CERN

The SHiP Facility

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On behalf of the SHiP Task Force

SHiP

Search for Hidden Particles

OUTLINE

- The requirements for SHiP
- The challenges
- Introduction to the facility
- Extraction and beam transport
- The target and target station
- The active muon shield
- The detector hall and detector implementation
- Civil engineering
- Radiation protection issues
- The impact on the SPS fixed target program
- R&D studies and Machine Developments
- Planning
- Outlook

THE SHiP REQUIREMENTS

- High-intensity proton beam: 4 10^{13} ppp, 4 10^{19} pot/yr
- Slow extraction to minimise pile-up (~1 sec flat top)
- O(400 GeV) is optimal beam momentum
- Minimal impact on running North Area program
- Dense target to stop π and K before they decay into $\mu+\nu$
- Effective muon shield
- Long evacuated decay volume to minimise interactions
- Effective veto system to reduce background

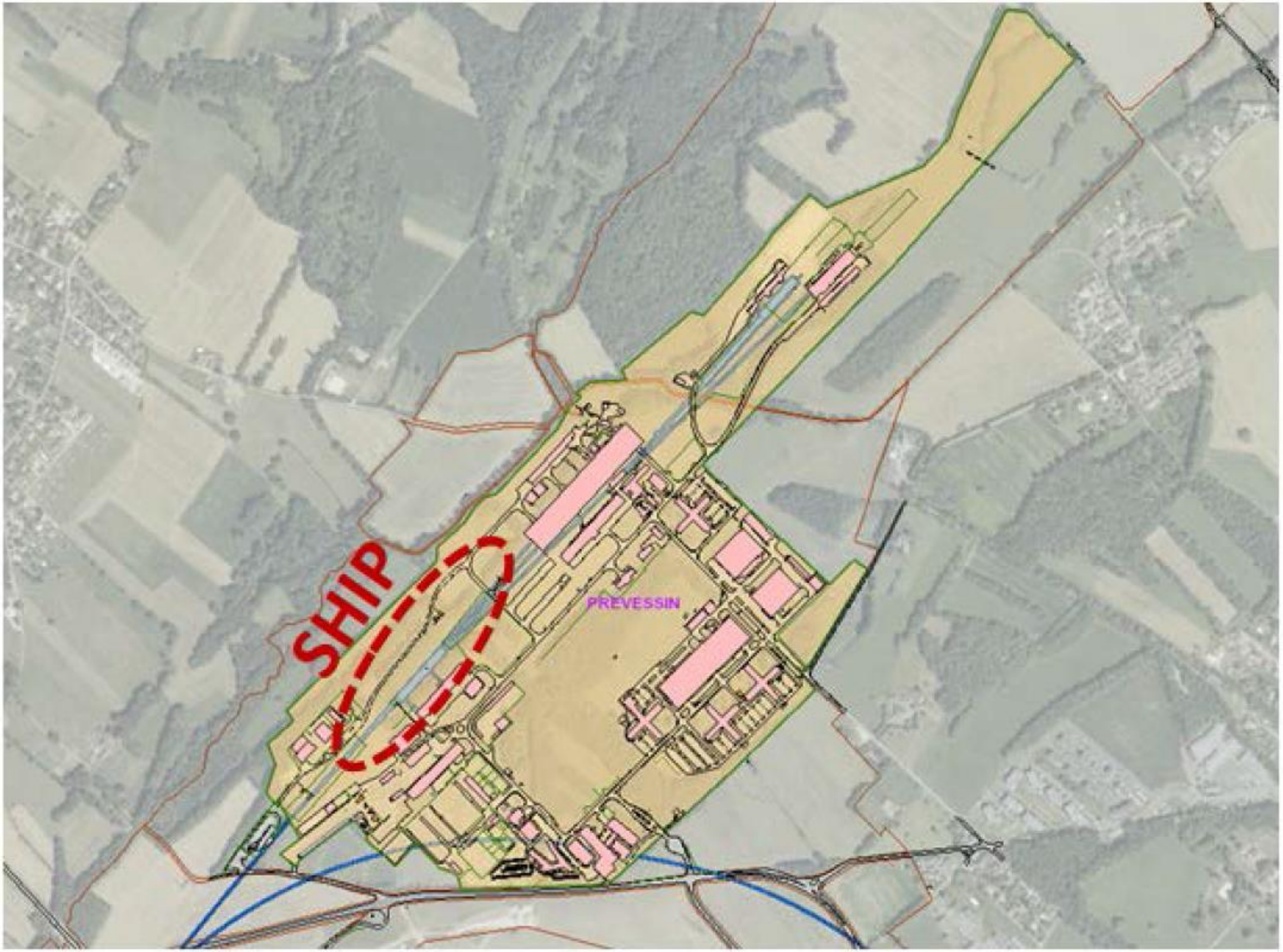
SHiP includes a new permanent facility for the North Area with unprecedented beam intensities for the NA

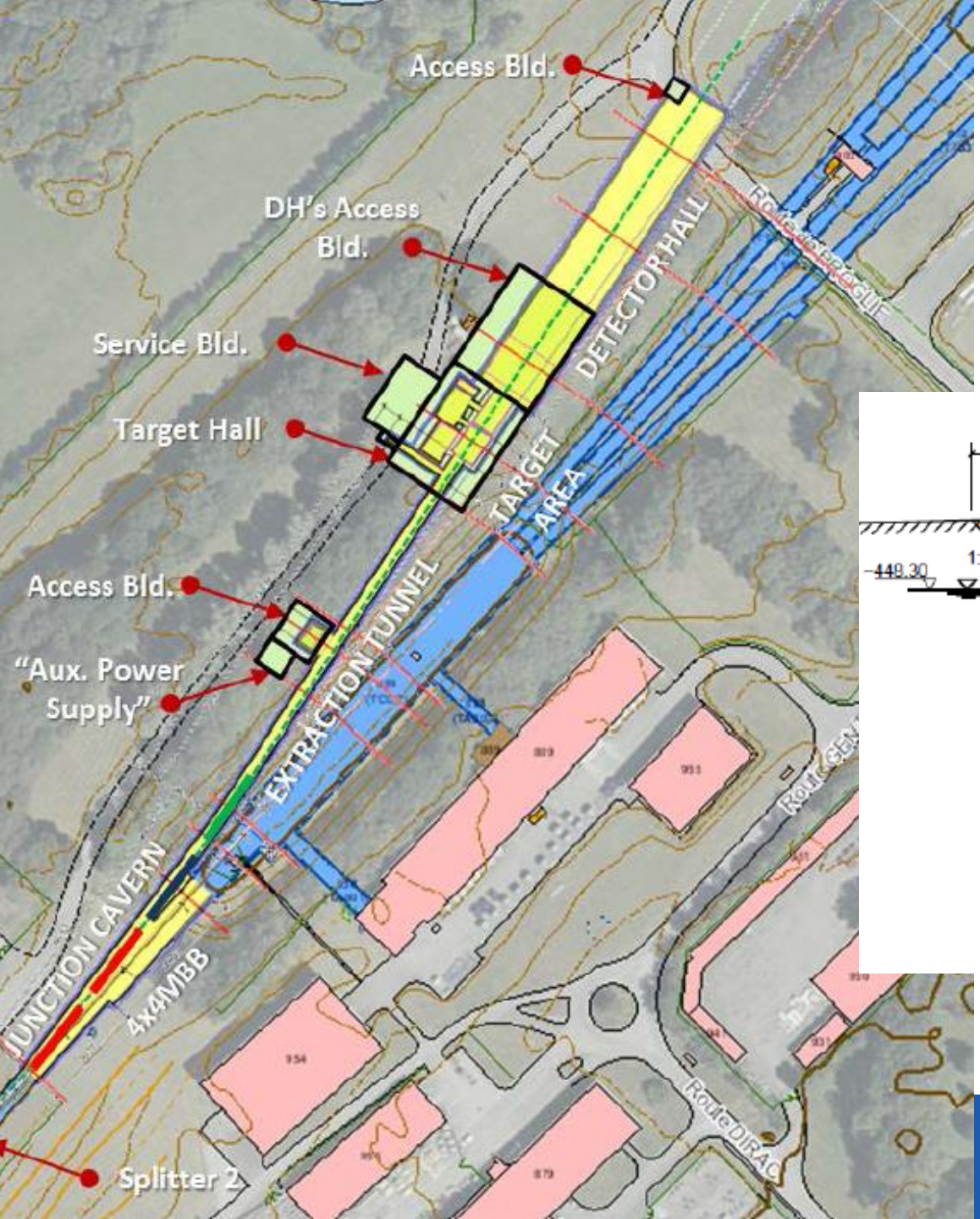
THE CHALLENGES

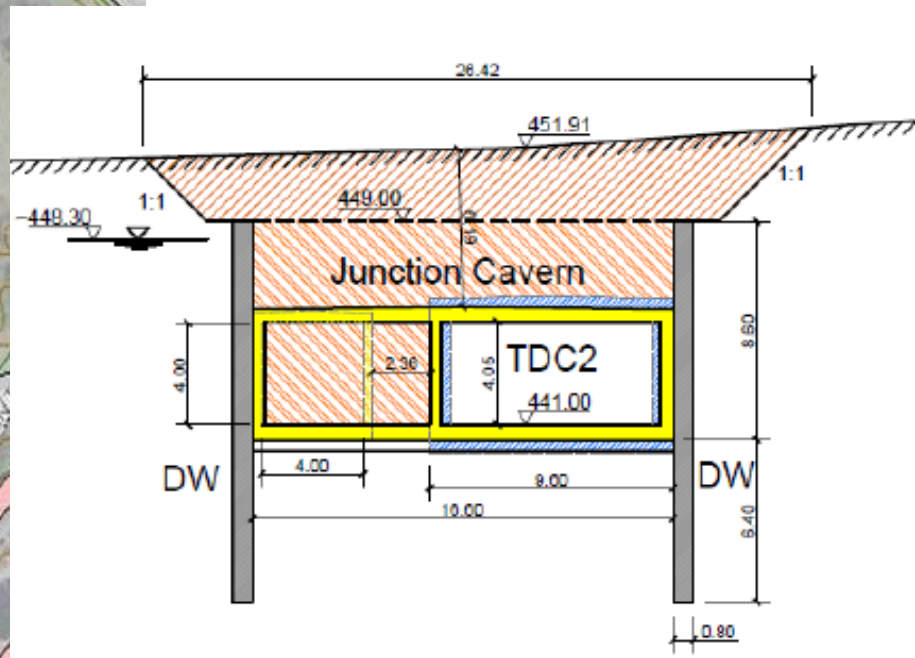
- High radiation doses
  - Injectors, extraction, target, …
- Radiation damage
  - Extraction septa, target and target station,
- Good compatibility with North Area operation
- Target design for survival
- Reliability and efficiency to be maintained
- Mitigation of muon and neutrino backgrounds
- Planning
  - Partial dismantling of TDC2, radioactive concrete
- Cost containment

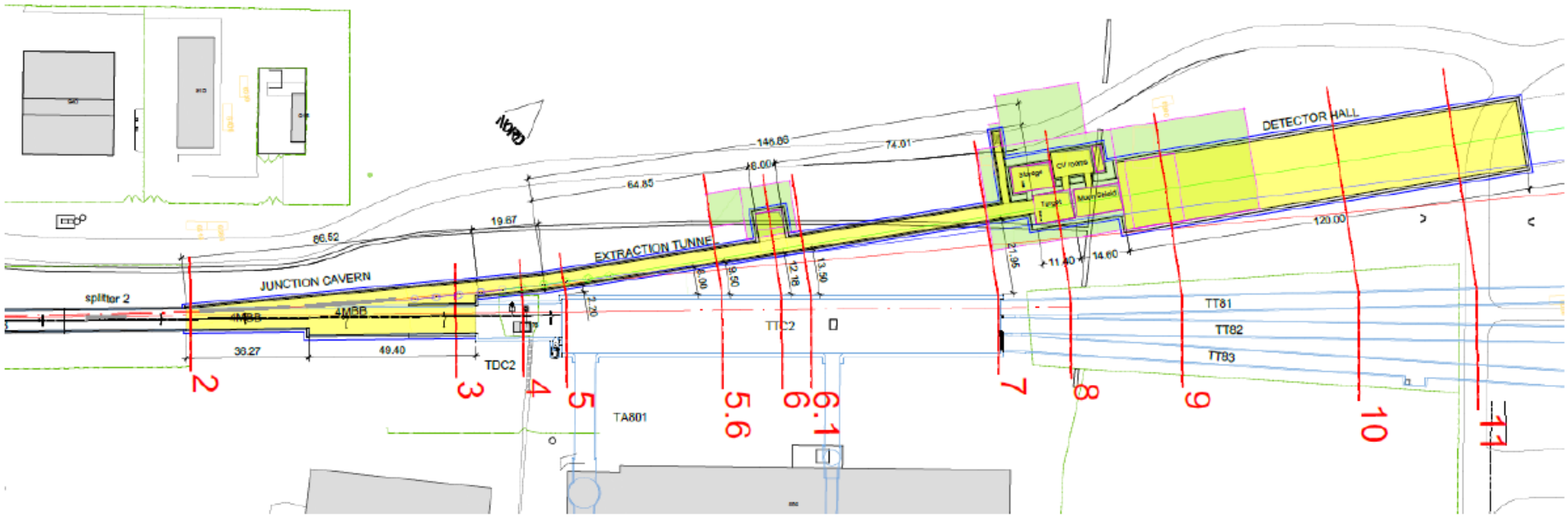
INTRODUCTION TO THE FACILITY

- Slow extraction into TT20 channel using existing septa
- Replace splitter 1 by laminated splitter/switch magnets
- Beam for SHiP is deflected towards Jura side by new splitter/switch magnets and 17 MBB magnets
- The beam exits from TDC2 via a junction cavern into the extraction tunnel
- The extraction tunnel: long to allow beam size to grow as well as getting away from the existing facilities (TCC2)
- Target cavern houses Mo+W target, water-cooled, followed by 5 m of iron (hadron stop)
- Active muon shield
- The detector cavern houses decay volume and detectors

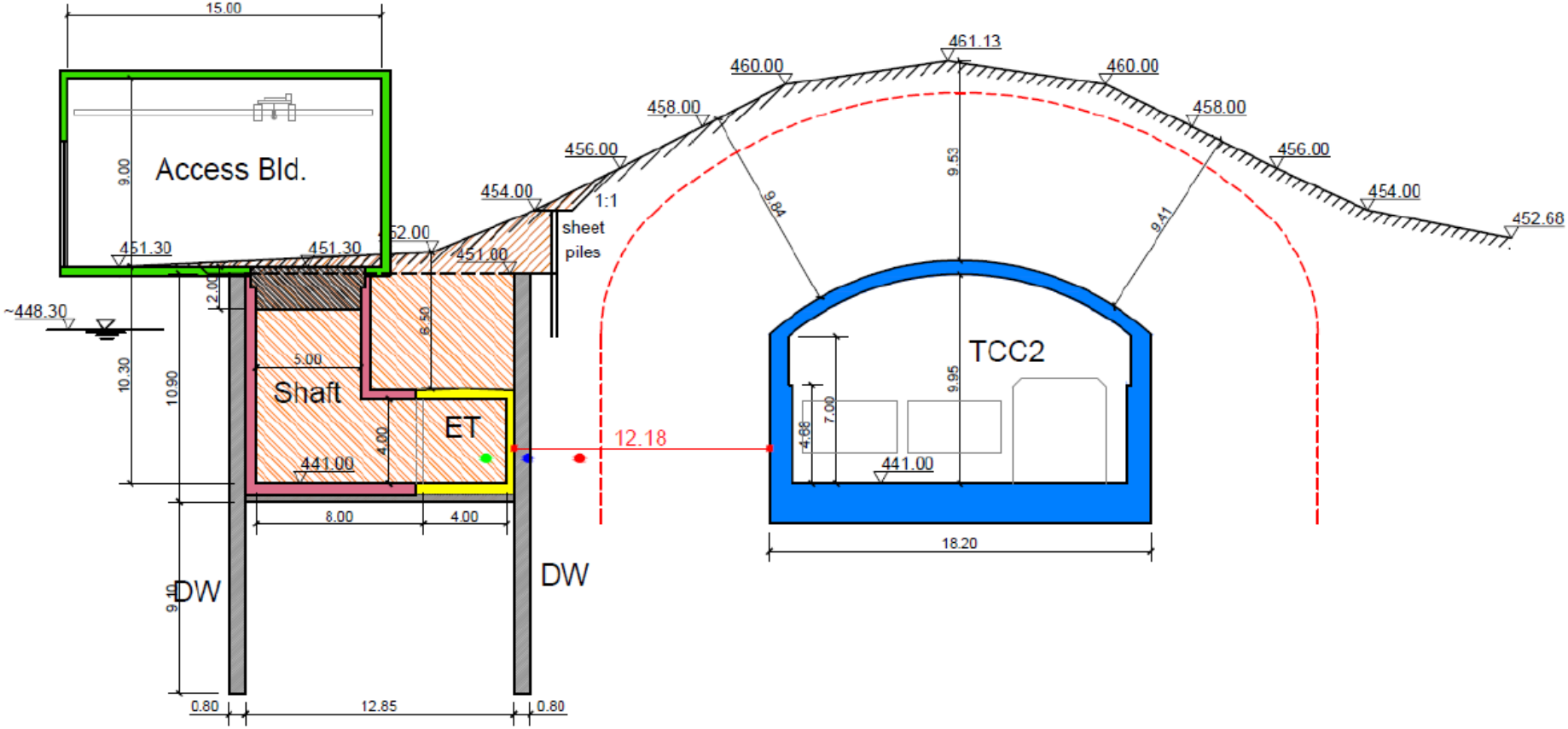

SHIP
PREVESSIN


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
4x4MBB
Route DIRAC


26.42
451.91
1:1
1:1
449.00
448.30
Junction Cavern
TDC2
441.00
2.36
4.05
4.00
8.50
DW
DW
4.00
9.00
10.00
5.40
0.80


DETECTOR HALL
EXTRACTION TUNNEL
JUNCTION CAVERN
splitter 2
4MBB
4MBB
TDC2
TTC2
TA801
TT81
TT82
TT83
146.66
74.01
64.85
6.00
19.67
66.52
120.00
14.60
11.40
21.96
12.18
13.50
2.20
30.27
49.40
2
3
4
5
5.6
6
6.1
7
8
9
10
11

Section 6:


15.00
Access Bld.
9.00
451.30
451.30
452.00
451.00
~448.30
12.00
10.30
10.90
5.00
Shaft
6.50
ET
4.00
441.00
8.00
4.00
DW
DW
9.10
0.80
12.85
0.80
454.00
456.00
458.00
460.00
461.13
460.00
458.00
456.00
454.00
452.68
1:1
sheet
piles
9.84
9.53
9.41
TCC2
9.95
7.00
4.66
441.00
12.18
18.20

EXTRACTION AND BEAM TRANSPORT

- Use slow extraction scheme as for NA, but 1 sec flat top
- SHiP cycle length is 7.2 s (note: CNGS cycle was 6 s)
- Momentum 5-10 GeV/c different from 400 GeV/c (safety interlock)
- **4 10^{13} ppp is historical maximum for slow extraction:**

  Unavoidable losses on septum concentrated in 1 second!

  Expect 4 10^{11} protons per spill to hit wires: T → 800°C

  (operational limit is 1000°C)

  Conditioning may take up to a week.

  SHiP operation doubles max. beam power so far: **sparking**!

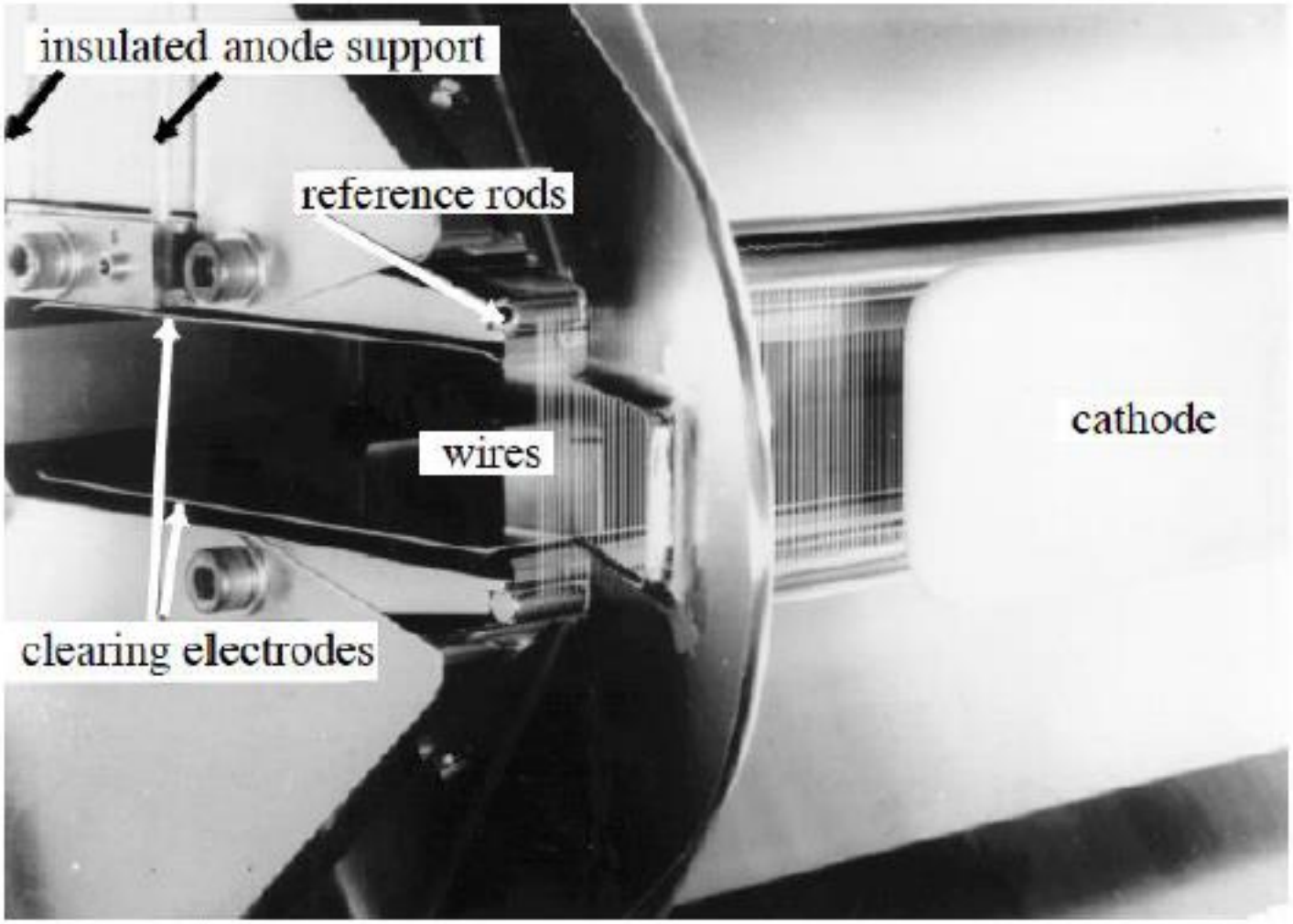
  Repairs may take **long cool down times**.

  This requires some Machine Developments

  Overall within reach, but requires **more interlocking, diagnostics, surveillance, trending, long-term control.**

Anyway good in general (ALARA)

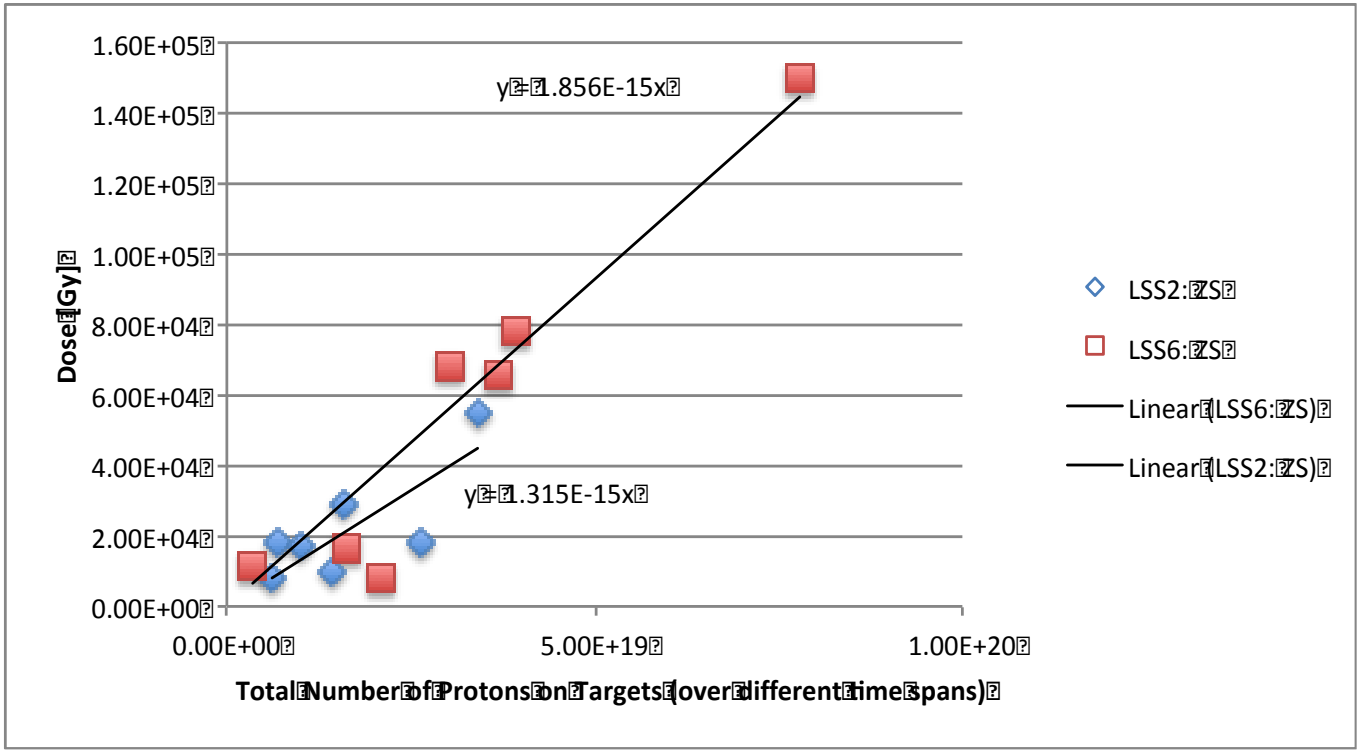
ZS ELECTRISTATIC SEPTUM:



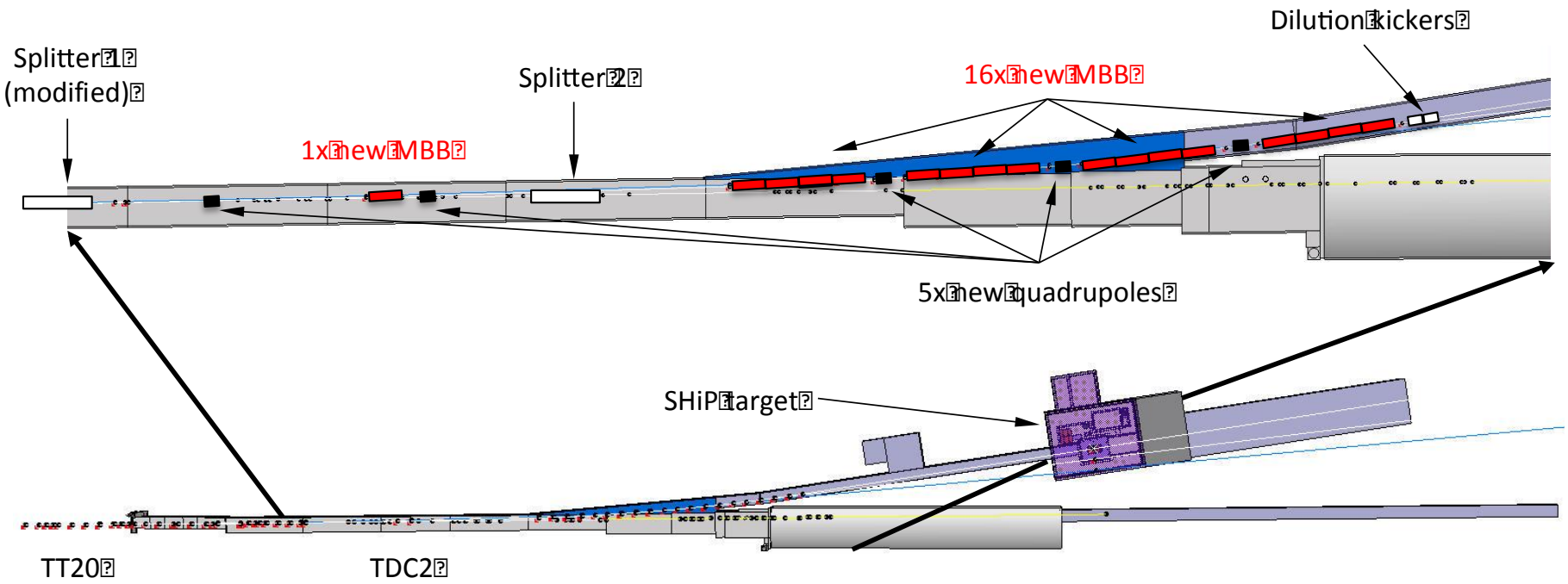
EXTRACTION AND BEAM TRANSPORT (2)

- **Higher extraction losses → higher dose levels**
  Comparisons have been made with e.g. WANF and LSS2 extraction so far. Slow is better than fast-slow!

Cable tray at 1 m from the ZS

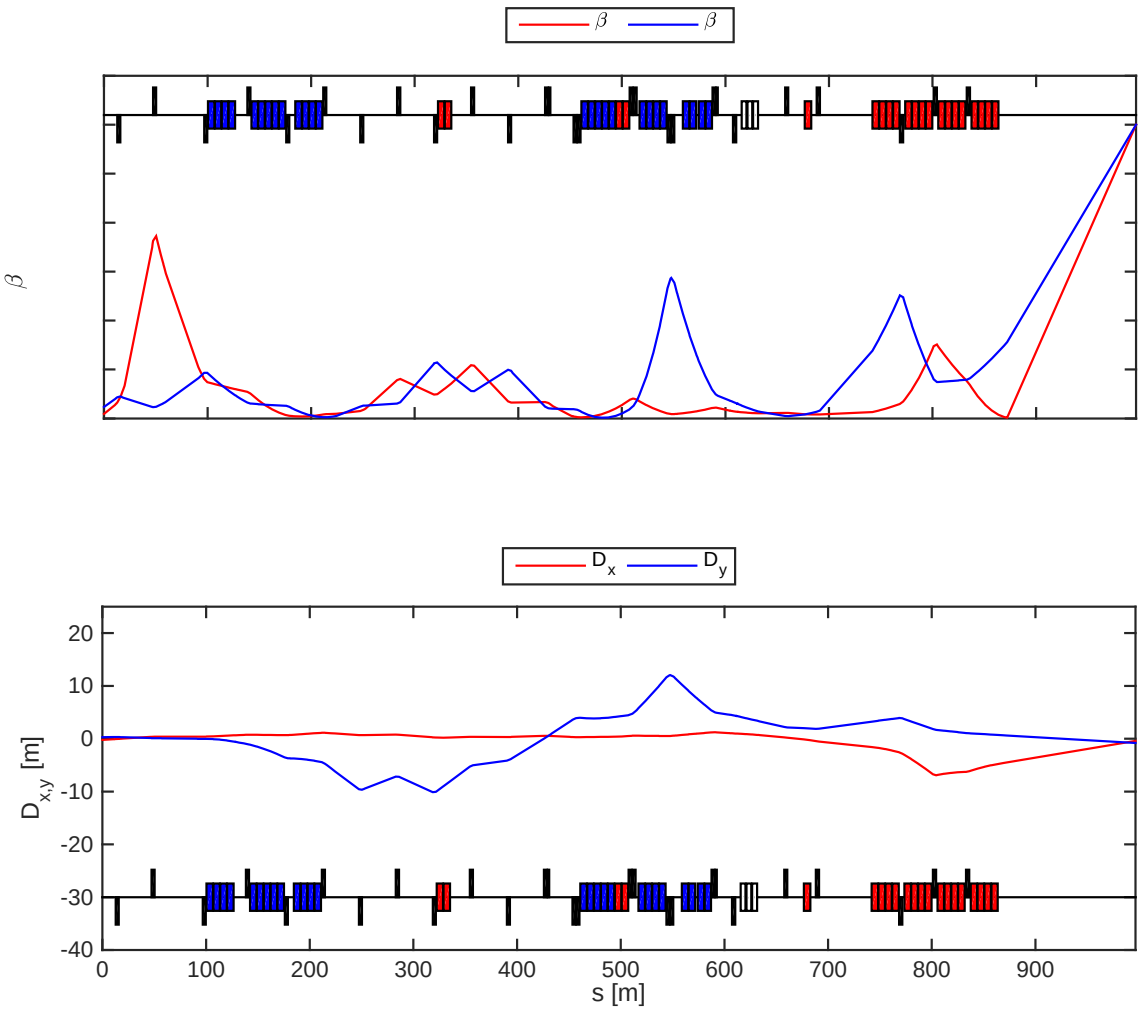


Transfer line layout



- Three new laminated splitters (small beam here for SHiP)
- 17 MBB magnets running at 1.73 T (8 mrad each)

OPTICS IN TT20

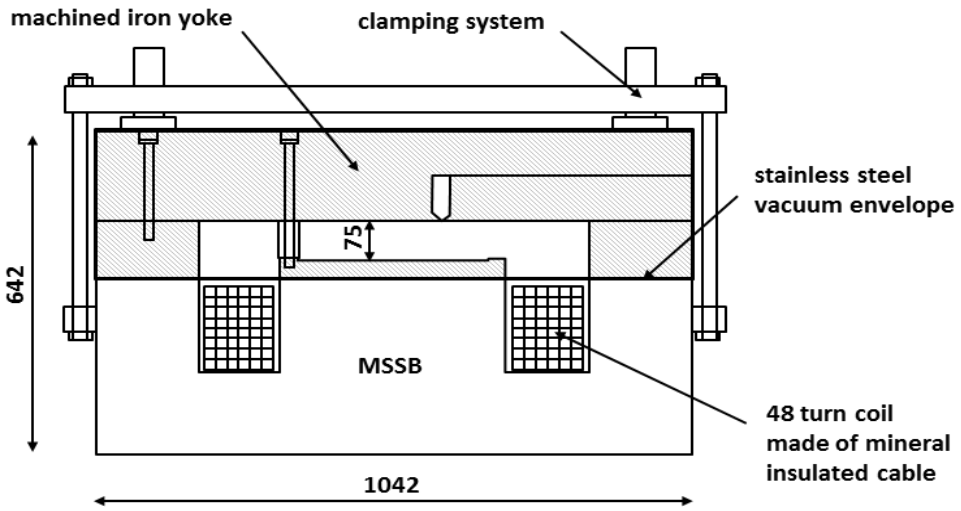


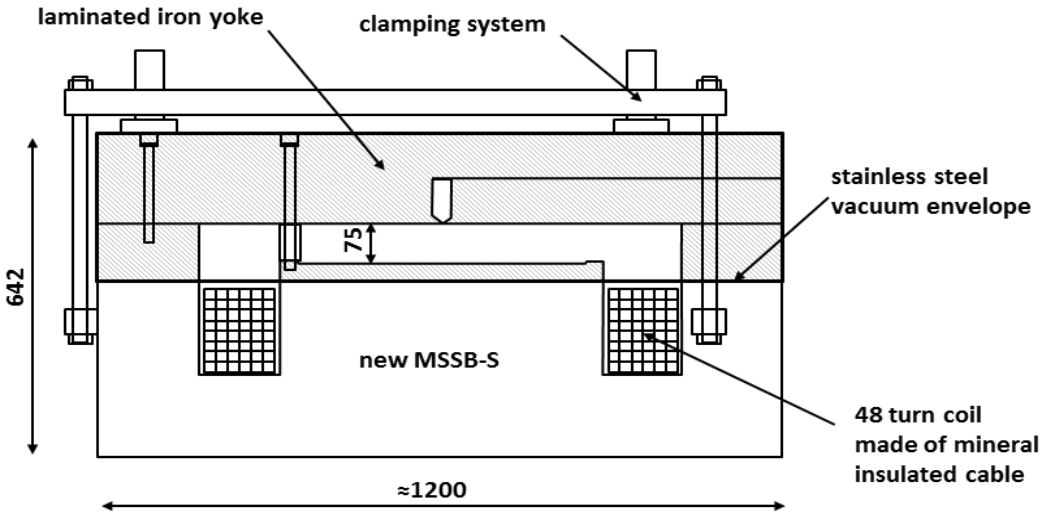
Splitter magnets

Polarity to be switched between T6 and SHiP operation

Larger horizontal gap

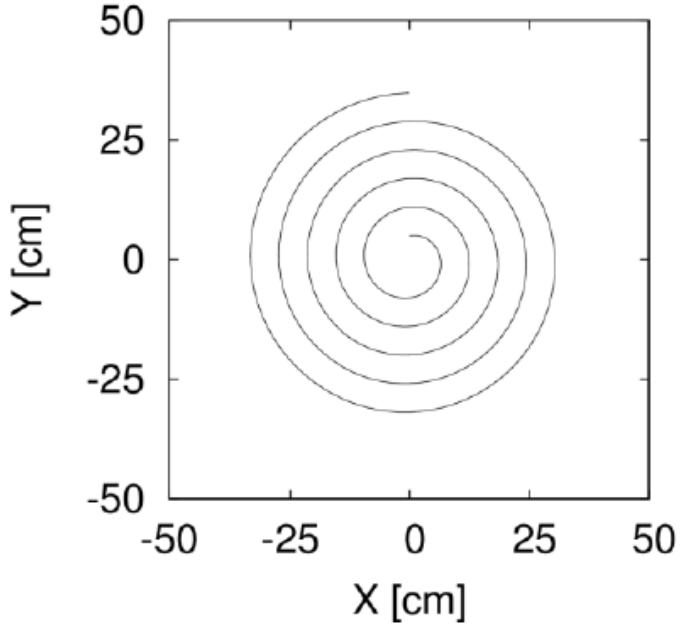
R&D should start at least 2.5 years before installation date

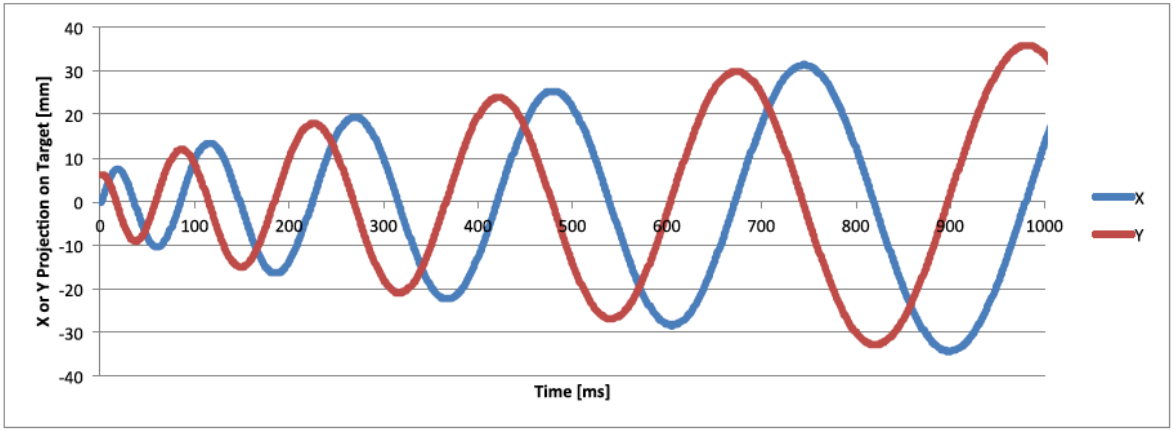




Archimedean spiral

To protect the target: 5 spiral turns in 1 sec,
I.e. sweep speed of 0.65 m/s





TARGET AND TARGET STATION

- The target must be as **dense** as possible
- This ensures that π and K are stopped before they decay and produce ν_e, ν_μ and muons
- Charm particles decay before being stopped and produce HNL (and others) as well as ν_τ
- However the high density leads to extremely high energy deposit per unit of volume, hence strong **heating**
- Hence the need of a **cooling system** (Tritium!)
- There are also issues with material damage due to atom displacement
- **Beam power is 355 kW, over 1 sec spill up to 2.56 MW**

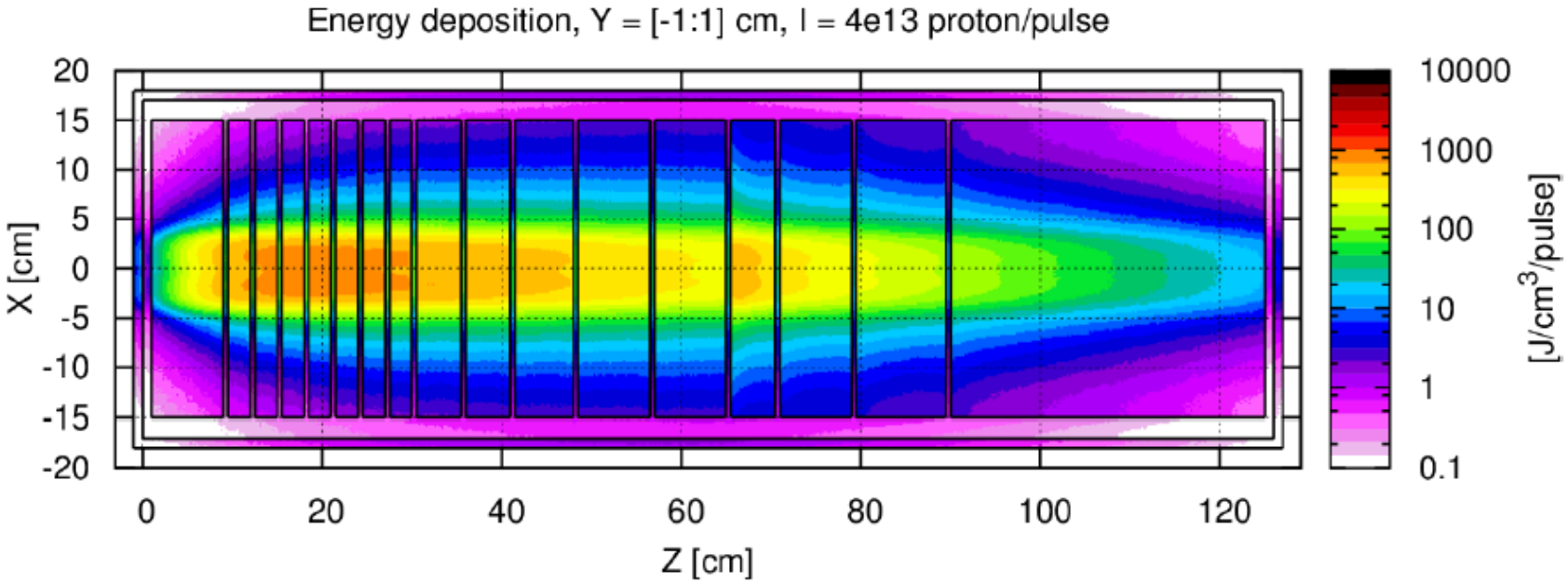
The target itself

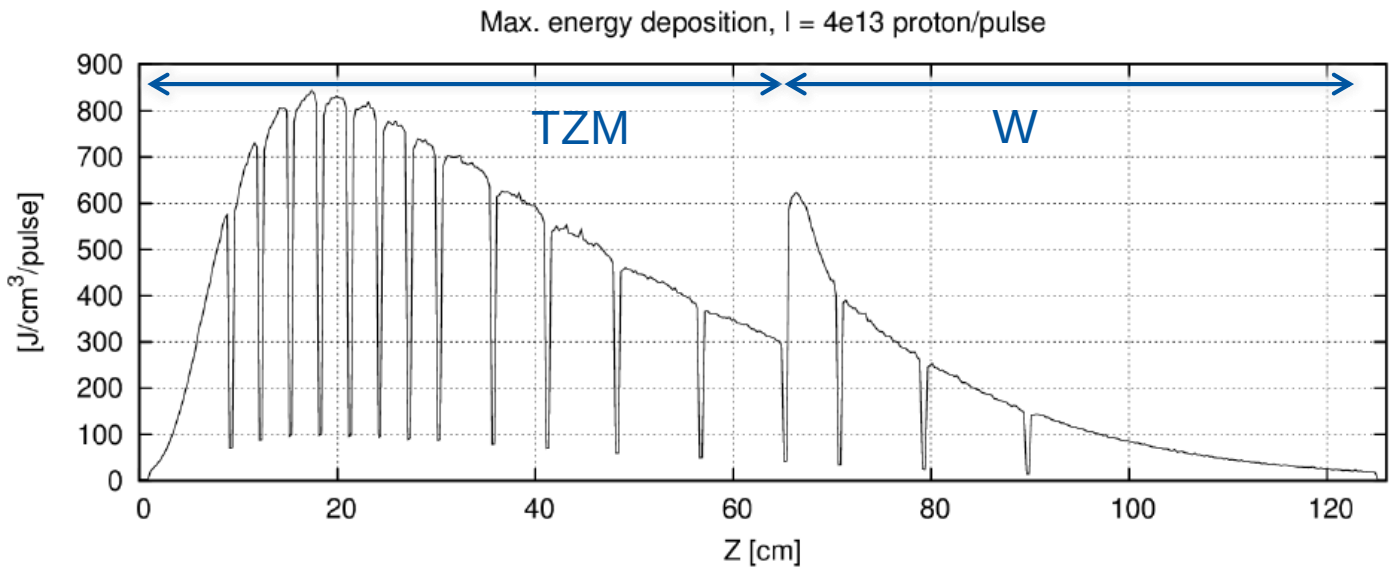
Hybrid solution:
Molybdenum alloy TZM
Pure tungsten

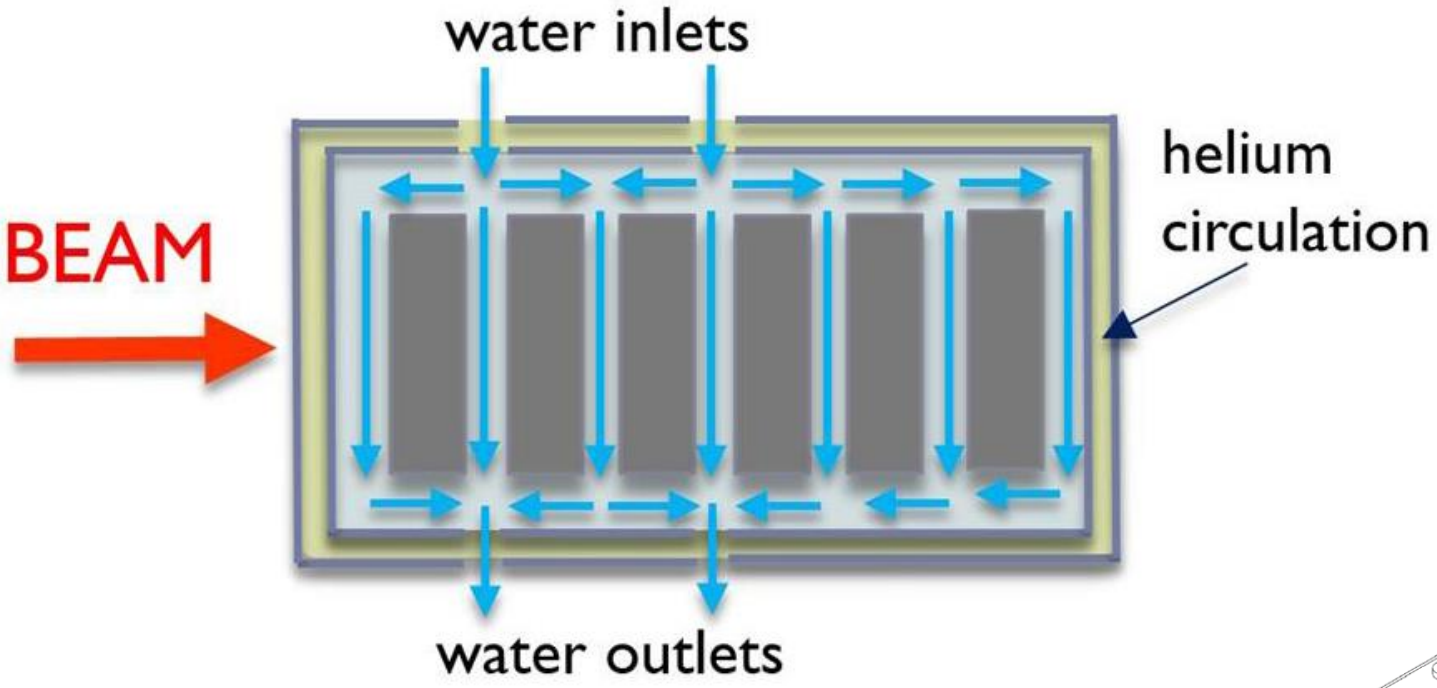
Total length 116 cm
Transverse size 30x30 cm^2
4λ of TZM + 6λ of W

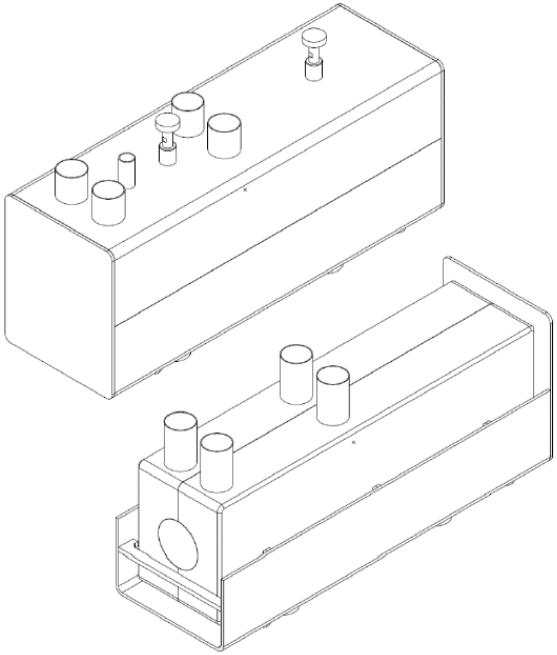
	DONUT [1)]	CHARM [2)]	SHiP
Target material	W-alloy	Cu (variable ρ)	TZM + pure W
Momentum (GeV/c)	800	400	400
Intensity	$0.8*10^{13}$	$1.3*10^{13}$	**$4*10^{13}$**
Pulse length (s)	20	$23*10^{-6}$	1
Rep. rate (s)	60	~10	7.2
Beam energy (kJ)	1020	830	2560
Avg. beam power (spill) (kW)	51	$3.4*10^{7}$ (fast)	2560
Avg. beam power (SC) (kW)	17	69	355
POT	Few 10^{17}	Few 10^{18}	**$2*10^{20}$**

Energy deposition





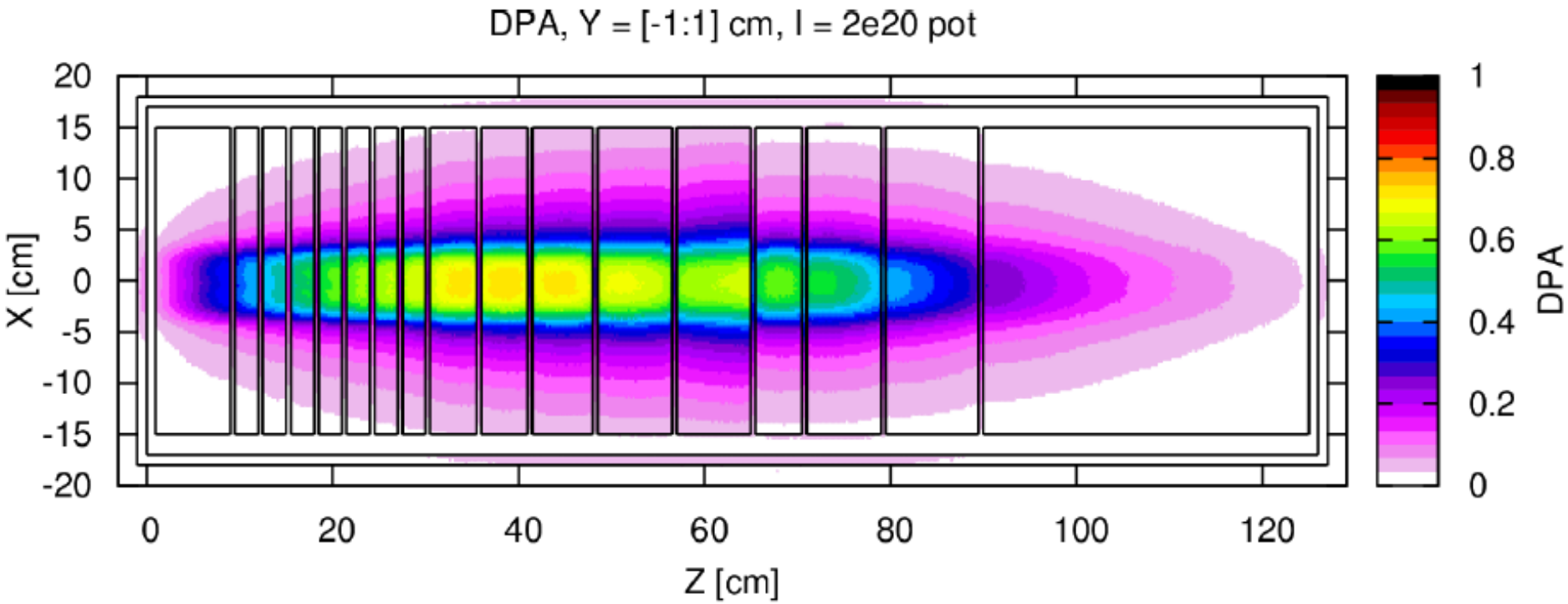




The target core is contained in a double walled stainless steel container.

The first containment is filled with He gas.

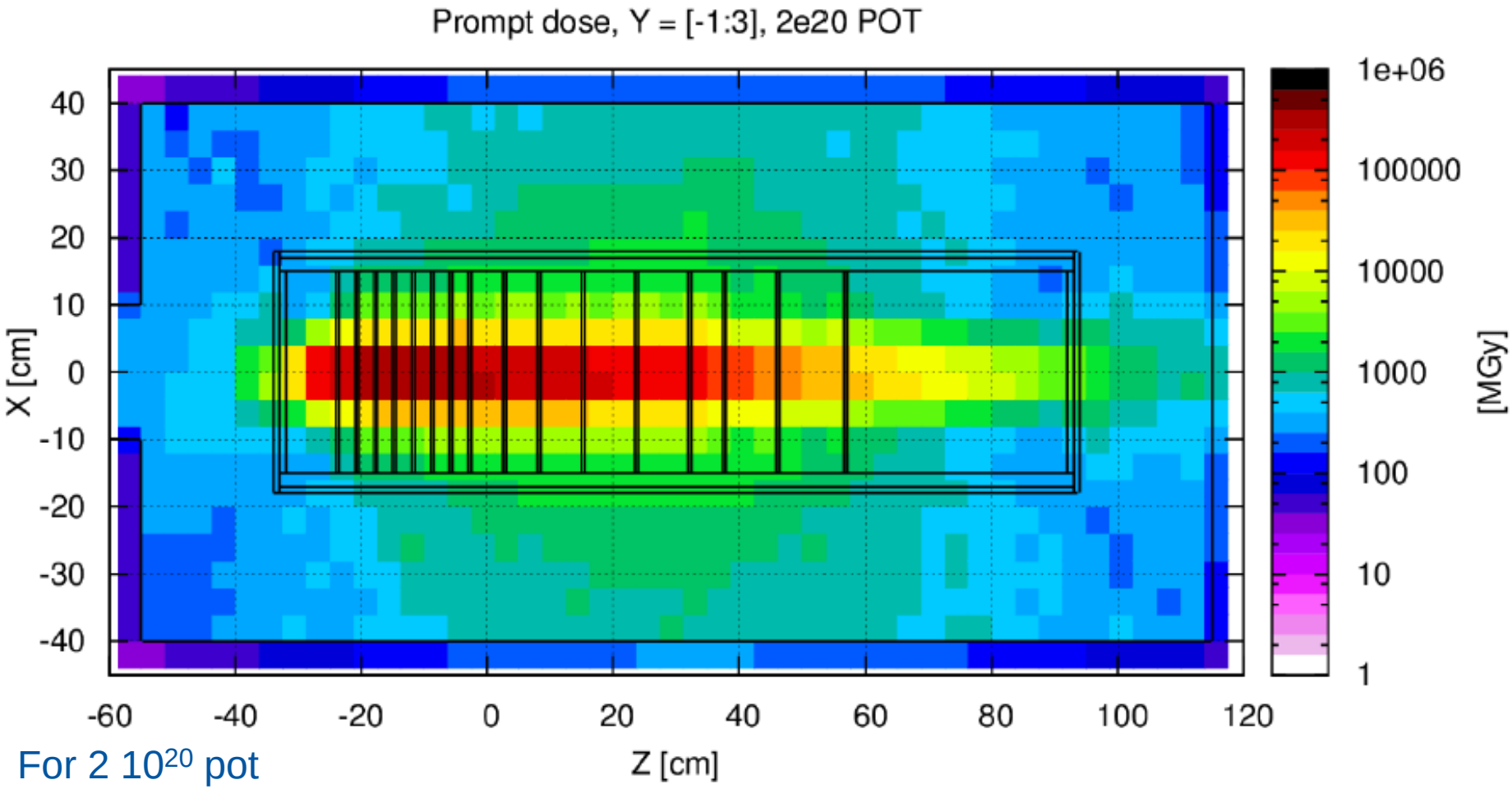
Displacement Per Atom (DPA)



May lead to significant bulk damage, e.g. change of yield strength → **R & D**

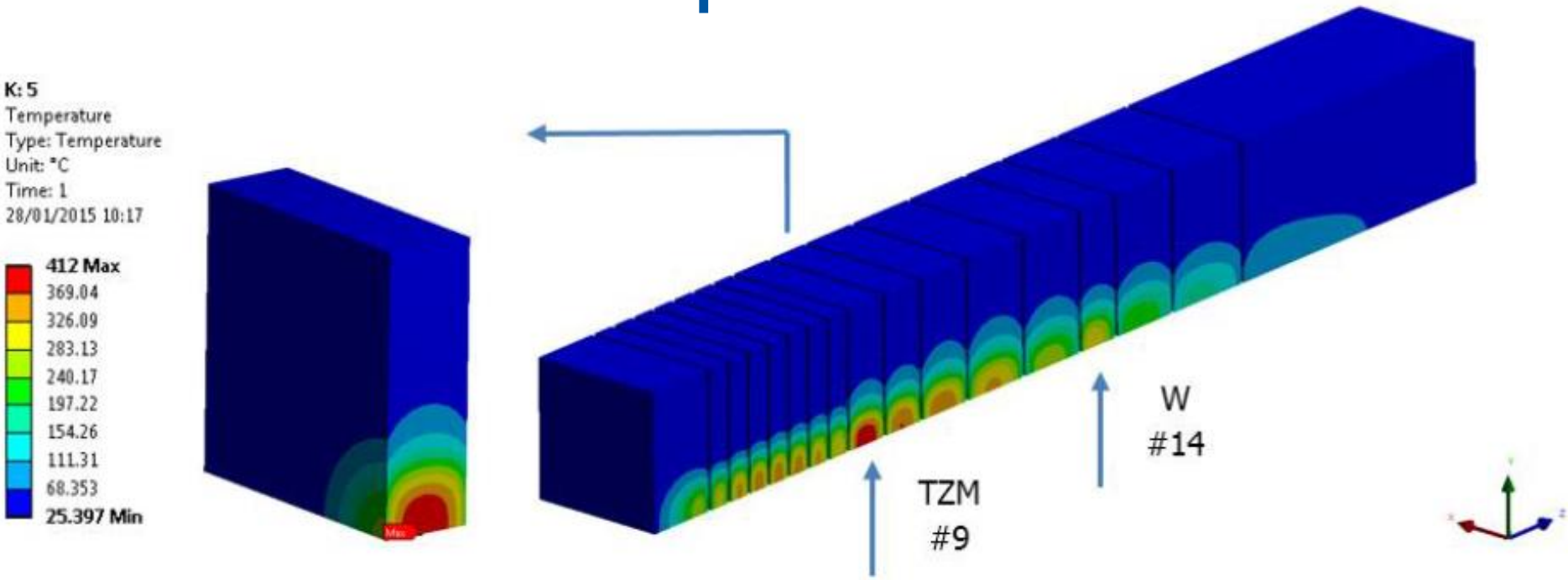
Dose around the Ship target

Yearly dose at 10 cm around target is 400 MGy



For 2 10^{20} pot

Maximum temperatures

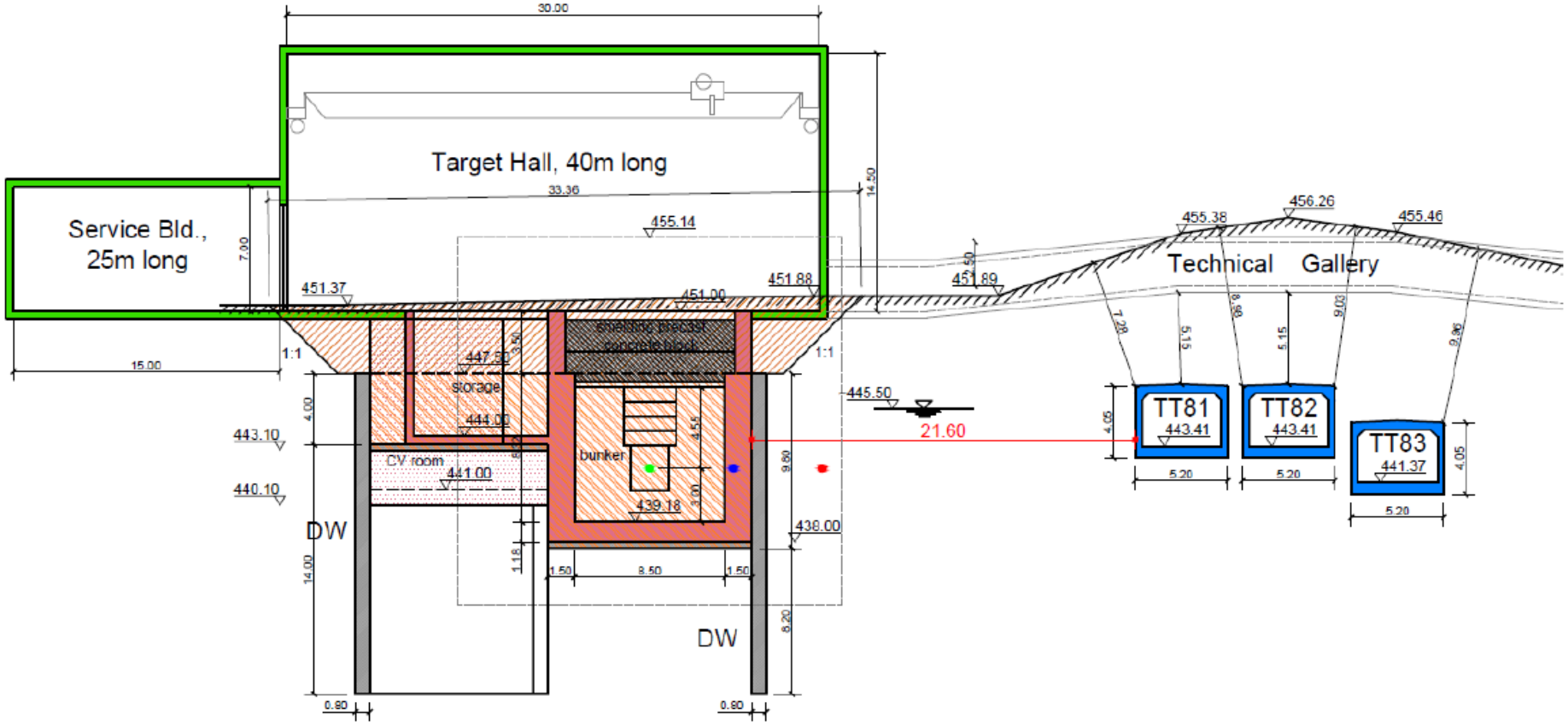


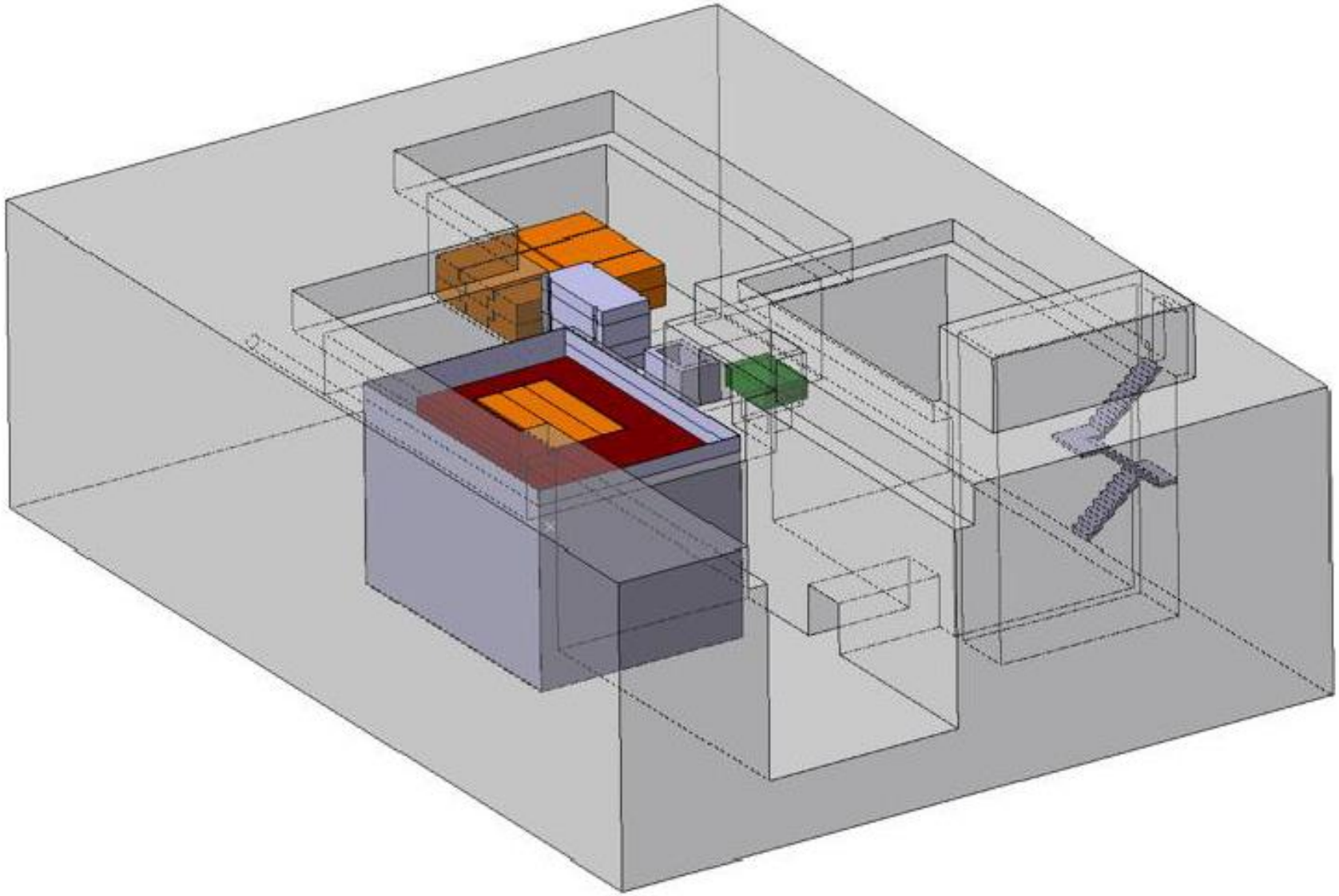
Max. temperatures in blocks 9 (TZM) and 14 (W)
Reached after 5 SPS cycles
Compressive stresses seem not too severe
If sweep fails, T rises up to 1400 ºC (risk of fracture, solved by interlocking, no melting)

The Target Complex

- Design profits from studies done for CENF
- Target is located underground, with surface hall 15 m above
- Target building includes first 15 m of muon shield
- Cast-iron hadron absorber encloses production target
  - The first layer is water cooled (embedded stainless steel pipes), the outer layers are passive blocks.
  - The total volume is 18+440 m^3
- Target and hadron absorber are inside helium vessel

Section 8:


30.00
Target Hall, 40m long
33.36
14.50
Service Bld.,
25m long
7.00
455.14
451.37
451.00
451.88
451.89
1:1
15.00
447.80
storage
444.00
CV room
441.00
bunker
439.18
445.50
21.60
443.10
440.10
DW
14.00
438.00
1.50
8.50
1.50
DW
0.80
0.80
455.38
456.26
455.46
Technical Gallery
TT81
443.41
TT82
443.41
TT83
441.37
5.20
5.20
5.20
4.05



Required R&D for target

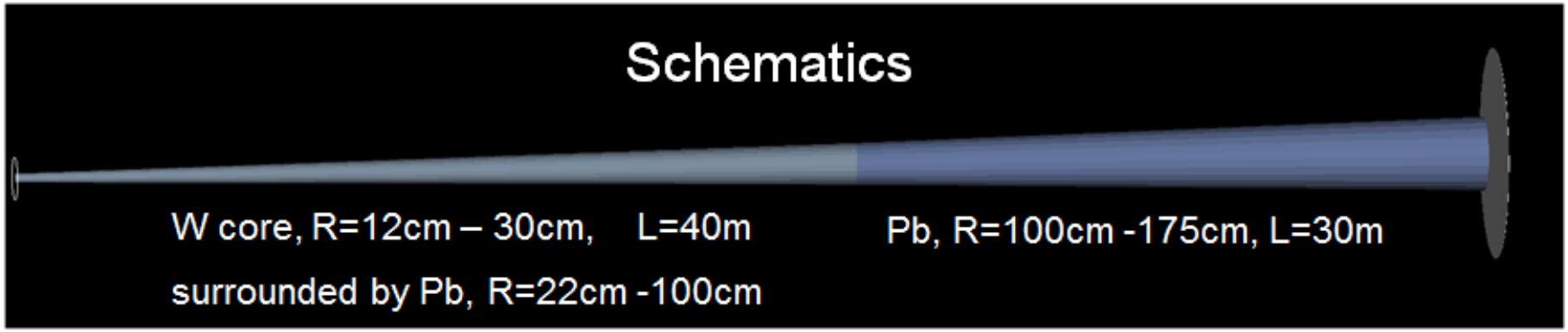
- Analysis of assembly, configuration and fabricability of cladded blocks
- Material R&D on TZM and W
- Study feasibility of water-cooled cast iron blocks with embedded steel pipes
- Develop full-metal plug-in systems
- Develop design of helium gas cooled target
  - as possible alternative to water cooling

THE MUON SHIELD

- Original idea (in EOI): passive shield

  110 tons of W, 2500 tons of Pb

  Total length 70 m

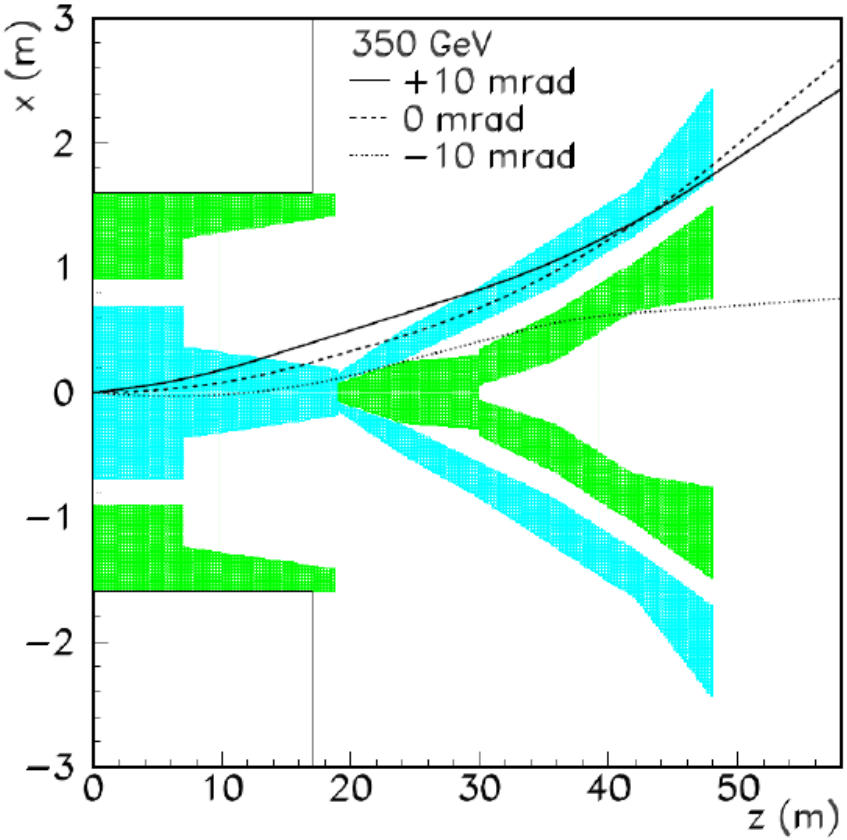


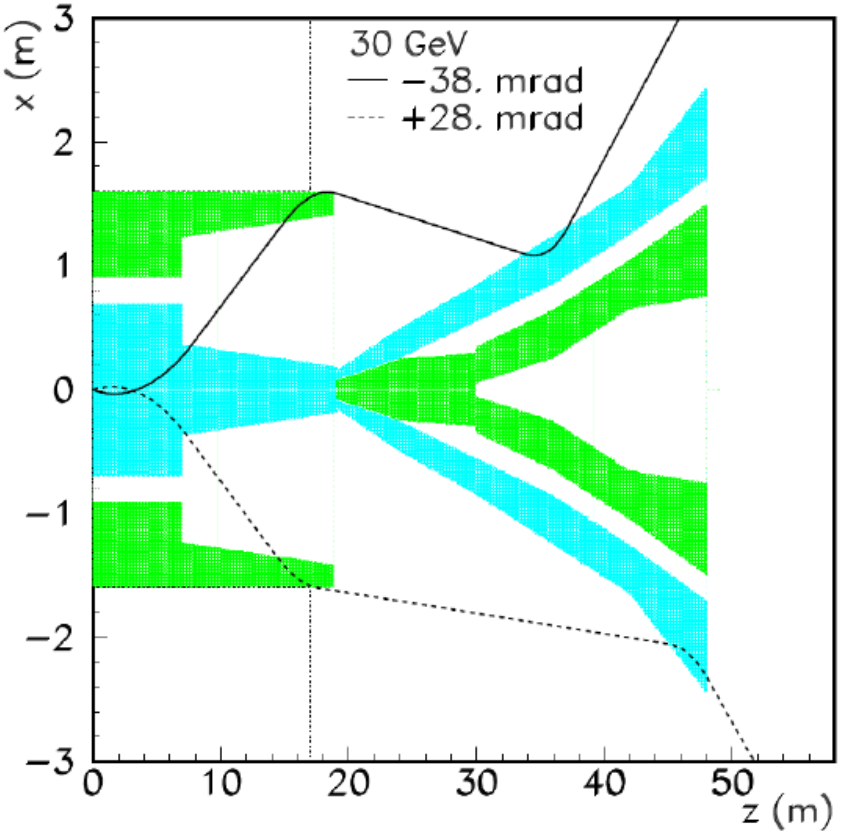
- Reduces muon flux per spill from 10^{10} to $\approx 10^{5}$
- Now replaced by ‘active’ shield (i.e. magnetised)

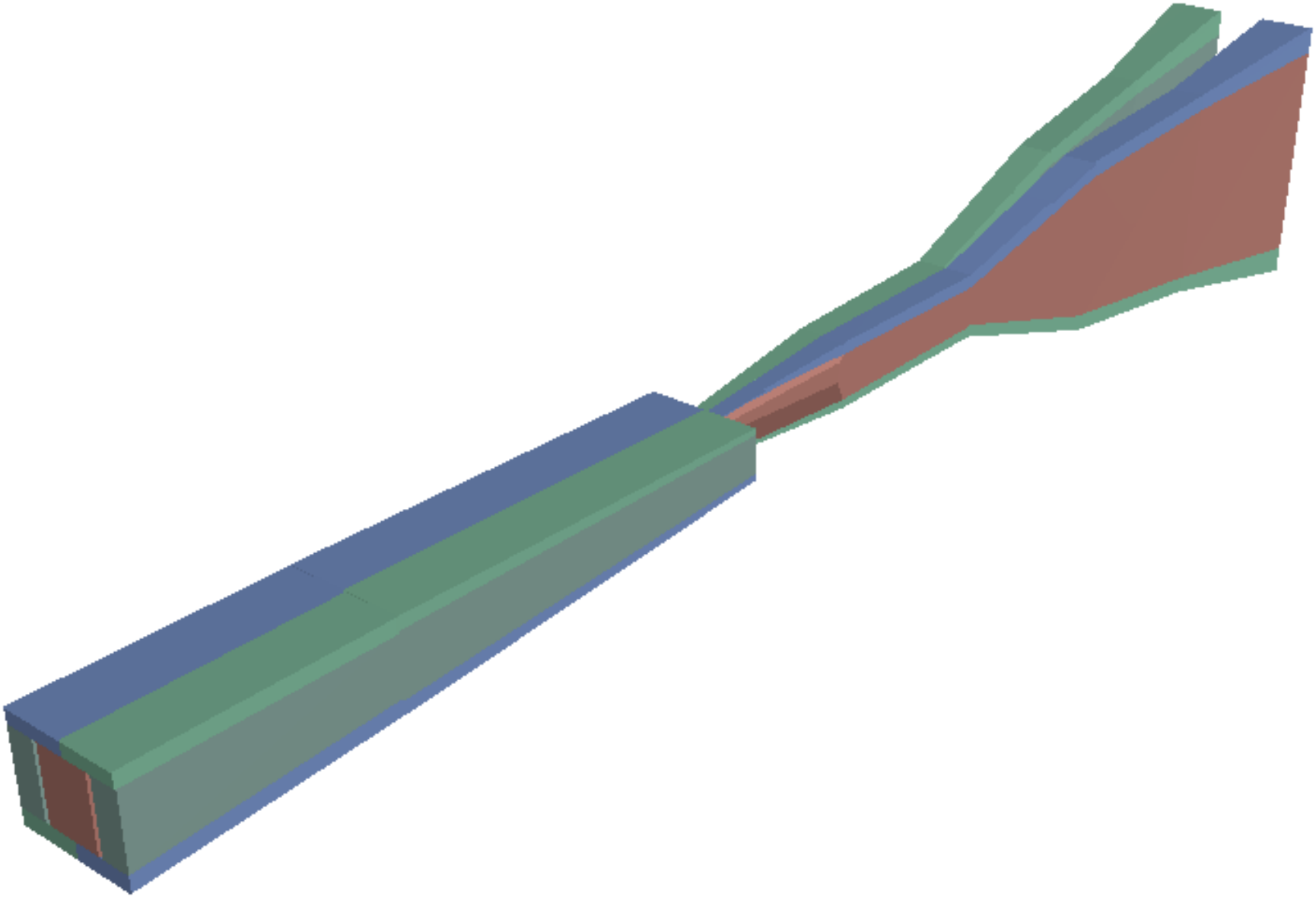
Active muon shield

- Muons are swept out of detector acceptance
- Challenge: avoid that low-momentum muons are swept back into the detectors by the **return fields**
- Muons are no longer stopped, but deflected: RP impact
- Muons may scatter back from cavern walls: CE impact
- Need an intelligent and optimised design (by SHIP): position return fields where there are (almost) no muons
- BL = 86.4 Tm, bending μ up to 350 GeV/c out of acceptance
- Total length 48 m, B-field 1.8 T
- Reduces muon flux per spill from 10^{10} to $\approx 7\ 10^{3}$

Magnetic layout of shield

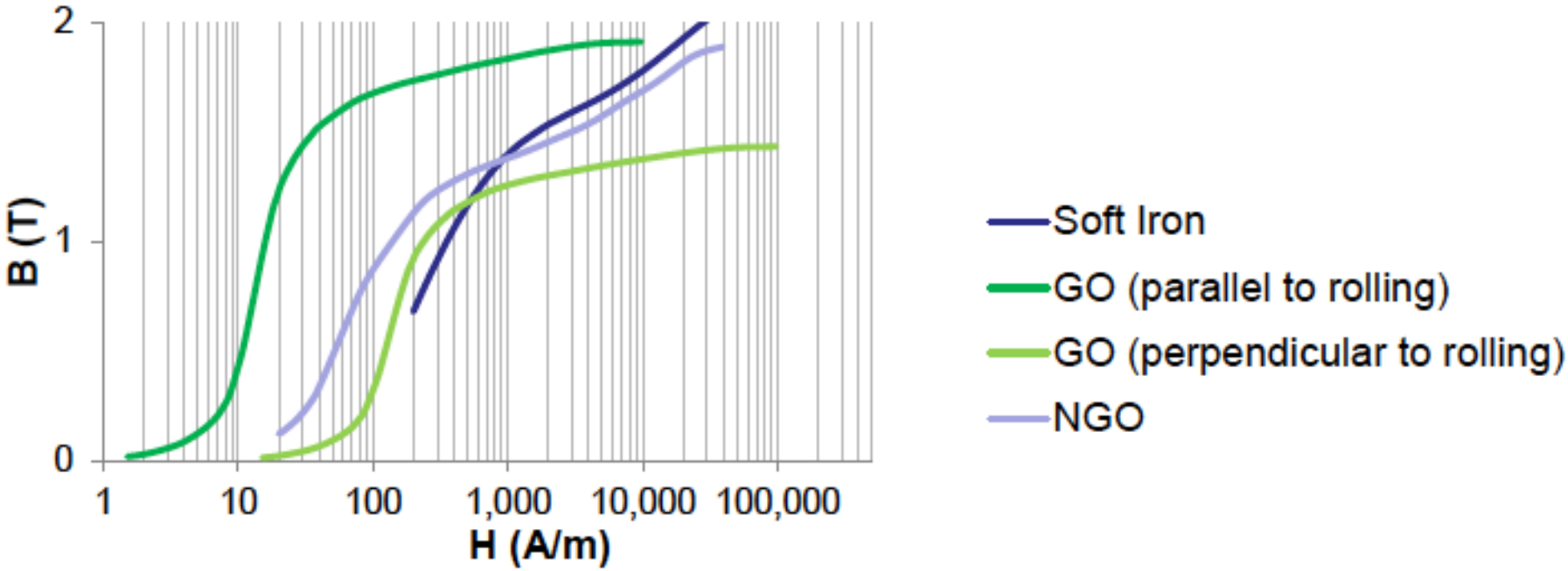






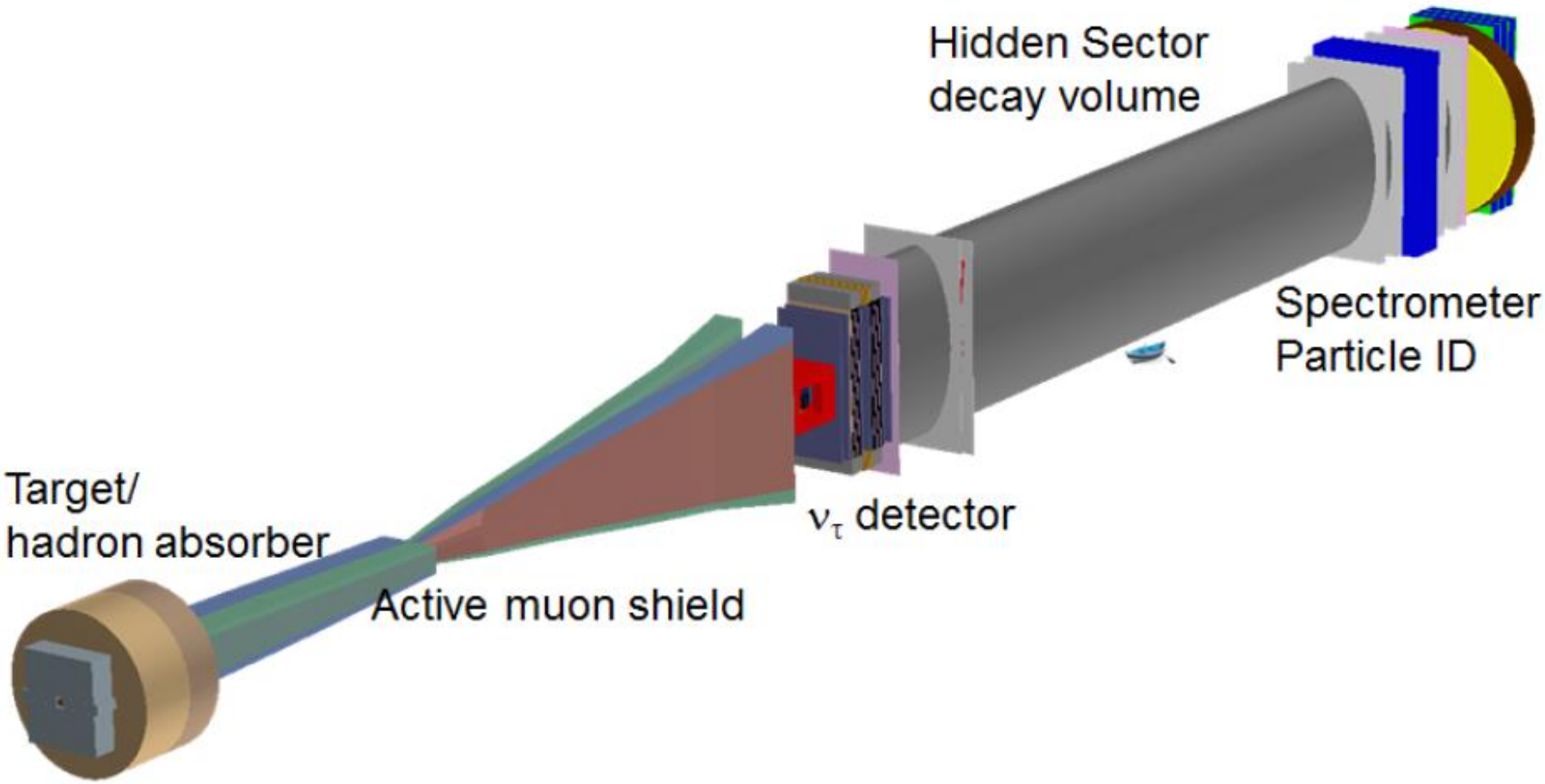
Some design considerations

- Grain oriented steel is more expensive, but reduces current

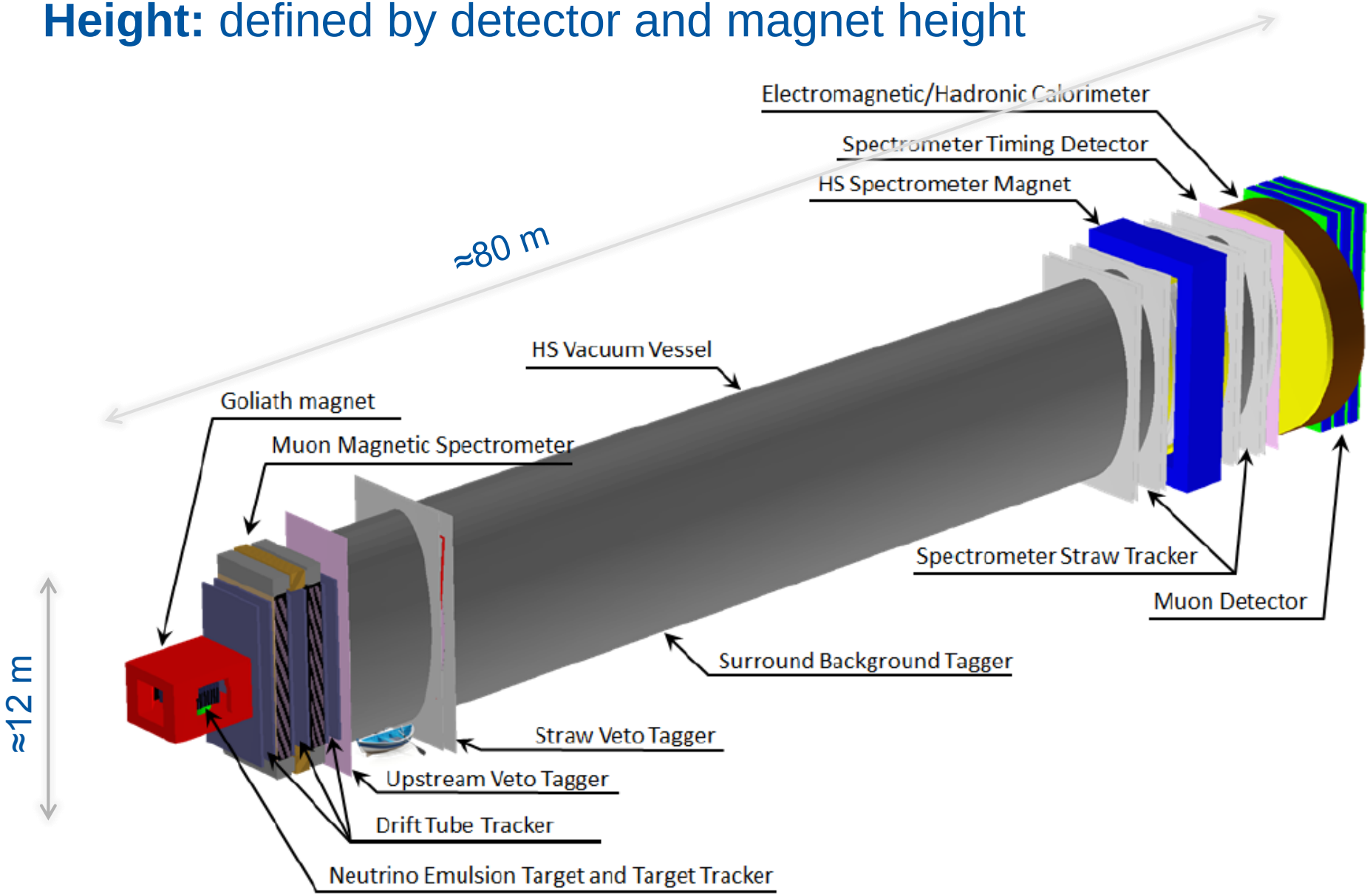


- Hence air cooling, lower power and conductor costs

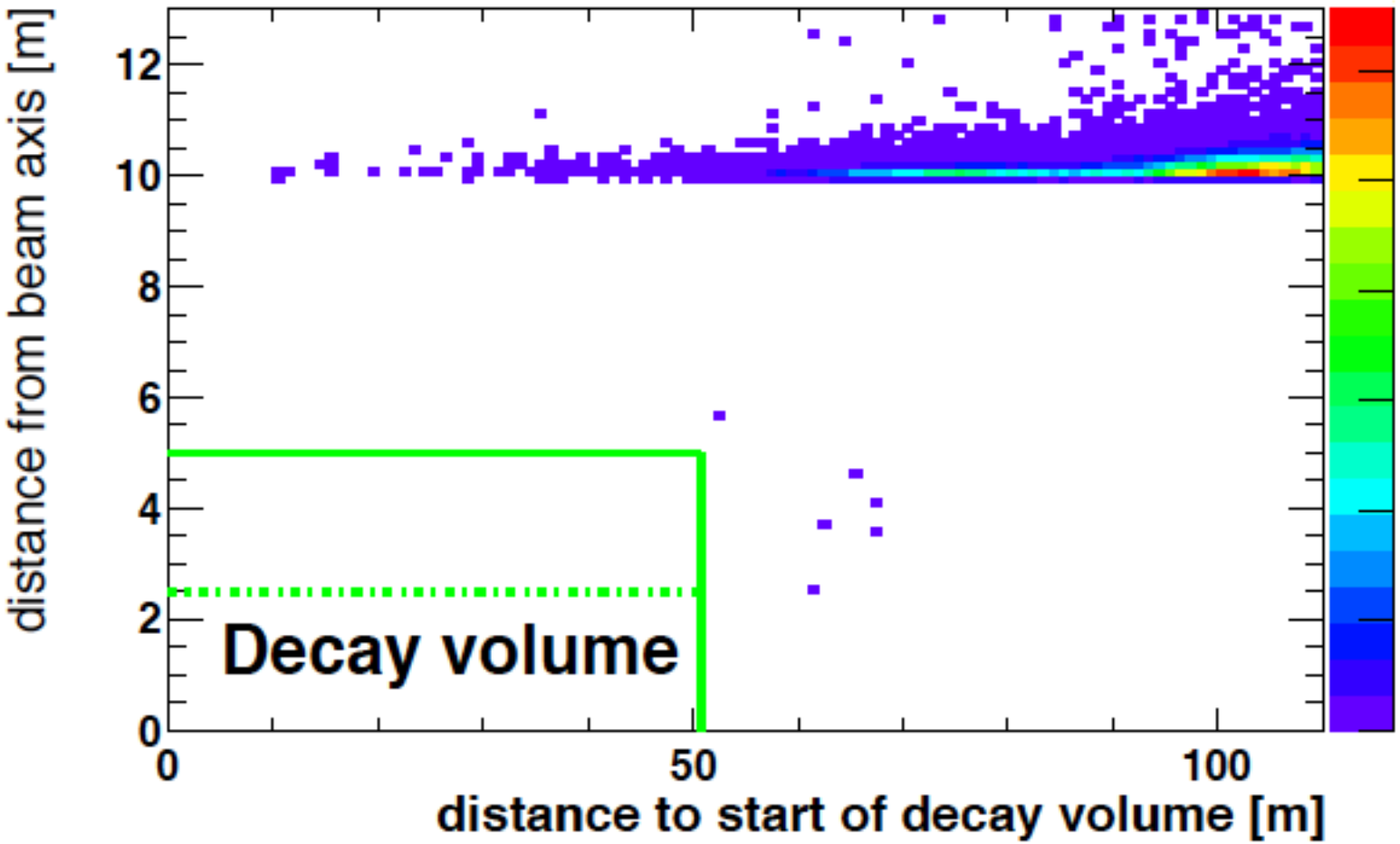
DETECTOR HALL AND DETECTORS



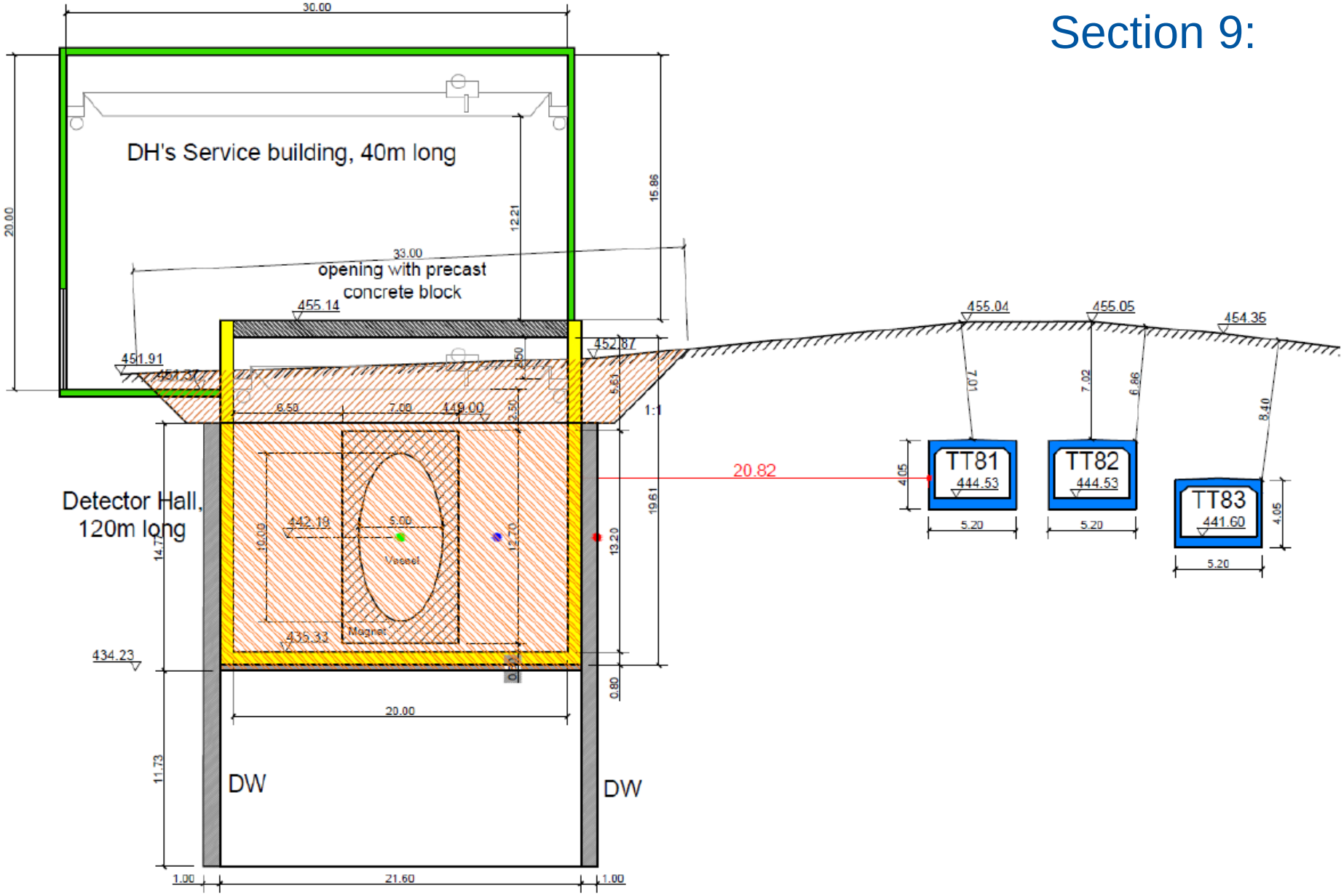
Height: defined by detector and magnet height



Width: defined by muon impact on cavern walls



Section 9:


30.00
DH's Service building, 40m long
20.00
12.21
15.86
33.00
opening with precast concrete block
455.14
451.91
452.87
8.50
7.00
449.00
2.50
5.63
1:1
Detector Hall, 120m long
442.19
5.00
Vessel
10.00
12.70
14.77
19.61
13.20
435.33
Magnet
434.23
0.80
20.00
11.73
DW
DW
1.00
21.60
1.00
455.04
455.05
454.35
7.01
7.02
6.86
8.40
20.82
4.05
TT81
444.53
TT82
444.53
TT83
441.60
5.20
5.20
5.20
4.05

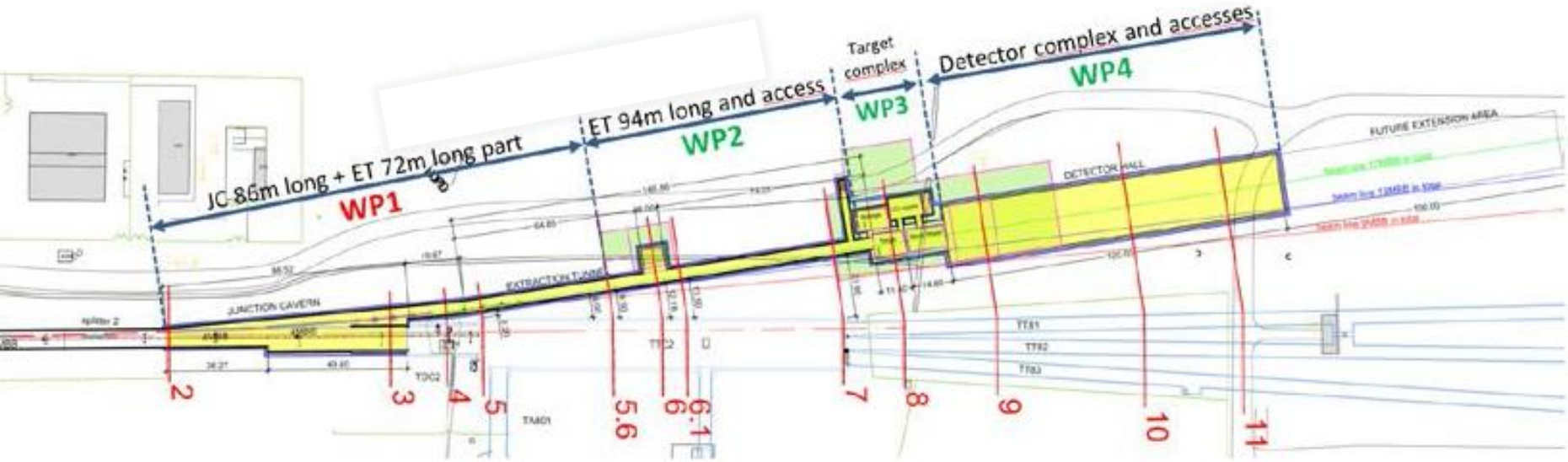
CIVIL ENGINEERING

- SHiP fits entirely on the Prévessin site
- Demolition of existing TDC2 to allow new junction cavern.
- Implies removal of almost 100 m of beam lines and infrastructure (need cool down before → ion run?)
- 166 m long extraction tunnel with access building + shaft
- 40x30 m^2 target hall with underground areas + service bldg
- 120x20 m^2 detector hall with 40x30 m^2 access building
- 140 m long technical gallery
- All underground works excavated with **diaphragm walls** (RP safe distance, water table levels)
- A detailed integration study is needed **before CE tendering**

Junction cavern and ET

- The junction cavern and most of the extraction tunnel must be constructed during a long stop
- TDC2 to be demolished over 100 m, this implies radioactive material and dust.
- Backfilling of demolished concrete and activated earth as first layer of new junction cavern and downstream facilities is being discussed
- Extraction tunnel has 40 ton crane
- The detector hall could later be extended by up to ~100 m

CE work packages



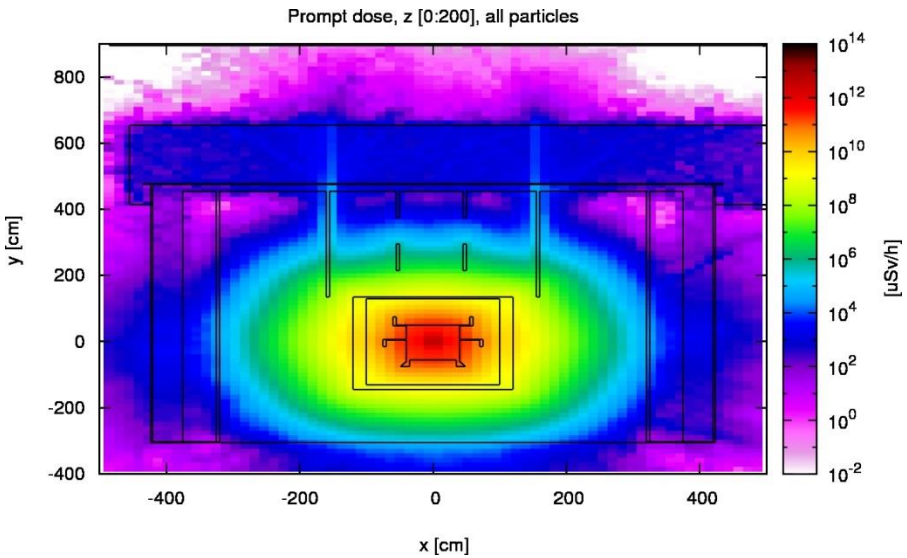
WP1 is very critical for and **drives the planning,** as it requires the North Area to be stopped (not SPS for LHC)

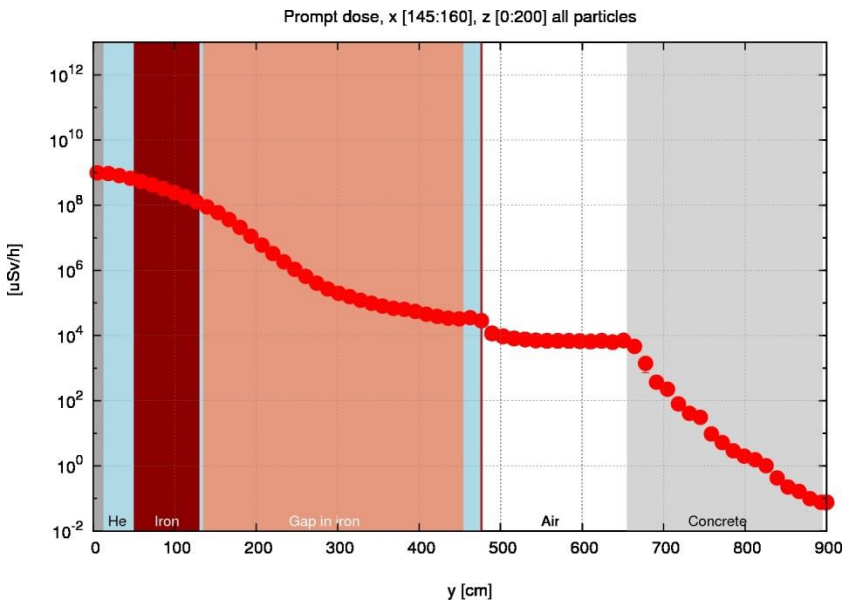
RADIATION PROTECTION ISSUES

- 355 kW primary proton beam power → RP determines design of the facility
- Prompt dose rates, residual dose rates → shielding and remote interventions in target area
- SPS extraction becomes crucial factor
- The target area and muon shield are particularly critical
- Environmental impact, dismantling, etc yet to be studied
- The SHiP facility has been implemented in a FLUKA simulation

RP for target complex

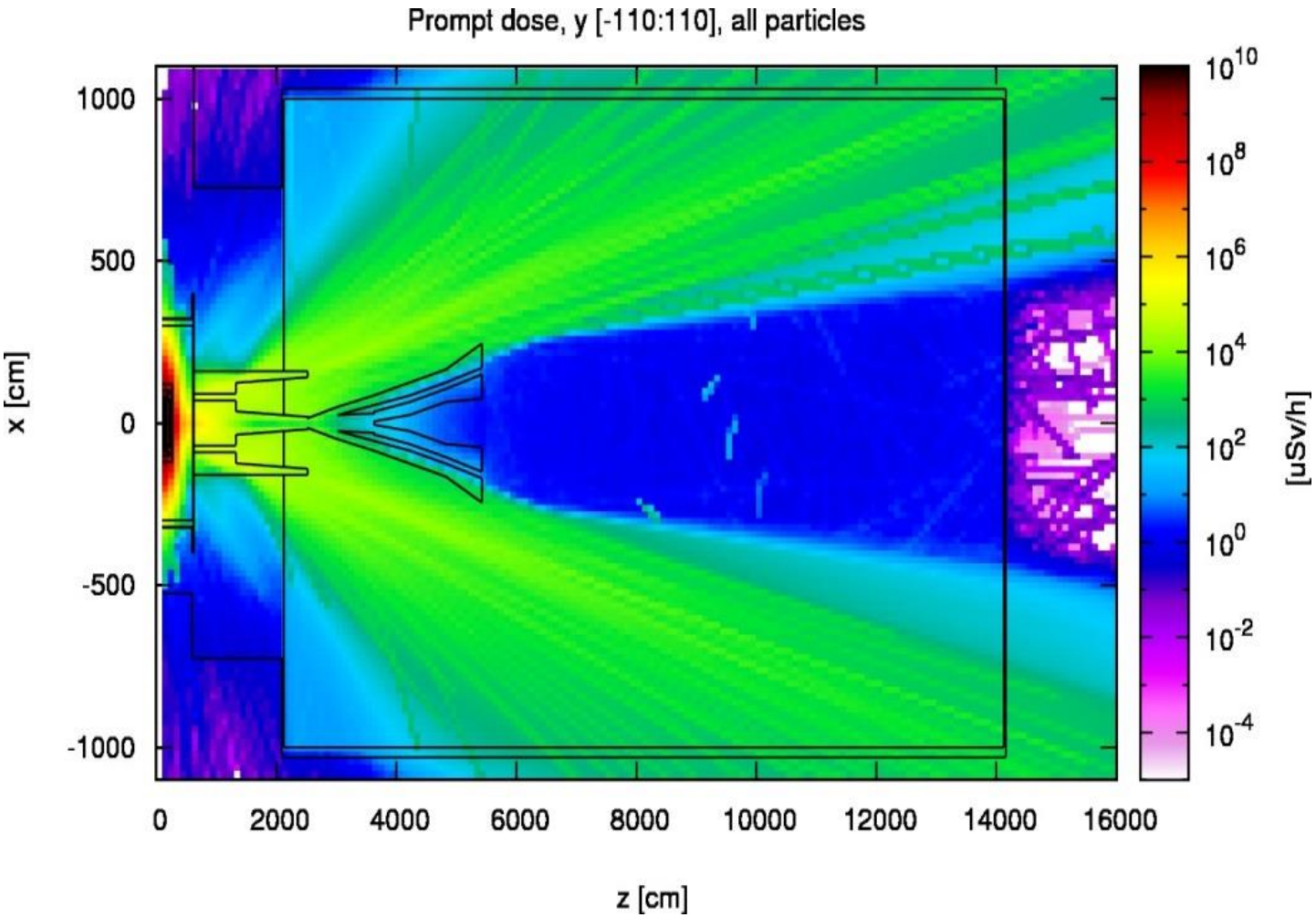
- Target hall can be accessed during operation, but not target bunker, dose reduced to few μSv/hr in target hall





- Ground activation remains acceptable (prompt dose < 1 mSv/hr)

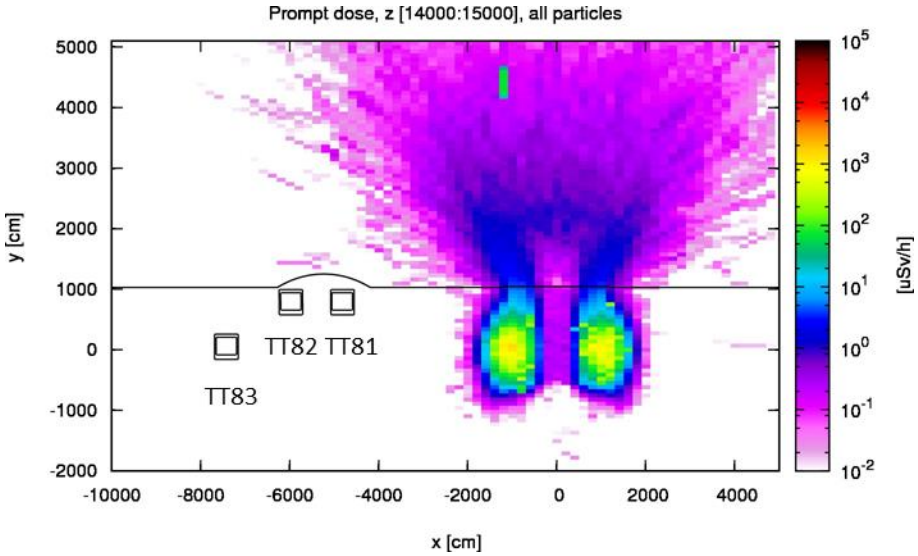
RP after muon shield

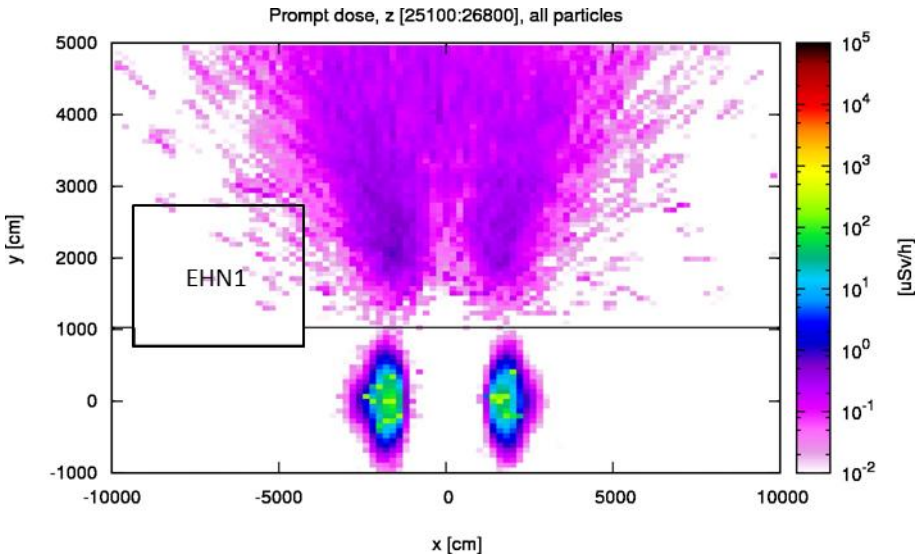


Few μSv/h in access building above detector hall (supervised area)

< 1 mSv/h in soil just behind muon shield, ok for soil activation

Impact on other facilities





SHiP operation has no impact on surrounding experimental areas
Dose at CERN fence is smaller than 5 μSv/yr: acceptable

Residual doses around target

- Target region is most critical: 100 Sv/hr after 1 week, but only few μSv/hr above He vessel.
- The dose of the Mo (TZM) part of the target drops to few 10s of Sv/hr after 1 week, the W part to 10 Sv/hr.
- **Remote handling is crucial**

RP for SPS extraction

- From data from LSS2 and LSS6 one expects 12 mSv/hr in the aisle next to the ZS, comparable to LSS6 data from the ring survey.
- It is therefore of prime importance to reduce the losses at the ZS (more interlocking, better instrumentation, …)
- Prompt dose rates from North Area operation indicate that **8 m soil thickness** is required around TDC2 and TCC2 during NA operation. This impacts SHiP CE works → WP1.
- Continuous 5% loss of regular North Area fixed target beam on splitters give 650 mSv/h.
  Therefore 50 m or concrete or 20 m of iron shield are needed to allow work in the extraction tunnel during operation.

IMPACT ON NA PROGRAMME

- Just adding SHiP cycles in the SPS-super-cycle would reduce the duty cycle for a ‘classical’ NA fixed target physics programme in a way similar to CNGS operation
- Like for CNGS this can be partly compensated by going to a longer flat top for the North Area beam lines
- There are constraints on the flat top and super-cycle from RMS power (39 MW for SPS) and magnet heating. They are slightly more severe for SHiP because of the 1 sec flat top
- Several scenarios have been studied based on a set of cycles composing the super-cycle
- Typically 18% duty-cycle for the NA can be achieved (cf ~20% during CNGS operation)

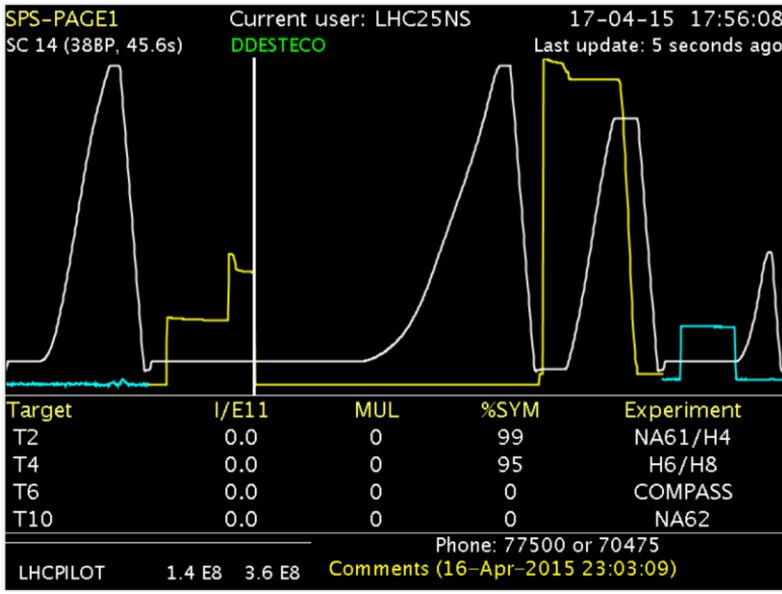

2.5
2
1.5
1
0.5
0
Protons on Target for TCC2 [10^19/year]
0
1
2
3
4
5
6
7
Protons on Target for SHIP [10^19/year]

R&D AND MACHINE DEVELOPMENTS

- SHiP requires some R&D activities and machine development studies already in the near future.
- Many of them are necessary for SHiP but are also extremely useful for the ‘classical’ North Area fixed target program (COMPASS, NA62, …)
- Main R&D concerns the extraction and beam transport and the target and target station
- On the short term necessary preparations for civil engineering WP1 include integration studies for the beam lines with their infrastructure

R&D for extraction and beam lines

- Deployment of the new SHiP cycle
- Extraction loss characterisation and optimisation
  - Reduce p density on septum wires
  - Probe SPS aperture limits during slow extraction
- ZS performance versus intensity
- Development of new TT20 optics
  - Change beam at splitter on cycle-to cycle basis
- Characterisation of spill structure
- R&D and development of laminated splitter and dilution (sweep) magnets



R&D for the target station

The SHiP target is feasible but, even if the SHiP target complex takes advantage of the CENF studies, R&D is necessary:

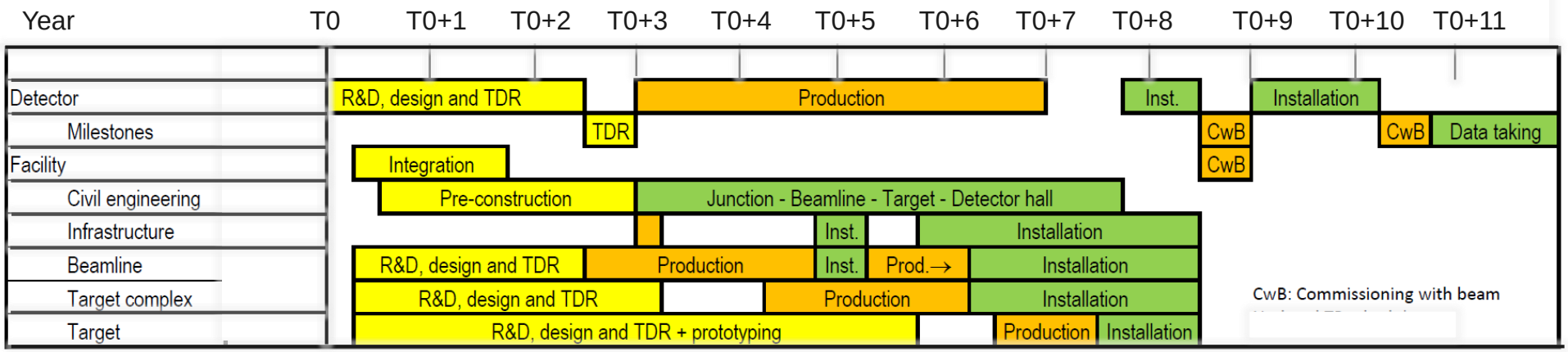
- Analysis of assembly, configuration and fabricability of the cladded refractory metal blocks
- Material irradiation R&D on TZM, Mo, W and W-TiC
- Feasibility of water-cooled cast iron blocks with embedded stainless steel pipes
- Develop high-pressure, high-flow rate compatible full-metal plug-in systems for fast and remote connection
- Design of He gas cooled SHiP production target

Planning rationale

- Motivated by timeliness and wide interest in physics case
- Respect the operation schedule of CERN complex and technical and financial constraints
- Take maximum advantage of existing shutdowns
- Short facility validation run with partial detector
- Start full physics as soon as possible

- Fully exploit the long shutdowns, for critical civil engineering and the beam and infrastructure modifications in and around TDC2
- **Start some preparations (+ resources) early on**!

A planning


Year
T0
T0+1
T0+2
T0+3
T0+4
T0+5
T0+6
T0+7
T0+8
T0+9
T0+10
T0+11
Detector
R&D, design and TDR
Production
Inst.
Installation
Milestones
TDR
CwB
CwB
Data taking
Facility
Integration
CwB
Civil engineering
Pre-construction
Junction - Beamline - Target - Detector hall
Infrastructure
Inst.
Installation
Beamline
R&D, design and TDR
Production
Inst.
Prod.→
Installation
Target complex
R&D, design and TDR
Production
Installation
Target
R&D, design and TDR + prototyping
Production
Installation
CwB: Commissioning with beam

Cost of the facility

Item	Cost MCHF	Staff FTE	Fellows MCHF
Civil engineering	57.4	10	0.7
Infrastructure and services	22.0	17.4	1.5
Extraction and beam line	21.0	31.5	1.5
Target and target comples	24.0	35	2.6
Muon shield	11.4	1.8	
Others		3.0	
Total	**135.8**	**102.7**	**6.3**

Fellows are already included in the cost

OUTLOOK

- SHiP would add a new facility to the North Area with much higher intensities than before
- The proposal has been presented at the SPSC in June
- If approved, the construction would take about 8 years and would take maximum advantage of long shutdowns

The SHiP Task Force

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