

## CERN GIF<sup>++</sup> : A new irradiation facility to test large-area particle detectors for the high-luminosity LHC program

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The high-luminosity LHC (HL-LHC) upgrade is setting new challenges for particle detector technologies. The increase in luminosity will produce a higher particle background with respect to present conditions. Performance and stability of detectors at LHC and future upgrade systems will remain the subject of extensive studies. The current CERN Gamma Irradiation Facility (GIF) has been intensively used to simultaneously expose detectors to photons from a <sup>137</sup>Cs source and to high energy particles from the X5 beam line in SPS West Area for many years. Since 2004, only the <sup>137</sup>Cs source is available for irradiations and the shutdown of the facility is scheduled for the end of 2014.

In this paper we present a joint project between the CERN engineering and physics departments to design and build the new GIF<sup>++</sup> facility. It will be a unique place where high energy charged particle beams, mainly muon beam with momentum up to 100 GeV/c, are combined with a 14 TBq <sup>137</sup>Cs source. The source will produce a background gamma field 30 times more intense than at GIF, allowing to cumulate doses equivalent to HL-LHC experimental conditions in a reasonable time. The 100 m<sup>2</sup> GIF<sup>++</sup> irradiation bunker has two independent irradiation zones making it possible to test real size detectors, of up to several m<sup>2</sup>, as well as a broad range of smaller prototype detectors and electronic components. The photon flux of each irradiation zone will be tuned using a set of Lead filters. Flexible services and infrastructure including electronic racks, gas systems, radiation and environmental monitoring systems, and ample preparation area will allow time effective installation of detectors. A dedicated control system will provide the overview of the status of the facility and archive relevant information. The collaboration between CERN and the users detector community, the latter providing detector specific infrastructures within the framework of the FP7 AIDA project, will bring the new facility to operation by the end of 2014.

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## 1. Introduction

Over the last years, the CERN Gamma Irradiation Facility (GIF) [1], located in the SPS West Area, has been extensively used for the characterisation of particle detectors, in particular the large area muon detector systems, and components for the Large Hadron Collider (LHC) [2]. Detectors could simultaneously be exposed to the photons from a  $^{137}\text{Cs}$  source and to high energy particles from the X5 beam line. Although from 2004 onwards only the Cs-Source was available for irradiation, the GIF continued to be fully booked all year round, providing irradiation to several users in parallel. However, there is a clear need for a stronger source and for regaining the possibility to carry out simultaneous detector performance tests with a high-energy beam, as outlined in [3]. The high-luminosity LHC (HL-LHC) upgrade is setting a new challenge for particle detector technologies. The increase in luminosity will produce a higher particle background with respect to present conditions. The detailed knowledge of the performance of detectors under such a high particle flux and a precise understanding of possible ageing of detectors and materials under permanent particle bombardment are crucial for an optimised design and efficient operation mode. Following a survey within the user community, a new Gamma Irradiation Facility (GIF<sup>++</sup>) was designed.

The GIF<sup>++</sup> is a joint project between the CERN Engineering- (EN) and Physics- Department (PH). The “Machines and Experimental Facilities” group (EN-MEF) provides the infrastructure for housing the irradiator and the detectors. This covers the civil engineering components (shielding, false floor etc.), the beam line elements, the control room and the supply of general infrastructure (electricity, gas supply, structured cabling for computer network) to the boundary limits of the service zone and the control room. The “Detector Technologies” group (PH-DT) provides the irradiator and the attenuator, the facility controls (GIF control System), the gas mixing and distribution systems, as well as the user coordination. In addition, a comprehensive user infrastructure is provided within the framework of the FP7 AIDA project.

Focused on the characterisation and understanding the long-term behaviour of large particle detectors, the GIF<sup>++</sup> combines a 14 TBq  $^{137}\text{Cs}$  source (a  $30\times$  higher photon intensity compared to the current GIF), with high energy charged particle beams from the secondary SPS beam line H4 in EHN1 (887). The H4 beam line in the North Area of CERN was designed to deliver secondary and tertiary beams of various particle types (hadron, electron, muon, ions), as well as an attenuated primary proton beam, to fixed target experiments located in the EHN1 experimental hall. The momentum range of the beam line is quite large, from 10 GeV/c up to the maximum SPS momentum of 450 GeV/c. Secondary beams are produced directly from the impinging primary beam from SPS onto the T2 target, while tertiary beams can be produced using a secondary target located at about 130 m downstream of the T2 target. For both cases, a spectrometer (length 300 m) constructed of six MBN dipole magnets (total bending angle 42 mrad) is used for the momentum selection. The maximum momentum acceptance of the beam line is  $\Delta p/p_{max} = \pm 1.4\%$  [4]. Located near the end of H4, GIF<sup>++</sup> will be the main user of the beam line for 6-8 weeks per year. In addition, the facility can receive parasitic muon beam for 30-50% of the SPS operation time, where the intensity and energy will depend on the settings chosen by the primary beam line user. Gamma irradiation will however be available throughout the whole year, except during short maintenance periods.

The 100 m<sup>2</sup> GIF<sup>++</sup> irradiation bunker has two independent irradiation zones, making it possible to test real size detectors, up to several m<sup>2</sup>, as well as a broad range of smaller prototype detectors

and electronic components. The facility will be equipped with a central control system to record all relevant environmental parameters, beam parameters, filter settings, as well as to redirect interlocks on gas mixtures qualities supplied to the detectors. A wide range of readily available gases can be used by connecting to the gas panels distributed throughout the facility. The facility will be equipped with fixed installed beam-trigger and cosmic-trigger systems.

## 2. The Irradiator and Attenuator System

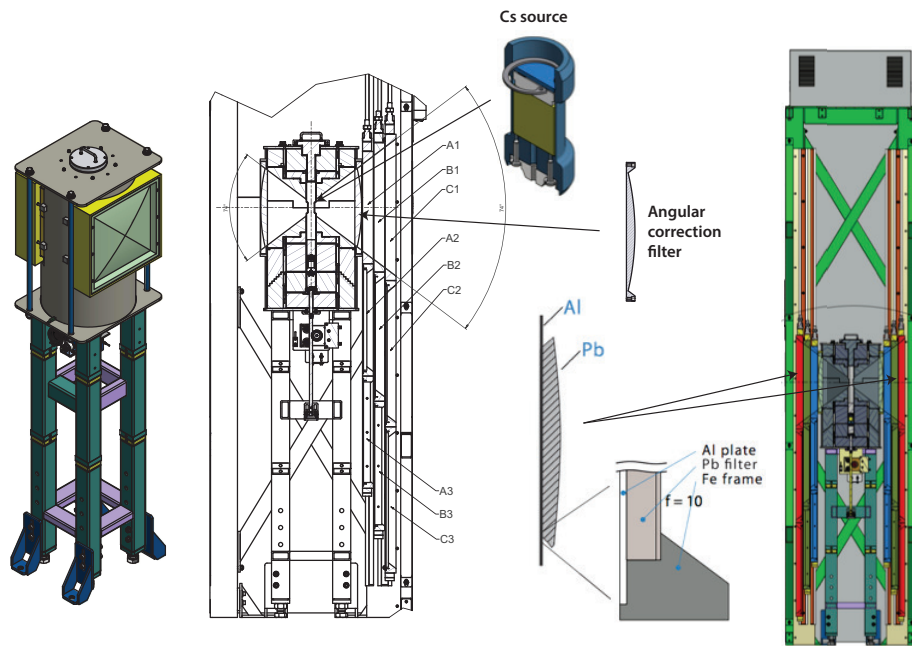
The irradiator has been developed in cooperation with VF a.s.<sup>1</sup> A <sup>137</sup>Cs source, embedded between two Tungsten blocks, can be moved from the garage position at the bottom of the support tube to the irradiation position on the top of the tube (figure 1). With two  $\pm 37$  degree panoramic collimators, the irradiation zone covers a large part of the bunker area, both in the downstream and upstream regions (figure 2). Mounted on an adjustable support, the centre of the irradiation window is at beam height, delivering up to 260  $\mu\text{Gy/s}$  ( $\approx 1\text{Gy/h}$ ) at a distance of 1 meter. Both collimators are equipped with a replaceable steel angular correction filter to provide uniform photon distribution for large area detectors. Embedded inside a common enclosure, two independent attenuation systems are available, each consisting of an array of 3 x 3 absorption filters, to fine tune the photon flux of each irradiation field individually. The arrangement of the attenuator filters for one field is shown in figure 1, the reduction factor of each filter is given in table 1. The convex filters are made of paint coated Pb, except the one with the smallest attenuation factor of 1.47 which is made out of steel. Mounted on aluminium support plates, the filters are positioned inside steel frames and connected to counter weights on the side of the irradiator. The attenuation factor can be set both via a dedicated control panel, as well as via the overall GIF control system. Attenuation between 0 and  $\approx 50.000$  can be selected according to the possible combinations from the 3 planes (A,B,C) listed. The irradiation can be started and stopped from the GIF<sup>++</sup> control room. For predefined durations a timer can be used.

Figure 3 shows the simulated dose equivalent rate in  $\mu\text{Sv/h}$  for the irradiation without angular correction lenses or attenuation filters. In the direct irradiation zones, 1 Sv/h is reached at a distance of one meter from the source. Due to multiple scattering of photons in the bunker area, the dose rate stays above several mSv/h throughout the whole centre zone. In the main access path, 0.1 mSv/h can be expected. As seen from table 2, these dose rates will allow the efficient testing of Muon systems against the expected HL-LHC background.

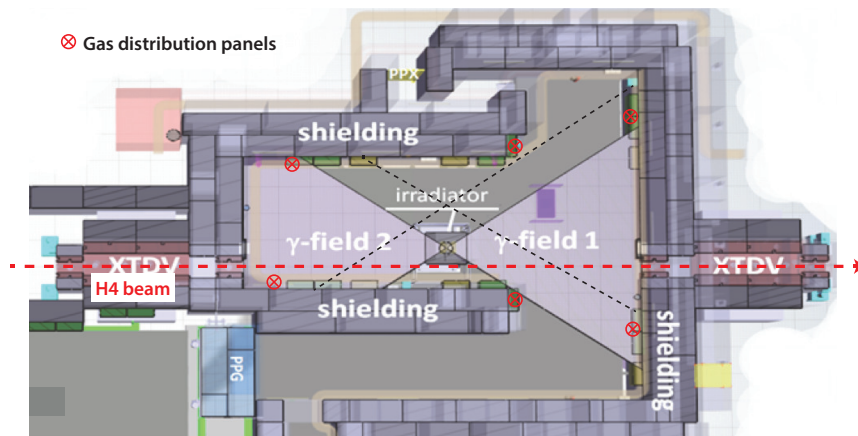
Plane :	A	B	C
Pos. 1	1	1	1
Pos. 2	10	1.47	2.15
Pos. 3	100	100	4.64

**Table 1:** Attenuation factors for the different filters, according to their position displayed in figure 1. 24 different attenuation factors can be realised. Attenuation “1” refers to an empty frame.

<sup>1</sup>VF a.s., Svitavská 588, 679 21 Černá Hora, Czech Republic, <http://www.vf.eu>



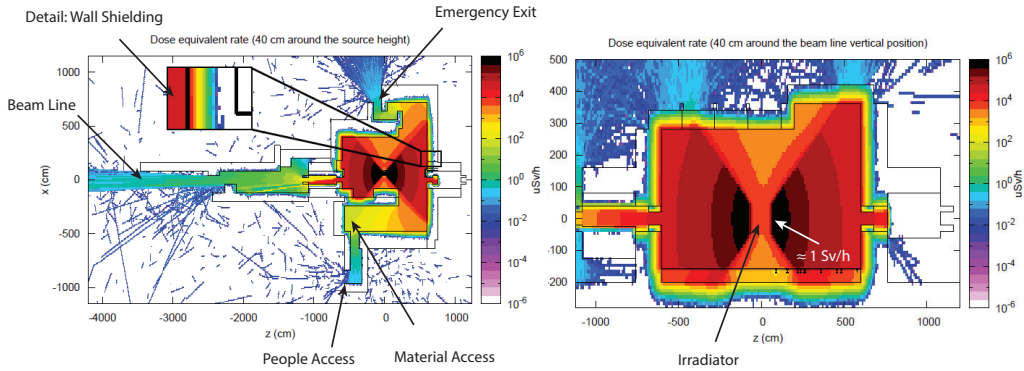
**Figure 1:** The Caesium irradiator with a sketch of the Lead attenuator filters. The  $^{137}\text{Cs}$  source delivers  $260 \mu\text{Gy/s}$  at a distance of one meter.



**Figure 2:** Layout of the irradiation bunker area. The dotted black lines indicate the boundary of the photon field when the irradiator is in the position away from the beam pipe. The red  $\otimes$  indicate the position of the gas distribution panels.

### 3. Irradiation bunker and general infrastructure

The irradiator will be hosted inside a newly constructed bunker, shielded by 1.6 m of concrete (figure 4). The bunker will be equipped with a material access door to allow easy installation of large detectors. If required, the roof of the bunker can be opened for the installation of detectors of several square meters and up to several tons. Alongside the bunker a two floor rack area has been constructed, which hosts the gas distribution (17 racks, upper floor), as well as the electronic equipment (17 racks, lower floor). The whole facility is equipped with a raised floor to allow the



**Figure 3:** Simulation of the dose equivalent rate (in  $\mu\text{Sv/h}$ ) for the two  $\pm 37$  degree irradiation fields without angular correction lenses or attenuations [5]. Left : Full bunker area including beam line, shielding and access chicane. Right : Detailed simulation of the centre irradiation zone.

Max. expected doses at HL-LHC	Equivalent time at GIF <sup>++</sup> (50 cm from source)
Si-trackers: $\sim \text{MGy/y}$	$\gg$ years
Calorimeters: $\sim 20 \text{ kGy/y}$	$< 1$ year
Muon systems: $\sim 0.1 \text{ Gy/y}$	$\sim$ minutes

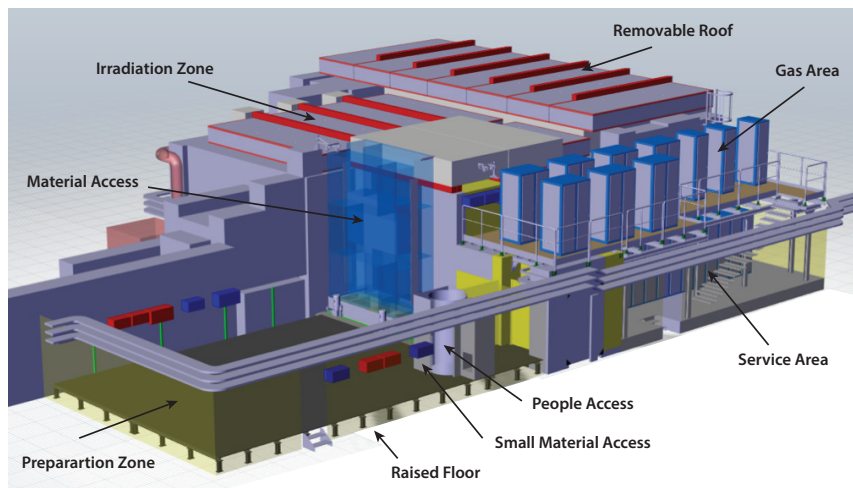
**Table 2:** Comparison between the expected dose at the HL-LHC and the required time at the GIF<sup>++</sup> for different detectors.

effective distribution of gas lines and cables. The shortest cable path is around 13 meters from the racks to a position in front of the irradiator. A large “Preparation Zone” ( $\approx 80 \text{ m}^2$ ) is available, where full size detectors can be setup and commissioned before moved to the radiation zone. Like the inside of the irradiation bunker, the Preparation Zone is completely equipped with gas lines, electricity, network and the detectors can already be connected to the final DAQ hosted in the service area. Signal cables and HV/LV patch panels will be added during a first upgrade, both in the preparation zone as well as inside the bunker.

During  $\approx 3$  weeks per year, an electron beam needs to be provided to the CMS electromagnetic calorimeter (ECAL) experiment, located downstream of the GIF<sup>++</sup>. In this case a beam pipe will be installed throughout the irradiation bunker, effectively linking the access mode to the H4 conditions set by CMS/ECAL. Irradiation from the Cs source can continue, except when access to the upstream or downstream areas is needed. To provide the same irradiation area, the irradiator including attenuators has been placed on a movable platform and can be shifted by 1.5 meters away from the beam line (see dotted lines in figure 2).

The GIF<sup>++</sup> will be equipped with a powerful and flexible gas service system. All gases needed<sup>2</sup> for the operation of particle detectors will be available in the gas mixing zone through dedicated primary supply panels. Additional gas supply lines will be available for R&D programs. At least 6 racks installed in the gas service area will be dedicated to the preparation of gas mixtures for particle detectors under test. The gas analysis systems will allow to monitor the flammability level

<sup>2</sup>Ar, CO<sub>2</sub>, N<sub>2</sub>, He, SF<sub>6</sub>, CF<sub>4</sub>, iC<sub>4</sub>H<sub>10</sub>, CH<sub>4</sub>, Ar/H<sub>2</sub>, C<sub>2</sub>H<sub>2</sub>F<sub>4</sub>



**Figure 4:** Overview over the GIF<sup>++</sup> area in EHN1. The 100 m<sup>2</sup> irradiation zone inside a concrete bunker is complemented by a 80 m<sup>2</sup> Preparation Zone, which allows the setup and commissioning of full size detectors before the irradiation experiment.

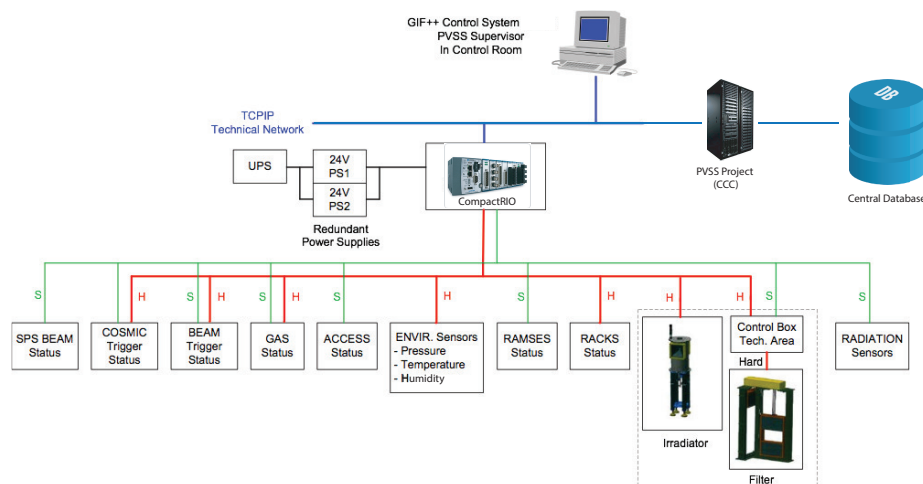
of mixtures containing flammable components. In addition, it will measure the Oxygen and water vapour contents on the supply lines and the returns from the detectors. The gas analysis system will perform automatic scans between all the gas streams selected. A gas chromatograph will be permanently connected to the gas analysis rack, allowing a more specific measurement of the gas quality. New gas recirculation systems have been designed for the GIF<sup>++</sup>, with one module available at startup. In the gas mixing zone, 8 gas distribution panels for a total of 48 gas lines (with supply and return pipes) will distribute the gas mixture to the irradiation bunker (figure 2) and the preparation zone. The gas system infrastructure will be controlled and monitored using the same concept as the gas systems for the LHC experiments. All data about consumption, mixture composition, pressures, etc. will be available through a PVSS interface and via DIP<sup>3</sup>.

#### 4. The Control System

The GIF<sup>++</sup> Control System is based on a CompactRIO hardware system from National Instruments in the service area, and a PVSS / WinCC Open Architecture project, hosted in the CERN Control Centre (CCC). The purpose of the control system is to monitor and archive all relevant operation parameters (irradiator source state, beam conditions, environmental conditions, access status.....) as well as to control the attenuation filters of the irradiators. It will provide interlocks (e.g. on gas system faults) to user equipment, and will allow the remote monitoring of the facility. To locally monitor the irradiation levels, 8 RADMON<sup>4</sup> sensors [6] will be available inside the bunker area, which can be attached directly to the detector under irradiation. Connected to the protected CERN Technical Network (TN), the control system will archive all parameters to a central CERN database. A user supervision PC will be available in the control room. The design layout of the control system is displayed in figure 5.

<sup>3</sup>CERN Data Interchange Protocol

<sup>4</sup>Configured with two RadFET detectors: one LAAS 1600 (up to 10 Gy) and one REM 250 (up to 2000 Gy)



**Figure 5:** Design of the central GIF<sup>++</sup> control system. Hardwired connections (H) drawn in red, software connections (S) drawn in green.

## 5. AIDA User Infrastructure

The user infrastructure, provided within the framework of the FP7 AIDA project will include beam- and cosmic-trackers, a gas and environmental monitoring, a radiation monitoring, a Detector Control System as well as a DAQ system [7].

The two beam trackers, located at the beam entrance and exit inside the bunker, will consist of two Thin-Gap-Chamber 4-plets ( $60 \times 40 \text{ cm}^2$ ) with strips, wires and pads in each gap. The spatial resolution measured in test beam was  $\sim 80 \mu\text{m}$ . In 2014, 4 layers will be equipped with temporary front-end and readout electronics, while the final electronics for the 8 layers will be implemented in 2015. The cosmic trigger will consist of a Roof Tracker, a Floor Tracker as well as an Underground Detector (confirmation plane). The Roof Tracker, installed in the downstream irradiation zone will consist of 4 independent Resistive Plate Chamber detectors ( $1.0 \times 0.5 \text{ m}^2$ ) with 3 cm wide readout strips and 1 or 2 fine tracking RPC ( $30 \times 30 \text{ cm}^2$ ) with 1 cm wide X-Y strips. The Floor Tracker will use the same  $1.0 \times 0.5 \text{ m}^2$  chambers as for the Roof Tracker, as well as one fine tracking RPC chamber. The underground detector consists of double layer RPC chambers with a total area of  $2.8 \times 2.4 \text{ m}^2$  with 4 cm strips in XY, and will be shielded by a 15 cm thick steel floor plate. The DCS will use the same PVSS/WinCC Open Architecture as currently operated in LHC experiments. The power system will be implemented with a CAEN Easy Power System consisting of one mainframe, one Power Generator, one or two crates with HV and LV boards and one ADC A-3801 board (128 channels). The mainframe along with the DAQ PCs and equipment will be located in the service area. For the radiation monitoring, 8 RADMON sensors will be available. In addition to the environmental monitoring on a room level covered by the GIF<sup>++</sup> control system, the DCS system will provide monitoring of temperature, pressure and relative humidity for 6 atmospheric and 4 gas sampling points. The DAQ system will create a trigger from the beam tracker (TGC) and/or the cosmic tracker (RPC), distribute this trigger to different Detectors Under Test (currently up to 5 DUTs) and synchronize the events from the TGC/RPC with the DUTs for tracking/efficiency purpose. The implementation is based on a “Trigger Logic Unit” module provided by the EUDET

[8] community and intensively used in test beams (DESY, CERN, FERMILAB ...). This unit provides trigger signal and trigger number to all detector DAQs.

## 6. Conclusions and Outlook

A unique irradiation facility is under construction at CERN, combining a strong gamma source with a high energy particle test beam and a very comprehensive service- and user-infrastructure. The facility has been designed to host full size gas detectors (several m<sup>2</sup>) as well as small test setups. With two independently attenuated photon fields, it offers the flexibility to fulfil the needs of a variety of different users at any time. With a Trigger and Detector Control System based on the same hardware and software currently used at the LHC experiments, it allows efficient integration and commissioning of new detector technologies in preparation for the HL-LHC. With an life time of >10 years, care has been taken to integrate the GIF<sup>++</sup> in the existing CERN infrastructure, from the electronic logbook (used at PS, SPS, LHC...) to the recording of relevant parameters in a CERN standard database. All interventions and space allocations inside of the bunker area will be organised via IMPACT<sup>5</sup> [9], guaranteeing a reliable traceability over the foreseeable future.

With the delivery of the irradiator at the end of September, the commissioning of the facility will start in October and continue until early December, when two days of dedicated SPS beam will allow the testing of the beam trigger. Therefore the GIF<sup>++</sup> is well on track to be fully operational early 2015.

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<sup>5</sup>Intervention Management Planning & Activity Coordination Tool, <http://impact.cern.ch>