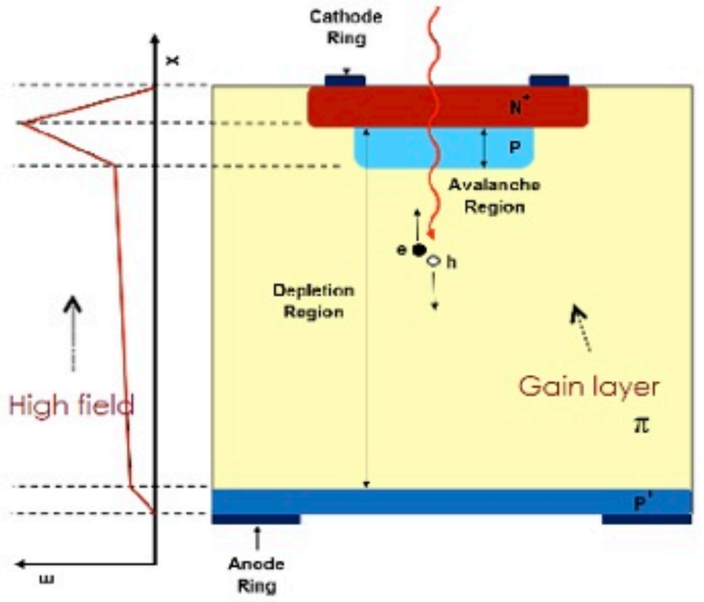
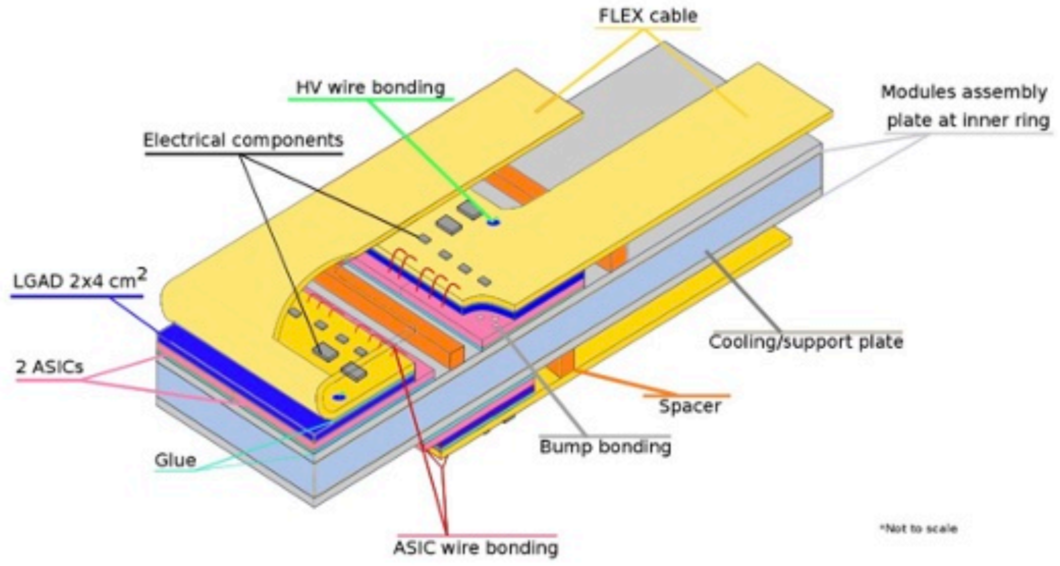
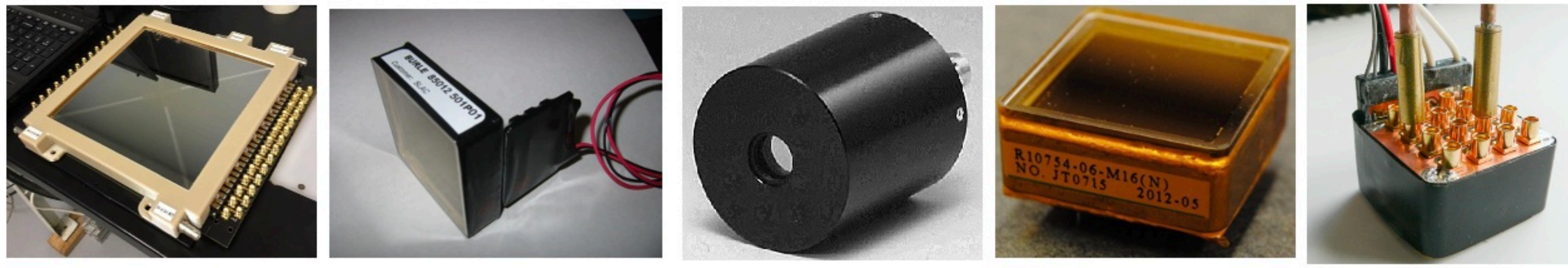
Recent Developments in PICOSEC: Precision Timing with MicroMegas

Low gain APDs

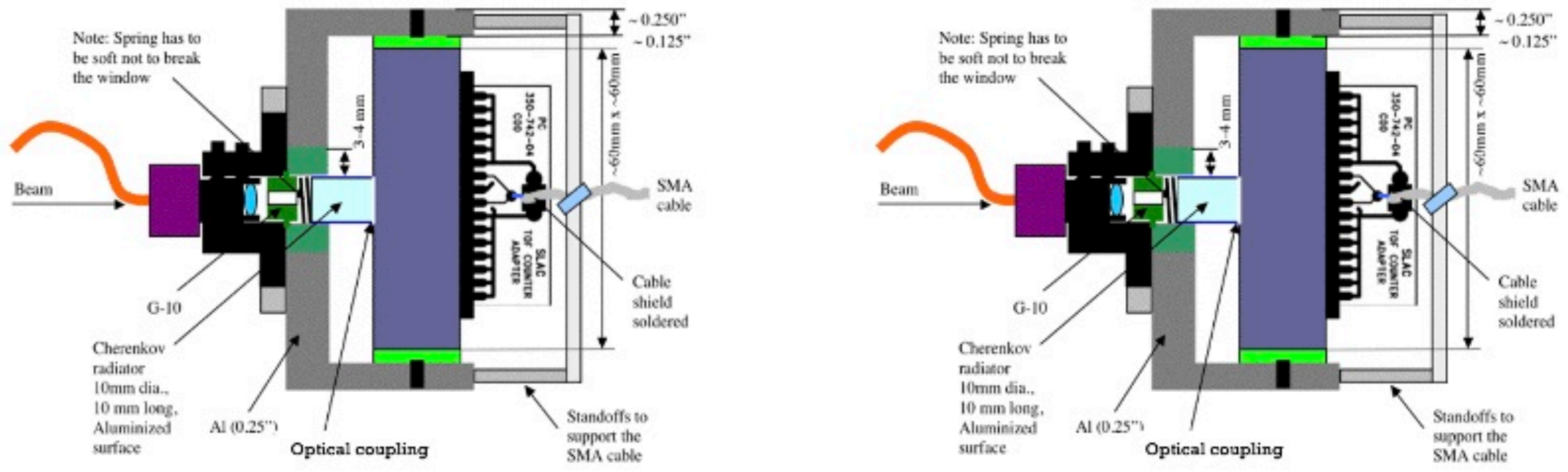




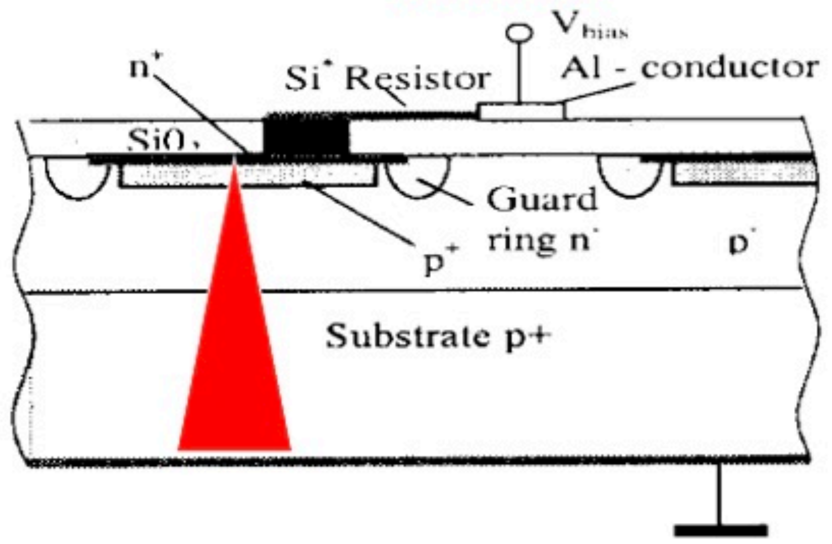
MCP-PMT shown without a fused silica radiator:



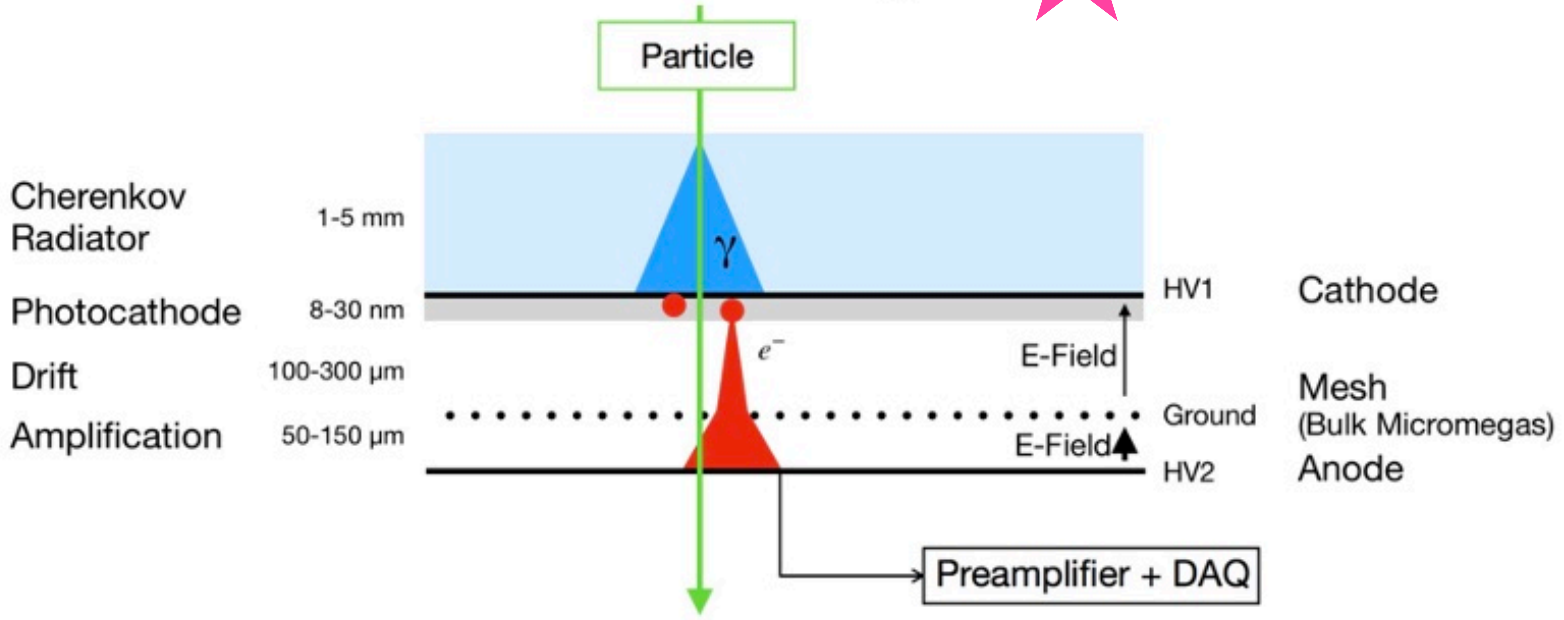
Example:

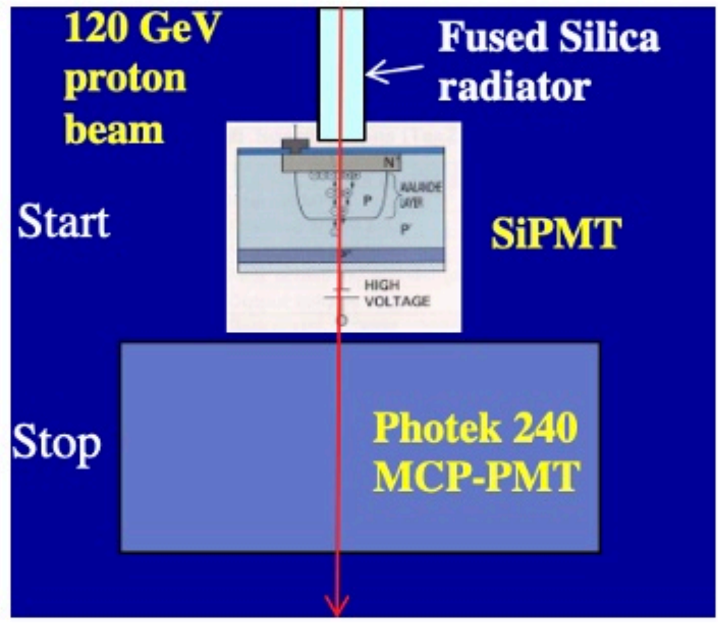


G-APD (SiPM)

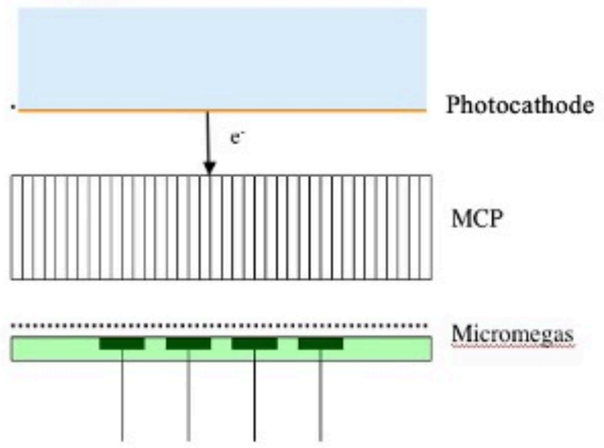


Micromegas ★

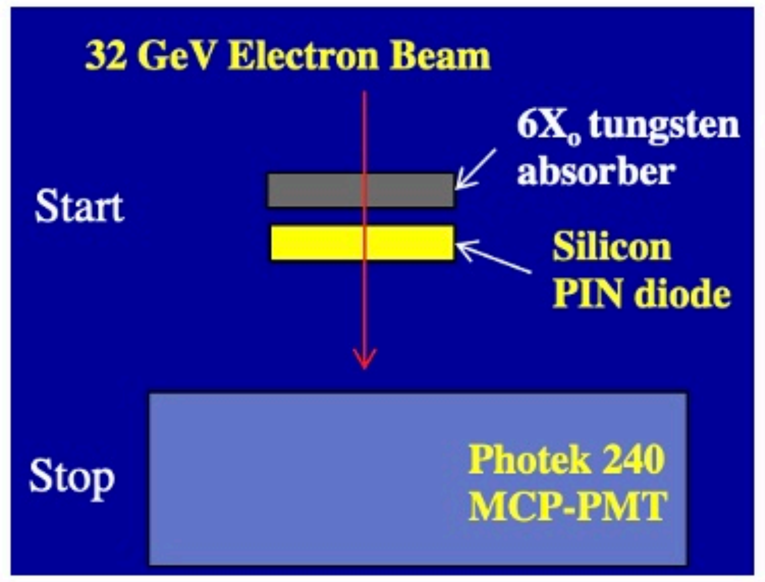




Micromegas + MCP

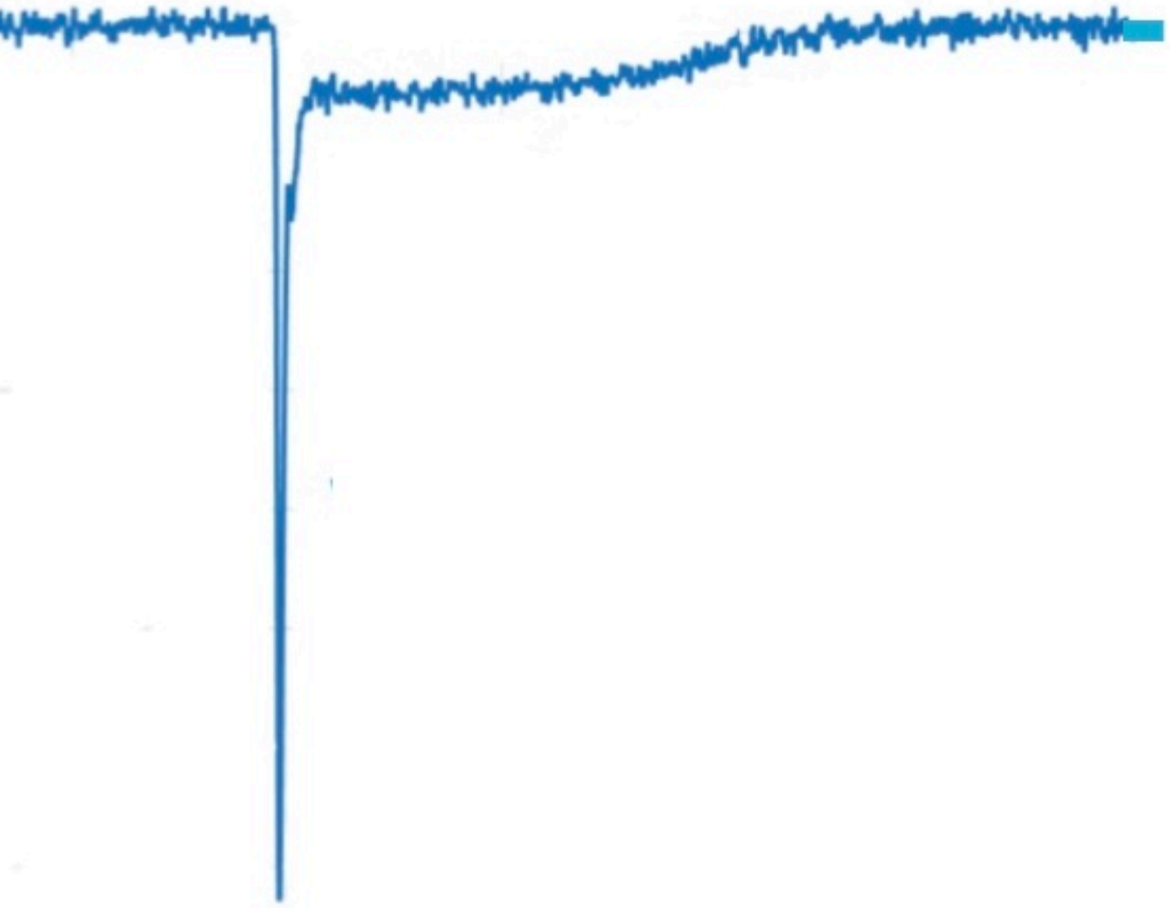


PIN diode + radiator



Slide courtesy of J. Va'vra

Sebastian White, CERN/U Va. FNAL Research Techniques seminar April 10 , 2023

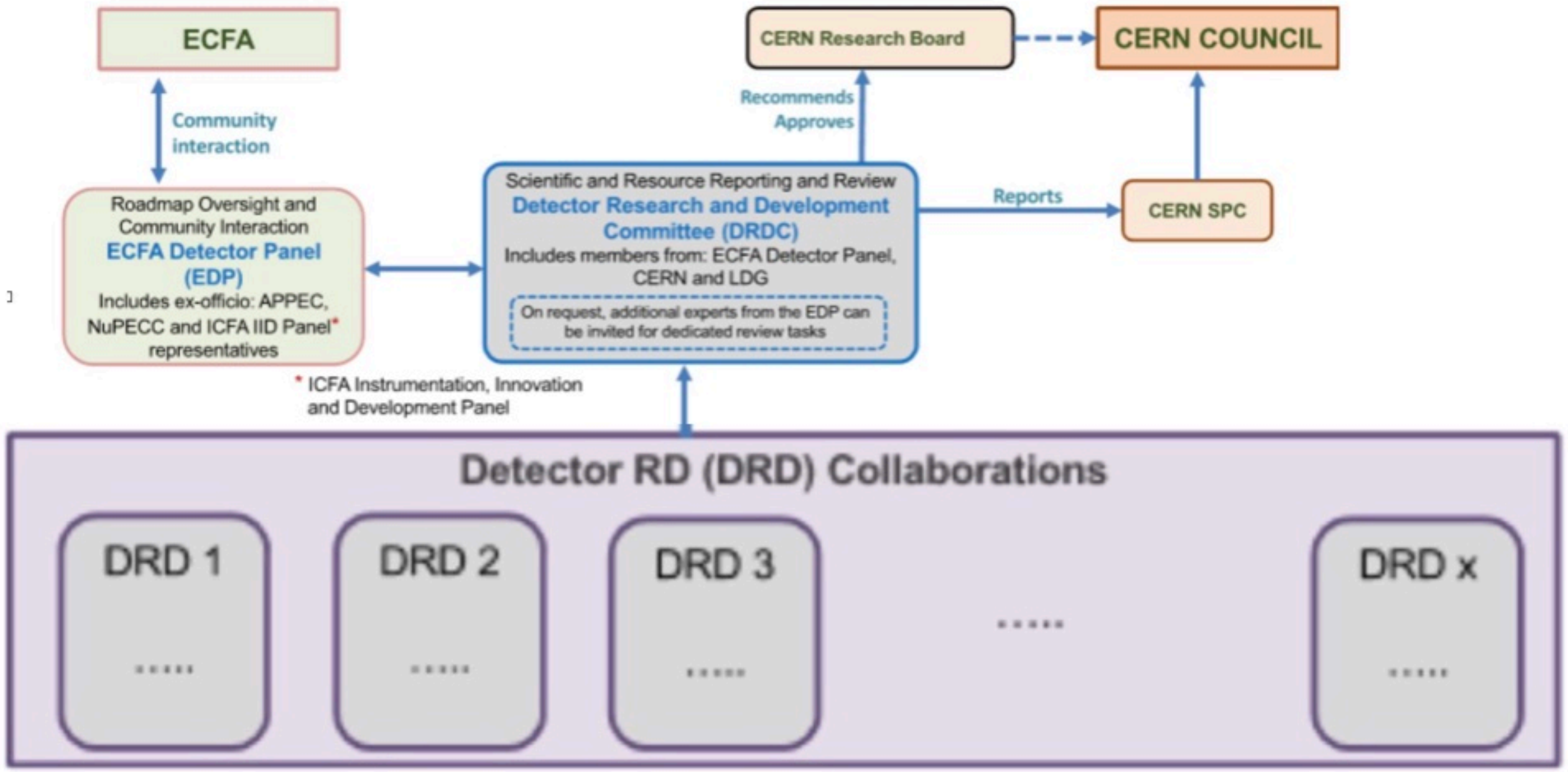


Outline

- I spent last decade at CERN in 2 R&D groups-> comments on that environment
- PICOSEC launched as RD-51 “Common Project” in 2015 -(SNW& I. Giomataris)
- Will report on milestones in evolution from concept to <20 picosecond, scalable
- Challenges for future in context of ECFA roadmap

My Personal Comments on European Experience:

Detector R&D structures: then and going forward



- “DRD” research categories meant to evolve from existing structures: RD50, RD51….created partly leading up to the LHC experiments.
- These (ie RD50, RD51..) will be terminated at end of 2023.

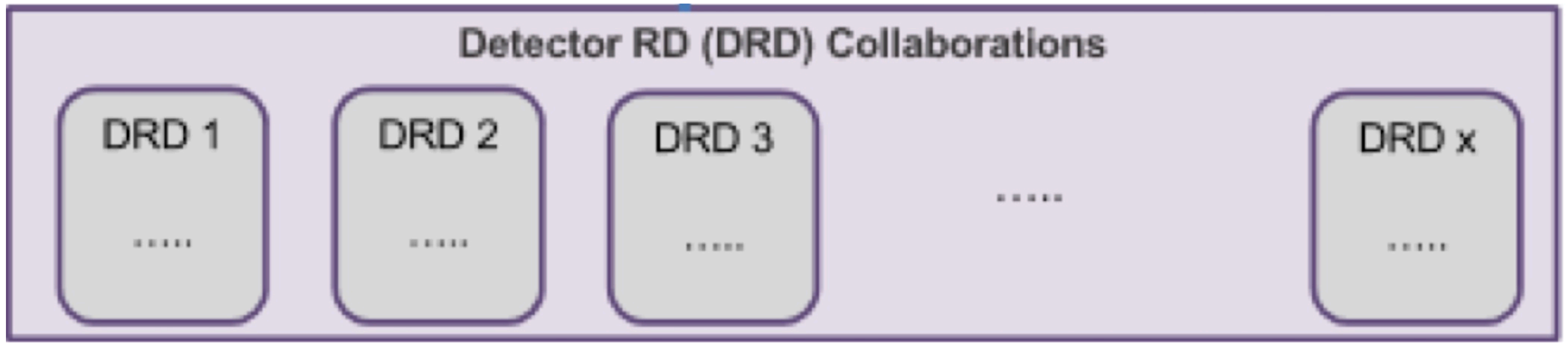
More on previous research structure:

- The “RD” collaborations available to researchers worldwide.
    - With access to funding beyond CERN- similar to future “DRD”
- CERN DD groups funded by CERN (’til end 2023). I worked in:
    - SDD- Silicon detector development group (M. Moll et al) and
    - GDD- Gas Detector Development group (formerly Charpak group)
- Hard to overstate benefits from related CERN centers:
    - Micro-electronics, LHC Instrumentation, CERN MPT workshop….
    - CERN PS & North Area test beams + experienced radiation facility

Many Examples of significant contributions to LHC experiments:

- RD51-> ATLAS new small wheel, ALICE TPC upgrades….
- RD49 -> expertise in rad effects in DC-DC…

IMHO: Benefits from Many in 1 campus(probably less so in DRD structures)..



As will see below for PICOSEC, relevance in many of these:

DRD 1	(Gas Detector)	Yes
DRD 2	(Liquid)	No
DRD 3	(Solid State)	A bit
DRD 4	Photo (PID)	Yes

DRD 5	Quantum	?
DRD 6	Calorimetry	?
DRD 7	Electronics	Yes
DRD 8	Integration	?

Geography of Olivieri respondents on DRD1 (Gas detectors)

Contrast this with US CPAD R&D structure

(RDC1) Noble Element Detectors: **cpad_rdc1@fnal.gov**

(RDC2) Photodetectors: **cpad_rdc2@fnal.gov**

(RDC3) Solid State Tracking and Picosecond Timing: **cpad_rdc3@fnal.gov**

(RDC4) Readout and ASICs: **cpad_rdc4@fnal.gov**

(RDC5) Trigger and DAQ: **cpad_rdc5@fnal.gov**

(RDC6) Gaseous Detectors: **cpad_rdc6@fnal.gov**

(RDC7) Low-Background Detectors: **cpad_rdc7@fnal.gov**

(RDC8) Quantum and Superconducting Sensors: **cpad_rdc8@fnal.gov**

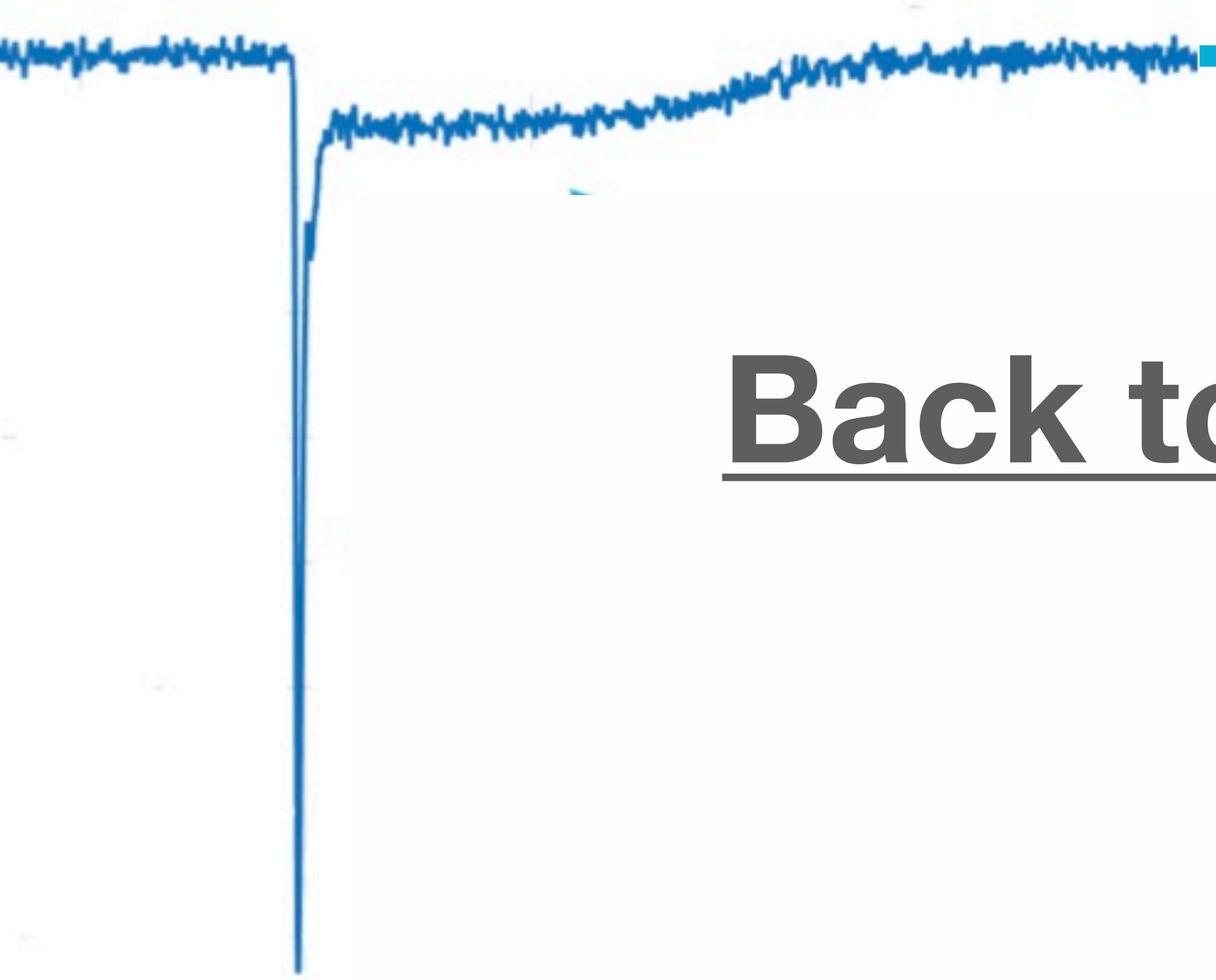
(RDC9) Calorimetry: **cpad_rdc9@fnal.gov**

IMHO very strange to break from
Technology organization of ECFA
To designate RDC3 as “timing”

What about RDC2?
Never heard of LAPPD?

What about Gaseous detectors? RDC6

Many proposals to do timing in
Calorimetry (RDC9)



OK. Enough with Comments.

Back to PICOSEC- Topic for rest of this Talk

Origins

- Since ~1990's demonstrations of <100 picosec MIP timing in Low Gain AD's (ie EGG)

- In 2010 with K. McDonald proposal for Deep Depleted Avalanche Diode(DDAD) timing to Accelerator Test Facility (AE-55)

See:

http://kirkmcd.princeton.edu/LHC/White/clermont_white.pdf

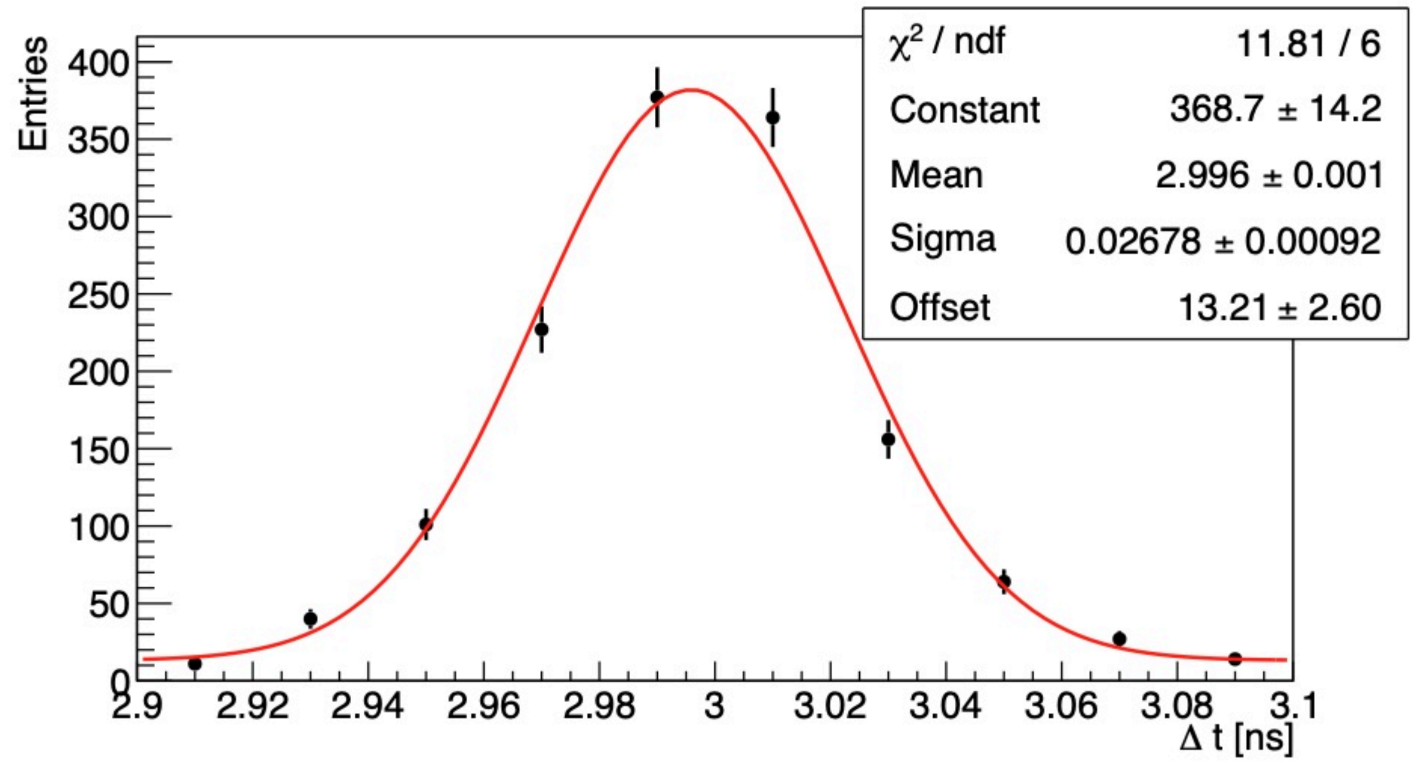
- Continued in SDD group @ CERN & Completed in 2018

- Good Timing, Hard to Manufacture

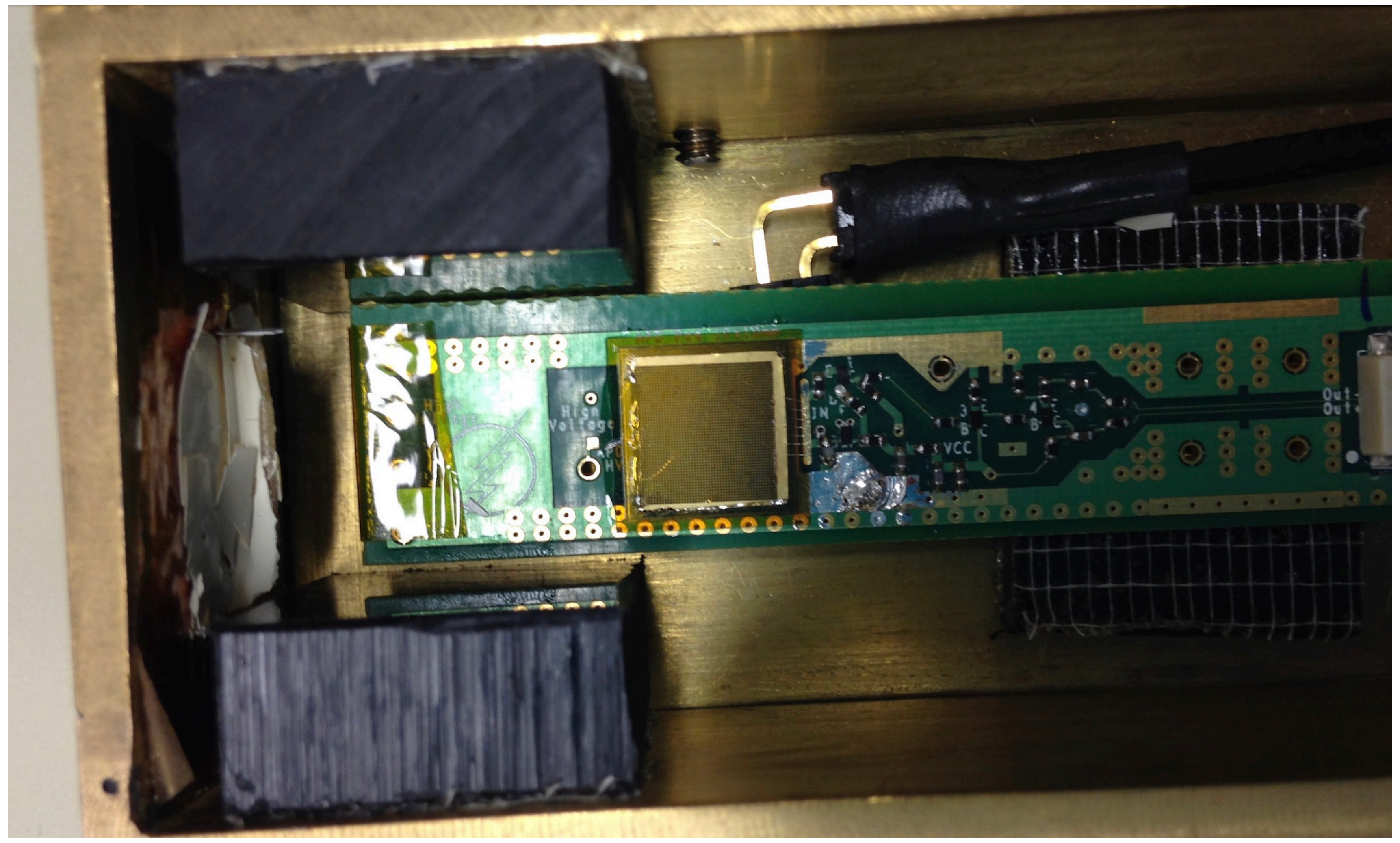
See NIM:

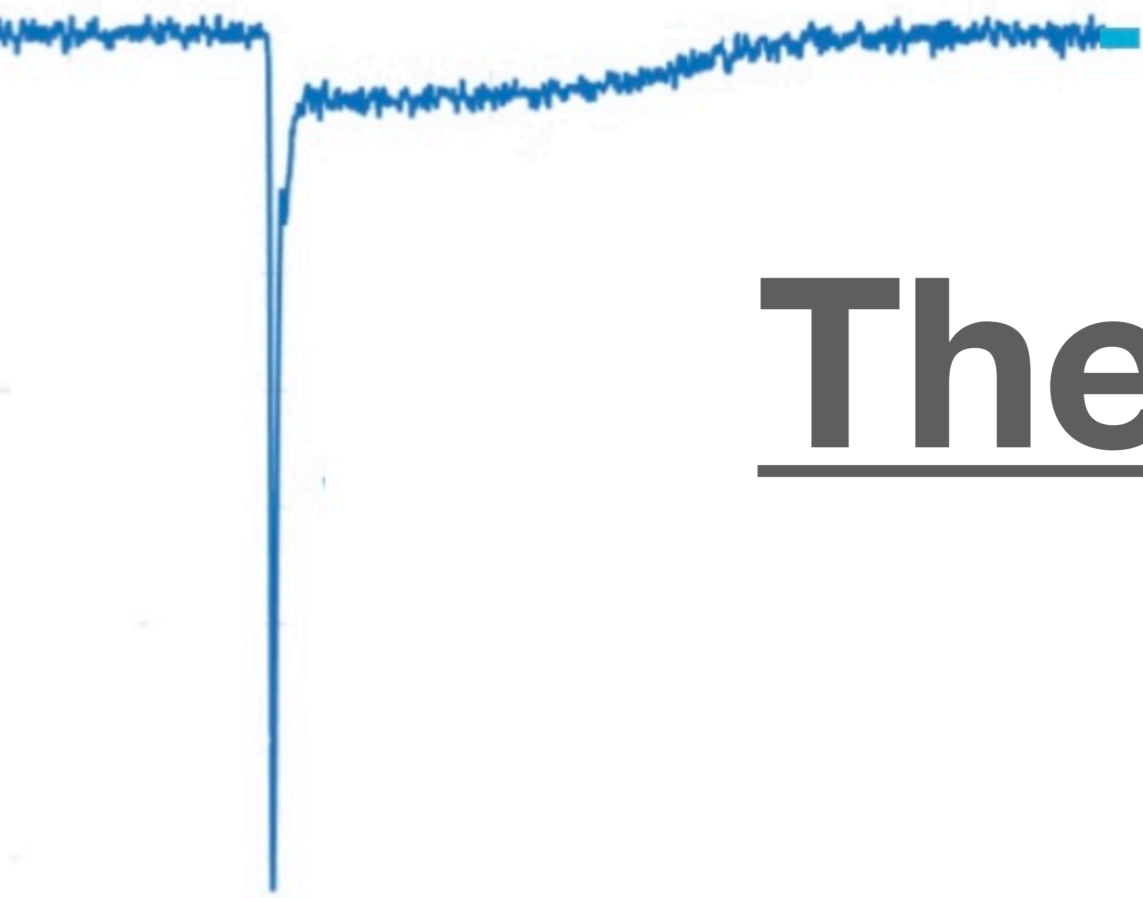
https://doi.org/10.1016/j.nima.2019.162930

<30 picosec RMS

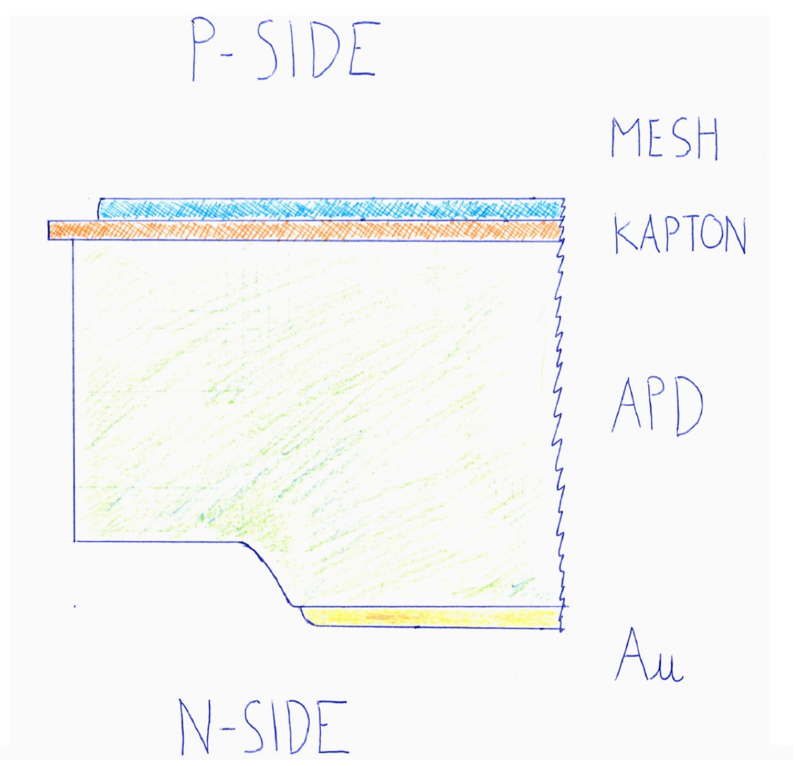


64 mm² DDAD sensor
With Mesh (ie AC-coupled) readout
Mounted on U. Penn
Fast TransImpedance Amp

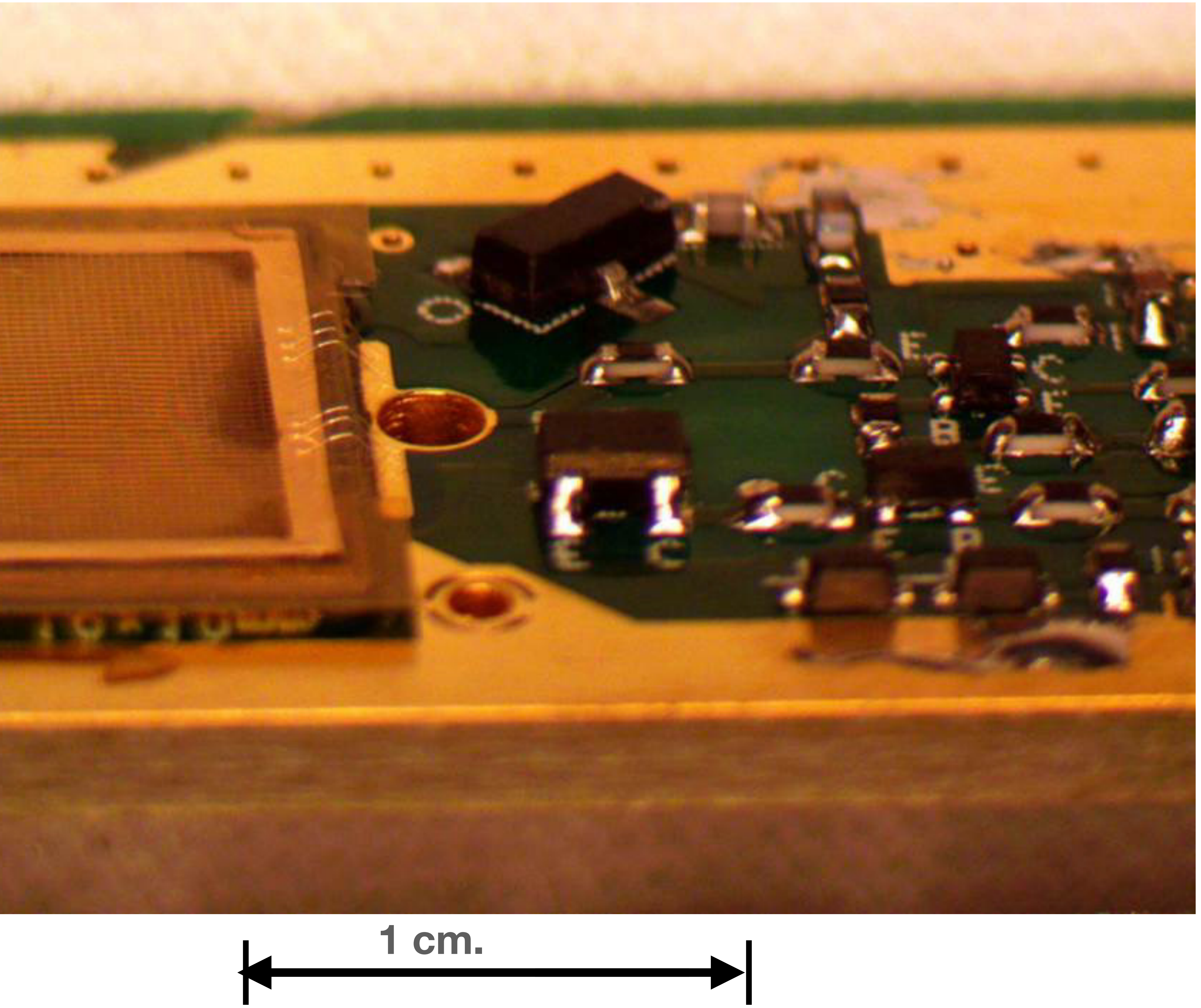




APDs with Mesh (AC coupled) Readout



The RD51 Connection



- We realized in 2012 that AC coupled readout
  -> control of timing uniformity.

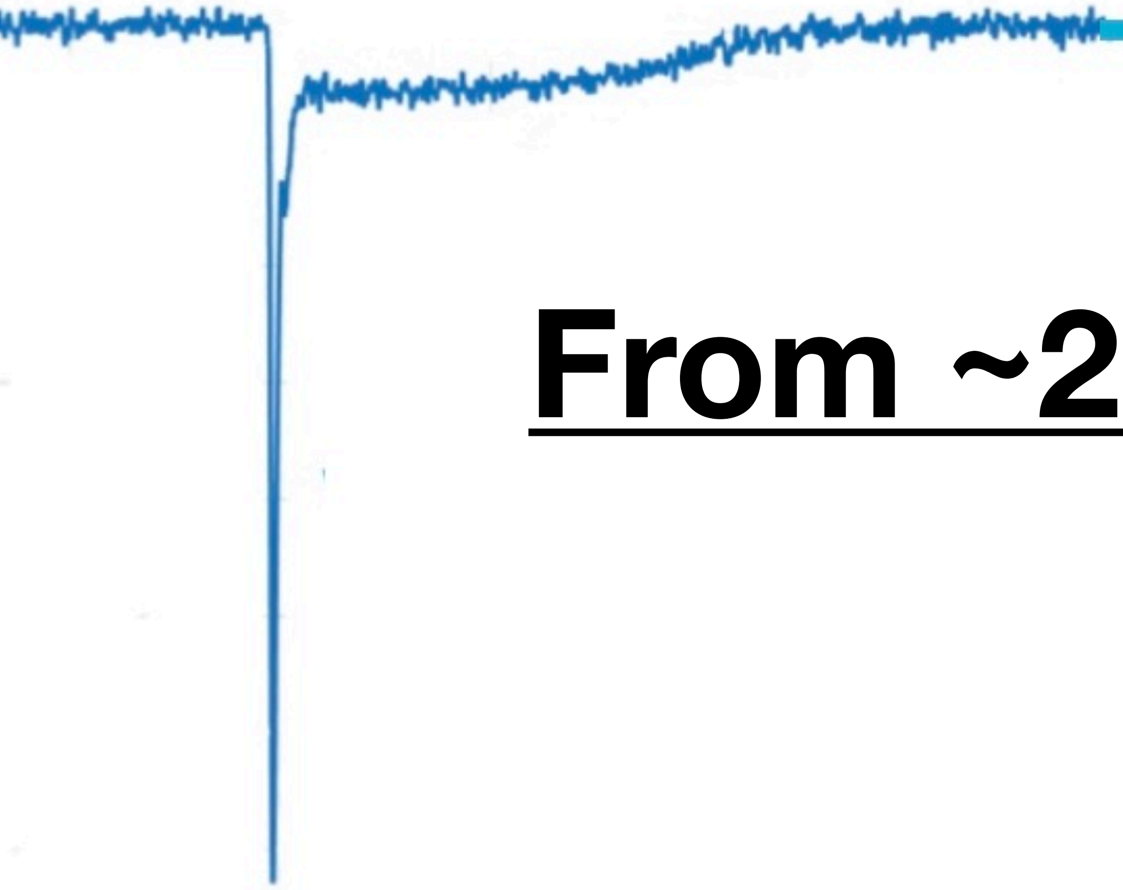
- However, Femto-second UV lasers indispensible for detector development.

- At the time many interactions w. Saclay/Orsay and RD51.

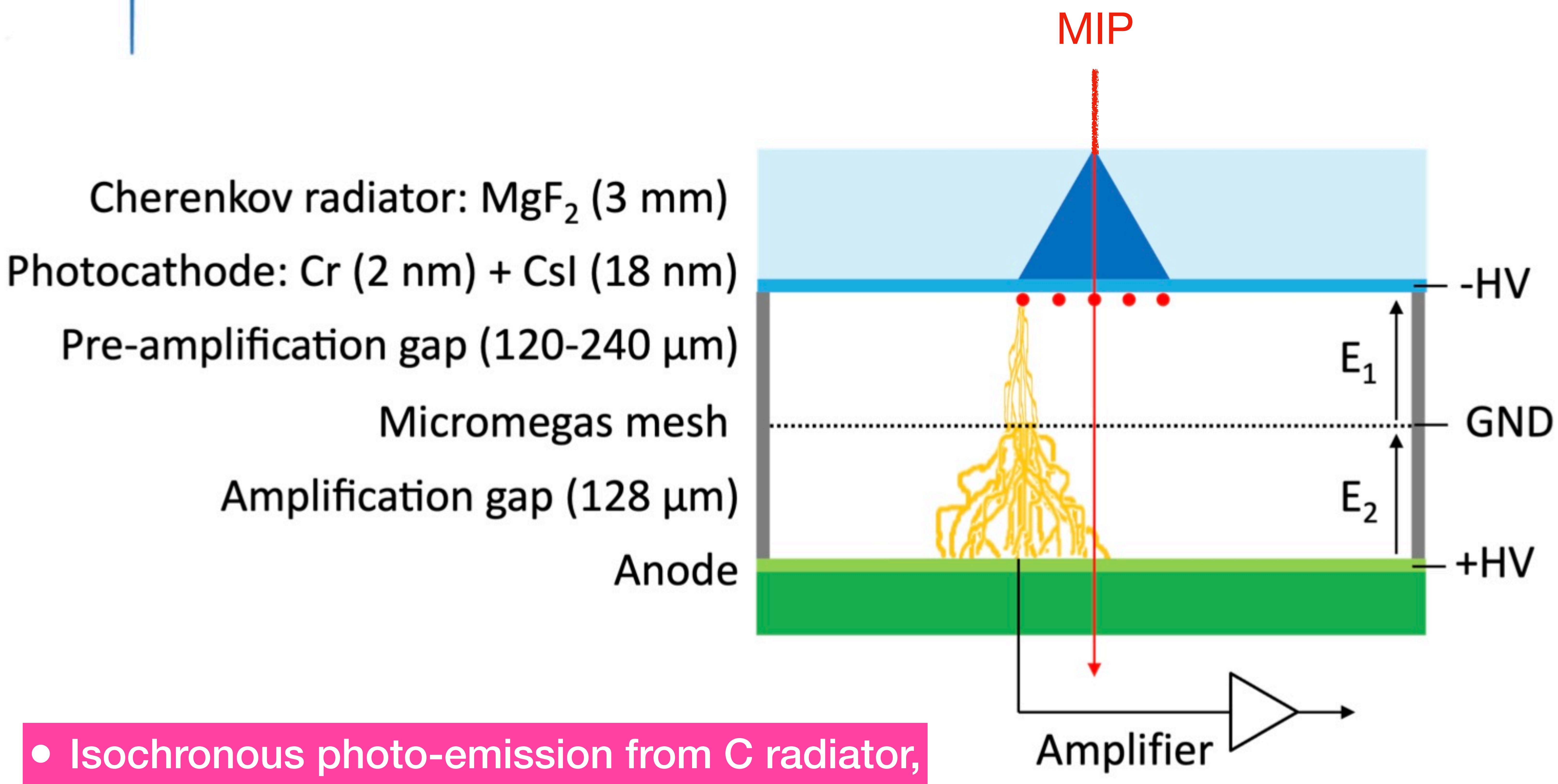
—>MicroMegas mesh for AC coupled terminal.

Published in 2013.

S. White,Proceedings, International Conference on Calorimetry for the High Energy Frontier (CHEF 2013) : Paris, France, April 22-25, 2013, 118-127



From ~2 nanosec to <20 Picosecond Timing in MPGD*

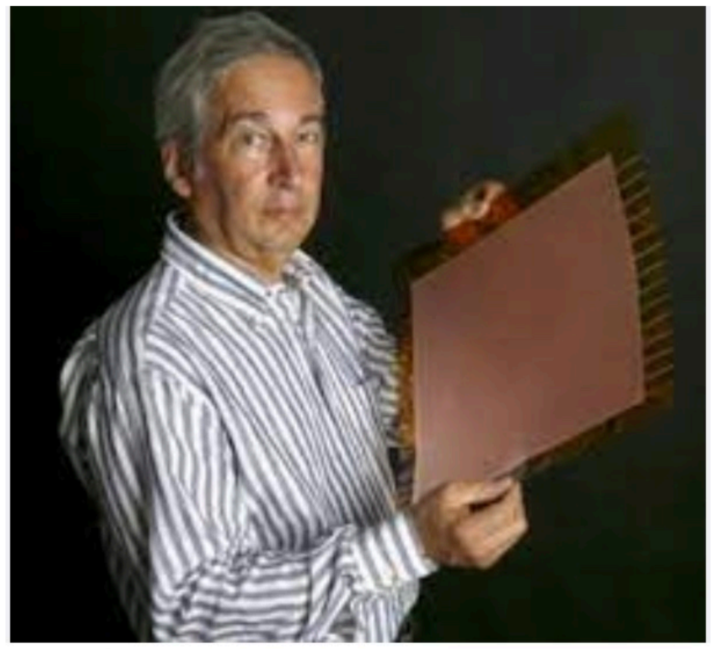


- Isochronous photo-emission from C radiator,
- Thin Prer-amp Gap
- High Field in " "

Mandatory Reading

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE

CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH



DRIFT AND DIFFUSION OF ELECTRONS IN GASES: A COMPILATION

(WITH AN INTRODUCTION TO THE USE OF COMPUTING PROGRAMS)

Anna Peisert

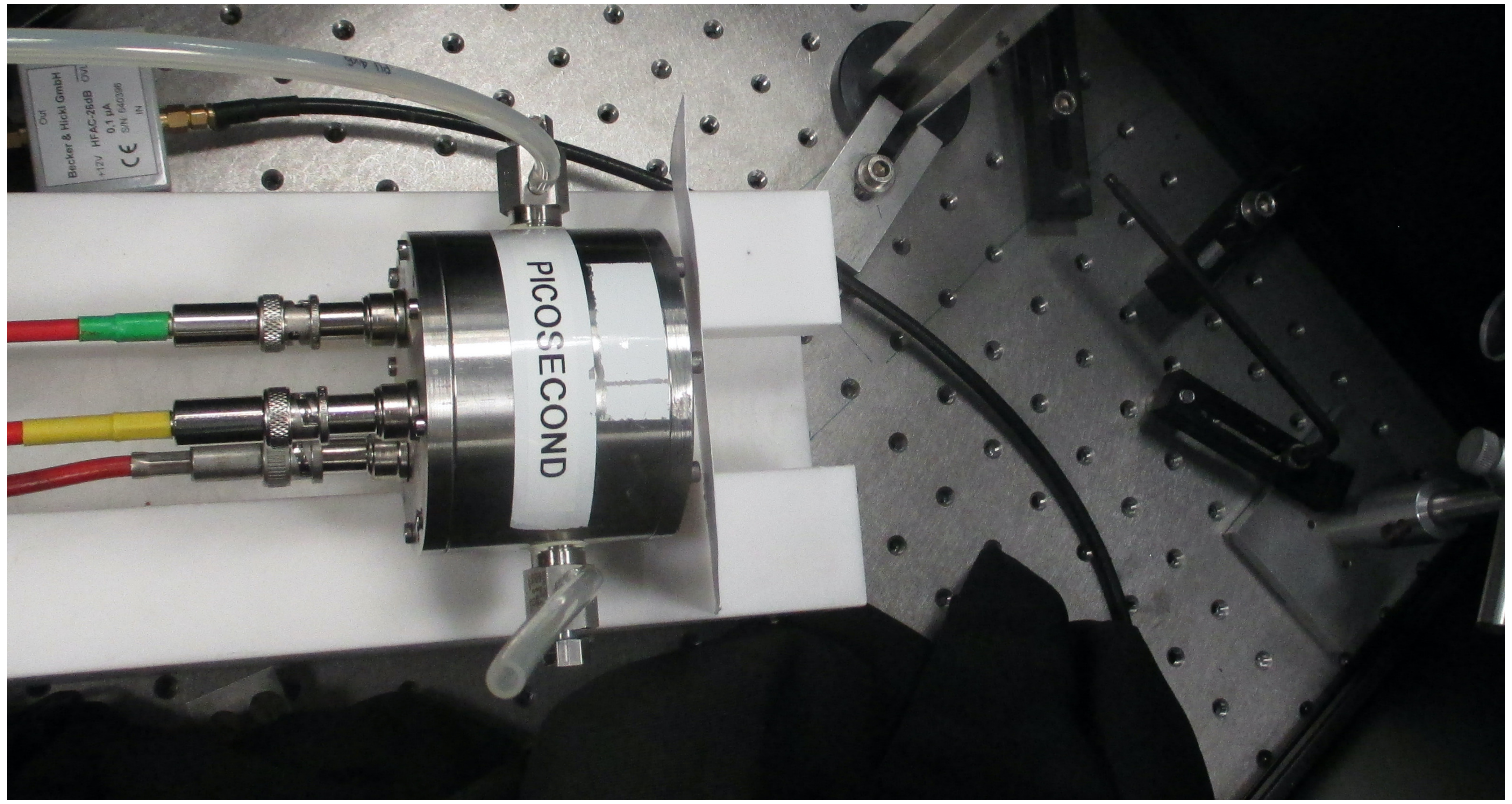
and

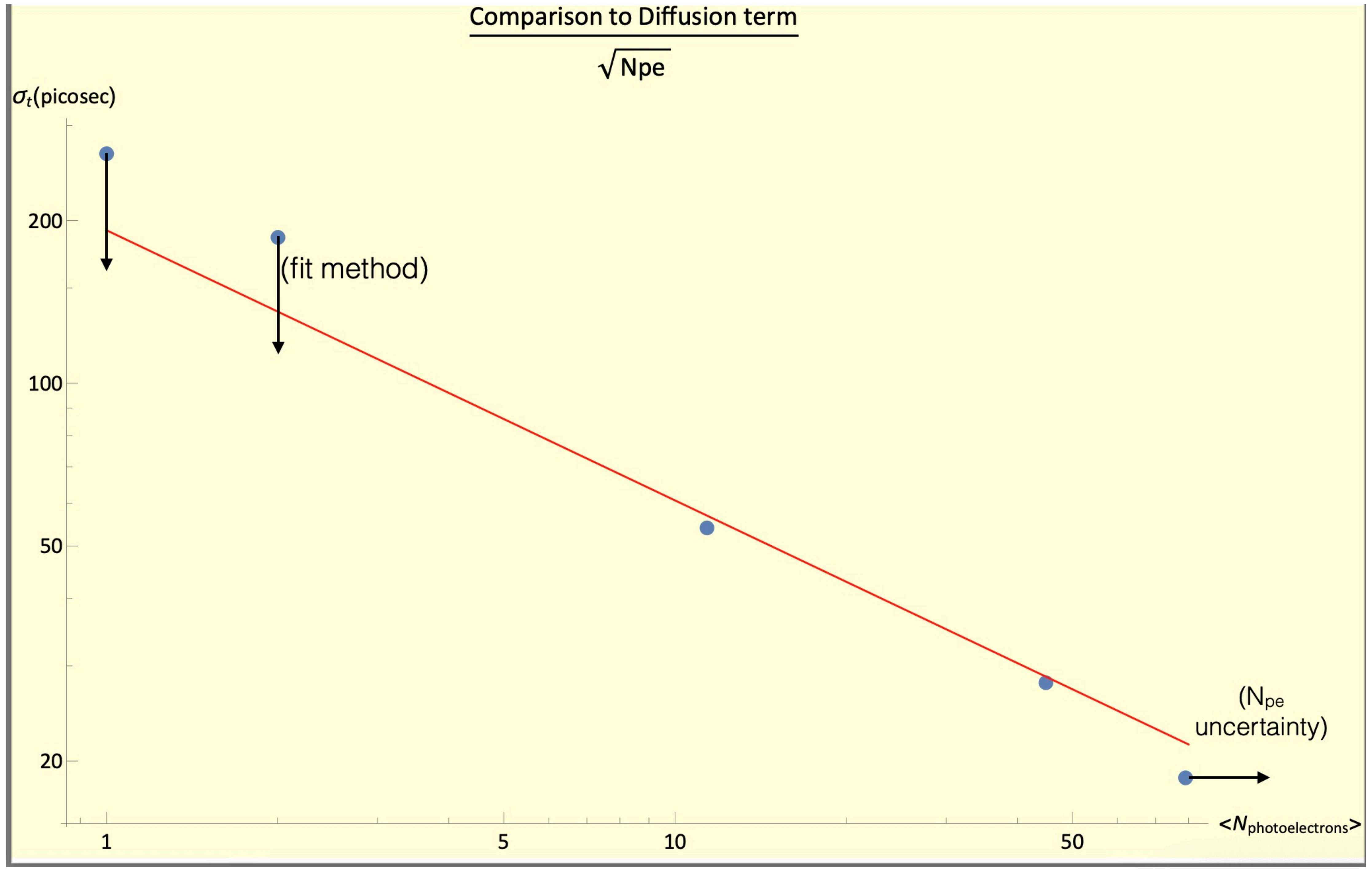
Fabio Sauli

* MPGD=Micro Pattern Gas Detector

First Demonstration of Principle

@ Saclay Laser Lab
of Thomas Gustavsson,
IRAMIS





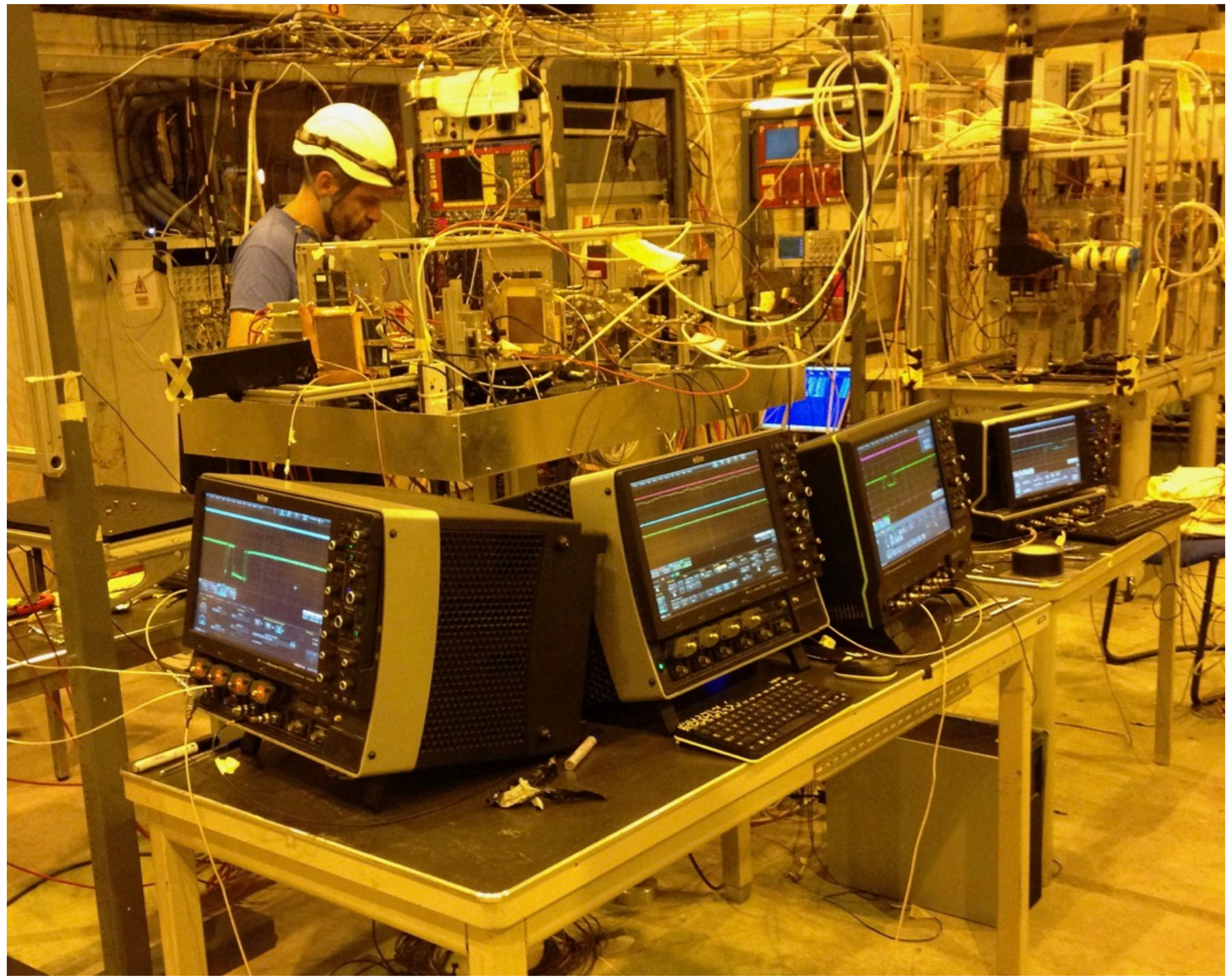
More on initial Laser Measurement

- Ti:Sa Laser sub-picosec pulse length, converted to 275 nm
- Different timing algorithms at extremes of 1->60 photoelectrons
- Laser Pulse split 1)to Detector Under Test 2)Major part to t0 photodiode
- Initial test with existing “ForFire” prototype, Neon-Ethane(10%)
- 200 micron preamp gap, ~10kV/cm
- Low QE Al photocathode
- Results demonstrated Longitudinal Diffusion reduced by Early Impact Ionization

Help in Fast Startup

Early adoption of CIVIDEC
E. Griessmeyer collaborated
For preamp input protection

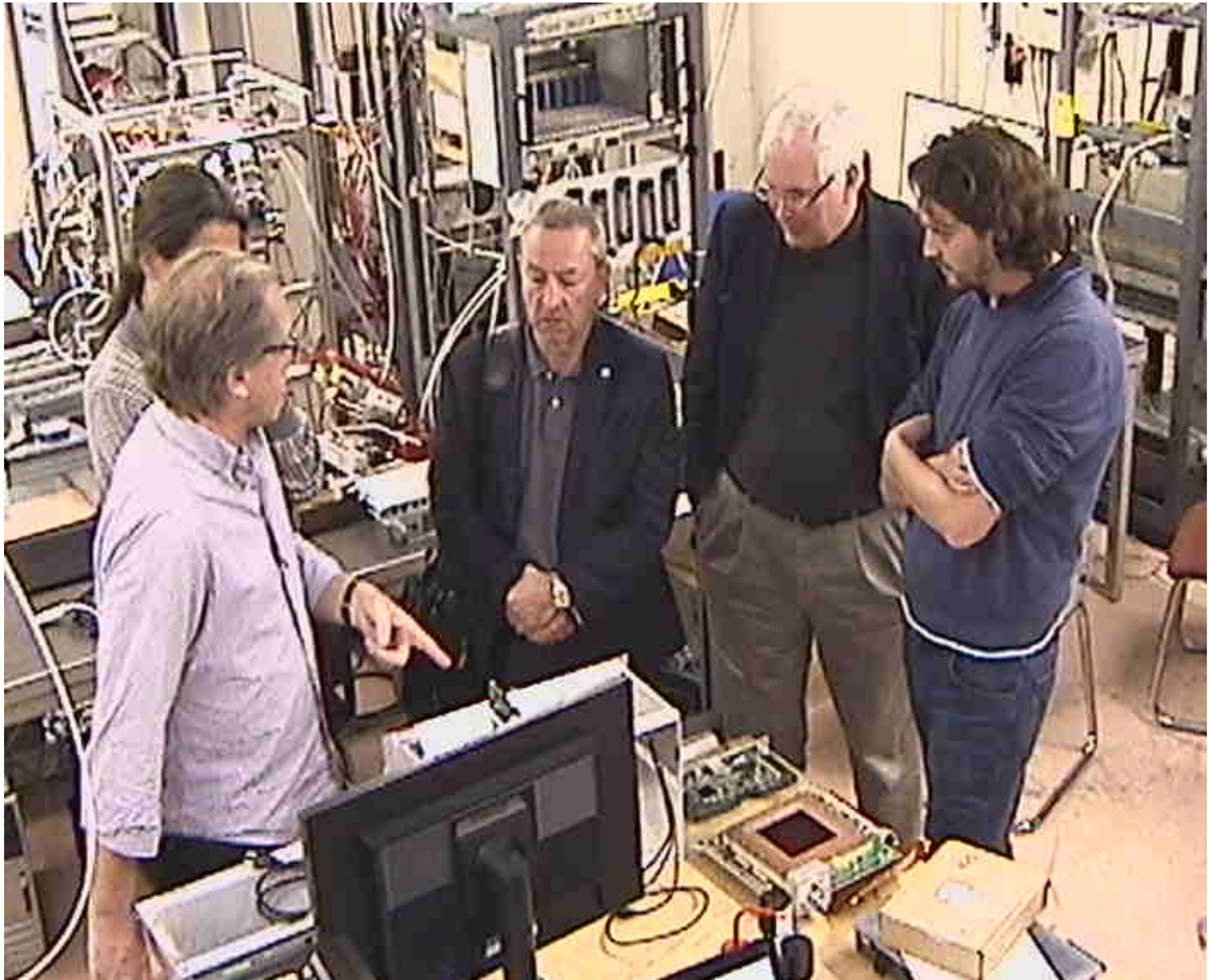
Lecroy was next door
Xavier very generous



Added scope channels
Until preposterous

-> SAMPIC Multichannel readout

Distinguished Visitors

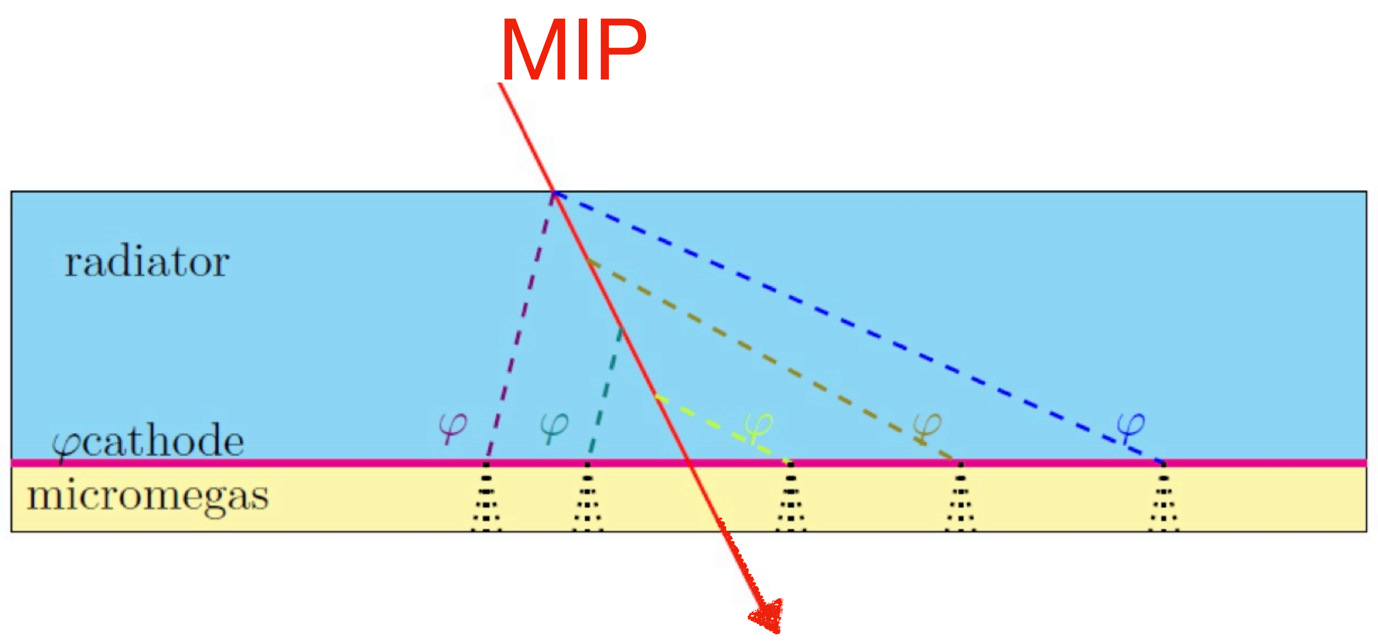


SNW, Nigel, Jim S. ,
Filippo Resnati
Captured on GDD group
Security camera

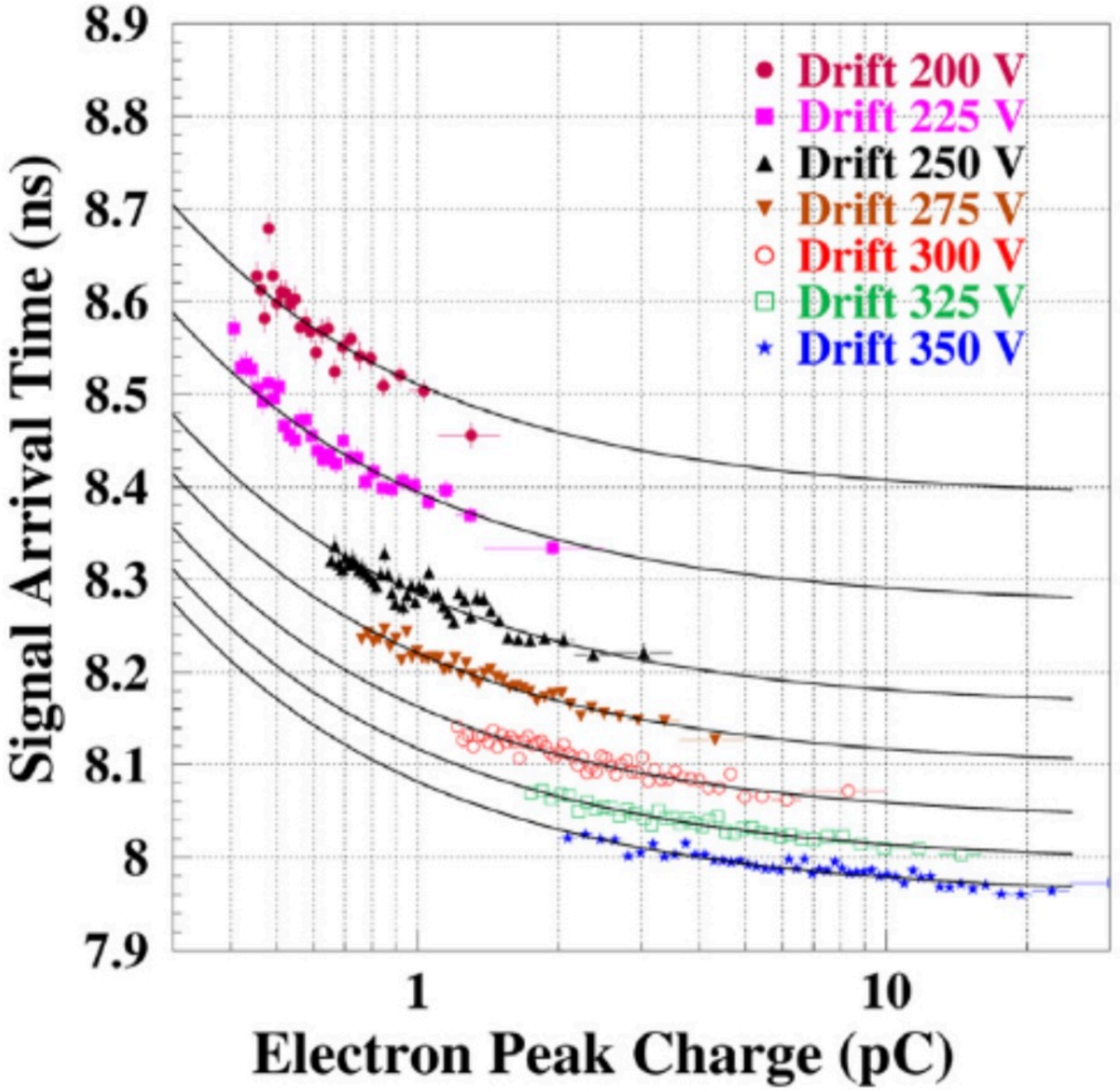
Evolution from initial 2015 prototype: Development areas

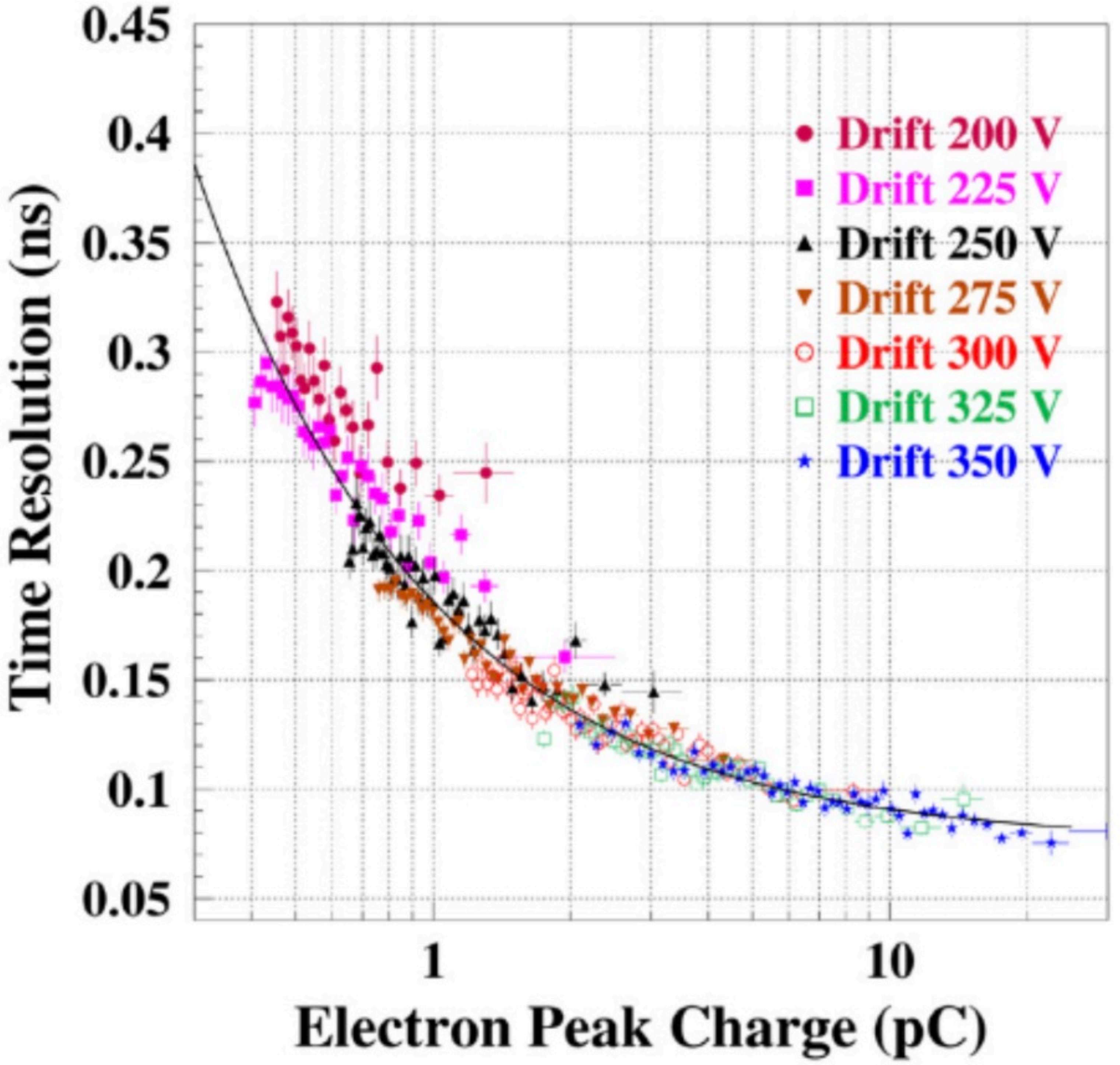
- Modeling Performance: Starting from tools of Rob Veenhof (collaborator)
- Further refinement: AUTH joins->ultimate modeling of timing due to Mmegas details
- Confirm that these dominated by MMmegas- not photon transport (ie Aleksan)
- Robust photocathode development (ie Diamond-like Carbon, B_4C, CVD, GaN…)
- Resistive MicroMegas-> rate capability and spark mitigation
- Scalable Detector-> overcome flatness issues, etc.
- Electronics for practical Multi-channel system

Modeling PICOSEC performance



Modeling Optics
Including reflection/absorption
Incidence angles, etc
Confirms small contribution
To resolution (~10-15 picosec)

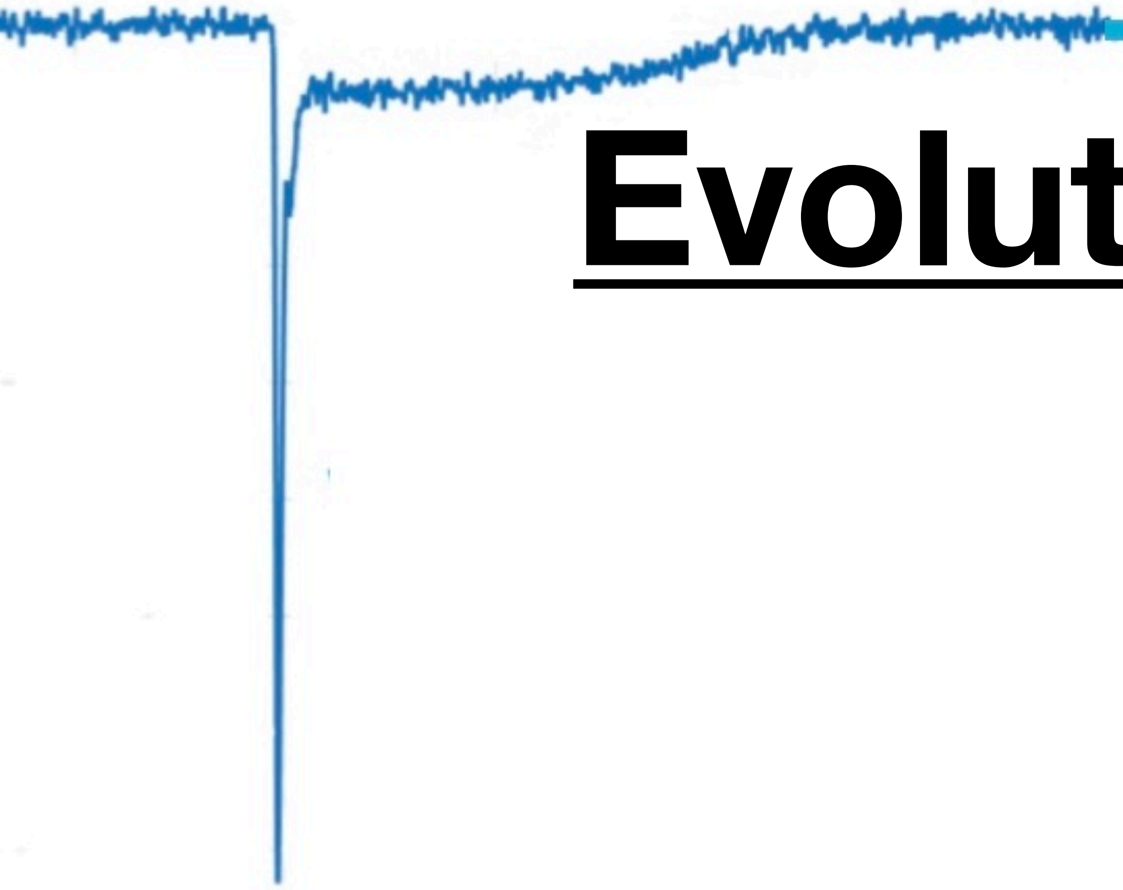




Main Features of timing
Reproduced by full modeling of Mmegas response:
Fluctuations in transit before impact ionization
-> varying signal amplitude
-> varying signal arrival time

J. Bortfeldt et. al. (RD51-PICOSEC collaboration), NIM A (903), 2018

Evolution of Single Photoelectron response (SPTR)

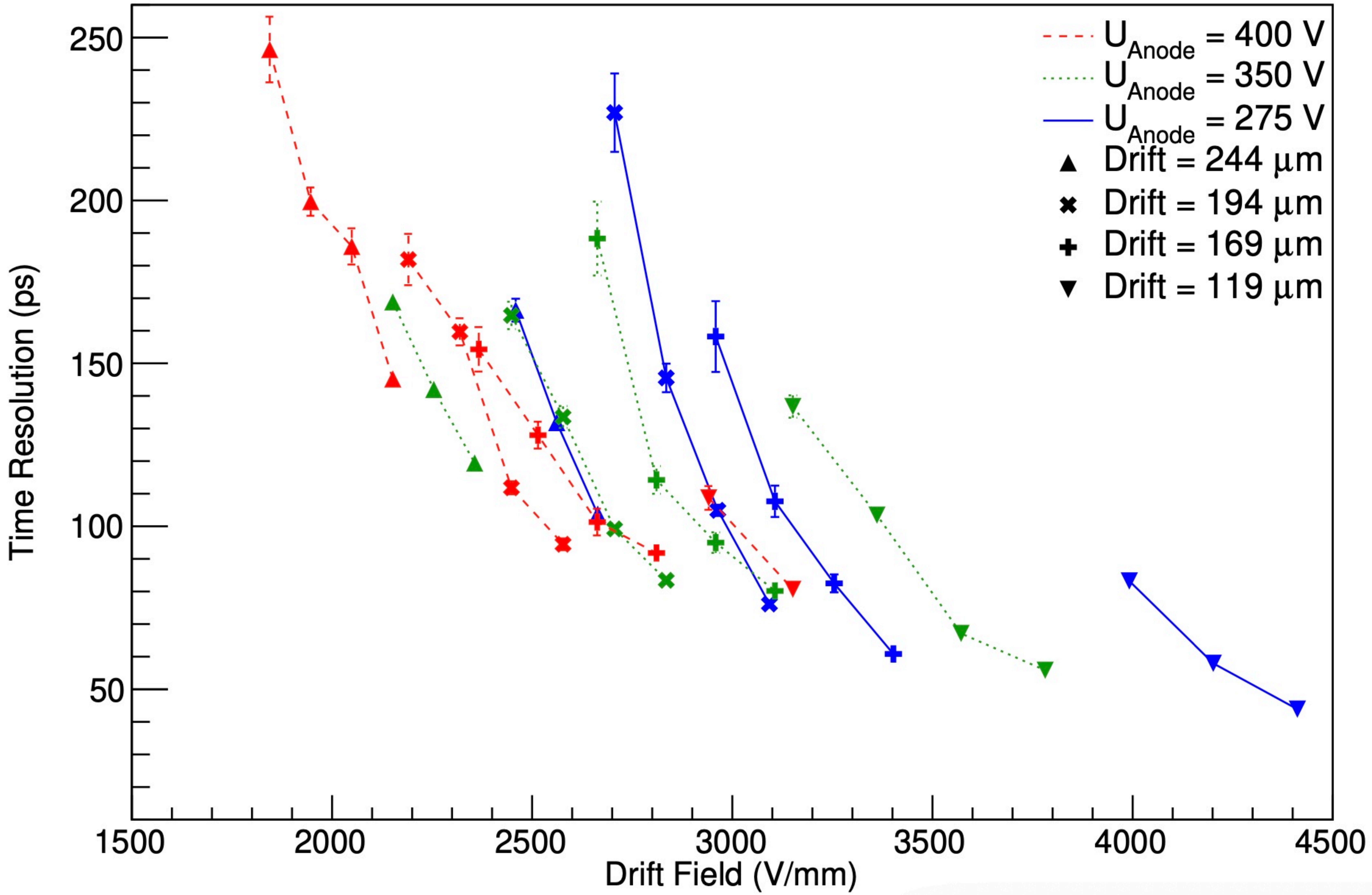


- Update from initial

  200 picosec (2015)

- Ne-Ethane-CF4

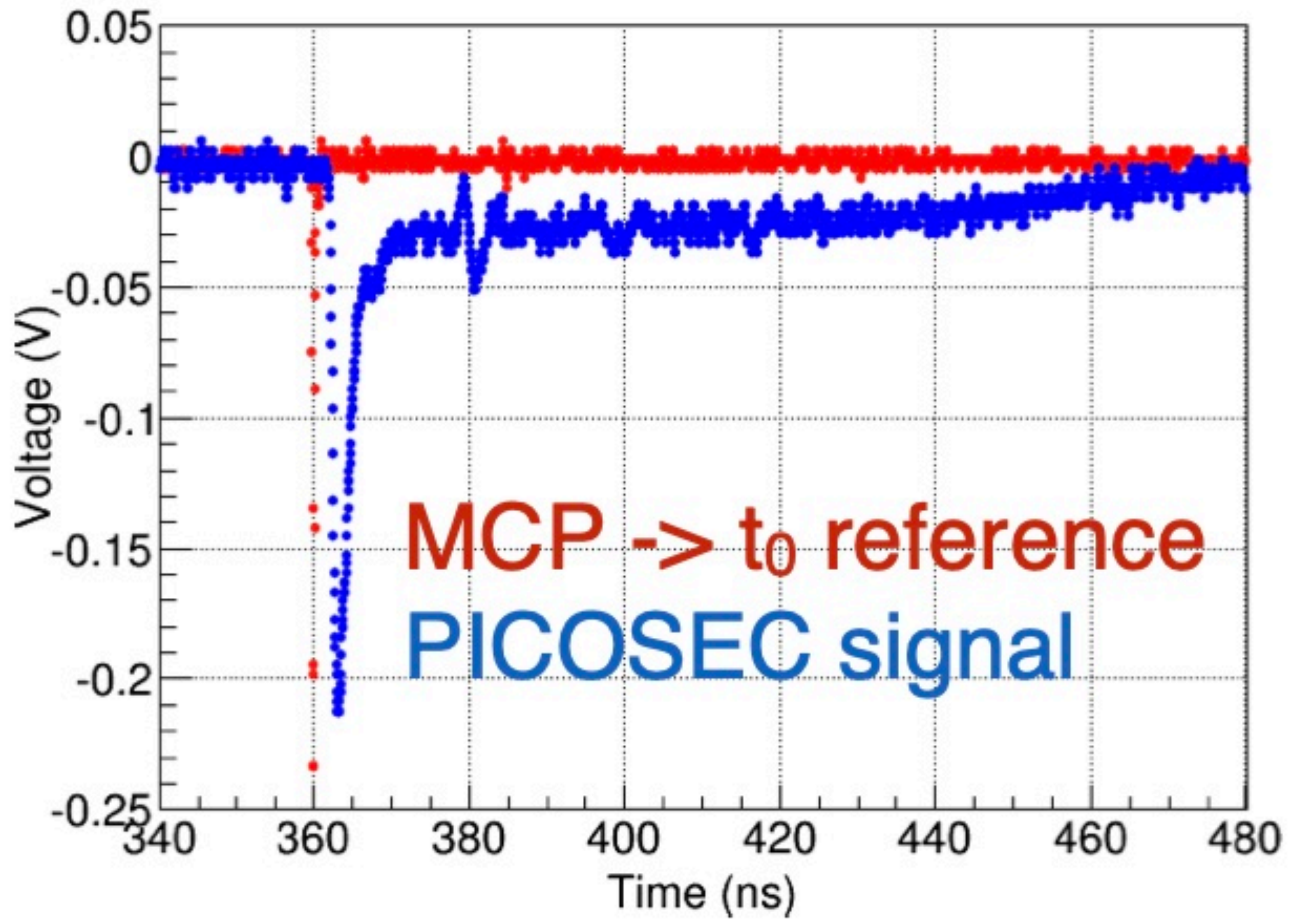
- gap in Preamp/Drift

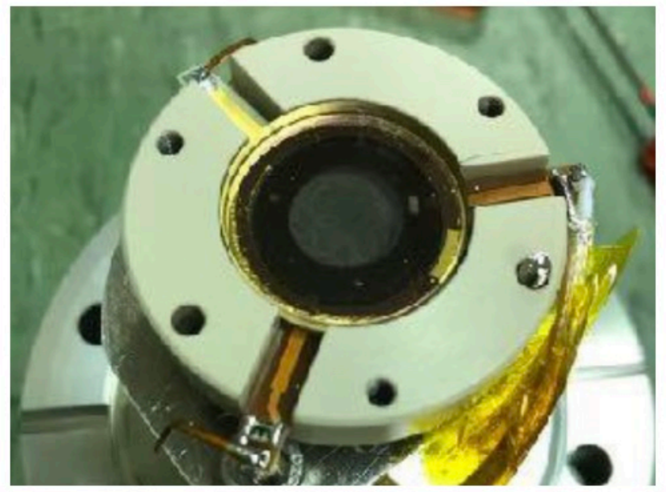


L. Sohl, et al., Single photoelectron time resolution studies of the PICOSEC- Micromegas detector,

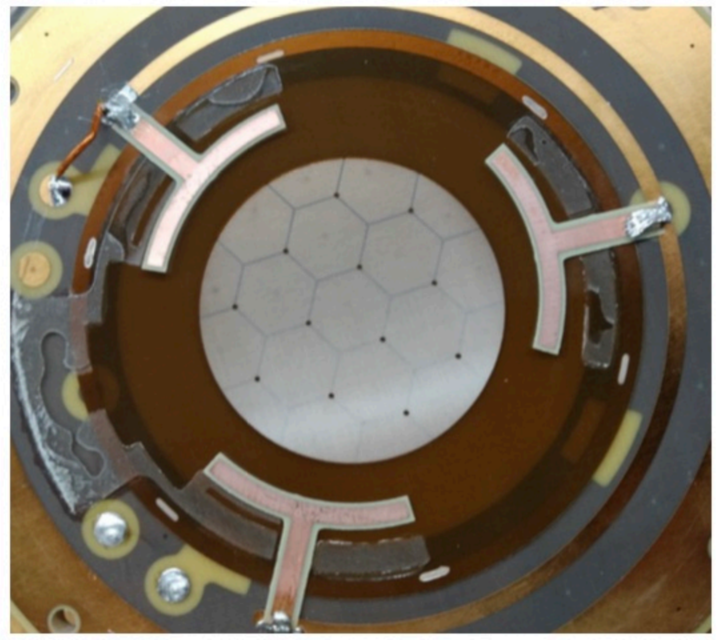
JINST Proc. of the 15th Topical Seminar on Innovative Particle and Radiation Detectors 2019, InPress (2020)

Scaling up from Single Channel Prototype

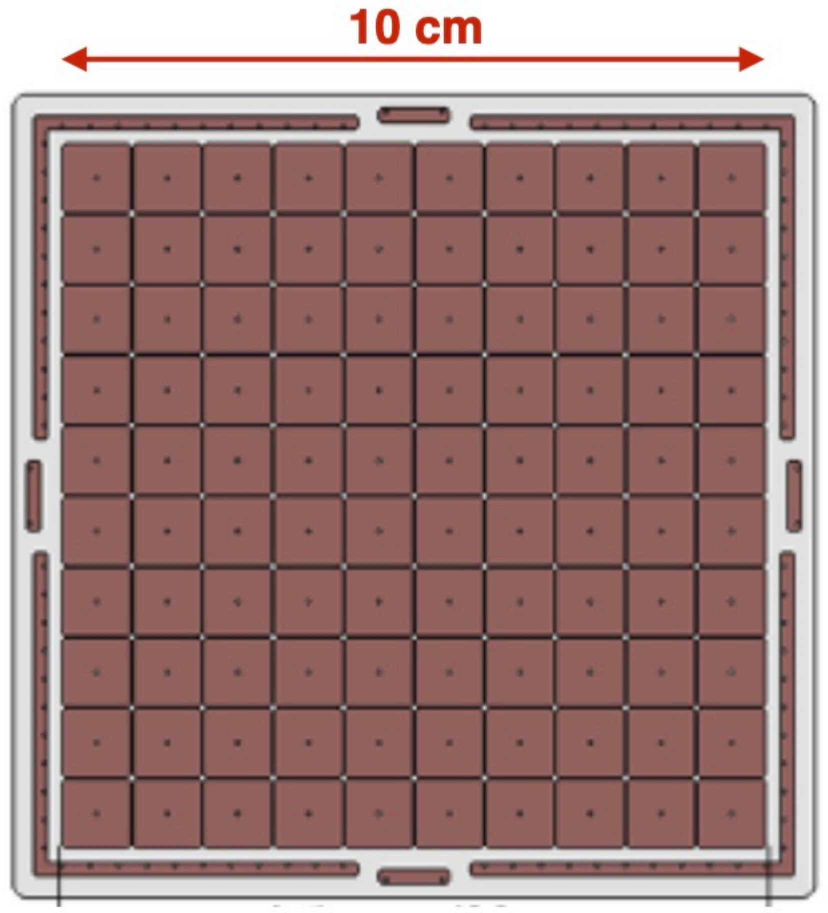




Single pad (2016)
ø1 cm



Multi pad (2017)
⬡ 1 cm



10x10 module
▫ 1 cm

- Initial Multipad (2017)

- Learned to combine pads for track impact at boundary

- Correctible distortion to timing when flatness exceeds ~10-20 microns.

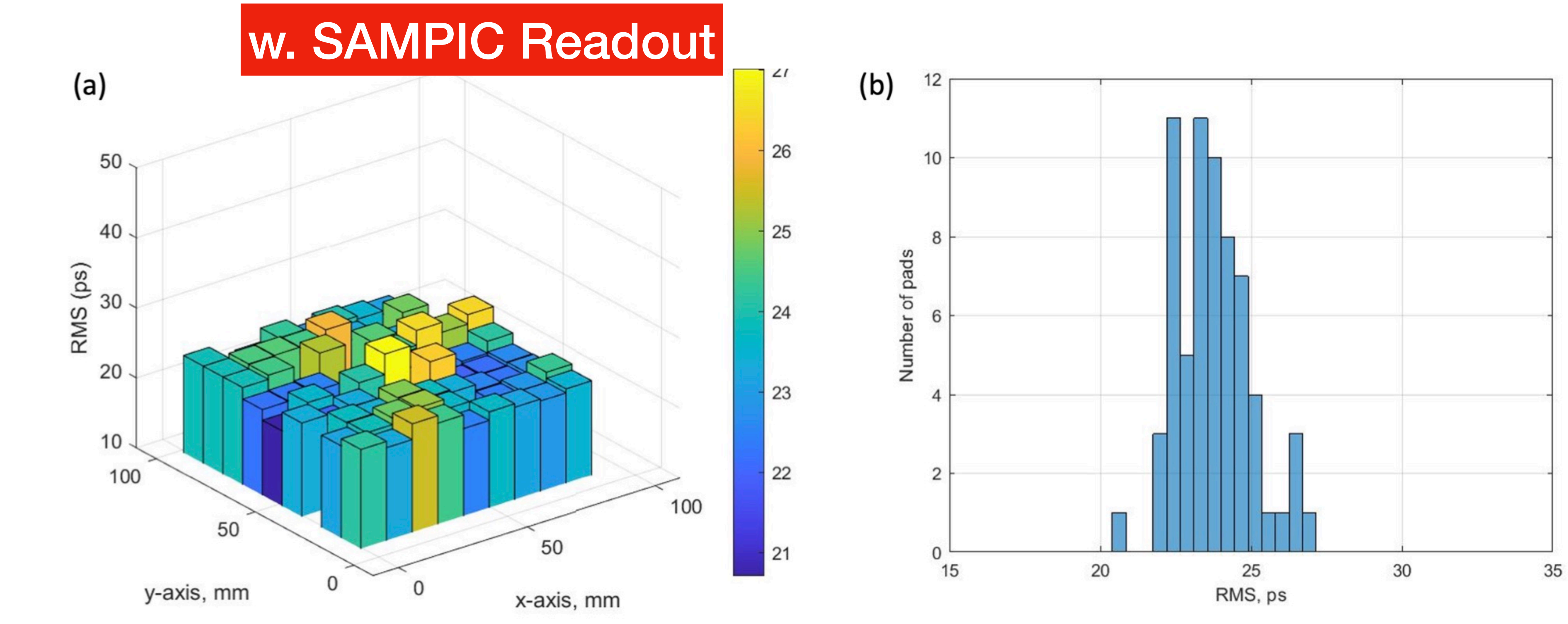
S. Aune et al., "Timing performance of a multi-pad PICOSEC-Micromegas detector prototype", NIM A (993), 2021, https://doi.org/10.1016/j.nima.2021.165076

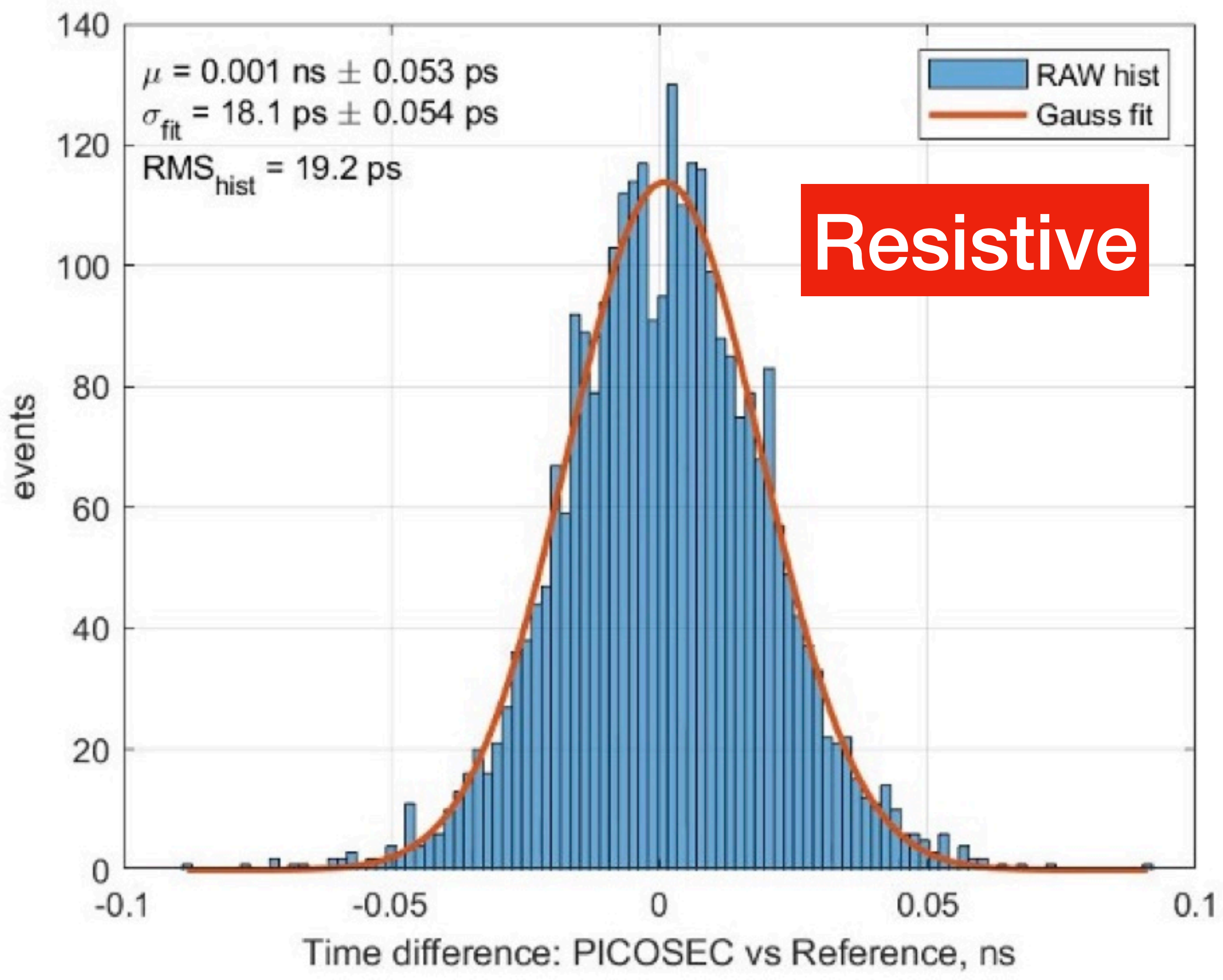
- All of this successfully overcome in 10x 10 module and results submitted to JINST

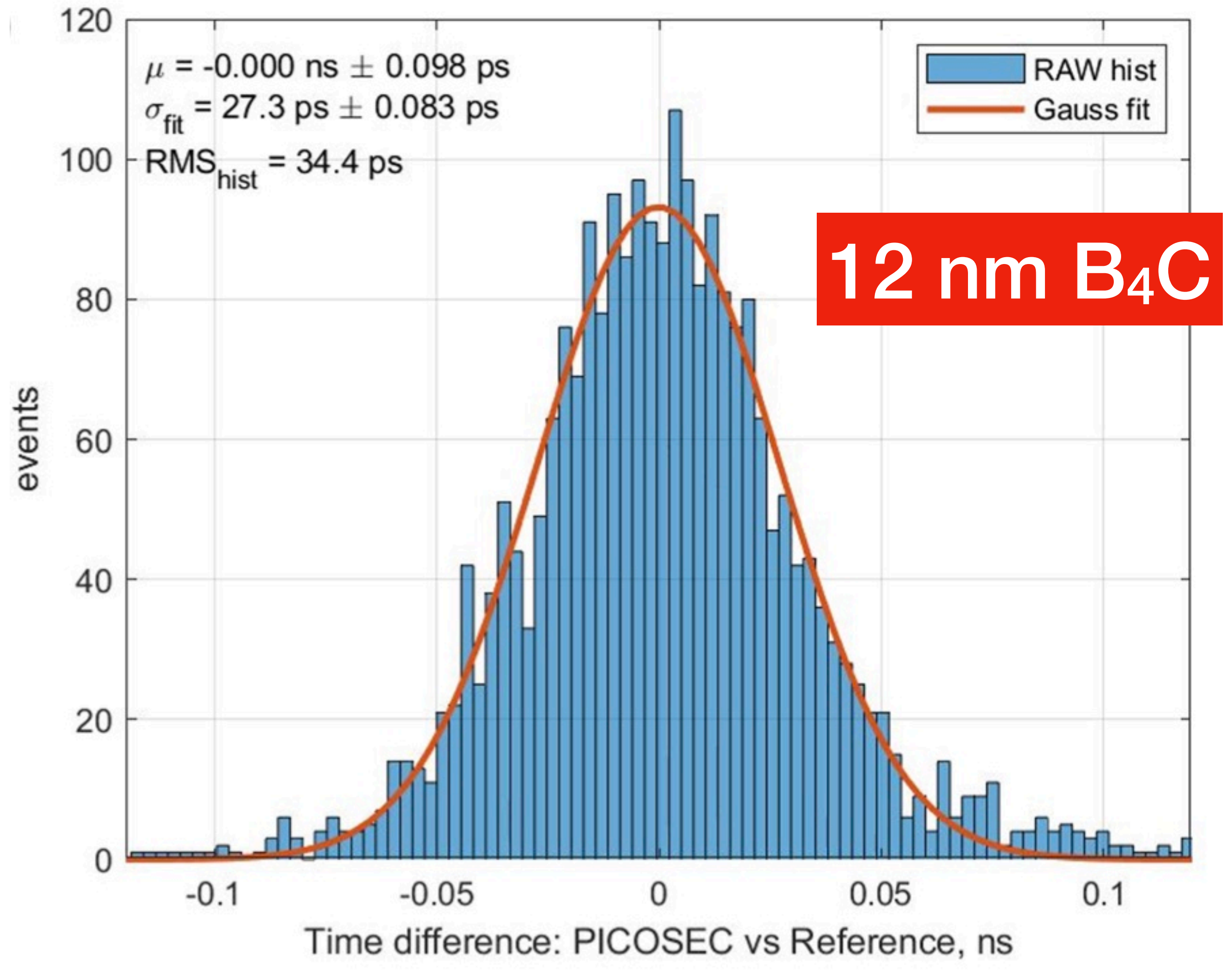
A. Utrobicic et al. ,"A large area 100 channel Picosec Micromegas detector with sub 20 ps time resolution" ,https://www.weizmann.ac.il/conferences/MPGD2022/program and M.Lisowaska, et al. (ibid)

Overview from 150 GeV muon beam tests of 10x10 PICOSEC

- Performance w. SAMPIC readout
- Excellent MIP resolution not degraded with resistive pads 20 MΩ/■
- Also CsI-> Robust photocathode (B_4C)







Our Surprise Human Interest Story:

- See: Antonija Utrobicic, for PICOSEC,

https://indico.cern.ch/event/1219224/

- Antonija took on task of Front end for 10x10,

ie for 100 channels, affordable, preserving timing.

Her husband built it on their kitchen table in St.Genis

Matched or exceeded commercial modules.

PICOSEC Challenges Going Forward

- Establish performance/robustness for new Photocathodes
- Evidence for SEM contribution- this would be a game changer
- Challenge of low mass, rigid construction (10 micron flatness?)
- Sealed detectors? Interaction w., “GasPMT” in Japan
- Learn requirements from future detector communities

RD51 PICOSEC Micromegas Collaboration

Y. Angelis[2], J. Bortfeldt[3], F. Brunbauer[4], E. Chatzianagnostou[2], K. Dehmelt[5], G. Fanourakis[6], K. J. Floethner[4,7], M. Gallinaro[8], F. Garcia[9], P. Garg[5], I. Giomataris[10], K. Gnanvo[11], T. Gustavsson[12], F.J. Iguaz[13], D. Janssens[4,14,15], A. Kallitsopoulou[10], M, Kovacic[16], P. Legou[10], M. Lisowska[4,25] J. Liu[17], M. Lupberger[7,18], S. Malace[11], I. Maniatis[4,2], Y. Meng[17], H. Muller[4,18], E. Oliveri[4], G. Orlandini[4,19], T. Papaevangelou[10], M. Pomorski[20], L. Ropelewski[4], D. Sampsonidis[2,21], L. Scharenberg[4,18], T. Schneider[4], L. Sohl[10], M. van Stenis[4], A. Tsiamis[2], Y. Tsipolitis[22], S.E. Tzamarias[2,21], A. Utrobicic[1], R. Veenhof[4,23], X. Wang[17], S. White[4,24], Z. Zhang[17], Y. Zhou[17]

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[5]Stony Brook University, Department of Physics and Astronomy, Stony Brook, New York 11794-3800, USA,
[6]Institute of Nuclear and Particle Physics, NCSR Demokritos, GR-15341 Agia Paraskevi, Attiki, Greece,
[7]Helmholtz-Institut für Strahlen- und Kernphysik, University of Bonn, Nußallee 14–16, 53115 Bonn,
[8]Laboratório de Instrumentacão e Física Experimental de Partículas, Lisbon, Portugal
[9]Helsinki Institute of Physics, University of Helsinki, FI-00014 Helsinki, Finland,
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[11]Jefferson Lab, Newport News, VA 23606, USA
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[16]Faculty of Electrical Engineering and Computing, University of Zagreb, 10000 Zagreb, Croatia,
[17]State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei 230026, China,
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[22]National Technical University of Athens, Athens, Greece,
[23]Bursa Uludag University, Görükle Kampusu, 16059 Niufer/Bursa, Turkey,
[24]University of Virginia, USA,
[25]Université Paris-Saclay, F-91191 Gif-sur-Yvette, France

PICOSEC Micromegas

2 US collaborators just recently added in above. Probably based at JLAB

PICOSEC Picnic in August

Backup

Lindsey Gray