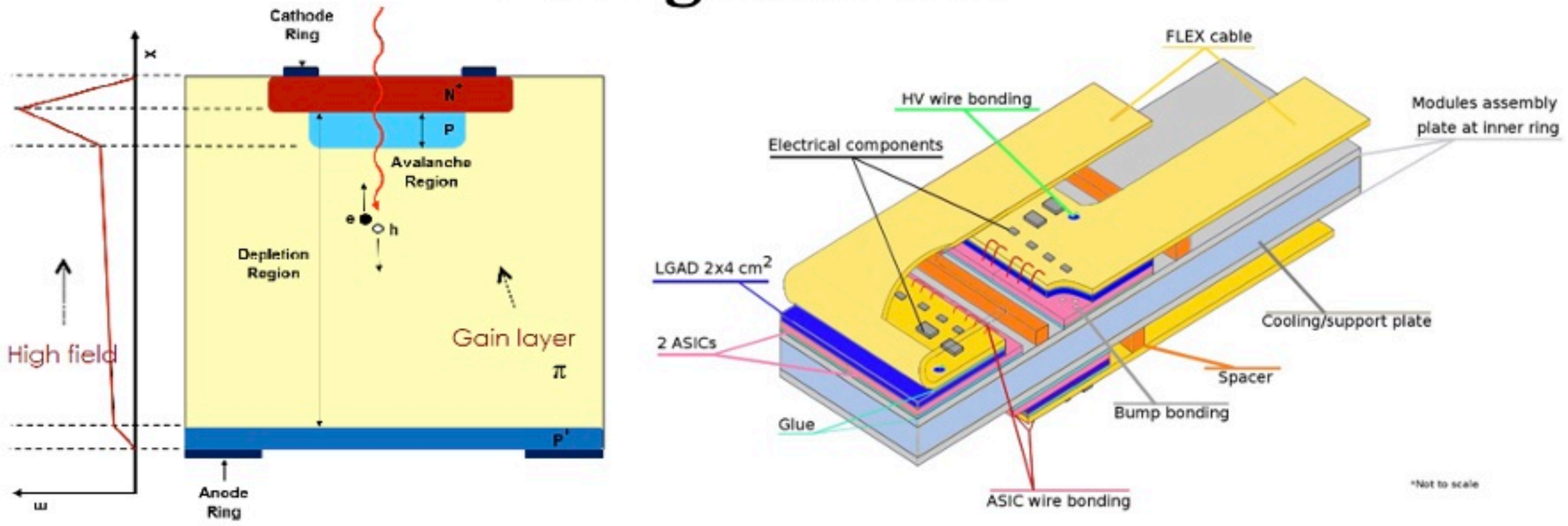
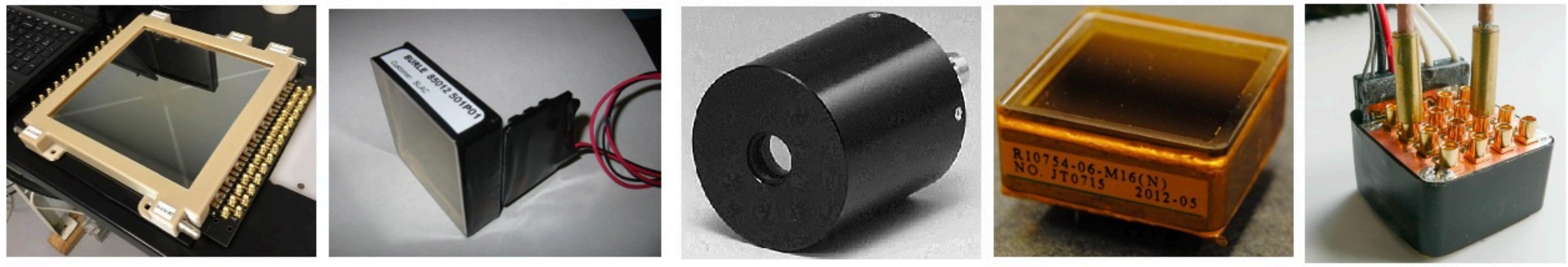
Towards robust PICOSEC Micromegas precise timing detectors

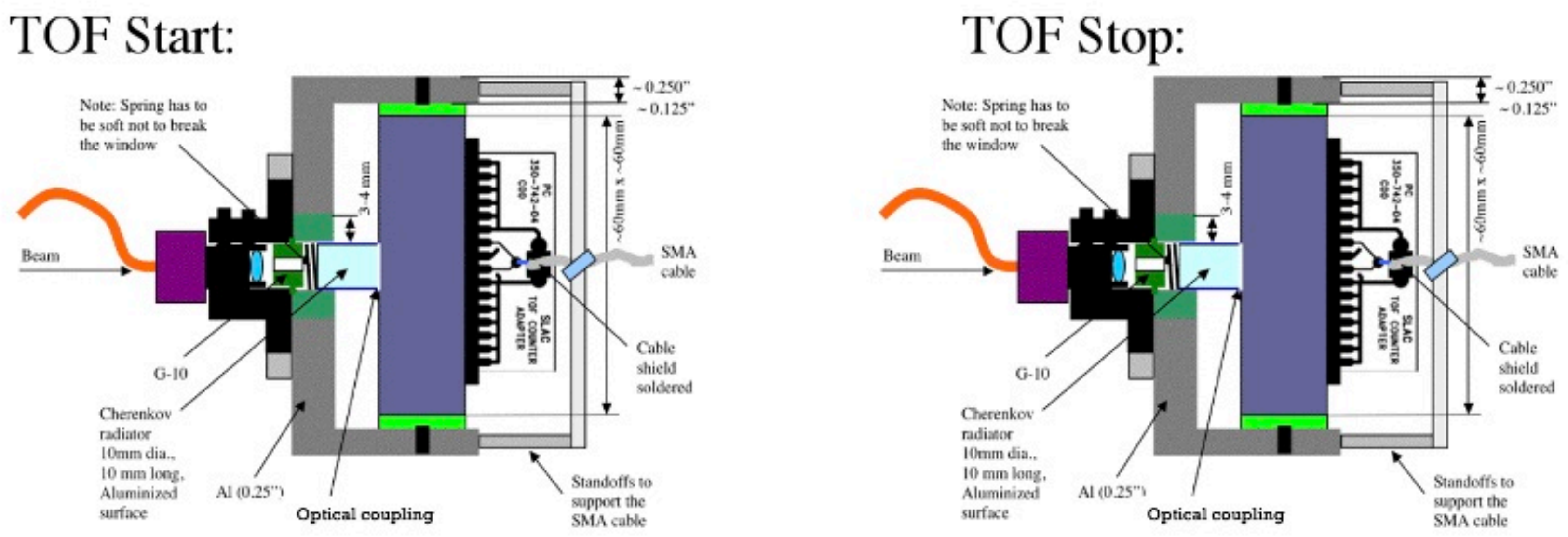
Low gain APDs



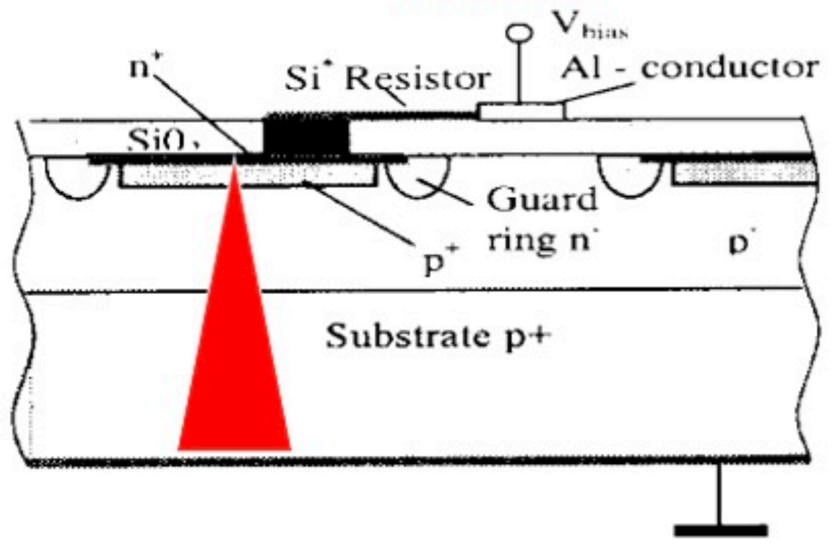
MCP-PMT shown without a fused silica radiator:

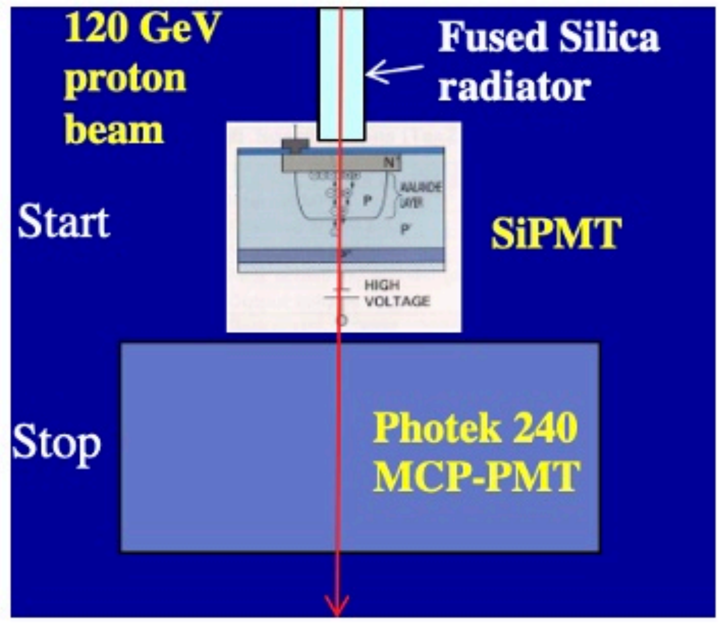


Example:

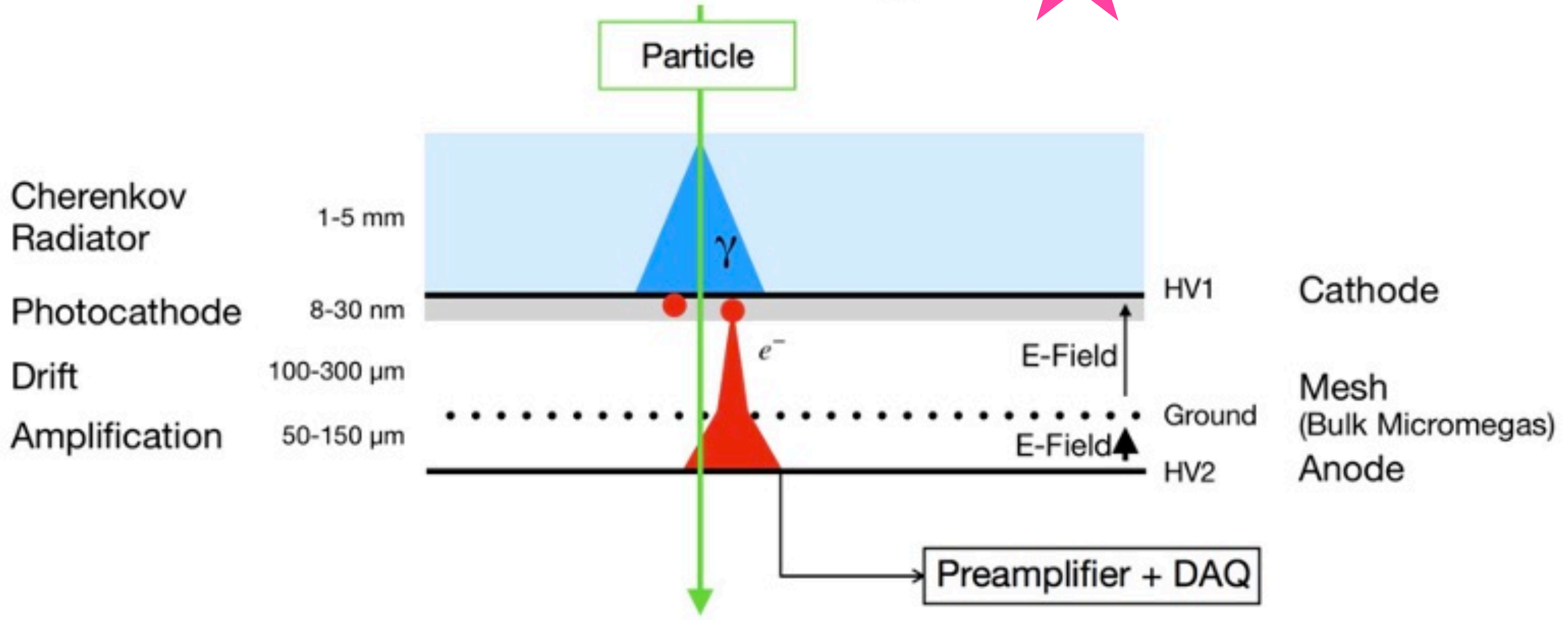


G-APD (SiPM)

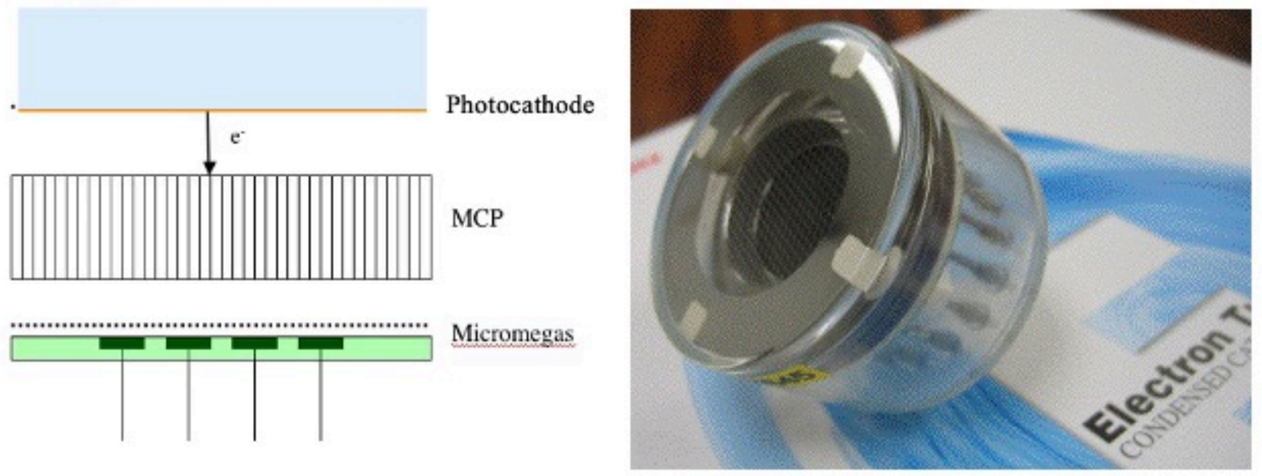




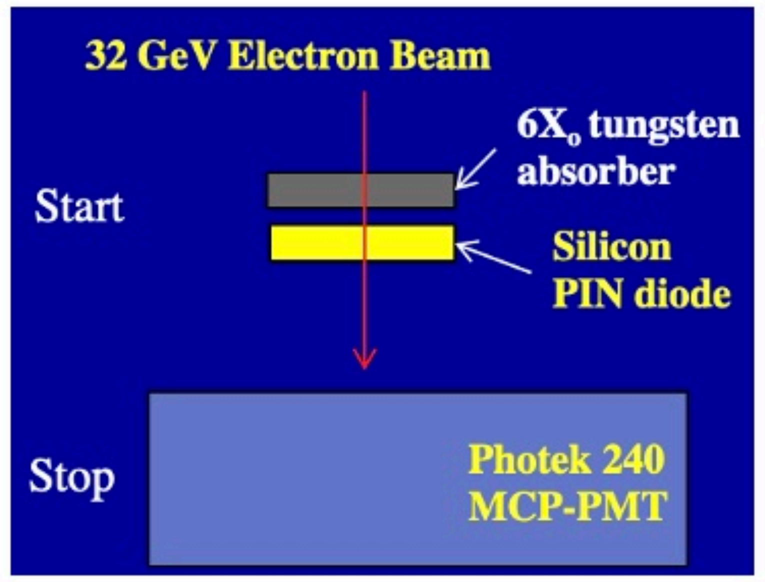
Micromegas ★



Micromegas + MCP

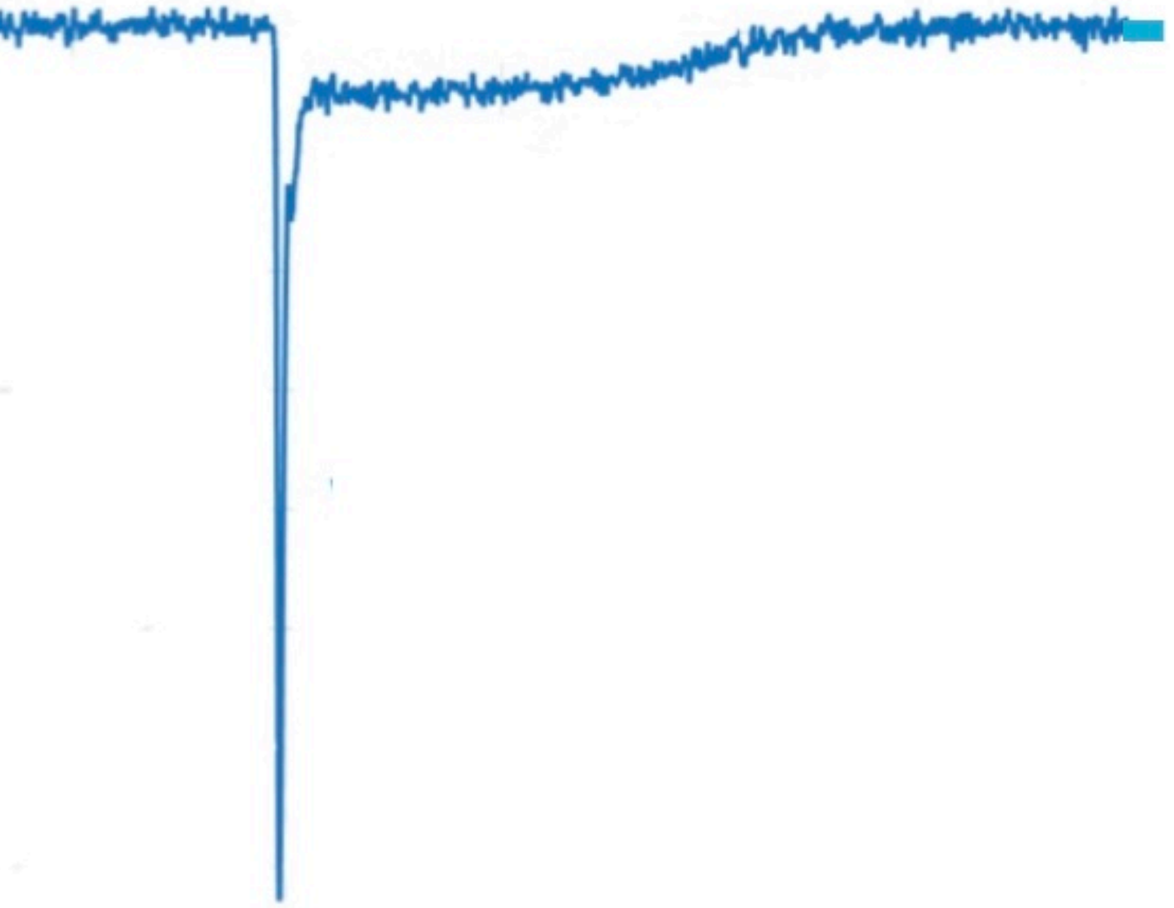


PIN diode + radiator



Slide courtesy of J. Va'vra

Sebastian White, CERN/U Va. US Future Circular Collider-ee Workshop MIT, March 26,2024



Outline

- I spent last decade at CERN in 2 R&D groups-> Silicon & Gas Detector Development
- 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/CPAD roadmap

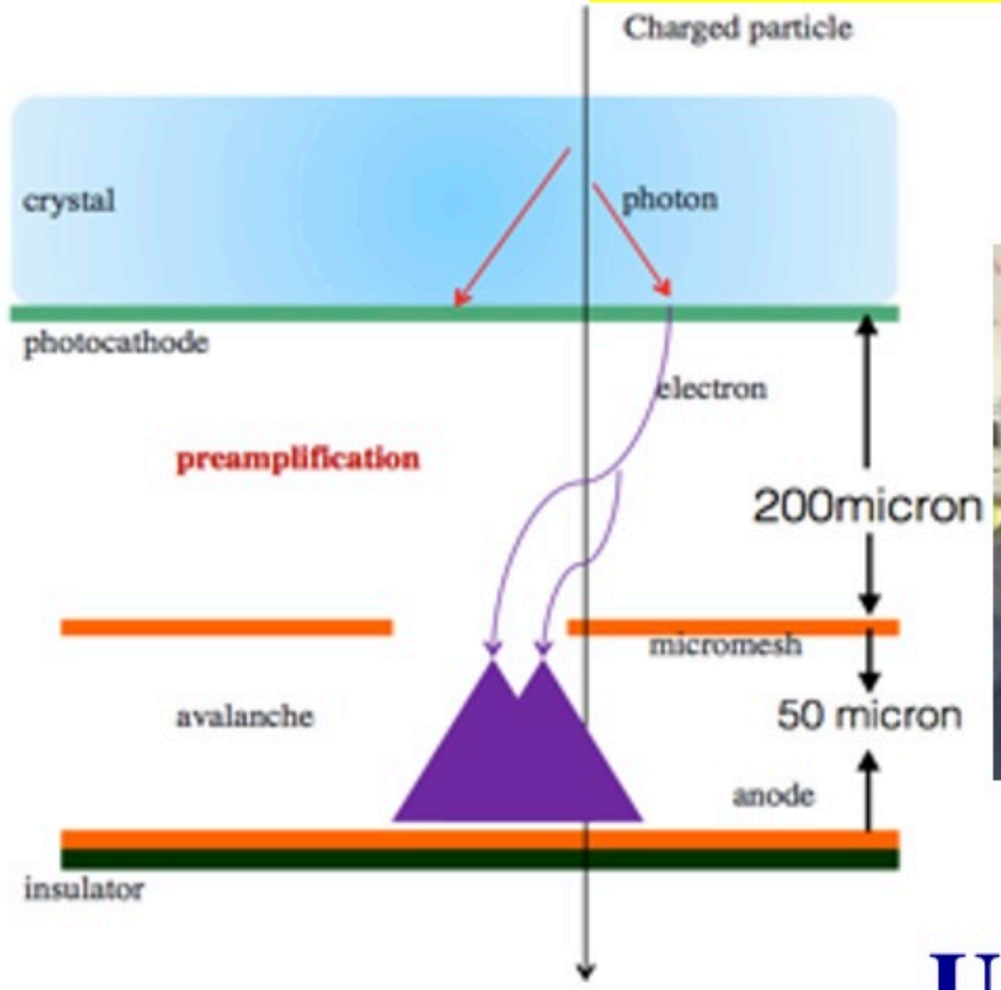
PICOSEC starts

RD51 proposal

2014

Fast timing Picosecond Micromegas

CEA-Saclay, CERN, Thessaloniki, Athens, Princeton, USTC



Test with UV fs laser @ IRAMIS-CEA

CERN beam tests

UV Photocathodes on MgF window:
CsI, Cr, Al, Diamond (10-50nm thick)

Slide from ICFA award to Giomataris At TIPP 2023

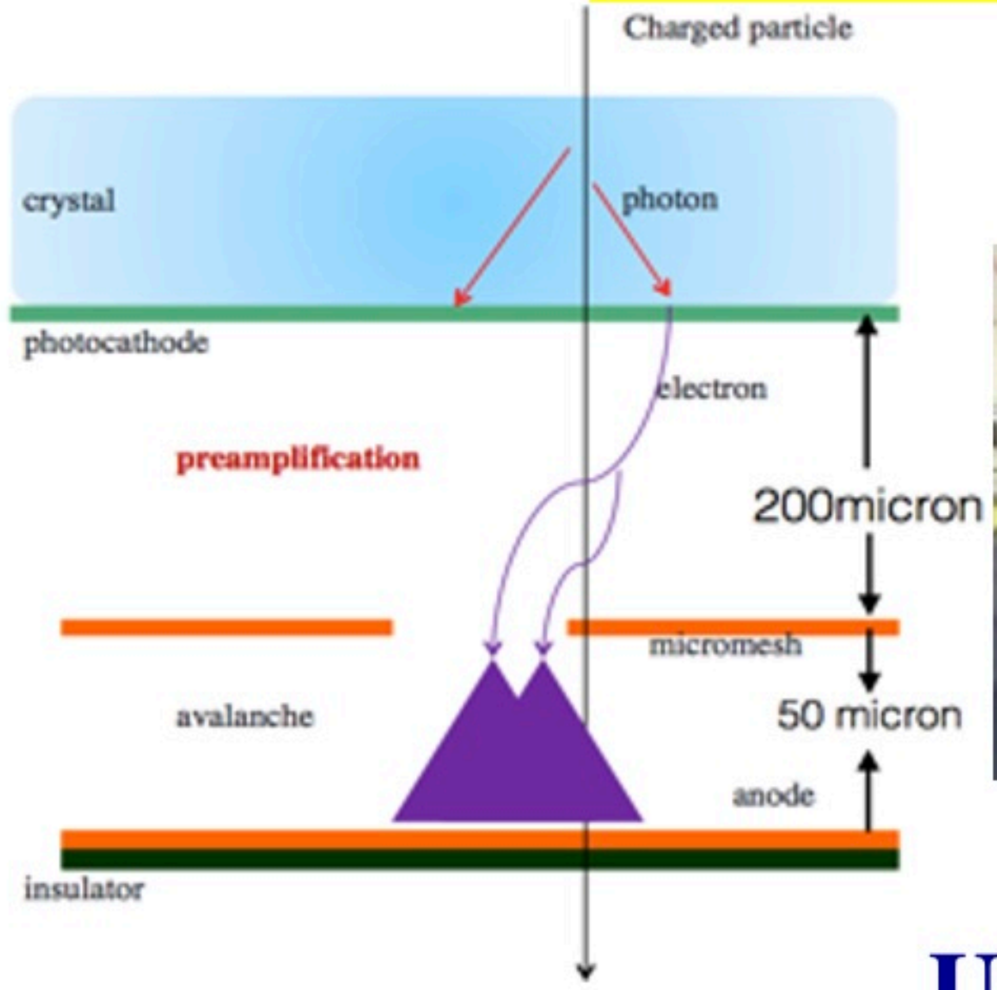
Recent application of MMegas

PICOSEC starts

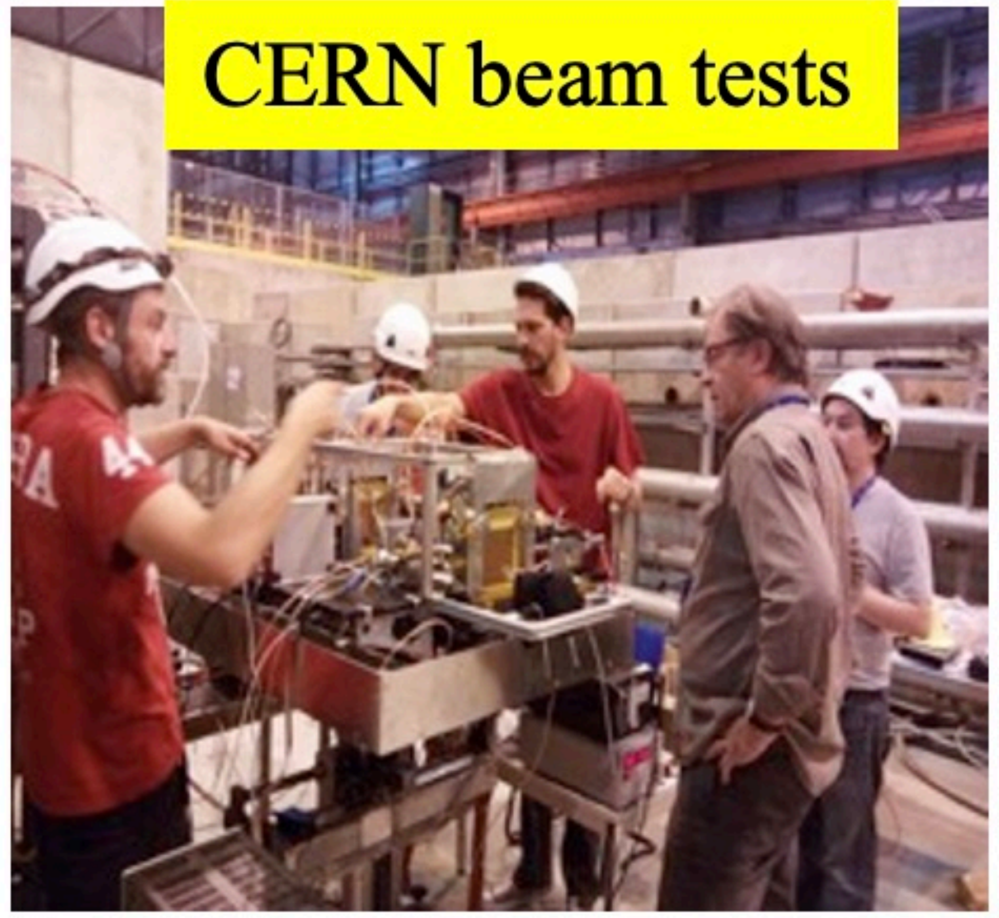
RD51 proposal

Fast timing Picosecond Micromegas

CEA-Saclay, CERN, Thessaloniki, Athens, Princeton, USTC



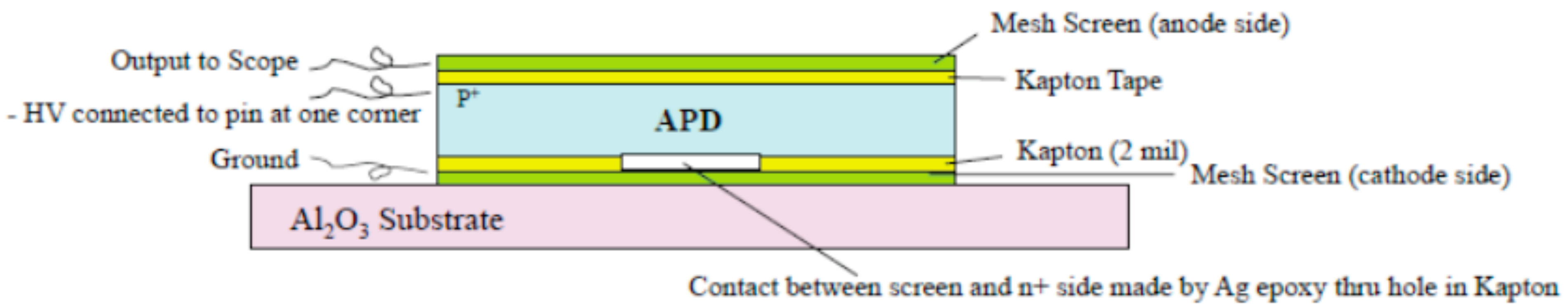
Test with UV fs laser @ IRAMIS-CEA

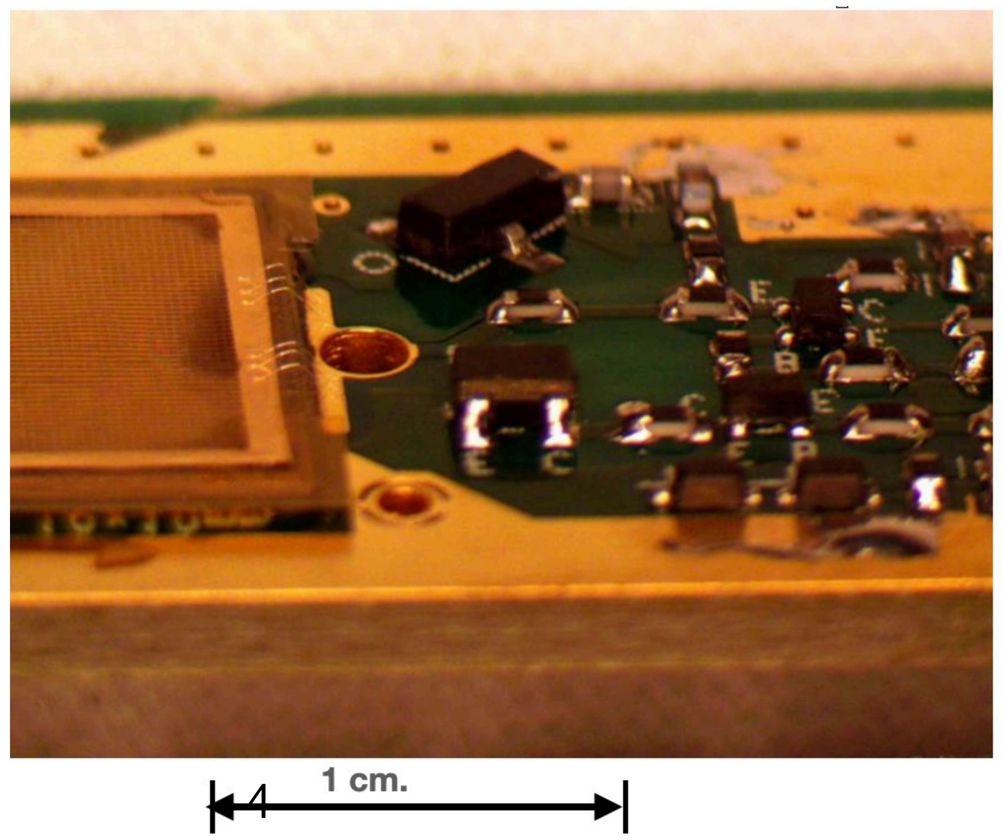


UV Photocathodes on MgF window:
CsI, Cr, Al, Diamond (10-50nm thick)

2014

Top Screen Output Connection (capacitively coupled)





Nearing completion of:
"Deep Diffused Avalanche Diodes for Timing"
https://doi.org/10.1016/j.nima.2019.162930

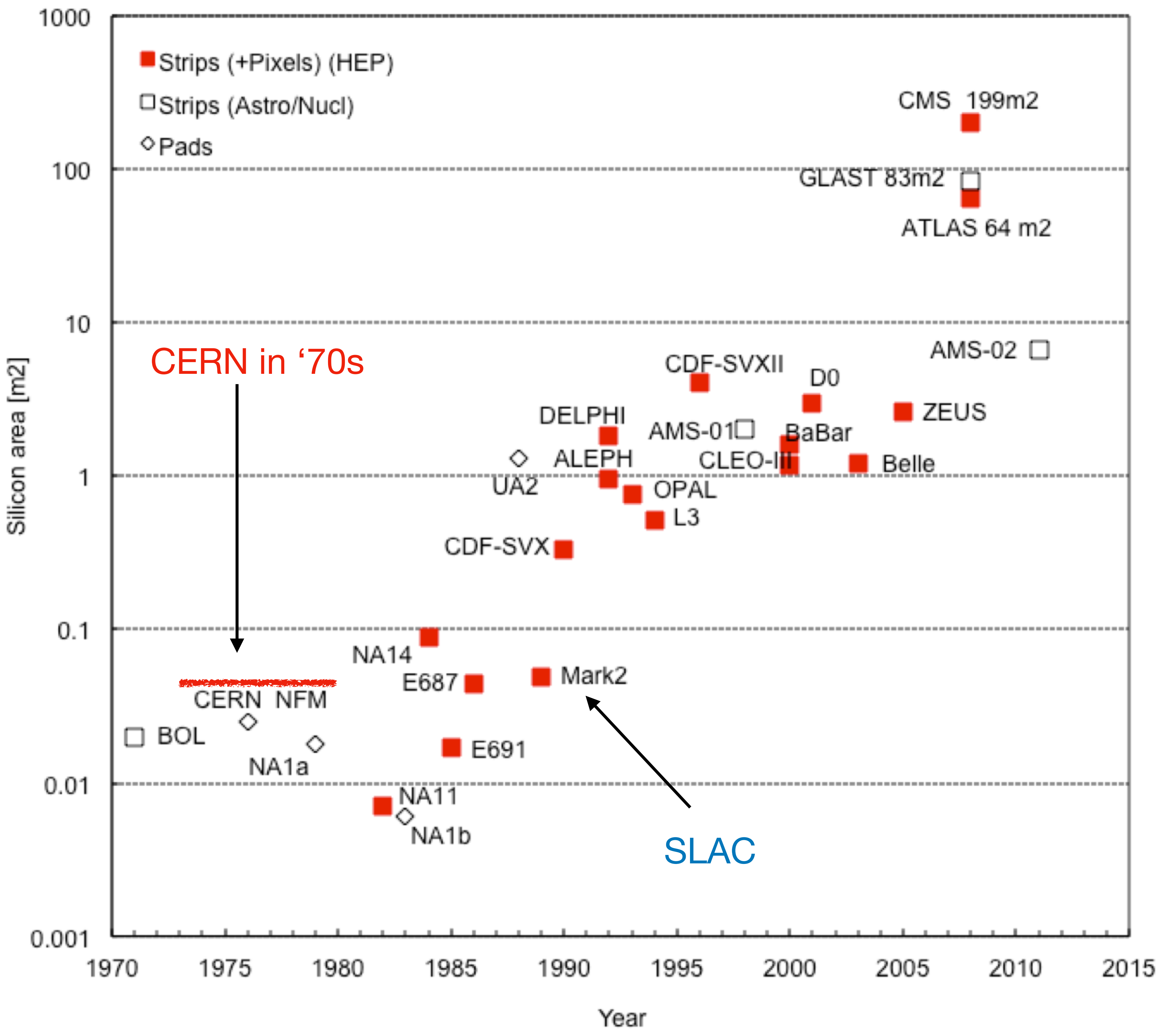
<30 picosecond MIP timing
64mm^2 pixels
AC coupled (via mesh)

Princeton, Penn, CERN
Rockefeller

Fast Timing and Vertexing with MicroPattern Detectors (Si)

Roughly concurrent w new Heavy Flavor mesons (w picosecond lifetimes) was technology that could enable picosecond domain.

file by Nobu Unno, KEK, updated June-August 2015 by Erik Heijne



"Neutrino Flux Monitor",Heijne, Jarron et al.,1976
November Revolution, c-quark, 1974
Upsilon, b-quark, 1979
A.B.Carter&A.I.Sanda, CP violation in b decay, 1981

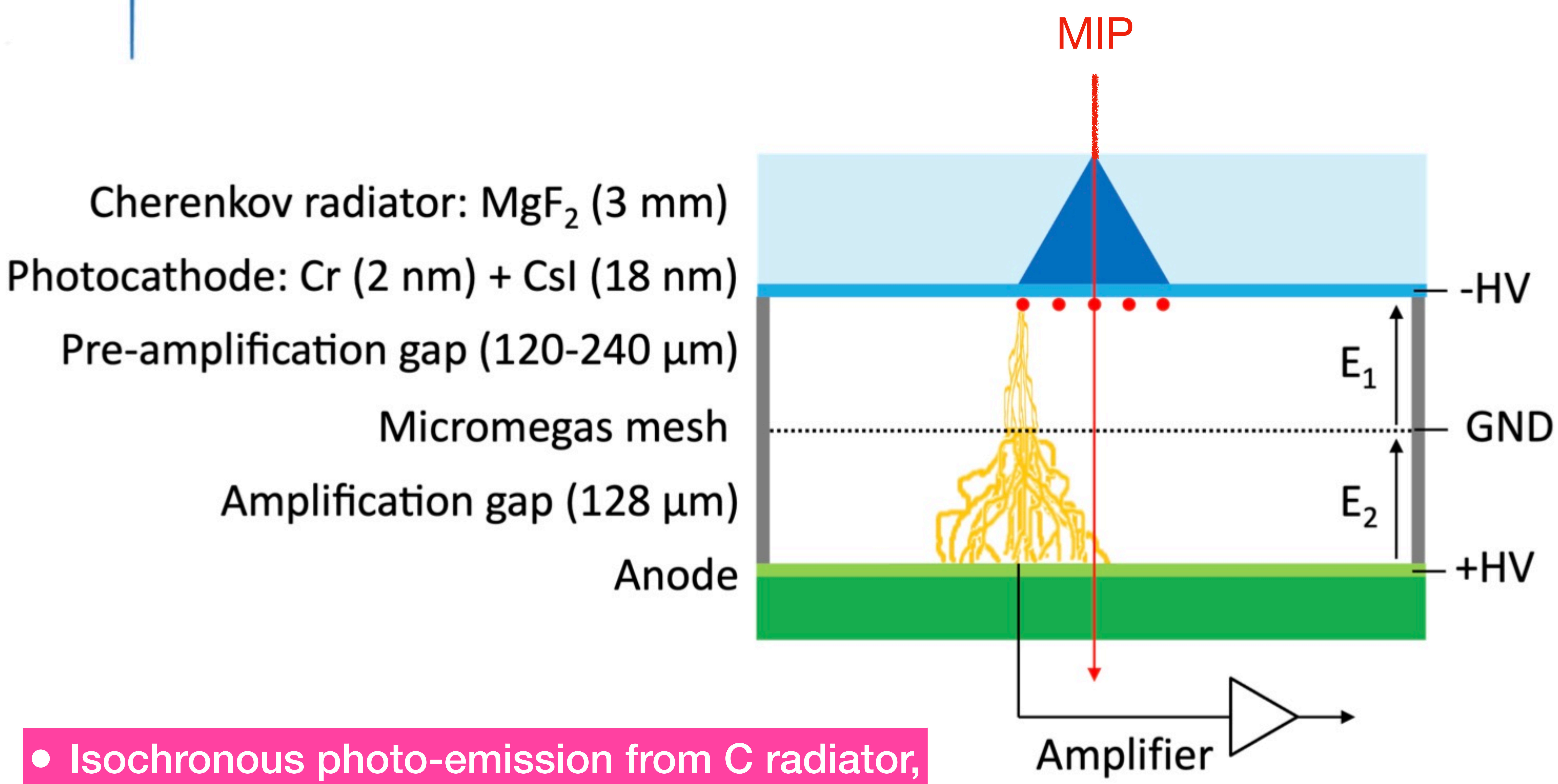
<u>miniaturization of sensor pattern (and required FEE)</u>

- enabled precision <u>vertex</u> measurement
- but also lowered C_D and <u>response time</u>
  (this was purpose of work at CERN on NFM)

- but, ultimately, HEP accessed picoseconds w vertexing
  (and timing used instead for pid)

- not until last 10 years that micro pattern detectors->
  Picosecond timing
  (more below)

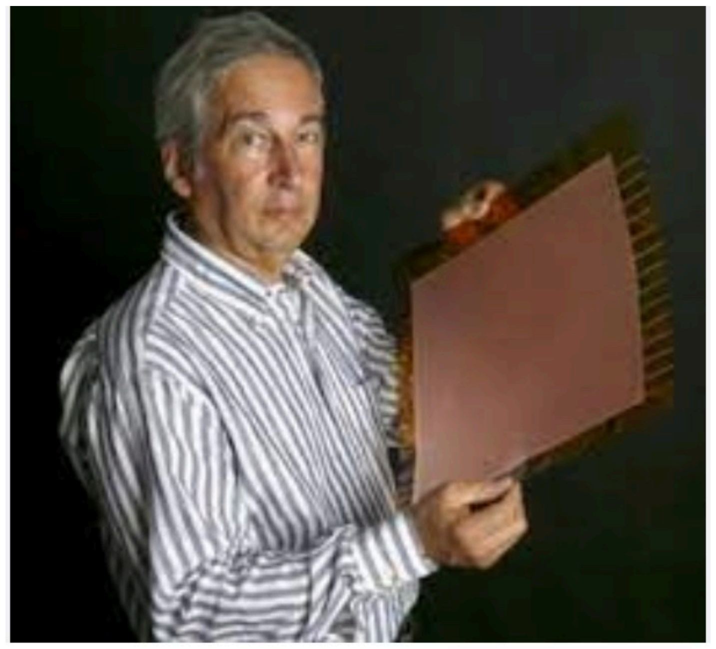
Back to PICOSEC: From ~2 nanosec to <20 Picosecond Timing in MPGD*



- 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

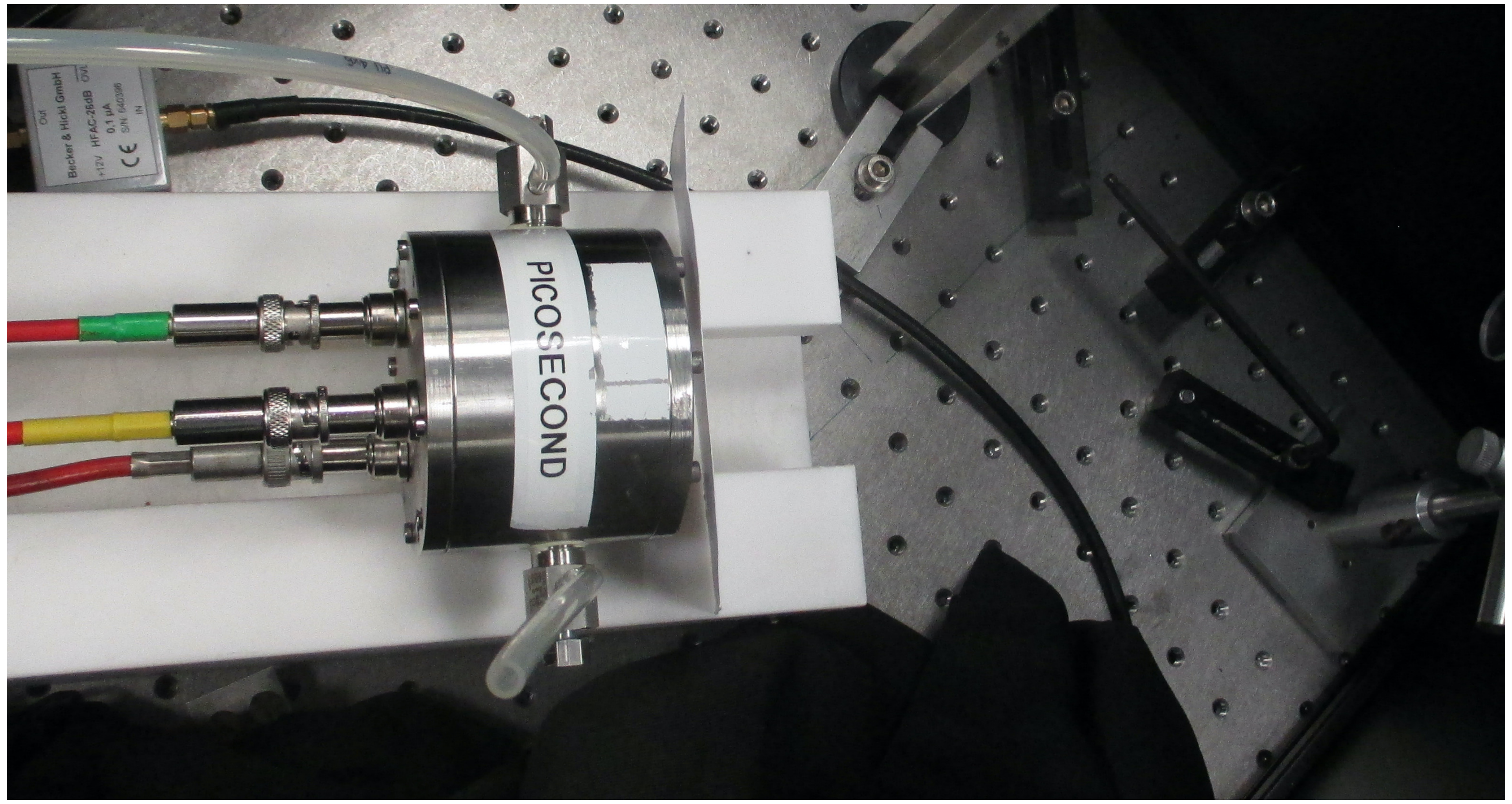
and

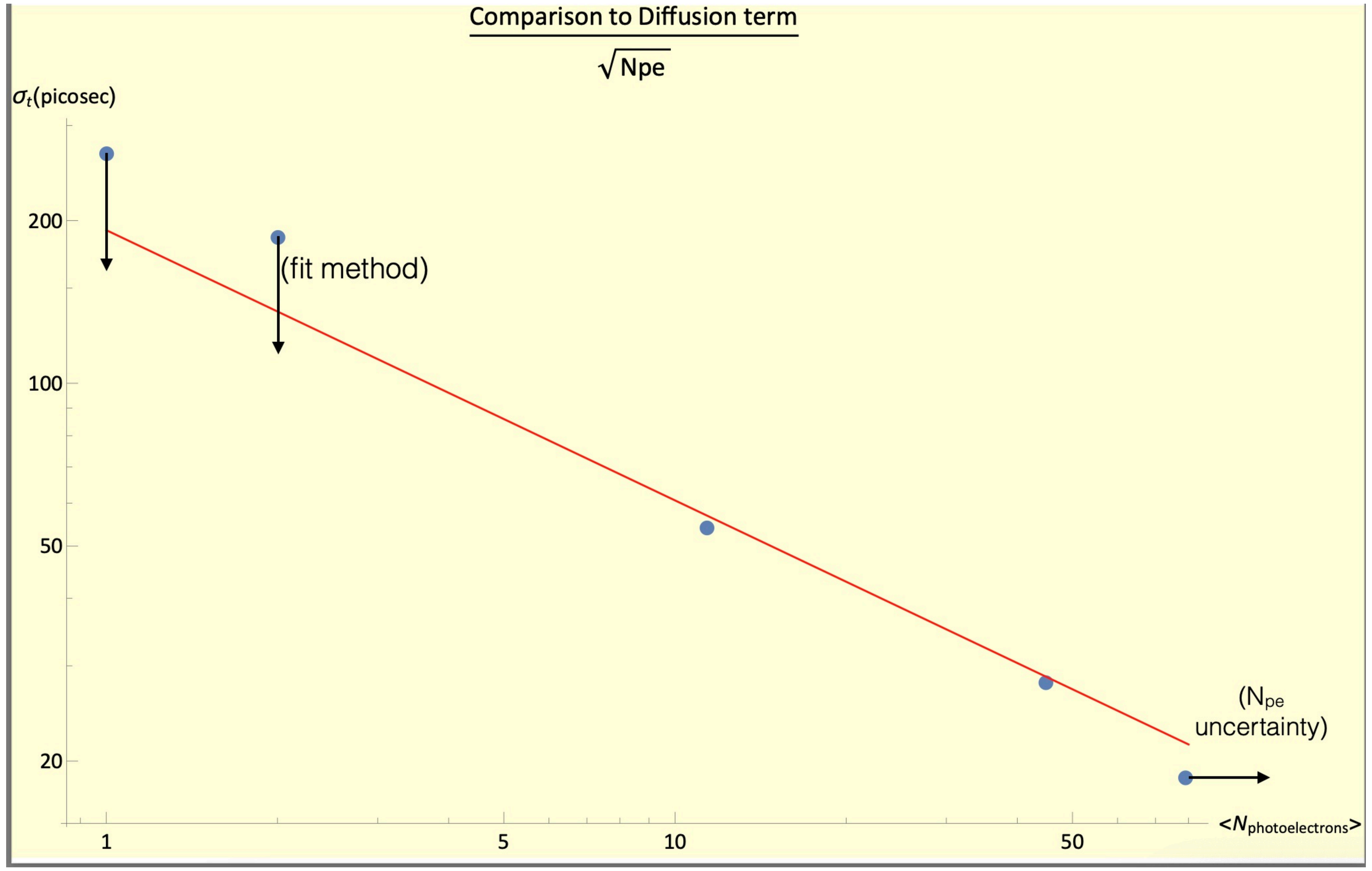
Fabio Sauli

* MPGD=Micro Pattern Gas Detector

First Demonstration of Principle

@ Saclay Laser Lab
of Thomas Gustavsson, IRAMIS





- First look with laser and external t0 reference encouraging:

~50 Picosecond jitter @ N_{PE}~10

- Subsequent improvements -mostly in preampfification region

(Gap thickness, gas choice and field)—> ~50 picosecond single PE jitter

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

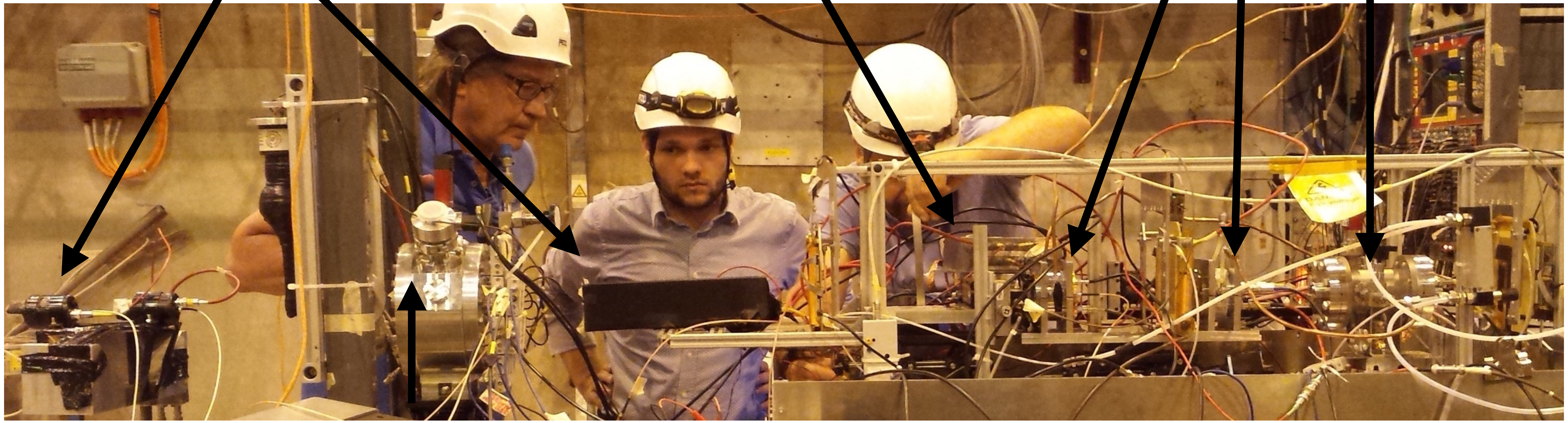
First beam(muon) tests in CERN North Area confirm MIP timing:

Bortfeldt, J., et al. "PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector." *NIM A* 903 (2018):

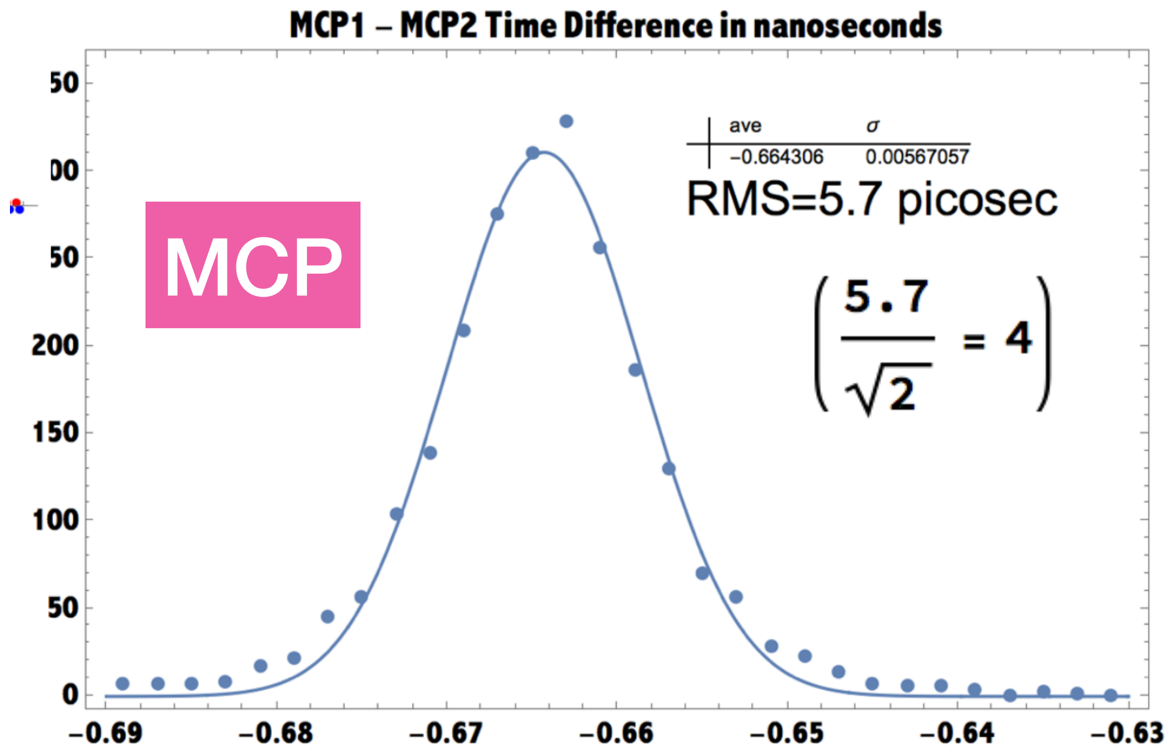
HPK MCP 's
+3mm Quartz
(measure ~4 picosec)

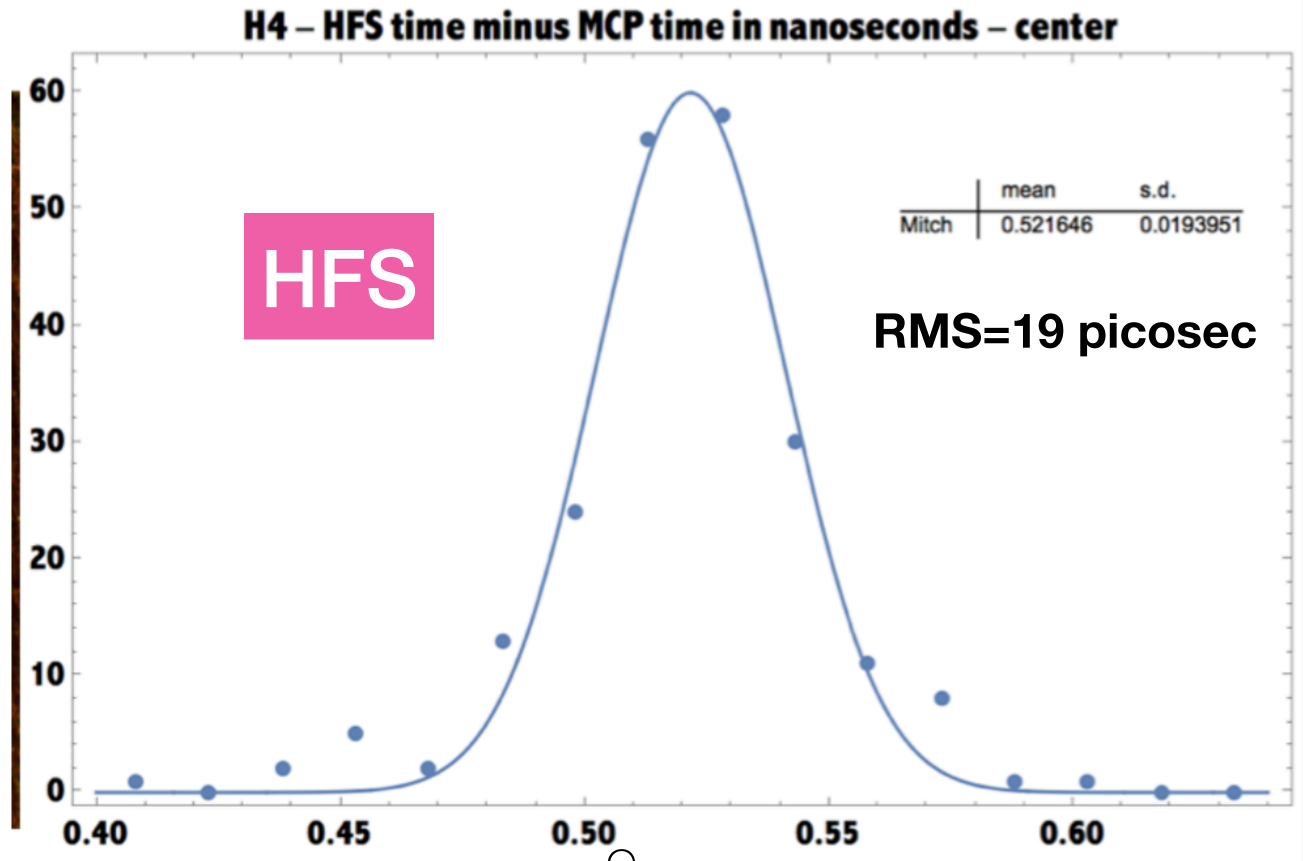
HyperFastSilicon(HFS)
64 mm² (AC coupled DD-AD)
(measure<20 picosec)

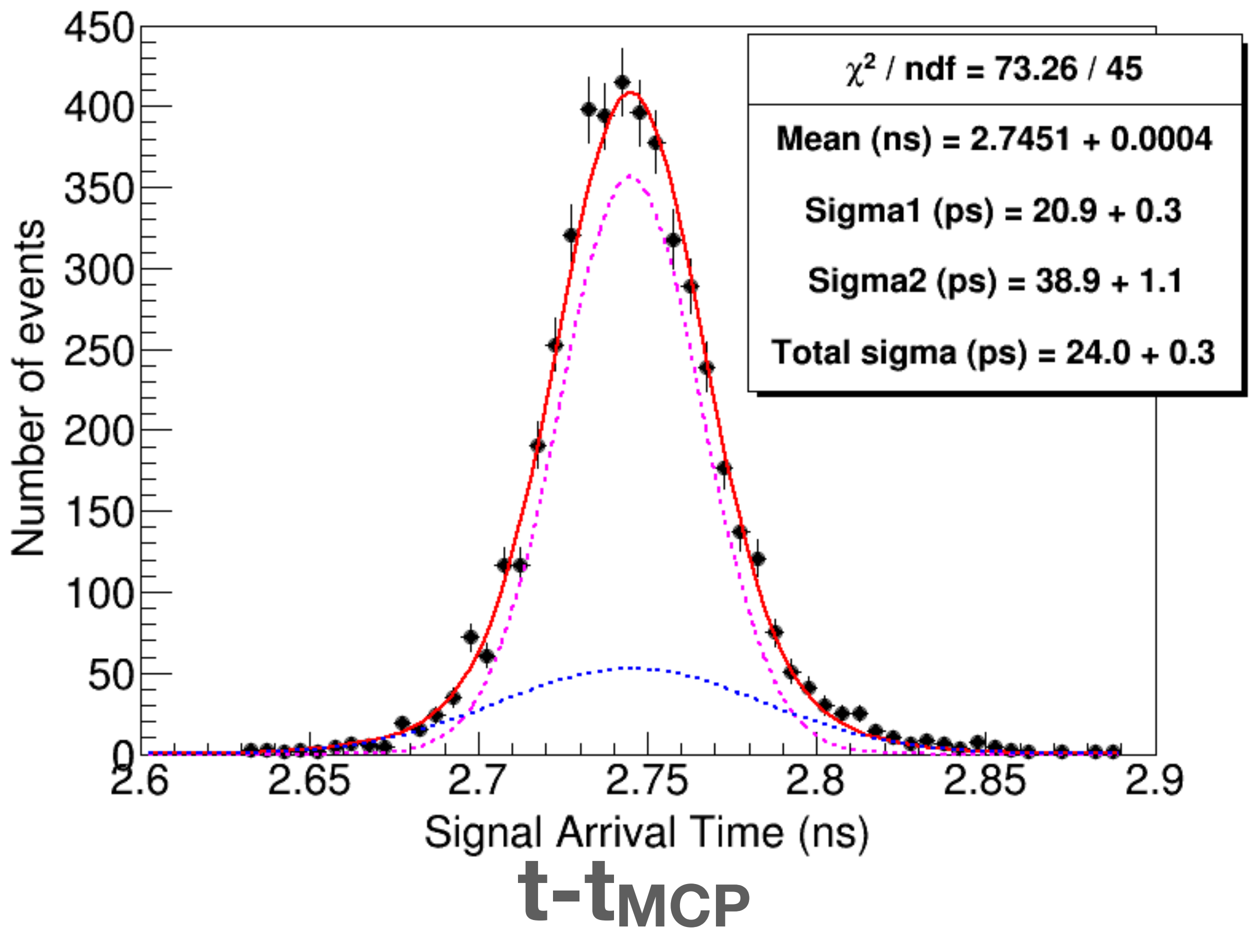
80 mm² MMegas-based
"PICOSEC"
(measure<25 picosec)



10 pad "PICOSEC"





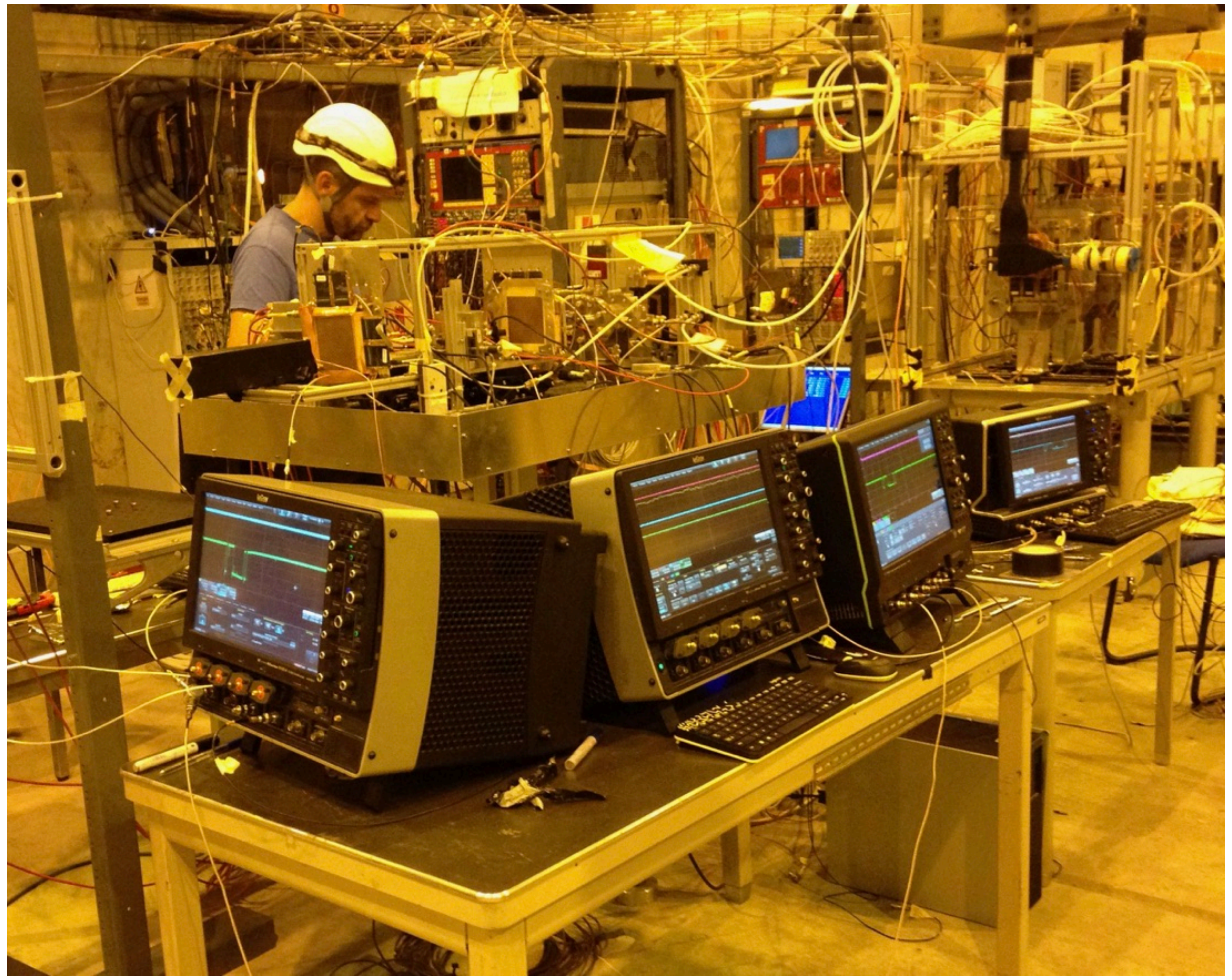


Ne/C2H6/CF4

Help in Fast Startup

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

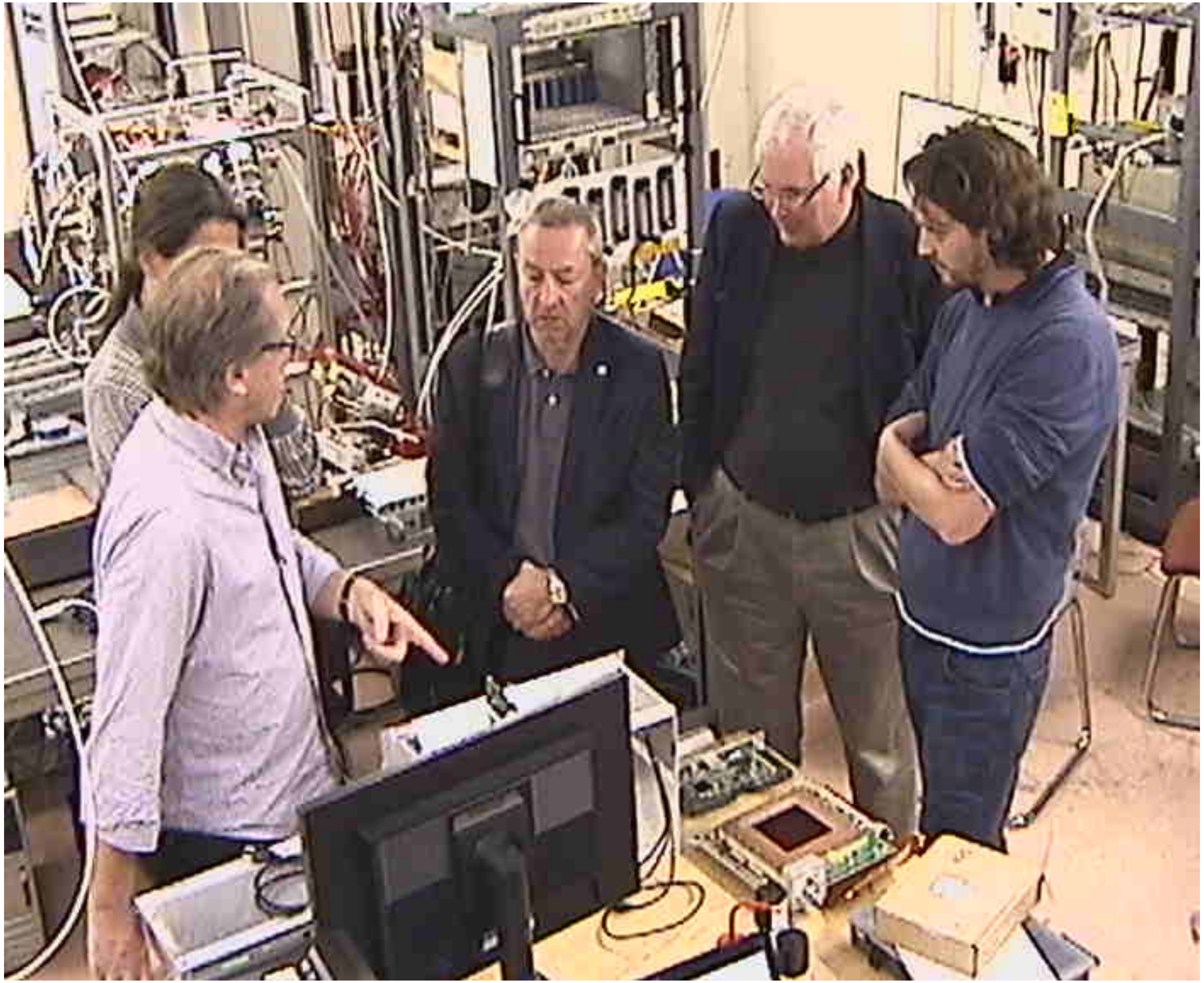
Lecroy was next door
Xavier very generous



Added scope channels
Until preposterous

-> SAMPIC Multichannel readout

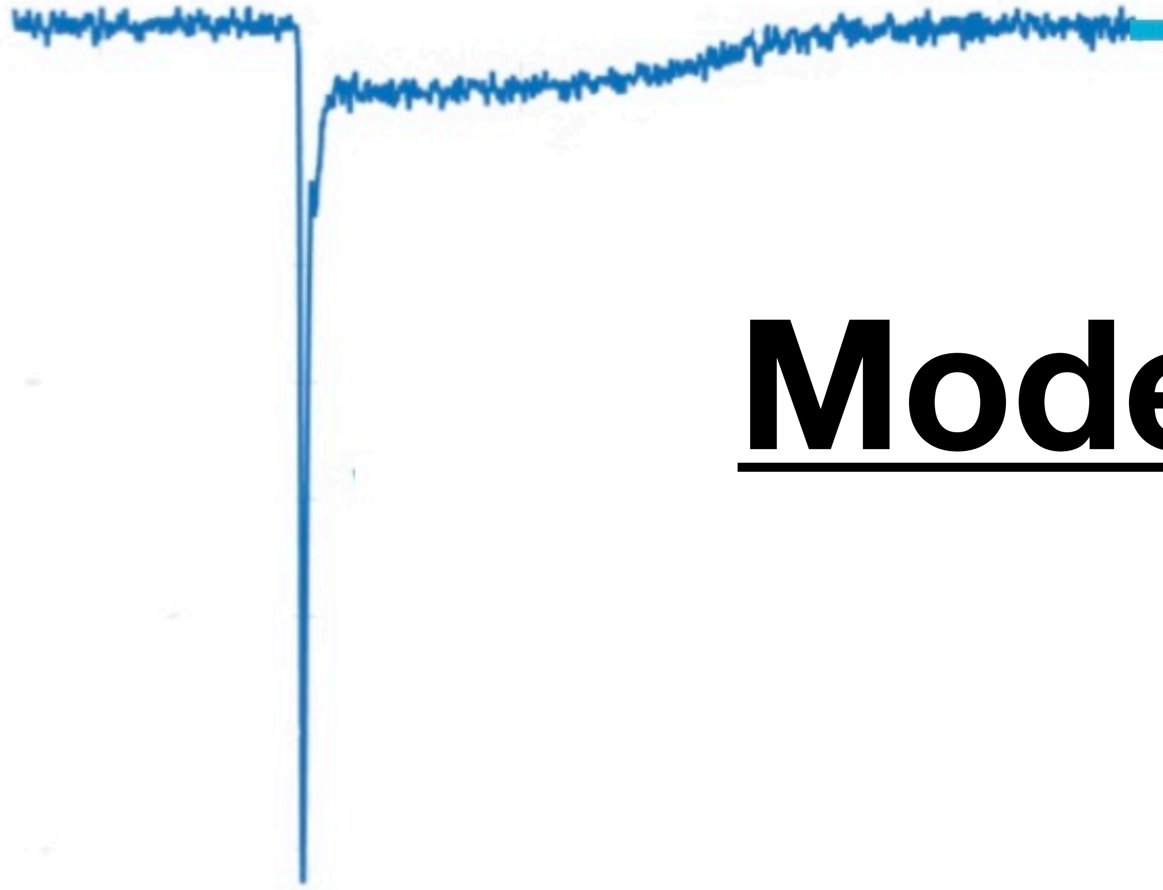
Distinguished Visitors



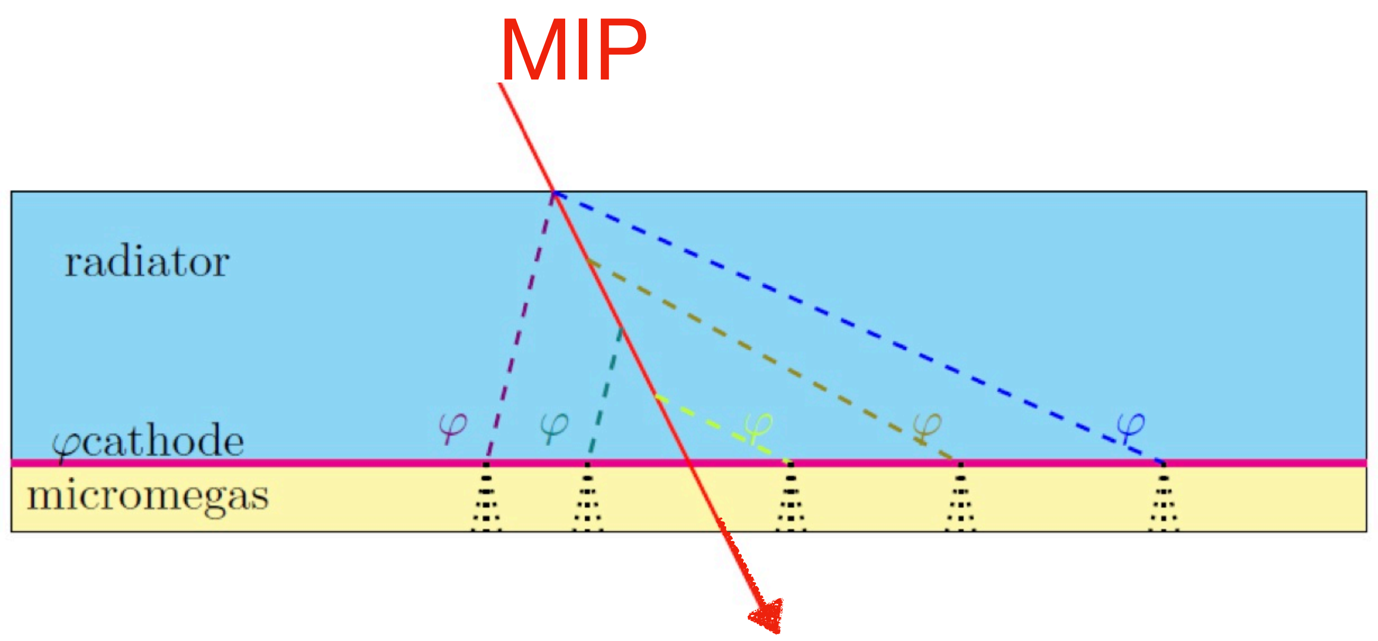
SNW, Nigel, Jim S. , Filippo Resnati
Captured on GDD group Security camera

Evolution from initial 2015 prototype: Development areas

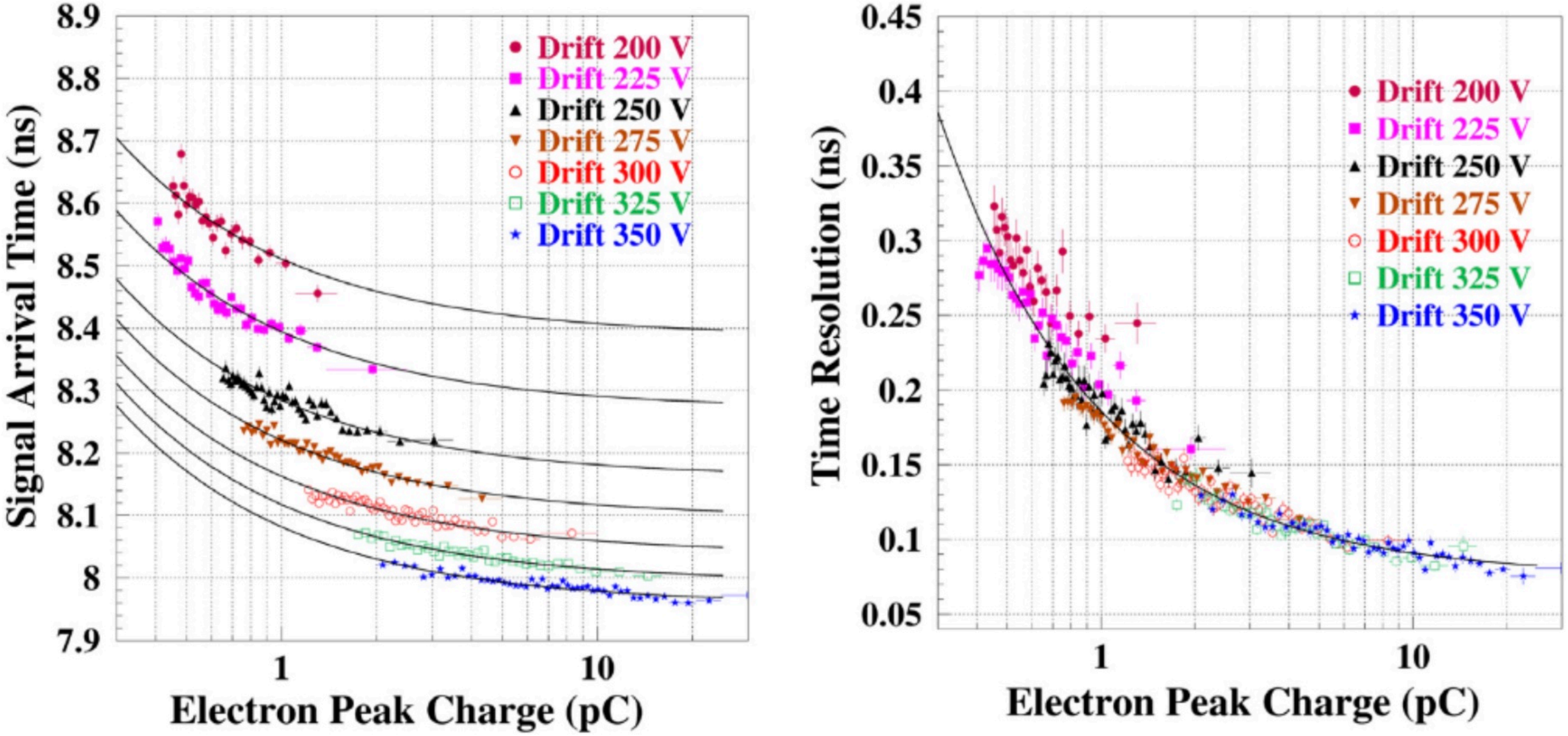
- Modeling Performance: Starting from tools of Rob Veenhof (collaborator)
- Further refinement: AUTH joins->ultimate modeling of timing due to Mmegas details
- Confirm that these dominated by MMmegas- not photon transport (ie Aleksan)
- Robust photocathode development (ie Diamond-like Carbon, B_4C, CVD,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



Modeling PICOSEC performance

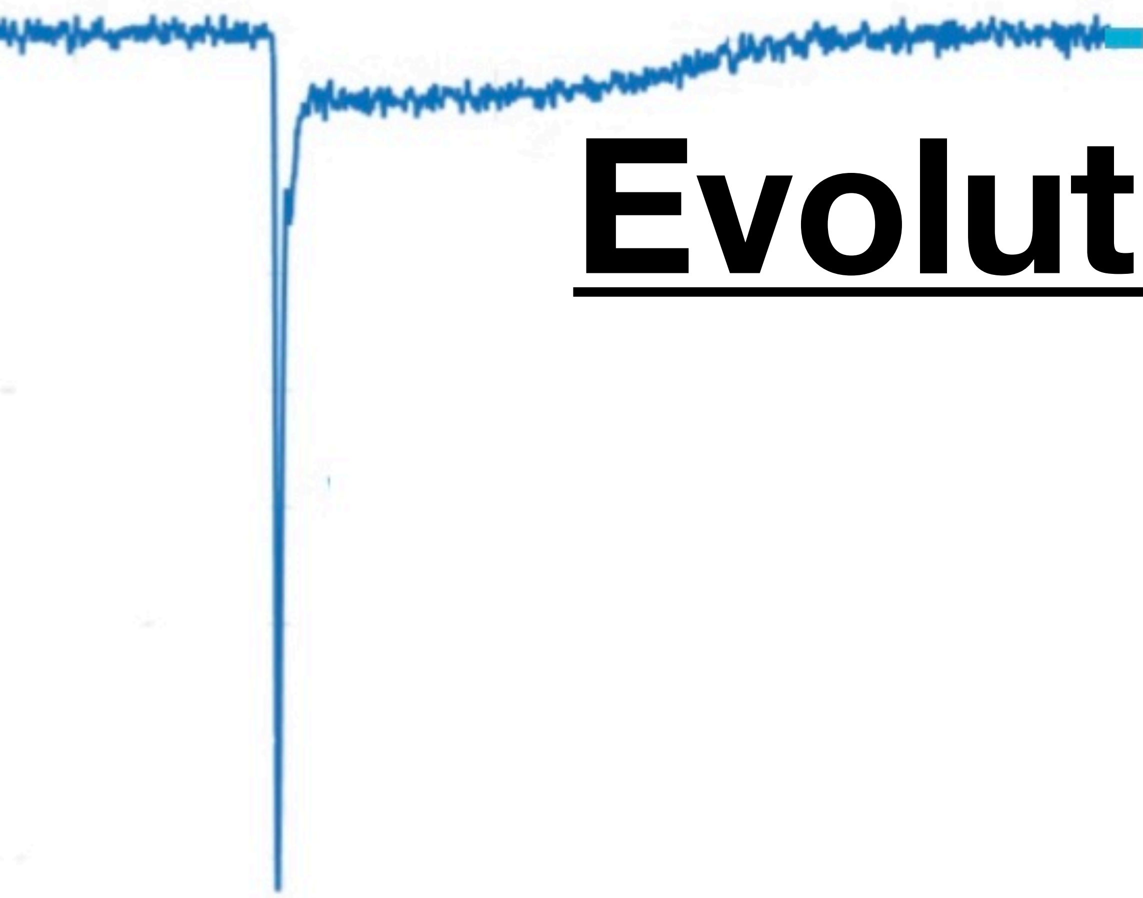


Modeling Optics
Including reflection/absorption
Incidence angles, etc
Confirms small contribution
To resolution (~10-15 picosec)



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

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

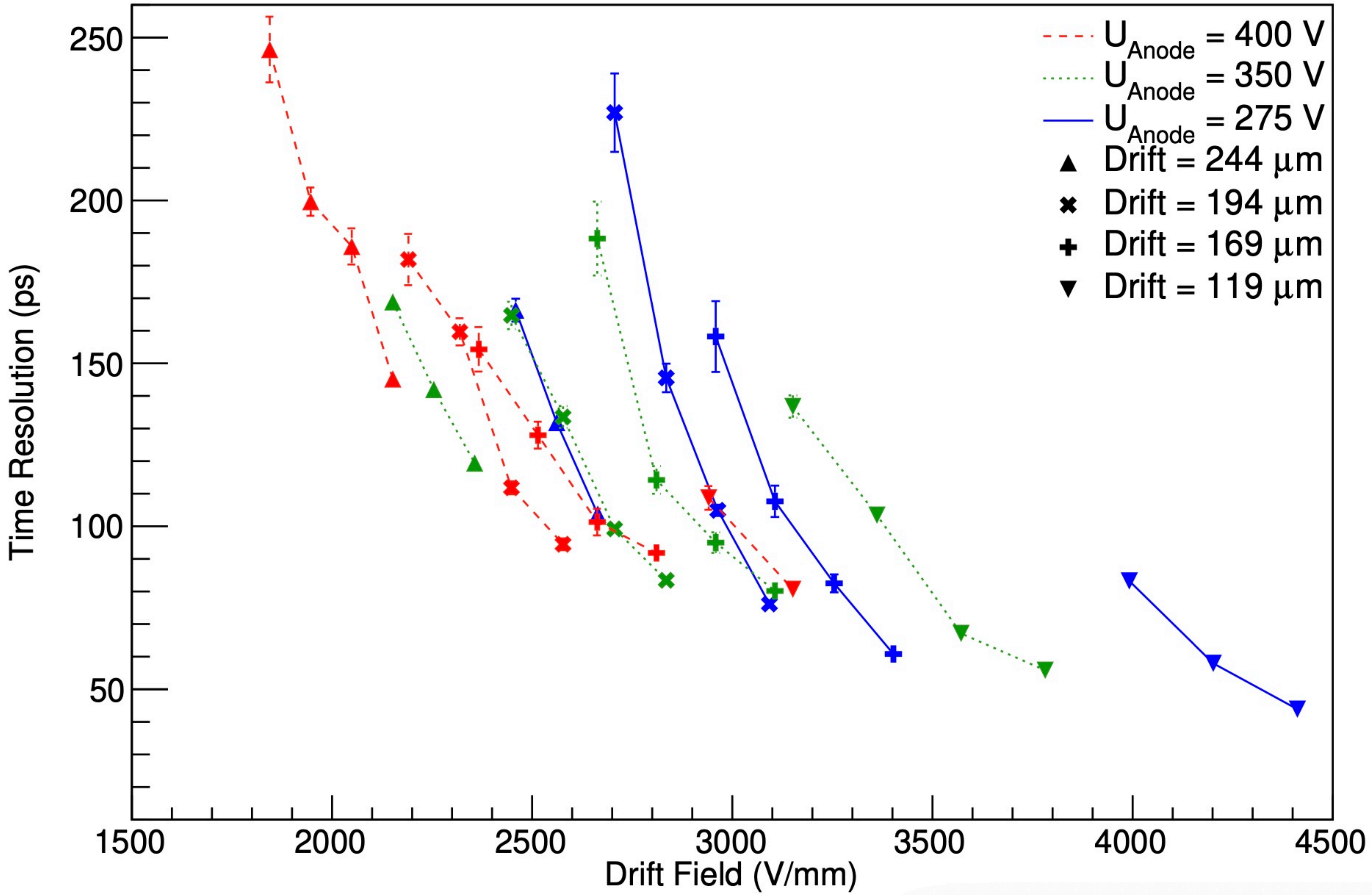


Evolution of Single Photoelectron response (SPTR)

- Update from initial

  200 picosec (2015)

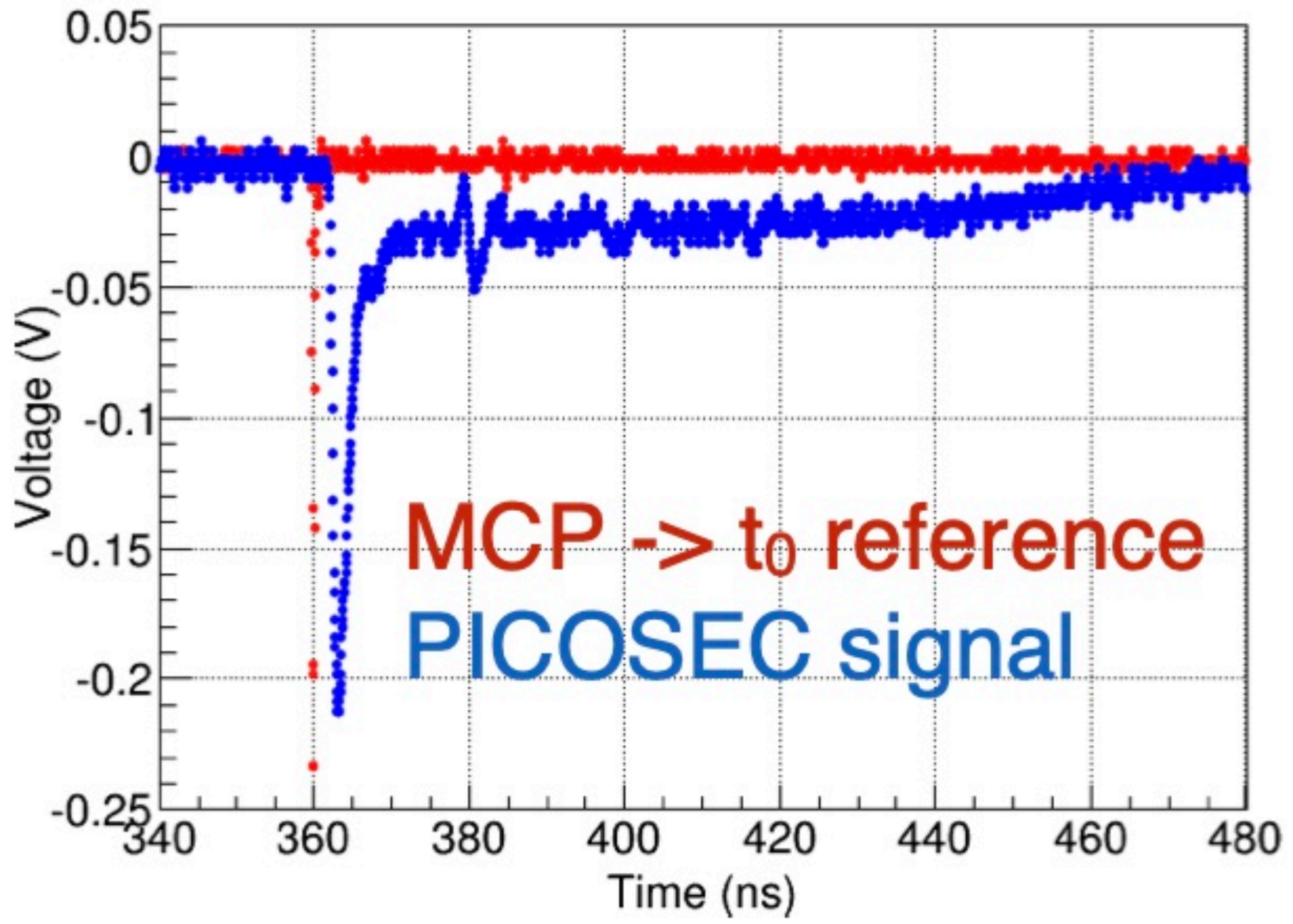
- Ne-Ethane-CF4
- gap in Preamp/Drift

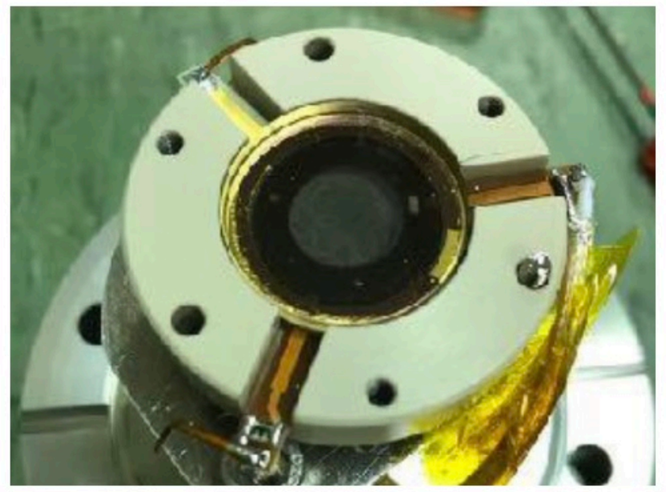


L. Sohl, et al., Single photoelectron time resolution studies of the PICOSEC- Micromegas detector,

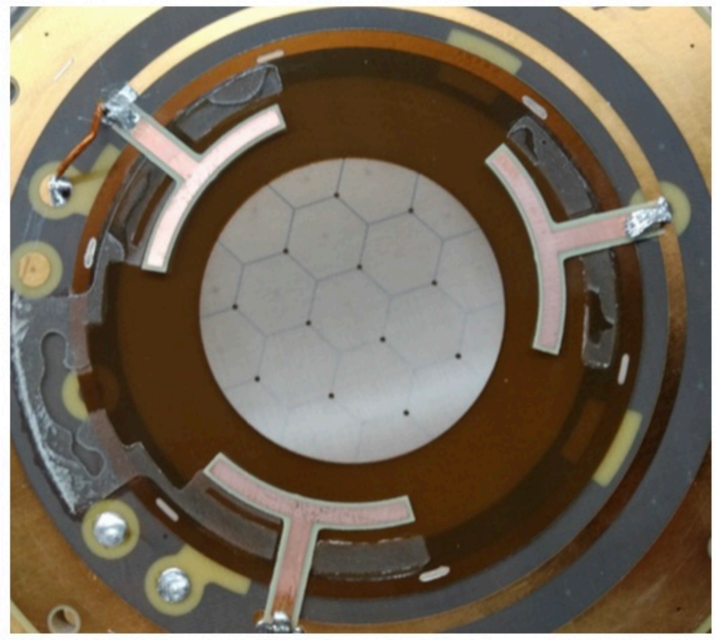
JINST Proc. of the 15th Topical Seminar on Innovative Particle and Radiation Detectors 2019, InPress (2020)

Scaling up from Single Channel Prototype

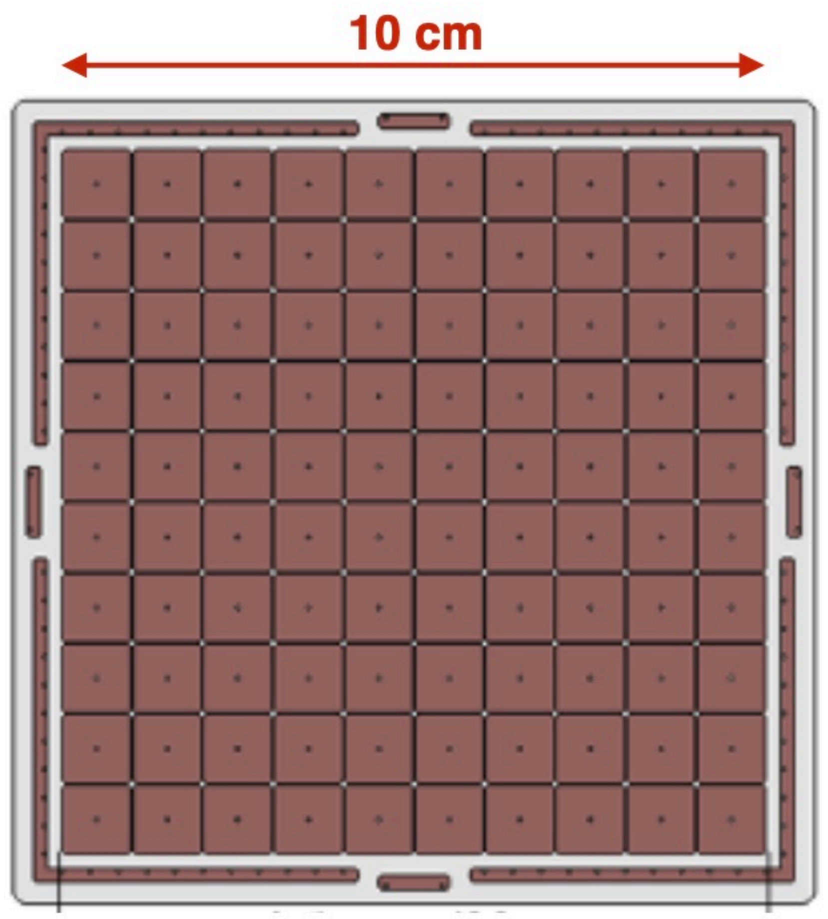




Single pad (2016)
ø1 cm



Multi pad (2017)
⬡ 1 cm



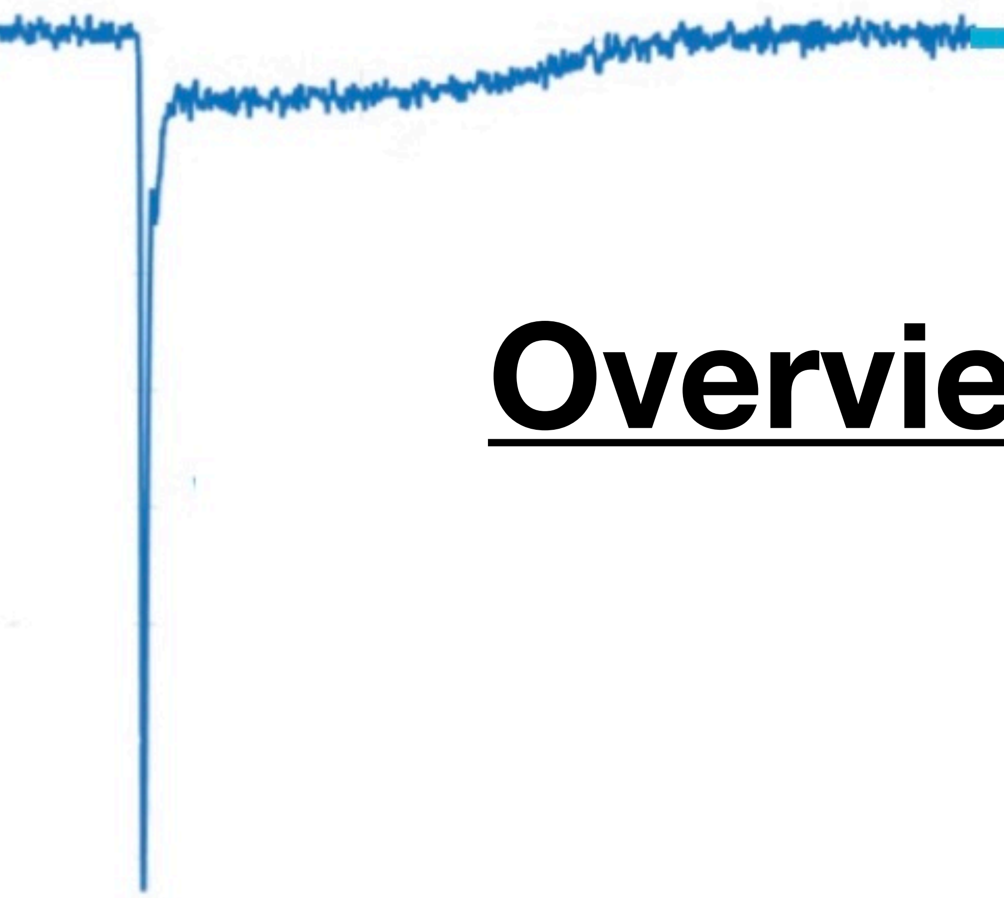
10x10 module
◻ 1 cm

- 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

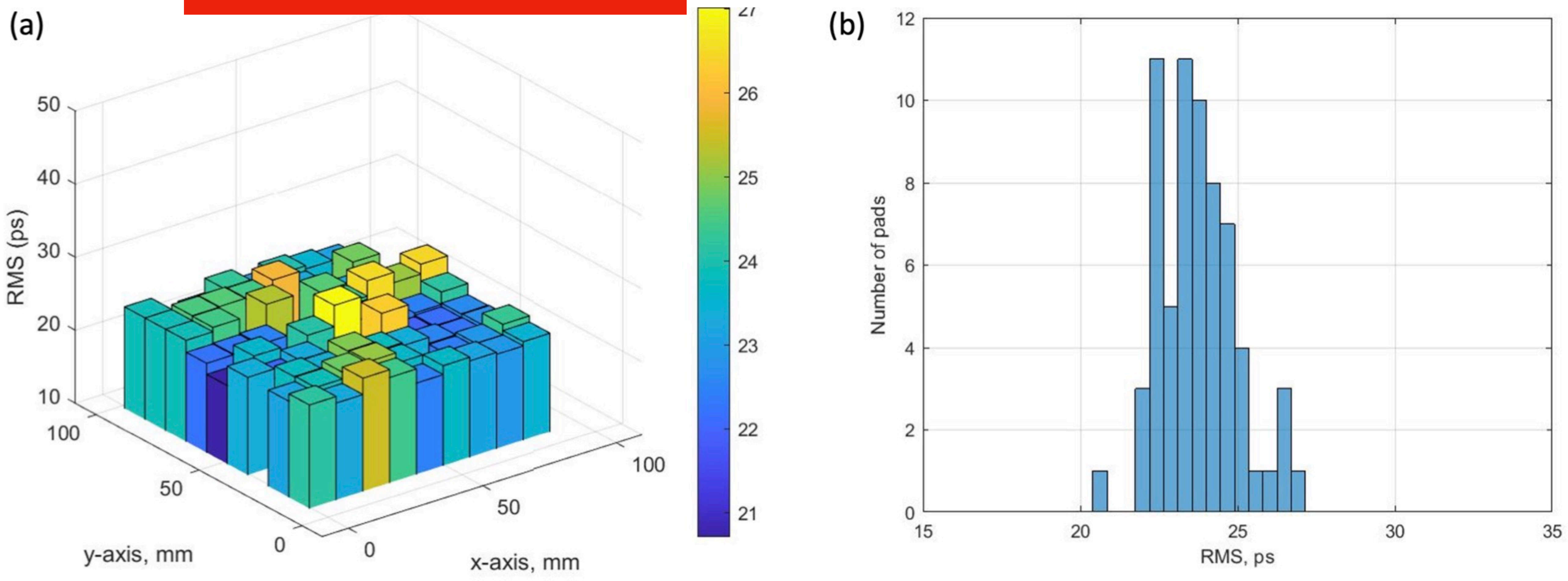
A. Utrobicic et al. ,“A large area 100 channel Picosec Micromegas detector with sub 20 ps time resolution” ,https://www.weizmann.ac.il/conferences/MPGD2022/program   and M.Lisowaska,   et al. (ibid)

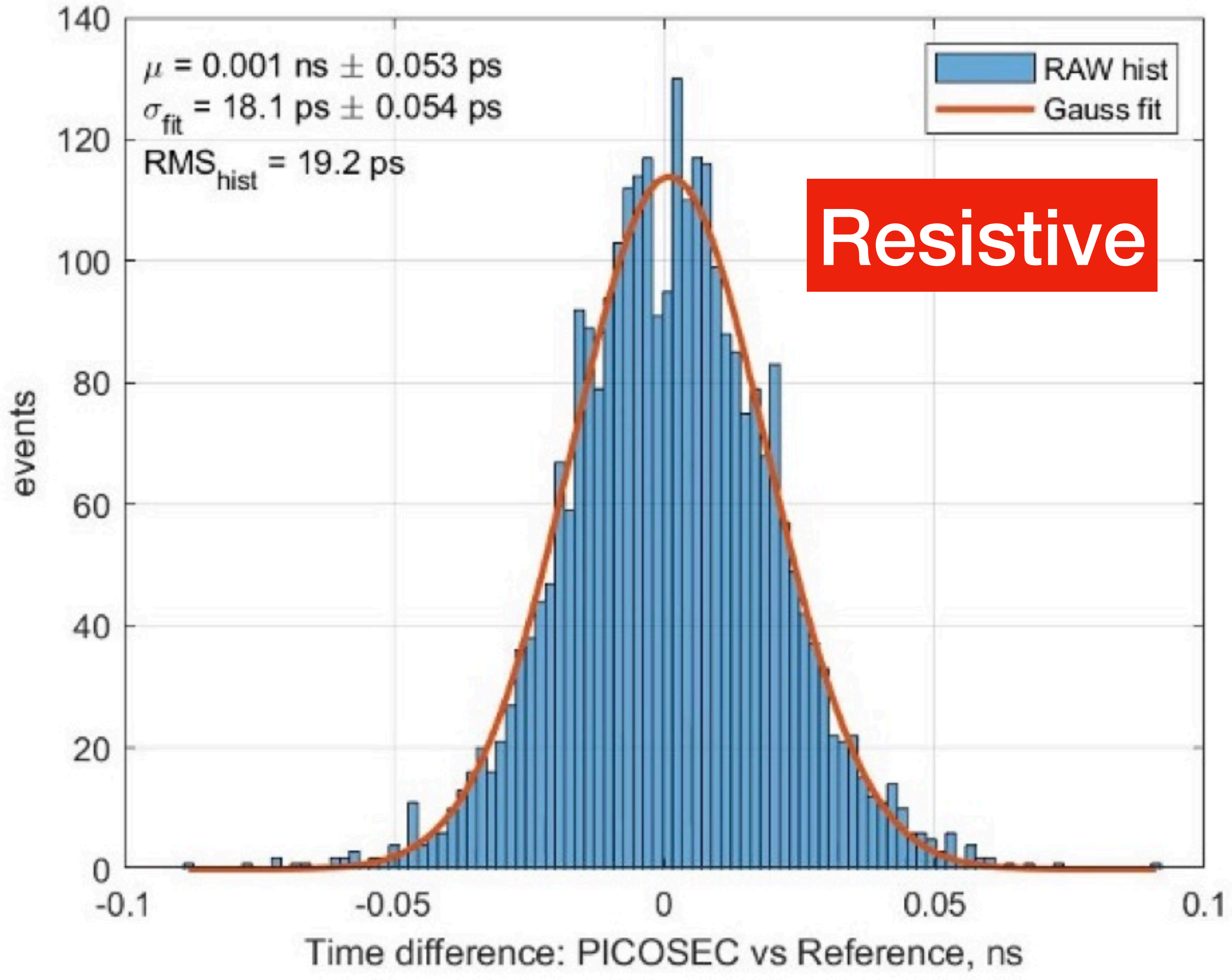


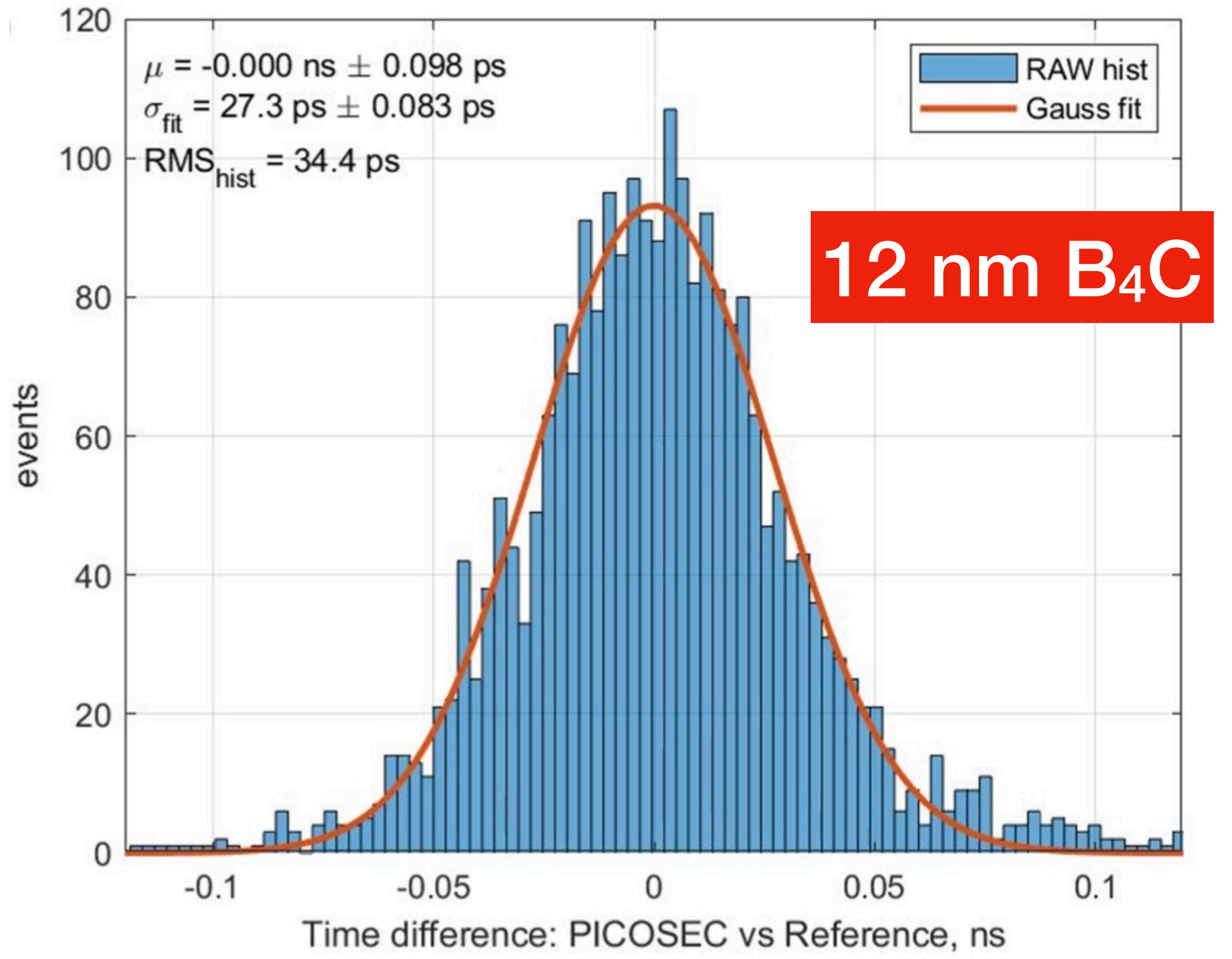
Overview from 150 GeV muon beam tests of 10x10 PICOSEC

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

w. SAMPIC Readout







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
- Challenge of low mass, rigid construction (10 micron flatness?)
- Sealed detectors? Interaction w., “GasPMT” in Japan
- Alternative eco-friendly gas
- Learn requirements from future detector communities

PICOSEC Micromegas

Studies on alternative gas mixtures

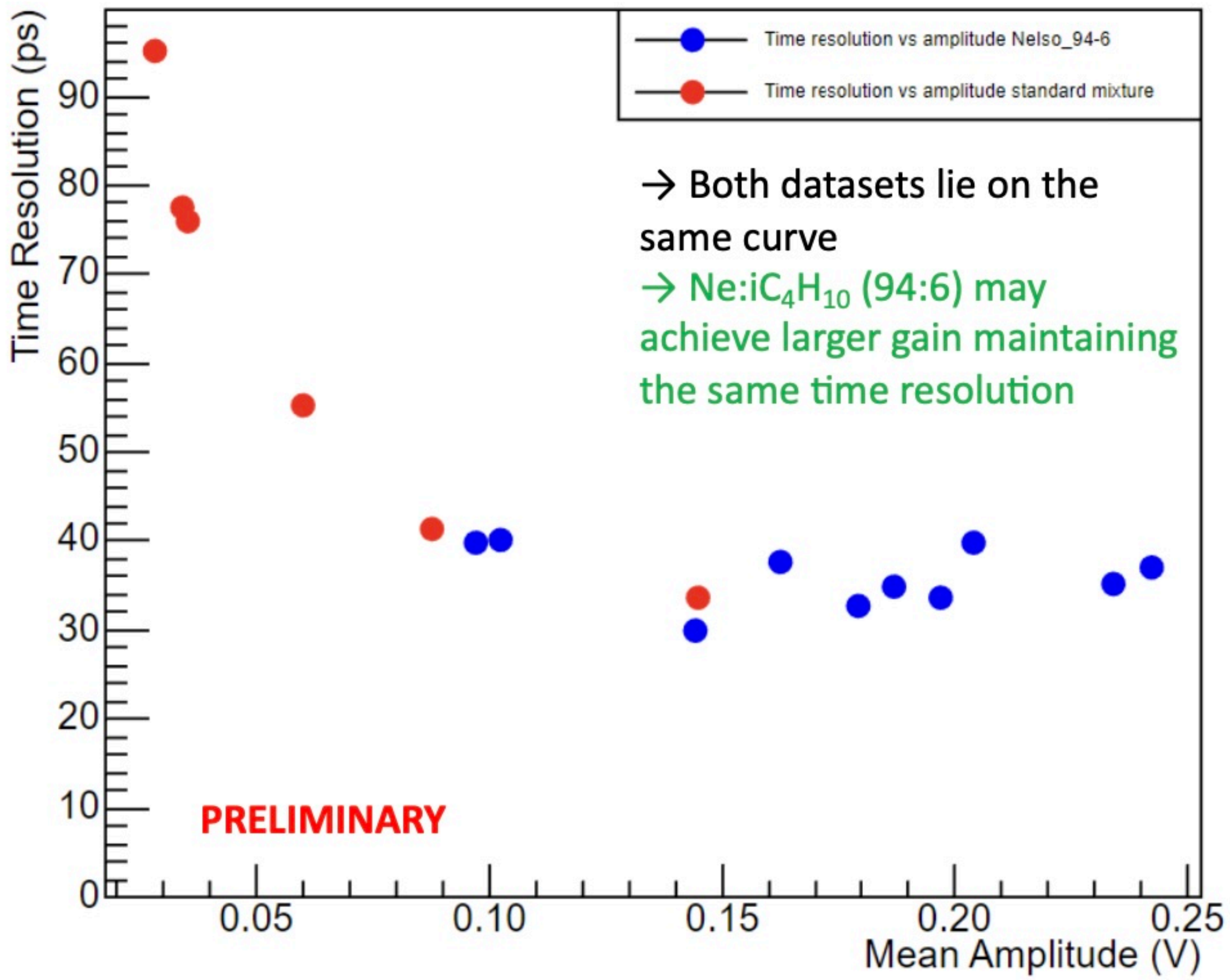
Alternative gas mixture studies But recall volume tiny!

- **PICOSEC standard gas mixture:** $Ne:CF_4:C_2H_6$ (80:10:10) → high gain, quenching, drift velocity, but expensive, **not eco-friendly**, flammable
- **Alternative gas mixture:** $Ne:iC_4H_{10}$ → CF_4 dropped, iC_4H_{10} as a replacement of C_2H_6 → low GWP (0.2 instead of 740), good quenching

Promising results with $Ne:iC_4H_{10}$, further studies on the alternative gas mixtures to be performed

$Ne:iC_4H_{10}$ (94:6)

CERN Chamber – 160 µm drift gap – rMM 82 MΩ/□ – CsI 18 nm



Ar-based gas mixtures:
→ $Ar:CO_2$ (93:7)
→ $Ar:CO_2:iC_4H_{10}$ (93:5:2)
also tested but showed unstable operation

Details: D. Fiorina, INFN Pavia, FAST2023: link

Robust photocathodes

Time resolution

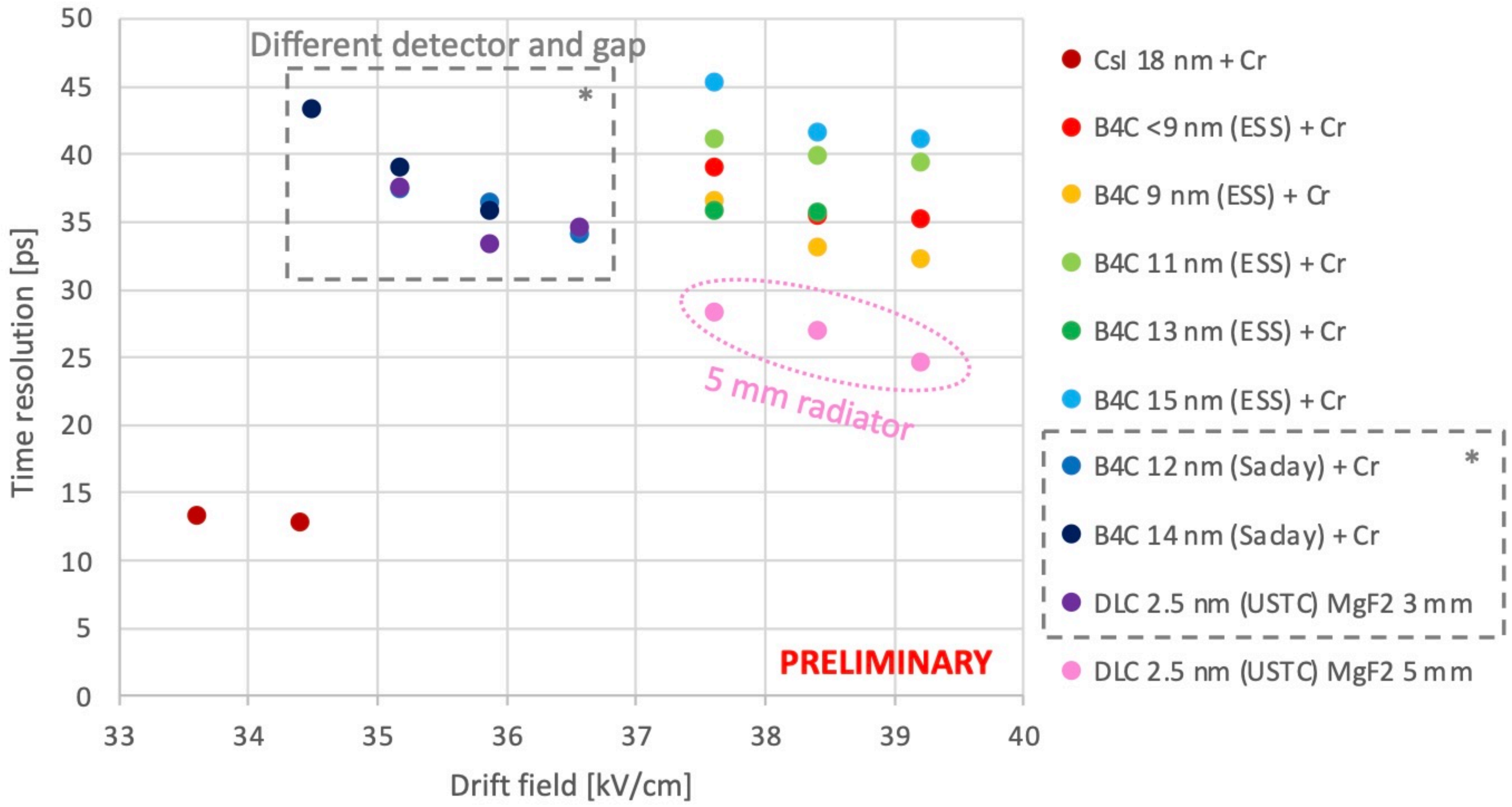
New promising results of robust photocathodes from 2023 test beams

- **Prototype**: Single pad non-resistive MM, pre-amplification gap 125/145 µm*
- **Photocathodes**: CsI, DLC, B_4C of different thicknesses from different collaborators**
- **Time resolution** after MCP subtracted:

$$\sigma_{PICO} = \sqrt{\sigma_{combined}^2 - \sigma_{MCP}^2},$$

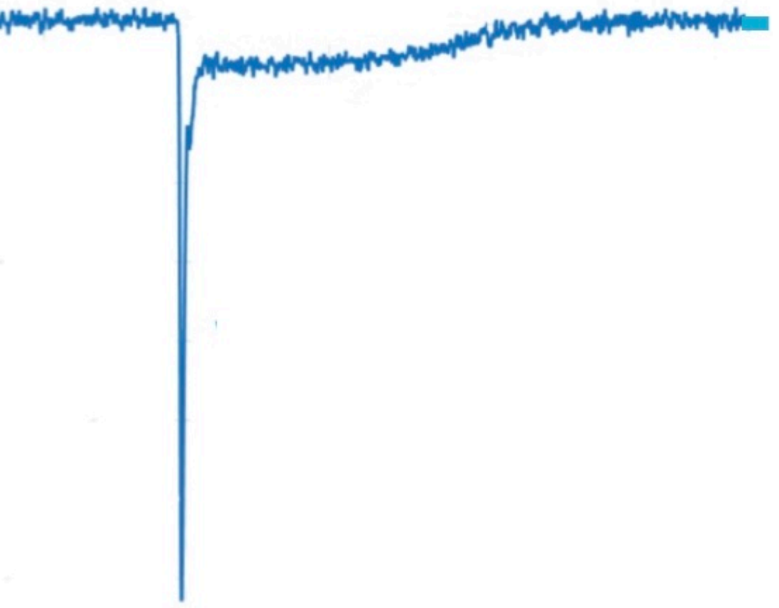
where MCP double split $\sigma_{MCP} \approx 7.67$ ps

[redacted]



*Samples measured in a new detector with 125 µm gap SEALED in August, except for 3 measured with Saclay detector with 145 µm gap FLUSHING in July (marked with a star)

**Depositions: CsI at CERN, DLC at USTC, B_4C at CEA Saclay and ESS



PICOSEC and the R&D landscape

- TOF/pid workhorse at LHC was ALICE gas MRPC: 141m^2 reaching rms~56 psec.
- PICOSEC natural evolution to Micro Pattern Gas Detectors(MPGD)
- Early demonstration of <25 then <20 psec. -> flexibility for developments
- Recently fast timing -> generic “CPAD_RDC11”
- Often noted that MPGD activities limited in US
- In NP already 2 US groups benefit from PICOSEC

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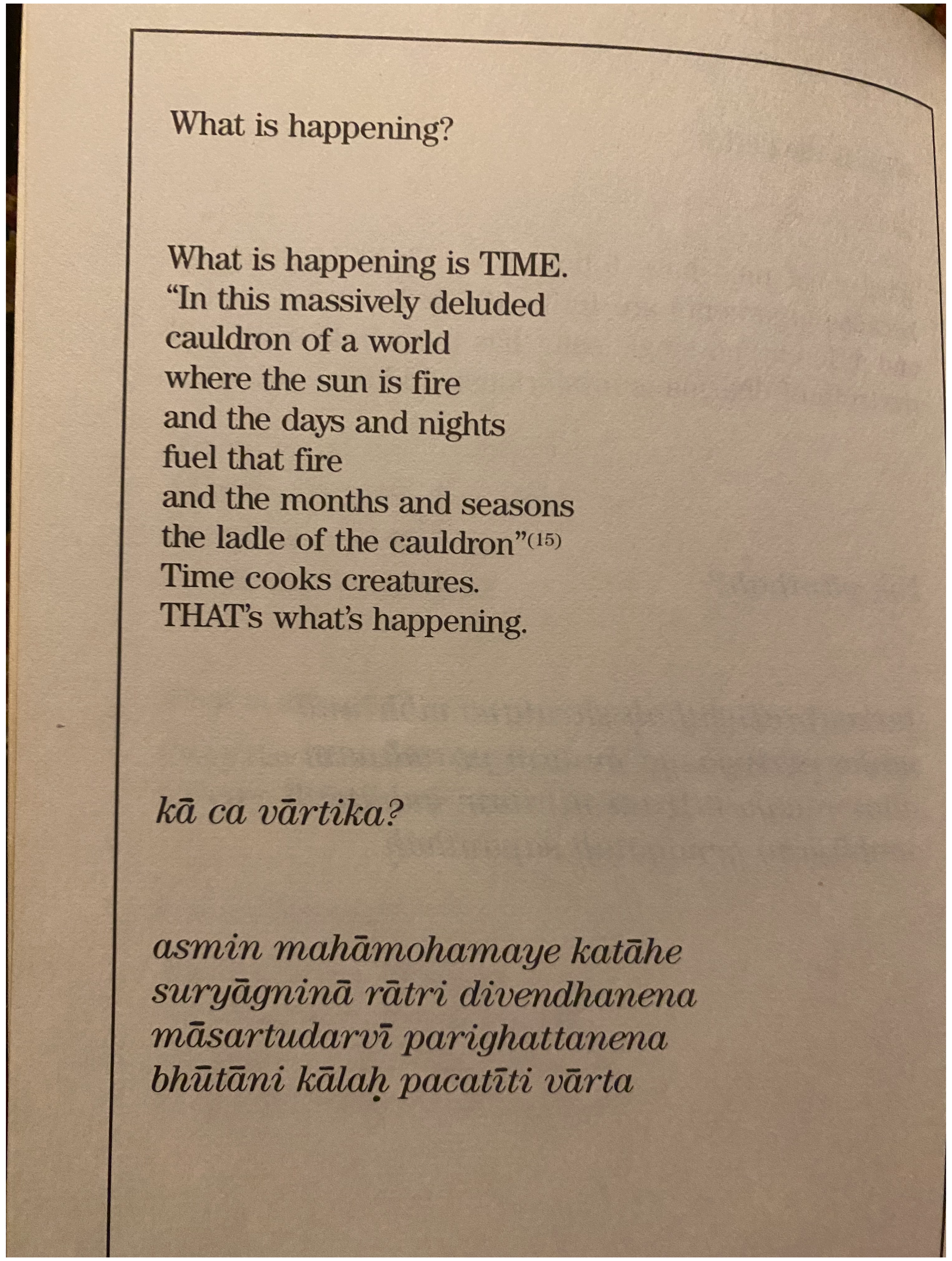
2 US collaborators just recently added in above. Probably based at JLAB

Sanskrit equivalent of The Riddle of the Sphinx:

Riddle contest between a Yaksha and Yudhishthira

Q:What is happening?

A: What is happening is TIME.


What is happening?

What is happening is TIME.
"In this massively deluded
cauldron of a world
where the sun is fire
and the days and nights
fuel that fire
and the months and seasons
the ladle of the cauldron"(15)
Time cooks creatures.
THAT's what's happening.

kā ca vārtika?

asmin mahāmohamaye katāhe
suryāgninā rātri divendhanena
māsartudarvī parighattanena
bhūtāni kālaḥ pacatīti vārta

अस्मिन् महामोहमये कटाहे सूर्याग्निना रात्रिदिवेन्धनेन ।
मासर्तुदर्वीपरिघट्टनेन भूतानि कालः पचतीति वार्ता ॥ ९९

thanks to Milind Diwan for this reference

Sebastian White