Collimator Scan based Beam Halo Measurements in LHC and HL-LHC

P. Hermes, M. Giovannozzi, C. E. Montanari,
S. Morales Vigo, M. Rakic, S. Redalli, B. Salvachua

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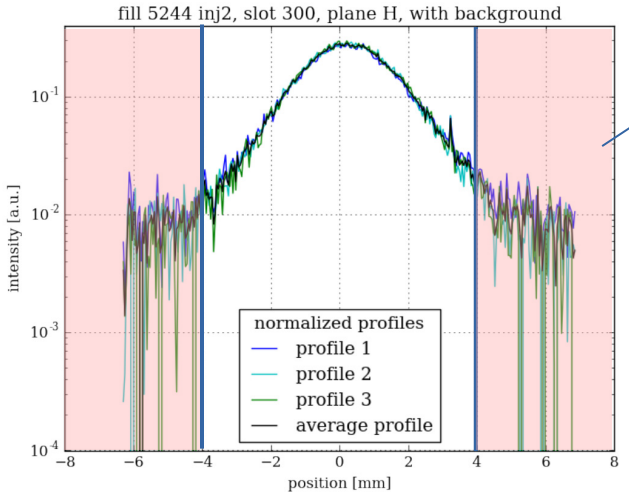
Contents

Introduction

Transverse Beam Halo Measurements

- **LHC transverse halo measurements :** relevant information for machine safety, background (…)
- Measurements needed with **highest intensity configurations**
- **Wire scans with upper limit** of some percent of nominal LHC intensity
- Synchrotron telescope **(BSRT) too high noise level** in region of interest
- **Relying on destructive collimator scans**

Figure by M. Fitterer, FERMILAB-TM-2657-AD-APC



LHC beam profile measured with BSRT

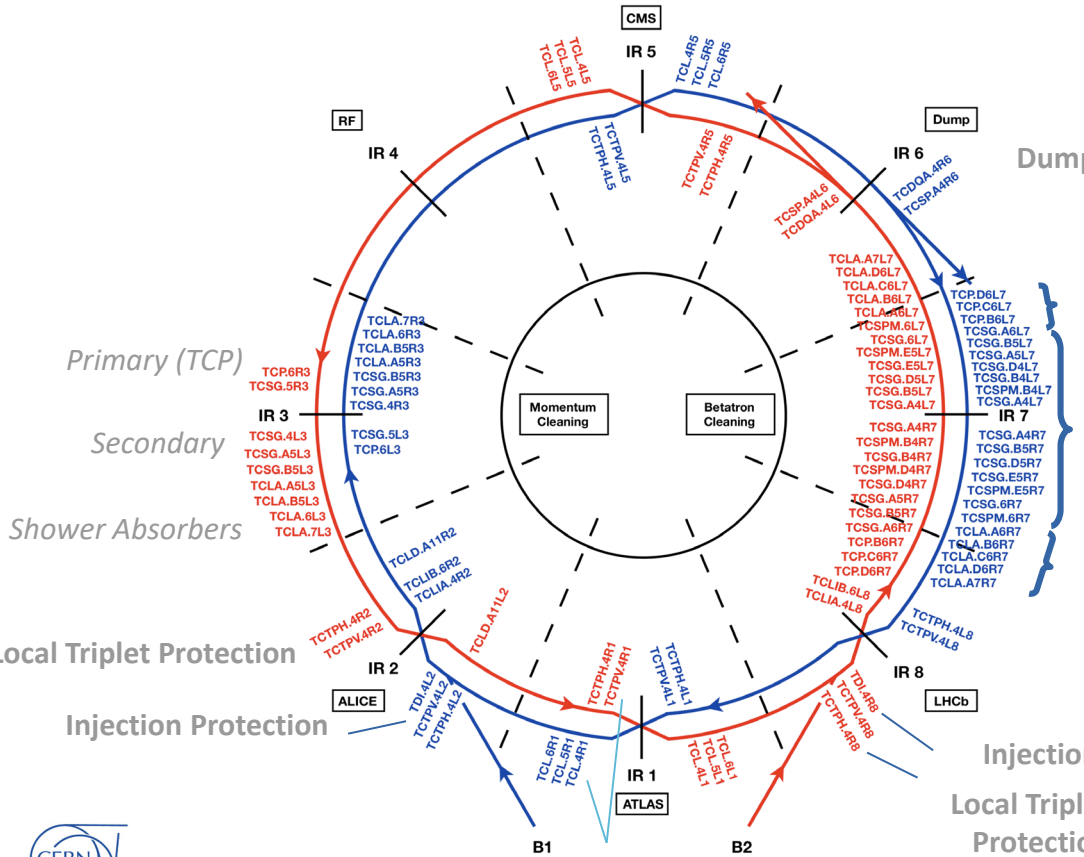
Transverse Beam Halo in the LHC

- **Halo over-population** observed in collimator scans during LHC Run 1 and 2
- Further measurements: **high priority task for LHC Run 3** with beams post LHC injector upgrade available
- **Crucial input: risk assessment &** defining required **hardware upgrades**
- **This contribution:**
  - **Transverse halo measurement technique**
  - **Results from LHC Run 2 and Run 3**
  - **Halo monitoring requirements in HL-LHC**

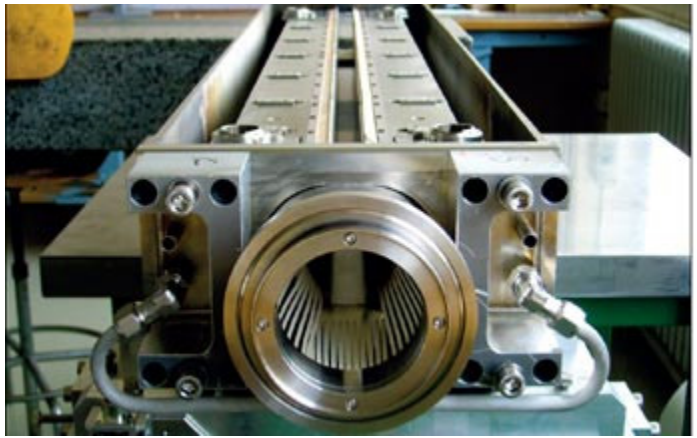
Halo Measurements by Collimator Scraping

The LHC Collimation System

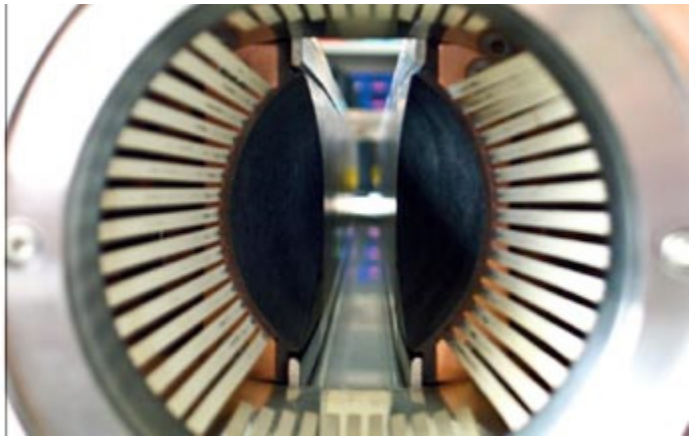
Figure: G. Azzopardi
ICALEPCS2021 (THPV012)



LHC Collimators



Collimator Assembly

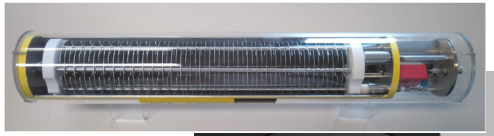


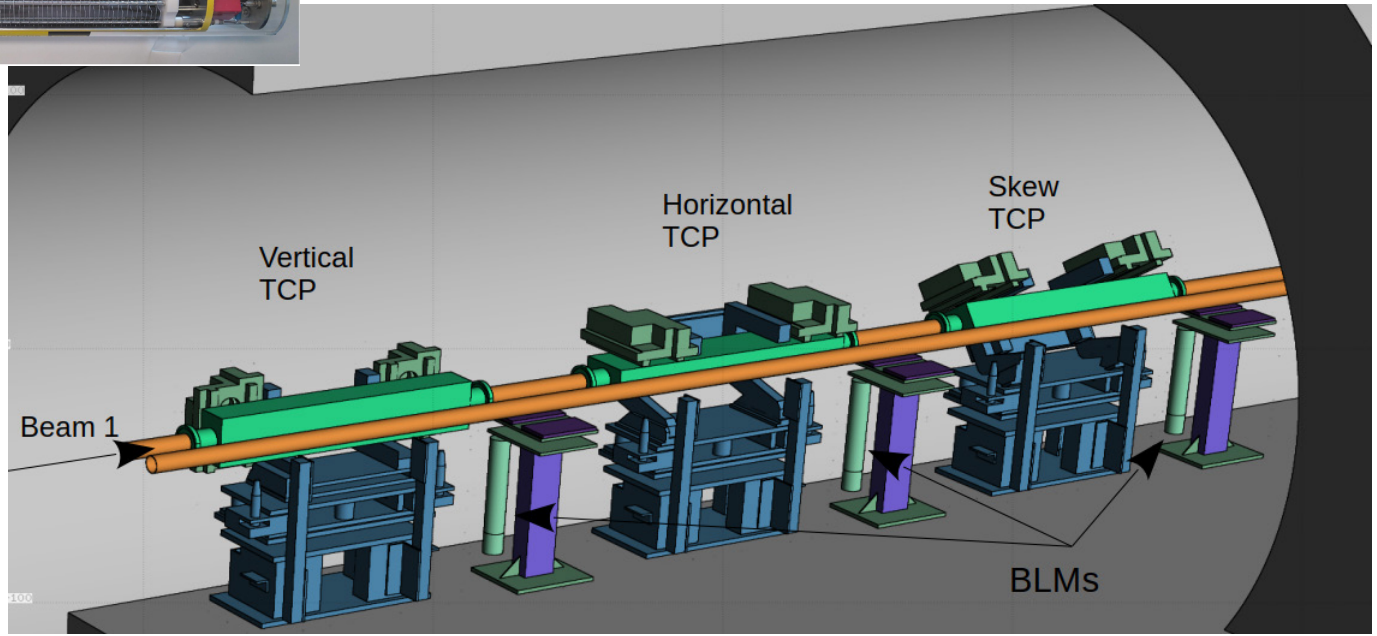
Movable collimator jaws

Figure: S. Redaelli, CERN Courier

Primary Betatron Collimators

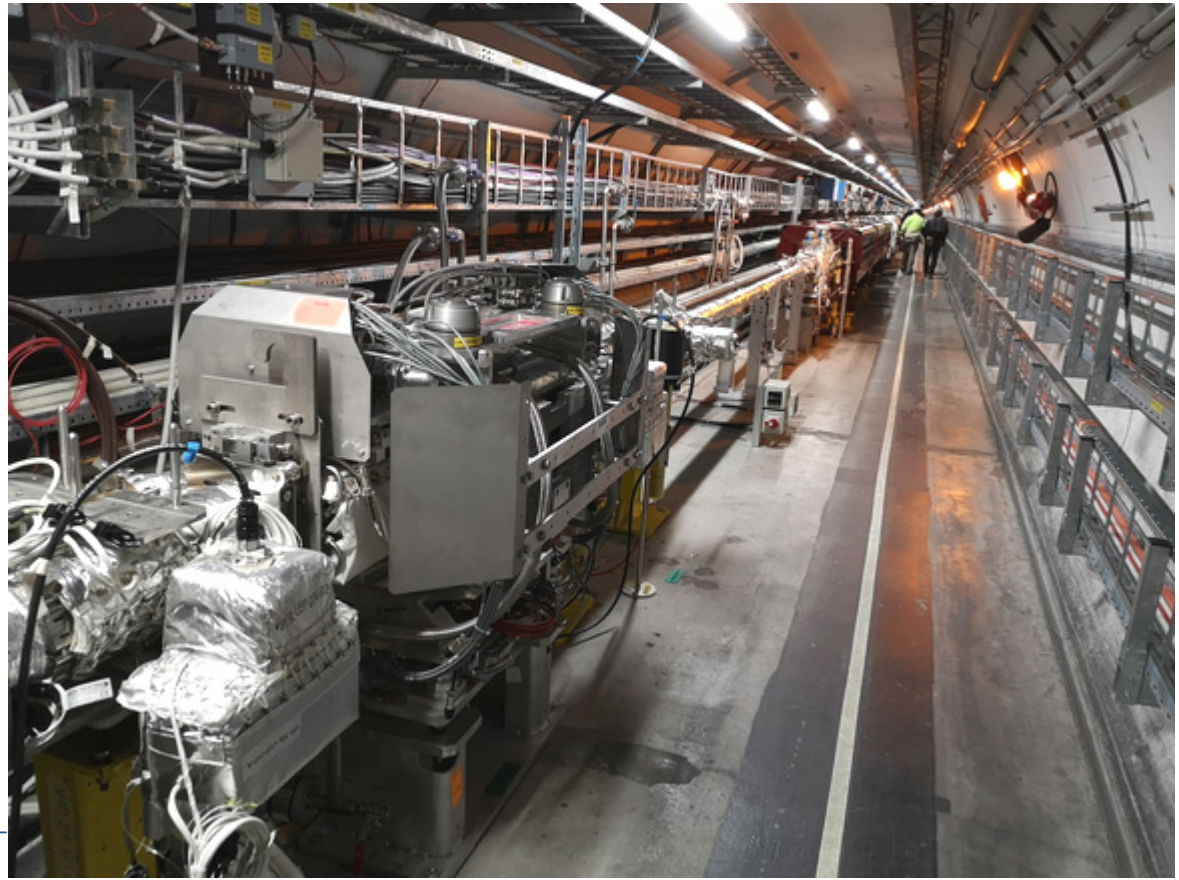
Source : S. Morales Vigo, Msc Thesis





Source: E. Skordis, CollWG 181

Example: Collimator assembly in tunnel



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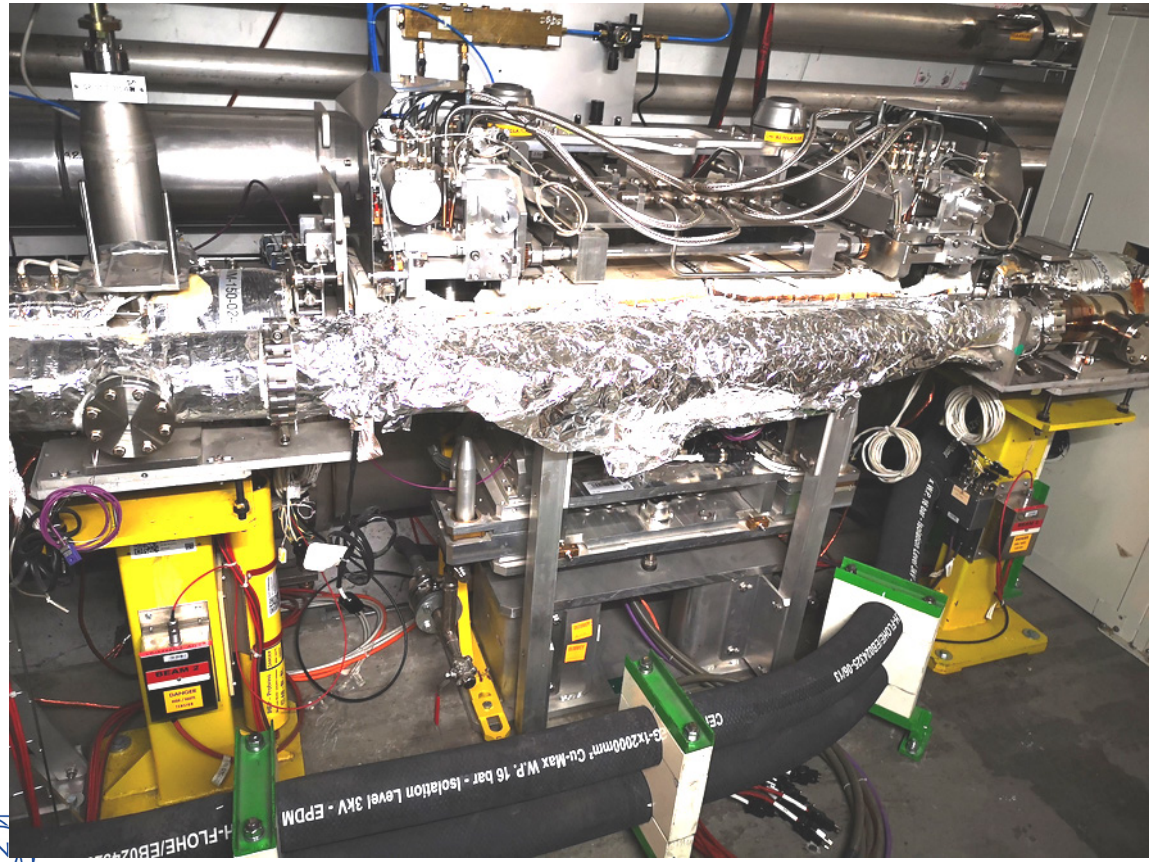
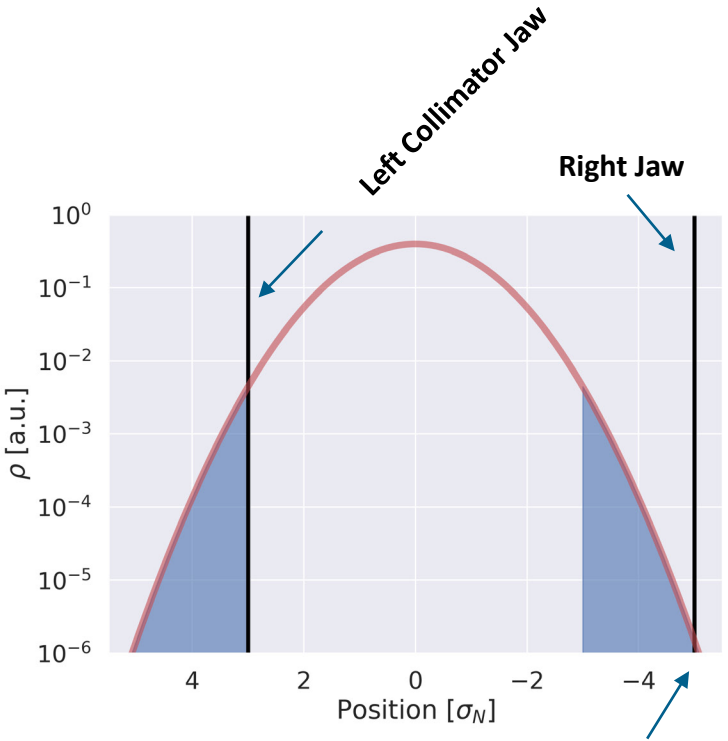
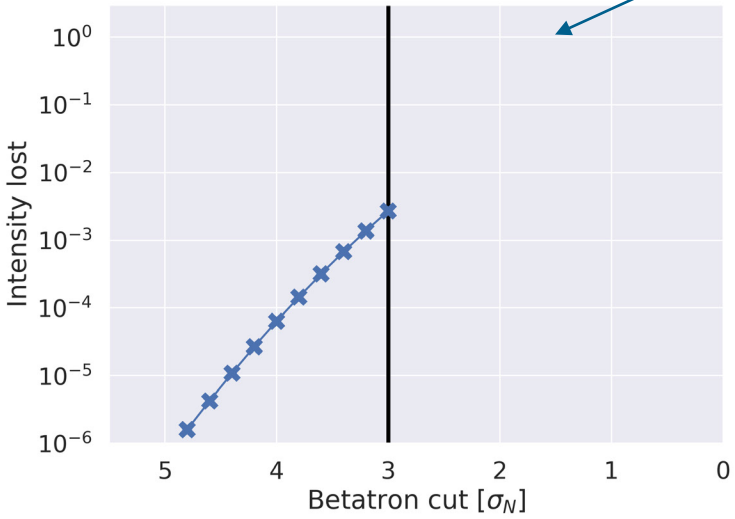


Principle of a Single Jaw Scraping Measurement

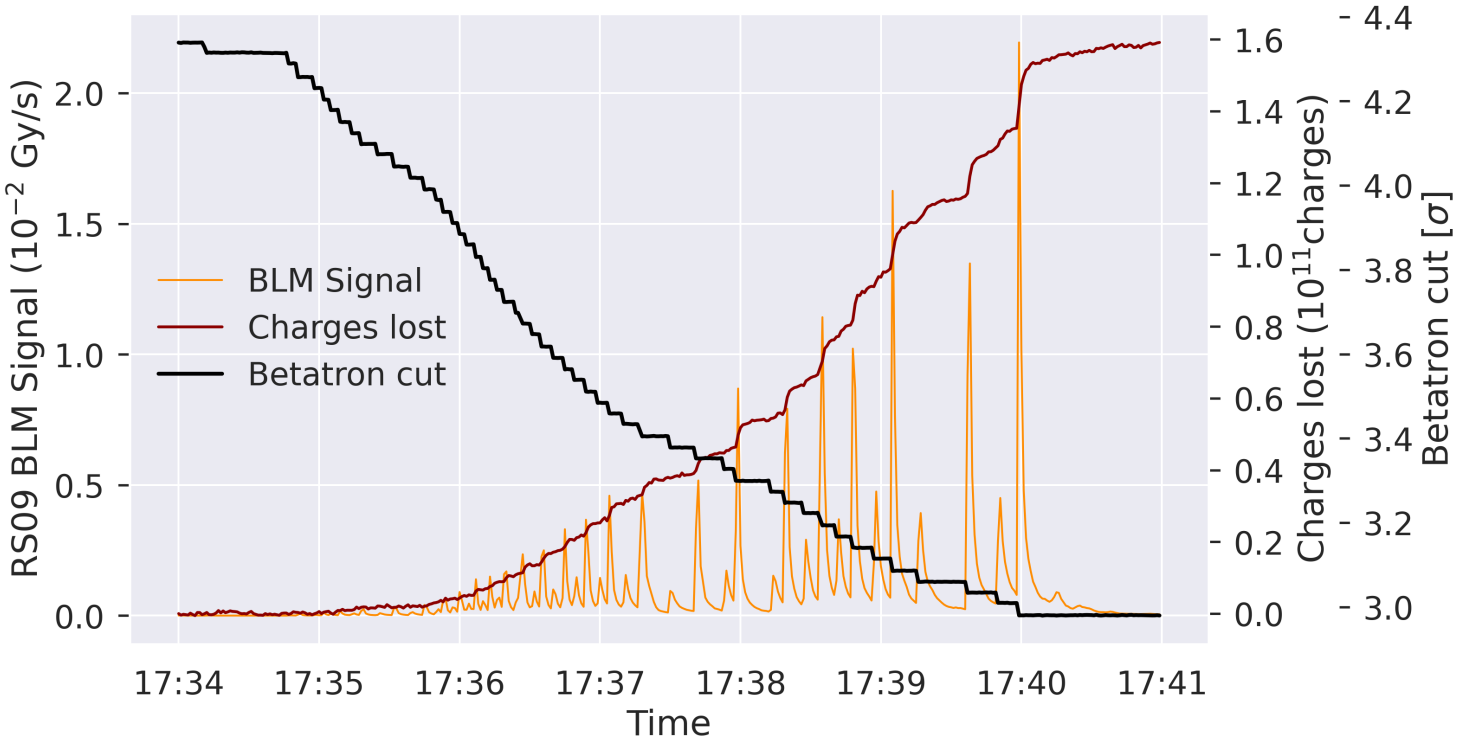


Only one jaw needed: betatron tune

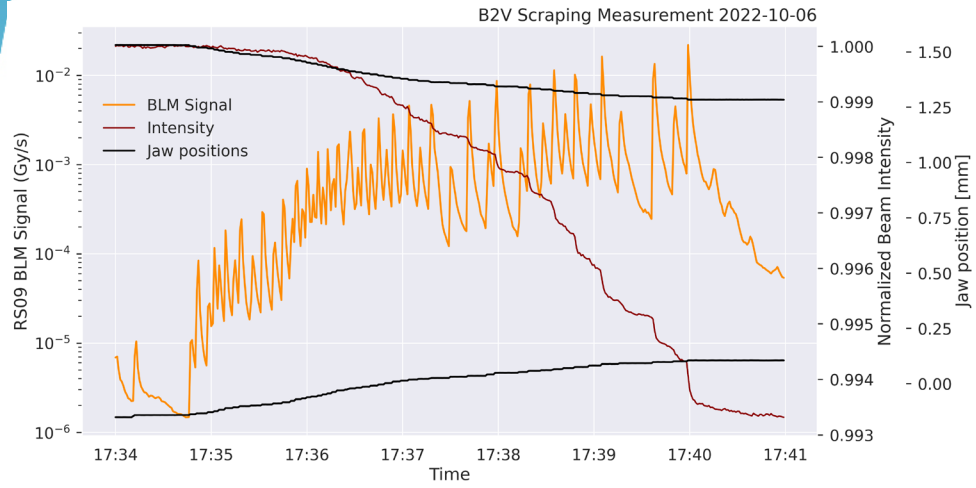
Instrumentation needed to quantify intensity lost vs. jaw opening

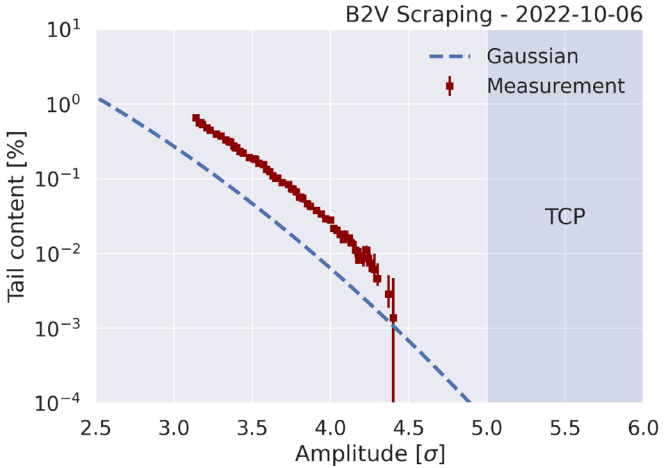


Available Measurement Data



Principle of BCT-based analysis





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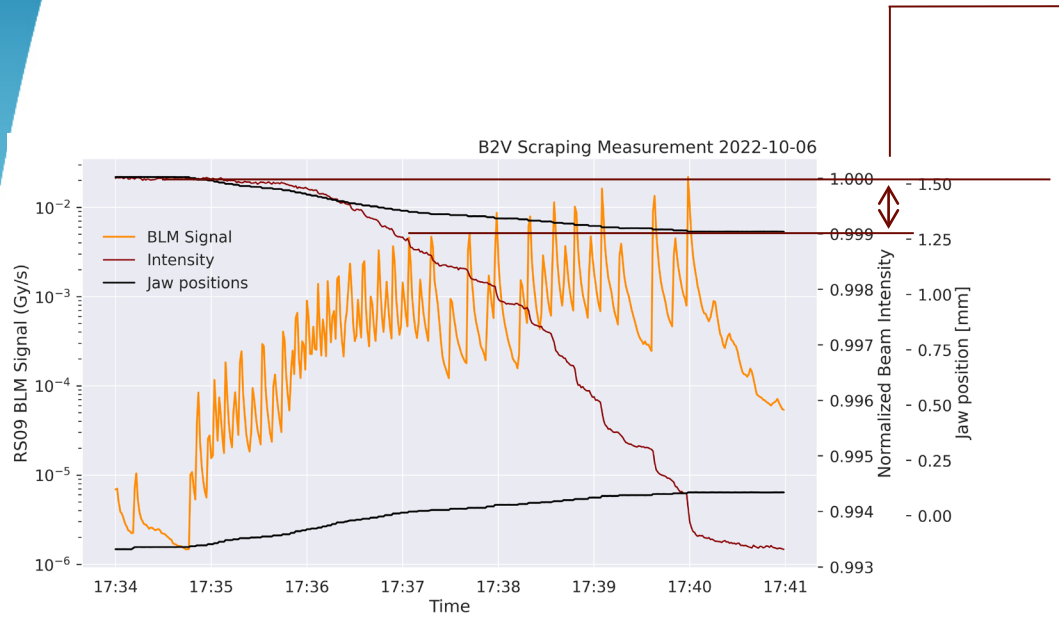

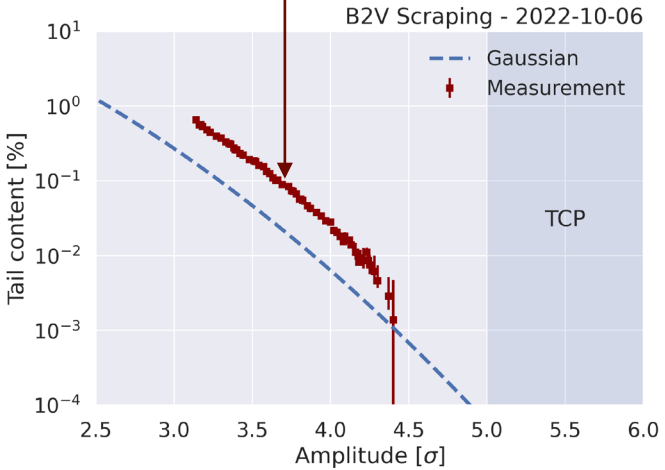

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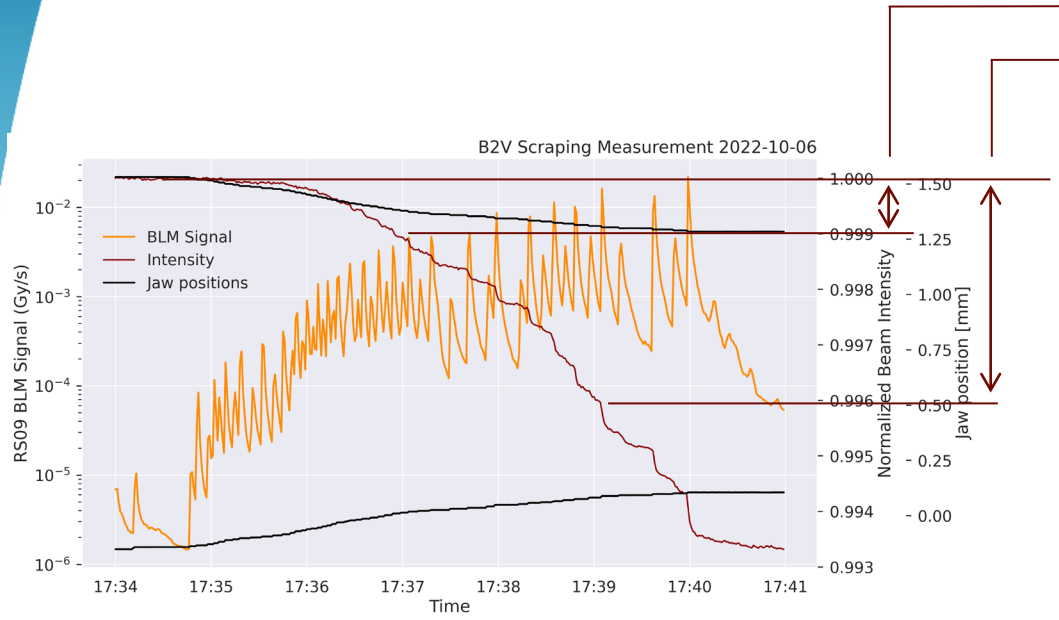

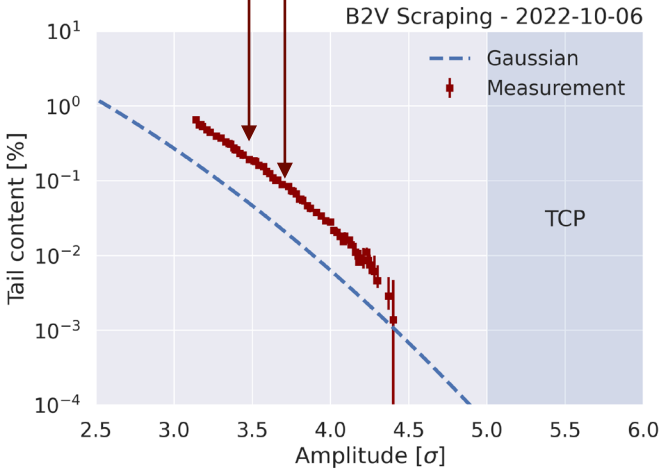

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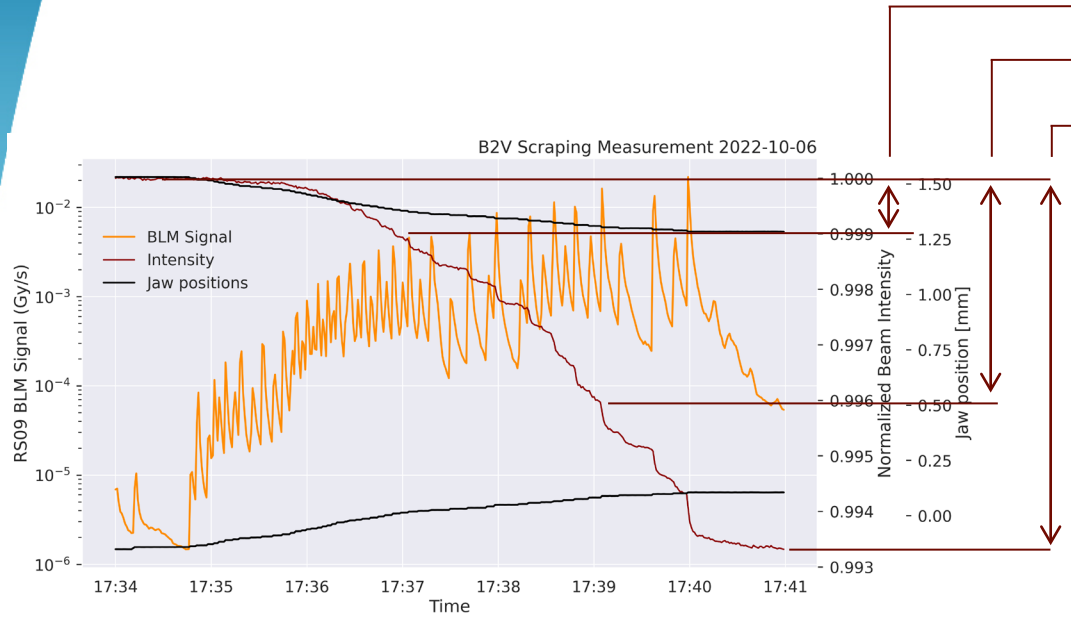
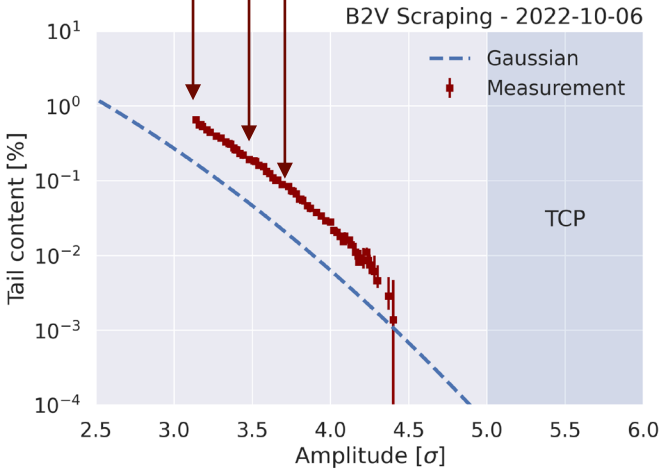
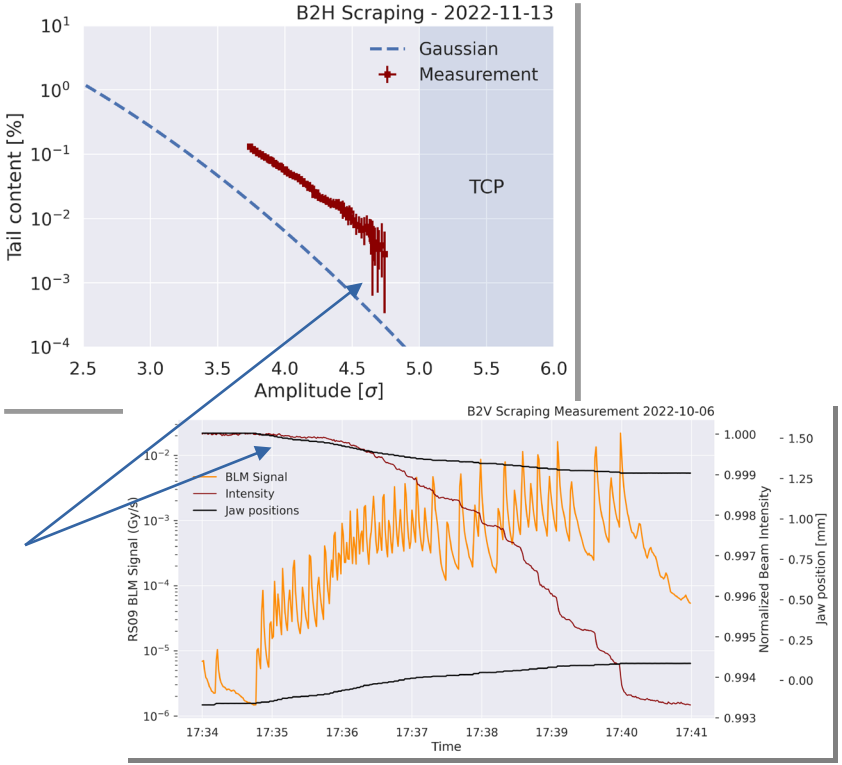




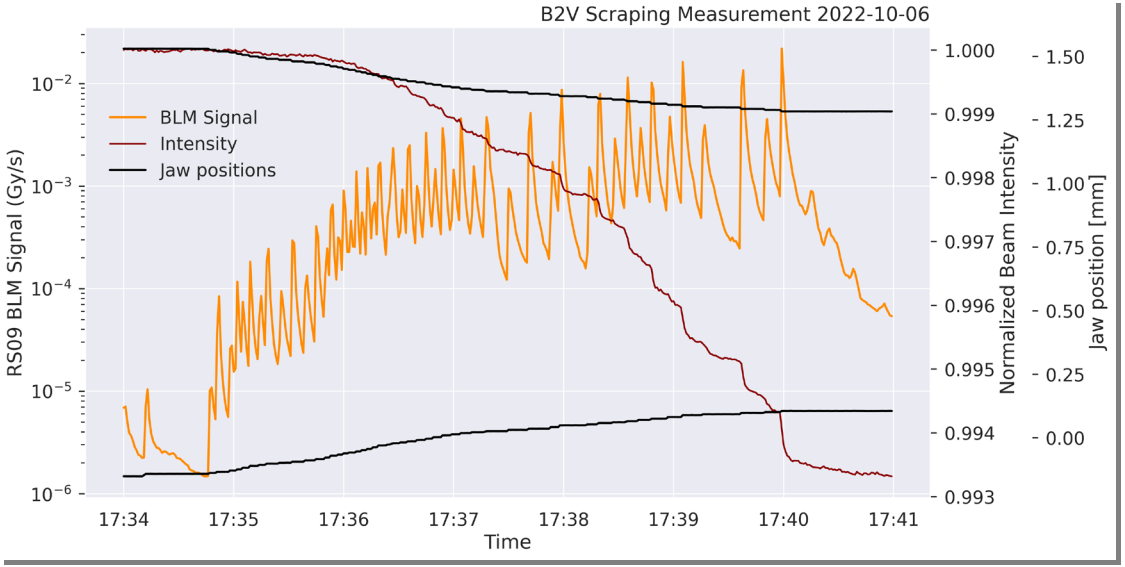
BCT-based analysis

- Direct measurement of charges lost
- Straightforward analysis
- F-BCT data for bunch-by-bunch halo content: ongoing study
- Minimum resolvable amount ~10^9 charges
- Halo content at large amplitudes with large error bars
- Less and less accurate for larger initial collimator cuts

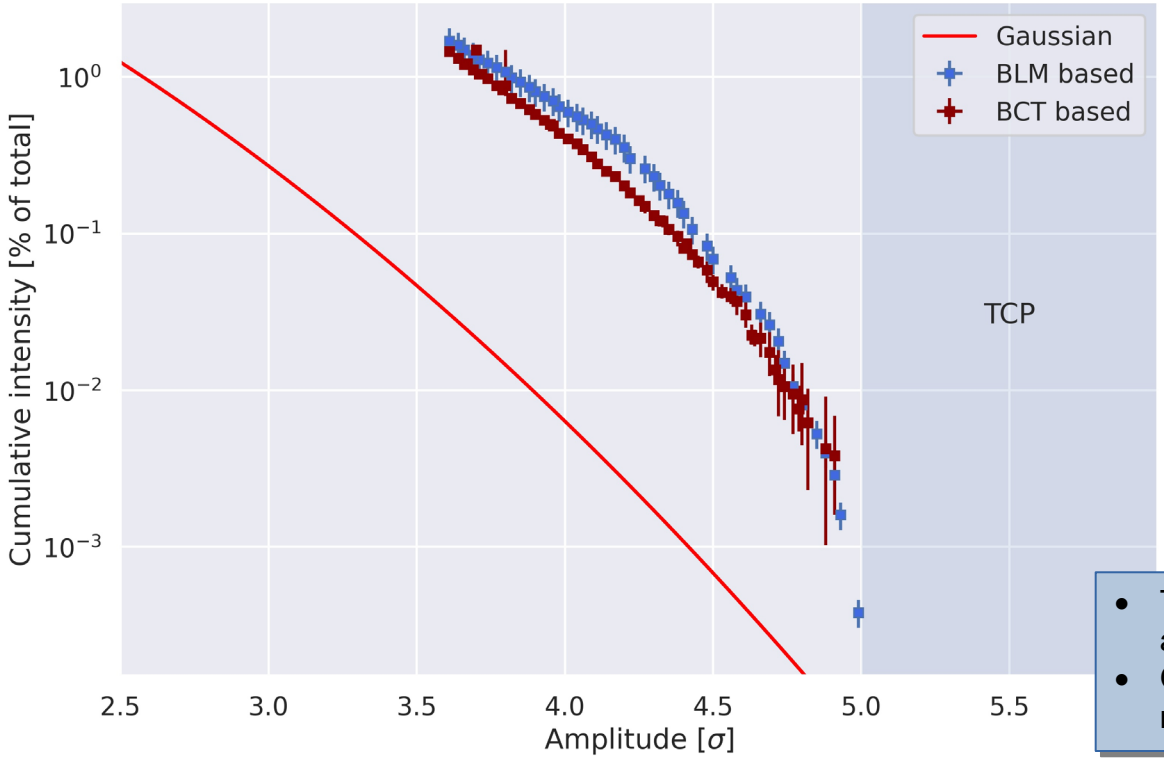


BLM-based analysis

- BLM system: large dynamic range (~8 orders of magnitude)
- Losses of ~5 × 10^4 charges can be detected
- Requires dedicated calibrations with BCT above resolution: Gy/s → charges



Comparison of BCT and BLM analysis

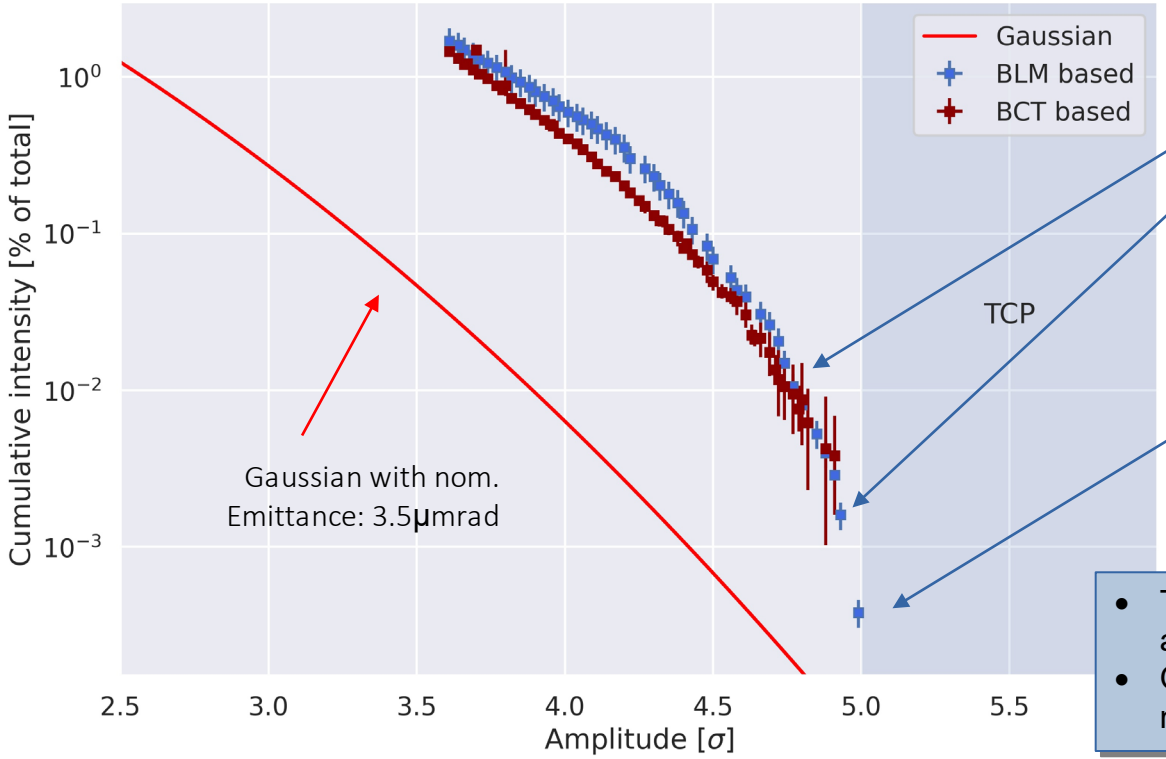


N.B. Measured emittances smaller than nominal

HL-LHC

- TCP settings of 8.5σ are considered
- Only BLM method might be usable

Comparison of BCT and BLM analysis



BCT error bars from signal fluctuation

BLM error bars from calibration uncertainties

Small loss amounts: Only measurable with BLMs

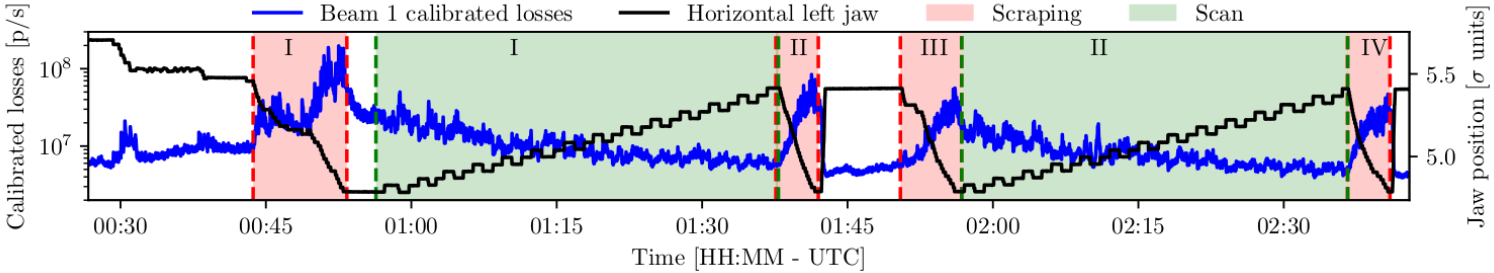
N.B. Measured emittances smaller than nominal

HL-LHC

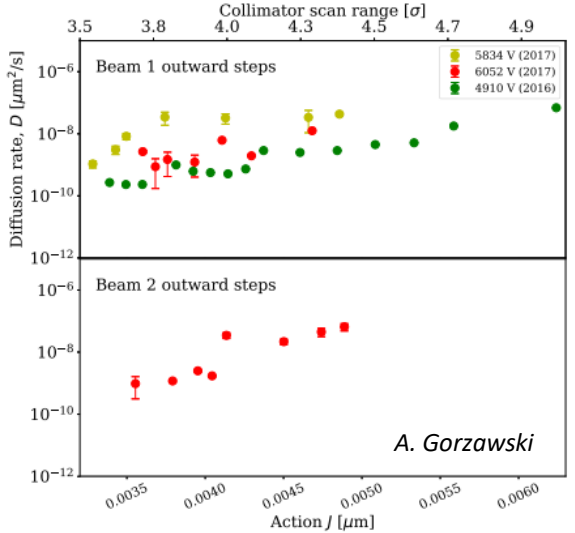
- TCP settings of 8.5σ are considered
- Only BLM method might be usable

Diffusion Measurements

C. E. Montanari, IPAC2023, WEPA022



- Scrapings typically combined with diffusion measurements
- **Run 1/2**: **Linear diffusion coefficient** estimates based on in- and outward movements (same studies performed at Tevatron, see G. Stancari, HB2014, WEO3AB01)
- **Run 3**: Data for **non-linear diffusion model** calibration: optimized collimator sequence [C. E. Montanari, IPAC23, WEPA022]



Results from LHC Run 2 and Run 3

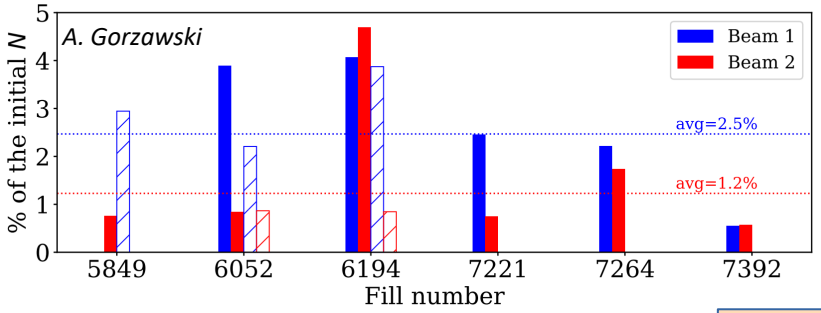
Halo Measurement Results

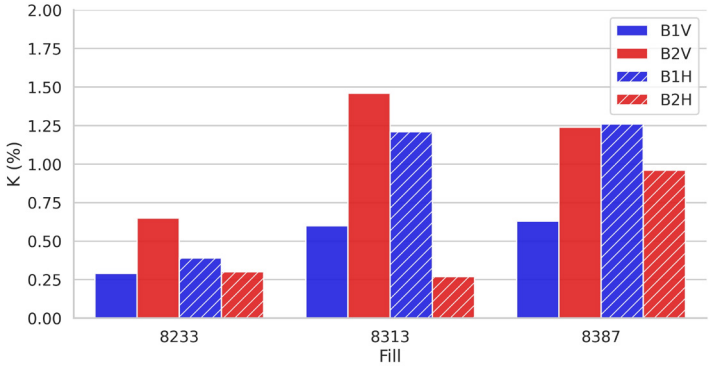
LHC Run 2

- Different optics and bunch intensities
- Smaller than nominal emittances
- Scrapings down to 3 – 3.5σ

LHC Run 3 (After LHC injector upgrade)

- All measurements at β*=30cm
- Smaller than nominal emittances
- Scrapings down to 3 – 3.5σ



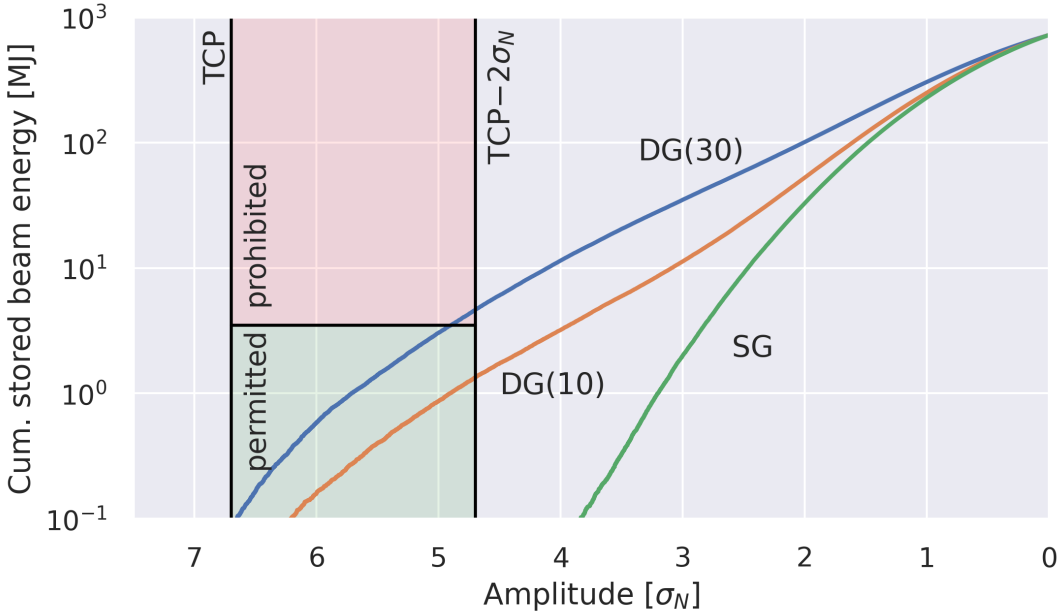


Note the different Scales!

HL-LHC
Halo Monitoring

Halo Monitoring Requirements

- HL-LHC: Active 2D halo monitoring needed
- Clearance of 2σ from TCP needed
- Imperatively non-destructive, for example synchrotron light
- Interlock on cumulative halo above defined threshold
- Required resolution of <0.1% of total intensity



Outlook

Plans for Run 3 Measurements

- Run 3 measurements after hours of collision still needed as HL-LHC bunch intensities are approached
- Some other exploratory studies planned (selection):

- **Measurements at injection energy**
- Probe halo at injection vs. scraping in SPS (LHC injector)
- Probe cross talk between horizontal and vertical plane

- **Measurements at top energy**
- Identify halo population after energy ramp (combine with injection scrapings)

Conclusions

Conclusions

- Halo measurements for high intensity machines are crucial and critical
- So far, no non-destructive solution available
- Technique: step-wise scraping with collimators - destructive and time consuming
  - BCT based analysis: direct measurement but relevant lower limit on ΔI
  - BLM based analysis: separate calibration but larger dynamic range
- Currently ongoing: further analyses of diamond BLM and FBCT data
  - Bunch by bunch analysis: can we understand halo origin and behavior better?

HiLumi
HL-LHC PROJECT