PICOSEC:
24 picosecond MIP timing using micro-MEGAS

Sebastian White, CERN/U.Virginia May 17, 2018

Workshop on Picosecond Timing, Torino

previous report on PICOSEC at 2014 Clermont-Ferrand meeting

https://arxiv.org/abs/1409.1165

“R&D for a dedicated fast timing layer…”, SNW et al.

(proposed in 2014 by Giomataris&SNW as a common project to RD51)

->approved by RD51 in March 2015

1st NIM article available online since April 2018

in press: detailed simulation article, multi-pad, robust photocathodes…

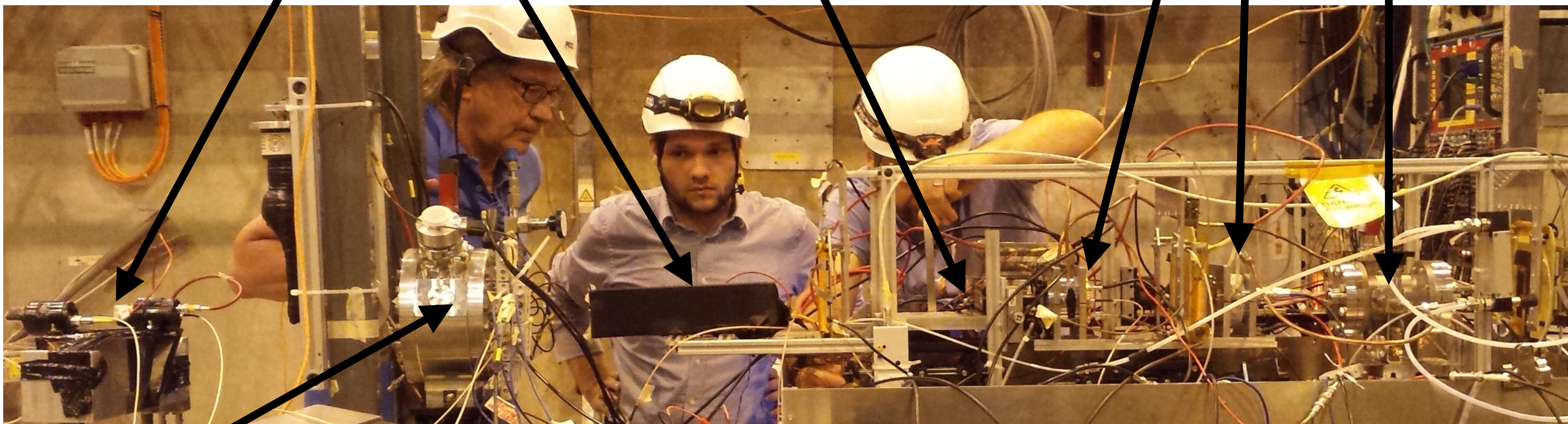
Viva Verdi

July/Aug 2017 PICOSEC data

4x 6micron HPK MCP 's
+3mm Quartz
(measure ~4 picosec)

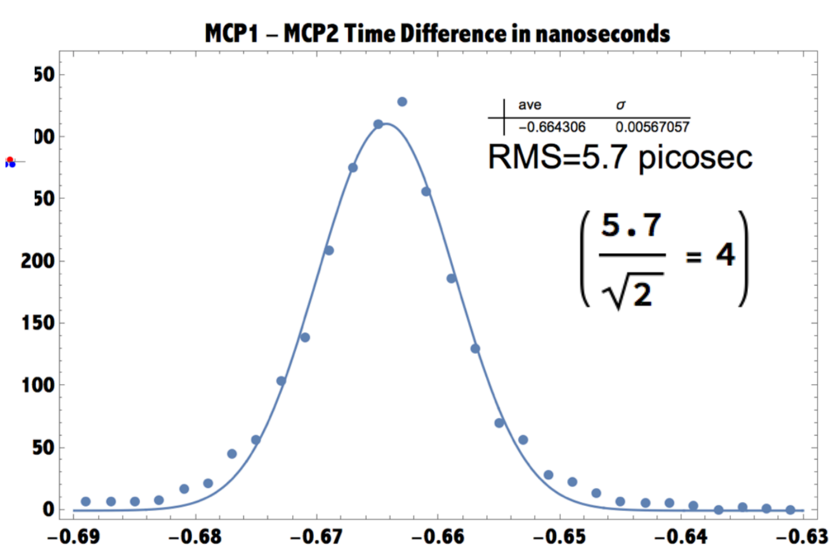
HyperFastSilicon(HFS)
(mesh readout DD-AD)
64 mm²/pixel
(measure<20 picosec)

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

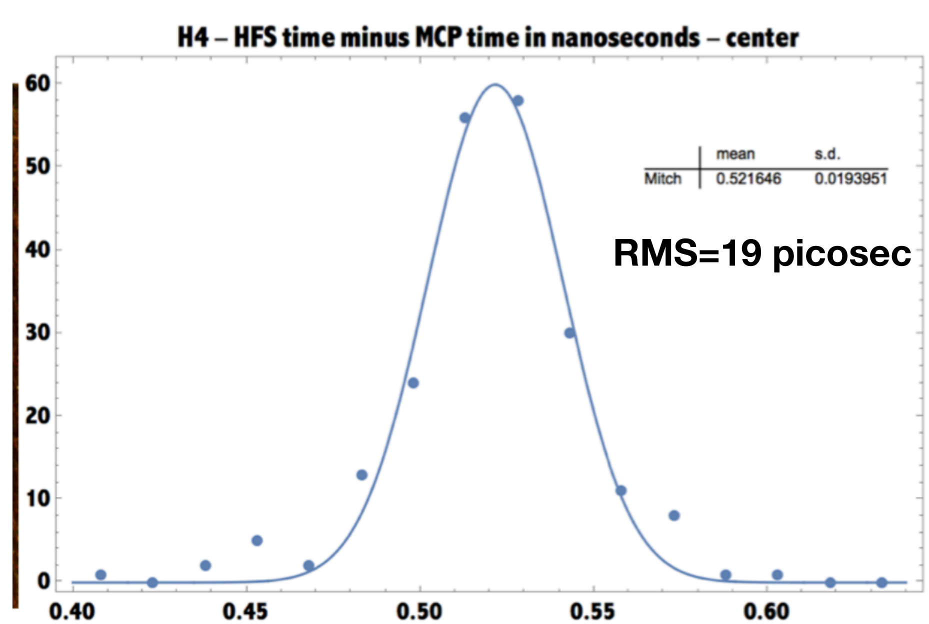


10 pad "PICOSEC"

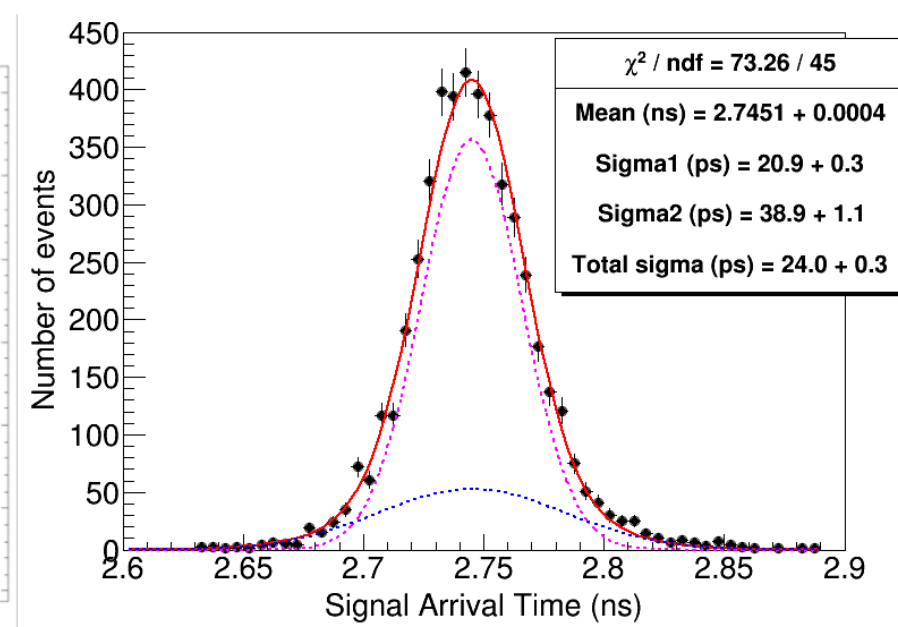
vacuum



Si- Gallium doped



Ne/C2H6/CF4



The PICOSEC collaboration

- **IRFU/Saclay (France):** D. Desforge, I. Giomataris, T. Gustavsson, C. Guyot, F.J. Iguaz, M. Kebbiri, P. Legou, O. Maillard, T. Papaevangelou, M. Pomorski, P. Schwemling.
- **CERN:** J. Bortfeldt, F. Brunbauer, C. David, J. Frachi, M. Lupberger, H. Müller, E. Oliveri, F. Resnati, L. Ropelewski, T. Schneider, L. Sohl, P. Thuiner, M. van Stenis, P. Thuiner, R. Veenhof, S. White[1].
- **USTC (China):** J. Liu, B. Qi, X. Wang, Z. Zhang, Y. Zhou.
- **AUTH (Greece):** I. Manthos, V. Niaouris, K. Paraschou, D. Sampsonidis, S.E. Tzamarias,.
- **NCSR:** G. Fanourakis.
- **NTUA:** Y. Tsipolitis.
- **LIPP:** M. Gallinaro.
- **IGFAE**: D. González-Díaz.

[1] Also University of Virginia.

HL-LHC provided a useful benchmark for timing:

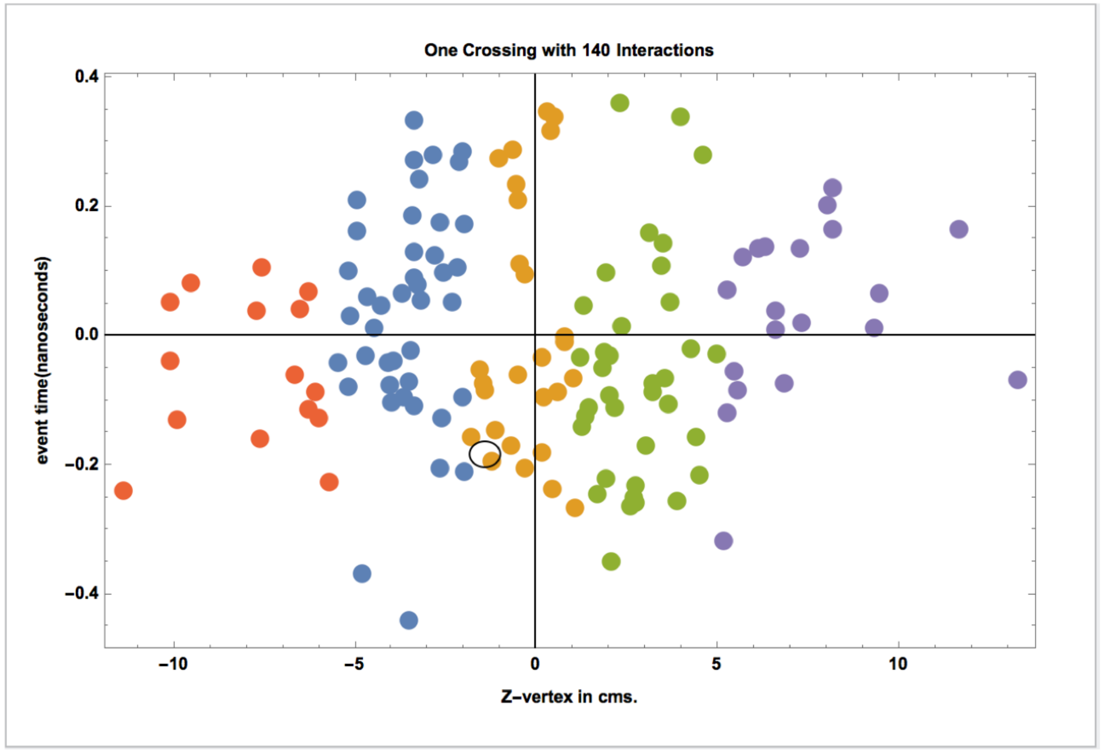
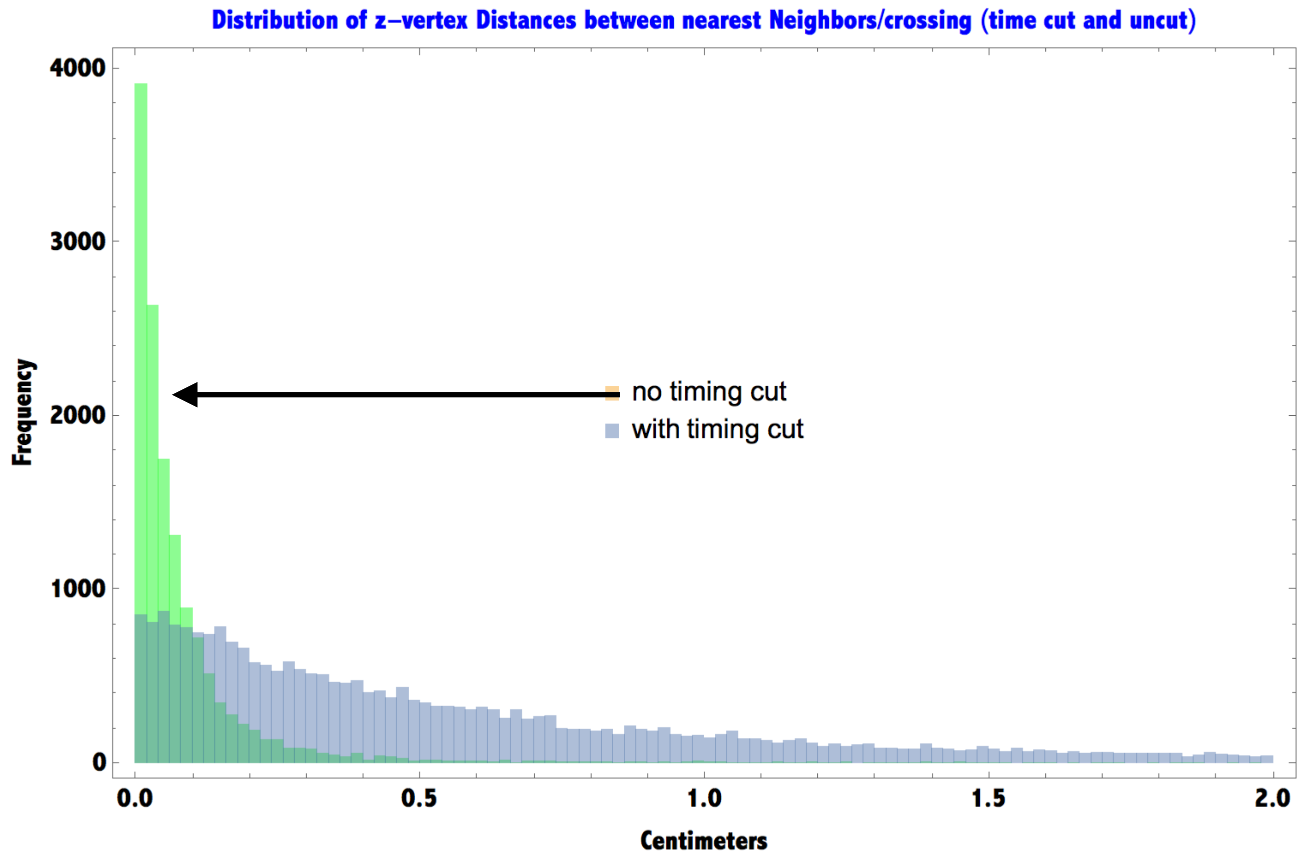


Fig. 1. Simulation of the space(z-vertex) and time distribution of interactions within a single bunch crossing in CMS at a pileup of 140 events- using LHC design book for crossing angle, emittance, etc. Typically events are distributed with an rms-in time- of 170 picoseconds, independent of vertex position.

https://arxiv.org/abs/0707.1500

HL-LHC ir profile-> ~6cms in z, 0.17 nsec in time @~200 interactions/xing-> ~30 psec tag rms ->extend vertex tag in z to z+time

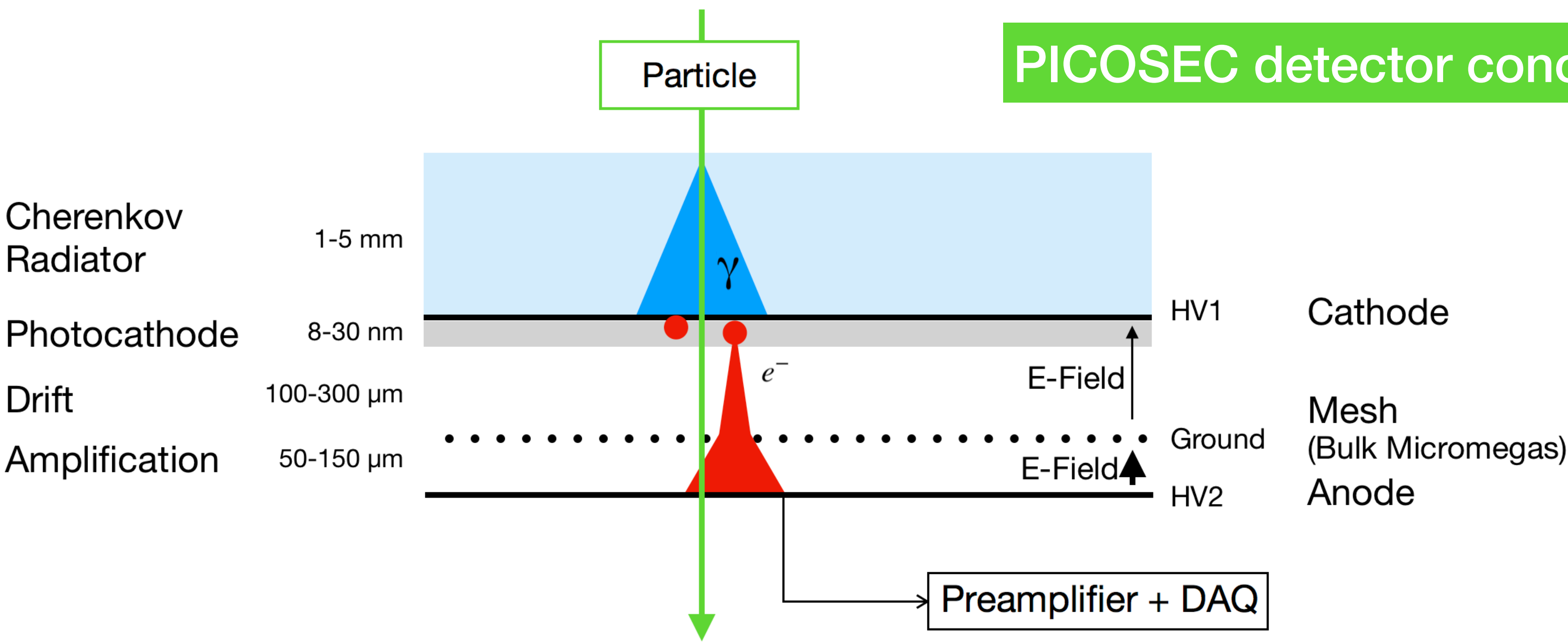


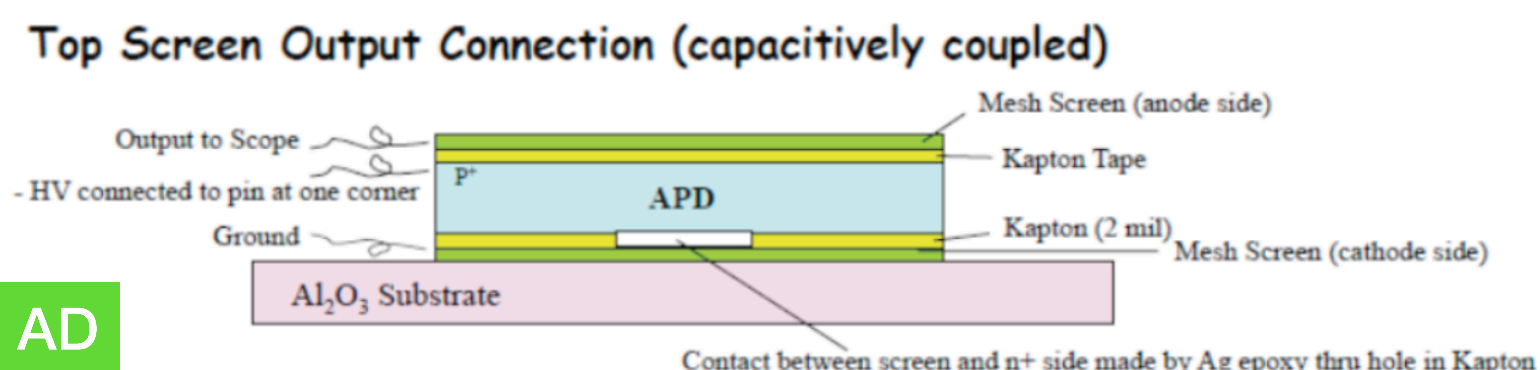
these same arguments from 10 years ago are now validated by full CMS simulation and physics payoff quantified-> equivalent to ~20 to 30% added luminosity

PICOSEC approach: given need to cover ~40m² in CMS (or more forgiving rate environment) and assume "right" granularity from occupancy (ie ~1 cm² pixel)
Challenge to achieve large (SNR ~100) signal and dV/dt , C_{det}~20 pF

Ionization or Photodetection?

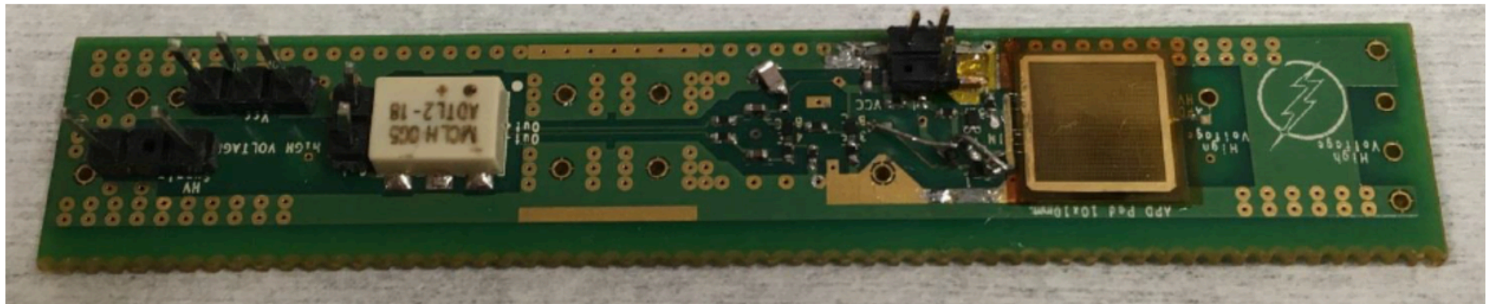
PICOSEC detector concept





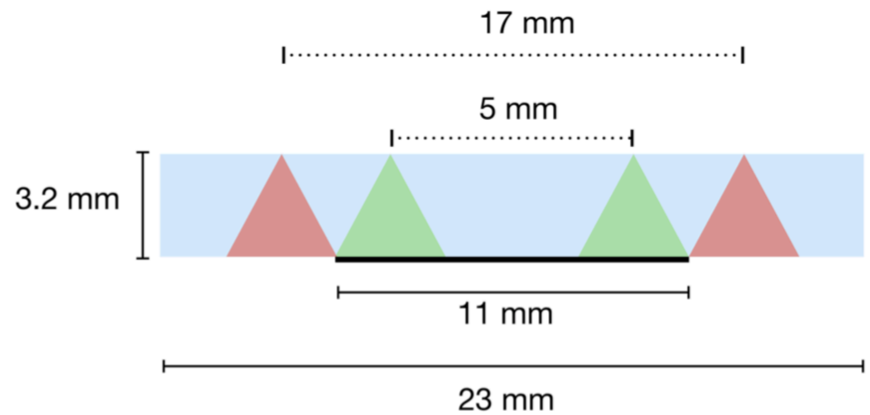
mesh readout deep-depleted AD
aka “HyperFast Silicon”

see M. Vignali talk, friday

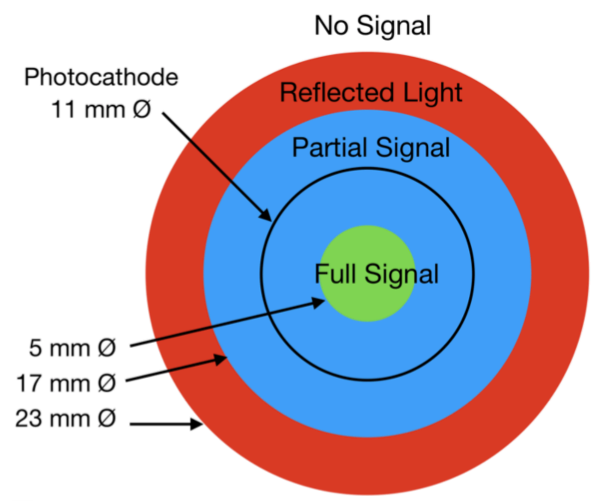


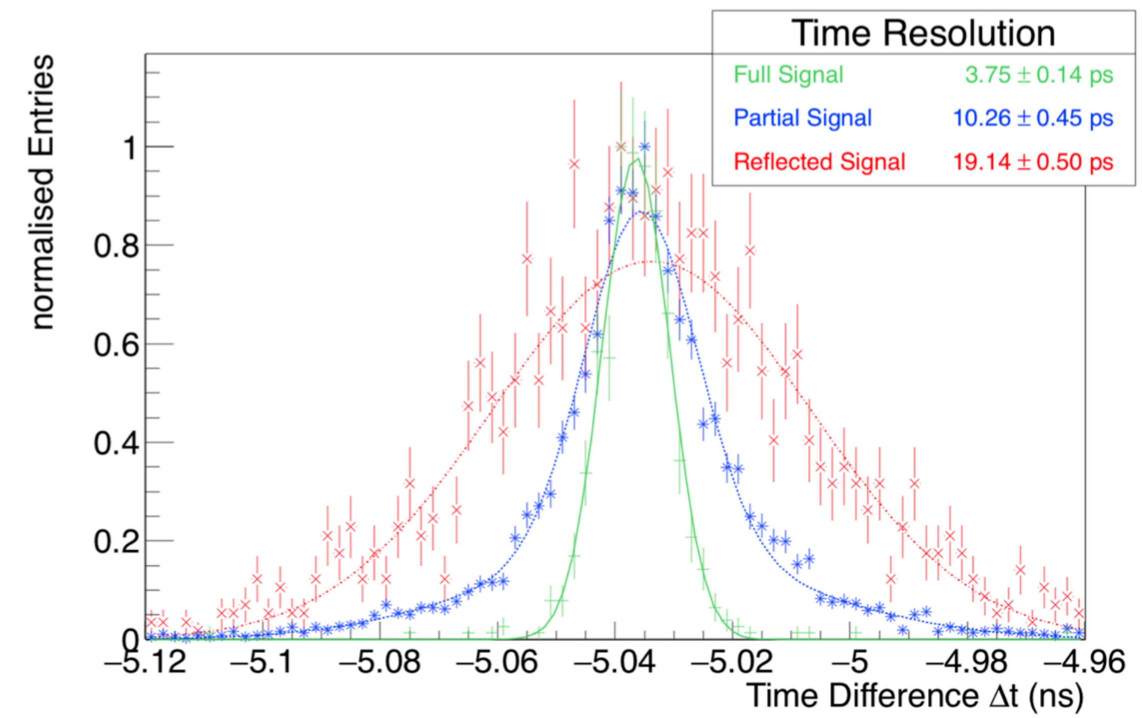
New Results in MCP from PICOSEC

see L. Sohl 2018 Elba poster

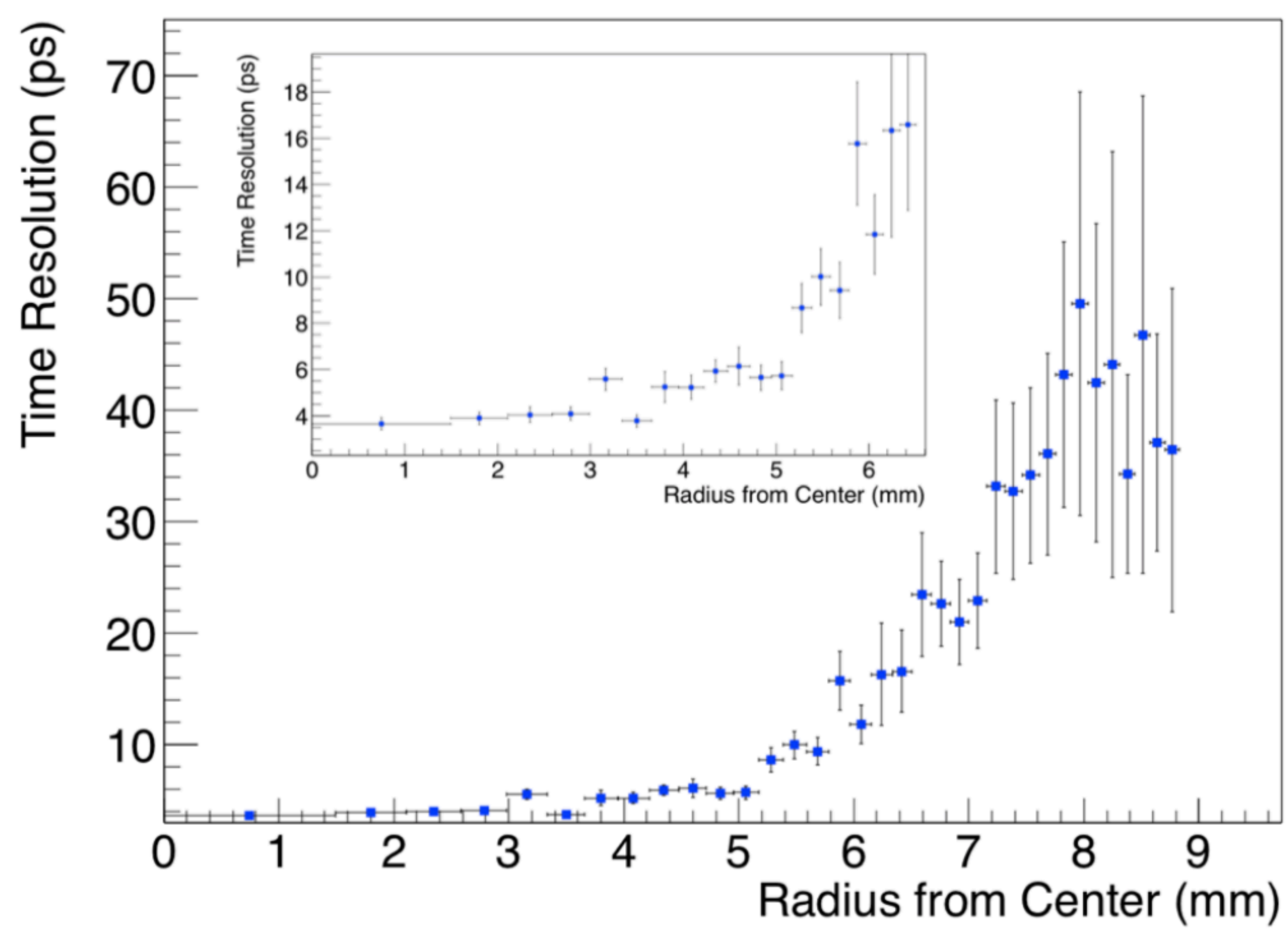


Cerenkov in HPK MCP window (note similar to MMegas 3mm)

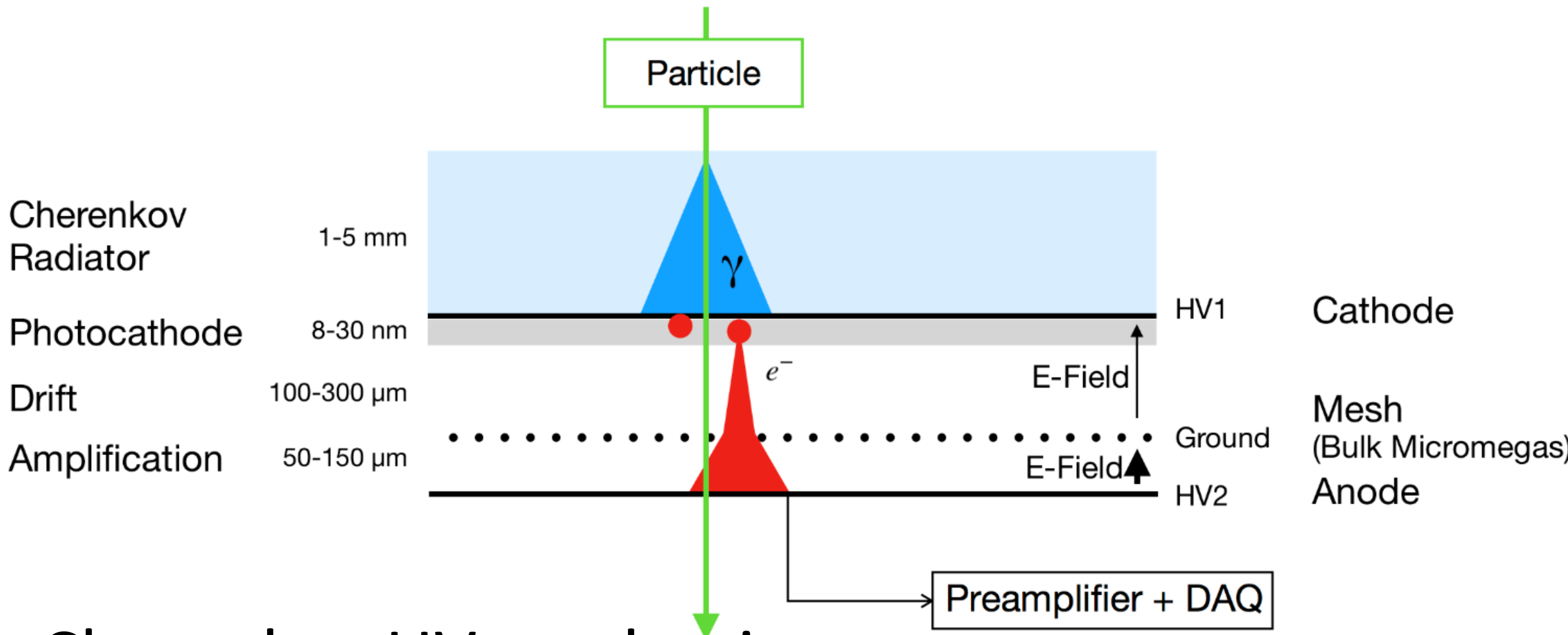




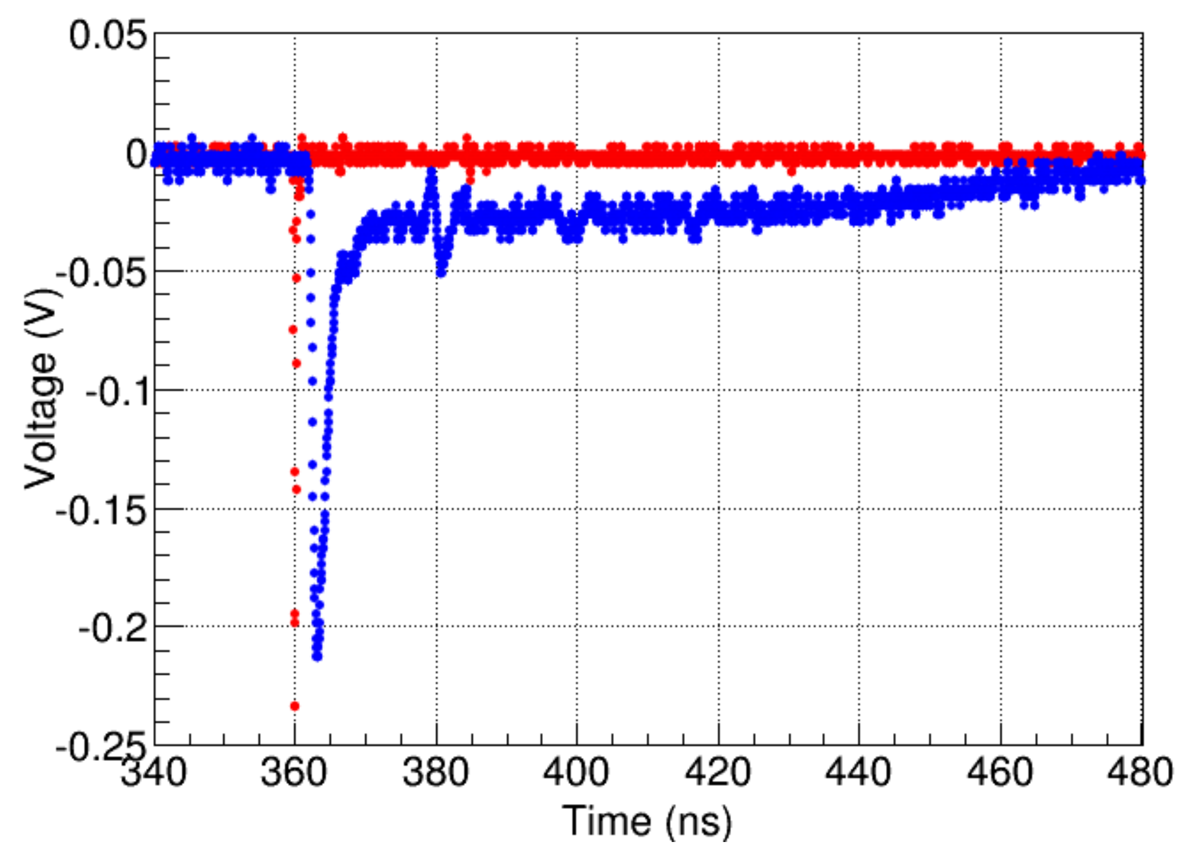
in multi-pad PICOSEC combine pads to restore “full signal”



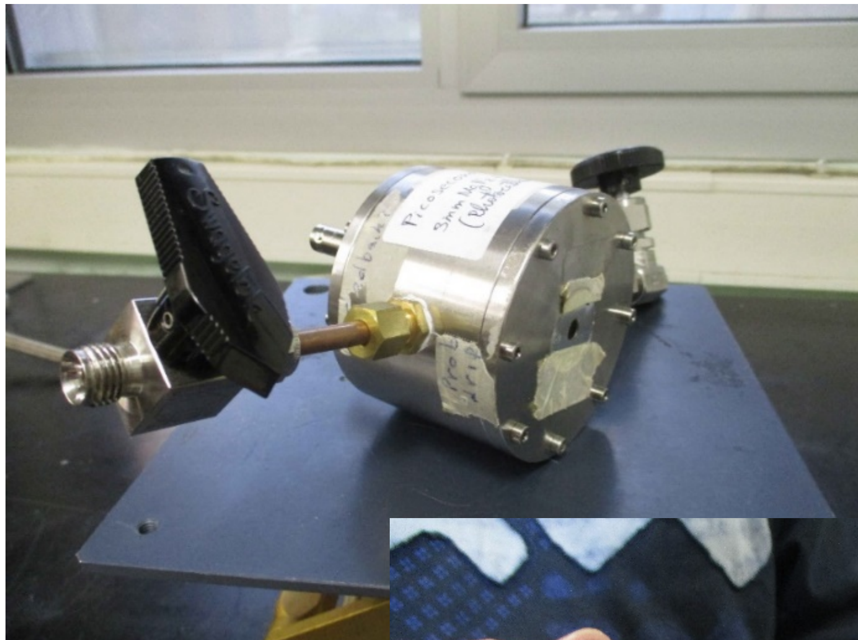
back to PICOSEC detection concept

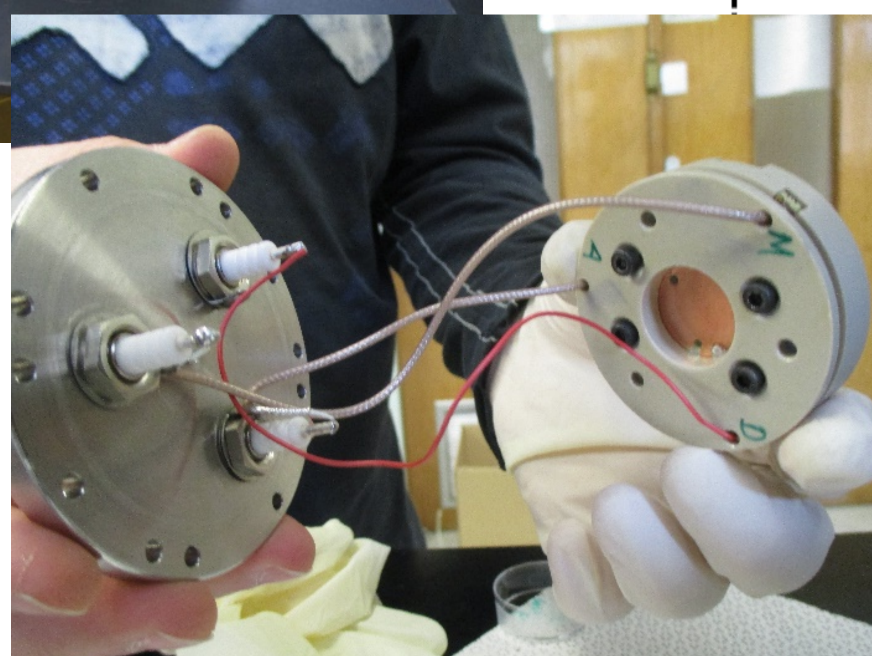


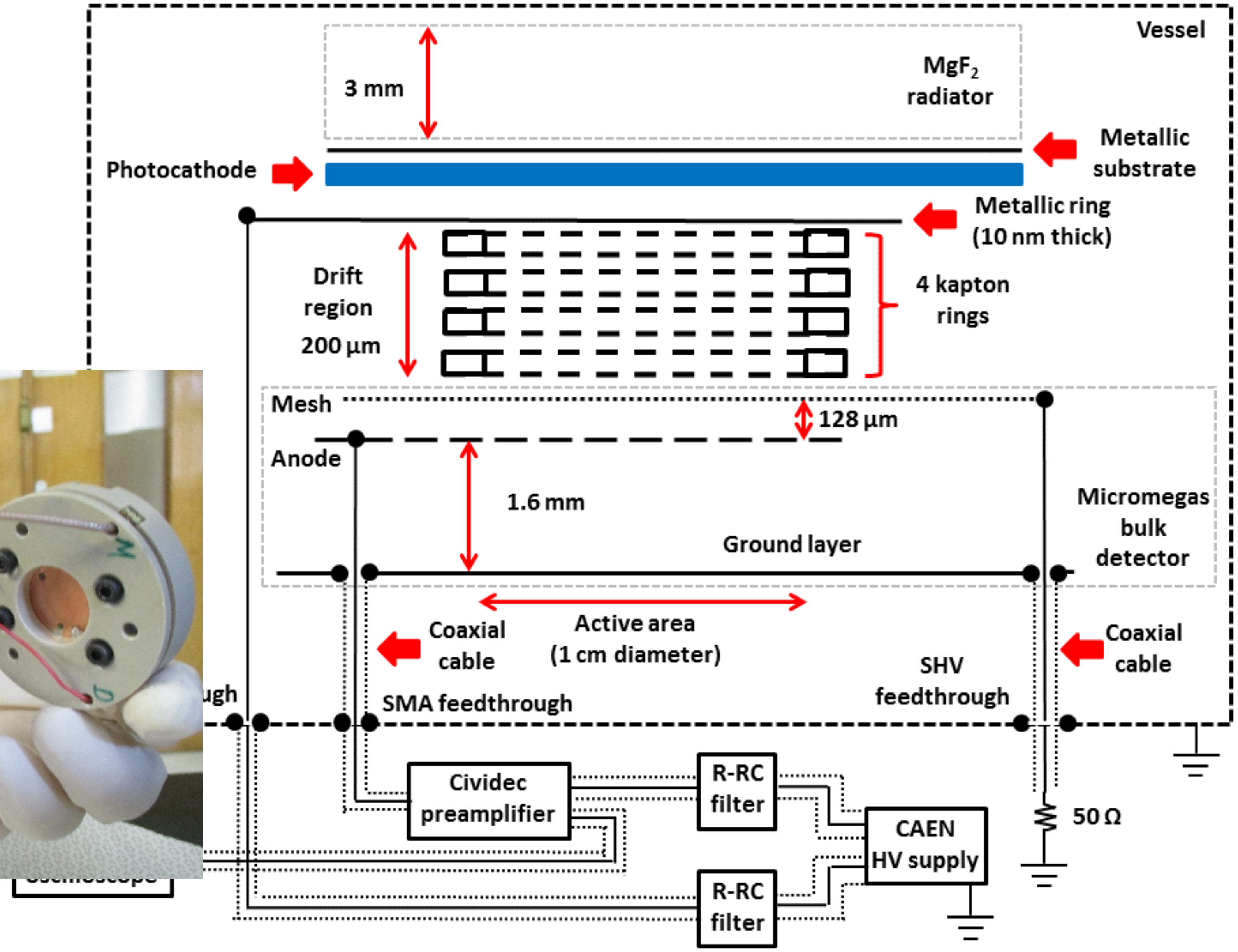
- **Radiator:** Cherenkov UV production.
- **Photocathode:** UV -> electrons.
- **Two-stage Micromegas (drift+amp):** electrons are amplified.
- Two signal components:
  - Fast: ***electron peak*** (~0.5 ns).
  - Slow: ***ion tail*** (~100 ns).



The first Picosec prototype





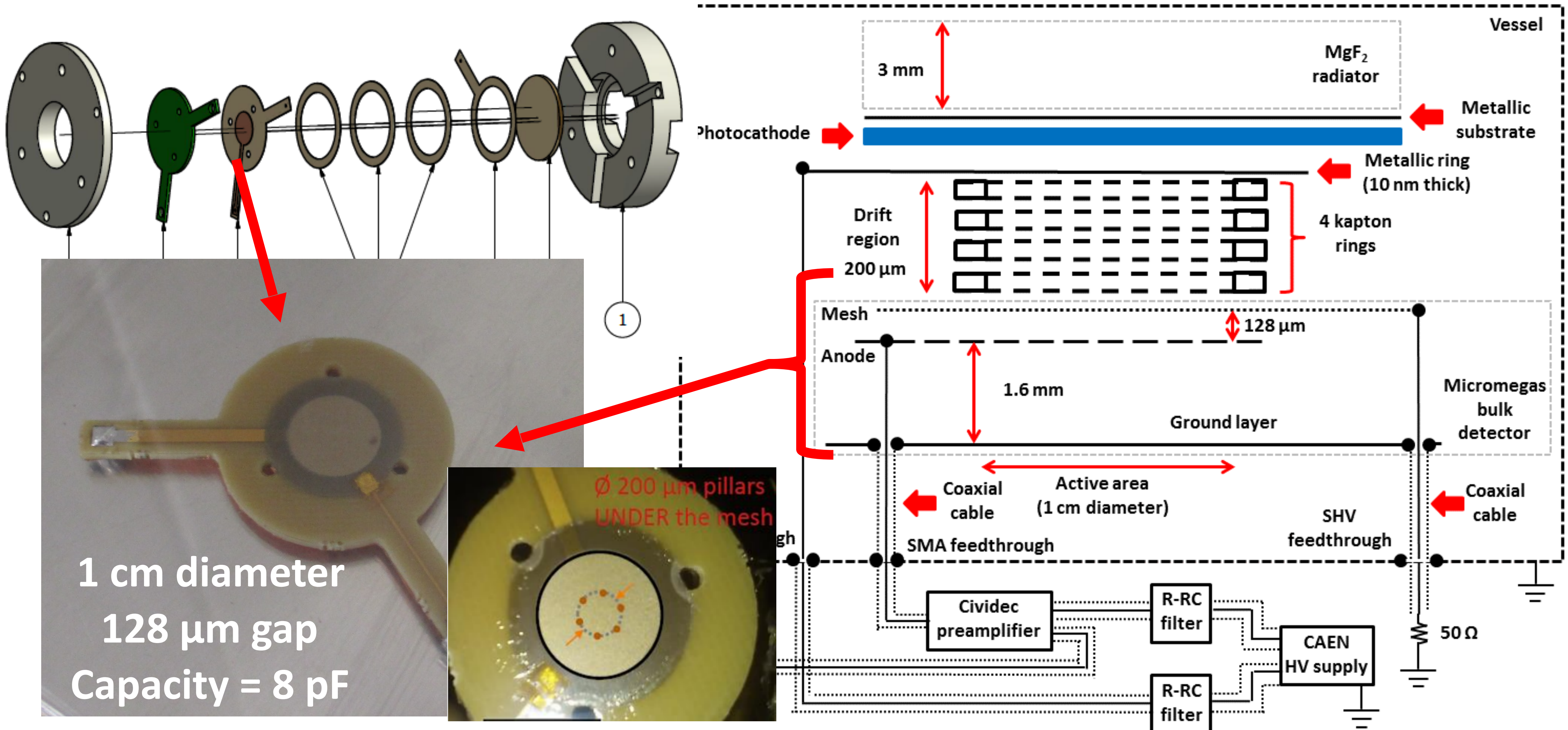


1 cm diameter active area

- **A small prototype.**
- **As a single pad, it is pretty large.**

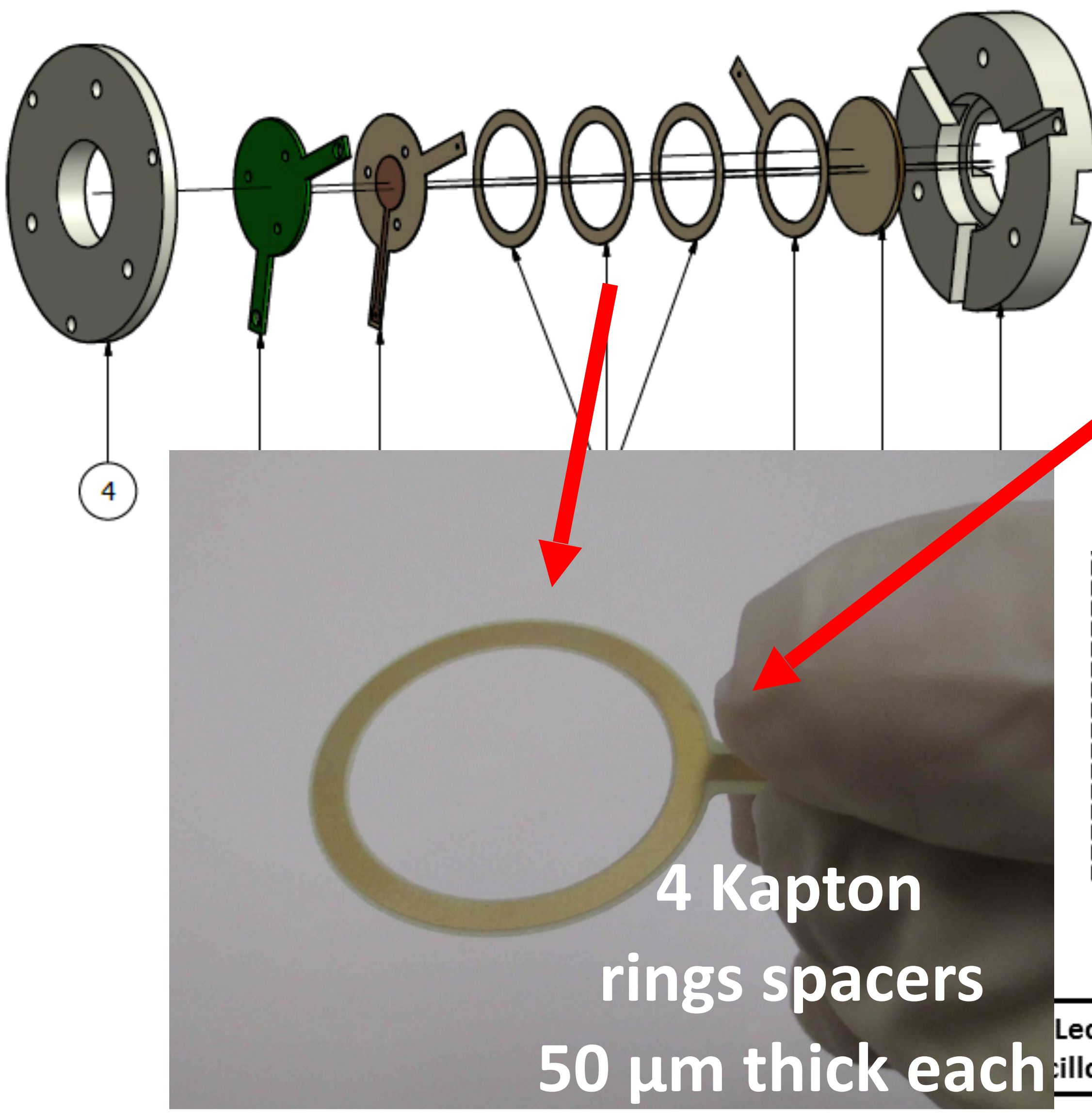
COMPASS gas: $80\%Ne+10\%C_2H_6+10\%CF_4$

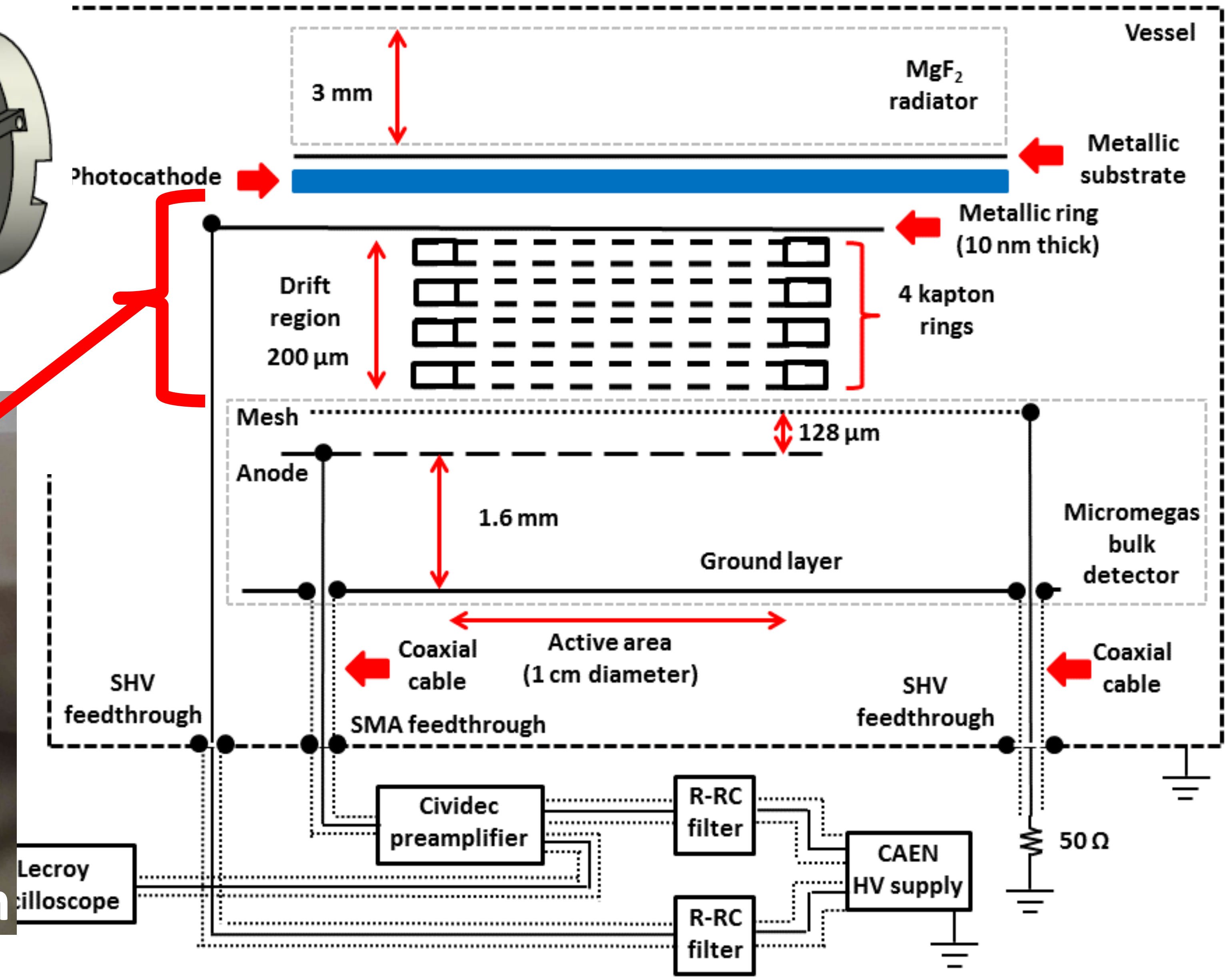
The first Picosec prototype



Main elements:
- Bulk MM readout (6 pillars).
- 4 kapton rings spacers -> 200 µm drift.
- Radiator + photocathode.

The first Picosec prototype



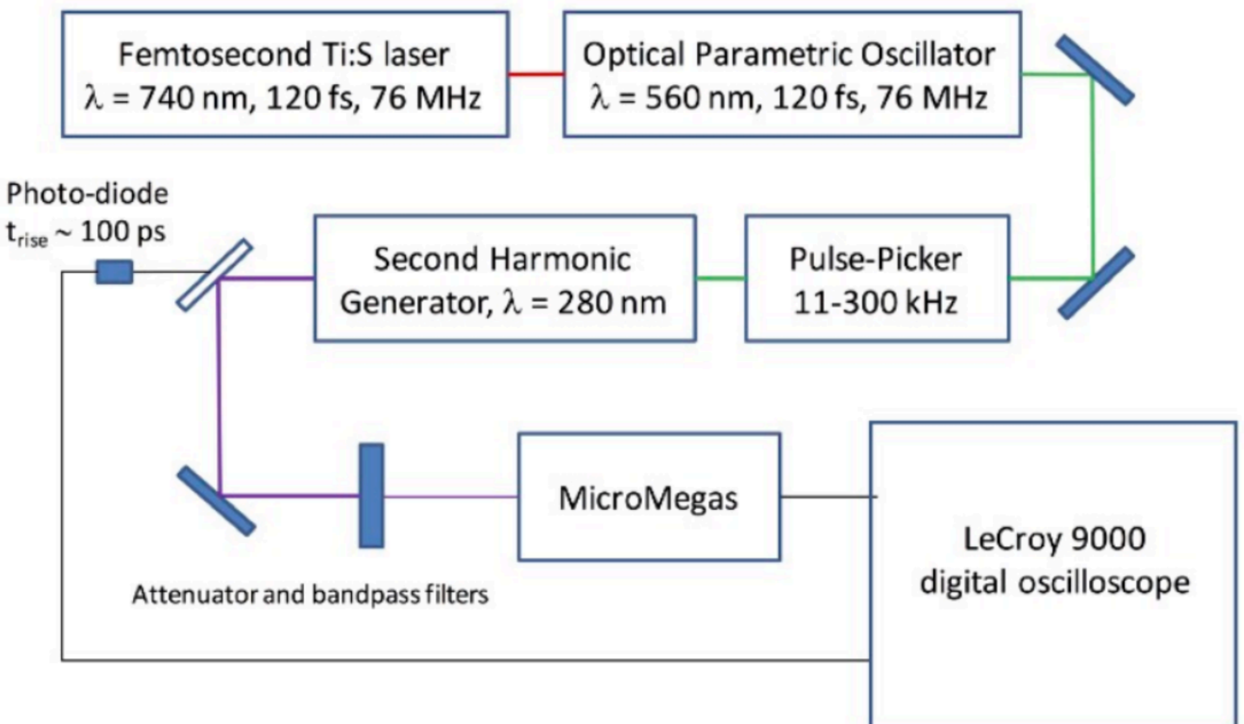


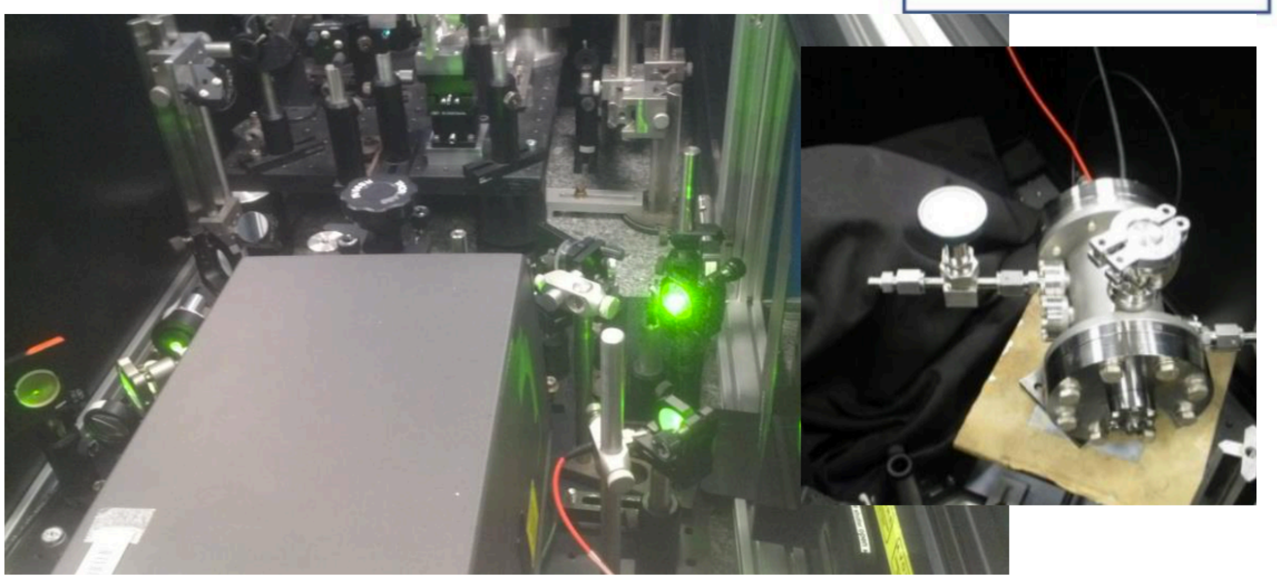
Main elements:

- Bulk MM readout (6 pillars).
- 4 kapton rings spacers -> 200 µm drift.
- Radiator + photocathode.

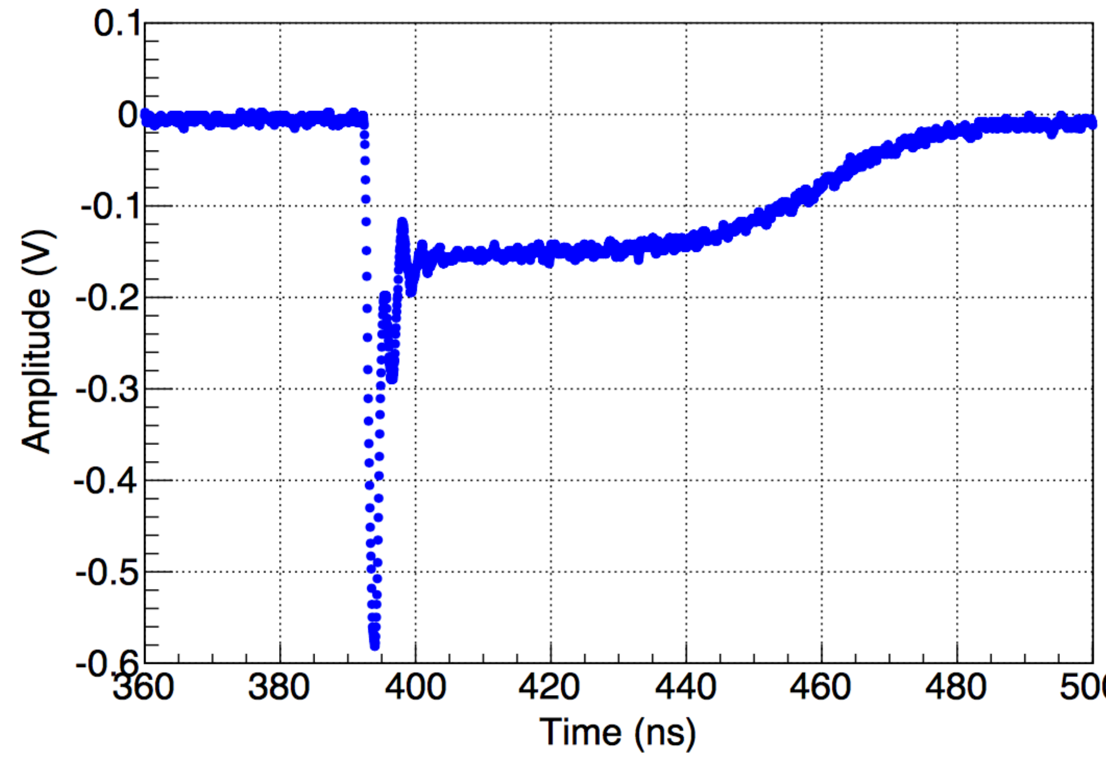
Ongoing Program of laser (for single photoelectron response) and H4 (150 GeV Muon beam)

Laser





typical single pe signal w. 40 dB CIVIDEC



we measure signal time-of-arrival
from leading edge of fast electron part
using “local CF”, Leading edge fit,
and full pulse modeling
ie corrected for electronic slewing

Gas choice:
optimize σ_L and v_{Drift}
but favor stability

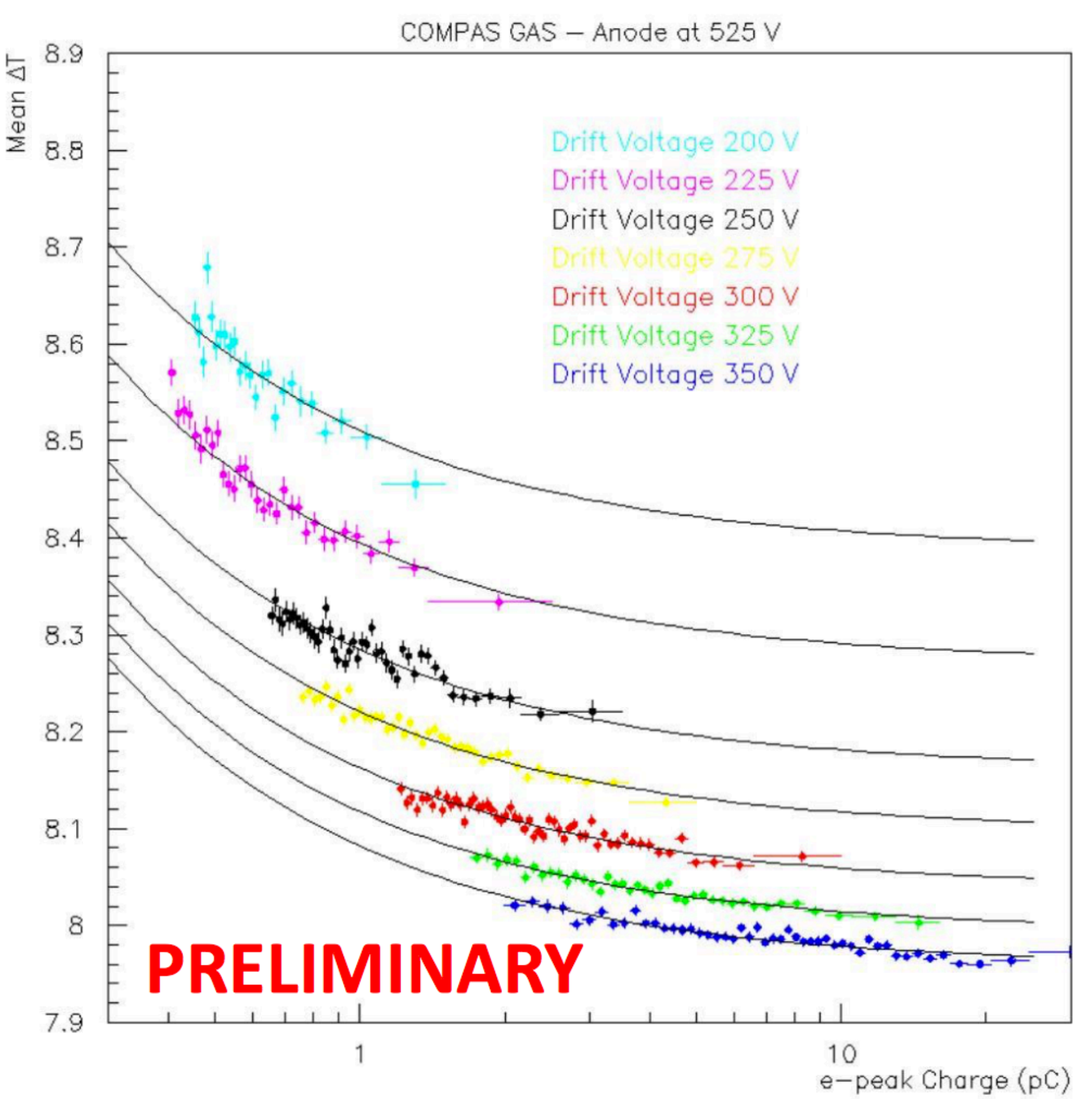
→

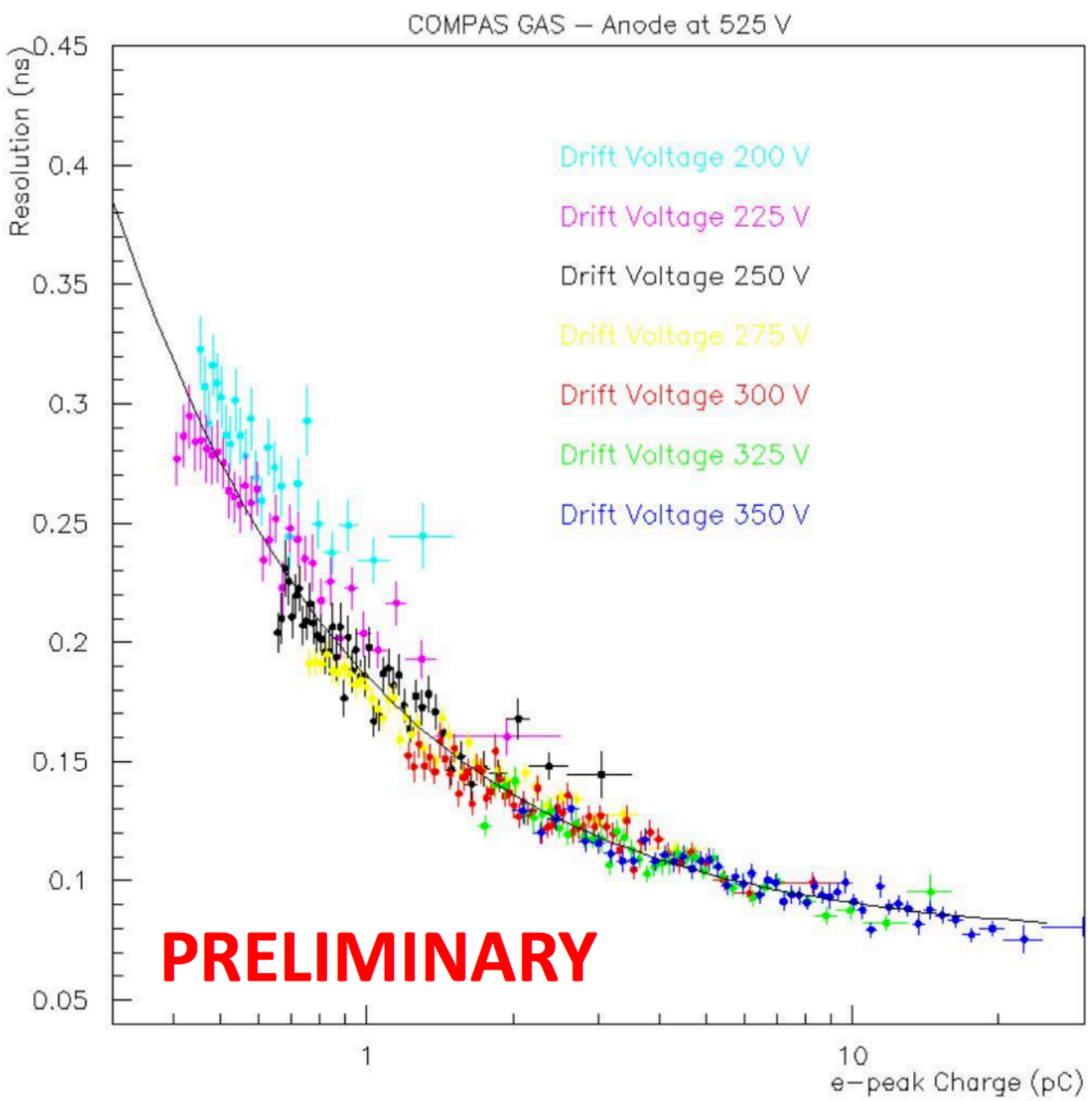
several CF4+ quencher
<u>Ne/Ethane/CF4</u>
<u>mostly showing 90:10:10</u>

Expectation that
Preamp Gain in drift
-> mitigate σ_L
see following

Key to MIP performance is:
time-of-arrival and jitter vs. single pe signal

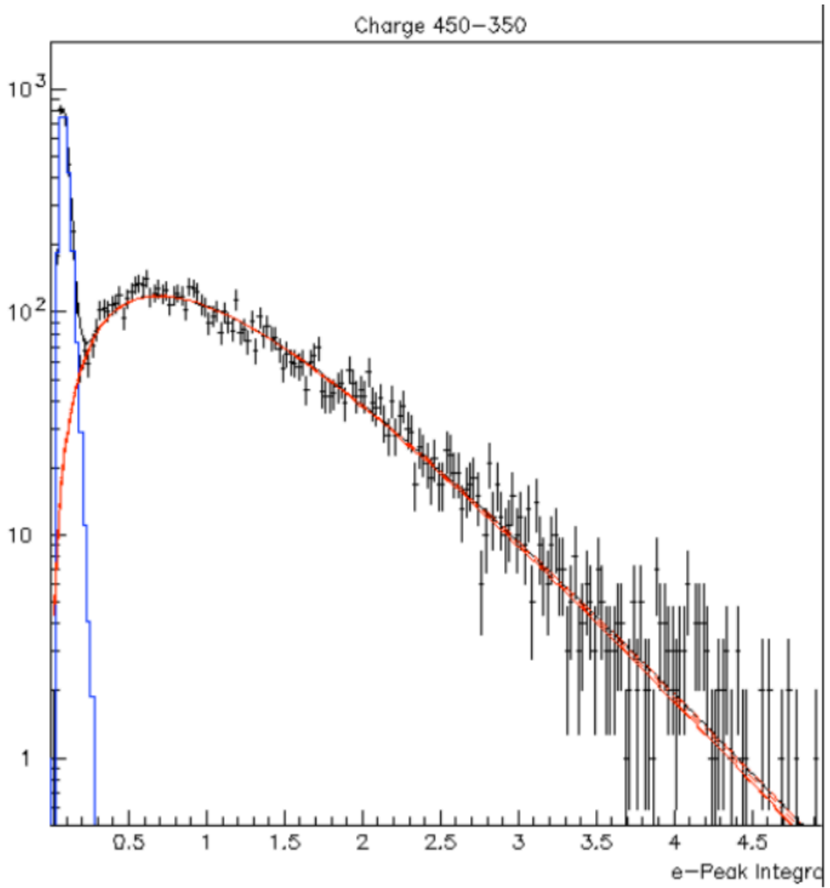
“Compass Gas”=Ne/Ethane/CF4 90:10:10

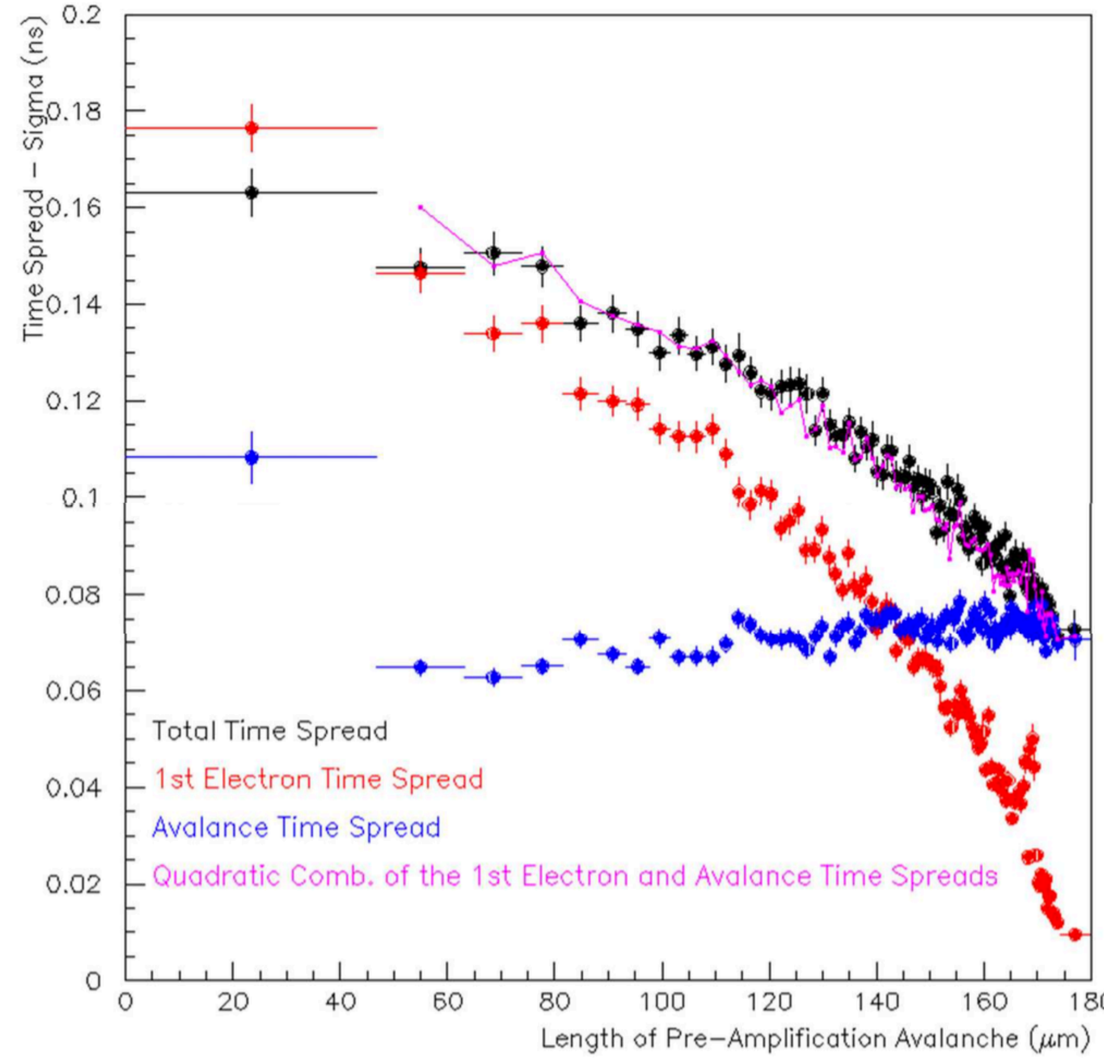




Nb: this amplitude dependence is not what you are used to from textbooks
these are Constant Fraction times
resolution independent (or increasing with) Anode Gain
detector physics (and initial Townsend Multiplication step) responsible

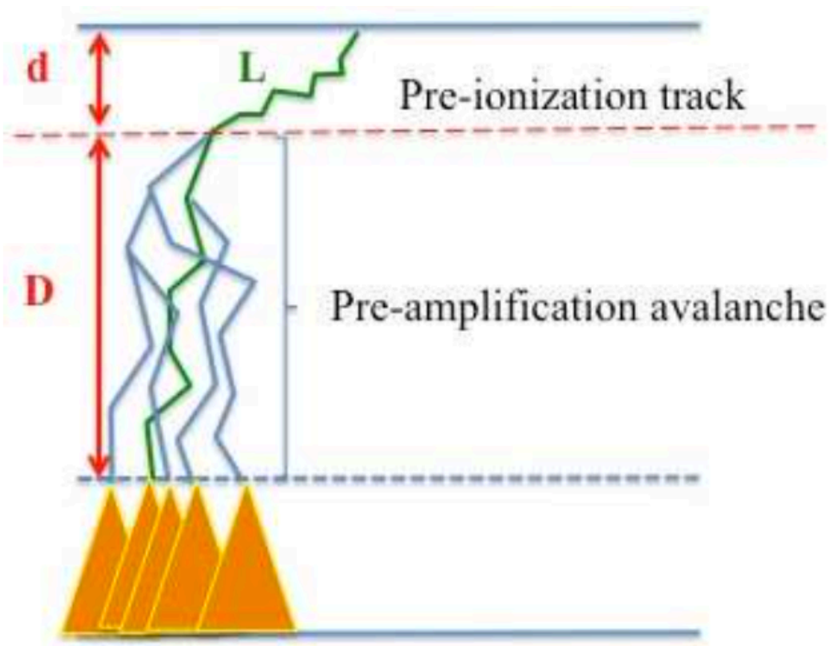
How does Signal Amplitude <-> photoelectron, Avalanche pathlengths?



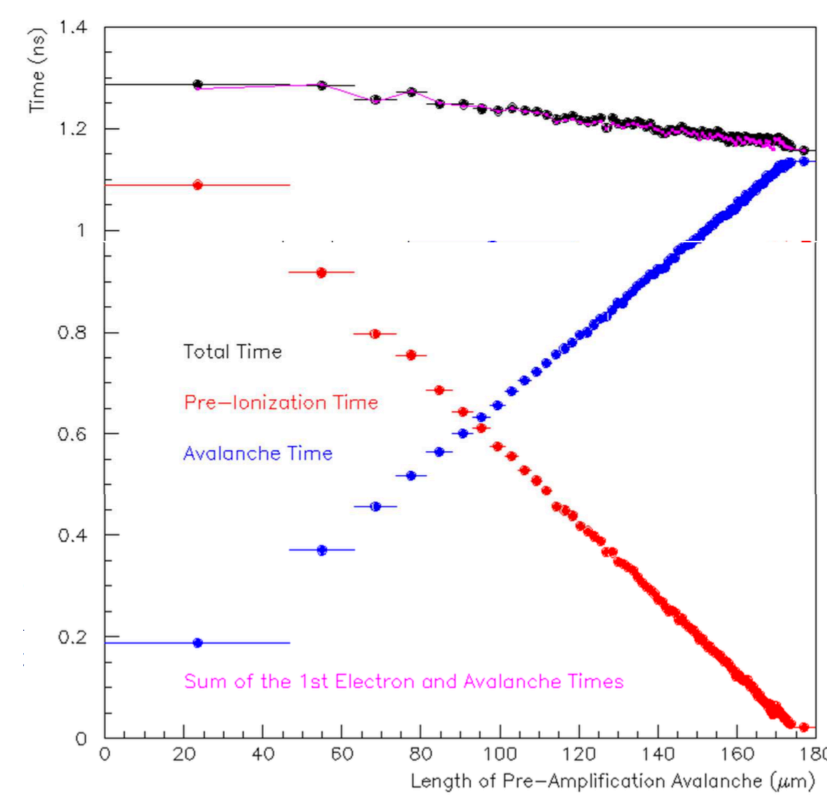


avalanche truncates diffusion!
-sim by R. Veenhof and Aristotle U group

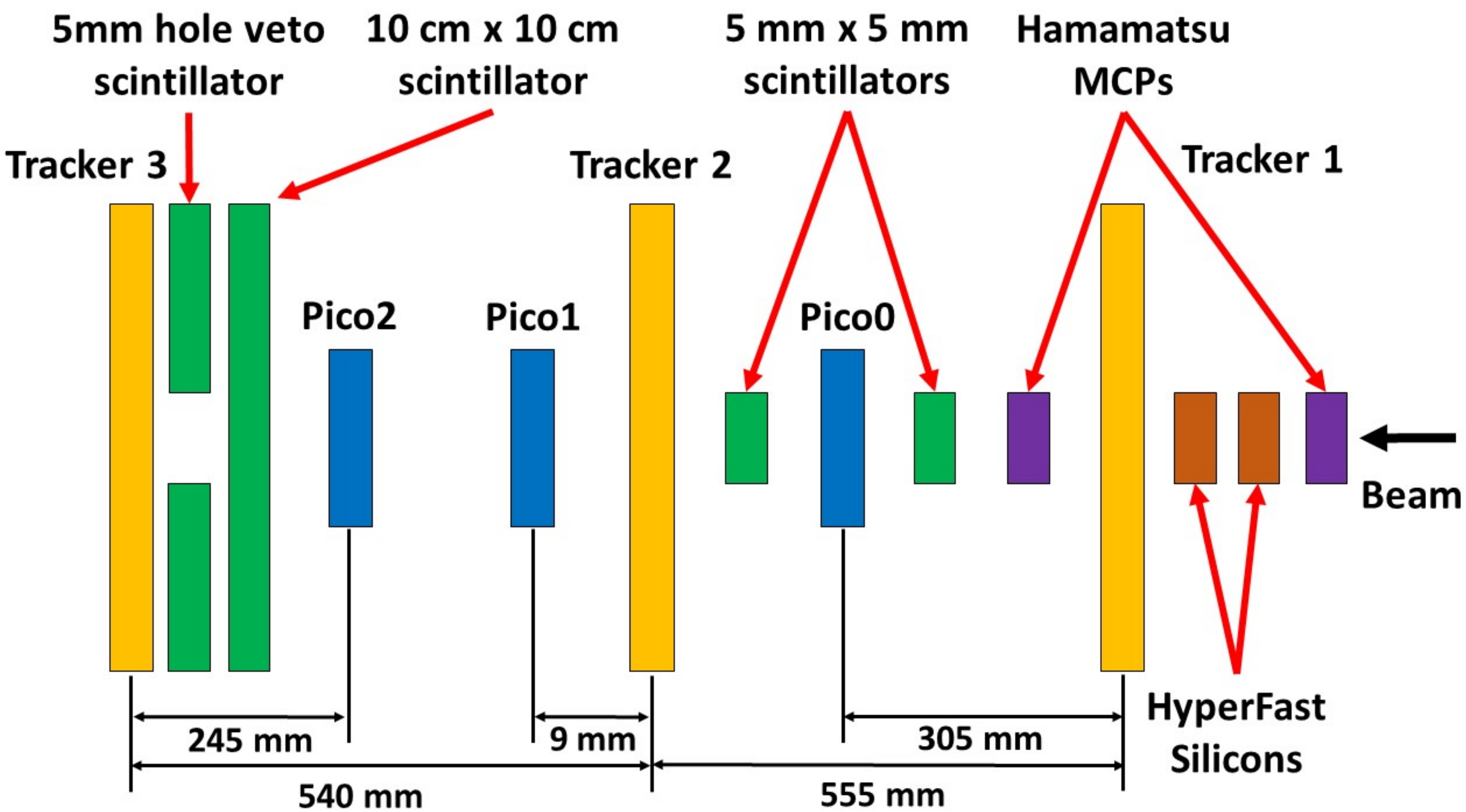
“Polya distribution” describes single pe resp.



detailed, microscopic simulation -> differing effective v_{Drift} in d, D regions

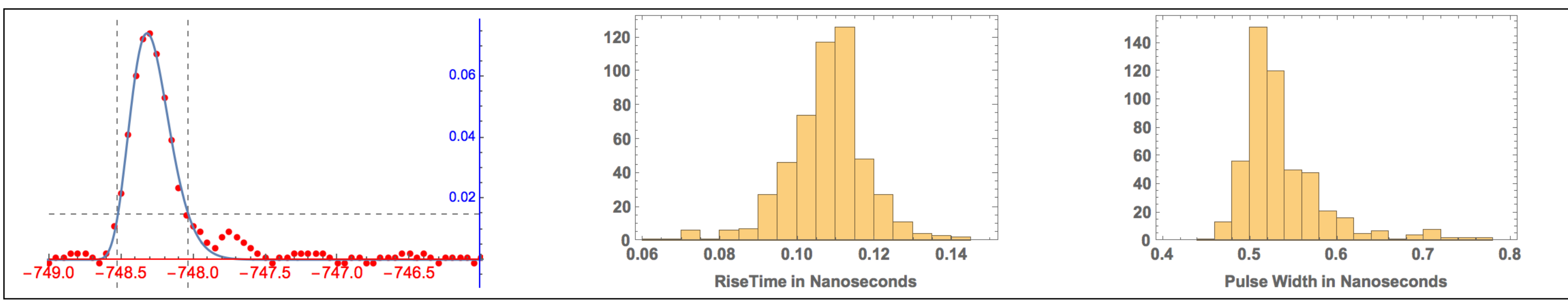


2017 PICOSEC Testbeam Campaigns



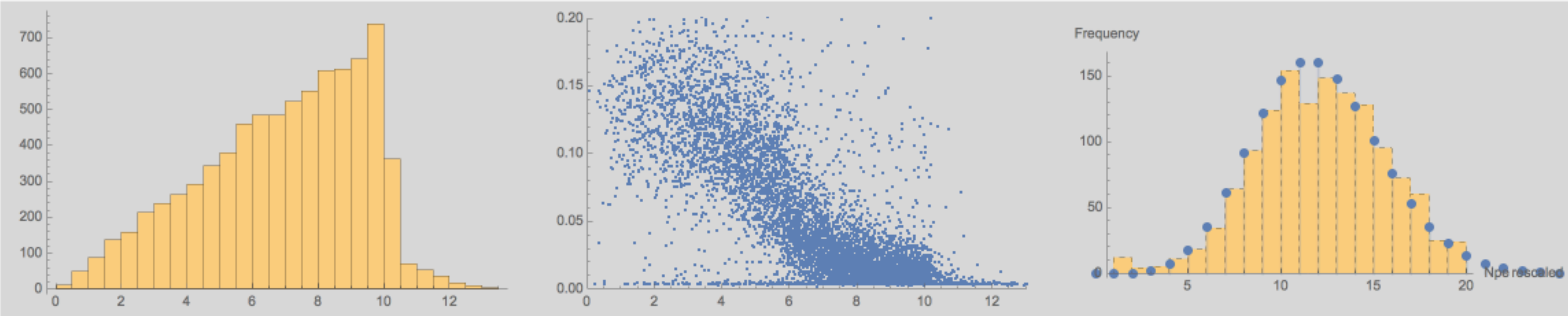
all data waveform digitized
loose scint trigger
R3809+3mm window time ref.
40 micron track precision

Typical MCP Signal fitted to Gamma Distribution – Risetime and Width Using 20 – 80 × % and 20 – 20 × %

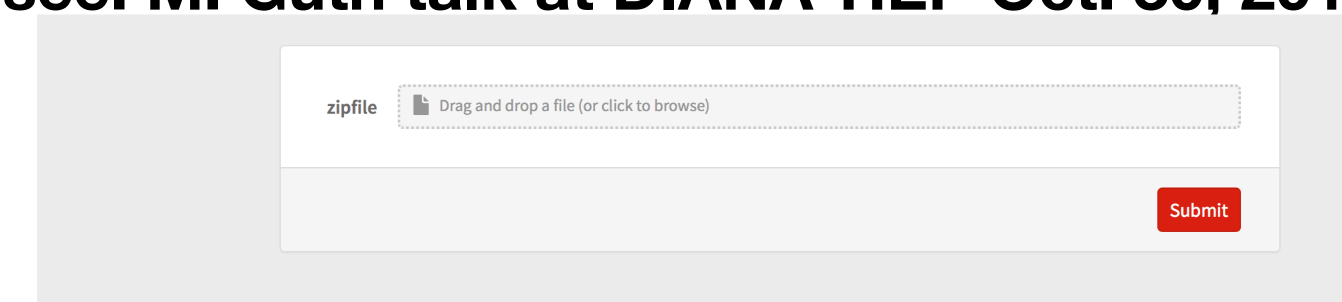


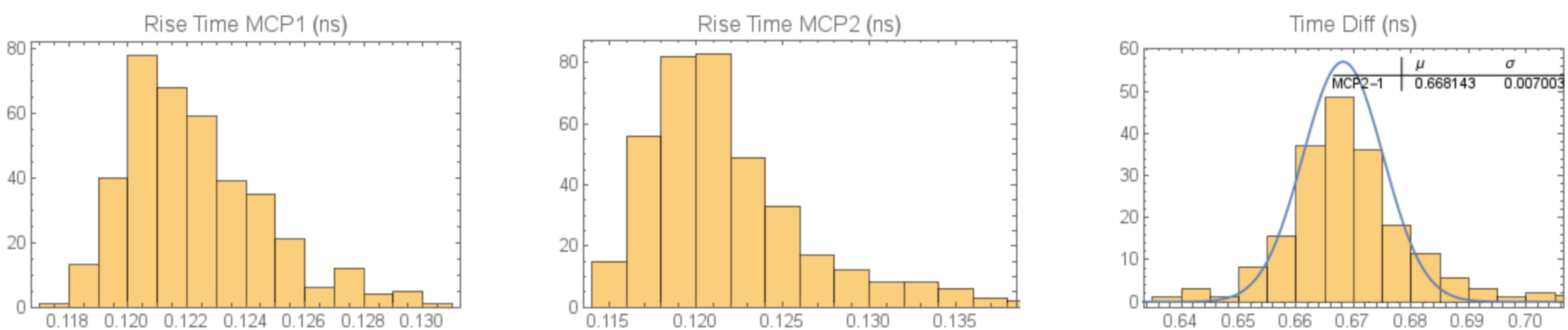
note: similar issues for MCP and PICOSEC- ie for single pixel-> contain Cerenkov cone

Track Impact for hits above noise in MCP, Peak Amplitude vs. Impact and Peak Distribution for RMCP < 4.5 mm

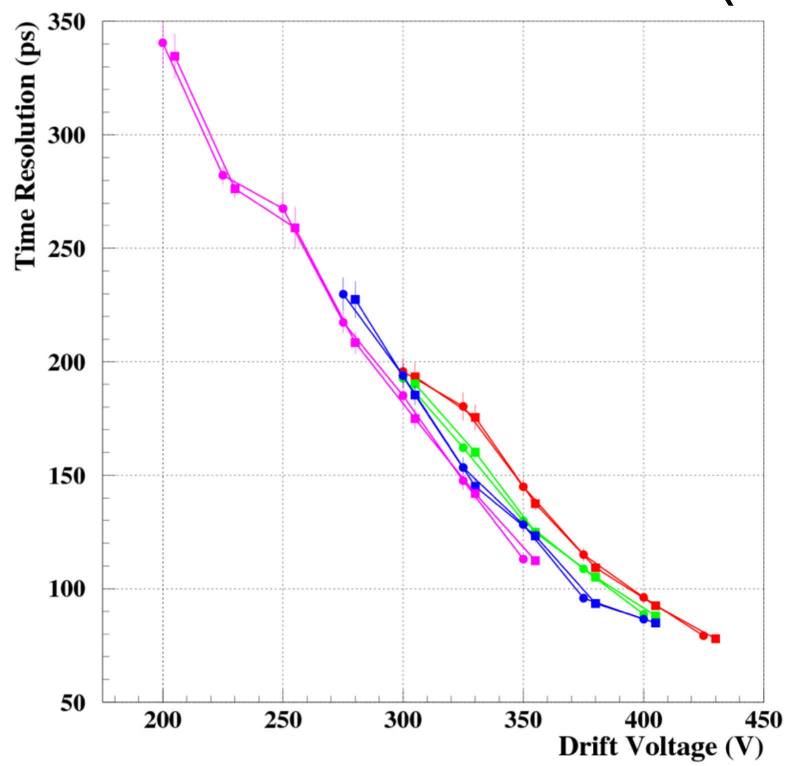


note on timing algorithms:HFS (and much MCP) analysis done in Mathematica and now more and more as joint activity w. Wolfram Research and a student
-> use general tools for signal recognition, modeling, machine learning, Cloud apps.
see. M. Guth talk at DIANA-HEP Oct. 30, 2017



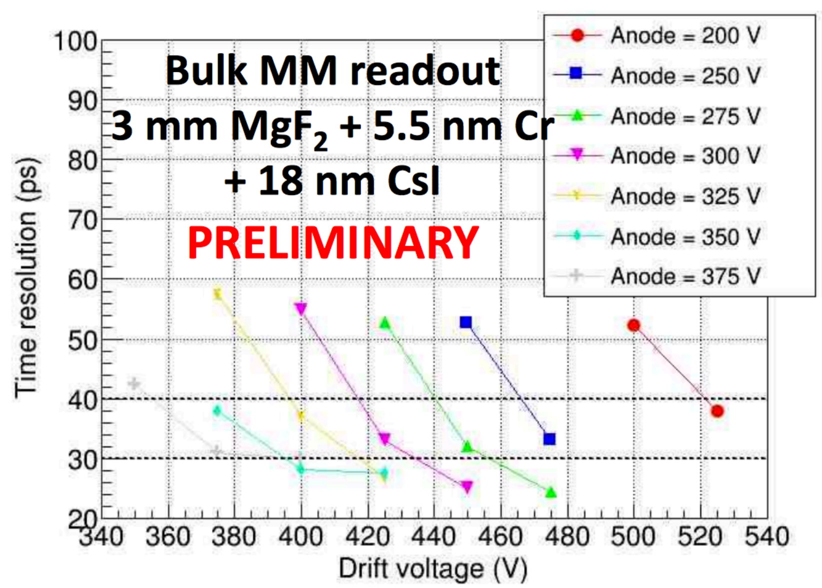


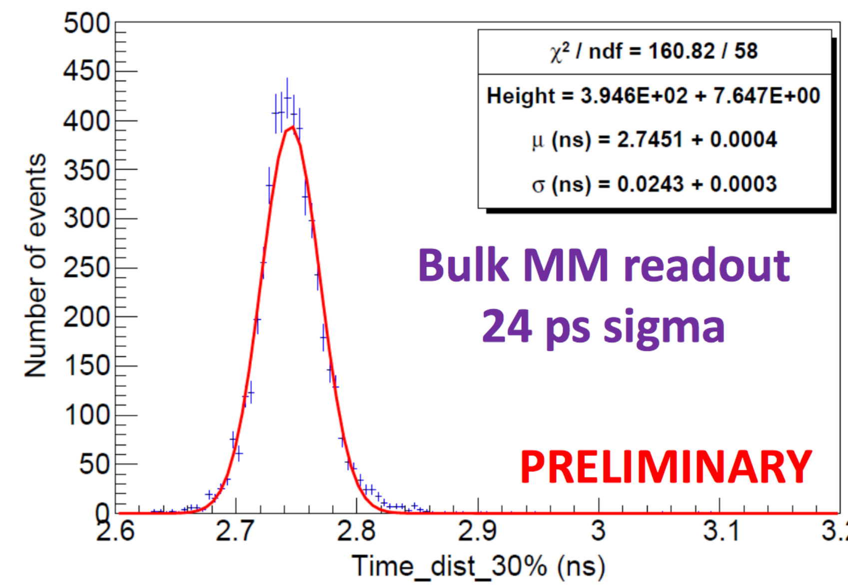
Summary of selected Single pe and MIP timing PICOSEC
(July, Aug, Oct 2017)



consistency between
<— — —single pe
and
150 GeV Muon results
$\langle N_{pe} \rangle \sim 10$

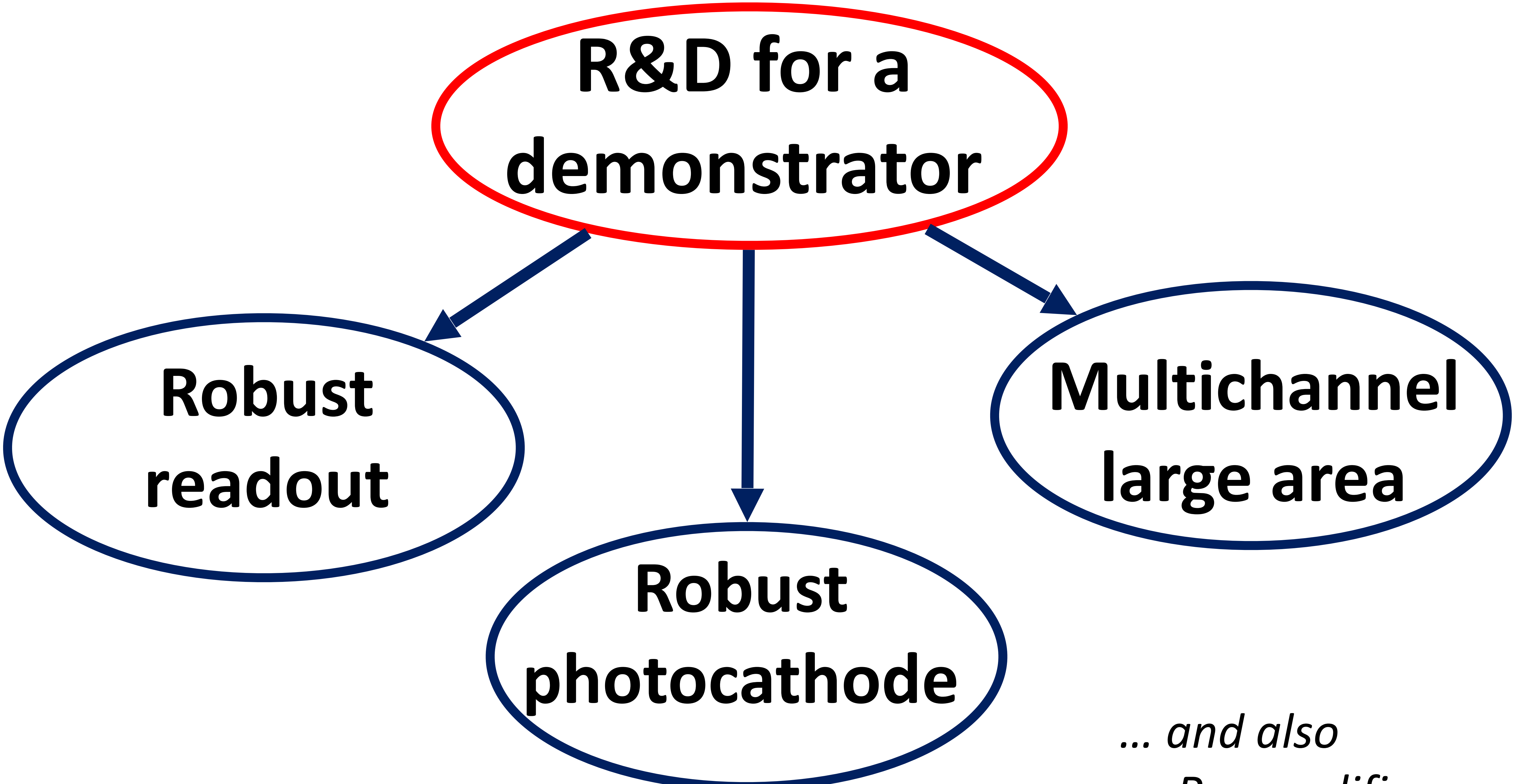
many similarities between PICOSEC and HFS mutually beneficial





Going Forward:

(see also F. Iguaz 2018 Elba)

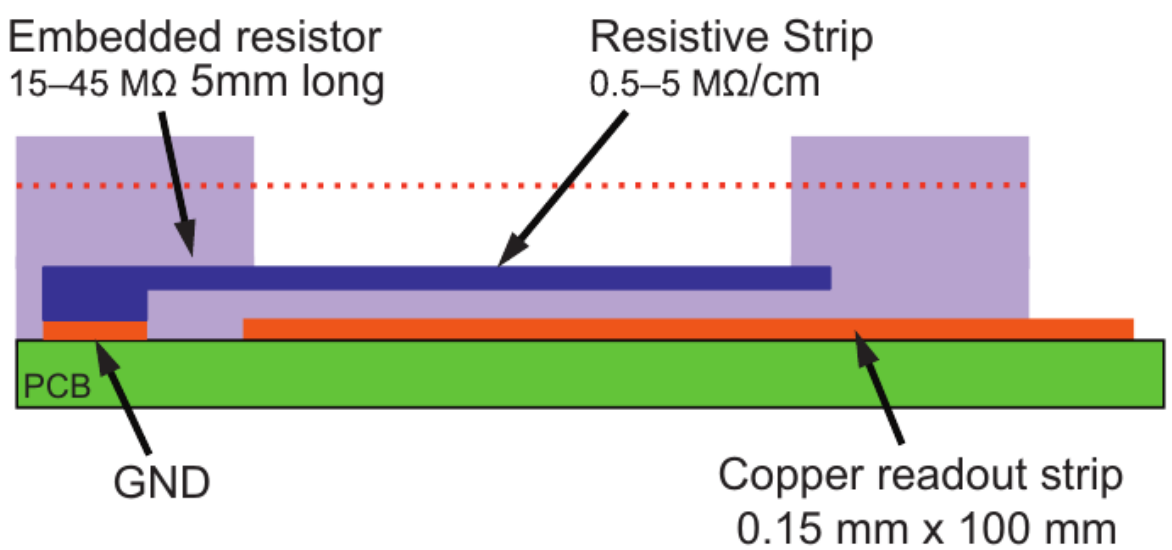


… and also

- *Preamplifiers*
- *Digitizers*

Robust readout: resistive Micromegas

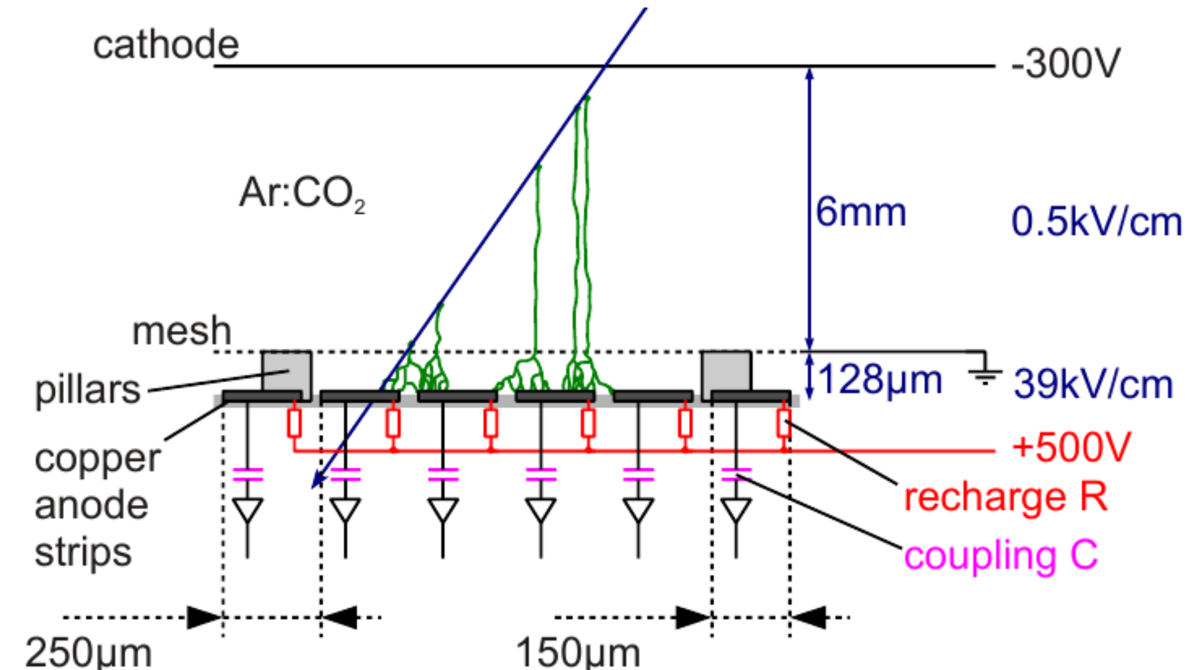
Resistive strips (COMPASS)



T. Alexopoulos *et al., NIMA* **640** (2011) 110-118.

Resistive strips over signal strips & grounded at one side.

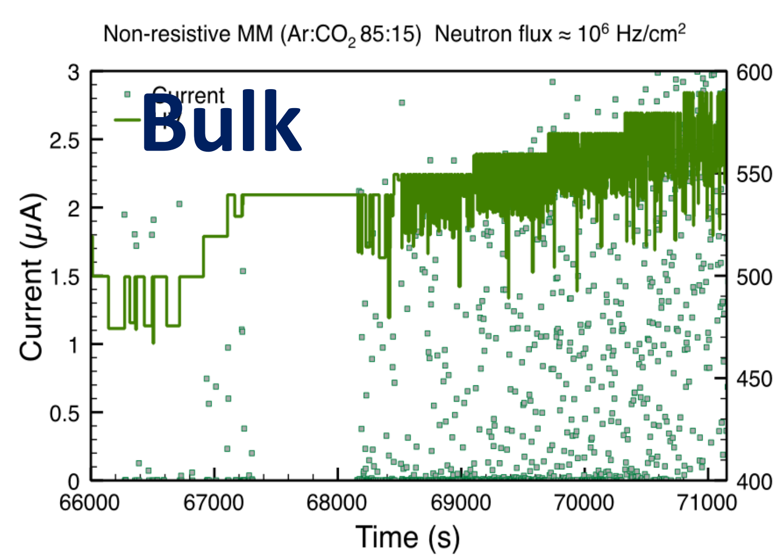
Discrete resistors (COMPASS)

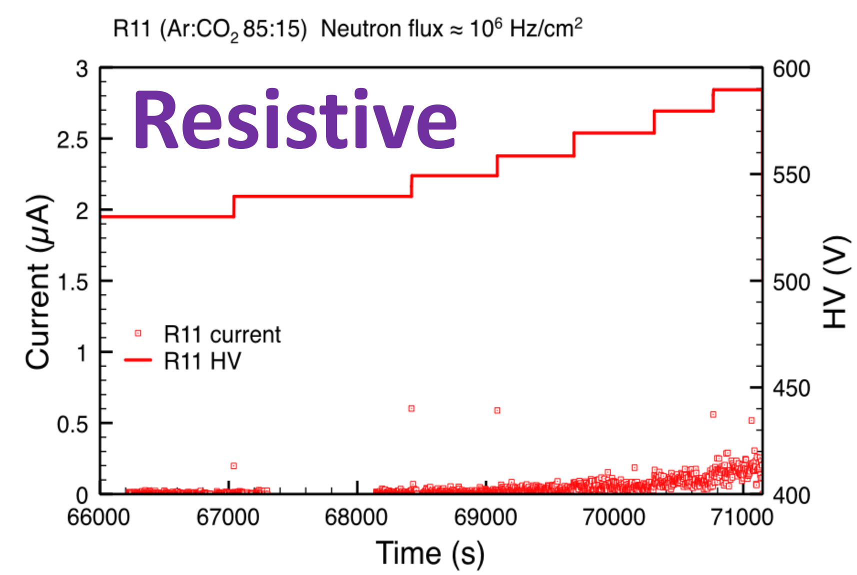


J. Bortfeldt, *PhD thesis, 2014.*

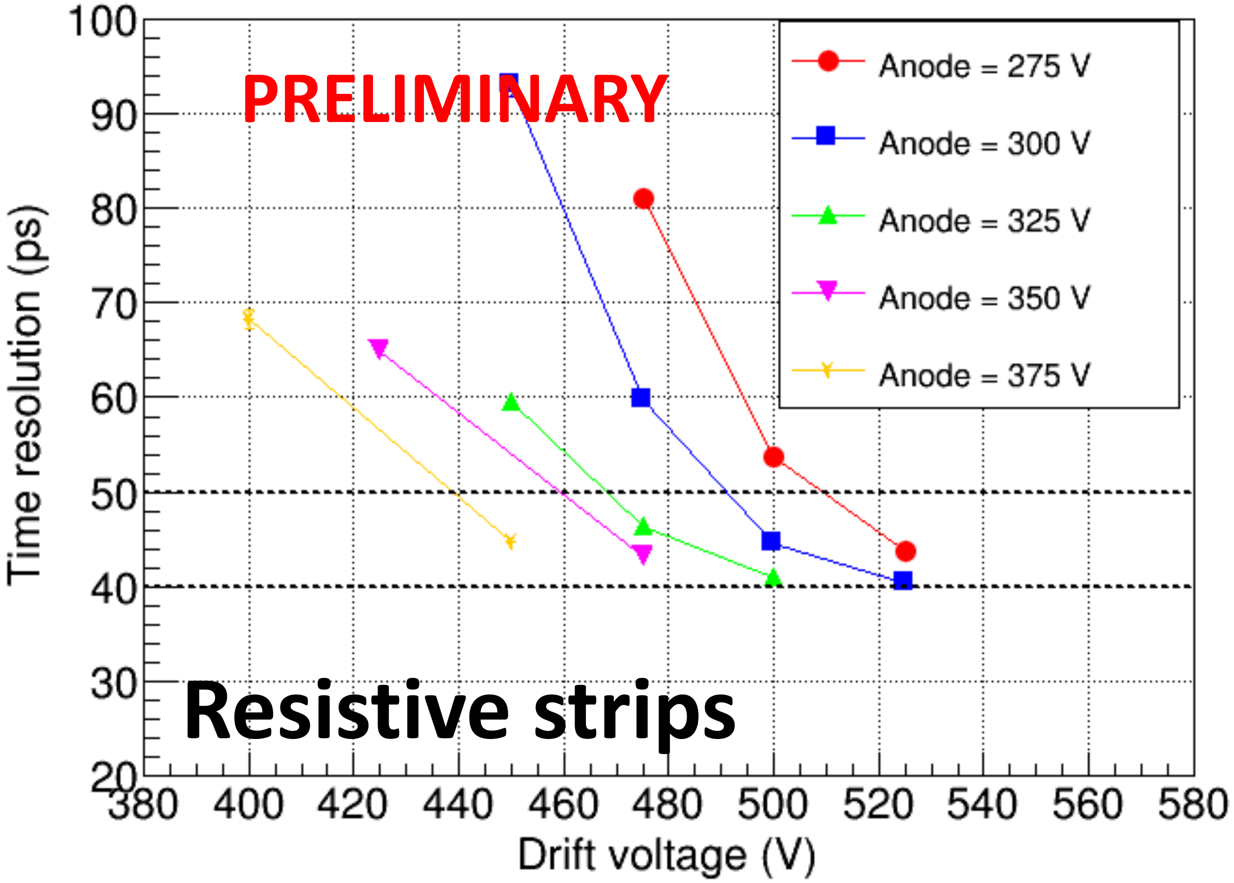
Anode strips individually connected to HV via resistors.

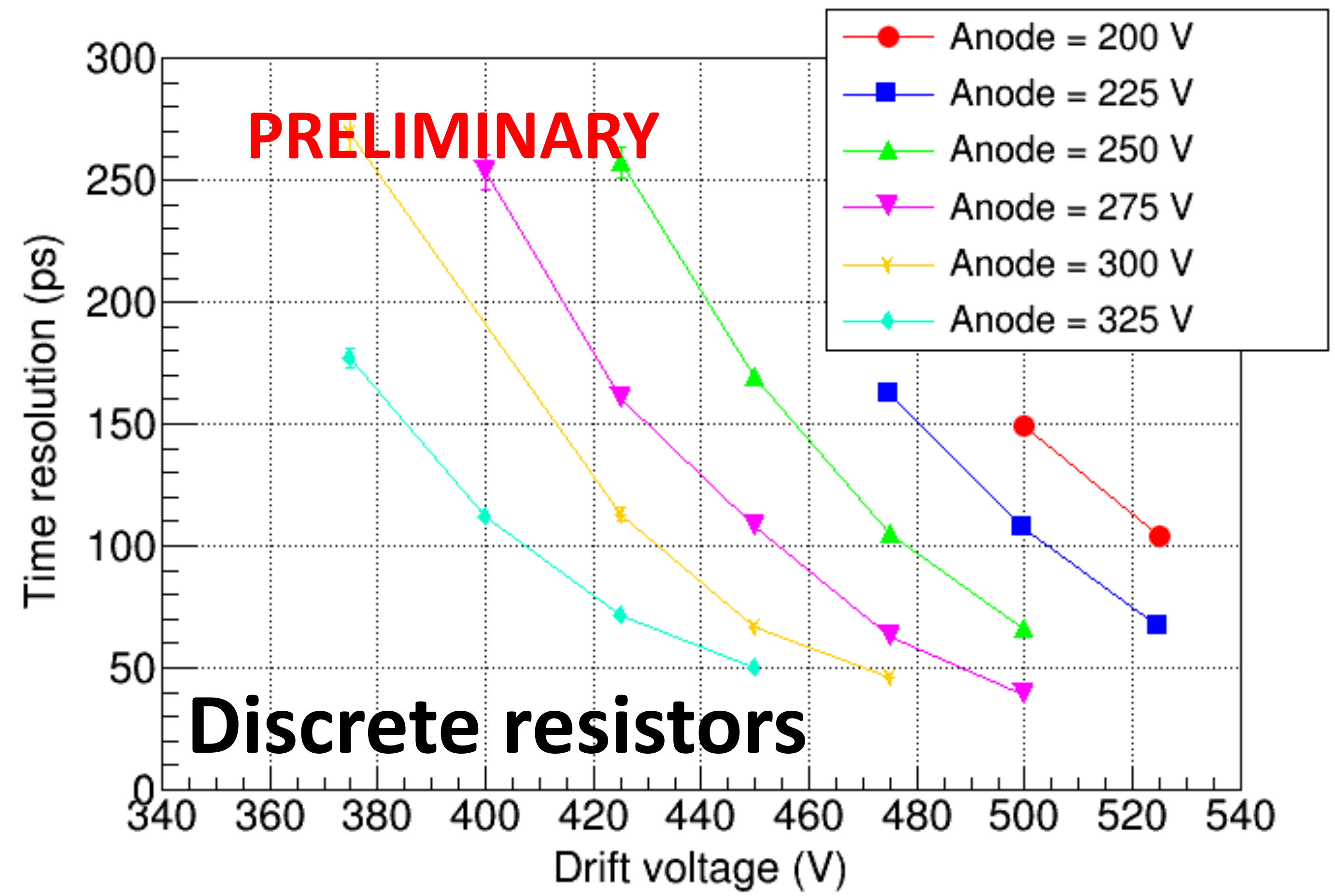
Resistive readouts operate stably at high gain in neutron fluxes of 10^6 Hz/cm^2.





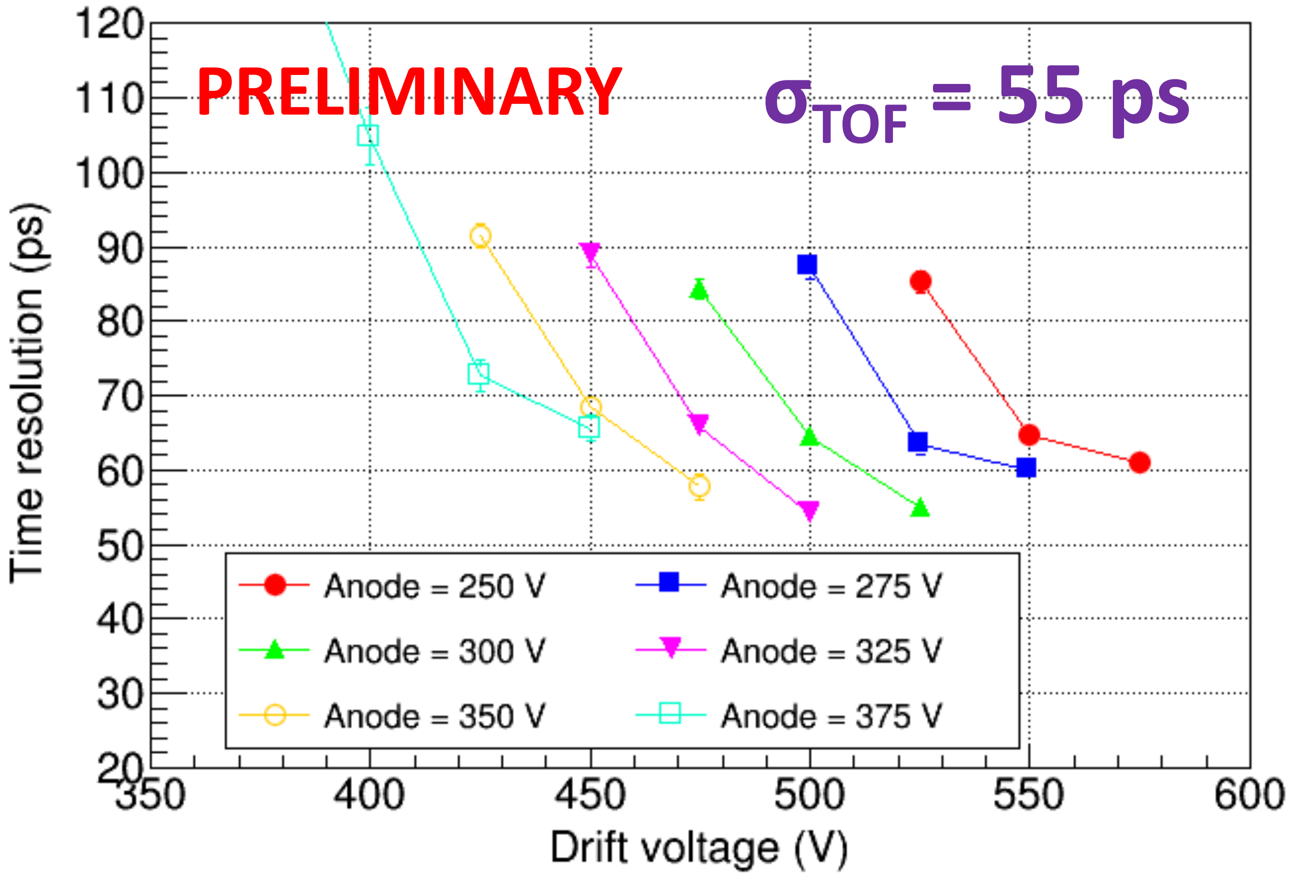
Robust readout: first results





- Values not far from the standard PICOSEC detector.
  - Resistive strips type: **40 ps** (10 MΩ/□), **35 ps** (300 kΩ/□).
  - Discrete resistors type: **40 ps** (25 MΩ).
- Resistive readouts worked for hours in intense pions beam.

Robust photocathode: several options



Pure metallic:

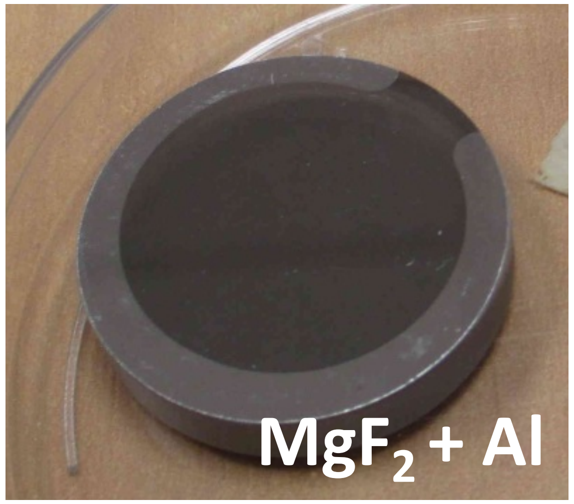
- Chromium, Aluminum.
- Some samples tested in beam.

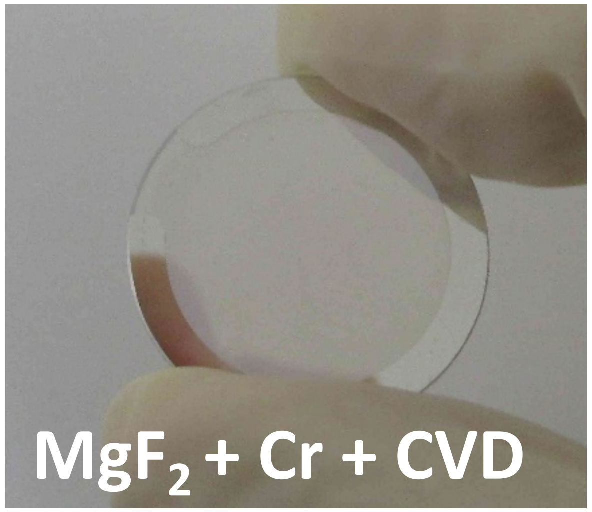
Diamond or secondary emitter

CsI protection layers:

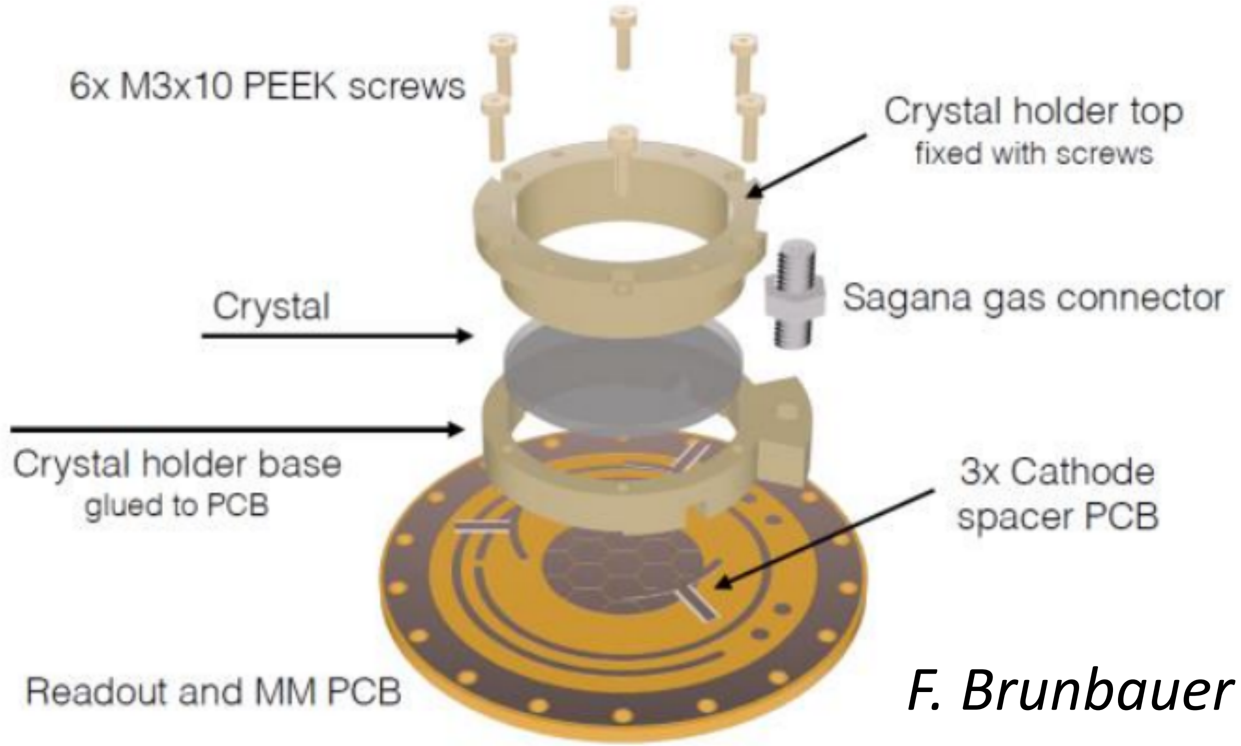
- Graphene shield.
- PC coating.

A 5 mm MgF2 + 10 nm Al photocathode showed in last beam a time resolution of **55 ps** and **~2.6 phe/muon**.

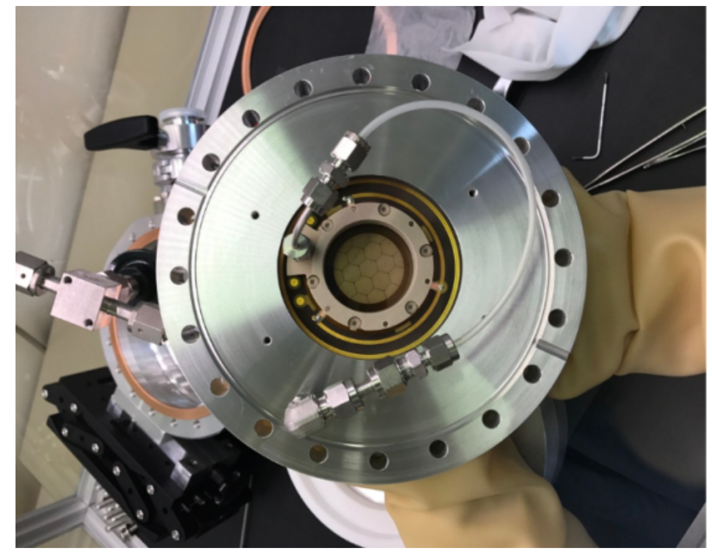


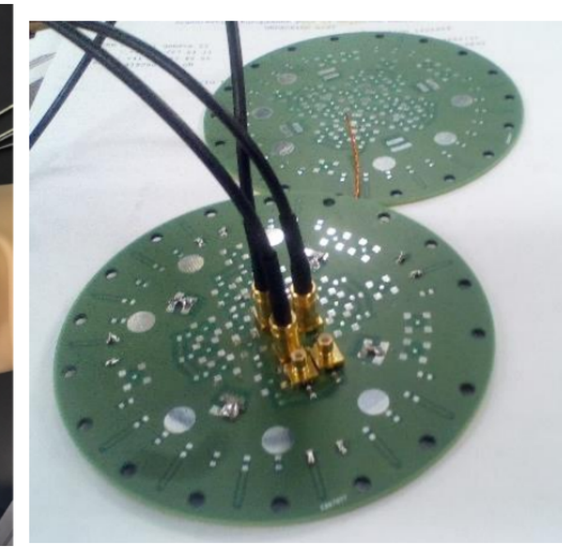


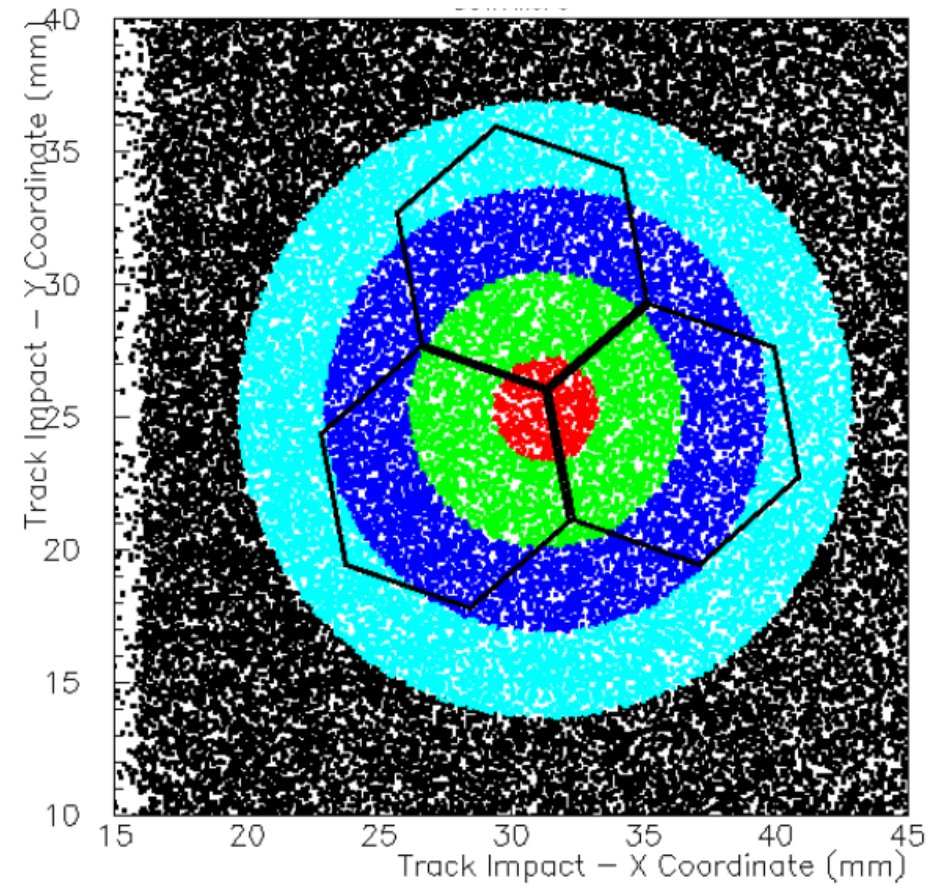
Scaling up: the Multipad detector



F. Brunbauer (CERN)





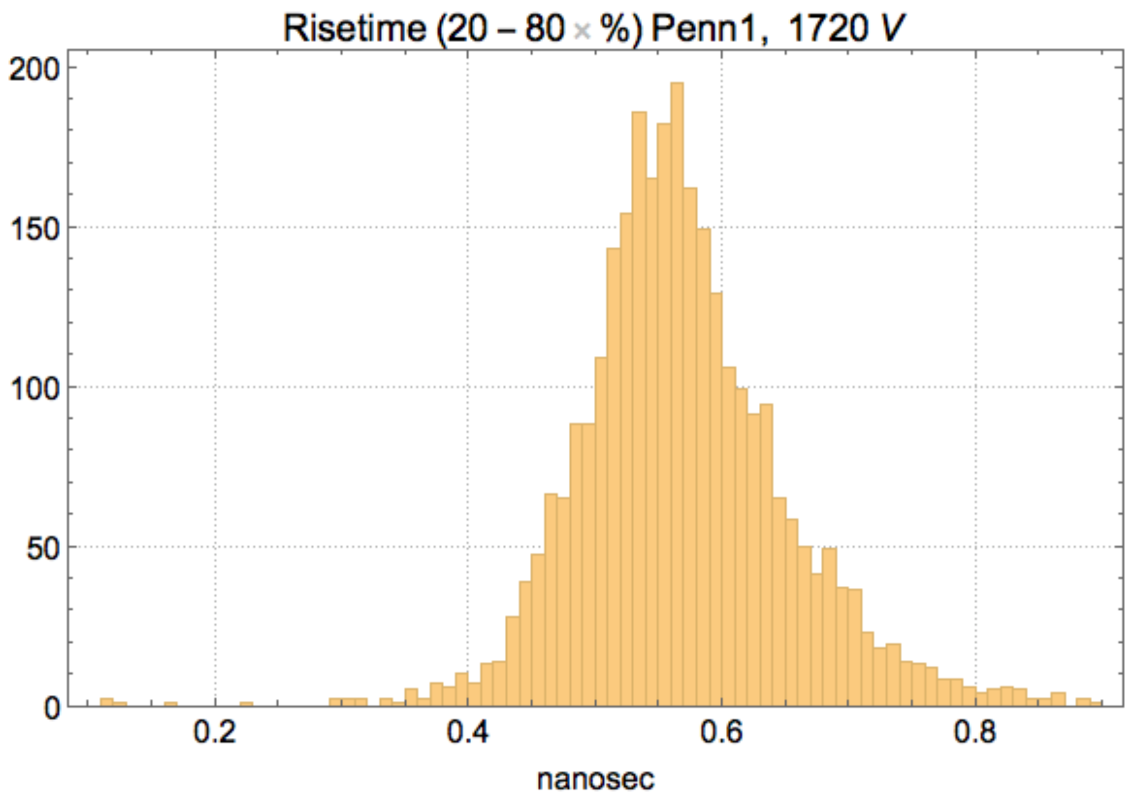


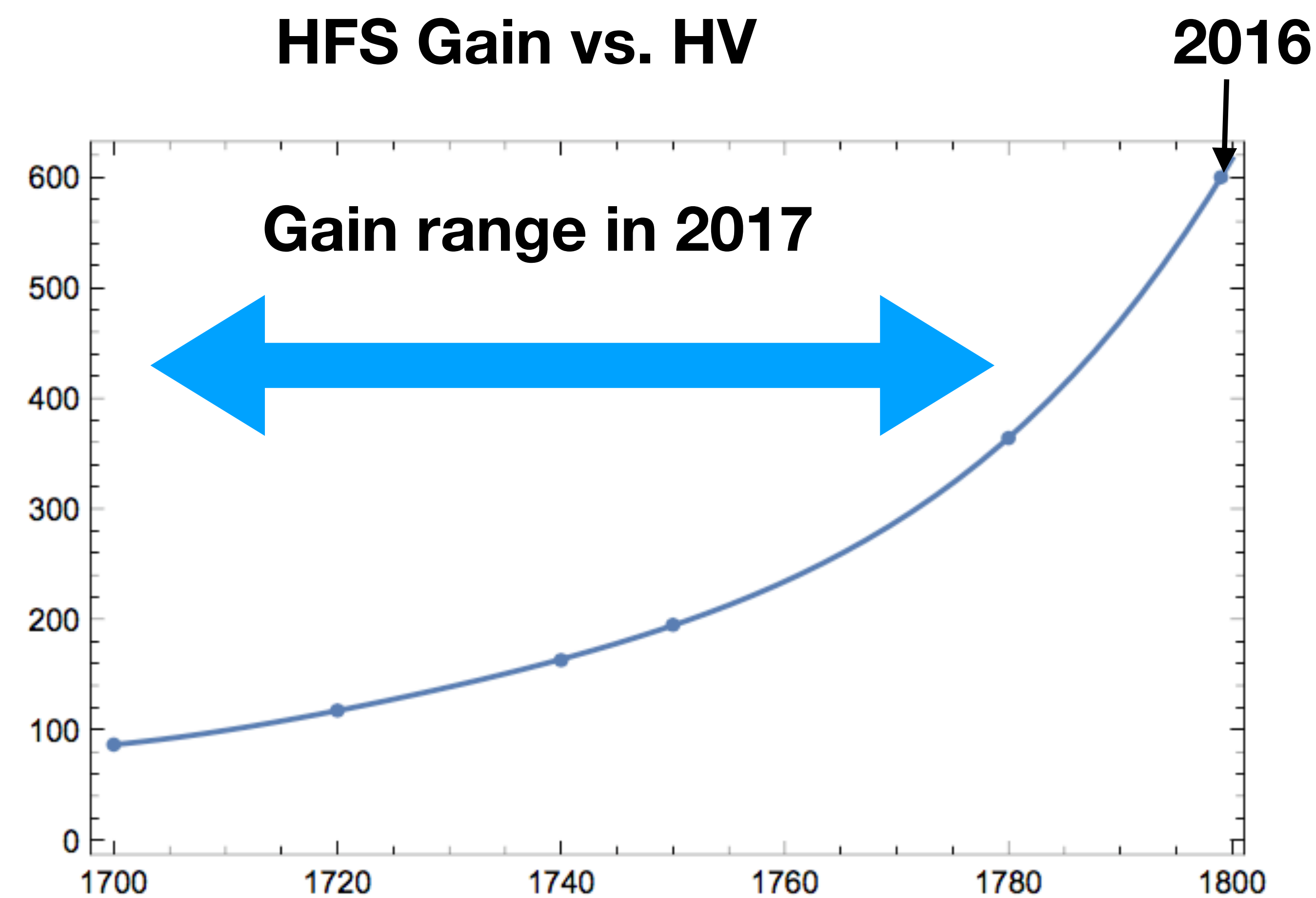
S. E. Tzamarias (AUTH)

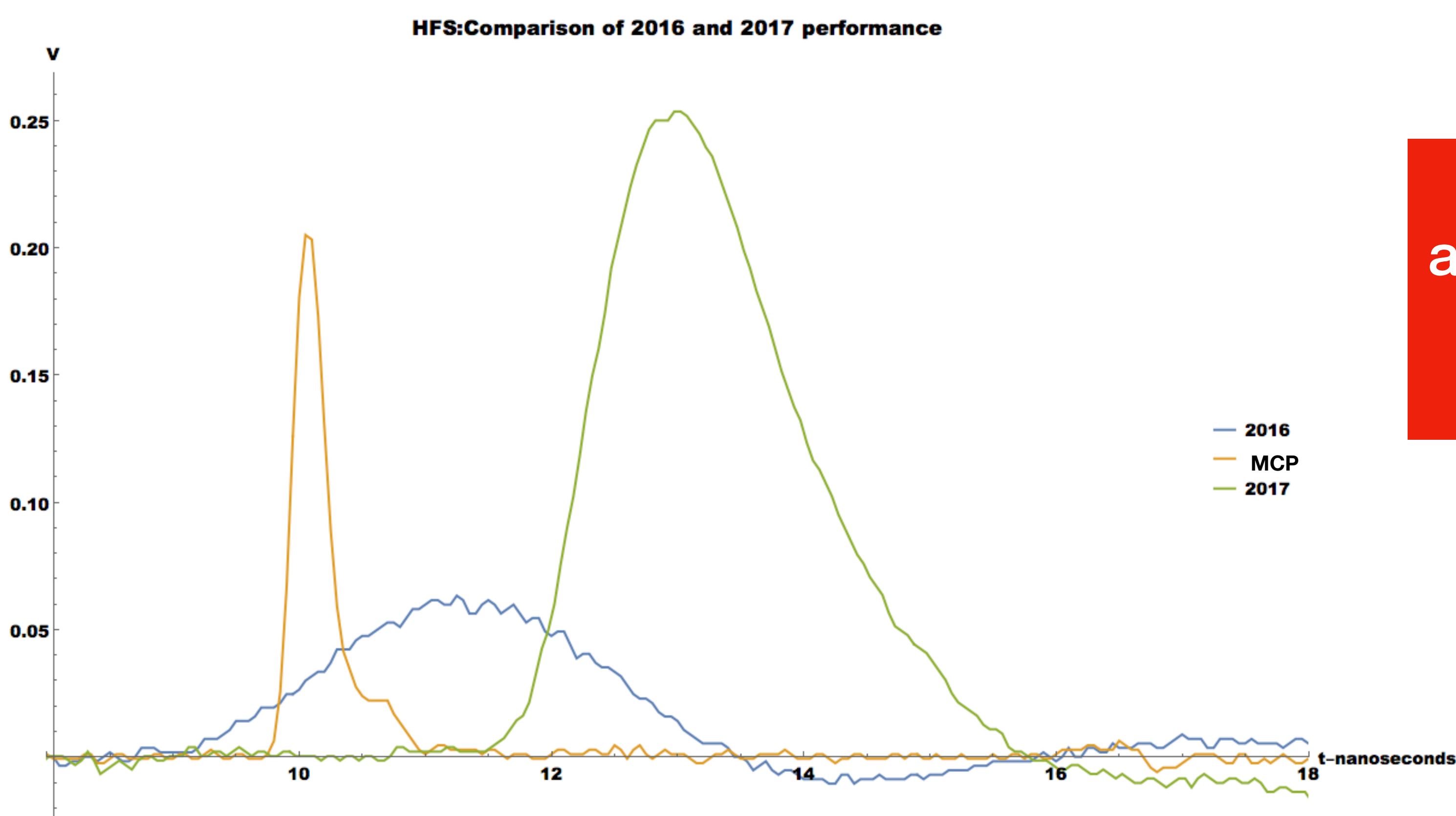
- 35 mm diameter area, 19 pads.
- Tested during Oct 2017 test beam.
  - One pad: **37 ps**.
  - MCP centered btw 3 PADs to study the charge/timing share btw them. Preliminary result: **30 ps**.

Growing, highly motivated group w. serious commitment to Instrumentation

2017 (July, Aug & October tests- 150 GeV muons)
FEE progress w. M. Newcomer





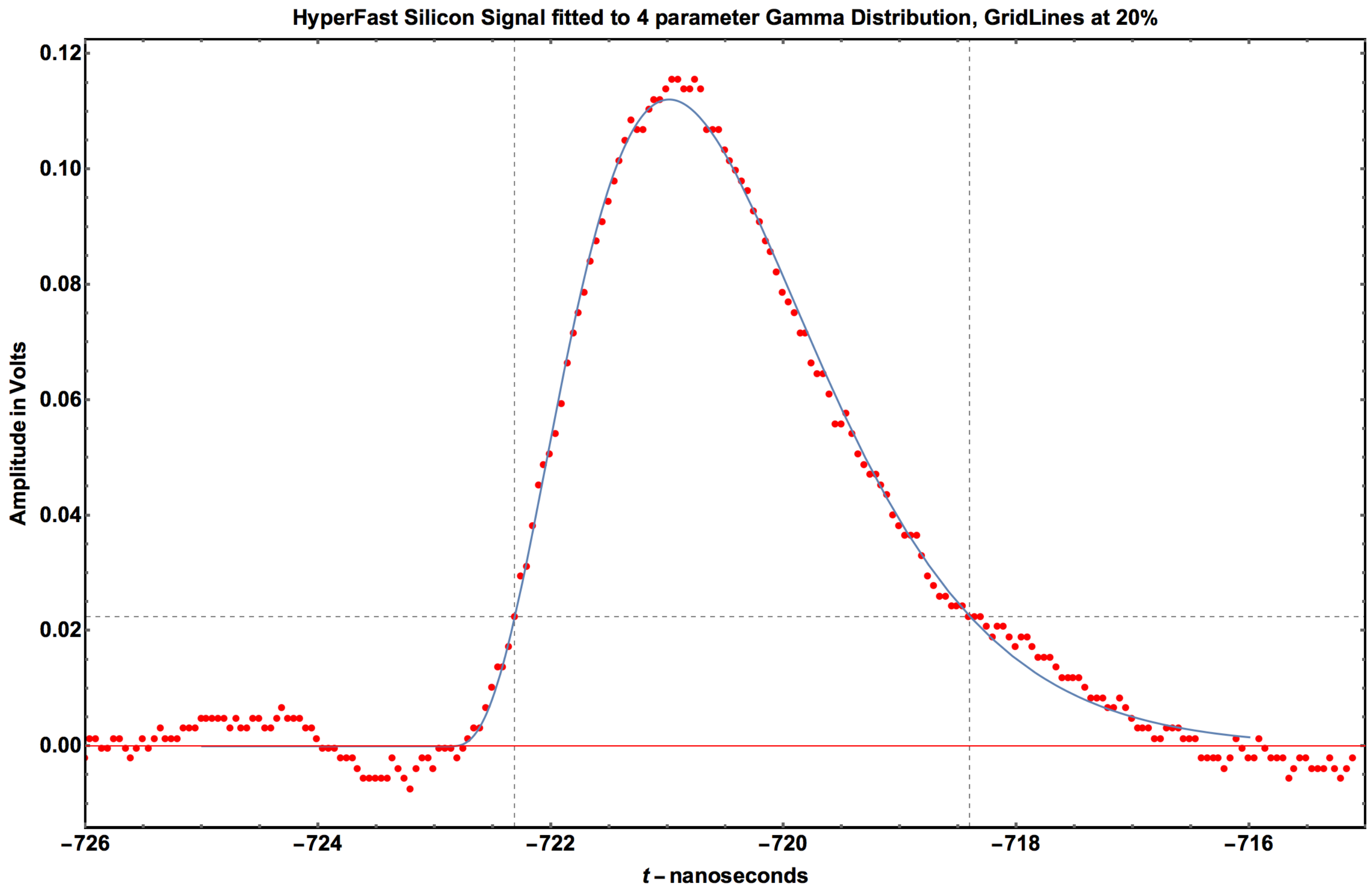


with improved integration
and constant iterations in Penn design
see real impact on signal quality
thank you Mitch & Bert!

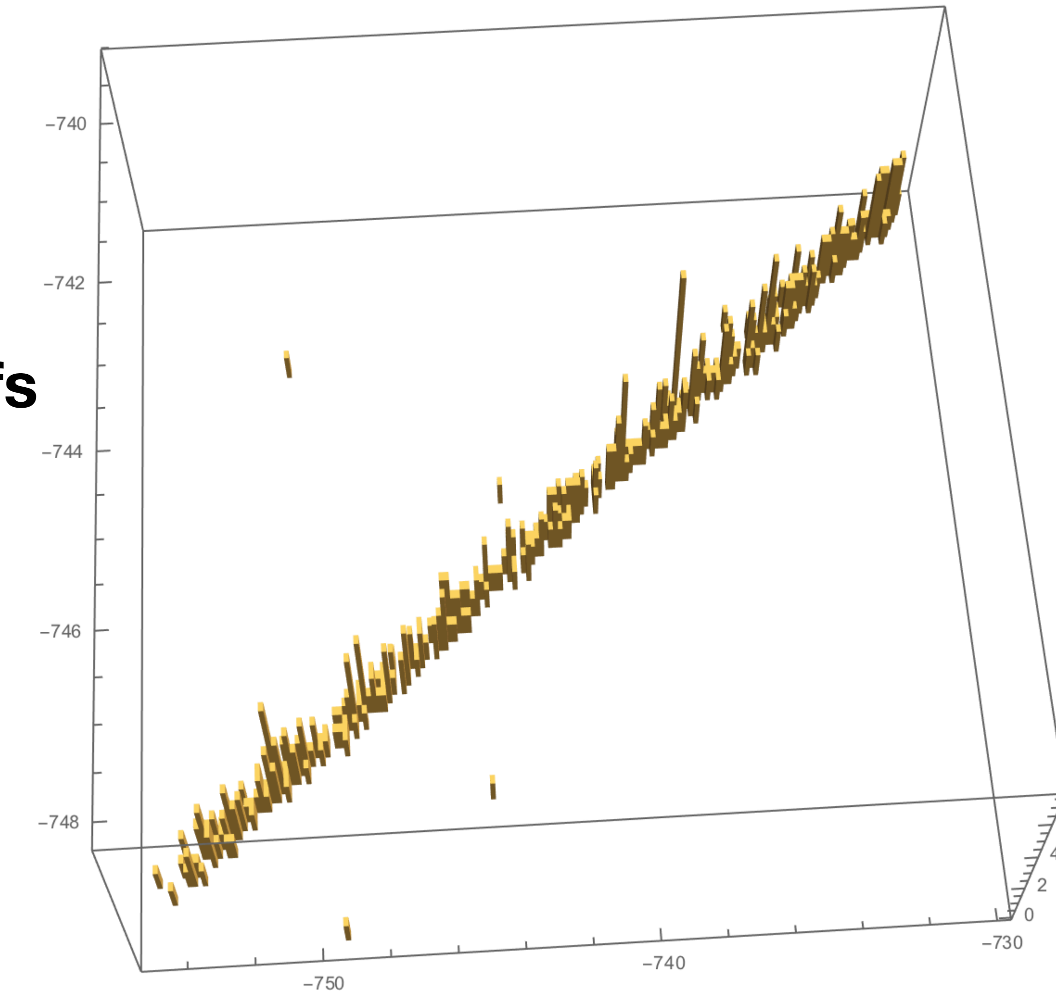
Mitch's ASIC (funded by US/CMS)
now back from MOSIS
-> bond lab-> 40 devices for
evaluation

2017 beam Campaigns within PICOSEC infractructure (cont)

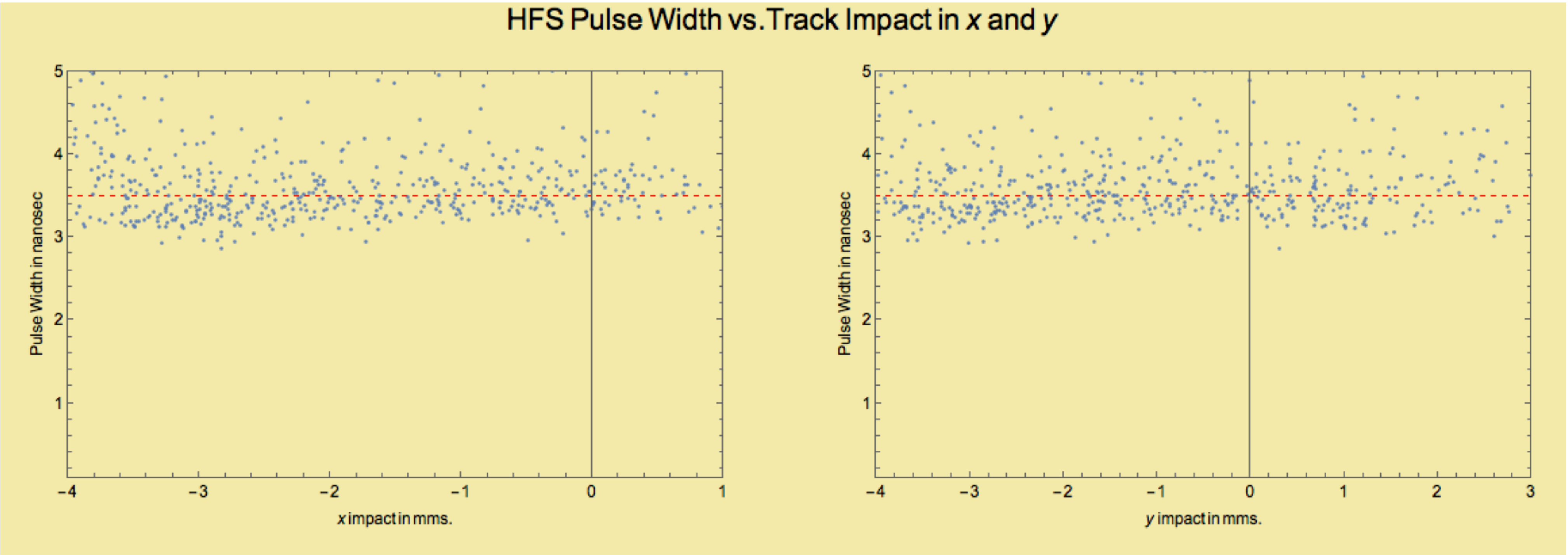
Signal modeling useful to probe position dependence



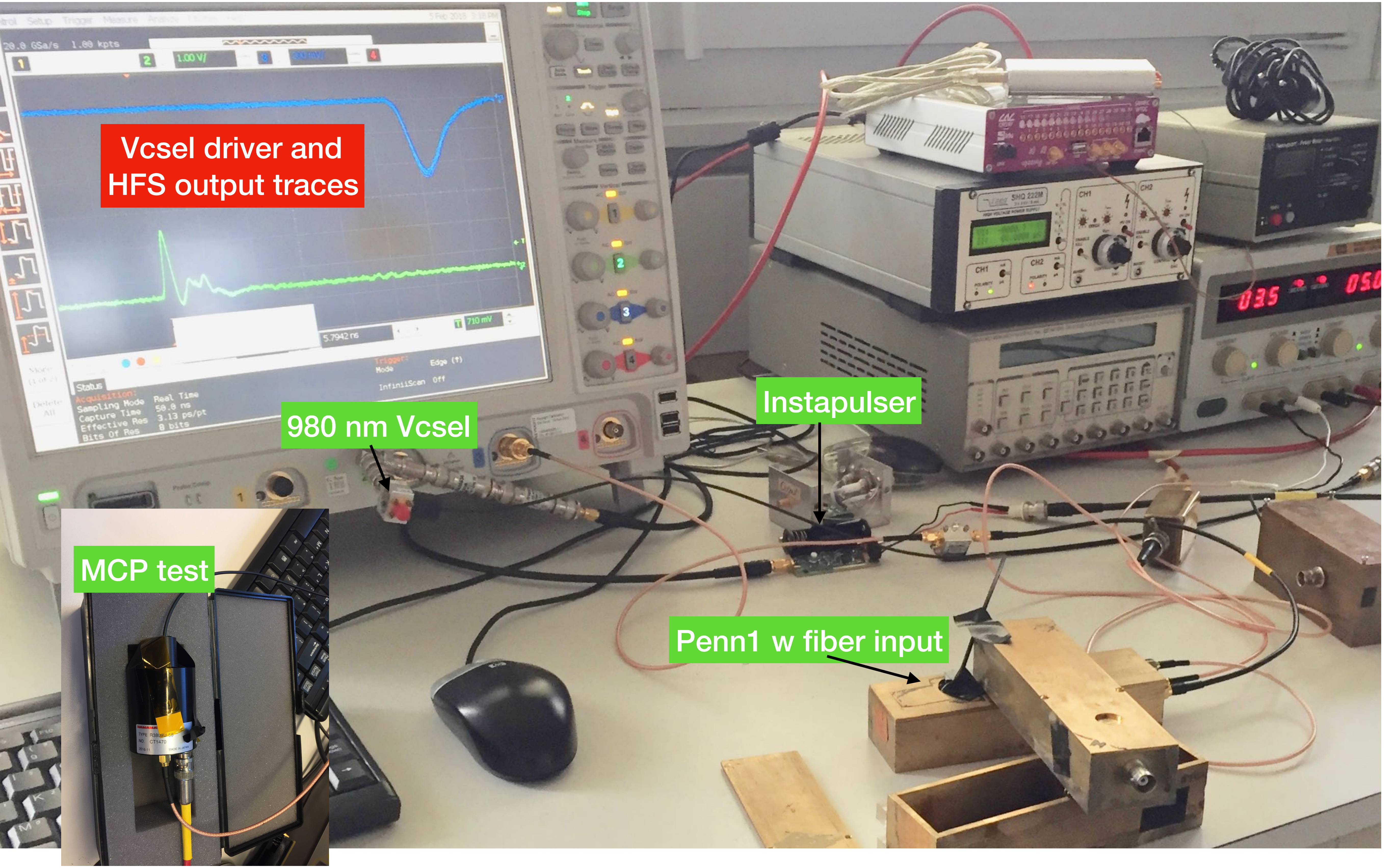
hfs



mcp

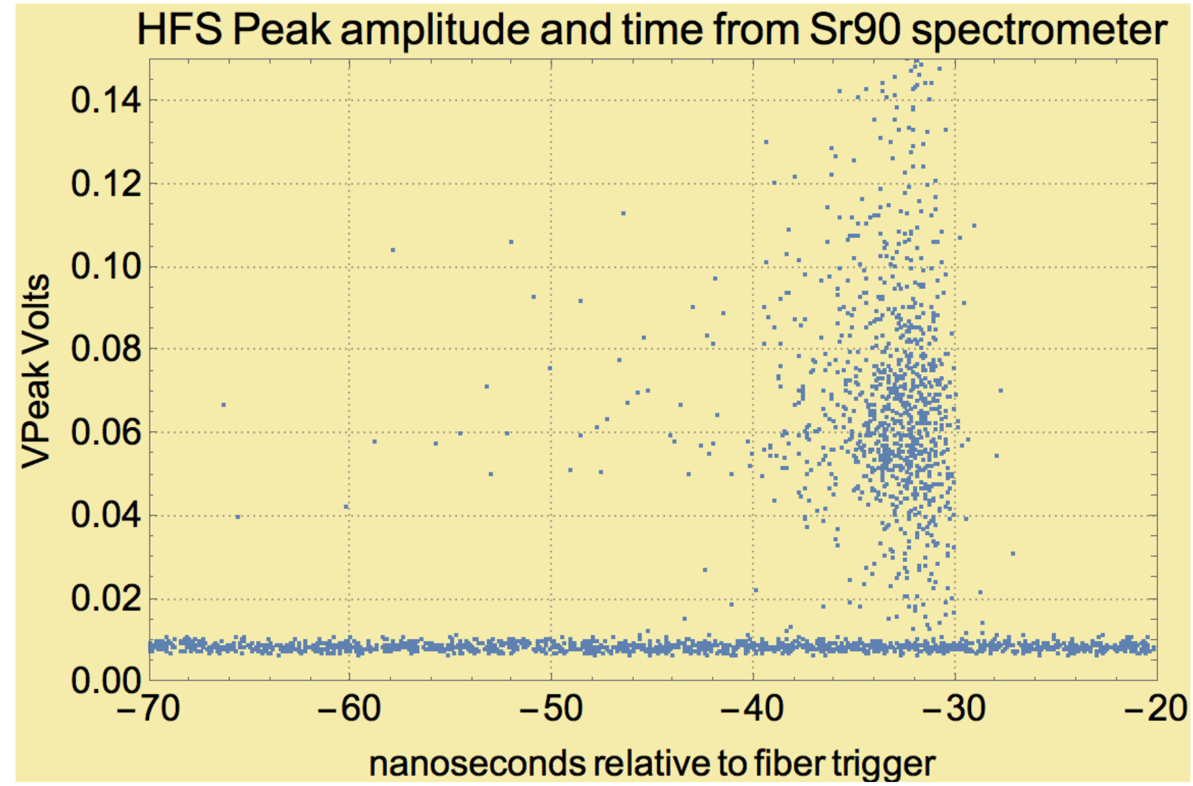


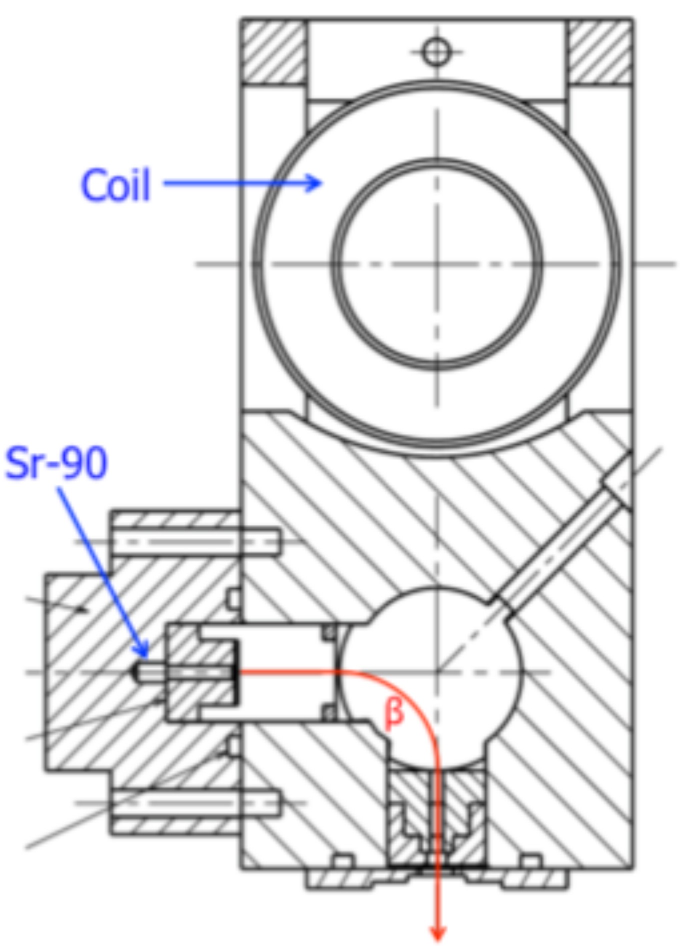
bench tests using our cheap sub-nsec pulser & vcsel

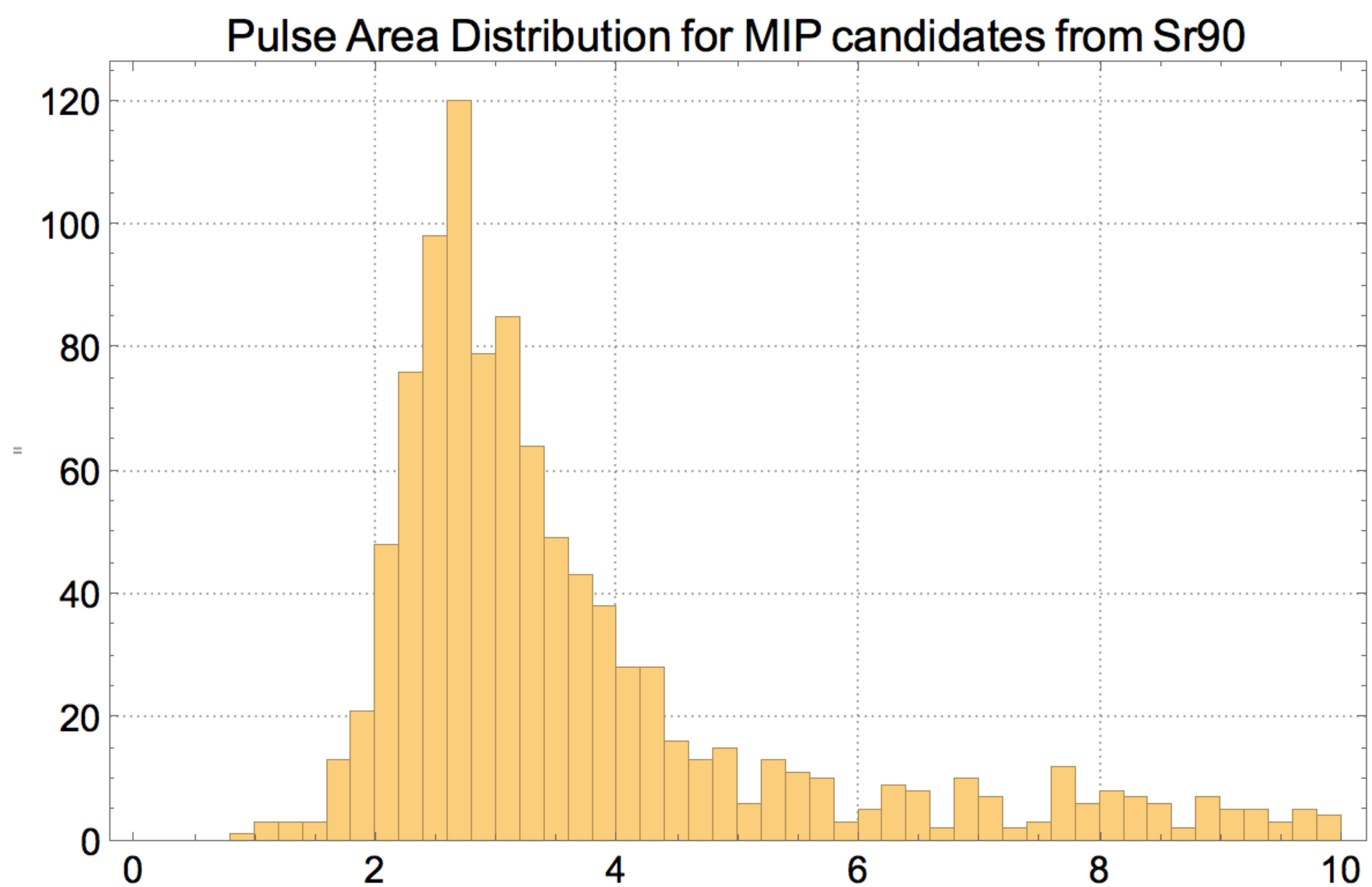


an alternative to HE beam

small device (~6”)
~1 Amp drive current
selects to +/-10% 1 MeV electrons
Argonne made similar in
SSC era, fell into disuse





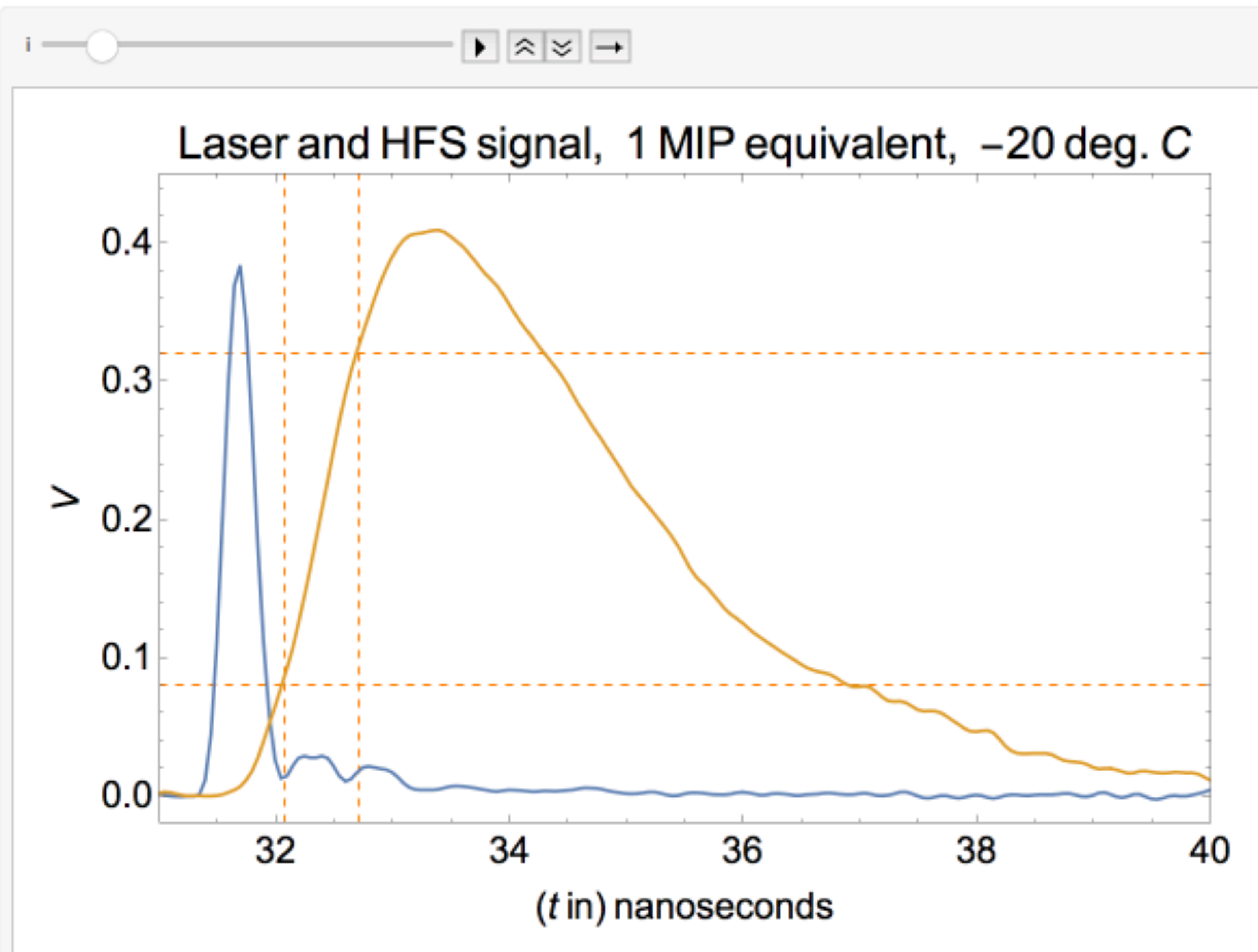


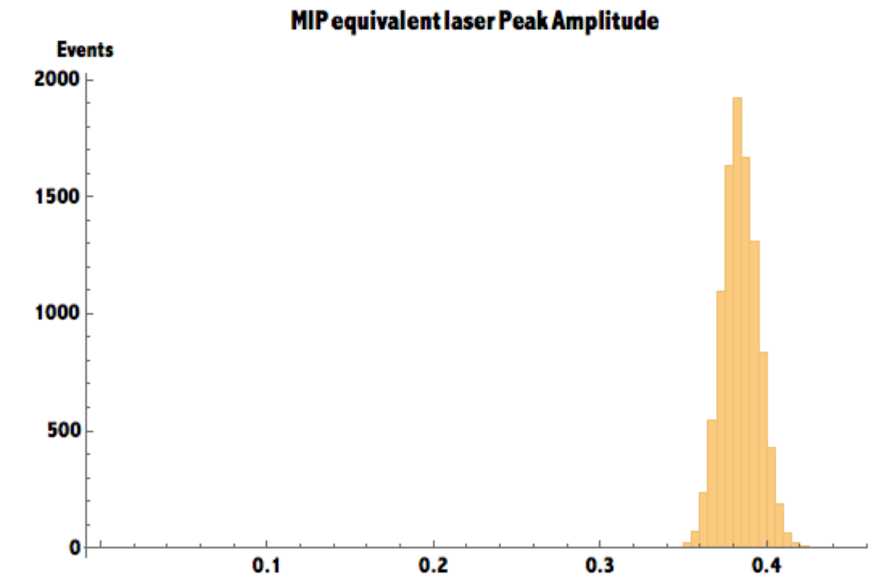
What is best time jitter for 1MIP equiv?

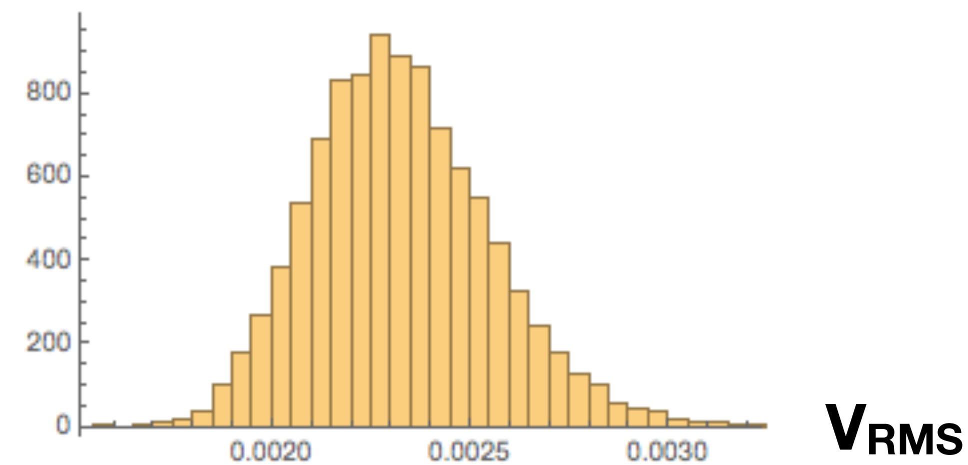
- Eric Delagnes and I tried this w. earlier FEE and SAMPIC see:

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

here we look at data from lab using Mitch’s amp







unfiltered baseline noise ~2.2mV rms ->SNR~400/2.2=180. Risetime=0.65ns

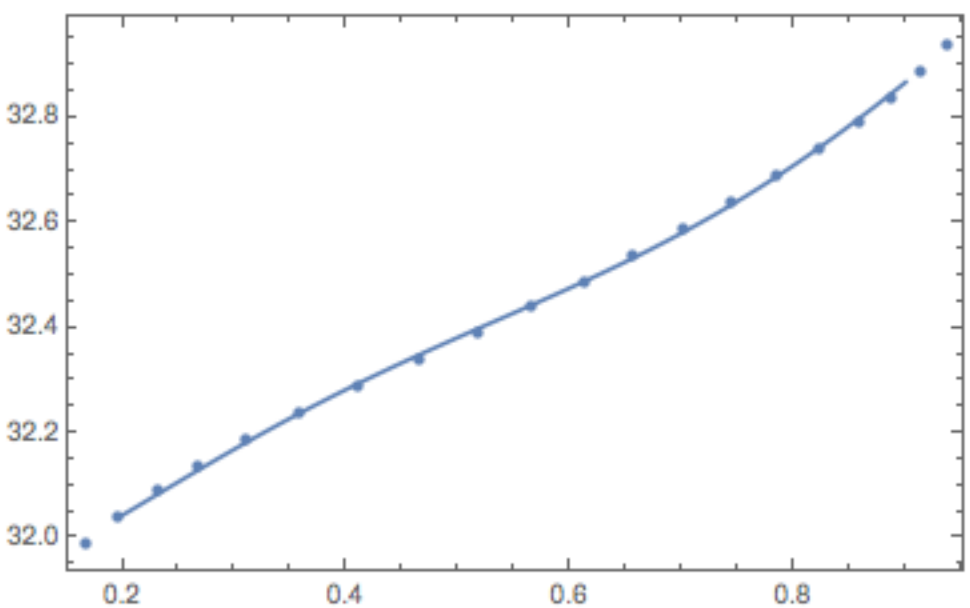
naively jitter from noise-> dt~tR/SNR=3.6 picosec

timing algorithm

- since there is some spread in laser amplitude we typically do simple Constant Fraction timing on the leading edge at ~20%. Other techniques such as filtering (usually Wiener) and fit, signal modeling, etc. all give equiv results for this example.

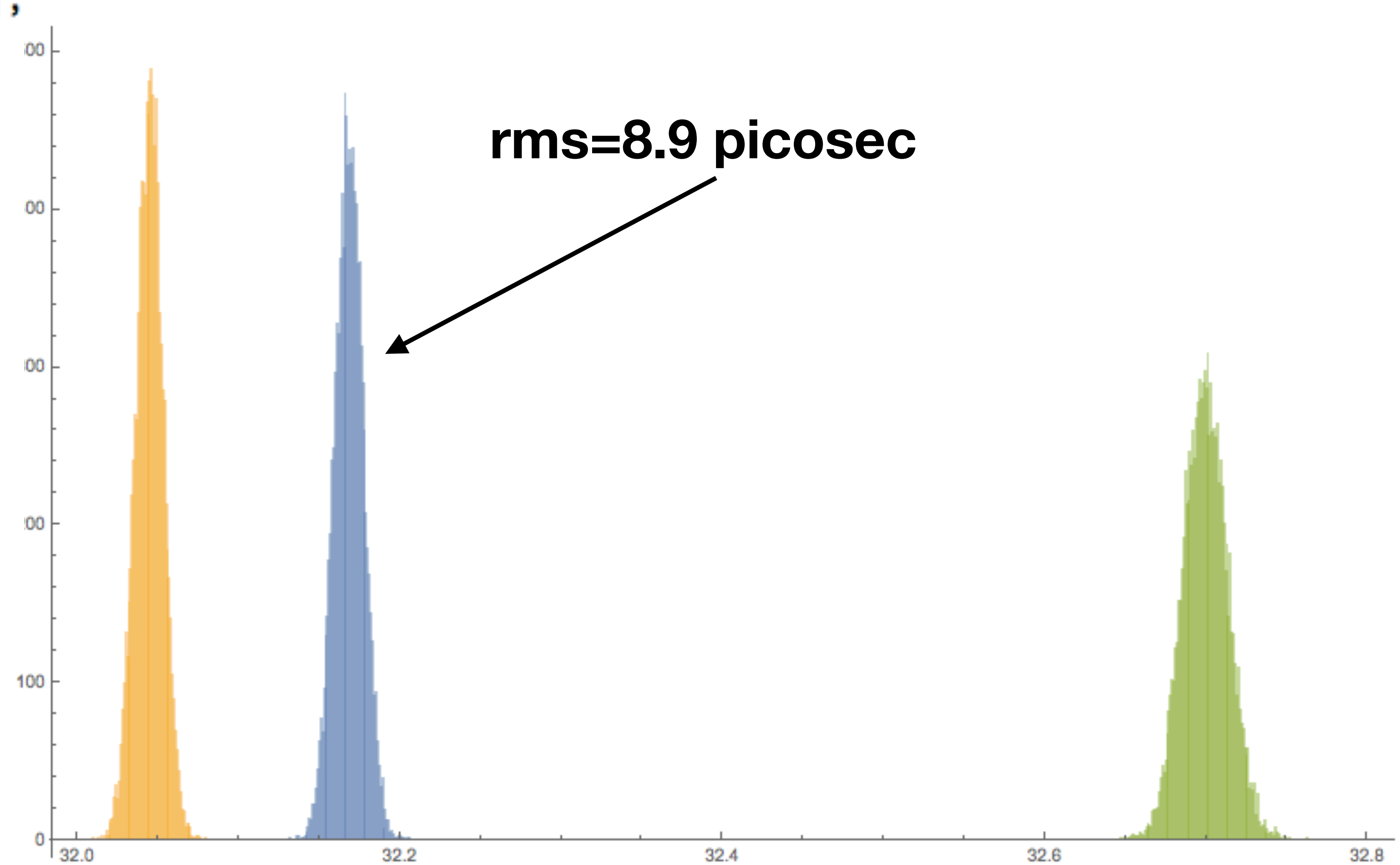
- here we do a simple power law fit to the full waveform.

```
Show[ListPlot[data], Plot[nlm[x], {x, 0.2, 0.9}],
```



nice result but
contribution from trigger jitter?

no



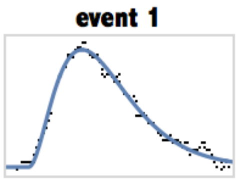
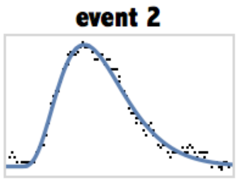
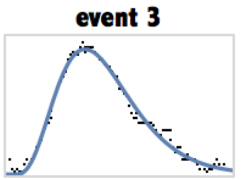
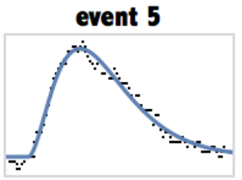
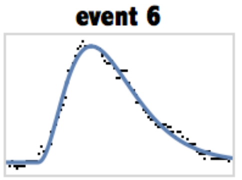
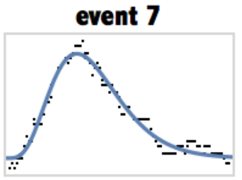
20 **30** **80% time(nsec)**

alternative to local Constant fraction fit is signal modeling for which Mathematica has some nice tools

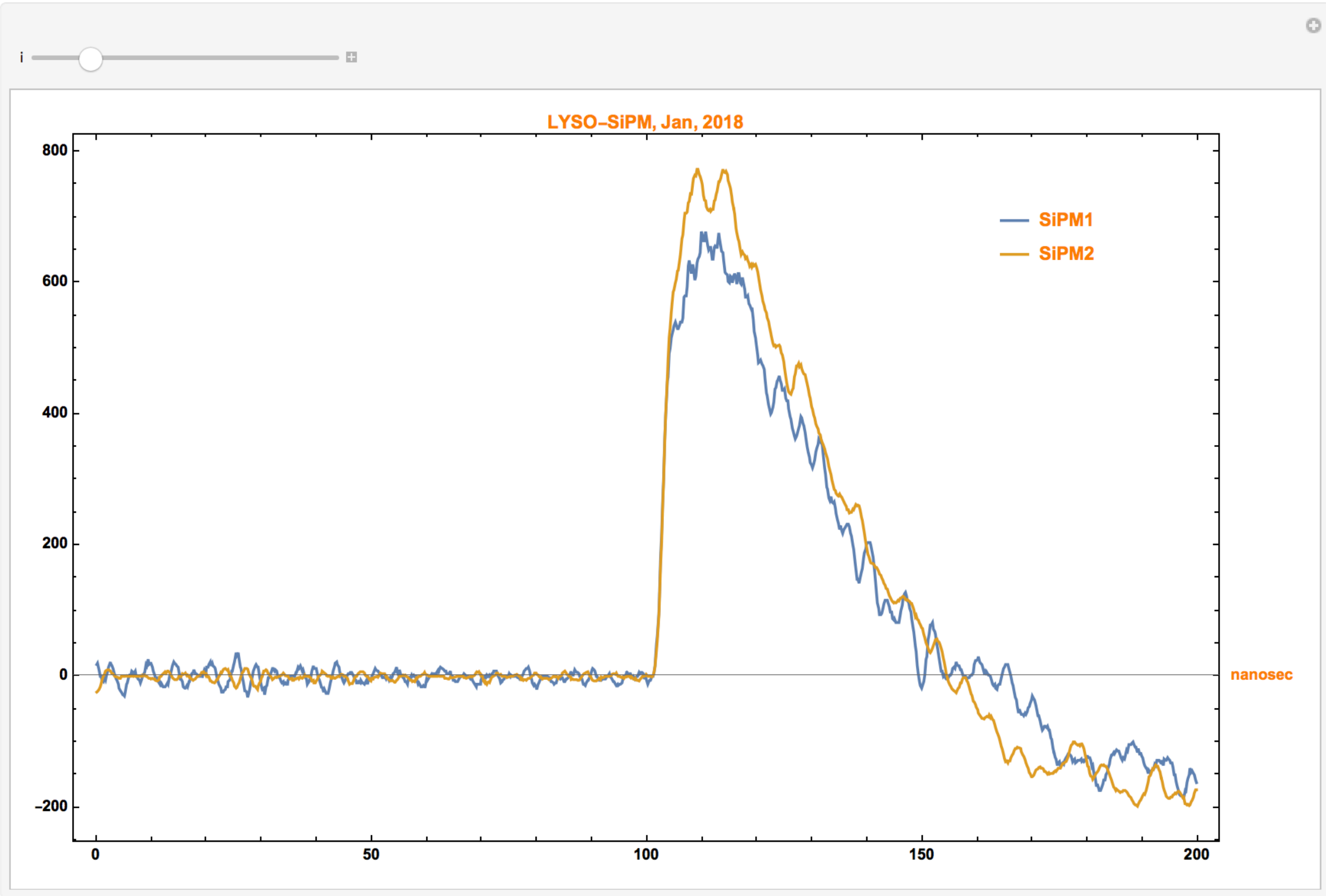
Map function across waves

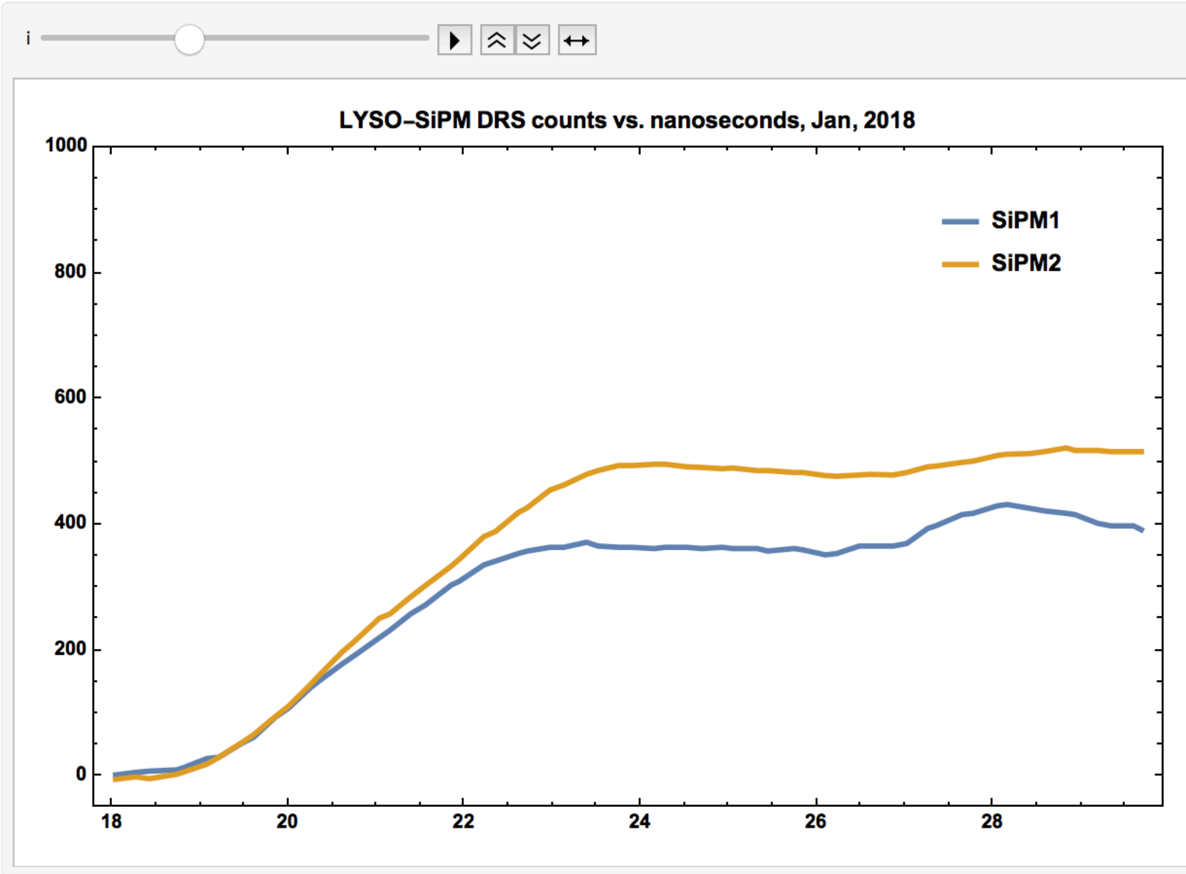
Here I use MapIndexed (this allows me to use the position as an argument). Dataset groups the results together.

```
ds = Dataset[MapIndexed[fit[#1, #2[[1]]] &, wave4[[1 ;; 100]]]]
```

event	bestFitParameters	adjustedRSquared	plot
1	{A → 0.119864, n → 2.11306, to → 0.592996, toff → 6.41963}	0.994857	
2	{A → 0.0962981, n → 3.7208, to → 0.401652, toff → 11.3142}	0.992228	
3	{A → 0.11766, n → 3.70992, to → 0.454327, toff → 4.29665}	0.994448	
4	NonlinearModelFit::sszero	—	
5	{A → 0.0926168, n → 2.05265, to → 0.595536, toff → 7.40185}	0.991077	
6	{A → 0.11257, n → 2.50197, to → 0.506459, toff → 17.7226}	0.9939	
7	{A → 0.0667517, n → 4.39367, to → 0.377799, toff → 27.448}	0.986334	

current emphasis in CMS
on Scintillating crystal with SiPM
(Silicon w. internal gain in Geiger mode)





very different time structure! Can we use similar techniques to optimize signal processing and electronics chain?

some conclusions:

- we are in an interesting domain where detector physics rather than electronics (SNR, rise time) govern resolution

- the principle technology choices of the LHC upgrades are based on Silicon with internal gain

- unlike the case with gas detectors, the fundamental timing limitations not fully modeled.-> well worth pursuing

- at the same time there is a real opportunity to use a combination of modeling and machine learning on a large data set to further develop signal processing algorithms. Subject of a current proposal with Wolfram Research.

thanks for your attention!