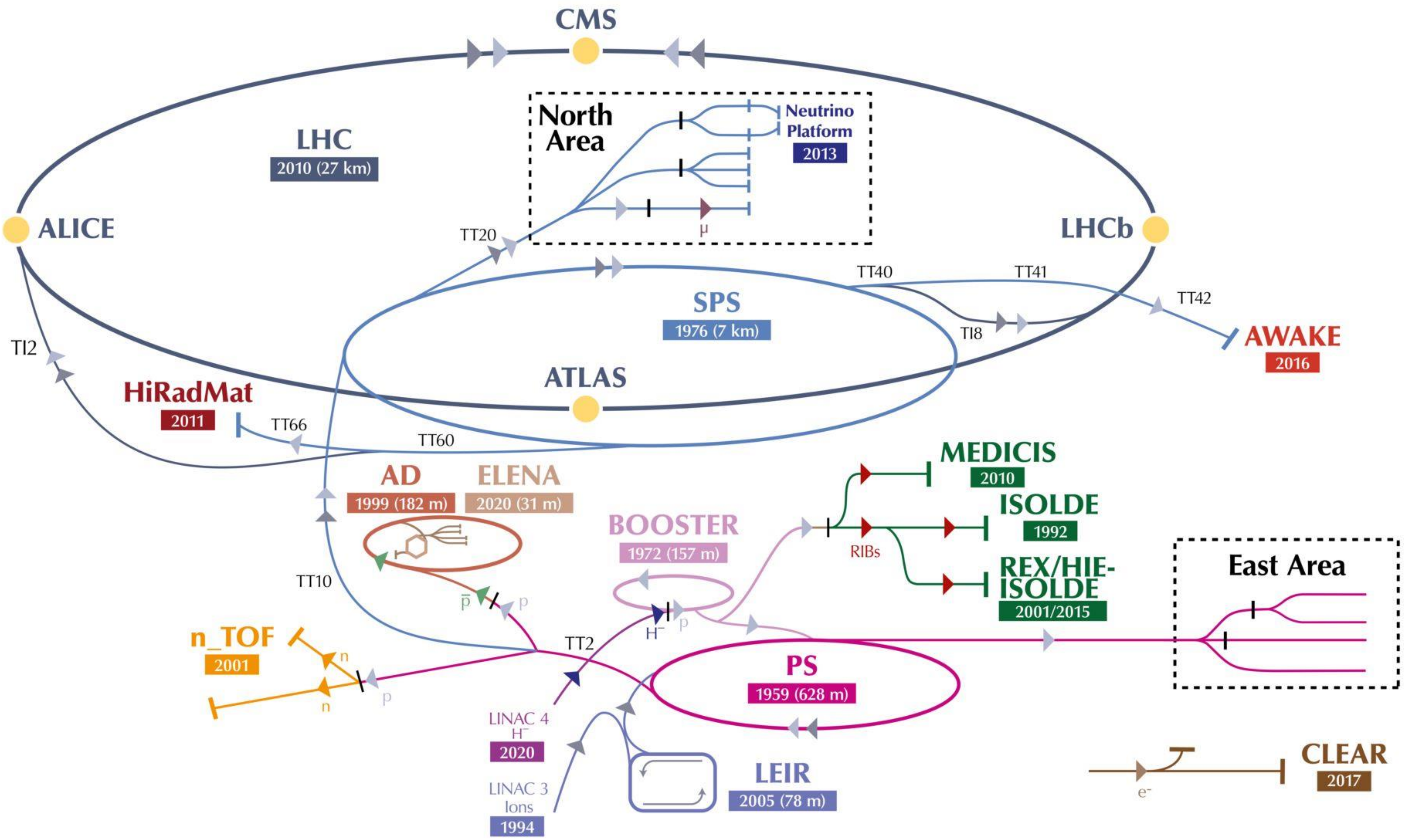
Introduction to the PSB:

Accelerator, Control Systems, Measurements

F. Asvesta, T. Prebibaj

03-07/06/2024
Advanced Training School on Operation of Accelerators
EURO-LABS Training Sessions @ CERN Facilities

Injectors complex & facilities



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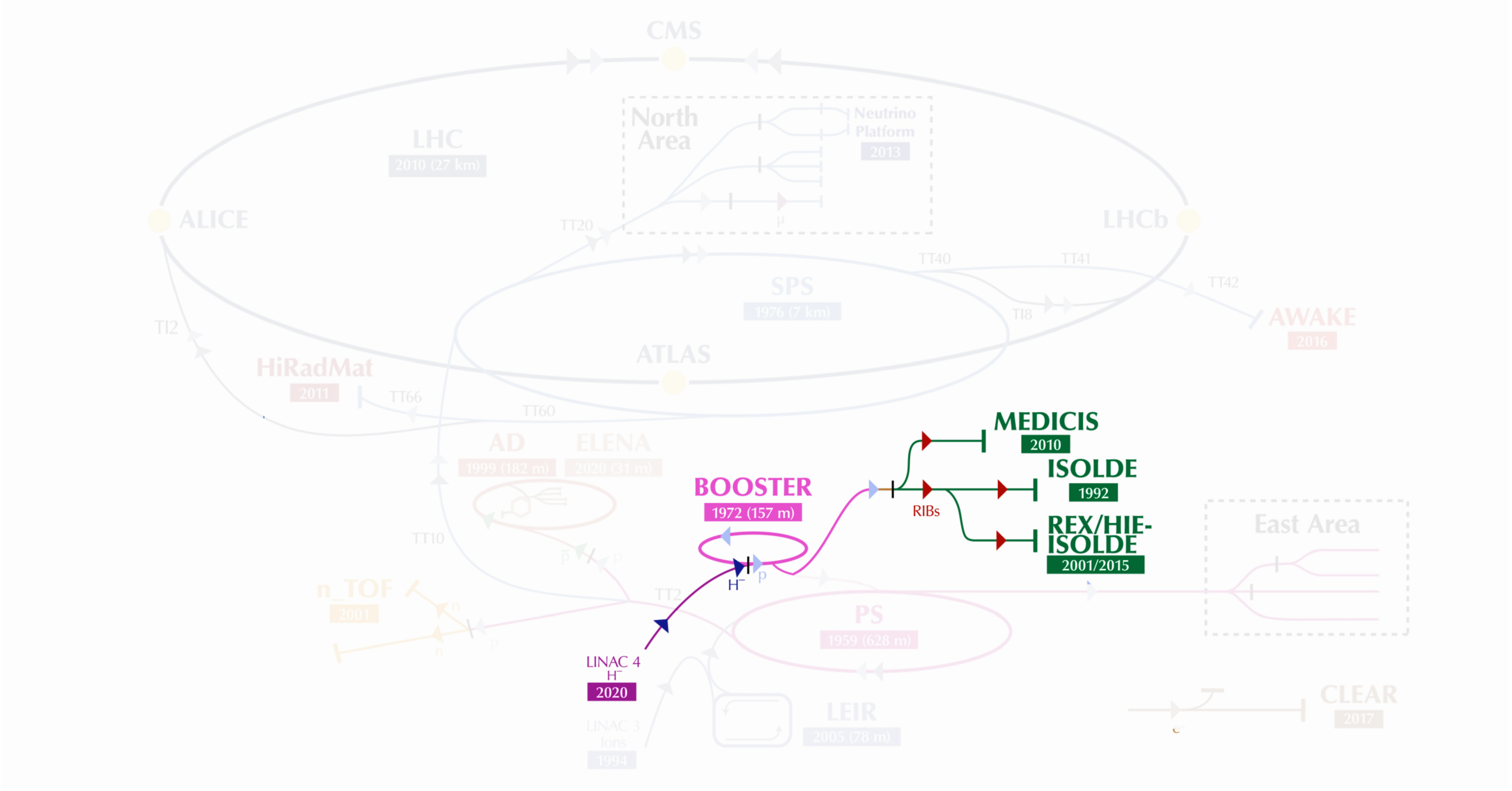

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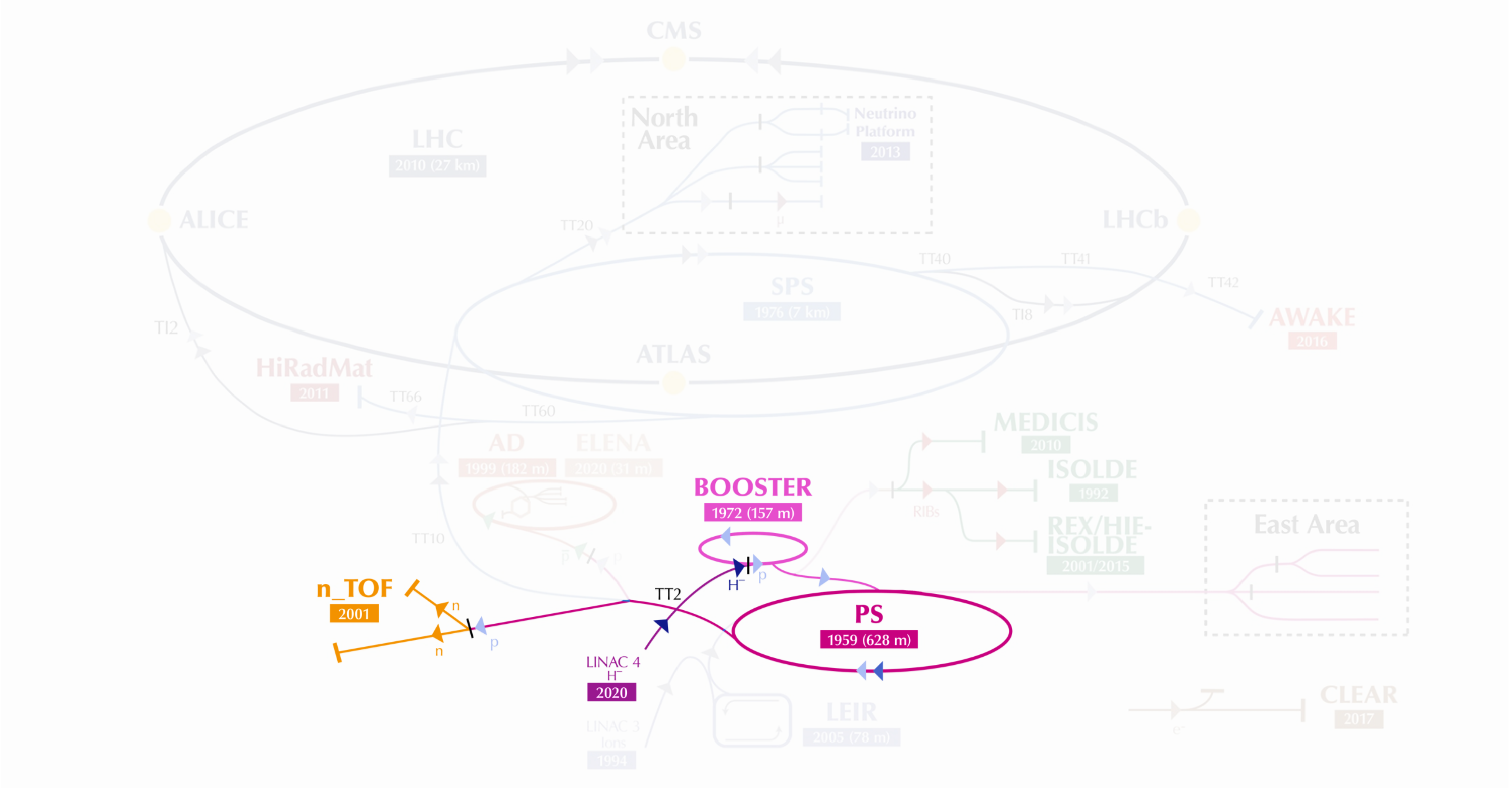

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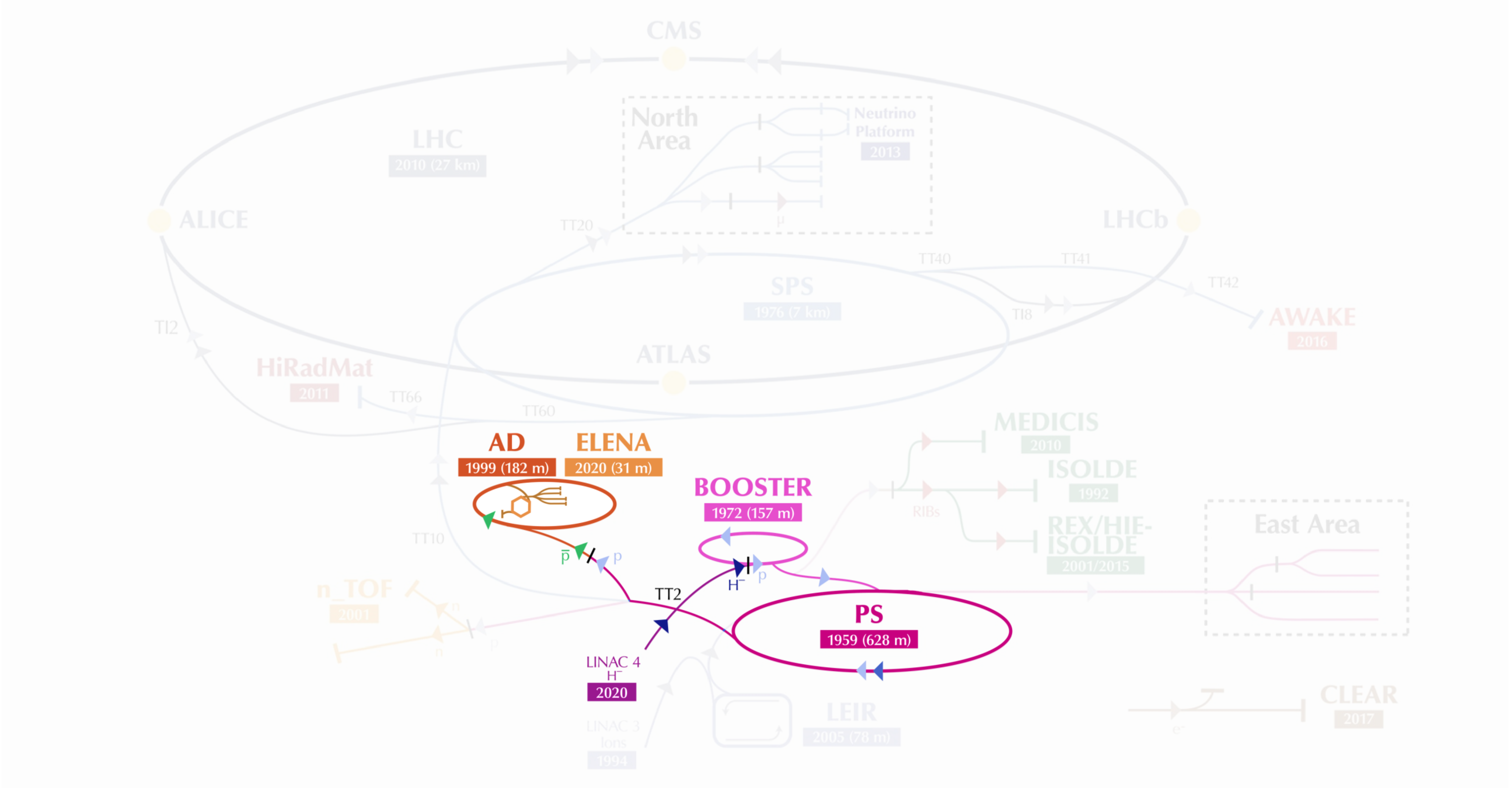

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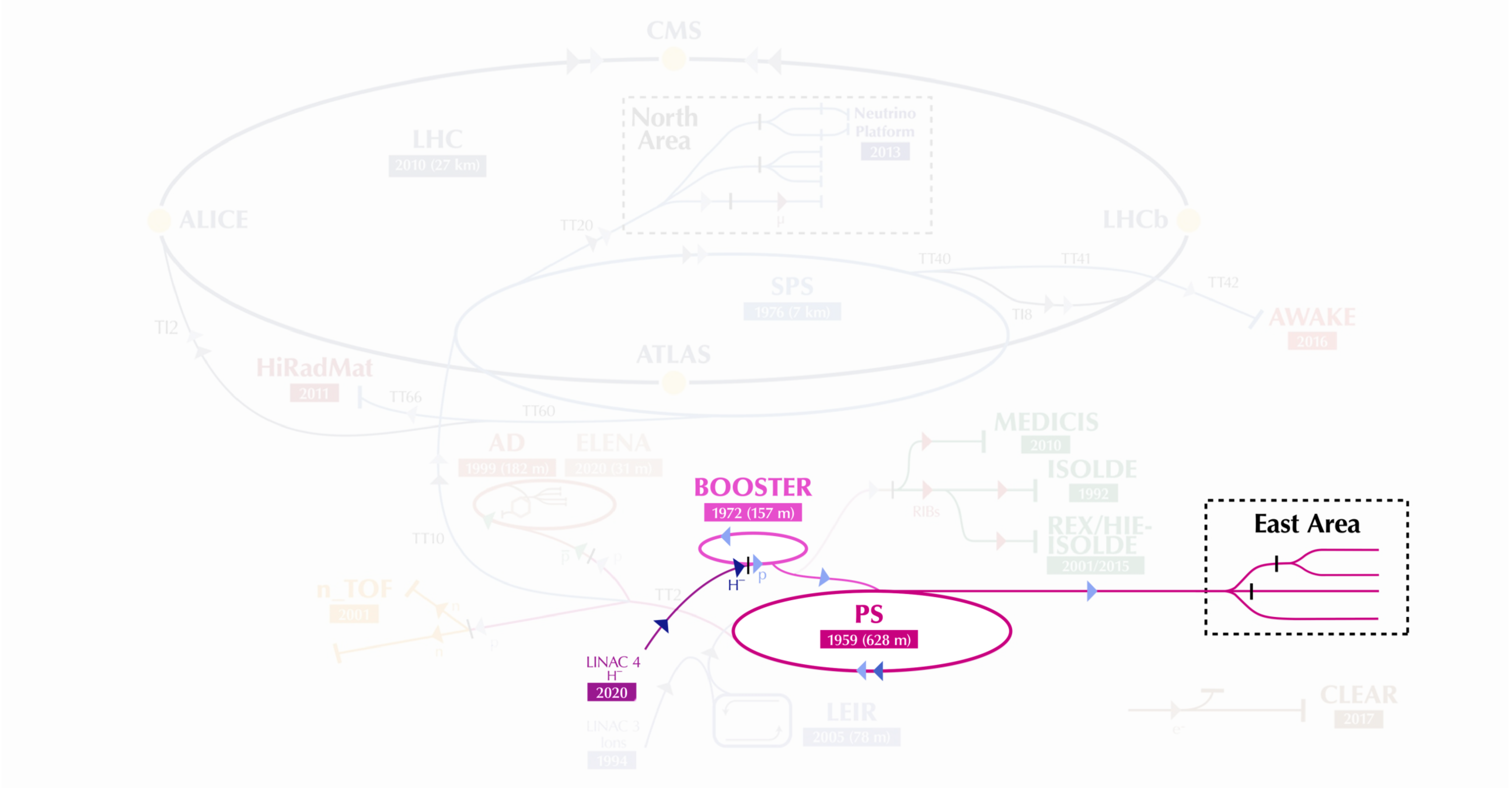

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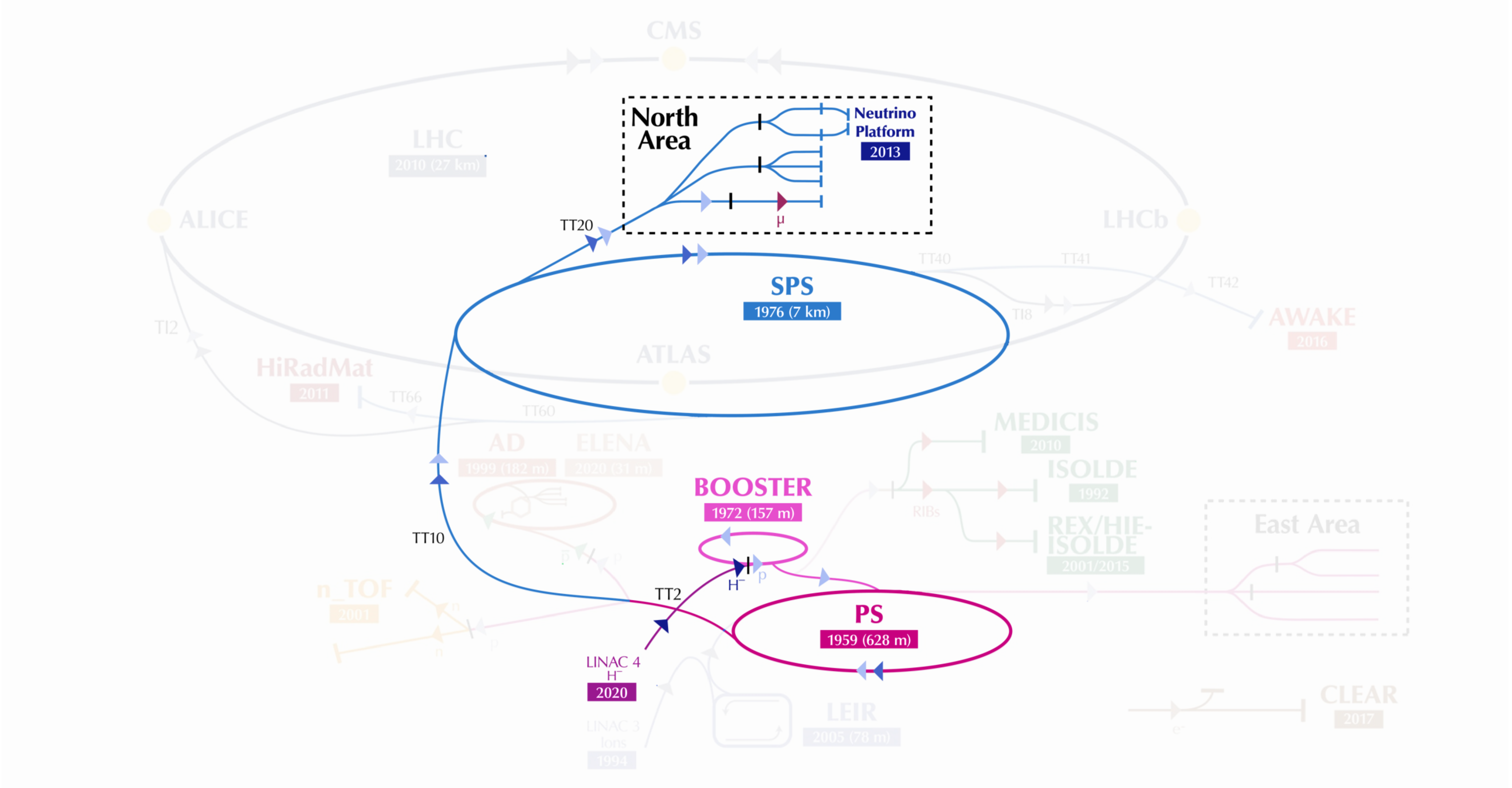

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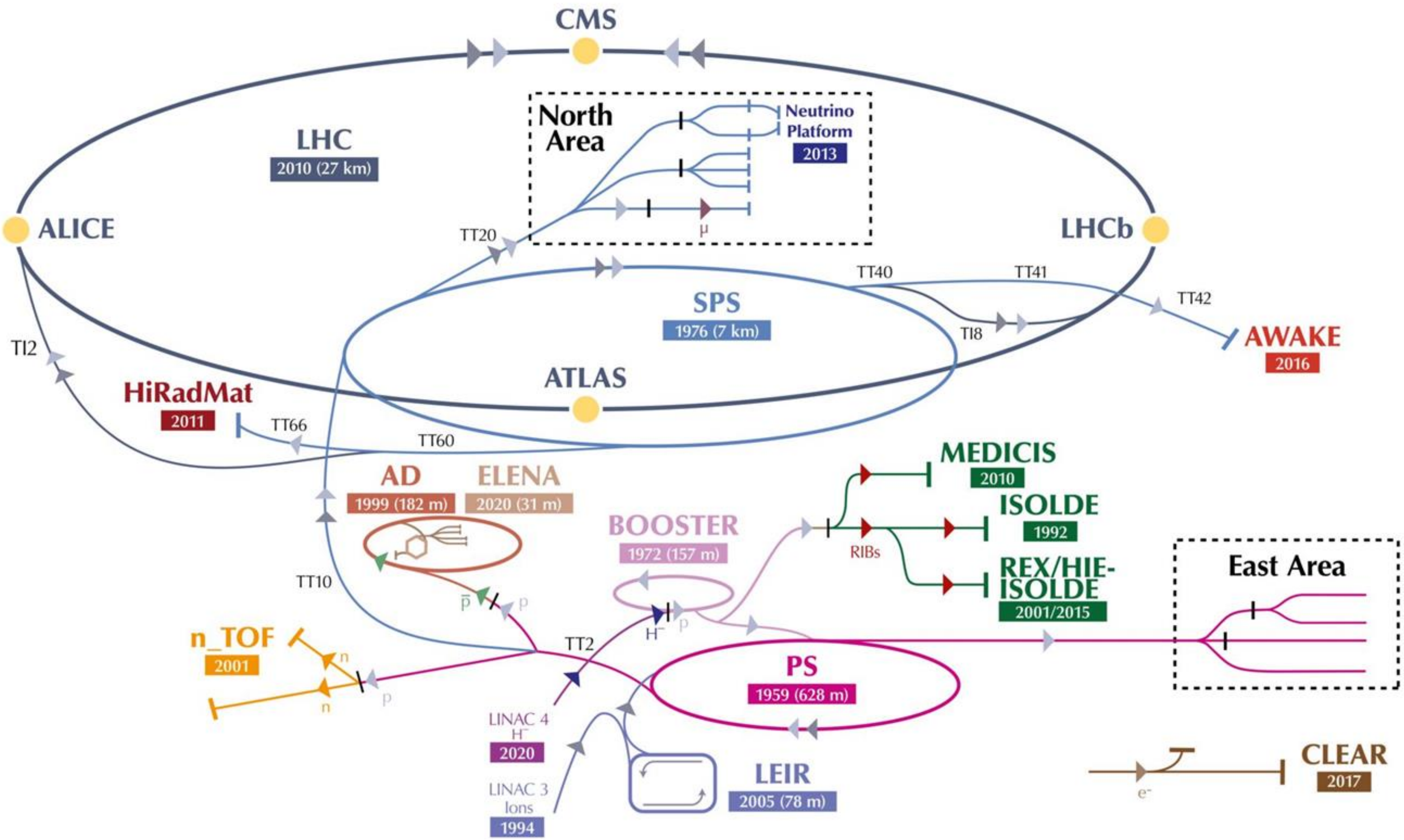

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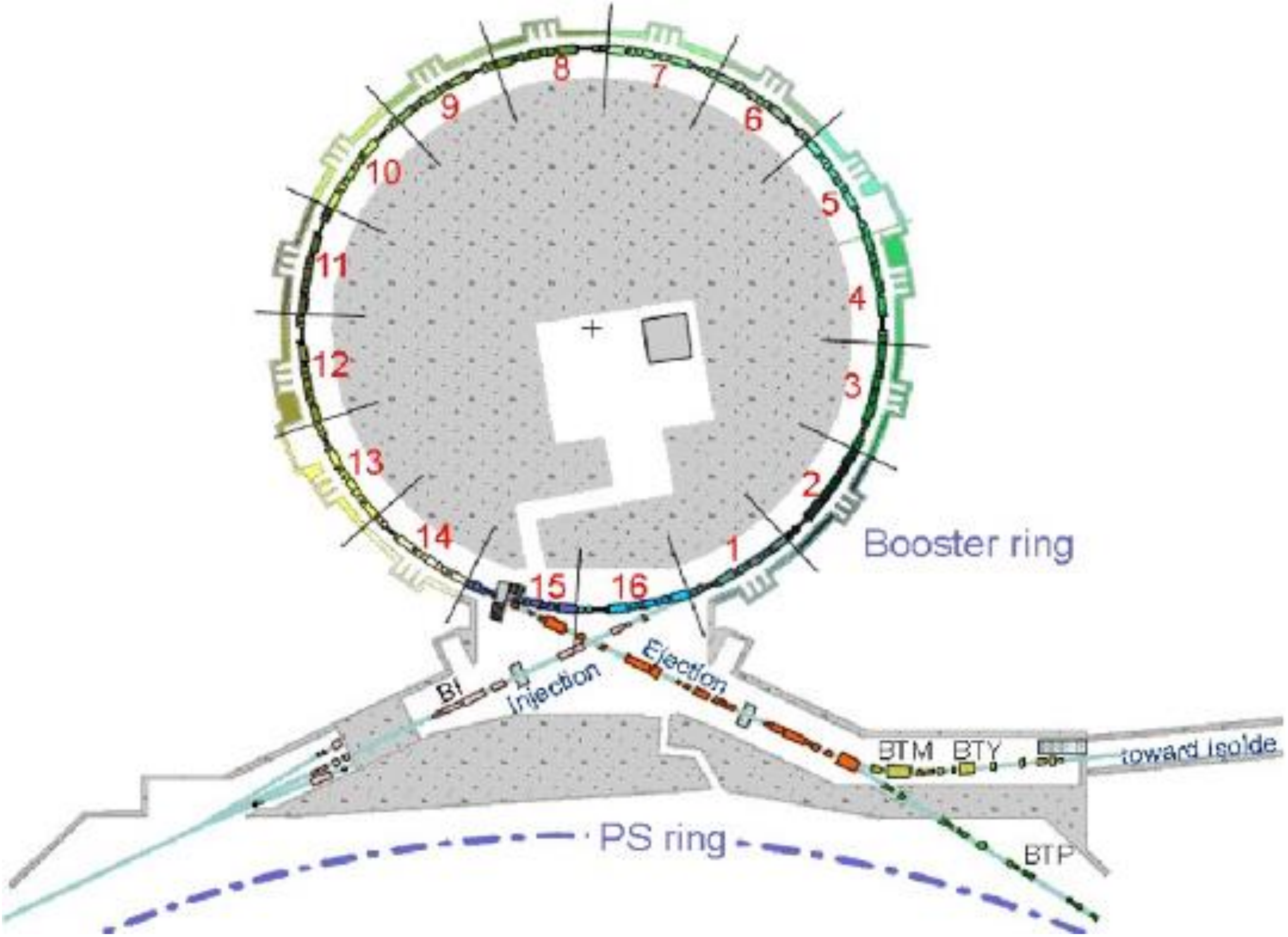
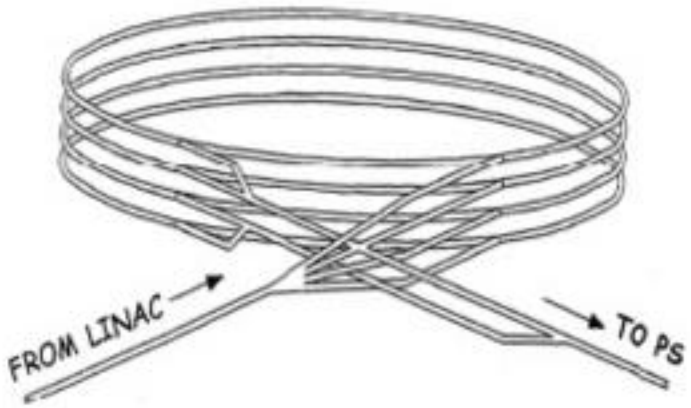
PSB layout



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



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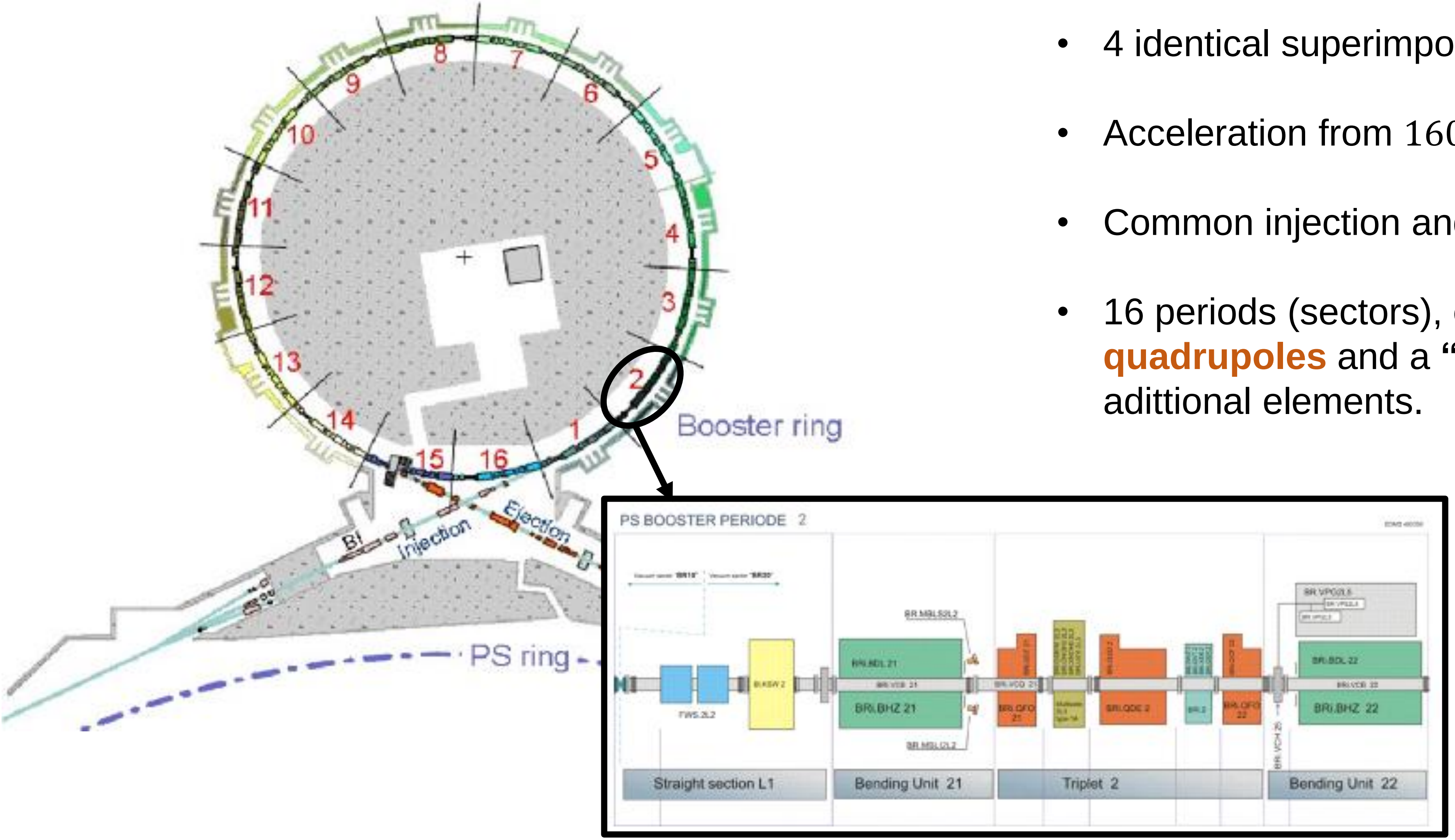

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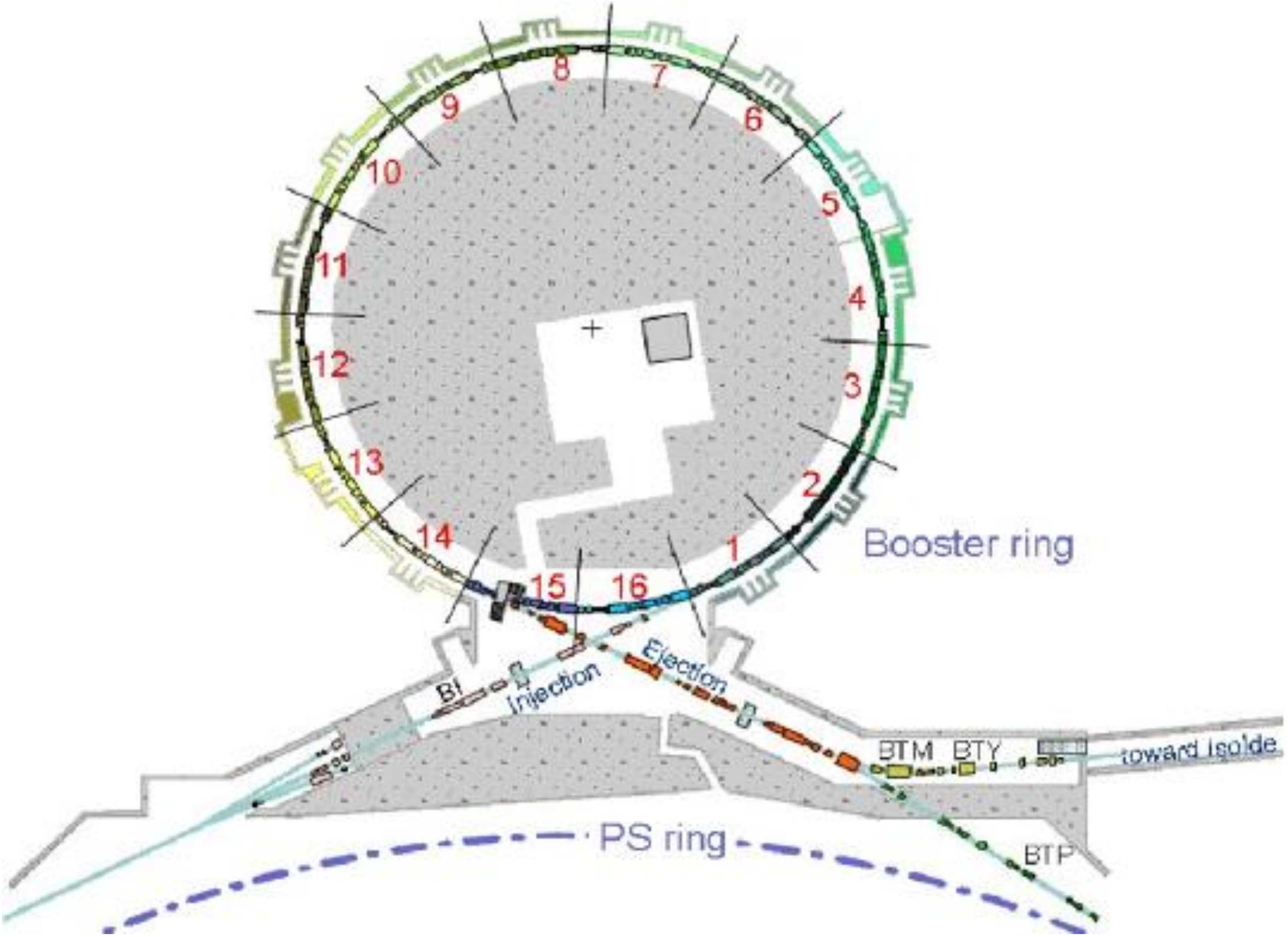

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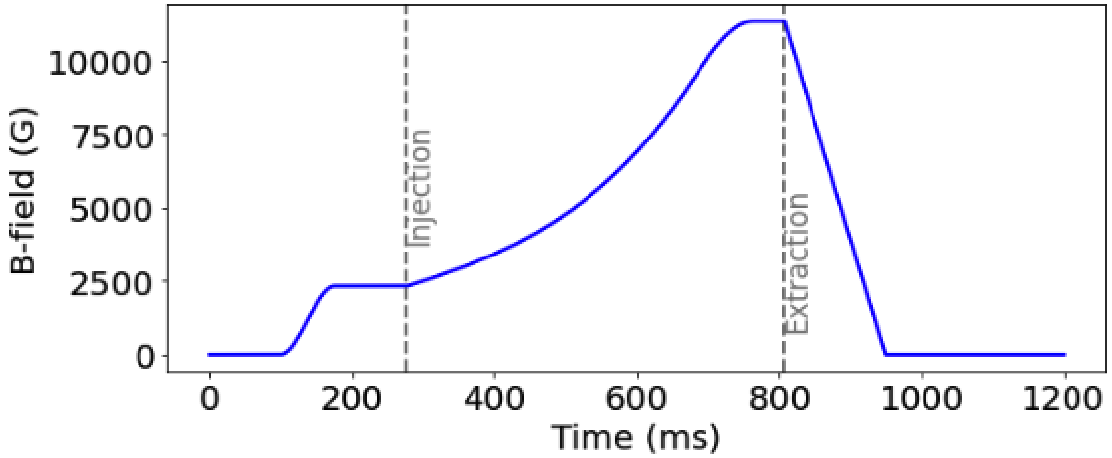
- Magnetic cycle of 1.2sec. Beam injection at 275ms and extraction at 805ms.



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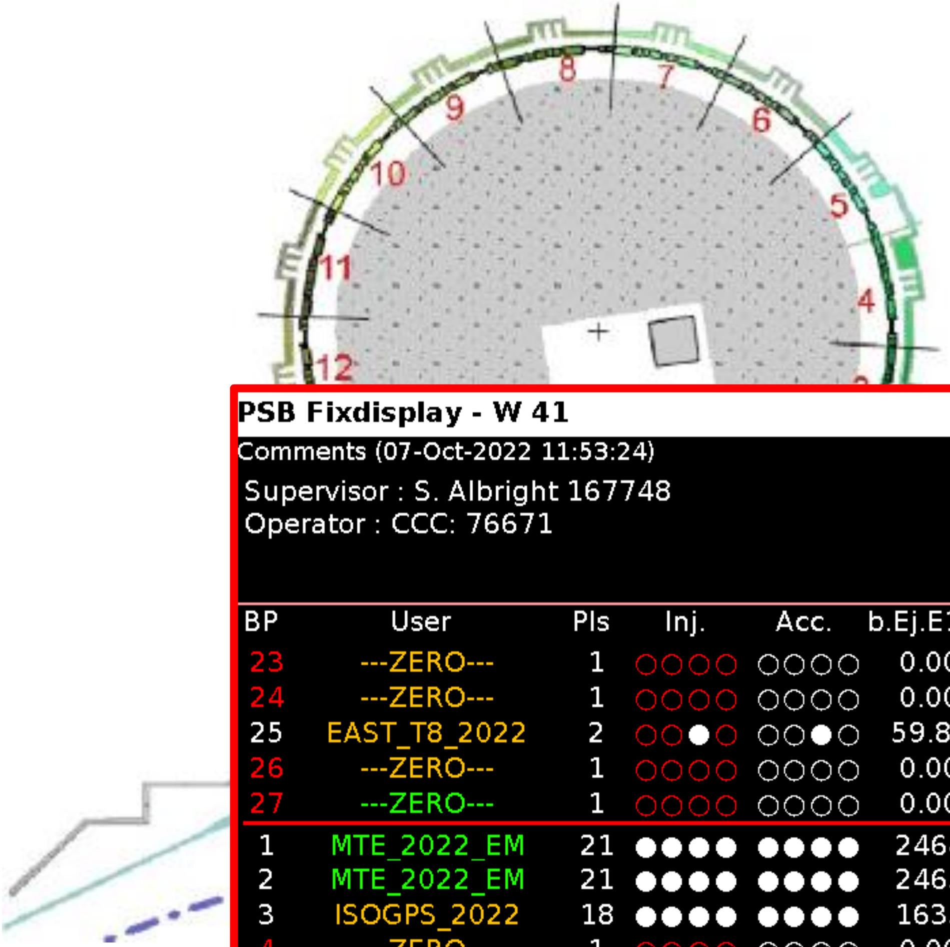

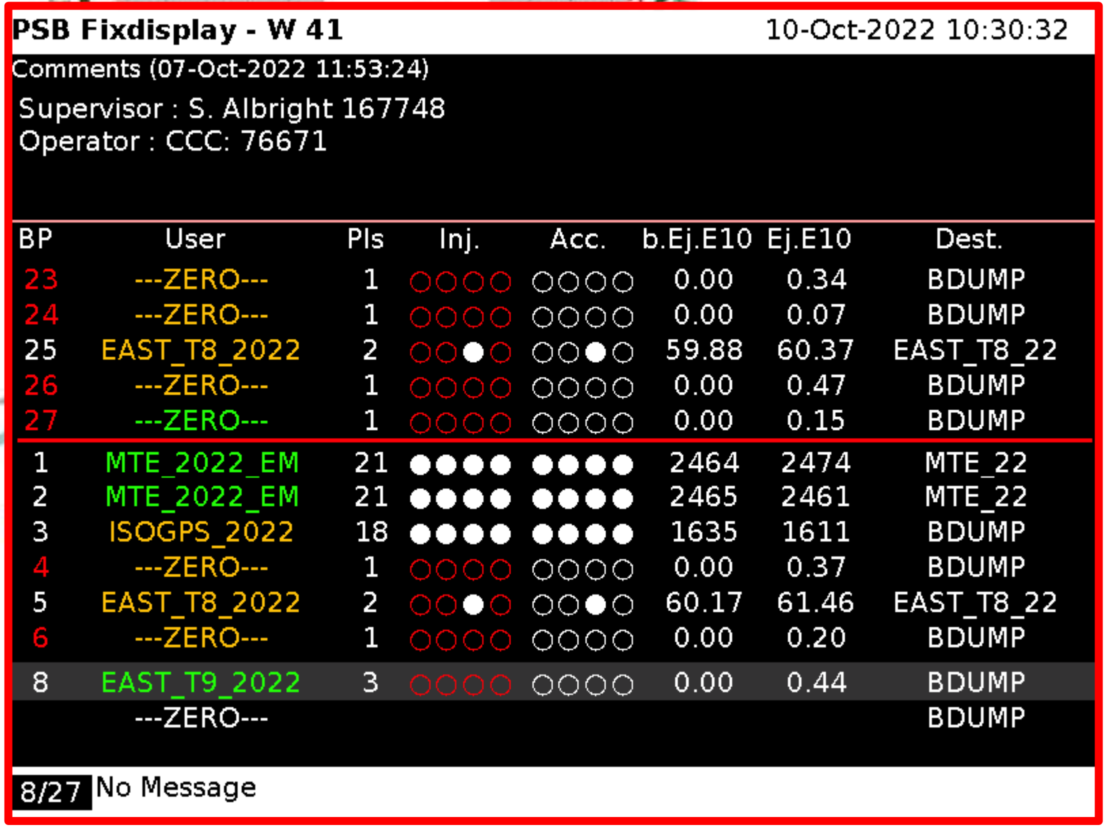

PSB Fixdisplay - W 41 10-Oct-2022 10:30:32

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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- 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.

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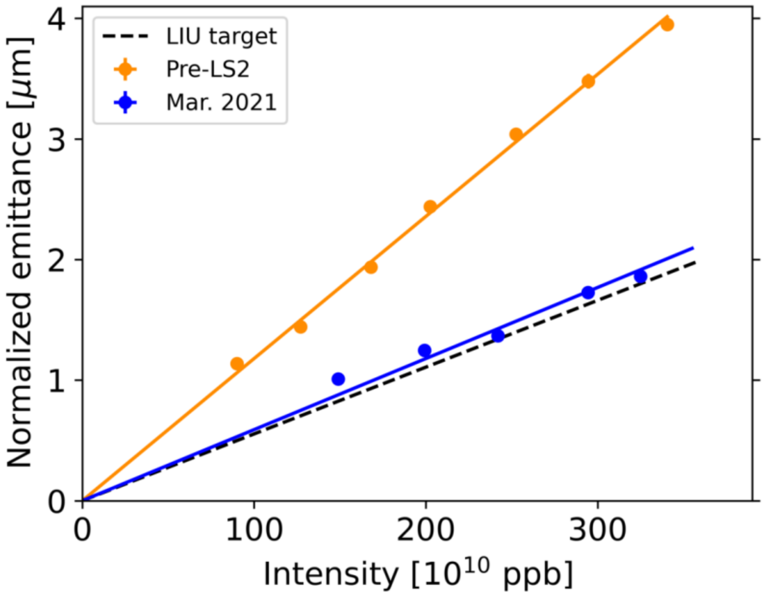
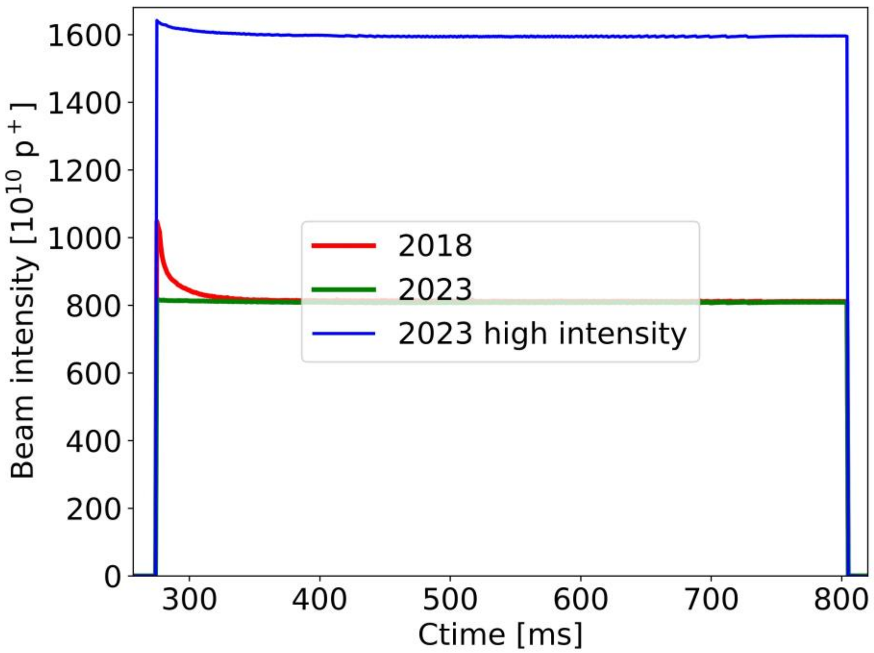
PSB beams

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)





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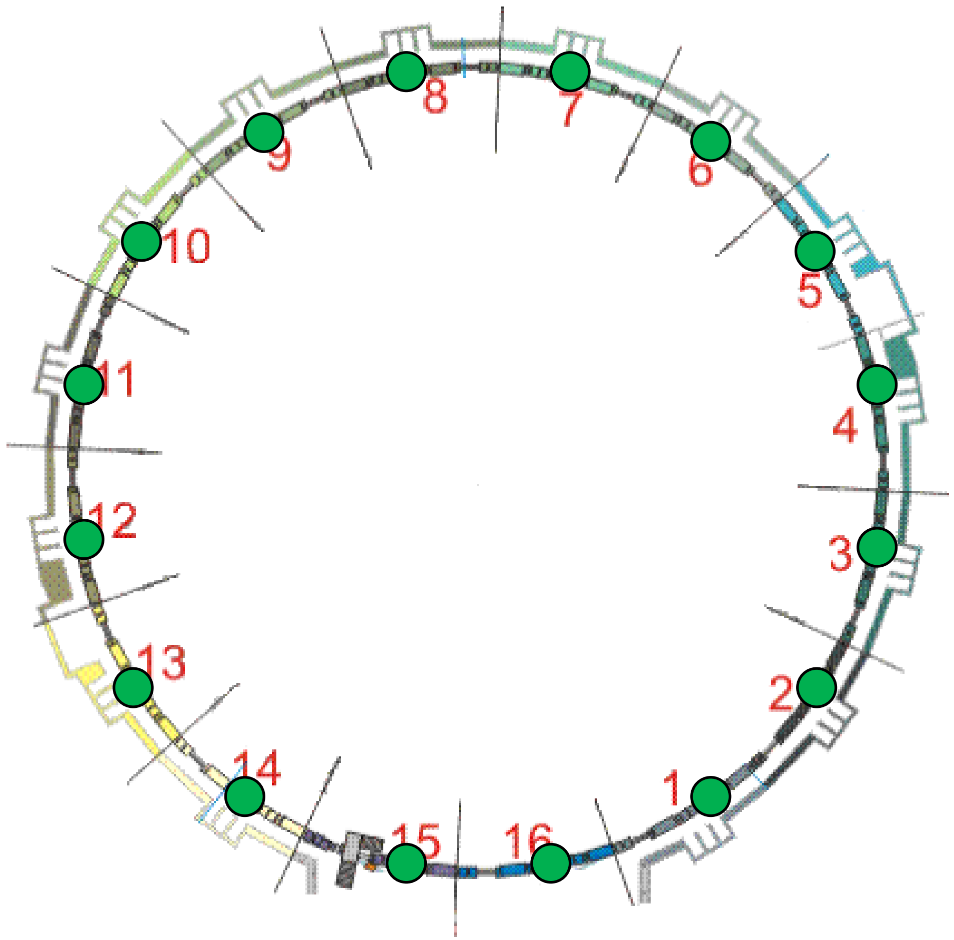
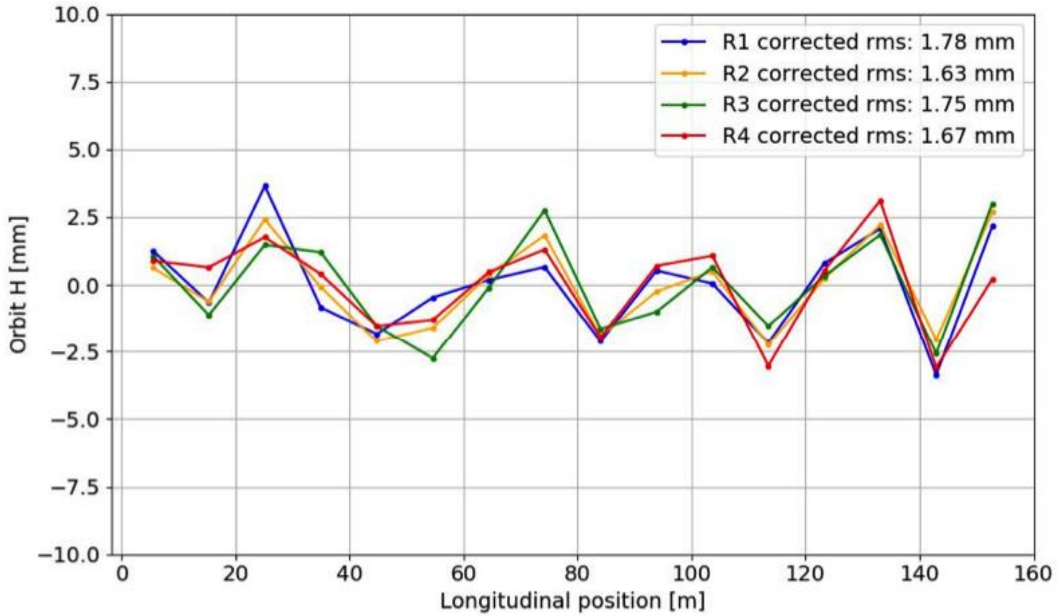
Devices



- **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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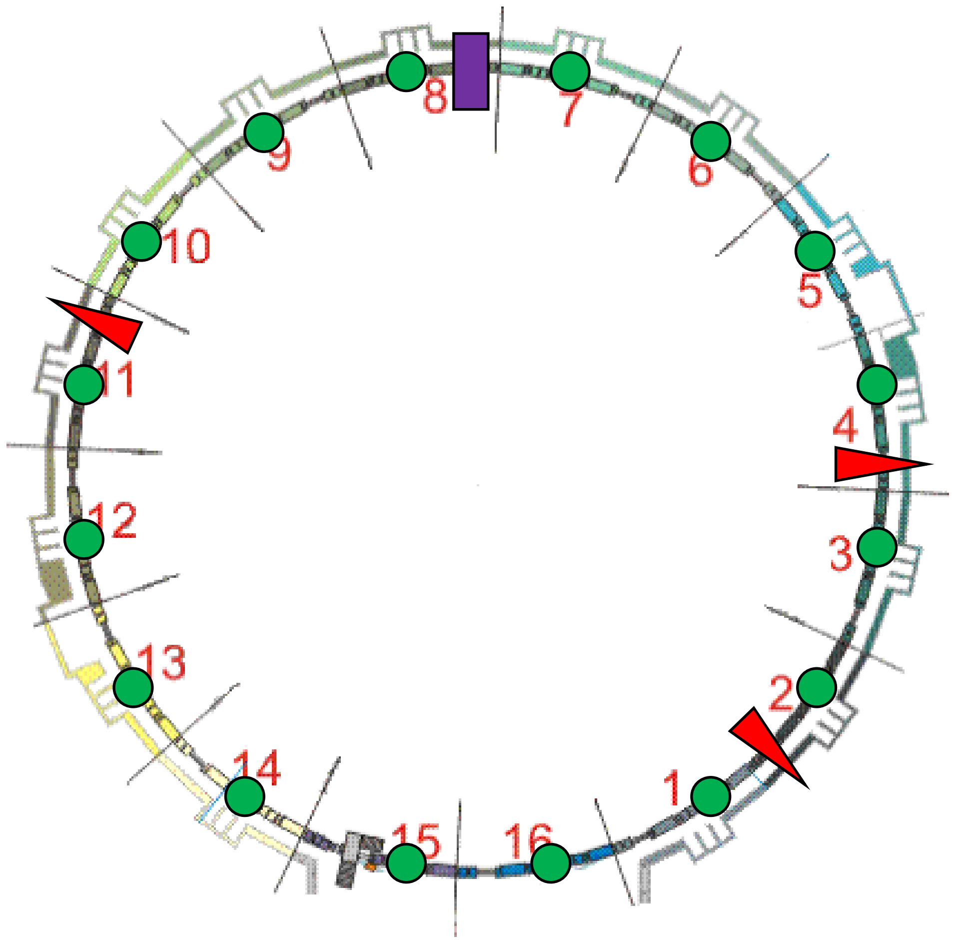

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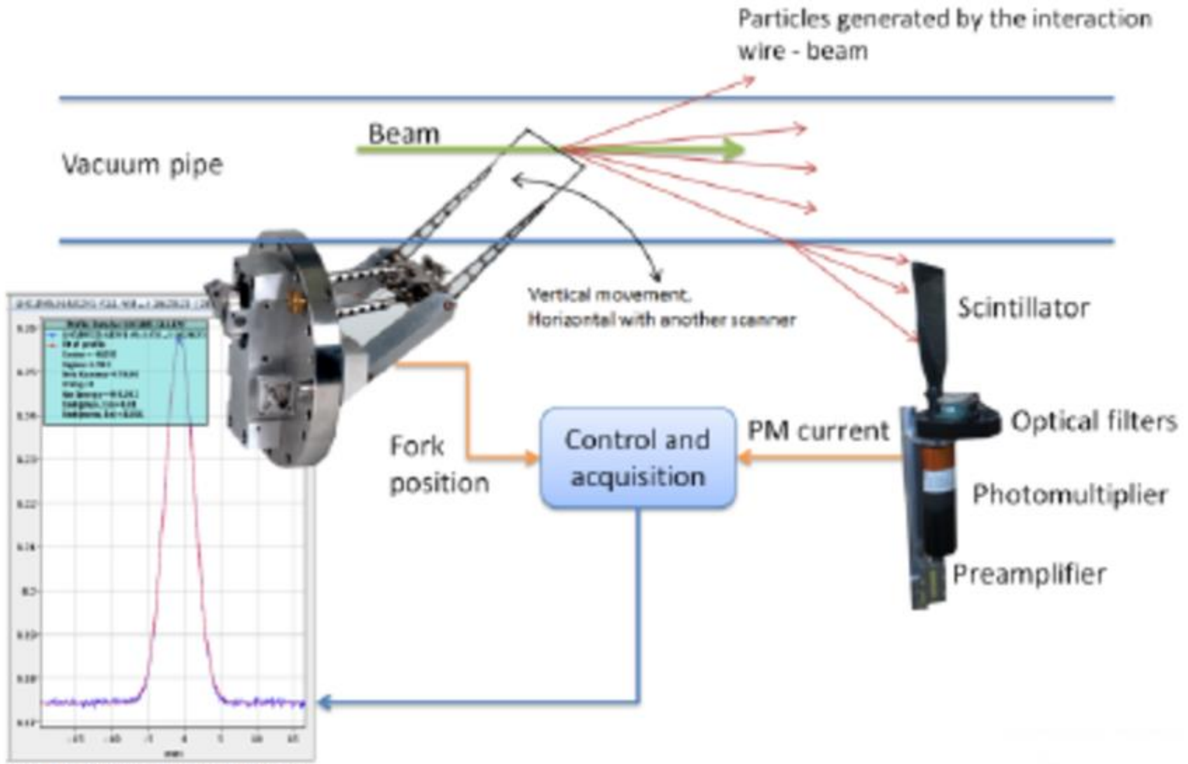
- **Wire Scanners (WS)**: measurement of the horizontal and vertical beam profiles at most twice within the cycle.



Example of a beam transversal profile

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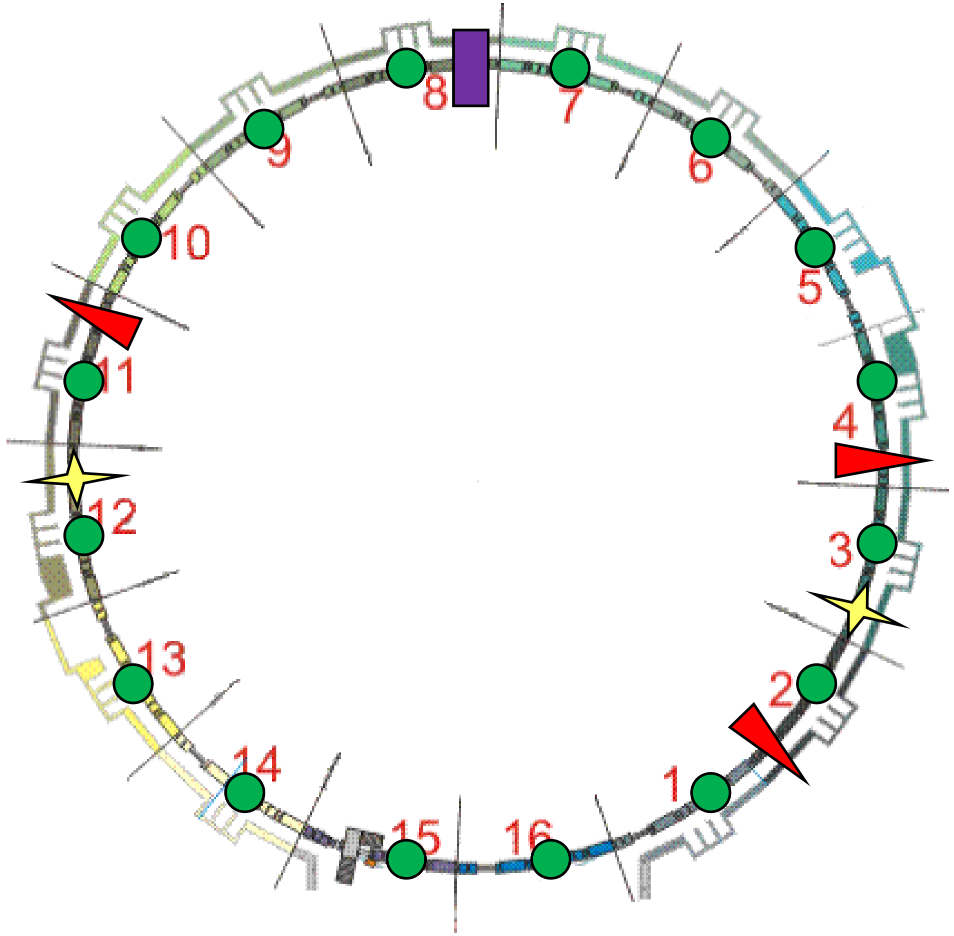
Devices



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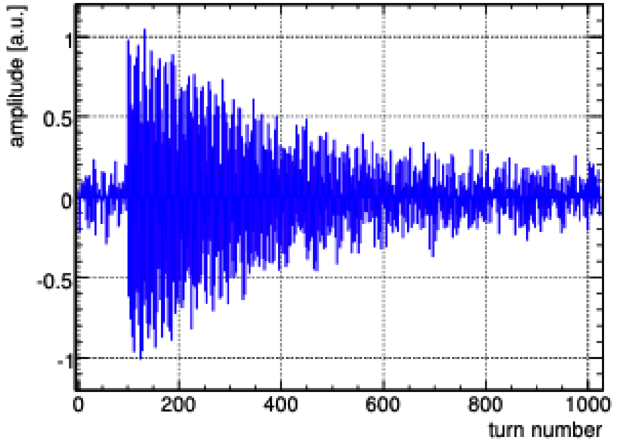

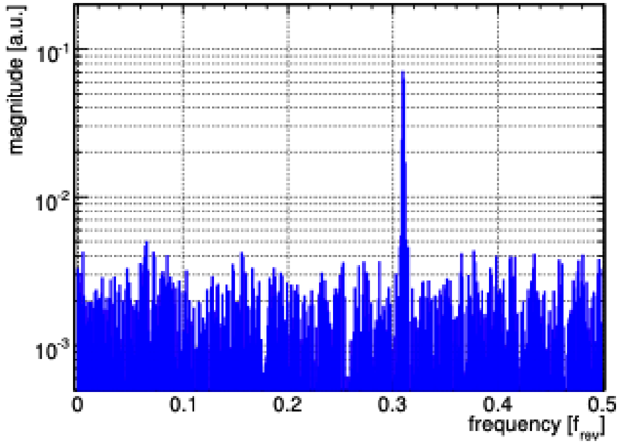

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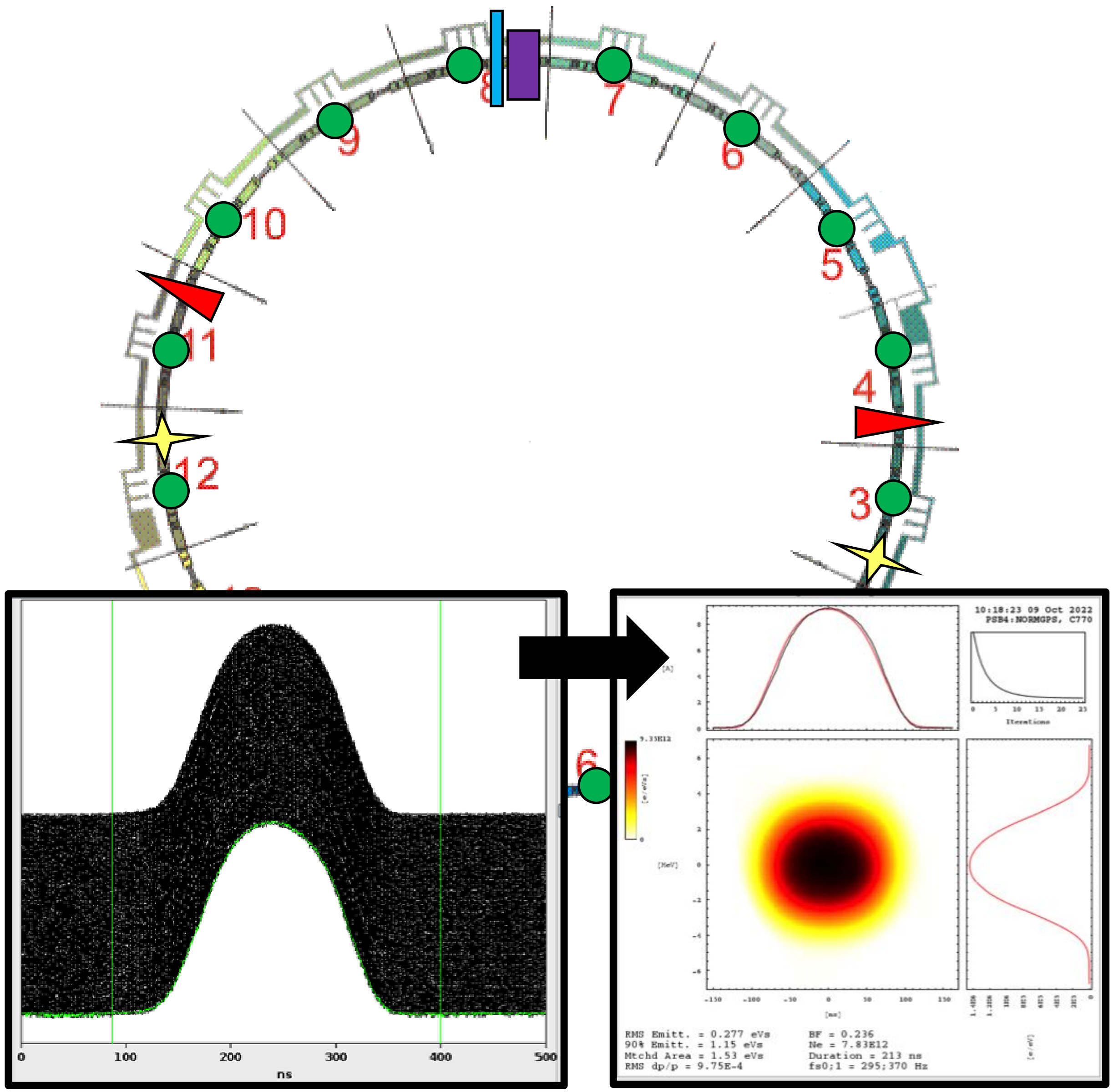

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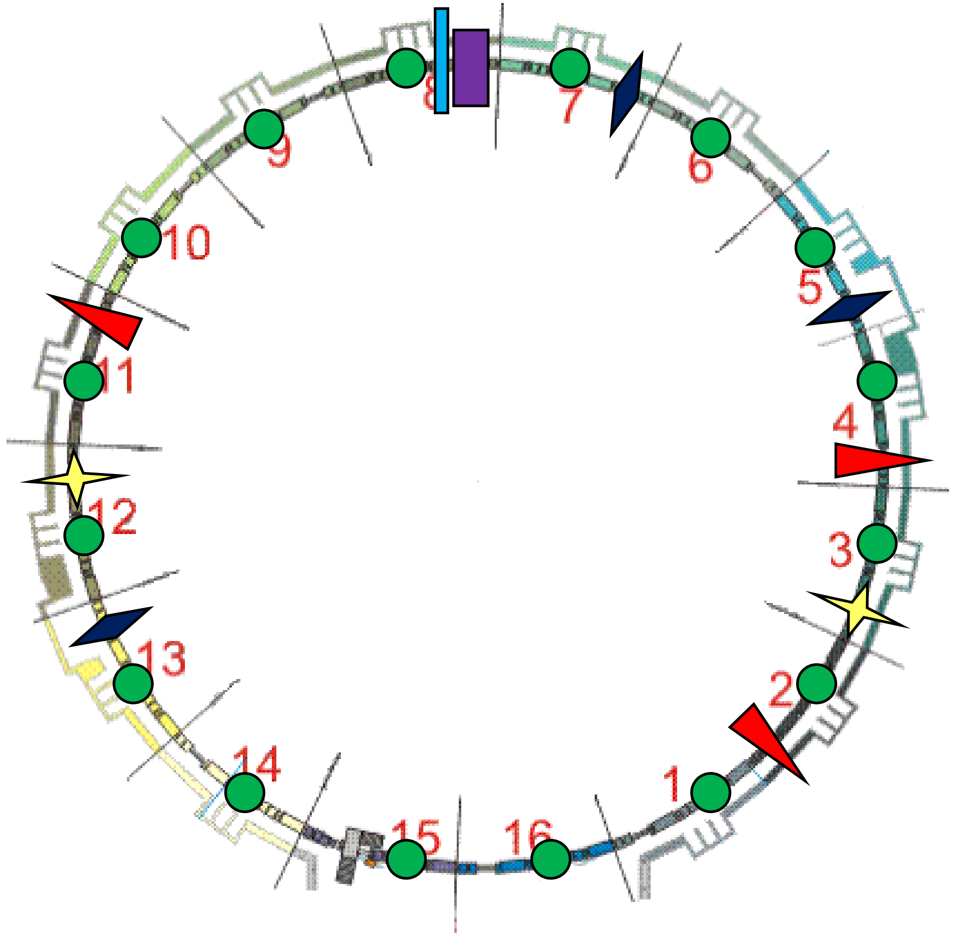

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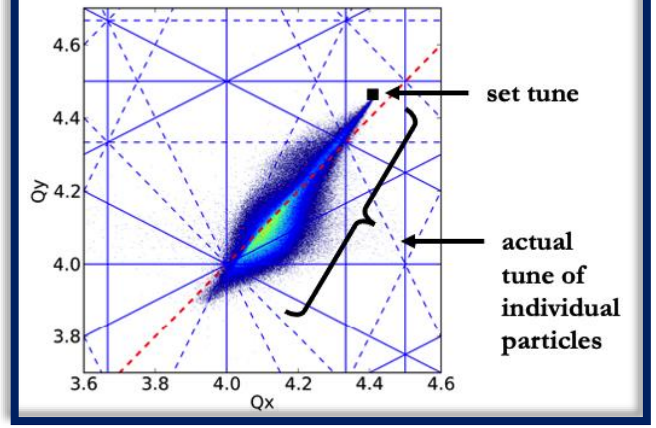
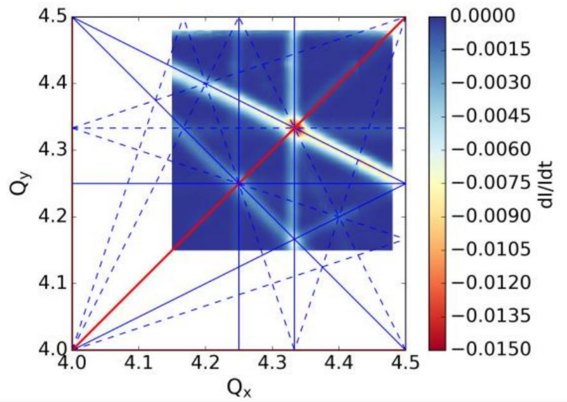
- **Radio-Frequency cavities (RF)**: for acceleration, longitudinal control (blow-up, higher harmonics, etc.).
- Plenty of quadrupole, sextupole and octupole correctors (normal and skew).

Beam Dynamics

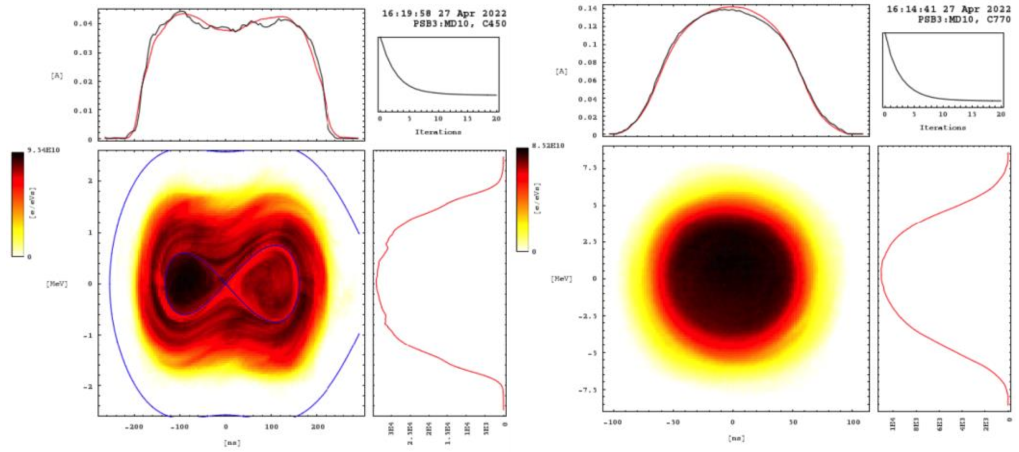
Space Charge



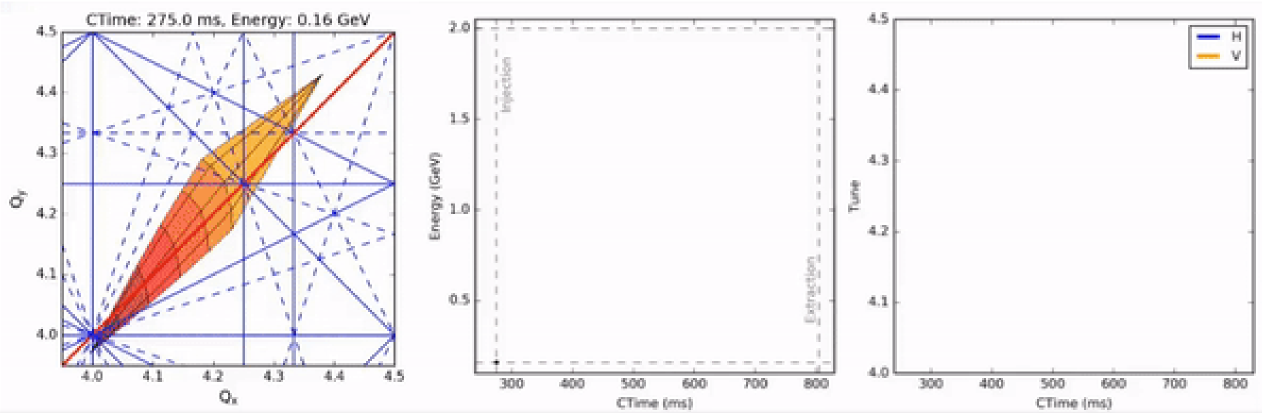
Resonances



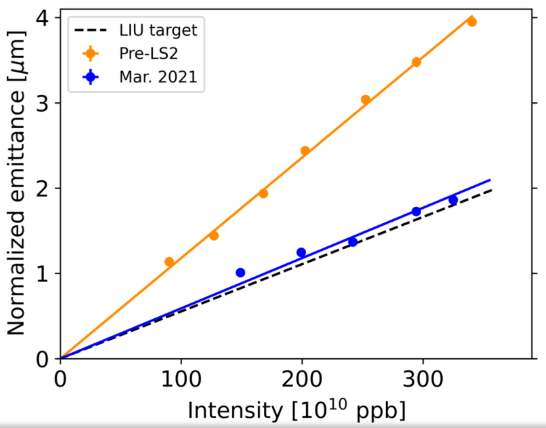
Beam goes from double harmonic to single harmonic to reduce the peak line density (therefore space charge)



While beam is accelerated, tunes are dynamically changed.



Brightness



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Control Systems

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

Back-End Severs

JAPC framework

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

Front-End Computers (FECs)

FESA classes (Device-Property model)

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

Accelerator Equipment

- 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 →
  MDXXXX_EUROLABS_160MeV_2024
- CERN Accelerators Logging Service (NXCALS), can be accessed from SWAN, Timber, etc.

CERN Gigabit Ethernet Technical Network (TN)

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Control Systems

- Data acquisition and monitoring scripts using python

```
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, less dangerous for accelerator, etc.)

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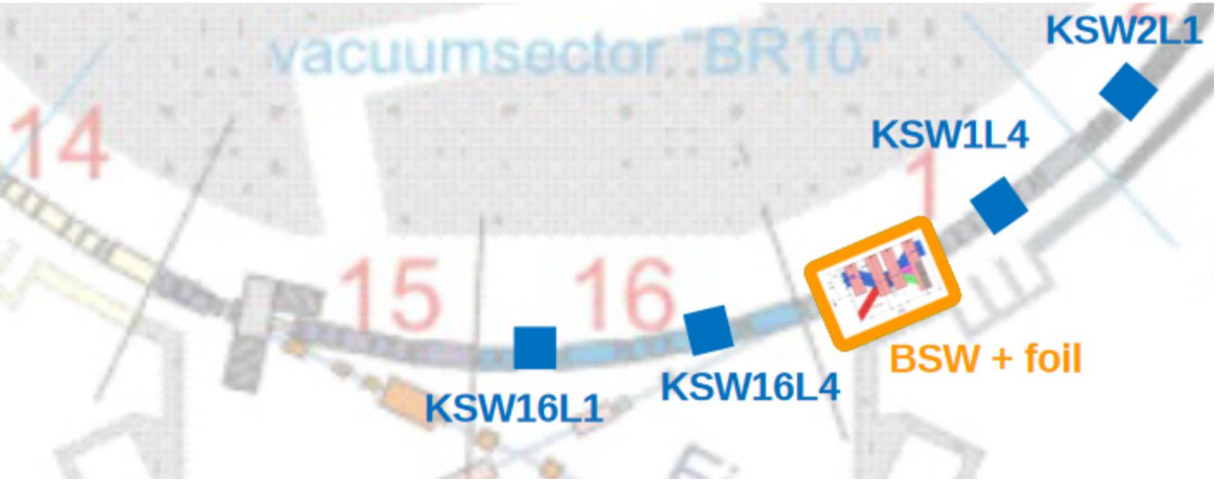
Measurements

PSB H^- Charge Exchange Injection System



Injection → beam orbit bump by:

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

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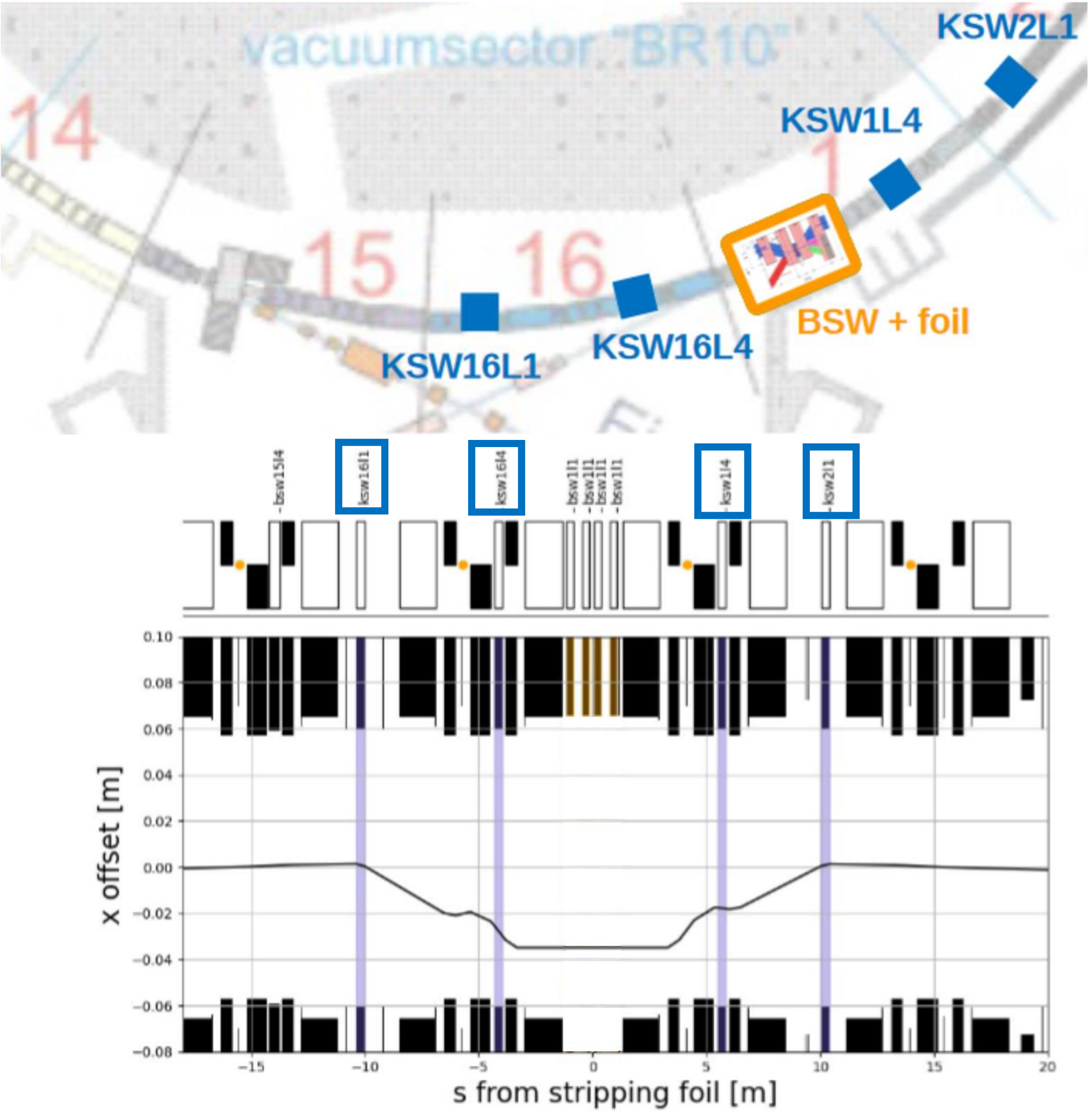

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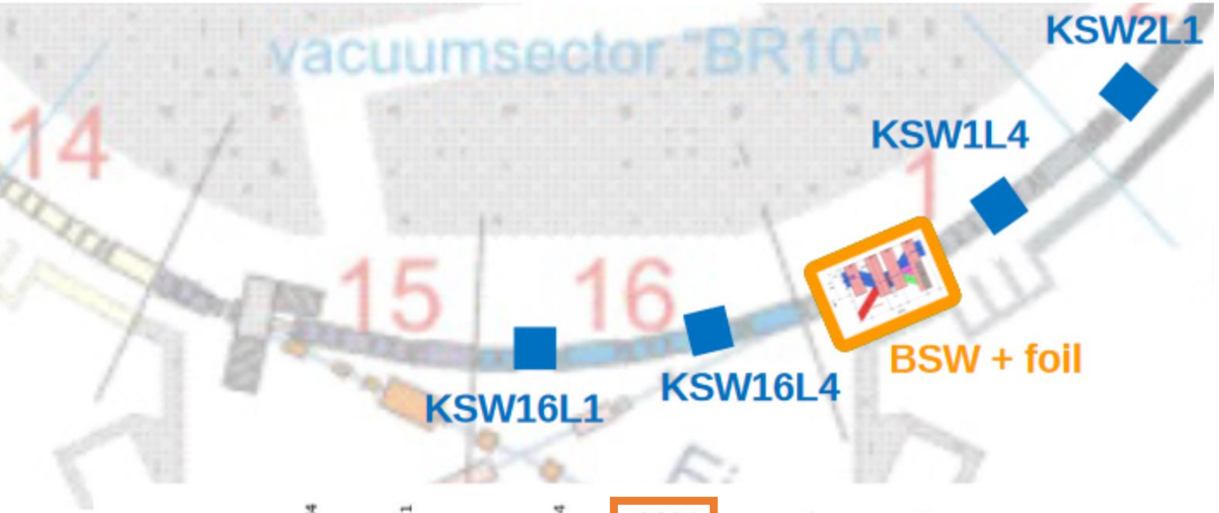

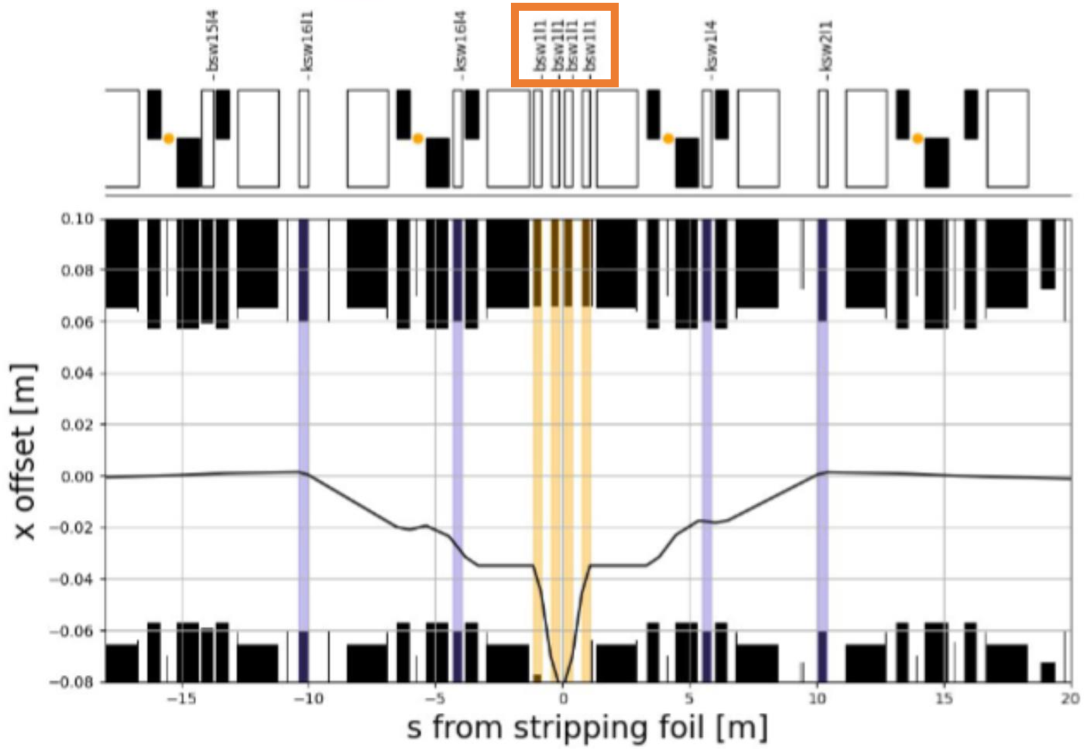

Injection → beam orbit bump by:

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- **4 horizontal chicane magnets (BSW)**

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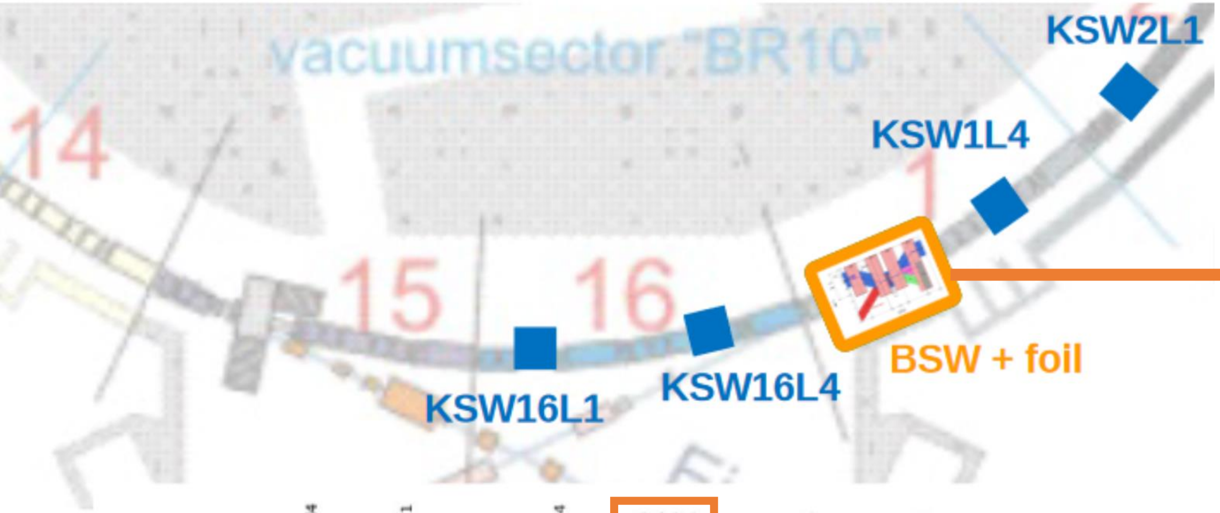

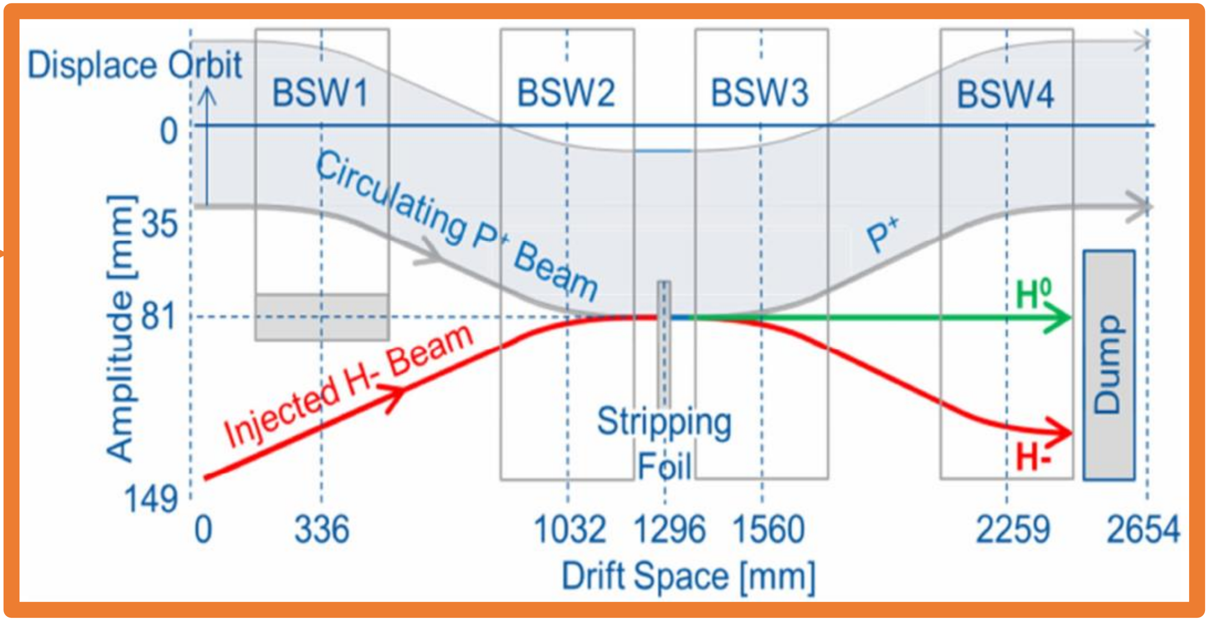

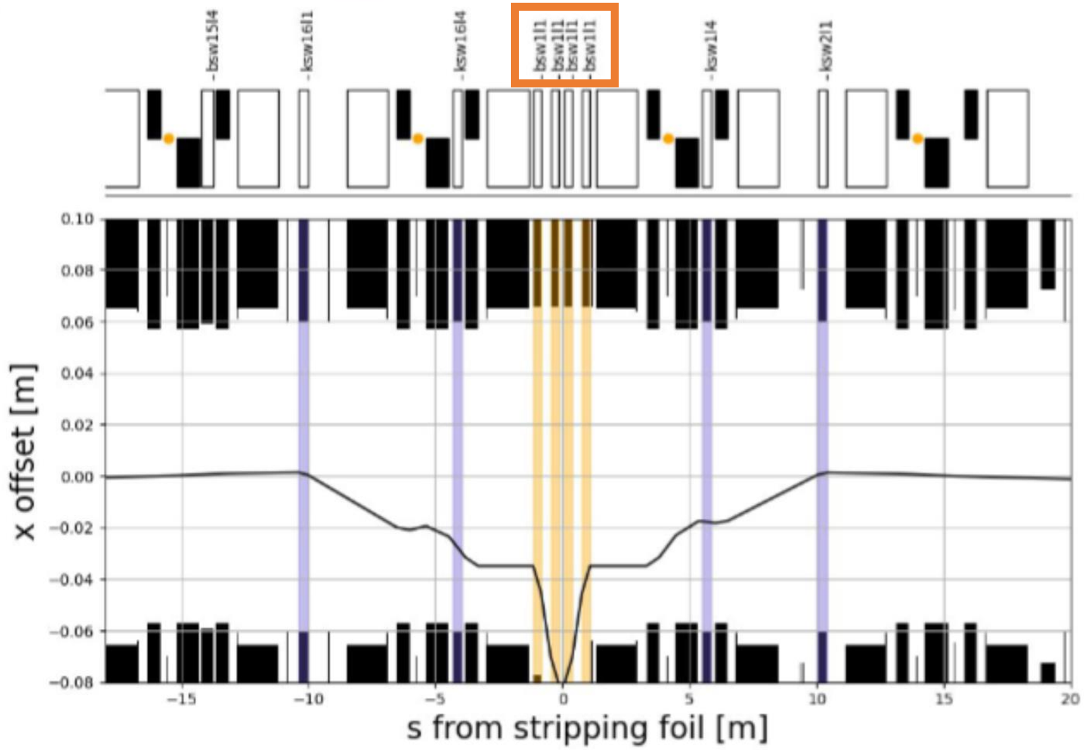

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Incoming hydrogen ion particles (**H^{-} beam**)

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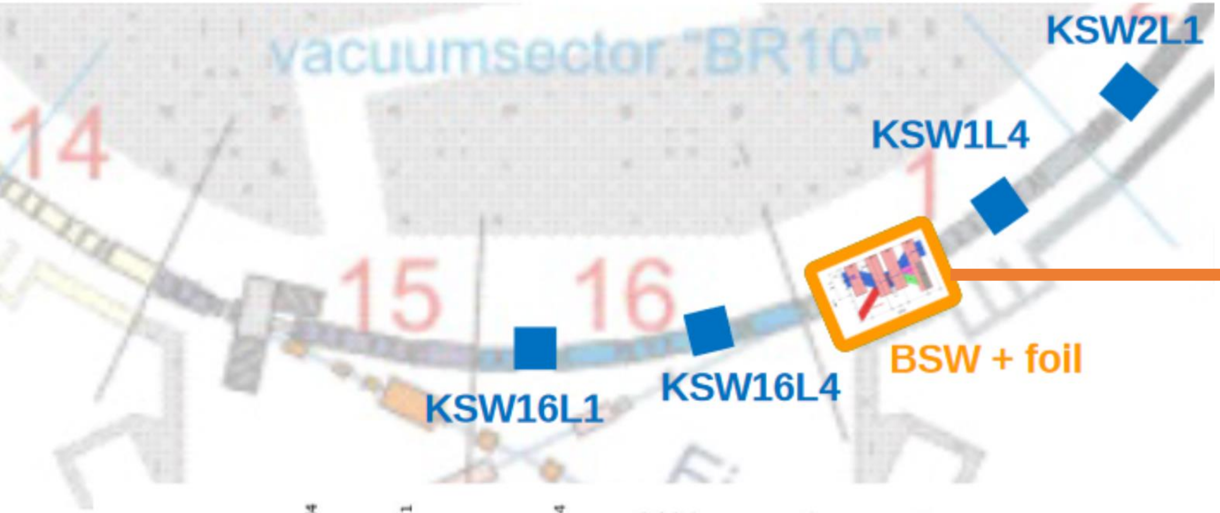

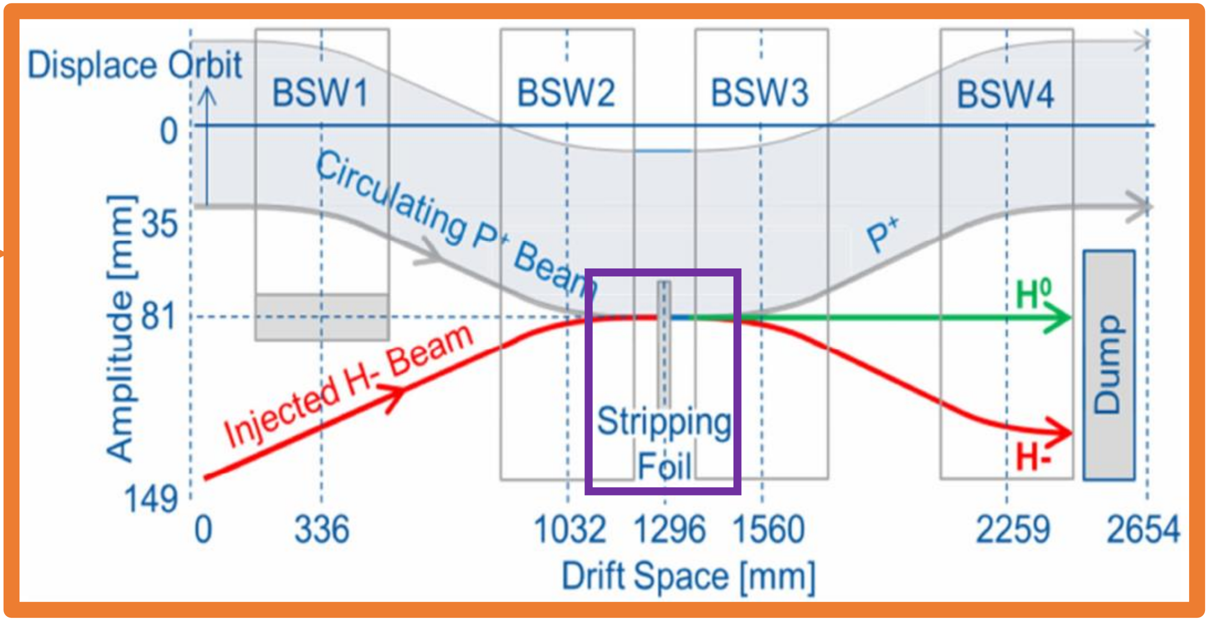

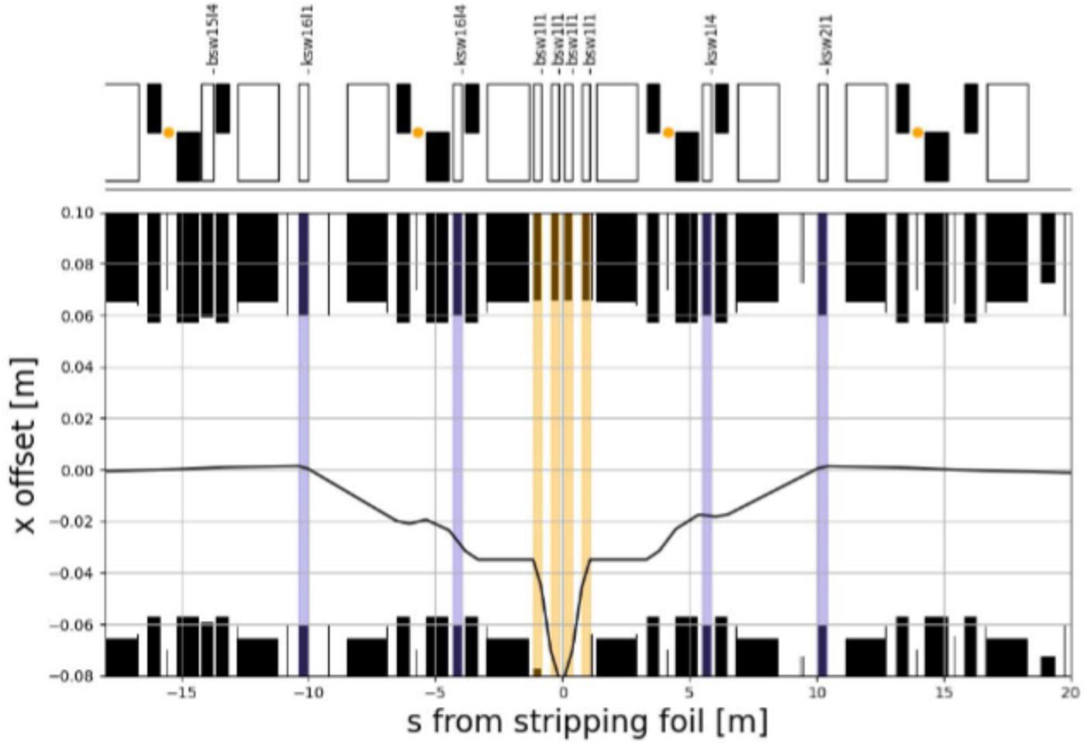

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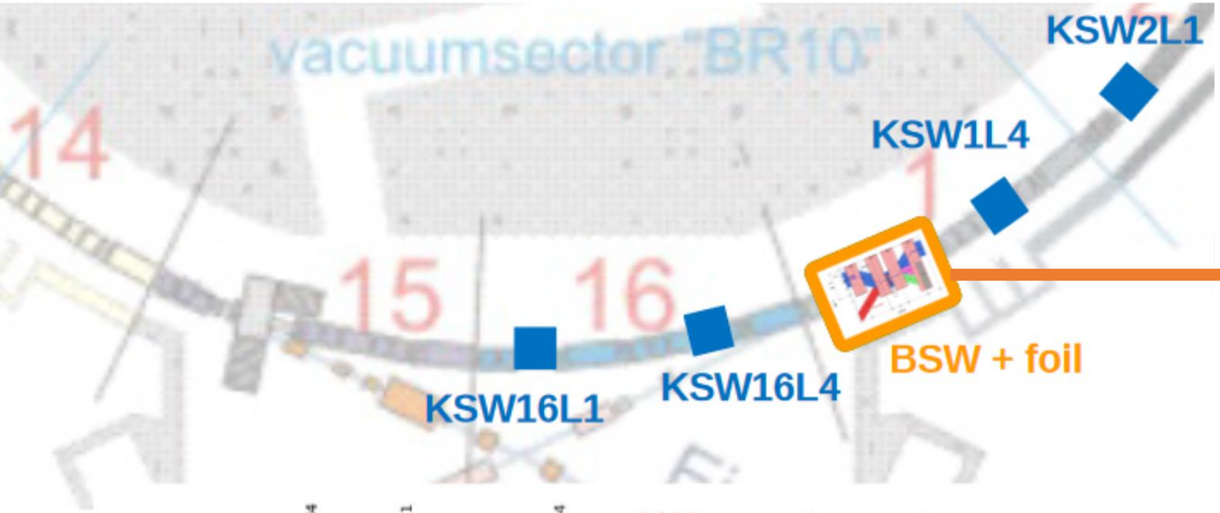
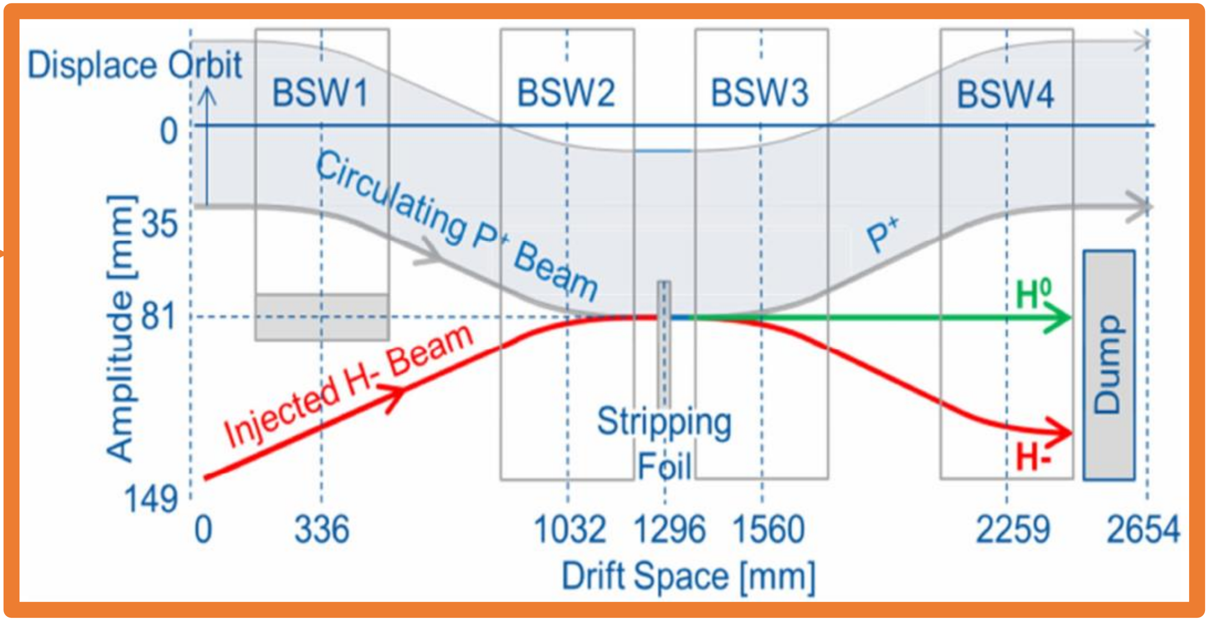
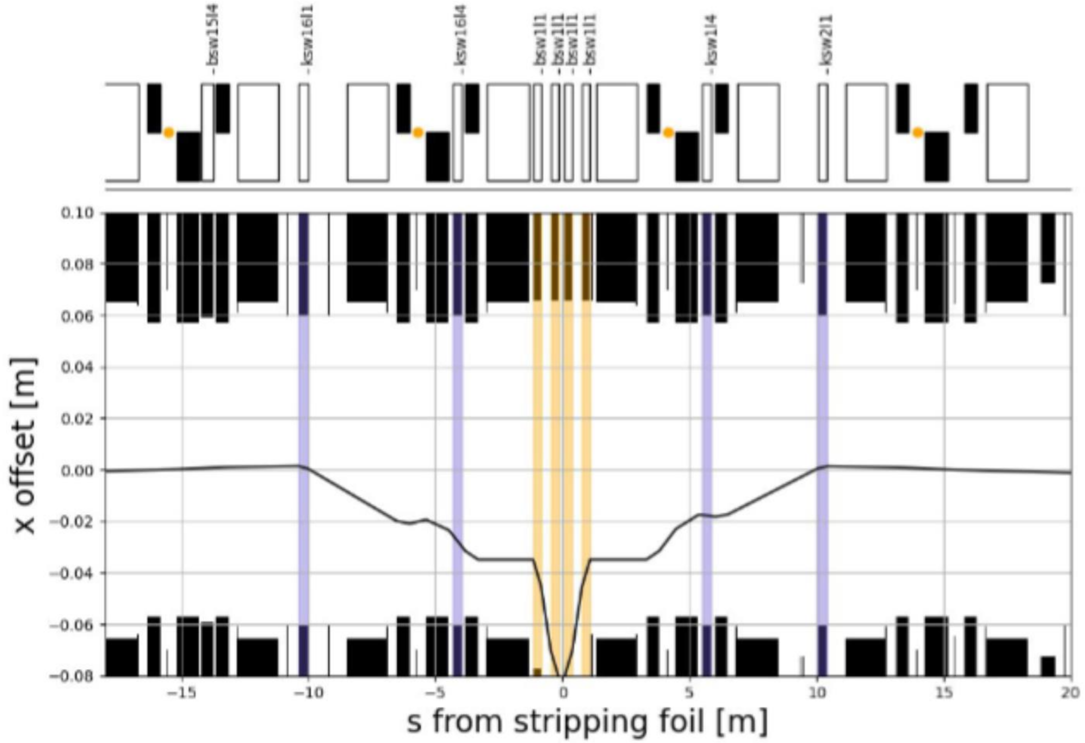
Incoming hydrogen ion particles (**H^- beam**) → **stripping foil** → protons.

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.

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

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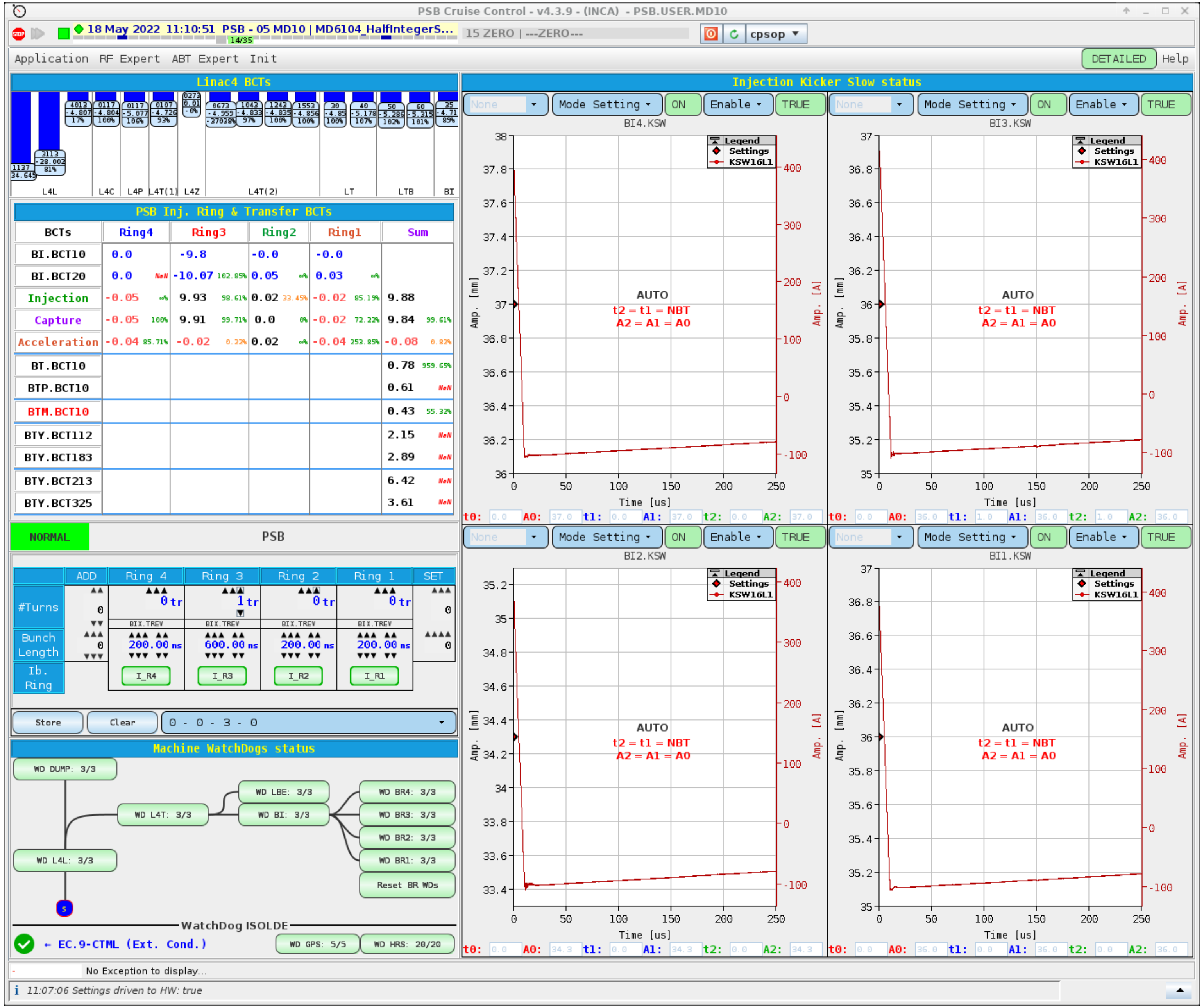
Beam parameter adjustments

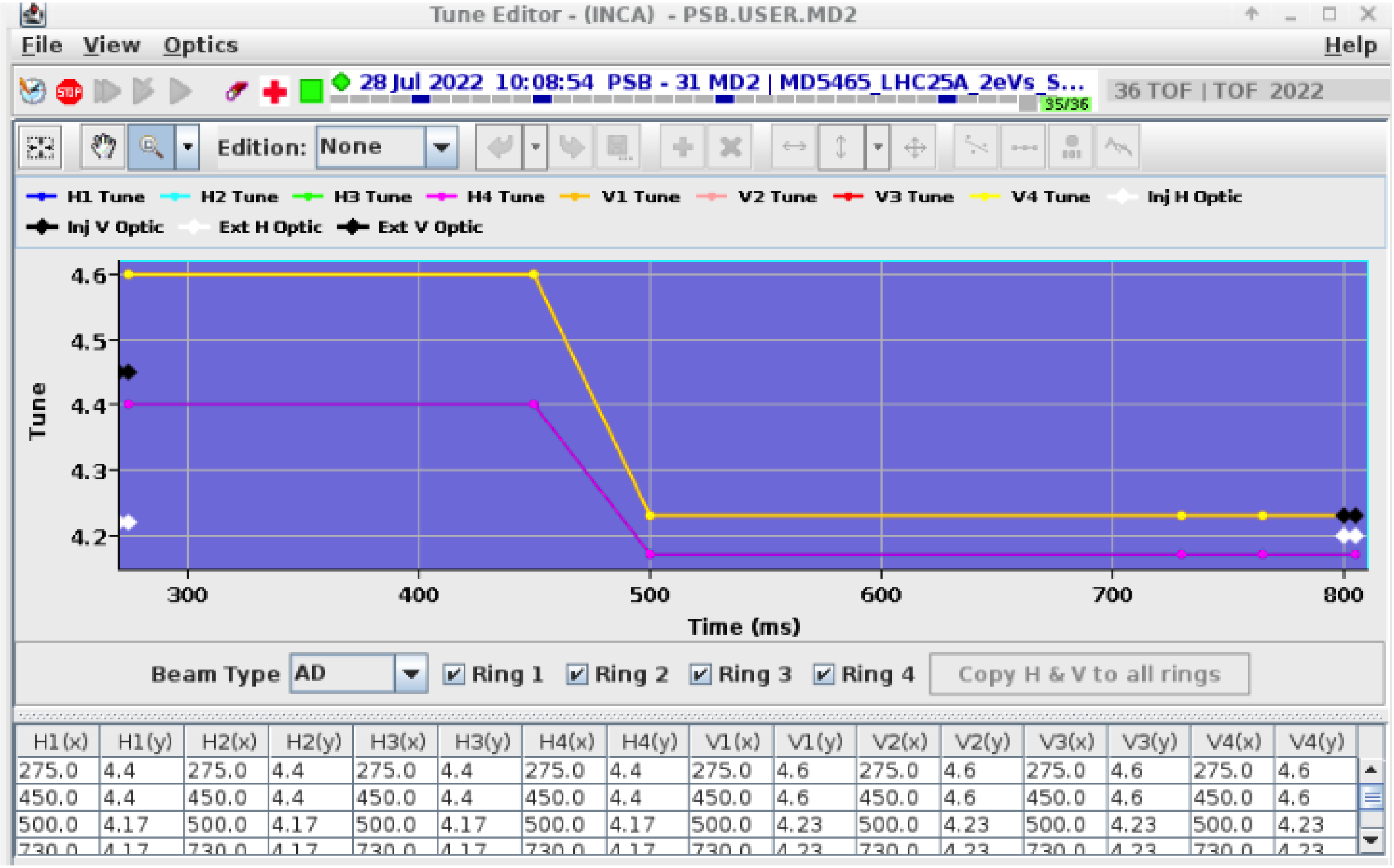
Intensity
Changing the number and length of the pulses injected from Linac4

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?

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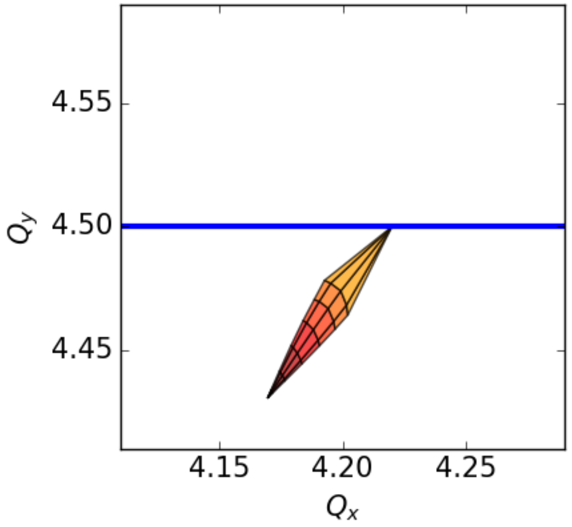
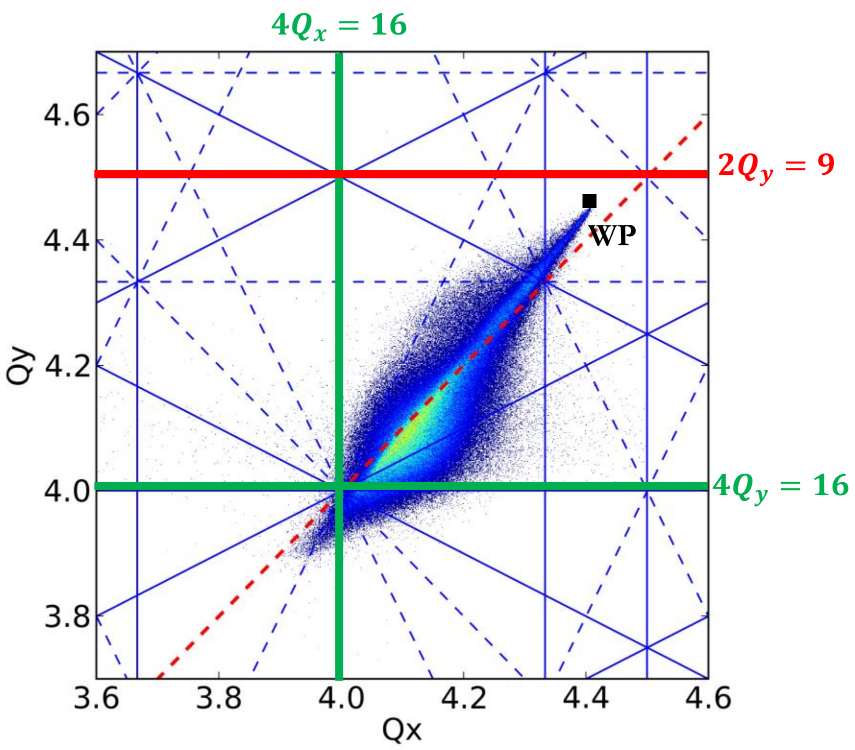
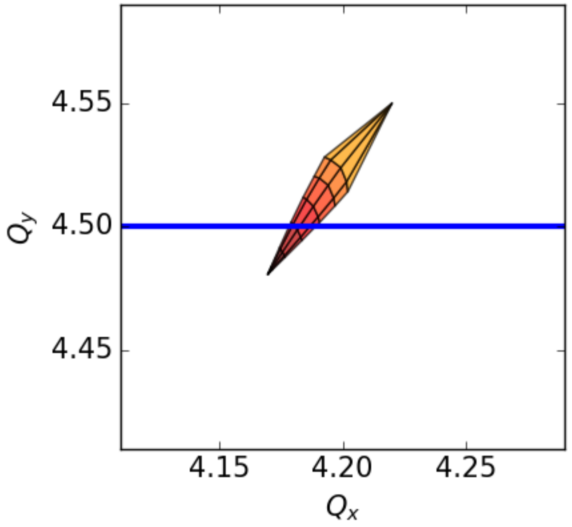
Tune setup: losses and emittance blow-up

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

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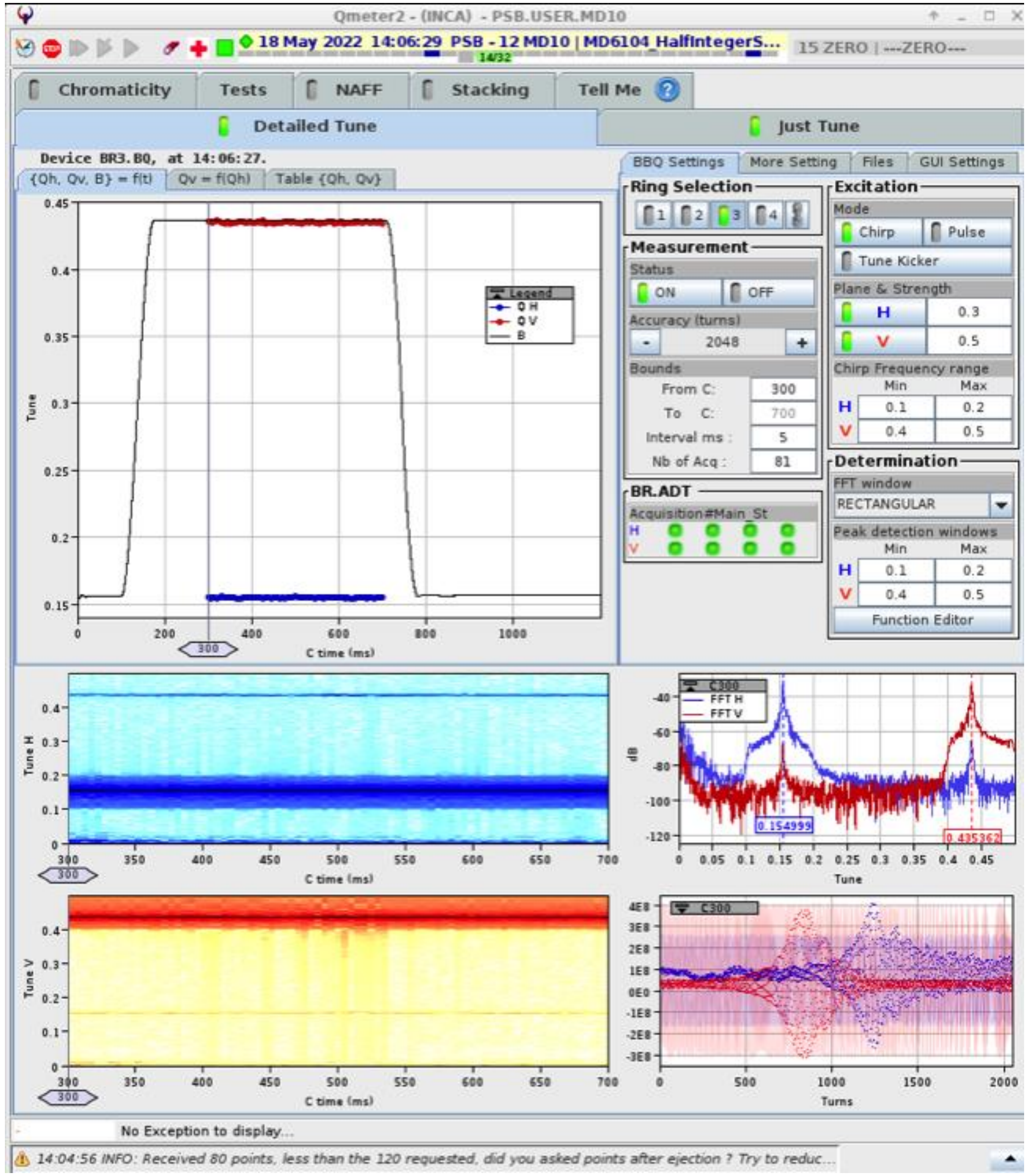
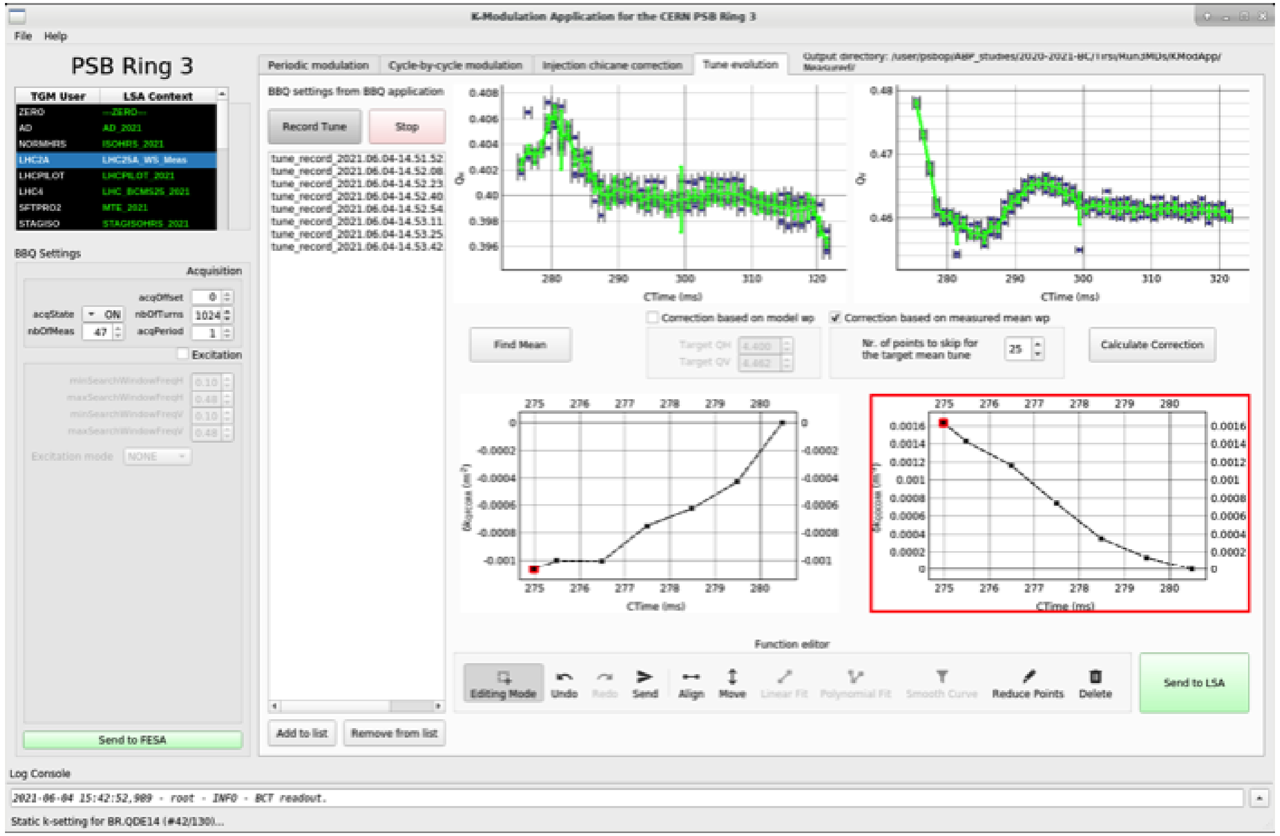
Tune measurement and correction





Tune correction based on the "make-rules":

Q → k → I

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Chromaticity measurement and correction

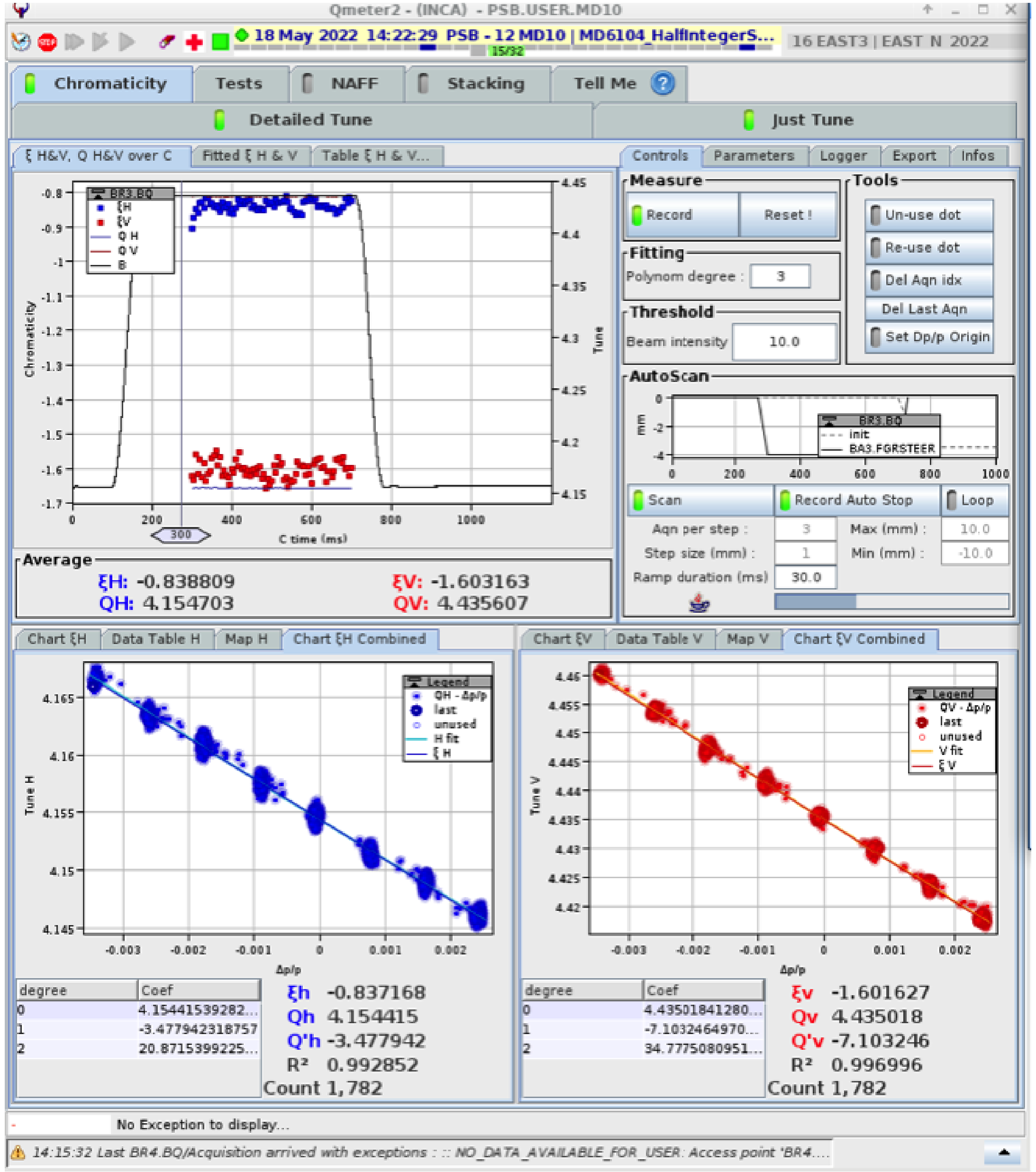
Chromaticity

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

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.



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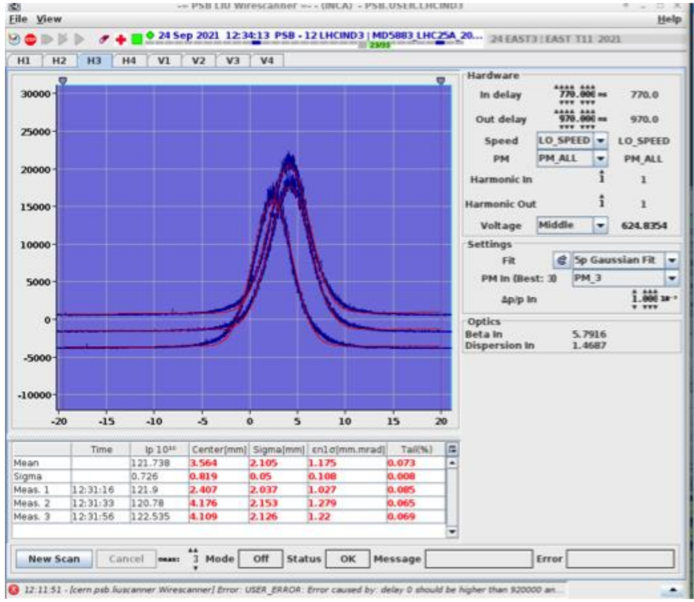
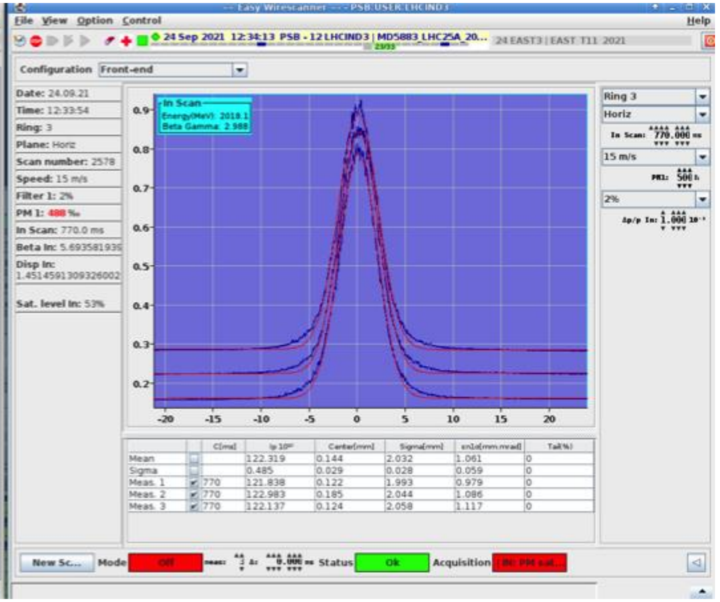
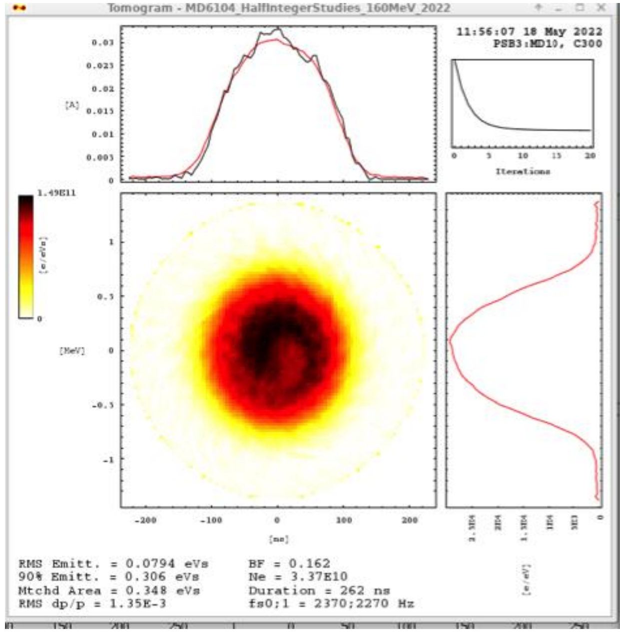
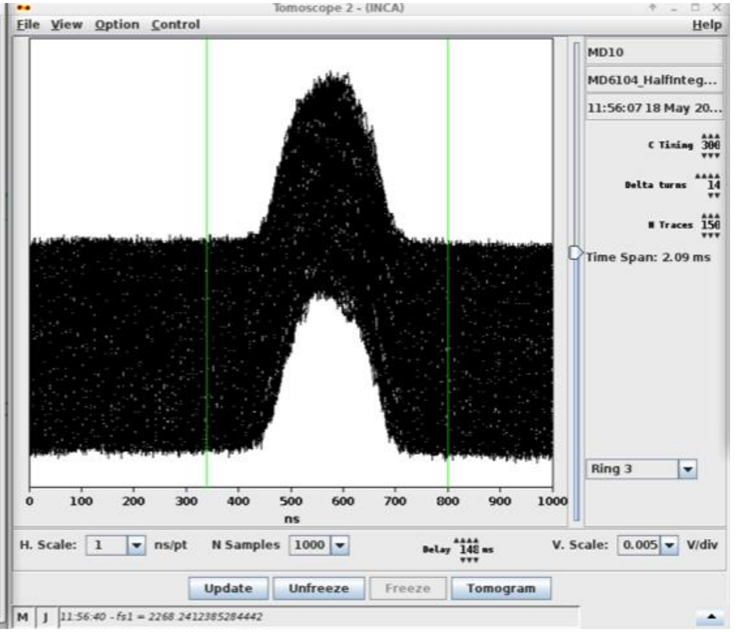
Transverse and longitudinal profiles









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

$$\epsilon_n = \epsilon_x \beta_{rel}\gamma_{rel}$$

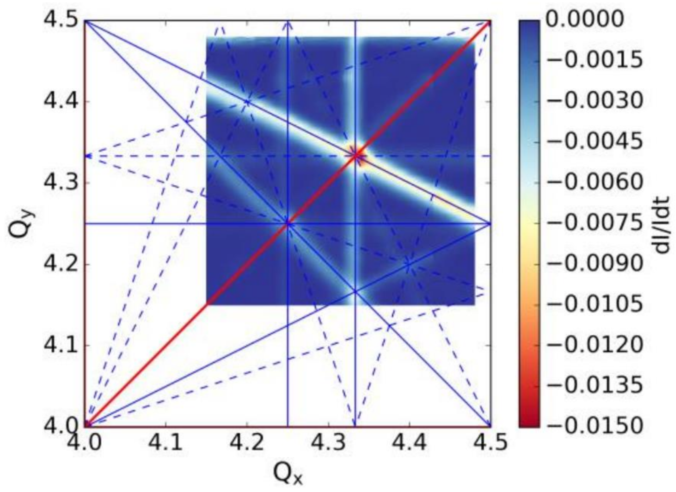
If at least one non-Gaussian

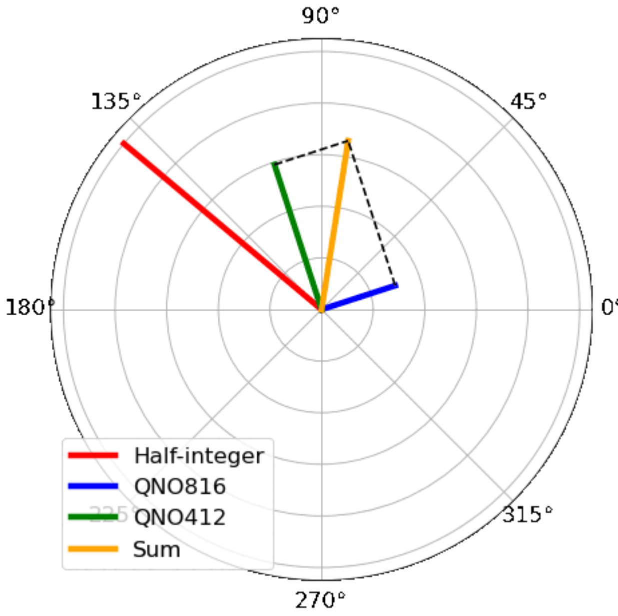
Deconvolution not trivial; need iterative algorithms

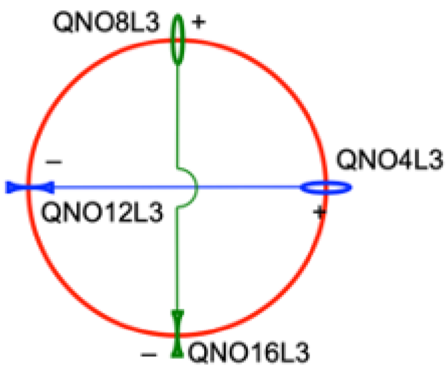
Brightness → Intensity/emittance

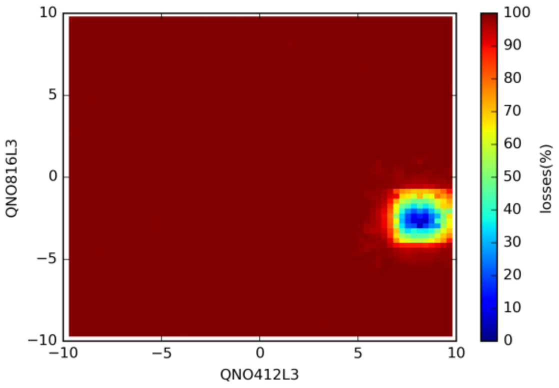
Resonance crossing and compensation

- 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.









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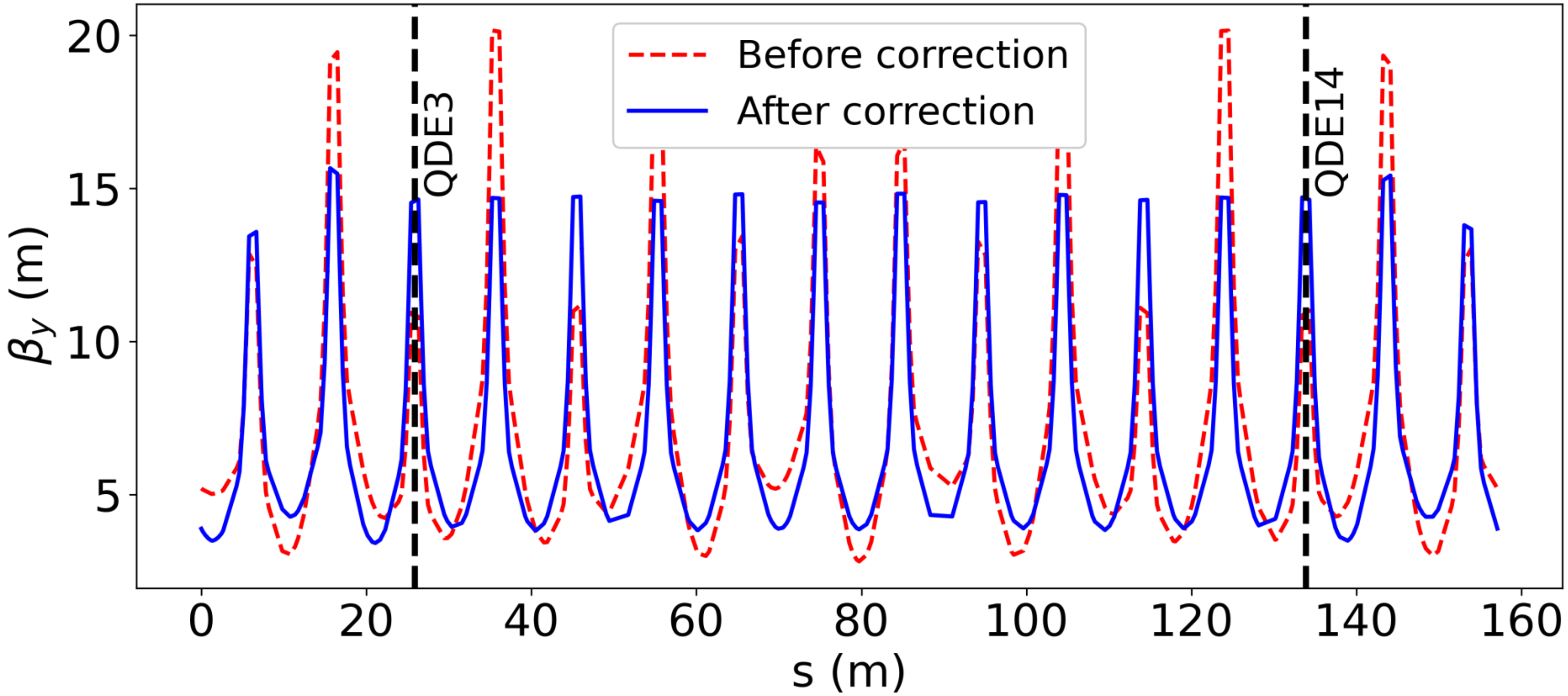
Beta-beating



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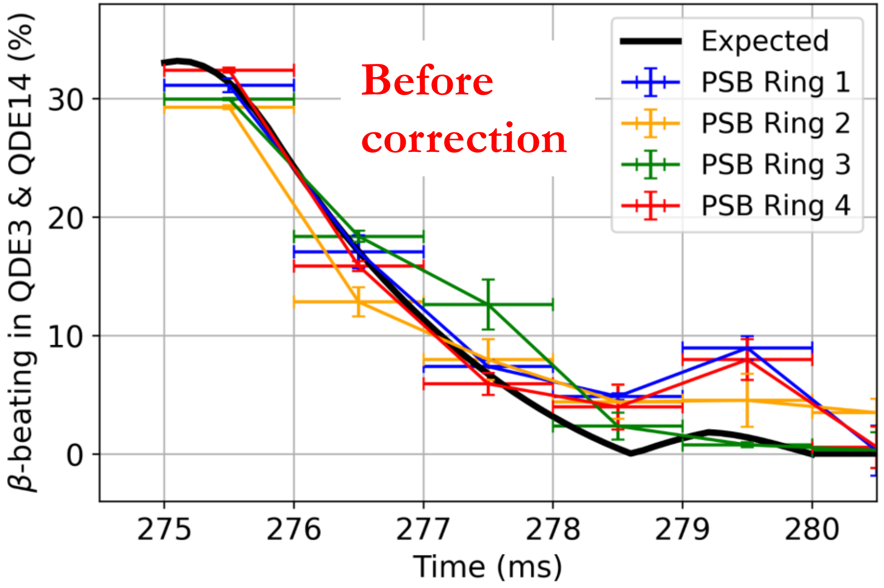
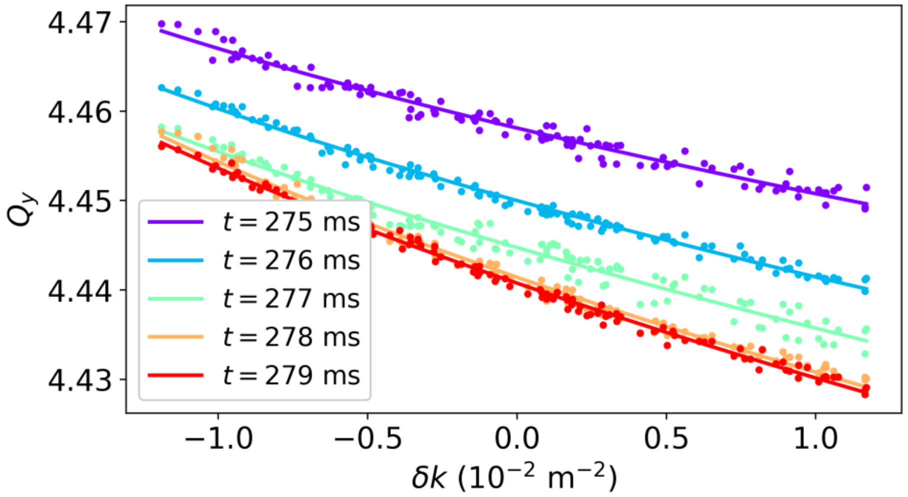
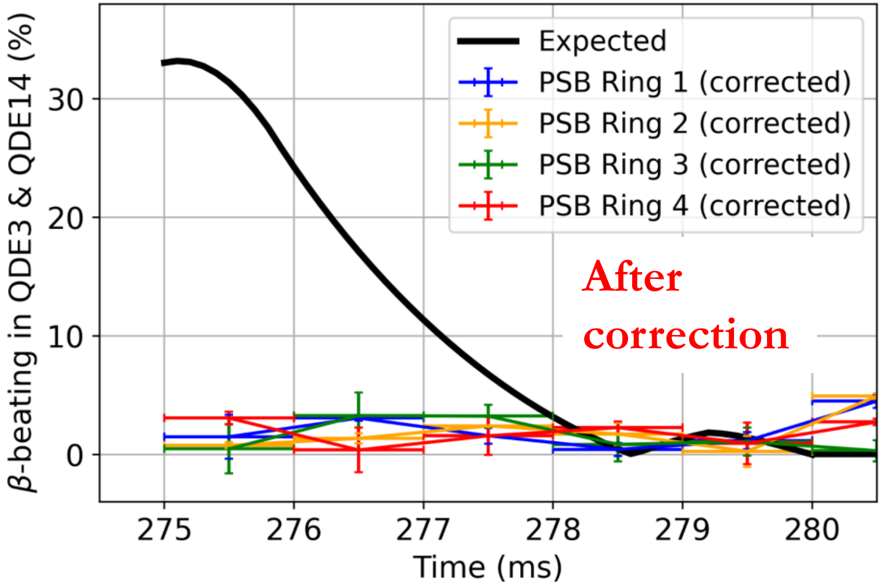
β-beating measurements at injection

- 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** which was applied to the machine.







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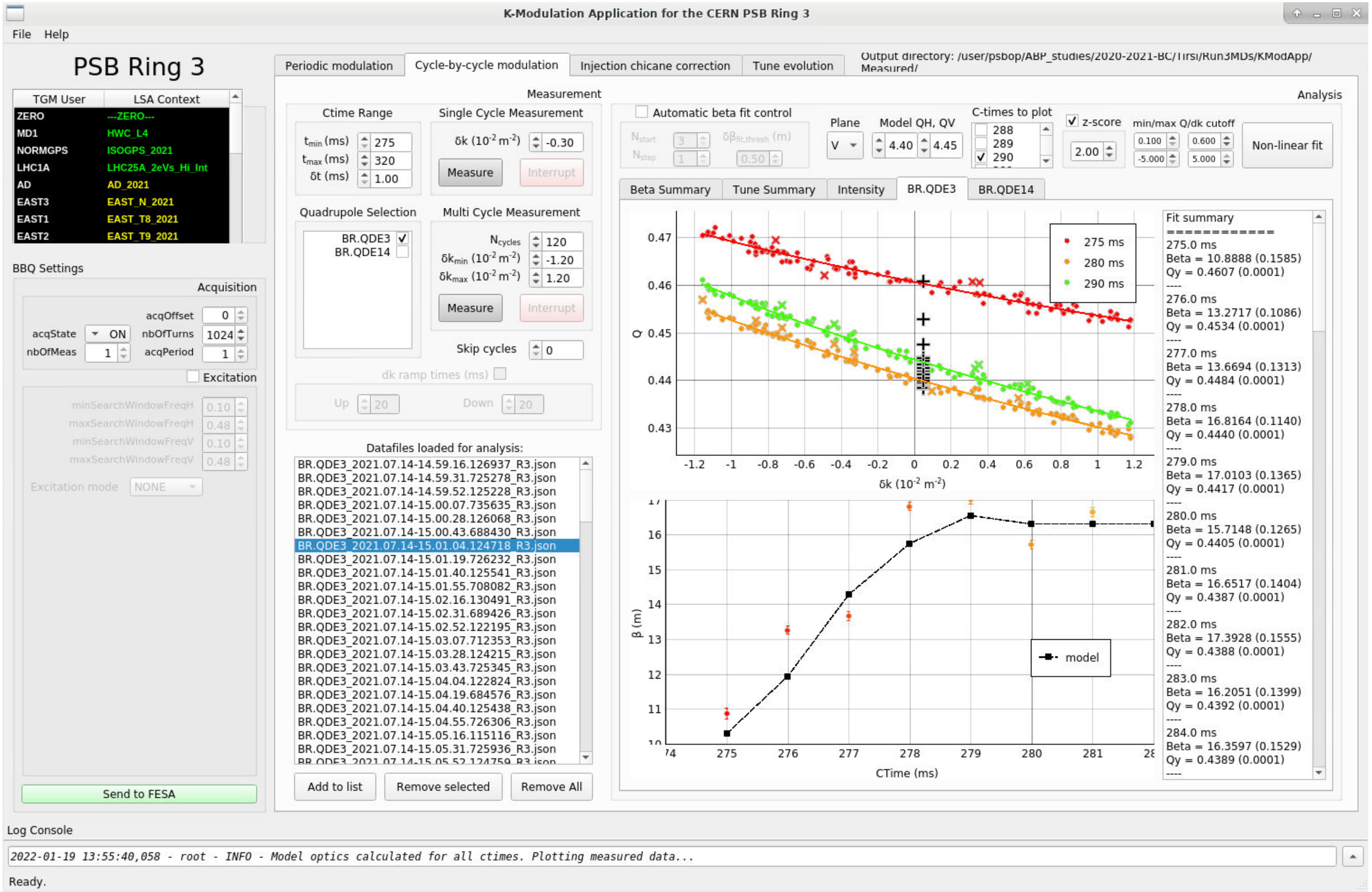
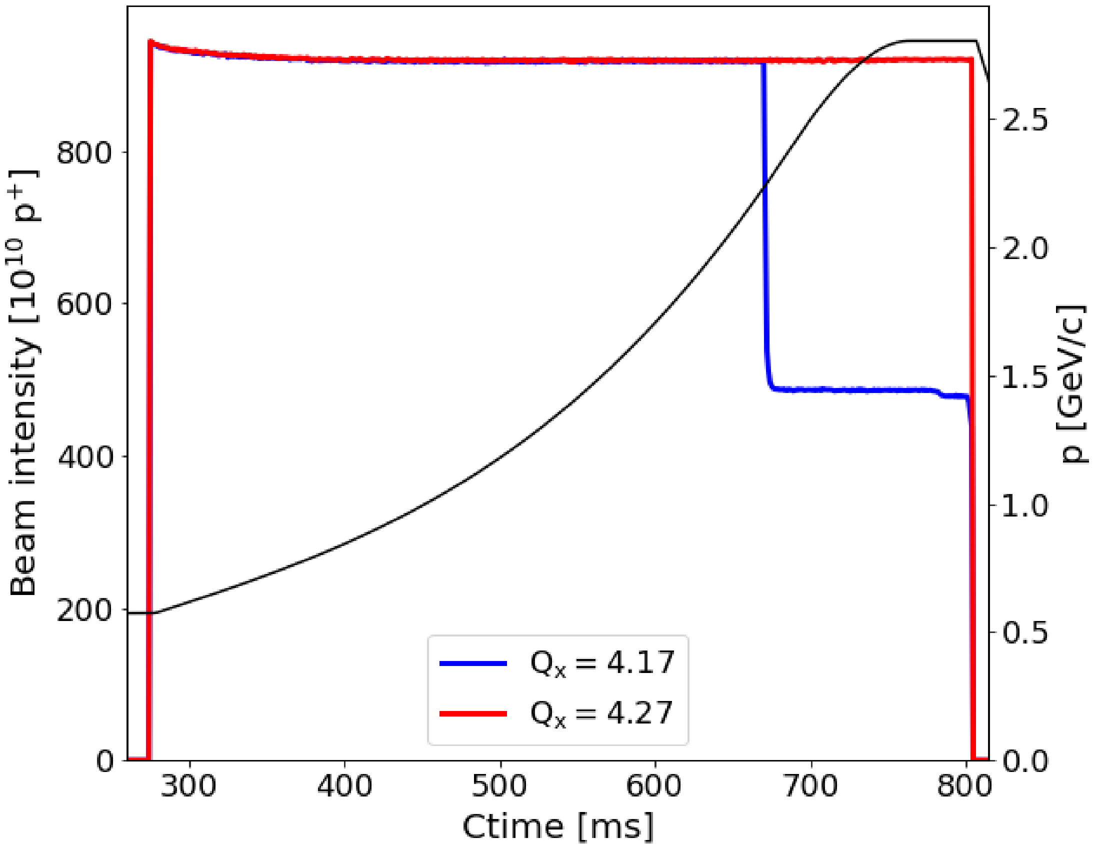
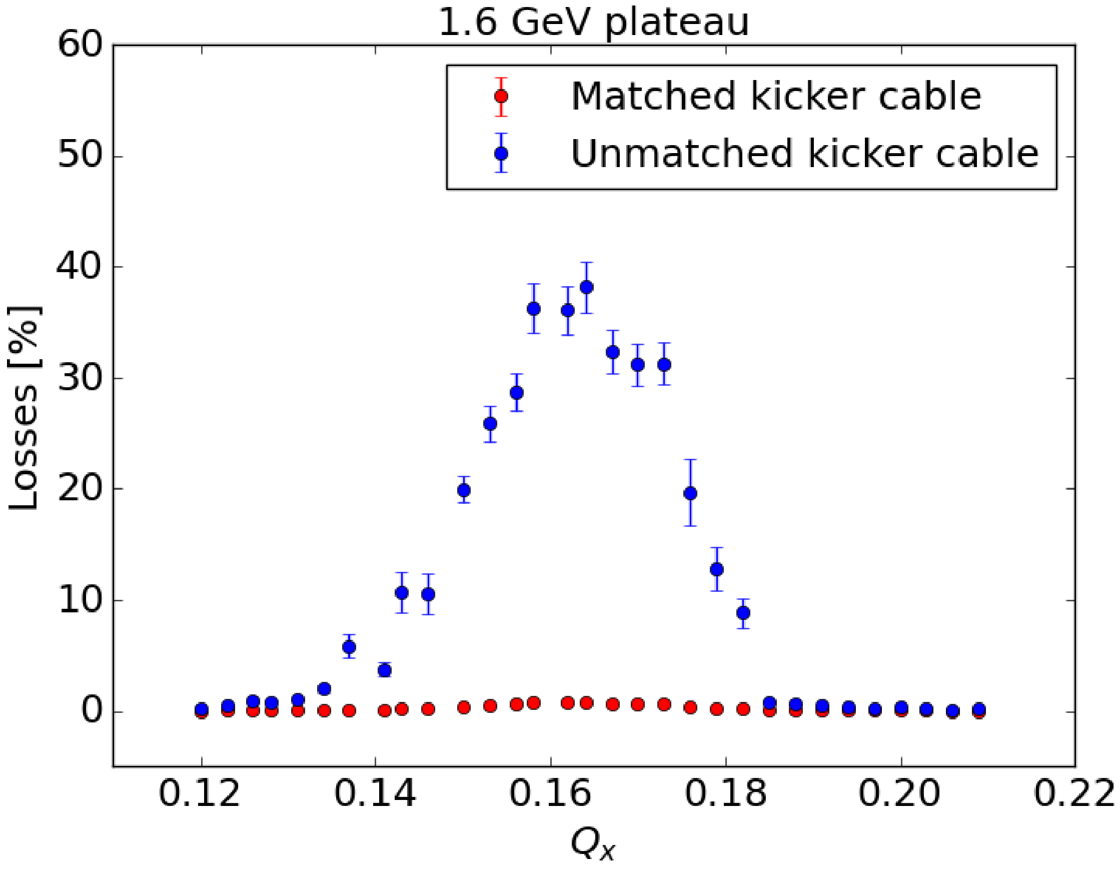
β-beating measurements at injection



Instabilities





Closed Orbit Measurement and Correction