Front-End electronics for CMS iRPC detectors

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RPC2020, Roma

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Introduction

- Motivation and Goals of Research & Development
  - CERN CMS RPC upgrade project
  - Rate Simulation

Prototype of iRPC

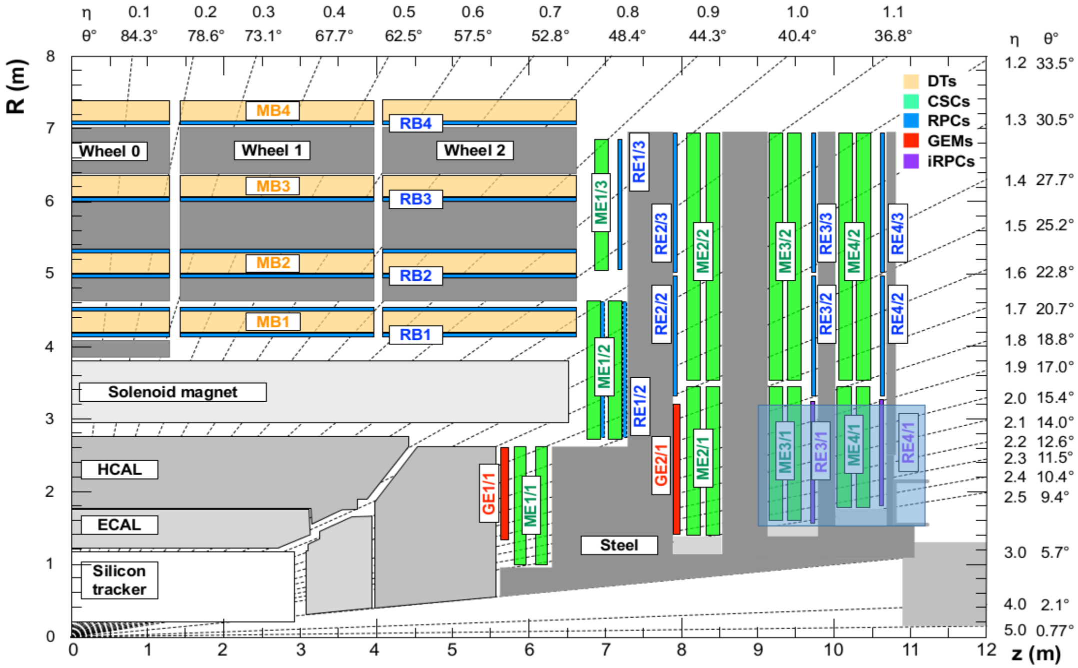
- Layout of improved Resistive Plate Chamber
- RETURN & COAX redout PCB-strip panels
- Front-End Electronic: ADC and TDC

Test of iRPC

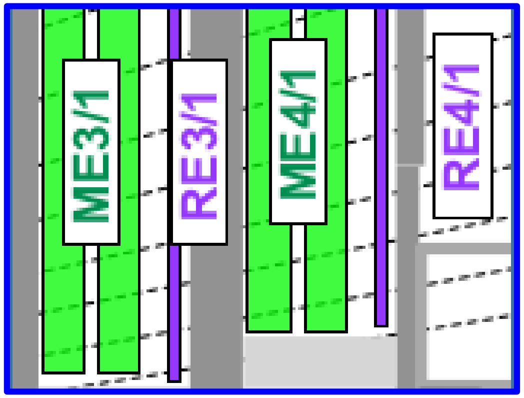
- Trigger for study perfomence of chambers
- Description of the tests for prototypes
- Output Data from iRPC
- Cluster Size and Clustering Algorithm
- Study of time resolution
- Efficiency study
- Trigger Setup in GIF++
- GIF++: Study of rate capability

Summary

CMS iRPC Upgrade Project

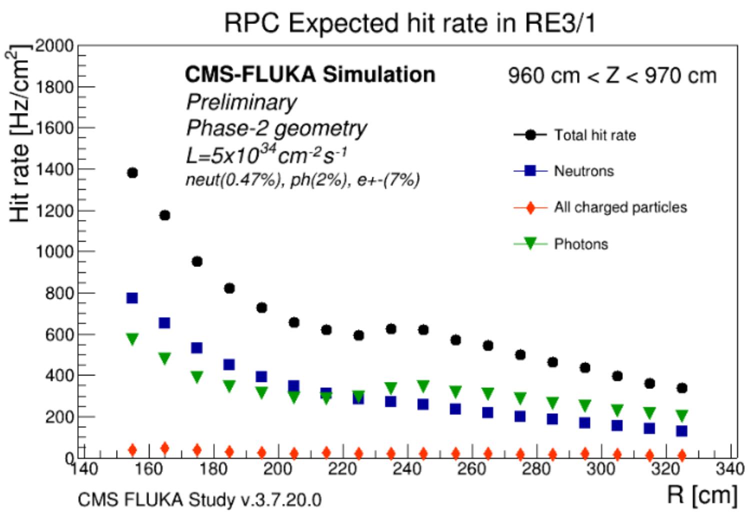


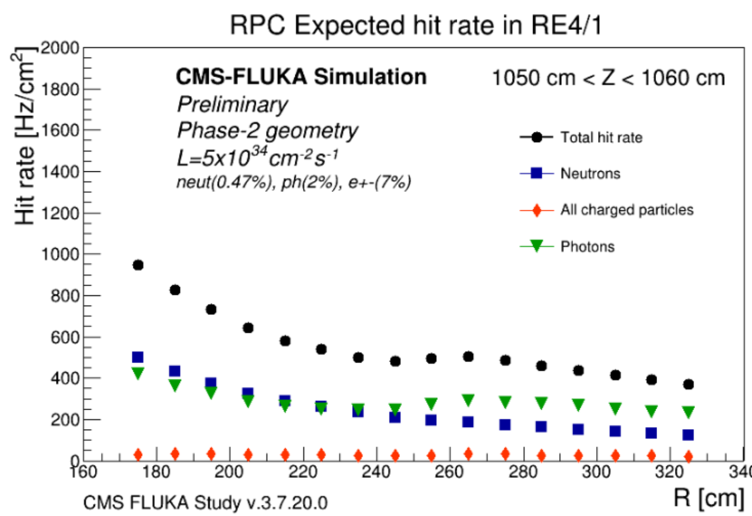
Layout of one quadrant of CMS. The slots RE3/1 and RE4/1 are to be instrumented by iRPC chambers for HL-LHC upgrade.



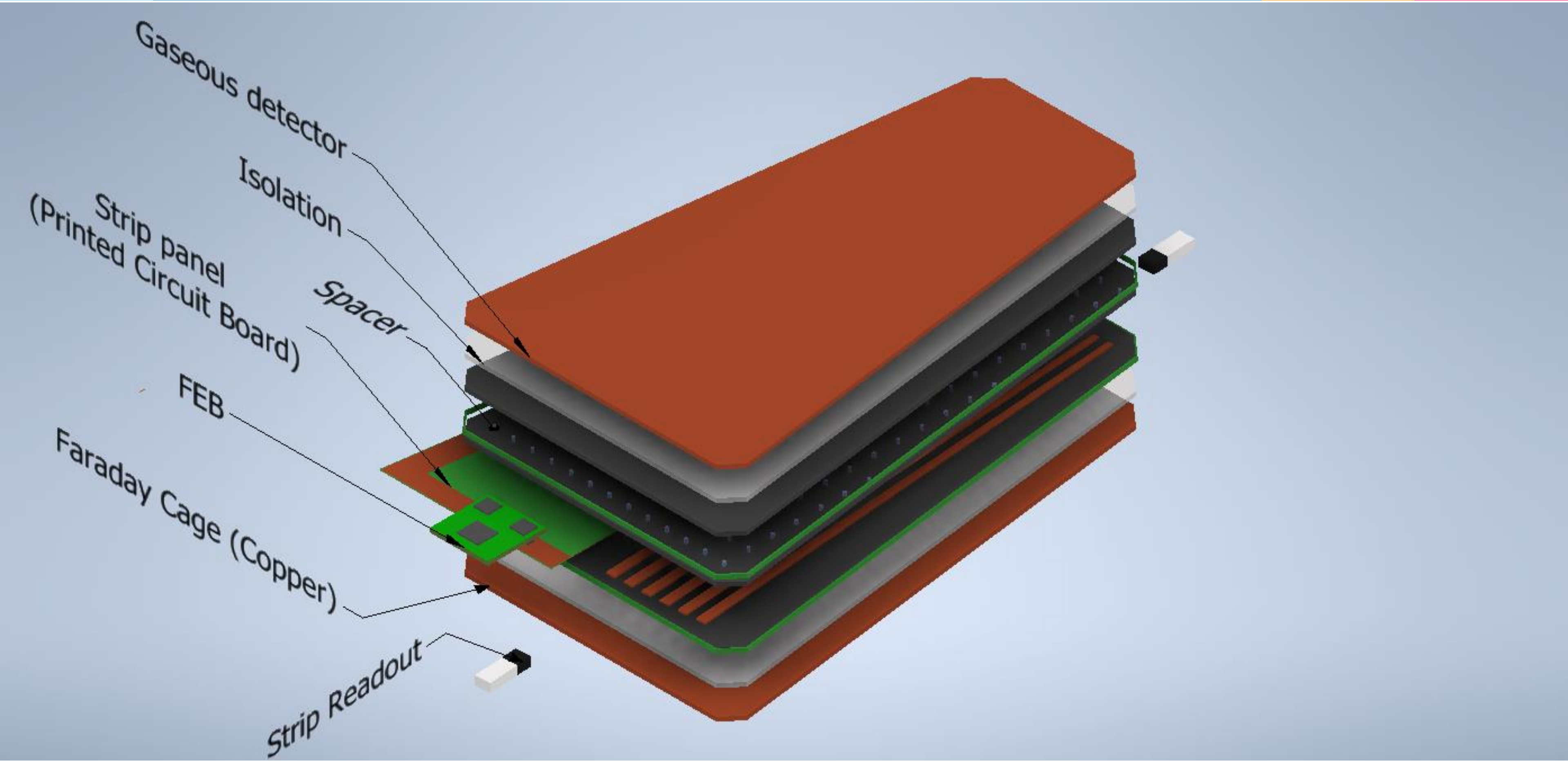
- To improve on the muon detector performance.
- To improve on the muon trigger efficiency at high 1.8 < |η| < 2.4

iRPC should be able to withstand high particle rates with safety factor: 2kHz*cm^{-2}



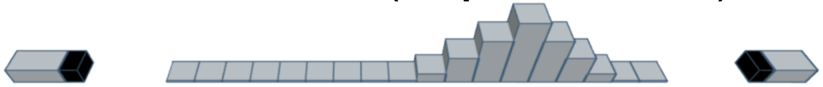


Layout of improved Resistive Plate Chamber



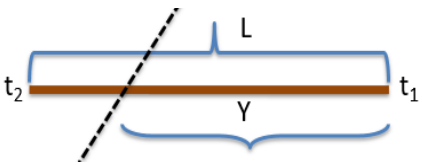
Standard Readout

Time of Arrival (Proposal Solution)



Determine position along a strip of the hit
with a resolution given essentially by the readout timing.

Time Difference of Arrival Method



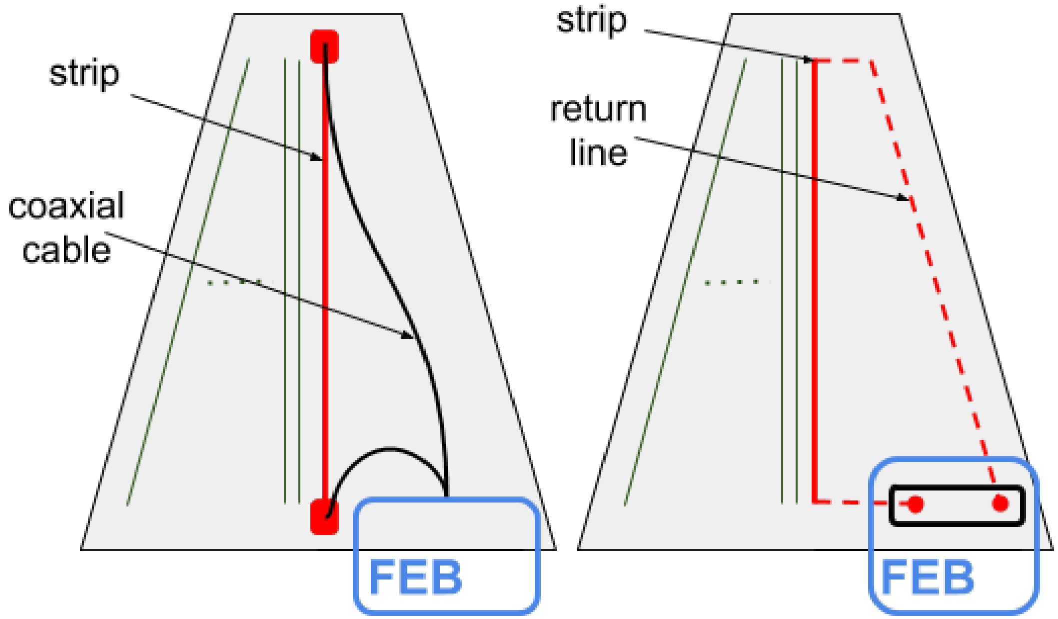
$$Y = L/2 - v * (t_2 - t_1)/2$$

$$\sigma(Y) = v * \sigma(T_2 - T_1)/2$$

RETURN & COAX redout of PCB-strip panels

Solution COAX Connect with coaxial cables. Cable impedance = 50 Ω..

Solution RETURN Connect with a return line within PCB (same impedance 45 Ω).



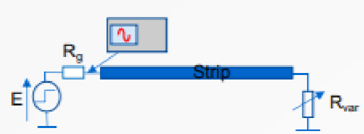
To minimize signal reflections, the stripline impedance must be controlled up to the asic. 3 methods were used to measure strip impedance :

- **Direct measurement of line parameters with a RLC meter (at 2MHz)**

Side	C_p (pF)	G_p (µS)	L_s (nH)	R_s (mΩ)	Z_c (Ω)
Wide	244	934	482	467	**43,5**
Narrow	244	934	487	461	**44**

- **Direct measurement with potentiometric line adaptation**

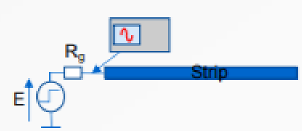
Z_c= 46 Ω



- **Reflection Method**

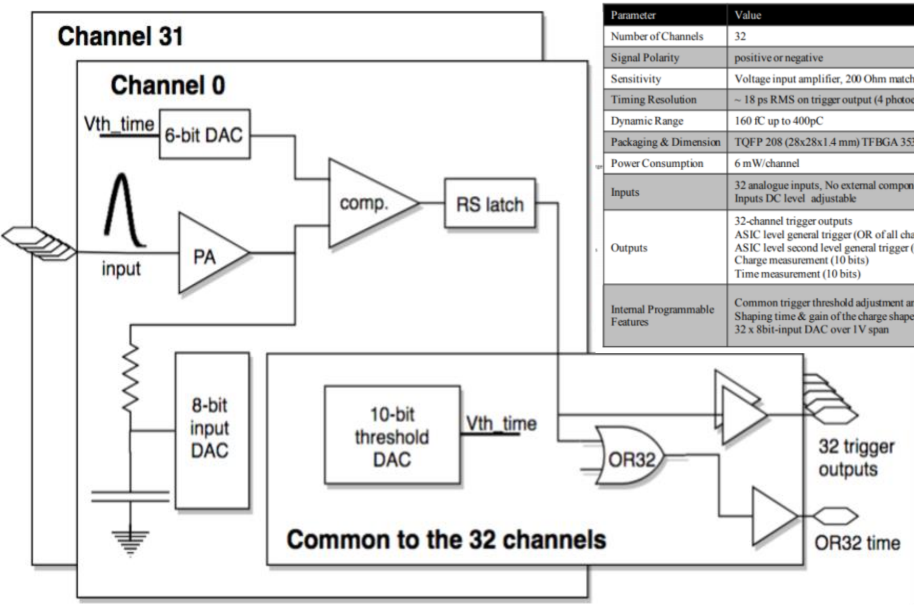
$$Z_c = \frac{R_g . V_s}{E - V_s}$$

Z_c=41Ω



Front-End Electronic: ADC and TDC

ASIC PETIROC: Analog Digital Converter

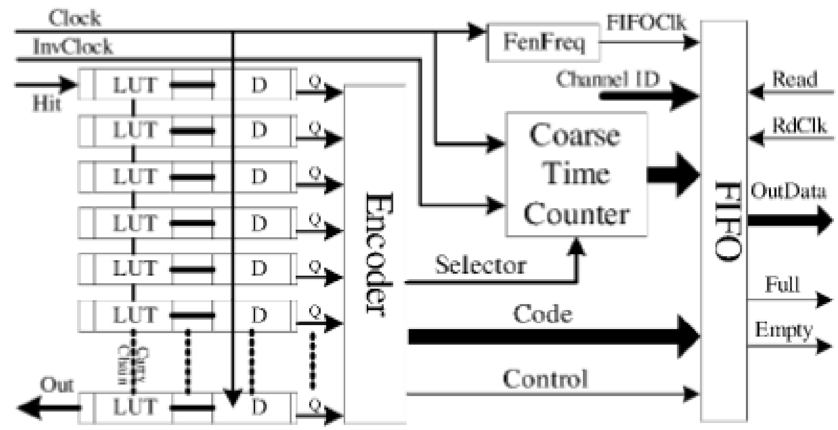


Parameter	Value
Number of Channels	32
Signal Polarity	positive or negative
Sensitivity	Voltage input amplifier, 200 Ohm matching
Timing Resolution	~ 18 ps RMS on trigger output (4 photoelectrons injected)
Dynamic Range	160 fC up to 400pC
Packaging & Dimension	TQFP 208 (28x28x1.4 mm) TFBGA 353 (12x12x1.2mm)
Power Consumption	6 mW/channel
Inputs	32 analogue inputs, No external component required Inputs DC level adjustable
Outputs	32-channel trigger outputs ASIC level general trigger (OR of all channel) ASIC level second level general trigger (OR of all channels) Charge measurement (10 bits) Time measurement (10 bits)
Internal Programmable Features	Common trigger threshold adjustment and 6bit-DAC/channel Shaping time & gain of the charge shaper 32 x 8bit-input DAC over 1V span

The Front-End Electronics Board (FEB) that hosts one PETIROC ASIC and the FPGA that includes the TDC and the schematics of the PETIROC ASIC

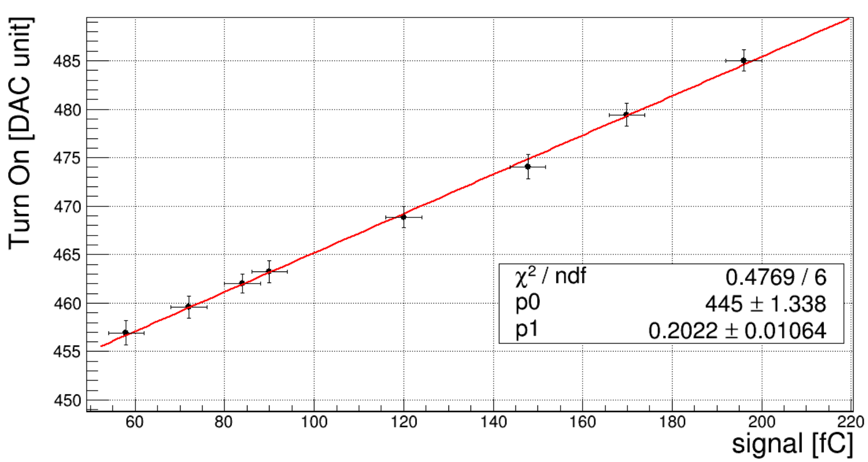
FPGA Cyclone: Titme Digital Converter

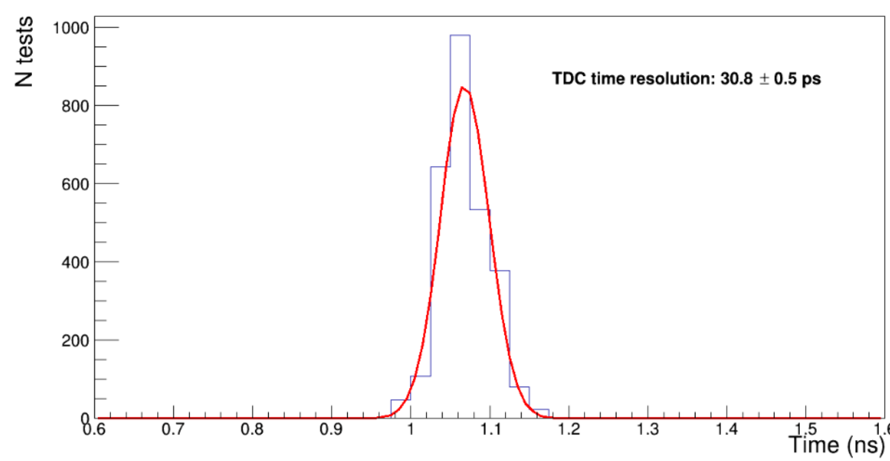
$$T_{\text{out}} = T_{\text{coarse}} + T_{\text{fine}}$$



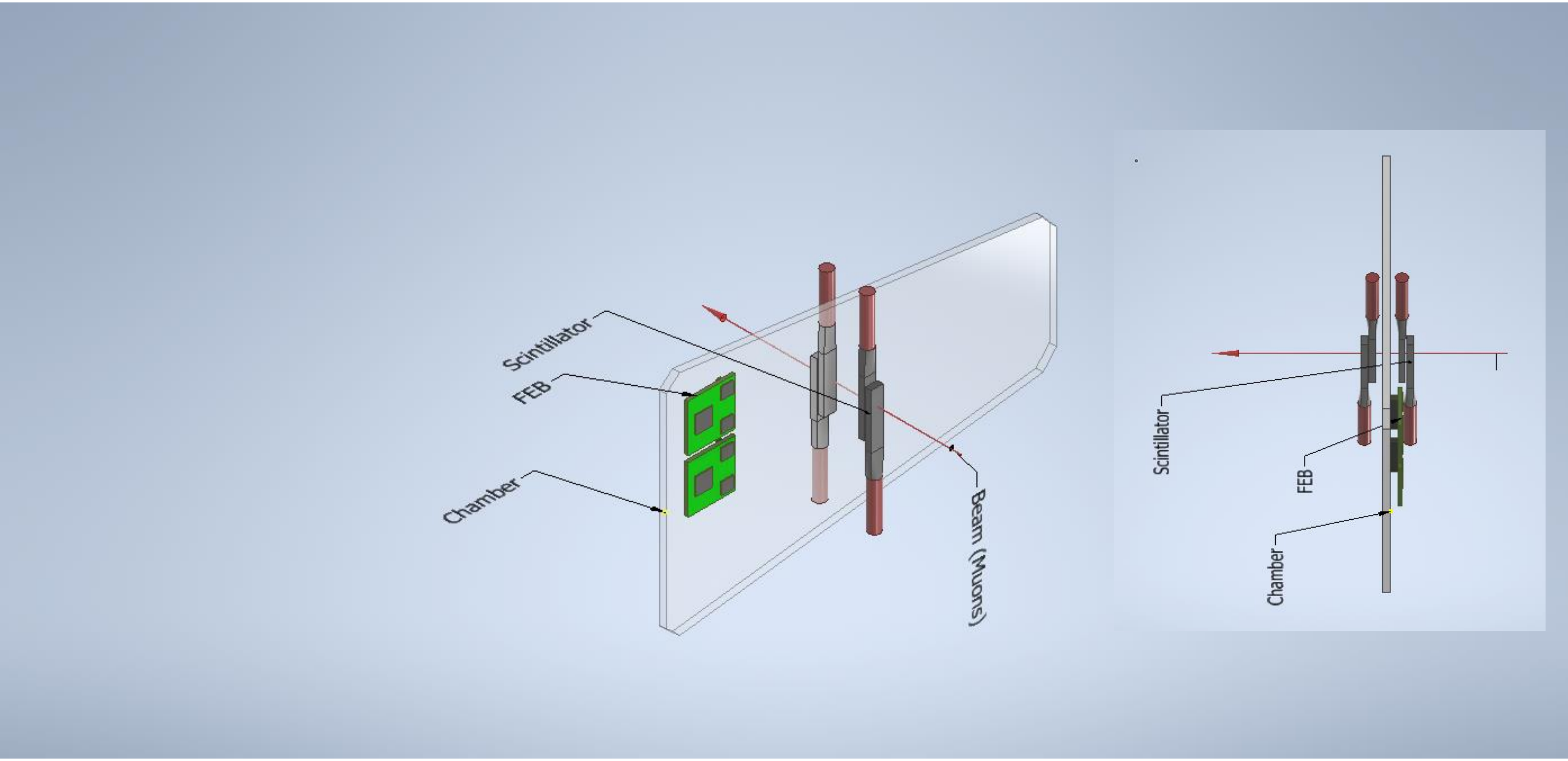
Block diagram of the time-to-digital converter implemented in a single FPGA device.

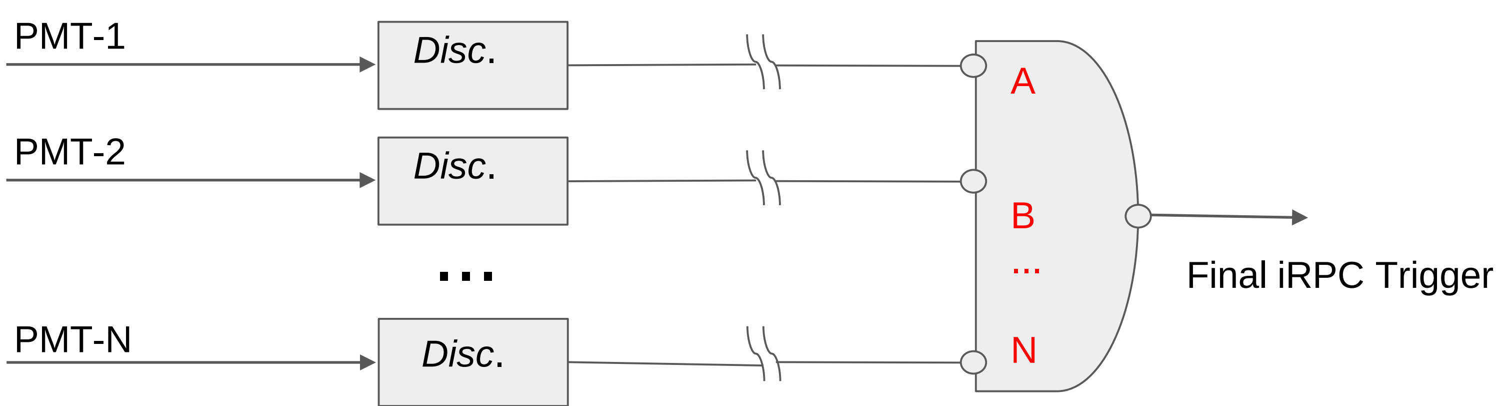
Turn On DAC vs signal from generator



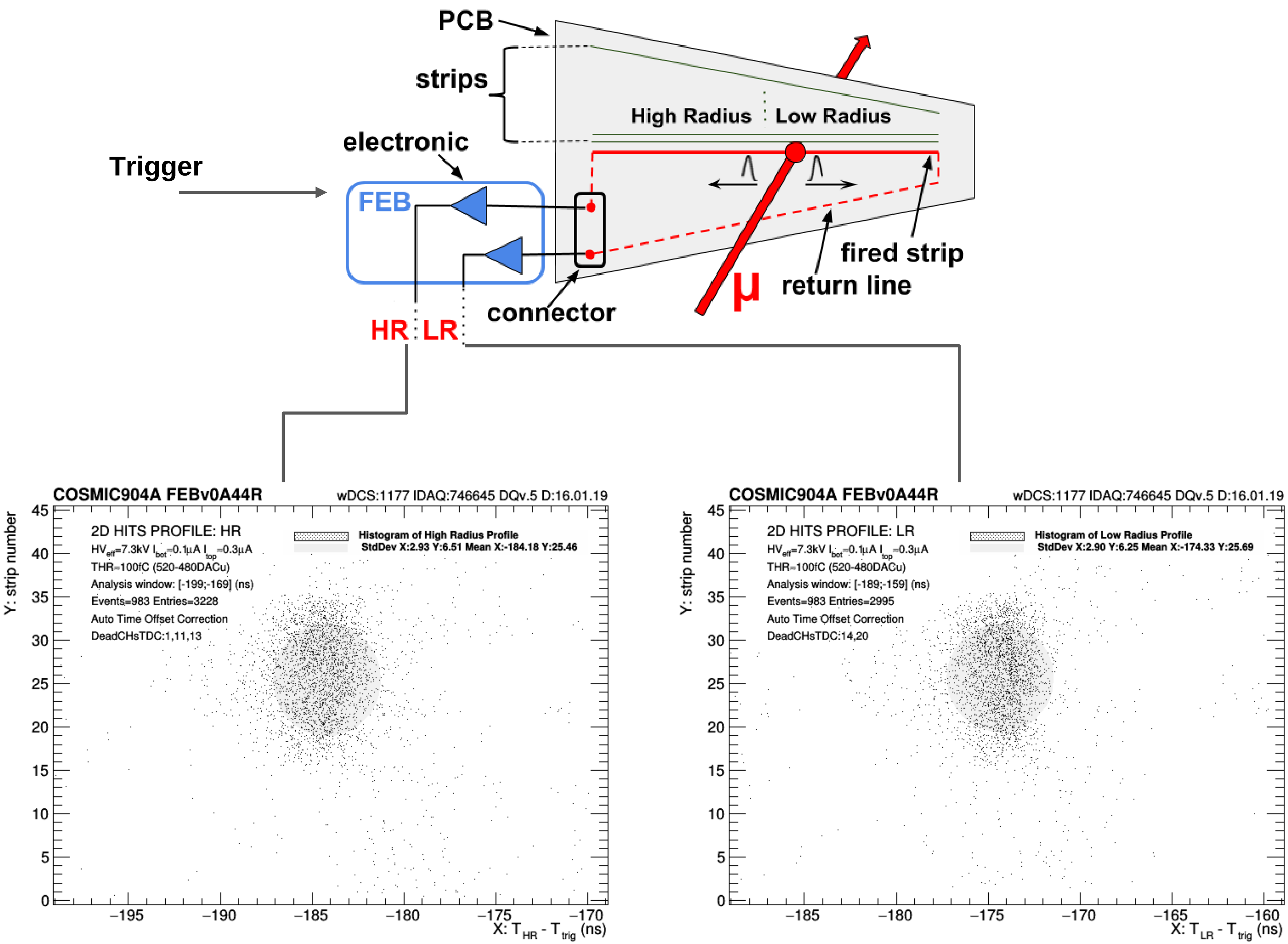


Trigger for study perfomence of chambers

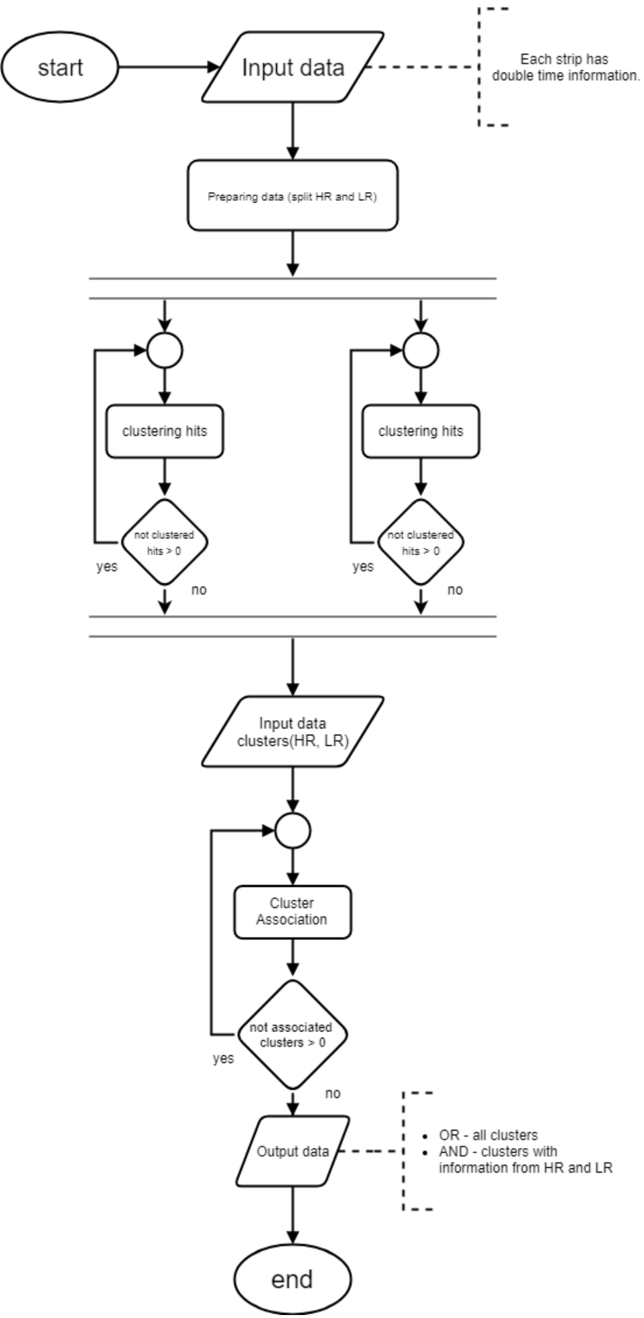


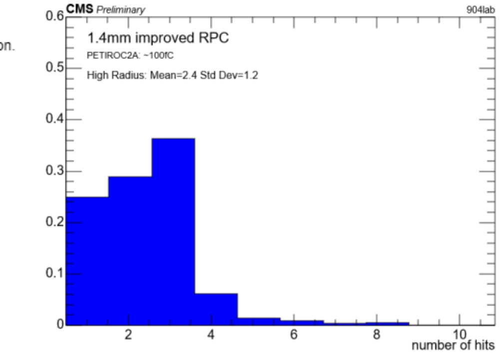


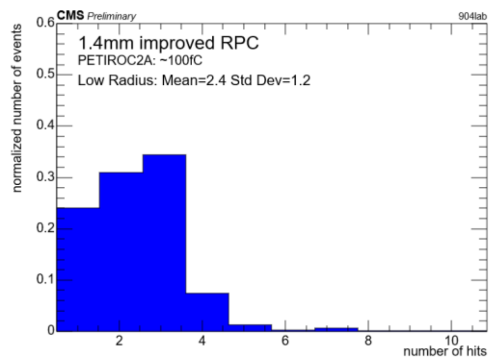
Output data from iRPC

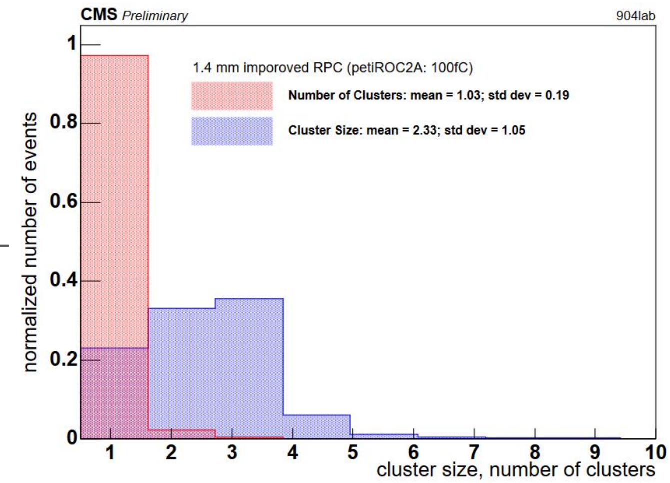


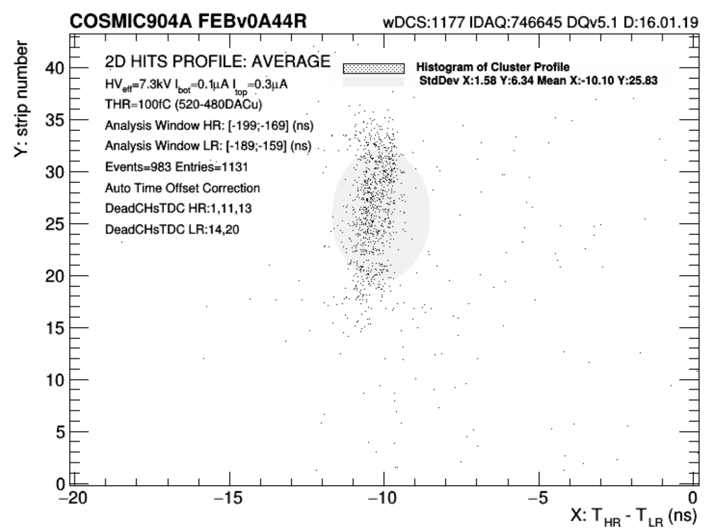
Cluster Size and Clustering Algorithm



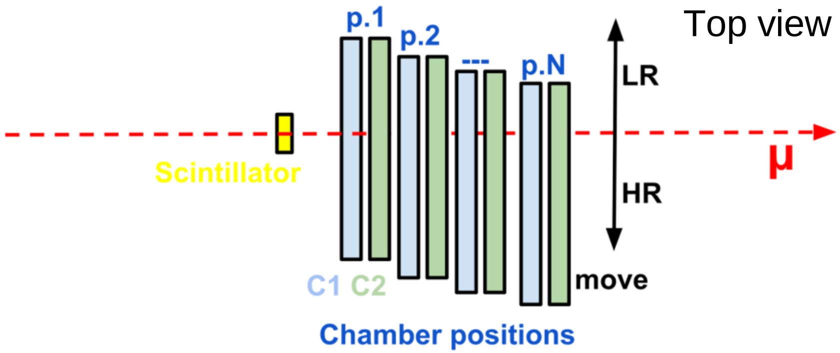




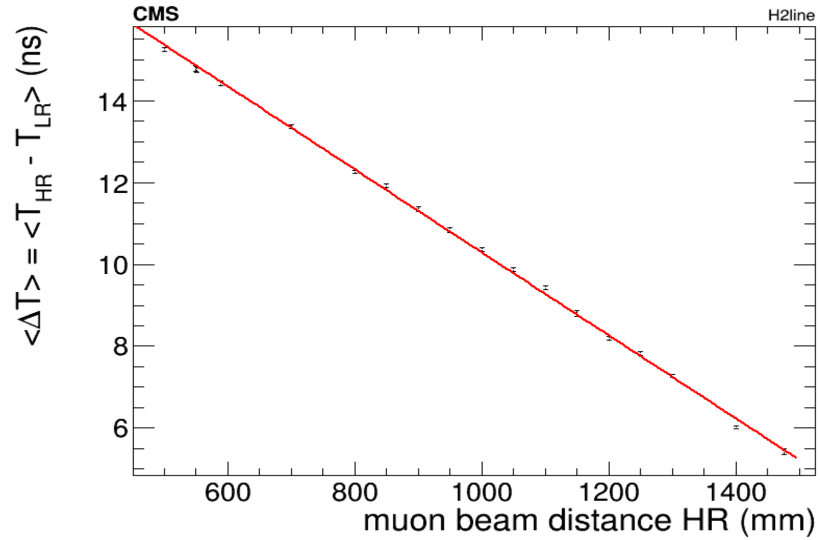




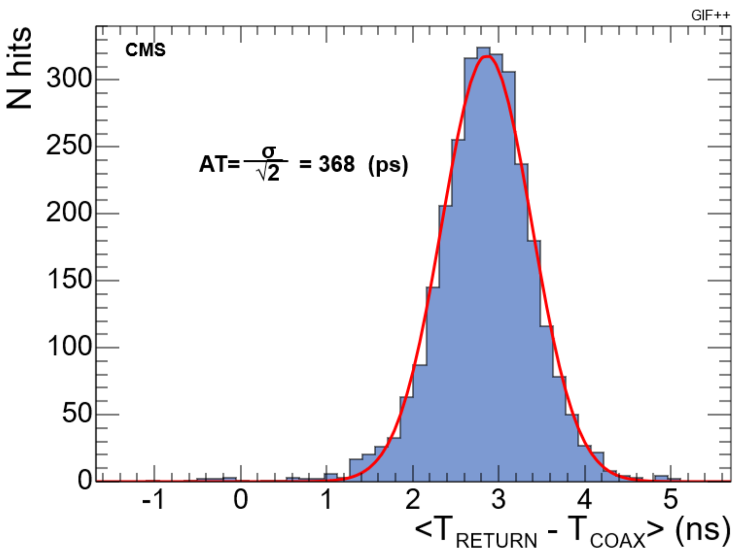
Time Resolution along the strip and absolute time resolution



Linearity along the strips



Absolute time resolution



$$\Delta t = t_1 - t_2 \rightarrow \sigma_{\Delta t} = \sigma_{t_1} - \sigma_{t_2} \rightarrow \sigma^2_{\Delta t} = \sigma^2_{t_1} + \sigma^2_{t_2} - 2 * \sigma_{t_1} * \sigma_{t_2}$$

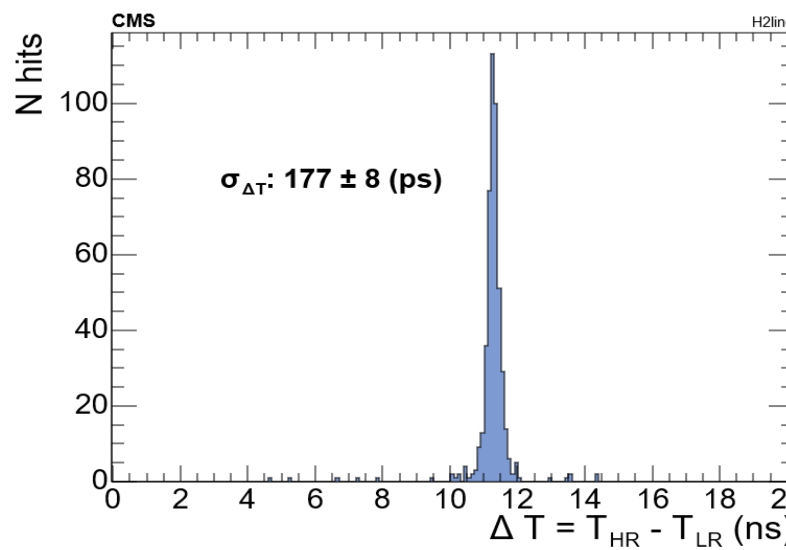
$$< \sigma^2_{\Delta t} >=< \sigma^2_{t_1} > + < \sigma^2_{t_2} > -2* < \sigma_{t_1} * \sigma_{t_2} >$$

$$< \sigma^2_{\Delta t} >=< \sigma^2_{t_1} > + < \sigma^2_{t_2} > -2 * cov(\sigma_{t_1} * \sigma_{t_2})$$

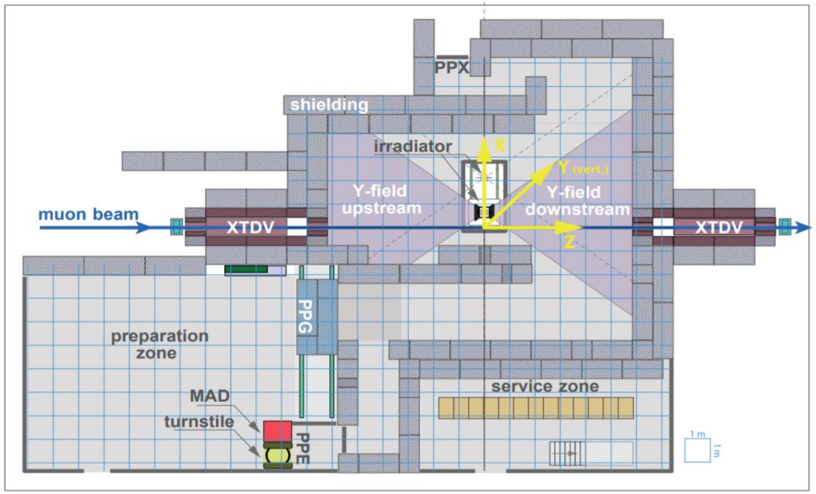
$$< \sigma^2_{\Delta t} >=< \sigma^2_{t} > + < \sigma^2_{t} > \quad if \quad detectors \quad are \quad independent$$

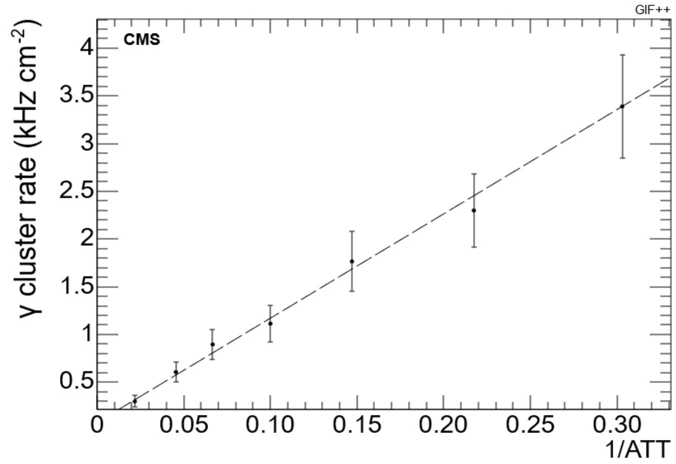
$$\frac{< \sigma_{\Delta t} >}{\sqrt{2}} =< \sigma_t >$$

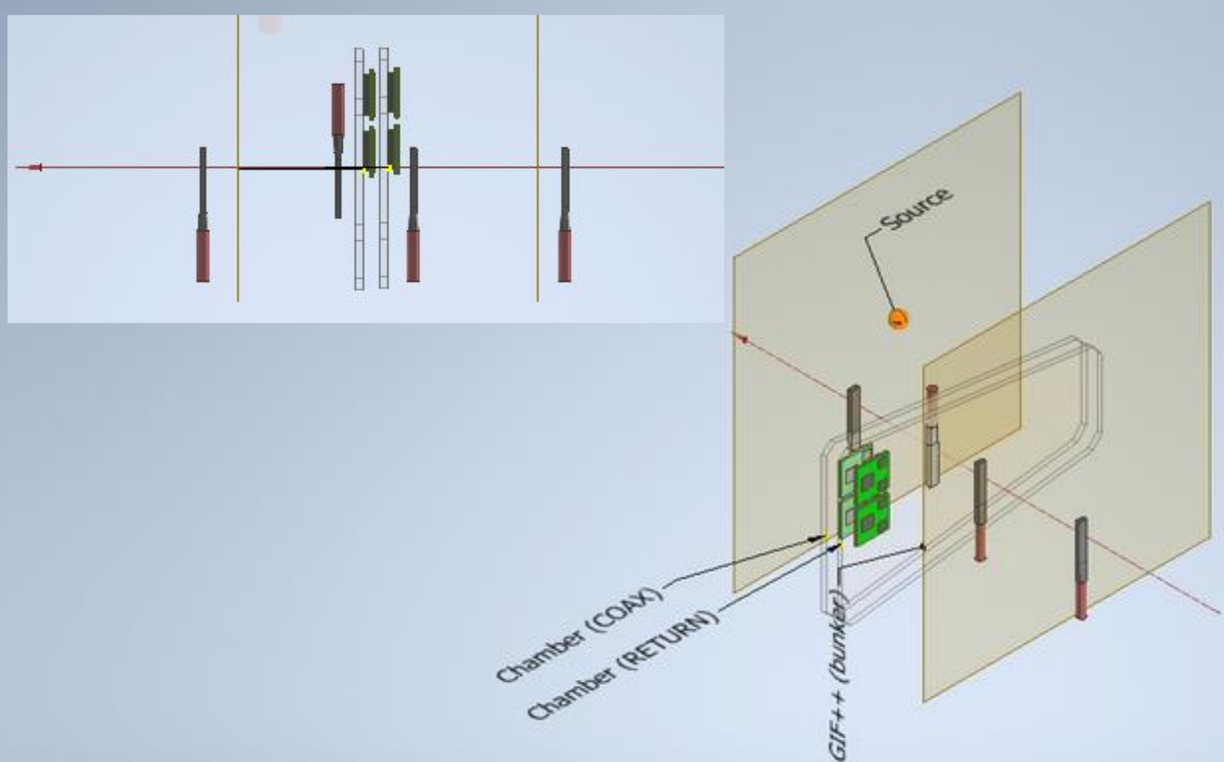
Time resolution of one strip



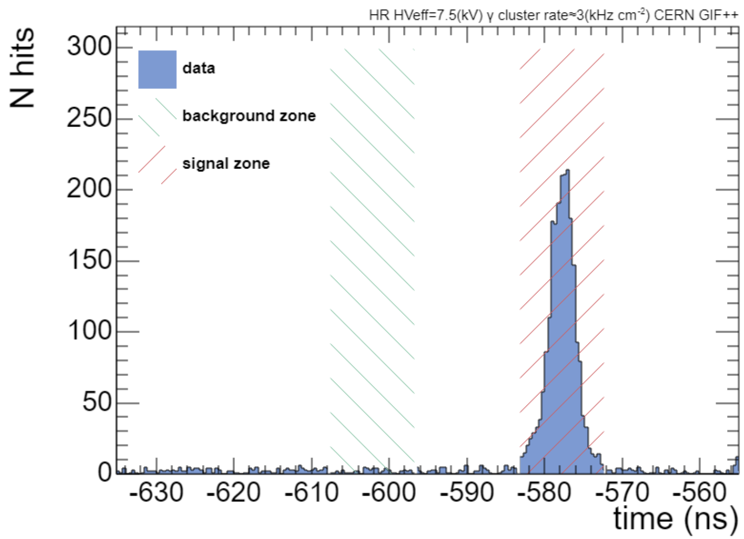
Trigger Setup in GIF++

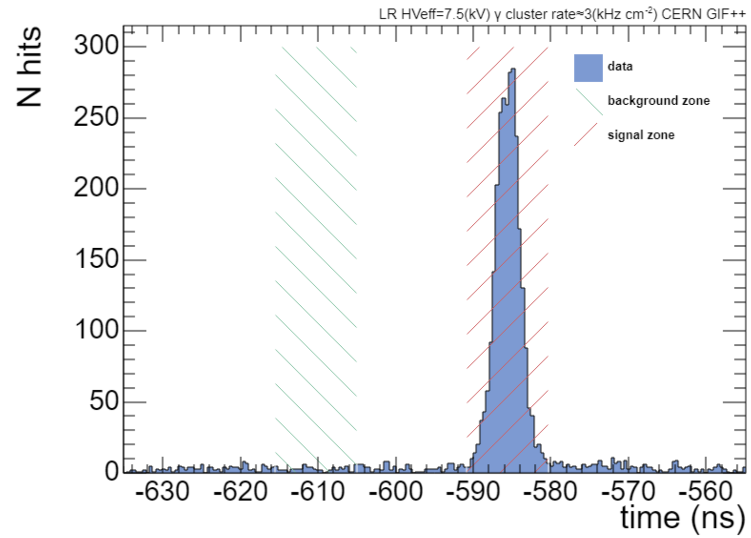


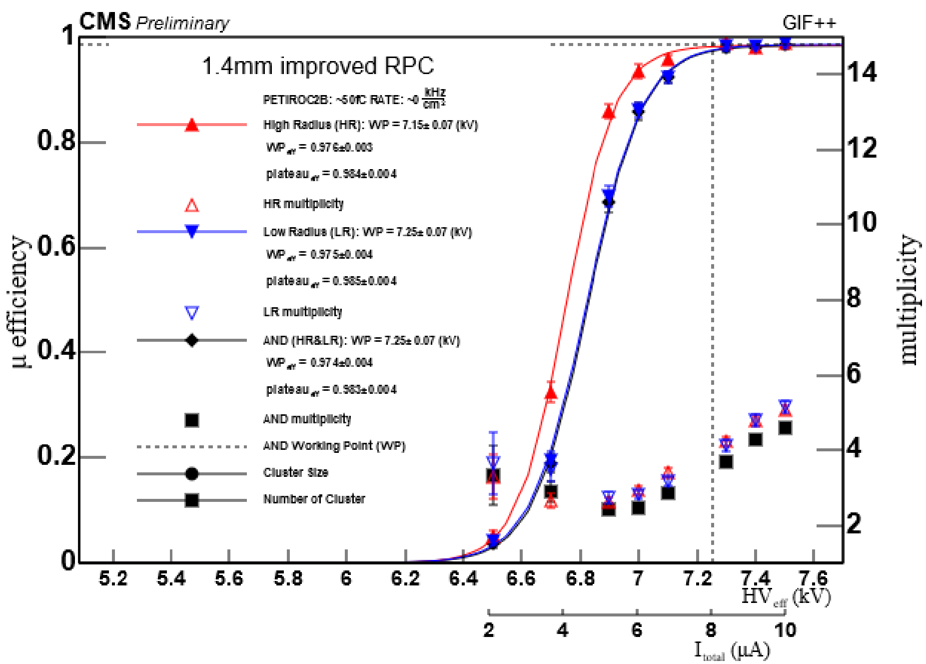




Efficiency study







EFFICIENCY

$$\varepsilon = \frac{\frac{N}{N_{trig}} - \frac{N_{bkg}}{N_{trig}}}{1 - \frac{N_{bkg}}{N_{trig}}}$$

ε: Muon Efficiency;

N_{trig}: Number of triggers;

N: Number of events for which at least a strip is fired (both ends);

N_{bkg}: Estimated by counting events for which at least a strip is fired (both ends) in a time interval of the same length but uncorrelated with the trigger.

HIGH VOLTAGE EFFECTIVE

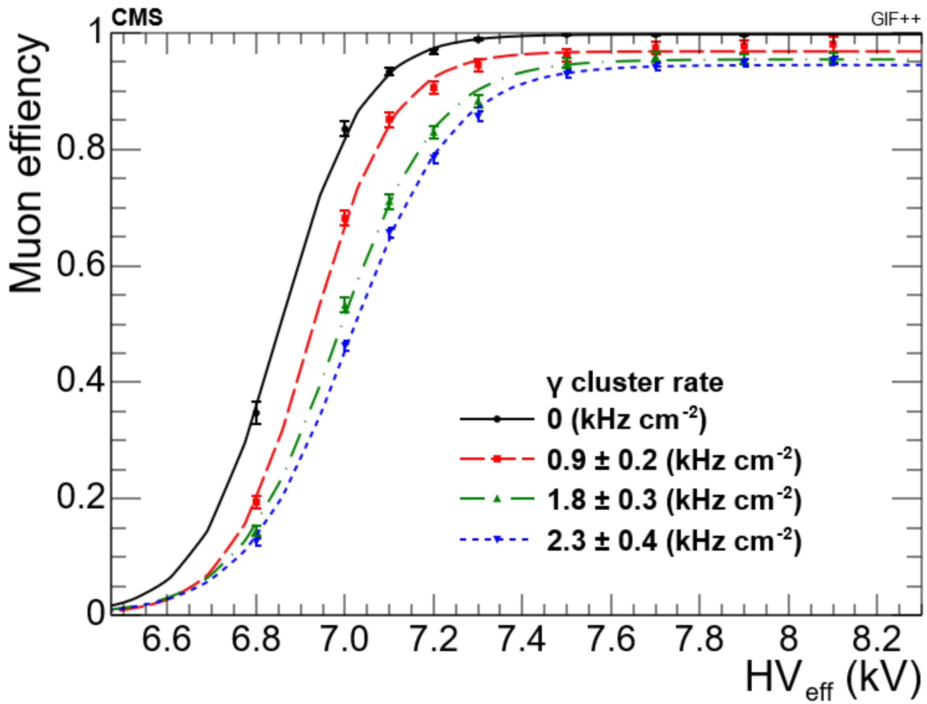
Effective HV takes into account the change in pressure and temperature with respect to an HV reference value V_0 at given pressure P_0 and temperature T_0.

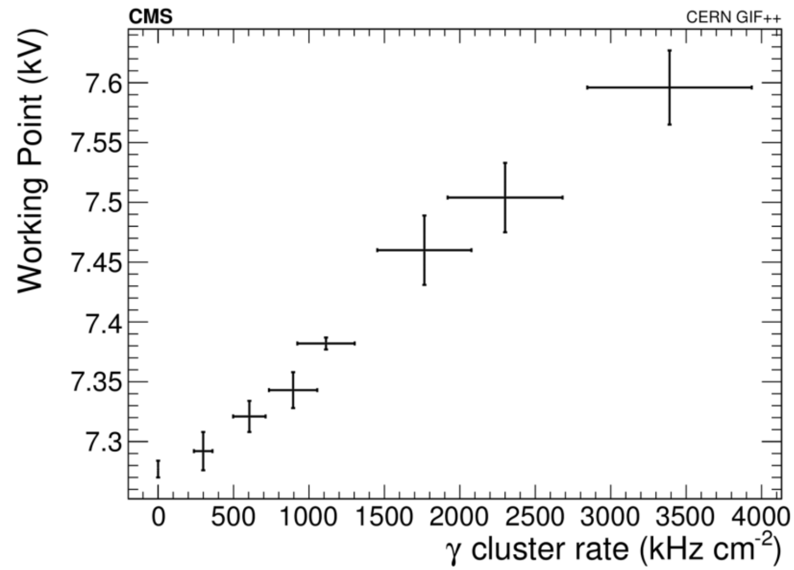
$$HV_{app} = \beta HV_{eff} = HV_{eff}\left((1-\alpha) + \alpha \frac{P}{P_0}\frac{T_0}{T}\right)$$

GIF++ Study of rate capability (FEBv0)

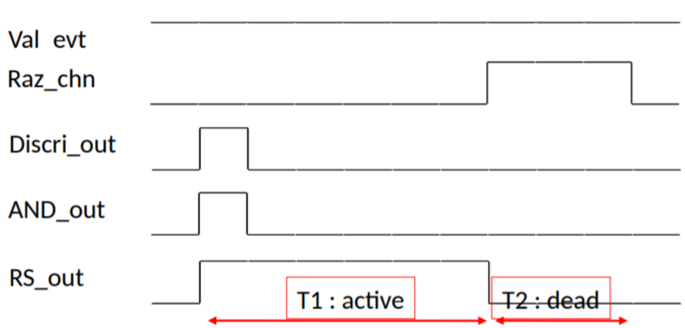
14 TBq 137Cesium is used in GIF++ with different attenuation coefficients is used to obtain different gamma irradiation levels.

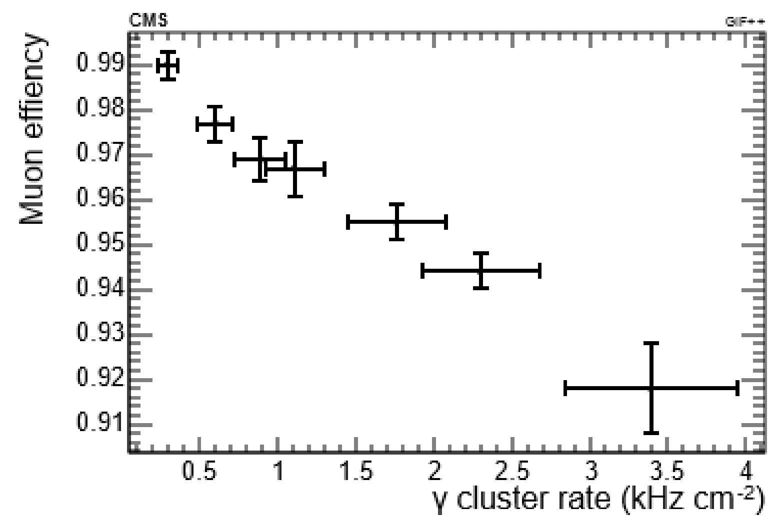
To test our chambers a rate of up to **2 kHz·cm^{-2}** needs to be **seen** in our chamber.





Dead Time of FEBs





Prototypes of FEBs for iRPC

FEBv0 tested in **2018** (Cosmic, GIF++, H2line)

A board that contains:

- ➢ **1 PETIROC2A ASIC + FPGA CYCLONE 2**
- ➢ Ethernet-based communication was conceived to read out the strips **FR4** PCBv.0 (**44** strips)

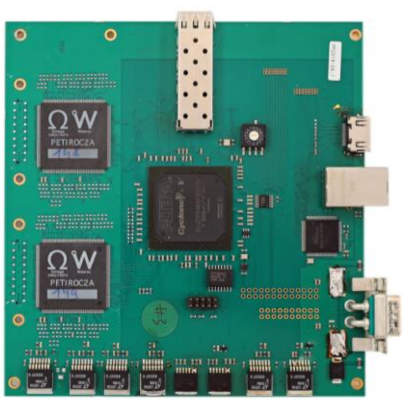
THR=~80fC with **DeadTime=10ns**

Efficiency at **~2kHz cm^{-2}** of background **95%**

Resolution: Along strip **~180ps**;

Absolute **~370ps**

FEBv1 is testing from spring **2019** (Cosmic, GIF++)



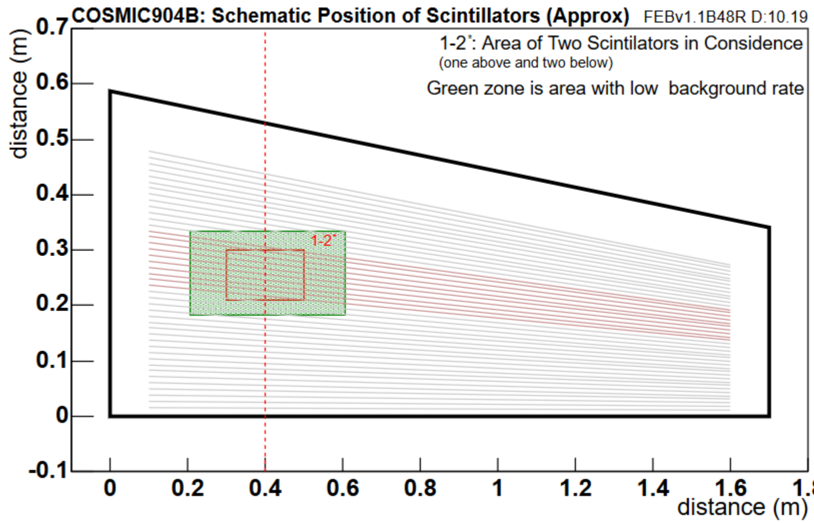
This was intended to come closer to the final board to be compatible with CMS DAQ:

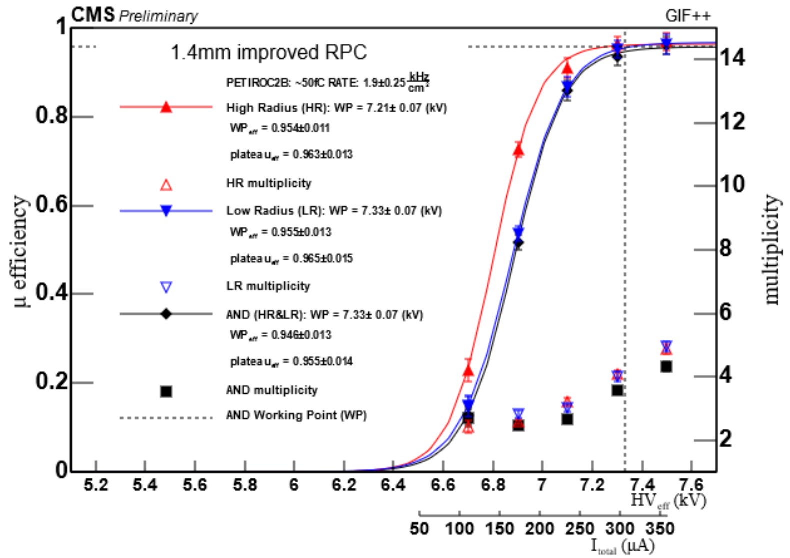
- ➢ **2 petiroc2A(B) + FPGA CYCLONE V**
- ➢ Ethernet-based communication is used to read out the strips **FR4** PCBv.1 (**48** strips)

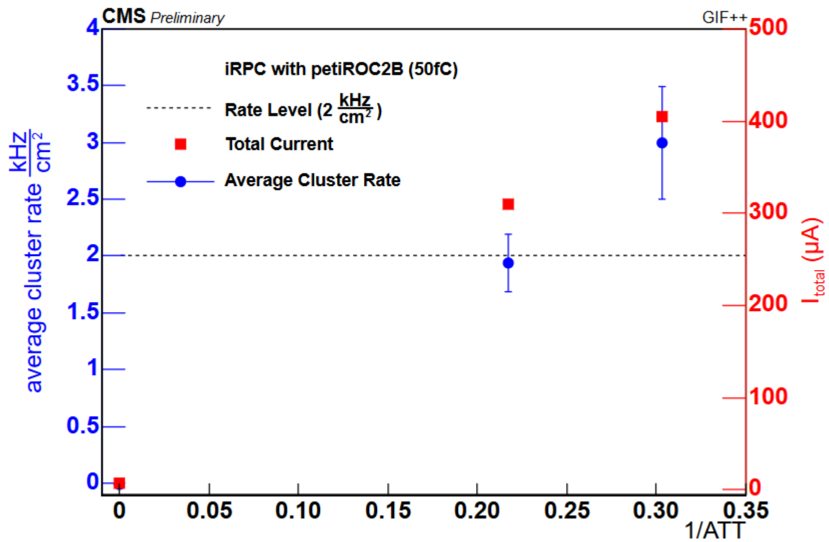
THR=**~50fC** with DeadTime=**10ns**

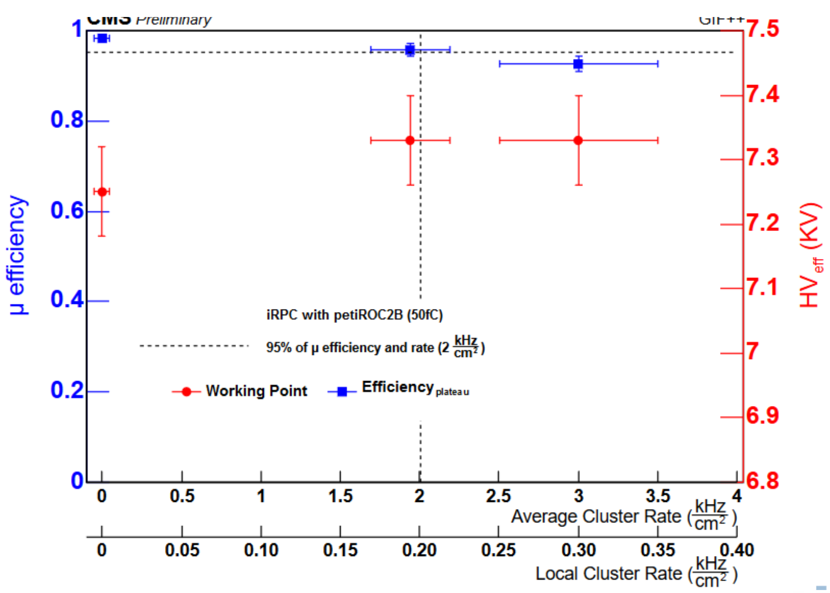
Summary of test for only FEBv1.1 in GIF++

This study can only be considered in terms of the behavior of electronics because level of **background rate on study area ~10 time smaller than average value of rate**.









Summary

- A method was proposed for measuring the efficiency of the detector when using signals from two ends of the strip.
- A new clustering algorithm using time information was proposed and successfully tested.
- The linearity of the TOA time measurements and the time resolution of the TOA are verified on CERN SPS-H2 beamline tests. Along strip resolution ~180ps.
- Calculated absolute time resolution ~370ps for a 2-gap chamber.
- Measurements of the detector characteristics equipped with FEBv0 were carried out at the required rate of $2kHz*cm^{-2}$ of the background. The efficiency of more than 95% was obtained. Also, we showed that FEBv1 (only FEBs performance study) has the same characteristics as FEBv0.

Thank for Your Attention!

Any questions:

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Reference

1. CMS Collaboration, The Phase-2 Upgrade of the CMS Muon Detectors, 145 Tech. Rep. CERN-LHCC-2017-012. CMS-TDR-016, CERN, 2017.
2. K. S. Lee, et al. Study of Thin Double-Gap RPCs for the CMS Muon 147 System. Journal of the Korean Physical Society 73 1080 (2018).
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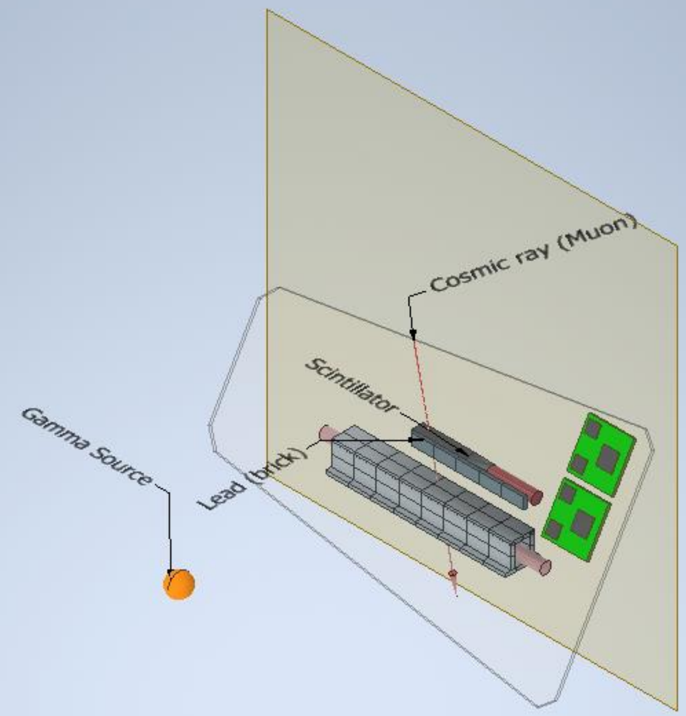
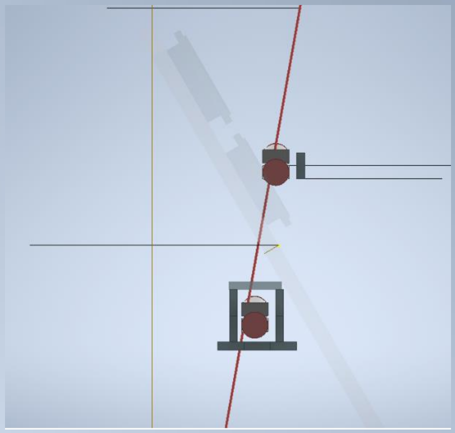
5. J. Song, Q. An and S.-B. Liu, A high-resolution time-to-digital converter implemented in field-programmable-gate-arrays, IEEE Trans. Nucl. Sci. 53 (2006) 236.
6. Lagarde, F, et al. High rate, fast timing Glass RPC for the high η CMS muon detectors. JINST 11 (2016).

Additional material


Cosmic ray (Muon)
Scintillator
Gamma Source
Lead (brick)



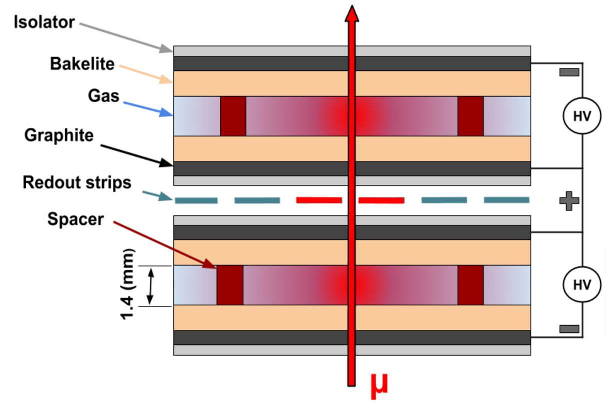
Resistive plate chambers (RPC) are fast gaseous detectors that provide a muon trigger system

Two parallel plates:

positively-charged anode

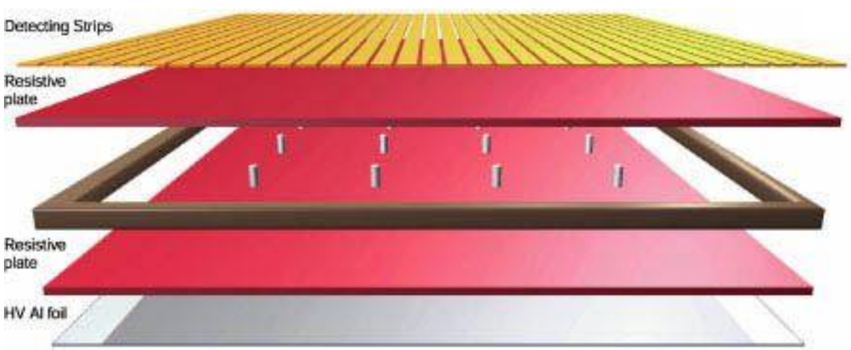
negatively-charged cathode

both made of a very high resistivity and separated by a gas volume.



	iRPC	RPC
High Pressure Laminate thickness	1.4 mm	2 mm
Num. of Gas Gap	2	2
Gas Gap width	1.4 mm	2 mm
Resistivity (Ωcm)	0.9 - 3 x 10^{10}	1 - 6 x 10^{10}
Charge threshold	50 fC	150 fC
η segmentation	2D readout	3 η partitions

The thinner gap in the double gap RPC detector & comparison between iRPC and RPC



Gas mix: 95.2% C2H2F4, 4.5% i-C4H10, and 0.3% SF6

For applications where high background rates are expected, chambers have to be operated in avalanche mode in order to keep the total produced charge low with benefits in terms of aging and rate capability. This is usually obtained with suitable gas mixtures that prevents the transition from avalanche to streamer modes keeping the detection efficiency.

1.4mm GAPs

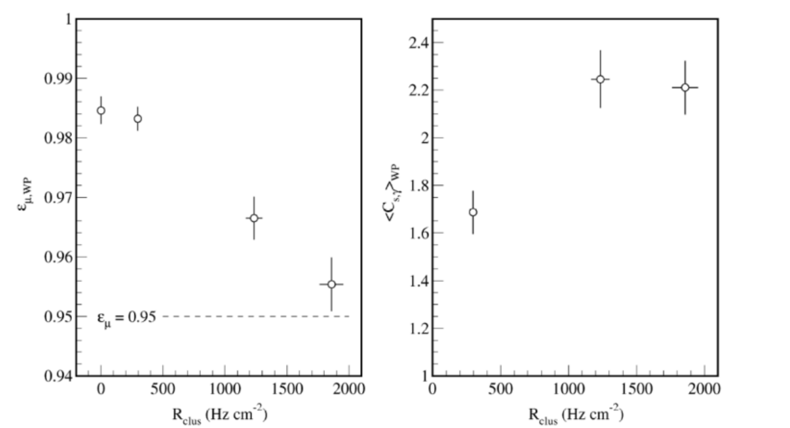
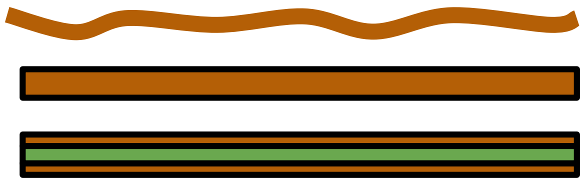


Figure 1.18: Efficiency (left) and average cluster size (right) at the working voltage, as a function of the cluster rate for the 1.4 mm double-gap RPC. The data were measured at the fixed threshold of 300 μV.

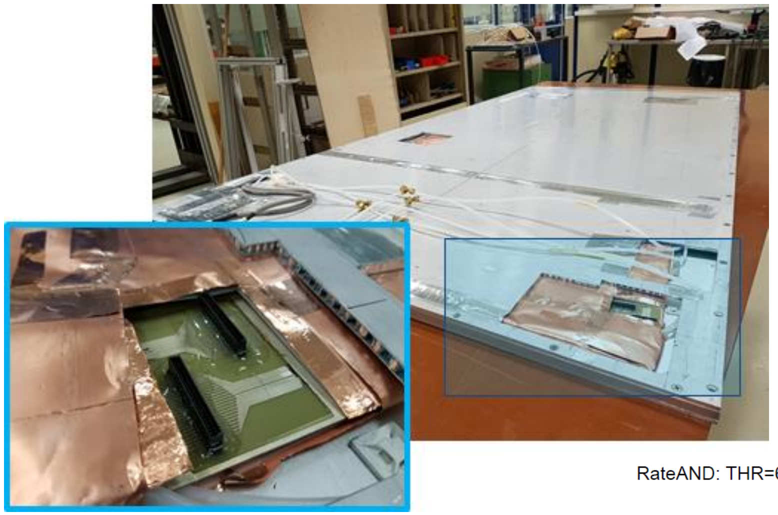
Three solution possible solutions

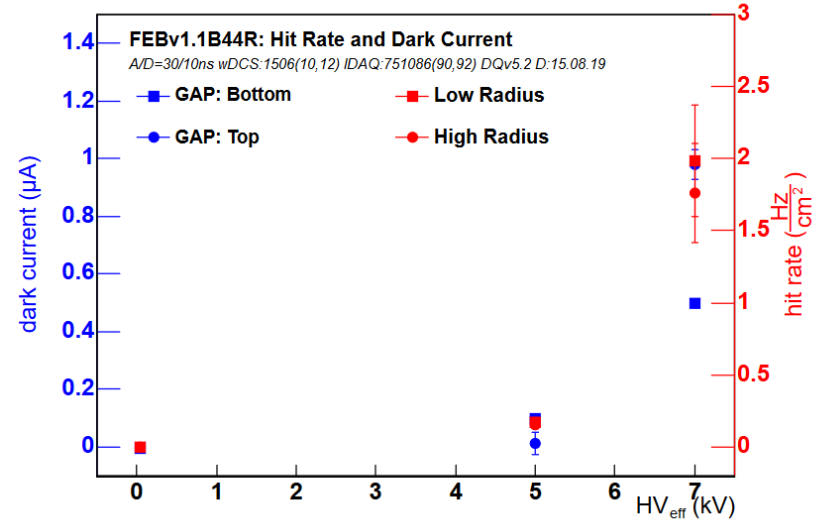


Foil

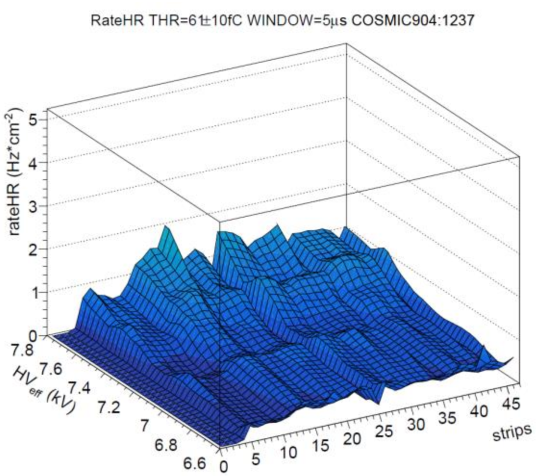
Plate

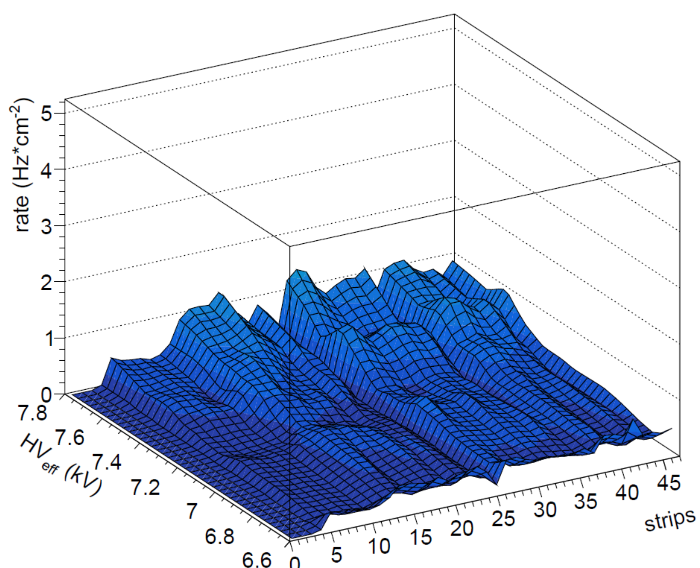
PCB

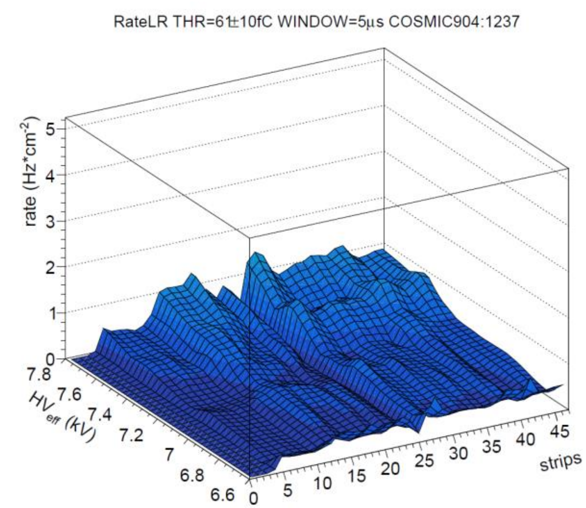




RateAND: THR=61±10fC WINDOW=5μs COSMIC904:1237







EFFICIENCY

$$\varepsilon = \frac{\frac{N}{N_{trig}} - \frac{N_{bkg}}{N_{trig}}}{1 - \frac{N_{bkg}}{N_{trig}}}$$

ε: Muon Efficiency;
N_{trig}: Number of triggers;
N: Number of events for which at least a strip is fired (both ends);
N_{bkg}: Estimated by counting events for which at least a strip is fired (both ends) in a time interval of the same length but uncorrelated with the trigger.

P = P_mu + P_bkg - P_mu . P_bkg (this is the probability formula when you have sets that are not independent or disjoint) where P = N/Ntrig, P_mu is the efficiency and P_bkg = N_bkg/Ntrig with N_bkg is estimated using a time interval with the same length but placed at a time uncorrelated with the muon trigger.

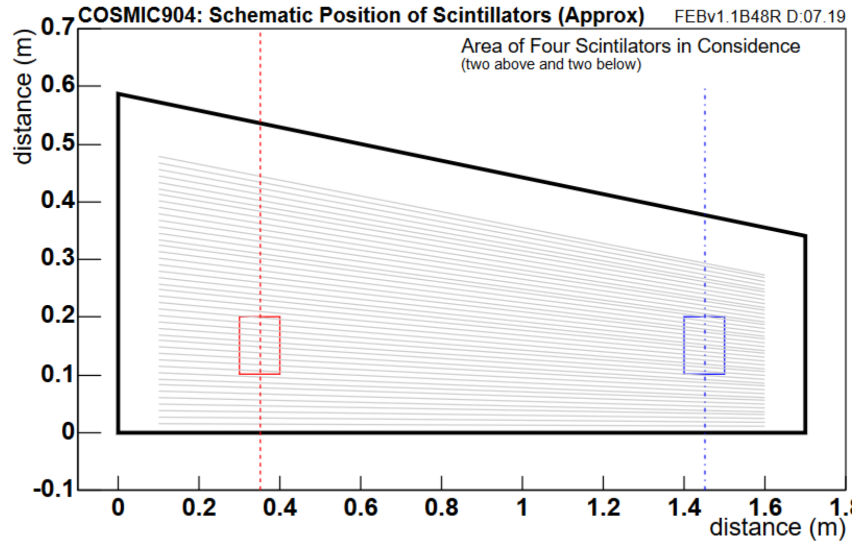
From above the exact formula is then: P_mu = (P-P_bkg)/(1-P_bkg)

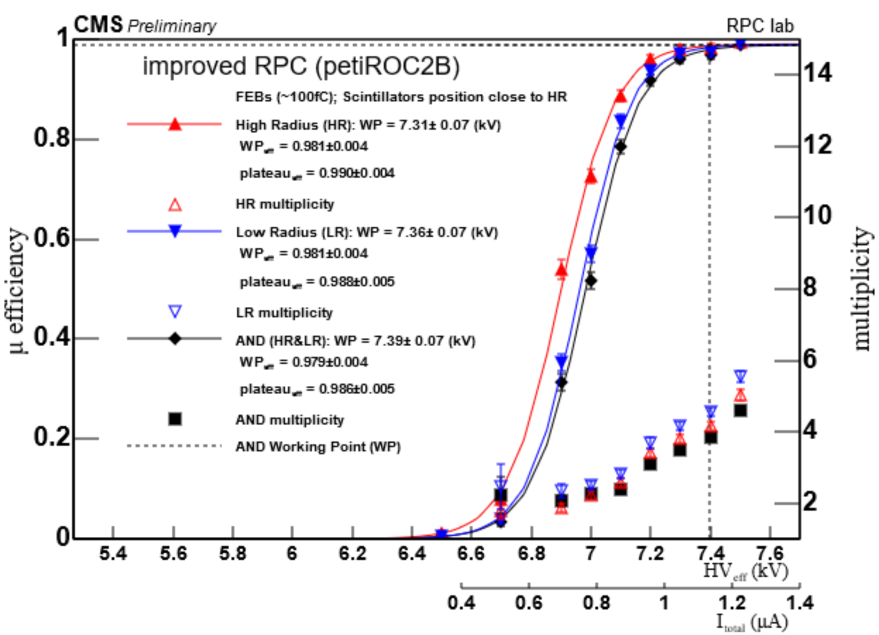
Study of FEBv1.1A48R with cosmic ray for two position along the chamber

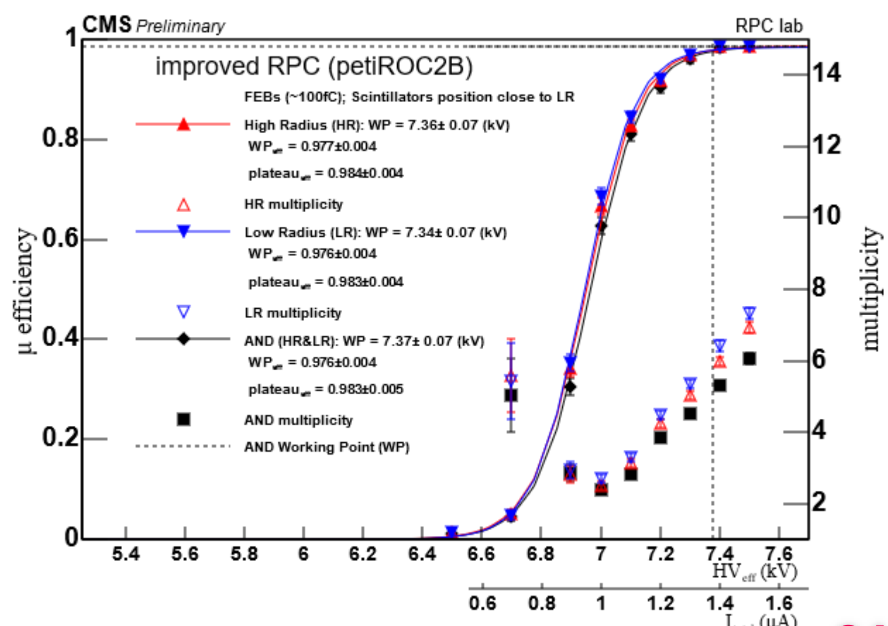
Description

In the beginning, we had a problem with firmware for new FEBs that allows us to work about 100fC threshold. For this configuration, we did a study of efficiency for two different positions. The results of this study are the loss of signal from propagation that could be shown with the degradation of efficiency for LR.

In this case, we decided to keep a worse position for all the next steps.



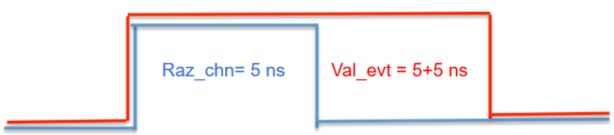




PETIROC2B

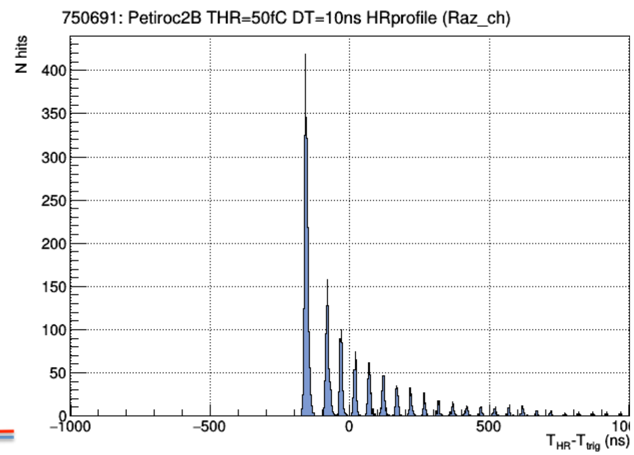
A new version of PETIROC was conceived and produced with the aim to reduce the threshold while keeping a good timing.

Retriggering problems are solved by using a combination of **Raz_ch** and **Val_ev** signals at **lvl 50fC**.

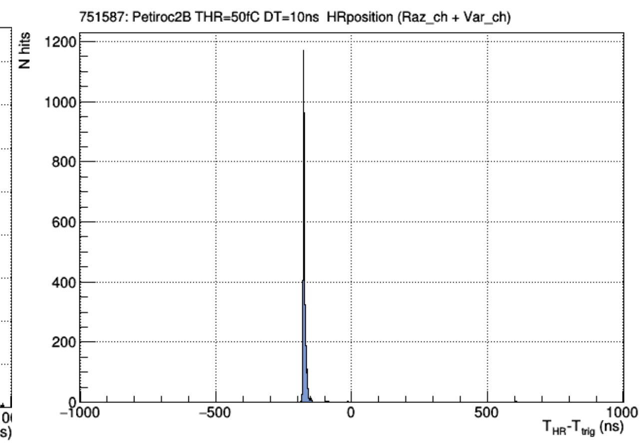


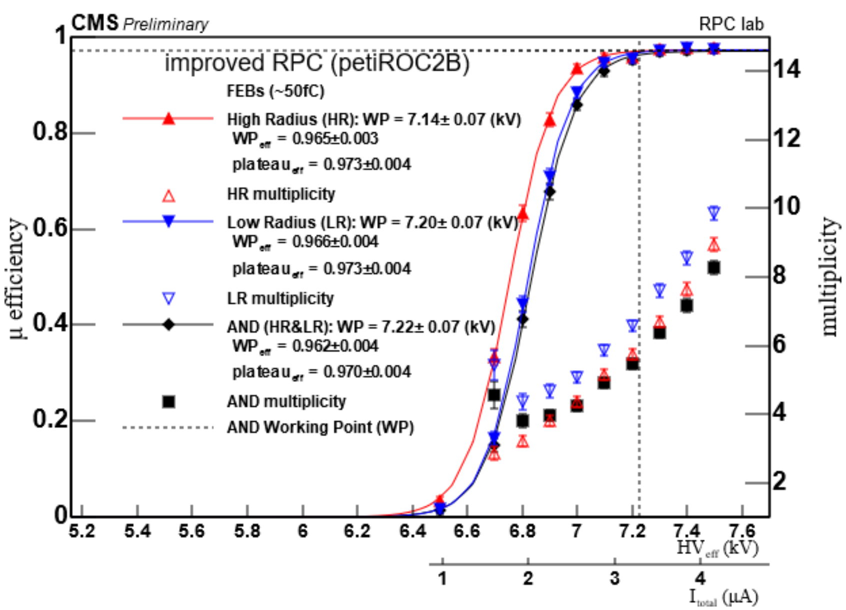
Examples of Re-triggering

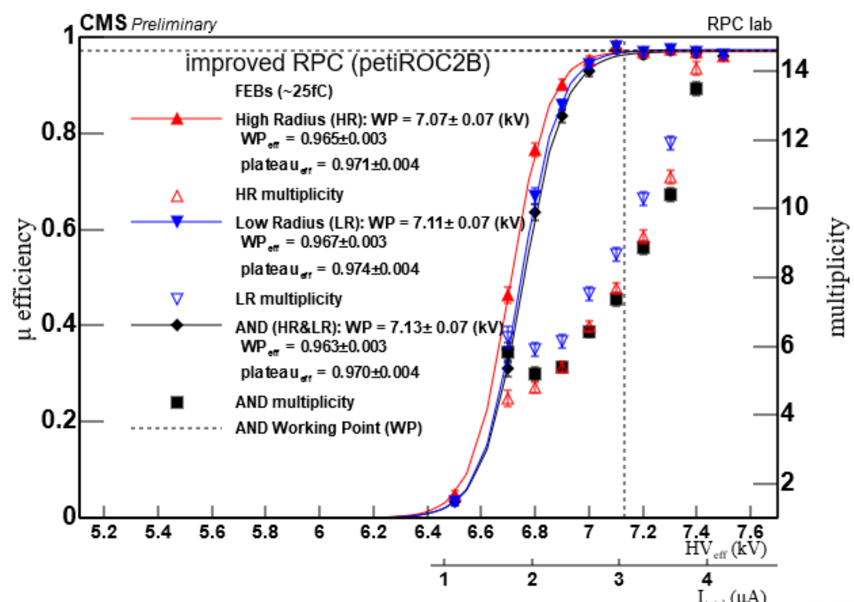
THR=50fC DT=10ns Raz_ch



THR=50fC DT=10ns (Raz_ch+Val_ch)







Rate defenition

$$hitRate = \frac{numberOfHits}{surface * time}, where$$

$numberOfHits - number\ of\ triggered\ channels\ of\ FEBs\ of\ one\ run;$

$sufrace - active\ PCB\ zone;$

$time - collection\ time: \ (timeWindow * numberOfEvents).$

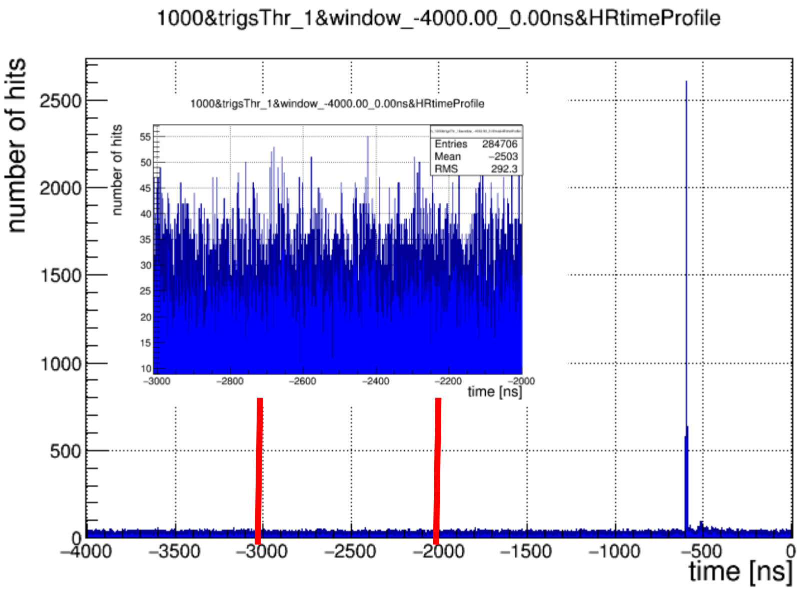
$$RATE_{HVeff} = \frac{ClusterRate}{efficiency_{HVeff}}$$

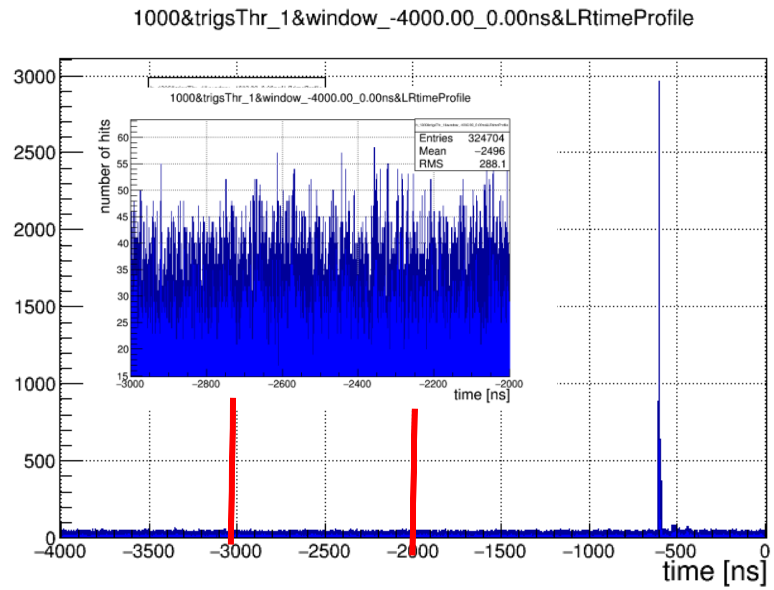
$$cluster\ Rate = \frac{numberOfClusters}{surface * time}, where$$

$numberOfClusters - number\ of\ clusters\ of\ one\ run;$

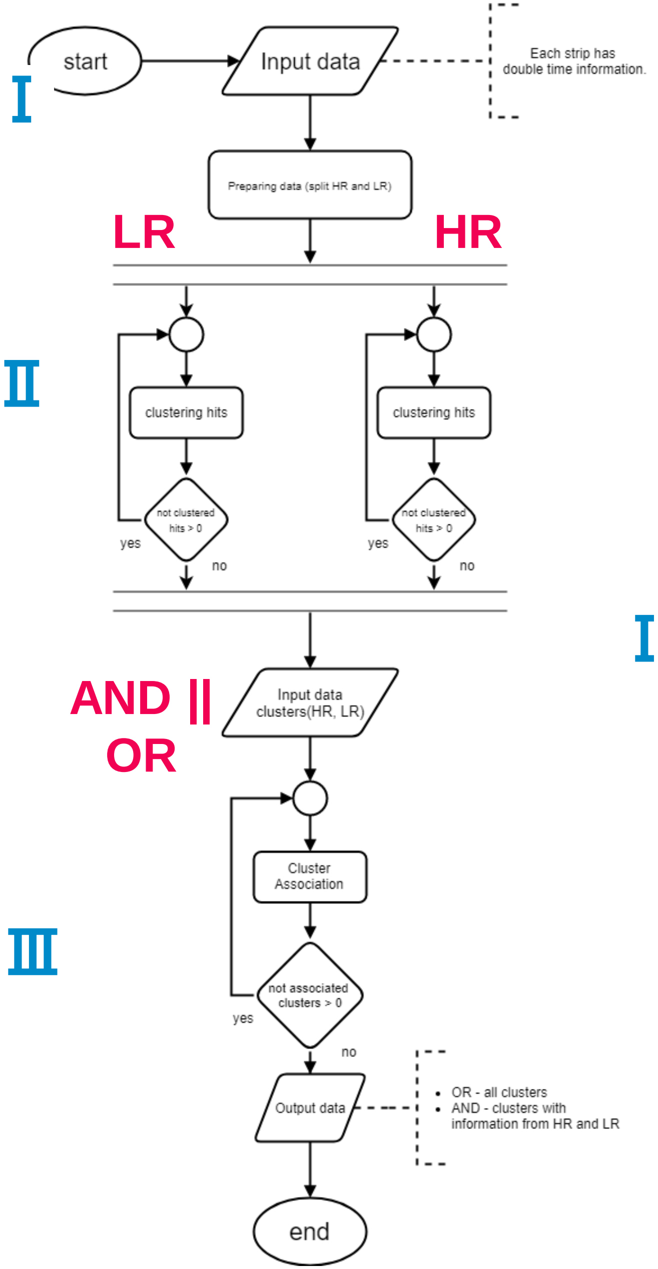
$sufrace - active\ PCB\ zone;$

$time - collection\ time: \ (timeWindow * numberOfEvents).$



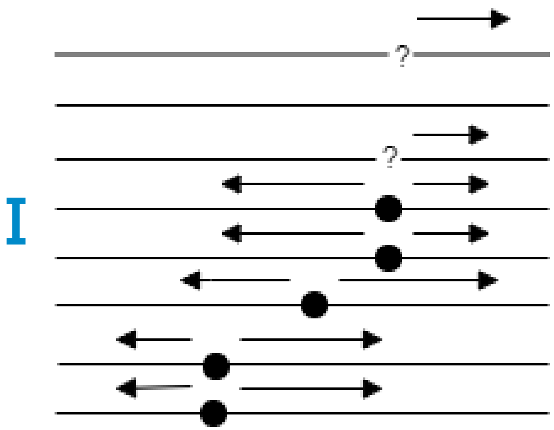


Cluster Algorithm

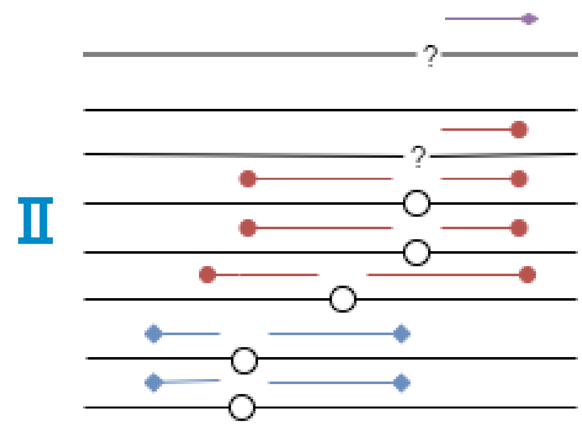


Strip (strip Number, HR-time, LR-time)

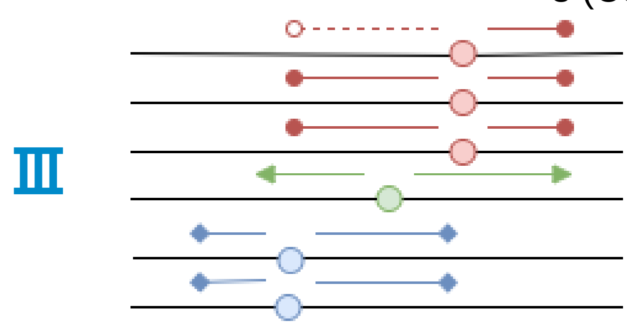
- Build clusters for **HR**:
  - **Space** - Nearby Strips ; **TIme**: Theshould
- Build Clusters for **LR**:
  - **Space** - Nearby Strips; **TIme**: Theshould
- Bulid **AND** clusters:
  - Associate clusters HR and LR with a minimum dtime;
  - Split cluster (HR, LR) if delta between signle strips more than time cut for AND.



5 hits LR; and 7 hits HR

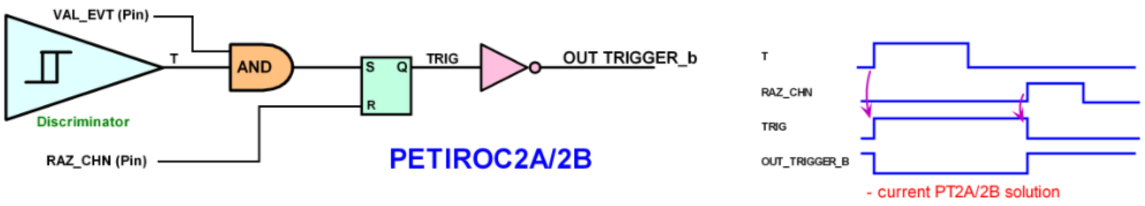


2 (CS:3,2) clusters LR;
3 (CS:1,4,2) clusters HR



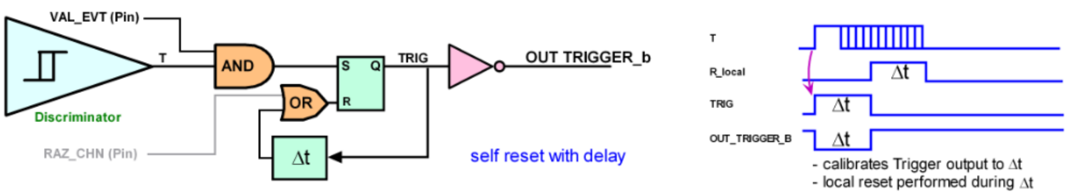
AND: 3 (CS:3,1,2)
OR: 4 (CS, 1*,3,1,2)
* - without y position

PETIROC2 :
Trigger logic



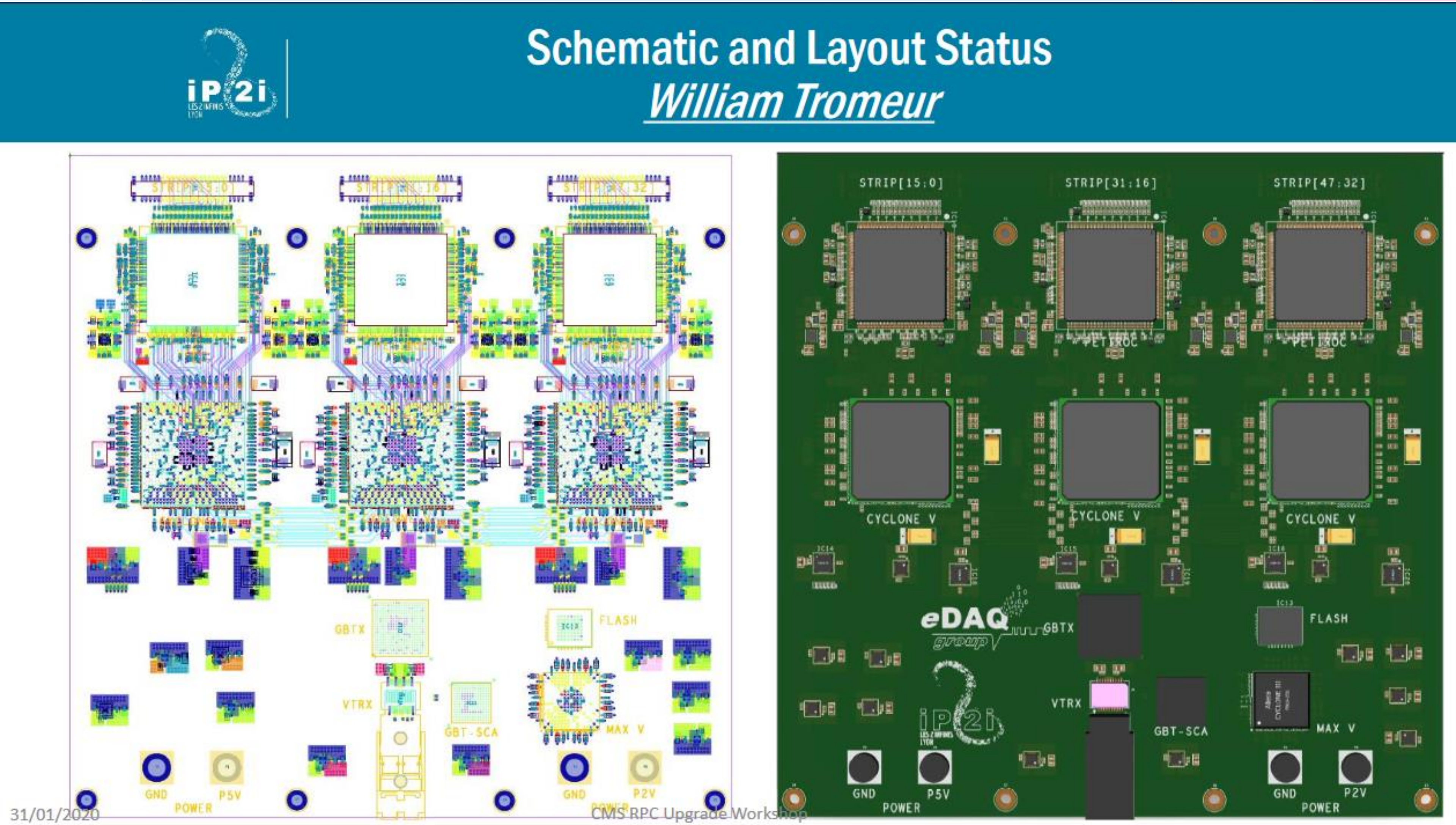
- Trigger is latched in RS cell
- Reset of this latch is common to all channels and create retriggering

PETIROC2C :
Trigger logic

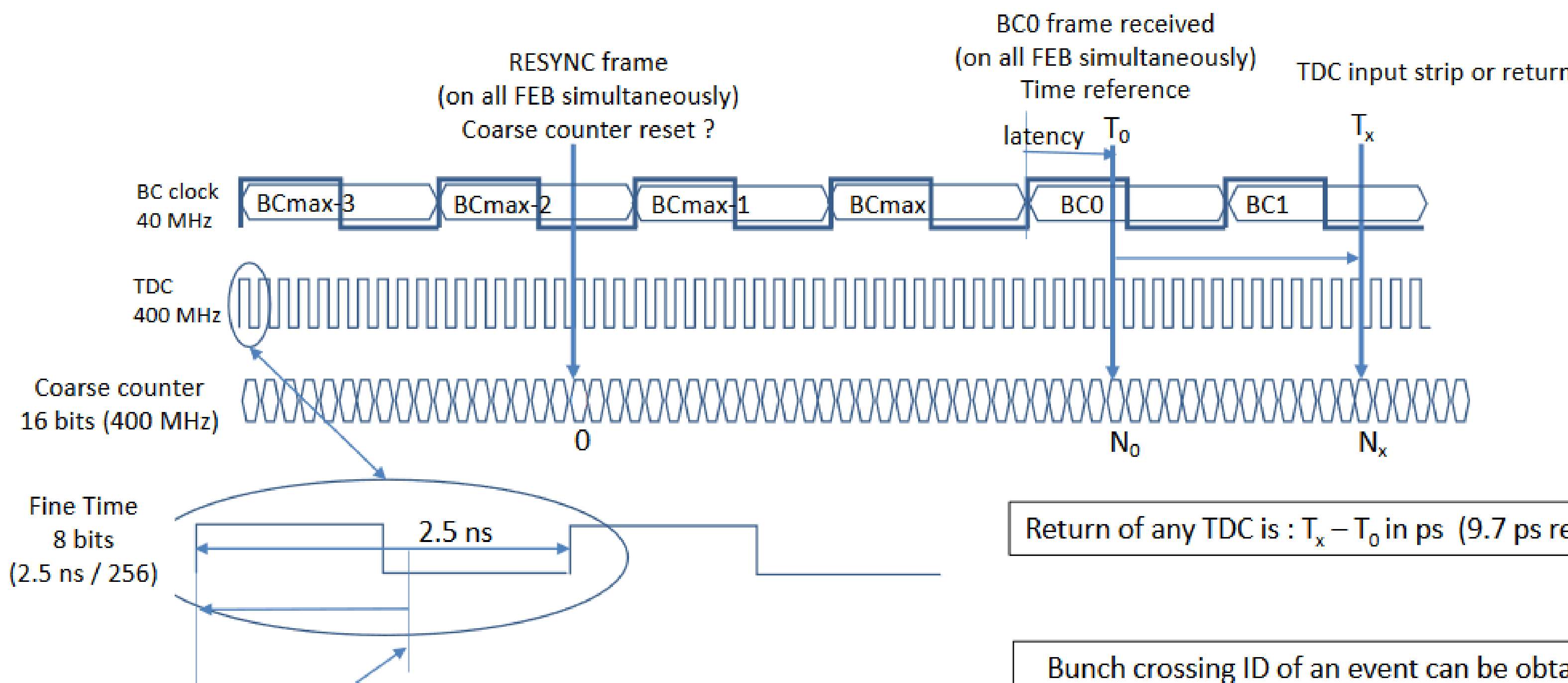


- Reset of this latch is individual
  - This local reset might solve the issue as only 1 ch has its logic toggling
  - Width of the pulse is now constant and provided by Δt

Schamatic of Finnal FEB



TDC measurements principle

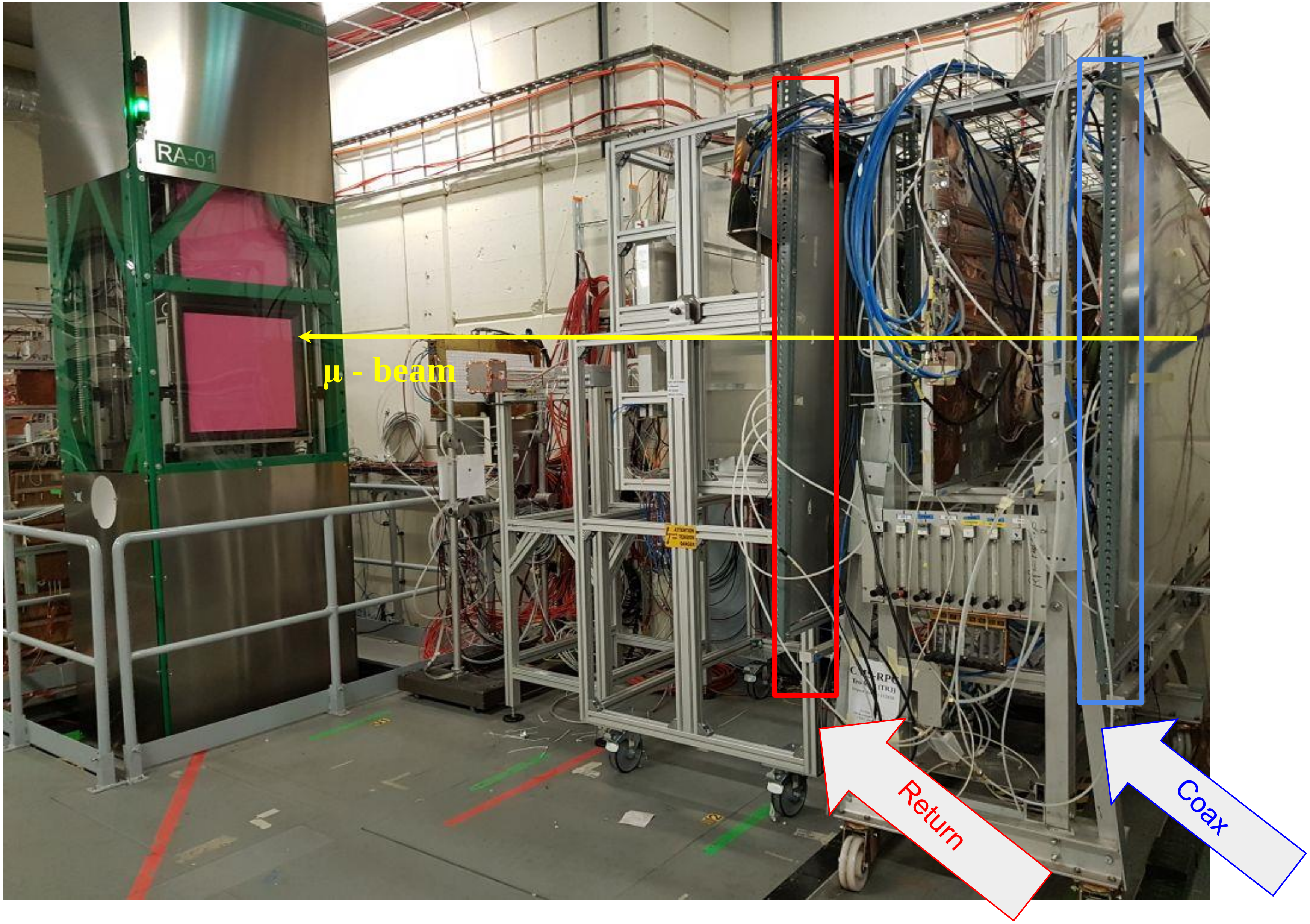


Return of any TDC is : $T_x - T_0$ in ps (9.7 ps res)

TDC Time = Coarse counter (16b) *2.5 ns + Fine Time(8b) * 2.5 ns /256
TDC Time = [CoarseCounter & Fine Time] (24b) * 2500 ps /256 (in ps)
Res : 2.5 ns / 256 = 9.7 ps

Bunch crossing ID of an event can be obtained by
TDC value (ps) / 25000 ps

GIF++ Setup for efficiency tests (Photo)



H2line Setup for time resolution tests (Photo)

GIF++ Setup for efficiency tests (2020 Photo)