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# Losses for LHC beams, up to LHC injection

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Acknowledgment: BE-ABP, BE-OP, BE-CEM, SY-ABT, SY-BI, SY-STI, TE-VSC

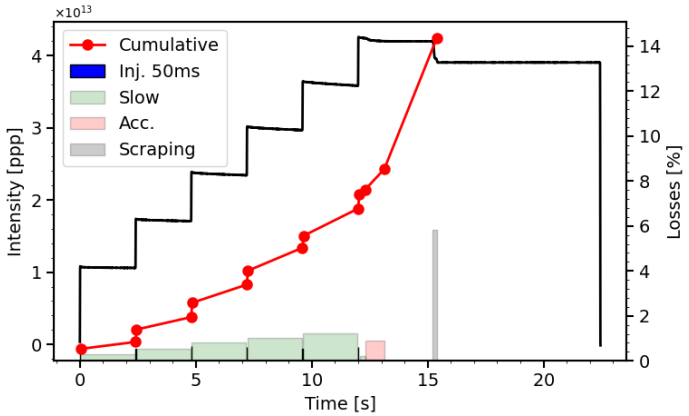
# Outline

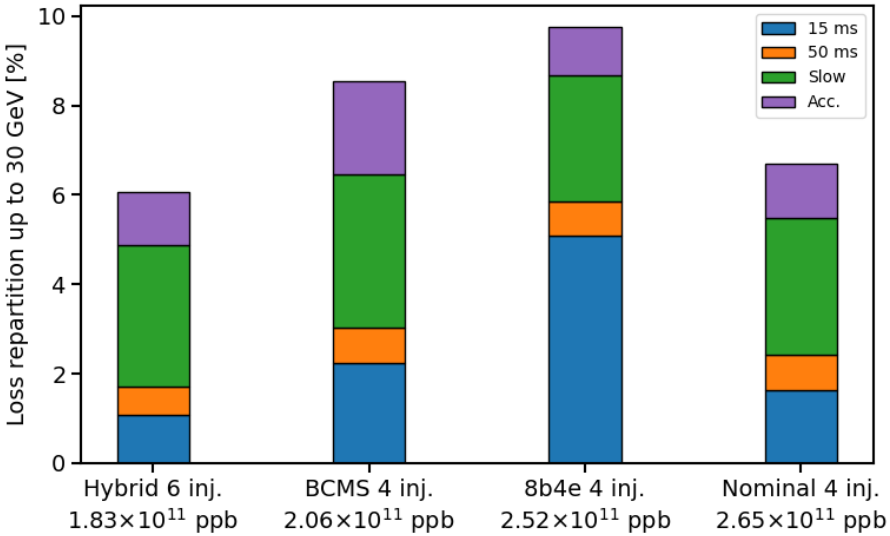
- SPS low energy losses
- LHC injection losses
  - State in 2023
  - Where losses come from ?
    - Data analysis
    - Profiles and tails
  - How many protons are we talking about ?
- What did we about losses in 2023?
  - MKE6 waveform
  - TL momentum steering
  - SPS scraping
- What can we do in 2024?
  - TCDIL alignment
  - Scraping
  - BLMs
- Prospects beyond 2024
- Conclusion

# SPS low energy losses

A. Lasheen

- Losses at SPS injection analysed from SPS BCT logged data
- Online tools developed to monitor and optimise those losses
- The transmission at LIU intensity from PS extraction to SPS 30 GeV was improved in 2023 to reach 93% (no scraping).
- Nonetheless, questions remain
  - What is the main mechanism behind losses right at injection and on the flat bottom ?
  - Is having smaller bunches from the PS beneficial ?
  - How to ensure good transmission in operation from one day to the next, especially at LIU intensity ?
  - What are acceptable losses in the SPS, before scraping ?

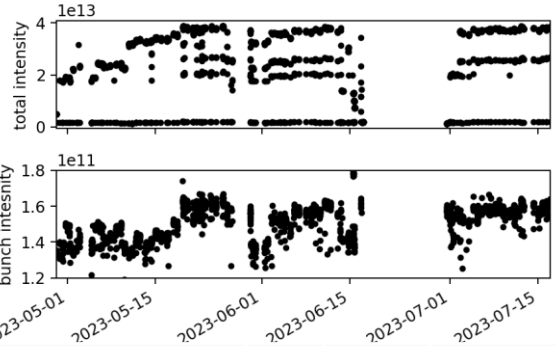


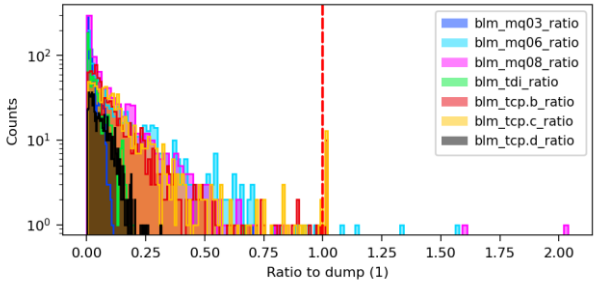

[1] A. Lasheen, PS-to-SPS transfer, 2023 studies and outlook for 2024 MDs, IPP 11/23

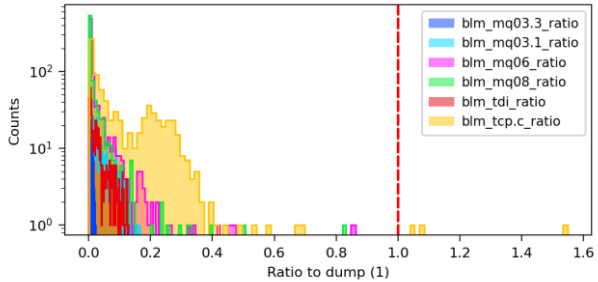
# LHC injection losses in 2023

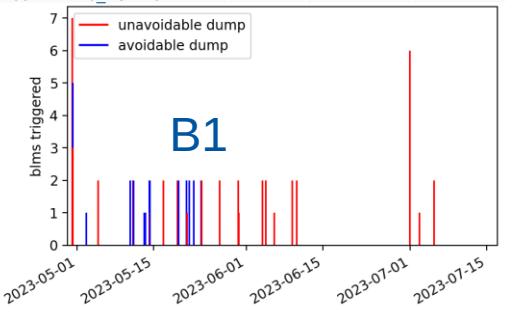
- High intensity proton injections from May to July
  - Up to 1.6-1.7E11 protons per bunch extracted from the SPS and 236 bunches per injection
- Injection losses
  - Cause dumps on the LHC side
  - Total of ~1200 injections with >100b
  - B1
    - Total of 41 (~3%) dumps during injection
    - Of which 14 could have been avoided by setting the TCPs thresholds to the electronic limit at the start of the run
    - Overall tense injection with P7 BLM signals routinely close to the limit
  - B2
    - 4 (~0.3%) dumps
    - Usually reasonably clean injections




| | BLM name | triggers | hypothetical triggers | BLM limit change relative change during the run |
|---|---|---|---|---|
| | B1 | | 41 out of 27 unavoidable | |
| P2 | BLMQI.06L2.B1E10_MQML | 5 | 5 | 1 |
| | BLMQI.08L2.B1E30_MQML | 3 | 3 | 1 |
| | BLMEI.06L2.B1E10_MSIB | 1 | 1 | 1 |
| | BLMQI.06L2.B1E20_MQML | 1 | 1 | 1 |
| | BLMQI.08L2.B1E10_MQML | 3 | 3 | 1 |
| | BLMAI.08L2.B2I23_MBA | 2 | 2 | 1 |
| | BLMAI.08L2.B2I22_MBA | 1 | 1 | 1 |
| P7 | **BLMTI.06L7.B1E10_TCP.C6L7.B1** | **38** | **23** | **2.5** |
| | **BLMTI.06L7.B1E10_TCP.B6L7.B1** | **30** | **16** | **2.5** |
| | | | | |
| | B2 | | 4 out of 4 unavoidable | |
| P8 | BLMQI.06R8.B1I30_MQML | 1 | 1 | 1 |
| P7 | BLMTI.06R7.B2I10_TCP.C6R7.B2 | 4 | 4 | 1.5 |
| | BLMTI.06R7.B2I10_TCP.B6R7.B2 | 1 | 1 | 1.5 |

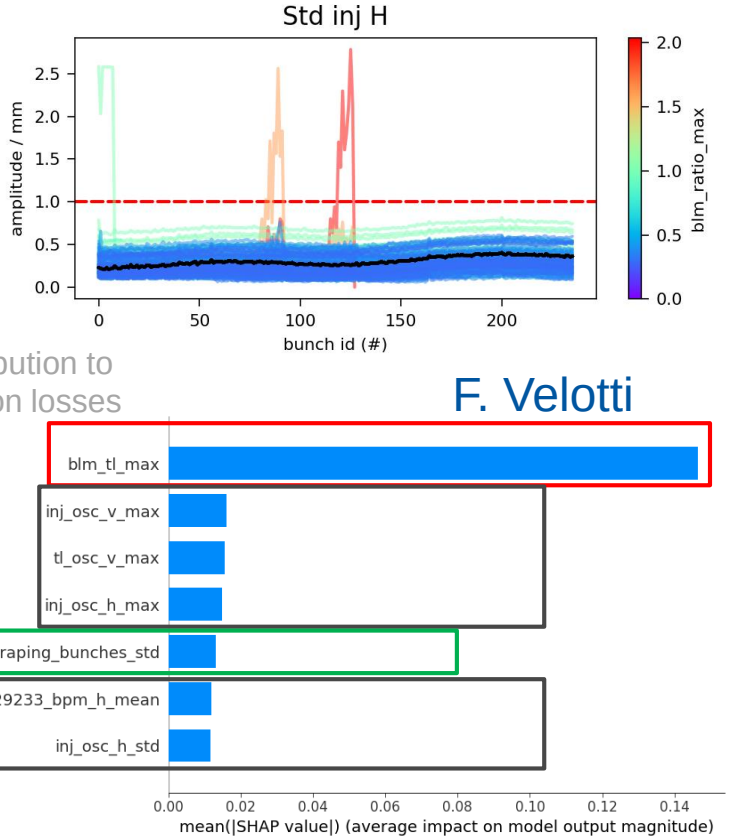


# Where losses come from? Data analysis

- Occasionally from instabilities
- Extensive data analysis to investigate correlations
  - Using PM and NXCALS data
  - Carried in 2022 [2] and 2023 [1] show correlations between transfer line and P7 losses -> relates to OP and ABT experience with difficult steering
  - New machine learning global analysis of ~35 parameters identified 3 important parameters [3]
    - **TL BLMs** main contributor to the model
    - **Quality of steering** is next
    - **Scraping homogeneity** 3rd most important
- Clear contribution from the steering across the TL collimators

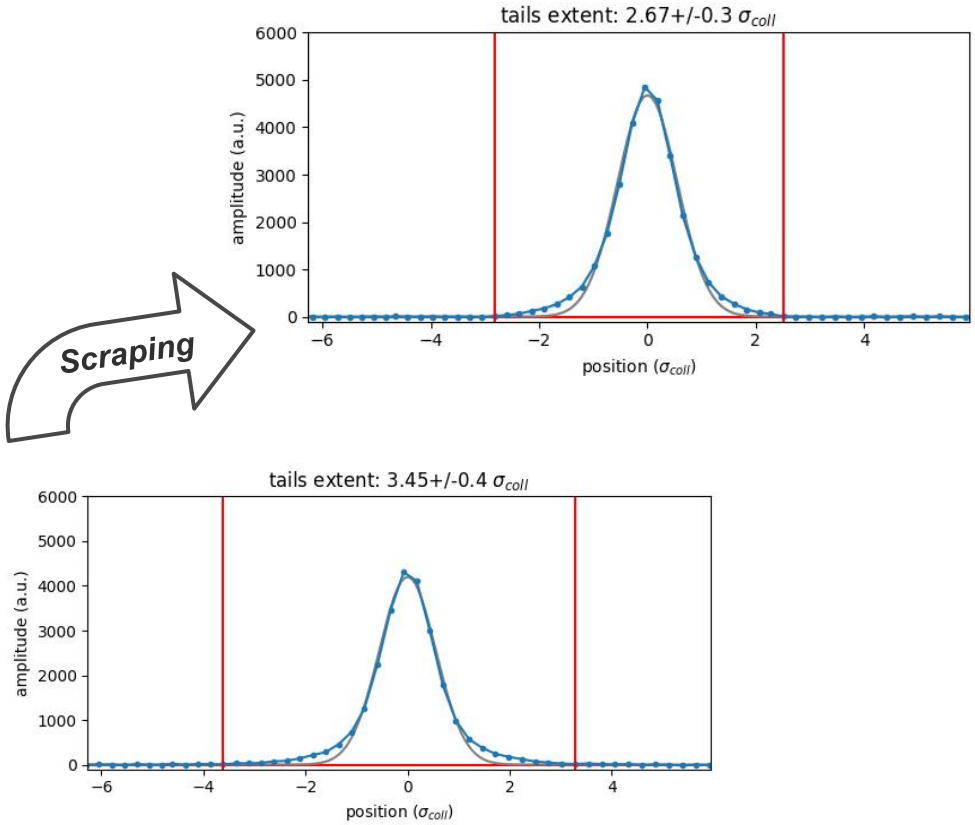




[1] F. Velotti, Why are B1 losses so high?, LBOC #152
[2] Y. Dutheil, Update on the investigations on the LHC side, IPP TF on tails, 09/2022
[3] V. Velotti, Report on SPS-LHC Transfer Issues, LMC #466
[4] B.Salvachua et al., BLMTWG Injection beam losses at the collimators, IR727 nov
[5] F.Velotti et al.,'Injection losses: do we need blindable BLMs?', BLMTWG 16 Jun

# Where losses come from? A look at profiles and losses

- More details in E. Lamb's talk (next)
- Profiles with and without scraping in the SPS
  - Data from 2022
  - After scraping and within the resolution of the measurement tails are <4$\sigma_{coll}$
  - Special settings can provide better resolution of the tails
- Collimator positions
  - Transfer line collimators set at 5$\sigma_{coll}$
  - LHC primary collimators set at 5.7 $\sigma_{coll}$
- Expecting very low level of losses from the tail population, in particular after scraping




[1]. F. Avesta, Transverse tails and Losses at LHC injection, JAPW22

# How many protons are we talking about?

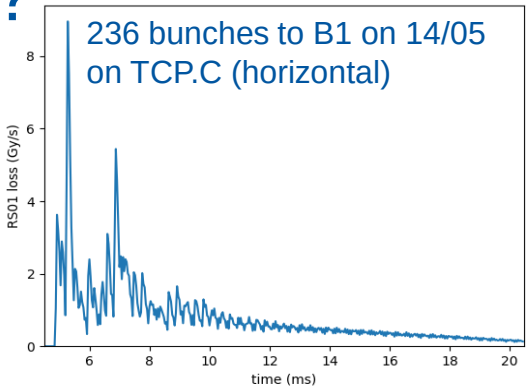
- LHC BLM calibration of losses
  - B. Salvachua and S. Morales (SY-BI) provided the BLM calibration and the processing instructions of the data which allow to estimate the number of protons lost in P7
- Using the PM BLM RS01 signal to extract peak and integrate losses
  - Example of 3.3E13 protons over 236 bunches to B1 on 14/05, nominal injection with reasonable losses

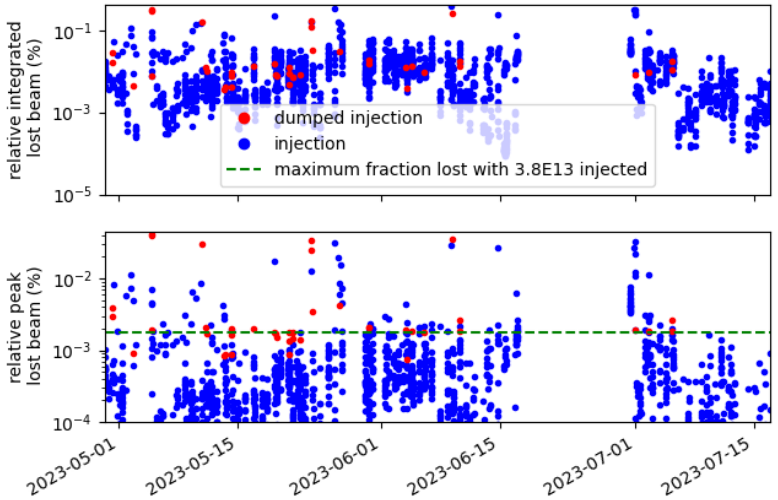
Peak loss of 2.6E8 protons or 8E-4% of the injected beam

Integrated loss of 8.9E9 protons or 3E-2% of the injected beam*

  - Integrated loss usually ~20x the peak on 40µs*

- Maximum allowed number of protons lost on the TCP
  - Peak loss of 0.67E9 protons within 40µs
  - With 3.8E13 protons (236x1.6E11)
    - Max peak loss of 0.0018% of injected beam
    - Max integ loss of ~0.04% of injected beam*




B1 only

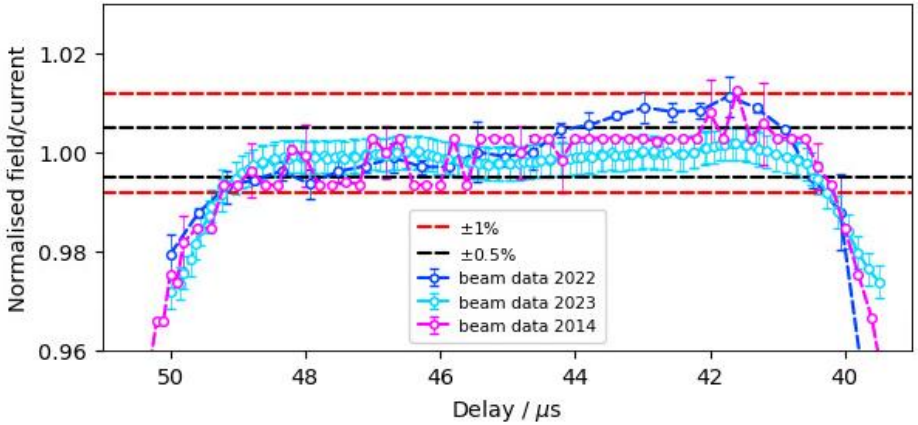
Relative to injected intensity, can be large for short trains

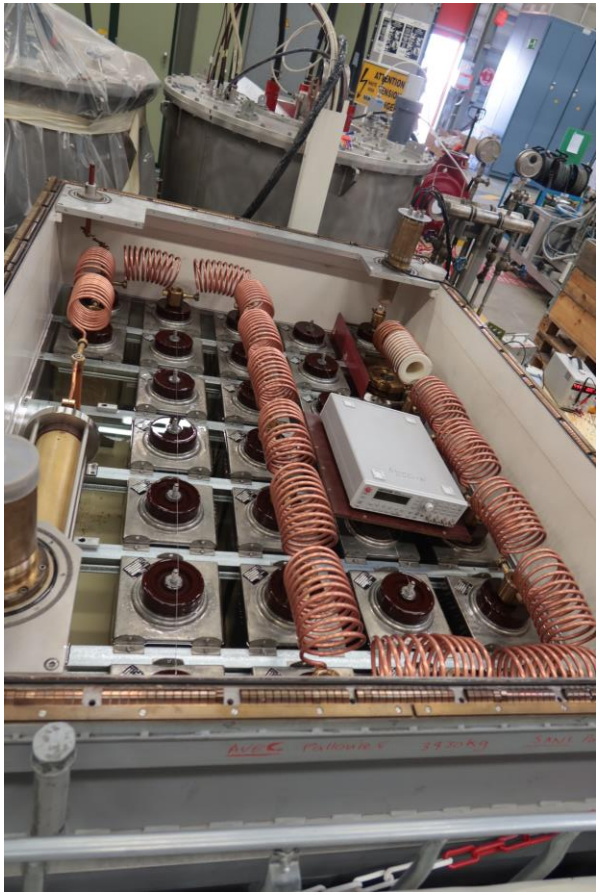
* Integrated loss as defined here appears to underestimate the total loss, typical beam lost at injection computed using larger RS BLM counters is ~ 0.1% [1]

[1] B. Salvachua, Private communication, 12/2023

# What did we do about losses? MKE6 flattening

- Measurements in 2022 showed a slope along the injected train
  - Tracked back to SPS extraction kicker MKE6 flatness [1]
  - Caused reduced margin at some TCDILs collimators and required an adjustment of 0.5σ to the gap of a collimator
- Hardware adjustment during YETS22/23 solved the issue
  - Carried by ABT-PPE team on the PFN

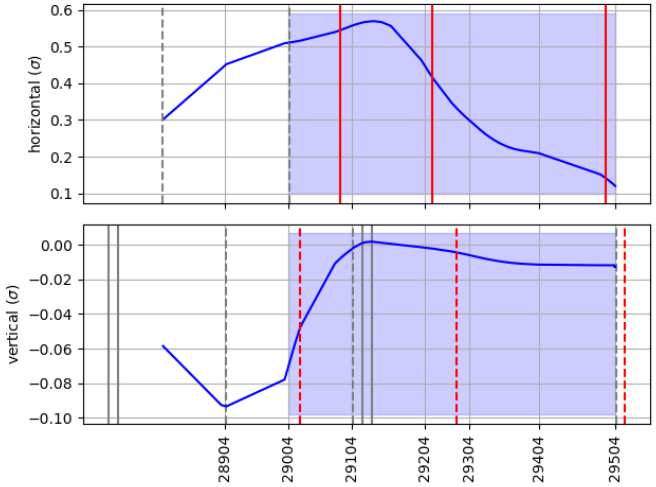


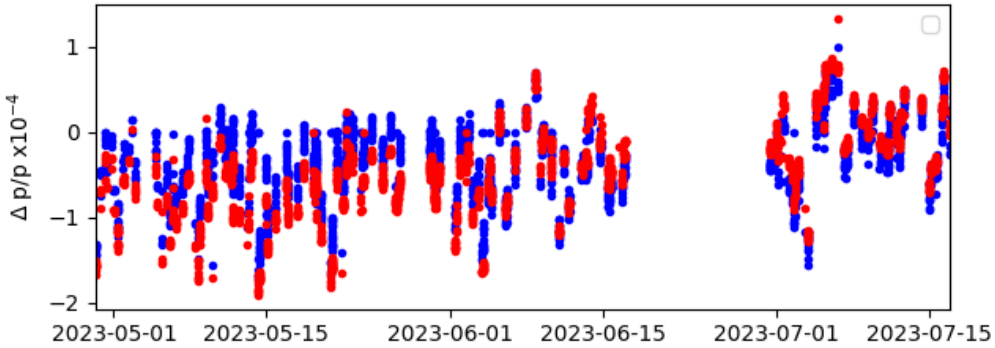



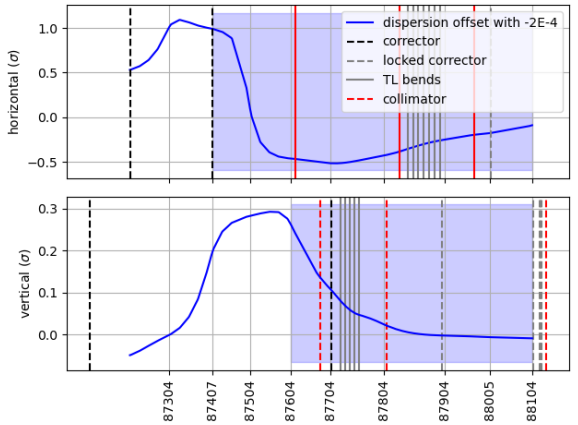
[1] C. Bracco, LHC injection: improvements and commissioning of beam-intercepting devices, JAPW22
[1] M. Barnes, Update on adjustment of the MKE6 PFN waveform, LIBD meeting 02/2023

# What did we do about losses? TL momentum steering

- Steering identified as strongly correlated with injection losses
- Momentum steering of the transfer line
  - Identified by J. Wenninger as the source of steering difficulties
  - Position offset caused by energy shift cannot be fully corrected with existing dipole correctors
  - B1 appears more challenging
- Occasional momentum steering carried by OP did improve the steering and level of losses



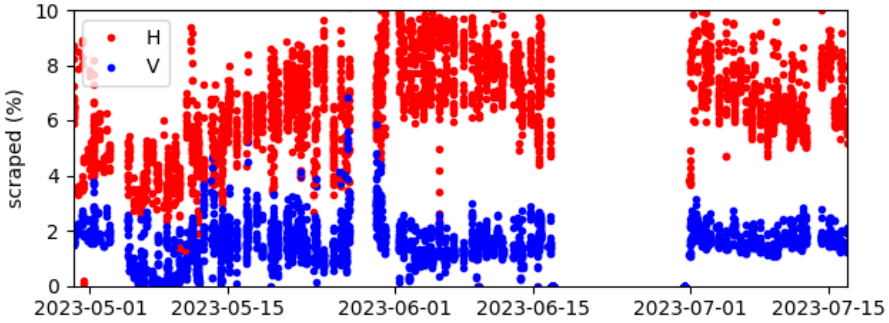



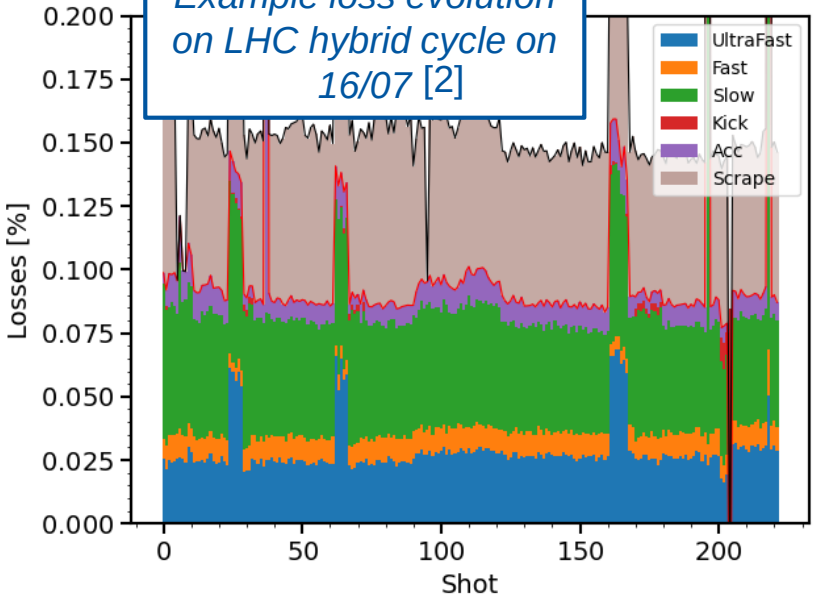

[1] J. Wenninger, SPS-LHC energy matching and TL momentum, LBOC #152

# What did we do about losses? SPS scraping

- Scraping is necessary and ~3% are considered in the LIU design report
- Done in the SPS at low energy to minimize induced radiations
- SPS beam is scraped in LSS1
  - In 2023 scraping was not stable and required continuous OP adjustments due to lost steps in motors
  - Some issues remain under investigations (see C. Sharp talk later today)
- Usual scraping levels in 2023 of ~7% in horizontal ~1-2% in vertical




*Example loss evolution on LHC hybrid cycle on 16/07* [2]




[1] Update on SPS scraper, SPS MPC #40
[2] A. Lasheen, PS-to-SPS transfer, 2023 studies and outlook for 2024 MDs, IPP 11/23

# Prospects for 2024: TCDILs alignment

- Converging indications that some TCDIL jaws have larger angle with the beam that what can be neglected
- TCDILs alignment
  - Long jaw (2m) are not meant to be angular aligned and any angle is neglected
  - Out-of-spec angles effectively reduces the available gap (± 5σ) but may also reduce the protection of the downstream elements
- Prospect for angular alignment
  - Beam is single pass -> one pilot every ~30s
  - FLUKA team investigating the possibility of measuring the jaw angle with beam and BLM signal [1]
- Automatic and simultaneous alignment of TCDILs under development
  - Only works for centroid alignment and does not align possible angles

[1] LIBD special LHC TCDIL, 10/2023

# Prospects for 2024: Scraping

- Hardware remains unchanged but operation and stability might be improved

- Similar levels of scraping as 2023
  - Present level of scraping does not seem to pose issue
  - SPS BLM and BPM crates are located in the arcs, and sufficiently far from the scraper

- Scraping studies
  - Profile characterisation with scraping
  - LHC injection losses Vs scraped fraction using trains

- Increased scraping is not sustainable with limited LIU margin
  - Maximum SPS injected bunch intensity specified at ~2.6E11, margin of 10% (losses + scraping)
  - Present scraping level with 1.6E11 reached ~10% (horizontal + vertical)

# Prospects for 2024: BLM

- Followed by the BLM Thresholds WG
- Commissioning of P2&8 BLM blinding
  - Every year hardware commissioning is completed, only missing commissioning with beam which is part of the injection commissioning procedure
  - Extension to P7 is not favored, and not possible in the short-term (See S. Morales talk)
- BLM displacement
  - Displacement of P7 BLMs to reduce their response
  - Under study by BI for possible implementation during the YETS
- LICs
  - Proposal to replace Secondary Emission Monitors (SEM) at the collimators by Little Ionization Chambers (LIC)
  - Only possible by LS3 to use for interlock, but request to populate Beam 1 with LIC during 2024 is on-going
- Diamond BLMs
  - Presently installed along the whole chain (SPS scraper, SPS extraction, LHC injection and LHC collimation)
  - Large quantity of data that could be reviewed and analysed together with BI
- see S. Morales Talk for detailed discussion on BLMs

# Prospect beyond 2024

- Scraping
  - Installation of new scraper during YETS 24/25 with possibility of multiple scrapings per SPS cycle
  - Reduction of the level of scraping is needed to reach LIU targets
- Identify the source of the losses (tail development, TCDI alignment, other ?)
  - Injection losses in the SPS, and slow losses at acceleration
  - Tail development across the chain, but in particular between SPS scraping and LHC P7
  - TCDI alignment and jaw angular characterisation
  - Try to identify the source of losses and mechanism of the tail development, and understand the B1/B2 loss asymmetry
- Reduced BLM response with different hardware (see S. Morales talk tomorrow)

# Conclusion

- SPS low energy losses
  - Highest transmission of LIU beam achieved of 93%
  - Improved online monitoring needed to reach and maintain optimal performances
- Injection losses in the LHC
  - This is a question of availability as the machine is and remains protected by the collimators
  - Problem is the very sensitive BLMs in P7
- What did we do in 2023?
  - TL momentum steering to improve the beam alignment through the TCDIL region
  - MKE6 flattening improved the effective aperture for long trains
- What can we do for 2024?
  - Scraping stability improvement which might reduce shot-to-shot variability
  - Set the RS01 TCP threshold to the maximum at the start of the run
  - BLMTWG reviewing the possibility of moving some P7 BLMs
  - FLUKA team is modelling the effect of TCDILs angles on measured losses to develop a possible angular alignment method before the restart
- Projection of present numbers need improvement to reach LIU target injected in the LHC
  - 93% transmission to 30GeV + 7-10% scraping against 10% total budget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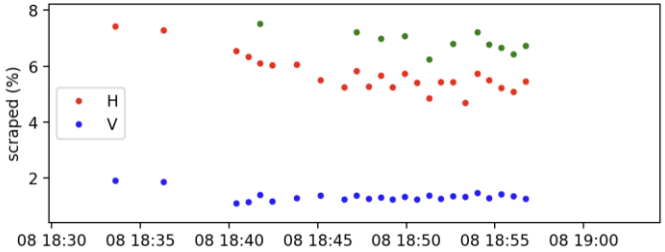
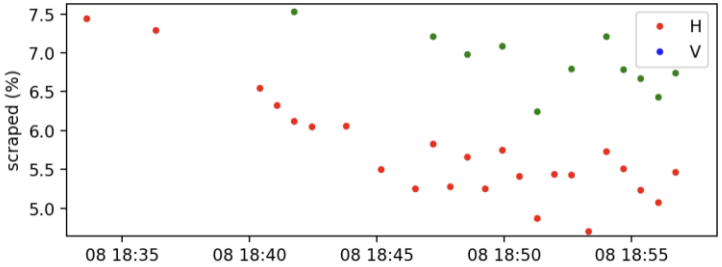
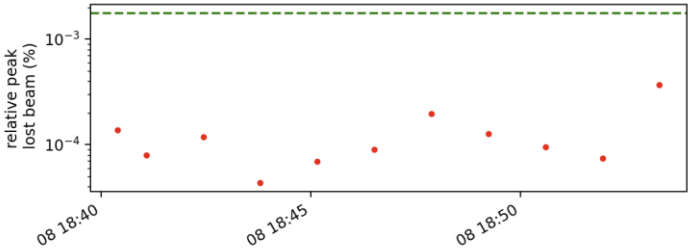
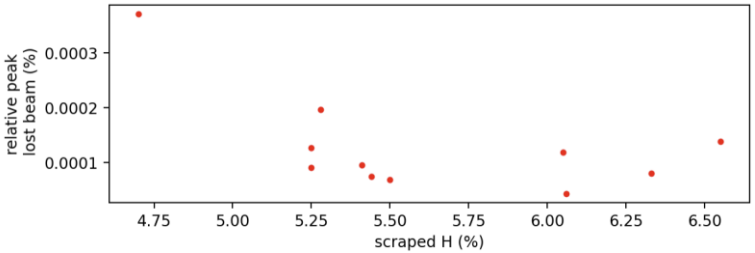
# Shot-to-shot variability

- Show shot-to-shot variability of losses and scraping, check correlation
- Example of fill on 2023-07-08, focus on B1



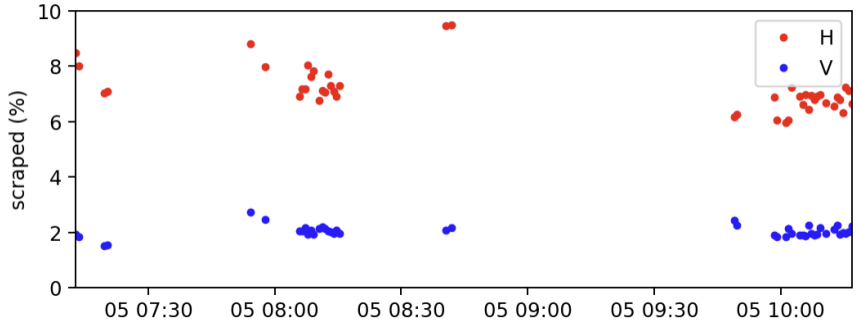



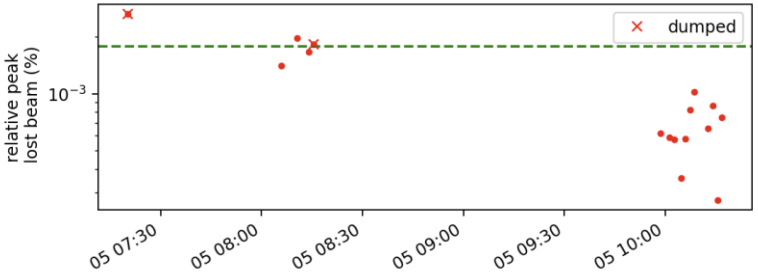



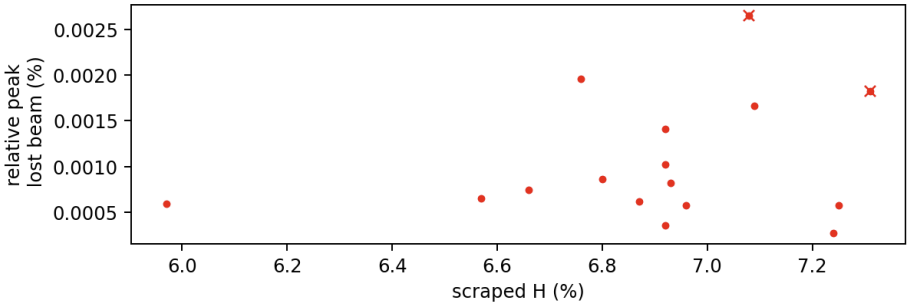



# Shot-to-shot variability

- Show shot-to-shot variability of losses and scraping, check correlation
- Example of fill on 2023-07-05, focus on B1
- This filling had 2 dumps



# SPS radiation survey LSS1

- SPS Radiation Survey Results
  Comparison of 30h measurement after RUN 2022 & RUN 2023, Florent PHILIPPON (HSE-RP-AS), 29/09/23
- SPS Sextant 1 – Comparison Nov 2022 – Sept 2023 (30h of cooldown)