The high voltage system the novel MPGD-based photon detectors of COMPASS RICH-1 and its development towards a scalable HVPSS for MPGDs

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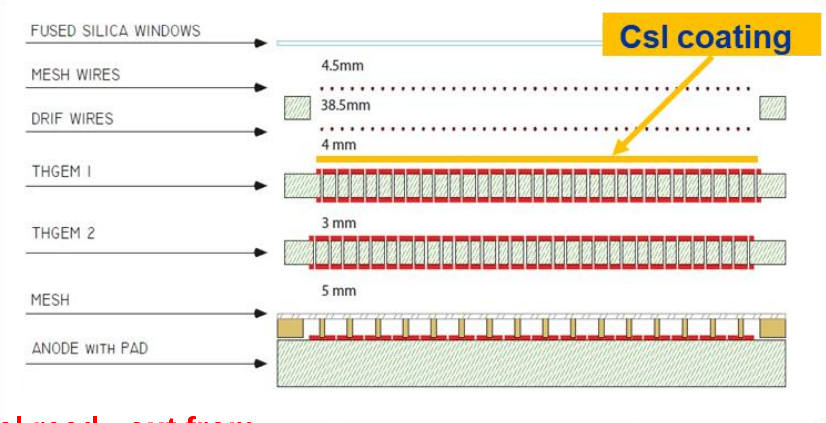
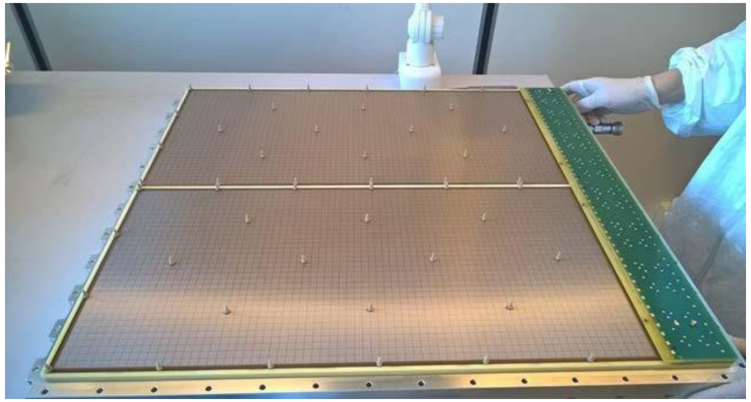
11th International Workshop on Ring Imaging Cherenkov Detectors

Outlook

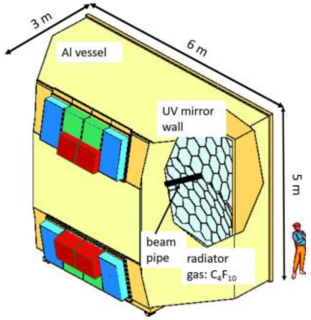
- **Present:**
  - The High Voltage system of the COMPASS RICH-1 Hybrid Photon Detector
    - Description and requirements
    - Control
    - Performance
- **Future perspectives**
  - The development of a dedicated High Voltage Power Supply System
    - Requested performance
    - The implementation scheme: hardware
    - Results and future developements

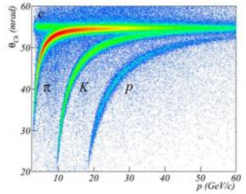
The High Voltage system of the COMPASS RICH-1 Hybrid Photon Detector: PD scheme



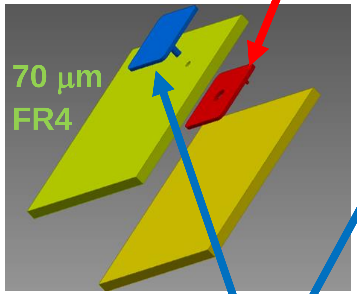


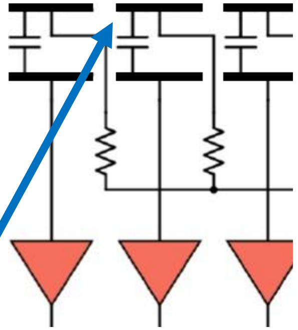
2016: in total 4 60 x 60 cm² detectors formed by 30 x 60 cm² active elements





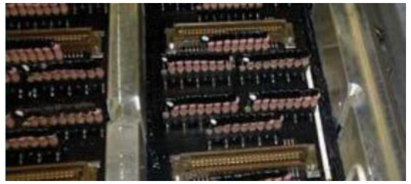
Signal read- out from the buried pad (original approach)

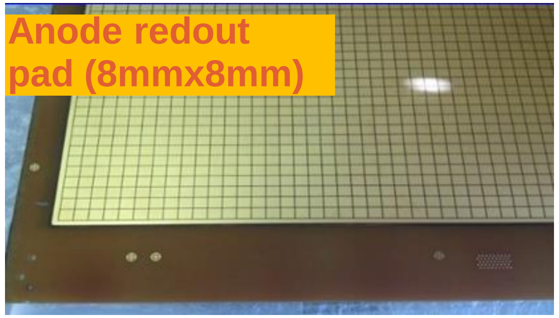




APV 25 FEE

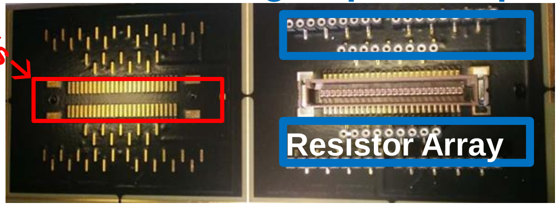
HV biasing pad

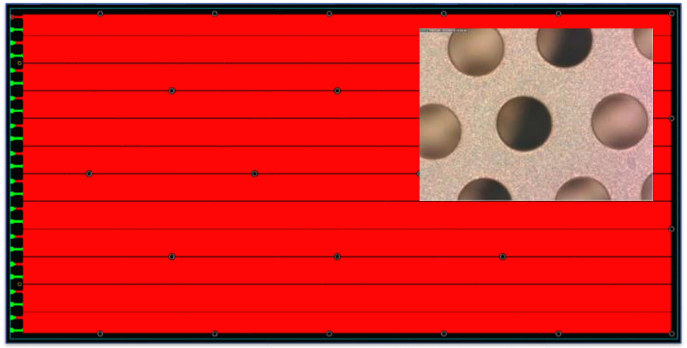




Connections for groups of 48 pads

Signals

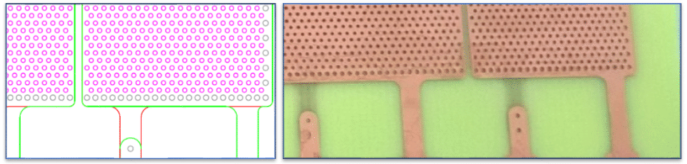




0.4 mm thick

0.4 mm diameter holes

0.8 mm pitch

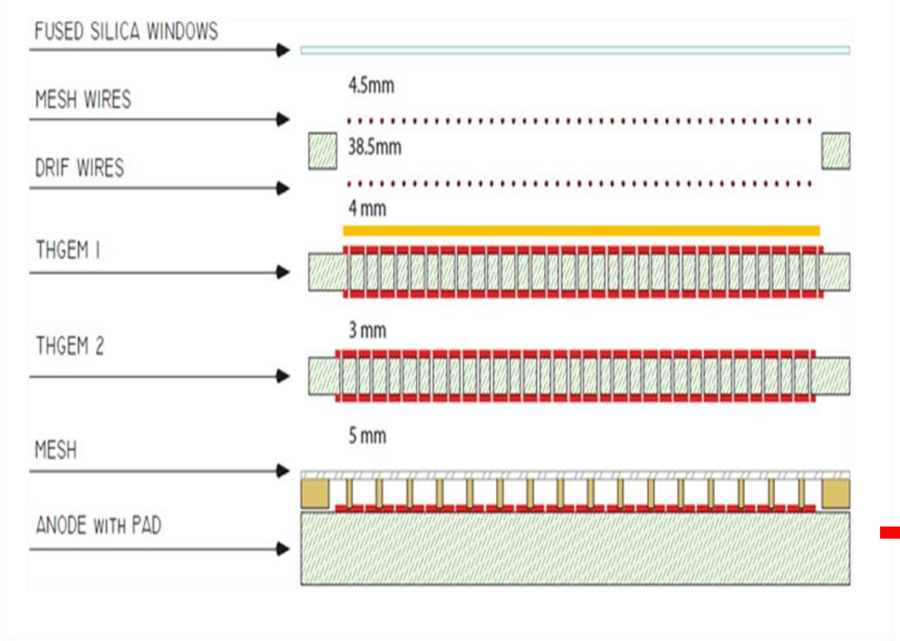


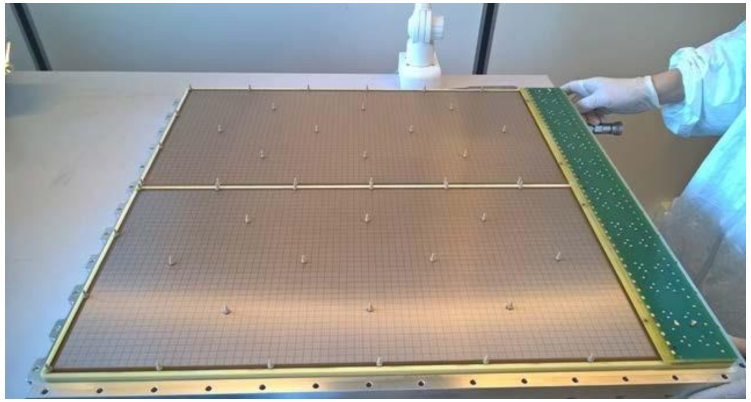
Segmentation of the THGEM the surface, flexibility in the HV distribution

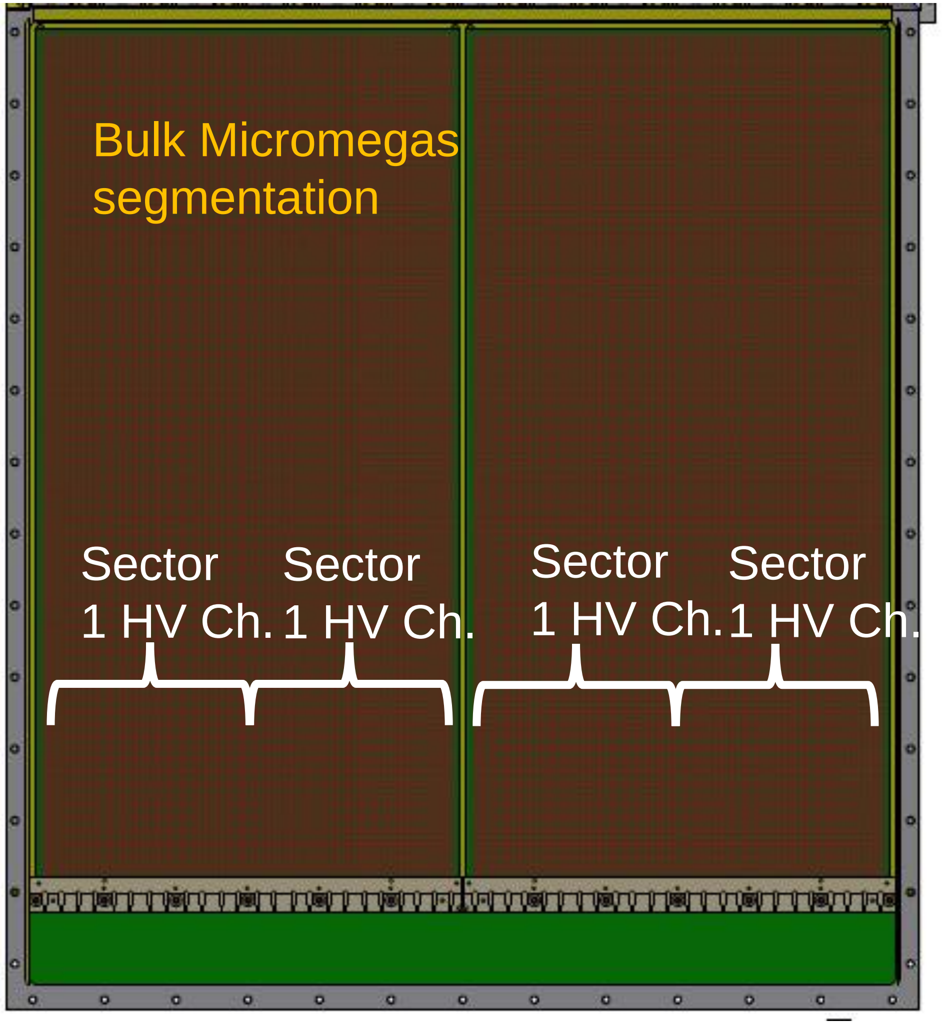
The High Voltage system of the COMPASS RICH-1 Hybrid Photon Detector: HV PD scheme MM

Typical electrical biasing voltages applied to the detector

-300 V
-3400 V
-3200 V
-2000 V
-1700 V
-500 V
0 V
+600 V

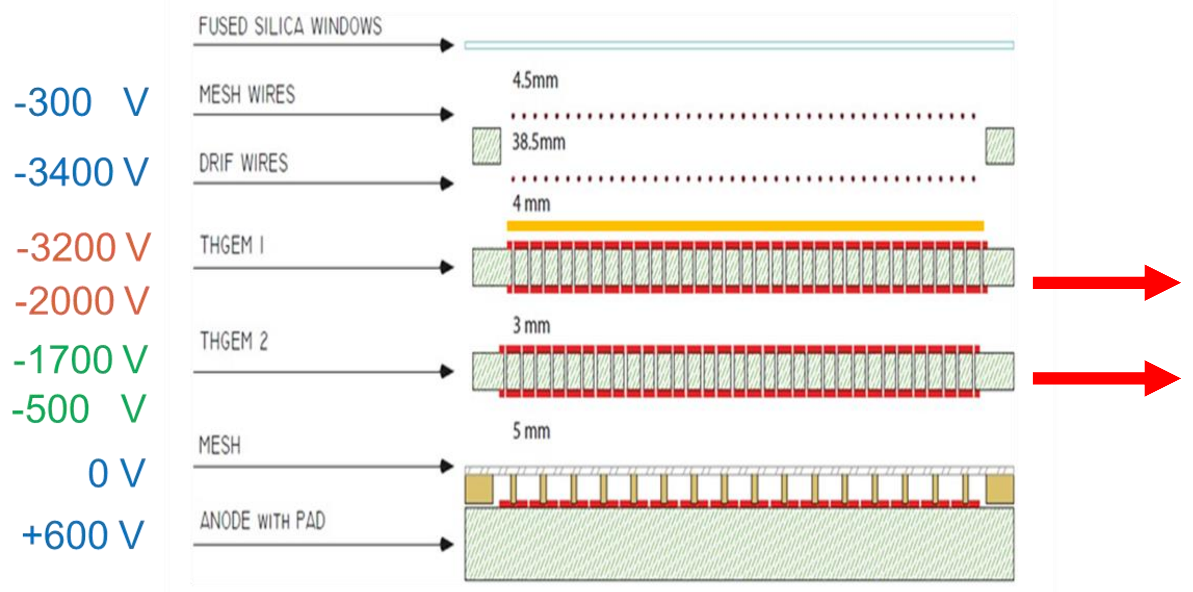


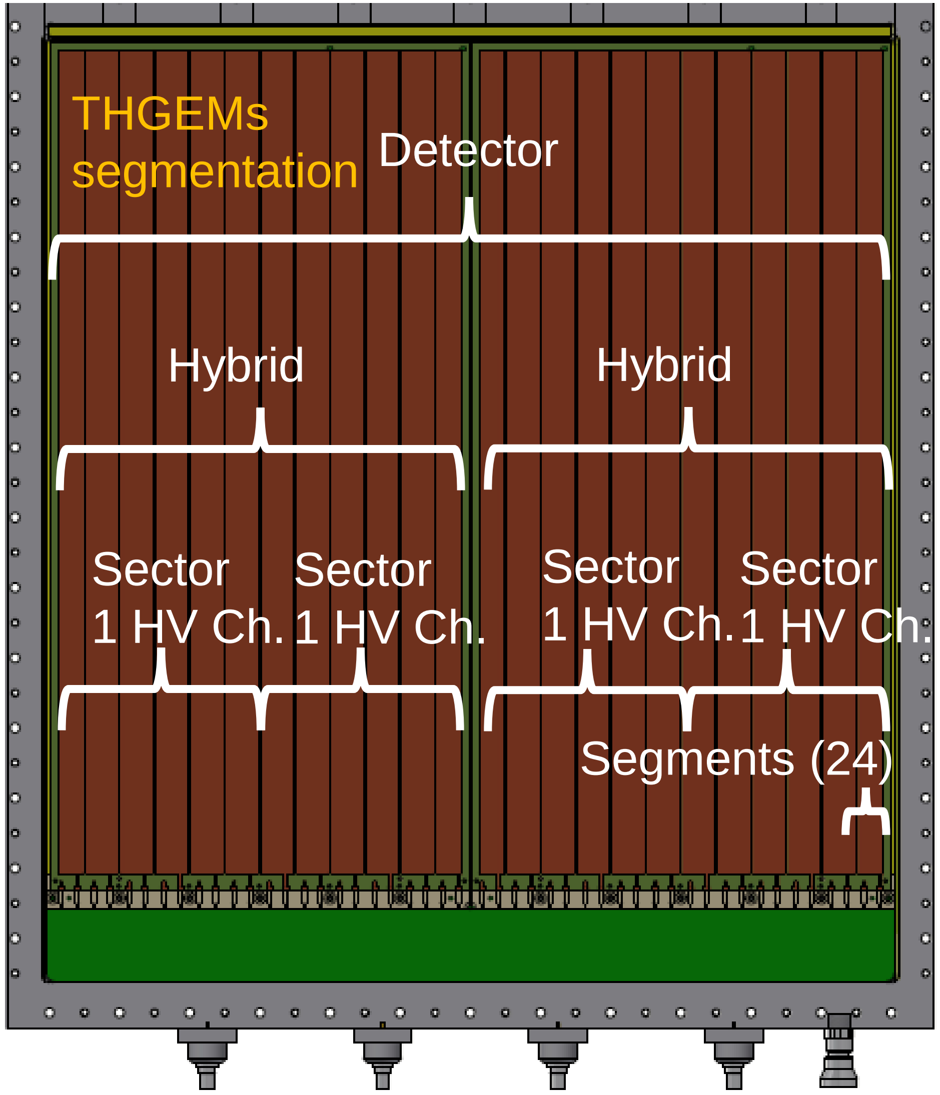


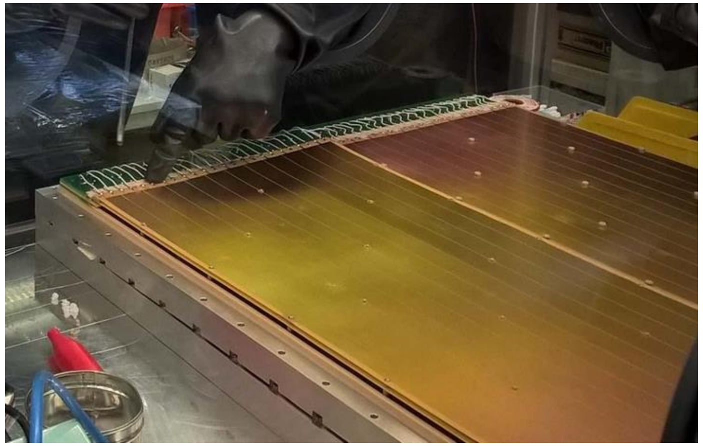


The High Voltage system of the COMPASS RICH-1 Hybrid Photon Detector: HV PD scheme TG

Typical electrical biasing voltages applied to the detector



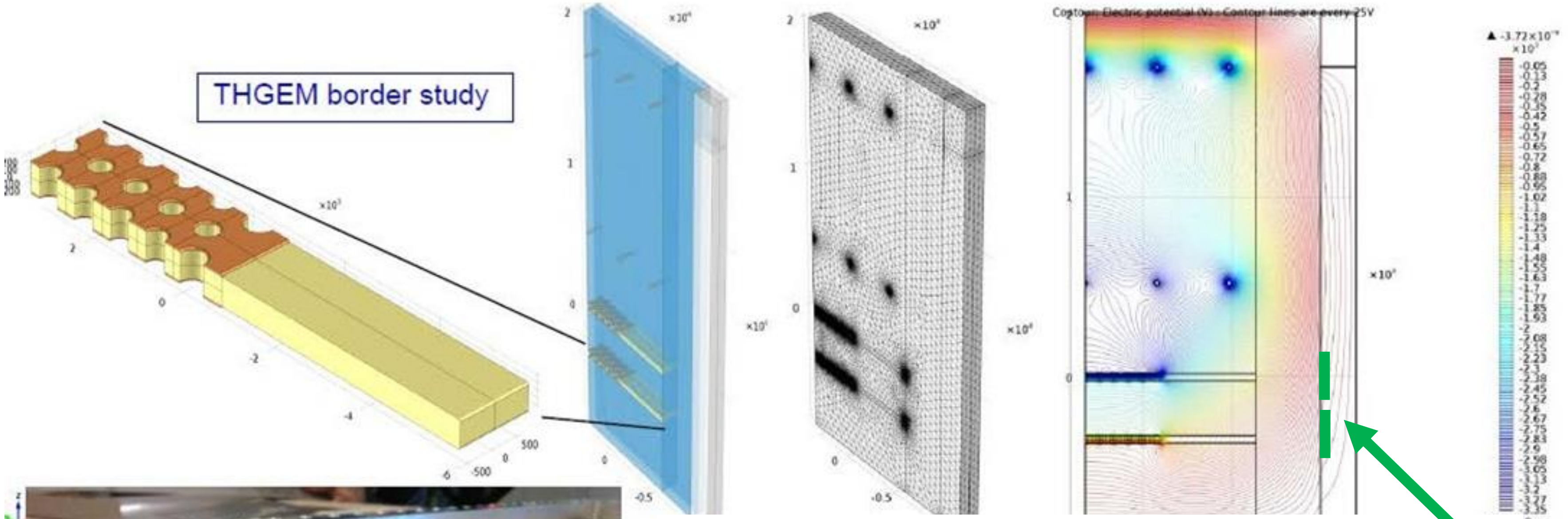




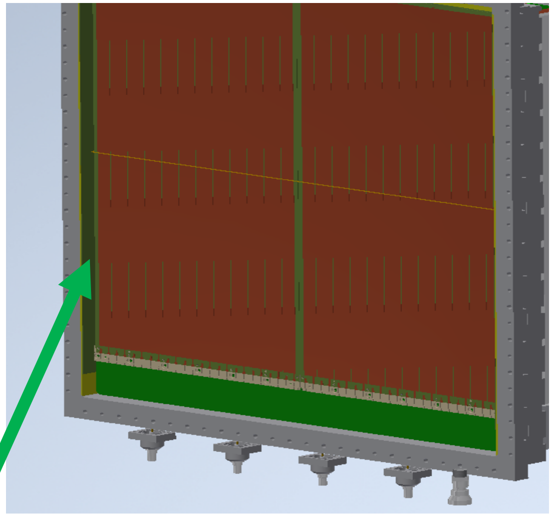
HV Channels Budget
4 Micromegas
4 x 2 x 2 layers THGEMs
1 Drift
1 Mesh wires
=22 independent HV channels per detector

The High Voltage system of the COMPASS RICH-1 Hybrid Photon Detector: Shaping electrodes

Need of shaping field electrodes → simulations



Large E fields values at the edges of the THGEM on guard wires→ field shaping needed



Field shaping electrodes
The applied voltage must properly scale with the THGEM voltage !

Tufnol 6F/45 insulating material

Field shaping electrodes embedded in the Tufnol material of the chamber frames → 4HV Ch.

The High Voltage system of the COMPASS RICH-1 Hybrid Photon Detector: The HV PS choice

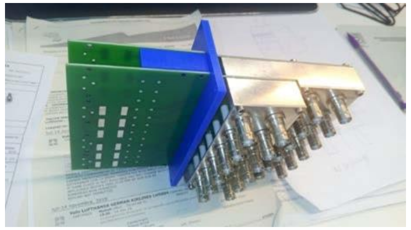
CAEN SY 4527 system

- THGEMs:
  CAEN A1561HDN, -6kV, SHV, 12 channels, 50 pA current monitor resolution fully satisfactory

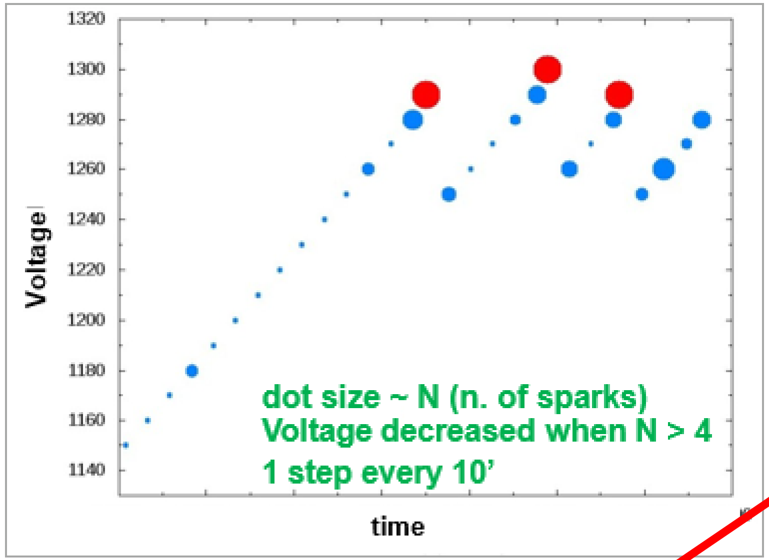
- MMs:
  CAEN A7030DP, +3kV, SHV, 12 channels, 2 nA current monitor resolution: not enough current resolution, unstable current off-set

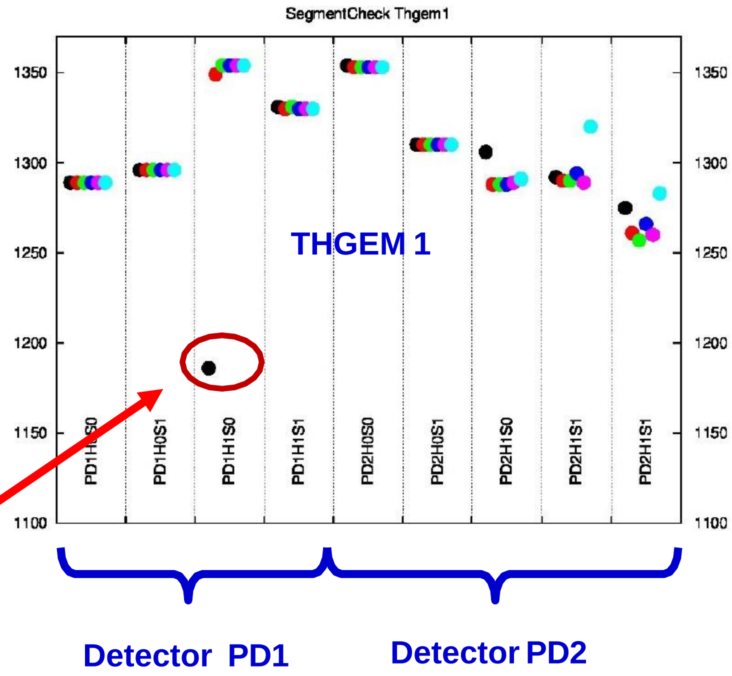
logging rate 1 Hz of ~ 100 channels (flexibility/cost).

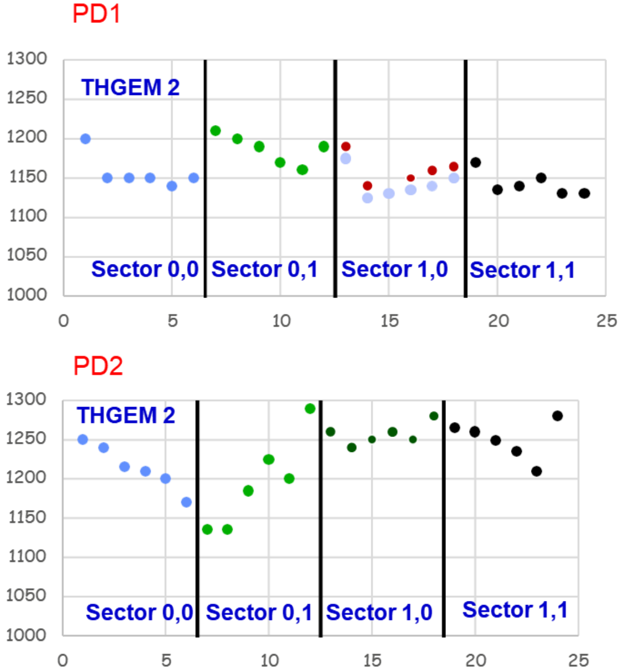
The High Voltage system of the COMPASS RICH-1 Hybrid Photon Detector: The importance of a flexible system



At the end of the first data taking year few channels have proven to be feeble (Stand lower ΔV). Dedicated campaign for the localization of the segments: **sparking rate vs V**, **maximum voltage** defined when the spark rate > 4 minute



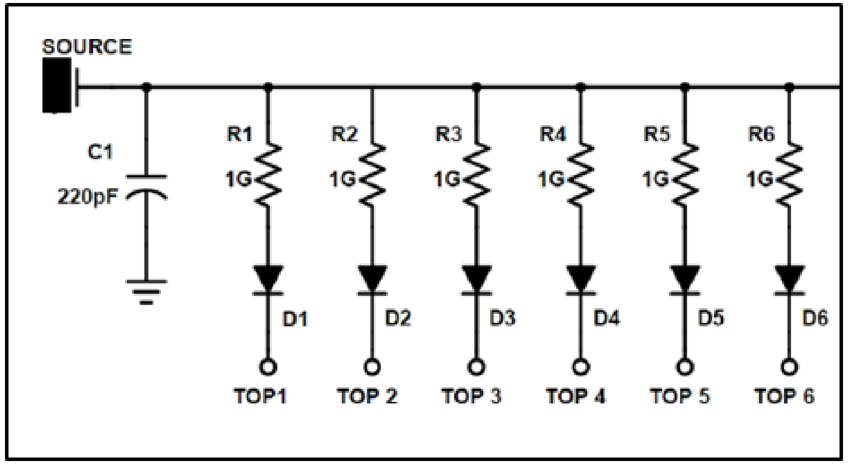




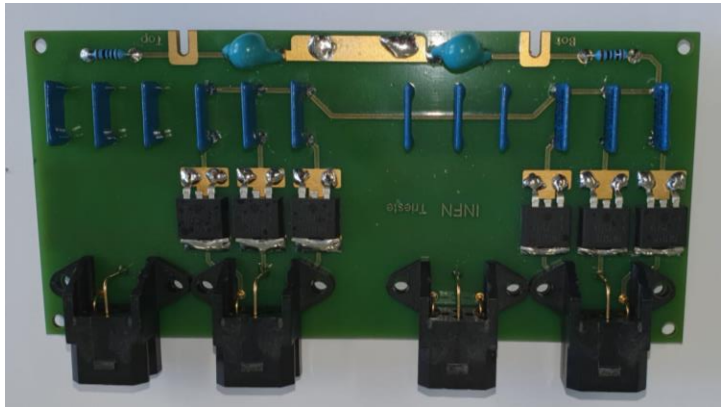
Feeble segment that matches with what observed during the data taking (2016)

Feeble Segments <10% of the total surface

The High Voltage system of the COMPASS RICH-1 Hybrid Photon Detector: Powering scheme

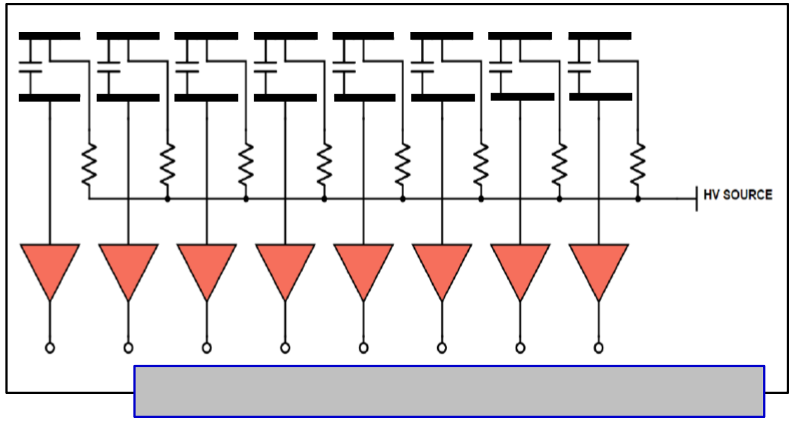


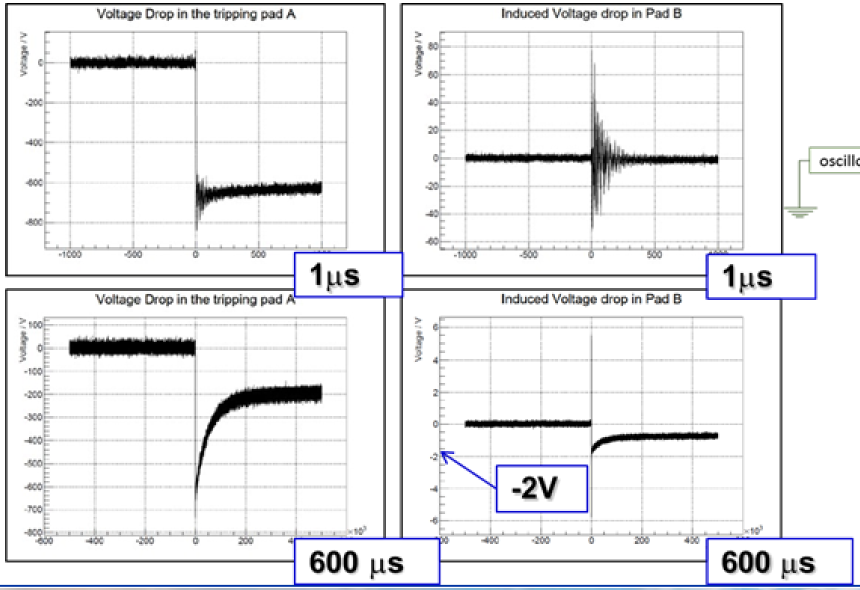
Each segment of the THGEM is powered via a 1 GΩ resistor in series with a 20ETS12S

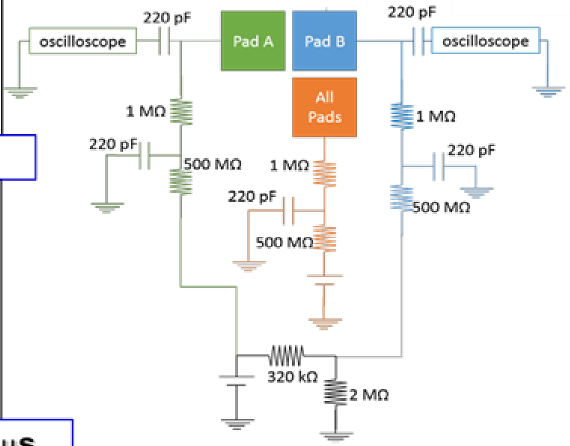


The segments of the same HV channel are efficient even if one of them trips

Pads A & B (the two adjacent pads being studied) are powered by the same PS





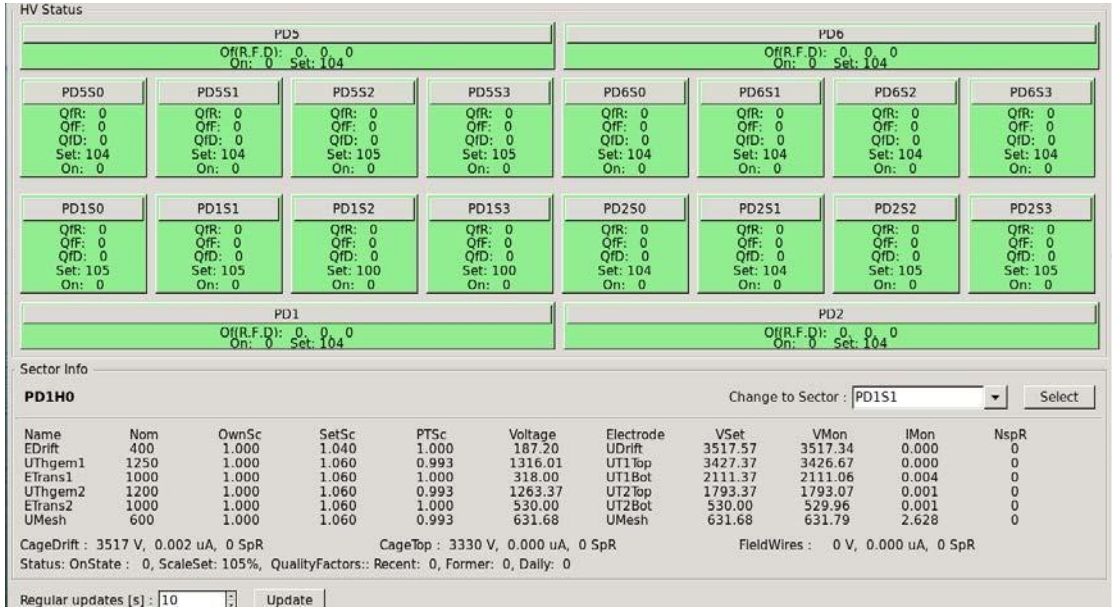


The HV of the non tripping pad is very limited affected: 2V drop ~4% drop in G :
R ~ 0.5 GΩ is preserving the non-tripping pads efficient all the time !

The High Voltage system of the COMPASS RICH-1 Hybrid Photon Detector: The HV SW control performance achieved

In total 136 HV channels

- Fully customized C++ and wxWidgets
- Data exchange with COMPASS DCS
- Own Scale method to fine tune gain uniformity
- V and I measured at **1 Hz**
- Auto decrease of Voltages in case of sparks
- Includes P/T correction

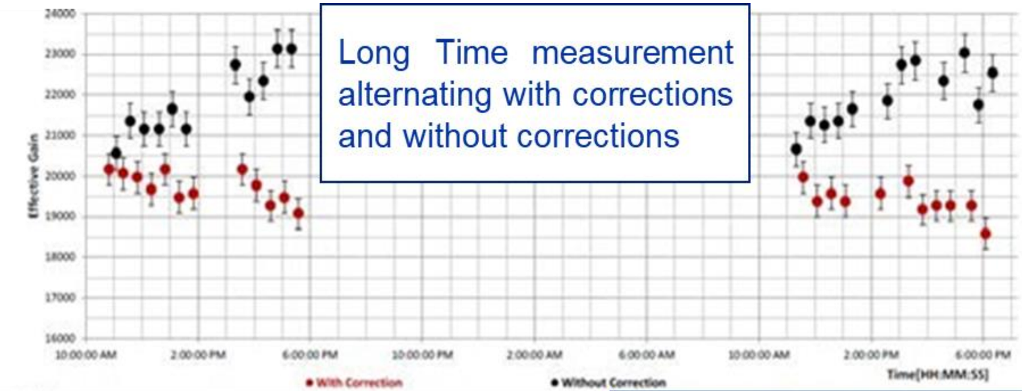


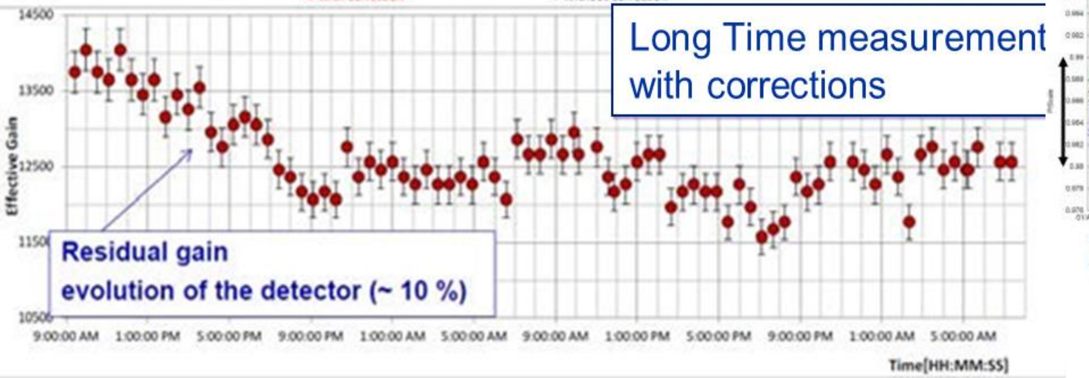
Gain stability vs P, T:

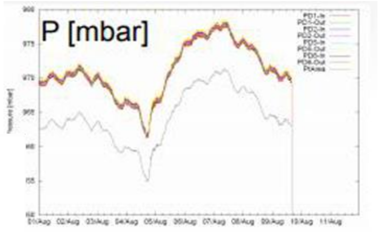
- G = G(V, T/P)
- Enhanced in a multistage detector
- $\Delta T = 1^{o}C \rightarrow \Delta G \approx 12\ \%$
- $\Delta P = 5\ mbar \rightarrow \Delta G \approx 18\ \%$

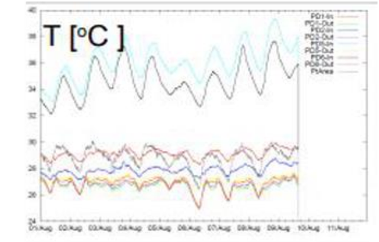
The correction method:

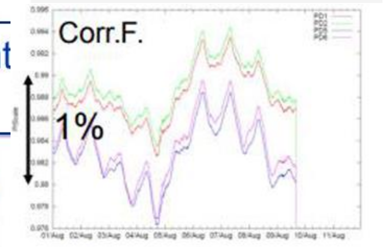
- Compensate T/P variations by V
  → Gain stability at 10% level











P/T: ~1% → 20
Gain: ~40%

The High Voltage system of the COMPASS RICH-1 Hybrid Photon Detector: The HV SW control performance achieved

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-V and I measured at 1 Hz
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Gain stability vs P, T:

- G = G(V, T/P)
- Enhanced in a multistage detector
- ΔT = 1°C → ΔG ≈ 12 %
- ΔP = 5 mbar → ΔG ≈ 18 %

The correction method:

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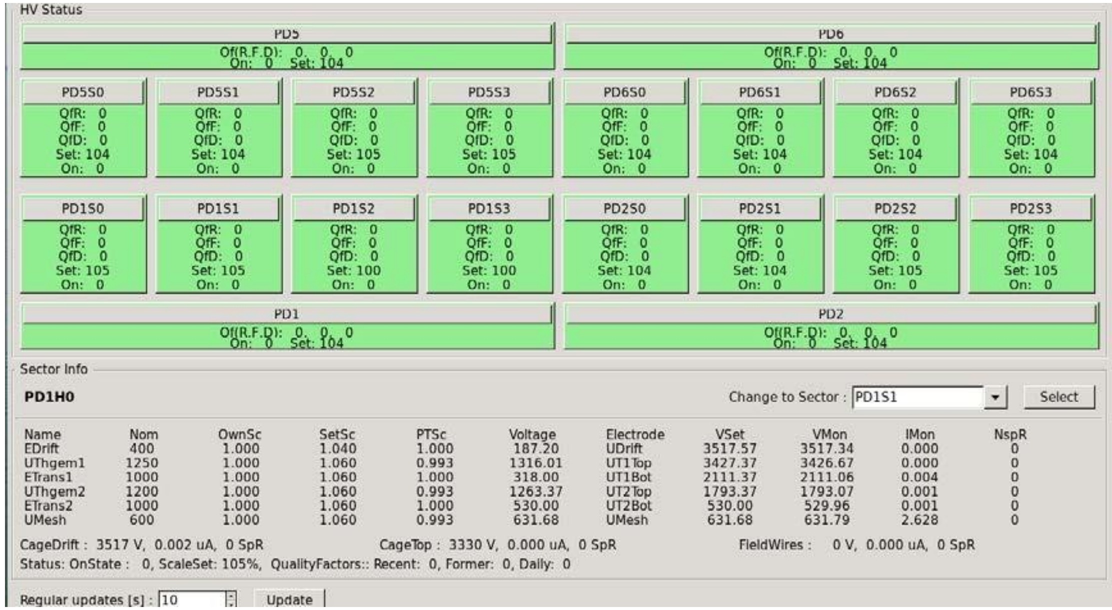
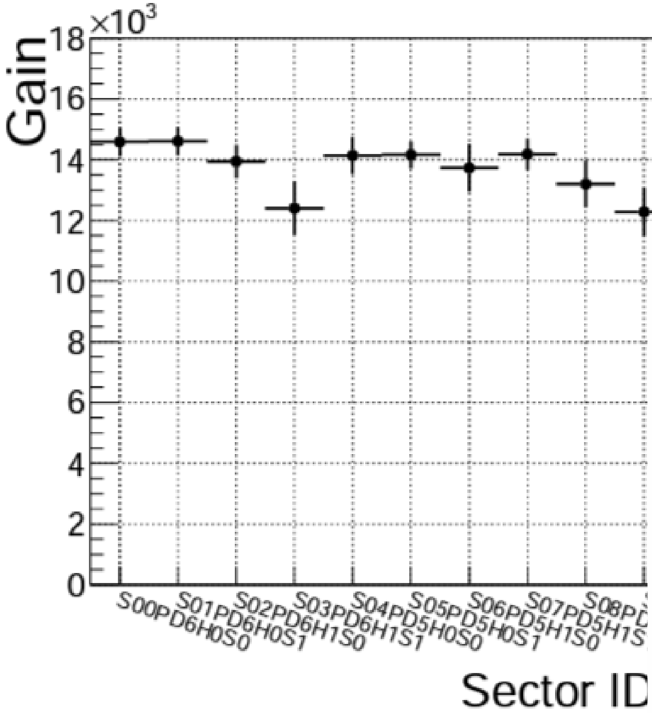
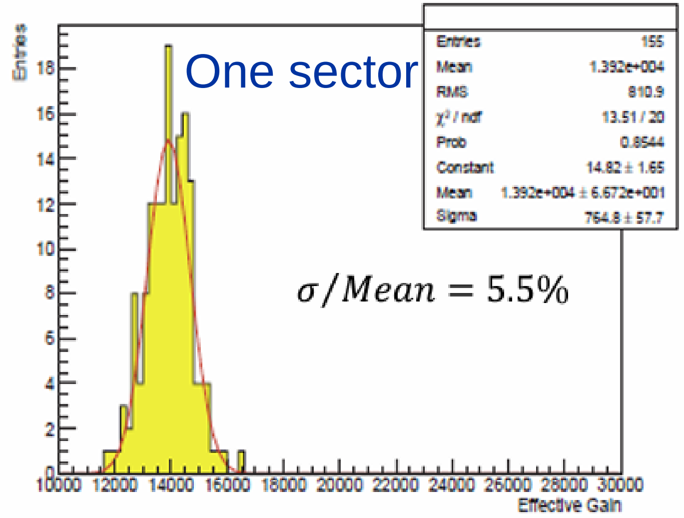


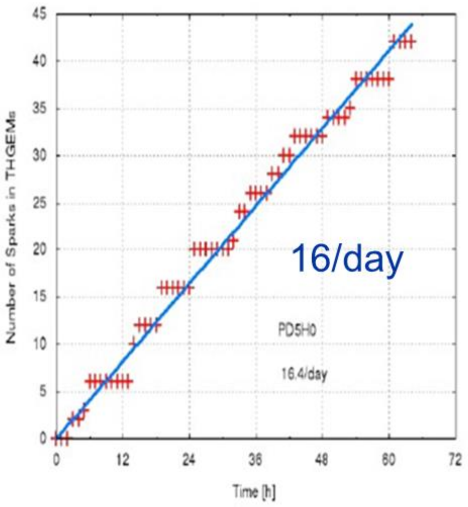


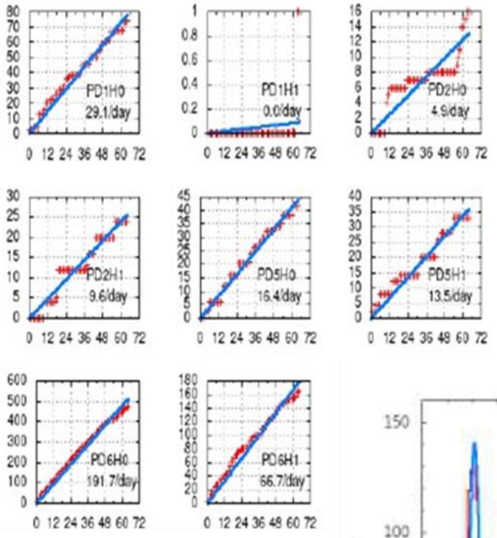


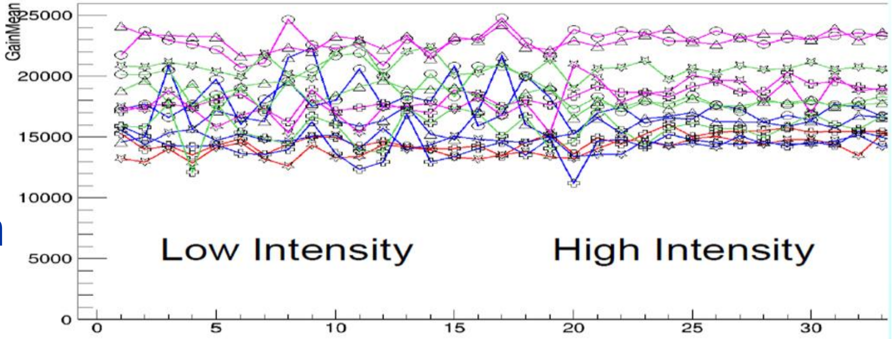
The High Voltage system of the COMPASS RICH-1 Hybrid Photon Detector: Lessons learnt 1/2

What have we learnt about **THGEMs (Spark = I > 23 nA)**

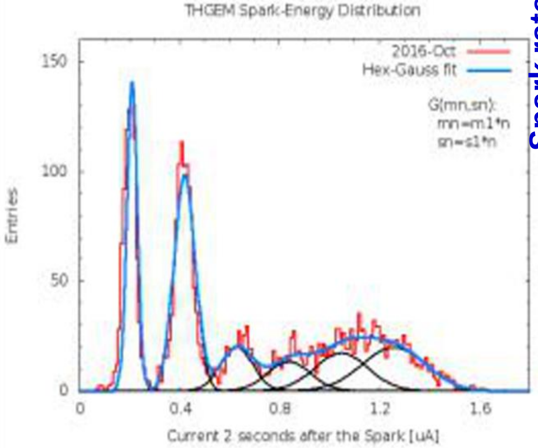
- Full correlation of discharges between THGEM 1 and THGEM 2
- Recovery time <10 s
- Discharge rates: ~ no dependence on beam intensity and even beam presence

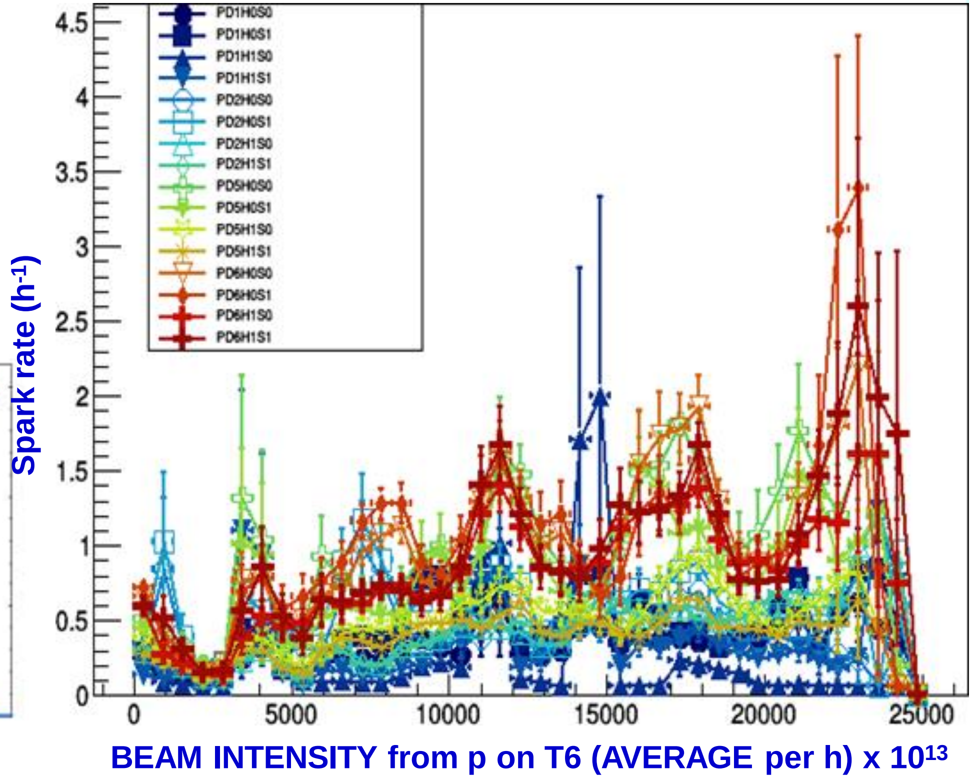






THGEM energy distribution for discharges →

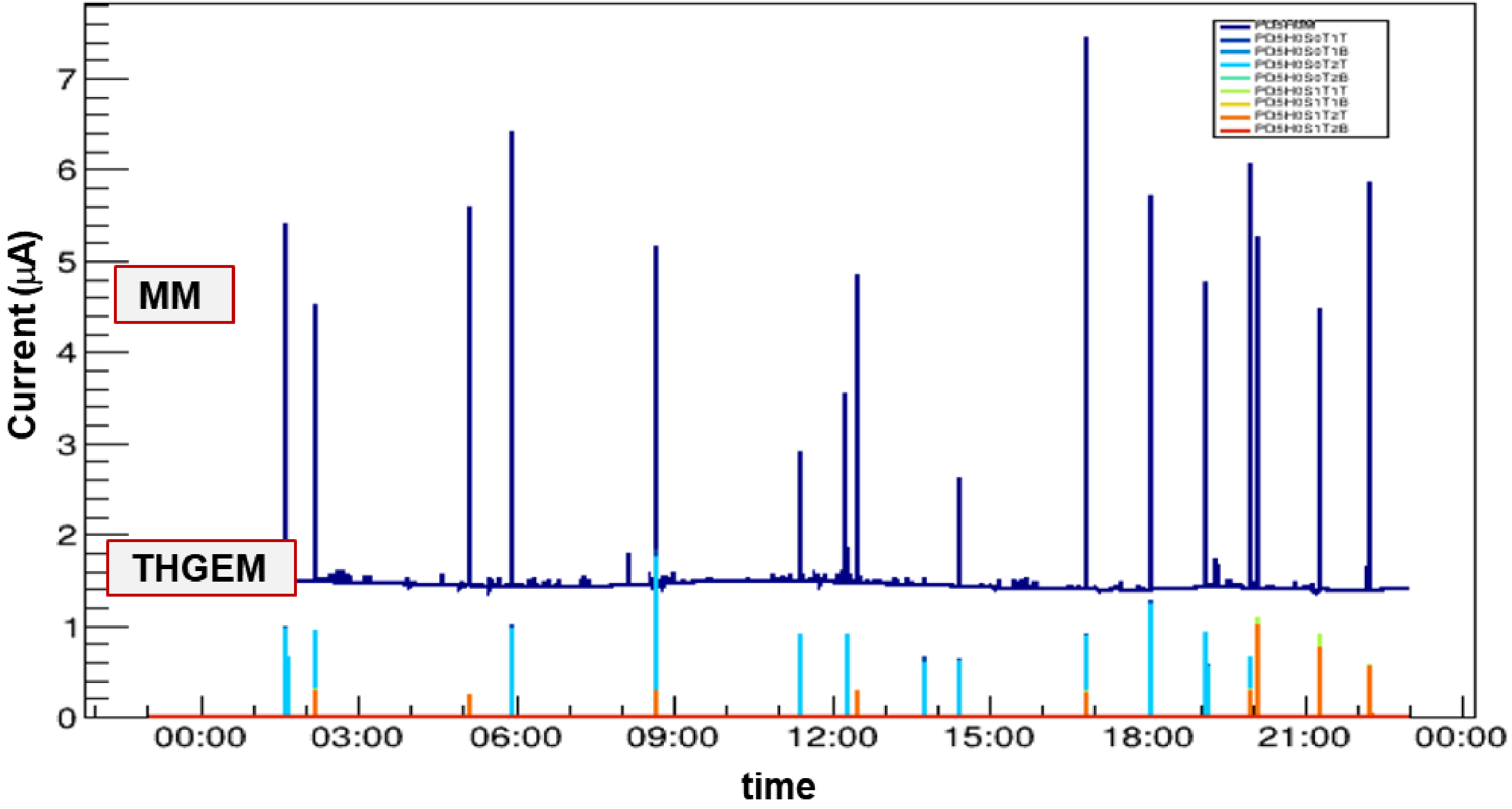




The High Voltage system of the COMPASS RICH-1 Hybrid Photon Detector: lesson leant 2/2

What have we learnt about **Micromegas**

- Full correlation between THGEM and MM sparks
- Recovery time ~1s



The High Voltage system of the COMPASS RICH-1 Hybrid Photon Detector: improving→ HVPSS

The result previously described and the corresponding insight on the the detector stability performance are coupled to the characteristics of the HIGH voltage power supply system employed.

several question that could not be answered, just a couple:

- Which segment of the THGEM triggered the discharge,
- Is it always the same ?
- Does it exist a precursor of the spark
- ……….

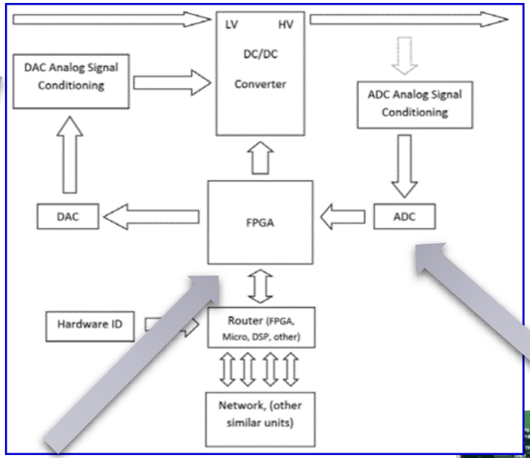
Is it possible to built a HV system (not commercially available) whose performance enable to answer to these questions ?

1. Time stamp resolution for current monitoring in the order of 10 ns or better
2. High resolution voltage monitoring better than 0.5 Volt on several kVolt scale
3. Precise current monitoring at the level of 10 pA
4. On board logic for decisional operation on predefined monitored parameters/conditions well as warning on “interesting” events to the user

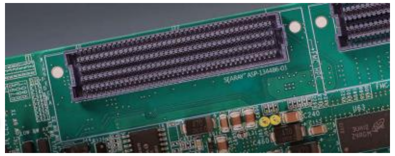
The new High Voltage Power Supply System : HVPSS components

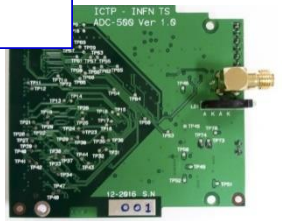
- DC-to-DC converter (Commercial device)

- ADC Board FMC standard adopted (Custom made)

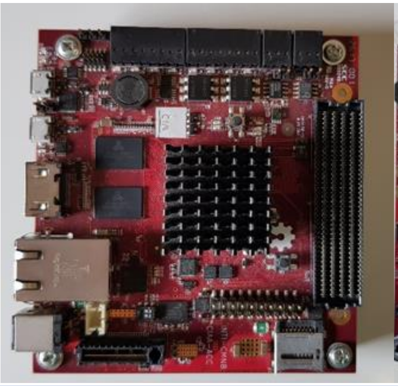


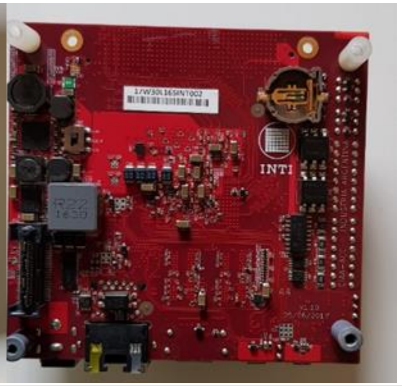
- A custom-made Pico ammeter (Custom made)





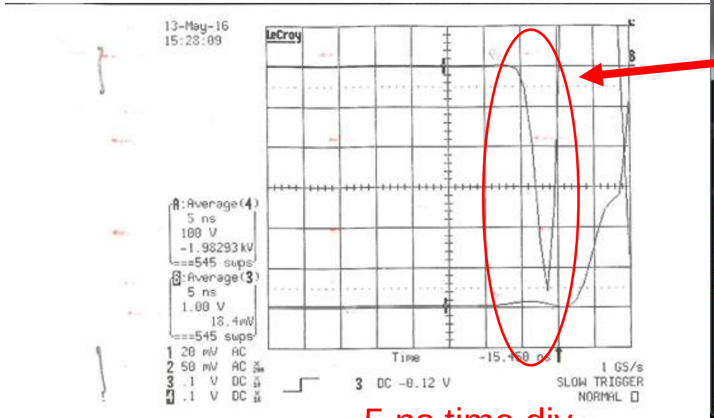
- Carrier (Developed SoC FMC carrier based on a Zynq-7030 CIAA ACC)



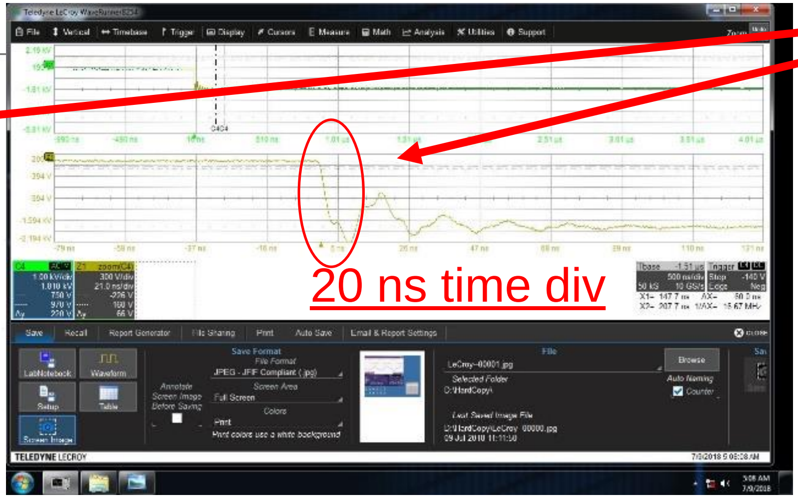


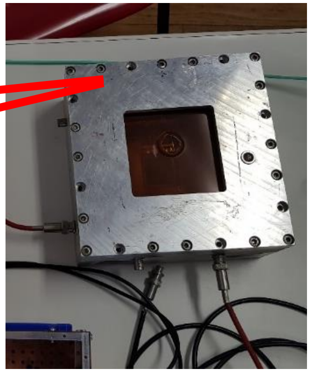
The new High Voltage Power Supply System : Timing needs and ADC choice

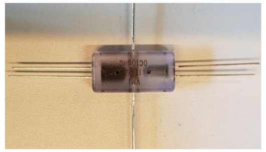
Discharge evolution time has driven the choice of the ADC Chip
Capability to detect fast transients

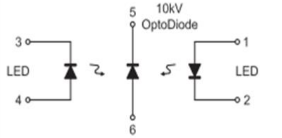


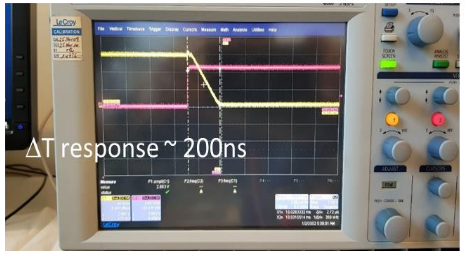
5 ns time div







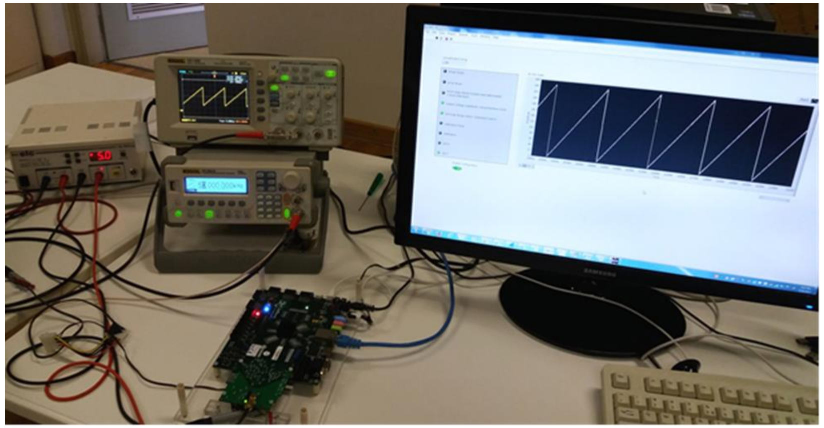




Discharge time evolution measured with HV probe

Discharges stimulated by increasing the Voltage across THGEM detector over the breakdown Voltage.

(time resolution: ~2ns)

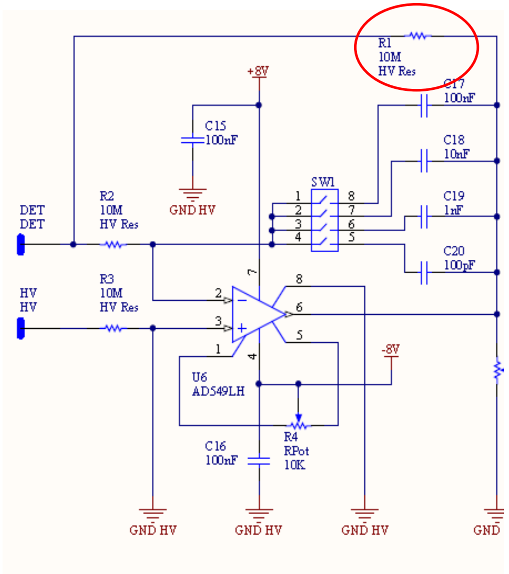


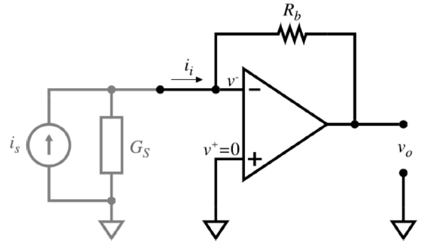
ADC read out @ full speed 500 MSPS

ADC:

- ADC08500 High Performance, Low Power 8-Bit, 500 MSPS A/D Converter

The new High Voltage Power Supply System : I measurement, V generation, P/T correction

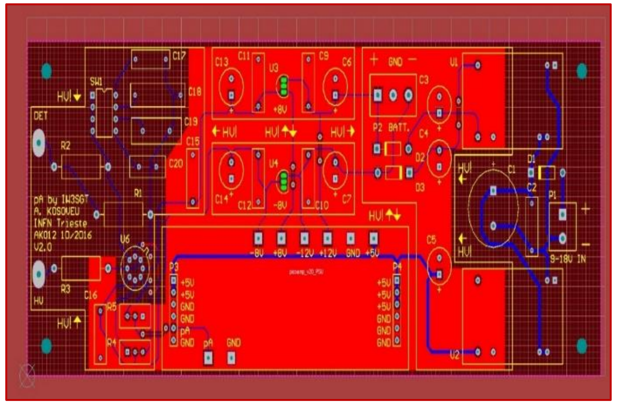


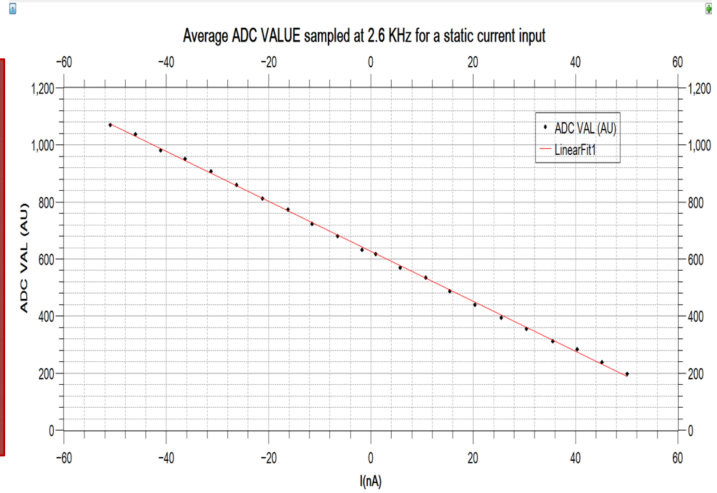


$$V_{out} = R_F \cdot i$$

Feedback resistor range 10 MΩ ÷ 100 MΩ → optimized

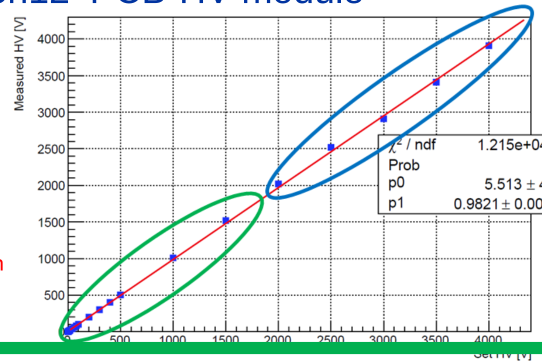
$$1\text{pA} \sim 10\mu V \ with \ (10M\Omega)$$



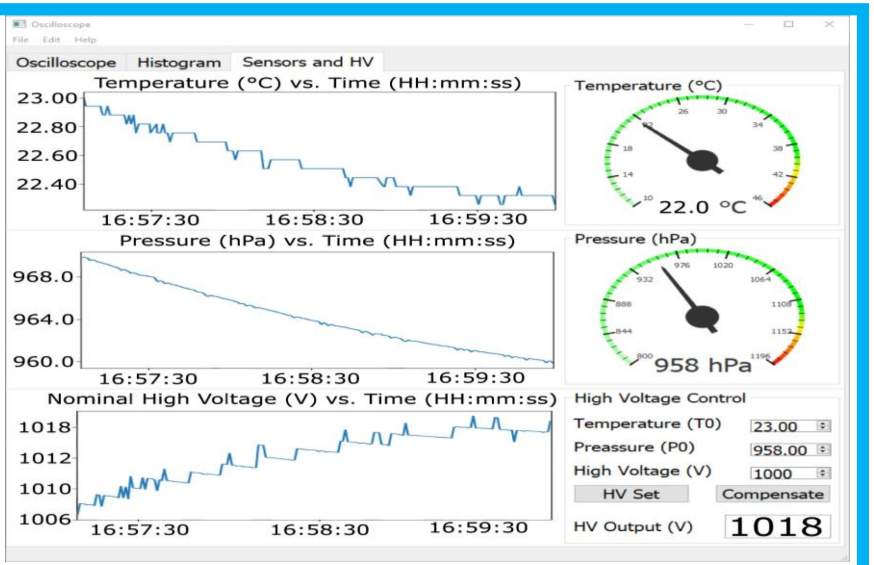


Good linearity

ISEG BP040105n12 PCB-HV-module
4W BPS series

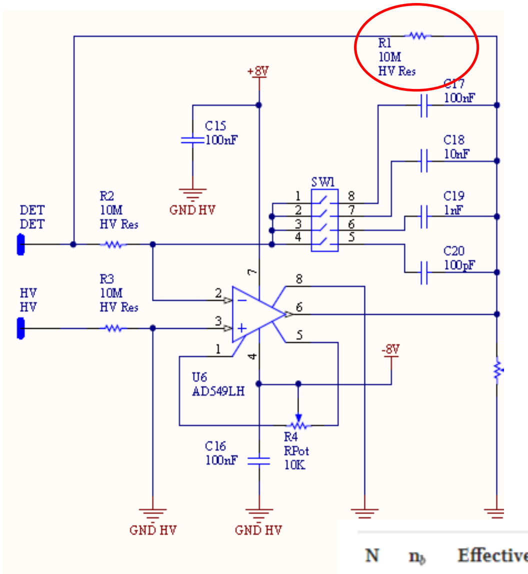


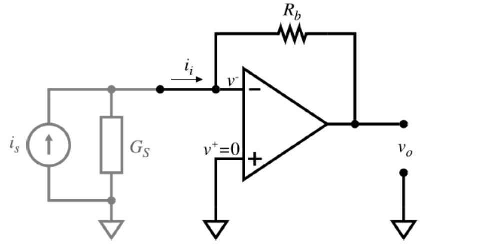
H. Voltage repeatibility: 0,4 V
Difference between V_{set} and V_{mon}
Region A < 2000V σ< 1 volt
Region B > 2000 V σ ~7 volt



$$V = V_0 * \left(1 + 0.5\left(\left(\frac{P}{P_0}\right)\left(\frac{T_0}{T}\right) - 1\right)\right)$$

The new High Voltage Power Supply System : I measurement, V generation, P/T correction

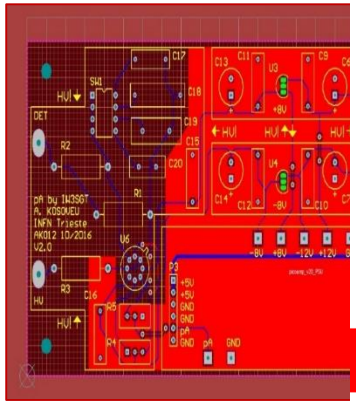




$$V_{out} = R_F \cdot i$$

Feedback resistor range 10 MΩ ÷ 100 MΩ → optimized

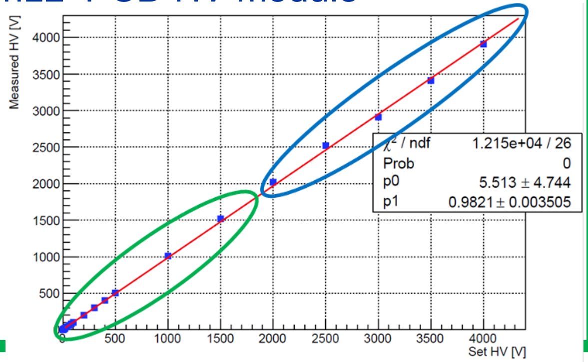
$$1\text{pA} \sim 10\mu V \; with \; (10M\Omega)$$



N	n_b	Effective sample rate (MHz)	Theoretical resolution Δ (nA)	Theoretical quantization error $\sqrt{\Delta^2/12}$ (nA)	Experimental statistical error σ (nA)
2	8.5	250.00	84.4	24.4	65.2
4	9	125.00	59.7	17.2	58.8
16	10	31.25	29.8	8.6	13.6
64	11	7.81	14.9	4.3	7.0
256	12	1.95	7.5	2.2	6.6
512	12.5	0.98	5.3	1.5	3.9

4 pA resolution at 100 kHz

ISEG BP040105n12 PCB-HV-module
4W BPS series



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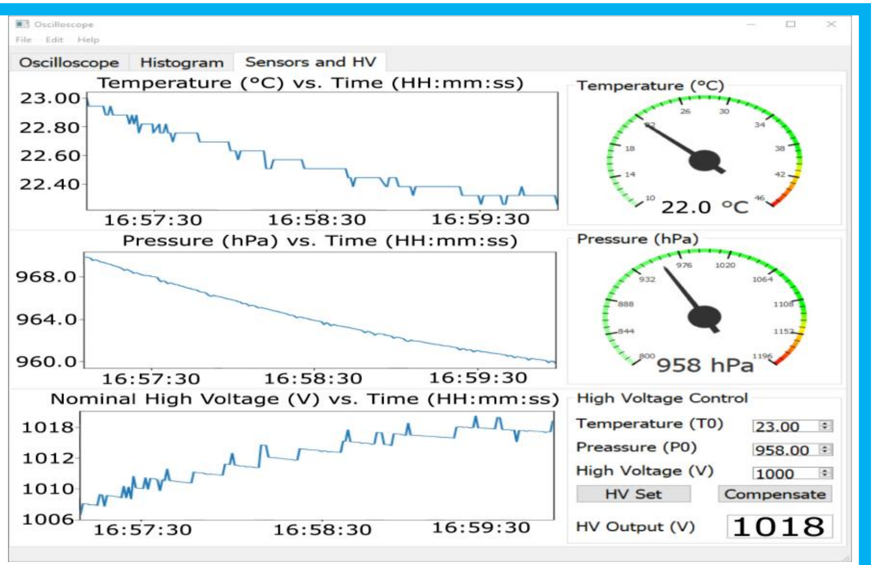
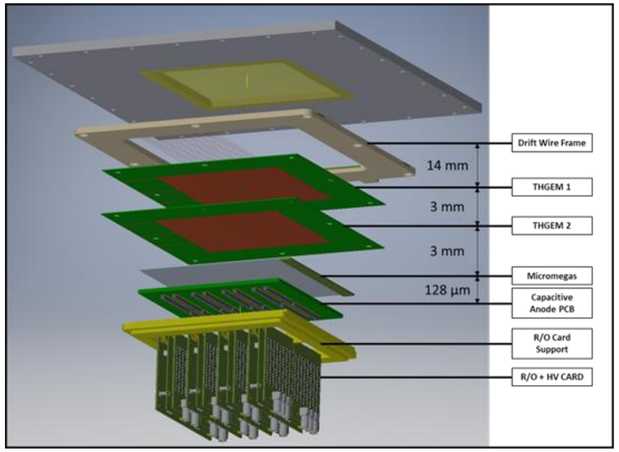
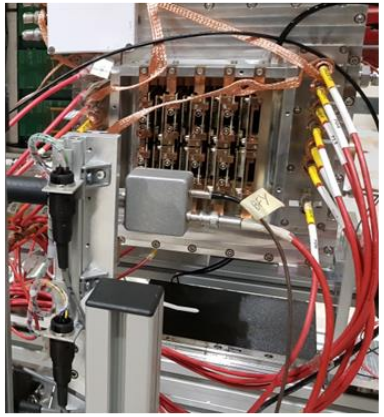


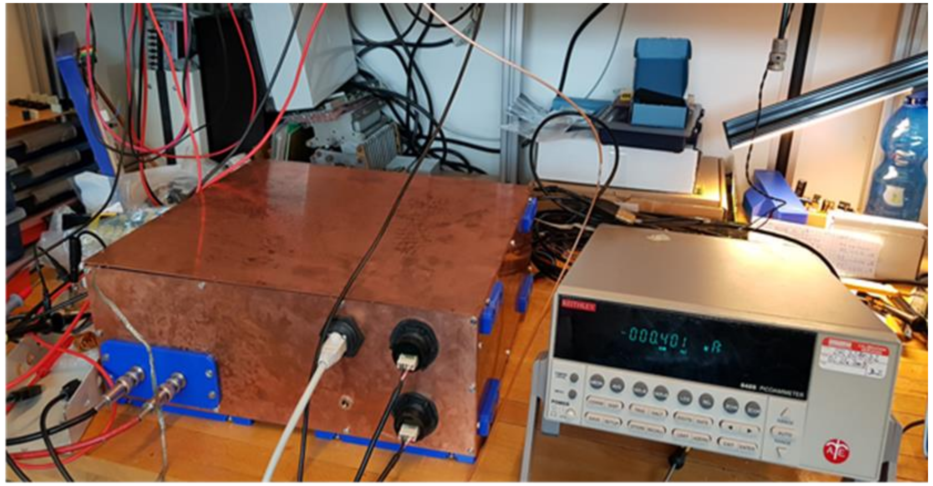
$$V = V_0 * \left(1 + 0.5\left(\left(\frac{P}{P_0}\right)\left(\frac{T_0}{T}\right) - 1\right)\right)$$

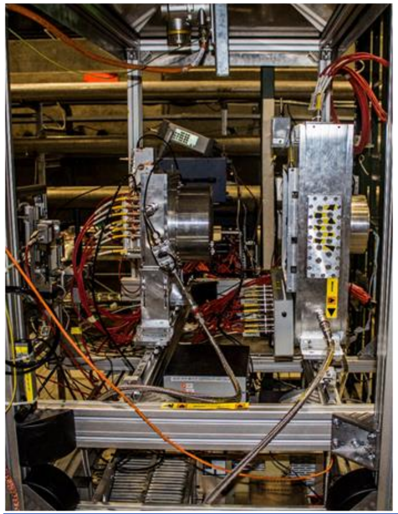
The new High Voltage Power Supply System : One Channel Test

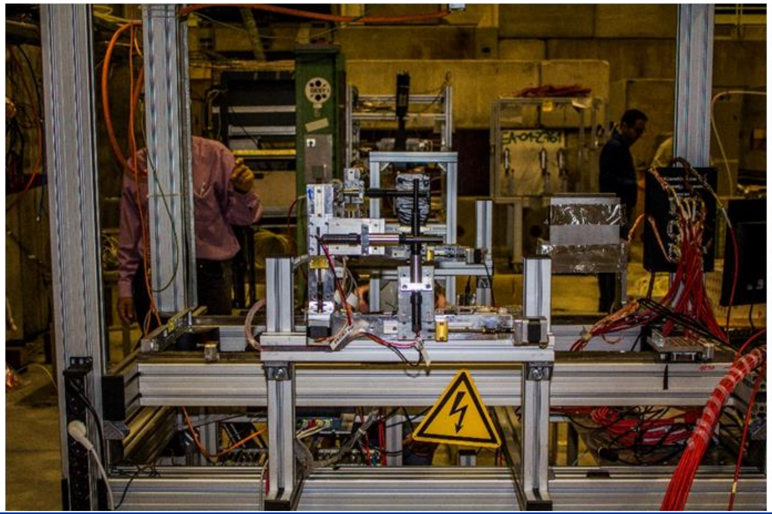
The HVPSS has been installed and operated during a test beam on a Hybrid detector prototype.
It was operated on the ***only non segmented electrode*** available, namely the Micromegas Mesh



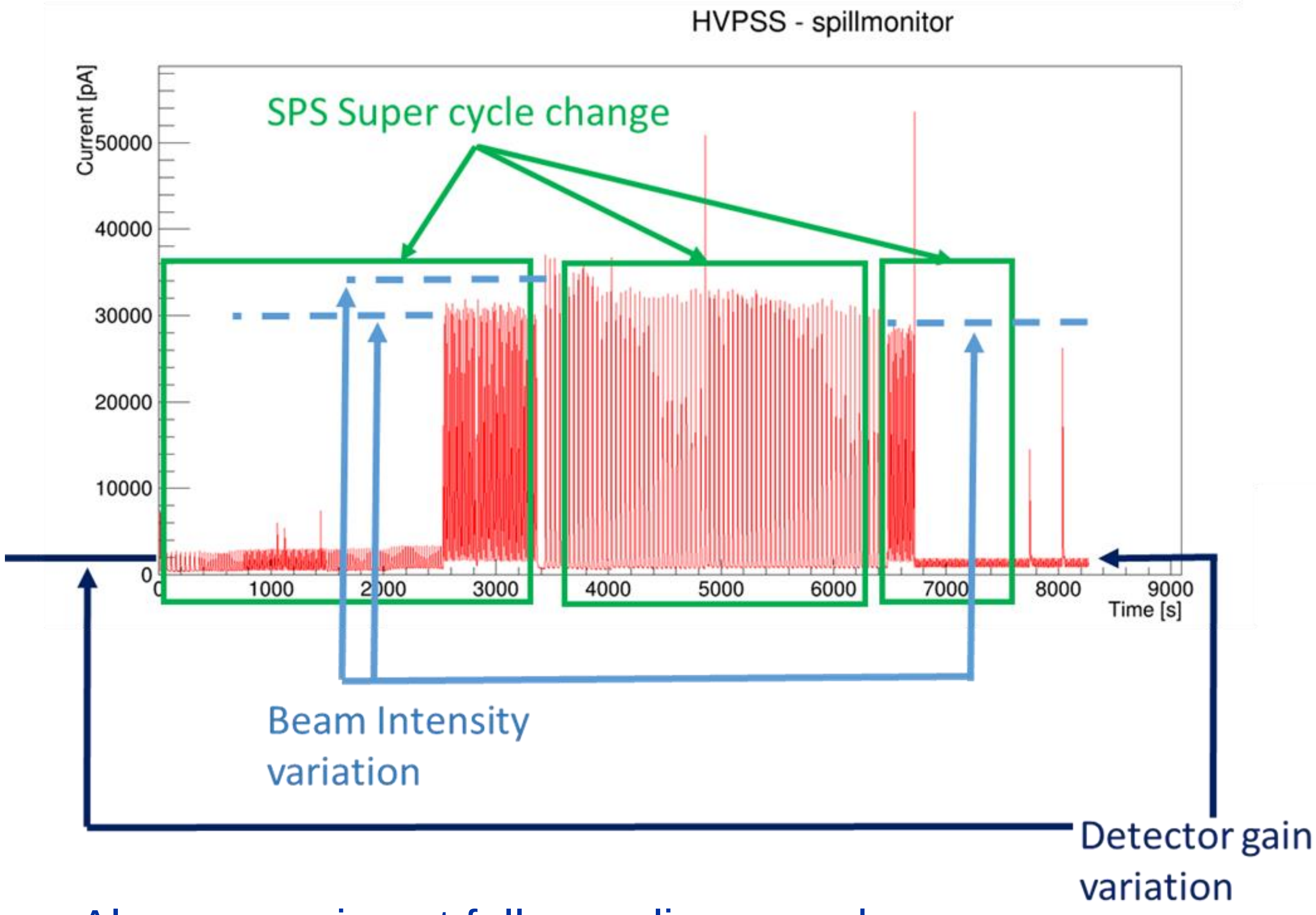




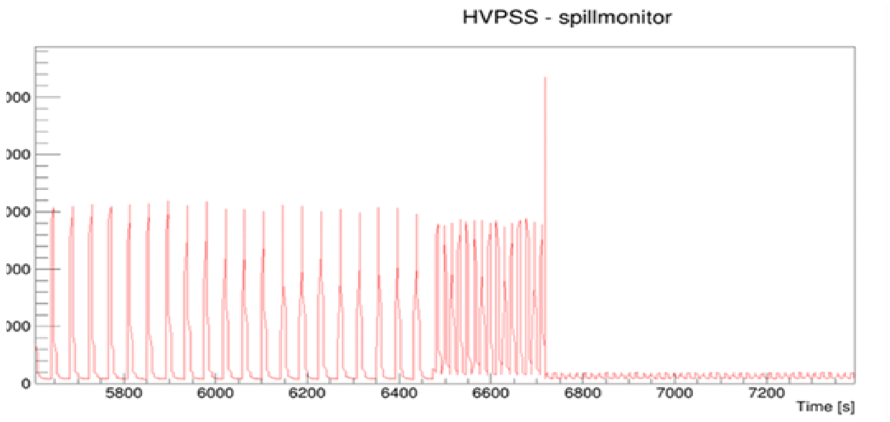




The new High Voltage Power Supply System : One Channel Test, some results



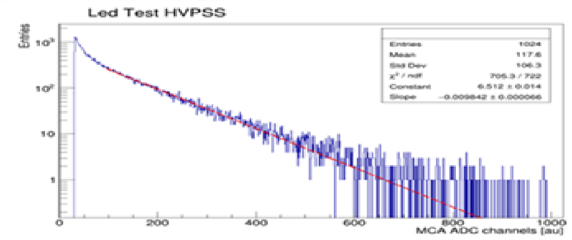
Always running at full sampling speed, averaged data is sent to user unless a *trigger* event occurs

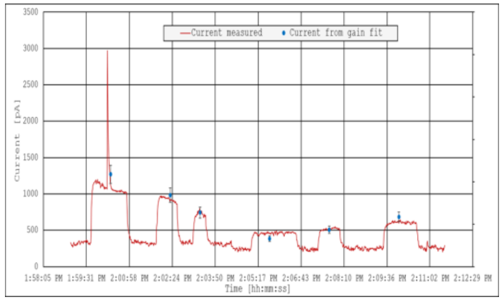


Performed x-check from current measurement by HVPSS (UV LED)

$$G_{eff} = \frac{I_{meas}}{C \cdot Rate \cdot \#e^{-}}$$

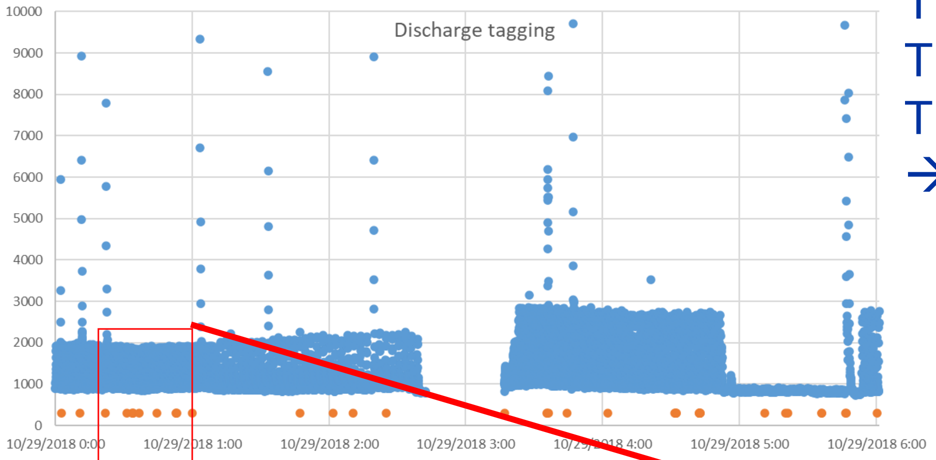
And from amplitude spectra





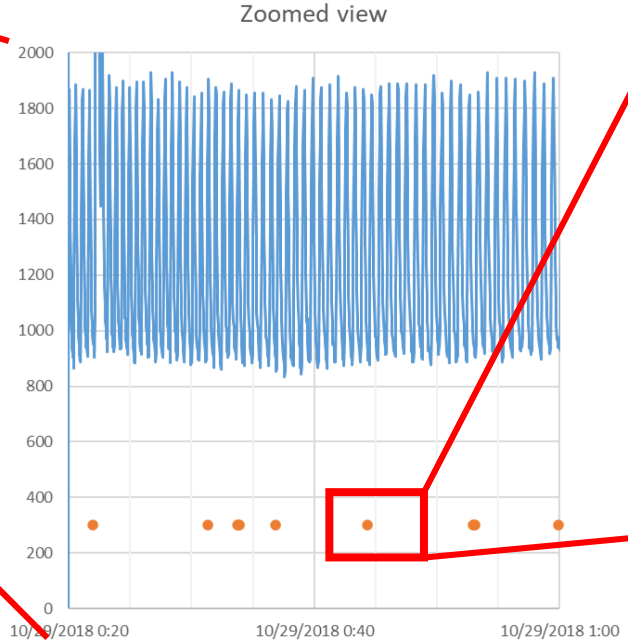
The new High Voltage Power Supply System : One Channel Test, data saving

"interesting" events to the user

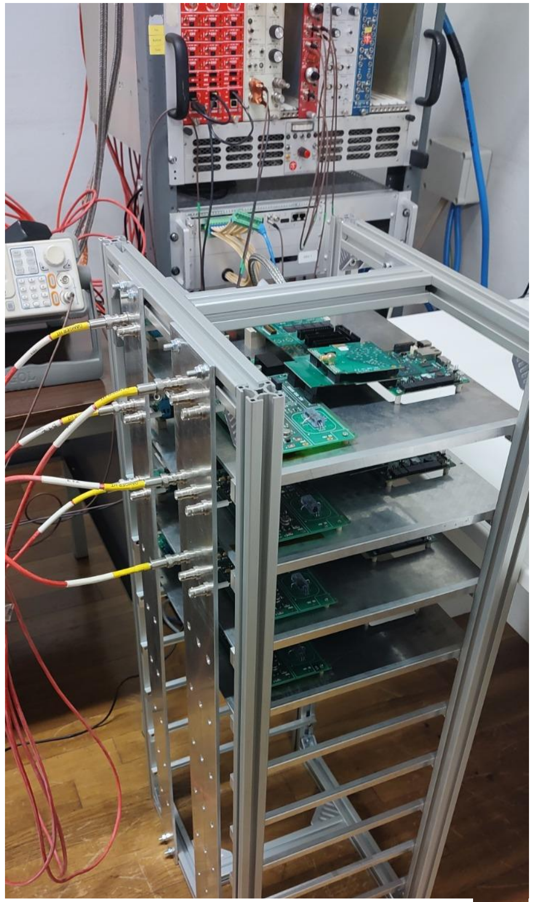


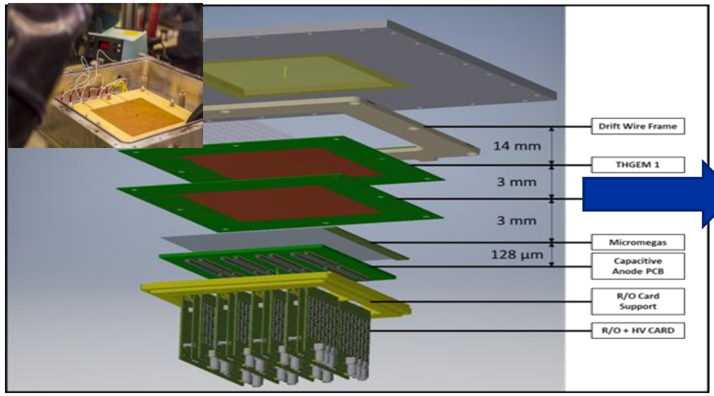
The *trigger* settings
The time before the trigger/event
The time after the trigger/event
→fully user customizable

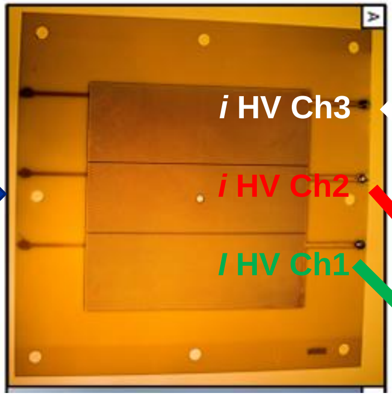
Trigger to save the event $\Delta i = i_{n+1} - i_n$ between two consecutive samples is larger than i_{thr}

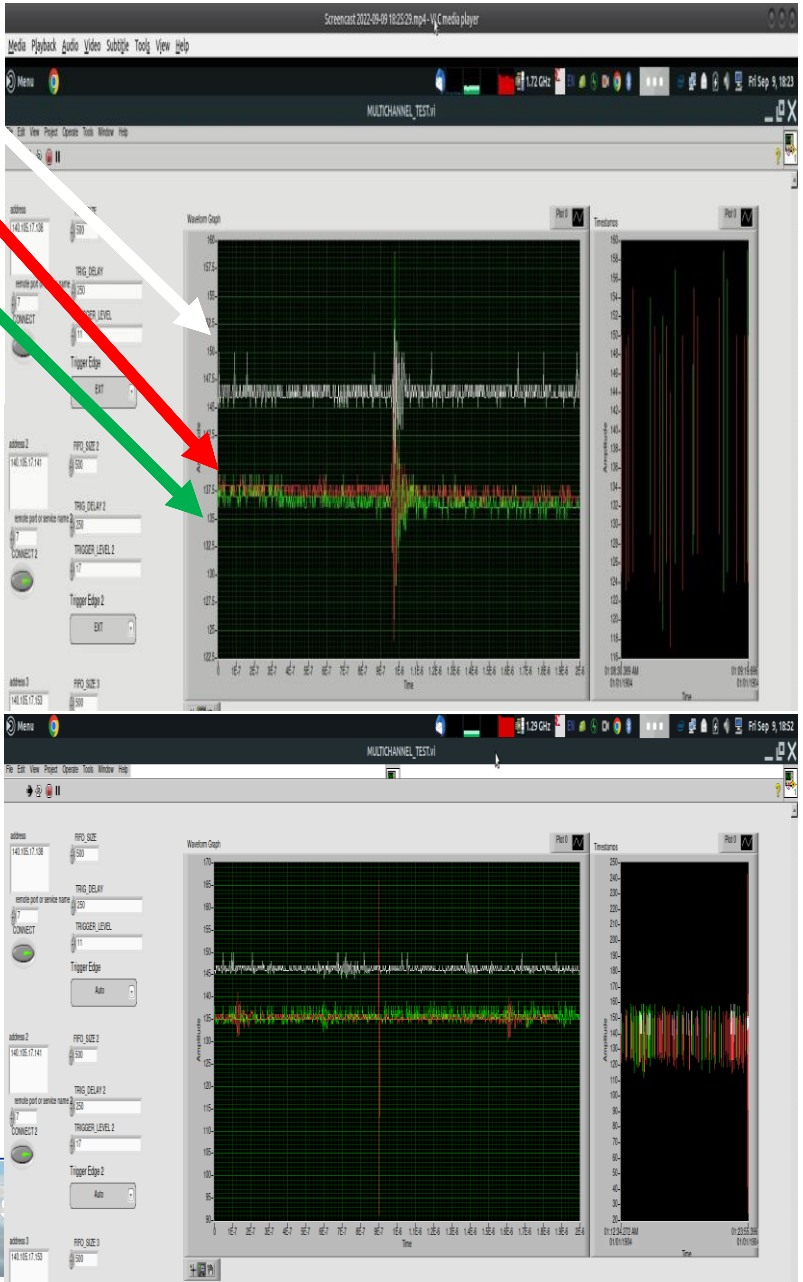


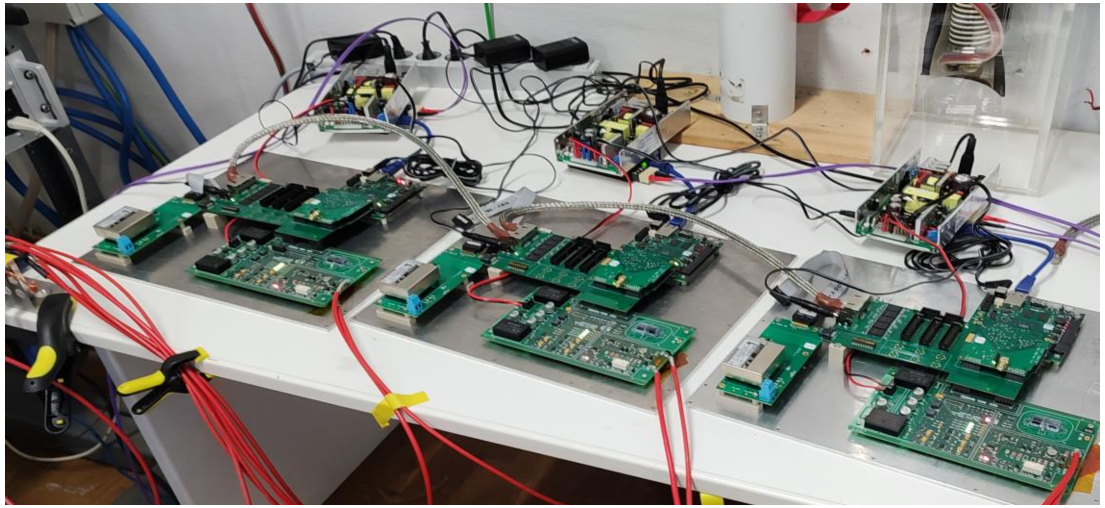
The new High Voltage Power Supply System : HVPSS the multichannel system operation

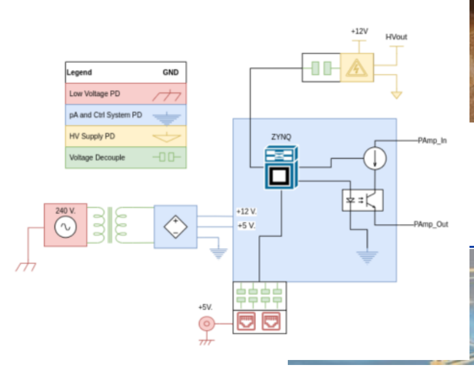


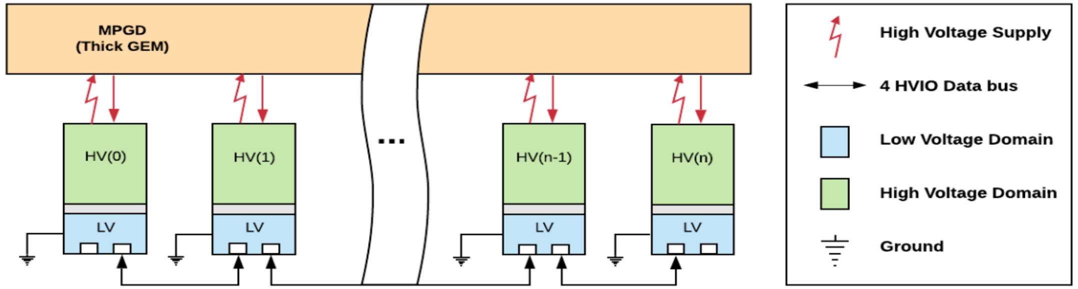




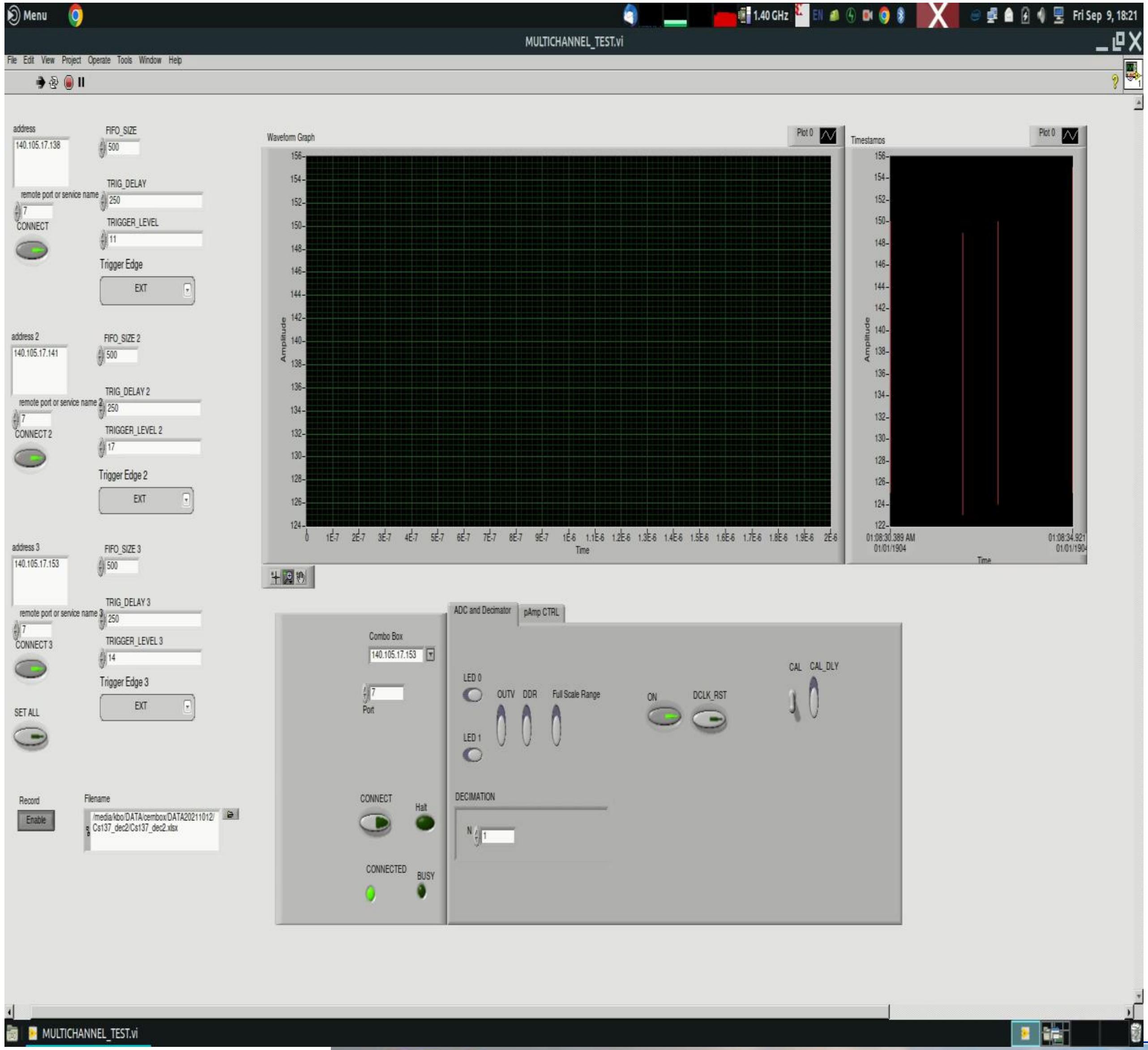




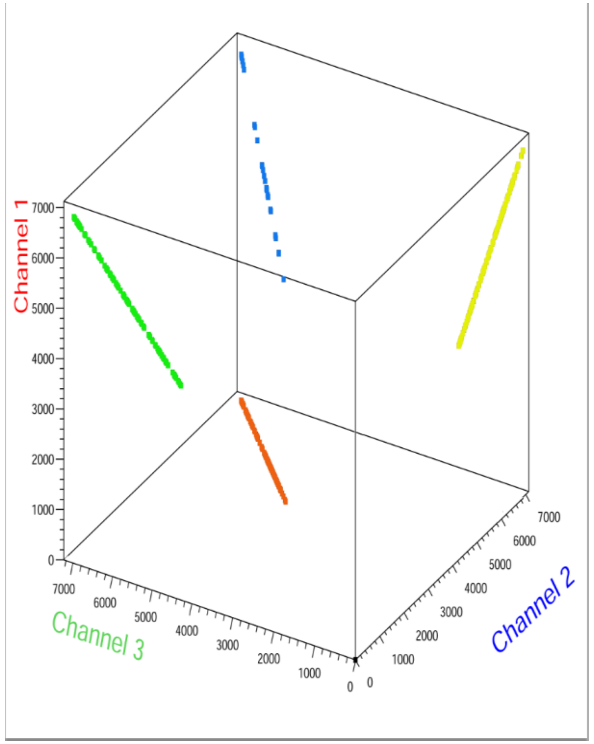


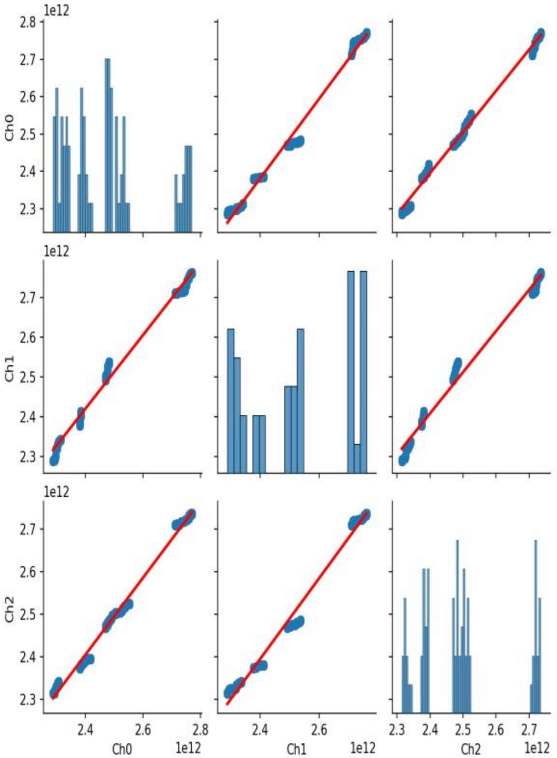


The new High Voltage Power Supply System : HVPSS the multichannel system operation



Preliminary tests! Raw data!





20ns time maximum time shift between different channel timestamp when in sync mode

Summary

Despite the complexity of RICH-1 PD high voltage system and the large number of channels:

- **The implemented HV system with sophisticated control allows for**
  - Safe detector operation
  - Collection of information to monitor the detector behavior and improve its performance
  - The electrical stability of the hybrid detectors is satisfactory at gains >/= 20 k
  - Not trivial: so far all MPGDs are operated in exp.s with gains < 10 k

A more performant multichannel HV system can improve further the detector performance

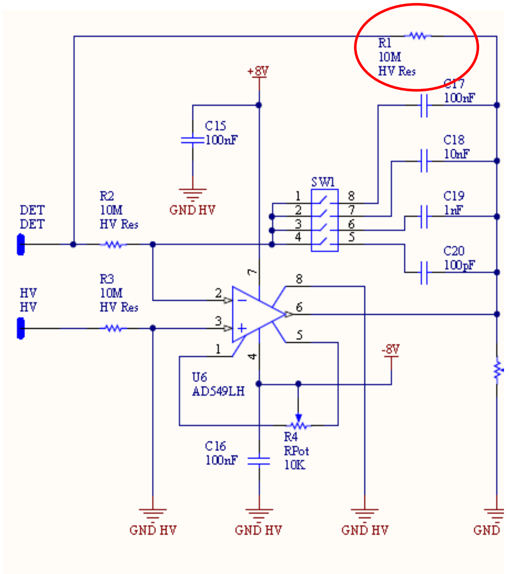
- **A MPGD-dedicated HV multichannel system is under development in Trieste, still work to go**
  - Generation of the HV at the detector
  - Real-time V, I information and handling
  - Goals:
    - Support to R&D activity
    - Tool for experiments (debugging, monitor, local feedback protocols)

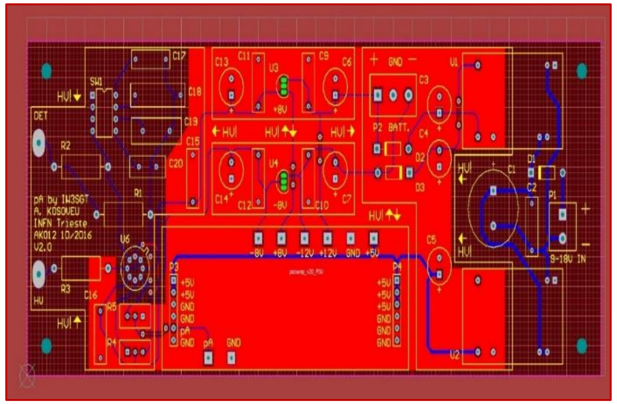
Thanks!

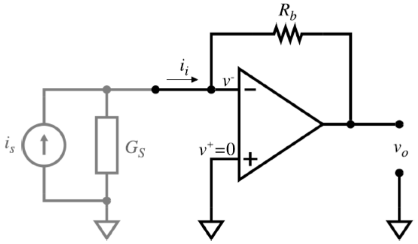
A scalable High Voltage Power Supply System with system on chip control for Micro Pattern Gaseous Detectors, NIMA Volume 963, 2020,

In case of need

The new High Voltage Power Supply System : I measurement, V generation, P/T correction







$$V_{out} = R_F \cdot i$$

Feedback resistor range 10 MΩ ÷ 100 MΩ → optimized

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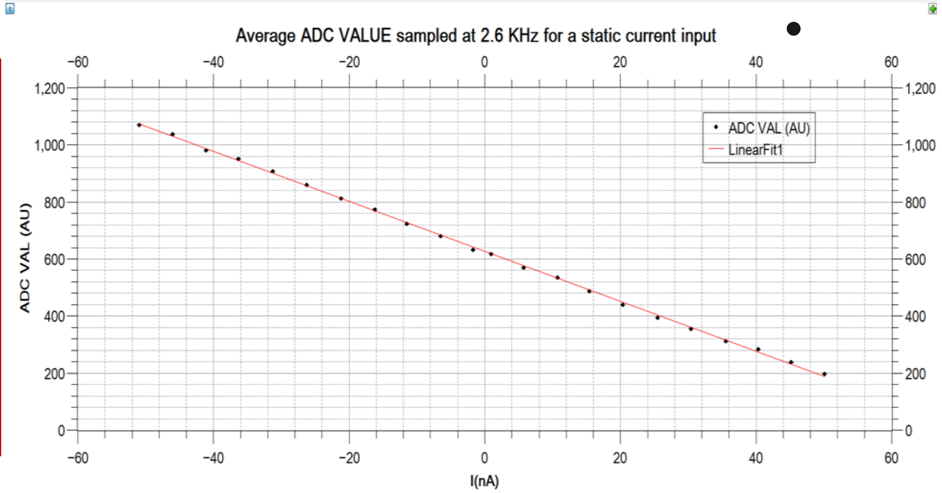

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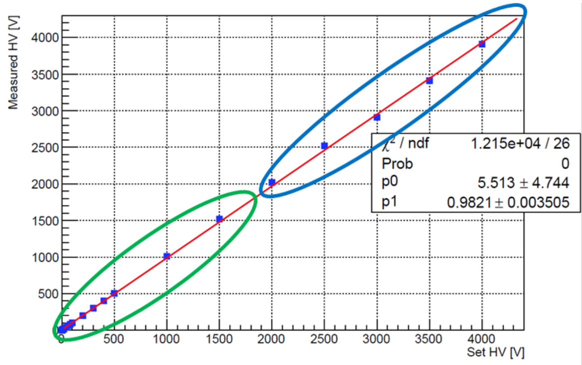
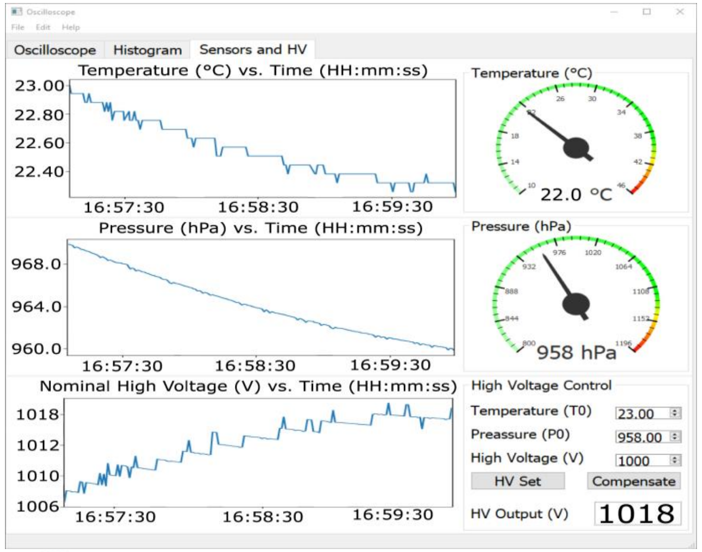
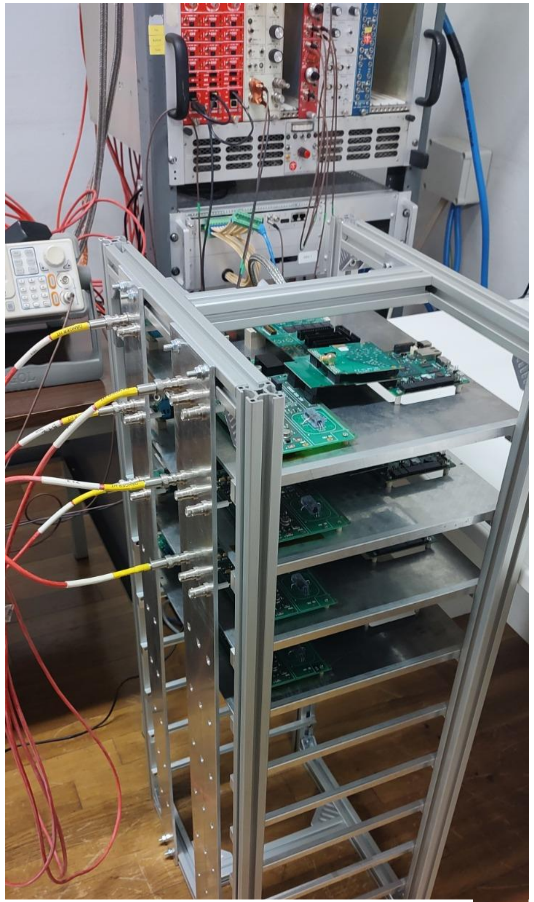
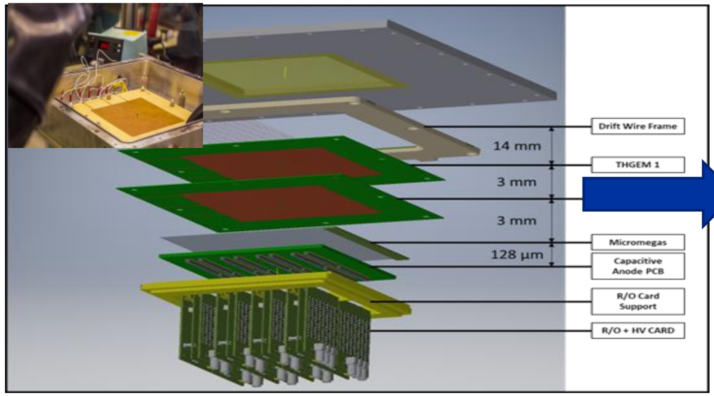


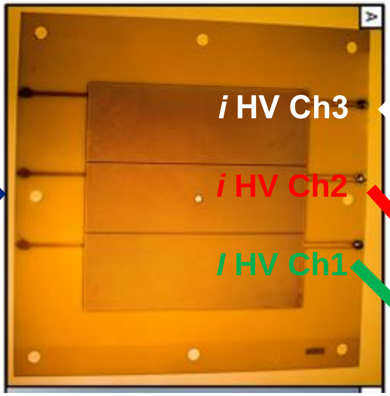


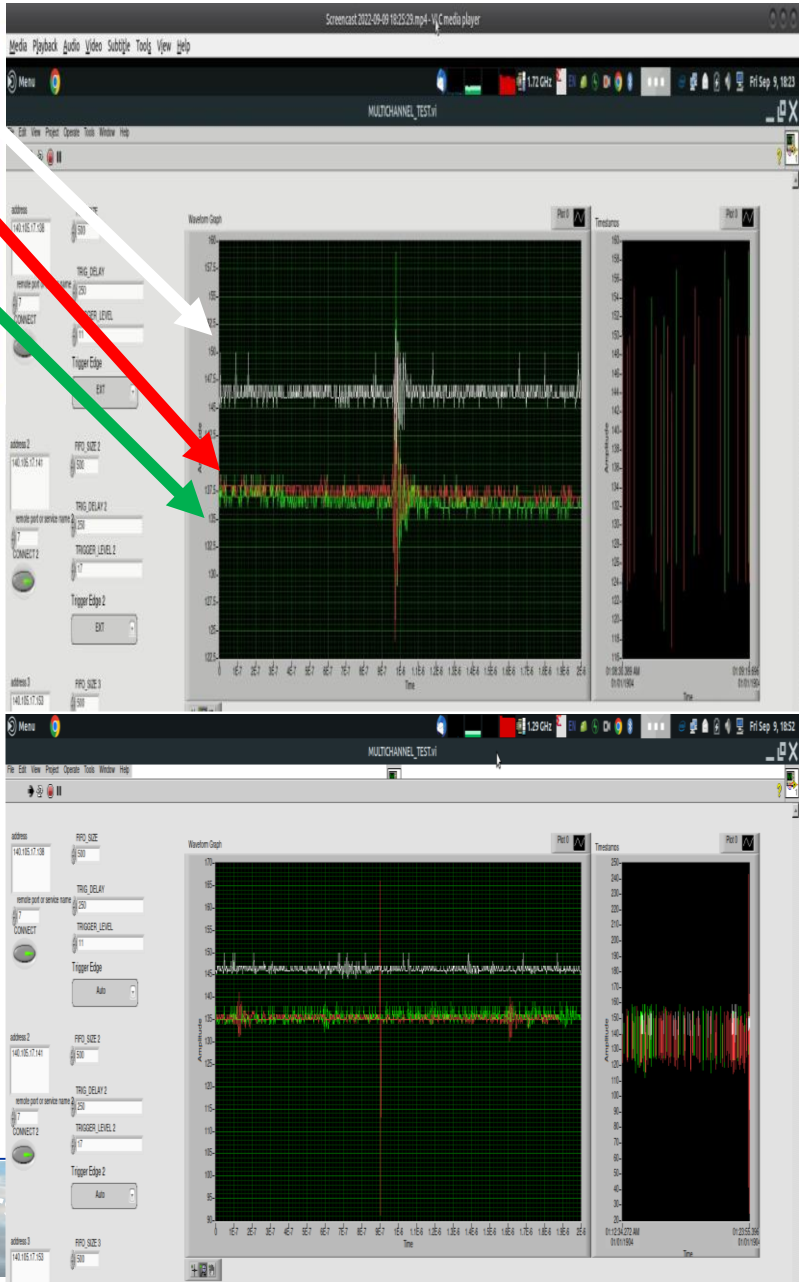
$$V = V_0 * \left(1 + 0.5\left(\left(\frac{P}{P_0}\right)\left(\frac{T_0}{T}\right) - 1\right)\right)$$

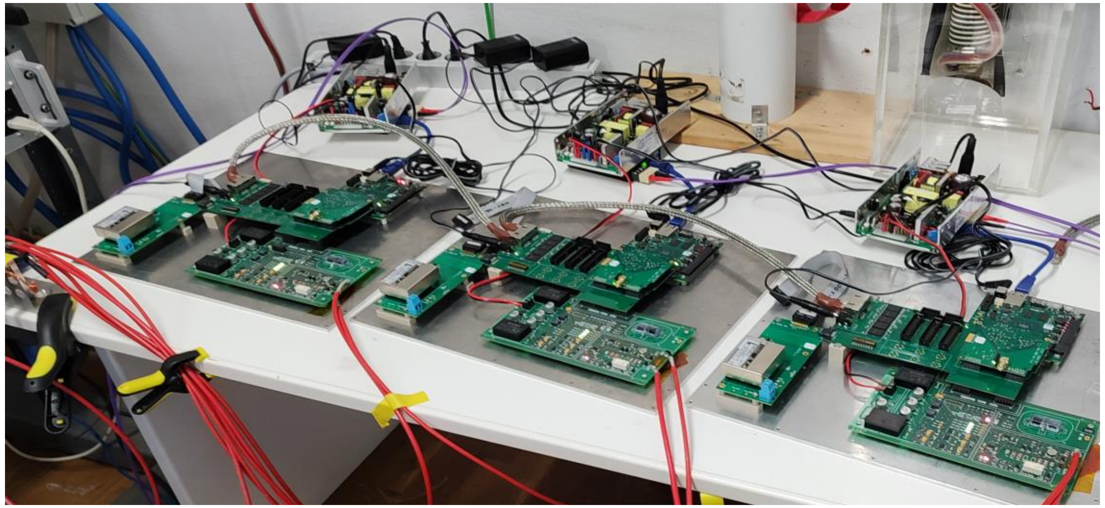
The new High Voltage Power Supply System : HVPSS the multichannel system

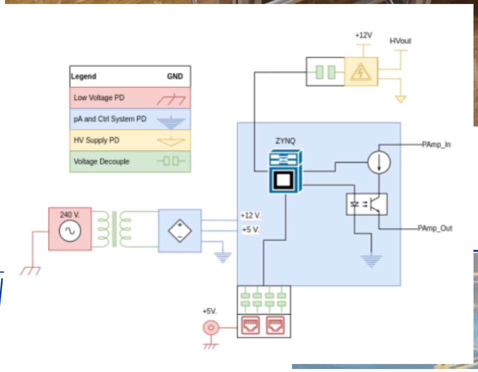


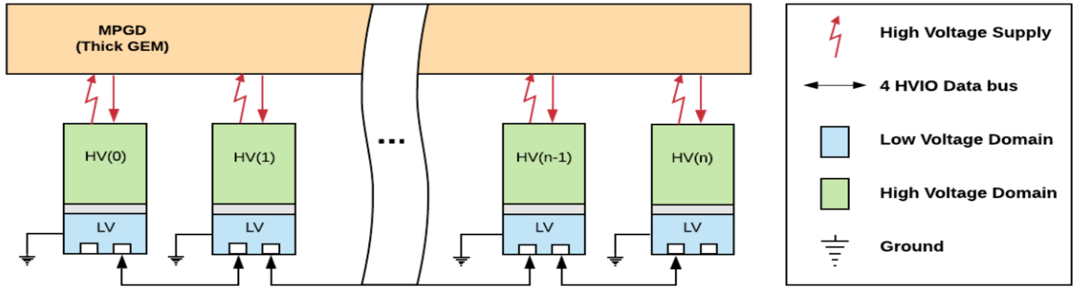












The High Voltage system of the COMPASS RICH-1 Hybrid Photon Detector: HV PD scheme

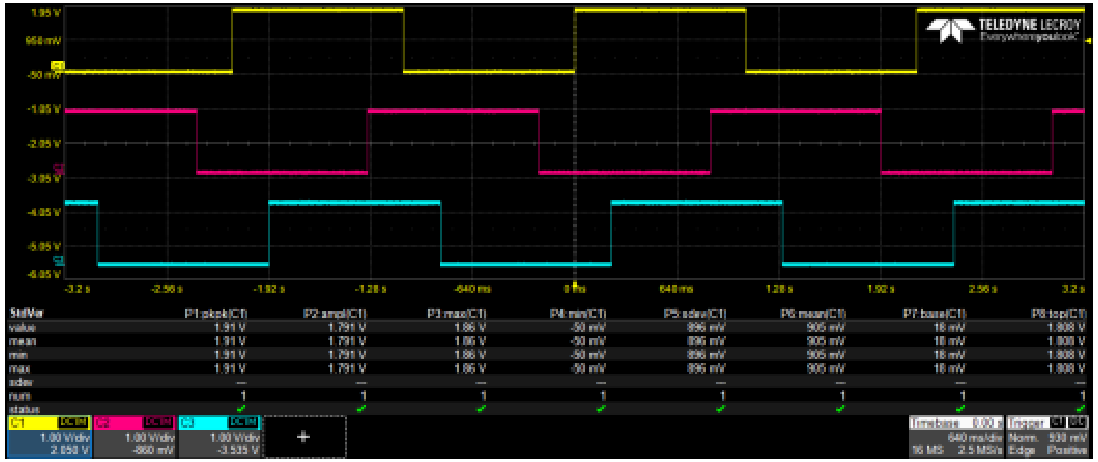


Figure 8. PPS signal before PTP implementation.

Figure 9. PPS signal after PTP implementation.

If we call Δ_n the time difference between the master clock time (MT) and the N slave clock time (SNT), the relation between both can be defined with the following equation:

$$MT = SNT + \Delta_n. \tag{1}$$

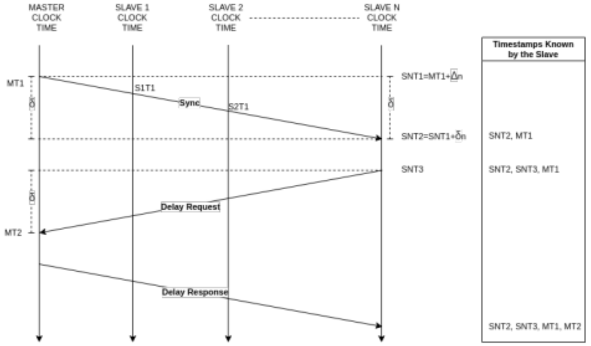


Figure 3. Simplified PTP principle of operation for multiple slaves.

To calculate this delay, the procedure is described below.

1. The master sends a *Sync* signal, its address, and the timestamp MT_1 to the slave N in a single package. All the slaves take a timestamp SNT_2 as soon as the *Sync* signal arrives, which is kept until the address is validated. The MT_1 time is then stored in the intended slave for synchronization;
2. In a time SNT_3, the slave sends a *Delay Request* to the master. The master takes a timestamp MT_2 as soon as the request is received;
3. The master sends the timestamp MT_2 to the slave with a header *Delay Response*, opening the communication channel;
4. The slave calculates the time correction using the obtained information.

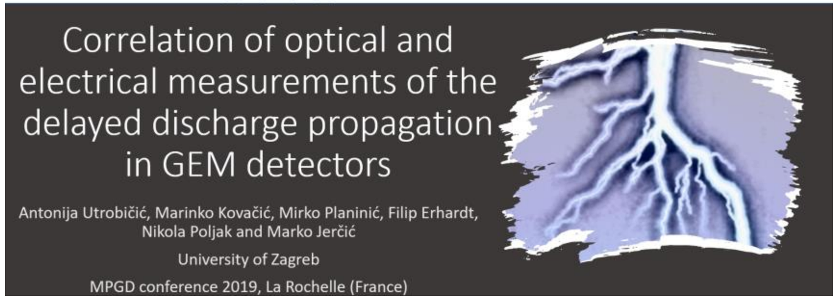
$$SNT_1 = MT_1 + \Delta_n;$$
$$SNT_2 = SNT_1 + \delta_n;$$
$$MT_2 - MT_1 - 2\delta_n = SNT_3 - SNT_2.$$

By simplifying these equations we obtain the following results:

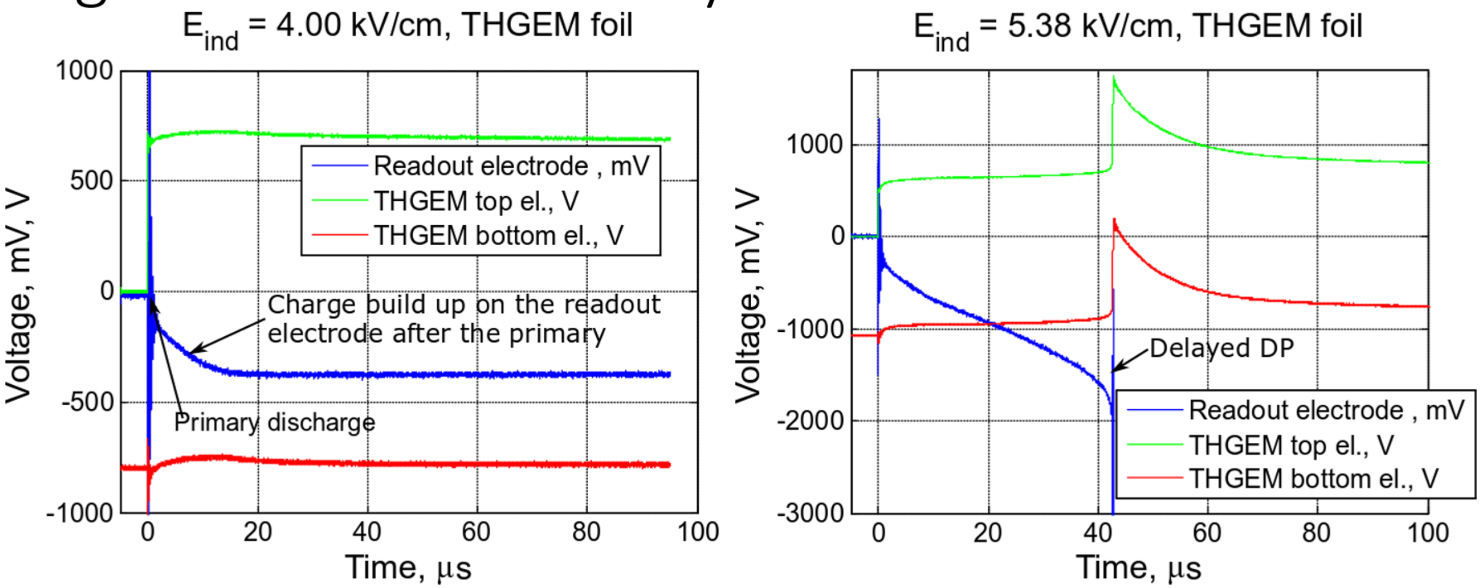
$$\delta_n = \frac{SNT_2 - SNT_3 + MT_2 - MT_1}{2};$$
$$\Delta_n = \frac{SNT_2 + SNT_3 - MT_1 - MT_2}{2}.$$

20ns time resolution in sync mode

Project is funded by the Croatian Science Fundation, project number IP-2018-01-4108



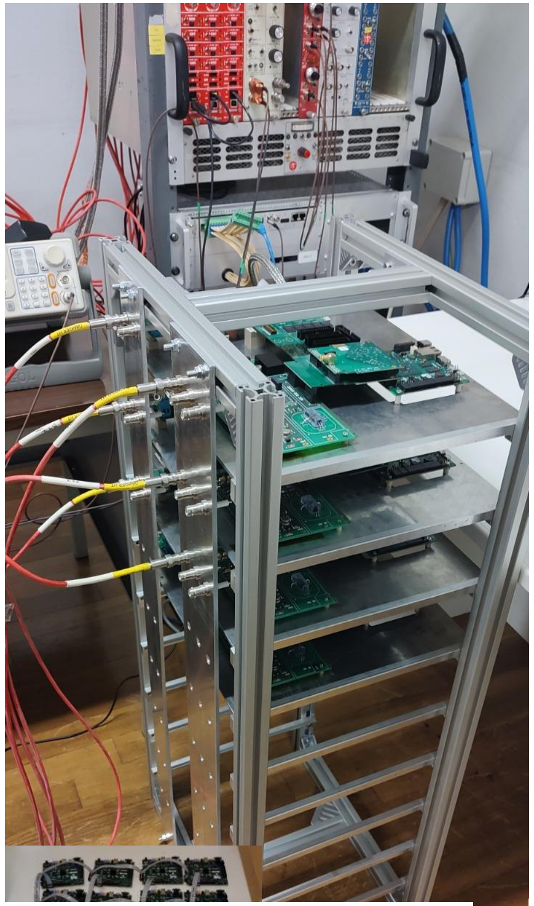
Single hole THGEM delayed DP waveforms

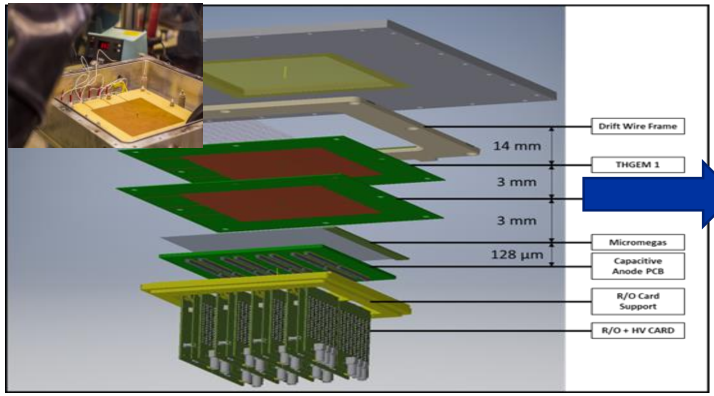


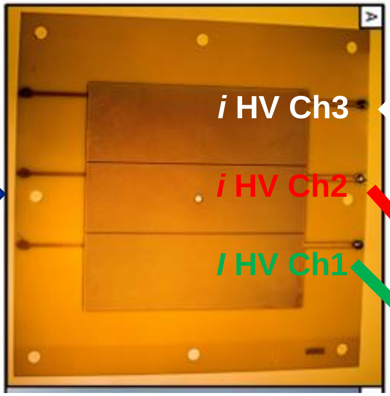
- Following the primary discharge, charge flows in the induction region for $\sim 15\ \mu s$. (4 kV/cm field)
- Charge build-up increases with the induction field.
- A constant slope in the charge build-up precedes the DP event.
- This can indicate that the charge transfer (current) is responsible for the DP.

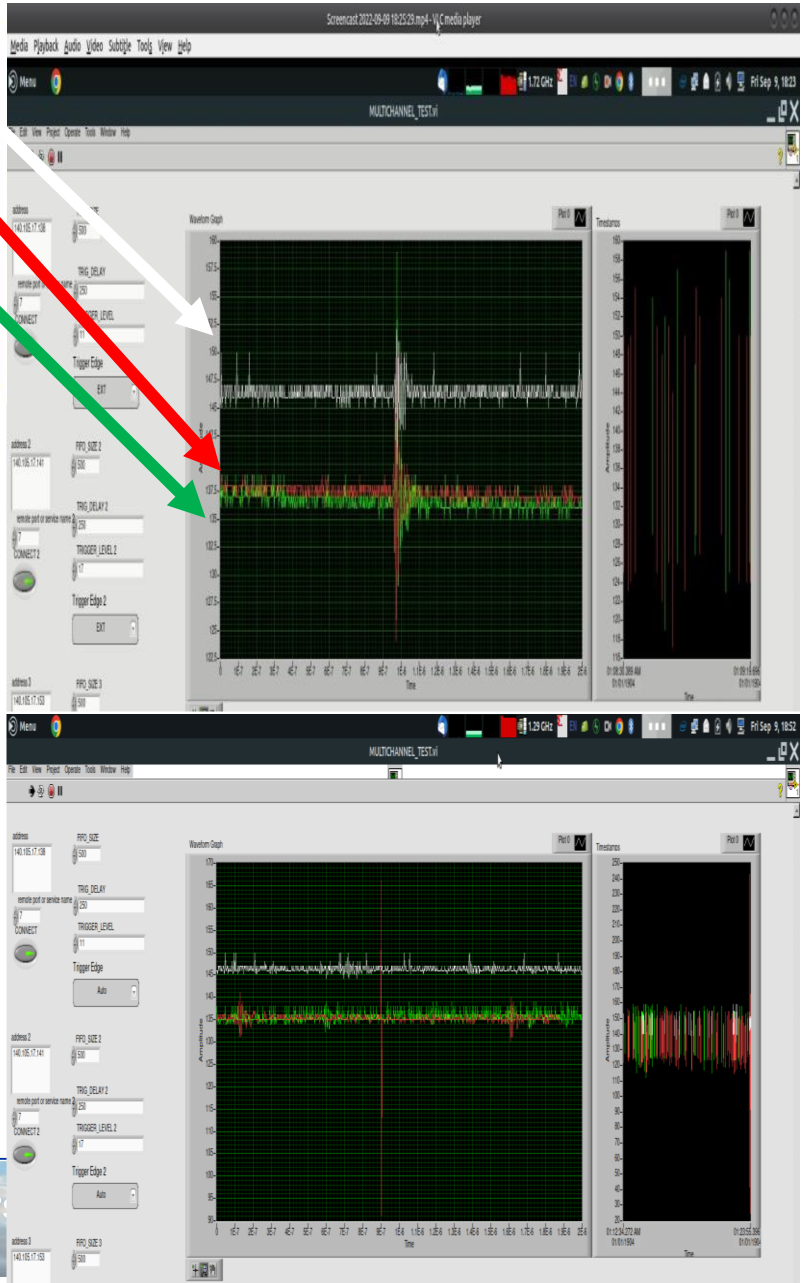
7

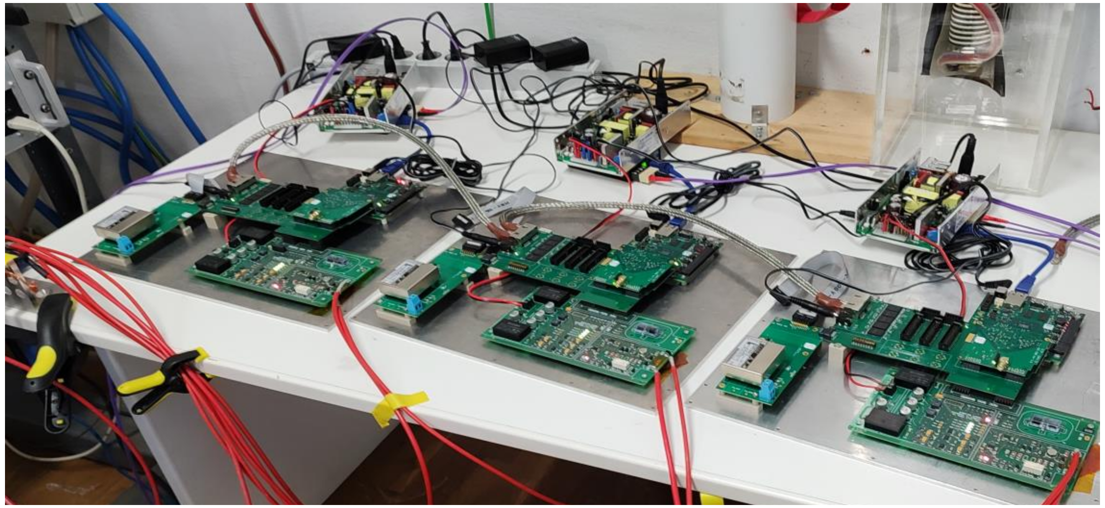
The High Voltage system of the COMPASS RICH-1 Hybrid Photon Detector: HVPSS results

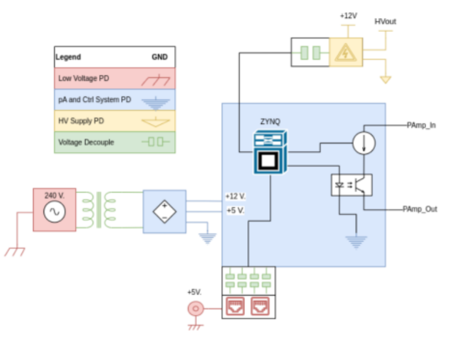


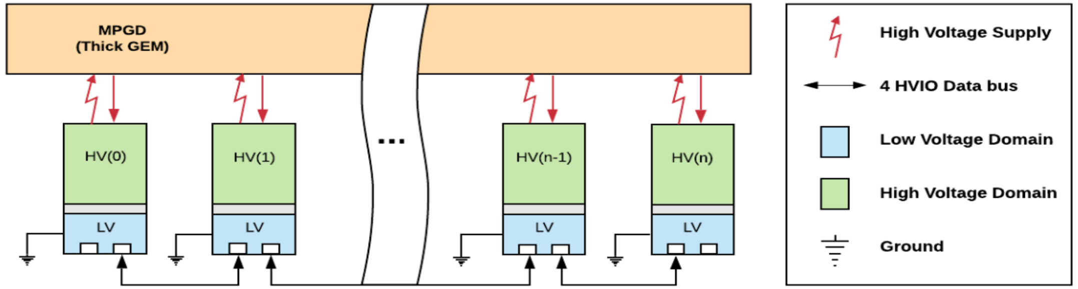




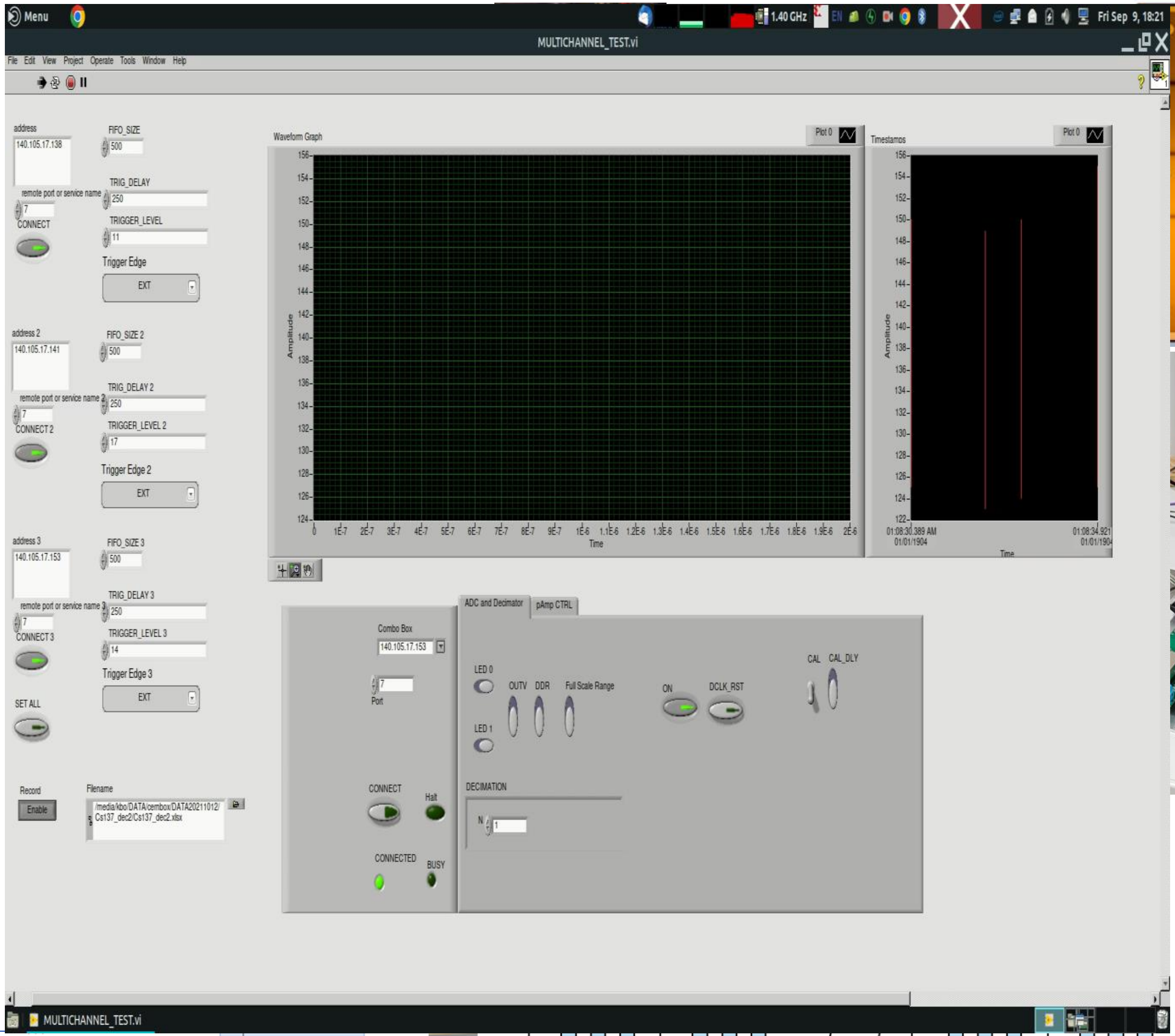


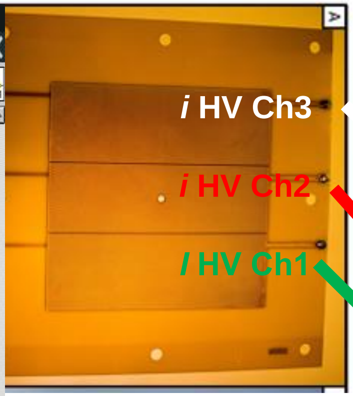


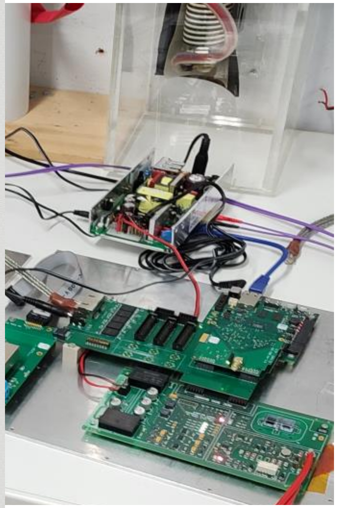




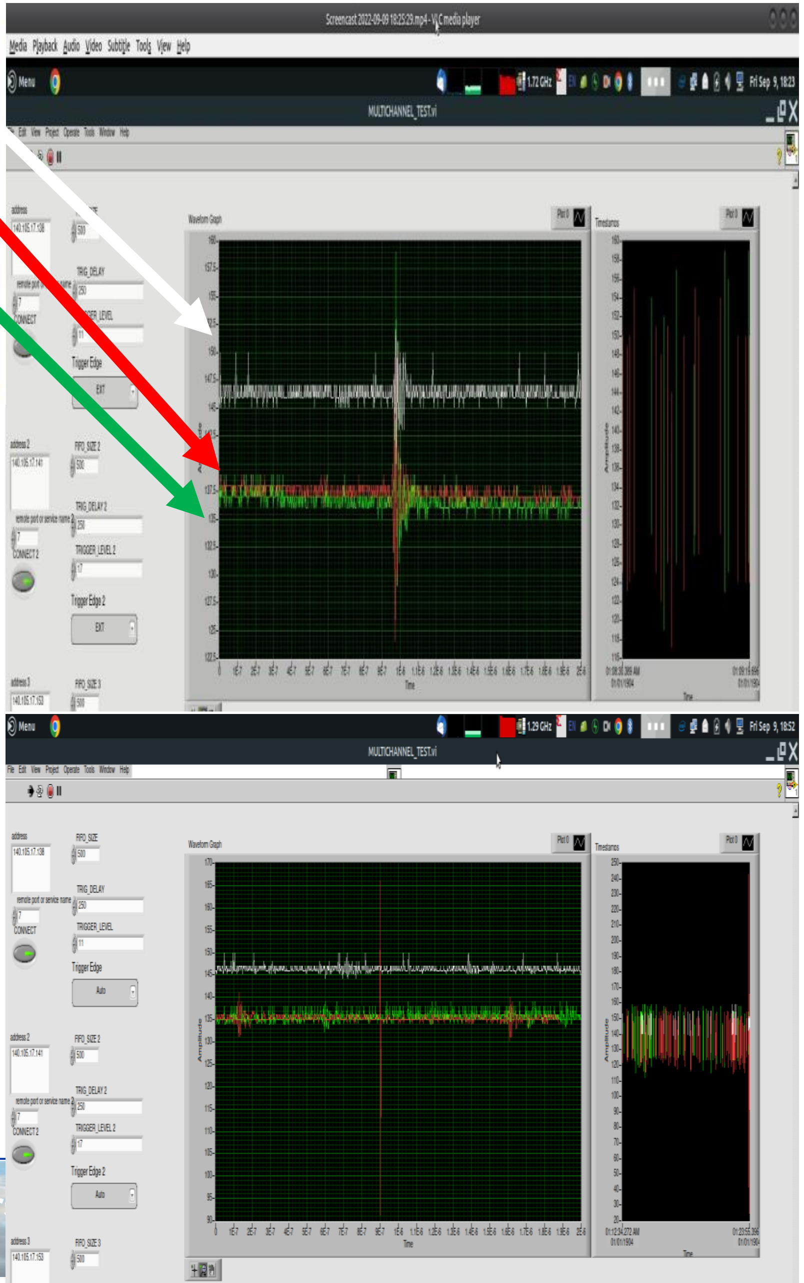
The new High Voltage Power Supply System : HVPSS the multichannel system operation







- High Voltage Supply
- 4 HVIO Data bus
- Low Voltage Domain
- High Voltage Domain
- Ground



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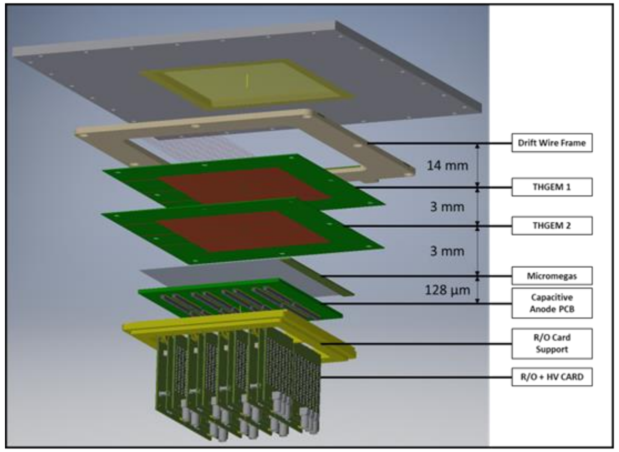
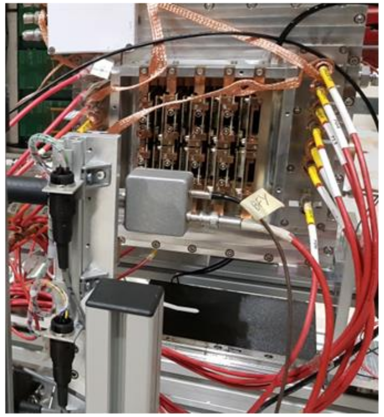
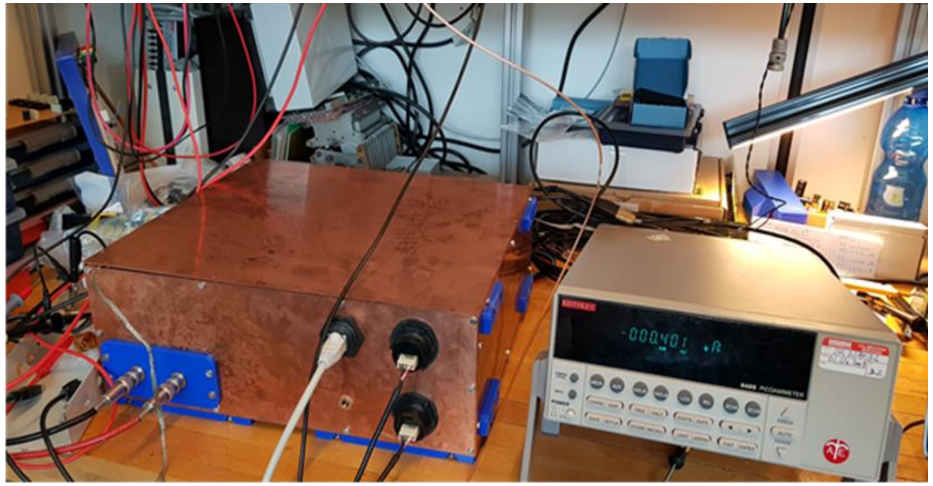
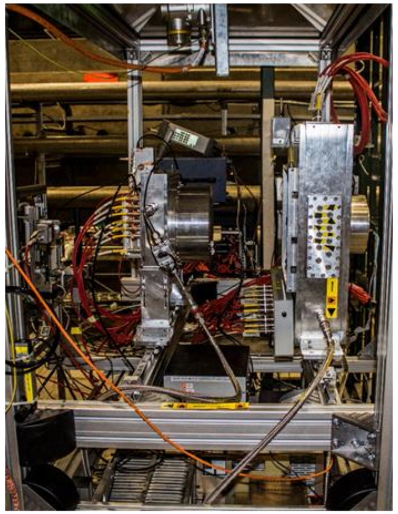
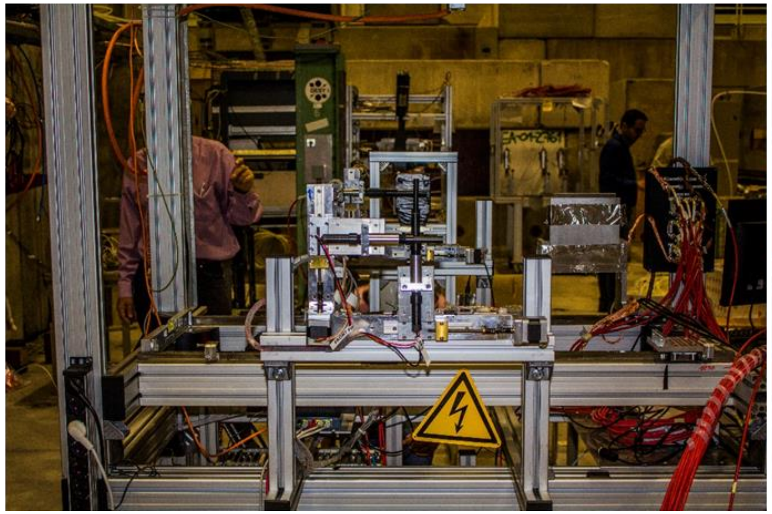
The HVPSS has been installed and operated during the RD51 October test beam on the hybrid prototype. It was operated on the ***only non segmented electrode*** available, namely the Micromegas Mesh







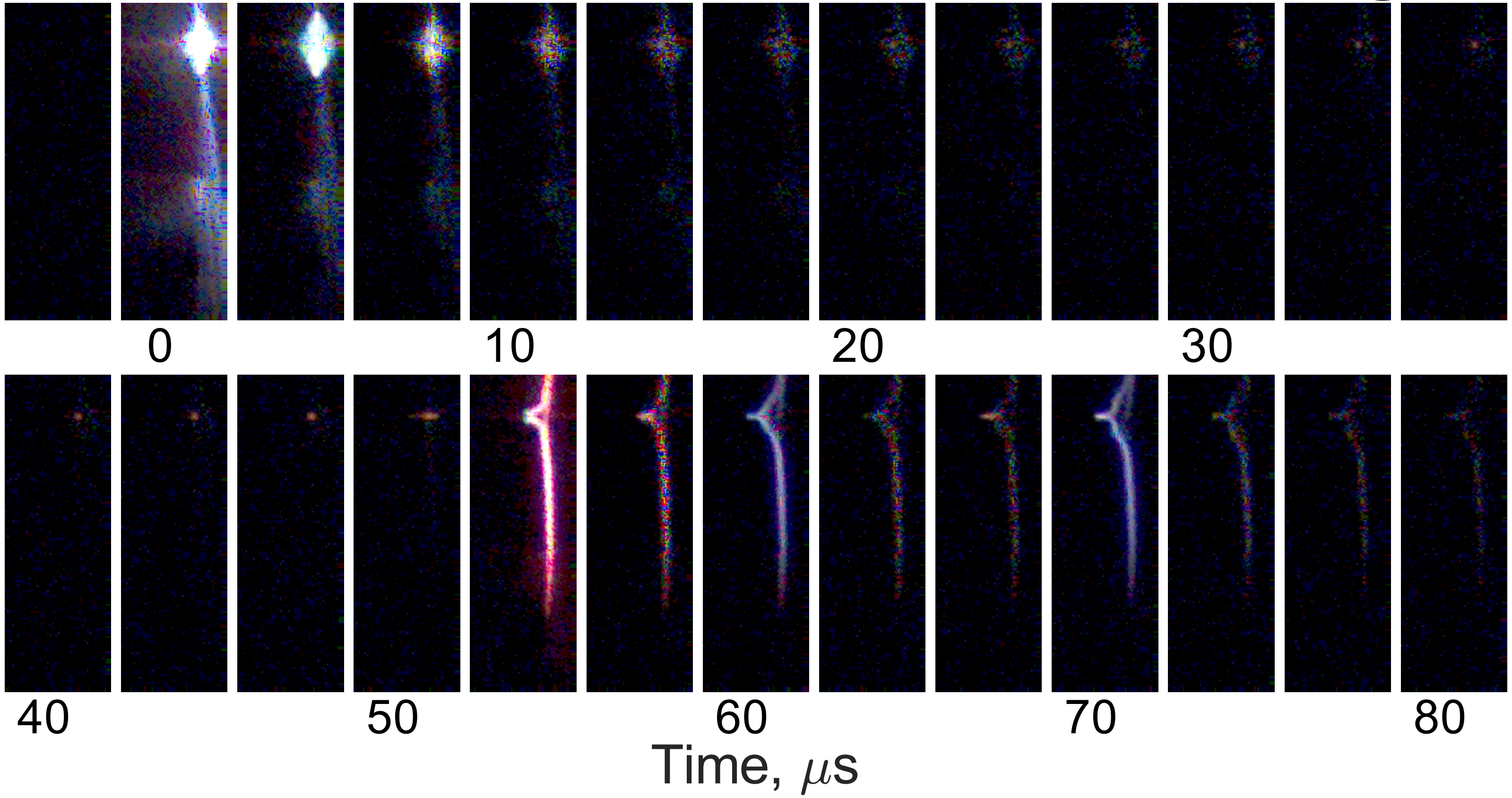


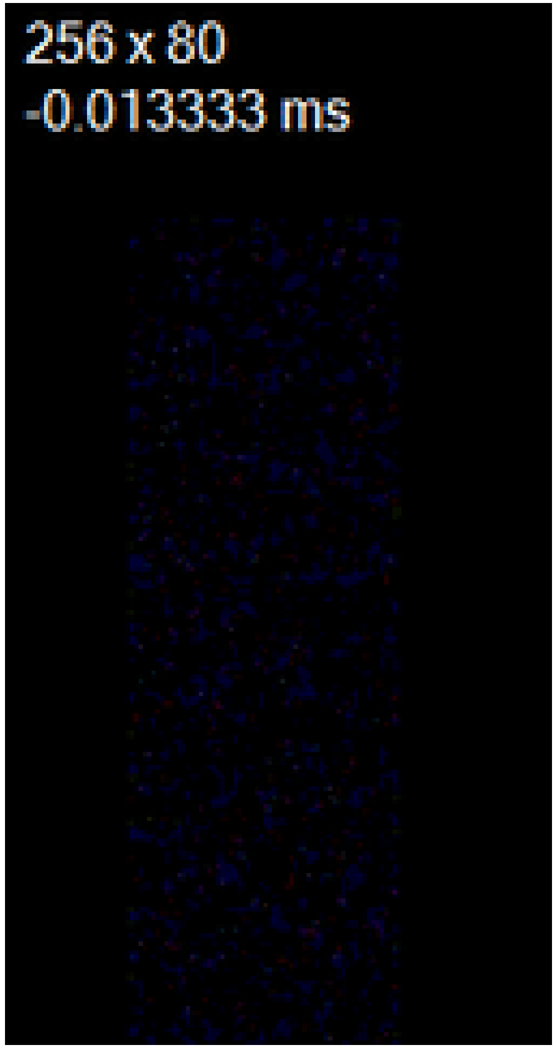


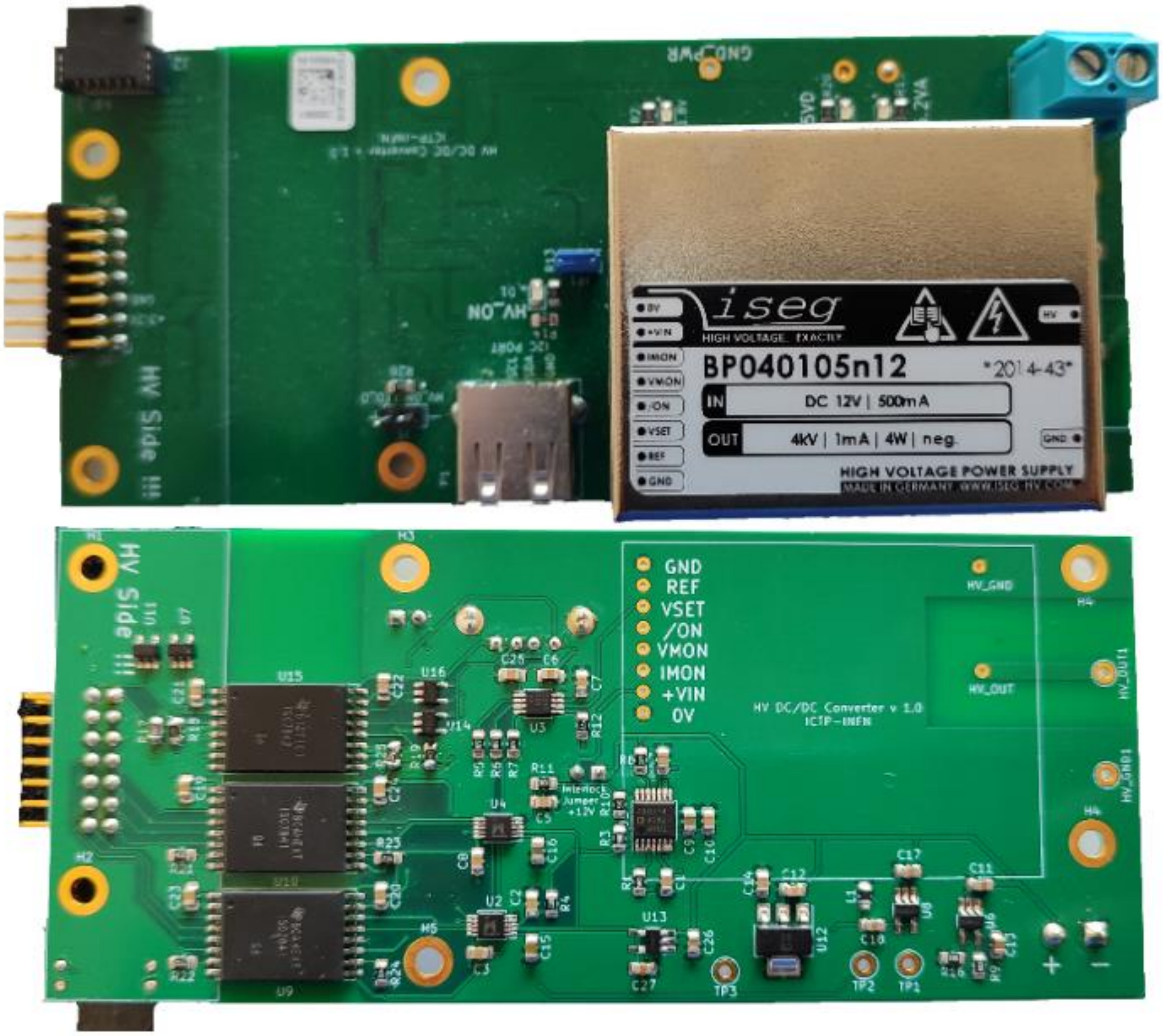
High speed camera measurements (GEM)

GEM @ E_{ind}=5.66 kv/cm, ΔV_{GEM}=500 V, R_{dec}=0 kΩ

PHOTRON SA-X2: 80x256, 300000 fps, S:1/583784, A:F2.8@100 mm







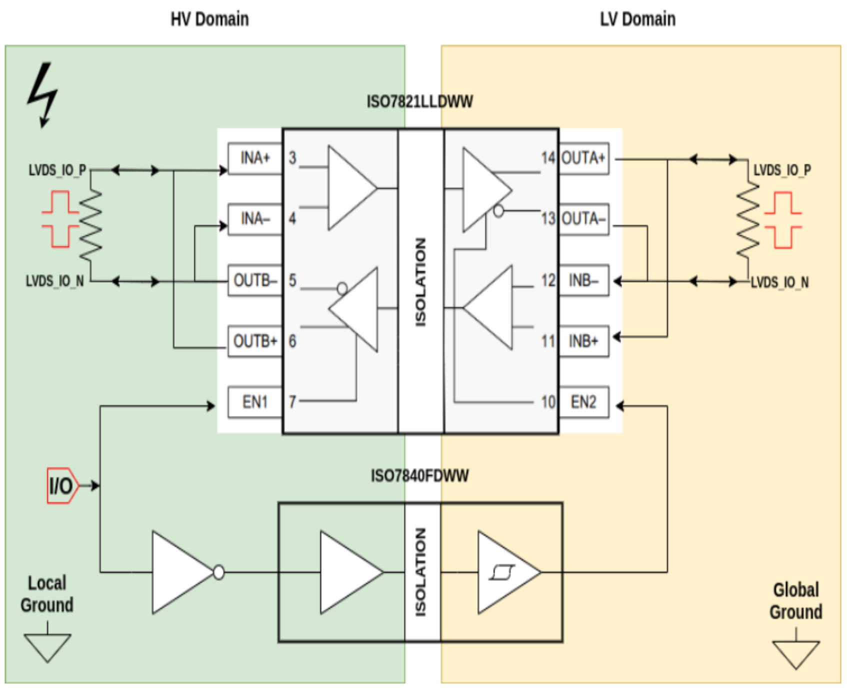
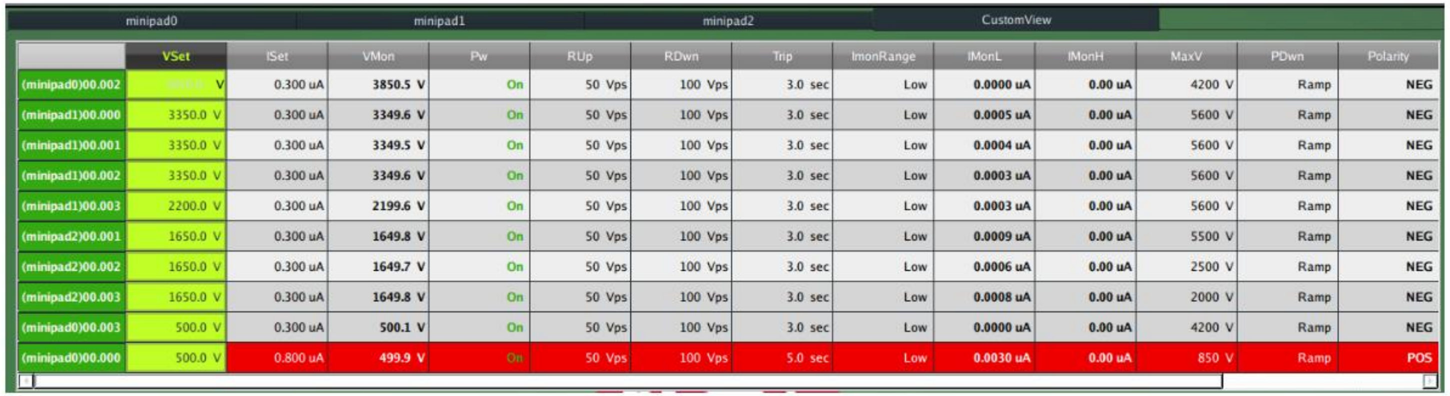


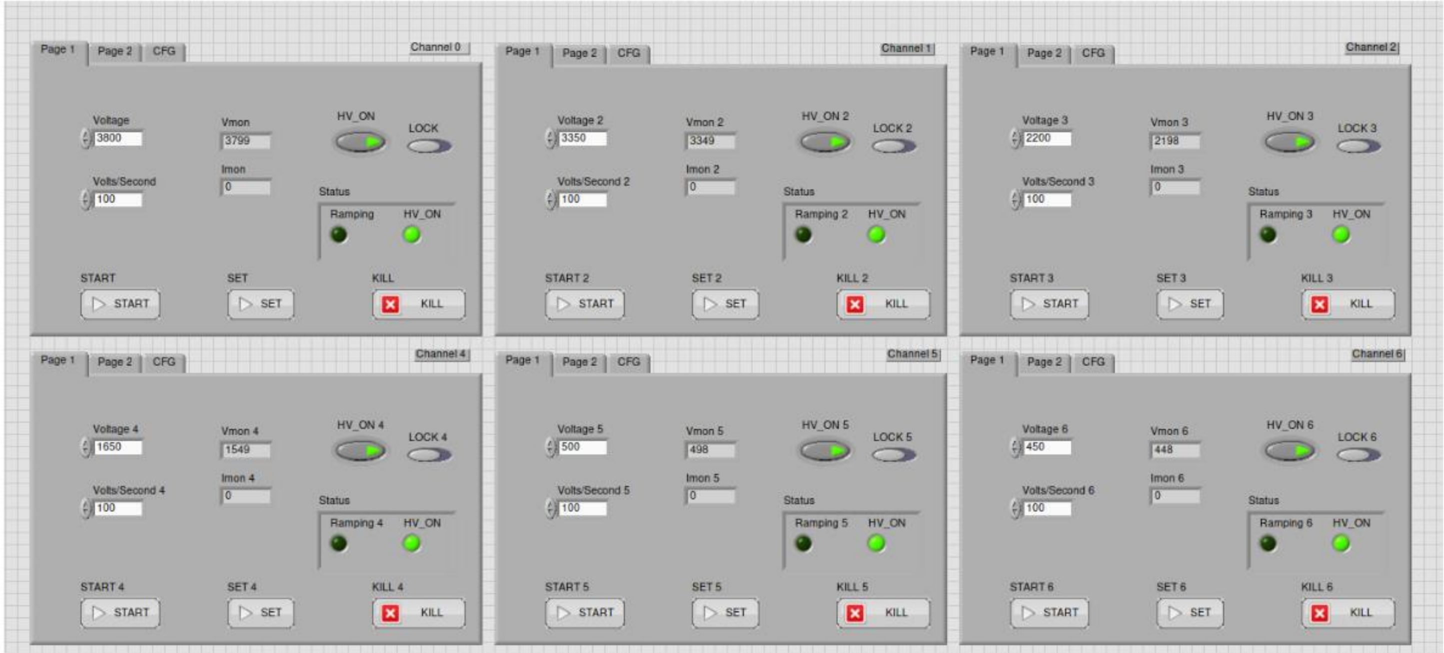
Figure 3.14: High Voltage Isolation Bidirectional Network Interface (HVIBNI)

ISO7821LLDW

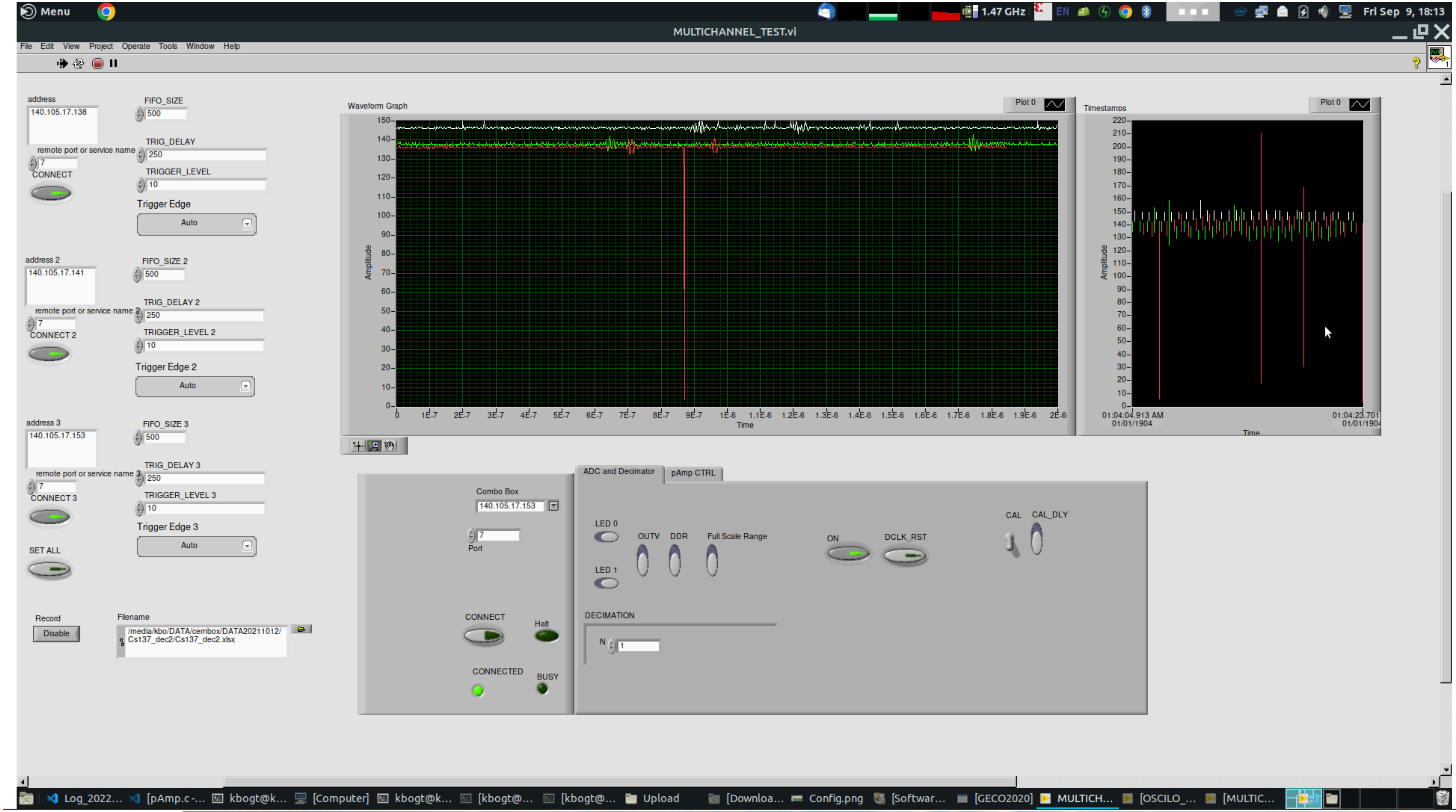


	VSet	ISet	VMon	Pw	RUp	RDwn	Trip	ImonRange	IMonL	IMonH	MaxV	PDwn	Polarity
(minipad0)00.002	[illegible] V	0.300 uA	3850.5 V	On	50 Vps	100 Vps	3.0 sec	Low	0.0000 uA	0.00 uA	4200 V	Ramp	NEG
(minipad1)00.000	3350.0 V	0.300 uA	3349.6 V	On	50 Vps	100 Vps	3.0 sec	Low	0.0005 uA	0.00 uA	5600 V	Ramp	NEG
(minipad1)00.001	3350.0 V	0.300 uA	3349.5 V	On	50 Vps	100 Vps	3.0 sec	Low	0.0004 uA	0.00 uA	5600 V	Ramp	NEG
(minipad1)00.002	3350.0 V	0.300 uA	3349.6 V	On	50 Vps	100 Vps	3.0 sec	Low	0.0003 uA	0.00 uA	5600 V	Ramp	NEG
(minipad1)00.003	2200.0 V	0.300 uA	2199.6 V	On	50 Vps	100 Vps	3.0 sec	Low	0.0003 uA	0.00 uA	5600 V	Ramp	NEG
(minipad2)00.001	1650.0 V	0.300 uA	1649.8 V	On	50 Vps	100 Vps	3.0 sec	Low	0.0009 uA	0.00 uA	5500 V	Ramp	NEG
(minipad2)00.002	1650.0 V	0.300 uA	1649.7 V	On	50 Vps	100 Vps	3.0 sec	Low	0.0006 uA	0.00 uA	2500 V	Ramp	NEG
(minipad2)00.003	1650.0 V	0.300 uA	1649.8 V	On	50 Vps	100 Vps	3.0 sec	Low	0.0008 uA	0.00 uA	2000 V	Ramp	NEG
(minipad0)00.003	500.0 V	0.300 uA	500.1 V	On	50 Vps	100 Vps	3.0 sec	Low	0.0000 uA	0.00 uA	4200 V	Ramp	NEG
(minipad0)00.000	500.0 V	0.800 uA	499.9 V	On	50 Vps	100 Vps	5.0 sec	Low	0.0030 uA	0.00 uA	850 V	Ramp	POS

(a) General Control Software (GECO) from CAEN HV power supply.



(b) HVPSS Control Interface, LabView


MULTICHANNEL_TEST.vi
File Edit View Project Operate Tools Window Help
address
140.105.17.138
remote port or service name
CONNECT
FIFO_SIZE
TRIG_DELAY
TRIGGER_LEVEL
Trigger Edge
Auto
address 2
140.105.17.141
CONNECT 2
FIFO_SIZE 2
TRIG_DELAY 2
TRIGGER_LEVEL 2
Trigger Edge 2
address 3
140.105.17.153
CONNECT 3
FIFO_SIZE 3
TRIG_DELAY 3
TRIGGER_LEVEL 3
Trigger Edge 3
SET ALL
Record
Disable
Filename
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Waveform Graph
Plot 0
Amplitude
Time
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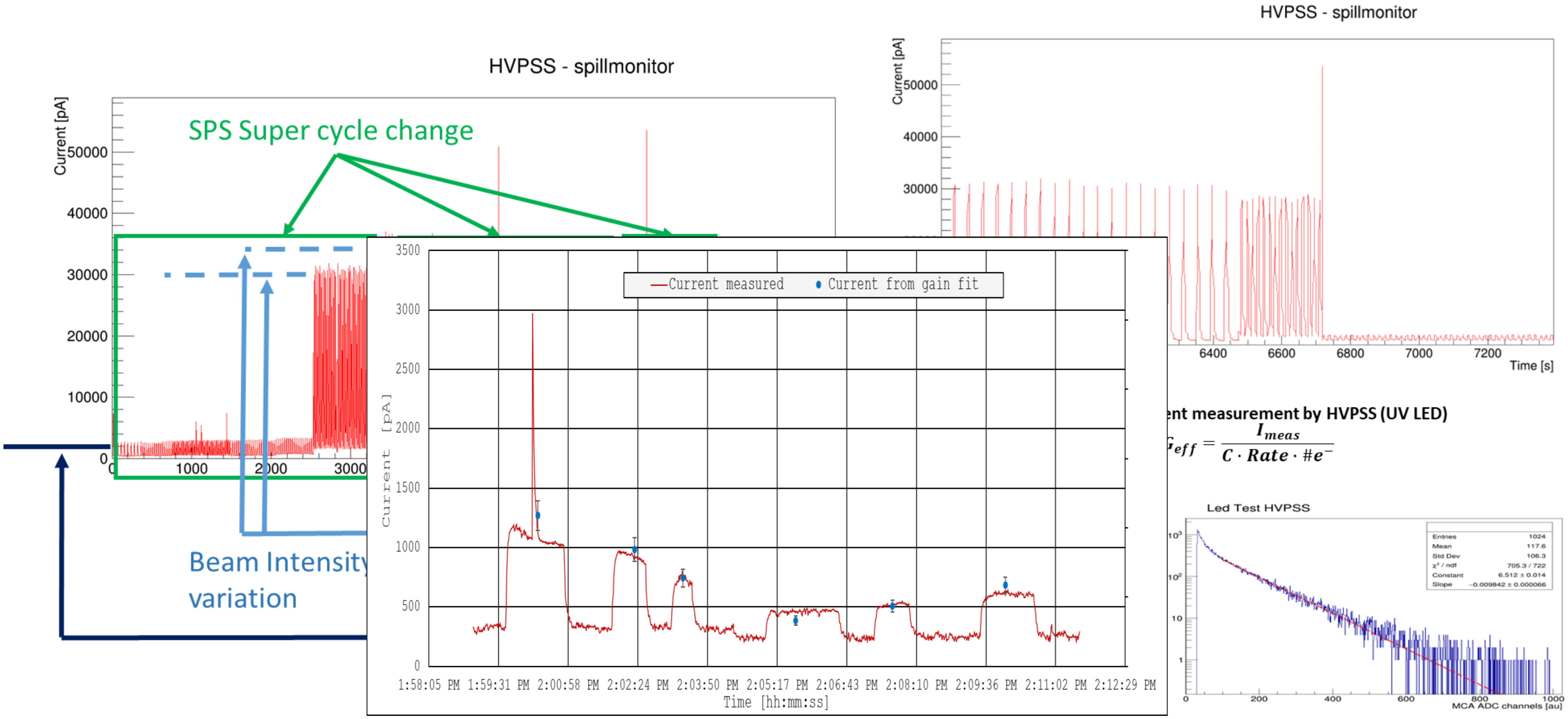
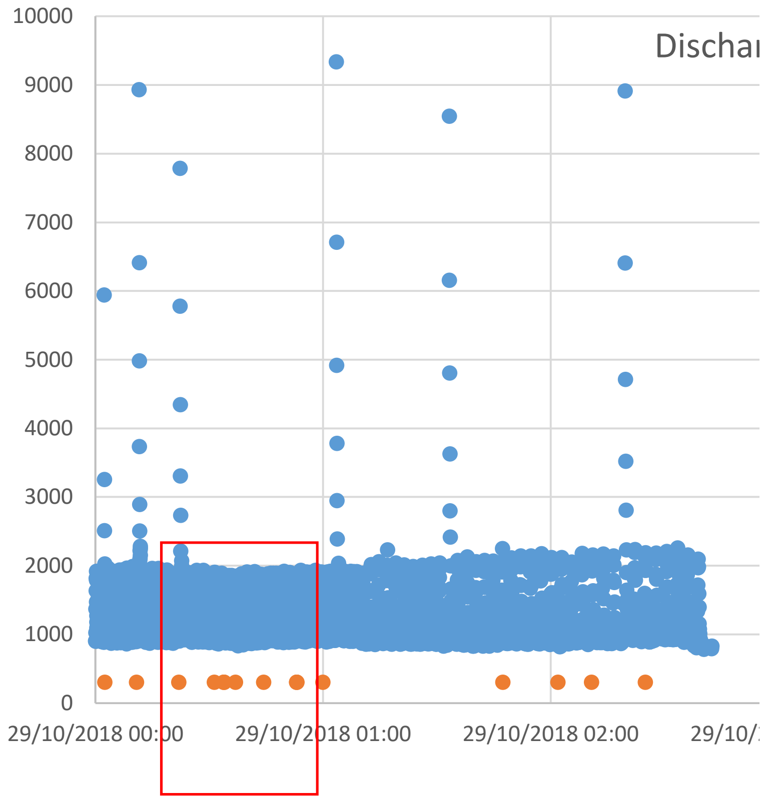
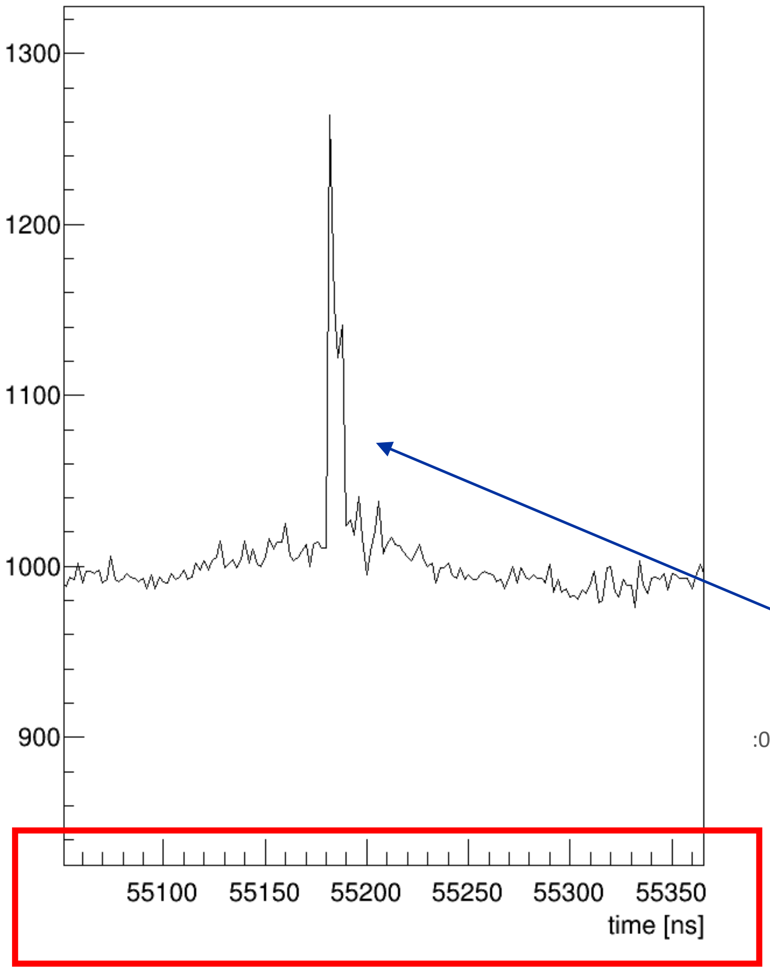
Combo Box
Port
CONNECT
Halt
CONNECTED
BUSY
ADC and Decimator
pAmp CTRL
LED 0
LED 1
OUTV
DDR
Full Scale Range
ON
DCLK_RST
CAL
CAL_DLY
DECIMATION
N

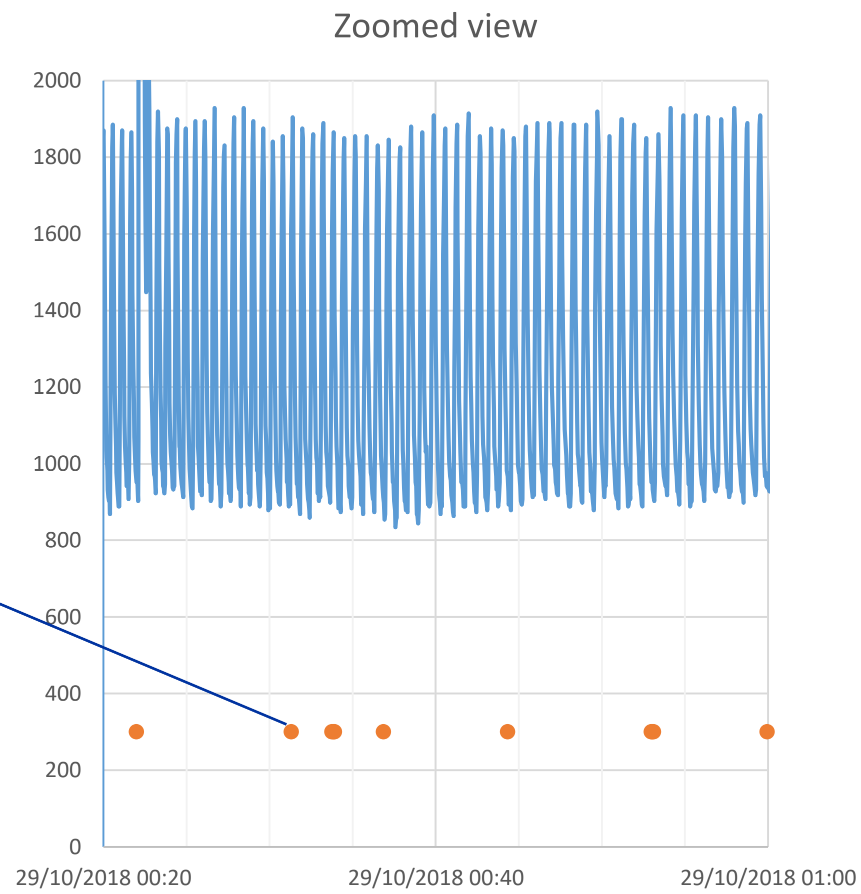
The High Voltage system of the COMPASS RICH-1 Hybrid Photon Detector: HVPSS results



The High Voltage system of the COMPASS RICH-1 Hybrid Photon Detector: HVPSS results

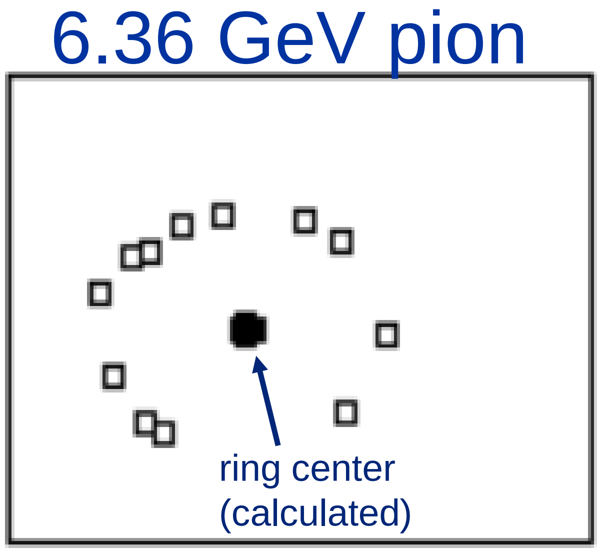


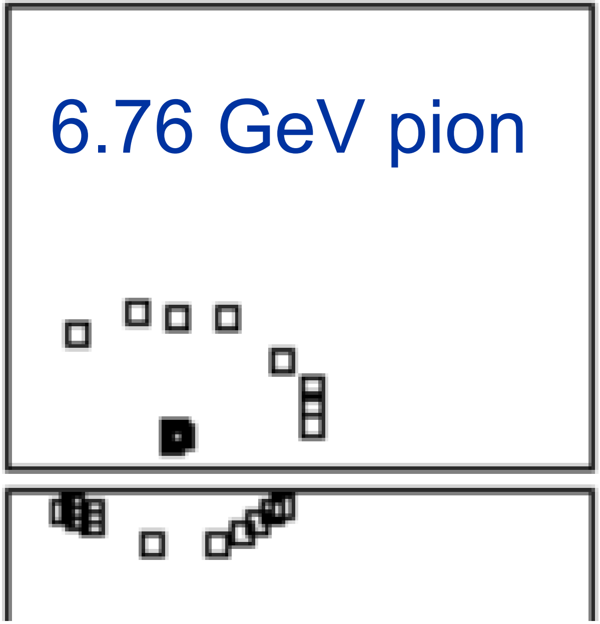


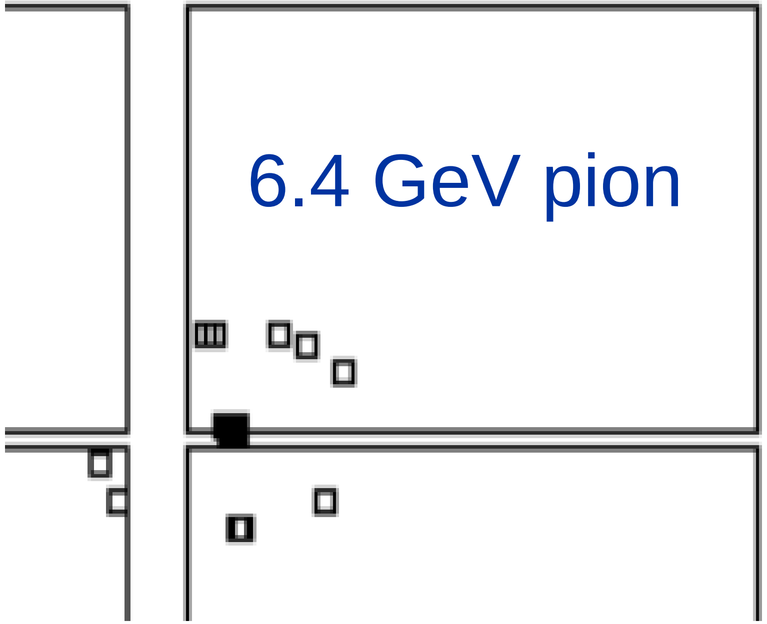


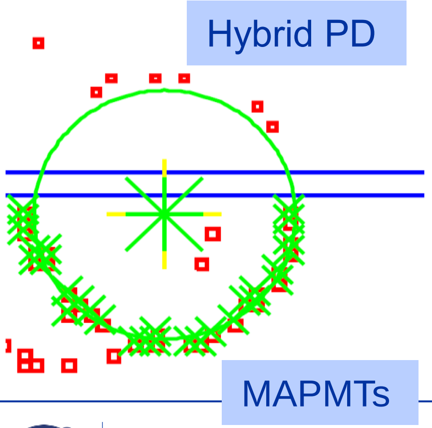
NICE RINGS

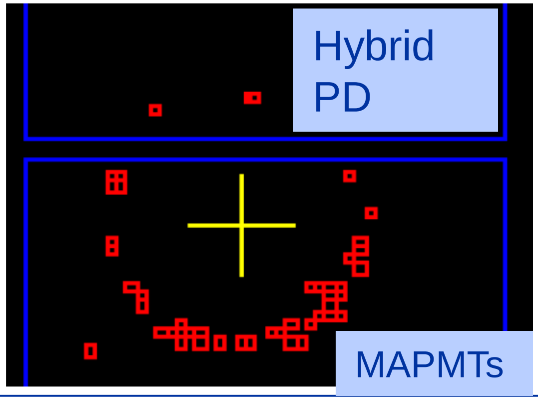
(in the 2017 run the Hybrid PDs were receiving Cherenkov photons from low p particles only)

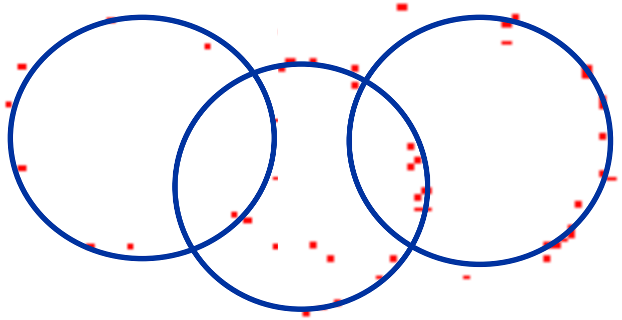


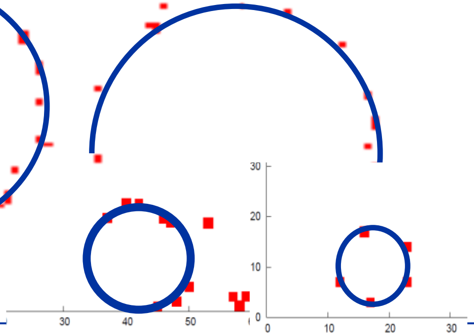




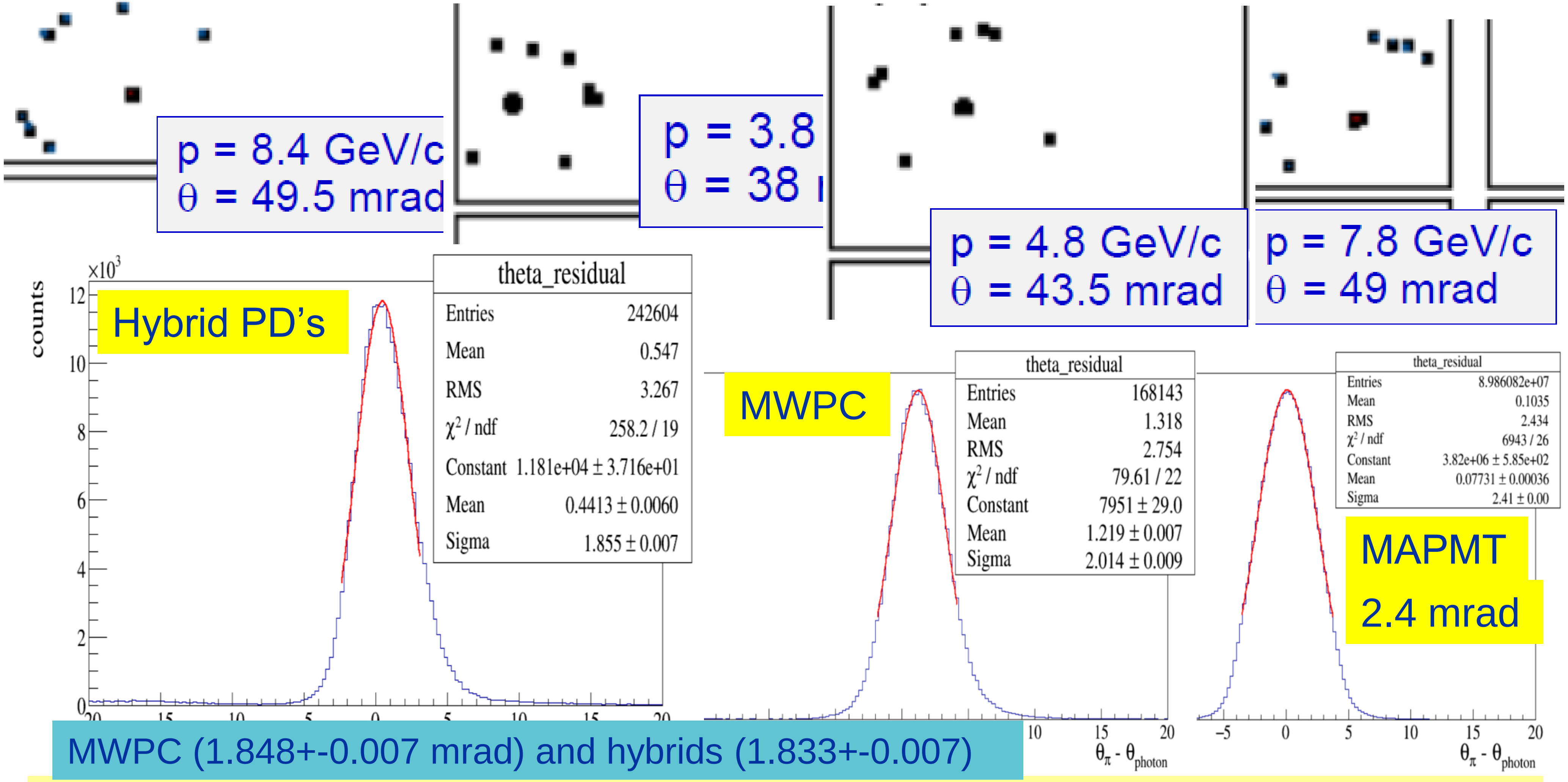








Single photon angular resolution



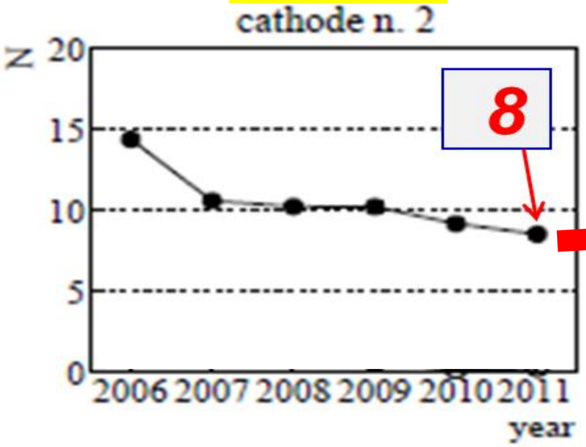
MWPC (1.848+-0.007 mrad) and hybrids (1.833+-0.007)

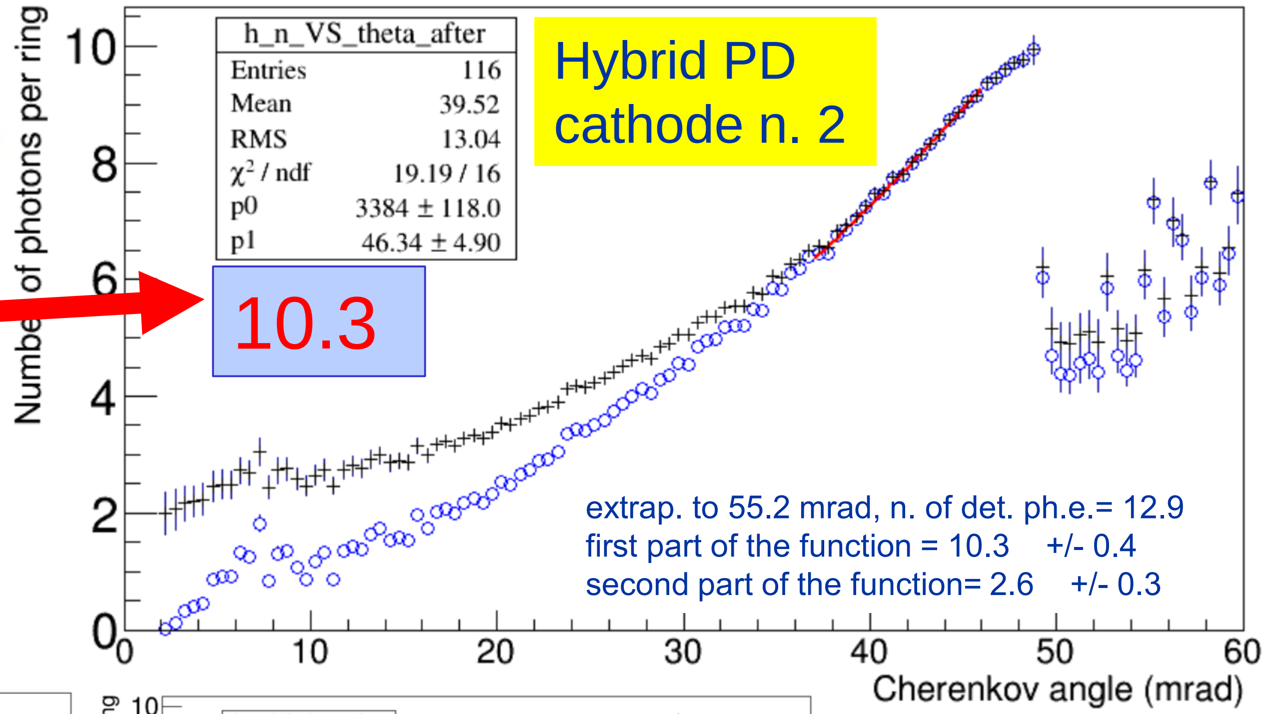
in terms of angular resolution the response of the new Hybrid detectors is similar. MAPMT's have larger pads

Number of detected photoelectrons per ring

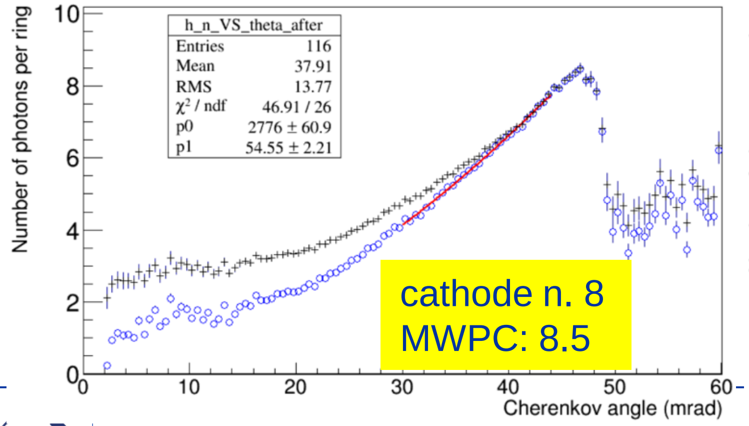
Critical chambers, have been changed from MWPC to Hybrid THGEM + Micromegas

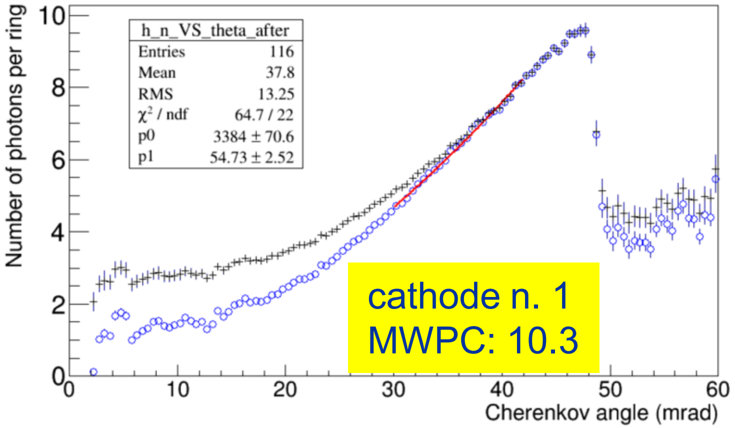
MWPC





the n. of det. ph.e. (55.2 mrad) in cathode n.2 was ~8 → 10.3





The number of detected photons per ring is in line with that of the good MWPC