Hyperfast Timing using High Gain Micro-Pattern Detectors: Update

Sebastian White, CERN/Princeton FTWG-June 10,'16

1) new sensor development based on MPGD and Deep Diffused Avalanche Diodes
2) the RD50/RD51 context
3) issues to be addressed by TB of last 2 weeks and August
4) how did we do?

How we started in RD50/51:

- pre-2012 the issue was high rate, ~20 picosec MIP timing for FP420 (which spawned CT-PPS, AFP)
- in 2007 no suitable technology existed although excellent low rate (ALICE TOF and Nagoya 6 picosecond timing w. Hamamatsu MCP-PMT)
- but in 2009 we proposed compact (suitable for pots) approach using Avalanche Diodes here:arXiv:0901.2530 [physics.ins-det]
- We (Princeton, Rockefeller, RMD and now CERN+Delhi) have been making progress toward that goal ever since
- in 2013 Joel B. broadened the scope with the charge to "build a community that goes beyond CMS to help develop these ideas and concepts" - in the context of Phase II upgrade "hermetic timing"

=> RD50/51 where Giomataris and I, as PIs, received approval for common fund project to develop MPGD timing and at M. Moll's lab where we have been simulating and characterizing the "Silicon Structures with Gain"(the title of our weekly meetings).

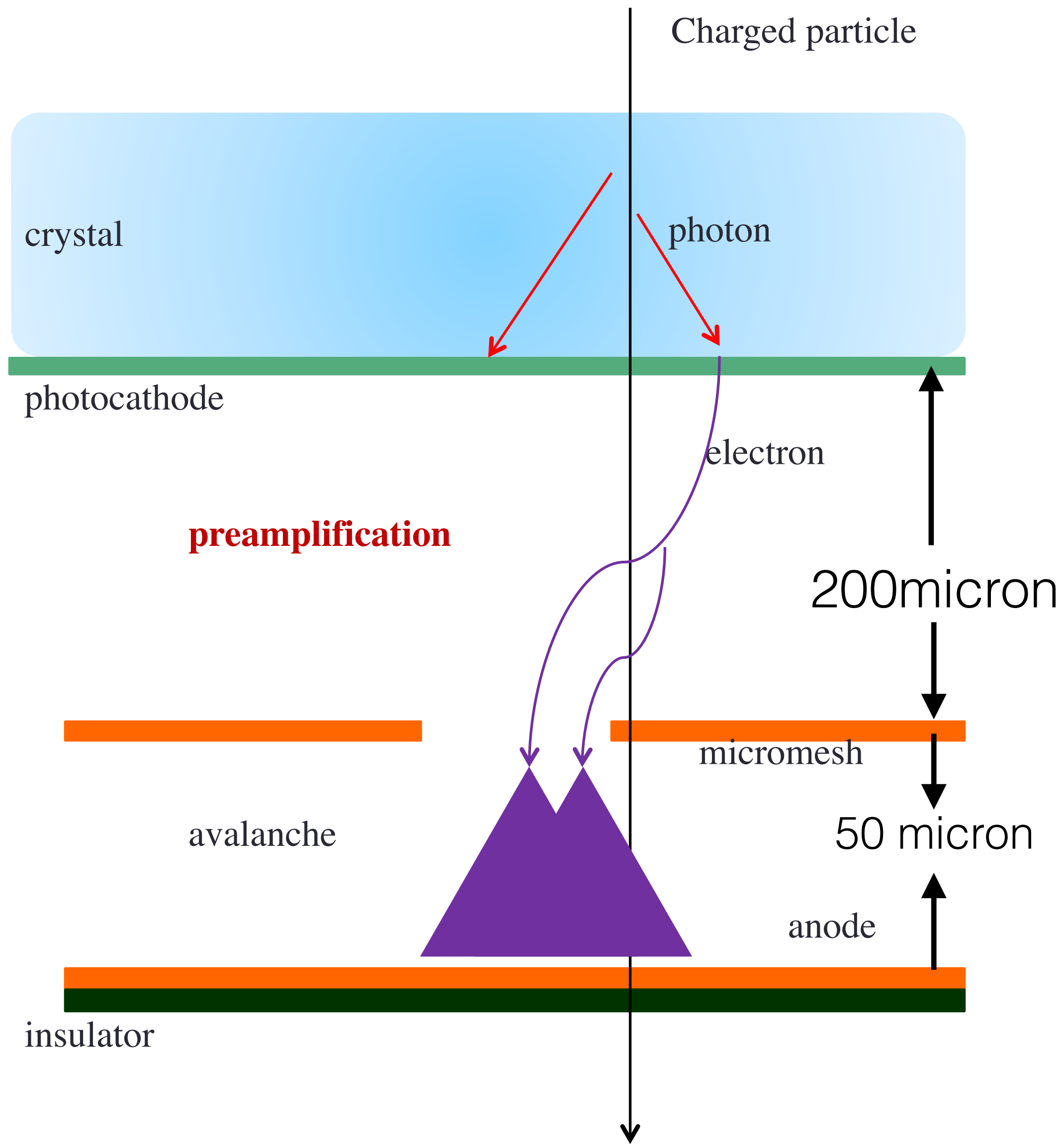
In addition we started a collaboration with U. Pensylvania (an ATLAS institution) to develop high bandwidth transimpedence front end suitable for needed pixel size.

Also this month: funding starting on SBIR w. RMD and a DOE award to Princeton for generic fast timing.

My opinion: CERN R&D groups are the right place for new sensor development=> their impact (ie Esteban for HGC timing) should be acknowledged more by CMS.

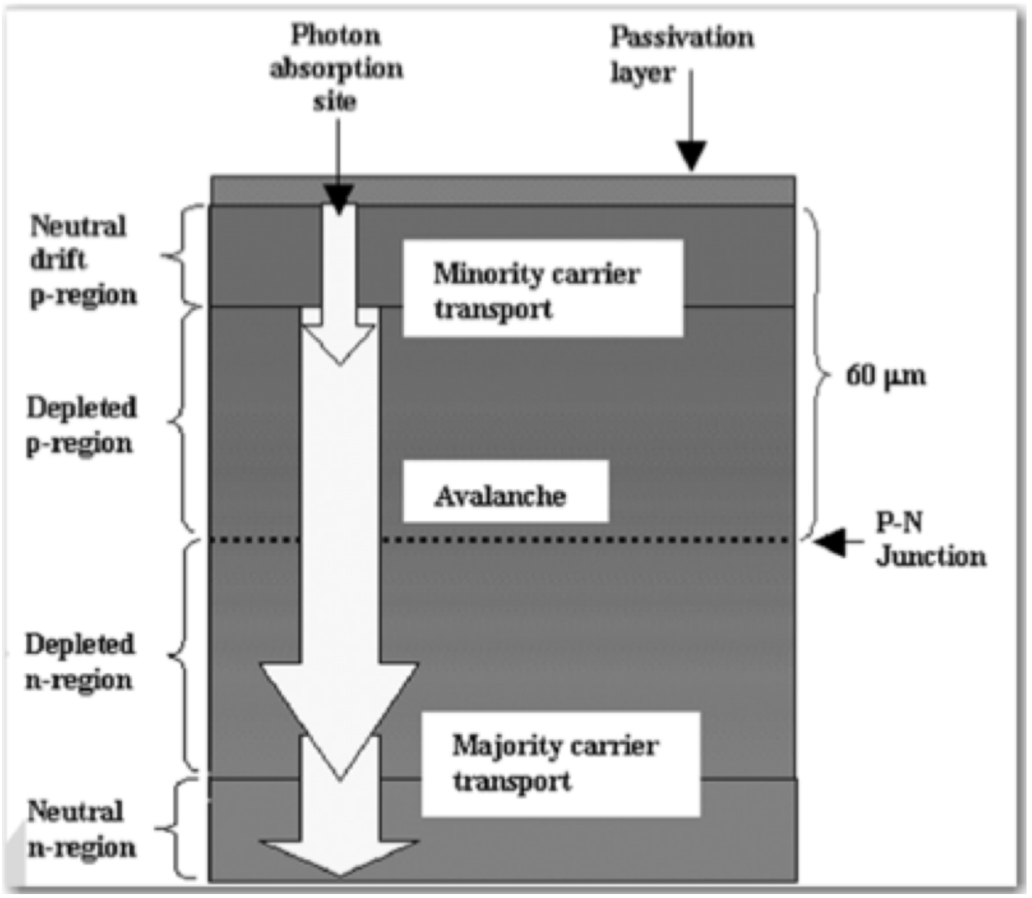
Issues ahead of this past TB campaign:

MPGD:



eliminates effect of stochastic energy deposition(Landau)
diffusion limit to time jitter (Gas choice)
robustness of photocathode (or secondary emitter)

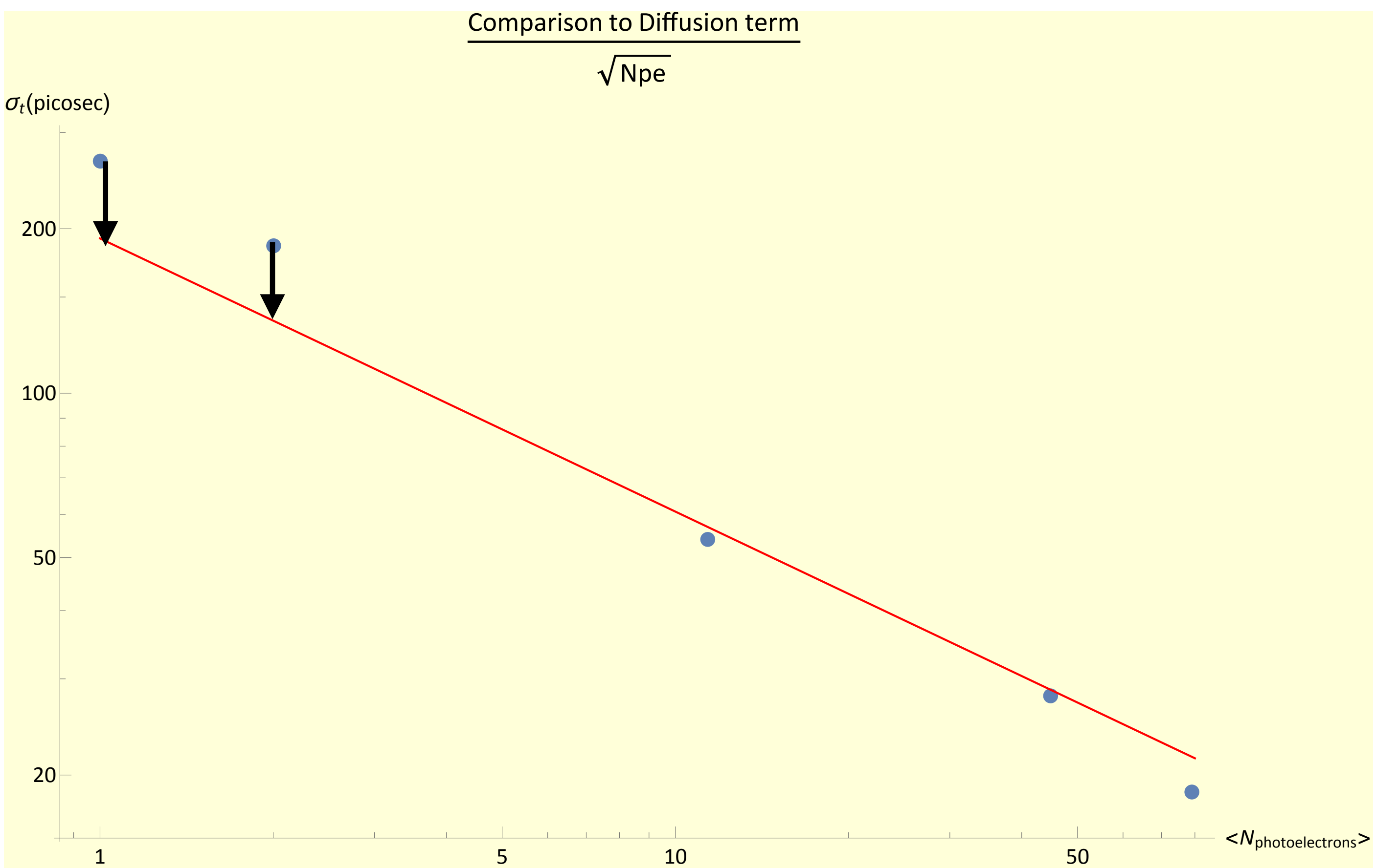
DD-AD(HyperFastSilicon)



front end and interconnects
rad hardness (so far 0.9 10^{14}p)
optimize structure/bias/algorithm for Landau

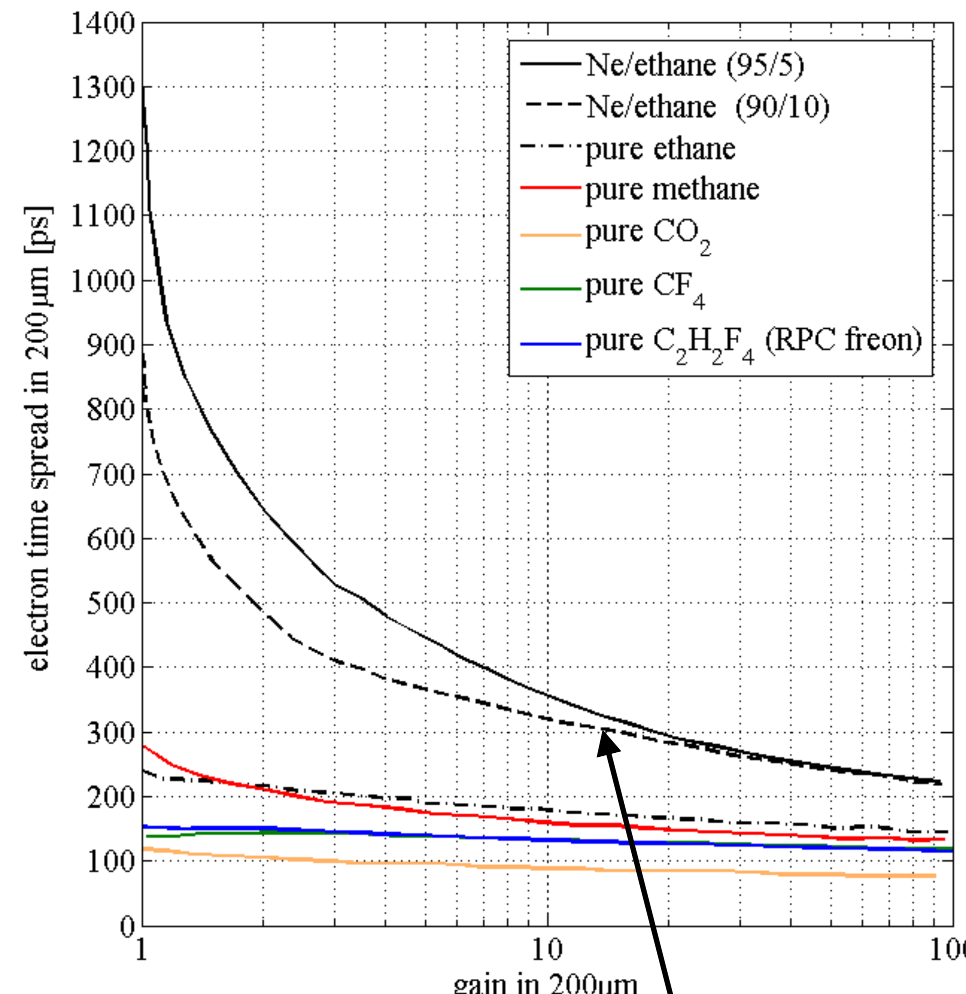
MPGD: reducing dominant detector physics (longit. diffusion)

2015 proof of Principle laser, NeEthane



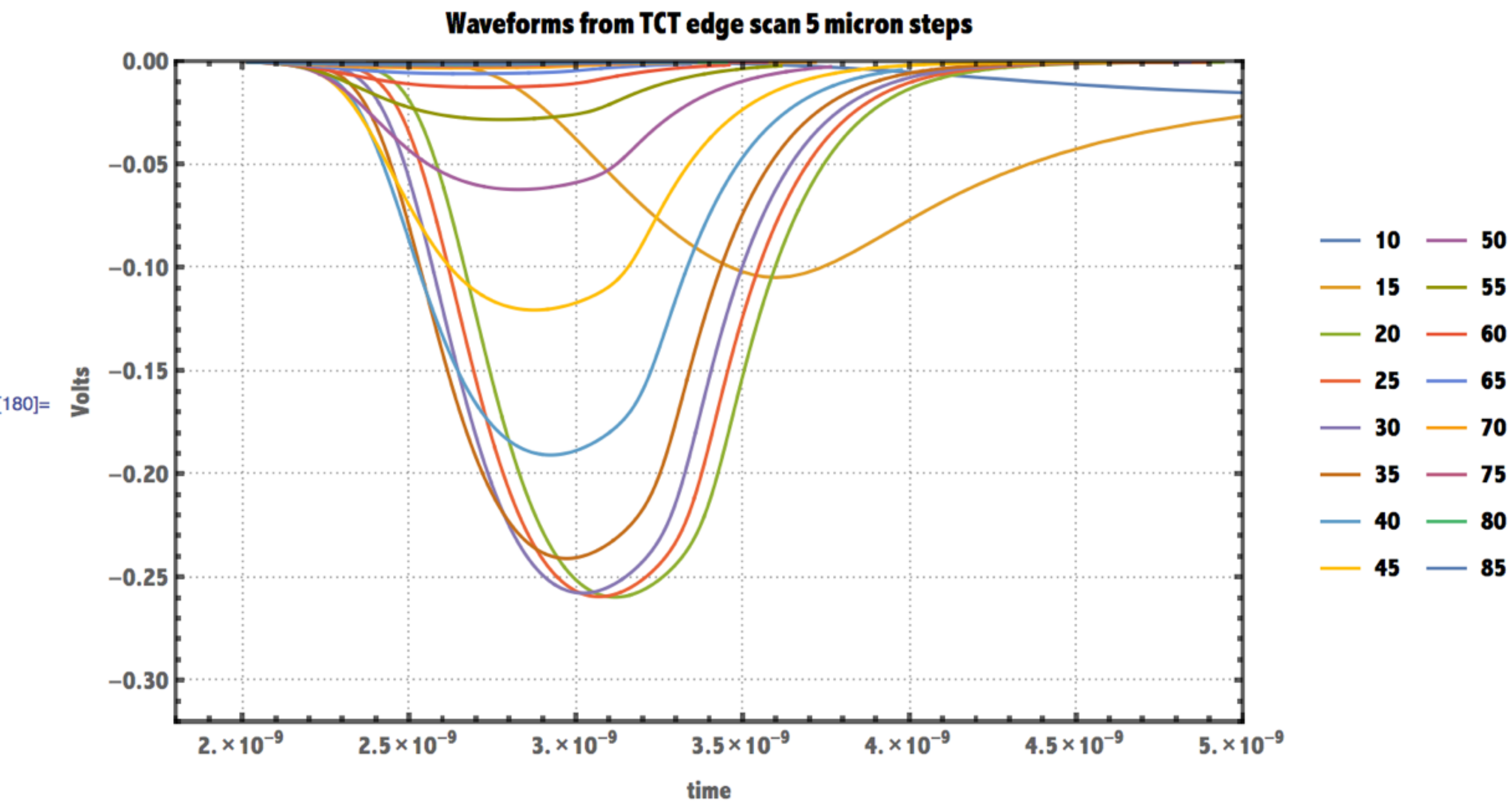
A factor of 3 in Single electron time spread=> few photoelectron regime

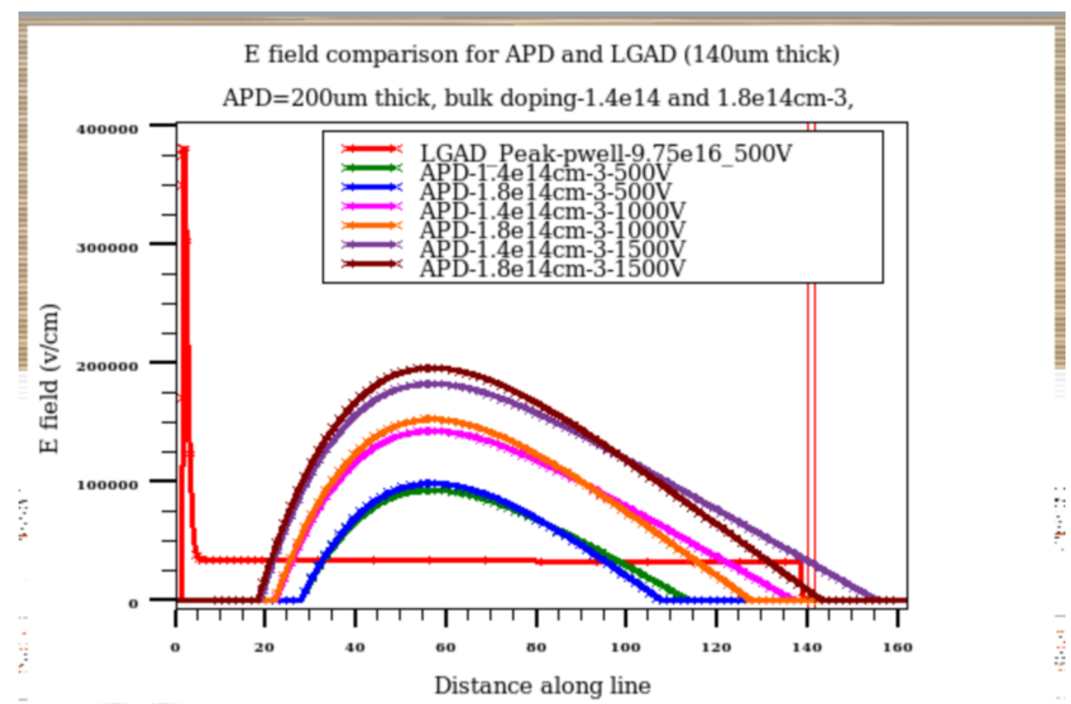
but clearly there could be better choices:



2015 operating point

Issues for Deep Depleted Avalanche Diodes





1- continued front end and packaging development
2- understand through simulation and beam the contribution of Landau/Vavilov to time jitter

Detectors and measurements preformed (H4 RD51 testbeam past 2 weeks)

Triggering, Tracking and Timing

Tracker3

5mm hole VETO scintillator

10cm x 10cm scintillator

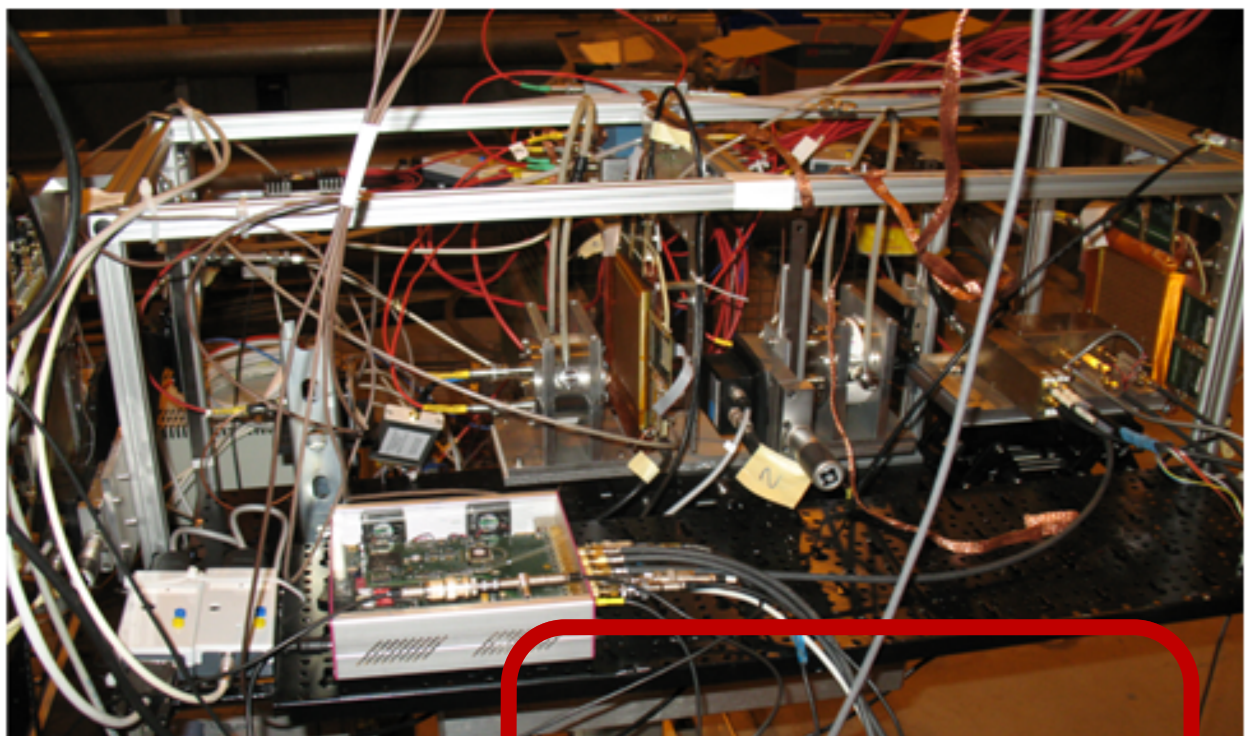
MCP-PMT

Tracker2

5mm x 5mm scintillator

5mm x 5mm scintillator

Tracker1



DUT

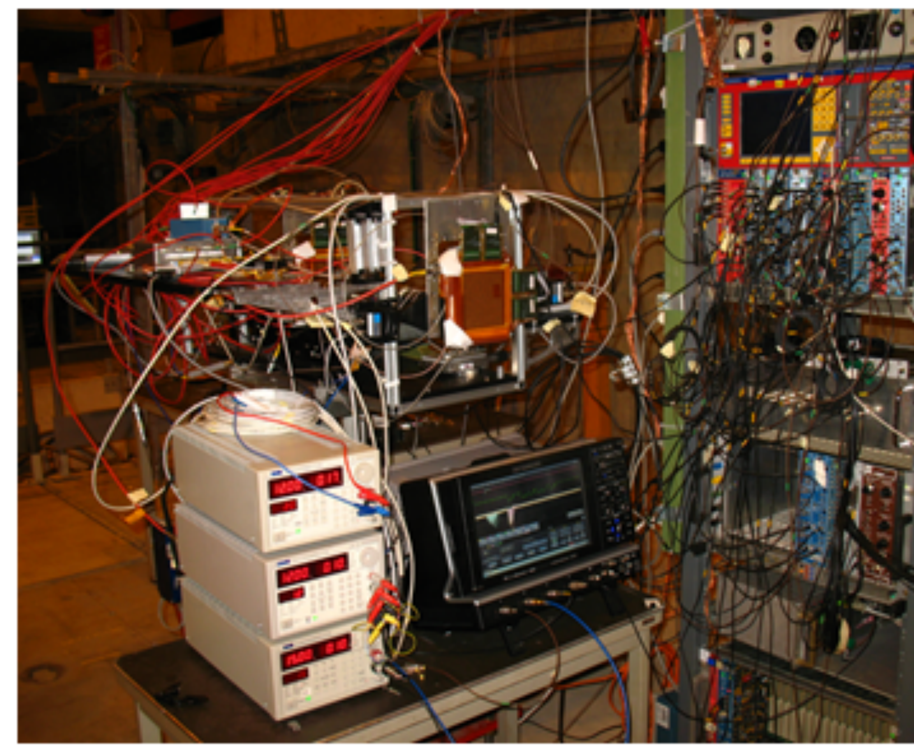
Picosec2

Picosec1

APD

DAQ

SAMPIC



Oscilloscope

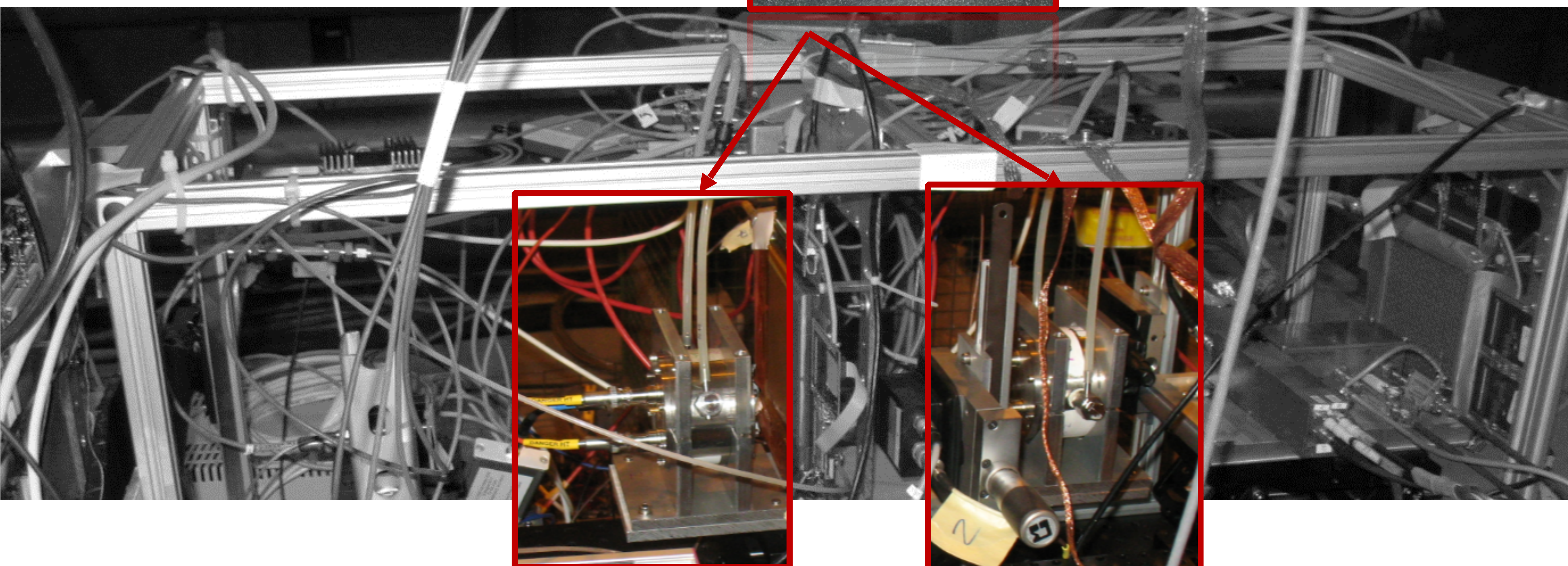
SRS

Photocathodes (from Saclay):

1. CsI
2. Al

Radiator: MgF_2 (3mm for CsI, 5m for Al)

Remarkable work done in Saclay for the photocathodes evaporation (Mariam Kebbiri)



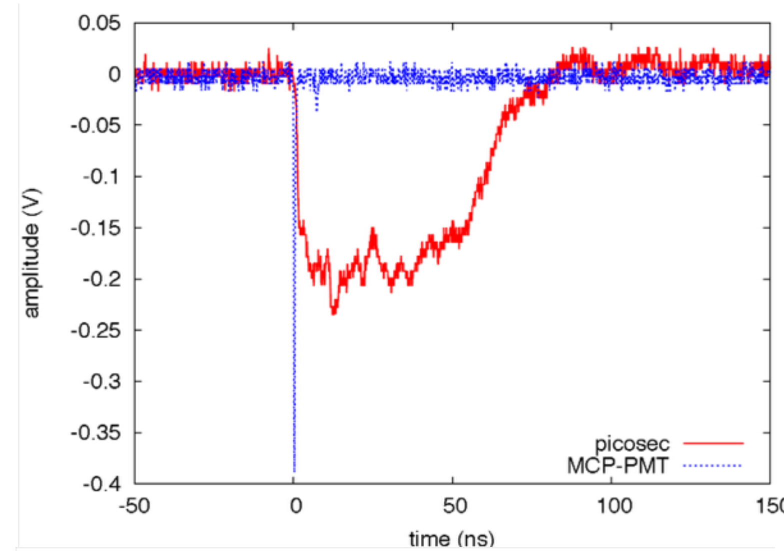
Measurements Performed:

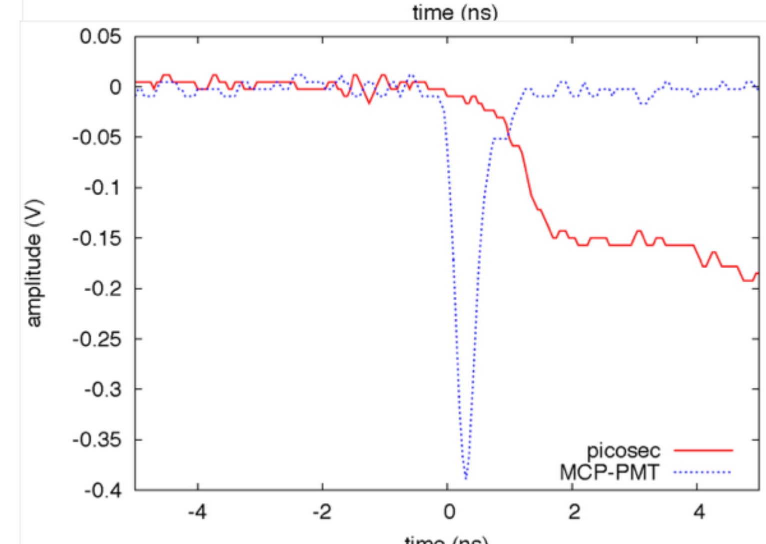
1. CsI and Ne-CF_4-C_2H_6 80-10-10 (Sealed)
2. CsI and Al in Ne-CH_4 95-5 (Sealed)
3. CsI in Pure CO_2 (Sealed)
4. Al in Pure CO_2 (Flushed)

Thanks to the Saclay colleagues Philippe Legou and Olivier Maillard that made a great job on improving the internal cabling, signal routing and grounding

Thanks to the COMPASS colleagues (Yann Bedfer et al.) for providing us some help with the gas

No results will be shown for the moment.. But (as appetizer)….





in Ne-CF4-C2H6 we reached…

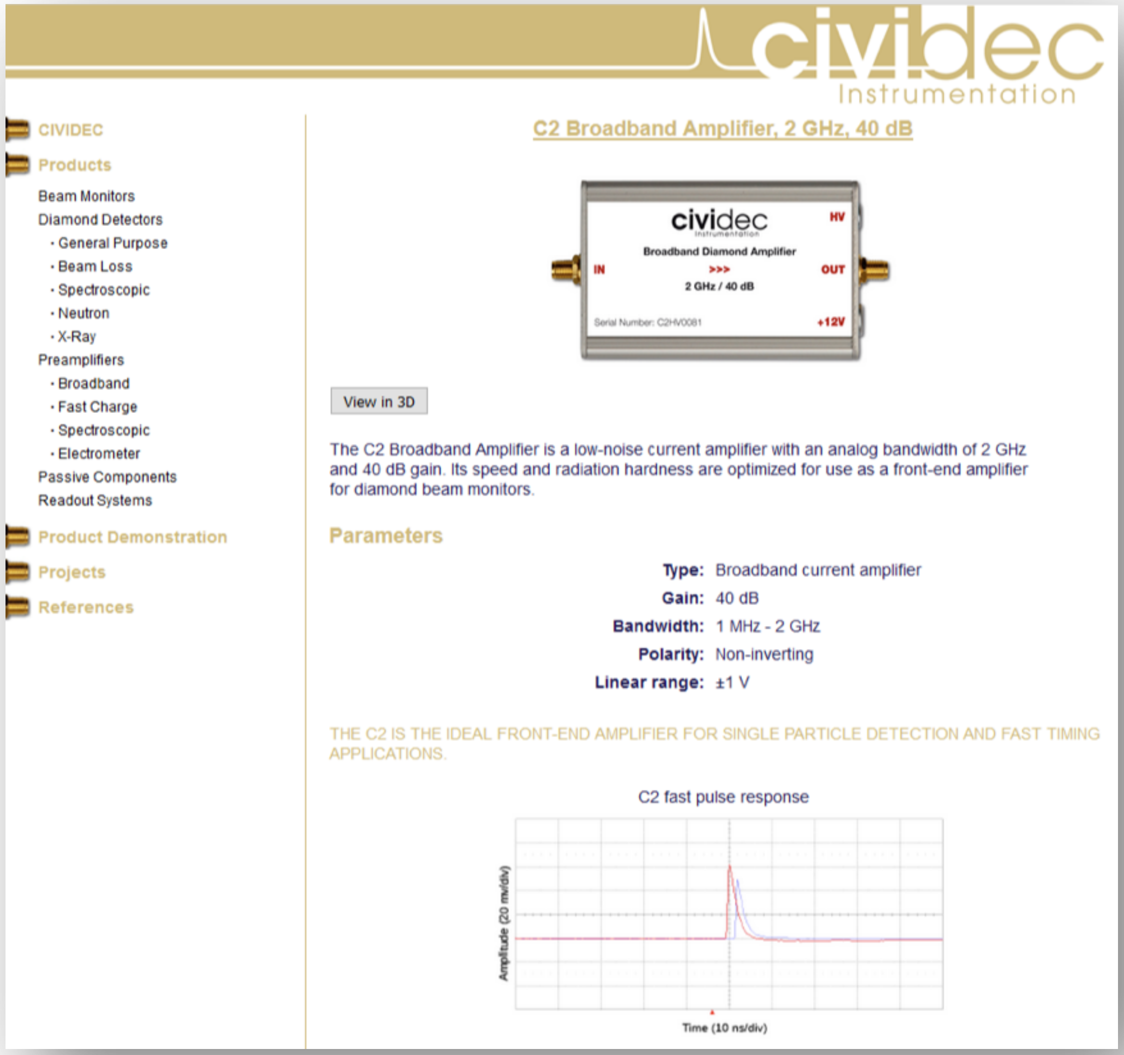
- Time resolution < 100ps
- nphe > 5
- Efficiency.. Practically 100%

with Al photocatode and 5mm radiator almost fully efficient…

in CO2 we got (nicely shaped) signal…

Data Acquisition

Signal processing and Data acquisition



https://cividec.at/index.php?module=public.product_show&id=15&cat=0

WaveRunner 625Zi

2.5 GHz, 20 GS/s, 4ch, 16 Mpts/Ch DSO with 12.1" WXGA Color Display. 50 ohm and 1 Mohm Input. 40 GS/s and 32 Mpts/Ch in interleaved mode.

Timing

Time reference (about 200ps Rise Time measured in beam)

HAMAMATSU
PHOTON IS OUR BUSINESS

MICROCHANNEL PLATE-PHOTOMULTIPLIER TUBES (MCP-PMT)
R3809U-50 SERIES

FEATURES

- **High Speed**
  Rise Time: 160 ps
  IRF (Instrument Response Function)[A]: ≤55 ps (FWHM)
- **Low Noise**
- **Compact Profile**
  Useful Photocathode: 11 mm diameter
  (Overall length: 70.2 mm Outer diameter: 45.0 mm)

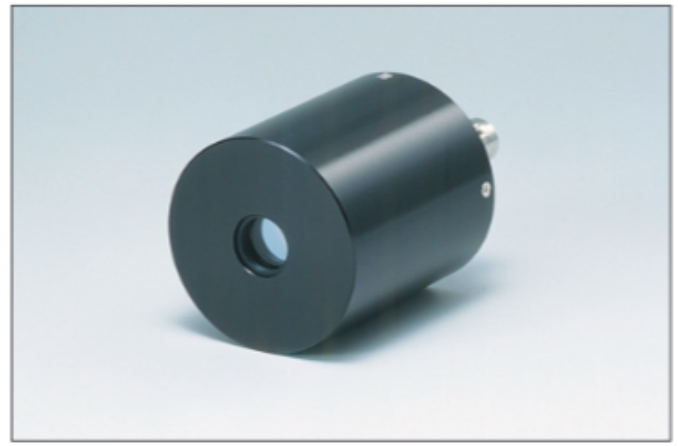
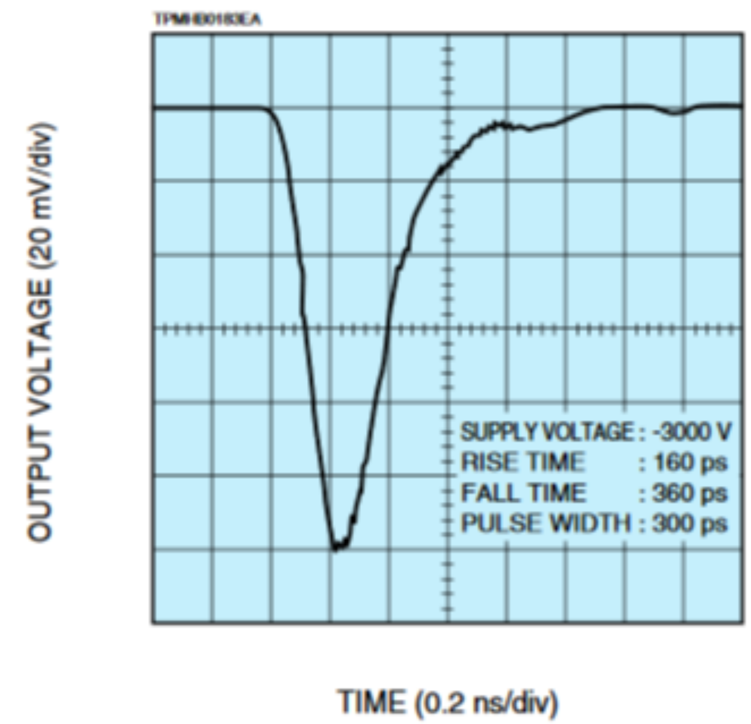
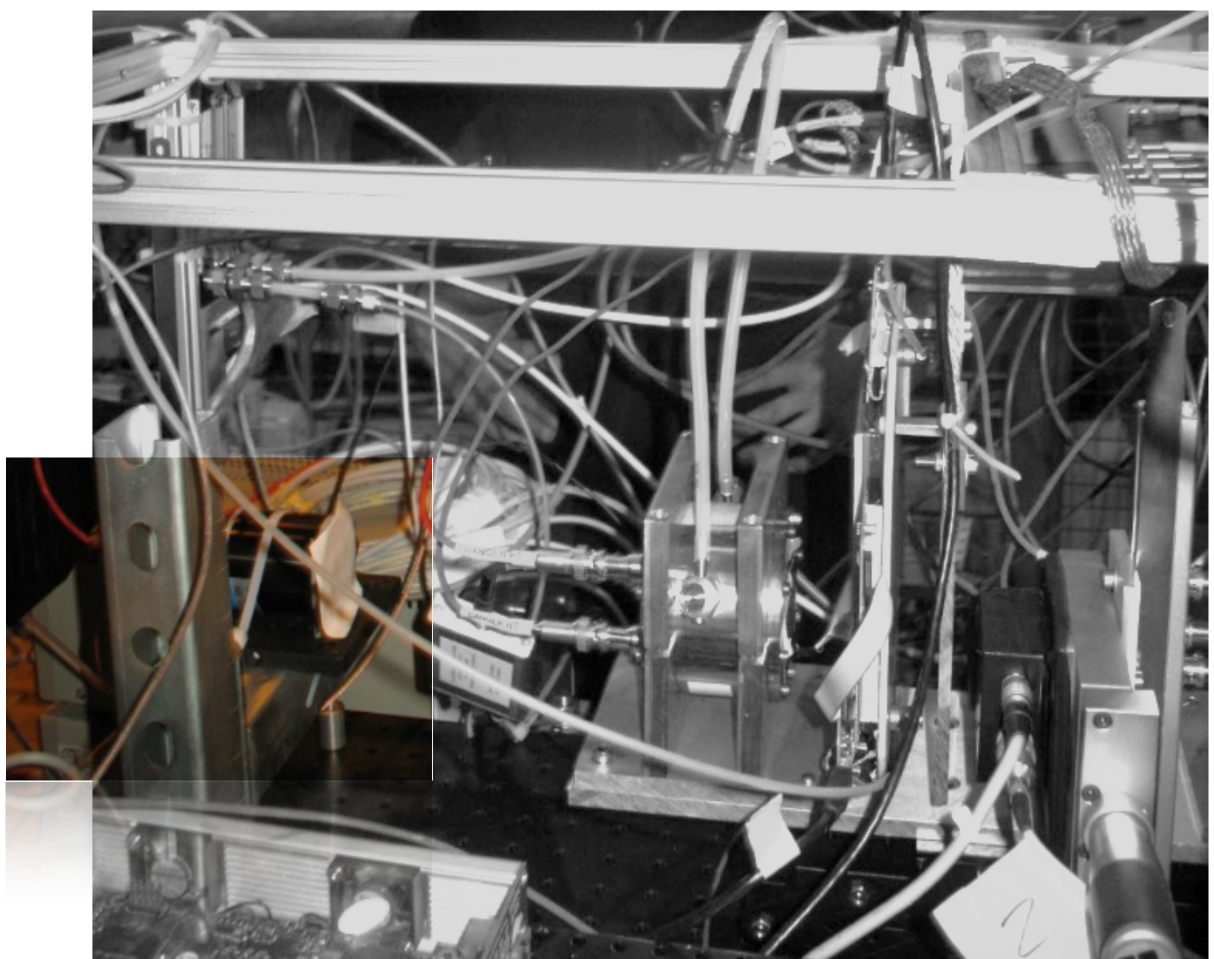


Figure 8: Typical Output Waveform





Thanks Sebastian and Stefano Mazzoni
CERN - Beam Instrumentation Group

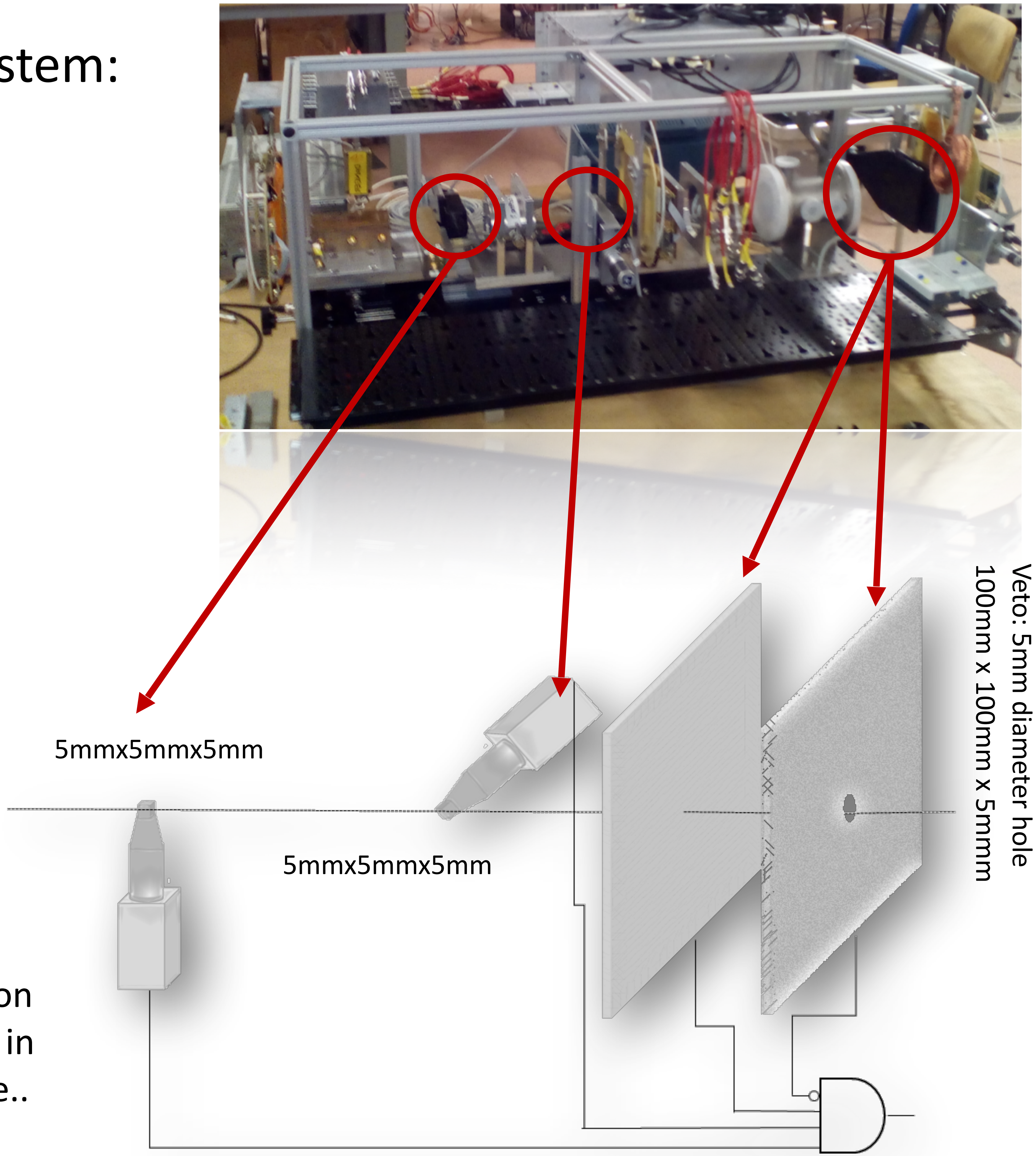
.. The most loved present for the aimed measurements

Events Selection
(Triggering and tracking)

Triggering Scintillators System:

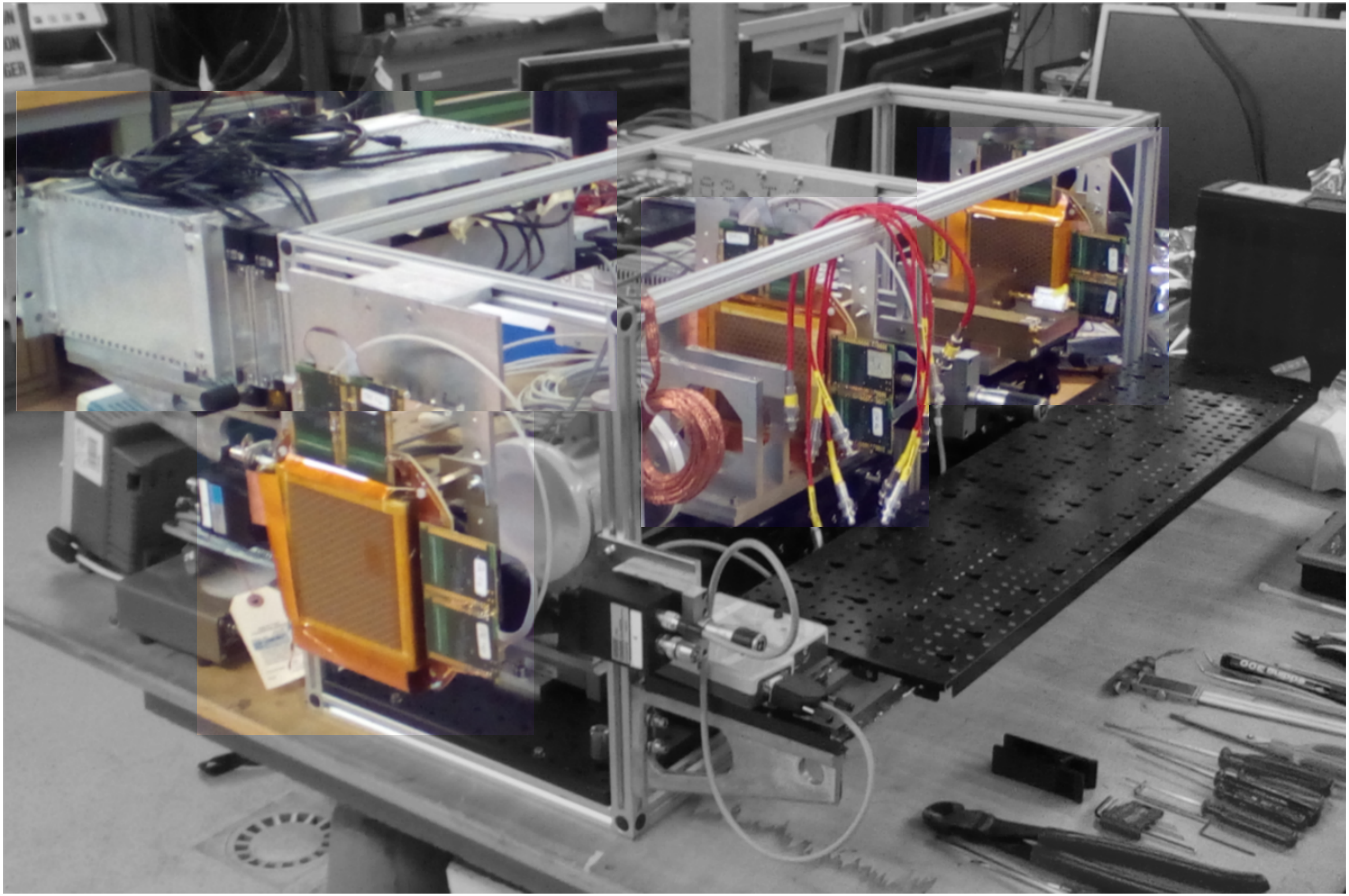
Efficiency measurement:
Triggering Area smaller than
Detector Active Area

Single muon event selection:
Rejection of high multiplicity
events (showers produced in our
system) – VETO scintillator 5mm
diameter hole



Essential help from Raphael Dumps on
defining and making the scintillators in
time for the beam.. with short notice..
Thanks!

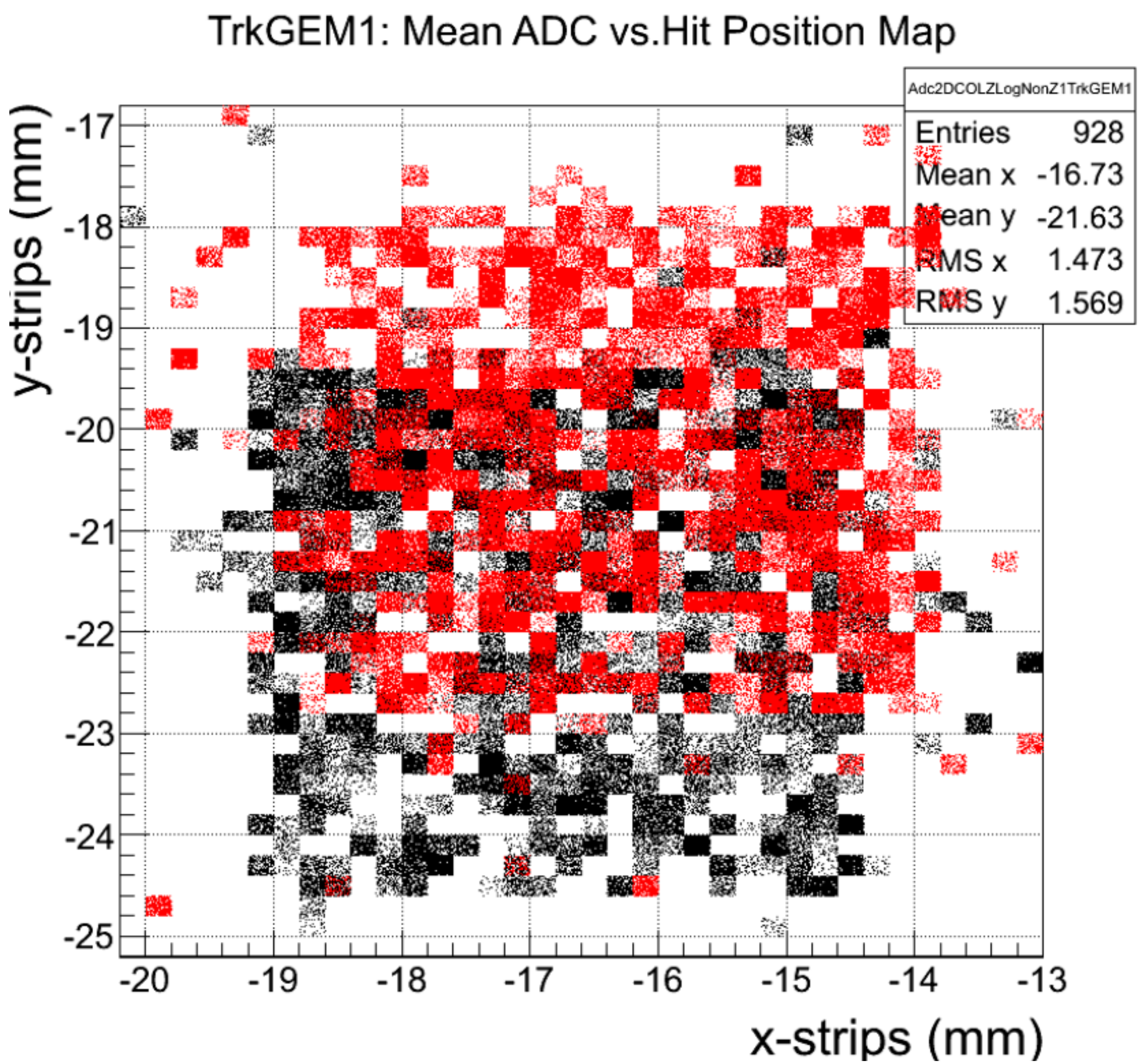
Tracking System: Triple GEM and SRS/APV25



Three Triple GEM, XY readout, 400um pitch

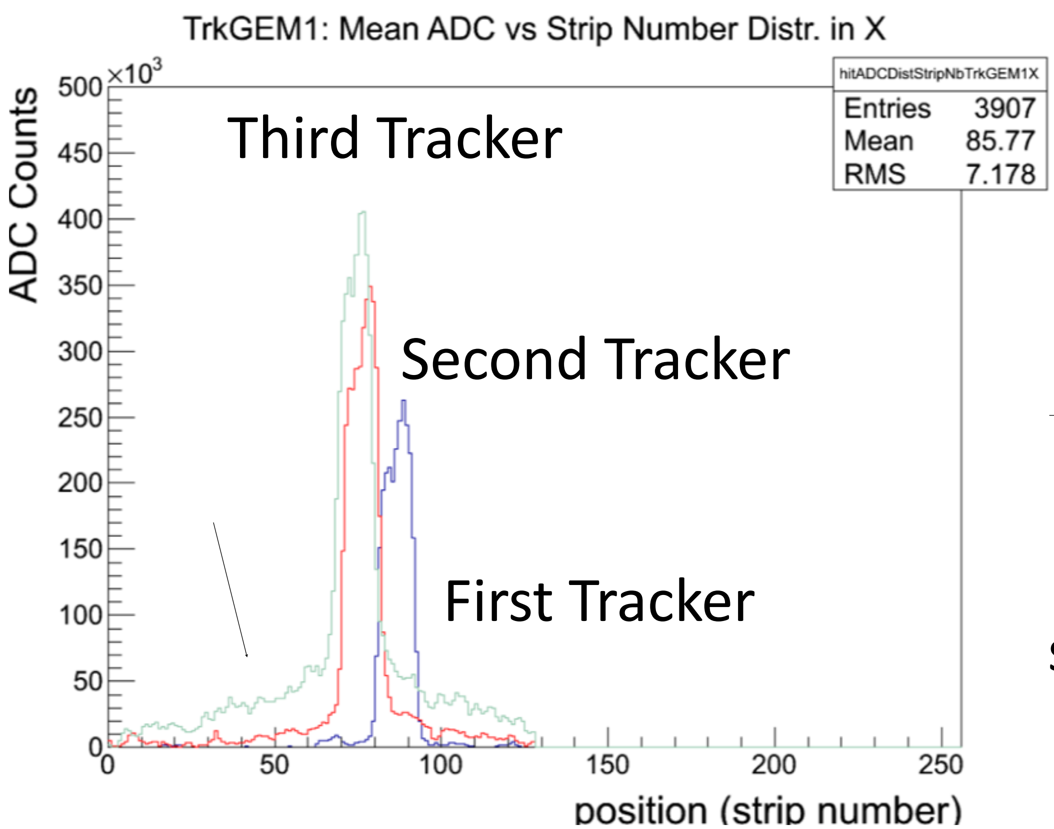
Alignment of scintillators and detectors.
Validate the capability of selecting clean (pure muon) events.
Synchronized data taking with the oscilloscope (uniformity of detector response,…)

Triple GEM tracker for alignment of scintillators and detectors

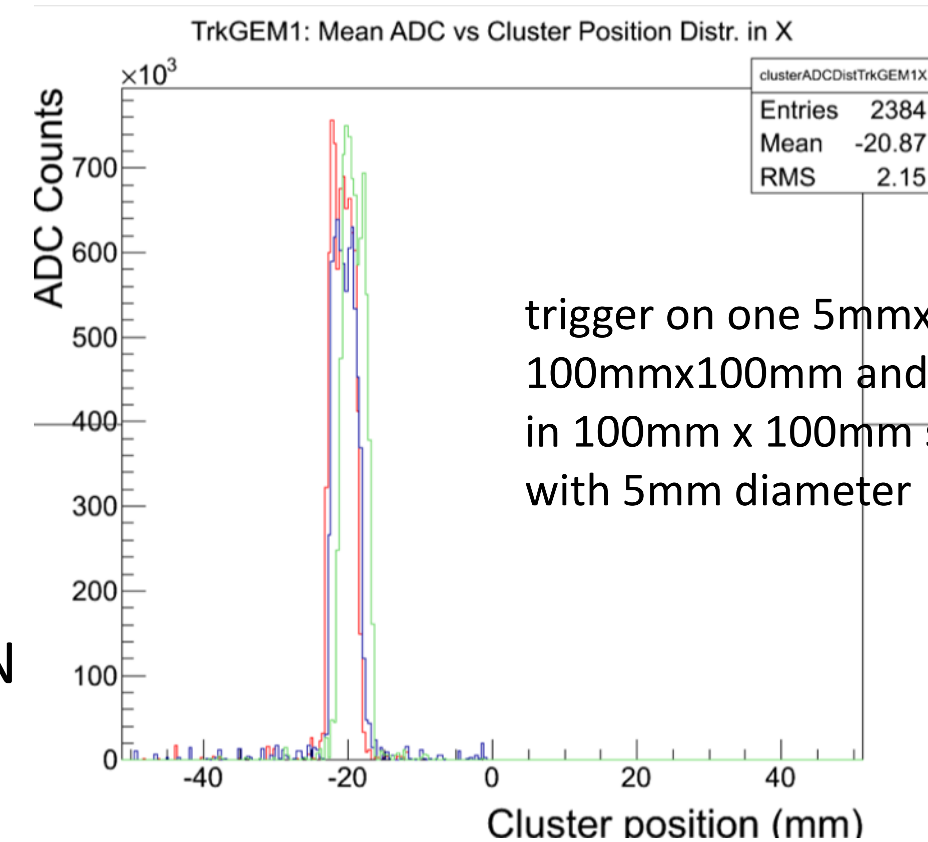


Misalignment (before the last alignment step) of the two 5mm x 5mm scintillators

Triple GEM tracker to validate the capability of selecting clean (pure muon) events



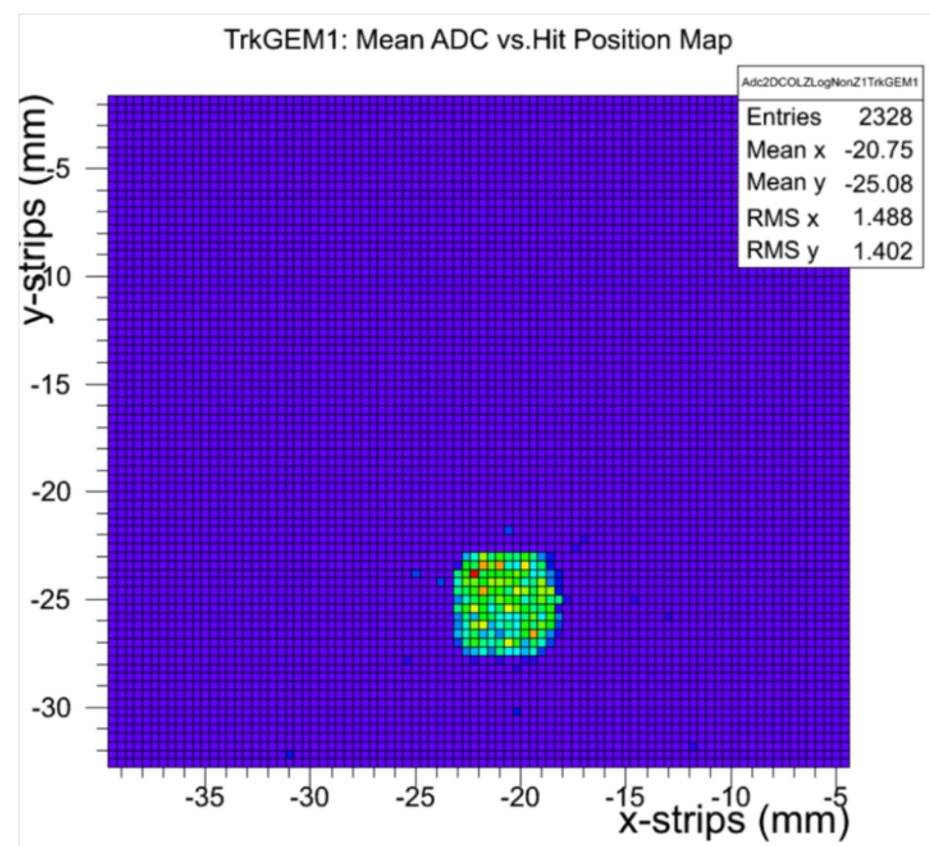
VETO scintillator IN
(plus improved alignment)



trigger on one 5mmx5mm, one 100mmx100mm and NOTHING in 100mm x 100mm scintillator with 5mm diameter hole

VETO scintillator out (before final alignment – trigger on one 5mmx5mm and one 100mmx100mm scintillator)

Final alignment and full coincidence



Synchronous data acquisition between picosec and tracker

DAQ Synchronization: Oscilloscope and Tracker SRS/APV25 readout

SRS Data Frame

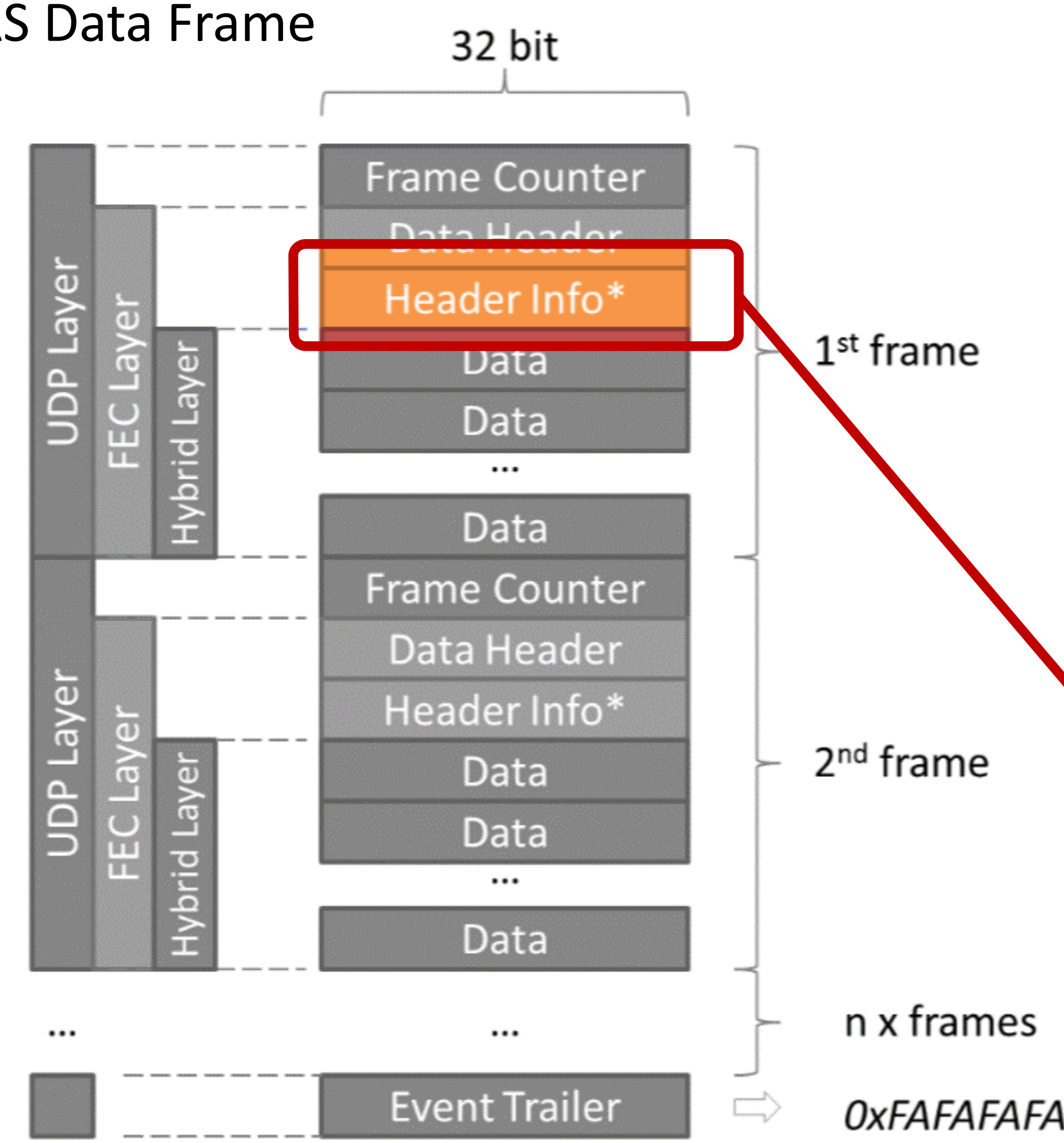


Figure 1. SRS general DAQ data format

Trigger Counter (written in each data frame of each APV) sent out in the “NIM OUT” FEC output (Michael upgrade in the FEC firmware) to be read in the oscilloscope together with the MCP and picosec signals

2.2.ADC data format

A. **FEC Layer**

- **Data Header.** The ADC data format is identified in *the Data Header* field by the ASCII characters "ADC", followed by the ADC channel number (*unsigned byte*):

	Byte 3	Byte 2	Byte 1	Byte 0
General format	H0	H1	H2	C#
ADC mode	“A”	“D”	“C”	C#

- **Header Info:** one 32-bit word (reserved – controlled by the EVBLD_EVENTINFODATA register of the APV Application Port)

Bit	31 - 16	15 -8	7 - 0
Name	HINFO_LABEL	HINFO_SEL	reserved
Descr.	Run label that can be copied in the most significant bytes of HEADER INFO FIELD of every event	Selects the content of HEADER INFO FIELD (see table)	

Table 1. EVBLD_EVENTINFODATA register

HINFO_SEL	HEADER INFO FIELD			
	31 - 24	24 - 16	15 -8	7 - 0
0x01	TRIGGER COUNTER (2 bytes)		EVBLD_DATALENGTH	
0x02	TRIGGER COUNTER (4 bytes)			
other	HINFO_LABEL		EVBLD_DATALENGTH	

Table 2. Content of HEADER INFO FIELD function of HINFO_SEL

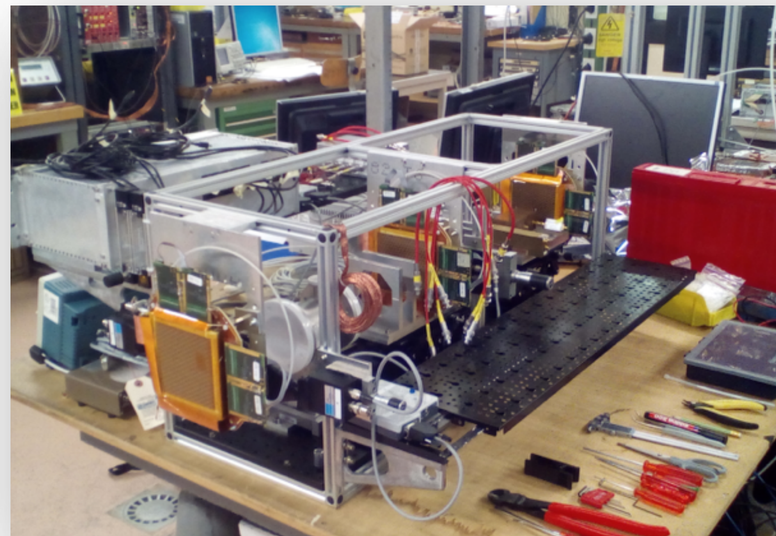
Mechanical support and alignment (internal and global with the beam)

Internal alignment: the new tracker with linear motion system

Status of the tracker two weeks before the beam

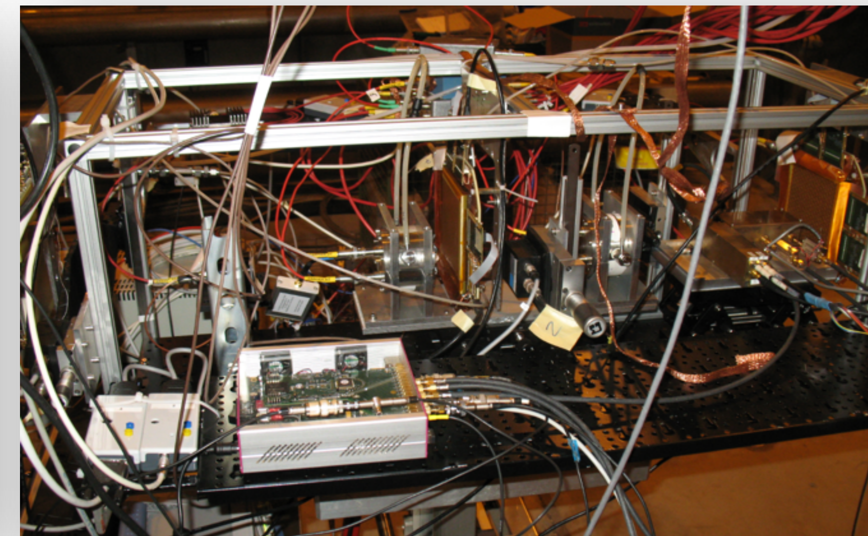
only sketches ad drafts…

Status of the tracker two days before the beam (no physicist still around)



ready to go…

Status of the tracker after one day in the hands of physicist



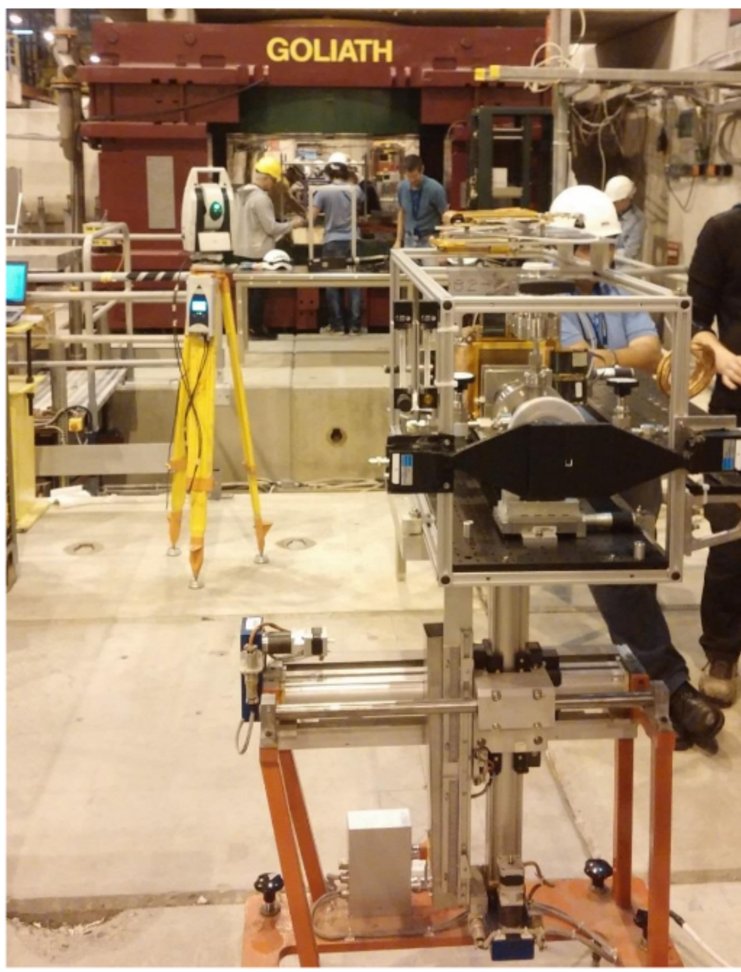
Super grazie to Miranda and her student for the impressive work done in a very short time

Global Alignment: Geometry Survey for the alignment with the beam

H4 TEST 25/05/2016

From :
Benoit CUMER EN/ACE
Antje BEHRENS EN/ACE

H4 TEST
ADJUSTMENT OF RD51 PICOSEC TRACKER
Measurement of May 25th, 2016



Remotely controllable table (M. Jeckel)

The EDMS document 1689847, containing this report can be found at the following address :
https://edms.cern.ch/document/1689847

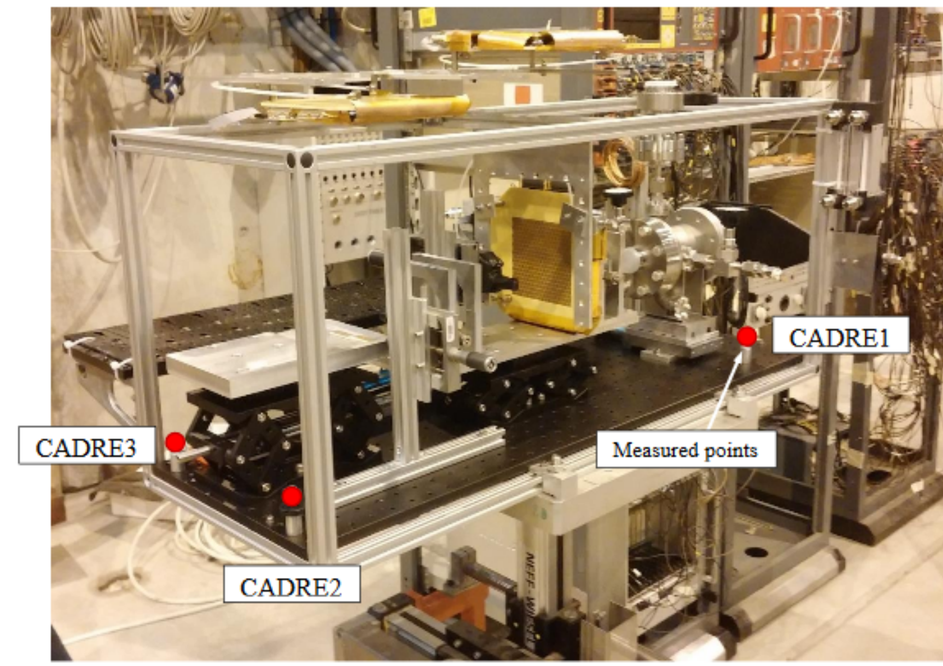


Figure 2 : Measured points on the detector, view from upstream side

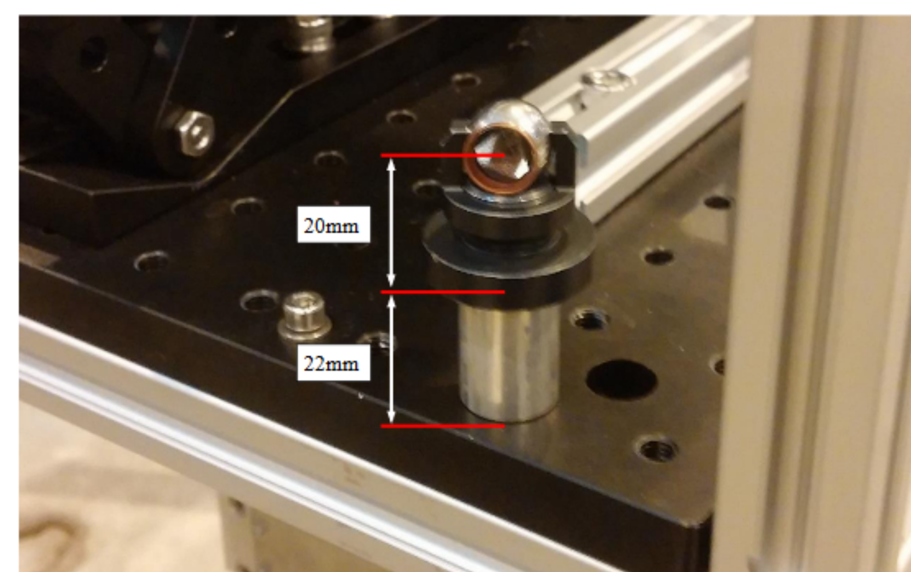
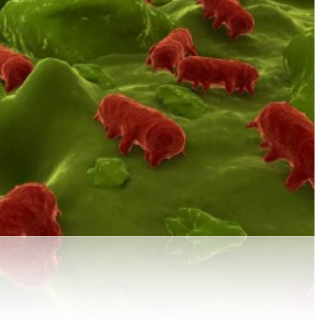


Figure 3 : Measured point on the detector

Special thanks to Antje and Benoit… for their patience



Synergistic measurement with Silicon Sensors
(S. White & M. Gallinaro)

RD50 RD50 Workshop June 2016, Torino, Italy

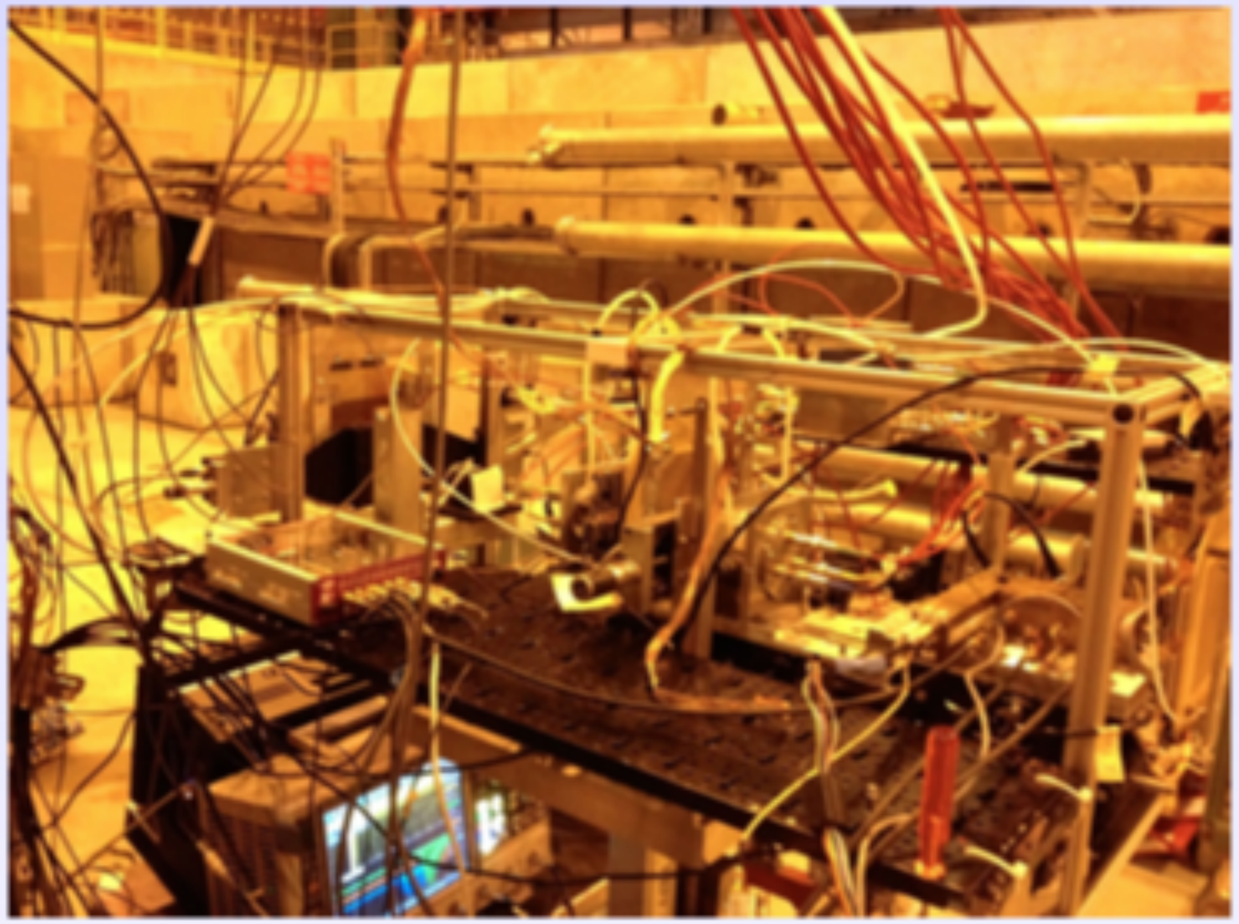
Silicon sensors with internal gain: Optimizing for charged particle fast timing

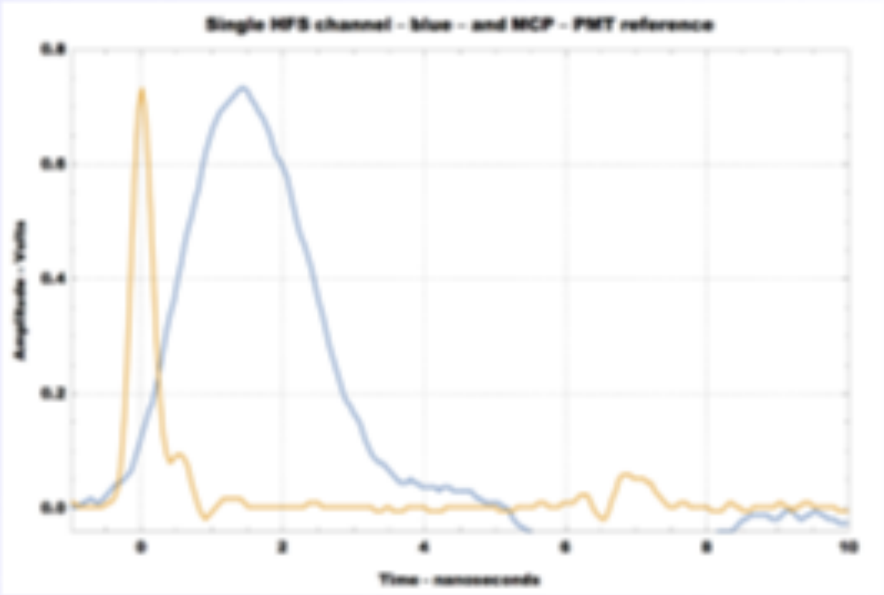
Characterization of
Deep Diffused APDs (non-irradiated) devices from RMD

Ashutosh Bhardwaj (Delhi), Ranjeet Dalal[1] (Delhi), Marco Fernandez Garcia (Santander), Geetika Jain (Delhi), Changuo Lu (Princeton), Michael Moll (CERN), Kirti Ranjan (Delhi), Sofia Otero Ugobono (CERN), Sebastian White (Princeton, CERN)

OUTLINE:
- **Concept of Deep Diffused APDs *("Hyperfast Detectors")***
- **First measurements: Study on homogeneity of response**
- **Simulation of charged particle fast timing**
- **Outlook**

- **Sunday 5.6.2016**
  - **Sensors with Sampic readout installed …. data for next RD**

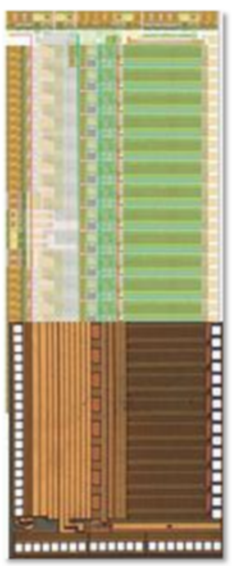




1. Signal trace @ 1800V and 50 dB preamp with MCP-PMT signal
2. Setup showing both the Si telescope on right and the SAMPIC on the left

Synergistic measurements with SAMPIC
(S. White & M. Gallinaro)

Frontier Detectors for Frontier Physics
13th Pisa meeting on advanced detectors, May 2015



SAMPIC: A 16-CHANNEL, 10-GSPS WTDC DIGITIZER CHIP FOR PICOSECOND TIME MEASUREMENT

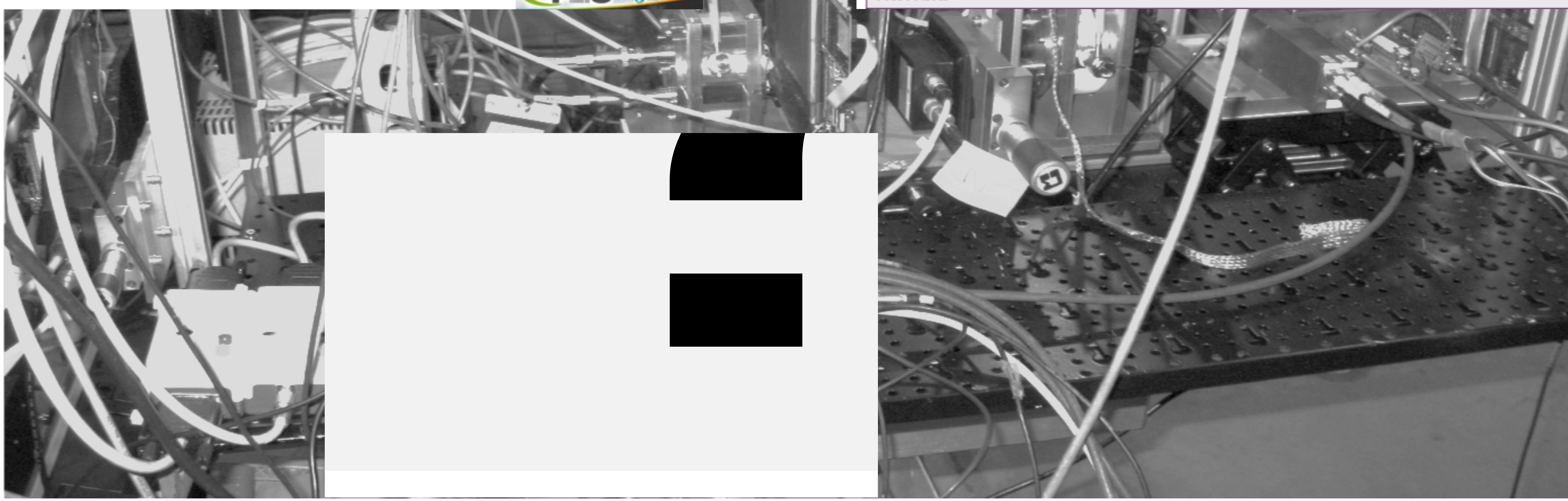
D. Breton[2], E. Delagnes[1], H. Grabas[1,3], O. Lemaire[2], J. Maalmi[2], P. Rusquart[2], P. Vallerand[2]

[1] CEA/IRFU Saclay (France)
[2] CNRS/IN2P3/LAL Orsay (France)
[3] Now with SCICPP Santa Cruz (USA)

This work has been funded by the P2IO LabEx (ANR-10-LABX-0038) in the framework « Investissements d'Avenir » (ANR-11-IDEX-0003-01) managed by the French National Research Agency (ANR).

SAMPIC: PERFORMANCE SUMMARY

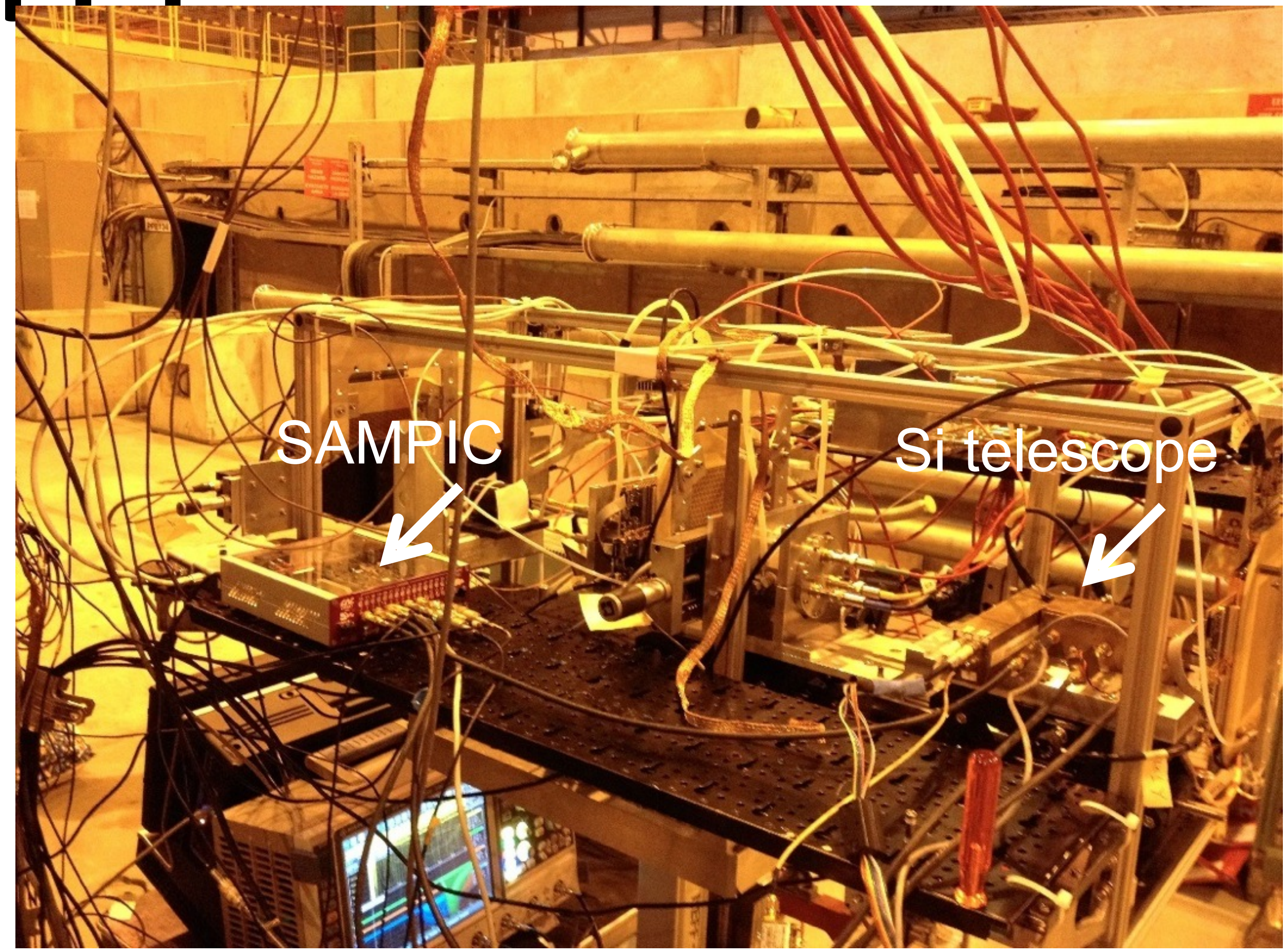
		Unit
Technology	AMS CMOS 0.18µm	
Number of channels	16	
Power consumption (max)	180 (1.8V supply)	mW
Discriminator noise	2	mV RMS
SCA depth	64	Cells
Sampling speed	1 to 8.4 (10.2 for 8 channels only)	GSPS
Bandwidth	1.6	GHz
Range (unipolar)	~ 1	V
ADC resolution	7 to 11 (trade-off time/resolution)	bits
SCA noise	< 1	mV RMS
Dynamic range	> 10	bits RMS
Conversion time	0.1 (7 bits) to 1.6 (11 bits)	µs
Readout time / ch @ 1Gbit/s (full waveform)	875	ns
Single Pulse Time precision before correction	< 15	ps RMS
Single Pulse Time precision after time INL correction	< 3.5	ps RMS

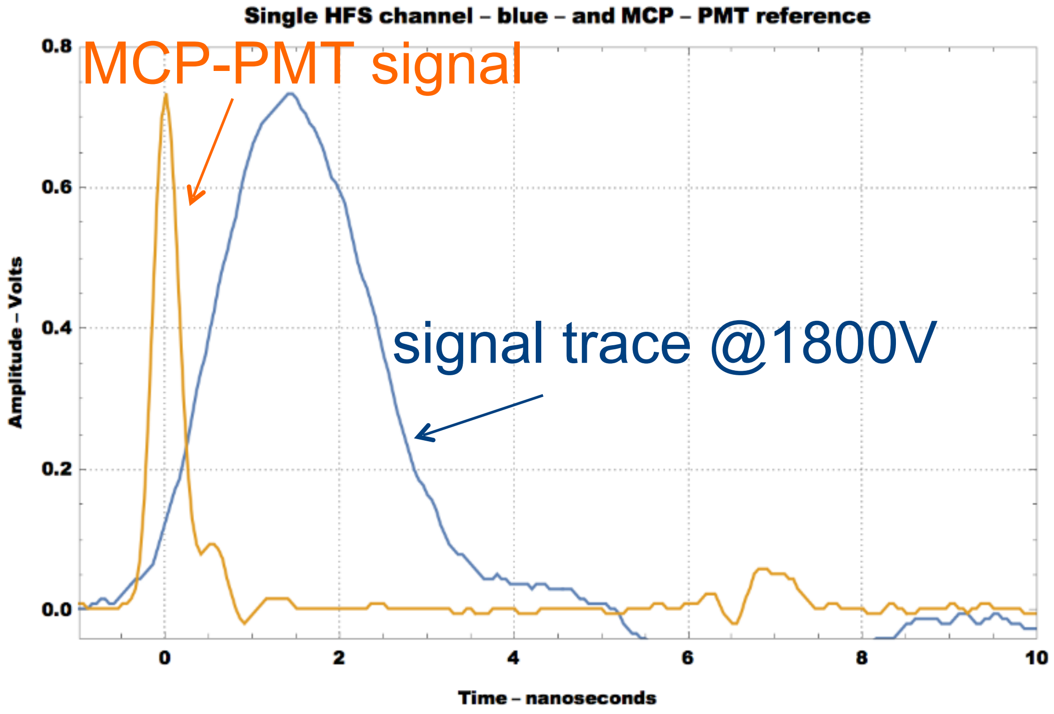


https://agenda.infn.it/getFile.py/access?contribId=138&sessionId=11&resId=0&materialId=slides&confId=8397

Test beam @ H4

- Sensors tested in parasitic mode
- Used both scope and SAMPIC multi-channel readout
  - SAMPIC is a waveform and time-to-digital converter
  - allows fine-time measurement (a few ps resolution)

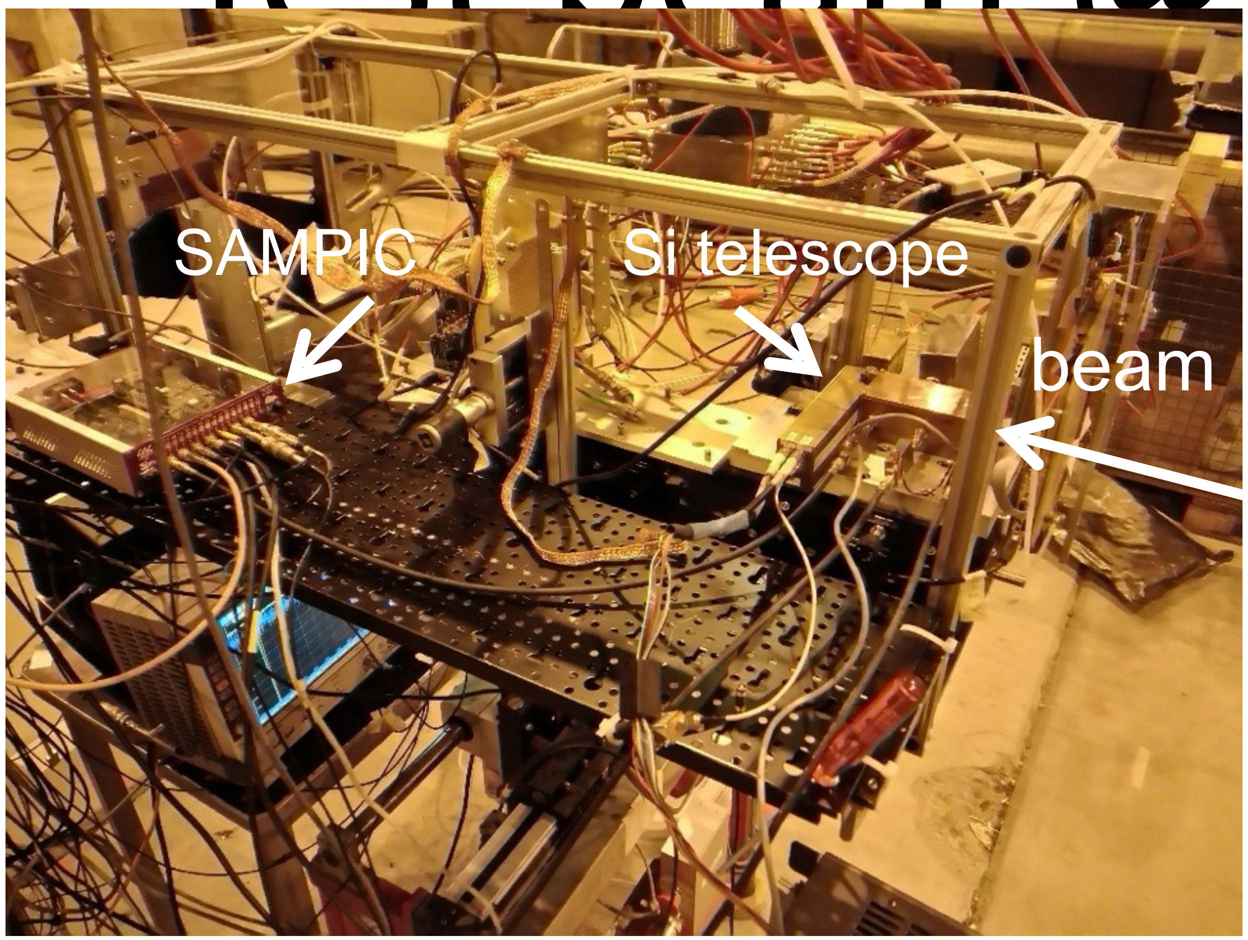


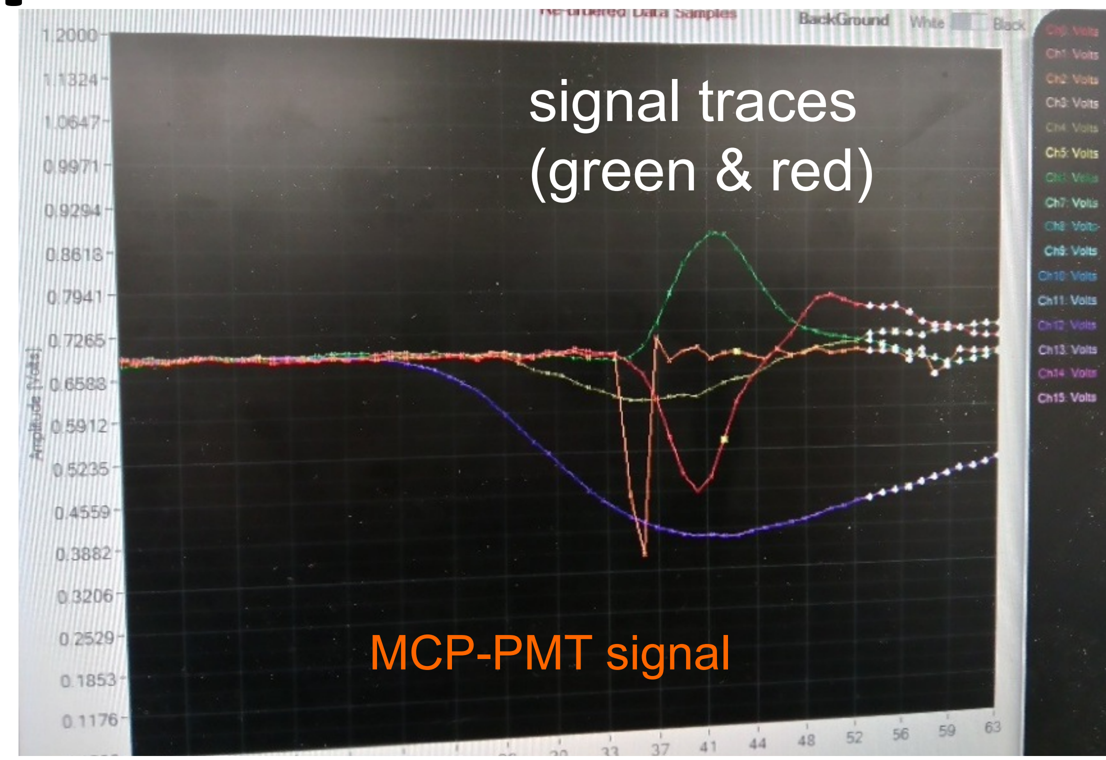


a) Setup with the SAMPIC and the Si telescope

b) Signal trace @ 1800V and 50 dB preamp with MCP-PMT signal

Test beam @ H4





- Signal traces from SAMPIC
- unpacked data

```
--------- Hit Info -----------
 HitNumber = 1026
 Channel = 0
 CellInfoForOrderedData = 15
 SampicTimeStampA = 3621
 SampicTimeStampB = 3620
 FPGATimeStamp = 196726445
 Cell0TimeStamp = 3934526180.000000
 TriggerCellTimeInstant = 3934526164.687500
 CFDTimeInstant = 3934526175.877658
 ADCCounter_LatchedAtEndOfConv = 2050
 DataSize = 64
0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0.998906 0.999279 0.998598 0.999878 0.999233 0.998442 0.998191 0.997647 0.999367 0.998410 0.998535 0.997473 0.998303 0.997335 0.998994
0.998553 0.999054 0.998908 0.997926 0.998786 0.997383 0.998249 0.999562 0.997274 0.998784 0.998384 0.998256 0.999139 0.997679 0.996736
0.994279 0.991182 0.987693 0.984339 0.977659 0.969598 0.960126 0.950064 0.940392 0.932378 0.928126 0.925521 0.926701 0.928497 0.931688
0.934432 0.940405 0.943751 0.946280 0.947305 0.948870 0.949718 0.950246 0.953187 0.955155 0.961041 0.965325 0.966598 0.970605 0.972785
0.973051 0.975327 0.977096 0.978340
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Future plans

- We are interested in the August Test Beam (even if GIF++ parasitic)
  - New photocathodes from the CERN Thin Film & Glass service (T. Schneider, M. Van Stenis and C David), Saclay and probably Hamamatsu
  - Secondary Emitters.. diamonds
  - Different/Proper gases – we were not ready for this test beam
  - Different Powering and Readout schema to reduce spark induced damages in case we want to exploit extreme configuration (one cividec killed during the test beam)
  - Resistive micromegas (?)
  - Different Radiators (?)
  - MCP time response characterization

For result you will have to wait but…

…maybe you can guess if we were happy or not …