CERN

# Beam Dump Facility

including TauFV and PASSAT extensions

Y. Dutheil, on behalf of the BDF working group

# Content

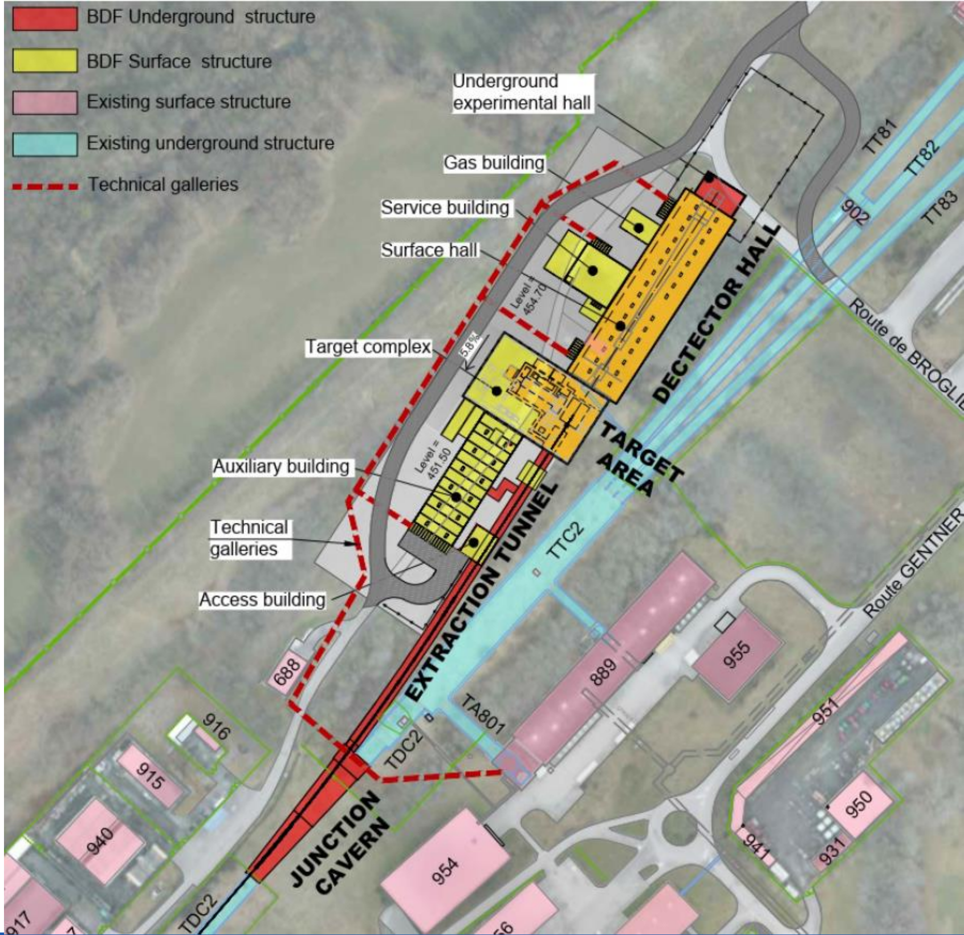
- Overview
  - Beam production from the SPS
  - Beam transfer
  - Target & target complex
  - Experimental hall
  - Radiation protection & environmental studies
  - Safety engineering & integration
  - Civil engineering
- TauFV experiment
- PASSAT experiment
- Costing & roadmap
- Conclusion

# Overview

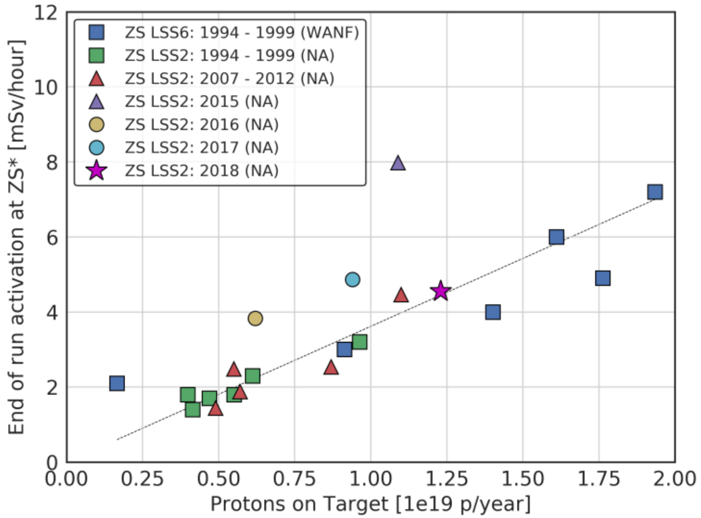
- The project integrates in the North Area complex
- Builds upon existing CERN expertise for high energy and high-power beam production and delivery
- Shorter than existing North Area experimental lines but challenging goals

# Overview

- New beam transfer tunnels and buildings are required
- Branches off existing North Area extraction line
- Ensures concurrent operation with the existing North Area experiments
- Large detector hall initially to host the SHiP experiment (see last SHiP Collaboration Meeting, 5-6 November 2019 link)



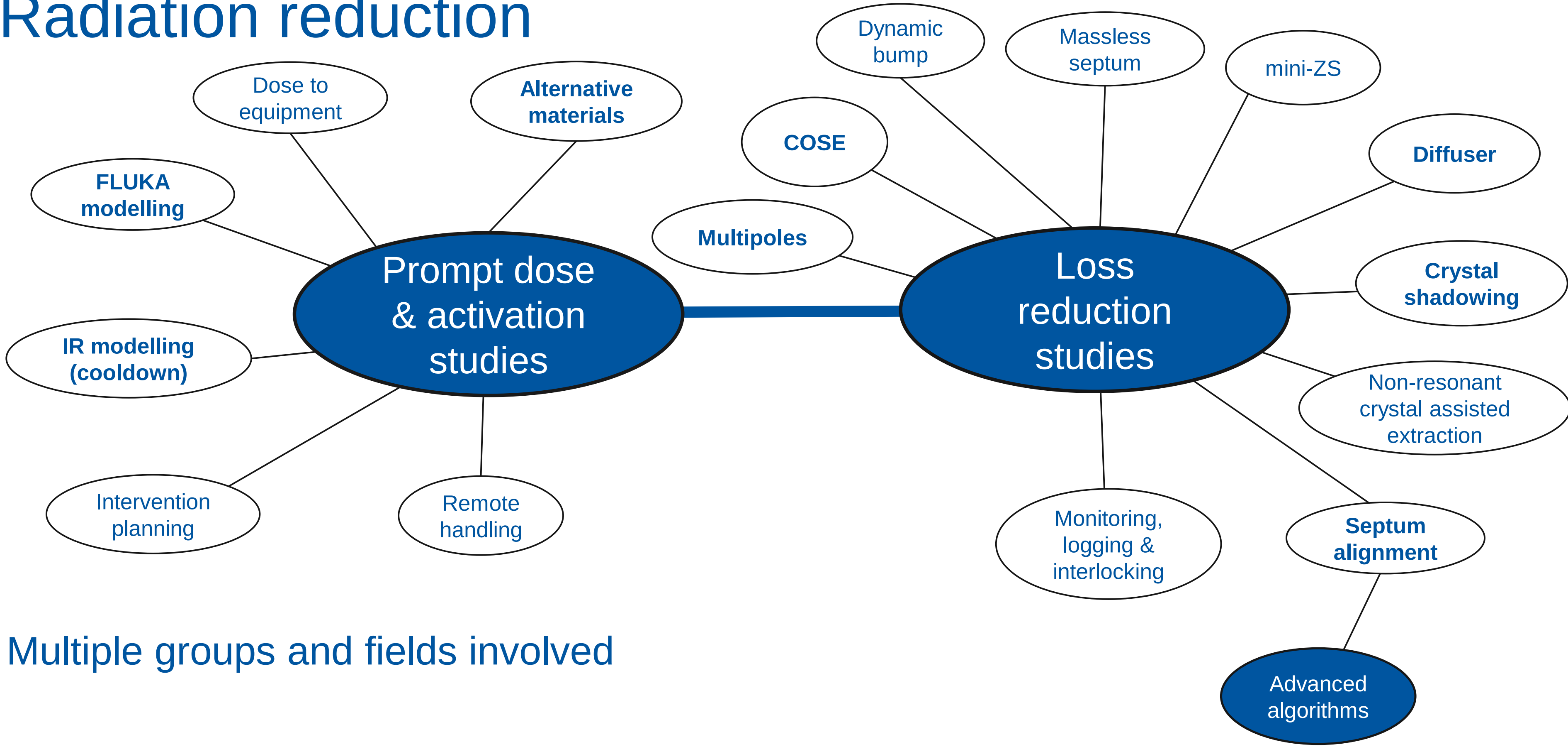
# Beam production




* 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 $3.5 \times 10^{13}$ protons/spill and $1.23 \times 10^{19}$ protons extracted in 2018
- SHiP requirements
  - **1 s** uniform spill with up to $4 \times 10^{13}$ protons/spill and ~ $\mathbf{4 \times 10^{19}}$ protons extracted per year
- Challenges
  - SHiP + current NA requirements totals ~ $5 \times 10^{19}$ protons extracted per year
  - Radiation & activation in the SPS extraction devices 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

# Radiation reduction

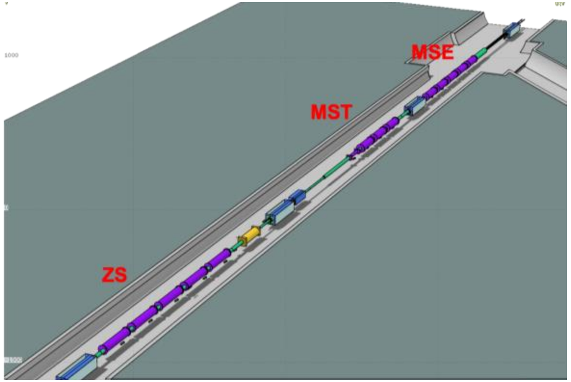


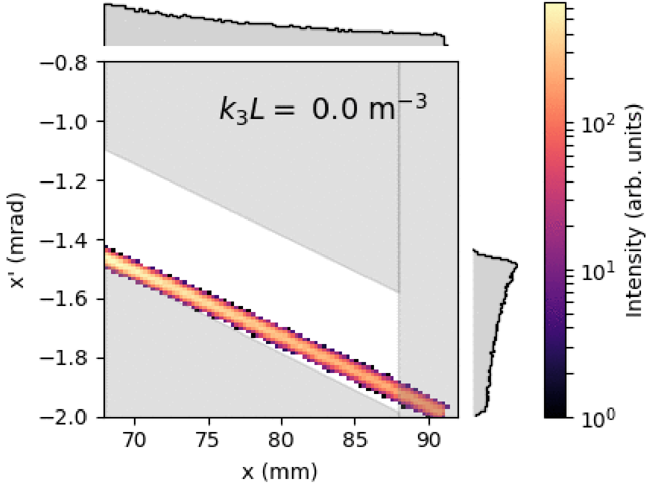

Multiple groups and fields involved

# Loss reduction efforts highlight

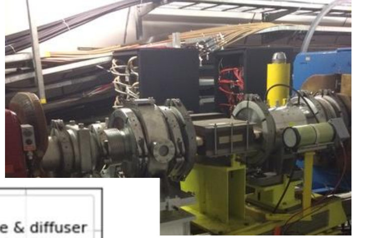
- Detailed LSS2 geometry and material inventory implemented in FLUKA with MADX-*pycollimate* source term:
  - To evaluate energy deposition maps and induced radioactivation
  - Benchmark with beam experiments and measurements

- Phase space folding
  - Use of octupole magnets to fold the extracted beam phase space and reduce the beam density at the ZS
  - Make use of Constant Optics Slow Extraction (COSE) to maintain the shape of the extracted beam during the spill

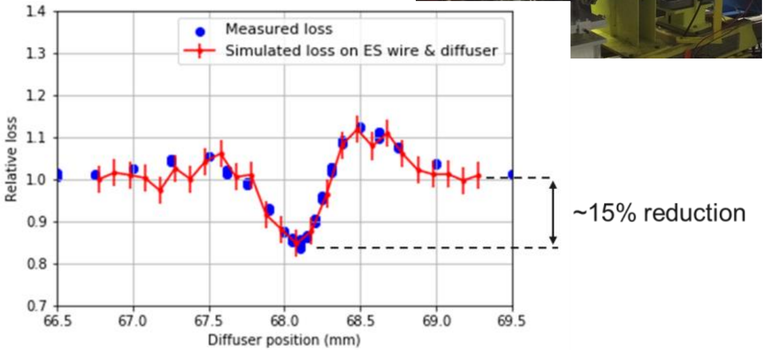


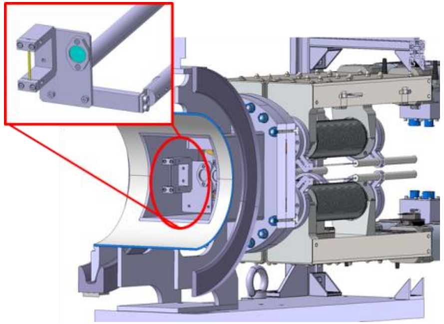
# Loss reduction efforts highlight



- Diffuser upstream the extraction region
  - Incoherent scattering of particles to reduce the beam density where particles would be lost on the ZS
  - Prototype installed in 2018
  - Loss gain of ~15% in very good agreement with simulated behavior

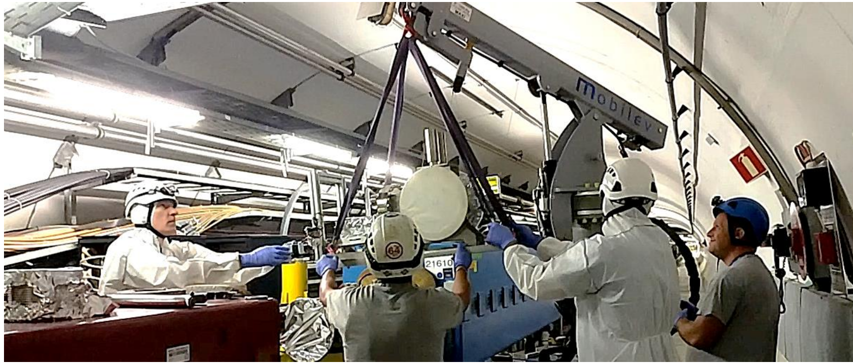


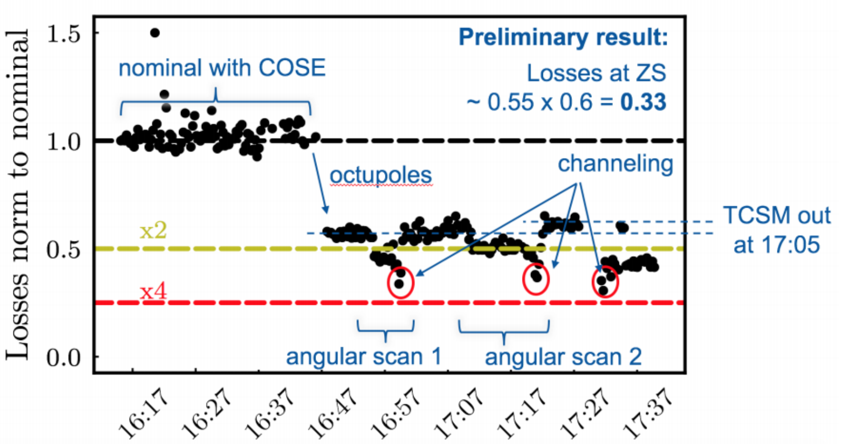

- Crystal upstream the extraction region
  - Coherent scattering on the crystalline structure of a bent crystal
  - High efficiency and strong loss reduction
  - Prototype developed with UA9 installed in 2018
  - Loss gain of 20% in volume reflection regime and ~40% in channeling regime



# Beam production

- Parallel work on several aspects of the slow extraction process to increase efficiency
  - Smart & automatic alignment of the electrostatic septa (ZSs)
  - Comprehensive FLUKA modeling of the extraction region and comparison with measured radiation/activation levels
  - New control of the SPS beam dynamics during the spill (COSE)
  - Passive and coherent scattering of the beam upstream of the ZSs
  - Horizontal phase space folding to reduce beam density at the ZSs
  - New equipment materials to reduce losses and activation
- Efficiency gain of a factor 3-4 demonstrated during on November 1st 2018
- Next steps
  - Beam tests preparations in 2020 to demonstrate slow extraction efficiency gain for continuous operation
  - New LSS4 system for an optimised crystal shadowing
  - Upgraded beam loss monitoring in the extraction region
  - Improved design of ZS with new tank and anode material

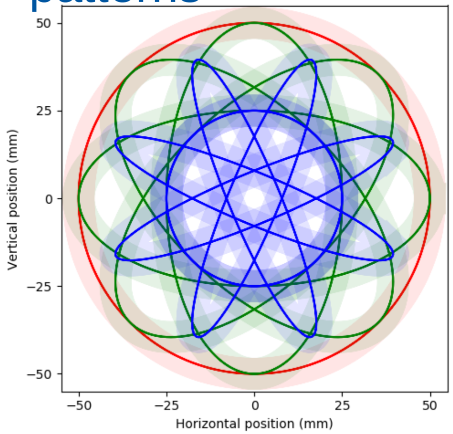


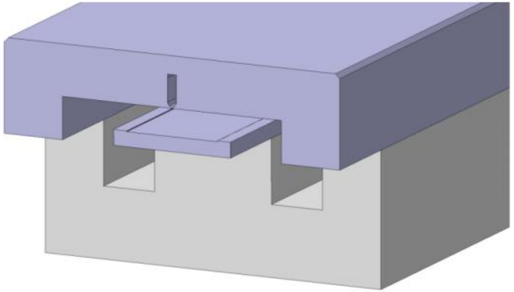
# Beam transfer

- 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, almost 300 tons in total
  - 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 between the regular NA and BDF lines in consecutive cycles
  - Design is constrained by manufacturing capabilities
  - New splitting schemes are being investigated to reach higher efficiencies by building upon the slow extraction expertise of CERN
- Next steps
  - Detailed risk analysis and failure cases
  - Design of splitter and possibly improved splitting scheme

## Possible beam dilution patterns

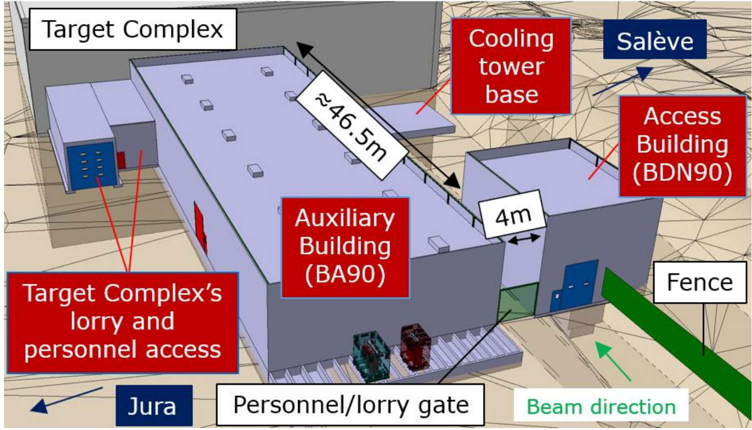



## Splitter model

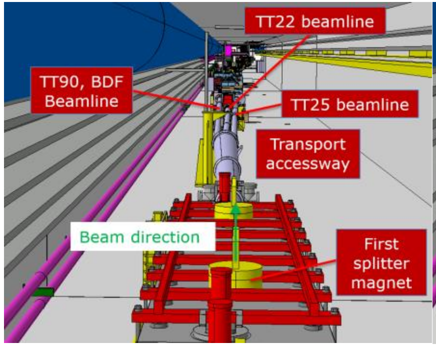


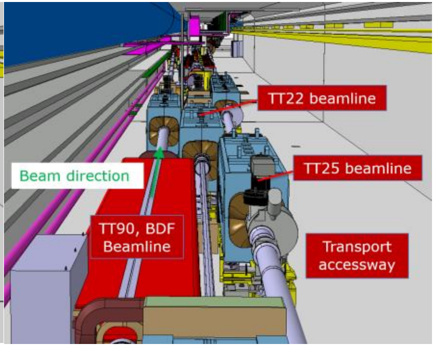
# Transfer line design

- Integration studies
  - Combines requirements from all sources, sometimes conflicting
  - In particular safety, transport, beam dynamics, radiation protection, civil engineering and cooling-ventilation



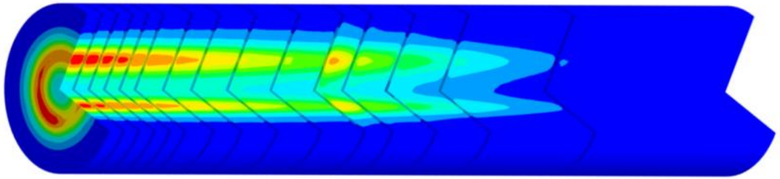

- Status
  - Comprehensive 3D model includes all requirements for the tunnel and associated surface buildings

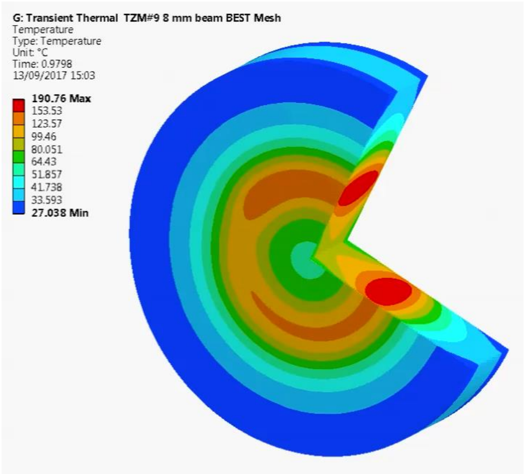


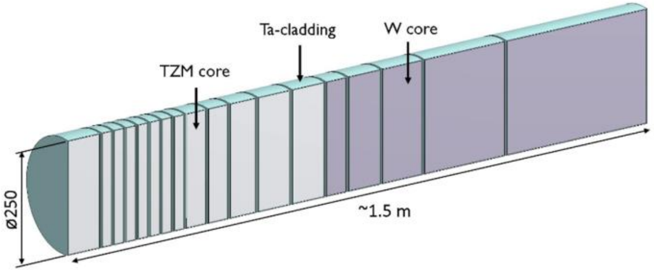

- Next steps
  - Layout consolidation, advance from layout towards TDR
  - Integration, optimization at logistics & hardware for beam-lines and services

# Target



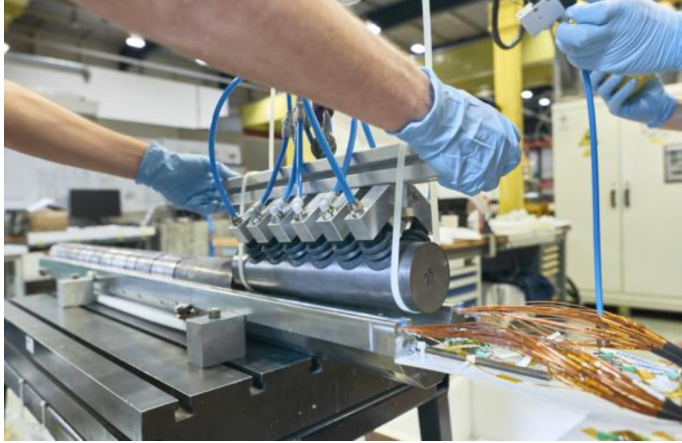



- Requirements
  - Target has to safely absorb the 400 GeV/c SPS proton beams
  - High beam power on the target of up to 2.56 MW during the 1s spill and 320 kW on average
- Challenges
  - High-Z material resilience to high flow of cooling water
  - Target block cladding behaviour under thermo-mechanical stre
  - Integrated design of target assembly for fully remote handling
- Next steps
  - Continuing unirradiated materials studies on Ta2.5W, zircalloy, etc…
  - R&D on target block cladding

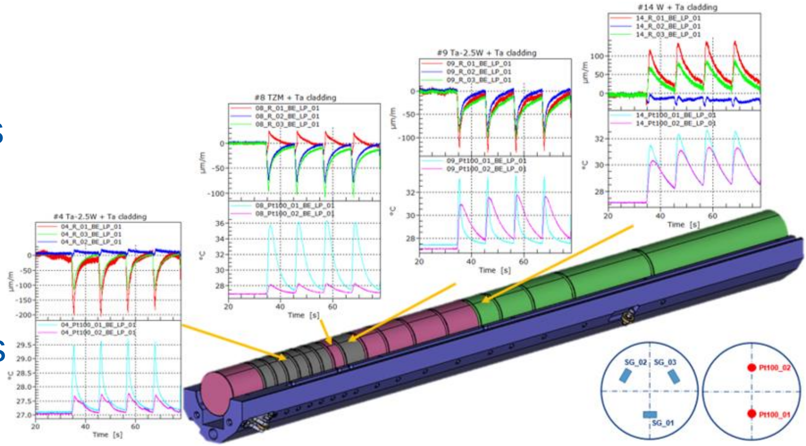



TZM: 0.08% titanium – 0.05% zirconium – molybdenum alloy

# Target prototype

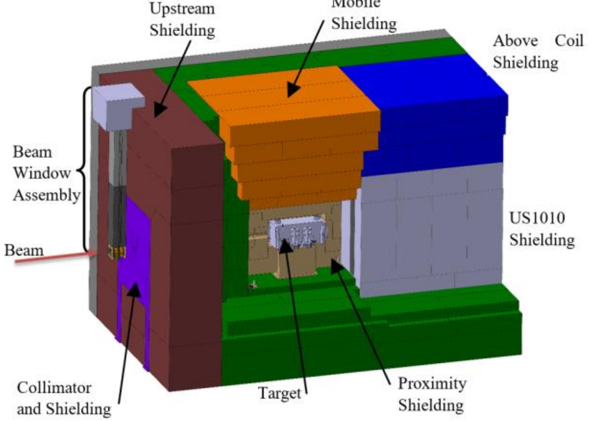


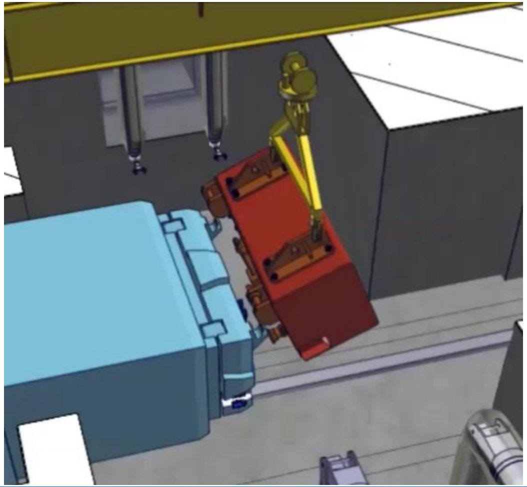
- Requirements
  - Reproduce experimentally the thermo-mechanical conditions of the final target
  - Cross-check the Finite Element Model simulations performed
  - Test target online instrumentation resilience
  - Perform detailed post-irradiation experiments
- Status
  - Beam tests in Fall 2018 with a total of 2.4 x$10^{16}$ protons target
  - Overall good agreement between online measurements simulations
- Next steps
  - Target dismantling preparation
  - Post irradiation experiment to characterise target blocks condition and integrity



# Target Complex

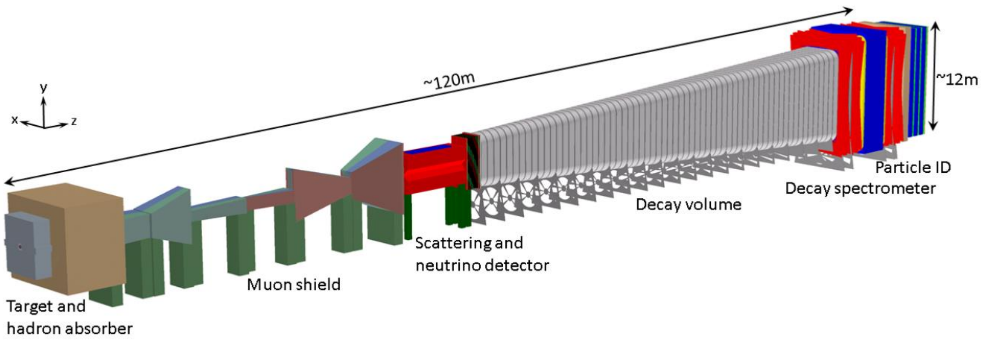
- Requirements
  - Heavy shielding and complex Helium passivation system
  - Comprehensive FLUKA modelling
  - Account for all possible accident scenario at the design stage
- Status
  - Civil engineering and integration designs of the target building with support system such as cooling and ventilation
- Next steps
  - Crane remote target handling concept development
  - Ramping up studies toward TDR
  - Helium passivation prototype for TDR



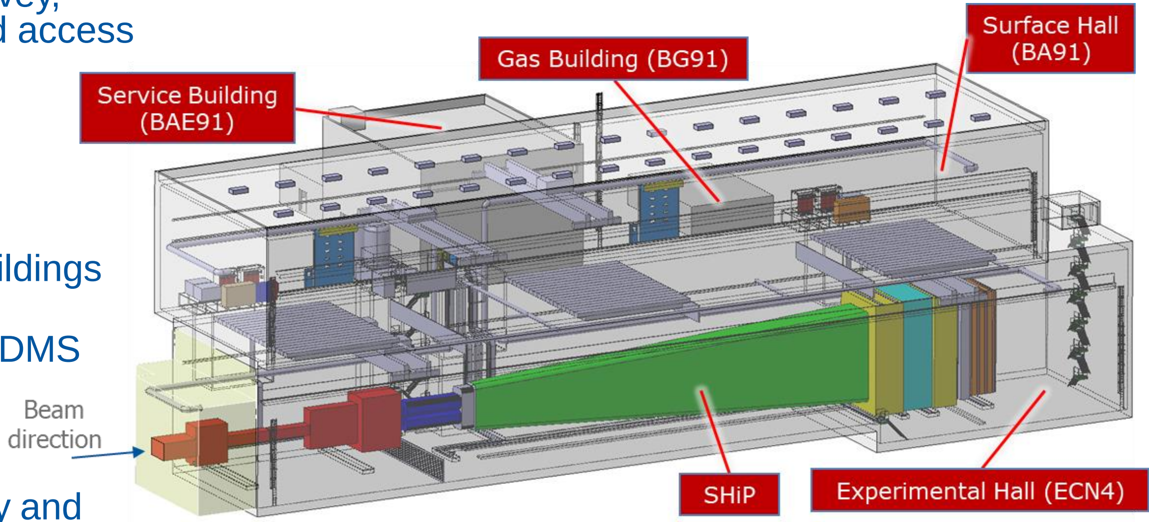



# Experimental complex

- Requirements
  - SHiP experiment is ~120 m long
  - Comprehensive FLUKA simulations
  - Inputs from civil engineering, transport and handling, electrical network system, power converters, cooling and ventilation, survey, radioprotection, safety, fire system, and access system
  - Account for assembling, installation, and operation of the detector




- Status
  - Preliminary integration layout of the buildings
  - and infrastructure based on the SHiP requirements(details can be found in EDMS 2032322 - link)




- Next steps
  - In depth study of the detector assembly and installation sequence and layout consolidation

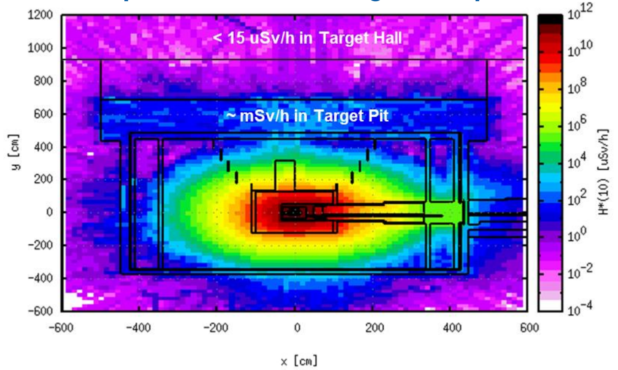
# Radiation protection & environment

- Radiation protection
  - Critical involvement for every aspects of the BDF project
  - Guiding of building and system designs using comprehensive FLUKA studies
  - Tritium out-diffusion experiments at the target prototype

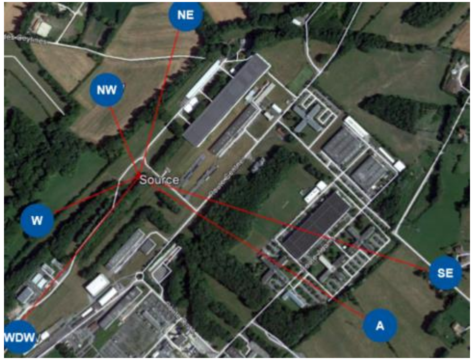
- Environmental impacts
  - Needed to ensure strict respect of legislations
  - Water and soil activation around the target complex and experimental hall

- Next steps
  - Finish H-3 out-diffusion experiments
  - Continued studies towards TDR
  - Preparation of host states legal approval

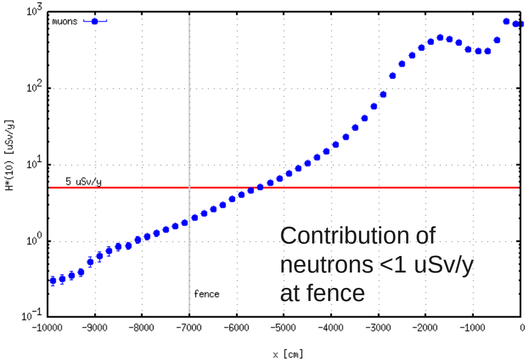
**Prompt dose rates in Target Complex**




**BDF reference groups**

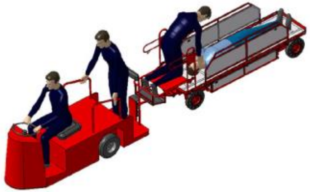


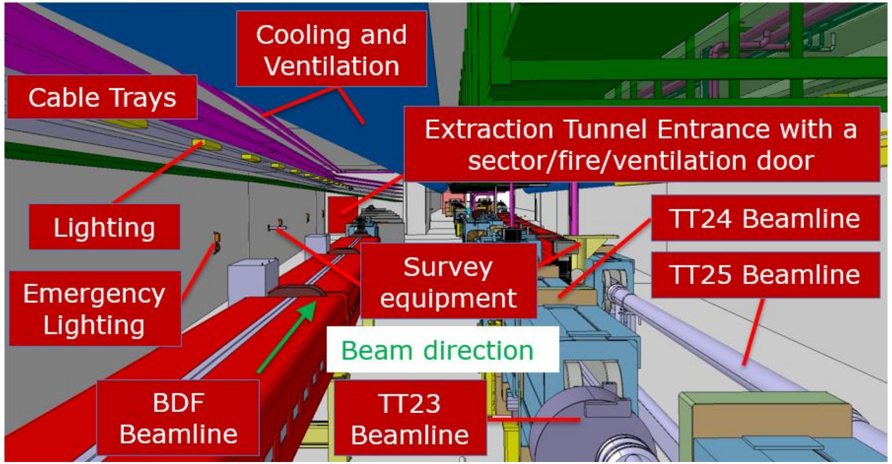

**Muon dose rate at CERN fence [μSv/y]**



# Safety engineering & integration

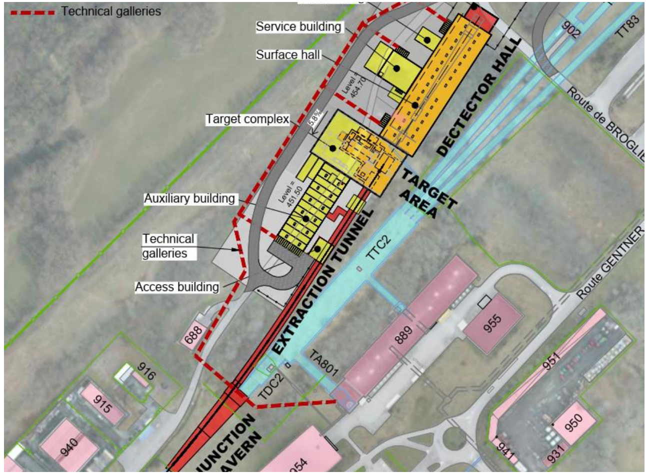
- Involved in all the aspects of the project
- Safety engineering
  - Identify hazards and optimise design
  - Fire safety, compartmentalisation and intervention
  - All risks physical, chemical, environmental, etc…
- Integration
  - Compiles all the requirements and builds a comprehensive 3D model of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

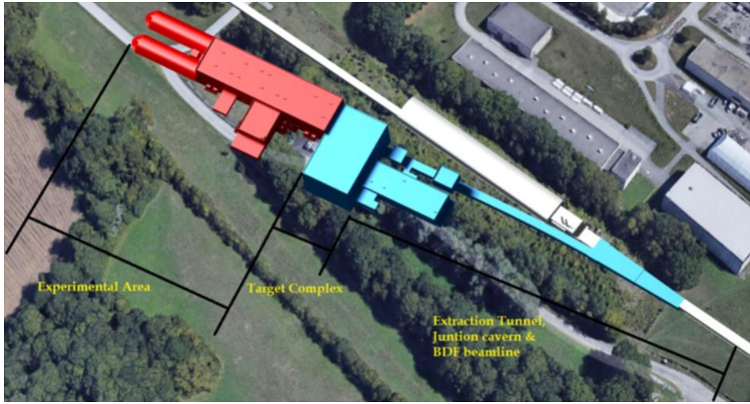




# Civil engineering

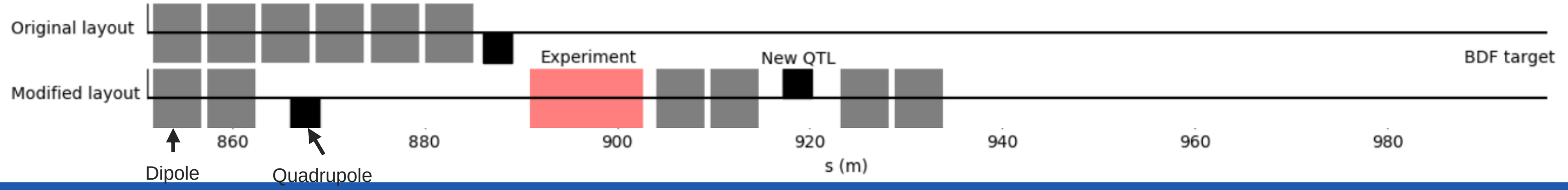
- Requirements
  - New beam transfer tunnel, target complex and experimental hall
  - Near existing lines and building
  - Open existing TDC2 tunnel to branch off the TT20 line
- Status
  - Comprehensive construction plan, reviewed by an external company
  - Soil activation measurements done in 2018
- 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
  - Ground investigations in the area



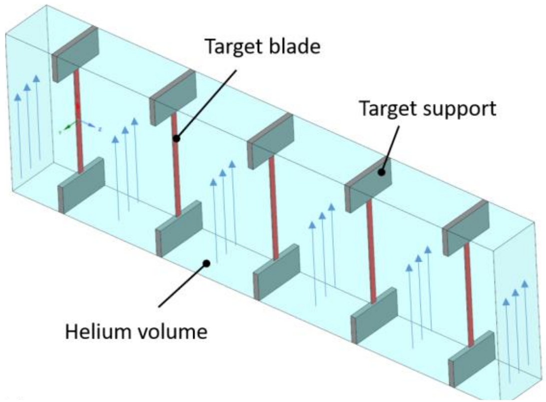
# TauFV experiment

- Strong physics case (see https://indico.cern.ch/event/755856/contributions/3263687/)
- Possible addon with minimum modification of the BDF project
- Requirements
  - Interception of ~2% of the beam delivered to the BDF target
  - Beam transverse RMS profile of >4 mm in one plane and <1 mm in the other
  - Space for detector of around 7.5 m long by 3 m wide
- Potential siting identified ~100 m upstream the BDF target requiring minor modification of the layout and a single additional quadrupole



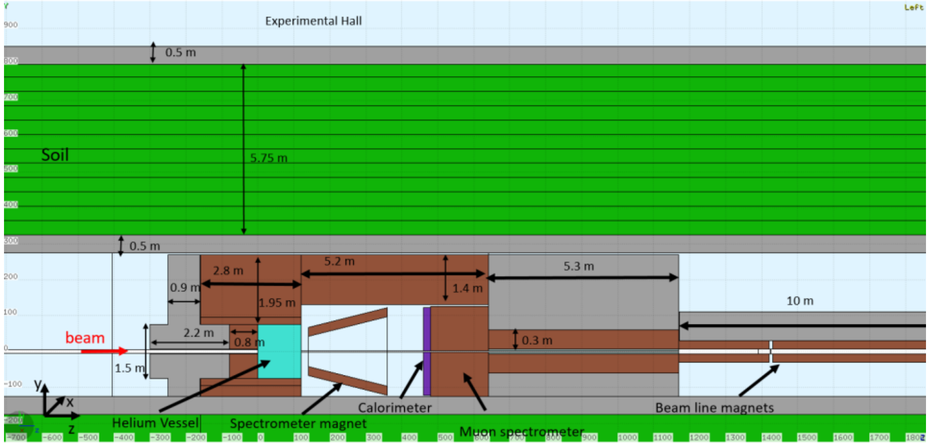
# TauFV experiment

- Target system
  - 5 tungsten blades of 40 x 2 x 0.4 mm$^2$
  - Cooled by the circulation of Helium
  - Target maximum temperature and mechanical stress well below material limits



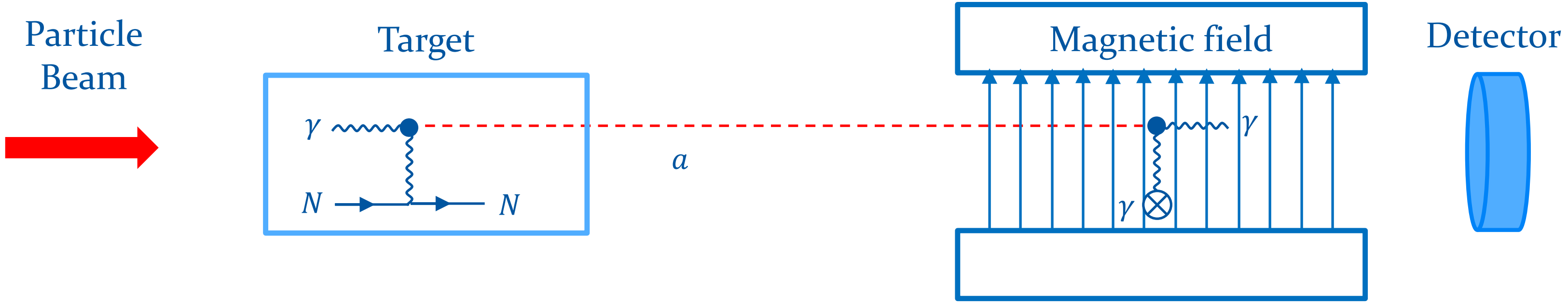

- Radiation aspects
  - Full FLUKA model of the target, detector and shielding
  - Prompt and activation losses require careful design of shielding

- Next steps
  - Shielding of radiation optimisation
  - Detailed study of the target configuration including installation handling concepts for a realistic assembly and operation plan
  - Integration with the BDF 3D drawings



# PASSAT experiment

- Particle Accelerator helioScopes for Slim Axion-like-particle deTection (PASSAT):
  - Utilizing the principle of the axion helioscope but replaces ALPs produced in the Sun with those produced in a target material
  - ALP conversion in magnetic field allows probing of light (slim) ALPs, otherwise inaccessible by laboratory-based experiments which rely on ALP decay
- Potentially complements astrophysics studies with a different reach
- Physics case discussed in detail at the last SHiP collaboration meeting https://indico.cern.ch/event/854346/contributions/3604231/



# Cost estimates

- Developed over the last 5 years
- Now includes all the aspects of the project
  - TauFV and PASSAT extensions not included

| 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 beamline** | **9.6** |
| Magnet refurbishment | 0.7 |
| Switch/Splitters | 2.1 |
| Dilution system (MDX) | 0.52 |
| Power converters | 3.0 |
| Beam instrumentation | 0.8 |
| Vacuum system | 0.6 |
| Interlocks | 0.2 |
| DC cabling | 1.62 |
| **Target and target complex** | **45.5** |
| Target assembly & annex equipment | 5.6 |
| Instrumentation package | 0.9 |
| Bunker iron shielding & US1010 | 14.0 |
| Concrete shielding | 0.85 |
| Magnetized coil for US1010 shield | 1.0 |
| Target & coil handling system | 19.1 |
| Target and coil shielding casks | 0.2 |
| Helium vessel (HW) | 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 |
| Controls infrastructure | 0.7 |
| **Integration and installation** | **3.6** |
| Installation | 2.6 |
| Installation, design support | 0.6 |
| Preparation, dismantling | 0.4 |
| **Total** | **158.4** |

# Roadmap

- Continued efforts in 2019 and 2020
- Includes
  - Post Irradiation Examination (PIE) of the prototype target tested in 2018
  - Tritium tritium out-diffusion experiments
  - Helium vessel design and preparation for prototyping
  - Construction and testing of the prototype laminated switch/splitter magnet
  - Intermediate iteration of system integration
  - Development and possible prototyping of the hadron absorber magnetisation system
  - Continued studies of loss reduction techniques during slow extraction in the SPS and the deployment of these techniques onto operational beams (planned for the SPS run starting in 2021)
  - Revision of experimental area along with updated information about SHiP assembly and installation
  - Site investigation required for a definitive civil engineering study
- By 2020, strong position to seek approval to work towards a TDR for delivery by 2022

# Roadmap

- Ideal timeline assumes approval to go ahead with TDR next year
- 2023 - 2024 : CE pre-construction
- 2023 - 2025 : Component production
- 2025 - 2027 : Underground CE
- 2026 - 2028 : Surface CE
- 2026 - 2028 : Installation
- Overall goal is to commence data taking as soon as early as reasonably possible in Run 4

# Publication list (non exhaustive)

- BDF ,SHiP and physics cases
  - W. Bonivento et al., *Proposal to Search for Heavy Neutral Leptons at the SPS*, CERN-SPSC-2013-024/SPSC-EOI-010, 2013
  - SHiP Collaboration, M. Anelli et al., *A Facility to Search for Hidden Particles (SHiP) at the CERN SPS*, Technical Proposal,CERN-SPSC-2015-040, SPSC-P-350, 2015, [arXiv:1504.04956].
  - S. Alekhin et al., *A facility to Search for Hidden Particles at the CERN SPS: the SHiP physics case*, Rept. Prog. Phys. 79 (2016), no. 12 124201, [arXiv:1504.04855].
  - SHiP Collaboration, C. Ahdida et al., *The experimental facility for the Search for Hidden Particles at the CERN SPS SHiP Collaboration*, JINST 14 (2019) no.03, P03025.
  - C. Ahdida et al., *SPS Beam Dump Facility Comprehensive Design Study*, CERN-PBC-REPORT-2018-001, submitted for publication as CERN Yellow Report,.

- Beam production and delivery
  - H. Bartosik et al., *SPS Operation and Future Proton Sharing scenarios for the SHiP experiment at the BDF facility*, CERN-ACC-NOTE-2018-0082, 2018
  - M.A. Fraser et al., *Demonstration of slow extraction loss reduction with the application of octupoles at the CERN Super Proton Synchrotron*, submitted to Phys.Rev.Accel.Beams , 2019
  - B. Goddard et al., *Reduction of 400 GeV/c Slow Extraction Beam Loss with a Wire Diffuser at the SPS*, submitted to Phys.Rev.Accel.Beams , 2019
  - V. Kain et al., *Resonant slow extraction with constant optics for improved separatrix control at the extraction septum*, Phys.Rev.Accel.Beams 22 (2019) no.10, 101001, 2019
  - F.M. Velotti et al., *Septum shadowing by means of a bent crystal to reduce slow extraction beam loss*, Phys.Rev.Accel.Beams 22 (2019) no.9, 093502, 2019
- Prototype target, target & target complex
  - Busom Descarrega, J., Calviani, M., Hutsch, T., López Sola, E., Pérez Fontenla, A. T., Perillo Marcone, A., Sgobba, S., Weißgärber, T.. *Application of hot isostatic pressing (HIP) technology to diffusion bond refractory metals for proton beam targets and absorbers at CERN*, *Mat Design Process Comm*. 2019; 1– 11. https://doi.org/10.1002/mdp2.101
  - K. Kershaw *et al, Design Development for the Beam Dump Facility Target Complex at CERN* 2018 *JINST* **13** P10011 (https://doi.org/10.1088/1748-0221/13/10/P10011)
  - P. Avigni *et al, Design of a Helium Passivation System for the Target Vessel of the Beam Dump Facility at CERN*, https://arxiv.org/abs/1910.00333, submitted to JINST
  - E. Lopez Sola *et al, Design of a high power production target for the Beam Dump Facility at CERN*, https://arxiv.org/abs/1904.03074, accepted by PRAB
  - E. Lopez Sola *et al, Beam impact tests of a prototype target for the Beam Dump Facility at CERN: experimental setup and preliminary analysis of the online results*, https://arxiv.org/abs/1909.07094, submitted to PRAB

# Conclusion

- Strong effort over the past few years to perform in-depth examination of all aspects
- The studies are well advanced as evidenced by the Yellow Report CERN-PBC-REPORT-2018-001, submitted for publication
- The BDF project initially supports the SHiP experiment
  - Possible additional experiments such as TauFV & PASSAT
  - Gives access to new levels of beam power
- Many achievements over the last few years that already benefit the existing complex, such as the improvement of beam extraction efficiency
- Strong support from all CERN departments and outside collaborations
- Critical support is needed over the next few years to productively continue the studies in preparation for deployment

# Thank you