Hardware and Software Upgrades for the Proton Irradiation Facility (IRRAD) after the LS2

Blerina Gkotse (EP-DT-DD)

on behalf of EP-DT Irradiation Facilities Team: Martin Jaekel, Alexander Smith Mølholm, Alfredo Maria Nunez Herrero, Giuseppe Pezzullo, Federico Ravotti, Ourania Sidiropoulou

Former IRRAD members contributors: Isidre Mateu Suau, Viktoria Meskova
MINES ParisTech: Pierre Jouvelot

EP-DT Seminar
28 October 2020

This project has received funding from the European Union’s Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.
Outline

- Proton Irradiation Facility (IRRAD)
- Software and Hardware Upgrades for IRRAD
- Software Developments for Users Community
- Towards Common Tools for Irradiation Facilities
Irradiation Facilities: what for?

- **Radiation damage studies on:**
  - materials used around accelerators / experiments
  - semiconductors / electronic components
  - materials / accelerator components exposed to high-intensity pulsed beams

- **Test and development of prototypes / final assemblies / electronic equipment before installation**
  - performance degradation / ageing (TID, NIEL,…)
  - functional degradation of electronics (SEU,…)
  - performance evaluation with background ("noise")

- **Test and calibration of components**
  - dosimeters, radiation monitoring / measurement devices
  - provide benchmark data for Monte Carlo particle transport codes
CERN Irradiation Facilities

GIF++
(gamma + muons)

CALLAB
(irradiation sources)

CERF
(mixed field)

See previous M. Jaekel EP-DT seminar (https://indico.cern.ch/event/791896/)

28 October 2020
CERN Proton Irradiation Facility (IRRAD)

- Testing components of HEP experiments
- 24 GeV/c, Gaussian 12×12 mm² FWHM
- Spills of 400 ms every ~10 s

- Fluence of $1 \times 10^{16}$ p/cm² in 14 days
- Scanning also in dimensions of 10×10 cm²
- Low temperature irradiation (-25°C)

cern.ch/ps-irrad
IRRAD Experiments in 2018

81 experiments, 97 users, 792 samples, 405 dosimeters, 2056 dosimetry measurements

© ps-irrad.cern.ch

Piezo actuators

ECAL crystal

RD53A modules

Full-tracking detector module

CLARO ASIC

Samples on shuttle

Si pad diode

NA62 GTK TDCpix
IRRAD Complex Experiment

Exposure of 32 FEAST2 at -25C at the CERN IRRAD facility
The facility run in a purposely modified configuration to expose the converters in a mixed field:
MANY THANKS to the IRRAD TEAM!

32 samples, both FEASTMP and CMS modules, are exposed and constantly monitored in a cold box (-25C) in the CERN IRRAD facility (May 2018).

2x FEAST2 DC/DC converters test in cold-box & RT with “thin” 10mm Cu target (EP-ESE)

1MeV eq. $\Phi$ simulation with Cu-target

© F. Faccio EP-ESE seminar, 2019
https://indico.cern.ch/event/788031
IRRAD Statistics for the Last 10 Years

Repartition of the users in 2018

28 October 2020
IRRAD Towards Phase II Upgrade

Semiconductor/inner detectors will face

\[ >10^{16} \text{n}_{eq}/\text{cm}^2 \text{ (HL-LHC)} \]

\[ >7 \times 10^{17} \text{n}_{eq}/\text{cm}^2 \text{ (FCC-hh)} \]

**Phase-II upgrade**

- New all-silicon Inner Tracker (ITK)
  - Strips: preproduction
  - Pixels: transitioned to final design phase

- High Granularity Timing Detector
  - TDR preliminarily approved
  - Upgrade cost group review this week \( \rightarrow \) last step before research board approval

**Experiments R&D on for Phase II upgrade:**

- 3D pixels, SiPM, LGADs, HV-CMOS, …
- CMS pixel, ATLAS ITk strips, CMS Timing Detector, ATLAS HGTD, …

**Electronic developments:** RD53, DC/DC, etc.

**Accelerator components:**

- Vacuum/Magnet parts, collimator actuators, …

**Increasing number of requests for IRRAD-RUN2!**

IRRAD-RUN2 from 18/10/2021
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Irradiation Experiment Workflow in IRRAD

Registration
- Users
- Experiments
- Samples

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

Operation
- Irradiation status
- Control system
- Beam Instrumentation

Dosimetry
- Gamma spectrometry
- Proton fluence calculations

Traceability
- Logistics/Infrastructure
- Transport

History
- Reproducibility
- Dissemination

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Before
During
After

28 October 2020
Data Management in IRRAD

Traceability (Before)

Facility Operation (During)

Dosimetry Results & Archive (After)
IRRAD Data Manager (IDM)

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

- URL: https://cern.ch/irrad.data.manager
- Accessible for people in the "irrad-ps-users" group
- Users register data for experiments, samples and other team users
High energy protons interact with all materials (not only samples!) in the beamline

To perform a “good” irradiation:

- Need to estimate the relevant “physics” parameters: interaction ($\lambda$) / radiation ($X_0$) lengths, etc.
- Feedback to the operation / planning of the whole (IRRAD/CHARM) facility

Same interactions responsible for making the material radioactive
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Planning

IRRAD Operating team:

- Experiments scheduling
- Beam interaction quantities calculations
- Generation of sample identification
- Dosimeters assignment

Planning which samples will be put in beam
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Operation – Irradiation Status

- Data extraction from IRRAD Beam Instrumentation
- Accumulated proton fluence estimation
- Notification of irradiation completion

Irradiation status
Operation – IRRAD Tables

- 9 remotely controlled stands
- Moving samples on axes x, y and rotating by $\theta$ angle
- 1 irradiation shuttle
Operation – Control Systems for IRRAD Tables

2008

Hardware Box
- manual control on-site
- no remote operation

2014 (LS1)

Graphical User Interface (GUI)
- Microsoft-based (Visual Studio, C++)
- Only operational on Windows

2021 (LS2)

New GUI
Operation – New Table Control System

- Based on pyQT (python) – no license required
- Compatible with Windows and Linux
- Database in the backend

New Table Control GUIs
Fixed IRRAD Beam Profile Monitors (BPMs)

BE-BI Intensity Measurement Instrumentation
Operation – BPMs

**Fixed BPM**
For the beam alignment

**Mini and single-pad BPMs**
IRRAD tables alignment purpose and “in-beam” detection

---

**Fixed BPM**

For the beam alignment

- **Fixed-BPM2**
- **Fixed-BPM detector**
- **Transversal beam profile**
- **BPM DAQ unit 25-35m away from fixed-BPM device**

---

**Mini and single-pad BPMs**

IRRAD tables alignment purpose and “in-beam” detection
Operation – BPM Pages used in CCC

BPM DISPLAY AT CCC

Reference profile

Transversal profile

Longitudinal profile provided by central pad charge

Measured profile

Fixed-BPM Gaussian fit

Beam monitoring at CERN Control Center (CCC)


E. Matli (BE-ICS)
Operation – New micro-BPM

- Understand the proprieties of ultra-thin [nm] metal layers exposed to ultra-high particle fluence levels ($\geq 10^{18} \text{ p/cm}^2$)

- Requirements:
  - simple
  - non-invasive
  - low-activation
  - high-sensitivity
  - radhard

- Use at IRRAD and possibly at lower-energy beam facilities (MeV, keV)
Ultra High-level Radiation Monitoring with Thin Metal Nano-layers (NanoRadMet)

Future EP-DT seminar

Material Studies / Fabrication techniques

Prototypes of new micro-BPM being tested at VESPER facility (200 MeV electrons)
Beam Instrumentation – New Hardware

- Better understanding of proton beam intensity:
  - T08 transport, calibrations, etc. ($10^{11}$ p/spill)
  - Low intensity ($10^9$-$10^{10}$ p/spill)
  - Heavy Ion runs

- New measurement point upstream IRRAD:
  - XION01
  - BCT01

- New XION02 downstream

- Devices on telescopic feet (IN/OUT)

- System being prepared in collaboration with EN-EA, EN-SMM, BE-BI
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  - Gamma spectrometry
  - Proton fluence calculations

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- **History**
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Dosimetry & Radiation Monitor

Beams Profile / Intensity from Activation of Aluminium foils

\[
{^{27}\text{Al}(p,3p)}^{24}\text{Na}, {^{27}\text{Al}(p,3p3n)}^{22}\text{Na}
\]

1x NaI spectrometer (+/- 6%)

24 Na, half-life 15h, \( E_\gamma = 1368.53 \text{ keV} \)

2x HpGe spectrometer (+/- 2%)

24 Na, 22 Na, half-life 2.6y, \( E_\gamma = 1274.54 \text{ keV} \)

Passive Dosimetry

Calibration curves Si-particle detectors

Active Sensors

Proton beam spot characterized with GAF films

Beam Profile / Intensity from Activation of Aluminium foils

(27Al(p,3p)n)24Na, 27Al(p,3p3n)22Na

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24 Na, 22 Na, half-life 2.6y, \( E_\gamma = 1274.54 \text{ keV} \)
Activation-foil Dosimetry

1. Aluminum-foils preparation
2. Beam exposure / activation
3. Gamma Spectrometry
4. Proton Fluence Calculation
Upgrade of Spectrometry Laboratory

- New HPGe detector (1998) recovered from HSE-RP:
  - refurbished (~x5 cheaper)
  - coupled to *Cryo-Cycle II* (LN$_2$) and new DAQ (*client-2*)
  - full lead background shield

- New measurement Lab in bld. 157 after the LS2:
  - Increase measurement capabilities (24Na Al-samples)
  - Decrease number of transports to Lab in bld. 14 (22Na Al-samples)
Dosimetry Results

- Canberra (Mirion) Software (Apex-Gamma) installations
- Collaboration with HSE-RP
- New software architecture
  - Openstack Virtual Machine (VM) Server
  - 2 spectrometry stations (IRRAD and Laboratory 14)
Dosimetry Results

- Dosimetry measurements through proprietary software
- Dosimetry data calculation through post-processing software
- Dosimetry results through IDM

Results availability in IDM

Canberra (Mirion) software

New
Future Work
Irradiation Experiment Workflow in IRRAD

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Measurement Laboratory at IRRAD Facility

- New detector technologies need proper equipment to be characterized at both wafer level and for packaged-part testing
- A configurable bench top system for characterizing devices
- **Suss PM8 Probe Station** (4 manipulators, thermo-chuck 5-125 ºC and a vibration isolated table in EM isolated dark box)
- **Keithley 4200A SPA**

+ **Keithley 2657A Extension**
  High Voltage SMU up to 3000V
TH100 **Temperature and Humidity Test Chamber** (LIB Industries)
- **Internal dimensions:** 40x50x50 cm³
- **Volume:** 100 litres
- **Temp. range:** -70 to 150 °C
- **RH range:** 20-98%

**LabVIEW Control system:** VI function blocks & controller

Calibration test-bench and LabVIEW-based DAQ for the RADMON portable readout system, Jes Rydall Larsen, AIDA-2020-NOTE-2020-002

J. Larsen
I. Mateu
(EP-DT 2019)
Extension of Technical Area

- Reduce transport of irradiated material
- Increase storage / handling capabilities
- Provide users with advanced samples characterization tools
Traceability

Mandatory traceability of tested components according to French and Swiss regulations

Use cases

TREC system

TREC data in IDM

A. Nunez (EP-DT)
Irradiation Experiment Workflow in IRRAD

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History
- Reproducibility
- Dissemination
History

Keeping experiments history for:

- documentation
- reproducibility
- optimisation
- dissemination

See previous EP-DT seminar (https://indico.cern.ch/event/952416/) – Material DB
Outline

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External Facilities

- Some irradiation experiments cannot be performed at CERN
  - DD, SEE in accelerator environment (p\(^+\) low-E / Heavy Ions)
  - TID, Polymers degradation (strong \(\gamma\)-sources)
  - Displacement in metals (\(n^0\) reactors / spallation sources)
  - etc.

- CERN facilities not always available
  - Accelerators Technical Stops, maintenance, upgrades, etc. (months)
  - Long Shutdown periods (years!)

- Need for information about worldwide external facilities
  - CERN experimental community is very diverse (not only for irradiation experiments)
  - Need of irradiation services for some applications
  - Fostering new collaborations, etc.
Irradiation Facilities Online Database

- **Online database platform** for searching irradiation facilities at **CERN and worldwide**
- Coordinators **inserting/updating** data
- **Annual reminders** for keeping data up-to-date
- **240** irradiation facilities
- **5500** visits from around the world
- Launched in 2017

http://cern.ch/irradiation-facilities
Test Beam Facilities Database

- Request for test-beam database
- Similar functionalities
- 16 test beam facilities
- 27 beamlines
- Launched in 2020

http://cern.ch/tbdb
CERN Directory

Experiments and projects

- CERN experiments (Grey Book)
- AEGIS
- ALICE
- ALPHA
- AMS
- ASACUSA
- ATLAS
- ATRAP
- AWAKE
- BASE
- CAST
- CERN Neutrino Platform
- CLIC
- CLOUD
- CNGS
- CMS
- COMPASS
- DIRAC
- ELENA
- FASER
- FCC
- GBAR
- H1-LHC
- Irradiation Facilities
- ISOLDE
- LHCb
- LHCF
- LiU project
- MoEDAL
- NA61/SHINE
- NA62
- NA64
- rTOW
- OSGAR
- PBC
- SHIP
- Test Beam Facilities
- TOTEM
- UA9
- WLCG

Applications

- ADaMS
- AIS Rates
- Book a room
- EDH
- EDMS
- E-groups
- CDS
- CET
- HRT
- IMPACT
- Indica
- OracleHR
- Phonebook
- Quailac
- Learning Hub
- SNOW

Admin and procedures

- Admin e-guide
- CERN design guidelines
- Computing accounts
- Users' Office

Maps and access

Finding a building, getting around
Outline

- Proton Irradiation Facility (IRRAD)
- Software and Hardware Upgrades for IRRAD
- Software Developments for Users Community
- Towards Common Tools for Irradiation Facilities
Irradiation Experiments

CERN Large Hadron Collider (LHC) ©cds.cern.ch

NASA’s Orion spacecraft ©arstechnica.com

Bottle sterilization by electron beam irradiation ©Courtesy Frank-Holm Roegner

Clinac® iX System linear accelerator ©medicalexpo.com
Bridging the Gap in Data Management

- Knowledge sharing among communities
- Small experiments, no strong IT support
- User Experience

- Standardization
- Automatic generation of web applications
- UI personalization

28 October 2020
Ontology Origin

Deriving from ancient Greek:

\[ \text{Ontology} = \text{On (ὄν)} + \text{logos (λόγος)} \]

**In philosophy:**

*subject of existence*, science of being, "what exists" in the world

**In computer science:**

formal description and classification of “what exists”, what can be represented as a knowledge fact
Ontology Use

- Standardization of domain knowledge
- Generation of web applications
- Recommender systems
Irradiation Experiments Data Management (IEDM) Ontology

- 115 classes
- 941 annotations
- 24 object properties
- 16 data properties

www.cern.ch/iedm
Web Application Generator (GenAppi)

Loading ontologies

Transforming domain classes and object/data properties to Model classes and attributes

Generating Django view files for data operations (CRUD)

Creating Django Template and URLs files for the UI

Grouping files in specific directories

Migrating Model and server ready for start

Loading Ontologies

Domain Ontology to Model Mapping

Creating Templates and URLs

Web Application Packaging

Migration and Server Settings
IEDM Use Case

- Input form for each domain-ontology class instance:
  - Data properties = input fields
  - Object properties =
    - selection fields, links to the corresponding class forms

- Django authentication and authorisation

- UI adaptable to user’s preferences

- Visualisation of domain ontology
User Interfaces Comparison: List Table

**IRRAD Data Manager**

**FCC-RADMON users**

<table>
<thead>
<tr>
<th>Name</th>
<th>Surname</th>
<th>E-mail</th>
<th>Telephone</th>
<th>Role</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blerina</td>
<td>Gkotse</td>
<td><a href="mailto:blerina.gkotse@cern.ch">blerina.gkotse@cern.ch</a></td>
<td>111111</td>
<td>User</td>
<td></td>
</tr>
</tbody>
</table>

**IDM list table**

**IEDM**

**User**

<table>
<thead>
<tr>
<th>surname</th>
<th>email</th>
<th>name</th>
<th>hasRole</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gkotse</td>
<td><a href="mailto:blerina.gkotse@cern.ch">blerina.gkotse@cern.ch</a></td>
<td>Blerina</td>
<td>Responsible</td>
<td>View Update Delete</td>
</tr>
</tbody>
</table>

**Iedm_APP list table**
## Comparison of IDM and generated application

<table>
<thead>
<tr>
<th>Purpose</th>
<th>IDM</th>
<th>Generated Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose</td>
<td>IRRAD facility data management</td>
<td>any domain</td>
</tr>
<tr>
<td>Software infrastructure</td>
<td>CERN</td>
<td>free and open-source</td>
</tr>
<tr>
<td>Storage</td>
<td>Oracle database</td>
<td>any relational database or ontology</td>
</tr>
<tr>
<td>Web Semantic technologies</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Functionalities</td>
<td>more advanced</td>
<td>CRUD(^2) operations</td>
</tr>
</tbody>
</table>

\(^1\)Web Semantics, the field dealing with ontologies  
\(^2\)CRUD = Create, Read, Update, Delete
UI Recommendations

Using recommender systems to suggest to users more user-friendly interfaces

What if this can be done also for scientific publications or (irradiation) experiments?

Different User Interfaces
Data Management Perspectives

- **Standardisation** of data management for irradiation experiments
  - Online documentation: [www.cern.ch/iedm](http://www.cern.ch/iedm)
  - Next planned work: **GIF++ data management**

- **Common tools** in the HEP community
  - IDM installed in the upcoming **FERMILAB** proton irradiation facility
  - Future extension to **ENEA-FNG**, collaboration with industry (**CAEN**)
  - Proposal in **AIDA innova**

- **More user-friendly interfaces** with recommender systems

- **Irradiation experiments publications recommendations**
  - Interest from **NEC-labs Europe** for building recommender systems for scientific publications
Conclusions

- **New software tools** for the support of the IRRAD irradiation experiments after LS2

- **New hardware (beam instrumentation,…), larger technical area and additional equipment**

- **Irradiation facilities and test-beam DBs** functional and used by the HEP community at large

- Working towards building **common tools** for irradiation experiments data management (at CERN and outside)
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MINES ParisTech: Pierre Jouvelot

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28 October 2020
Ontology: Structure

- **Class**: a set of entities of a specific domain of knowledge
- **Relation**: a semantic link among classes, also called *object property*
- **Property**: attribute of specific type, also called *data property*

Excerpt from SOSA (Sensors, Observations, Samples and Actuators) ontology
Knowledge Base (KB)

- Individual instances of domain’s classes
- RDF triples (Resource Description Framework)
- Stored in triple stores

19/09/2019 12:19

resultTime

Temperature Sensor1

madeBySensor

Sensor

observes

Observable Property

isObservedBy

Temperature

observedProperty

xsd:dateTime

resultTime

hasSimpleResult

20°C

hasSimpleResult

xsd:dateTime

resultTime

rdfs:Literal

hasSimpleResult

rdfs:Literal

resultTime

madeObservation

madeBySensor

TS1Observation42

hasSimpleResult
Knowledge Graph (KG)

- Term coined by Google (2012)
- Knowledge bases from a variety of sources
- Used in academia and industry
Ontology-based Web Application Ontology (OWAO)
OWAO UI Preferences Example

Excerpt from OWAO ontology showing “User1” instance and UI Preferences (displayed from web Protégé)
Ontology Embedding

Ontology instances $\rightarrow$ words, text

(e.g. TemperatureSensor1 observes Temperature)

Word representation as feature vectors for tracking

- similar words and
- words appearing in the same context

Used in recommender systems for suggesting similar items

<table>
<thead>
<tr>
<th>Feature1</th>
<th>Feature2</th>
<th>Feature3</th>
<th>Feature4</th>
</tr>
</thead>
<tbody>
<tr>
<td>car</td>
<td>bike</td>
<td>cake</td>
<td>chocolate</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Feature space
New embedding: **ontowalk2vec**

New hybrid NLP model:
- *node2vec* → explicit structure of the ontology
- *RDF2Vec* → RDF triples

**Algorithm:**

- *node2vec* random walks
- *RDF2Vec* triples
- **Feature Vectors**