Geometry of beam line for BDF/SHiP final focus and dilution system

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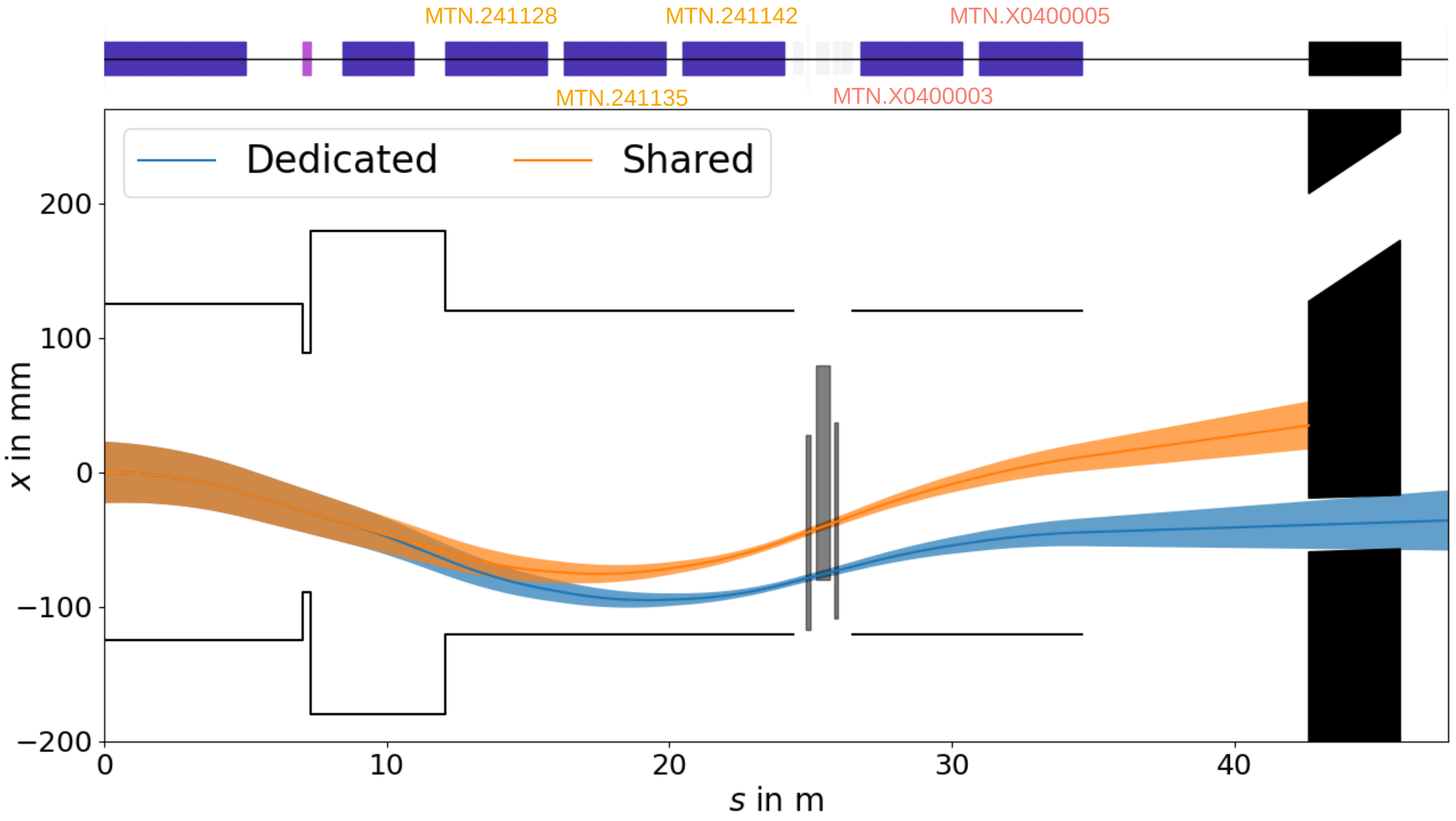
29.08.2024

TCC2 XTAX modifications

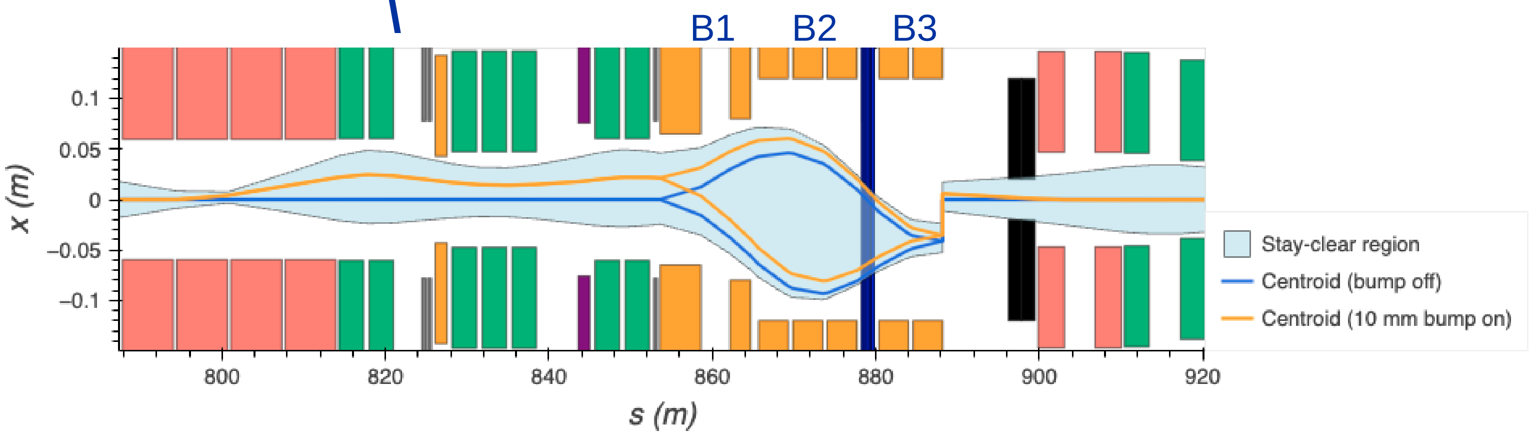
Negative wobbling (q<0, pc -> H8 = 300 GeV)



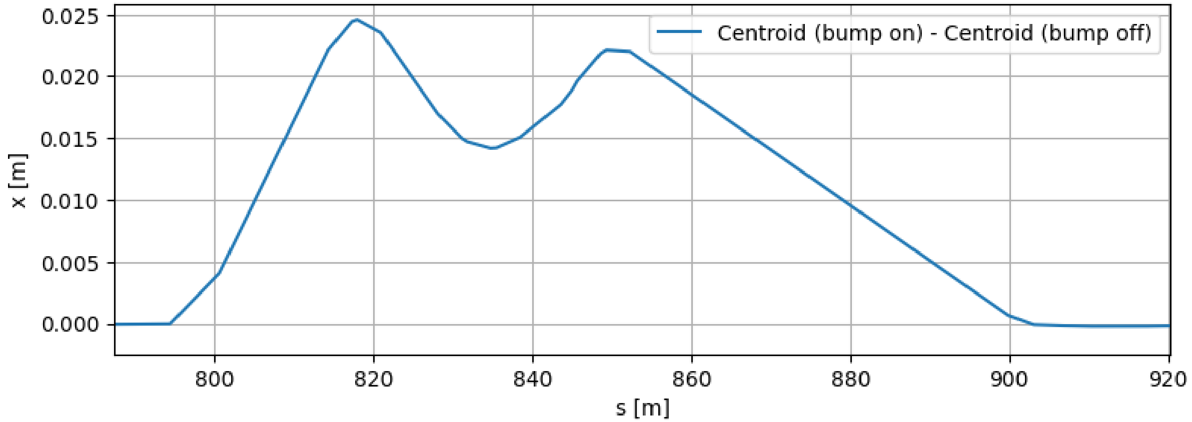
We need to change the geometry of the P42 line for the new XTAX concept.

Horizontal offset at T4

Stay-clear region allows to offset the beam at T4 by maximum 10 mm



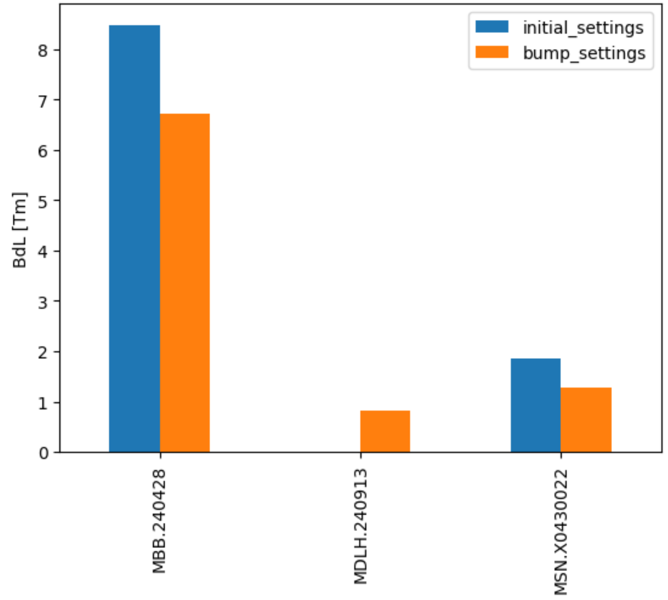
MBB.240428 MDLH.240913 MSN.X0430022



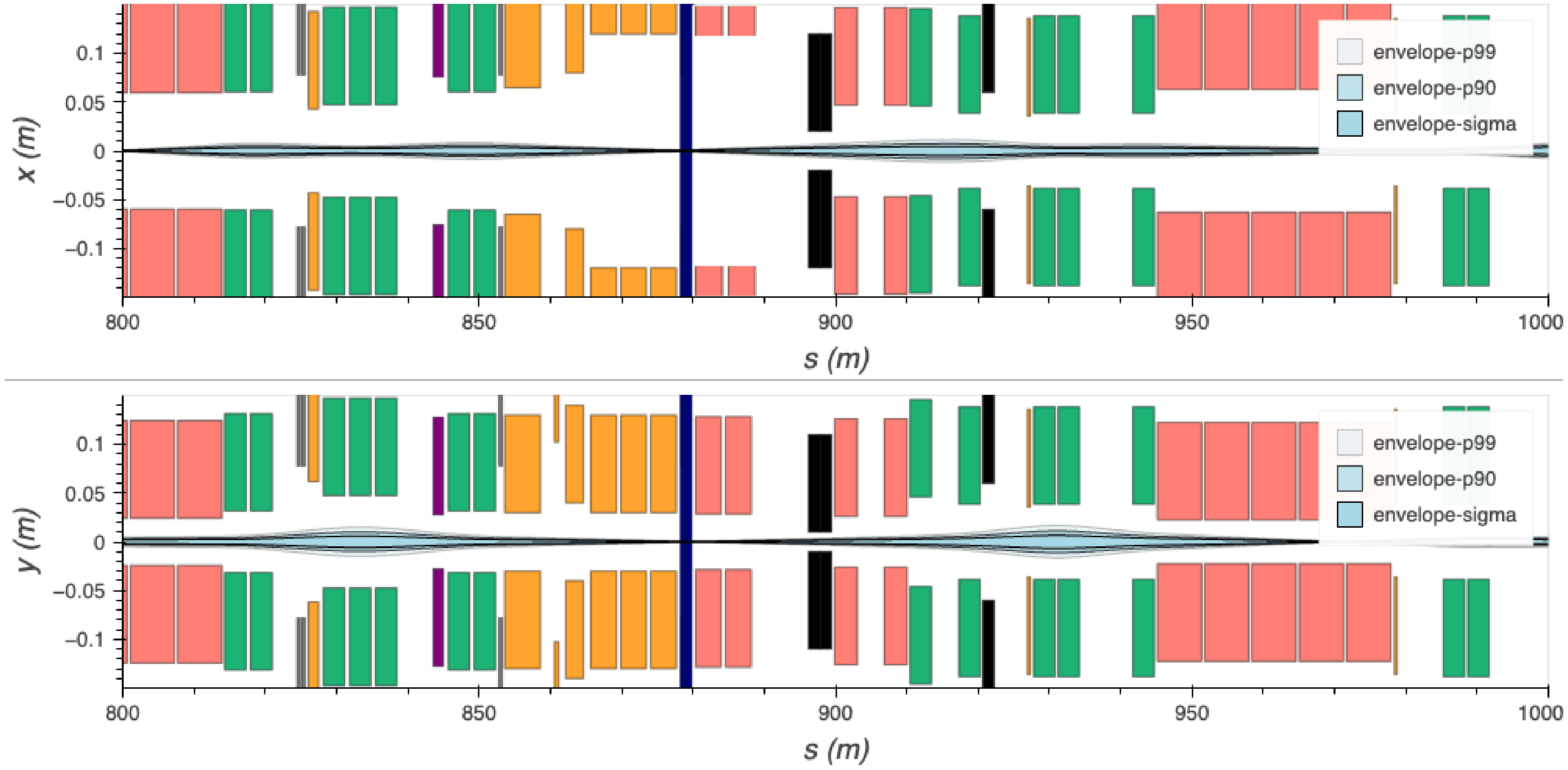
Bumpers:

- MBB.240428
- MDLH.240913
- MSN.X0430022

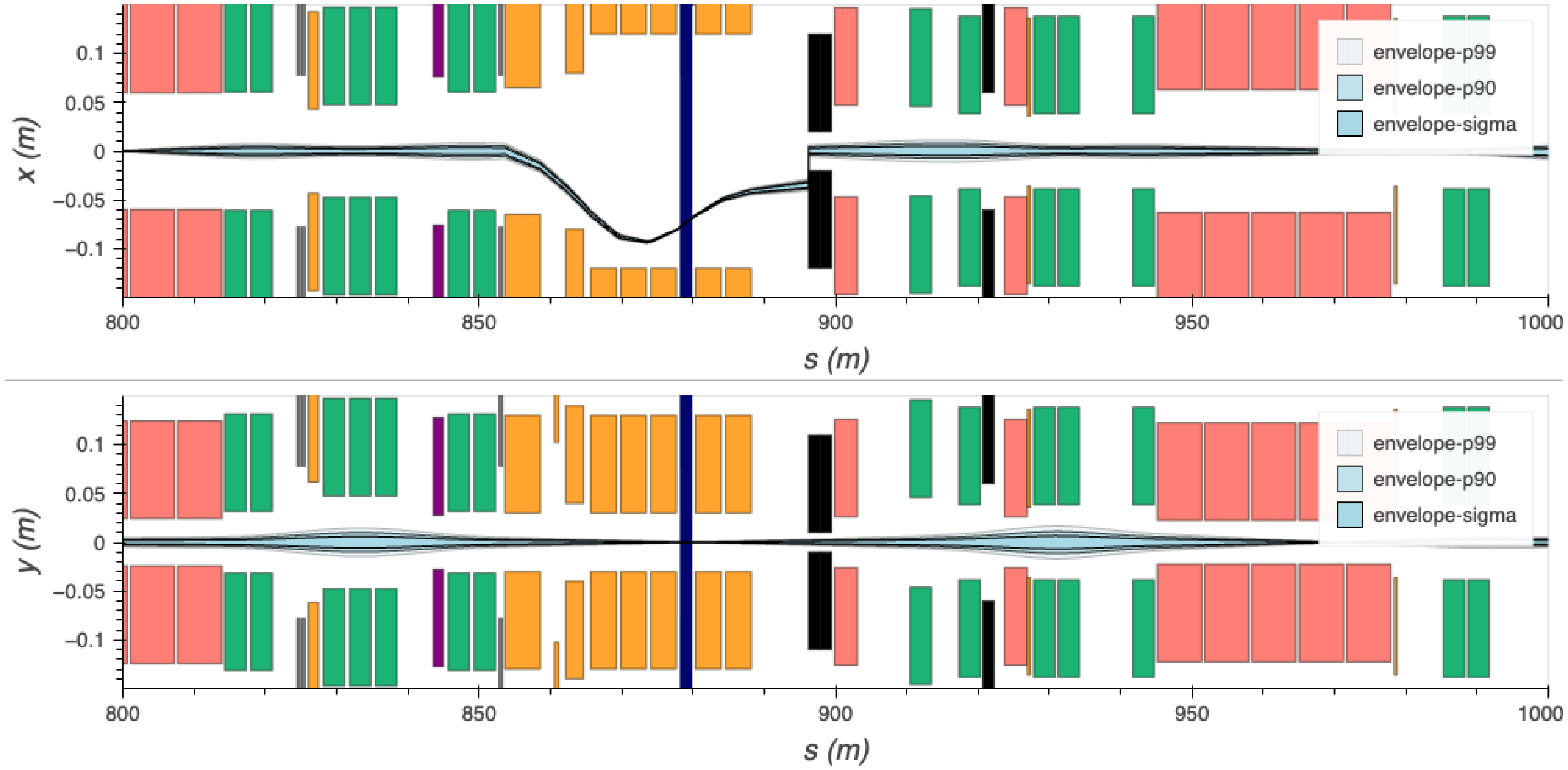
Bumpers settings



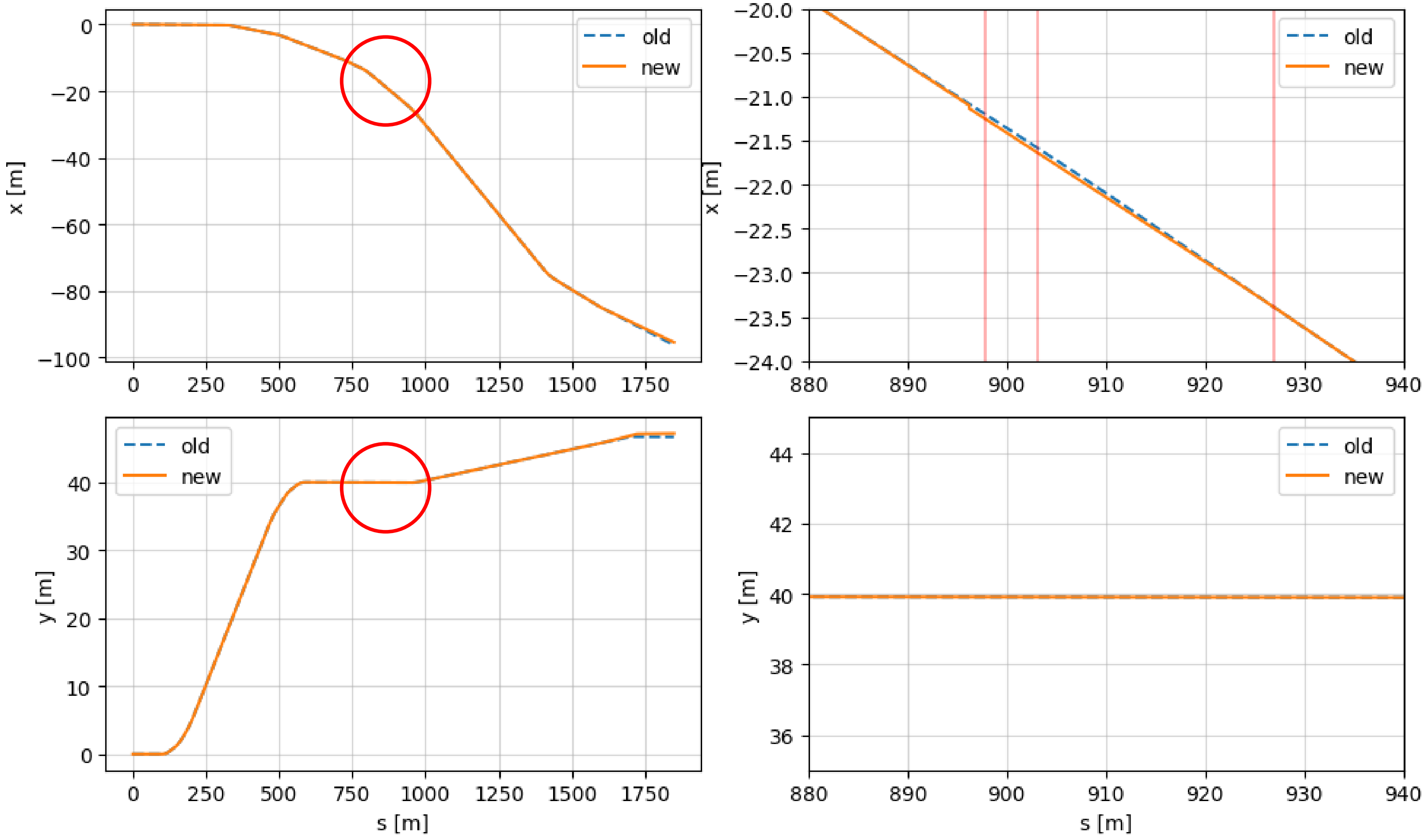
Horizontal offset at T4: P42 modifications



Horizontal offset at T4: P42 modifications

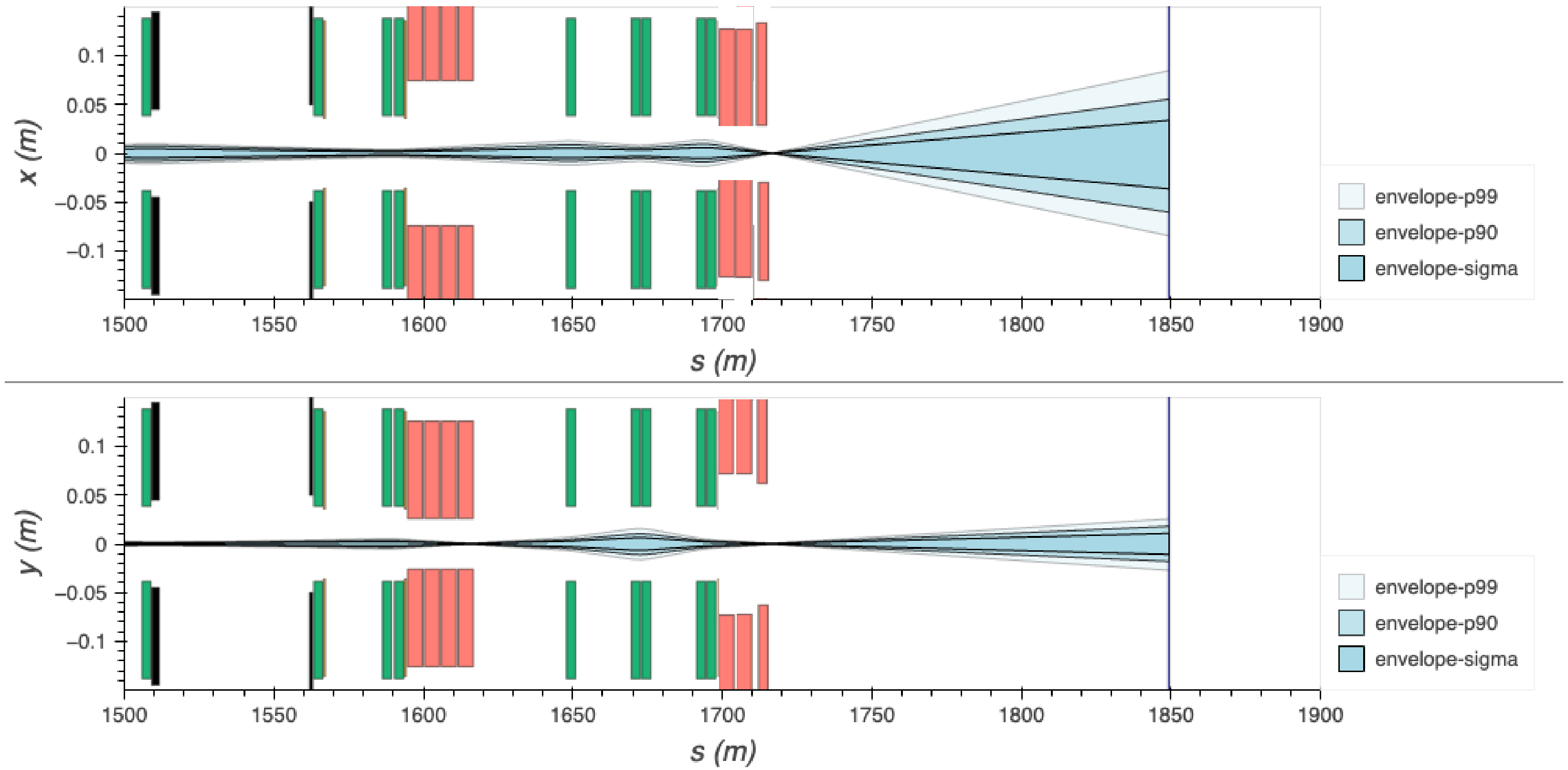


Horizontal offset at T4



Offset at BDF target

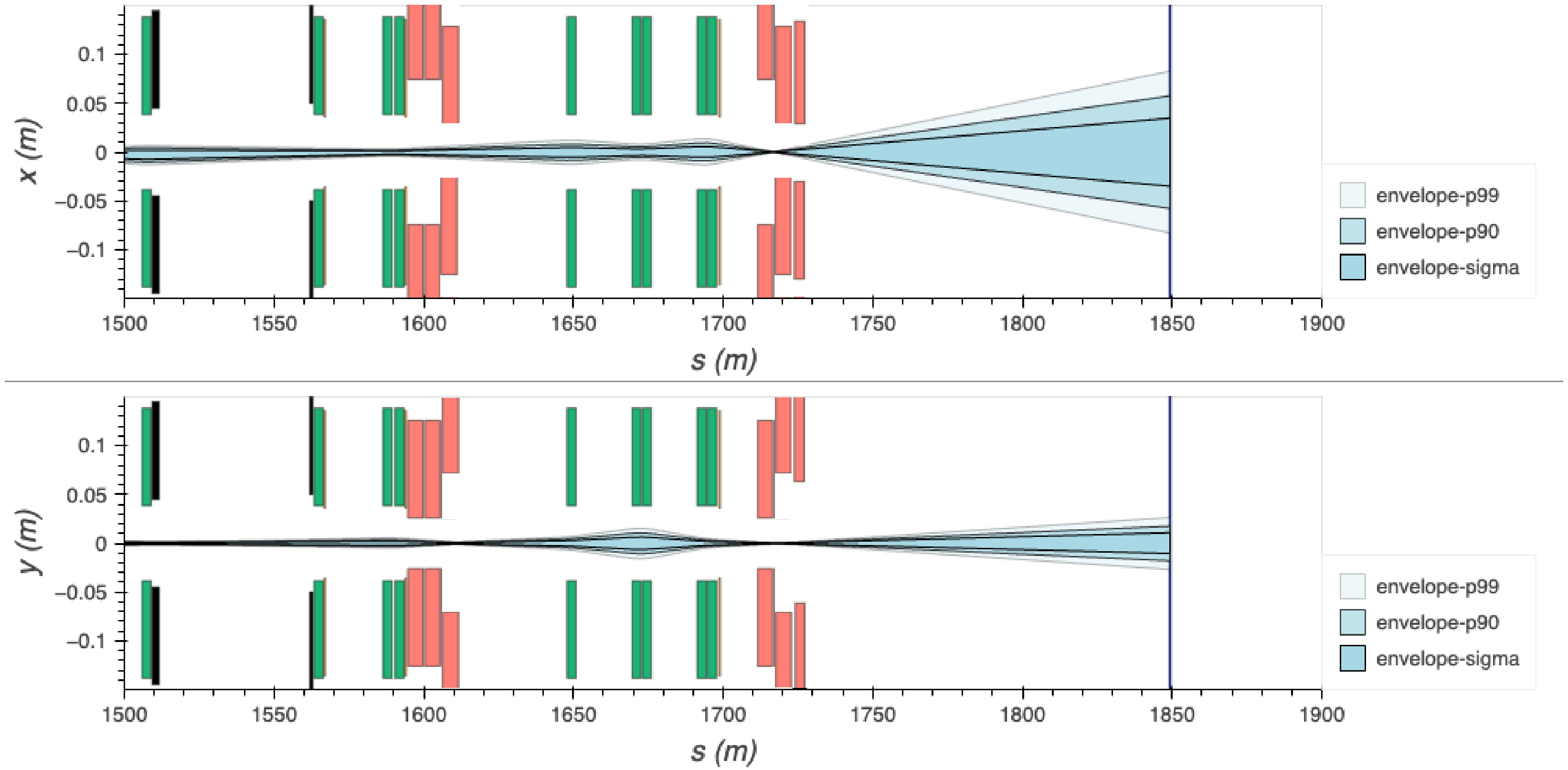
MBNV.X0450823
MBNV.X0450829
MBNH.X0430730 MBXGD.X0450834



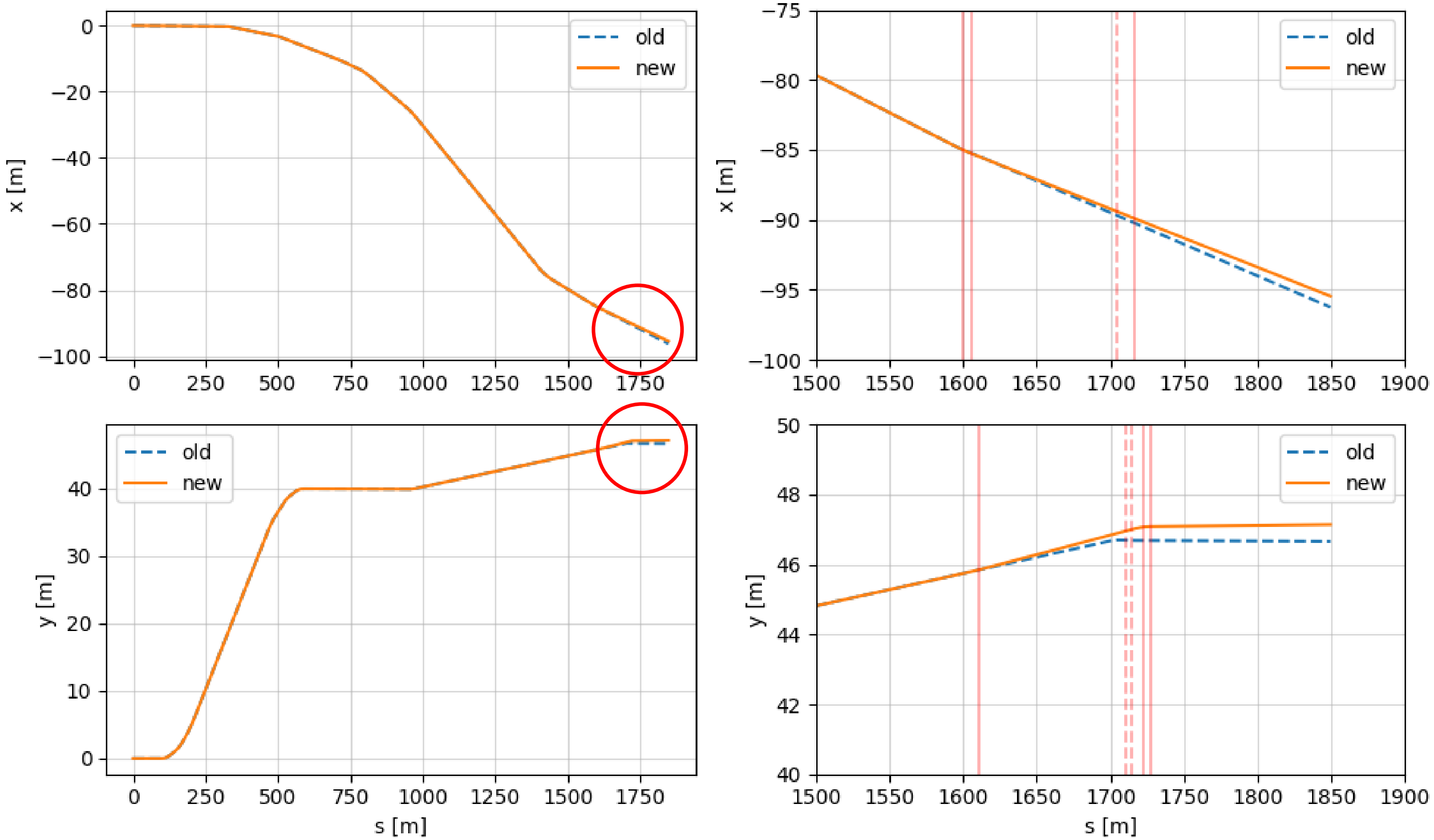
Offset at BDF target

MBNH.X0450823
MBNV.X0450829
MBXGD.X0450834

MBNV.X0430730



Horizontal offset at T4



0.8 m shift towards Jura

0.5 m vertical shift

Summary of the changes in P42

Element	Original position	New position	Original bending angle	New bending angle
MSN.X0430029	31.030	47.8950	0.0028	0.00311
MSN.X0430022	24.0500	24.0500	0.0014	0.0000441 (for the 10 mm bump case)
MBNH.X0430718	720.73013	720.73013	-0.0071455	-0.0059
MBNH.X0430724	726.390146	726.390146	-0.0071455	-0.0059
MBNH.X0430730	732.050148	732.050148	0.0029436	-0.001804 (turned vertical)
MBNH.X0430735	737.710150015	Not used	0.0029436	Not used
MBNV.X0450823	825.56016	837.56016	0.006963100	-0.000111 (turned horizontal)
MBNV.X0450829	831.220167	843.220167	0.006025400	0.007300
MBXGD.X0450834	835.928169	847.928169	-0.0033351	0.0033351

Final focus and dilution system: requirements

SPS Beam Dump Facility - Comprehensive Design Study: CERN-2020-002

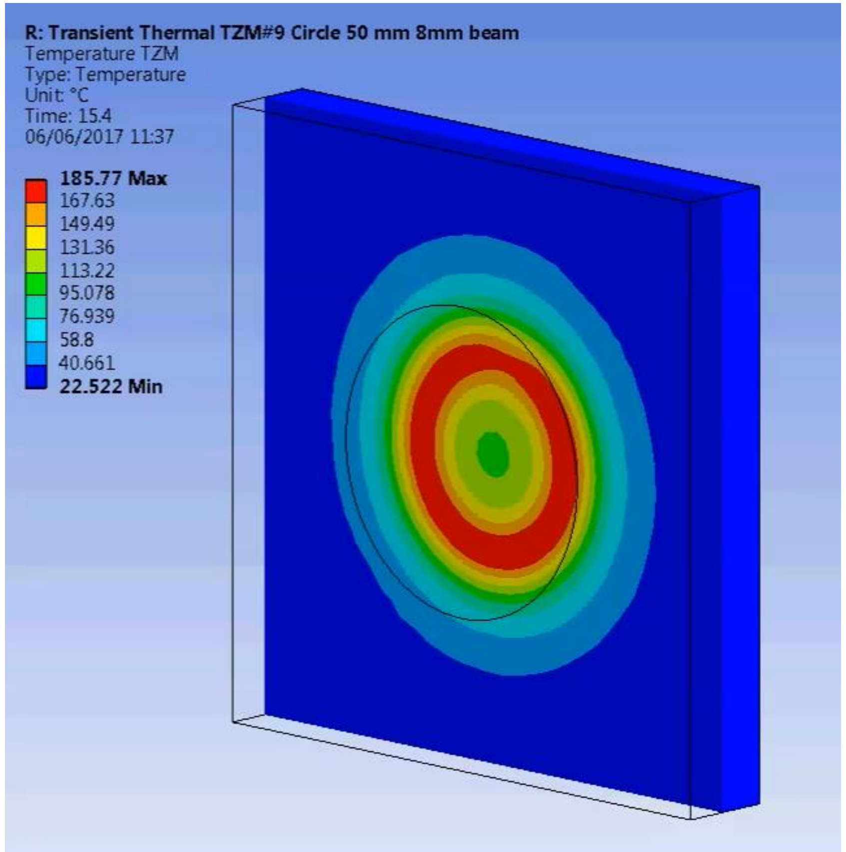
- Round beam with σ = 8 / 16 mm on target
- 50 mm sweep radius @ 4 Hz
- About 120 m drift

Possible solution – 4 magnets (2 per plane)

Magnet type	Aperture height	Total length	Imax PLS	Resistance	Inductance	Bdl	Lamination thickness	End plate thickness	# of mag req	I req	I rms	U req / mag	PC
HCMBXW_001	63	3820	750	60	145	4.358	1.5	80	1	115	81	419.1	2S
PXMBXGDCWP	70	3500	1000	68	139	4.63	1.5	54	1	145	103	506.6	2S
PXMBXHCCWP	80	3120	1434	15.9	62.9	3.38	1.5	50	1	283	200	447.4	2S
new MDX	100	630	240	320	221	0.509	0.5	15	2	157.5	111	874.8	4S
PXMBXHACWP	108	3085	1275	15.9	52.8	2.97	1.5	50	1	287	203	380.9	2S

About 80 m is needed to fit 4 magnets and achieve 50 mm sweep.

The model is to be updated.



Summary and the next step

- We need to iterate the madx model comparing it to the 3D integration model.
  Currently 154.5 m from QNL.X0430817 entrance

- Double check the target position and the angle between NA62 and future SHiP line.
  Currently 3.878 mrad

- Current concept of the dilution system is feasible for the new beam line geometry. The model is to be updated.

Thanks for your attention!

Final focus and dilution system: dilution failure

Since 4 magnets are needed we can do:

- **π/2 scheme: 2x orientated in H + 2x orientated in V, de-phased by 90 degrees**
- π/4 scheme: each magnet rotated by 45 degrees, and each de-phased by 45 degrees

- Dilution system failure showed the 90 degrees scheme is better
- Loss of one magnet for 1 full spill does not require replacement of the target in π/2 scheme

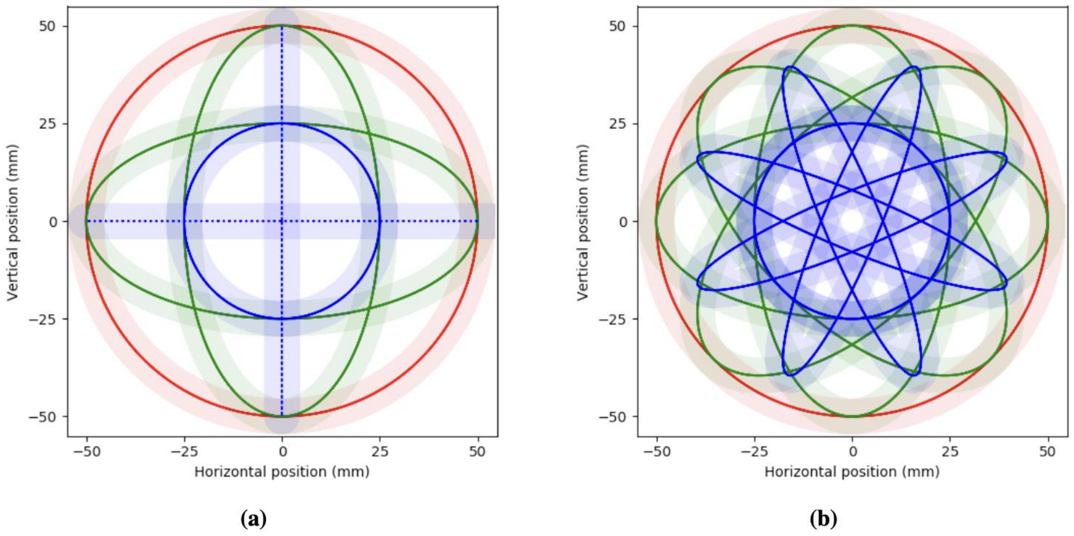


Fig. 4.8: Possible dilution patterns on the target with all four circuits (red), three circuits (green), and only two circuits (blue). Part (a) shows patterns for the $\pi/2$ scheme, while the possible patterns for the $\pi/4$ scheme are shown in (b).

Stay clear region

$$R_{sc} = 7 \cdot \sigma + k_{oerror}\sqrt{\frac{\beta(s)}{\beta_{max}}} + k_{berror}\sigma + k_{derror}D\Delta_p + k_{aerror}$$

$$k_{oerror} \approx 5\,\mathrm{mm}$$

$$k_{berror} = \frac{\delta\beta\varepsilon + \delta\varepsilon\beta}{2\beta\varepsilon} \approx 10\%$$

$$k_{derror} = \frac{\delta D}{D} \approx 10\%$$

$$k_{aerror} \approx 1\,\mathrm{mm}$$

More info: C. Bracco, Injection: Hadron Beams, CAS 2017

Stay clear reagion (SCR) takes into account beam size plus size, orbit, dispersion and alignment errors.

SCR at T4: Both wobbling scenarios

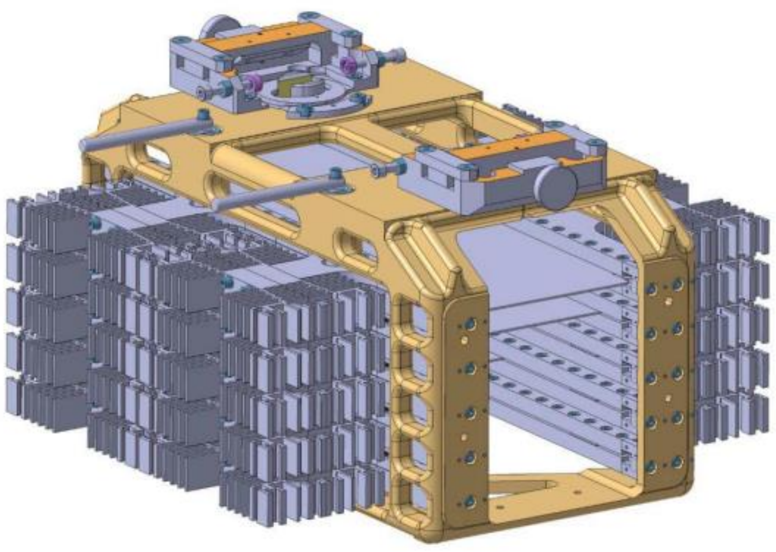
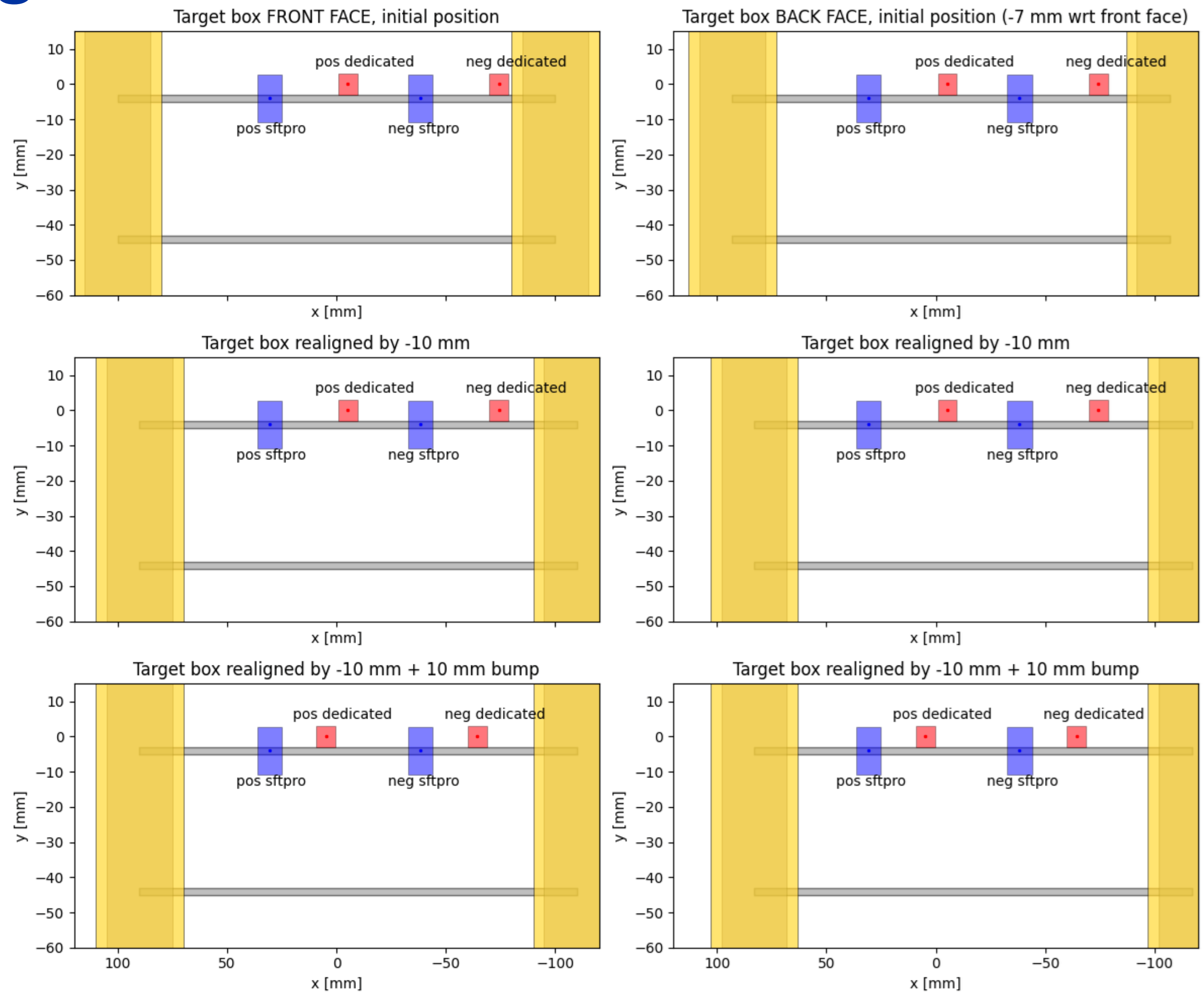


Figure 6: T2, T4 and T6 target box/head



Dedicated

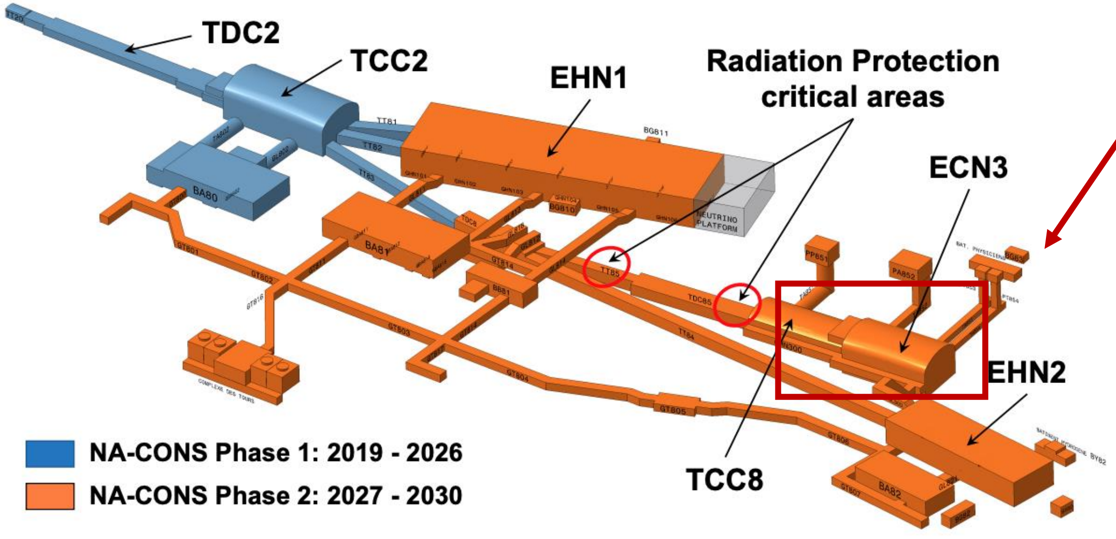
$\sigma_x = 0.45$ mm
$SCR_x = \pm 4.5$ mm
$\sigma_y = 0.25$ mm
$SCR_y = \pm 3$ mm

SFTPRO

$\sigma_x = 0.75$ mm
$SCR_x = \pm 6.6$ mm
$\sigma_y = 0.8$ mm
$SCR_y = \pm 7$ mm

Delivery for ECN3: overview

Final SHiP location



(a) NA-CONS project baseline scope and timeline

*Study of alternative locations for the SPS Beam Dump Facility

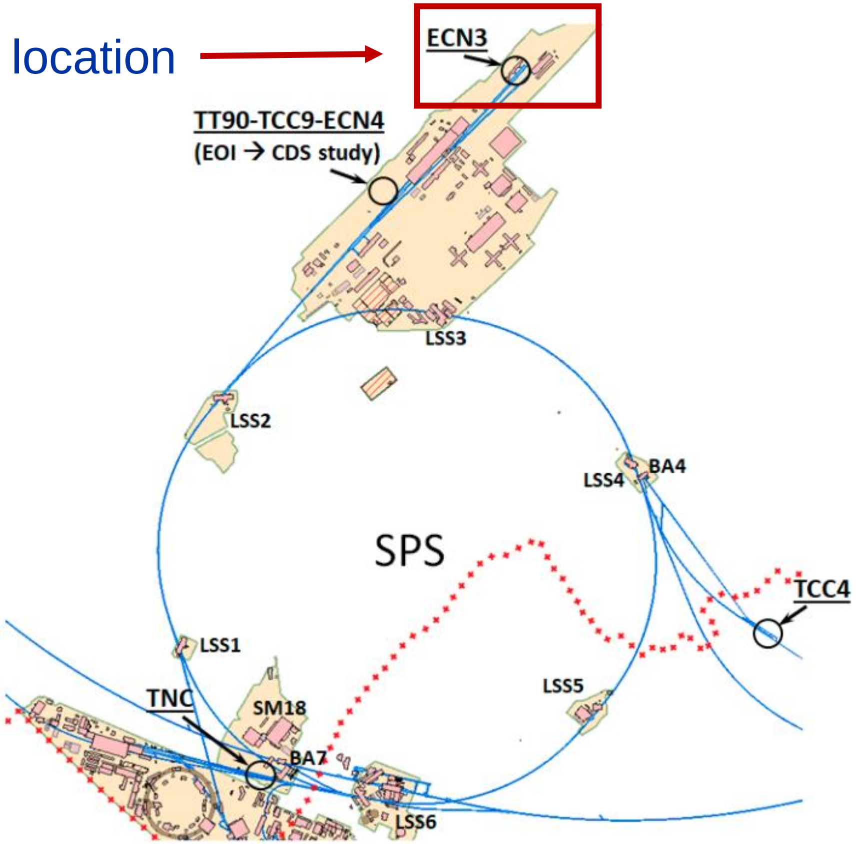
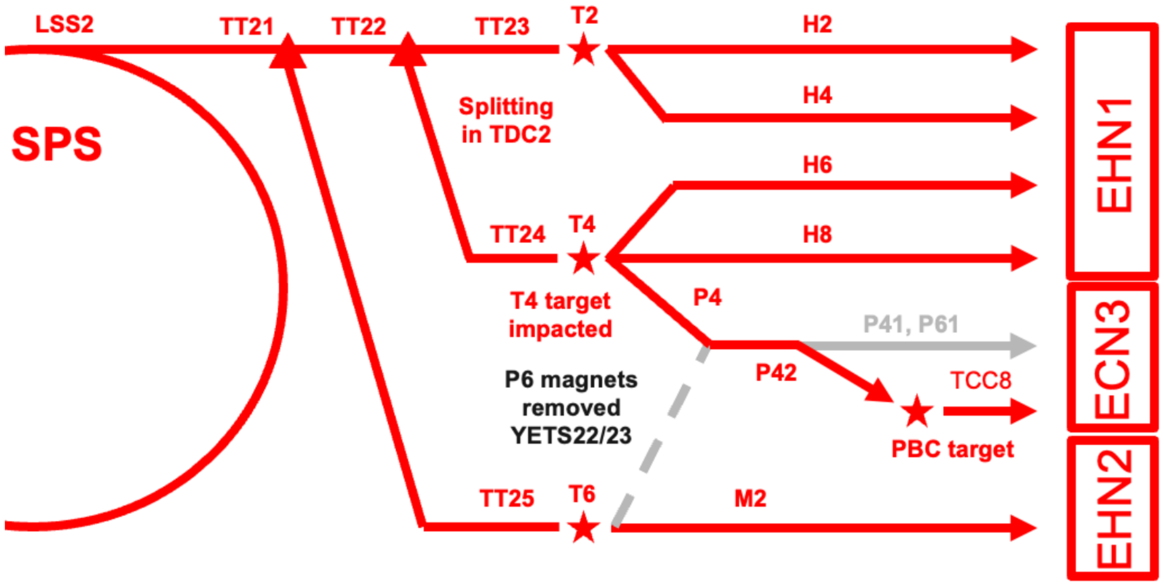


Figure 1: Overview of the locations considered for the implementation of the BDF.

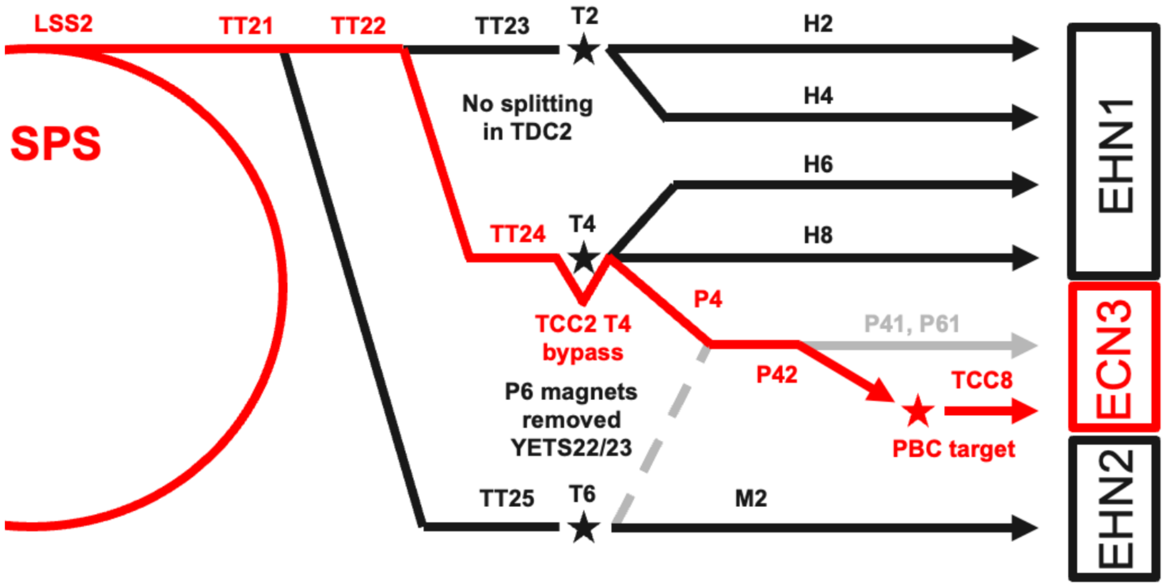
*Study of alternative locations for the SPS Beam Dump Facility

Multiple locations, such as TNC, ECN4, ECN4 and TCC4 were concidered for BDF/SHiP. Eventually, ECN3 was approved providing the opportunity to benefit from slow-extracted beam from LSS2 and synergy with NA-CONS project.

Delivery for ECN3: operation scenarios



(a) Shared ECN3 scenario (similar to today's operational scenario - SFTPRO)



(b) Dedicated ECN3 scenario

*Findings of the Physics Beyond Colliders ECN3 Beam Delivery Task Force

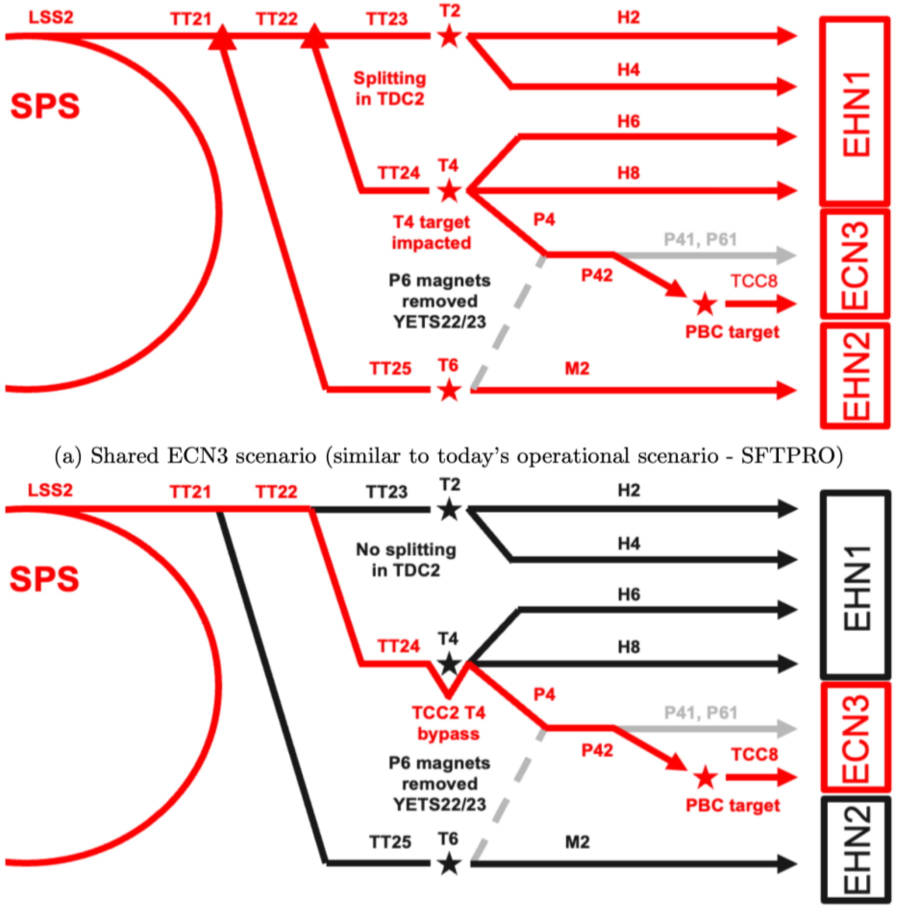
Beam delivery for ECN3 starts in SPS LSS2 with slow-extraction to TT21. Then the beam is either split at the end of TT21 and TT22 or not depending on scenario. Downstream the line it passes through the T4 target in TCC2 and P42 line until it is finally transferred to T10 target in TCC8.

Delivery for ECN3: beam parameters

Findings of the Physics Beyond Colliders ECN3 Beam Delivery Task Force

TCC2 (SFTPRO)			ECN3 (SHiP, CNGS-like)			SC length [s]	TCC2 & ECN3 FT Duty Cycle [%]
FT Length [s]	N_{cycles} [/SC]	Duty Cycle [%]	FT Length [s]	N_{cycles} [/SC]	Duty Cycle [%]		
4.8	1	11.1	1.2	4	11.1	43.2	**22.2**
9.6	1	17.4	1.2	4	8.7	55.2	**26.1**

Experiment	Duration [years]	Spill Intensity [10^{13}]	Spill Length [s]	PoT/year [10^{19}]	Total PoT [10^{19}]	N_{spills}/year [10^6]
HIKE phase I (K^+)	4	1.3	≥ 4.5	0.8	3.2	0.62
HIKE/SHADOWS (beam dump)	4	2.0	≥ 4.5	1.2	4.8	0.60
HIKE phase II (K^0_L)	5	2.0	≥ 4.5	1.2	6.0	0.60
BDF/SHiP (beam dump)	15	4.0	≥ 1.2	4	60	1.0



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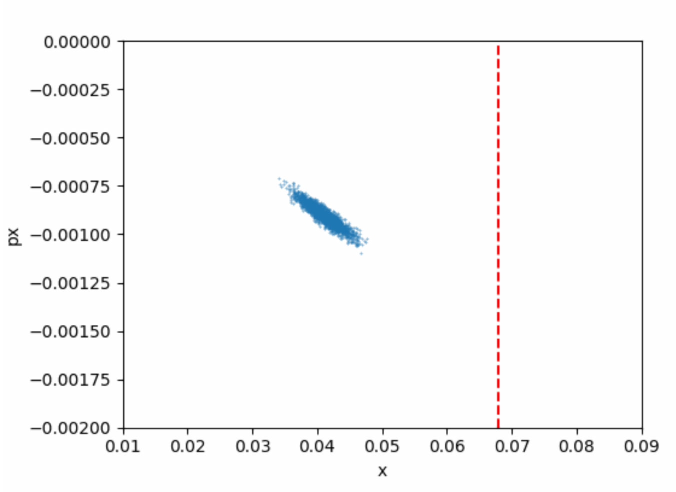
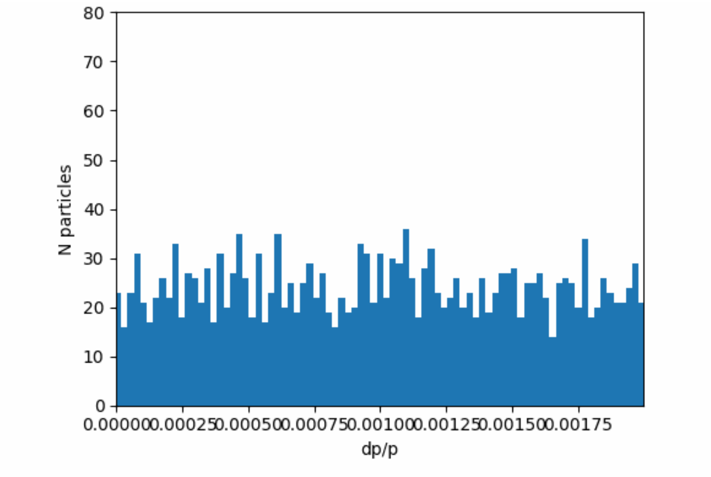
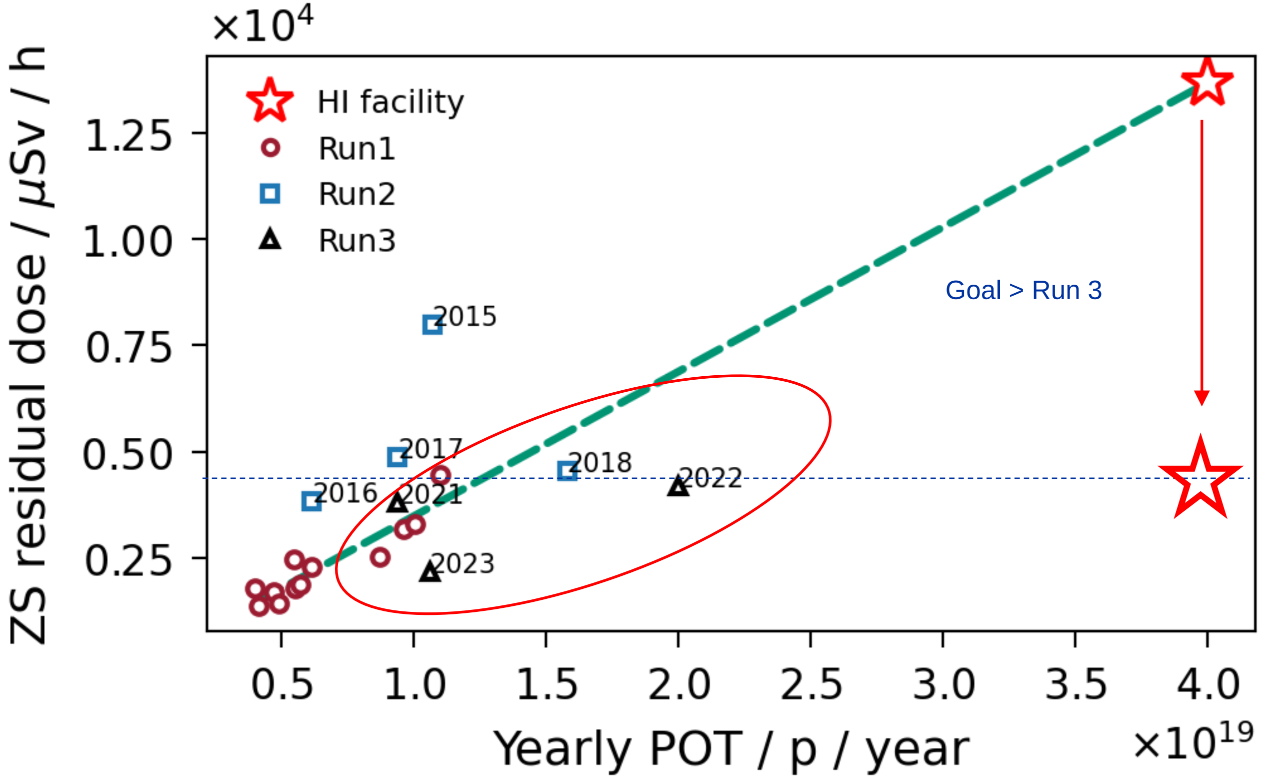
Slow extraction in LSS2: ZS activation problem

COSE: Constant Optics Slow Extraction





Beam losses on ES cause activation and, thus, limit max POT. We need to significantly reduce these losses (x4) to keep the dose at the level of Run 3.



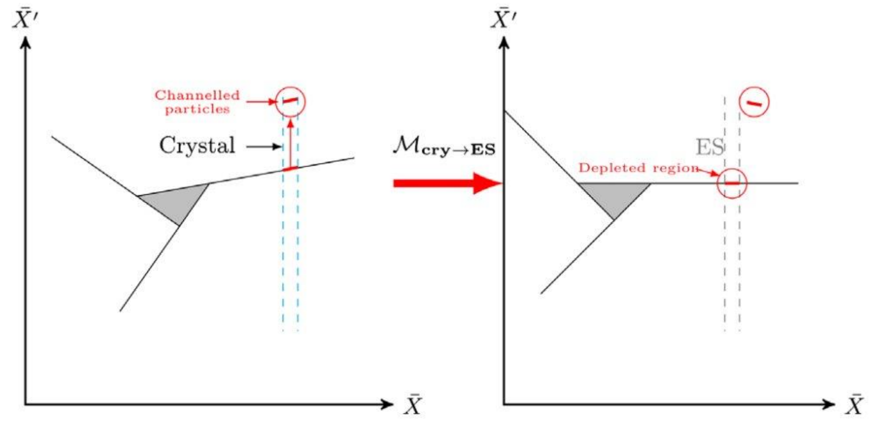
Slow extraction in LSS2: losses reduction (CS)

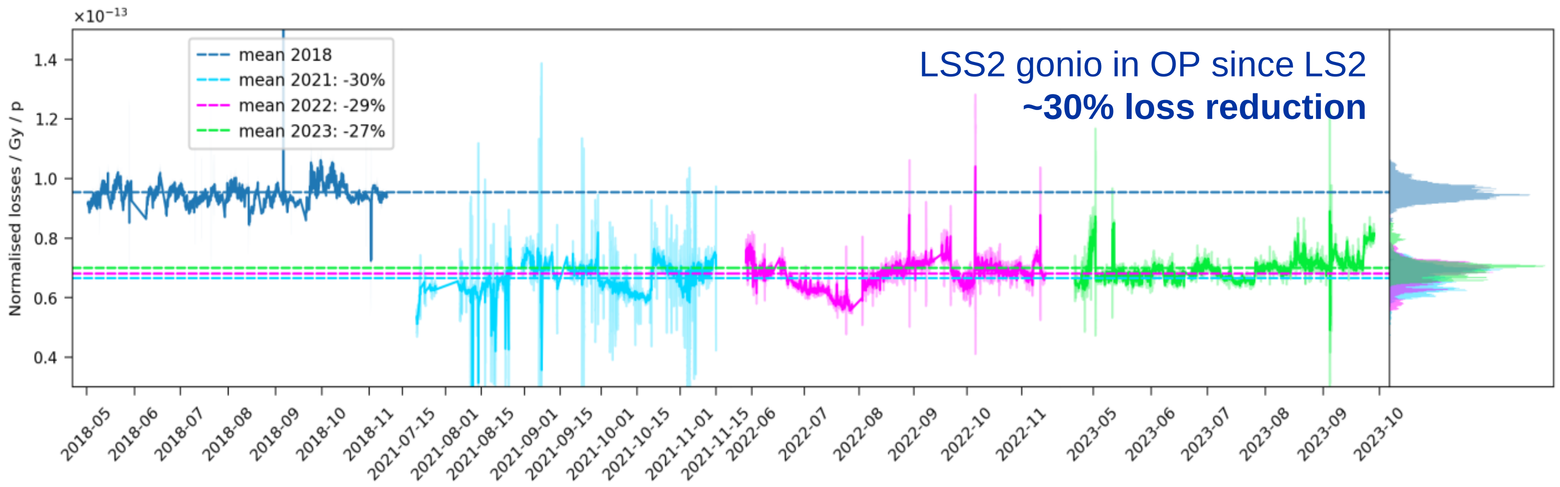
Crystal shadowing of ZS is now proven technique:

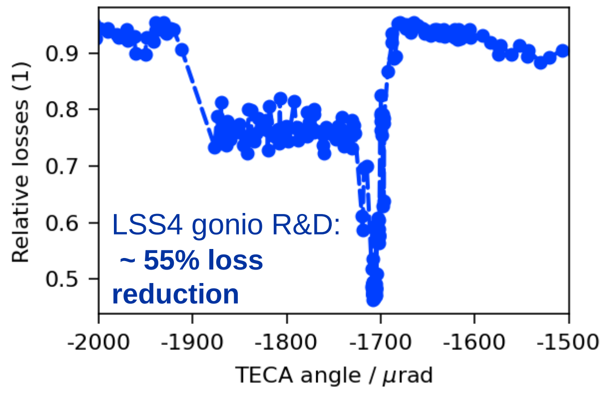
- Operational goniometer in SPS LSS2

CERN in-house development of advanced crystal technology (DECRYCE project):

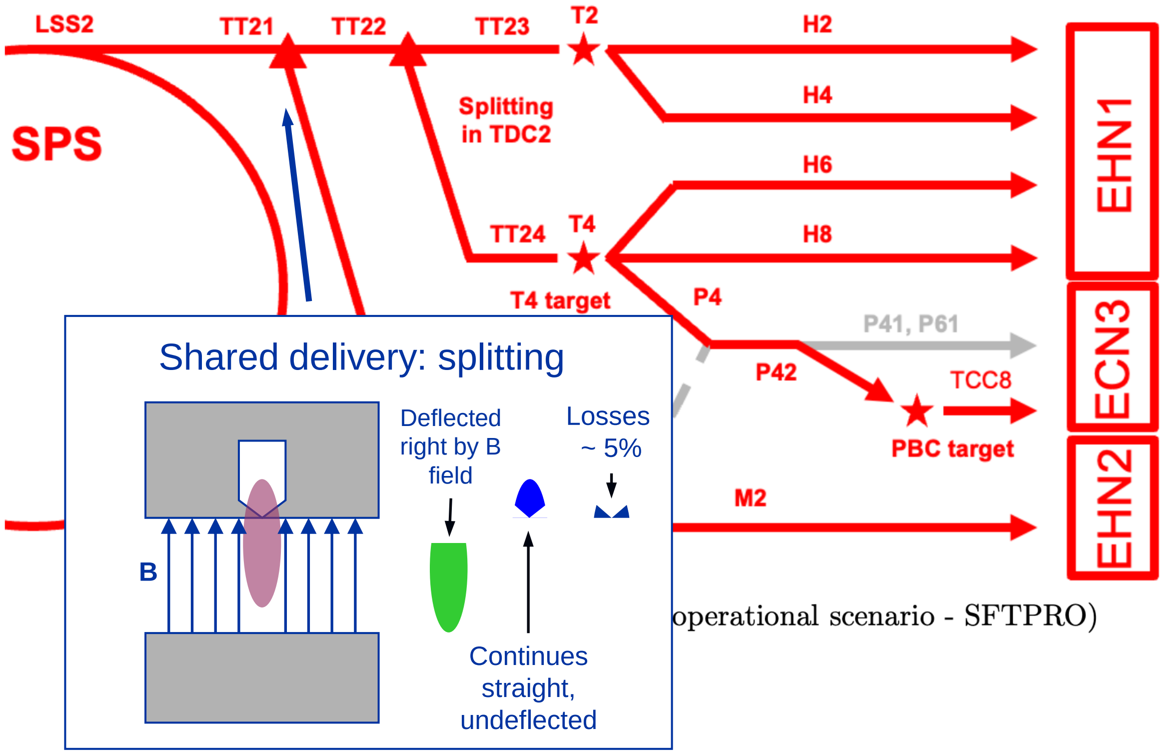
- Now: single crystal aligned in shadowing (VR) for LSS4 ~ factor 2 loss reduction
- Future: arrays of crystals aligned in volume reflection promising up to a factor 10 beam loss reduction and replacement of septa with crystals altogether

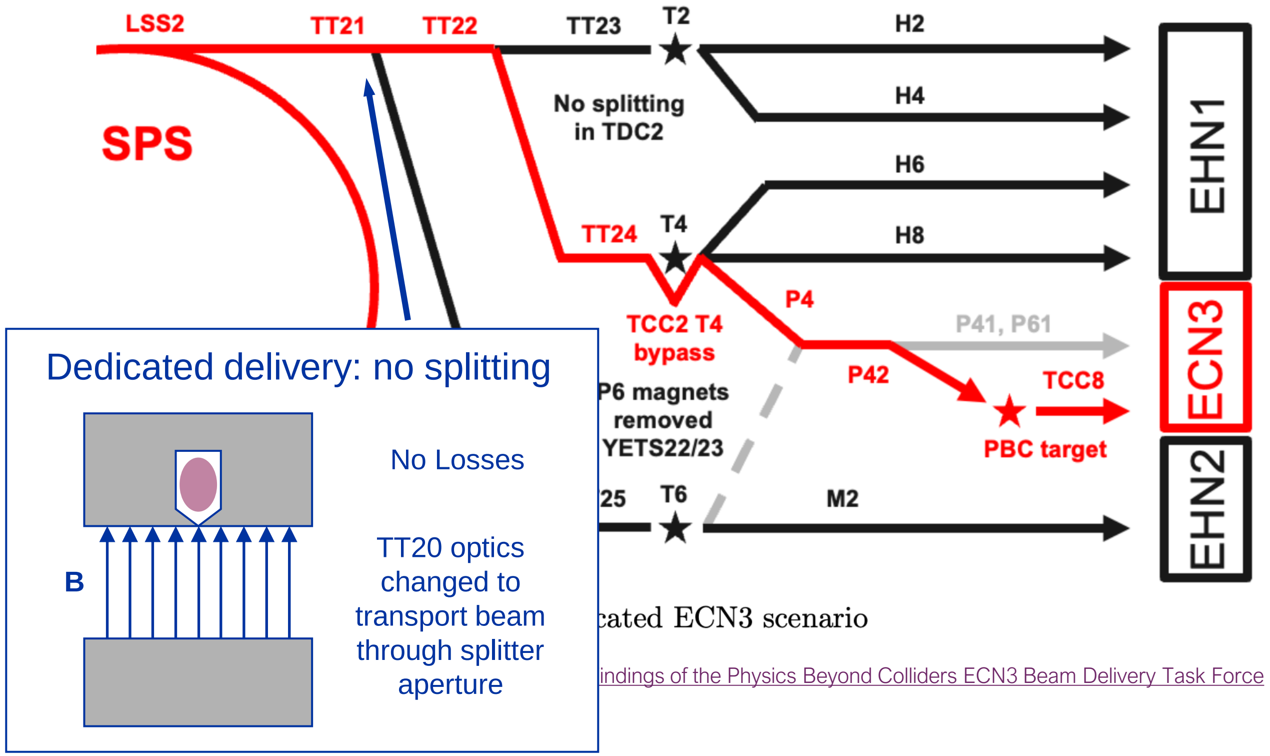






Delivery for ECN3: splitting VS dedicated





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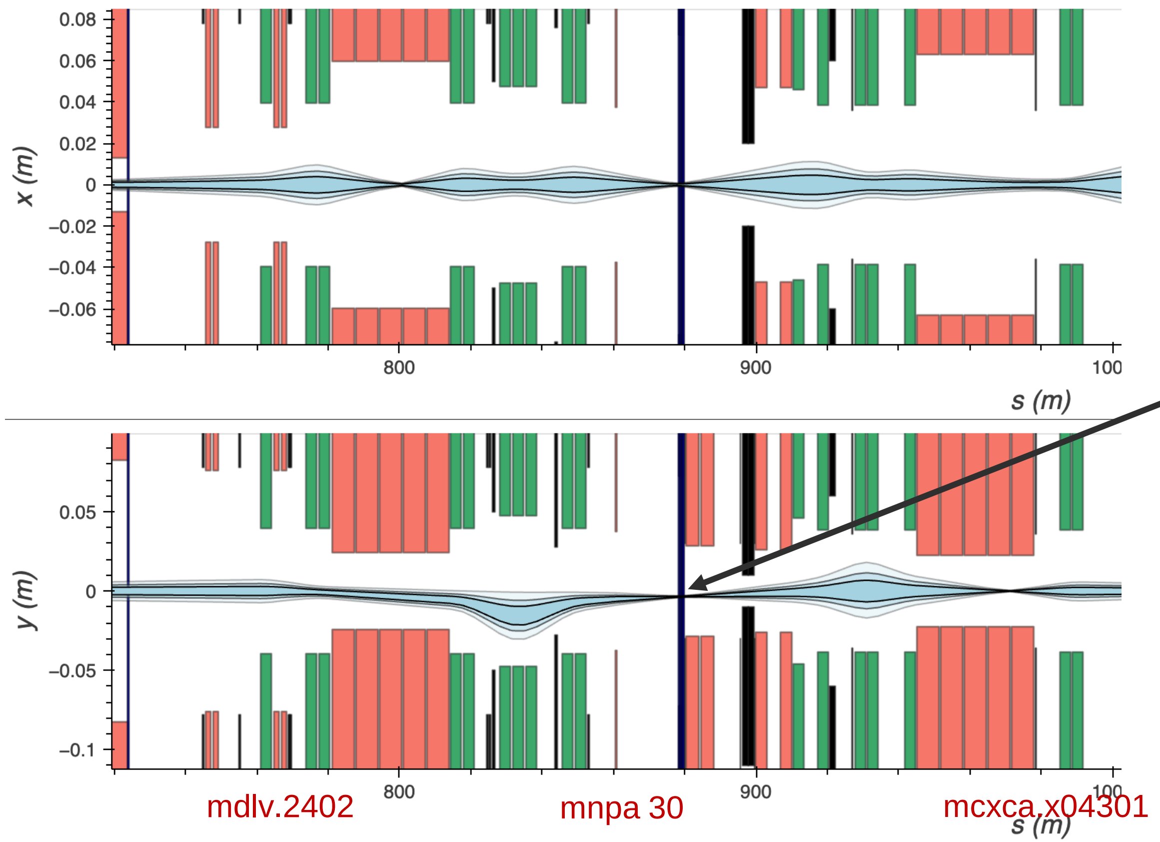
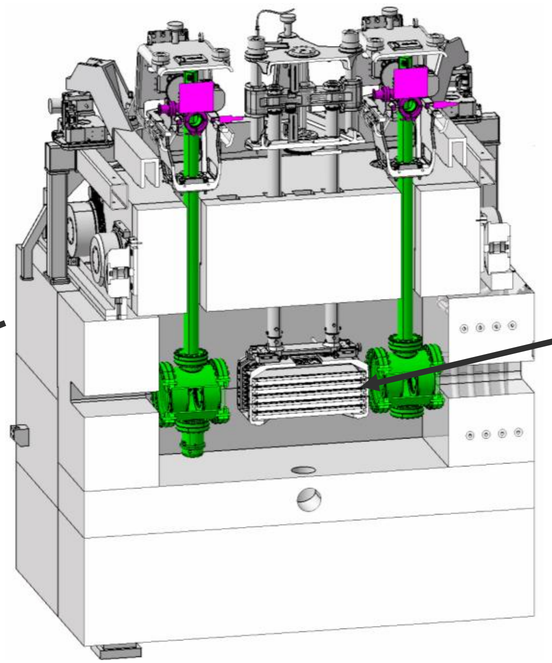
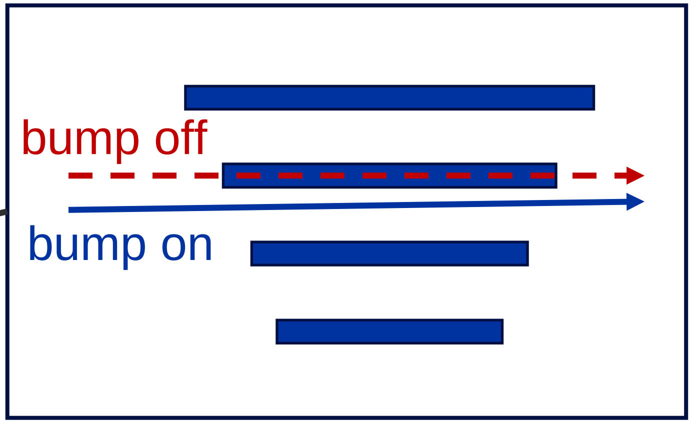
Delivery for ECN3: bumping around T4



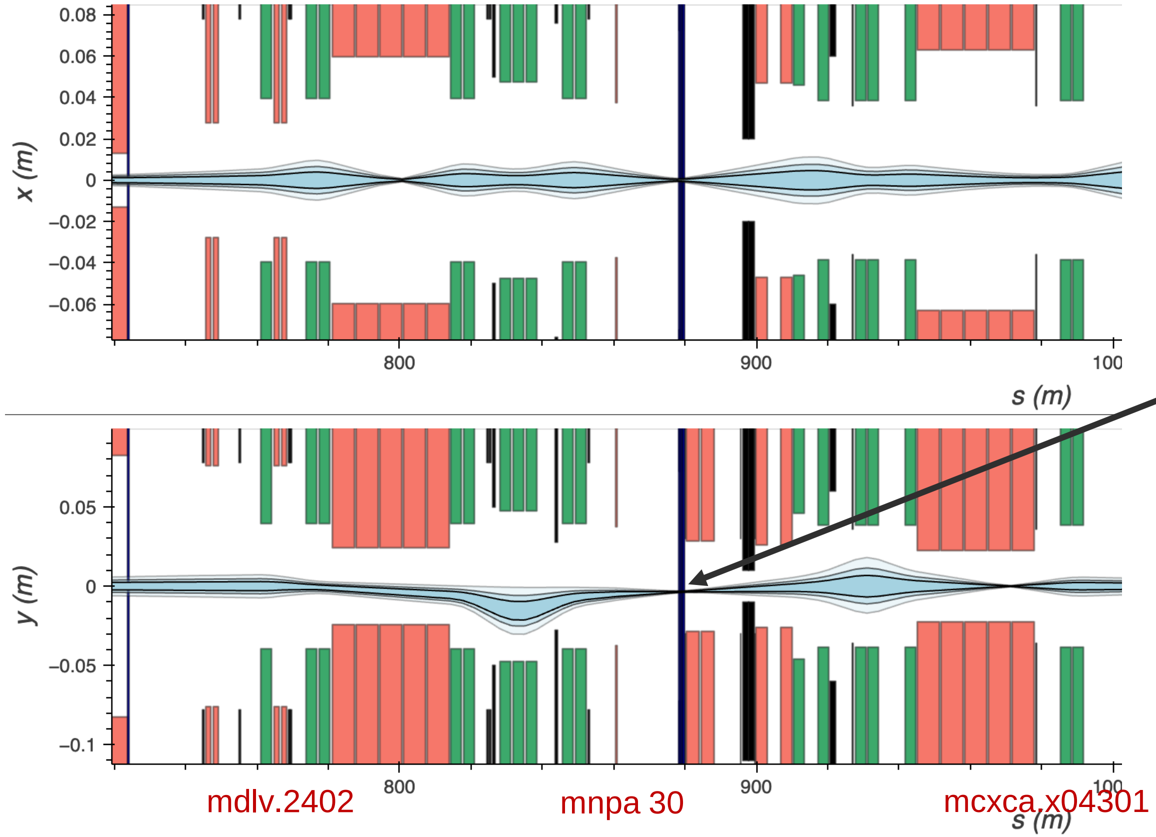


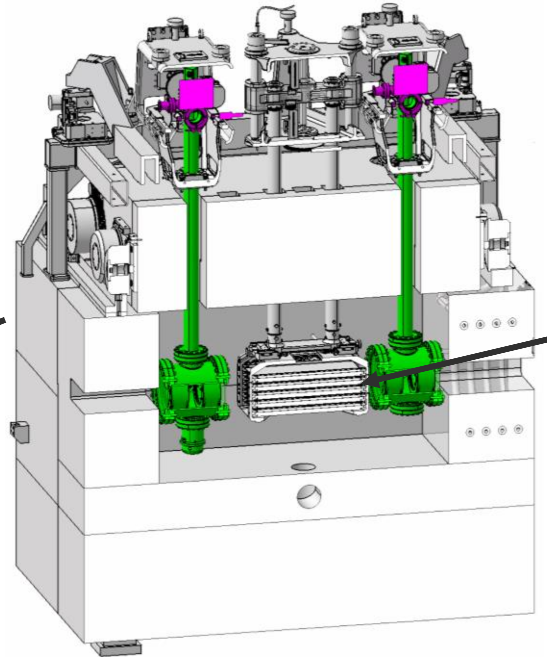


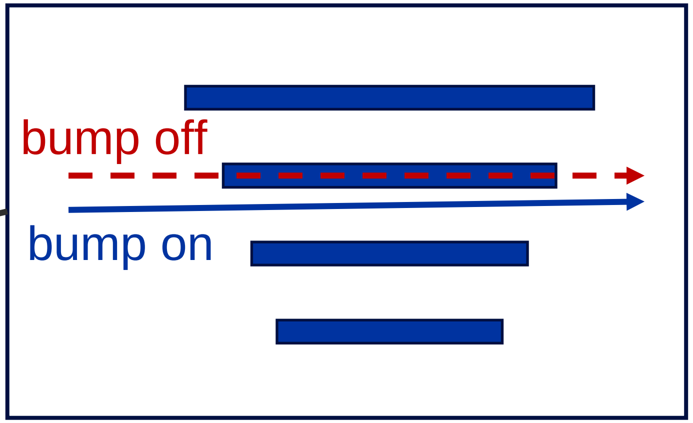
On SHARED cycle one of the sheets in T4 target is aligned with the beam orbit. In case of DEDICATED cycle, there is no need to hit T4 target, so it is proposed to bump around using mdlv.2402, mcxca.x04301 and new mnpa 30 correctors.

Modifications to equipment in TCC2 for SHiP need urgent design and specification to meet NA-CONS Phase 1 deadlines (installation in LS3), namely a simplified P42 XTAX under vacuum.

Delivery for ECN3: bumping around T4







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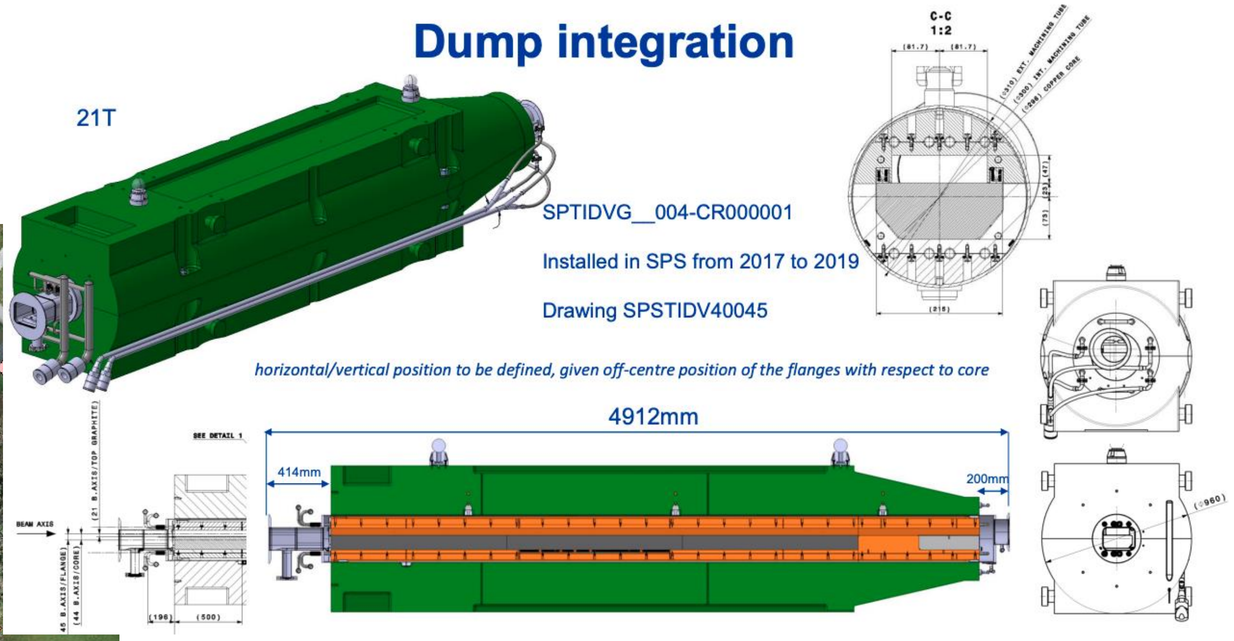
An optimized solution for SHiP and future H6/H8 operation is under urgent design.

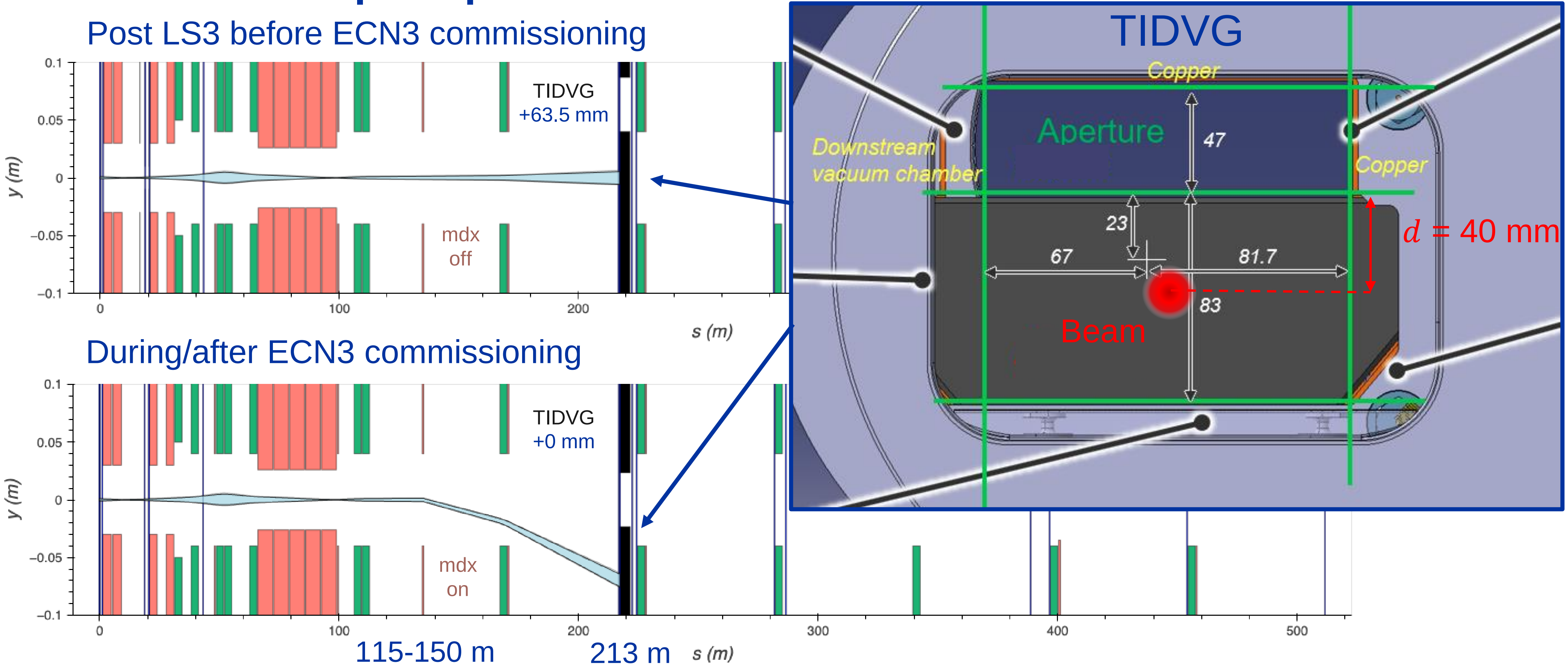
P42 beam dump: location



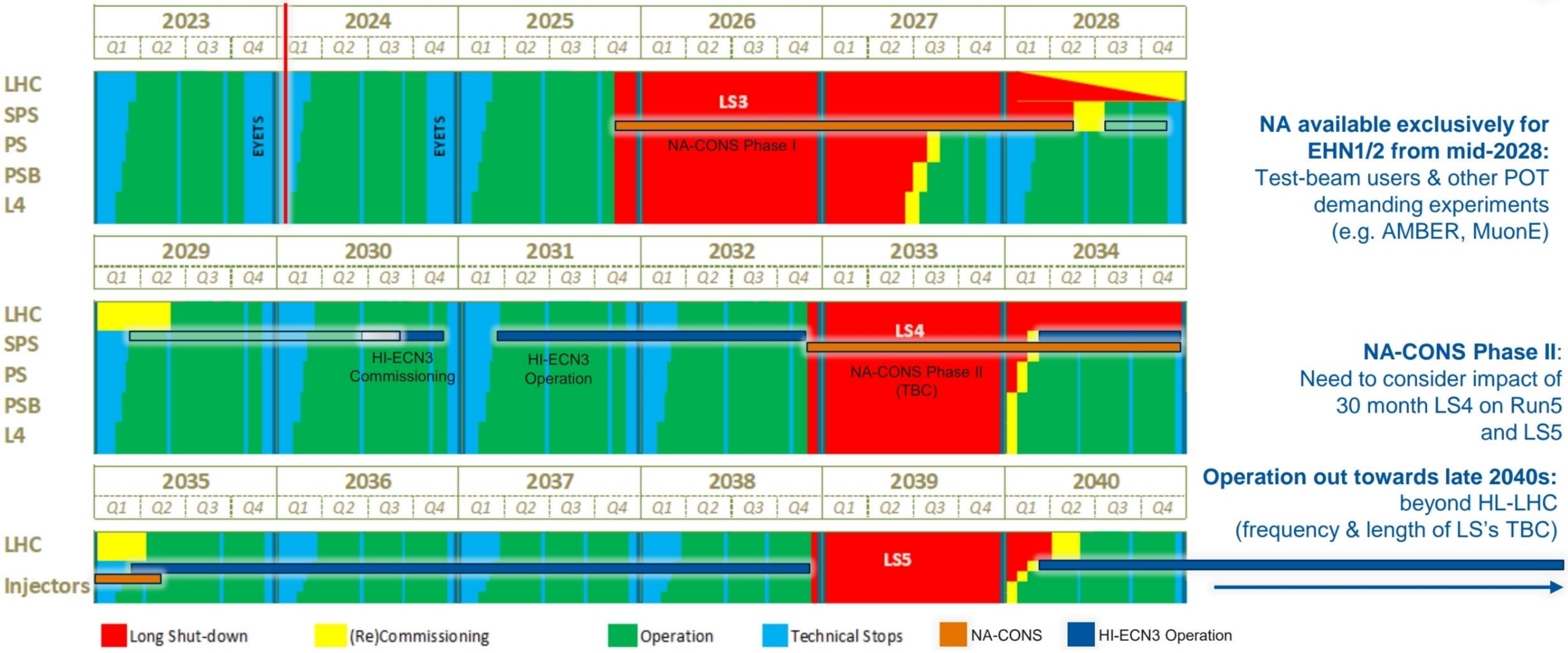
*Damien Grenier, Rui Ximenes, Maria Ornedo, ECN3 High Intensity P42 Dump

Also, it is proposed to install a new dedicated absorber in the upstream part of P42 (Absorber face is 213 m downstream T4 center). Protons on the SHARED cycle will be dumped either if (1) transmission losses in P42 are above the acceptable level or (2) the beam pose problems for the experimental user in ECN3. Protons on the DEDICATED cycle will be dumped only in case of emergency.

P42 beam dump: operation



After LS3, but before ECN3 commissioning TIDVG will be installed with a vertical offset in order to block the beam from coming to ECN3 target and keep this area safe for intervention. During and after ECN3 commissioning the dump vertical position will be lowered, so the protons are dumped only when the upstream corrector is on.

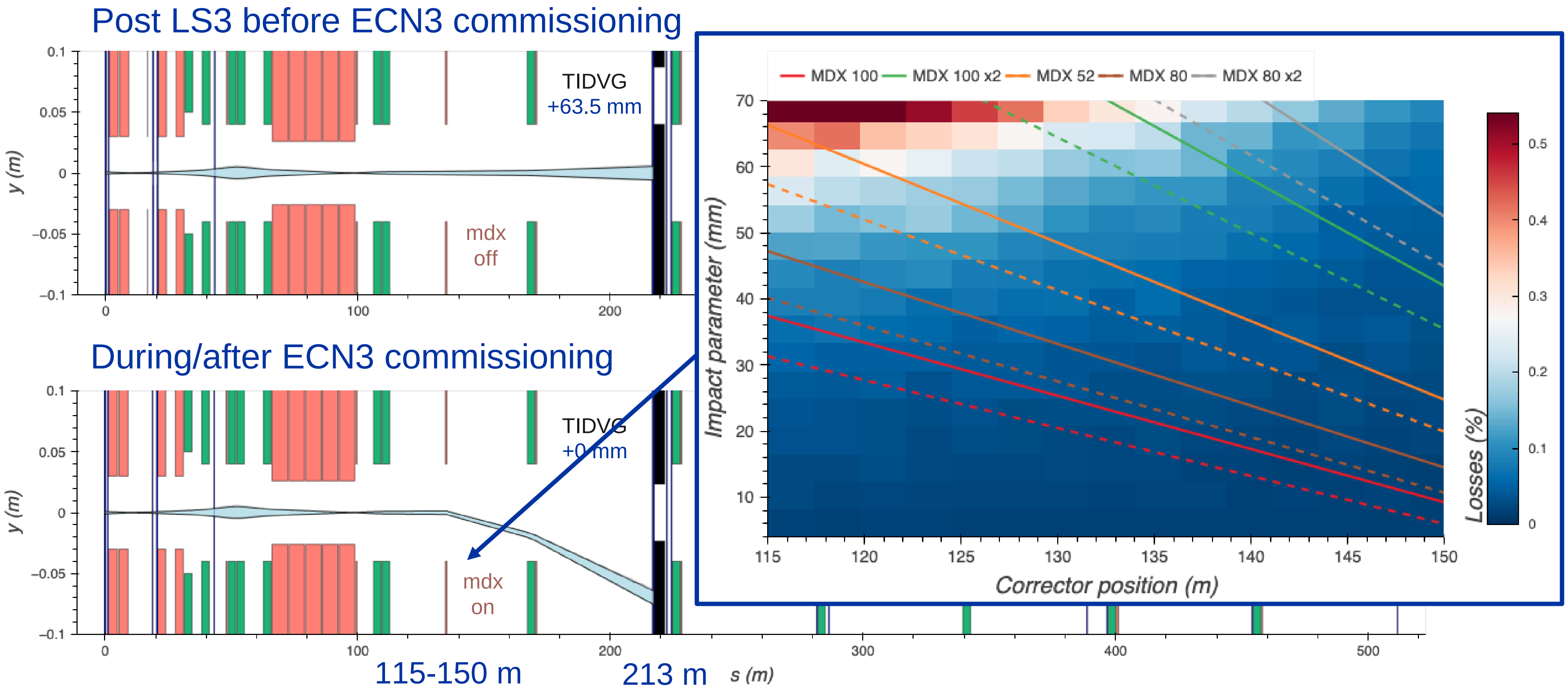


NA available exclusively for EHN1/2 from mid-2028:
Test-beam users & other POT demanding experiments (e.g. AMBER, MuonE)

NA-CONS Phase II:
Need to consider impact of 30 month LS4 on Run5 and LS5

Operation out towards late 2040s:
beyond HL-LHC
(frequency & length of LS's TBC)

P42 beam dump: required modifications

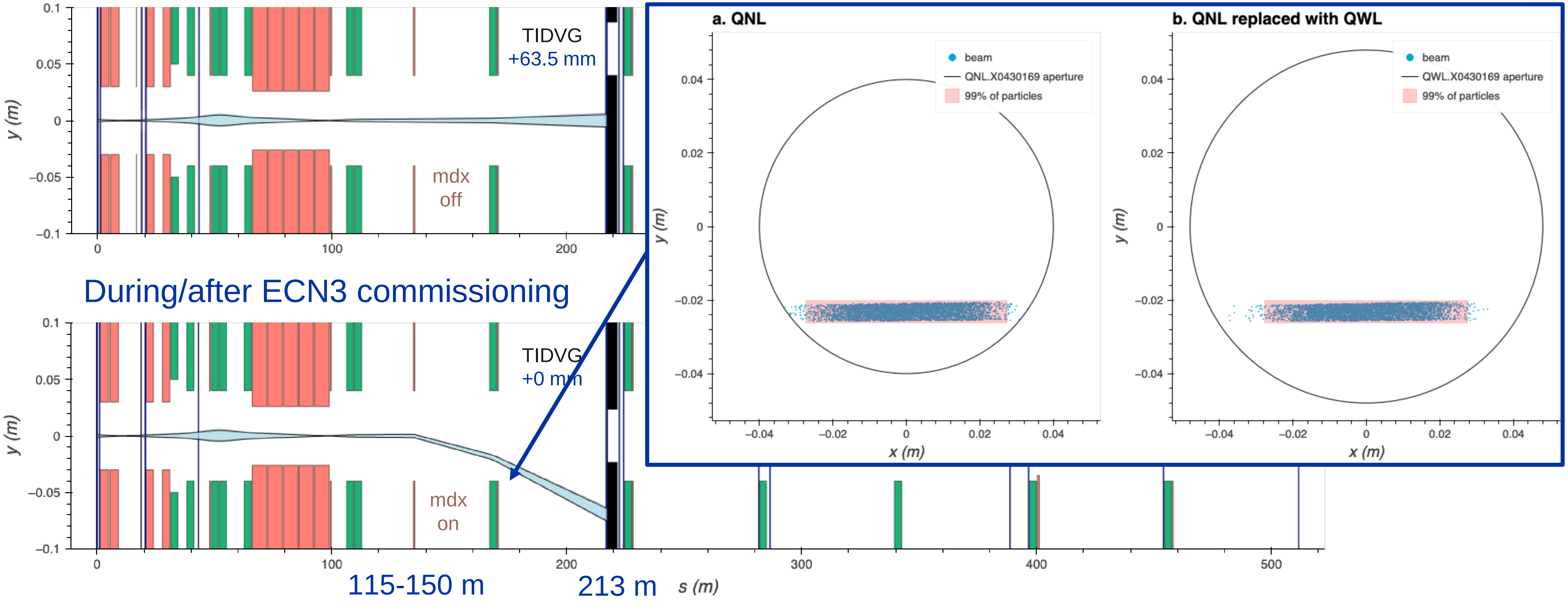


Location for the dump corrector should be chosen between 115 and 150 m downstream T4 center depending on the magnet type. Two MDX with 100 gap give enough strength to install the corrector close to downstream quadrupole and be able to dump the protons at any vertical position on the absorber face with minimal losses.

P42 beam dump: required modifications

Post LS3 before ECN3 commissioning

During/after ECN3 commissioning



QNL.X0430169 and MCXCA.X0430171 will be replaced with QWL and MCXCA having larger apertures to minimize unwanted losses and provide more flexibility in dumping angle.

Hardware

4 MDX magnets (2 per plane)

4 SIRIUS_2S (1 per magnet):

- 2S to get 1.8 kV for 4 Hz
- Fully programmable function
- 4 quadrant operation (bipolar current & voltage)
- Info from Gilles Le Godec (2018)

Drift of 100 m from dilution system to target (no optics in between)

Table 4.4: Preliminary specifications for the laminated MDX magnet design

Aperture in bending plane	140 mm
Aperture in non-bending plane	100 mm
Total length	630 mm
Maximum integrated field	0.509 T·m
Maximum current	240 A
Resistance	320 mΩ
Inductance	221 mH

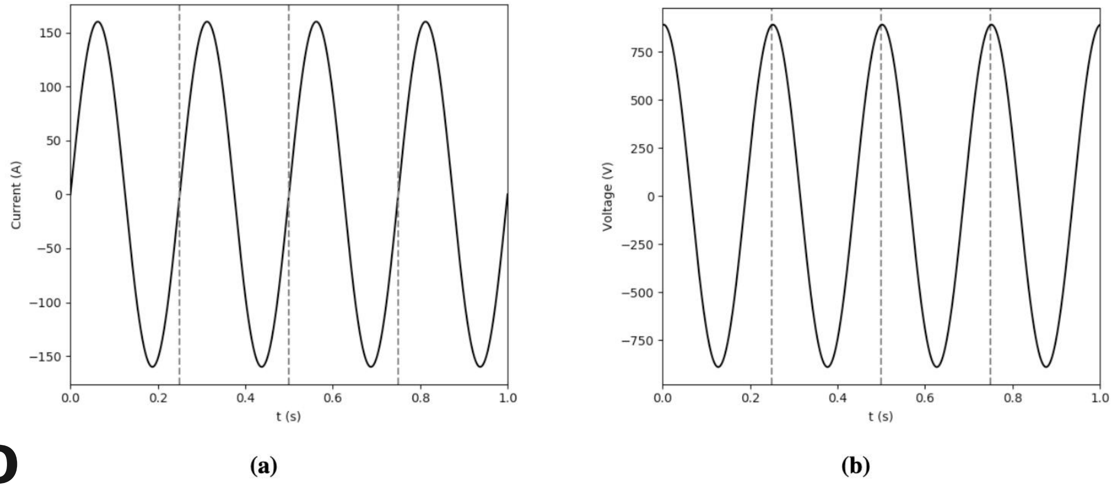


Fig. 4.7: Required current (a) and voltage (b) for the MDX magnet for the dilution system as a function of time.

Final focus and dilution system: beam instrumentation

For BDF/SHiP CDS BI considered:

- A 2D position & beam size monitoring system, screen-type, ~ 50m upstream the target for offline monitoring and images every 100 ms
- A beam current monitor
- A target beam monitoring system

To be discussed:

- Live beam position monitoring
- CCC in TCC8 or SEM device
- Do we need to look at target front-face