EP-DT
Detector Technologies

STUDIES ON GAS MIXTURE AND GAS RECIRCULATION EFFECTS ON GEM DETECTORS OPERATION

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OUTLINE

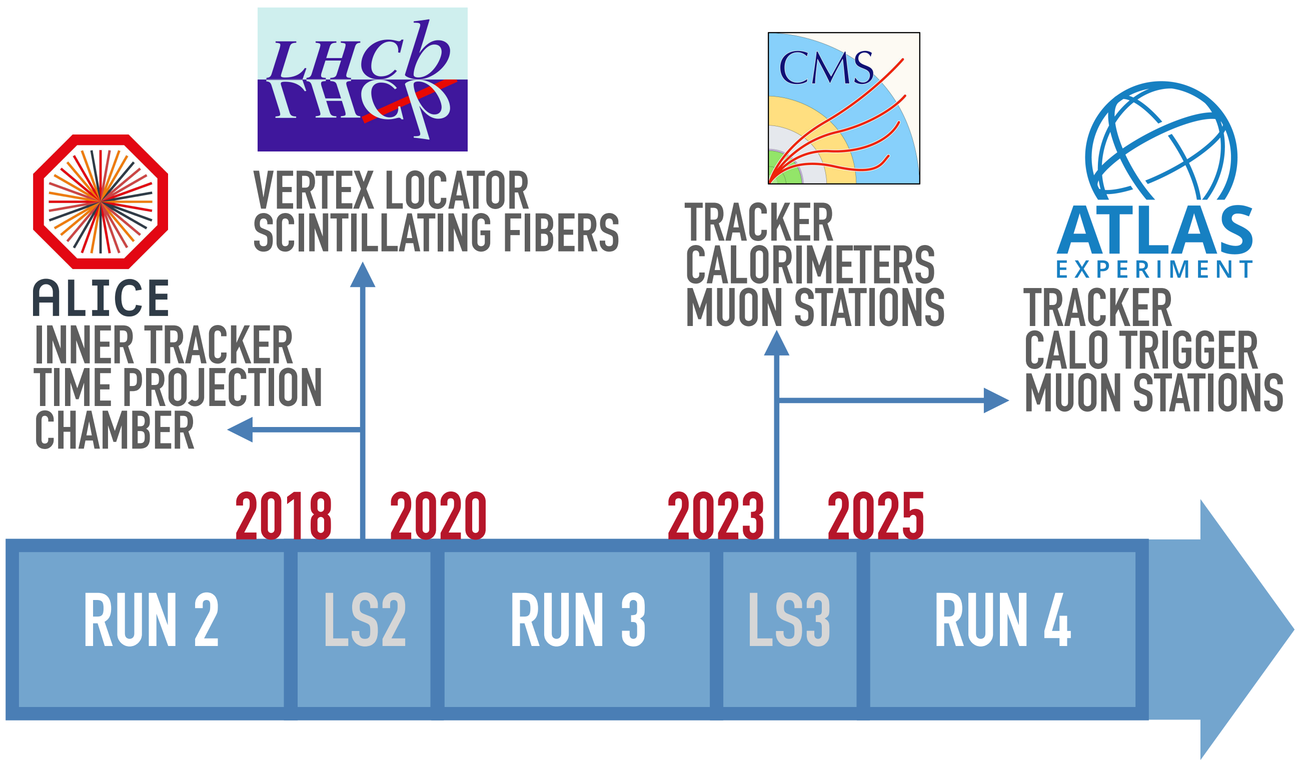
- LHC and High-Luminosity: Muon Systems Upgrade
- Triple-GEM Detectors: Working Principle, Detector Characterization
- Specific Gas Mixture Studies:
  - Input Flow Variations
  - CO_2 Percentage in Standard Mixture
  - O_2 Concentration in Standard Mixture
- GIF++ : Gamma Irradiation Facility:
  - GEM Irradiation Campaign
  - Test Beam: Performance and Efficiency Measurement
- Conclusion - Future Plans

HL-LHC AND MUON SYSTEMS

LHC AND HIGH-LUMINOSITY
MOTIVATIONS AND UPGRADES

- The **Large Hadron Collider** will reach in 2025 its **High-Luminosity phase**, to **enlarge experimental data samples and push forward its Physics Program**
- Improved performance of LHC will come from **Accelerator upgrades**, but the future **high particle rate** imposes **consolidation and upgrades for LHC Experiments** too
- All detectors systems will be affected: **Tracker, Calorimeters, Muon Systems**
- Upgrades will take place in **LS2 for ALICE and LHCb**, while major improvements will be faced by **ATLAS and CMS mainly during LS3**

"Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade for the machine and detectors."

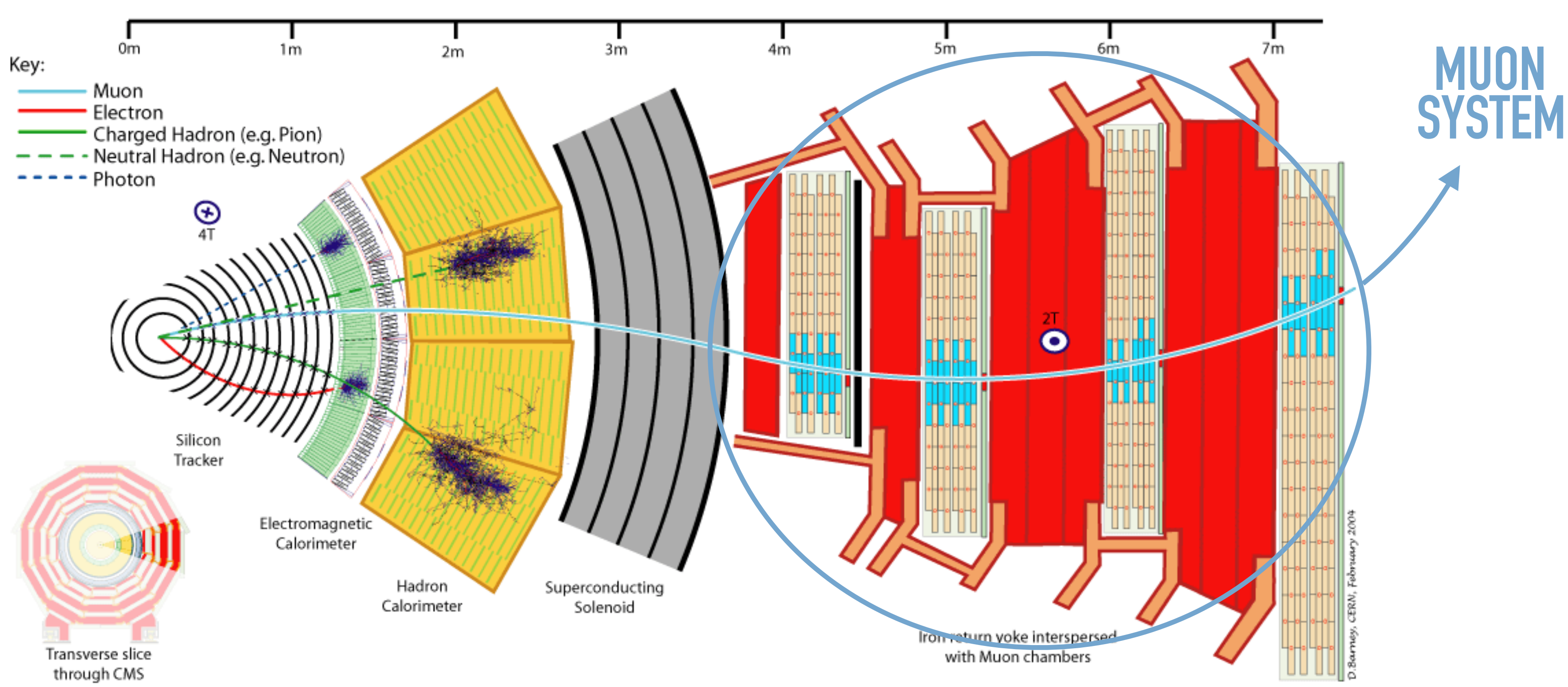


MUON SYSTEMS UPGRADES
GASEOUS DETECTORS FOR MUON IDENTIFICATION

- **Muons** escape Electromagnetic Calorimeter: **detected with dedicated systems**
- Muon systems are composed of **various layers of Gaseous Detectors**: Multi-Wire Chamber, Cathode Strip Chambers, Resistive Plate Chambers, …
- **Muon detectors** are capable of **identifying, tracking and measuring Muons momentum**

Muon Systems Upgrades:

- New Detector Systems
- Number of Detectors
- Readout Electronics
- **Gas Mixtures**

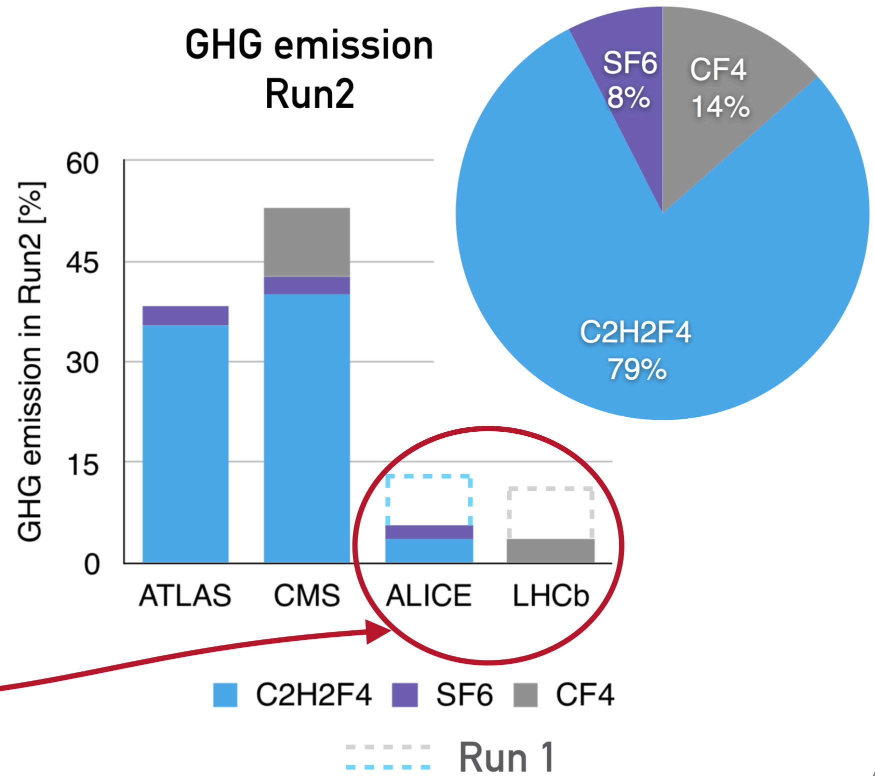


MUON SYSTEMS UPGRADES
GAS MIXTURES AND ENVIRONMENTAL ISSUES

- **Gas Mixture is the primary element influencing Gaseous Detector performance**: its **quality and stability** are fundamental for good and safe long-term operation
- Some of the **gases used in LHC Experiments have a high Global Warming Potential** and their emission favours **Greenhouse effect**
- The use of Greenhouse gases is **discouraged by European Union**, their cost will start increase and some will be phased out by 2030

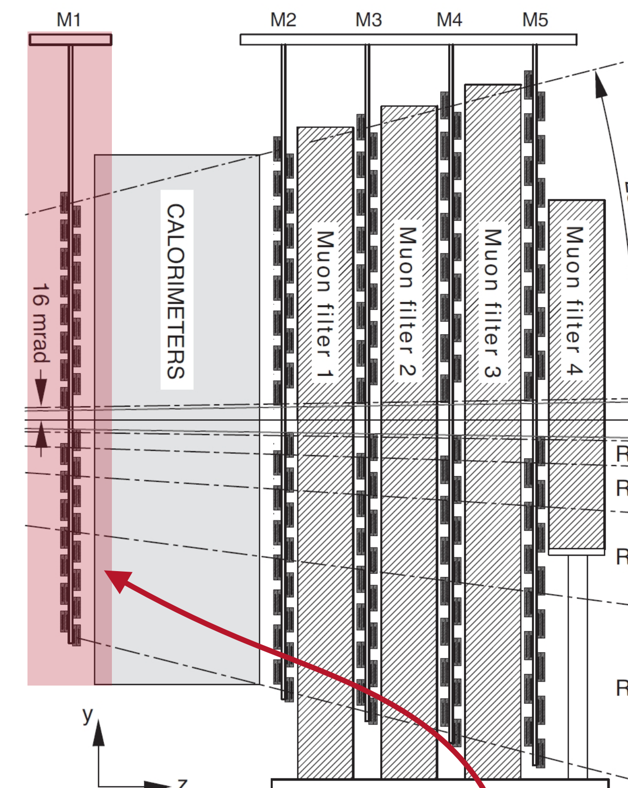
CERN is taking steps to reduce their emission to avoid further damage to the environment and to limit the cost of Gas Systems

- Recuperation of exhaust Greenhouse gases
- R&D on Environmental Friendly Mixtures
- **Operation of Gas Systems with Recirculation**



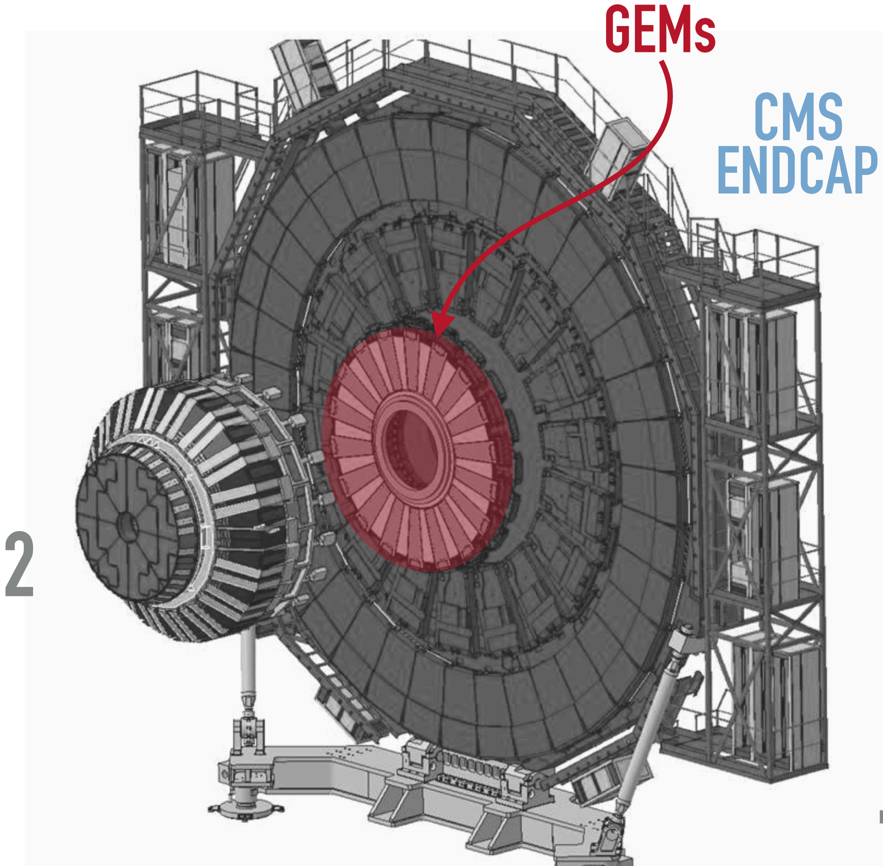
TRIPLE-GEM DETECTORS IN LHC EXPERIMENTS

- **GEMs** are currently installed in **LHCb Muon System** and they are planned to be installed in **CMS Endcaps** during the upgrades taking place in LS2
- GEMs are useful in **high-rate regions**, better performance than other gaseous chambers
- **GEMs Gas Mixture can contain CF_4**, a Greenhouse Gas with **Global Warming Potential = 6500**
- While R&D is ongoing to find efficient ways to recuperate CF_4, or eco-friendly alternatives, **Systems can be operated with gas recirculation**
- **LHCb** already moved **from Open Loop to Recirculation** in LS1, with a **reduction of 90% of GHG emission** during Run2



LHCb MUON SYSTEM

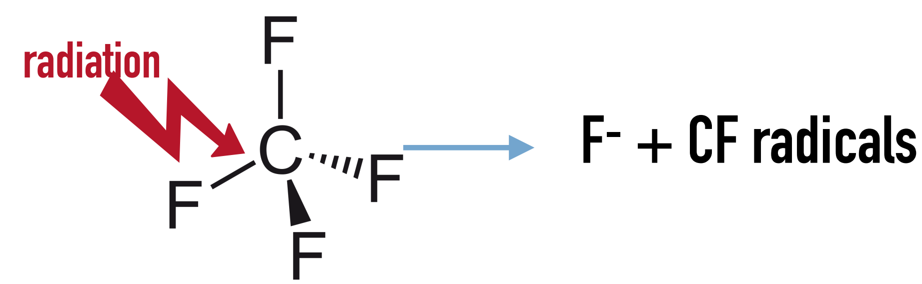
GEMs



CMS ENDCAP

GAS RECIRCULATING SYSTEMS
IMPURITIES ACCUMULATION & DETECTORS PERFORMANCE

- Operating **Gas Systems with Recirculating Gas** means **accumulation of impurities**
- Common impurities are **H_2O and O_2** (from detectors or system itself): they can be **reduced with purifier modules**
- **Freon gases, as CF_4, can break in presence of high radiation** and create **F− and free radicals,** that could be dangerous if deposited on GEM foils



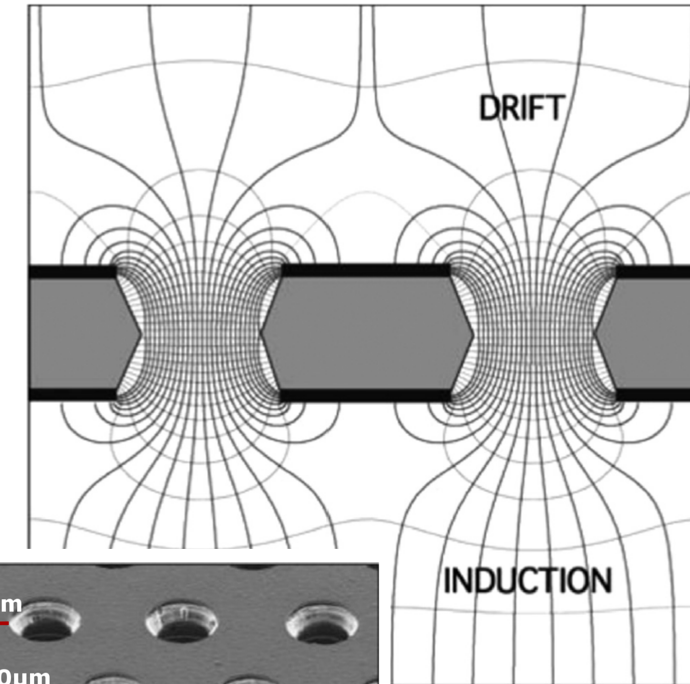
THESIS PURPOSE

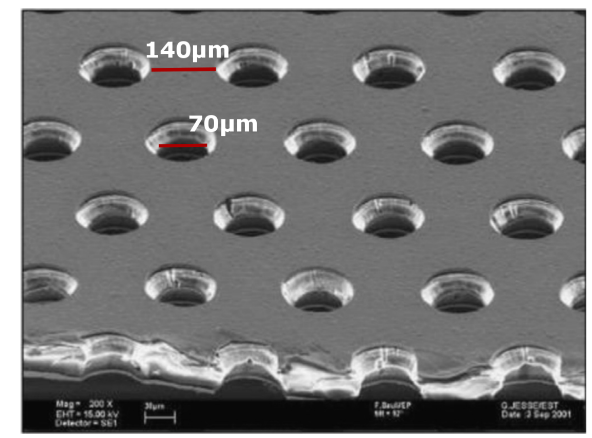
VALIDATE GEM OPERATION IN GAS RECIRCULATING SYSTEMS, IN PRESENCE OF HIGH RATE RADIATION AS THERE WILL BE IN HL-LHC

- Study the **effects on GEMs performances of specific variations** in the gas mixture
- Study **GEMs operation** with a small replica of LHC **recirculating gas system** with **radiation conditions as similar as possible to the ones in HL-LHC**

TRIPLE-GEM DETECTORS

TRIPLE-GEM DETECTORS
WORKING PRINCIPLE



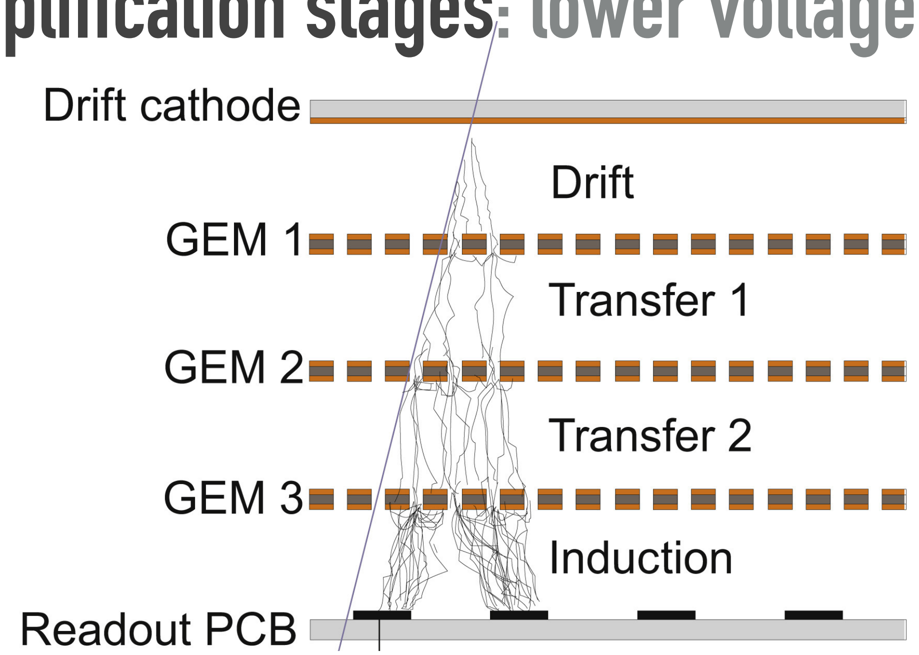


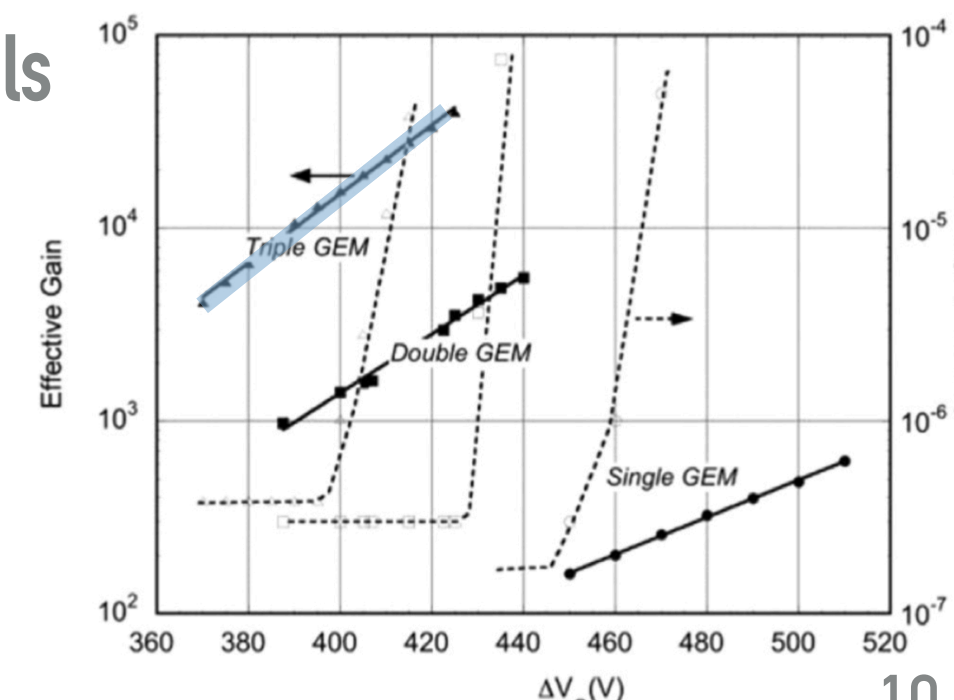
GEMs belong to the class of Micro-Pattern Gaseous Detectors

- GEM electrode = 5 μm Kapton + Cu coating
- 70 μm holes, acting locally as a proportional amplifier

Triple-GEMs

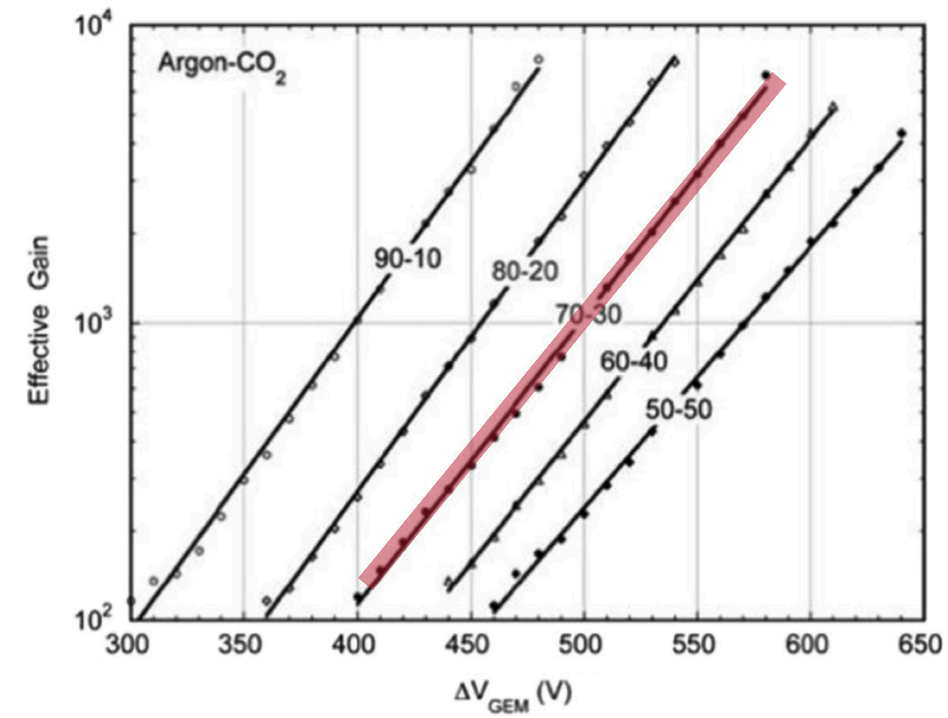
- Three foils with consecutive injection electrons
- Three amplification stages: lower voltage to single foils

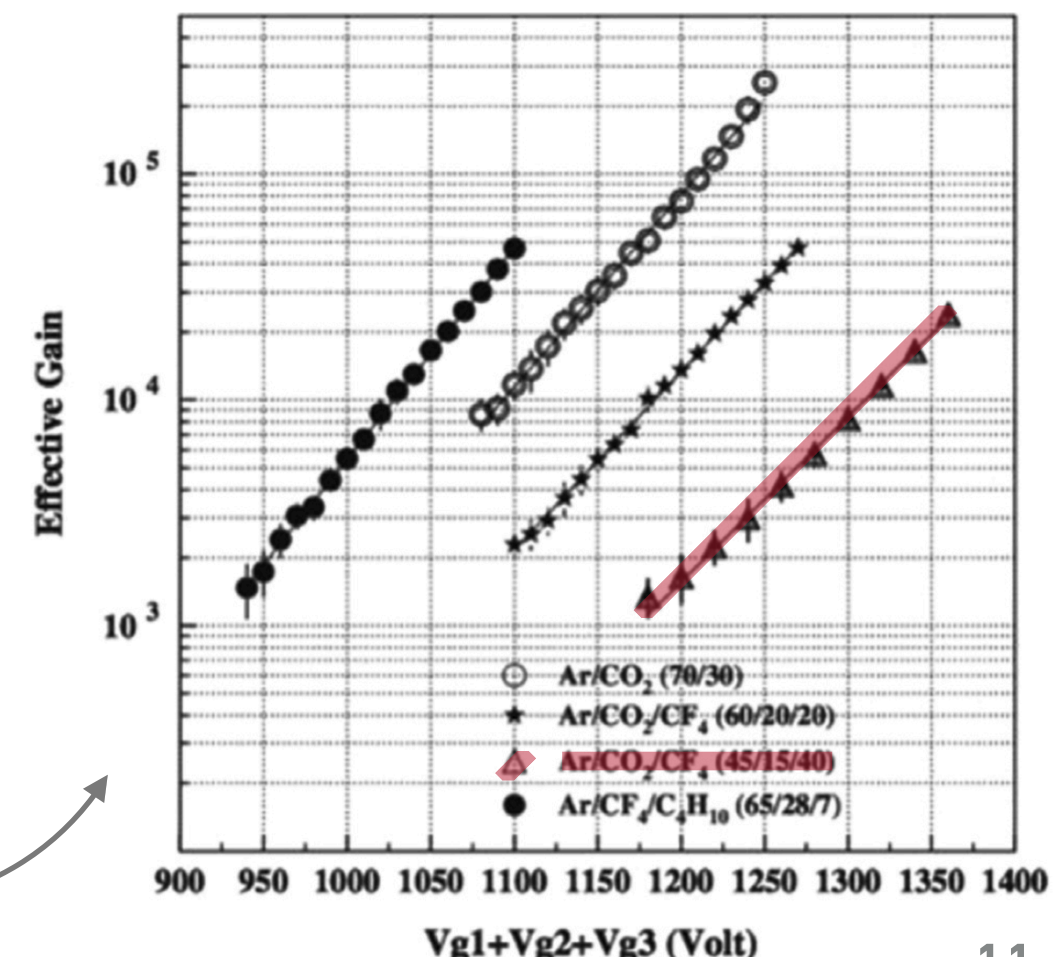




TRIPLE-GEM DETECTORS
WORKING PRINCIPLE

- GEMs standard gas mixture is composed by 70% of Argon and 30% of CO_2: reasonable gain can be reached with intermediate voltage supply to the foils
- Alternative mixtures have been studied, finding advantages in the addition of CF_4
- $Ar/CO_2/CF_4$ mixture in proportions 45/15/40 was found to be a good compromise for:
  - Reaching a sufficiently high gain
  - Not excessive high voltage on the foils
  - Significantly enhanced time resolution



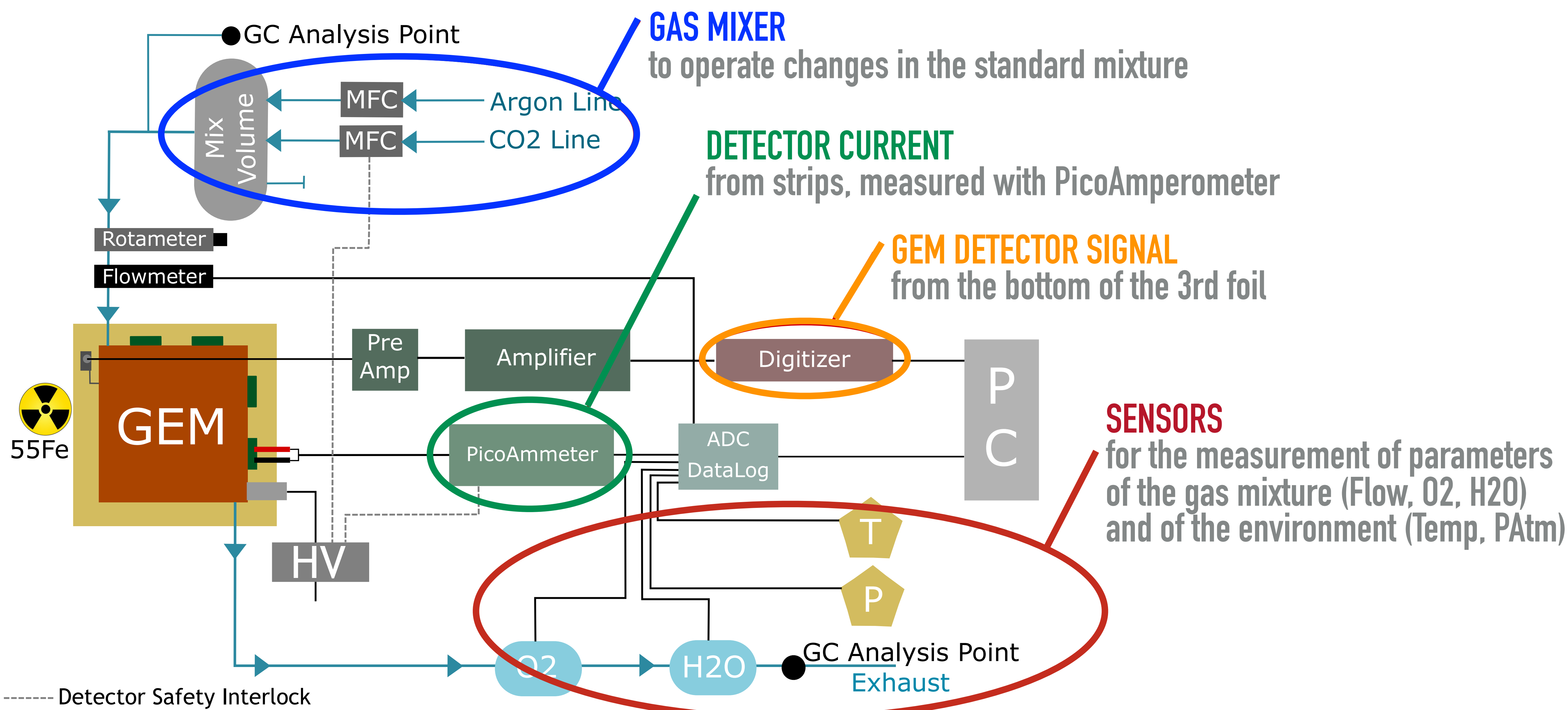


"The gas electron multiplier (GEM): Operating principles and applications", F. Sauli

GAS-RELATED STUDIES

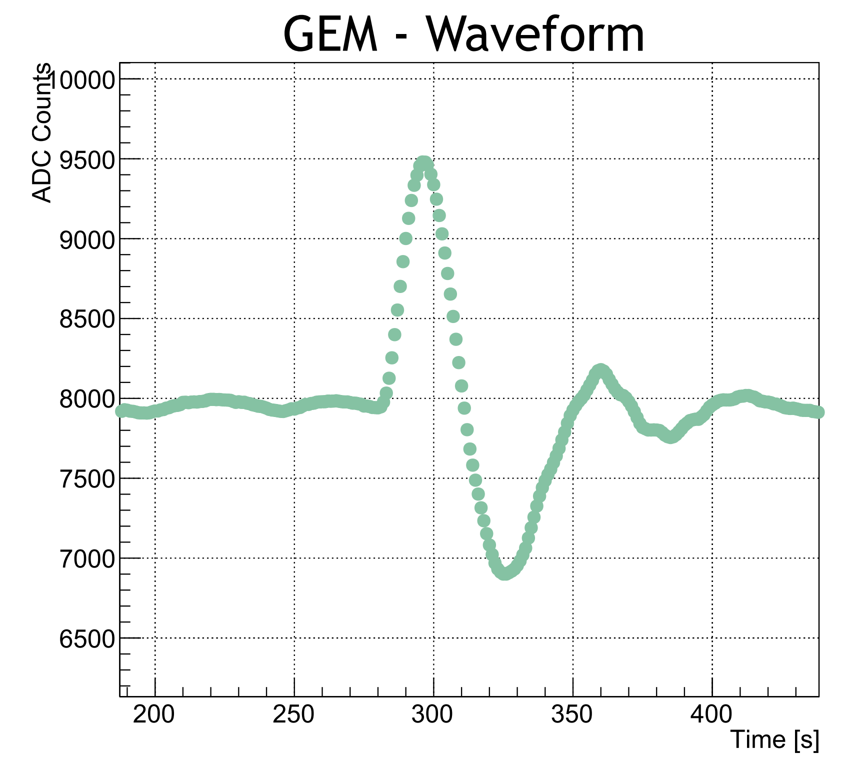
TRIPLE-GEM DETECTORS
EXPERIMENTAL SETUP

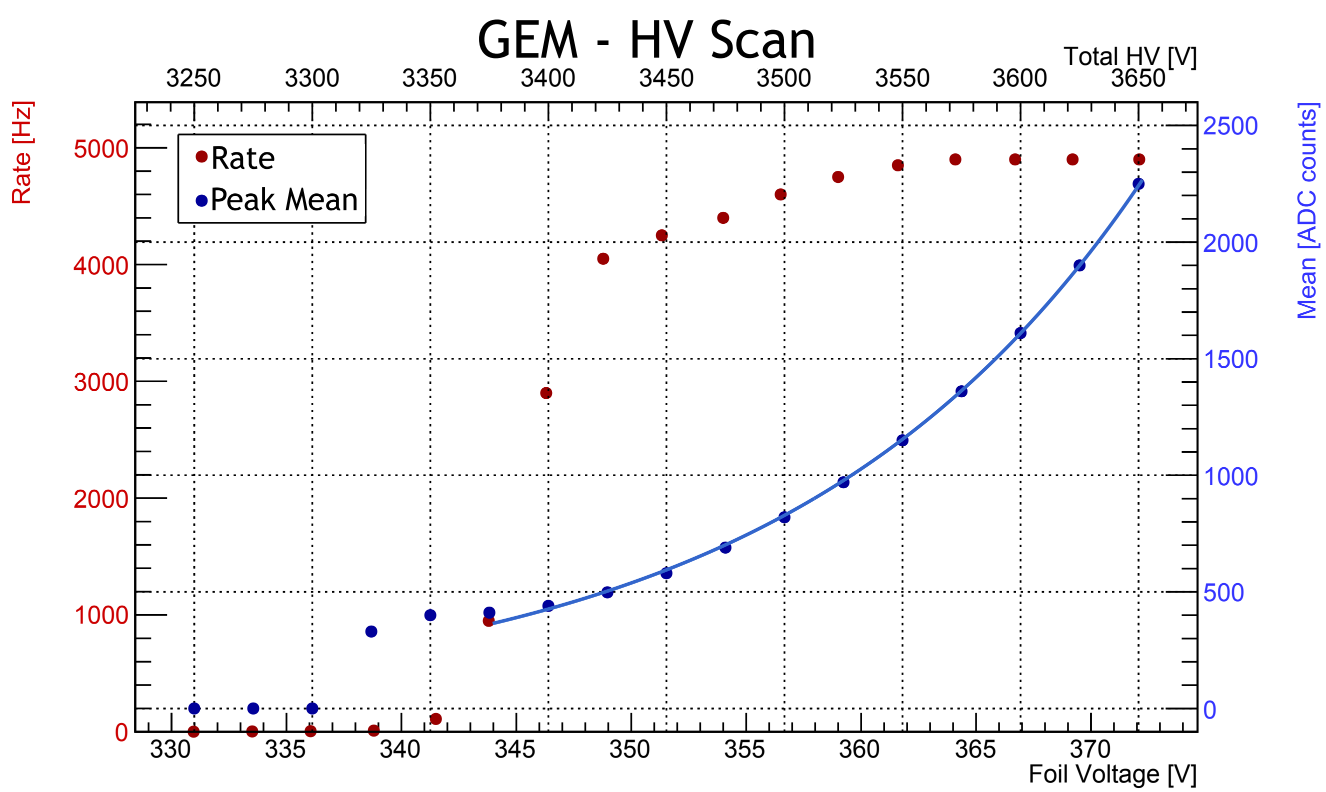
- **10x10cm² prototypes**, gap configuration 3-1-2-1 mm
- **Electronic chain** for **DAQ** (detector current&signal), **gas** and **environmental parameters**

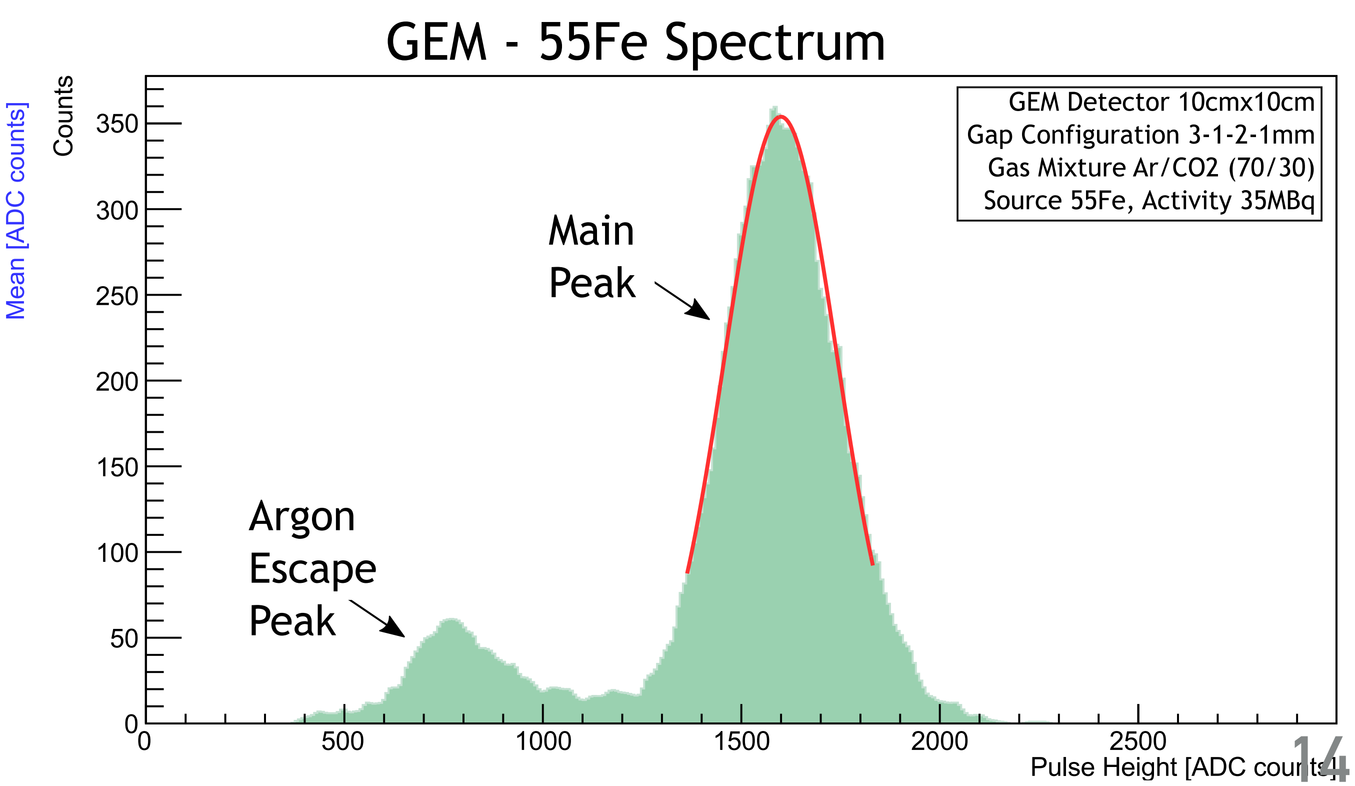


TRIPLE-GEM DETECTORS CHARACTERISATION

- Measured **signal** is used to obtain **pulse height spectrum**
- **Detector current and peak mean position** are **proportional to the effective amplification gain**
- **Efficiency** is tested with **HV scans** (Gain and Rate)
- **Performance** is monitored with **gain prolonged acquisition**

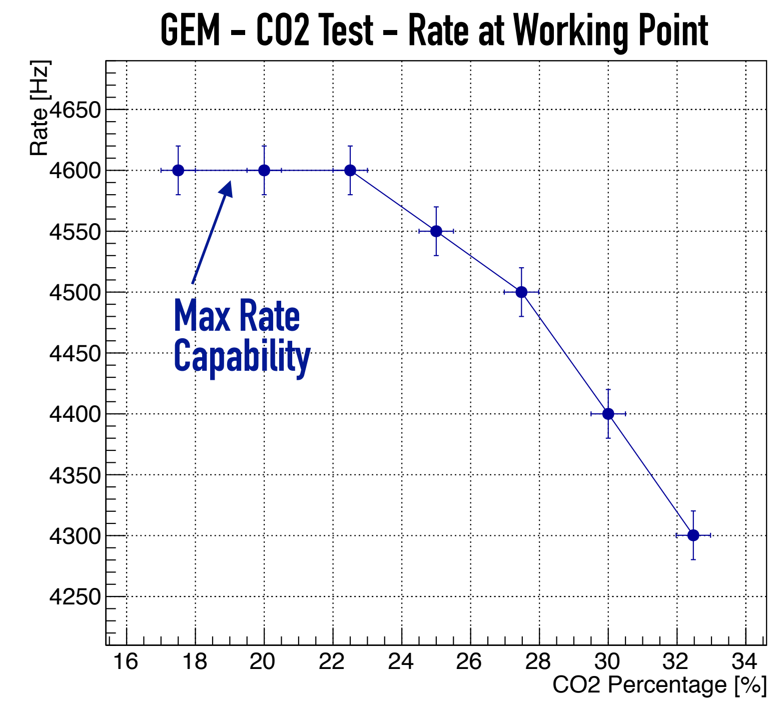




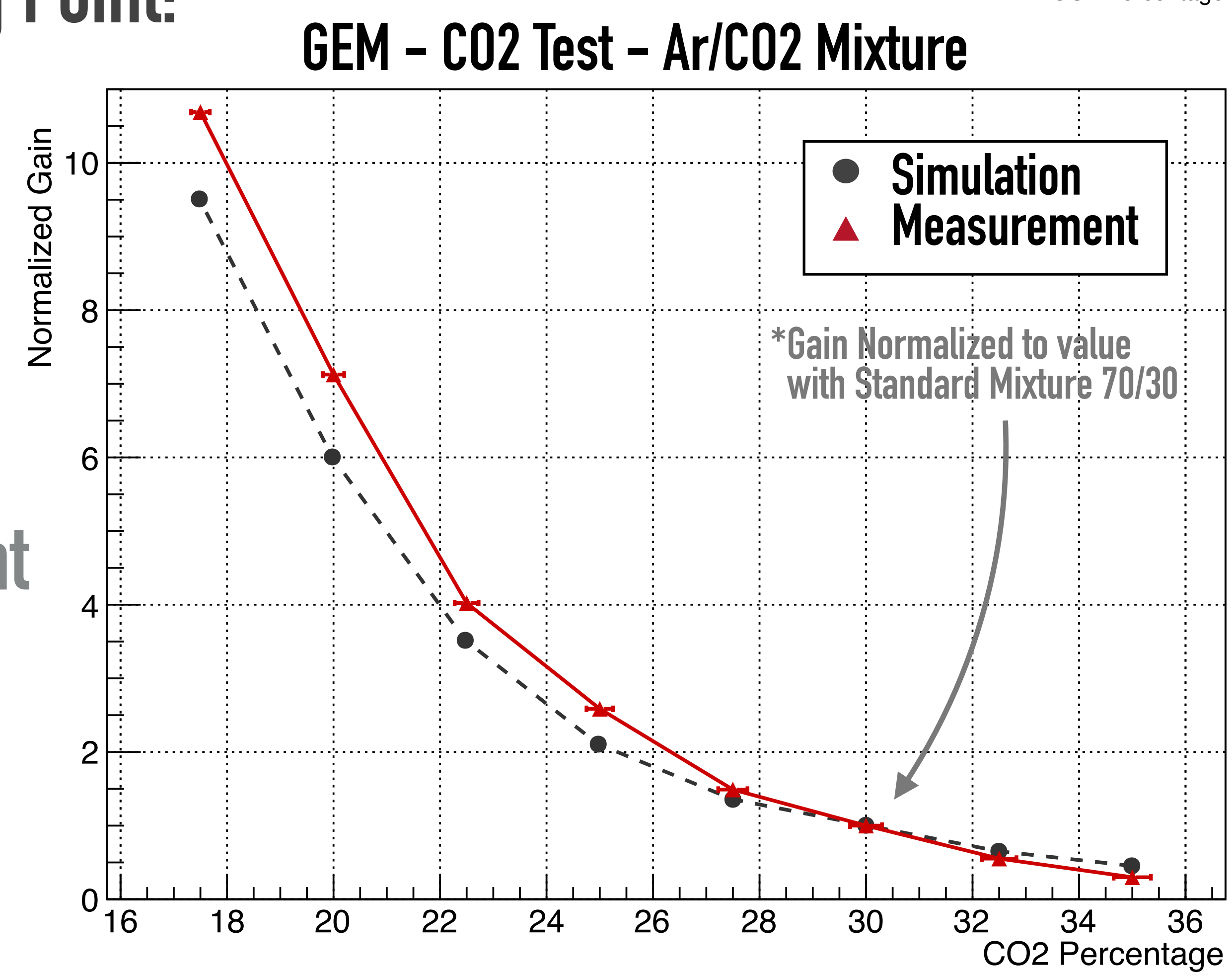


GAS-RELATED STUDIES
CO_2 CONCENTRATION IN STANDARD MIXTURE

Standard GEM mixture is composed by Ar/CO_2 70/30:
How much CO_2 variations can influence GEM response?



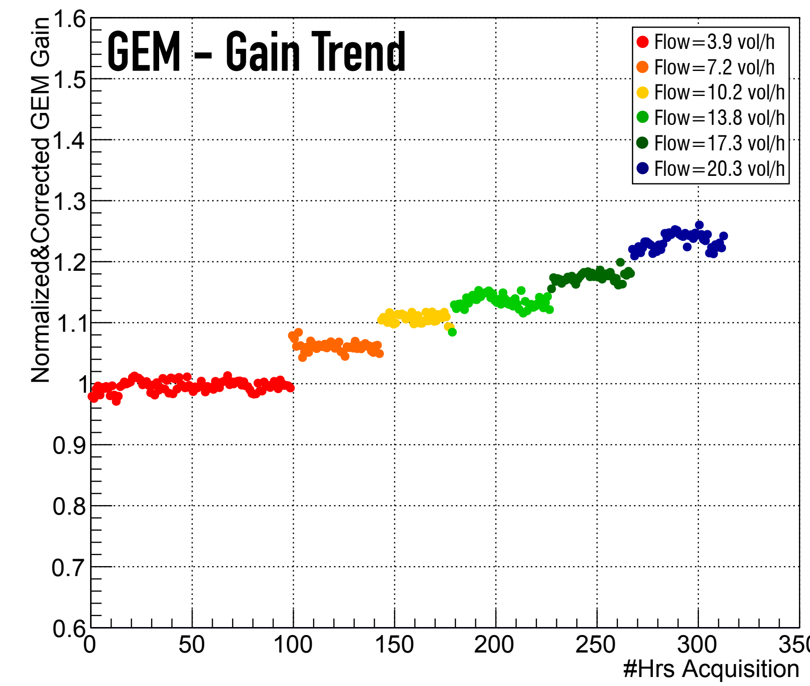
- CO_2 is a **quencher gas**: absorbs gamma from excitation
- **Increasing CO_2 leads to a higher Working Point:** +25V for 1% of CO_2 increase
- Rate measurement shows how **the increase in CO_2 causes a decrease in the detector's rate capability**
- **Increasing CO_2** in the mixture means **a lower gain** at the detector Working Point
- **Good accordance between results from experimental setup and GARFIELD simulation (Triple-GEM)**

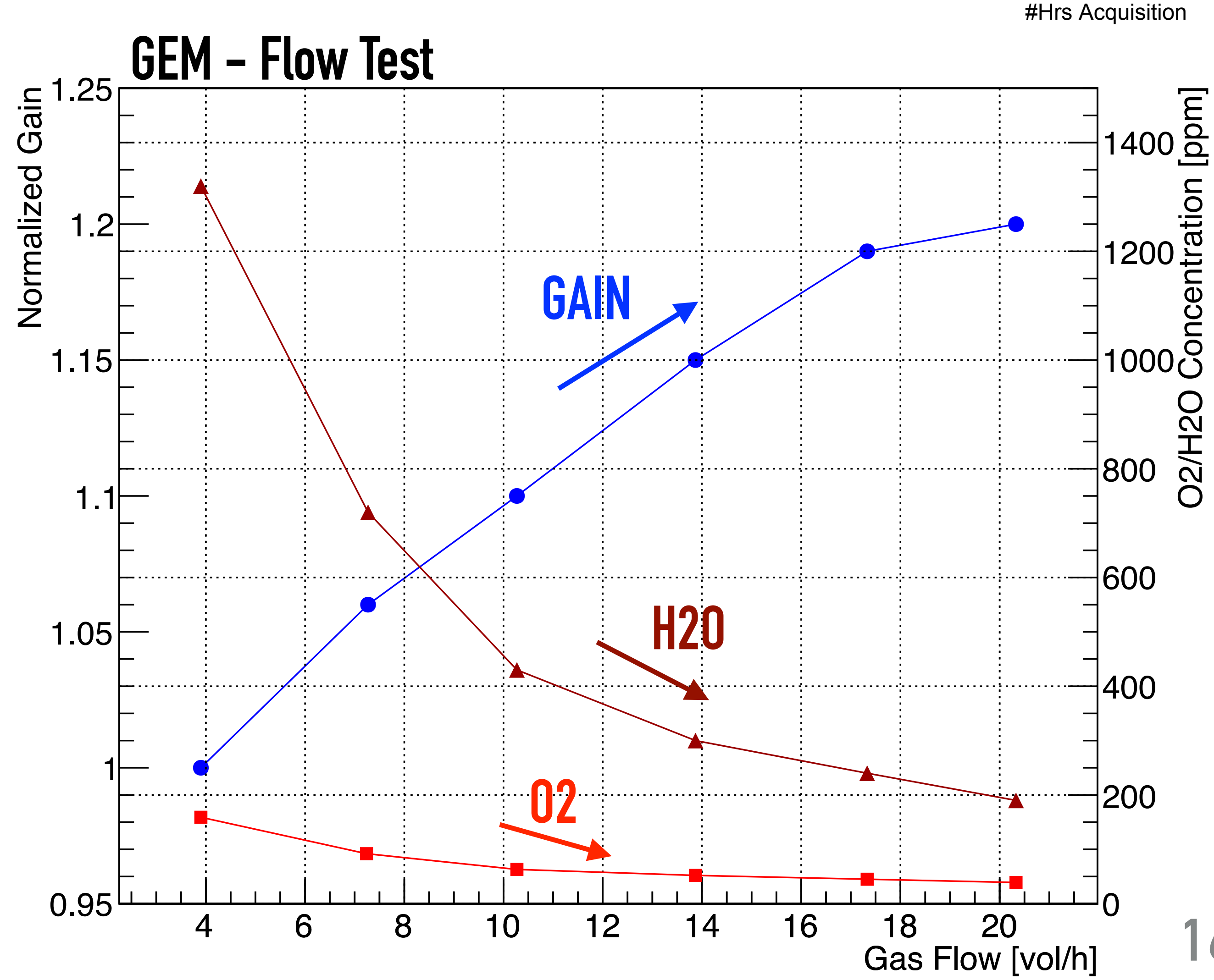


GAS-RELATED STUDIES
DETECTOR GAS FLOW

Operation **flow of gaseous detectors** is around **0.5/1 volume/hour**: **What is the flow suitable for GEMs?**

- Flows tested up to 20 vol/hour
- **GEM gain considerably increases with higher gas flows**
- The loss in performance is caused by the **impurities absorption for lower gas flows (O_2, H_2O)**
- No effects measured on rate capability
- **High flows (>10 vol/h) allow to reduce impurities accumulation, thus to operate at higher gain**

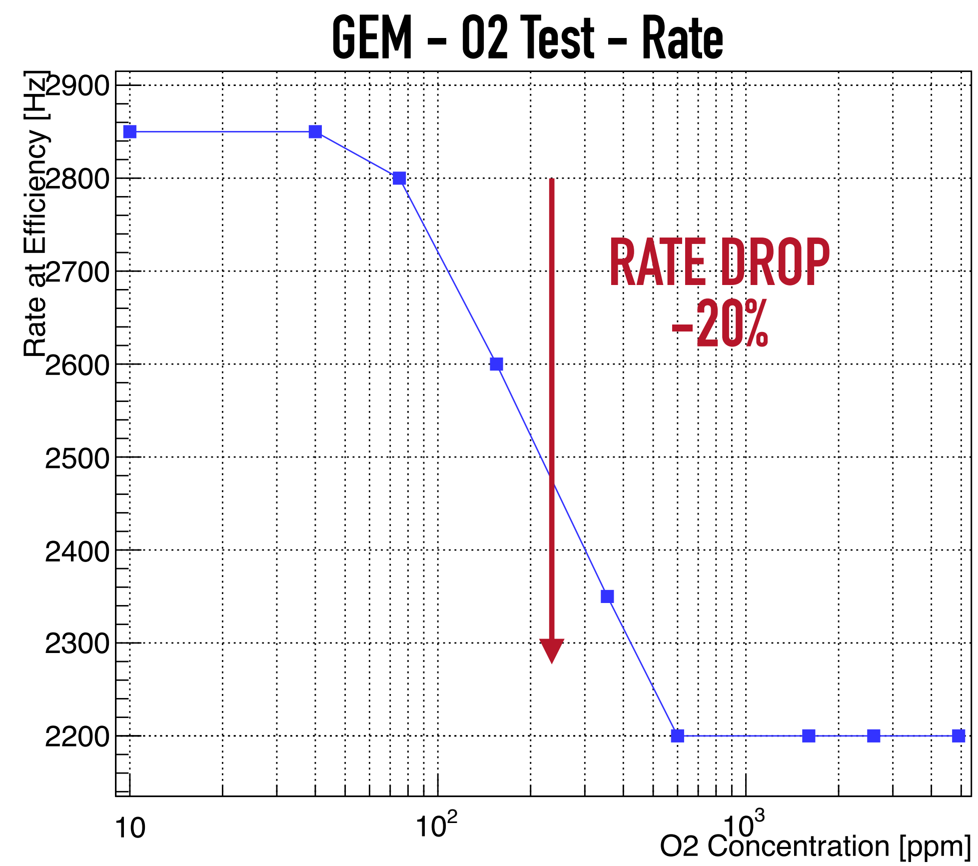


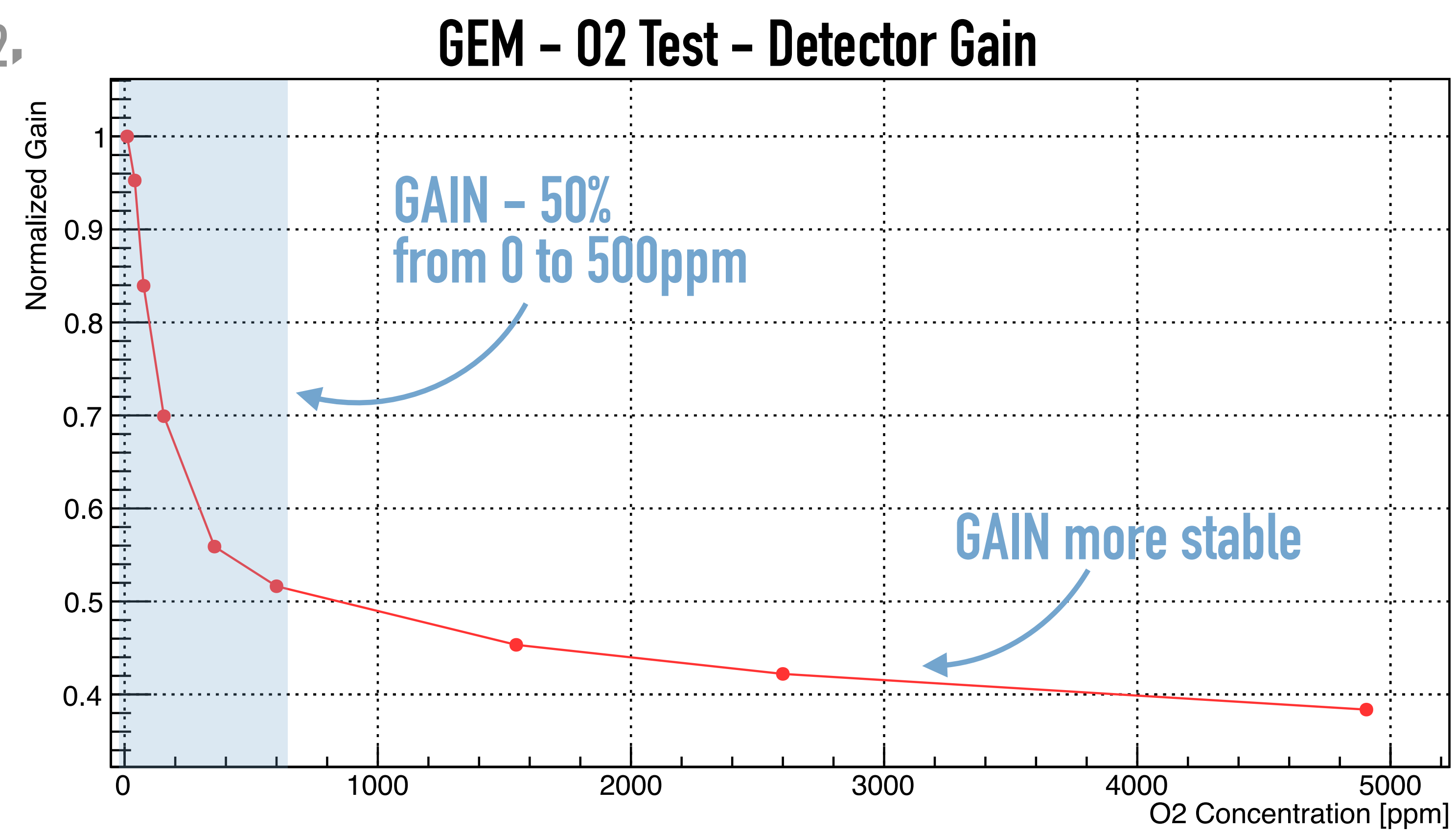


GAS-RELATED STUDIES
PRESENCE OF O_2 AS POLLUTANT

O_2 is a common impurity in LHC Gas Systems:
What is its impact on GEMs performance?

- O_2 has high electron attachment coefficient, it has the tendency to attract electrons
- Rate decrease of 20% with high O_2 concentration
- Gain decrease with increase of O_2, up to -60%, with most of variation in the range 0-500 ppm
- Efficiency is reached at higher High Voltages for higher O_2
- O_2 limits both primary ionisation and avalanche development



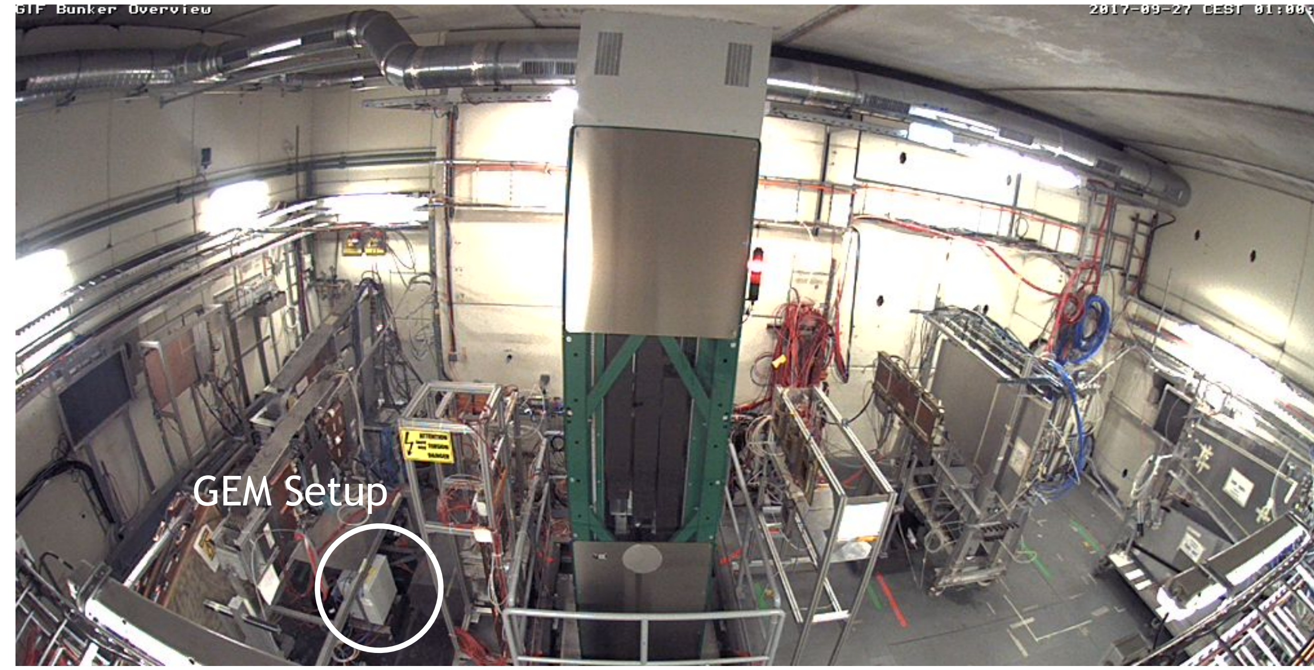


GIF++

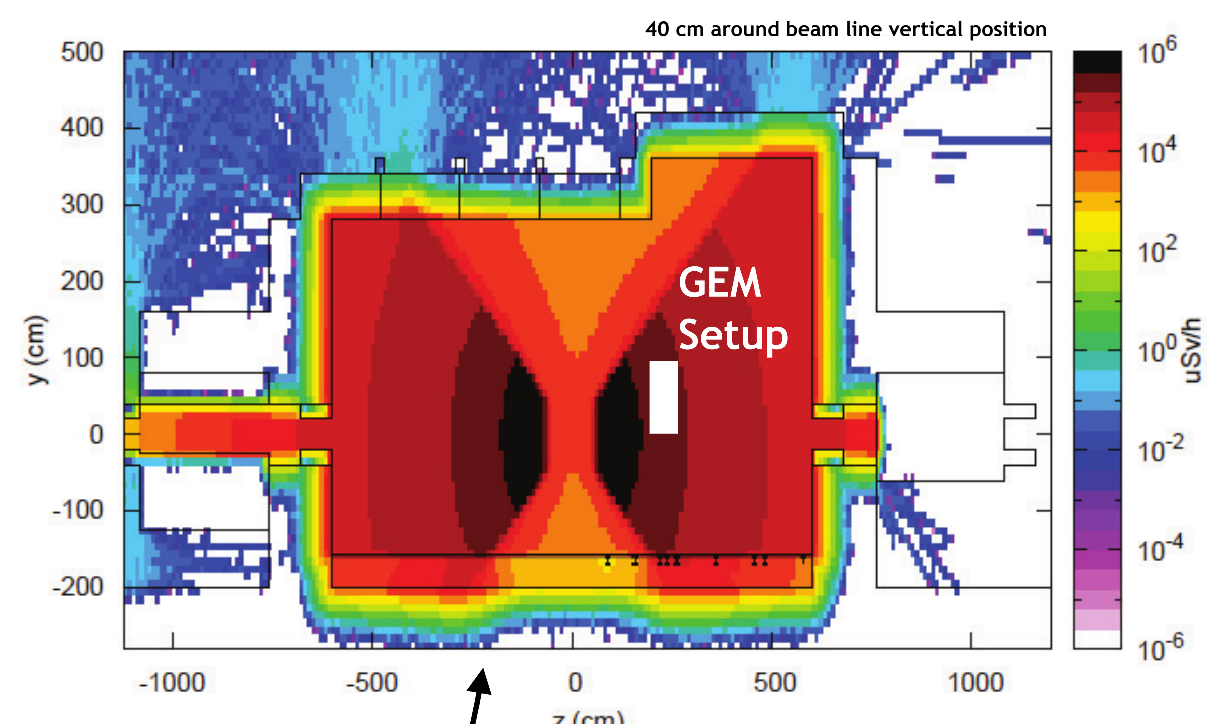
CERN GAMMA IRRADIATION FACILITY

GIF++
GAMMA IRRADIATION FACILITY

- A dedicated **test zone for large-area muon chambers**, for **performance characterisation** and **ageing test**
- **Muon beam** available from the SPS
- Provides **irradiation with ^{137}Cs** (662 keV photons), with possibility to vary source intensity through integrated filter-system
- Source activity = **14 TBq**
- **Dose rate** is suitable to mimic high radiation rate in **HL-LHC** (1Gy/h at 1m)
- More than 15 setup are currently installed



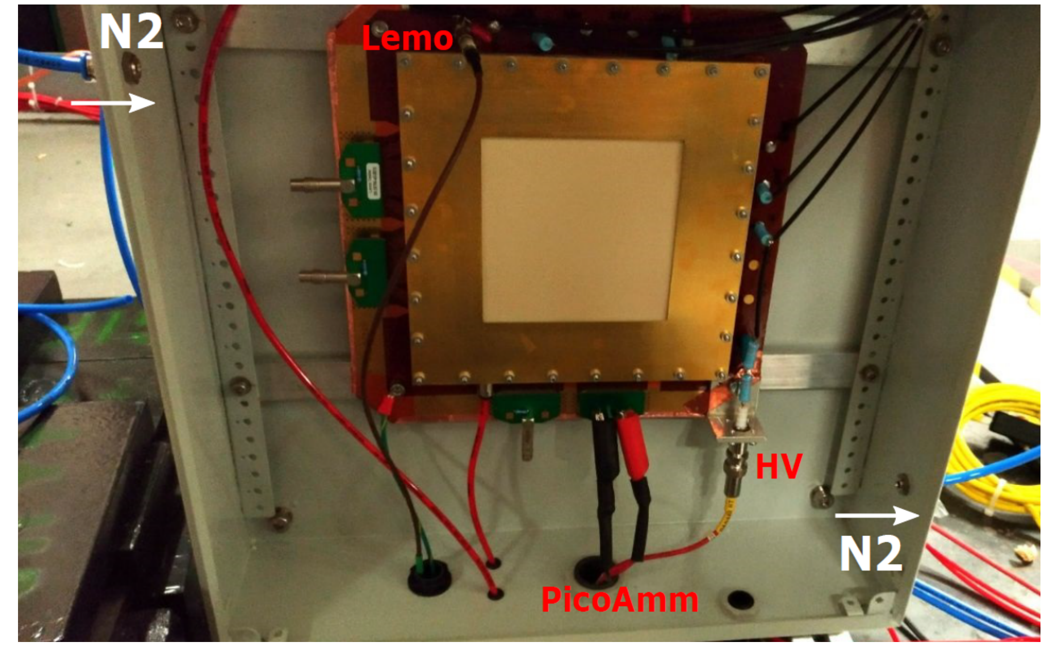
Irradiation Bunker Area



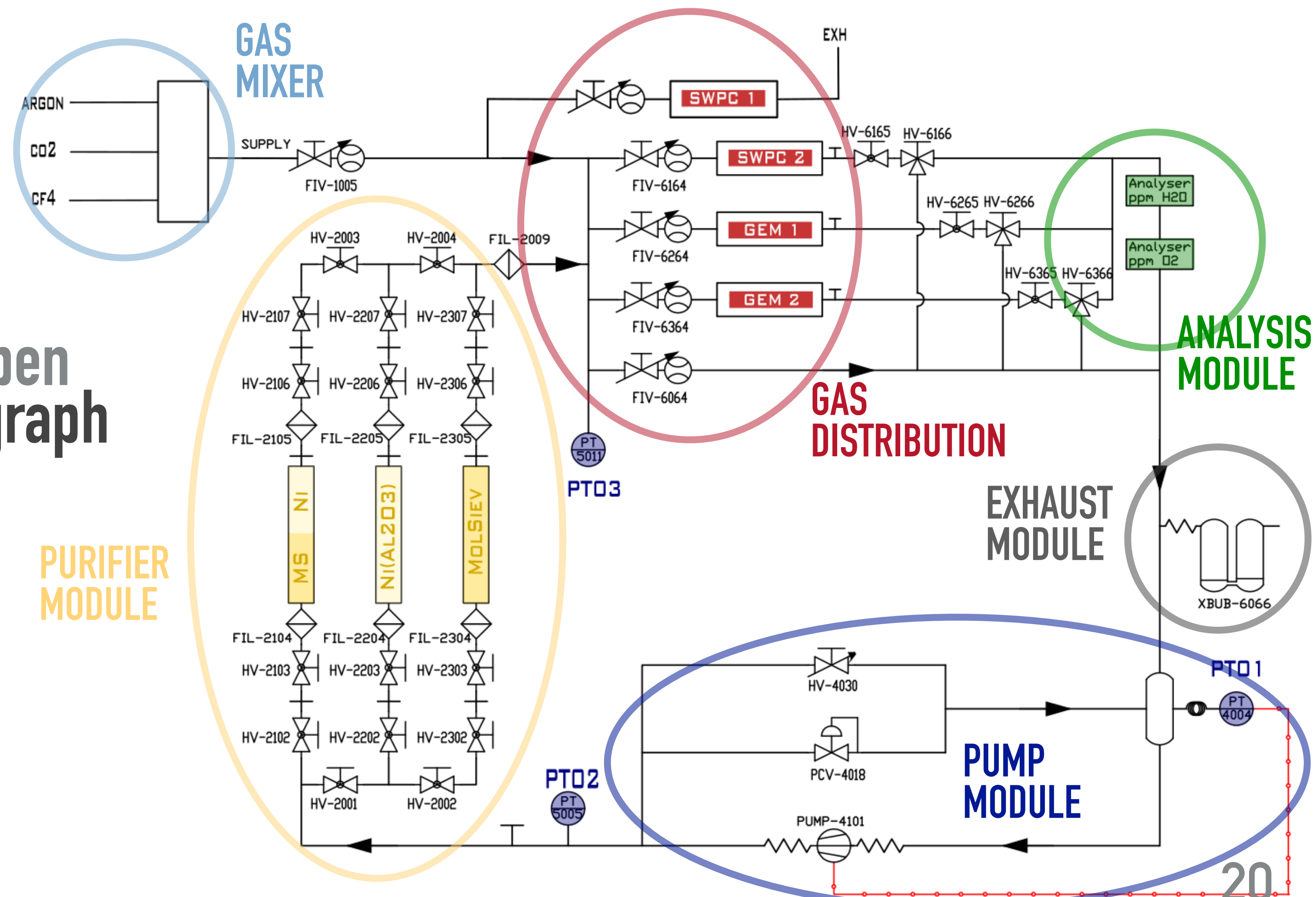
Dose Equivalent Rate

GIF++
GEM R&D SETUP

- **2 Triple-GEM detectors**
  - Gas Mixture: Ar/CO_2 70/30, $Ar/CO_2/CF_4$ 45/15/40
  - Irradiated with ^{137}Cs and ^{55}Fe
  - Setup along Muon beam line

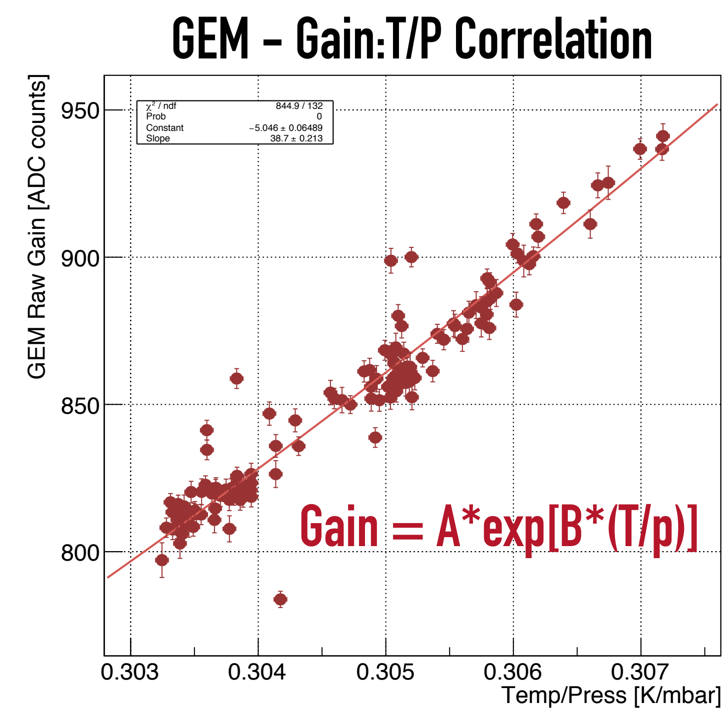


- **Closed Loop Gas System:**
  - Small replica of LHC Gas Systems
  - Purifier Module for H_2O and O_2
- **Monitoring of Gas Quality:**
  - Single Wire Proportional Chambers, one in the Closed Loop and one in Open
  - Standard Analysis + Gas Chromatograph
- **Data Acquisition:**
  - Detector Current and Signal (Picoammeter, Digitizer)
  - Environmental&Gas Parameters (ADC data logger)

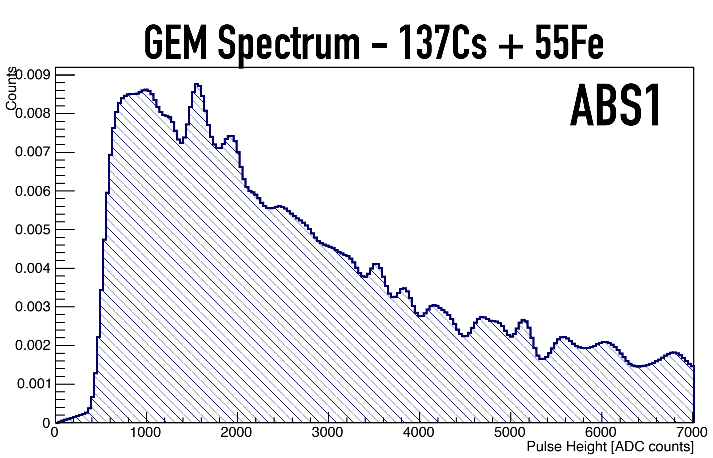


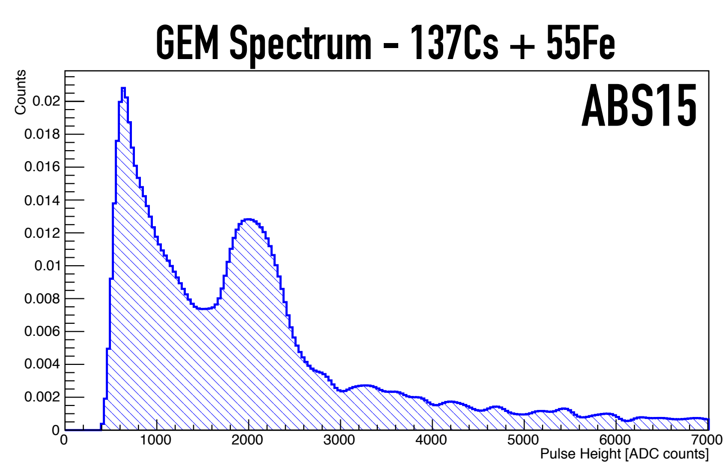
GEM IRRADIATION CAMPAIGN

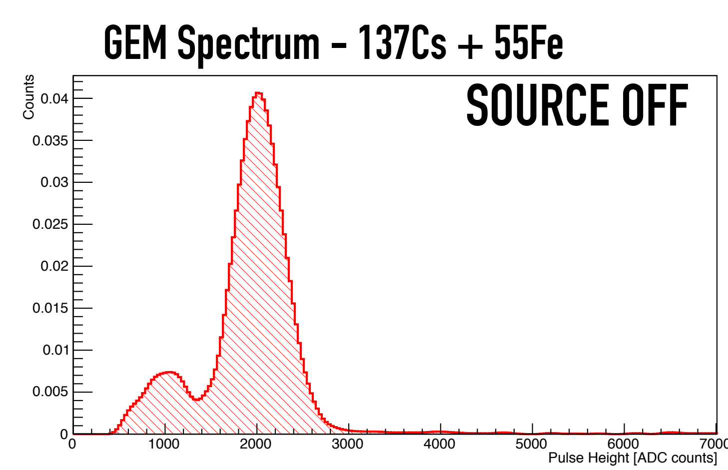
GEM IRRADIATION AT GIF++
MEASUREMENT CAMPAIGN



- Continuous monitoring of detector current from ^{137}Cs irradiation
- Weekly scans in ^{55}Fe (source is OFF for weekly access)
- Current is proportional to gain: trend in time gives indication on performance stability
- Current trend is corrected for Temperature and Atmospheric Pressure dependence
- Cs source can be attenuated with different filters (from 1 to 46K):
  *Campaign initially with ABS1, then ABS15
  *Weekly filter scans showed a consistent behaviour of GEMs





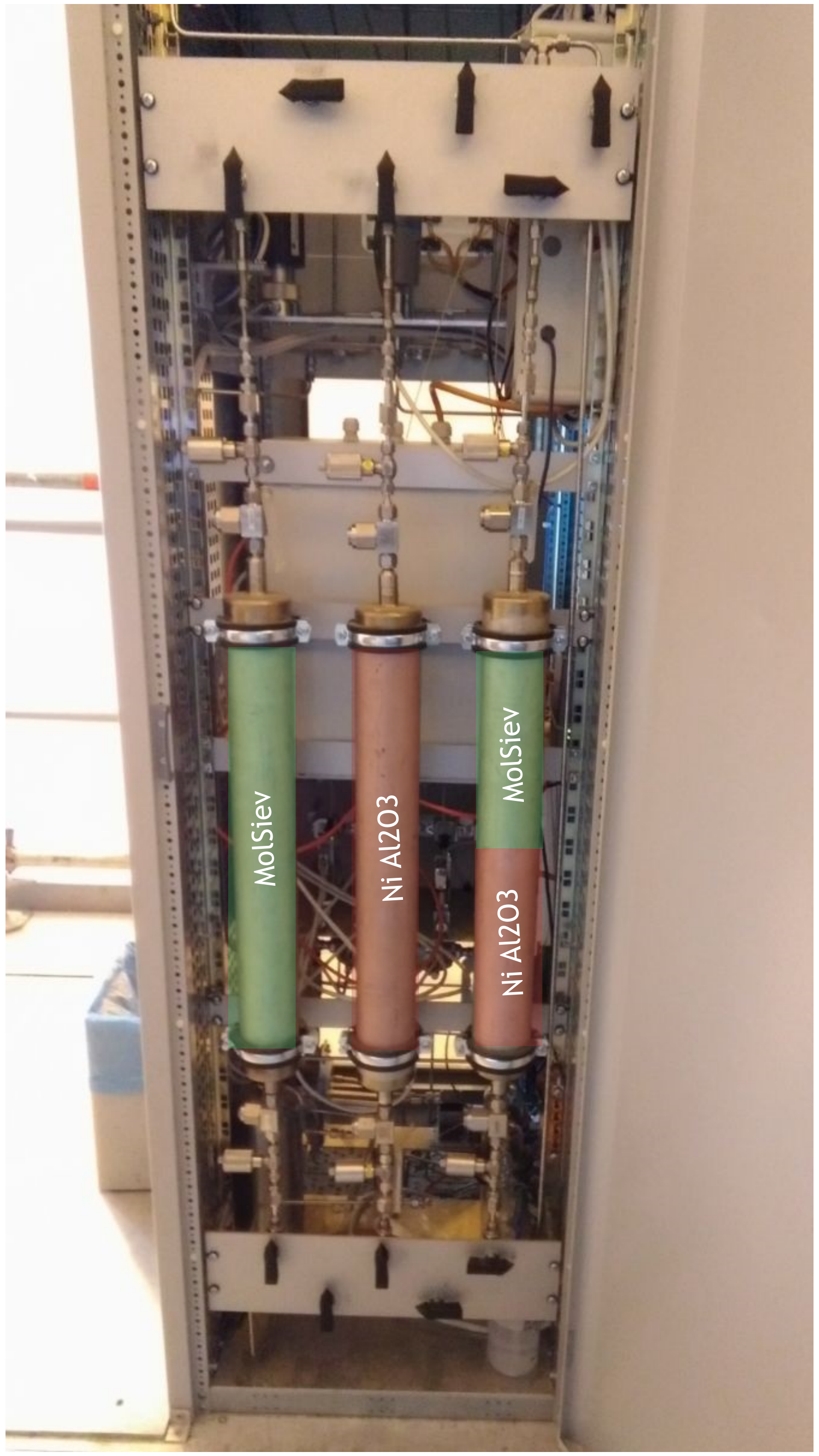


GEM IRRADIATION AT GIF++
GAS SYSTEM RESULTS

- Purifier modules are the same as the ones installed in LHC Gas Systems:
  - **Molecular Sieve**, traps **H_2O** molecules
  - **Nickel on Al_2O_3**, reacts with **O_2** and retains it
- **O_2 can be reduced by four times, from 200 ppm to less than 50 ppm** in 90% recirculation
- **H_2O** is instead **around 100 ppm, and can be lowered to less than 10 ppm** when purifiers are open

  * It is fundamental to work with low H_2O levels because F^- could react with H_2O molecules creating deposits on GEM foils

- **The use of purifiers also allowed to maintain H_2O and O_2 very stable** (variations of 2/3%), **avoiding oscillations in GEMs performance**

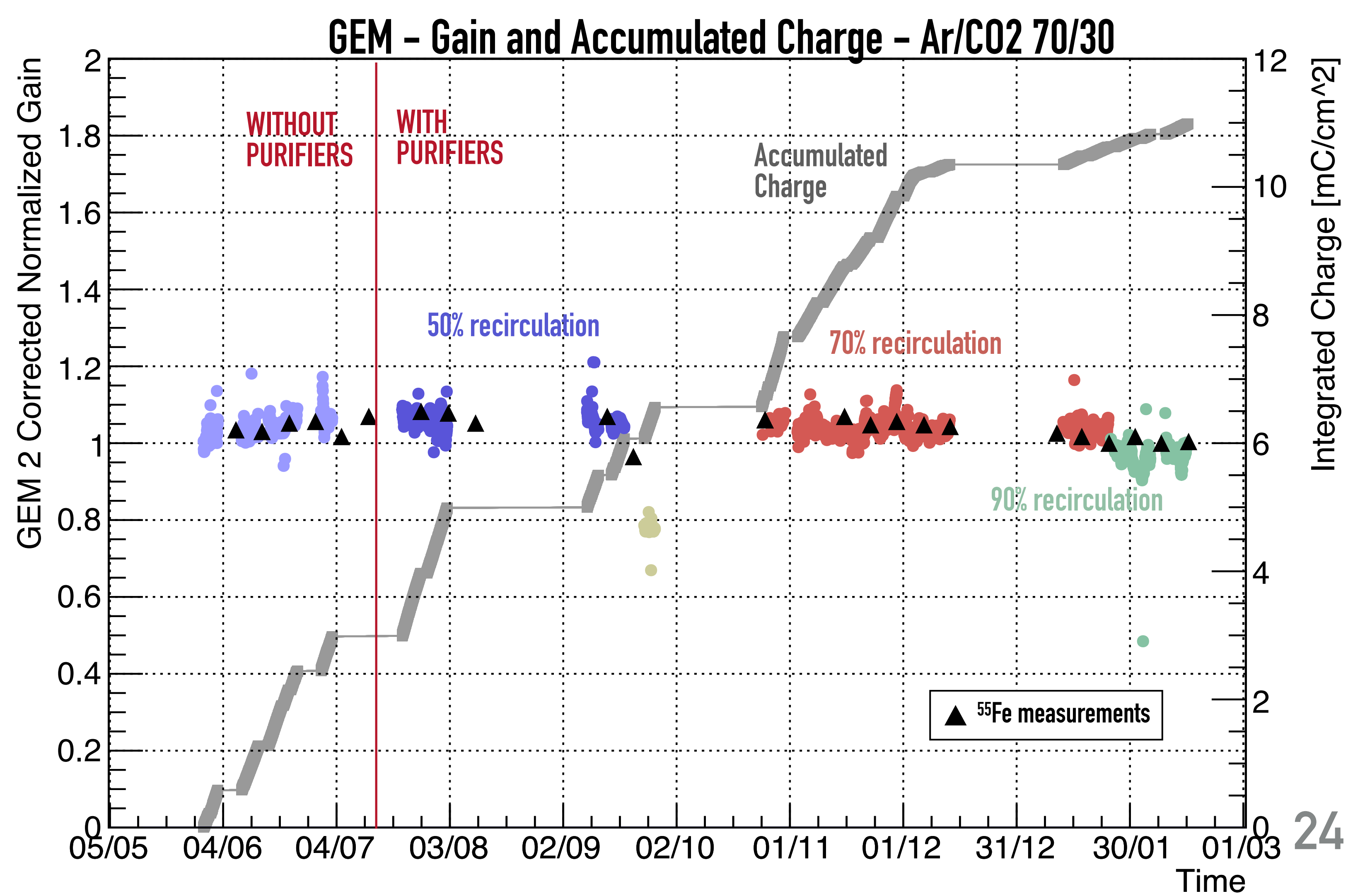


GIF++ GEMs Gas Rack
Purifier Cartridges

GEM IRRADIATION AT GIF++
IRRADIATION RESULTS

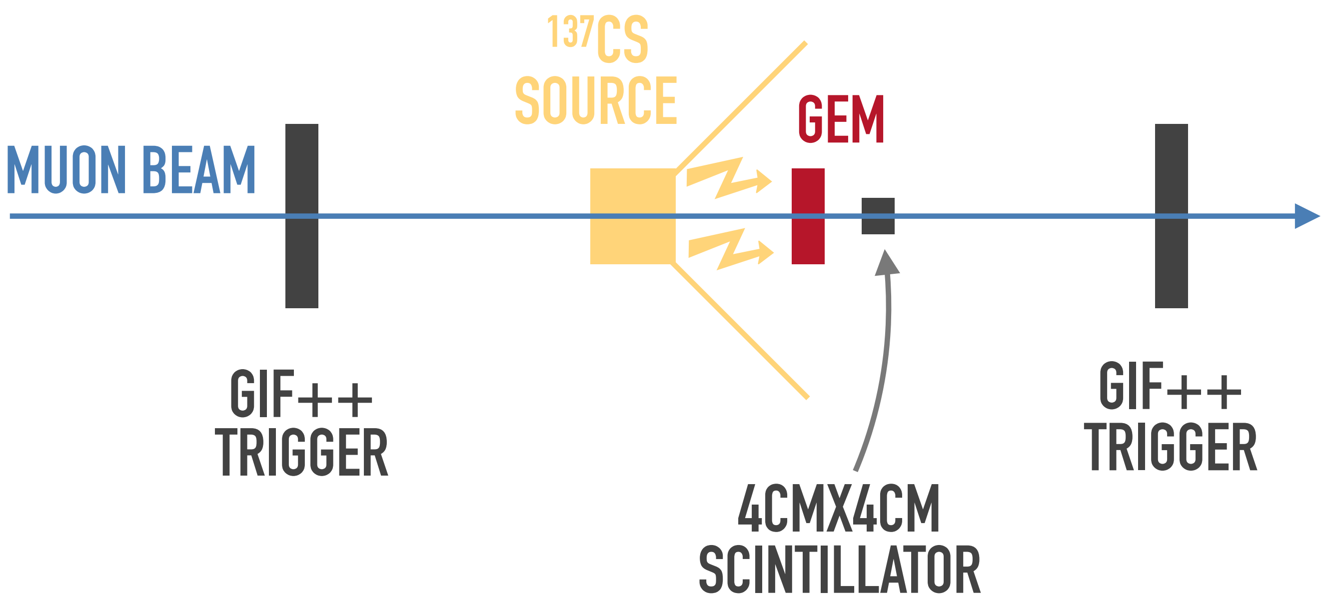
- Gas Mixture tested: Ar/CO_2 70/30, recirculating fractions: 50%, 70%, 90% as LHC Systems
- **Accumulated charge** around **10 mC/cm²** for both chambers
- Gain from ^{55}Fe always consistent with progressive detector current
- Slight decrease of gain with higher recirculation due to impurities

All detectors showed a stable response regardless the recirculating fraction and the source attenuation

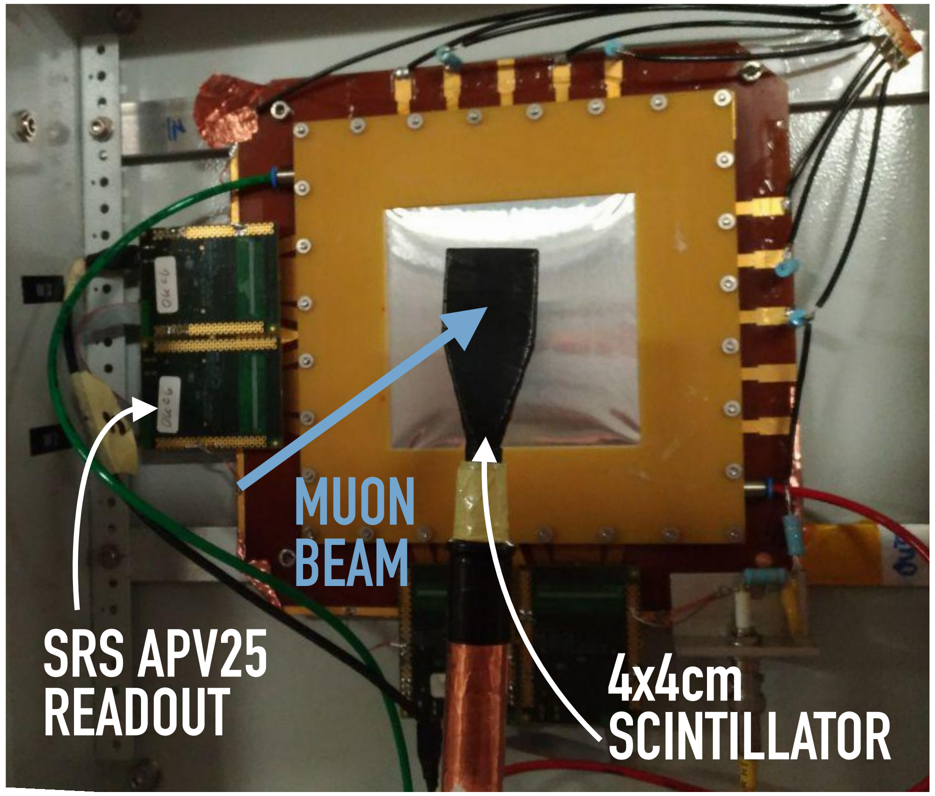


MUON TEST BEAM WITH HIGH-RATE BACKGROUND

MUON TEST BEAM
PURPOSE & DATA TAKING

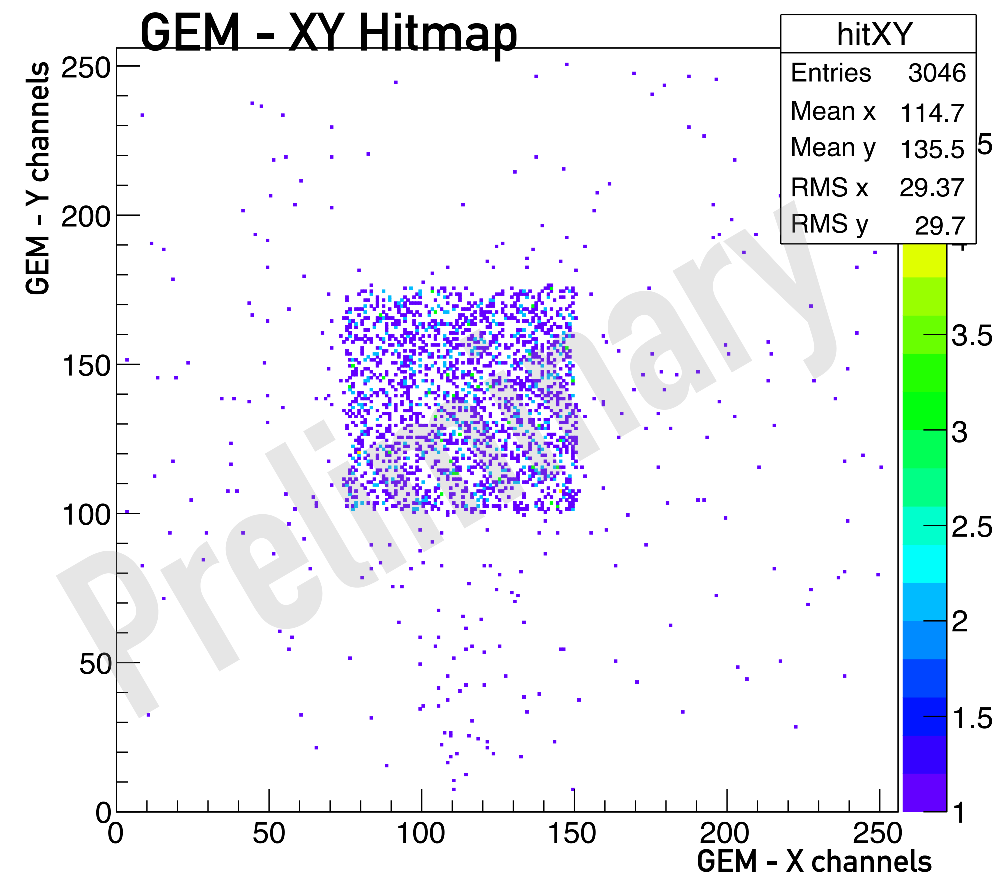


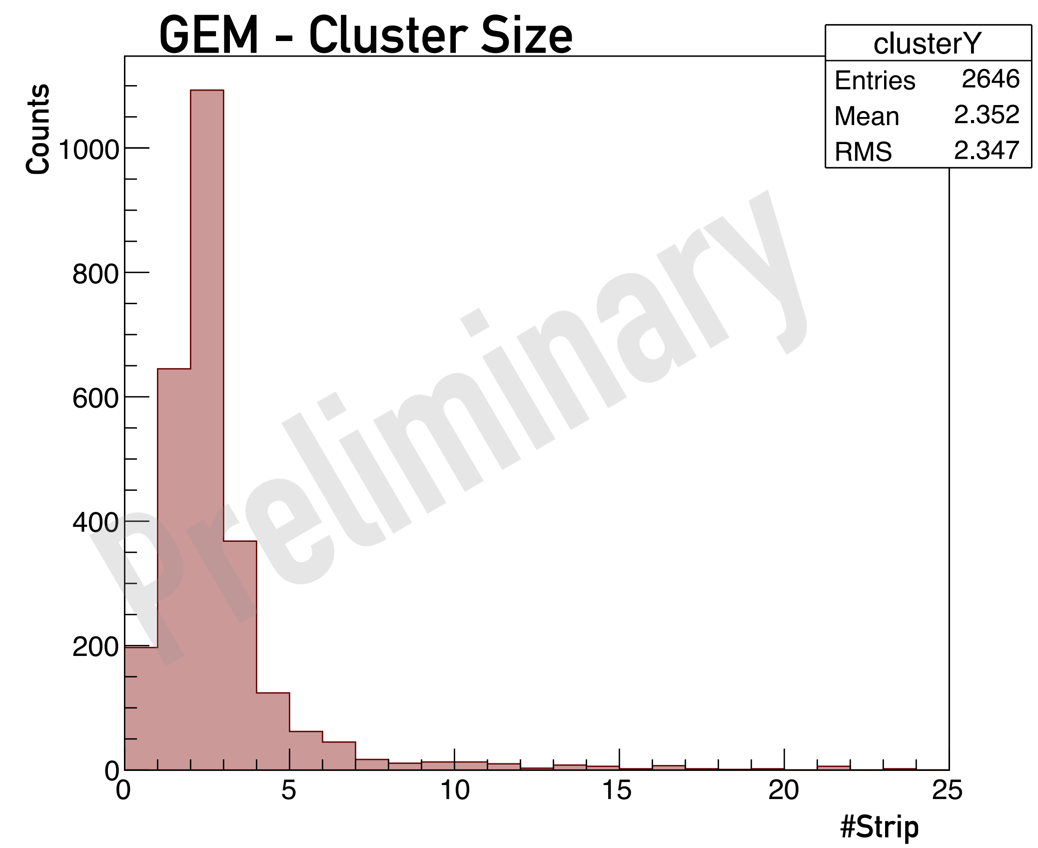
- **GEMs are part of Muon Systems**: interesting to study their performance for Muon detection in presence of HL-like gamma background (^{137}Cs)
- **GEM placed along Muon Beam**, with 4cmX4cm scintillator to provide trigger counts to DAQ electronics
- DAQ is the SRS System from RD51(CERN), capable of reading **256x256 readout strips** giving information on **XY position and charge**
- **GEM Efficiency = #GEMcounts/#TRIGGERcounts**
- **Deposited charge is proportional to Muon energy**: charge distribution is a Landau, which MPV is proportional to Detector Gain



MUON TEST BEAM
RESULTS

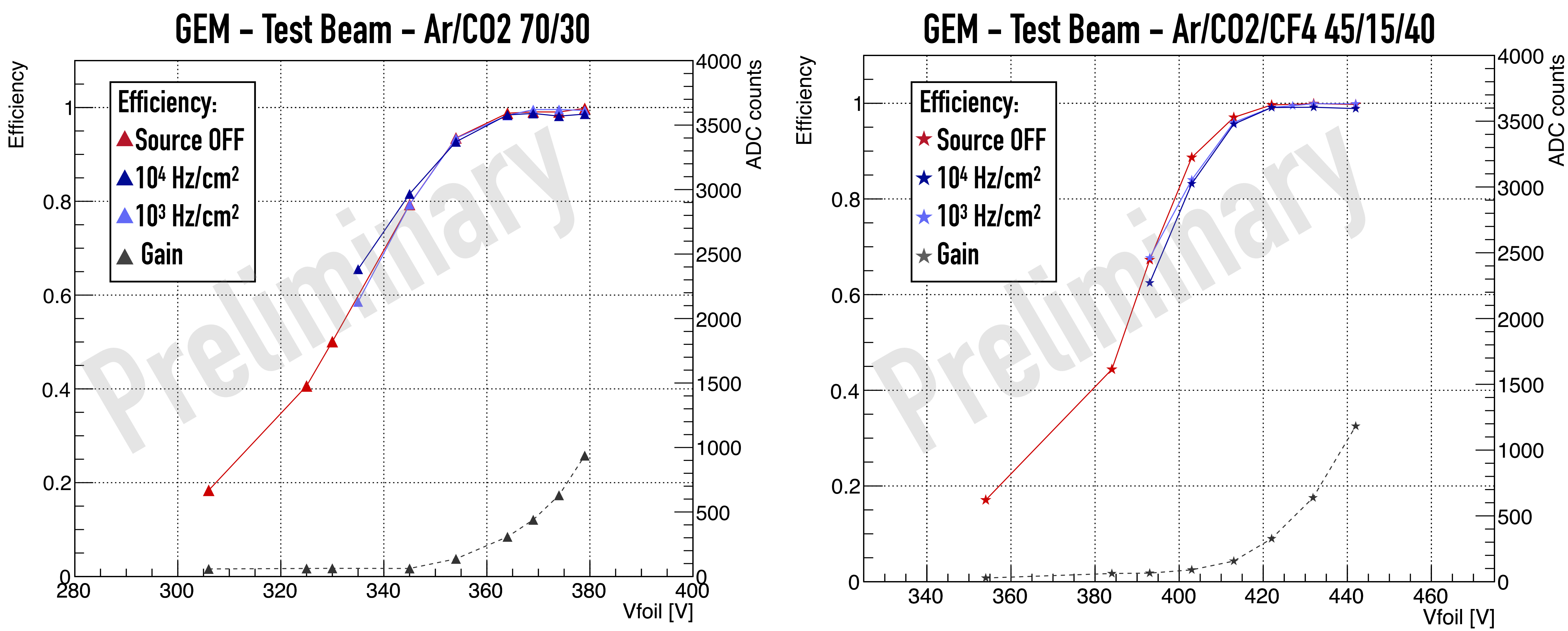
- Being scintillator's area smaller than GEM's area, **all the trigger counts are inside the GEM surface:** **efficiency can reach the 100%,** without geometric effects
- **Scintillator's profile can be seen in the hitmap of the XY plane**, combining the X-strips and Y-strips readout
- **Cluster size is found to be around 2.3** (literature says around 1.8)
- **Data analysis is still ongoing, to better understand cluster size, double events, . . .**





MUON TEST BEAM
RESULTS

- **Efficiency curve** shows the **difference in Working Point between Standard Ar/CO_2 mixture and CF_4-based mixture**
- **GEM showed good efficiency** (close to 100%) both with only Muon Beam and **with different ^{137}Cs source intensities** (up to 10^4 Hz/cm^2)



CONCLUSIONS & NEXT STEPS

CONCLUSIONS

- **Several studies** were performed on **specific changes in GEMs Gas Mixture**
- **GEMs performance with Ar/CO_2 mixture in Gas Recirculating System is stable in presence of high-rate radiation** (as in the future HL-LHC phase)
- **Purifier module** in Gas Systems are **efficient in removing impurities** that can accumulate in the Closed Loop systems (H_2O, O_2)
- **GEMs are efficient in presence of high-rate gamma background** (up to 10^4 Hz/cm^2)

NEXT STEPS

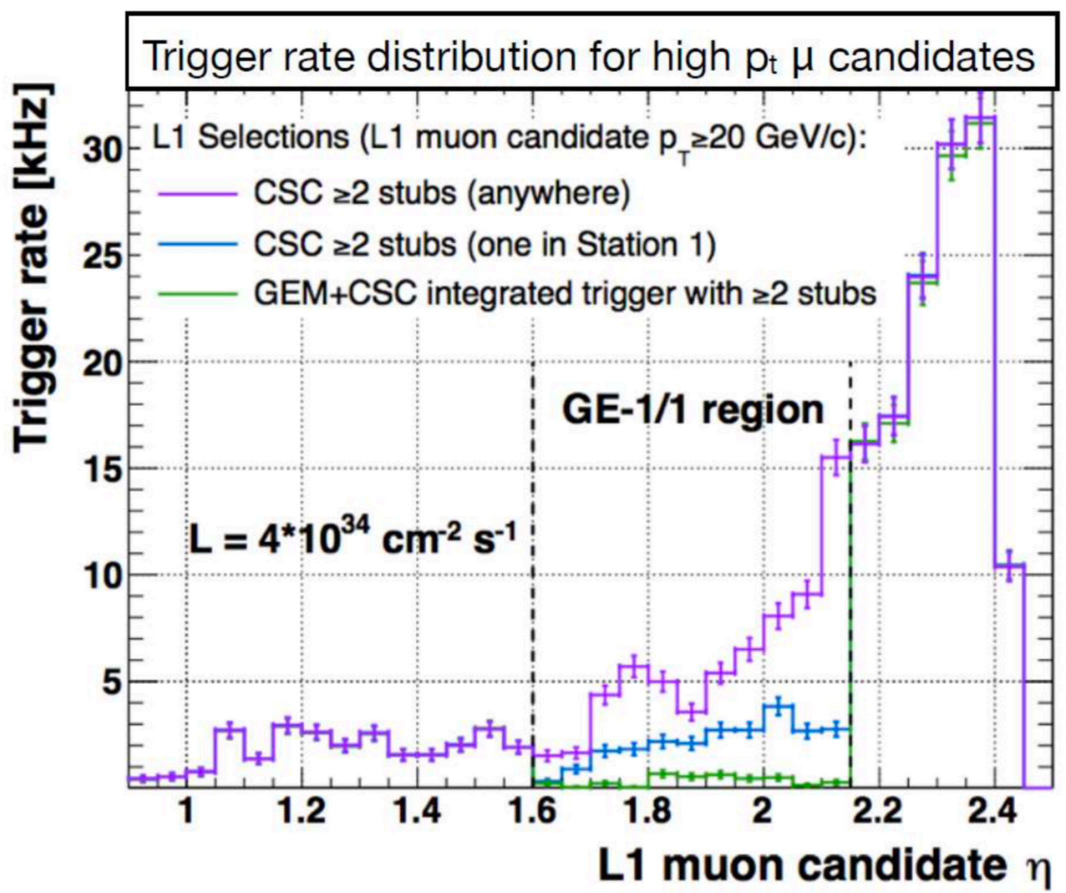
- Complete the **irradiation campaign with CF_4 mixture**
- **Study impurities accumulation in recirculation systems** with CF_4 mixture and high rate radiation
- Continue with **studies on** the effect of specific gas mixture variations and **pollutant addition** (H_2O, Air, . . .)

THANK YOU FOR YOU ATTENTION!

BACKUP

HIGH LUMINOSITY LHC
EXPERIMENTS UPGRADE : CMS

- CMS Muon System plans an upgrade in the forward region
- High-rate background in HL-LHC can compromise the measurement of Muons momento, worsening the measurement resolution
- The future installation will see two new stations in the end-cap region, composed of a double layer of Triple-GEM detectors
- It will allow to have a reduced trigger rate on muon candidates



WHY GEM DETECTORS?
RATE CAPABILITY

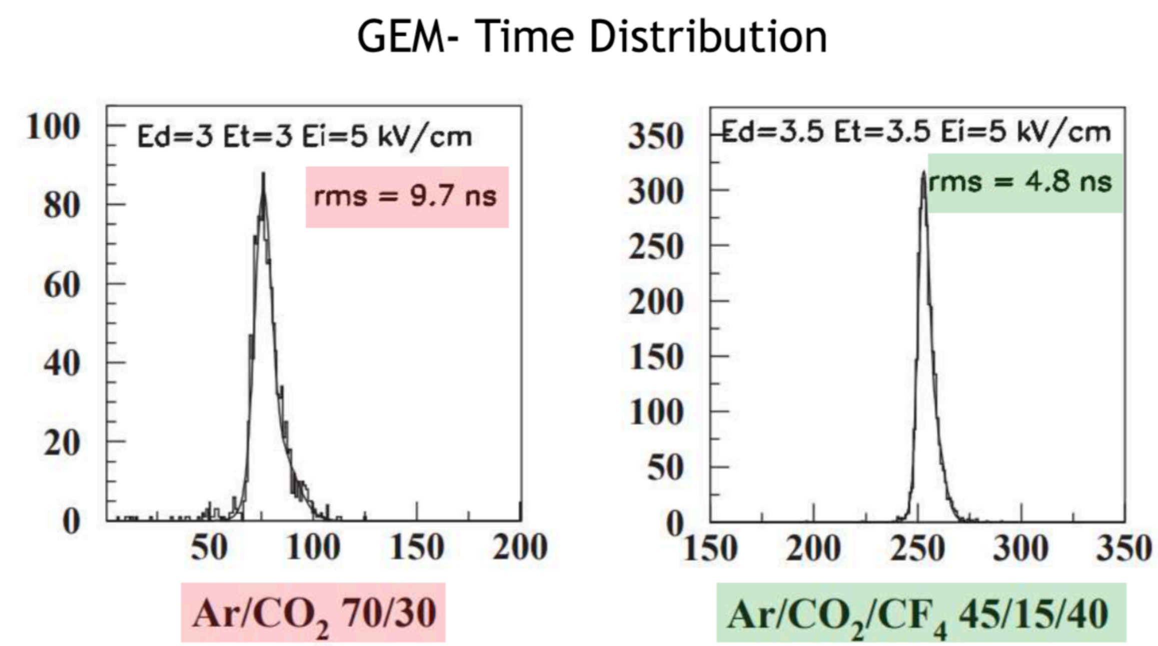
GEMs fulfill the needs of Muon Systems upgrades

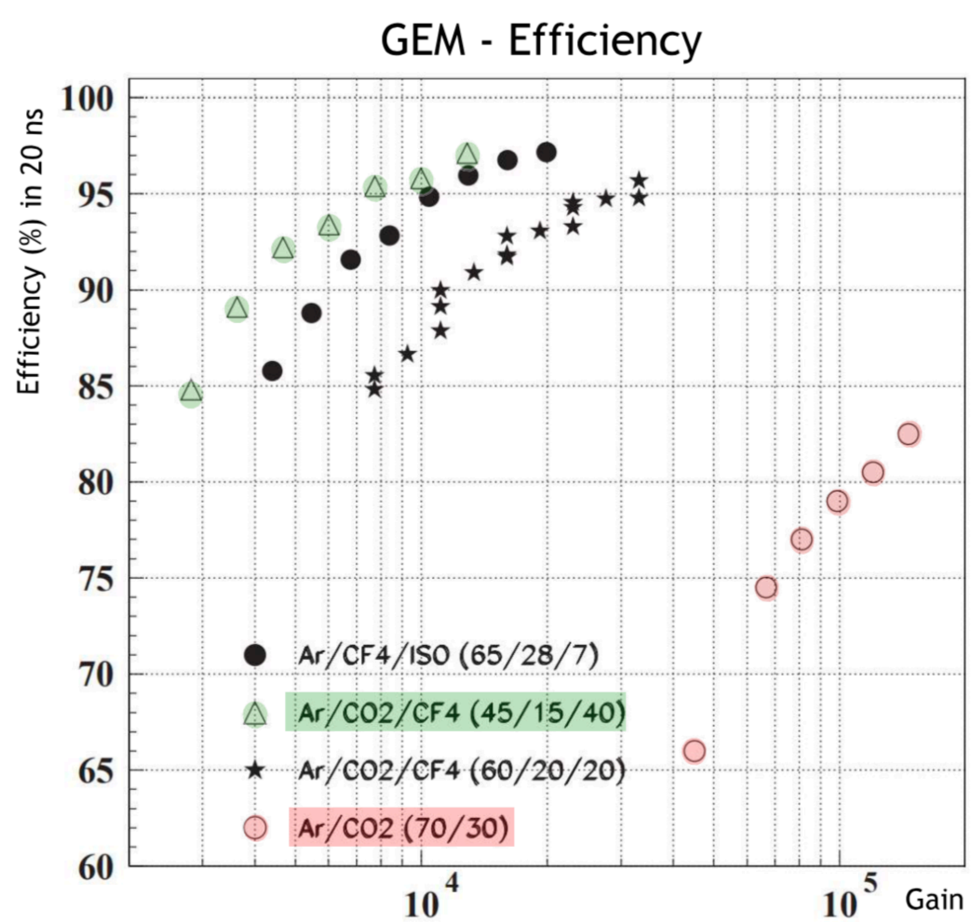
- Extremely high rate capability : up to 10^6 Hz/cm^2
- Good trigger efficiency in short time window : around 96% in 20ns
- Limited signal width (50 ns) to limit trigger dead time
- Proved radiation hardness for about 10 years of operation

- RPC cannot handle high background particle rate for high-η regions
- MWPCs will be replaced in high rate regions : cannot stand high radiation
- Many GEMs layer can fit in the tight spaces left in Muon Systems

WHY CF_4?
GEM TIME RESOLUTION

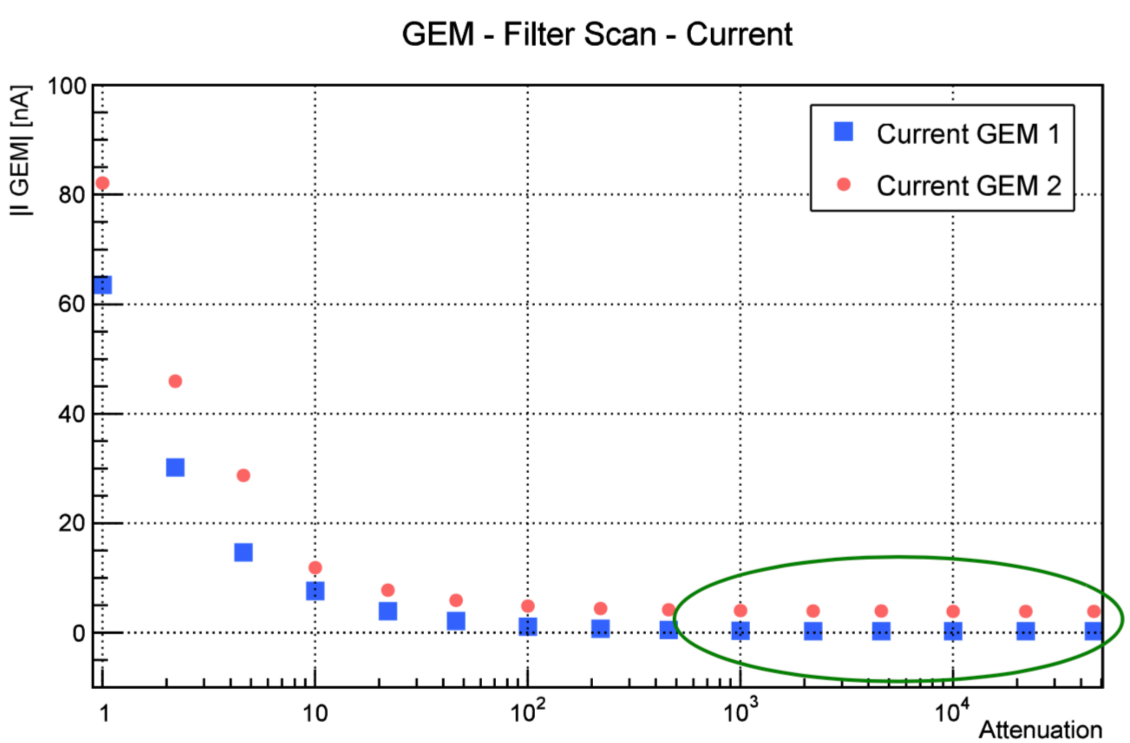
- Time resolution is proportional to the inverse of drift velocity, i.e. electrons velocity in gas
- A good time resolution is obtained with high drift velocity
- $Ar/CO_2/CF_4$ gas mixture exhibits a drift velocity of 10 cm/μs, while Ar/CO_2 only 6 cm/μs
- CF_4 allows then to reach a time resolution better than 5 ns in a 20 ns time window

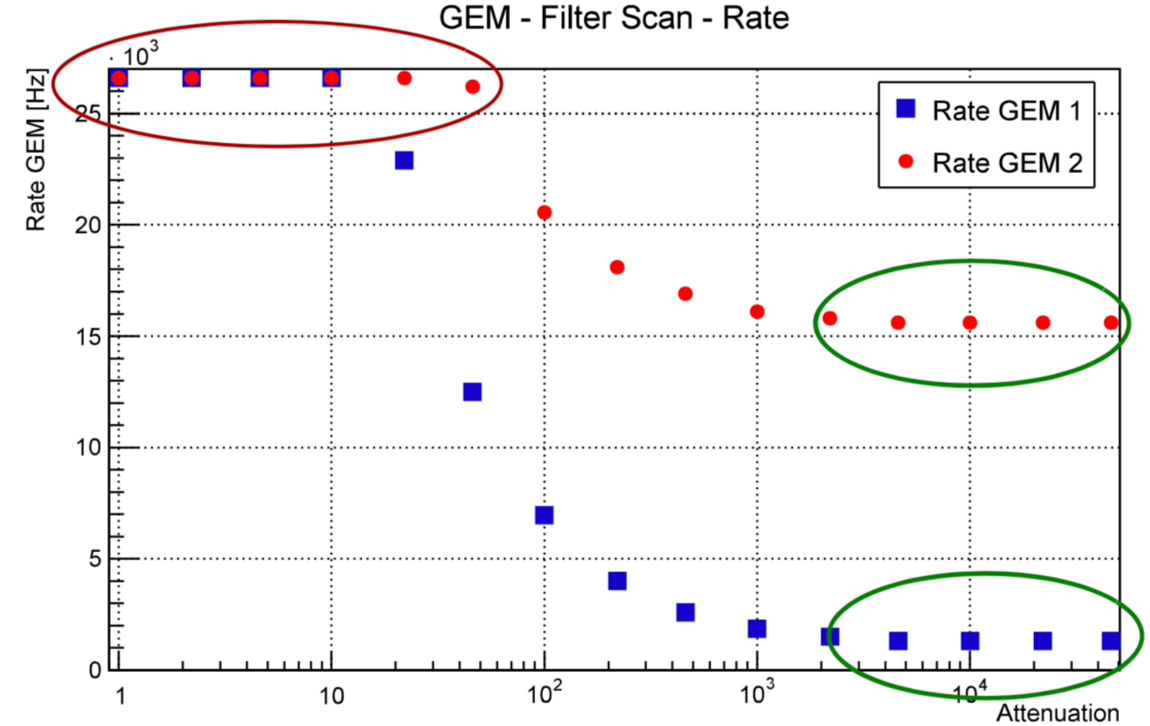




GIF++, FILTER SCAN
RATE AND GAIN MEASUREMENT

- Current/rate offset for high filters comes from ^{55}Fe irradiation
- Different ^{55}Fe baseline comes from different source activities (0.1 MBq and 35 MBq)
- Rate plateau for low filters : electronics saturation (digitizer)



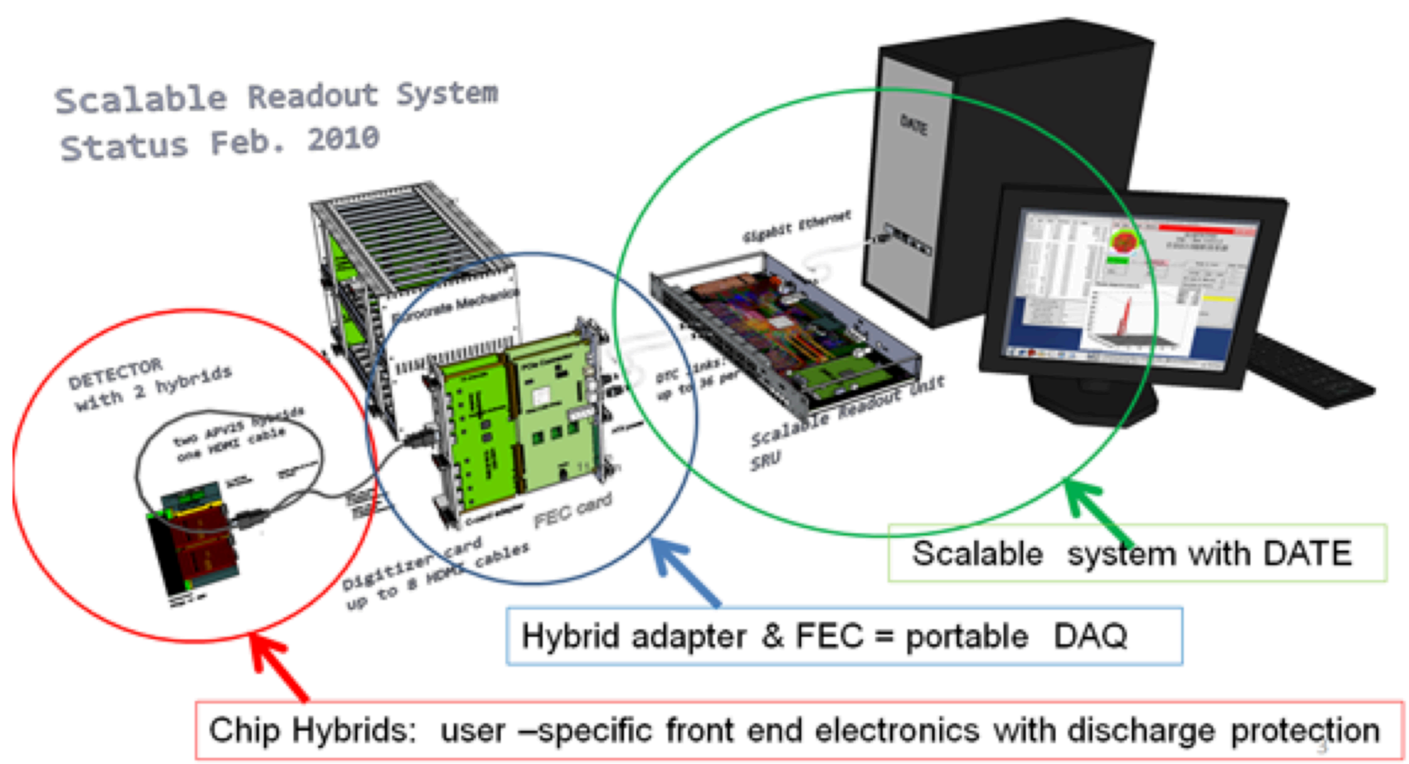


DAQ ELECTRONICS
CAEN DESKTOP DIGITISER

- Standard signal acquisition is realised with the **CAEN Desktop Digitizer DT5724**
- After the analogical electronics chain to shape and amplify GEM signal, it **allows to digitize the analogical input** and register it with a dedicated software
- It can handle **100 MSample/second:** for full intensity gamma irradiation it saturates in rate (max 30 kHz)
- Input range of 2.25 Vpp, suitable for GEMs amplified signals
- **Programmable software for parallel and continuous acquisition: good for monitoring long-term detector performance**

DAQ ELECTRONICS
SCALABLE READOUT SYSTEM – SRS

- The **SRS is an acquisition system** developed by the **RD51 CERN collaboration**
- It allows the **digitalization and collections of signal** from various types of front-end electronics (in GEMs case, **APV25 chips**)
- **Dedicated software** allows to configure the system and perform data acquisition



More info here

GAS QUALITY MONITORING
SINGLE WIRE PROPORTIONAL CHAMBERS

- Wire chambers are used to monitor gas quality
- SWPC1: **Fresh mixture** injected in the system
  SWPC2: **Recirculating mixture**, parallel to GEMs
- Both showed **good stability**, gain variation within 3%