CERN

Beam Transfer for the High Intensity facility at ECN3 for the Search for Hidden Particles experiment

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

13th International Workshop on Neutrino Beams and Instrumentation (NBI2024)

AYA'S LABORATORY Quantum Beam Research Center (AQBRC), Tokai, Japan

7 – 10th October 2024

SHiP
Search for Hidden Particles

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 HI-ECN3 project in CERN's Medium-Term Plan ratified by CERN Council in June 2024.

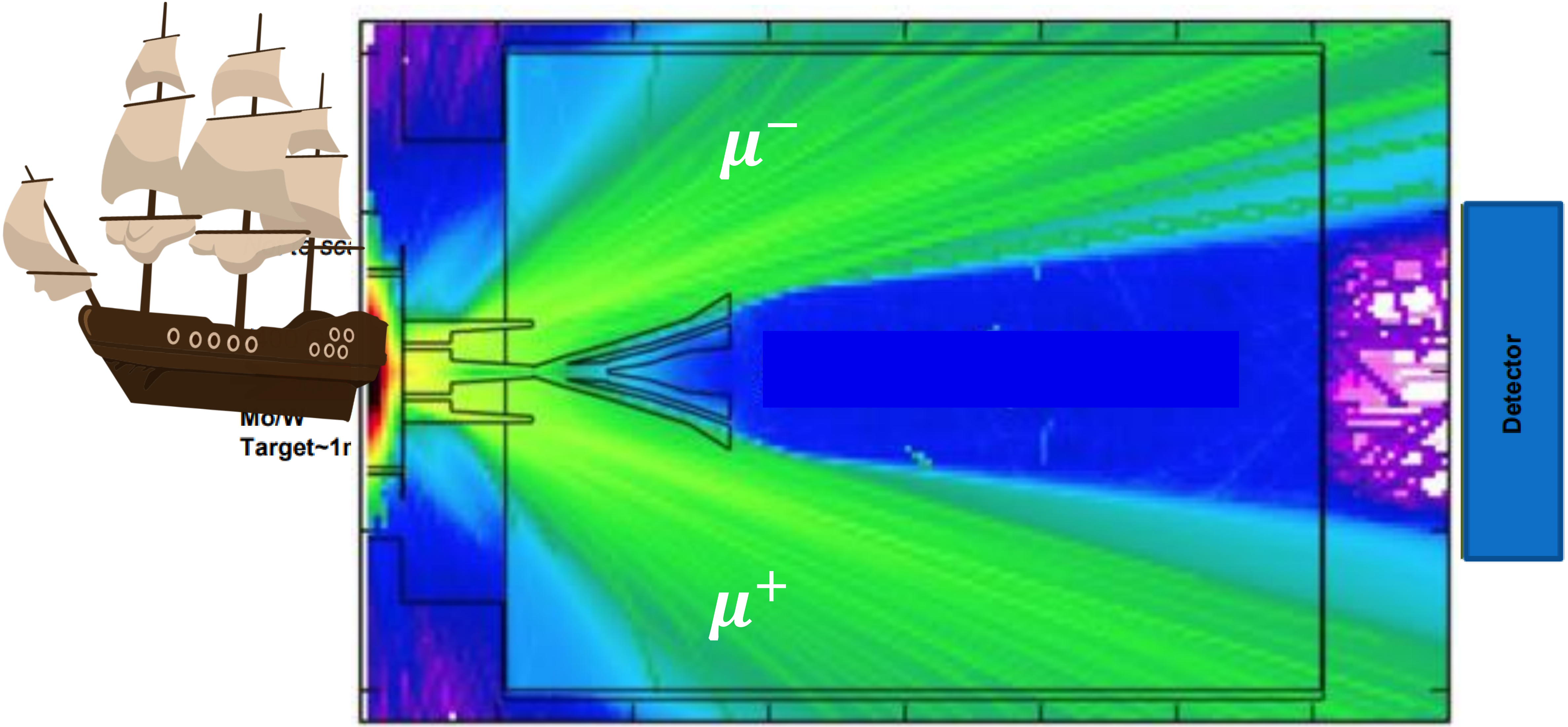
Approved together with ~ 170 MCHF for consolidation of the North Area (NA-CONS project)

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

SHiP has a bow wave…



HI-ECN3 Project Structure

PL: Matthew FRASER
DPL: Claudia AHDIDA

WP1
Project Management

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

WP8
Radiation Field & R2E/R2M Effects
Luigi ESPOSITO

HI-ECN3

WP3
Target & Beam Intercepting Devices
Rui FRANQUEIRA XIMENES

WP7
Infrastructure, Services & Civil Engineering
Fernando PEDROSA

WP4
Target Complex
Jean-Louis GRENARD

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

Other HI-ECN3 contributions at NBI 2024

The Search for Hidden Sector experiment and its tau neutrino program
Current & future facilities session: **Richard JACOBSSON**

Radiation protection studies and considerations for the ECN3 high intensity project
Radiological & safety issues session: **Claudia AHDIDA**

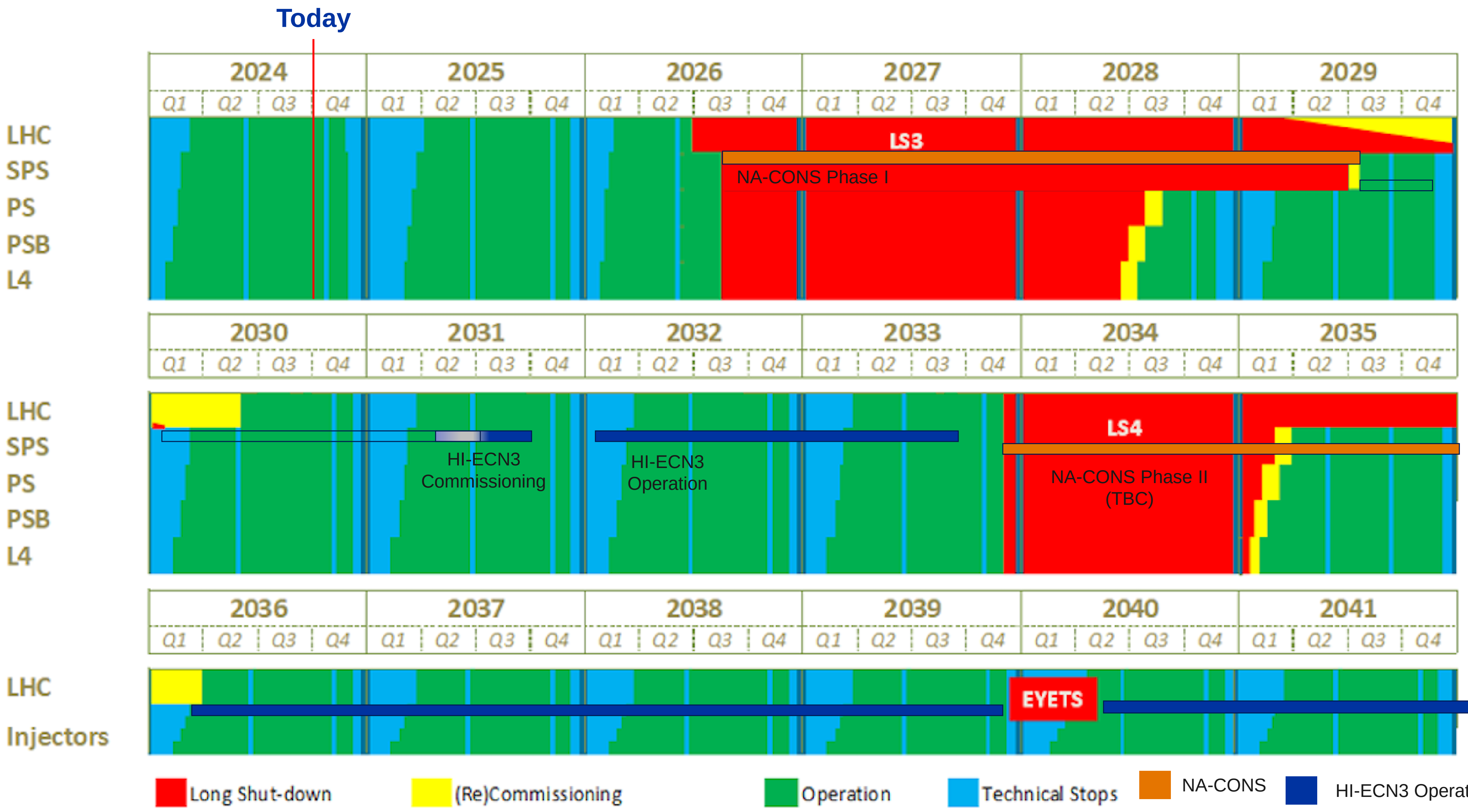
BDF target station design
Secondary beamline session: **Jean-Louis GRENARD**

Design considerations for the BDF/SHiP production target
Target and beam window session: **Rui Franqueira XIMENES**

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

SHiP
Search for Hidden Particles

CERN Accelerator Schedule



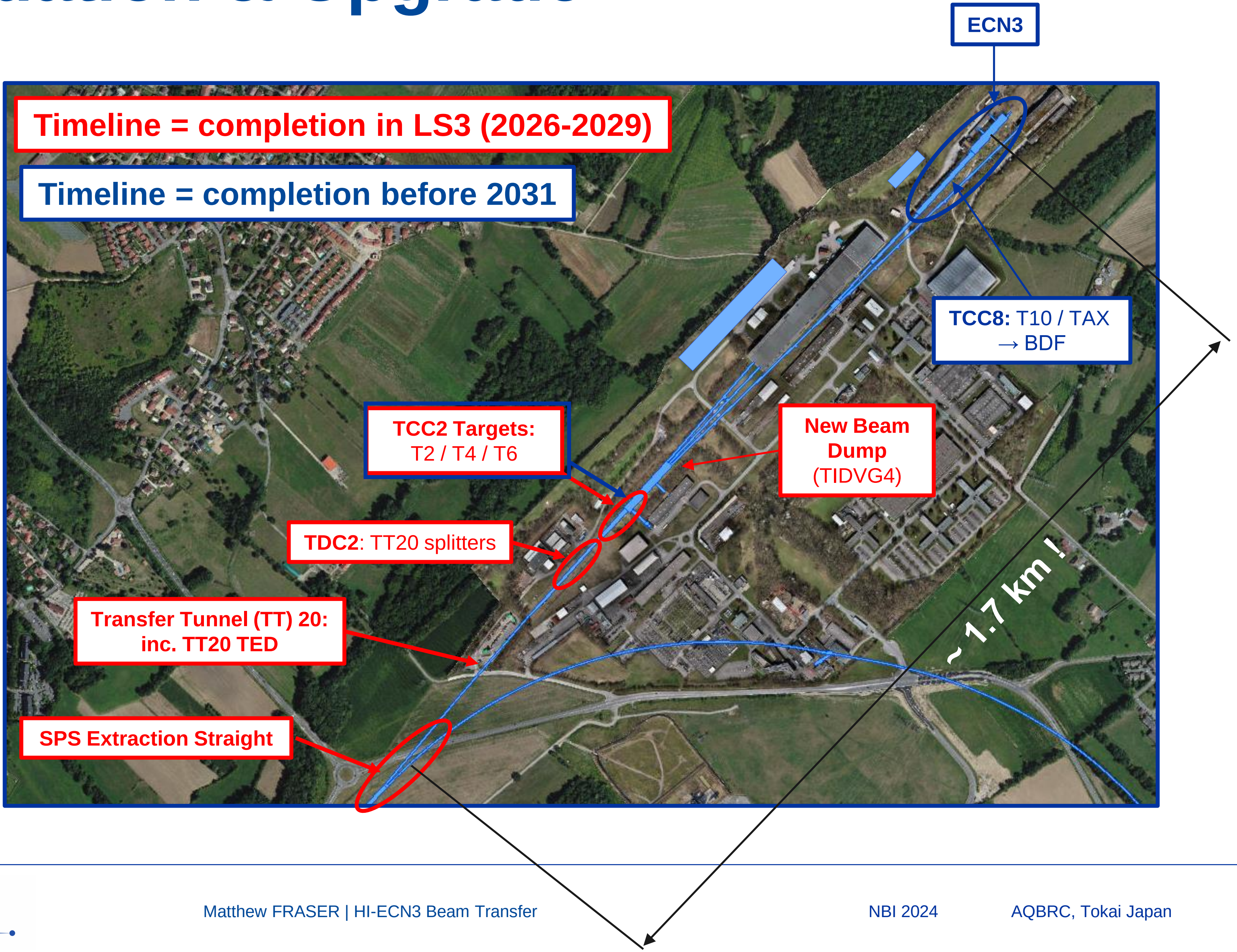
NA available exclusively for EHN1/2 from mid-2029:
Test-beam users & other POT demanding experiments (e.g. AMBER, MuonE)

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)

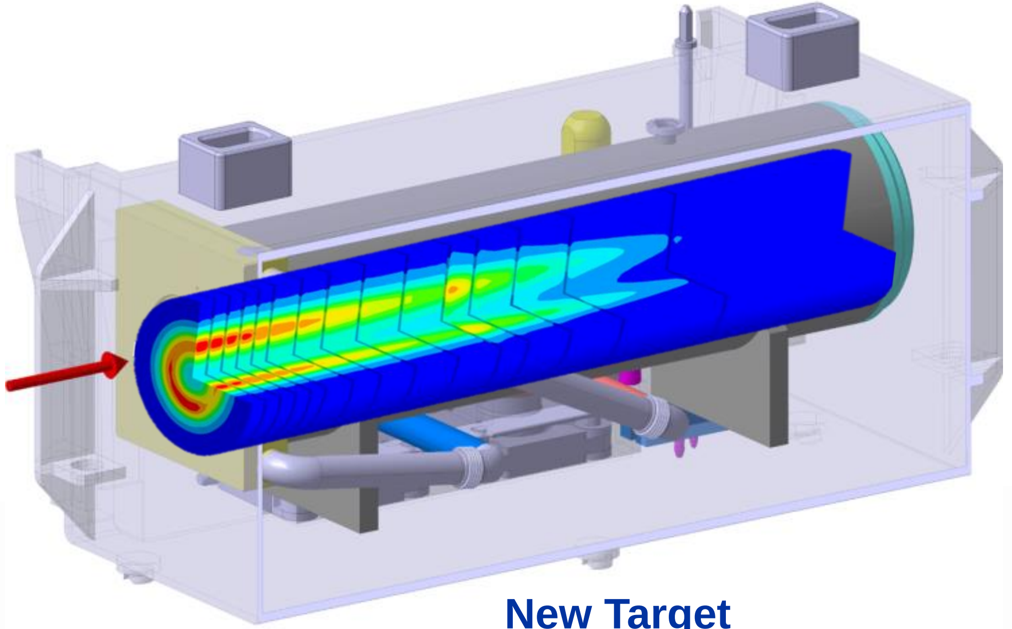
Consolidation & Upgrade

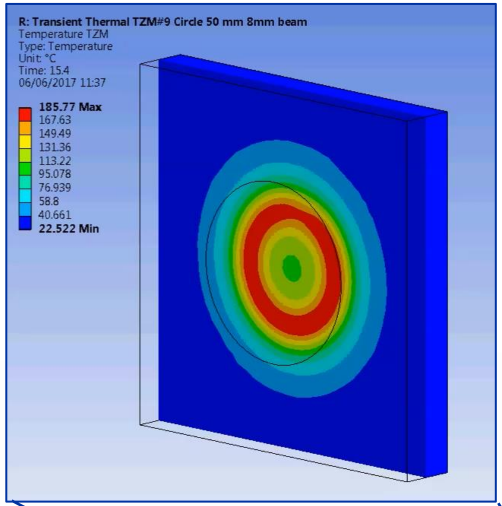
NA-CONS consolidation project
HI-ECN3 project

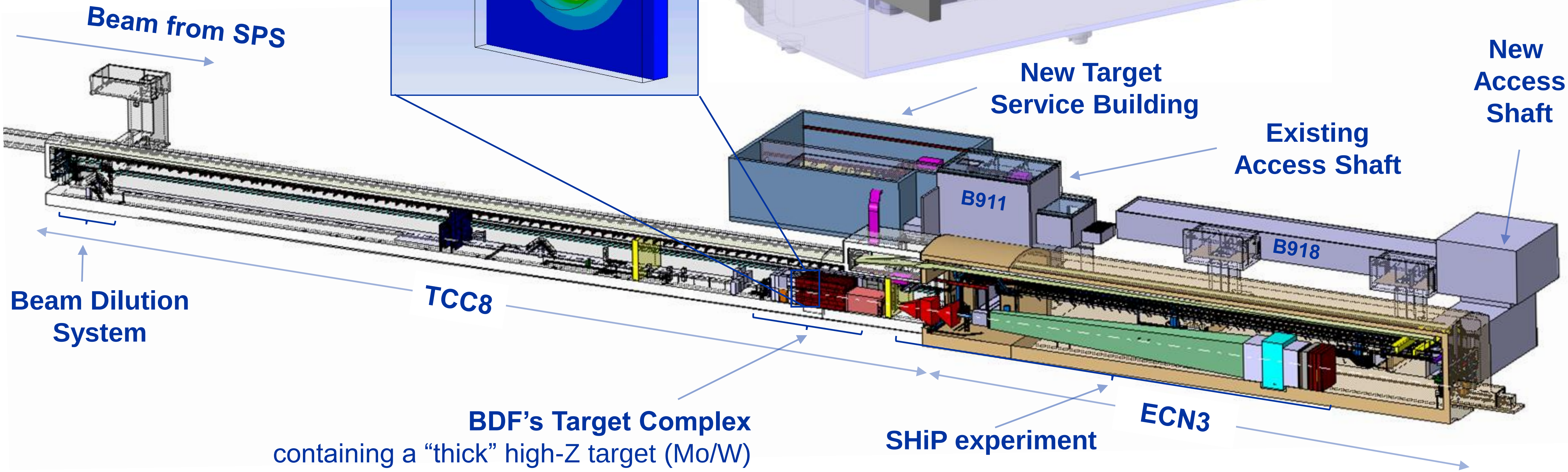


BDF/SHiP in ECN3

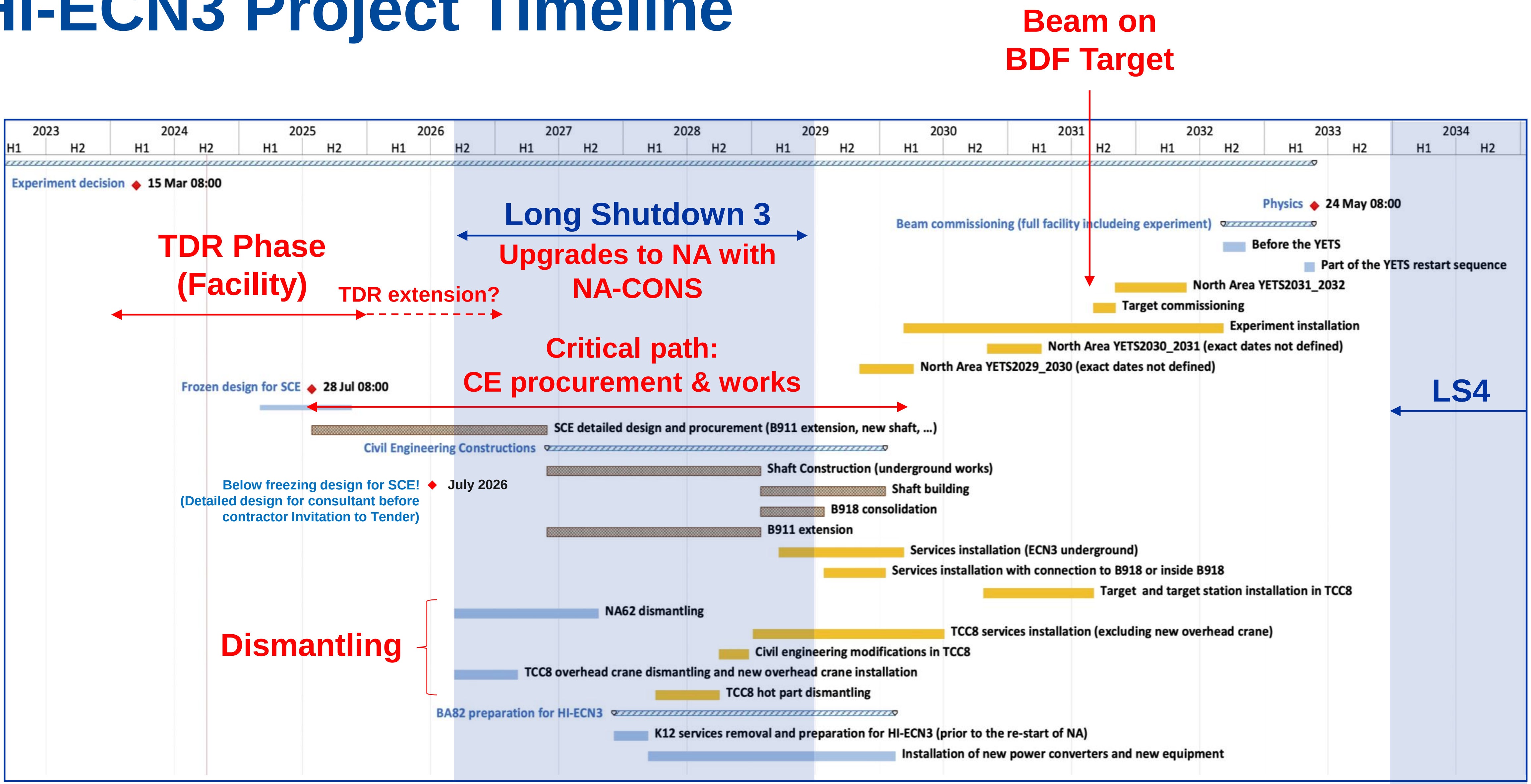
~ 300 kW (avg.)
~ 2.3 MW (spill)
1 second spill
4 Hz sweep







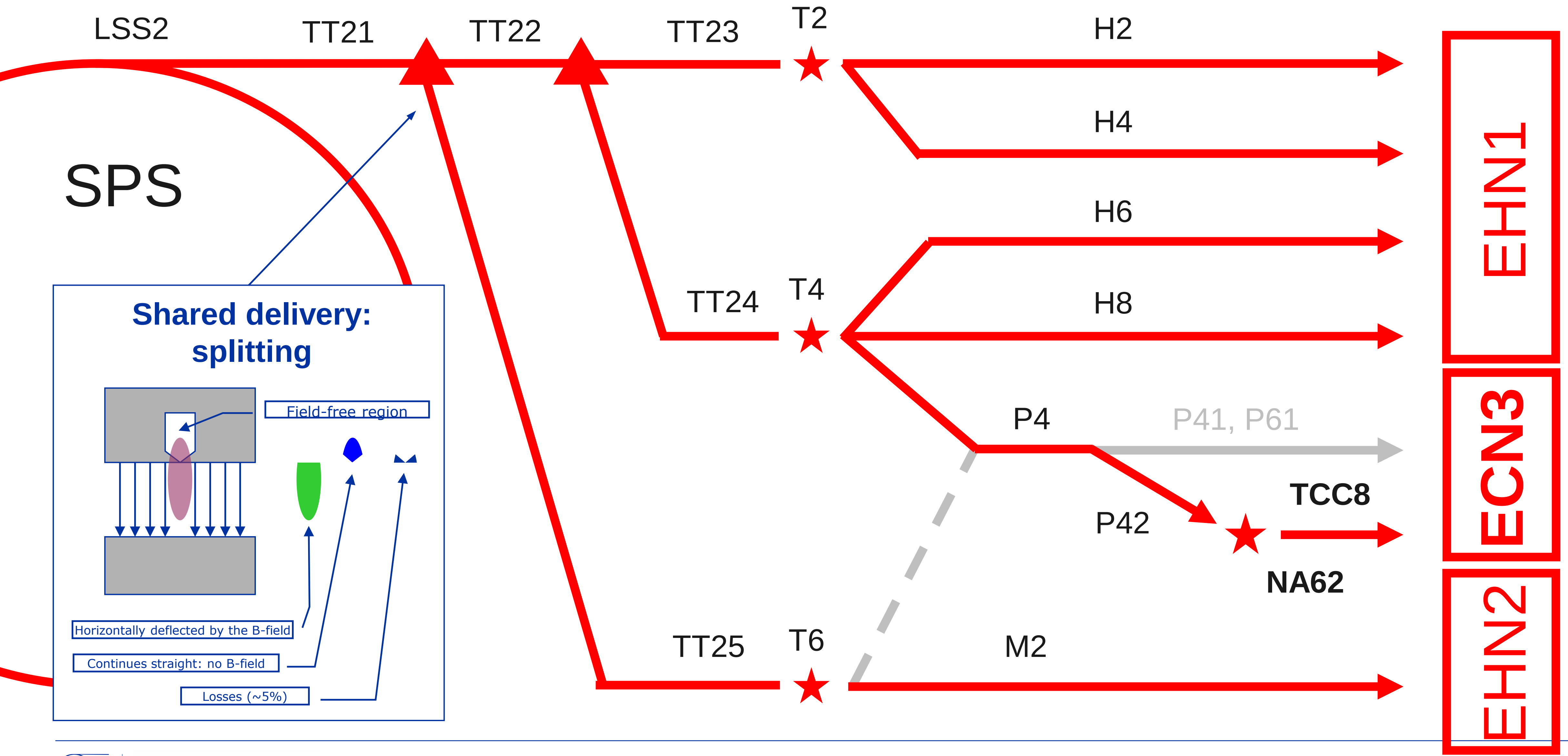
HI-ECN3 Project Timeline



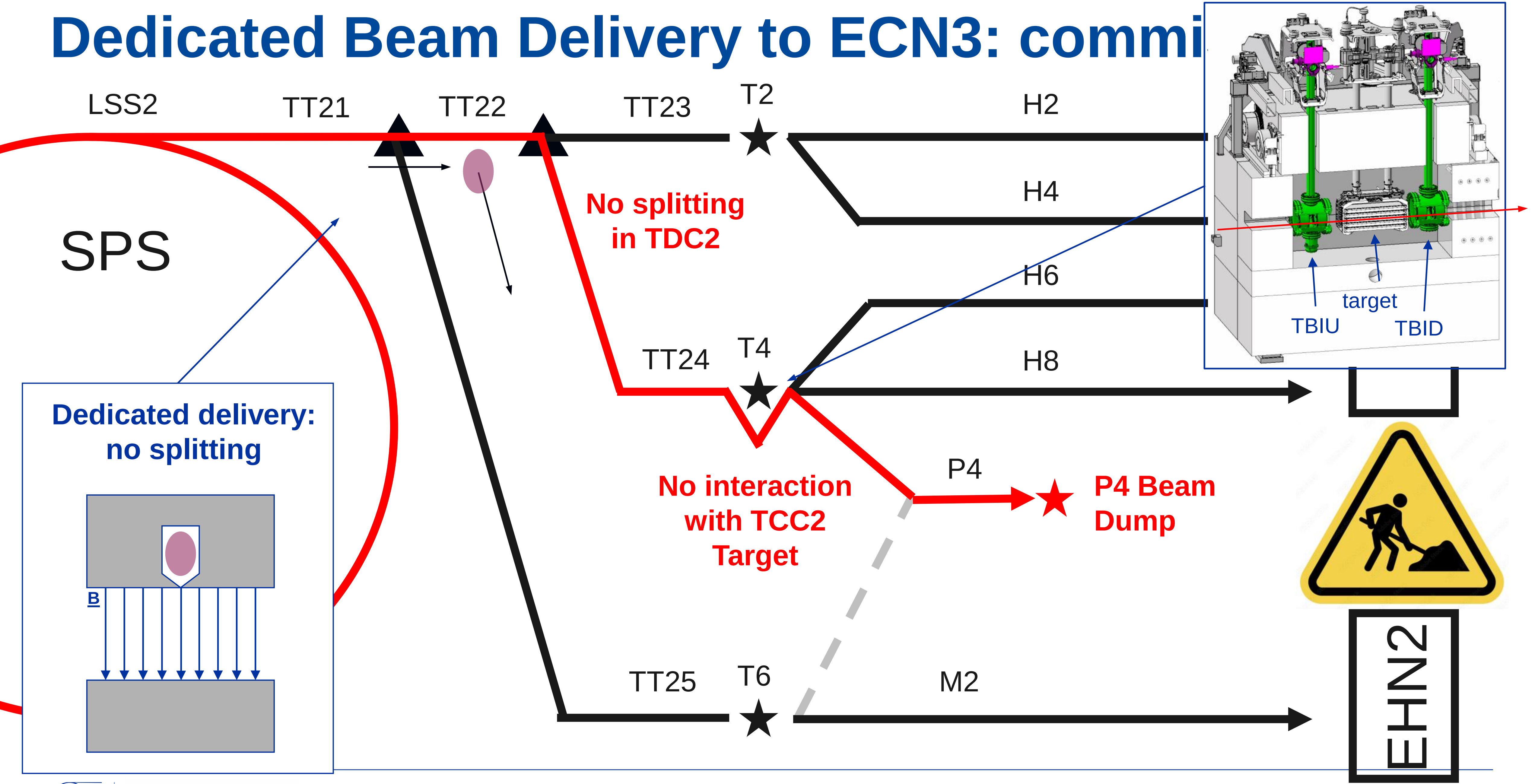
SHiP beam parameter request

BDF Parameter	Value
POT / year [10^{19}]	4.0 (similar to CNGS)
Spill intensity [10^{13}]	≥ 4.2 (including conservative transmission)
Spill length [s]	~ 1.0 on a 1.2 s flat-top (longer spills reduce achievable POT)
Spill quality	*… to be formailsed with SHiP*
BDF spills / year [10^{6}]	1.0
Vertical emittance	can be as bright as possible for transmission, **no splitting:** final focus will be adjustable (~ 8×8 mm spot size, swept on target)
Total POT on BDF	60×10^{19}
Duration [years]	15 (at 4×10^{19} POT/year)

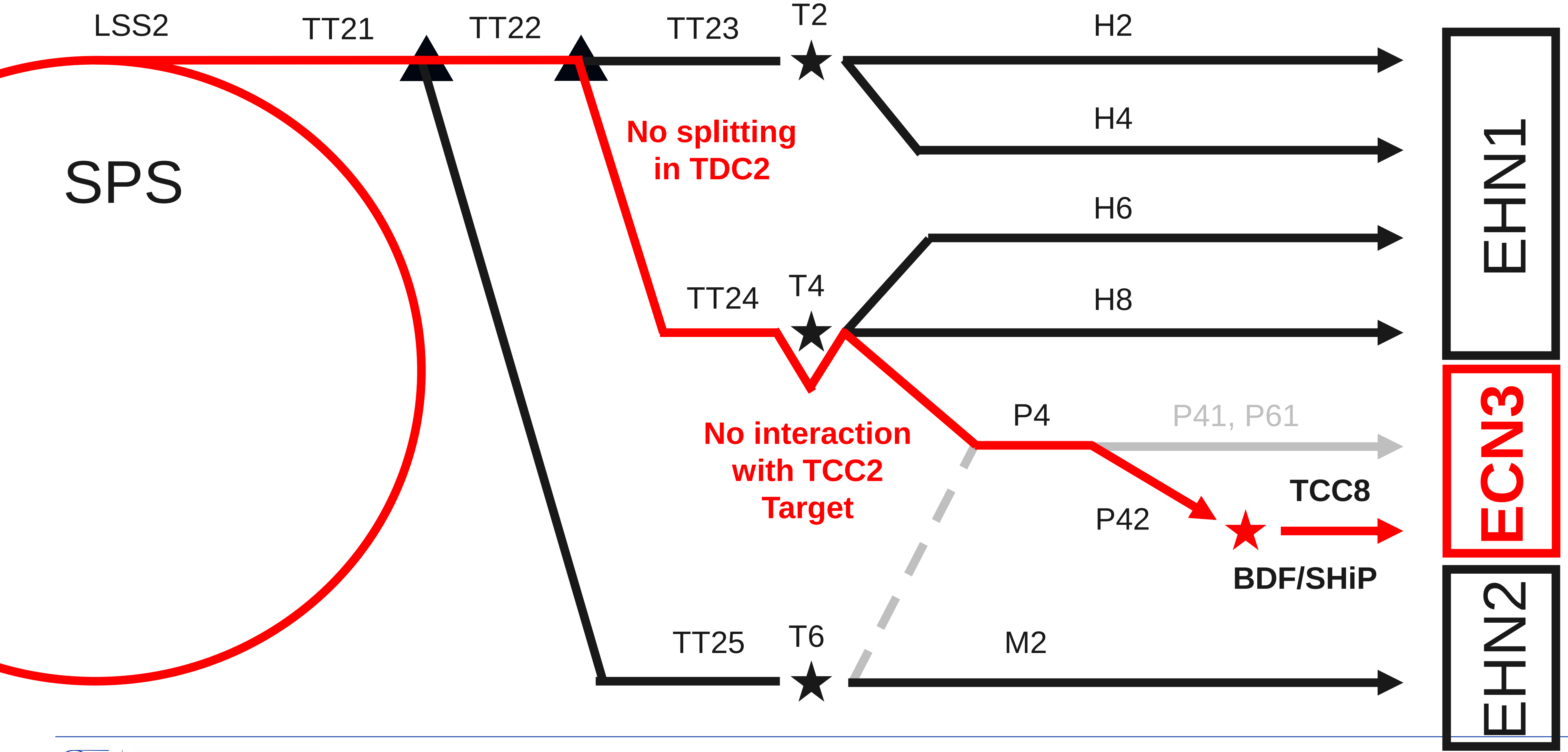
~~Shared Beam Delivery to ECN3~~



Dedicated Beam Delivery to ECN3: commi

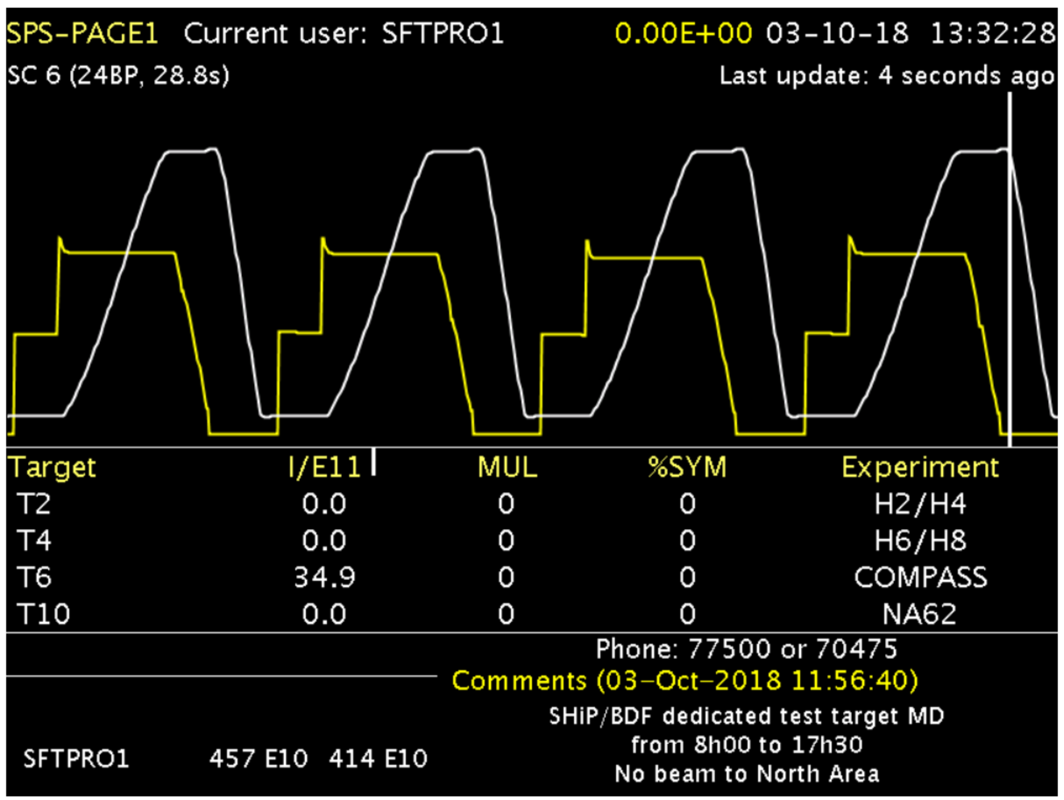


Dedicated Beam Delivery to ECN3



How many protons for BDF / SHiP? (i)

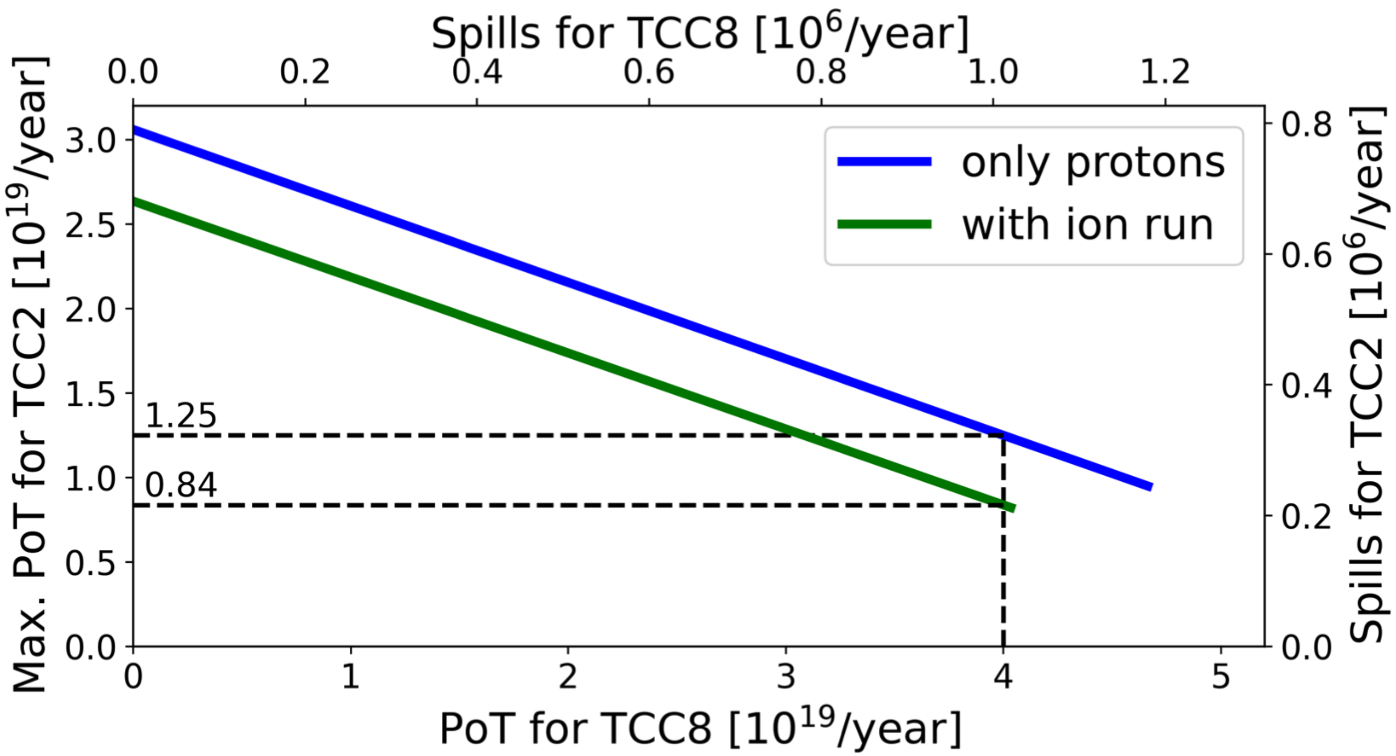
Short CNGS-like 7.2 s SFTPRO cycle with a 1.2 s FT (~ 1 s spill)



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)



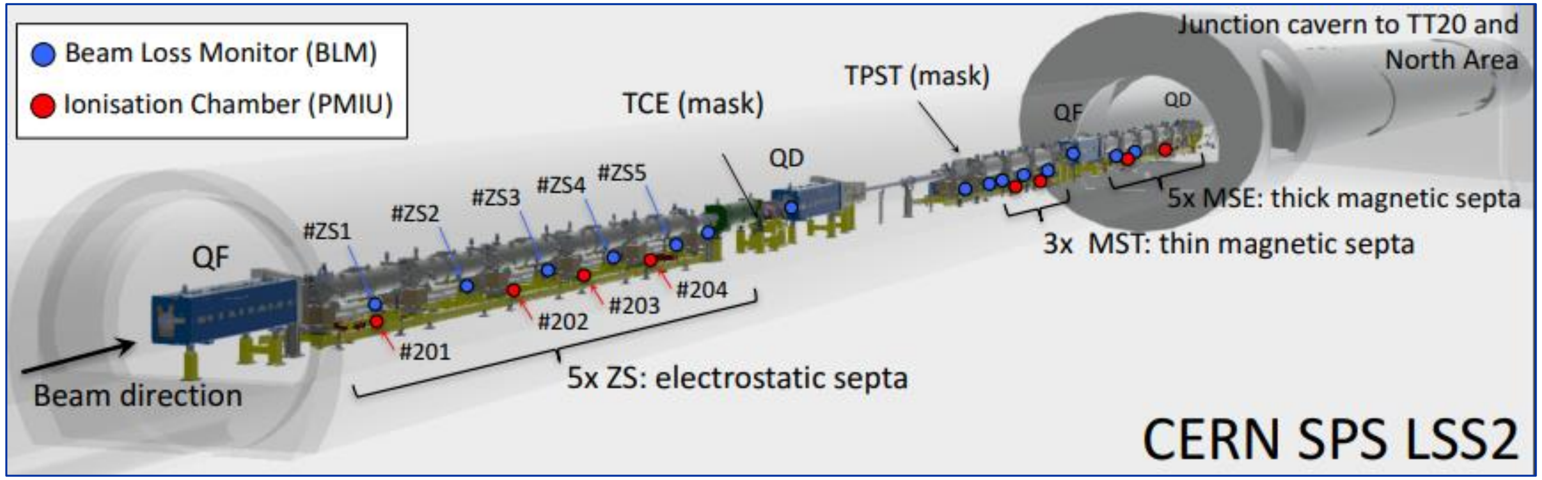
Protons to ECN3 (BDF/SHiP)

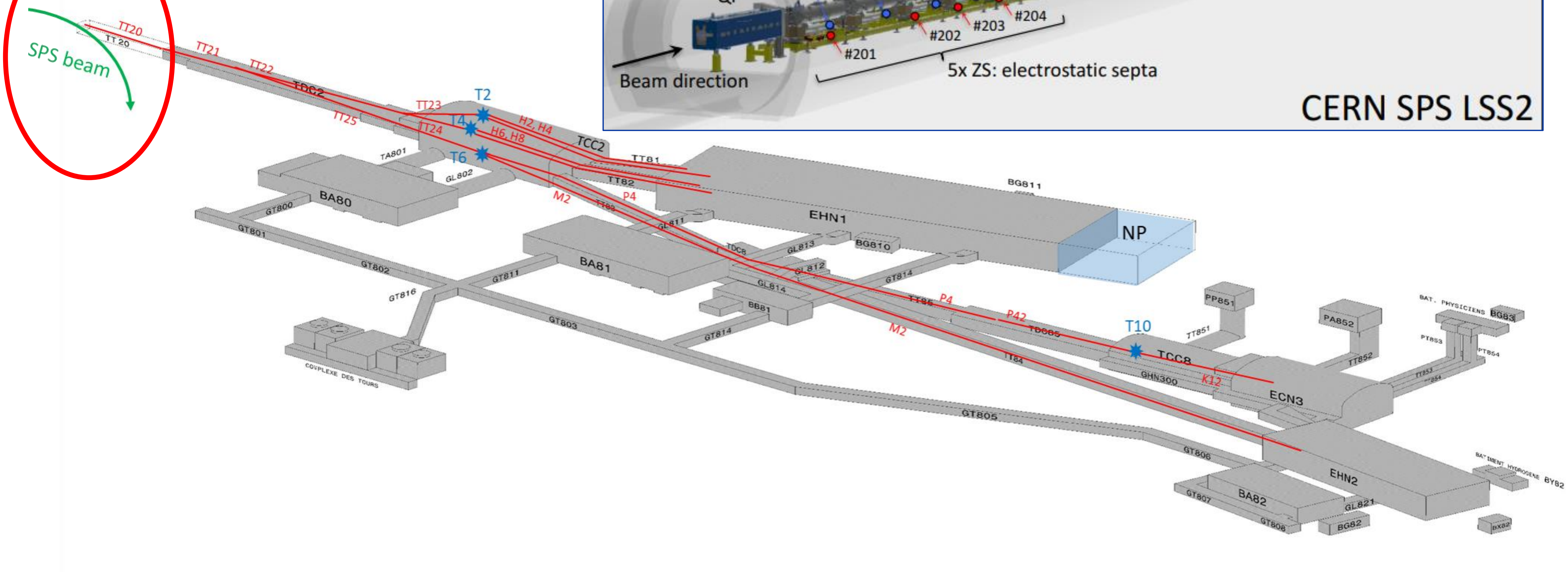
North Area needs
~ 5×10^{19} protons/year…
a la CNGS (~4×10^{19} p^+/y)

… but, slow extracted…

…unprecedented !

Slow Extraction from LSS2 in SPS

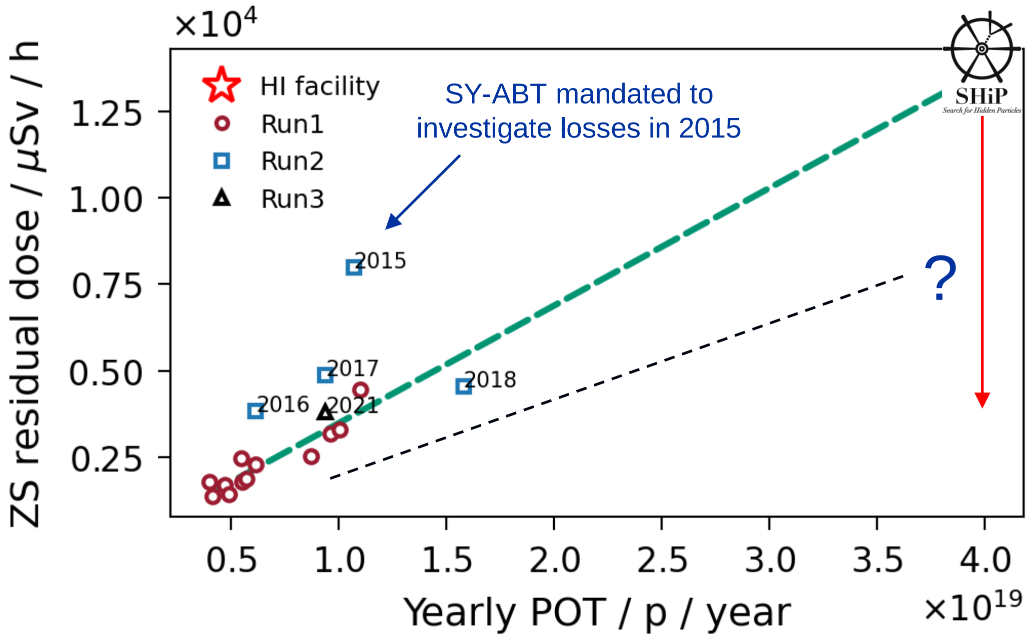




Slow extraction beam loss reduction

Objective: to achieve a beam loss reduction factor of ~ 4 in stable, in long-term operation

Correlation between end of year activation dose rate (peak at electrostatic septum) and annual POT

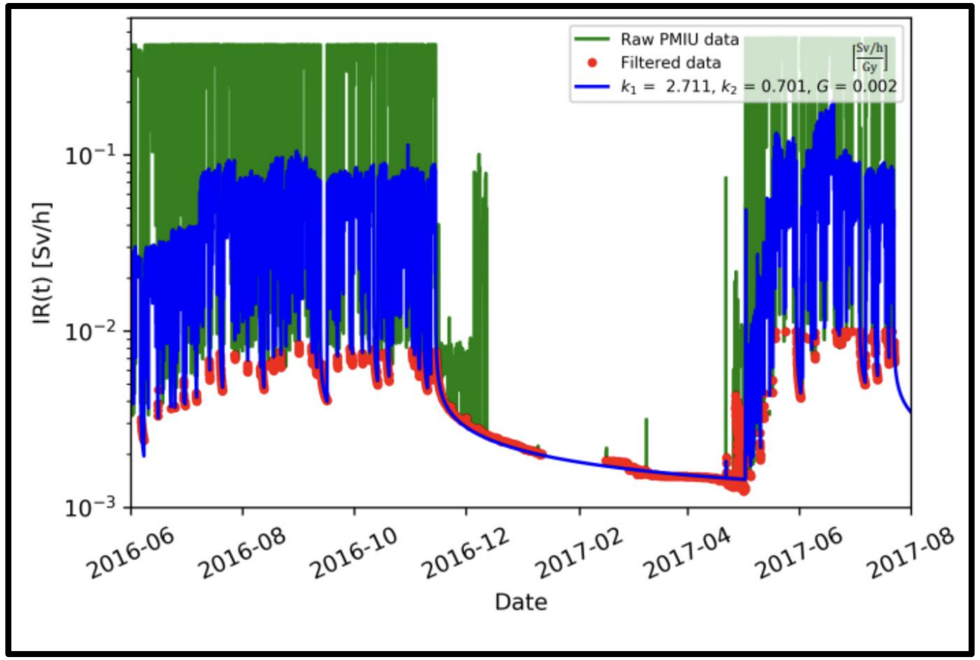


Modelling induced radioactive in the SPS

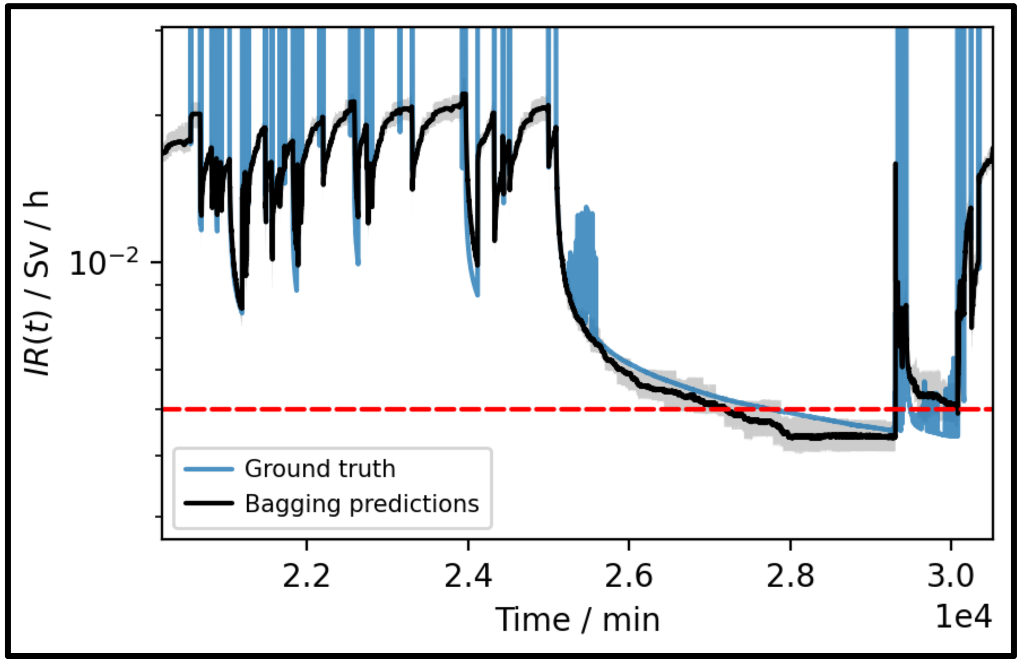
Radiation hazards of future operational scenarios can be predicted using **data driven models**: fit measured prompt beam loss [Gy] & proton flux [p⁺] to RP monitor [Sv/h]

Semi-analytic: $\mathrm{IR}(t) \propto \exp\left(-k_1 \ln(t)^{k_2}\right)$

Machine Learning: LightGBM: A Highly Efficient Gradient Boosting Decision Tree

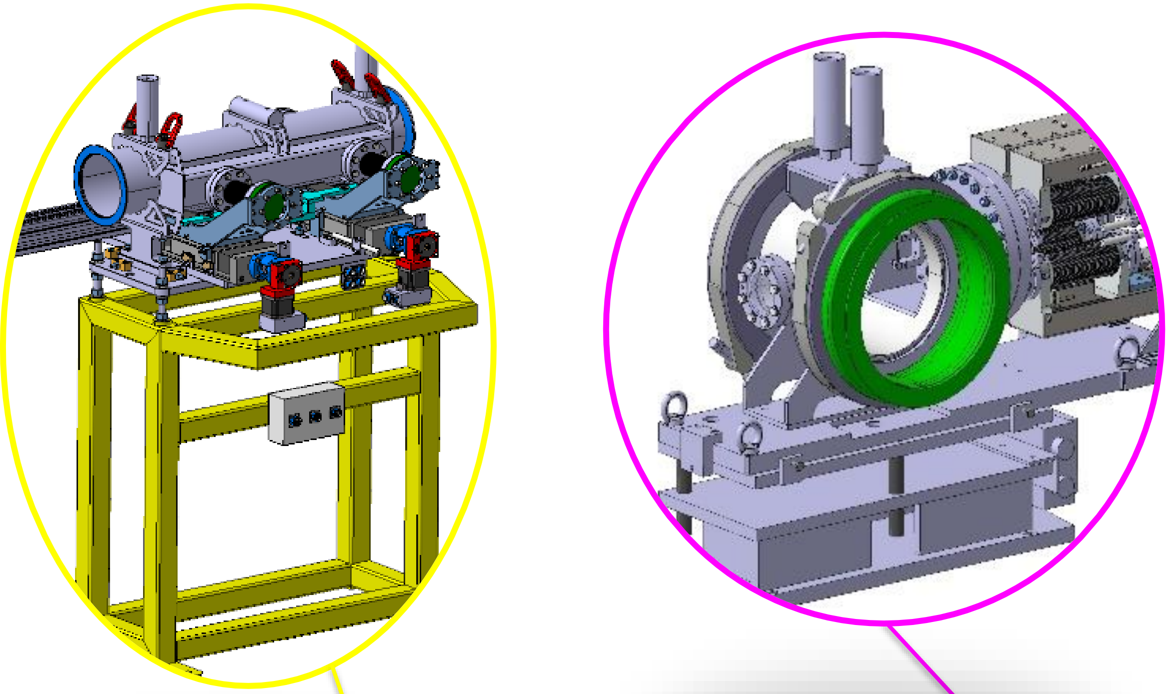


t(function call) ~ minute

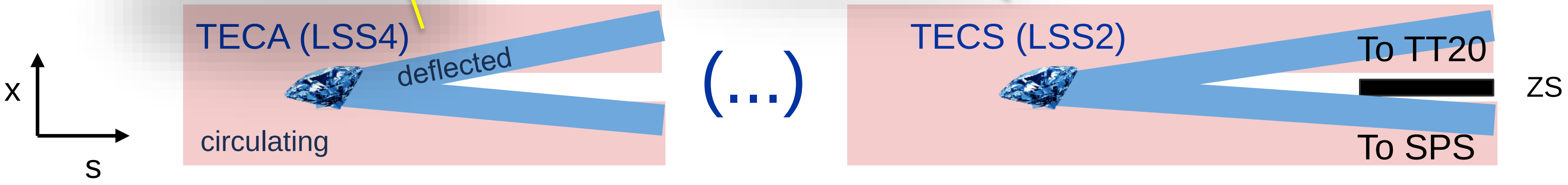


t(function call) ~ ms

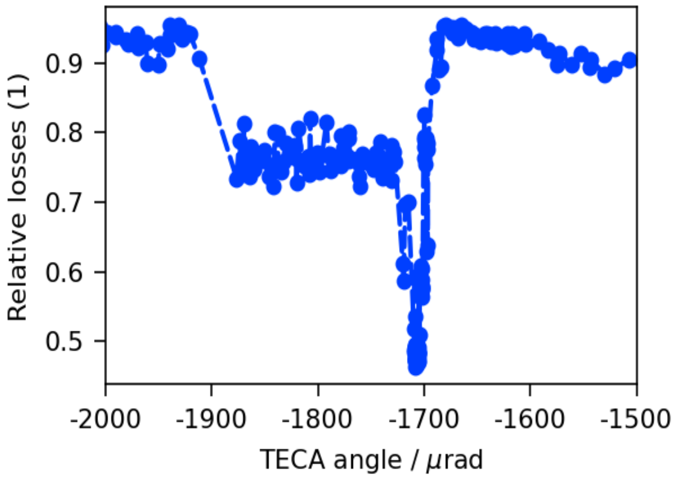
Crystal Shadowing of electrostatic septa

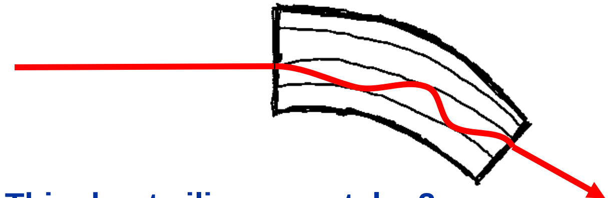


LSS2 gonio already operational with 20% loss reduction



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



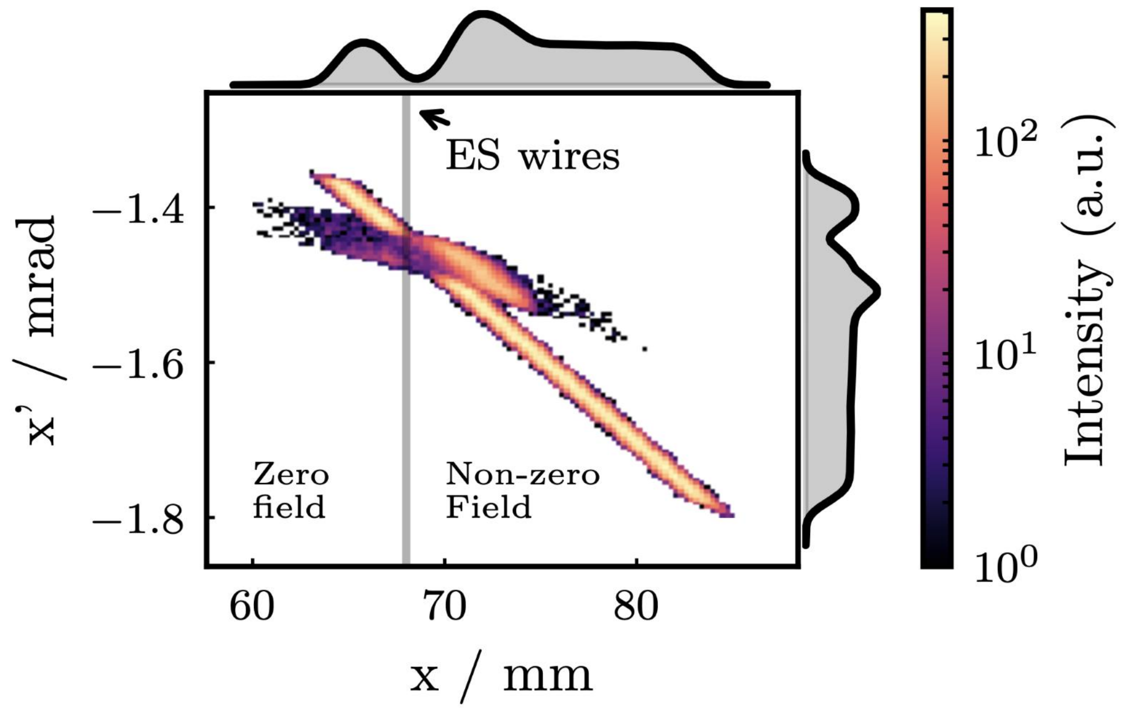


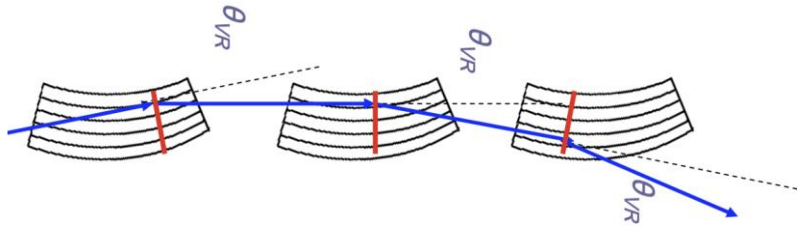
Thin, bent silicon crystal ~ 2 mm thick, 2 mm long

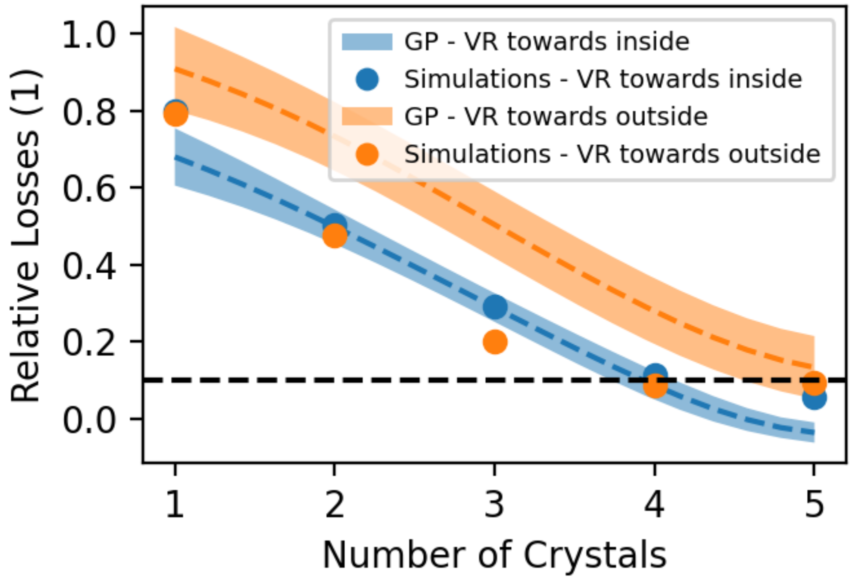
Crystal Shadowing of electrostatic septa (ii)

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

- Prototype might be available for tests in 2025 (mechanics developed in-house at CERN)



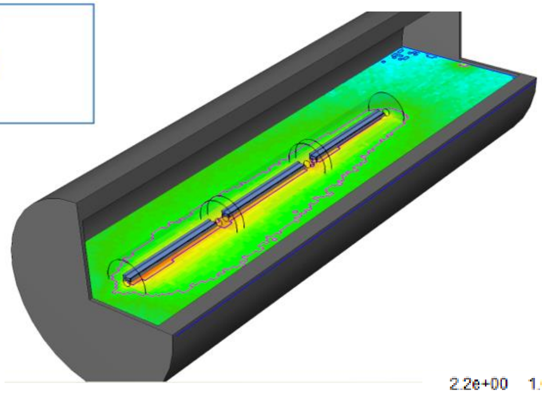




Low-density septa

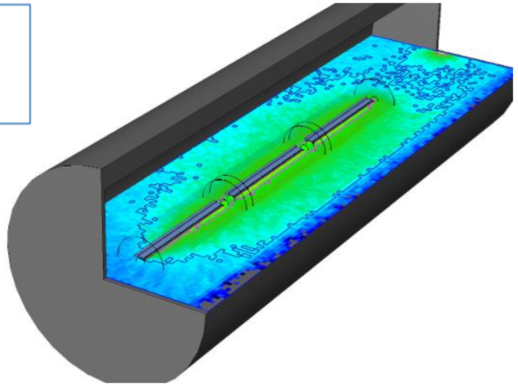
Today

Wires: Re/W
Anode: Steel
Tank: Steel



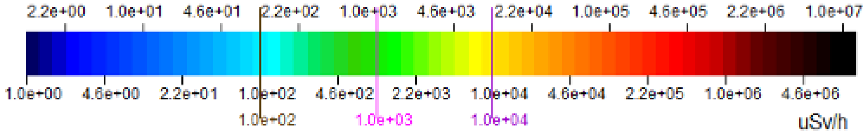
Dream world

Wires: Be
Anode: Aluminium
Tank: Aluminium



20x reduction!

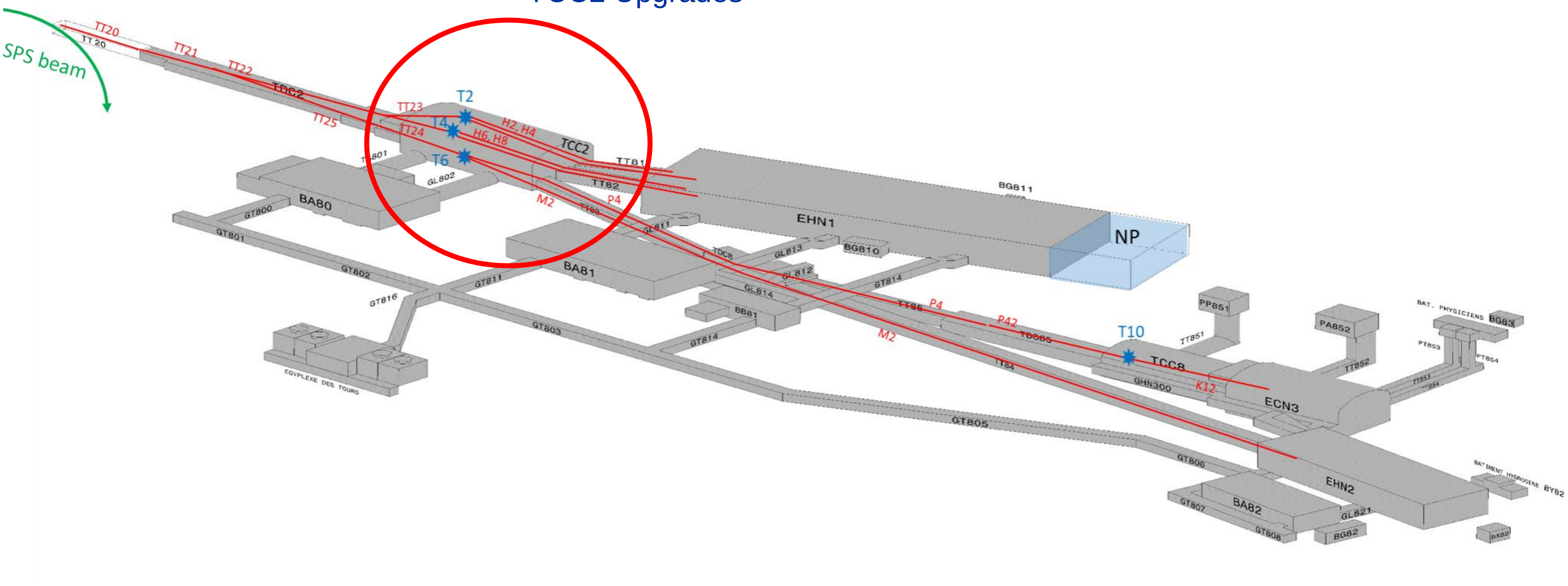
Residual dose rate after 1 week



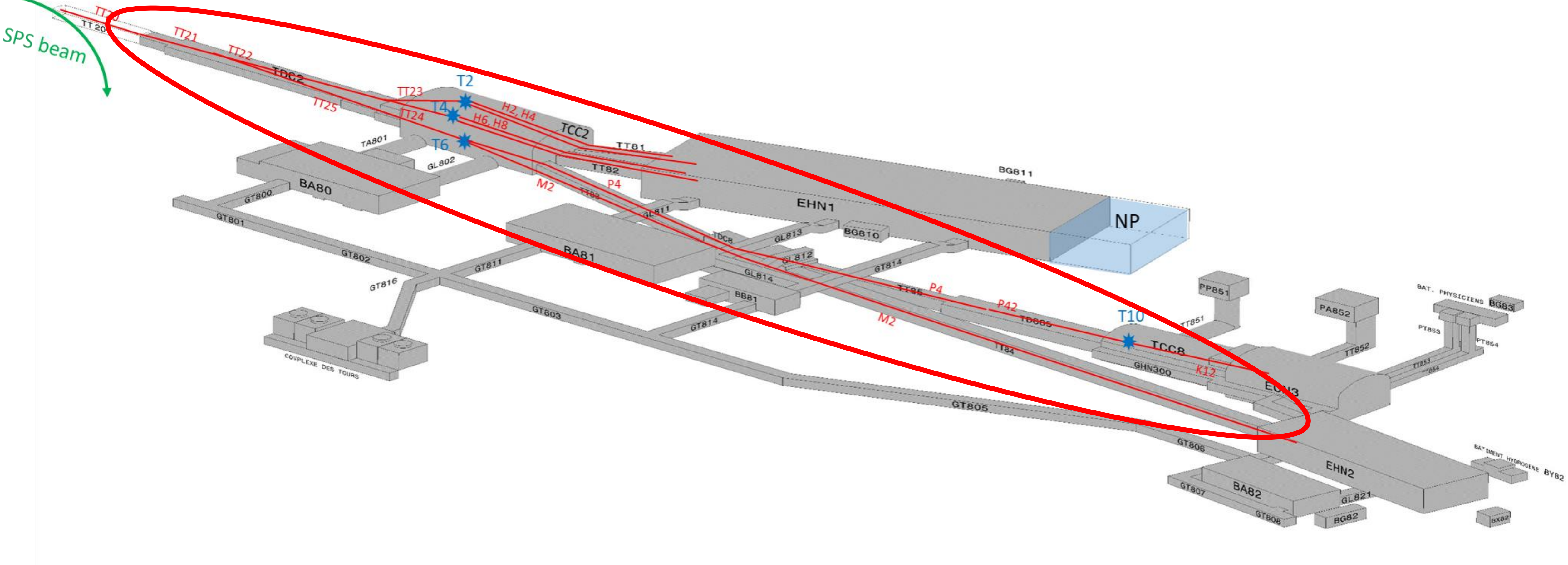
Efforts focused on tank material as the best candidate: feasible + factor 2 dose reduction

- Selection of alloy → Al 5083
- Design of low-Z flanges → Bimetallic flange
- Buckling tests → mass reduction of 2.7x w.r.t. current tank
- Manufacturing → mock-up + welding tests

TCC2 Upgrades



Beam transfer from SPS to EC3

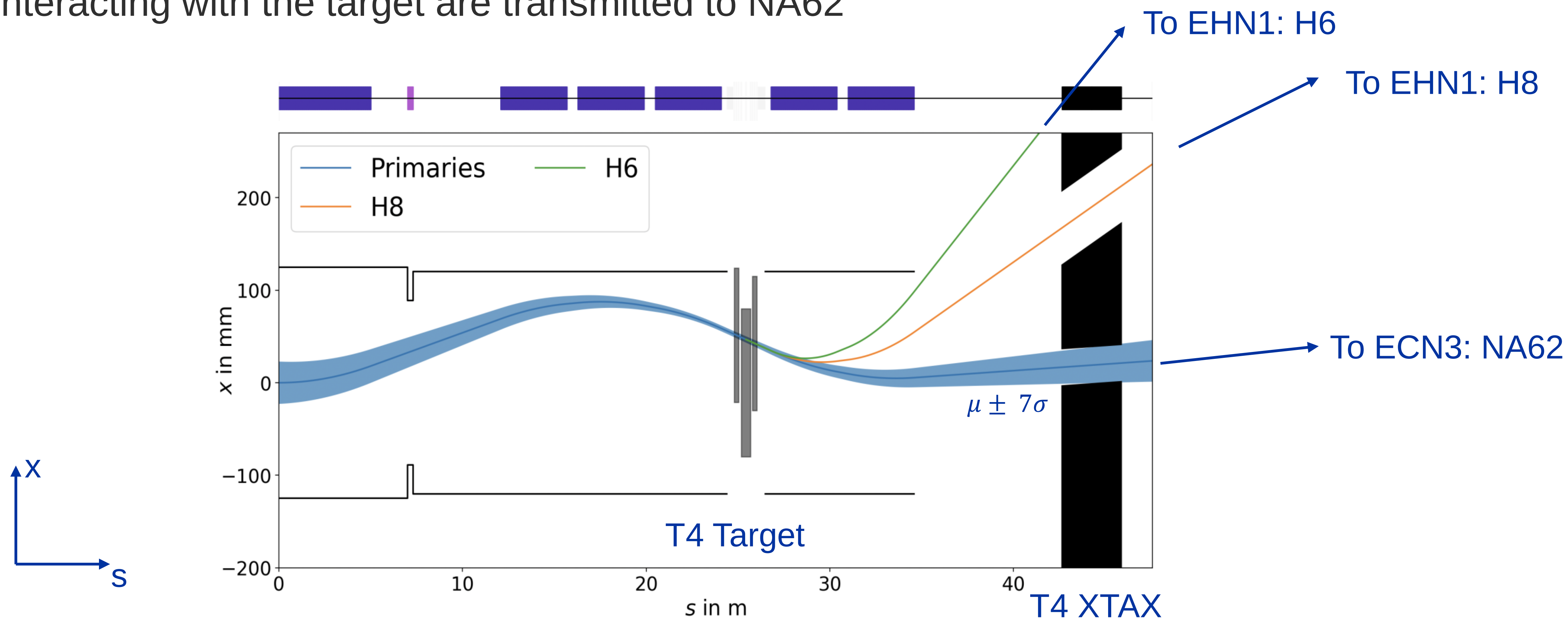


A huge effort is ongoing to improve understanding of old 1970's transfer line equipment

Existing TCC2 Target T4 Region

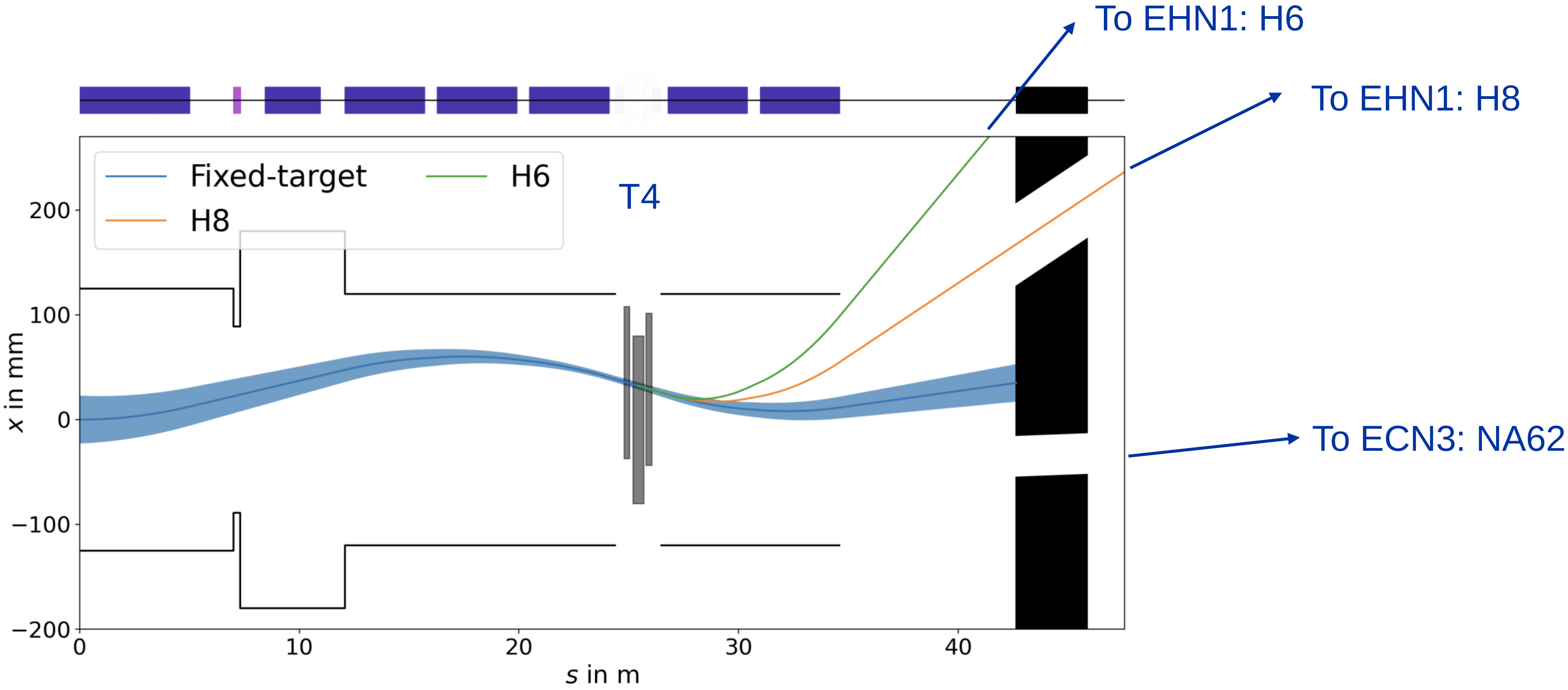
Today, operation of EHN1 (H6/H8 test beams) is coupled with ECN3 (NA62)

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



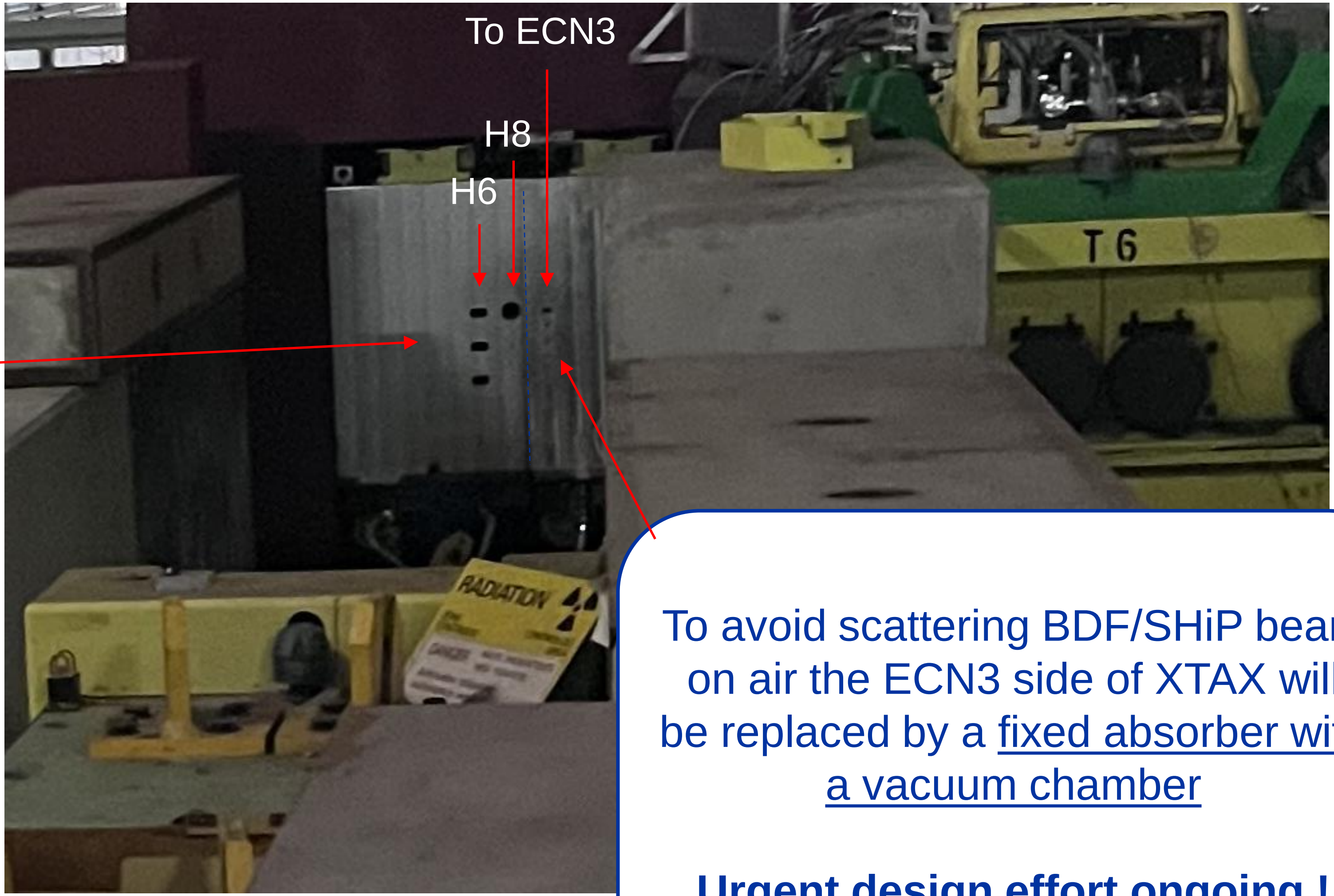
Upgrade for BDF/SHiP

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)



T4 XTAX absorber in TCC2

Looking downstream from on top of T4 target

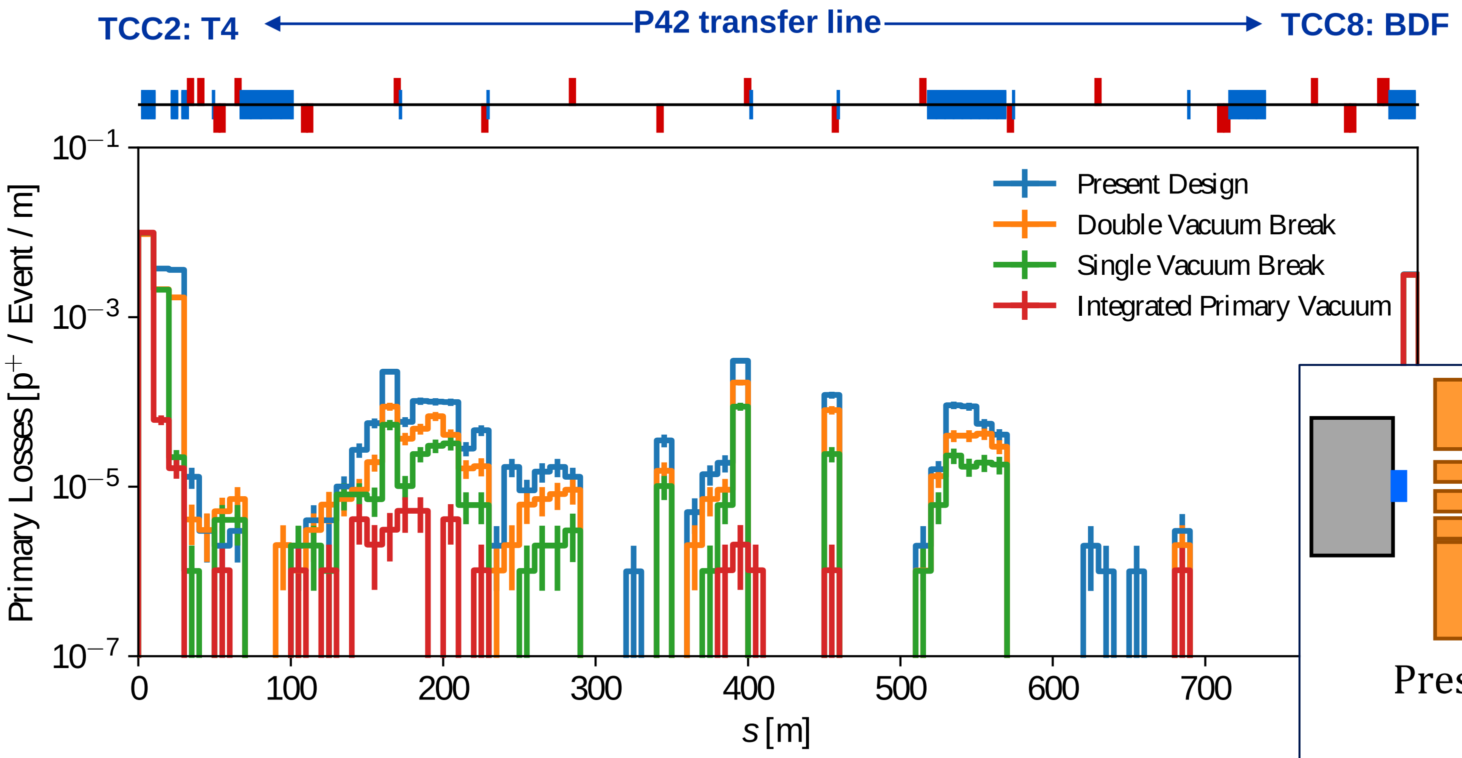


To avoid scattering BDF/SHiP beam on air the ECN3 side of XTAX will be replaced by a <u>fixed absorber with a vacuum chamber</u>

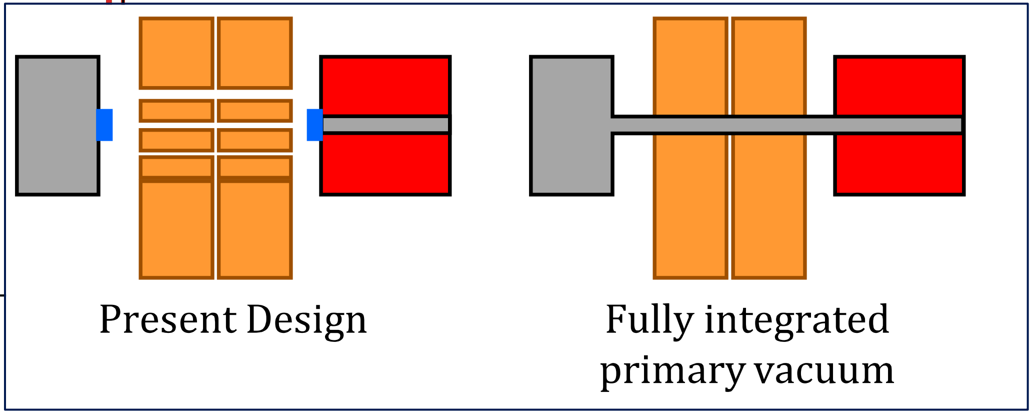
Urgent design effort ongoing !

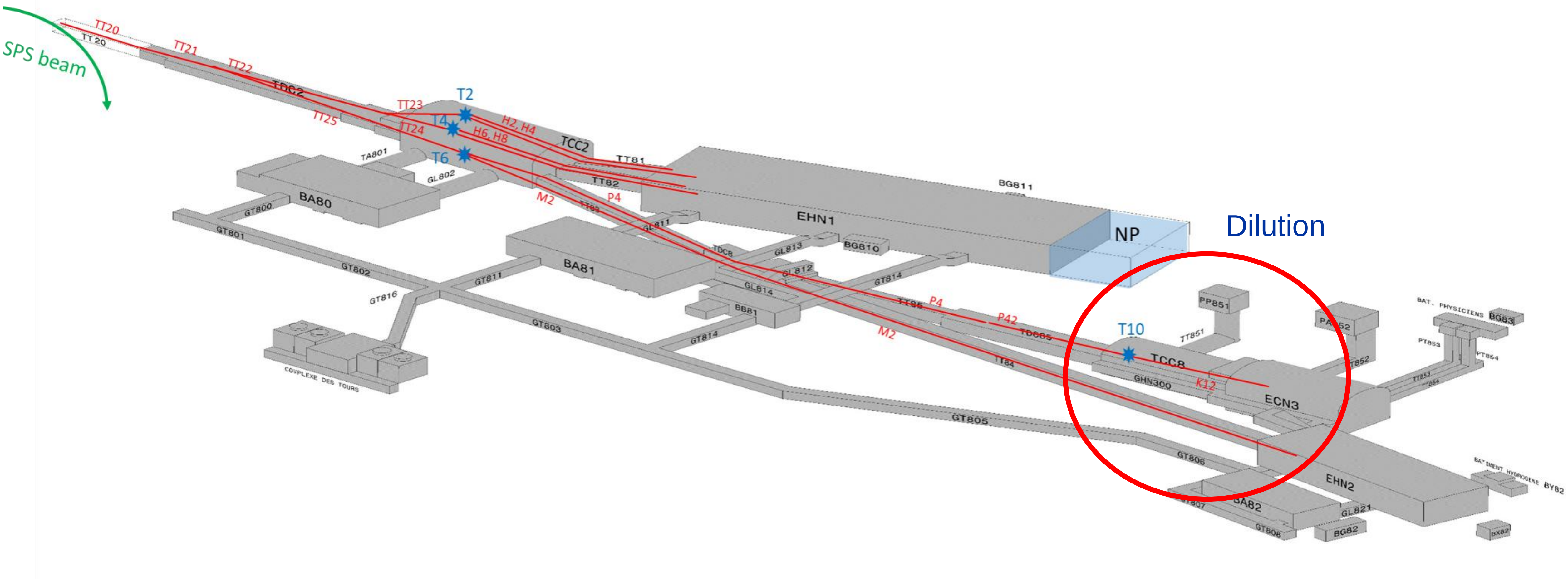
TCC2 Target System Upgrade

- **Reduce beam loss in P42 transfer line to ECN3:**
  - Putting XTAX under a continuous primary vacuum of ~10^{-3} mbar will reduce the beam loss in the shallow transfer tunnels from TCC2 to ECN3 caused by scattering of BDF/SHiP (by up to a factor ~ 50!)



Detailed design underway




SPS beam
TT20
TT21
TT22
TDC2
TT23
TT24
TT25
T2
T4
T6
H2, H4
H6, H8
TCC2
TT81
TT82
M2
P4
EHN1
BG811
NP
Dilution
BA80
BA81
T10
TCC8
K12
ECN3
EHN2
P42
GT805
GT803
GT802
GT801
GT800
COMPLEXE DES TOURS

BDF Dilution System

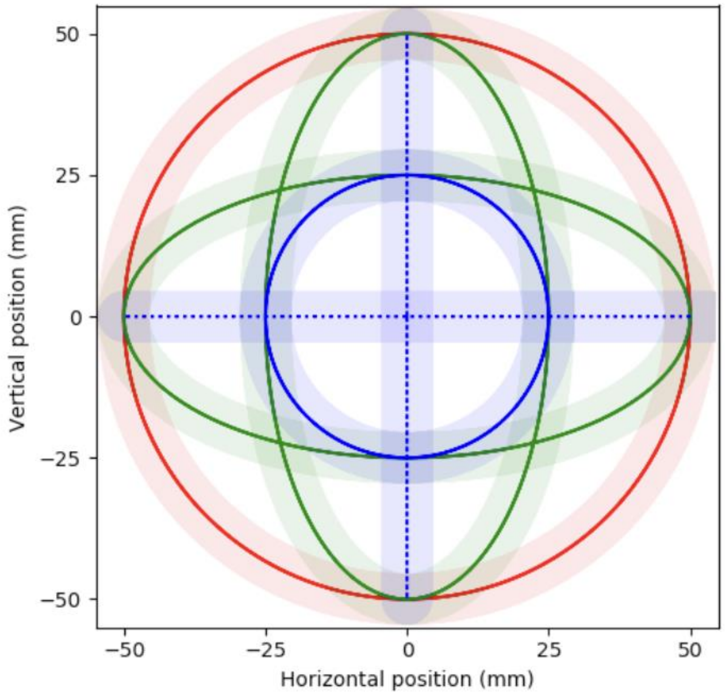
Present baseline:

- 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

Summary

- BDF/SHiP was approved in 2024
- CERN has reserved budget in its MTP for a new facility in ECN3 under the project named HI-ECN3
- We are under pressure to meet NA-CONS deadlines for Long Shutdown 3 and in the last 6 months we have focused on beam delivery in the North Area
- Some ~ 10 years of slow extraction R&D will converge into a Technical Design Report as part of the HI-ECN3 TDR
- HI-ECN3 TDR to be published in 2026, aiming at beam on target in 2031 !

home.cern