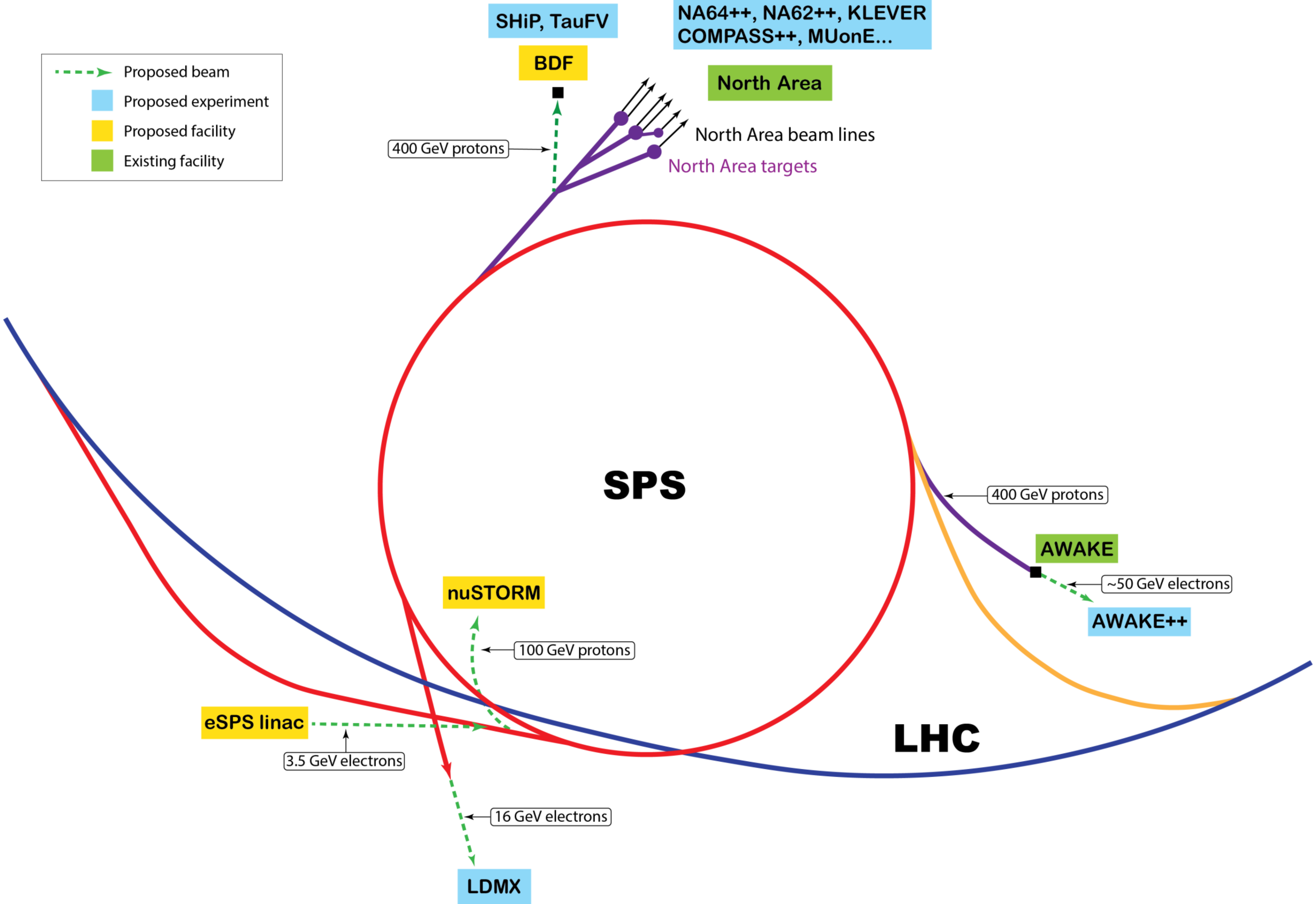
Beam Dump Facility

C.C. Ahdida , P. Avigni , F. Bardou , J. Bauche , J. Busom , M. Calviani , M. Casolino , L. Dougherty , Y. Dutheil , M.A. Fraser , L. Gatignon , J. Gall , B. Goddard , JL. Grenard , D. Grenier , C. Hessler , R. Jacobsson , V. Kain , K. Kershaw , E. Koukovini Platia , M. Lamont , E. Lopez Sola , S. Marsh , Y Muttoni , P Ninin , J.A. Osborne , A. Perillo Marcone , J. Prieto Prieto , F. Sanchez Galan , P. Santos Diaz , L. Stoel , Heinz Vincke , Helmut Vincke , F.M. Velotti , T. Wijnands .


Proposed beam
Proposed experiment
Proposed facility
Existing facility
SHiP, TauFV
NA64++, NA62++, KLEVER
COMPASS++, MUonE...
BDF
North Area
400 GeV protons
North Area beam lines
North Area targets
SPS
400 GeV protons
AWAKE
~50 GeV electrons
AWAKE++
nuSTORM
100 GeV protons
eSPS linac
3.5 GeV electrons
LHC
16 GeV electrons
LDMX

North Area

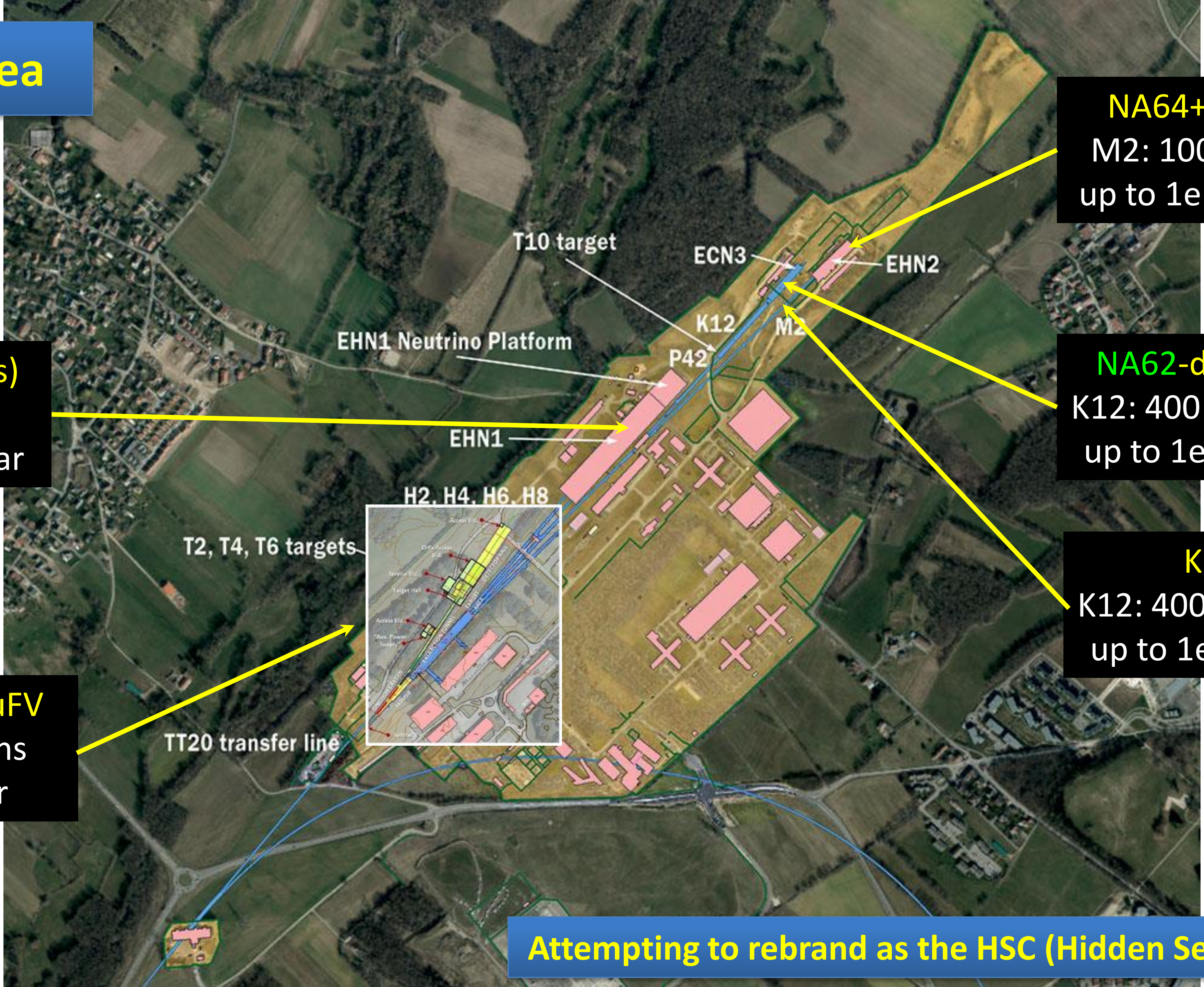
NA64++ (muons)
M2: 100 – 160 GeV
up to 1e13 mot/year

NA64++ (electrons)
H4: 100 GeV
up to 5e12 eot/year

NA62-dump mode
K12: 400 GeV protons
up to 1e19 pot/year

KLEVER
K12: 400 GeV protons
up to 1e19 pot/year

BDF -> SHiP, TauFV
400 GeV protons
4e19 pot/year

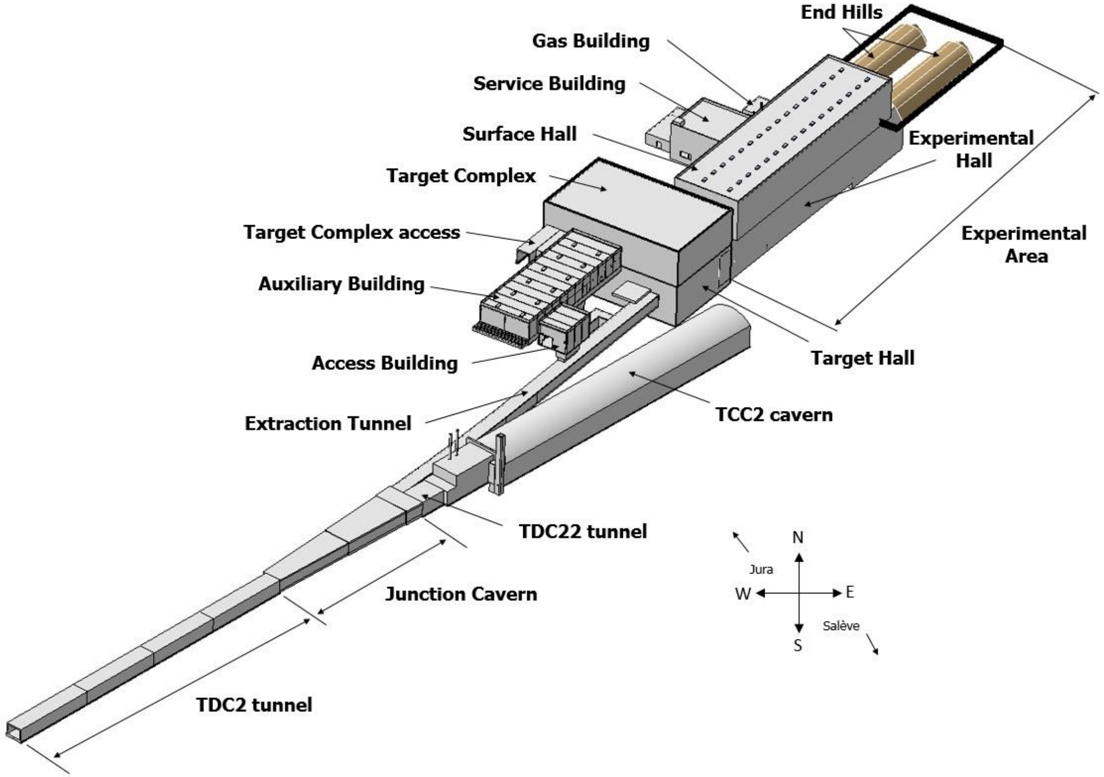


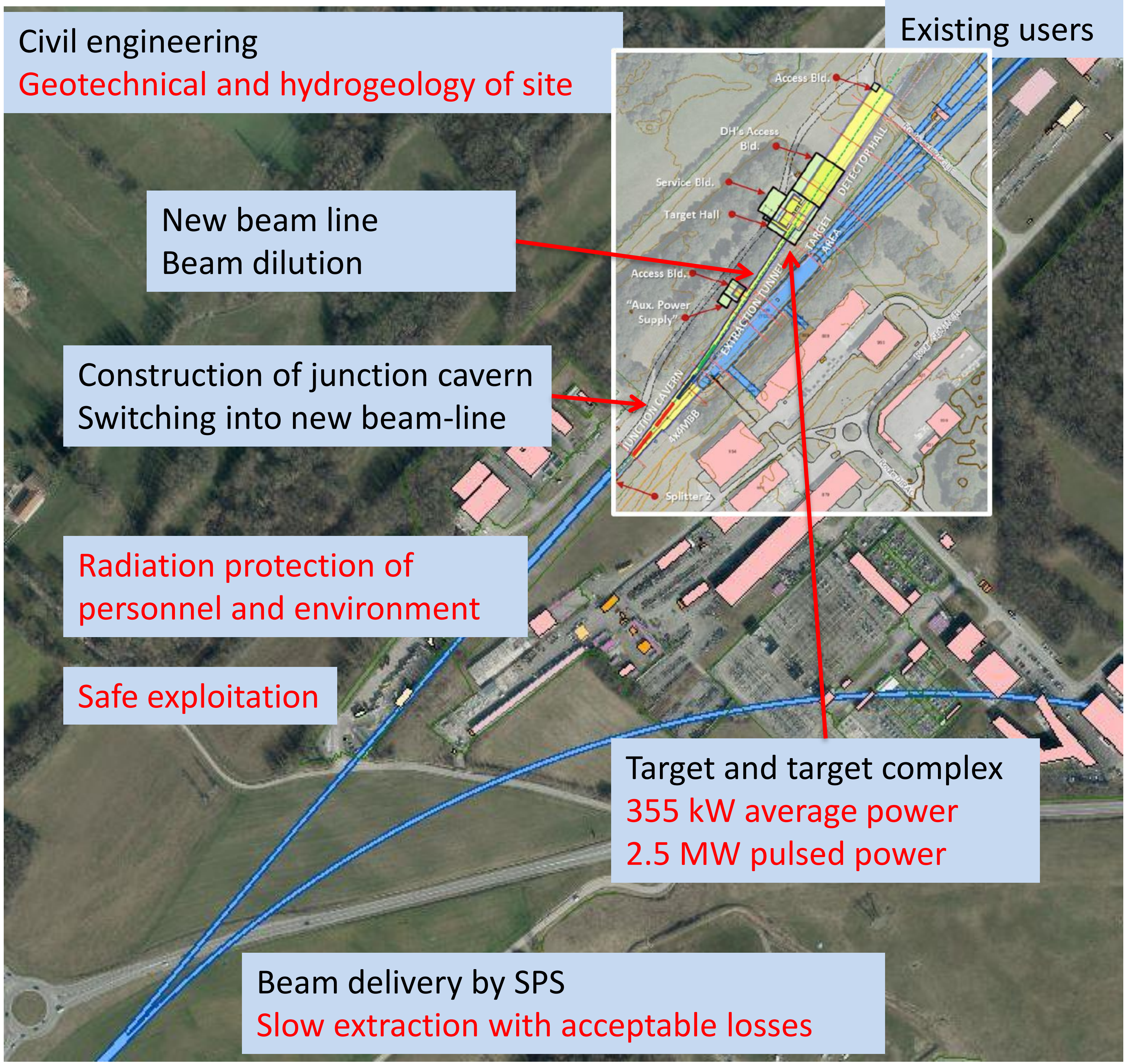
Attempting to rebrand as the HSC (Hidden Sector Campus)

SPS Beam Dump Facility (BDF)

- Slow extraction from SPS into existing TT20 transfer line
- Switch to new transfer line at existing North Area splitters
- Heavy target plus hadron absorber
- Target complex with sophisticated handling capabilities
- Underground Experimental Hall

Momentum	400 GeV/c
Beam intensity on target per cycle	4.0e13
Cycle length	7.2 s
Spill duration	1 s
Avg. power on target	355 kW
Avg. power on target during spill	2560 kW
Protons on target (PoT) per year	4e19
PoT in 5 years’ data taking	2.0e20



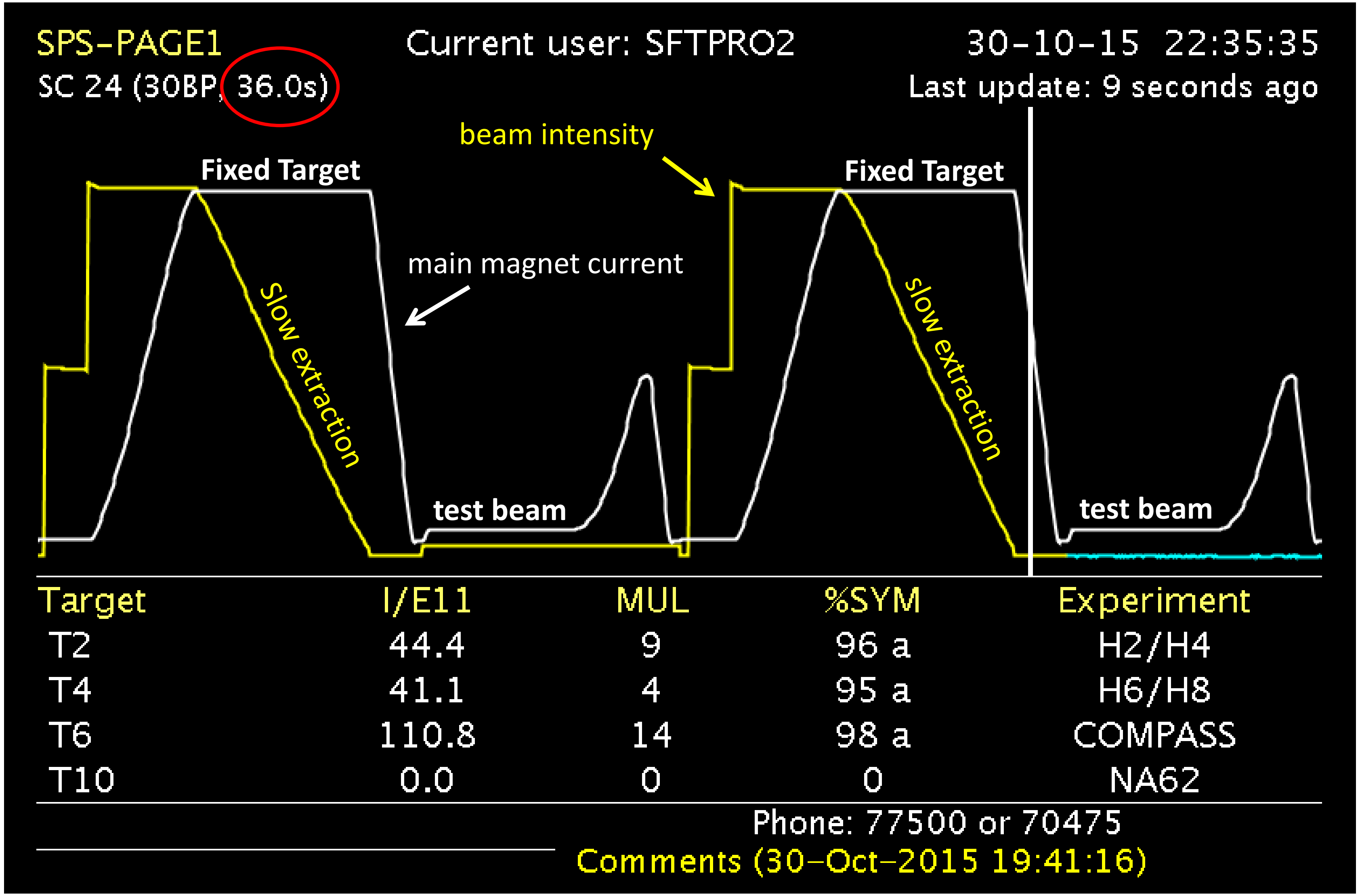

Civil engineering
Geotechnical and hydrogeology of site
Existing users
New beam line
Beam dilution
Construction of junction cavern
Switching into new beam-line
Radiation protection of
personnel and environment
Safe exploitation
Target and target complex
355 kW average power
2.5 MW pulsed power
Beam delivery by SPS
Slow extraction with acceptable losses
Access Bld.
DH's Access Bld.
Service Bld.
Target Hall
Access Bld.
"Aux. Power Supply"
Splitter 2
DETECTOR HALL
TARGET AREA
EXTRACTION TUNNEL
JUNCTION CAVERN

Work packages

- Beam production in the SPS and extraction
- Beam transfer
- Target & target complex
- Experimental hall
- Radiation protection & environmental studies
- Safety engineering
- Integration
- Civil engineering

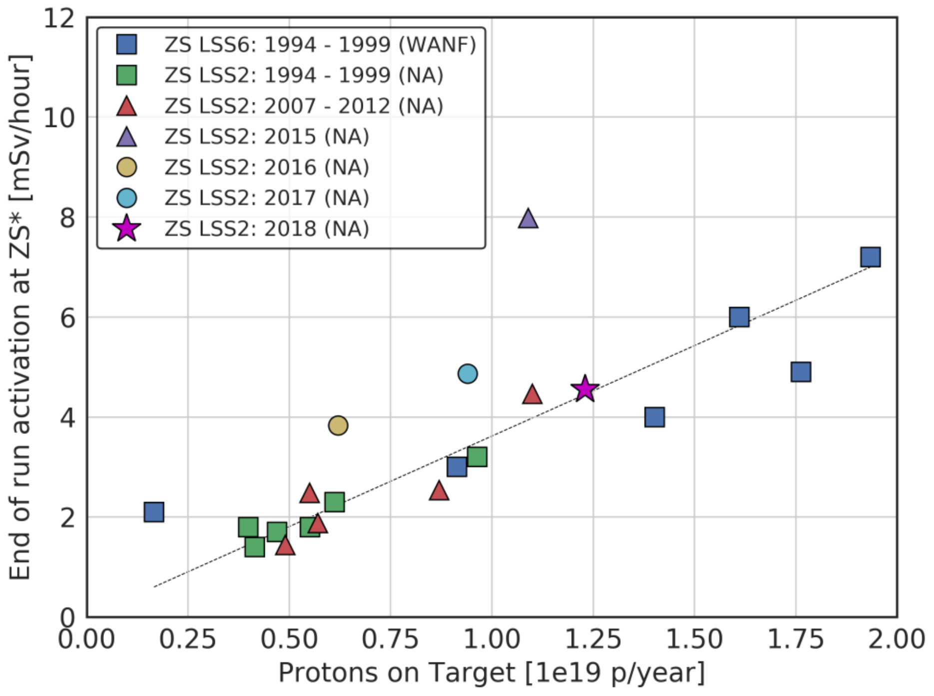
SPS super-cycles

2015 in a period without LHC filling



- Duty cycle of fixed target beam limited by **RMS power dissipation in SPS magnets**
- Different configuration during LHC filling …

Beam production

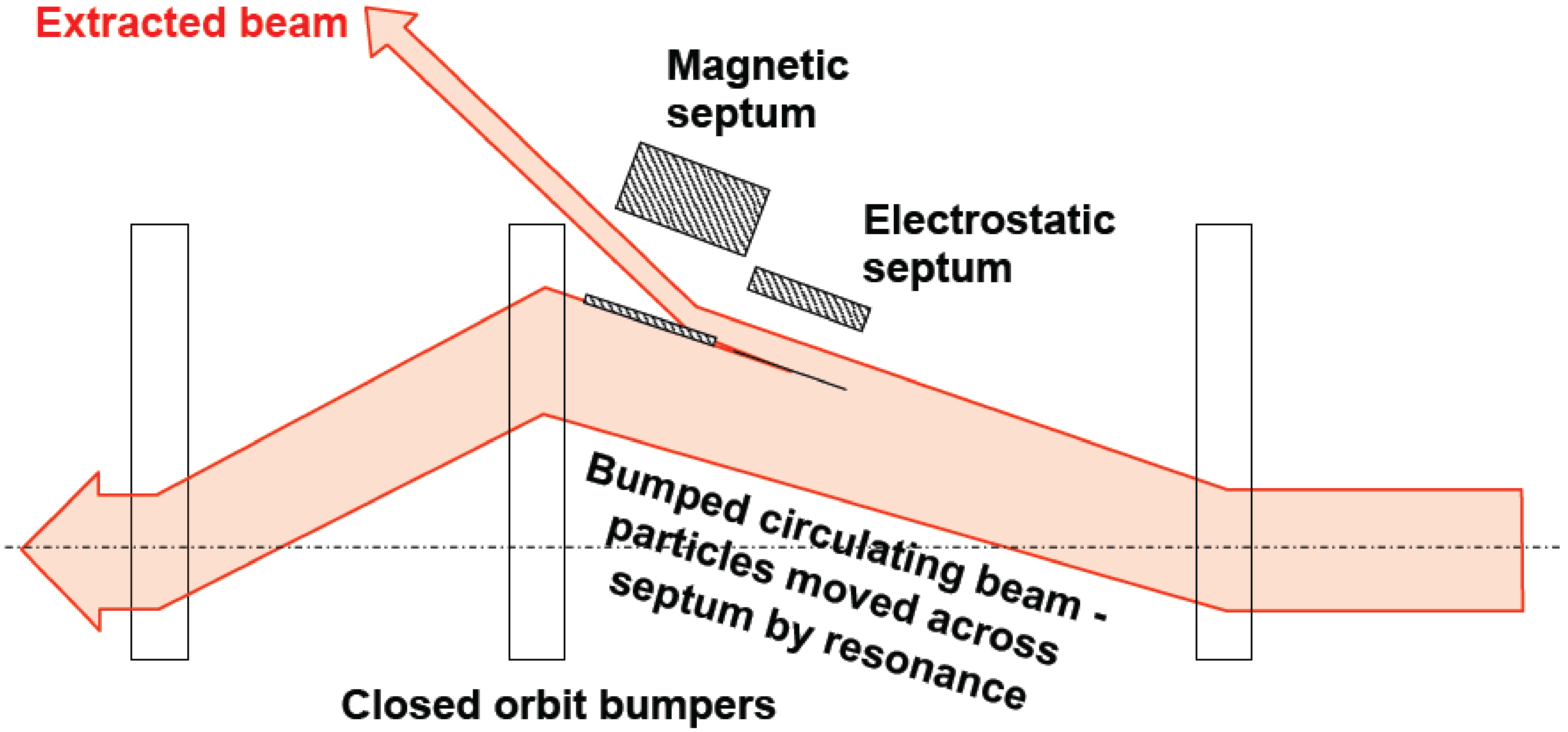


* Measured ~30h after shutdown at ~1 m from beam line, peak at ZS plotted.

- Existing North Area beam delivery performances
  - 400 GeV/c proton beam produced using slow extraction
  - 4.8 s uniform spill with up to 3.5×10^{13} protons/spill and 1.23×10^{19} protons extracted in 2018
- SHiP requirements
  - **1 s** uniform spill with up to 4×10^{13} protons/spill and ~ $\mathbf{4 \times 10^{19}}$ protons extracted per year
- Challenges
  - SHiP + current NA requirements totals ~ 5×10^{19} protons extracted per year
  - Radiation & activation in the SPS extraction is proportional to the number of protons extracted
  - The BDF requires an increase in the slow extraction efficiency to maintain radiation and activation at current levels

Resonant multi-turn (slow) extraction

Non-linear fields excite resonances that drive the beam slowly across the septum

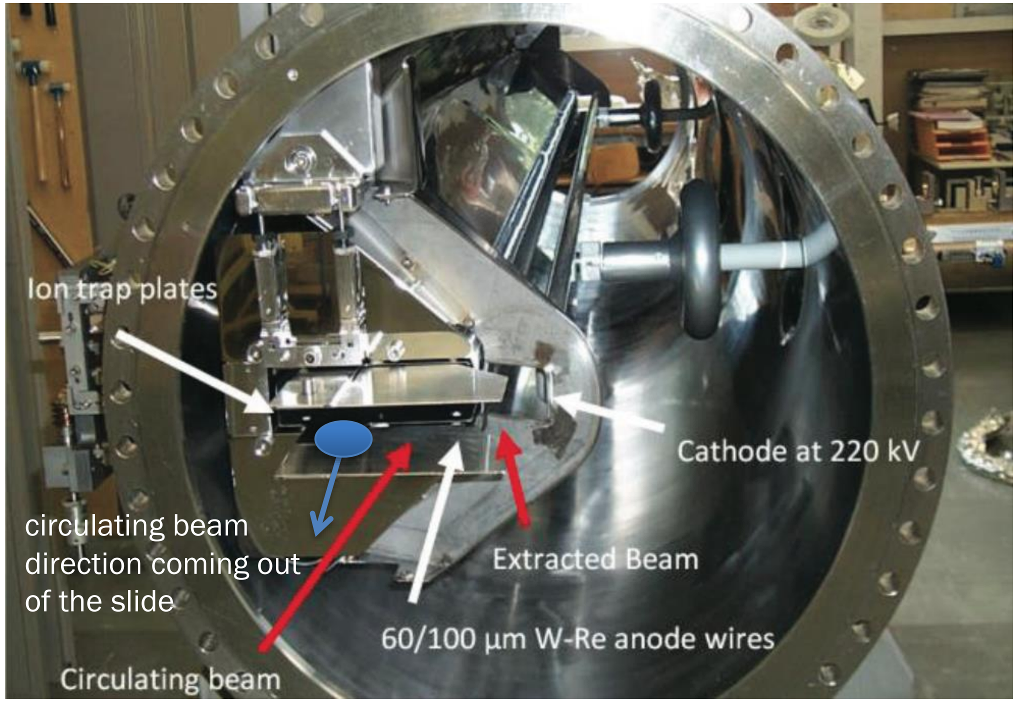


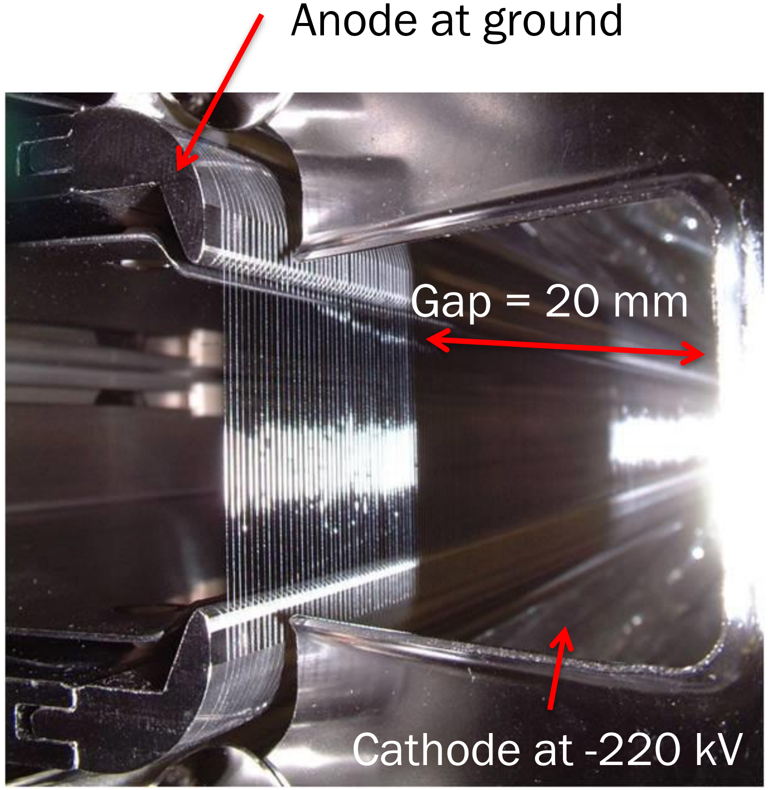
- Slow bumpers move the beam near the septum
- Tune adjusted close to n^{th} order betatron resonance
- Multipole magnets excited to define stable area in phase space, size depends on $\Delta Q = Q - Q_r$

Extraction from SPS to NA

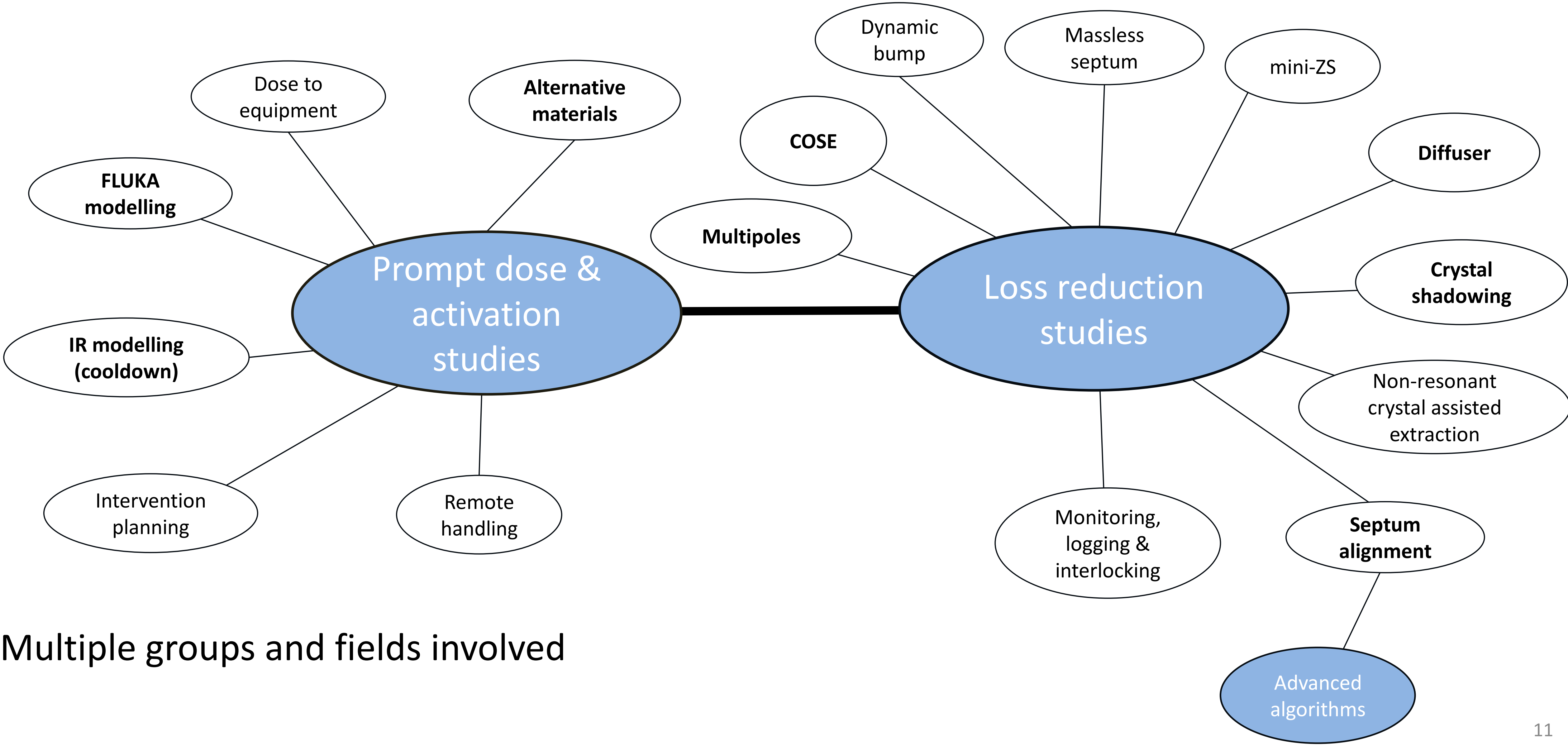
- Long Straight Section (LSS) 2:

- 5 electrostatic septa [ZS] aligned over ~20 m:





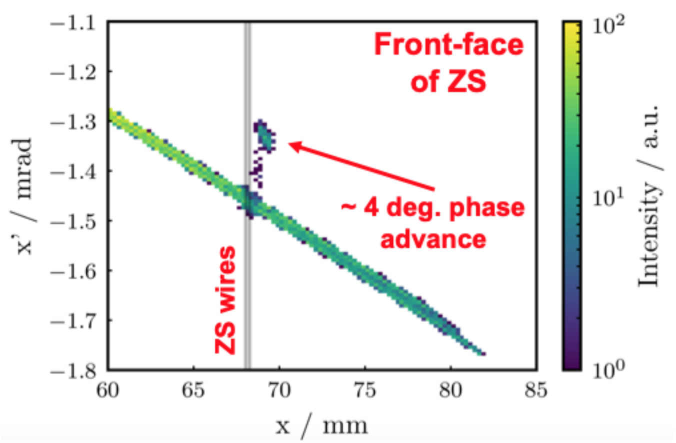
Loss reduction : recent efforts

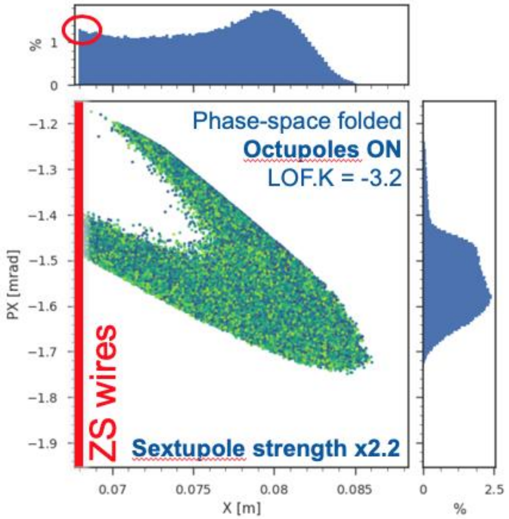


Multiple groups and fields involved

Major effort to reduce losses

- Implementation of dynamic optics control (COSE) to hold separatrix stationary during spill
- Thin bent crystal installed upstream ZS
  - Crystal channeling creates depleted density region at ZS wires
- Apply higher-order multipole fields during extraction:
  - Reduce density of beam impinging the ZS wires: **35 – 45%**
  - At the expense of increasing extracted beam emittance



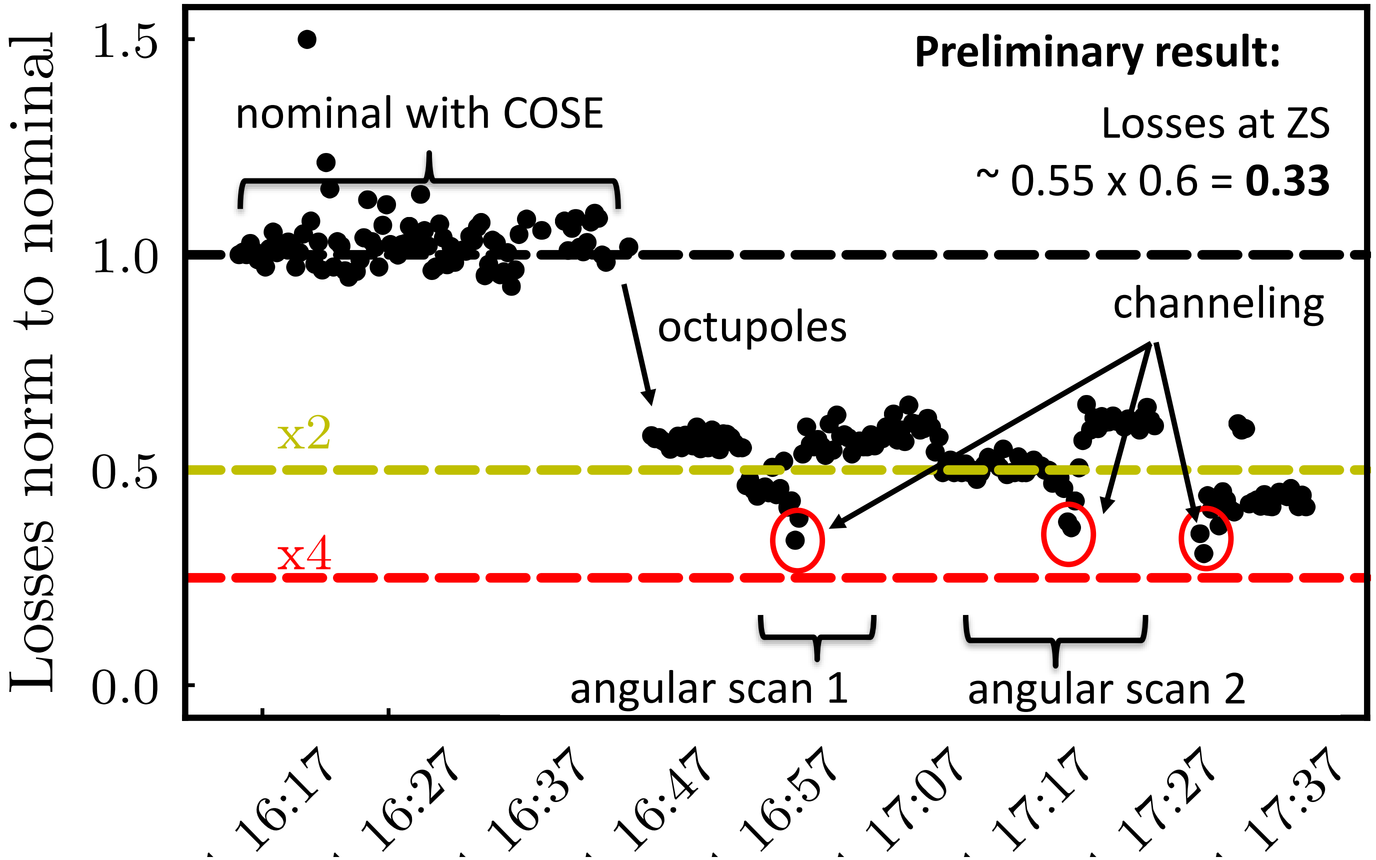


Driven and supported by the members of SPS-CASE WG and SLAWG
Fruitful collaboration between a large number of groups and experimental collaborations!
Dedicated R&D effort including 2 PhD thesis topics

Brennan Goddard, Matthew Fraser et al

Combining techniques

Crystal inserted and aligned with **octupoles** during afternoon of 1st November 2018:



In 2018, different loss reduction concepts were validated in MD tests:

- Included passive and active diffusers (crystal shadowing of ZS) and phase space folding
- Factor of ~ 3 - 4 loss reduction at ZS demonstrated
- Scope for further loss reduction improvement

The magic factor of 4 - 5 reduction to accommodate SHiP/BDF does appear to be in reach!

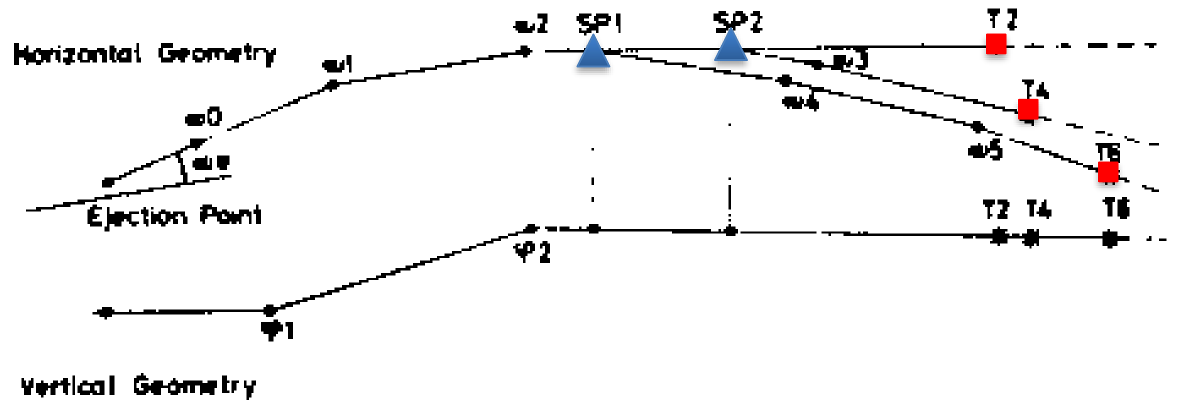
THE EXTERNAL PROTON BEAM LINES
AND THE SPLITTER SYSTEMS OF THE CERN SPS

L. Evans, A. Hilaire, A. Ijspeert, B. de Raad, N. Siegel, E. Weisse

Paper presented at the 1977 Particle Accelerator Conference - Chicago
March 16 - 18, 1977.

3. The North Area Beam Transfer Lines

The beam lines to the North Area have been designed for 400 GeV/c. The geometry is shown in Figure 3.



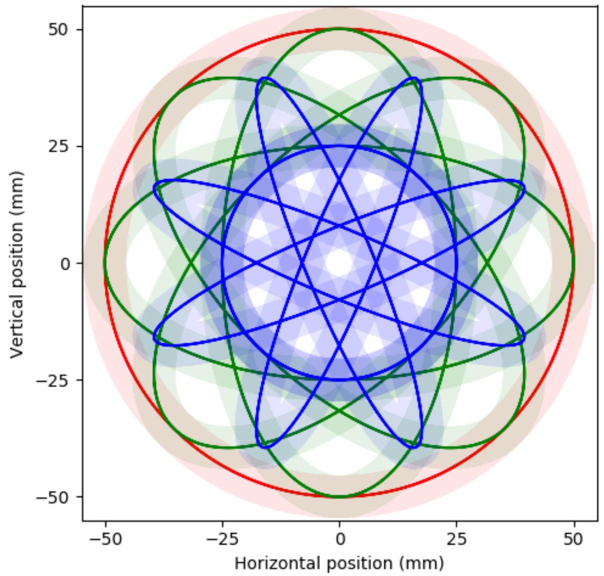
Angles	in mrad
α 0	- 0,700
α 1	- 16,552
α 2	- 16,552
SP1	- 8,200
SP2	- 8,200
α 3	- 31,800
α 4	- 35,176
α 5	- 4,824
φ1	109,391
φ2	-109,519

Fig. 3 Geometry of the proton beam lines to the North Area

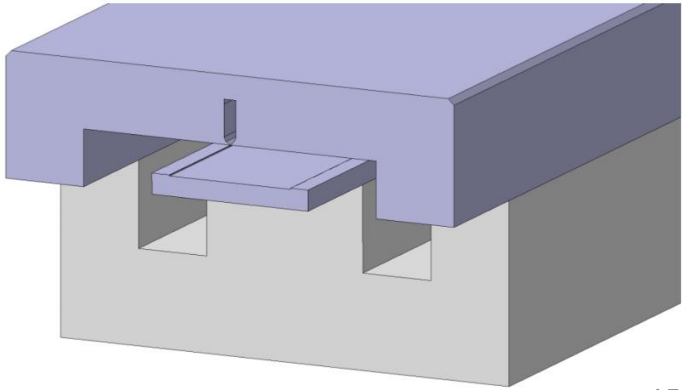
Beam transfer

- New beamline branches off the existing TT20 line
  - New optics and powering scheme using the existing capabilities of the TT20 lines
  - Use of existing magnets available in CERN stores
  - Accounting for failure and accidental scenario to safely transport the beam
  - Dilution system to reduce material stress on the target
- New splitter design to shift the beam direction betwe the regular NA and BDF lines in consecutive cycles
- Next steps
  - Detailed risk analysis and failure cases
  - Design of splitter and possibly improved splitting scheme

Possible beam dilution patterns



Splitter model

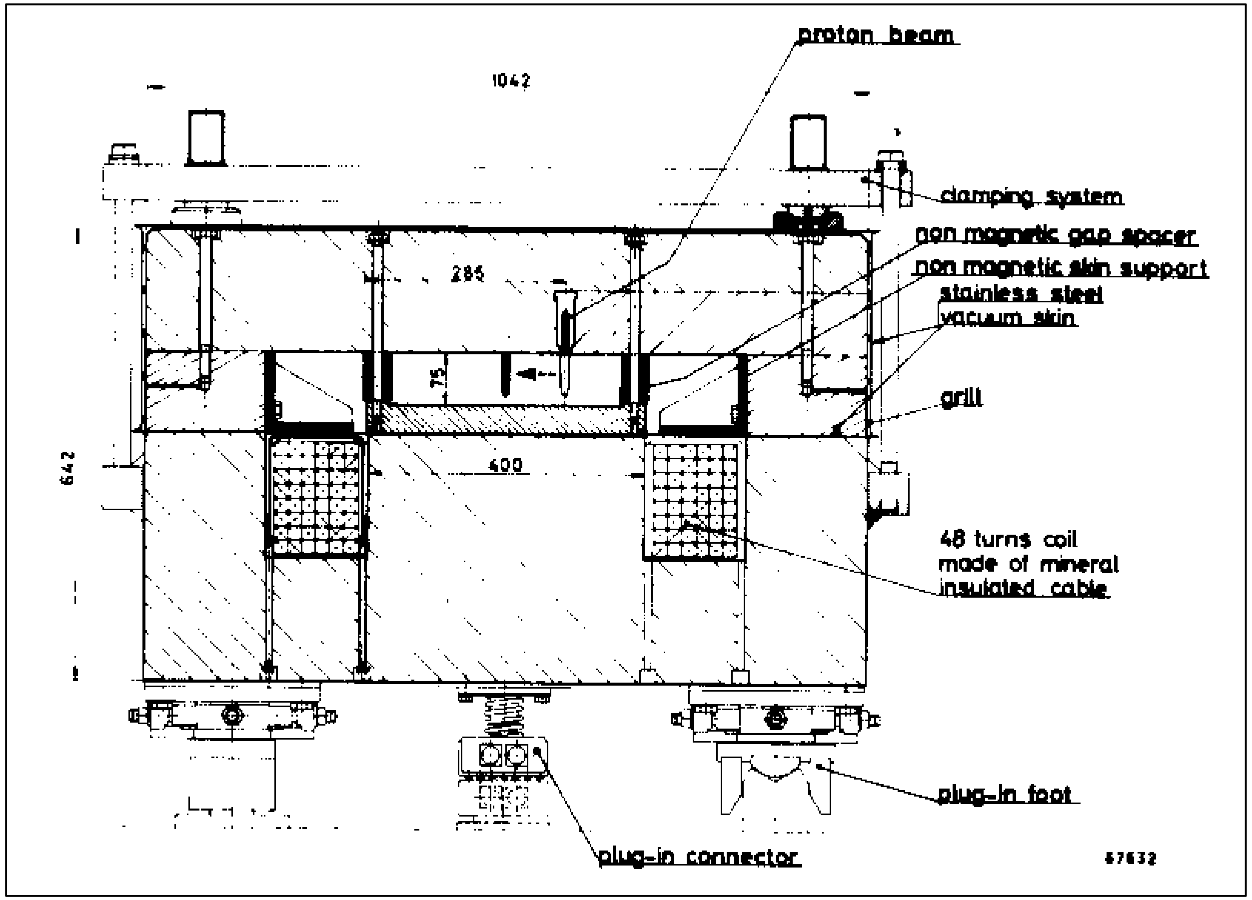


THE STEEL SEPTUM MAGNETS FOR BEAM SPLITTING AT THÉ CERN SPS

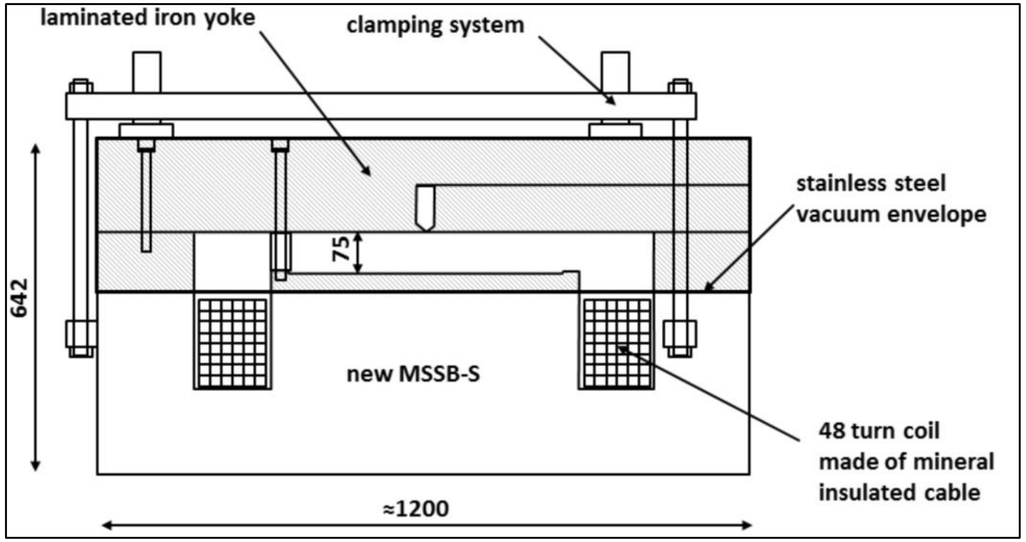
by

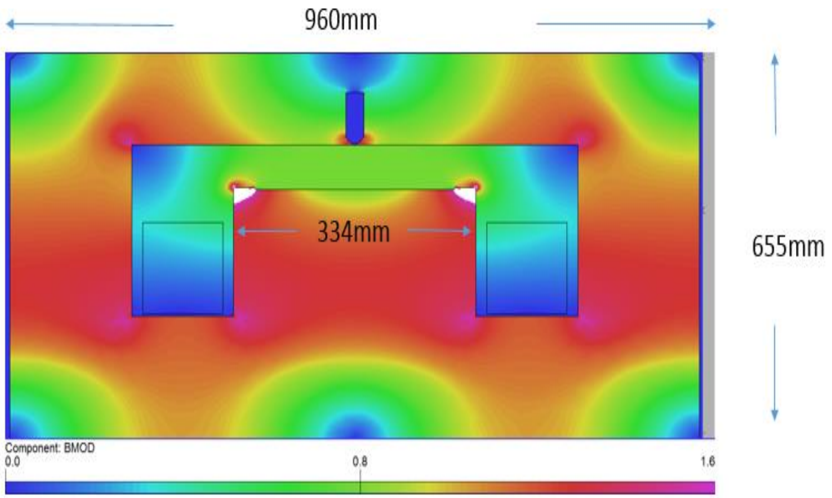
L. Evans, A. Ijspeert, B. de Raad, W. Thomi, E. Weisse

CERN-SPS/ABT/77-13



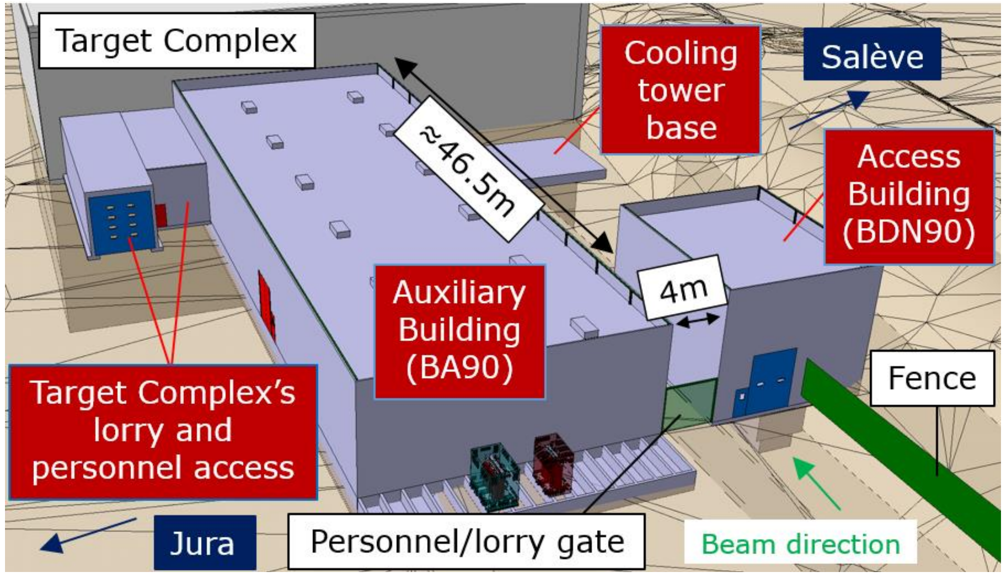
New laminated bipolar splitter/switch with reduced saturation

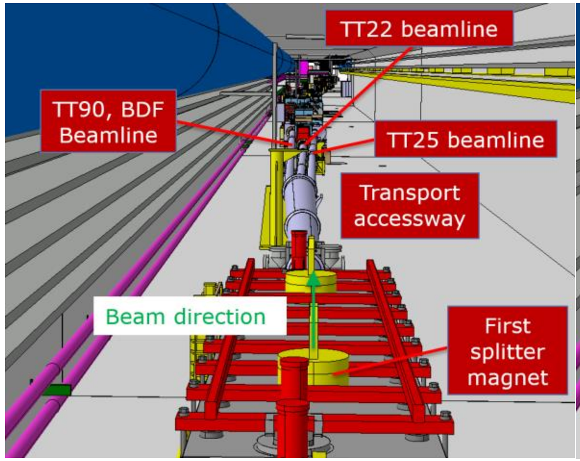


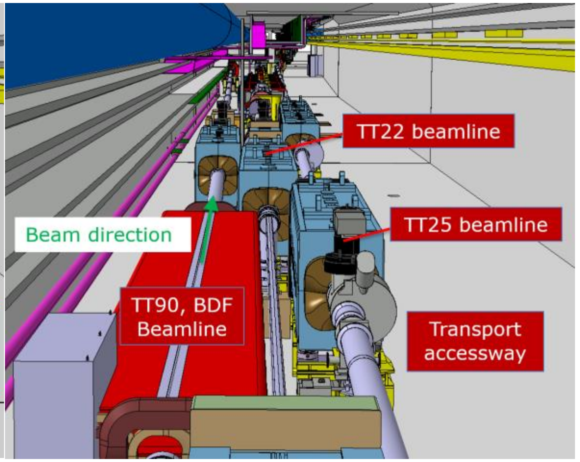


Transfer line design

- Integration studies
  - Combines requirements from all sources, sometimes conflicting
  - In particular safety, transport, beam dynamics, radiation protection, civil engineering and cooling-ventilation
- Status
  - Comprehensive 3D model includes all requirements for the tunnel and associated surface buildings
- Next steps
  - Layout consolidation, advance from layout towards TDR
  - Integration, optimization at logistics & hardware for beam-lines and services

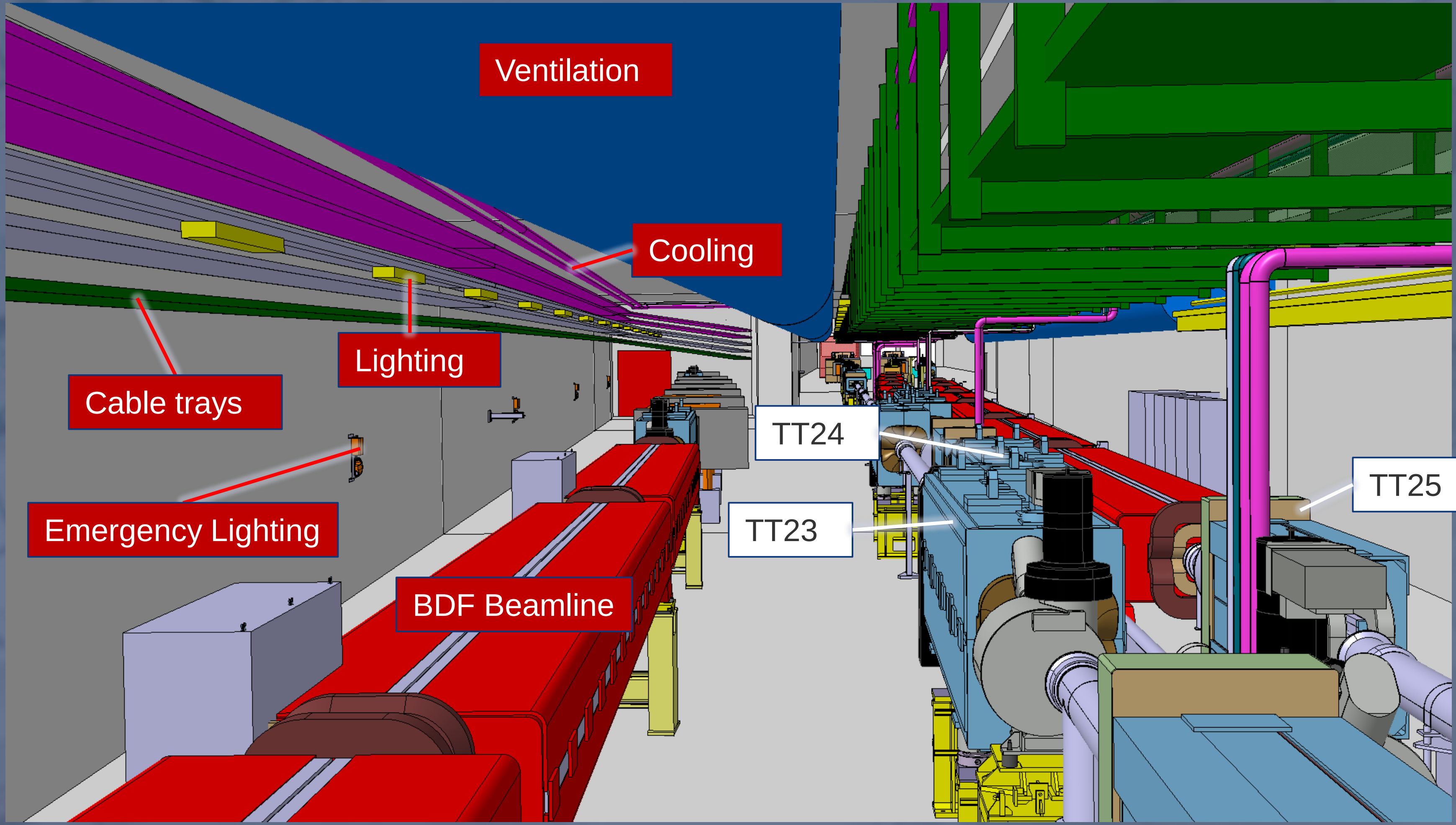






Integration

Junction Cavern



Video

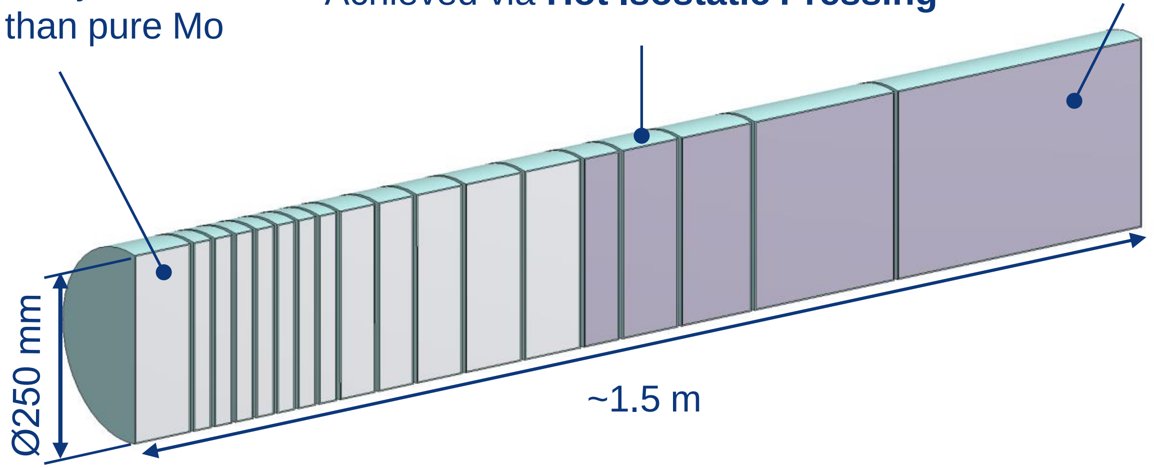
BDF target

- Main functions:
  - **Full SPS 400 GeV/c beam absorption → Target/dump**
  - Maximize the production of **charmed mesons →** physics performance
- Material requirements: **High-Z materials + short interaction length**

1[st] part: **TZM core**
Molybdenum alloy, higher strength and recrystallization temperature than pure Mo

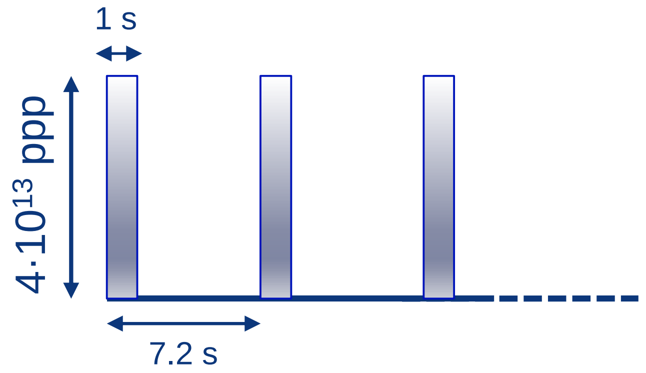
Ta/Ta2.5W cladding
To avoid **corrosion/erosion effects**
Achieved via **Hot Isostatic Pressing**

2[nd] part: **Tungsten core**
High-Z and good performance under irradiation



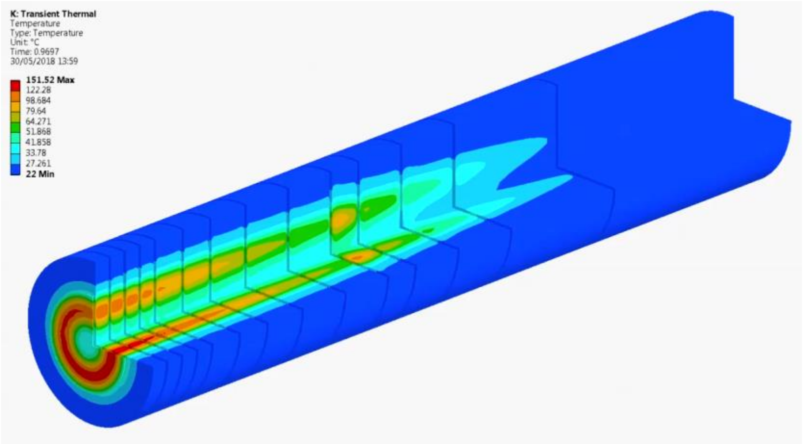
Operational conditions

Baseline characteristics	
Proton momentum	**400 GeV/c**
Beam intensity	$4.0 \cdot 10^{13}$ p+/cycle
Cycle length	7.2 s
Spill duration **(slow extraction)**	1.0 s
Average beam power deposited on target	**320 kW**
Average beam power on target during spill	2.3 MJ



⇨ Challenging target design

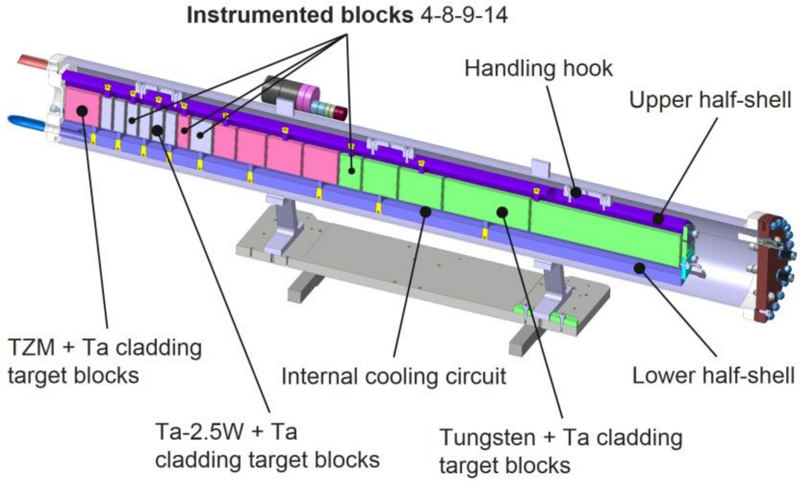
- **Circular dilution of the beam** by the upstream magnets
- 50 mm radius, 4 turns in 1 second
- **Large beam spot:** 8 mm 1σ

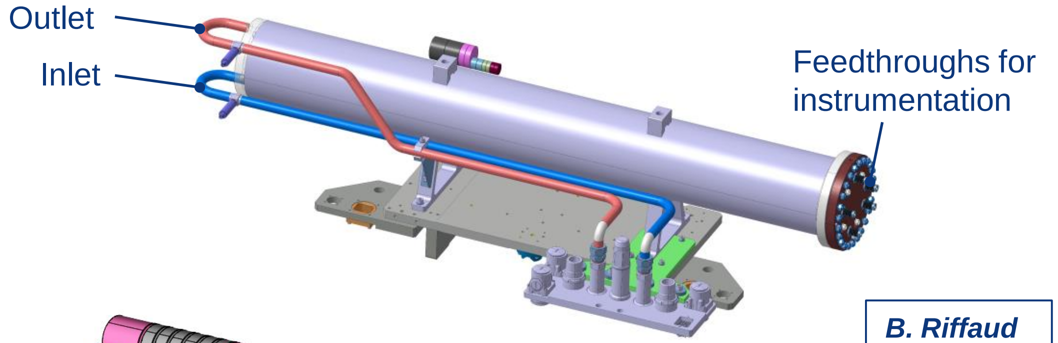


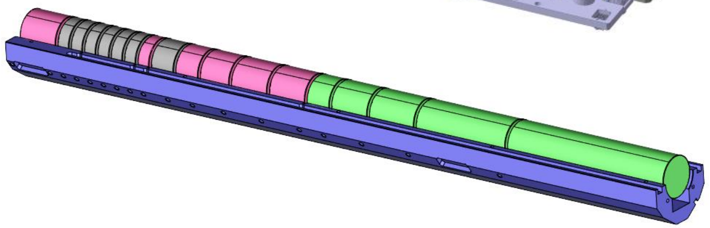
Target prototype design

- **Reduced scale prototype**
  - Same total length (~1.5 m)
  - Reduced diameter **(80 mm)**
  - Same block length distribution
  - TZM/W core, Ta/TaW cladding

- **Two concentric tanks**
  (~ final target)
  - Outer tank:
    - Leak tightness
    - Connections interface
  - Inner tank: two half shells
    - Target core blocks holder
    - Enclosing cooling circuit







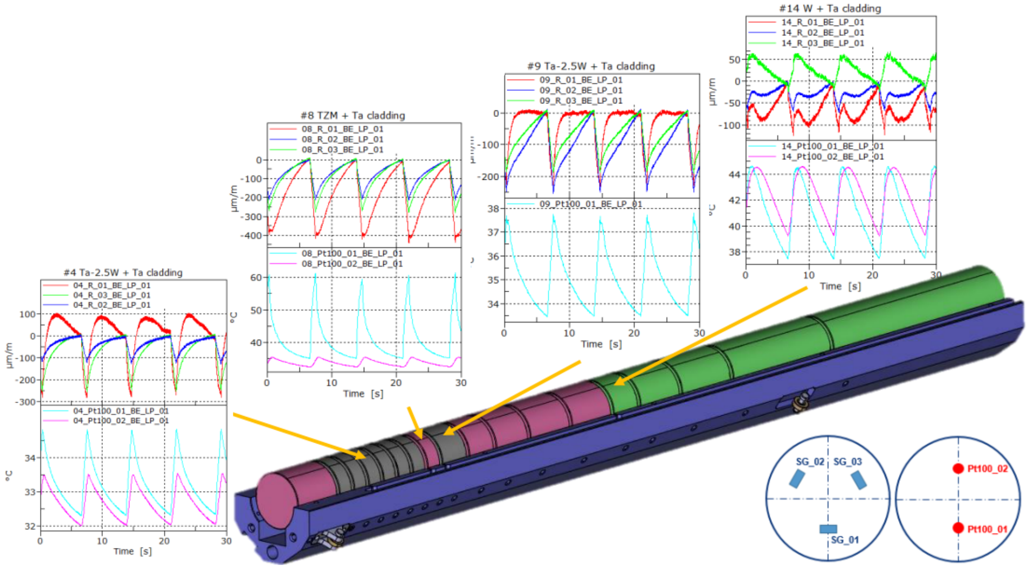
B. Riffaud (EN/MME)

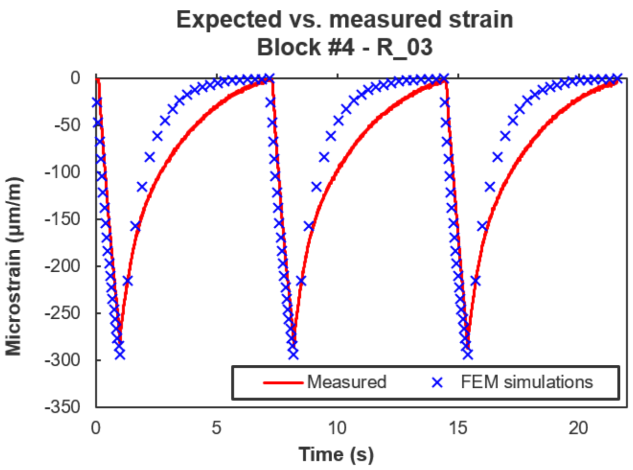
Target prototype assembly

Installation & assembly photos
http://cds.cern.ch/record/2635418
http://cds.cern.ch/record/2638991

BDF MD day 1

- Target instrumentation successful
  - Almost all sensors survived **high levels of radiation, pressure, temperature and water speed**

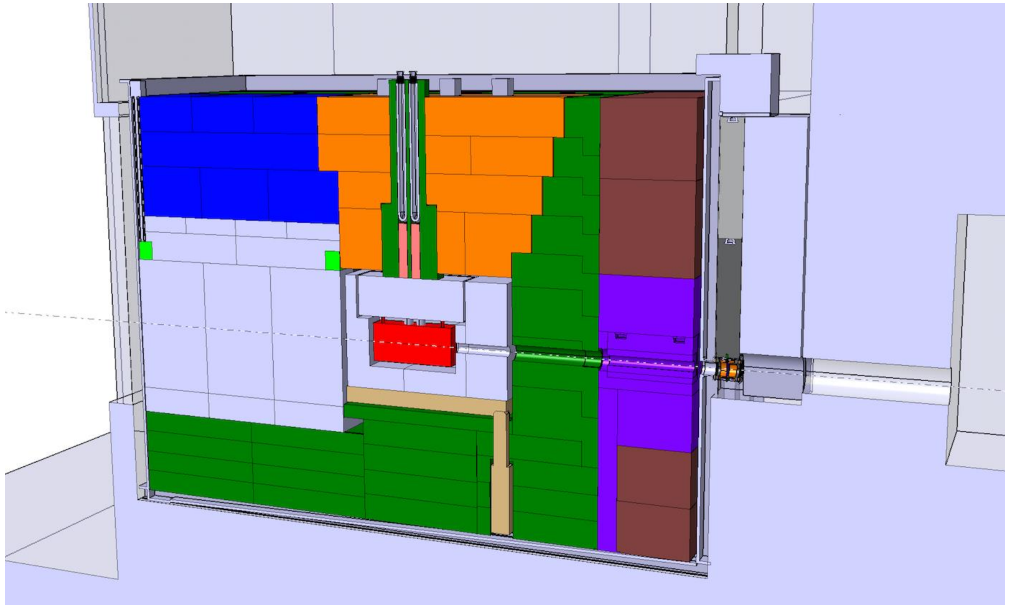


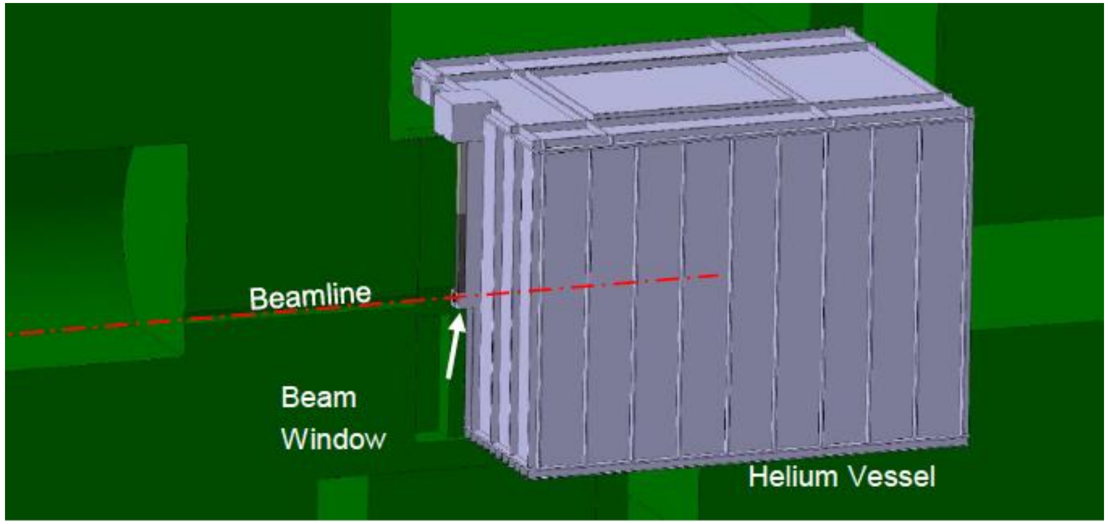


- Instrumentation results **coherent with FEM simulations**

Target shielding and helium vessel

- Target surrounded by iron shielding to stop hadrons
- Target and shielding are underground to reduce radiation levels in the building and the surroundings …
- … and housed in a helium vessel to prevent air activation and corrosion
- After 5 years of irradiation and 1 week of cooling time, residual dose rates are hundreds of Sv/h around the target and the proximity shielding





10m long, 8.5m wide at a depth ~12m from surface

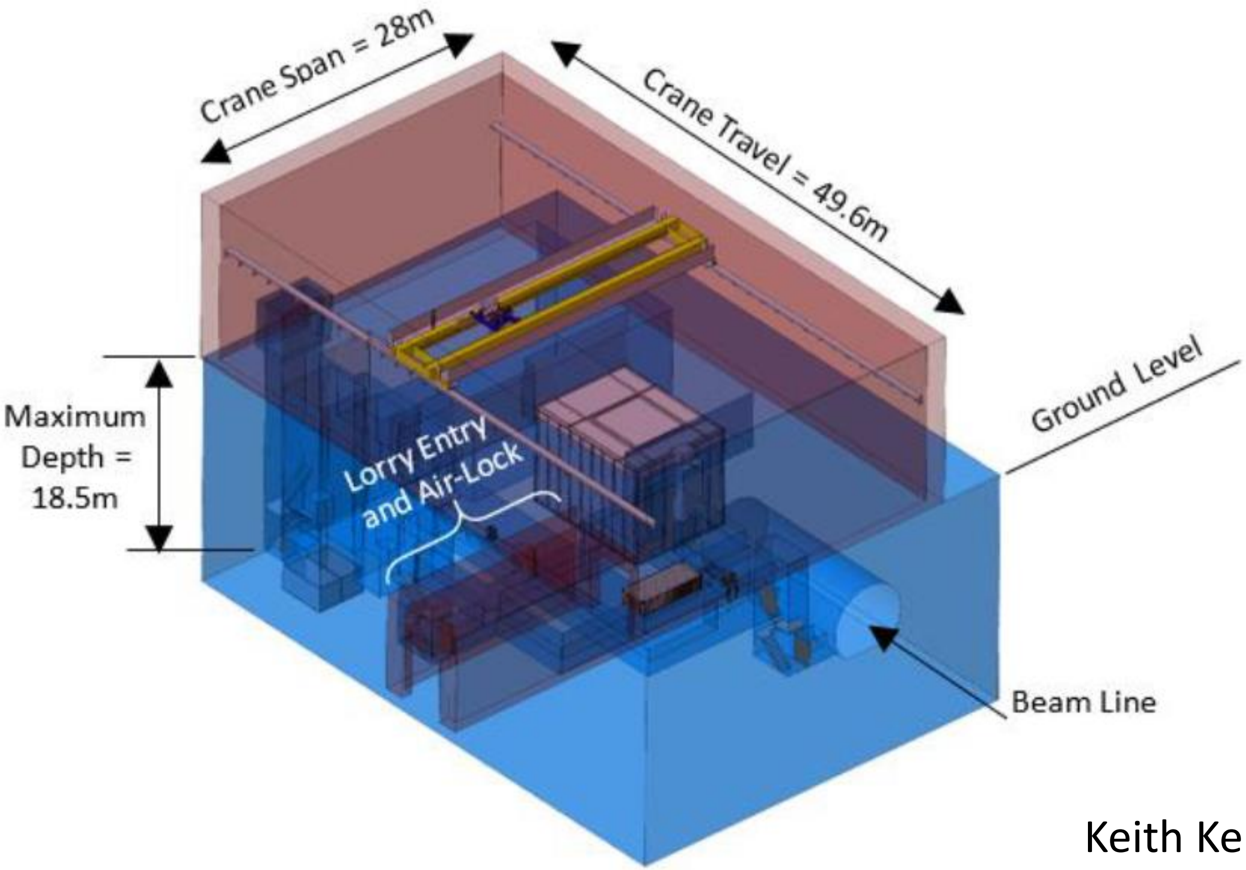
Integration and remote handling study

Study aims

- Develop integration design of target complex
- Considering key handling and remote handling operations during the life of the facility

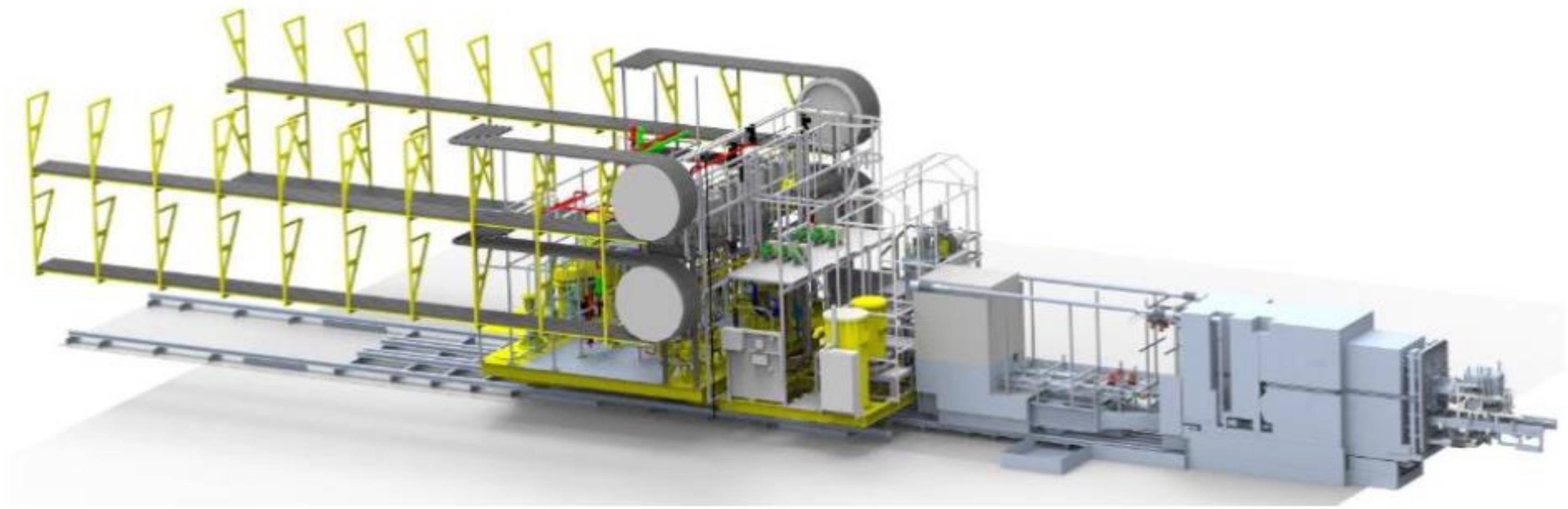
CERN + Oxford Technologies
"Foreseen" and "unforeseen" handling operations (consider failures and damage)

Outputs: 3-D models, layout drawings, reports, animations

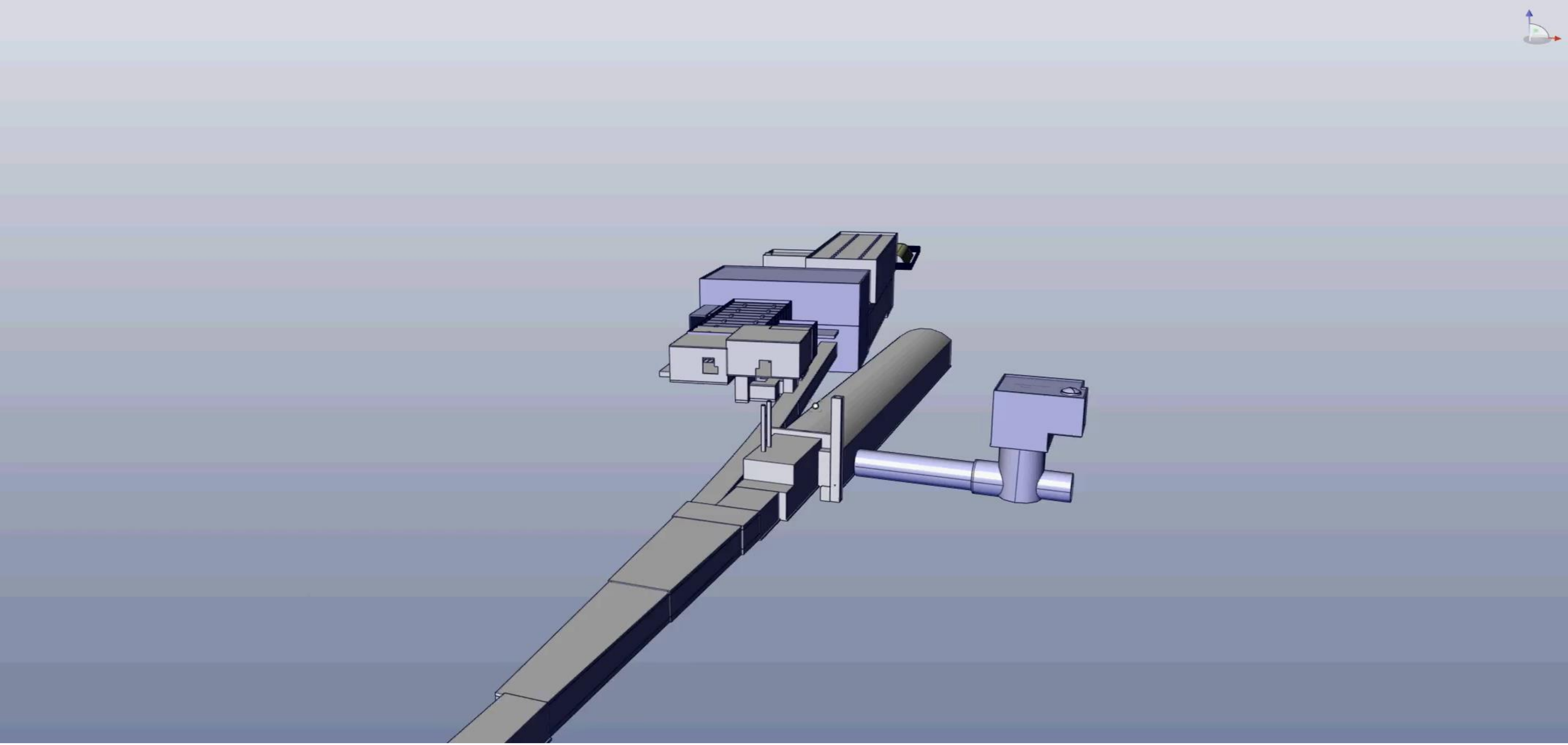


Two handling concepts studied

- **Crane concept** – all foreseen handling by overhead travelling crane.
- **Trolley concept** – target and its services mounted on trolley (as ISIS)

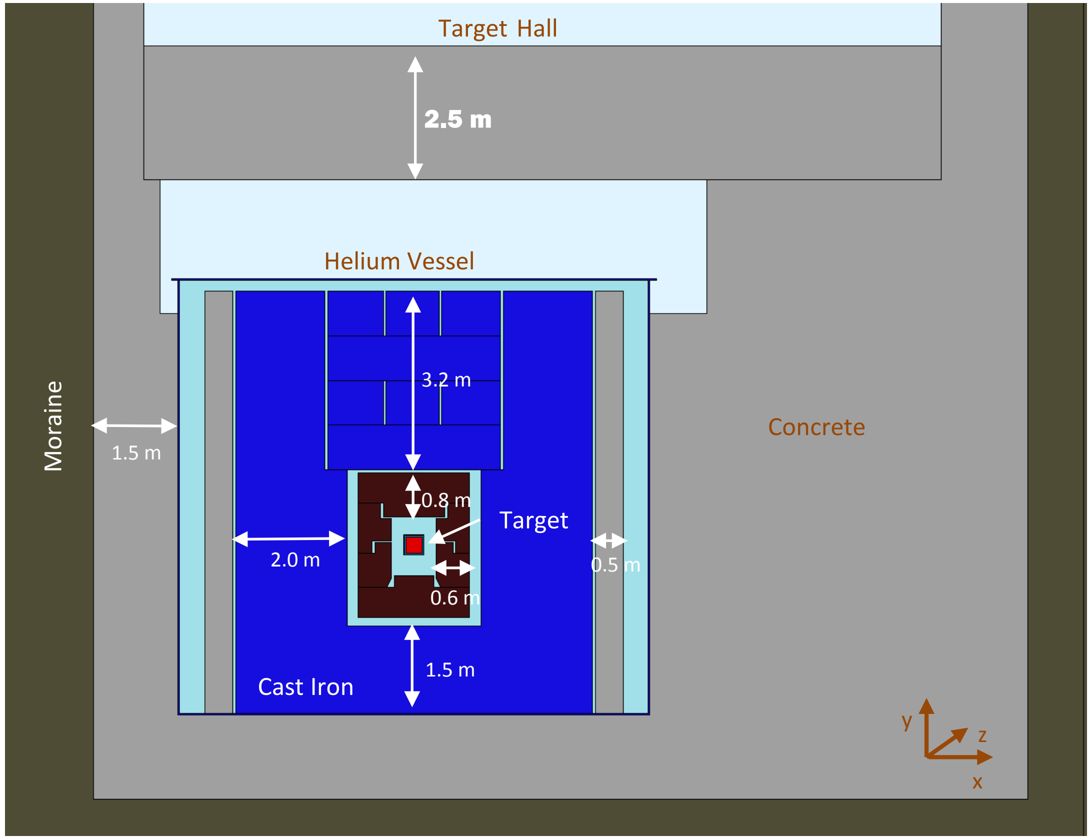


Courtesy ISIS



RP evaluation based on FLUKA simulations

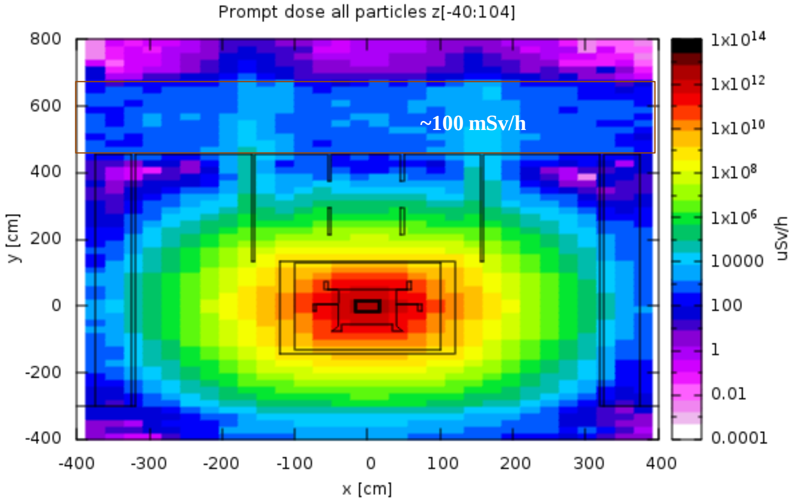
BDF/SHiP as implemented in FLUKA – Cross-sectional view



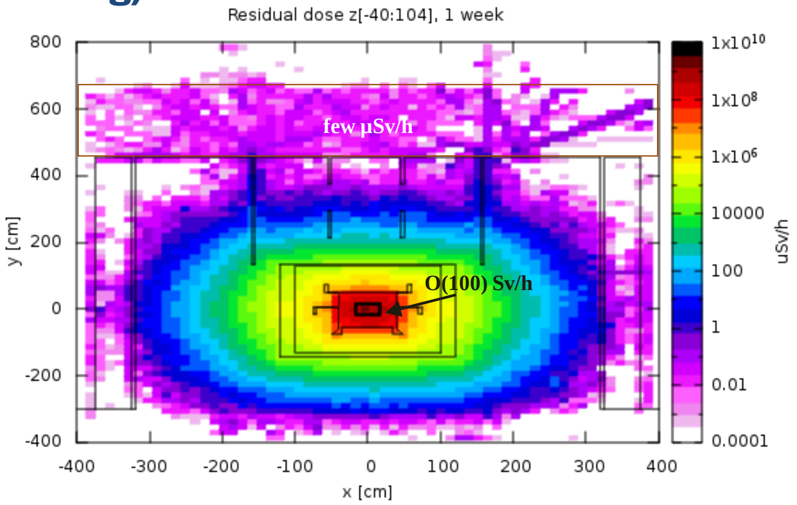
- Most critical area embedded in He-environment
- Shielding optimized to reduce ground activation to negligible levels
- Accurate material compositions were used (AISI316LN w 0.1% Cobalt, ASTM A48 w 0.04% Cobalt, US1010, CENF moraine, …)

RP evaluation based on FLUKA simulations

Prompt dose rate for $4×10^{13}$ p / 7.2s



Residual dose rate for $2×10^{20}$ pot (1 week cooling)



Prompt dose rates reach ~100 mSv/h above He-vessel and drop down to < 1 μSv/h above top concrete shielding (conservative gaps)

→ Expected classification: Supervised Radiation Area (up to 2000h/year) (< 3 μSv/h) in the target hall

Residual dose rates of **a few μSv/h** above and next to He-vessel

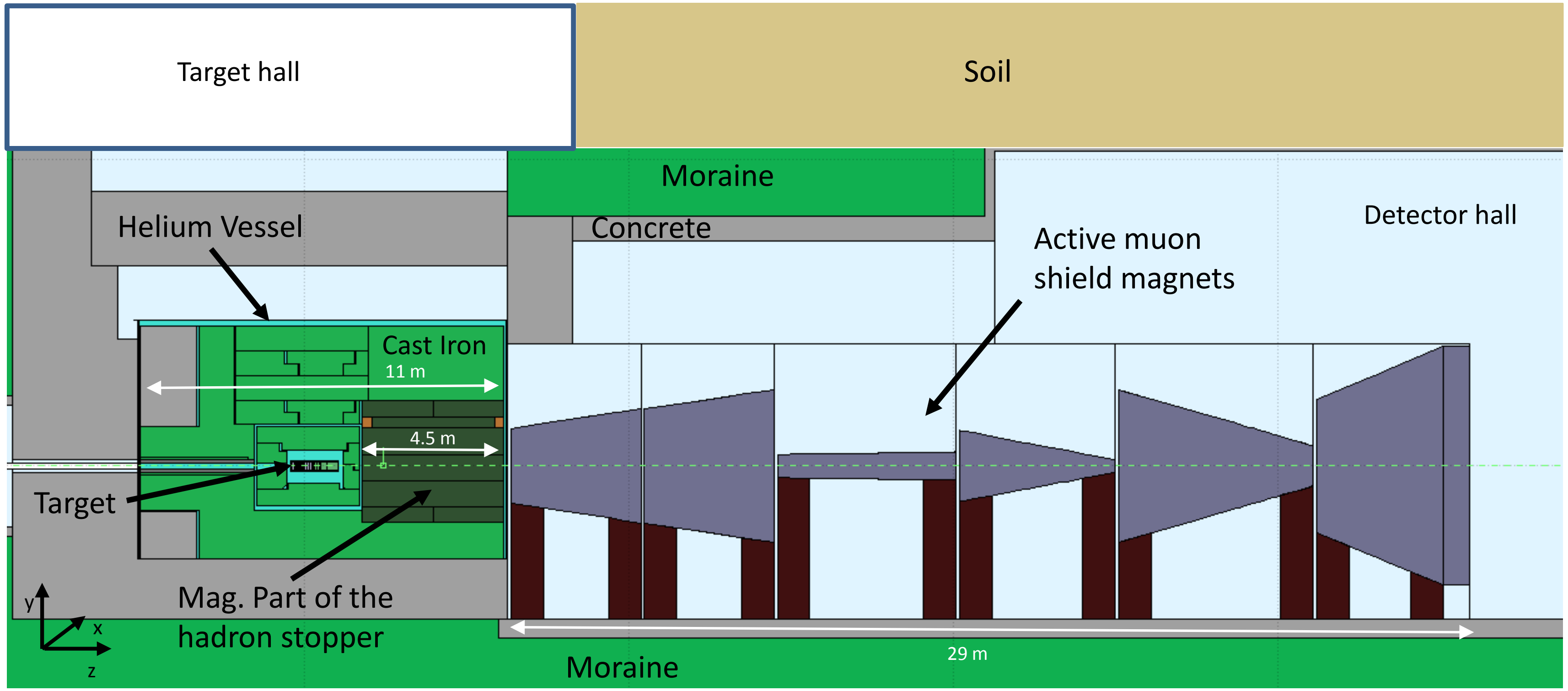
Very high residual dose rates next to target and cast iron shielding **O(100) Sv/h**

→ **Remote handling** and designated storage areas are therefore foreseen for these elements

100 rem = 1Sv

RP evaluation based on FLUKA simulations

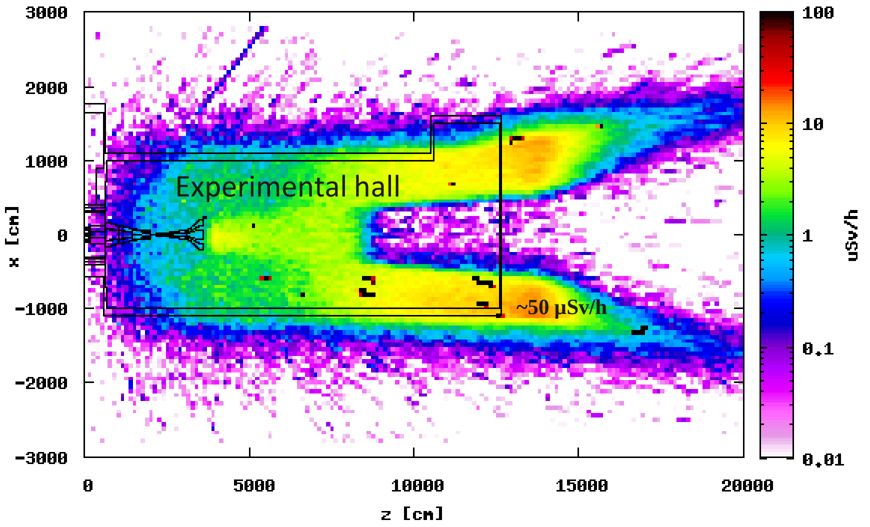
BDF/SHiP as implemented in FLUKA
Side view



- **No access during operation** into the detector hall is the main condition for current design
- **Massive shielding** to keep prompt/residual dose rate and airborne **radioactivity as low as possible**
- Active muon shield with magnets (1.8 T) from the SHiP experiment was included

Expected muon dose rates in the surrounding areas

Prompt muon dose rate for 4×10^{13} p / 7.2s

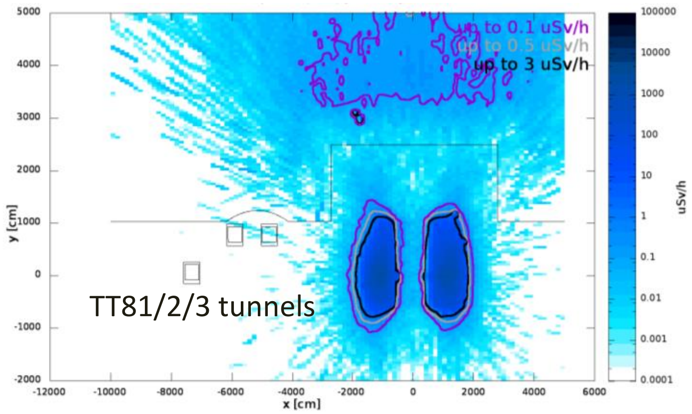


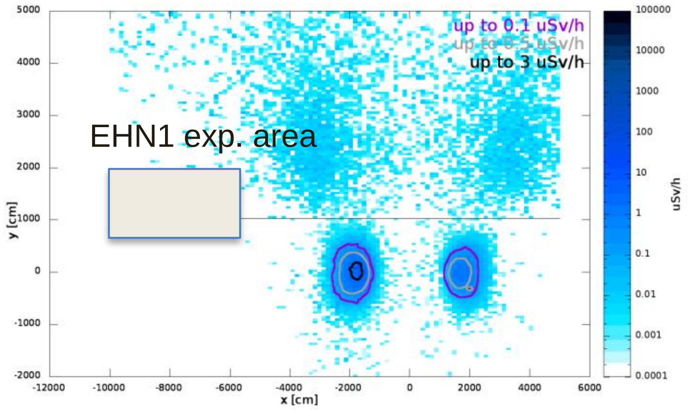
Prompt muon dose rate above experimental hall ~50 µSv/h

→ Need to cover area with at least 3 m of soil on top to allow for non-designated area level (<0.5 µSv/h)

→ Area behind experimental hall fenced

100 rem = 1Sv

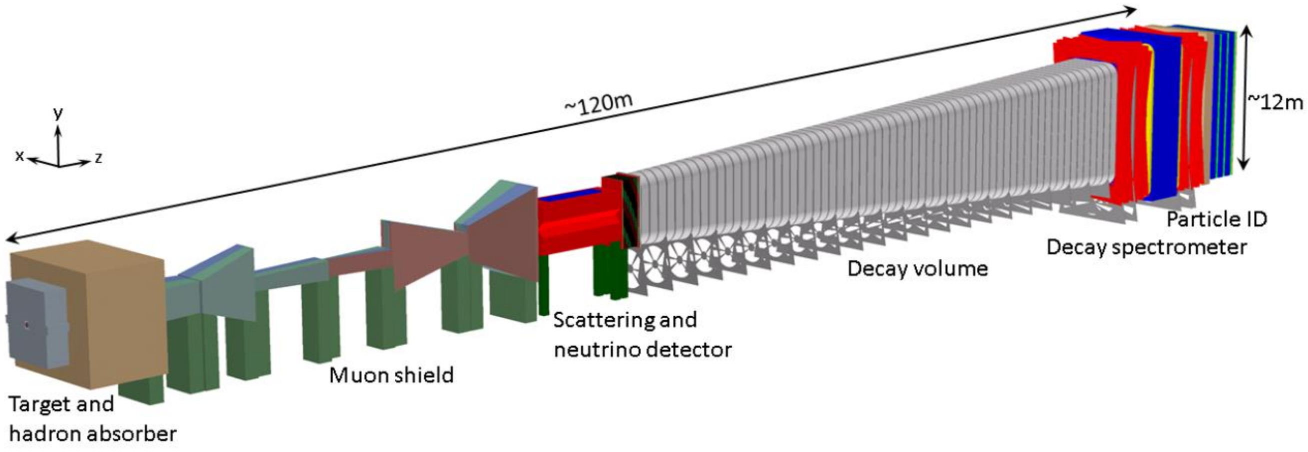


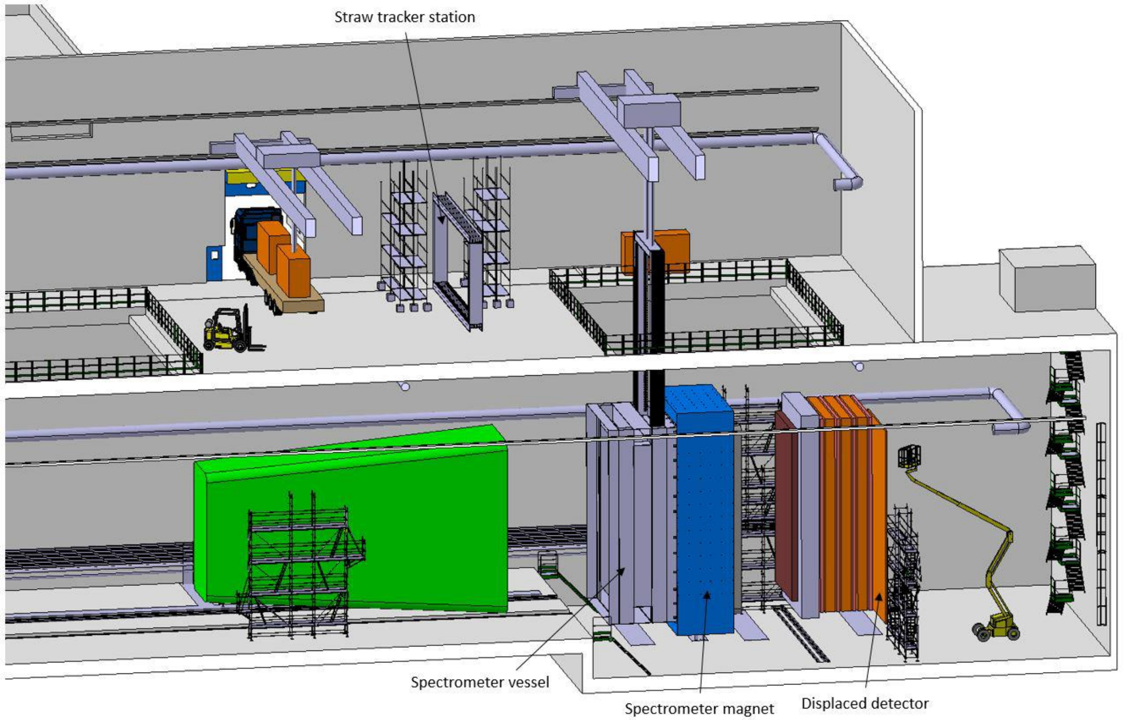


Prompt muon dose around existing facilities **below** non-designated area level (<0.5 µSv/h)

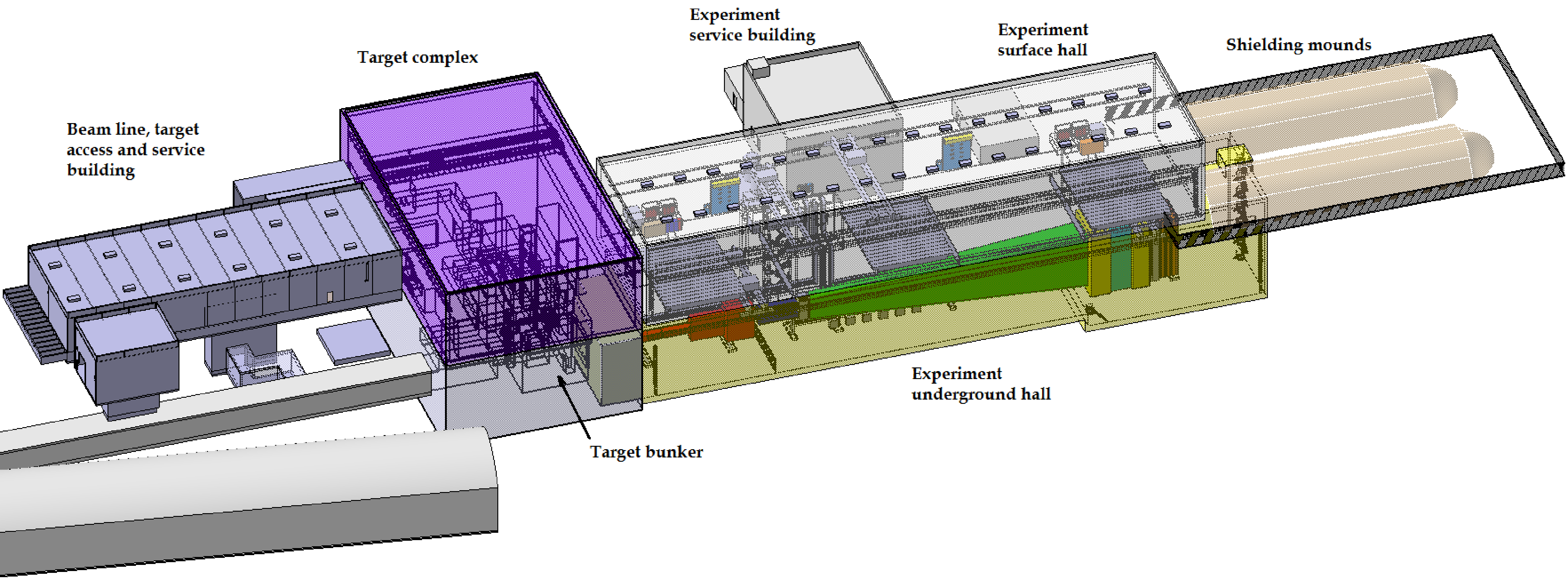
Experimental hall

- Requirements
  - SHiP experiment is ~120 m long
  - Comprehensive FLUKA simulations
  - Account for assembling and installation of the detector
- Status
  - Civil engineering and integration designs of the building, with supporting systems such as cooling and power supplies
- Next steps
  - Logistics of the detector assembly and installation





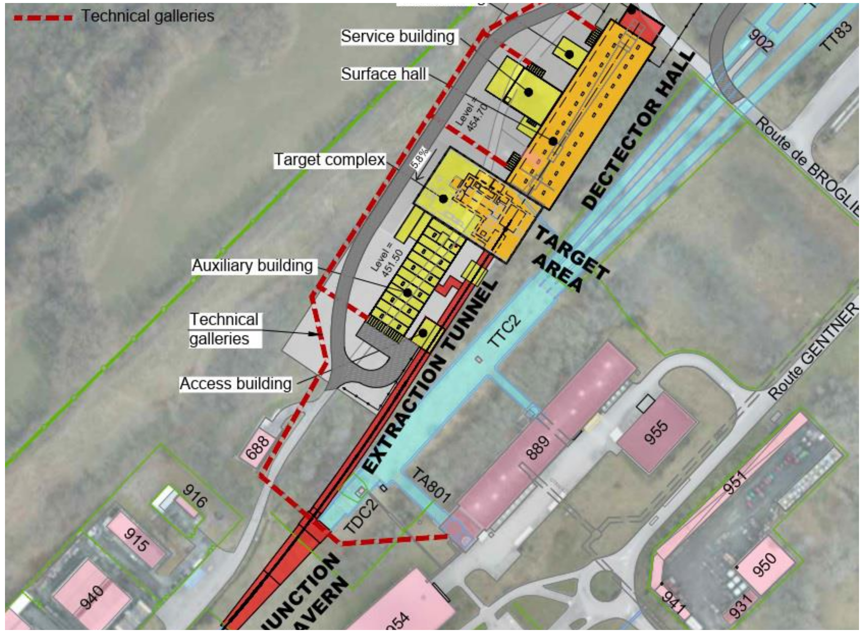
Integration – Target Complex & Exp. Area



Pablo Santos Diaz

Civil engineering

- Requirements
  - New beam transfer tunnel, target complex and experimental hall
  - Near existing lines and building
  - Open existing TCC2 tunnel to branch off the TT20 line
- Status
  - Comprehensive construction plan, reviewed by an external company
  - Soil activation measurements done in 2018
- Next steps
  - Consider more granular look at installation and what is included to ensure nothing is overlooked
  - Detailed review and optimisation required following discussion of best way forward

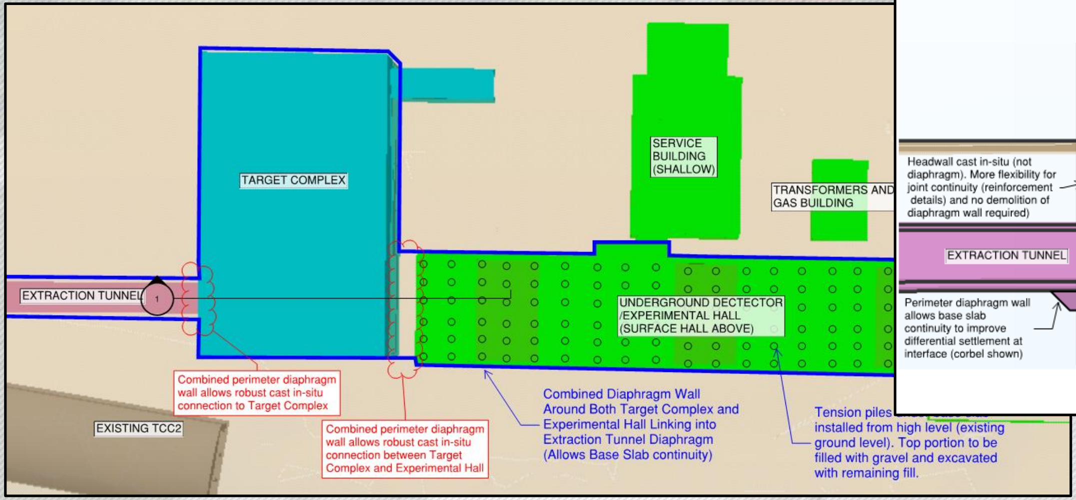


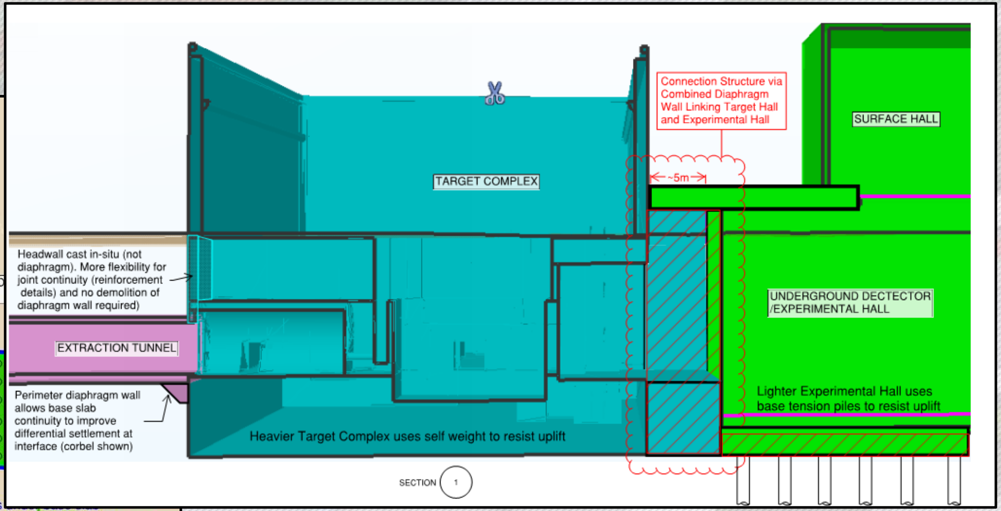
Civil engineering – preliminary studies signed off

e.g. Task 2 – Target Complex

Jonathan Gall

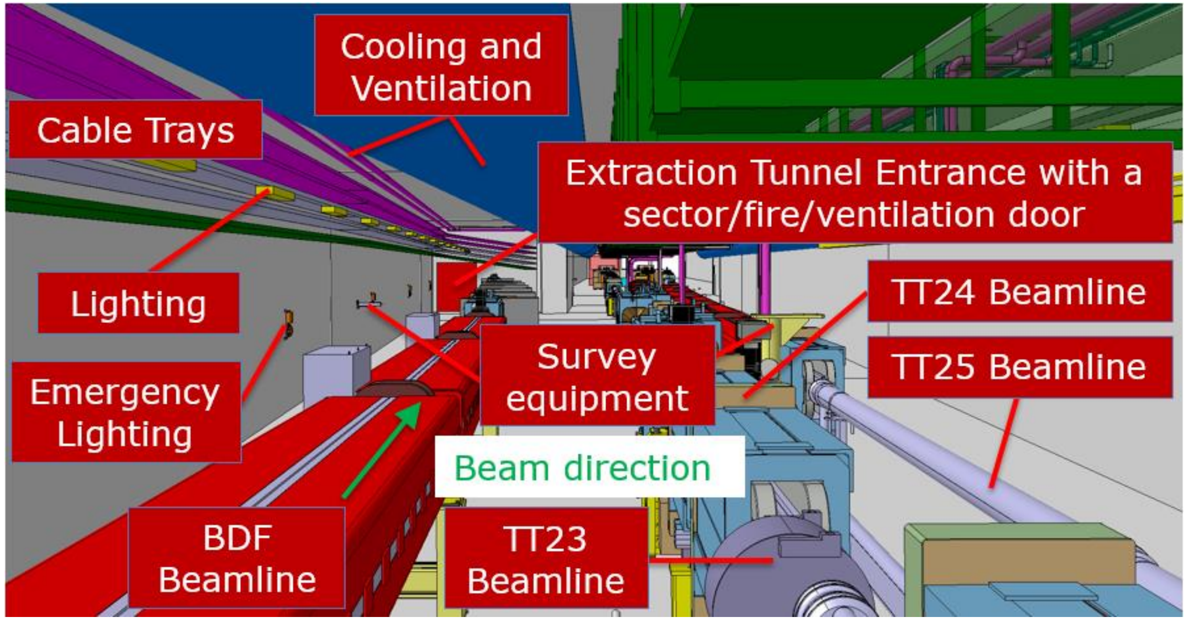
- Combined perimeter diaphragm wall
- ‘Bottom up’ construction sequence to allow complex internals to be built
- Shared cast in situ connections to minimise ground movement and settlement
- Foundation analysis - ‘Floating’ raft foundations due to weight of building (heavy internal structure) or possible tension piles





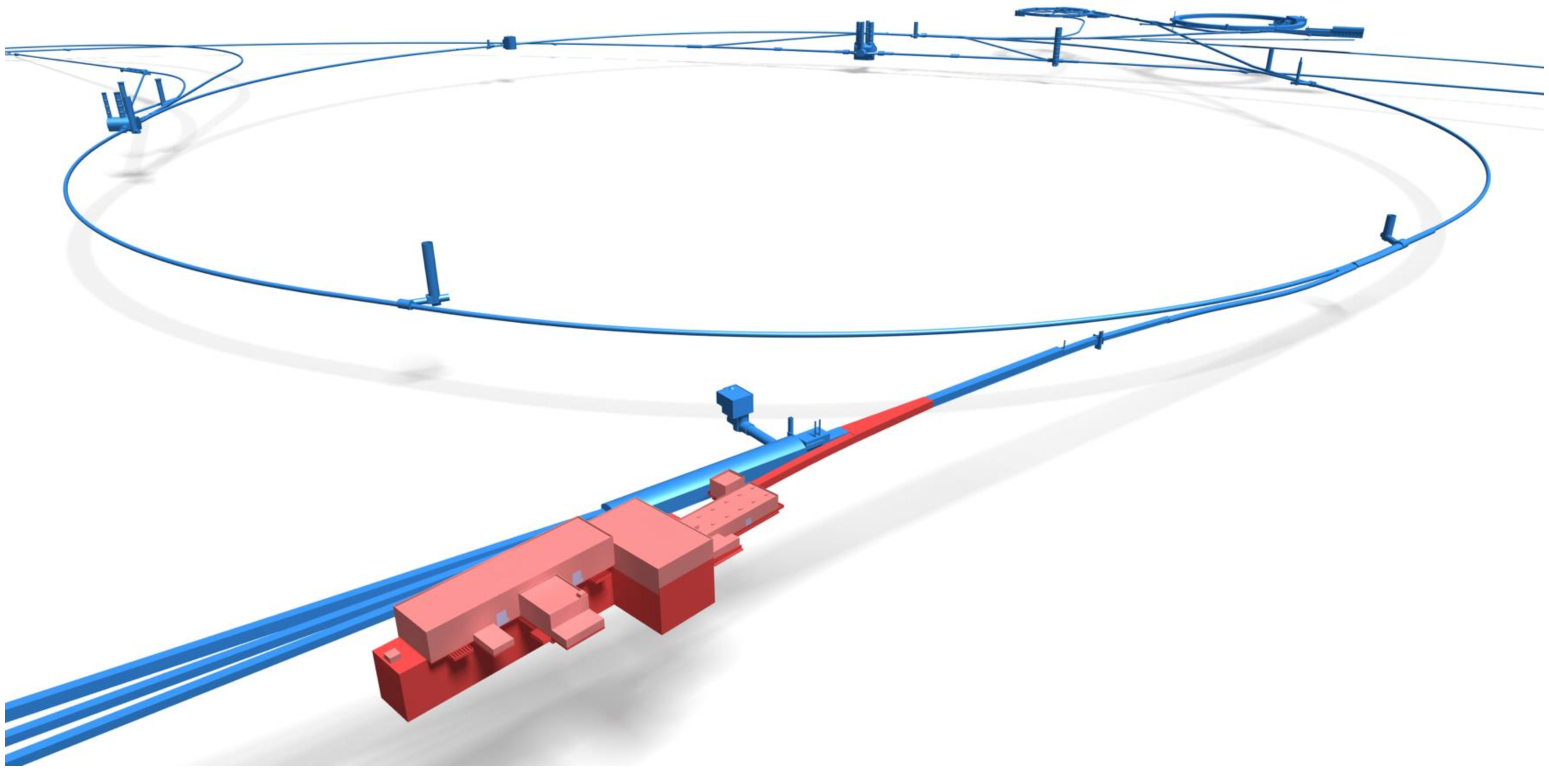
Safety engineering & integration

- Involved in all the aspects of the project
- Safety engineering
  - Identify safety hazards optimize designs
  - Fire safety, compartmentalization and rescue
  - All risks physical, chemical, environmental, etc…
- Integration
  - Compiles all the requirements and builds a comprehensive 3D model of the whole project
  - Critical at the design stage for all the groups, from beam dynamics to civil engineering



SPS Beam Dump Facility: Comprehensive Design Study

- CERN Yellow Report (with the printers!)
- https://arxiv.org/abs/1912.06356
- All work packages fully documented
- Includes cost estimates and roadmap



Cost estimate

Work package	Estimate (MCHF)
Civil engineering	68.2
Work Package 1	31.7
Work Package 2	16.5
Work Package 3	10.9
Work Package 4	7.3
Work Package 5	1.3
Site investigation	0.6
Extraction and beam line	9.6
Magnet refurbishment	0.7
Switch/splitters	2.1
Dilution system (MDX magnet)	0.52
Power converters	3.0
Beam instrumentation	0.8
Vacuum system	0.6
Interlocks	0.2
D.C. cabling	1.62

Target and target complex	45.5
Target assembly and annexe equipment	5.6
Instrumentation package	0.9
Bunker iron shielding and US1010	14.0
Concrete shielding	0.85
Magnetizing coil for US1010 shield	1.0
Target and coil handling system	19.1
Target and coil shielding casks	0.2
Helium vessel	2.3
Integration	0.6
Beam window(s)	0.6
Collimator(s)	0.5
Infrastructure and services	31.5
Cooling	7.4
Ventilation	6.3
Electrical distribution	5.6
Survey and alignment	1.1
Access system	1.4
Fire safety system	3.5
Radiation monitoring	0.4
Transport (inc. cranes and lifts)	5.1
Control infrastructure	0.7
Integration and installation	3.6
Installation	2.6
Installation, design support	0.6
Preparation, dismantling	0.4
Total	158.4

Possible timeline

2020	Approval to go ahead with Technical Design Report
2020	Continued design studies and prototyping
2021–2022	Engineering design studies towards Technical Design Report
	Detailed integration studies
	Specification towards production
	Begin CE pre-construction activities: environmental impact study and detailed CE design and pre-tender process
2022	Technical Design Report delivery
2023	Seek approval
2023+	Tender, component production, CE contracts

Conclusions

- Impressive progress over the last 3 years
- In depth Comprehensive Design Study completed
- In a strong position to seek approval to work towards a TDR for delivery by 2022

Many thanks to the management for their trust and support over the last 3 years