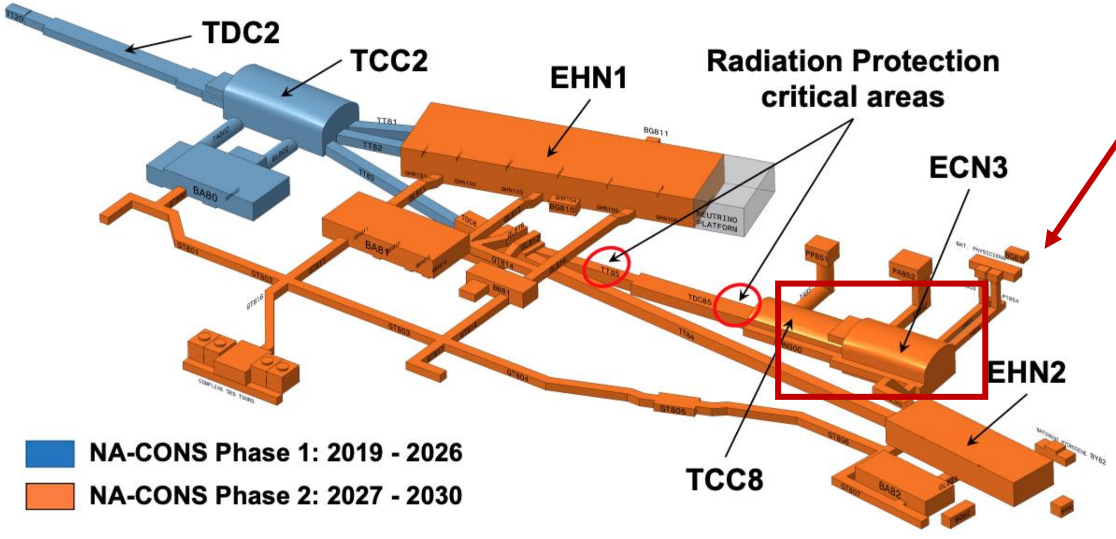
Beam delivery for HI-ECN3

Alexander Gorn on behalf of WP2 (Francesco Velotti and Laurie Nevay)

29.04.2024

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

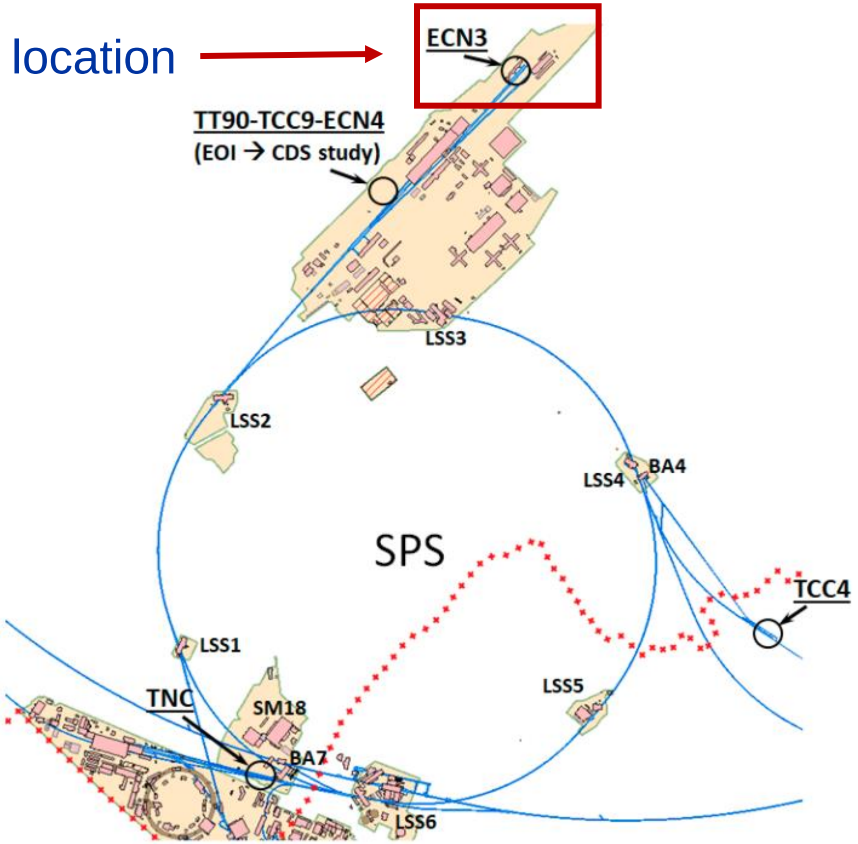
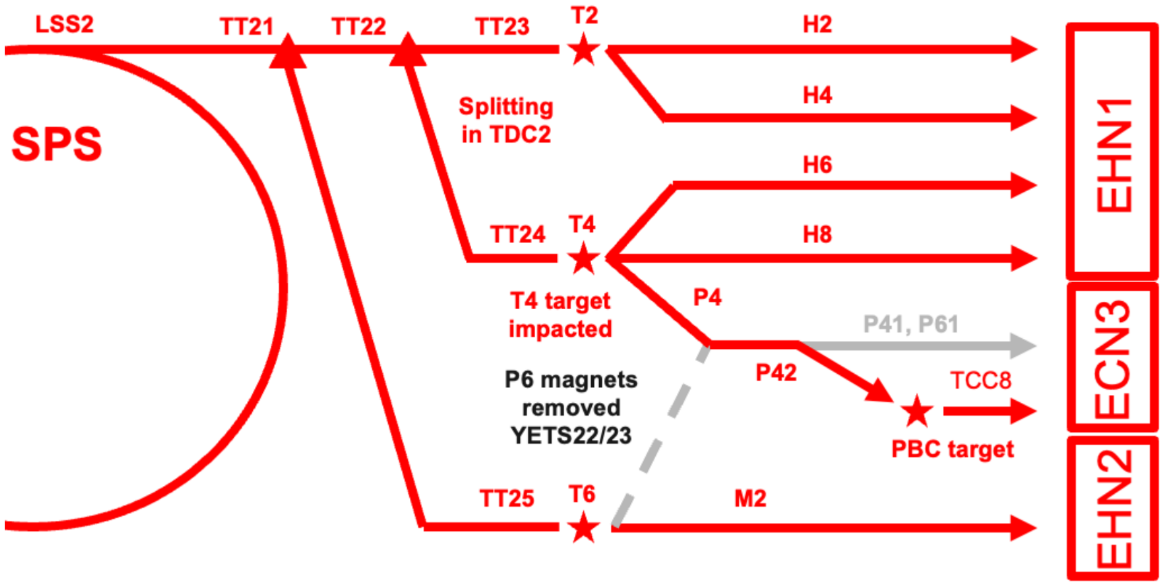


Figure 1: Overview of the locations considered for the implementation of the BDF.

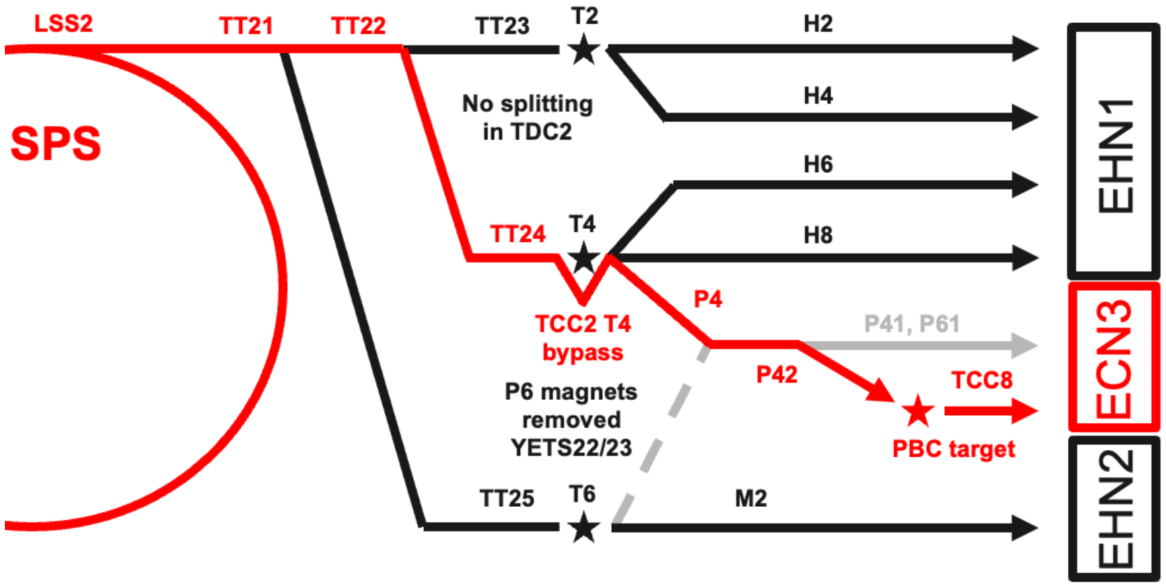
*Study of alternative locations for the SPS Beam Dump Facility

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

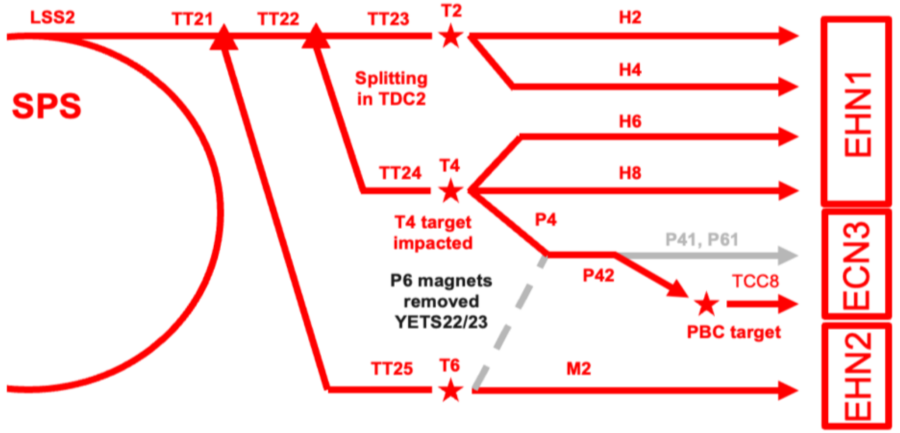
Beam delivery for ECN3 starts in SPS LSS2 with slow-extraction to TT21. Then the beam is either split at the end of TT21 and TT22 or not depending on scenario. Downstream the line it passes through the T4 target in TCC2 and P42 line until it is finally transferred to T10 target in TCC8.

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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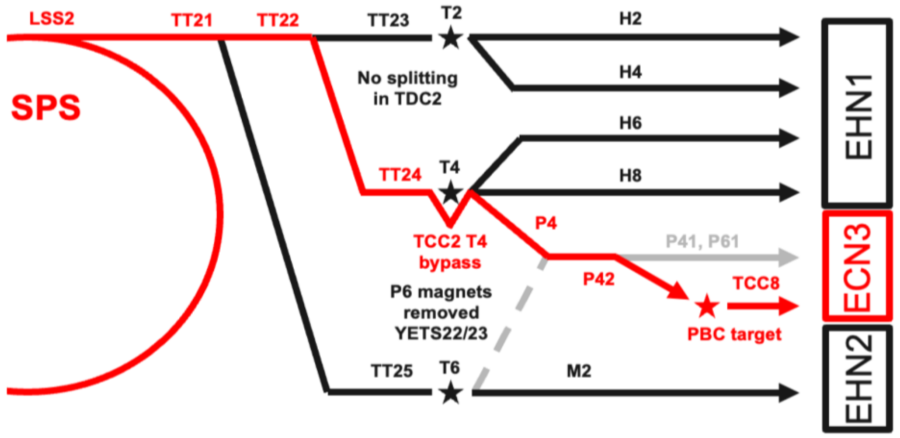
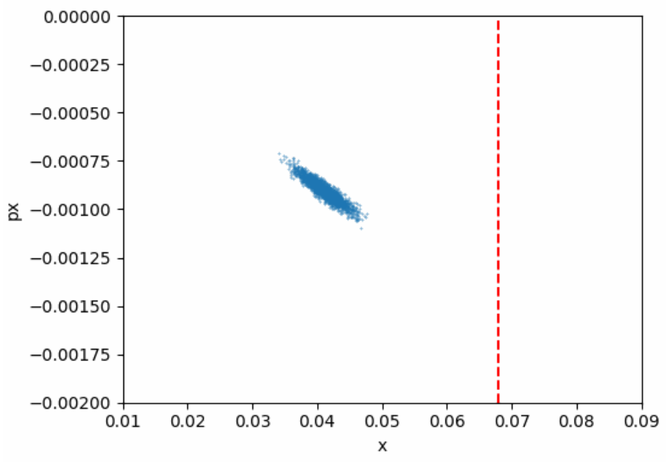


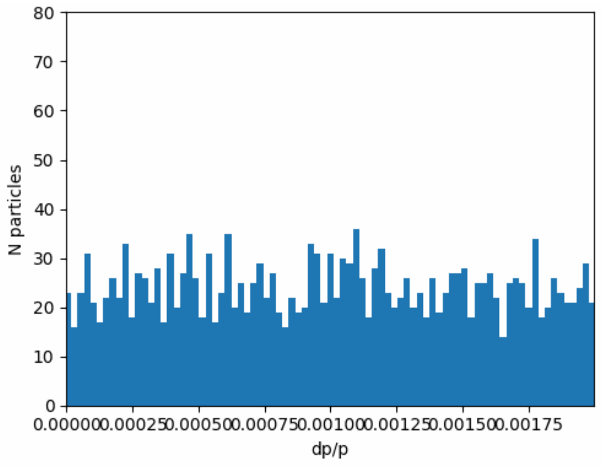
(b) Dedicated ECN3 scenario

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.

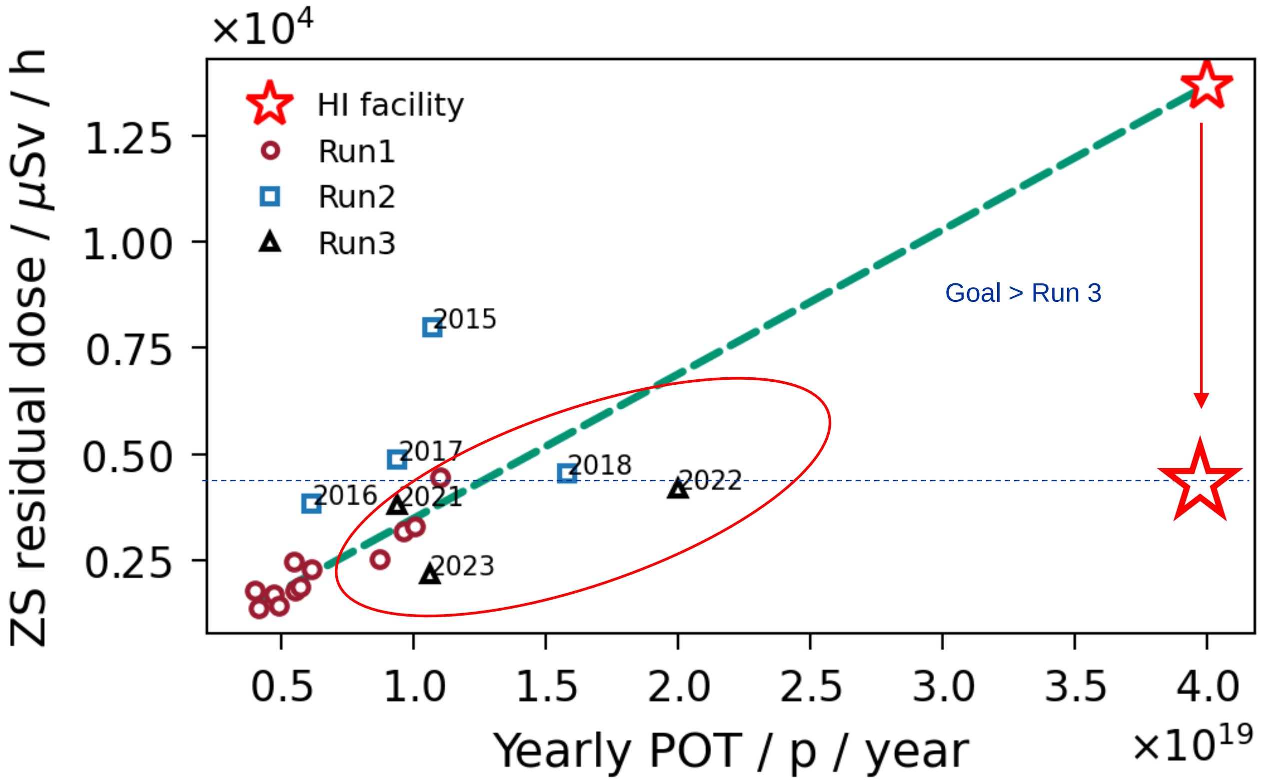
Slow extraction in LSS2: ZS activation problem

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.



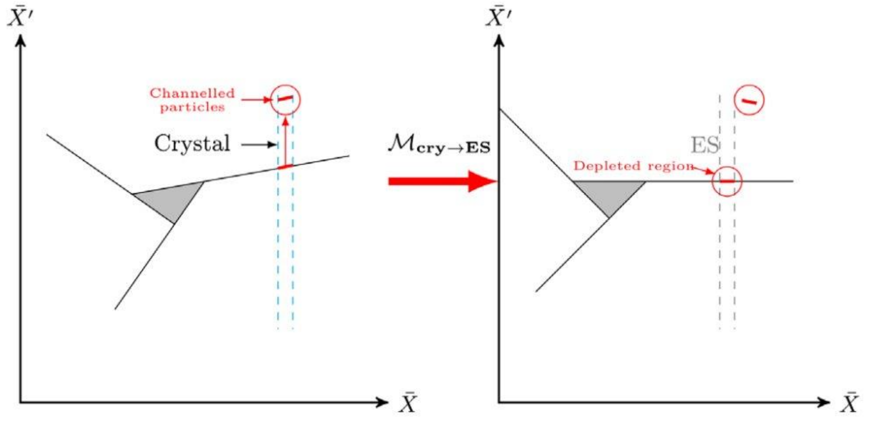
Slow extraction in LSS2: losses reduction (CS)

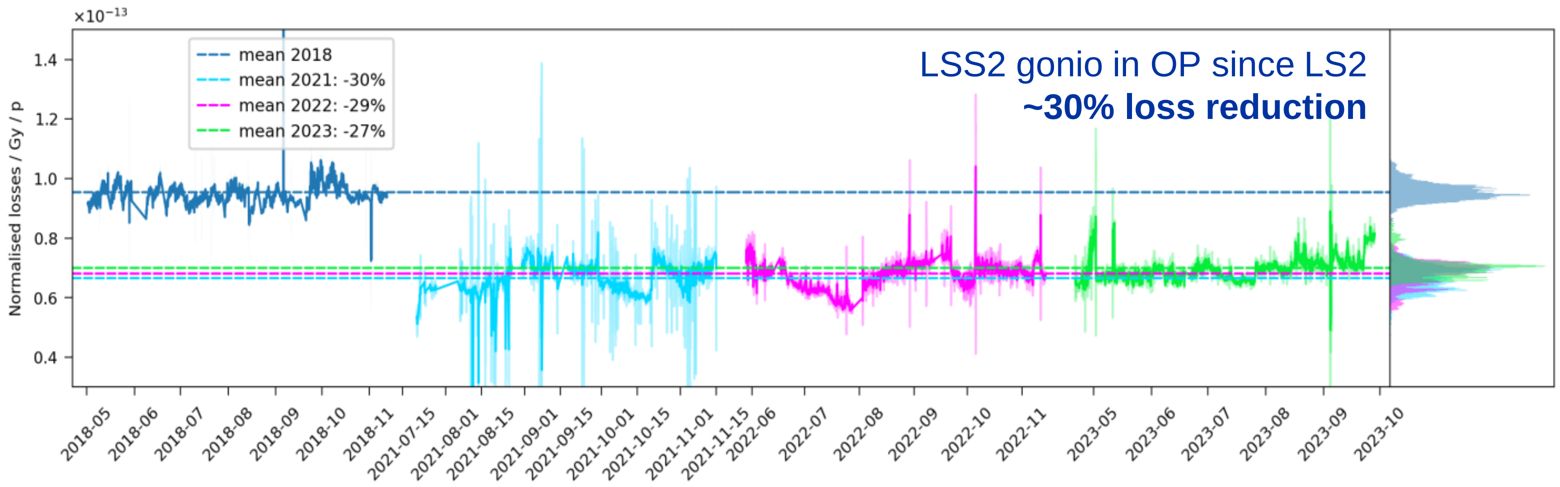
Crystal shadowing of ZS is now proven technique:

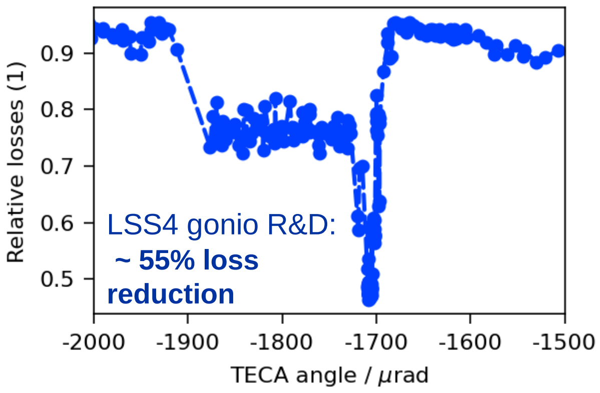
- Operational goniometer in SPS LSS2

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

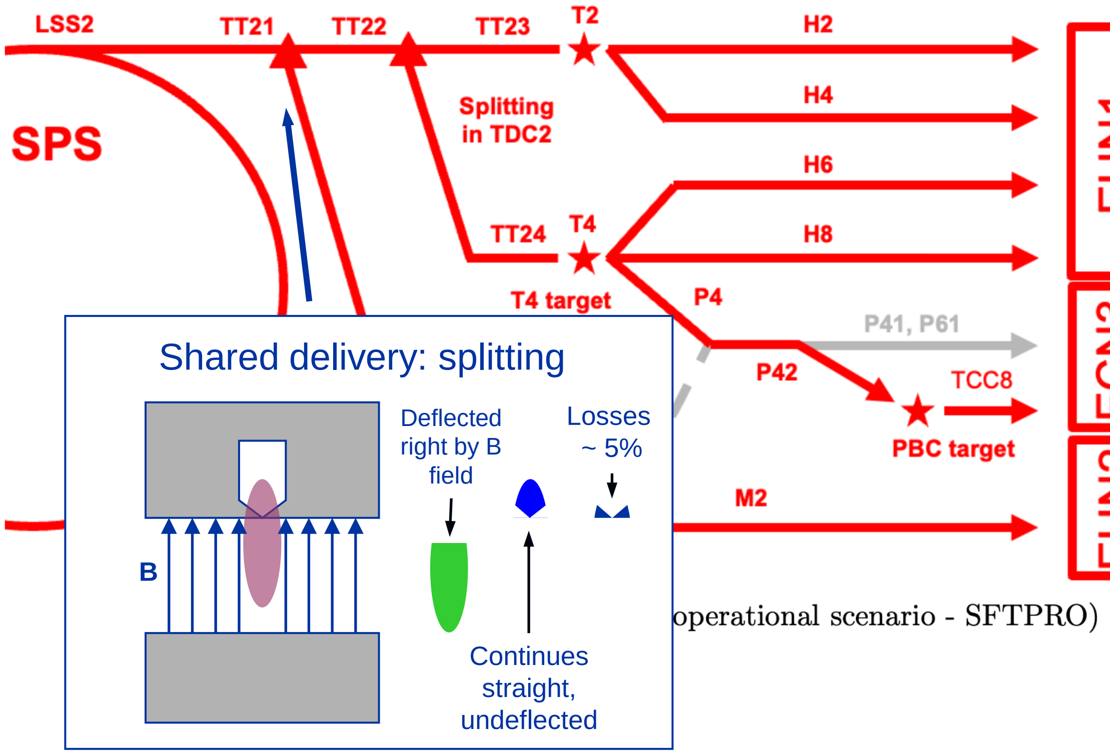
- Now: single crystal aligned in shadowing (VR) for LSS4 ~ factor 2 loss reduction
- Future: arrays of crystals aligned in volume reflection promising up to a factor 10 beam loss reduction and replacement of septa with crystals altogether

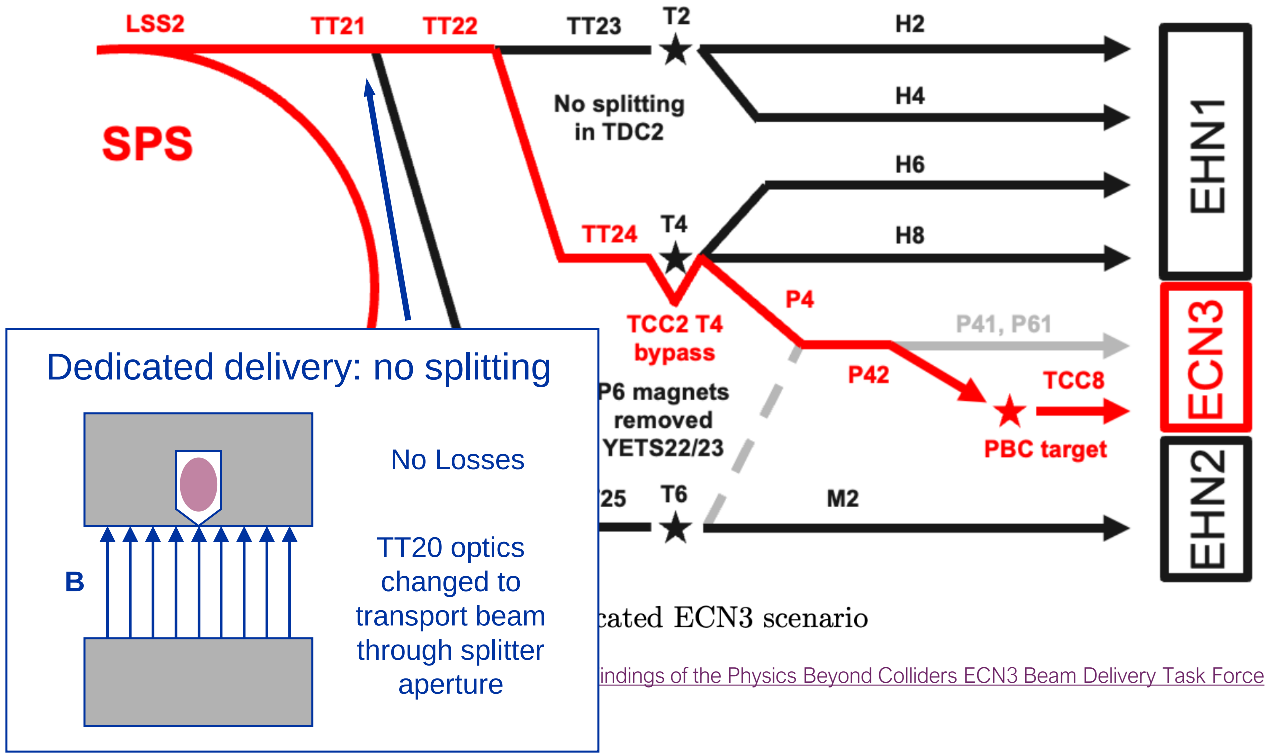






Delivery for ECN3: splitting VS dedicated





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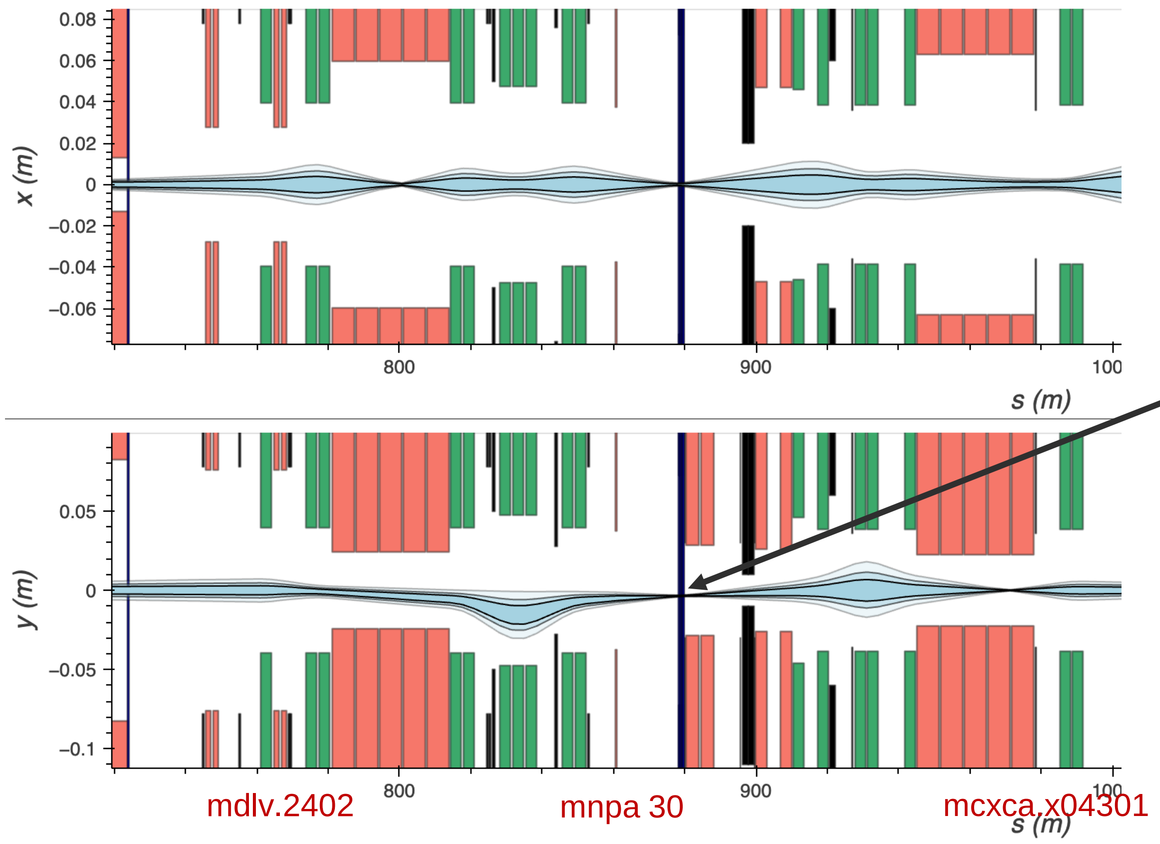
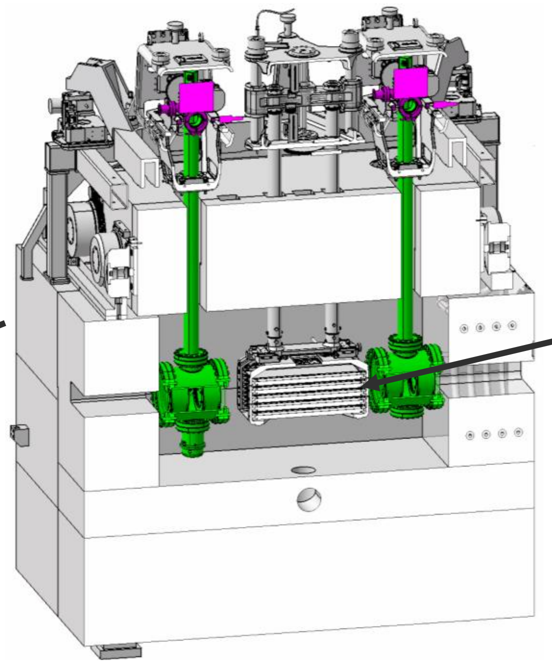
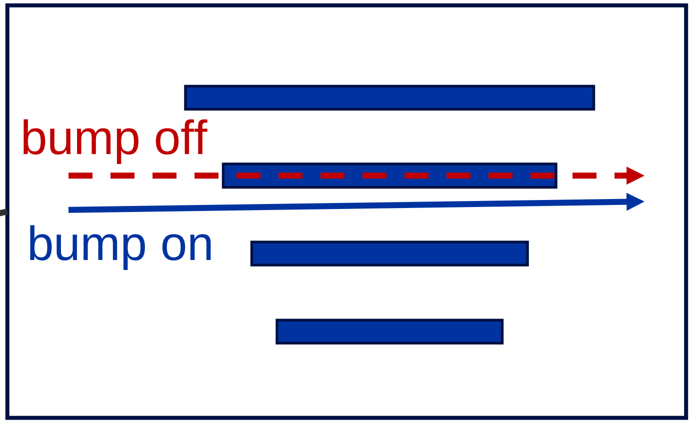
Delivery for ECN3: bumping around T4



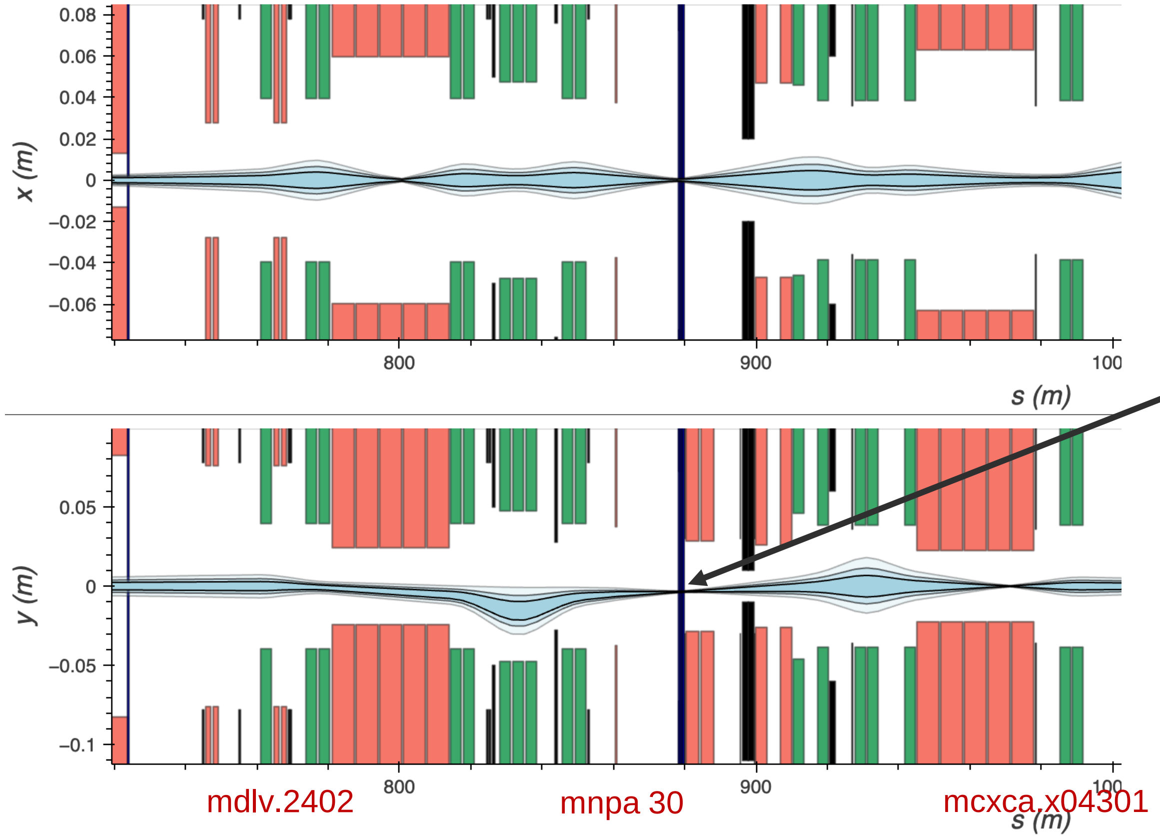


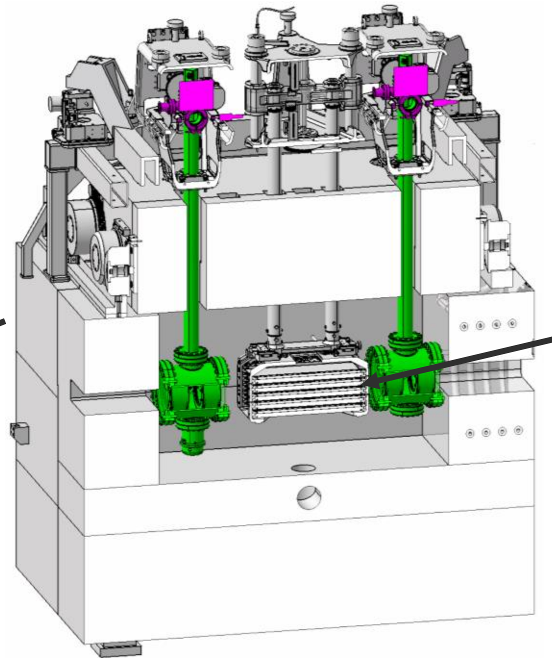


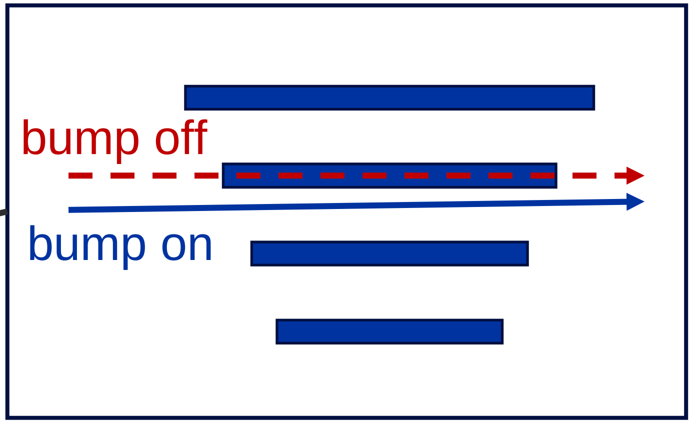
On SHARED cycle one of the sheets in T4 target is aligned with the beam orbit. In case of DEDICATED cycle, there is no need to hit T4 target, so it is proposed to bump around using mdlv.2402, mcxca.x04301 and new mnpa 30 correctors.

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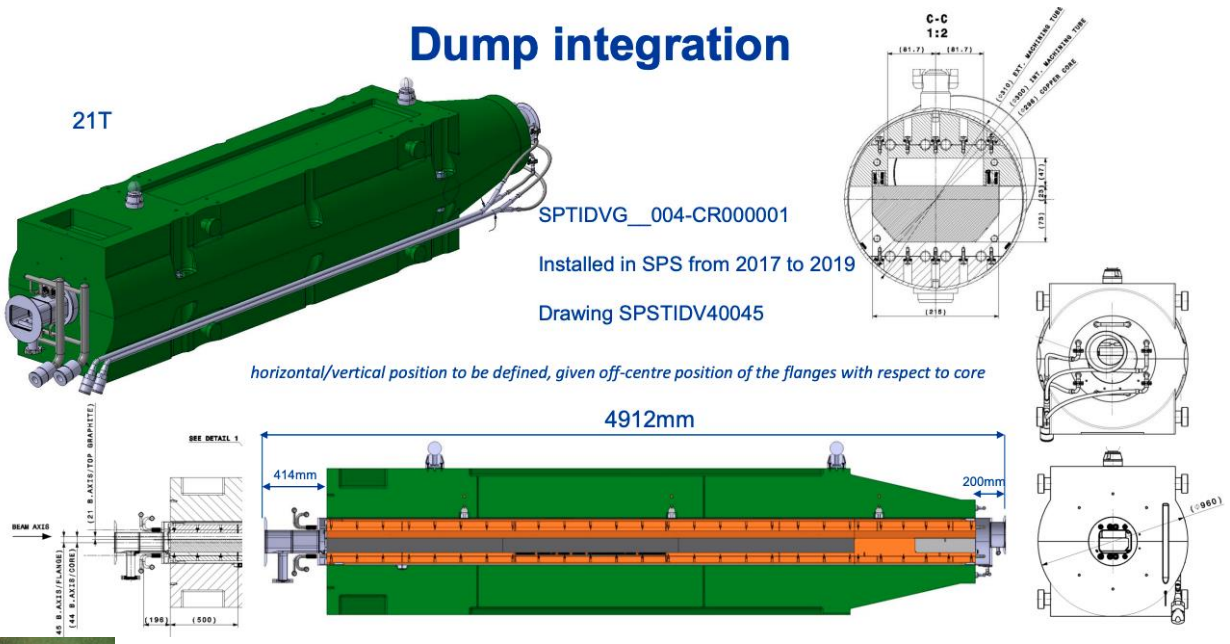
An optimized solution for SHiP and future H6/H8 operation is under urgent design.

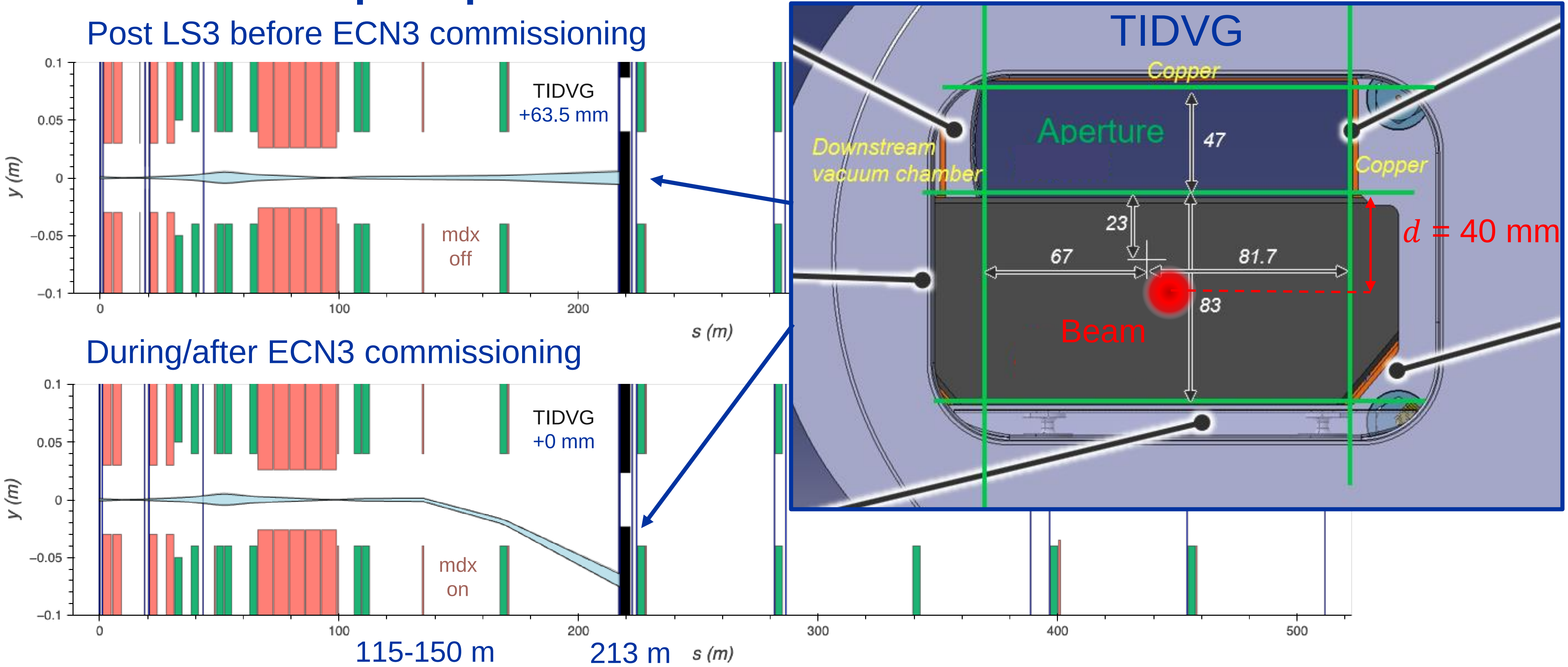
P42 beam dump: location



*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.

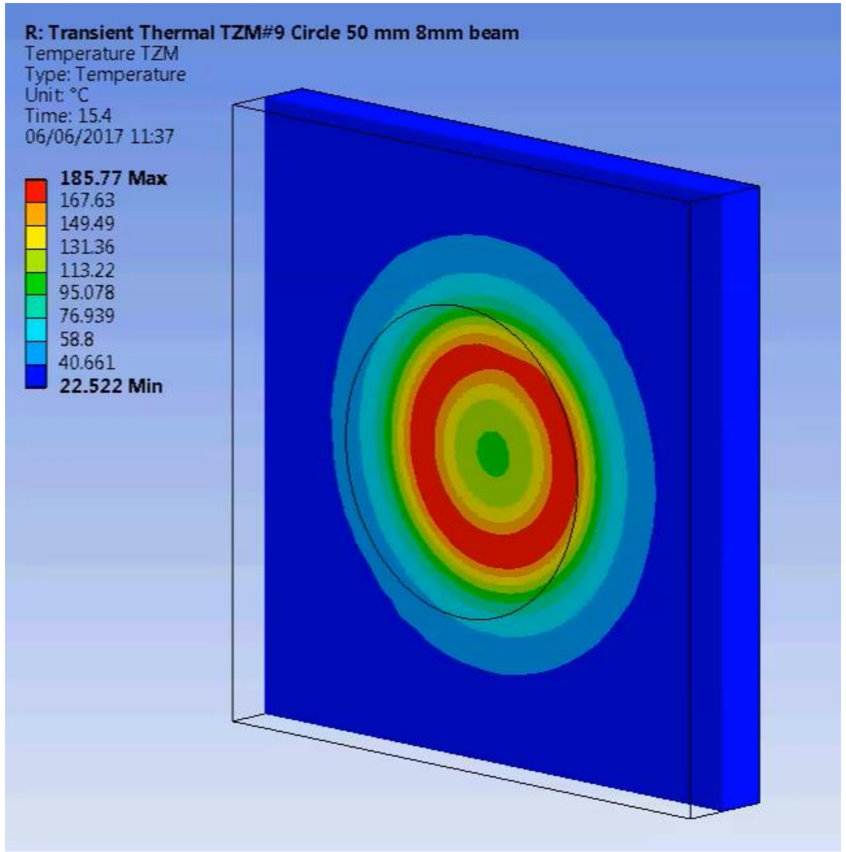
Final focus and dilution system: requirements

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

Round beam with σ = 8 mm on target and 50 mm sweep radius @ 4 Hz

About 100 m drift = 0.5 mrad

BL = 1334 Tm x 0.5 mrad = 0.67 Tm



Possible solution -
4 MDX magnets
(2 per plane)

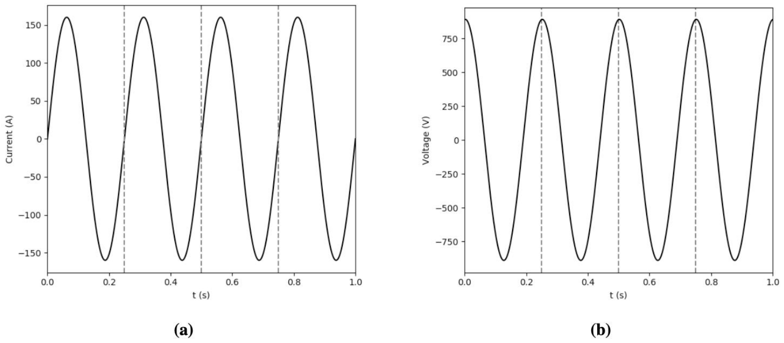


Fig. 4.7: Required current (a) and voltage (b) for the MDX magnet for the dilution system as a function of time.

Final focus and dilution system: 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

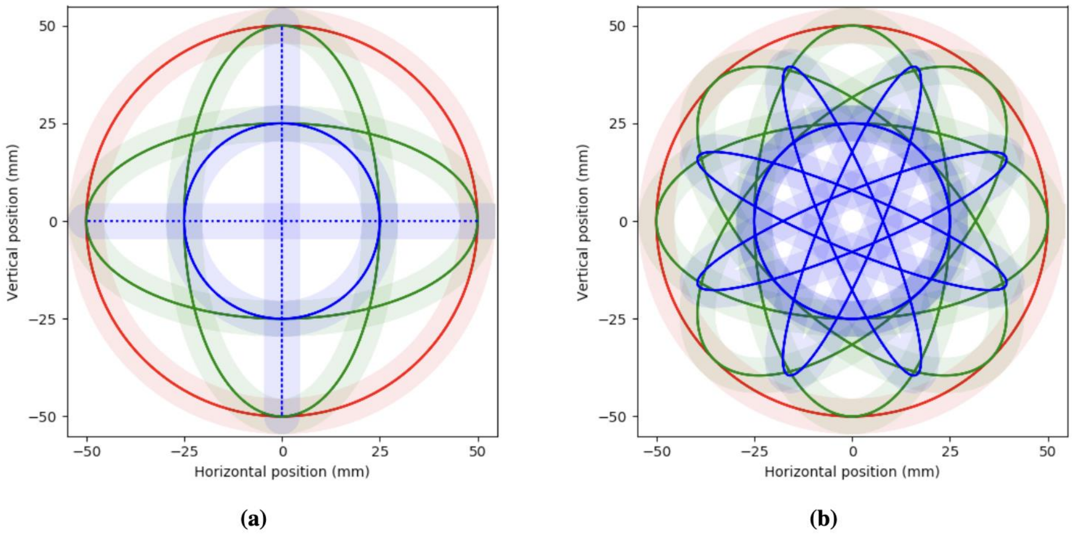


Fig. 4.8: Possible dilution patterns on the target with all four circuits (red), three circuits (green), and only two circuits (blue). Part (a) shows patterns for the $\pi/2$ scheme, while the possible patterns for the $\pi/4$ scheme are shown in (b).

Final focus and dilution system: machine protection

- Check beam dilution power converter's FGC internal check at 1kHz and direct connection to BIS
- XPOC-type of system with post-analysis of every extraction and interlocking in case of anomalies
- Instantaneous beam losses (rate) with suitable placed BLM
- Additional hardware system based on analogic signal could be considered, e.g. live monitoring of BTV or target instrumentation

We need to converge on an acceptable interlocking and machine protection approach to protect target

Timeline

BDF/SHiP at HI-ECN3 - Indicative Schedule & Constraints									
Machine/Facility/Experiments	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**
LHC				LS3			Commissioning		
SPS				LS3					
NA-CONS	Preparation & YETS Implementation Phase			NA-CONS Phase 1 (LS3)					
HI-ECN3 Beam Delivery via NA-CONS	Engineering & Implementation Phase			Installation (LS3)		Commissioning			
BDF Target Complex in TCC8	Engineering Design Phase			Final Opt. & PRR	Preparation, Dismantling	Procurement / Assembly	Procurement/ Installation	Installation/ Commissioning	
SHiP Experiment in ECN3	Proposal	TDR	TDR	TDR/PRR	Production	Construction	Installation/Commissioning		

- **Critical deadlines for input to NA-CONS already impending in 2024:** P42 XTAX design choice
- TDR ready by mid-2025
- P42 dump – To be installed with offset before the end of LS3 to allow commissioning of TCC2 in 2028
- P42 dump to be realigned in 2029 or 2030 – to transfer beam to ECN3
- 2029/30 installation and commissioning of dilution system and target station

Summary and future plans

SPS extraction:

- Improvements in losses main topics for extraction ➔ currently can do x2 reduction ➔ aim for x4!
- Different solutions under investigations

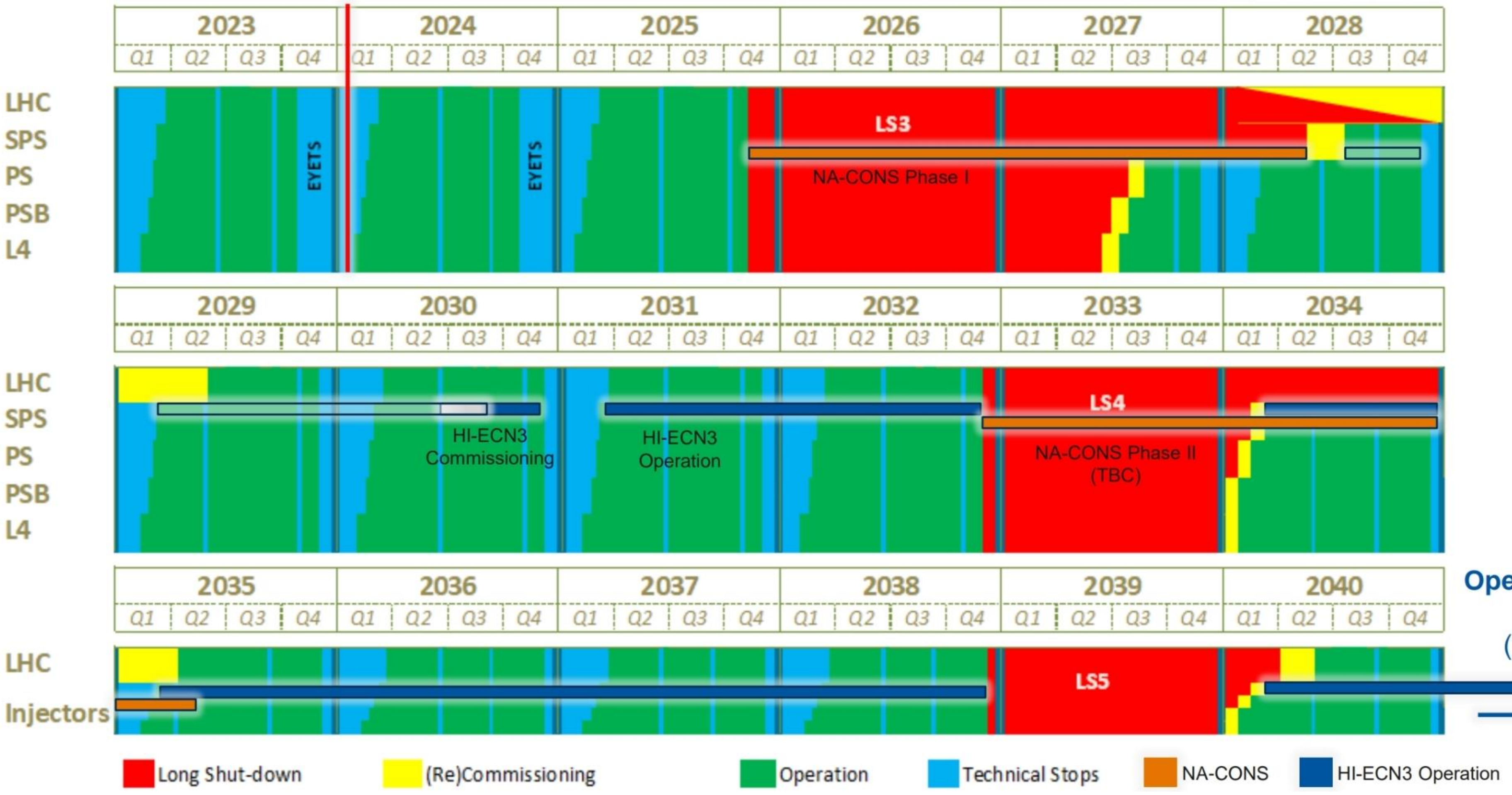
North area TL upgrades:

- Optics is rematched for DEDICATED cycle, optimization for SHARED cycle is ongoing
- Splitting optimization
- Minimization of losses in TCC2 (Bumping around T4 target, wobbling system and XTAX modifications)

Dilution system and final focus:

- Summarizing requirements in a FS with input needed from the target requirements (WP3)
- Interlock system will take this into account too

Thanks for your attention!



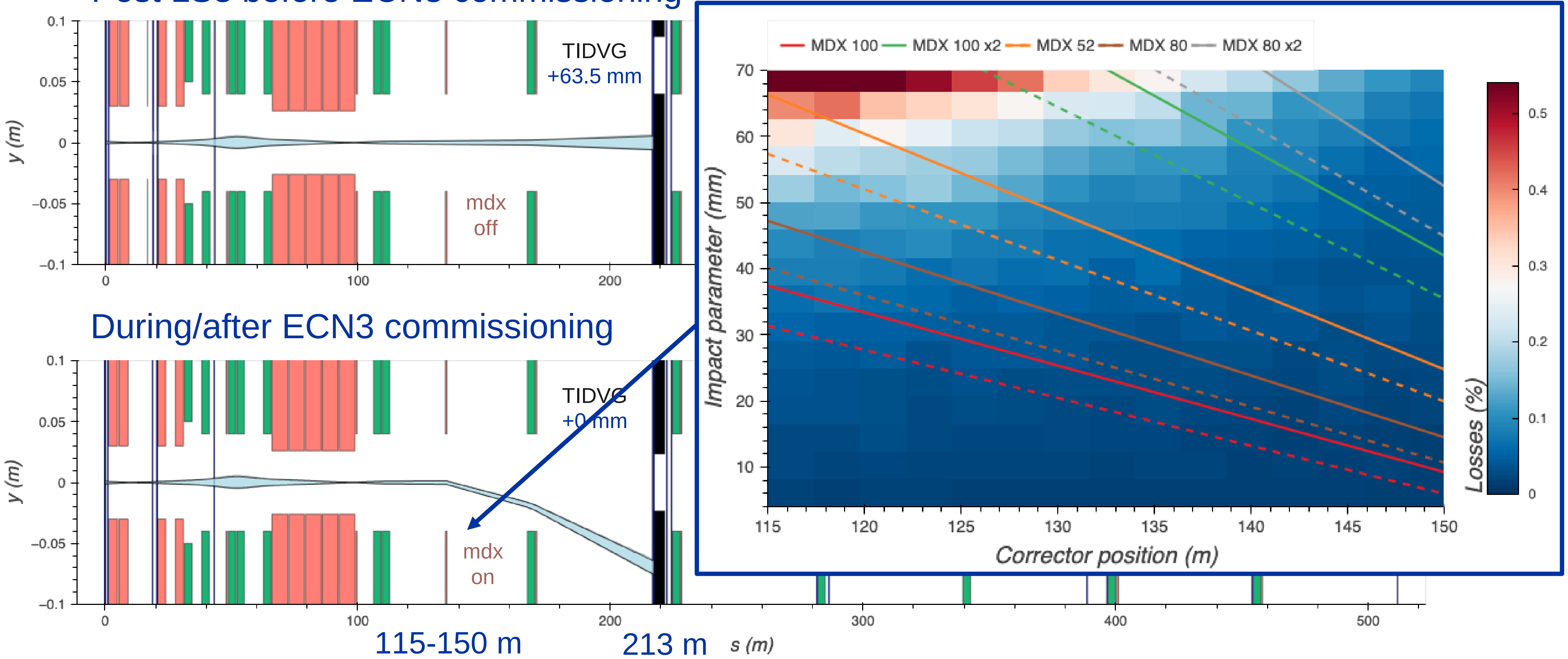
NA available exclusively for EHN1/2 from mid-2028:
Test-beam users & other POT demanding experiments (e.g. AMBER, MuonE)

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

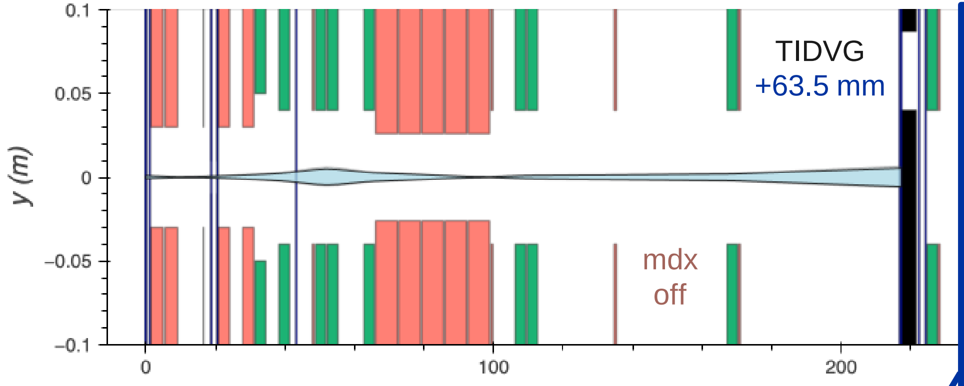
Post LS3 before ECN3 commissioning



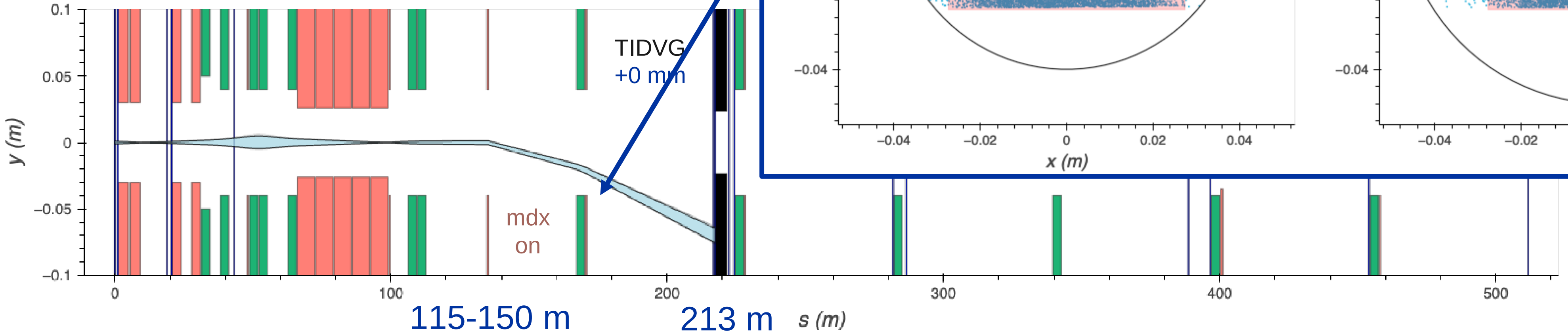
Location for the dump corrector should be chosen between 115 and 150 m downstream T4 center depending on the magnet type. Two MDX with 100 gap give enough strength to install the corrector close to downstream quadrupole and be able to dump the protons at any vertical position on the absorber face with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

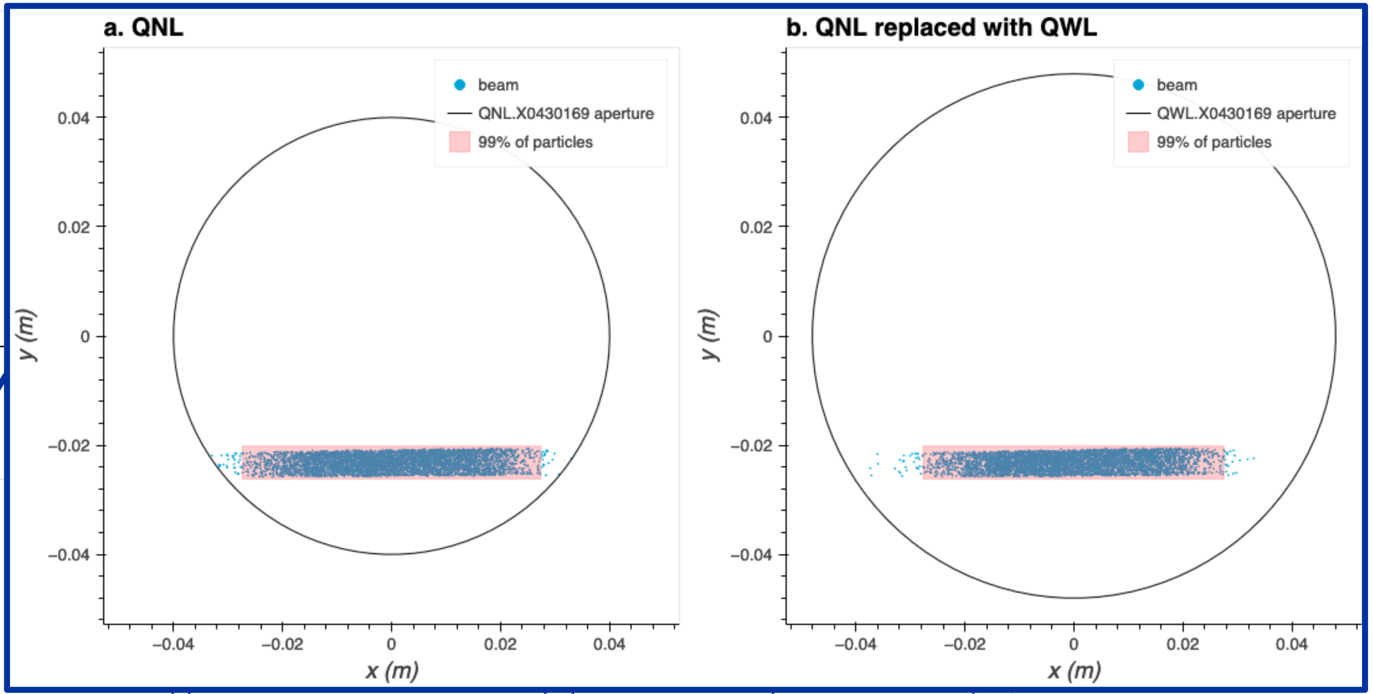
P42 beam dump: required modifications

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

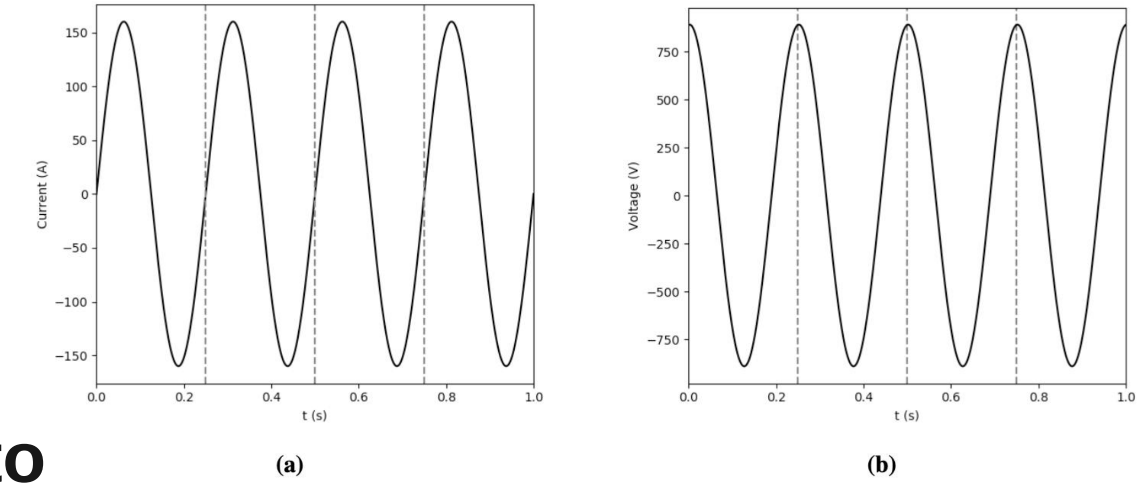


Fig. 4.7: Required current (a) and voltage (b) for the MDX magnet for the dilution system as a function of time.

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