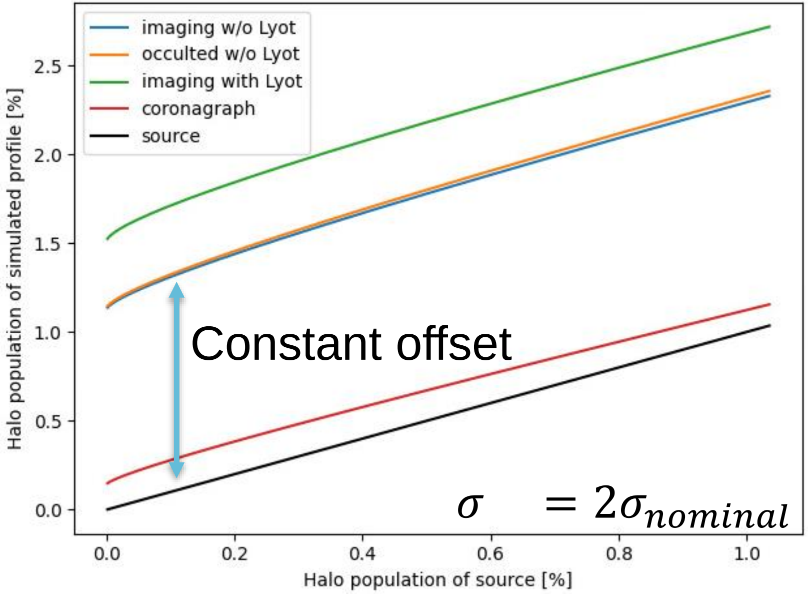
$1.6x10^9$

Subtract background (known from collimator position) makes the measurement only relative

Simulation proof of linearity

- Diffraction creates offset, yet linearity unchanged (for the "Gaussian" blow up)



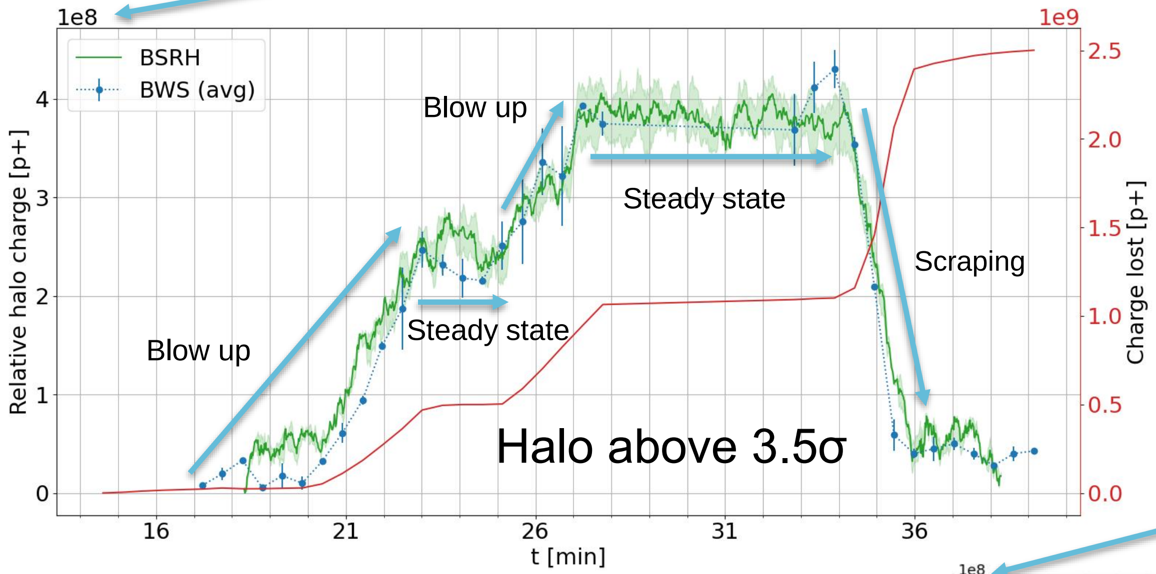


Courtesy of D. Butti

Performance overview

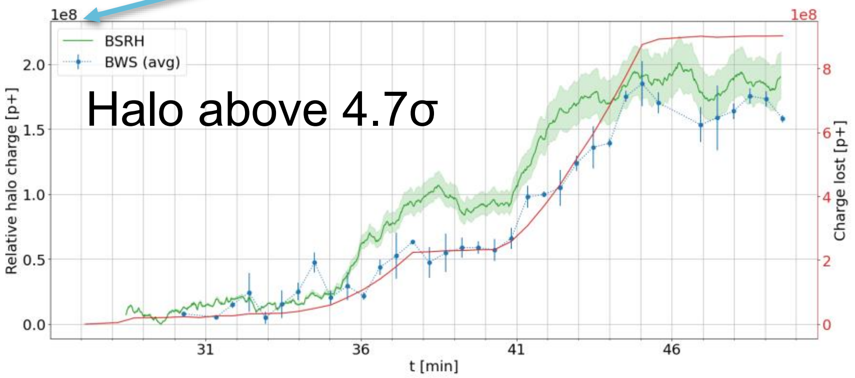
Vertical plane

Total population = 9×10^{10}

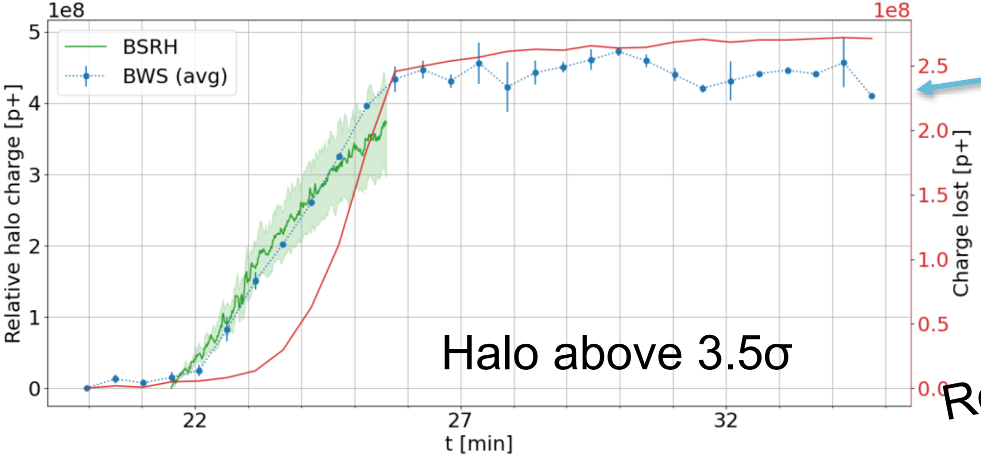


Green curve = 15s moving average of the BSRH data, gated on 10 pilot bunches
Blue curve = BWS (average of IN/OUT) of the single pilot
Red curve = FBCT reading of the single pilot

Total population = 10^{11}



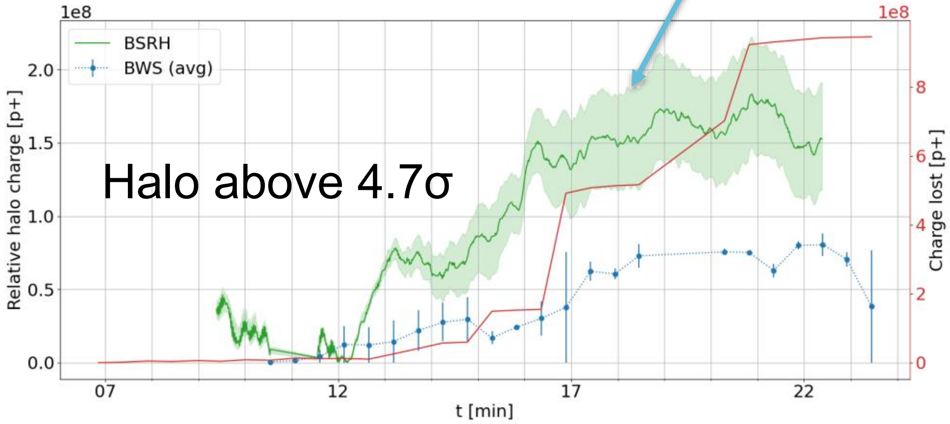
Horizontal plane



Single bunch measurement, 2s moving average, limit of “static” core

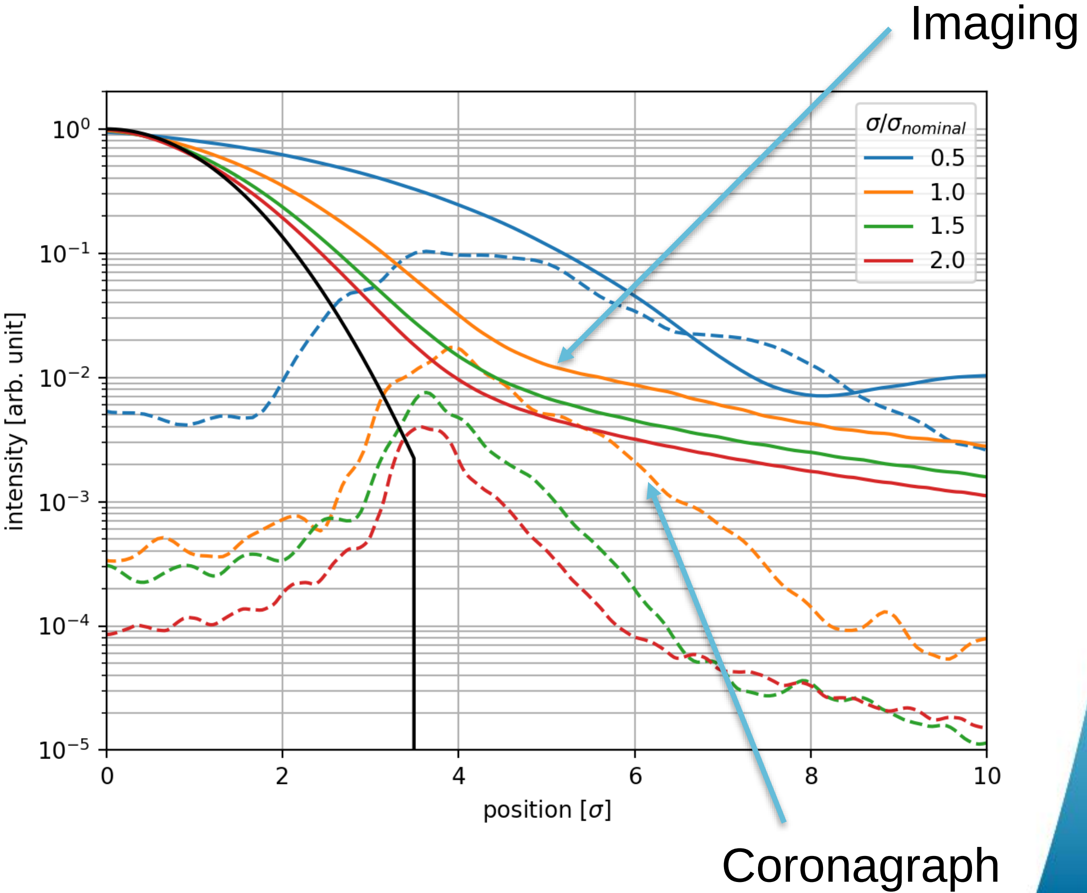
Reason behind the difference is **unclear**
Factor 2…

Measurement of 10 pilots, one blown up, 15s moving average



System status

- YETS underway
  - Solving the image intensifier ripples
  - Splitting the optical line BSRT to BSRH t
  - Apodizer to be tested
- Demonstrate pote
- Prepare procedur during physics fills
- Only way to increa the beam size



Summary Table

Performance Metric	Required Range	Use Case(s)	BSRH
Contrast	10^-4 to 10^-6	Collimation: 10^-4 at upper bound MP: 10^-6 at 6.7σ	Currently unknown
Relative Integral	0.2% to 5%	Collimation: 5% to 0.5% MP: 1.4% to 0.2%	<0.1% (relative)
Absolute Integral	10^10 to 10^12	Collimation: 1.5×10^12 MP: (1-4)×10^10	Currently unknown (~1.5% during MD)
1D Profile Capability	Yes/No	Required for Beam-Beam	Yes
2D Image Capability	Yes/No	Required for Beam-Beam	Yes
Max. Acquisition Rate	10-60 seconds	MP: ~10s Others: ~60s	~20Hz (time for full beam depends on the gated sample - >100s for full machine bunch per bunch, around 3s for 48b., limited by data processing)
Bunch-by-Bunch Gating	Yes/No	Required for Beam-Beam	Possible
Number of Turns Needed	-	All cases accept multi-turn	Order of 100 turns (depends on gated sample)
Interlock Capability	Yes/No	Required for MP	Warning possible, Software interlock?

Final words

- Important measurements during 2 MDs
- A lot of SW work in the future
- Hopefully in 2025 first halo data of physics run
  - Currently only relative
  - Through additional MDs we might lower the uncertainty and prove possible deconvolution of the measured profile/image and the PSF

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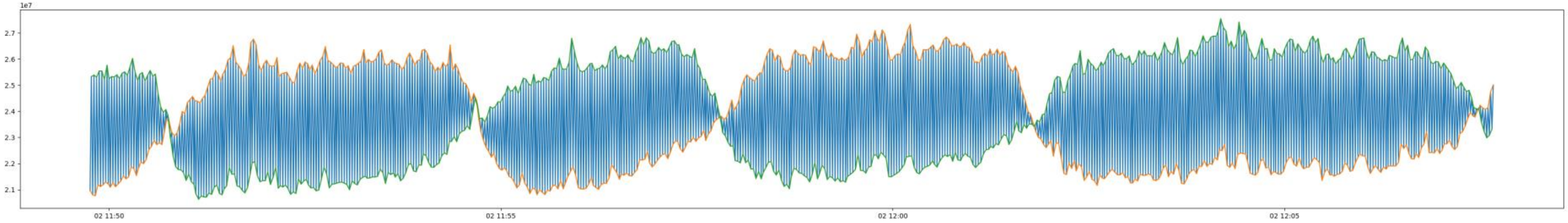
Thank you for your attention

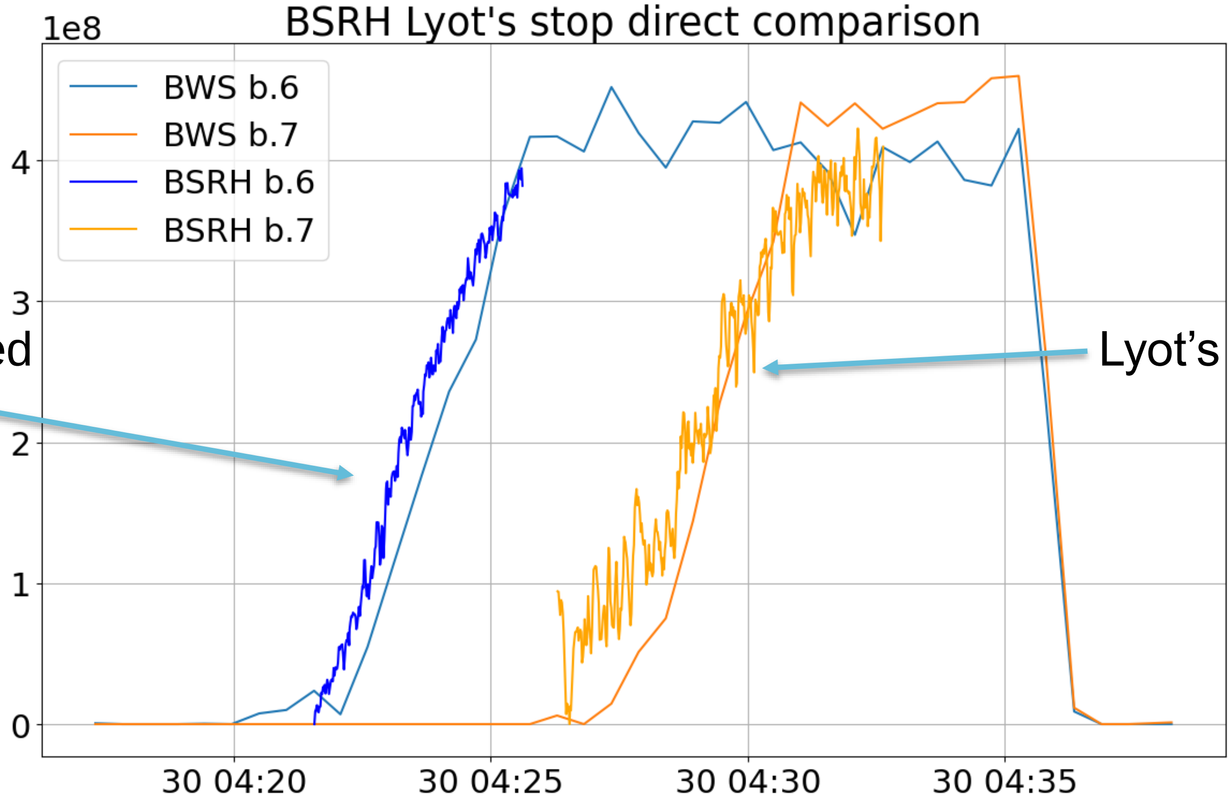
Backup

BSRH intensity problem



±10% intensity oscillation due to finite capacitance of the intensifier – change of intensifier model

Lyot’s stop - data



Lyot’s stop closed

Lyot’s stop opened