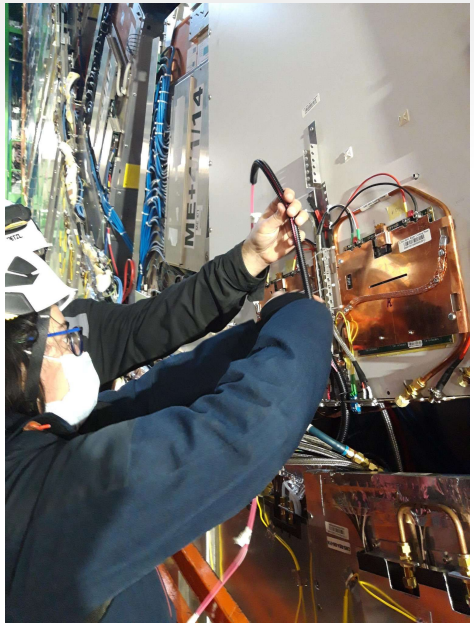
CMS iRPC FEB development and validation

RPC 2022

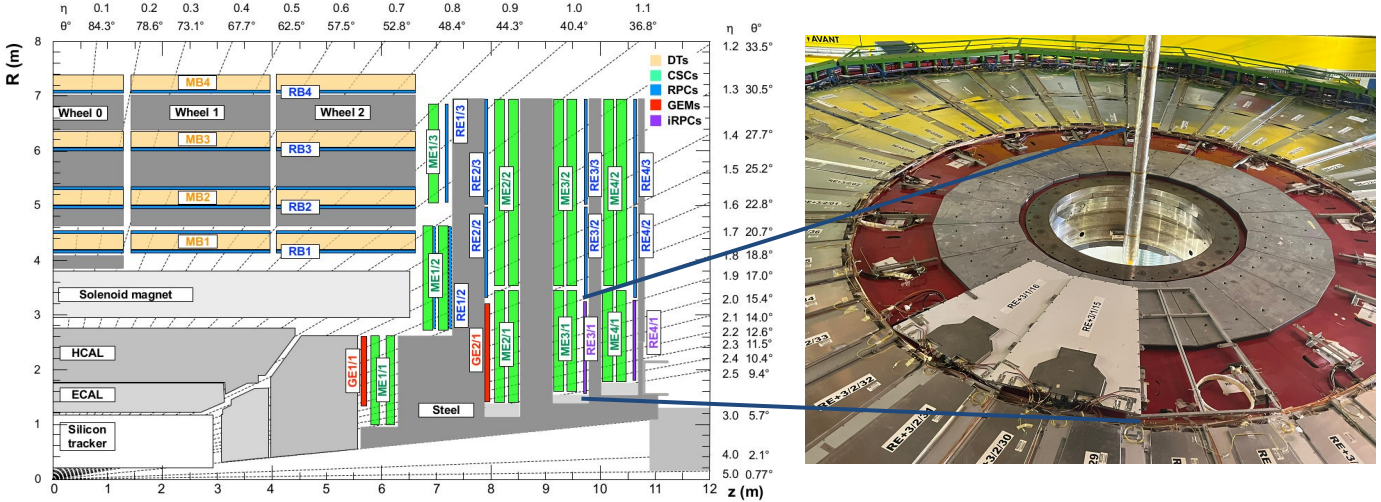
Maxime Gouzevitch on Behalf of CMS Muon groups
IP2I, Lyon, France

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

1) FEB for iRPC upgrade for HL-LHC



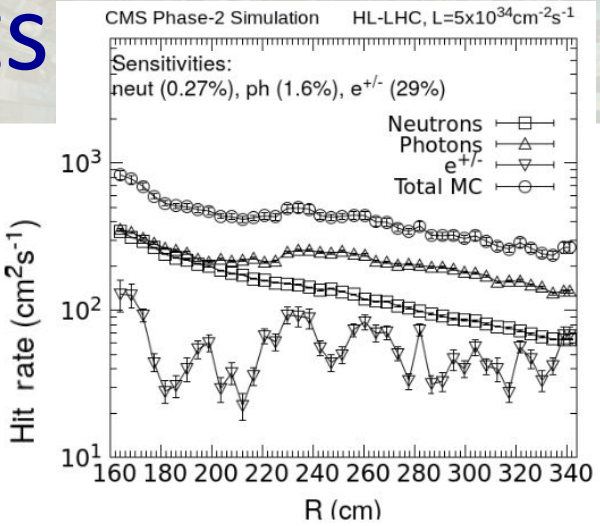
iRPC project for HL-LHC phase



- 18*2 RE3/1 and 18*2 RE4/1 chambers.
- Redundancy with CSC chambers.
- Coverage of CSC dead regions fr the trigger.
- Excellent absolute timing resolution for L1 trigger: O(500 ps).
- Dedicated trigger for Heavy Stable Charged Particles.

iRPC project constraints

	Present system	iRPC
$\|\eta\|$ coverage	0 – 1.9	1.8 – 2.4
Max expected rate (Safety factor SF = 3 included)	600 Hz/cm^2	2 kHz/cm^2
Gap size	2 mm	1.4 mm
Average charge / MIP	> 60 pC	~ 40 pC
Electronics threshold	150 fC	30-50 fC
TDC T resolution		20 ps

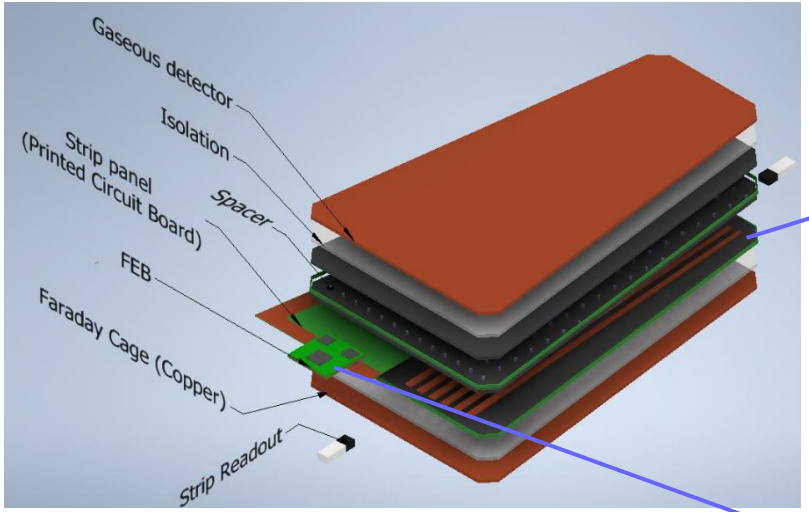


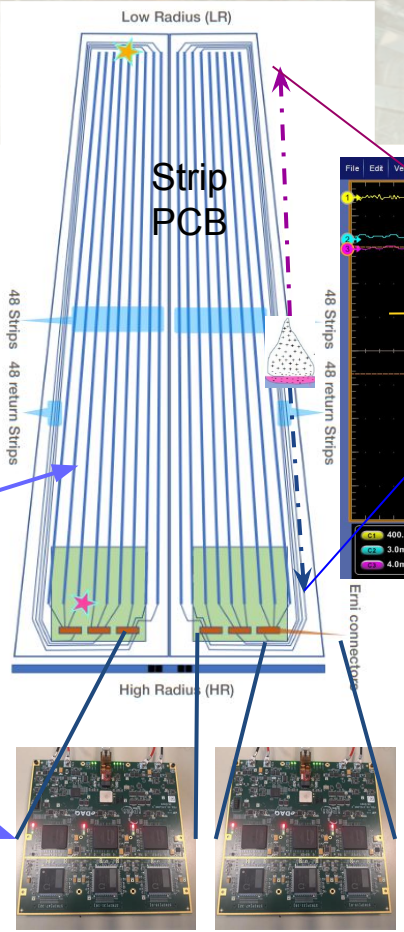
A dedicated iRPC electronics designed compared to RPC one:

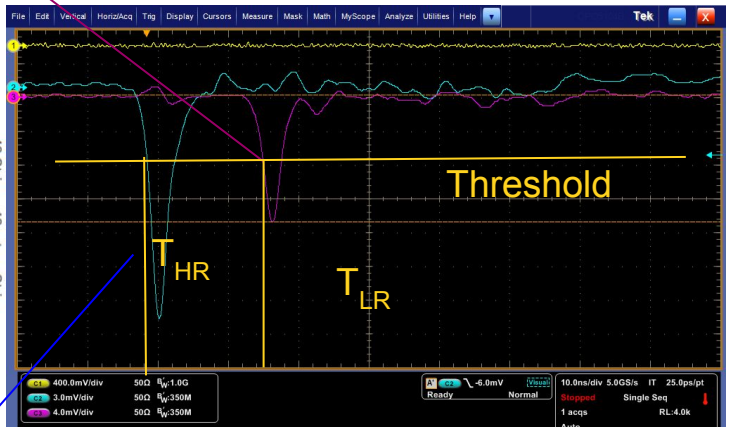
- Higher rate capability
- Fast and high rate optical fiber readout
- Provide absolute time resolution < 100 ps for space resolution and absolute time resolution.
- Sensitivity to 3 times lower threshold.
- Low noise.
- Radiation tolerance.

iRPC readout

- Twin gap chamber like RPC chamber.







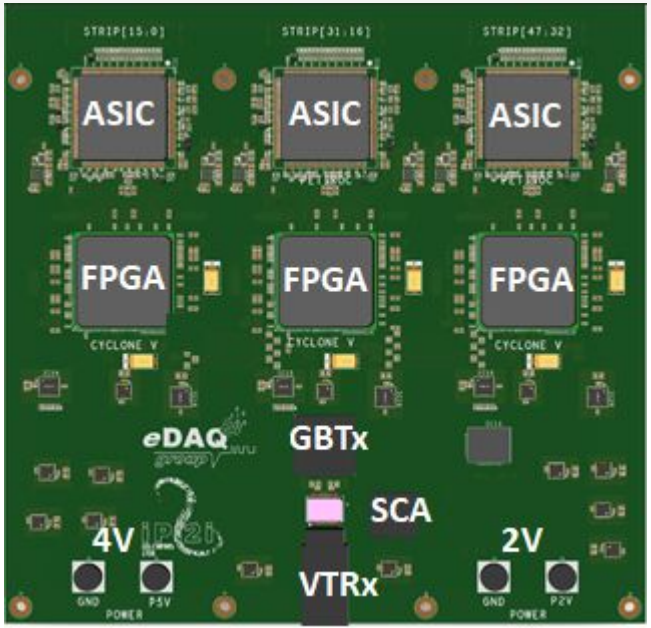
FEBv2

- Finer strip pitch for better φ resolution: < 1 cm
- Double sided readout of long strips using timing to localise the signal position

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

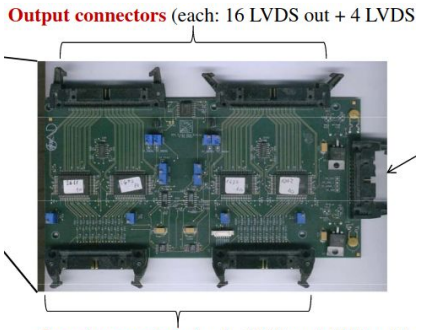
$\sigma_{\Delta T} \sim 200$ ps $\rightarrow \sigma_{\eta} \sim 2$ cm

2) FEB design

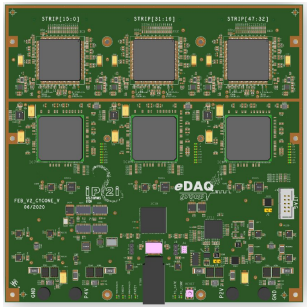

STRIP[15:0]
STRIP[31:16]
STRIP[47:32]
ASIC
ASIC
ASIC
FPGA
FPGA
FPGA
CYCLONE V
CYCLONE V
CYCLONE V
eDAQ
GBTx
SCA
4V
2V
VTRx
GND
P5V
POWER
GND
P2V
POWER

Technical specifications

➢ **Difference wrt to previous FEBs**



- RPC FEB:
  - Connected to 1 side of a copper strip through shielded cables (endcap)/kapton flex (barrel).
  - Custom CMS electronics (amplification & discrimination)
  - Time association (BX) done at level of Link System.
  - FEB → twisted pair cable (LVDS signal) → Link system



- iRPC FEB:
  - Connected to both ends of a PCB strip through an internal return line (inside PCB): 2D signal readout
  - PETIROC ASIC: preamplifier + discriminator (custom OMEGA).
  - Time measurement with a TDC FPGA on board.
  - FEB → Optical fiber → BackEnd

History of the FEB

First proto

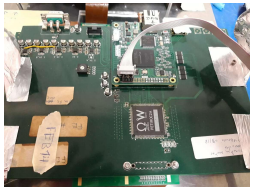
2017
proof of principle for
CMS-MUON-TDR-016

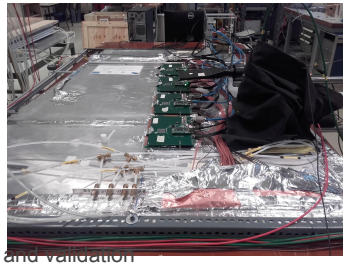
2 PetiROC2A
+ FPGA Cyclone II
+ ETHERNET
directly on strip PCB
(50 cm)

Feb V0

2018
First FEB (Conf. note)

1 PetiROC2A +
MEZZANINE with
FPGA Cyclone II
+ ETHERNET





Feb V1

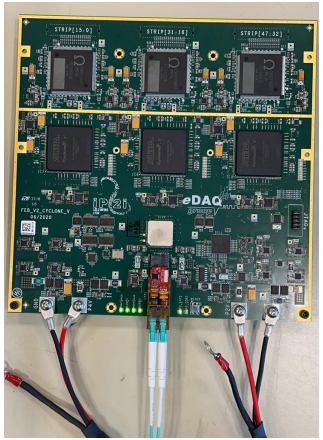
2019
FEB without
mezzanine

2 PetiROC2B
+ FPGA Cyclone V
+ ETHERNET

Feb V2

2021
Non-rad hard
for iRPC Demo

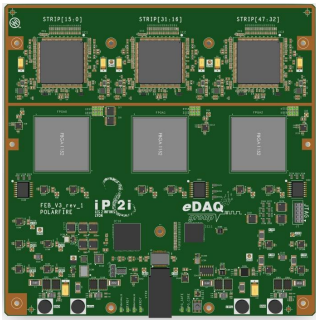
6 PETIROC2C
+ 3 FPGA Cyclone V
+ Optical GBT



Feb V3

→ 2023
Rad hard
final

6 PETIROC2C
+ 3 FPGA PolarFire
+ Optical GBT

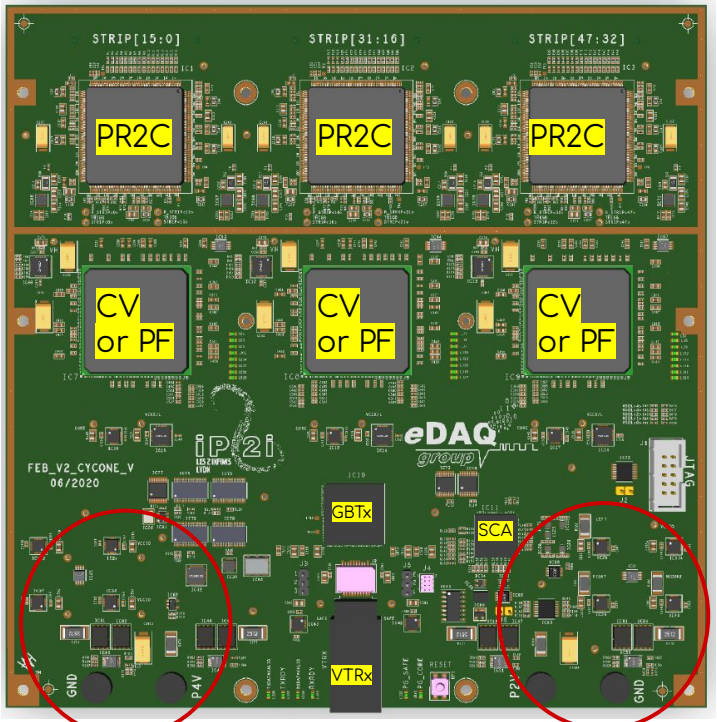


FEBv2 details

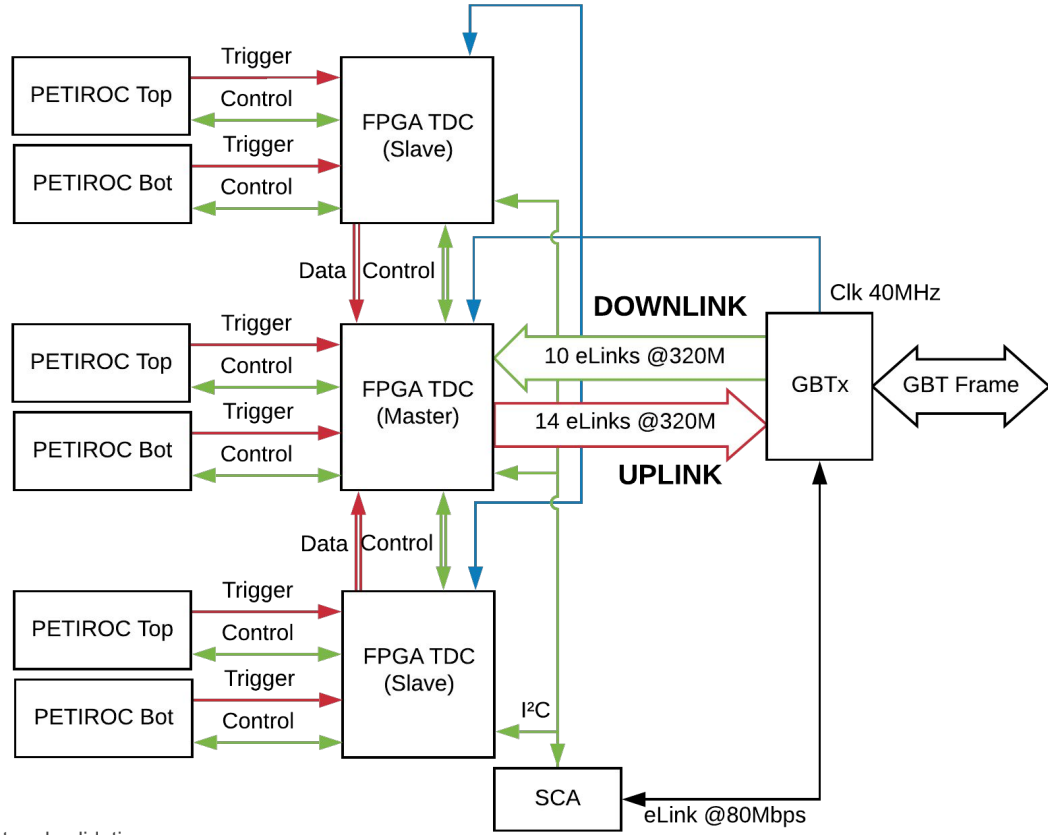
- 2 FEBs / Chamber → 144 (+16 spares) FEBs in total
- 3 Erni connectors with 32 channels each.
- 6 ASIC PetiROC2C (PR2C):
  - Specially designed by OMEGA group for CMS RPC project based on Petiroc2A

- 3 FPGAs (96 + 6 TDC channels)
  - FEBv2: CYCLONE V (non rad-hard)
  - FEBv3: POLARFIRE (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).



FEBv2 logical scheme



PetiROC ASIC

PETIROC2A designed for PET

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

Limitations: low rate expected

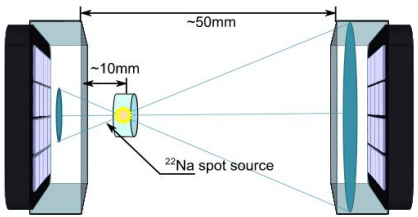


Figure 2. Setup structure used during the experiments.

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 :

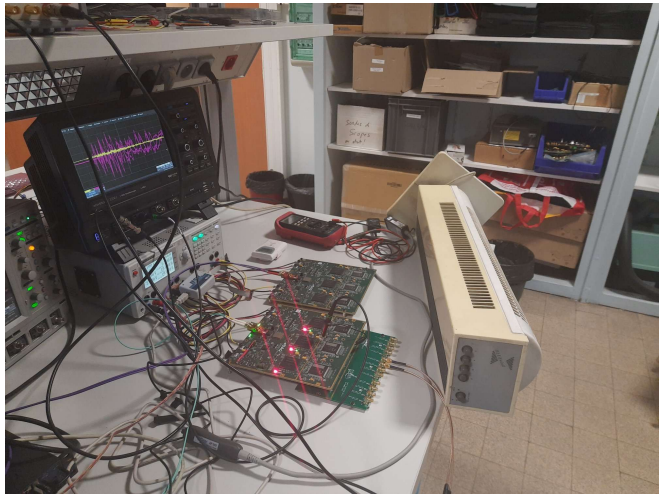
- Reduce preamp. frequency
- Thr ~ 100 fC
- 10-20 ns / ASIC dead time introduced to remove retriggering

→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.

3) Certification, calibration and integration



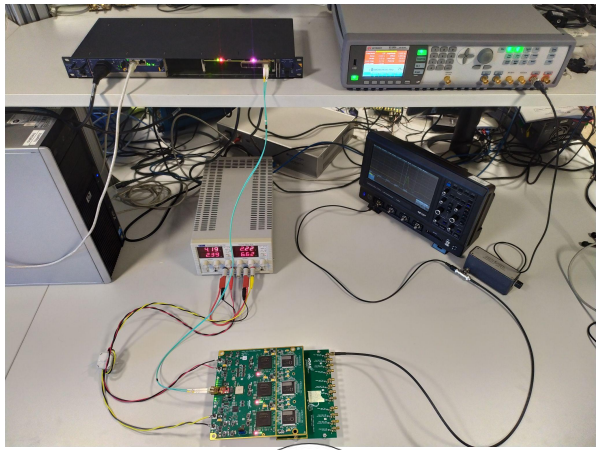
FEB certification steps in IP2I, Lyon

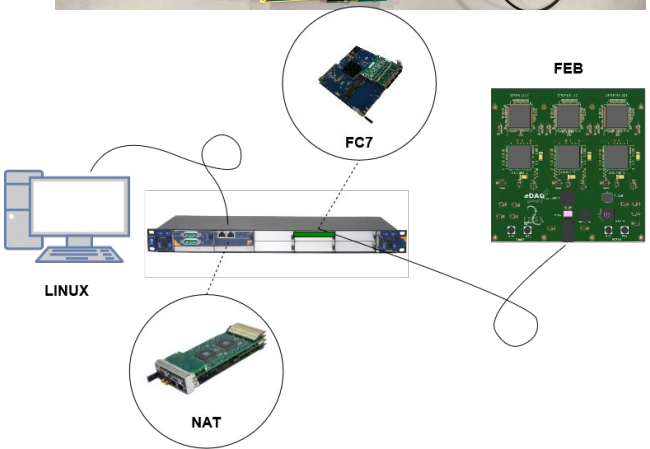
Based on the **FC7 card (Tracker certification card)** system and controlled by **Python software** tools.

➢ <u>Perform a Quality Check Process to validate :</u>

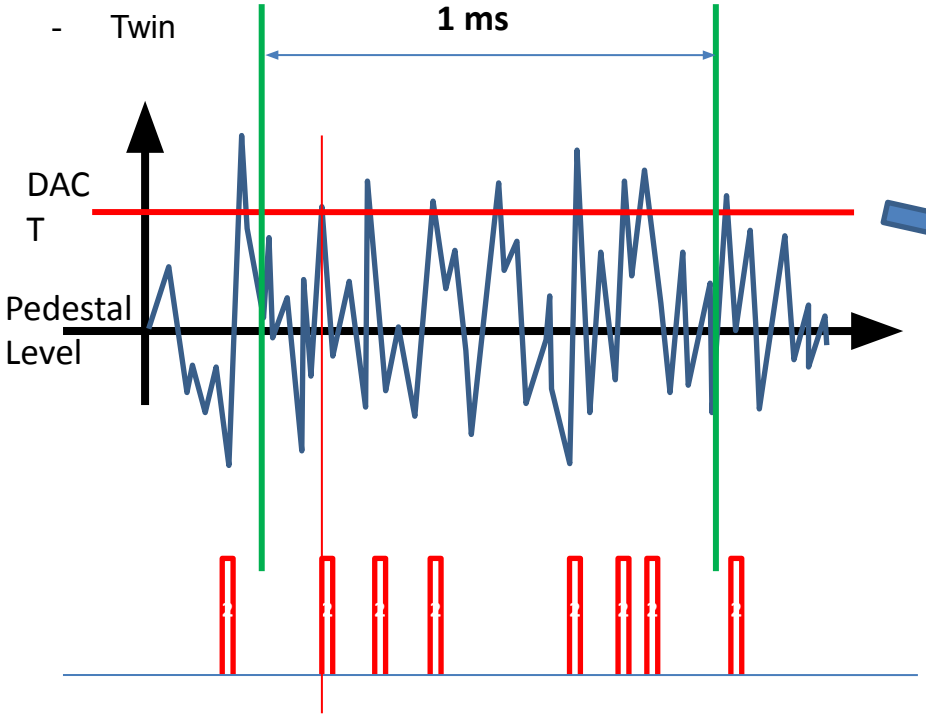
- Each electronic block of the FEB independently (SCA, GBTx, Power Supplies, tests points)
- The data integrity of the system
- The operation of the FEB firmware designed in the FPGA(s)
- The operations of the TDC(s) and ASIC's

➢ Simulation and validation of real operation with injection board

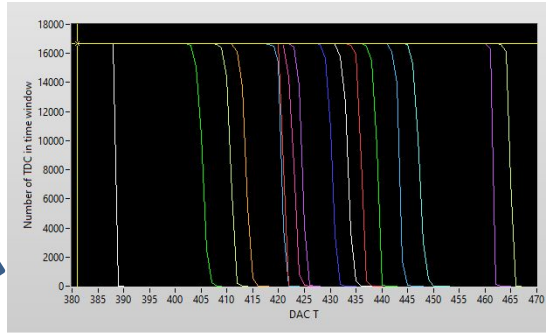




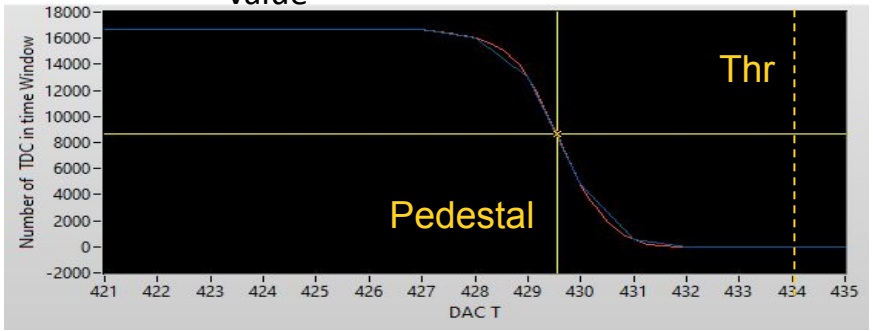
FEB pedestal alignement method



TDC counting (for each channel)



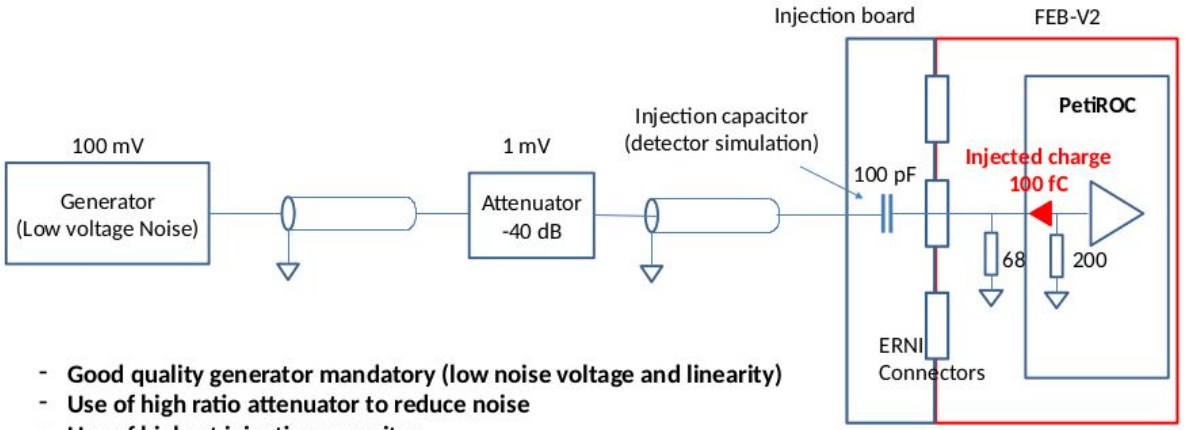
All pedestals aligned to same “median” value



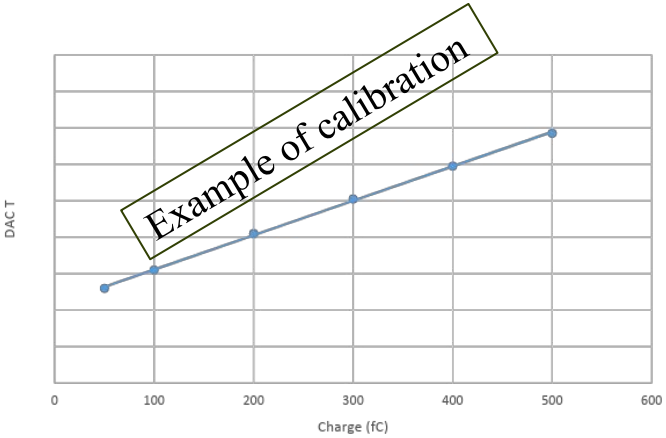
Threshold applied well above noise level

FEB calibration

DAC T vs Charge
Measurement setup considerations



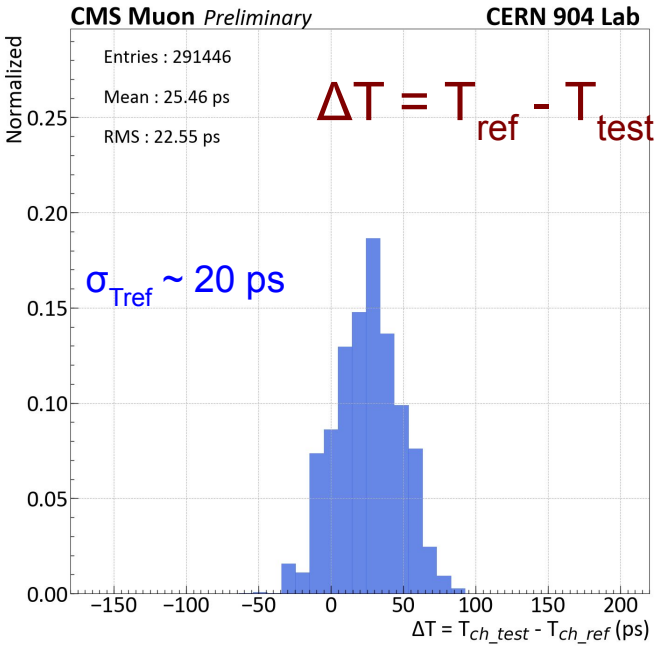
- **Good quality generator mandatory (low noise voltage and linearity)**
- **Use of high ratio attenuator to reduce noise**
- **Use of highest injection capacitor**

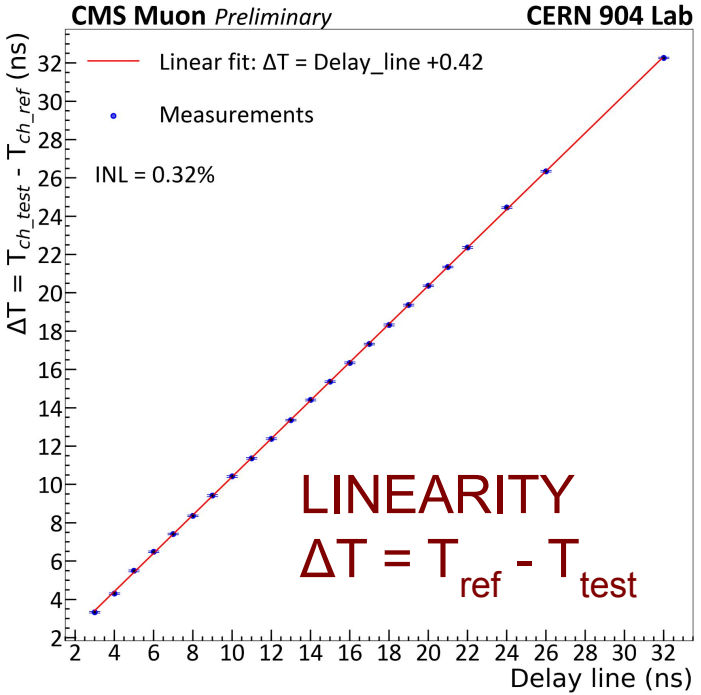


Calibration factor = 4.6 ± 0.5 fC/DAC T

THR: Specification
50 fC ≒ 11 DAC T
Used in test beams
32 fC ≒ 7 DAC T

TDC time resolution

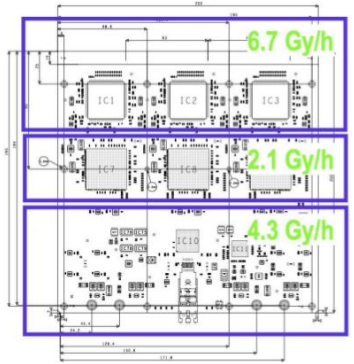




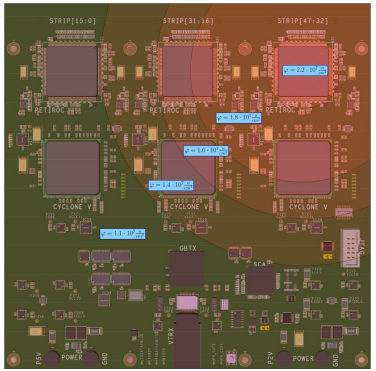
Pure TDC time resolution was measured using 2 channels test and a reference.

FEB radiation hardness

1) TID passed (γ's) -- Facility ENEA Casaccia Calliope ^{60}Co :
   Requested: 20 Gy
   Certified:
   - FPGA Cyclone V (50 Gy):
   - Petiroc (160 Gy);
   - Power supply zone (100 Gy)



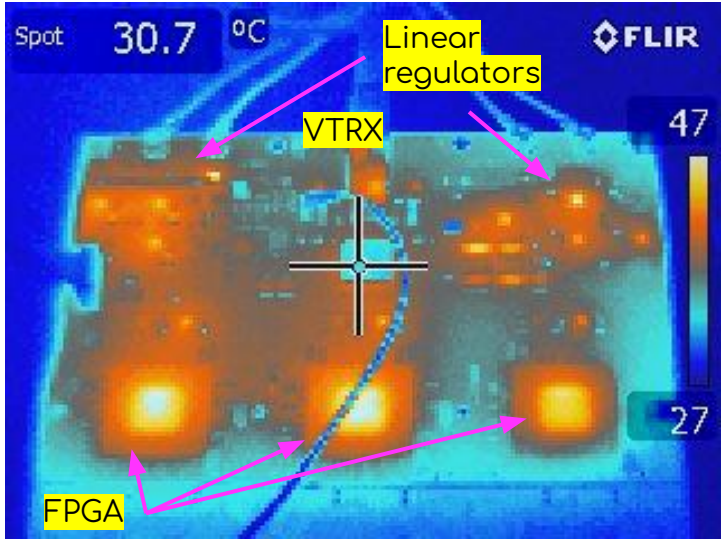
2) TNID passed (neutrons) - Facility FNG Frascati, with support from RADNEXT March 2022
   Requested: 2.5e12 neq1MeV/cm^2:
   Certified: 2.5e12 neq1MeV/cm^2:
3) Neutron flux passed -
   Requested: 50.000 neq1MeV/cm^2/s
   Certified: Up to 10 requested flux
4) SEU (charged hadrons) - Foreseen in CHARM, CERN in Oct. 2022



Exemple of iradiation map

FEB power consumption

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



Hottest elements:

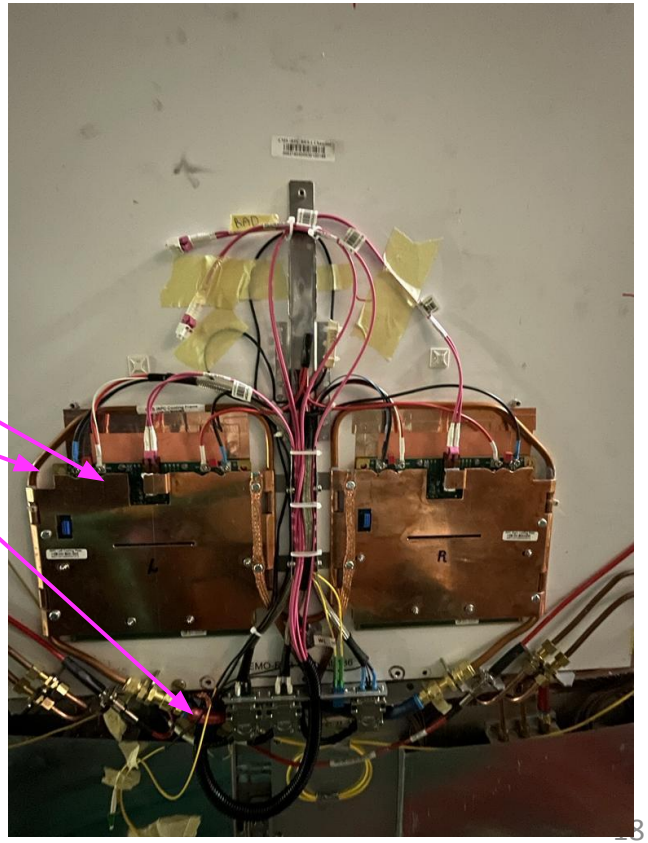
- linear regulators - Ohmic effect
- Optical communication
- FPGA - logic

Cooling system

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

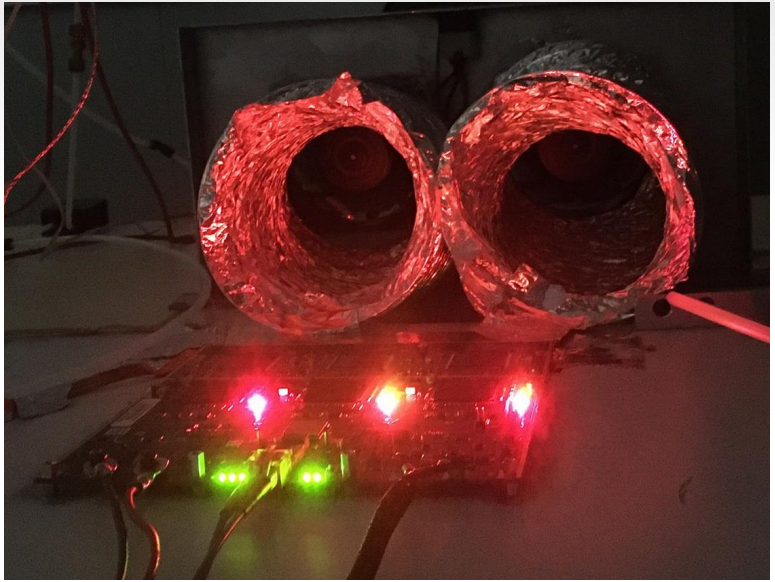
Max temperature < 50 C

Play also the role of grounding plane



CONCLUSIONS

- Non-rad hard FEBv2 with Cyclone V FPGA is designed and certified.
- Time and threshold calibration finalised.
- Feb integrated into the Chamber
- The rad tolerance of the FEB seems to be higher than expected. Tests for SEU are ongoing.
- Rad hard FEBv3 with PolarFire FPGA is ready for prototyping.



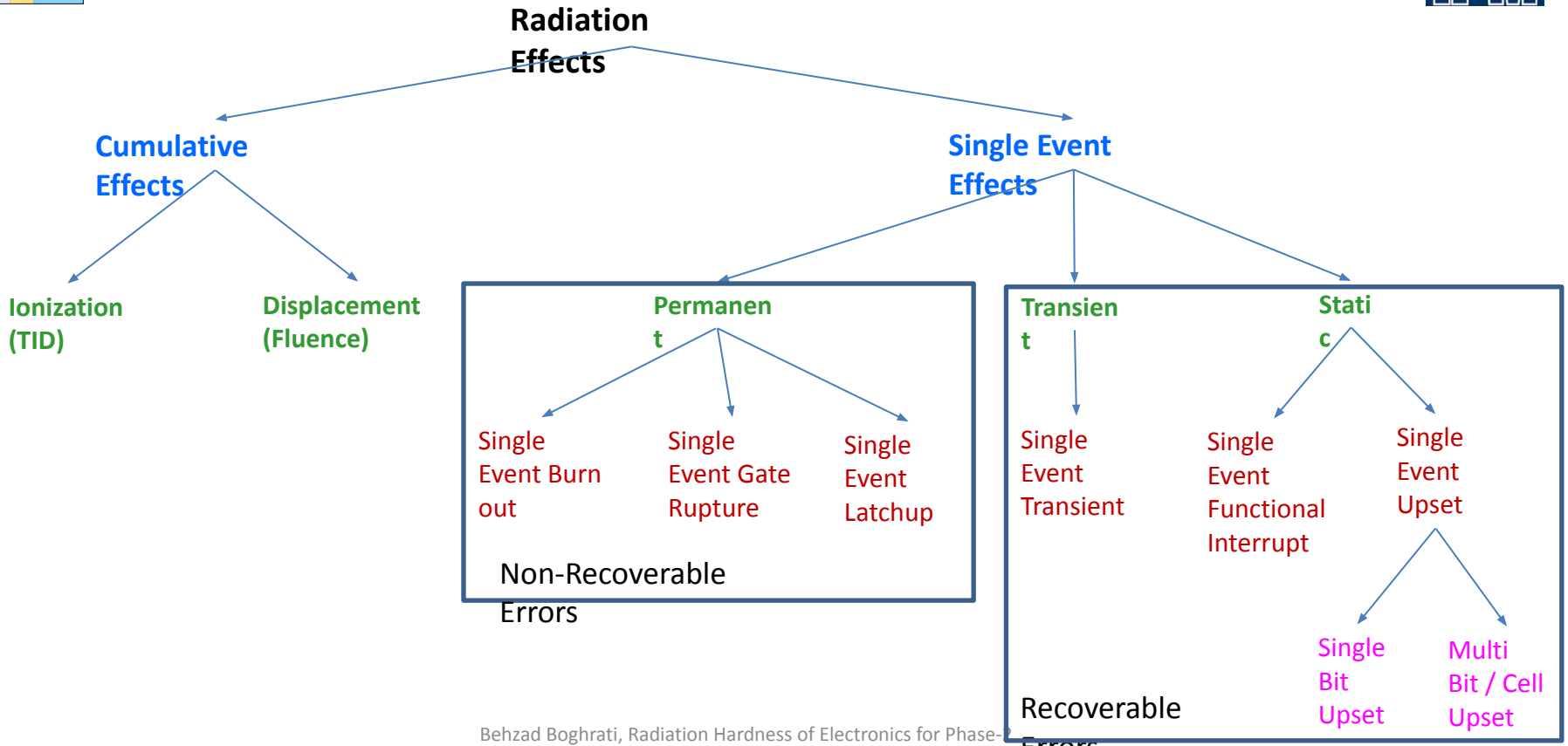
IN MEMORIAM

Claude Girerd left us 26/08/2022 after a long illness.

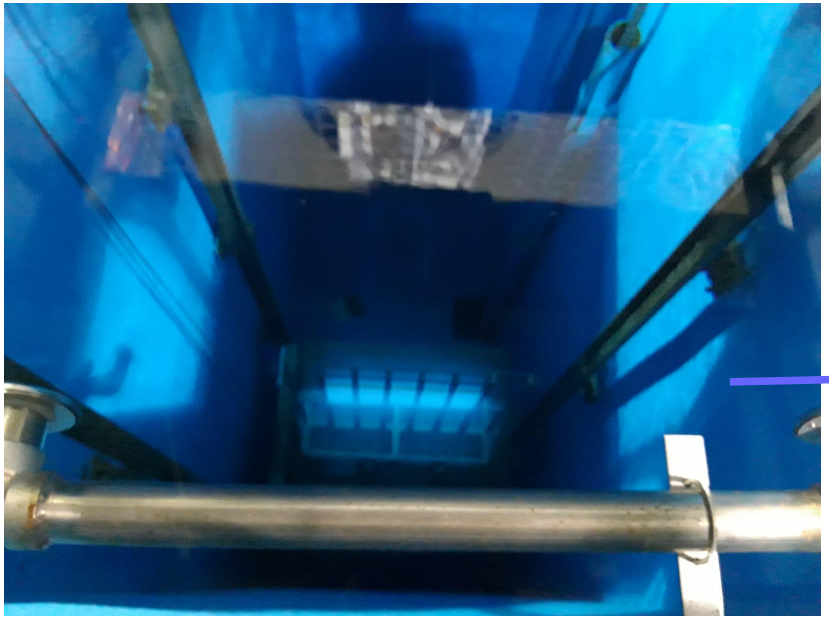
- One of the most brilliant French electronics engineers in HEP.
- 2006 Crystal Medal of the CNRS for FEB for OPERA experiment.
- Technical coordinator of iRPC electronics project from 2019 to 2021. Lead FEBv2 design and certification.

BACKUP

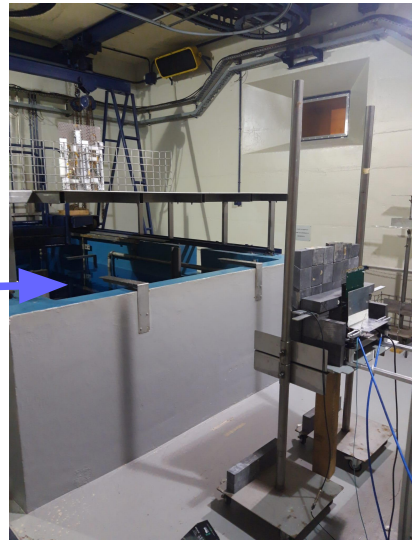
Radiation Effects in Electronics



Validation en radiation gamma



Caliope a ENEA Casaccia a côté de Rome



FEB certification steps

FEB Test Bench - In Lyon (IN2P3/IP2I)

Based on the **FC7 acquisition** system and controlled by **Python software** tools.

➢ <u>Perform a Quality Check Process to validate :</u>

- Each electronic block of the FEB independantly (SCA, GBTx, Power Supplies, tests points)
- The data integrity of the system
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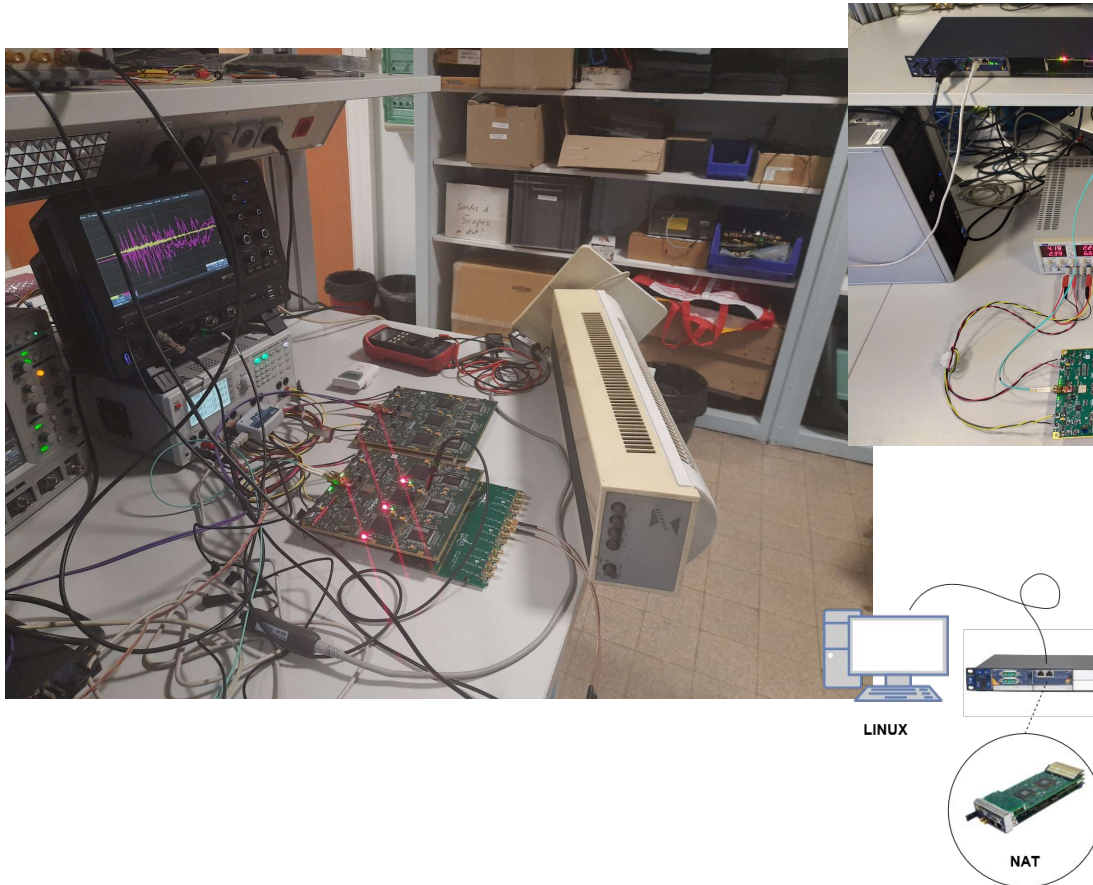
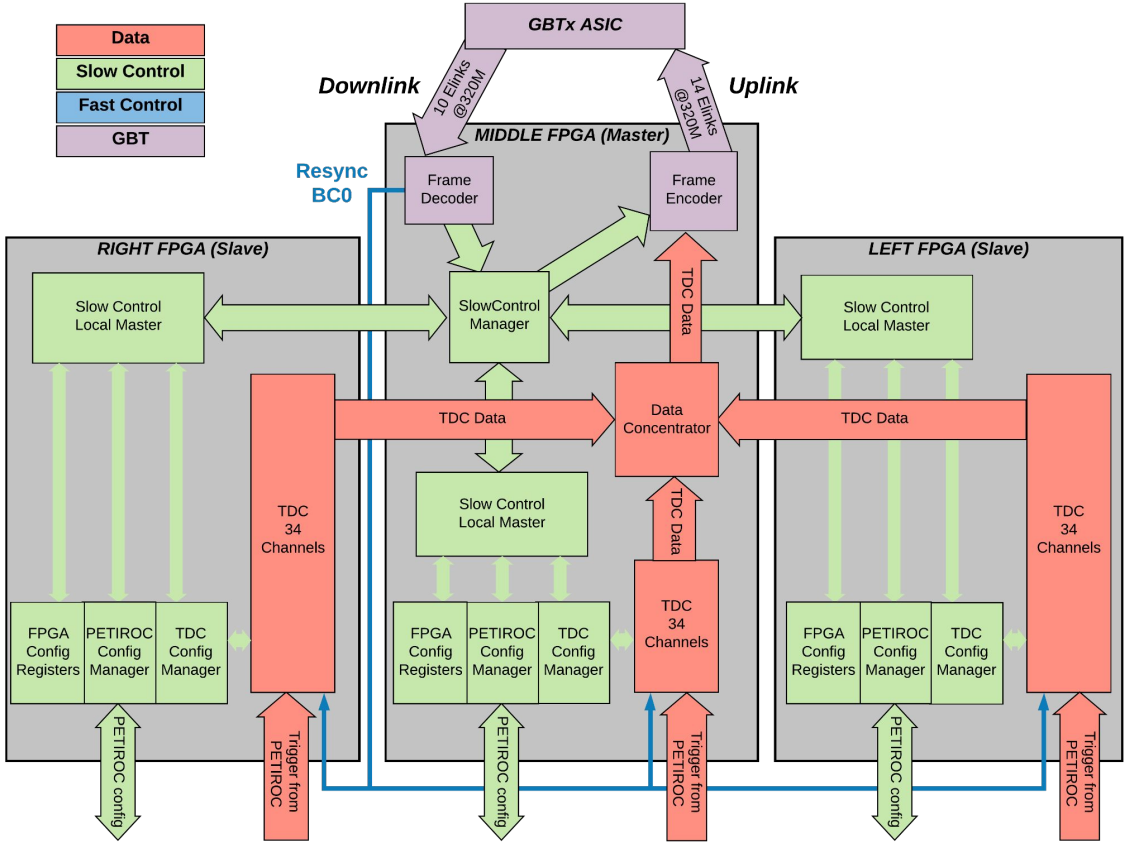
➢ Simulation and validation of real operation with injection board

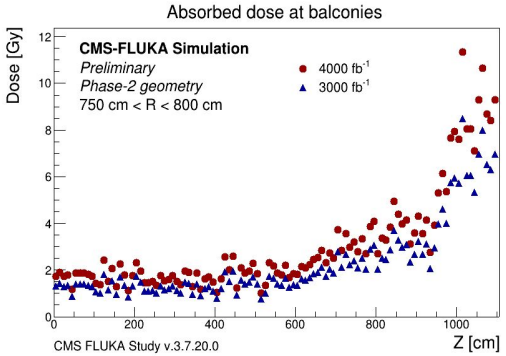


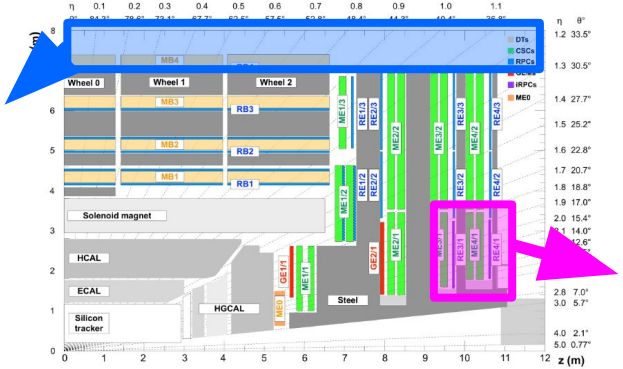
Test bench in IP2I Lyon

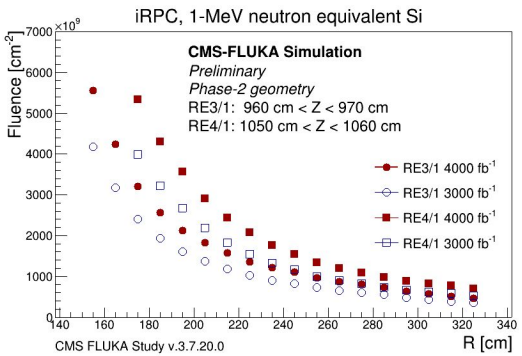
FEBv2 logical scheme

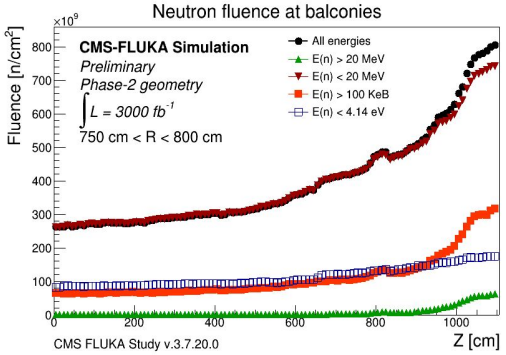


Expected Fluence and Dose at HL-LHC









- 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**