A few comments to the ps workshop

J. Va'vra, SLAC

Content

- BW, S/N, σ_{TTS} of MCP-PMT
- Timing resolution limit
- Can G-APD arrays compete with MCP-PMTs for TOF ?
- SLAC test beam this year.
- Next MCP-PMT test at SLAC.
- Super-B detector in Italy.

MCP-PMT: BW, S/N and σ_{TTS}

Hamamatsu MCP-PMT R3809U-50

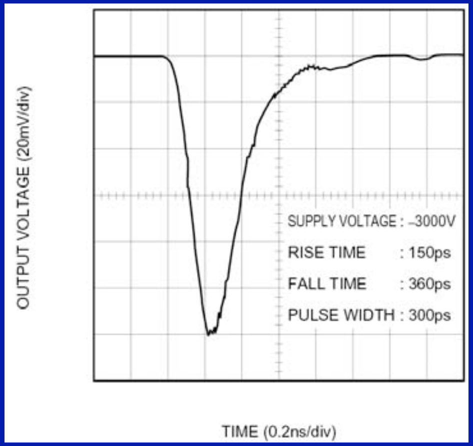
Hamamatsu data sheets

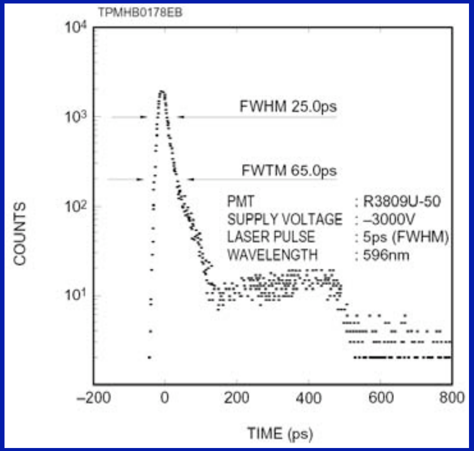
MCP-PMT R3809U-50:

- **6 μm MCP hole diameter**
- Useful photocathode dia.: **11 mm**
- Rise time: **~150 ps** => BW ~ 0.35/150ps ~**2.3 GHz**
- Single pixel device.
- MCP-to-anode capacitance: **~3pF**
- **σ_{TTS} = 10-11 ps**
- Light source jitter: ~ 5 ps (FWHM)

Hamamatsu C5594-44 amplifier

1.5 GHz BW, 63x gain



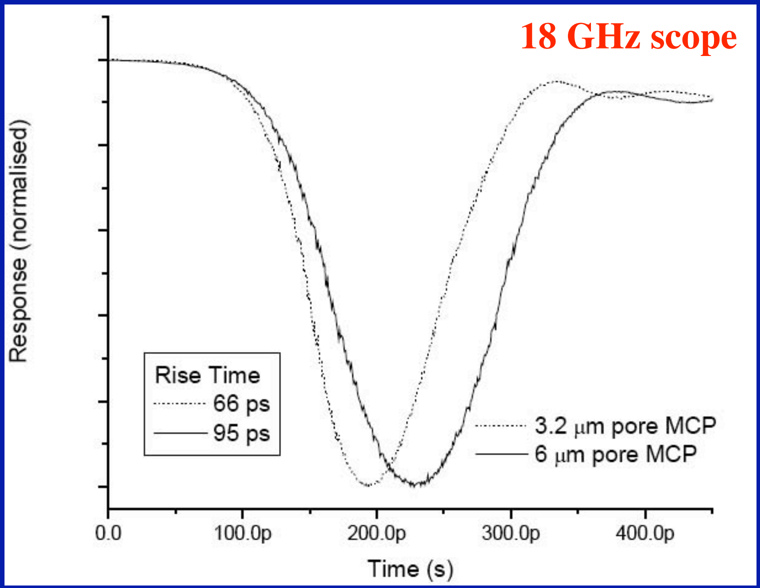


This is one of the fastest commercialy available photon detector

Photek MCP-PMT

(J. Milnes and J. Howorth, Photek Ltd. information)

- **3.2 & 6 μm MCP hole diameter**
- Rise time: **~66 ps** (**3.2 μm**) => BW ~0.35/66ps ~**5.3 GHz**
- Rise time: **~95 ps** (**6 μm**) => BW ~0.35/95ps ~**3.7 GHz**
- Agilent 86100C sampling scope (18 GHz), average over 18 samples
- No amplifier used in this test, to my understanding
- 10 mm dia. single pixel anode
- Laser wavelength 650nm



This is the fastest photon detector, to my knowledge

Burle/Photonis MCP-PMT 85012

J.V., log book #3

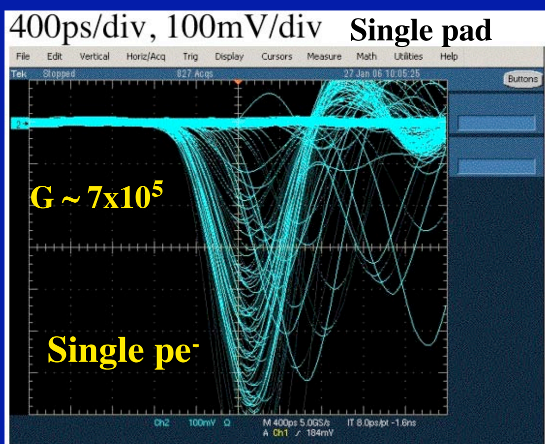
MCP-PMT 85012-501:

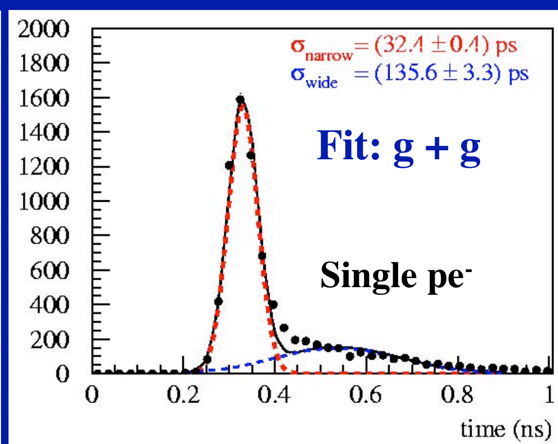
- **10 µm MCP hole diameter**
- 64 pixel devices (use a single pad, ground the rest)
- $C_{\text{Anode-to-ground}} \sim 5.5$ pF
- A 1 GHz BW scope - limits the rise time
- MCP-PMT rise time: $\sqrt{\{500^2-350^2-230^2\}}$ **~ 270 ps**
  => $BW_{\text{MCP-PMT}} \sim 0.35/270\text{ps} \sim$**1.3 GHz**
- **PiLas red laser diode (635 nm):**

$$\sigma_{TTS} \sim \sqrt{(\underbrace{32^2-13^2}_{\text{PiLas laser diode}}-\underbrace{11^2}_{\text{Electronics (TDC mainly)}})} = 27 \text{ ps}$$

Hamamatsu C5594-44 amplifier

1.5 GHz BW, 63x gain





S/N MCP-PMT 85012

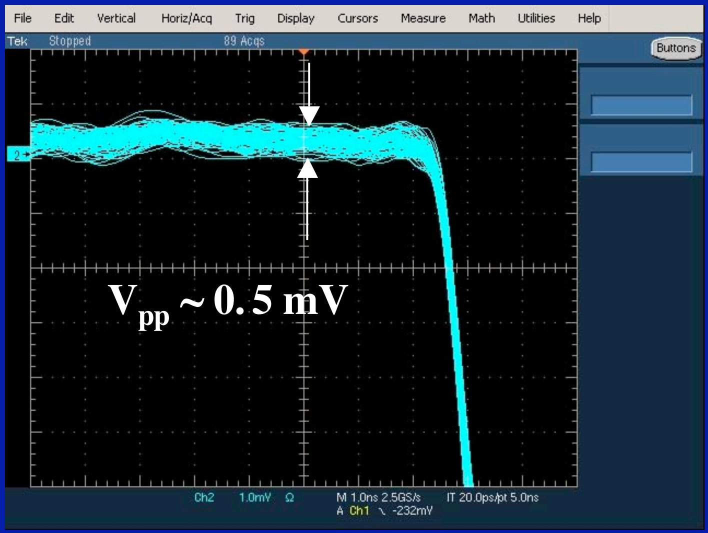
J.V., log book #5

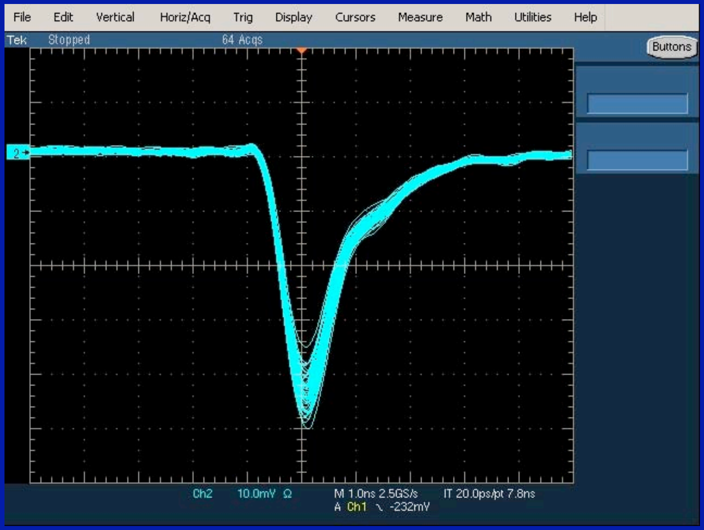
With a 1 GHz BW scope:

Run 386, **Laser pulse**, var. att. after MCP left in, **~50 pe$^-$**, **no amplifier**, Gain ~ 1.4 x10^5, 10mV/div, 1ns/div, 2.22kV, 4 pads connected

!

1mV/div, 1ns/div

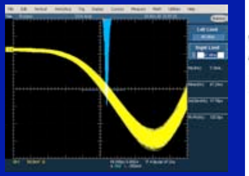




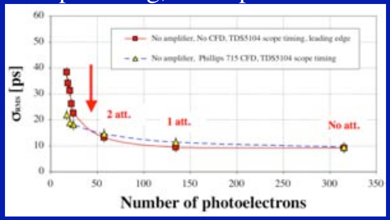
$$\boxed{(S/N)_{pp} \sim 43mV/0.5 \sim 80}$$

Various timing schemes

Timing strategies

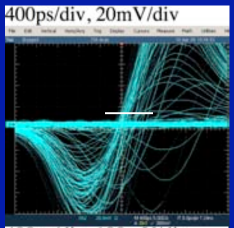


Scope timing, no amplifier:



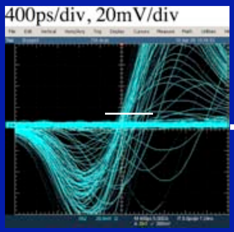
1) High gain operation:

- **Either <u>no</u> amplifier, or a small amplification only:**
  - One would expect much worse aging effects due to a high gain operation.
- **Single pe- sensitivity (with an amplifier):**
  - In addition to the above comment, a very poor pulse recovery



2) Low gain, linear operation:

- **Constant-fraction-discriminator (CFD).**
- **CFD + additional pulse height correction.**
  - A slight time-walk as number of photoelectrons corrected by the QTNT + ADC



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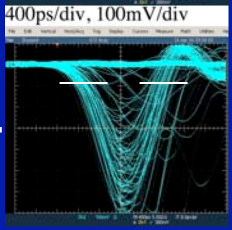
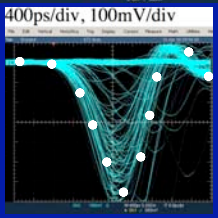
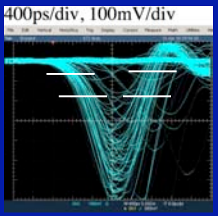


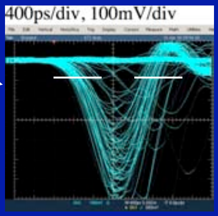
- **Waveform sampling (a'la Gary Varner's design from U. of Hawaii).**
  - The most powerful timing method.



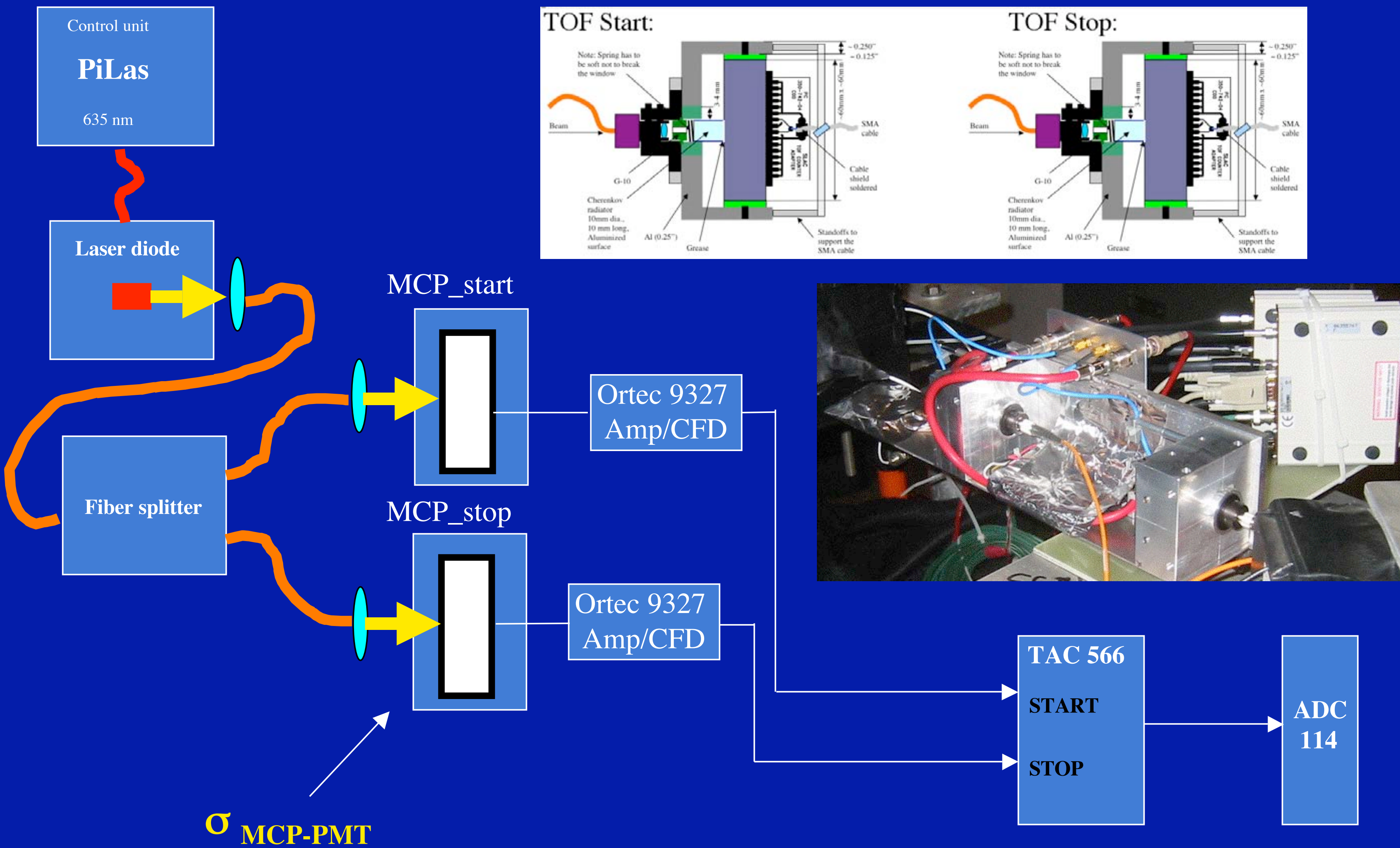
- **Double-threshold timing on both leading and trailing edges.**



- **Single threshold on both leading and trailing edges.**
  - The most simple.



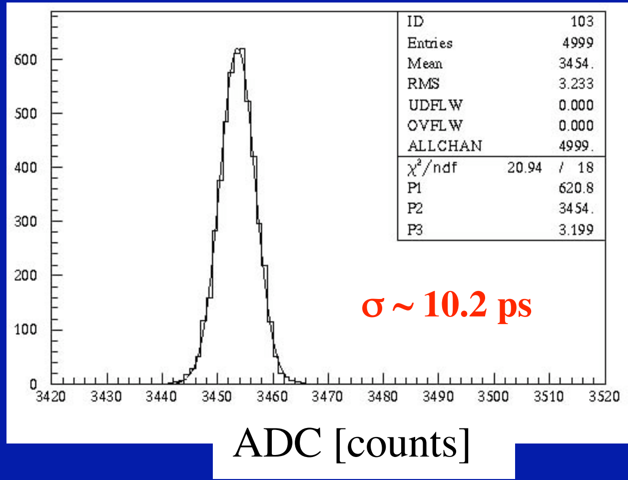
Beam setup with two MCP-PMTs and a fiber splitter



A laser-based result with two TOF counters

(SLAC-PUB-13073, Jan. 2008)

Two detector resolution (Npe ~50 pe ea.):

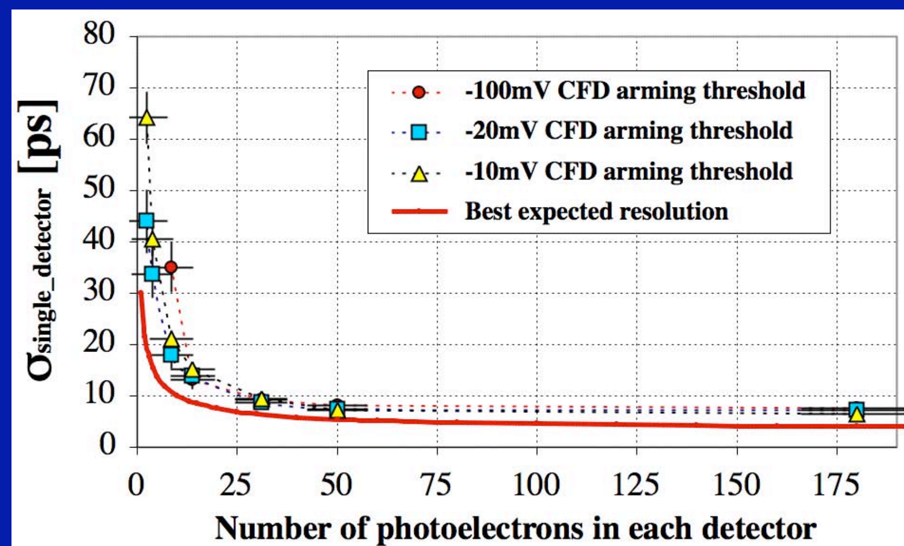


Each detector has Npe ~ 50 pe$^-$:

$\sigma_{\text{single detector}} \sim (1/\sqrt{2})\ \sigma_{\text{double detector}}$
~ 7.2 ps

Running conditions:

1) Low MCP gain operation (~1.4x10^5)
2) Linear operation
3) CFD discriminator
4) No additional ADC correction

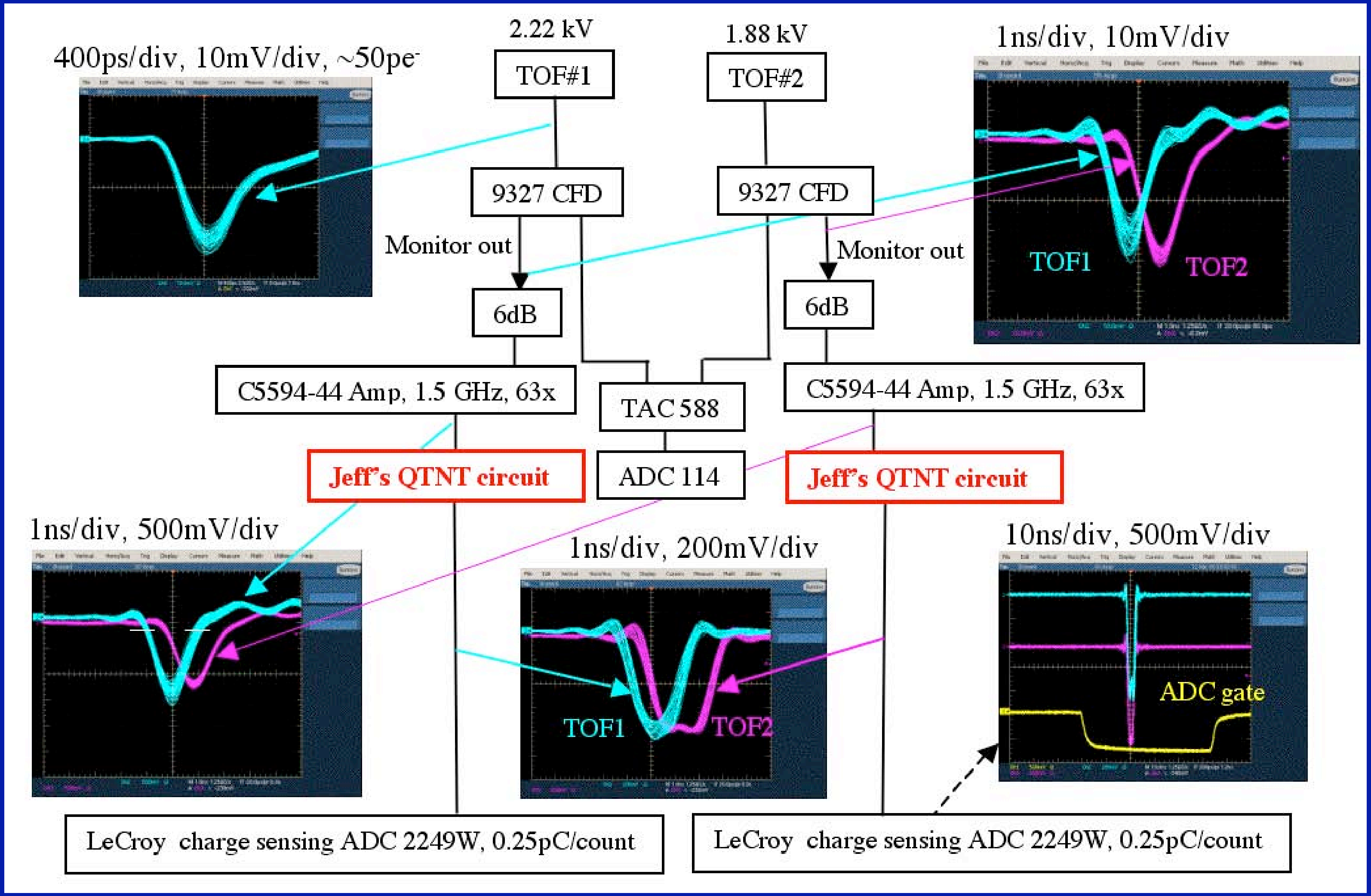


- Two Burle/Photonis MCP-PMTs with 10 µm MCP holes operating at 2.27 & 1.88 kV.
- Ortec 9327Amp/CFD (two) with a -10mV threshold and a walk threshold of +5mV & TAC566 & 14 bit ADC114

Can one improve the CFD timing resolution with an additional pulse height correction ?

CFD timing pulse height correction with QTNT

J.V., log book 5

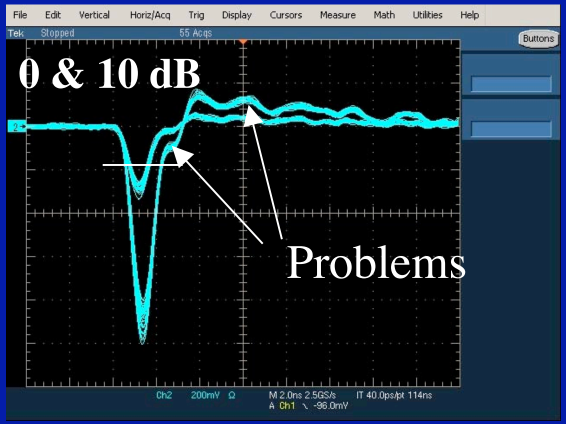


QTNT circuit problems and advantages

J.V., log book 5

Attenuator after the amplifier:

HPK amp. output, 200,V/div. 2ns/div

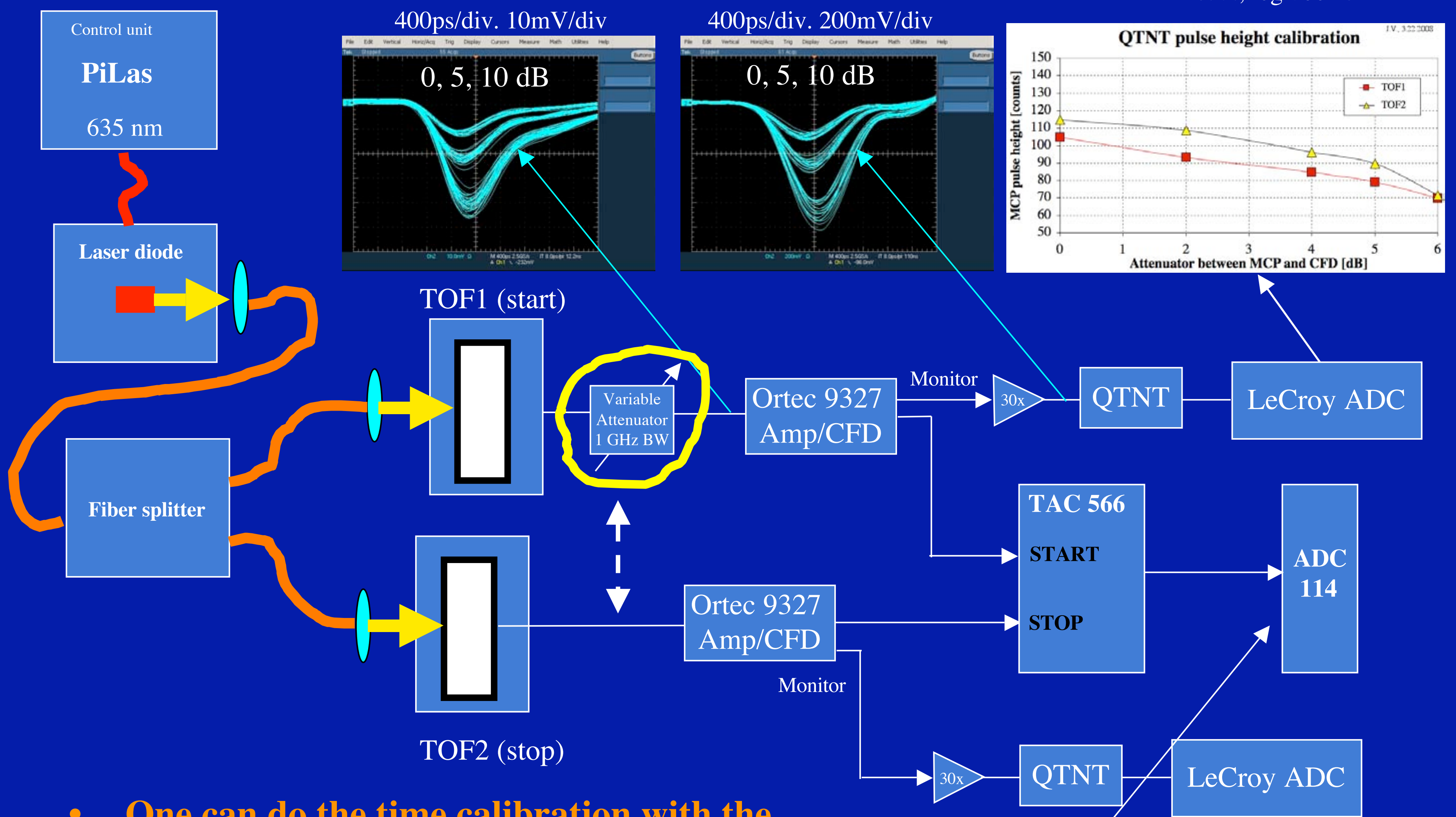


QTNT output, 200,V/div. 1ns/div

- Advantage of the QTNT circuit approach is that one does not integrate the pulse wiggles.
- Disadvantage of this approach is that its linearity depends on the trailing pulse shape.

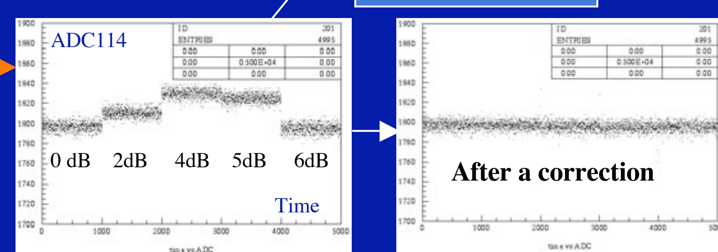
Pulse height calibration of the QTNT electronic

J.V., log book 5



- One can do the time calibration with the attenuator also, but it is <u>somewhat tricky:</u>

  (these jumps have to corrected empirically)

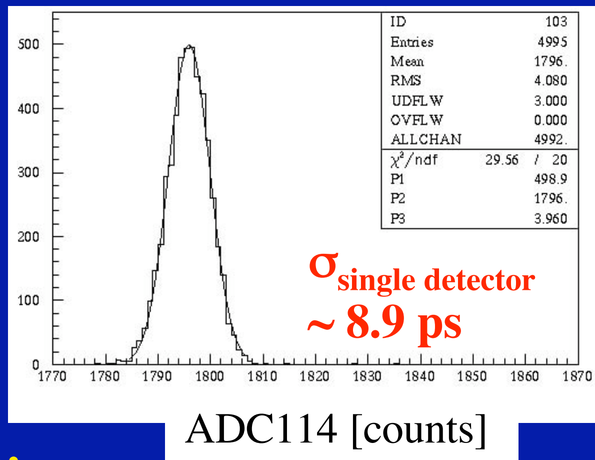


Pulse height correction of the CFD timing

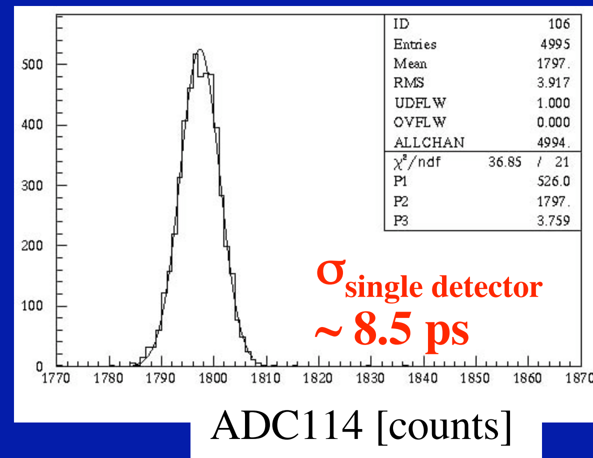
J.V., log book 5, Laser test with a variable attenuator: 0 - 6dB

$N_{pe} \sim 50pe^-$:

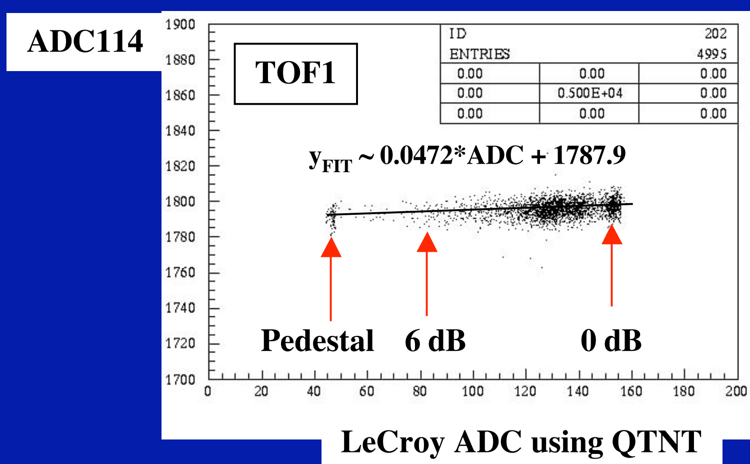
TOF1-TOF2 - uncorrected



TOF1-TOF2 - corrected with LeCroy ADC



Correction:

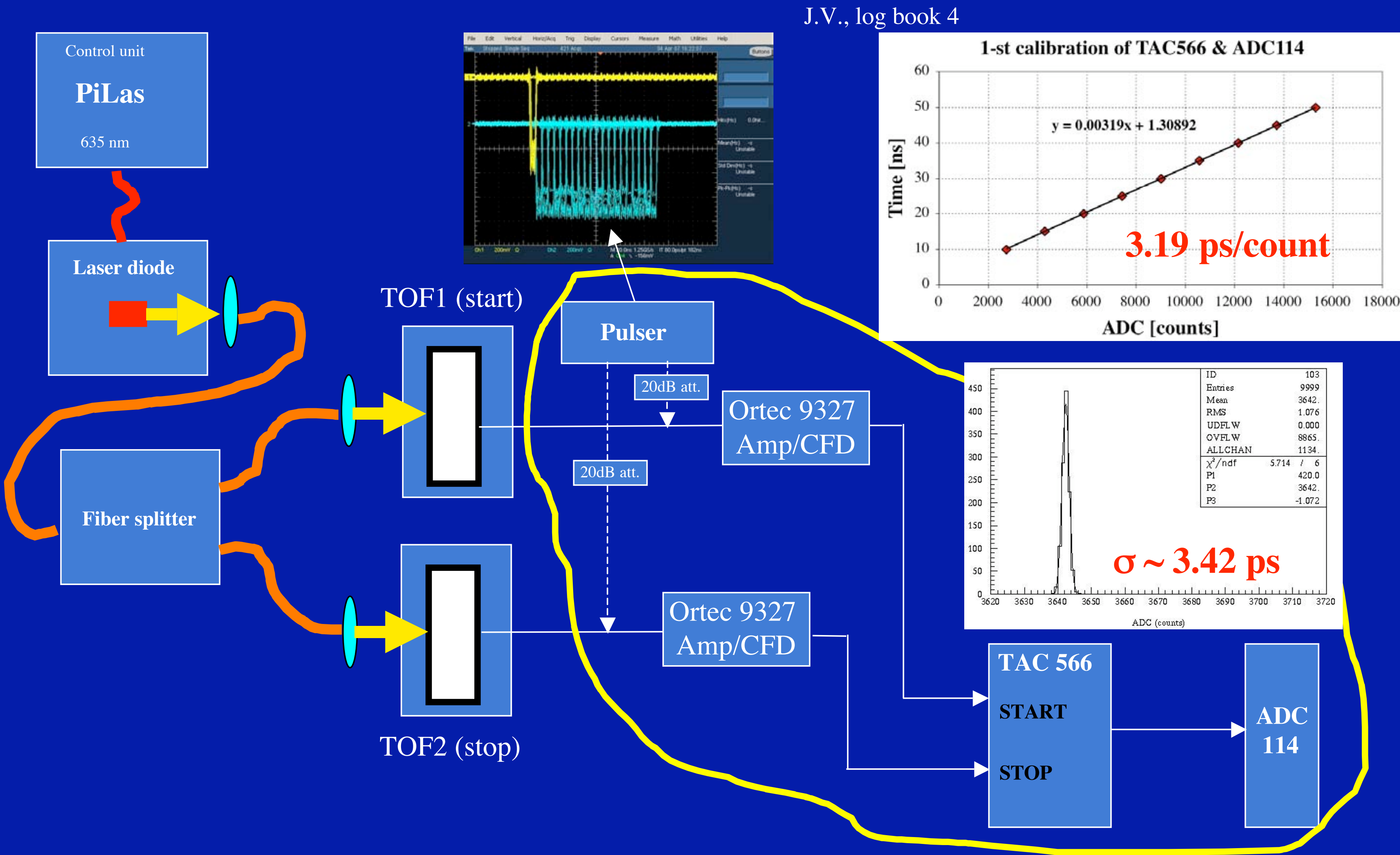


$\sigma_{\text{single detector}} \sim (1/\sqrt{2})\ \sigma_{\text{double detector}}$

- **Observe only a slight improvement of the CFD timing resolution after a pulse height correction with the QTNT circuit**
- Note: The above result is slightly worse than my best earlier laser test result ($\sigma_{\text{single detector}} \sim 7.2$ ps) because (a) a larger dynamic range now, (b) the attenuator is left in the circuit, and (c) may be the corrections are not perfect because I did not spend enough time on this.

What is the resolution limit ?

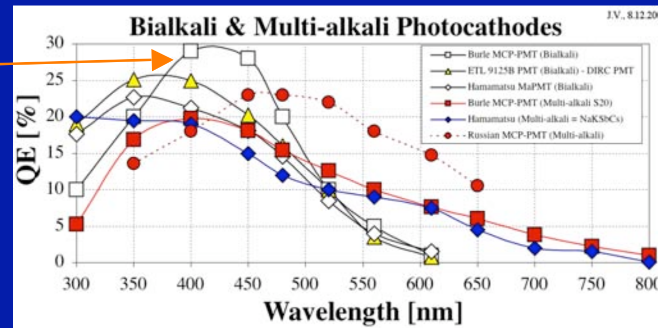
Time calibration of the electronics



- One of the best electronics performance, to my knowledge.

What resolution do we expect to get ?

- A calculation indicates **N_{pe} ~50** for **1 cm-long** Fused Silica radiator & Burle/Photonis Bialkali photocathode:



- **Expected resolution (for a single pad):**

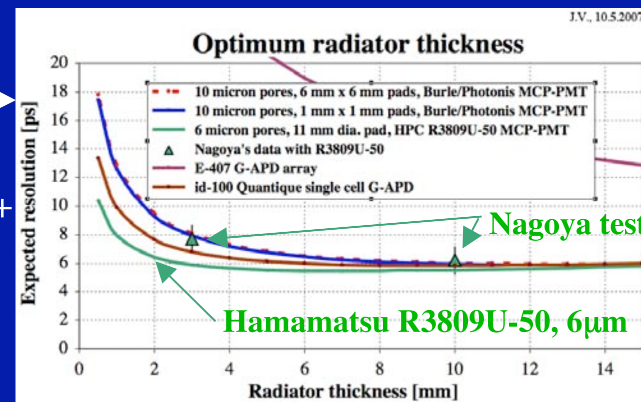
  a) Beam (Radiator length = 10 mm + window):

  $\sigma \sim \sqrt{[\sigma^2_{\text{MCP-PMT}} + \sigma^2_{\text{Radiator}} + \sigma^2_{\text{Pad broadenibng}} + \sigma^2_{\text{Electronics}} + \dots]} =$

  $= \sqrt{[(\sigma_{TTS}/\sqrt{N_{pe}})^2 + (((12000\mu m/\cos\Theta_C)/(300\mu m/ps)/n_{group})/\sqrt{(12Npe)})^2 +}$

  $+ ((6000\mu m/300\mu m/ps)/\sqrt{(12Npe)})^2 + (3.42\ ps)^2\ ] \sim$

  $\sim \sqrt{[3.8^2 + 3.3^2 + 0.75^2 + 3.42^2]}$ **~ 6.1 ps**

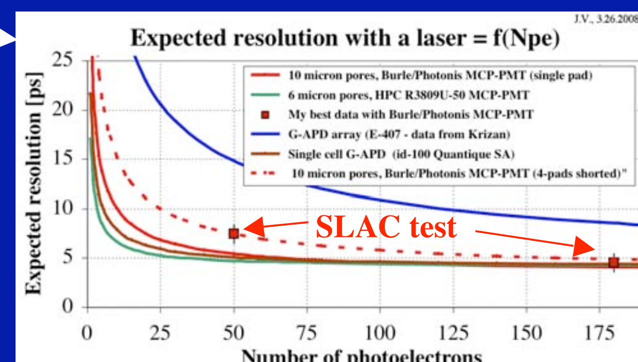


  b) Laser (N_{pe} ~ 50 pe^-):

  $\sigma \sim \sqrt{[\sigma^2_{\text{MCP-PMT}} + \sigma^2_{\text{Laser}} + \sigma^2_{\text{Electronics}} + \dots]} =$

  $= \sqrt{[\sigma_{TTS}/\sqrt{N_{pe}})^2 + \sqrt{((FWHM/2.35)/\sqrt{N_{pe}})^2} + (3.42\ ps)^2\ ]} \sim$

  $\sim \sqrt{[3.8^2 + 1.8^2 + 3.42^2]}$ **~ 5.4 ps**



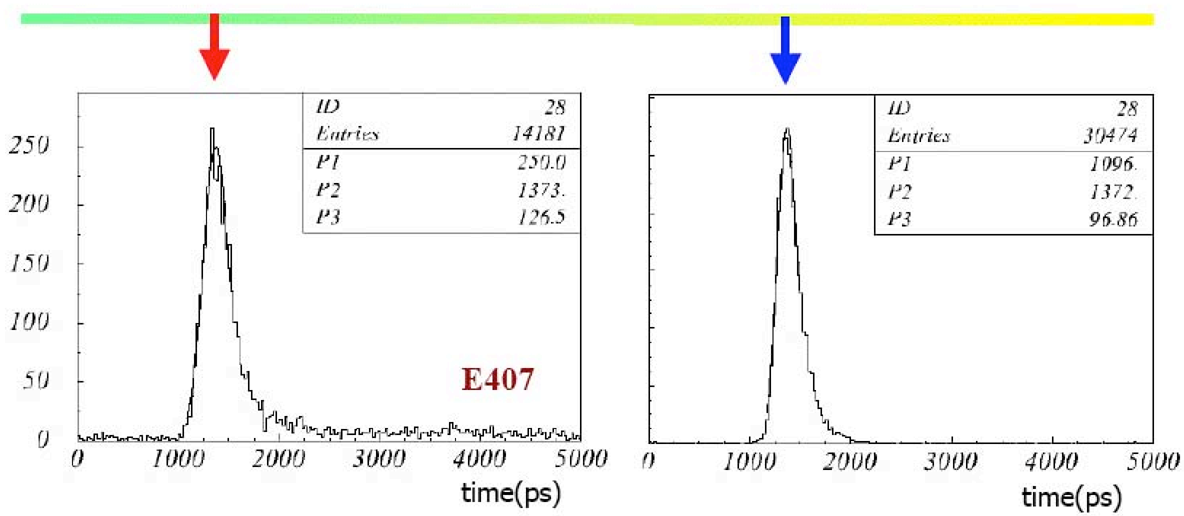
SLAC test with Burle MCP-PMT, 10µm : σ_{TTS} (1 pad)~ **27 ps** (my data)
SLAC test with Burle MCP-PMT, 10µm : σ_{TTS} (4 pads shorted)~ **40-50 ps** (my data)
Nagoya test with HPK R3809U-50, 6µm: σ_{TTS} ~ **10-11 ps** (Hamamatsu data)
E-407 G-APD array: σ_{TTS} ~ **100 ps** (Krizan's data for blue wavelength)
id-100 Quantique single cell G-APD : σ_{TTS} ~ **17 ps** (company's data)

Why G-APD does not compete with MCP-PMT at present ?

G-APD array σ_{TTS}

Measurements by Krizan's group

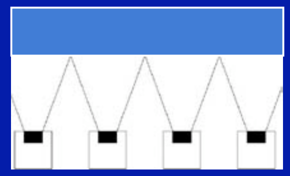
Time resolution: blue vs red



		E407	S137	H100C	H050C	H025C
635 nm:	σ_{red} (ps)	127	182	145	212	154
404 nm:	σ_{blue} (ps)	97	151	136	358	135

Mephi — Photonique — Hamamatsu

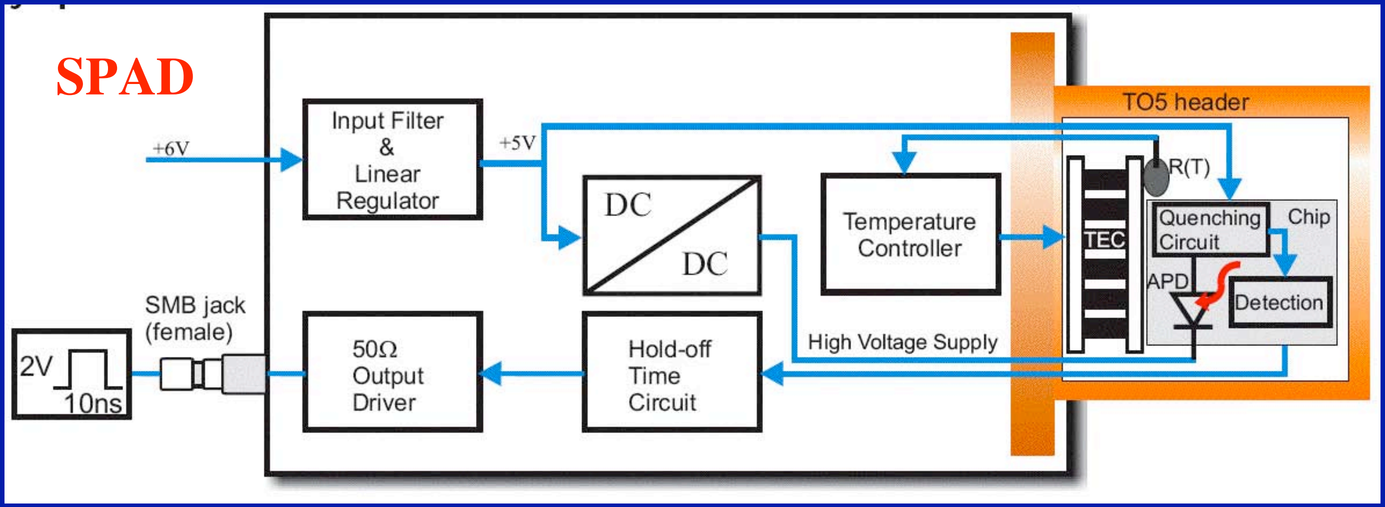
A possible TOF application:



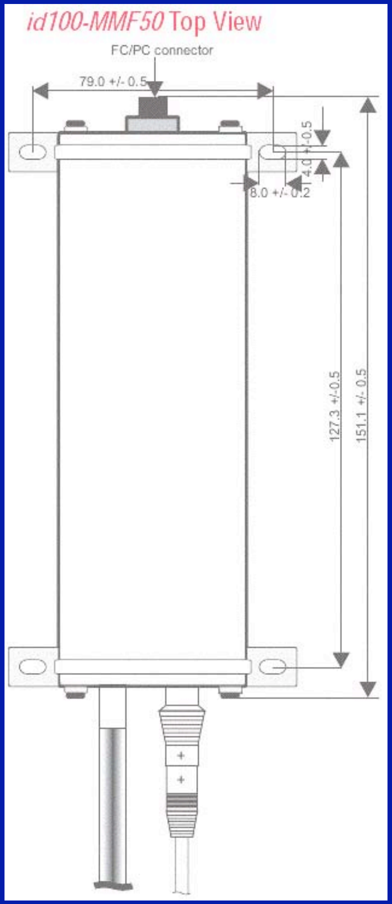
- **These G-APD arrays are not as good as the best single cell G-APDs.**
- **What is the reason ? The passive quenching, or technology ?**

Single cell G-APD σ_{TTS}

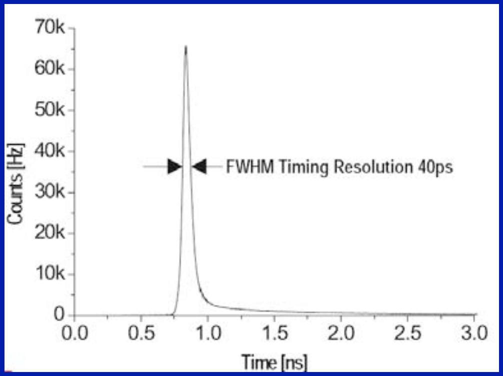
Measurements by id Quantique



Fiber coupling:



TTS:



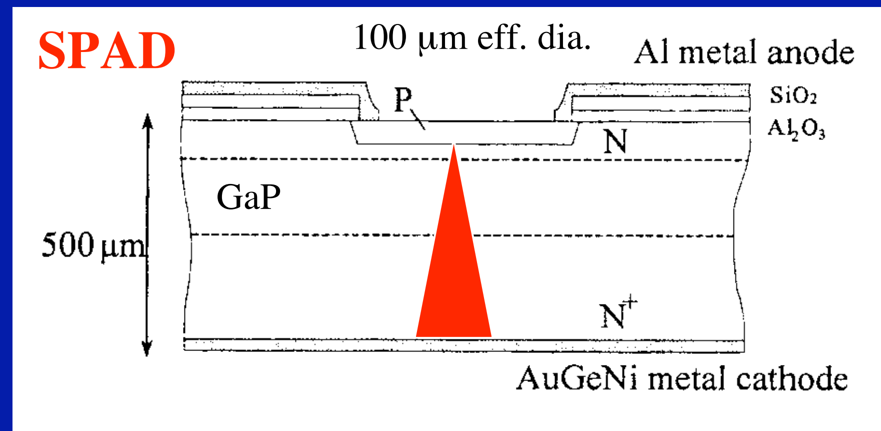
Photocathode	Si
σ_{TTS}	~ 17 ps
Low noise	< 20Hz
Spectral range	350-900 nm
After pulsing probability	< 3%
Dead time	~ 50 ns
Maximum rate	~ 20 MHz
Active area	~ 50 µm

- A a single G-APD cell id-100 is made by "id Quantique SA", Switzerland

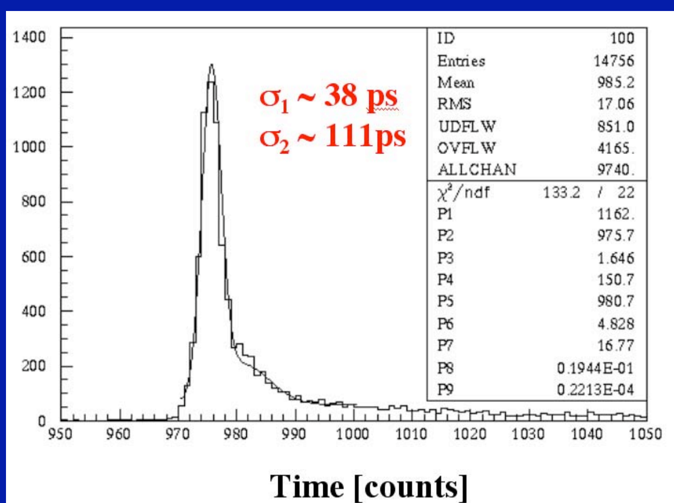
Single cell G-APD σ_{TTS}

Measurements by J.Va'vra, G-APD from Sopko, active quenching from Prochazka, CVUT Prague

G-APD:



Single photoelectron timing resolution:



- **G-APD operating in a Geiger mode with active quenching and temperature control.**
- **With a PiLas red (λ = 635 nm) laser diode operating in the single pe mode, I obtained:**

$$\sigma_{TTS} < \sqrt{(38^2-13^2-11^2)} \sim 35 \text{ ps}$$

PiLas   Electronics

Next slide was added after the workshop

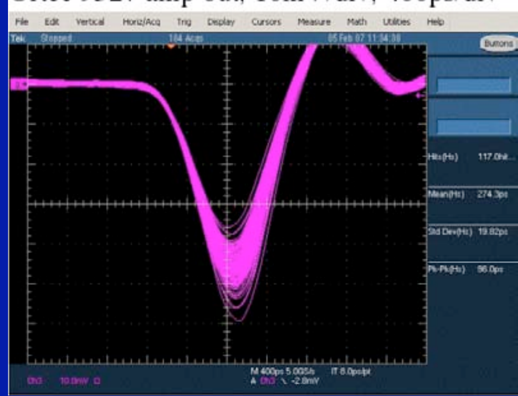
Single pad vs. 4-pads shorted together

(this addendum is a response to a question Krzysztof asked me one day after the workshop)

Single pad:

Run 213, single pad, 9327 mon, 2.33kV, ~50pe$^-$, TOF1

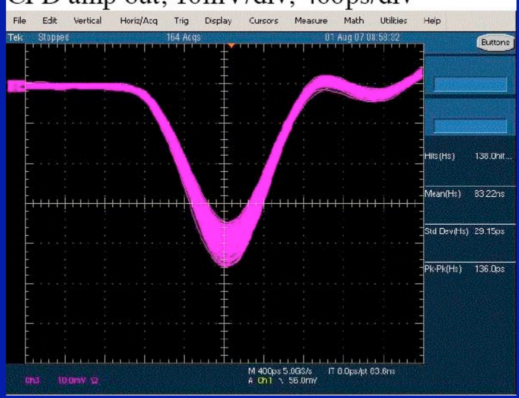
Ortec 9327 amp out, 10mV/div, 400ps/div



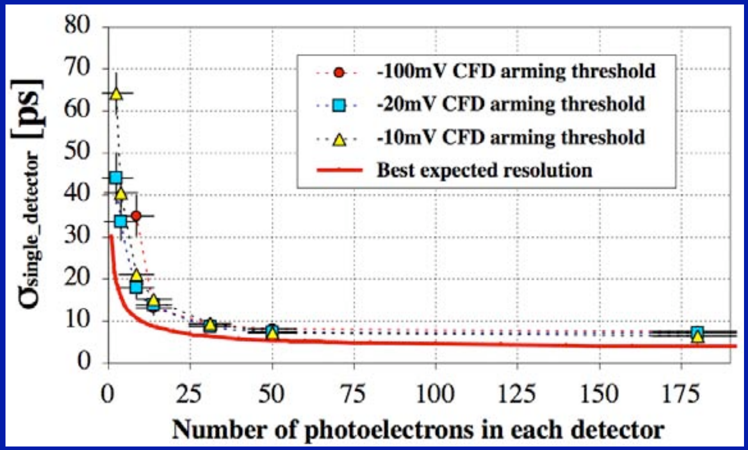
4-pads shorted together:

Run 261, four pads shorted, 9327 mon, 2.33kV, ~50pe$^-$, TOF1

CFD amp out, 10mV/div, 400ps/div



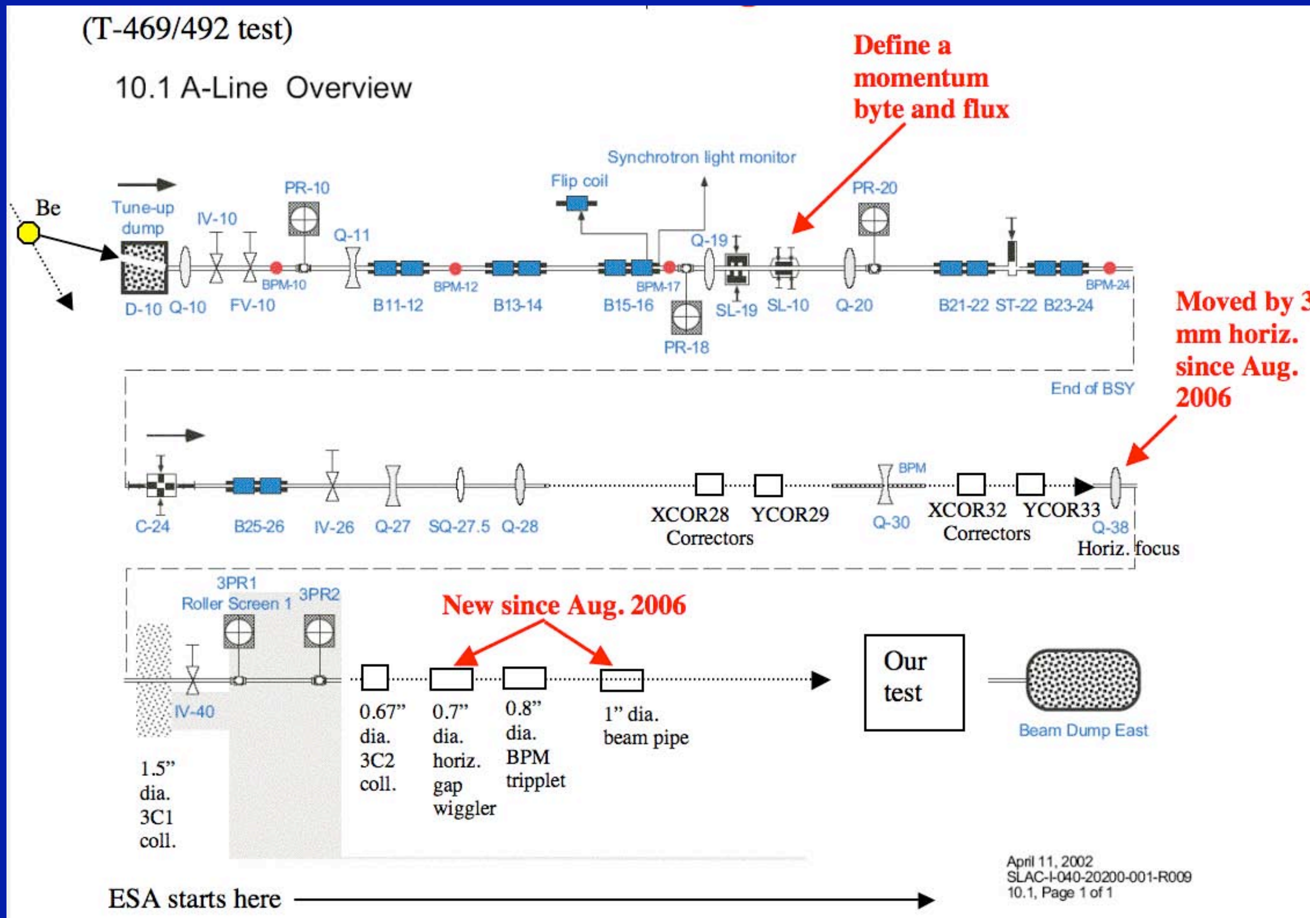
4-pads shorted together:



- A single pad capacitance to ground is ~5.5pF, 4-pads shorted together represent ~ 20pF. Therefore, one would expect a degradation in rise time. Indeed that is what one observes.
- In addition, in the resolution plot, extrapolating towards Npe ~ 1, one observes σ_{TTS} (4-pads) ~ 40-50 ps, which is worse than σ_{TTS} (1-pads) ~ 27 ps, shown on slide 6.
- The two conditions were the same except the pad connections

SLAC test beam this year

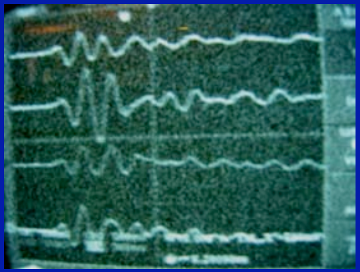
End Station A (ESA) beam line



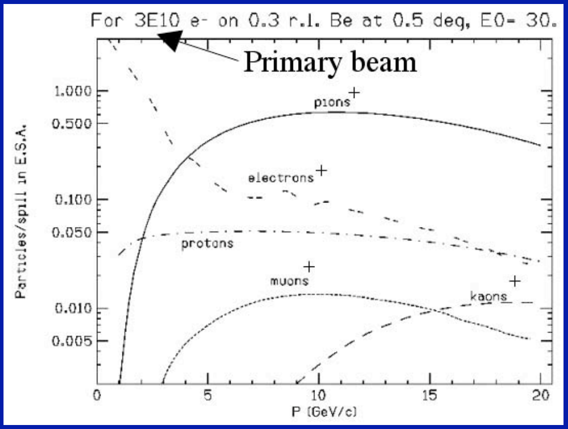
- Configuration during the last FDIRC test.
- We use it as a secondary beam running electrons off the Be target.
- Use correctors XCOR32 & YCOR33 to move the beam at our test end.

Running conditions at present

- The ESA secondary electron test beam momentum was set to **10 GeV/c**, with LCLS beam energy of **14.5 GeV/c**. Previously we were always running **28 GeV/c** primary electron beam. Until this run it was not clear (a) if it is even possible to run parasiting with the LCLS operation, and (b) if the particle yield is sufficient at such a low LINAC energy. We proved that it is possible, and that we get a good rate of **0.2-0.3 ppp** with a momentum byte of **+-0.2%**, that we get a good beam spot of **σ = 1-2 mm** at far end of ESA, and good cleanliness judging from the lead glass spectrum.
- **Monitoring of the primary LINAC beam by MCC operators:**
  - Monitoring the primary beam - pick up electrodes on Be target →
  - Plus a usual LINAC monitoring



- **Monitoring of the secondary beam by MCC operators:**
  - Scalars indicating a particle flux going through our test
  - Our own monitoring histograms, such beam spots in the hodoscopes, lead glass spectra, rates, etc.
- **Particle yields:**
  - The following graph shows the yield for positive polarity →
  - For negative beam one gets mostly electrons
  - Generally MCC people encourage negative beam polarity i.e., one needs some political umpf to re-cable magnets into the positive polarity and spend a week to tune the beam; the last test to do this was the Glast experiment.

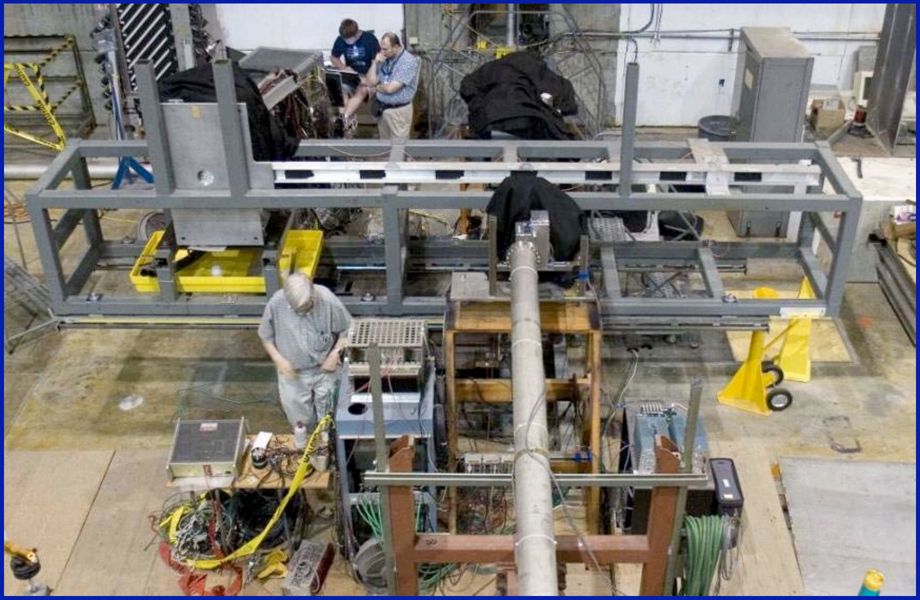


Summary of beam parameters

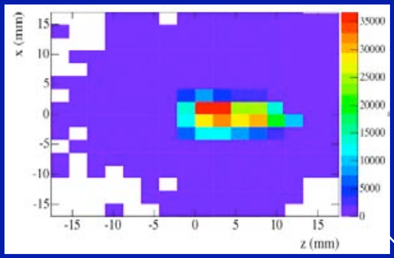
a) Height from the floor:	**7 feet ± 2 inches**
b) Total left-right clearance:	**> 10 meters**
c) Beam spot size at the bar entrance:	**~1 mm**
d) Beam position knowledge:	**± 1mm** (after tuning correctors)
e) Beam divergence:	**± ~0.6mrad** (based on the hodoscopes)
f) Particle type:	**Electrons (mostly)**
g) Polarity:	**Negative** (typically)
g) Particle flux during the test:	**~ 0.2 ppp**
h) Rate:	**10 - 30 Hz**
i) Secondary beam momentum:	**10 GeV/c**
j) Primary beam momentum:	**14.5 GeV/c** (when LCLS is controlling)
k) Target:	**~1 ft-long 0.3 r.l. Beryllium**
l) Production angle:	**0.5^0**
m) Timing signals:	**AB01-8-09 , AB01-8-10** (programmable)

Latest 2007 Beam Test Setup

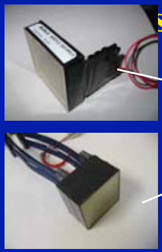
- **Instrumentation available:**
  - 2 x-y scint. fiber hodoscopes
  - START #1 counter to monitor flux
  - Time start from the LINAC RF signal, but correctable with a local START #1 counter
  - Lead glass to monitor beam multiplicity (very important in SLAC's beam)

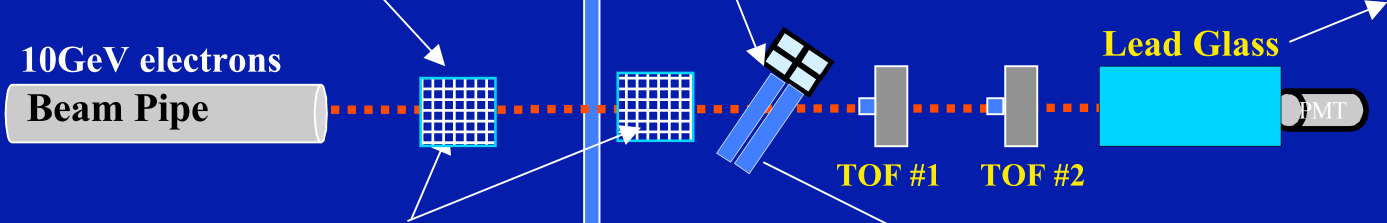


Beam spot: σ < 1mm

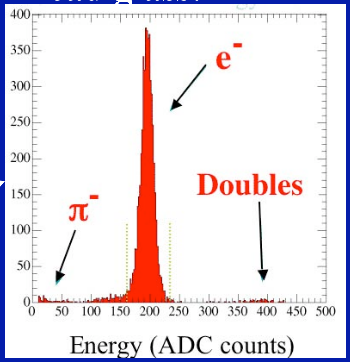


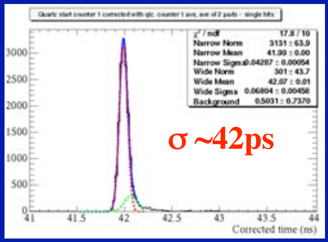
Prototype





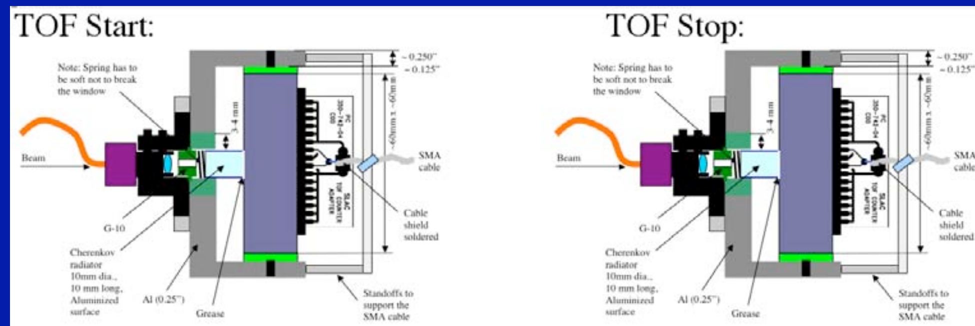
Lead glass:

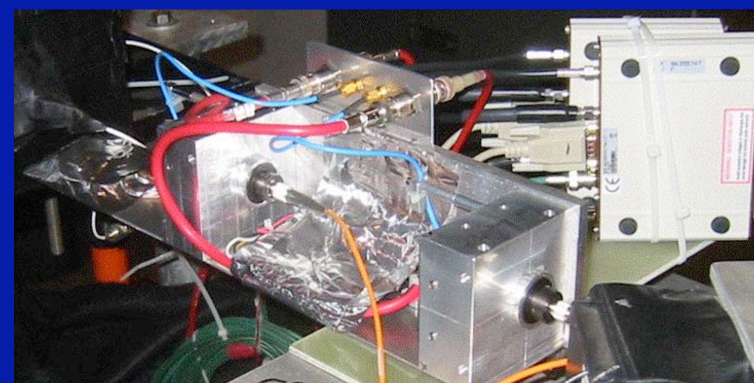


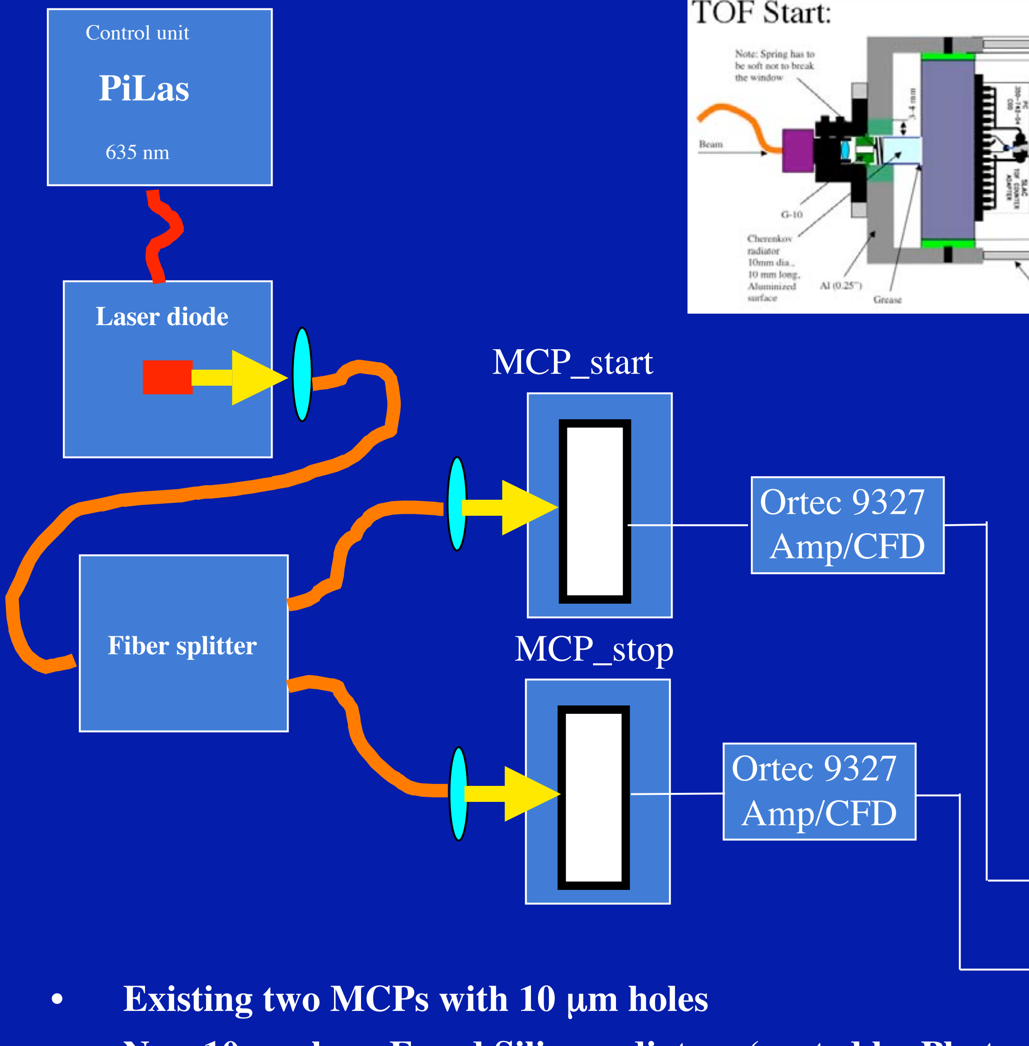


Next MCP-PMT tube to test at SLAC in the beam

Existing MCP-PMTs with improvements - May test

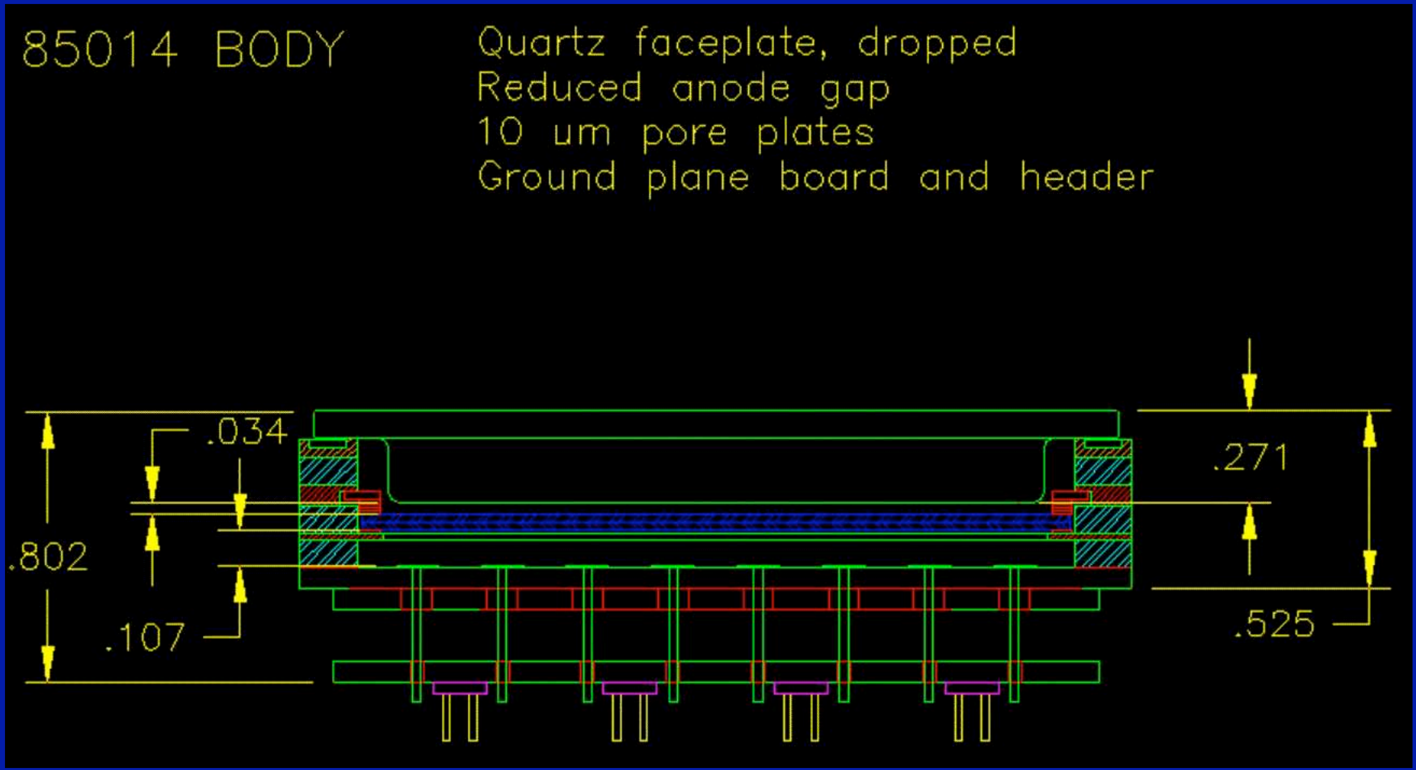






- Existing two MCPs with 10 μm holes
- New 10mm long Fused Silica radiators (coated by Photonis)
- Pulse height-corrected CFD timing (with the QTNT scheme)

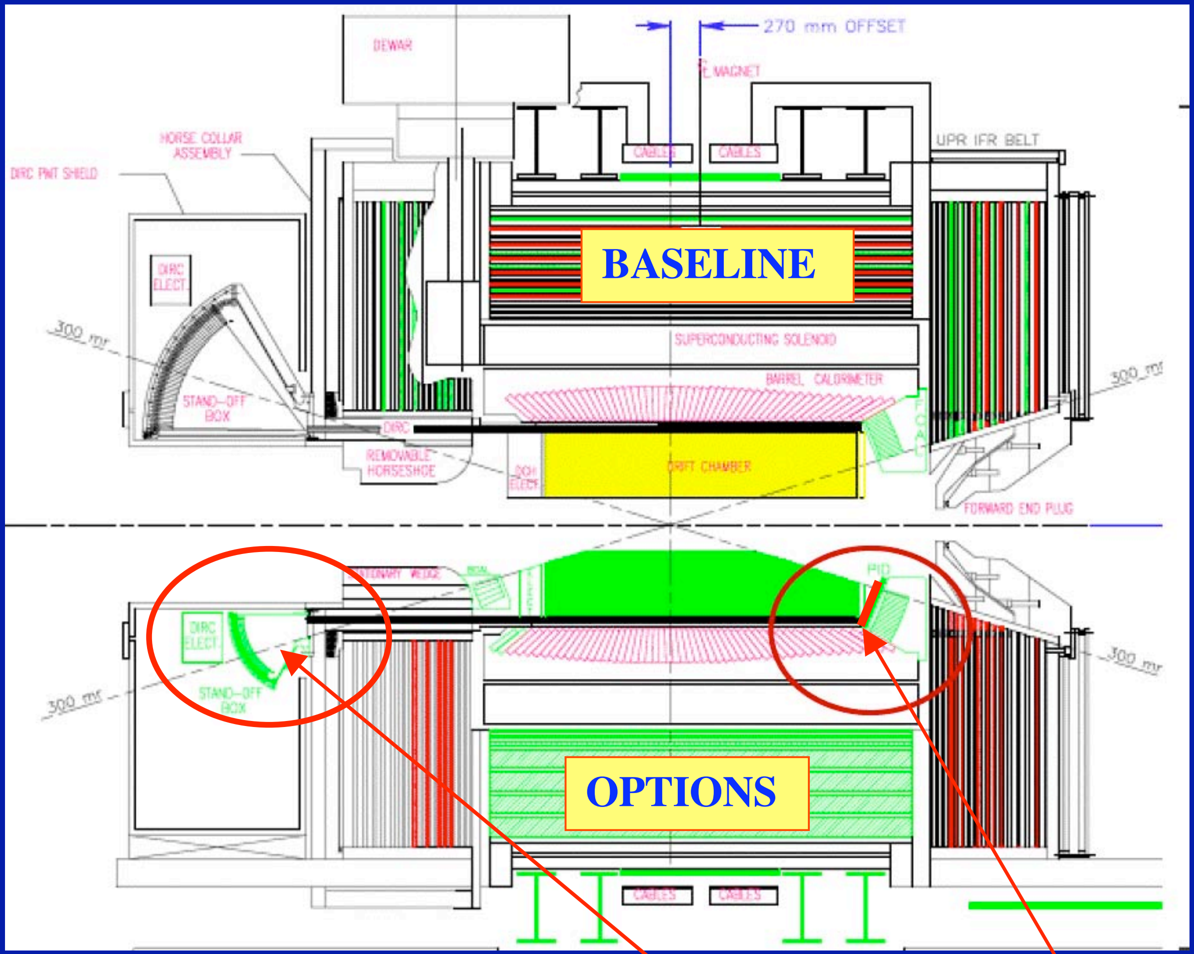
Burle/Photonis MCP-PMT 85014 - for July SLAC tests



- **~6.9 mm thick quartz radiator**
- **Cathode-to-MCP gap: ~864 μm**
- **MCP-to-Anode gap: ~2.7 mm**
- **Charge spread on ~16 pads => no more suitable for a few channel electronics test.**
- **Gary's electronics (need 16 channels)**

Super-B detector in Italy

PID systems in Super-B



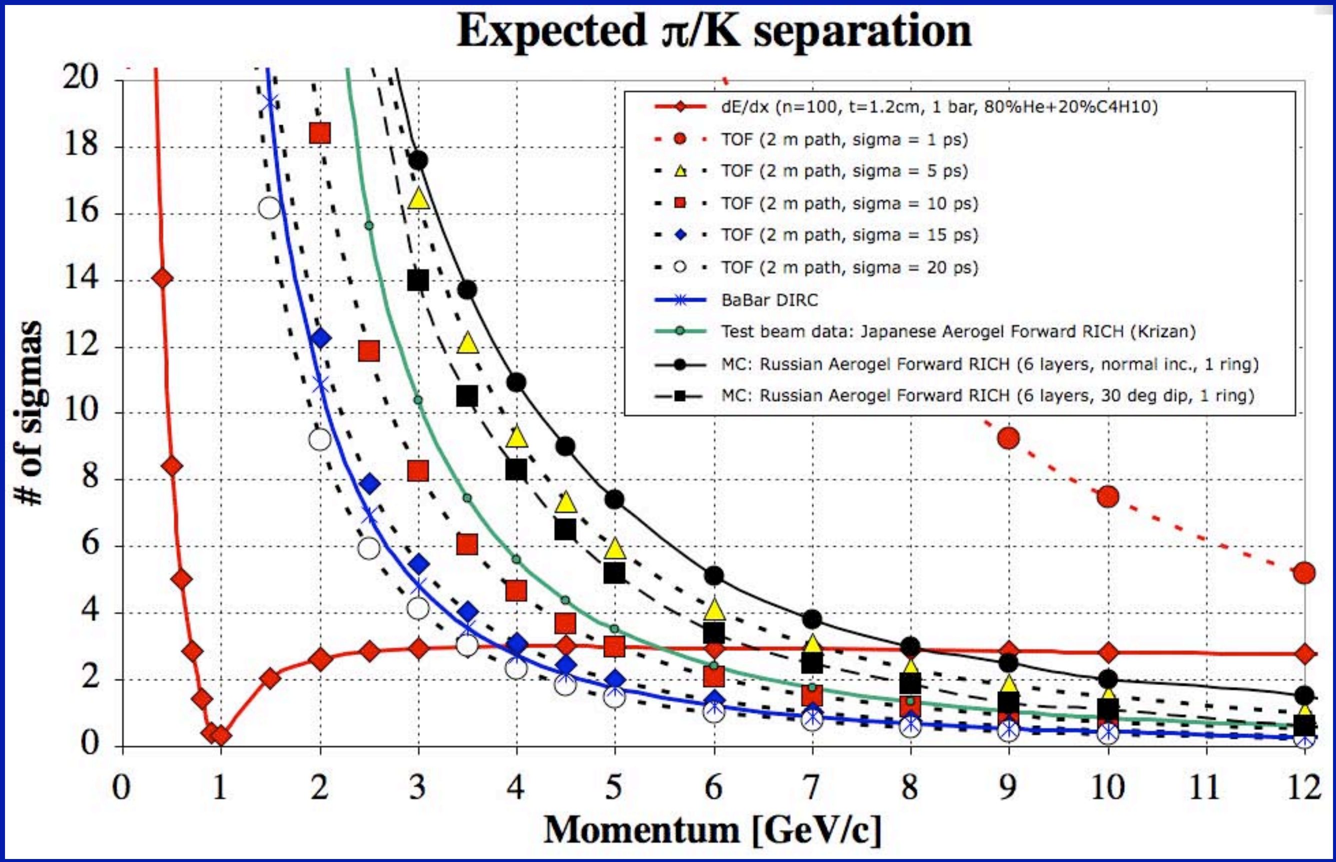
- **Converging on two PID systems:**

Barrel Focusing DIRC & Forward TOF

Timing at a level of σ ~15ps can start competing with the RICH techniques

Example of various Super-B factory PID designs:

Calculation done for Flight Path Length = 2m



- **The PID performance of a forward TOF system with σ ~15-20ps is equivalent to the PID performance of the BaBar DIRC.**
- **Adding a TOF system would improve the hermeticity of the PID coverage.**