CERN PS-IRRAD Facility Operation Overview

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Nicola MINAFRA (KU and CERN) for the BPM project

Acknowledgements: colleagues from CHARM team (BE-CEM), R2E project (SY-STY), Beam Operation and Physics (BE-OP, SY-ATB), Beam Instrumentation (SY-BI) and Radiation Protection group (HSE-RP)

FNAL Irradiation Test Area Workshop, 10 August 2022, INDICO 55366

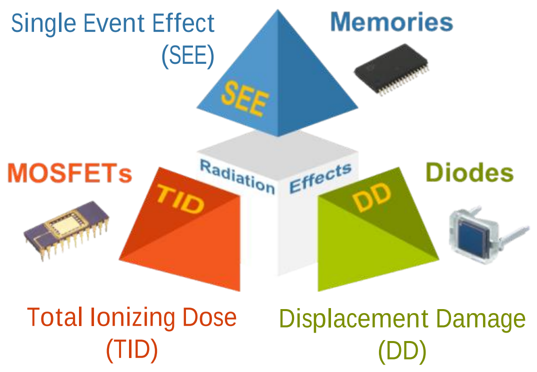
Outline

- **Irradiation Facilities at CERN**
- **PS East Area Proton Irradiation Facility (IRRAD)**
  - Characteristics, Dosimetry and Beam Instrumentation
- **User Operation**
  - Safety, Experiment Workflow, Data Management Tool (IDM) and User Infrastructure
- **Future Upgrades**
- **User Support**
- **Summary**

Irradiation Facilities Needs in HEP

- **Radiation damage studies on:**
  - **semiconductor** devices (silicon,…), other **sensitive media** (crystals,…)
  - **materials** used around accelerators & experiments (cables, glues,…)
  - **electronics components** COTS (transistors, memories,…) or ASICs
  - accelerator **parts exposed to high-intensity pulsed beams** (collimators,…)
- **Qualification of components, prototypes, full systems:**
  - **performance degradation** after long exposure / ageing (TID, NIEL,…)
  - **functional degradation** during operation (SEE, latch-up,…)
  - **performance evaluation under background** ("noise") conditions
- **Radiation testing for:**
  - **components calibration** (sensors, dosimeters, measurement devices,…)
  - **providing benchmark data for Monte Carlo** transport codes

Radiation Effects in Electronics



ASTM Shear Strength Test

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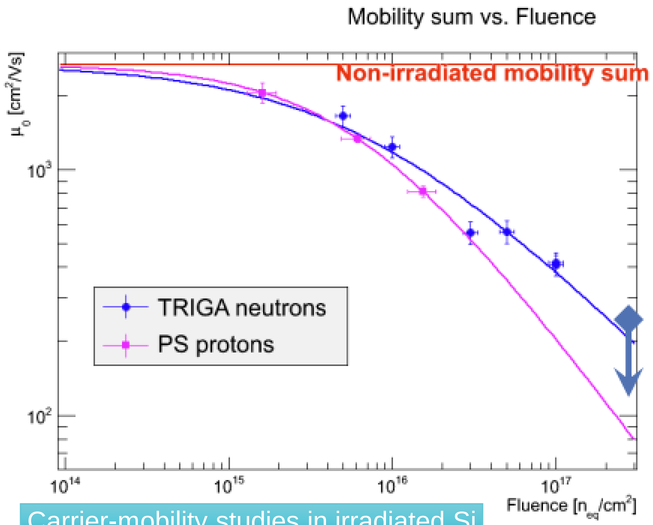
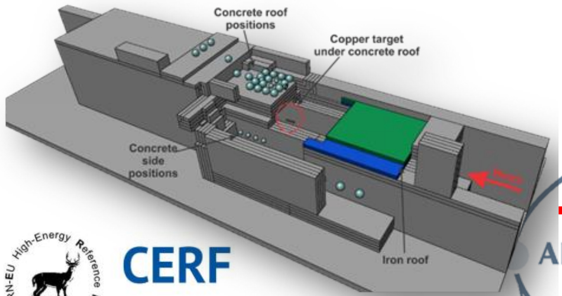


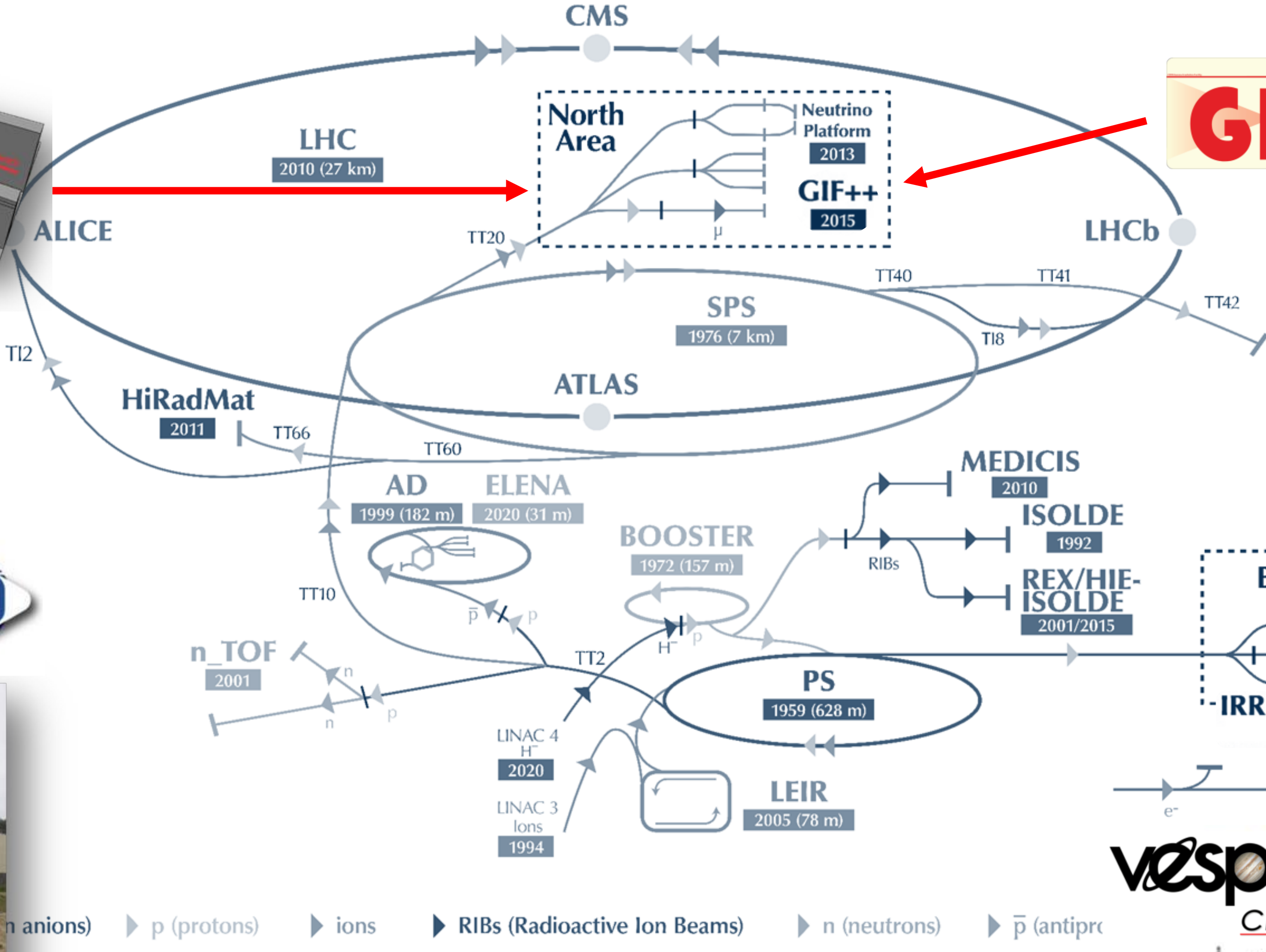
Carrier-mobility studies in irradiated Si

© M. Mikuz (JSI)

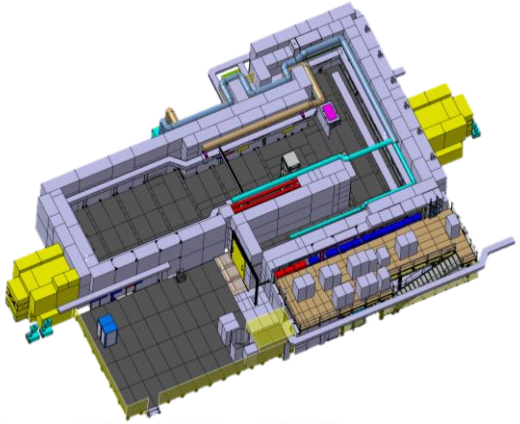
CERN Irradiation Facilities

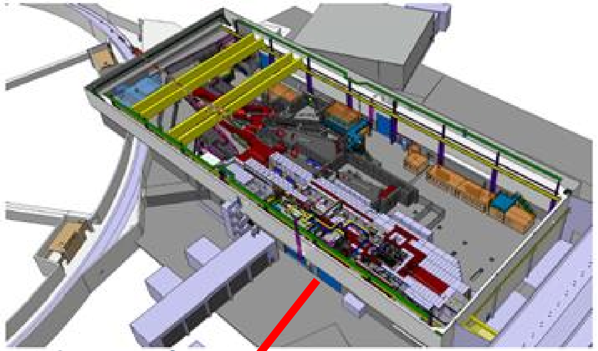


CERN-EU High-Energy Reference Field
CERF
The CERN-EU high energy Reference Field facility



GIF++

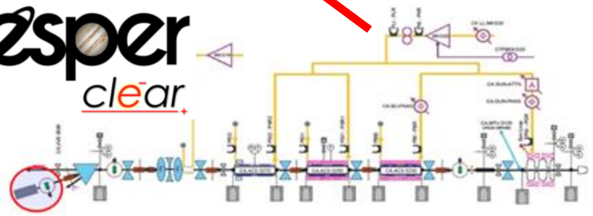




IRRAD Proton Facility

CALLAB & CC60

vesper clear



see B. Gkotse, et al. (RADECS 2017): https://doi.org/10.1109/RADECS.2017.8696163

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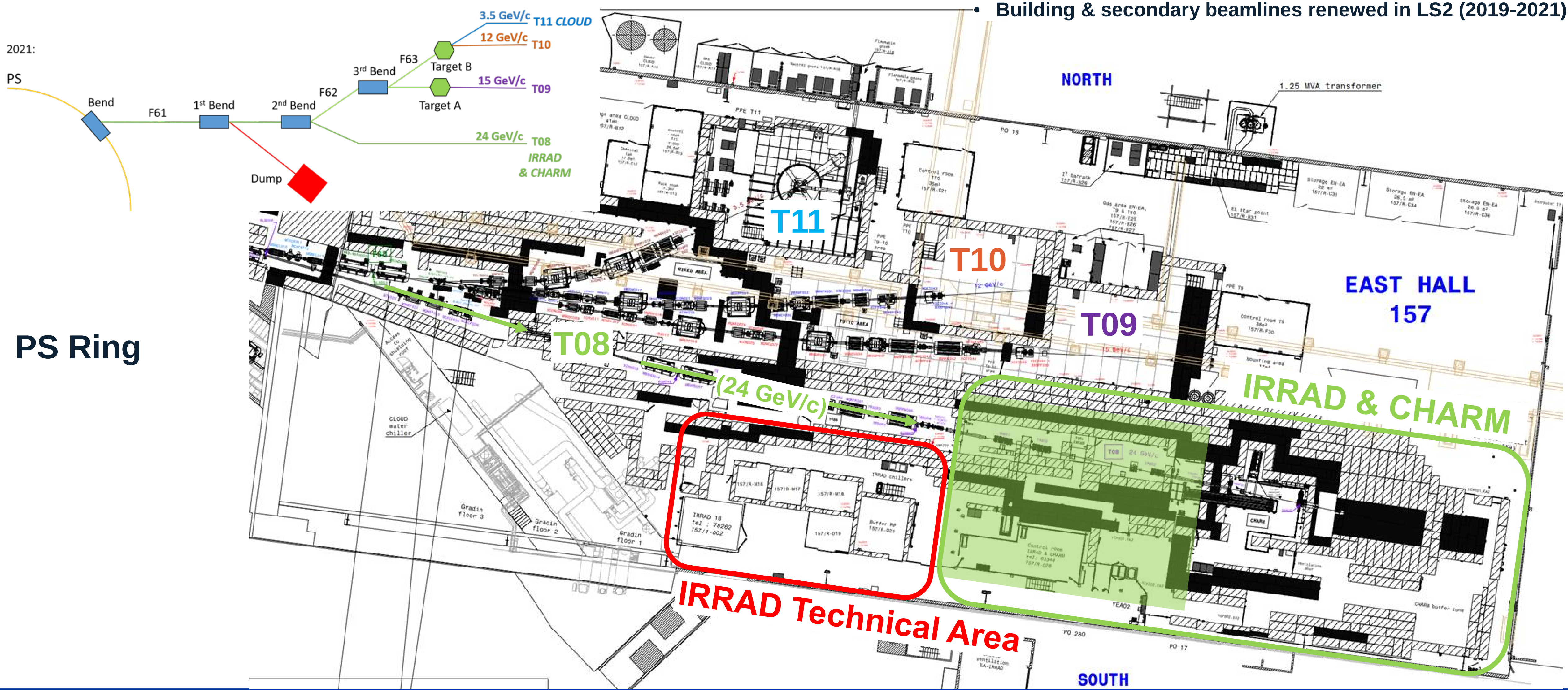
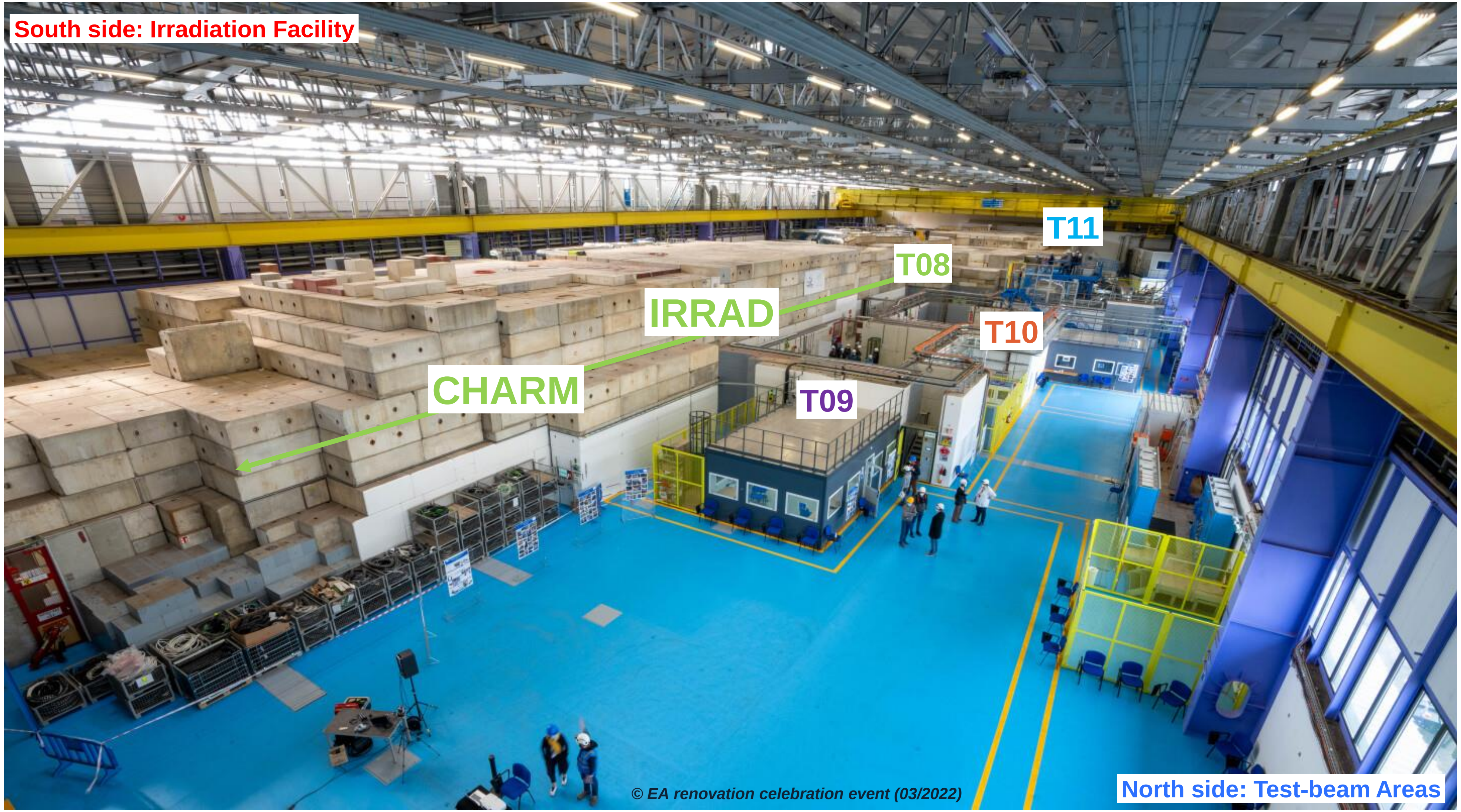
PS East Area bld. 157

- Irradiation Facility built during LS1 (2013-2014)
- Building & secondary beamlines renewed in LS2 (2019-2021)

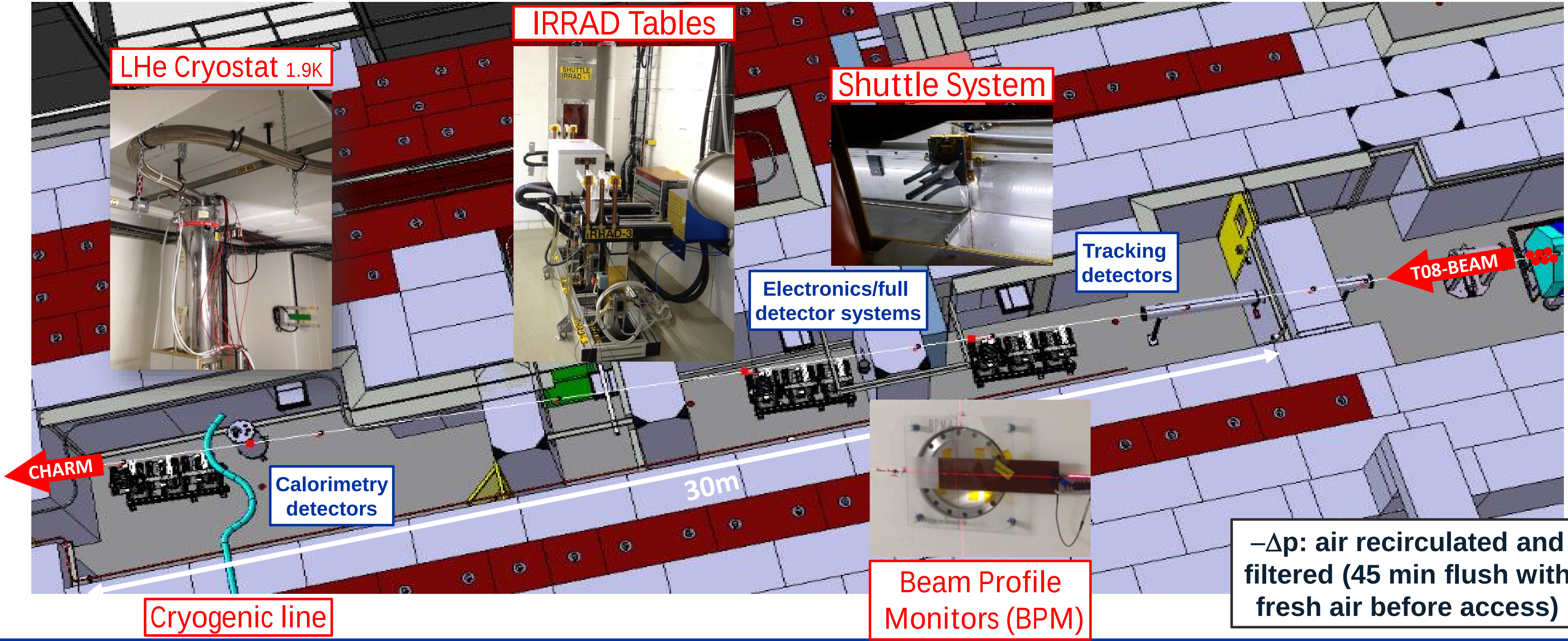


PS Ring

PS East Area b.157 (renewed during LS2)



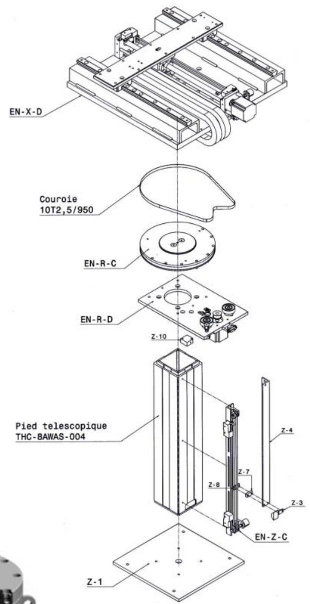
CERN Proton Irradiation Facility (IRRAD)

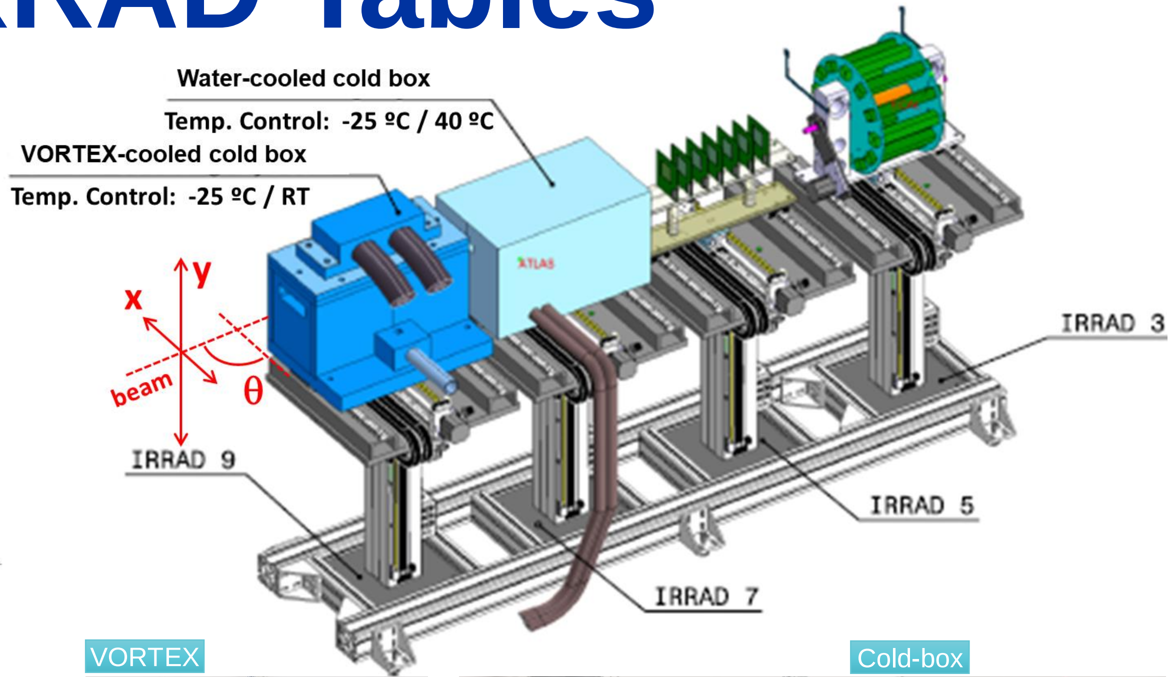


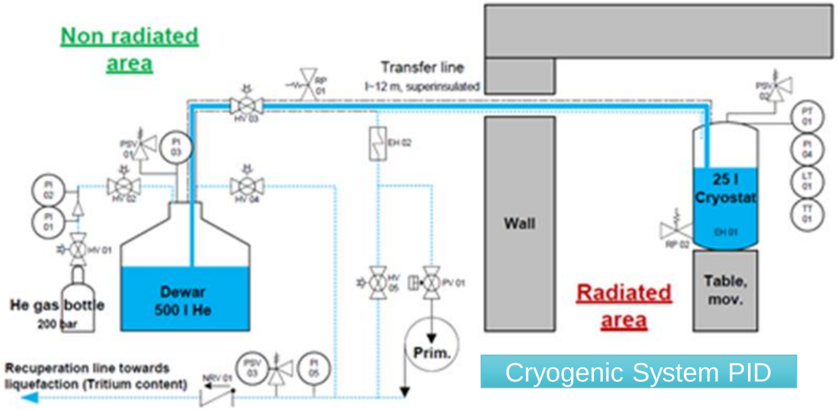
–Δp: air recirculated and filtered (45 min flush with fresh air before access)

Irradiation Systems: IRRAD Tables

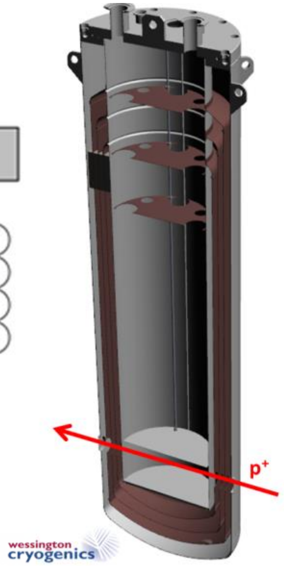
- 9 irradiation tables
  - 6x at room temperature
    - $V_{max} = 20\times20\times50\ cm^3$
    - Scan over 10-20 cm (X-axis)
  - 2x with cold boxes (-25°C)
    - $V_{max} = 12\times4\times38\ cm^3$
  - 1x cryogenic setup (1.9K)
    - $V_{max} = 5\times5\times20\ cm^3$





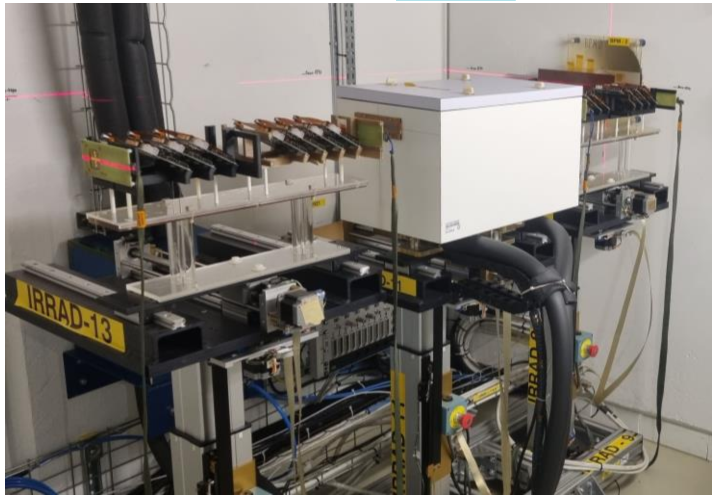


Cryogenic System PID



VORTEX

Cold-box

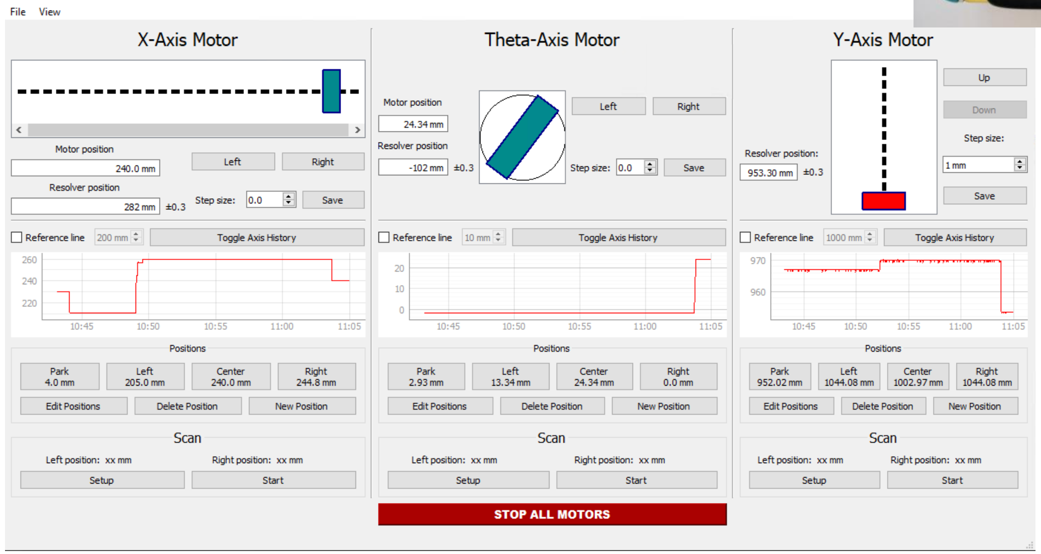


IRRAD Systems: Controls & Infrastructure

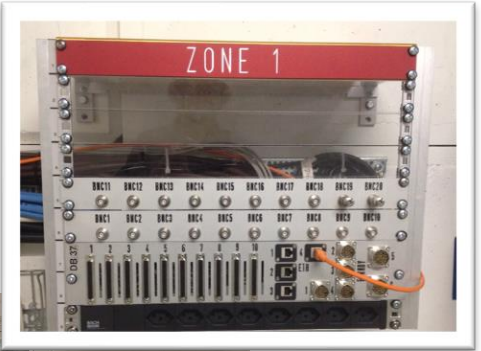
- IRRAD Motor Control Application (LS2 Upgrade)
  - based on pyQT (python)
  - open source
- Hardware Control Unit
- Database in the back-end

Motor Control Unit

Table Control GUIs



- Cabling infrastructure
  - 4 Patch Panels with variety of connections (BNC, SHV, HF, D-SUB, Burndy, Ethernet, micro-coax, etc.)
- Piping network:
  - Neutral gases (N_2, user bottles or compressed-air)

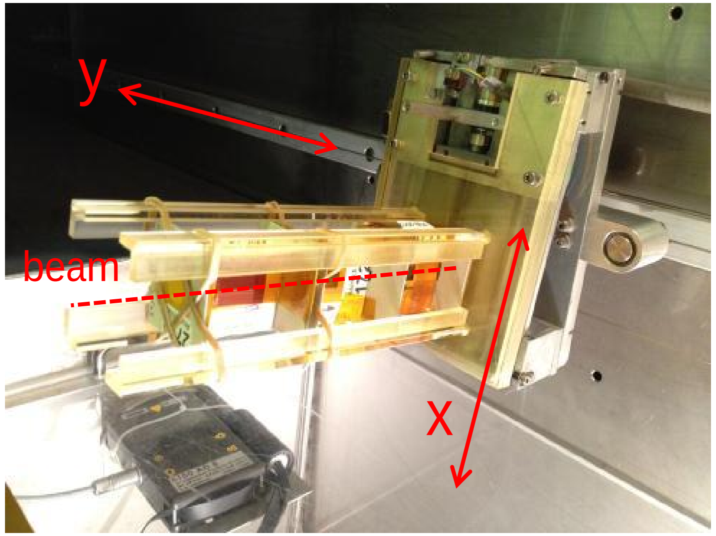


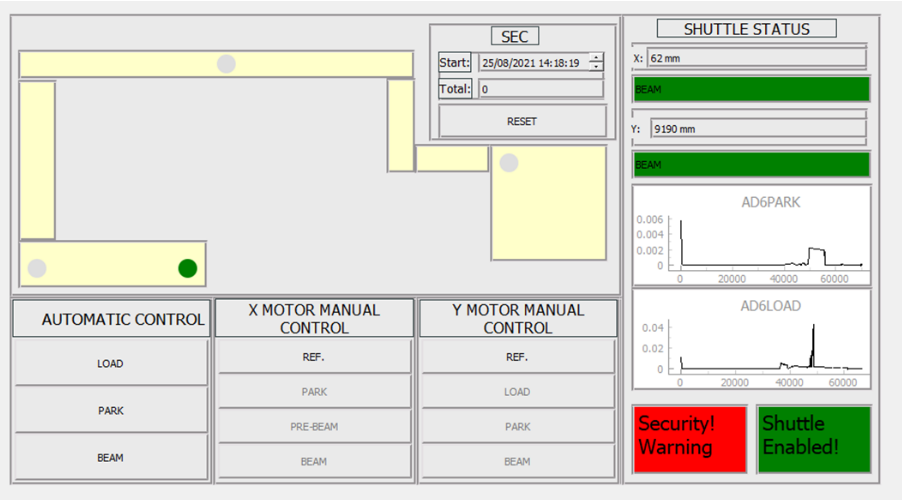
IRRAD Control Room

Irradiation Systems: IRRAD Shuttle

- 1 irradiation shuttle
  - room temperature
  - $V_{max} = 5\times5\times15\ cm^3$
  - mainly passive samples (with bias)
- Beam-independent operation
- Python-based (pyQT), open source, motor control application (LS2 upgrade)

Shuttle Conveyer and Sample Holder





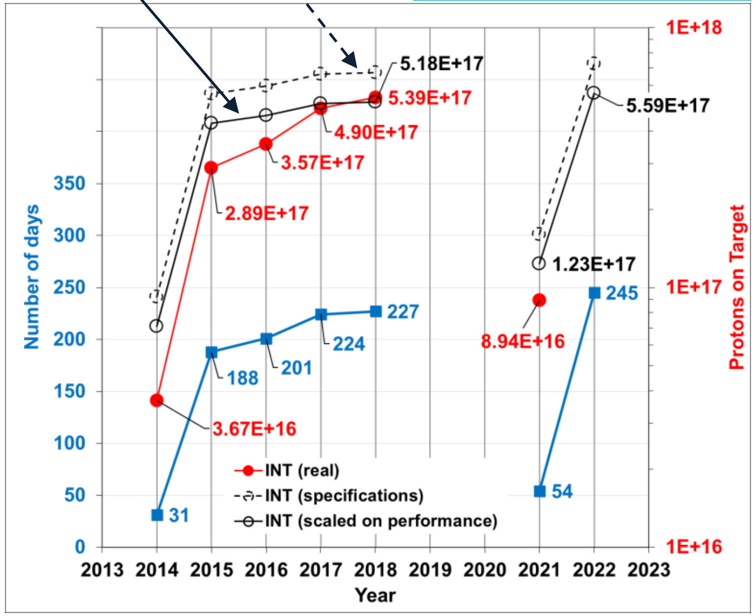
Motor Control Application GUI

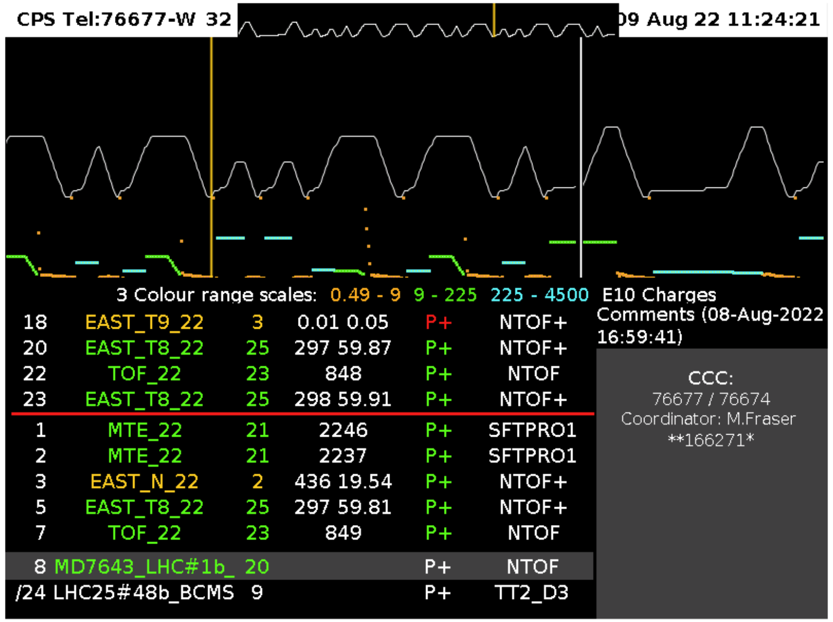
IRRAD1 Shuttle Loading Station

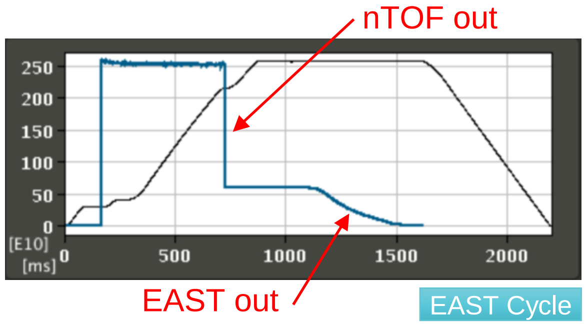
24 GeV/c Proton Beam Delivery

- Slow-extracted beam shared (EAST and n-TOF)
  - *EAST_T8* ~ 6.0×10[11] p/spill
- Specifications (2014):
  - 3 spills/CPS of ~30s. duration during >220 days [max.: 6 spills]
  - >2.0×10[16] p/week
- Performance in 1[st] run (2018):
  - ~1.6×10[16] p/week
  - ~1.0×10[16] p/cm[2]/2w[(*)] [10mm×10mm] (~30% higher on smaller area)
  - MIPs, TID in MGy range
- After the LS2 (2021):
  - Priority to re-commissioning
  - Introduced new KPIs
  - Getting first "new" requests:
    - >10[17] p/cm[2(*)] !

T08 Proton Intensity History







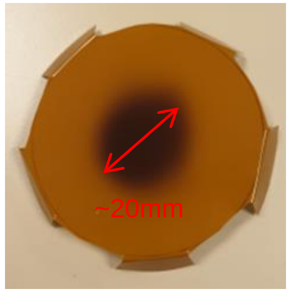
EAST Cycle

(*) NIEL Factor k~0.62 for 24GeV/c protons to 1MeV-n_{eq}

Irradiation Beam Requirements

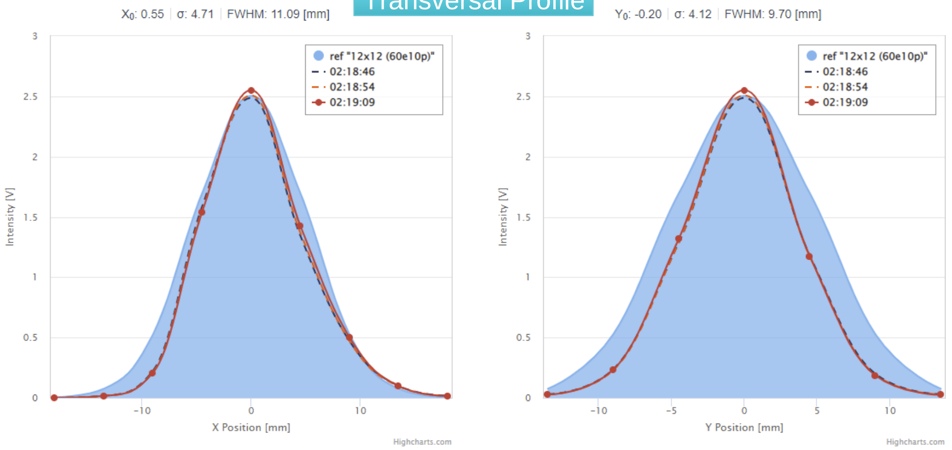
- Intensity:
  - **5×10^{11} p/spill** at facility location
  - Stable spill-by-spill, max. extraction & transmission efficiency
- Transversal profile:
  - Gaussian, **12mm×12mm (FWHM)**
  - Shape constant along IRRAD
- Longitudinal profile:
  - Slow-extracted, **400ms**
  - Homogeneous (user-dependent)

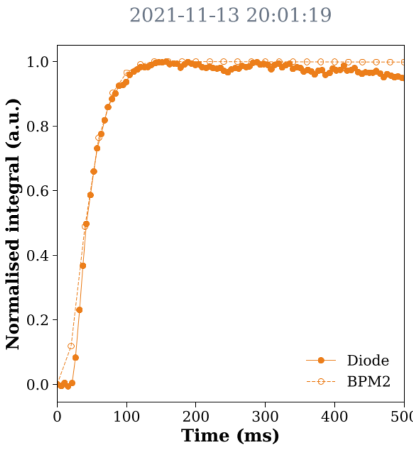
- Special conditions on demand:
  - Fast Extraction ~O(10ns)
  - Very low intensity ~10^9 p/spill
- Information available on-line to users, operation and logging



Beam Spot at CHARM

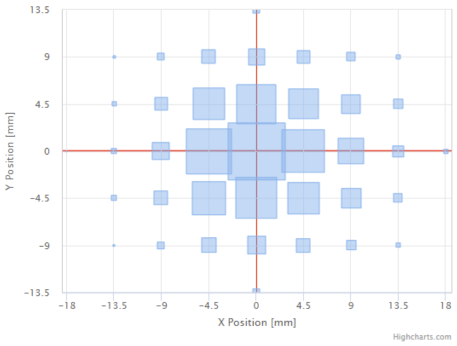
Transversal Profile





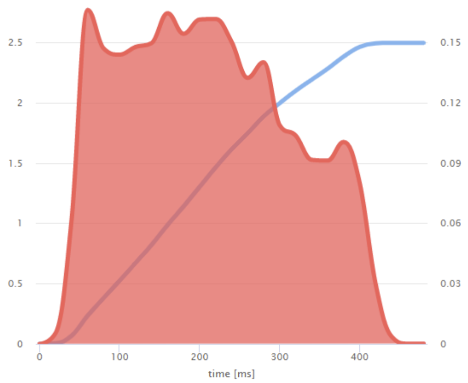
Fast-extracted beam response

© N. Emriskova (CERN)

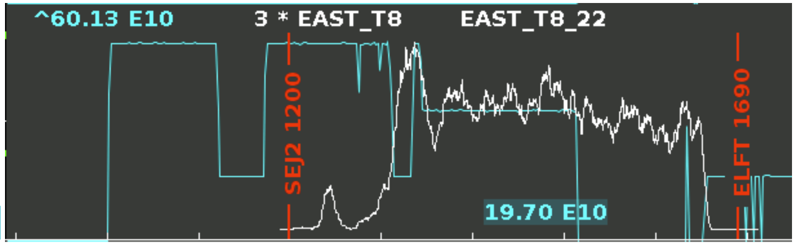


Beam Spot at IRRAD

Longitudinal Profile



Intensity



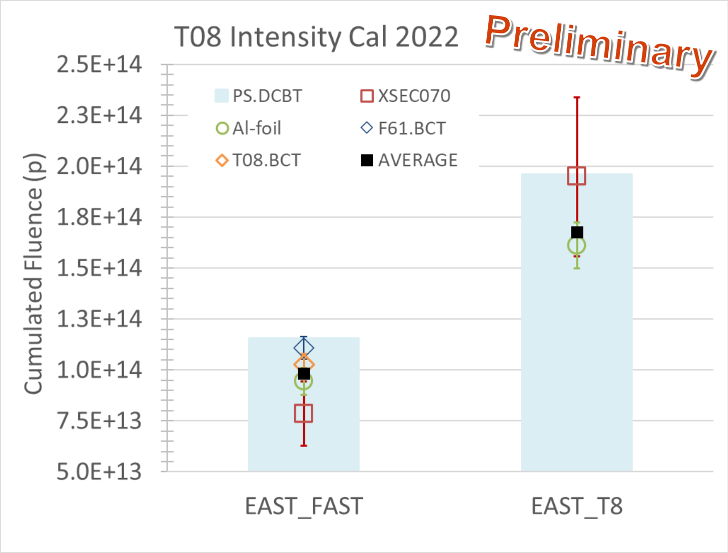
Beam size vs. Samples size

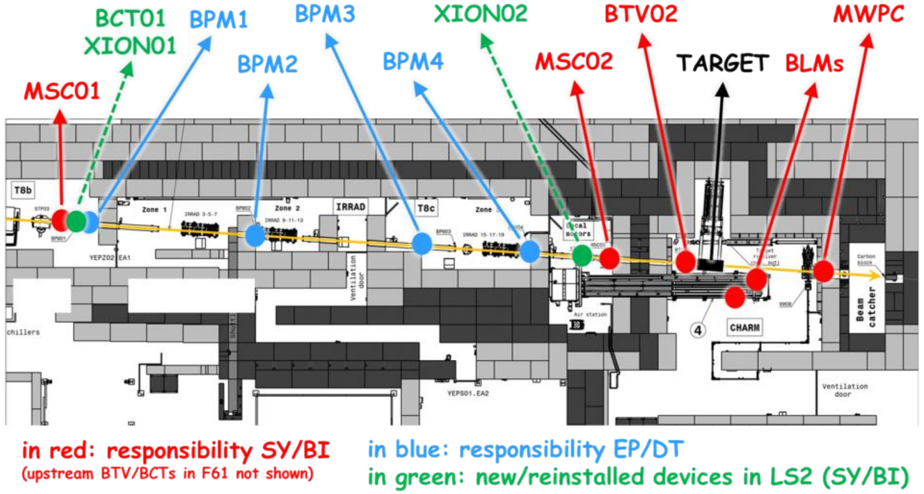
- These represent the majority of our samples …
- … but not only!
  - Machine Development periods being organized to consolidate the optics model for the T08 beamline

LHCb SciFi prototype

Beam Instrumentation (upgraded in LS2)

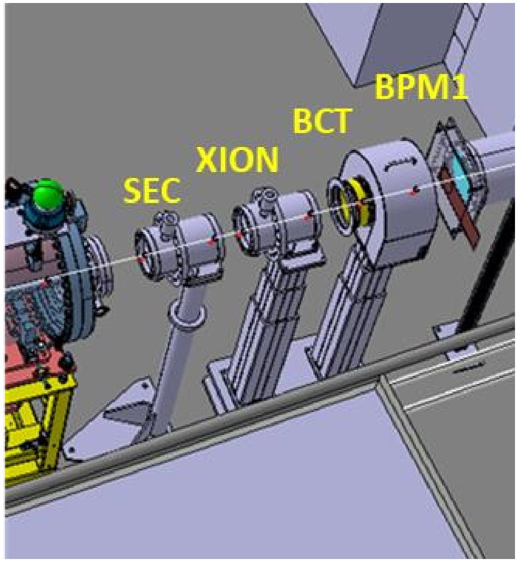
- Improving the T08 BI:
  - Better monitor the delivered proton intensity (extend range)
  - Future use of the beamline (HI beams)
  - Better inter-calibrate all instruments
- New measurement location for cross-calibration:
  - Slow- and fast-extracted beams





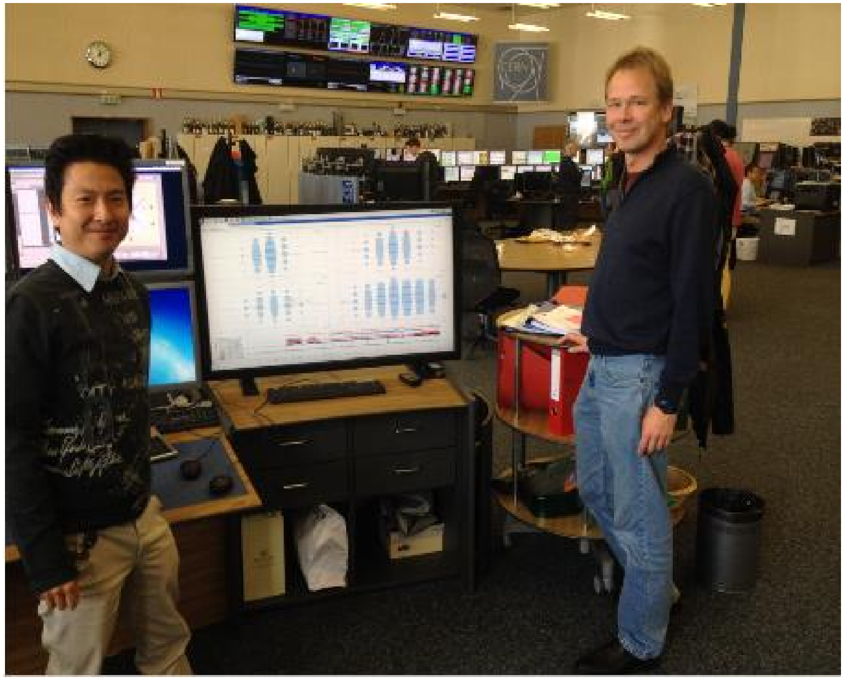
XION02

XION01 and BCT01



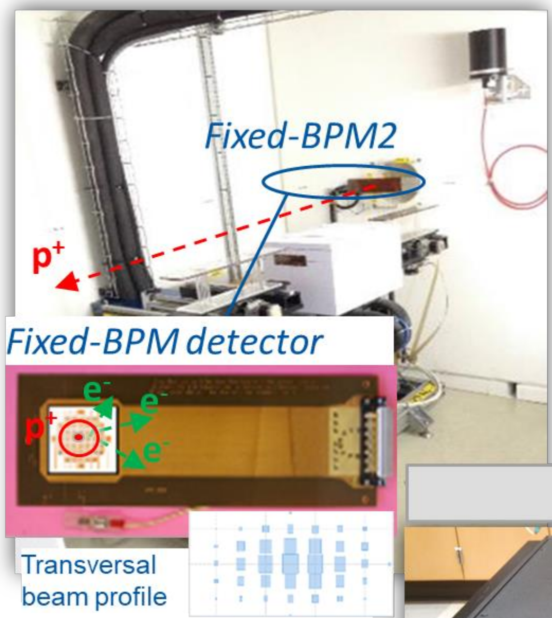
IRRAD Beam Profile Monitor

BPM Display at CCC



Fixed BPM

For beam steering (~40mm×30mm)

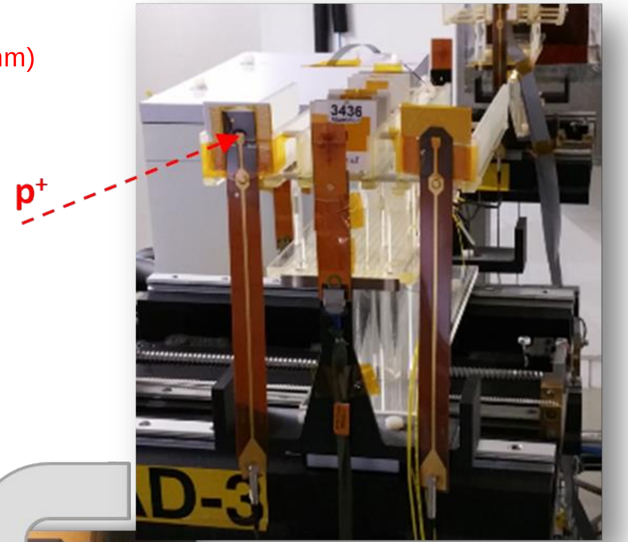


BPM System Architecture

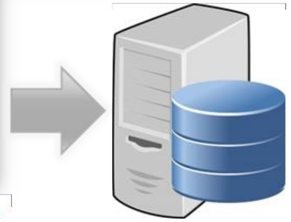
Mini and single-pad BPMs

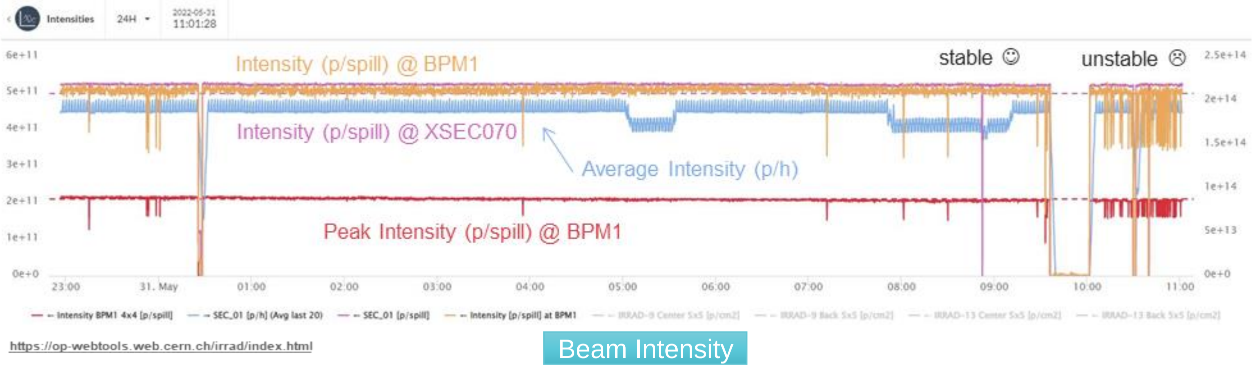
IRRAD tables alignment purpose and "in-beam" detection

(~20mm×20mm)



BPM DAQ unit 25-35m away from fixed-BPM device





Beam Intensity

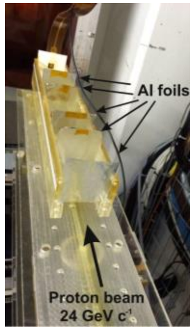
- Pixelized devices based on SEE in metal
- Data Integrated in accelerator logging (LS2 upgrade)

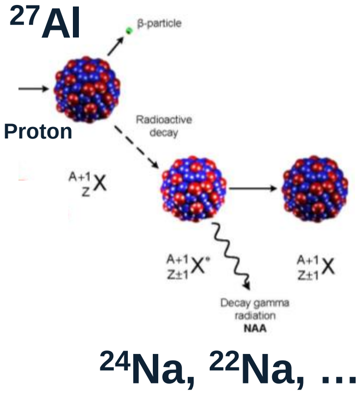
Proton Beam Dosimetry

- Activation of thin Al-foils:
  - Calibrate beam instrumentation
  - Evaluate cumulated fluence on samples:
    - Typical dosimeters sizes: 5×5 or 10×10 mm^2
- Reactions: ^{27}Al(p,3pn)^{24}Na, ^{27}Al(p,3p3n)^{22}Na
- Pure Aluminum:
  - High availability
  - Easy to handle
  - Relatively cheap
  - Good knowledge of σ
- Technique Error: +/- 7%
  - Activity statistical ε < few %
- MIRION APEX-gamma
  - 1x VM server on *OpenStack*
  - 2 clients **(4 detectors)** in different locations at CERN (LS2 upgrade)

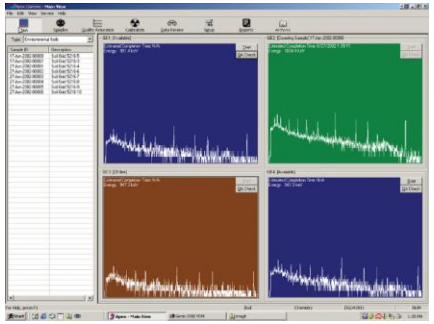
Spectrometry Lab bld. 14/R-012

(1) Foil preparation





(2) Exposure / activation



(3) Gamma Spectrometry

(4) Fluence Calculation

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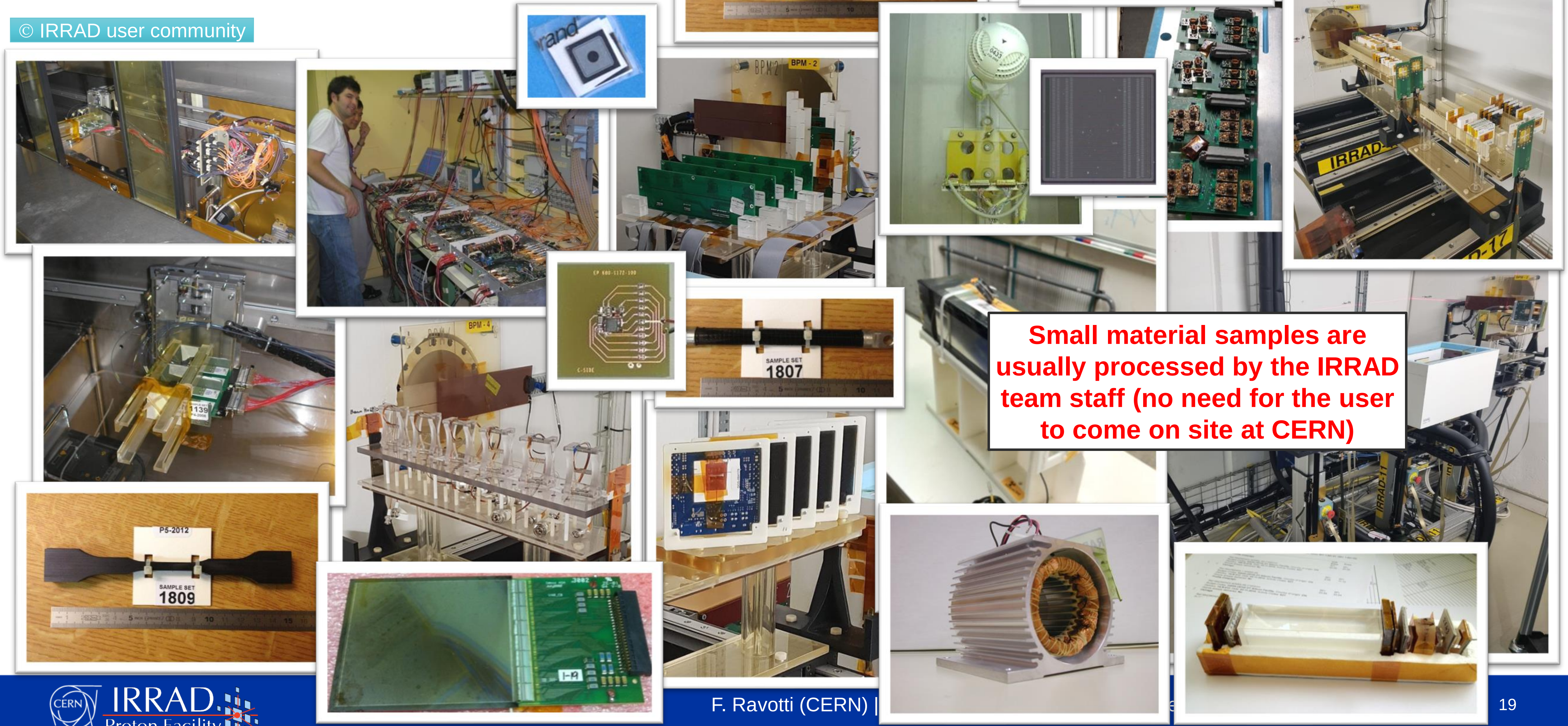
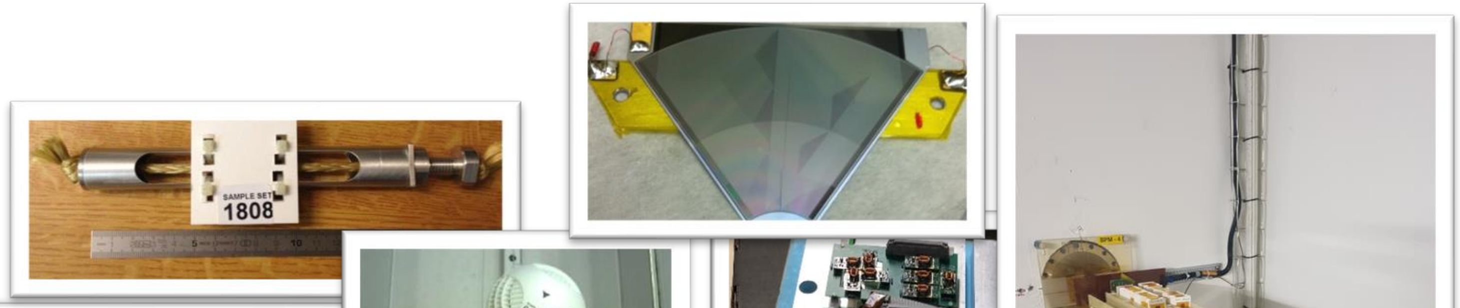
Material Samples





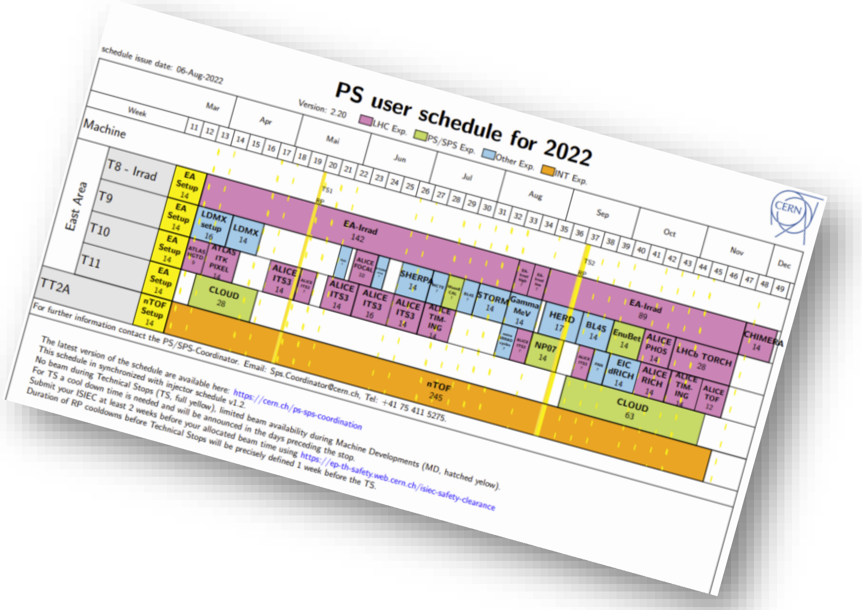
Small material samples are usually processed by the IRRAD team staff (no need for the user to come on site at CERN)

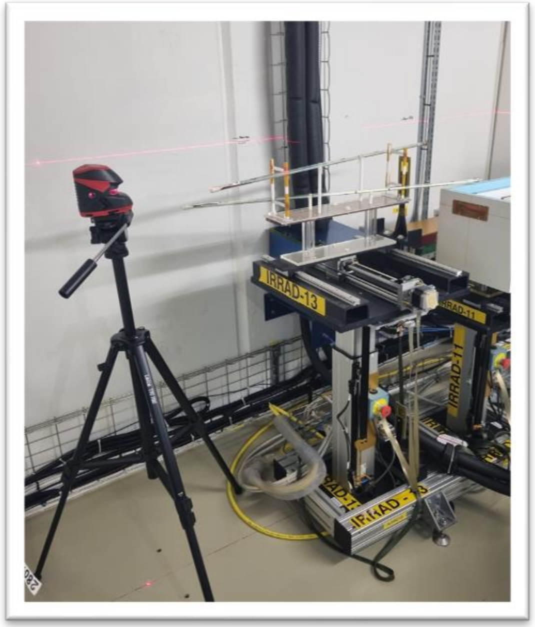
Operational insights

- User Planning:
  - Experiments are discussed separately with IRRAD/CHARM users and scheduled in a common “masterplan”
  - **Evolving during the year** according to the requests

- Facility Commissioning (2 weeks):
  - Beam is **characterized**
  - Beam Instrumentation is **calibrated** (Al-foils & GaF films)
  - Irradiation systems are **aligned**

- Weekly Operation:
  - Dedicated e-group for coordination:
    - Usually, **area in access on Wednesday morning**
  - Intervention **prepared & supervised by the IRRAD staff**
    - Installation/removal, connection/disconnection, local checks of the setup's alignment





User Operation: Safety

- Risks during facility operation:

  - Dedicated access rights, wear Personal Protective Equipment, mandatory safety courses, etc.
  - https://ps-irrad.web.cern.ch/ps-irrad/safety.php

- Safety is integral part of the irradiation workflow:

Before
  - Safety documentation (**irradiation permit**), if applicable
    - PRP17 to implement ALARA process
    - Formally approved before the experiment takes place

During
  - Manufacturing of sample holders:
    - Optimize layout & materials respecting guidelines (IS41, etc.)

After
  - Samples handling:
    - Work organization, tools, personal and operational dosimetry, cool-down time, post-irradiation meas., logistics, etc.

Contact the IRRAD Facility team to:

1. Discuss the details of your experiment and the **potential radiation safety implications**
2. Discuss the **preparation of the safety documentation** (if applicable to your case)

To fulfill the optimization principle (ALARA) **a formal approval of your irradiation experiment may be required** following a dedicated Radiation Protection Procedure (PRP17), EDMS 1717433

Contact the IRRAD team as early as possible while planning your irradiation experiment

Irradiation Experiments Workflow

Before

Registration
- Users
- Experiments
- Samples

Planning
- Schedule
- Beam interaction quantities
- Dosimeter / sample assignment

During

Operation
- Irradiation status
- Control system
- Beam Instrumentation

Dosimetry
- Gamma spectrometry
- Proton fluence calculations

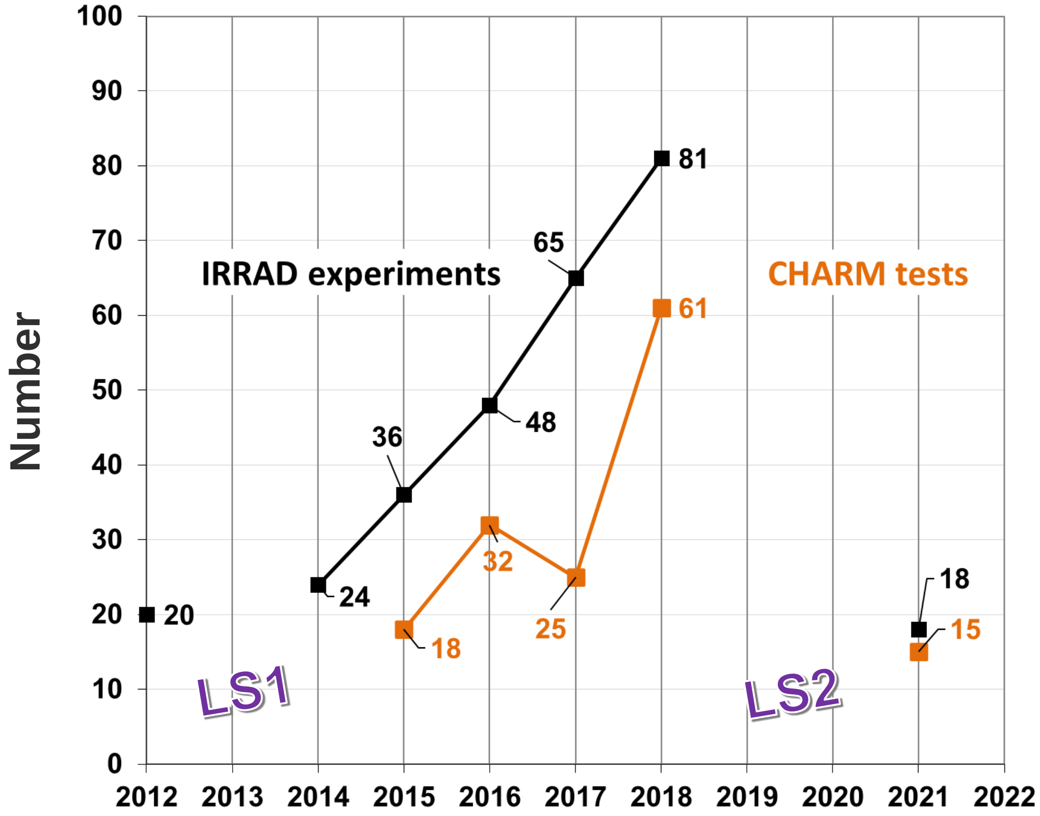
After

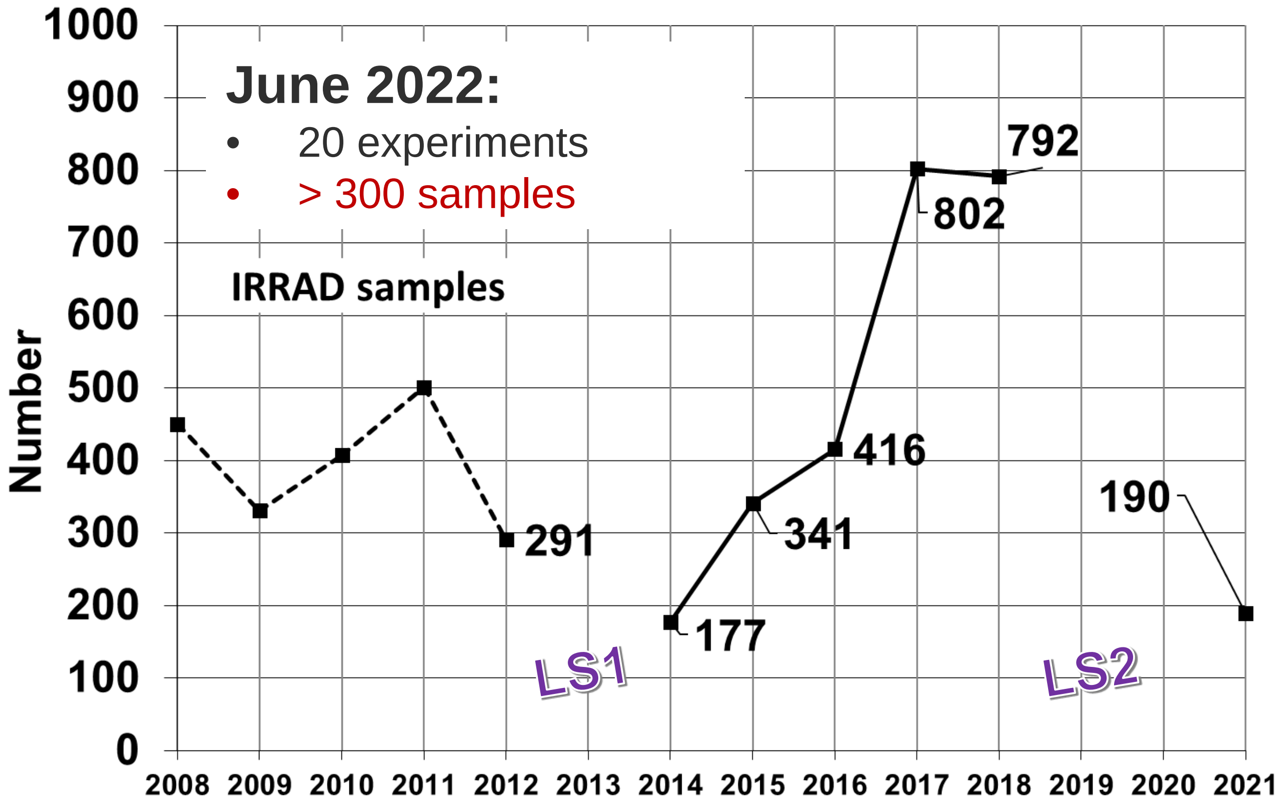
Traceability
- Logistics
- Transport
- Infrastructure

History
- Reproducibility
- Dissemination

see B. Gkotse PhD, (2020): https://cds.cern.ch/record/2743492

IRRAD Annual Facility Statistics

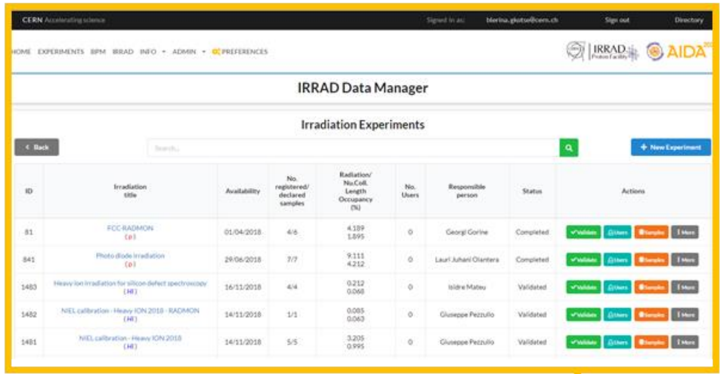


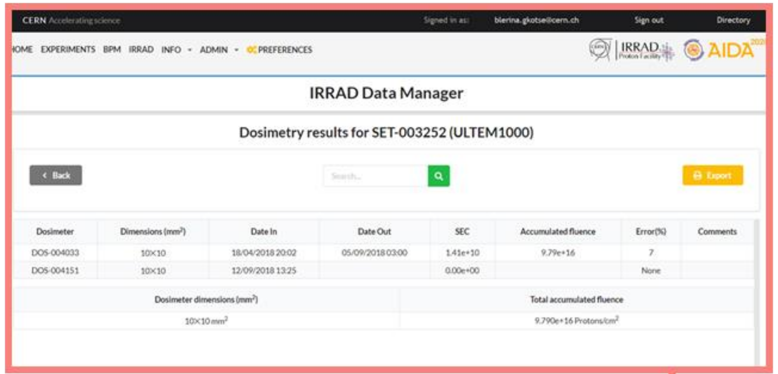


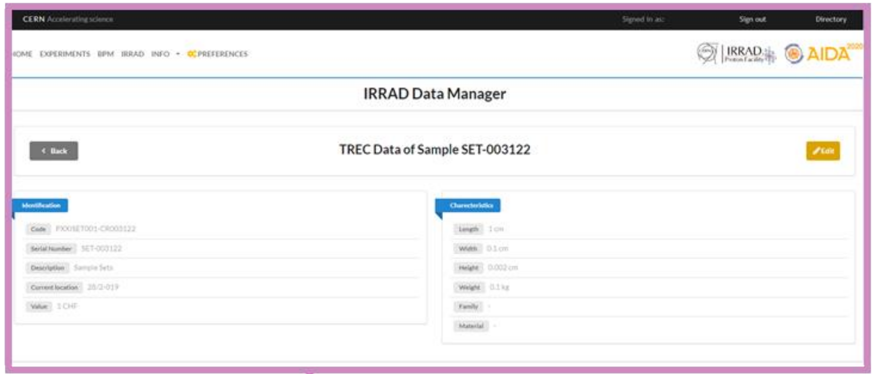
- + *O(1000)* activation foils measurements each year!

IRRAD Data Manager (IDM)

A **unified data management tool** for Irradiation Experiments follow-up



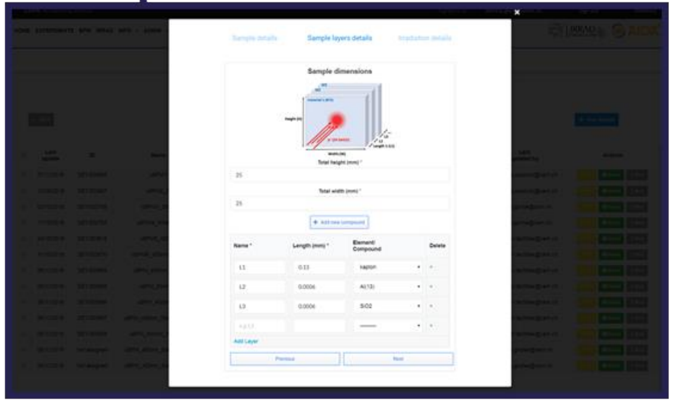


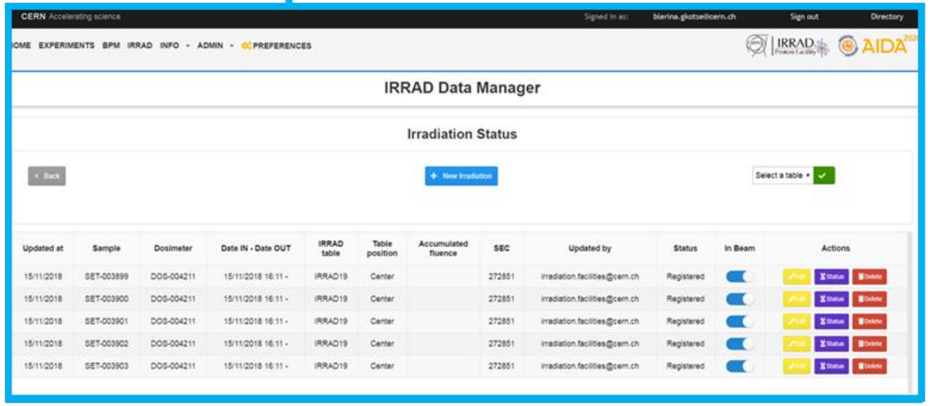


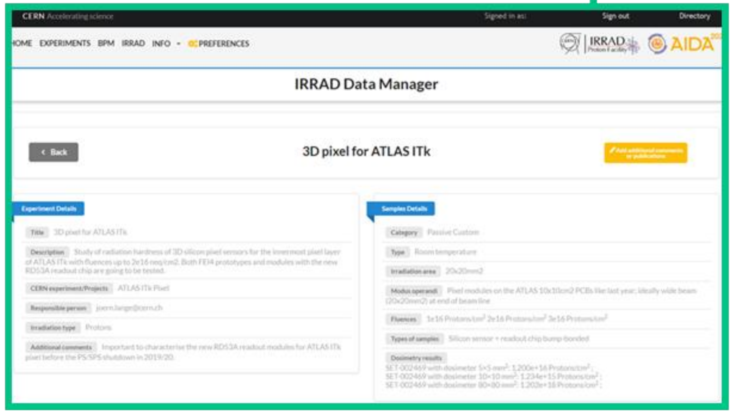
Registration → Planning → Operation → Dosimetry → Traceability → History

Apex-Gamma™ Gamma Spectroscopy

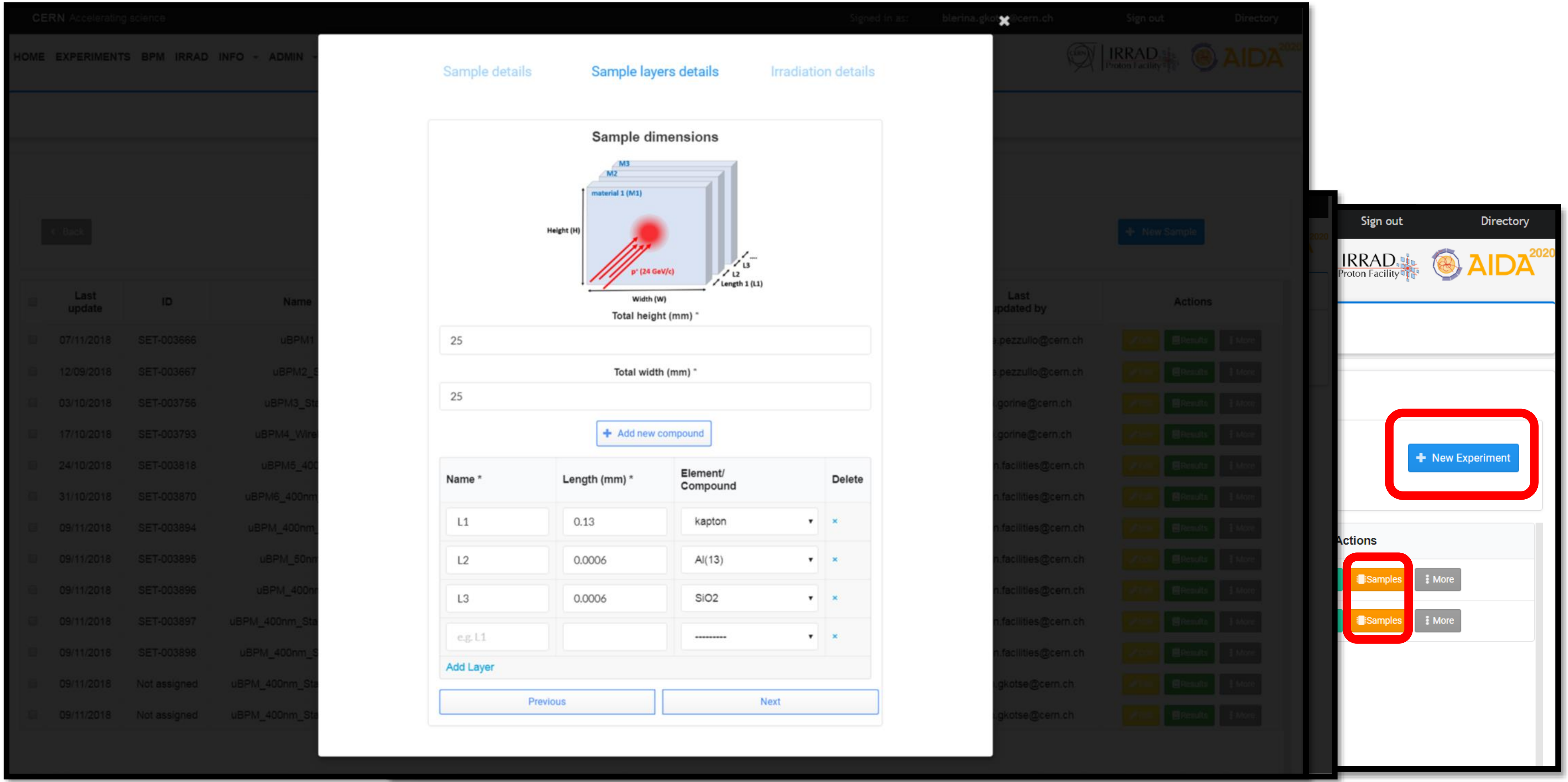
TREC







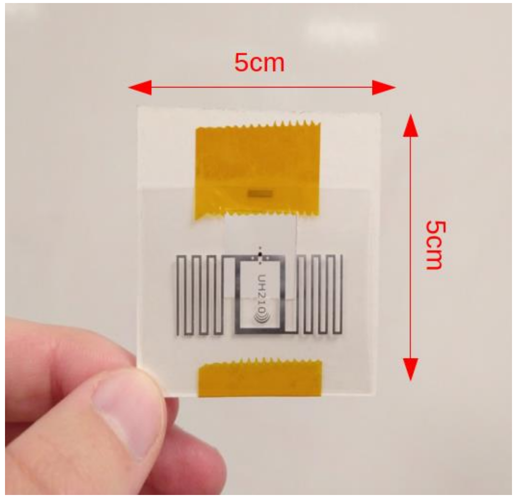
Registration in IDM (Example)



Traceability in IDM (Radiation Protection)

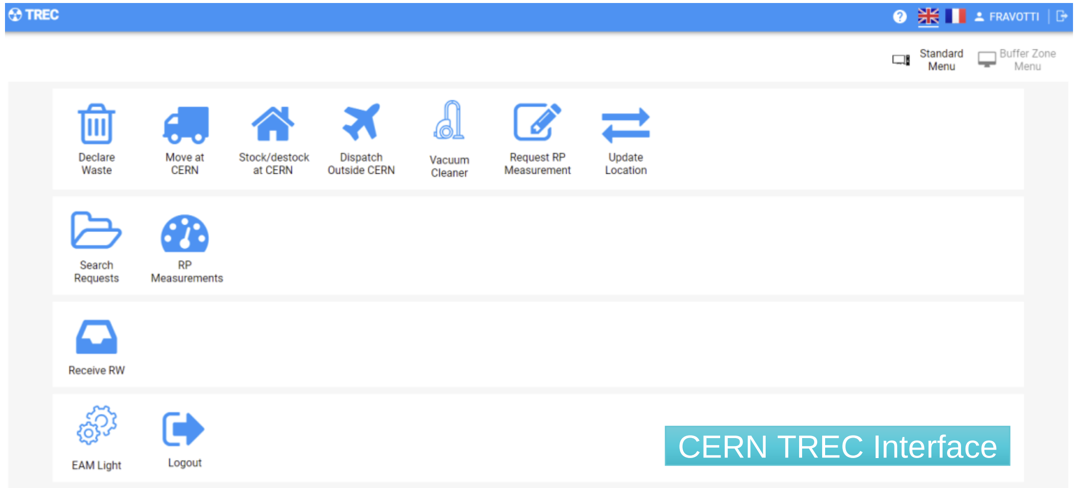
- IDM assign unique ID during registration:
  - Samples and Dosimeters
  - New Labels format & QR code (upgraded in LS2)
  - Study the usage of RFIDs:
    - https://doi.org/10.5281/zenodo.5846411

- Material Logistics (Transport / Shipping):
  - Generally, 2/3 weeks cooldown before proceeding
  - Follow the general CERN procedure:
    - Hand-over (material, responsibility and sample data to TREC) done in the "buffer-zone"
    - RP job is requested: classification done according to destination and foreseen manipulation (dose-rate, smear-tests, etc.)



RFID tag (© CAEN, IT)

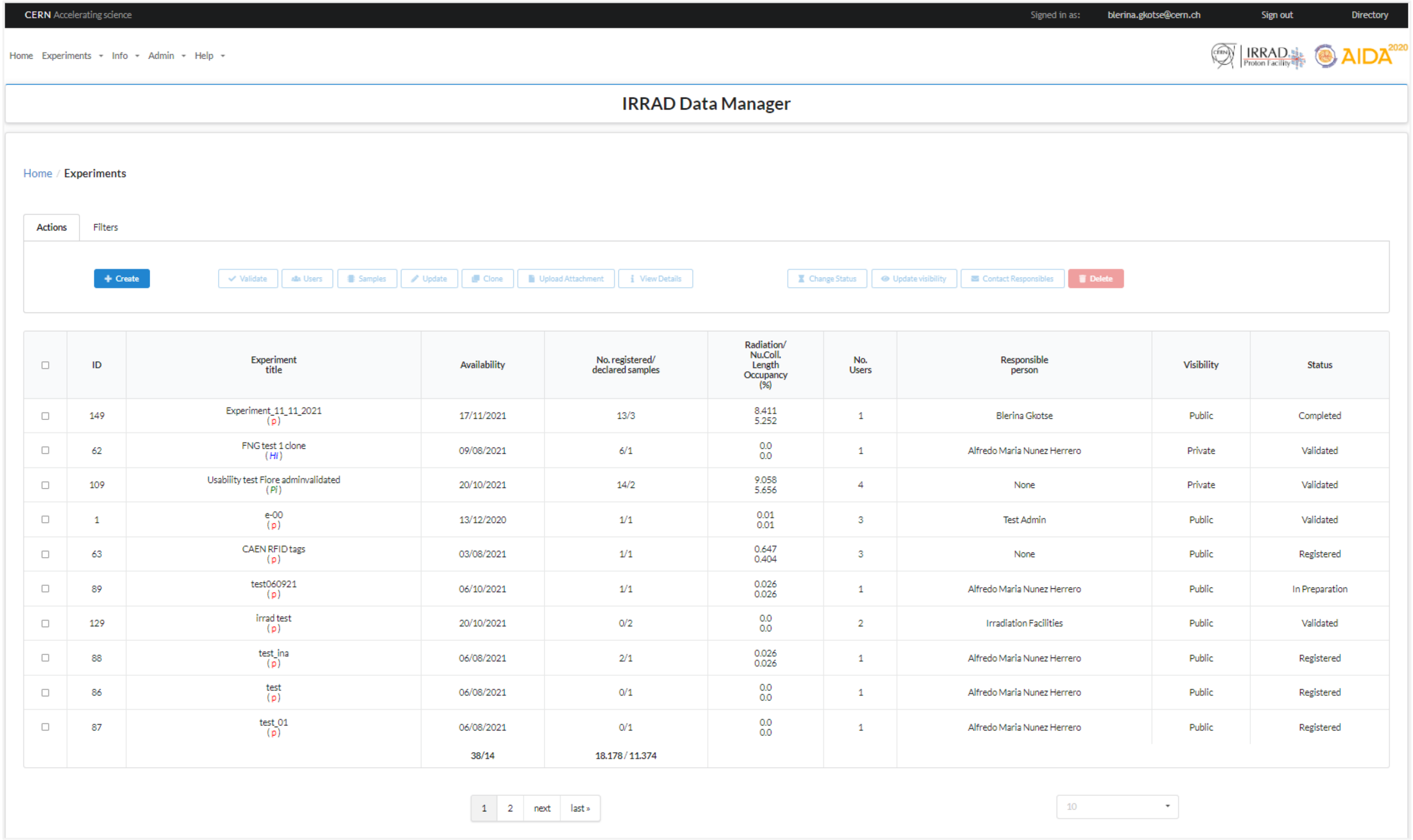
1cm×2cm
IDM Traceability ID



CERN TREC Interface

IRRAD Data Manager Upgrades

- The IRRAD tool to register irradiation experiments and samples:
  - Under development since 2017
- Upgrades in LS2:
  - Several improvements and bug fixing
  - New User Interface style
  - Documentation finalized: https://edms.cern.ch/document/2664569/
  - GitLab repository: https://gitlab.cern.ch/irrad1/irrad-data-manager
- Next step:
  - Full integration with APEX-gamma (ARAMIS project)



CERN Accelerating science | Signed in as: blerina.gkotse@cern.ch | Sign out | Directory

Home Experiments Info Admin Help

IRRAD Data Manager

Home / Experiments

Actions | Filters

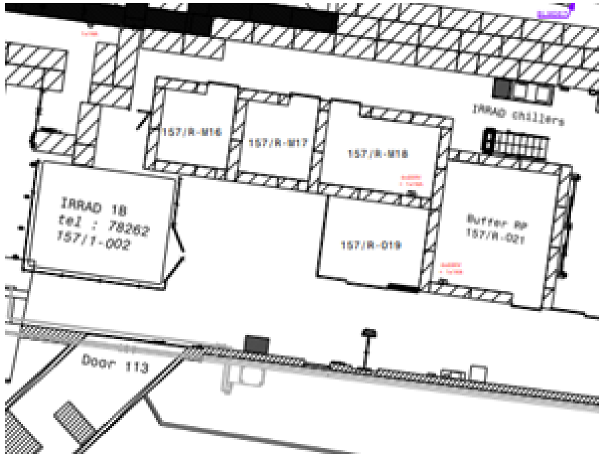
Create | Validate | Users | Samples | Update | Clone | Upload Attachment | View Details | Change Status | Update visibility | Contact Responsibles | Delete

☐	ID	Experiment title	Availability	No. registered/ declared samples	Radiation/ Nu.Coll. Length Occupancy (%)	No. Users	Responsible person	Visibility	Status
☐	149	Experiment_11_11_2021 (p)	17/11/2021	13/3	8.411 5.252	1	Blerina Gkotse	Public	Completed
☐	62	FNG test 1 clone (HI)	09/08/2021	6/1	0.0 0.0	1	Alfredo Maria Nunez Herrero	Private	Validated
☐	109	Usability test Fiore adminvalidated (Pi)	20/10/2021	14/2	9.058 5.656	4	None	Private	Validated
☐	1	e-00 (p)	13/12/2020	1/1	0.01 0.01	3	Test Admin	Public	Validated
☐	63	CAEN RFID tags (p)	03/08/2021	1/1	0.647 0.404	3	None	Public	Registered
☐	89	test060921 (p)	06/10/2021	1/1	0.026 0.026	1	Alfredo Maria Nunez Herrero	Public	In Preparation
☐	129	irrad test (p)	20/10/2021	0/2	0.0 0.0	2	Irradiation Facilities	Public	Validated
☐	88	test_ina (p)	06/08/2021	2/1	0.026 0.026	1	Alfredo Maria Nunez Herrero	Public	Registered
☐	86	test (p)	06/08/2021	0/1	0.0 0.0	1	Alfredo Maria Nunez Herrero	Public	Registered
☐	87	test_01 (p)	06/08/2021	0/1	0.0 0.0	1	Alfredo Maria Nunez Herrero	Public	Registered
			38/14	18.178 / 11.374					

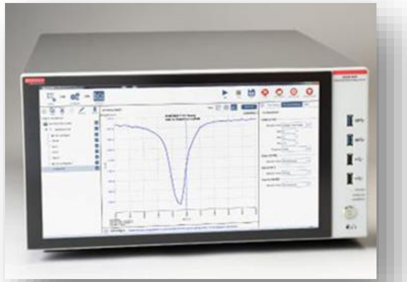
1 2 next last »

User Infrastructure (upgraded in LS2)

- reduce transport of irradiated material
- increase **samples storage** (room and -25ºC) / **handling capabilities** (work supervised by HSE-RP)
- provide users with a **laboratory**, required **manipulation tools** & advanced **characterization tools**

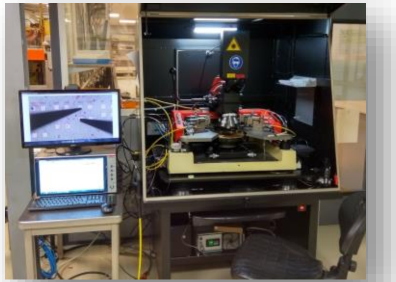


IRRAD Technical Area



Keithley 4200A SPA

Keithley 2657A Extension
HV SMU up to 3kV NEW



Suss PM8 Probe Station

TH100 Climatic Chamber

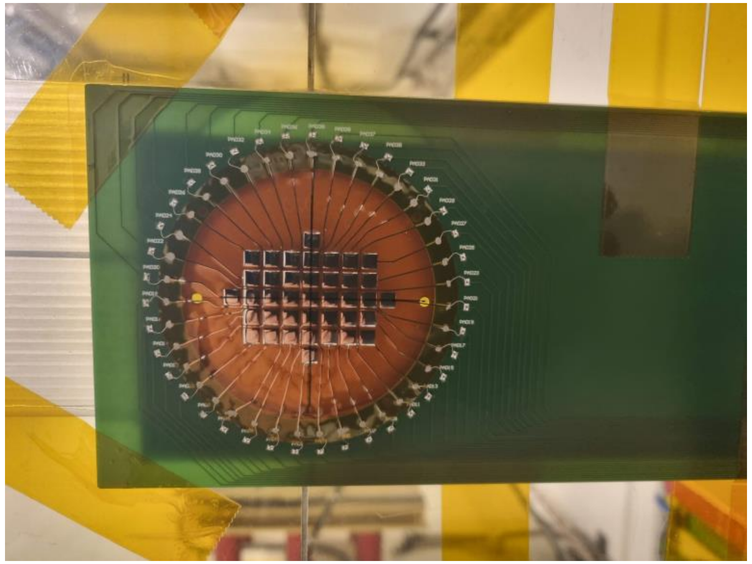
HpGe Gamma Spectrometer station NEW

Outline

- Irradiation Facilities at CERN
- PS East Area Proton Irradiation Facility (IRRAD)
  - Characteristics, Dosimetry and Beam Instrumentation
- User Operation
  - Safety, Experiment Workflow, Data Management Tool (IDM) and User Infrastructure
- **Future Upgrades**
- User Support
- Summary

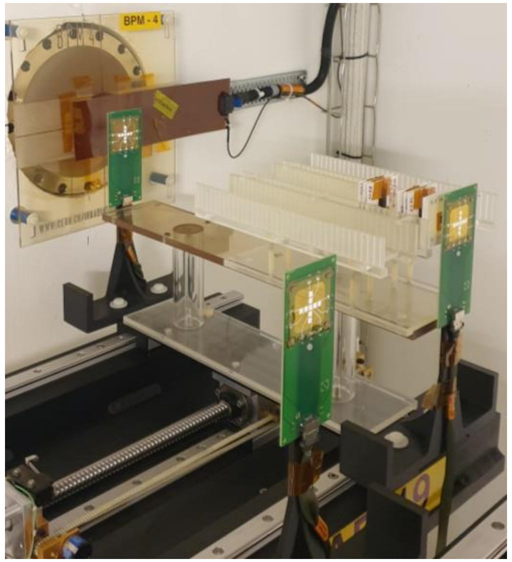
IRRAD Beam Profile Monitors Upgrade

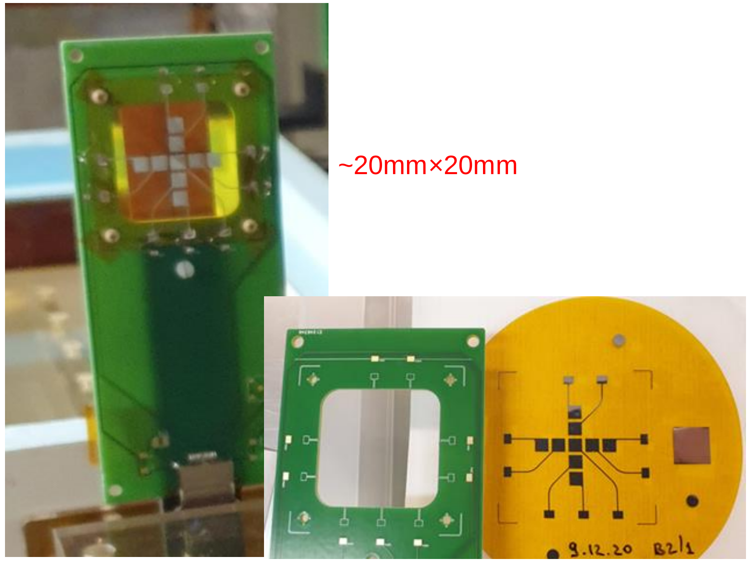
- Innovative Beam Profile Monitor Devices:
  - Traditional **BPMs Cu/FR4** **(140/600μm)** had several drawbacks:
    - Limited sensitivity, low radiation hardness, high material activation, etc.
  - New **mini-BPM Al/Kapton** **(0.3/25μm)** produced, tested in IRRAD, now operational
    - >30× reduced material budget, X_0 < 1%
  - Large pattern (40ch.) **micro-BPM Al/Kapton** **(0.2/25μm):** first prototype tested, new production ongoing



~40mm×30mm

40ch. micro-BPM device



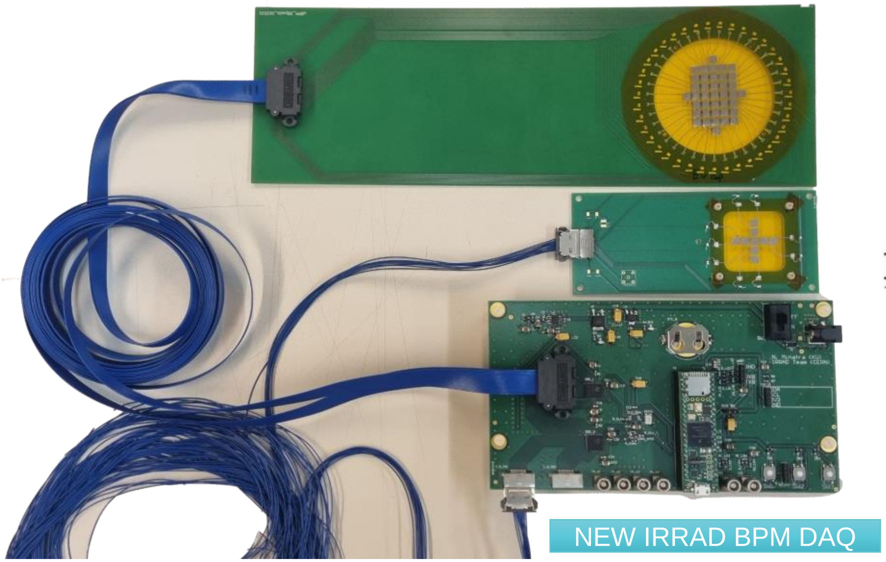


~20mm×20mm

New mini-BPMs

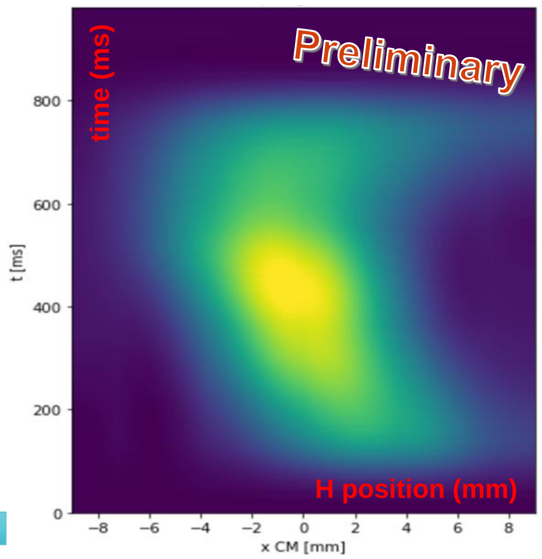
BPM DAQ Electronics Upgrade

- New DAQ Electronics being designed:
  - Previous DAQ electronics (~ 10 years old) had several limitations:
    - 20ms **sampling time**, limited **number of channels** and **dynamic range** (matching with new detector technology), **longitudinal profile availability** (one channel only), etc.
  - Need to cope with new operational requirements:
    - slow- and **fast-extracted beams**, **heavy ion** beams, **new sensor technology**, increase information available for MD studies, etc.
  - **Scalable system** (data bus), **sampling time down to 100's μs**, first prototype being tested

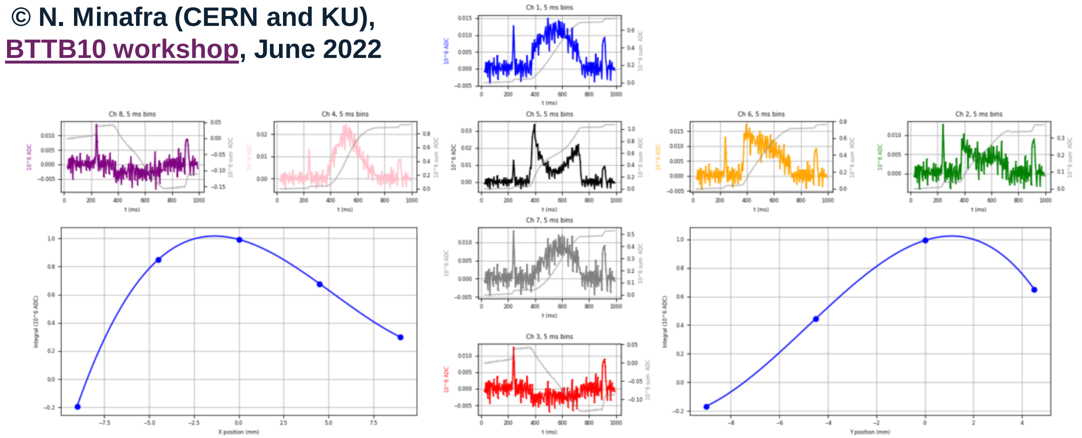


NEW IRRAD BPM DAQ

Evolution of H beam position with time



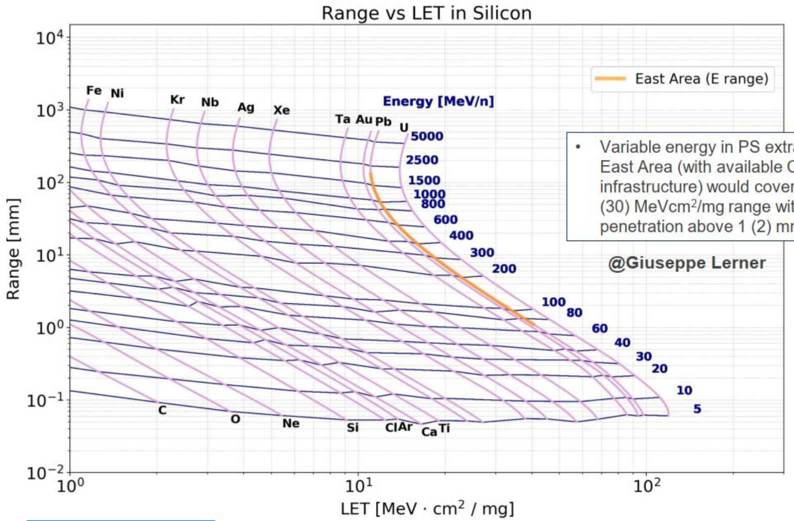
© N. Minafra (CERN and KU), BTTB10 workshop, June 2022



H and V beam profiles from a mini-BPM in IRRAD

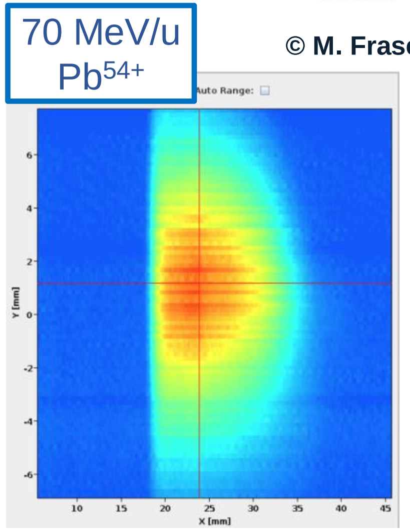
CHIMERA (Charm High-energy Ions for Micro Electronics Reliability Assurance)

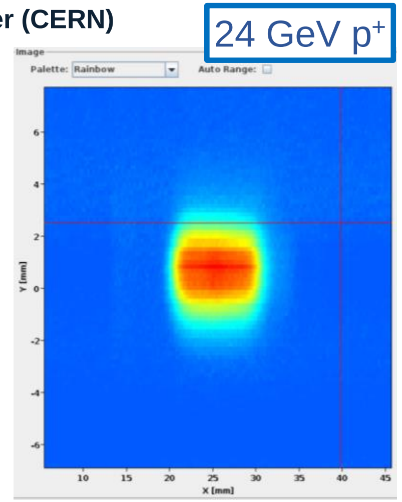
- Electronics testing with high-energy heavy-ions:
  - Interest for testing state-of-the-art / complex packaged microelectronics structures:
    - High-LET (> 20 MeVcm^2/g) **cyclotron ions (E~10-20 MeV/n)** have **range (Si) <200um**: vacuum test with de-lidded parts
  - High-energy ions **70 MeV/n – 2 GeV/n** have **range (Si) ~mm**
    - Scarce availability worldwide and very expensive (only at NSRL, USA and GSI, DE)
    - Collaboration agreement CERN-ESA on this topic (2019)
  - Use **downstream position in T08** (CHARM) to achieve:
    - **Large beam spot** (20×20 cm^2)
    - **Low ion fluxes** (10^2-10^5 ion/cm^2/s)
- In 2021:
  - **70 MeV/u ion beam (Pb^{54+})** extracted into F61
  - **Slow-extracted ion beam at 6 GeV/u** propagated into T08 (2 days)
- In 2022: 2 weeks ion run in the schedule



- Variable energy in PS extraction to East Area (with available CHARM infrastructure) would cover the ~10-40 (30) MeVcm^2/mg range with silicon penetration above 1 (2) mm

© M. Fraser (CERN)





BTV at SMH57

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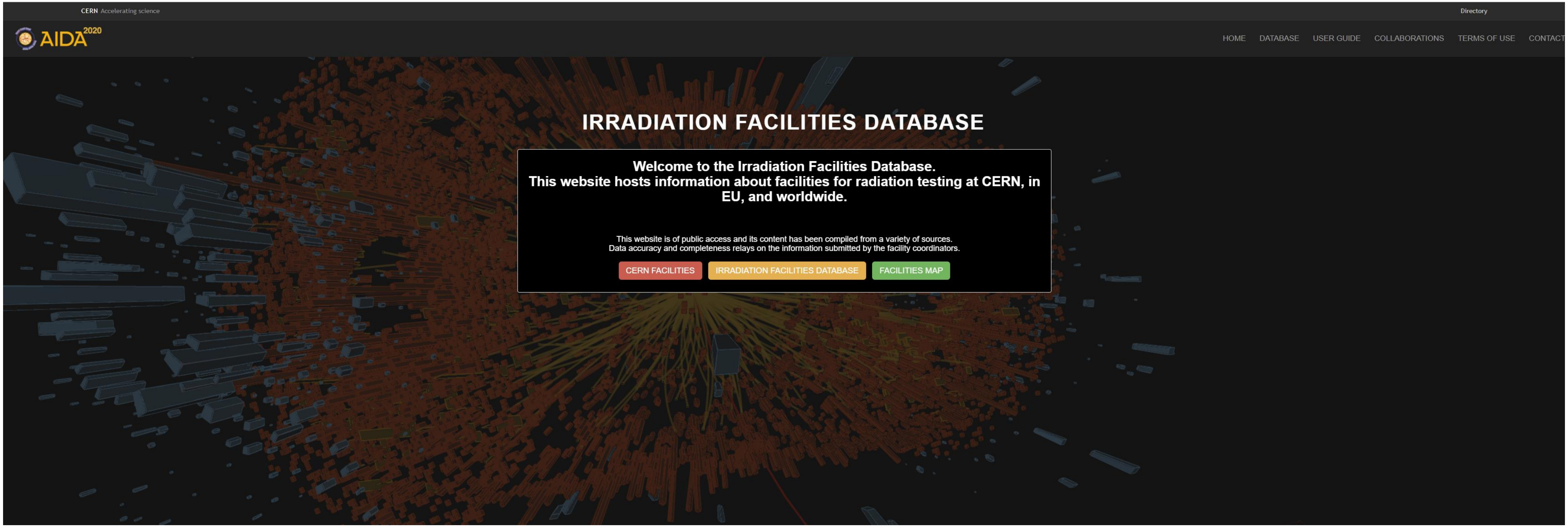
Irradiation Facilities Database



A unified entry point for **CERN and worldwide irradiation facilities** with an essential collection of information

https://www.cern.ch/irradiation-facilities/

Irradiation Facilities Database

- **A database platform for listing essential information about irradiation facilities at CERN and worldwide:**
  - **open source** developed at CERN (EP dept.) within the EU-funded project AIDA-2020
  - list infrastructures **across application domains**
  - information under the **responsibility of the facility coordinators**:
    - automatic **annual reminders for updates**
    - information **validated by database admin**
  - >210 entries initially listed (2017) from "paper" data collections, webpages, etc. (often outdated)
  - **Today:**
    - **228 valid facility entries** (160 with full location info)
    - **~8100 visits** since launch

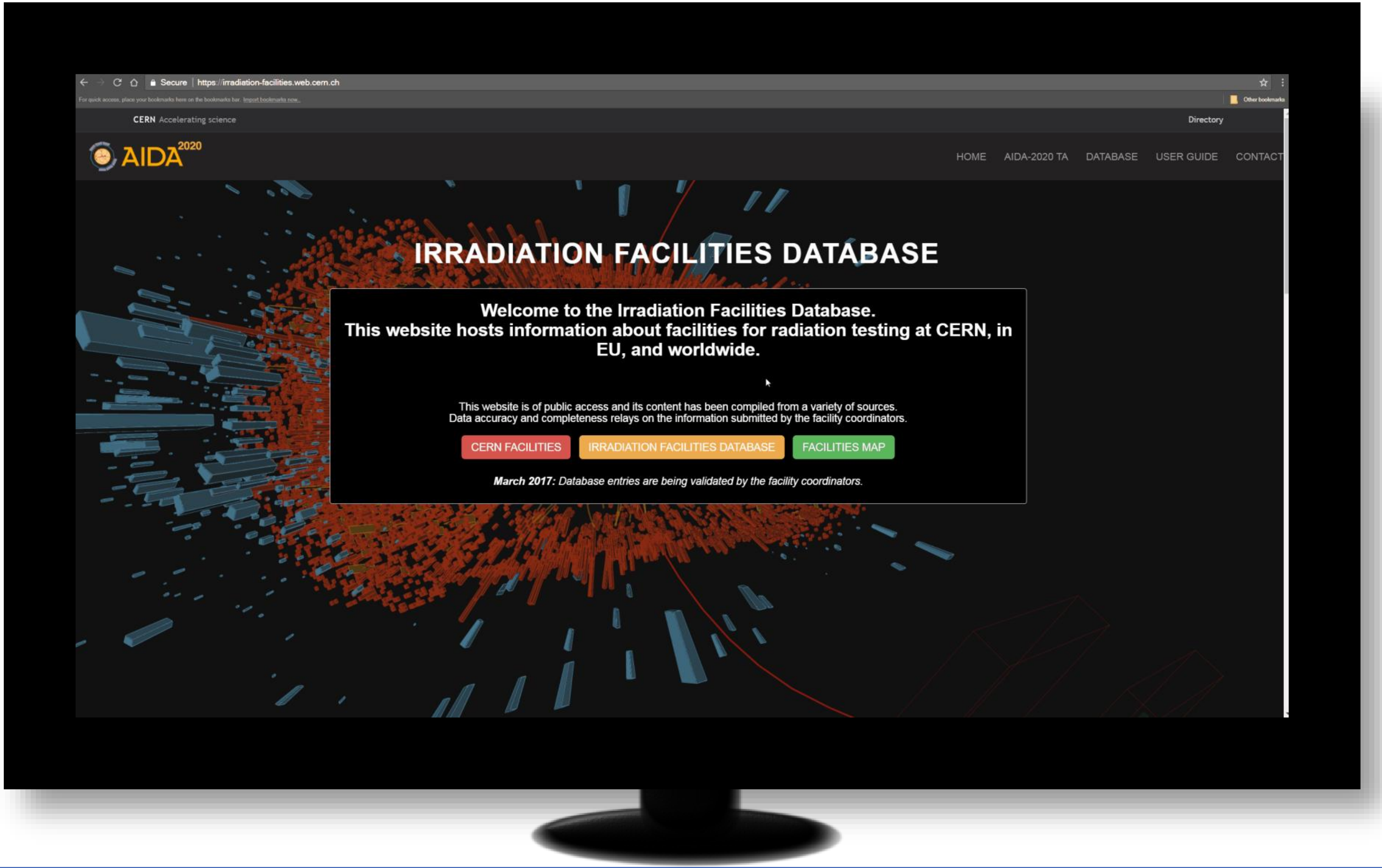
Piwik web statistics (CERN)

COUNTRY	VISITS
Switzerland	2,727
United States	1,119
France	913
Italy	456
United Kingdom	359
Germany	346
China	330

Location of the facilities in the database

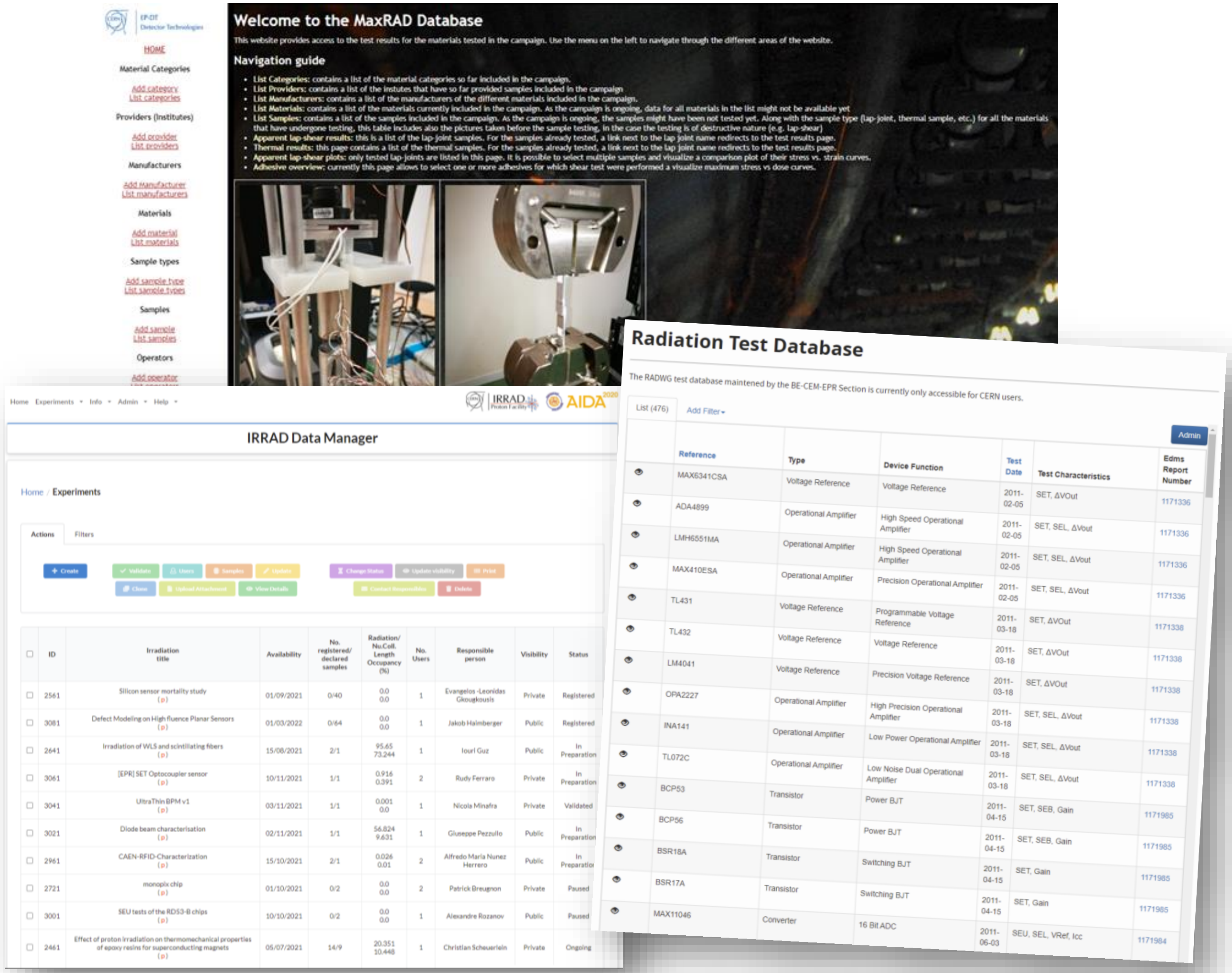
Irradiation Facilities Database

- **Features:**
  - **CERN facilities portal**
    - including CERN partner facilities (not shown here)
  - **worldwide map view**
  - **a form for each facility entry**:
    - contact information
    - facility data
    - irradiation conditions
    - safety
    - accessibility
    - comments
  - **search functionalities**
  - **editing functionalities** (protected by CERN SSO, support external "lightweight" accounts)
  - **user manual:**
    - AIDA-2020-NOTE-2017-002



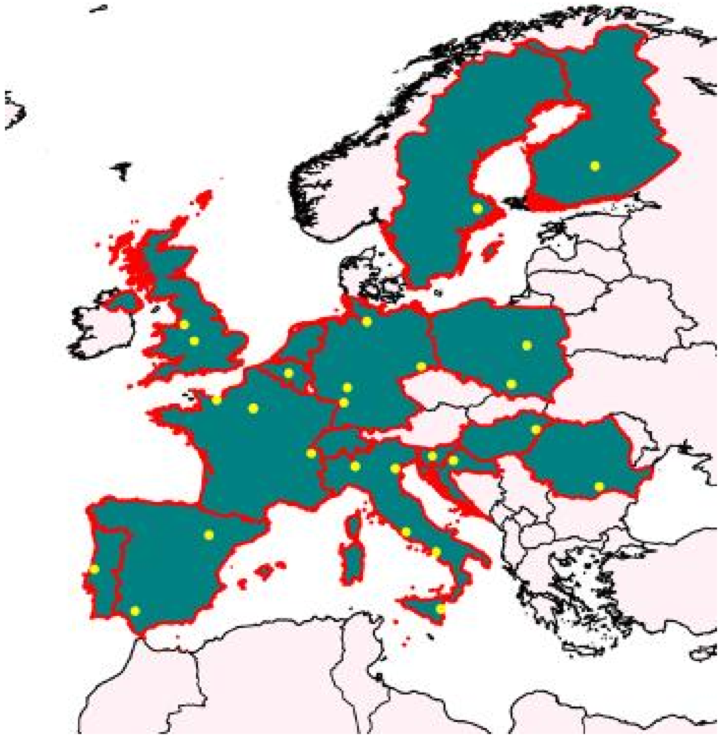
Informative Resources & Tools

- **Availability of Irradiation Test Results**
  - **RADWG online database:**
    - results of **electronics components** radiation tests
    - URL (access CERN RADWG members)
  - **MaxRAD online database:**
    - results of **structural materials** radiation tests
    - URL (access upon request)
  - **CERN-IRRAD Data Manager:**
    - results of **detector component** radiation tests (mainly)
    - URL (access upon request)
  - **IMHOTEP online database:**
    - results of **components for LHC detector upgrades** tests
    - URL (free access)
  - **CERN Yellow Reports on Radiation Damage:**
    - historic “catalogues” collection (free): URL with list



EURO-LABS Project

- A consortium of thirty-nine Research Infrastructures (RIs) from twelve countries in Europe
- First joint EU proposal between Nuclear Physics, HEP accelerators and HEP detectors
- Mostly Transnational Access (TA) and service improvements:
  - **TA to CERN IRRAD and GIF++**
- Foreseen to start 1st September 2022(*)
  - Kick-off meeting in Bologna, Italy beginning of October

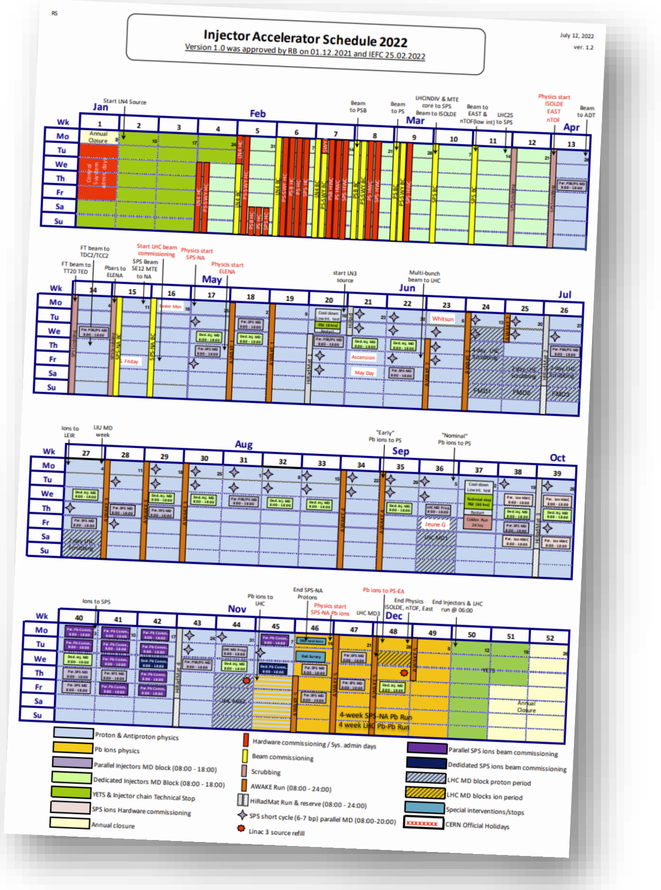


EURO-LABS
EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCES

(*) see Paolo Giacomelli's presentation: https://indico.cern.ch/event/1104064/contributions/4797462/

Summary

- **The Proton Irradiation Facility (IRRAD) at CERN provide:**
  - A **variety of irradiation systems** and a **dedicated infrastructure** meeting the evolving radiation testing needs of the CERN/HEP community for the HL-LHC
  - The **availability of a versatile 24 GeV/c proton beam** during about 35 w/year
- **Continuous improvements are made for its operation & users:**
  - **Beam instrumentation** (ATTRACT), safety procedures, **data management**, post-irradiation **laboratory infrastructure** and tools (AIDAinnova),etc.
- **… as well as for supporting the user community at large:**
  - **Irradiation facilities database** (AIDA-2020), informative resources, **access funds through EU-projects** (EUROLABS),etc.
- **Challenging future requirements:**
  - Beam quality always improving, but **hitting the limitations for the post HL-LHC!**
    - It is time soon to look for alternatives ! → first study starting end 2022 (RADNEXT)
  - Qualify the facility for **testing with high-energy heavy-ions** (CHIMERA)



This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA no 101004761.

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