UPDATE FROM DECEMBER 2024 SUPERKEKB SECONDMENT

200TH FCC-ee ACCELERATOR DESIGN MEETING & 71ST FCCIS WP2.2 MEETING

J. Salvesen

with thanks to G. Iadarola, G. Broggi, R. Ueki, H. Sugimoto, Y. Funakoshi, M. Masuzawa, K. Oide, F. Zimmermann, P. Burrows

Funding statement

EAJADE

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without whom this work would not have been possible

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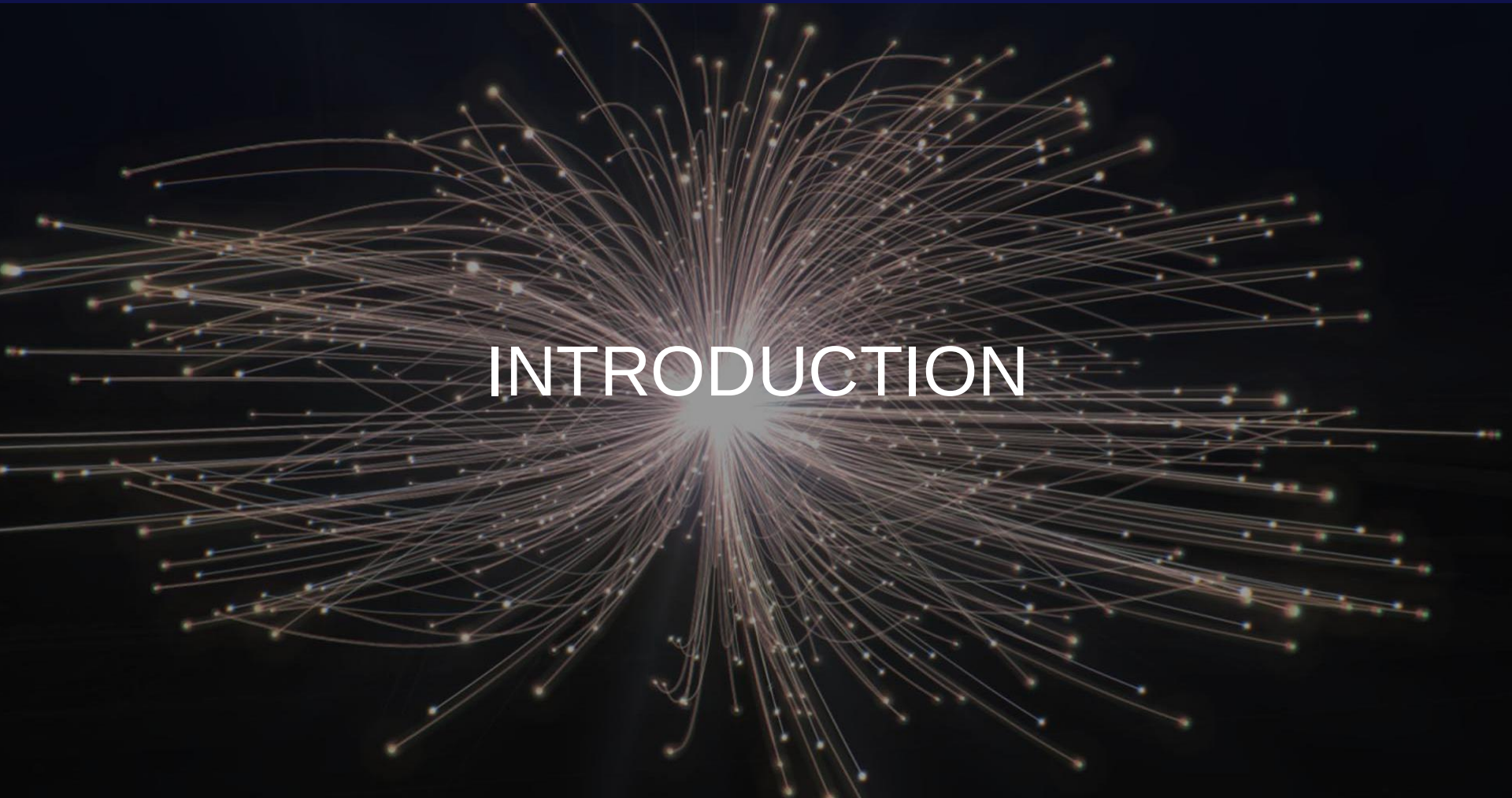
EAJADE coordinators, who enabled this collaboration

And more not mentioned here



INTRODUCTION

Thesis Goal

Develop a realistic, self-consistent, model of the FCC-ee IP collision feedback system

- Realistic modelling of the measurable signals (BPMs, luminometers and more)
- Realistic feedback hardware considerations (corrector magnets, processing time)
- Self-consistent 6D lattice tracking including modelling of beam-beam interaction

Using this model, study the luminosity performance in the presence of magnet vibrations

But first, can I demonstrate this for SuperKEKB?

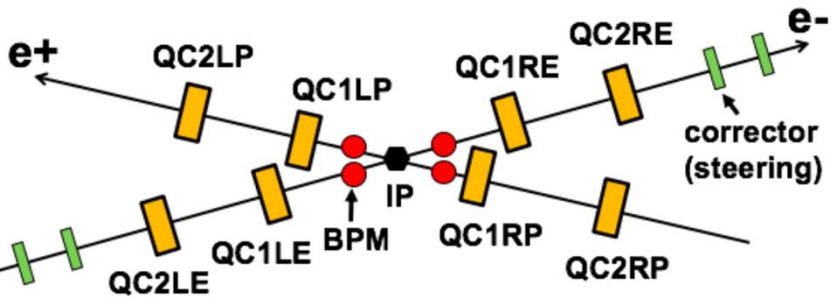
Relevant Presentations

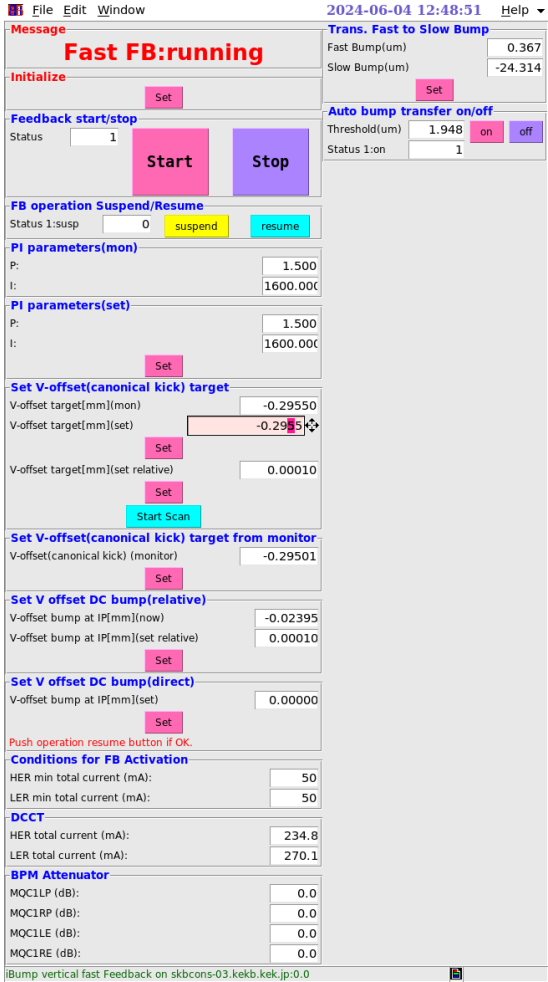
- **Report on IP Feedback studies at SuperKEKB**
  - 188th FCC-ee Accelerator design meeting & 59th FCCIS WP2.2 Meeting [10/07/24]
  - https://indico.cern.ch/event/1433104/
- **Introduction to Xsuite: An integrated beam physics simulation framework**
  - SuperKEKB MDI Taskforce meeting [19/12/24]
  - https://kds.kek.jp/event/52865/
- **iBump Feedback Target Dependence Studies**
  - コミッショニング・ミーティング (56) [13/12/24] *{Commissioning Meeting (56)}*
  - https://kds.kek.jp/event/53089/
- **Update on SuperKEKB Xsuite Modelling**
  - コミッショニング・ミーティング (56) [13/12/24] *{Commissioning Meeting (56)}*
  - https://kds.kek.jp/event/53089/
- **SuperKEKB Xsuite Model Development**
  - Modelling SuperKEKB with Xsuite [30/10/24]
  - https://indico.cern.ch/event/1471245/

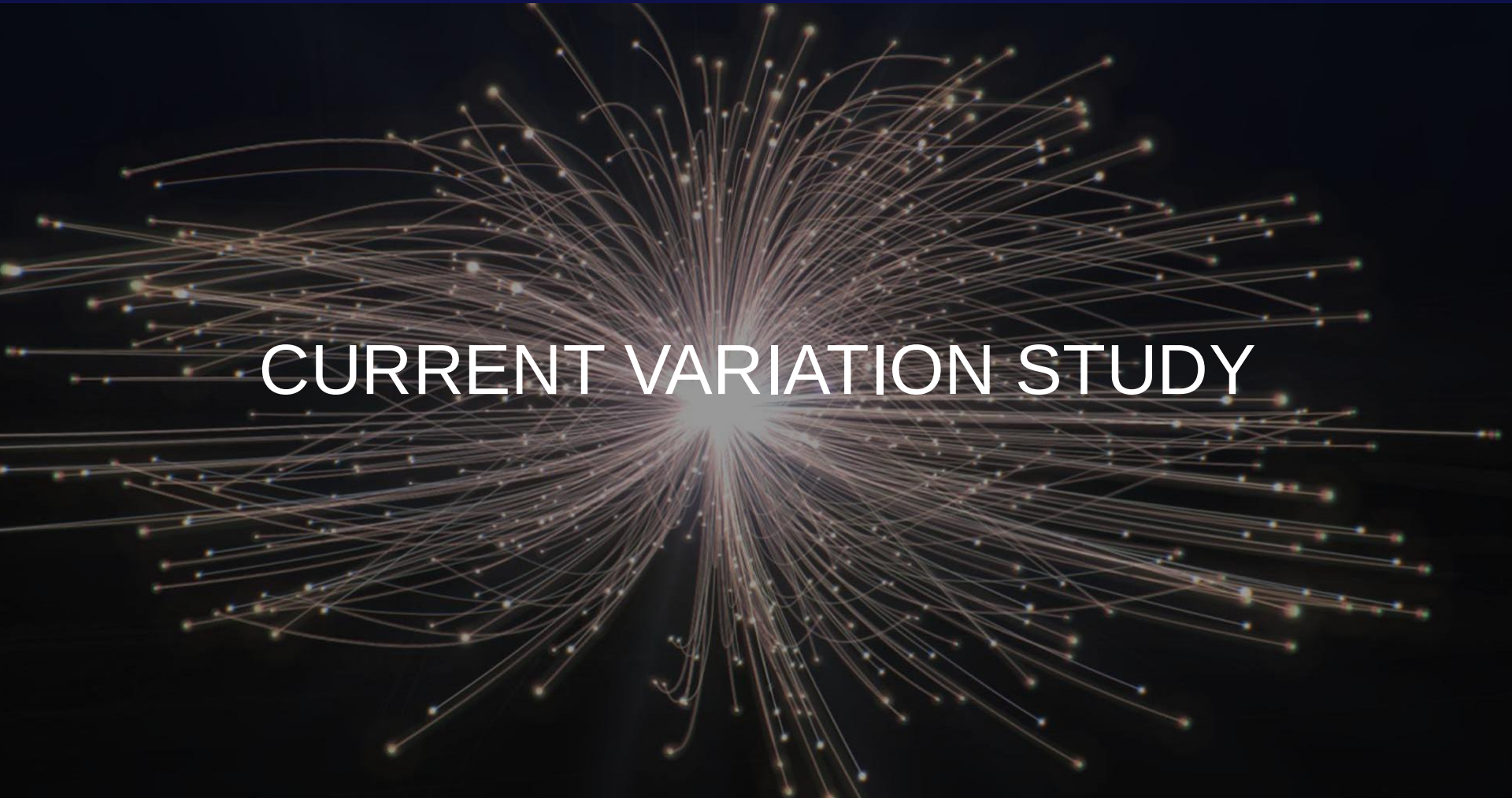
PART I: IBUMP FEEDBACK SYSTEM STUDIES

SuperKEKB iBump Feedback

- IP Fast Feedback based on beam-beam deflection
- Input signal:
  - 4BPMs ~0.5m up/downstream of IP, ~0.2um @ 3.6A resolution
  - Mechanically coupled to IP (BELLE-II)
- Correctors:
  - 8 vertical correctors, 4 horizontal correctors, 100urad max kick angle
  - Before and after final focus quadrupoles
- Linear matrix approach to calculate corrections



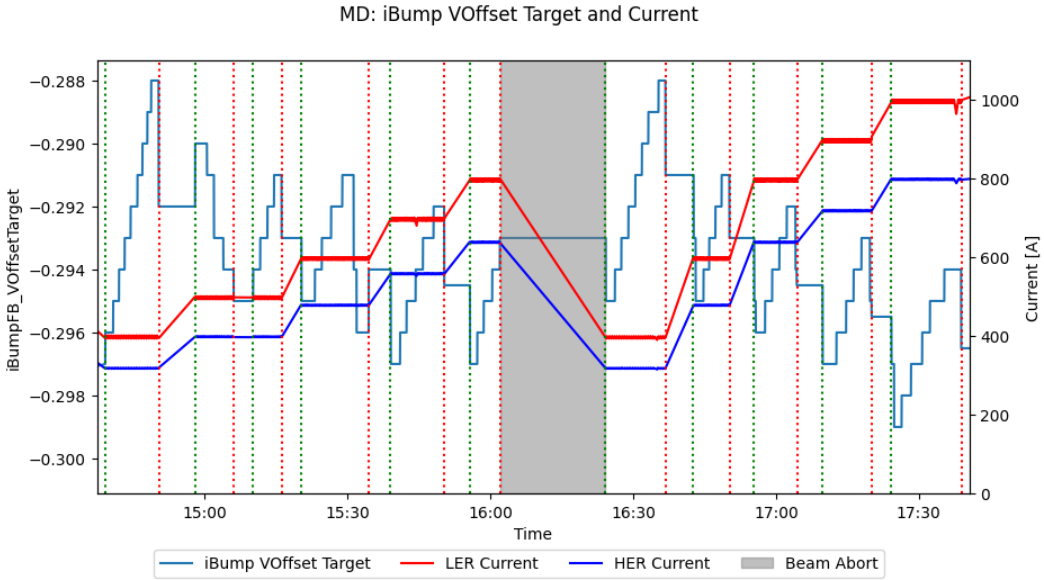




CURRENT VARIATION STUDY

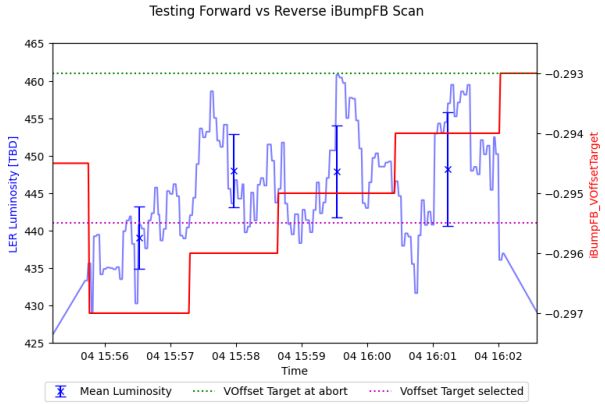
MD Overview

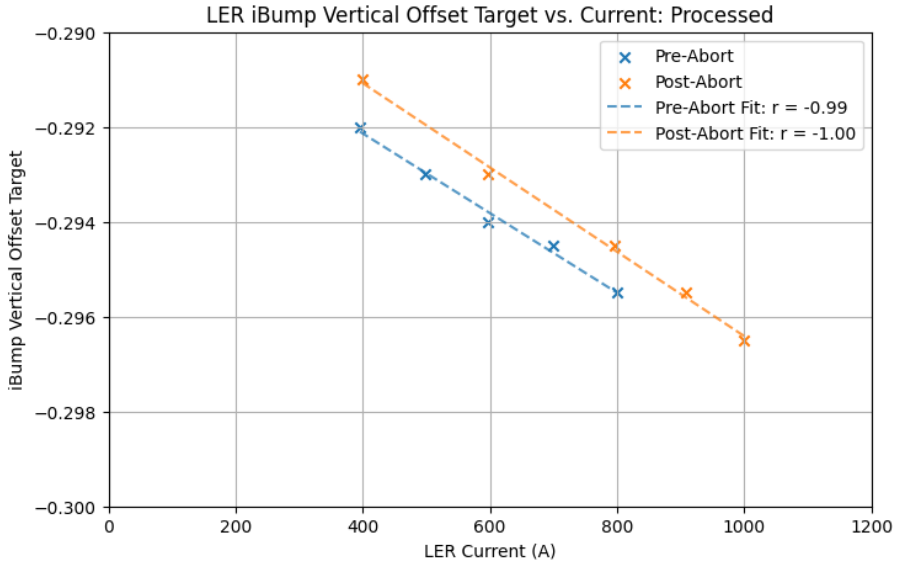
- 04/06/24: 14:00-18:00
  - Beam abort at ~16:15
- Optics and collision tuning initially performed at low current before MD
- During MD, current ramped to new level then feedback target scan performed
- Wide range of currents tested
  - Pre abort: 400, 500, 600, 700, 800 mA
  - Post abort: 400, 600, 800, 900, 1000 mA



Current Dependance

- Strong linear dependence of optimal iBump feedback target on current observed
- Constant offset observed before and after beam abort
- High levels of noise in data
  - Optimal point chosen based on luminosity data
  - Data from two different luminosity monitors (LumiBelle2 & CsI) do not always agree
  - Fit to data performed, and position of optimum not always clear

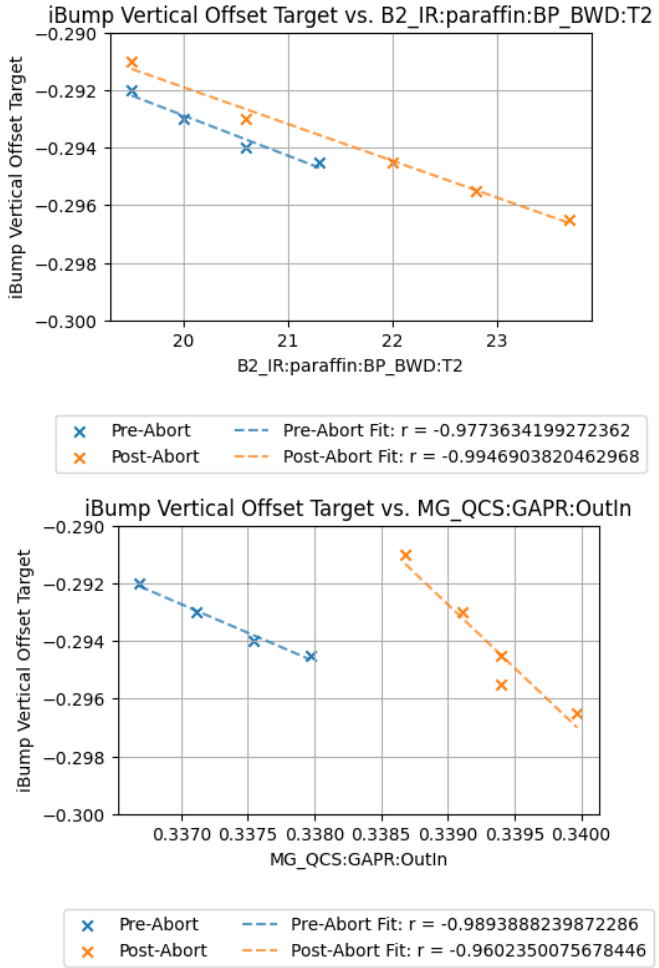


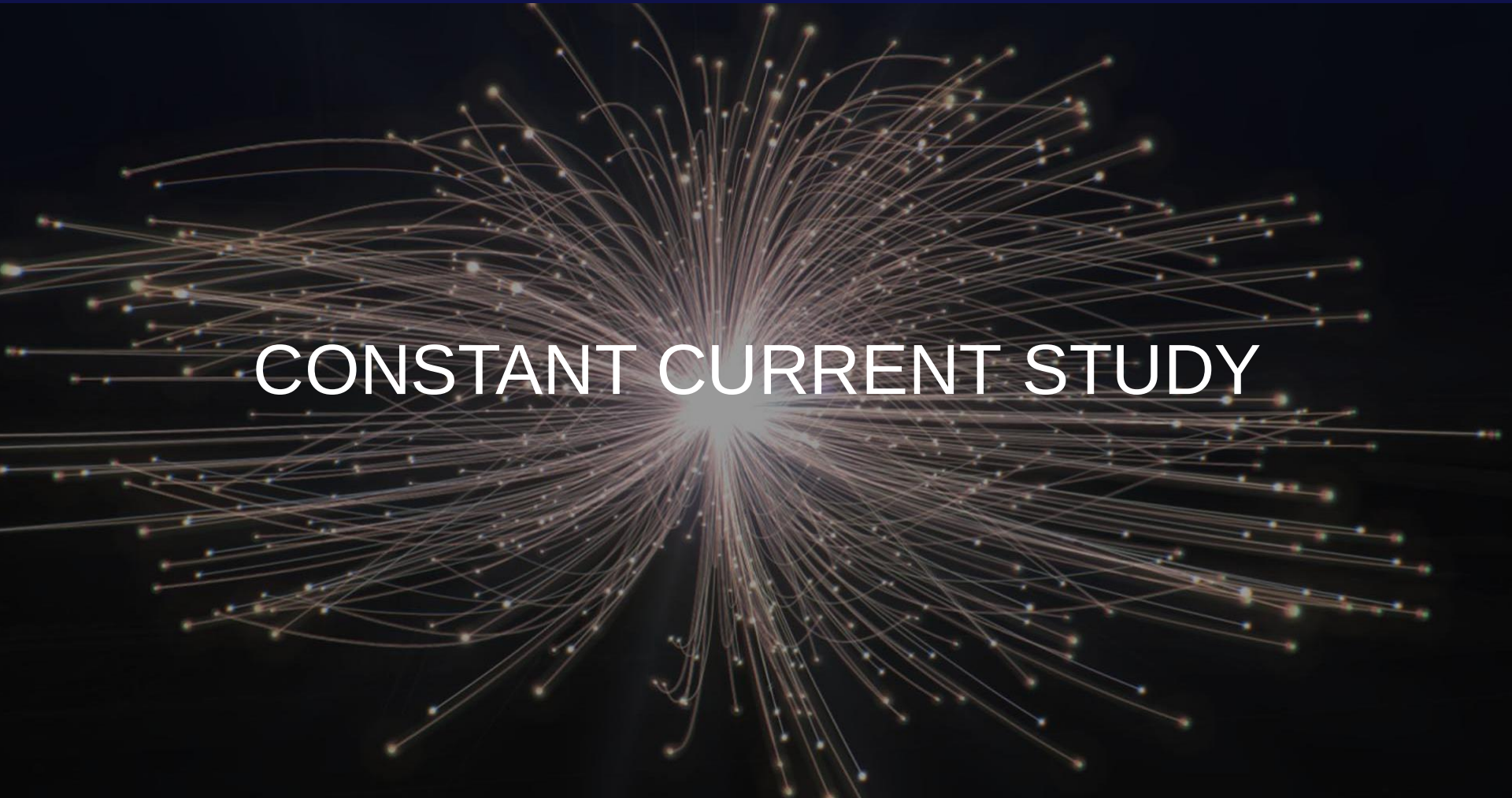


Offline Analysis

- Logging data for a wide range of parameters tested for correlations e.g.
  - Temperature
  - Quadrupole gap sensor
  - BPMs
- Several other parameters seem strongly correlated e.g. gap sensors and temperature
- The pre/post abort discrepancy applies in almost all cases

Many parameters at play: need a baseline study to ensure this is directly due to the current -> **constant current MD**

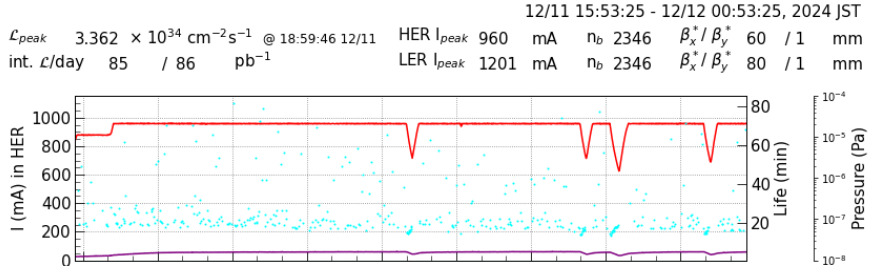


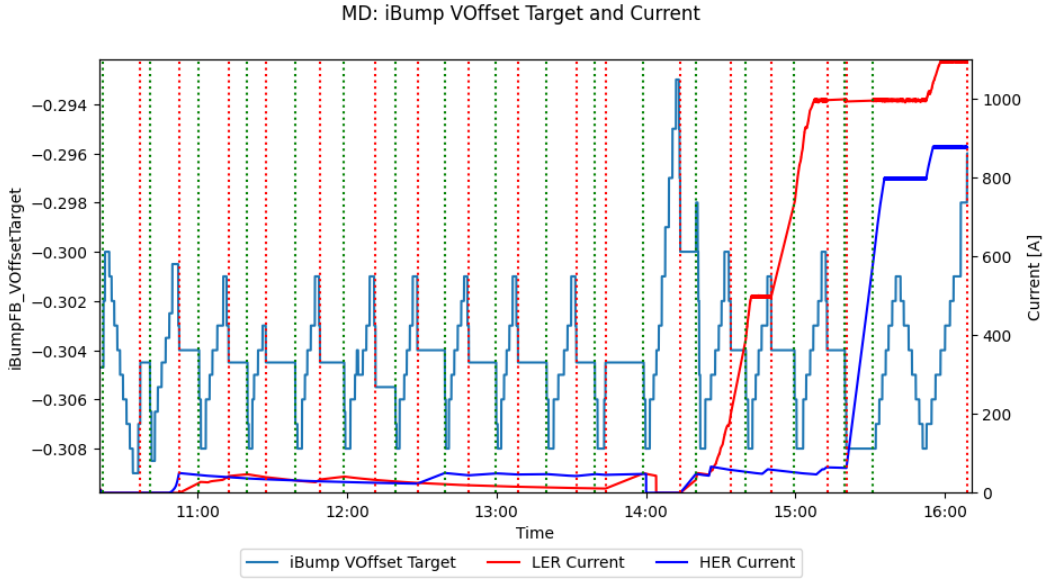


CONSTANT CURRENT STUDY

MD Overview

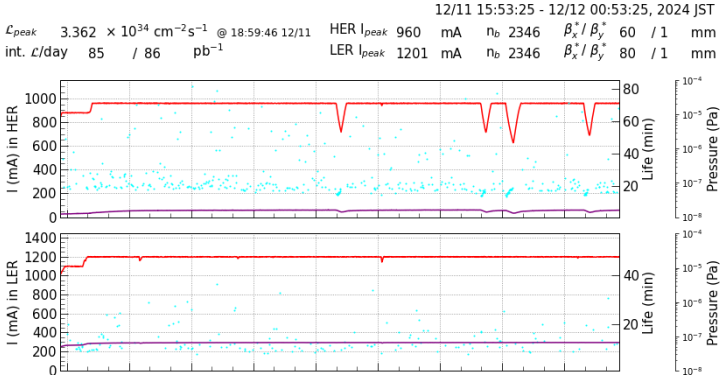
- 11/12/24: 19:20-25:00
  - RF issues caused small current drops
  - Issue with data logging
- Optics and collision tuning initially performed at low current before MD
- During MD, current maintained at1200/950mA (LER/HER)
- Feedback target scans performed every 20 minutes

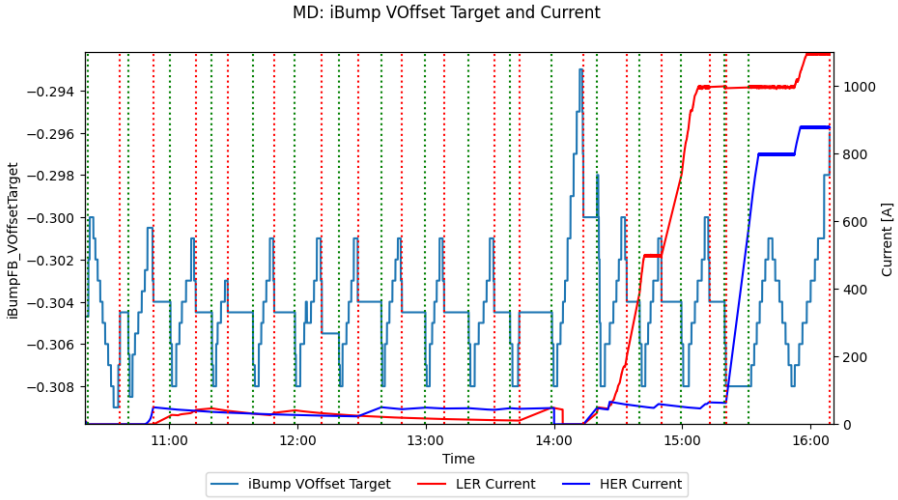




Target Value Stability

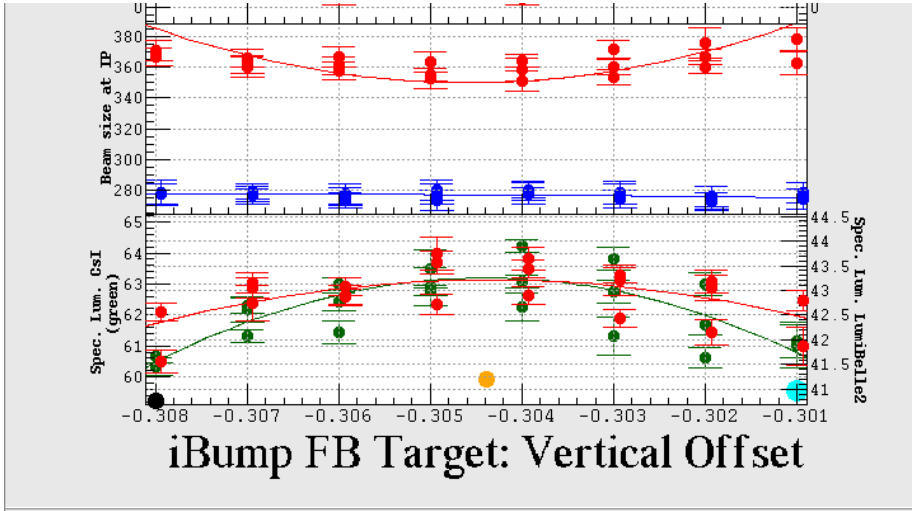
- With constant current operation, the optimal vertical offset target was stable
- Variation of offset target observed when current dropped during RF issue
  - Poor measurement as current varied during measurement
  - Target value clearly higher in these periods while current reduced
  - This agrees with the previous MD data
- Processed data analysis TBD
  - Logger issue causing problems with data analysis

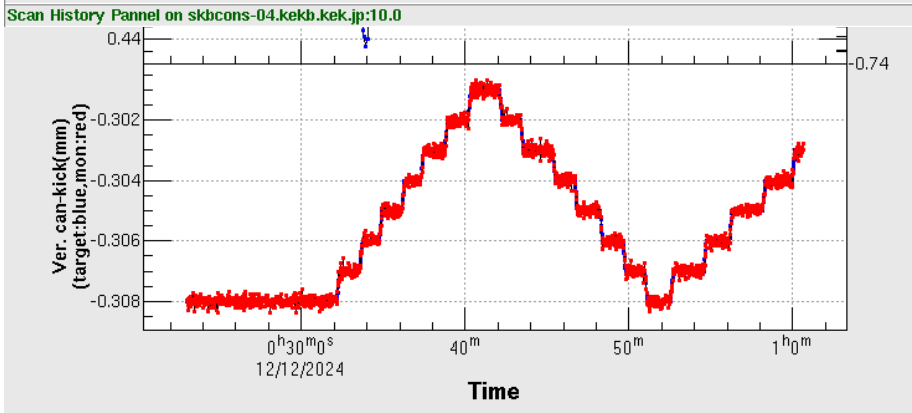




Scan Reproducibility

- During both MDs, all scans had been performed in the same direction, to ensure no other biases
- Test by scanning forwards and backwards
  - Trend remained the same
  - Fit remained the same
  - Large errors seen on all points taken

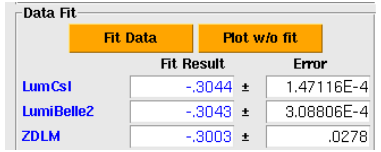




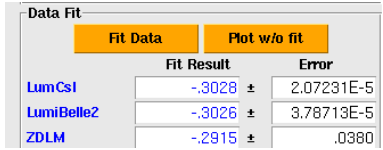
Fit Issues

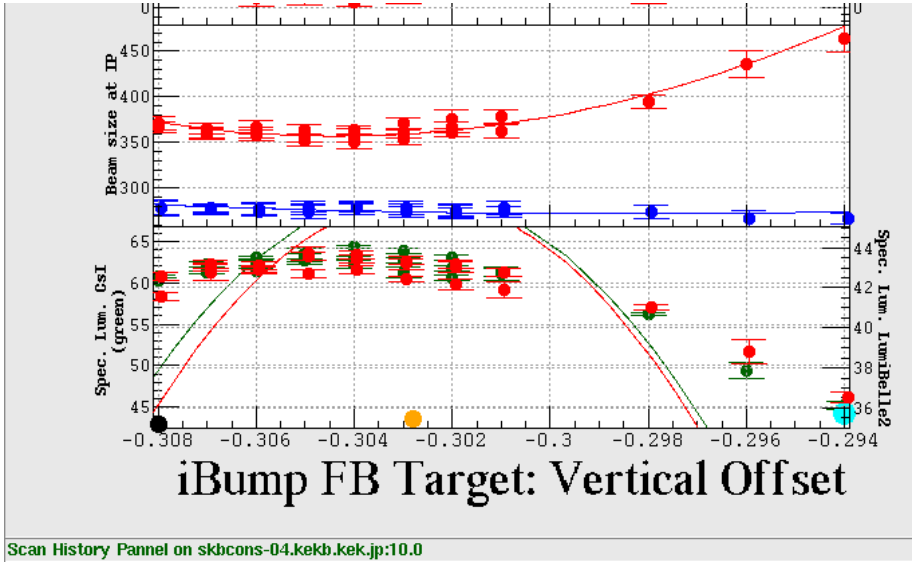
- Fit fails if data points are taken too far from optimal values
  - The fit tries to remain quadratic (?) and fails
- Relies on operator discretion
  - Automation based on fit not currently possible
  - Luminosity measurement discrepancies: LumiBelle2 vs CsI
- Luminosity vs Feedback target very flat
  - Very positive: for an incorrectly configured Target, only a very minor luminosity degradation occurs

Without far values



With far values





HISTORICAL DATA ANALYSIS

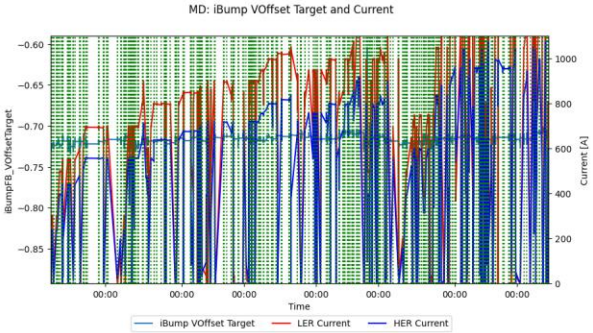
Historical Data

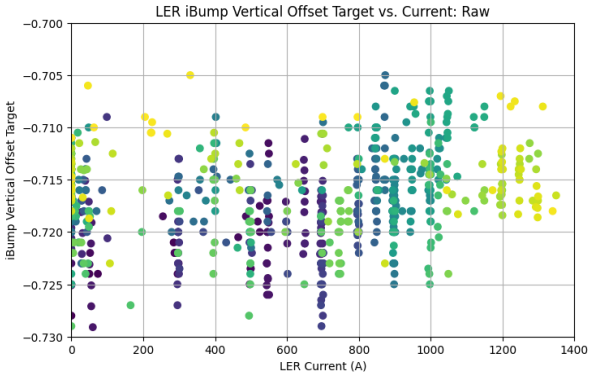
Many target scans at a variety of machine configurations

No clear correlations observed

- Too many parameters at play
- Perhaps possible to isolate these dependencies over shorter time periods

All 2022





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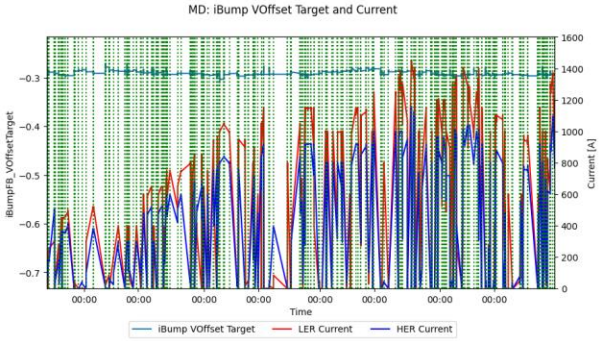
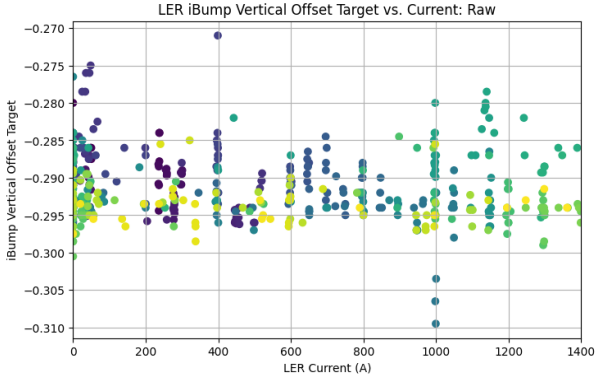




PART II: UPDATE ON SUPERKEKB OPTICS MODELLING

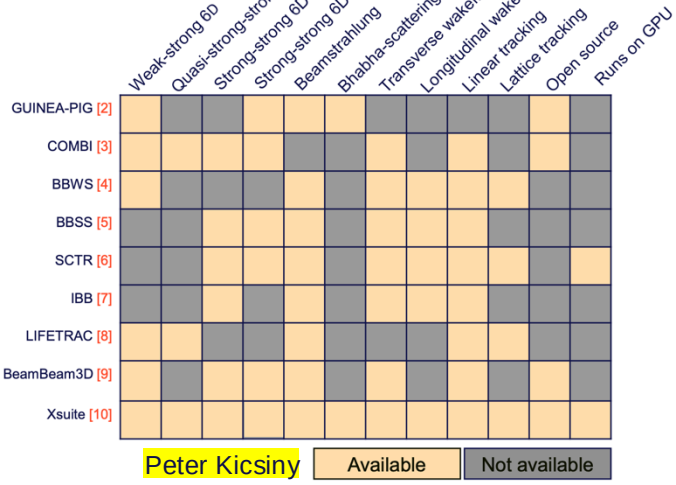
Motivation

- Large number of CERN studies on SuperKEKB:
  - IP feedback studies (*J. Salvesen*)
  - Collimation studies (*G. Broggi*)
  - Optics studies (*J. Keintzel*)
  - Beam Based Alignment studies (*C. Goffing*)
  - Impedance studies (*R. Soos*)
  - Beam-beam studies (*P. Kicsiny*)
  - And more…
- SuperKEKB Beam-Beam working group
- Interest from BELLE-II for IR upgrade model
- And more….

Whilst computationally expensive, with Xsuite functionality, full **self-consistent** simulations including many effects are possible Lattice, *Beam-beam, Space-Charge, Wakefields, Collimation, …*

Xsuite Functionality

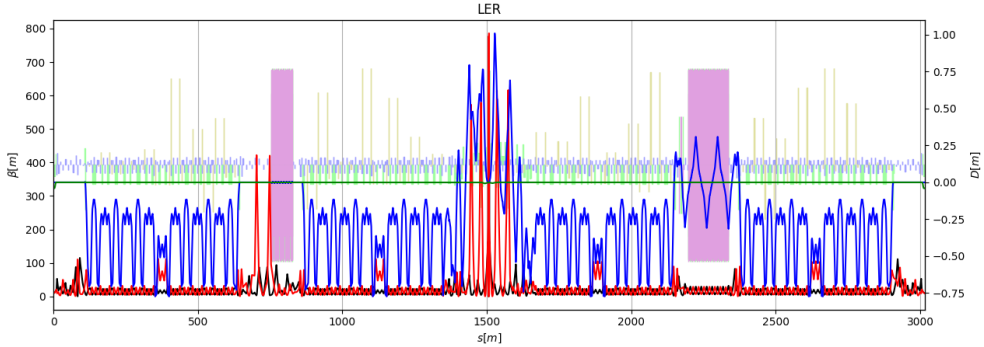
- Developed at CERN, since 2021
- Collection of python packages: Xtrack, Xfields …
- Multithreaded CPU and GPU support
- Demonstrated at: PS, SPS, LHC and more…

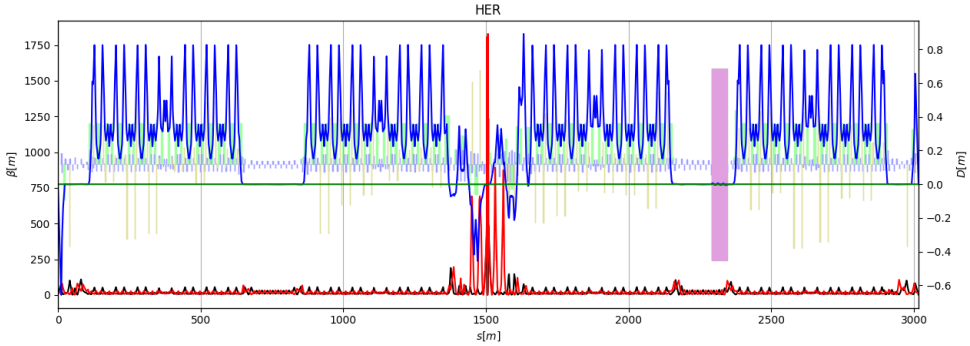


DEVELOPMENTS

Solenoid Installation

- **Solenoid installed succesfully**
  - Optics tests ongoing
- **Coupling matching**
  - SAD approach of R1, R2, R3, R4 not currently available in Xsuite
  - Xsuite natively uses Mais-Ripken formalism
  - Custom implementation currently in use for testing





The lattice version being converted has residual coupling (R3) at the IP in SAD. Coupling matched to 0 in Xsuite -> optics differences

Radiation Testing

- **Emittance**
  - Order of magnitude looks good, but details to be investigated
  - Further matching required to achieve exact values
- **Momentum Acceptance and Dynamic aperture**
  - MA and DA reduced vs SAD values
    - Not the case in previous FCC studies- implying a lattice issue
    - Longitudinal acceptance similar
    - Transverse planes reduced
  - Likely due to IR coupling discrepancy

e.g. HER

```
------------------------------------
Emittance:
------------------------------------
Emittance x:                    4.4524e-09 m
Emittance y:                    2.2624e-16 m
Emittance y (min coupling):     8.9048e-12 m
Emittance z:                    3.2955e-06 m
------------------------------------
Beam Sizes:
------------------------------------
IP Beam Size x:                 1.6354e-05 m
IP Beam Size y:                 4.7566e-10 m
IP Beam Size y (min coupling):  9.4368e-08 m
Beam Size z:                    5.1384e-03 m
------------------------------------
Energy:
------------------------------------
Energy Spread:                  6.4135e-04
Energy loss per turn:           2.5030e+06 eV
Damping Constants:              1.7833e-04, 1.7776e-04, 3.5753e-04 /Turn
Damping Time:                   1.7724e+01, 1.7668e+01, 3.5535e+01 /s
Damping Partitions:             0.9985, 0.9953, 2.0018
------------------------------------
Tunes:
------------------------------------
Tune x:                         45.5319
Tune y:                         43.5810
Tune z:                         0.0272
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Momentum Compaction:
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Momentum Compaction:            4.5911e-04
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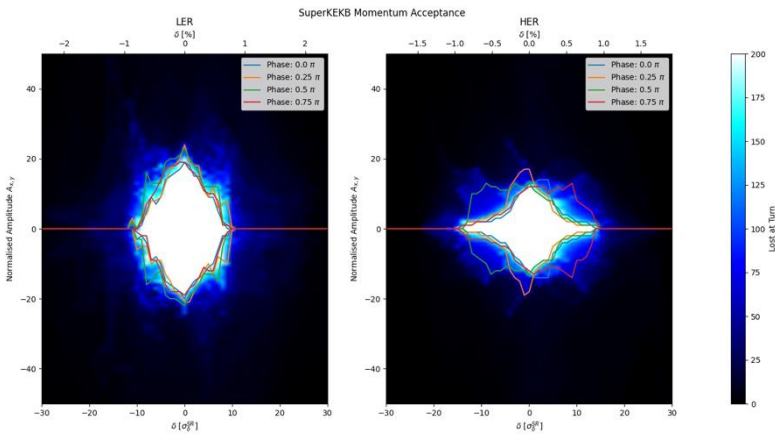
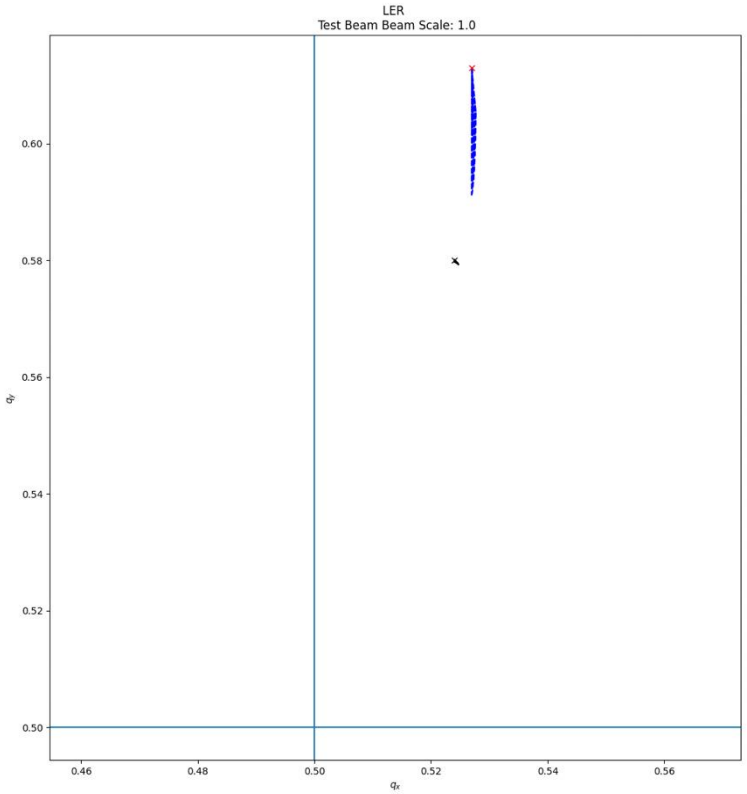


Initial Beam-Beam testing

- **Beam beam installation working**
  - Possible to run in weak-strong and strong-strong configurations
- **Tune footprints**
  - Initial tests performed
  - Order of magnitude looks correct, but no extensive checks

NB: extensive testing not yet performed due to optics and radiation troubleshooting ongoing

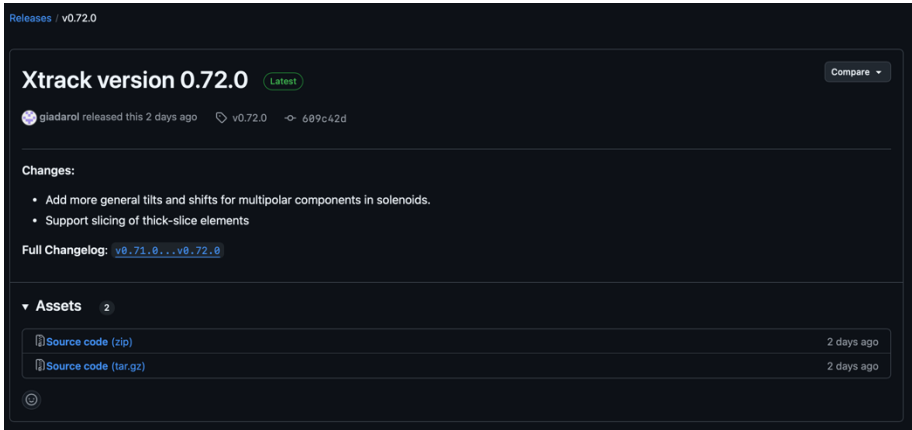


Xsuite Developments

- **Multipole offsets and rotations inside a solenoid**
  - Required for modelling SuperKEKB IR
- **Update to radiation handling with slicing**
  - Update to thin slicing of previously thick sliced elements
  - Better modelling of synchrotron radiation

Xtrack 0.72.0 or higher required to use the SuperKEKB model

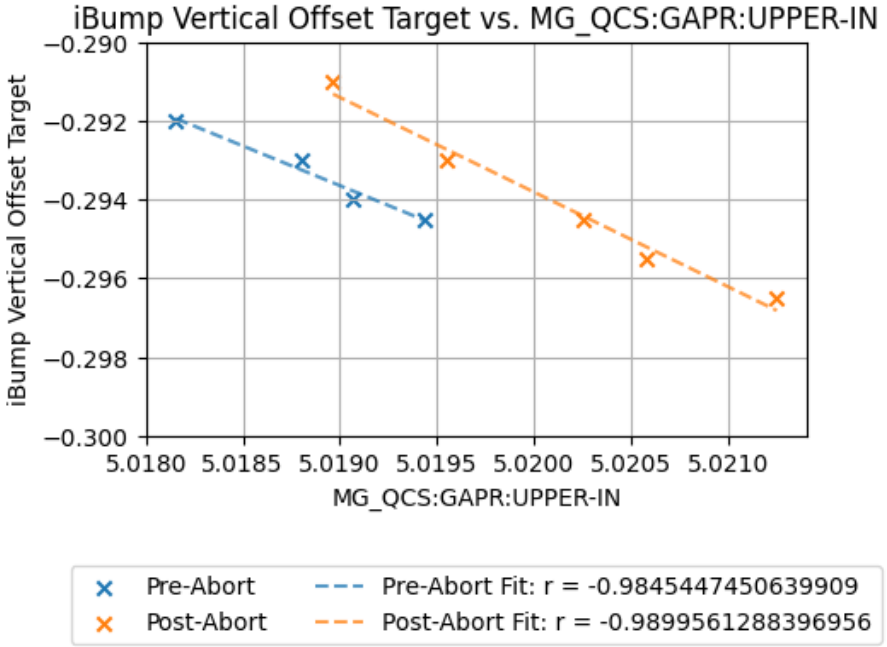
Giovanni Iadarola



OUTLOOK

Outlook: iBump Feedback Studies

- Further analysis of constant current MD data once logging information available
- Further historical data analysis
- Simulation
  - With new Xsuite model of SuperKEKB, intend to do self consistent iBump feedback simulations



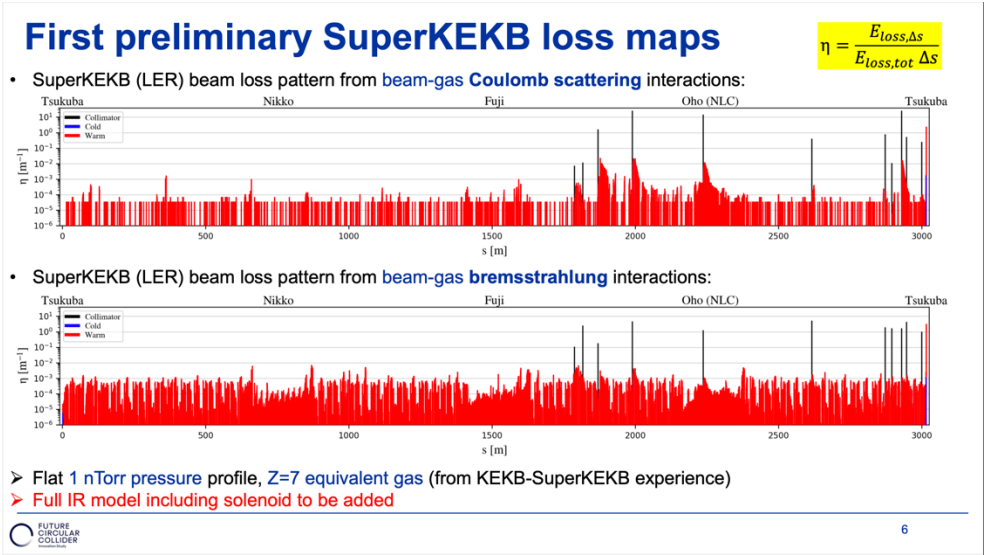
Upcoming publication(s):

- *Operational Challenges of the SuperKEKB iBump Feedback System [IPAC25]*

Outlook: SuperKEKB Xsuite Model

- Lattice already being used for initial studies
  - G. Broggi results with no-sol lattice for collimation studies (https://indico.cern.ch/event/1471245/)
- Correction coupling match to use SAD R1, R2, R3, R4 natively
- Radiation and beam-beam benchmarking

Giacomo Broggi



Upcoming publication(s):

- *Consistent representation of lattices between optics code for FCC-ee, SuperKEKB, and more [eeFACT25]*
- *Modelling Optics and Beam-Beam Effects of SuperKEKB with Xsuite [IPAC25]*

Thank you for your attention.