Picosecond

Summary of 2016 activities and future plans

The Collaboration

Started as an RD51 common fund project:

Fast Timing for High-Rate Environments: A Micromegas Solution

Awarded 3/2015

Collaborating Institutes:

- **CEA (Saclay)**
  T. Papaevangelou , I Giomataris, M. Kebbiri, M. Pomorski, T. Gustavsson, E. Ferrer-Ribas, D. Desforge, I. Katsioulas, G. Tsiledakis, O. Malliard, P. Legou, C. Guyot, P. Schwemling
- **CERN**
  *L. Ropelewski, E. Oliveri, F. Resnati, R. Veenhof, S. White, H. Muller, F. Brunbauer, J. Bortfeldt, M. van Stenis, M. Lupberger, T. Schneider, C. David, D. González Díaz**
- **NCSR Demokritos**
  G. Fanourakis
- **Princeton University**
  S.White, K.T. McDonald, Changguo Lu
- **University of Thessaloniki**
  S. Tzamarias
- **University of Science and Technology of China (USTC), Hefei**
  Zhiyong Zhang, Jianbei Liu, Zhou Yi

** Present Institute: University of Santiago de Compostela*

outline

- Introduction to picosecond
- Summary of 2016 activities
- Future R&D plans
  - Intrinsic Resolution… looking for the limit
  - Detector Optimization and Scaling… towards applications

References for more details…

- *A picosecond Micromegas EUV photodetector*, T. Papaevangelou, 8th symposium on large TPCs for low-energy rare event detection, 5-7 December 2016, Paris (https://indico.cern.ch/event/473362/contributions/2317653/attachments/1384392/2105987/TPapaevangelou_MM_PicosecondPhotodetector.pdf)

- *(Ultra-) Fast tracking of Minimum Ionizing Particles with a Micromegas detector*, T. Papaevangelou, 14th Topical Seminar on Innovative Particle and Radiation Detectors (IPRD16) 3 - 6 October 2016 Siena, Italy (http://www.bo.infn.it/sminiato/sm16/04_Giovedi/Mattina/10_Papaevangelou.pdf)

- *Report on PICOSEC Beam tests* , S. White, MPGD Applications Beyond Fundamental Science Workshop and the 18th RD51 Collaboration Meeting, Aveiro, Portugal (https://indico.cern.ch/event/525268/contributions/2298965/attachments/1335651/2008896/aveiroSeb.pdf)

- *Picosec: test beam summary and outlook*, F. Resnati, MPGD Applications Beyond Fundamental Science Workshop and the 18th RD51 Collaboration Meeting, Aveiro, Portugal (https://indico.cern.ch/event/525268/contributions/2297868/attachments/1336635/2010819/testBeam.pdf)

- *RD51–H4 –May/June 2016 Test beam*, M Lupberger, RD51 Mini-Week 6-9 Jun 2016, CERN (https://indico.cern.ch/event/532518/contributions/2195706/attachments/1287366/1915899/PicosecondeTestBeam.pdf)

- *Fast Timing for High-Rate Environments with Micromegas*, T. Papaevangelou, MPGD 2015 & RD51 Collaboration meeting 12-17 October 2015 Trieste – Italy (https://agenda.infn.it/contributionDisplay.py?contribId=83&sessionId=2&confId=8839 , https://arxiv.org/abs/1601.00123)

Why tens of picoseconds are interesting….

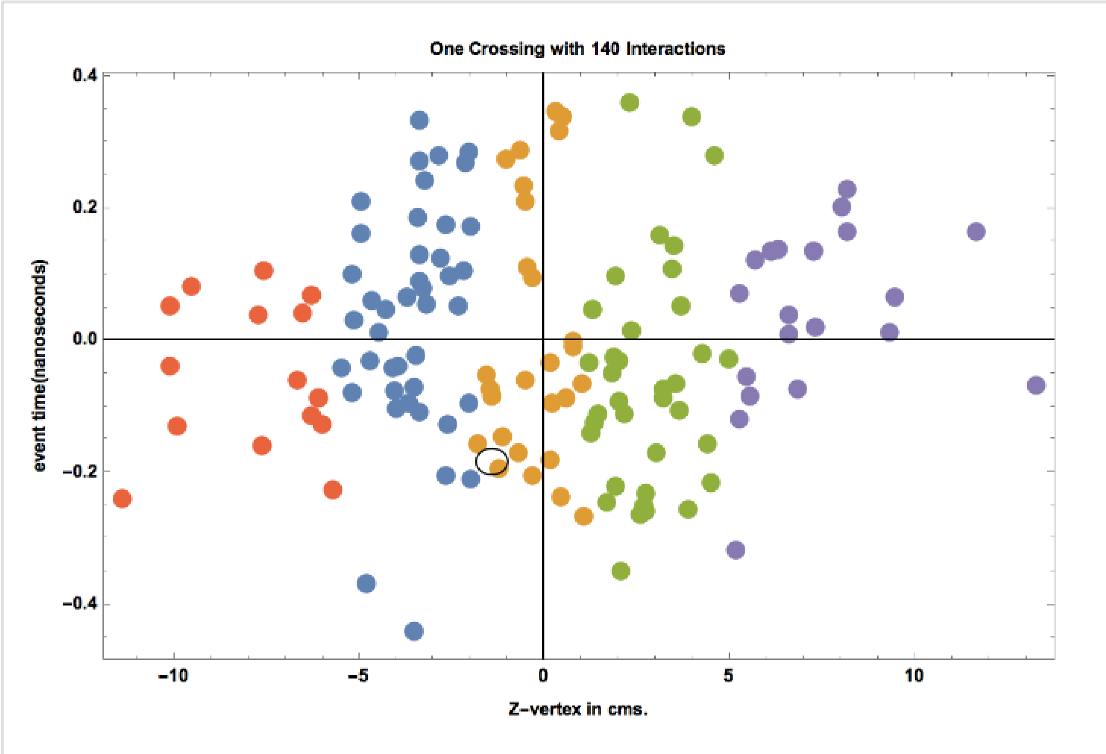
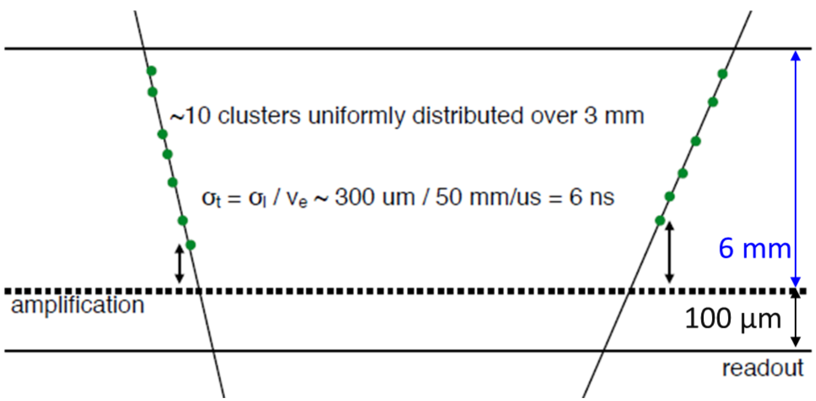


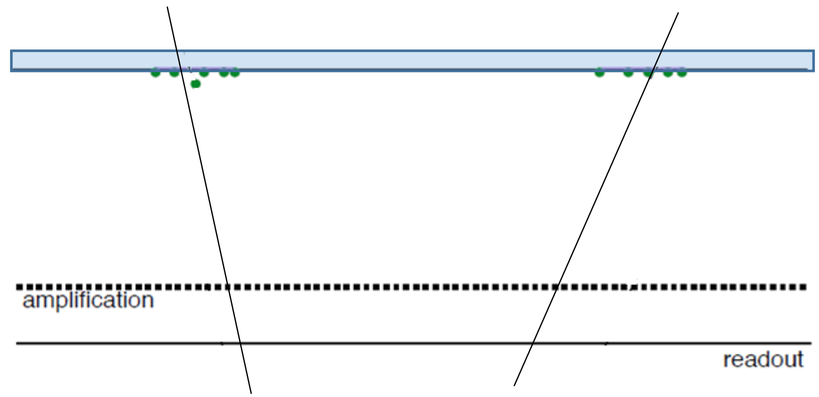
Fig. 1. Simulation of the space(z-vertex) and time distribution of interactions within a single bunch crossing in CMS at a pileup of 140 events- using LHC design book for crossing angle, emittance, etc. Typically events are distributed with an rms-in time- of 170 picoseconds, independent of vertex position.

R&D for a Dedicated Fast Timing Layer in the CMS Endcap Upgrade S. White
https://arxiv.org/pdf/1409.1165v2.pdf

Being fast and precise with gaseous detector….

At the same time in the same place





Direct ionization in gas limits the time response

"primary" electrons localized in time and space (electrons from solid converter) with negligible contribution from the ionization in the gas

A picosecond Micromegas EUV photodetector, T. Papaevangelou, 8th symposium on large TPCs for low-energy rare event detection, 5-7 December 2016, Paris

Photoconverters… CsI….

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

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]
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[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.

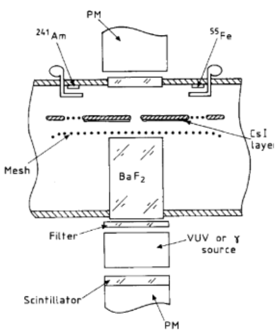

Fig. 1. Schematic view of the experimental setup.

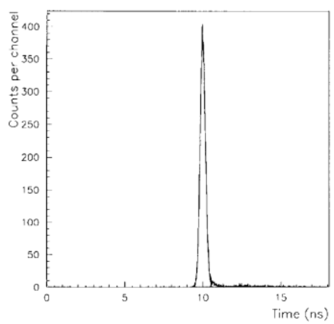

Fig. 7. Time resolution; the FWHM is 500 ps.

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Nuclear Instruments and Methods in Physics Research A 449 (2000) 314–321
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
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Fast signals and single electron detection with a MICROMEGAS photodetector

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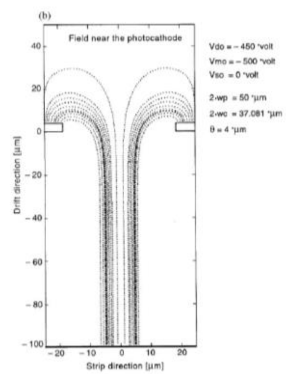
Received 3 December 1999; accepted 14 December 1999

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.



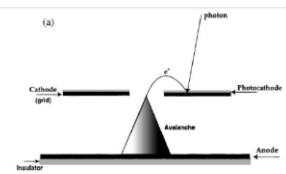


Fig. 1. (a) Principle of the photodetector in the reflective mode; (b) simulation of the electric field lines relevant for photoelectron collection.

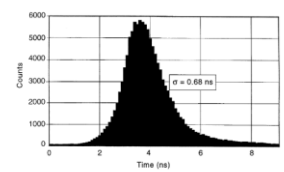


Fig. 11. Time distribution of the anode discriminated current signal of single photoelectrons for the CsI photoconverter.

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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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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

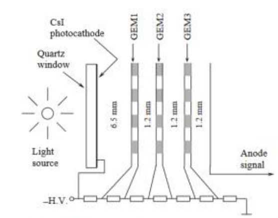


Fig. 1. A schematic view of the triple-GEM photomultiplier (GPM).

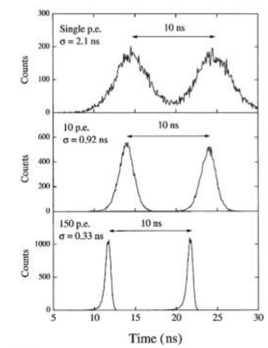
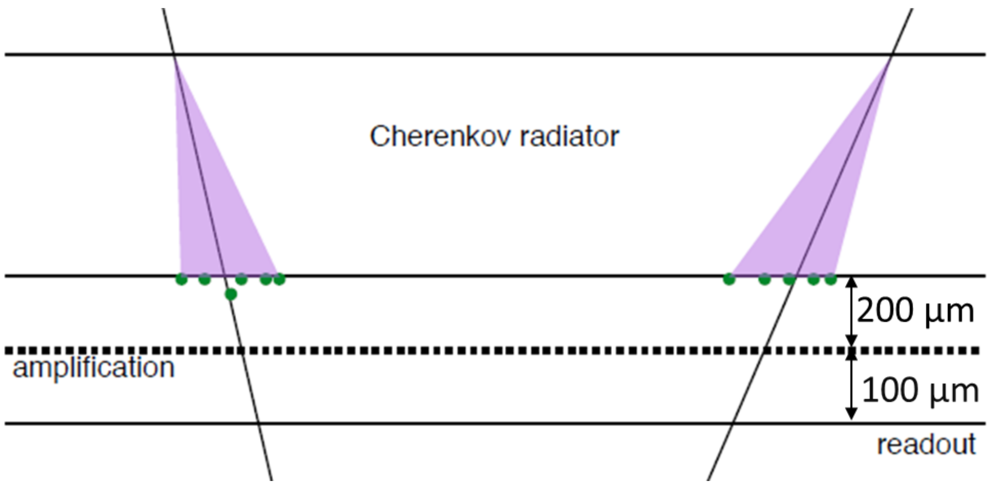


Fig. 6. Detector time resolution in CF_4. Time distributions of two groups of GPM anode pulses, delayed by 10 ns, with respect to the H_2 lamp trigger are shown. The distributions for 1, 10 and 150 photoelectrons released from the photocathode per light-pulse are shown. The data were measured at a gain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

Sub-nanosecond time response

Saclay&CERN/Princeton (Ioannis&Sebastian..) proposal: Fast Timing for High-Rate Environments:

A Micromegas Solution



(semitransparent photocathode configuration)

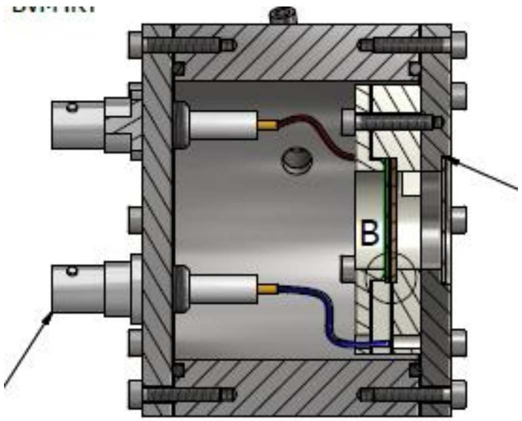
Cerenkov radiator
- prompt photon source

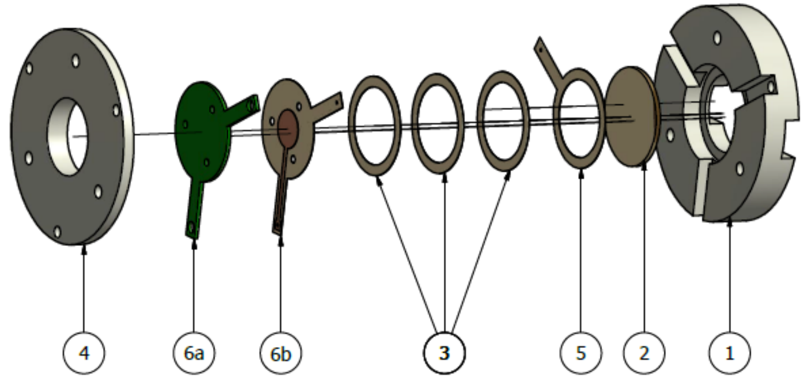
Small Drift
- low primary ionization in gas
- low diffusion

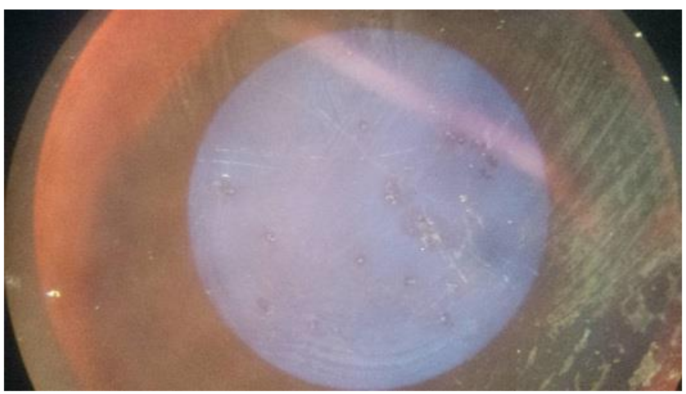
Pre-amplification
- longitudinal diffusion reduced
- effects of primary ionization in gas reduced

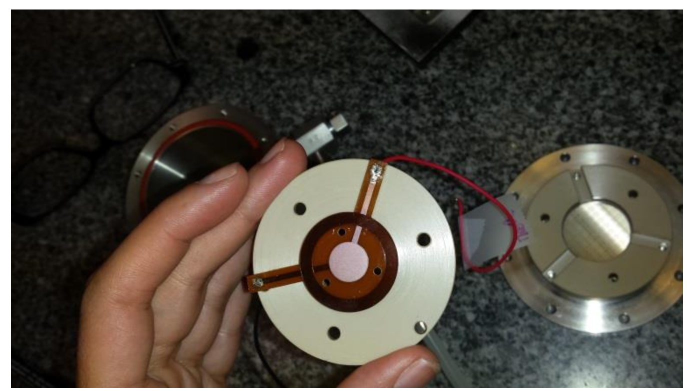
RD51 common fund project

Starting form the first Picosec prototype (1cm diameter active area)….



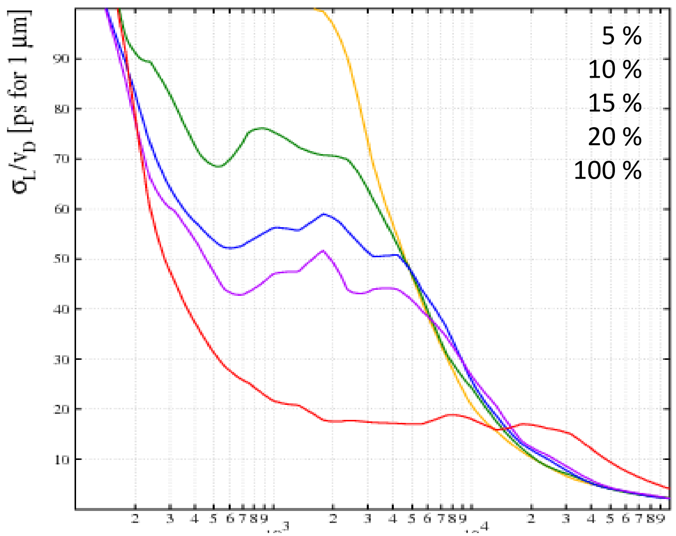




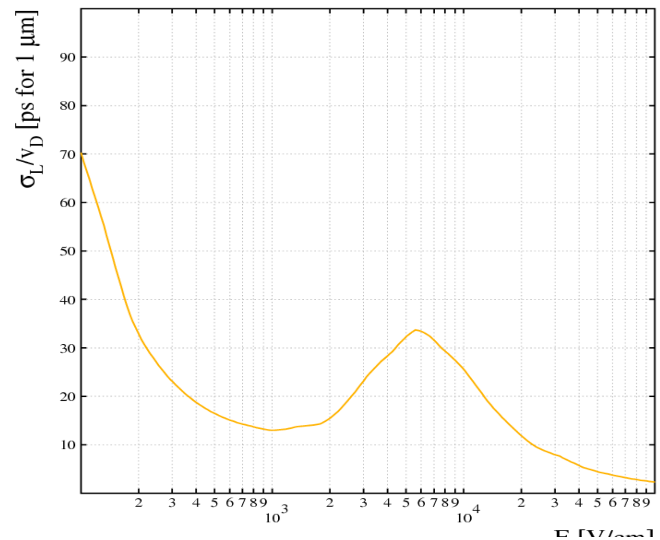


..plus some hints from (Rob) simulation for the gas choice….

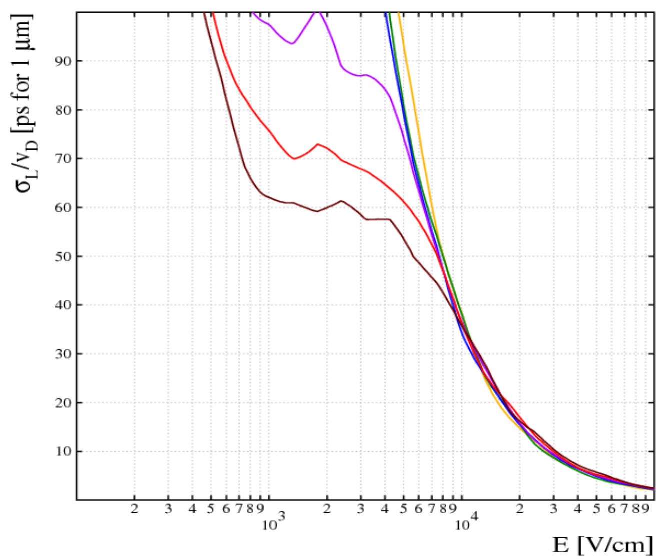
Ne-C_2H_6



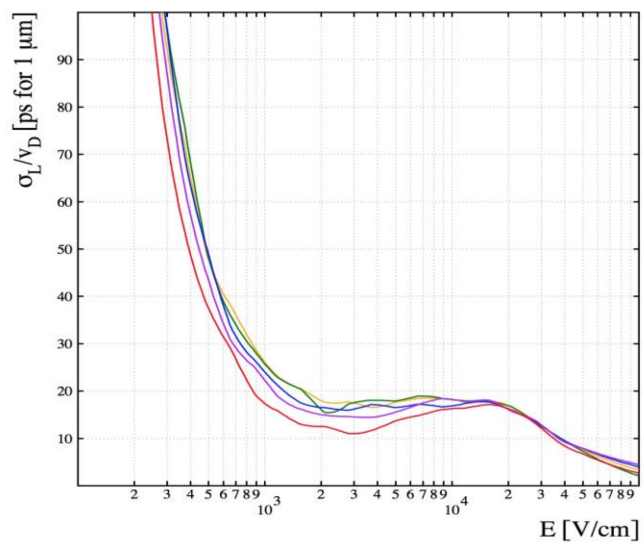
Ne-CF_4-C_2H_6



He-C_2H_6



CF_4-iC_4H_{10} **@ 0.5 bar**

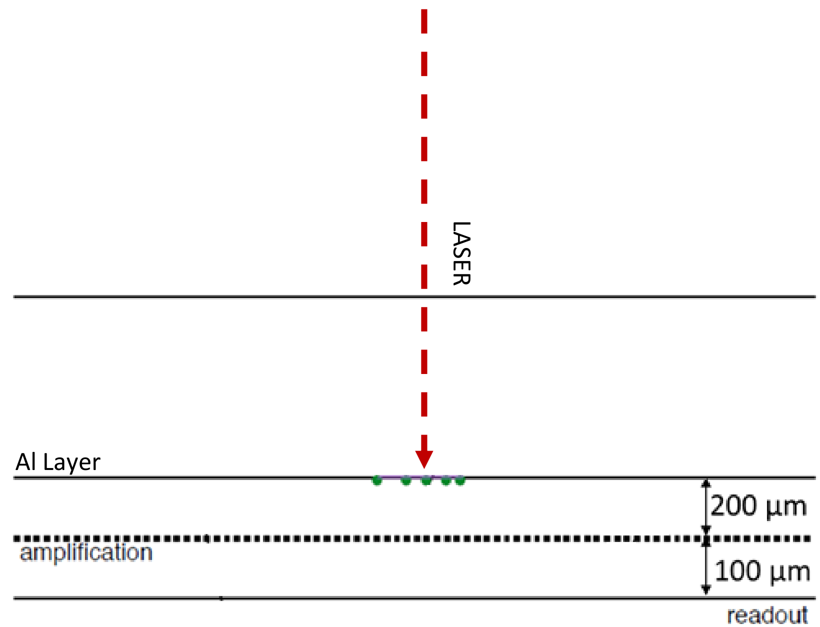


... the first validation of the idea came (2015)

Time response vs photoelectrons – Laser Tests

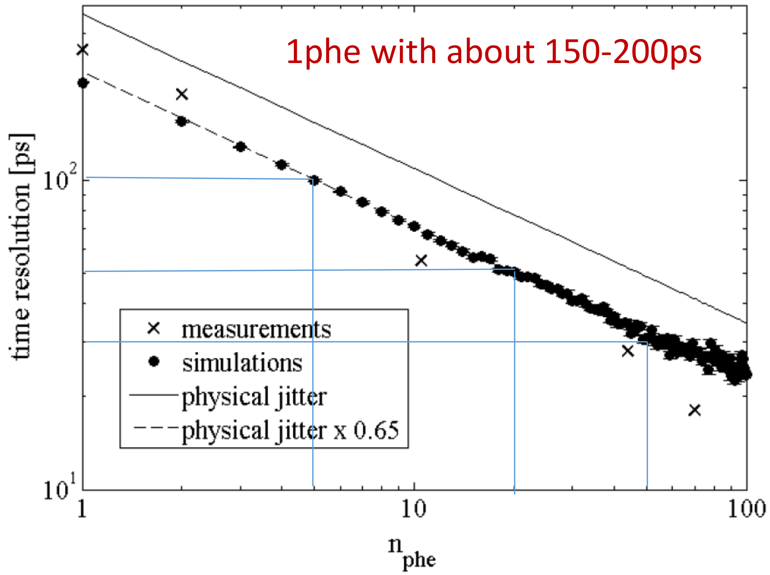
IRAMIS facility @ CEA Saclay

UV laser with σ_t << 100 fs

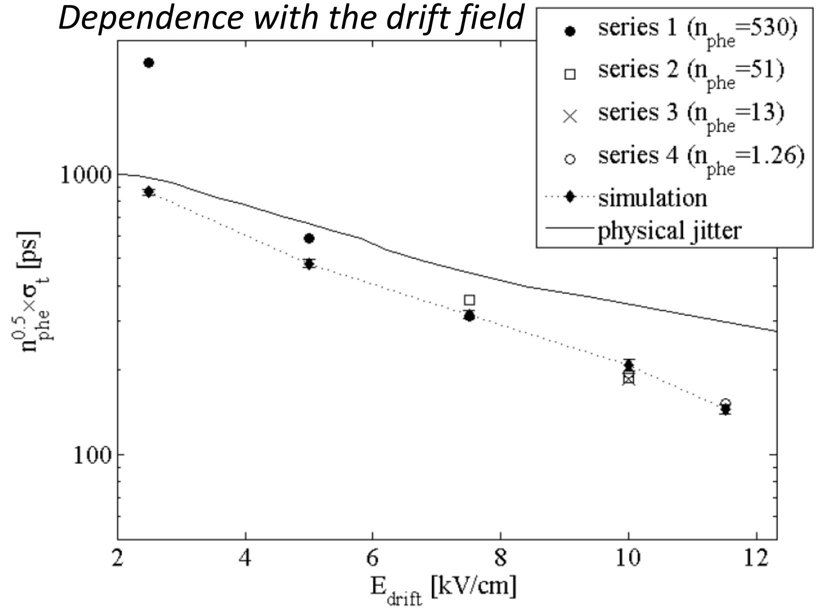


You forget about radiator and photo conversion…
you stay focused on n_{phe} … no matter how they are produced

Dependence with the number of photoelectrons



Dependence with the drift field



100ps → 5phe

(*) 50ps → 20phe

30ps → 60phe

2015 run: Ne (90%) + C2H6 (10%)

No gas circulation - gas renewed every 24 h

Single p.e. σt~180 ps @ ~12 kV/cm2

(*) Results relative to the specific configuration used, to be NOT considered as the best results achievable.

Fast Timing for High-Rate Environments with Micromegas, T. Papaevangelou, MPGD 2015 & RD51 Collaboration meeting 12-17 October 2015 Trieste – Italy (https://agenda.infn.it/contributionDisplay.py?contribId=83&sessionId=2&confId=8839 , https://arxiv.org/abs/1601.00123)

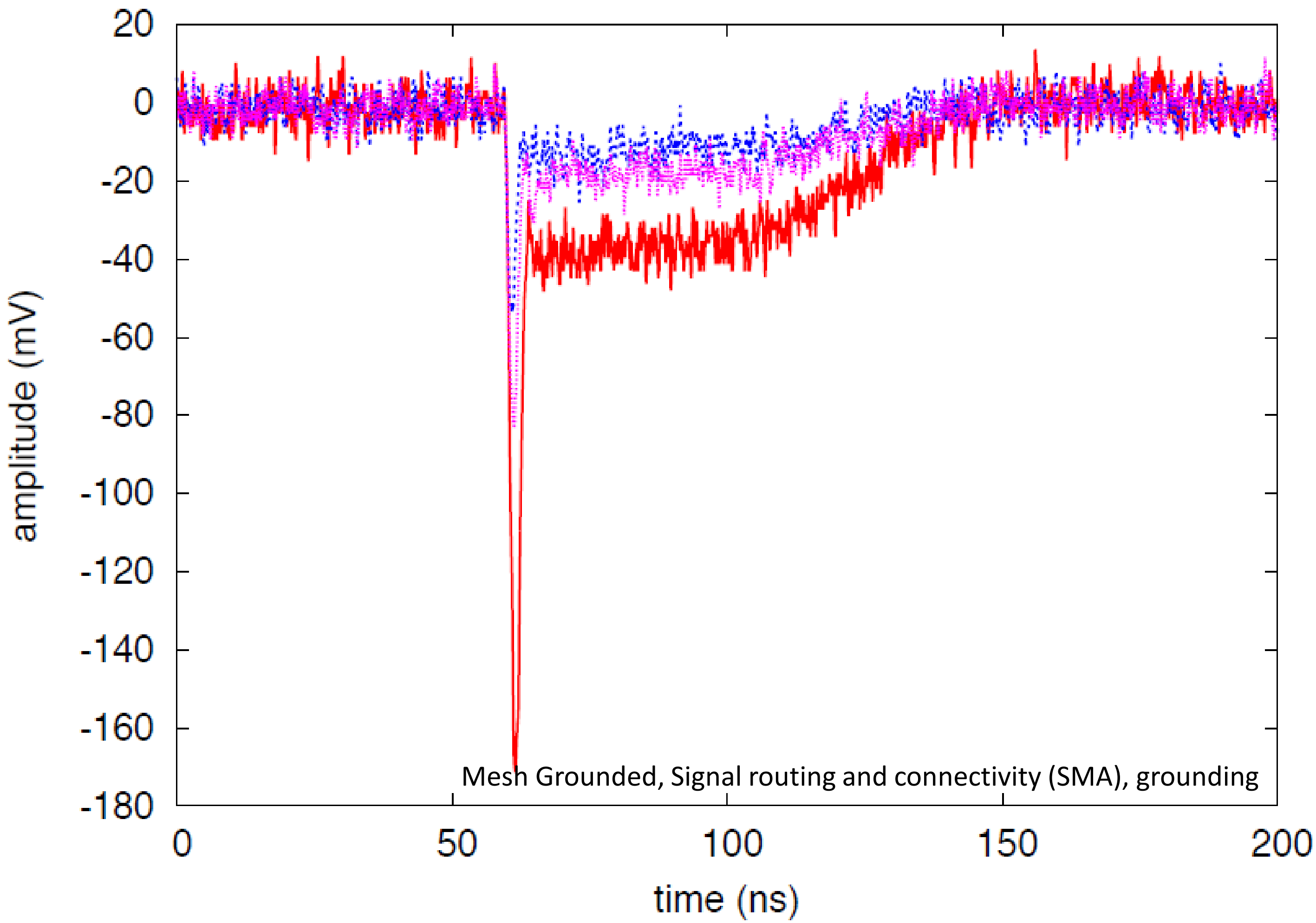
After the laser test… next step … validation with charged particles (MIPs):

Time response with muons beam (150GeV)

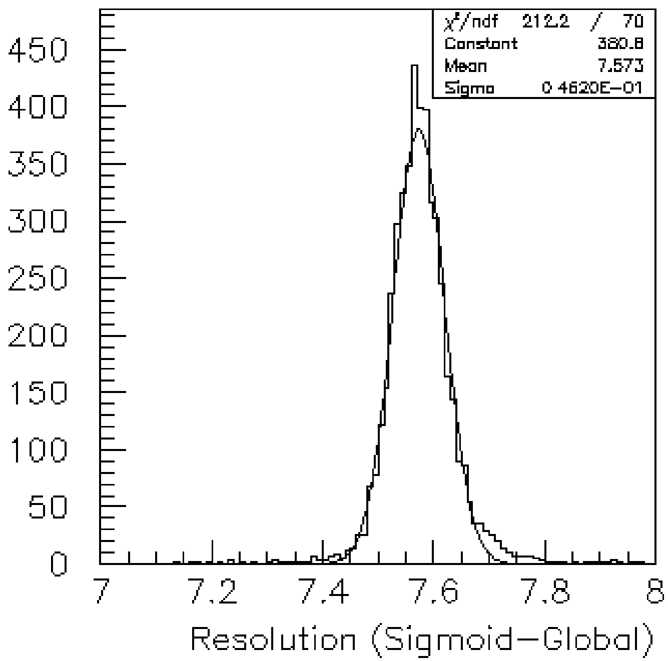
- Picosec Readout: Cividec C2 2GHz, 40 db preamplifier acquired via (LeCroy) Oscilloscope

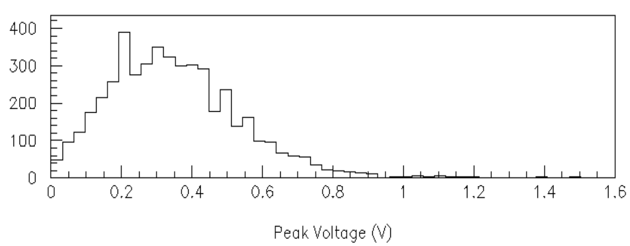
- Timing: MCP-PMT (see S. White talk in WG1 session)

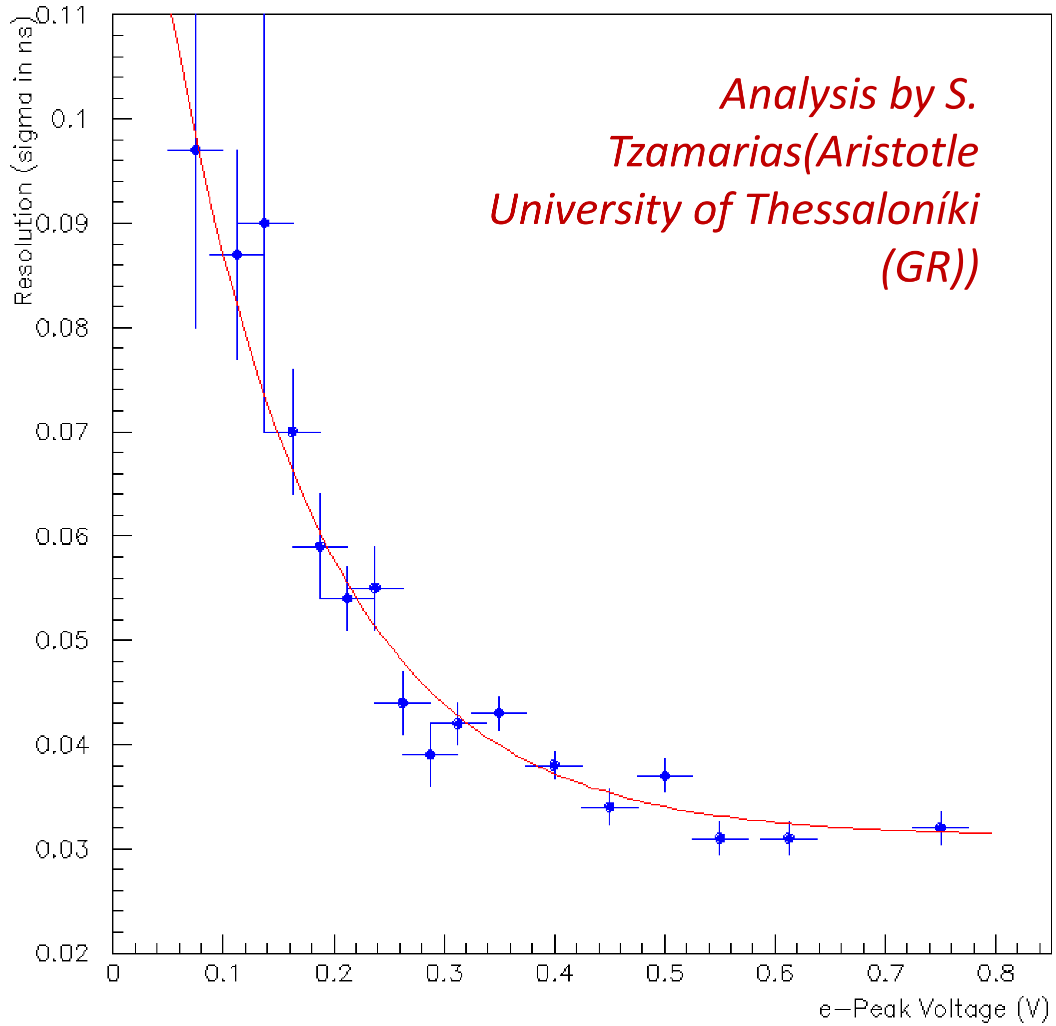
During the 2016 test beam campaign we learned how to get "clean" signal out of picosec…



Development of robust analysis

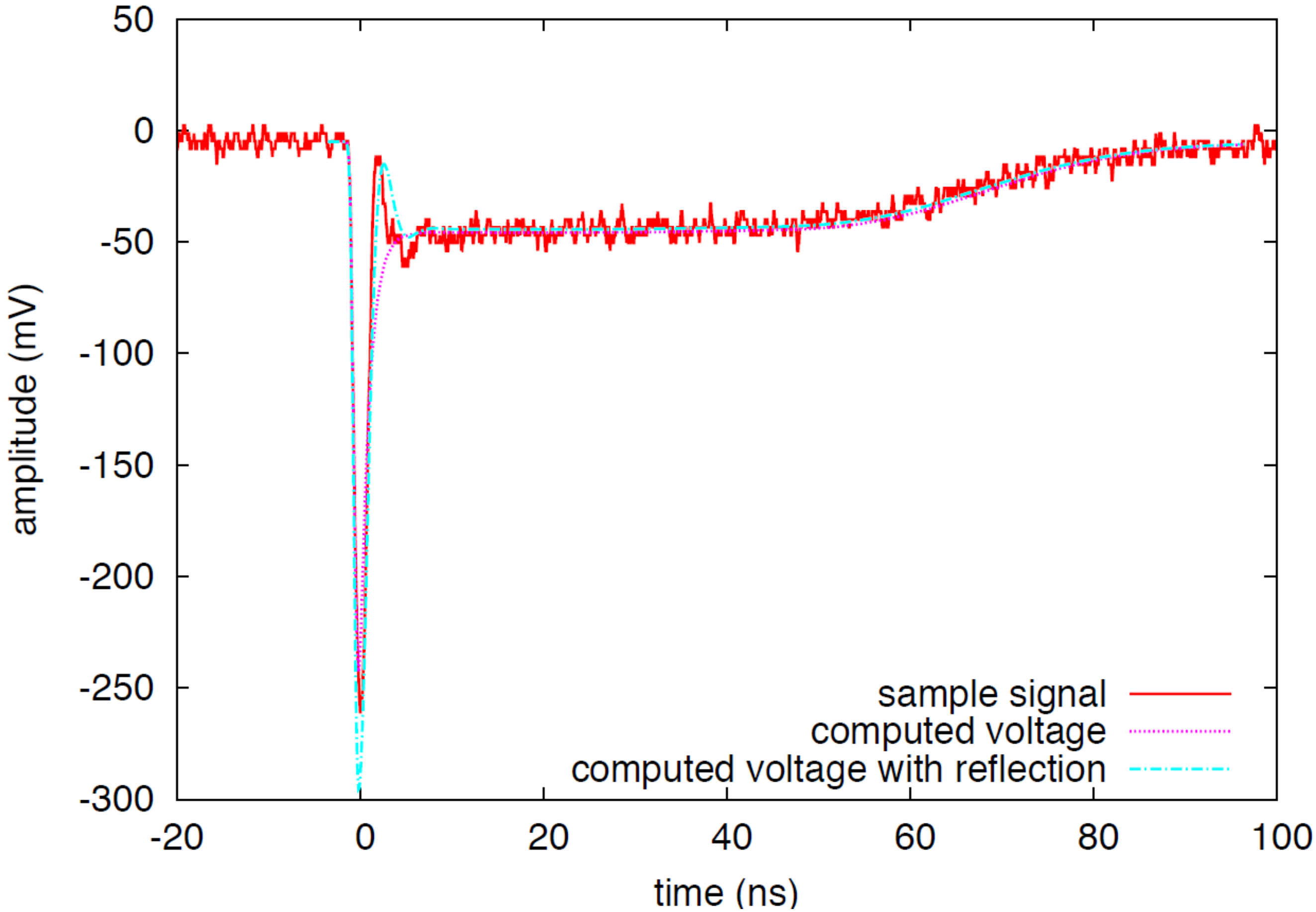






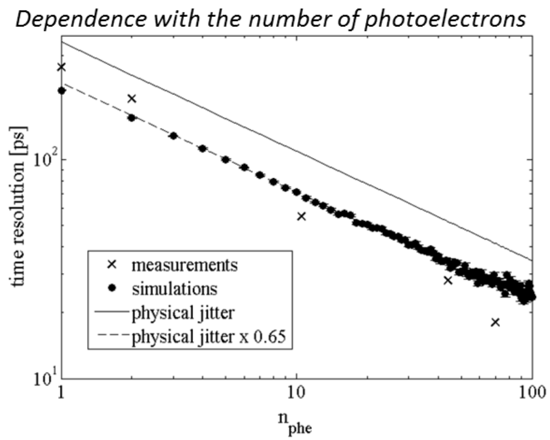
See mini week talk: Re-analysis of picosec-Micromegas detector, WG2 session, Wednesday 14th

Development of simulations of the induced signals

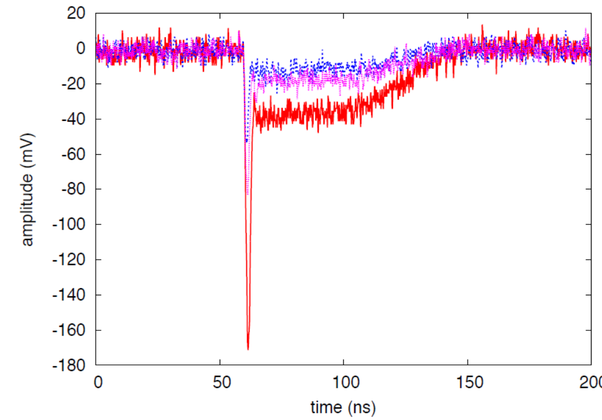


F. Resnati, Internal GDD-FT Joint Meeting

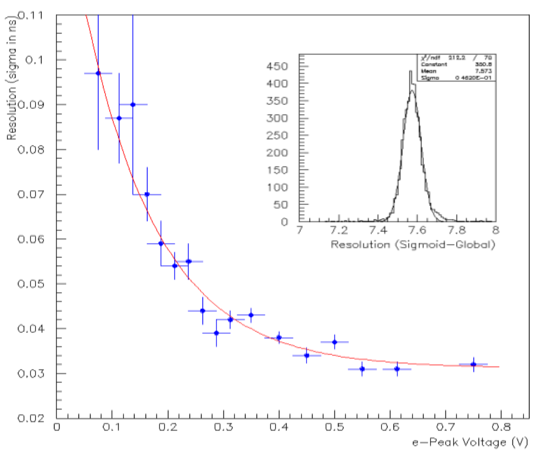
Current status of measurements, developments and tools of the Picosec Collaboration



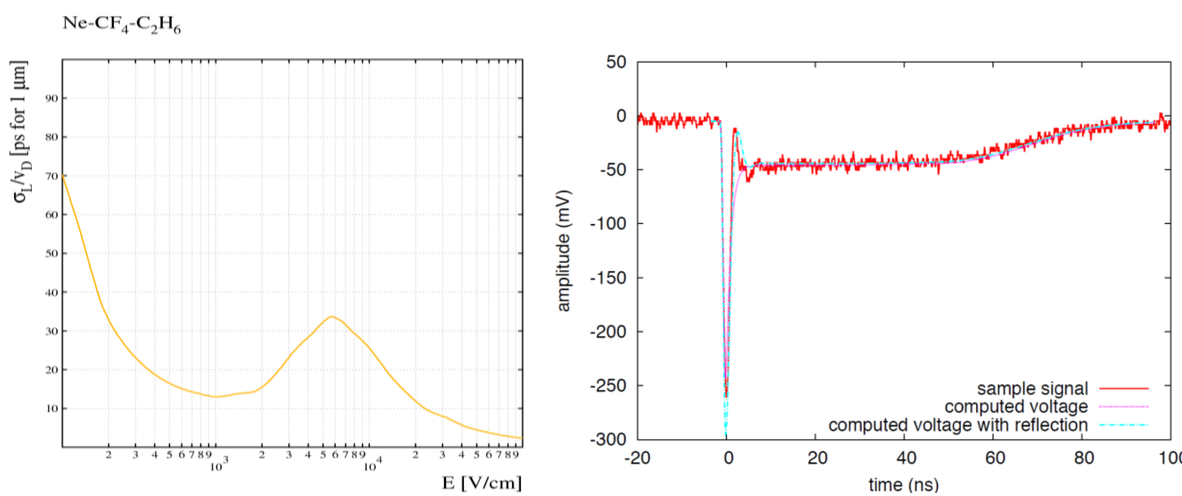
Photoelectron response (laser)



(Clean) MIPs Response (test beam)



Robust data analysis

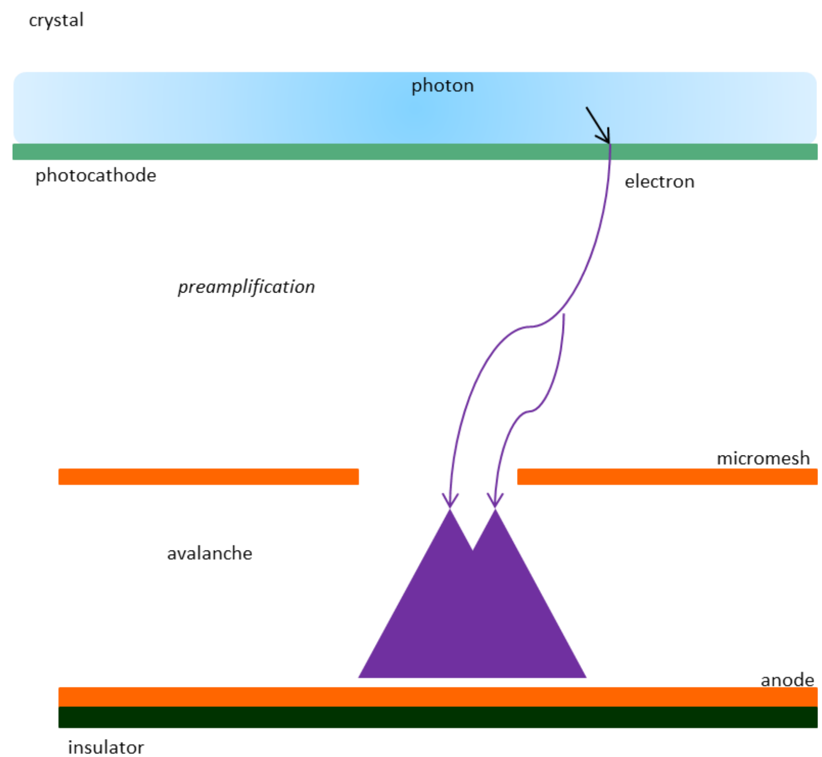


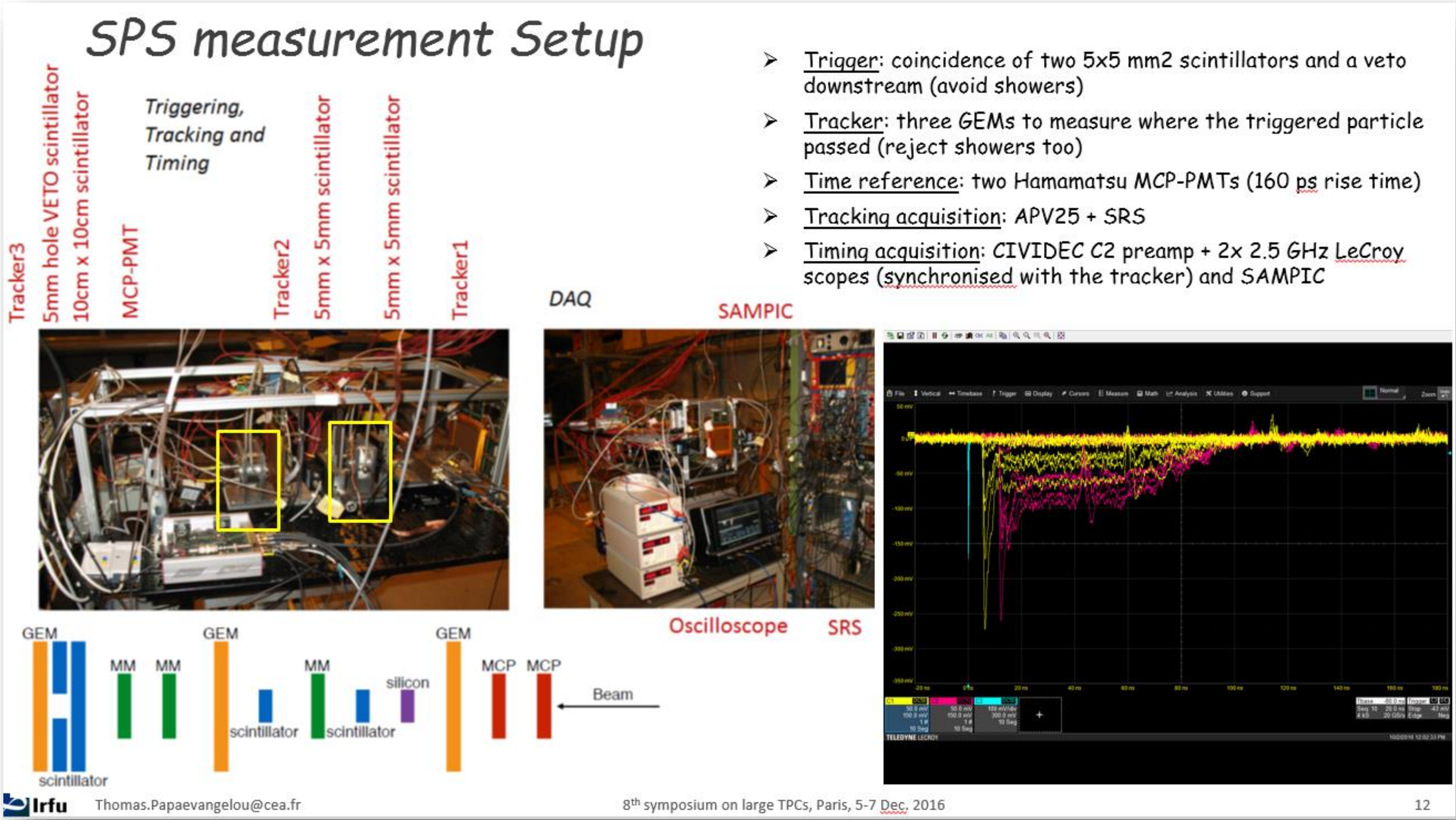
Simulation (and prediction) of Induced Signal

2016 Test Beam Campaign

150GeV muons, SPS North Area Extraction lines, RD51 Test beam (H4 area)

- Picosec Readout: Cividec C2 GHz, 40 db preamplifier acquired via (LeCroy) Oscilloscope
- Timing: MCP-PMT (see S. White talk after)
- Triggering: small active area (efficiency) 5x5mm^2 with preliminary veto for single muon selection or large area (border effects) 2x2cm^2 scintillators
- Tracking: triple GEM tracker (secondary veto for single muons selection, spatial response of picosec)

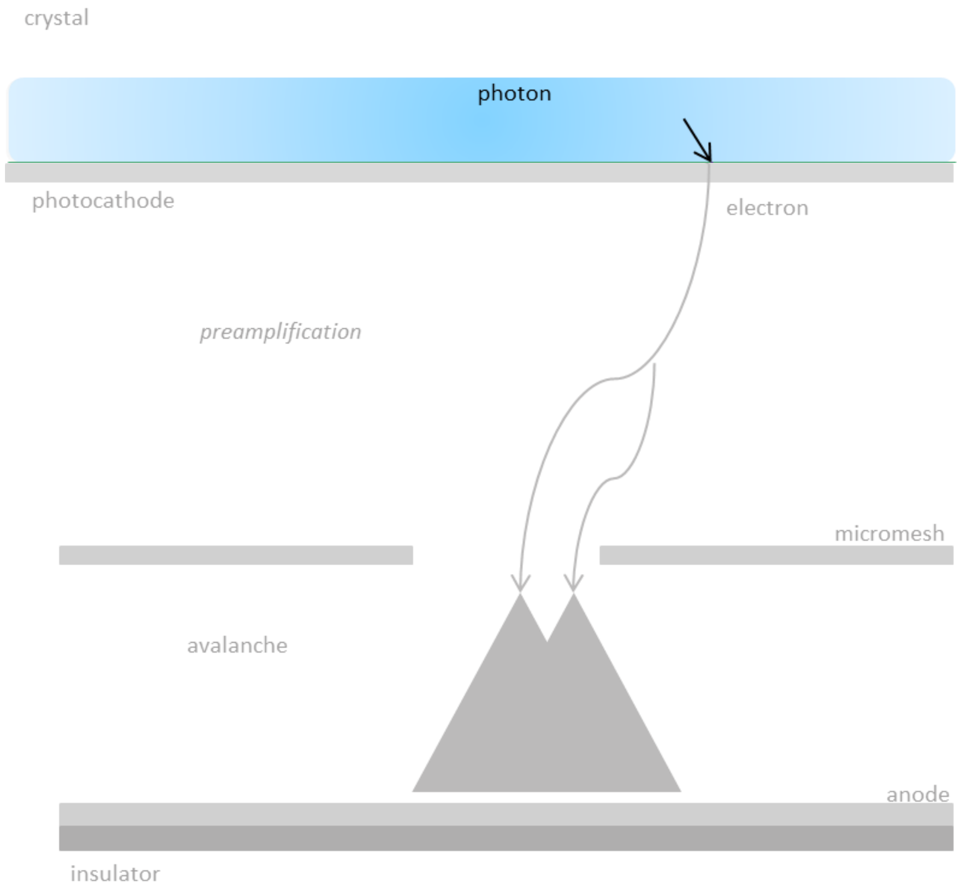




Signal (Timing,amplitude) info from Oscilloscope (Picosec/MCP-PMT)
Synchronization with SRS-APV25 GEM tracker (J. Bortfeldt) for uniformity/border effects/…

Analysis tools almost finalized (Spyros)… Binary data conversion and compression (Yi) ready to start

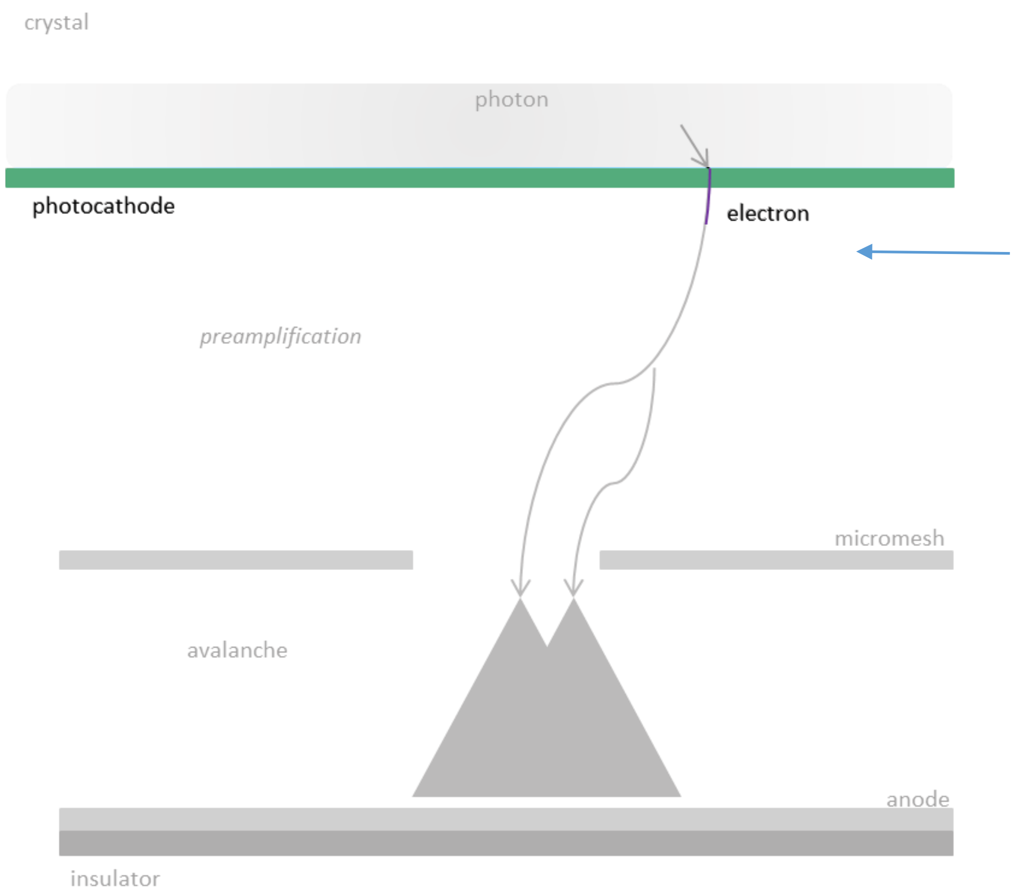
Radiator



Crystal:

- Different Thicknesses of MgF2 (2,3,5mm)
- Different MgF2 producer

Photocathodes



Photocathodes:

CsI

- different "producer" (CERN, Saclay, Hamamatsu)
- different thicknesses (11, 18, 25, 36nm)
- different metallic layer (Al, Cr)
- different metallic layer thickness (Cr 3,5.5nm)

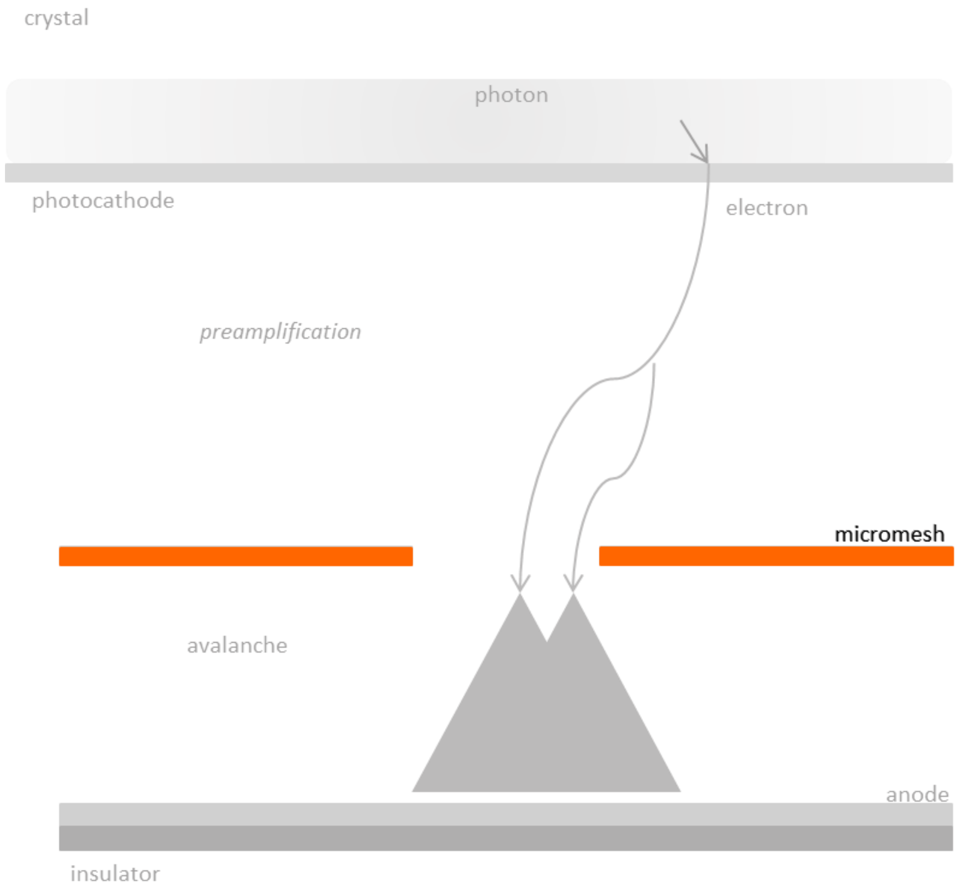
Metallic

- Al, Cr (10,15,20nm)

Diamond

- B-doped Diamond on Cr

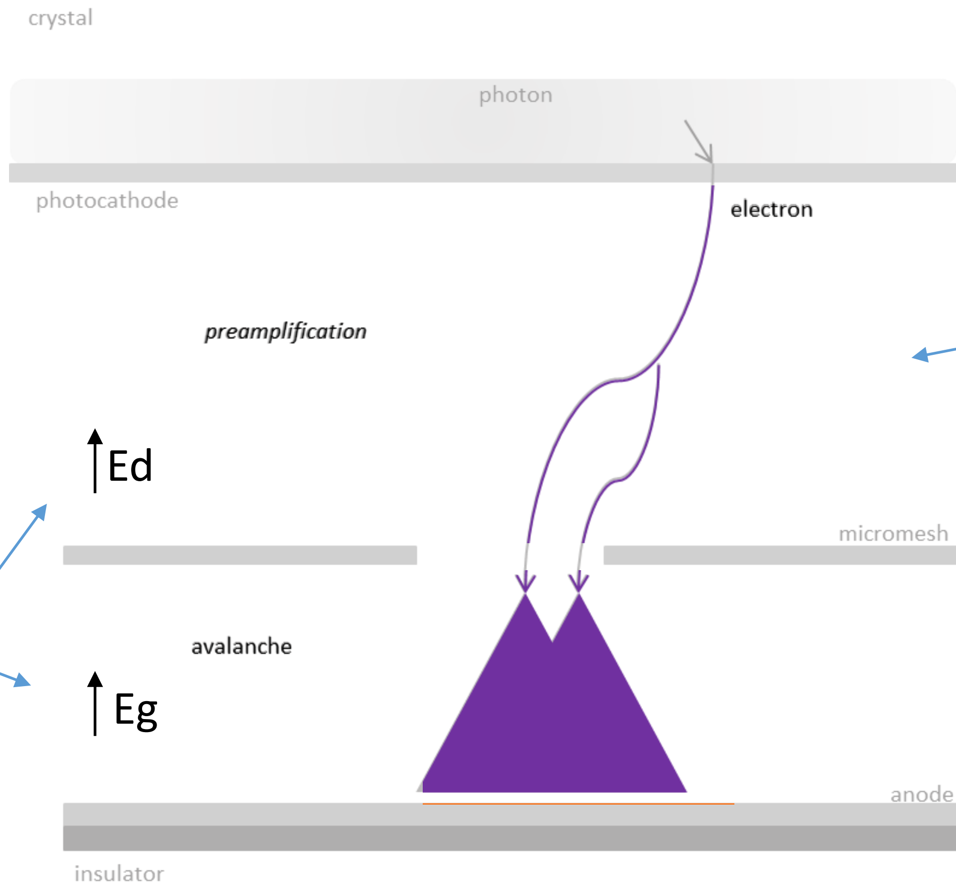
Sensor (Micromegas mesh)



Different Meshes Tested:

- standard bulk
- bulk with reduced number of pillars
- thin mesh
- micro-bulk (laboratory tests)

Gas and Fields



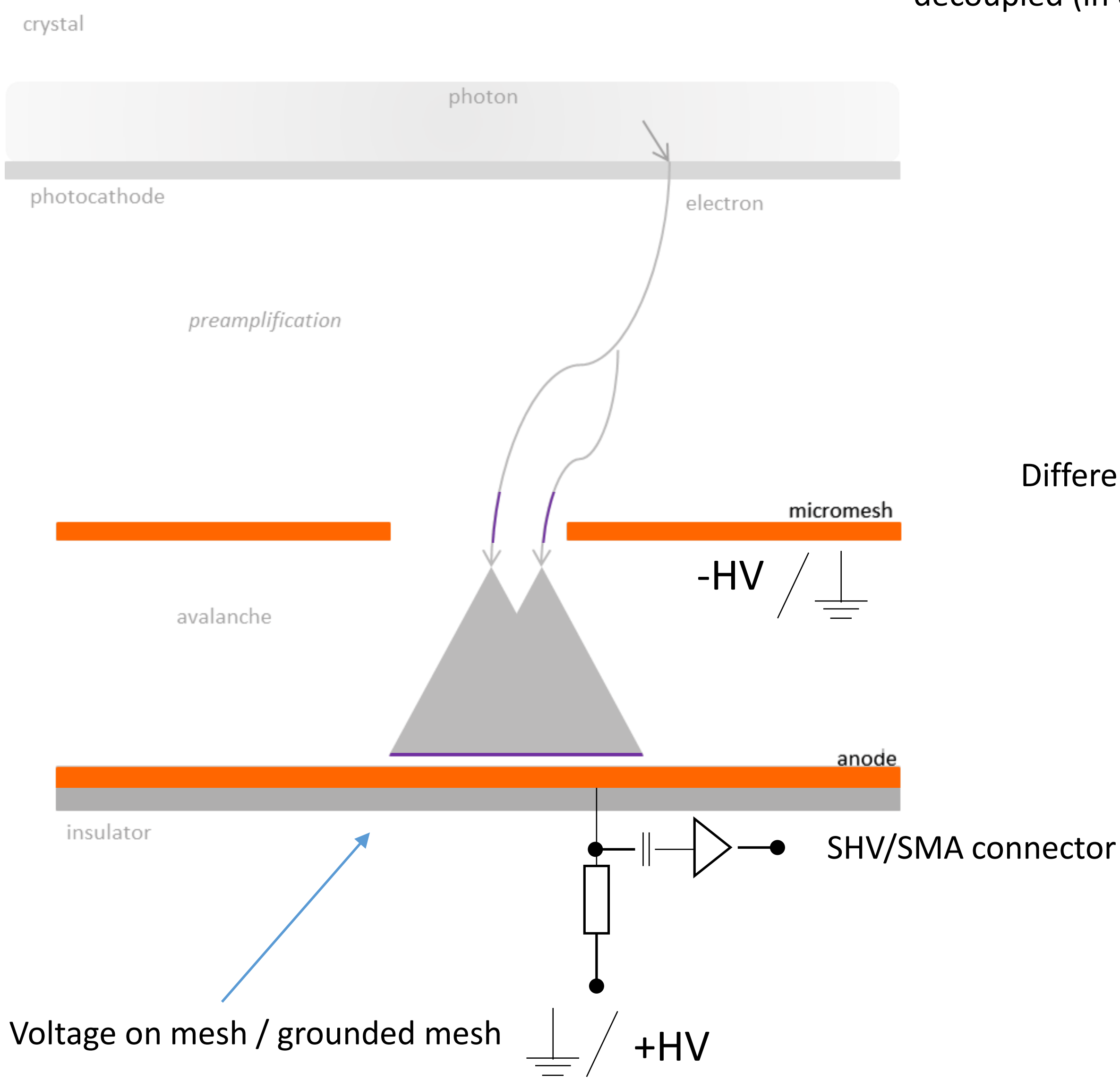
Test at different gas mixture

Test at different fields

Grounding and Signal routing

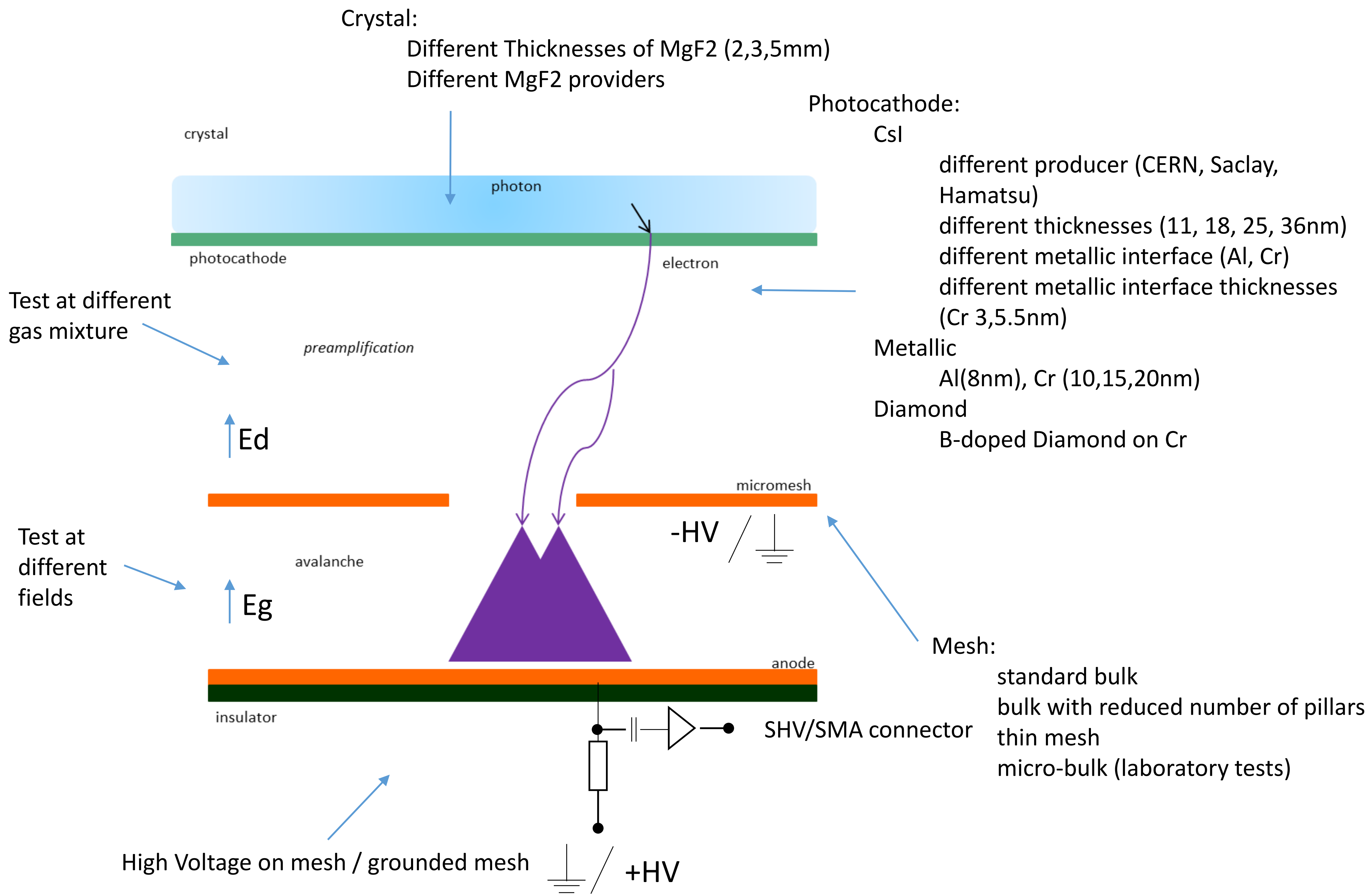
Important Improvement in the Signal Integrity

Mesh ground: amp and drift field (more) decoupled (in case of sparks)



Different grounding configuration

High Voltage on mesh / grounded mesh



Crystal:
Different Thicknesses of MgF2 (2,3,5mm)
Different MgF2 providers
Photocathode:
CsI
different producer (CERN, Saclay, Hamatsu)
different thicknesses (11, 18, 25, 36nm)
different metallic interface (Al, Cr)
different metallic interface thicknesses (Cr 3,5.5nm)
Metallic
Al(8nm), Cr (10,15,20nm)
Diamond
B-doped Diamond on Cr
crystal
photon
photocathode
electron
Test at different gas mixture
preamplification
Ed
micromesh
-HV
Test at different fields
avalanche
Eg
anode
insulator
Mesh:
standard bulk
bulk with reduced number of pillars
thin mesh
micro-bulk (laboratory tests)
SHV/SMA connector
High Voltage on mesh / grounded mesh
+HV

2017 R&D Activities

Intrinsic Resolution (pure detector physics R&D):
- photoelectrons extraction (crystal, photocathodes,…)
- gas and fields optimization
- meshes and gaps

Detector Optimization (towards application):
- photocathode aging: measurement and improvement (protection layer, metallic photocathodes, diamond,…)
- photocathode robustness: sparks
- Resistive micromegas

Detector Scaling (towards application):
- multi-anode readout
- Larger area

2017 R&D Activities

To be ready to face future problems

Detector Optimization (towards application):

photocathode aging: measurement and improvement (protection layer, metallic photocathodes, diamond,…)

photocathode robustness: sparks

CsI…

How to preserve its properties.. *Not necessarily bad but for sure difficult to handle in some applications*

CsI Aging (std units $\mu C/cm^2$-mm^2) and sparks (protecting, quenching..)

From literature…

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

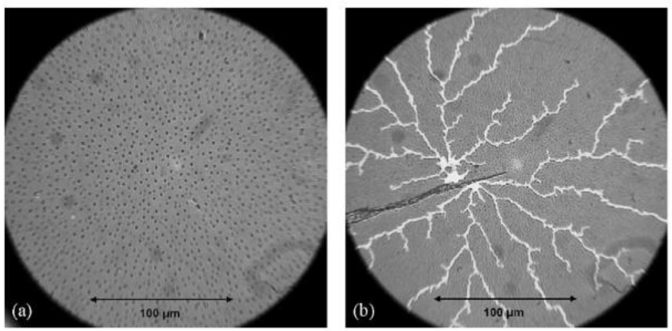
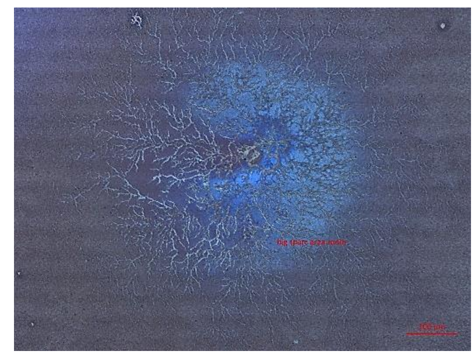


Fig. 5. Microscope images of two semi-transparent photocathodes. The left figure shows a fresh photocathode. The photocathode in the right picture shows the destruction caused by a spark in the detector. To make the usually clear CsI layer visible, the photocathodes have been exposed to humid air before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

From the August Test Beam…..



Picosec (T. Schneider)

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)

2017 R&D Activities

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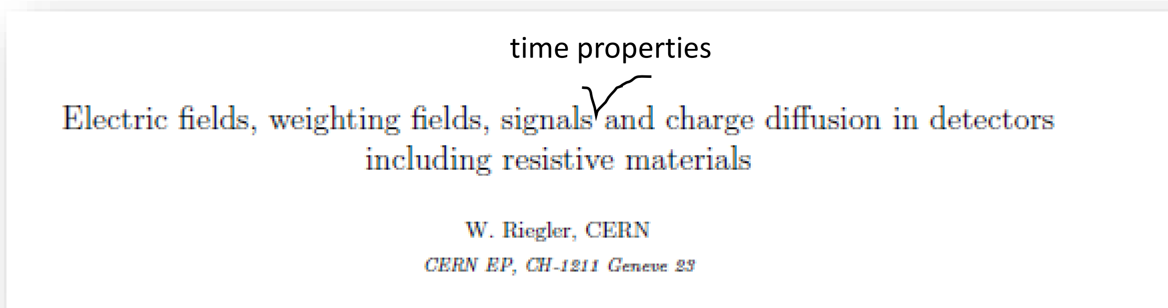
Resistive Micromegas… More stable and spark quenching…

Resistive Micromegas

First step… same detector size as now (single channel, 1cm diameter active area)
Easy to test… no needs of beam… a lighter will be enough…

Induced Signal (analytical and simulation)
Interest expressed already by Supratik/Nayana…

Maybe the next task for W. Riegler: timing properties of induced signal in presence of resistive material…


time properties

Electric fields, weighting fields, signals and charge diffusion in detectors including resistive materials

W. Riegler, CERN
CERN EP, CH-1211 Geneve 23

2017 R&D Activities

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- photocathode aging: measurement and improvement (protection layer, metallic photocathodes, diamond,…)
- photocathode robustness: sparks

Metals…
Not 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 (parallelepipedes)….
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

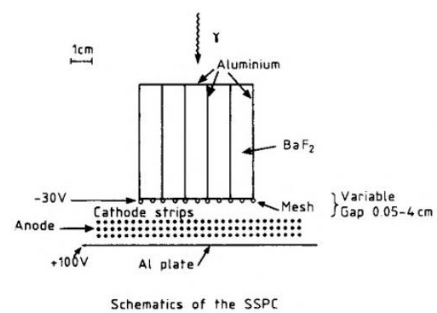
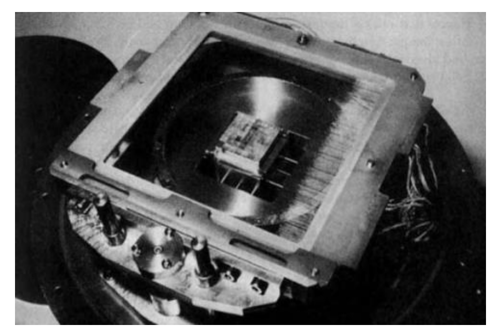


Fig. 1. Schematics of the SSPC.



2017 R&D Activities

To be ready to face future problems

Detector Optimization (towards application):

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(protection layer, metallic photocathodes, diamond,…)
photocathode robustness: sparks

New materials..
Diamond … the first one we are looking more deeply….

Diamond…. as photocathodes… or as secondary emitter… ongoing activities and different "collaborators-producer" involved

Saclay (Pomorski et al) … tested already on beam

Aveiro (Joao Veloso et al)… sample in the lab to be tested

Russian Academy of Sciences, Moscow (Mikhail Negodaev)… preliminary sample in the lab, partially tested, new production ready to go after specs defined more precisely

Detector Scaling (towards applications):

Larger area.. MgF2.. 50mm standard production … possible to go for larger area too…

preserving the signal integrity and stability with ***larger meshes***

preserving the ***gaps uniformity*** on larger surfaces

…

multi-anode readout *(*standard Micromegas 2x2, 4x4,.. Pads of about 1cm^2*)*

preserving signal integrity with routing/vias/…

coupling between channels and S/N

….

multi-anode readout with Resistive Micromegas (resistive layer, discrete/embedded resistors,…)

Electronics...

Cividec for sure at the beginning but some new development (amplifier) could be needed to cope with a larger numbers of channels

Oscilloscopes and multichannel fast digitizer (SAMPIC,..)

Summary

- Successful measurement campaigns in 2016
  - Less than 50ps - "100%" efficient (MIPs) - achieved with CsI

  (in one of the good configuration, not necessarily in one of the best ones)

- Complete analysis of the different configurations tested to be done
  - To quantify and verify the actual feeling we have on the collected data

- Interesting and exciting R&D (not exclusively Picosec related) in front of us
  - Touching the intrinsic limit…
  - Detector Optimization (***new photocathodes, protection layer, secondary emitter***,.., resistive mm)
  - Detector Scaling.. Larger area and multi channel

Mandatory in view of certain applications
Large community (not only in our field) involved on this subject