The time challenge:
PICOSEC

E. Oliveri, CERN GDD (EP-DT-DD), RD51

A "soft" discussion on timing with gaseous detectors

(Subtitle... Nothing is a priory defined or frozen in our detector... We need to deeply understand the physics behind if we want to reach/push the limits)

Three examples, the last one focused on recent results we had with micromegas (MPGD) based PICOSEC R&D project - i.e. the original title

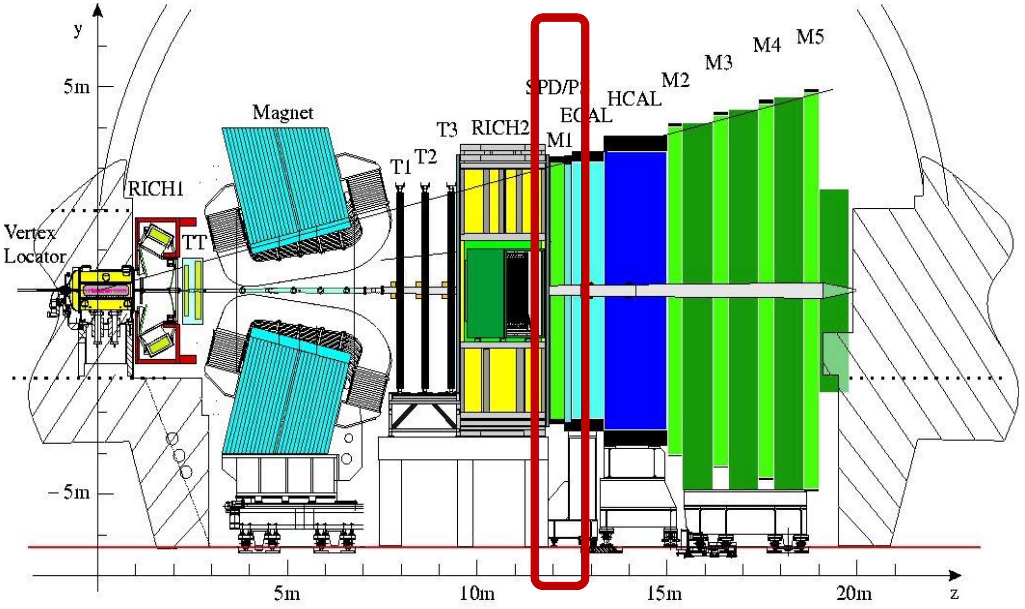
1st Example: LHCb GEM…

A tribute to people present in the room

How to speed up the response of a triple GEM detector… following the basics of the Rob’s lectures

To my (very limited) knowledge the first time that timing optimization has been done on (triple) GEM with direct ionization of the gas as primary signal…

LHCb GEMs for muons station M1 (before the calorimeter)



High-rate particle triggering with triple-GEM detector, Alfonsi et al., NIMA 518, 106-112

http://cds.cern.ch/record/5701

High Rate Capability: up to 500kHz/cm2

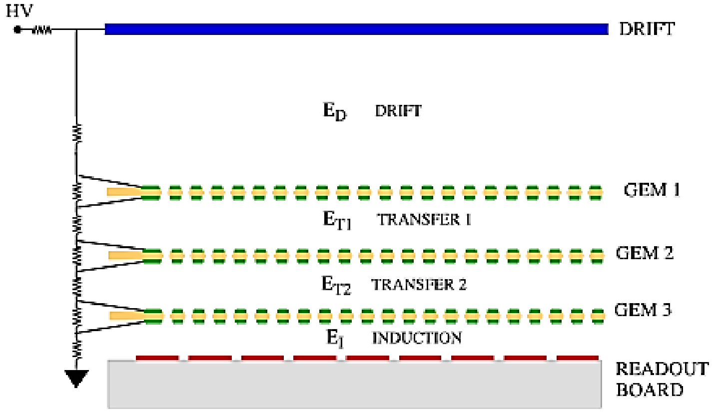
Radiation hardness: 6C/cm2 in 10 years @10k Gain

Low material budget

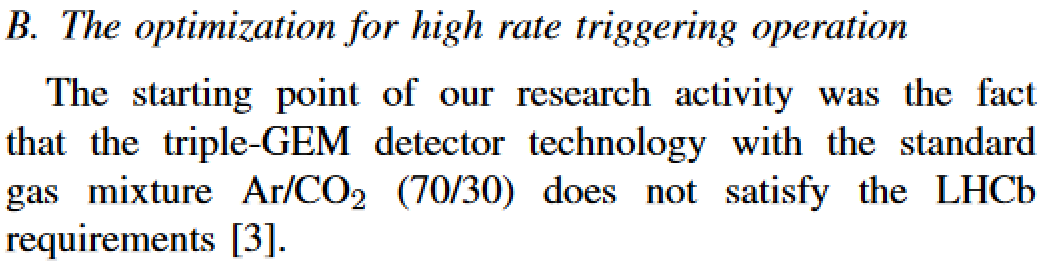
Cluster Size < 1.2 for a 10x25mm2pad size

Triggering System

Station Efficiency: >96% in 20ns time Window for two detectors in "OR"



http://gdd.web.cern.ch/GDD/

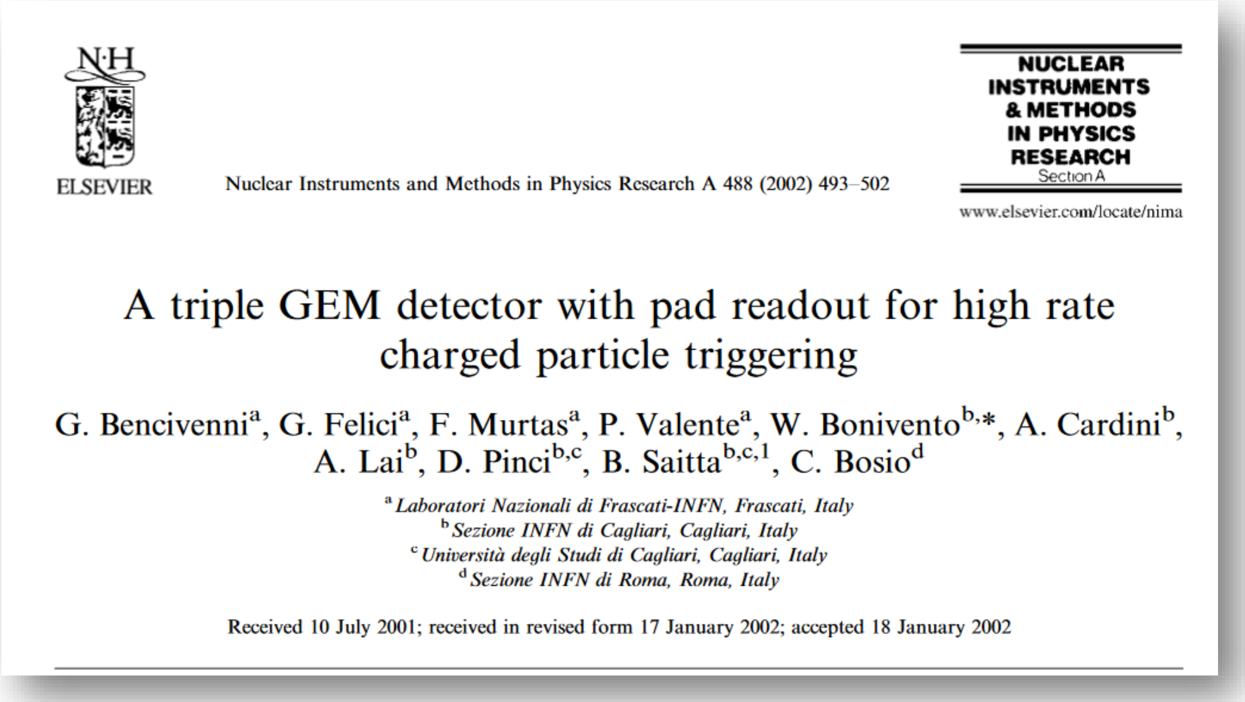


B. The optimization for high rate triggering operation

The starting point of our research activity was the fact that the triple-GEM detector technology with the standard gas mixture Ar/CO_2 (70/30) does not satisfy the LHCb requirements [3].

(M. Alfonsi et al., ieee 2004, http://ieeexplore.ieee.org/document/1462057/)

http://www.roma1.infn.it/~pinci/Articles/NIMA_488_493.pdf



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Nuclear Instruments and Methods in Physics Research A 488 (2002) 493–502

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

www.elsevier.com/locate/nima

A triple GEM detector with pad readout for high rate charged particle triggering

G. Bencivenni[a], G. Felici[a], F. Murtas[a], P. Valente[a], W. Bonivento[b,*], A. Cardini[b], A. Lai[b], D. Pinci[b,c], B. Saitta[b,c,1], C. Bosio[d]

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[b] *Sezione INFN di Cagliari, Cagliari, Italy*
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Received 10 July 2001; received in revised form 17 January 2002; accepted 18 January 2002

"Standard" Triple GEM…
A la COMPASS…
A lot of studies behind…

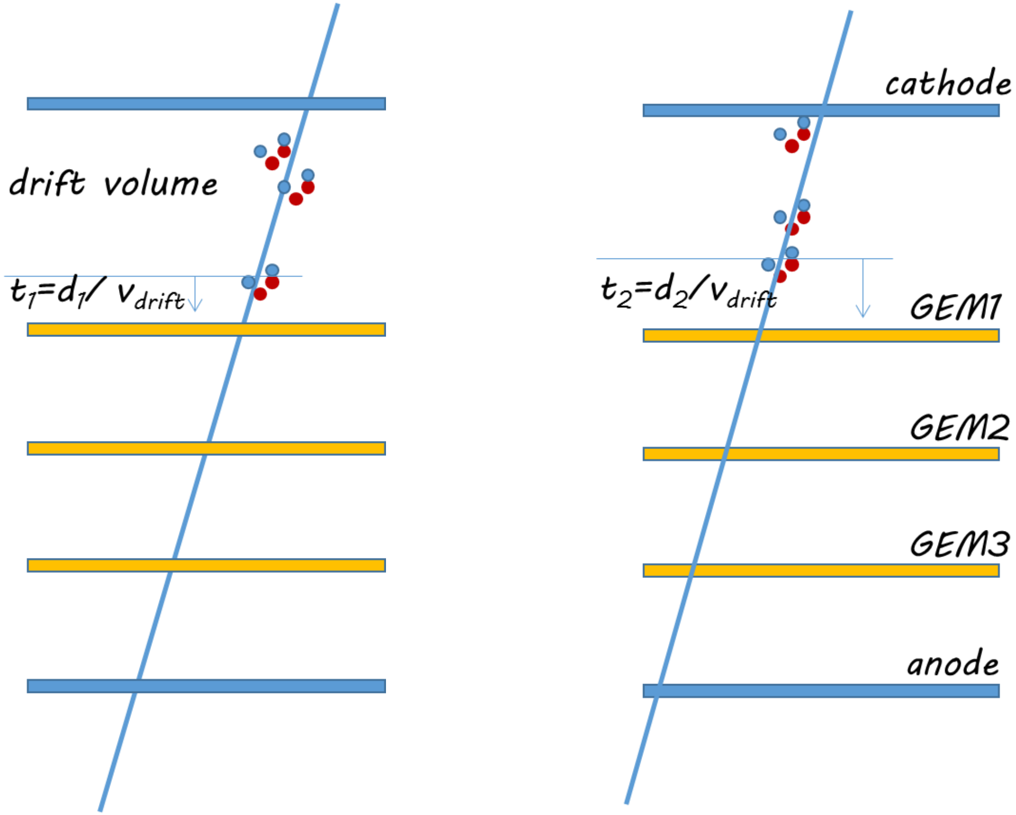
Ar/CO2 (70/30)
3mm/2mm/2mm/2mm gaps
….

Intrinsic time Resolution

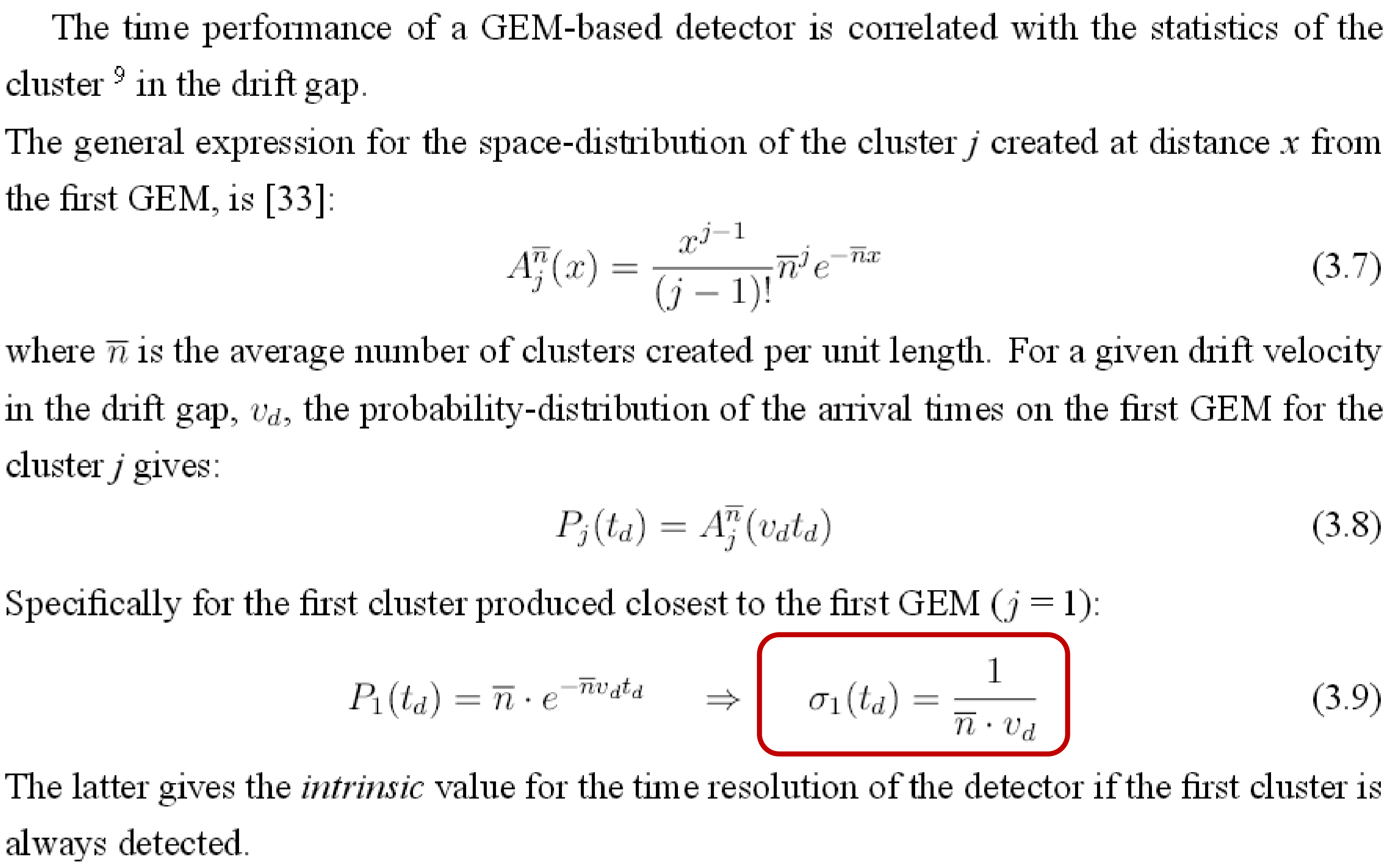
Closest Cluster to the top of first GEM

=

First contribution (rising) of the induced signal



M. P. Lener, Triple-GEM detectors for the innermost region of the muon apparatus at the LHCb experiment, Doctoral Thesis, https://cds.cern.ch/record/940631/files/thesis-2006-013.pdfm



The time performance of a GEM-based detector is correlated with the statistics of the cluster[9] in the drift gap.

The general expression for the space-distribution of the cluster j created at distance x from the first GEM, is [33]:

$$A_j^{\overline{n}}(x) = \frac{x^{j-1}}{(j-1)!}\overline{n}^j e^{-\overline{n}x} \tag{3.7}$$

where $\overline{n}$ is the average number of clusters created per unit length. For a given drift velocity in the drift gap, v_d, the probability-distribution of the arrival times on the first GEM for the cluster j gives:

$$P_j(t_d) = A_j^{\overline{n}}(v_d t_d) \tag{3.8}$$

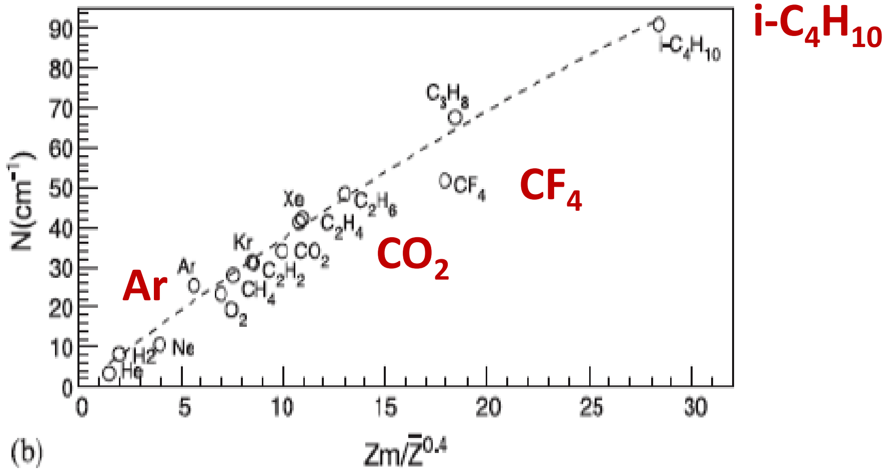
Specifically for the first cluster produced closest to the first GEM ($j = 1$):

$$P_1(t_d) = \overline{n} \cdot e^{-\overline{n}v_d t_d} \quad \Rightarrow \quad \boxed{\sigma_1(t_d) = \frac{1}{\overline{n} \cdot v_d}} \tag{3.9}$$

The latter gives the *intrinsic* value for the time resolution of the detector if the first cluster is always detected.

$\sigma(t)=1/(\bar{n}v_d)$

PROGRAM HEED:
NUMBER OF PRIMARY INTERACTIONS
(CLUSTERS) IN GASES AT STP



Ar

CO_2

CF_4

i-C_4H_{10}

I. B. Smirnov, Nucl. Instr. and Meth. A554(2005)474

http://consult.cern.ch/writeup/heed/

Fabio Sauli EDIT 2011

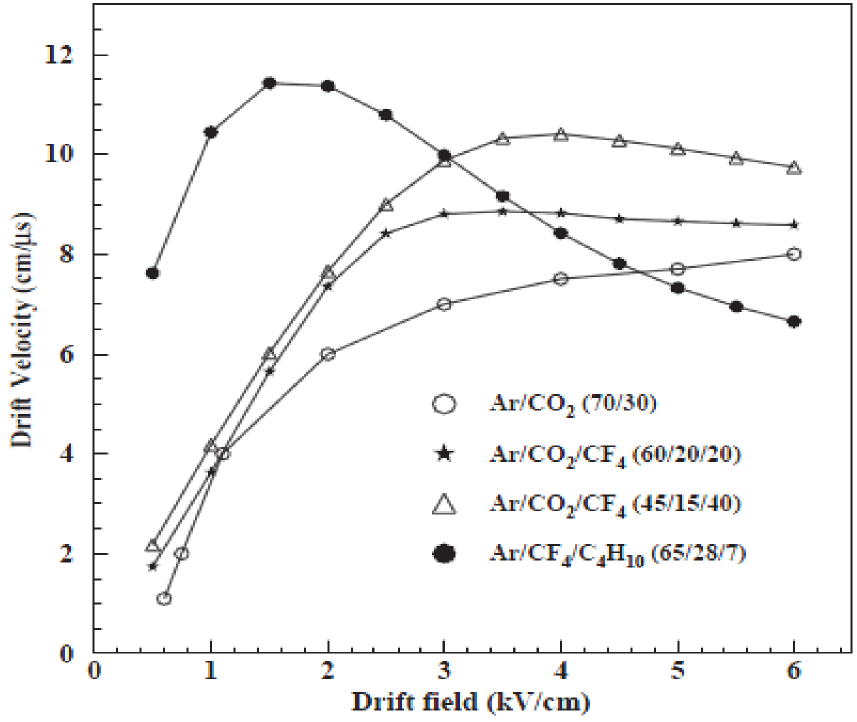
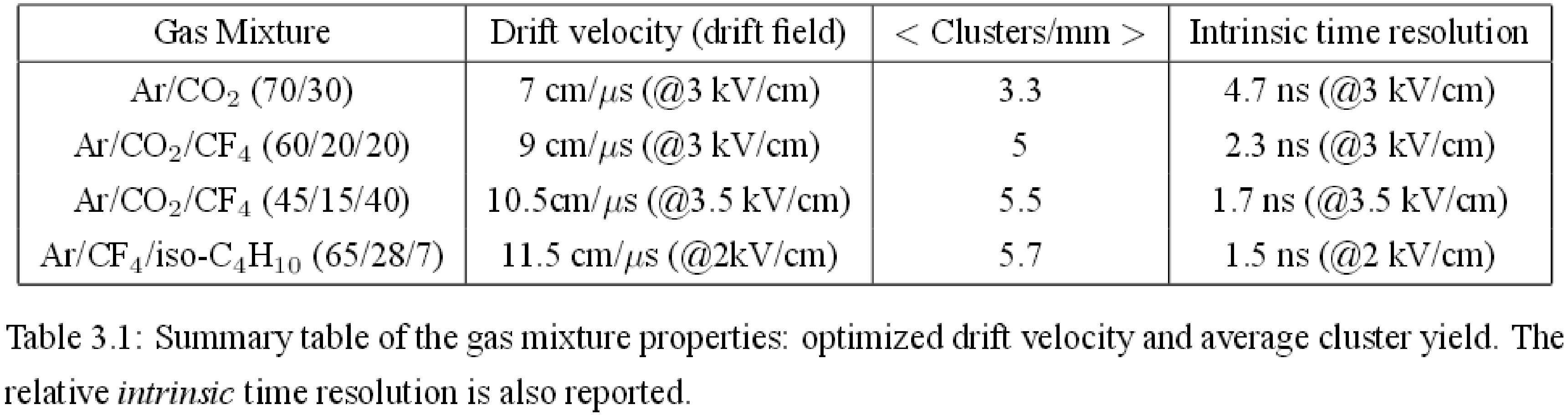


Fig. 2. Electron drift velocity for the tested gas mixtures.

M. P. Lener, Triple-GEM detectors for the innermost region of the muon apparatus at the LHCb experiment, Doctoral Thesis, https://cds.cern.ch/record/940631/files/thesis-2006-013.pdf

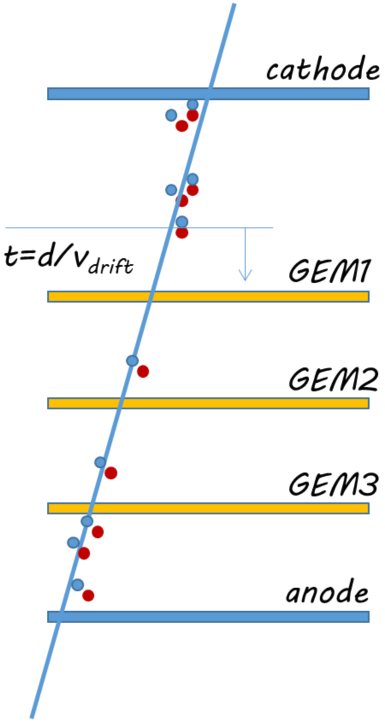
M. P. Lener, Triple-GEM detectors for the innermost region of the muon apparatus at the LHCb experiment, Doctoral Thesis, https://cds.cern.ch/record/940631/files/thesis-2006-013.pdfm



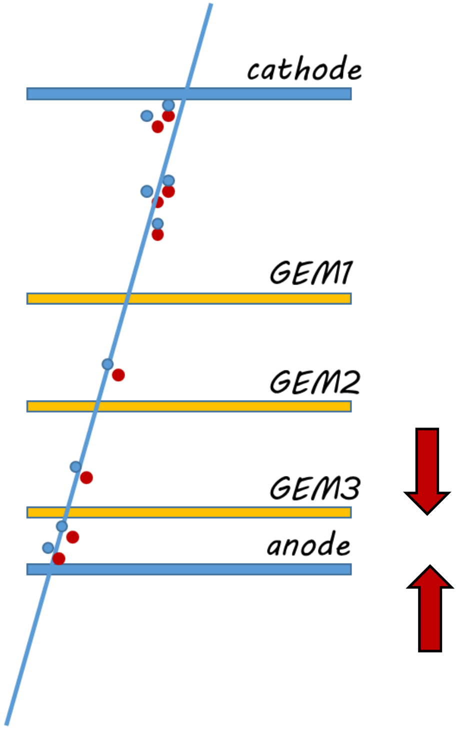
Gas Mixture	Drift velocity (drift field)	< Clusters/mm >	Intrinsic time resolution
Ar/CO_2 (70/30)	7 cm/μs (@3 kV/cm)	3.3	4.7 ns (@3 kV/cm)
$Ar/CO_2/CF_4$ (60/20/20)	9 cm/μs (@3 kV/cm)	5	2.3 ns (@3 kV/cm)
$Ar/CO_2/CF_4$ (45/15/40)	10.5cm/μs (@3.5 kV/cm)	5.5	1.7 ns (@3.5 kV/cm)
Ar/CF_4/iso-C_4H_{10} (65/28/7)	11.5 cm/μs (@2kV/cm)	5.7	1.5 ns (@2 kV/cm)

Table 3.1: Summary table of the gas mixture properties: optimized drift velocity and average cluster yield. The relative *intrinsic* time resolution is also reported.

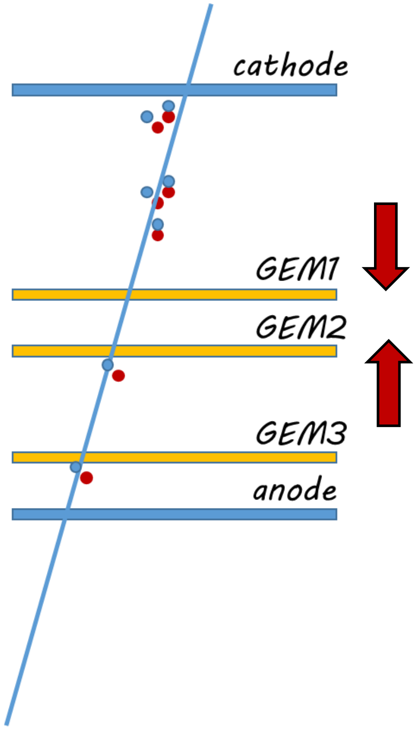
A good example of detector optimization…



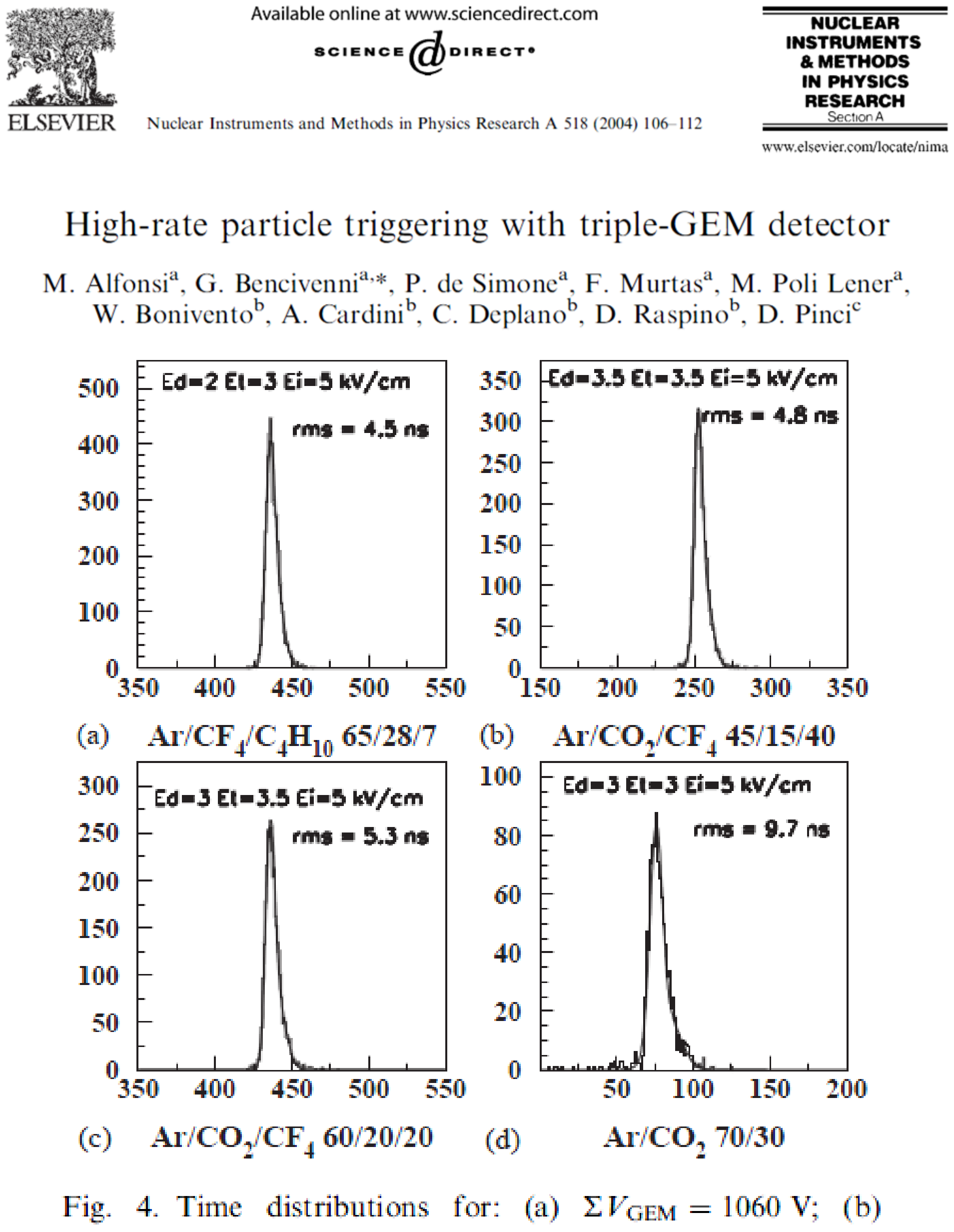
Proper Gas (to achieve the best intrinsic resolution)



Smaller Induction gap to increase the signal current ($I=-qv_d/Gap_{Ind}$)



Smaller Gap in the first transfer to be protected against Double GEM Signals. Very important if you are a triggering system.



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Nuclear Instruments and Methods in Physics Research A 518 (2004) 106–112
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A
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High-rate particle triggering with triple-GEM detector

M. Alfonsi[a], G. Bencivenni[a,*], P. de Simone[a], F. Murtas[a], M. Poli Lener[a],
W. Bonivento[b], A. Cardini[b], C. Deplano[b], D. Raspino[b], D. Pinci[c]

(a) Ar/CF$_4$/C$_4$H$_{10}$ 65/28/7 (b) Ar/CO$_2$/CF$_4$ 45/15/40

(c) Ar/CO$_2$/CF$_4$ 60/20/20 (d) Ar/CO$_2$ 70/30

Fig. 4. Time distributions for: (a) $\Sigma V_{\mathrm{GEM}} = 1060$ V; (b) $\Sigma V_{\mathrm{GEM}} = 1325$ V; (c) $\Sigma V_{\mathrm{GEM}} = 1250$ V; (d) $\Sigma V_{\mathrm{GEM}} = 1230$ V.

LHCb M1 GEM...

A very good example of detector optimization toward specific requirements...

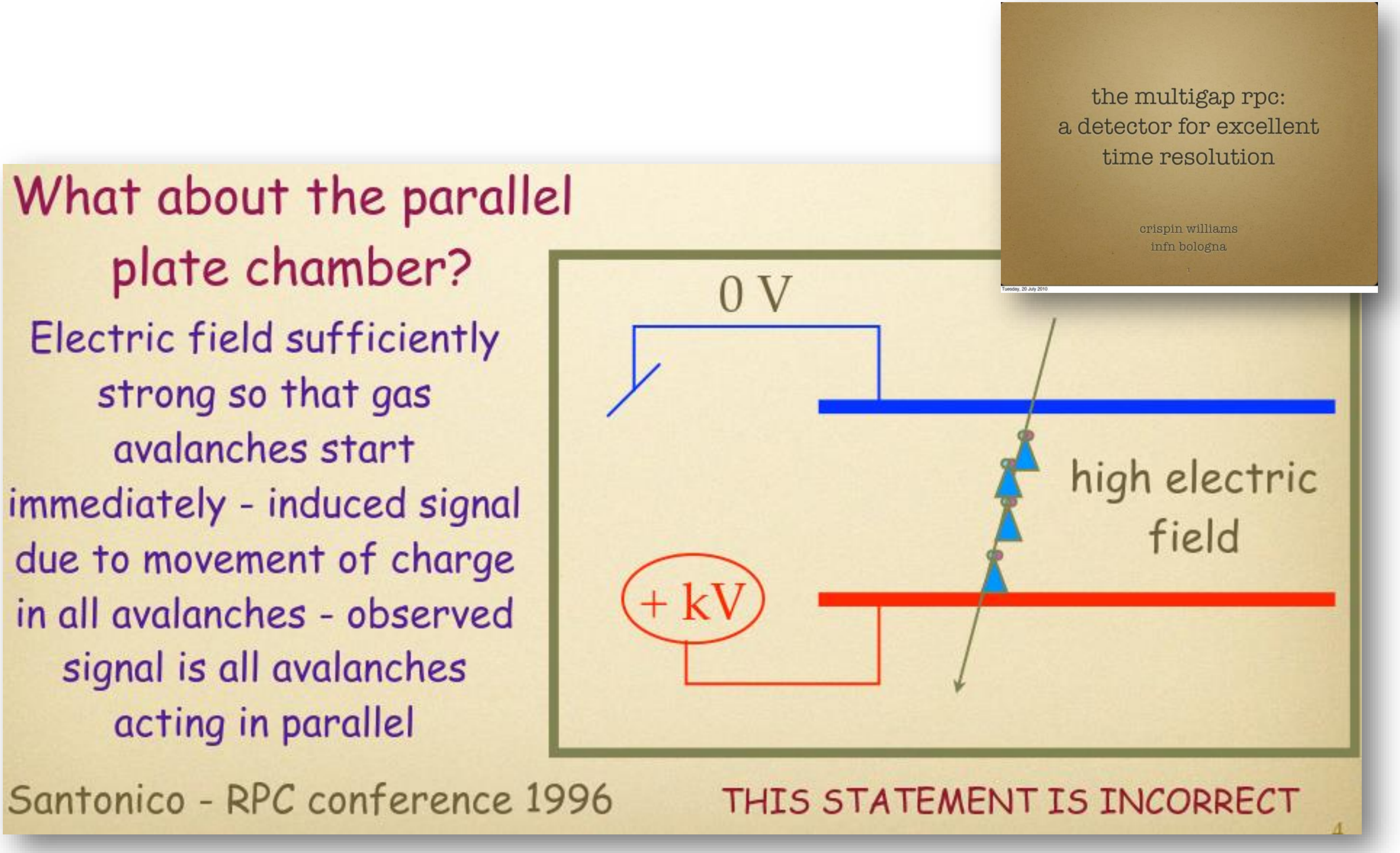
CMS GEM upgrade GE1/1 based its initial R&D phase on these studies.

2^{nd} example… from RPC to MRPC

literally copied from Crispin Williams

NB: I’m not really expert of RPC, i.e. be hypercritical

and forgive me if something is not precisely described



the multigap rpc:
a detector for excellent
time resolution

crispin williams
infn bologna

Tuesday, 20 July 2010

What about the parallel plate chamber?

Electric field sufficiently strong so that gas avalanches start immediately - induced signal due to movement of charge in all avalanches - observed signal is all avalanches acting in parallel

Santonico - RPC conference 1996

THIS STATEMENT IS INCORRECT

4

C. Williams, https://indico.cern.ch/event/98658/contributions/1291608/attachments/1119123/1597001/williams-mrpc.pdf

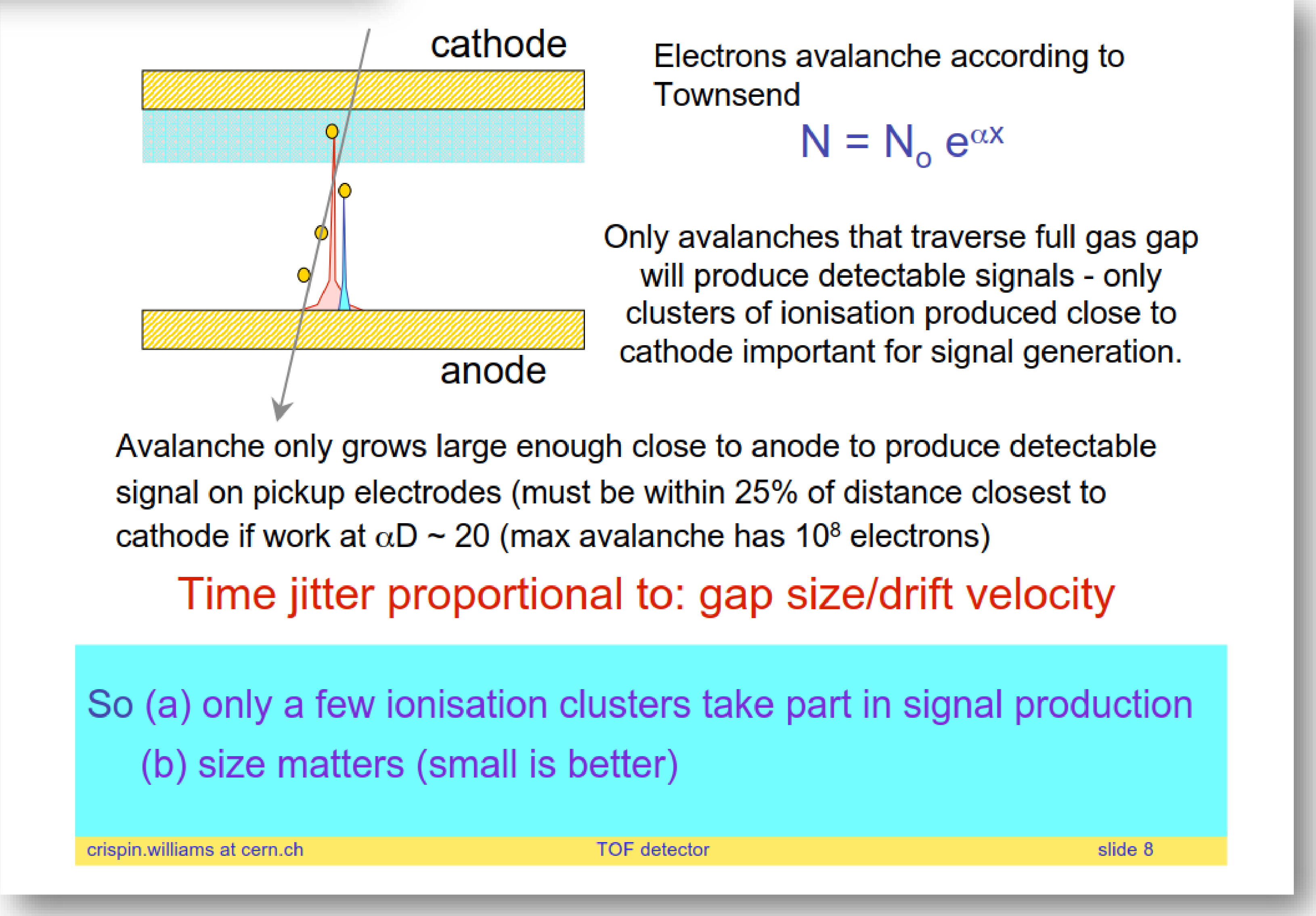
Innovative Detectors for Supercolliders

29 Sep 2003, 09:00 → 3 Oct 2003, 19:00 Europe/Zurich

Erice (Italy)

Nappi, E. / Seguinot, J.

C. Williams, https://indico.cern.ch/event/415278/contributions/997124/attachments/848946/1183143/Williams.pdf



Electrons avalanche according to Townsend

$$N = N_o\, e^{\alpha x}$$

Only avalanches that traverse full gas gap will produce detectable signals - only clusters of ionisation produced close to cathode important for signal generation.

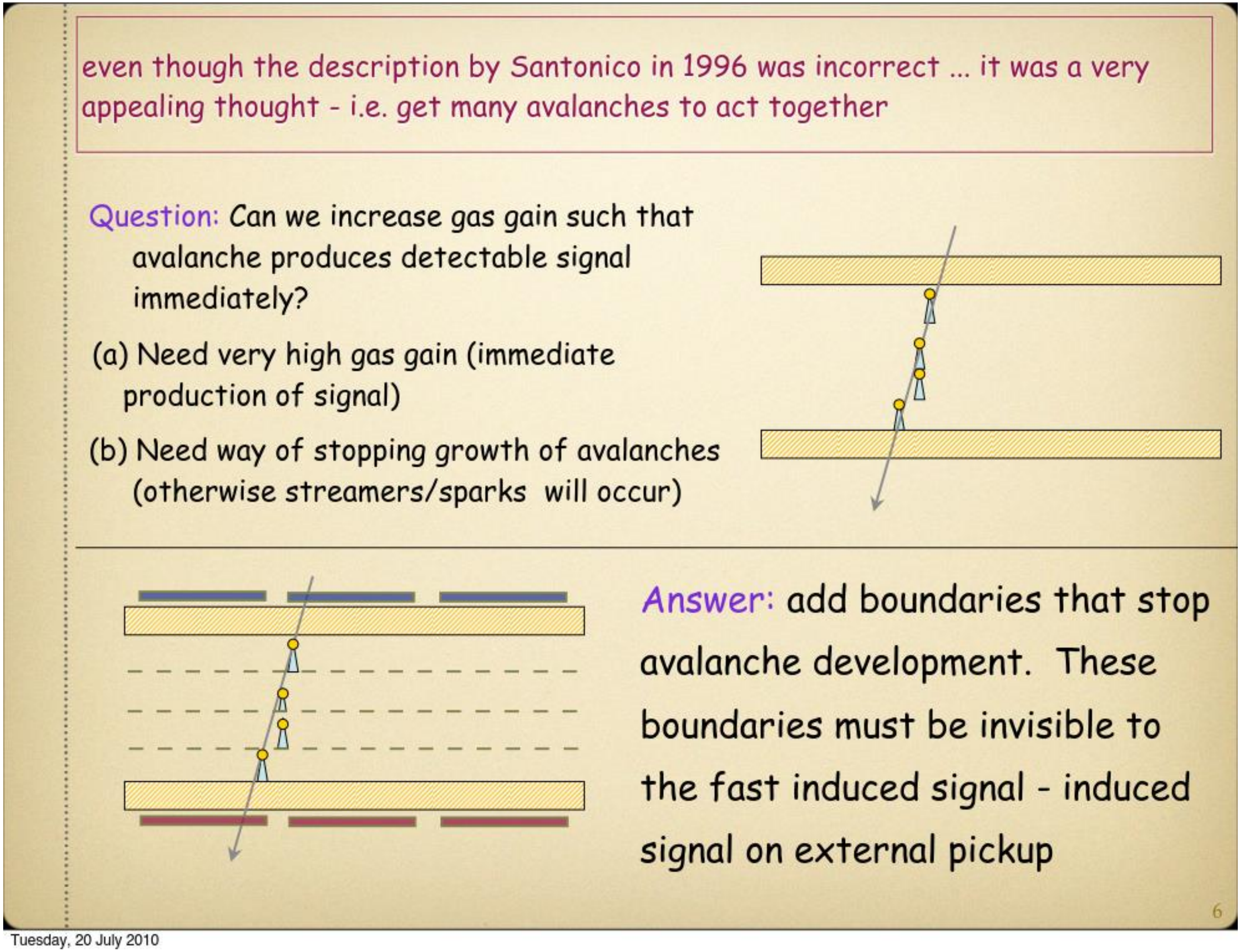
Avalanche only grows large enough close to anode to produce detectable signal on pickup electrodes (must be within 25% of distance closest to cathode if work at $\alpha D \sim 20$ (max avalanche has 10^8 electrons)

Time jitter proportional to: gap size/drift velocity

So (a) only a few ionisation clusters take part in signal production

(b) size matters (small is better)

crispin.williams at cern.ch TOF detector slide 8



even though the description by Santonico in 1996 was incorrect … it was a very appealing thought - i.e. get many avalanches to act together

Question: Can we increase gas gain such that avalanche produces detectable signal immediately?

(a) Need very high gas gain (immediate production of signal)

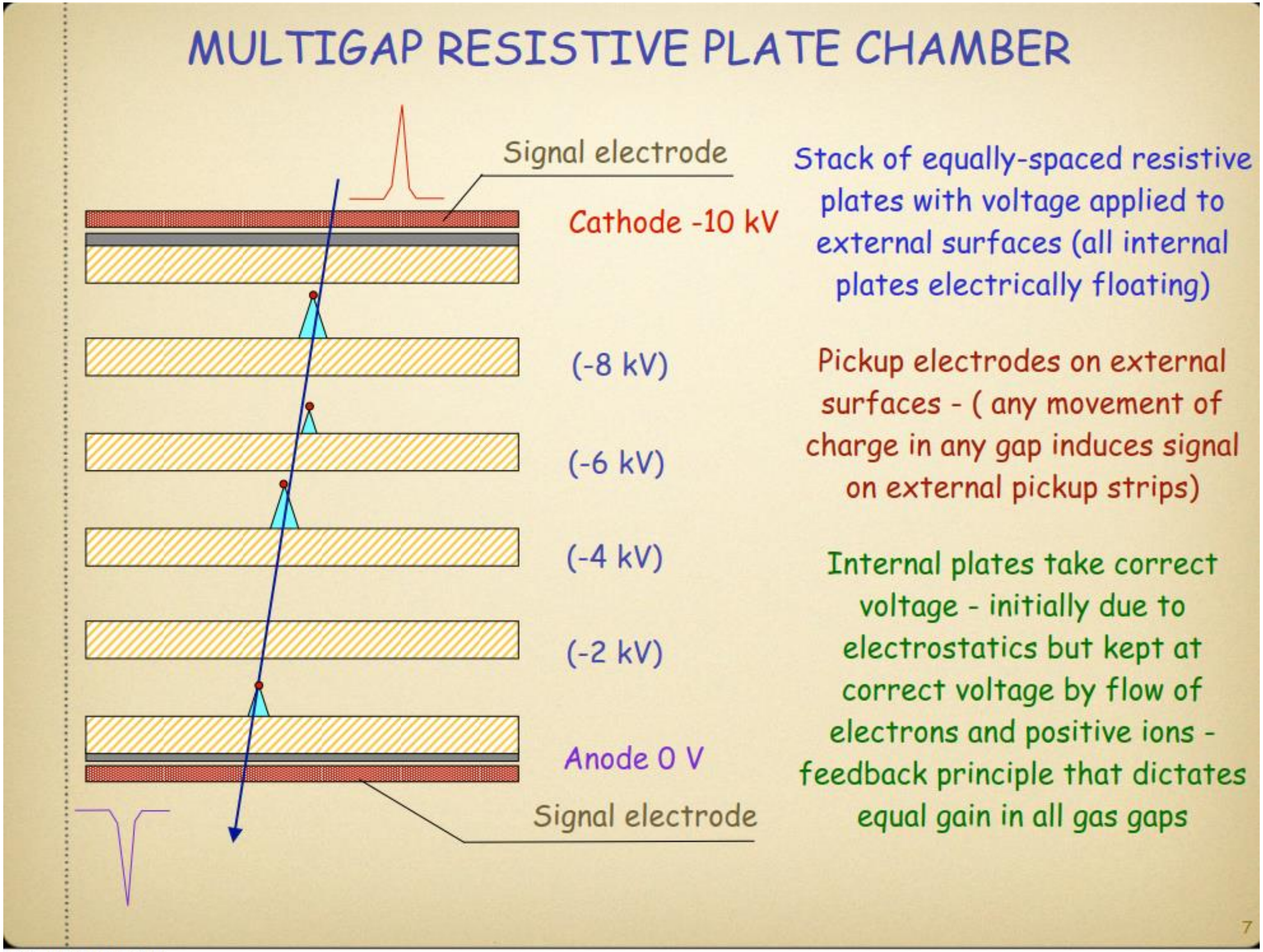
(b) Need way of stopping growth of avalanches (otherwise streamers/sparks will occur)

Answer: add boundaries that stop avalanche development. These boundaries must be invisible to the fast induced signal - induced signal on external pickup

6

Tuesday, 20 July 2010

C. Williams, https://indico.cern.ch/event/98658/contributions/1291608/attachments/1119123/1597001/williams-mrpc.pdf



MULTIGAP RESISTIVE PLATE CHAMBER

Signal electrode

Cathode -10 kV

(-8 kV)

(-6 kV)

(-4 kV)

(-2 kV)

Anode 0 V

Signal electrode

Stack of equally-spaced resistive plates with voltage applied to external surfaces (all internal plates electrically floating)

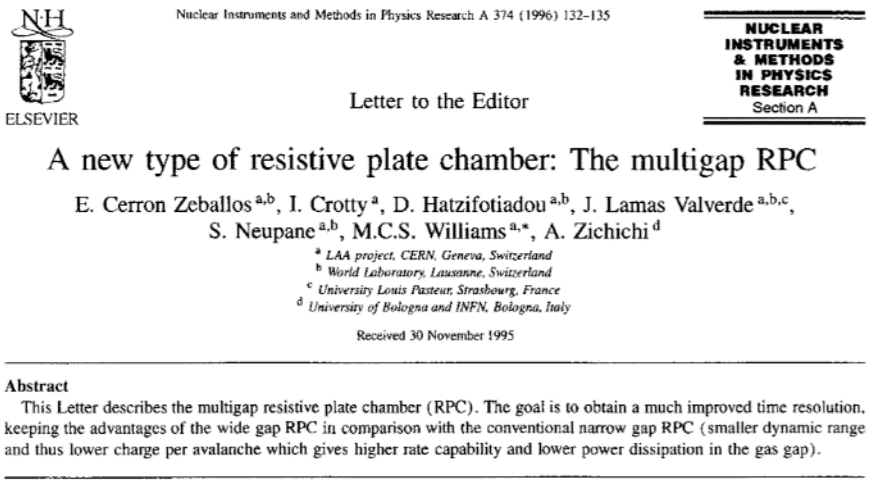
Pickup electrodes on external surfaces - (any movement of charge in any gap induces signal on external pickup strips)

Internal plates take correct voltage - initially due to electrostatics but kept at correct voltage by flow of electrons and positive ions - feedback principle that dictates equal gain in all gas gaps

Tuesday, 20 July 2010

C. Williams, https://indico.cern.ch/event/98658/contributions/1291608/attachments/1119123/1597001/williams-mrpc.pdf

https://ac-els-cdn-com.ezproxy.cern.ch/0168900296001581/1-s2.0-0168900296001581-main.pdf?_tid=8e7ddda6-f964-11e7-bc04-00000aacb35f&acdnat=1515959774_958d2061bc8d322c5391ca9d3f4de87a



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Nuclear Instruments and Methods in Physics Research A 374 (1996) 132–135

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

Letter to the Editor

A new type of resistive plate chamber: The multigap RPC

E. Cerron Zeballos [a,b], I. Crotty [a], D. Hatzifotiadou [a,b], J. Lamas Valverde [a,b,c], S. Neupane [a,b], M.C.S. Williams [a,*], A. Zichichi [d]

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[b] *World Laboratory, Lausanne, Switzerland*
[c] *University Louis Pasteur, Strasbourg, France*
[d] *University of Bologna and INFN, Bologna, Italy*

Received 30 November 1995

Abstract

This Letter describes the multigap resistive plate chamber (RPC). The goal is to obtain a much improved time resolution, keeping the advantages of the wide gap RPC in comparison with the conventional narrow gap RPC (smaller dynamic range and thus lower charge per avalanche which gives higher rate capability and lower power dissipation in the gas gap).

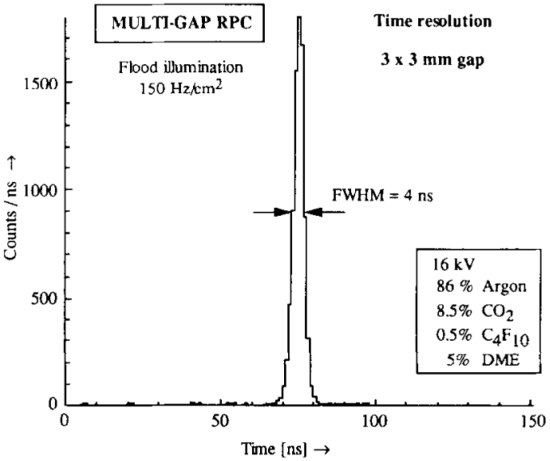


Fig. 3. Time spectra of the average of the leading and trailing edge timing at 16 kV (200 V above the knee of the efficiency plateau).

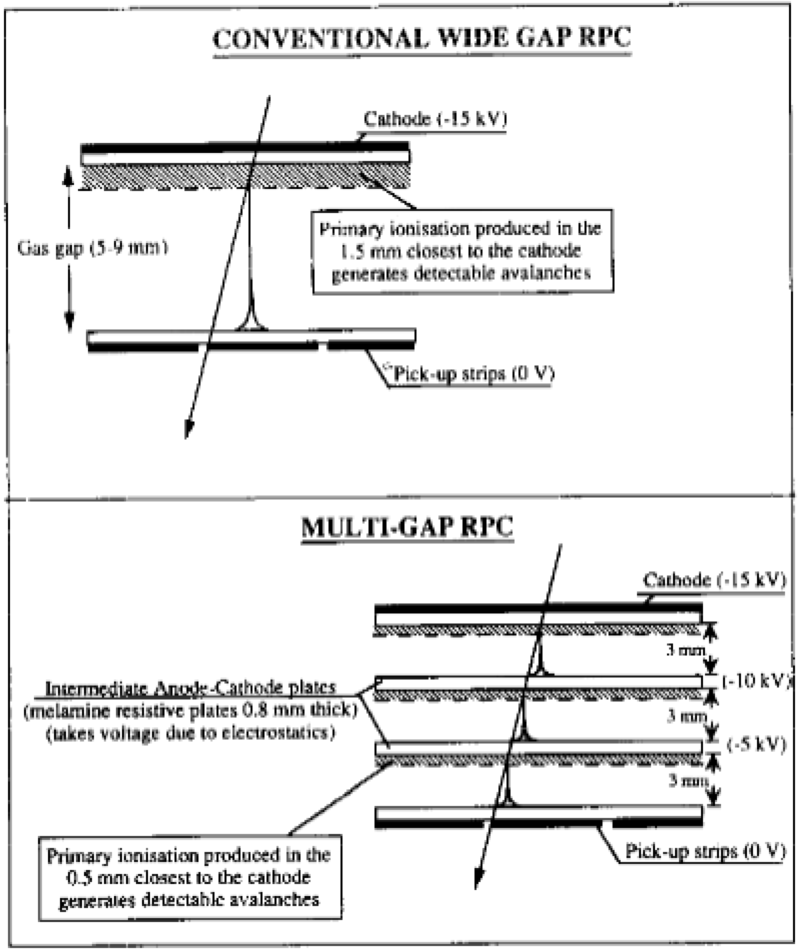
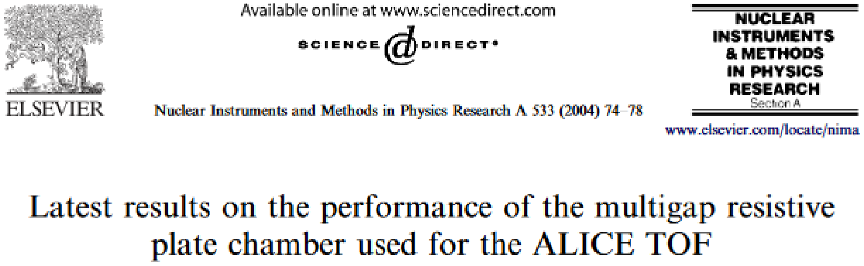


Fig. 1. Schematic diagram and principle of operation of multi-gap RPC compared to a conventional 9 mm single gap RPC.



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Nuclear Instruments and Methods in Physics Research A 533 (2004) 74–78

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

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Latest results on the performance of the multigap resistive plate chamber used for the ALICE TOF

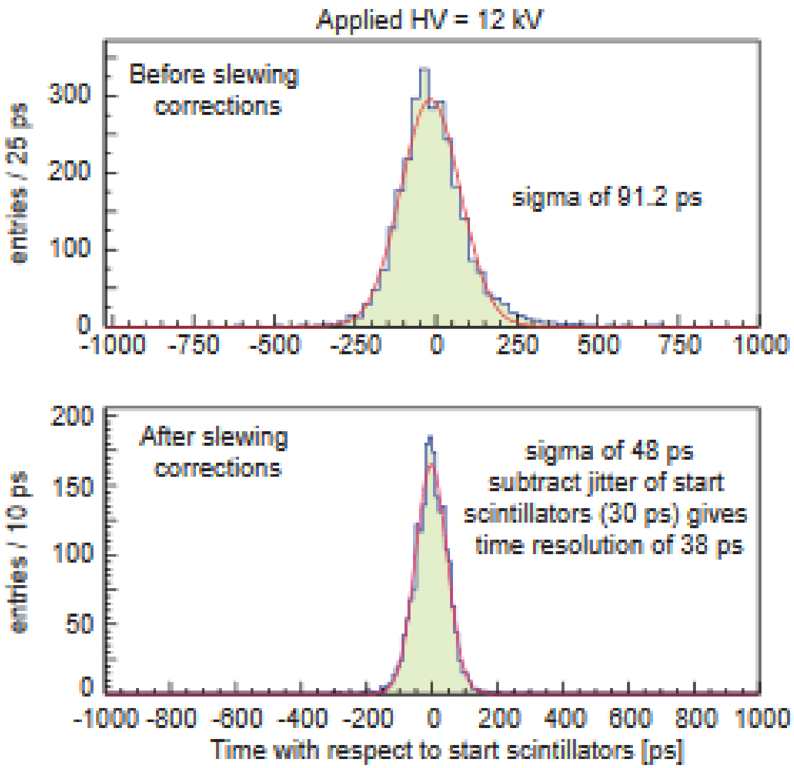


Fig. 3. Time distribution of MRPC before and after slewing corrections.

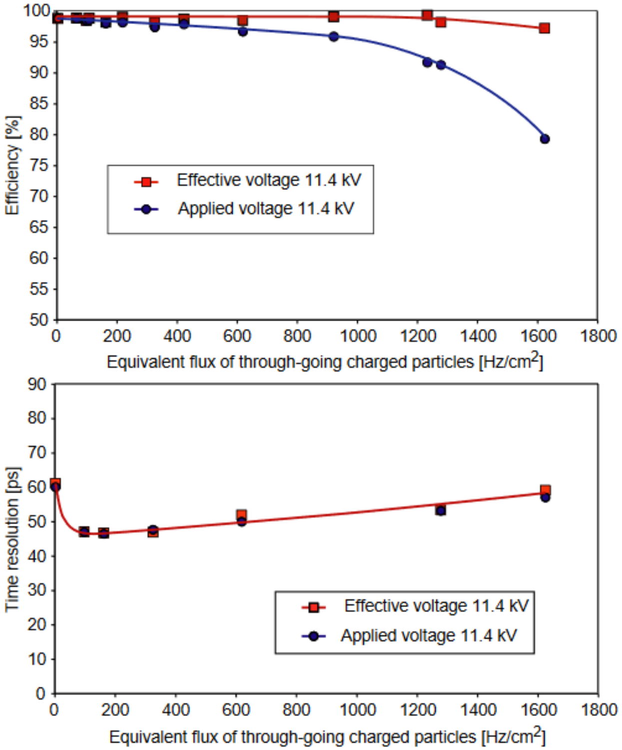
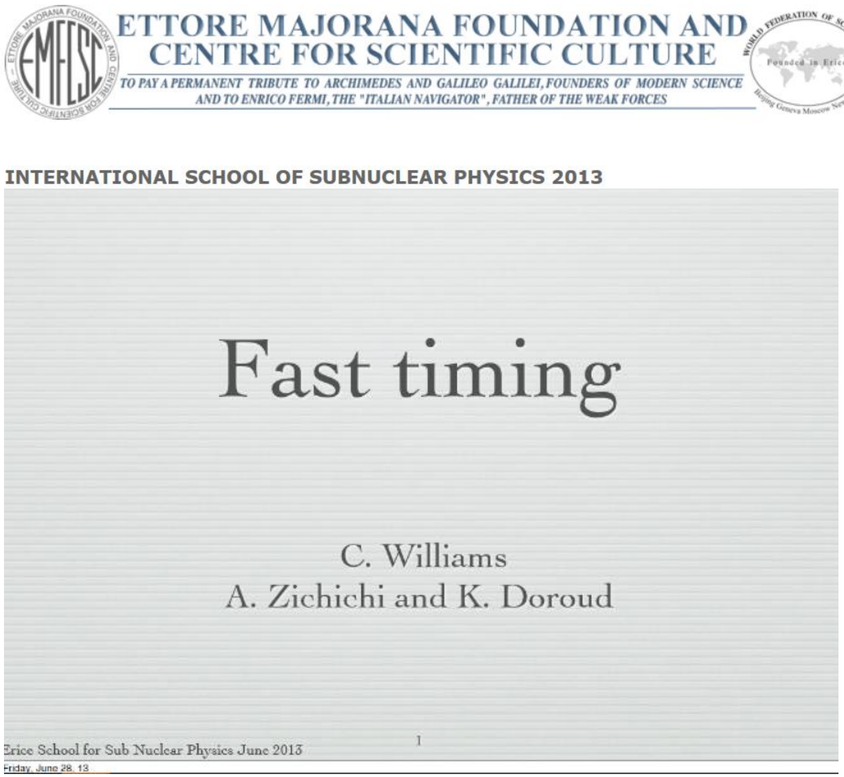


Fig. 6. Efficiency and time resolution versus equivalent flux of charged particles for MRPC tested at the GIF.

https://www-sciencedirect-com.ezproxy.cern.ch/science/article/pii/S0168900204014081



ETTORE MAJORANA FOUNDATION AND CENTRE FOR SCIENTIFIC CULTURE

TO PAY A PERMANENT TRIBUTE TO ARCHIMEDES AND GALILEO GALILEI, FOUNDERS OF MODERN SCIENCE AND TO ENRICO FERMI, THE "ITALIAN NAVIGATOR", FATHER OF THE WEAK FORCES

INTERNATIONAL SCHOOL OF SUBNUCLEAR PHYSICS 2013

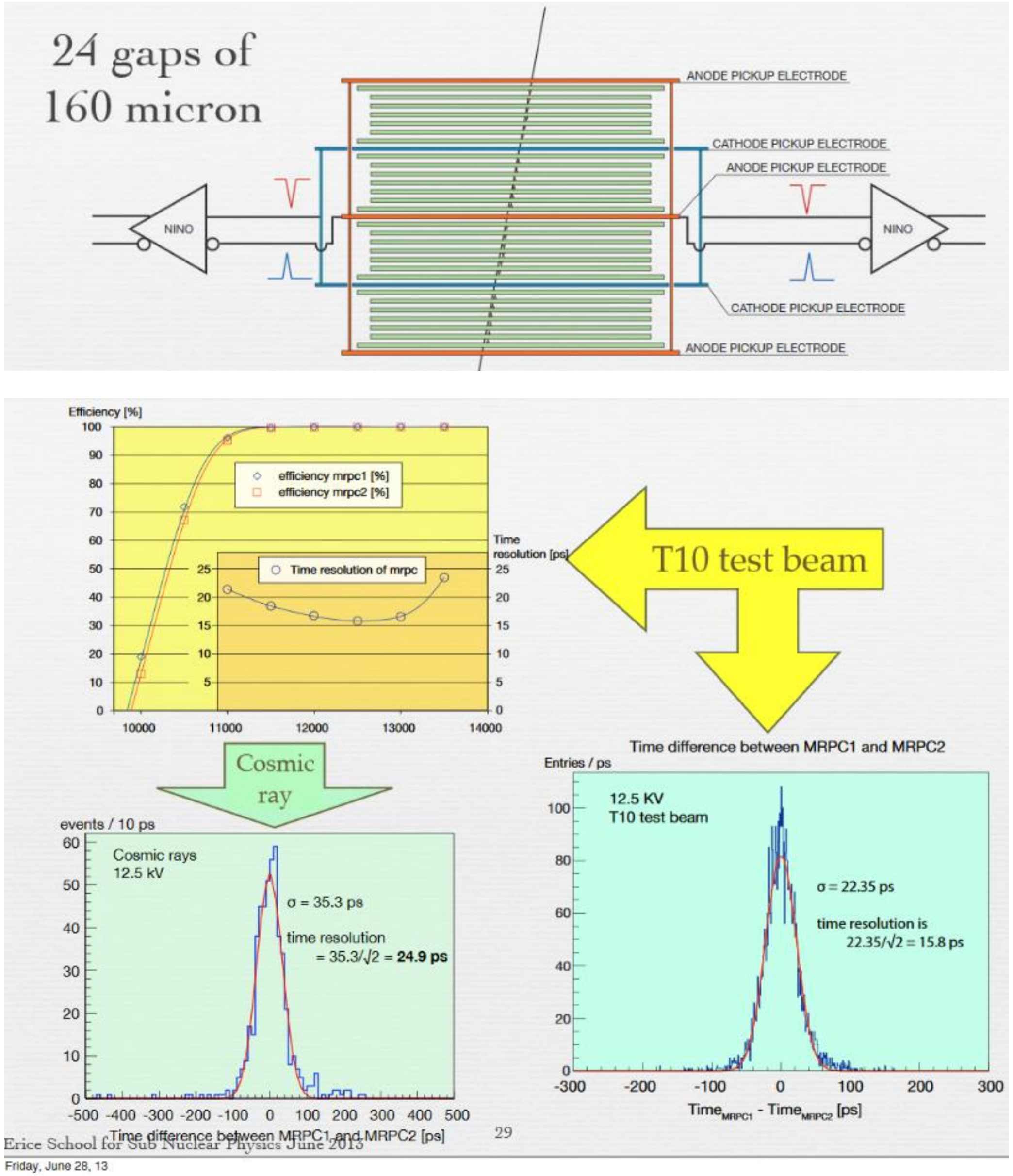
Fast timing

C. Williams
A. Zichichi and K. Doroud

Erice School for Sub Nuclear Physics June 2013 1
Friday, June 28, 13

Erice School for Sub Nuclear Physics June 2013

http://www.ccsem.infn.it/issp2013/docs/erice%202013%20williams.pdf

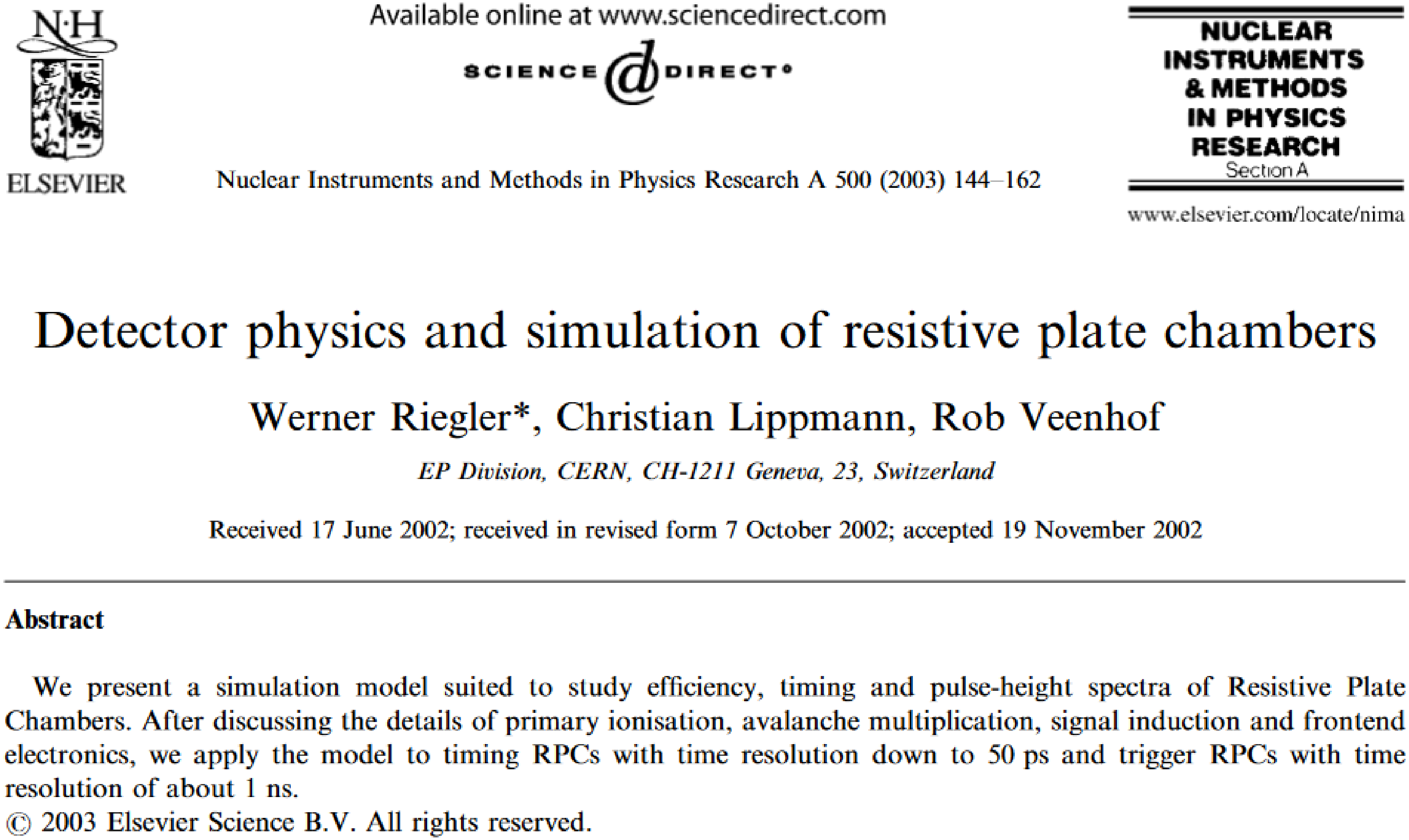


24 gaps of 160 micron

T10 test beam

Cosmic ray

Erice School for Sub Nuclear Physics June 2013 29
Friday, June 28, 13



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Nuclear Instruments and Methods in Physics Research A 500 (2003) 144–162

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

www.elsevier.com/locate/nima

Detector physics and simulation of resistive plate chambers

Werner Riegler*, Christian Lippmann, Rob Veenhof

EP Division, CERN, CH-1211 Geneva, 23, Switzerland

Received 17 June 2002; received in revised form 7 October 2002; accepted 19 November 2002

Abstract

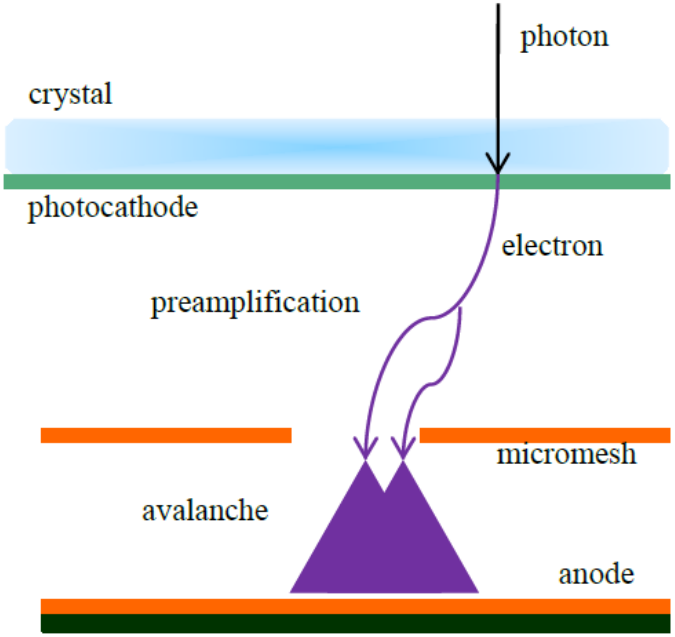
We present a simulation model suited to study efficiency, timing and pulse-height spectra of Resistive Plate Chambers. After discussing the details of primary ionisation, avalanche multiplication, signal induction and frontend electronics, we apply the model to timing RPCs with time resolution down to 50 ps and trigger RPCs with time resolution of about 1 ns.

https://pdfs.semanticscholar.org/8718/1731d38a92512ac931f75c1dbeb1a42c4fc1.pdf

Now… let's move to the original title

3rd Example: The time challenge: PICOSEC

The PICOSEC project



I. Giomataris et al.

Proof of principle

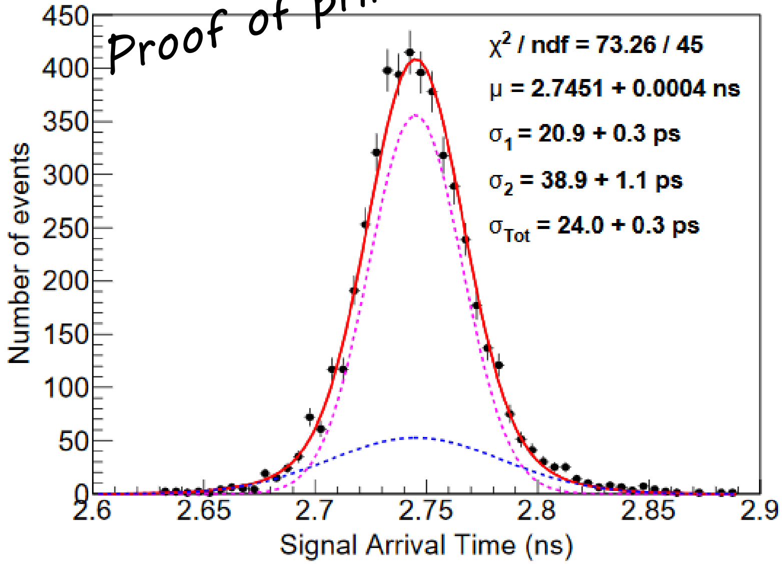
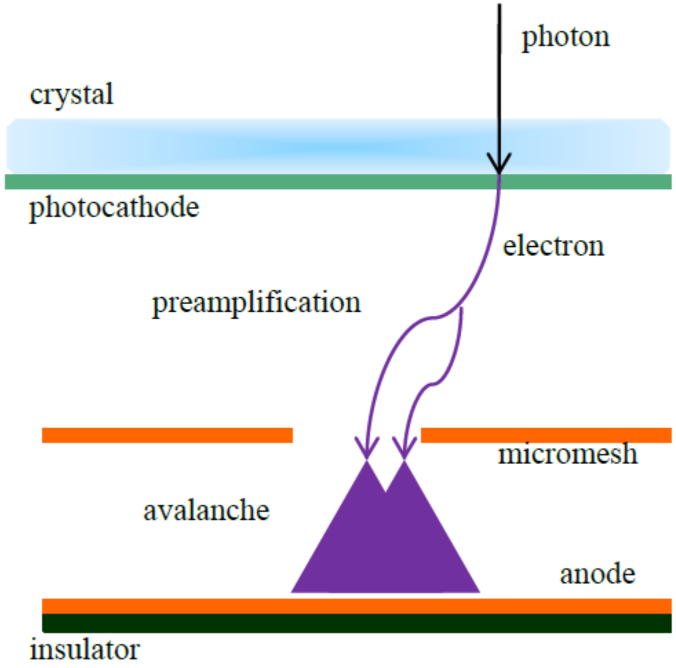
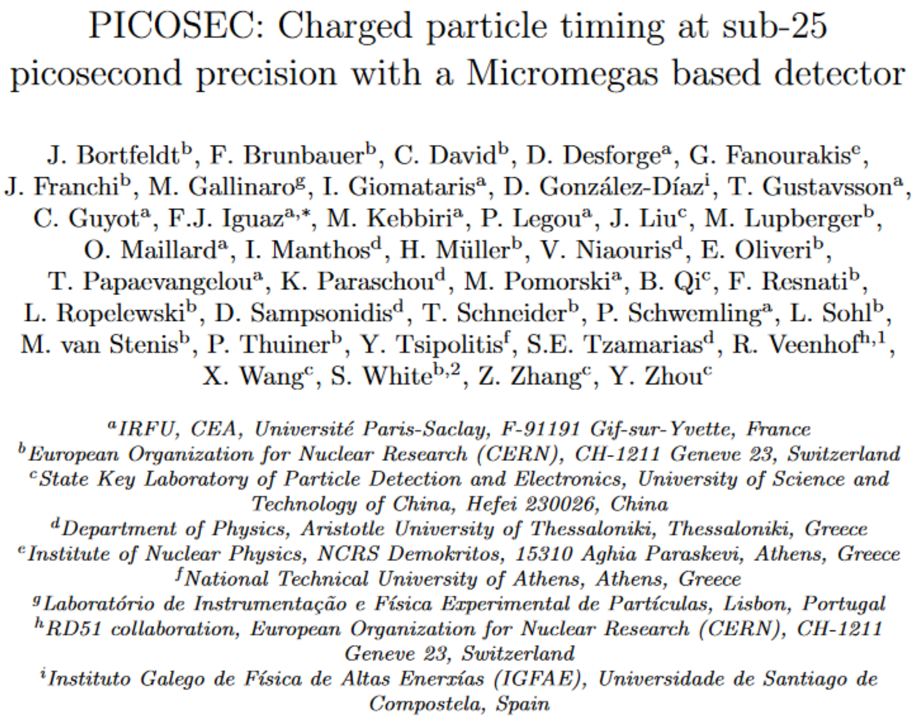


Figure 13: Beam test: An example of the signal arrival time distribution for 150 GeV muons, and the superimposed fit with a two Gaussian function (red line for the combination and dashed blue and magenta lines for each Gaussian function), for an anode and drift voltage of 275 V and 475 V, respectively. Statistical uncertainties are shown.

https://arxiv.org/pdf/1712.05256.pdf

The PICOSEC project





PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector

J. Bortfeldt[b], F. Brunbauer[b], C. David[b], D. Desforge[a], G. Fanourakis[e], J. Franchi[b], M. Gallinaro[g], I. Giomataris[a], D. González-Díaz[i], T. Gustavsson[a], C. Guyot[a], F.J. Iguaz[a,*], M. Kebbiri[a], P. Legou[a], J. Liu[c], M. Lupberger[b], O. Maillard[a], I. Manthos[d], H. Müller[b], V. Niaouris[d], E. Oliveri[b], T. Papaevangelou[a], K. Paraschou[d], M. Pomorski[a], B. Qi[c], F. Resnati[b], L. Ropelewski[b], D. Sampsonidis[d], T. Schneider[b], P. Schwemling[a], L. Sohl[b], M. van Stenis[b], P. Thuiner[b], Y. Tsipolitis[f], S.E. Tzamarias[d], R. Veenhof[h,1], X. Wang[c], S. White[b,2], Z. Zhang[c], Y. Zhou[c]

[a] IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France
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[f] National Technical University of Athens, Athens, Greece
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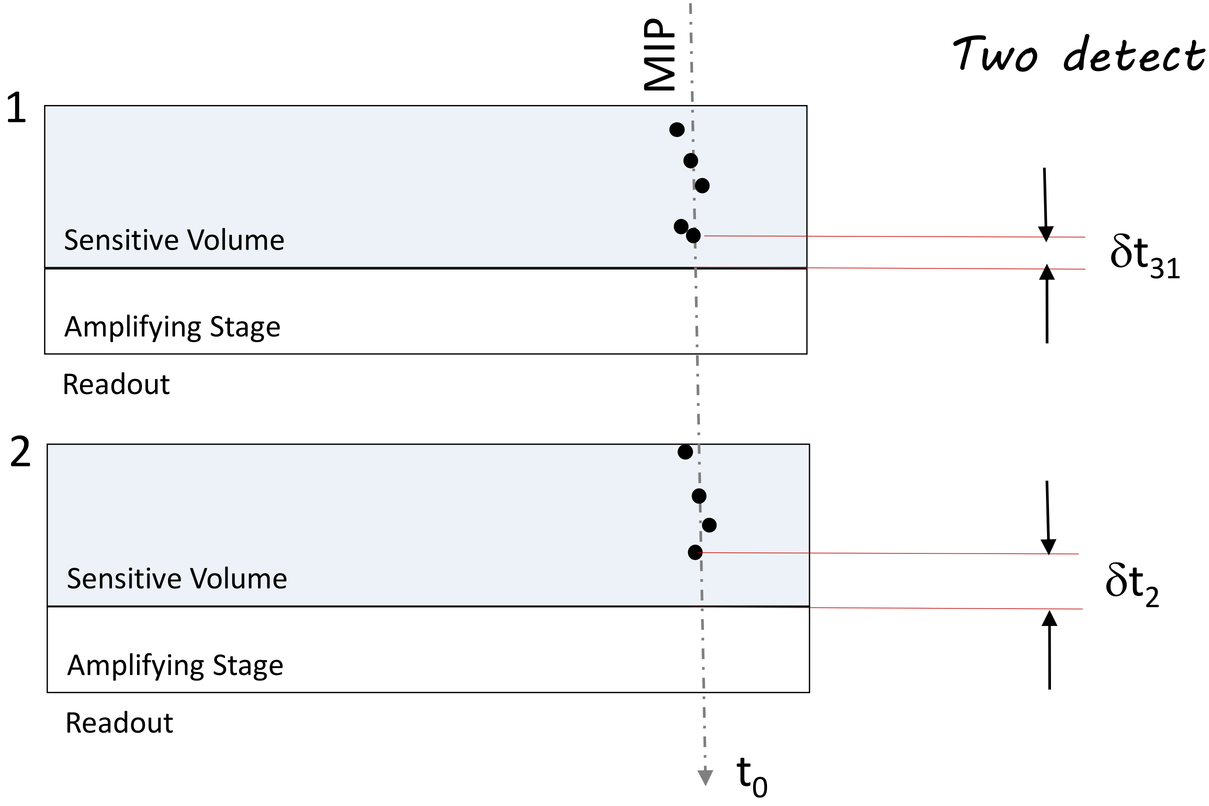
[h] RD51 collaboration, European Organization for Nuclear Research (CERN), CH-1211 Geneve 23, Switzerland
[i] Instituto Galego de Física de Altas Enerxías (IGFAE), Universidade de Santiago de Compostela, Spain

https://arxiv.org/pdf/1712.05256.pdf

Starting point··
The same as the one we saw before in LHCb... Direct Ionization of the gas as primary signal is not good...

Leading Edge of the signal... closest cluster to the amplification stage/readout



From Sauli Yellow Reports

PRINCIPLES OF OPERATION OF MULTIWIRE
PROPORTIONAL AND DRIFT CHAMBERS

https://cds.cern.ch/record/117989/files/CERN-77-09.pdf

F. Sauli 1977

2.8 Statistics of ion-pair production

Consider, in particular, the distribution of the pair closer to one end of the detection volume,

$$A_1^n(x) = n\,e^{-nx} \quad , \qquad (5)$$

which is represented in Fig. 8, for n = 34, as a function of the coordinate across a 10 mm thick detector. If the time of detection is the time of arrival of the closest electron at one end of the gap, as is often the case, the statistics of ion-pair production set an obvious limit to the time resolution of the detector. A scale of time is also given in the figure, for a collection velocity of 5 cm/μsec typical of many gases; the FWHM of the distribution is about 5 nsec.

FWHM ~ 5nsec

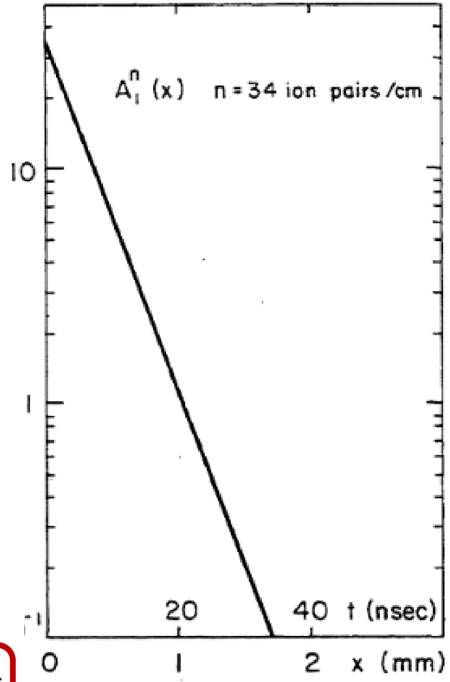


Fig. 8

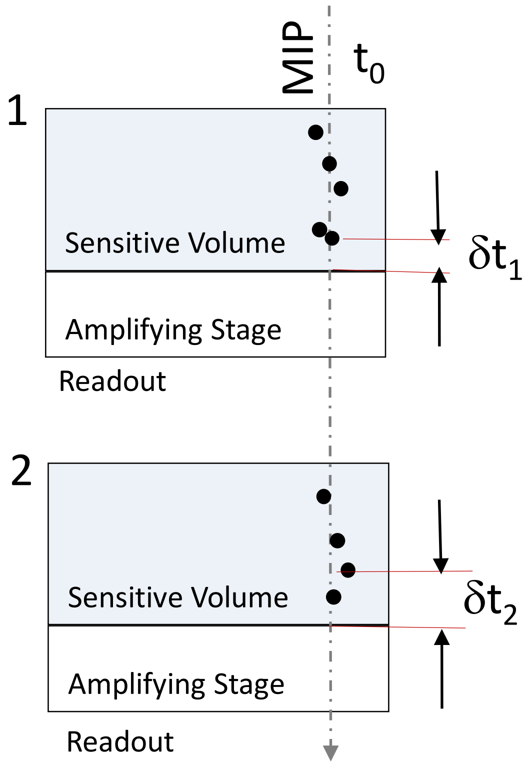
Statistics of primary ion pair production: probability of finding the closest pair at a distance x from one electrode in a counter, in argon-isobutane 70-30. The corresponding electron minimum collection time is shown, for a typical drift velocity of electrons of 5 cm/μsec.

Intrinsic Time Resolution

$$\sigma(t_d)=1/nv_d$$

There is no hope of improving this time resolution in a gas counter, unless some averaging over the time of arrival of all electrons is realized.

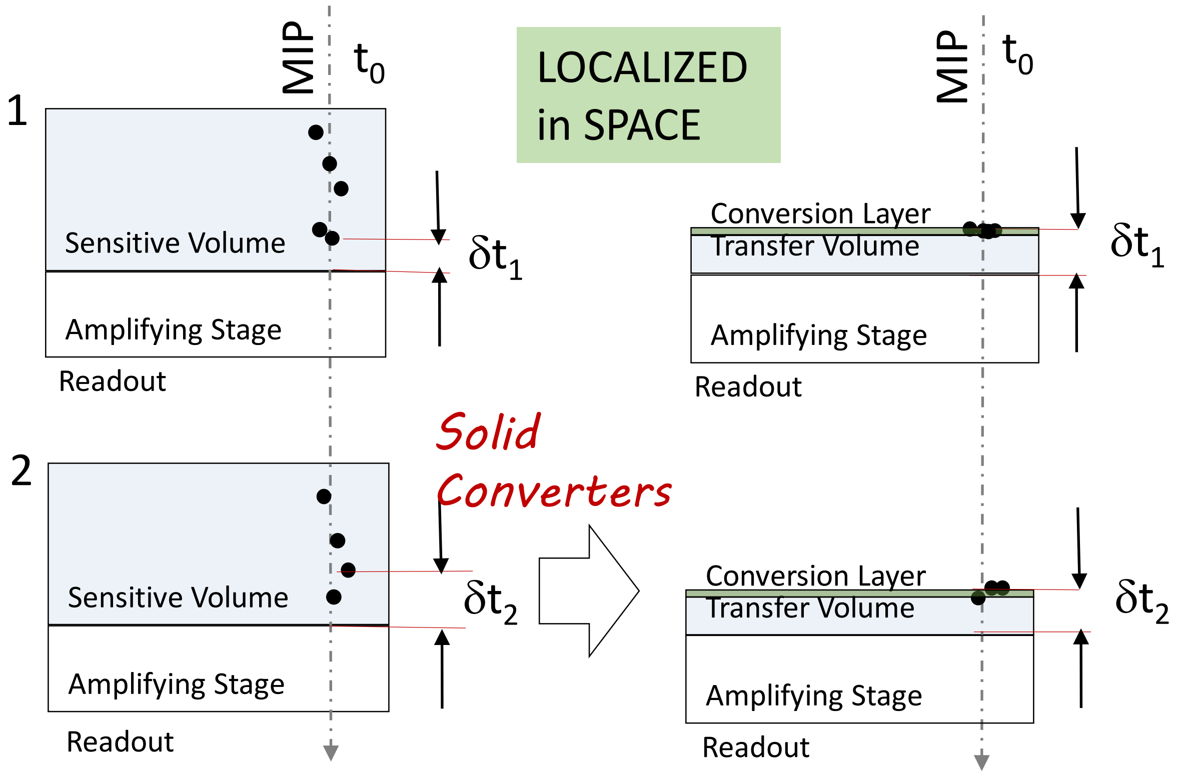
Starting point…
direct ionization of the gas



The main problem…
The distribution in space/time of the primary charge

It would be strongly improved if primaries would have been produced in a well define region

Solid Conversion Layer



LOCALIZED in SPACE

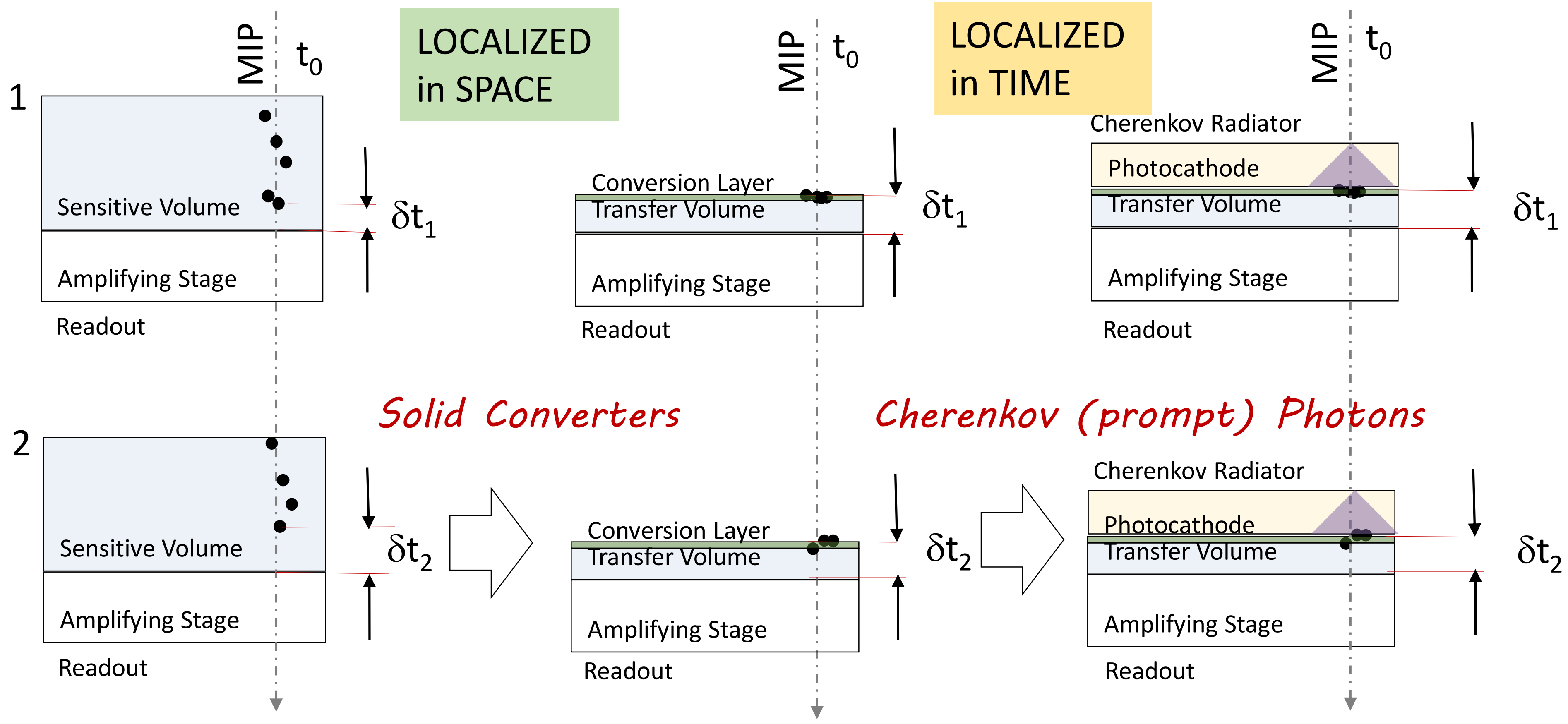
Solid Converters

Sensitive volume not needed anymore for primary ionization, actually to be reduced in order to:

- *Avoid direct gas ionization*
- *Reduce diffusion*

Due to the fact that the aim is to go to tens of ps, localization in space maybe not enough…

Prompt Cherenkov Radiator



LOCALIZED in SPACE

LOCALIZED in TIME

1

MIP t_0

Sensitive Volume

Amplifying Stage

Readout

δt_1

MIP t_0

Conversion Layer

Transfer Volume

Amplifying Stage

Readout

δt_1

MIP t_0

Cherenkov Radiator

Photocathode

Transfer Volume

Amplifying Stage

Readout

δt_1

Solid Converters

Cherenkov (prompt) Photons

2

Sensitive Volume

Amplifying Stage

Readout

δt_2

Conversion Layer

Transfer Volume

Amplifying Stage

Readout

δt_2

Cherenkov Radiator

Photocathode

Transfer Volume

Amplifying Stage

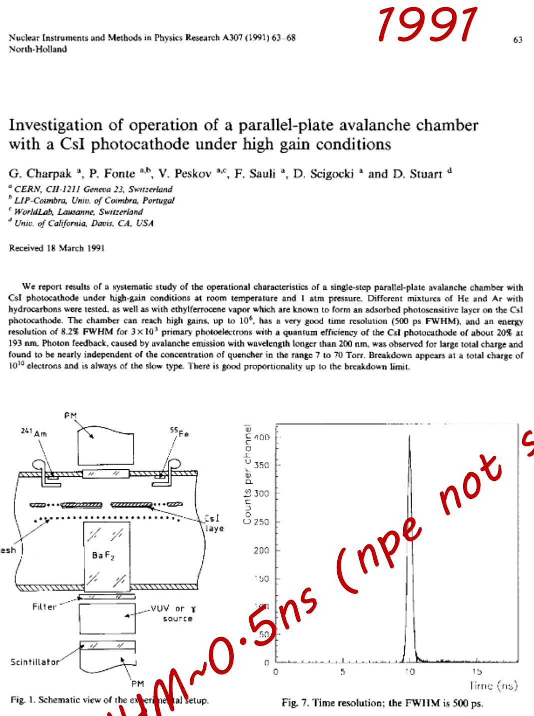
Readout

δt_2

Primary electrons at the same time in the same place

Sub-nanosecond time response

1991



Nuclear Instruments and Methods in Physics Research A307 (1991) 63–68
North-Holland
63

Investigation of operation of a parallel-plate avalanche chamber with a CsI photocathode under high gain conditions

G. Charpak [a], P. Fonte [a,b], V. Peskov [a,c], F. Sauli [a], D. Scigocki [a] and D. Stuart [d]

[a] *CERN, CH-1211 Geneva 23, Switzerland*
[b] *LIP-Coimbra, Univ. of Coimbra, Portugal*
[c] *WorldLab, Lausanne, Switzerland*
[d] *Univ. of California, Davis, CA, USA*

Received 18 March 1991

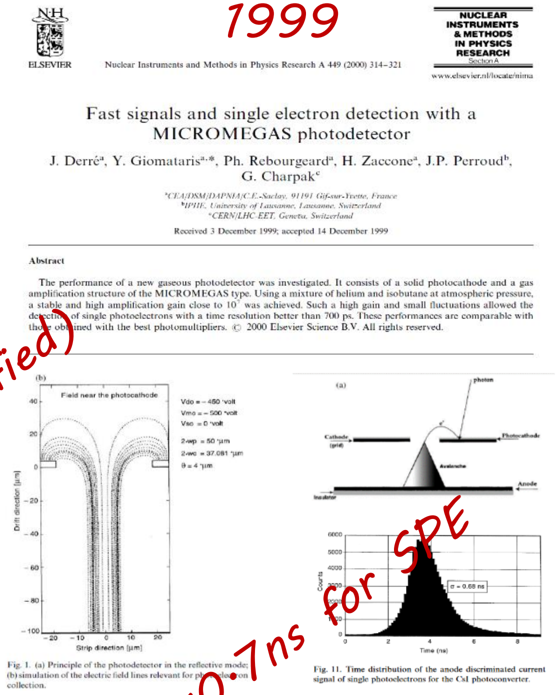
We report results of a systematic study of the operational characteristics of a single-step parallel-plate avalanche chamber with CsI photocathode under high-gain conditions at room temperature and 1 atm pressure. Different mixtures of He and Ar with hydrocarbons were tested, as well as with ethylferrocene vapor which are known to form an adsorbed photosensitive layer on the CsI photocathode. The chamber can reach high gains, up to 10^6, has a very good time resolution (500 ps FWHM), and an energy resolution of 8.2% FWHM for 3×10^3 primary photoelectrons with a quantum efficiency of the CsI photocathode of about 20% at 193 nm. Photon feedback, caused by avalanche emission with wavelength longer than 200 nm, was observed for large total charge and found to be nearly independent of the concentration of quencher in the range 7 to 70 Torr. Breakdown appears at a total charge of 10^{10} electrons and is always of the slow type. There is good proportionality up to the breakdown limit.

Fig. 1. Schematic view of the experimental setup.

Fig. 7. Time resolution; the FWHM is 500 ps.

pp, FWHM~0.5ns (npe not specified)

1999



ELSEVIER
Nuclear Instruments and Methods in Physics Research A 449 (2000) 314–321
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.nl/locate/nima

Fast signals and single electron detection with a MICROMEGAS photodetector

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[a] *CEA/DSM/DAPNIA/C.E.-Saclay, 91191 Gif-sur-Yvette, France*
[b] *IPHE, University of Lausanne, Lausanne, Switzerland*
[c] *CERN/LHC-EET, Geneva, Switzerland*

Received 3 December 1999; accepted 14 December 1999

Abstract

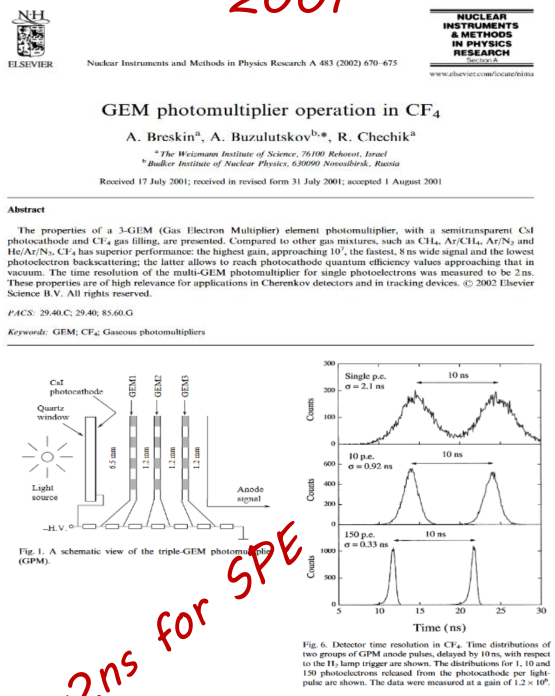
The performance of a new gaseous photodetector was investigated. It consists of a solid photocathode and a gas amplification structure of the MICROMEGAS type. Using a mixture of helium and isobutane at atmospheric pressure, a stable and high amplification gain close to 10^7 was achieved. Such a high gain and small fluctuations allowed the detection of single photoelectrons with a time resolution better than 700 ps. These performances are comparable with those obtained with the best photomultipliers. © 2000 Elsevier Science B.V. All rights reserved.

Fig. 1. (a) Principle of the photodetector in the reflective mode; (b) simulation of the electric field lines relevant for photoelectron collection.

Fig. 11. Time distribution of the anode discriminated current signal of single photoelectrons for the CsI photoconverter.

mm, σ<0.7ns for SPE

2001



ELSEVIER
Nuclear Instruments and Methods in Physics Research A 483 (2002) 670–675
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

GEM photomultiplier operation in CF_4

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[a] *The Weizmann Institute of Science, 76100 Rehovot, Israel*
[b] *Budker Institute of Nuclear Physics, 630090 Novosibirsk, Russia*

Received 17 July 2001; received in revised form 31 July 2001; accepted 1 August 2001

Abstract

The properties of a 3-GEM (Gas Electron Multiplier) element photomultiplier, with a semitransparent CsI photocathode and CF_4 gas filling, are presented. Compared to other gas mixtures, such as CH_4, Ar/CH_4, Ar/N_2 and $He/Ar/N_2$, CF_4 has superior performance: the highest gain, approaching 10^7, the fastest, 8 ns wide signal and the lowest photoelectron backscattering; the latter allows to reach photocathode quantum efficiency values approaching that in vacuum. The time resolution of the multi-GEM photomultiplier for single photoelectrons was measured to be 2 ns. These properties are of high relevance for applications in Cherenkov detectors and in tracking devices. © 2002 Elsevier Science B.V. All rights reserved.

PACS: 29.40.C; 29.40; 85.60.G

Keywords: GEM; CF_4; Gaseous photomultipliers

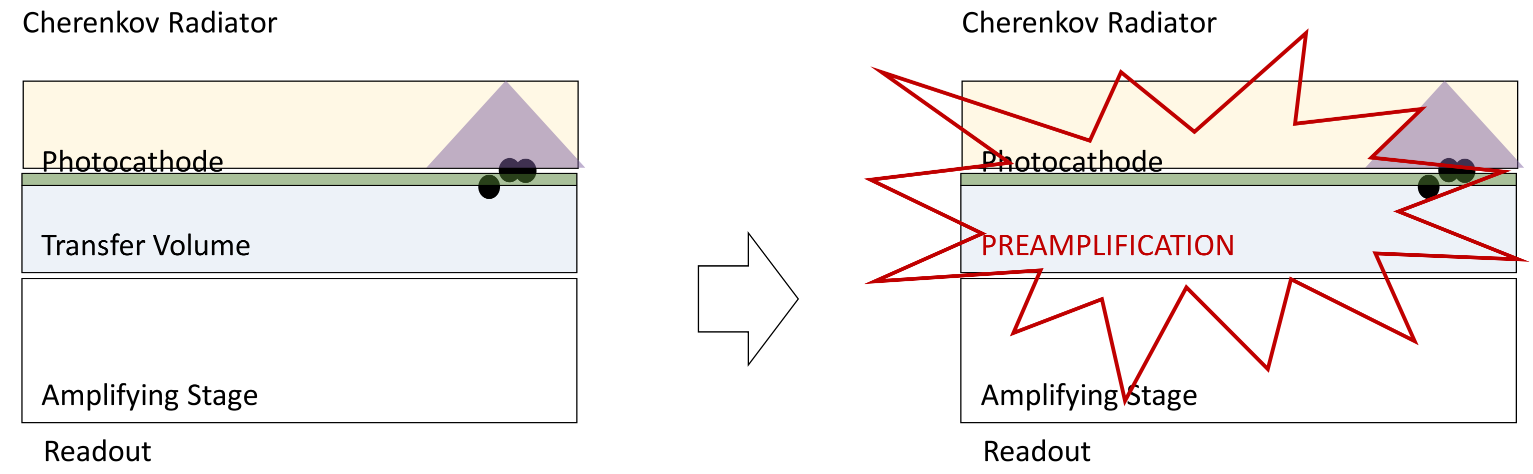
Fig. 1. A schematic view of the triple-GEM photomultiplier (GPM).

Fig. 6. Detector time resolution in CF_4. Time distributions of two groups of GPM anode pulses, delayed by 10 ns, with respect to the H_2 lamp trigger are shown. The distributions for 1, 10 and 150 photoelectrons released from the photocathode per light-pulse are shown. The data were measured at a gain of 1.2×10^6.

GEM, σ~2ns for SPE

.. But we want to go down to tens of ps...

Pre-amplification in the first transfer.. The last step toward the results shown before

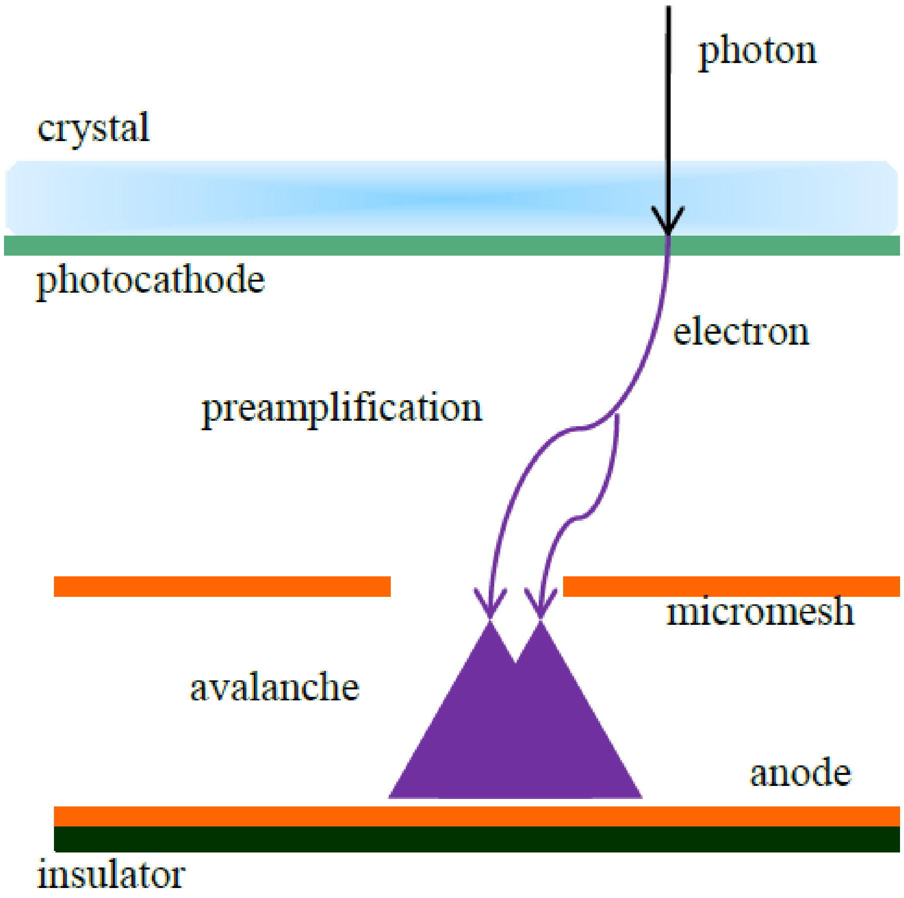


Sensitive volume reduced in order to:

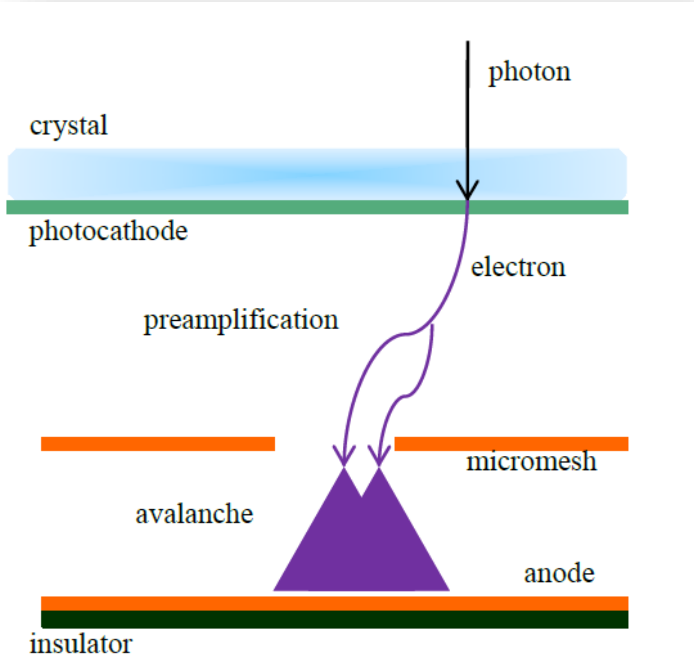
- Avoid direct gas ionization
- Reduce diffusion

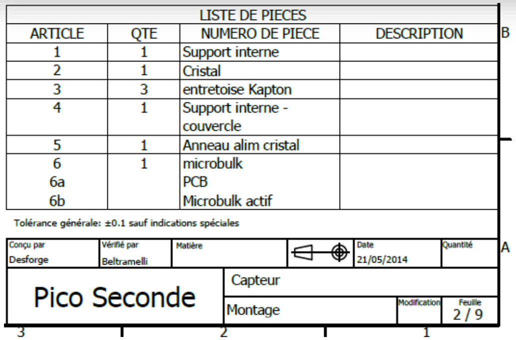
Pre-amplification: direct gas ionization and diffusion effect even more reduced, initial differences of pe levelled in the avalanche processes

PICOSEC, detector concept



First prototype (1cm Diameter)

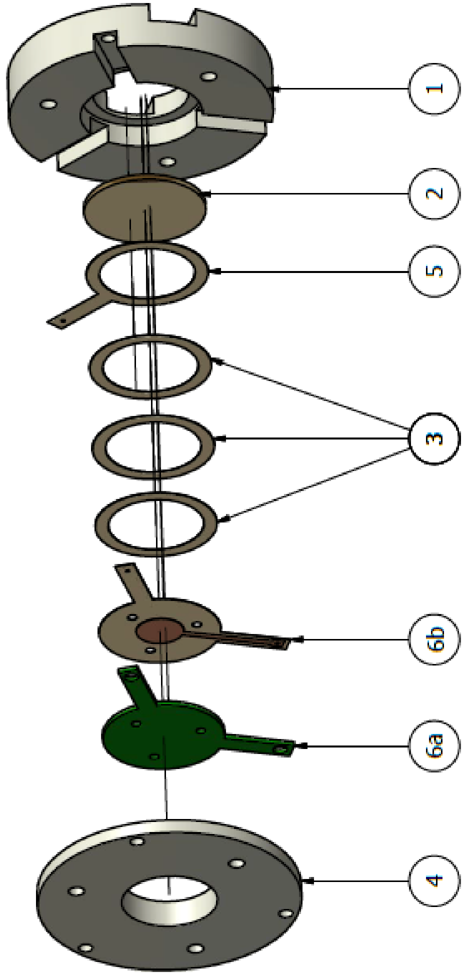




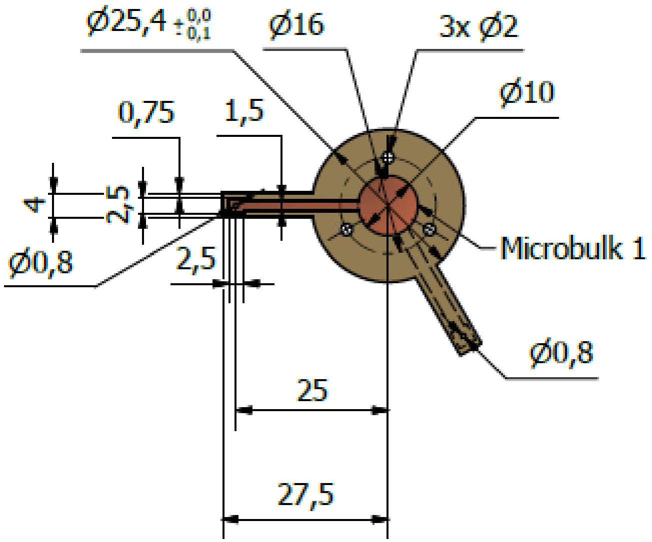
LISTE DE PIECES			
ARTICLE	QTE	NUMERO DE PIECE	DESCRIPTION
1	1	Support interne	
2	1	Cristal	
3	3	entretoise Kapton	
4	1	Support interne - couvercle	
5	1	Anneau alim cristal	
6 6a 6b	1	microbulk PCB Microbulk actif	

Tolérance générale: ±0.1 sauf indications spéciales

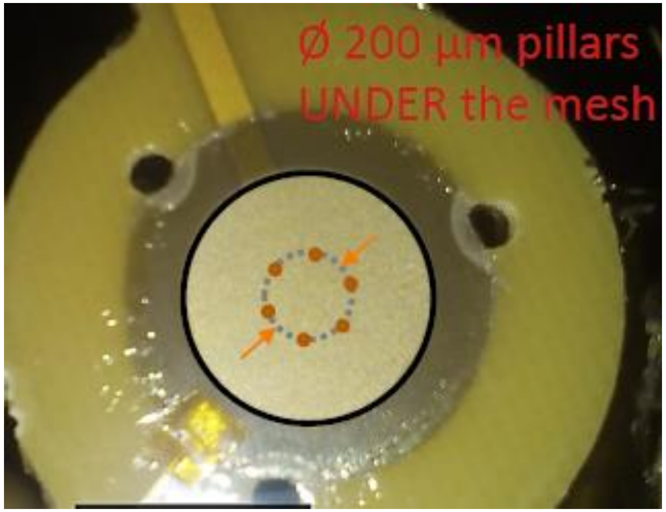
Conçu par Desforge	Vérifié par Beltramelli	Matière		Date 21/05/2014	Quantité
Pico Seconde		Capteur			
		Montage		Modification	Feuille 2 / 9

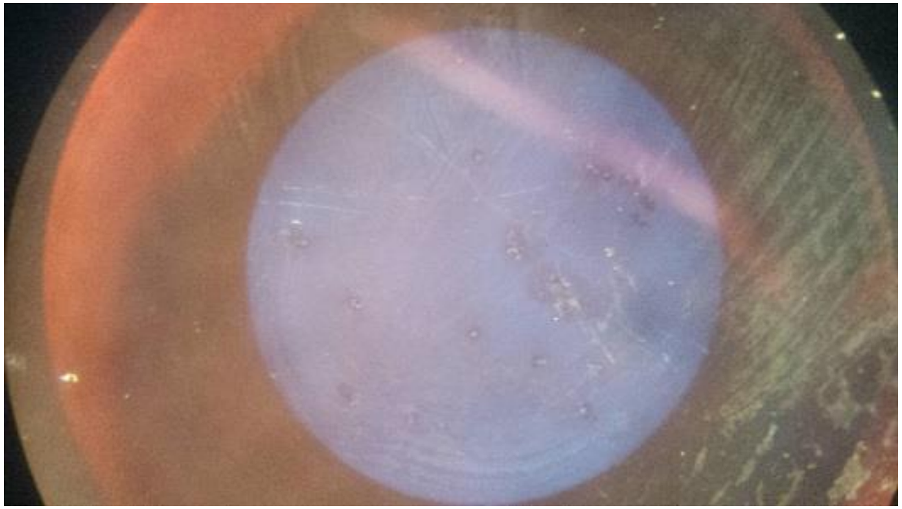


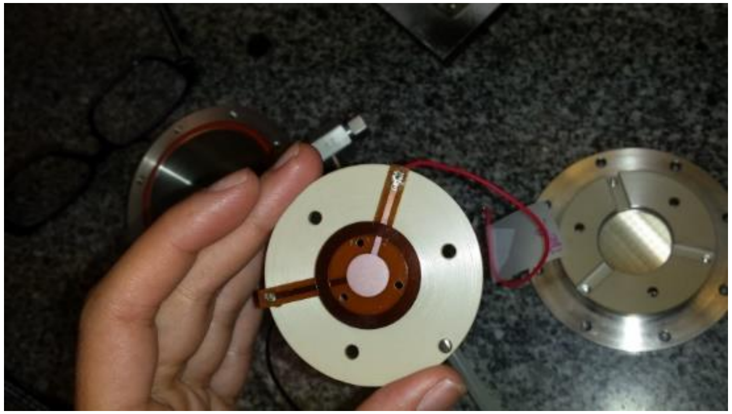
Montage Pico Seconde
Dossier de plans, Saclay

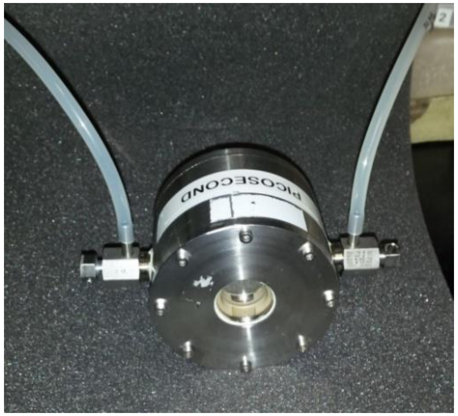


First prototype (1cm Diameter)







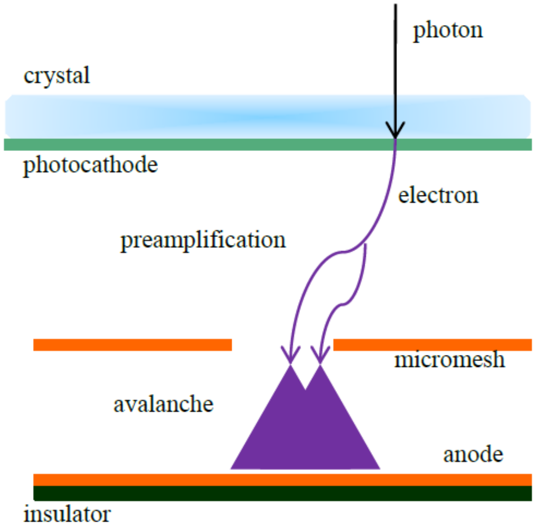


As a detector: pretty small
As a readout channel: pretty large

• What to measure?

- Single Photo Electron (SPE) response
  - response of the detector once the PE is released in the gas

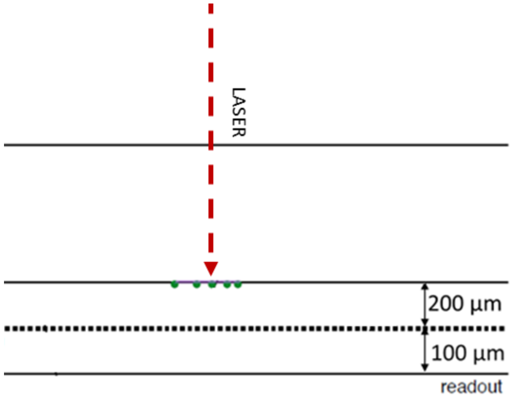
- MIP response
  - SPE response + PE production (radiator, photocathode, extraction in gas)



- **Laser**

  IRAMIS facility @ CEA Saclay

  UV laser with σ_t << 100 fs

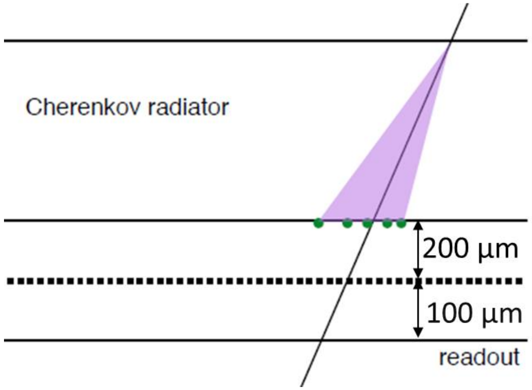


You forget about radiator and photo conversion.
Just focused on n_{phe} , no matter how they are produced..
Main interest on n_{phe} =1

- **Muon Beam**

  H4 North Area SPS Extraction Line

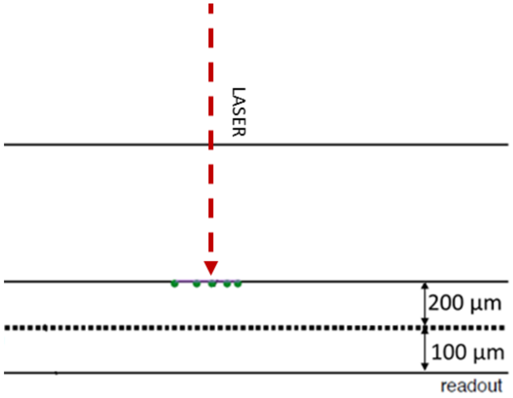
  150 GeV muons

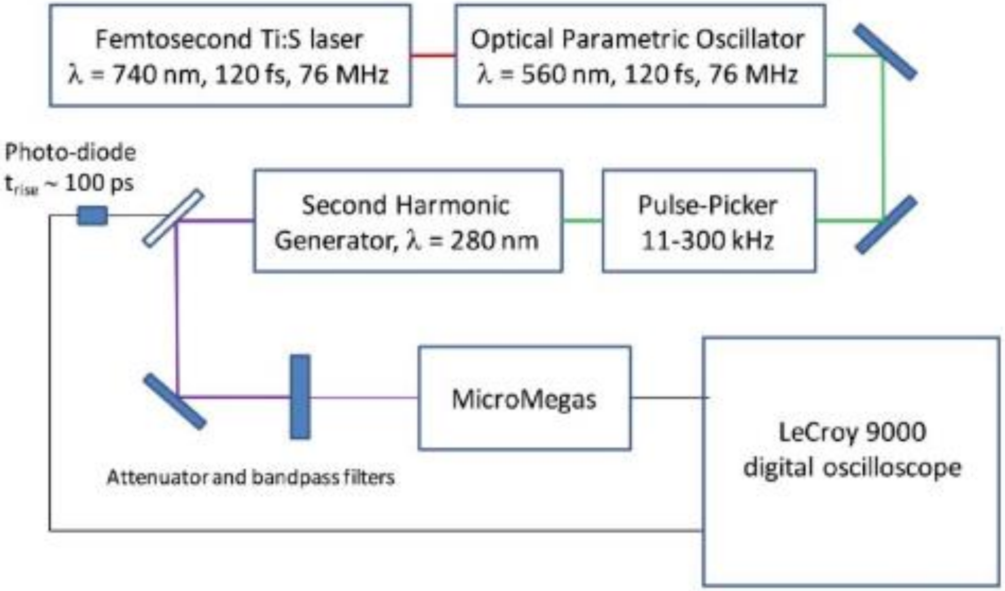


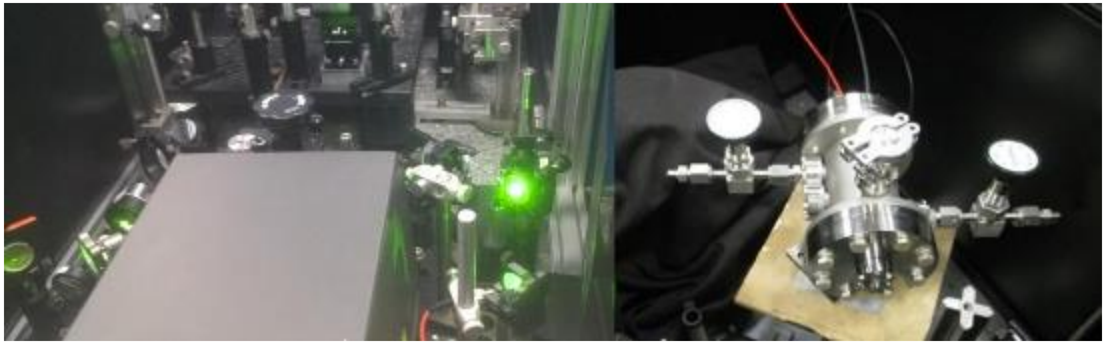
Cherenkov **production, transmission, conversion and pe extraction** in the business

Measurements - Single PE - Laser

IRAMIS facility @ CEA Saclay







First set of Laser Data (2015)

LIDyL laboratory (CEA/Saclay).

Ti:sapphire laser (Coherent MIRA 900) 120 fs pulses at 550 nm.

Ne-C2H6, 90-10

Al Cathode

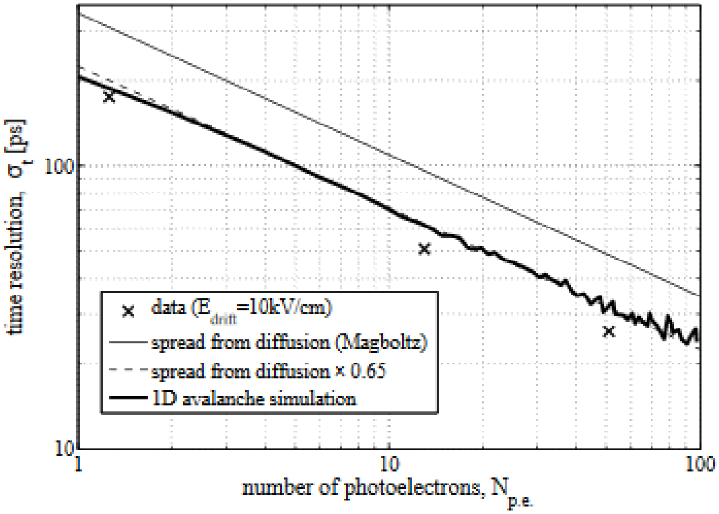


Figure 8. Dependence of the measured time resolution with the mean number of photoelectrons, for fixed amplification and drift fields. A resolution of 200 ps per single photoelectron and 27 ps for 50 photoelectrons has been achieved.

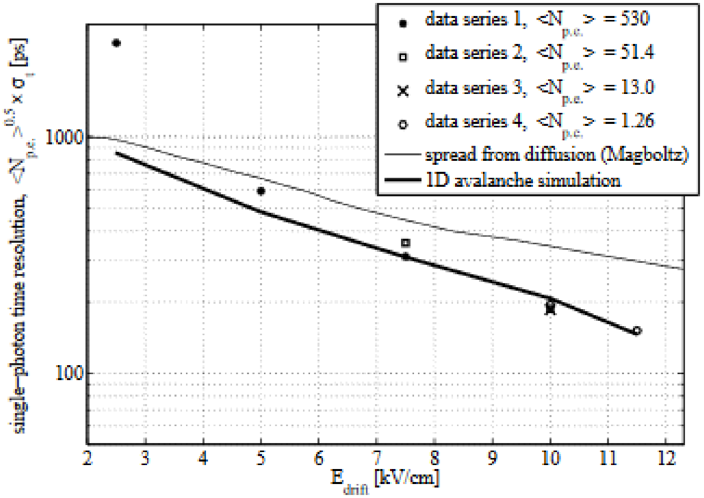


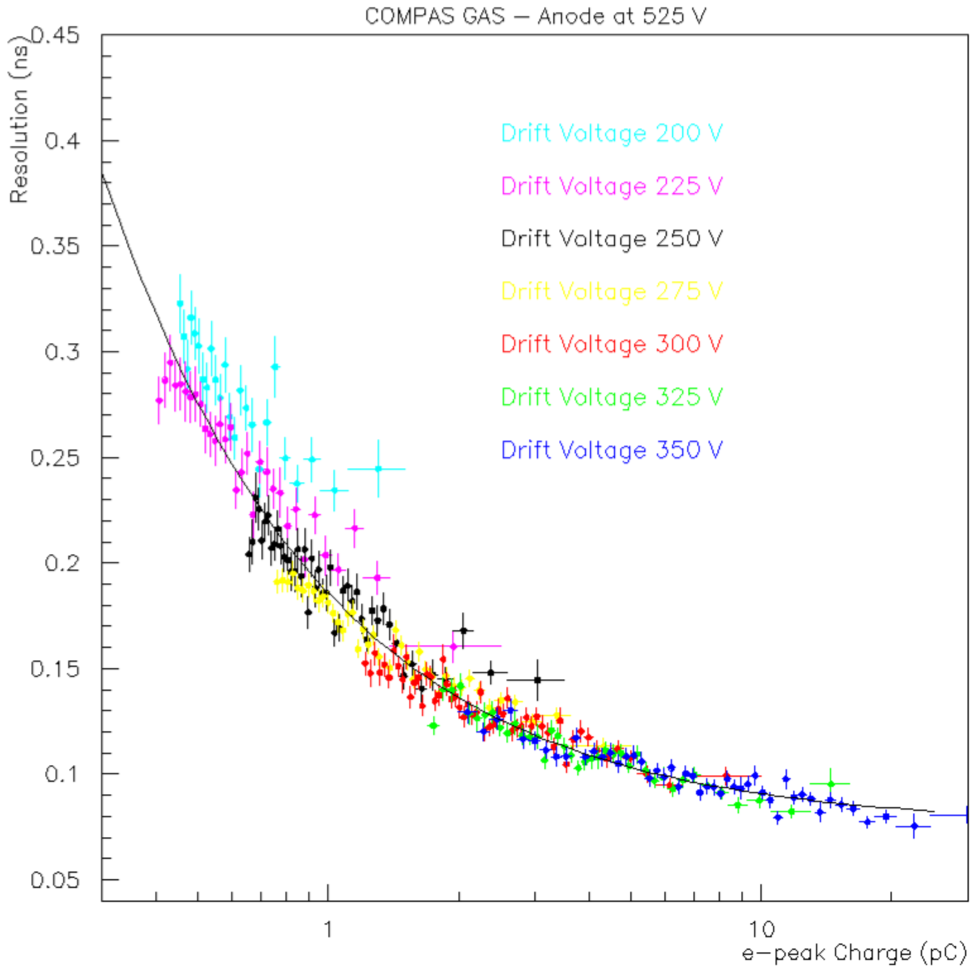
Figure 7. Dependence of the measured time resolution with the drift field, scaled to the single photoelectron case. The difference between the thin and thick lines indicates the improvement due to pre-amplification, according to a stochastic 1D avalanche model.

T. Papaevangelou et al. Fast Timing for High-Rate Environments with Micromegas, MPGD 2015 & RD51 Collaboration meeting, 12-17 October 2015 Trieste, Italy

https://agenda.infn.it/contributionDisplay.py?contribId=83&confId=8839

https://agenda.infn.it/getFile.py/access?contribId=83&sessionId=2&resId=0&materialId=paper&confId=8839

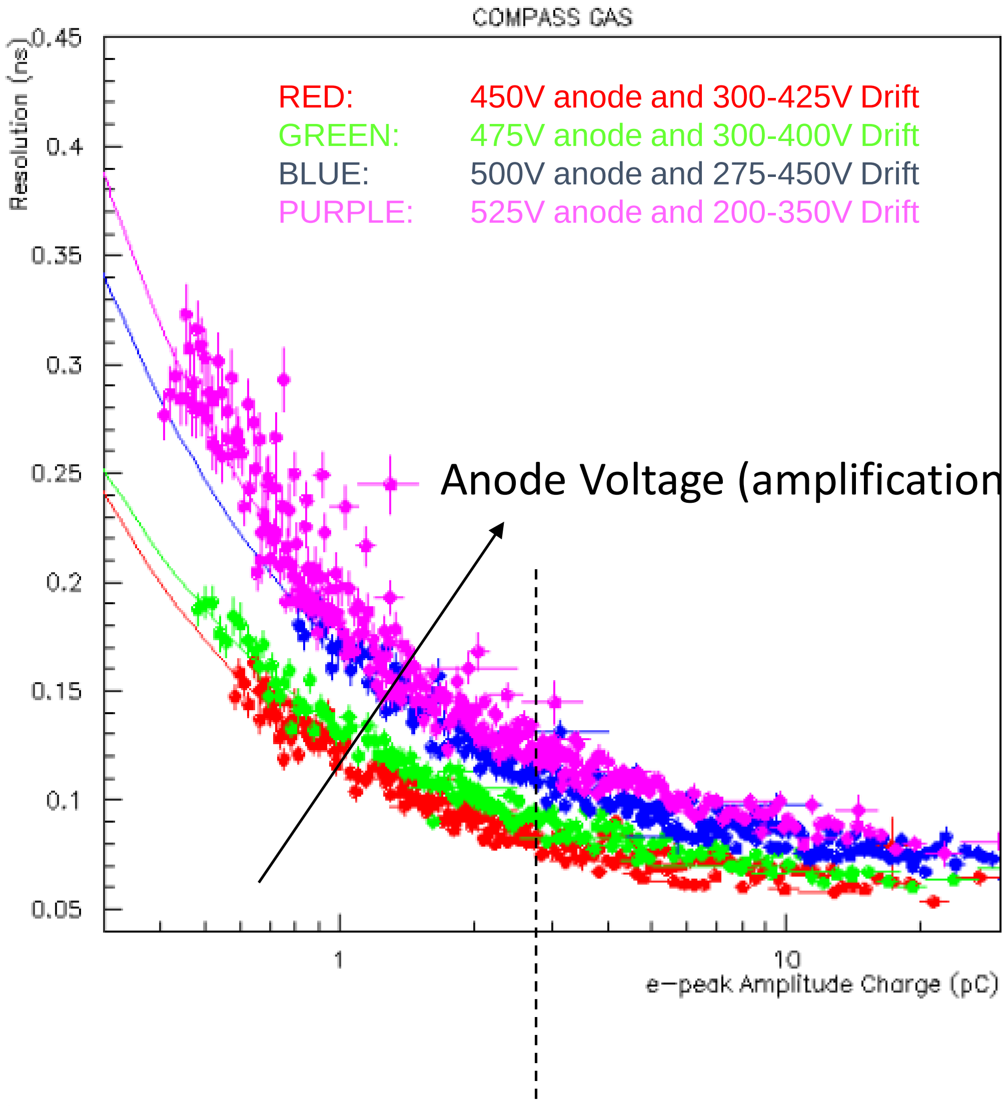
Laser Test (2017) - SPE



Single-Photoelectron Time Resolution

I. Manthos

Laser Test (2017) - SPE



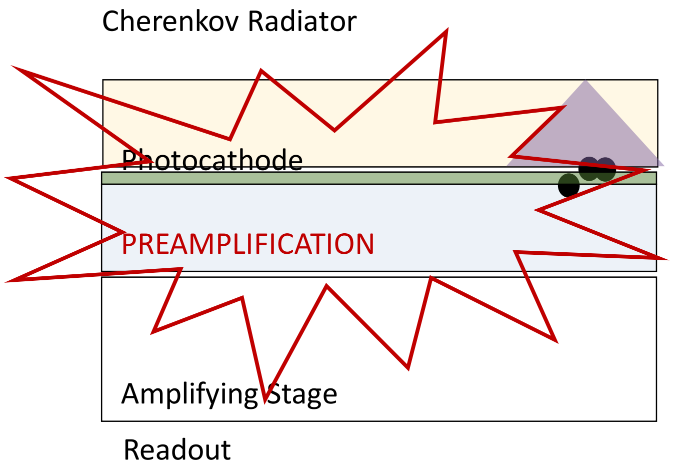
I. Manthos

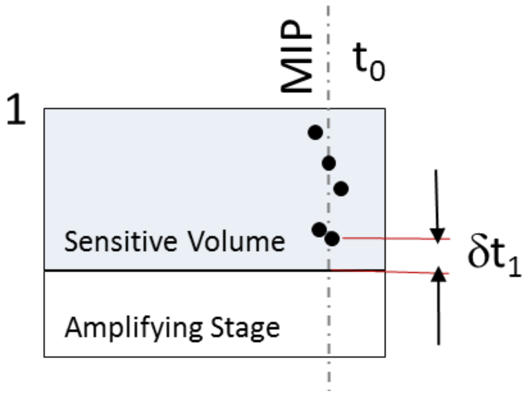
Single-Photoelectron Time Resolution

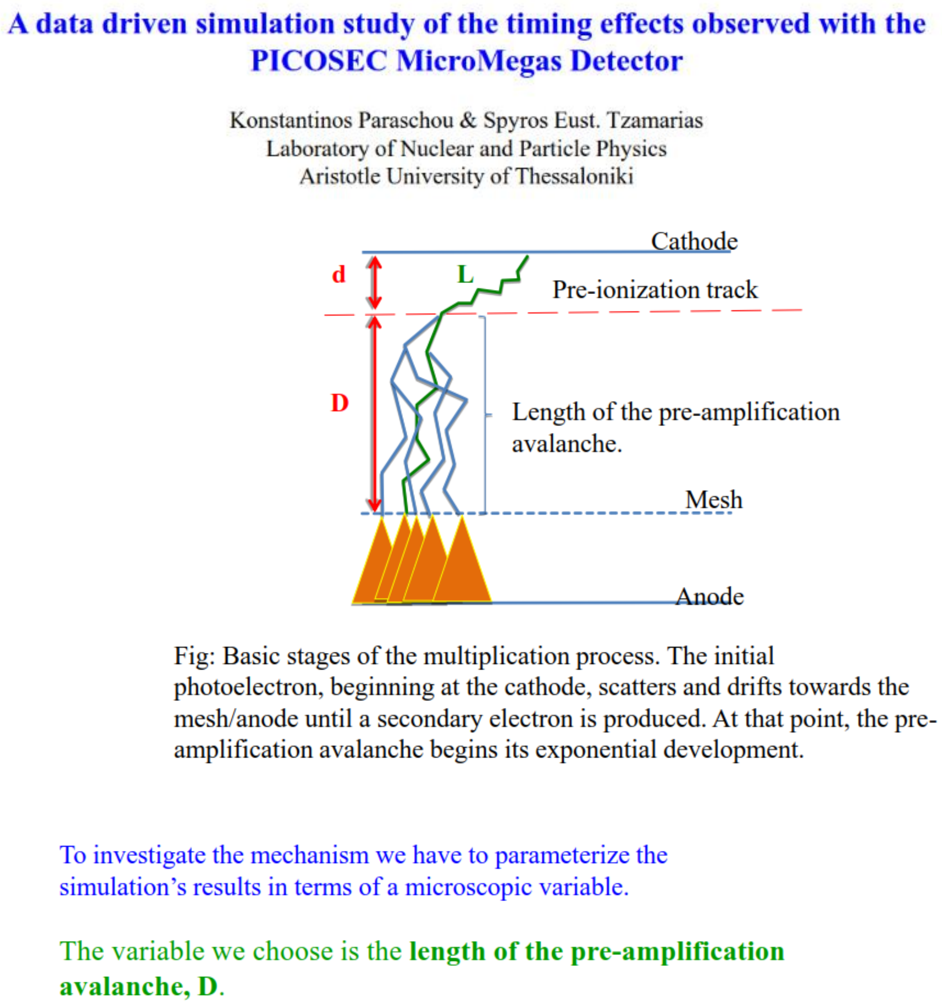
Given the same e-peak Amplitude Charge,
Higher Anode Voltage (higher Amplification - lower Pre-amplification) has a worse energy resolution

The pre-amplification drives the time resolution

Modelling… crucial







A data driven simulation study of the timing effects observed with the PICOSEC MicroMegas Detector

Konstantinos Paraschou & Spyros Eust. Tzamarias
Laboratory of Nuclear and Particle Physics
Aristotle University of Thessaloniki

Fig: Basic stages of the multiplication process. The initial photoelectron, beginning at the cathode, scatters and drifts towards the mesh/anode until a secondary electron is produced. At that point, the pre-amplification avalanche begins its exponential development.

To investigate the mechanism we have to parameterize the simulation's results in terms of a microscopic variable.

The variable we choose is the **length of the pre-amplification avalanche, D**.

https://indico.cern.ch/event/676702/contributions/2809871/attachments/1574857/2486512/Konstantinos_RD51_miniweek.pdf

MIP response…
Test beam measurement setup

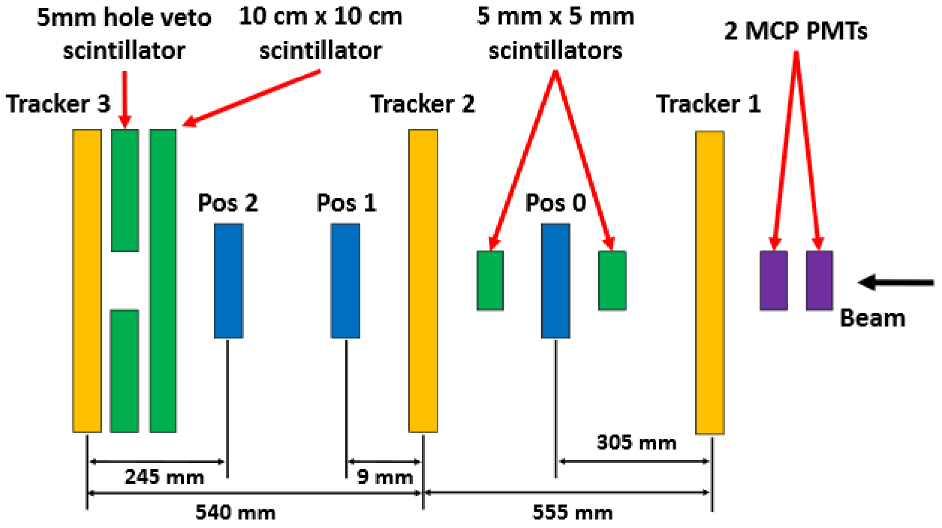
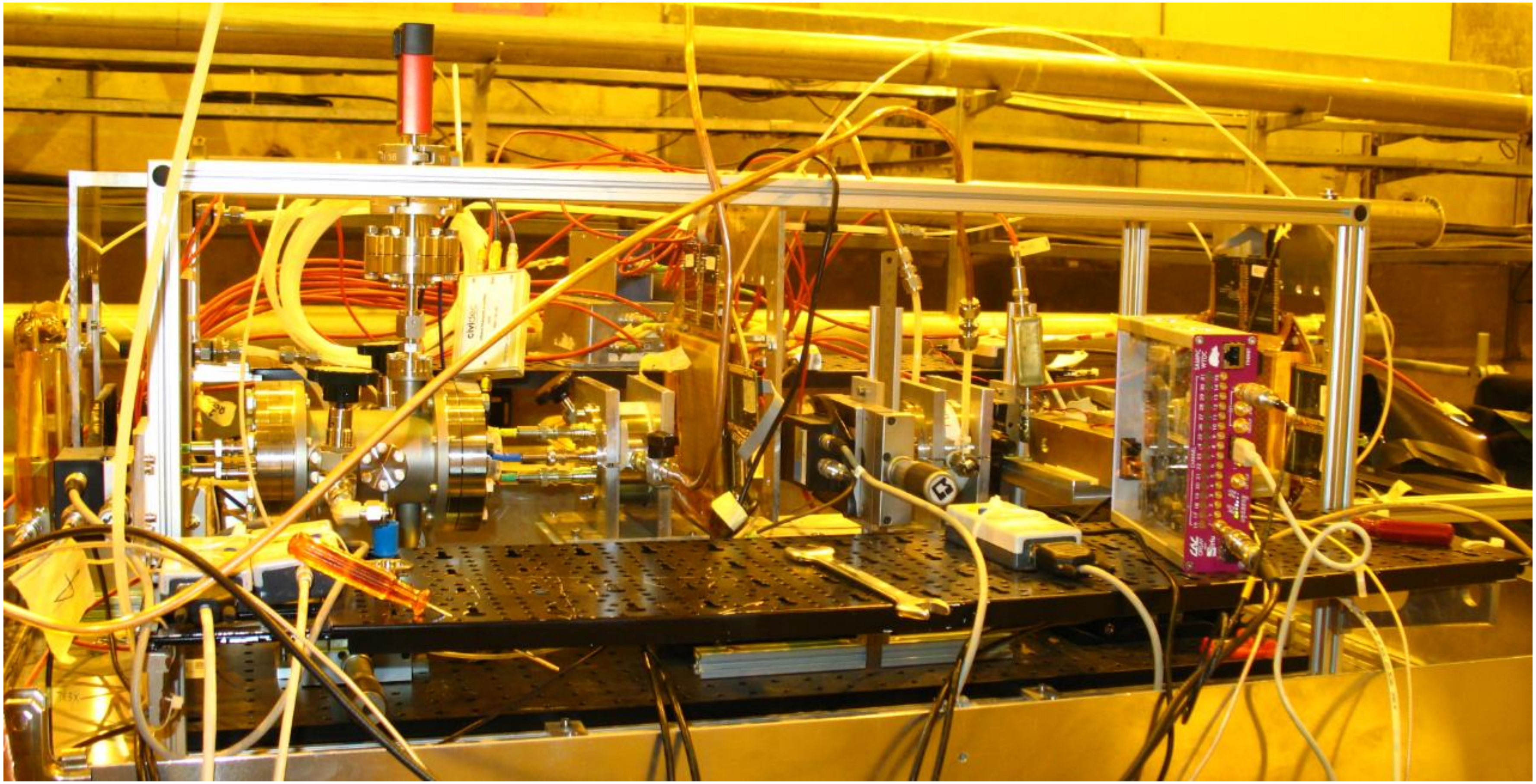


Figure 6: Layout of the experimental setup (not to scale) during the beam tests. The incoming beam enters from the right side of the figure; events are triggered by the coincidence of two $5 \times 5\,\mathrm{mm}^2$ scintillators in anti-coincidence with a "veto" scintillator. Three GEM detectors provide tracking information of the incoming charged particles, and the timing information is measured in three PICOSEC detectors (Pos0, Pos1, Pos2). Details are given in the text.

https://arxiv.org/pdf/1712.05256.pdf

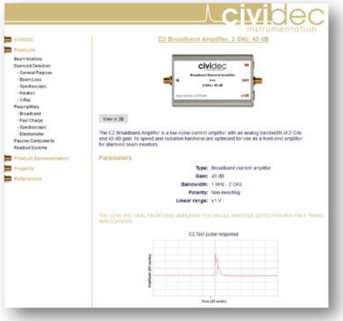
Test beam measurement setup



Test beam measurement setup

DATA ACQUISITION:

CIVIDEC C2 Broadband Amplifier, 2GHz, 40dB + 20Gs/s-2.5GHz Oscilloscope



cividec
Instrumentation

- CIVIDEC
- Products
  - Beam Monitors
  - Diamond Detectors
    - General Purpose
    - Beam Loss
    - Spectroscopic
    - Neutron
    - X-Ray
  - Preamplifiers
    - Broadband
    - Fast Charge
    - Spectroscopic
    - Electrometer
  - Passive Components
  - Readout Systems
- Product Demonstration
- Projects
- References

C2 Broadband Amplifier, 2 GHz, 40 dB

View in 3D

The C2 Broadband Amplifier is a low-noise current amplifier with an analog bandwidth of 2 GHz and 40 dB gain. Its speed and radiation hardness are optimized for use as a front-end amplifier for diamond beam monitors.

Parameters

Type: Broadband current amplifier
Gain: 40 dB
Bandwidth: 1 MHz - 2 GHz
Polarity: Non-inverting
Linear range: ±1 V

THE C2 IS THE IDEAL FRONT-END AMPLIFIER FOR SINGLE PARTICLE DETECTION AND FAST TIMING APPLICATIONS.

C2 fast pulse response

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: MCP-PMT (<6ps time resolution measured on beam)

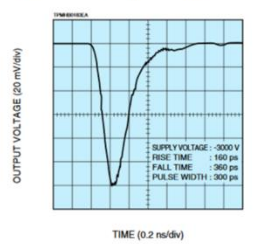
HAMAMATSU
PHOTON IS OUR BUSINESS

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

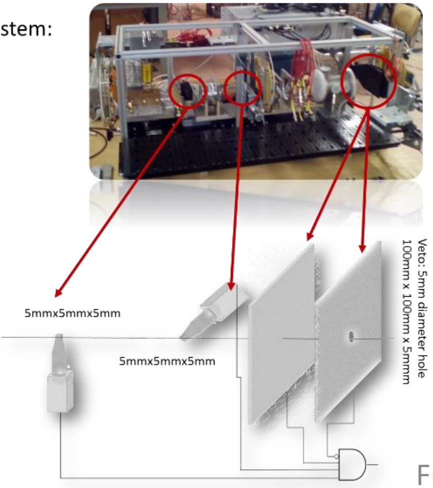


TRIGGERING: Scintillators

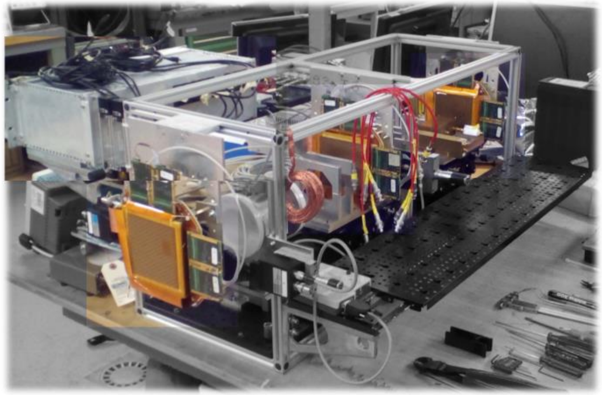
Triggering Scintillators System:

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

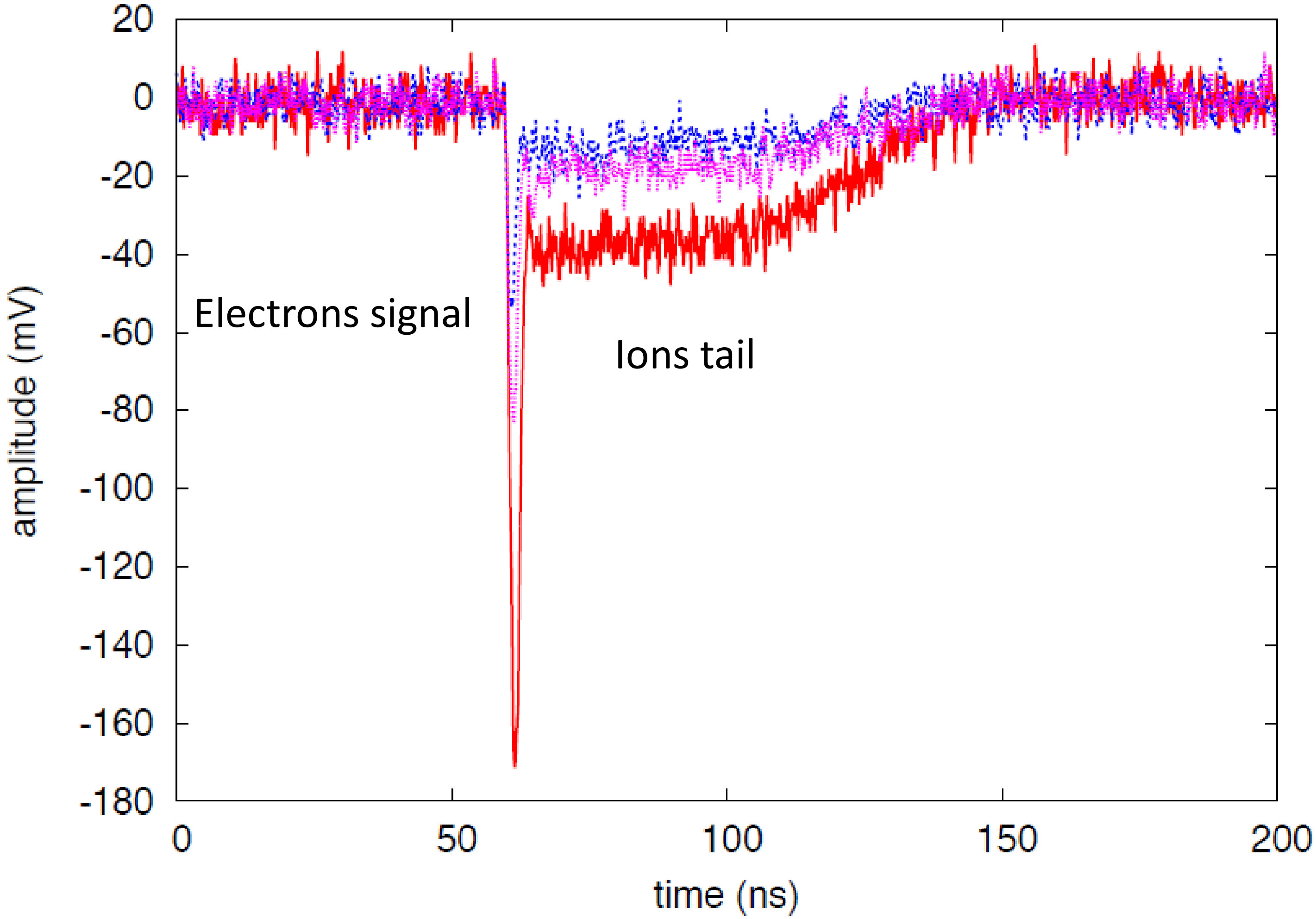


TRACKING: Triple GEM (50um resolution)

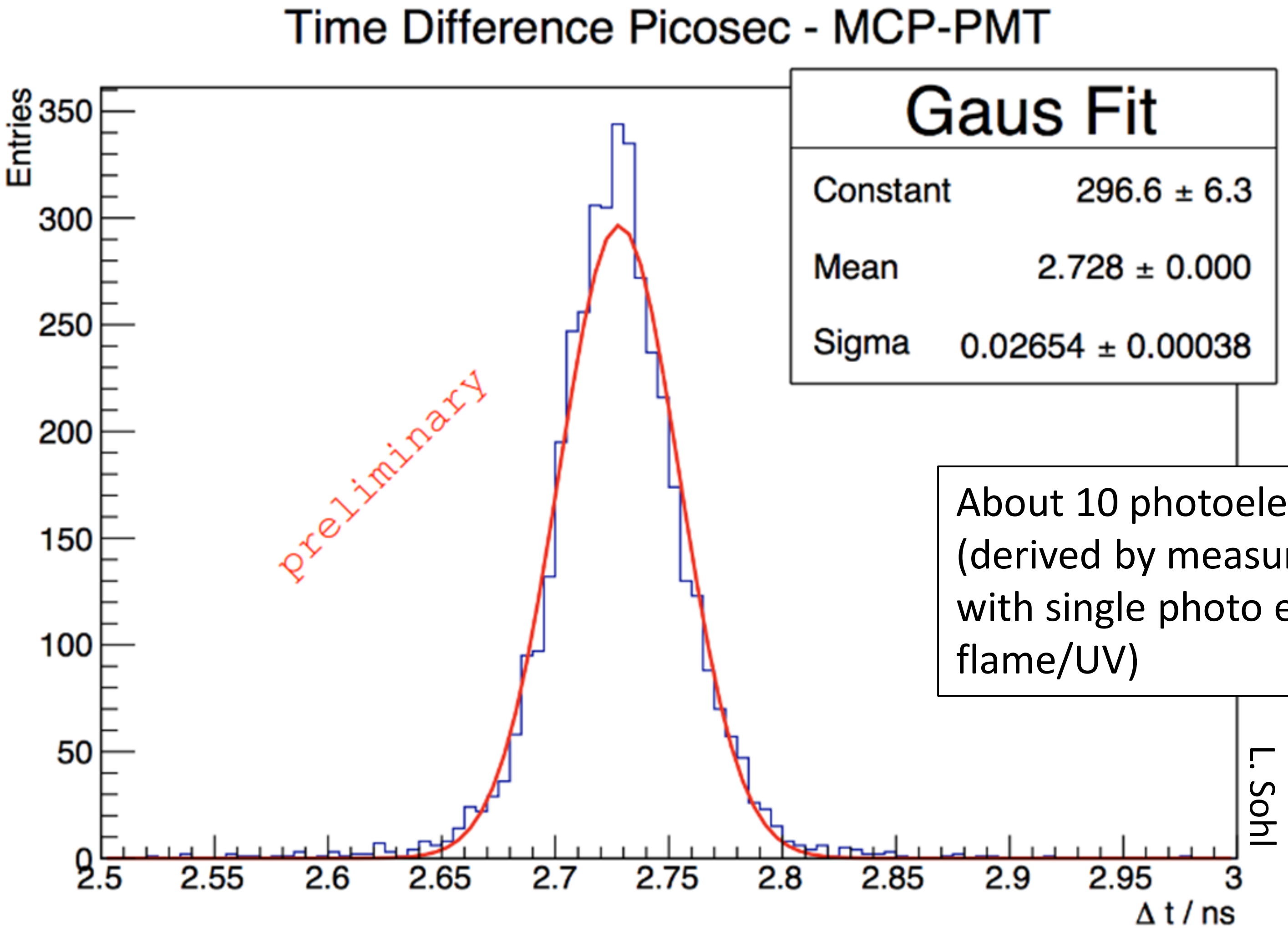


Three Triple GEM, XY readout, 400um pitch

Measurement - MIP(muons)



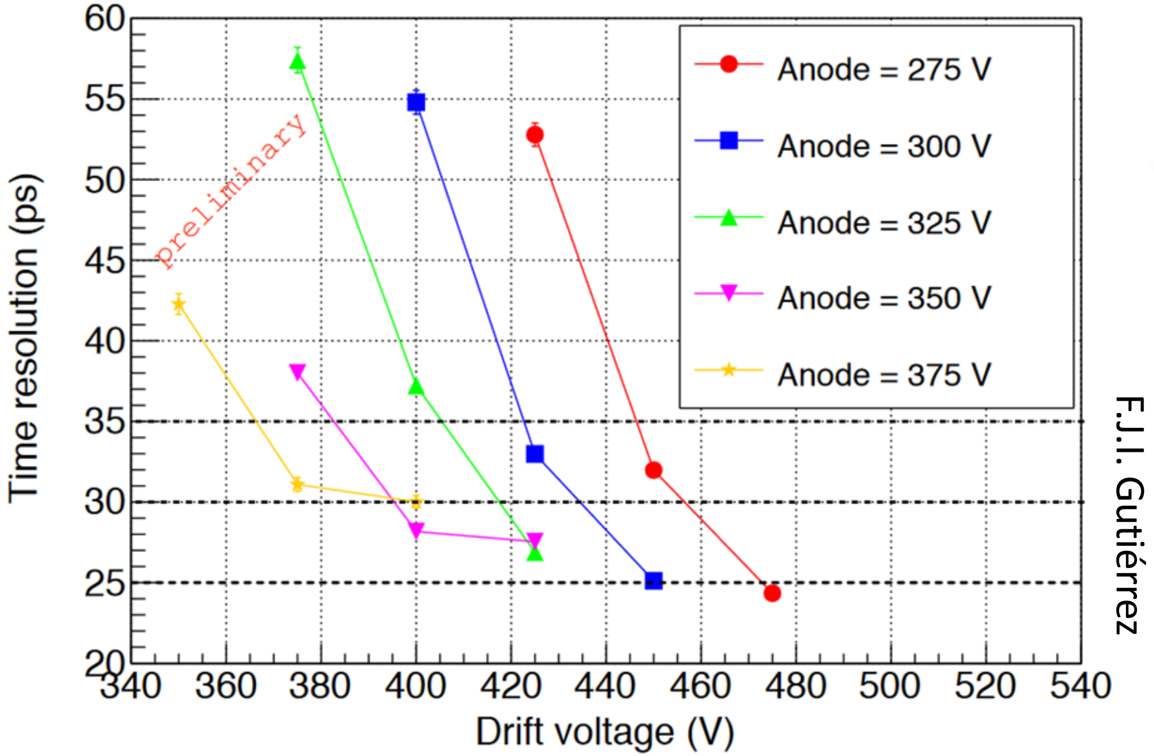
One of the best results achieved among the run analyzed…

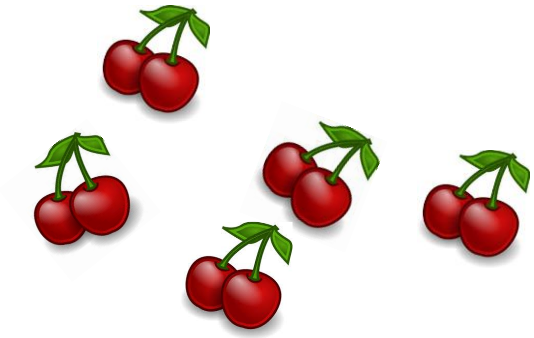


About 10 photoelectrons (derived by measurements with single photo electron flame/UV)

New Bulk MM readout
3 mm MgF2 + 5.5nmCr + 18nm CsI
Drift = -425V, Anode=+325V

Cherry picking… but we are not in front of a single cherry….





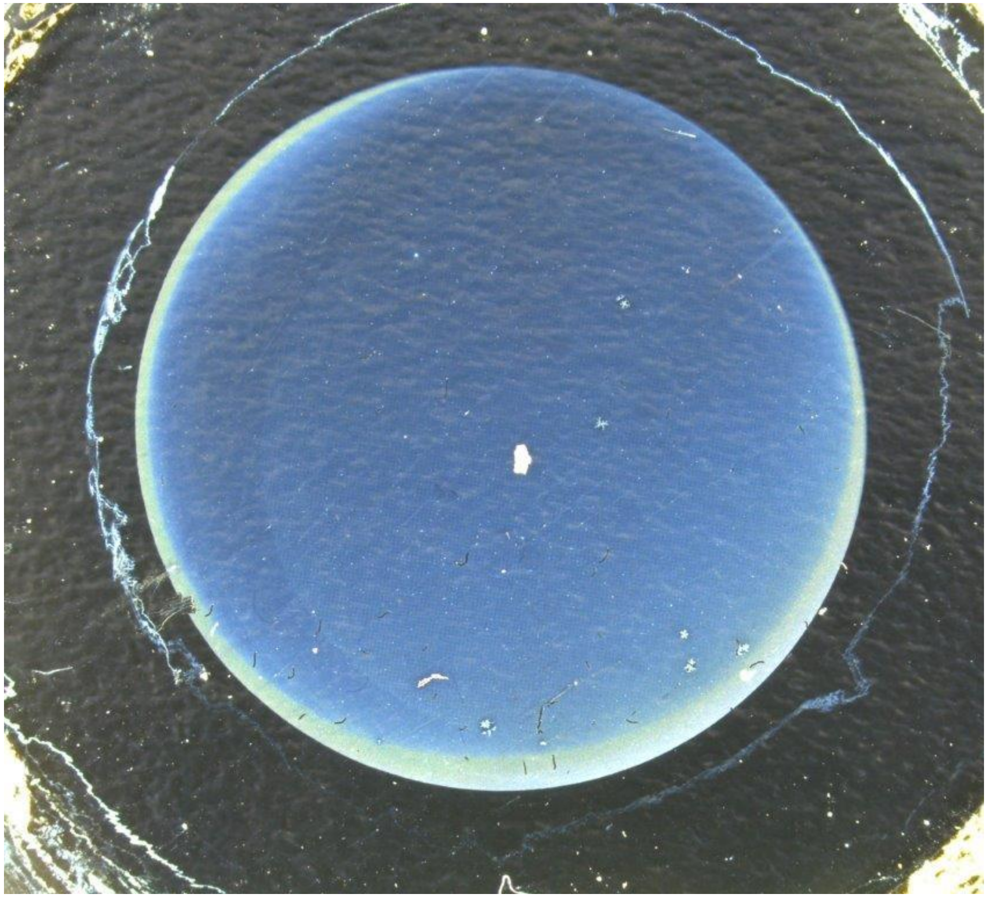
many Data still to be analysed …

New Bulk MM readout
3 mm MgF2 + 5.5nmCr + 18nm CsI

Among several future activities (resistive, multi-pad and larger, electronics… see backup) probably the most exiting and difficult R&D is the photocathode

Longevity (photocathode, CsI)

(not necessary a serious problem in all the possible application requiring fast timing but to be addressed clearly in the high rate ones)

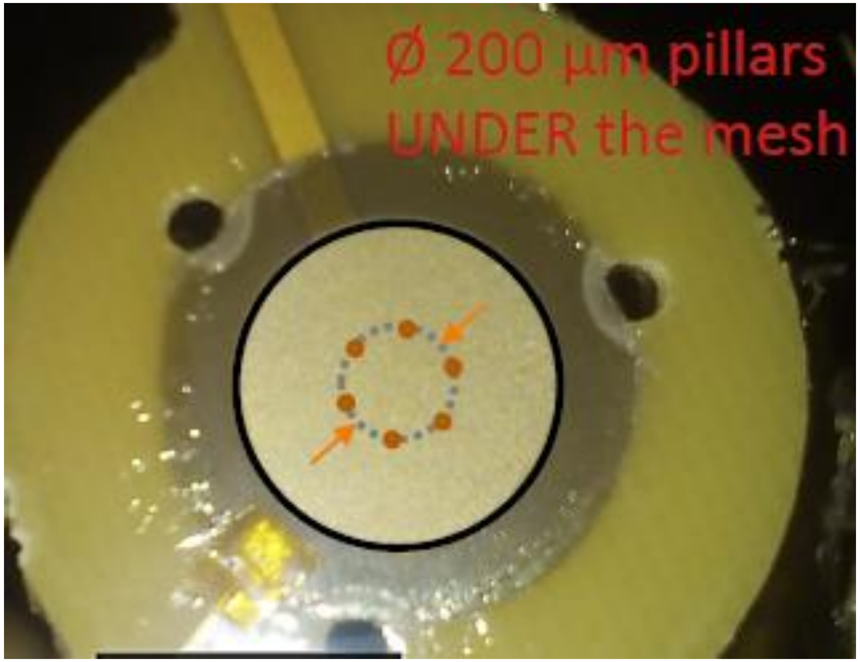


:

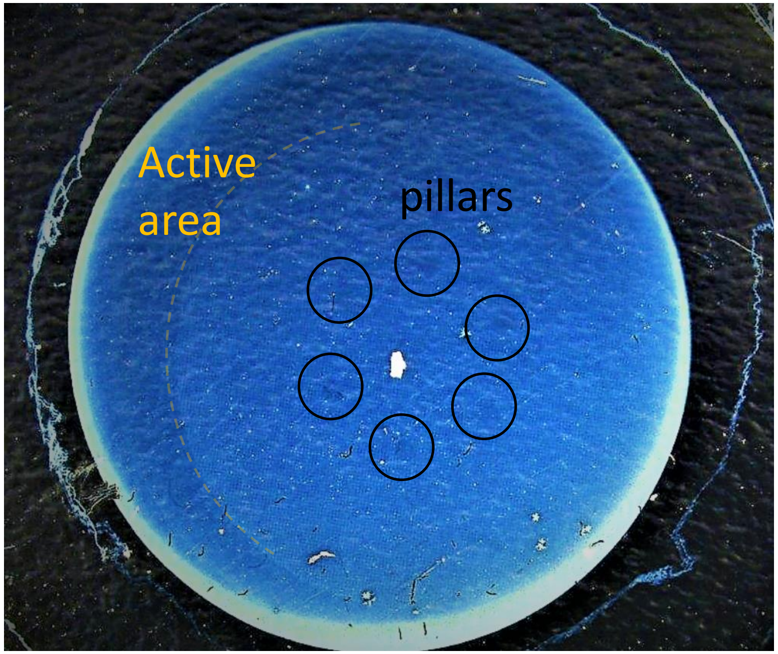
Self Portrait of Picosec micromegas, Prevessin-Moen, 2017

Photocathode:

Self Portrait of Picosec micromegas, Prevessin-Moen, 2017

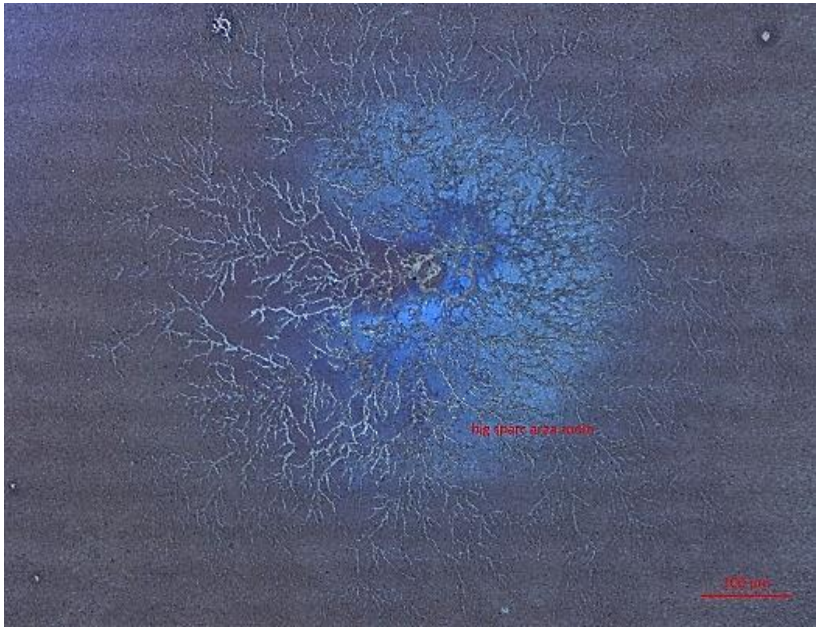


Resistive Picosec
Long run in high intensity pion beam
About 0.1-0.2mC/cm2
air exposed to take the picture

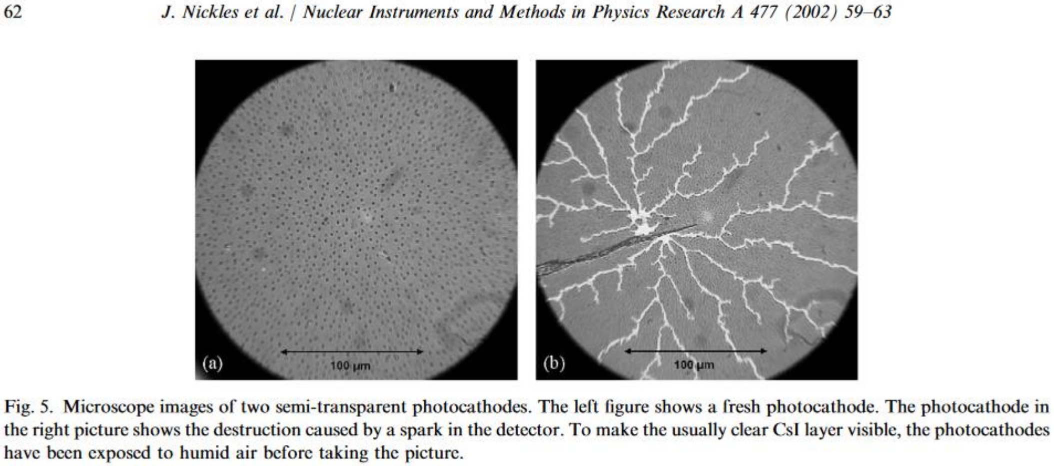


Misalignment
Mesh structure
Pillar

Photocathode: Picture of a sparks



Picosec (T. Schneider)



62 J. Nickles et al. / Nuclear Instruments and Methods in Physics Research A 477 (2002) 59–63

Fig. 5. Microscope images of two semi-transparent photocathodes. The left figure shows a fresh photocathode. The photocathode in the right picture shows the destruction caused by a spark in the detector. To make the usually clear CsI layer visible, the photocathodes have been exposed to humid air before taking the picture.

Photocathode – replacing CsI

- Diamond: Saclay (Pomorski et al) … preliminary test doe already on beam

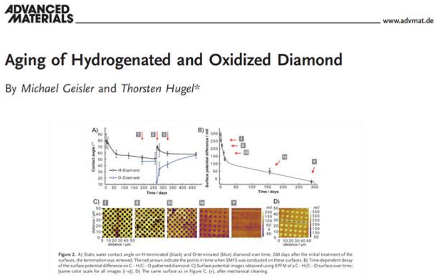
Diamond Coatings – Material Science

Mikhail Negodaev, Russian Academy of Sciences (RU)

- Diamond: Russian Academy of Sciences, Moscow (Mikhail Negodaev) PC production ready to go after specs defined more precisely by us.

Surface Treatment (lowering work function): hydrogenation (hydrogen absorption).

The sample with hydrogenation of surface can be stored on air, but not a long time (for some weeks). The kinetics of the loss of hydrogen at room temperature during the year, see Fig. 2 of article (in attachment).



ADVANCED MATERIALS www.advmat.de

Aging of Hydrogenated and Oxidized Diamond

By *Michael Geisler* and *Thorsten Hugel**

Figure 2. A) Static water contact angle on H-terminated (black) and O-terminated (blue) diamond over time. 260 days after the initial treatment of the surfaces, the termination was renewed. The red arrows indicate the points in time when SMFS was conducted on these surfaces. B) Time-dependent decay of the surface potential difference on C–H/C–O patterned diamond. C) Surface-potential images obtained using KPFM of a C–H/C–O surface over time; [same color scale for all images (i–v)]. D) The same surface as in Figure C, (v), after mechanical cleaning.

Diamond Doping:

Nitrogen doping is possible in the CVD process, however, they note that the donor level of nitrogen is 1.7 eV (can not be activated at room temperature).

Boron Doping not possible

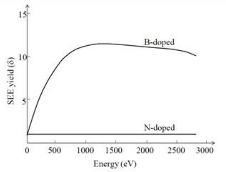


Figure 1.14- SEE yield δ obtained from an N-doped diamond film in comparison with a B-doped film with resistivity in the range of 50-170 kΩ cm, both H-terminated.[122]

http://www.chm.bris.ac.uk/pt/diamond/raquelthesis/Raquel-Vaz-PhD-thesis.pdf

- DLC
- Metals,… MgO,….
- Not photocathode but secondary Emitter

Innovative photocathodes by ND powder (Trieste group)

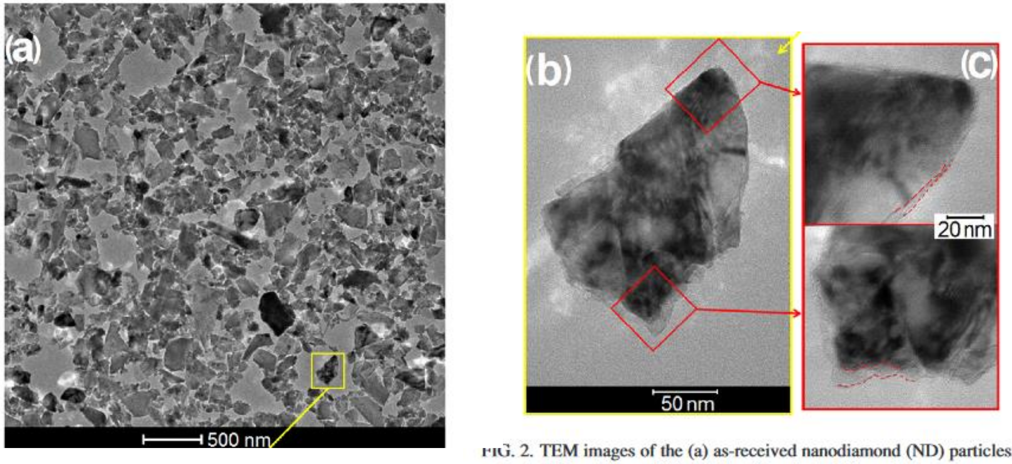
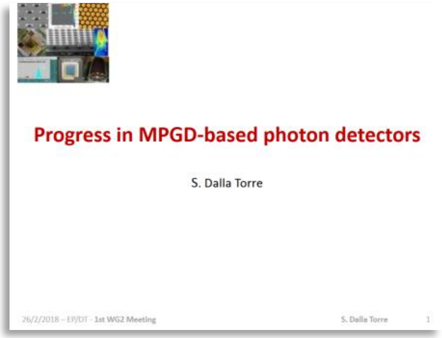


FIG. 2. TEM images of the (a) as-received nanodiamond (ND) particles, (b a single ND particle and (c) details of the single ND particle.

Highly efficient and stable ultraviolet photocathode based on nanodiamond particles
L. Velardi, A. Valentini, and G. Cicala, Appl. Phys. Lett.108, 083503 (2016)

S. Dalla Torre,
https://indico.cern.ch/event/702148/contributions/2901005/attachments/1606391/2548975/EP-DT_WG2_16022018_Dallatorre_gaseousPD.pdf



Progress in MPGD-based photon detectors

S. Dalla Torre

26/2/2018 – EP/DT - 1st WG2 Meeting S. Dalla Torre 1

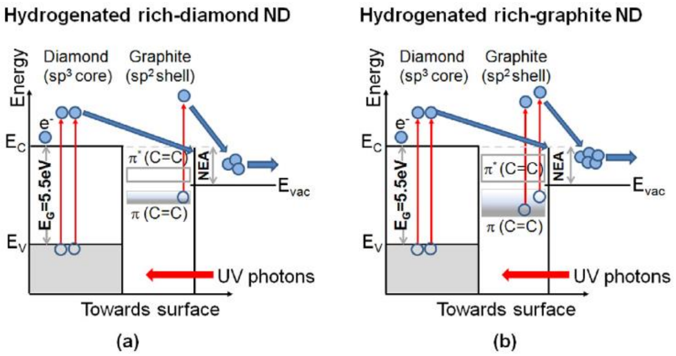


Fig. 6. Schematic energy-band representing the electron emission process from hydrogenated (a) rich-diamond and (b) rich-graphite ND particle surfaces under UV photon irradiation. Bands for diamond (sp^3 core) and bonding (π) and anti-bonding (π*) states for graphite (sp^2 shell), whose state density depends on the ND particle type.

L. Velardi, A. Valentini, G. Cicala,
UV photocathodes based on nanodiamond particles: Effect of carbon hybridization on the efficiency,
Diamond and Related Materials, Volume 76, 2017,Pages 1-8
(http://www.sciencedirect.com/science/article/pii/S0925963516306999)

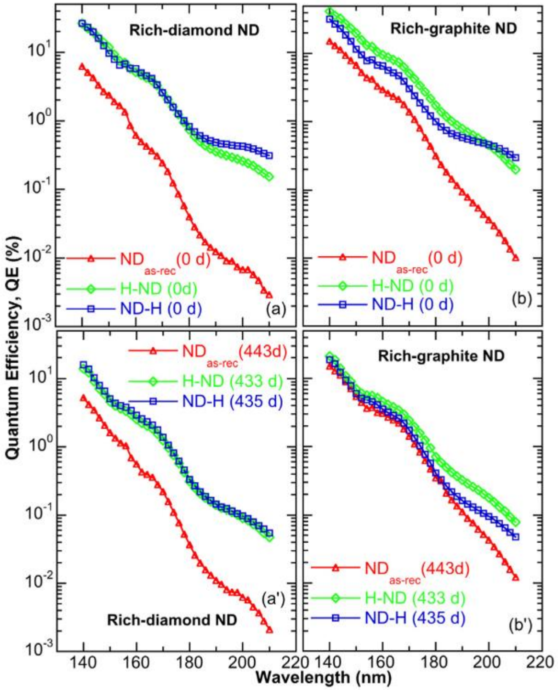


Fig. 4. Quantum efficiency of photocathodes based on (a–a') rich-diamond and (b–b') rich-graphite ND layers vs wavelength and aged at (a–b) 0 and (a'–b') ≥433 days.

Metals… Not too bad… but to be improved

Metals…· Al, Cr … interesting results from beam measurements…

… looking for possible optimization (thickness, other metals/oxides…)··

or for an higher number of photons…

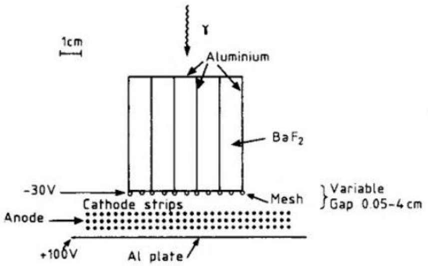
Thicker Crystal (more photons) in a pattern with reflective surfaces (parallelepipeds)…· To preserve position and high multiplicity operation? Maybe…· Already exploited in different application…

TEST OF A BaF_2–TMAE DETECTOR FOR POSITRON-EMISSION TOMOGRAPHY

P. MINÉ, G. CHARPAK, J.-C. SANTIARD and D. SCIGOCKI,
CERN, Geneva, Switzerland

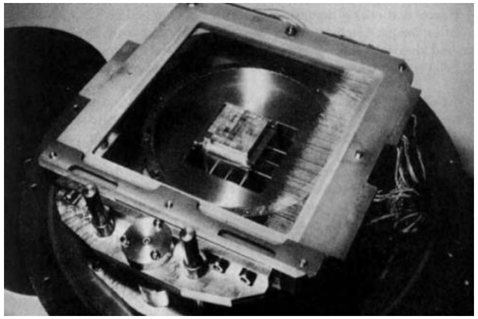
M. SUFFERT
CRN, Strasbourg, France

S. TAVERNIER
IIHE, VUB and ULB, Brussels, Belgium



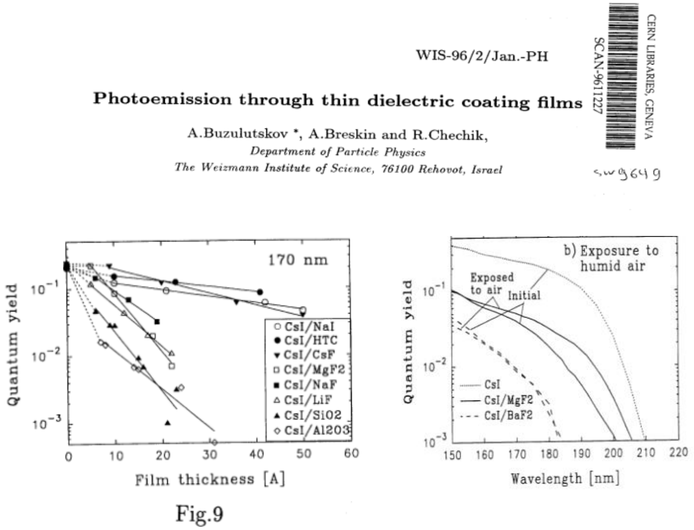
Schematics of the SSPC

Fig. 1. Schematics of the SSPC.



Photocathode - protecting CsI

PC coating @ the Thin Film & Glass Lab @ CERN



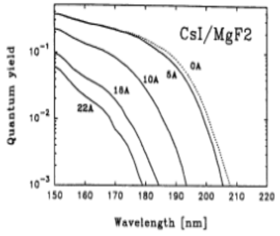
WIS-96/2/Jan.-PH

Photoemission through thin dielectric coating films

A.Buzulutskov *, A.Breskin and R.Chechik,
Department of Particle Physics
The Weizmann Institute of Science, 76100 Rehovot, Israel

sw9649

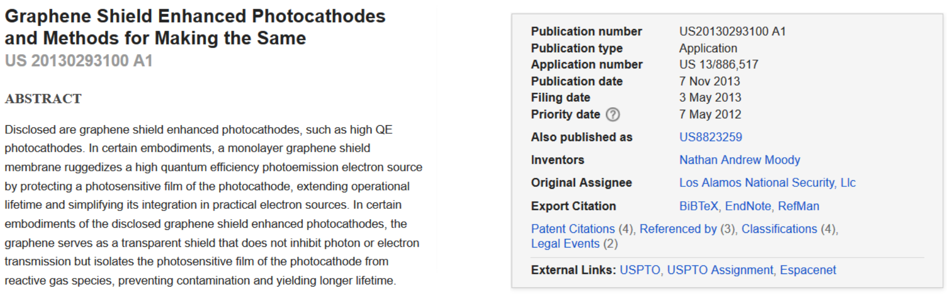
Fig.9



http://cds.cern.ch/record/315752/files/SCAN-9611227.pdf

Protection Layers (looking for new materials and protective structures… starting from literature – Va'vra[WIS]
https://cds.cern.ch/record/287770/files/SCAN-9509070.pdf
just as an example)

Under Investigation @ CERN (P.Thuiner)



Graphene Shield Enhanced Photocathodes and Methods for Making the Same
US 20130293100 A1

ABSTRACT

Disclosed are graphene shield enhanced photocathodes, such as high QE photocathodes. In certain embodiments, a monolayer graphene shield membrane ruggedizes a high quantum efficiency photoemission electron source by protecting a photosensitive film of the photocathode, extending operational lifetime and simplifying its integration in practical electron sources. In certain embodiments of the disclosed graphene shield enhanced photocathodes, the graphene serves as a transparent shield that does not inhibit photon or electron transmission but isolates the photosensitive film of the photocathode from reactive gas species, preventing contamination and yielding longer lifetime.

Publication number	US20130293100 A1
Publication type	Application
Application number	US 13/886,517
Publication date	7 Nov 2013
Filing date	3 May 2013
Priority date ?	7 May 2012
Also published as	US8823259
Inventors	Nathan Andrew Moody
Original Assignee	Los Alamos National Security, Llc
Export Citation	BiBTeX, EndNote, RefMan

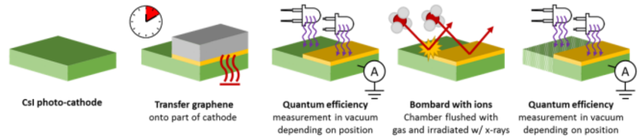
Patent Citations (4), Referenced by (3), Classifications (4), Legal Events (2)

External Links: USPTO, USPTO Assignment, Espacenet

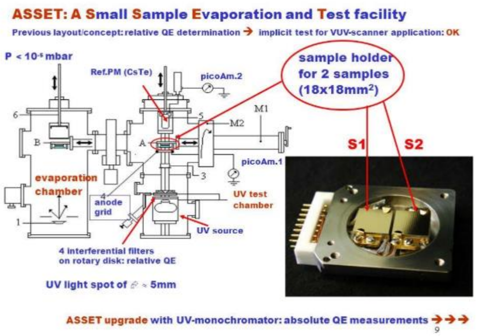
Photo-cathode protection
Ongoing study

Degradation of photo-cathodes' **quantum efficiency** during operation with time due to **ion bombardment**

Graphene as **protective layer** transferred onto photo-cathodes



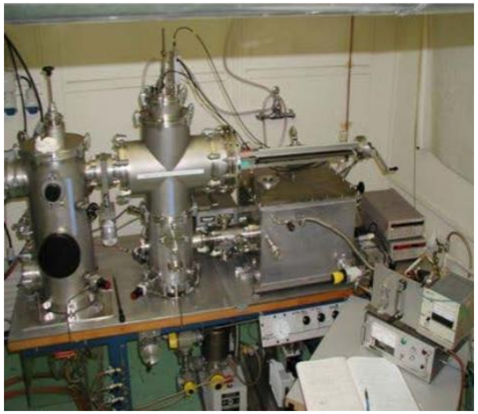
Setup to characterize photocathodes performances



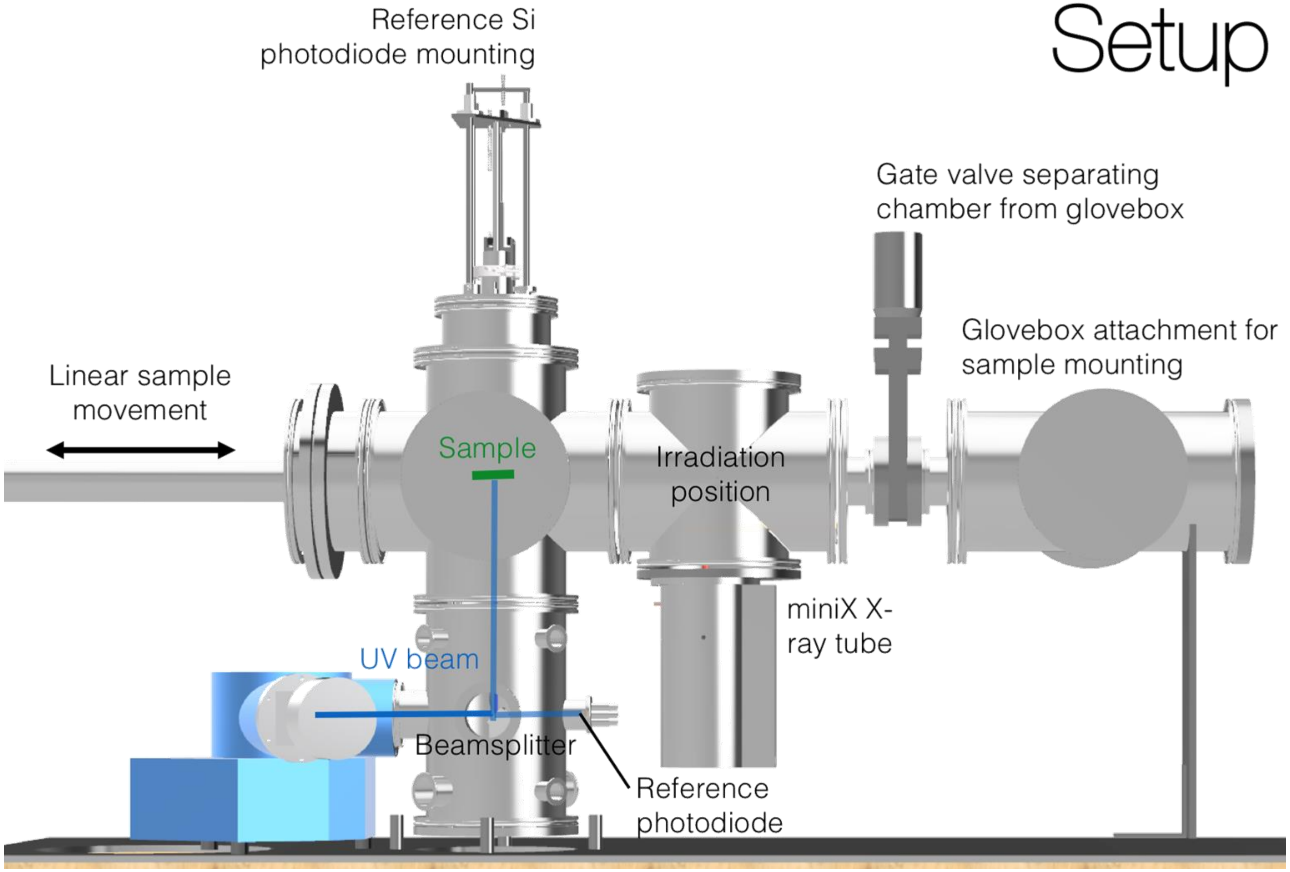
ASSET: A Small Sample Evaporation and Test facility

Previous layout/concept: relative QE determination → implicit test for VUV-scanner application: OK

ASSET upgrade with UV-monochromator: absolute QE measurements →→→



ALICE set up for photocathode evaporation/testing

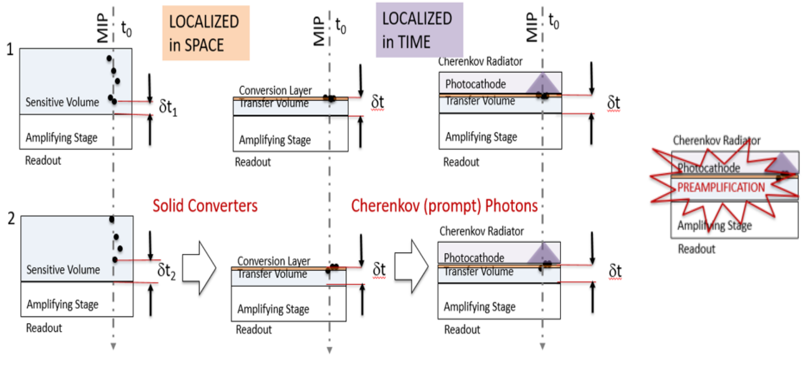


F. Brunbauer (GDD/CERN)

Looking at the next lecture…

Picosec- micromegas

LGAD ~ direct ionization micromegas



Primary electrons at the same time in the same place

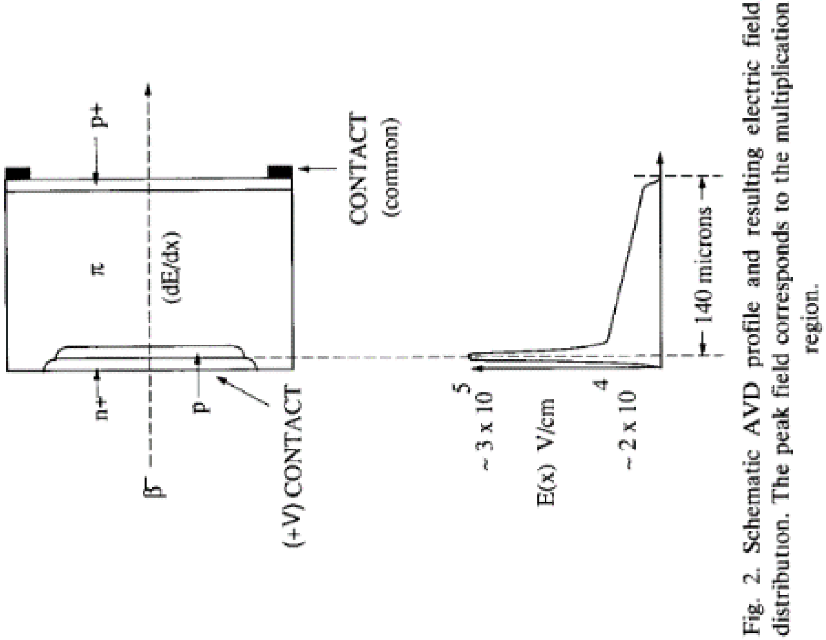
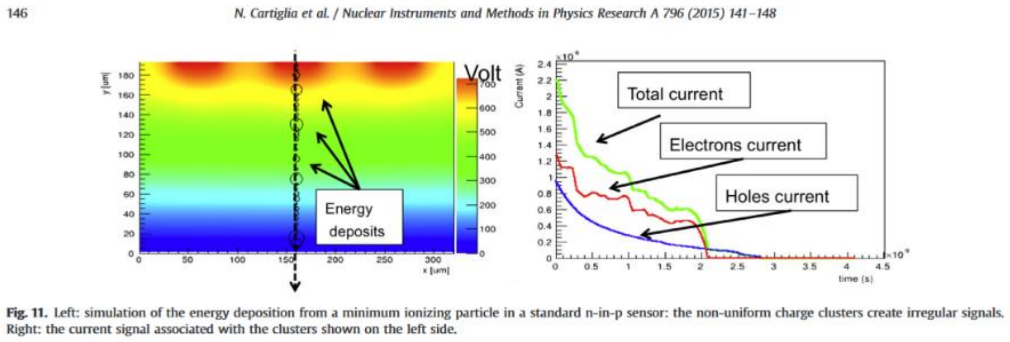


Fig. 2. Schematic AVD profile and resulting electric field distribution. The peak field corresponds to the multiplication region.

direct ionization micromegas



146 N. Cartiglia et al. / Nuclear Instruments and Methods in Physics Research A 796 (2015) 141–148

Fig. 11. Left: simulation of the energy deposition from a minimum ionizing particle in a standard n-in-p sensor: the non-uniform charge clusters create irregular signals. Right: the current signal associated with the clusters shown on the left side.

Vacuum …
Optimization of SPTR…
Charge Sharing as in Multi Anode MCP…
Photocathode ·· Secondary emission

long list of possible similarity

Summary/PICOSEC

- Proof of principle fully achieved
- In view of detector operation and scaling up: resistive micromegas and multi-pad detectors are showing good performances (not shown today, a little in backup). No limitation from the sensor point of view
- Most important R&D in front of the collaboration is photocathode
- Depending of the specific application the project can be "close to" or "far from" being ready.

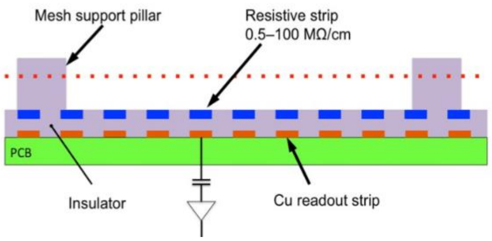
Summary/General…

- Three examples of detector optimization for timing
- In all the three examples, it is the proper understanding of the detector that allowed the breakthrough
- New technologies and techniques could help on moving from proof of principle to final detector

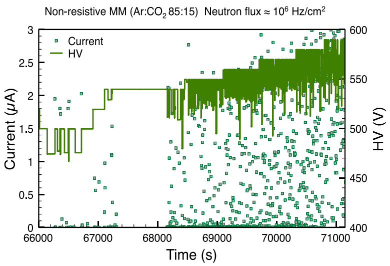
backup

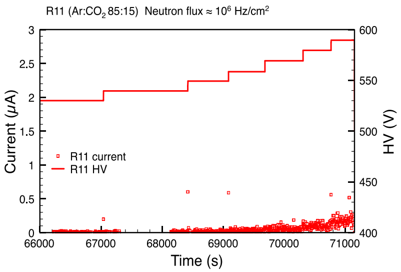
Robustness

ATLAS New Small Wheel - MicroMegas (J. Wotschack et al.)



G. Iakovidis, arXiv:1310.0734v1 [physics.ins-det] 2 Oct 2013





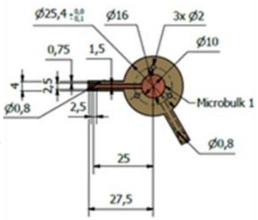
Nuclear Instruments and Methods in Physics Research A 640 (2011) 110–118

A spark-resistant bulk-micromegas chamber for high-rate applications

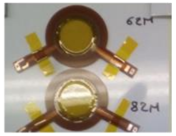
T. Alexopoulos [a], J. Burnens [b], R. de Oliveira [b], G. Glonti [b], O. Pizzirusso [b], V. Polychronakos [c], G. Sekhniaidze [d], G. Tsipolitis [a], J. Wotschack [b,*]

Resistive mesh / photocathode protection…. ?

- A: Resistive plane a la “mamma”
    - Better protection
- B: Discrete Resistors a la “compass RICH” (Trieste)
    - Larger flexibility on resistor value
- C: Embedded Resistors a la “Chefdeville-Geralis-Peskov”
    - Tested using low resistivity plane a la “mamma” with discrete resistor a la “compass RICH”

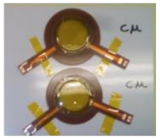


Type A, High Resistivity



Type A, Low Resistivity

Type B, Discrete resistors



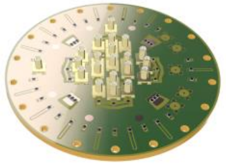
CERN MPT Workshop (A. Texteira et al.)

- Spark damage and spark rate minimized
- Capability f running in high rate pion beam in SPS
- Time resolution slightly worse

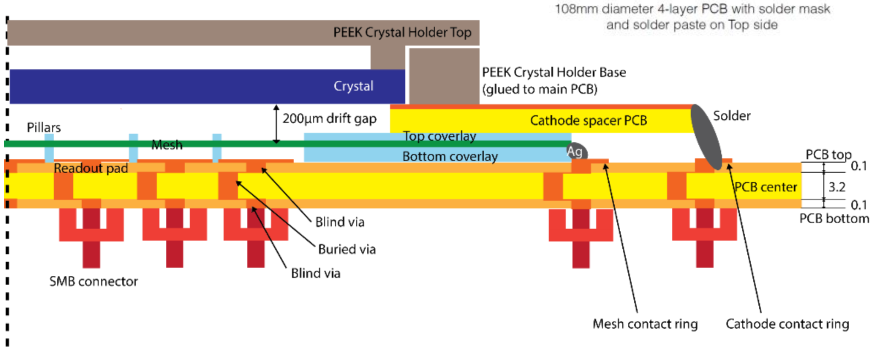
Detector Scaling (towards applications):

preserving the signal integrity and stability with ***larger meshes***
preserving the ***gaps uniformity*** on larger surfaces
...
preserving signal integrity with routing/vias/...
coupling between channels and S/N
...·

PCB



108mm diameter 4-layer PCB with solder mask and solder paste on Top side



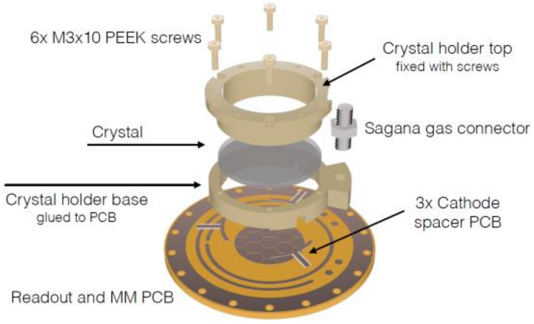
multiPad picoSec

Design details and production reference

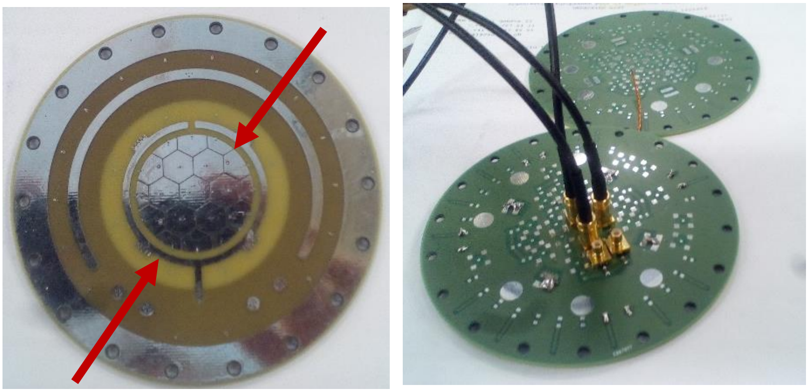
Florian M. Brunbauer

on behalf of the GDD group
May 9, 2017

Detector assembly



PCB prototype to signal routing/coupling test



~35mm Active area, 19 pads (7 full size)

Electronics
…going towards integrated/multichannel…

2018 (and beyond..) Picosec Electronics

- Amplifier

For single channel readout more than happy with CIVIDEC and with their important support.. Not feasible for multichannel readout

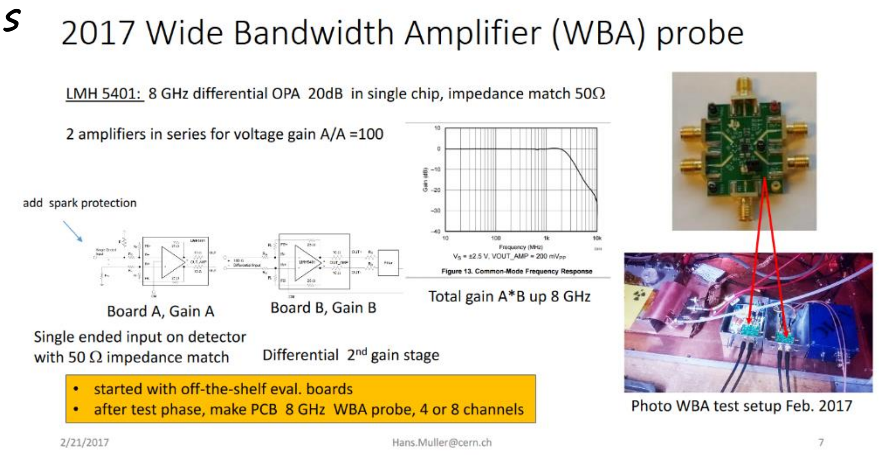
  - Custom (CERN/RD51)
  - Custum/Embedded Electronics (Saclay)
  - Multichannel.. Far future…

- Digitizer

Oscilloscope… same comment as for CIVIDEC

  - SAMPIC
  - DRS4

- …



2017 Wide Bandwidth Amplifier (WBA) probe

LMH 5401: 8 GHz differential OPA 20dB in single chip, impedance match 50Ω

2 amplifiers in series for voltage gain A/A =100

add spark protection

Board A, Gain A

Board B, Gain B

Single ended input on detector with 50 Ω impedance match

Differential 2nd gain stage

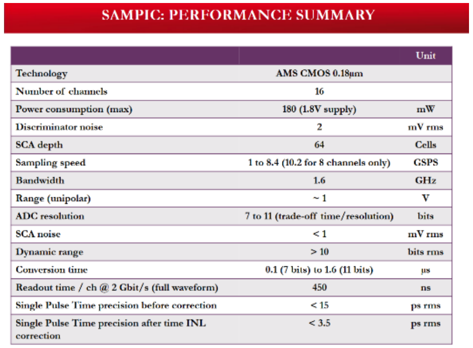
Total gain A*B up 8 GHz

- started with off-the-shelf eval. boards
- after test phase, make PCB 8 GHz WBA probe, 4 or 8 channels

Photo WBA test setup Feb. 2017

2/21/2017 Hans.Muller@cern.ch 7

H. Muller, Precise Timing Workshop, Feb 2017 https://indico.cern.ch/event/607147/contributions/2476905/attachments/1415650/2398258/Plans_fast_electronics_for_MPGD.pdf

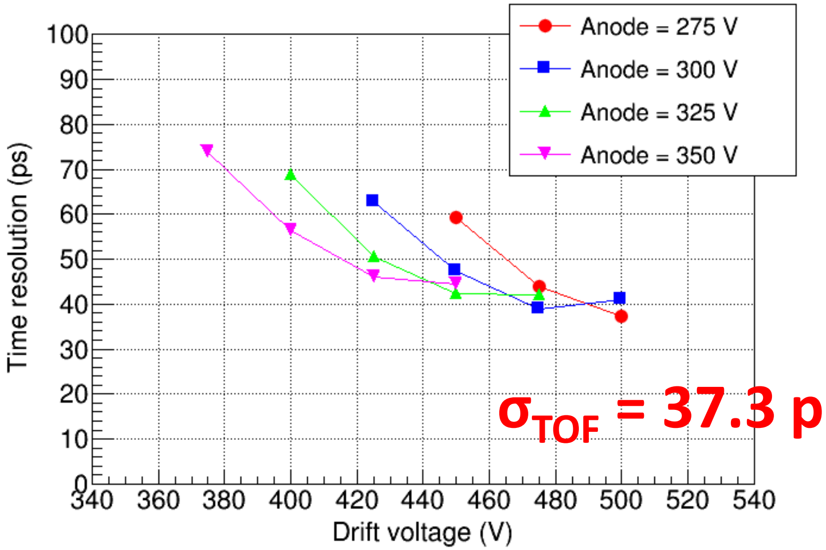


SAMPIC: PERFORMANCE SUMMARY

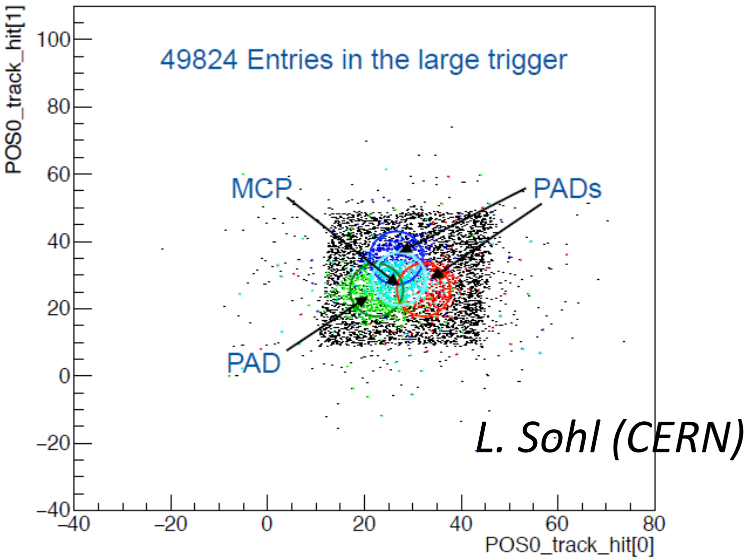
		Unit
Technology	AMS CMOS 0.18µm	
Number of channels	16	
Power consumption (max)	180 (1.8V supply)	mW
Discriminator noise	2	mV rms
SCA depth	64	Cells
Sampling speed	1 to 8.4 (10.2 for 8 channels only)	GSPS
Bandwidth	1.6	GHz
Range (unipolar)	~ 1	V
ADC resolution	7 to 11 (trade-off time/resolution)	bits
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 @ 2 Gbit/s (full waveform)	450	ns
Single Pulse Time precision before correction	< 15	ps rms
Single Pulse Time precision after time INL correction	< 3.5	ps rms

Status of development on the SAMPIC Waveform TDC, D. Breton, RD51 precise Timing Workshop, 21-22 February 2017, CERN, https://indico.cern.ch/event/607147/contributions/2476911/attachments/1415361/2168327/SAMPIC_RD51_Breton.pdf

Scaling up: preliminary results from first prototype



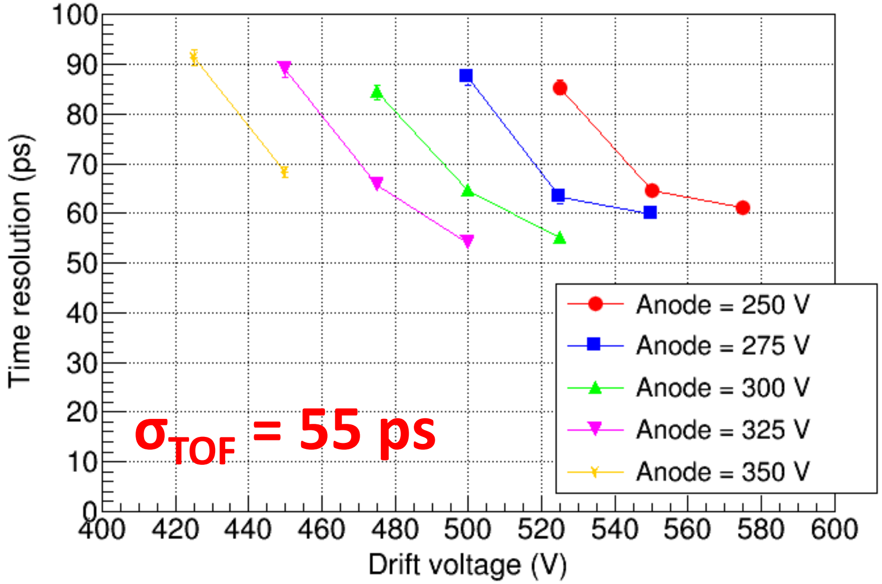
σ_{TOF} = 37.3 ps



L. Sohl (CERN)

- Field scan centered in one pad: **37 ps**.
- MCP was centered btw 3 PADs -> High statistics (>10^6 events) study of charge/timing sharing btw them.

Robust photocathodes: pure metallic



σ_{TOF} = 55 ps

- Previous tests showed modest results:
  - 5 mm MgF2 + 10 nm Cr: ~100 ps, Nphe = 2.2.
  - 5 mm MgF2 + 100 nm CVD: 180 ps, Nphe = ~2
- Pure metallic one (5 mm MgF2 + 20 nm Al): 54 ps!

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