Beam Dump Facility (BDF) at CERN – Radiological and environmental assessment

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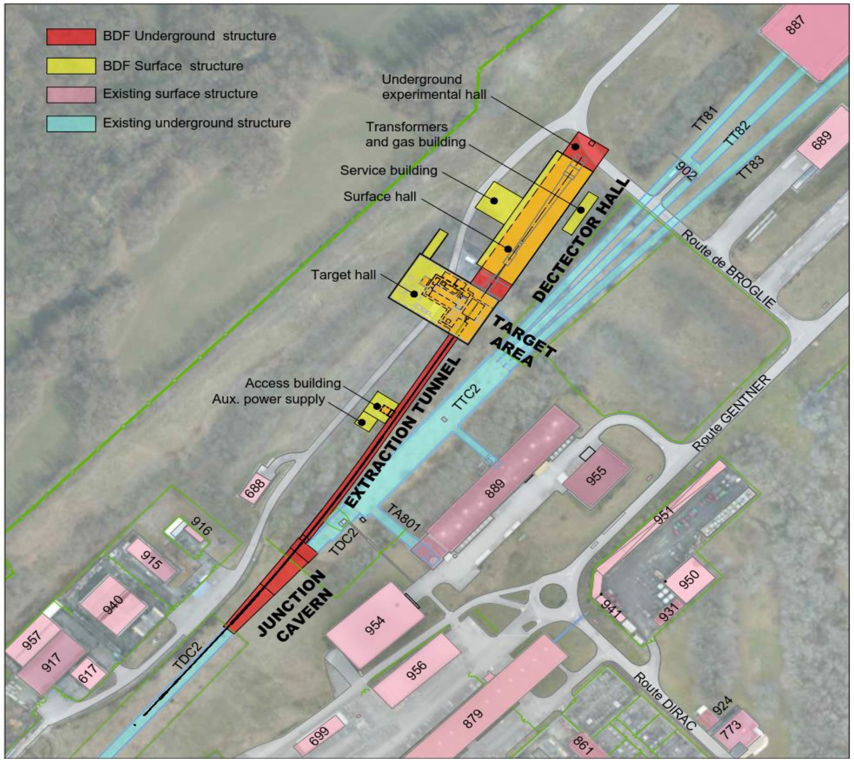
Outline

- BDF concept and requirements
- General RP considerations
- RP evaluation for the BDF target complex
  - Prompt and residual dose
  - Air and He activation
  - Radioactive waste
- Summary & conclusion

BDF requirements

Layout of BDF and surrounding facilities



More details about target and facility in talks from Lopez Sola, Kershaw and Lamont

BDF is a proposed permanent facility in the North Area at CERN

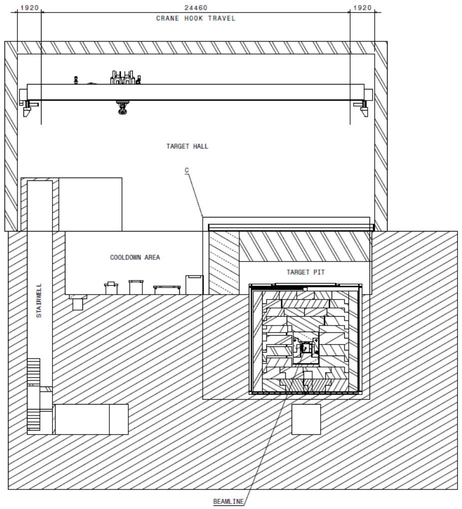
- High intensity proton beam: **4*10^{13} p^{+}/pulse, 355 kW average beam power, 2*10^{20} pot/5 years**
  → RP constraints on design due to prompt/residual dose
- Location close to experimental and public areas
  → **Minimize impact on other facilities and environment**
- Dense TZM and W target
  → **High activation expected**
- Keep **flexibility for future installations**
  → Ventilation system
  → Dismantling and waste treatment

Key BDF beam parameters	
Momentum [GeV/c]	400
SPS beam Intensity per cycle [10^{13}]	4.0
Cycle length [s]	7.2
Spill duration [s]	1
Avg. beam power on target [kW]	355
Avg. beam power on target during spill [kW]	2500
Protons on target (POT)/year	4×10^{19}
Total POT in 5 year’s data taking	2×10^{20}

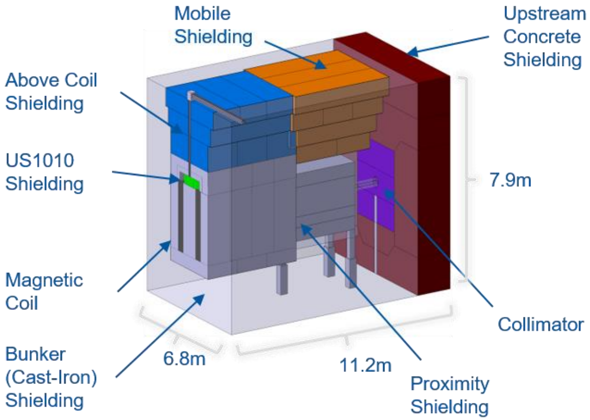
BDF target complex

- Target is located 15 meters underground
- Iron hadron absorber encloses production target
- Target and hadron absorber are inside a He vessel
- Fully remote handling/manipulation
- Significant attention to radiation protection
- Crane and trolley concepts → equivalent shielding, but target handling safer with trolley

Crane concept overview

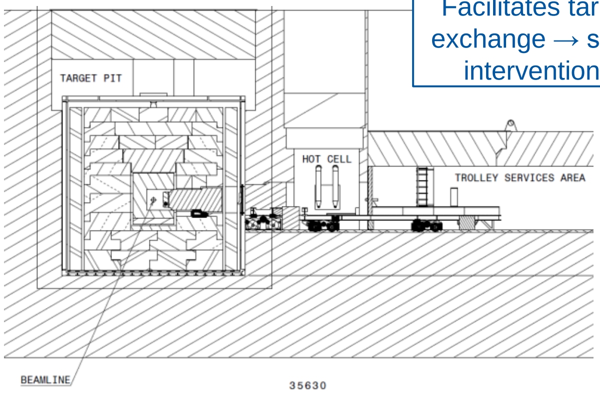


Target and hadron absorber



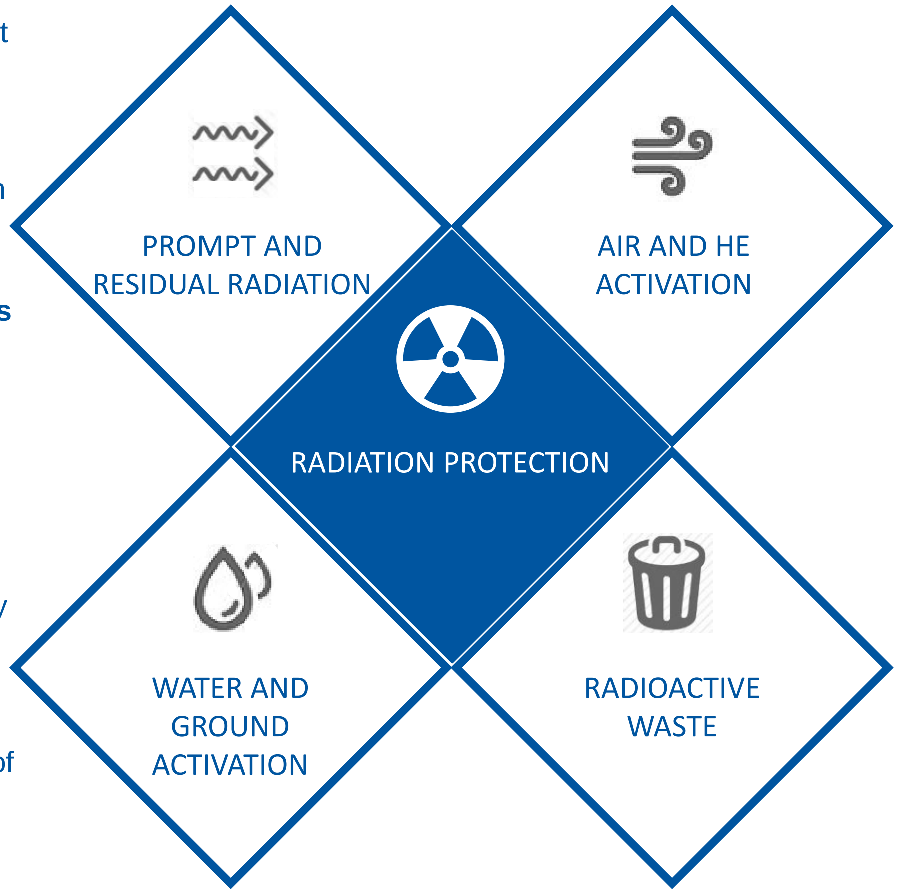
Trolley concept overview

Facilitates target exchange → safer interventions



General considerations for the BDF target complex

- **High prompt dose** in BDF target area calls for adequate shielding around the target
- **Only** absolute **necessary equipment** should be installed in **“hot” areas**
- Depending on residual dose rate and tasks, **manual interventions** should partially/completely be **replaced** by **remote maintenance/repair**



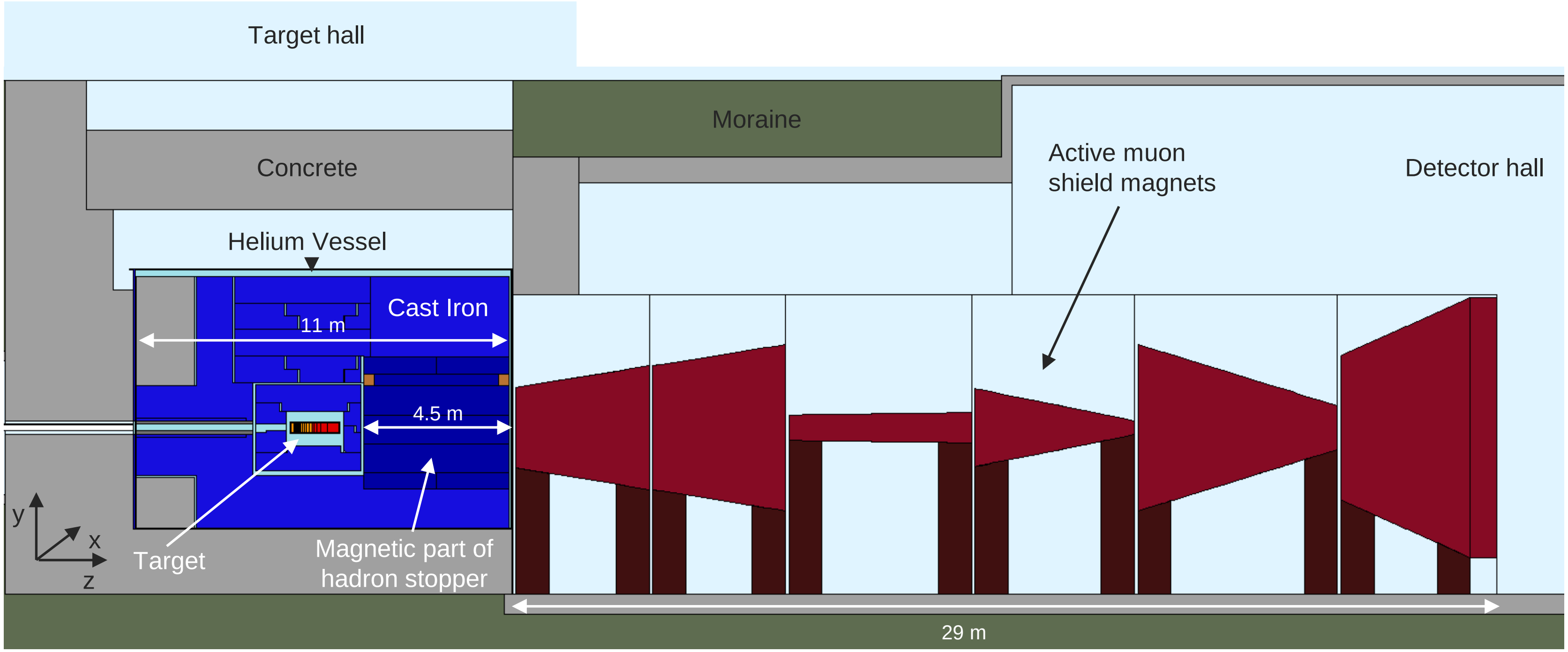
- **Air volumes** to be **minimized** in ‘hot’ areas or to be **replaced by He/vacuum** environment
- **Static confinement** of air by physical barriers to separate air in contaminated areas from outside
- **Dynamic confinement** by a ventilation system guaranteeing a pressure cascade from low to high contaminated areas

- **Water cooling circuits** for highly radioactive elements should be **closed and separated** from others
- **Activation** and **contamination** of ground water and earth to be **avoided**

- The design must consider minimization, decommissioning and dismantling of radioactive waste

RP evaluation based on FLUKA simulations

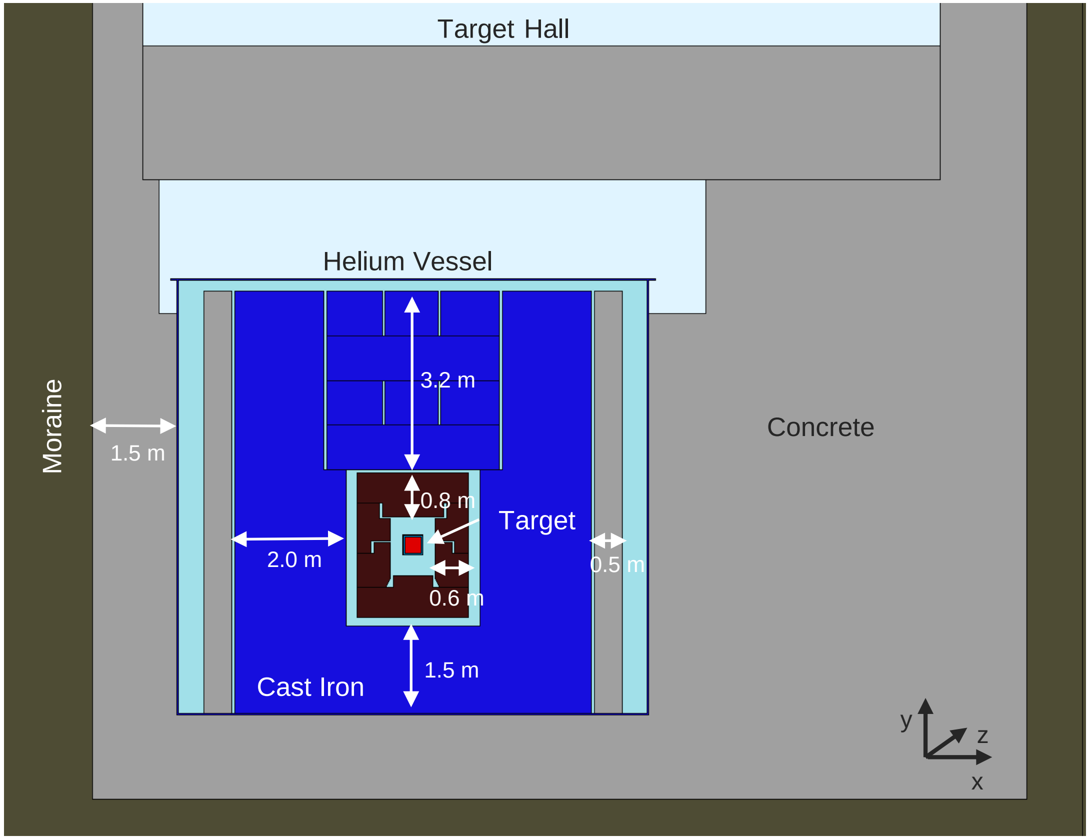
BDF/SHiP as implemented in FLUKA – Side view



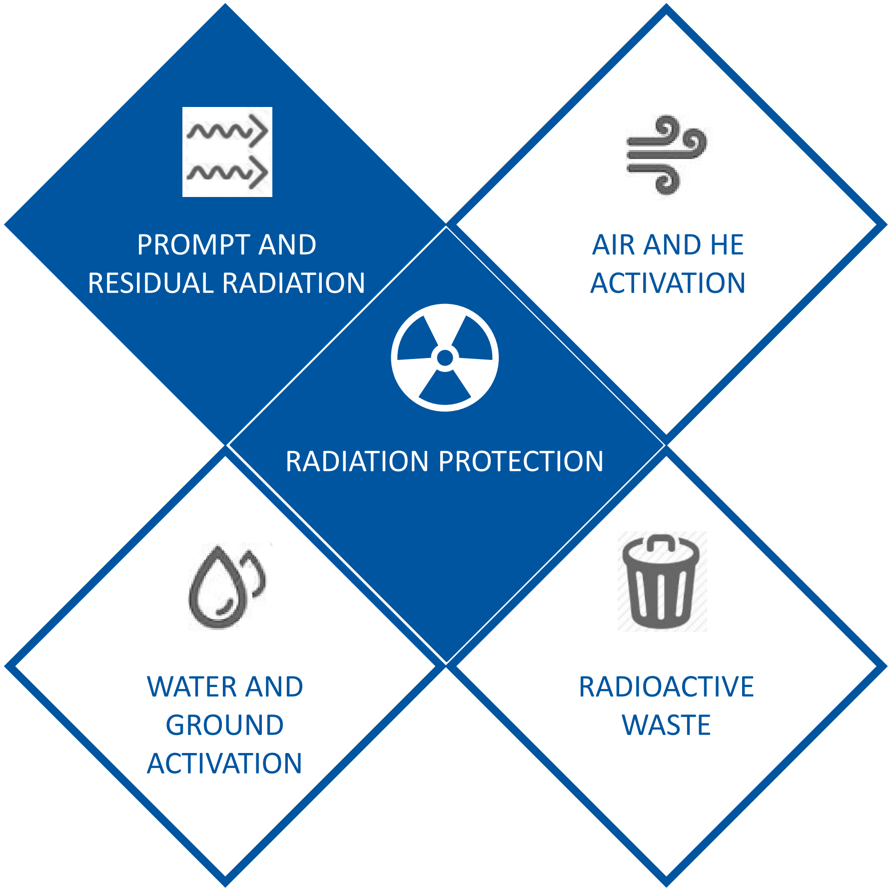
- **No access during operation** into the detector hall is the main condition for current design
- **Massive shielding** to keep prompt/residual dose rate and airborne **radioactivity as low as possible**
- Active muon shield with magnets (1.8 T) from the SHiP experiment was included

RP evaluation based on FLUKA simulations

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



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


PROMPT AND
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AIR AND HE
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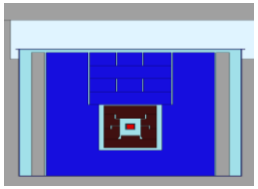
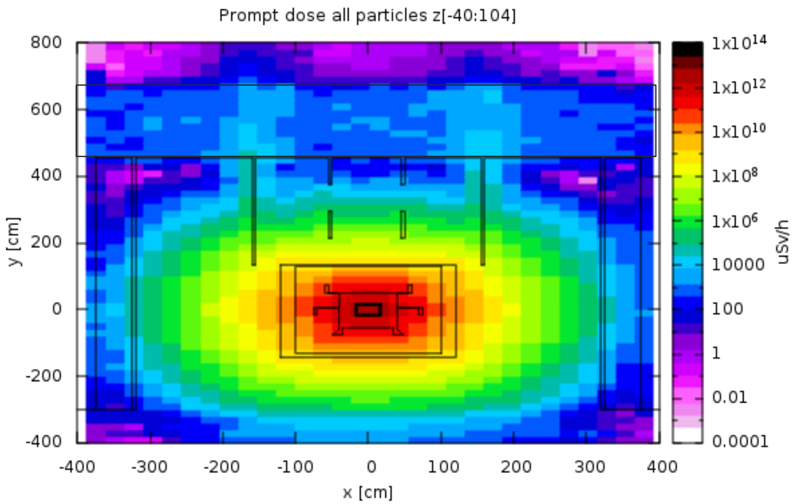
Expected dose rates in the target area

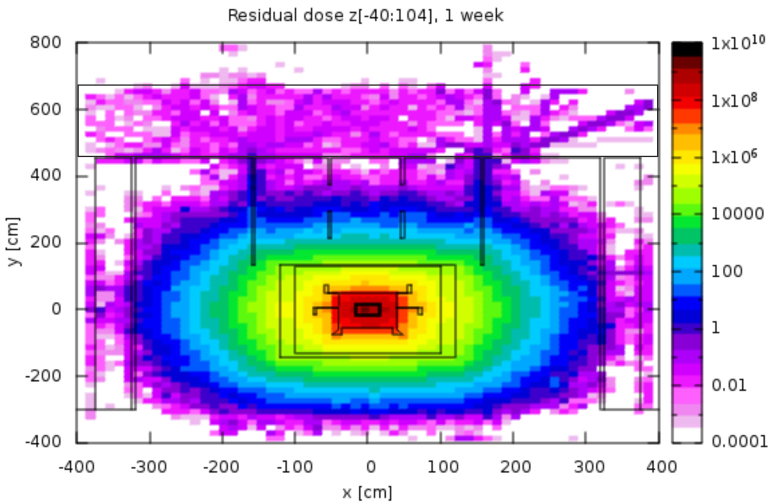
Prompt and residual radiation



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



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



Prompt dose rates reach **~10 - 100 mSv/h** above He-vessel and drop down to **< 1 μSv/h** above top concrete shielding (conservative gaps 5 cm)

→ 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

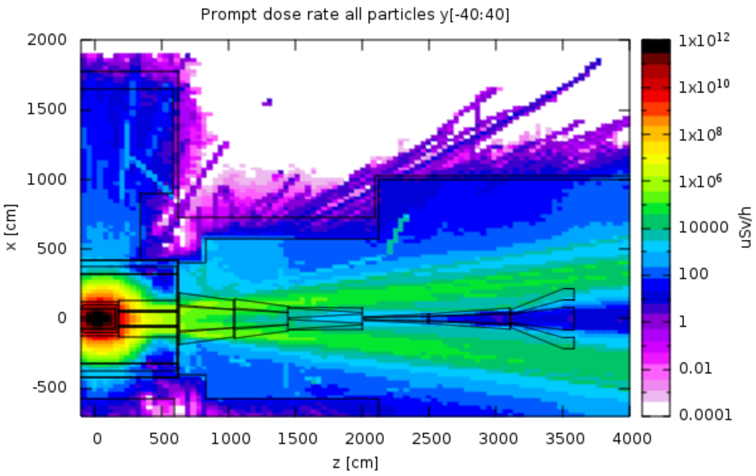
Very high residual dose rates next to target and cast iron shielding **O(100) Sv/h**

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

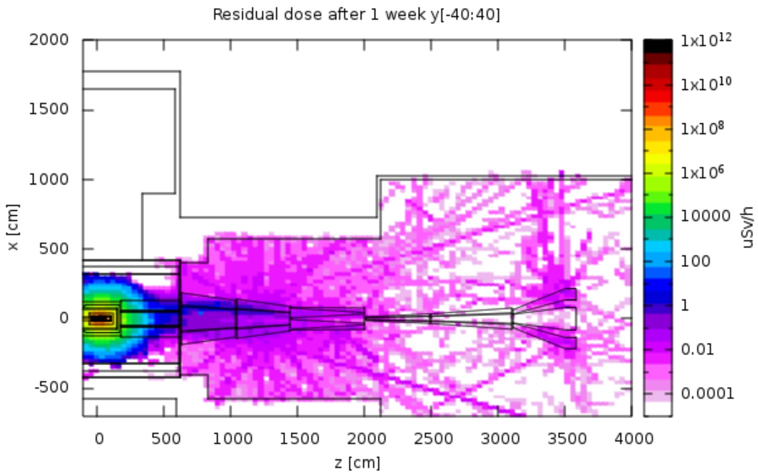
100 rem = 1Sv

Expected dose rates in the experimental area

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



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



Prompt dose rates reach **~100 mSv/h** at magnet mainly due to muons

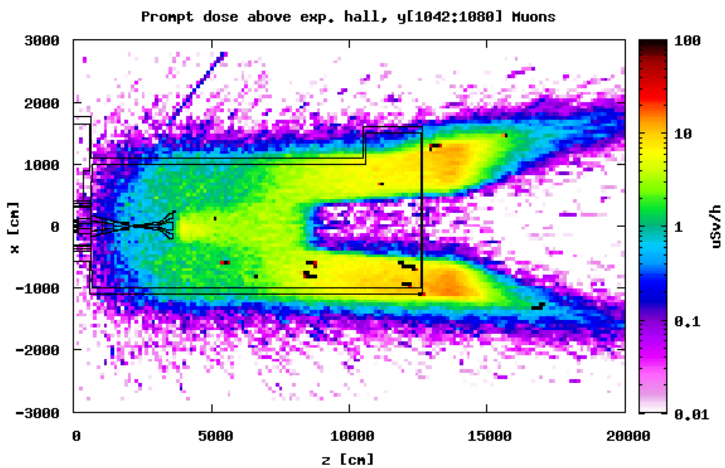
Residual dose rates close to first part of muon shield reach **~10 µSv/h**

→ Expected classification: **Supervised Radiation Area (<15 µSv/h)** in experimental hall

100 rem = 1Sv

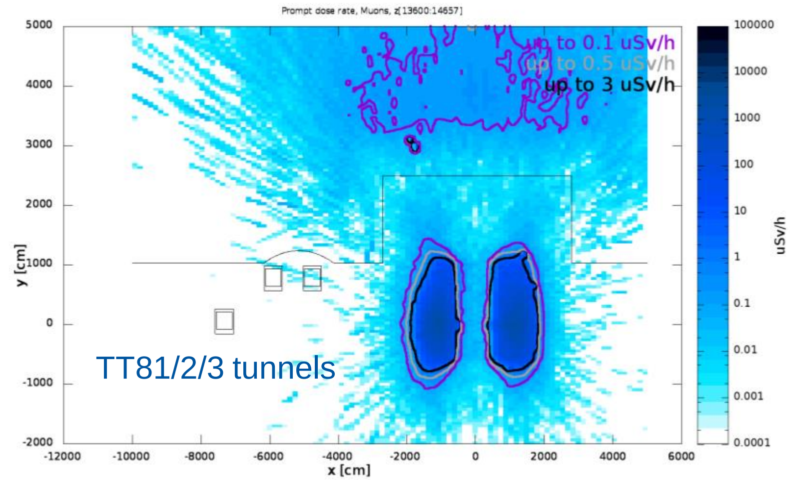
Expected dose rates in the surrounding area

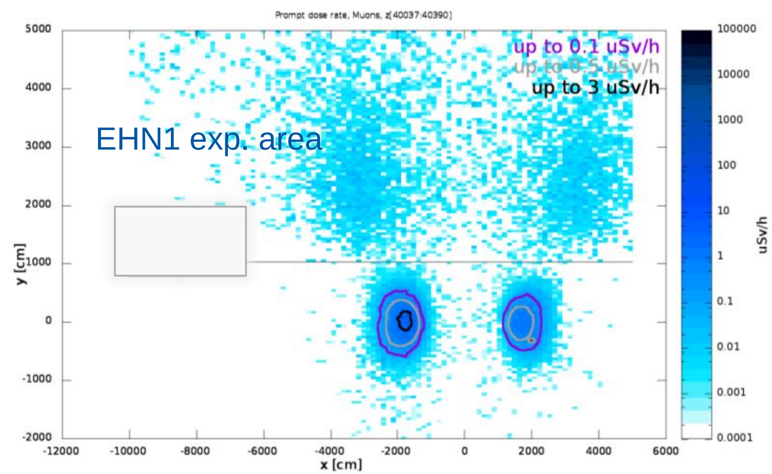
Muon prompt dose rate at $4{\times}10^{13}$ p / 7.2s



Muon prompt dose above experimental hall
~50 µSv/h

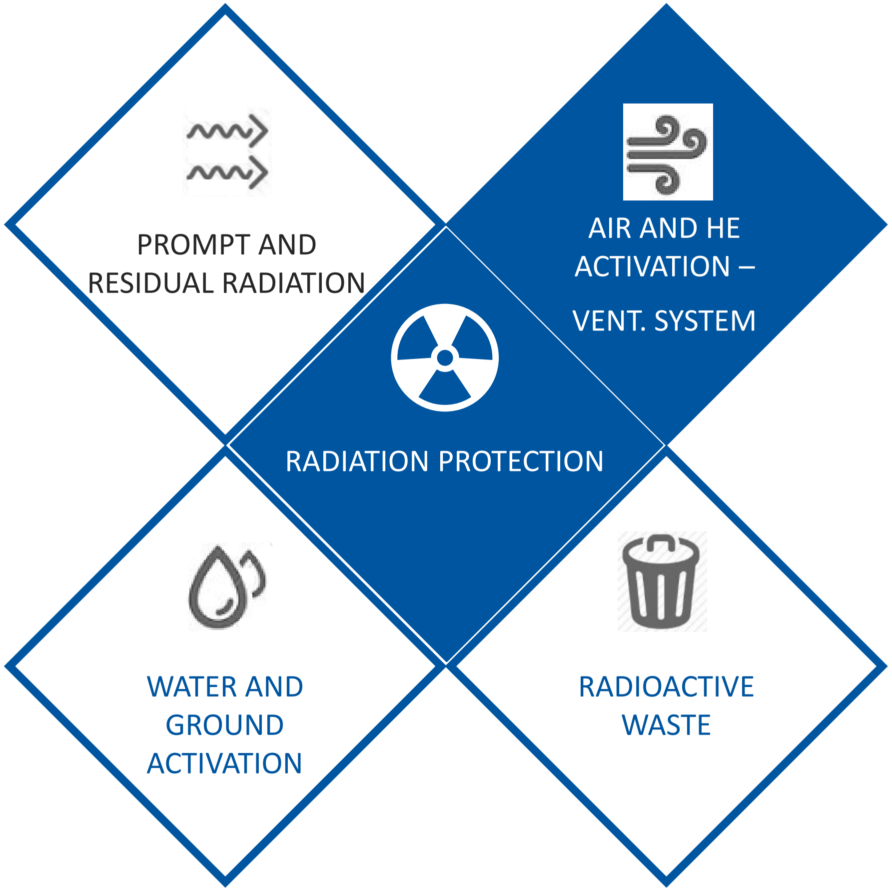
→ Need to cover area with at least **3m of soil on top** to allow for non-designated area level (<0.5 µSv/h)





Muon prompt dose around existing facilities both underground and above-ground **below** non-designated area level (<0.5 µSv/h)

100 rem = 1Sv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Classification of the ventilation system

- Ventilation system requirements inspired by **ISO 17873:2004**
- Four possible classifications:

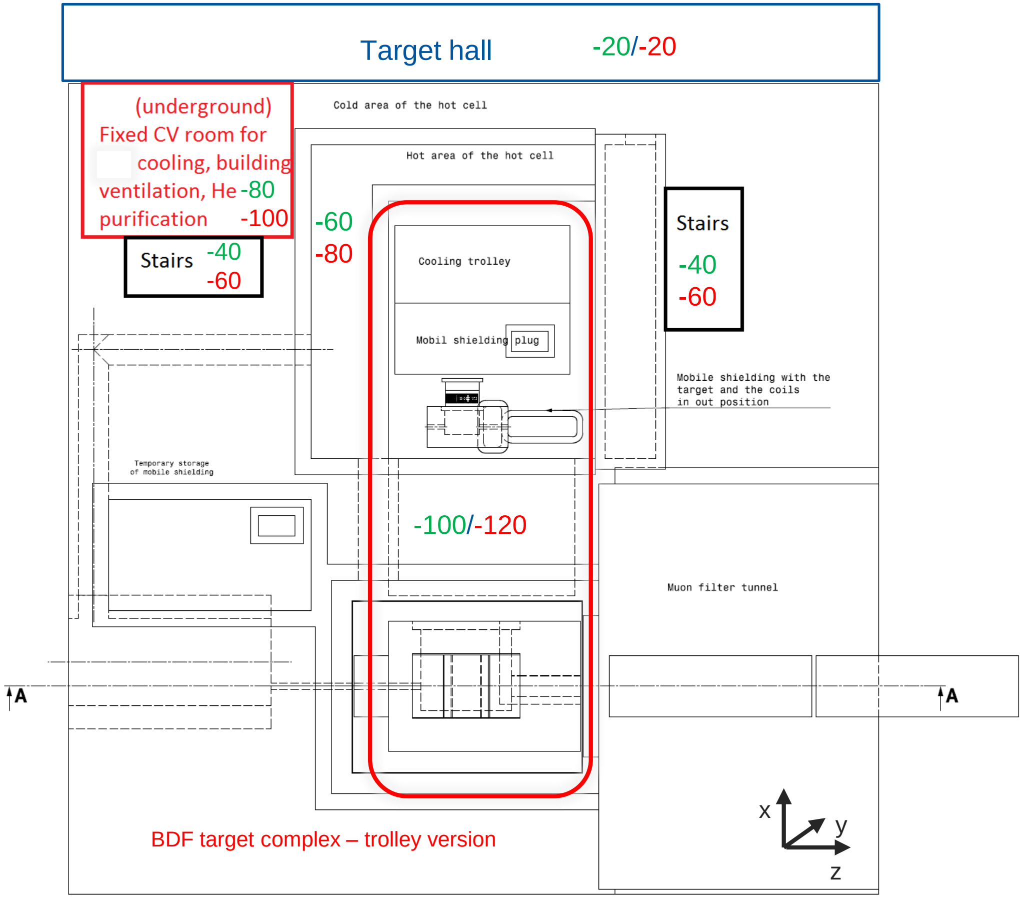
Classification	Depression values	DAC[1] values permanent (accident)
C1	<60 Pa	0 (<1)
C2	80 to 100 Pa	<1 (<80)
C3	120 to 140 Pa	<1 (<4000)
C4	220 to 300 Pa	>1 (any)

ISO 17873:2004:
Nuclear facilities — Criteria for the design and operation of ventilation systems for nuclear installations other than nuclear reactors

- Normal operation DAC < 1
- Accident case analysed → **He vessel breakdown**
  - **99.9% He purity** from He purification system → assumed 0.1% air contamination
  - DAC values calculated mixing He and air of closed loop
  - DAC for accident ~ 2.7
  - Inhaled dose 8 μSv in ~1 hour in case of accident
- Classification for ventilation system: **C2**
  - For flexibility for future installations could be classified as **C3**
  - Defined pressure differences between compartments to have dynamic confinement

[1]DAC ... Derived Air Concentration.

Classification of the ventilation system



C2/C3

Values in Pa

Radiological impact of releases

- Identified 6 reference groups around new BDF target facility

- Parameters of ventilation stack not yet defined
  - Conservative approach: ground release

	Workers waste treatment center	North-East	North-West	West	South-East	Agriculture
Received dose [nSv/year]	0.07	0.3	0.5	0.5	0.08	0.1

→ negligible doses

Tritium production

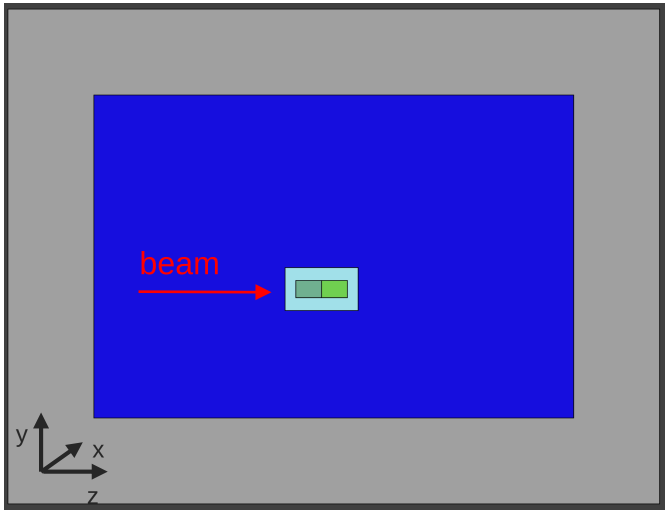
H-3 has very low radio-toxicity however can be a radiation hazard when:

- inhaled
- ingested via food or water
- absorbed through the skin

A simplified geometry was used:

- Target: 1 section of Mo, 1 section of W, no water cooling, no Ta cladding
- Region between target and proximity shielding filled by He
- Proximity shielding and passive shielding in Cast Iron
- 2 m concrete thick walls around passive shielding

Simplified FLUKA geometry



Tritium production and out-diffusion

10 TBq = 270 Ci

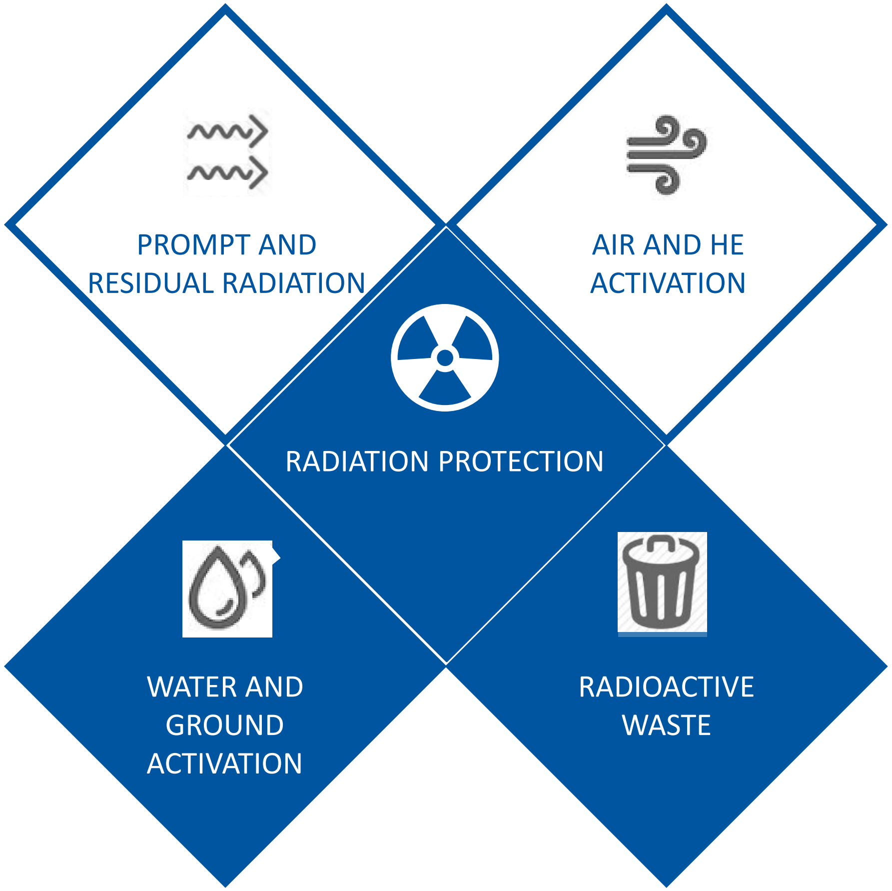
H-3 production for different materials

Material	H-3 activity
Mo	10 TBq
W	8 TBq
He	0.9 GBq
Cast Iron	1 TBq
Concrete	2 MBq

5 years of operation
→ $2*10^{20}$ pot

- 95% of H-3 produced in the target
- H-3 can be absorbed by target cooling water (HTO form)
- For iron and concrete shielding H-3 outgassing contributes to air contamination even during no beam periods

In order to better quantify the ‘out-diffusion’ of H-3 we will add samples of **Tungsten, Tantalum, TZM, Cast Iron and Concrete** to the BDF target prototype being irradiated in Sep/Oct 2018 at CERN **and** measure the out-diffusion of H-3.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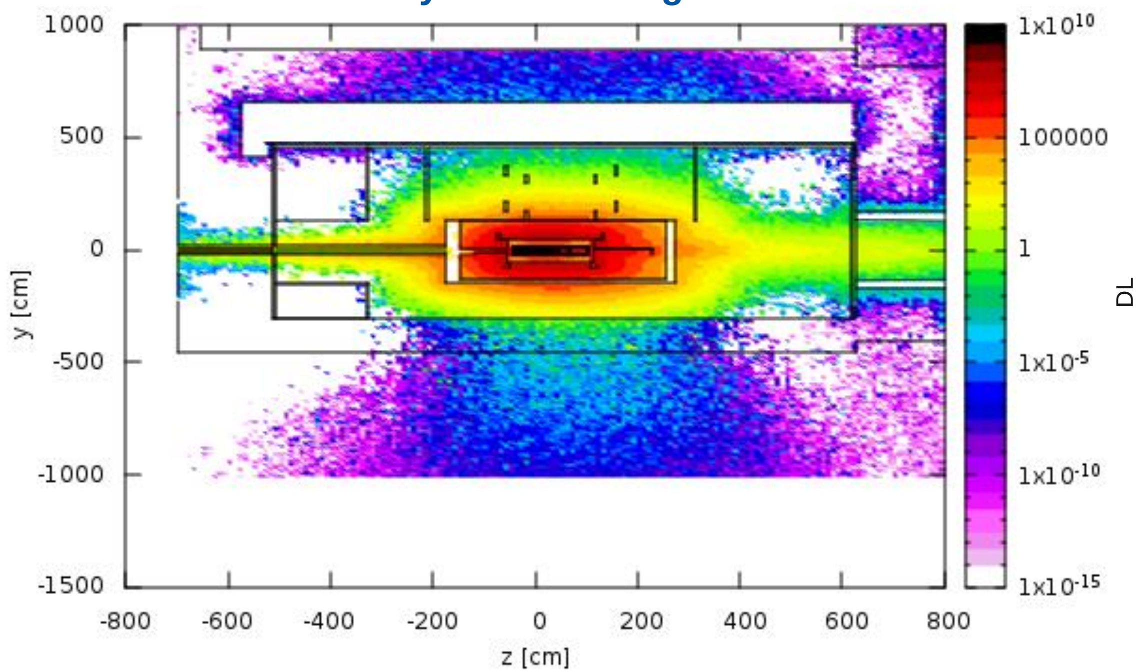
Radioactive waste production

- Calculations performed assuming 5 years operation → 2 * 10^{20} pot
- Results presented in terms of Design Limits (DL)
  → If DL > 1 the material/waste is radioactive
- Floor below the target slightly radioactive, increase iron thickness in the helium vessel to leave the facility 'clean' for future installations

1 year of cooling



$$DL = \sum_{i=1}^{n} \frac{a_i}{LL_i}$$

a… specific activity,
LL .. 'clearance' limit

Summary & conclusion

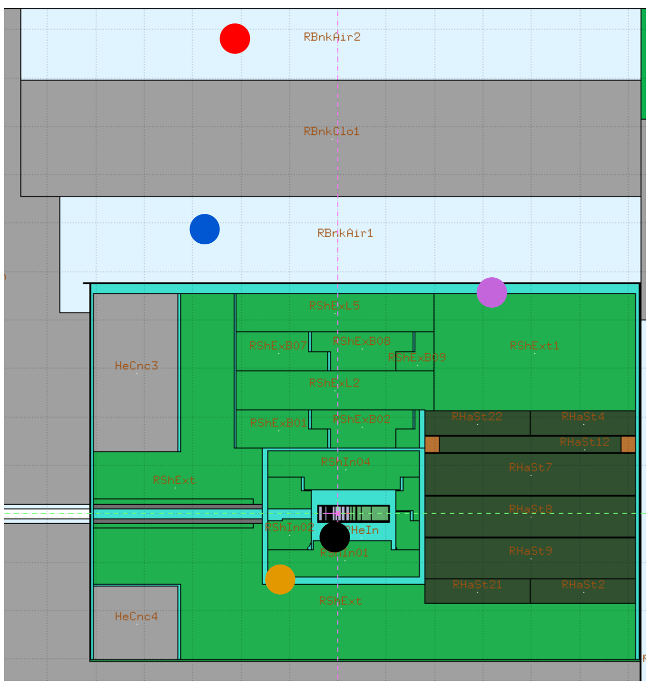
- The proposed BDF would be a **new permanent facility in the North Area** with unprecedented average beam power
- An in-depth study of the proposed BDF at CERN's is underway.
  - Target design needed careful studies and R&D
  - Target area particularly critical – embedded in a Helium vessel
  - High prompt & residual dose rates → massive shielding and remote interventions
- The design is based on significant experience at CERN with such facilities (WANF, CNGS, etc.)
- The BDF project team aims to produce a comprehensive design study by end 2018 … as input for the next update of the European Strategy for Particle Physics (ESPP).

Thank you for your attention!

Air activation

- Calculations performed assuming 5 years operation → 2 * 10^{20} pot
- **99.9% He purity** from He purification system → assumed 0.1% air contamination
- For the CA[1] calculation:
  - Assumed a standard breathing rate (1.2 m^3/h)
  - For the moment no leakage term

[1] Person working 40h/w, 50w/y with standard breathing rate in air contaminated environment with CA = 1 receives 20 mSv.



	Activity (Bq) after 60 s cooling	Multiple of CA
Air in inner He volume	5.6×10^{7}	7.5×10^{5}
Air in middle He volume	7.8×10^{5}	1.3×10^{3}
Air in external He volume	1.5×10^{2}	2×10^{-2}
First air volume	1.7×10^{7}	0.7
Second air volume	8.3×10^{4}	6.7×10^{-3}
Inner He volume	2.8×10^{9}	0.42
Middle He volume	4.1×10^{7}	8.7×10^{-4}
External He volume	9×10^{3}	1.5×10^{-8}

Tritium out-diffusion

- Assumption of an immediate **release efficiency of 100%** can be **over-conservative**
  - Tritium releases were measured years after the shutdown of CERN facilities (e.g. CNGS)
- Diffusion equation has to be solved for arbitrary geometries
  - A newly coded **plug-in for FLUKA [1]** solves diffusion equation using a Monte Carlo approach
  - It transports nuclides using a stochastic approach in the continuous limit
- In literature **diffusion coefficients** for tritium are **available only for few materials** and not in the full temperature range
  - Arrhenius equation used to extrapolate to operational temperatures
- Study of feasibility to **measure out-diffusion of tritium** from Tungsten, Tantalum, TZM, Cast Iron and Concrete
  - Possibility to measure diffusion constants
- **Simulated out-diffusion** @298K (@423K) from **Iron** shielding after 2 months is about **33%** (38%), while from **Tungsten** is **0.18%** (2.43%)

[1] Development of a computational model for the out-diffusion of radioisotopes from metals, C.Theis and H.Vincke, CERN-RP-2016-173-REPORTS-TN

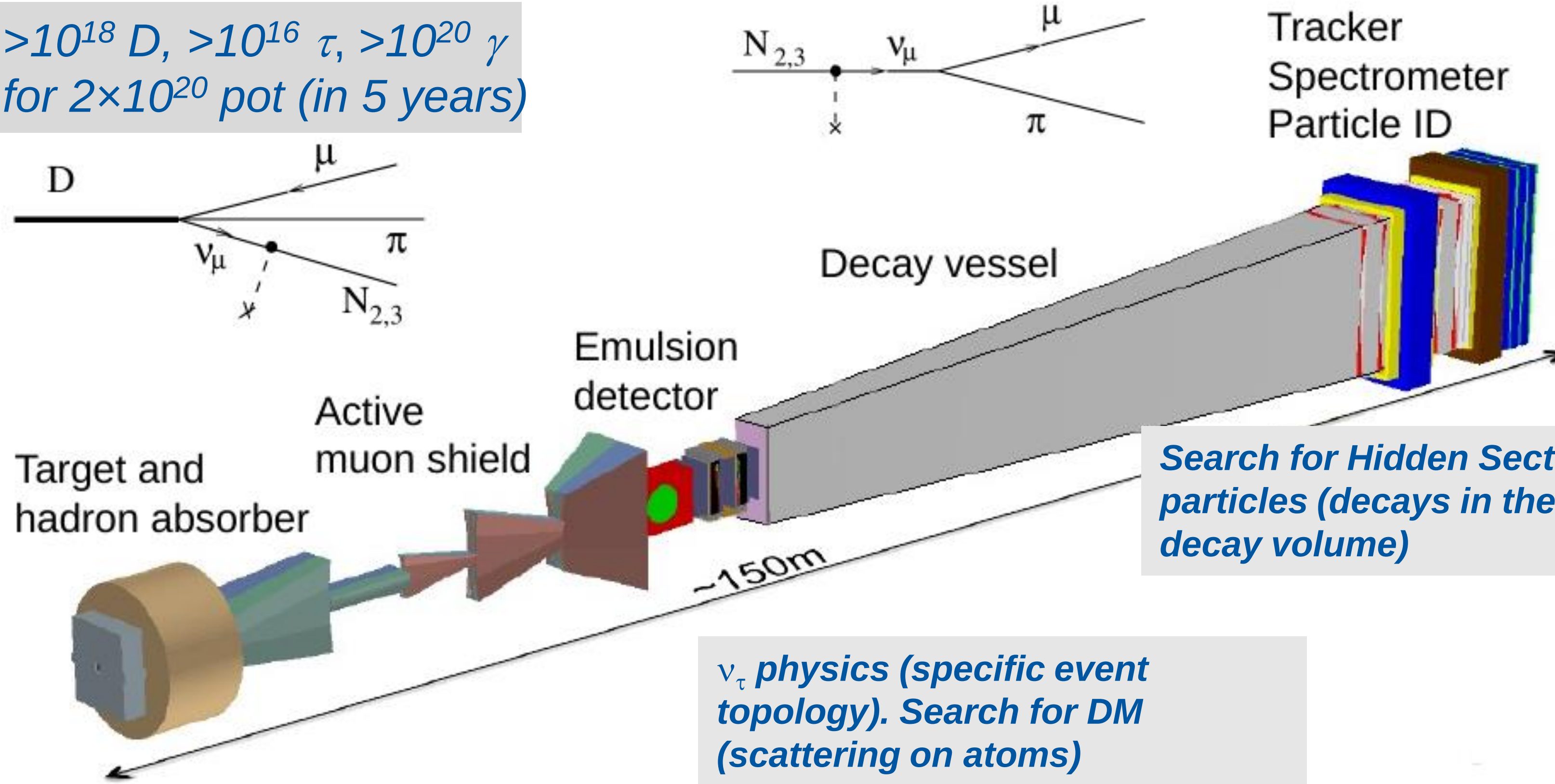
Search for **Hi**dden **P**articles (SHiP) at BDF

SHiP is aimed at exploring the domain of hidden particles and make tau neutrino measurements

http://ship.web.cern.ch/ship/

"Zero background" experiment
- Muon shield
- Surrounding Veto detectors

>10^{18} D, >10^{16} τ, >10^{20} γ for 2×10^{20} pot (in 5 years)



Search for Hidden Sector particles (decays in the decay volume)

ν_τ physics (specific event topology). Search for DM (scattering on atoms)