
CERN

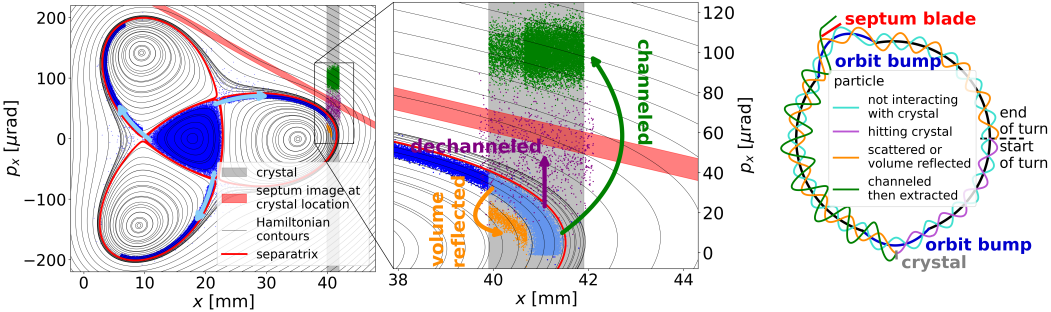
Beam Manipulations with Stable Islands and Bent Crystal Near the 3rd-order Resonance in the SPS

Dora Veres, Hannes Bartosik, Massimo Giovannozzi, Konstantinos Paraschou, Frederik van der Veken, Francesco Maria Velotti

Thanks: SPS OP, Bjorn Lindstrom, Stefano Redaelli

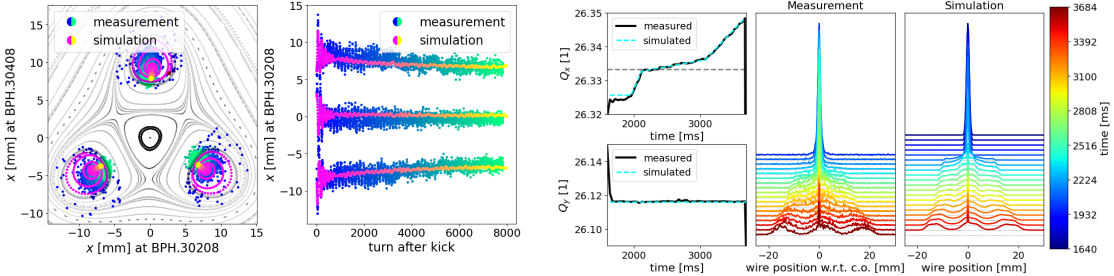
Motivation

- Test a new approach to slow extraction that combines particle trapping in stable islands with channeling by a bent crystal to reduce losses on the extraction septum (for details see this paper or this talk)



Short Parallel MDs

- Preliminary studies at 100 GeV of creating and trapping in stable islands near the 3rd-order resonance
- Phase space with islands detected and reconstructed by kicking the beam
- Trapping achieved by sweeping the tune across the resonance, as well as by radial steering
- Measurement results in excellent agreement with simulations



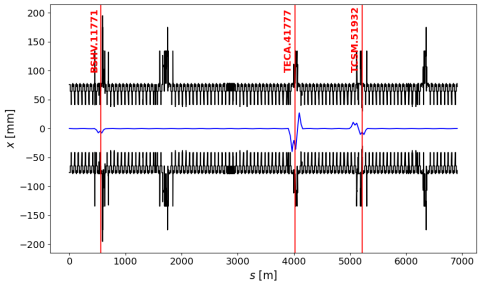
Dedicated MD – Goals

- First attempt at a proof-of-principle test **without extraction to protect septa**
- Demonstrate particle transport in stable islands to the crystal (TECA.41777)
- Channel particles by crystal onto the collimator (TCSM.51932)
  - Channelled beamlet intercepted by positive collimator jaw in the same turn as channelling or two turns later by the negative jaw
  - Use the scraper (BSHV.11771) as secondary bottleneck to reconstruct channelled distribution from collimator linear scan

Dedicated MD – Machine settings

- **Optics:** LHC Q26
- **Tune:** $Q_x = 26.31,\ Q_y = 26.11$
- **Chromaticity:** $Q'_x = -13.8,\ Q_y = -0.6$
- **Energy:** 100 GeV
- **Energy ramp at flat top:** 0.33 GeV over $\sim$4 s
- **Non-linear elements:**
  - LSE.40602: $k_2 = 0.4$ m^{-3} (extraction sextupole to drive resonance)
  - LOF: $k_3 = -6.0$ m^{-4} (octupoles to ensure presence of stable islands)

- **Beam:**
  - No. of bunches: 4 $\rightarrow$ debunched at flat top
  - Intensity: 1e10 p/b
  - Emittance: $\epsilon_x^* \simeq 0.8\,\mu$m, $\epsilon_y^* \simeq 0.8\,\mu$m
- **3 closed orbit bumps:**

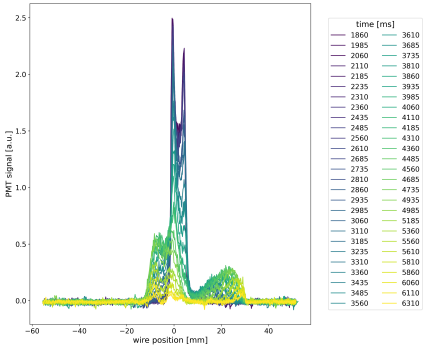


Dedicated MD – Expectations and results

- Stable islands visible in wire scanner profiles
- Beam intensity is steadily depleted
- Clear difference in the start of losses with and without crystal
- Losses only at collimator and/or scraper depending on the setup

Dedicated MD – Expectations and results

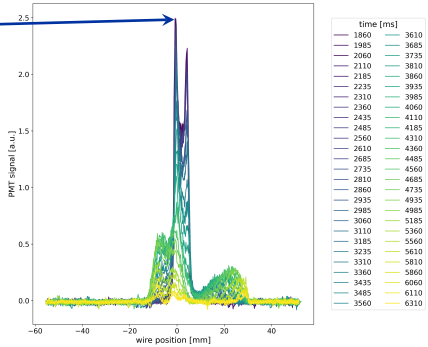
- **Stable islands visible in wire scanner profiles** ✓
- Beam intensity is steadily depleted
- Clear difference in the time of the start of losses with and without crystal
- Losses only at collimator and/or scraper depending on the setup



Dedicated MD – Expectations and results

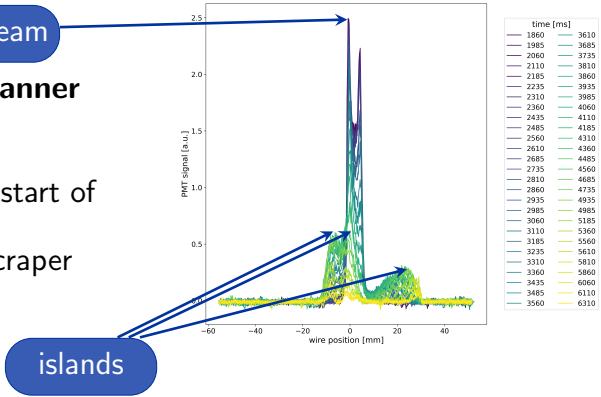
hollow beam

- **Stable islands visible in wire scanner profiles** ✓
- Beam intensity is steadily depleted
- Clear difference in the time of the start of losses with and without crystal
- Losses only at collimator and/or scraper depending on the setup



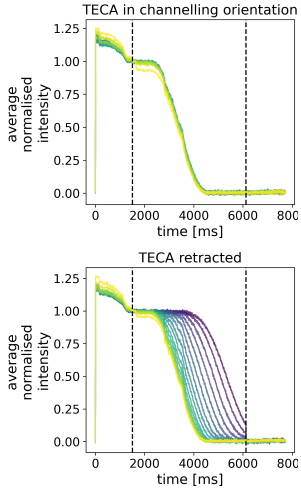
Dedicated MD – Expectations and results

- **Stable islands visible in wire scanner profiles** ✓
- Beam intensity is steadily depleted
- Clear difference in the time of the start of losses with and without crystal
- Losses only at collimator and/or scraper depending on the setup



Dedicated MD – Expectations and results

- Stable islands visible in wire scanner profiles
- **Beam intensity is steadily depleted** ✓
- **Clear difference in the start of losses with and without crystal** ✓
- Losses only at collimator and/or scraper depending on the setup



Dedicated MD – Expectations and results

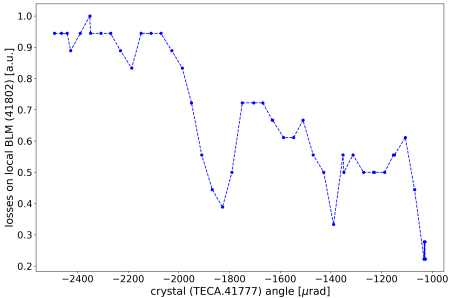
- Stable islands visible in wire scanner profiles
- Beam intensity is steadily depleted
- Clear difference in the start of losses with and without crystal
- **Losses only at collimator and/or scraper depending on the setup** X

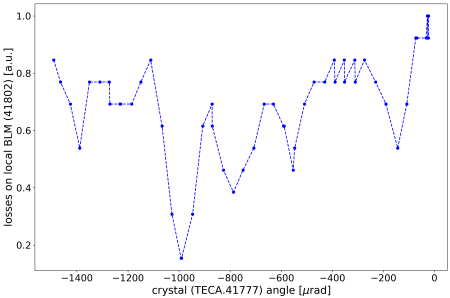
- Losses observed at:
  - TCSM (BLMR.52020, BLML.52108, BLMR.52108)
  - TECA (BLMR.41804)
  - additional bottleneck upstream of TECA (BLMR.41607)
- Scraper was not exposed

Dedicated MD – Expectations and results

TECA alignment

- Position fixed – only angular alignment necessary
- Done automatically using tool developed by Francesco
- Minimum step 30 µrad – critical angle is 20 µrad at 100 GeV
- Crystal aligned 180 µrad off from expected
- Skew planes?

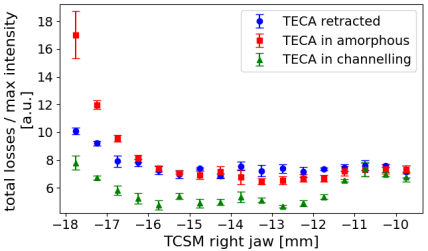


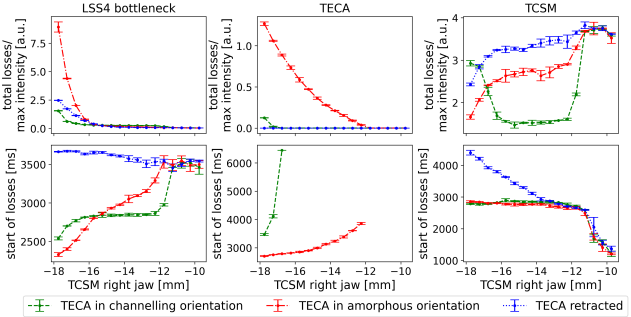


Dedicated MD – Expectations and results

Direct quantitative comparisons based on BLM signal magnitudes are not possible

- 200 Hz BLM closest to TCSM is already ∼30 m downstream
- BLM closest to TECA is ∼10 m downstream
- Total losses in ring change as a function of collimator and crystal settings

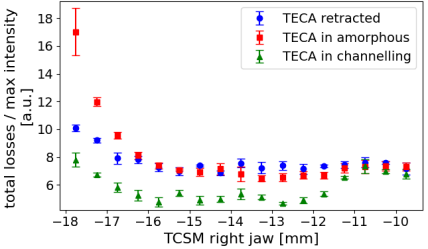




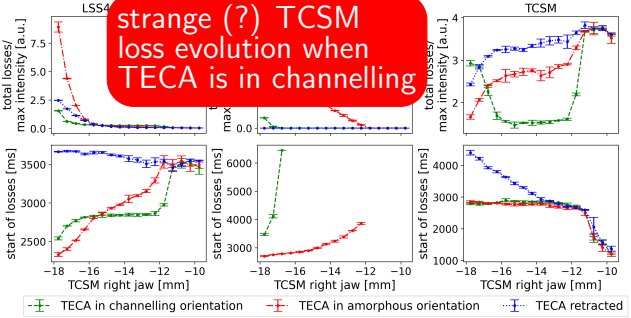
Dedicated MD – Expectations and results

Direct quantitative comparisons based on BLM signal magnitudes are not possible

- 200 Hz BLM closest to TCSM is already ∼30 m downstream
- BLM closest to TECA is ∼10 m downstream
- Total losses in ring change as a function of collimator and crystal settings

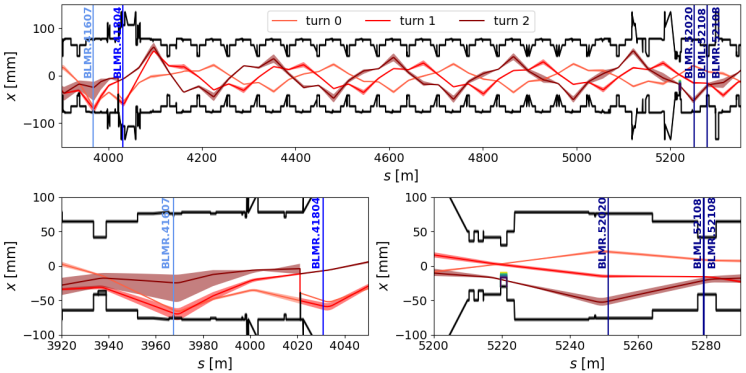


strange (?) TCSM loss evolution when TECA is in channelling



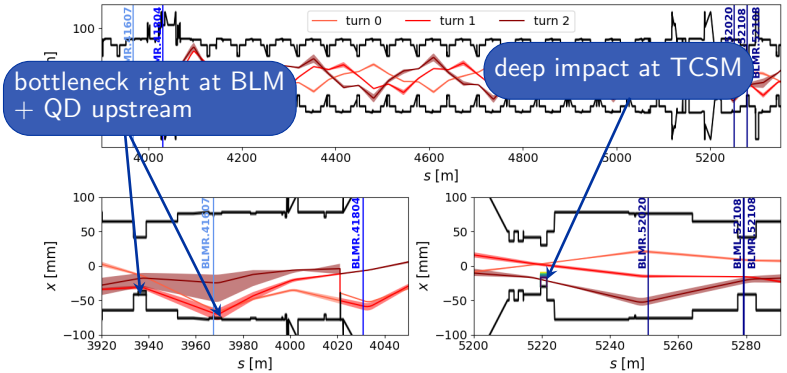
Dedicated MD – Expectations and results

- Simulation without closed orbit error and with measured TECA angle
- Crystal bending 160 µrad instead of 174 µrad (see this talk by Francesco)



Dedicated MD – Expectations and results

- Simulation without closed orbit error and with measured TECA angle
- Crystal bending 160 µrad instead of 174 µrad (see this talk by Francesco)



- LSS4 bottleneck is likely a combination of two sources (at QD and at BLM) that may differ depending on different scenarios and settings
- We observed that the LSS4 bottleneck could be removed by a different bump at the crystal ⇒ to be fixed next time!

2024 experience

Issues

- Complicated measurements with many ingredients that can fail individually
- No possibility to do full test in parallel MDs $\Rightarrow$ limited time
- Difficult to reconstruct actual losses with lack of BLM calibration in special conditions
- Difficulty retrieving wire scanner data at low intensity with islands
- We were unable to use the full scheduled time during the dedicated MD due to issues with the cycle and the usual interruptions from LHC fills

Highlights

- Many opportunities for short parallel MDs with generally good availability
- Great flexibility from SPS OP and parallel users in accommodating requests
- Dedicated MD could be extended into the night to make up for lost time

2025 requests

- Despite some issues, we observed several expected features successfully in 2024 MD, BUT some open questions remain $\Rightarrow$ we would like to repeat a refined measurement
- Ideally 2 dedicated MD slots to
  - better measure and correct closed orbit,
  - measure crystal position in nonresonant conditions
  - repeat 2024 procedure with refined orbit bump at crystal
- No extraction needed
- Would be ideal during beam commissioning period

Thank you!

Dedicated MD – Approach

- Large $Q'_x \Rightarrow$ different δ_p particles "see" different phase space
- Changing $p_0c \Rightarrow$ changing $Q_x \Rightarrow$ trapping in stable islands
- Risk of recapturing particles in the core $\Rightarrow$ kick beam at the start to deplete the origin of phase space