DRD1 COLLABORATION MEETING

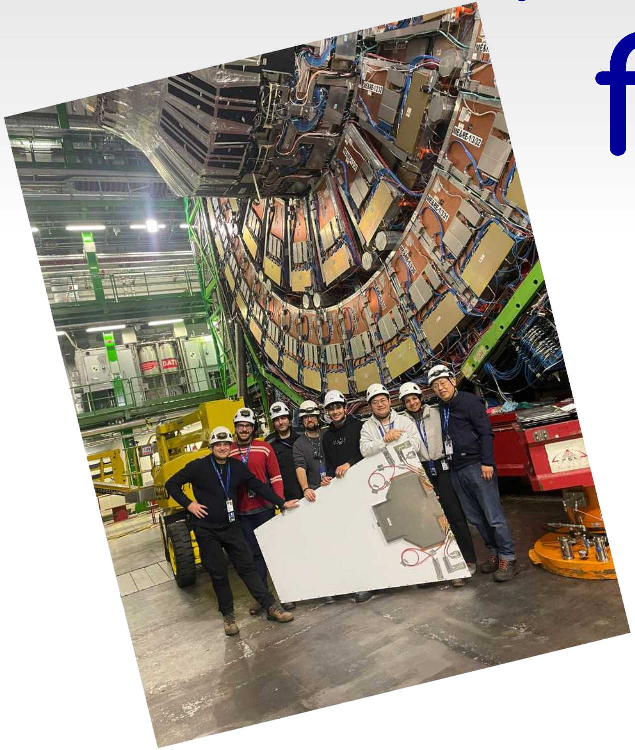
CMS iRPC readout electronics

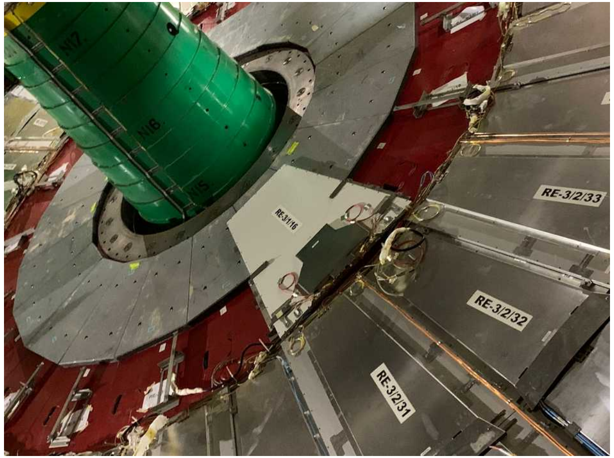
Maxime Gouzevitch on Behalf of CMS Collaboration

IP2I, Lyon, France

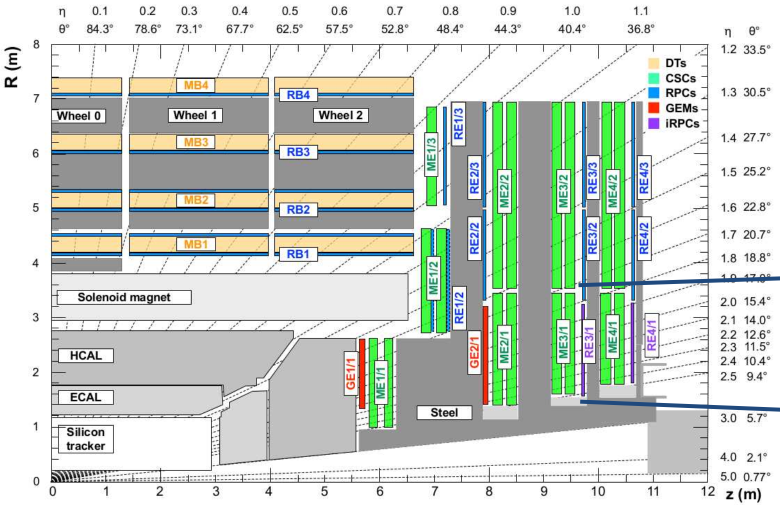
1) iRPC project for HL-LHC
2) FEB design
3) FEB certification, calibration and production

1) iRPC project for HL-LHC





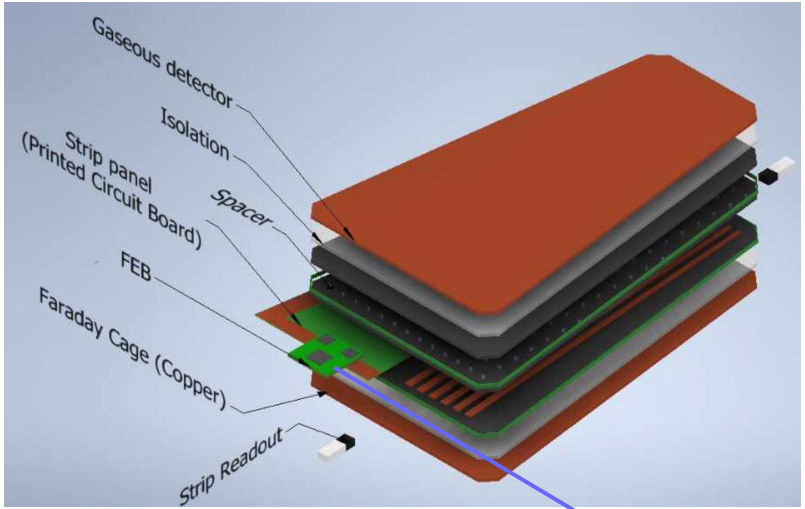
1.1) iRPC project for HL-LHC phase

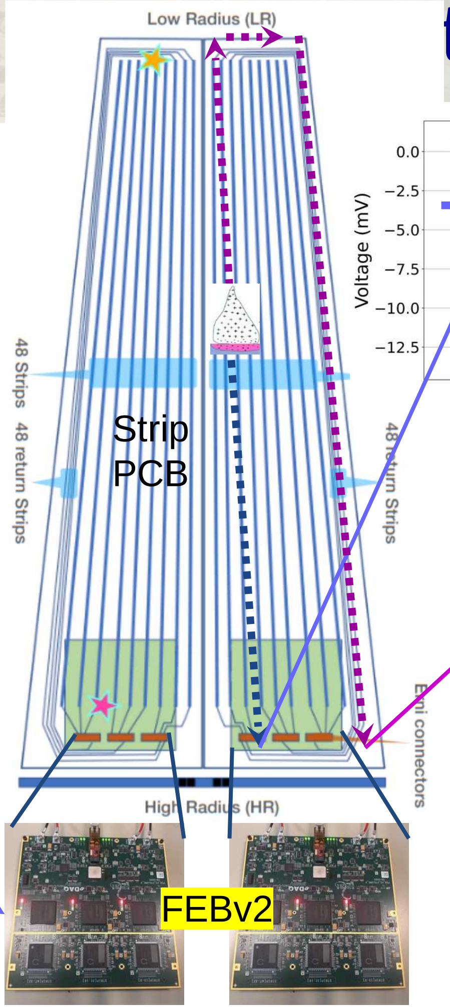


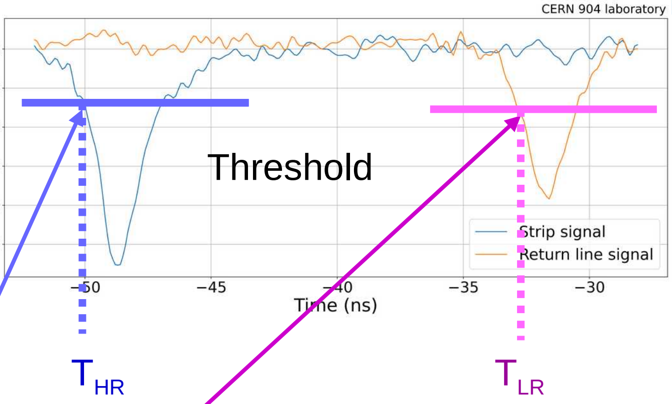
4 stations of 18 trapezoidal chambers complementing the Forward Muon Spectrometer in the most forward rings :

- Sub-ns timing resolution
- High background capability up to 2 kHz/cm²
- Requires an innovative FEB with low sensitivity threshold (below 50 fC), an excellent timing resolution, and high transmission rate.

1.3) iRPC







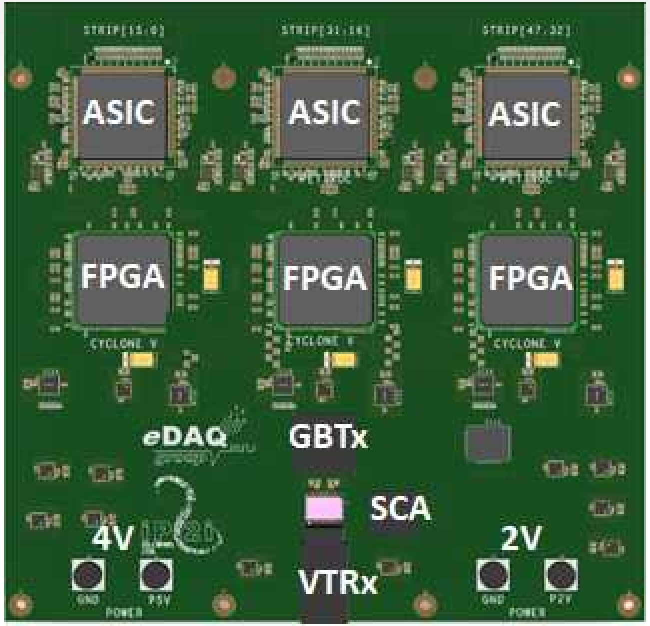
- Strip pitch : 0.5 – 1 cm
- Double sided readout of long strips using timing to localise the signal position

$\Delta T = T_{HR} - T_{LR}$

$\sigma_{\Delta T} \sim 150$ ps $\rightarrow \sigma_{\eta} \sim 1.5$ cm

M. Gouzevitch: iRPC front-end board readout electronics. DRD1 6th workshop

2) FEB design



M. Gouzevitch: iRPC front-end board readout electronics. DRD1 6th workshop

2.1) History of the FEB

First proto

2017

proof of principle for

CMS-MUON-TDR-016

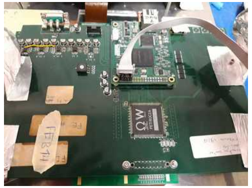
2 PetiROC2A
+ FPGA Cyclone II
+ ETHERNET
directly on strip PCB
(50 cm)

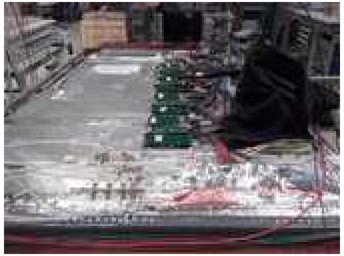
Feb V0

2018

First FEB (Conf. note)

1 PetiROC2A +
MEZZANINE with
FPGA Cyclone II
+ ETHERNET





Feb V1

2019

FEB without
mezzanine

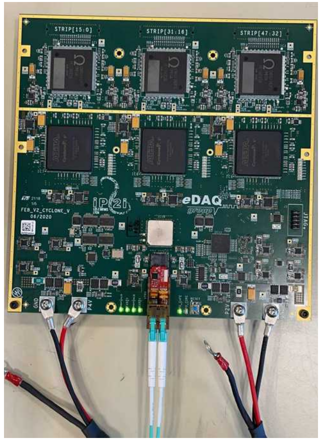
2 PetiROC2B
+ FPGA Cyclone V
+ ETHERNET

Feb V2_1,2

2021

Non-rad hard
for iRPC Demo

6 PETIROC2C
+ 3 FPGA Cyclone V
+ Optical GBT



Feb V2_3

2023

Mass production
prototype

FEBv2_1 + firmware
update feature by
optical GBT

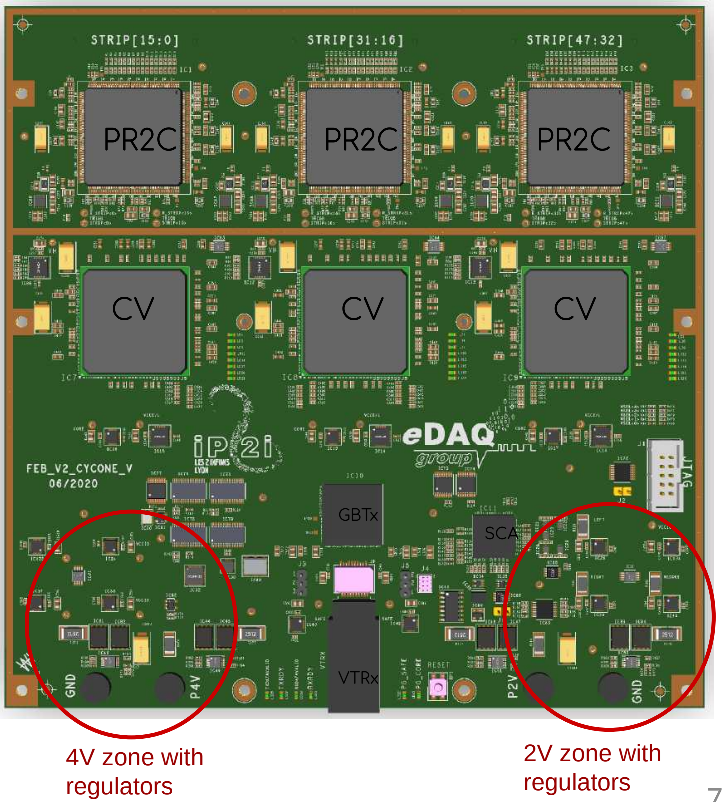
2.2) FEBv2 details

- 2 FEBs / Chamber → 144 (+16 spares) FEBs in total
- 3 Erni connectors with 32 channels each.
- 6 ASIC PetiROC2C (PR2C):
  - Specially designed by OMEGA group for CMS RPC project based on Petiroc2A

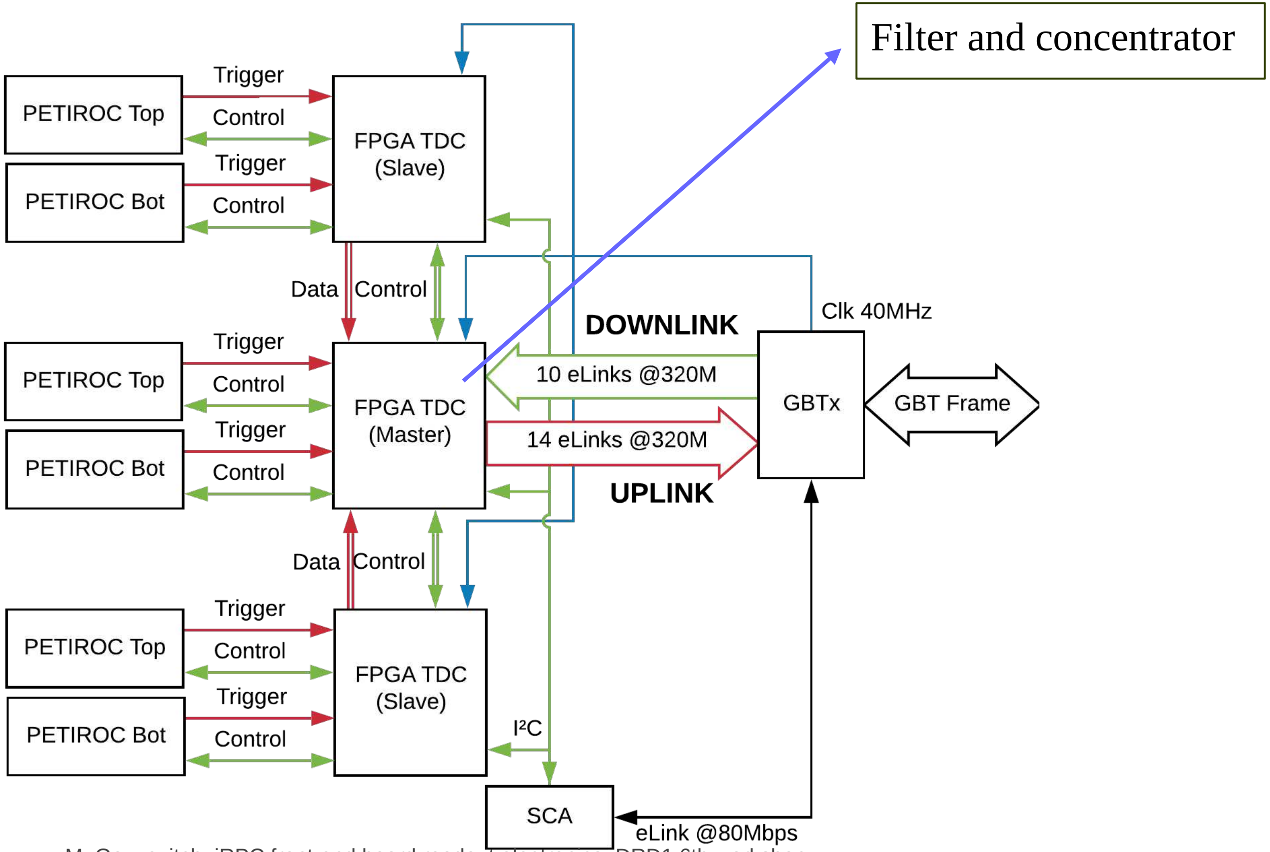
- 3 FPGAs (96 + 6 TDC channels)
  - FEBv2: CYCLONE V (non rad-hard)

- CERN ASICS: GBTx + GBT-SCA + VTRx
  - for the communication ald slow control

- Separated 2V and 4V power zone for Analog and Digital components. Latchup protection (Overcurrent detection).



2.3) FEBv2 logical scheme



2.4) ASIC – Petiroc or iRPCROC

PETIROC2A designed for PET

- High frequency preamp
- Thr > 60 fC
- Time resolution < 100 ps

Limitations: low rate expected

PETIROC2A for RPC :

- Retriggering and inter-channels cross-talk
- Thr > 100 fC
- Time resolution < 200 ps

PETIROC2B modif for iRPC :

- Reduce preamp. frequency
- Thr ~ 100 fC
- 10-20 ns / ASIC dead time introduced to remove retriggering

→2-3% efficiency loss / chamber

iRPCROC (PETIROC2C) :

- Removed useless components from PR2A.
- Thr < 50 fC
- 40 ns auto-reset / channel te remove retriggering.
- 1050 required including spares, a set of 1300 available with uniform behaviour.

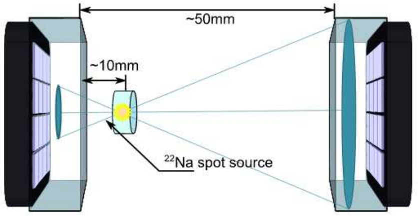


Figure 2. Setup structure used during the experiments.

https://dx.doi.org/10.1109/NSSMIC.2018.8824464

2.5) Radiation hardness

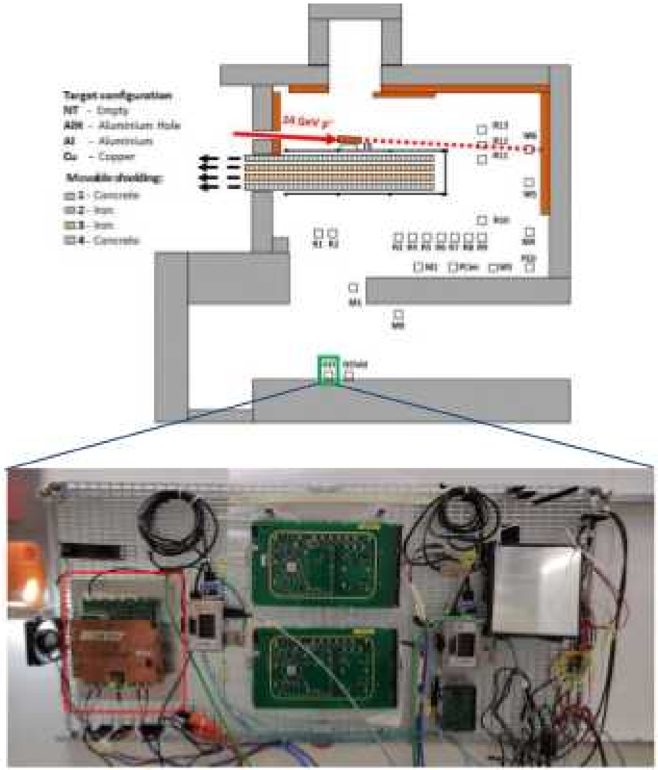
1) TID (charged hadrons, thermal neutrons)
in CHARM, CERN

Dose Requested: 17 Gy
Certified: ~ 57 Gy
SF: 3.3

Fluence Requested: 0.9e11 HEH/cm2; 2.7e11 ThN/cm2
Certified: ~ 1.6e11 HEH/cm2; 3.3e11 ThN/cm2
SF: 1.8; 1.2

2) SEU (charged hadrons, thermal neutrons)
in CHARM, CERN

Flux Requested: 1.4 kHEH/cm^2/s; 4.2 kThN/cm^2/s
Certified: 140 kHEH/cm^2/s; 280 kThN/cm^2/s
SF: 100; 67



2.5) Radiation hardness

- **Functional certification :**
  No persistant radiation damage is observed on any components of the FEB for the doses under consideration :
  → performences of the FEB doesn’t change with accumulated dose.

  - **Petiroc :**
    No Single Events Upsets (SEU) observed in Petiroc2C

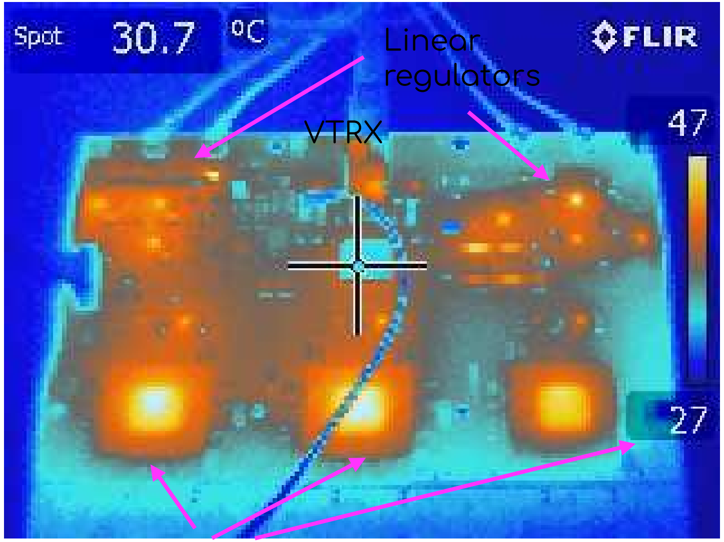
  - **Power supply :**
    Few Single Event Latchups (SEL) observed in power supply well catched by the overcurrent protection.

  - **Cyclone V :**
    → We estimate that during HL-LHC phase 1 Cyclone V needs a soft reset (1 second) every 10 hours of CMS data-taking.
    → Soft reset can be performed in a transparent way for CMS data taking and trigger.

- **Mass production :**
  The FEBv2_3 passer successfully the test in CHARM to certify all the components from the lot used for mass production.

2.6) FEB power consumption

Total consumption: 2V*6.3A+4V*2.3A = 22 W



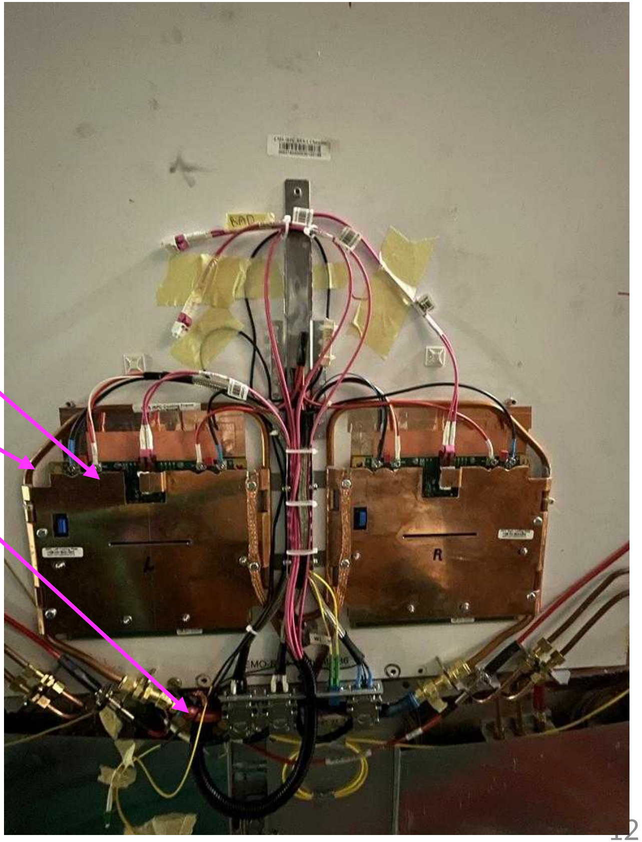
FPGA

Cooling system

1) Thermal pads + copper plate
2) Cooling pipe
3) Cool water: 15 C

Max temperature < 50 C

Play also the role of grounding plane



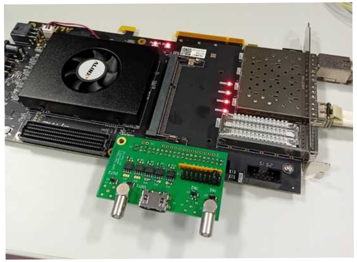
Hottest elements:

- linear regulators - Ohmic effect
- Optical communication
- FPGA - logic

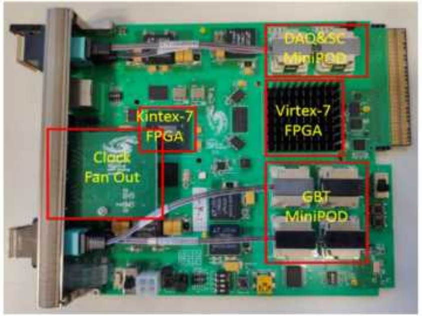
2.7) Back End Board

Back-end functions

- ❑ fast/slow control and monitor
- ❑ cluster finding and trigger primitive generation
- ❑ timing reference adjustment
- ❑ data acquisition



Light BEB based on ALINX Kintex 7 dev board :
- Read 1 FEB (2 in Future)
- Cheap and easy to purchase :
Full BEB System costs ~800 euros

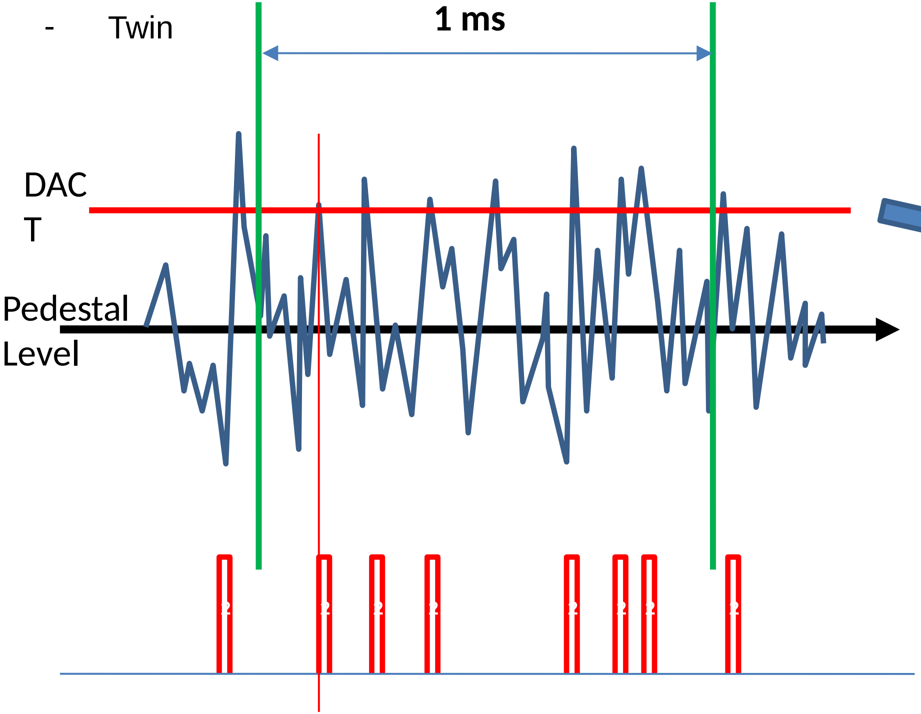


mTCA based BEB from CMS Phase 1 muon system (IHEP):
- Read 4 FEBs in parallel
- Only few prototypes availables for R&D/QC

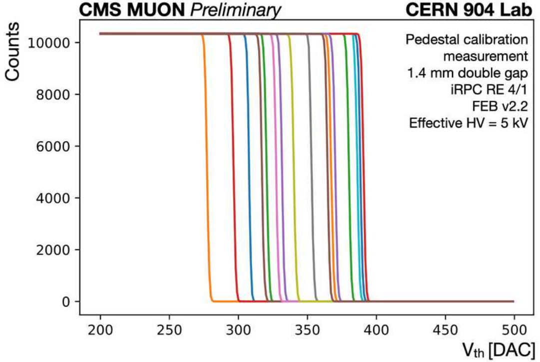
aTCA based BEB for HL-LHC:
- Read up to 24 FEBs in parallel
- Based on powerful CMS Trigger/DAQ serenity board (only prototypes available up to now).
- BEB dev. just started.

3) Certification, calibration and production

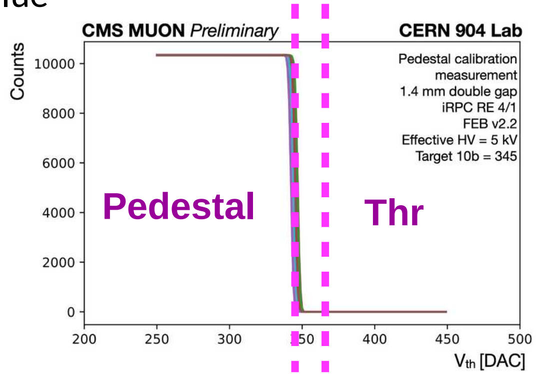
3.1) FEB pedestal alignement method



TDC counting (for each channel)



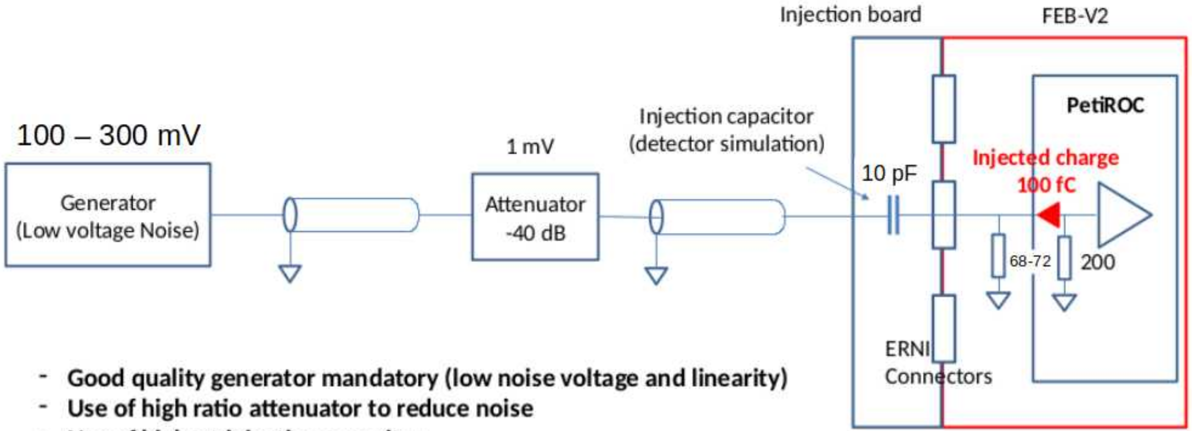
All pedestals aligned to same "median" value



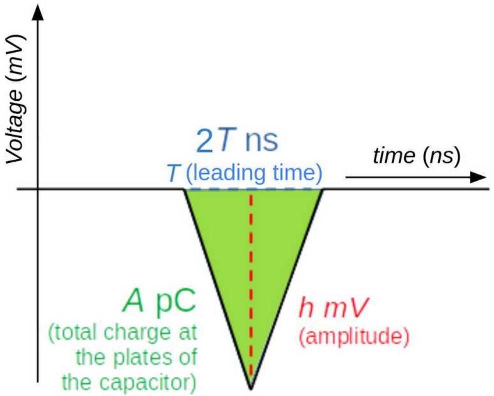
Threshold applied well above noise level

3.2) FEB calibration

DAC T vs Charge
Measurement setup considerations



- Good quality generator mandatory (low noise voltage and linearity)
- Use of high ratio attenuator to reduce noise
- Use of highest injection capacitor



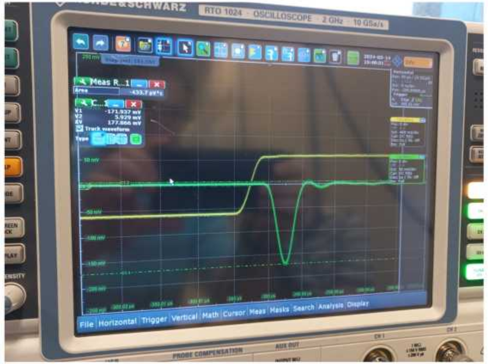
Mean V_{inj} vs DAC slope

$$A(pC) = \frac{2T(ns)\times h(mV)}{2R(\Omega)} = \frac{T\times h}{R} \Longrightarrow A(pC) = T\times \frac{\boxed{f(mV/DAC)}\times h_{DAC}}{R} \Longrightarrow \boxed{\frac{A(pC)}{h(DAC)}} = T \times \boxed{\frac{f(mV/DAC)}{R}}$$

Conversion factor mV - DAC

Calibration factor

3.3) FEB calibration

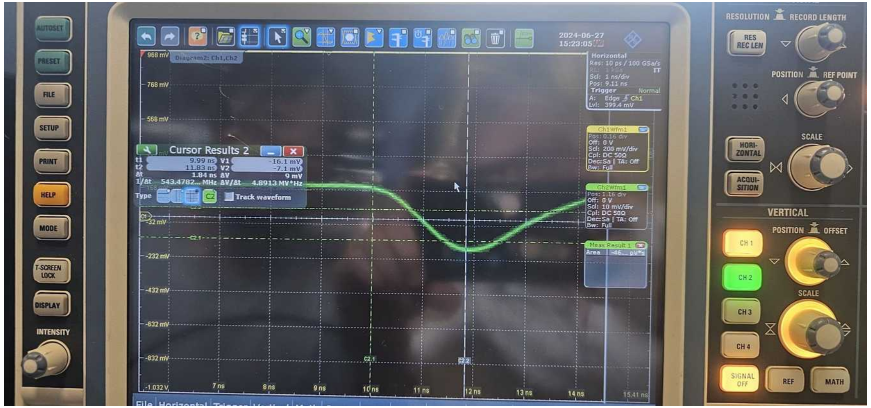


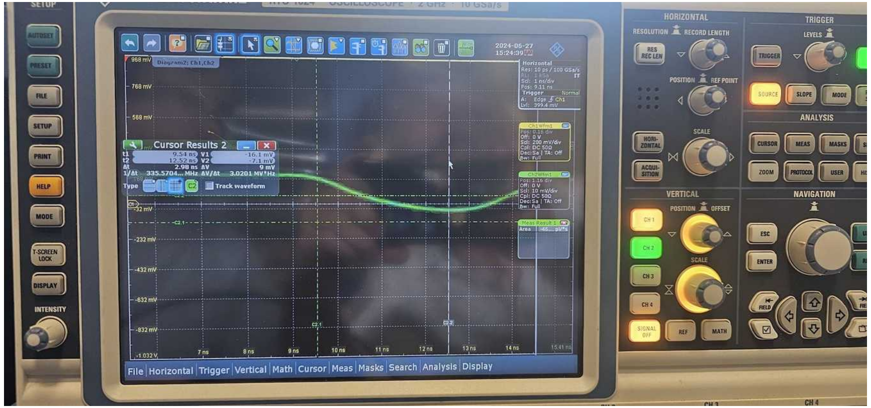
- Signal generator (left)
- Attenuator (center low)
- Injected signal (right):

  Yellow – signal before capacitor

  Green – signal after capacitor and attenuator.

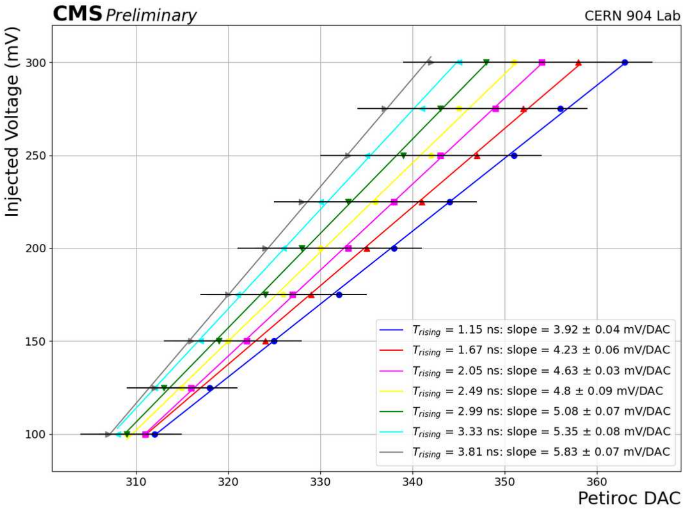
3.2) FEB calibration

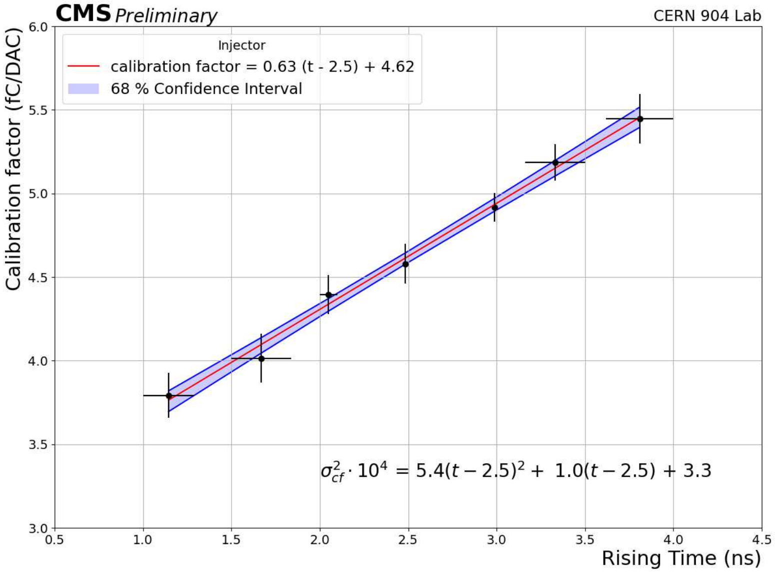




- 1 ns rising time
- 2.5 ns rising time

3.2) FEB calibration

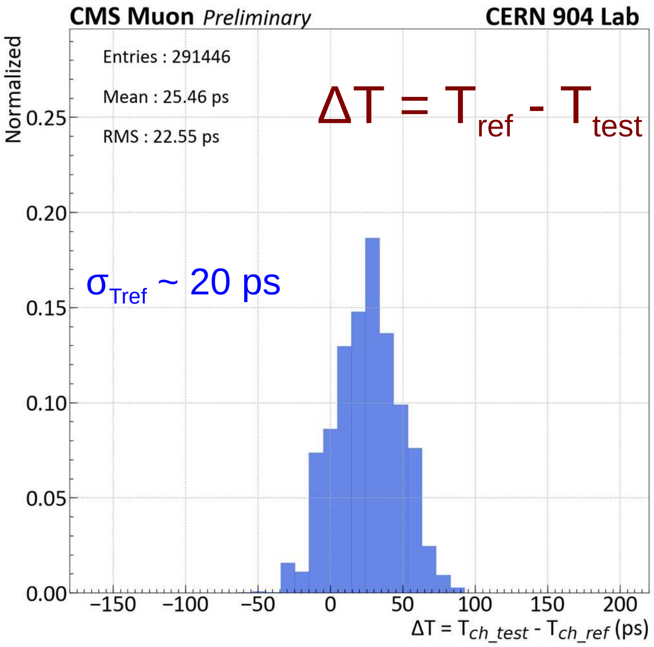


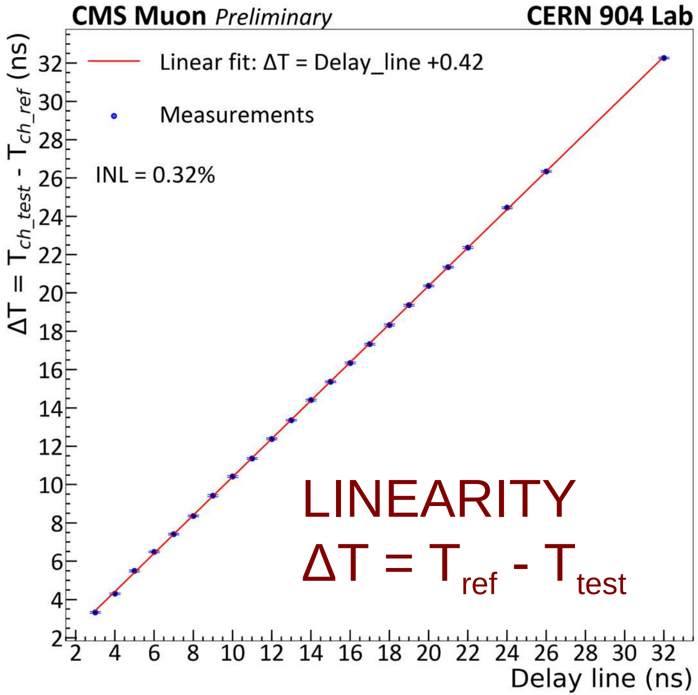


Typical RPC rising time : 1.8-2. ns
Calibration factor = 4.2-4.3 fC/DAC

Threshold: Specification
10 DAC ⇆ 42-43 fC → Safe operating WP
7 DAC ⇆ 29-30 DAC → Can be used to reduce current in chambers

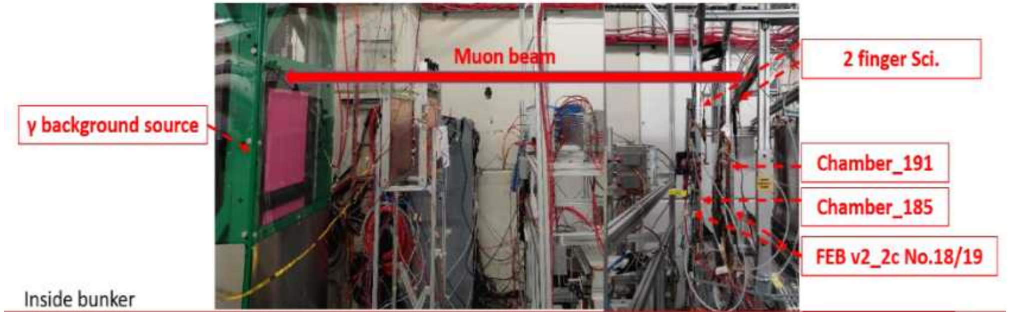
3.3) TDC time resolution

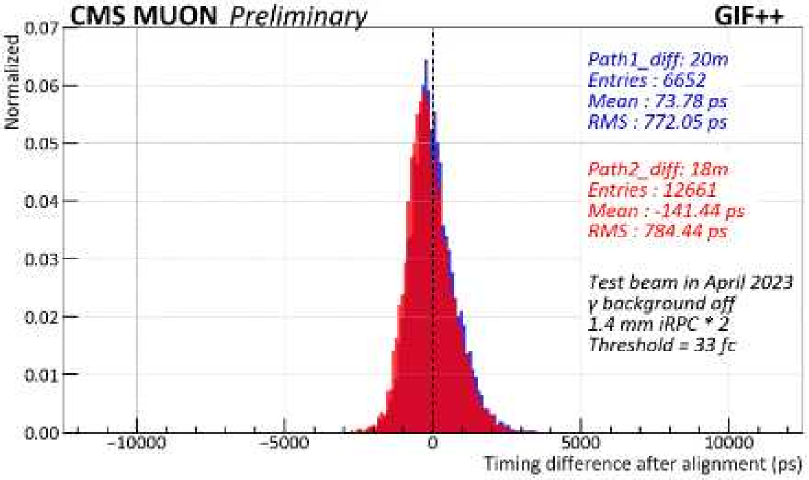




Pure TDC time resolution was measured using 2 channels test and a reference

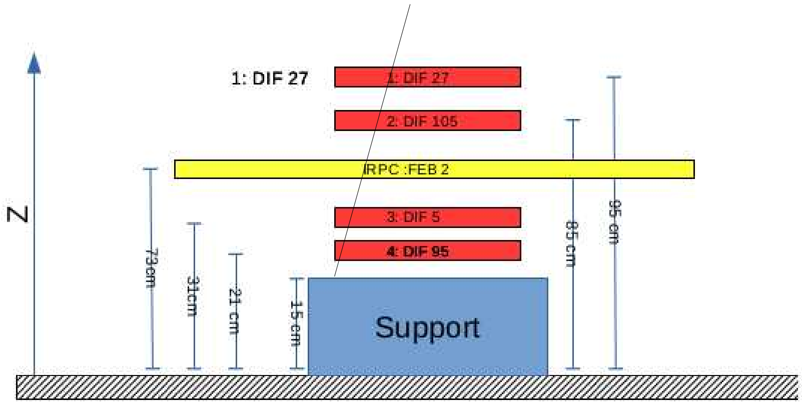
3.3) Chamber absolute time resolution

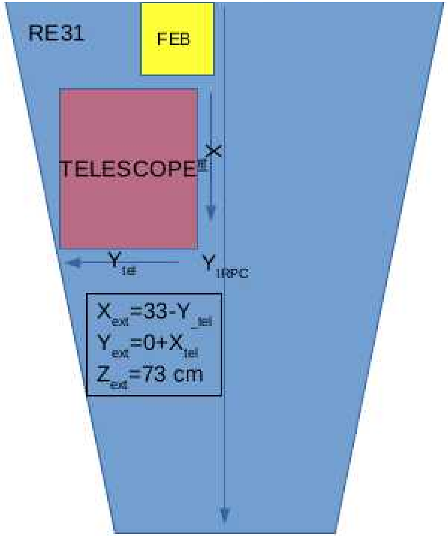




- 2 chambers iRPC chambers in test beam in Gamma Irradiation Facility (GIF++) at SPS CERN.
- Absolute time resolution of the system : 780 ps → per chamber 780/√2 ~ 550 ps

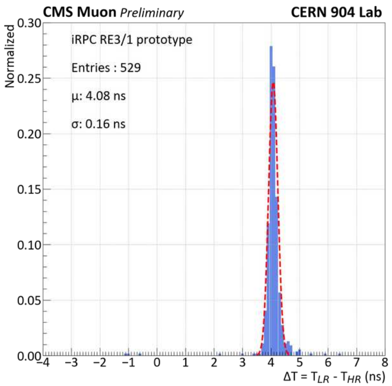
3.4) Space resolution





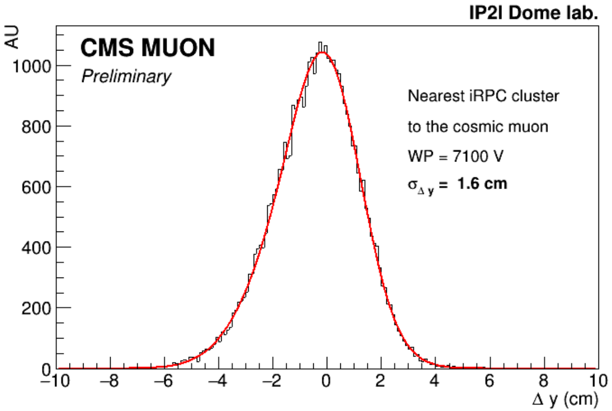
- A cosmic telescope is made of 2+2 RPC chambers with 1x1cm² pads.
- iRPC chamber in sandwitch.
- Comparing extrapolated track and actual position of the RPC hit.

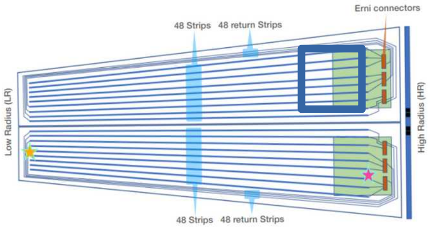
3.5) Space resolution



$\Delta T = T_{HR} - T_{LR}$

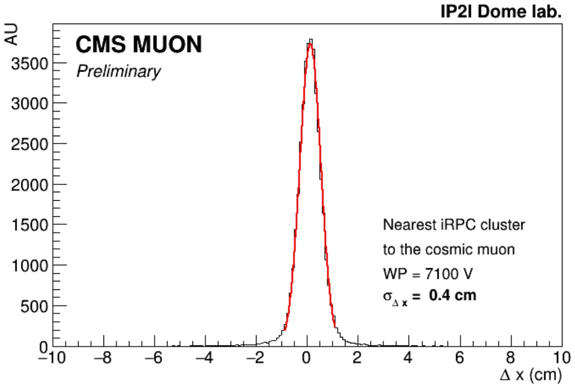
$\sigma_{\Delta T} \sim 150$ ps $\rightarrow \sigma_Y \sim 1.5$ cm





Strip pitch in telescope region ~ 0.8 cm

$\sigma_X \sim 0.4$ cm



3.6) Mass production

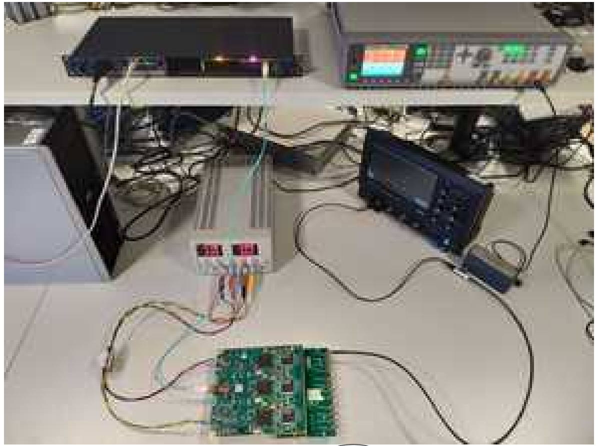
Production of 160 is done by French company FEDD :

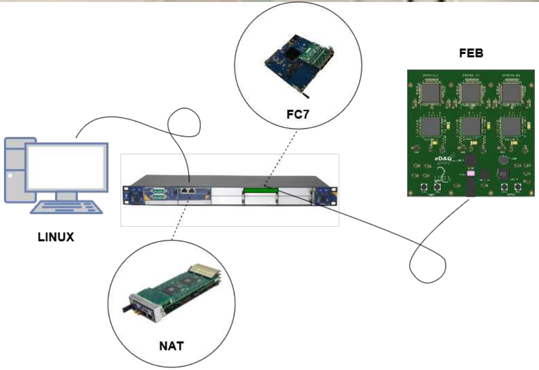
1) PCB production : SOMACIS

2) Stuffing + QC factory : FEDD

3) Functional QC1 at IP2I on test bench

4) QC on final chamber at CERN

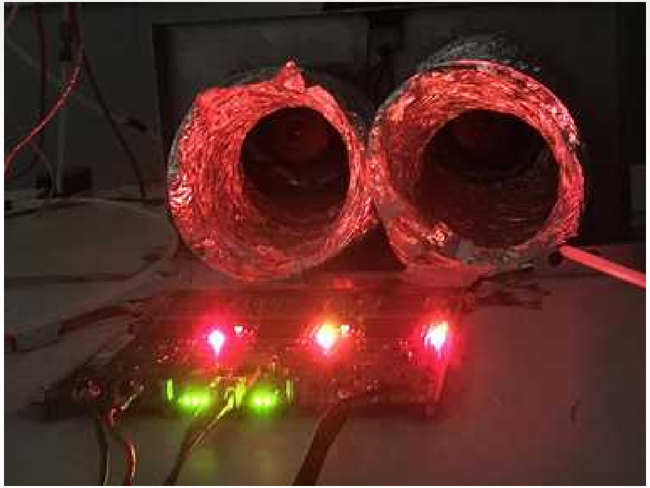




Production successfully finished in July 2025
with 171 FEBs : 10 from pre-production and 161 from mass production.

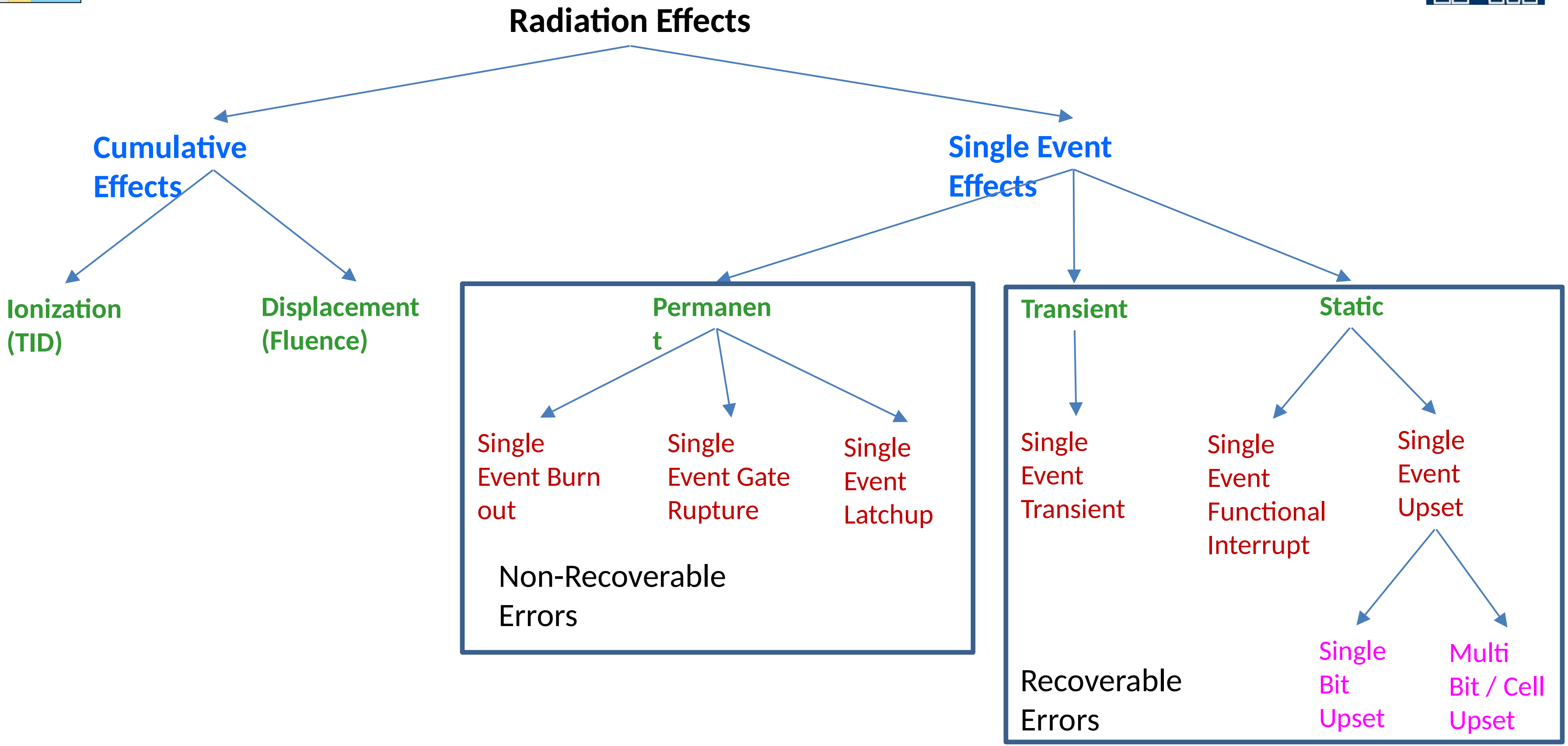
CONCLUSIONS

- iRPC FEB desinged/certified, integrated into the chamber. Mass production of 161+10 FEB finished and QC.
- The rad tolerance of the FEB are sufficient for O(100 Gy) projects.
- Time and threshold calibration finalised and caracteristics meets the HL-LHC requirements :
  - Threshold : below 50 fC (down to 30 fC)
  - Space resolution :
    1.6 cm along strip, 0.4 cm perp. to strip
  - Time resolution : 500 ps

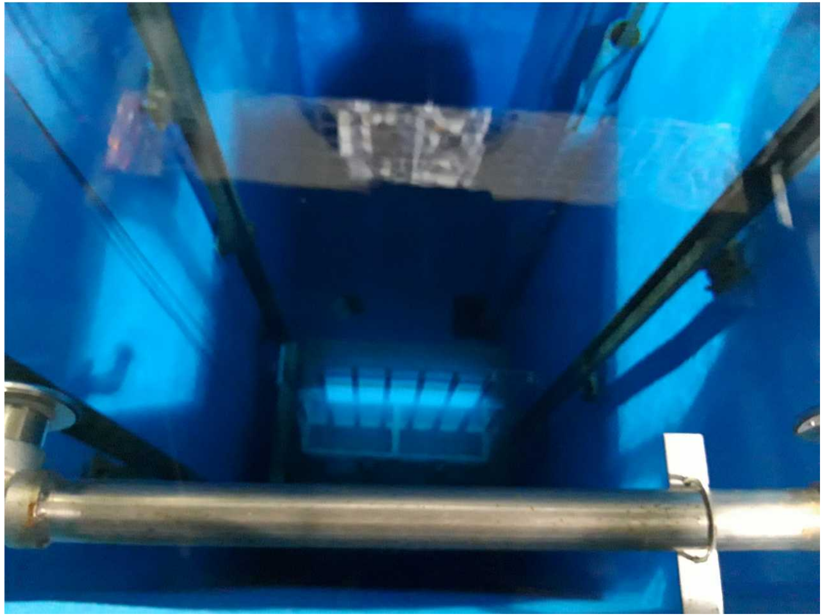


BACKUP

Radiation Effects in Electronics

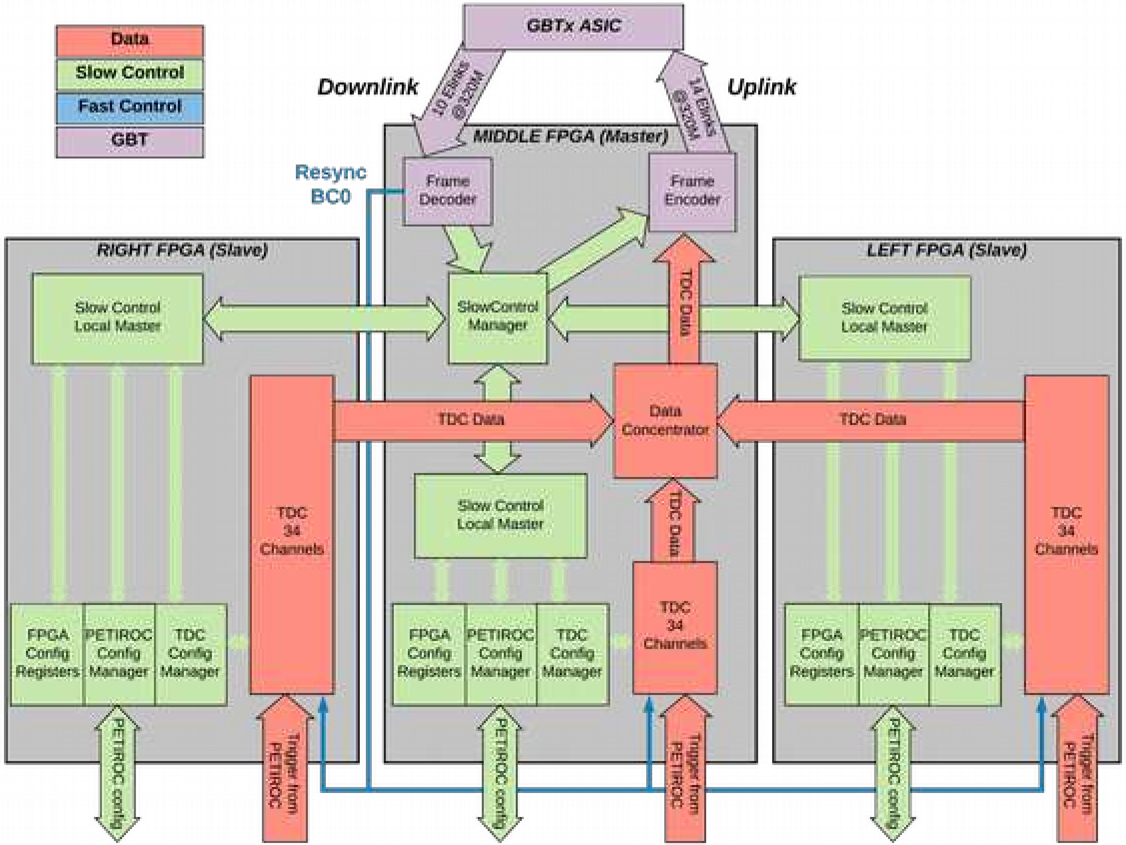


Validation en radiation gamma

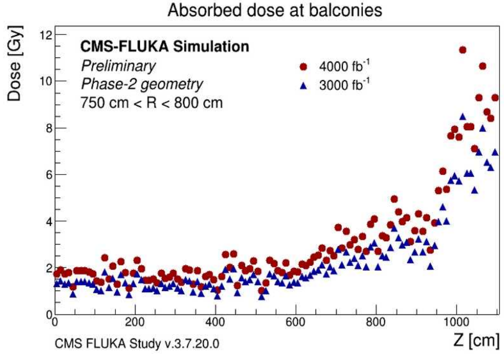


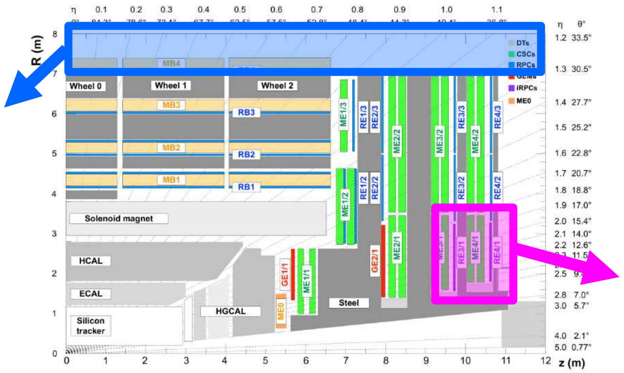
Caliope a ENEA Casaccia a côté de Rome

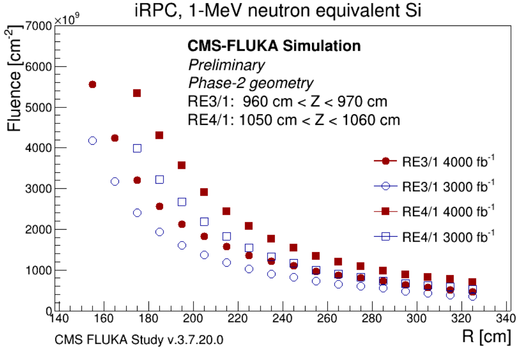
FEBv2 logical scheme

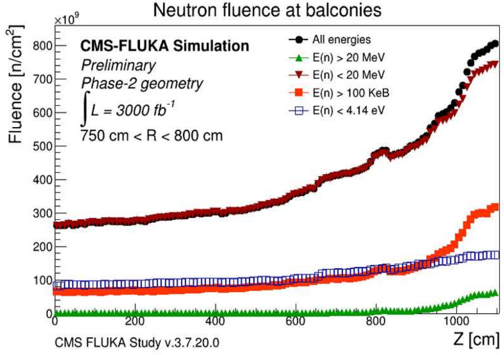


Expected Fluence and Dose at HL-LHC

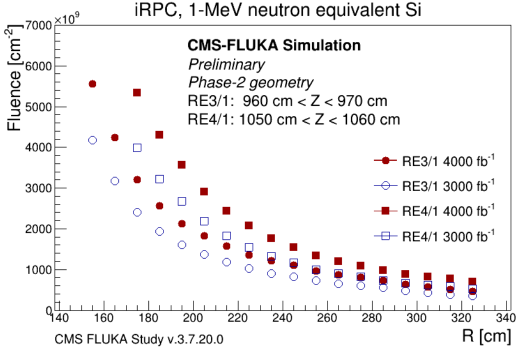








- Expected fluence and dose (RE34/1 FEBs)
  - at R=303 cm for RE3/1 is ~**4.3 (5.8) x10^{11} n/cm^{2}**, and
  - at R=304 cm for RE4/1 it is about **6.2 (8.2) x10^{11} n/cm^{2}**,
  - at R=303 cm for RE3/1 is ~**10** (**13.6**) Gy
  - at R=304 cm for RE4/1 it is about **18** (**24**) Gy
  - where R=303 (304)cm are the expected FEB positions
- Expected fluence and dose (Balcony)
  - The total irradiation fluence **800 x 10^{9} cm^{-2}**
  - Maximum integrated dose is about **10 Gy**



2.8) Extrapolation to HL-LHC

Estimation using flux
(same method used for LB ESR)

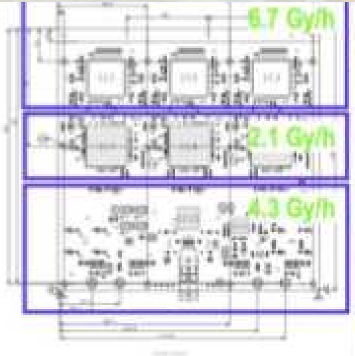
	CHARM	HL-LHC (continuous data taking at max intensity for 1 day)
Flux (HEH+ThN) ($/cm^2/s$)	4.2e5	5.6e3
SEU	1/8.2 mn	1 / 10.3 h 2.3 / day

Estimation using fluence

(HEH+ThN)/SEU from CHARM	(HEH+ThN)/year at HL-LHC (10 years of data taking)	SEU/year
210e6	3.2e10	150/year

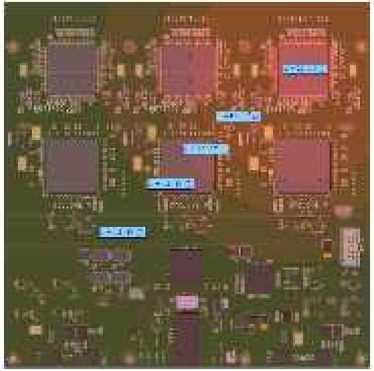
- We could assume this as the worse case.
- Among these stops only a fraction would require an FPGA power cycle (see slide 14).
- 1500 FPGA power cycles in full FEB life. During CHARM tests we performed around 3000 FPGA power cycles without problems.

2.5) Radiation hardness



1) TID (γ's) -- Facility ENEA Casaccia Calliope ^{60}Co July 2022
   Requested: 17 Gy
   Certified:
   - FPGA Cyclone V (50 Gy):
   - Petiroc (160 Gy);
   - Power supply zone (100 Gy)
   - **Safety Factor: 3 - 9**

2) TNID (neutrons) - Facility FNG Frascati, with support from RADNEXT March 2022
   Requested: 6e11 neq1MeV/cm^2:
   Certified: 25e11 neq1MeV/cm^2:
   SF: 4



3) Neutron flux -
   Requested: 10e3 neq1MeV/cm^2/s
   Certified: 450e3 neq1MeV/cm^2/s
   SF: 45