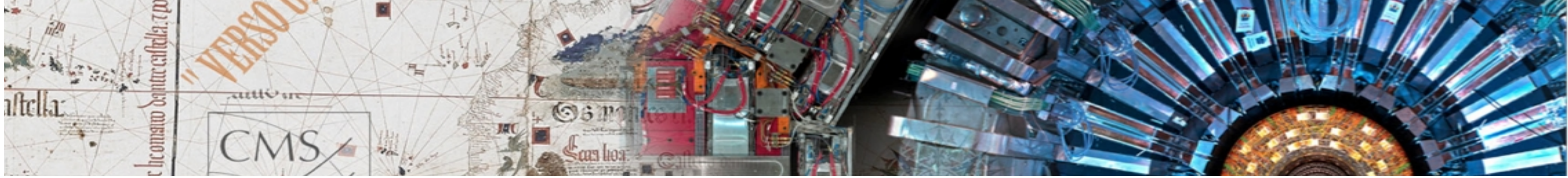


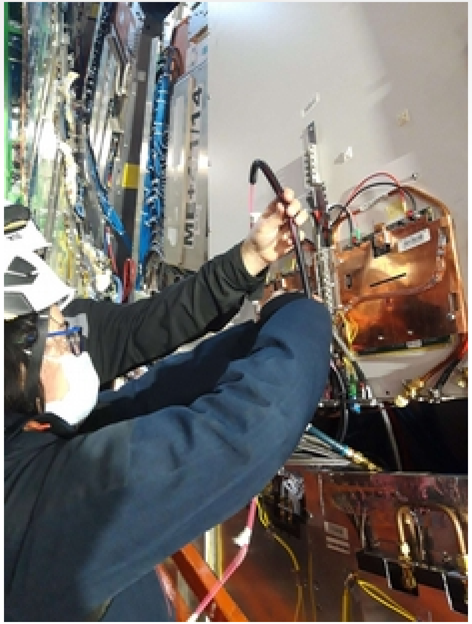
CMS iRPC FEB development and validation

TWEPP 2023 Topical Workshop on Electronics for Particle Physics

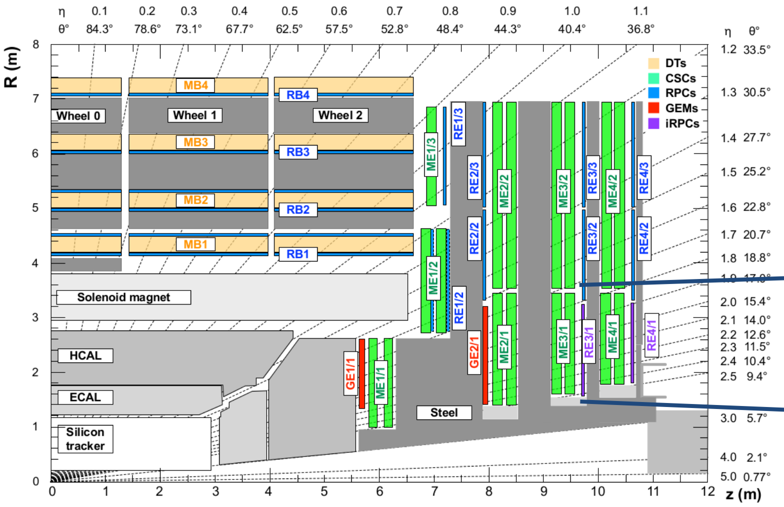
Maxime Gouzevitch on Behalf of CMS Muon groups
IP2I, Lyon, France

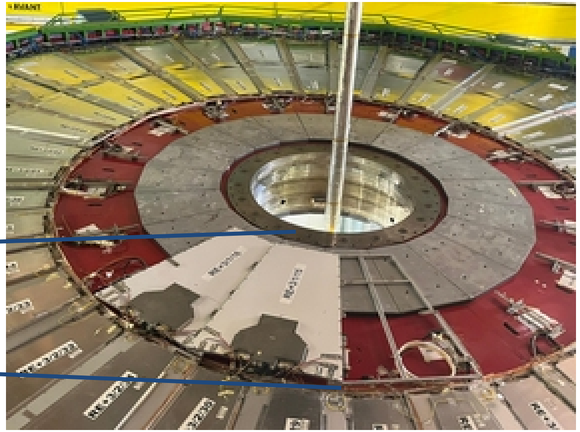
1) iRPC project for HL-LHC
2) FEB design
3) FEB certification, calibration and integration

1)iRPC project for HL-LHC



1.1) iRPC project for HL-LHC phase

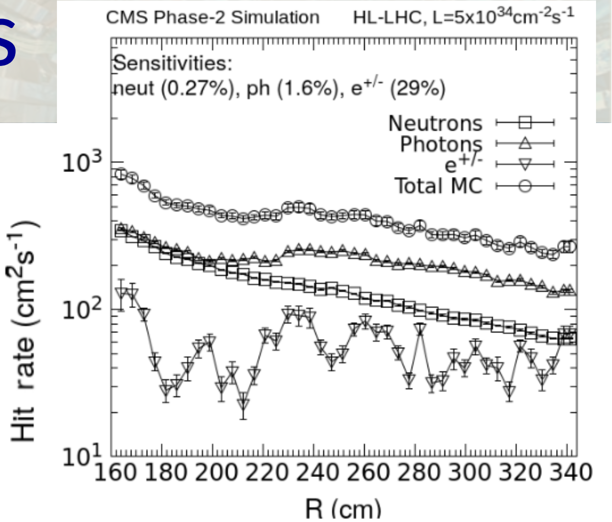




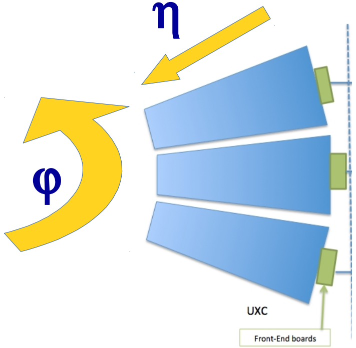
- 36 petal-like chambers.
- Redundancy with CSC chambers providing high granularity space resolution.
- Excellent absolute timing resolution for L1 trigger: O(500 ps).
- Dedicated trigger for Heavy Stable Charged Particles.

1.2) iRPC project constraints

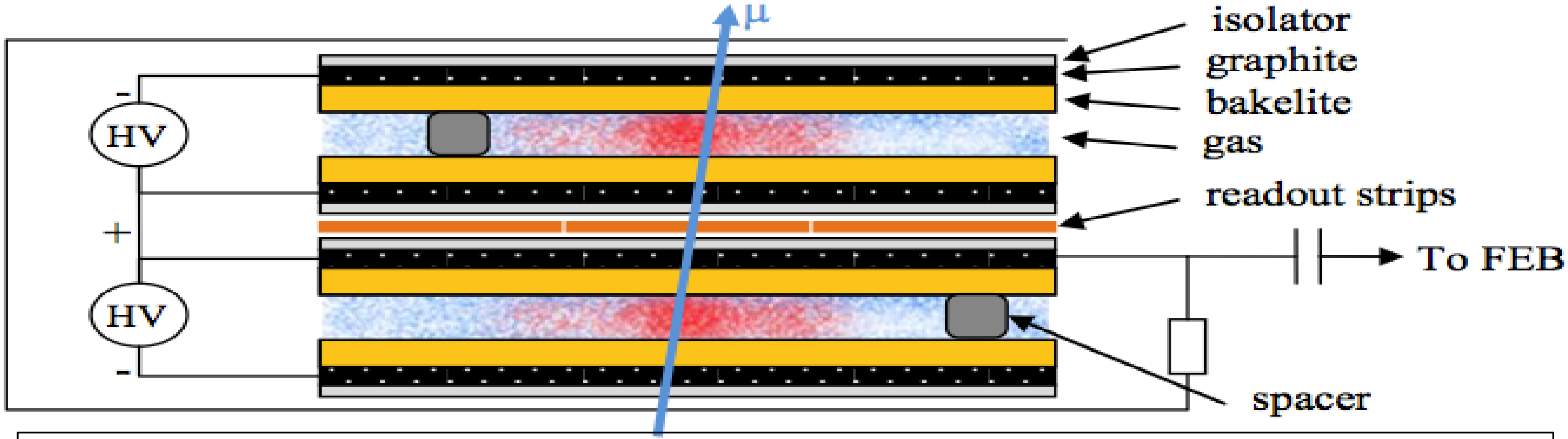
	Present system	iRPC
|η| coverage	0 – 1.9	1.8 – 2.4
Max expected rate (Safety factor SF = 3 included)	600 Hz/cm²	2 kHz/cm²
Gap size	2 mm	1.4 mm
Average charge / MIP	~ 120 pC	~ 40 pC
Electronics threshold	150 fC	30-50 fC
TDC T resolution		20 ps



A dedicated iRPC electronics designed to fulfill higher background conditions.



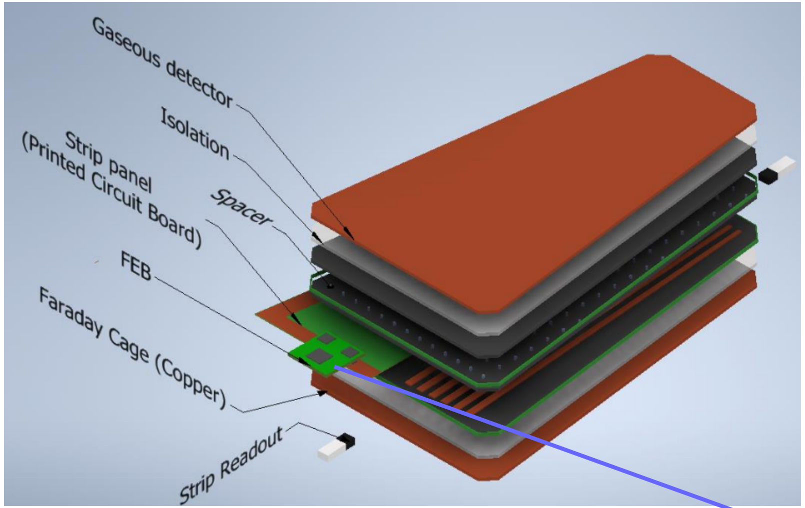
1.3) What is an RPC chamber

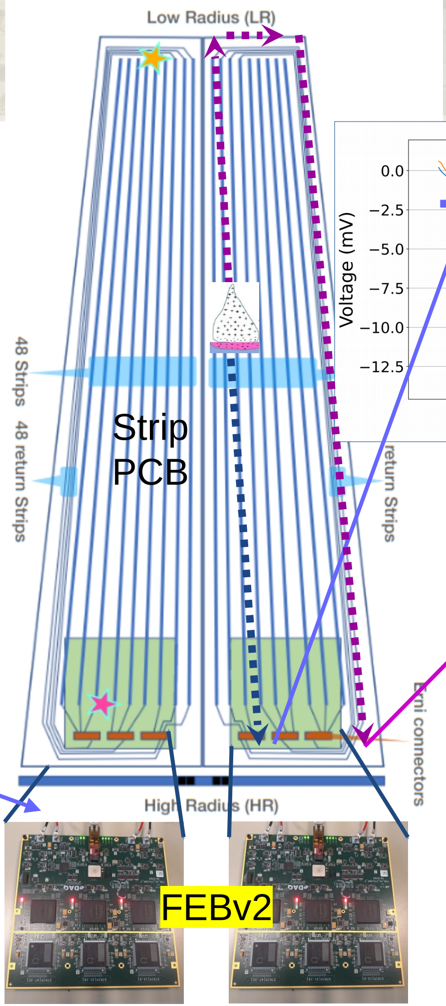


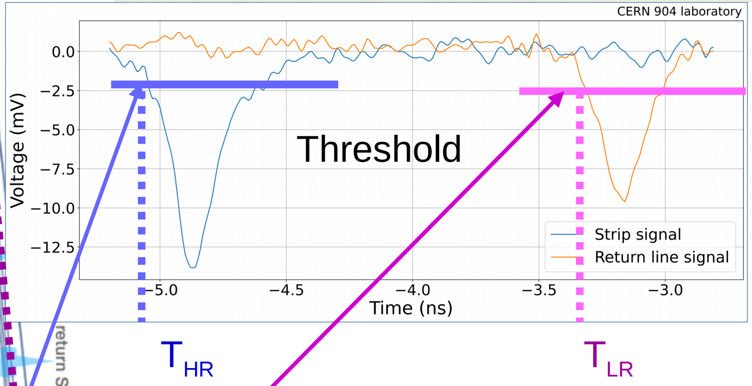
- Muon crossing the chamber generates small avalanches in 2 gas gaps
- A signal is induced in copper strips located outside of the gas gaps.
- Signal transported to the FEB where it is amplified, dscriminated and time tagged.

1.4) iRPC readout

-





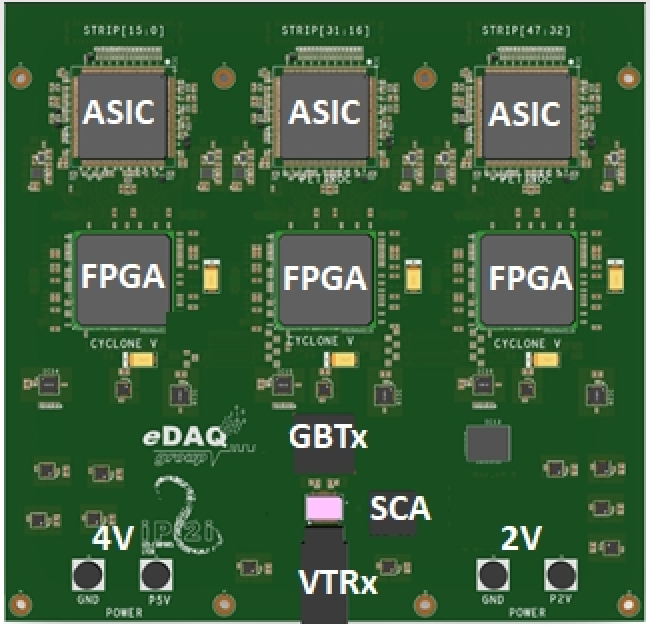


- Strip pitch : 0.5 – 1 cm
- Double sided readout of long strips using timing to localise the signal position

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

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

2) FEB design



M. Gouzevitch: FEB for CMS iRPC project

2.1) History of the FEB

First proto

2017

proof of principle for

CMS-MUON-TDR-016

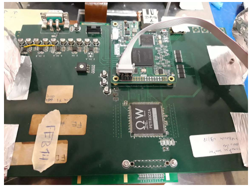
2 PetiROC2A
+ FPGA Cyclone II
+ ETHERNET
directly on strip PCB
(50 cm)

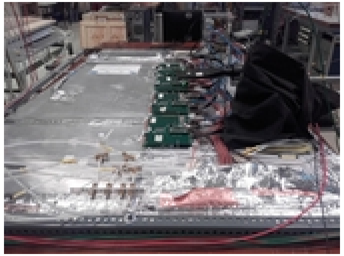
Feb V0

2018

First FEB (Conf. note)

1 PetiROC2A +
MEZZANINE with
FPGA Cyclone II
+ ETHERNET





Feb V1

2019

FEB without
mezzanine

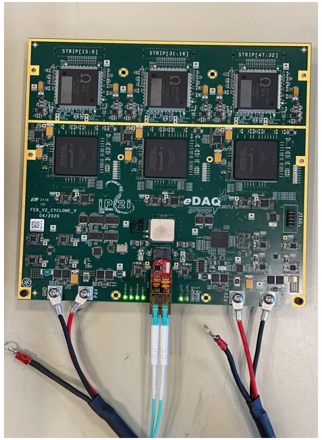
2 PetiROC2B
+ FPGA Cyclone V
+ ETHERNET

Feb V2_1,2

2021

Non-rad hard
for iRPC Demo

6 PETIROC2C
+ 3 FPGA Cyclone V
+ Optical GBT

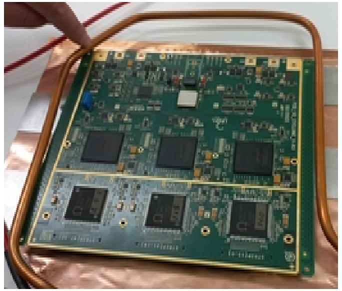


Feb V2_3

2021

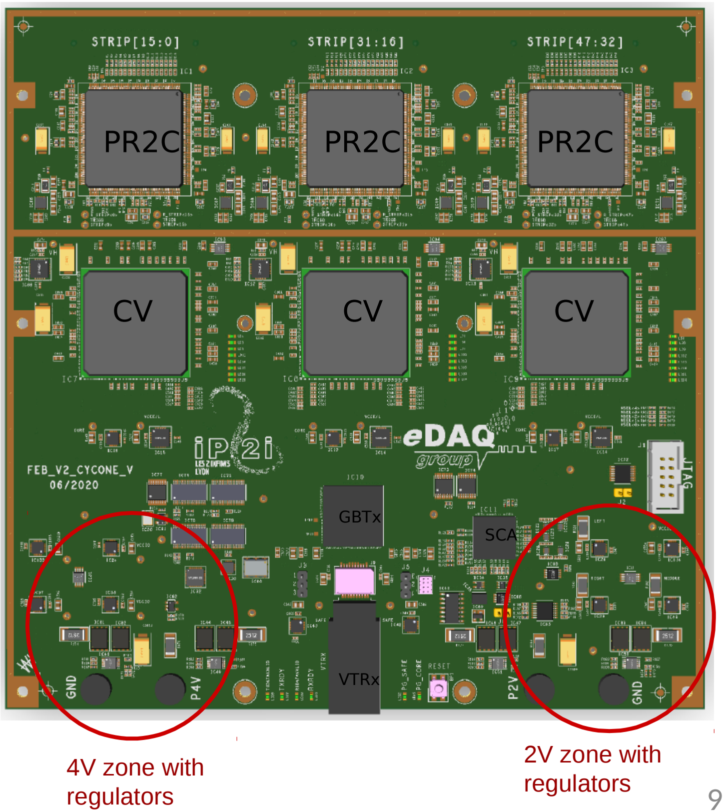
Mass production
prototype

FEBv2_1 + firmware
update feature by
optical GBT

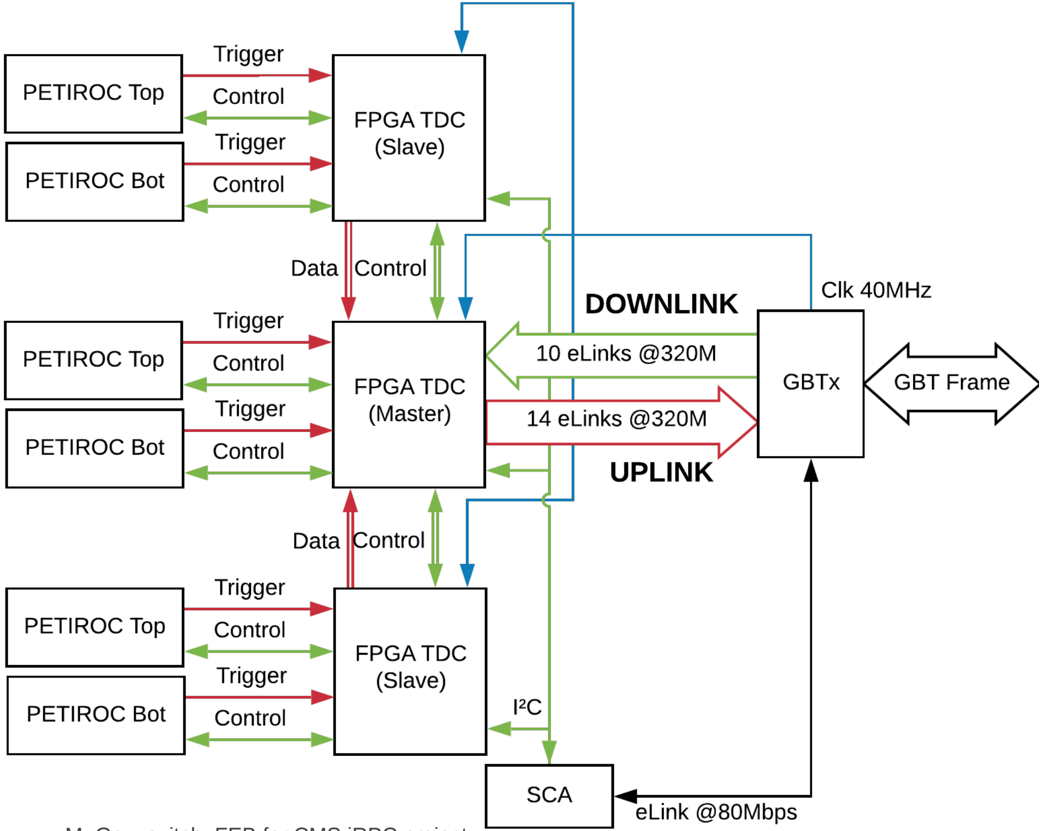


2.2) FEBv2 details

- 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) PetiROC ASIC

PETIROC2A designed for PET

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

Limitations: low rate expected

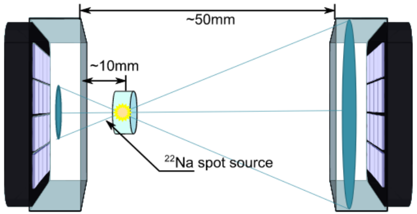


Figure 2. Setup structure used during the experiments.

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

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

PETIROC2C re-designed for iRPC :

- Removed useless components from PR2A.
- Thr < 50 fC
- 40 ns auto-reset / channel te remove retriggering.
- 864 (+ 96 spares) required, 900 available, 1000 under production.

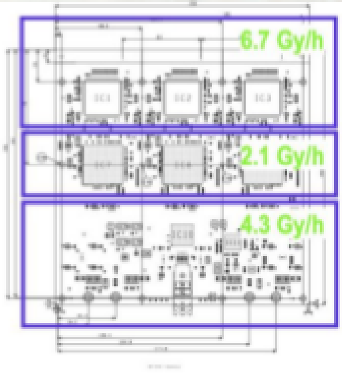
2.5) Radiation hardness

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:

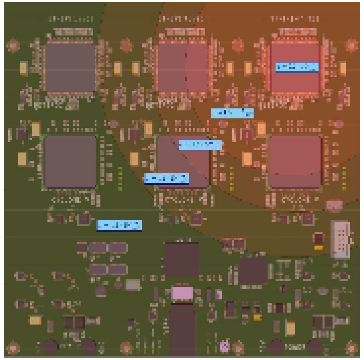
SF: 4

3) Neutron flux -

Requested: 10e3 neq1MeV/cm^2/s

Certified: 450e3 neq1MeV/cm^2/s

SF: 45



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

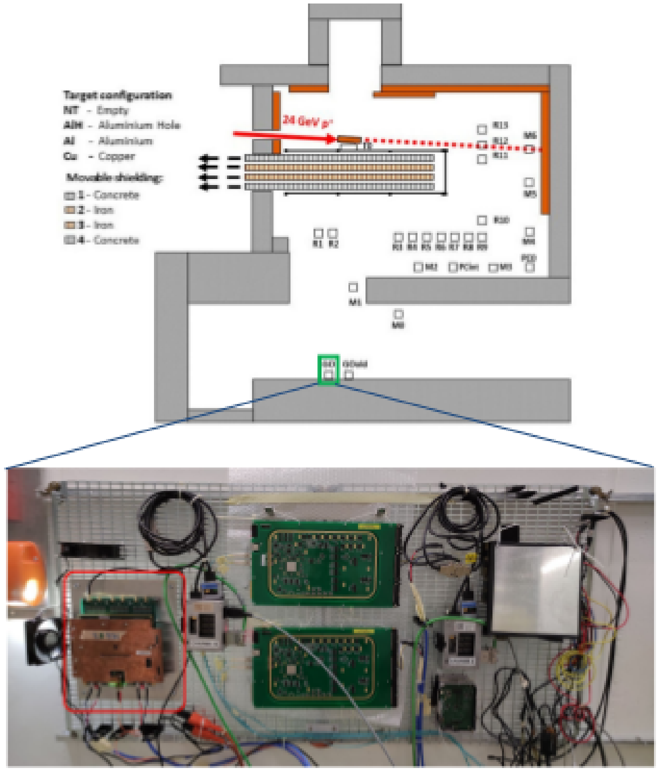
SF: 1.8; 1.2

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

- 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.

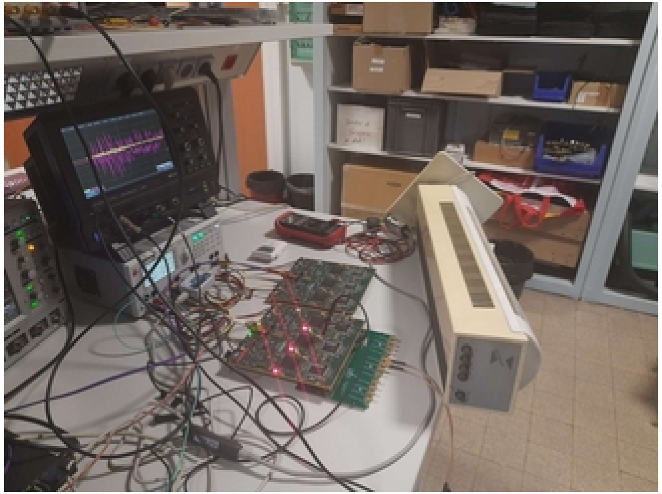
- No Single Events Upsets (SEU) observed in Petiroc2C

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

- SEU’s observed in 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.

3) Certification, calibration and integration

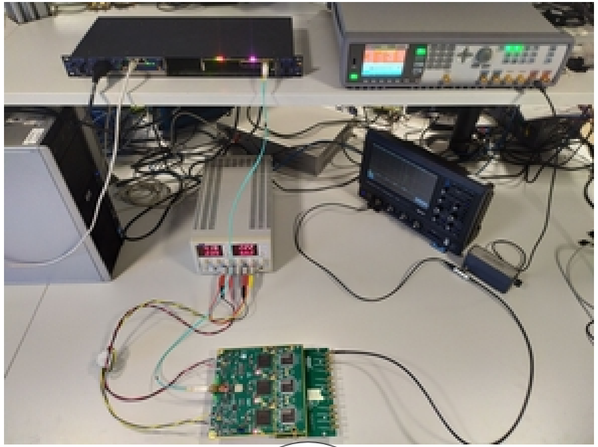
Relevant physics parameters :
1) Sensitivity to RPC signal : pedestal alginements and calibration
2) TDC Time resolution and time alignement.

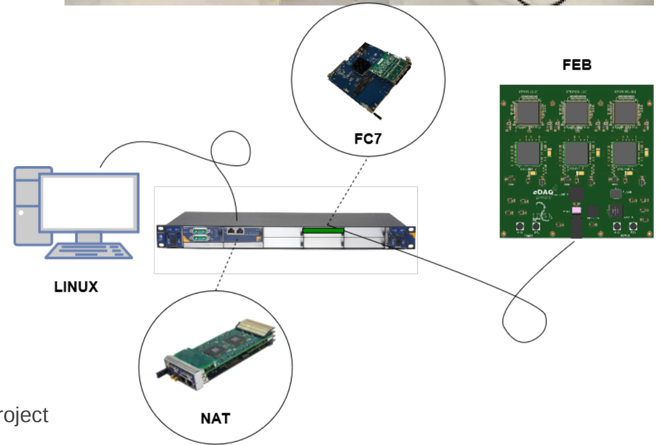


3.1) FEB certification steps in IP2I, Lyon

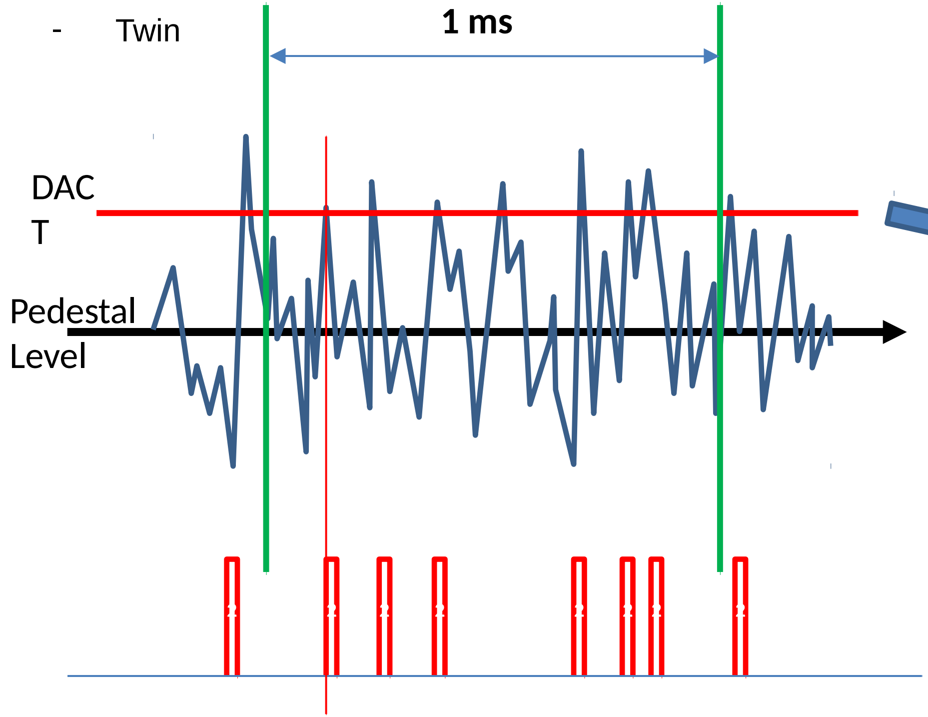
Based on the **FC7 card (Tracker certification card)** system and controlled by **Python software** tools.

- ➢ Perform a Quality Check Process to validate :
- - Each electronic block of the FEB independently (SCA, GBTx, Power Supplies, tests points)
- - The data integrity of the system
- - The operation of the FEB firmware designed in the FPGA(s)
- - The operations of the TDC(s) and ASIC's
- ➢ Simulation and validation of real operation with injection board

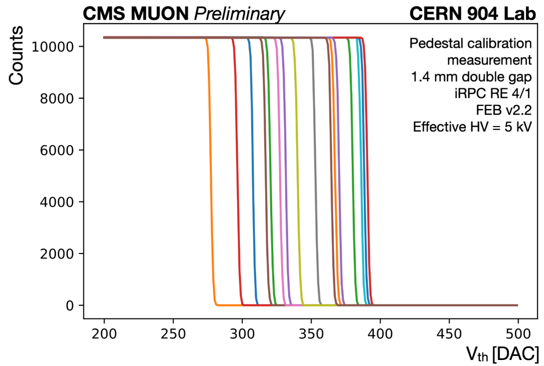




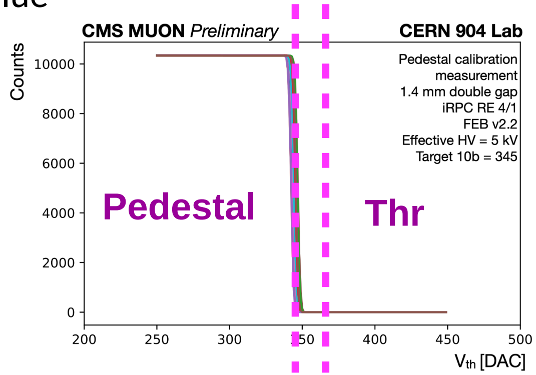
3.2) FEB pedestal alignement method



TDC counting (for each channel)



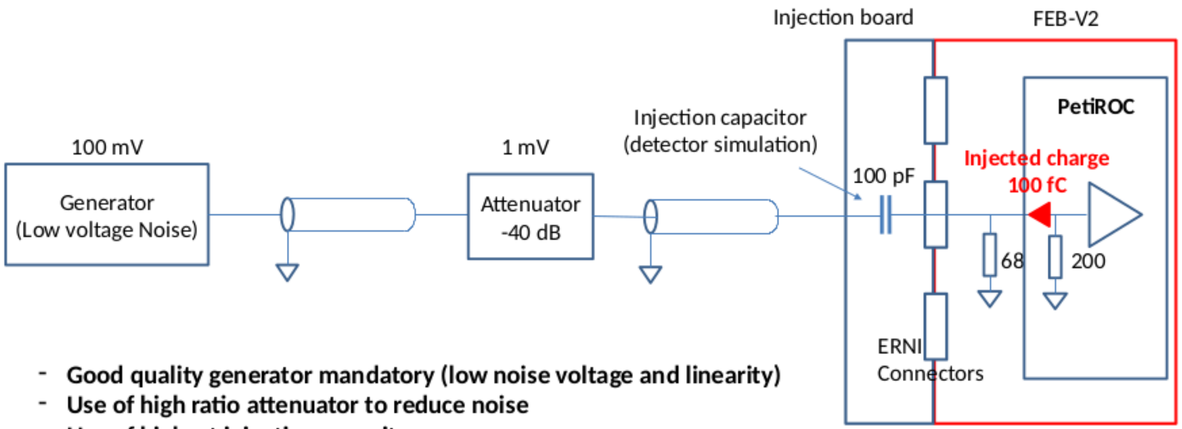
All pedestals aligned to same “median” value



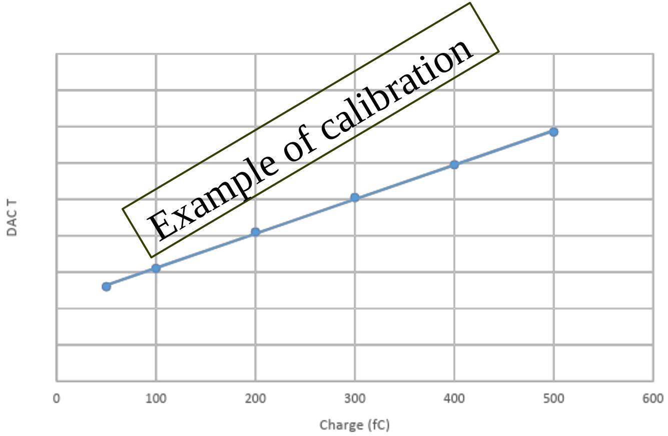
Threshold applied well above noise level

3.3) 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**



Calibration factor = 4.6 ± 0.5 fC/DAC T

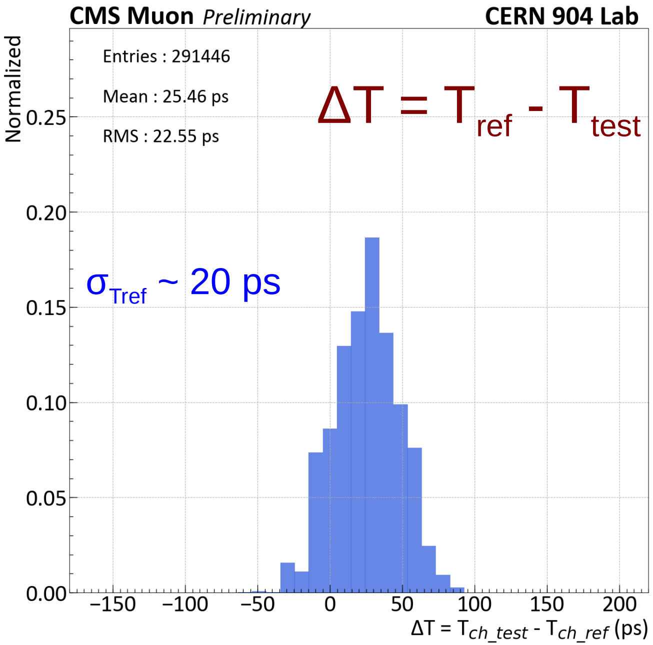
THR: Specification

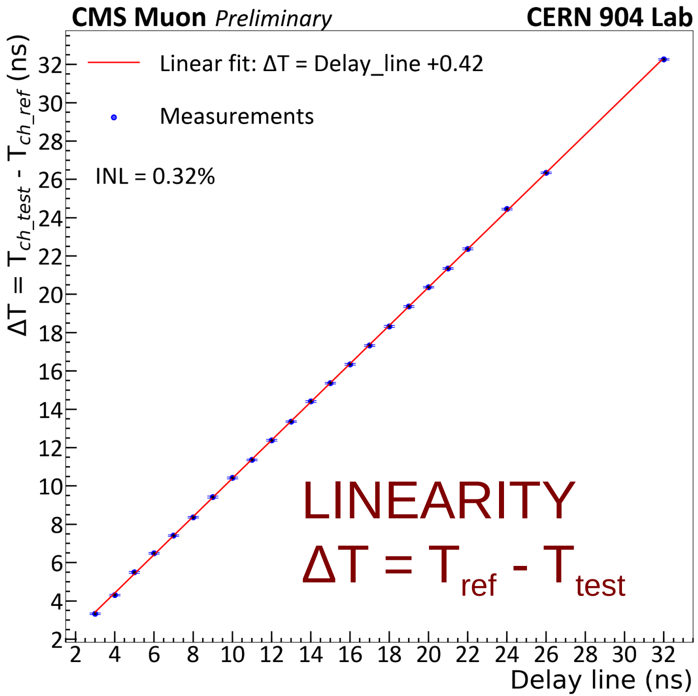
50 fC ⇆ 11 DAC T

Used in test beams

32 fC ⇆ 7 DAC T

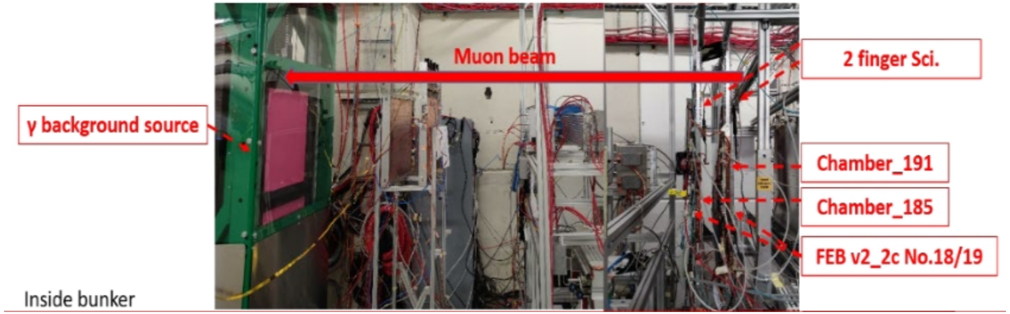
3.4) TDC time resolution

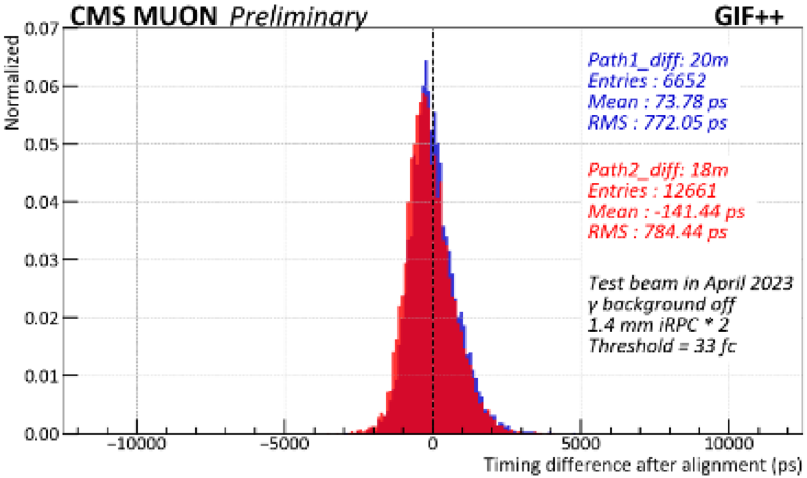




Pure TDC time resolution was measured using 2 channels test and a reference:

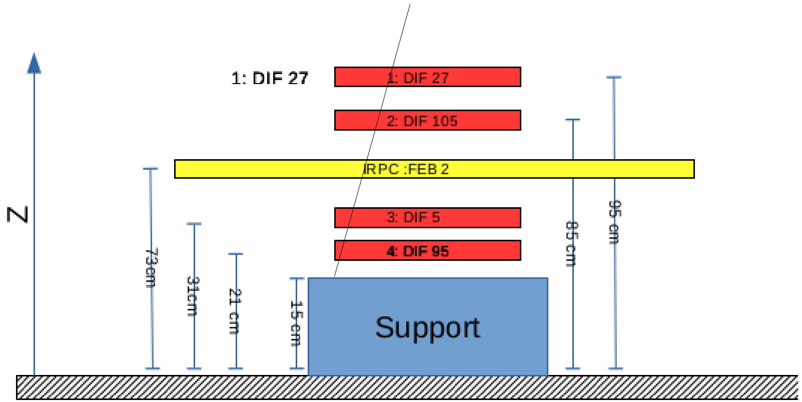
3.5) Chamber absolute time resolution

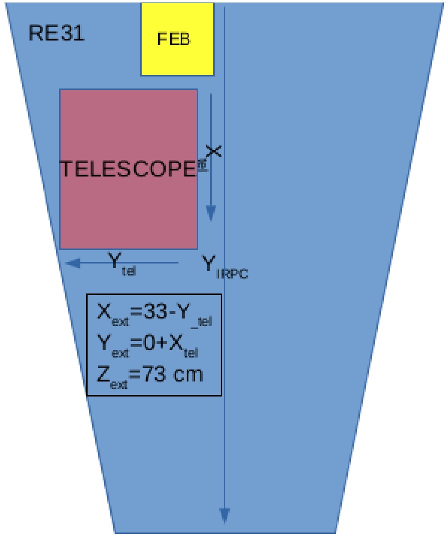




- 2 chambers iRPC chambers in test beam in Gamma Irradiation Facility (GIF++) at SPS CERN.
- Absolute time resolution of the system : 780 ps → per chamber 780/√2 ~ 550 ps

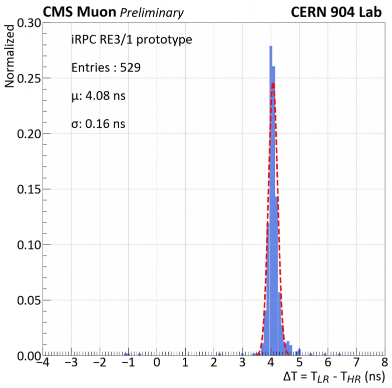
3.5) Space resolution





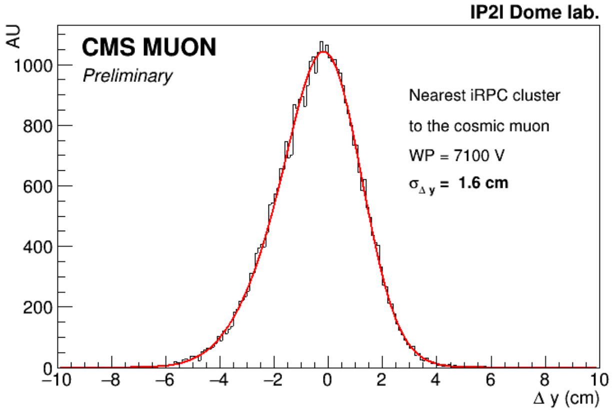
- A cosmic telescope is made of 2+2 RPC chambers with 1x1cm² pads.
- iRPC chamber in sandwitch.
- Comparing extrapolated track and actual position of the RPC hit.

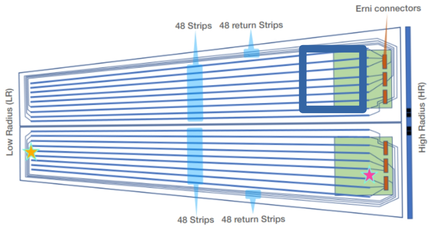
3.5) Space resolution



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

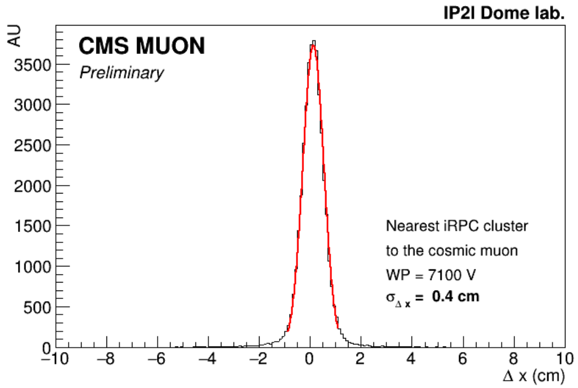
$\sigma_{\Delta T} \sim 150$ ps $\rightarrow \sigma_Y \sim 1.5$ cm





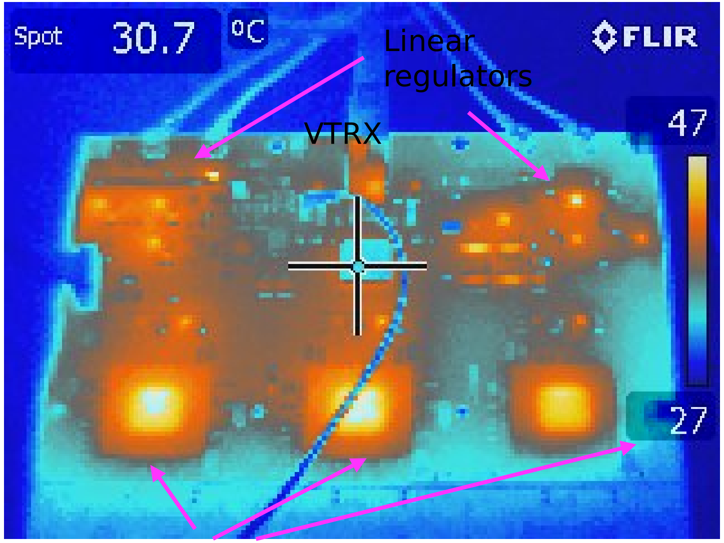
Strip pitch in telescope region ~ 0.8 cm

$\sigma_X \sim 0.4$ cm



3.6) FEB power consumption

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



FPGA

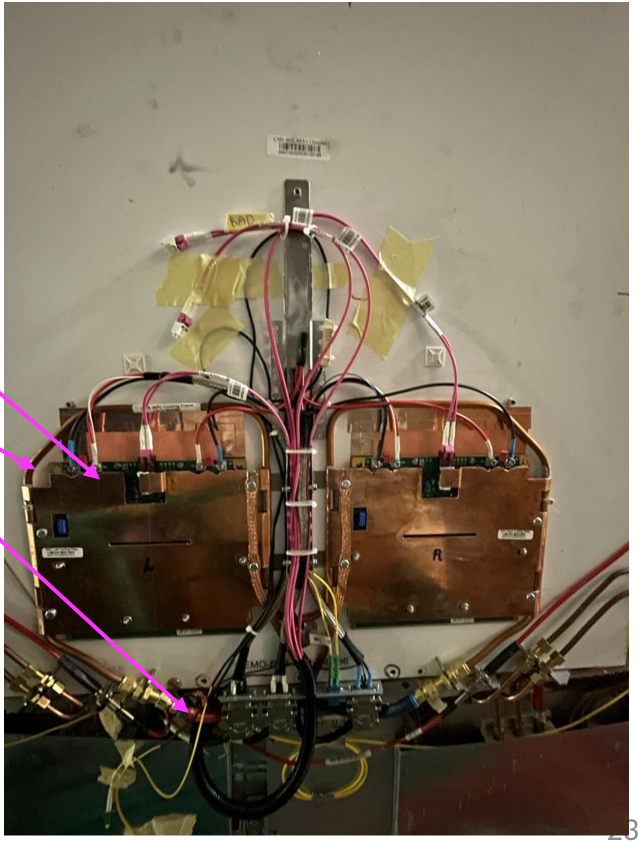
Hottest elements:
- linear regulators - Ohmic effect
- Optical communication
- FPGA - logic

Cooling system

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

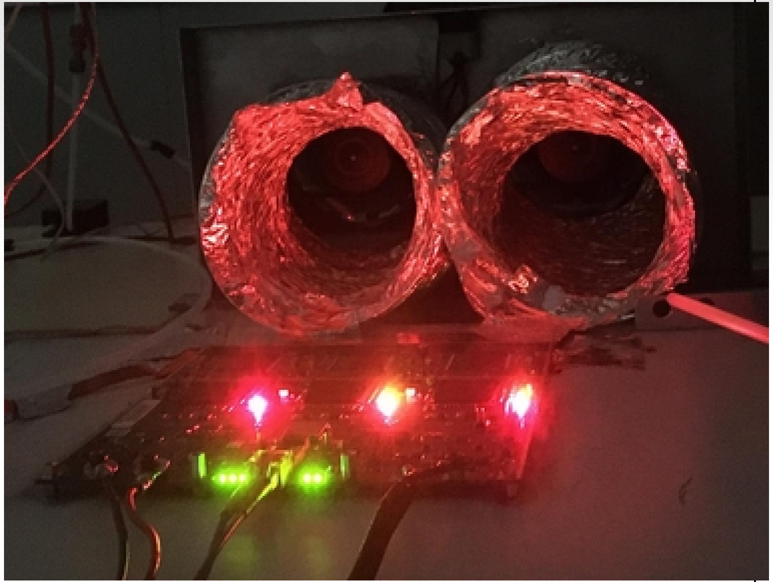
Max temperature < 50 C

Play also the role of grounding plane



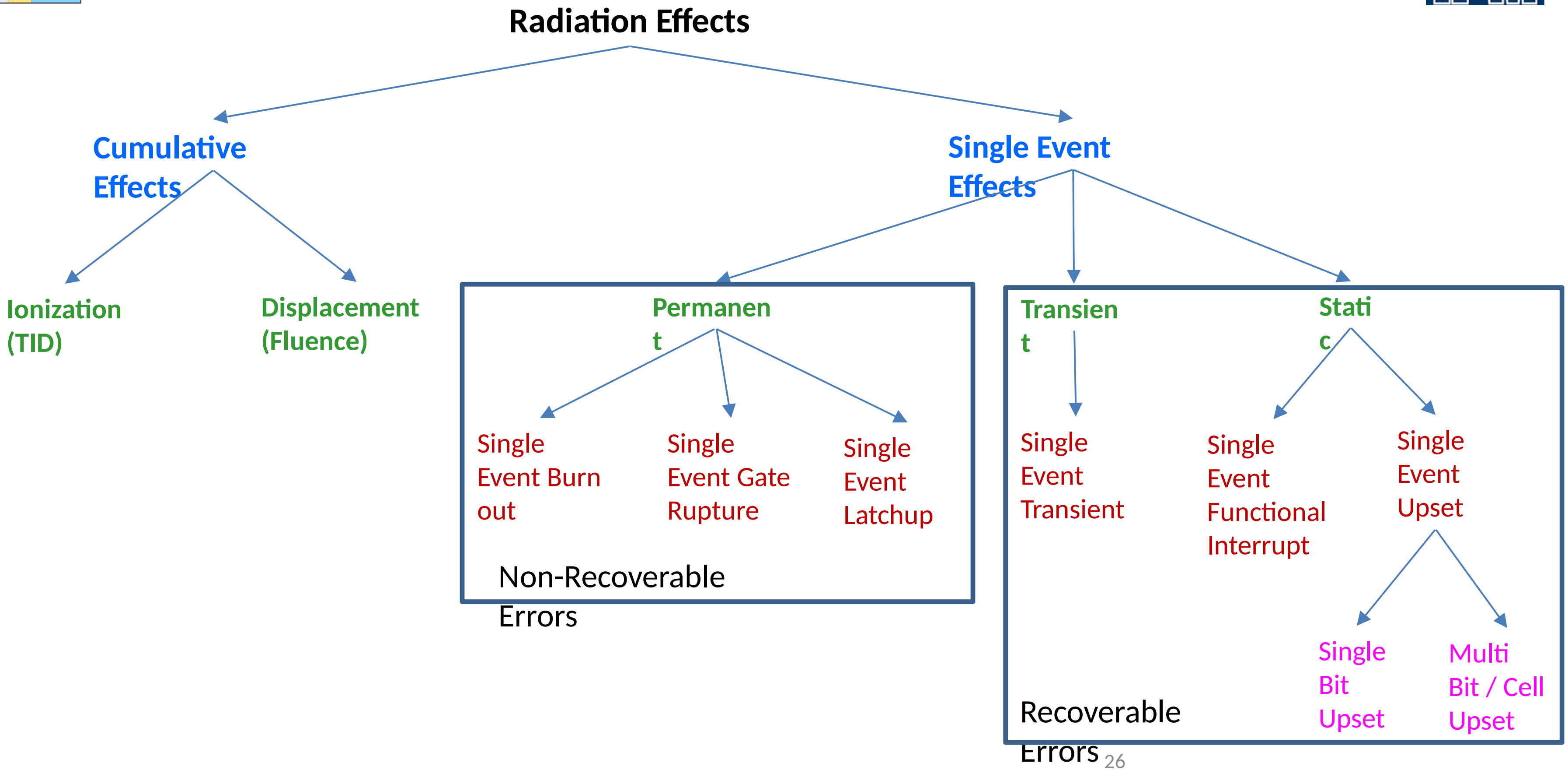
CONCLUSIONS

- iRPC FEB desinged/certified, integrated into the chamber and ready for mass production.
- The rad tolerance of the FEB are sufficient for project requirements
- Time and threshold calibration finalised and caracteristics meets the HL-LHC requirements :
  - Threshold : 30 fC
  - Space resolution :
    1.6 cm along strip, 0.4 cm perp. to strip
  - Time resolution : 500 ps

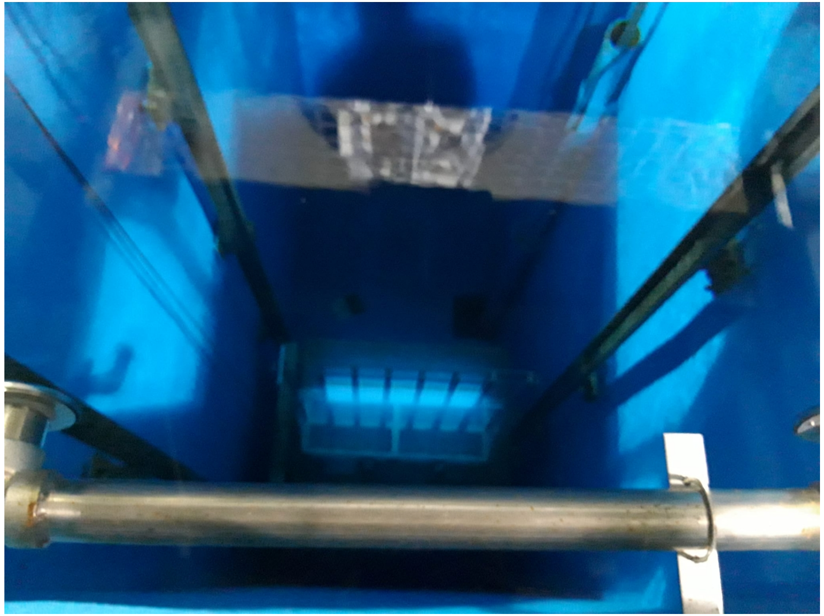


BACKUP

Radiation Effects in Electronics

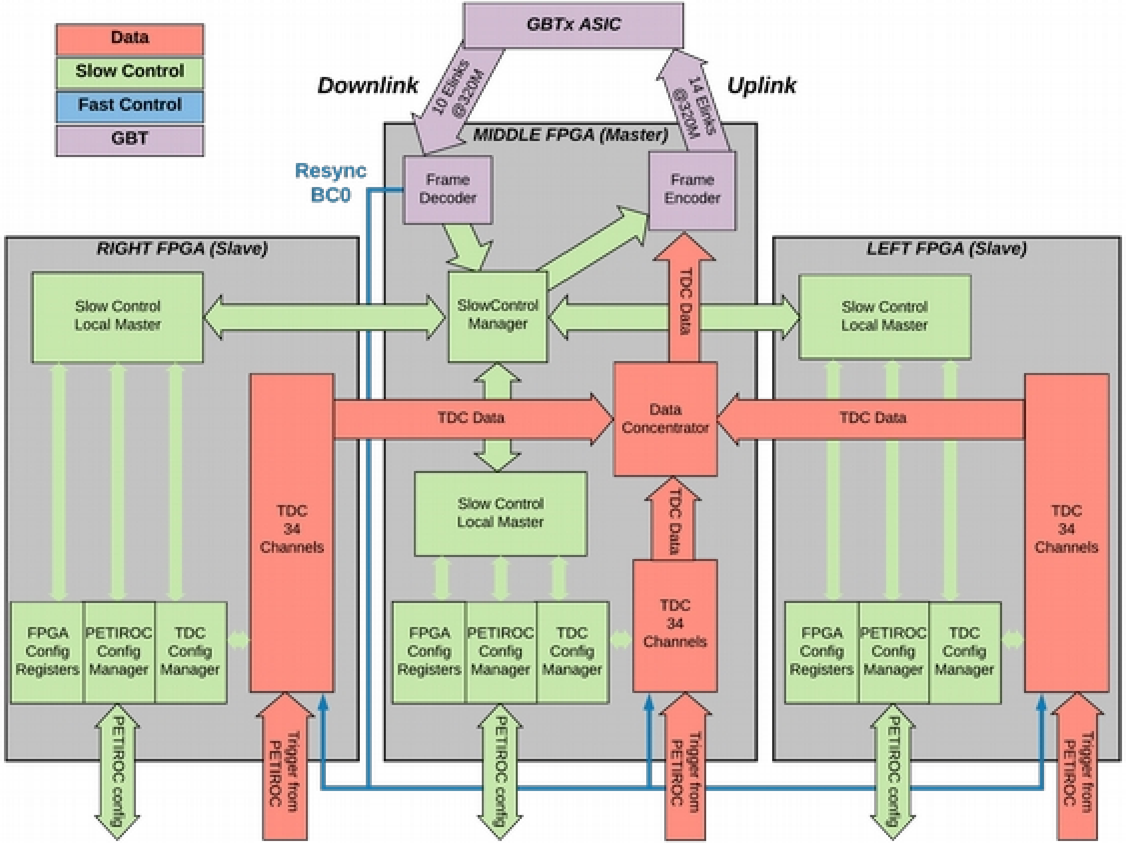


Validation en radiation gamma

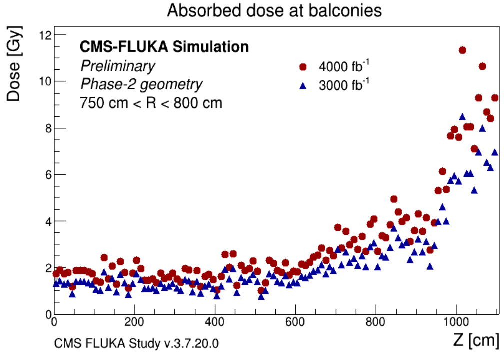


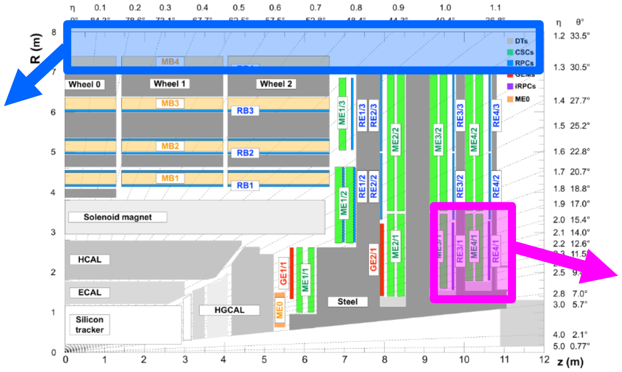
Caliope a ENEA Casaccia a côté de Rome

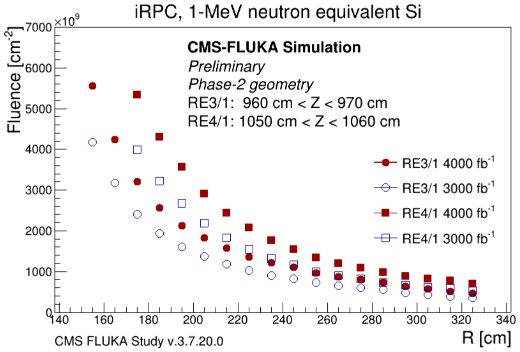
FEBv2 logical scheme

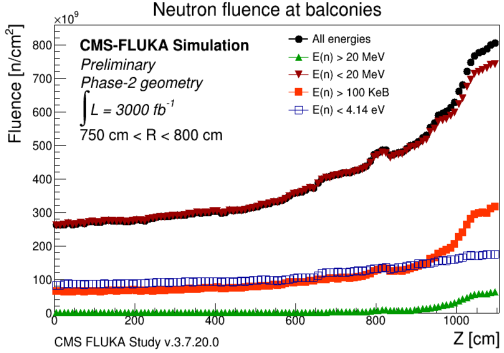


Expected Fluence and Dose at HL-LHC

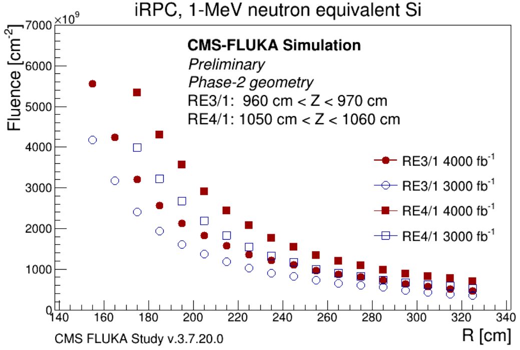








- Expected fluence and dose (RE34/1 FEBs)
  - at R=303 cm for RE3/1 is ~**4.3 (5.8) x10^{11} n/cm^2**, and
  - at R=304 cm for RE4/1 it is about **6.2 (8.2) x10^{11} n/cm^2**,
  - at R=303 cm for RE3/1 is ~**10 (13.6)** Gy
  - at R=304 cm for RE4/1 it is about **18 (24)** Gy
  - where R=303 (304)cm are 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.