CERN irradiation facilities supporting collider programs and targetry technologies

M. Calviani (Systems Department, Sources Targets Interactions Group)

18th June 2021

Disclaimer

This is partial and personal view of the "irradiation" topic, seen from Targetry Systems perspective, as within the scope of the present workshop

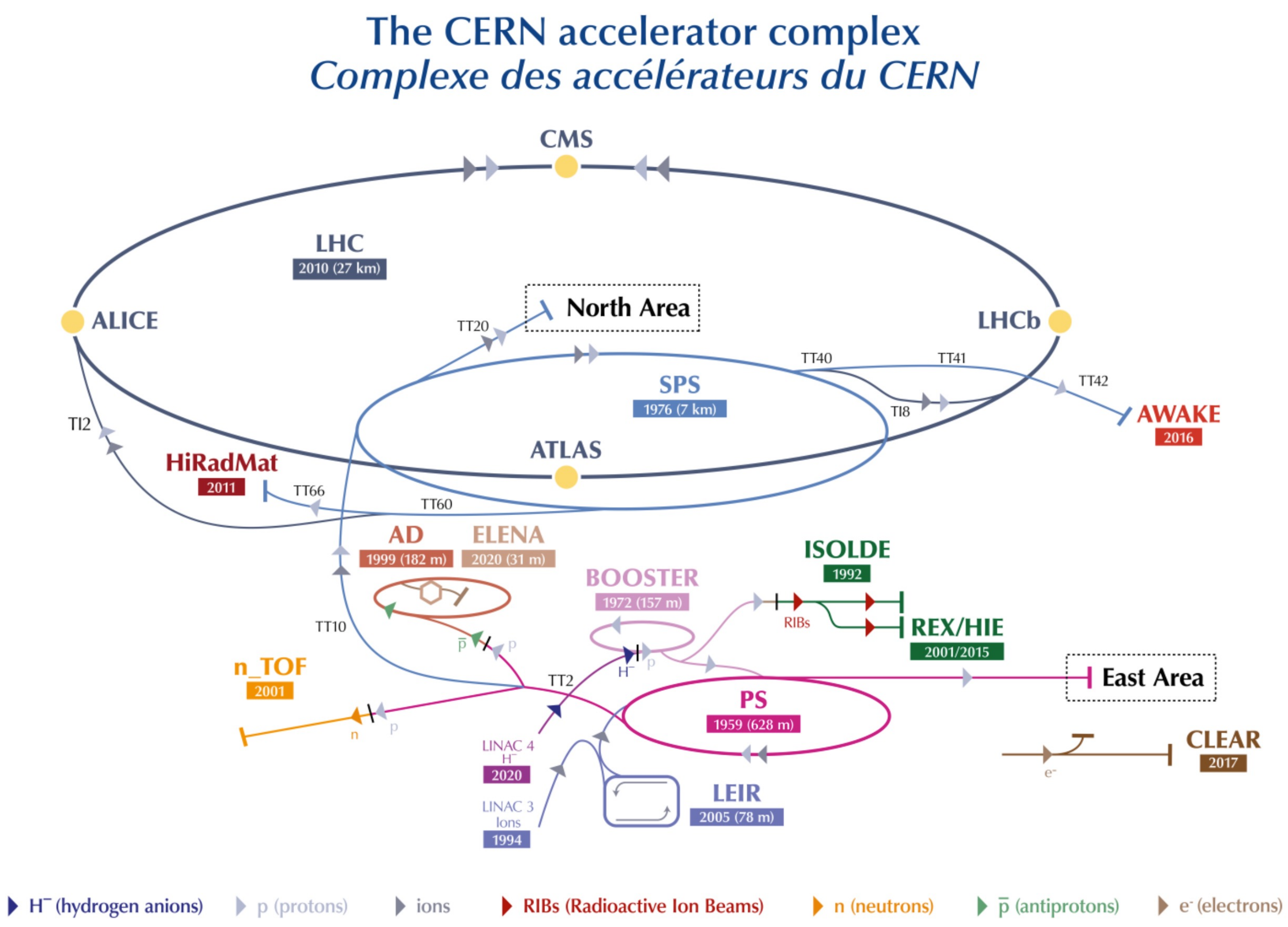
Acknowledgments

N. Charitonidis, R. Garcia Alia, S. Rothe, J. Vollaire, S. Stegemann, A.-P. Bernardes, F.-X. Nuiry, T. Stora, M. Ferrari, D. Senajova, O. Aberle, F. Ravotti, P. Fernardez-Martinez, S. Gilardoni, A. Perillo-Marcone, R. Ximenes

Outline

- What is the role of irradiation facilities at CERN
- Irradiation facilities supporting Beam Intercepting Devices (BIDs) and Target Systems
- Irradiation facilities in support of collider technology and respective systems
- Conclusions

CERN Accelerator Complex



- Accelerating particles up to TeV energies requires multiple acceleration stages: LINAC, PSB/LEIR, PS, SPS, and LHC
- Each single accelerator can typically increase the particle energy by a factor ~30
- Only a very small fraction of the protons accelerated at CERN end up in the LHC storage ring at 7 TeV, most are used in the experimental areas of the PS (24 GeV) and SPS (450 GeV) (70% to ISOLDE, 25% n_TOF)
- Ions (e.g. Xe or Pb) are also accelerated during some weeks at the end of every year

Role of irradiation facilities

- **Two categories could be generally considered**

1. **Test of complex systems such as beam intercepting or protection devices**
   - Testing of thermal shock resistance of absorbing block
   - Validation of integral components
   - Single pulse or long-term irradiation infrastructure
2. **Irradiation facilities supporting equipment installed in accelerator environment and big experiments**
   - Irradiation of COTS components for accelerator systems
   - Irradiation of equipment for LHC and non-LHC experiments

- **Given the scope of the current Snowmass process, focus will be given on #1 – internal and external ”irradiation” support is critical**

Beam Interception at CERN

- **Beam intercepting devices for a variety of different functions, from particle production (RIBs, neutrons, pbars, etc.) to collimators and beam absorbers/dumps**

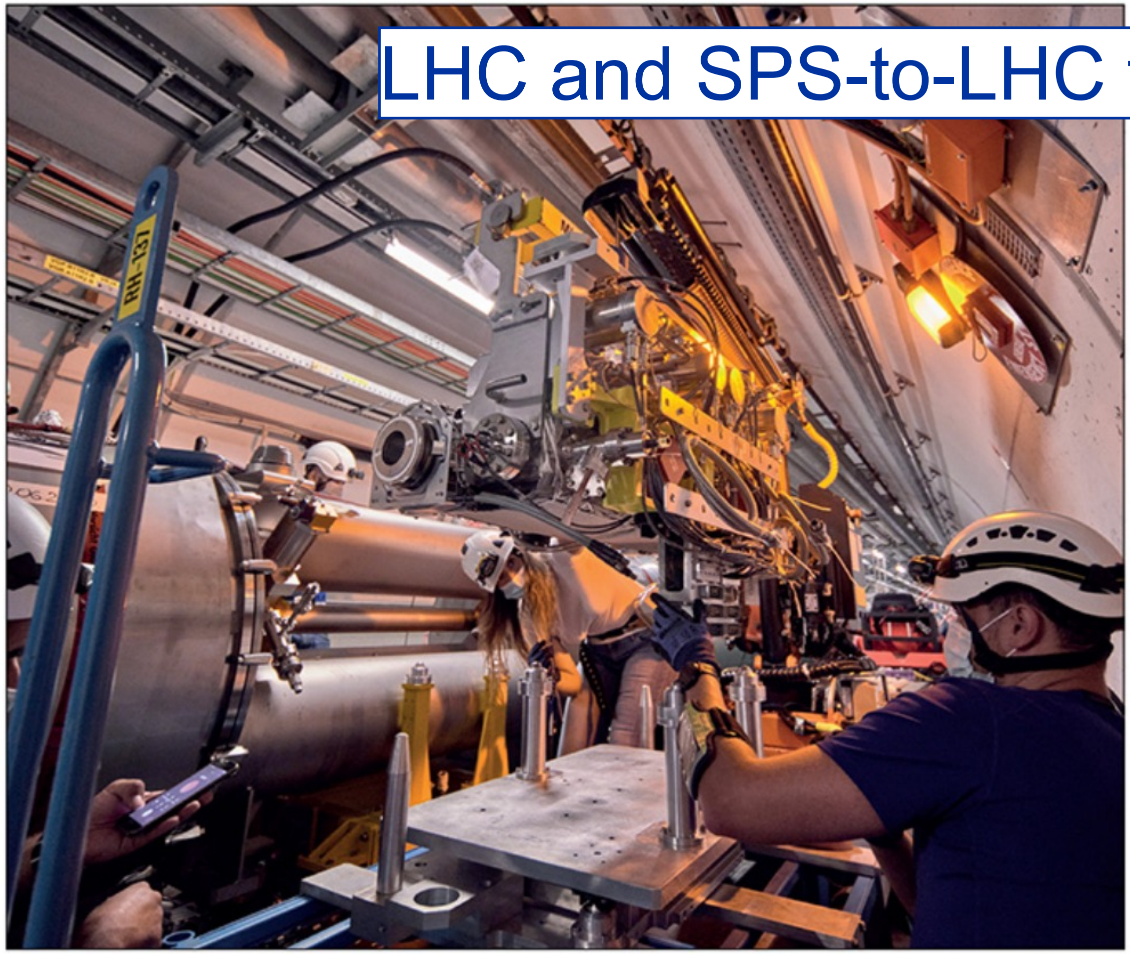
- **Testing of integral or sub-component with beam is essential to validate technologies and functions**

SPS internal dump, 300 kW in UHV

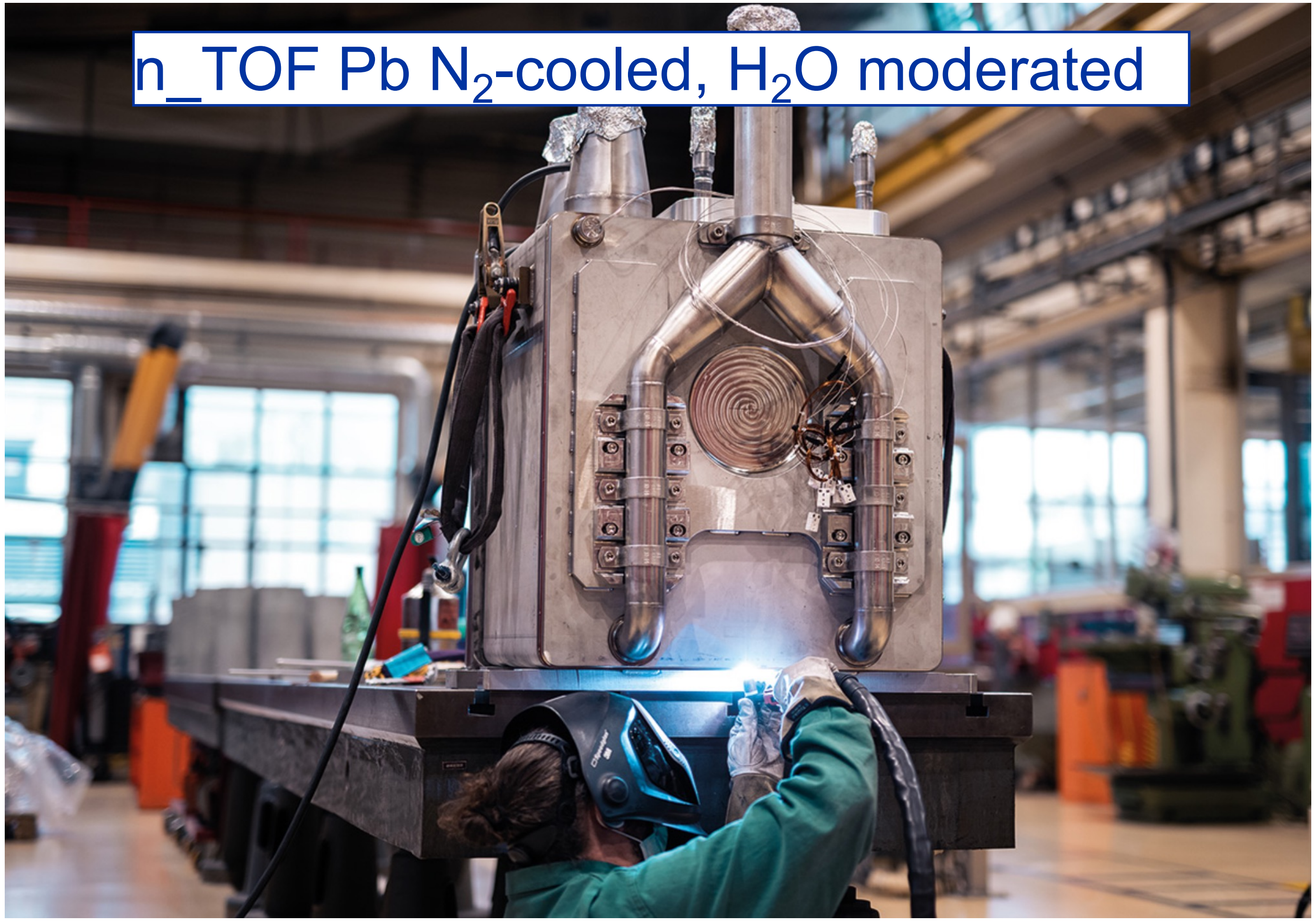
LHC external dump, 500 MJ/dump

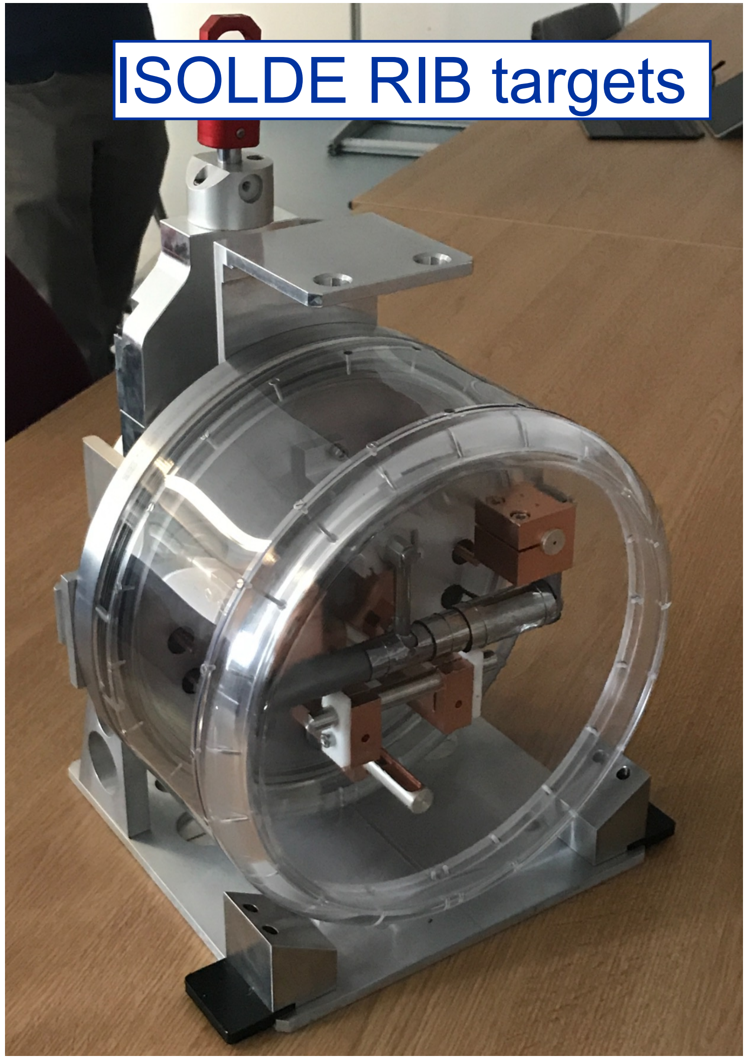
Beam Interception at CERN

LHC and SPS-to-LHC transfer line collimators



Beam Interception at CERN





Test of complex systems such as beam intercepting or protection devices

HiRadMat facility

Contact: N. Charitonidis

- **A unique, high-energy, high-intensity pulsed beam facility** dedicated to targetry & accelerator components material R&D
- **LHC-like proton or ions beams, with a maximum pulse intensity of 3.4×10^{13} protons / pulse** can be delivered in controlled conditions and to be monitored with special instrumentation.

HiRadMat Proton Beam	
Beam Momentum	440 GeV +- 0.3%
Pulse Energy (max)	2.46 MJ
Bunch Intensity	5.0×10^{9} to 1.2×10^{11} protons
Number of Bunches	1 to 288
Minimum Pulse Intensity	5.0×10^{9} protons (1bunch)
Maximum Pulse Intensity	3.5×10^{13} protons (288b at 1.2×10^{11} ppb)
Bunch length (1σ r.m.s)	375 ps
Bunch Spacing	min. 25 ns, max 150 ns
Batch Spacing	250 ns
1 σ r.m.s. beam radius	0.5 to 4.0 mm
Total typically allocated protons/year	**2×10^{16}** protons (equivalent to approx. 10 experiments year)

An upgrade study of the beam dump and windows is ongoing, in order to be able to allow LIU beam parameters (smaller emittance & 2.3×10^{11} protons / bunch

Experiments in HiRadMat

A unique facility to test the effects of *high-intensity SINGLE pulsed beams* on materials

- Targets
- Accelerator components
- Beam instrumentation or machine protection
- Highlights of experiments on various aspects have been presented e.g here

1 HiRadmat pulse with the maximum intensity (288 bunches, 3.5×10^{13} p/pulse) can be seen as having an instantaneous energy of :

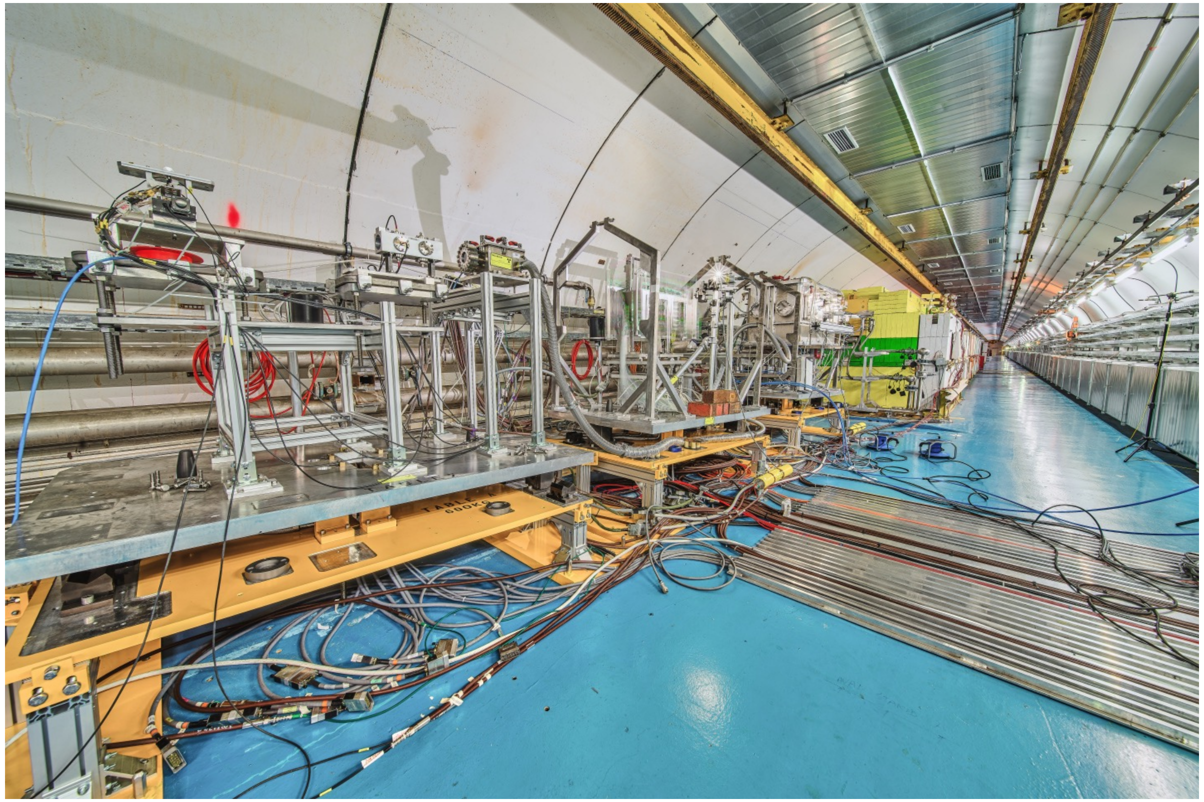
P[J/pulse] = 440 x 1.6E-10 x 3.5E13 = 2.46 MJ/pulse

This "power density" in tandem with the very short pulse length (7.2 μs) allows to test or simulate realistic energy depositions of high power beams on materials.

At the same time, only 1 pulse per ~min currently → Low average power, imposed mainly from availability and concurrence with LHC

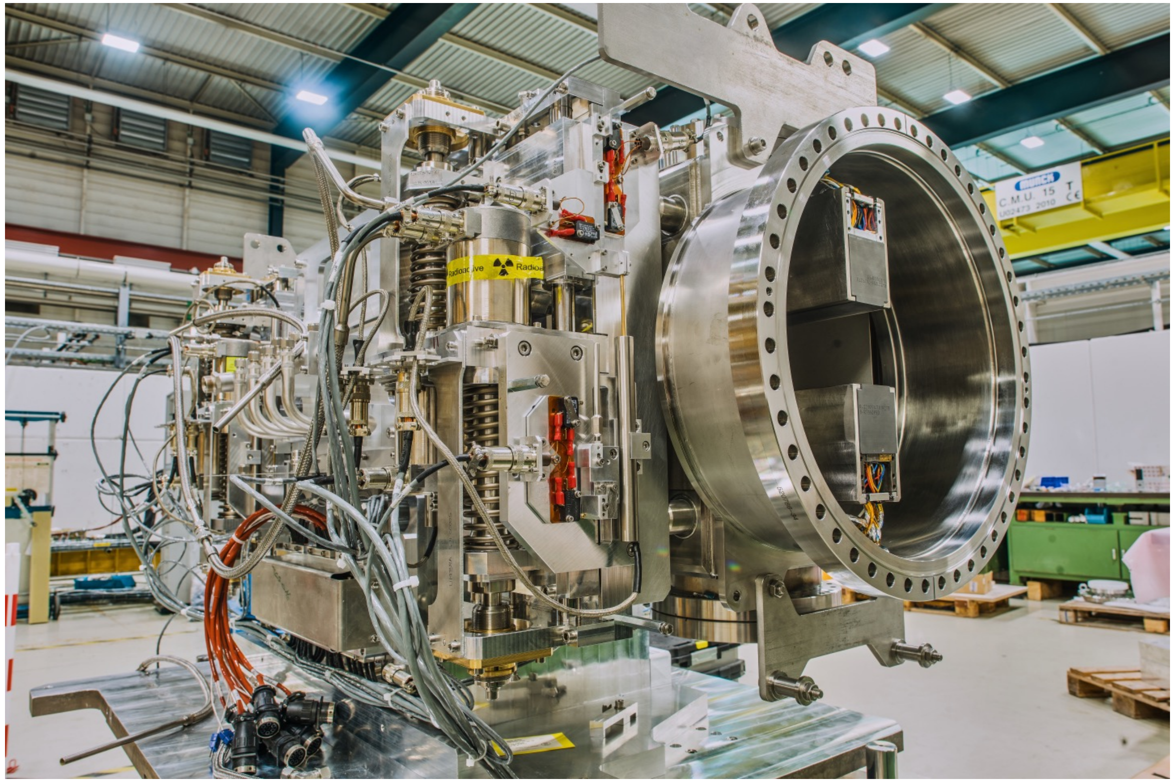
HiRadMat Facility Layout

- **A specially designed underground facility, specially prepared and equipped with mobile supports, cabling, instrumentation for high intensity *pulsed* beam experiments.**



Examples of HRMT tests

- Integral testing of an internal dump at the end of SPS injector towards LHC
- Graphitic material inserted in a TZM backstiffener w/ TiGr5 holding plates

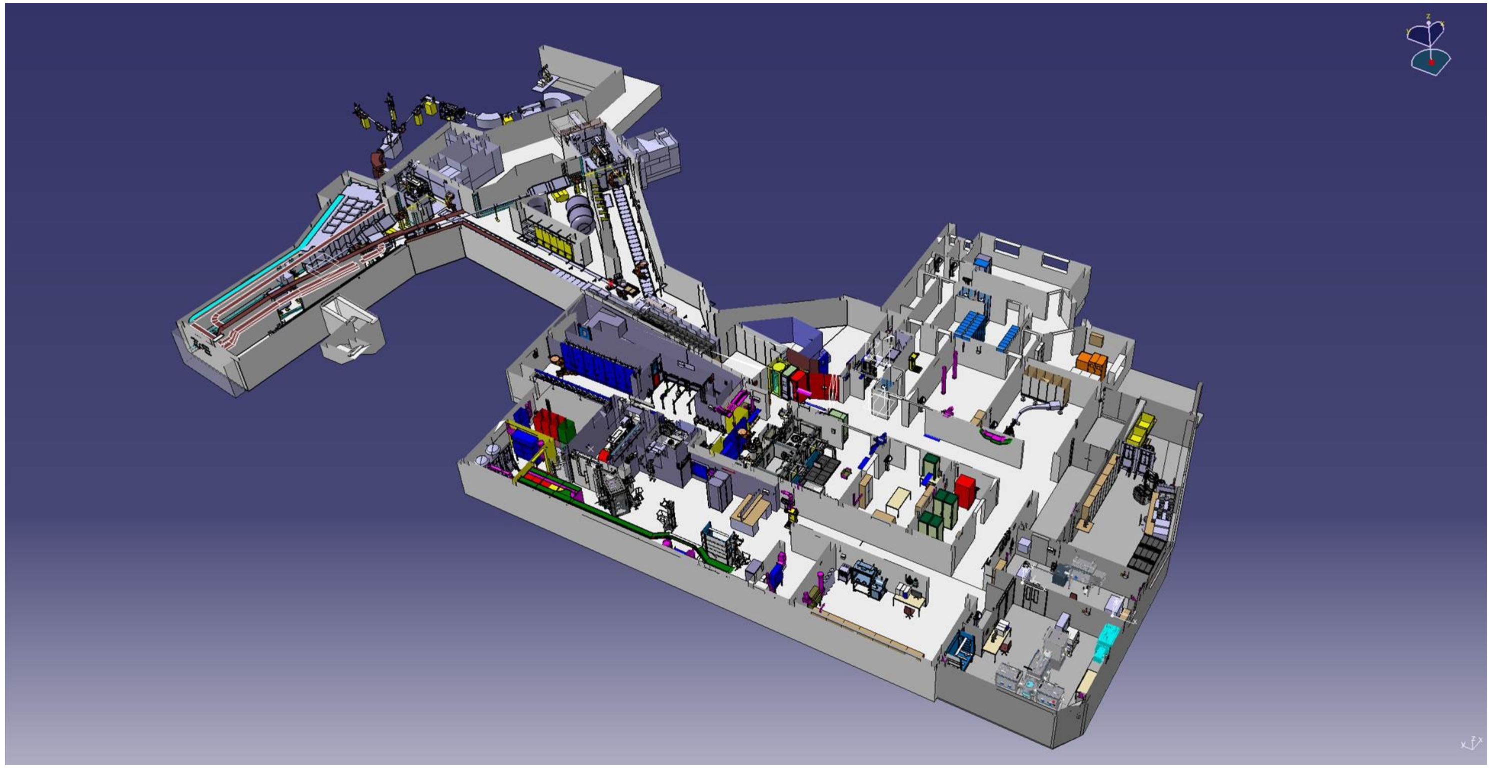


http://cds.cern.ch/record/2633513?ln=en

ISOLDE Facility

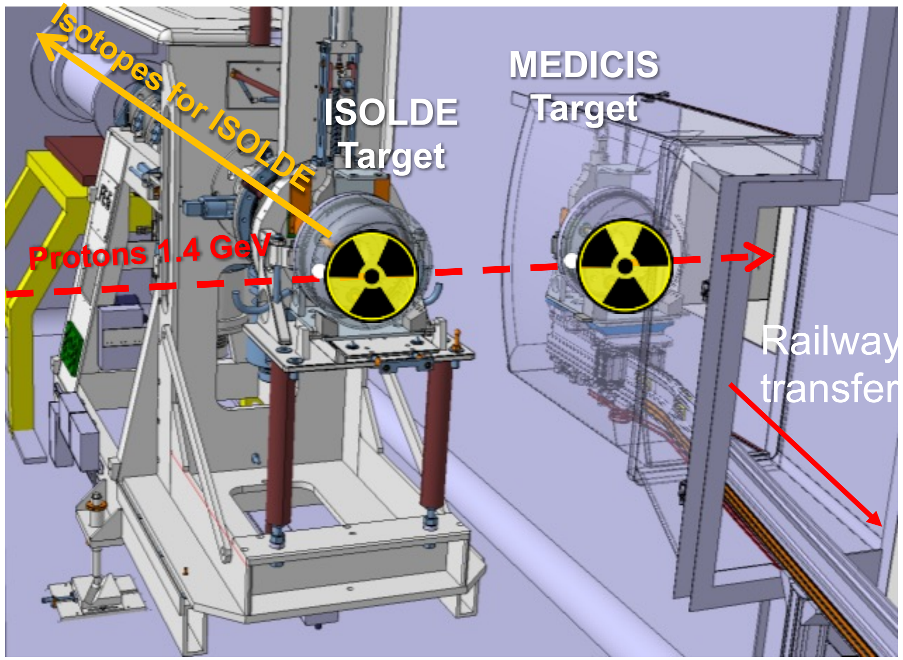
Contact: J. Vollaire

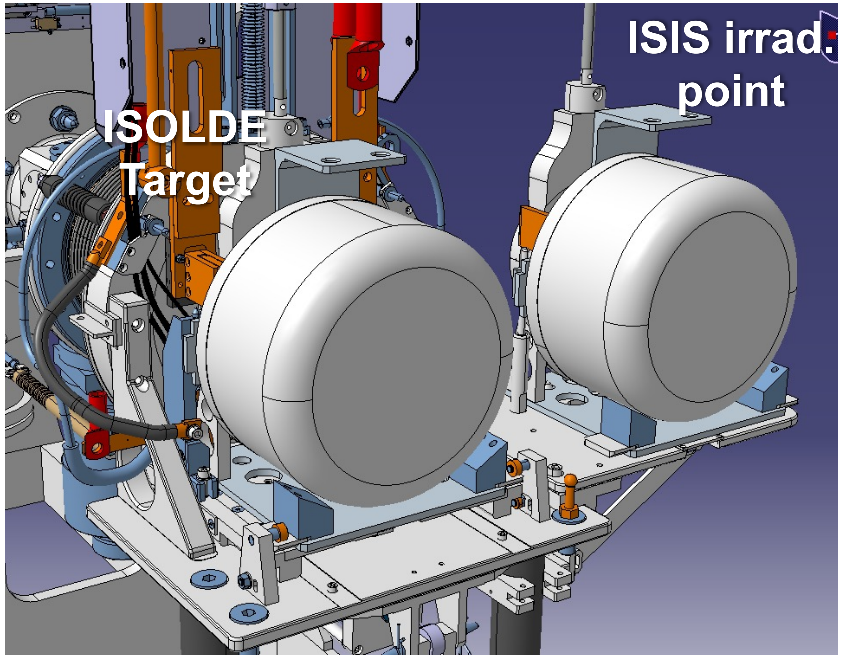
- Facility for RIB production at PS Booster (1.4 GeV/c)
- 2 Target stations and separators for high purity and high-resolution beams
- Hot-cell zones



CERN ISOLDE infrastructure

HRS



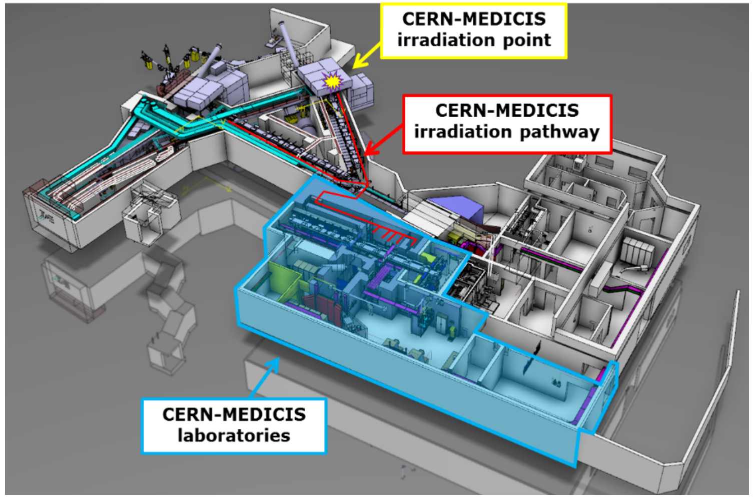


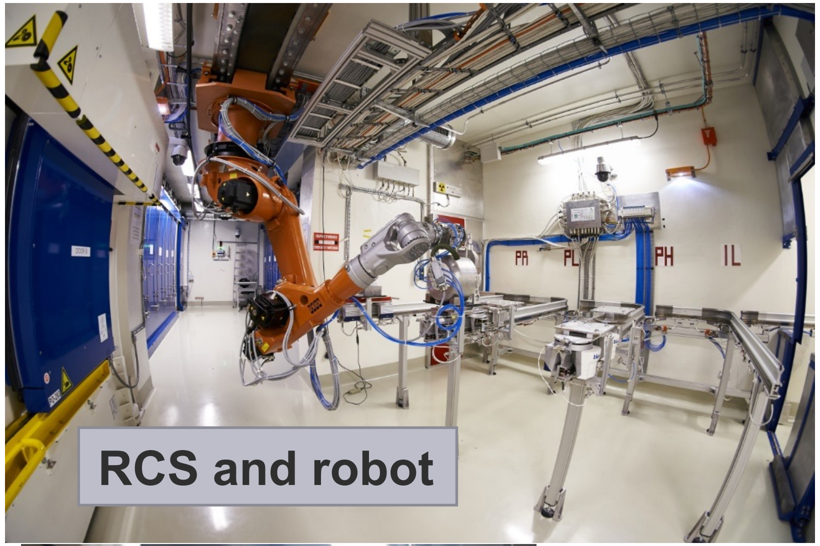
GPS

- ISOLDE target for physics research
- MEDICIS target recycles protons that did not interact
- Railway (MONTRAC) system allows transport to class A lab. (~ 15 min)
- Offline manipulation (e.g., medical isotope collection)

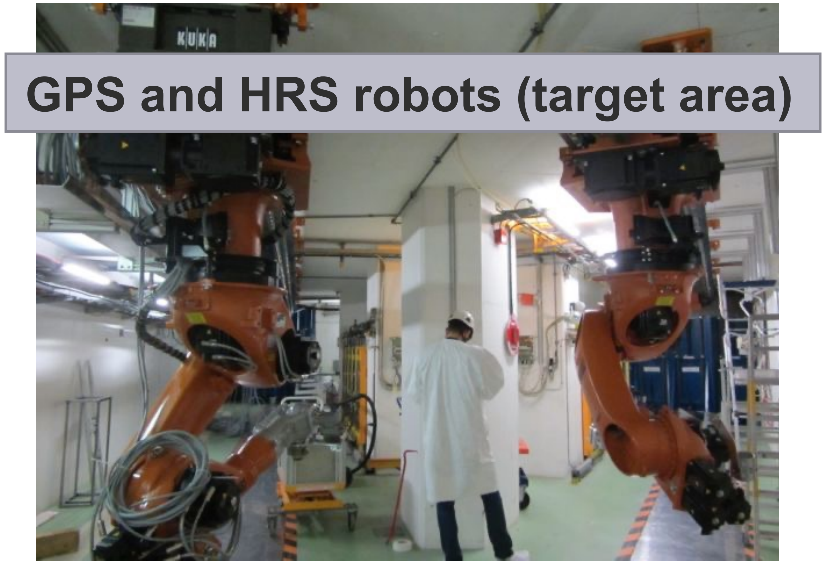
- ISOLDE target for physics research
- Fixed ISIS irradiation point
- Foreseen to operate in sync. with ISOLDE operation
  (Bringing in/out with GPS target change)

CERN ISOLDE infrastructure

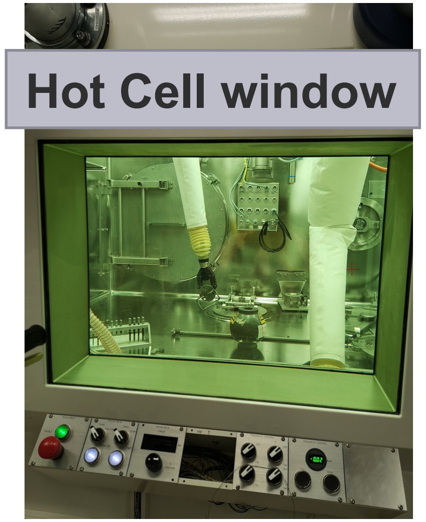



RCS and robot


Targets Storage


GPS and HRS robots (target area)

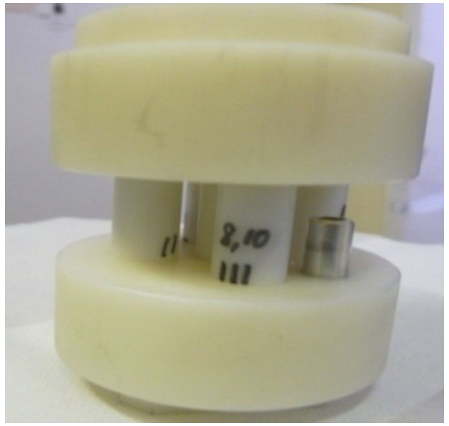

Target Loading

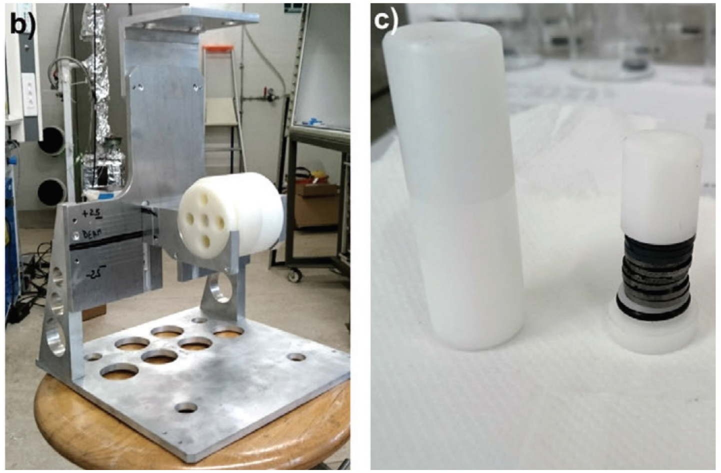

Hot Cell window

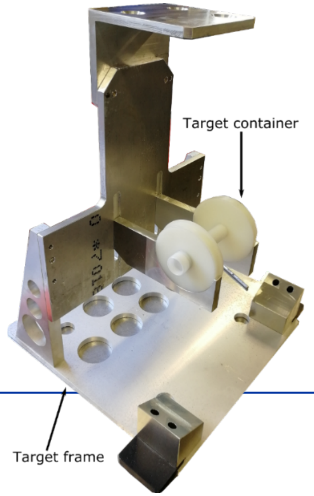

Telemanipulator

Example of activation studies at MEDICIS

- **Irradiation of lead-bismuth eutectic targets to measure produced radionuclides (e.g. short-lived and those produced by secondaries)**
  - Especially short-lived and those produced by secondaries
- **Release studies from TiC-CB (carbon black)**
- **^{11}C release study from activated BN targets**







S. Stegeman et al. Journal of the European Ceramic Society, 41 (7) (2021), 4086-4097

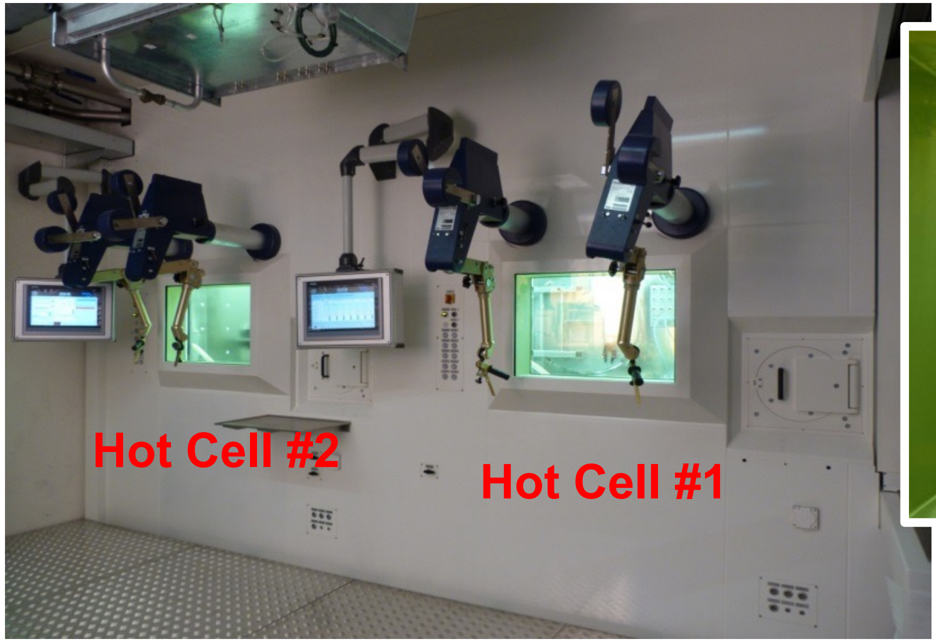
Contact: S. Stegemann, T. Stora

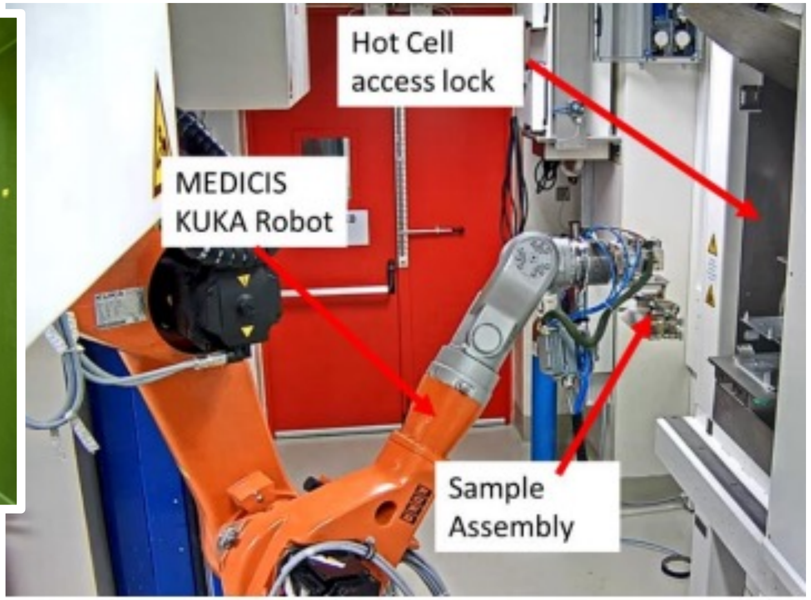
ISOLDE Facility α-γ hot-cell

Contact: J. Vollaire

Operator Side

Material side (remote handling, waste drums…)





- **Two compartment hot cell with tele manipulator**
- **Hot Cell #1 & # 2 operate in under pressure (#2 can operate under inert atmosphere)**
- **Remote handling capabilities with KUKA robot (ISOLDE target gripper system and weight/dimensions)**

ISOLDE Facility α-γ hot-cell – scope of use

- **Dismantling (material categorisation in view of waste elimination) and autopsy of ISOLDE targets (Hot Cell #1)**
- **Re-oxidation of irradiated uranium carbide pills (pyrophoric risk) in view of elimination (Hot Cell #1)**

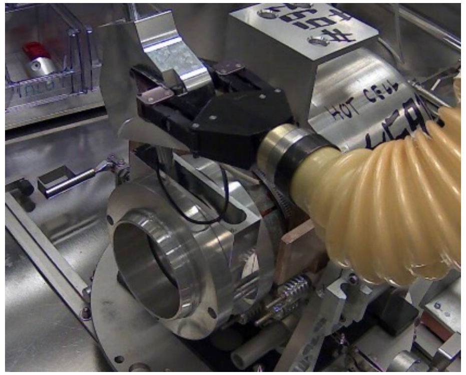
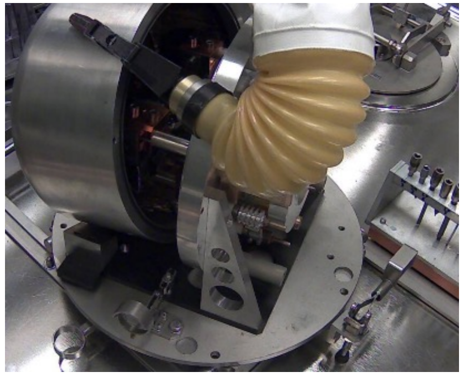
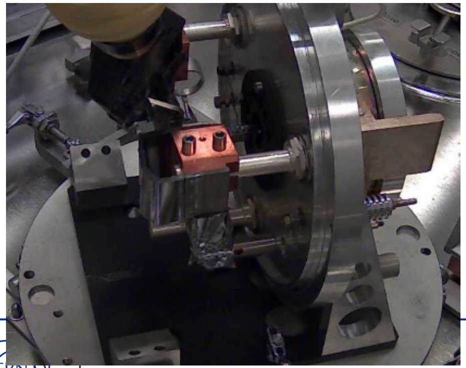
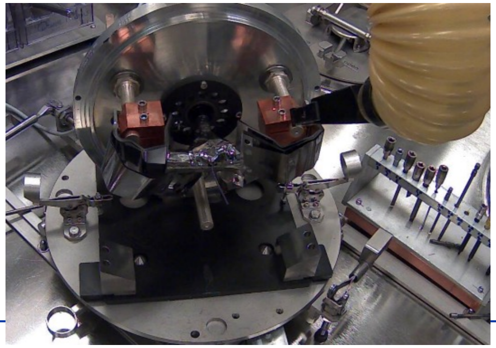
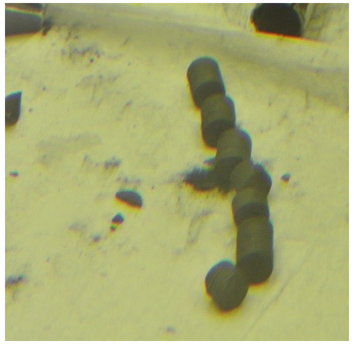
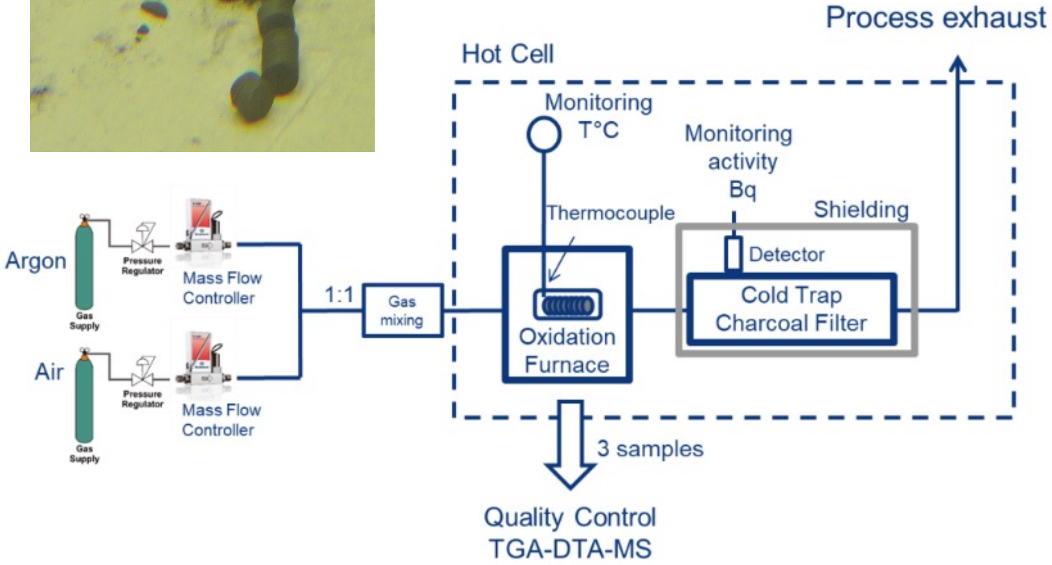
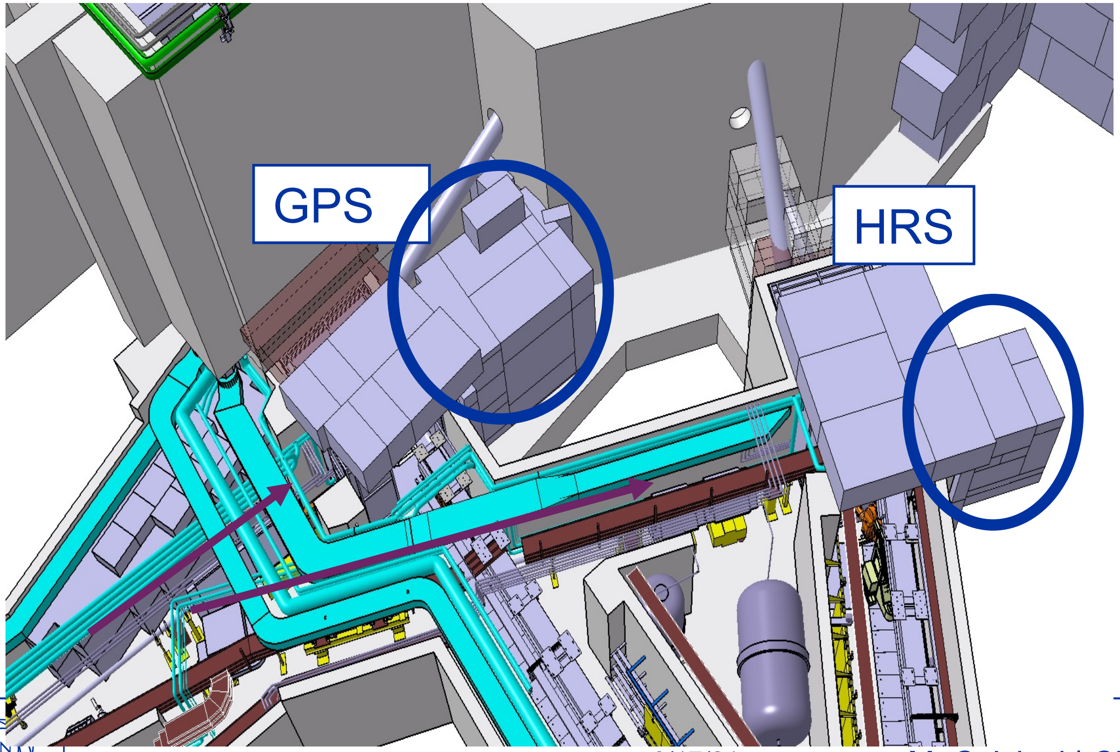







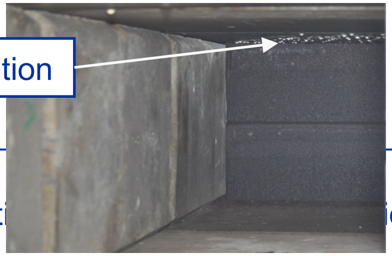
Figure 5 - Schematic of proposal oxidation set-up in Hot Cell

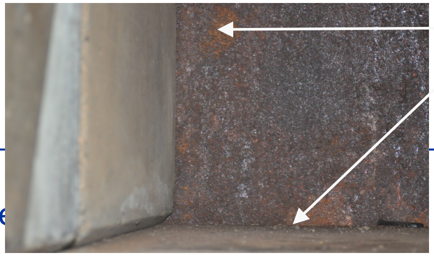
ISOLDE beam Dump Replacement Study

Contact: A.-P. Bernardes

- **Current ISOLDE configuration dates to 1991-1992 (ISOLDE 4)**
- **Beam dumps were designed for a proton beam of 0.8/1 GeV. Not compatible with 2 GeV beam upgrade following PSB maximum deliverable energy**
- **Signs of corrosion, condensation and molten material on the visible face**





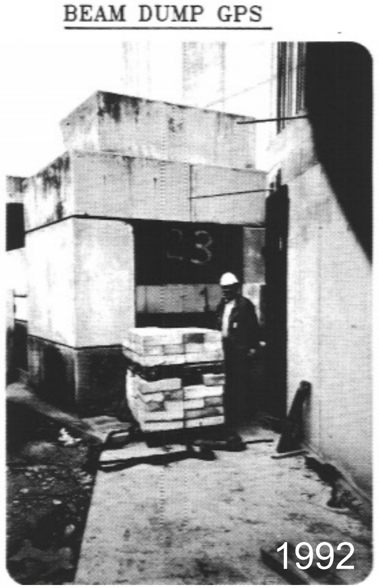


ISOLDE beam Dump Replacement Study

- **Challenging worksite - planned during 2025-2026 if**
- **Dose rate and radioactive management (activated earth, iron/concrete blocks and dumps)**
- **Not remote handling compatible**

Example of buried shieding removal
(not radioactive)

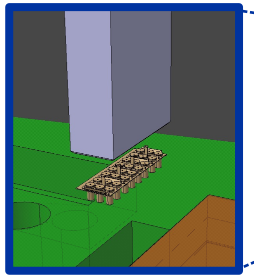
ISOLDE dumps buried in earth

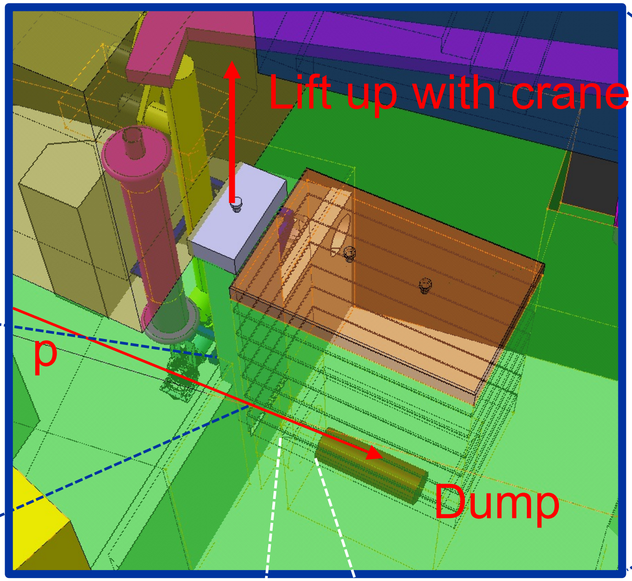


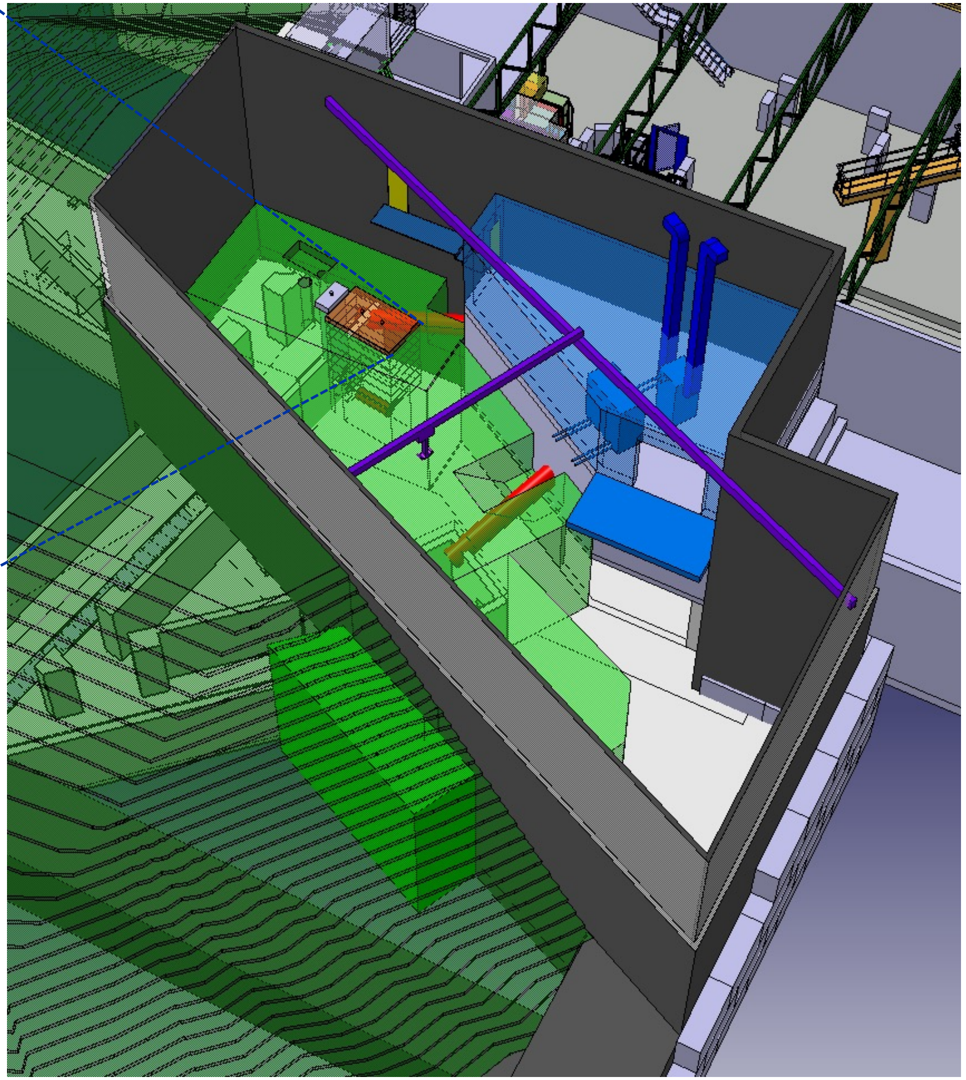
Not remote handling compatible

ISOLDE dump irradiation station possibility

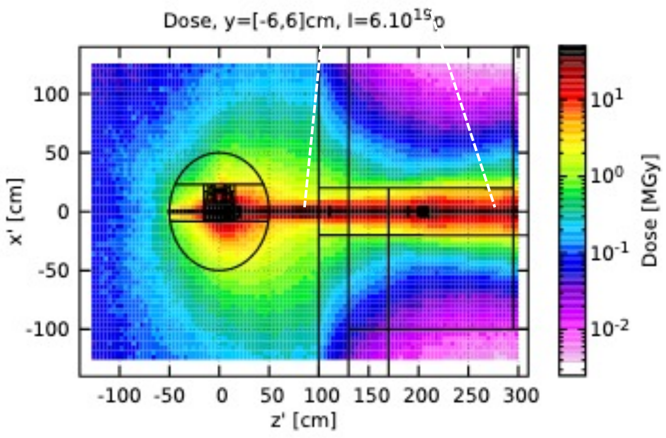
An irradiation station could be integrated before the dumps







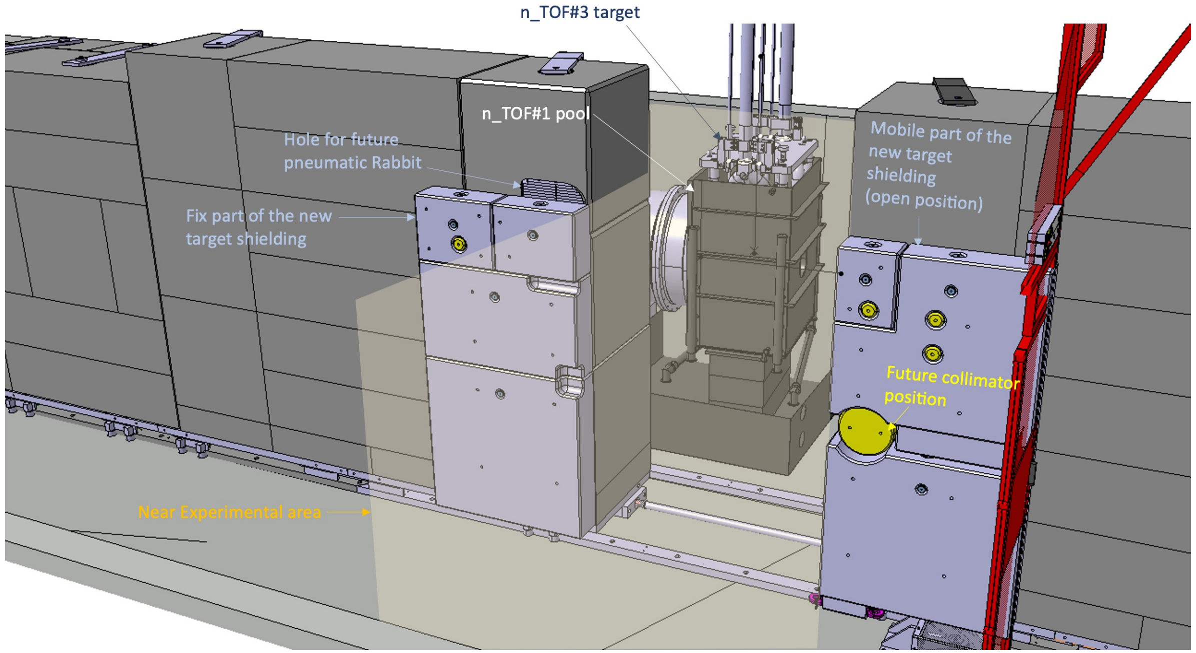
- TID up to 50 MGy/y, mixed field, possibility for reduced dose with intermediate irradiation

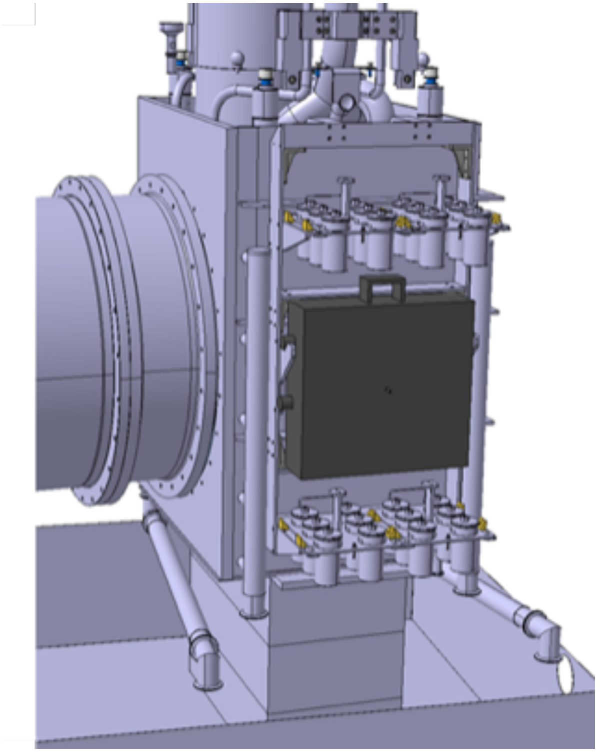


n_TOF NEAR irradiation station

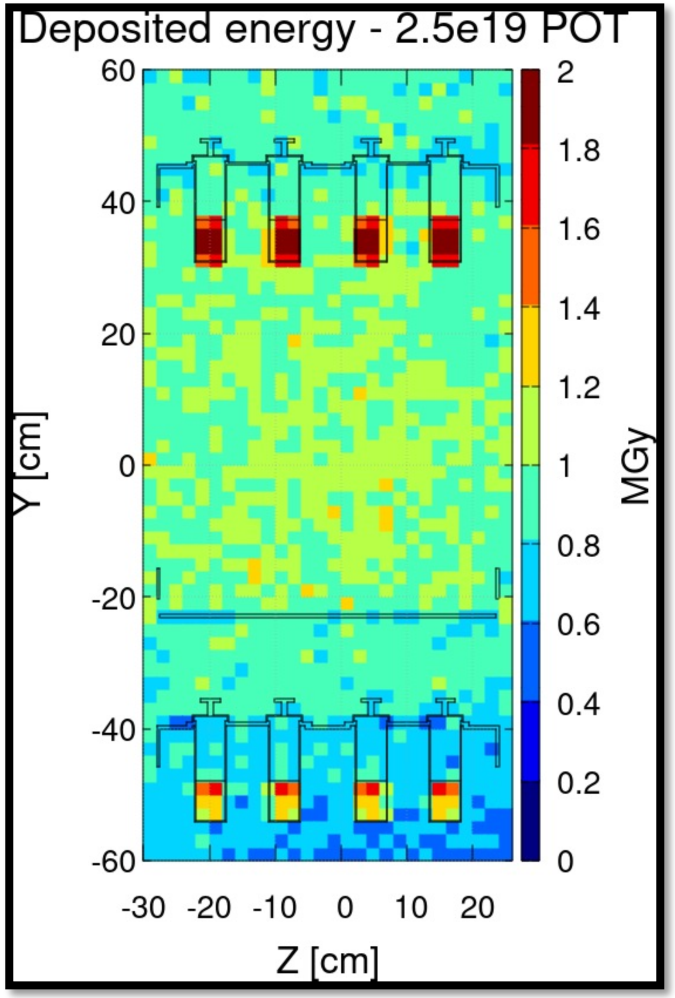
Contact: A.-P. Bernardes

- CERNs owns a white neutron source based on a 20 GeV/c proton Pb spallation target
- An updated nitrogen cooled target with 2 decoupled moderators has been installed in 2021
- A shelf with 24 samples position has been installed on the target





n_TOF NEAR Mixed Field – expected dose



IRRADIATION CONDITIONS

- ✓ **Neutron dose 90% (in organic materials)**
- ✓ **Neutrons in MeV range: dominant component**
- ✓ **±2 MGy/y – top shelf**
- ✓ **±1 MGy/y – bottom shelf**
- ✓ **Satisfactory homogeneity**

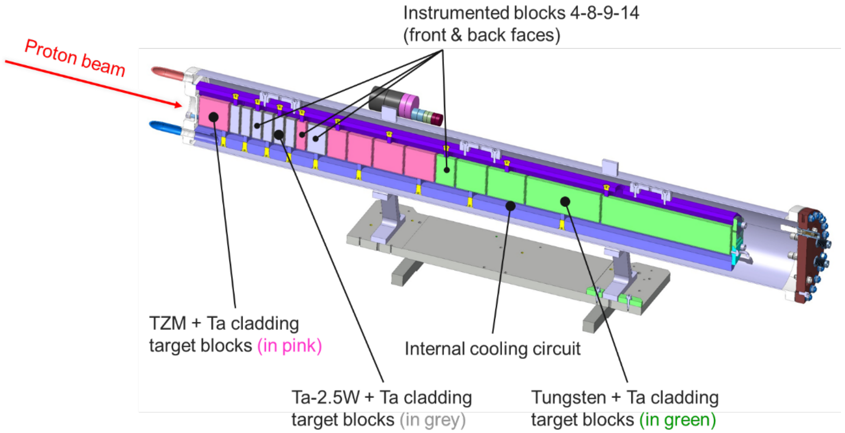
Total absorbed dose in the samples (FLUKA)

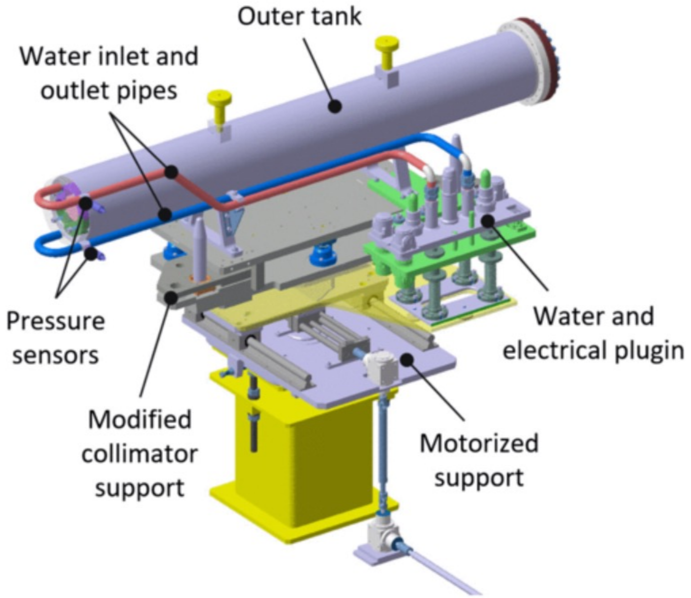
Slow Extraction high intensity test bench in TCC2

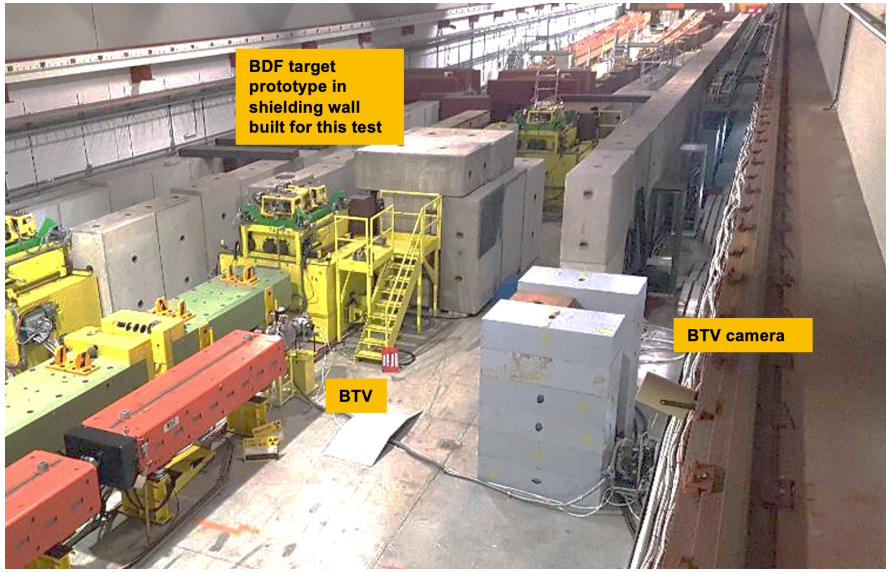
Contact: O. Aberle

- **Beam Dump Facility Project requested the testing and validation with beam of a slowly-extracted 50 kW (350 kJ/pulse) rated heavy target made of W/TZM cladded with Ta and Ta2.5W**

- **This required the setup of a “test area” in the North Area Target zone TCC2)**

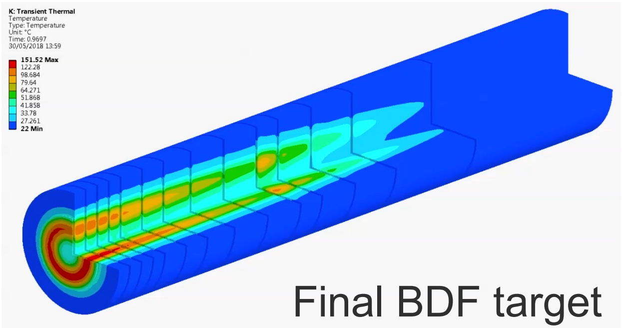


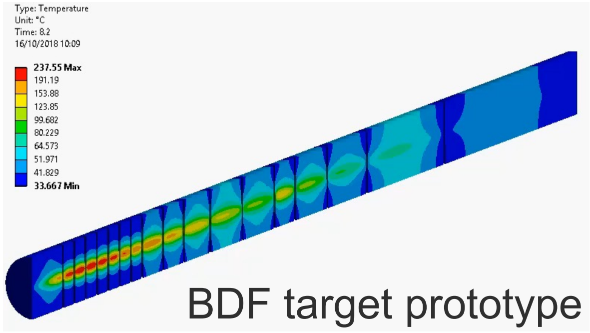




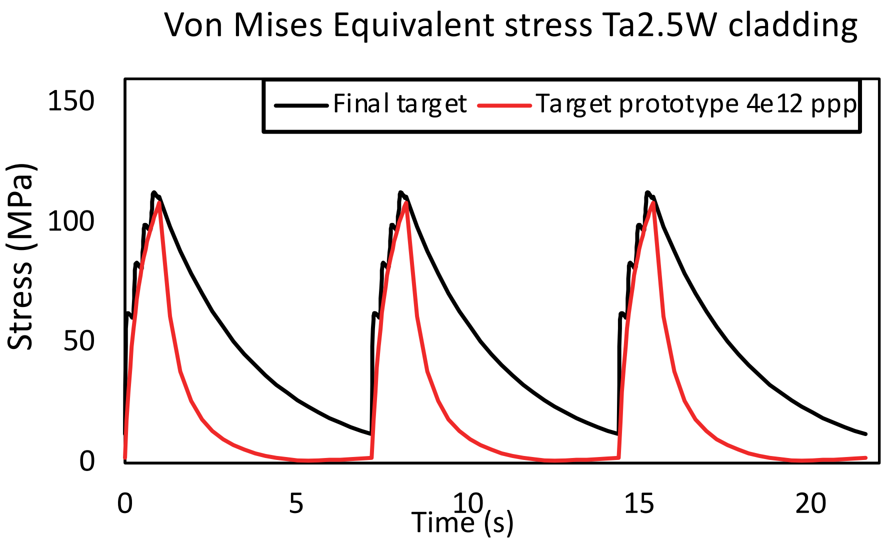
E. Lopez Sola et al. Phys. Rev. Accel. Beams **22**, 123001 (2019)

Slow Extraction high intensity test bench in TCC2

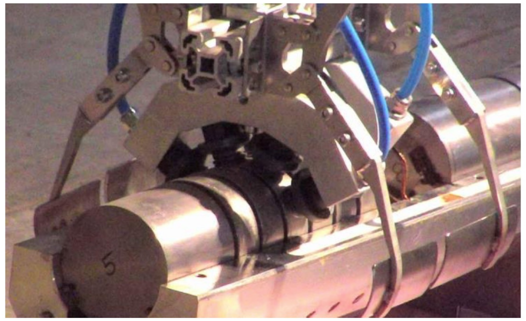


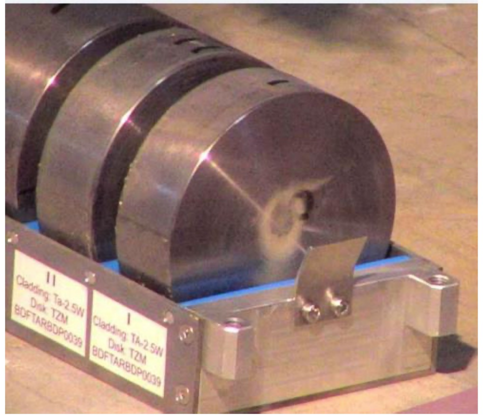


- **Test area proves to be very interesting to test integral components exposed to relatively high beam power**
- **Fully remote handling (already during design phase)**
- **Dedicated water cooling (rated at ±80 kW)**
- **Not a “facility” but a nice addition to the suit of testing (complementary to HiRadMat)**



Reasonable approximation of the level of stresses in the core and cladding materials





Irradiation facilities supporting equipment installed in accelerator environment and experiments

Radiation environment in High Energy Accelerators

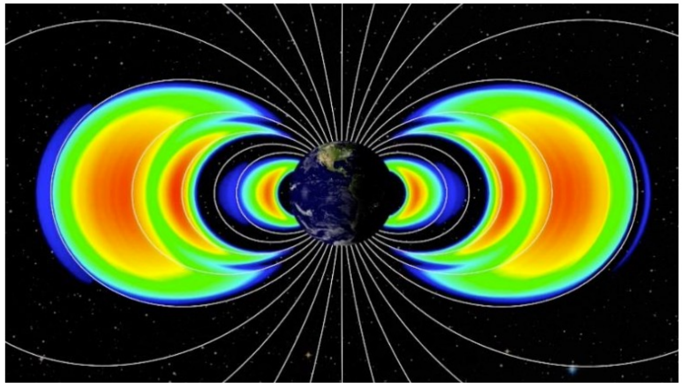
Contact: R. Garcia Alia

- **Hadronics and electro-magnetic showers originates from the interaction of high-energy protons or ions with the different elements**
- **Main sources of radiation**
  - Collision debris from interaction points
  - Interactions with beam intercepting objects
  - Beam-gas (residual) interaction
- **Source is similar to that of atmospheric radiation: HE protons generatic hadronic (SEEs, TID, DD) and electromagnetic (TID) showers**
- **Mixed Field radiation environment composed of p, n, pions, electrons, gamma...**

Radiation Environment in High Energy Accelerators

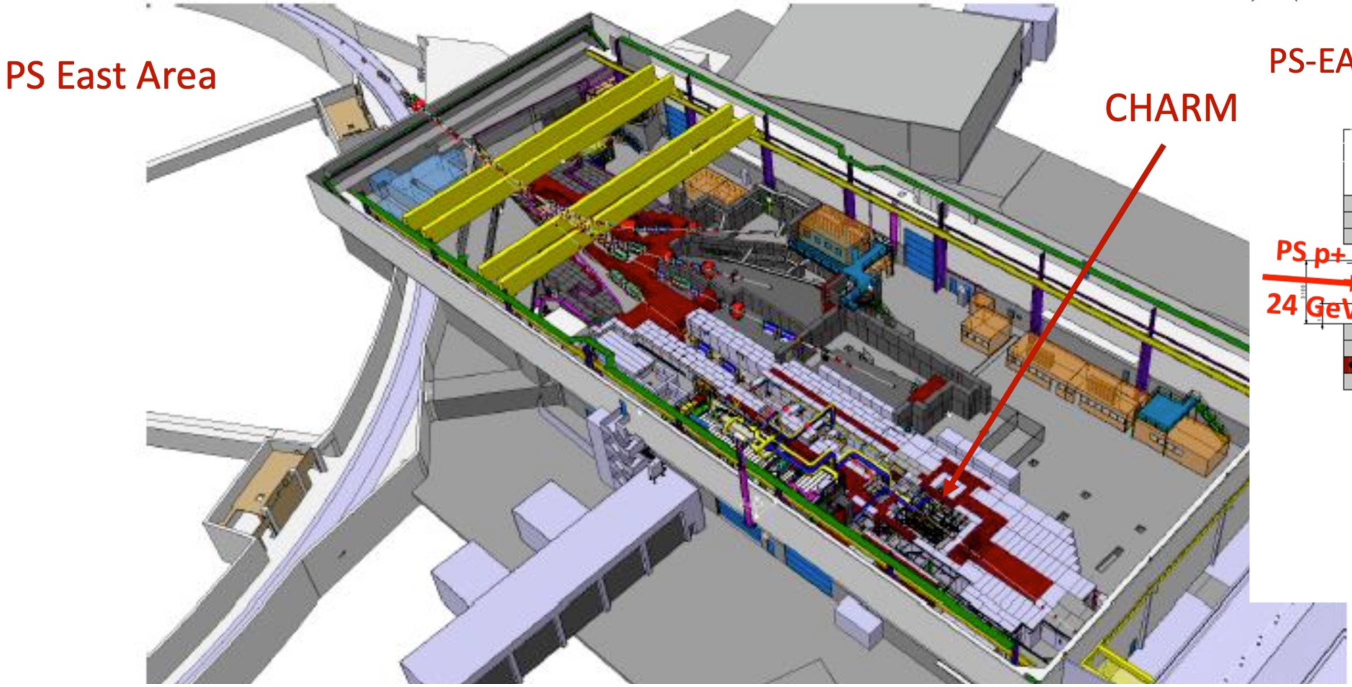
- When compared to **atmospheric environment** (avionic, ground-level):
  - Similar neutron environment, especially for shielded accelerator areas, but typically with larger fluxes (mainly SEE related)
  - Additional presence of charged hadrons and electromagnetic showers, therefore also inducing high TID levels

- When compared to **space environment**:
  - Similar levels and effects than those present in trapped proton belt (i.e. high-energy protons)
  - No low energy trapped protons and electrons, therefore local shielding (e.g. mm to cm range) is inefficient
  - No heavy ions, therefore SEEs are mainly induced through nuclear interactions from hadrons (i.e. protons, neutrons, pions)

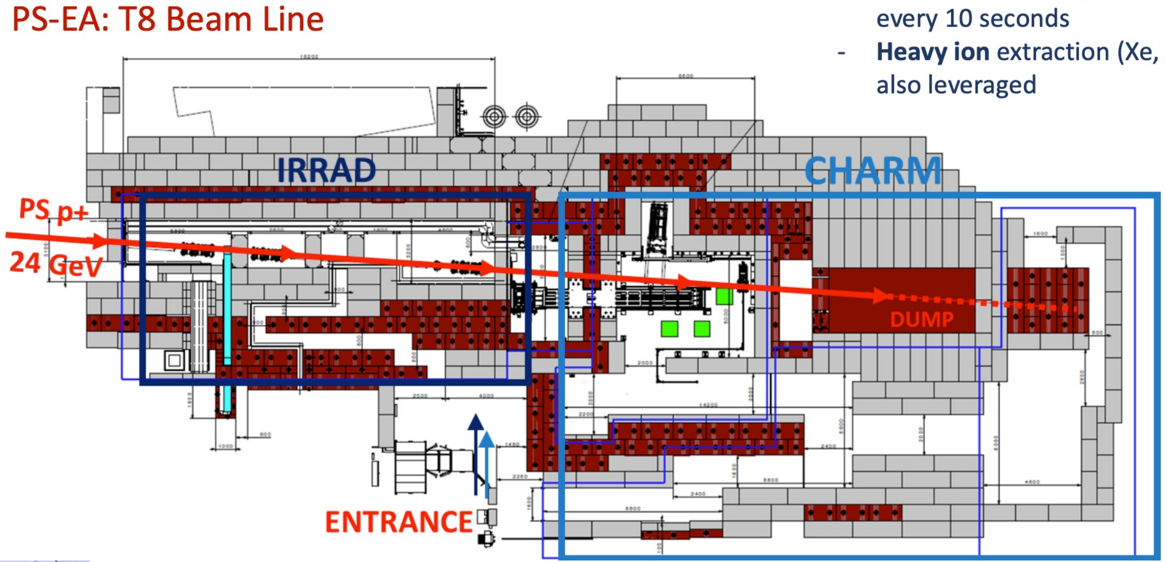


CHARM – CERN High Energy Accelerator Mixed Field

- **Main purpose: radiation test of electronics equipment and components in a radiation environment similar to some representative radiation fields**



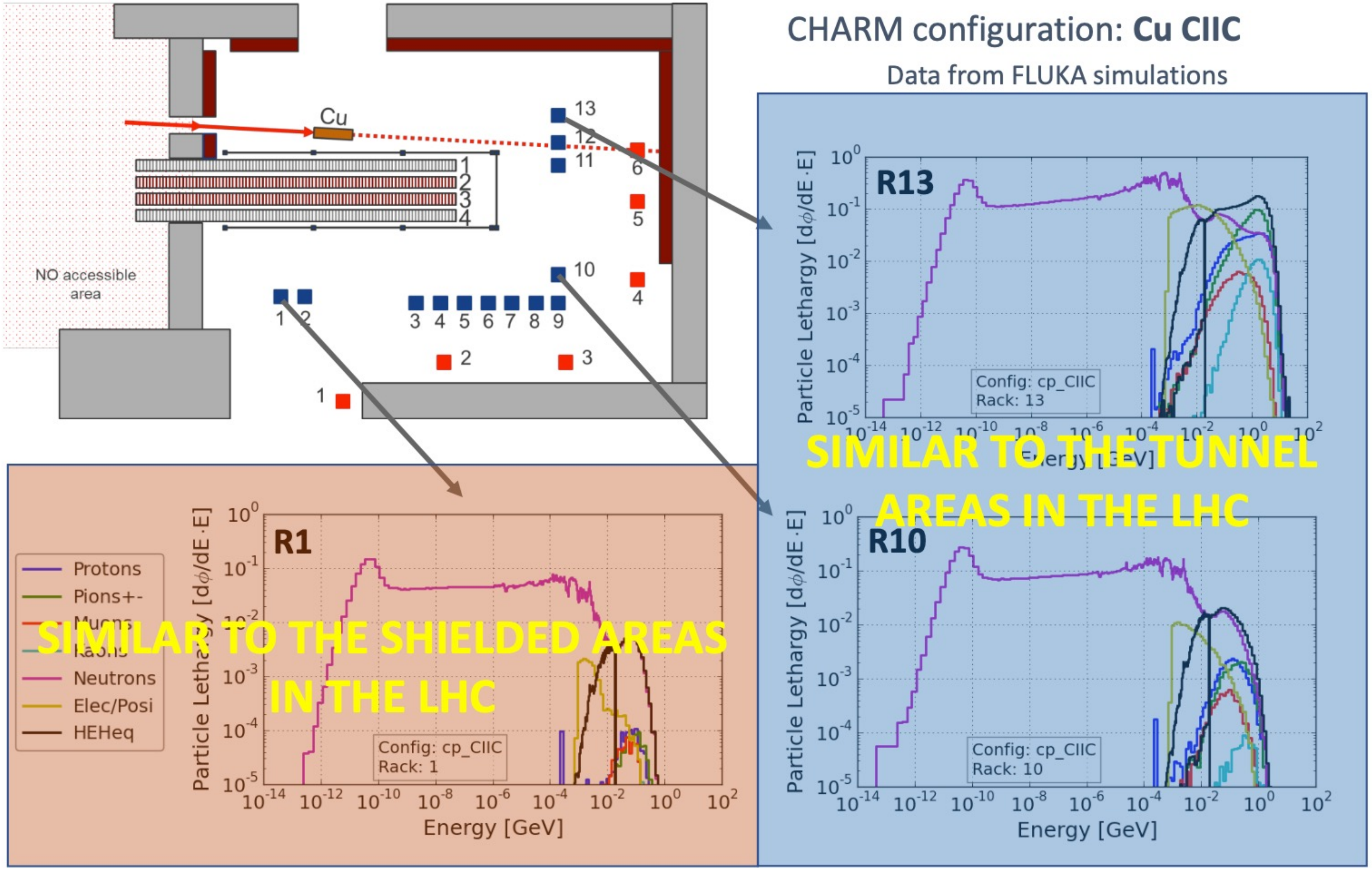
- Typically extracts **24 GeV protons**
- Protons arrive in spills of ~350 ms every 10 seconds
- **Heavy ion** extraction (Xe, Pb) has bee also leveraged



Spectra Vs. Position

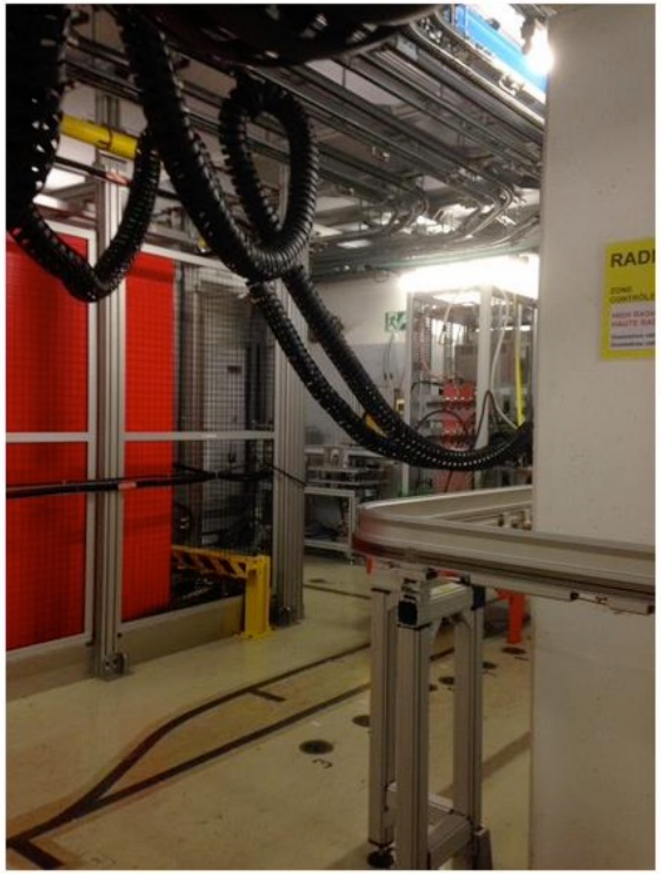
CHARM configuration: **Cu CIIC**

Data from FLUKA simulations



System Level Testing: Qualification of Power Converters

Y. Thurel
RADECS2018



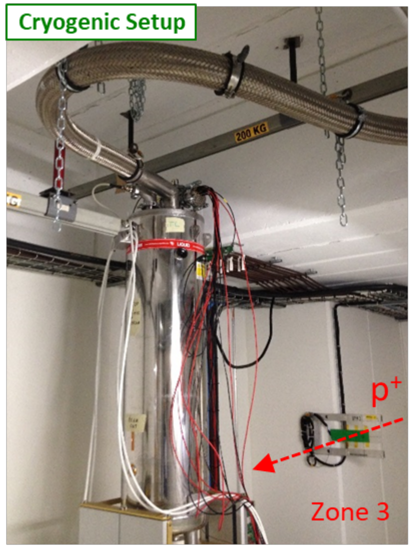
Converters successfully tested at CHARM. (From dry-test area up to irradiated test area).

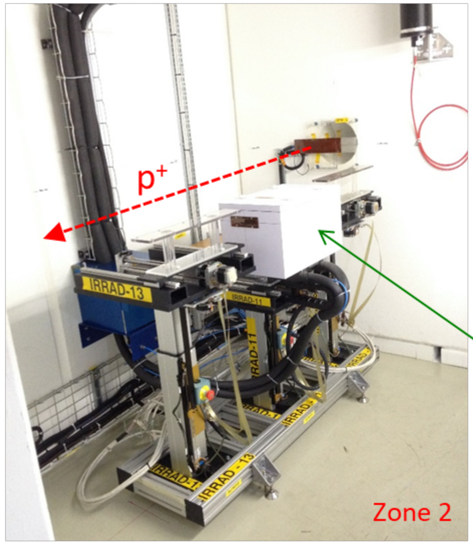
Irradiation facilities for CERN experiments

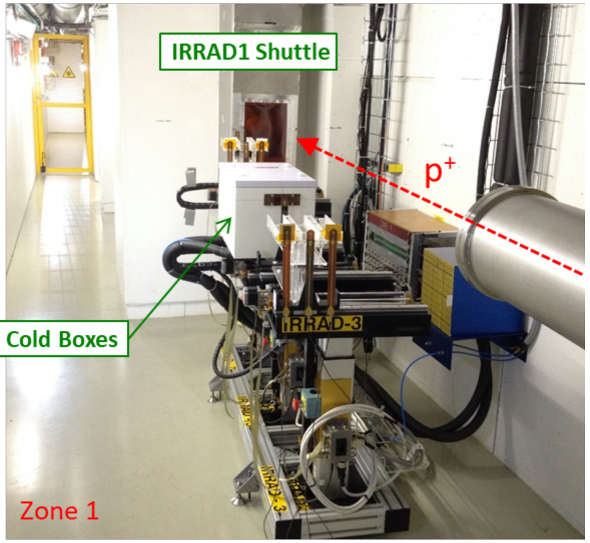
Contact: F. Ravotti

- IRRAD: radiation test of solid-state/calorimetry detector components, electronics (DD,SEE), materials for HL-LHC
- 24 GeV/c p^+, 400 ms spills
- ±1E16 p/cm^2/5 days, beam spot: 12x12 mm^2 FWHM
- 1 shuttle system (small samples)

- 9 irradiation tables
  - 6x room temperature
  - 2x cold boxes (-25°C)
  - 1x cryogenic setup (1.9K)



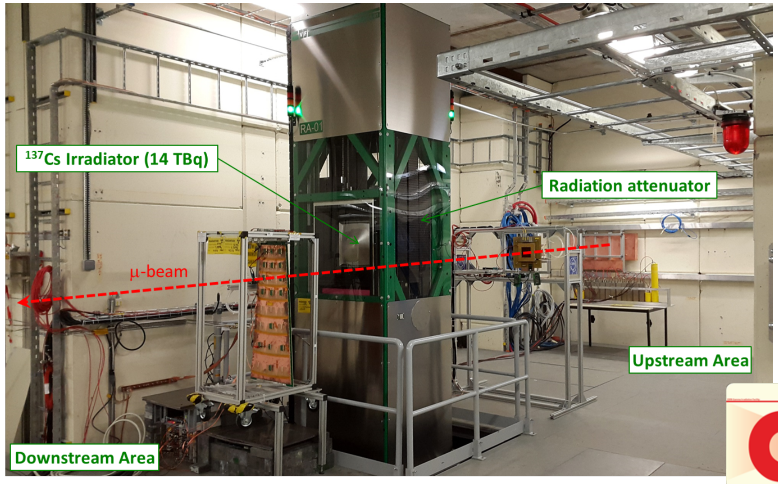




Irradiation facilities for CERN experiments

Contact: F. Ravotti

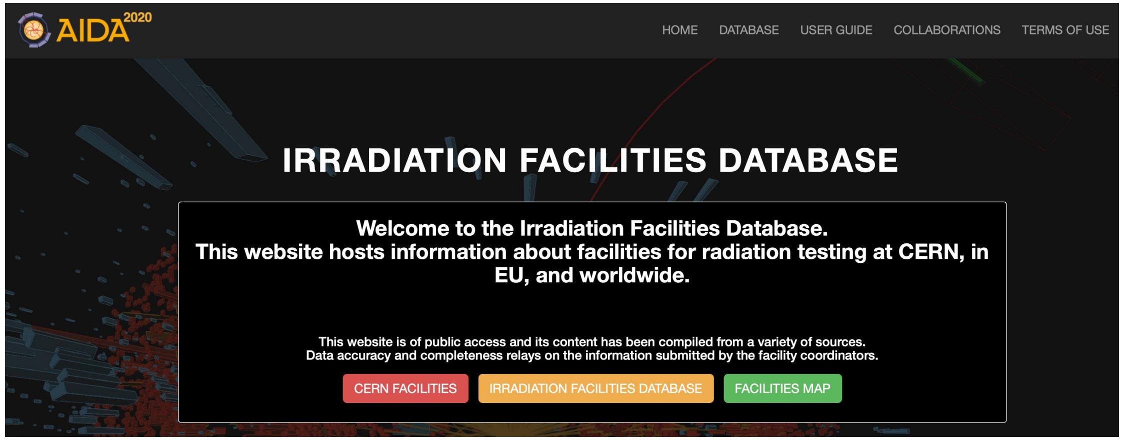
- GIF++: radiation (& beam performance) test of muon detector systems, electronics (TID), gas mixtures for HL-LHC
- ^{137}Cs γ-ray source 12 TBq today, max rate ±2.5 Gy/h @0.5 m
- 2 symmetric radiation field, 37° wide angle collimators, >100 m^2 floor space for DUTs
- μ-beam (100 GeV, 10^4 /spill), gas infrastructure available



Irradiation experiments support

Contact: F. Ravotti

- **CERN Irradiation Facilities Database**
  - www.cern.ch/irradiation-facilities
  - CERN portal + database of worldwide facilities
  - Knowledge of available external facilities important:
    - to complement in-house means (R&D, qualification, etc.)
    - to increase testing availability (shutdown periods, etc.)
  - Entries maintained by the facility coordinators:
    - more than 220 entries to date!
    - automatic reminders for maintaining the information over time
  - Tool developed within EU-project AIDA-2020
- **Potentially of interest for the community?**



- **A similar tool exist for the management of irradiation experiments**
  - Operational for CERN-IRRAD, being deployed at Fermilab

Future perspectives

- **Future medium/long term infrastructure foreseen at CERN (or supported by CERN) will require development of BIDs or electronics equipment that will need to be exposed either to long-term irradiations or high intensity single pulse**

- **Amongst the projects to be considered**
  - Beam Dump Facility and other Physics Beyond Colliders Initiatives at CERN (ENUBET, etc.)
  - Muon Collider Demonstrator and Muon Collider Systems Testing
  - FCC, in both the e^+e^- and hh forms (both for positron sources as well as for dumps and collimators)
  - Upgrade of ISOLDE, including EPIC

- **Requirements for these installations are still pending clarifications, but irradiation facilities should evolve to support these programs**

Conclusions

- **CERN's project and facilities operation require regular support from irradiation experiment, of different type – ranging from BIDs to electronic equipment to experimental setup**
- **CERN can offer a variety of different facilities, some of them "user", other serving internal needs**
- **International Collaboration (such as RaDIATE) is essential for information exchange and sharing across facilities**

home.cern