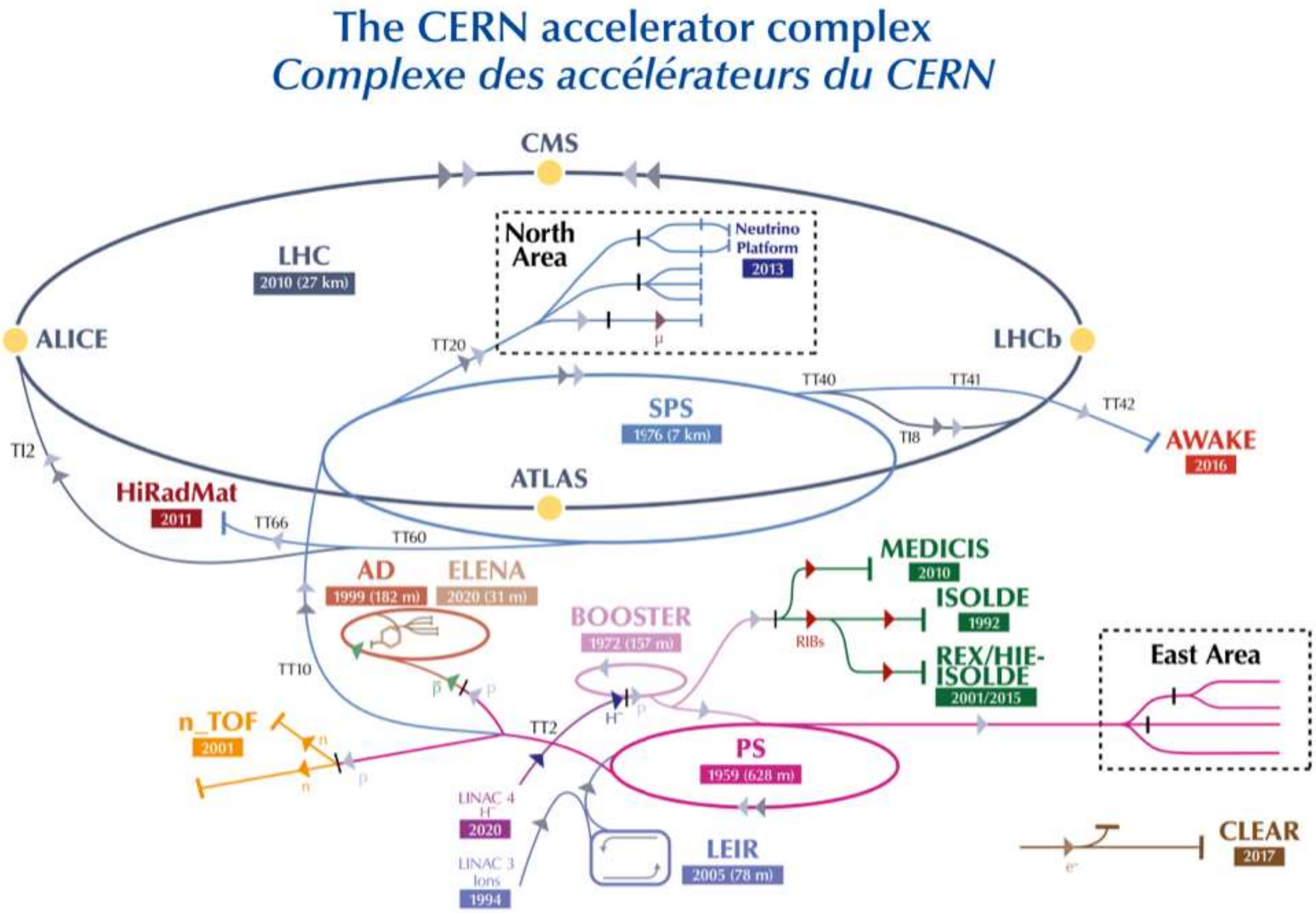
Training possibilities at the PSB

F. Asvesta, T. Prebibaj

26/09/2023

EURO-LABS Training Sessions @ CERN Facilities

Layout



tirsi.prebibaj@cern.ch

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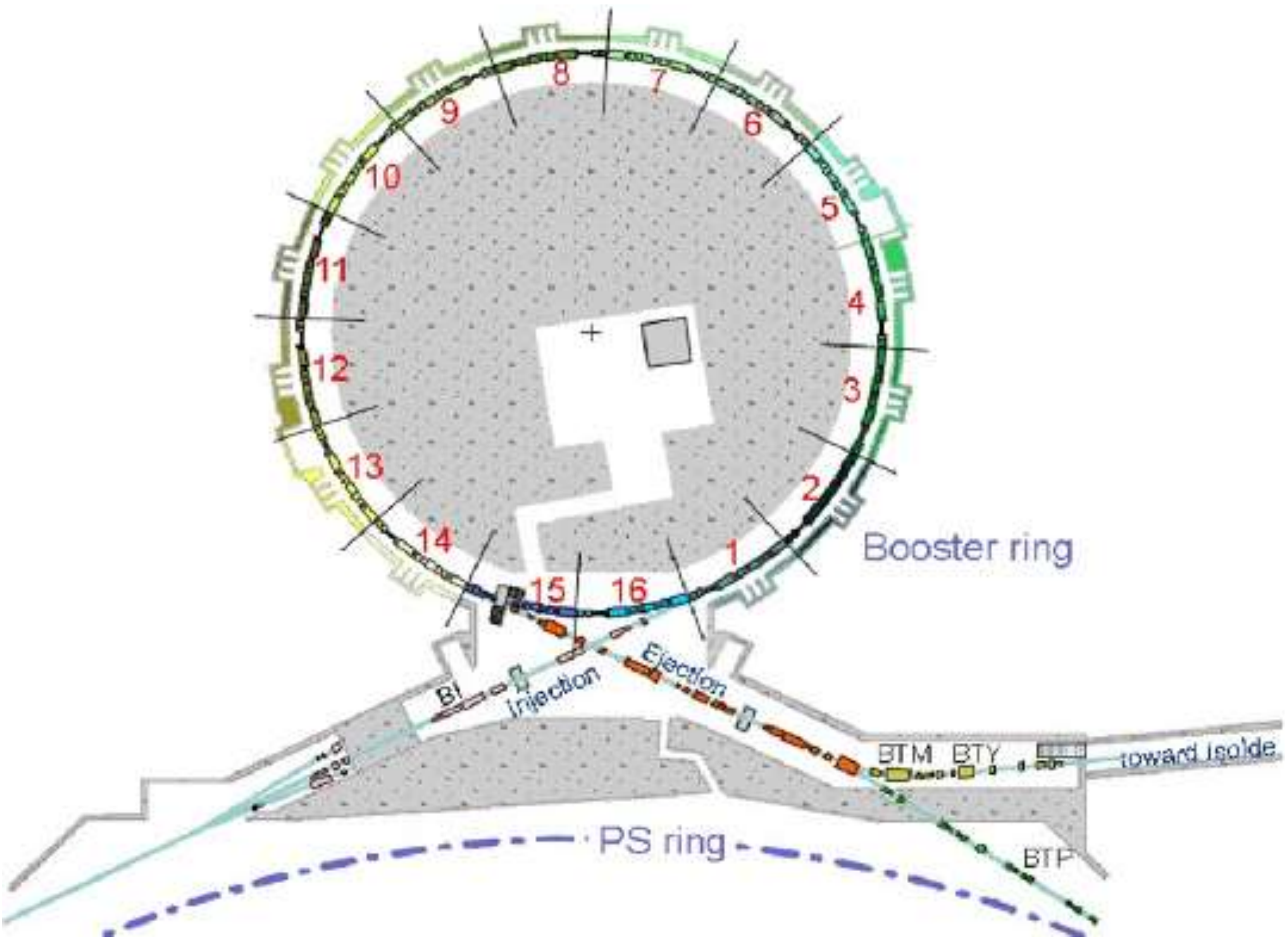
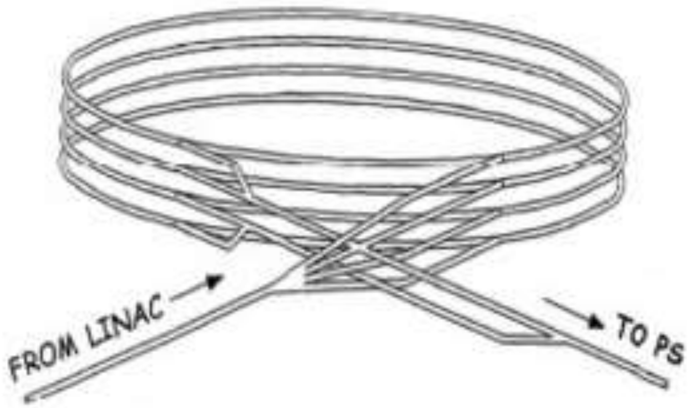


- 4 identical superimposed rings of 25m radius.
- Acceleration from 160MeV to 2GeV in ~0.5sec.
- Common injection and extraction line.



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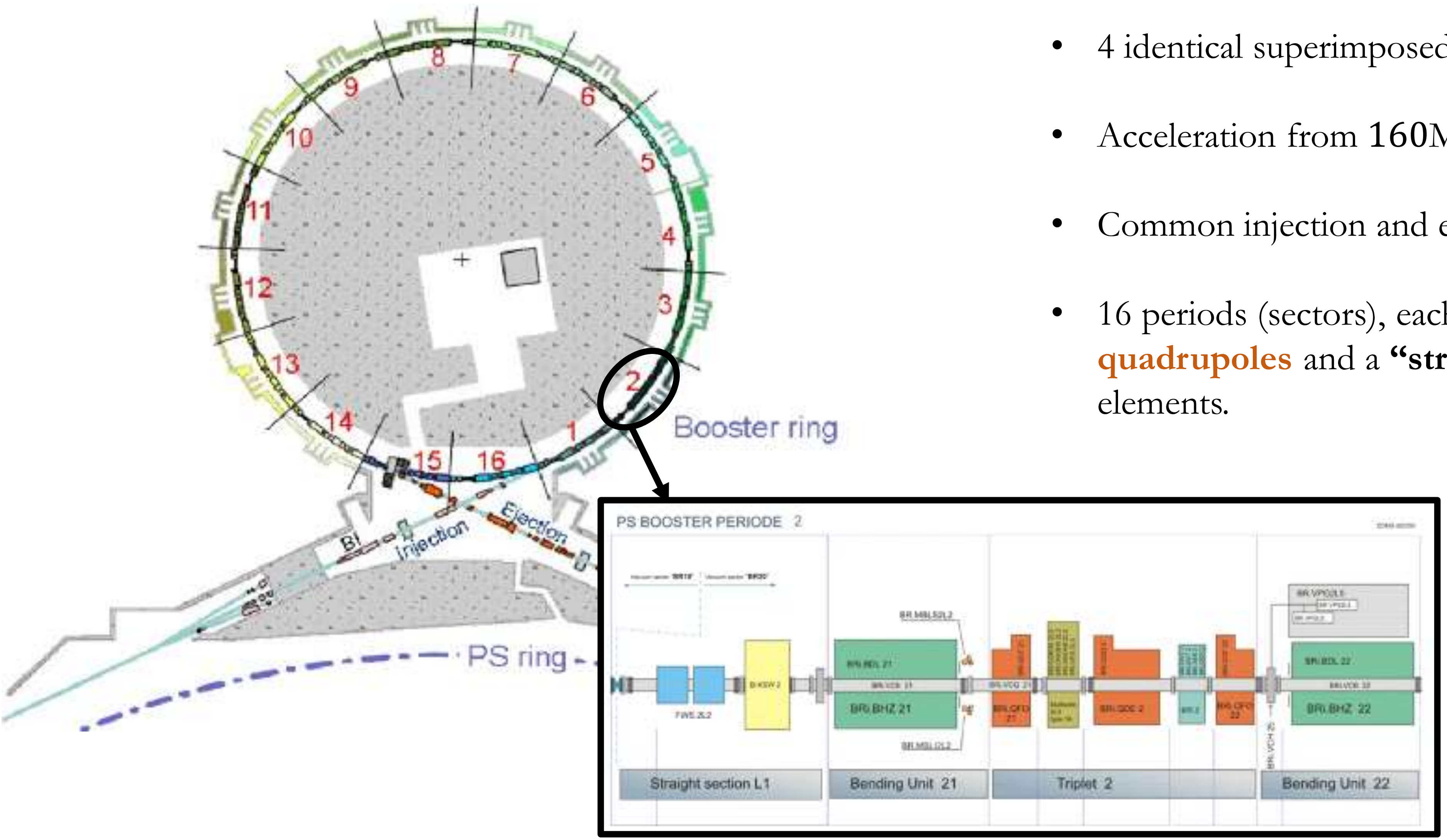

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- Acceleration from 160MeV to 2GeV in ~0.5sec.
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- 16 periods (sectors), each with **two dipoles**, **three quadrupoles** and a **"straight section"** for adittional elements.

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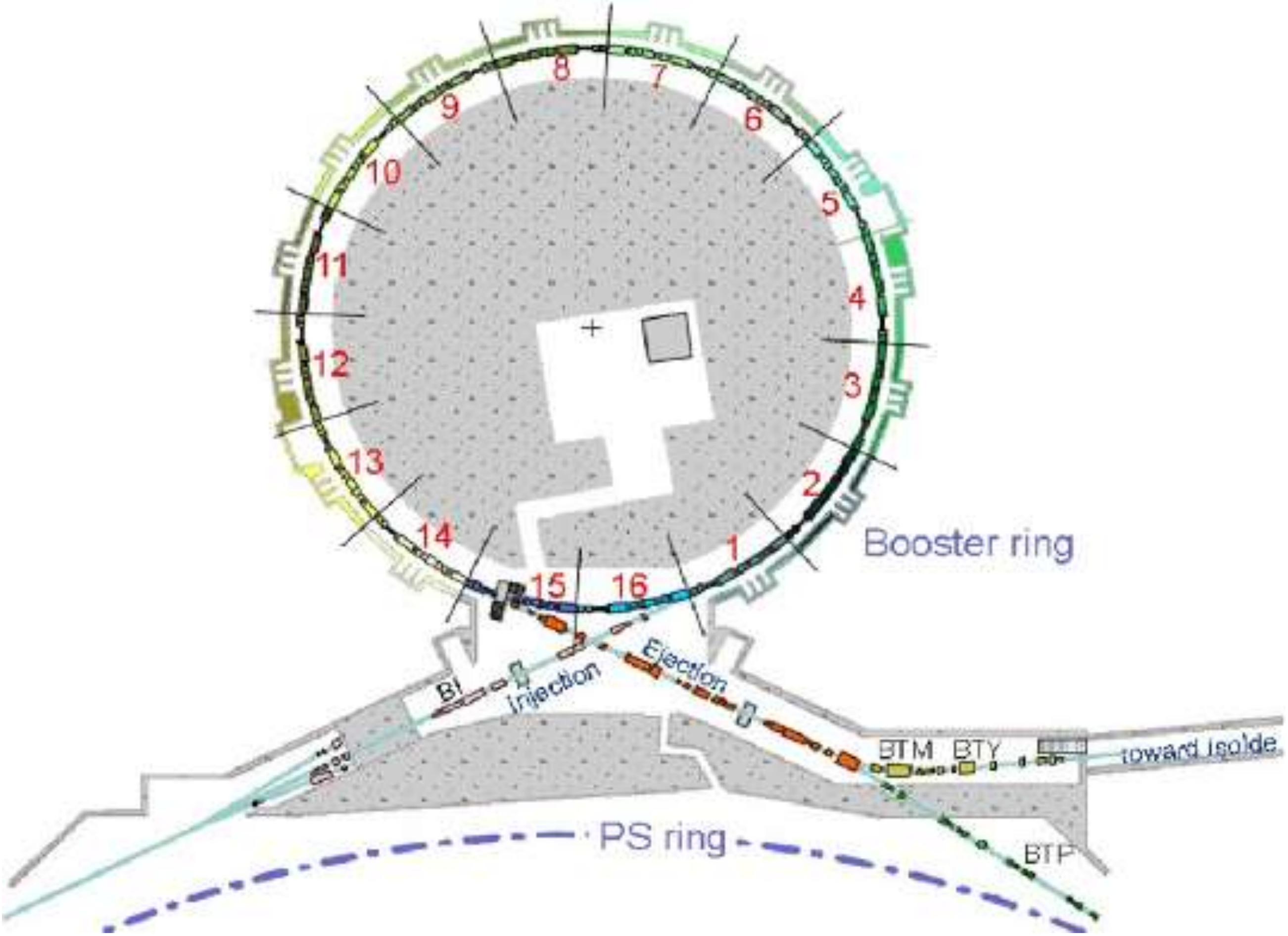

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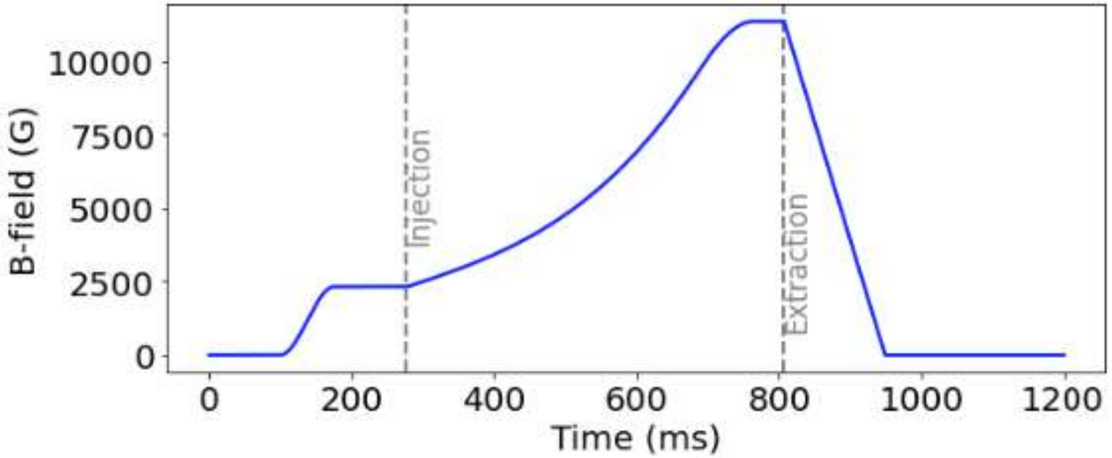
- Acceleration from 160MeV to 2GeV in ~0.5sec.
- Common injection and extraction line.
- 16 periods (sectors), each with **two dipoles**, **three quadrupoles** and a **"straight section"** for adittional elements.
- Magnetic cycle of 1.2sec. Beam injection at 275ms and extraction at 805ms.



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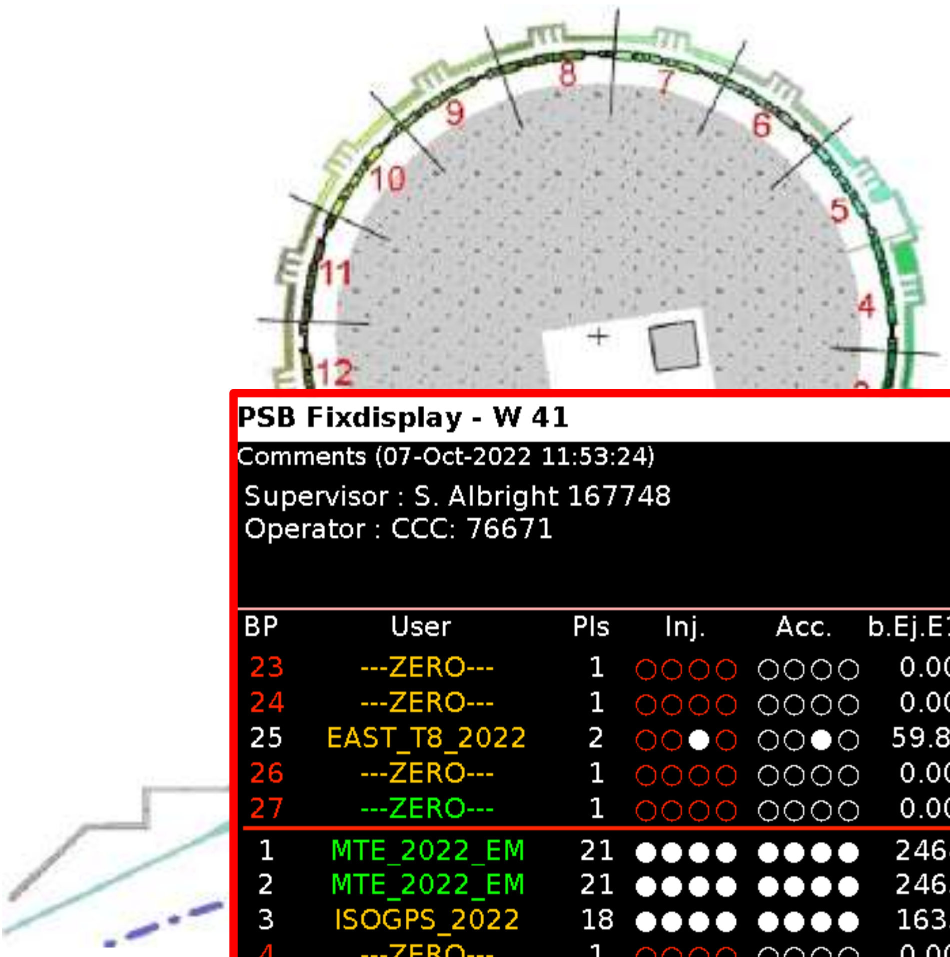

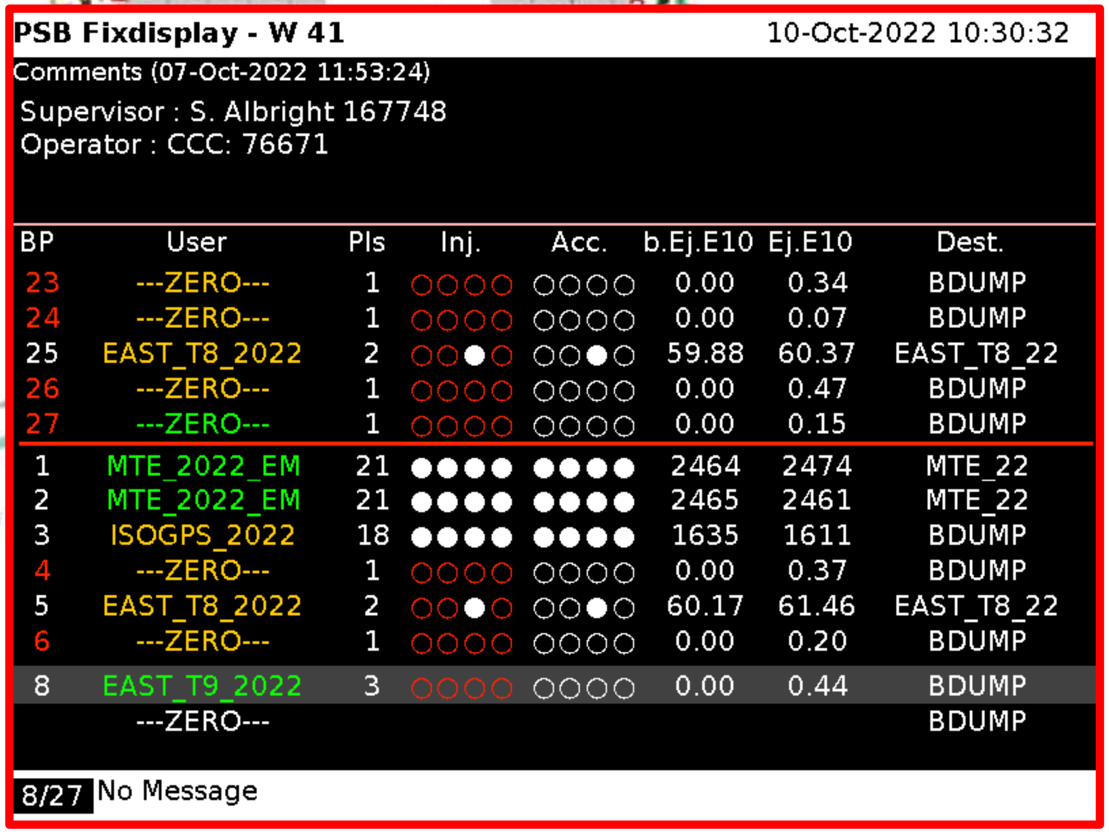

PSB Fixdisplay - W 41 10-Oct-2022 10:30:32

Comments (07-Oct-2022 11:53:24)

Supervisor : S. Albright 167748
Operator : CCC: 76671

BP	User	Pls	Inj.	Acc.	b.Ej.E10	Ej.E10	Dest.
23	---ZERO---	1	○○○○	○○○○	0.00	0.34	BDUMP
24	---ZERO---	1	○○○○	○○○○	0.00	0.07	BDUMP
25	EAST_T8_2022	2	○○●○	○○●○	59.88	60.37	EAST_T8_22
26	---ZERO---	1	○○○○	○○○○	0.00	0.47	BDUMP
27	---ZERO---	1	○○○○	○○○○	0.00	0.15	BDUMP
1	MTE_2022_EM	21	●●●●	●●●●	2464	2474	MTE_22
2	MTE_2022_EM	21	●●●●	●●●●	2465	2461	MTE_22
3	ISOGPS_2022	18	●●●●	●●●●	1635	1611	BDUMP
4	---ZERO---	1	○○○○	○○○○	0.00	0.37	BDUMP
5	EAST_T8_2022	2	○○●○	○○●○	60.17	61.46	EAST_T8_22
6	---ZERO---	1	○○○○	○○○○	0.00	0.20	BDUMP
8	EAST_T9_2022	3	○○○○	○○○○	0.00	0.44	BDUMP
	---ZERO---						BDUMP

8/27 No Message

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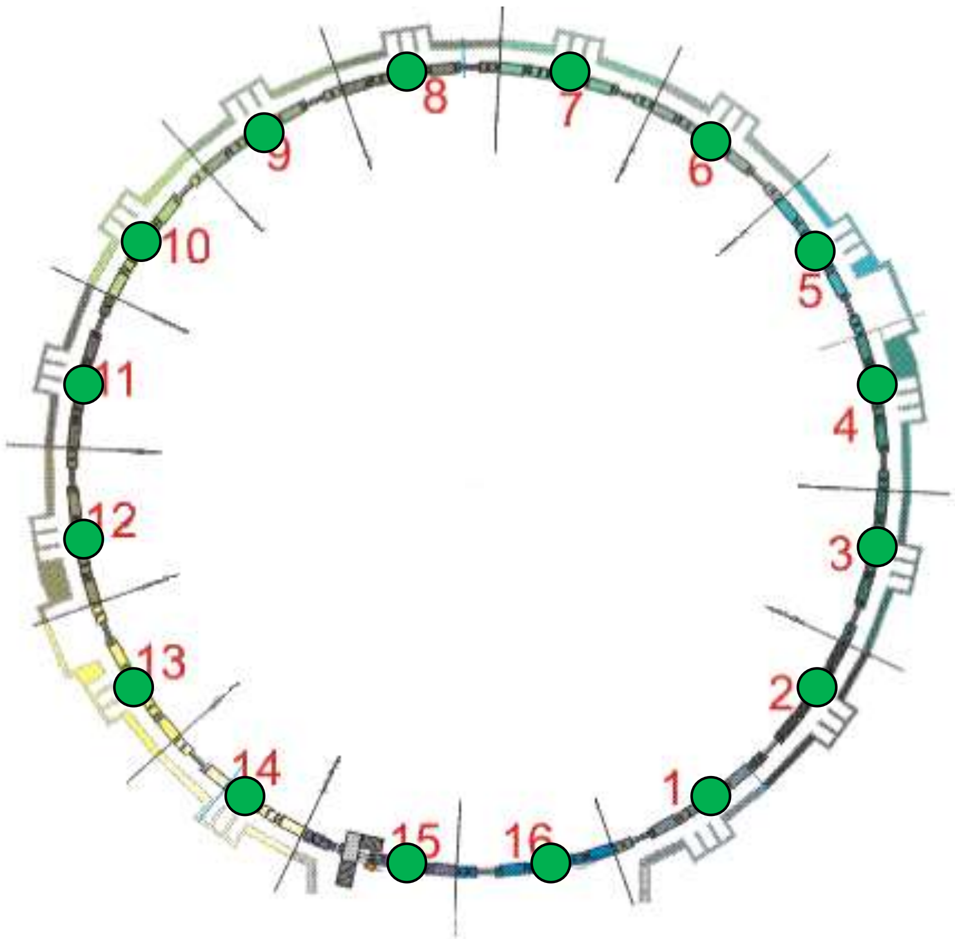
- Acceleration from 160MeV to 2GeV in ~0.5sec.
- Common injection and extraction line.
- 16 periods (sectors), each with **two dipoles**, **three quadrupoles** and a **“straight section”** for adittional elements.
- Magnetic cycle of 1.2sec. Beam injection at 275ms and extraction at 805ms.
- PSB is constantly cycled with different beams. The cycles follow a predefined **super-cycle** which is repeated many times.

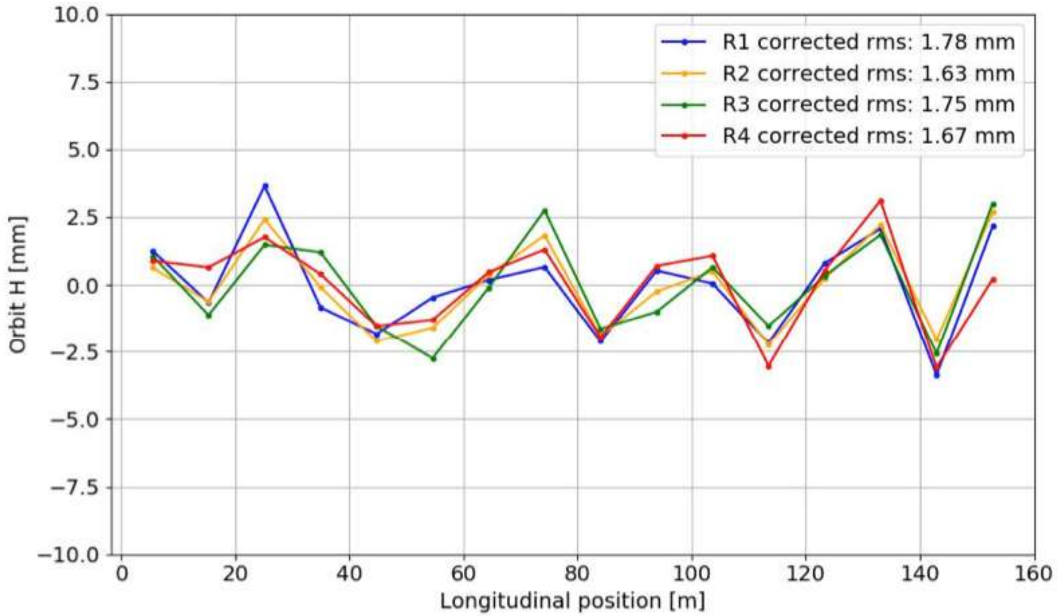
Beams

PSB Beams						
Type	N_b [10^{10}ppb]	ϵ_x [μm]	ϵ_y [μm]	ϵ_δ [eVs]	h	Destination
LHC25	165	< 2.2	< 2.2	1.3	1	LHC
BCMS	85	< 1.2	< 1.2	0.9	1	LHC
EAST	170	$1-2$	$1-2$	< 1.3	1	East area (PS)
STAGISO	200-300	< 5	< 4	< 1.6	1	ISOLDE (PSB)
AD	400	9	5	1.3	1	AD (PS)
SFTPRO_MTE	< 600	$< 6-8$	< 4	< 1.3	2	North area (SPS)
NORMGPS/HRS	800	< 15	< 8	< 1.8	1	ISOLDE (PSB)
TOF	900	12	8	1.7	1	nTOF (PS)

Devices



- **Beam Position Monitors (BPMs)**: turn-by-turn measurement of the beam center of mass. 16 horizontal and 16 vertical for each ring.



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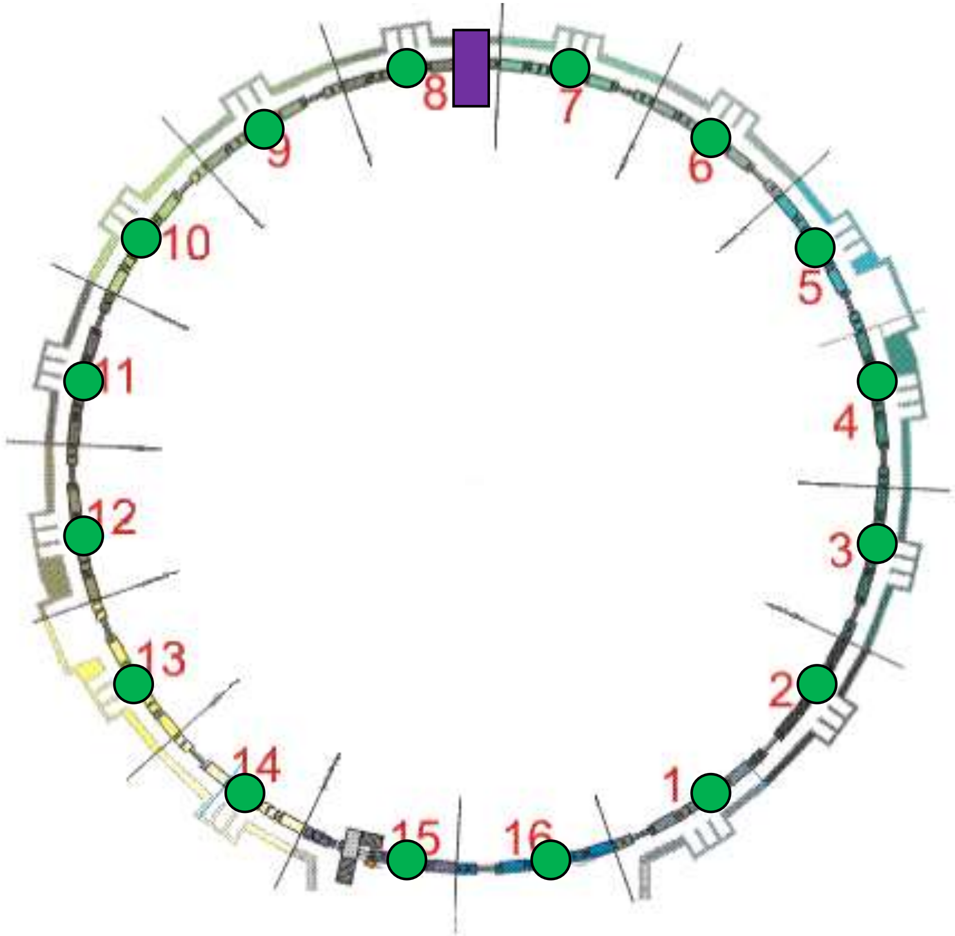

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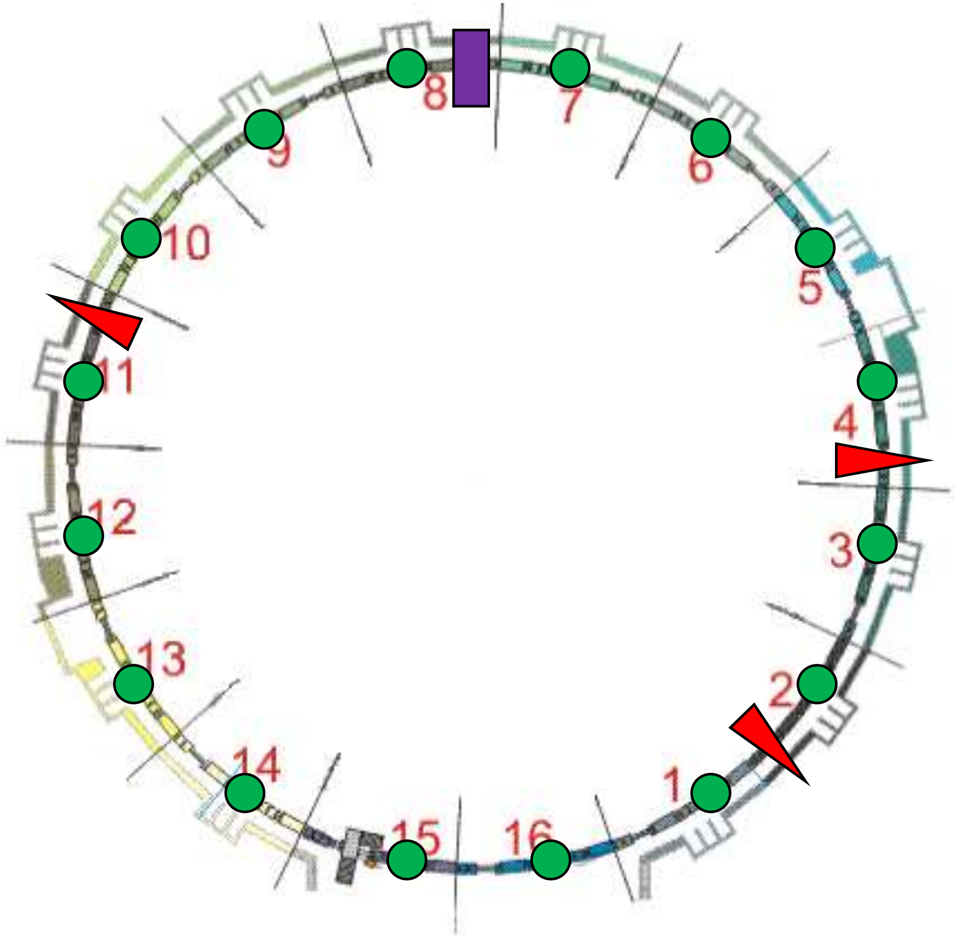
- **Beam Current Transformer (BCT)**: measures average beam current every 1ms.

Devices



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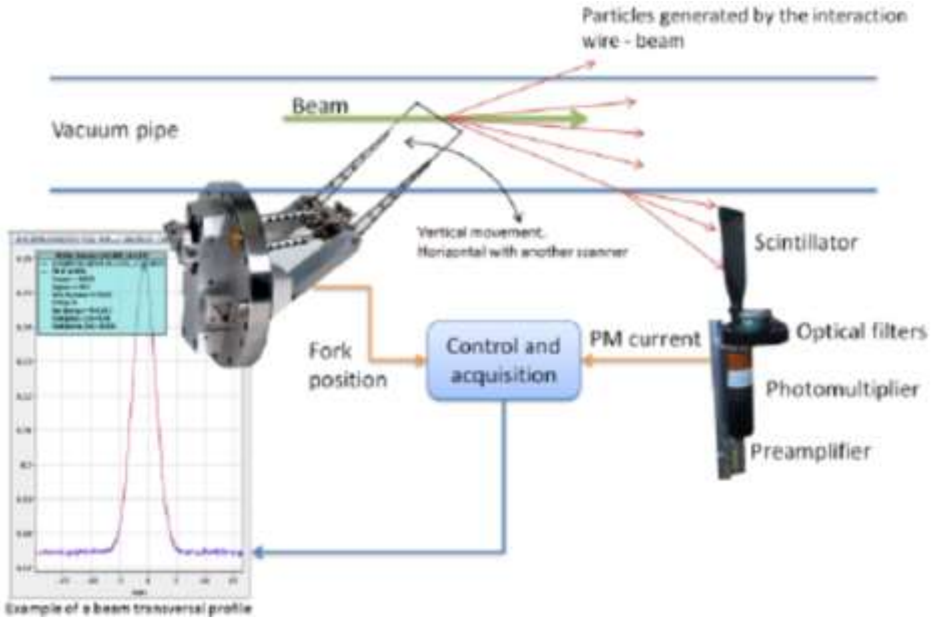
- **Wire Scanners (WS)**: measurement of the horizontal and vertical beam profiles at most twice within the cycle.



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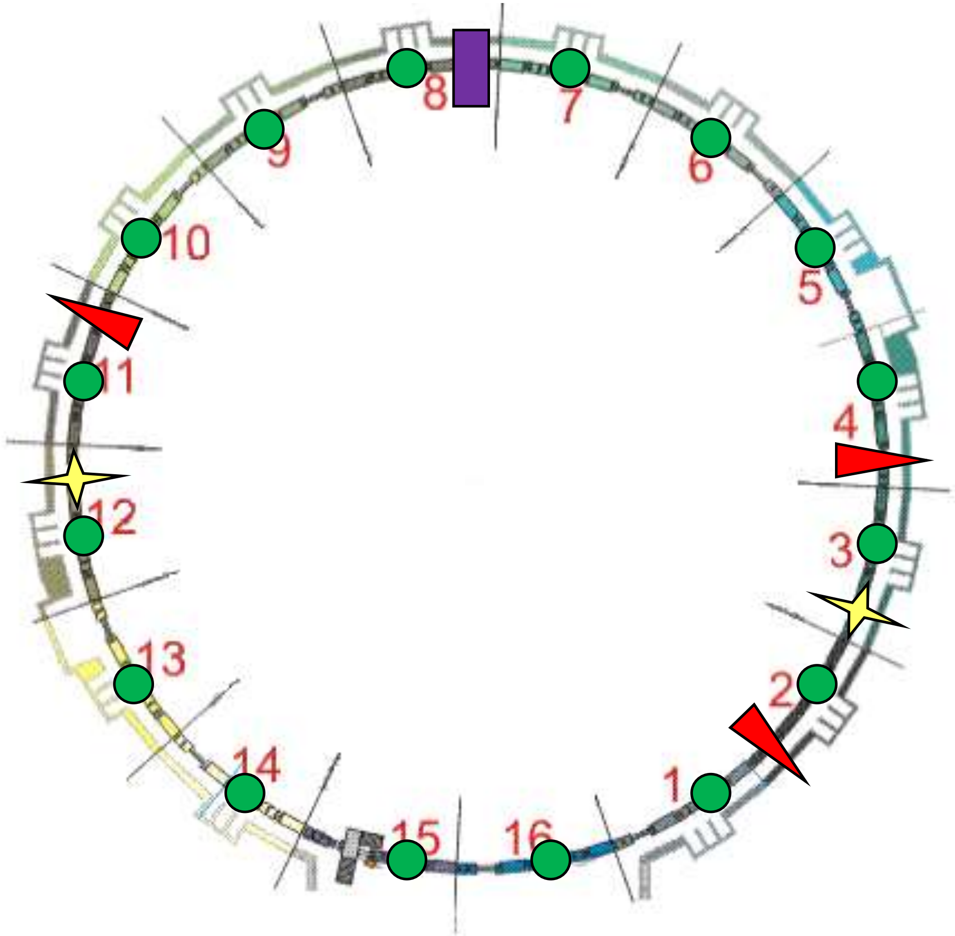

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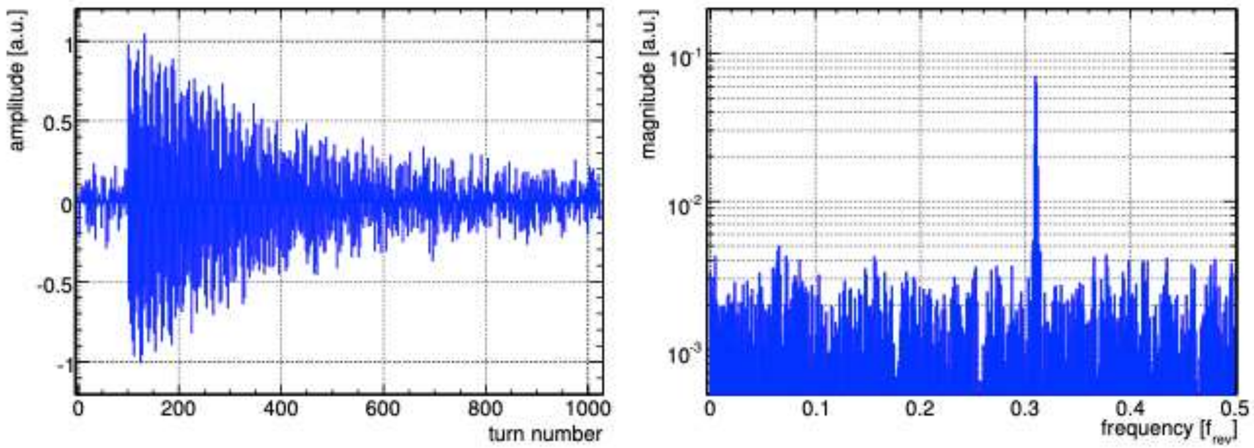
- **Base-Band-tune pickup system (BBQ)**: tune measurement by exciting the beam with a transverse damper (by applying a frequency chirp) and recording the turn-by-turb data through a pickup. Tune is extracted by FFT algorithms.



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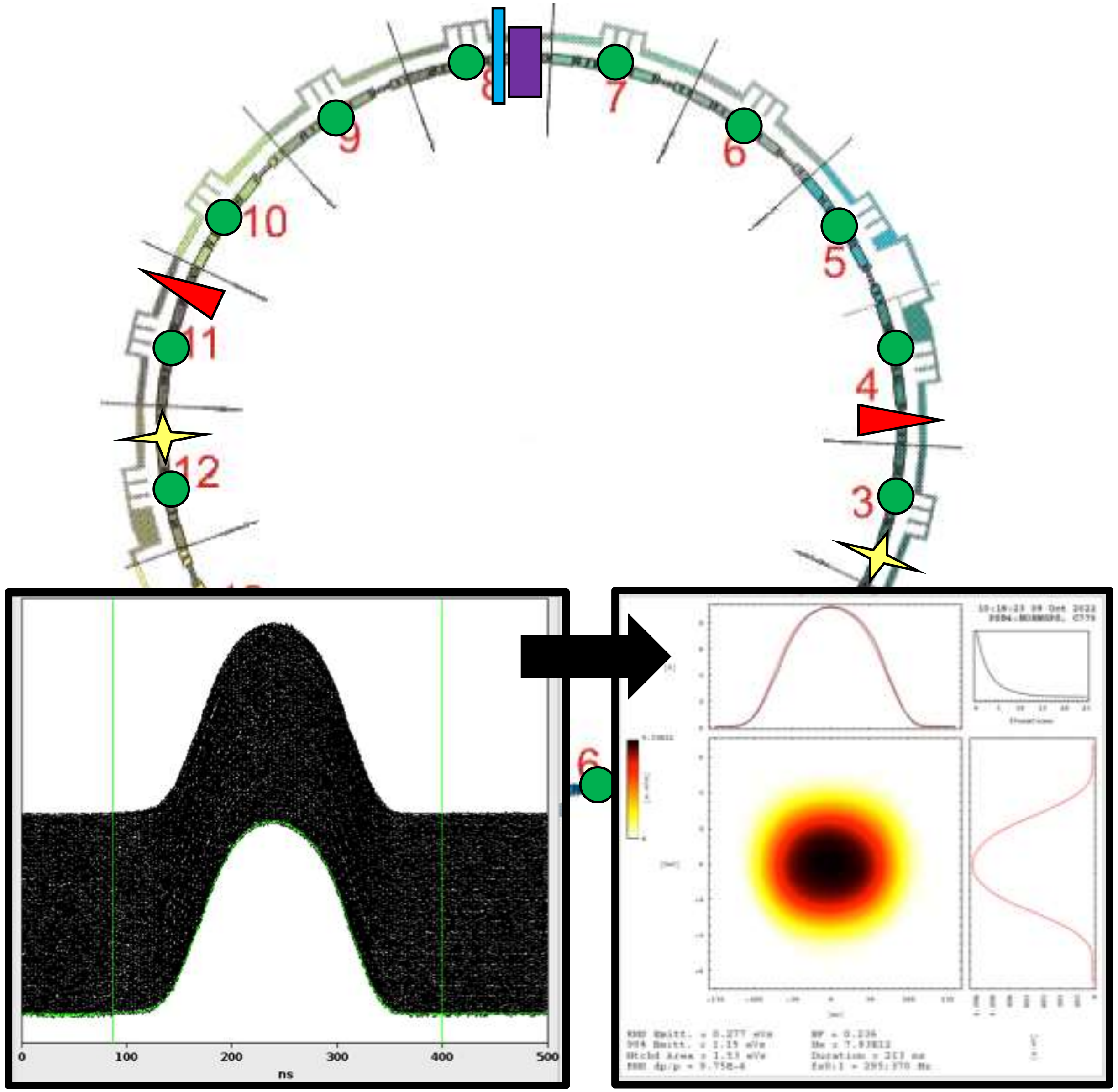

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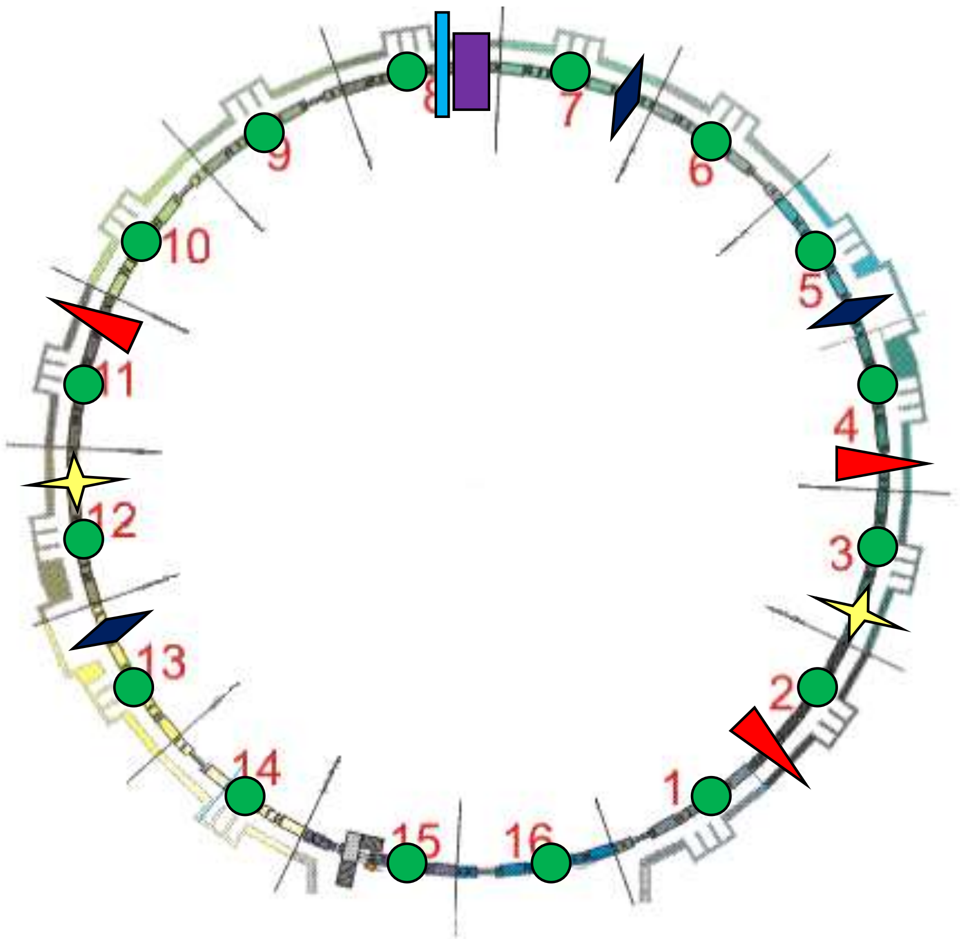

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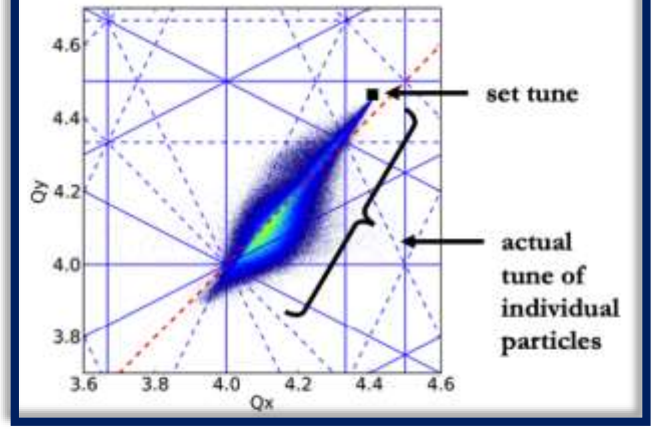
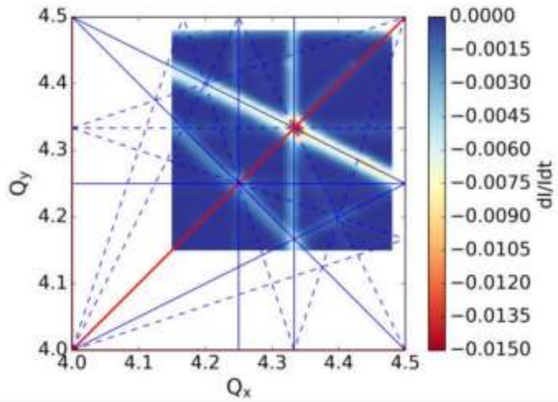
- **Radio-Frequency cavities (RF)**: C02 (acceleration), C04 (second harmonic), C16 (longitudinal blow-up).
- Plenty of quadrupole, sextupole and octupole correctors (normal and skew).

Beam Dynamics

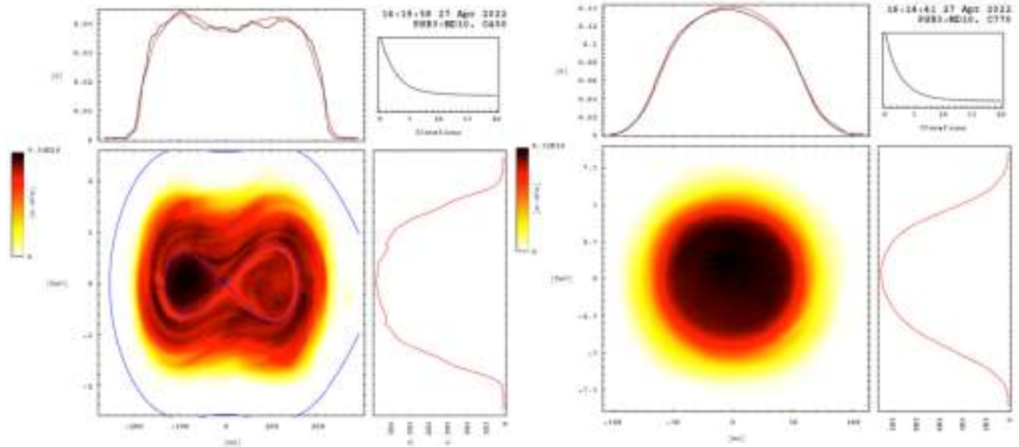
Space Charge



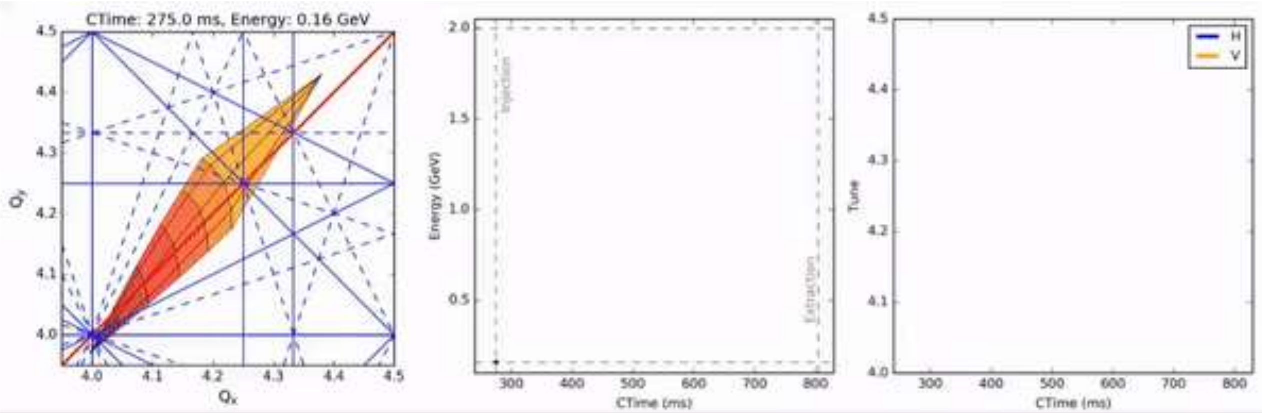
Resonances



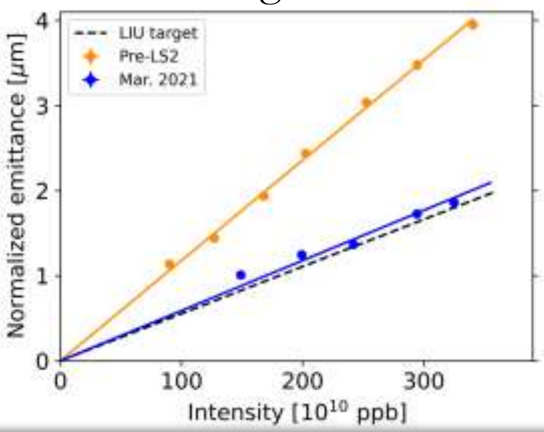
Beam goes from double harmonic to single harmonic to reduce the peak line density (therefore space charge)



While beam is accelerated, tunes are dynamically changed.



Brightness



Control Systems

CCC Consoles
(Linux-based with high-level Java/Python GUIs)

Back-End Severs

Front-End Computers (FECs)

Accelerator Equipment

JAPC framework

Access of JAPC parameters: “set” or “get” interactions , “subscribe” to get notified when their value changes.
See: PyJAPC, PyJAPCScout

FESA classes (Device-Property model)

device/property#field
e.g.: BR3.BWS.11V1/Scan#scanSelection
Controls Configuration Data Editor: ccde.cern.ch

- LSA/InCA: control system of the settings management
- Cycle selector:
  machine.USER.user_name
  e.g..: PSB.USER.MD2
- A cycle selector is mapped with a specific LSA user:
  e.g.: MD2 → MD6104_HalfIntegerStudies_160MeV_2022
- CERN Accelerators Logging Service (NXCALS), can be accessed from SWAN, Timber, etc.

CERN Gigabit Ethernet Technical Network (TN)

Control Systems

```
from pyjapcscout import PyJapcScout

# start a PyJAPC interface for a specific user
myPyJapc = PyJapcScout(incaAcceleratorName='PSB')
mySelector = 'PSB.USER.MD5'
myPyJapc.setDefaultSelector(mySelector)
myPyJapc.rbacLogin() # Get and RBAC token by location


# Device properties to monitor
signalsToMonitor = []
rings = ['R3']
for ring in rings:
    signalsToMonitor.append('B%s.BCT-ST/Samples'%ring) # BCT for intensity measurement
    signalsToMonitor.append('B%s.BQ-H-ST/Samples'%ring) # BBQ device for tune measurement
    signalsToMonitor.append('B%s.BQ-V-ST/Samples'%ring) # BBQ device for tune measurement
    signalsToMonitor.append('B%s.BWS.4L1.H/Acquisition'%ring) # Horizontal Wire Scanner
    signalsToMonitor.append('B%s.BWS.11L1.V/Acquisition'%ring) # Vertical Wire Scanner


# Callback function
def myCallback(data, h):
        print( 'Shot ' + str(len(glob.glob(h.saveDataPath + '2021*'))))
        indx = len(glob.glob(h.saveDataPath + '2021*'))

        if indx == total_number_of_shots:
                h.stopMonitor()
                print("#####################################################")
                print('Measurement finished and monitor stopped.')


# Create subscriptions
myMonitor = myPyJapc.PyJapcScoutMonitor(mySelector, signalsToMonitor, onValueReceived=myCallback,
                                        selectorOverride = mySelector, groupStrategy = 'extended',
                                        allowManyUpdatesPerCycle=False, strategyTimeout=5200,
                                        forceGetOnChangeAndConstantValues=False)


# saving data configuration
myMonitor.saveDataPath = './orbit/data2/'
myMonitor.saveData = False
myMonitor.saveDataFormat = 'parquet' # or 'parquet' or 'pickle' or 'pickledict' or 'mat'

# start acquisition
myMonitor.startMonitor()
```

Measurements that we could try today

- Beam parameter adjustments (intensity, emittance blow-up, energy spread).
- Betatron tune measurement and correction.
- Chromaticity measurement and correction.
- Transverse profiles measurement and emittance/brightness reconstruction.
- Closed orbit measurement and correction (?)
- Resonance crossing and compensation.
- Beta-beating measurement and correction.
- Instabilites (?)
- Other ideas?

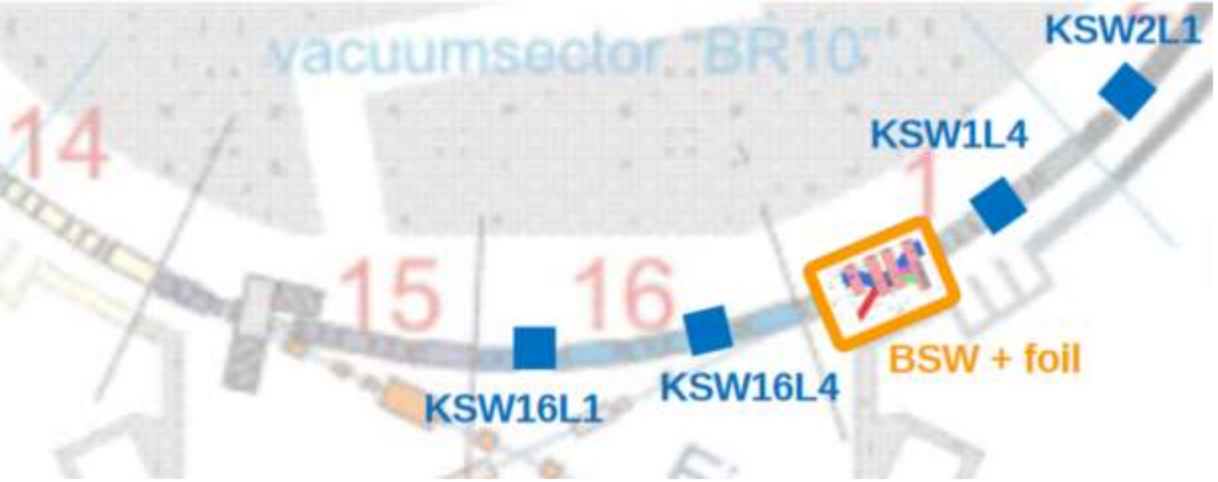
In principle, we should avoid having high losses at high energy, **mind the beam intensity**.

With the non-accelerating flat bottom (160 MeV) cycle have more flexibility (unbunched beam, resonance trapping etc.)

MDs rarely go as planned, be gentle ☺

Measurements

PSB H^- Charge Exchange Injection System



Injection → beam orbit bump by:

- **4 phase space painting kicker magnets (KSW)**

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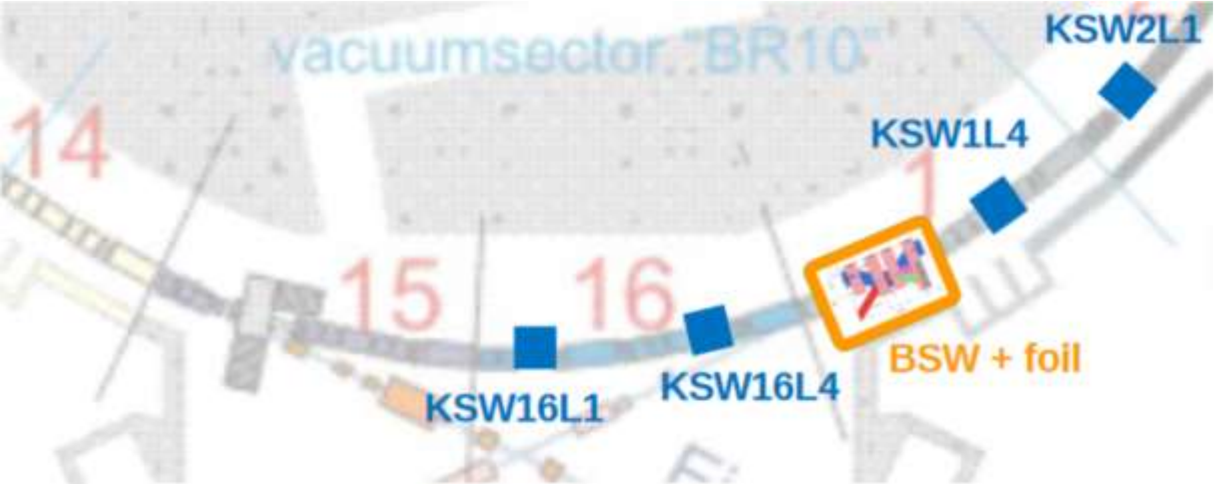

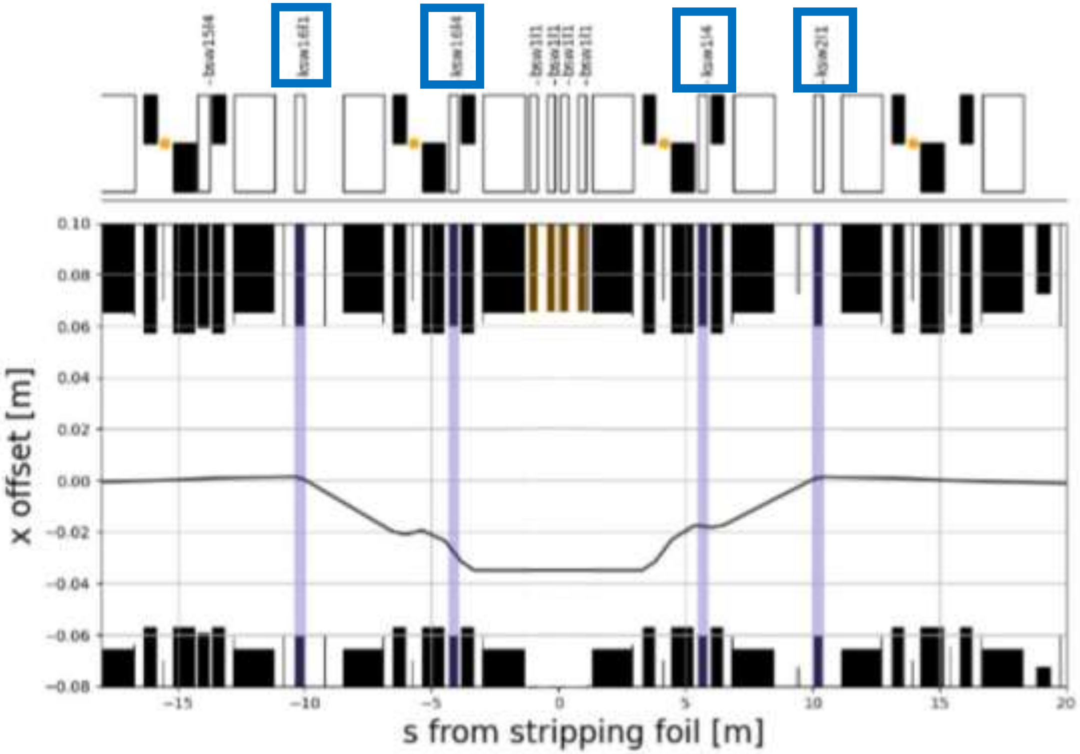

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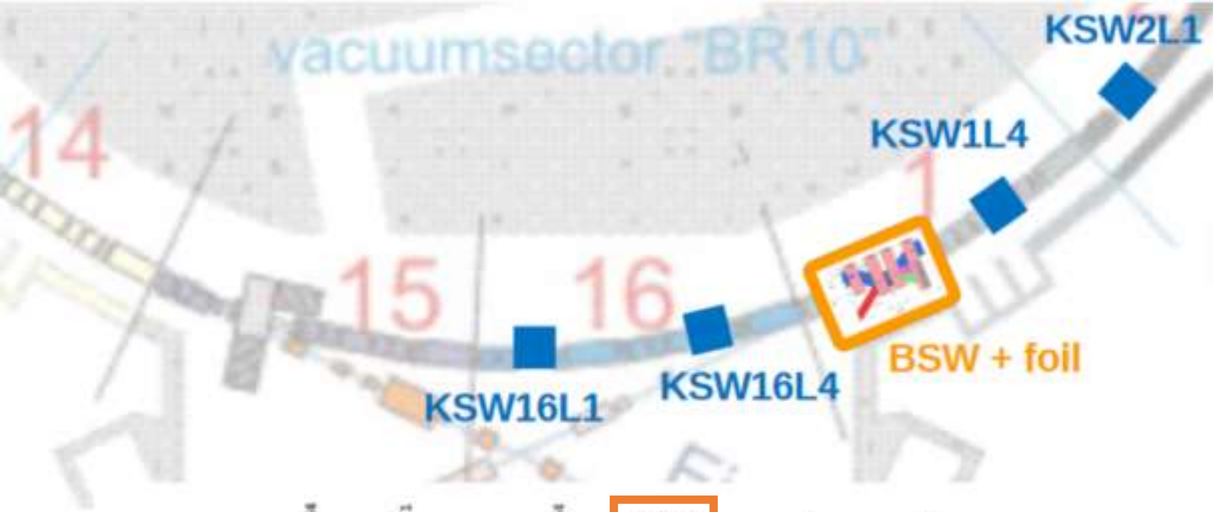

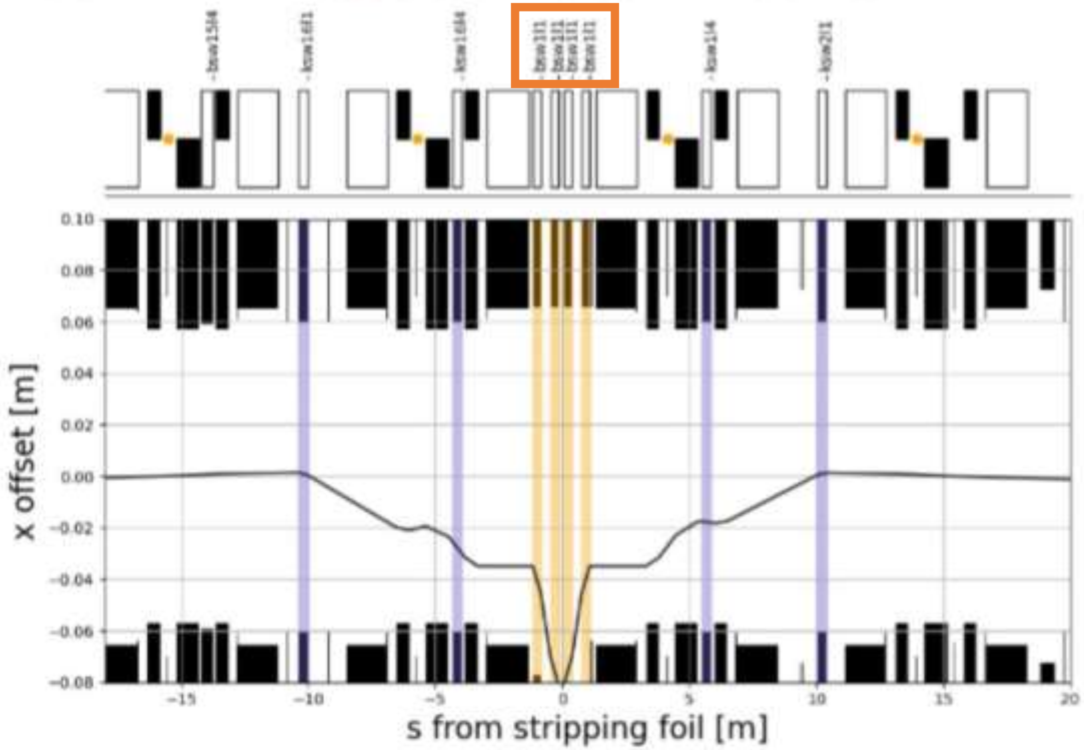

Injection → beam orbit bump by:

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- 4 horizontal chicane magnets (BSW)

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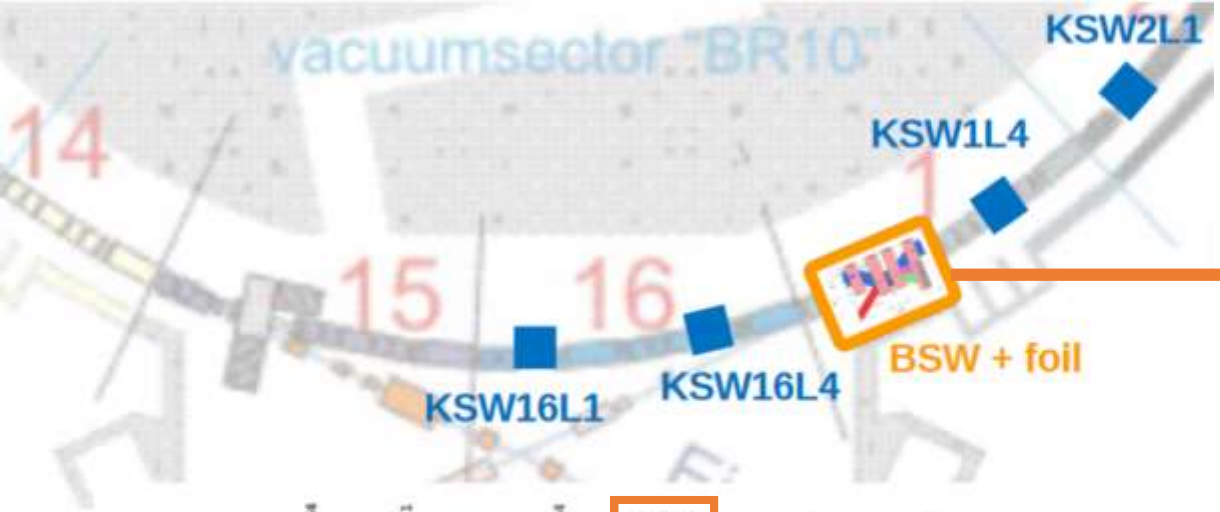

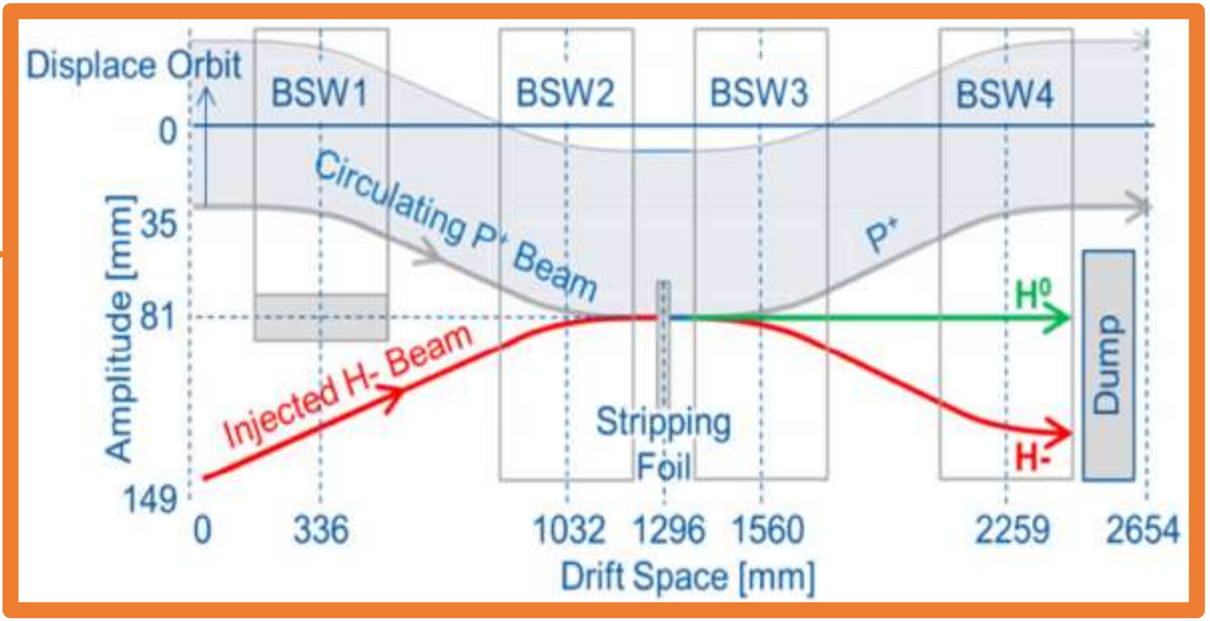

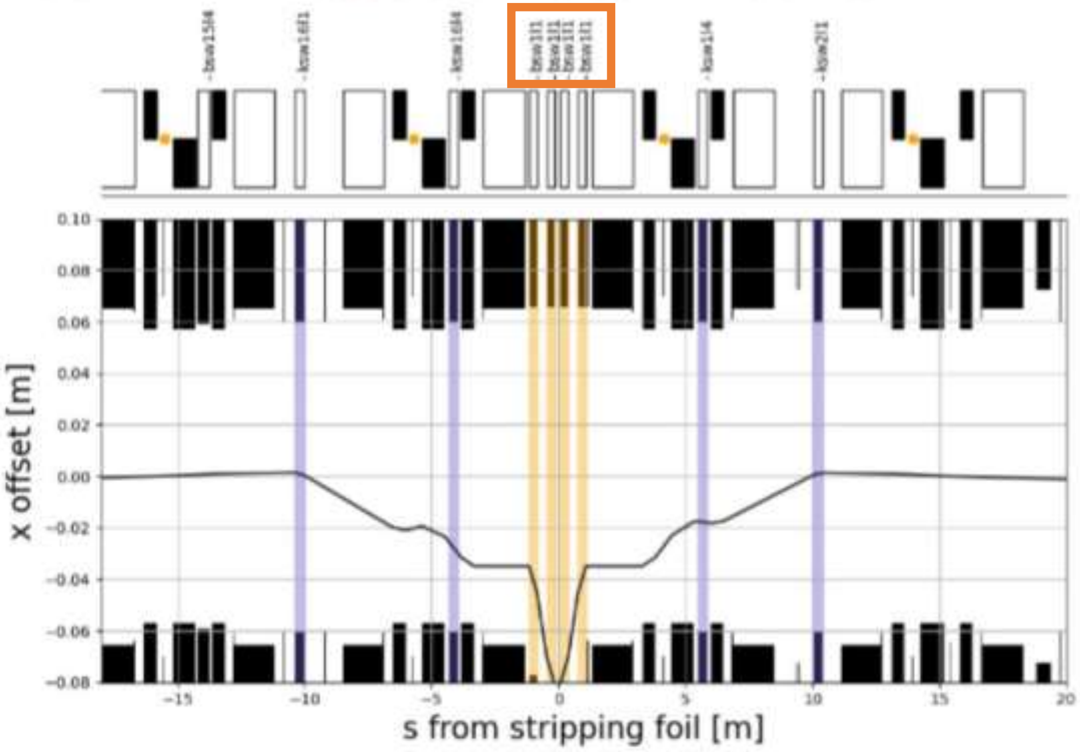

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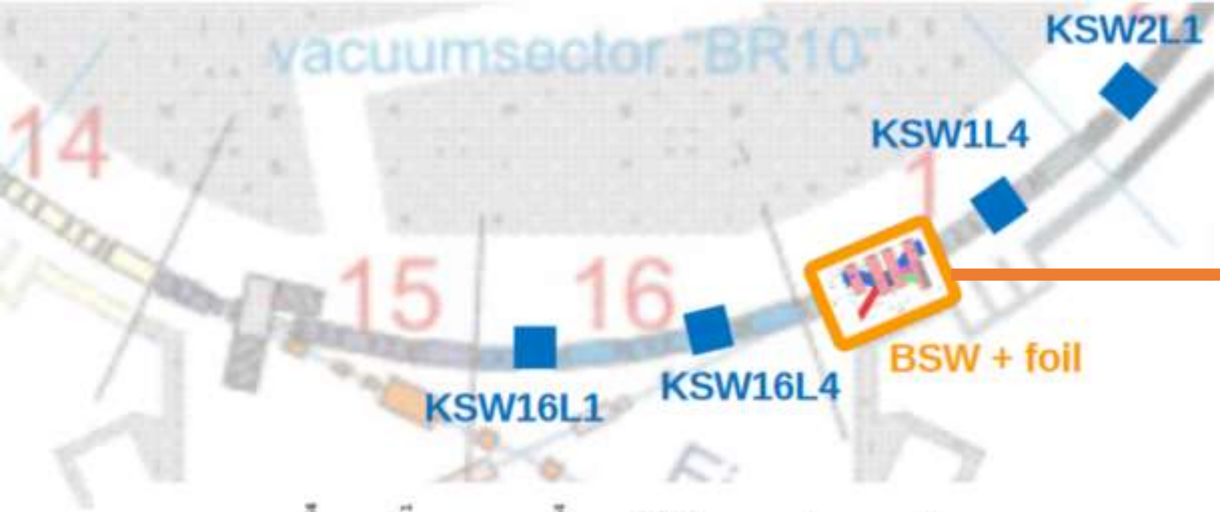
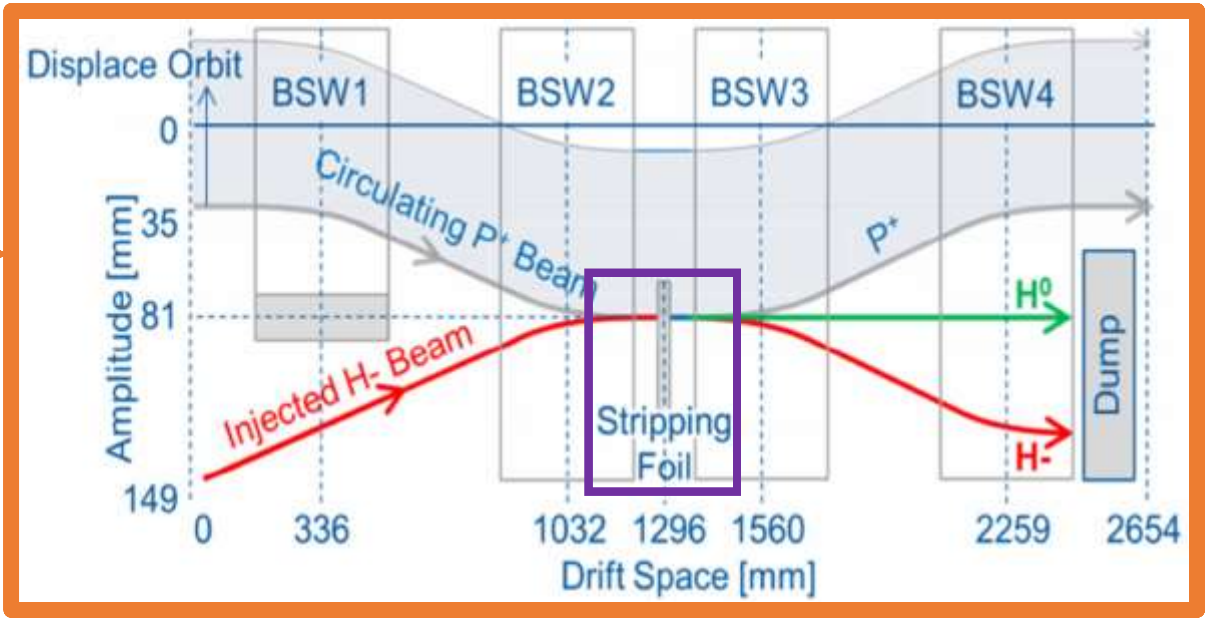
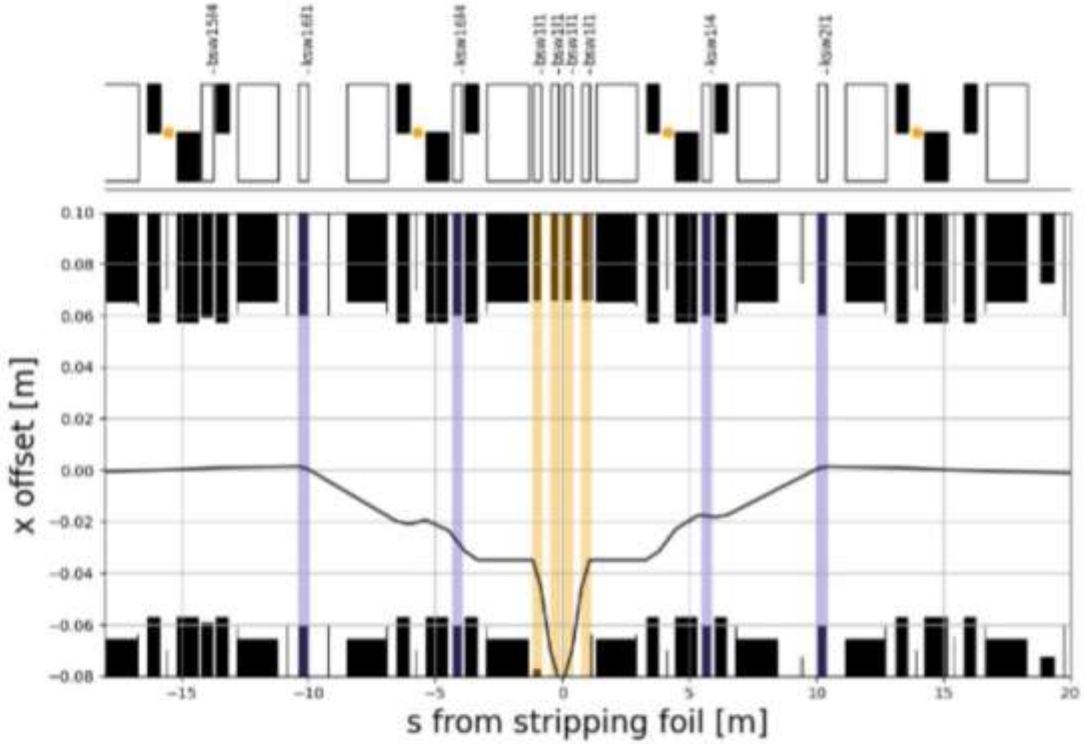
Incoming hydrogen ion particles (***H^-* beam**)

PSB H^- Charge Exchange Injection System





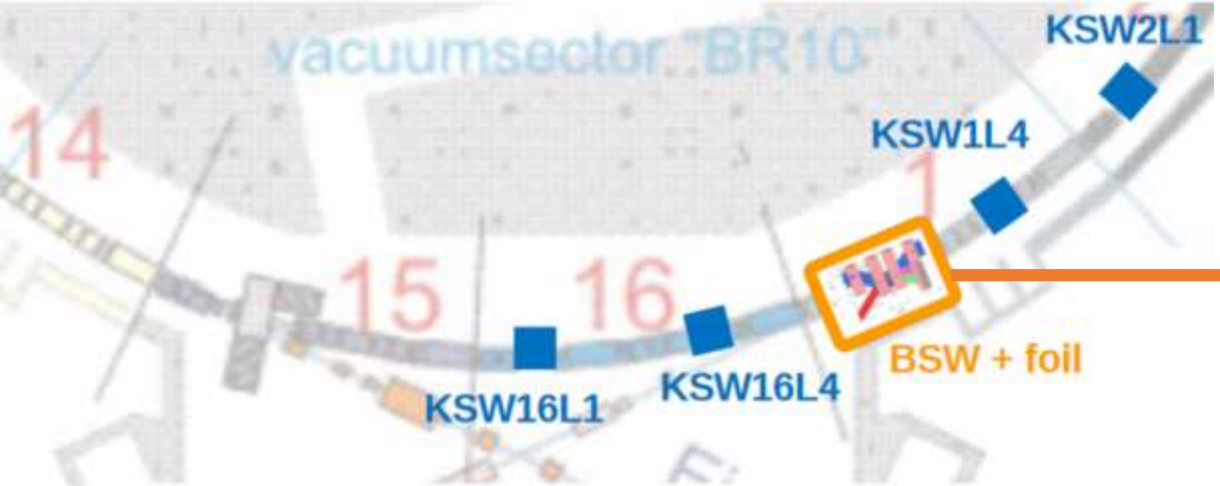


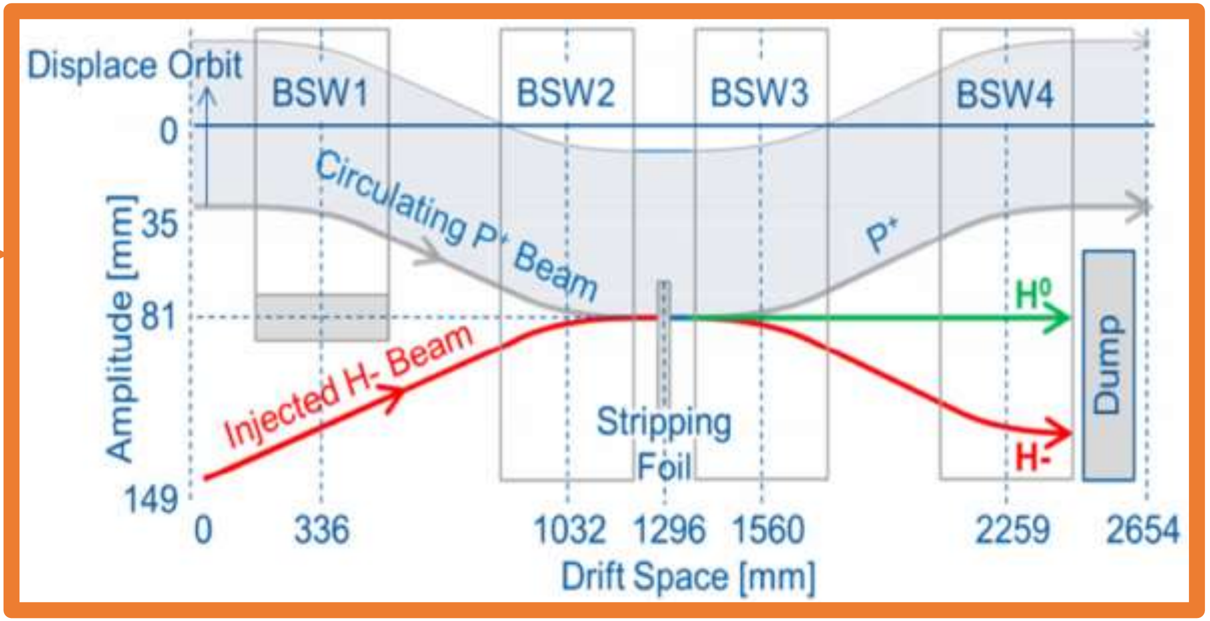
Injection → beam orbit bump by:

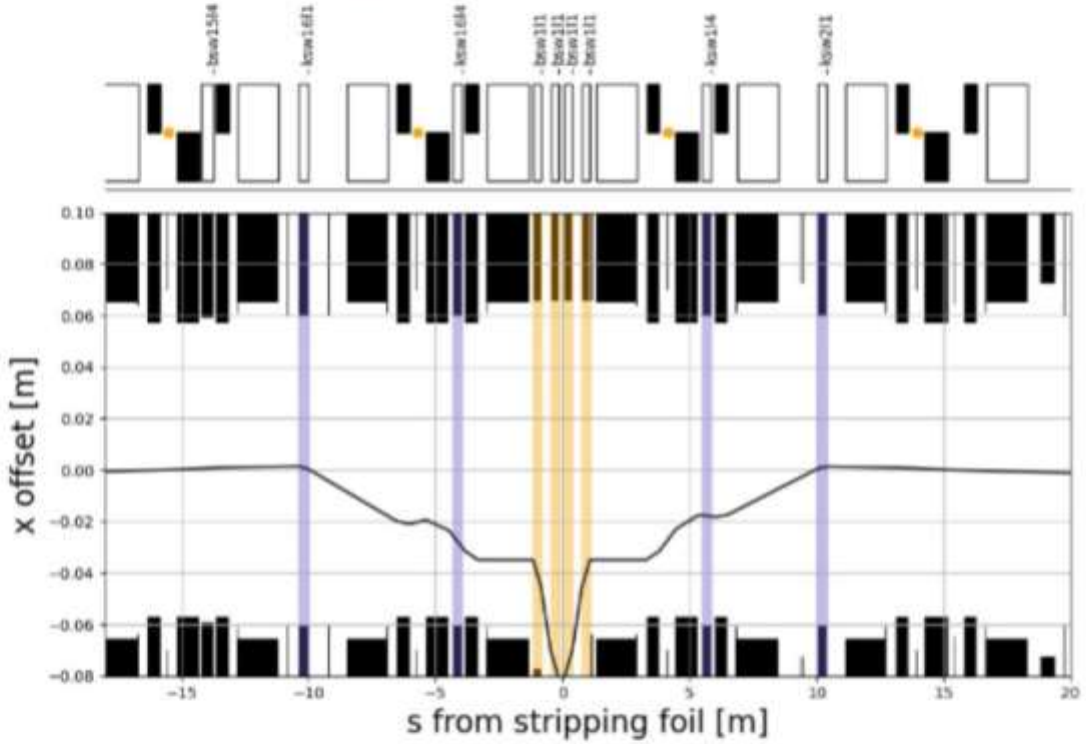
- **4 phase space painting kicker magnets (KSW)**
- **4 horizontal chicane magnets (BSW)**

Incoming hydrogen ion particles (***H***$^-$ **beam**) → **stripping foil** → protons.

PSB H^- Charge Exchange Injection System







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- 4 phase space painting kicker magnets (KSW)
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Incoming hydrogen ion particles (***H^-* beam**) → **stripping foil** → protons.

Injection process over ~100 turns (**multi-turn injection**). Closure of the bump over 5000 turns (~5ms).

Beam parameter adjustments

Intensity

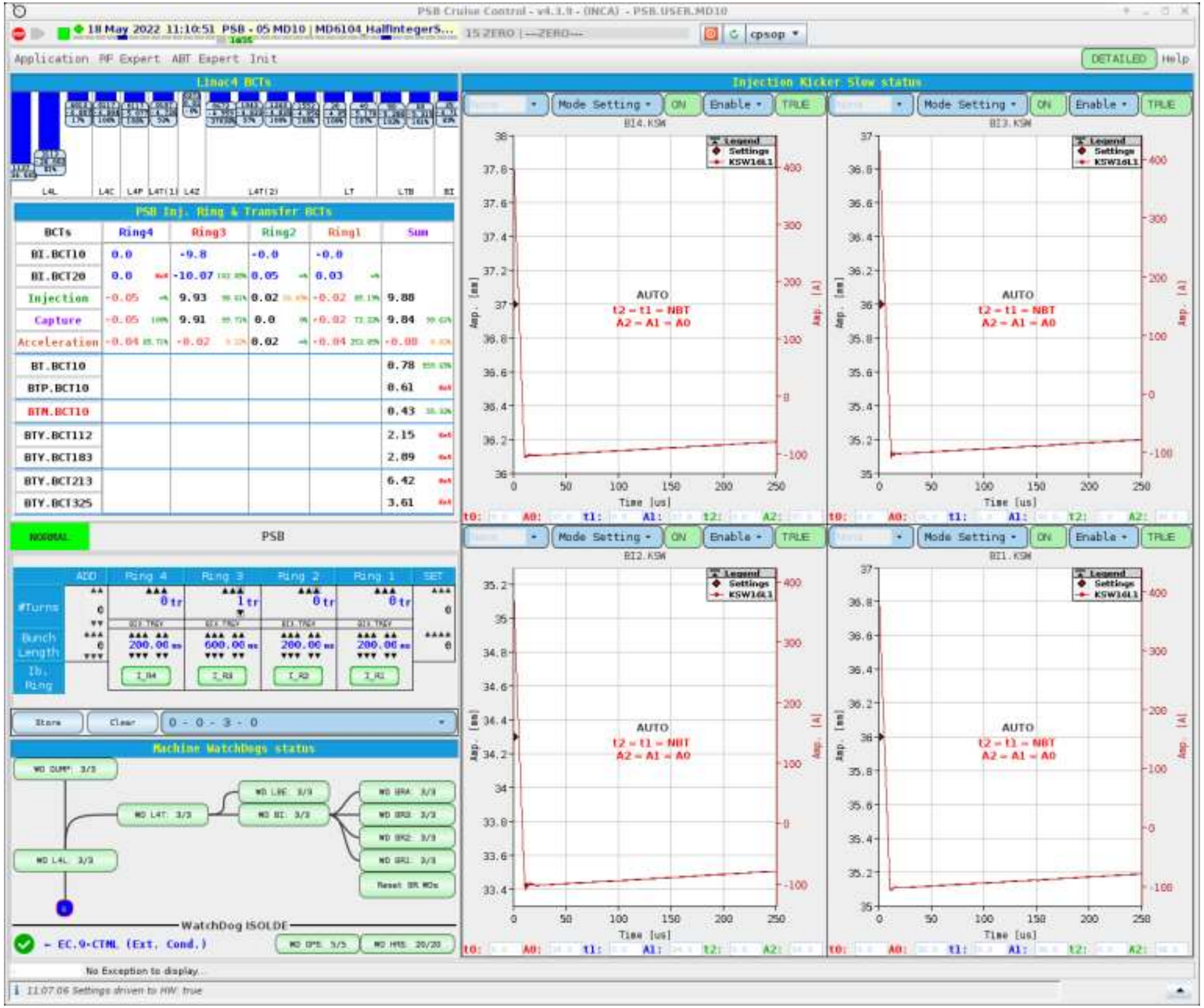
Changing the number and length of the pulses injected from Linac4

Momentum spread

Change the energy spread of the Linac4 pulse.

Emittance blow-up

- Change the number of foil crossings
- Injection misteering (injection oscillations)



Tune setup

$$(Q_x, Q_y) = (4.17, 4.23)$$

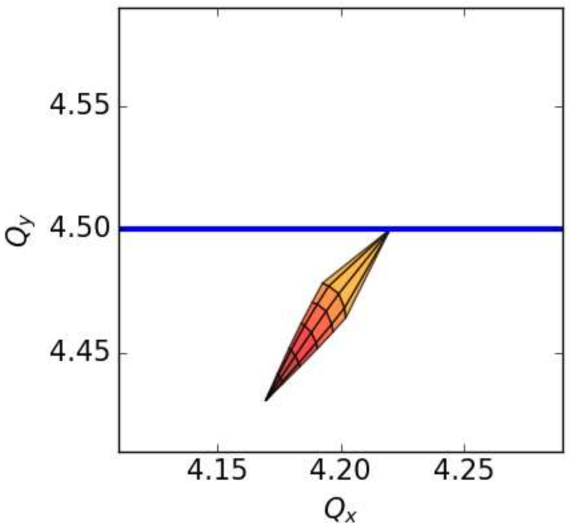
Working point at which the extraction is setup.

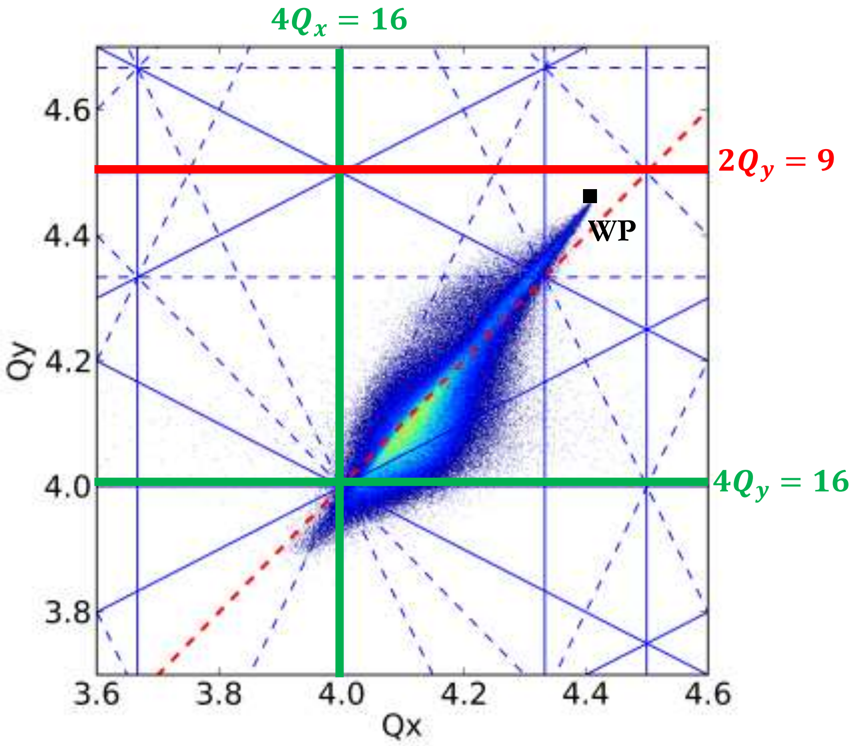
Dynamic tune change during the PSB cycle

What is the optimal tune ramp?

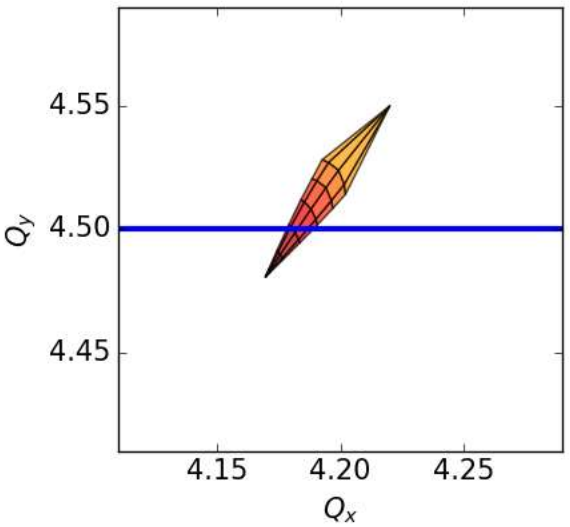
Tune setup: losses and emittance blow-up

High amplitude (tails) particles interact with the resonance: **losses**



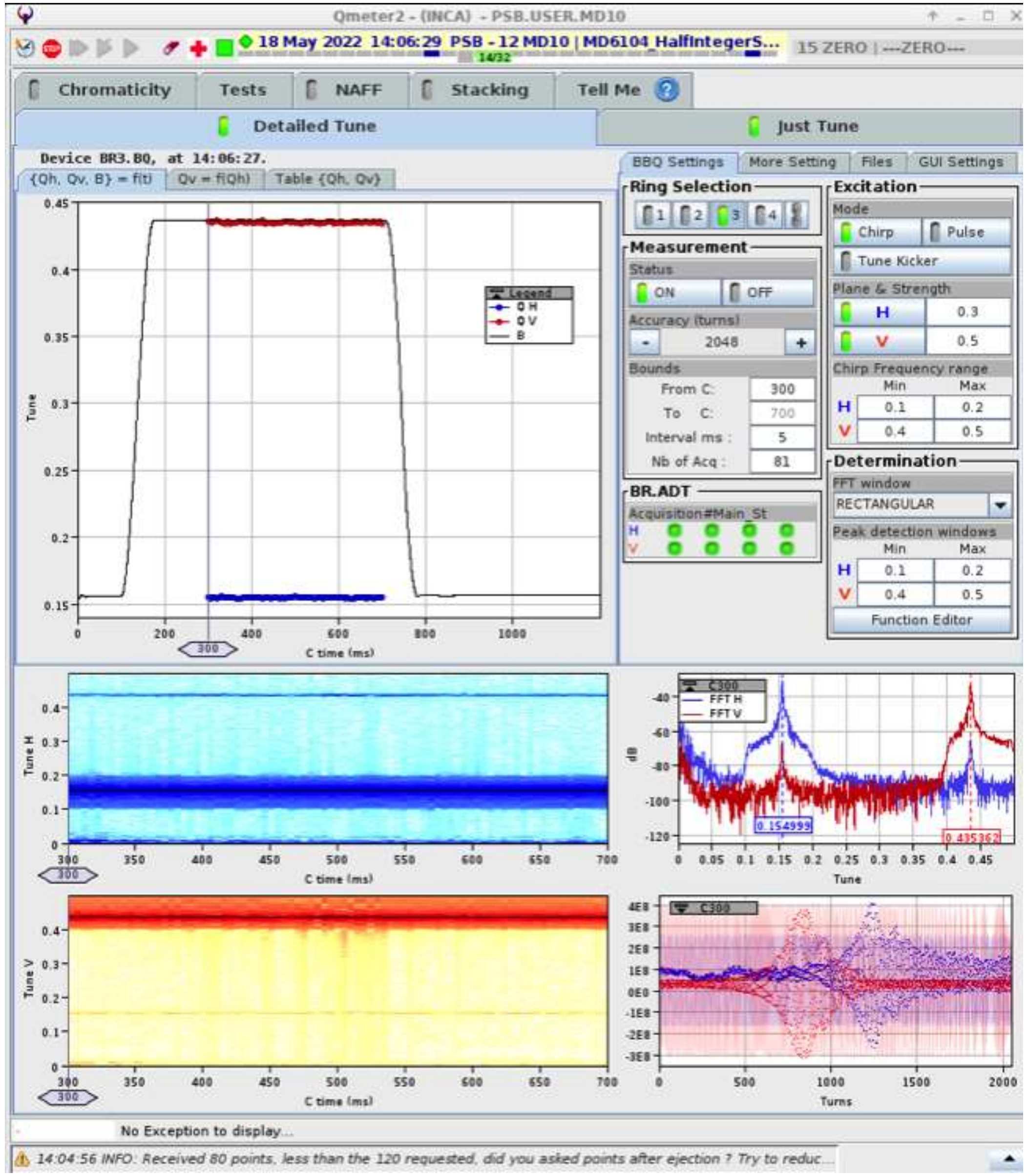


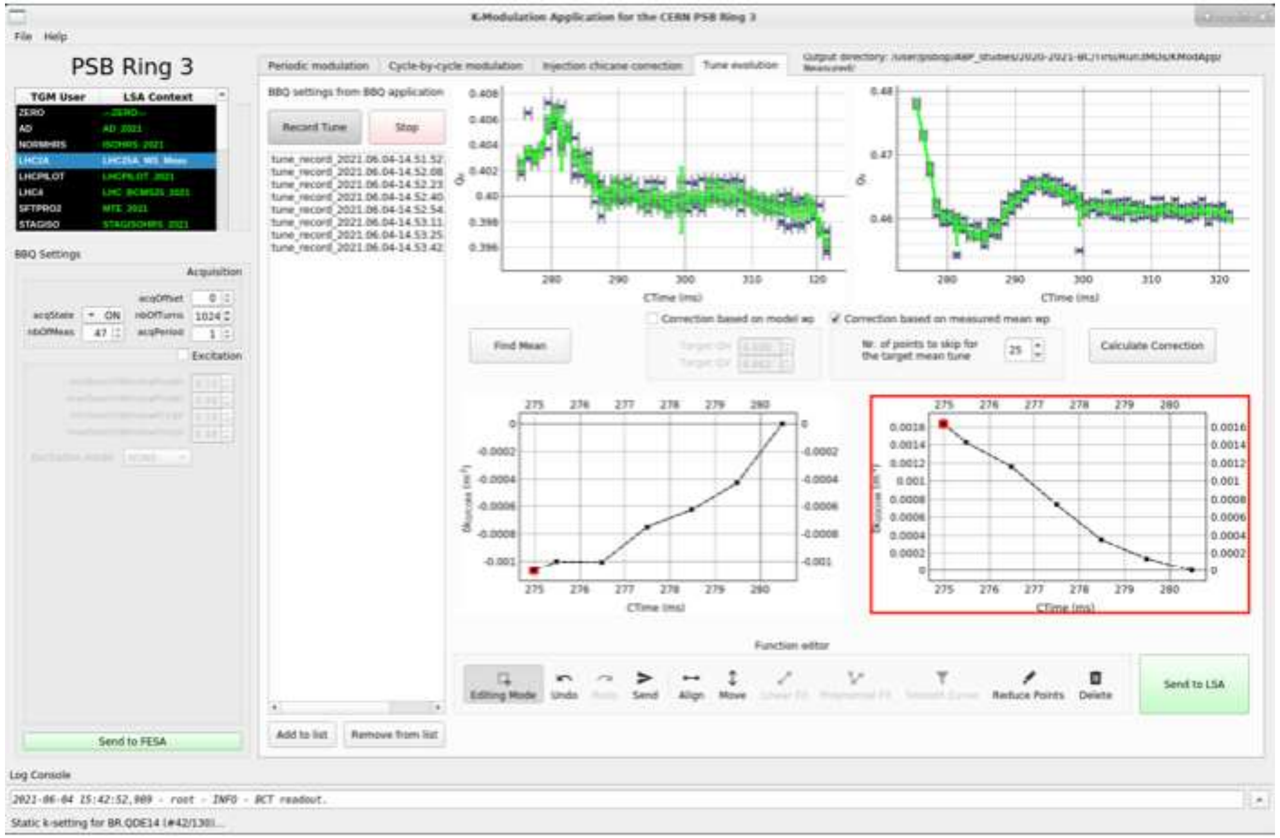
Low amplitude (core) particles interact with the resonance: **emittance blow-up**



PSB operates in the brightness limit:
space charge tune spread larger than 0.5

Tune measurement and correction





Tune correction based on the "make-rules":

$$Q \rightarrow k \rightarrow I$$

Chromaticity measurement and correction

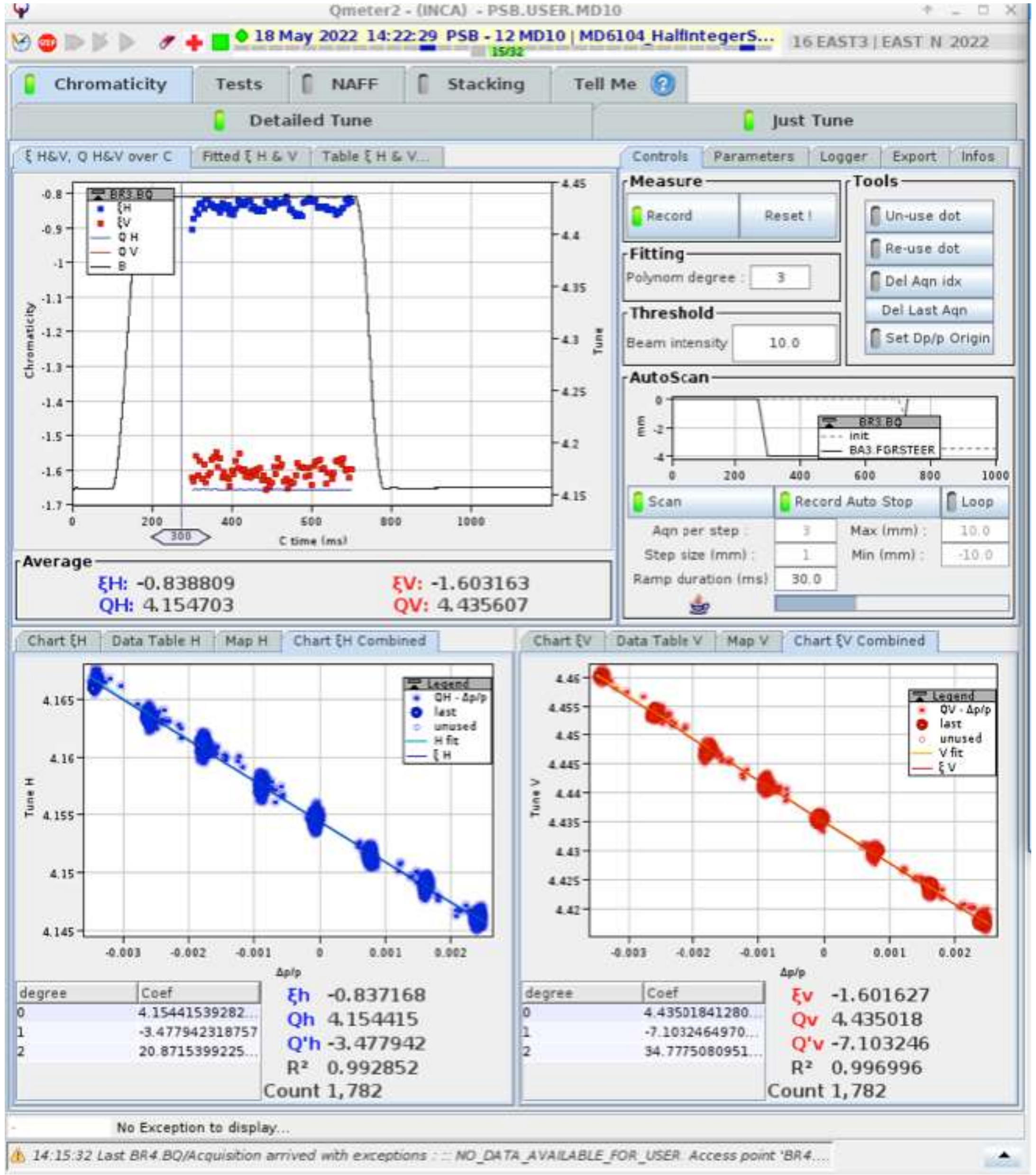
Chromaticity

$$\xi = \frac{\delta Q}{(\delta p/p)} \text{ or } Q' = \frac{(\delta Q/Q)}{(\delta p/p)}$$

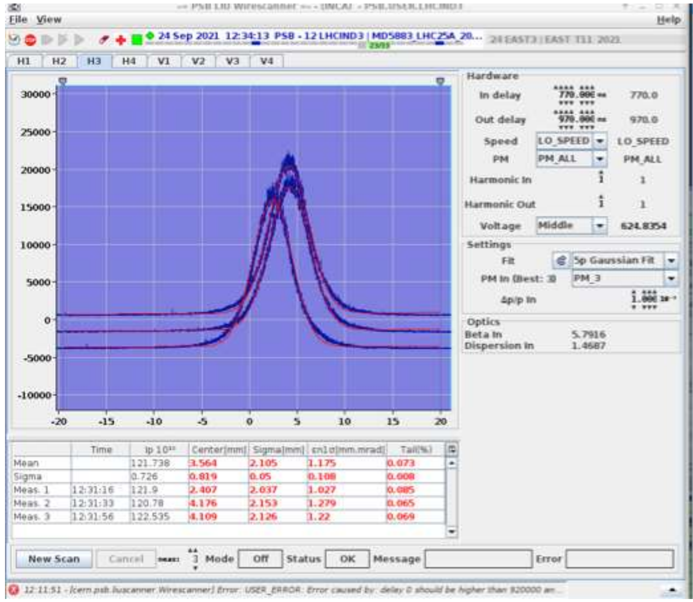
Chromaticity is measured by measuring the tune shift for different radial steerings.

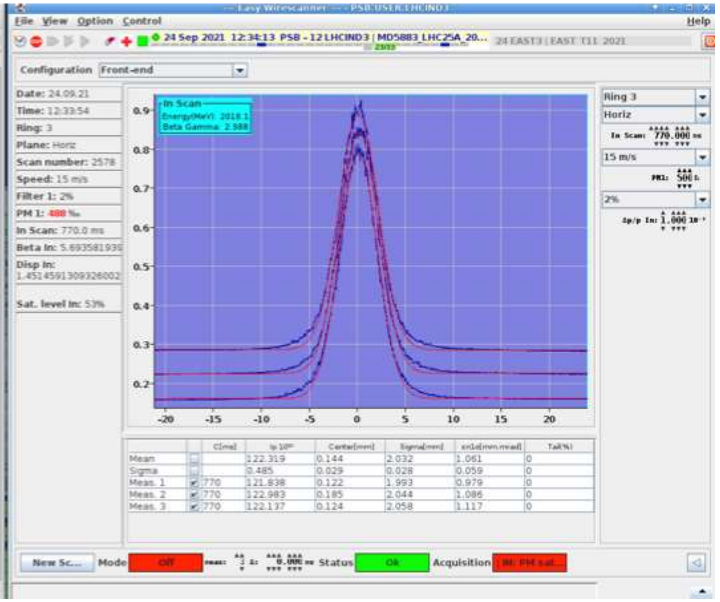
$\frac{\delta p}{p} = \frac{1}{\eta}\frac{\delta f_{rev}}{f_{rev}}$, where η the phase slippage factor and $f_{RF} = h f_{rev}$

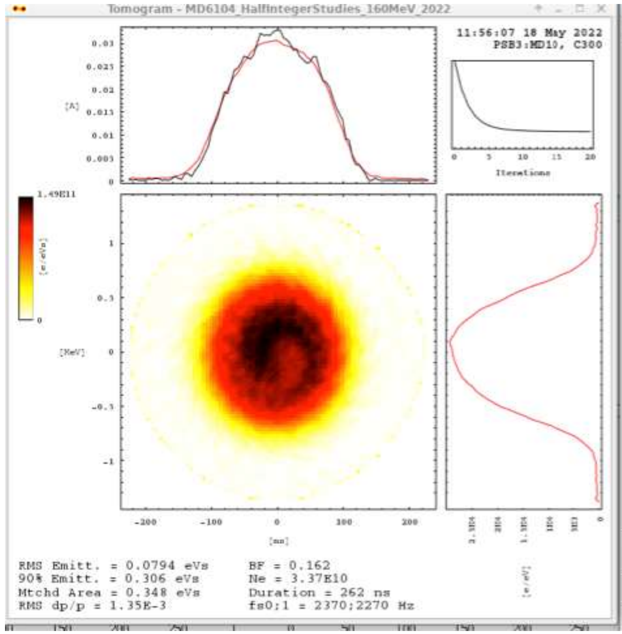
Chromaticity is very close to the model. MAD-X can be used to find the sextupole strength to compensate it.

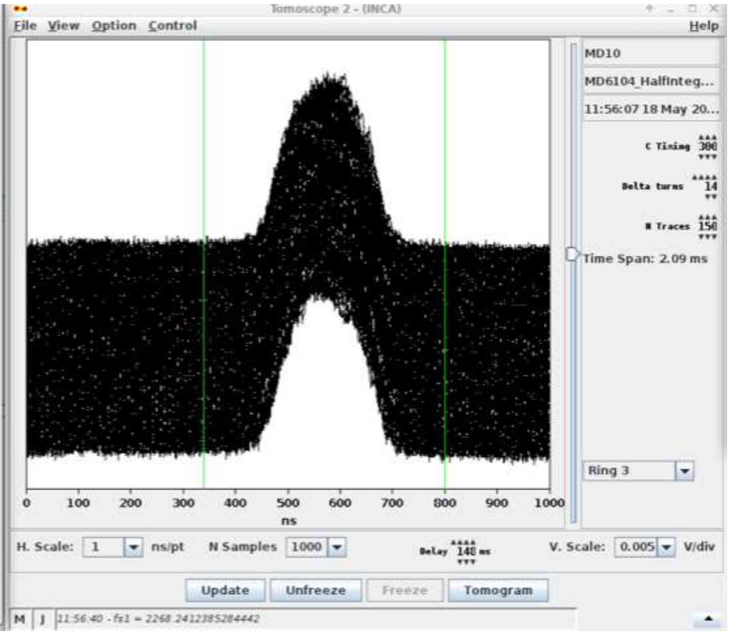


Transverse and longitudinal profiles









Emittance and Brightness

In the PSB we have non-zero dispesion: coupling between transverse and longitudinal motion →
growth of the horizontal phase space that the beam occupies

$$\langle x\rangle_{measured} = \langle x\rangle_{betatronic} * \langle x\rangle_{dispersive}$$
$$\langle x\rangle_{measured} = \langle \epsilon_x \beta_x\rangle * \langle D_x \, \delta p/p\rangle$$

If all three Gaussian

$$\sigma_{measured} = \sqrt{\epsilon_x \beta_x + \left(D_x \frac{\delta p}{p}\right)^2}$$

Emittance → Normalized emittance
$$\epsilon_n = \epsilon_x \beta_{rel} \gamma_{rel}$$

If at least one non-Gaussian

Deconvolution not trivial; need iterative algorithms

Brightness → Intensity/emittance

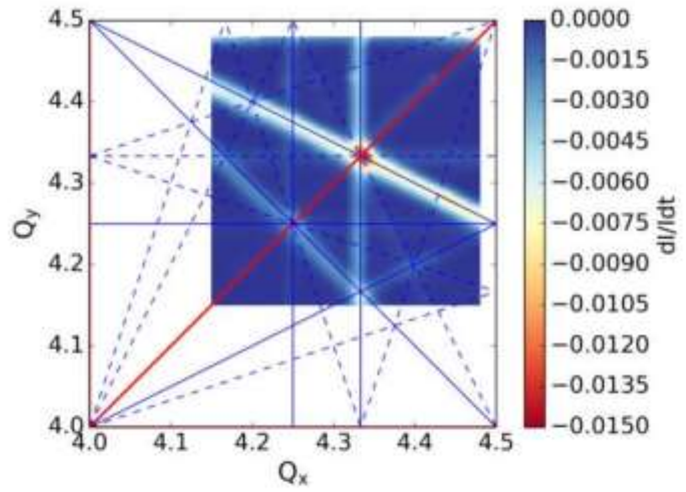
Closed Orbit Measurement and Correction

Resonance crossing and compensation

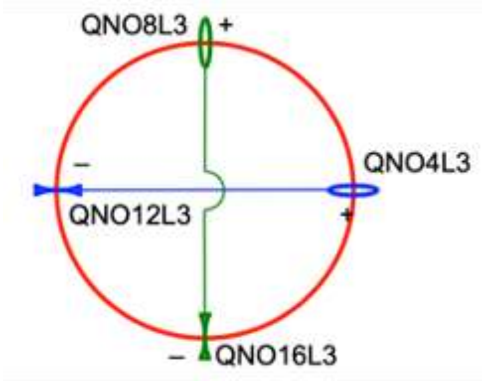
- Third and fourth order resonances are dynamically crossed at different times during the acceleration cycle.

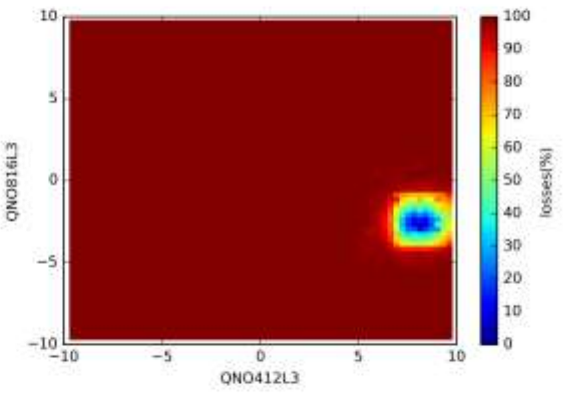
- Resonance compensation is applied using the available quadrupole, sextupole and octupole correctors, only when the resonance is crossed.

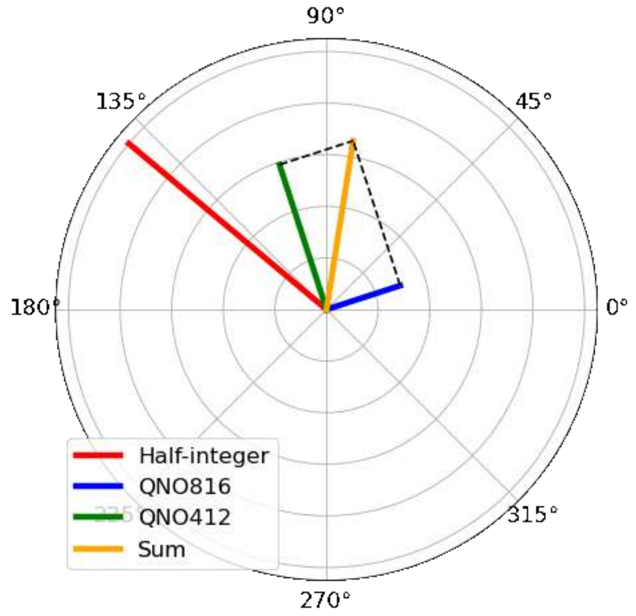
- One corrector can perturb the compensation of other resonances. Attempts have been made for a global resonance compensation.



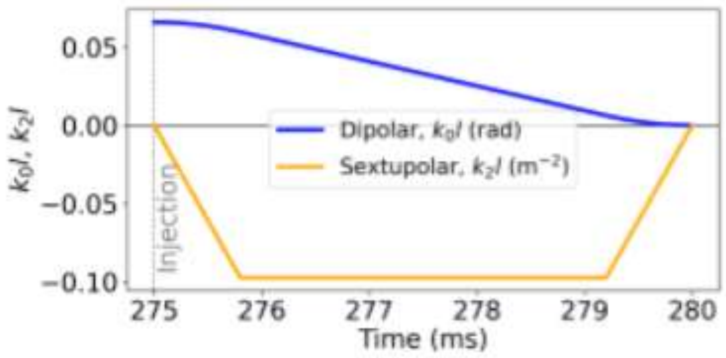
- The compensation is done experimentally by finding a suitable magnet pair for the correction and changing the driving tern that they create.

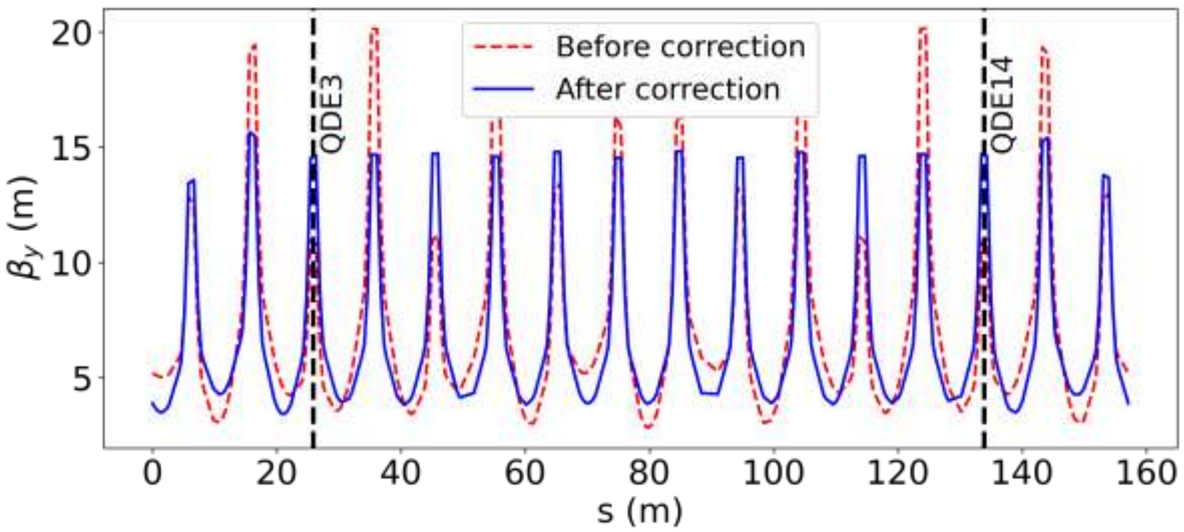


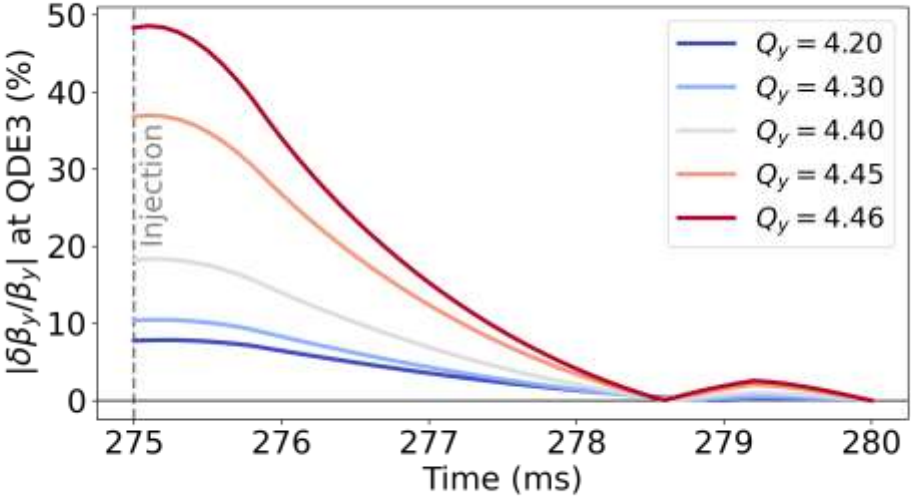




Injection chicane beta-beating

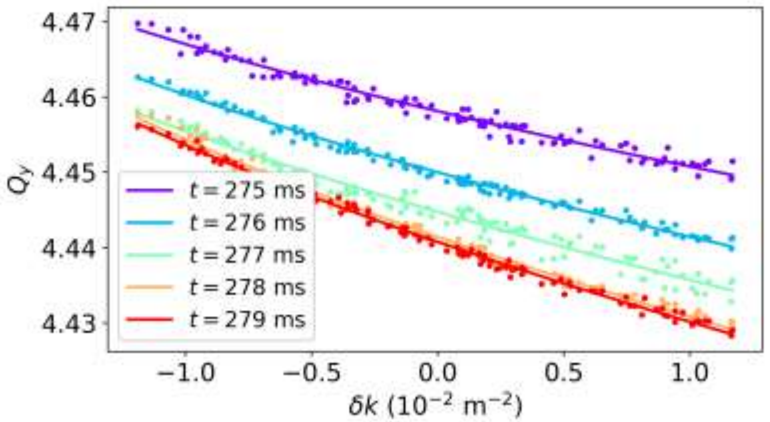






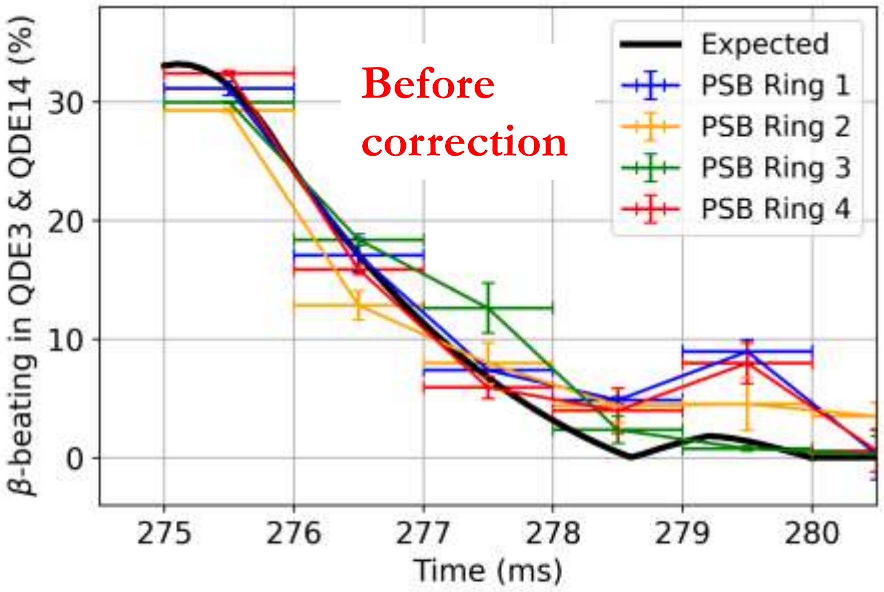
β-beating measurements at injection

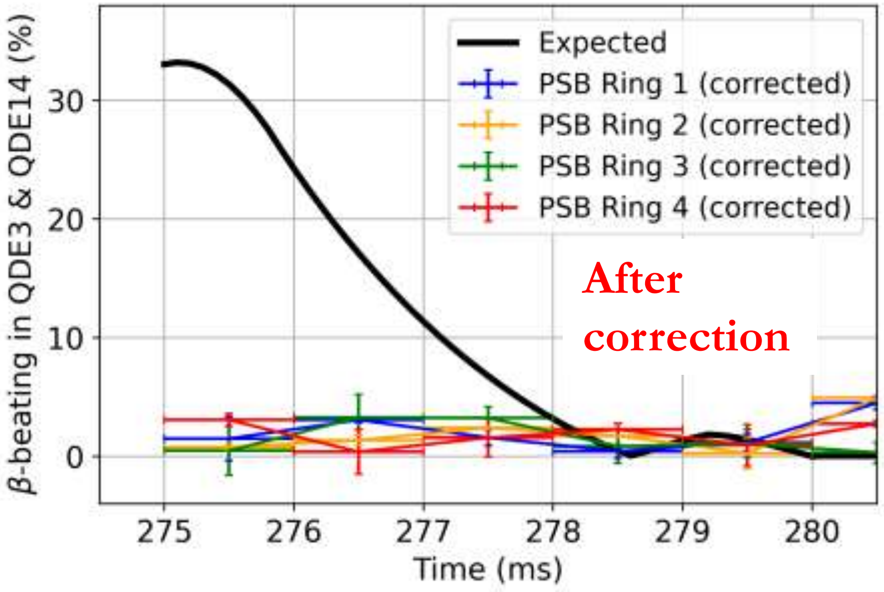
- MD5465 used during the 2020-2021 PSB beam commissioning for the:
  - Measurement of the **β-beating during the fall of the injection chicane** using k-modulation (excellent agreement with expected perturbations).
  - Calculation of the **dynamic correction** [1] which was applied to the machine.



- Measurements acquired with a **k-modulation GUI** [2], available in the CCC (a user manual is currently being written).

> ✓ Measurement would not be possible without the **important contributions** of OP, RF, ABT, EPC (improved regulation of quadrupole circuits), ABP (resonance compensation and tune control), BI (BBQ application).

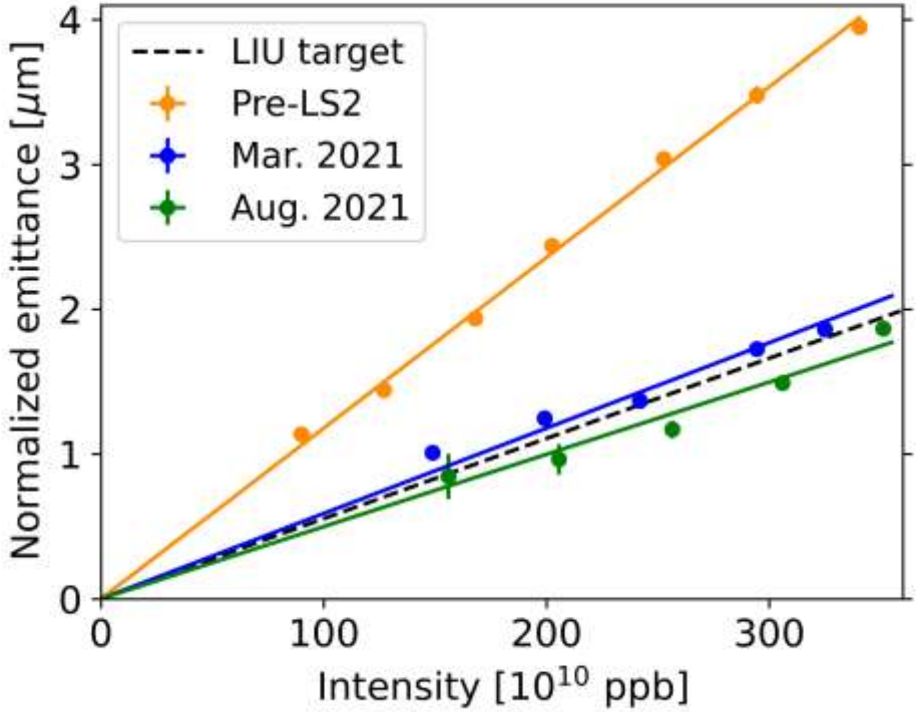




Dynamic β-beating correction and impact on brightness

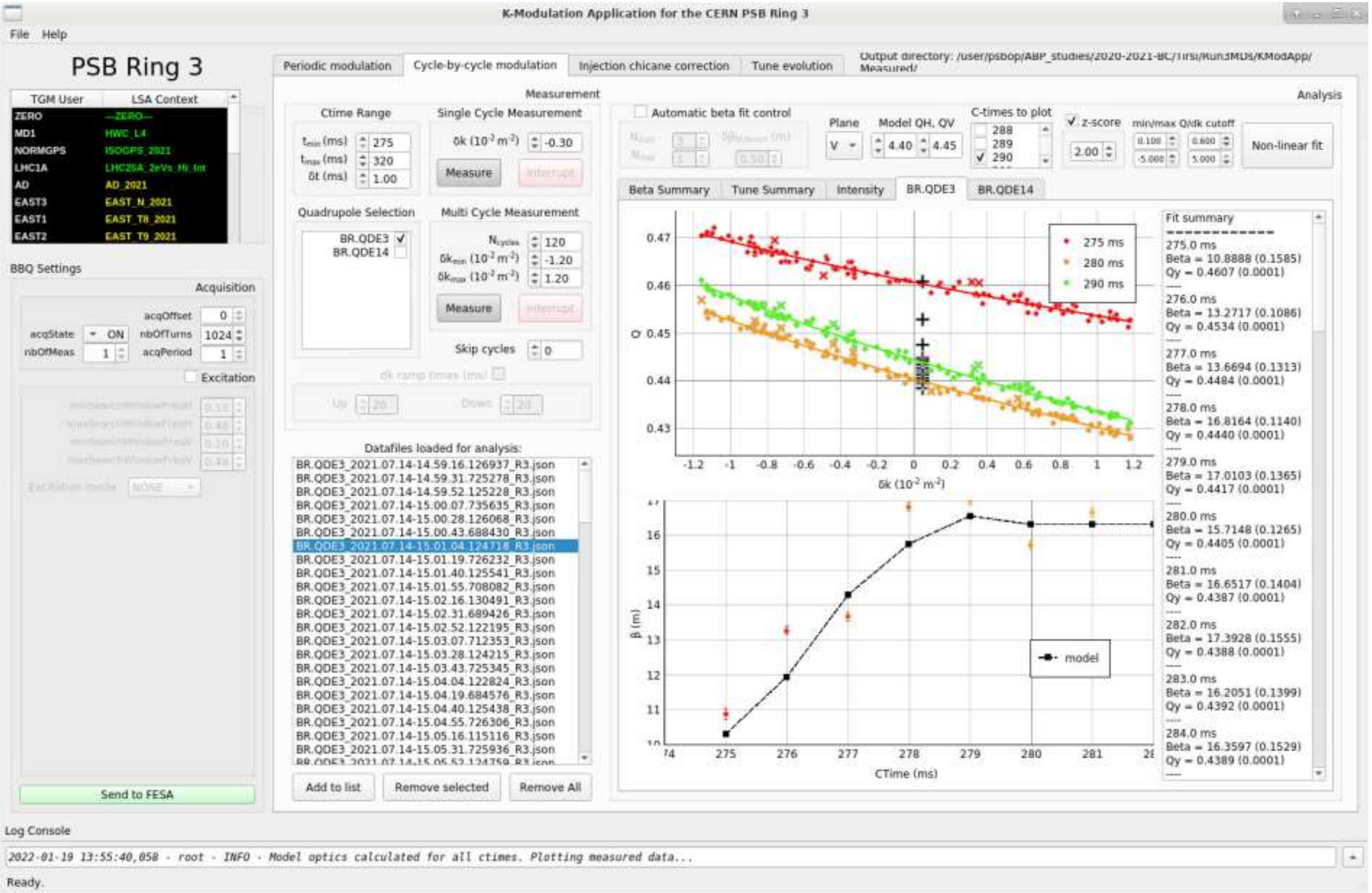
- MD results had a positive impact on the brightness performance:

  - Correction of the β-beating allowed the stable beam operation much closer to the half-integer resonance, which further mitigated the space charge effects at injection and **contributed to an increased brightness** [1].
  - **Brightness curve measurements** were performed after the optimization of the resonance compensation, the β-beating correction and tune evolution.



- Dynamic β-beating correction was **operational in 2021**. MD5465 to be used for **reviewing the correction functions** after the restart of the machine.

Injection chicane beta-beating



Instabilities