EP-DT
Detector Technologies

The new CERN Gamma Irradiation Facility to Test Large-Area Detectors for the HL-LHC Program

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on behalf of the GIF++ collaboration:
CERN EN department,
CERN EP department
AIDA - users

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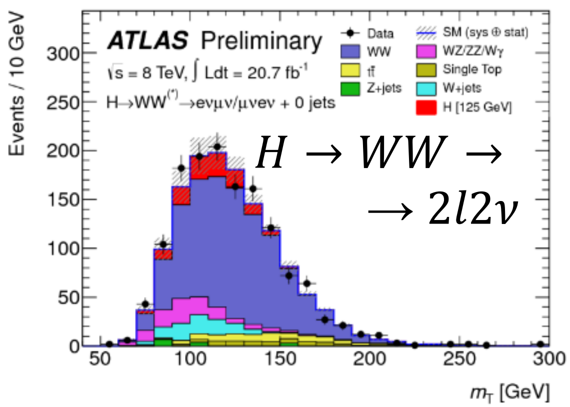
Outline

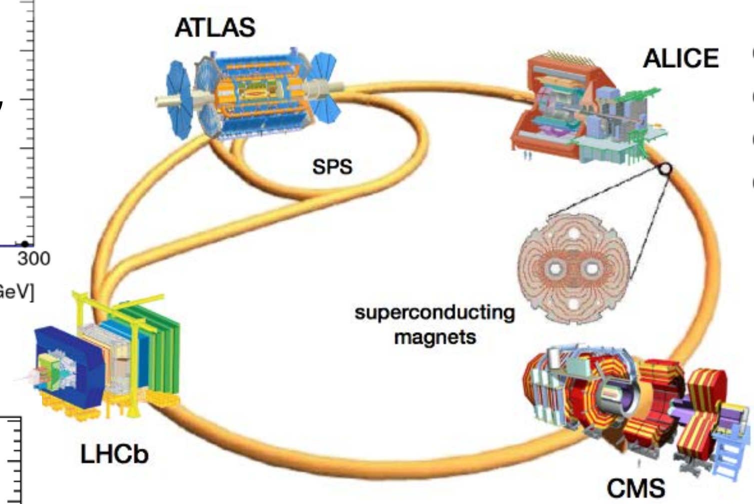
- Introduction and motivations
  - Muon detector systems at LHC and beyond
  - Background radiation at LHC
  - Challenges for the HL-LHC physics program and detector upgrade plans
  - Irradiation facilities for R&D and detector validation
- The new GIF++ facility:
  - GIF++ collaboration
  - Gamma irradiator and muon beam
  - Infrastructures and tools for users
- Overview of the R&D programs and detector technologies
- Conclusions

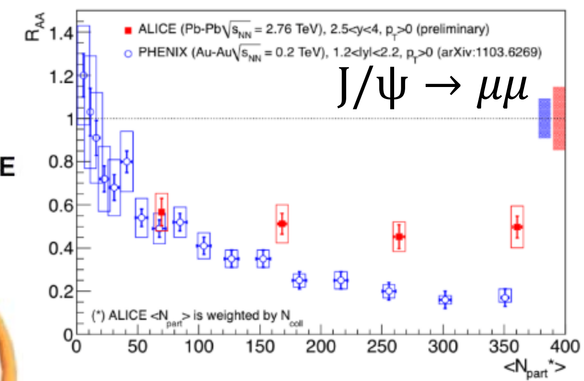
All around R&D for Muon Detectors

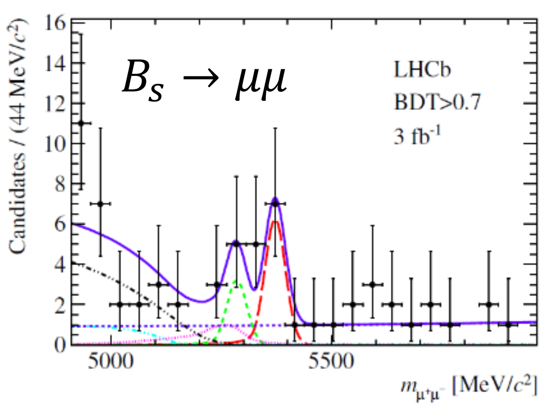
The LHC experiments:

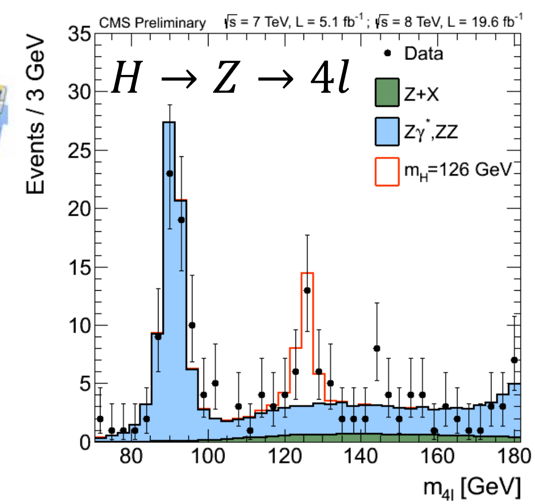
- different in physics programs, detector designs and technologies
- so similar in their reliance on muon triggering and detection for reaching their physics goals











Background radiation at LHC

The LHC experiments are embedded into a high radiation environment produced by p-p collisions.

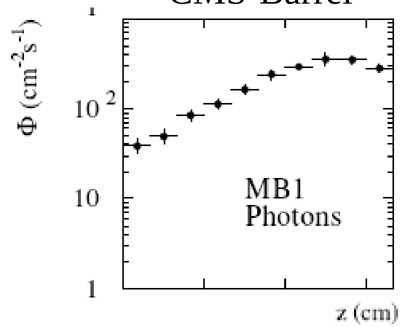
The CMS example for neutral radiation background

CMS Max flux:
Barrel ~ 460 Hz/cm^2
Forward ~ 10-50 kHz/cm^2

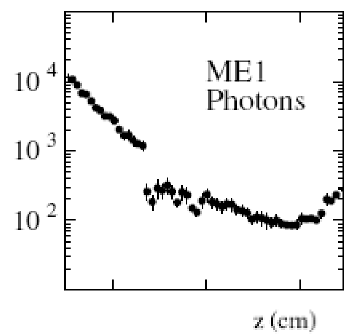
Energy:
20 keV - 100 MeV

Integrated dose:
< 1 Gy (Muon Barrel and most Forward regions)

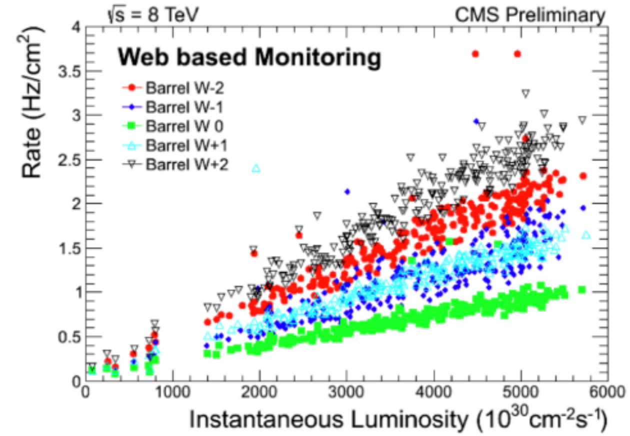
CMS-Barrel



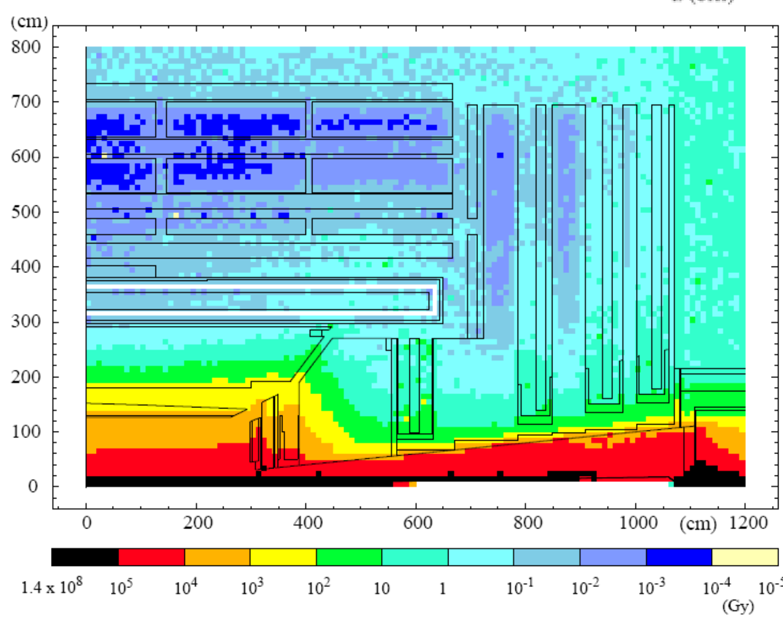
CMS-Forward

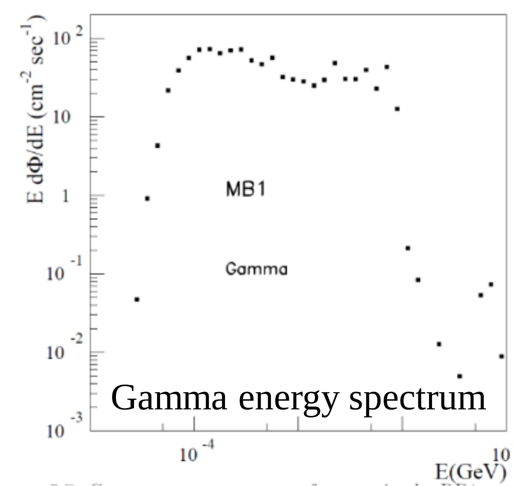


Measured rate in CMS-Barrel stations



CMS- experiment:
Integrated dose





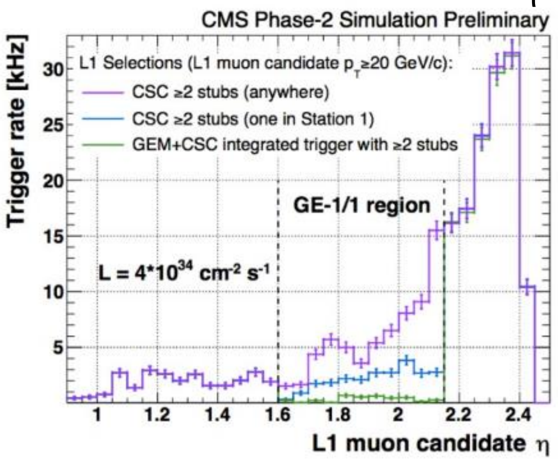
Experiments at HL-LHC

Robust muon triggering and identification will continue to be the major discovery drivers at the LHC.

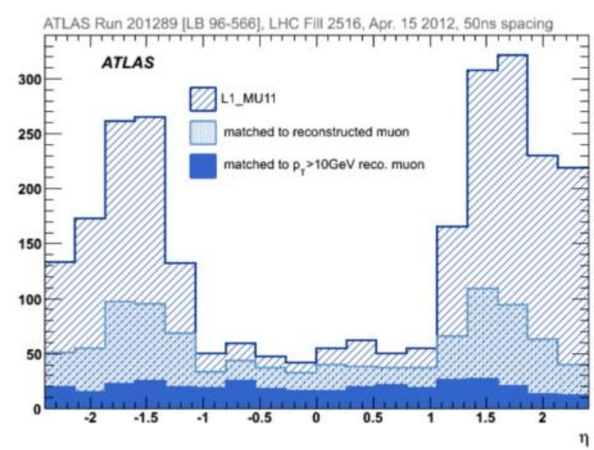
The increase of luminosity (up to HL-LHC) can adversely affect the muon systems performance

- **Forward region |η|≥2.0 especially challenging**
  - Rate of the order of 10’s of kHz/cm^2 or higher
  - Increase fake trigger rate
- **Ageing/longevity need to be verified**
  - Accumulated charge in C/cm^2
- **New requirements often exceed capabilities of the existing electronics**

CMS-L1 muon candidate vs η



Triggered vs reconstructed muon



Effects induced by background radiation

It is imperative that the design of a pp experiment at the LHC takes account of the hostile radiation environment engendered at high luminosity
(CMS Letter of Intent, CERN-LHCC 92-3, 1 Oct. 1992*)*

Two mechanisms:

- **instantaneous particle rate → *detector occupancy***
- Related to the detector efficiency to background radiation
  - Rate capability
  - Sensitivity/efficiency to background radiation
  - Uniformity

- **cumulative effects → *ageing***
- Related to the integrated particle fluence, dose and current in the detector
  - Detector performance vs accumulated charge equivalent to the one expected on the experiment
  - Detector performance with gas recirculation system (accumulation of pollutants in the gas mixture)
  - Detector components

A dedicated facility is needed to study the expected background

LHC experiments: Muon upgrade plan

The CMS example

	LS1					LS2				LS3	
2012	**2013**	**2014**	2015	2016	2017	**2018**	2019	2020	2021	**2022**	**2023**

Detector consolidation

Anticipated phase-2 upgrades

HL-upgrades

GE1/1 installation

CSC + GEM trigger

Additional detectors GEM+ME0+iRPC in forward region of all 4 stations

Rapidity extension of tracker, CAL, muon to |η|~4

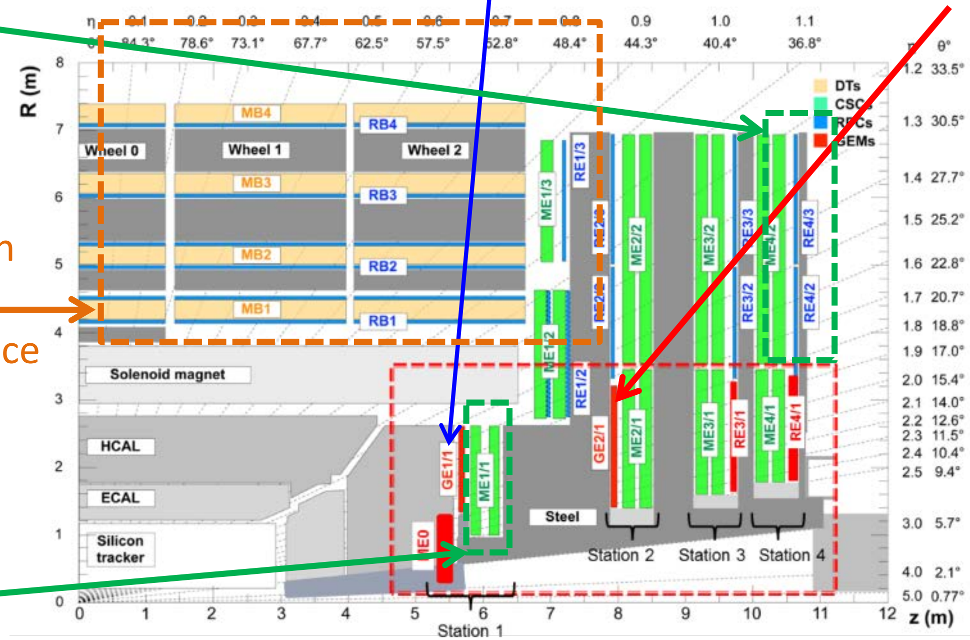
Detectors

ME4/2 + RE4/2 installed

Move part of DT electronics from detector to cavern and redesign in higher performance µTCA technology.

Electronics

Upgrade ME1/1 electronics.



Redesign of DT on-chamber electronics

The new CERN - GIF++

Strong needs from the LHC and HL-LHC detector and accelerator communities

- GIF++ follows up on the very successful GIF facility (1998-2013) were currently installed detectors were validated
- The GIF++ facility reflects the needs for new detector R&D in view of future upgrades

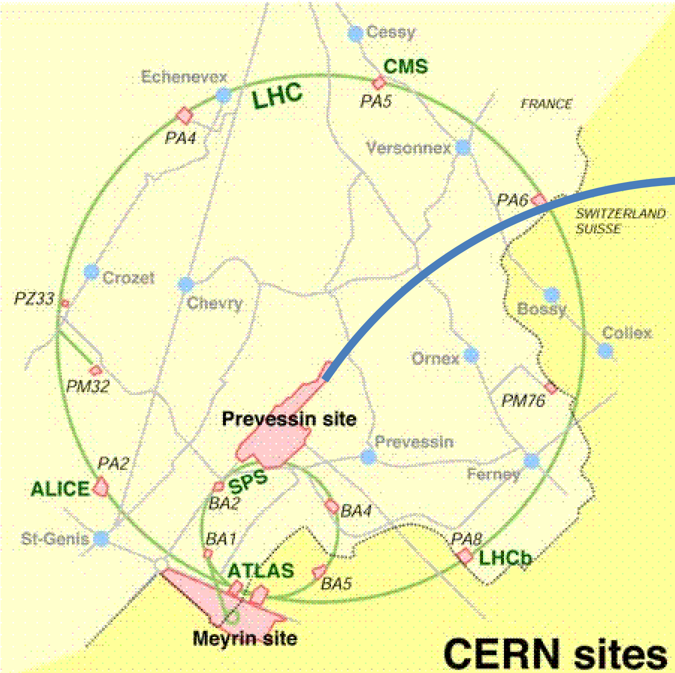
GIF++: a unique place for detector R&D

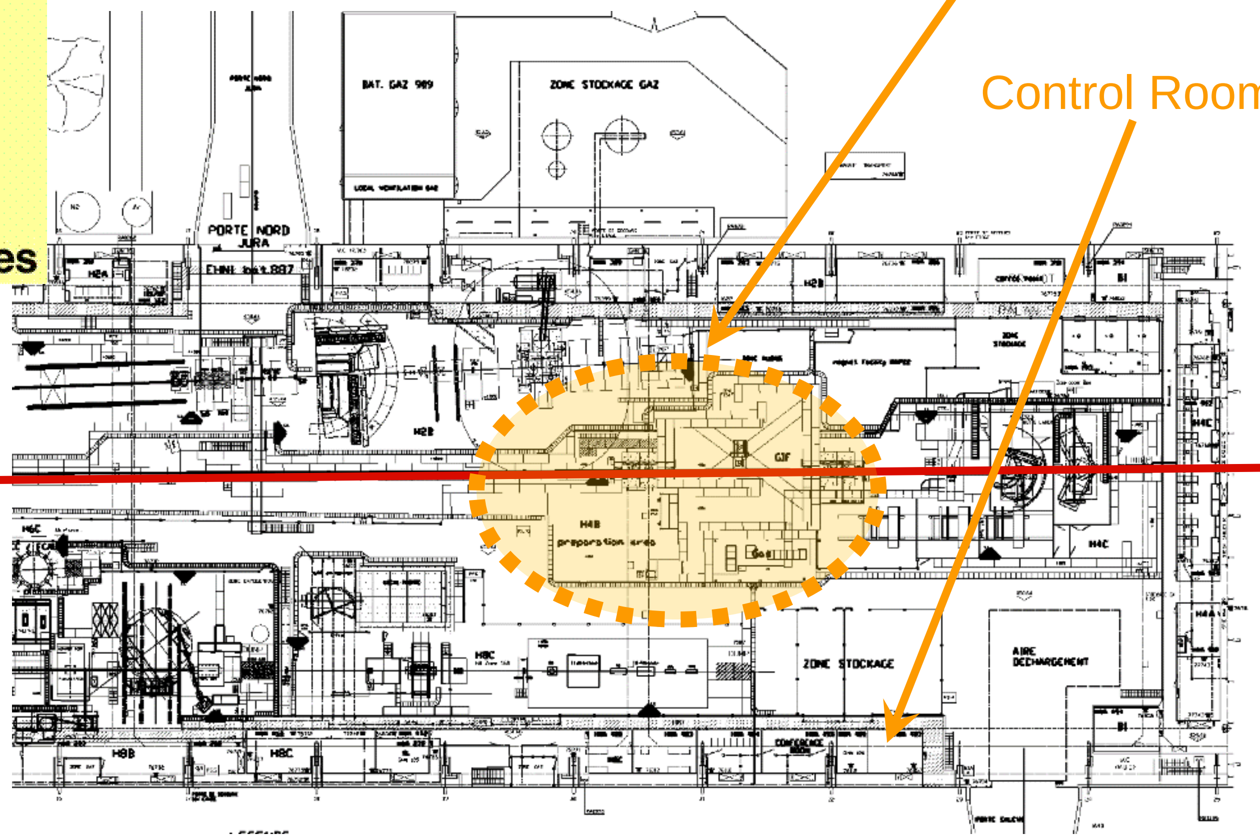
- Strong gamma source
- Particle beam available
- Excellent gas and electronic infrastructures
- Unified control/monitoring system
- Setups for beam & cosmic trigger, radiation monitoring, environmental monitoring, DAQ, …

GIF++ collaboration

- The CERN EN-department (EN-MEF)
  - provides the infrastructure for housing the irradiator and detectors: civil engineering components (shielding, false floor …), beam line elements, control room and the supply of general infrastructure (electricity, gas …)
  - provides the gas distribution lines inside the facility (about 5 km)
- The CERN EP-department (EP-DT)
  - provides the irradiator & attenuator, the facility controls (GIF control system), the gas systems, as well as the user management
- The user community
  - providing the detector specific infrastructures (beam trigger, cosmic trigger, …)

GIF++ facility: location





GIF++ facility: key numbers

New Gamma Irradiation Facility: 14 TBq ^{137}Cs 662 keV gamma source :

Distance from source	GIF++
1.5 m	58.7
3.0 m	14.7
4.5 m	6.5

Gamma flux ($\cdot 10^6$ cm^{-2} s^{-1})
(dose rate @ 5 m of ~20 mSv/h)

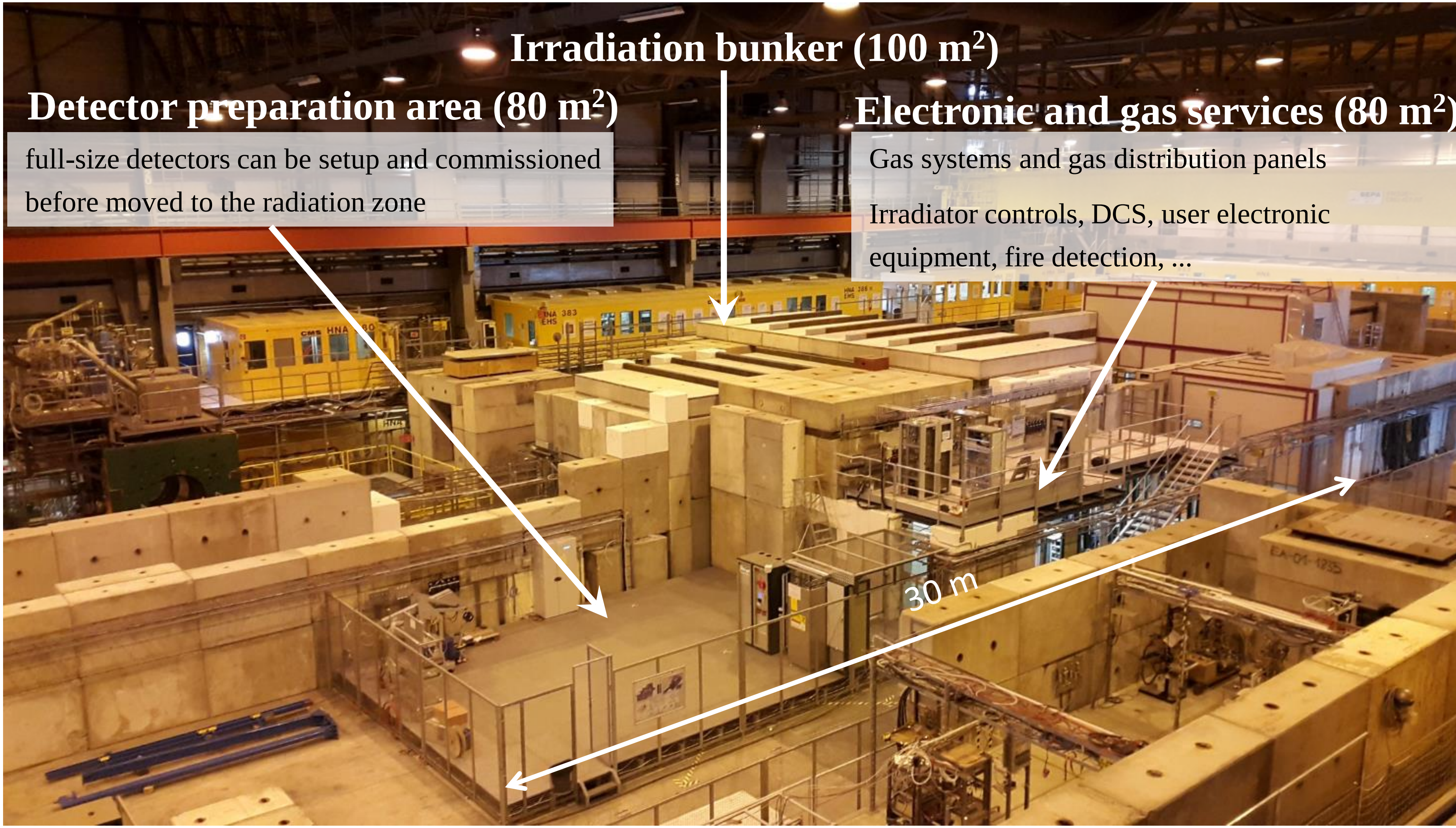
Max. expected doses at HL-LHC	Equivalent time at GIF++ (~ 1 m from source)
Si-trackers: ~ MGy/y	>> years
Calorimeters: ~ tens kGy/y	< 1 year
Muon systems: ~< Gy/y	*"days to months"*

Other CERN facilities available (Si-trackers, Calorimeters)

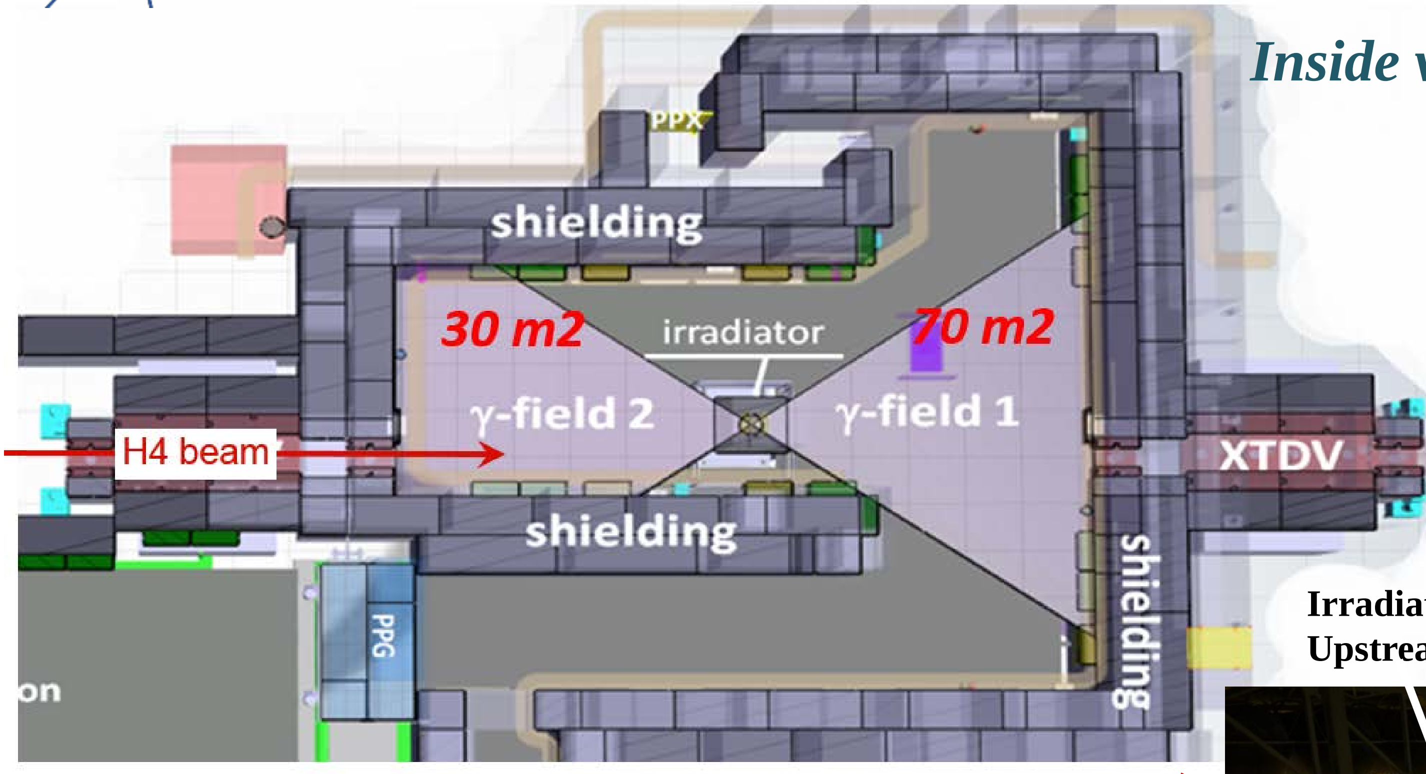
→ GIF++ (Muon systems)

- Possibility to tune gamma radiation intensity in a wide range
- Muon beam (100 GeV and 10^4 muons/spill) 6-8 weeks/year GIF++
- Parasitic beam use is available during some more weeks

GIF++ facility

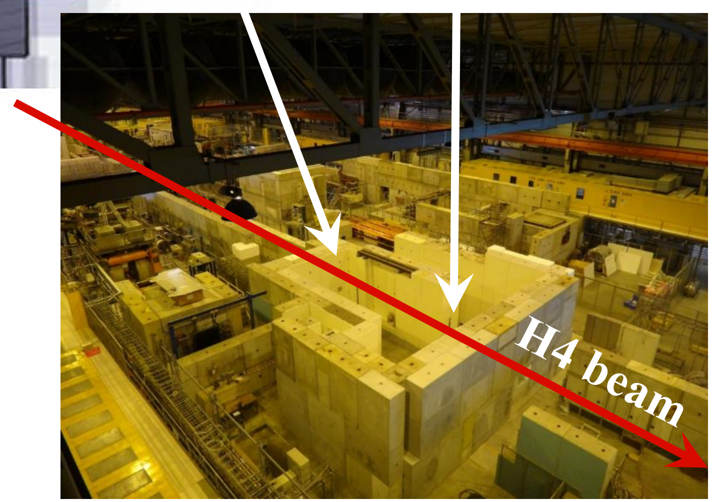


GIF++ facility



Inside view of the facility

Irradiation areas:
Upstream and downstream γ-fields



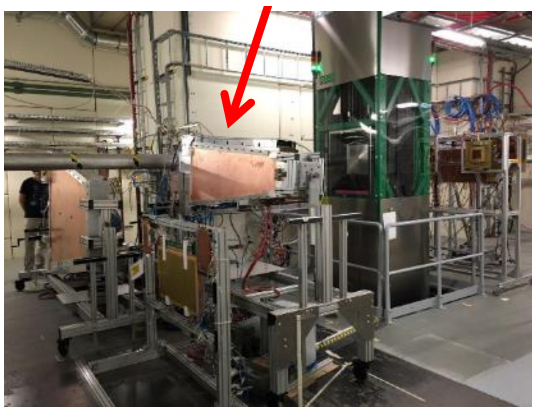
June 2014: bunker in construction with roof opened

GIF++ facility

Panoramic view of the inside of the bunker

^{137}Cs irradiator

Downstream area **Upstream area**



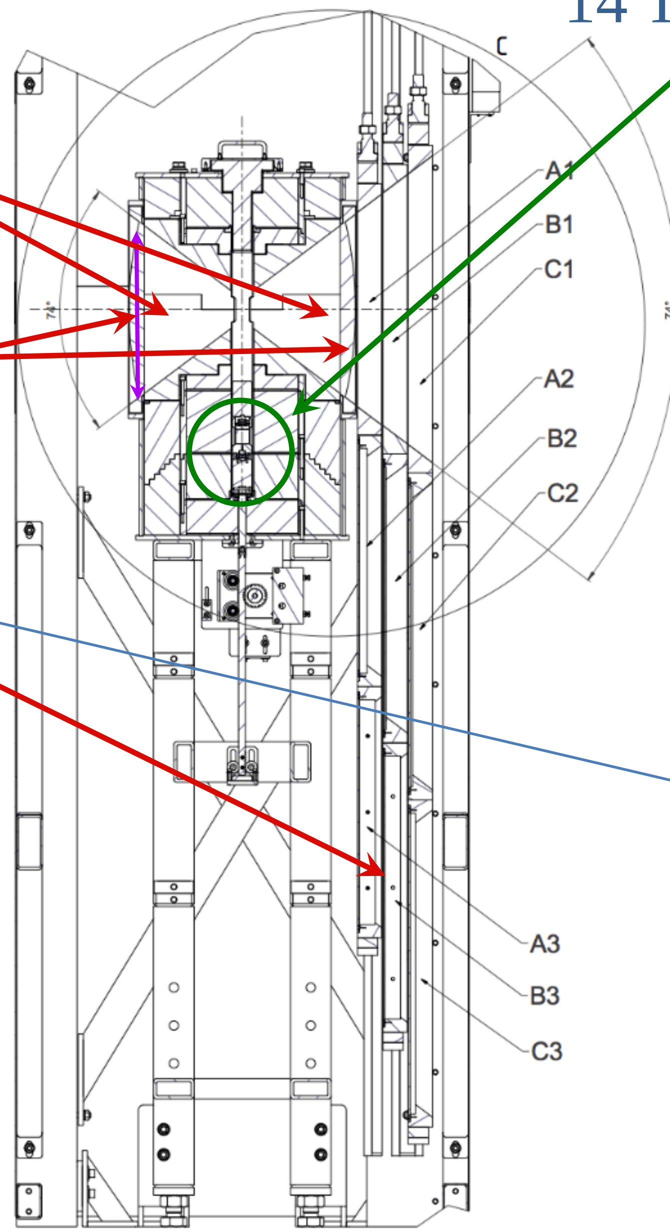
GIF++ irradiator

14 TBq ^{137}Cs

Two opening fields:
identical and 74° wide

Angular correction lens:
uniform gammas distribution on flat large area detectors

Radiation Attenuator:
3 Pb plates on each side
Attenuation factor up to 50.000



rate capability study

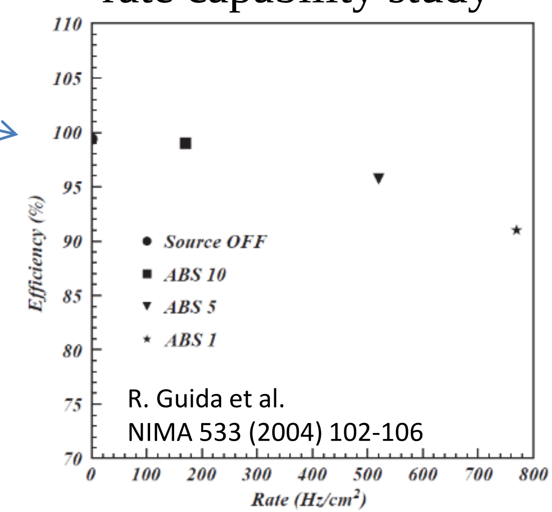


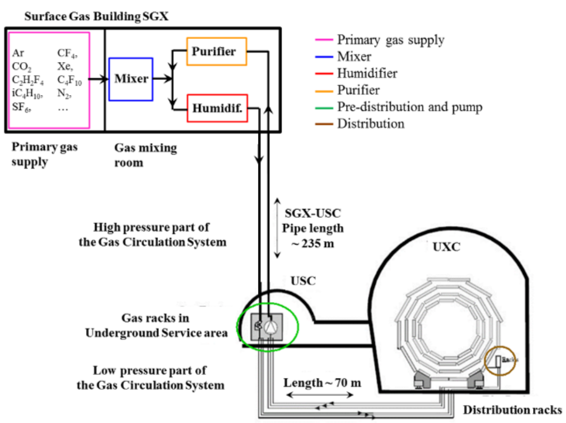
Fig. 5. Maximum efficiency reached by one of the RB1 chambers at different source conditions.

Gas systems service

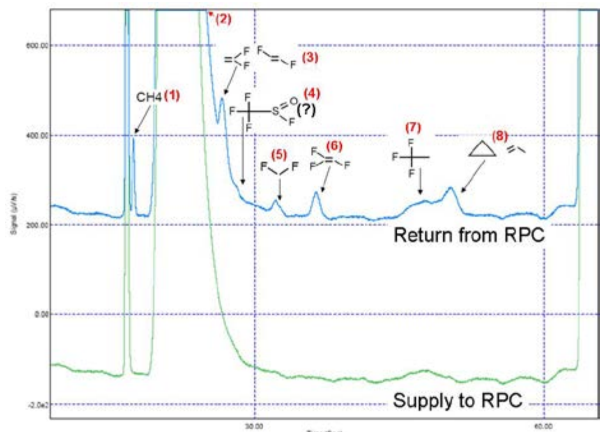
In addition to standard gas infrastructure (i.e. gas supply, distribution and mixing systems):

- Gas analysis module with online gas chromatograph
- New flexible gas recirculation systems developed for reliable R&D

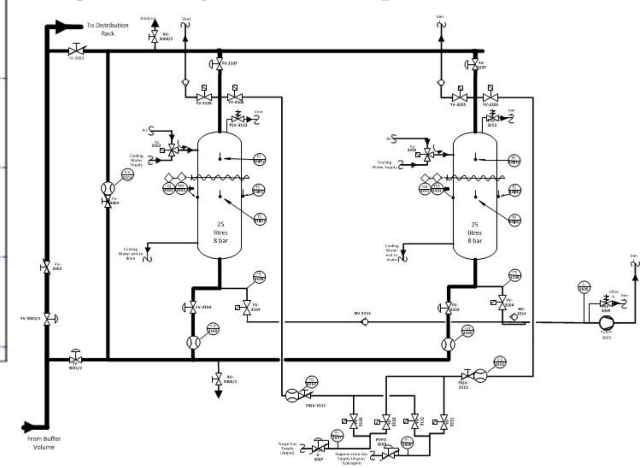
Large volume → gas recirculation
High radiation background



→ Issue:
Accumulation of impurities



→ Solution:
mixture purification mandatory
-new cleaning agents
-new purifier cycle
-gas analysis techniques



Services and infrastructures

- GIF control system:

Monitoring of the GIF++ facility and data distribution

- ELOG:

operation, planning, gas chromatographic analysis, …

- Beam trigger:

TGCs based not yet operational (work ongoing); temporary replaced by plastic scintillators

- Cosmic trigger:

To be used when beam is not available; RPCs based system, installation ongoing

- Environmental and gas sensors

- Radiation monitors:

Several sensors available for radiation monitoring at each setups position

- Detector DCS

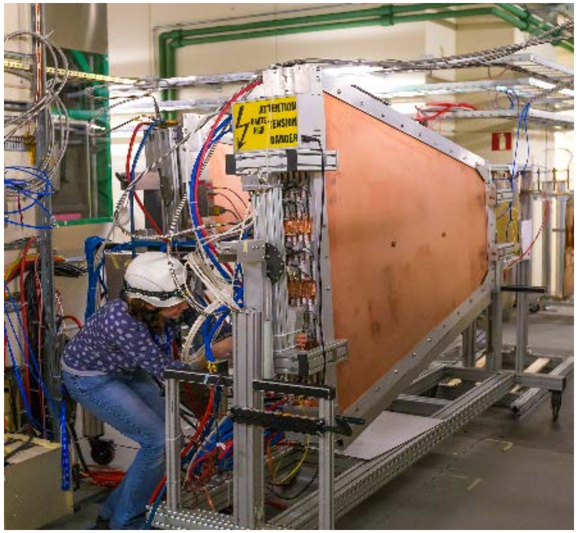
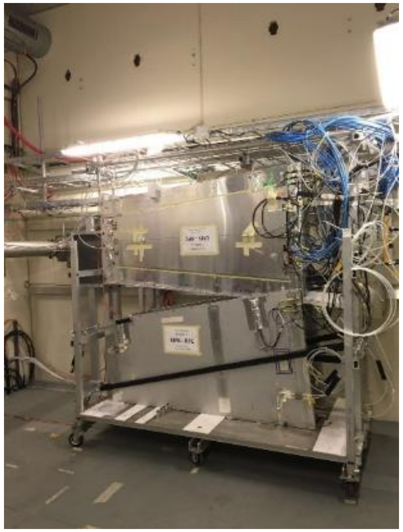
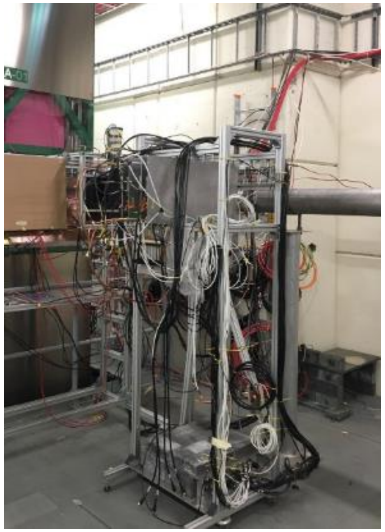
- Centralized detector DAQ: under development

A large variety of tests

- Detector validation up to new HL-LHC expected dose
- Detector and electronic development
- Performance of *recent* detector developments
- Test on real size detectors (>> m^2) and prototype
- Studies with new environmentally friendly gases
- New gas systems for detector upgrades

6 types of detector technologies:

- DT, MDT
- CSC
- RPC, iRPC, GRPC
- MM
- GEM
- sTGC

Quality control

Test large detector productions for performance at high rate before installation

- ATLAS-NSW
  - The innermost end-cap stations of the Muon spectrometer (Small Wheels) will be replaced for Phase-1 upgrade
  - The New Small Wheels (~10 m diameter) will be equipped with 8 layer each of sTGC and MM
  - Total active surface 1280 m^2

- ALICE-TPC
  - 80 MPGD (GEM-MM) – under discussion
- LHC-BLM
  - The Beam Loss Monitoring (BLM) system of the CERN accelerator complex consists from various types of BLMs (about 4000 ionization chambers): IC, LIC, FIC
  - The main task of the BLM system is to prevent the superconducting magnets from quenching and protect the machine components from damages, as a result of critical beam losses.

GIF++ is the only facility where such tests on the full production can take place

Conclusions

- The CERN-GIF++ irradiation facility is operational:
  - **GIF++ is a unique place for detector R&D**: Strong gamma source, particle beam available, excellent gas and electronic infrastructures, unified control/monitoring system, setups for beam & cosmic trigger, radiation monitoring, environmental monitoring, DAQ, …
  - 2015: the first year of operation was very hectic - facility already fully exploited, large collaboration (about 80 persons involved), several real-size detectors, several experiments taking data, …
  - 2016: collaboration further increased in size - facility fully exploited (irradiation and beam time)

More info about the GIF++ facility:

Roberto.Guida@cern.ch

https://indico.cern.ch/event/387753/

Further information

HL – LHC phase and Detector upgrades

Future plans:

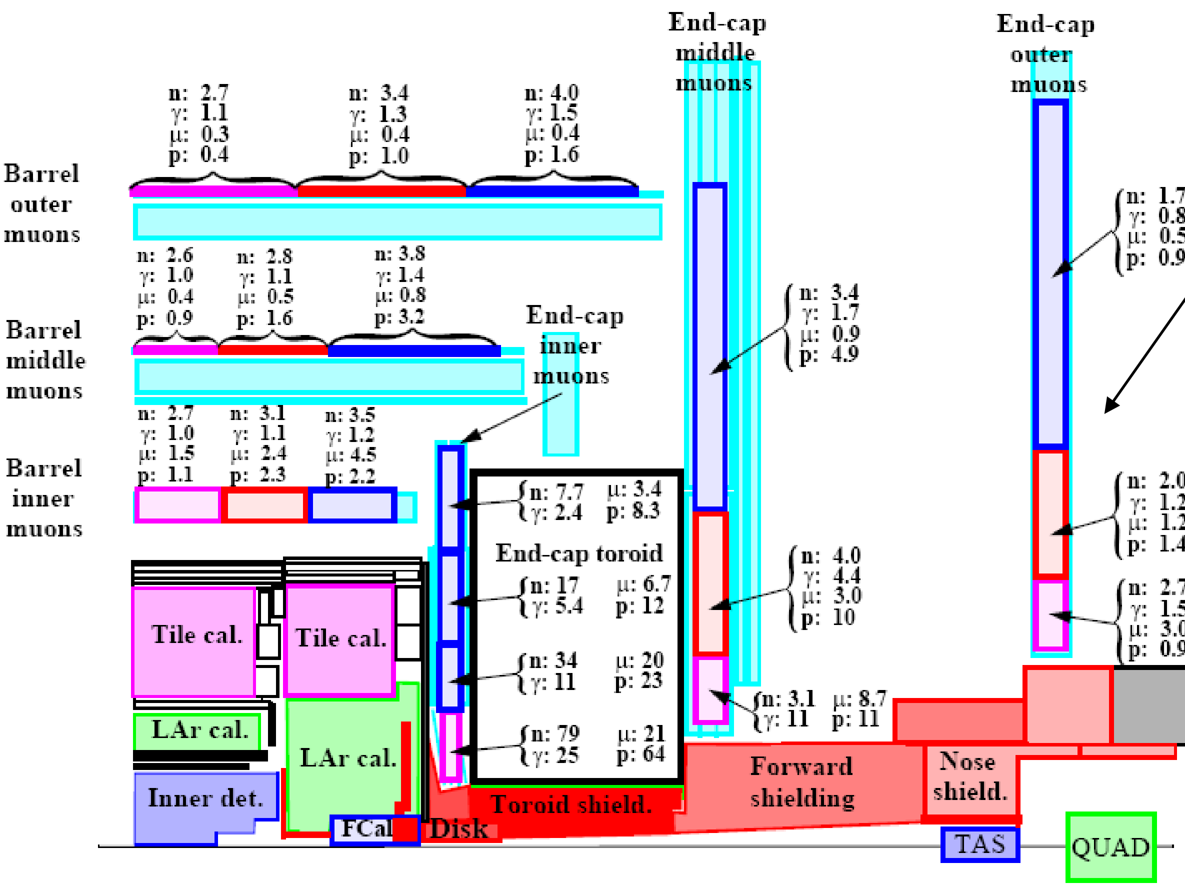
HL-LHC a big step towards higher luminosity → Challenge for LHC and Detector upgrade programs

2009	LHC Start-up	0.9 TeV		
2010				
2011	Run1	7-8 TeV	$6\ 10^{33}$ cm^{-2} s^{-1} 50 ns	25 fb^{-1}
2012				
2013	LS1	Accelerator and detector upgrades in view of nominal luminosity		
2014				
2015				
2016	Run2	13-14 TeV	$1\ 10^{34}$ cm^{-2} s^{-1} 25 ns	75-100 fb^{-1}
2017				
2018	LS2	Upgrade to ultimate design luminosity; Several detector upgrades		
2019				
2020	Run3	14 TeV	$2\ 10^{34}$ cm^{-2} s^{-1} 25 ns	~350 fb^{-1}
2021				
2022				
2023				
2024	LS3	Interaction region, Crab cavities; Several detector upgrades		
2025				
…		14 TeV	$5\ 10^{34}$ cm^{-2} s^{-1} 25 ns	~3000 fb^{-1}
2035?				

Charged background

ATLAS Max flux:
Barrel ~ 5 Hz/cm^2
Forward ~ 10 Hz/cm^2

μ, p fluxes in Hz/cm^2
n, γ fluxes in kHz/cm^2

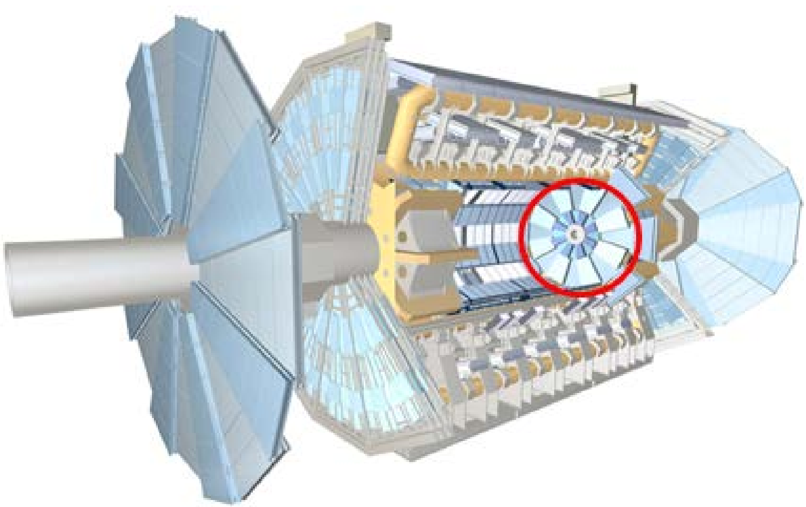


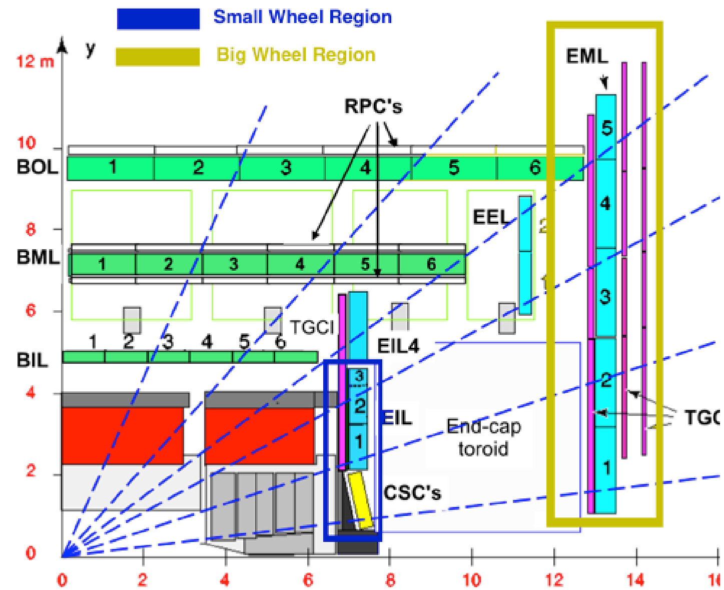
ATLAS Muon upgrade plan

LS2: Installation of the New Small Wheels and other upgrades

The New Small Wheel NSW detectors are designed to have lower occupancies and more capabilities to reduce the backgrounds.

Current detector and location of the SW





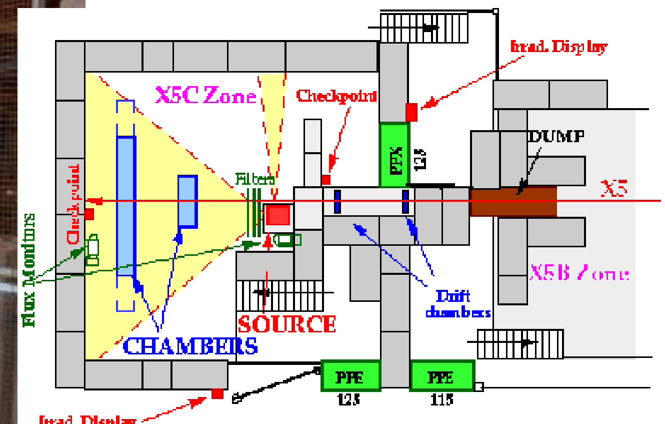
The old Gamma Irradiation Facility – LHC phase

The old CERN-GIF: experimental area where muon beam was available together with an intense (~650 GBq ^{137}Cs) gamma source.
Many tests were performed from 1999 to 2014

LHC gas detector technologies have been validated at the GIF:

- CMS (RPC, CSC, GEM, GRPC, ECAL)
- ATLAS (MDT, RPC, TGC, CSC)
- ALICE (TOF, AMS, CPC, RPC)
- LHCb (MWPC)
- LHC-BLM
- COMPASS detectors

and more.



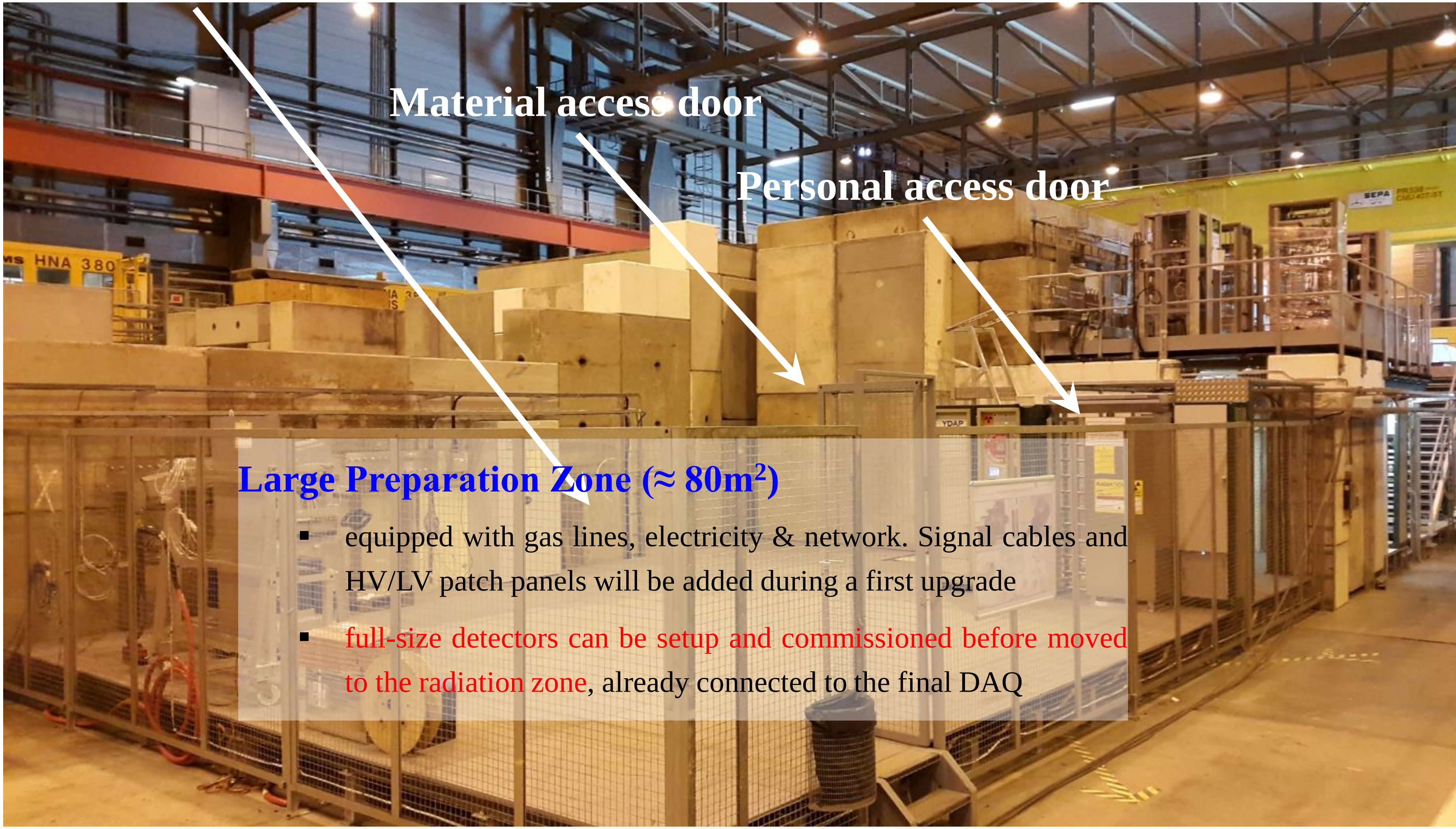
The old GIF was used to validate detectors for LHC experiments

GIF++ facility: key numbers

	Details	Dimensions
GIF++ facility	Building 887 - H4 beam line in EHN1	225 m^2
Detector preparation area	Area for detector preparation directly accessible from control room	83 m^2
Services area	Area hosting large part of the peripheral infrastructure and services (gas supplies and systems)	2 x 40 m^2
Bunker	Experimental area: 14 TBq ^{137}Cs source (662 keV gammas)	100 m^2
Control room	Control rooms for services and users close to the preparation area	

GIF++ facility: detector preparation zone

Detector preparation: Setup and pre-test detector & DAQ before entering the irradiation zone



Large Preparation Zone (≈ 80m²)

- equipped with gas lines, electricity & network. Signal cables and HV/LV patch panels will be added during a first upgrade
- full-size detectors can be setup and commissioned before moved to the radiation zone, already connected to the final DAQ

GIF++ service areas

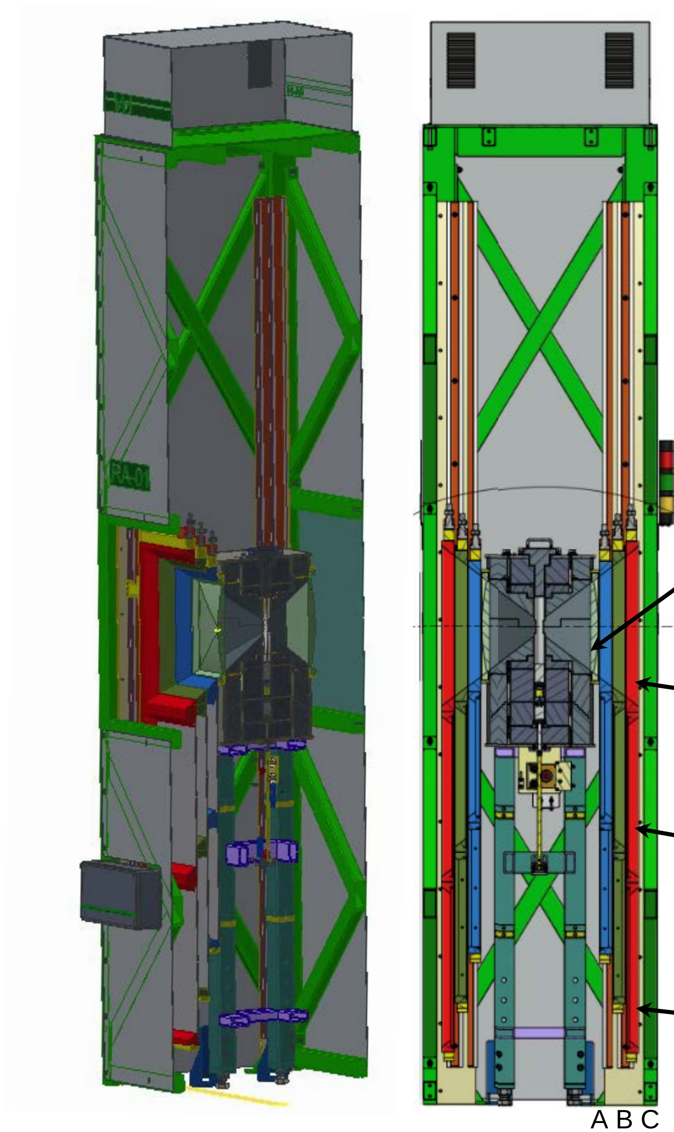
First floor:

17 gas racks and distribution panels (40 m^2 net area)

Ground floor:

17 electronic racks hosting the irradiator controls, DCS, user equipment, fire detection, ...

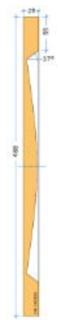
Radiation attenuation system



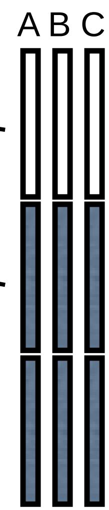
How it is implemented:

Two identical attenuation systems:

- one angular correction filter (Fe)
- 6 absorption filters (per side)

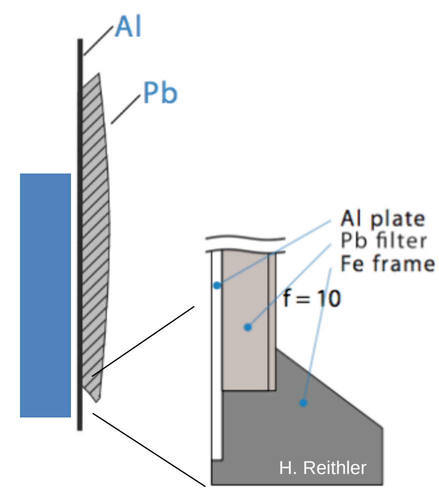


Angular correction filter provides uniform photon distribution on the surface of large area detectors



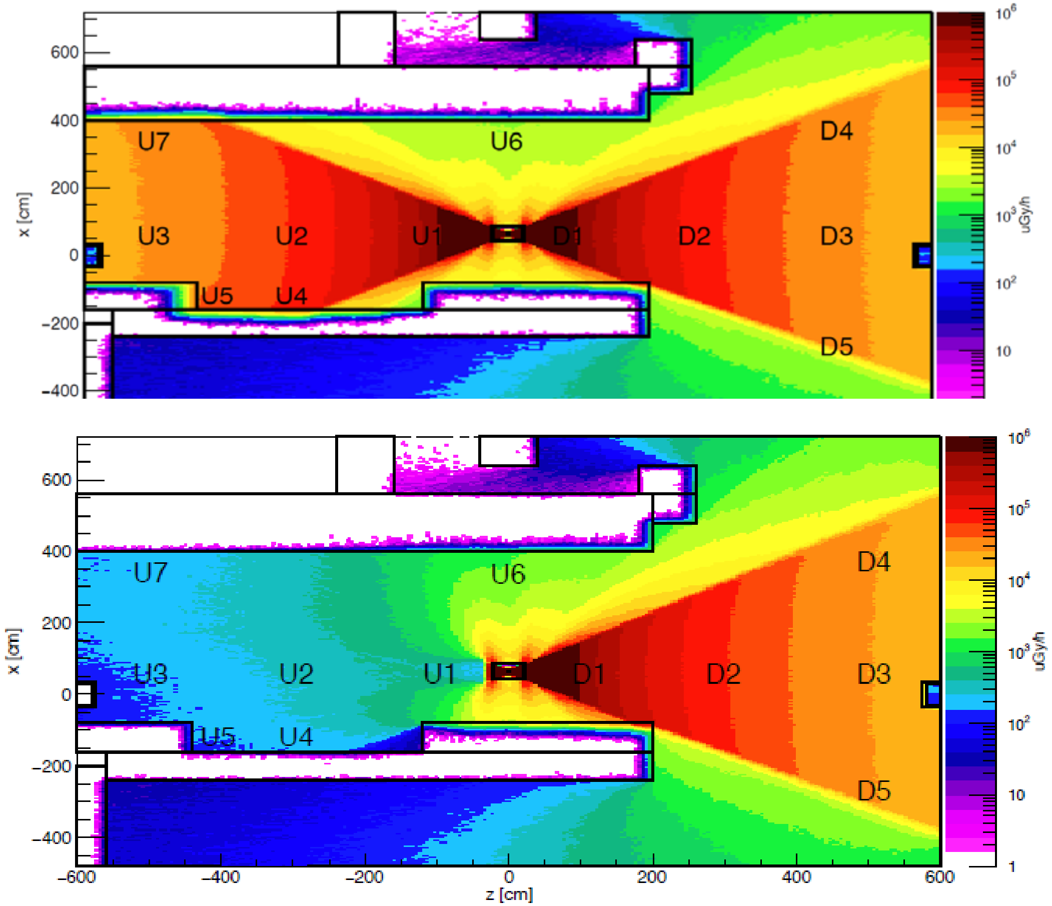
Filter System :

Absorption factor		
0	0	0
10	1.47	2.15
100	100	4.64

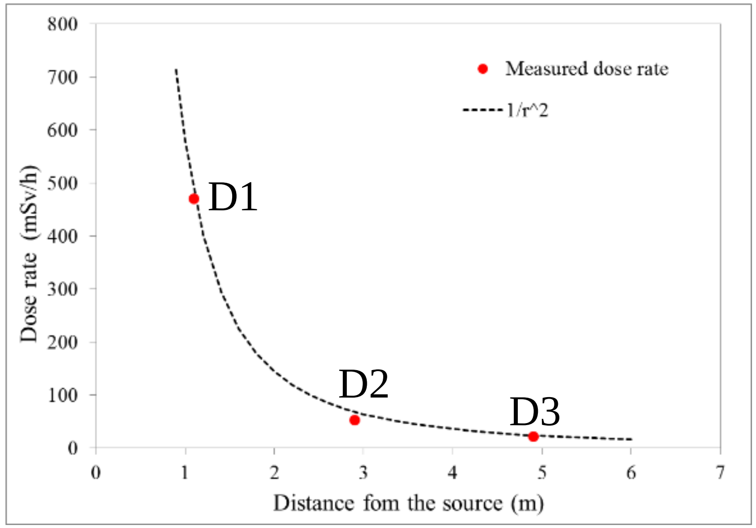


Gamma field simulation and measurement

The dose rate has been measured in several points and compared to simulation.



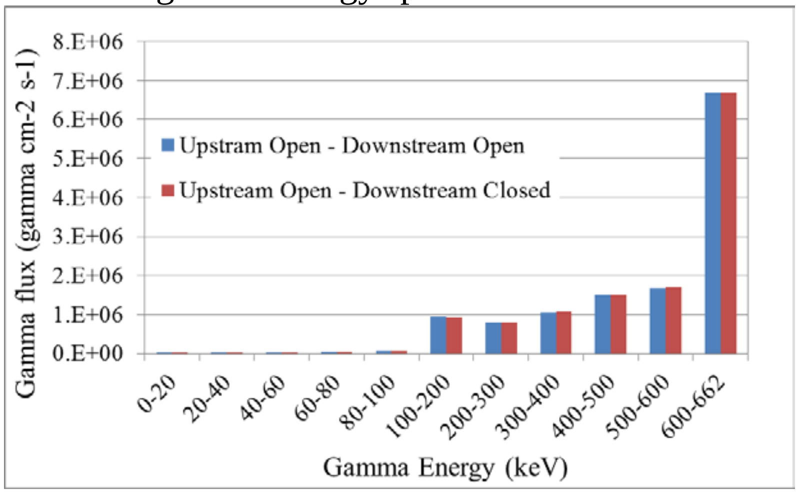
D. Pfeiffer et al. CERN EP-Technical Note



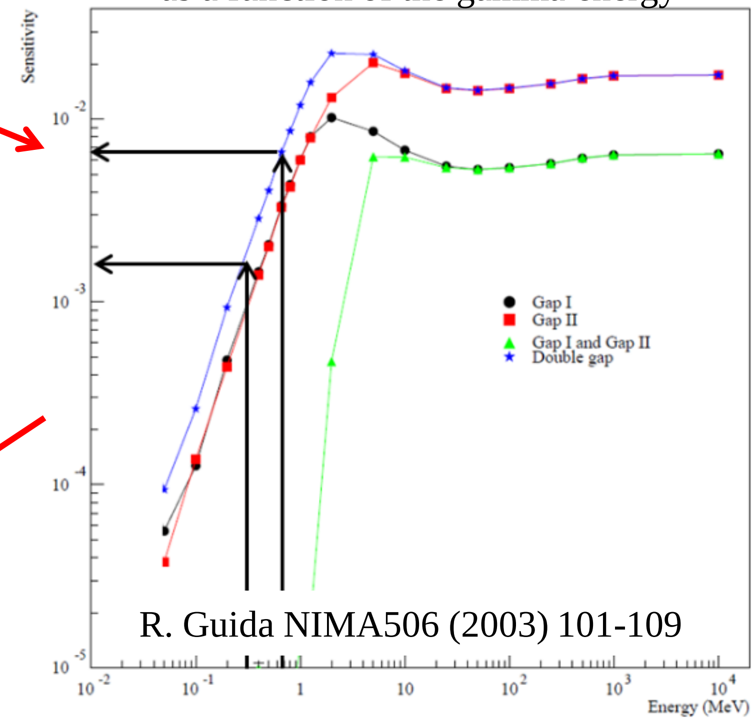
- Gamma field in the facility is well understood
- Uniform radiation on flat detector surface
- Good independence between upstream and downstream irradiation areas

Gamma field simulation and measurement

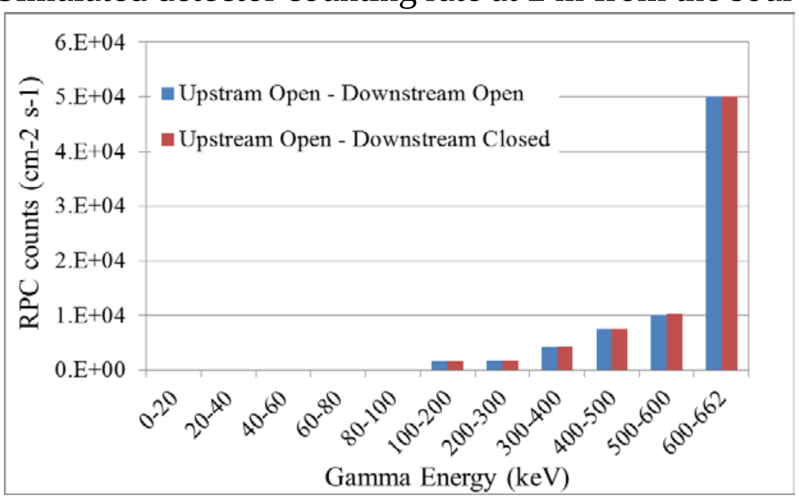
Simulated gamma energy spectrum at 2 m from the source



Simulated RPC gamma sensitivity
as a function of the gamma energy



Simulated detector counting rate at 2 m from the source

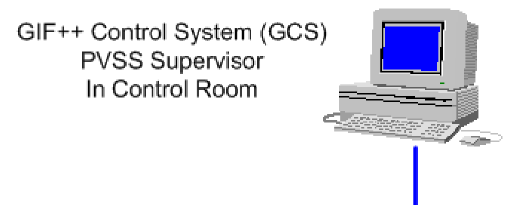


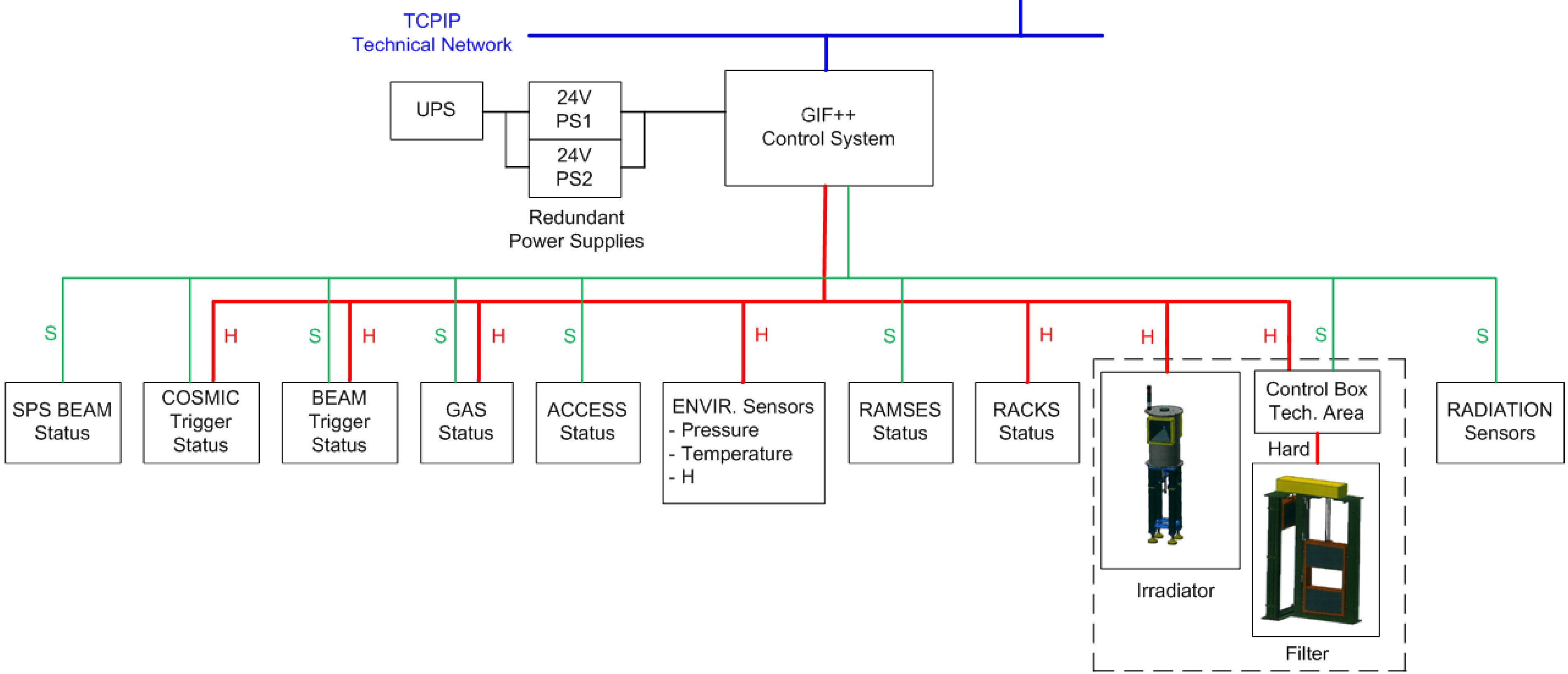
- Background of low energy scattered gamma similar to the old facility
- Good independence between upstream and downstream irradiation areas

GIF Control System

G. Maire, S. Ravat, A. Kehrli (CERN EP-DT)

- Monitoring of the GIF++ facility
- Record all useful data
- Produce Warning & Alarms





Users' setups: Beam trigger setup

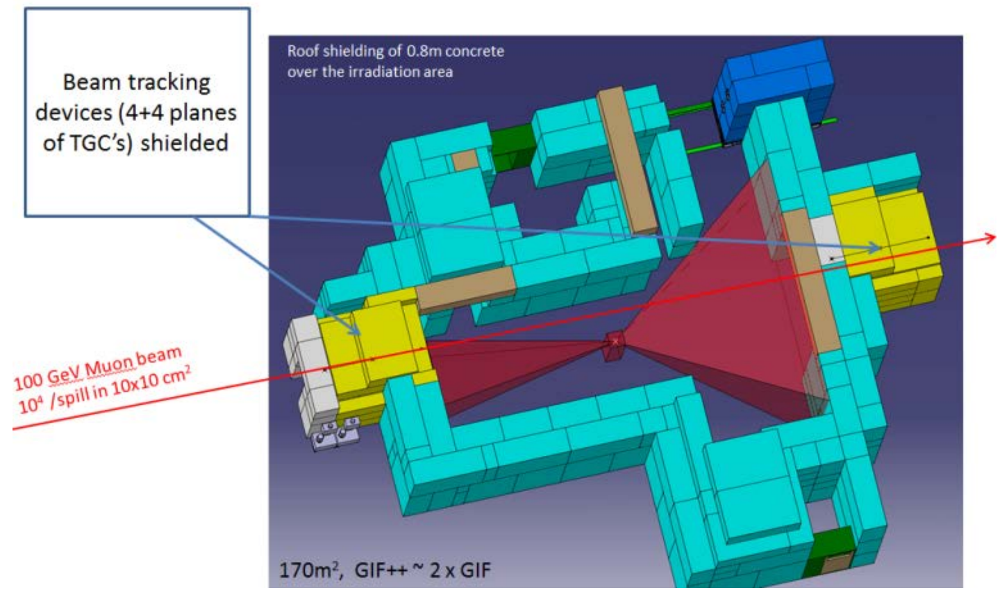
George Mikenberg (ATLAS-TGC group)

Using the beam, it is possible to see inner structure of the detector and to make detector alignment.

Resolution between 110 -180 μm depending on the angle (however, at the GIF the angle will be quite small → resolution close to 110 μm).
New electronics under development.

Positioned upstream and downstream the facility

One of the two TGC beam chambers installed in the bunker



Users' setups: Cosmic ray trigger setup

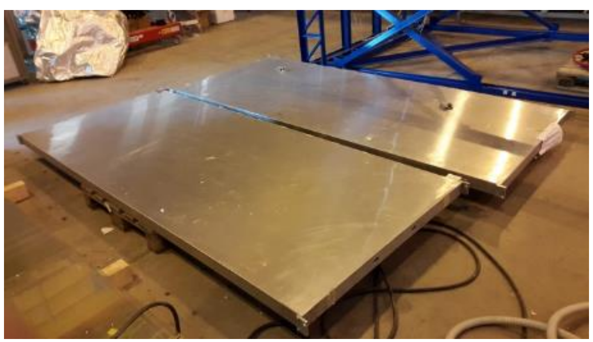
G. Aielli, R. Cardarelli, R. Santonico (ATLAS-RPC group)

Ensure test operation for most of the time

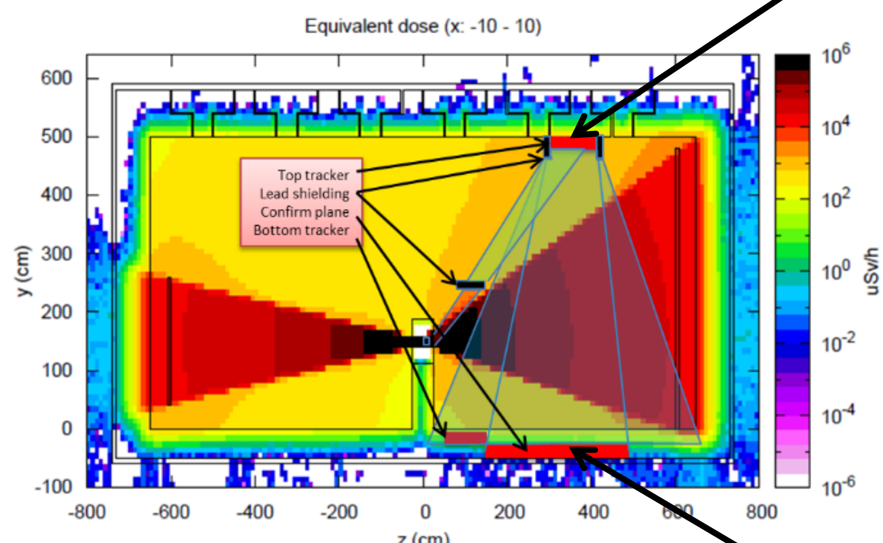
4 independent detectors area 1 x 0.5 m^2 + small area (30 x 30 cm^2) high resolution tracker
Timing performance ~0.5 ns to provide a clean trigger and good TOF capability

Detector attached to the roof and under the floor
High rate to be sustained ~1 kHz/cm^2 if no shielding is applied.

RPC detectors ready to be commissioned before installation



RPCs attached to the roof



RPC under the floor

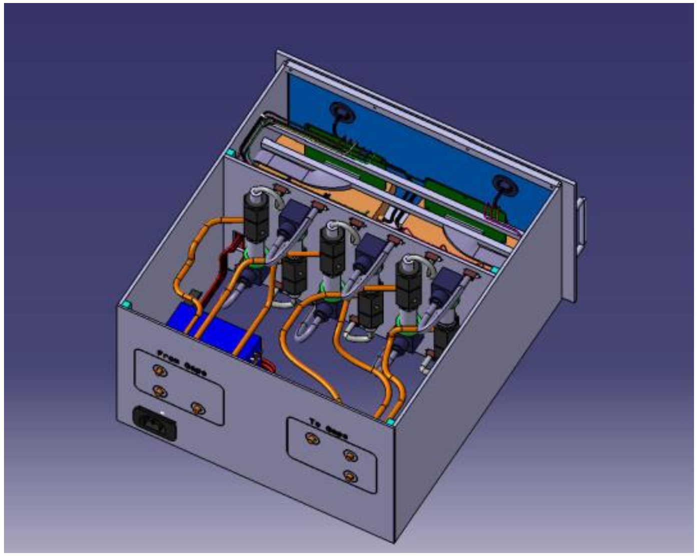
Users' setups: Environmental sensors

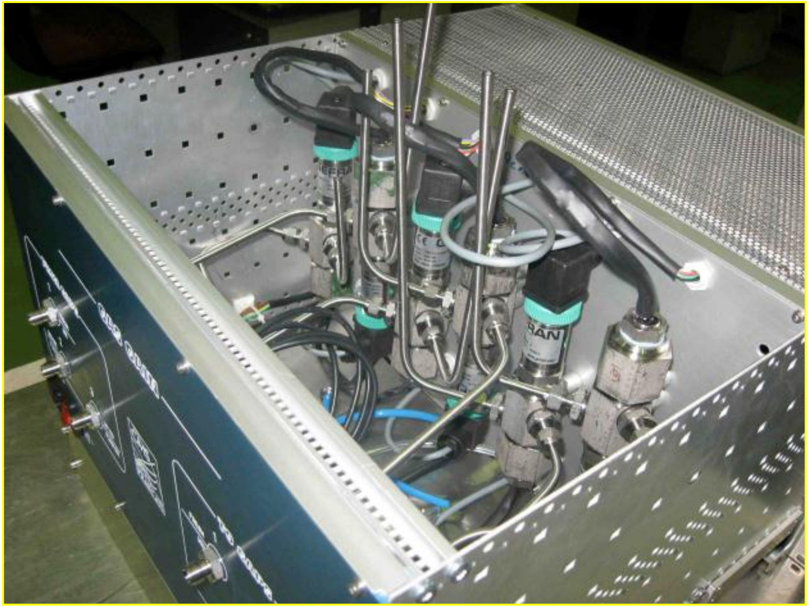
S. Bianco, Frascati and Napoli (CMS-RPC group)

Environmental sensors to monitor atmospheric pressure, temperature, relative humidity.
Sensors for water vapour concentration in gas mixture (needed for RPC)

Precision ±0.2 ºC, ±2 %RH
Order of ~ 10 sensors
Integration in GIF++ dcs (pvss like interface)

Example of baseline design in operation at CMS: sensors box used for the GasGainMonitoring system for the CMS-RPC





Users' setups: Radiation sensors

Plamen Iaydjiev (University of Sofia, CMS-RPC group)

Monitor the dose rate inside the GIF++ facility and, as an "old" user, I would add close to the detectors (useful to measure the attenuation produced by other setups and to evaluate long term stability with very simple measurements)

Two sensors for different dose ranges:
Thick oxide → up to 10 Gy
Thin oxide → up to 200 Gy
System/DAQ proposed for 10 sensors.

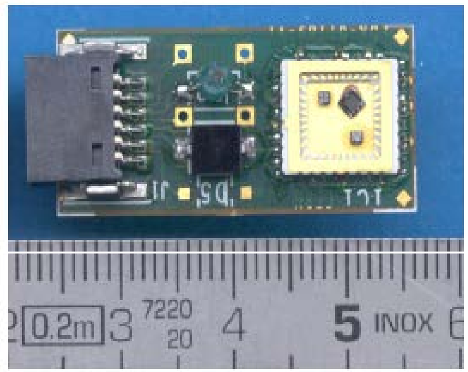
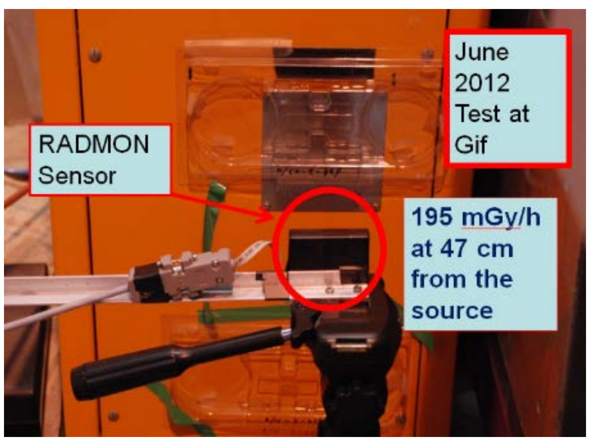


Fig. 3: Integrated Sensor Carrier (ISC)



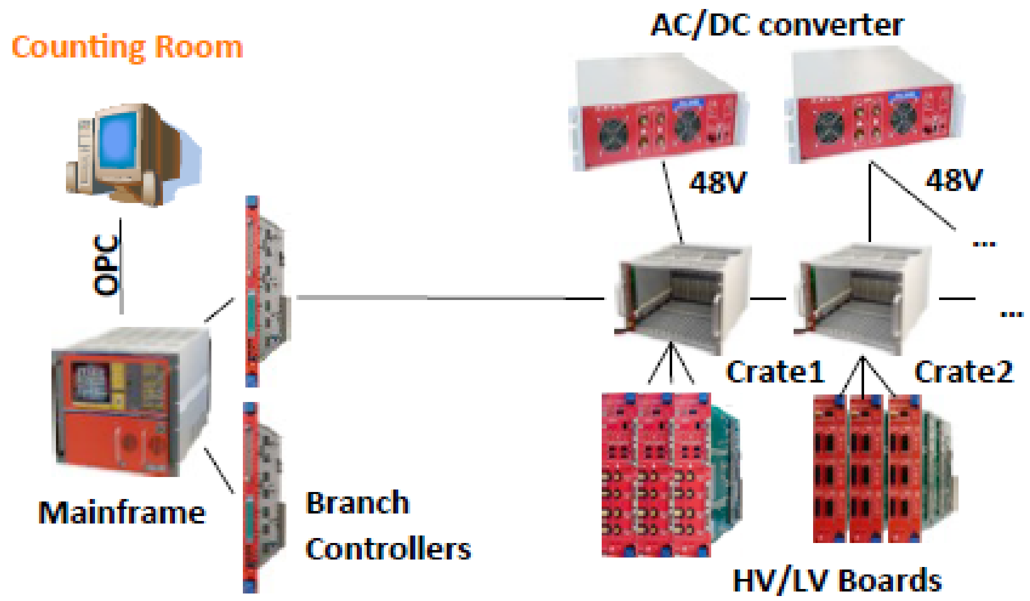
Radiation monitoring detectors installed with long cables inside the bunker

Users' setups: detectors DSC

A. Polini, M. Romano (University of Bologna)

- Use PVSS/WinCC OA (as in LHC experiments)
- CAEN Easy Power System [1 mainframe, 1 Power Generator, 1-2 crates + with HV and LV boards and 1 ADC A-3801 board for monitoring (123 channels), also for ENV and gas monitoring]

- Mainframe and PC in proximity of the control room (radiation-free area) along with DAQ PCs and equipment
- EASY crates and other equipment closer to detector area



Users' setups: centralized DAQ

Y. Benhammou (University of Tel Aviv)

Requirements

- Create a trigger from beam tracker (TGC) and/or cosmic tracker (RPC)
- Distribute the trigger to different Detectors Under Test (currently up to 5 DUTs)
- Synchronize the events from the TGC/RPC with the DUTs for tracking/efficiency purpose

Implementation

- Based on a **Trigger Logic Unit** module provided by EUDET community and intensively used in test beams (DESY, CERN, FERMILAB, …)
- Unit provides **trigger signal** and **trigger number** to all detector DAQs
- Requires busy signal from detectors DAQs
- This module synchronizes the different DAQ systems