High rate and fine space resolution RPCs operated with eco-gases

G. AIELLI FOR THE WP13.2.3 COLLABORATION

AIDA KICKOFF MEETING - CERN – 4/6/2015

Motivations tasks and strategy

- Almost 10000 RPCs have been installed for the experiments at LHC (Alice, ATLAS, CMS)
- An established standard: Gas, Material, Internal structure.
- A new challenge: a new generation of RPCs for HL-LHC and beyond
- Inherit the overall simplicity in the new standard
- **We target at a new level of performance** in (non necessarily at the same time):
  - Rate capability → tens of kHz/cm^2
  - 6x packing factor for installing in narrow spaces
  - Space-time resolution up to → 0.2 ns x 100 μm
  - Ability to run with inexpensive and eco-compatible gases
- **The strategy: strong integration of detector and electronics**
  - A new generation of FE electronics, based on SiGe transistors
  - Inexpensive high performance low power FE from Amplifier to the TDC
- This opens a wide parameter space in the detector design and now exploitable

Task organization within the WP

Task table

Activity	Institute	Main focus	Facility
Eco-Gas	INFN-TOV	Charge distribution vs. mixture	CR test +High grade electronics setup
	INFN-LNF	Precise analysis of the gas mix	CR test + gas chromatograph
	INFN-TO	Non flammable gas mix – ALICE case	Large area large acceptance CR test
	Gangneung Wonju	New mixtures on MRPCs	MRPC test setup
	CERN	An eco compatible gas system	CERN gas group lab and GIF++
New RPCs	INFN-TOV	Optimize more gap layouts for high rate and resolution	Detector construction and test workshop.
	INFN-BA	New materials and procedures	By the RPC production companies
	INFN-BO	The ATLAS case and GIF++ CR trigger	CR test station
High Space resolution	INFN-TOV	High grade large size faraday cage	Detector construction and test workshop.
	MPI Munich	High grade mechanics	Detector construction site

Overall planning

Full test of a New RPC with recirculated eco-gas M13.2

Chemical analysis after irradiation

Start of recirculating ageing test at GIF++

Identify one or few gas mixtures with good performance under cosmic test

2015	2016	2017	2018	2019

High rate and performance of low spatial resolution chambers

ATLAS/CMS/ALICE new prototypes test

High resolution prototype working at high rate

Optimization of large-size precise RPC structures D13.3

High rate High resolution, large surface test

Research of a new gas mixture

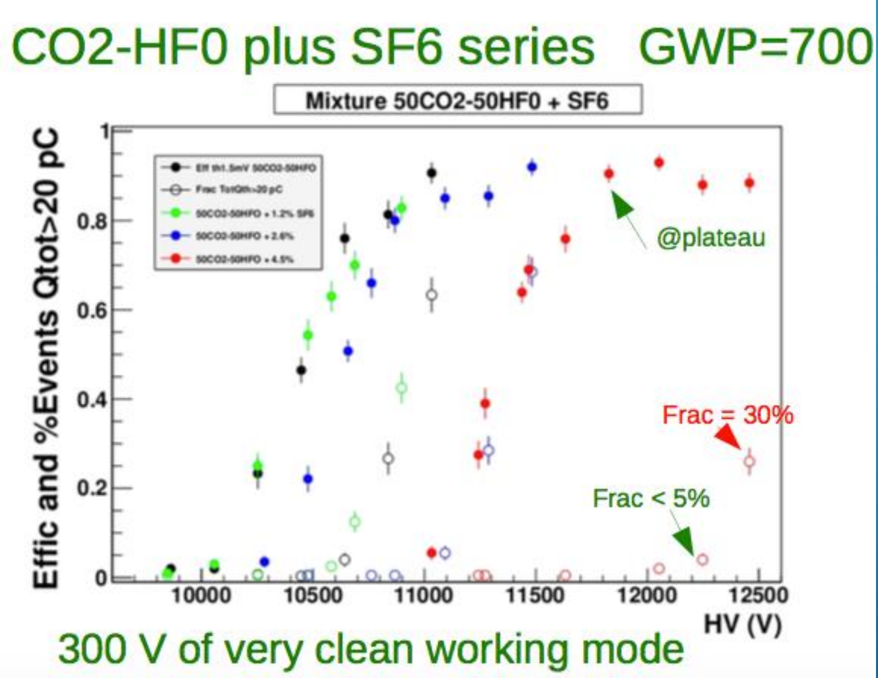
- The European Community has prohibited the production and use of gas mixtures with Global Warming Power > 150 (GWP(CO_2) = 1)
  - This is valid mainly for industrial (refrigerator plants) applications
  - Scientific laboratories would be excluded
  - CERN could require to stick to these rules anyhow
- $C_2H_2F_4$ is the main component of the present RPC gas mixture:
  - GWP($C_2H_2F_4$) = 1430, GWP(SF_6) = 23900, GWP(iC_4H_{10}) = 3.3
  - $C_2H_2F_4$ and SF_6 Crucial to ensure a stable working point in avalanche
- To test molecules similar to $C_2H_2F_4$ but with lower GWP
  - See http://arxiv.org/abs/1505.00701v1 for a review
- HFO=1234ze (1,3,3,3-Tetrafluoropropene) has been identified as a possible choice

State of the art:

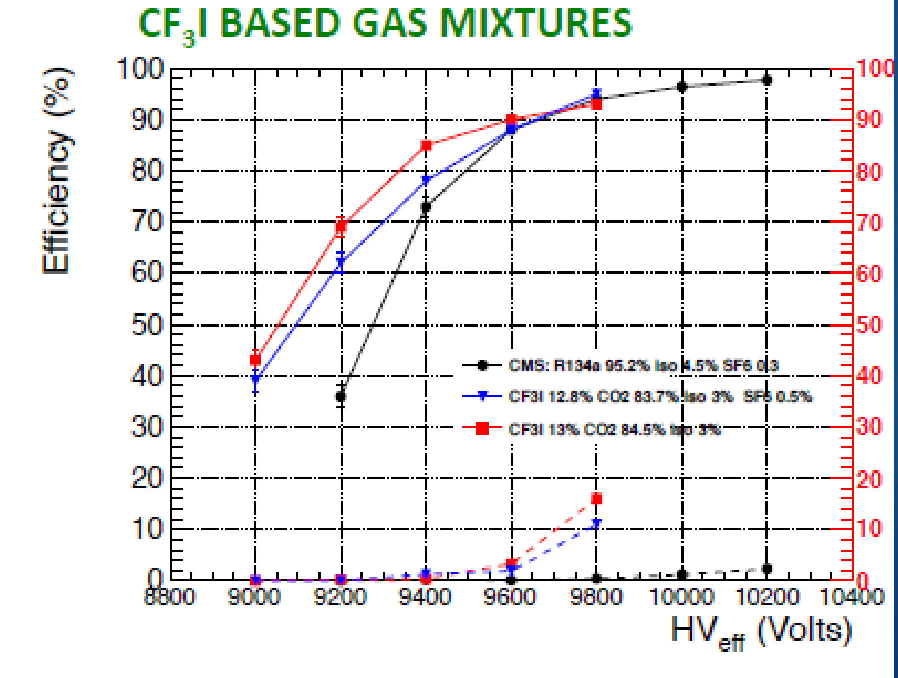
- "new RPC gas mixtures for large area apparatuses" Presented at RPC14 workshop by B. Liberti and Published on JINST: R. Cardarelli et al. JINST 9 C11003 doi:10.1088/1748-0221/9/11/C11003
- "A study of HFO-1234ze (1,3,3,-Tetrafluoropropene) as an eco-friendly replacement in RPC detectors. : L.Benussi et al. http://arxiv.org/abs/1505.01648

Eco Gas progress

- Several results have been published as proceedings of the RPC2016 conference (authors have been reminded to authors AIDA2020 logo…)
- Common ATLAS-CMS effort
- Start to see promising gas candidates to have a sufficient streamer free operation point



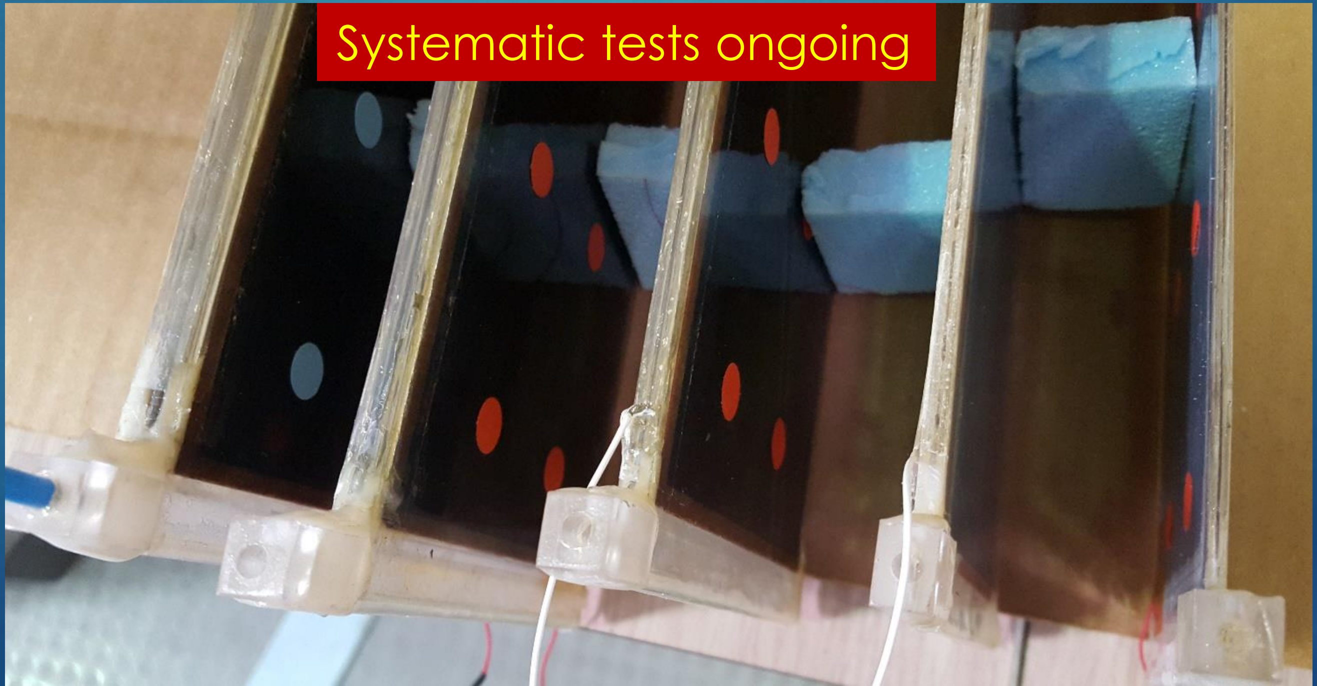
B. Liberti et al.



D. Piccolo et al.

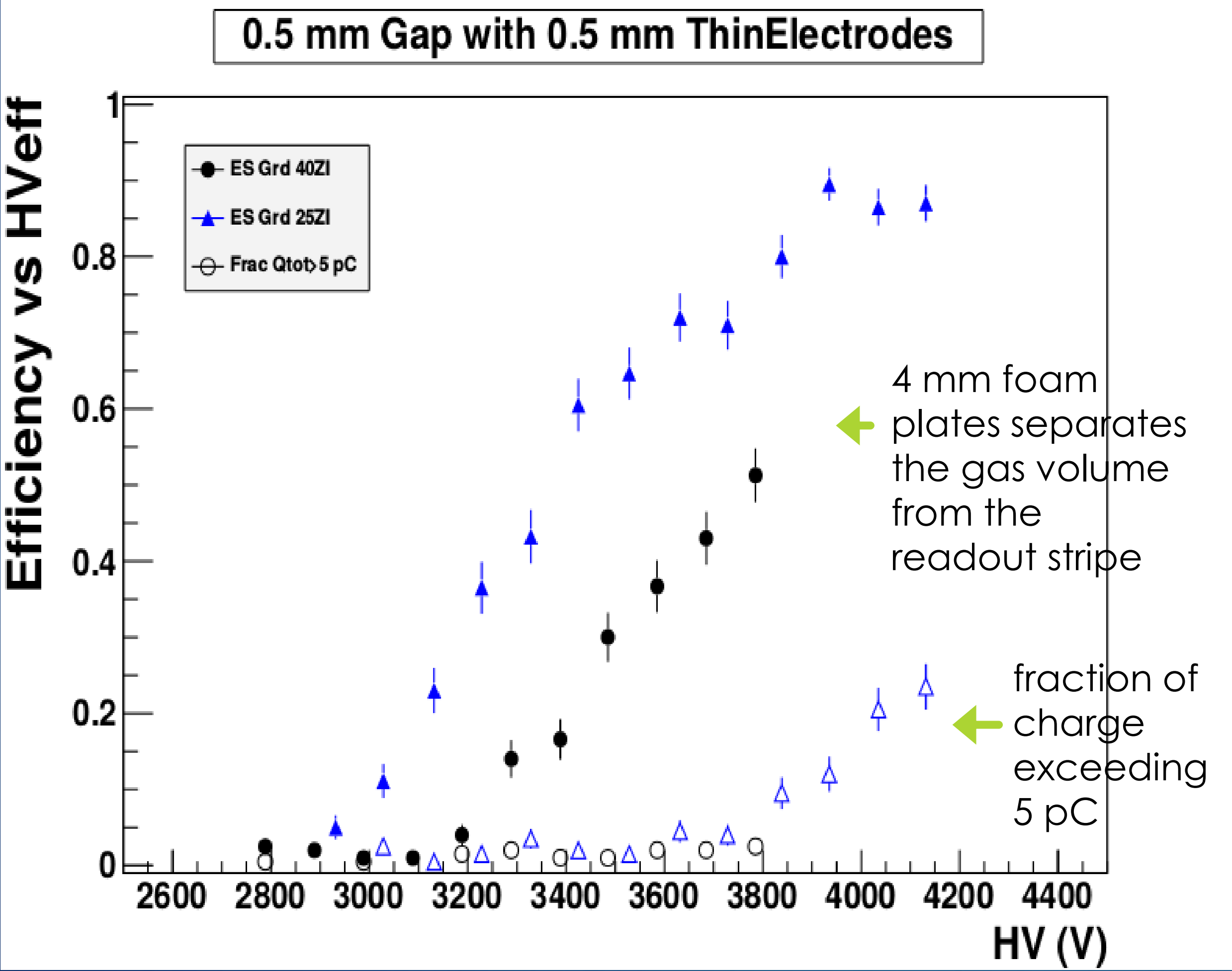
Further R&D for Phase2

- Thinner gas gaps for higher rate and time resolution → systematic comparison between 2 mm, 1 mm, 0.5 mm
- Thinner electrodes with respect to ATLAS and CMS (1.8 and 2 mm)
- Tested 1.2 mm and 0.8 mm
- New materials for the electrodes under study (phenolic glass)
- Better mechanical properties, same resistivity as bakelite…

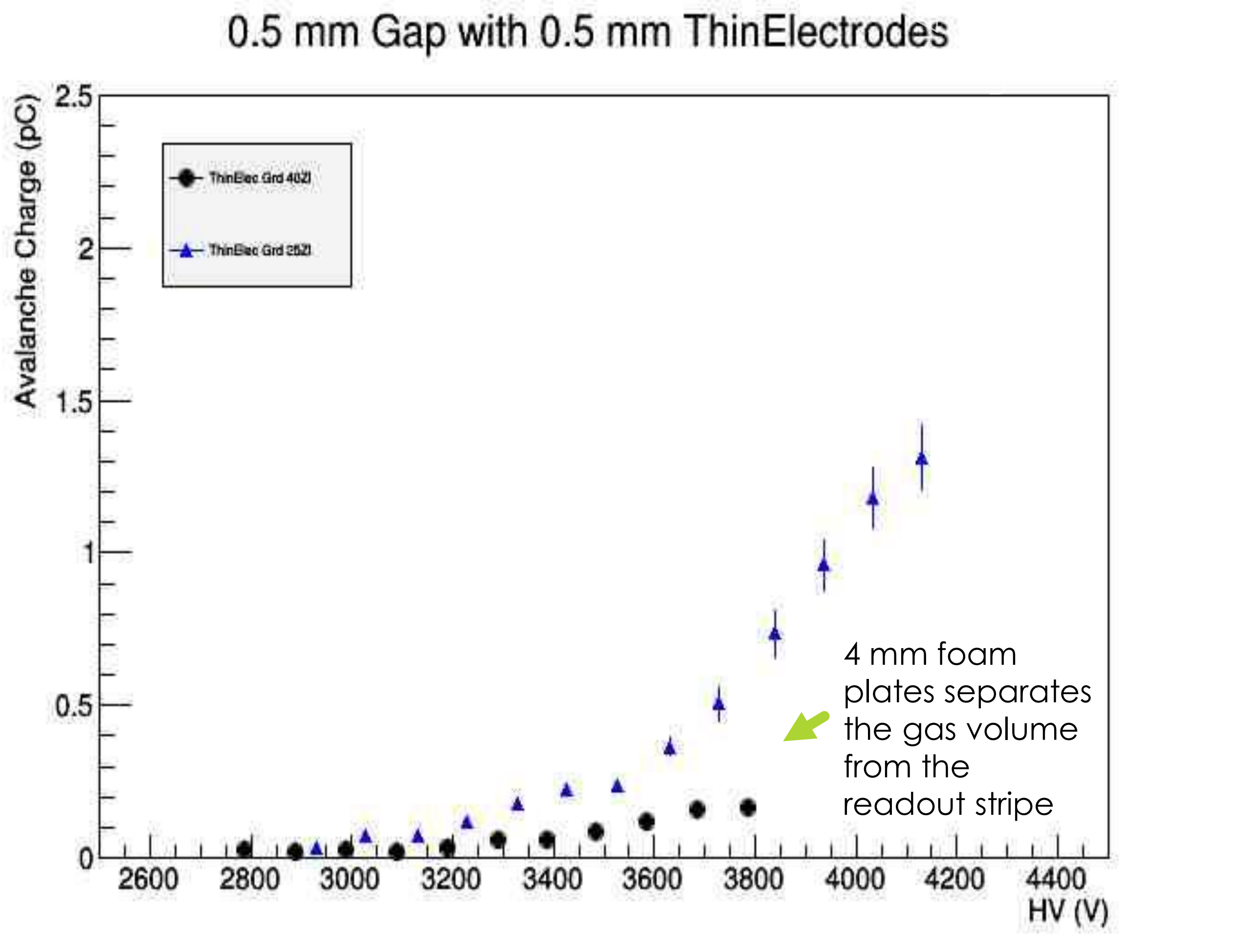


Pushing classic RPC to the limit

Pure phenolic glass Efficiency vs HV



Prompt charge comparison vs HV

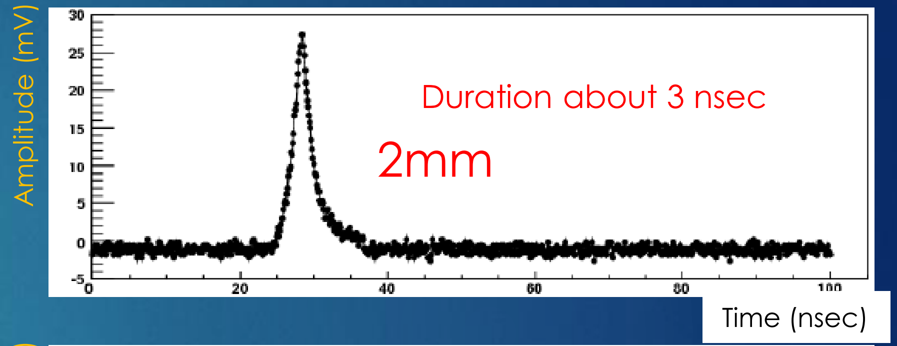


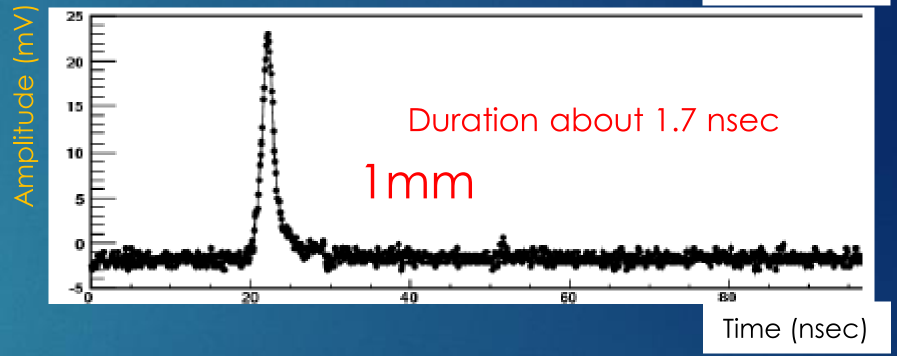

A new generation of
RPCs is coming…

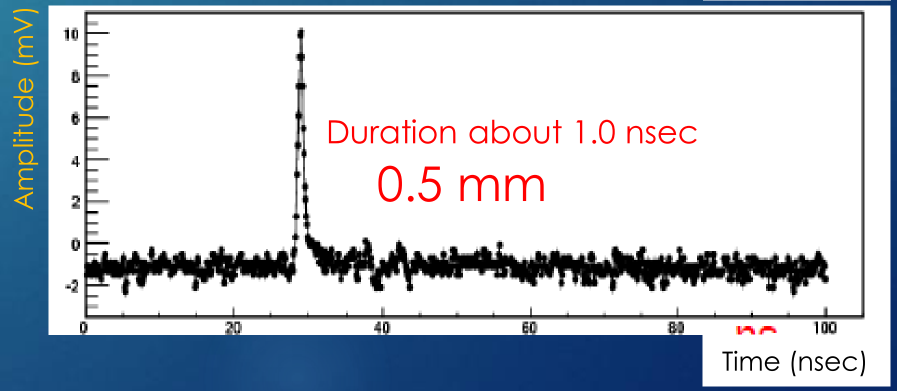
A new generation of RPCs

R&D themes and initiatives

- **Form Factor**: exploring gap and electrode thickness and segmentation
  - Thinner gas gap → better timing, position, lower thickness
  - Thinner electrodes → better S/N, lower weight
  - Multi-gap → better efficiency, timing, charge spectrum
- **High spatial resolution readout**:
  - Form factor optimization→ higher signal localization
  - High grade Faraday cage → allows sensitive FE
  - Charge through ToT → charge centroid
- **New FE concept:**
  - New design: Fast, sensitive and low capacitance noise
  - Si-Ge technology: extremely low noise and high speed

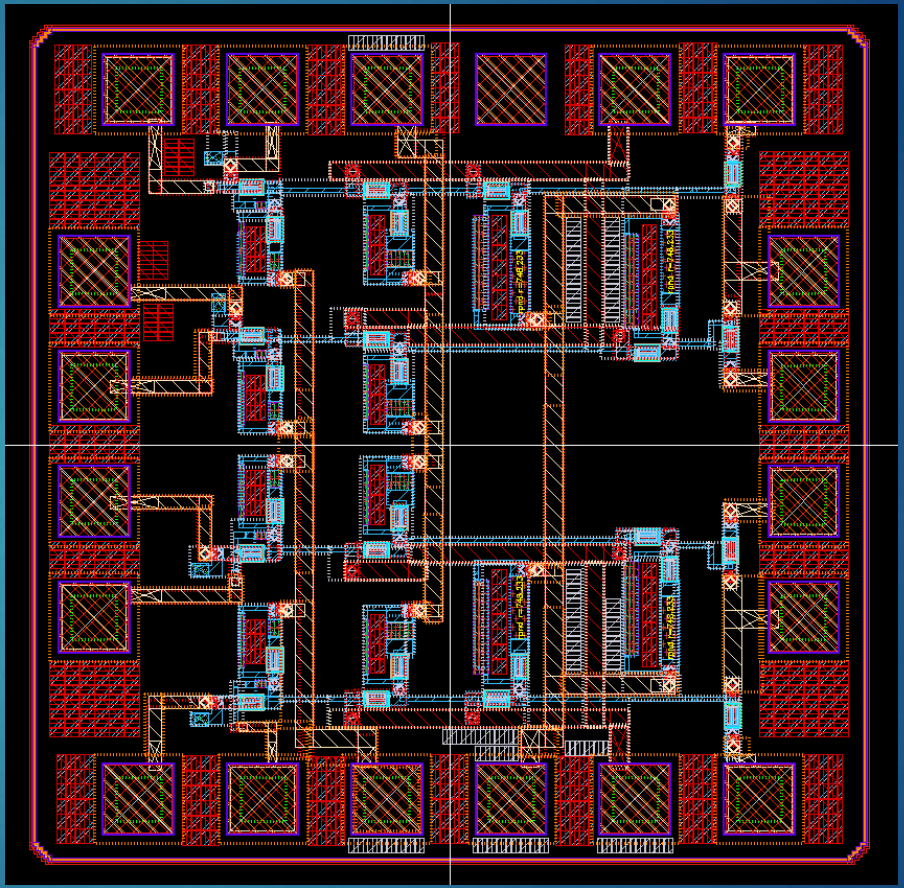






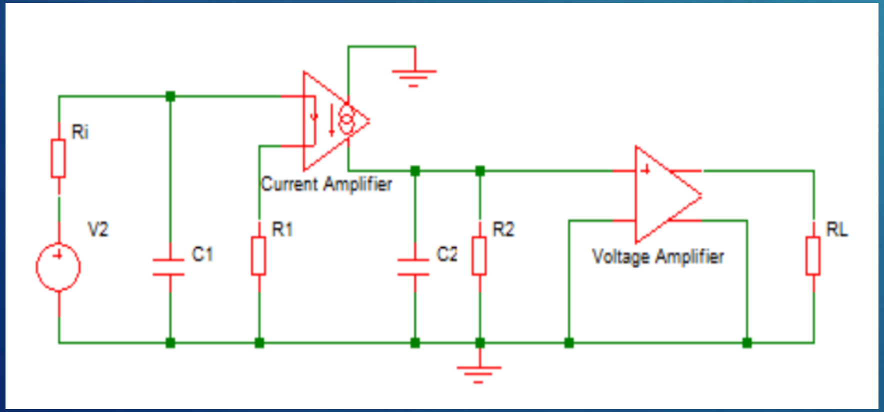
The new FE electronics

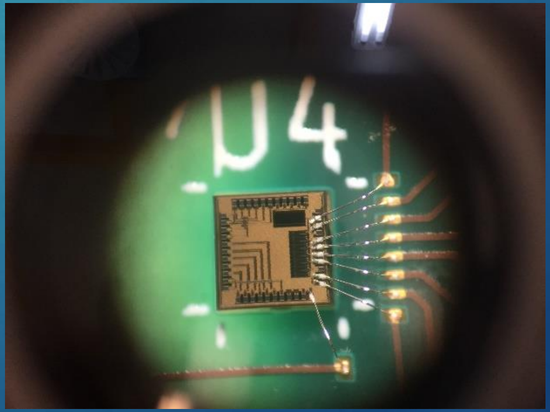
- High sensitivity to increase the rate
- High time precision for charge readout and meantimer functions



The new Amplifier

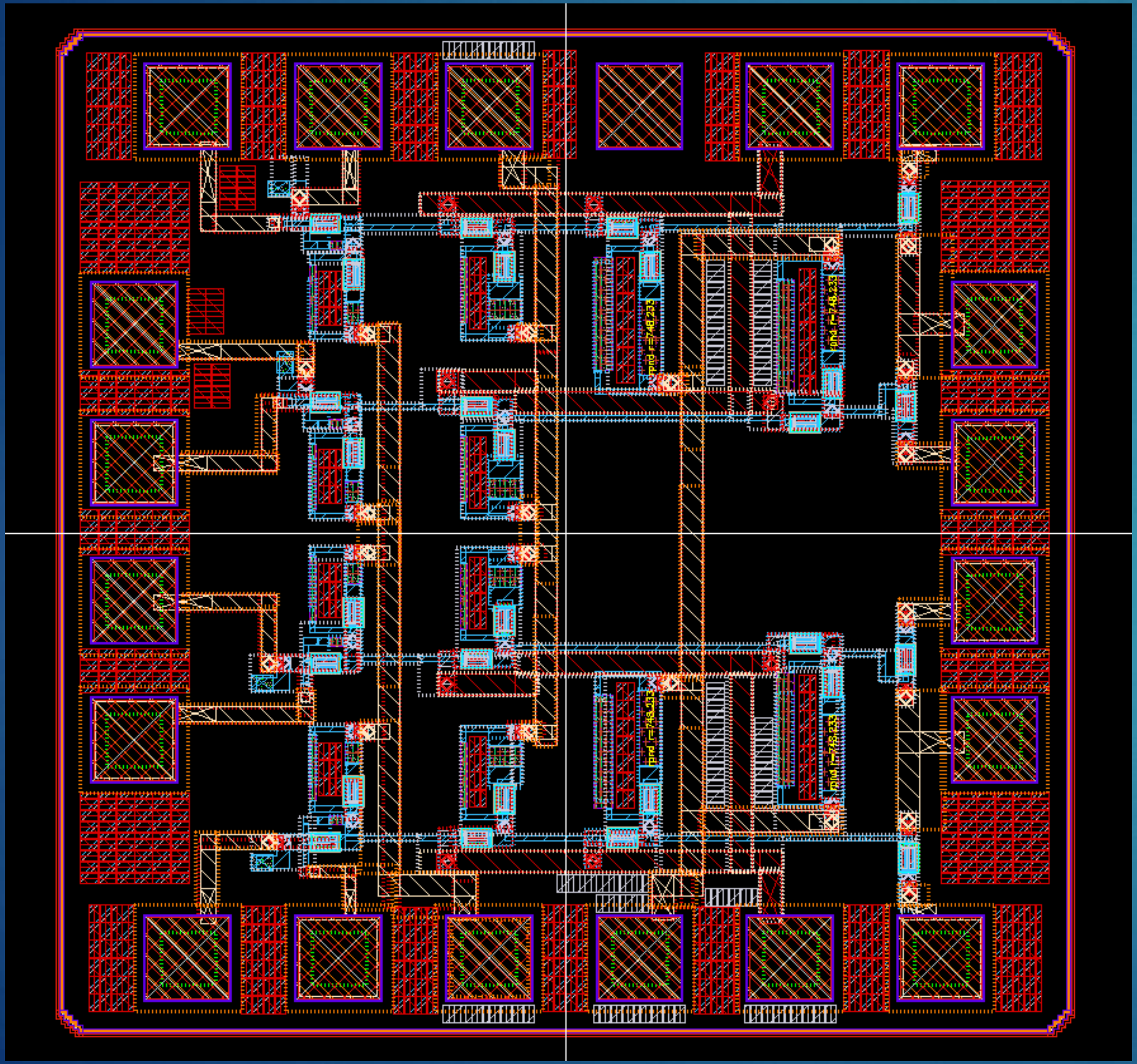
Feature	BJT Si (BIS78)	Bi-CMOS SiGe
Year established	2008	2016
Voltage supply	3-5 Volt	3-5 Volt
Sensitivity	2-4 mV/fC	3.5 - 6 mV/fC
Noise (up to 20 pF input capacitance)	**1500 e^- RMS**	**500 e^- RMS**
Input impedance	100-50 Ohm	100-200 Ohm
B.W.	10-100 MHz	100-200 MHz
Power consumption	10 mW/ch	10 mW/ch
Rise time $\delta(t)$ input	300 – 600 ps	200 – 400 ps
Radiation hardness	1 Mrad, 10^{13} n cm^{-2}	50 Mrad, 10^{15} neq cm^{-2}



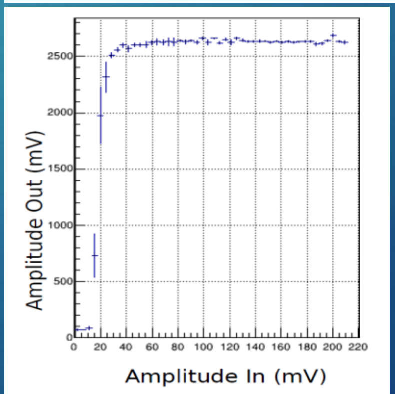


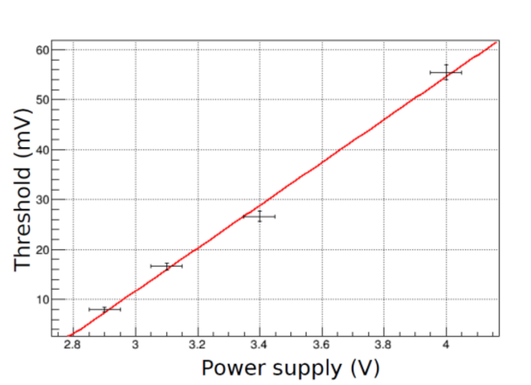
Test IC produced and tested on Diamond and Silicon

A new discriminator

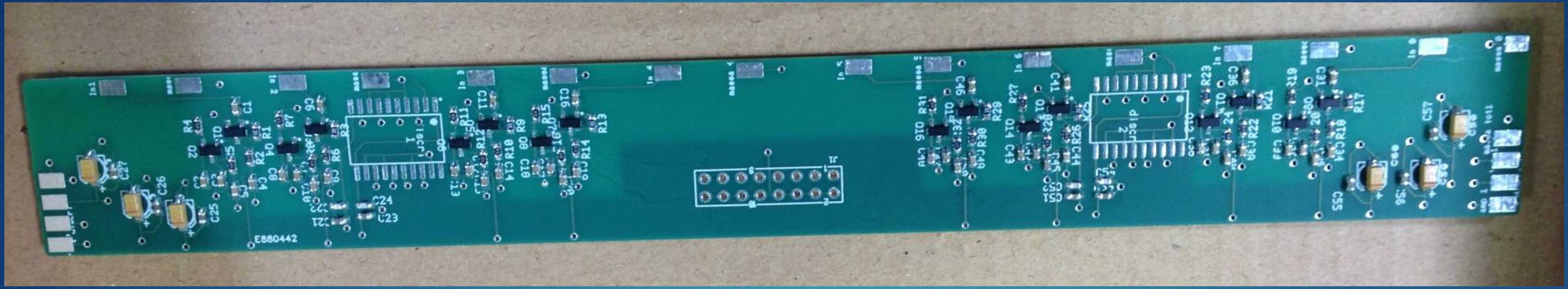


Feature	value
Technology	BiCMOS IHP SiGe
Voltage supply	2-3 V
Threshold	3-200 mV
Input impedance	100 Ohm
B.W.	500 MHz
Power consumption	10 mW/ch
Rise time output	300 ps
Radiation hardness	1 Mrad, 10^{13} n cm^{-2}
Discriminator type	Updating
Min. duration input pulse	0.5 ns
Double pulse separation	1 ns
Channels per chip	4

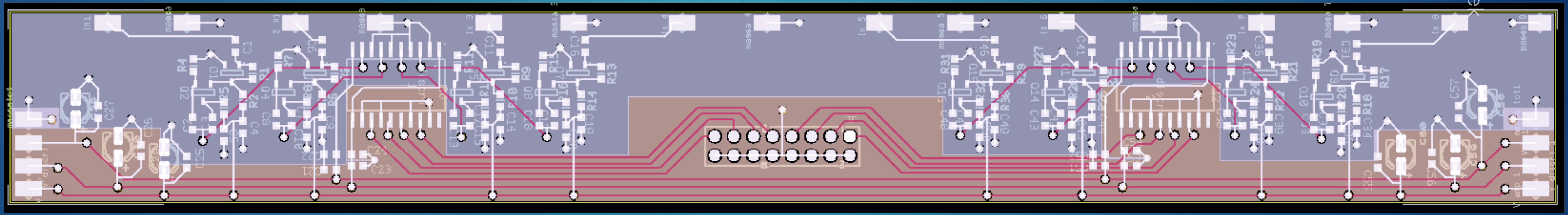




RPC FE electronics for Phase1 projects

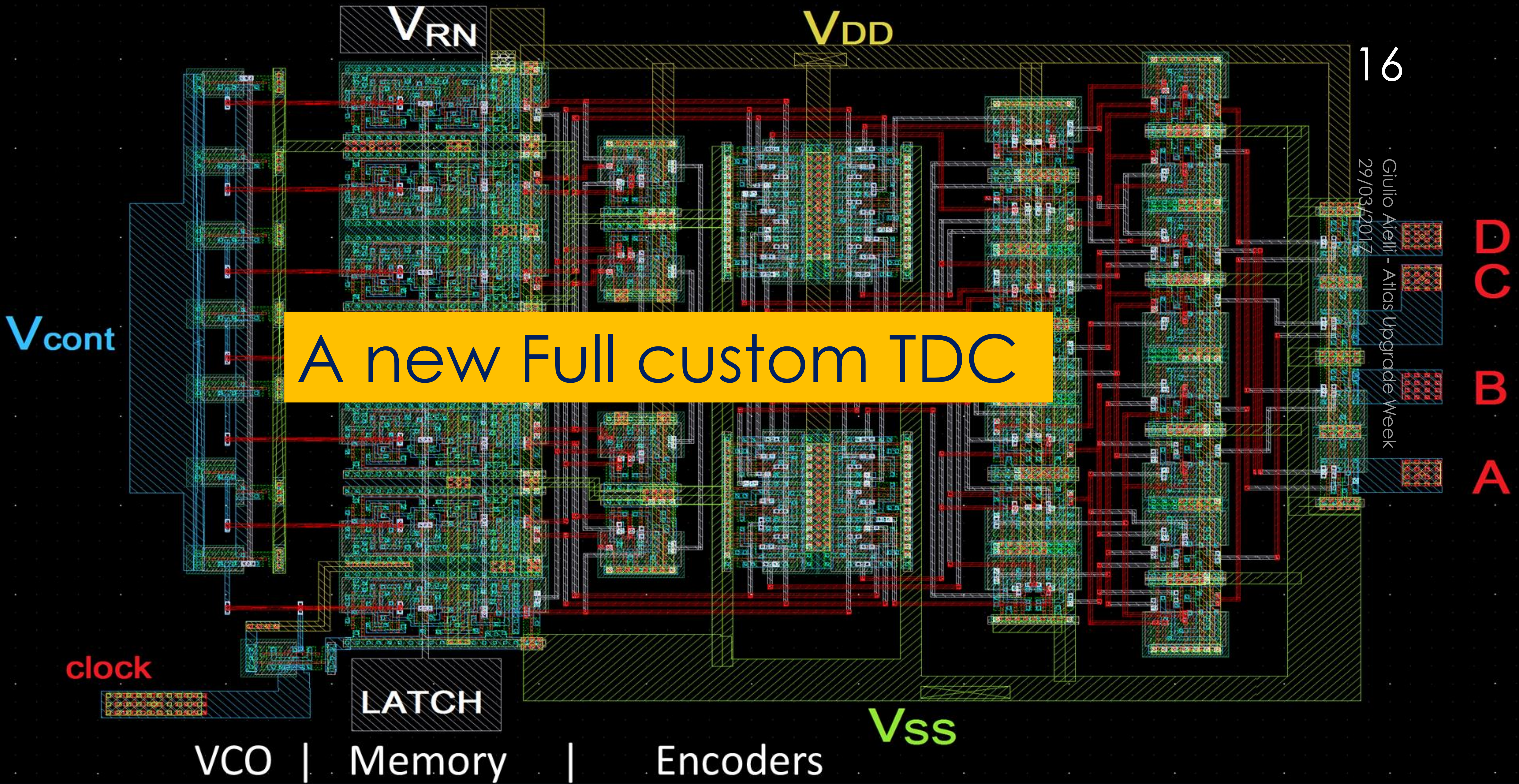


Final prototype FE boards



Layer 1 : In, Components, Amplifier and Discriminator
Layer 2 : Analogic Ground plane
Layer 3 : Amplifier/Discriminator connection and TTL Output
Layer 4 : Digital Ground plane

A new Full custom TDC



TDC development

- Why a new TDC? Nothing suitable found on the market
- This TDC is a multipurpose circuit suitable for fast devices and developed within an independent project by R. Cardarelli.
- Scheduled for RPC upgrade, Silicon PET scanners,
- Three foundry run performed.
- **Achieved**:
  - 4 channels TDC
  - 30 pS; 1 mW/channel
- **Next steps**:
  - Integrate Analog and digital part (Amplifier-discriminator-TDC)
  - Multichannel final prototype
- **Ultimate goal**: 1 ps TDC ~1mW/channel

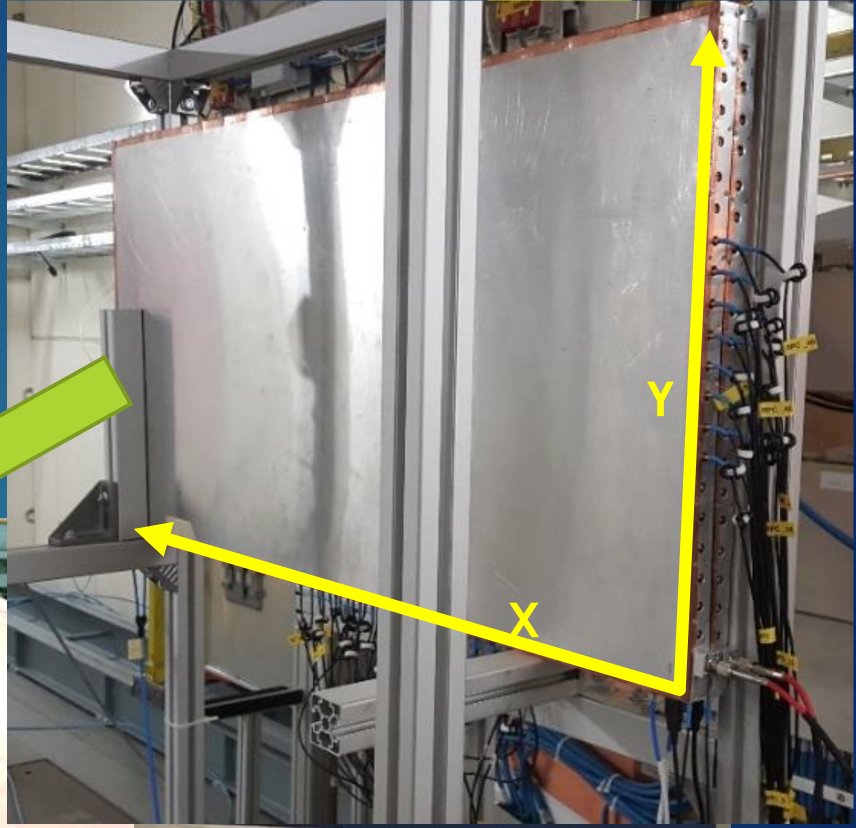
High rate test on a multiplet

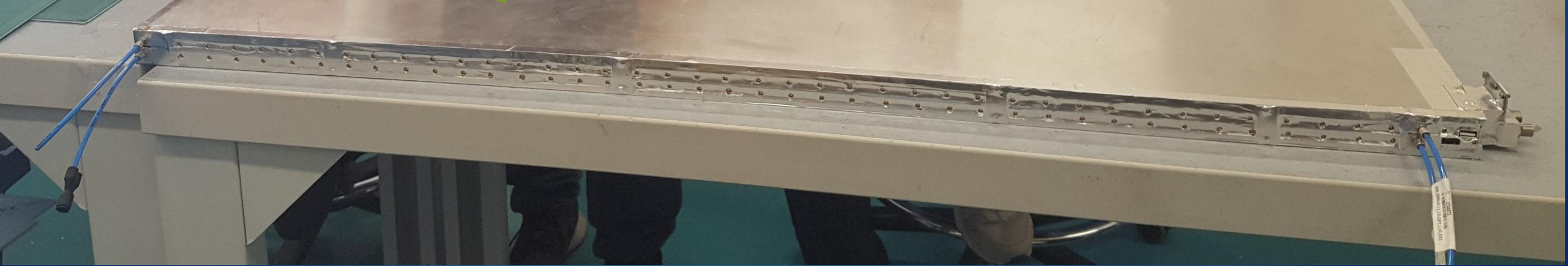
Intermediate size 50 x 100 cm^2 singlets with full X-Y readout → 2x X-Y doublet

A crucial test: Inner Faraday cages independency

- 35 mm total thickness all in
- Tested gap cross talk < 10^{-4}

Gas gap: 1 mm
Electrodes: 1.2 mm

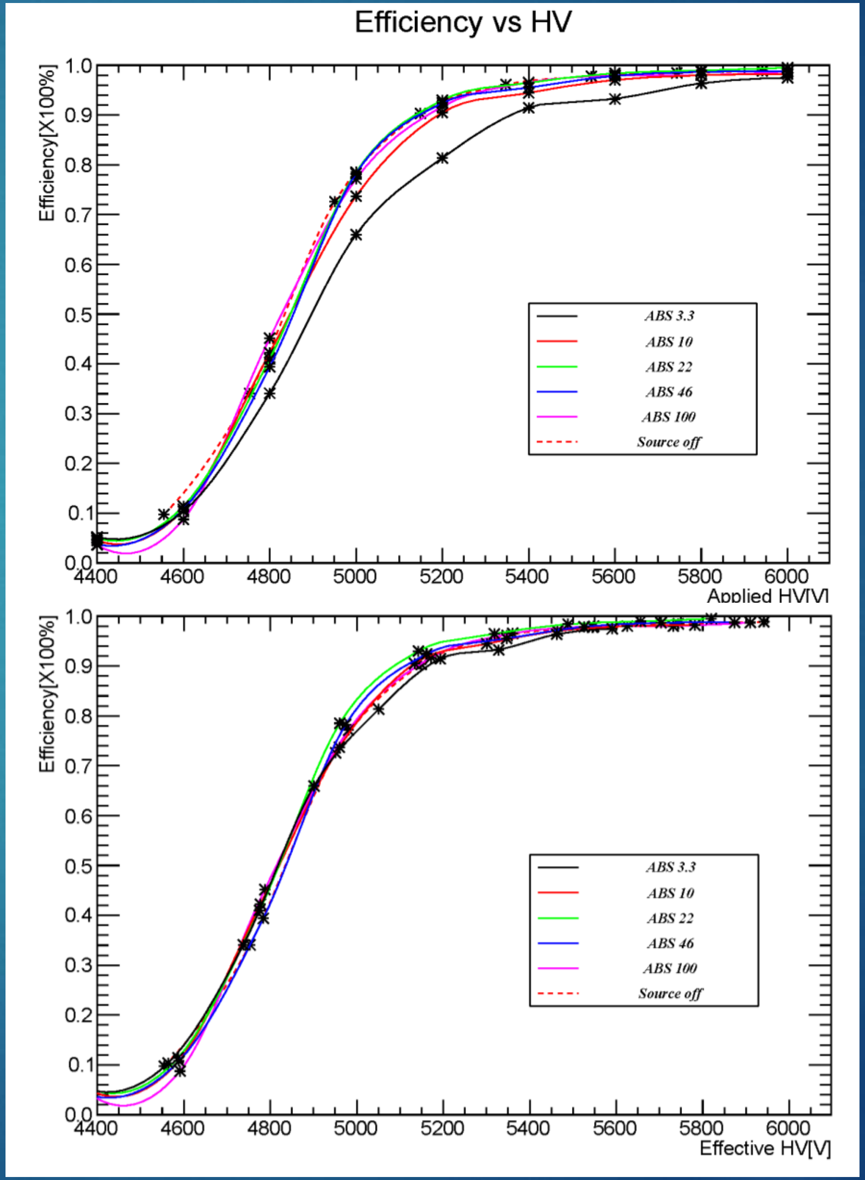




Efficiency at high rate

- Trigger from 2 scintillators 12x12 cm^2
- Use 1 chamber as monitor and calculate the efficiency of the other chamber.
- An efficient hit must be correlated in time (20 ns) and space (+- 1 strip) with the monitor hit on both x-y views
- Analysis debugged and results improved !

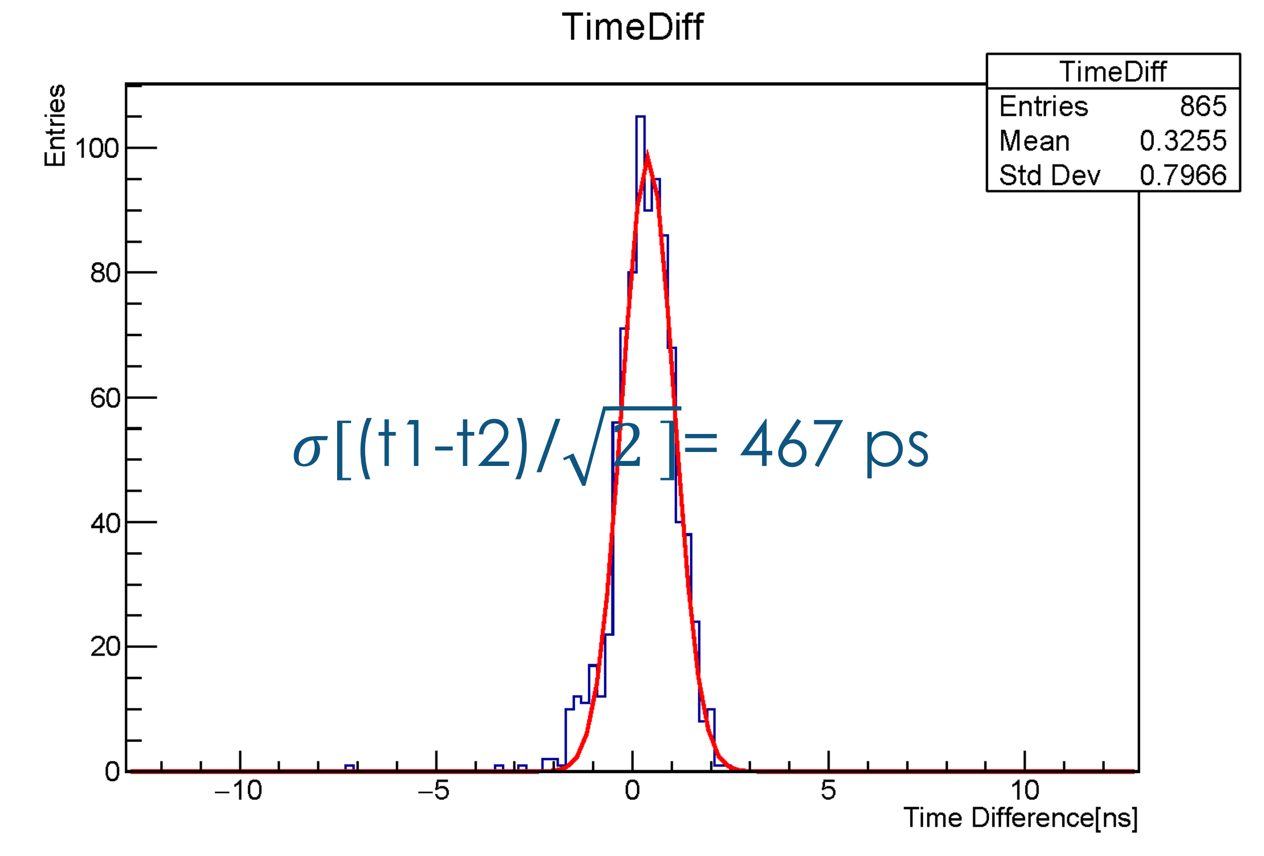
5400V is an excellent working point (95% eff.)

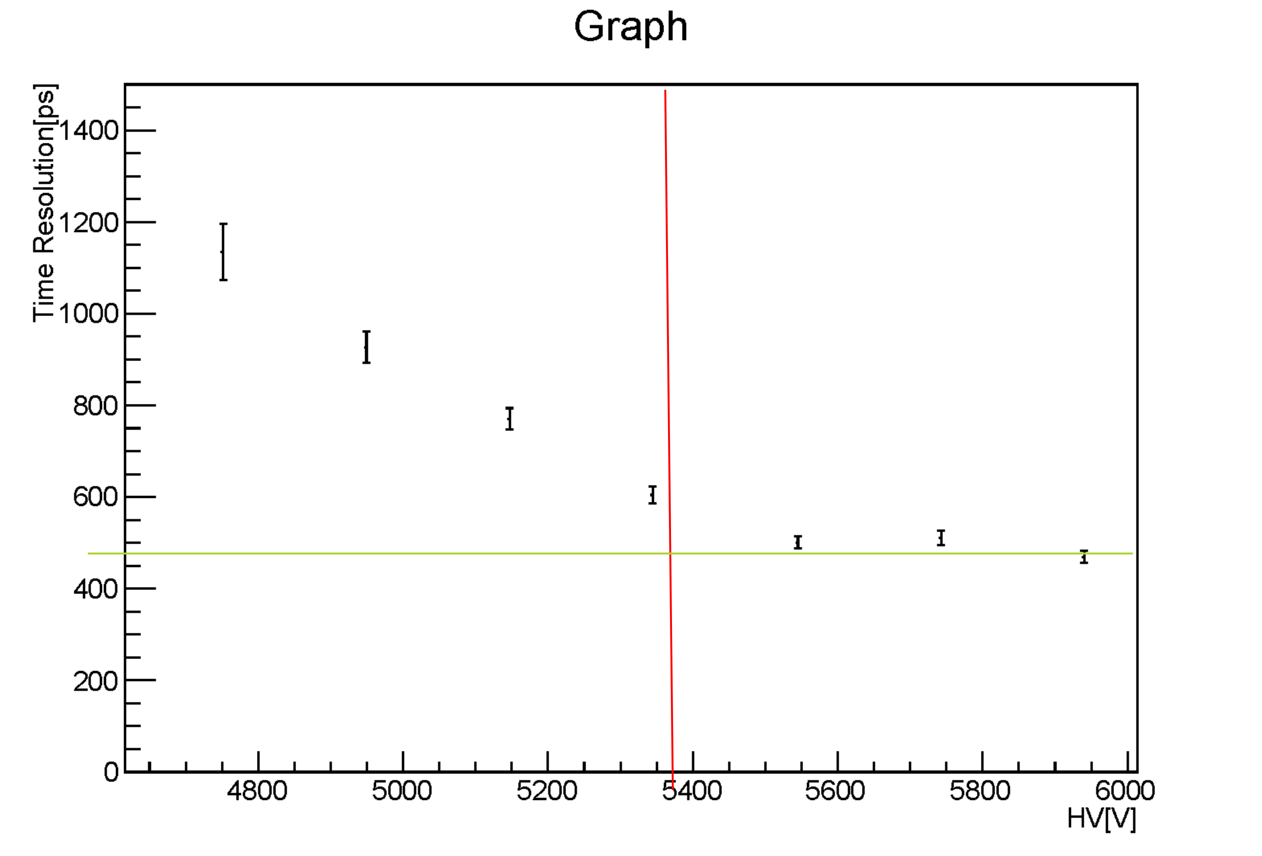


~ HL-LHC background

~7*HL-LHC background

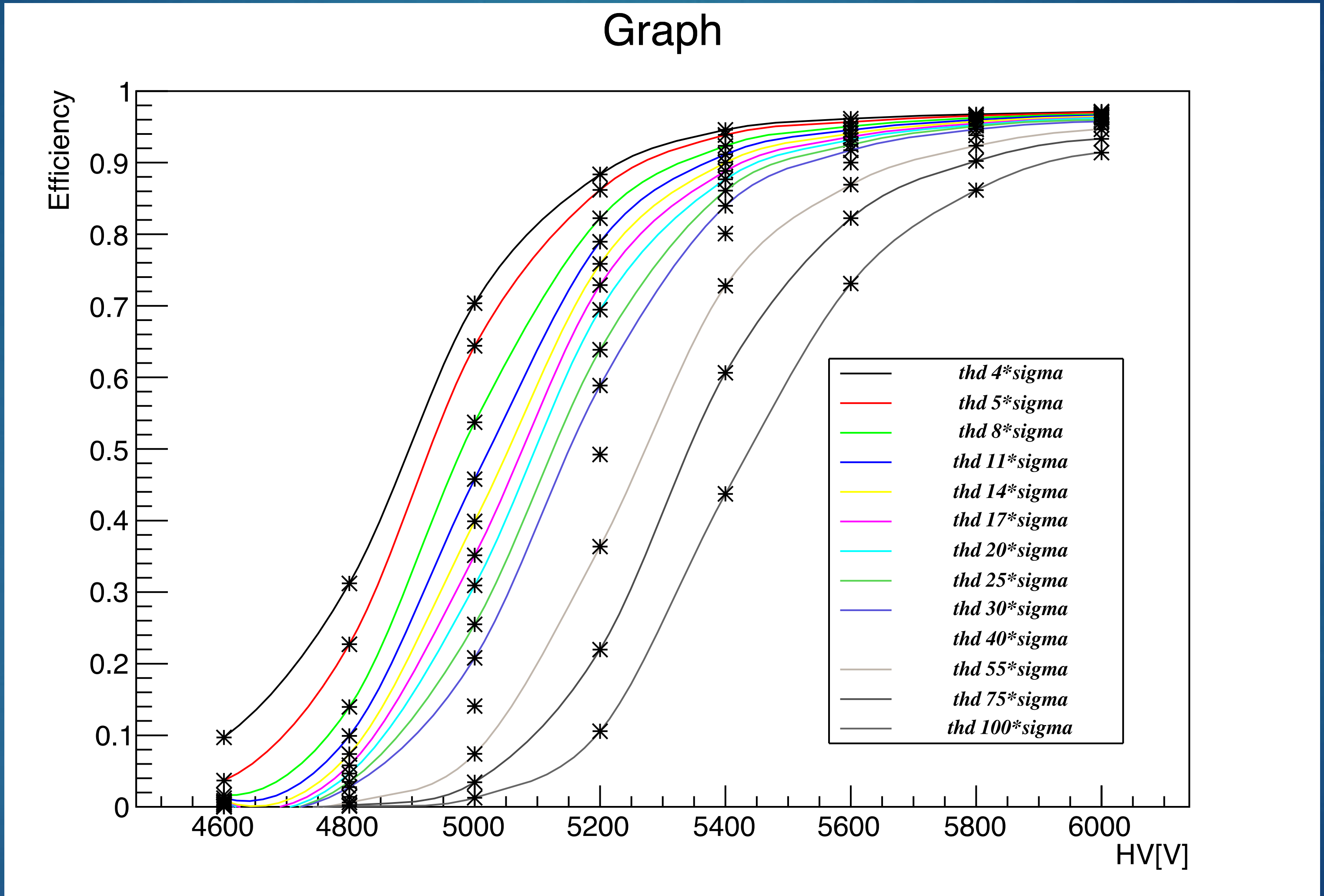
Time resolution at high rate



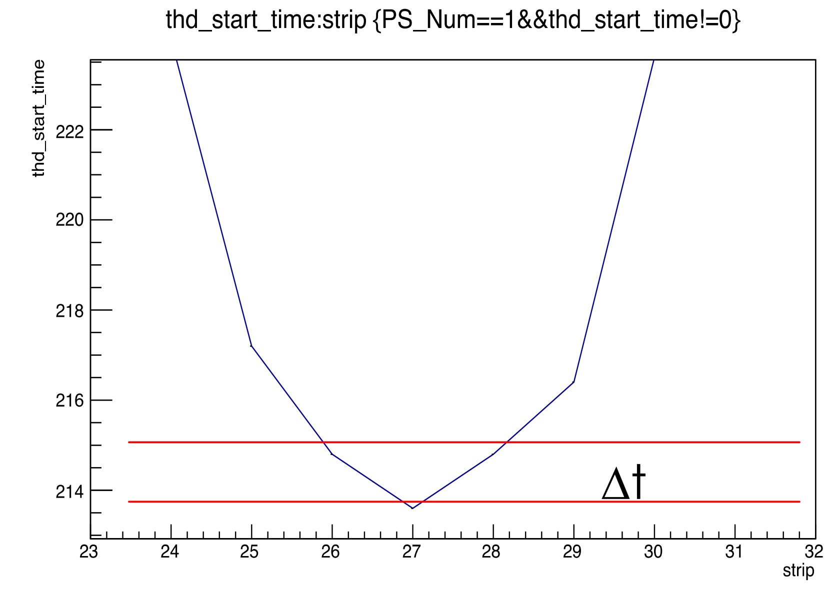


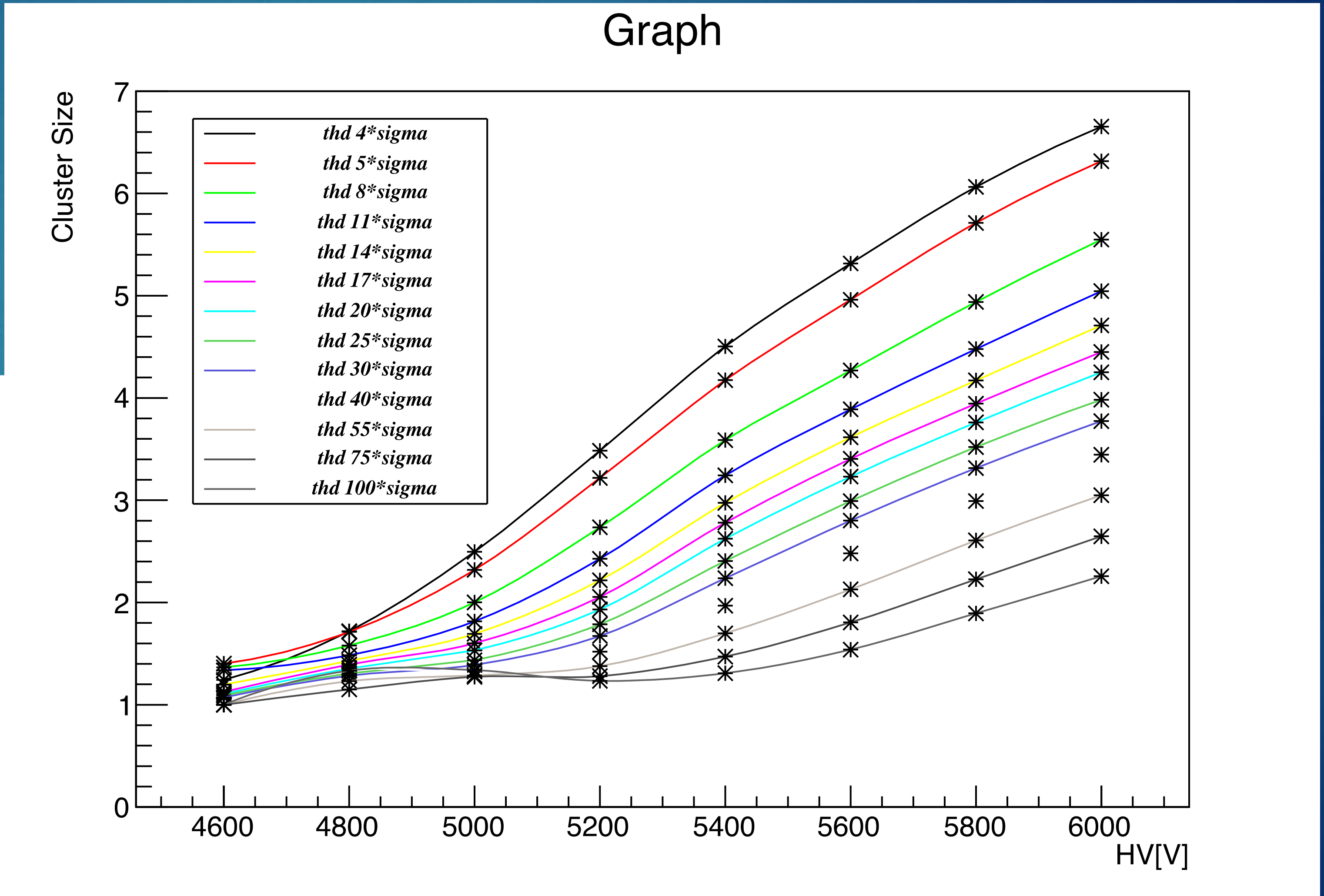
- The hv in time resolution is corrected by temperature and humidity.
- Time diff is at 6000 V without source.
- No skew correction and no channel calibration applied

Efficiency VS HV

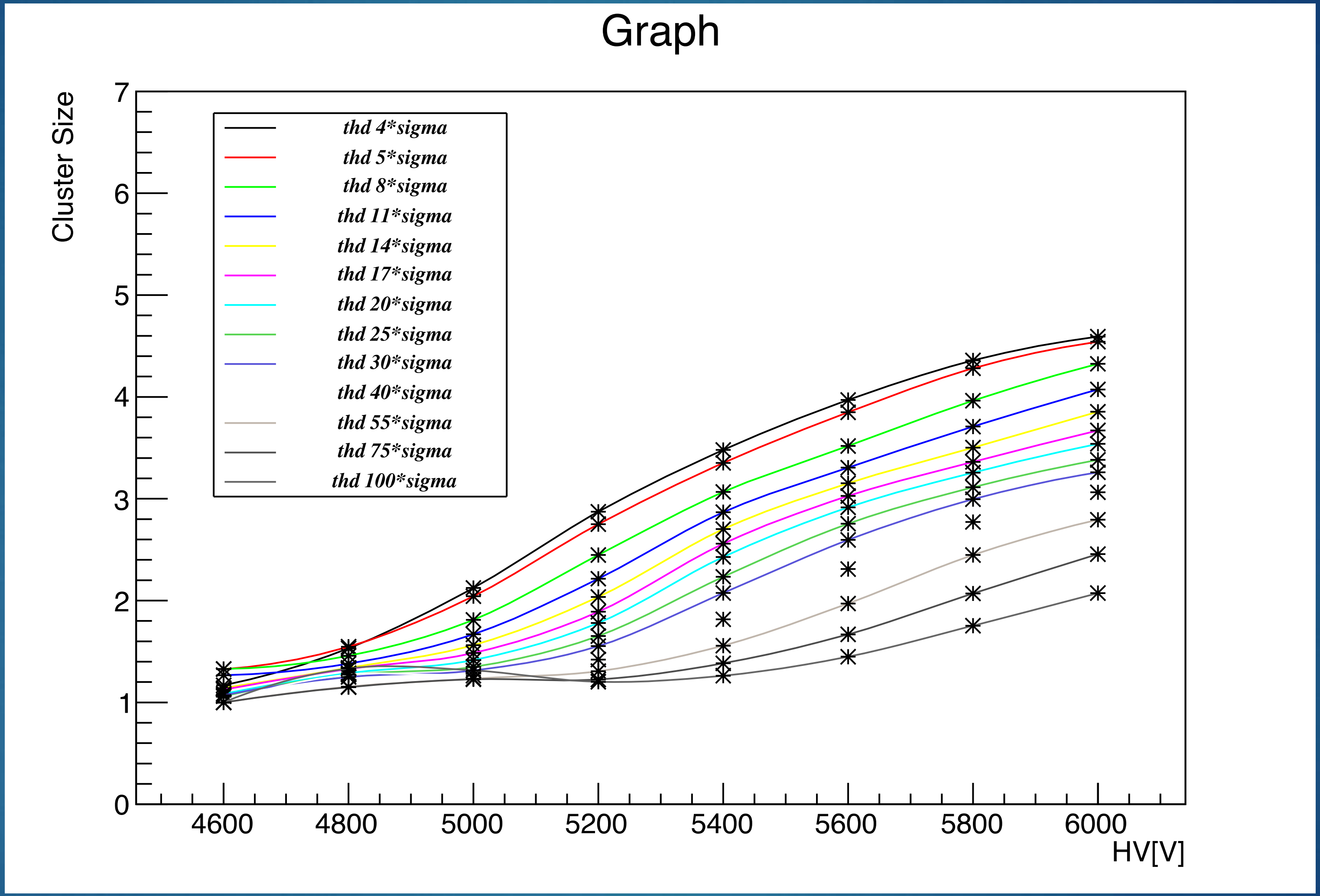


Cluster Size VS HV(no time cut is applied)

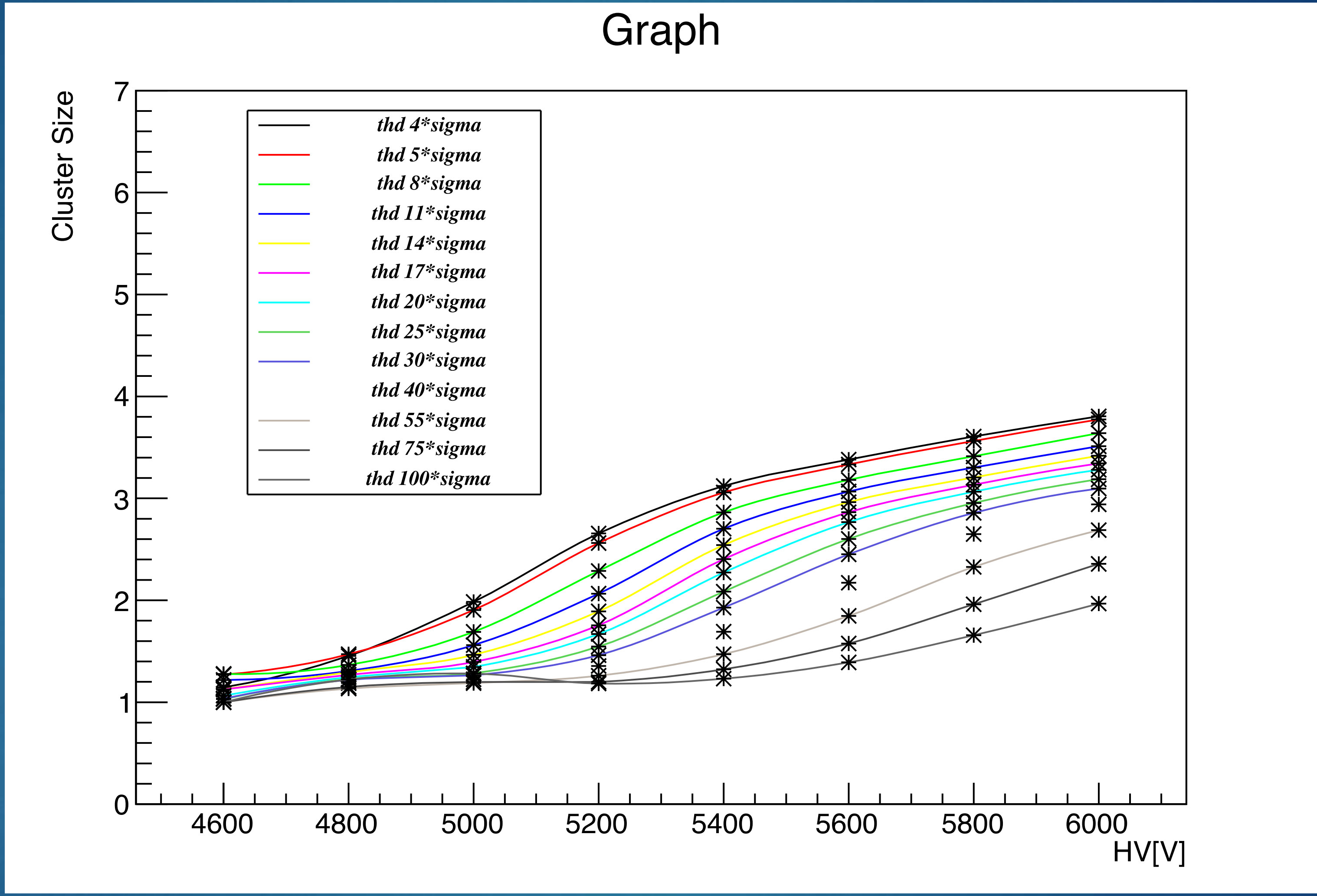




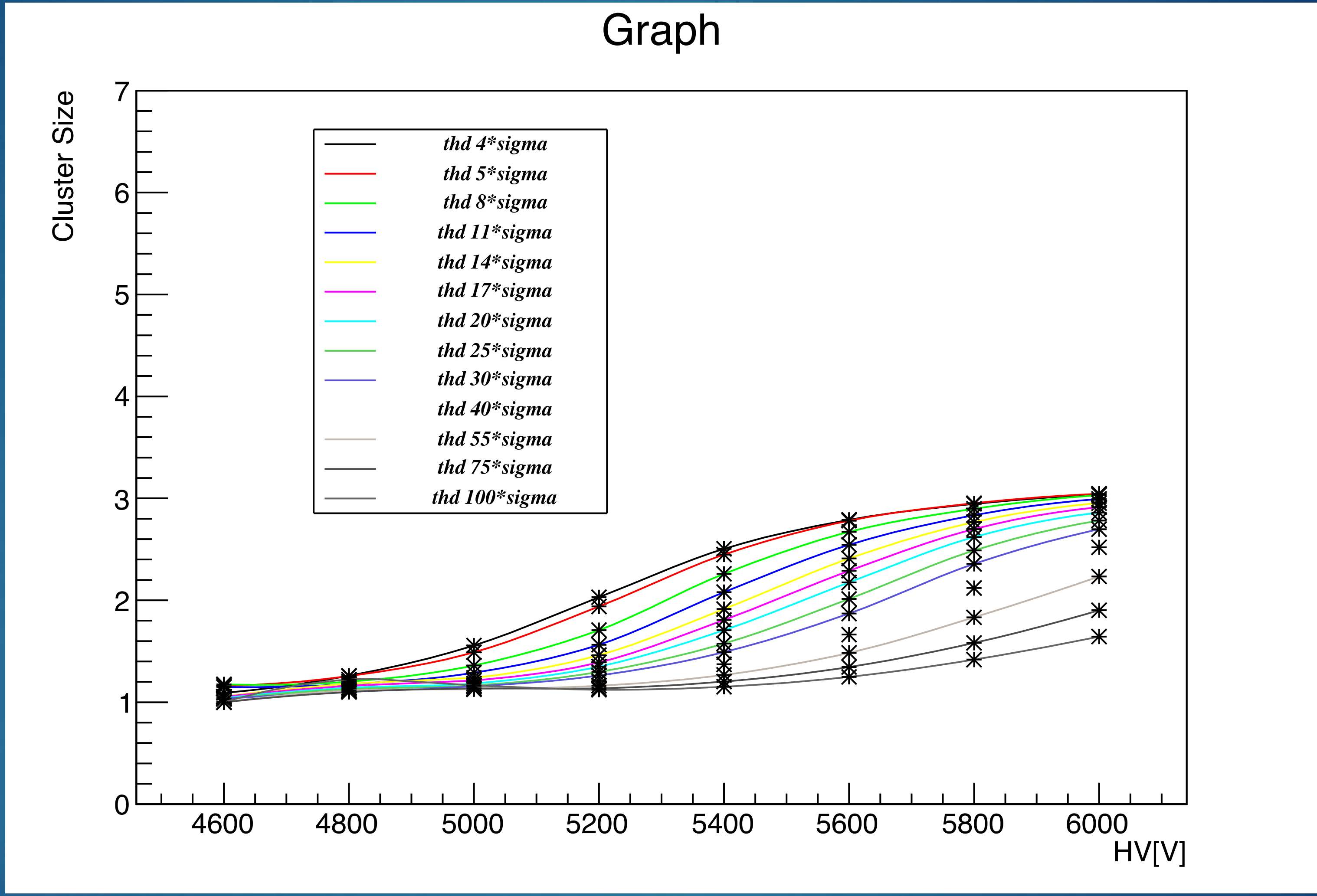
Cluster Size VS HV(4ns time cut is applied)



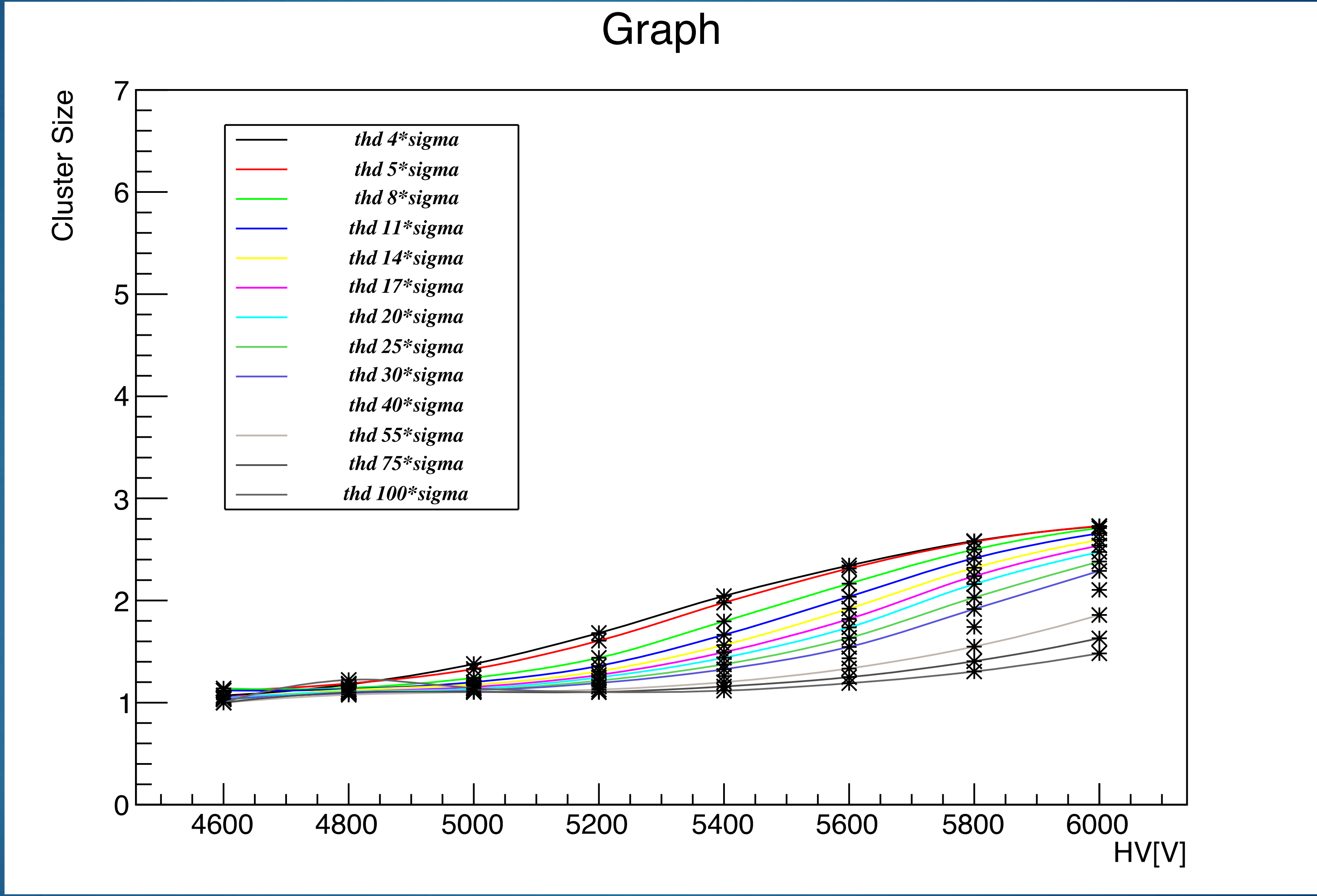
Cluster Size VS HV(3ns time cut is applied)



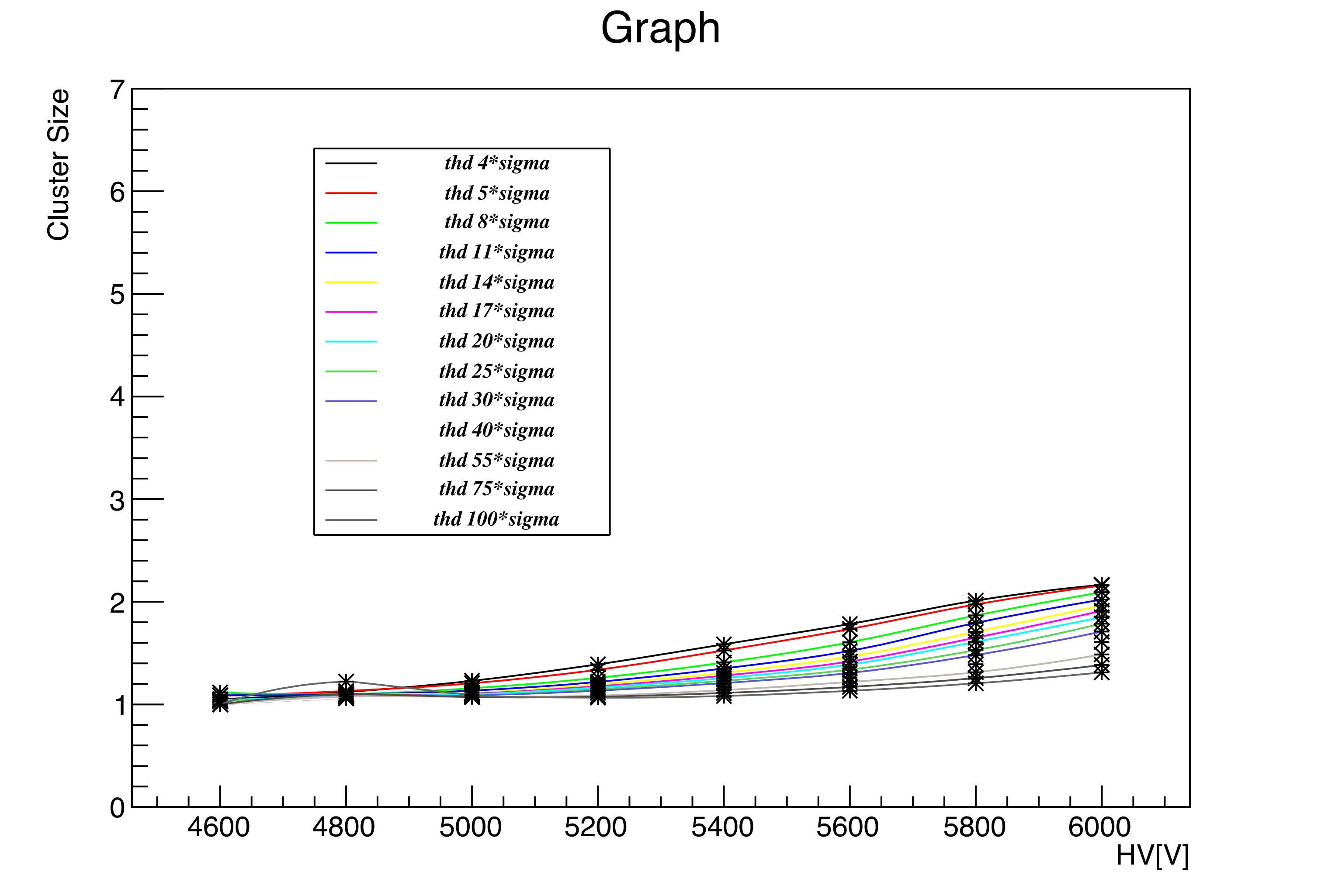
Cluster Size VS HV(2ns time cut is applied)



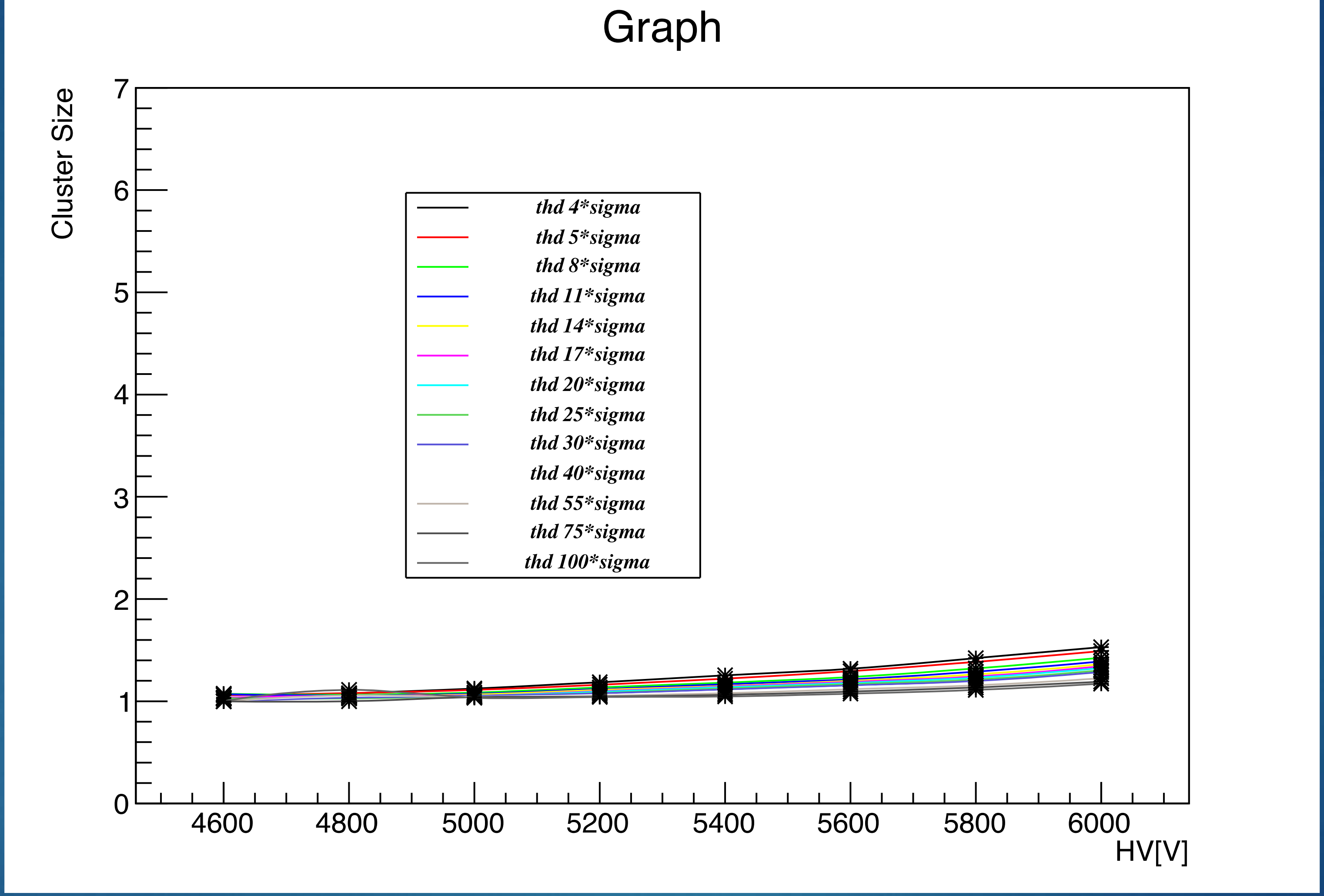
Cluster Size VS HV(1.5ns time cut is applied)



Cluster Size VS HV(1ns time cut is applied)



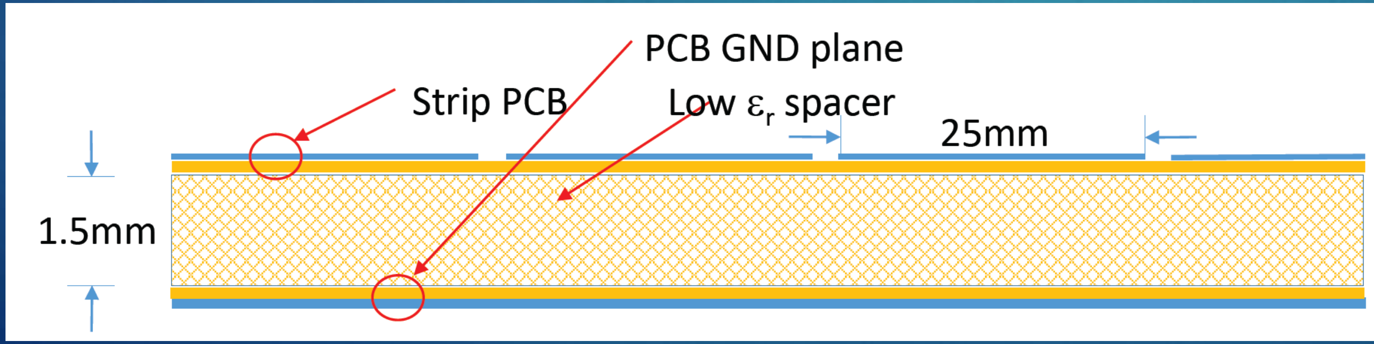
Cluster Size VS HV(0.7ns time cut is applied)



Simulation of the readout panel

- A major effort is required in redesigning the new readout panel
- An extensive simulation is needed systematically exploring a vast parametric space including (non exhaustive list):

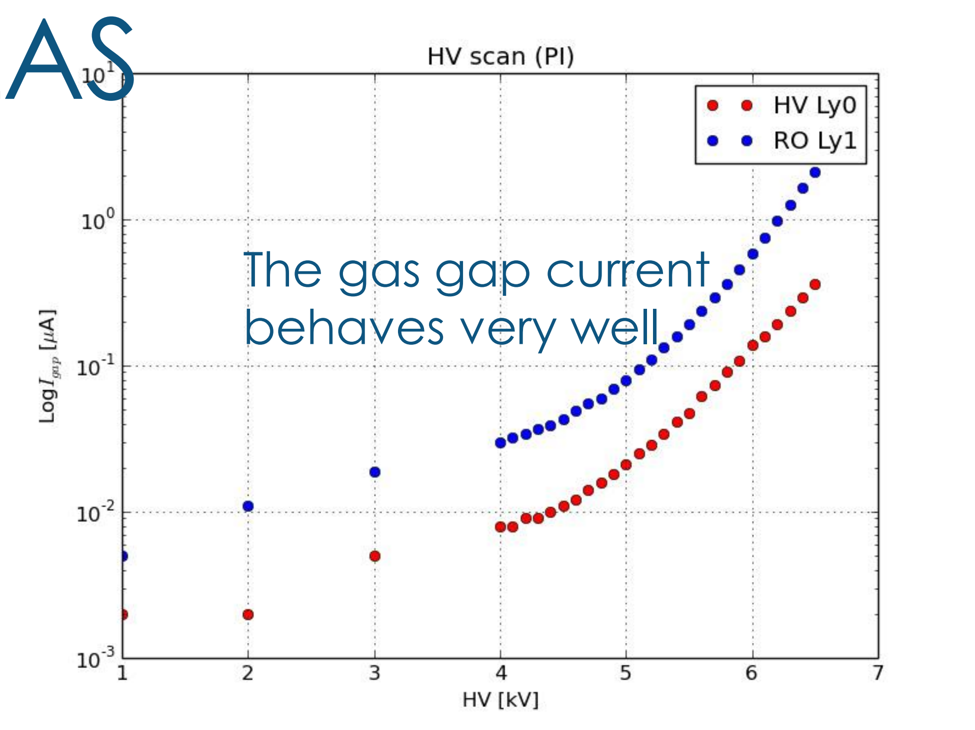
- Strip pitch
- Strip distance
- Strip inner segmentation
- Guard wire
- Dielectric thickness
- Dielectric permittivity
- Strip termination
- Presence of orthogonal readout strips
- Distance of the strips
- Resistive electrode thickness
- Resistive electrode material
- Gas gap width
- Graphite thickness

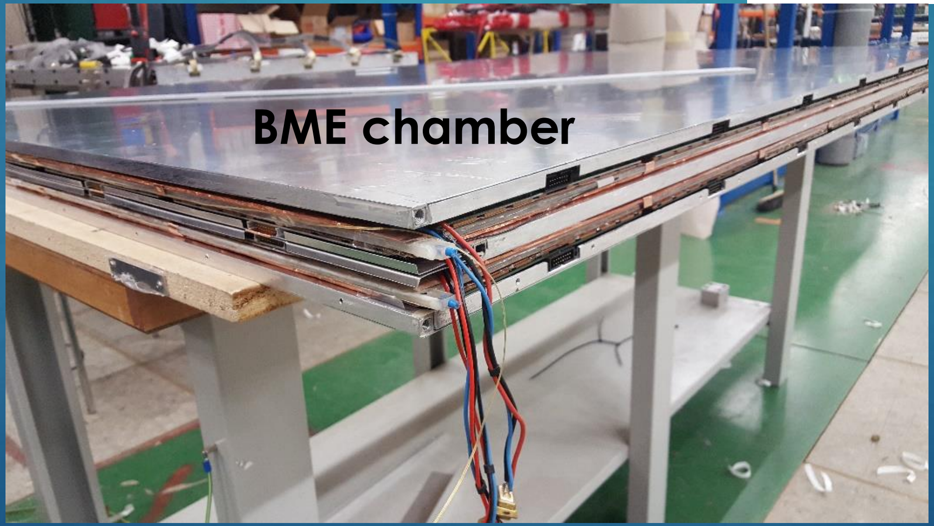


A collaboration can be created to:
- setup a MW Studio simulation
- Produce and test prototypes

Large prototypes in ATLAS

- 8 large size gaps have been produced
- 1 mm gas gap
- 1.2 mm electrodes
- 180X100 cm^2





- Two real ATLAS stations assembled and installed in sector 13
- This is a large scale test of the new gap technology

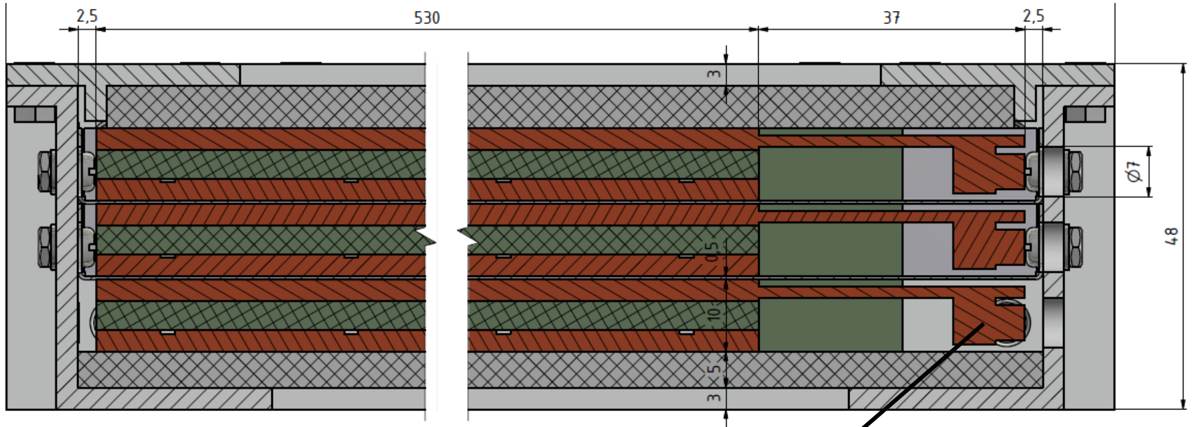
Status of AIDA-2020 WP 13.4.1

Preparation for large series production: large-detector size preserving mechanical precision

Hubert Kroha

Max-Planck-Institut für Physik, Munich

Thin-Gap RPC Prototype Design and Assembly

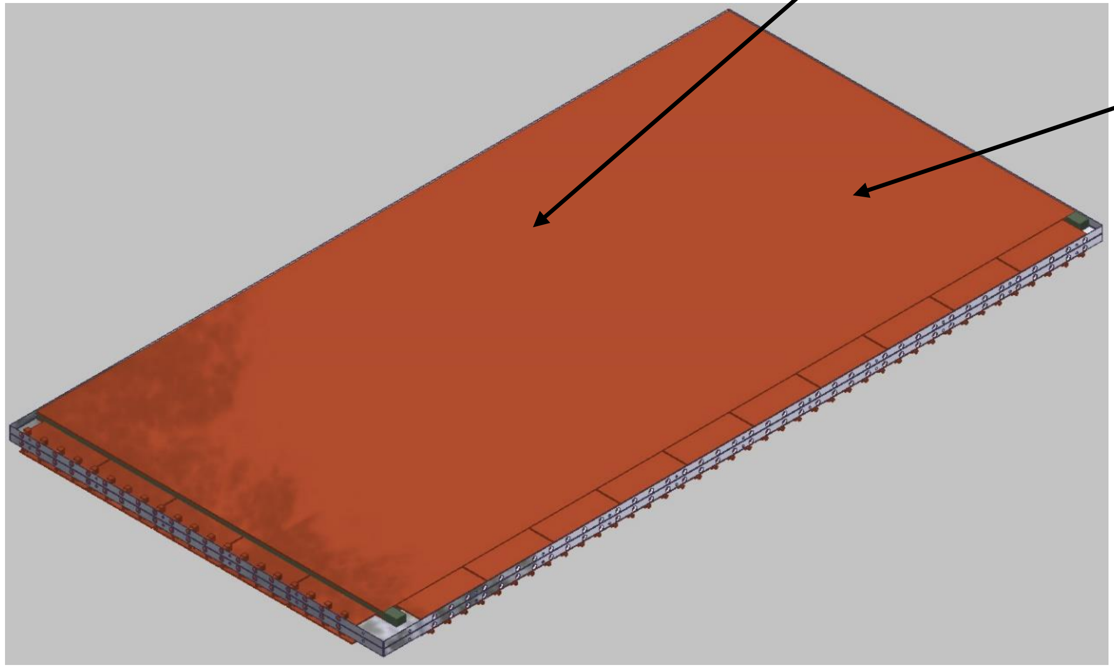


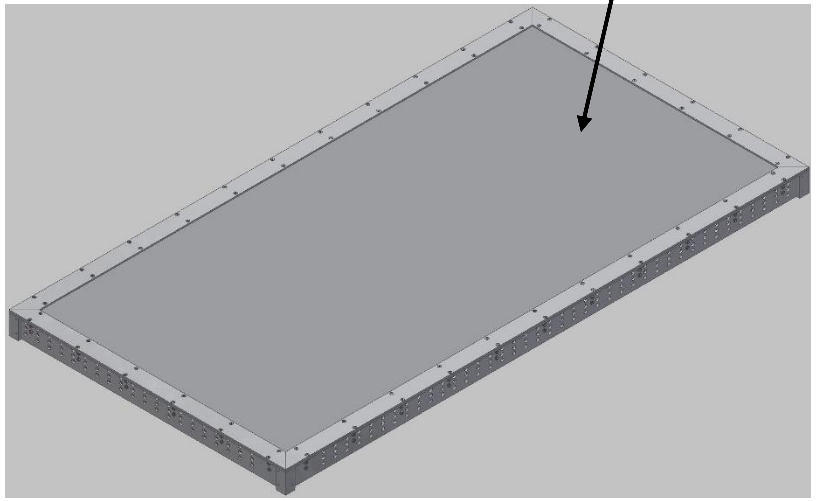
Triplet of thin-gap RPCs with 1mm gas gap in support frame and Faraday cage with only 48 mm overall thickness as needed for the ATLAS muon detector for HL-LHC.

Design of prototype chamber optimised and completed in 2016.

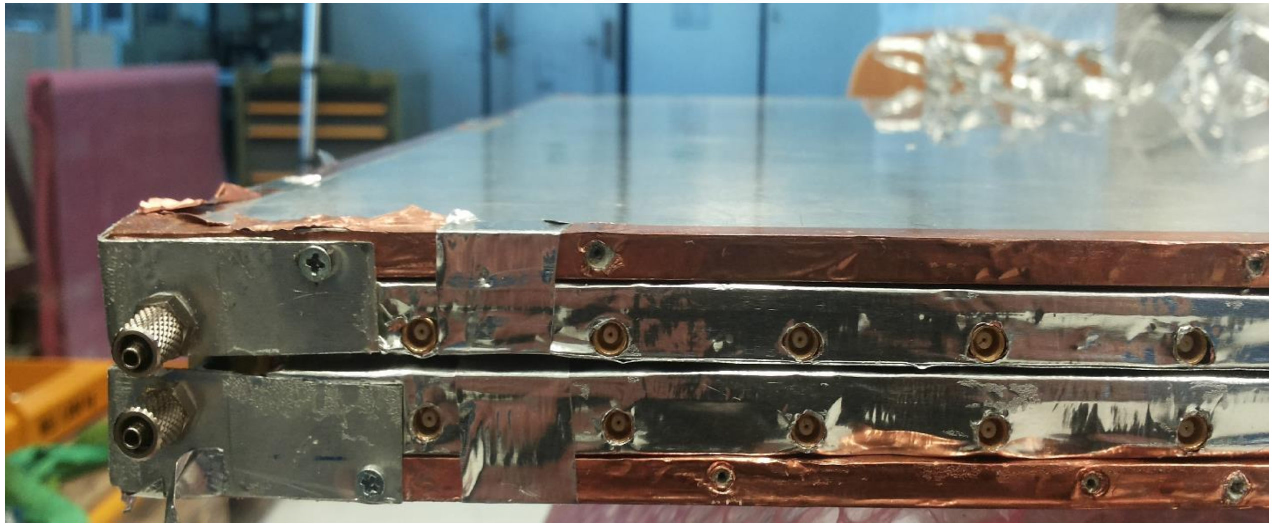
Prototype assembly is in progress:

Mounting of gas gaps with readout strip panels and electronics produced by Univ. Rome II into the Faraday cage and support structure.

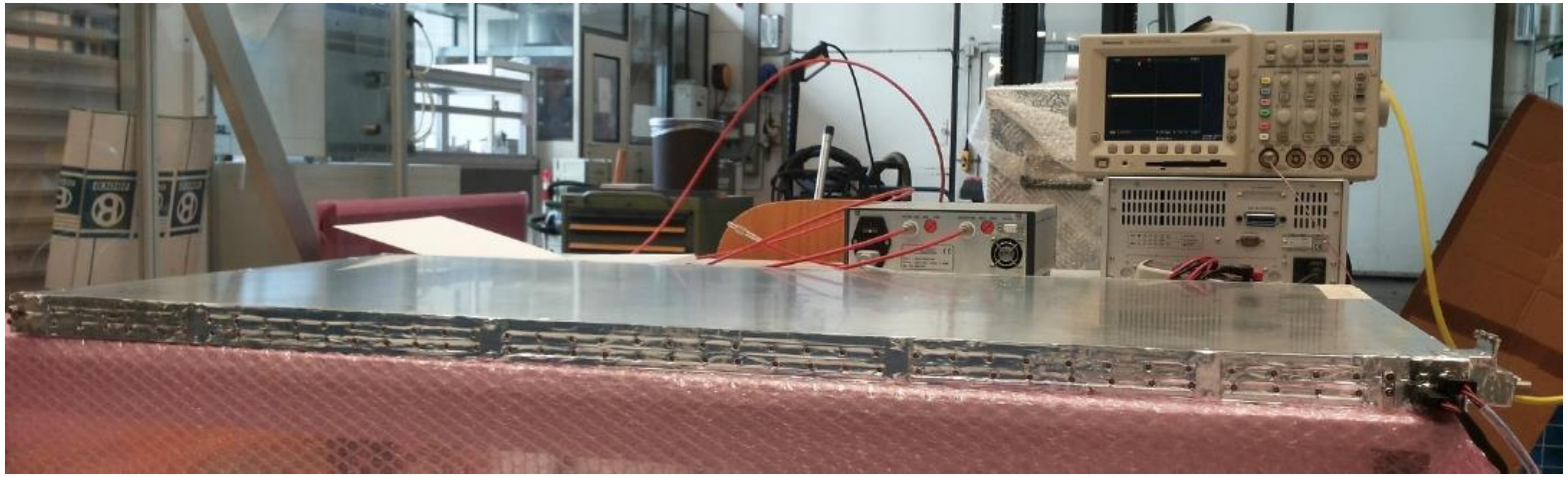




Prototype Assembly and Test



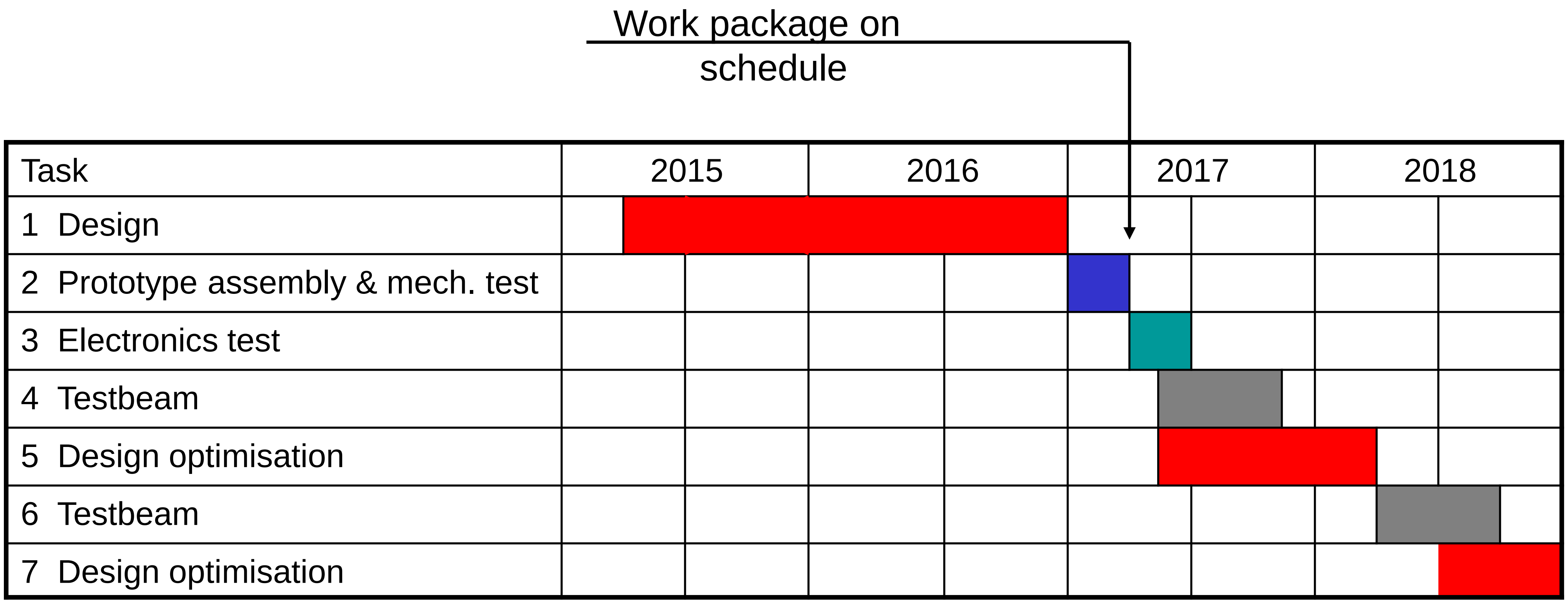
Thin-gap RPC gas gap test and preparation for triplet prototype assembly at MPI.



Preparation for Assembly of Large Chambers

Clean room with large (4.5 m x 2.5 m), precise (5 µm) granite table with x-y-z glueing machine (left) and large (2 m x 1.5 m x 1m) coordinate measuring machine and other measuring equipment (right) ready for assembly and measurement of large, thin RPCs and micro-pattern gas detectors.

Conclusions and Schedule



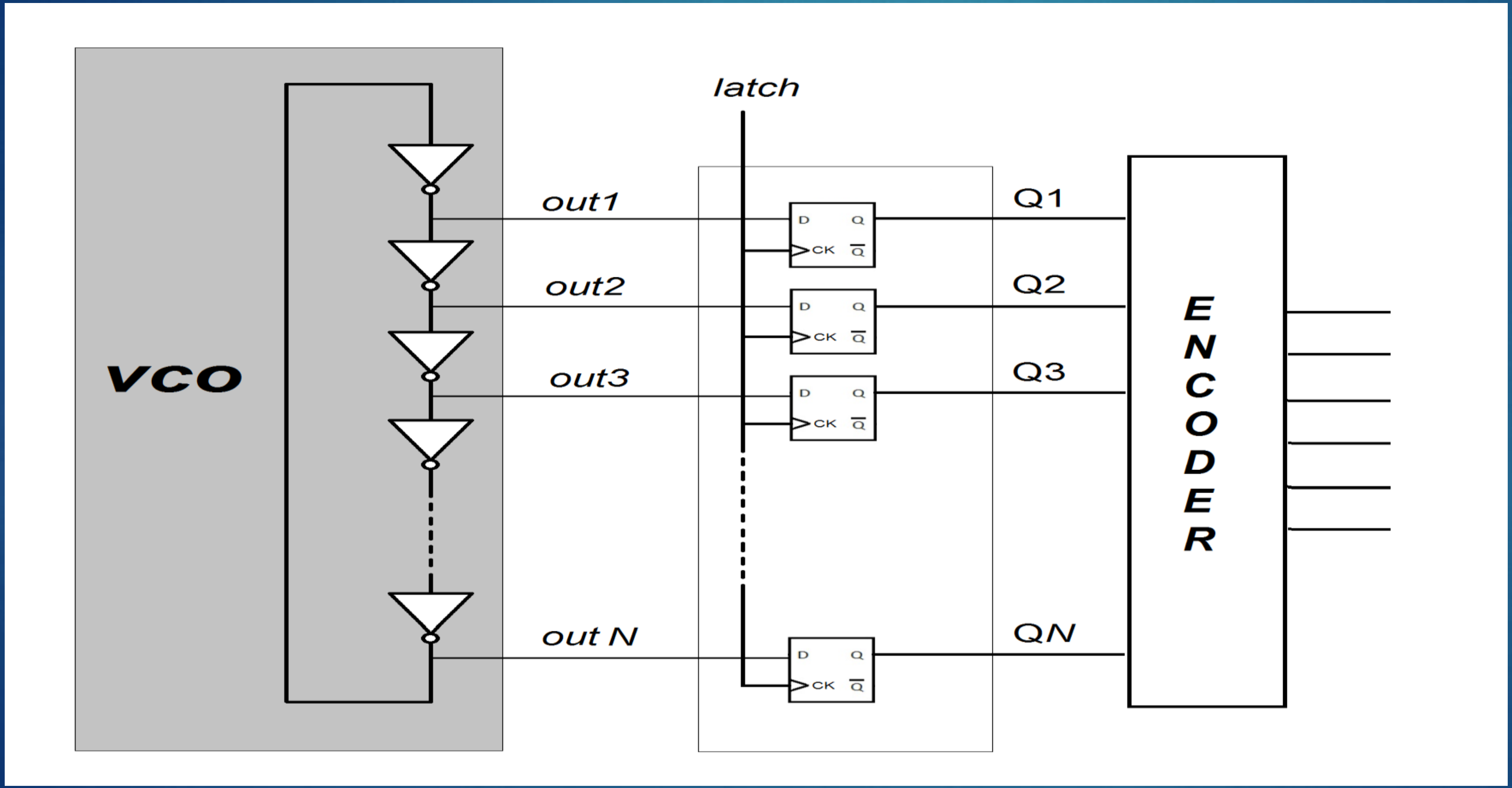
BACKUP

Research framework and resources

- Part of this research subjects are co-founded by:
  - **INFN R&D** program for HL-LHC RPCs, which involves the Italian groups
  - **ATLAS/CMS/ALICE** respective upgrade programs
- It will exploit the already **existing facilities** of the associated institutes for test and prototype construction purposes
- It will exploit the **GIF++ facility** both as users and as developers
- It will benefit of the results of an **existing R&D program** focused on the development of a **next generation FE** for fast detectors (e.g. RPCs, solid state, etc), which is a pre-requisite for many aspects of the proposed research
- Gangneung-Wonju National University will benefit **Korean matching fund for AIDA-2020**

TDC block diagram

Simple design, exploiting the SiGe technology performance

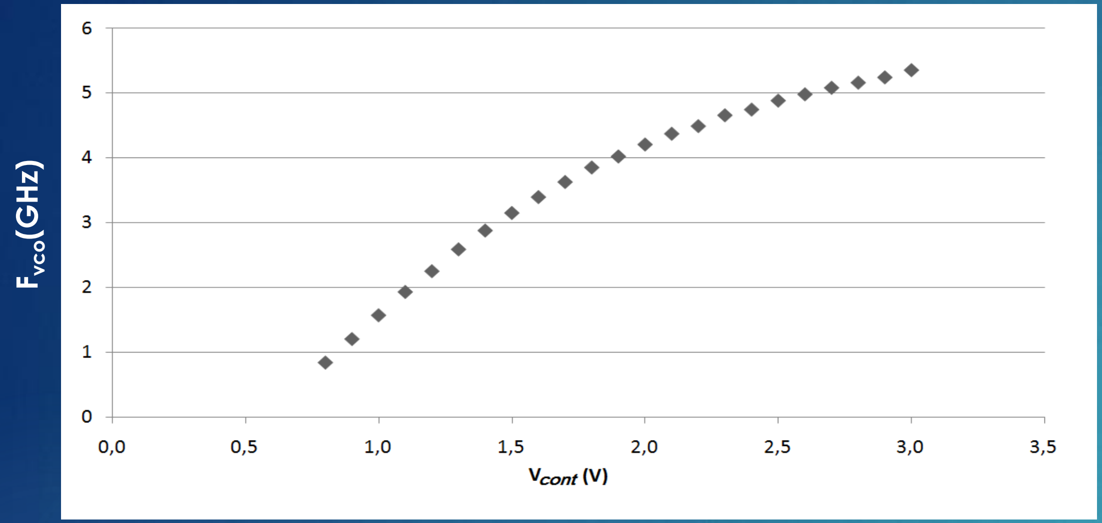


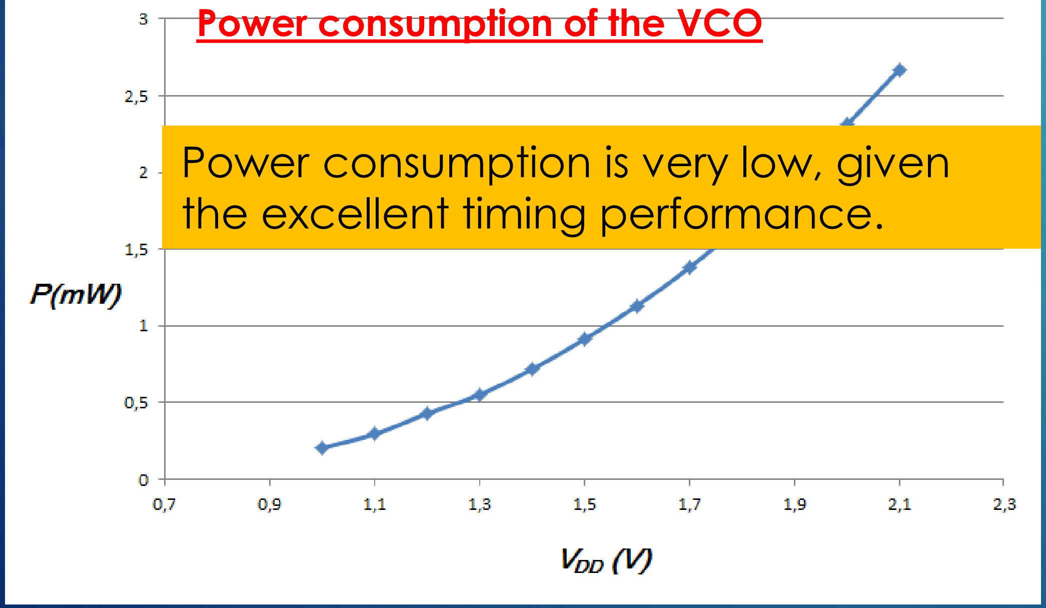
- The new TDC prototype is produced and tested in lab successfully
- Peak performance 20 pS!
- Power consumption 1-2 mW/channel

Simulation by Virtuoso software

Experimental Test bench

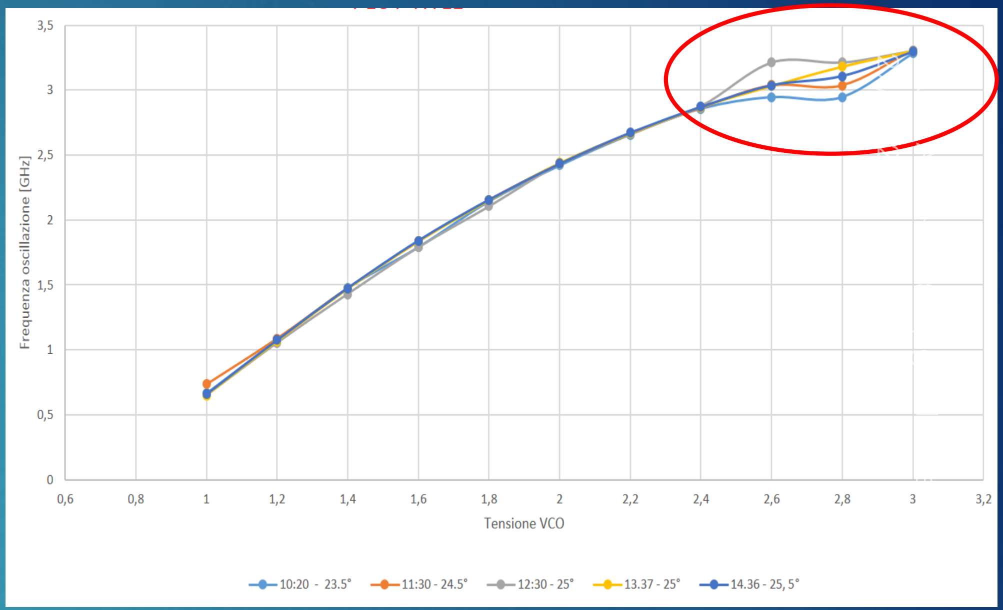
Range Frequency oscillation Vs applied voltage





Power consumption is very low, given the excellent timing performance.

Range Frequency oscillation Vs voltage applied

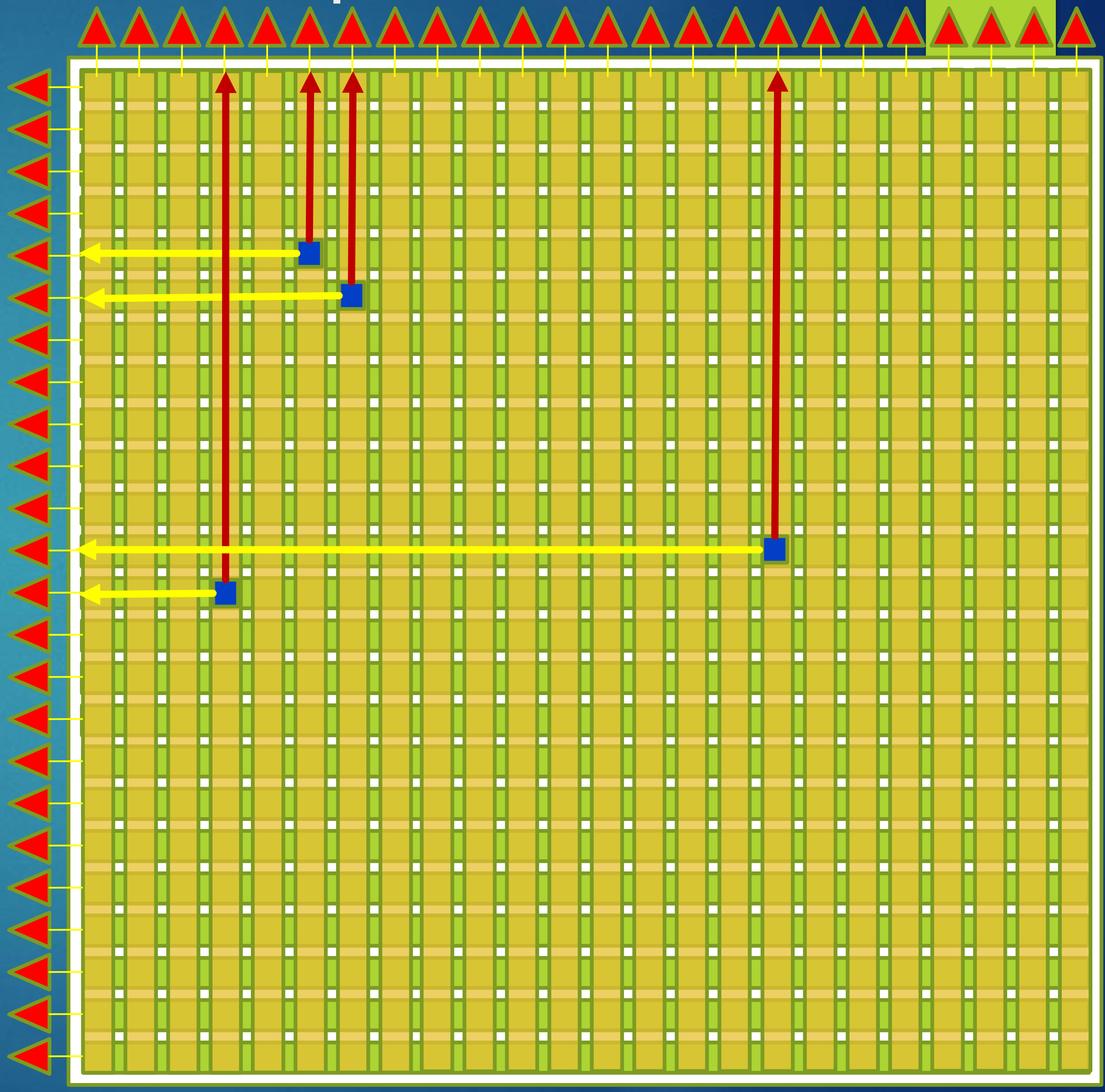


- We repeated the measurements at different times and different temperatures.
- In this test we supplied voltage only to the VCO.
- Comparing simulation and test bench, there is a deterioration of about 35%, as expected.
- The oscillations appear by applying higher then foundry specifications voltages

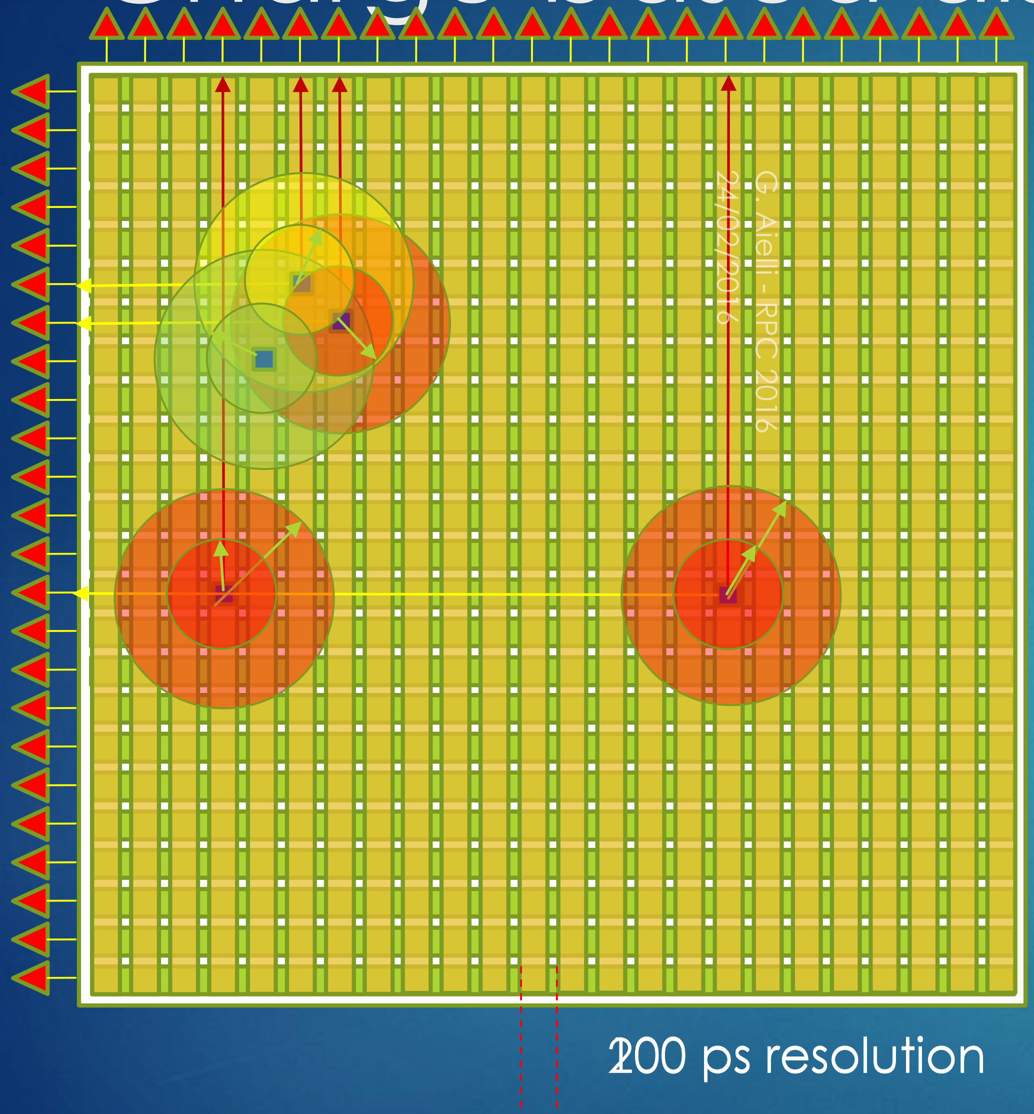
The 2d meantimer concept

Combining the advantages of x-y strip readout and of the meantimer.

- 2N channels for 2D homogeneous readout
- No limitation of the detector resolution due to the meantimer
- Electronics out of the active area
- Performance driven by the FE electronics and the digitization: it requires high performance Amplifier-discriminator-TDC chain
- Conceptually it is compatible with the classic ATLAS RPC layout down to the discriminator so it can be retrofitted on the present ATLAS RPCs. It would be sufficient to replace the readout electronics

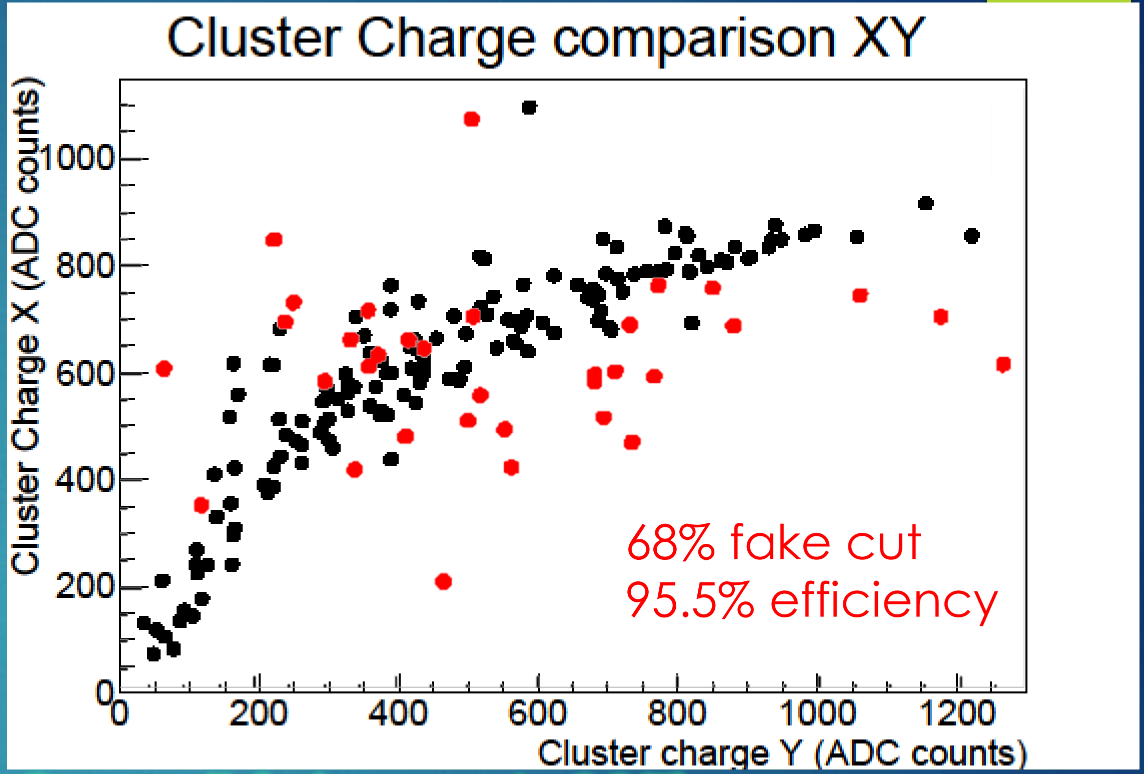


Charge based discrimination



200 ps resolution

1cm



Overall fakes cut: 89%

Overall efficiency: 95%

…Using a poor time resolution

Saturated and uncalibrated amplifiers

Non optimized CS

Cable length uncertainties….