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Study of Secondary emitters (SE) as active layer for fast and high radiation resistant Shower Maximum (SM) detector or calorimeter

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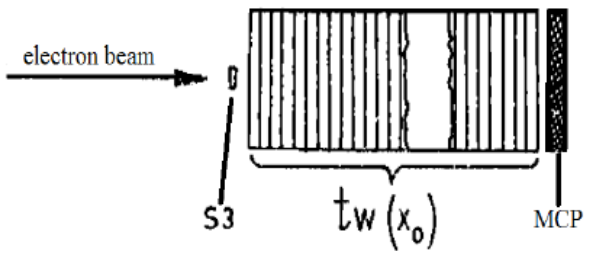
Fermilab
Hawaii, February 18, 2015

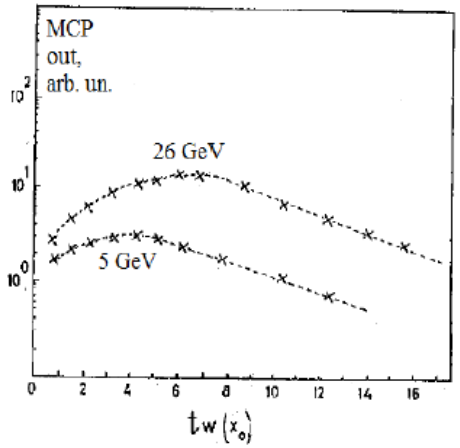
We proposed to use an electron multipliers, e.g. MCPs, venetian blind or meshes dynode as the active elements for new type of calorimeters (rad resistant and fast) in 1990 [1].

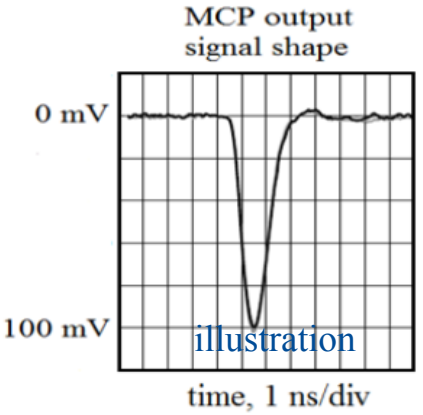
- Proposed approach allows to make a fast and radiation resistant calorimeter or shower maximum (SM) detector. The longitudinal shower profile was measured at 5 GeV and 26 GeV electron beams. The obtained signal was very short (~1 ns) with big pulse amplitude (up to 100 mV/100 Ohm). This was clear approval of efficient direct detection of secondary particles of electromagnetic (EM) shower. We had not reliable MC for EM shower secodaries below 10 keV, that's why we did the measurements.
- The cost of MCP was the main limit to make such detectors. That's why we stopped the R&D about 25 years ago. But the cost could be reduced significantly (due to LAPPD), that's why we started the R&D again. We should emphasize that we do not need LAPPD photocathode (PC) for the application. This also could be additional saving in development of such detectors.
- Up to now we have measured: timing of SM with MCP at FTBF and got ~37 ps of time resolution. We have approved T1058 experiment at FNAL. The goal is to make and test secondary emitter calorimeter (SEC). LAPPD MCPs without photocathode (PC) could be one of the option of active layers in such calorimeter. Another attractive properties of such SM or calorimeter could be 2-dimentional map of energy and timing information at each sampling depth, and possible separation of electromagnetic and hadron's energy based on difference in timing and size.

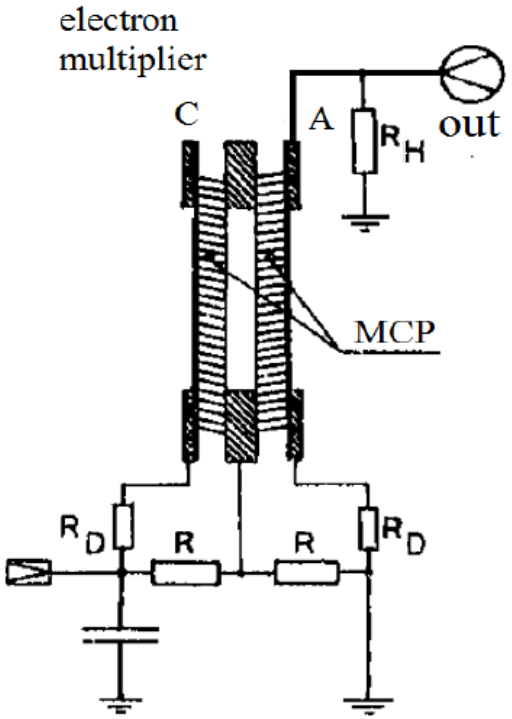
[1] On possibility to make a new type of calorimeter: radiation resistant and fast. Derevschikov A. at al., Preprint IHEP 90-99, Protvino, 1990.

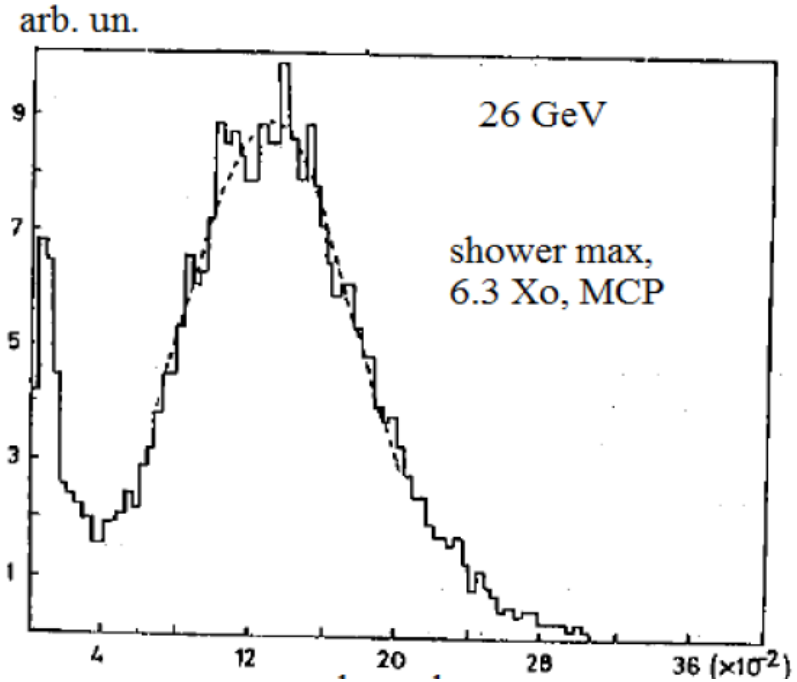
Old Test Beam data, SM on MCP, chevron, 37 mm diameter



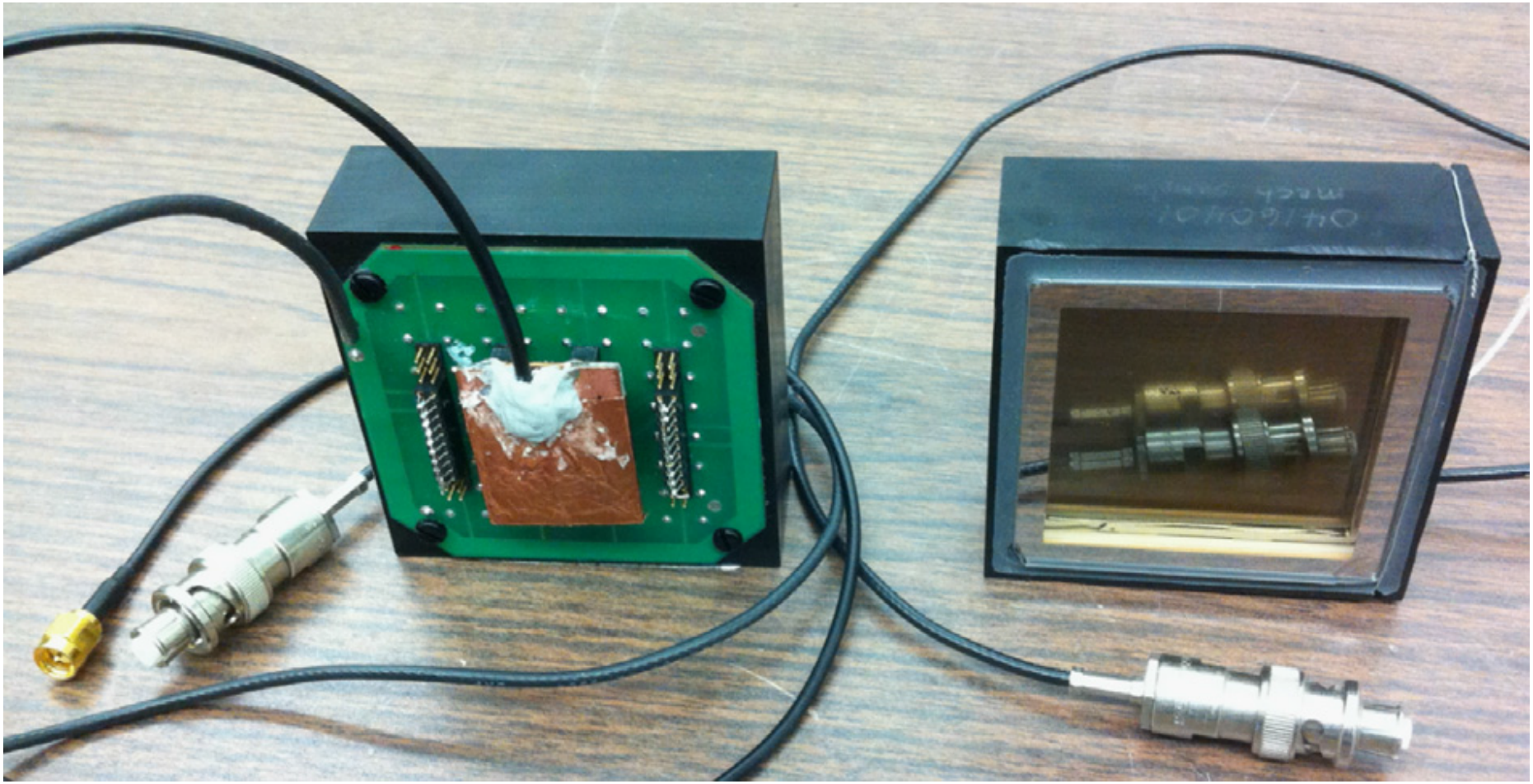




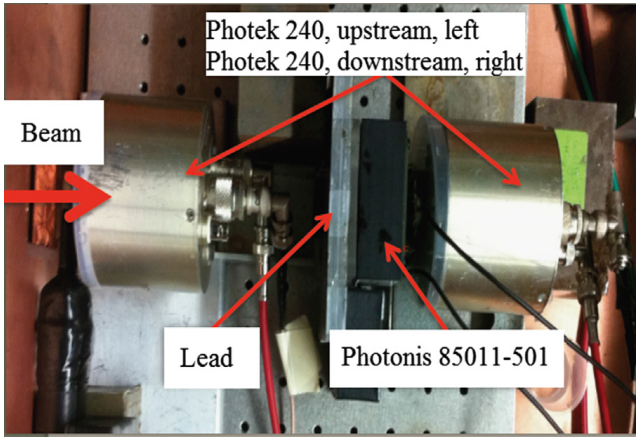


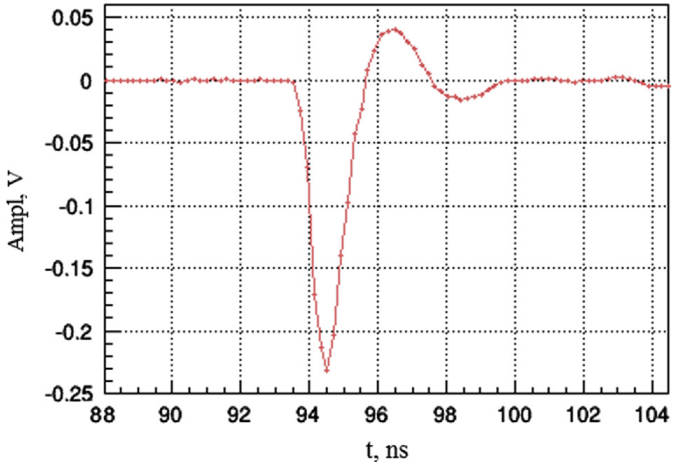


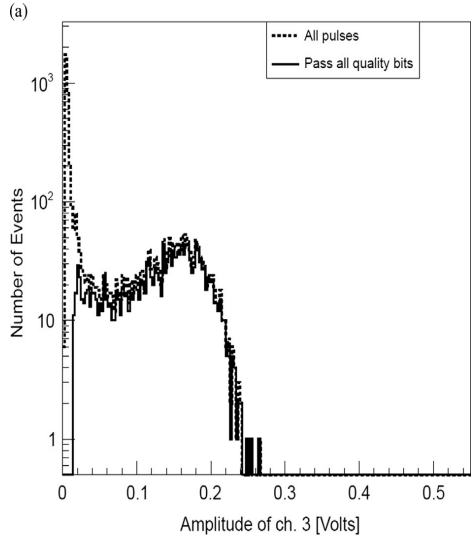
Photonis XP85012, sum of 4x4 pixels, 24x24 mm2

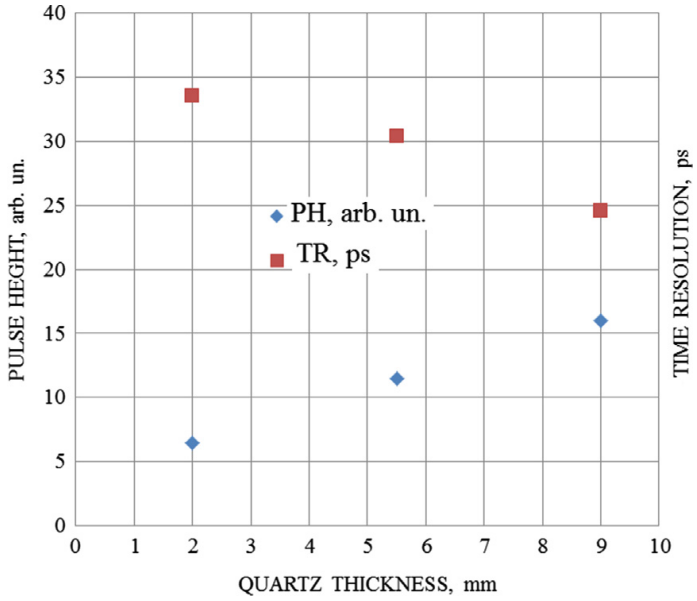


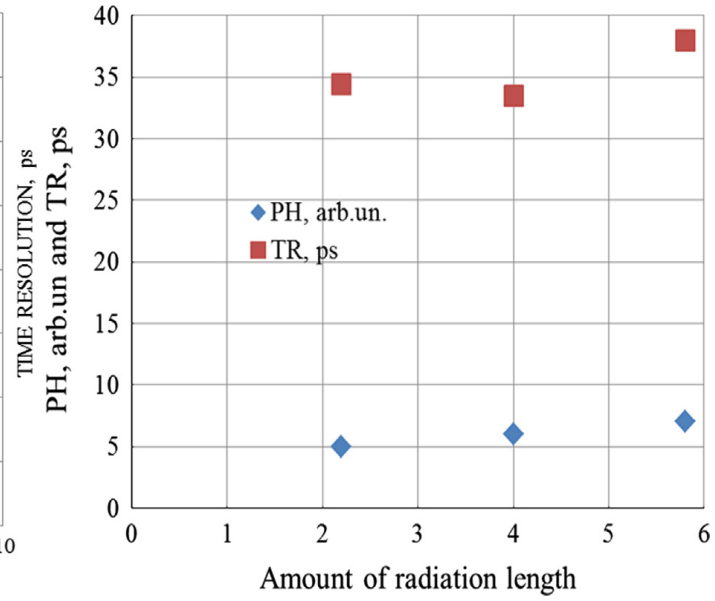
2014, our first SM results. 12 GeV electrons, ~ 2-4 Xo of Pb before Photek240, TR ~25 ps. The lead before Photonis XP85011, TR ~35 ps. NIM A759(2014) p.65–73

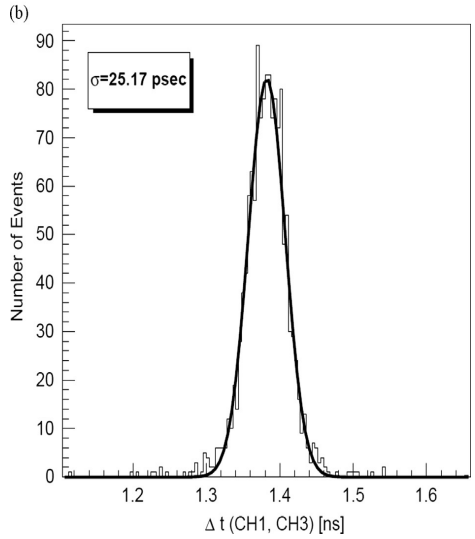




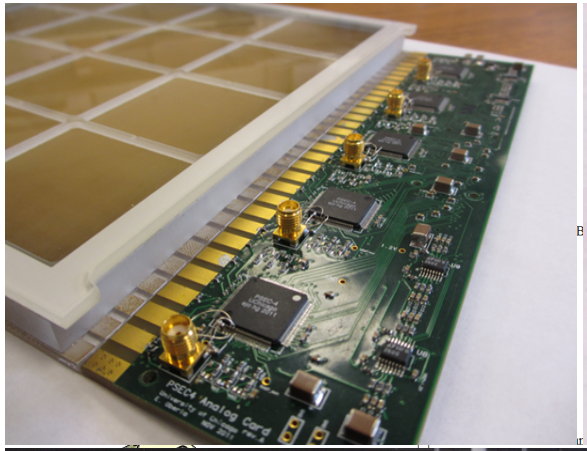


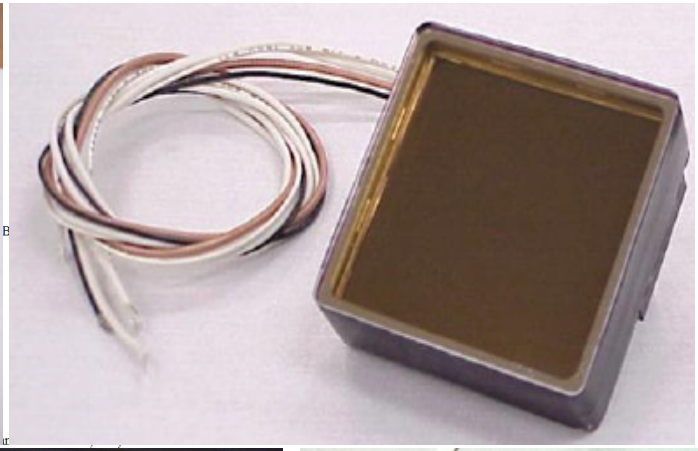


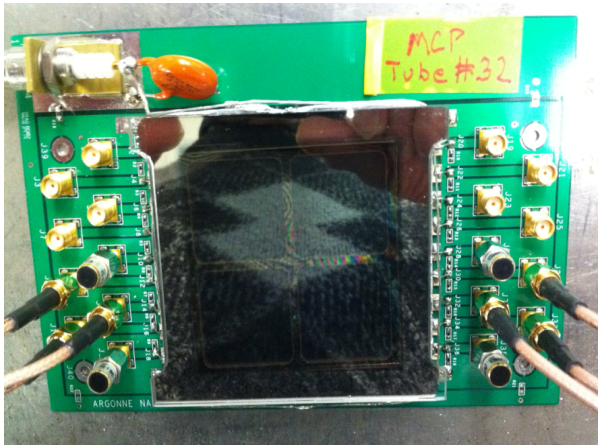


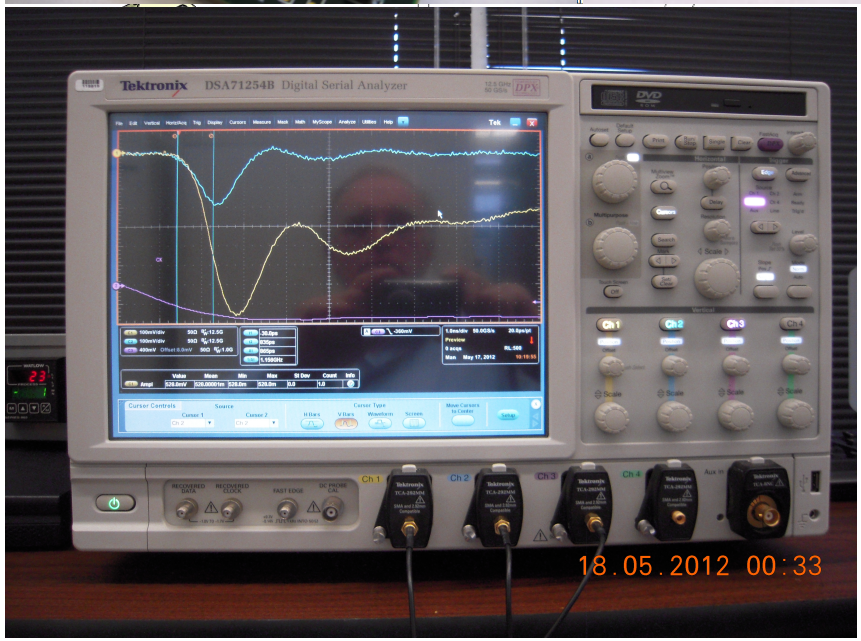


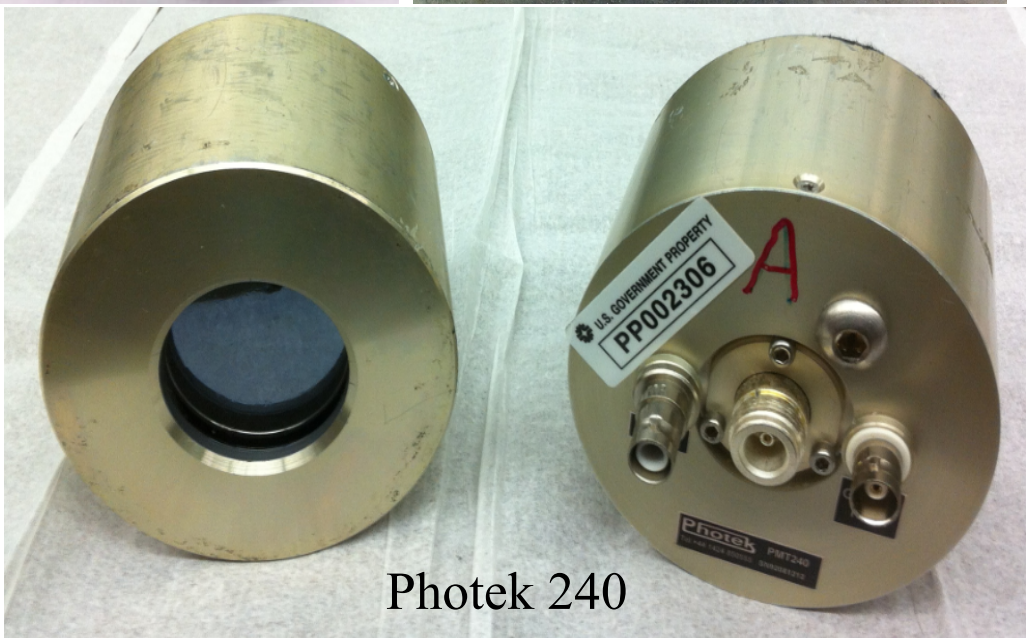
Best MCP-PMT for timing. Photek 240, Photonis XP85012. But we need MCP w/o PC











DSA7125B digital serial analyzer, 20 ps sampling, borrowed from AD, we made database for Spicing

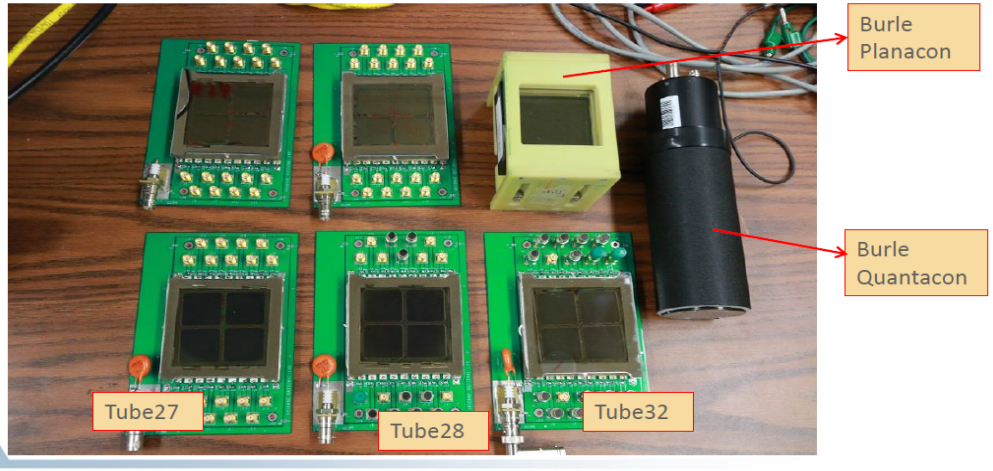
Timing nonuniformity of the Photek 240 across 41 mm diameter <1.7 ps. SPTR ~35 ps.

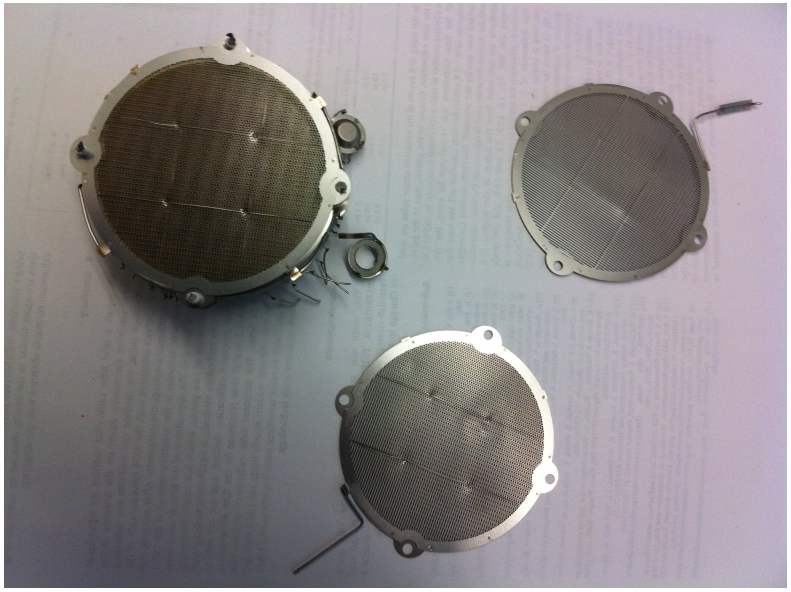
"Development of a 10 ps level time of flight systems in the Fermilab Test Beam Facility". A. Ronzhin, M. Albrow, M. Demarteau, S. Los, S. Malik, A. Pronko, E. Ramberg, A. Zatserklianiy. NIM, A 623 (2010) 931-941.

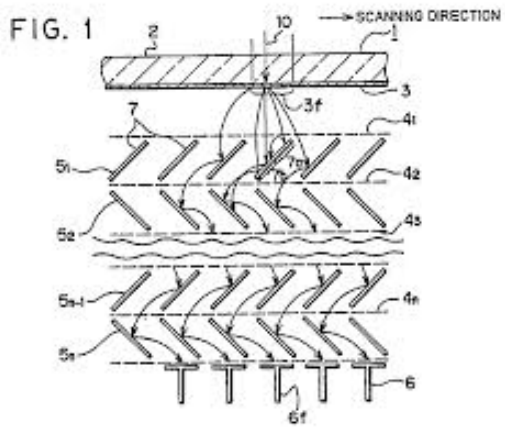
During LAPPD review at ANL on October 21, 2014, we agreed to test the 6 cm x 6 cm MCP, produced at Argonne as an active layer of the SM detector at Fermilab TB.

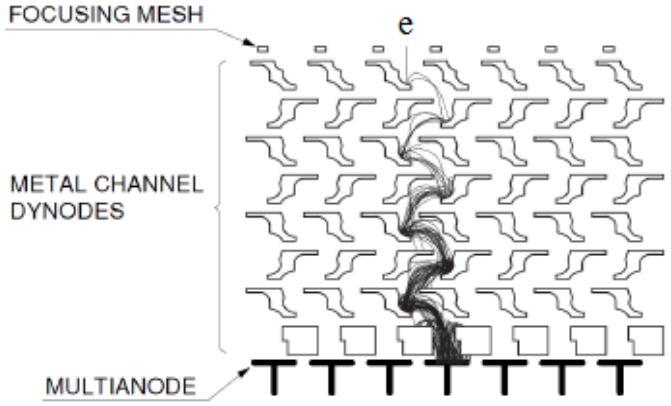
Another possible SE options to test for SM could be meshes, venetian blinds, etc.

- Burle Quantacon and Planacon MCP-PMT as reference detectors
- Tube27, Tube28 and Tube32 tested with a blue laser @ANL-HEP

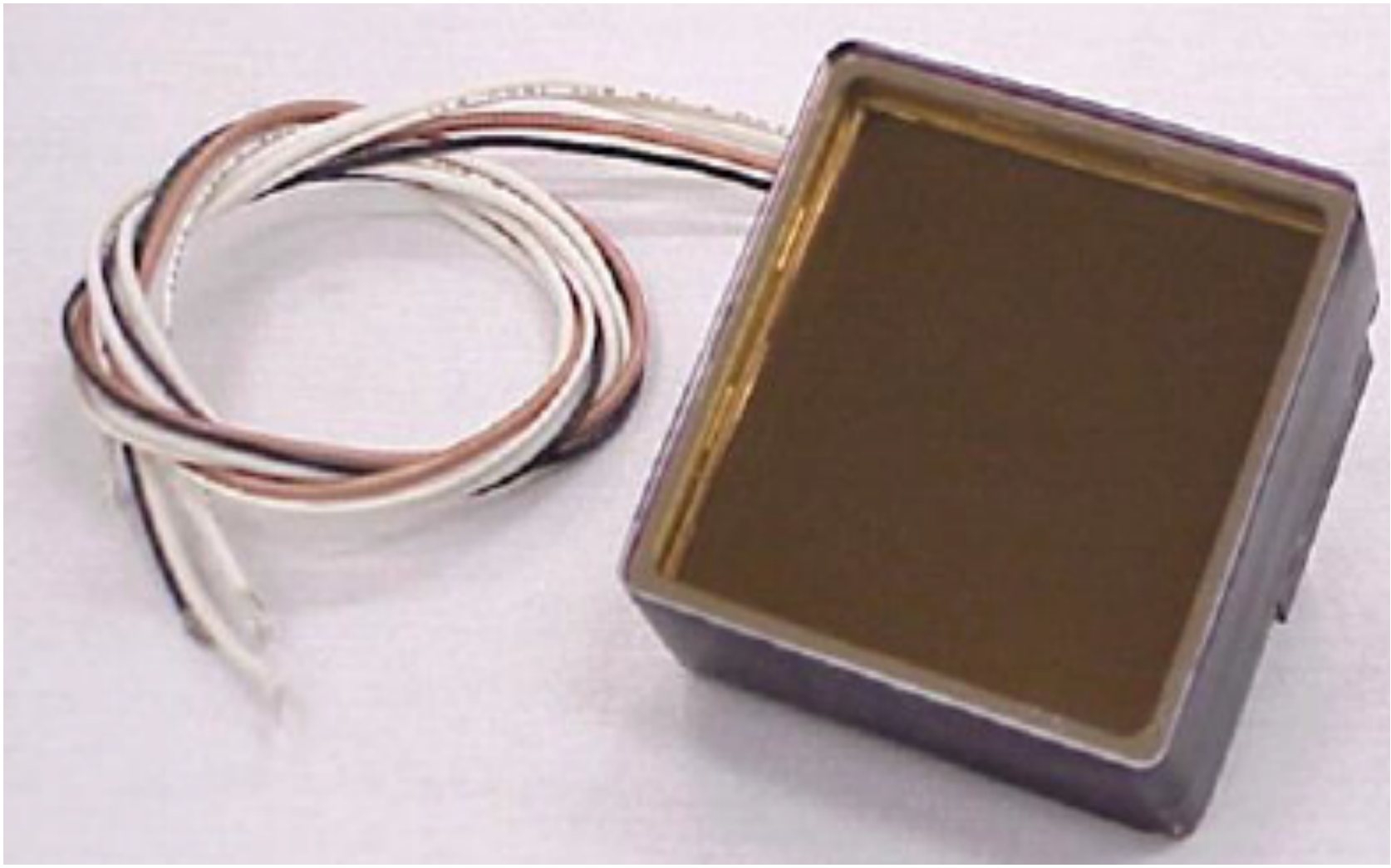




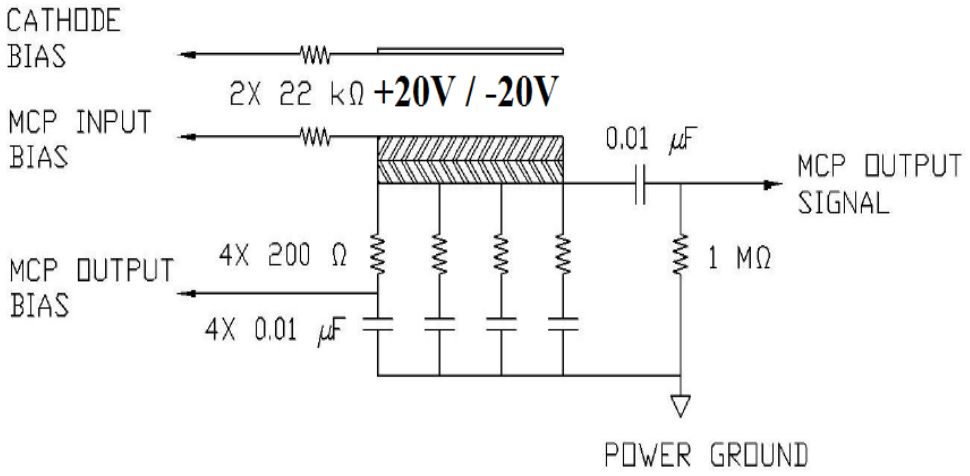


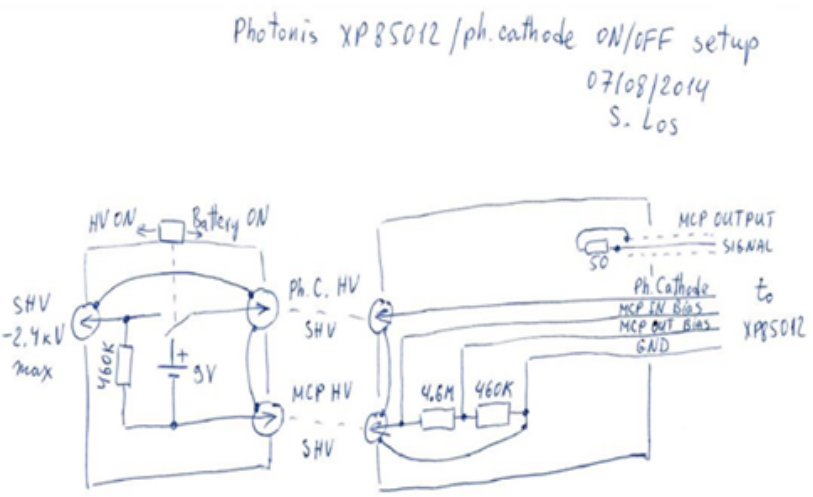


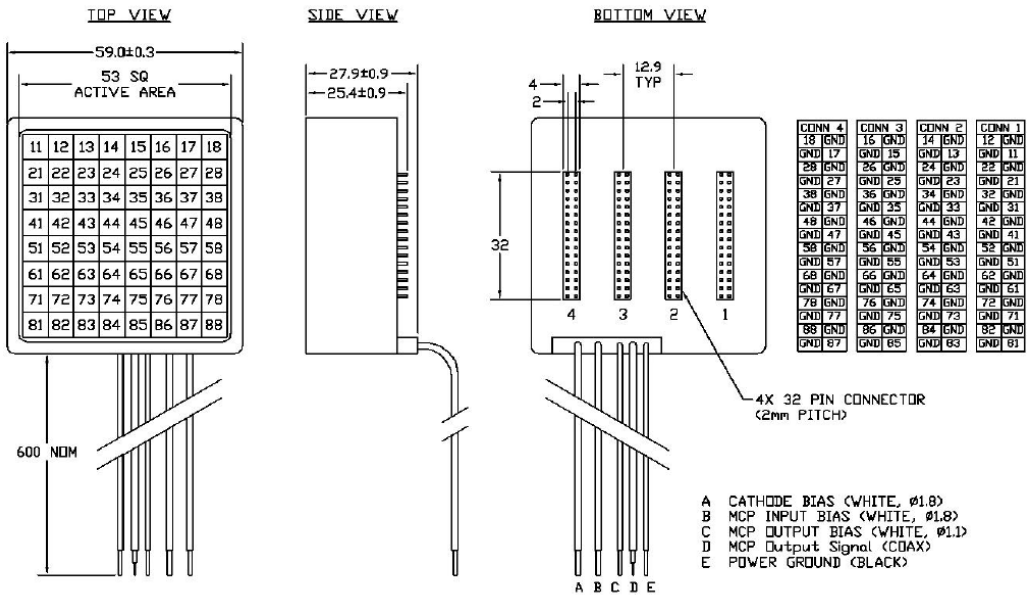
Photonis XP85012, HV divider allows make PC ON and OFF



Modified HV divider, possible to make PC ON or OFF

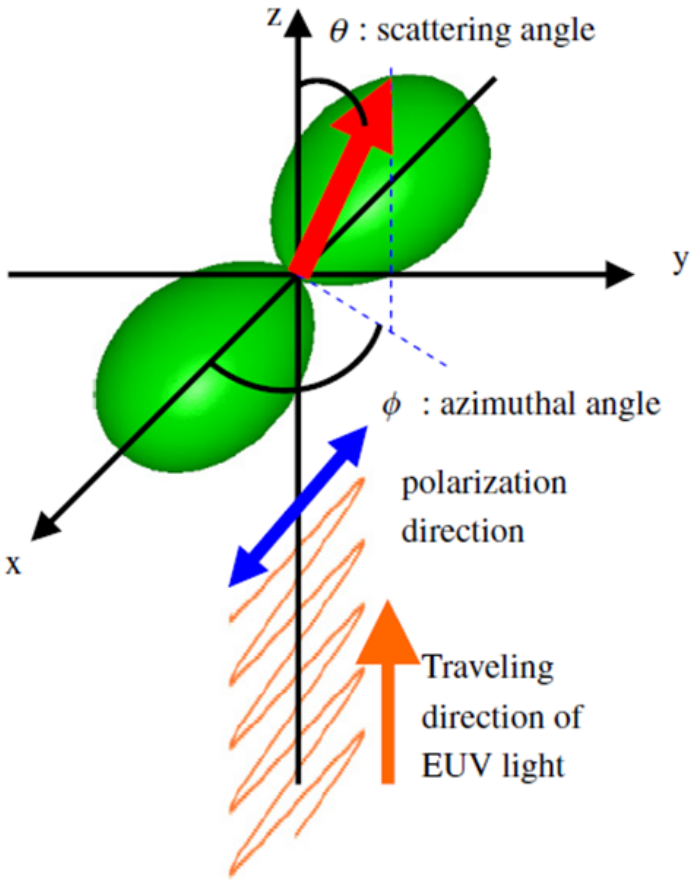


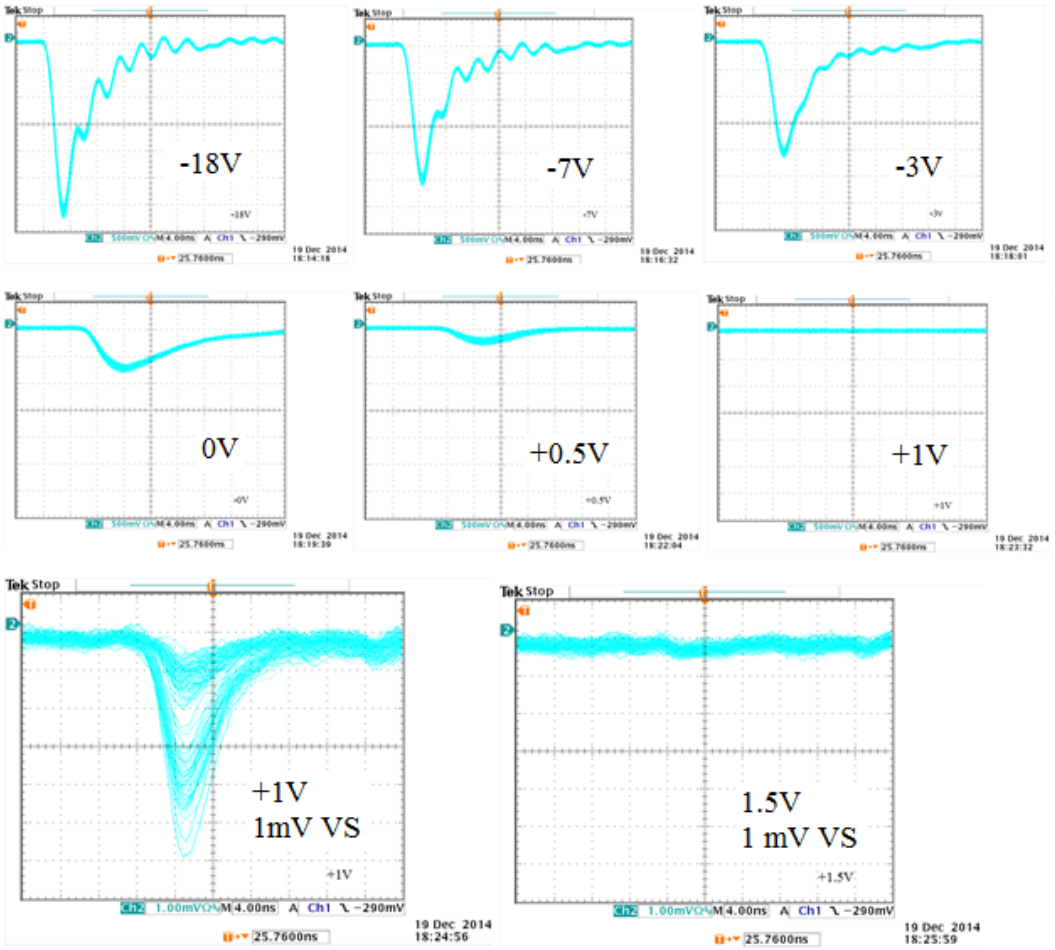




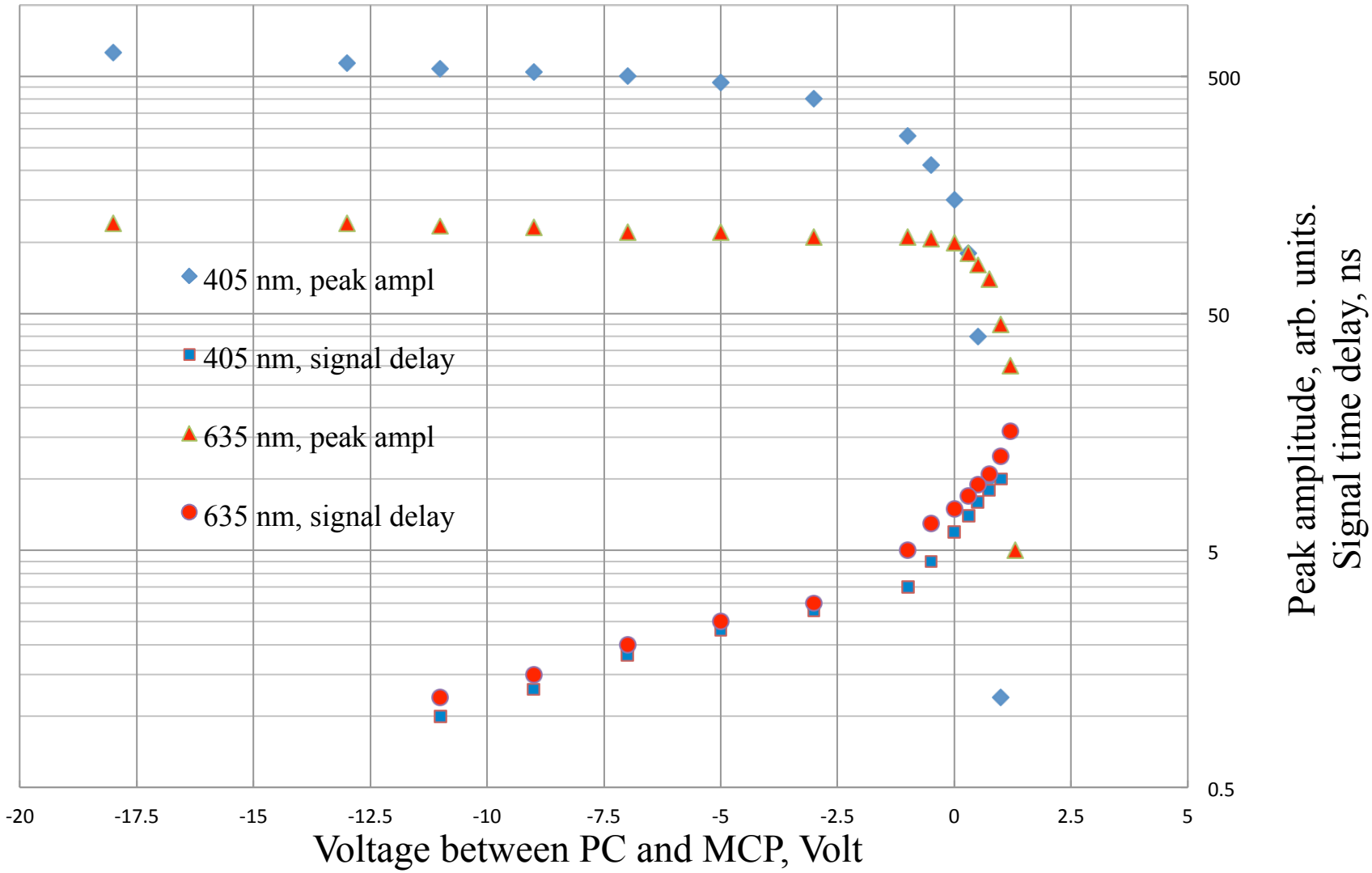
Measured XP85012 output signal shape, time delay, charge and amplitude in dependence on bias between photocathode and MCP . Bias range +20 V / -20V. Data taken for 405 nm and 635 nm. Results are below.

NB. Einstein's formula. $E_{kin\_phe} = E_{photon} - W_{f.}$ Stopping potential, U

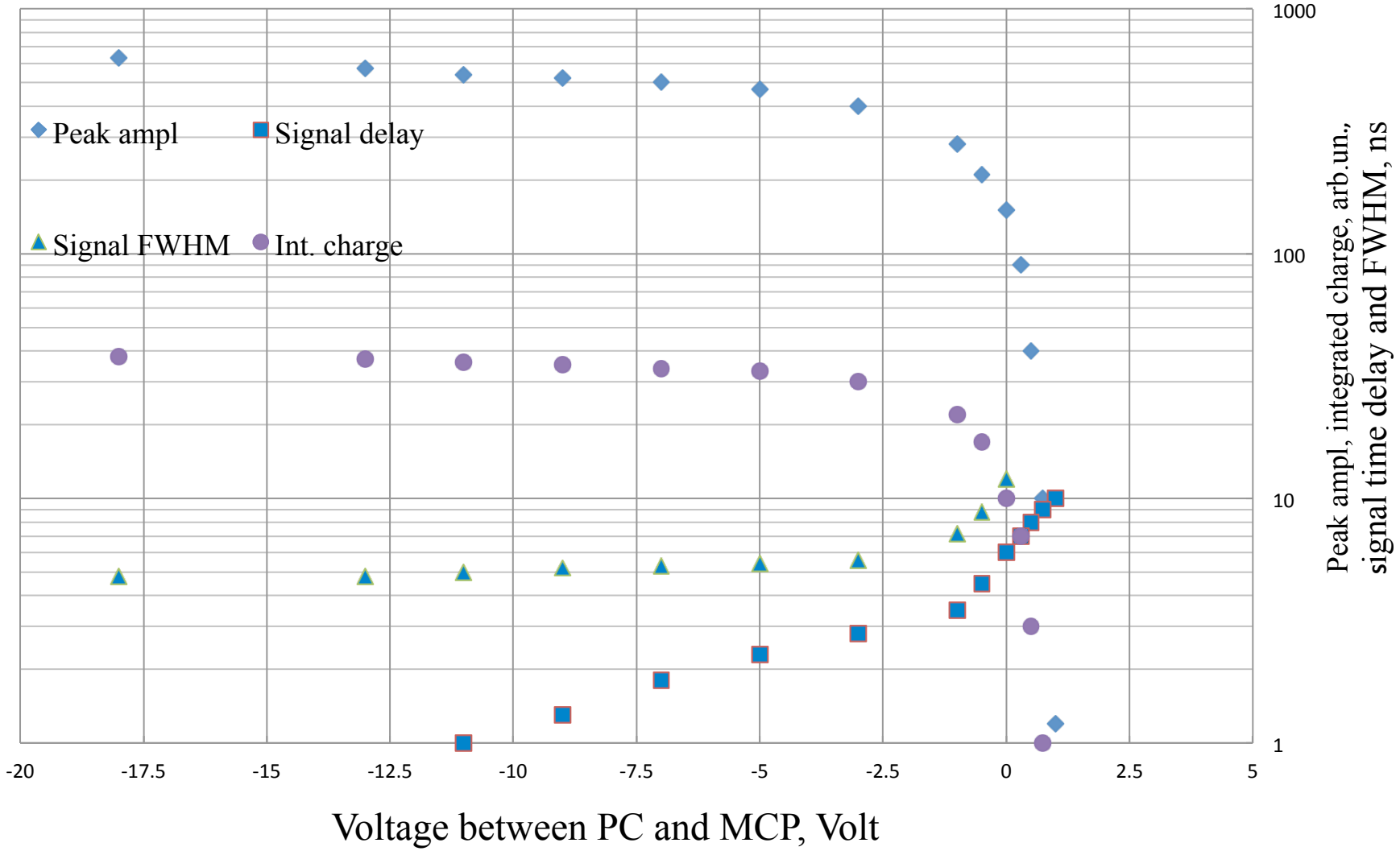




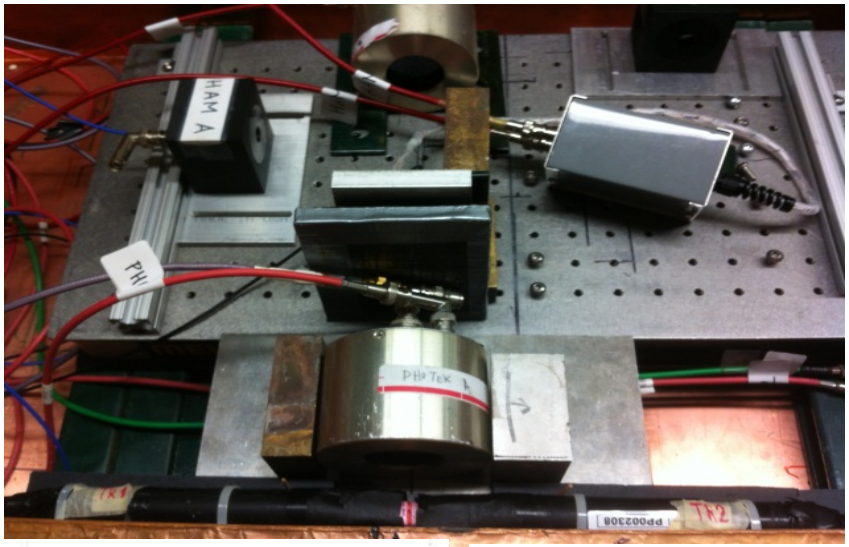
XP85012 signal dependence on voltage between PC and MCP

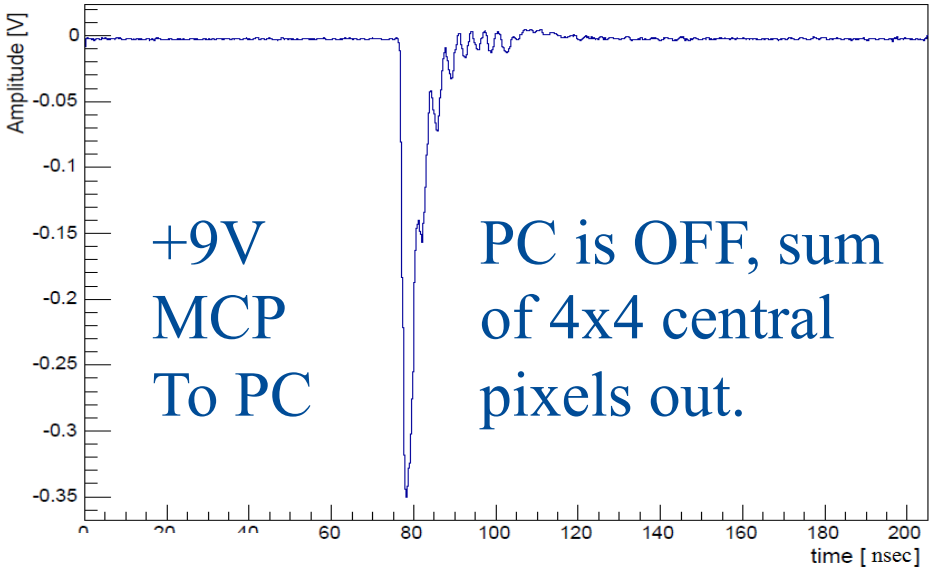


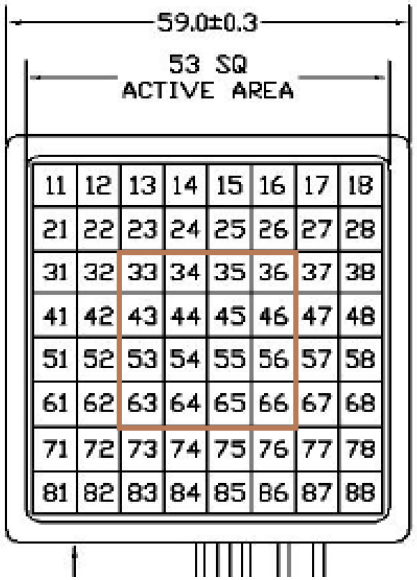
XP85012 signal dependence on voltage between PC and MCP

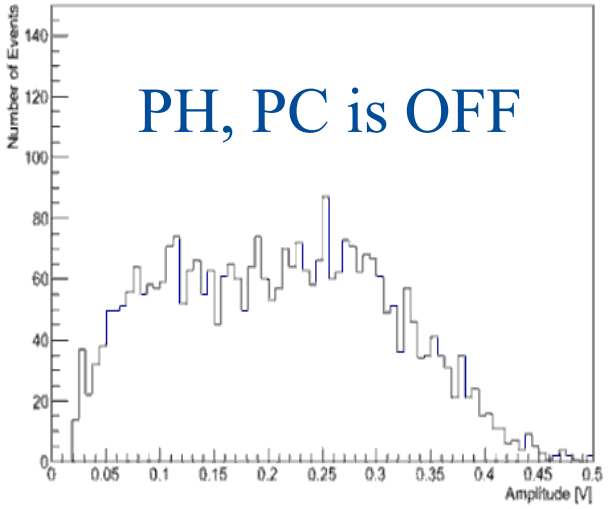


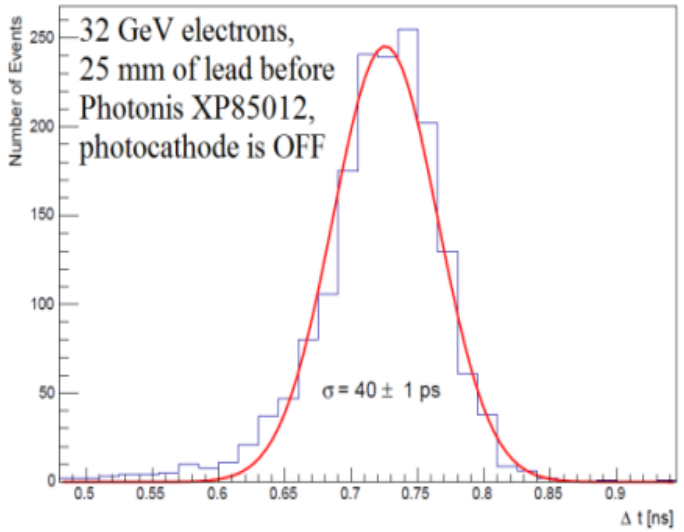
32 GeV electrons, XP85012, photocathode (PC) is OFF, sum of 4x4 pixels, 6x6 mm2 pixel size, 24x24 mm2 sensitive area



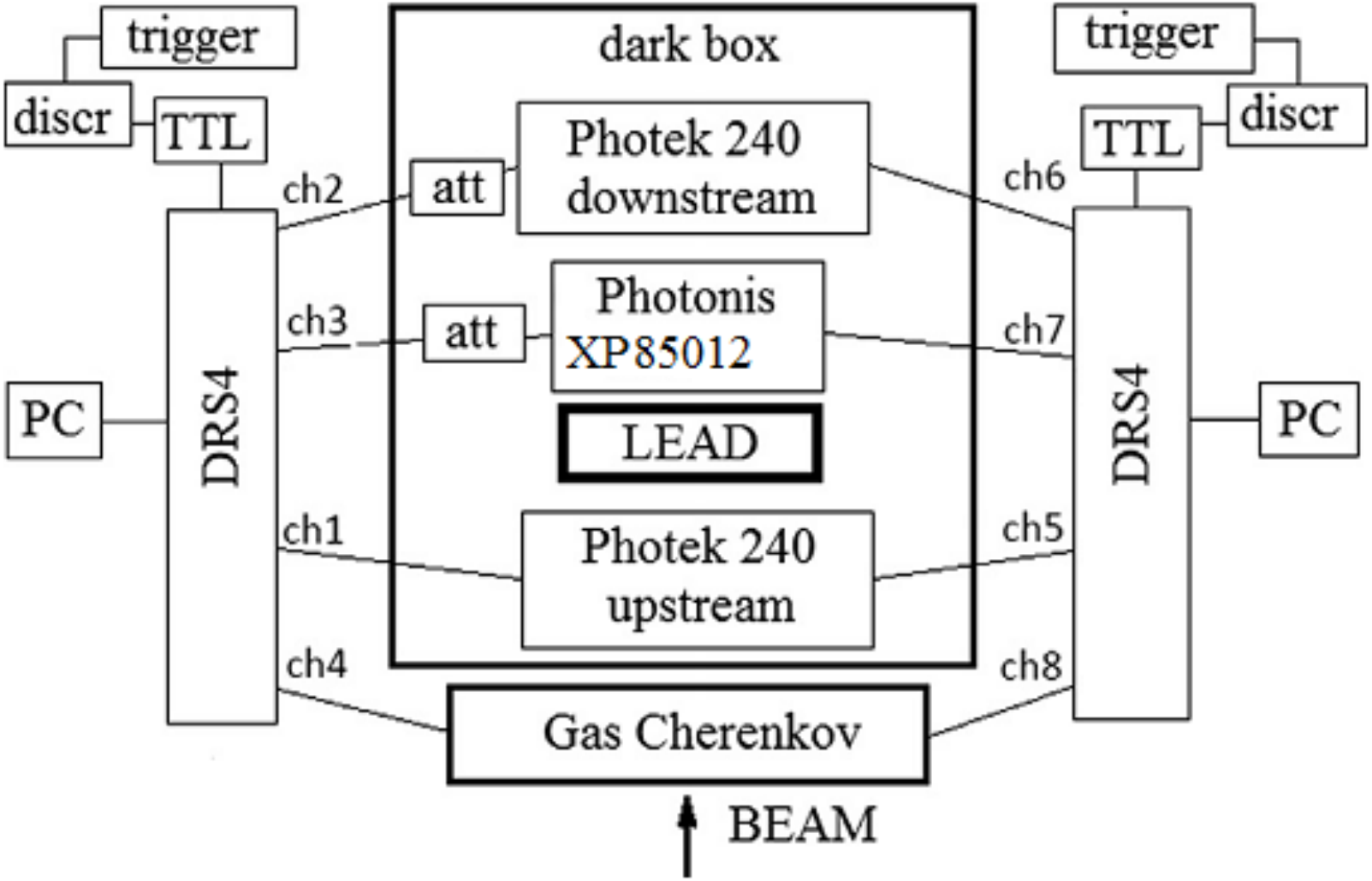






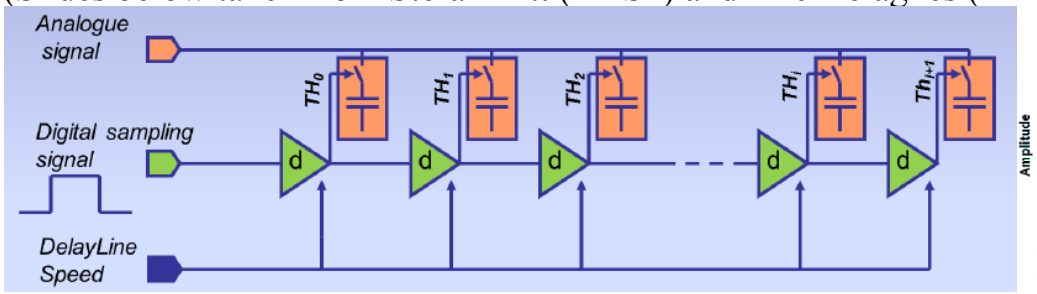


Readout

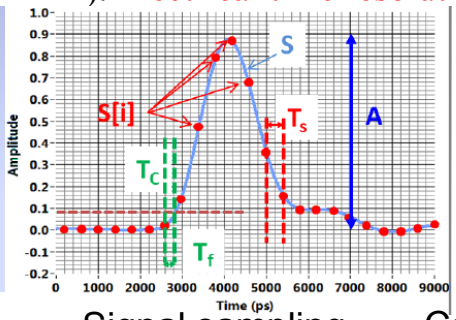

trigger
discr
TTL
dark box
Photek 240
downstream
att
ch2
ch6
trigger
discr
TTL
Photonis
XP85012
att
ch3
ch7
PC
DRS4
LEAD
DRS4
PC
ch1
Photek 240
upstream
ch5
ch4
ch8
Gas Cherenkov
BEAM

FTBF Readout: DRS4 (Domino Ring Sampler), introduced by Stefan Ritt, PSI

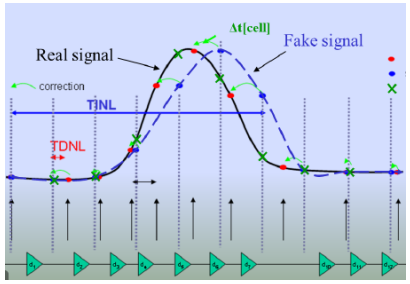
Principle: Sample & Store an incoming signal in an array of capacitors, waiting for (selective) readout and digitization= bank of Track & Holds. DRS4 can replace old classic TDC, ADC traditional readout. PH and TR measured by the same unit. Used one is capable to digitize 4 input channels at sampling rates 5 Giga-samples per second (GSPS, 200ps/cell). Individual channel depth of 1024 bins and effective range of 12 bits. BW is up to 850 MHz. DRS4 is based on Switch Capacitor Array (SCA). "Aperture" and "random" time jitter. Correction of "aperture" jitter. Noise floor ~1 mV/50 Ohm (Slides below taken from Stefan Ritt (DRS4) and Eric Delagnes (LAPPD). Electrical time resolution obtained 2.5ps



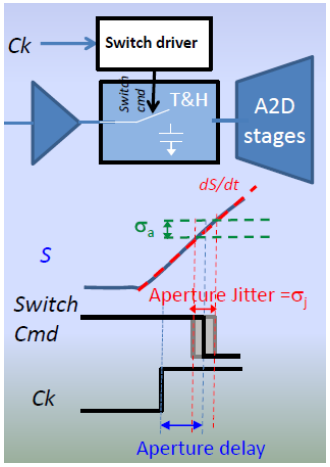
Switch Capacitor Array (SCA).



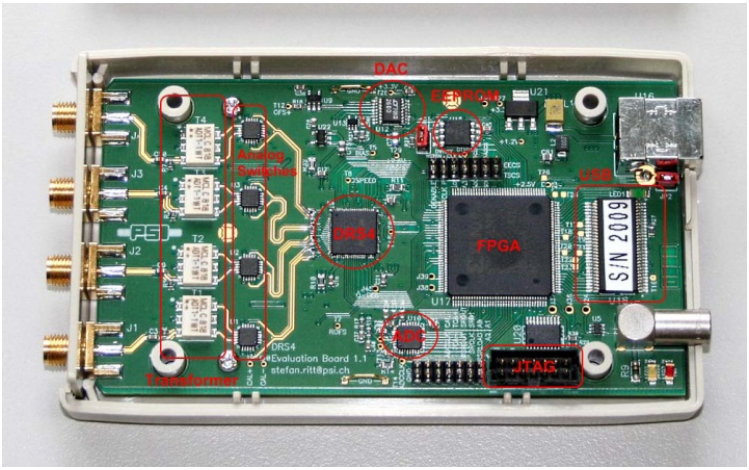
Signal sampling



Correction of "aperture" jitter



Key parameters of DRS4



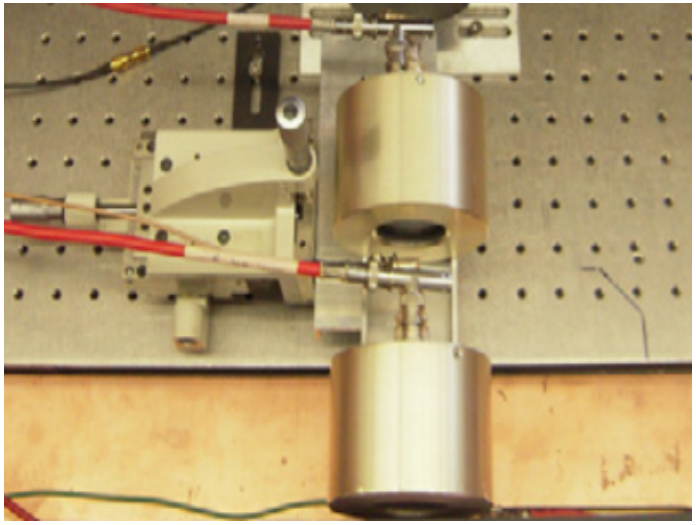
DRS4 unit open, (old) version

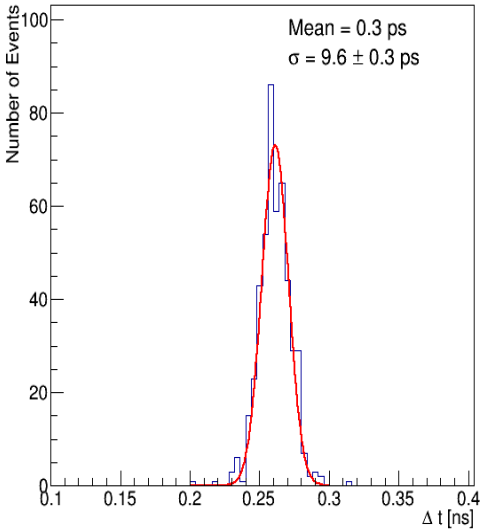
DRS4, last version

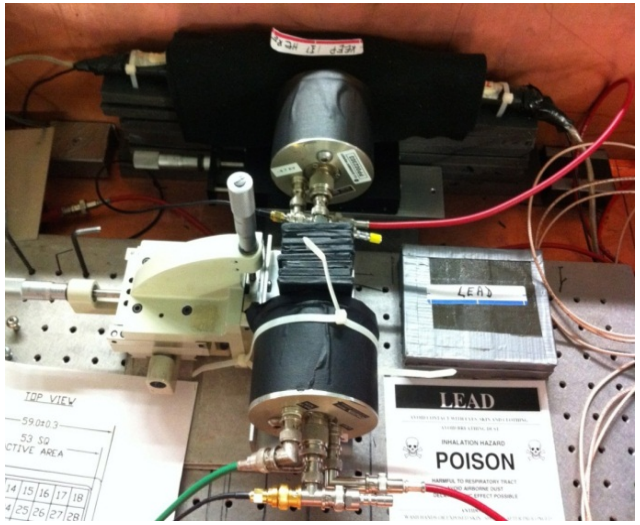
CAEN V1742

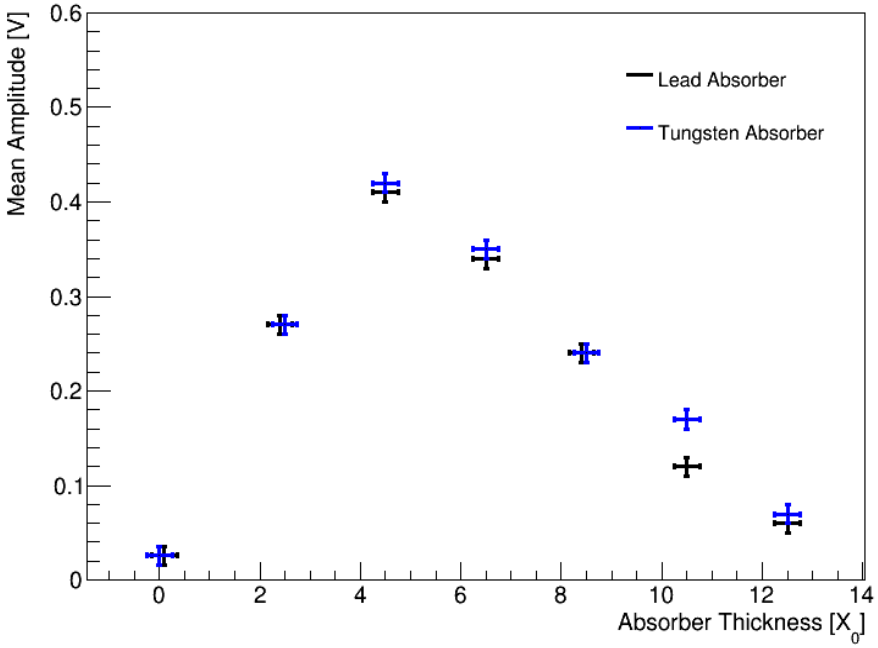
"Waveform digitization for high resolution timing detectors with silicon photomultipliers". A. Ronzhin, M.G. Albrow, S. Los, E. Ramberg, Y. Guo, H. Kim, A. Zatserklyaniy, M. Mazzillo,B. Carbone, G. Condorelli, P. Fallica, A. Piana, D. Sanfilippo, G. Valvo, S. Ritt. NIM, A 668 (2012) pp. 94-98.

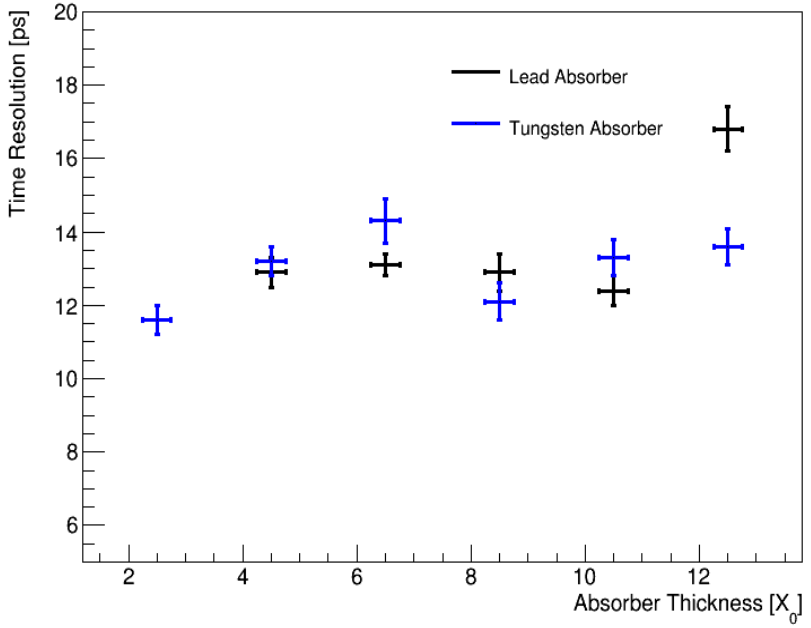
9.6 ps obtained for TOF, based on Photek 240



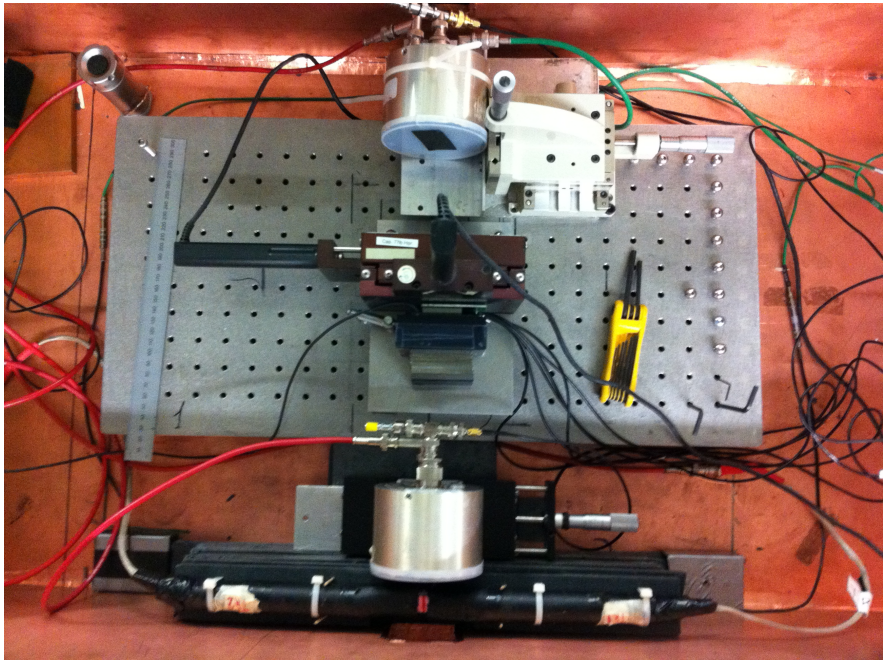


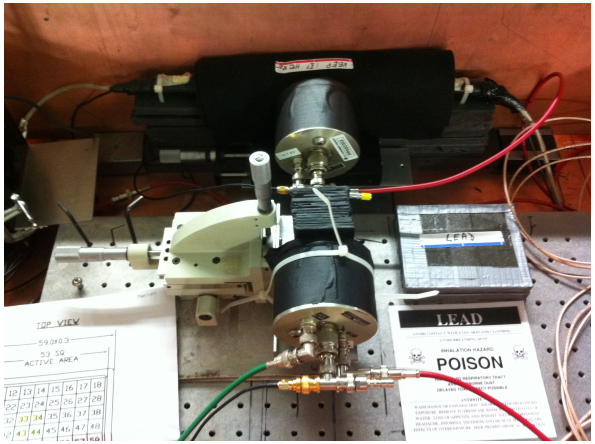


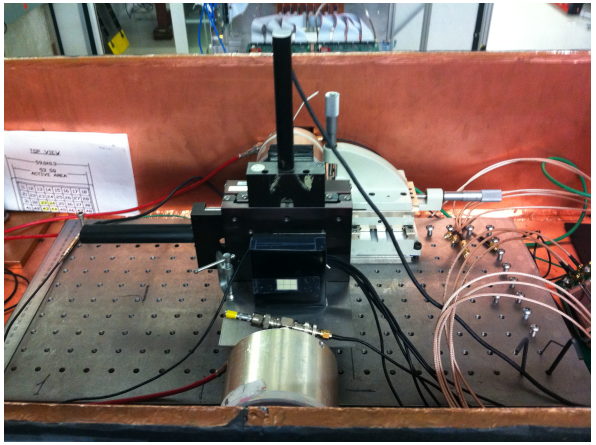


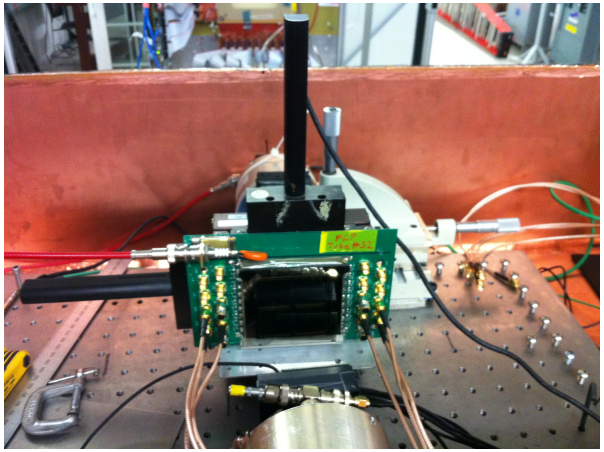


Jan-Feb_2015 test beam FTBF setups

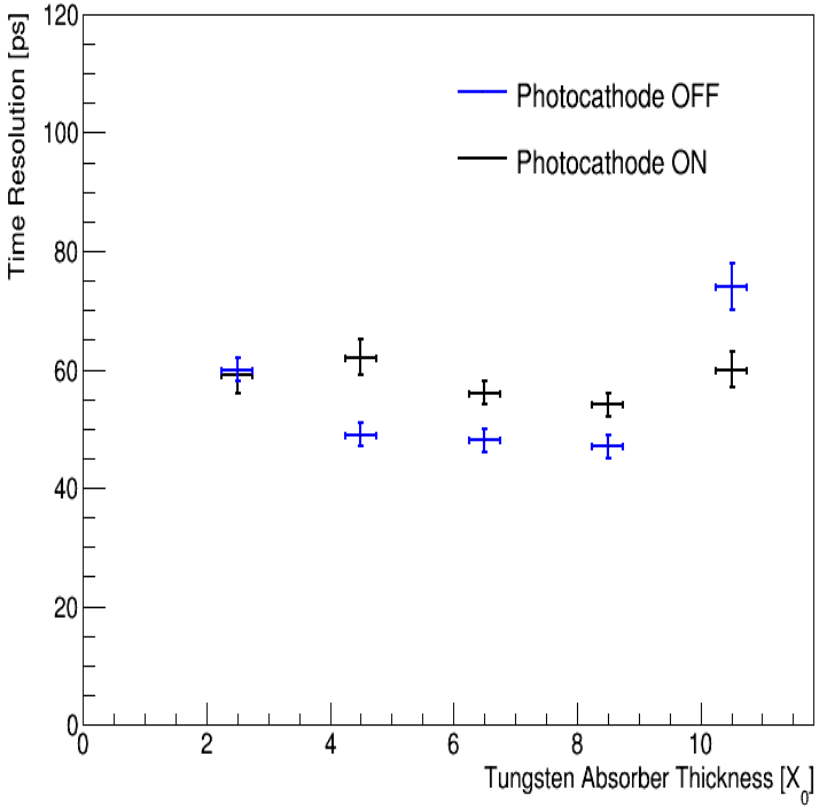




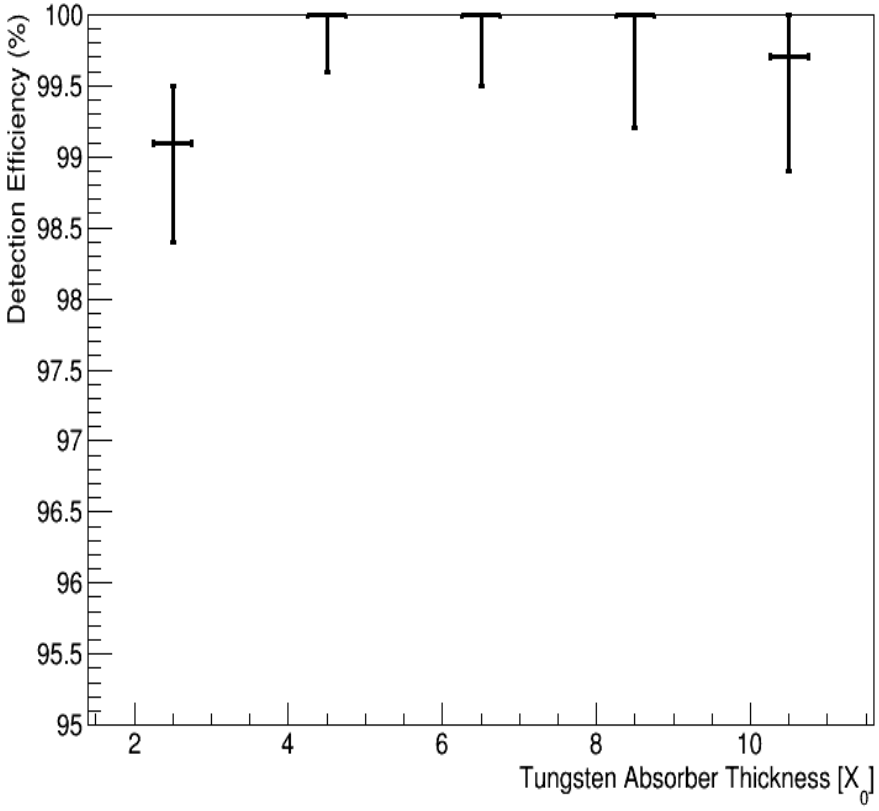




TR ~ 50 ps, (flat), obtained with XP85012 (PC OFF), 40 ps as best.

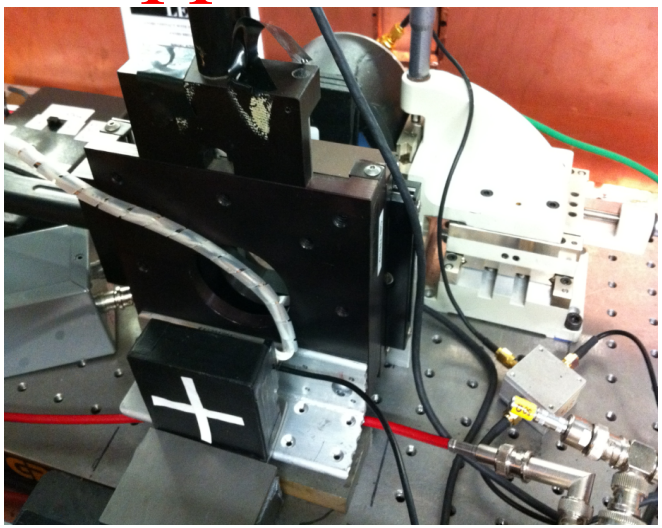


Time resolution PC ON and PC OFF in dependence on tungsten thickness

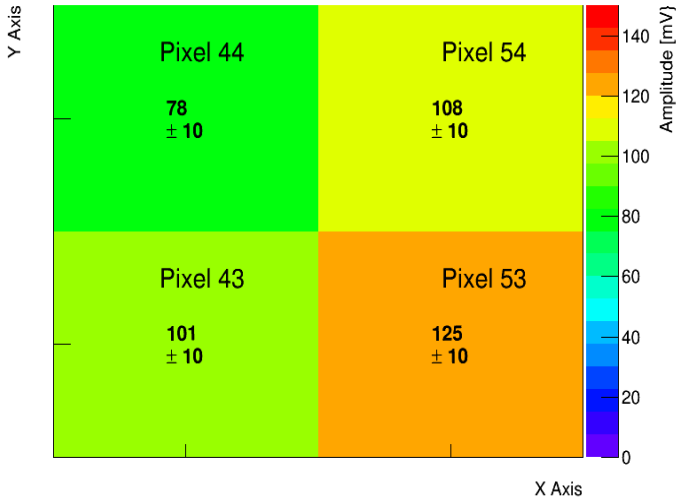


Registration efficiency in dependence on tungsten thickness

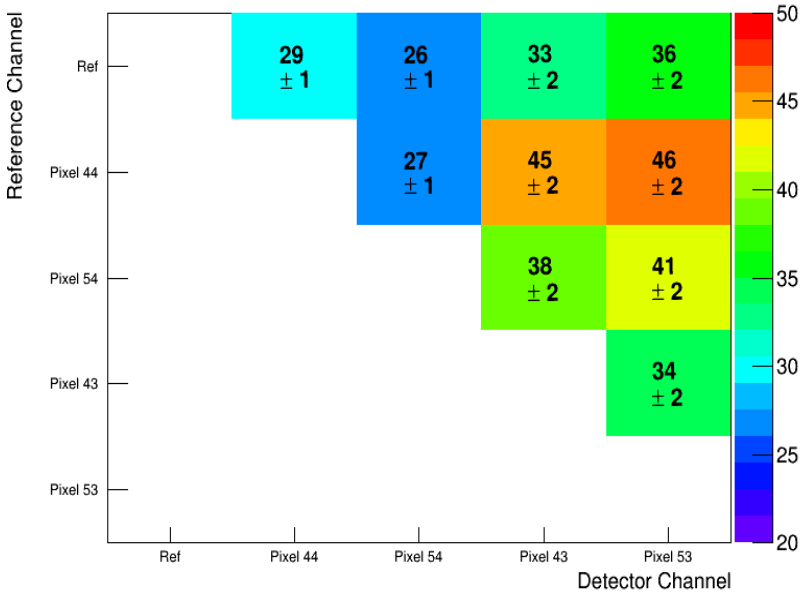
Appendix, XP85012, PC ON (and OFFOFF)



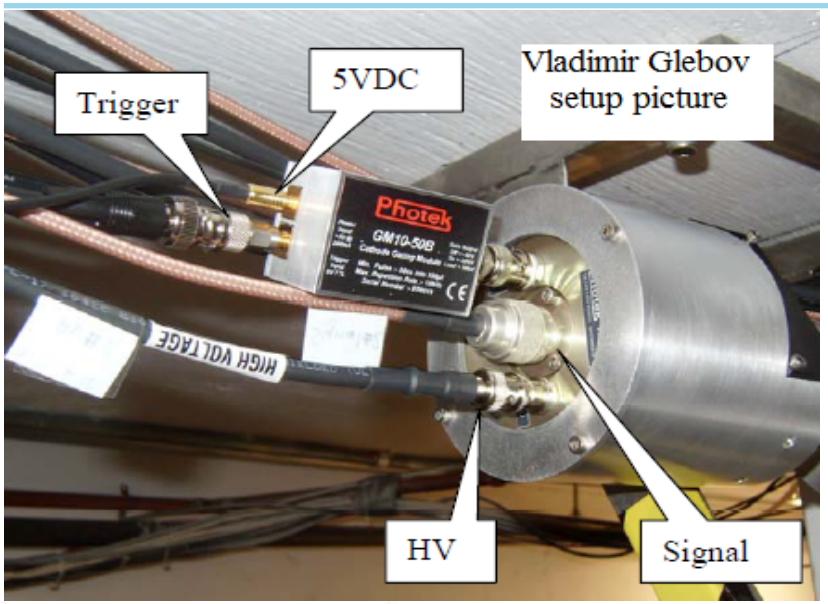
18	28	38	48	58	68	78	88
17	27	37	47	57	67	78	87
16	26	36	46	56	66	76	86
15	25	35	45	55	65	75	85
14	24	34	**44**	**54**	64	74	84
13	23	**33**	**43**	**53**	63	73	83
12	22	32	42	52	62	72	82
11	21	31	41	51	61	71	81

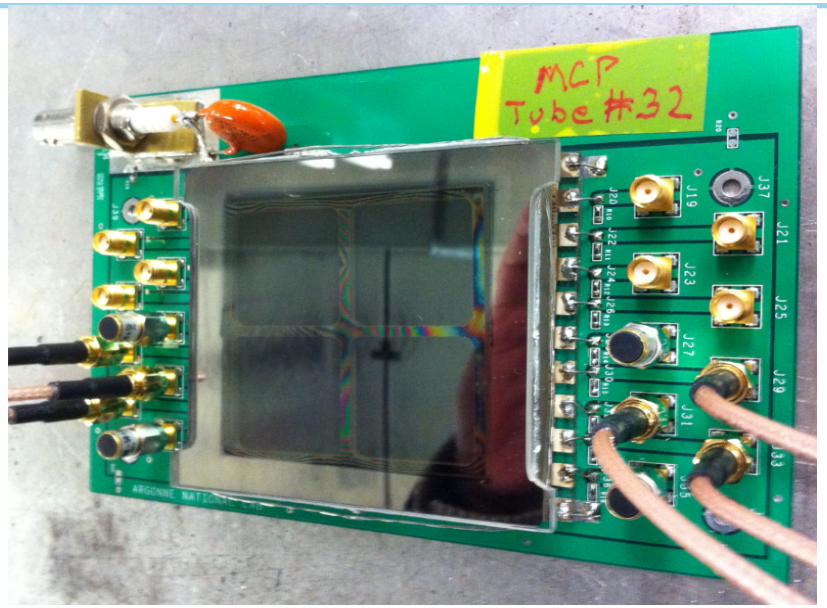


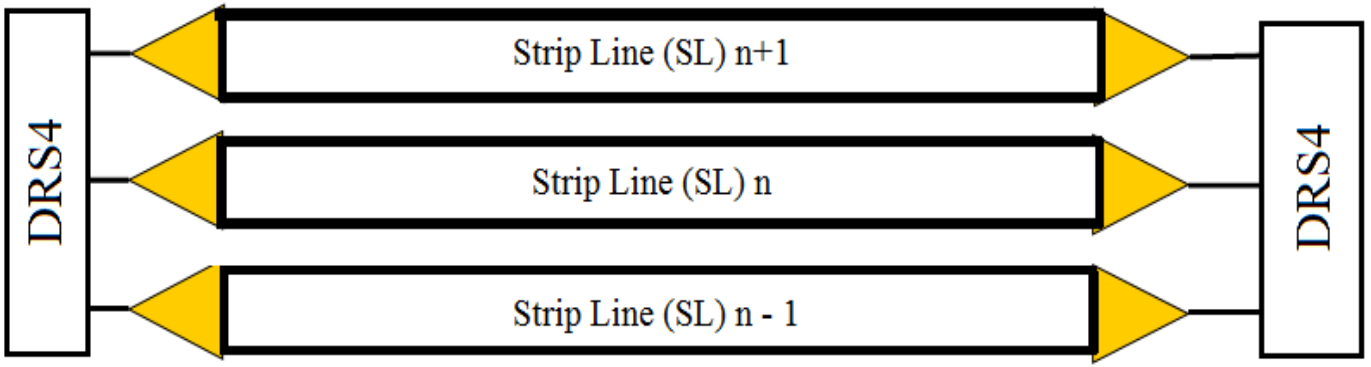
Time resolution from reference to pixel 54 is 33ps.
Time resolution from reference to pixel 44 is 37ps.
Time resolution from reference to pixel 43 is 40ps.
Time resolution from reference to pixel 53 is 46ps.
Time resolution between pixel 54 and pixel 44 is 32ps. Space resolution ~1 mm with individual Photonis XP85012 pixels readout.
The TR is a bit worse for photocathode (PC) turned OFF.



Each of 6 pixels of XP85012readout and LAPD, 6x6 cm2, 3 SL readout







The TR for 6x6, ANL LAPD is 40 ps so far

Jan-Feb_2015 test beam FTBF plan

We already obtained time resolution (TR) of shower maximum (SM) detector at level of 11-13 ps. Conditions: Photek240 w/o gate, PC is ON. Next goal is to measure TR, SM profile and space resolution (SR) in dependence of absorber thickness (Pb or W) at different beam momentum and with different readout (Pixels, Strip Line (SL). All SM detectors for the test are MCP-PMT. They are: Photek 240, XP85011, and 6 cm x 6 cm LAPD from Argonne.

We start with second Photek 240 as SM detector. The plan is to measure time (TR) resolution and pulse height (PH) distribution depending on absorber thickness placed upstream of the Photek 240. (for Pb Xo = 5.6 mm, Molier is ~ 20 mm). We detect ~ 95% of shower energy, because transverse size of the Photek 240 sensitive is 41 mm with diameter. We will measure longitudinal shower profile with 2 Xo step. The beam momentum will be 8 GeV, 16 GeV and 32 GeV.

The position of the dark box relative to the beam should be optimized for each energy. The next could be the same measurement, but with W instead of lead. We have W, each is about one Xo. Xo = 3.5 mm for W, Molier is ~ 10 mm . So it will be 3 measurements with different absorber thickness. We use 3 DRS4 channels (from possible 8) in the measurements, just for first and second Photek 240, and Cherenkov counter.

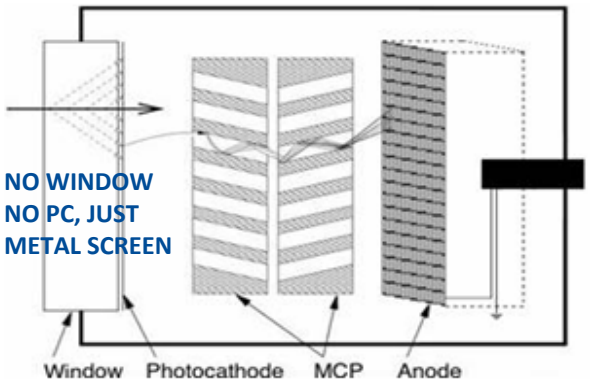
Another devices to study is 6x6 LAPD from ANL. 3 strip line (SL) will be hooked up to DRS4. We can use X-Y moving stage inside the dark box to measure space resolution and partially the transverse SM profile. The absorber will be W. The size of strip line?

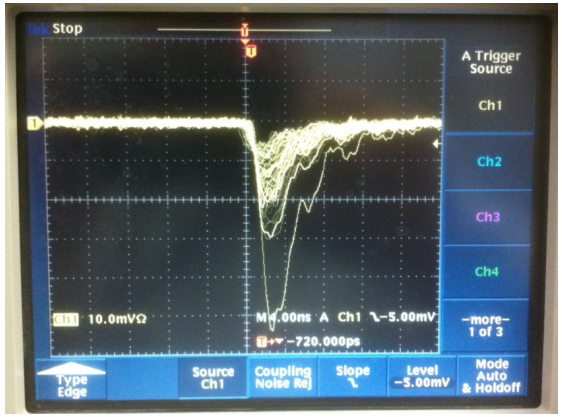
XP85011. Sergey made 6 pixels PCB (2x3 matrix) so far for the readout so far. Each pixel size is ~ 6 mm x 6 mm. Again we can start with 2x2 matrix (transverse size of the sensitive area is only 12 mm x 12 mm) if we will need Cherenkov. The center of the SM could be placed into cross, so each 4 pixels should have about the same PH. The TR and PH measurements are with W. It is useful to make ~ +/- few mm shift of the SM center, just to see redistribution of PH inside the 4 pixels.

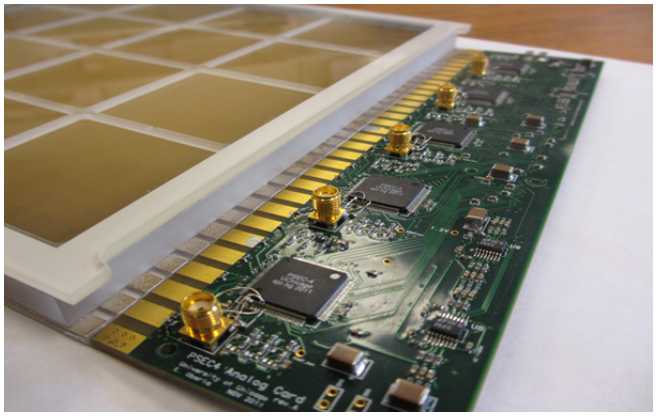
Fermilab

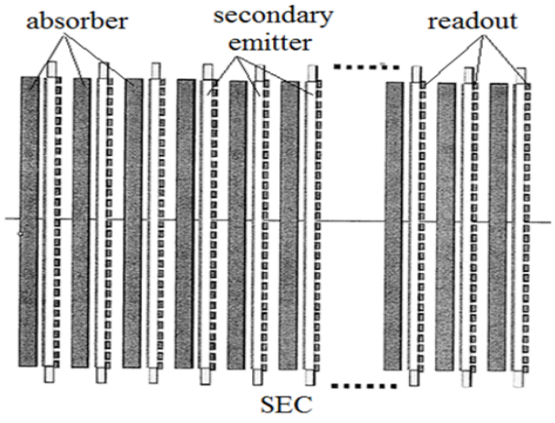
FNAL, Caltech, UC. Test of Shower Maximum (SM) Detector at FTBF. Possibly to insert the SM into CMS HGCAL, needs in ~15 mm of slot size. T1058, SEC.

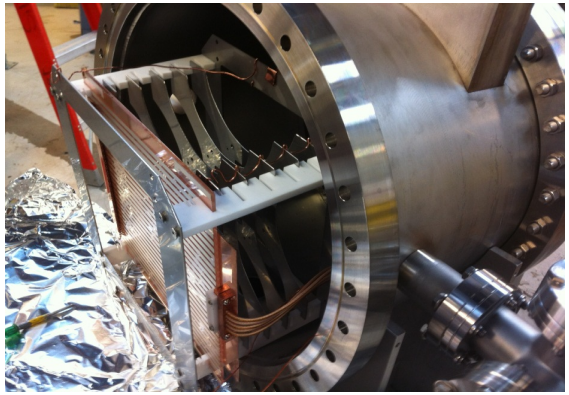
MCP is an electron multiplier that detects and multiplies electrons in two dimensions. MCP is sensitive to ions, vacuum UV rays, X-rays, etc., and so can be used as devices to detect their position and energy. So far radioactive sources to check MCP functionality used. But we still need more precise tool to monitor and control stability of MCP gain, noise, etc. It is no PC.

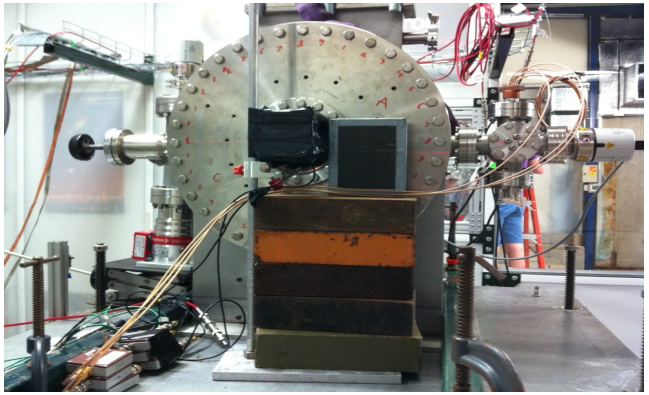












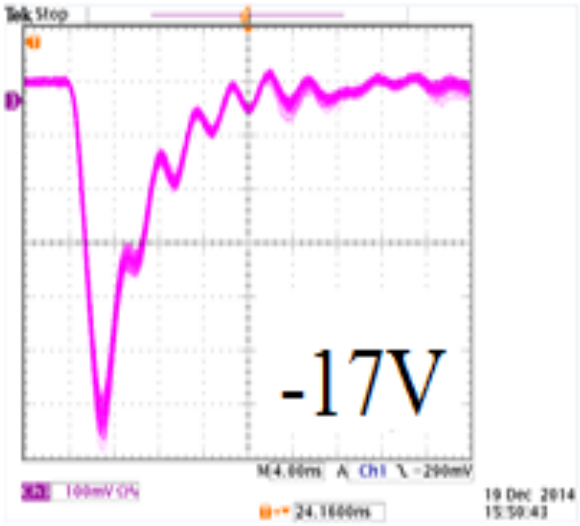
Summary

- Next test beam. Chevron program. Continue study of SMs with secondary emitters (SE) as an active layer. Check MCPs of different size. Test different absorber materials. Currently we study SM with XP85012 (PC OFF, 4x4) as the SM active layer. ANL, 6cmx6cm MCP PMT is another option. We also can study different type of SE (meshes, venetian blinds, etc.) for the SM depending on results of MCP irradiation (e.g. in Warrenville proton cancer center).
- We already obtained ~ 40 ps time resolution (TR) of the SM with MCP at FTBF (PC is OFF). TR for PC ON a bit better due to Cherenkov light deposit. The TR is slowly dependent on electron beam energy in the range 8 GeV - 32 GeV. Continue timing improvement with new readout (Photonis XP850112, 8x8 matrix) based on fast wave forms digitizers (e.g. DRS4, PSEC?). New digitizer test goal is to obtain more readout channels at low cost and check reliability. Test different type of readout with anodes as strip line (SL), pixels, and matrix. Goal is measurements of timing and spacing.
- We plan to make Monte Carlo for the SEC (Nikolai Mokhov, FNAL, CERN)
- Test beam. Continue test of SEC (also as SM on SE) in frame of T1058. Check MCP efficiency and timing for MIPs, measure charge per tile and pulse shape examples with protons. Equalize the gains, inter calibrate different MCPs. Calibrate the strips within the MCP, scan perpendicular to strip lines, measure response uniformity, space and time resolution. Repeat some of measurements with muons for final calibration. Possible two shower separation, each anode pixel is readout separately.
- Measurements on electron beam. Measure longitudinal and transverse profiles. Time resolution between individual tiles. Time resolution with respect to the reference. Resolution on the start of the shower position, transverse and longitudinal, energy resolution.
- Perform energy scan going up in electron energies to 8, 12, 16, 32 GeV.
- Perform MCPs radiation study.

Future plans

- Same data on the beam were taken with MCP PMT, but only one, Photonis XP850, was possible with PC ON and PC OFF
- Next test, all detectors will be mostly with PC OFF
- XP85012 will be tested with all individual 64 pixels readout.
- We used so far DRS4 for our readout8x8 XP85012, what about PSEC?
- Professional support of PSEC, probably with beam participation (at FTBF), would be appreciated.
- Paperwork for our new T1065, Shower Maximum (SM) with secondary emitters (SE) experiment at FTBF is almost done.
- We still working on Secondary Emission Calorimeter (SEC) in frame of T1058 experiment.

appendix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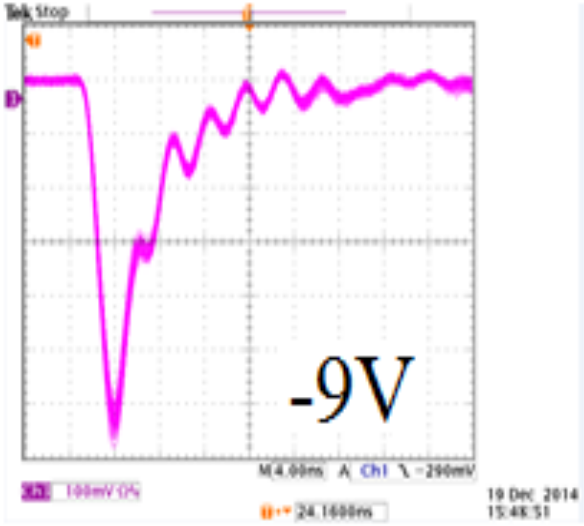
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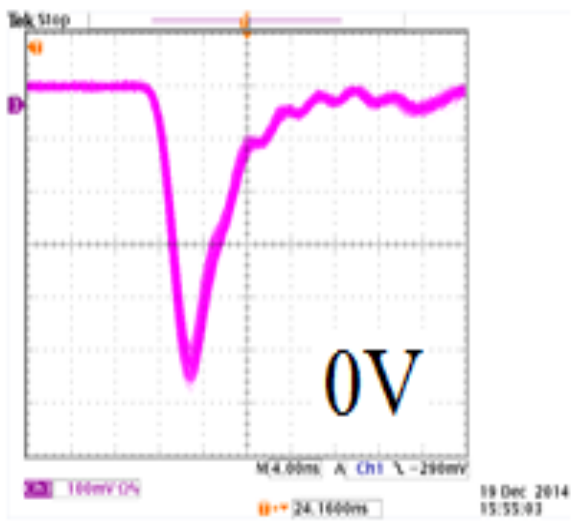
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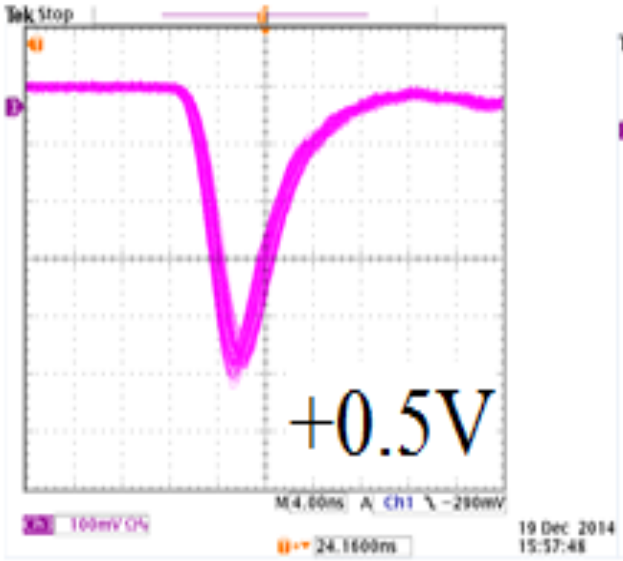
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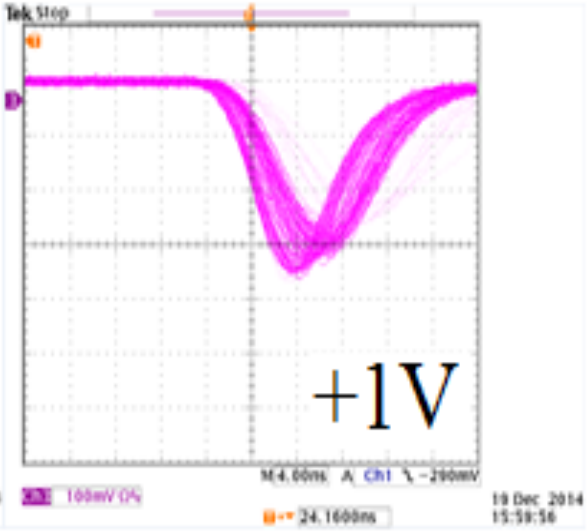
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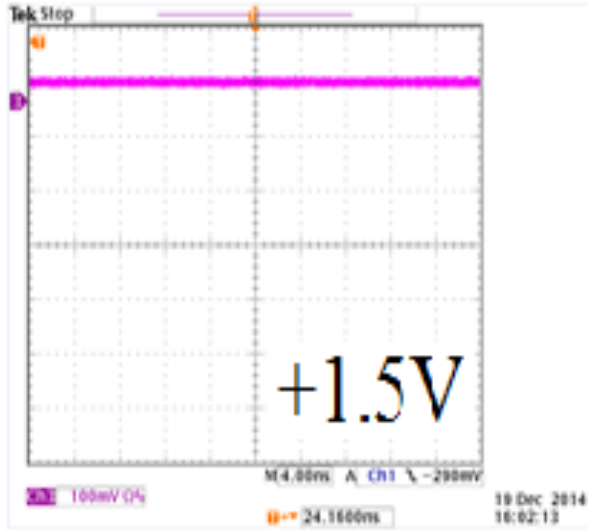
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