CERN

High Intensity ECN3 (HI-ECN3) Project:
SPS Beam Dump Facility

M. Fraser (SY-ABT-BTP) presenting on behalf of the HI-ECN3 Project Team

214th TE-TM meeting, CERN, Geneva, Switzerland

4th November 2024

Beam Dump Facility (BDF) / SHiP

Direct search for Feebly Interacting Particles (FIPs) at a new **Beam Dump Facility to be installed in ECN3** to exploit 4×10^{19} protons (400 GeV/c) per year for 6×10^{20} POT over 15 years to overcome the small cross-section of ultra-rare events:

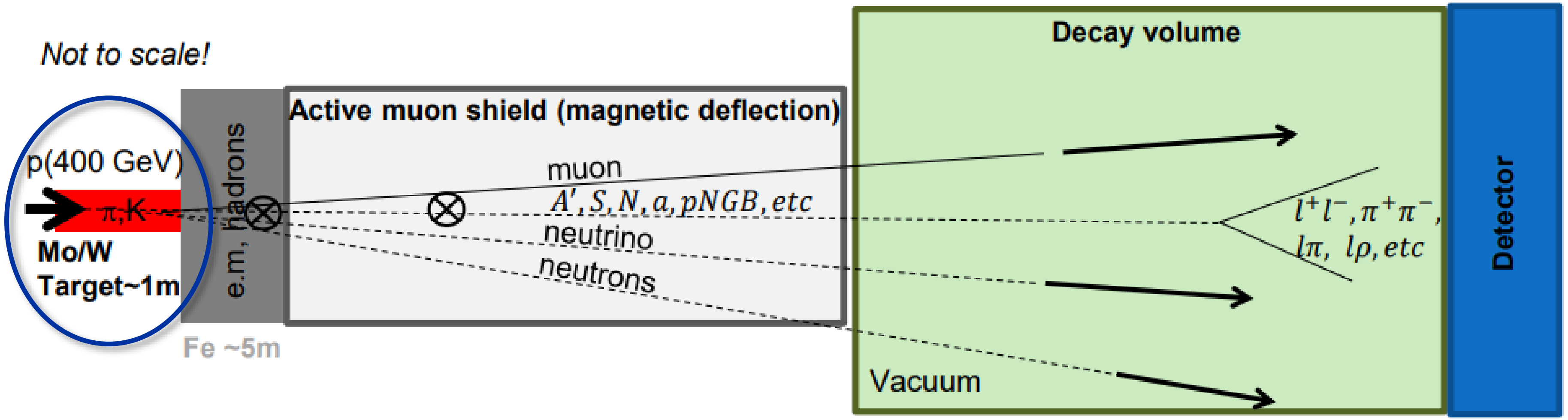
- SHiP Physics Proposal: Rep. Prog. Phys. 79 (2016) 124201 published 2016
- SPS Beam Dump Facility Comprehensive Design Study: CERN-2020-002 published 2020

High energy → production of charmed and beauty mesons

High ppp & POT → overcome small production cross-section of rare events of hidden particles

High ρ, Z & A → maximize p$^+$ interaction

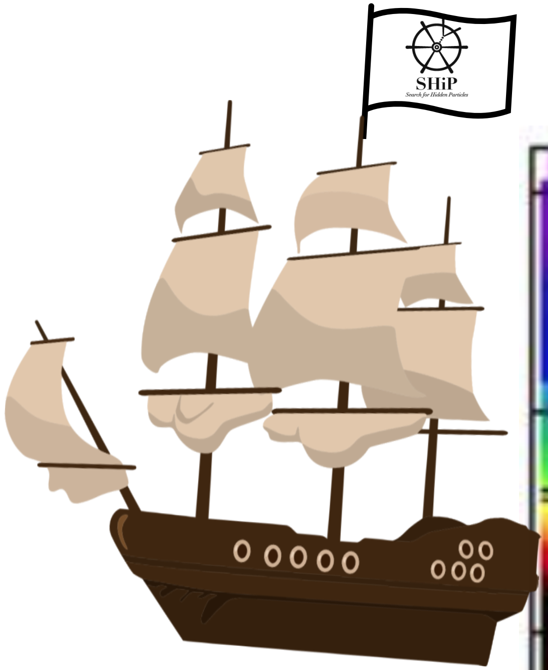
Shortest λ → force absorption of K & π to reduce muon & neutrino background

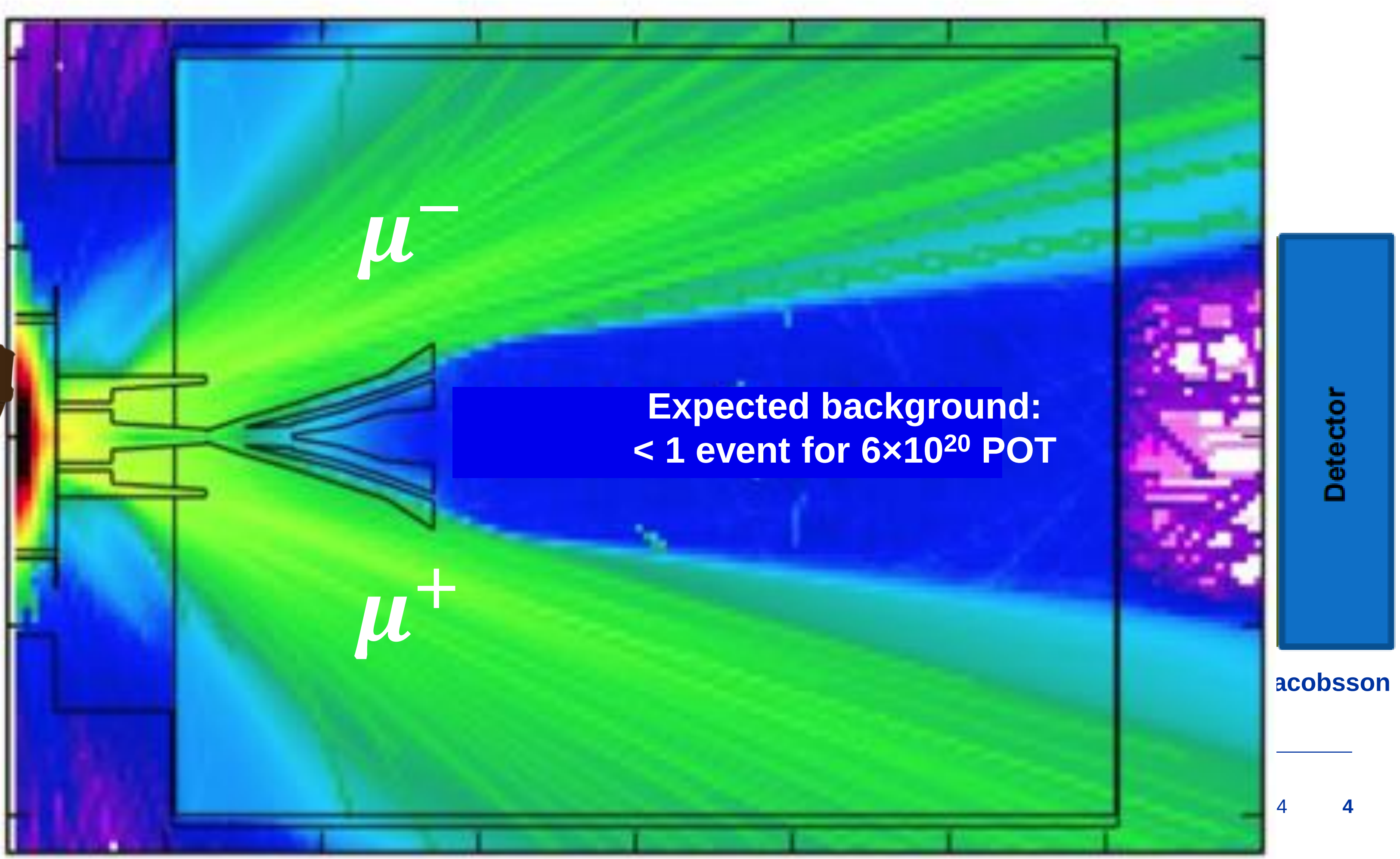


R. Jacobsson

SHiP's bow wave is made of μ & $\overline{\mu}$ …

Richard will discuss the SHiP magnet systems in detail





acobsson

Study Project → Approved Project

Upgrade of beam intensity at North Area and SHiP beam-dump (BDF/SHiP) experiment approved recently…

… with ~ 62 MCHF (over 7 years) reserved for the High Intensity upgrade of ECN3 (HI-ECN3) project in CERN's Medium-Term Plan ratified by CERN Council in June 2024.

Approved together with ~ 170 MCHF for consolidation of the North Area (NA-CONS project)

The HI-ECN3 project is a part of CERN's…

"…broad diverse scientific programme, complementary to the collider and carried out mainly at the injectors: continuously upgraded and expanded (e.g. recently the ECN3 beam intensity upgrade at the North Area)."

Fabiola Gianotti

For more information on the competitive ECN3 decision process:

- **C. Ahdida** *et al.*, *Findings of the Physics Beyond Colliders ECN3 Beam Delivery Task Force*, **CERN-PBC-REPORT-2023-001**
- **G. Arduini, C. Vallée, J. Jaeckel** (eds.) *Post-LS3 Experimental Options in ECN3*, **CERN-PBC-REPORT-2023-003**

HI-ECN3 Project Structure

Experiment Project Leader: Richard JACOBSSON
SHiP Experiment Safety Correspondent: Letizia DI GIULIO

TE in SHiP Collaboration
- **TE-MSC:** SHiP spectrometer magnet

PL: Matthew FRASER
DPL: Claudia AHDIDA

WP1
Project Management

TE in WP2
- **TE-MSC:** TCC2 magnets / BDF dilution system
- **TE-MPE:** Machine protection

WP2
Beam Extraction, Transfer & Delivery
Francesco VELOTTI & Laurie NEVAY

WP8
Radiation Field & R2E/R2M Effects
Luigi ESPOSITO

TE in WP3
- **TE-MPE:** Machine protection

WP3
Target & Beam Intercepting Devices
Rui FRANQUEIRA XIMENES

HI-ECN3

WP7
Infrastructure, Services & Civil Engineering
Fernando PEDROSA

TE in WP4
- **TE-MSC:** Magnetised hadron stopper

WP4
Target Complex
Jean-Louis GRENARD

TE in WP5
- **TE-CRG:** Dismantling NA62 LKr calorimeter / cooling of SHiP muon shield

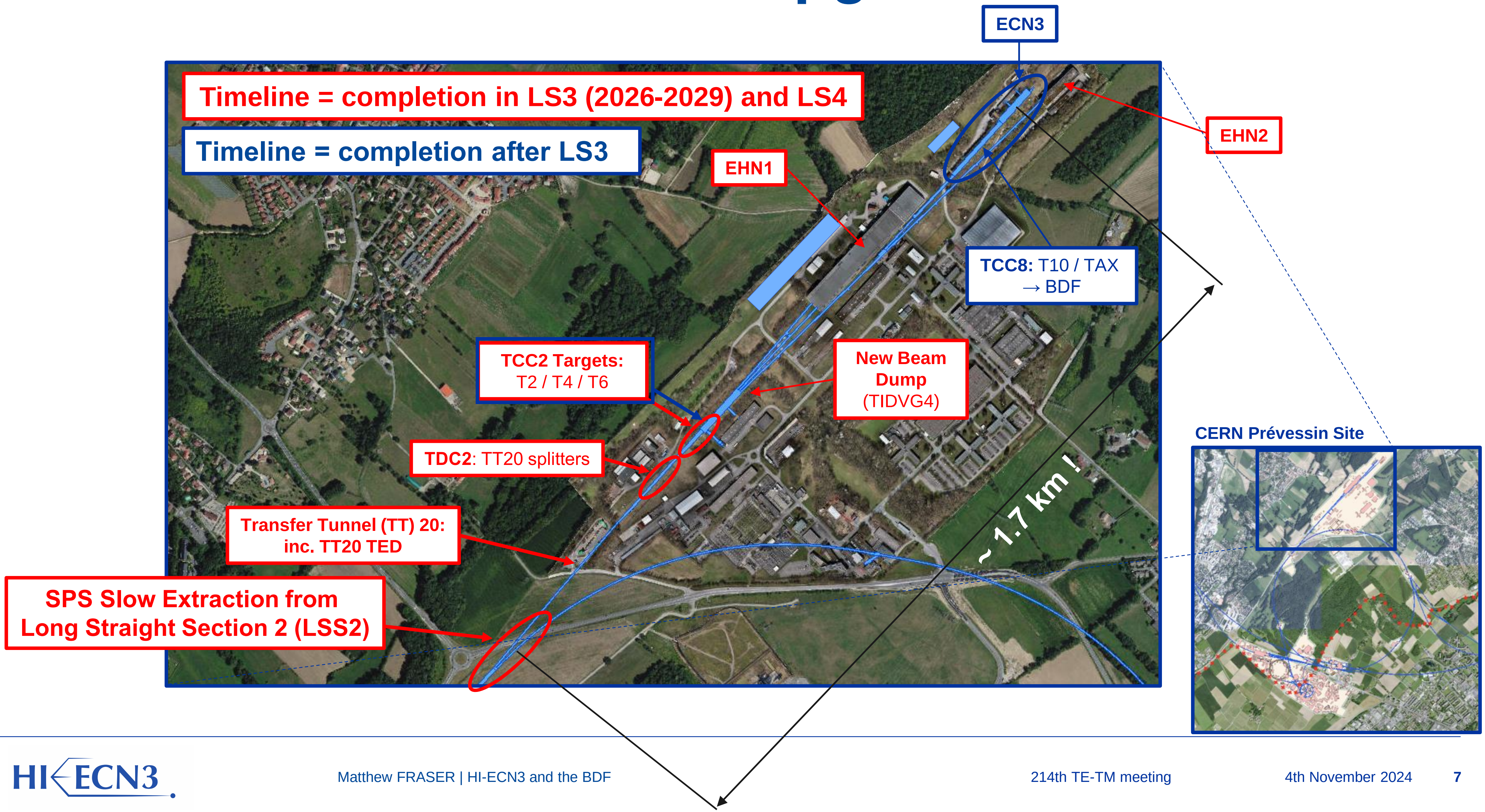
WP6
Radiation Protection & Safety
Claudia AHIDIDA
Project Safety Officer (PSO): Melania AVERNA
Project & Experiment Safety Support (PESS) Correspondent: Jamie CURRIE

WP5
Experimental Area, Interface & Integration
Francois BUTIN

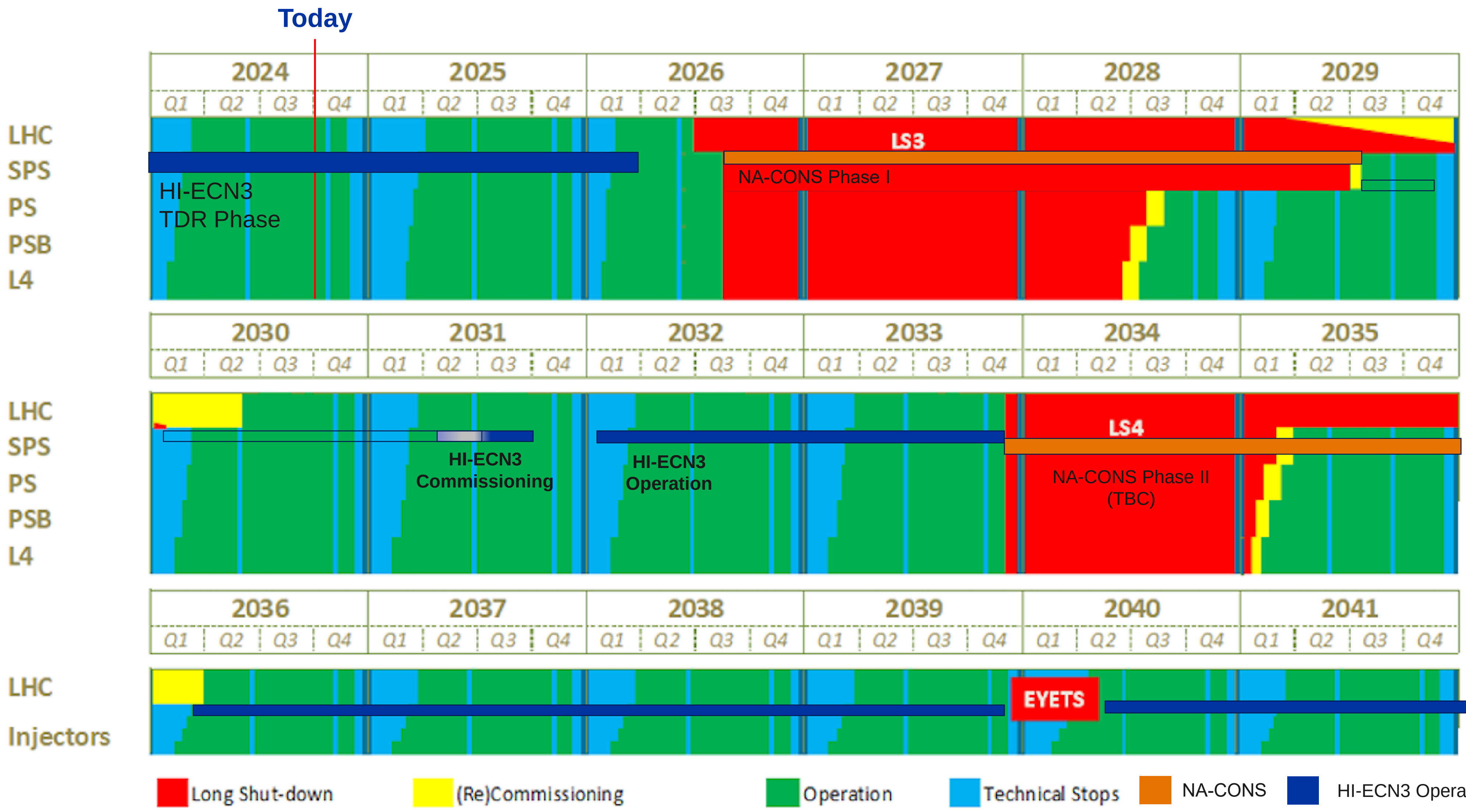
North Area Consolidation & Upgrade

NA-CONS consolidation project

HI-ECN3 project



CERN Accelerator Schedule

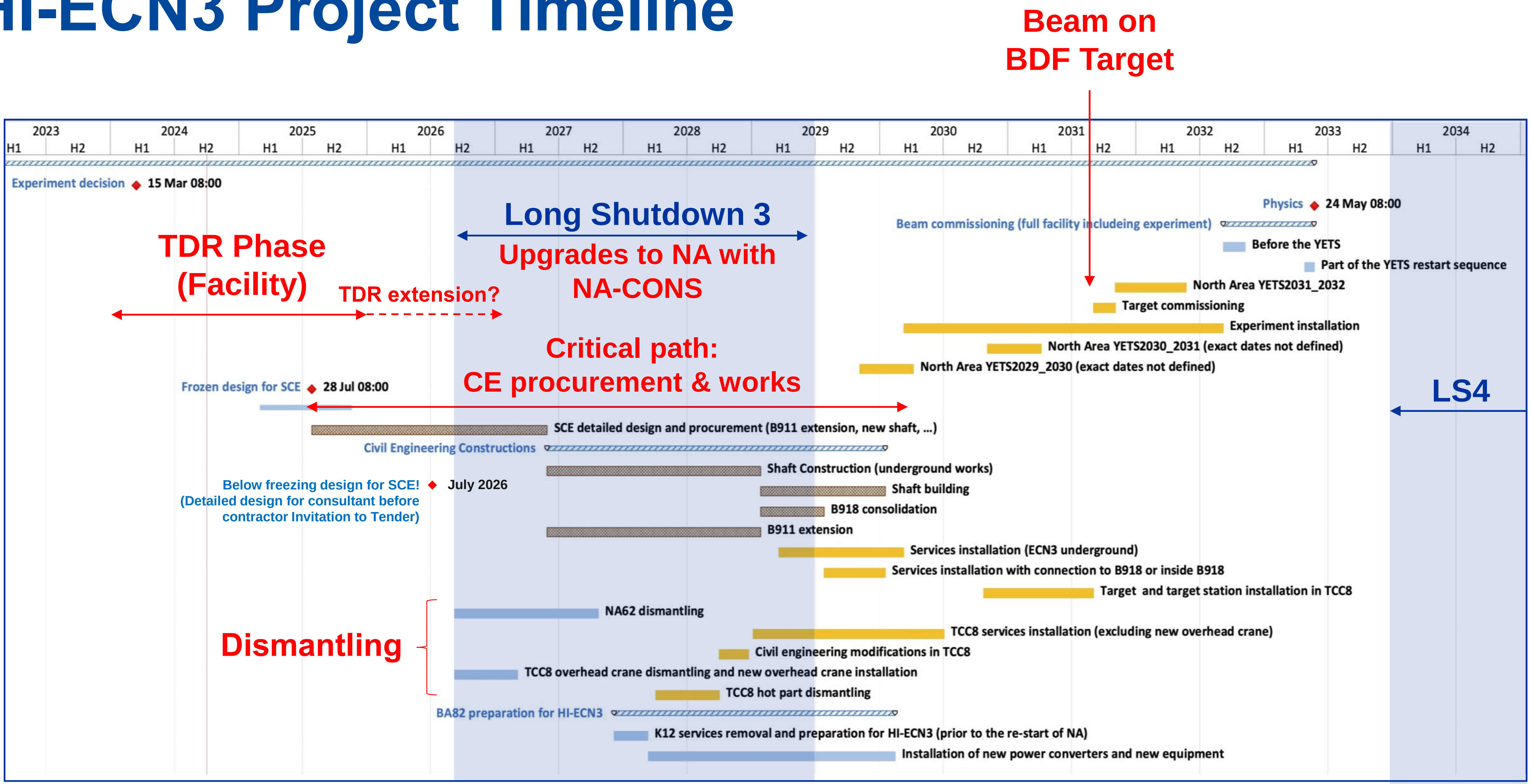


NA available exclusively for EHN1/2 from mid-2029:
Test-beam users & other POT demanding experiments (e.g. AMBER, MuonE)

ECN3 beam to dump in P42 for commissioning of TCC2 whilst construction ongoing

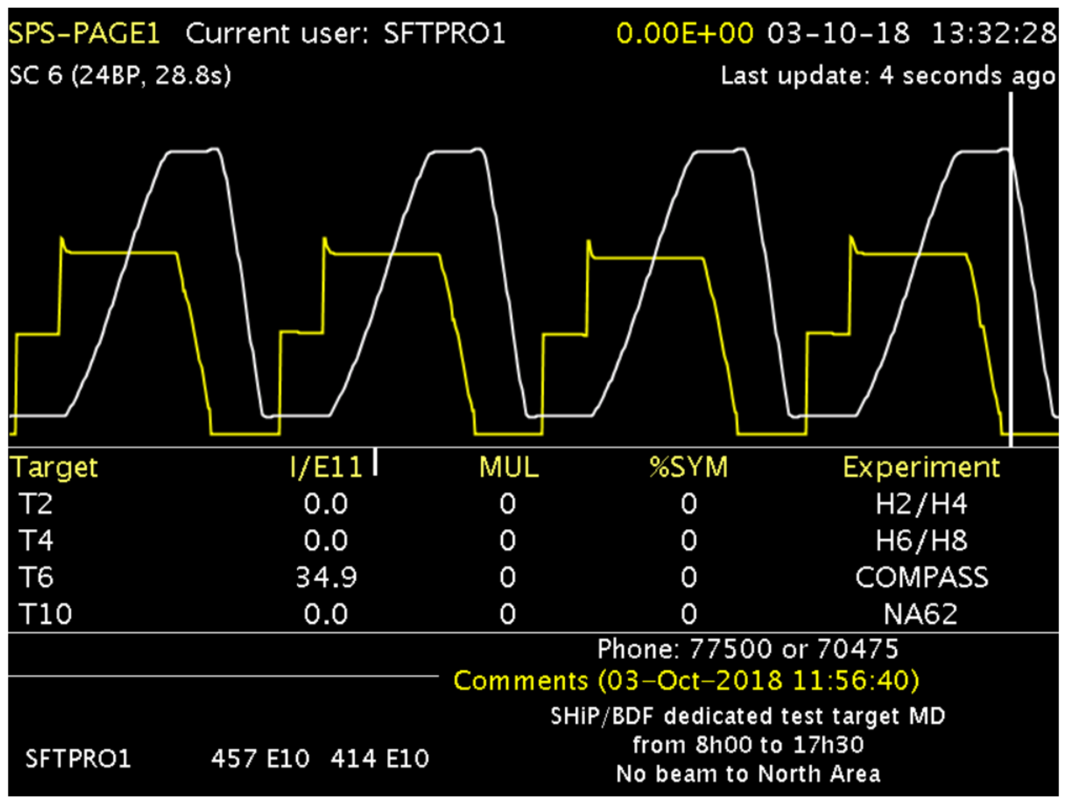
Operation out to late 2040s:
beyond HL-LHC
(frequency & length of LS's TBC)

HI-ECN3 Project Timeline



How many protons for BDF / SHiP? (i)

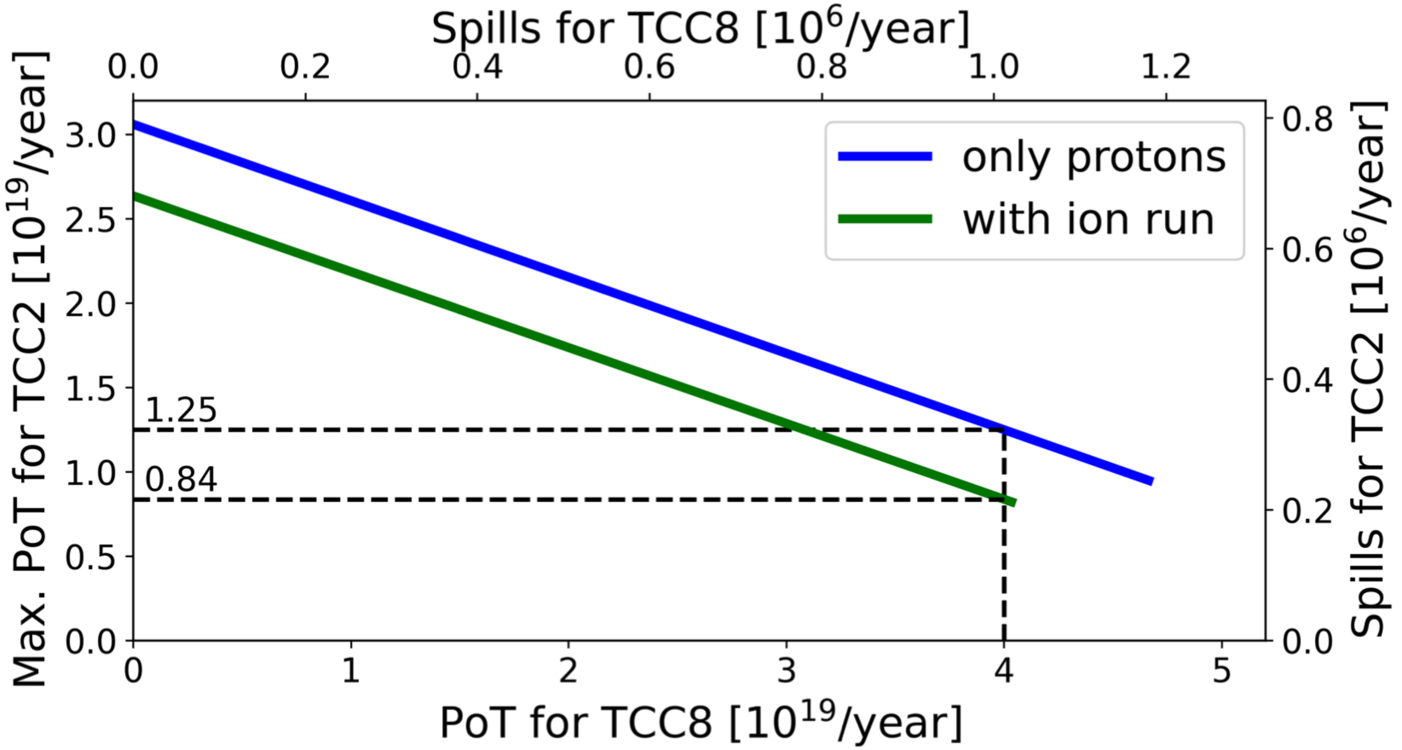
Short 7.2 s SHiP cycles with a 1.2 s FT (~ 1 s spill) vs. 14.4 s SFTPRO period



SPS Page 1 during BDF prototype target test at T6 in 2018

How many protons for BDF / SHiP? (ii)

Protons to TCC2 (other NA users)



Protons to ECN3 (BDF/SHiP)

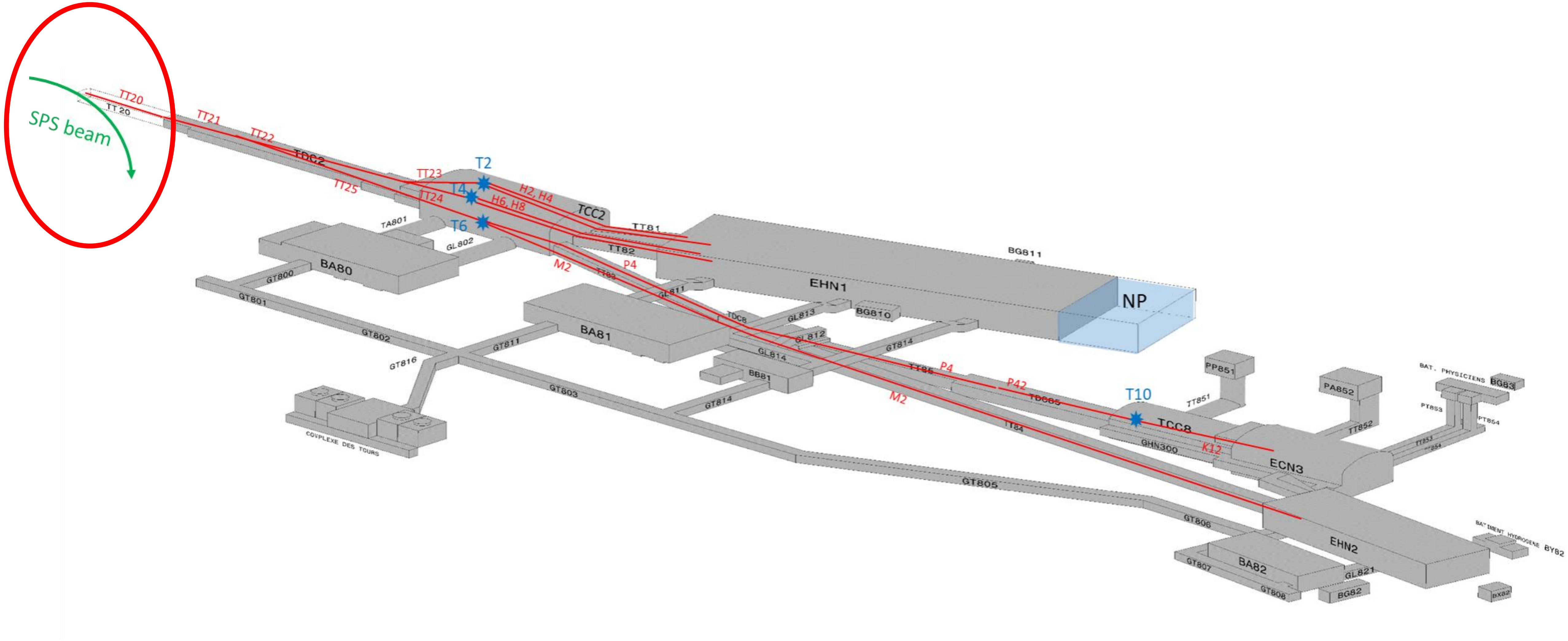
North Area needs
~ 5×10^{19} protons/year…
a la CNGS (~4×10^{19} p^+/y)

… but, slow extracted…

…unprecedented !

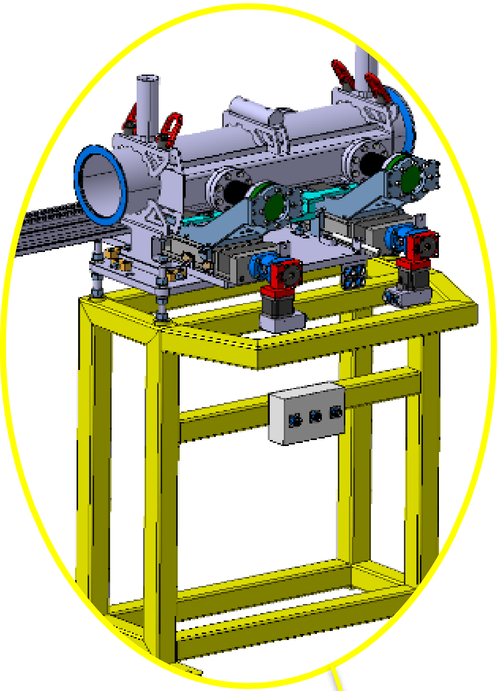
Possible after ~ 10 years of SX R&D with bent crystals

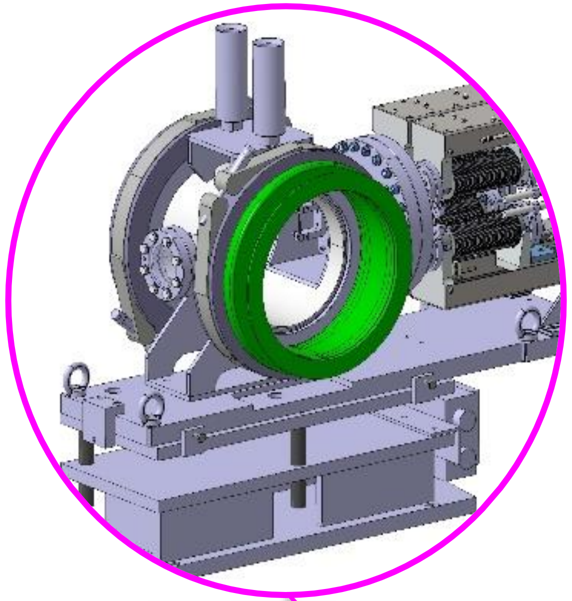
Slow Extraction from LSS2 in SPS

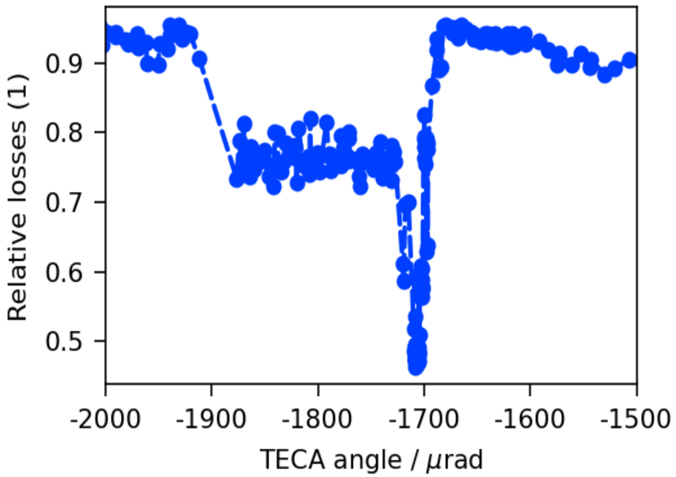


Crystal Shadowing of electrostatic septa

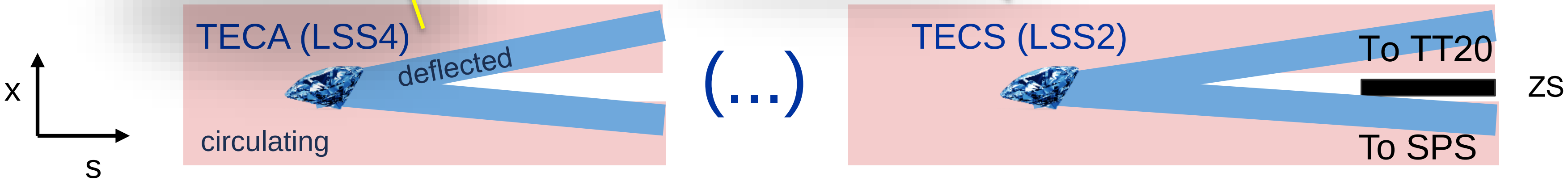
LSS4 gonio R&D:
~ 55% loss reduction
To be deployed operationally in 2024

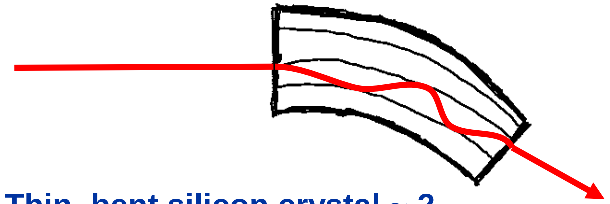






LSS2 gonio already operational with 20% loss reduction



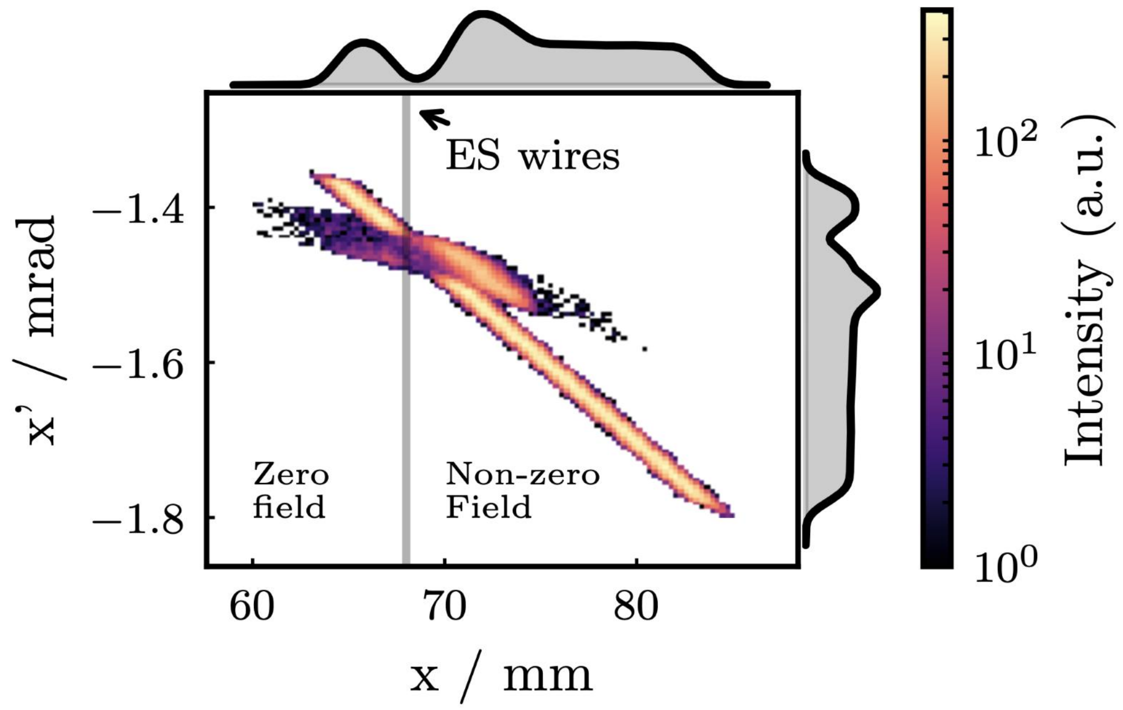


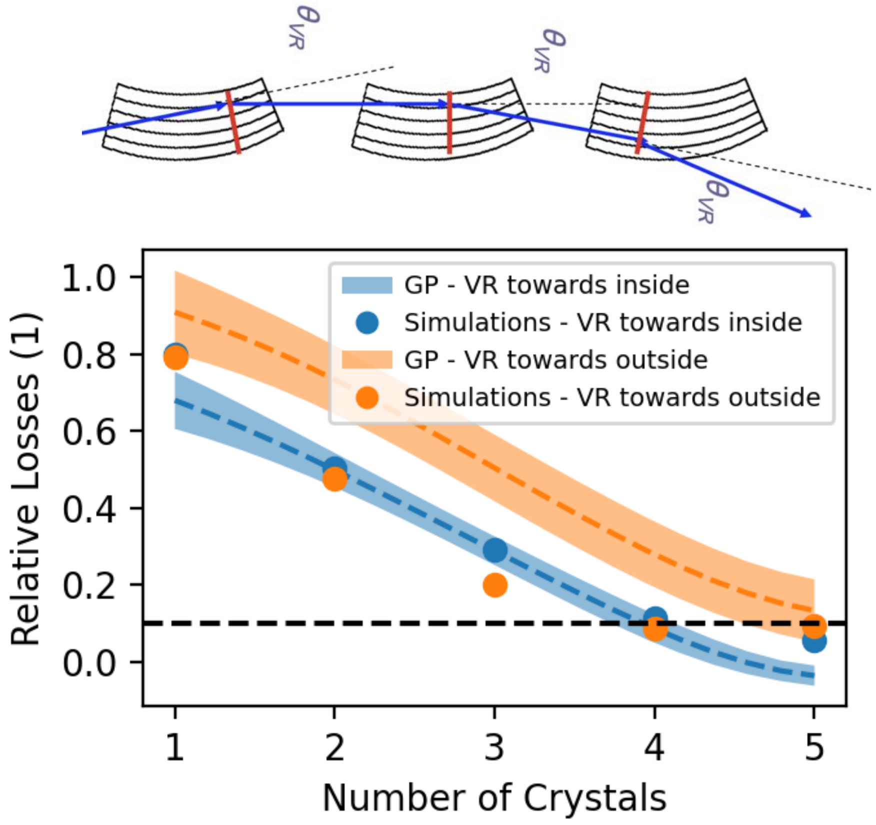
Thin, bent silicon crystal ~ 2 mm thick, 2 mm long

L. Esposito *et al.*, *Progress on optimised TECA and MVRA production*, SLAWG #76: Crystal shadowing and production, August 2024
F. M. Velotti *et al.*, Phys. Rev. Accel. Beams 22, 093502 (2019)

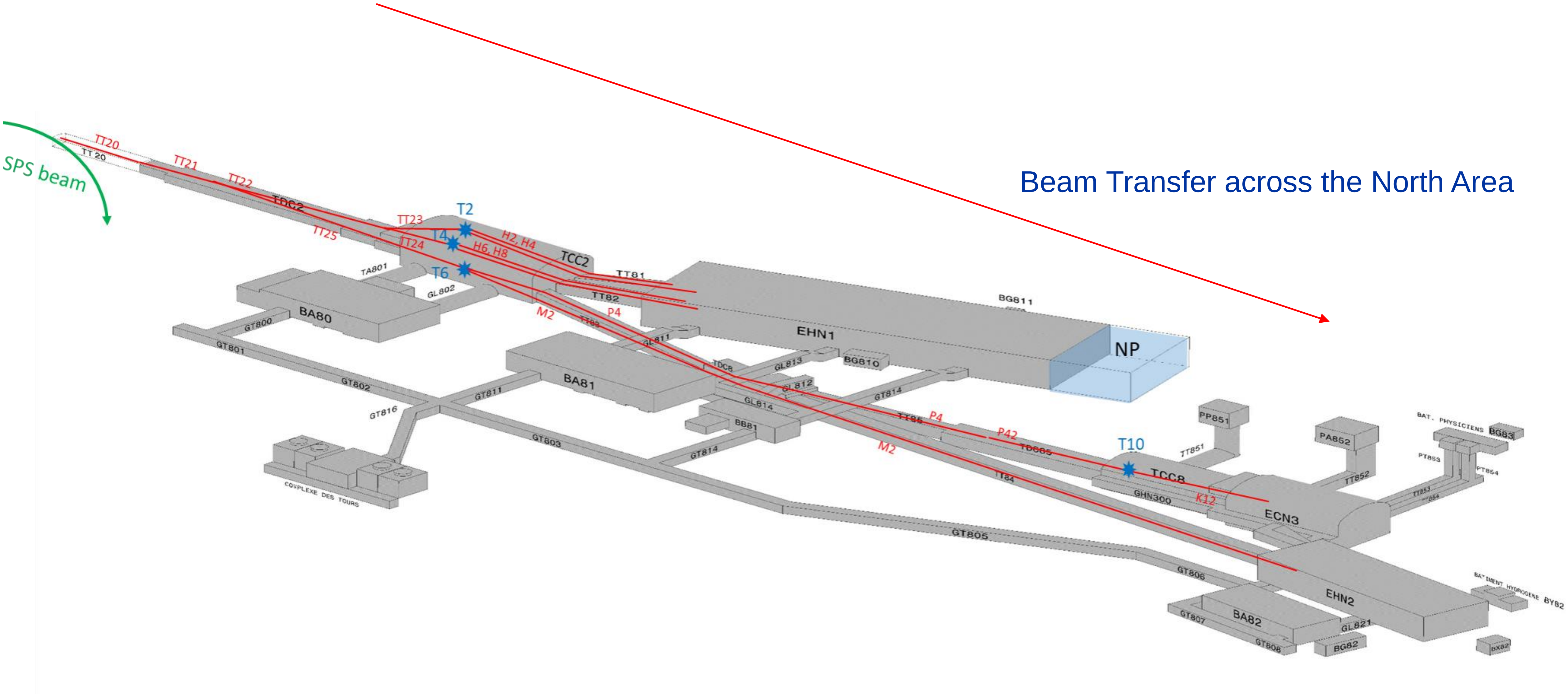
Crystal Shadowing of electrostatic septa (ii)

Objective: achieve an even higher loss reduction factor (x10?!) with advanced crystal technology (**multiple thin, bent crystals aligned for Volume Reflection**) installed in SPS

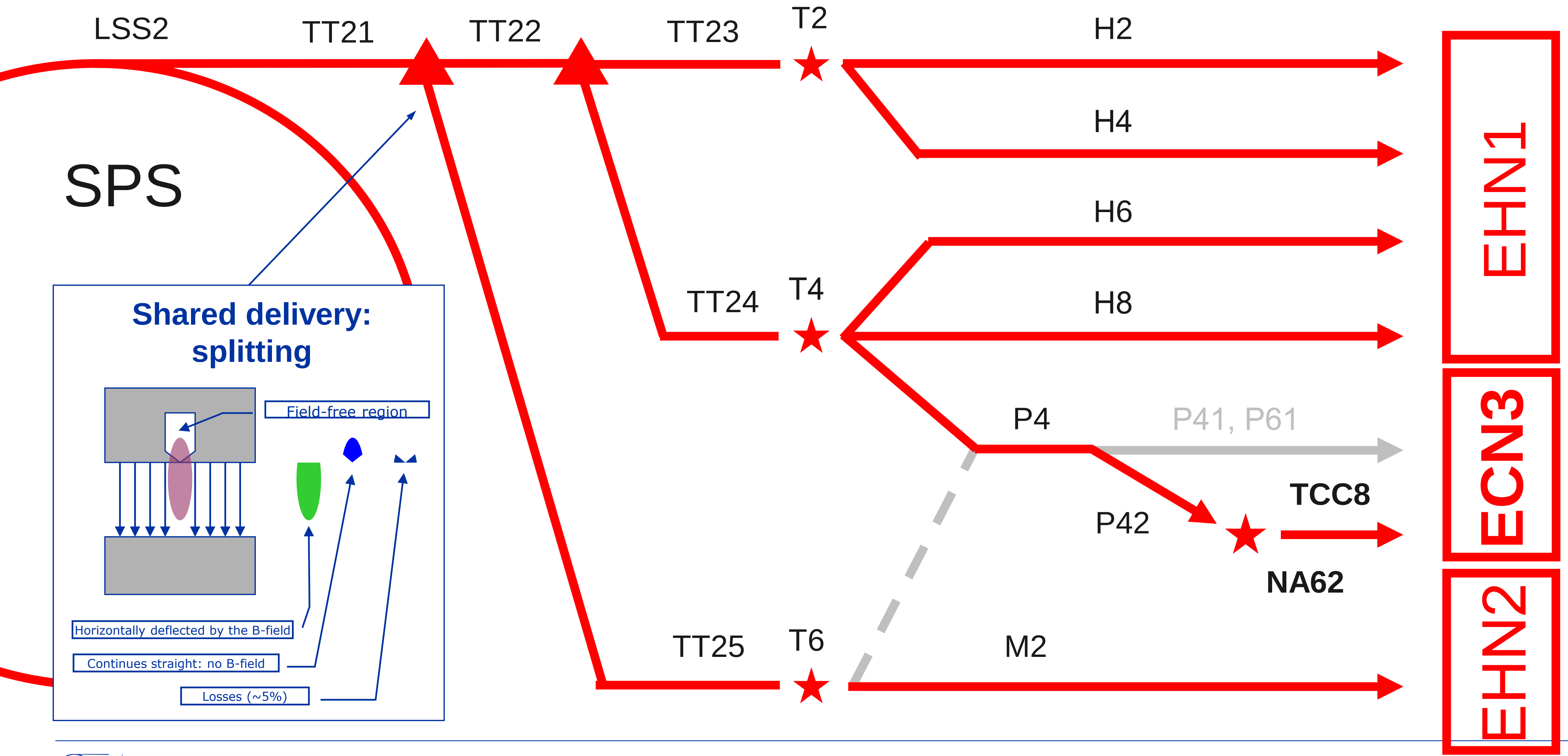




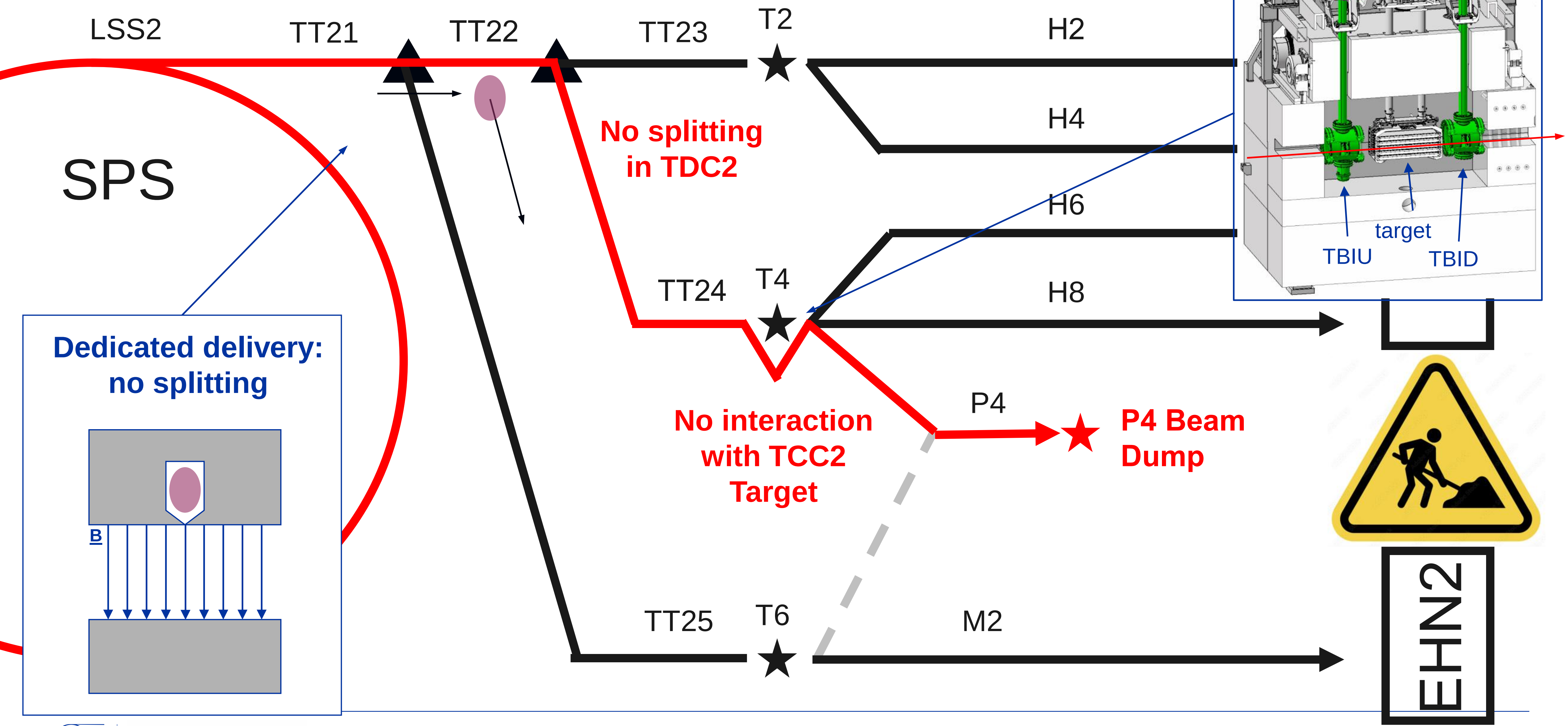
Beam Transfer across the North Area



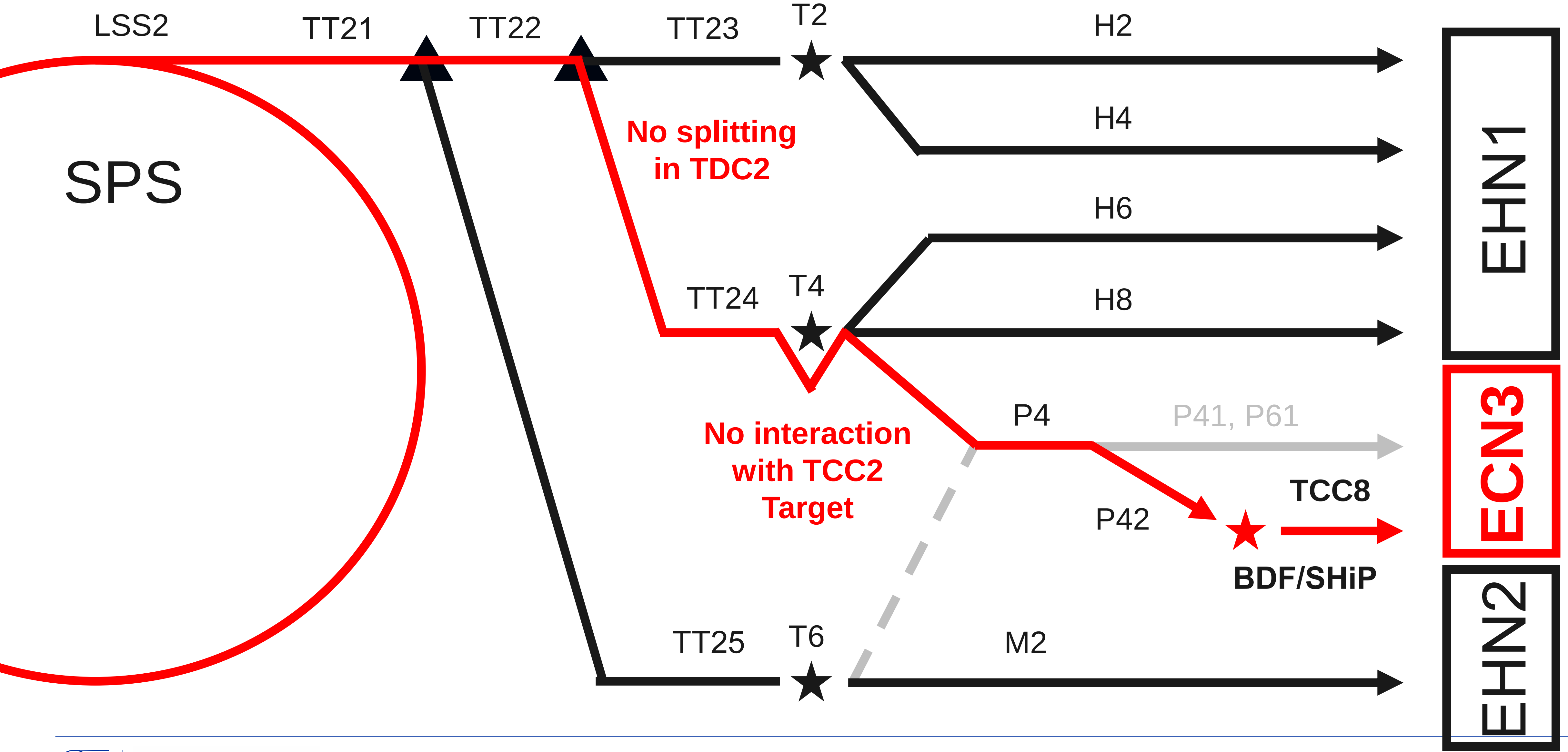
~~SFTPRO shared Beam Delivery to ECN3~~



Dedicated Beam Delivery to ECN3: commi

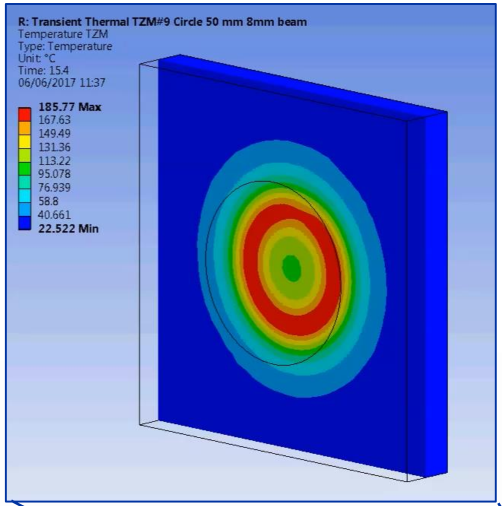


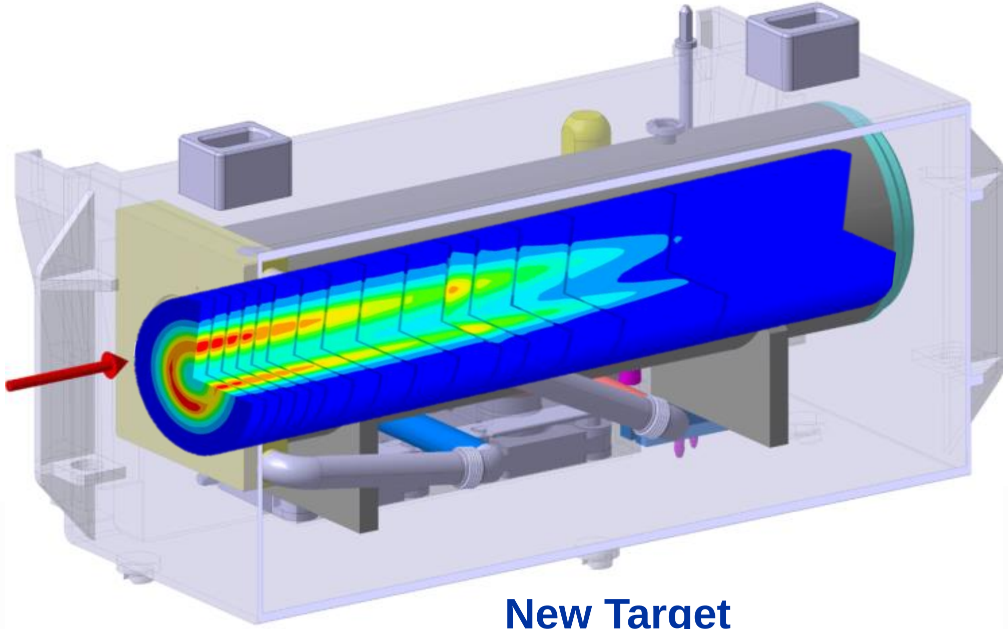
Dedicated Beam Delivery to ECN3

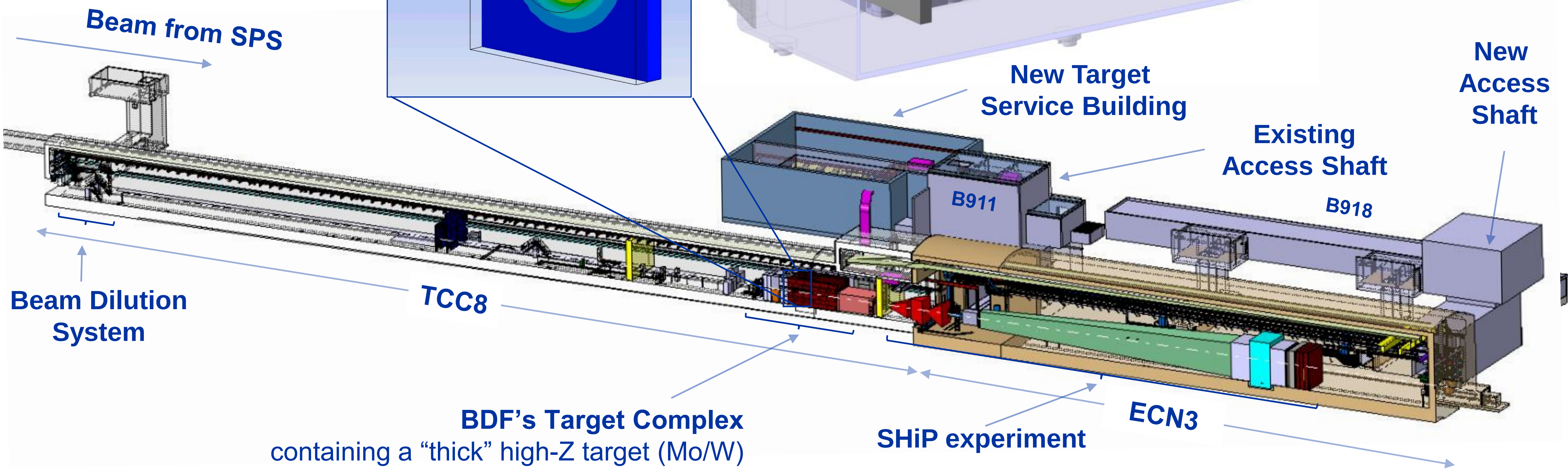


BDF/SHiP in ECN3

~ 300 kW (avg.)
~ 2.3 MW (spill)
1 second spill
4 Hz sweep

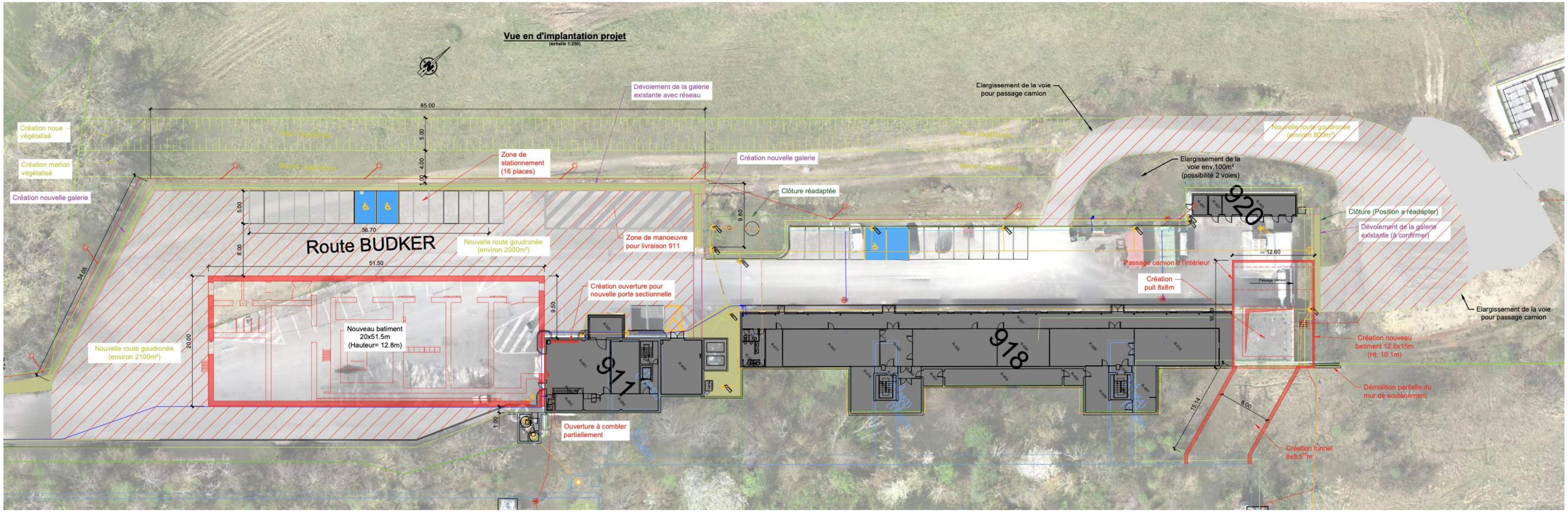






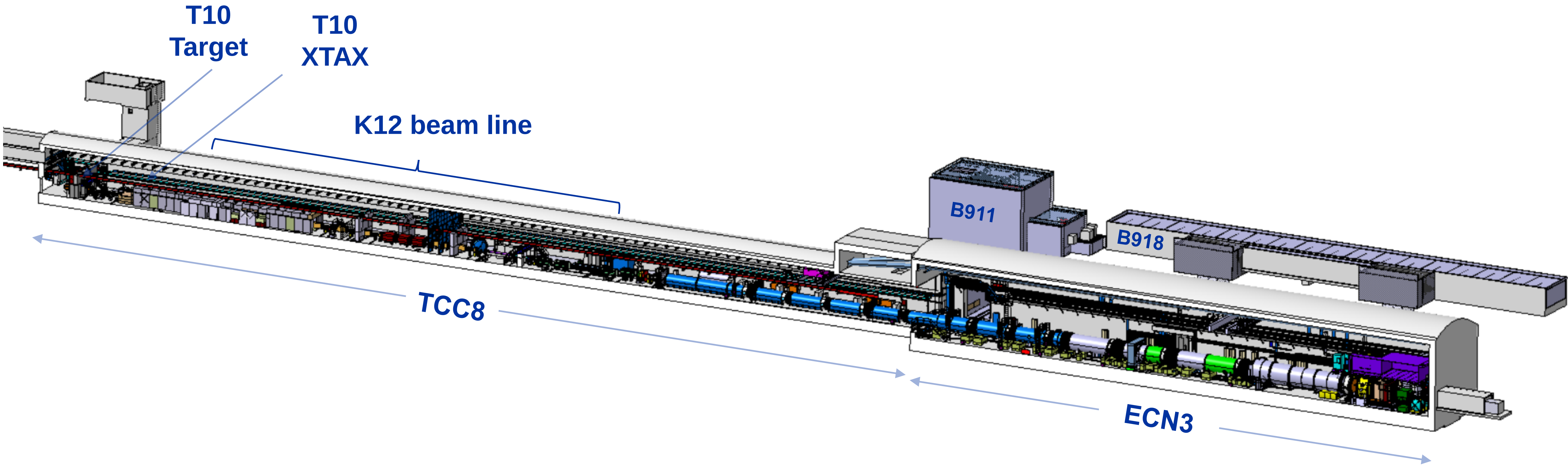
Civil Engineering Scope

- New target building: adjacent to building 911 → B. 754 / BB85
- New access shaft (PA855), connecting tunnel to ECN3 and access building→ B. 758 / BA85
- Underground excavations: in Target complex (TCC8) and Experimental Area (ECN3)



NA62 in ECN3

- **Dismantling will start immediately in LS3 to allow civil engineering works to get underway ASAP**



*F. Duval, *Plans for the NA62 dismantling* at LS3C#8, 24 July 2024

NA62 Dismantling: an example

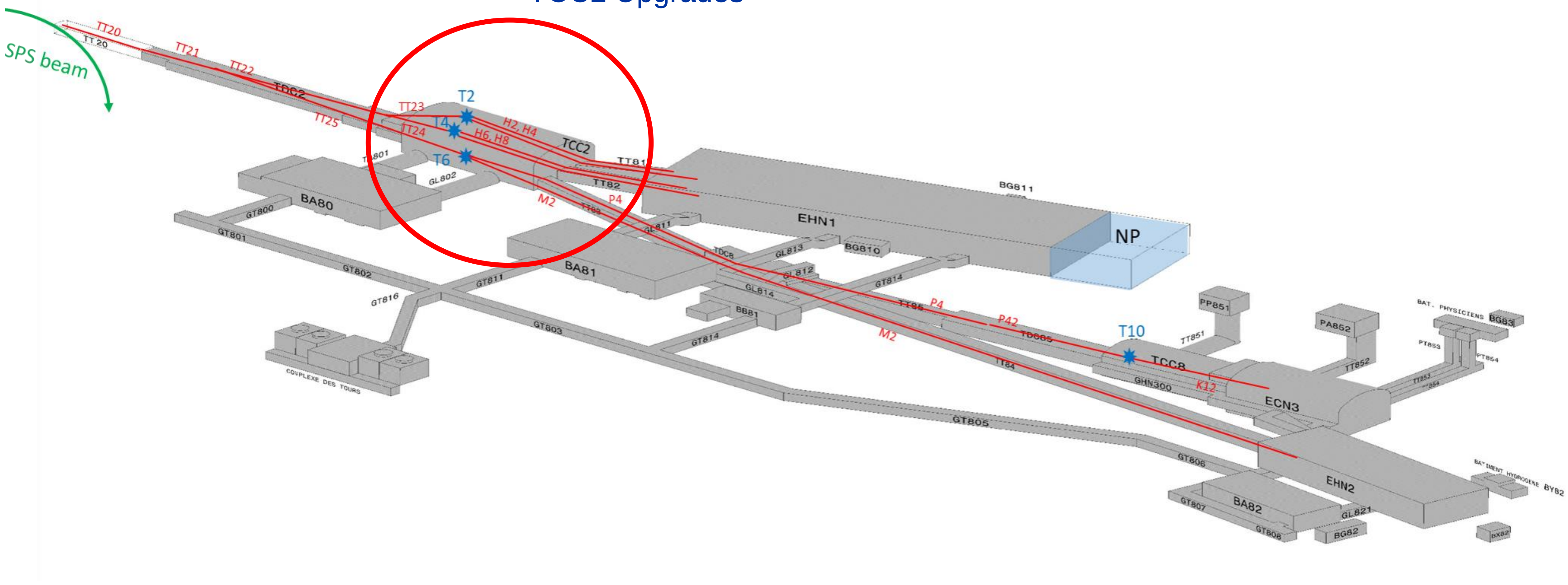
Expert technical support from Johan BREMER (TE-CRG)

LKr area

- Very complicated task due to the density of equipment in 3 dimensions
- Limited documentation
- Cryogenics : LKr , LN2
- First task: Secure the liquid Krypton ~10m^3
  - Transfere the LKr to the storage dewar for transport out of the cavern.

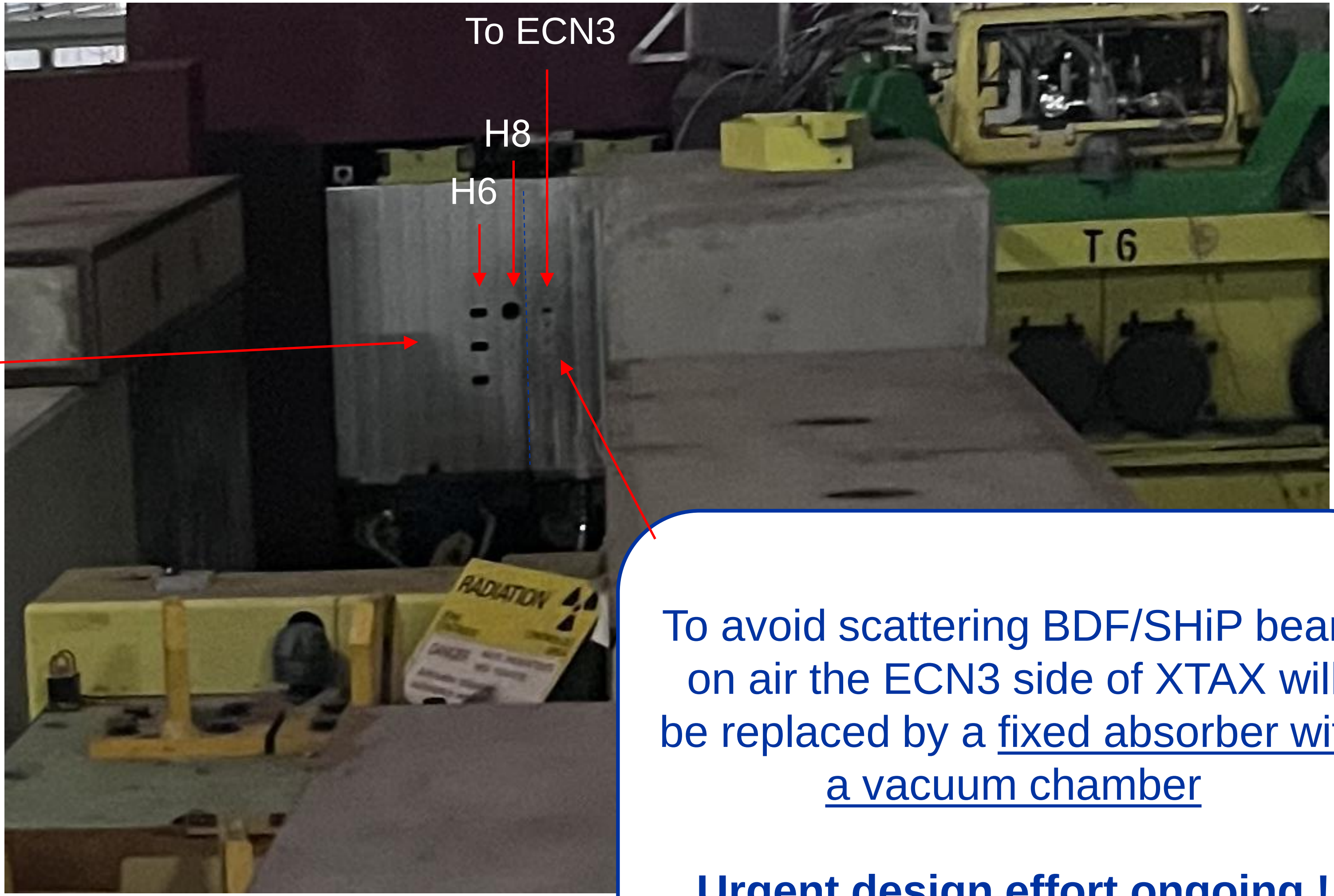
Part of the NA48 setup: a liquid krypton electromagnetic calorimeter.

TCC2 Upgrades



Upgrade of TCC2 T4 Target System for BDF/SHiP (i)

Looking downstream from on top of T4 target



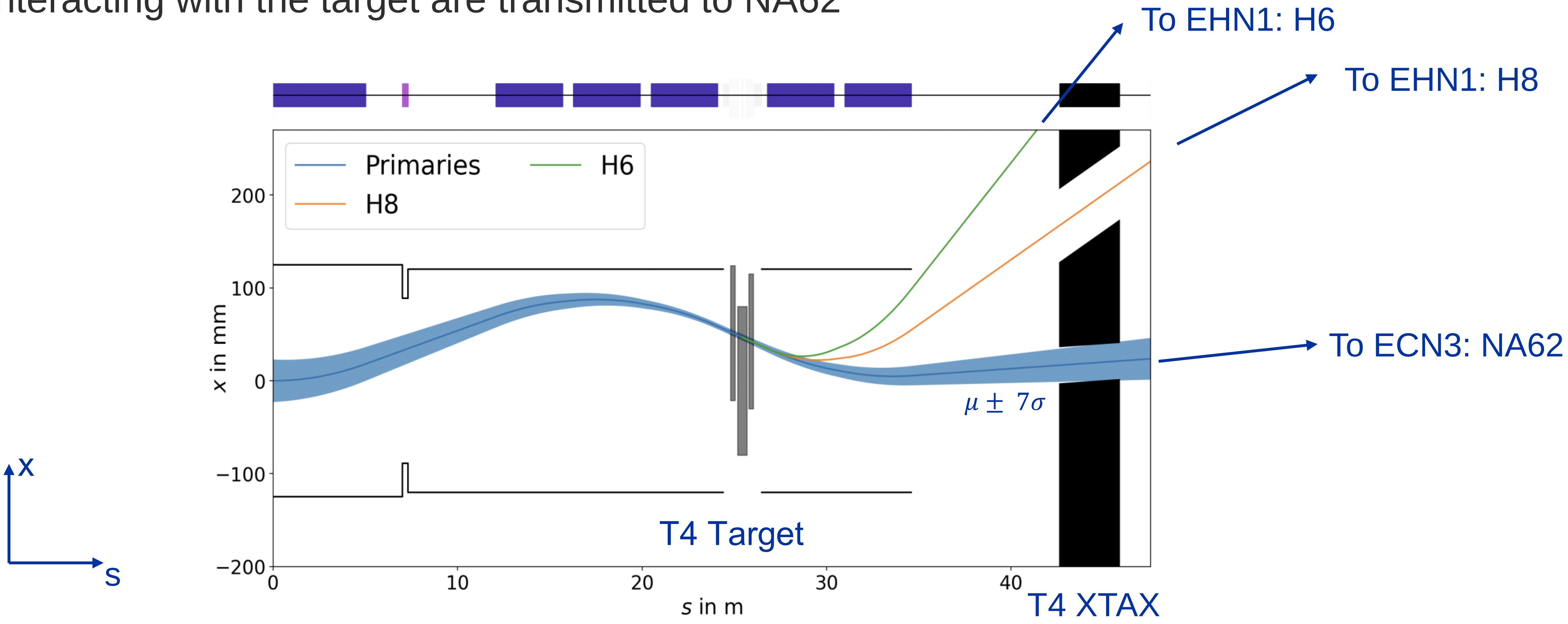
To avoid scattering BDF/SHiP beam on air the ECN3 side of XTAX will be replaced by a fixed absorber with a vacuum chamber

Urgent design effort ongoing !

Upgrade of TCC2 T4 Target System for BDF/SHiP (ii)

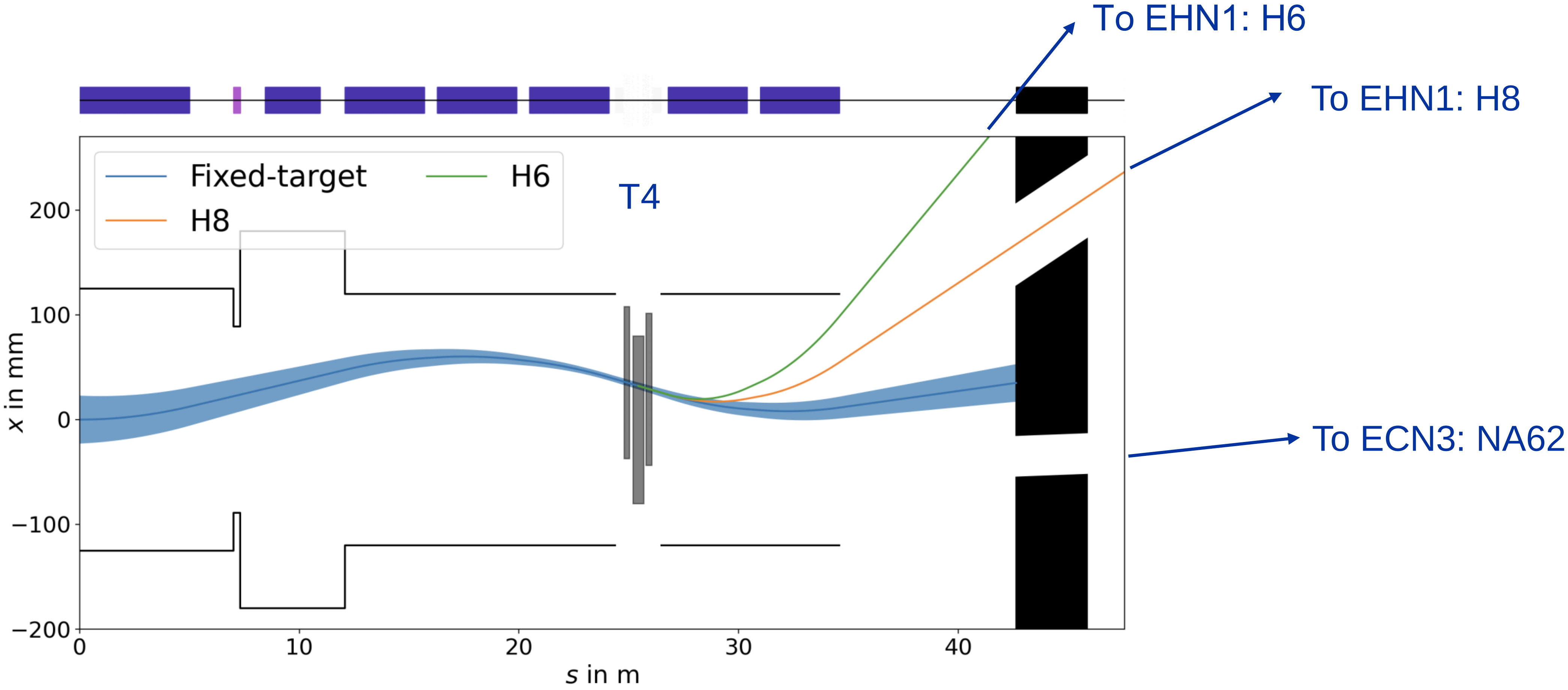
Today, operation of EHN1 (H6/H8 test beams) is coupled with ECN3 (NA62)

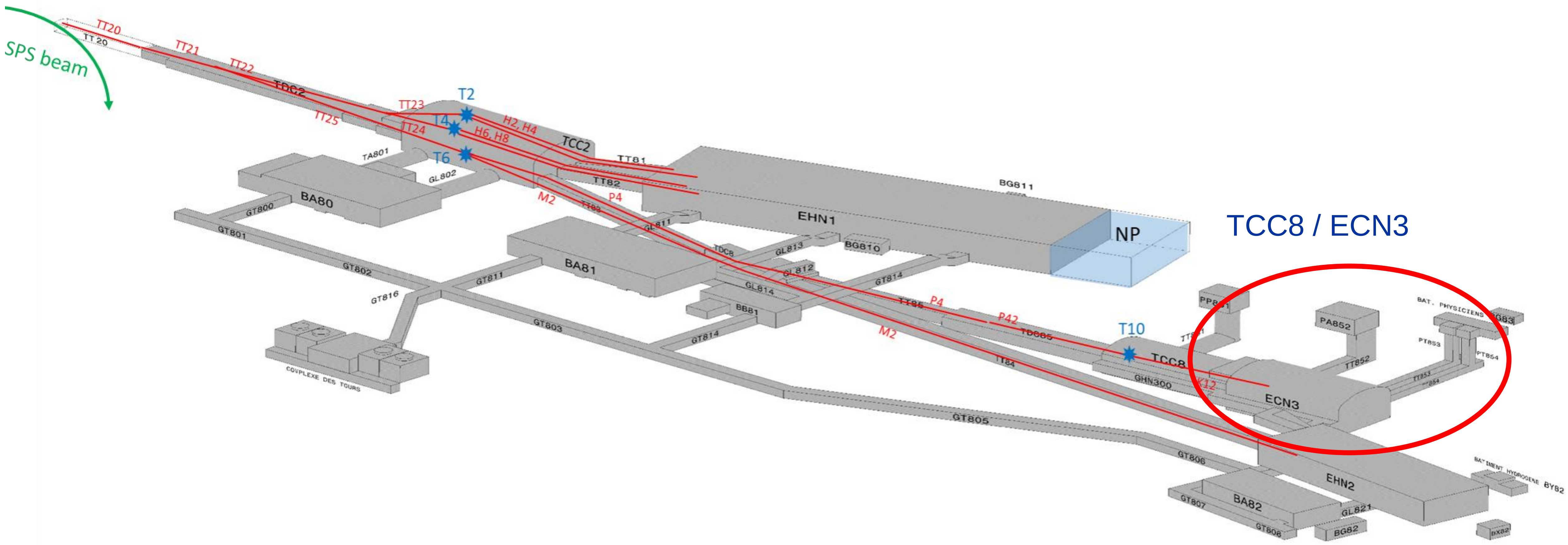
- Secondary particles for EHN1 are selected using magnet wobbling system, whilst protons not interacting with the target are transmitted to NA62



Upgrade of TCC2 T4 Target System for BDF/SHiP (iii)

A pulsed magnet allows us to decouple proton beams on the dedicated HI-ECN3 cycle in the horizontal plane (in addition to vertical separation to avoid target)




SPS beam
TT20
TT21
TT22
TDC2
TT23
TT24
TT25
T2
T4
T6
H2, H4
H6, H8
TCC2
TT81
TT82
M2
P4
BA80
BA81
EHN1
BG811
NP
TT85
P42
T10
TCC8
K12
ECN3
EHN2
BA82
GT805
GT803
GT802
GT801
COMPLEXE DES TOURS

TCC8 / ECN3

BDF Dilution System

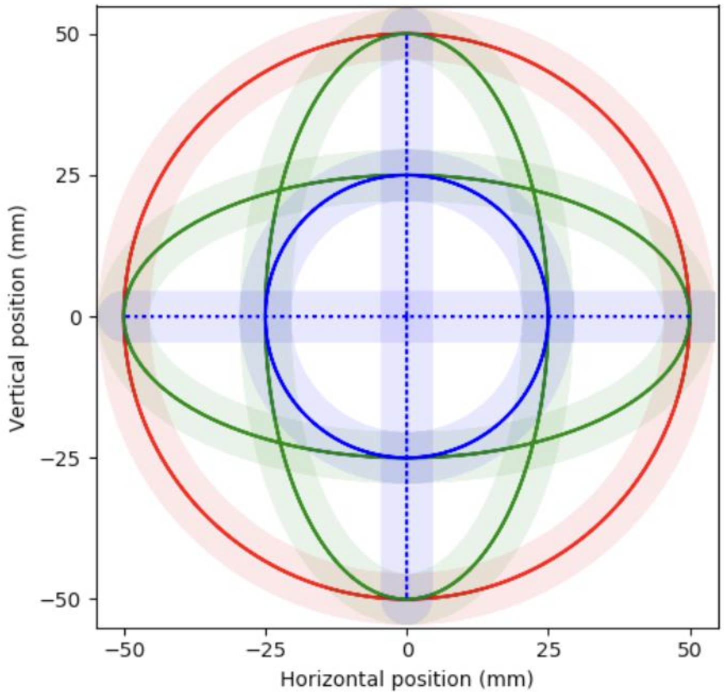
Present baseline:

- Slow sweep = 4 Hz over a 1 second spill
- $\pi/2$ scheme: independently powered laminated dipole magnets:
  - 2H + 2V magnets (~ 0.5 mrad, 0.7 Tm per plane)
  - de-phased by 90 degrees to give circular spill

- Beam profiler(s) to check beam position, size & sweep post-operatior

- **Challenge:** protection of the target critical, loss of dilution during single spill will likely damage the target

- **Independent interlock system needed for redundancy**:
  - Independent DCCTs measurement current in dilution dipole magnets
  - Dedicated “live” beam position monitoring of beam during its sweep



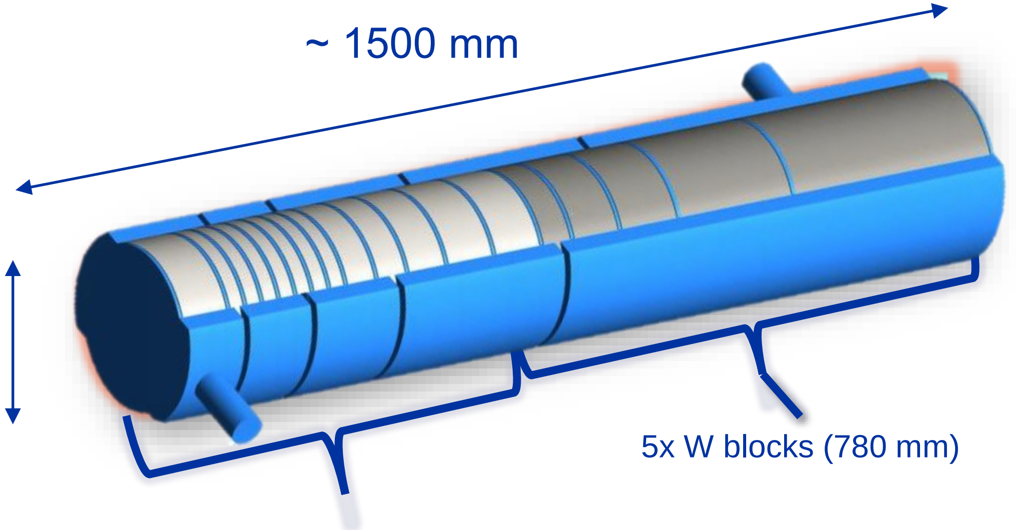
Failure Scenario:

Failure 2H OR 2V

Failure 1H OR 1V

Failure 1H AND 1V

BDF Target Baseline Design



Baseline beam parameters of the BDF Target operation. *https://doi.org/10.23731/CYRM-2020-002*

Proton momentum (GeV/c)	400
Beam intensity (p^+/cycle)	4×10^{13}
Cycle length (s)	7.2
Spill duration (s)	1.0
Beam dilution pattern	Circular
Beam sweep frequency (turns/s)	4
Dilution circle radius (mm)	50
Beam sigma (H, V) (mm)	(8, 8)
Average beam power (kW)	356
Average beam power deposited in target (kW)	305
Average beam power during spill (MW)	2.3

~ $4.0{\times}10^{19}$ p^+/y

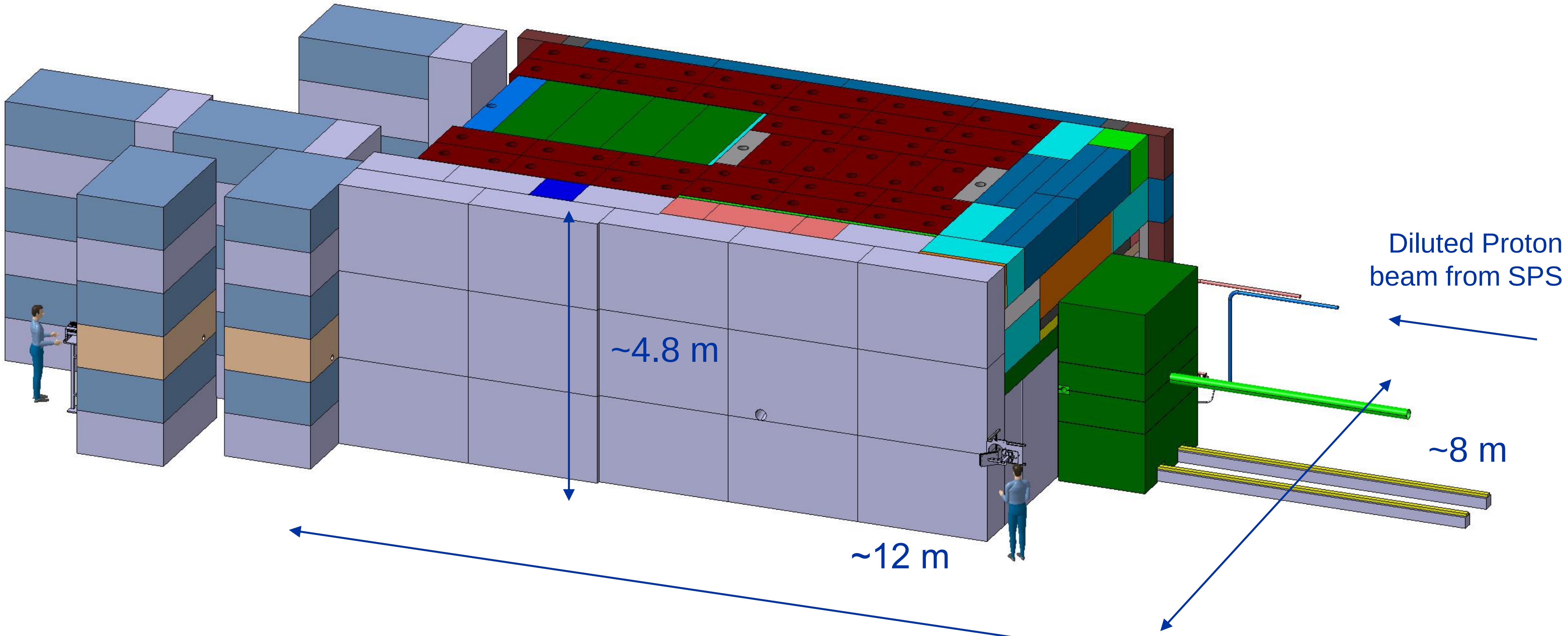
Baseline design:

- Water-cooled, Mo & W blocks (cladded with Ta)
- Tested with beam in 2018 & PIE

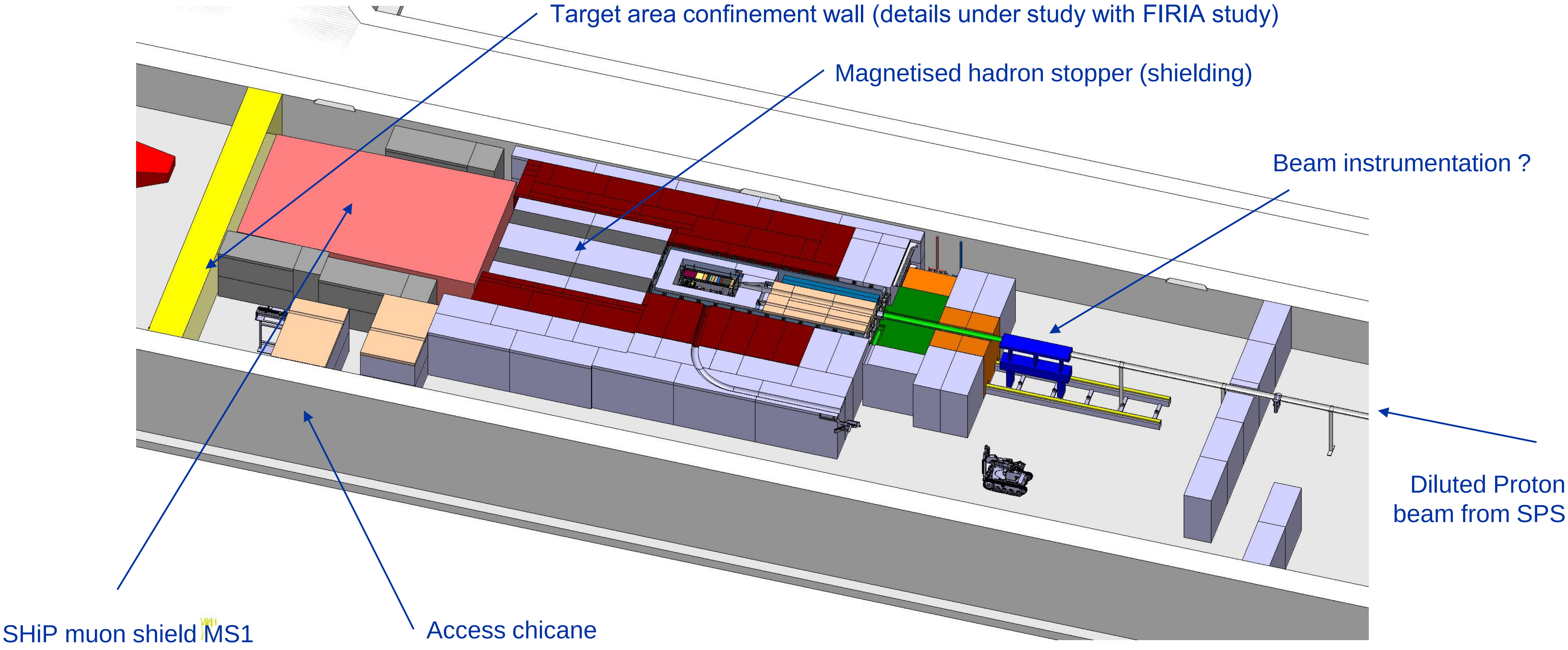
TDR phase needed to improve CDS design:

- Alternatives to water-cooling to avoid cladding and the risk of development of free radicals (hydrogen)
- **Helium-cooled pure W design now being prototyped: tests in TCC2 planned in 2025 and 2026**

BDF Target Complex in TCC8 (i)



BDF Target Complex in TCC8 (ii)



Summary

- BDF/SHiP has been approved to search directly for dark matter at the North Area
- CERN has reserved budget in its Medium-Term Plan for the construction of a new facility in ECN3 under the project named HI-ECN3 to fully exploit the investment being made in the North Area Consolidation project
- Some ~ 10 years of R&D will converge into a Technical Design Report to realise a slow extracted beam power of 300 kW (avg.) to the North Area
- HI-ECN3 TDR will be published in 2026, building on the SPS BDF Comprehensive Design Study published in 2020
- First beam on target expected in 2031 to give SHiP at least 2 years of beam before LS4

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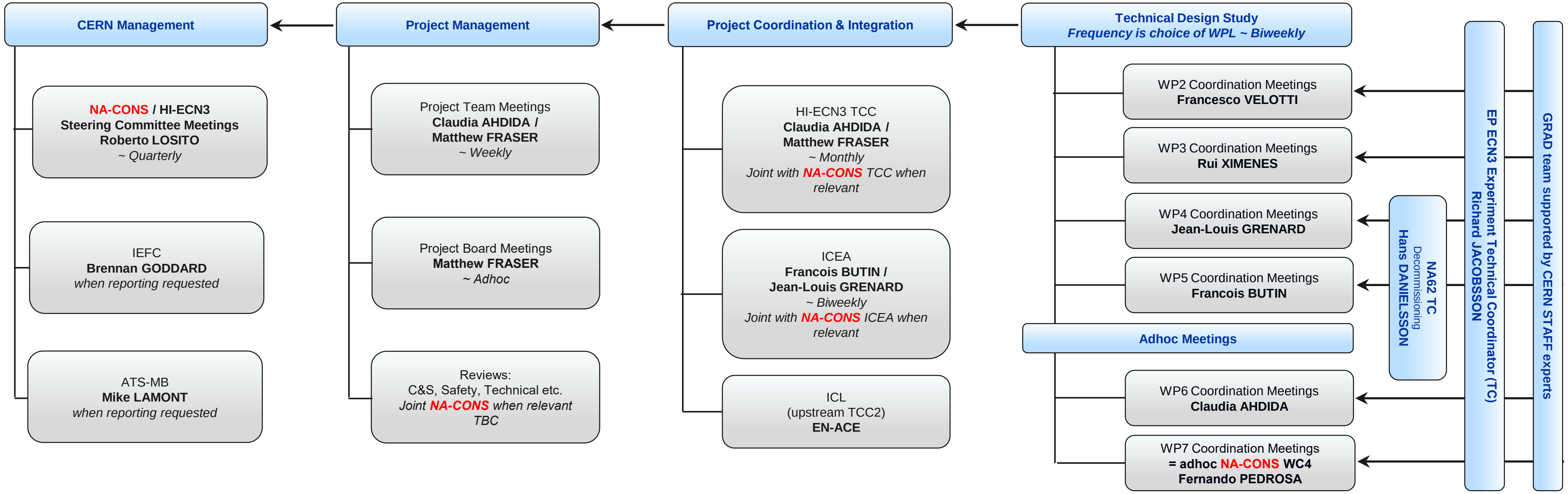
*M.A Fraser & Y. Kadi, ICEA Mandate for the HI-ECN3 Study Project, Memorandum, EDMS#3018359, 25 Jan 2024

NA-CONS / HI-ECN3 Synergy

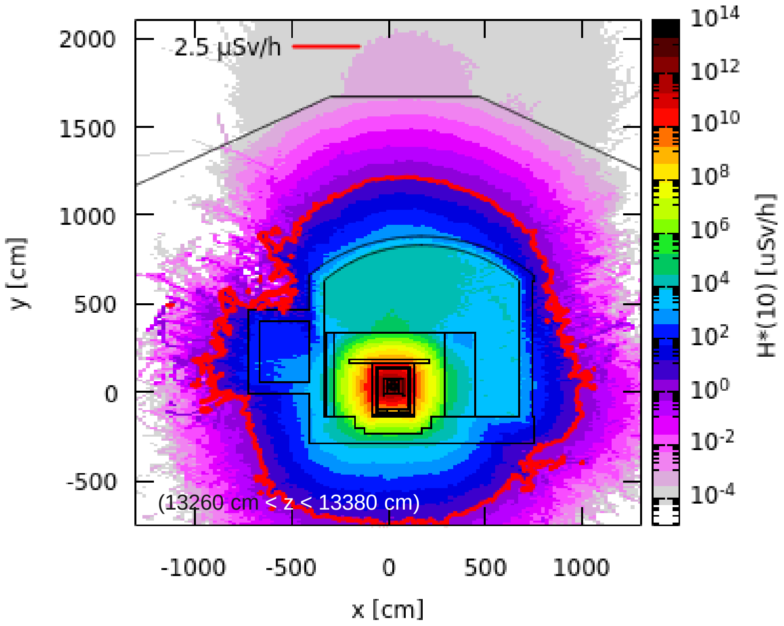


- **Joint NA-CONS / HI-ECN3 TCC meeting series:** critical for advancement of TCC2 upgrades fro BDF & implicated systems, next items include P42 dump and BA82
- **HI-ECN3 ICEA:*** first dedicated agenda on integration to take place in two weeks (impacted NA-CONS items already discussed in ICEA for many months) co-chaired by Francois Butin and Jean Louis Grenard
- **WP7.1 NA-CONS Synergism:** collecting and documenting impacted systems and NA-CONS WPs key role played by Fernando PEDROSA & Thomas ZICKLER (timing, magnets, power converters, BA82, etc.)

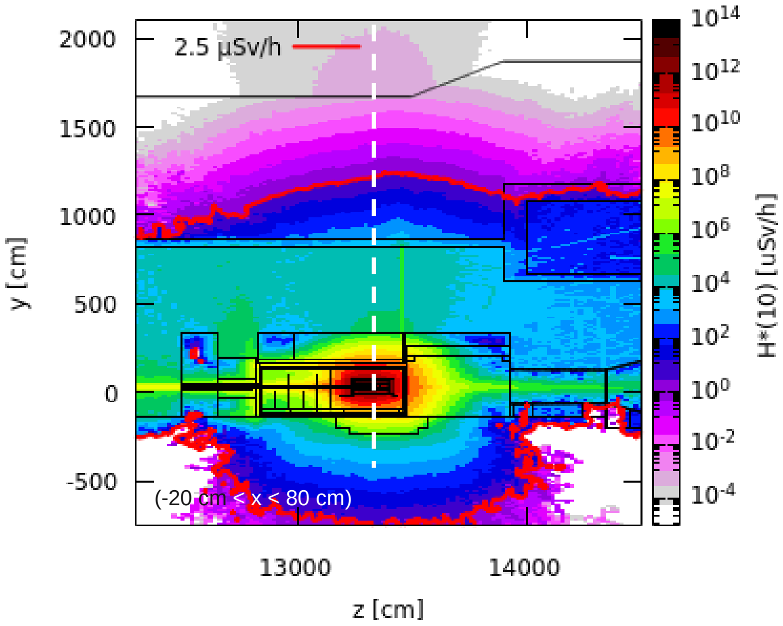
Prompt Radiation in TCC8

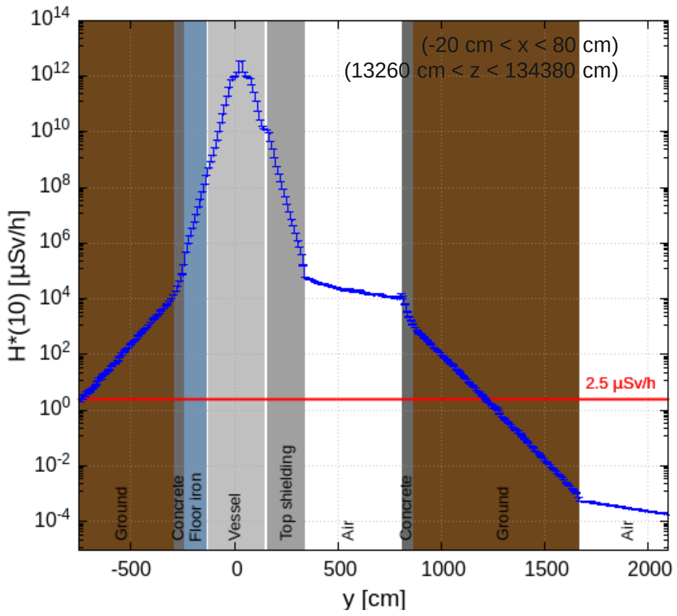
Avg. intensity of 5.6×10[12] p/s

Cross-sectional view



Side view





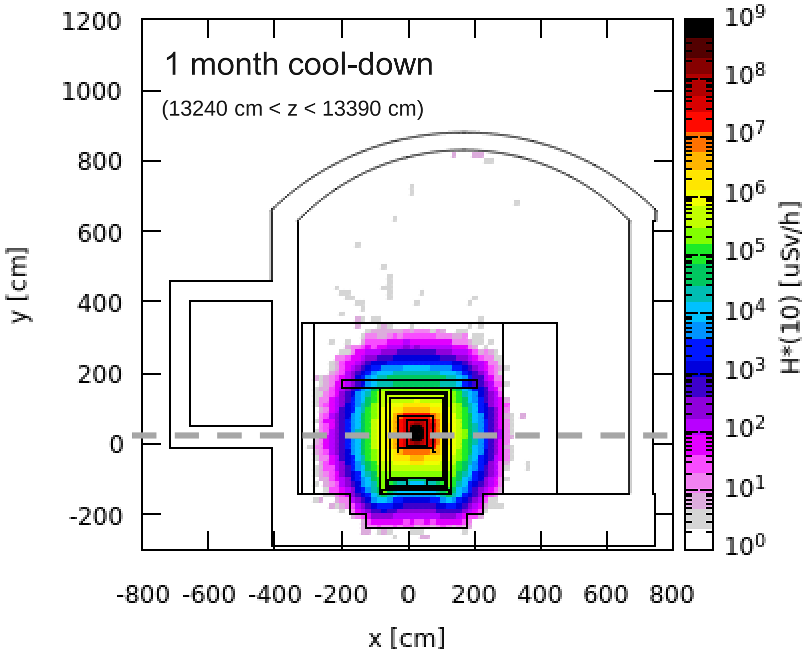
➢ Shielding design is well optimized for the prompt radiation

	Area	Annual dose limit (year)	Ambient dose equivalent rate permanent occupancy	Ambient dose equivalent rate low occupancy	Sign
	Non-designated	1 mSv	0.5 µSv/h	2.5 µSv/h	
Radiation Area	Supervised	6 mSv	3 µSv/h	15 µSv/h	Dosimeter obligatory / Dosimètre obligatoire
Radiation Area / Controlled Area	Simple Controlled	20 mSv	10 µSv/h	50 µSv/h	SIMPLE CONTROLLED / CONTRÔLÉE SIMPLE
Radiation Area / Controlled Area	Limited Stay	20 mSv	-	2 mSv/h	LIMITED STAY / SÉJOUR LIMITÉ
Radiation Area / Controlled Area	High Radiation	20 mSv	-	100 mSv/h	HIGH RADIATION / HAUTE RADIATION
Controlled Area	Prohibited	20 mSv	-	> 100 mSv/h	NO ENTRY / DÉFENSE D'ENTRER

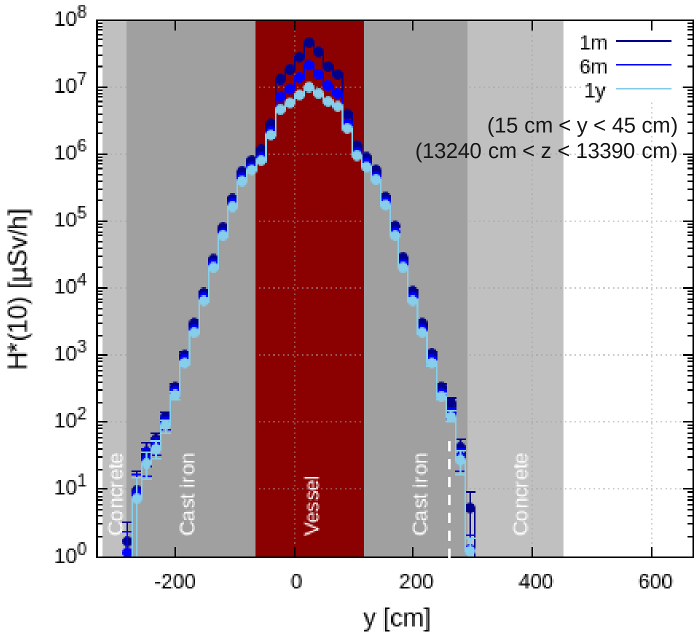
Prompt Radiation in TCC8

Total POT 6×10^{20}

Cross-sectional view, target level

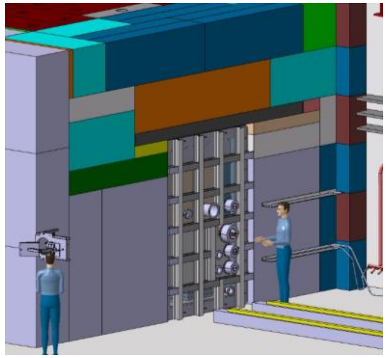


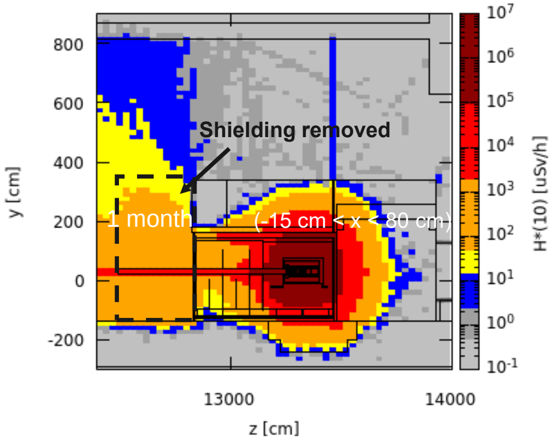
Along x-axis, working height



Upstream of vessel w/o upstream shielding

Preliminary worst case manual intervention scenario





- After opening vessel & removing shielding, residual dose rates of several 100 µSv/h are expected
- Supervised Radiation Area on the sides
- Further optimization by movable shielding

- The shielding design contains well the high residual dose rates reaching in the central target region several 10 Sv/h after 1 month of cool-down
- The residual dose rates outside the shielding are < 1 µSv/h

Area	Annual dose limit (year)	Ambient dose equivalent rate: permanent occupancy	Ambient dose equivalent rate: low occupancy	Sign
Non-designated	1 mSv	0.5 µSv/h	2.5 µSv/h	
Supervised	6 mSv	3 µSv/h	15 µSv/h	Dosimeter obligatory / Dosimètre obligatoire
Simple Controlled	20 mSv	10 µSv/h	50 µSv/h	SIMPLE CONTROLLED / CONTRÔLÉE SIMPLE; Dosimeter obligatory / Dosimètre obligatoire
Limited Stay	20 mSv	-	2 mSv/h	LIMITED STAY / SÉJOUR LIMITÉ; Dosimeters obligatory / Dosimètres obligatoires
High Radiation	20 mSv	-	100 mSv/h	HIGH RADIATION / HAUTE RADIATION; Dosimeters obligatory / Dosimètres obligatoires
Prohibited	20 mSv	-	> 100 mSv/h	NO ENTRY DÉFENSE D'ENTRER

Radiation Area; Controlled Area

100 rem = 1Sv

Environmental Aspects

POT 4×10^{19} per year

Dose from air releases

- Used max. dose coefficients from different age groups

Effective dose estimates

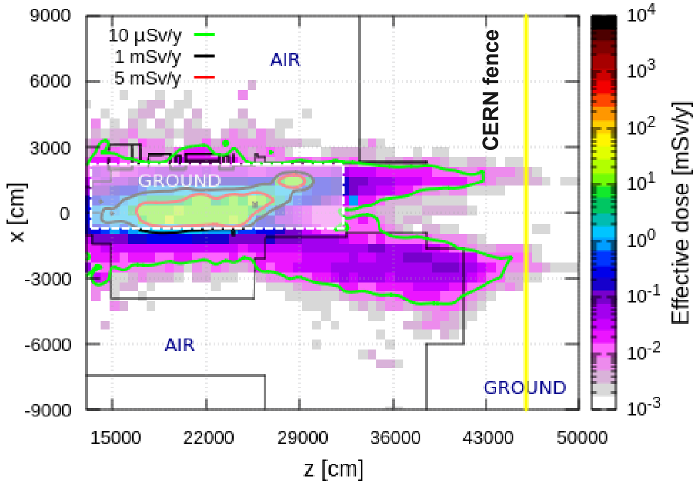
Air	Total A [Bq]	Effective Dose [μSv/y]
CASE 1	3.69×10^{6}	1×10^{-5}
CASE 2	1.19×10^{11}	3×10^{-3}

H-3 release due to air activation of ~80 kBq

Positions of nearby population groups

Dose from stray radiation

Annual effective dose from muons



Muon prompt radiation aboveground downstream ECN3

➢ Annual limit of Non-designated Area on CERN domain and at CERN fence (1 mSv/y) as well as dose objective for members of the public (10 uSv/y) is by far met