2D fast timing readout system and hits clustering approach for new generation of RPC

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JRJC'2019

Outline

Motivation and Goals

- **Motivation and Goals of Research & Development**
  - CERN CMS upgrade project
  - Scheme of Resistive Plate Chambe

Protypype of RPC

- **Improve RPC (iRPC): RETURN and COAX prototypes**
  - Printed Circuit Board (strips)
  - RETURN and COAX prototypes
  - Front-End Board with Petiroc 2A(B)
- **Electronic PETIROC2A(B): Pedestal, Injection, Noise**
  - Pedestal alignment
  - Calibration with injection signal form generator
- **Description of the stand for tests of the prototype**
  - Scintilators setup
  - Raw data profiles

Test of RPC

- **H2 line: Study of time resolution**
  - Stand Description, Results
- **GIF++: Study of rate capability**
  - Stand Description, Results

CMS Upgrade Project & Rate Capability

High η CMS RPC upgrade project

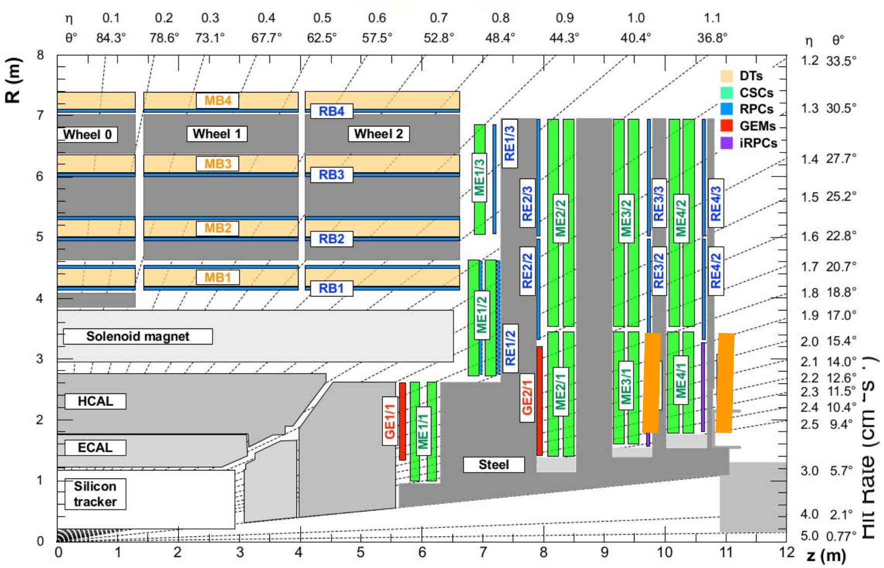
RE3/1-RE4/1 muon stations motivation:

- To improve on the muon detector performance..
- To improve on the muon trigger efficiency at high η

$$1.8 < |\eta| < 2.4$$

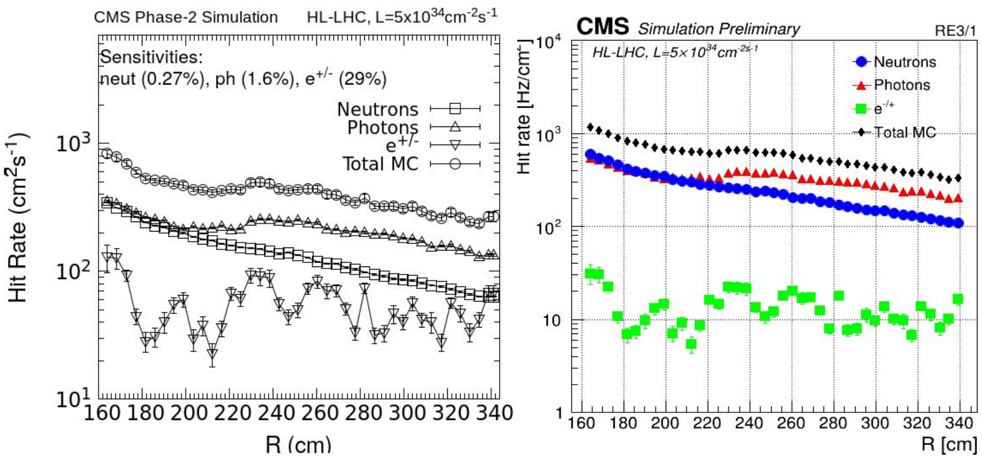
- Detectors should be able to withstand high particle rates:

$$2\ kHz \cdot cm^{-2}$$

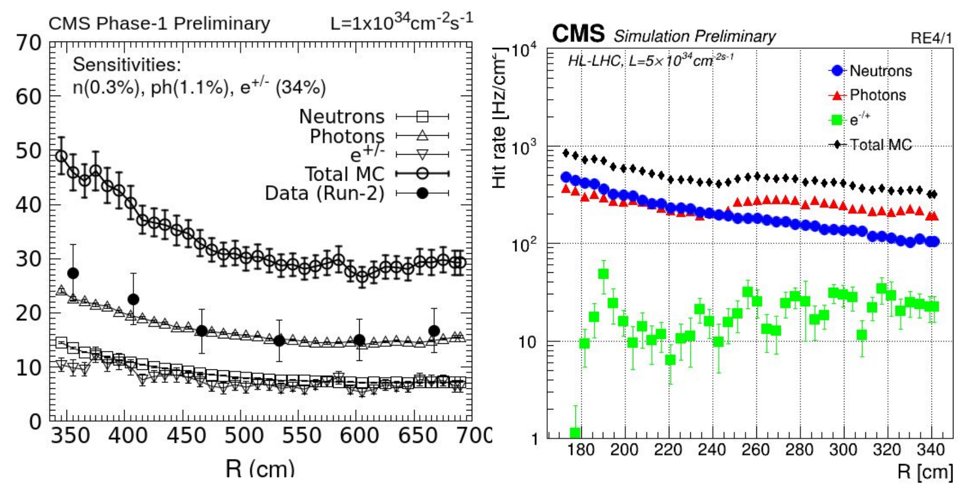


Layout of one quadrant of CMS.
The slots RE3/1 and RE4/1 are to be instrumented by RPC chambers for HL-LHC upgrade

RE3/1: Average rate: 0.6 (safe:1.8) $kHz \cdot cm^{-2}$



RE4/1: Average rate: 0.5 (safe:1.5) $kHz \cdot cm^{-2}$



Last Fluka simulation v3.7.19.1 reduced shielding layers in HGCAL

Resistive Plate Chamber

Resistive Plate Chamber (RPC)

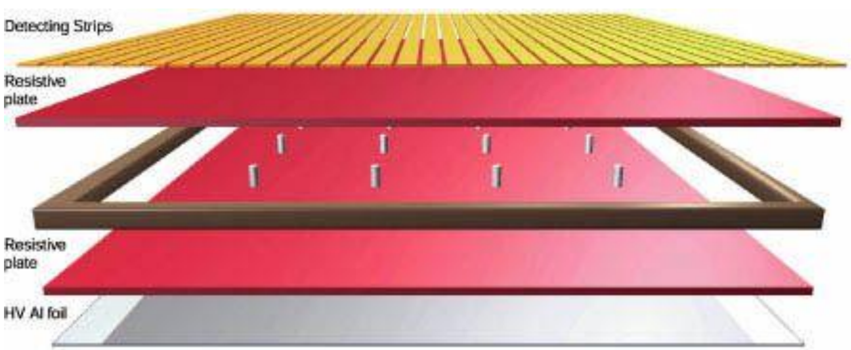
Resistive plate chambers (RPC) are fast gaseous detectors that provide a muon trigger system

Two parallel plates:

positively-charged anode

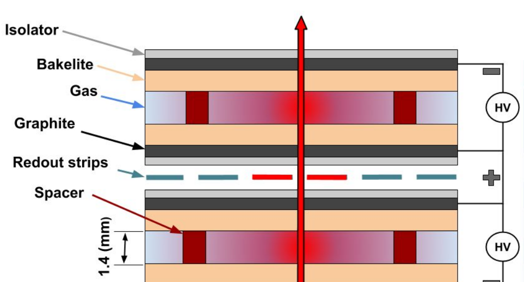
negatively-charged cathode

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

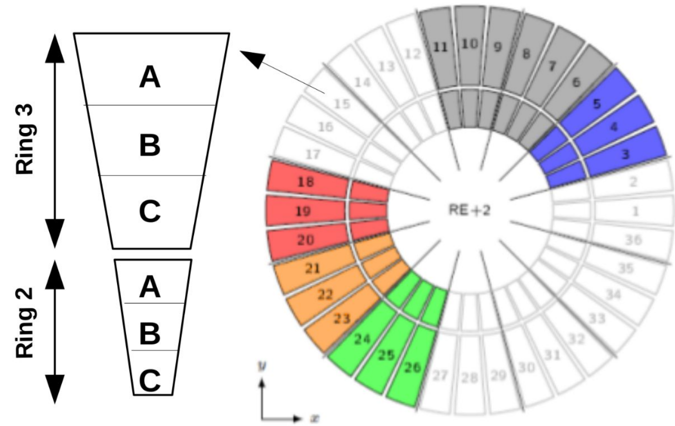


Gas mix: 95.2% $C_2H_2F_4$, 4.5% i-C_4H_{10}, and 0.3% SF_6

Improve Resistive Plate Chamber (iRPC)



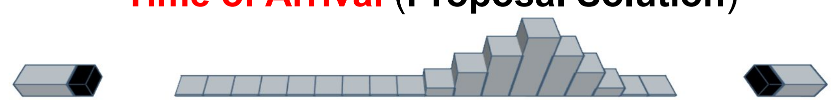
	iRPC	RPC
High Pressure Laminate thickness	1.4 mm	2 mm
Num. of Gas Gap	2	2
Gas Gap width	1.4 mm	2 mm
Resistivity (Ωcm)	0.9 - 3 x 10^{10}	1 - 6 x 10^{10}
Charge threshold	50 fC	150 fC
η segmentation	2D readout	3 η partitions



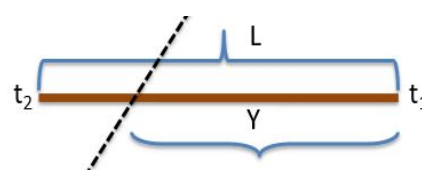
The thinner gap in the double gap RPC detector & comparison between iRPC and RPC

Standard Readout

Time of Arrival (Proposal Solution)



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



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

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

RETURN & COAX readout PCB-strip panels

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

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

RETURN prototype better than COAX.

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**

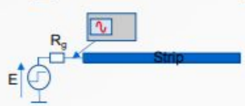
- **Direct measurement with potentiometric line adaptation**

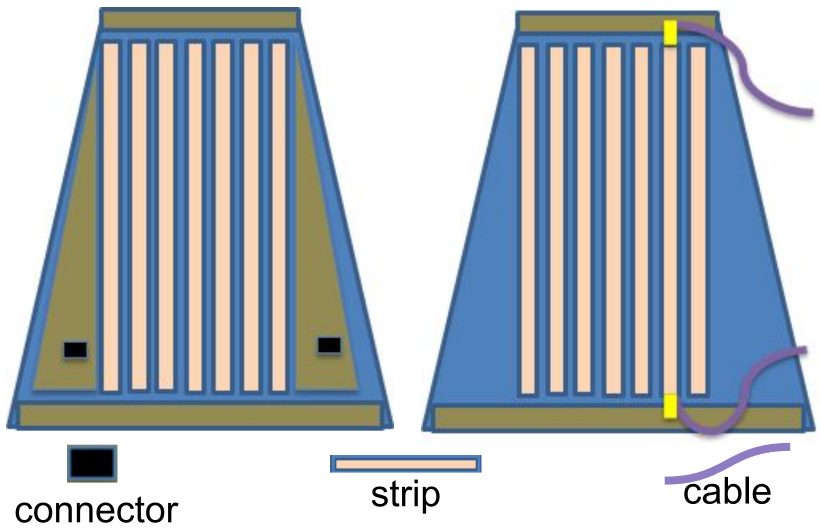
Z_c= 46 Ω

- **Reflection Method**

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

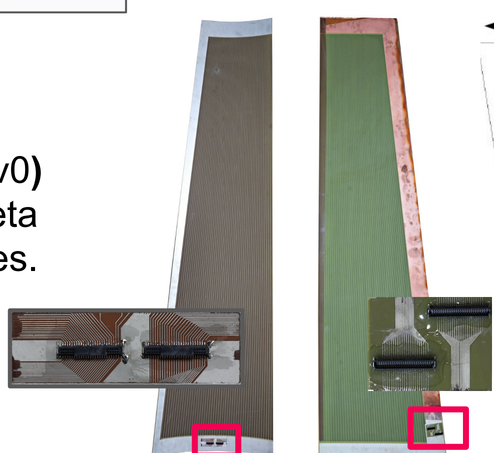
Z_c=41Ω

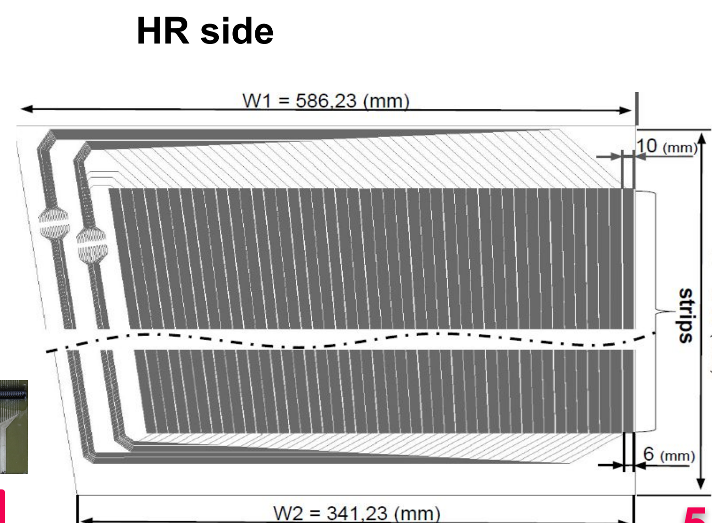




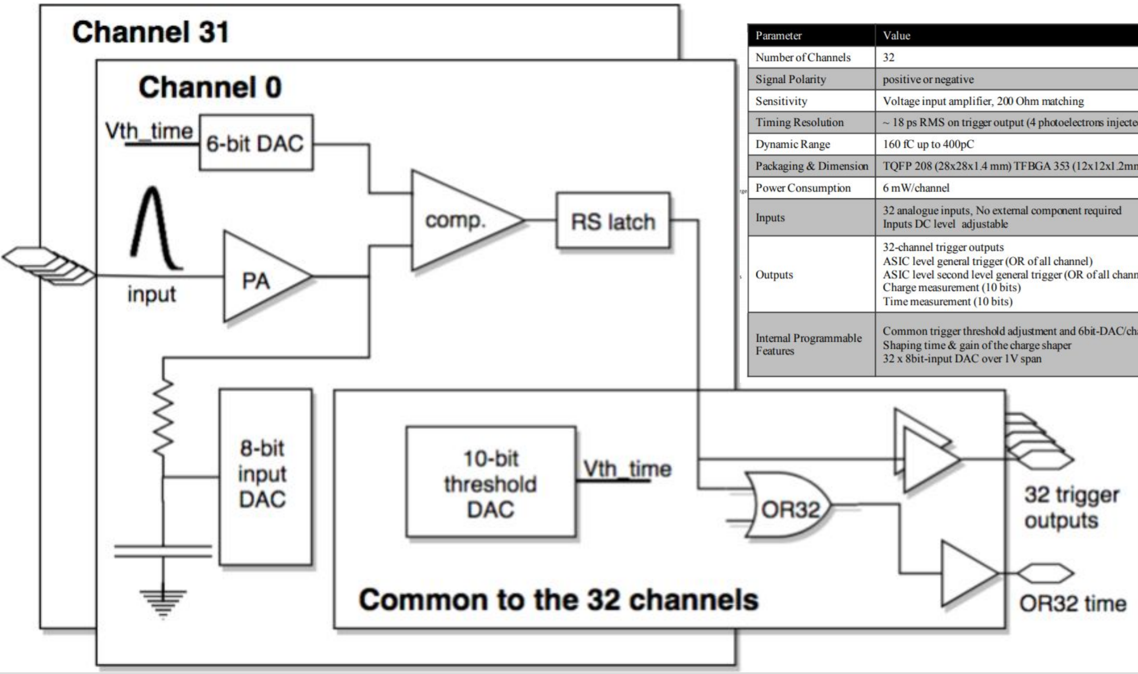
PCBv1 and PCBv0

Two Return-PCB with **48** (v1) **or 44** (v0) **strips** with connectors placed on the high eta region to take into account integration issues. This is also helpful to X-talk or fake hits.





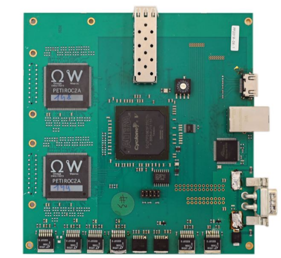
Readout Electronic



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

FEBv0

FEBv1

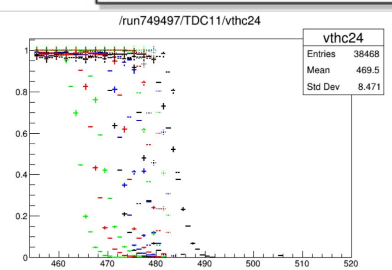


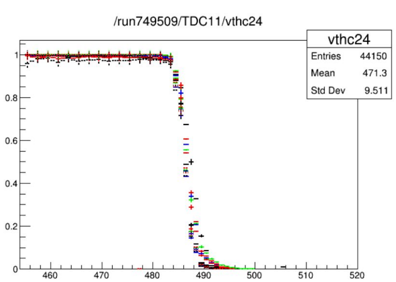
FEBv0: A board that contains:

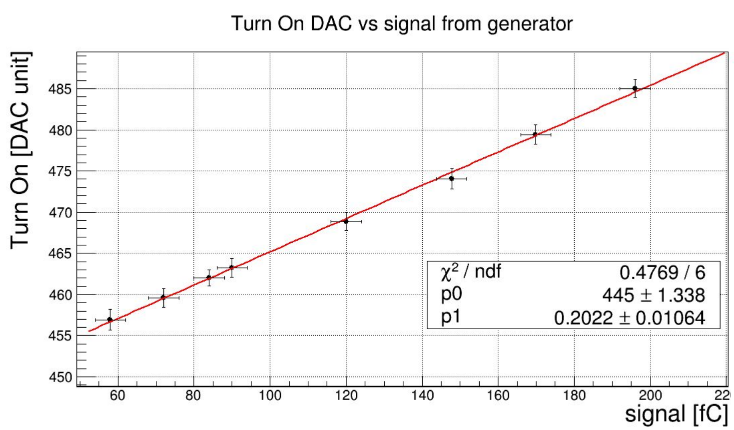
- ➢ **1 PETIROC ASIC + FPGA (CYCLONE 2)**
- ➢ Ethernet-based communication was conceived to read out the strips PCBV0 (44 strips) THR=**~80fC** with DeadTime=**10ns**

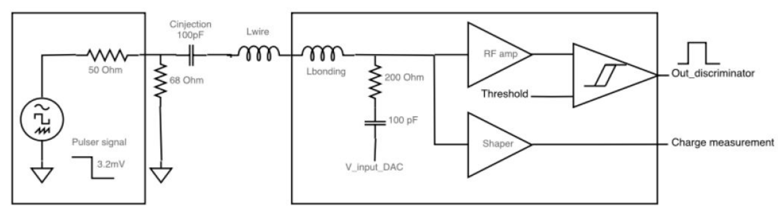
FEBv1: This was intended to come closer to the final board to be compatible with CMS DAQ:

- ➢ **2 petiroc2A(B) + FPGA CYCLONE V**
- ➢ Ethernet-based communication is used to read out the strips PCBV1 (48 strips)
  THR=**~50fC** with DeadTime=**10ns**
  THR=**~25fC** with DeadTime=**15ns**



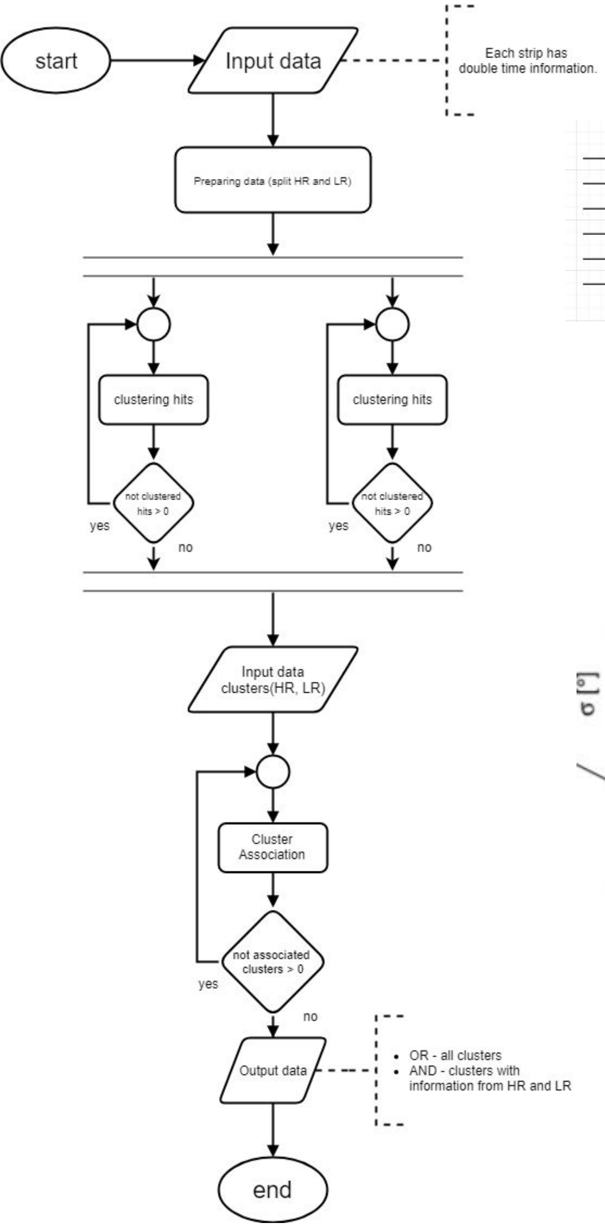


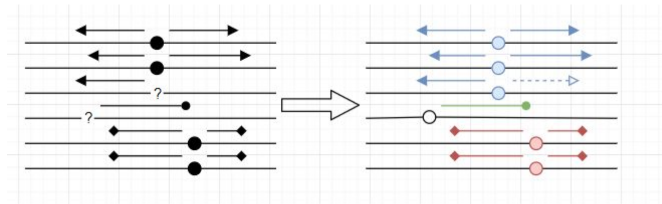


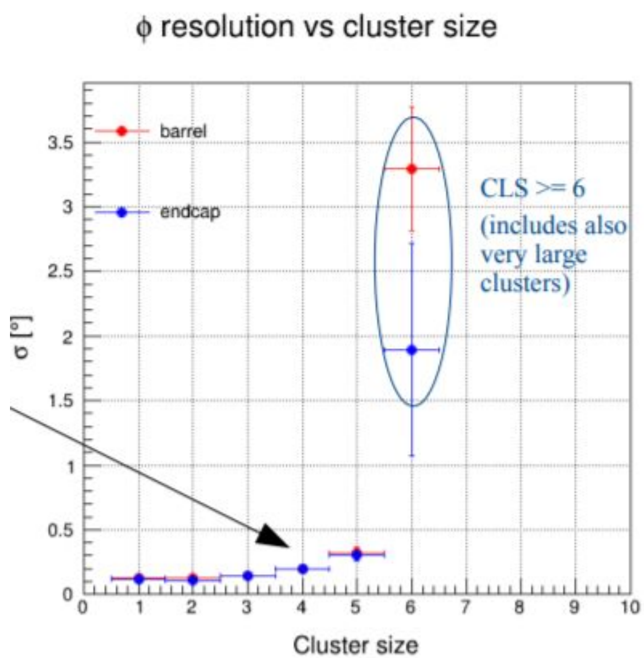


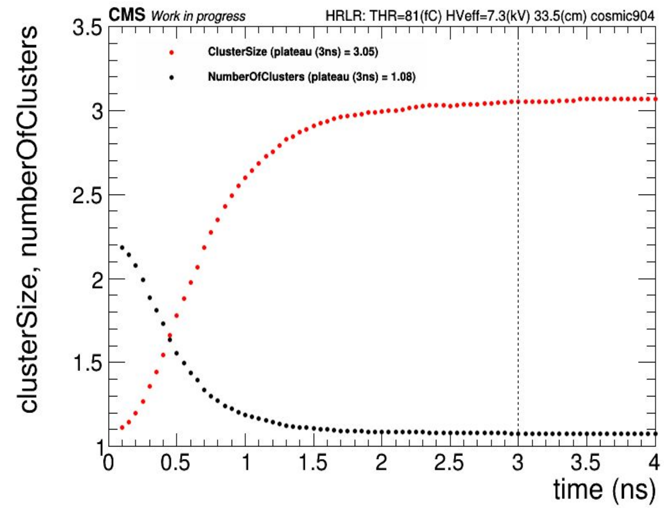
The Front-End Electronics Board (FEB) that hosts one PETIROC ASIC and the FPGA that includes the TDC and the schematics of the PETIROC ASIC.

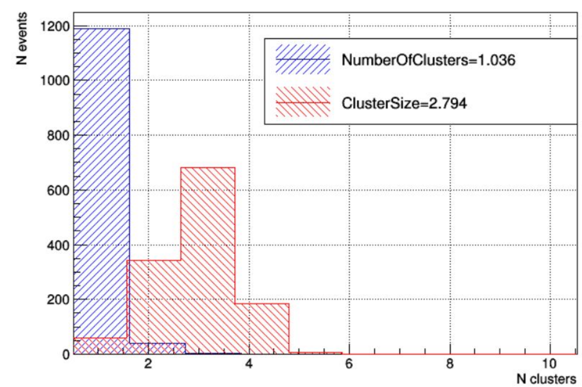
Description of clustering algorithm









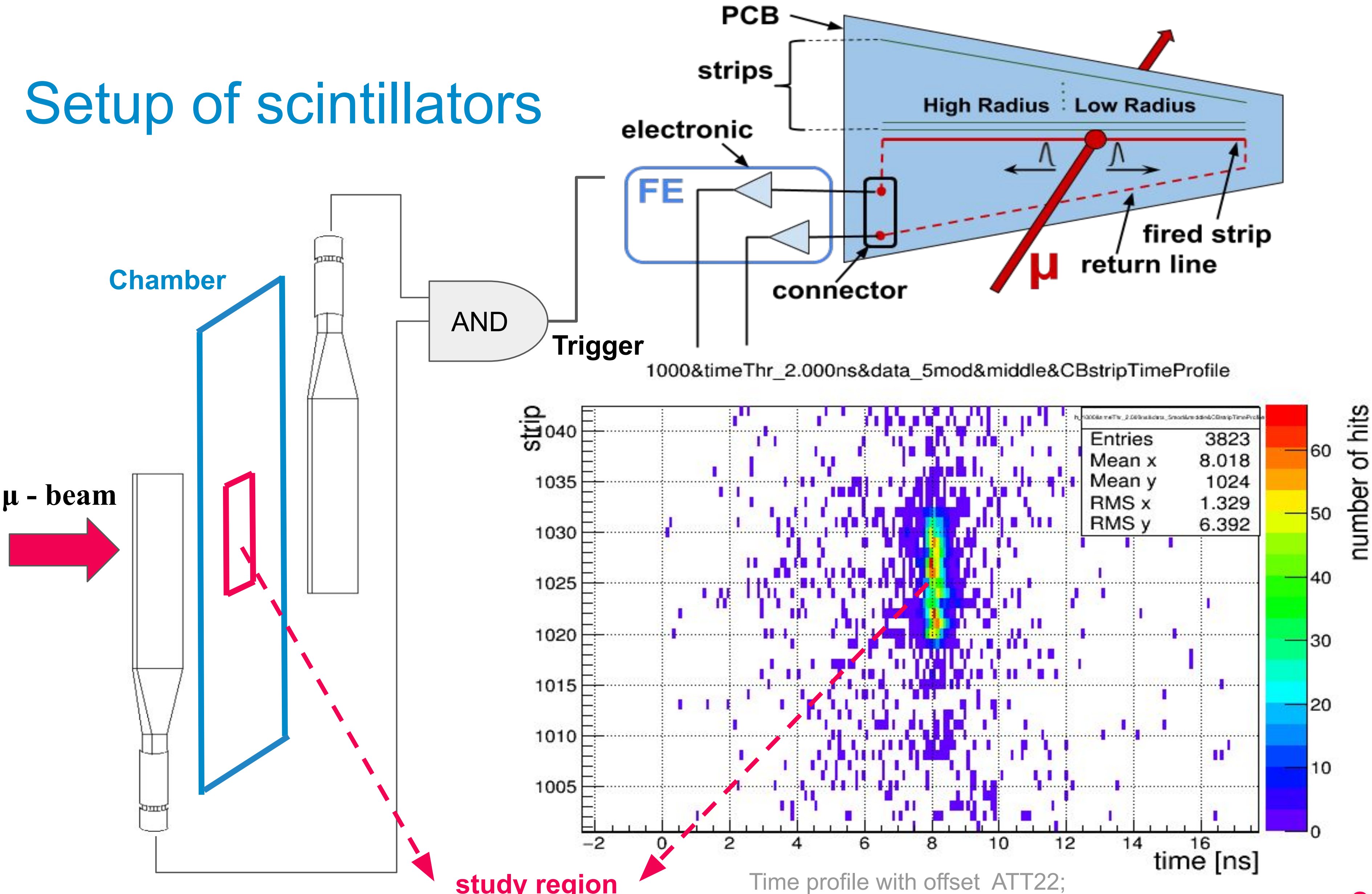


- RPC hits are slustered before to be used by track finders
- Only clusters with less than 3 strips have been used at L1 so far

Not negligible fraction of muon hit has cluster size (CLS) hiher than 3 - their phi resolution remains resonable.

Description of the test stand of the prototype

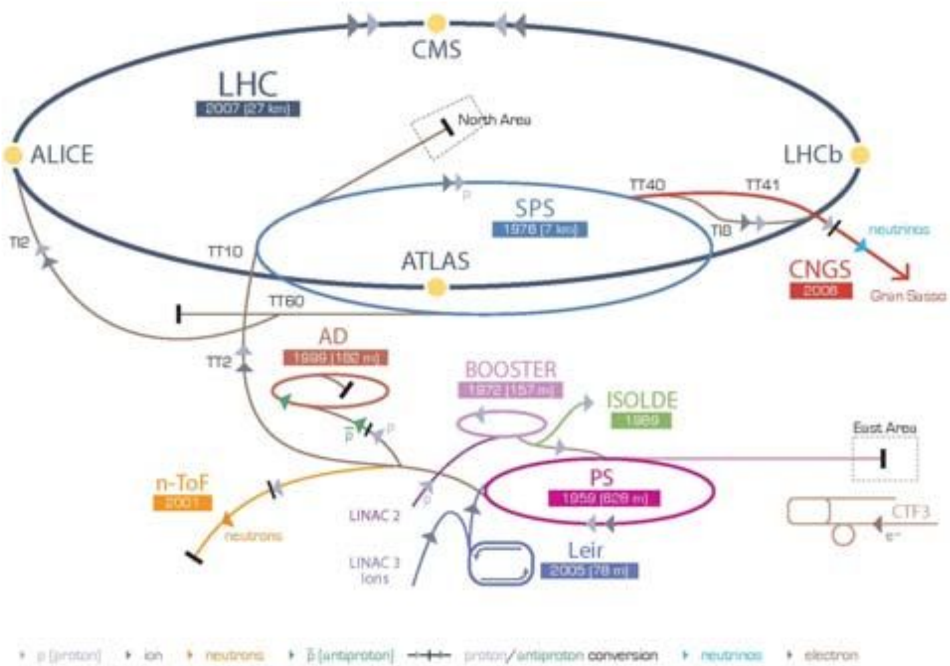
Setup of scintillators



Time profile with offset ATT22; HVeff=7500; THR=510; dead 20ns

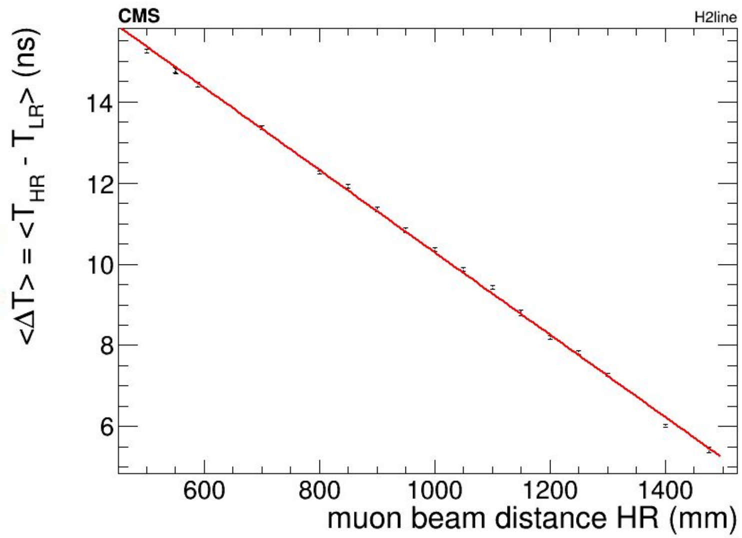
H2 line: Study of time resolution

SPS North Test Beam Area

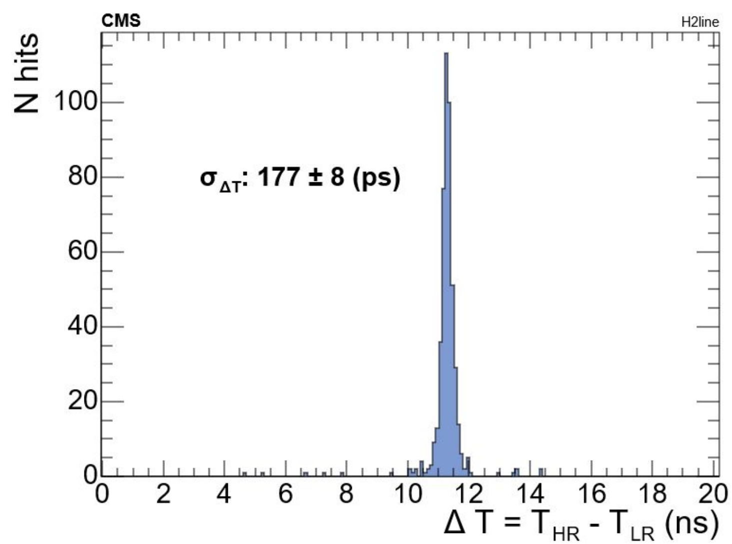


- Muon bean
- Timy scintilators (~1.5cm)
- Scan studieswere performed using moving   tables (~1mm resolution)

Linearity along the strips



Time resolution of one strip

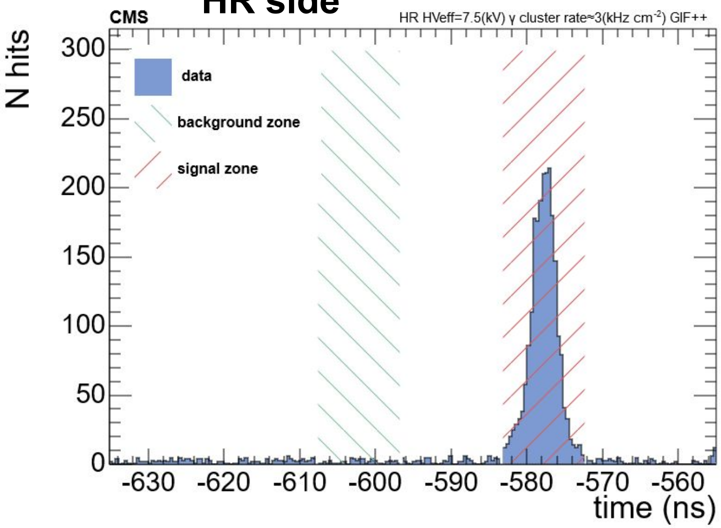


H2line: Resolution Study (Photo)

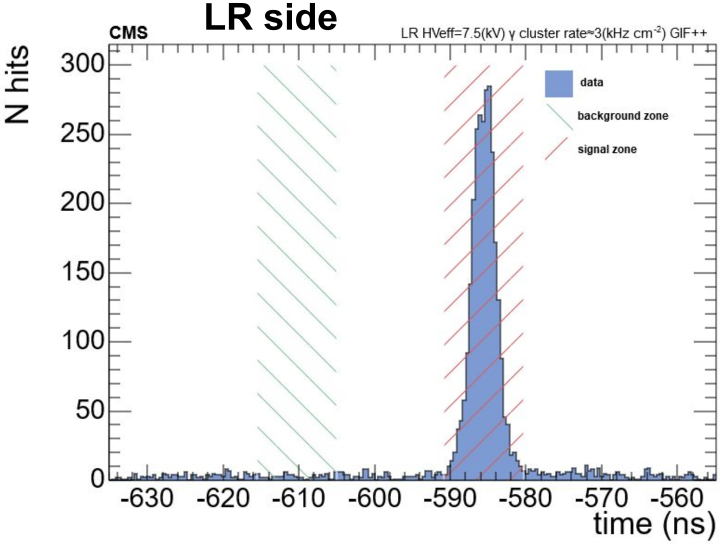
Efficiency & Rate estimation

Examples time profiles

HR side



LR side



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 for AND) in a time interval of the same length but uncorrelated with the trigger.

RATE

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

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

$numberOfClusters - number\ of\ clusters\ of\ one\ run;$
$sufrace - active\ PCB\ zone;$
$time - collection\ time: \ (timeWindow * numberOfEvents).$

HIGH VOLTAGE EFFECTIVE

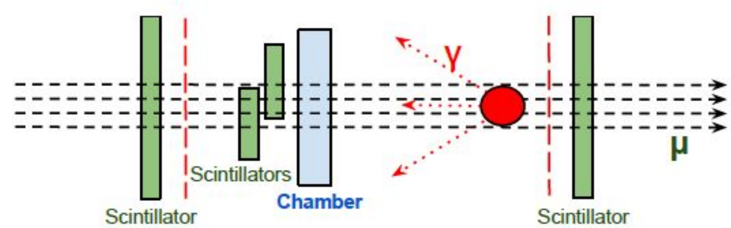
Effective HV takes into account the change in pressure and temperature with respect to an HV reference value V_0 at given pressure P_0 and temperature T_0.

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

GIF++: Study of rate capability

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.



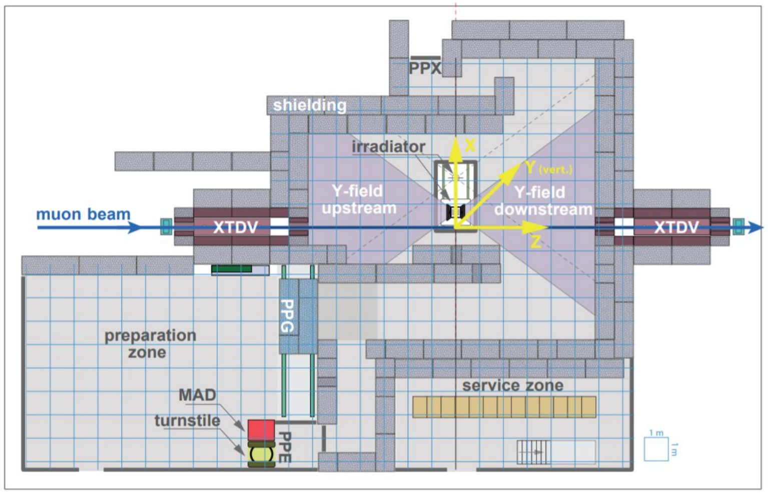
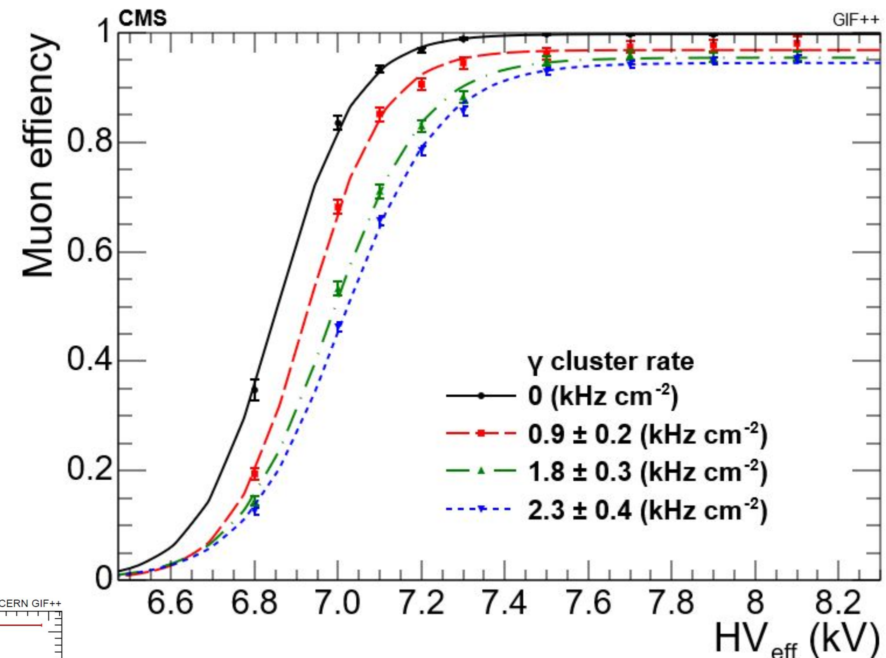
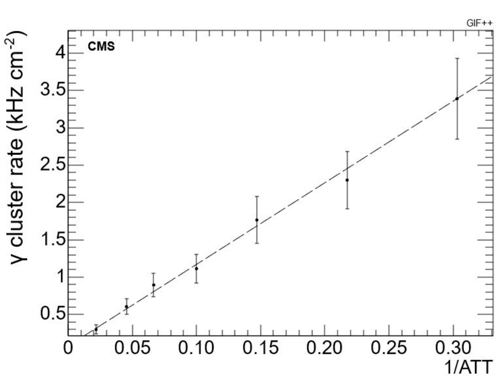
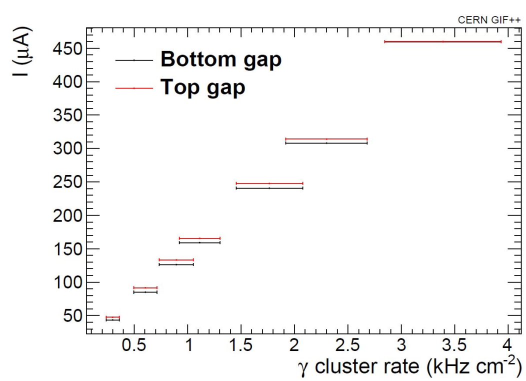
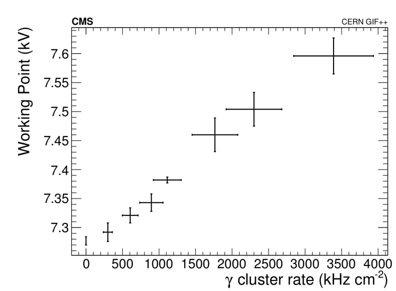


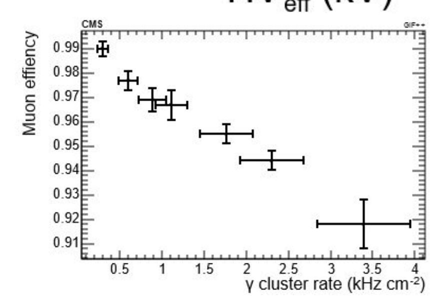
Fig.4 Floor plan of the GIF++ facility



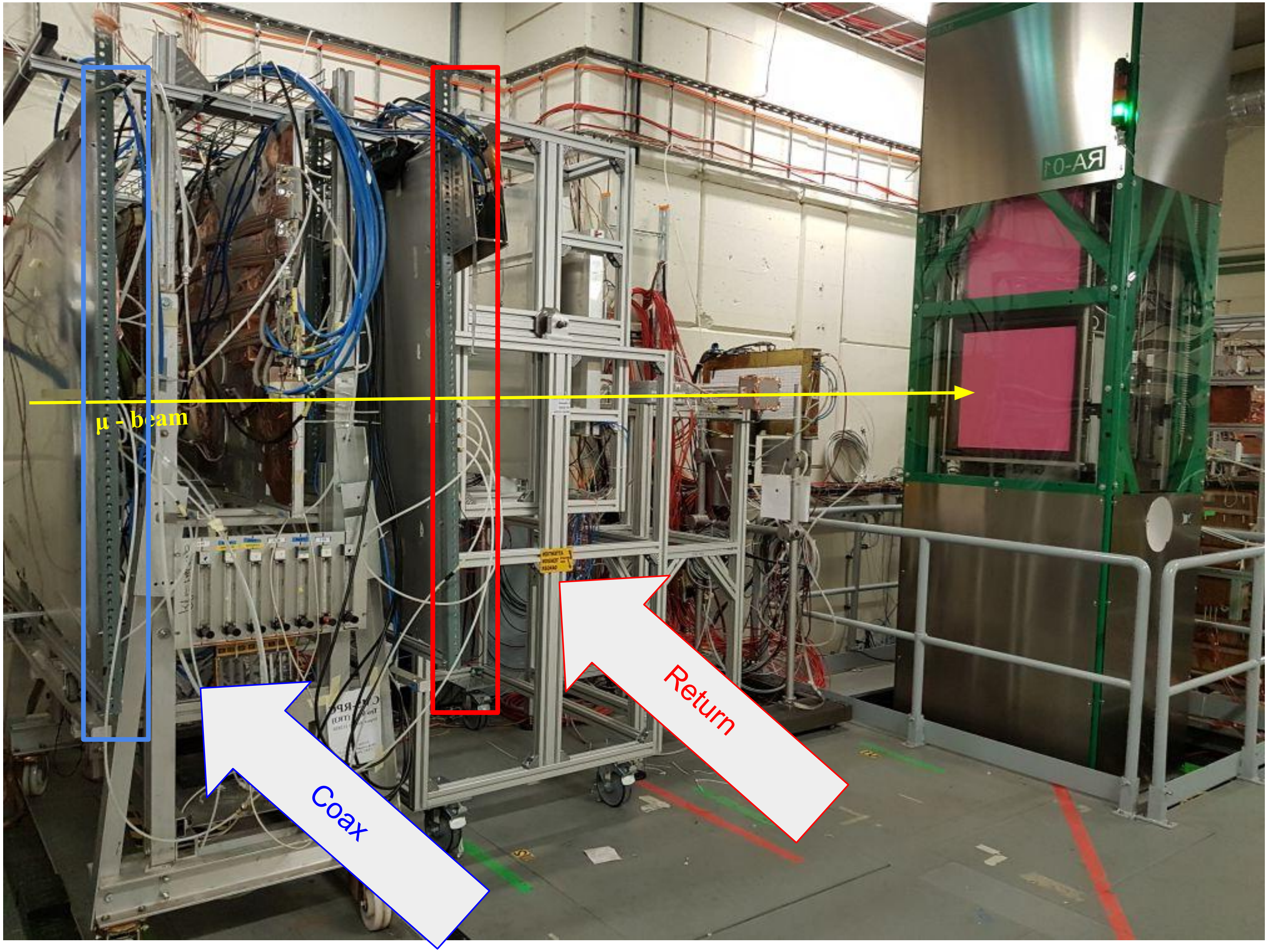




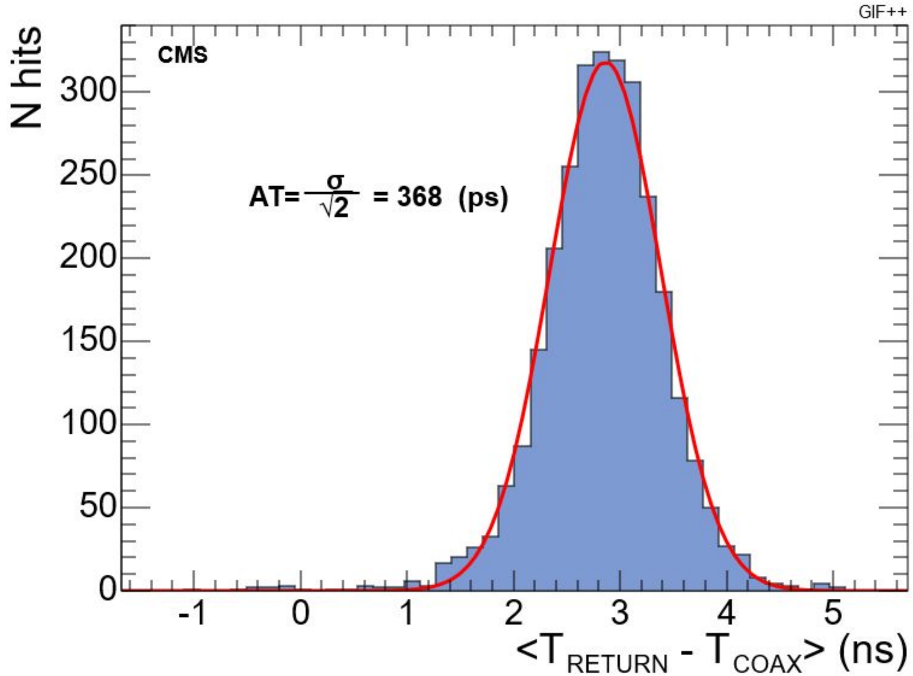




GIF++: Study of rate capability (Photo)



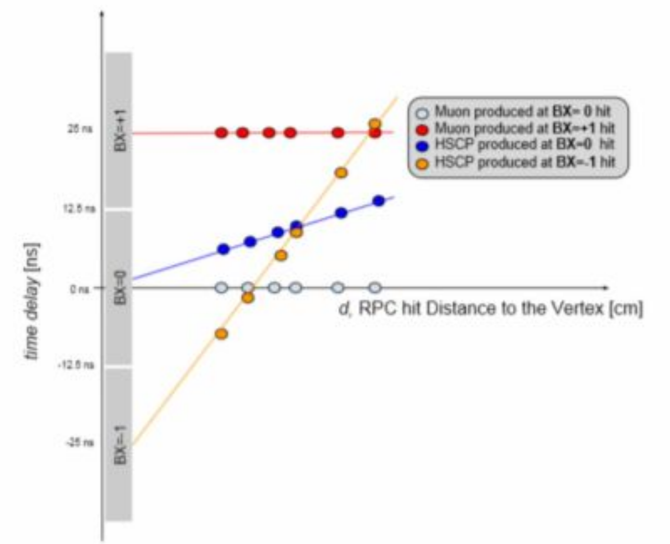
Absolute time resolution and HSCP search



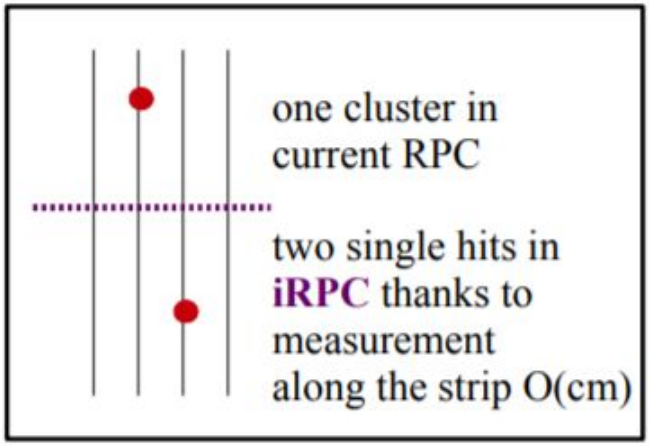
$$\Delta t = t_1 - t_2 \rightarrow \sigma_{\Delta t} = \sigma_{t_1} - \sigma_{t_2} \rightarrow \sigma^2_{\Delta t} = \sigma^2_{t_1} + \sigma^2_{t_2} - 2 * \sigma_{t_1} * \sigma_{t_2}$$

$$< \sigma^2_{\Delta t} > = < \sigma^2_{t_1} > + < \sigma^2_{t_2} > -2* < \sigma_{t_1} * \sigma_{t_2} >$$
$$< \sigma^2_{\Delta t} > = < \sigma^2_{t_1} > + < \sigma^2_{t_2} > -2 * cov(\sigma_{t_1} * \sigma_{t_2})$$
$$< \sigma^2_{\Delta t} > = < \sigma^2_{t} > + < \sigma^2_{t} > \quad if \quad detectors \quad are \quad independent$$
$$\frac{< \sigma_{\Delta t} >}{\sqrt{2}} = < \sigma_t >$$

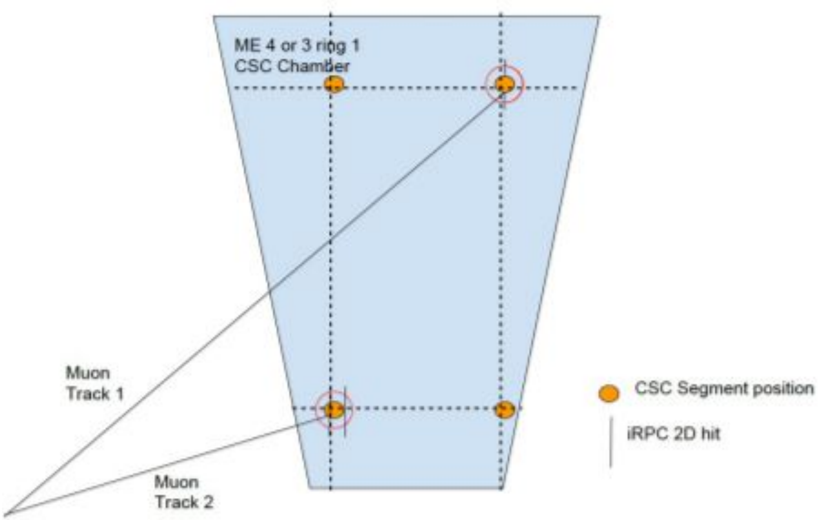
- Heavy stable charged particles (HSCP) look like 'slow muons'
- Current L1T algorithms are inefficient for $\beta < 0.7$
- Dedicated HSCP trigger can be built based on time of flight using (i)RPC sub-BX time information

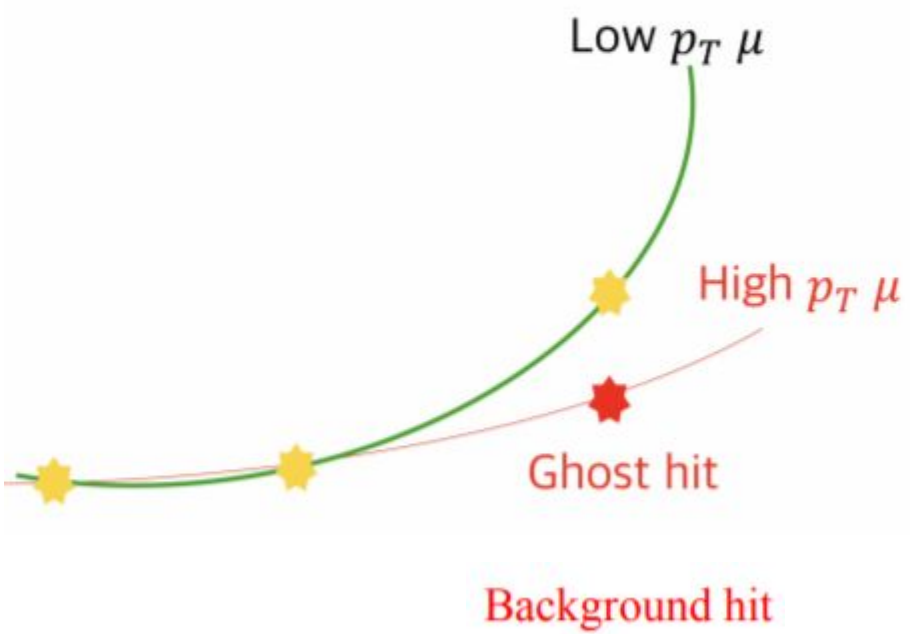


Possible usage of iRPC 2D measurement in L1T



- Ghost signals can arise in CSC Local Charged Track (LCT) when two hits occur in the same chamber within ±1 BX (two 1D readouts)
- The RPC/CSC matching procedure could also be used to reject background hits in CSC's





Conclusion

Summary

- A method was proposed for measuring the efficiency of the detector when using signals from two ends of the strip.
- 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 were carried out at the required rate of 2kHz of background.Efficiency of more than 95% was obtained.
- A new clustering algorithm using time information was proposed and successfully tested.

Thank for Your Attention!

Any questions:

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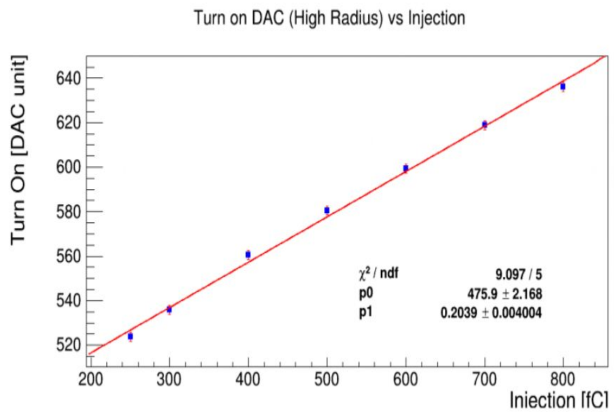
Additional material

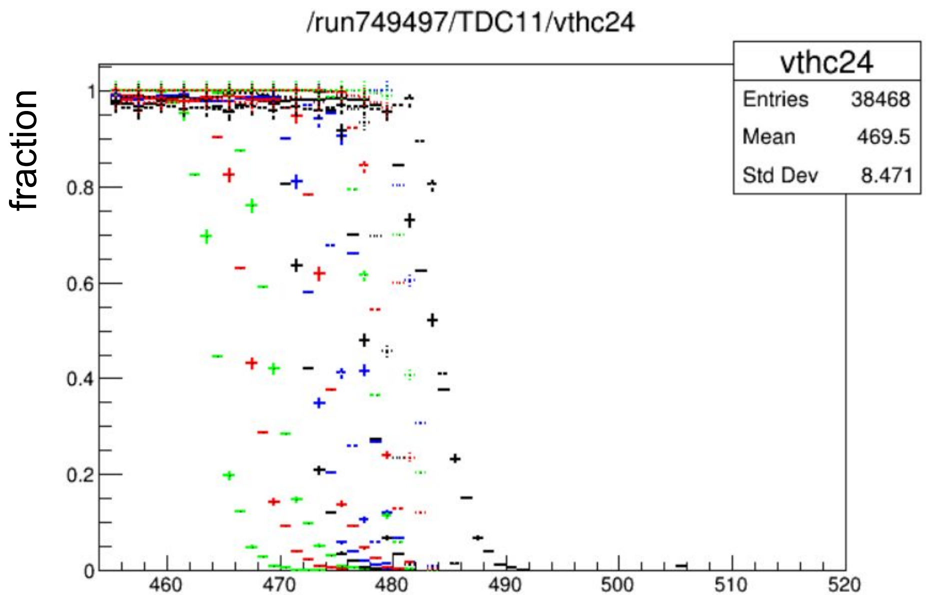
Electronic PETIROC2A: Pedestal, Injection, Noise

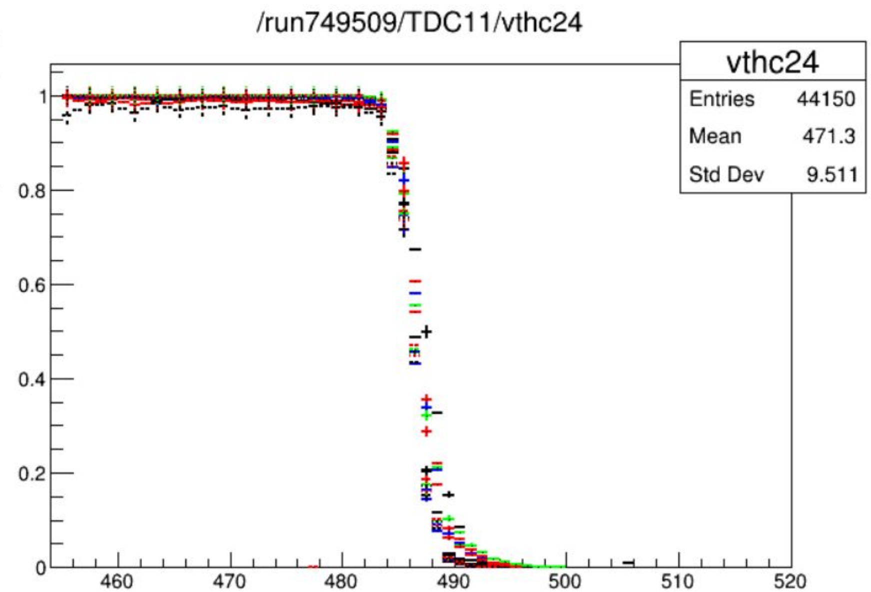
The parameters of each channel (6-bit DAC) is adjusted so the pedestal S-curves of all channels are similar.



- This allows a uniform esponse of the 32 chs.
- Easy control threshold with 10-bit DAC

1DACunit = 4.90fC per strip
1DACunit = 2.45fC per DAQch





DAC unit

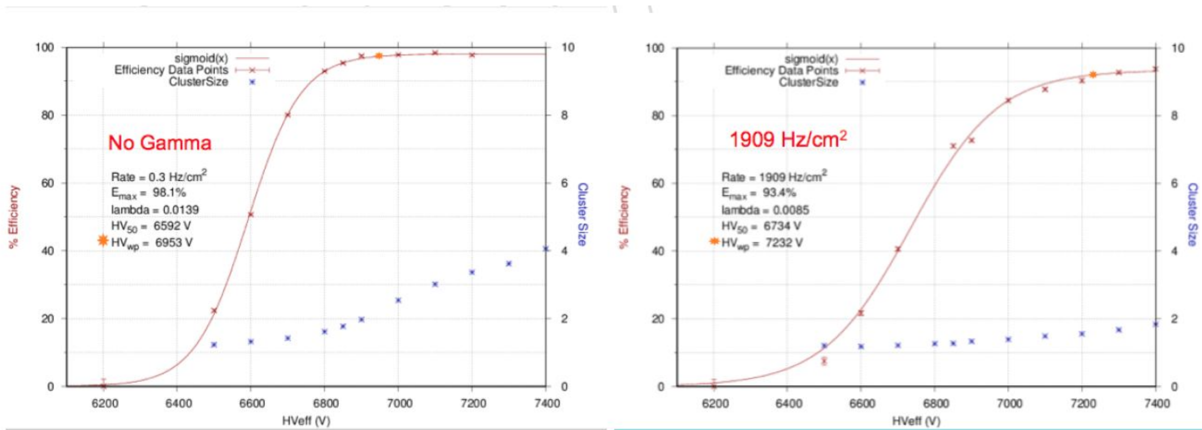


Figure 1.19: Efficiency and average cluster size of a 1.4 mm double-gap RPC large size chamber as a function of the effective voltage, tested without gamma background (left) and under a gamma background rate of 1.91 kHz/cm^2 (right). The data were measured at the fixed threshold of 300 μV.

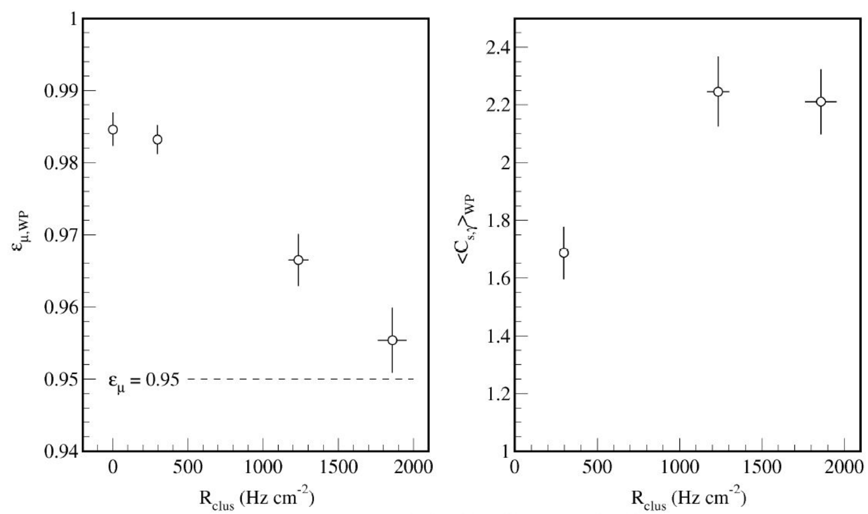


Figure 1.18: Efficiency (left) and average cluster size (right) at the working voltage, as a function of the cluster rate for the 1.4 mm double-gap RPC. The data were measured at the fixed threshold of 300 μV.

DEFINITION: Rate

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

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

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

$sufrace - active\ PCB\ zone;$

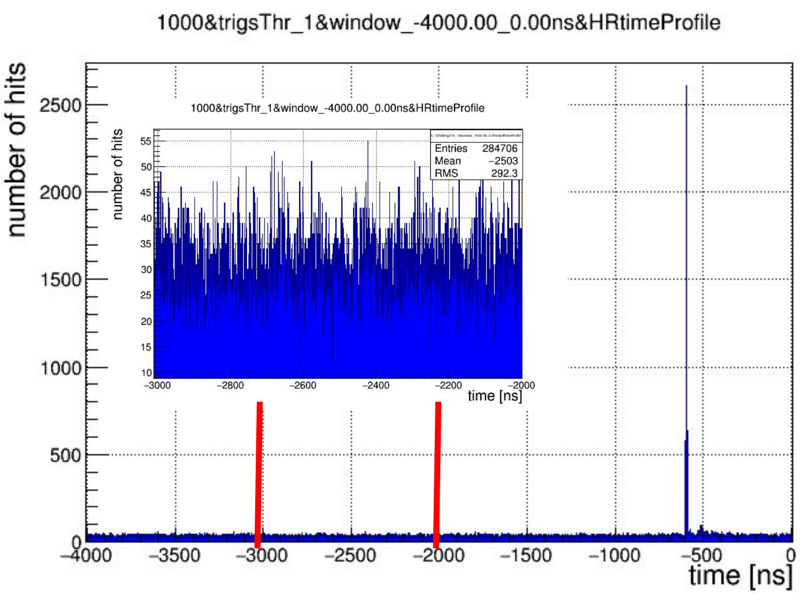
$time - collection\ time:\ (timeWindow * numberOfEvents).$

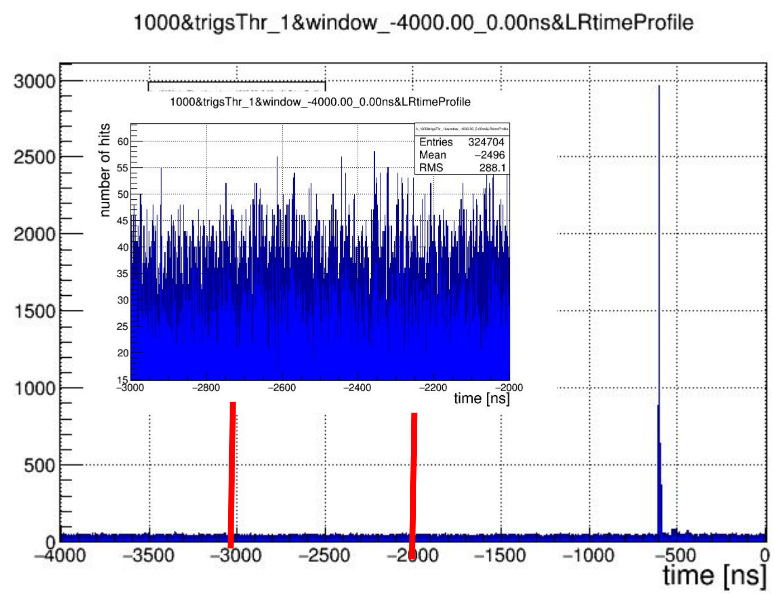
$$cluster Rate = \frac{numberOfClusters}{surface * time}, where$$

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

$sufrace - active\ PCB\ zone;$

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

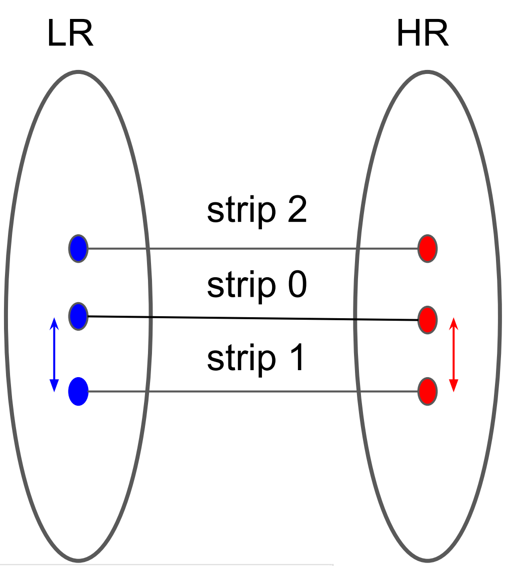


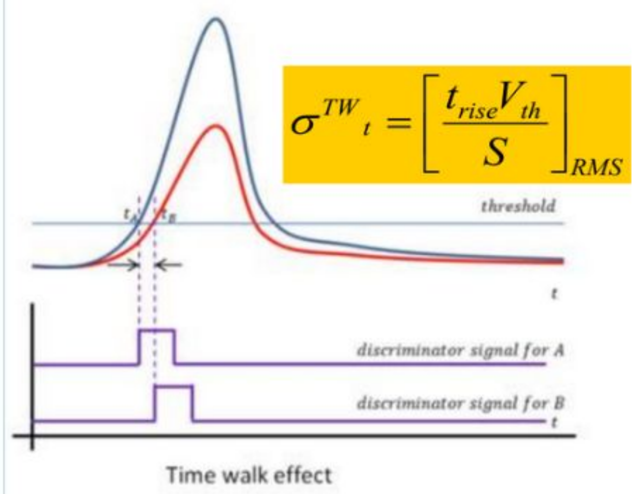


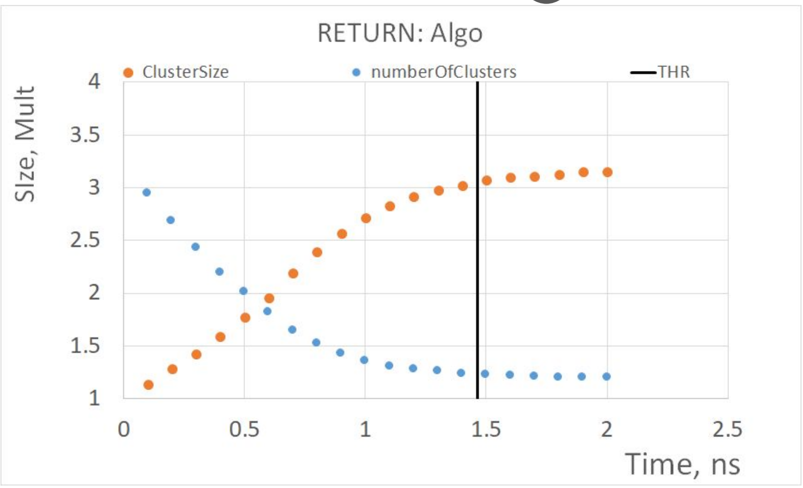
Time Walk and Time over Threshold

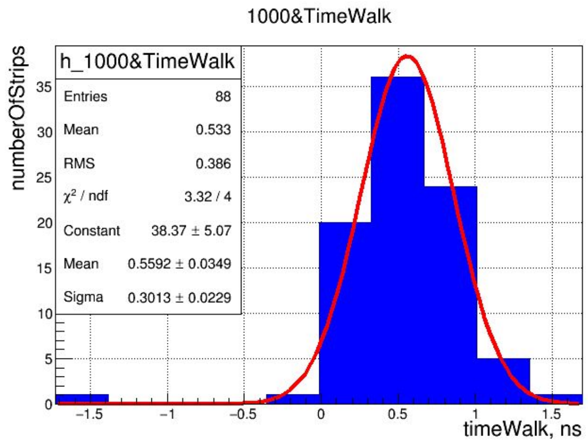
Time Walk it is a delay with correspond charge of the signal.
Δ(LRstr0-HRstr0) = delay;
Δ(LRstr0-LRstr1) = offset + timeWalk;
Δ(HRstr0-HRstr1) = offset + timeWalk;

To show time walk: Plot only events where pure cluster with size 3. It should split symmetrical signal between strip2 and strip1 and delta strip0-strip1 give timewalk delay.

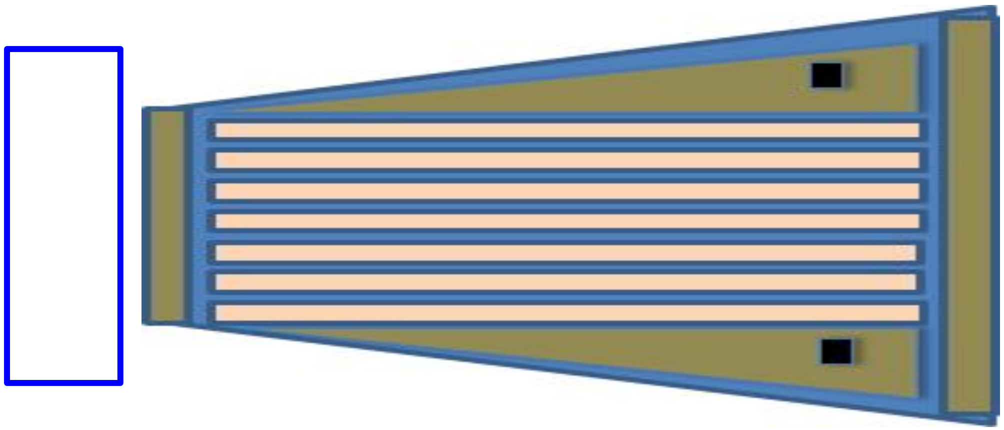




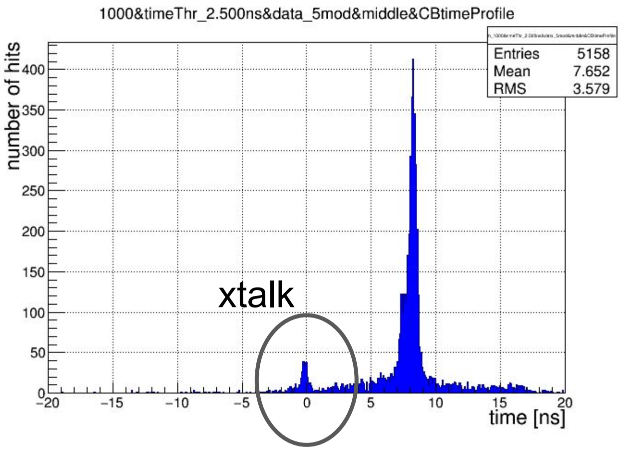


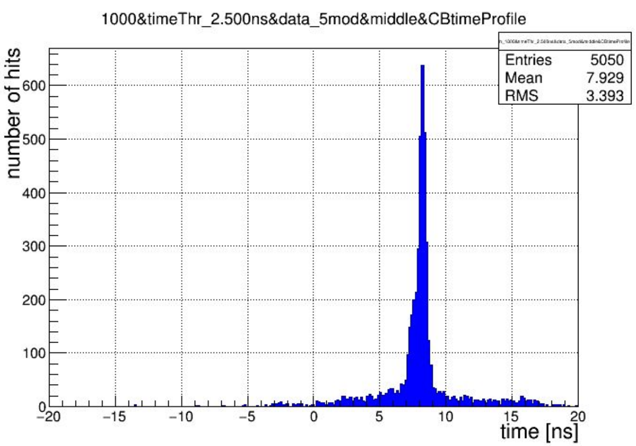


XTALK. webdcs: 798; TimeProfiles; (Example: ATT=22; HVeff=7500)



Cluster time profiles: with and without filter;





if the return line is longer than strip this type of noise can be filtered without loss of the active zone of the PCB. For the “RETURN” chamber, the geometrically cut zone behind the real psb zone (blue square).

Readout Electronic: re-tirggering problem & solutions

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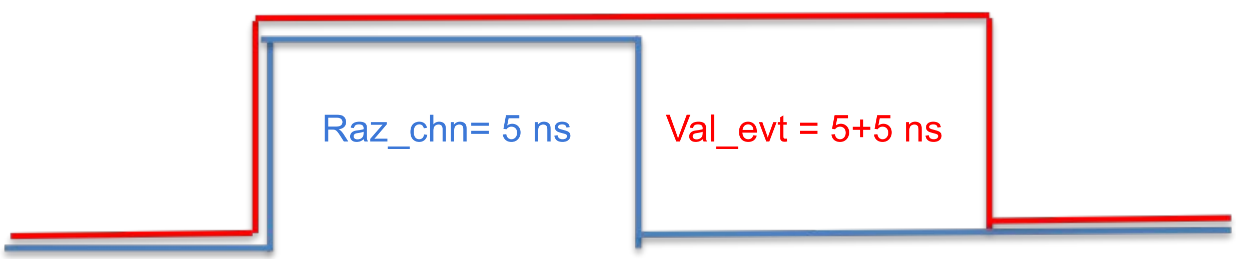
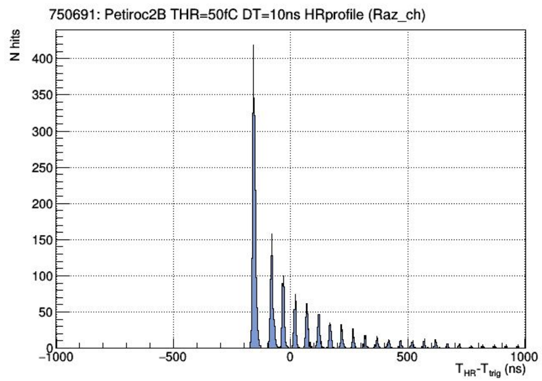
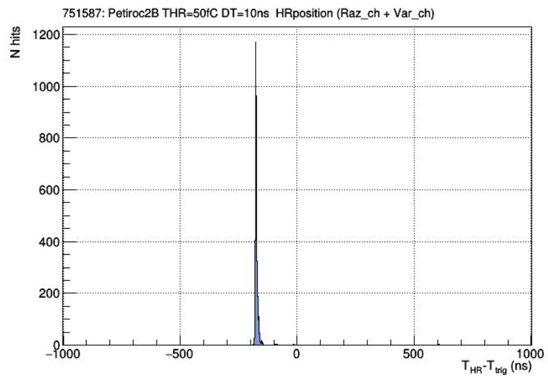


Examples of Re-triggering

THR=50fC DT=10ns Raz_ch



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



Improvements to come

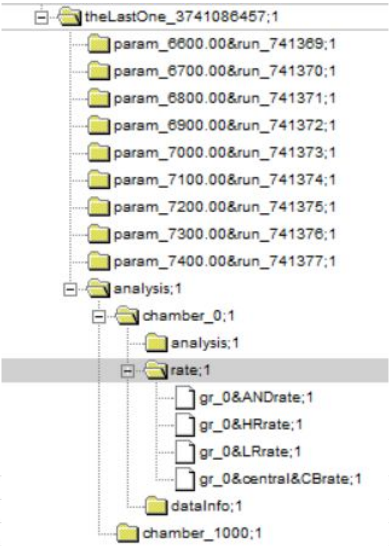
- We are working on reducing at least the time difference between Val_ev and Raz_ch
- We will reduce the loss of amplitude along the strip by replacing the FR4 by a new dielectric material with less loss (EM888)

Software for analysis raw data format from DAQ

Software

- C ++ modular program;
- Read and Analysis (efficiency, clustering, etc.) raw data from DAQ.
- Allows to input parameters with easy way: Google Drive table, .csv, and any sheet format of files;
- Output analysis with .root format.
- Python scripts for analysis and comparing outputs.

Example of program




```
#--------------------------------------------------------------------------
                    DataQuest - Life is Endless Analysis.
#--------------------------------------------------------------------------
#MOD: analysis
#---

Getting ingredients for cookies...

#---
N: 2 chamber(s) in Processing: index=0 index=1000
N: 1 file(s) in Processing... / N: 1 run(s) in Processing...

Cookies are ready, invite you to enjoy the taste!
#--------------------------------------------------------------------------

Run[0]: 746298
CONFIG loop...
    File[251]: SMM_151218_190942_746298.dat
100% [||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||]
ANALYSIS loop...
    File[251]: SMM_151218_190942_746298.dat
100% [||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||]
End of Processing!
#--------------------------------------------------------------------------

Comparing cookies and Cleaning the kitchen...
You're welcome!
#---

#COMMENT: efficiency_3758367438
#OUTPUT FILE: ~/projects/dataQuest/results/default/1169.root
#OUTPUT[0]: ~/projects/dataQuest/results/

#LOG FILE: ../cards/basic/logs/LyPeti_default_3758367438.csv
#--------------------------------------------------------------------------
```

<table>
<tr><td>mods</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>LR|HR|AND|central&CB</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>filter&all_is</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>filter&triger_is</td><td>filter&triger_thr</td><td>filter&numBoard</td><td></td><td></td><td></td></tr>
<tr><td>1</td><td>1</td><td>4</td><td></td><td></td><td></td></tr>
<tr><td>filter&deadTime_window</td><td>filter&deadTime_is</td><td></td><td></td><td></td><td></td></tr>
<tr><td>50</td><td>0</td><td></td><td></td><td></td><td></td></tr>
<tr><td>filter&window_beg</td><td>filter&window_end</td><td>filter&window_is</td><td></td><td></td><td></td></tr>
<tr><td>-205</td><td>-180</td><td>1</td><td></td><td></td><td></td></tr>
<tr><td>filter&noise_beg</td><td>filter&noise_end</td><td>filter&noise_is</td><td>algo&noiseUnit</td><td>0&algo&chamberArea</td><td>1000&algo&chamberArea</td></tr>
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<tr><td>filter&BCID_beg</td><td>filter&BCID_end</td><td>filter&BCID_is</td><td></td><td></td><td></td></tr>
<tr><td>2</td><td>100000000</td><td>0</td><td></td><td></td><td></td></tr>
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<tr><td>3</td><td>4</td><td></td><td></td><td></td><td></td></tr>
<tr><td>runs</td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>values</td><td></td><td></td><td></td><td></td><td></td></tr>
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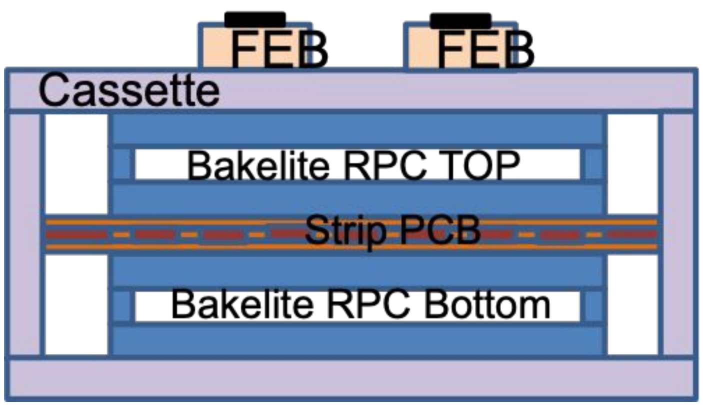
</table>

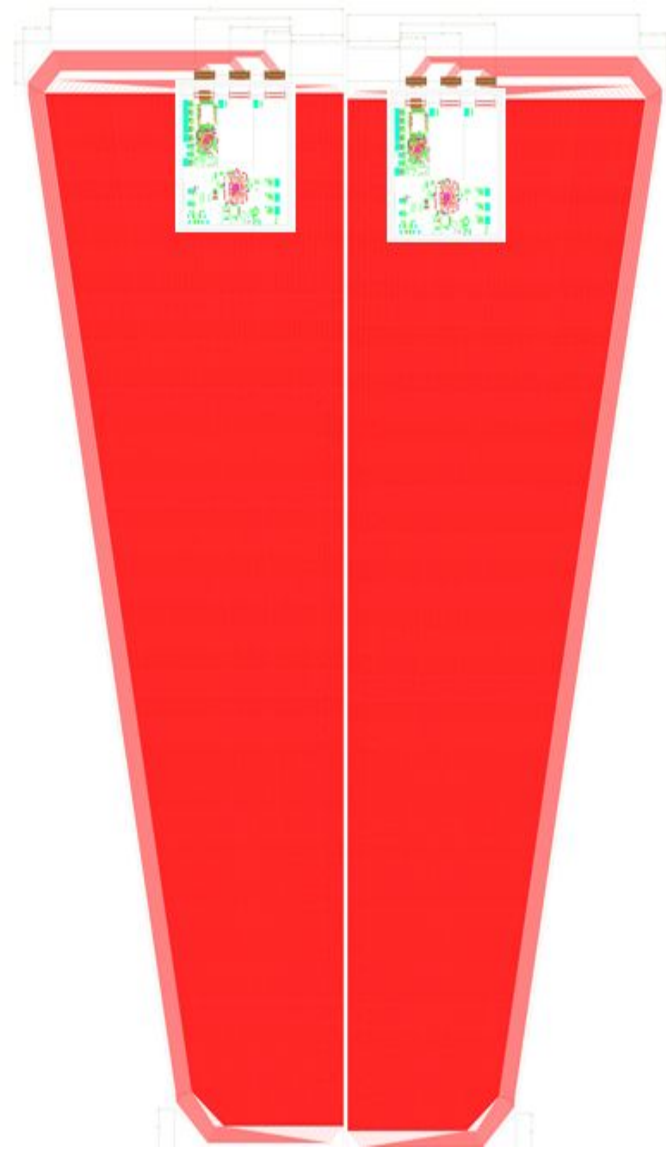
Final design

Strip PCB:

The final design of the strip PCB is completed.
If the new dielectric (EM888) confirms its good performance with respect to (FR4) it will be used in future productions.

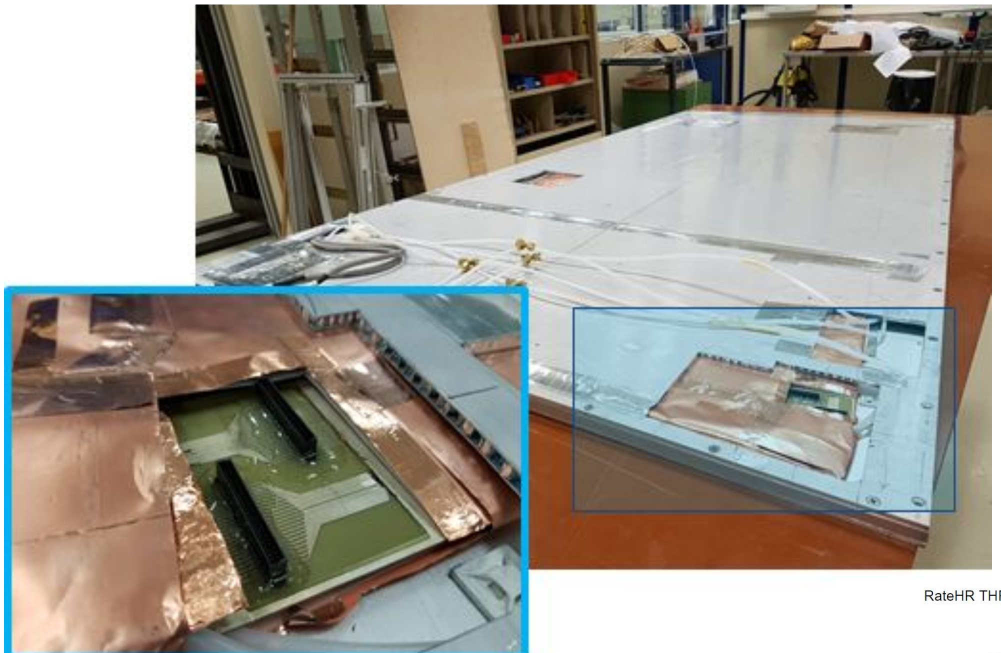
There will no impact on the thickness of the PCB.

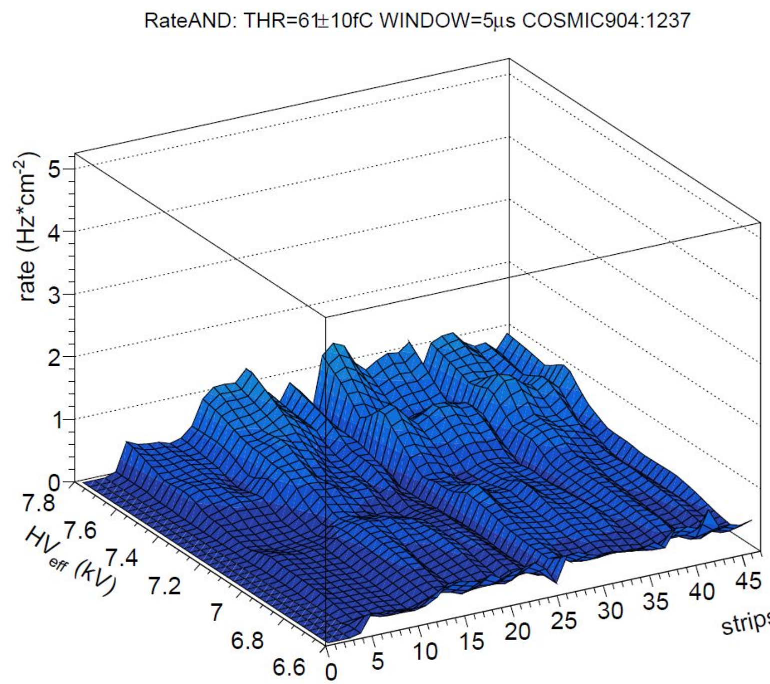


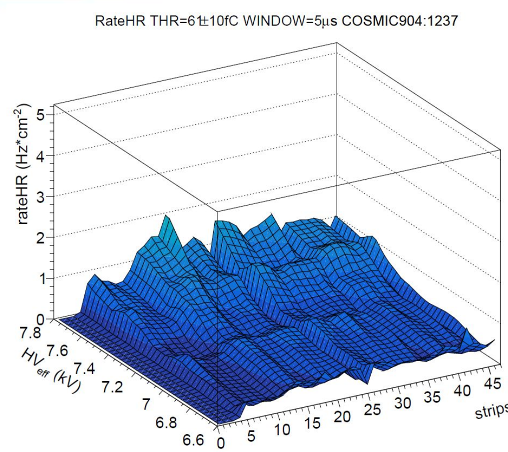


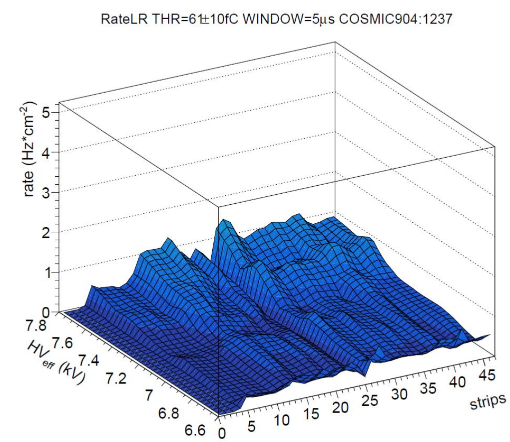
The final design of the FEB is ongoing but the number of connectors between the strip PCB and the FEB is frozen.

Chamber Noise









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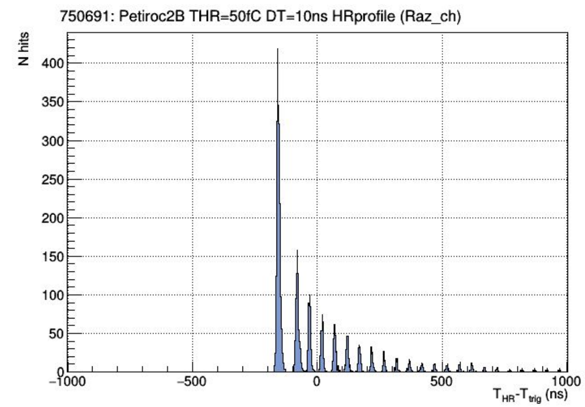
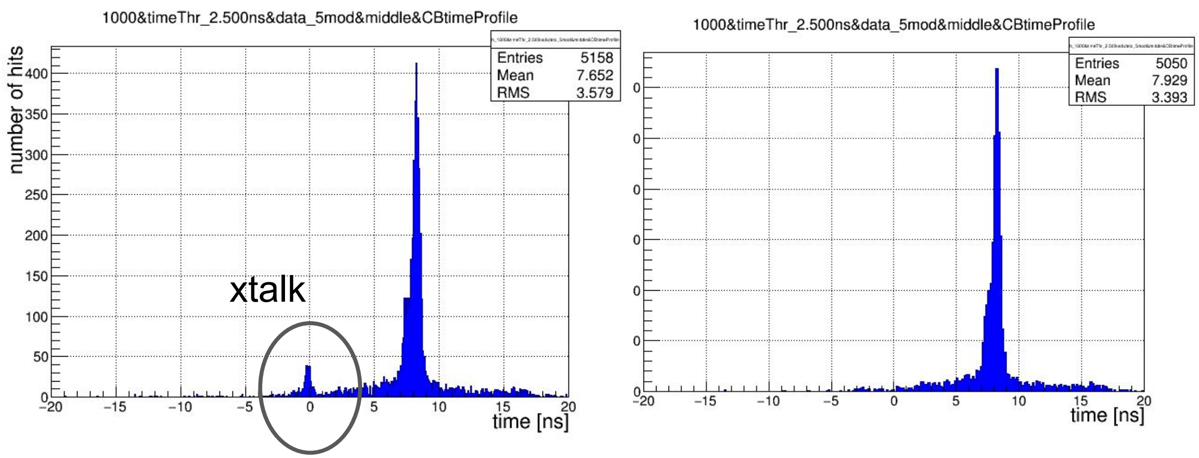
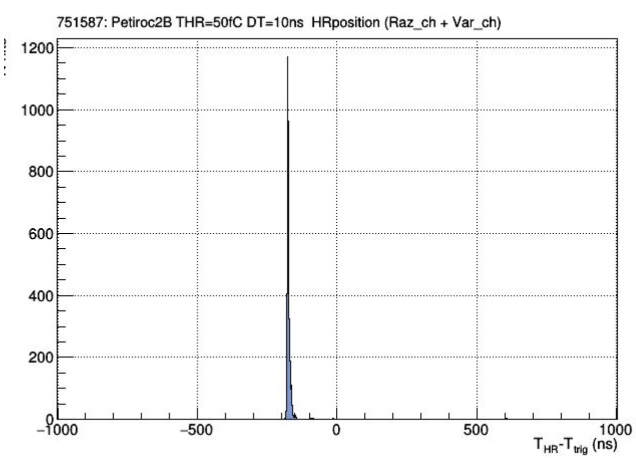


Cluster time profiles: with and without filter X-talk;



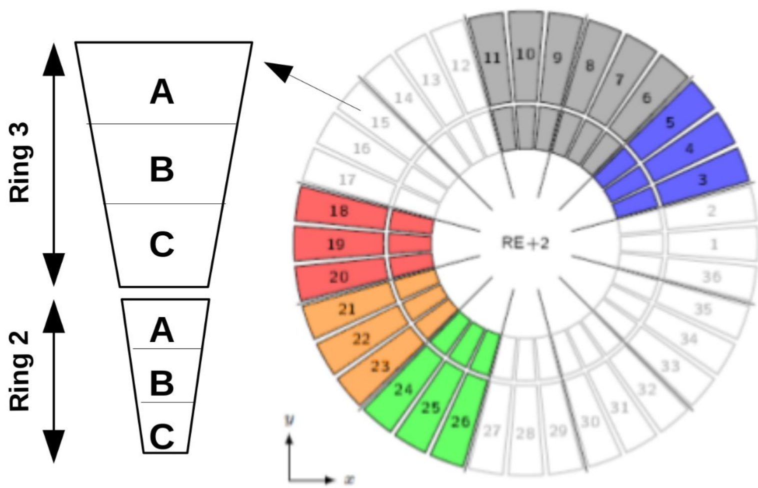
THR=50fC DT=10ns (Raz_ch+Val_ch)



2D Readout Electronics

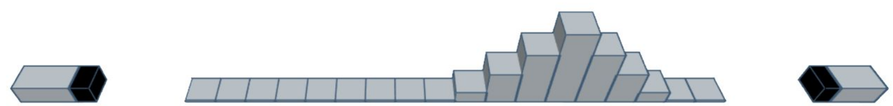
lower charge → less aging → needs more sensitive electronics
higher rate → more combinatory → needs better space resolution

Particions (Standard Readout)



Standard Readout

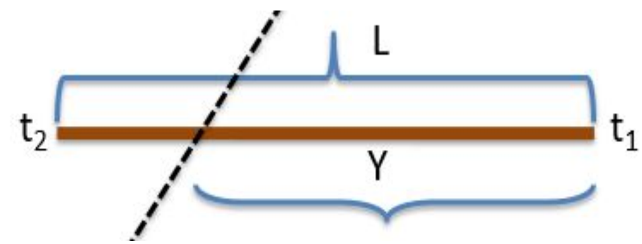
Time of Arrival (Proposal Solution)



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

Improvement

- Better Y determination:
- Less channels (2/eta rather than 4 for large detector);
- Good absolute timing: reduced jitter due to better electronics and reduced gas gap.



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

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