30ps timing resolution for single photons

J. Va'vra
SLAC

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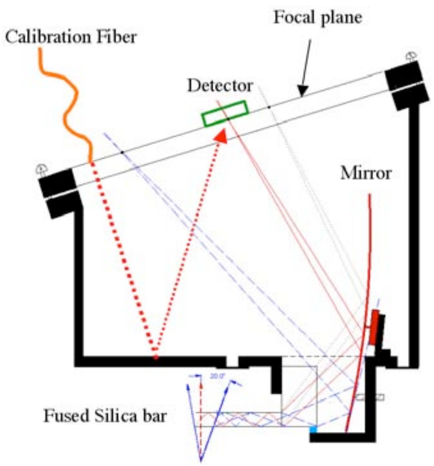
- **Motivation for this work**
- **Method to measure high precision timing**
- **Results**

- **Single photon** timing resolution with Burle 25μm hole MCP-PMT
- **Single photon** timing resolution with Burle 10μm hole MCP-PMT
- **Multi-photon** timing resolution with Burle 10μm hole MCP-PMT
- **Compare results with amplifiers of different bandwidth**
- Timing measurements at **B = 15kG**

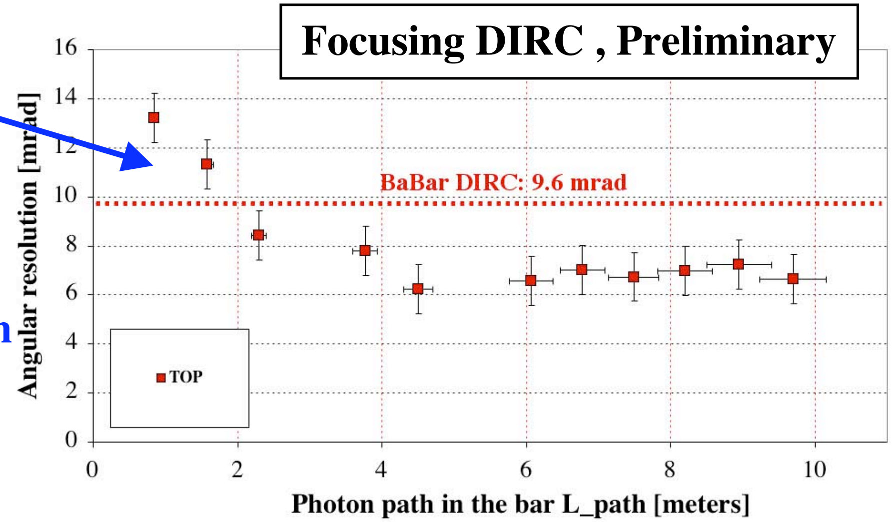
- **Possible trouble points**
- **Compare results with our competition**
- **Conclusions**

Motivation

Present Focusing DIRC prototype at SLAC



For short path lengths the Cherenkov angle resolution is limited by the timing resolution of the present photon detectors. For long path lengths the resolution contribution is small (~1 mrads).

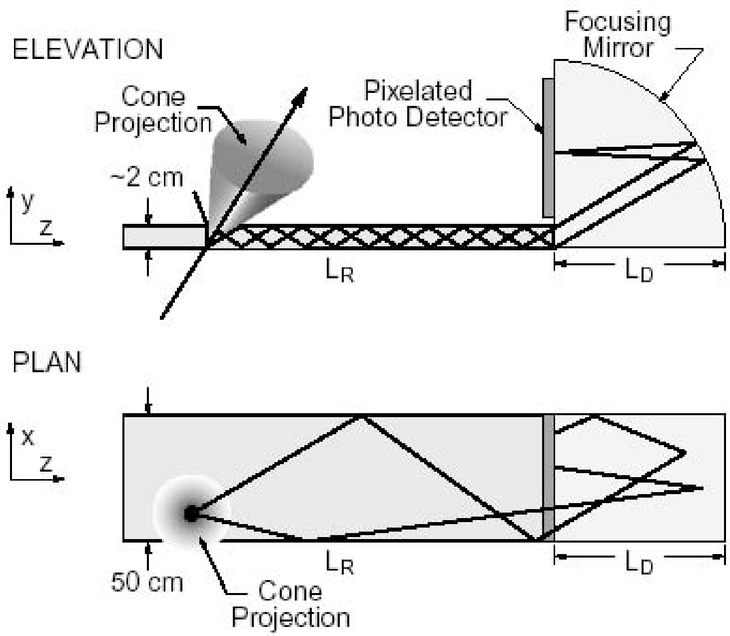


- Beam enters perpendicularly to the prototype's Fused Silica bar during the present test.
- A typical resolution of two types of photon detectors is: Burle 25μm pore 85011 MCP-PMT has **σ ~100-120ps**, and Hamamatsu H-8500 MaPMT has **σ ~150-200 ps**, when integrated over an entire area of the pixels (in an ideal position in the middle of a pixel the respective numbers are ~70-80ps and ~140ps).
- For long photon paths, the time-based Cherenkov angle resolution of the present prototype is already better than what the BaBar DIRC achieved using pixels. For long lath lengths the timing resolution contribution is small (~1 mrads). However, the timing resolution dominates the Cherenkov angle error for short path lengths.
- **If we achieve the timing resolution better than ~50ps the time is competitive with pixel-based resolution** (except for class of tracks where the photons travel almoust parallel to the bar).

Focusing DIRC detector for Super B-factory

B. Ratcliff, Nucl.Instr.&Meth., A502(2003)211

A solution inside A 16kG magnet:



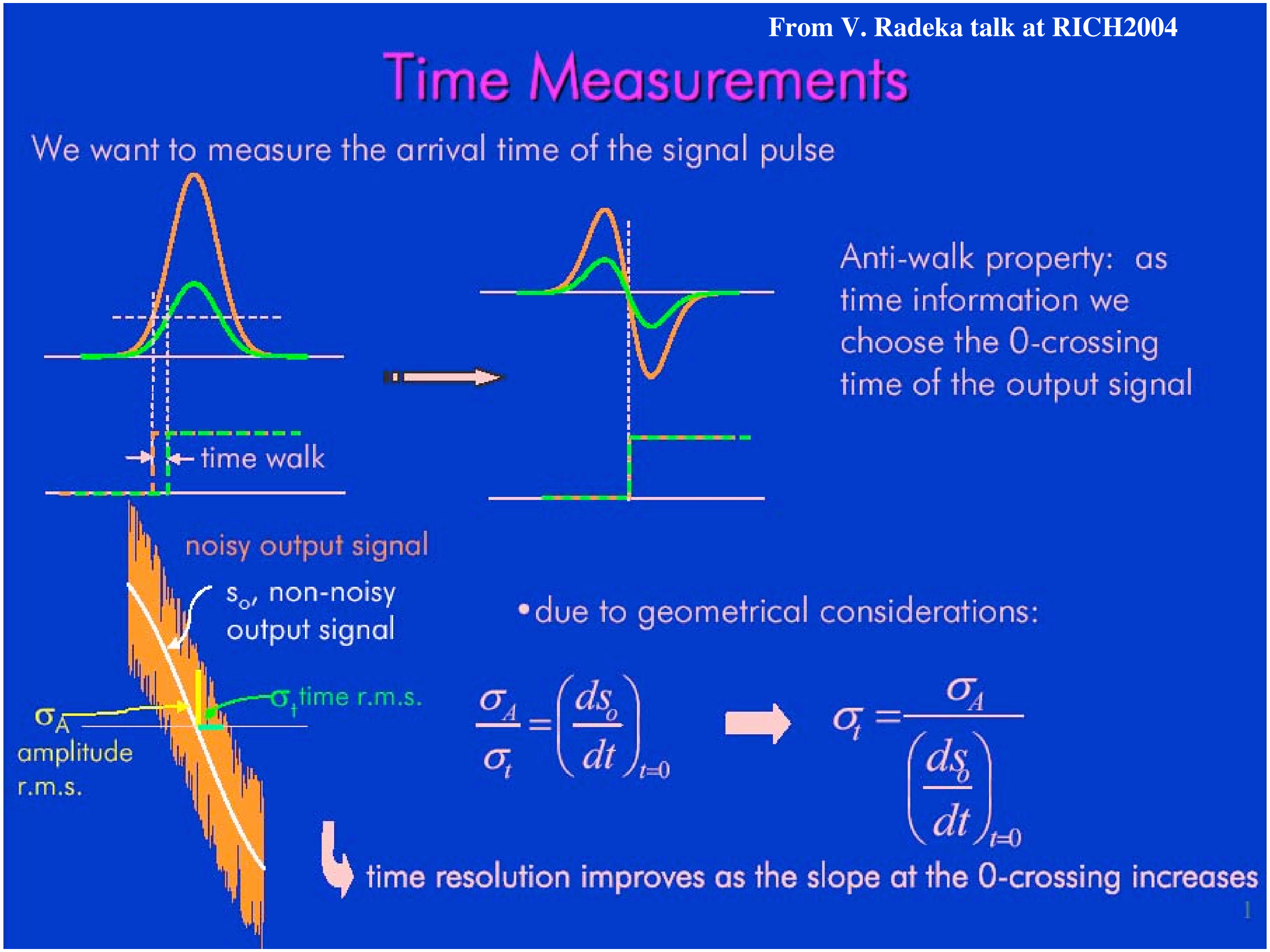
- 3D imaging for single photons (x,y and time).
- For a simple maintenance, small cable plant, and easy access one would prefer to have detectors outside of the magnet. In that case we have several candidates for the photon multi-pixel detector (MaPMT or MCP-PMT).
- **The real question is what would be a photon detector if the detector is in the 16kG magnetic field !! A year ago we did not have any solution !!!**

Method

High Resolution Timing

- **Timing methods:**
  - Leading edge discriminator + single TDC + ADC correction
  - Constant fraction discriminator (CFD) + single TDC
  - Two leading edge discriminators with two TDCs per channel
- **The amplifier rise time must be comparable to the photon detector's rise time, and both have to be fast:**
  - Hamamatsu C5594-44, gain 63x, 1.5 GHz BW
  - Ortec VT120A, gain 200x, ~0.4 GHz BW
  - Ortec 4306, gain 100x, 1.0 GHz BW
  - Texas Instr. THS4303, 10x, 1.8GHz BW, tandem of 2
- **Light source:**
  - PiLas laser diode with a light pulse width of 35ps FWHM.

Speed of the amplifier & detector is essential for good timing



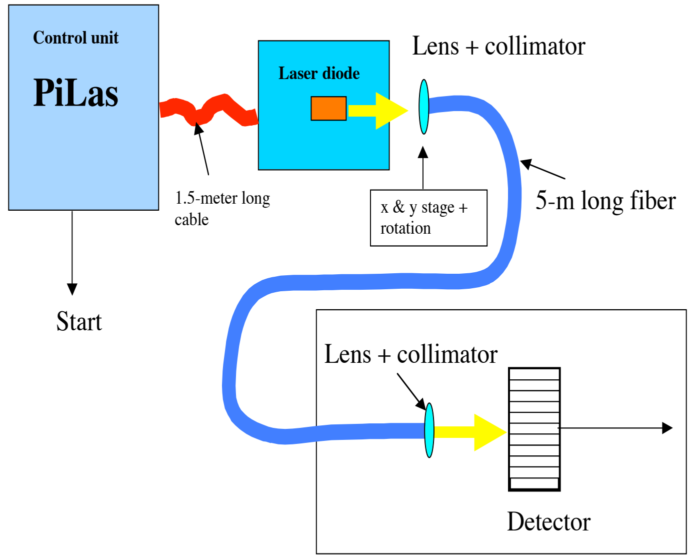
Timing with CFD

σ = f(gain, noise, detector BW, amplifier BW, CFD BW, amplifier pulse shape uniformity (partial saturation), amp-to-CFD delay, CFD delay, CFD threshold, TDC resolution, TDC diff. linearity, wiring, drifts, etc.)

Trick to success is to find a minimum of this function

Laser diodes for testing the fast detectors

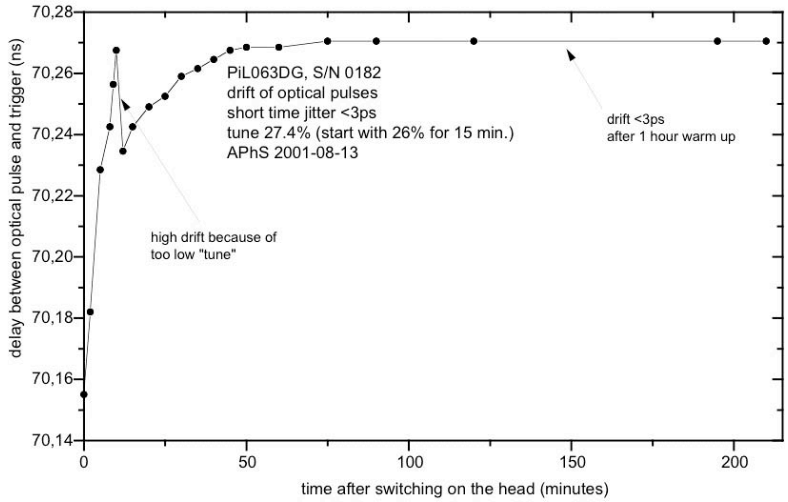
PiLas setup in my lab:



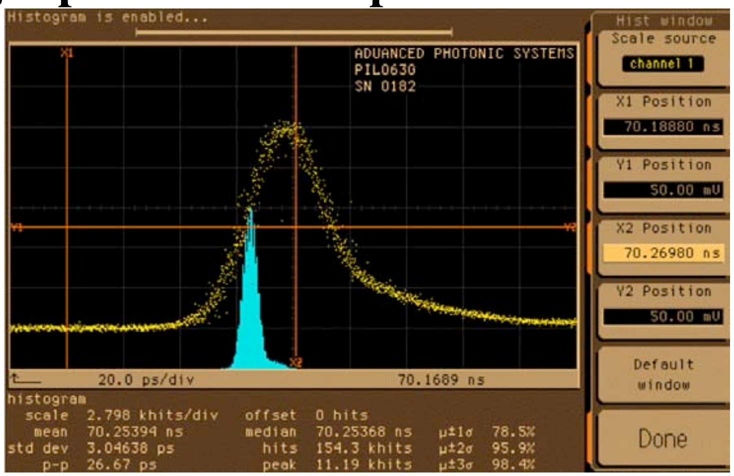
Parameter	PiLas 043G	PiLas 040G	PiLas 063G	Hamamatsu
Wavelength	430 nm	405 nm	635 nm	394 nm
Tolerance [nm]	± 10	± 10	± 5	
Spectral width [nm]	< 7	< 5	< 7	
FWHM of light pulse spread	< 60 ps	~45 ps	~35 ps	34 ps
Light pulse jitter relative to trigger	~2 ps	<3 ps	~2 ps	±10 ps
Peak power [mW]	> 140	> 400	> 200	
Comment	Borrowed from Sumyioshi (1 month)	Used in scanning setup	Used for my best timing results	Used by Nagoya people

PiLas laser diode drift and pulse width

Drift between optical pulse and trigger:



Light pulse width: 35ps FWHM + tail



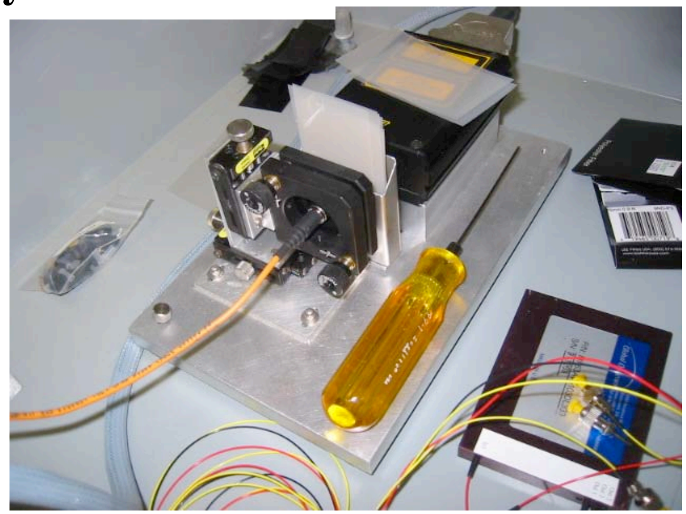
- **PiL063DG red diode**
- **Data provided by the company**
- **Light pulse width is 35ps FWHM. However, there is also a long tail.**

=> Neglecting the tail, for $N_{pe} \sim 25$, expect timing error of $\sigma < 3$ ps.

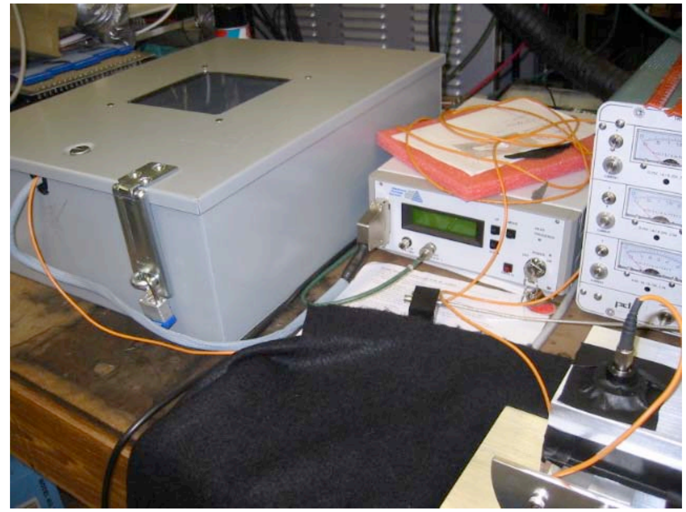
- **Drift between the optical pulse and trigger is:**
- **>100ps drift in the first 10min**
- **10ps/hr after 20min**
- **< 3ps/hr after 1 hour**
- **Therefore one has to wait at least 1-2 hours before any high precision measurement is started.**

PiLas laser diode and fiber optics

Mylar absorbers:



Controller & a box to limit the noise:



Fiber & lens:

- **Achieved σ ~ 30ps with:**

- laser diode with a 635 nm wavelength
- 63μm diameter ~5m-long multi-mode fiber
- “Home-made” alignment with the x&y small stage
- Mylar absorbers to get single photons
- standard electronics, which includes the CFD discriminator, or TDC/ADC

The cost of good laser diodes is high

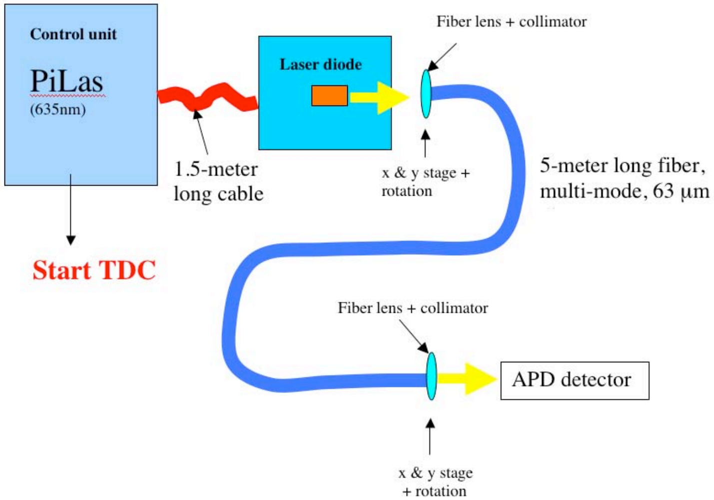
PiLas:

Item	Quantity	Description	Price/EA
1	1	Model EIG 1000D. PiLas digital control unit. External trigger (repetition rate: single shot to 1 MHz); internal trigger (repetition rates can be set for single shot, 10Hz, 100kHz, 200kHz, 500kHz, 1MHz). Jitter between pre-trigger and optical output pulse is typically < 3ps	$4,480.00
2	1	Model PIL040. PiLas optical head. Wavelength 405 nm ±10nm, spectral width <5nm, pulse width (FWHM) <45ps, peak-power through collimating optics typ. >400mW, incl. collimating optics with f=4.5mm. This leads to a collimated beam shape of max. ~5mm by ~2mm. The head is optimized for repetition rates ≤100kHz.	$8,600.00
3	1	Model PiL 040 SM or MM Fiber coupling optics, single mode or multimode fibres with 5 or 50µm core diameter, FC/PC-connector. With 2m MM fibre 50µm and FC/PC plug, completely adjusted. Reduced coupling efficiency to get 200mW nominal pulses at the FC/PC.	$2,795.00

Not necessary if one is willing to make his own alignment setup →

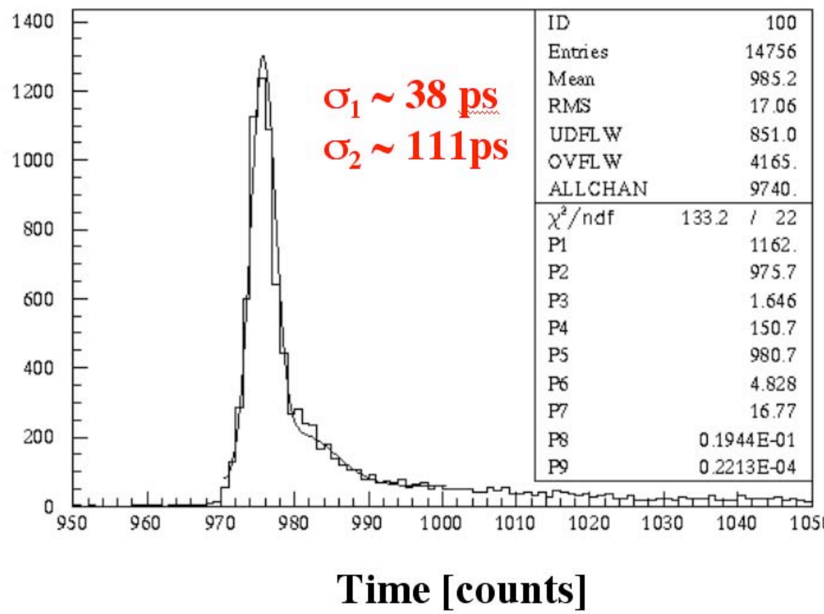
Use a SiPMT detector to check the PiLas laser diode

J.Va'vra, Erice 2003 proceedings



SiPMT:

Single photon resolution:

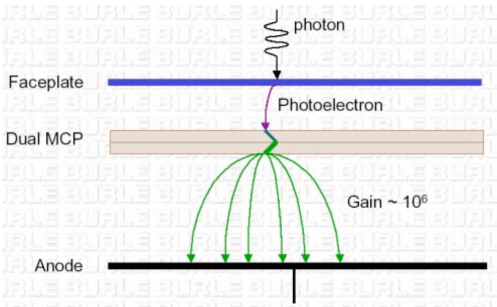


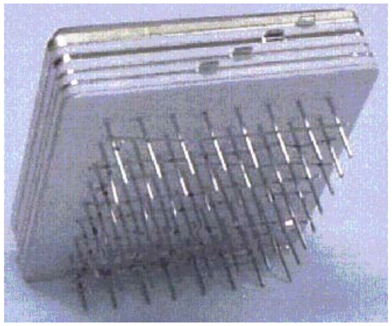
- **The authors of the SiPMT quote a timing resolution: σ_{diode} ~ (FWHM = 58/2.35) ~ 25 ps for the single photoelectron regime. Therefore, we expect: $\sigma_{PiLas} \sim \mathrm{sqrt}(\sigma_{result}^2 - \sigma_{APD}^2 - \sigma_{electronics}^2)$ ~ sqrt(38^2-25^2-17^2) ~23 ps (however, PiLas data sheet quotes: (35/2.35) ~15ps).**
- Electronics chain in this test: SLAC CFD, 30mV threshold, CFD analog output to the LeCroy 2228ATDC (25ps/count).
- Detector: 100 μm dia. GaP APD (SiPMT) operating in a Geiger mode with active quenching. APD developed by Sopko & Prochazka, CVUT Prague.

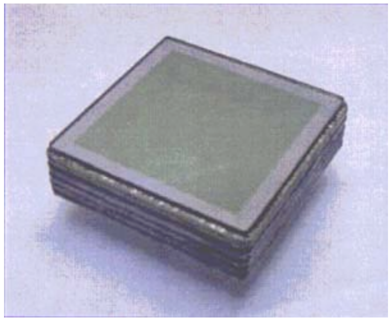
Photon detectors

Burle 85011 MCP-PMT parameter list

Burle Co. data sheet + SLAC measurements + my interpretation







Burle data on 85011 MCP-PMT (some SLAC measurements included)

Parameter	H85011-501	H85011-403	Future tube
Open area design (small margin around edges)	No	No	Yes
Photocathode type	Bialkali	Bialkali	Bialkali
MCP hole diameter	**25µm**	**25µm**	**10µm**
MCP hole pitch	32µm	32µm	12µm
Number of MCPs per PMT	2	2	2
Total average gain @ -2.3kV	~$5x10^5$	~$5x10^5$	~10^6
Cathode-to-MCP distance	**6-7mm**	**0.75mm**	**0.75mm**
MCP hole angle relative to perpendicular	12°	12°	12°
Geometrical collection efficiency (hole dia. & pitch)	45-50%	45-50%	55-60%
Geometrical packing efficiency (outside dead space)	67%	67%	85%
Fraction of late photoelectron arrivals (SLAC estimate)	~20%	Tail is cut	Tail is cut
Total fraction of "in time" photoelectrons detected	**30-35%**	**30-35%**	**45-50%**
Single electron resol. (σ_{narrow}) – SLAC data for B = 0 kG	60-80ps + tail	60-80ps	< 50ps
Single electron resol. (σ_{narrow}) – SLAC data for B = 15 kG	-	-	~50-60ps
Amplifier used in SLAC measurements	Elantec 2075C	Elantec 2075C	Ortec-VT120A
Amplifier voltage gain used in SLAC measurements	130x	130x	200x
Matrix of anode pixels	8 x 8	8 x 8	32 x 32
Number of pixels	64	64	1024
Pixel size	6mm x 6mm	6mm x 6mm	1.4mm x 1.4mm
Pixel pitch	6.57 mm	6.57 mm	1.6 mm

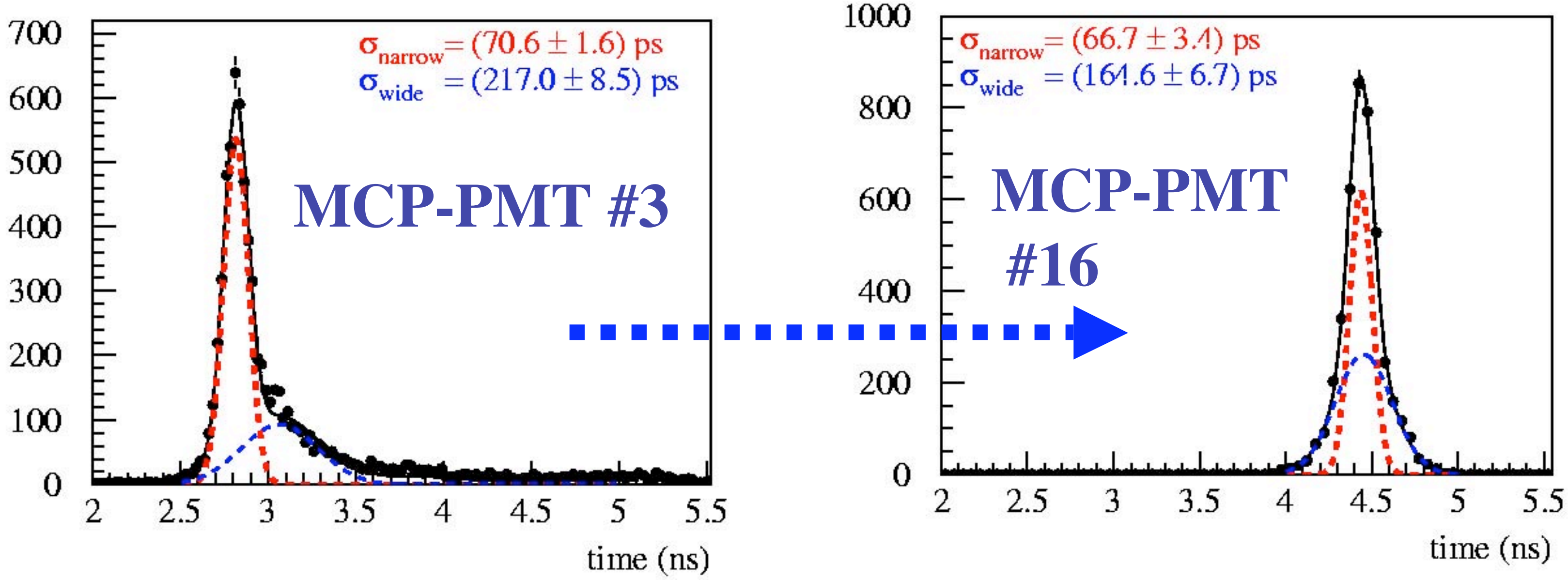
!!

Single photoelectron timing resolution at B = 0 kG (25 μm pore MCP-PMT)

Dependence on the MCP PMT design

Old design (85011-501):
MCP-to-Cathode distance = 6 mm

New design (85011-430):
MCP-to-Cathode distance = 0.75 mm

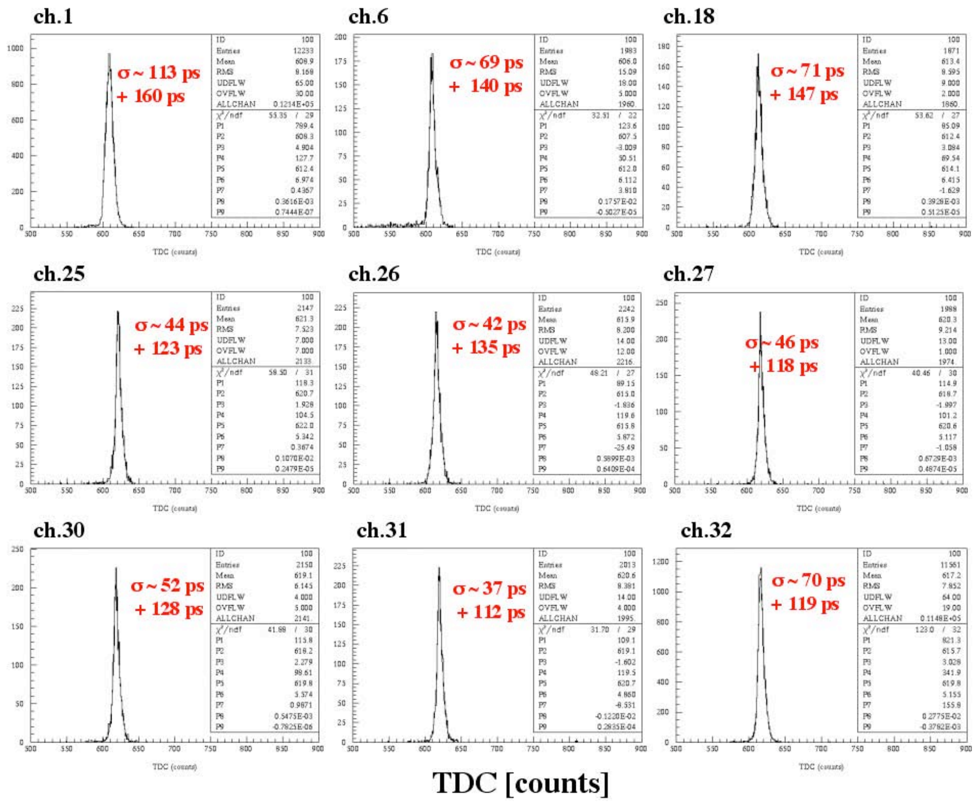


- Double Gaussian fits.
- **The reduction of the MCP-to-Cathode distance to 0.75mm limits the rate of recoiling photoelectrons from the MCP surface, which reduces the tail in the timing spectrum. These electrons are, however, lost from the detection efficiency, but the spectrum is more Gaussian. Nevertheless, tails would complicate the analysis, and we prefer to cut them.**
- Electronics chain used in this test: Final SLAC amplifier, final SLAC CFD, LeCroy 2228A TDC (25ps/count).
- Light source: PiLas laser diode in the single photoelectron mode (635nm).

Ideal goal: no tails in the distributions

MCP-PMT
#16
(64 pixels)

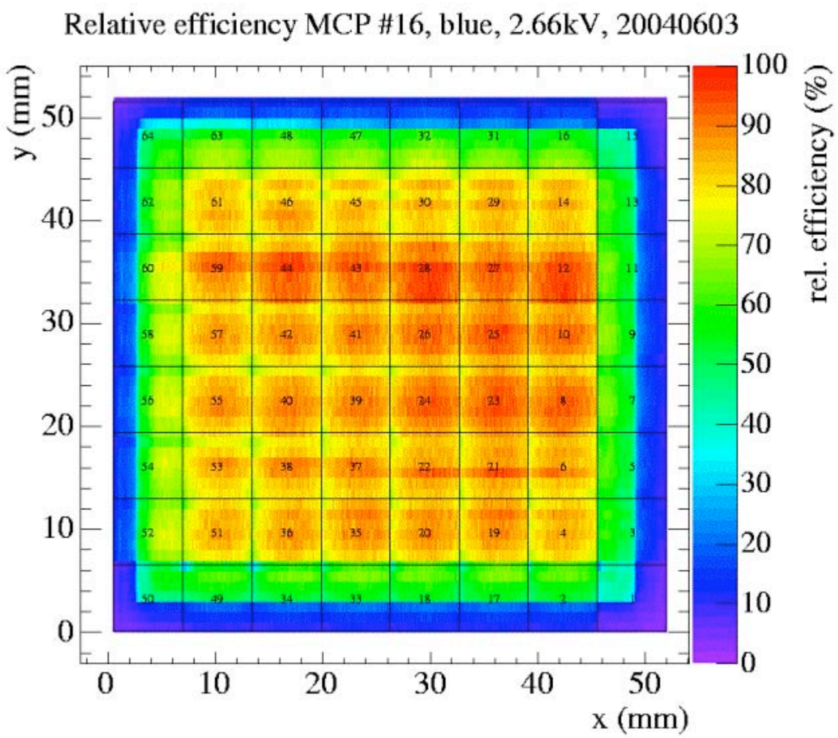
- MCP-PMT #16 with 0.75mm cathode-to-MCP distance (85011-430)
- CFD 2, 100mV thershold



- Double Gaussian fits.
- **No tail in this type of MCP-PMT.**
- **Some pixels are better than others.**

However, the new tube is inefficient around the edges

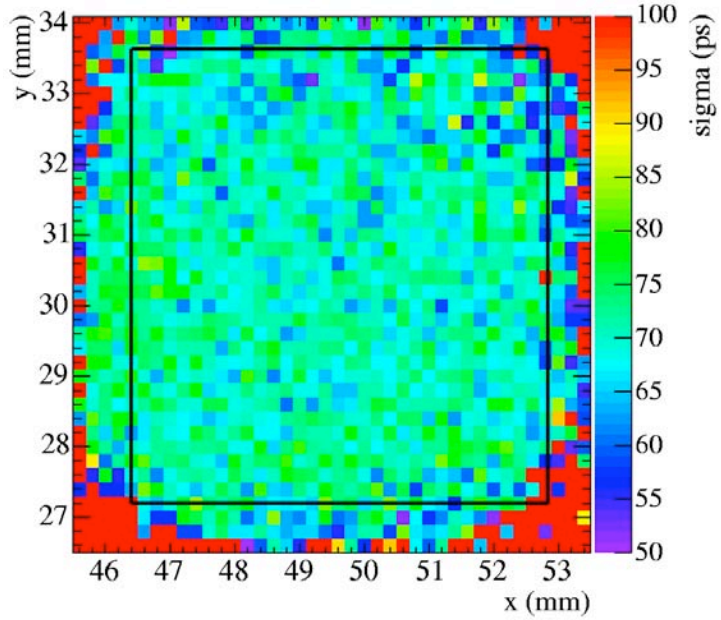
New design (85011-430):
MCP-to-Cathode distance = 0.75 mm



- The efficiency drops to zero half way through all edge pads.
- This inefficiency is related to the electrostatic design near the edges.
- Perhaps, one can have a small light collector around the boundary

Timing resolution near pad adges

MCP-PMT #16, Pad 14

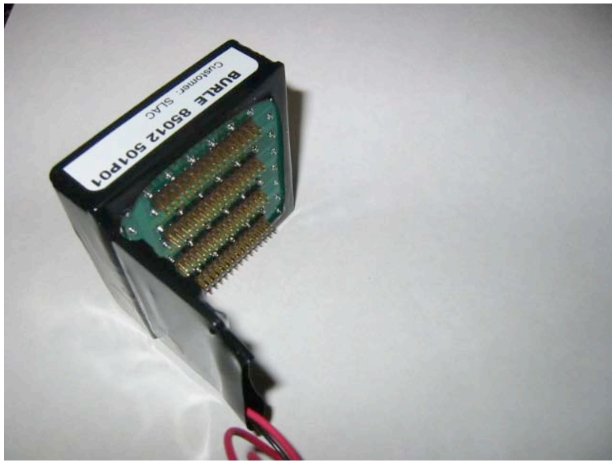


- **Single Gaussian fit** to the timing distribution generated in each laser head location.
- **Measure typically σ = 70-80ps in the central pad region, about ~20% worse near the boundary. This is due to the charge sharing, causing lower pulse height, and possibly also the cross-talk.**
- Electronics chain in this test: final SLAC amplifier, final SLAC 32-channel CFD, Phillips 7186 TDC (25ps/count).
- Detector in this test: MCP-PMT #16 with MCP-to-Cathode distance of 750μm, 8x8 pads, 2.6kV.
- Light source in this test: PiLas laser diode in the single photoelectron mode (635nm).

Single & multi-photoelectron timing resolution at B = 0 kG (10 μm pore MCP-PMT)

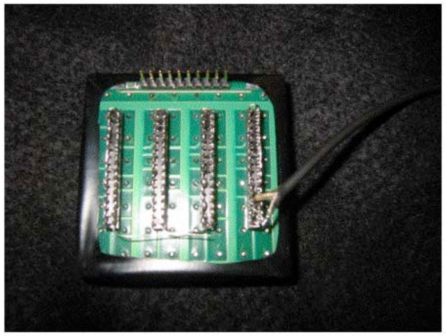
“Open area” Burle MCP 85012-501

10μm hole 64 pad MCP-PMT (S/N 11180401)



- 10 μm MCP hole diameter
- 64 pixel devices
- Pad size: 6 mm x 6 mm.
- Small margin around the boundary
- The MCP-PMT still has 6-7 mm cathode-to-MCP distance, thus making a long tail in the timing distribution
- So far, did not change the resistor chain.
- Need as fast amplifier as its risetime, which is about 500-600ps.

Signal connection:

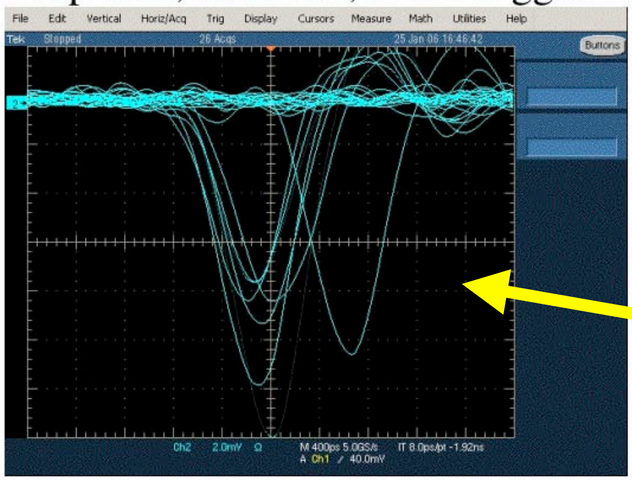


“Open area” Burle MCP 85012-501

10μm hole 64 pad MCP-PMT (S/N 11180401)

Raw MCP pulses:

400ps/div, 2mV/div, PiLas trigger



With Hamamatsu amp. C5594-44:

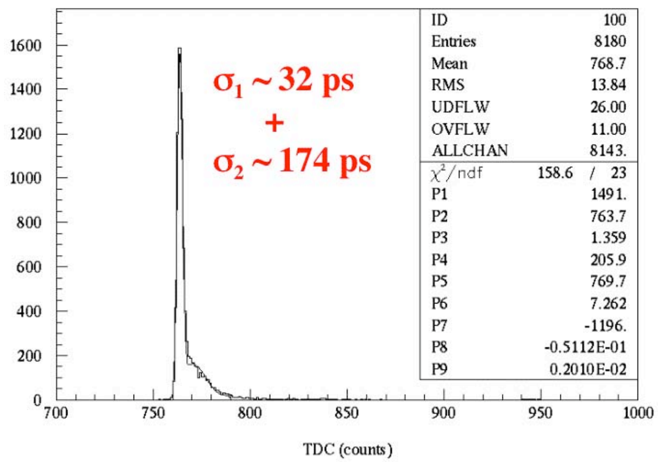
400ps/div, 100mV/div

- -2.80 kV
- PiLas laser diode
- **Single photoelectrons**
- **One needs a fast amplifier to follow the speed of MCP.**
- **Raw pulses from MCP-PMT (directly from MCP-PMT to scope):**
  risetime: ~600ps
  width: ~800ps (FWHM).
- **Amplified pulses (Hamamatsu C5594-44 with a gain of 63x, 1.5 GHz BW):**
  risetime: ~700ps
  width: ~900ps (FWHM).
- **Scope: Tek 5104, 1GHz BW (~350ps rise time - not fast enough to see the MCP true rise time), 5GS/s**

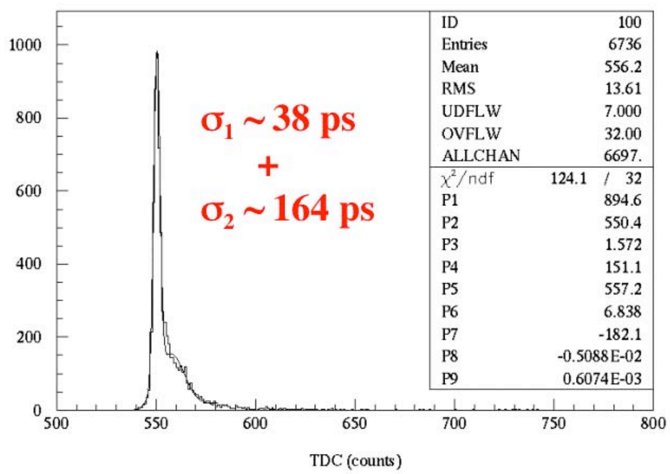
Hamamatsu amplifier C5594-44

1.5 GHz BW, 63x gain

Amplifier-CFD delay ~ 40 ns (BNC cable):



Amplifier-CFD delay ~ 4 ns (SAM cable):



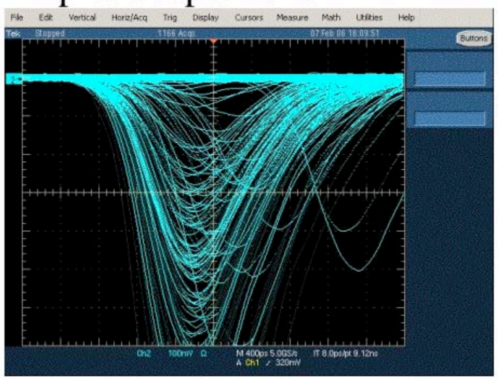
- -2.80 kV
- **Single photoelectrons**
- **"Open area" Burle MCP 85012-501**
- 10μm hole 64 pad MCP-PMT
- S/N 11180401
- **Phillips 715 CFD:**
  25mV threshold
- **CFD delay:**
  1cm jumper (~300ps delay)
- **Detector-amplifier delay:**
  ~ 2 ns
- **LeCroy TDC:** 24ps/ct

- This is an example which shows that one has to tune at around each operating point
- Is this all because the Phillips CFD is a 300MHz BW ?

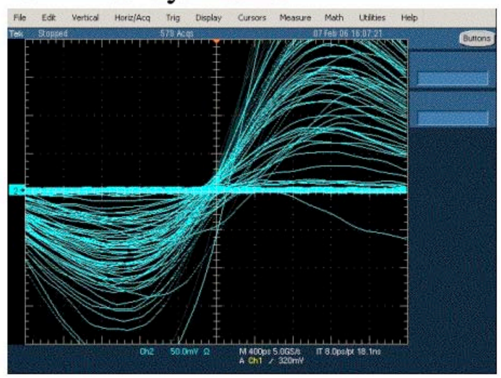
Ortec amplifier VT-120A with a 6dB att.

~0.4 GHz BW, 200x gain

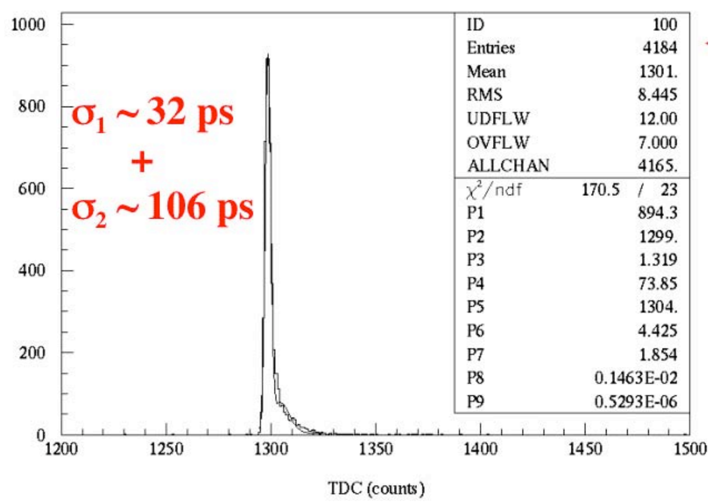
Signal:
400ps/div, 100mV/div, **6dB att.**
Amp-to-scope: 20ns



CFD zero-crossing monitor:
400ps/div, 50mV/div, **6dB att.**
CFD delay: **1.5ns**



Amplifier-CFD delay ~ 20 ns (BNC cable):

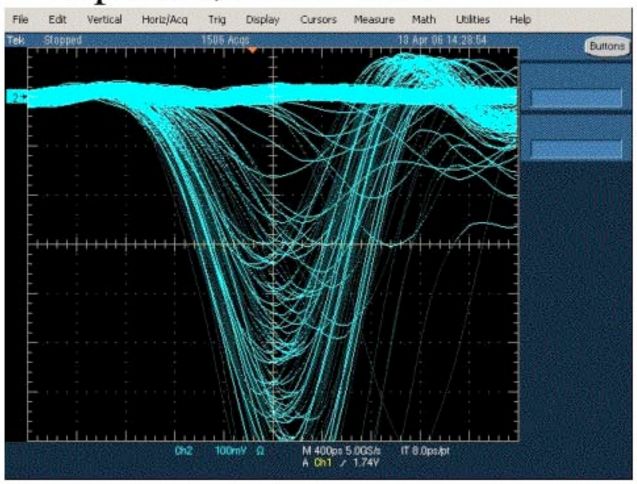


- -2.80 kV
- **Single photons**
- **"Open area" Burle MCP 85012-501**
- 10μm hole 64 pad MCP-PMT
- S/N 11180401
- **Phillips 715 CFD:**
  25mV threshold
- **CFD delay:**
  1.5ns (plus ~250ps int. delay)
- **Detector-amplifier delay:**
  ~ 2 ns
- **LeCroy TDC:** 24ps/ct
- **Add 6dB attenuator after VT-120A amp.**
- **Best result overall.**
- **Scope: Tek 5104, 1GHz BW (~350ps rise time - not fast enough to see the MCP true rise time), 5GS/s**

Ortec amplifier 9306

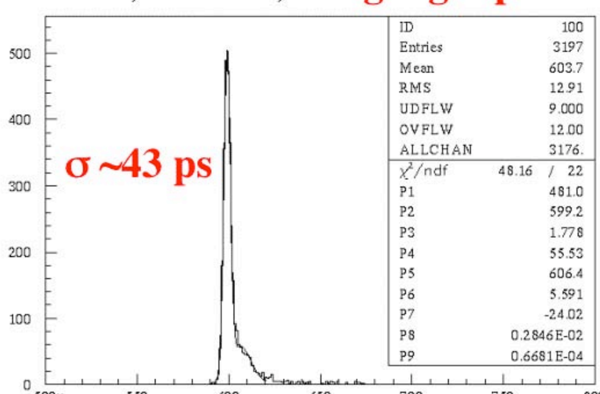
1.0 GHz BW, 100x gain

400ps/div, 100mV/div



Amplifier-CFD delay ~5 ns (SAM cable):

Run 69, 8 att. in, Fit: **g + g + p2**

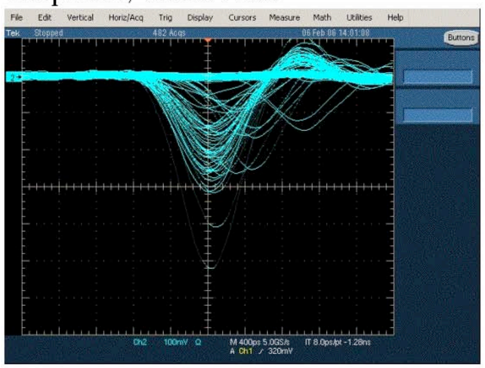


- -2.80 kV
- **Single photons**
- **"Open area" Burle MCP 85012-501**
- 10μm hole 64 pad MCP-PMT
- S/N 11180401
- **Ortec 9307 "pico":**
  25mV threshold
- **Detector-amplifier delay:**
  ~ 2 ns
- **LeCroy TDC:** 24ps/ct
- **Scope: Tek 5104, 1GHz BW (~350ps rise time - not fast enough to see the MCP true rise time), 5GS/s**

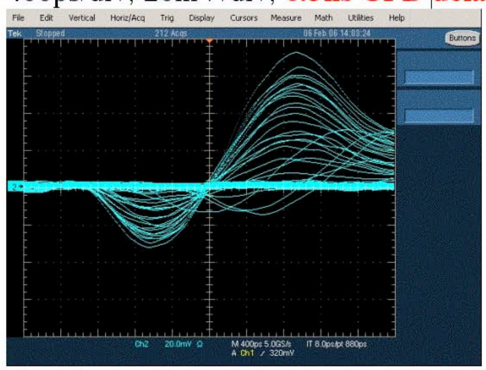
Texas Instr. amplifier THS 4303

Tandem-of-two chip, total gain of 30-40x (each chip has a gain of 10x & 1.8 GHz BW)

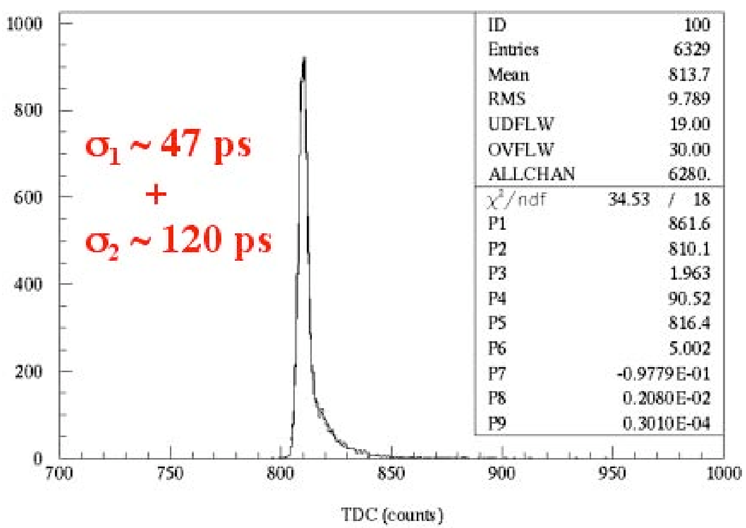
Amplifier output:
400ps/div, 100mV/div



CFD zero-crossing monitor:
400ps/div, 20mV/div, **0.5ns CFD delay**



Amplifier-CFD delay ~ 5 ns (SAM cable):

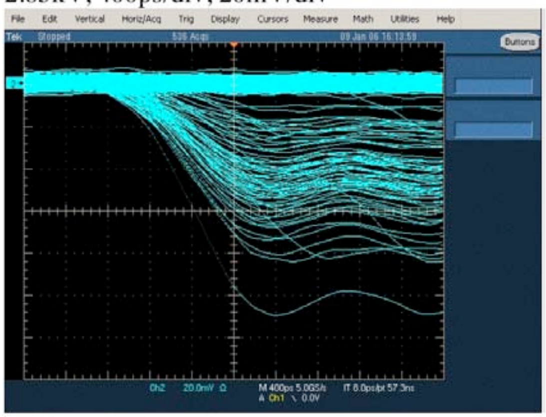


- -2.80 kV
- **Single photons**
- **"Open area" Burle MCP 85012-501**
- 10μm hole 64 pad MCP-PMT
- S/N 11180401
- **Phillips 715 CFD:**
  25mV threshold
- **CFD delay:**
  0.5ns (plus ~250ps int. delay)
- **Detector-amplifier delay:**
  ~ 2 ns
- **LeCroy TDC:** 24ps/ct
- **Making a tandem of two THS4303 chips meakes a total effective gain of 30-40x (marginal).**
- **Scope: Tek 5104, 1GHz BW (~350ps rise time - not fast enough to see the MCP true rise time), 5GS/s**

Elantek 2075

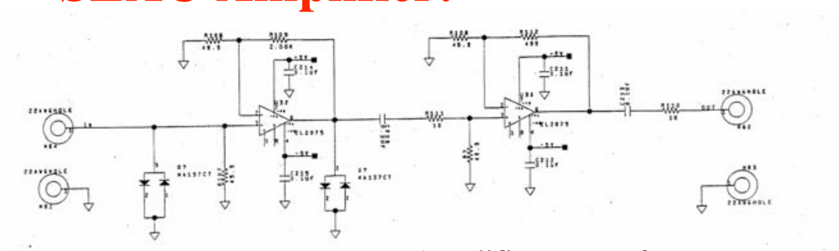
Tandem-of-two, total gain of 130x (each chip has a gain of 10x & 1.5GHz BW)

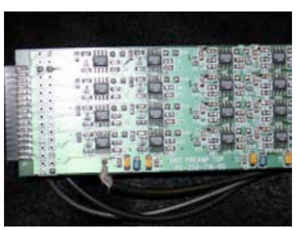
2.85kV, 400ps/div, 20mV/div



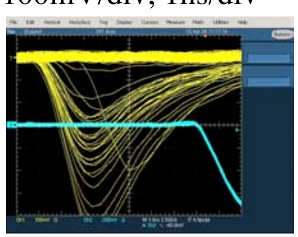
- **Single photoelectrons**
- **"Open area" Burle MCP 85012-501**
- 10μm hole 64 pad MCP-PMT
- S/N 11180401
- A very small signal even at 2.85kV
- **The amplifier is too slow to follow the fast signal from the 10 μm hole MCP-PMT**

SLAC Amplifier:

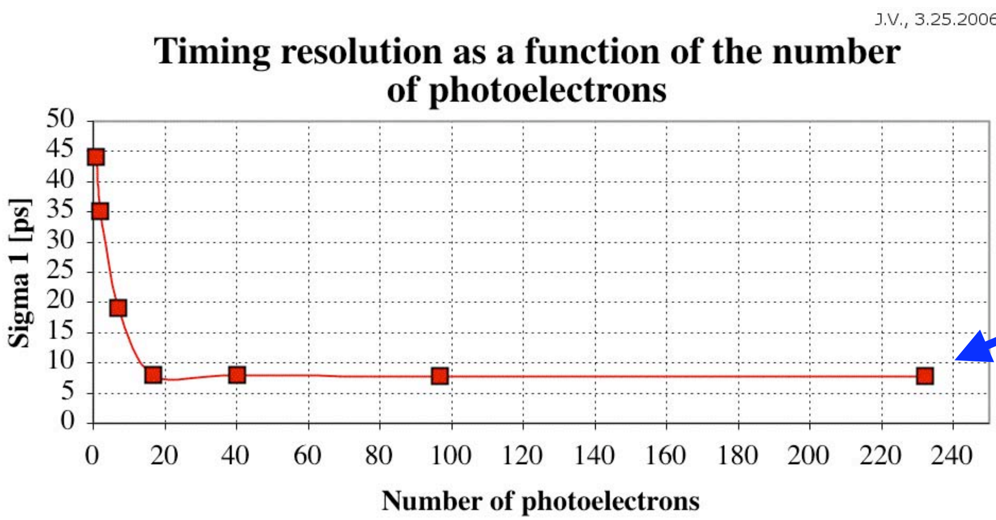




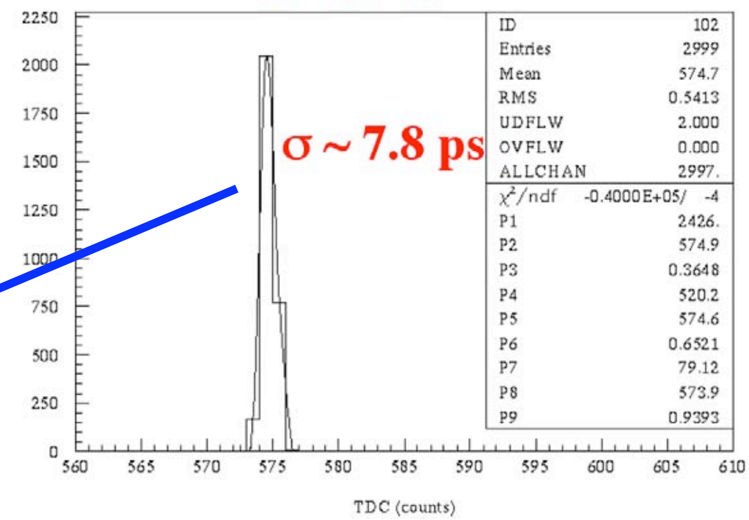
Amplifier output from
MCP-PMT (25μm holes)PiLas), Pilas trigger
100mV/div, 1ns/div



Timing resolution = f($N_{photoelectrons}$)



Run 55, fit: **g + g + g**

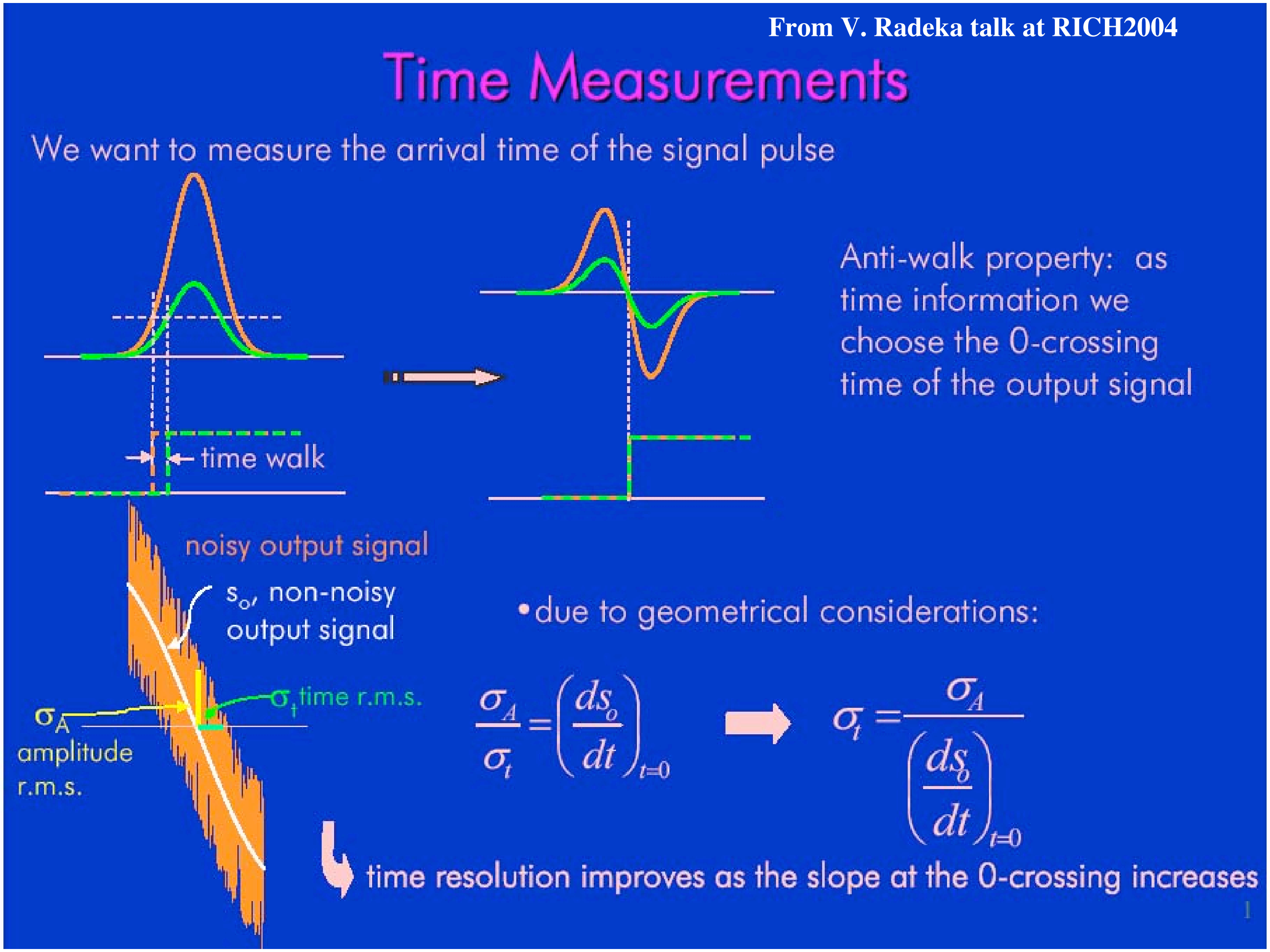


- **Achieved σ ~7-8ps for N_{pe} >20**
- **10μm hole 64 pad Burle "open area" MCP-PMT 85012-501, -2.80kV**
- **Hamamatsu C5594-44 amplifier. Very similar results with Ortec 9306 amp.**
- Phillips 715 CFD, 25mV th., delay:1ns (+250ps internal delay)
- LeCroy TDC 24 ps/count (It would be better to have a TDC with 12ps/count)
- In real application, need to measure ADC to correct for a variation in N_{pe}.

<u>Not bad at all</u>, considering that there is a large number of "sins" in my setup.

- PiLas trigger has a poor rise time (should one trigger on light ?)
- PiLas trigger cable is a long BNC cable (32ns)
- NIM-to-TTL convertor is an ordinary off-shelve very old circuit
- Limited by the TDC resolution (25ps/count). Need 12ps/count.
- Detector has a short LEMO cable before it goes into SMA cable
- CFD has a LEMO connector - need SMA-to-BNC-LEMO adaptor
- Phillips CFD is not a high BW circuit (300MHz BW)
- etc.

Speed of the amplifier & detector is essential for good timing



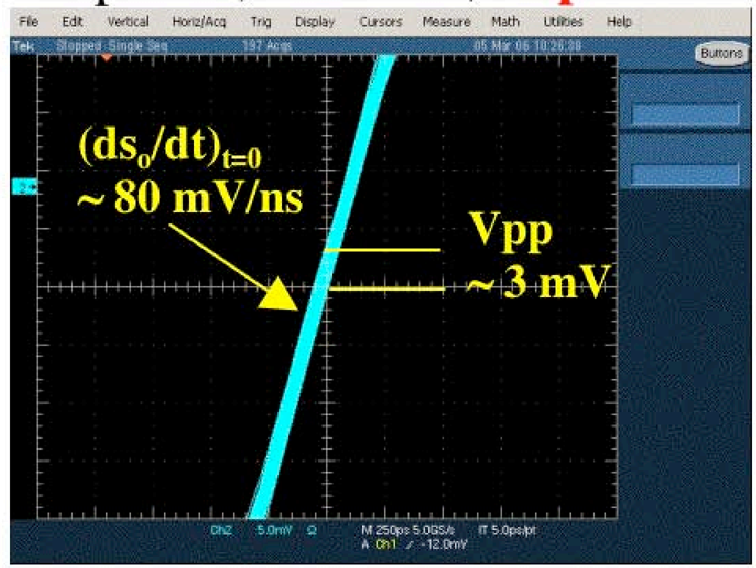
Expected CFD resolution for Npe >25 pe^-

Amp-to-CFD delay: **4 ns**

CFD monitor-to-scope delay: **16 ns**, CFD delay: **1.5ns**

1.25ns/div, 100mV/div

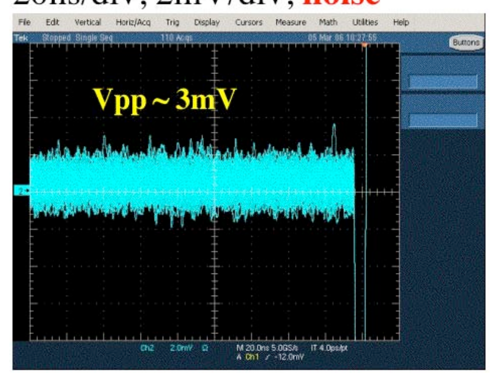
250ps/div, 5mV/div, **slope**



Zero-crossing point of Phillips 715 CFD:

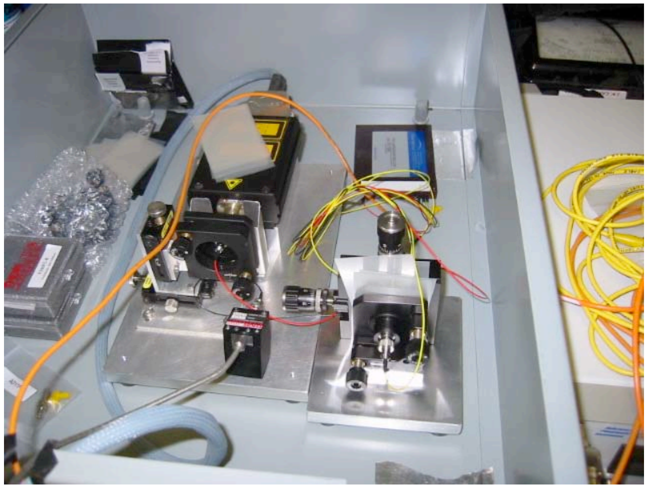
- Noise at the zero-crossing point: Vpp ~ 3 mV
- Noise at the zero-crossing point: $\sigma_A \sim Vpp/3 = 1$ mV
- Slope: $(ds_o/dt)_{t=0} \sim 40mV/500ps = 80mV/ns$
- $\sigma_t \sim \sigma_A/(ds_o/dt)_{t=0} \sim 1\ mV/(40mV/500ps) \sim$ **12 ps**

20ns/div, 2mV/div, **noise**



Can one further improve the resolution triggering on light ?

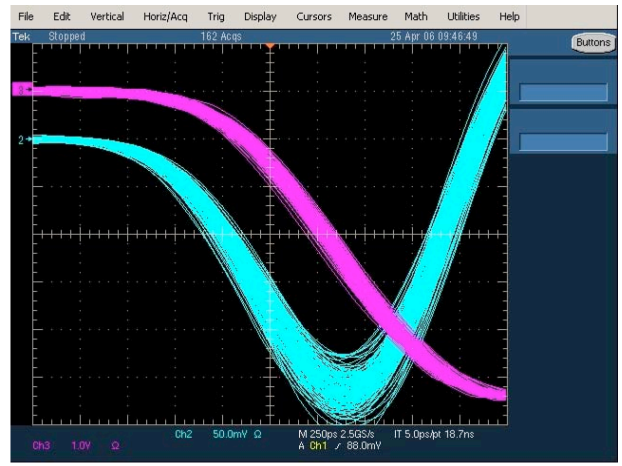
Add a fiber splitter & 2-nd x&y stage:



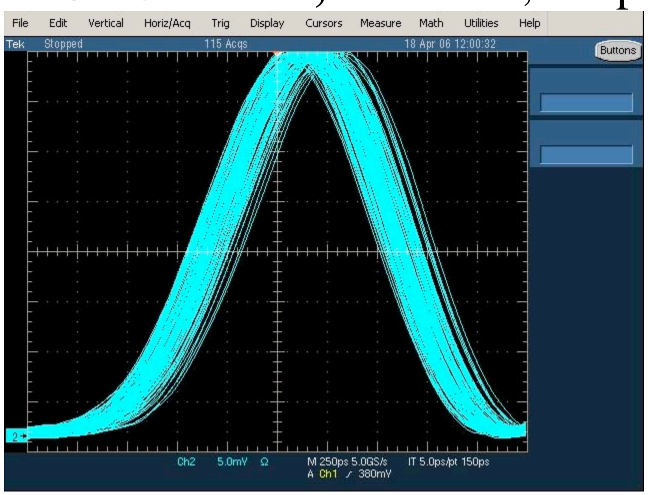
Trigger scope on PiLas electrical pulse:

MCP signal (no amp): 50mV/div, 250psec/div

Si diode signal: 1V/div, 250ps/div



Trigger on PiLas, and look at Si diode
SV2-FC 2GHz BW, 5mV/div, 250psec/div



So far, I did not get a better resolution when triggering on the light.

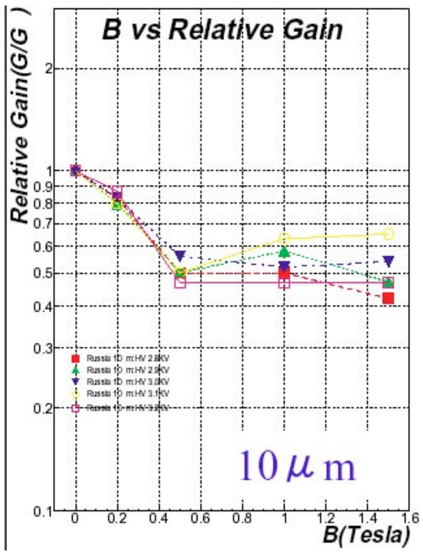
Note on triggering on light:
Si diode -> inv. -> VT120 -> SAM cable -> Phillips CFD

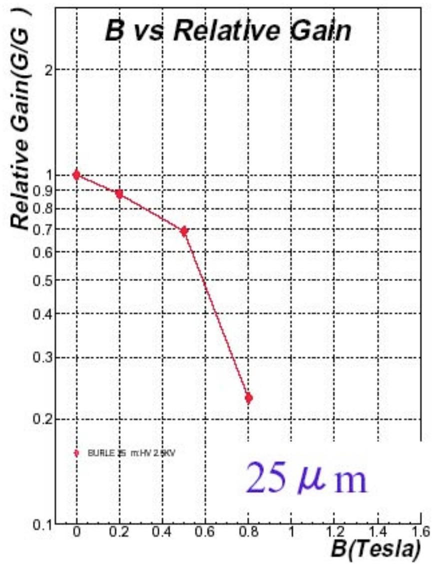
Single photoelectron timing resolution at B = 15 kG (10 μm pore 4-pad MCP-PMT)

MCP peration in the magnetic field

Measurements by M.Akatsu et al., Nagoya, Japan - preliminary

Russia MCP: Burle MCP:



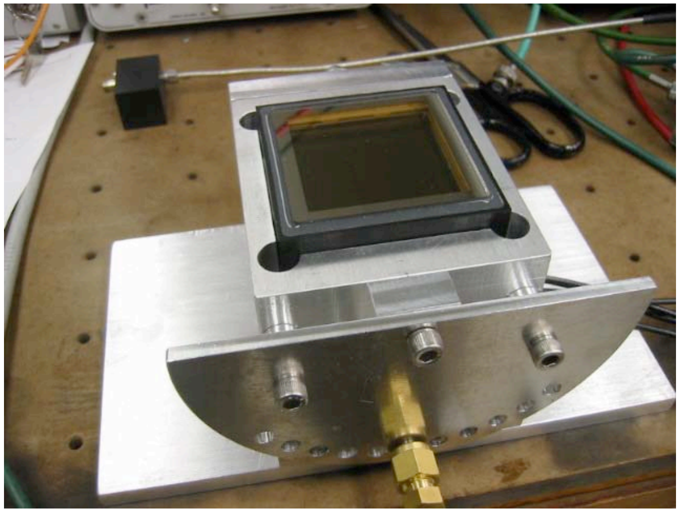


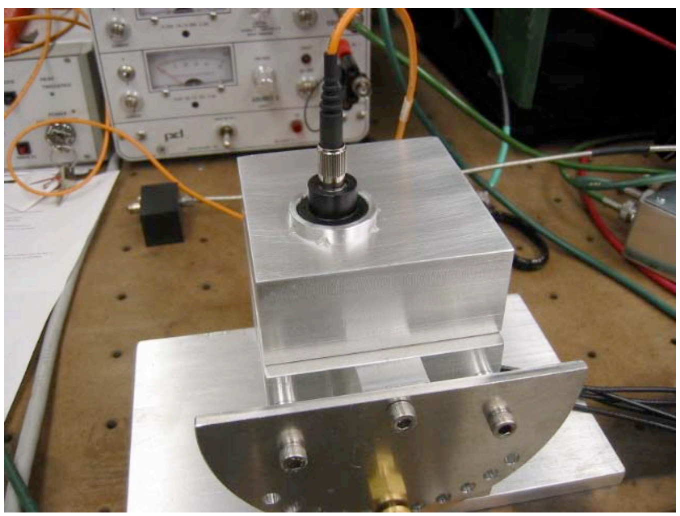
- **Gain in MCP:**
  $G \sim e^{(A*\text{MCP thickness/MCP dia})}$

  gets severely reduced in a large magnetic field of 1.5 Tesla.

  The 25μm dia. holes are too large. One needs to reduce their size to ~10μm dia., or even less. This is our next step.
- In addition, one needs to increase the electric field between anode and cathode.

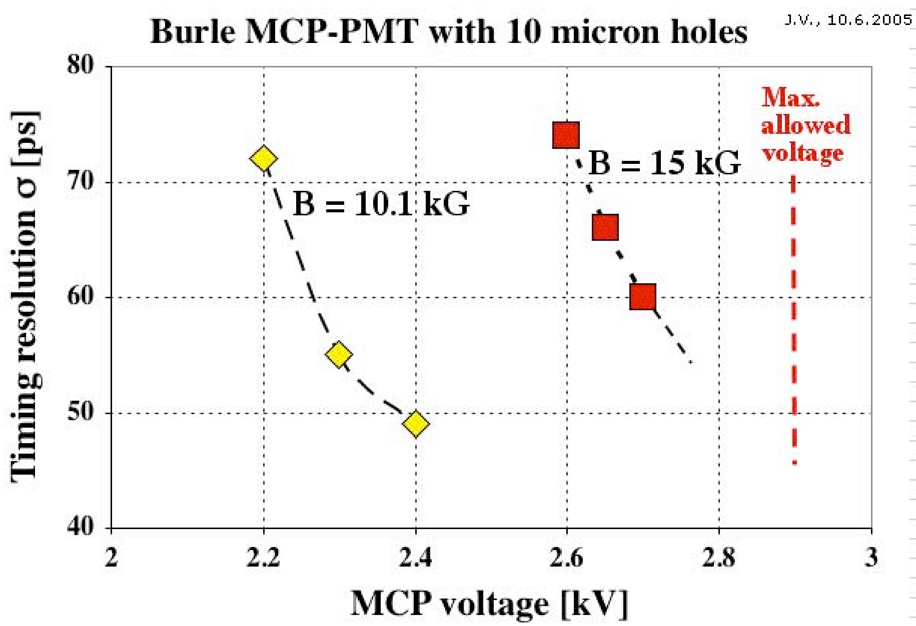
Burle MCP-PMT with 10μm holes





- 4-pixel MCP-PMT 85001-501 P01 tube for the initial tests.
- PMT has two MCPs with 10 μm dia. holes
- Cathode-to-MCP distance ~6mm
- According to Burle, this particular 10μm MCP should produce a gain of ~10^6 at –2.2kV.
- Setup had a capability to measure sensitivity to angles in 5° steps between the magnetic field and axis perpendicular to the face plate.

Timing results at B = 15 kG

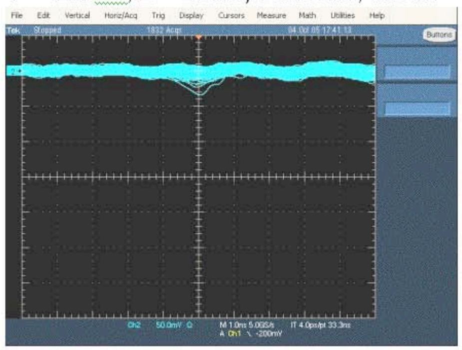


- **Ortec VT-120A amp**
- **Initially, there was some confusion what the maximum allowed voltage. Burle initially thought that it is -2.4kV. After I have "overvoltaged" the tube to -2.7kV to get a decent timing result at 15kG, Burle corrected the max voltage value to -2.85kV. I could have gone higher….**
- **This means that it is possible to reach a resolution of σ ~50ps at 15kG.**

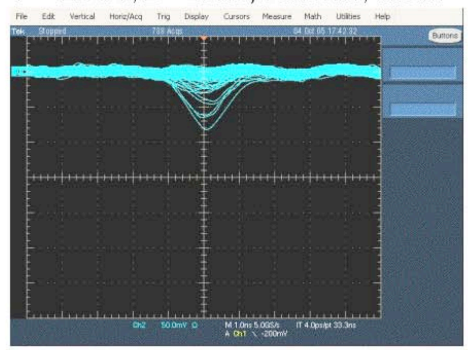
Sensitivity to MCP voltage at B = 15kG

Ortec VT-120A amp, -2.65kV, 50mV/div, 1ns/div:

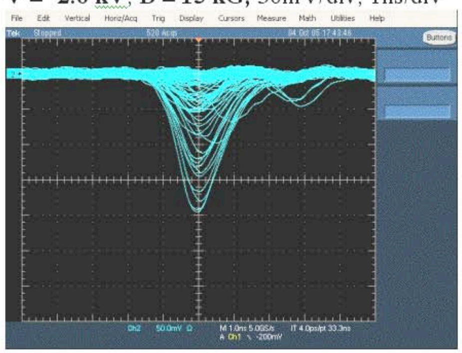
V = -2.4 kV, B = 15 kG, 50mV/div, 1ns/div



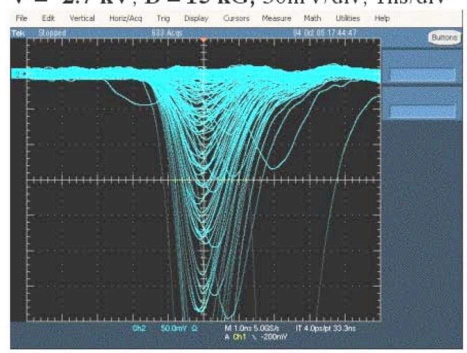
V = -2.5 kV, B = 15 kG, 50mV/div, 1ns/div



V = -2.6 kV, B = 15 kG, 50mV/div, 1ns/div



V = -2.7 kV, B = 15 kG, 50mV/div, 1ns/div

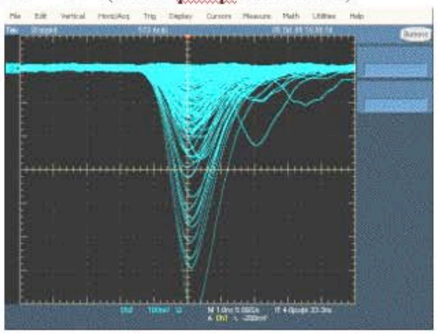


- **The necessary voltage to get a good timing resolution is 2.7-2.8kV.**

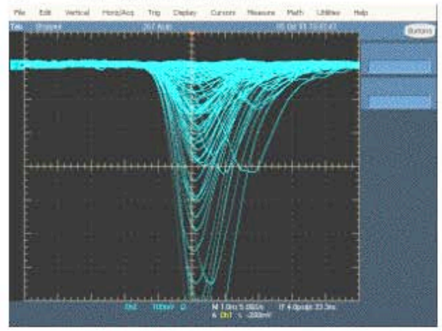
Sensitivity to angular rotation at B = 15kG

Ortec VT-120A amp, -2.65kV, 100mV/div, 1ns/div:

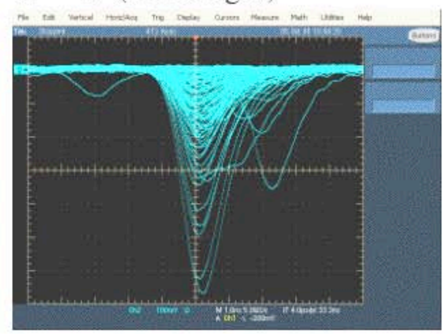
Θ = 0° (face perp. to field)



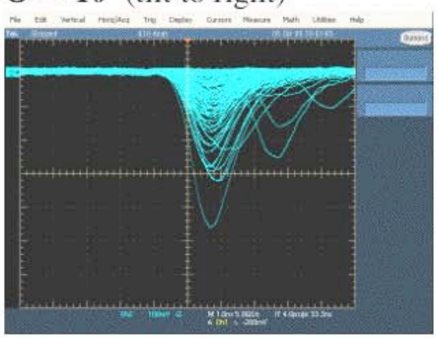
Θ = +3° (tilt to left)



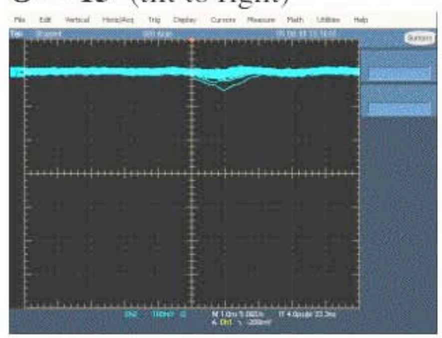
Θ = -3° (tilt to right)



Θ = -10° (tilt to right)



Θ = -15° (tilt to right)



Θ = -20° (tilt to right)

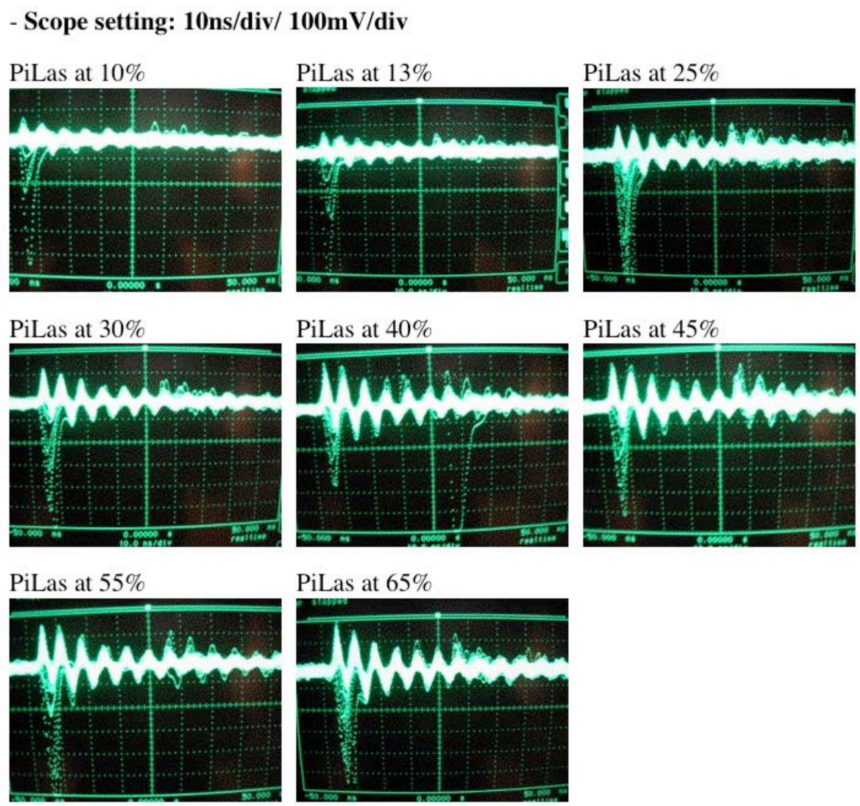
- **The MCP can be tilted by 3-5° before pulse height is affected. At 10°, one sees a clear reduction of pulse height, but the tube can still be used. At 15° and above, the response is killed entirely.**

Coherent resonance effects ?

(observed in the prototype)

This is what may happen when one tries to be too fast…

Coherent excitation resonance effects

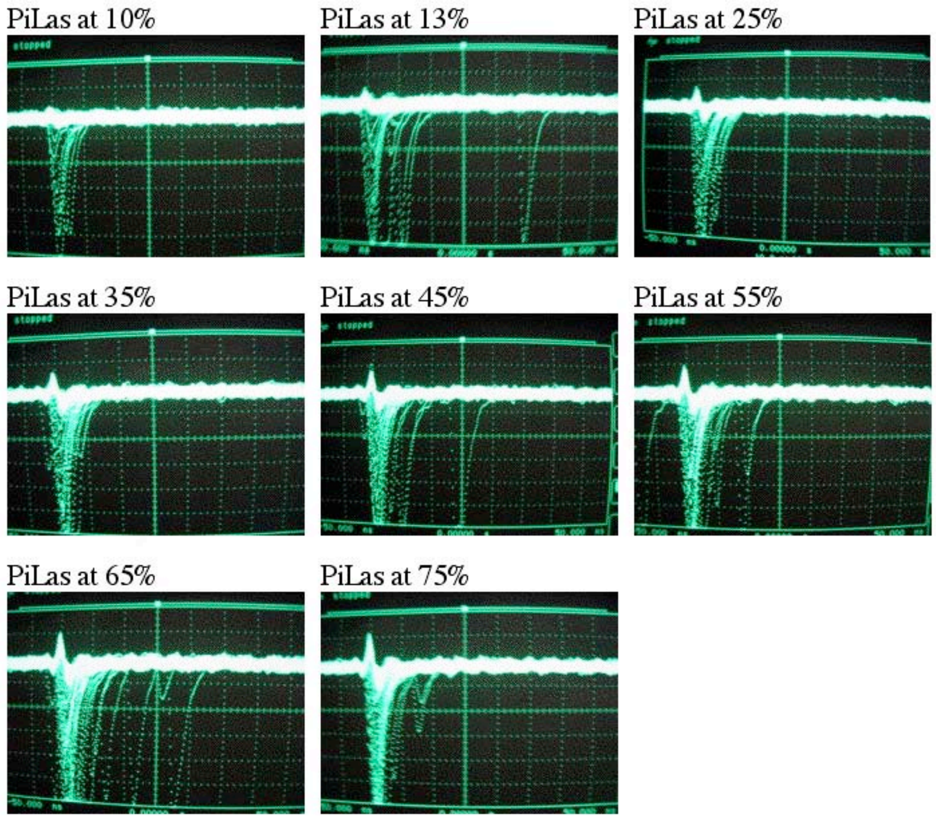


During the run we typically get 3-4 Cherenkov photons, which do not arrive at the same time, so we probably do not suffer from this problem. However, this needs to be fixed.

- **The effect generated by a PiLas producing enough light that multiple pixels fire. At a power of 25% we get a 10% probability to get a hit, which means that something like 6-7 pixels fire per one PiLas trigger. The pulses arrive to the MCP-PMT within < 1 ns, and are capable to excite the standing resonance.**

Coherent excitation resonance effects

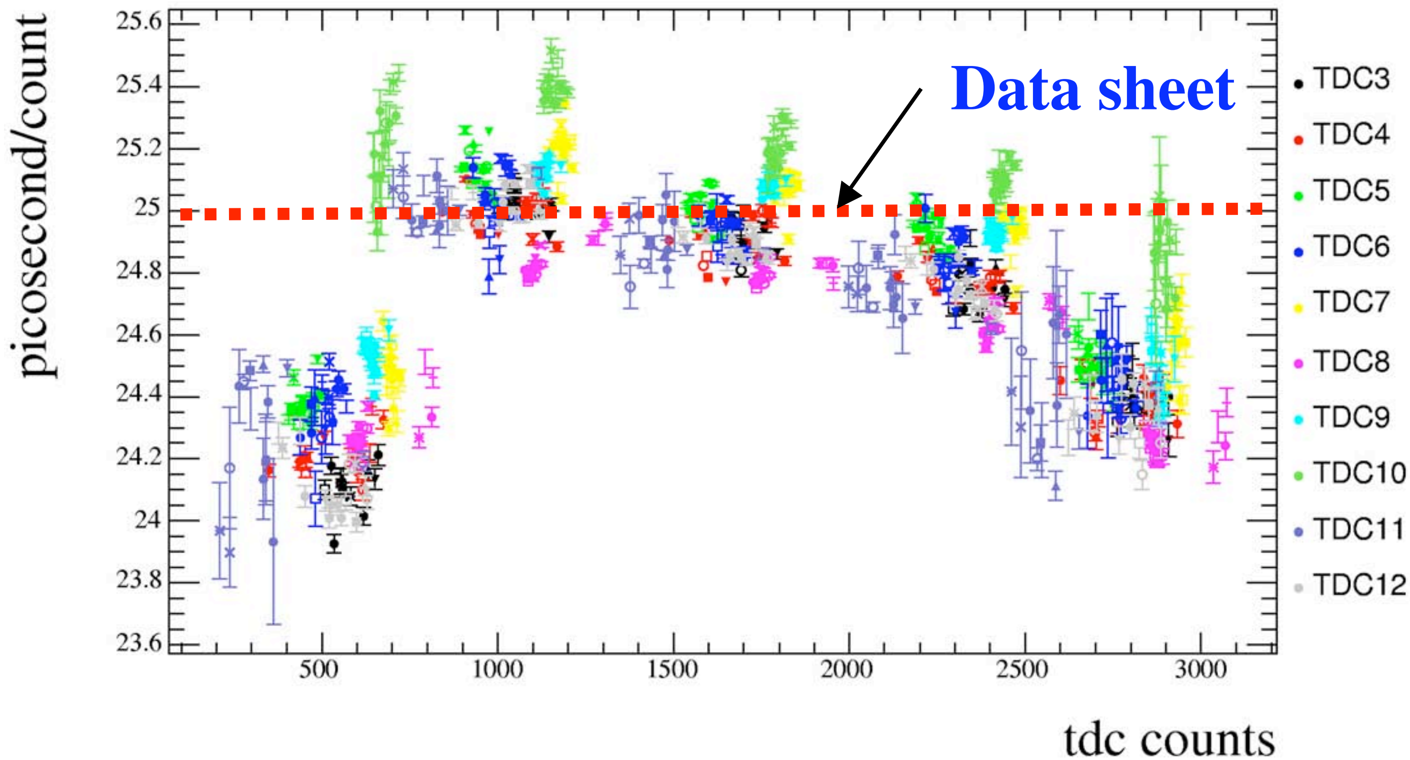
- Scope setting: 10ns/div/ 100mV/div, PiLas trigger
- 0.85 kV:



- **The effect does not exist with the Hamamatsu MaPMTs (the same amplifier, the same LV PS, the same grounding).**

Other problems

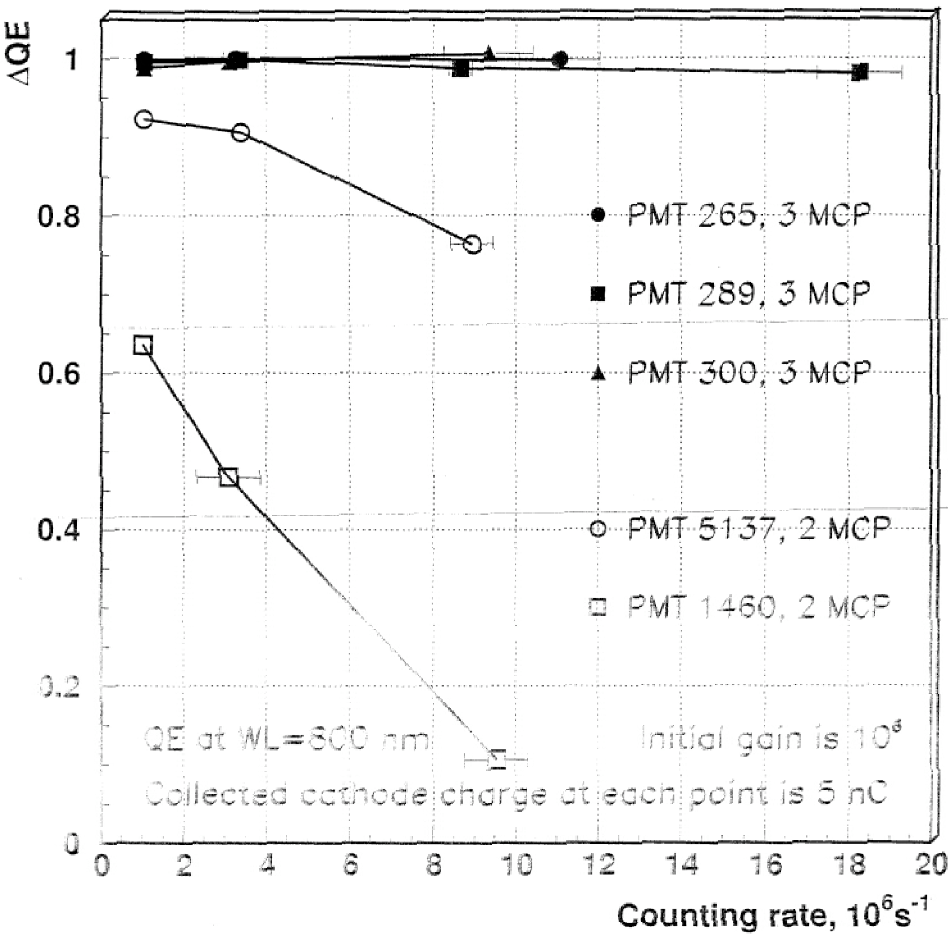
Phillips TDC calibration



- **Is it stable in time ? How often we have to measure this ?**
- The differential linearity measured with the calibrated cables. May have to automatize process with a precision digital delay generator if we get convinced.

Results from Russian MCP-PMT studies

by M. Baryshnikov, SNIC

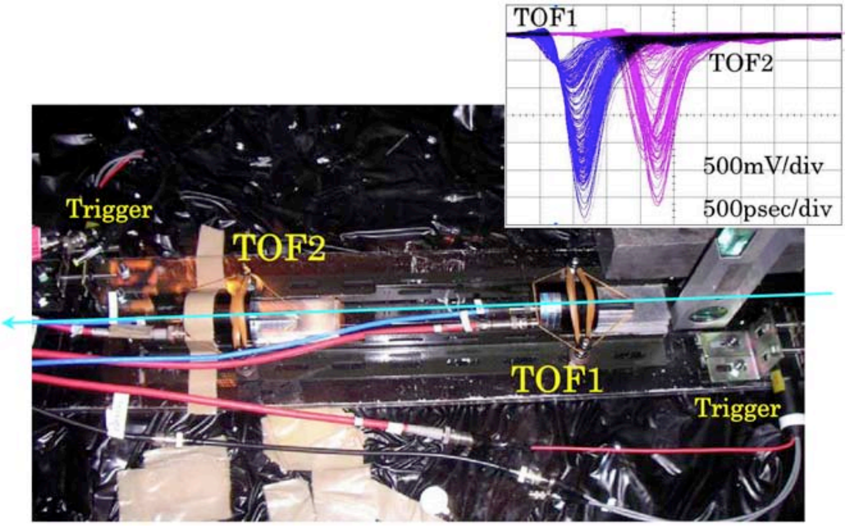


- Russian MCP-PMT
- Damage of QE depends on the rate
- 3 MCP geometry does better from aging point of view
- No film protection in these MCP studies

Compare results with the competition

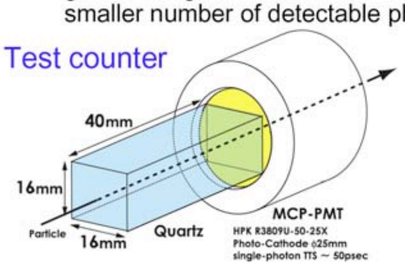
High precision TOF system

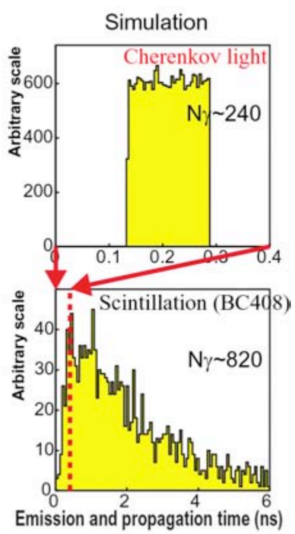
K.Inami, Nagoya Univ., Japan - SNIC conf. at SLAC, April 2006



- Structure
  - Small-size quartz (cm~mm length)
    - Cherenkov light (Decay time ~ 0) extremely reduce time dispersion compared to scintillation (τ ~ ns)
  - MCP-PMT (multi-alkali photo-cathode)
    - TTS < 50ps even for single photon gives enough time resolution for smaller number of detectable photons

Test counter



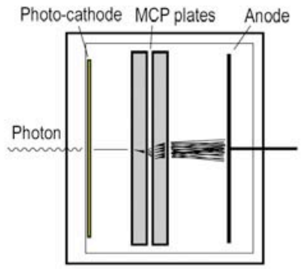


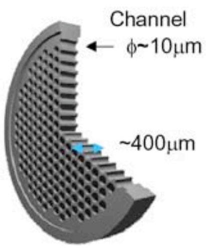
- **New MCP with 6 μm holes**
- **Multi-alcali photocathode**
- **TTS < 50ps**
- **11 mm dia.**
- **Gain of 10^6 for 2-stage MCP**
- **SPC-134 TDC 813 ps/count**
- **Aging results with & without film protection**
- **Electronics resolution: σ ~ 4.7ps**
- **Result: σ ~ 6.7ps**

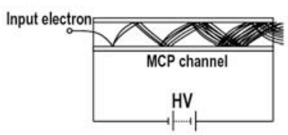
MCP-PMT & electronics & timing resolution

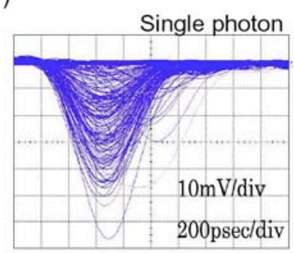
K.Inami, Nagoya Univ., Japan - SNIC conf. at SLAC, April 2006

- Micro-Channel-Plate
  - Tiny electron multipliers
    - Diameter ~10μm, length ~400μm
  - High gain
    - ~10^6 for two-stage type
  - → Fast time response
    - Pulse raise time ~500ps, TTS < 50ps
  - can operate under high magnetic field (~1T)



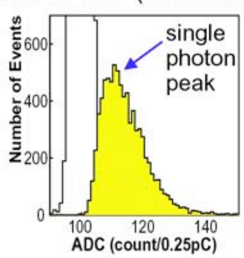


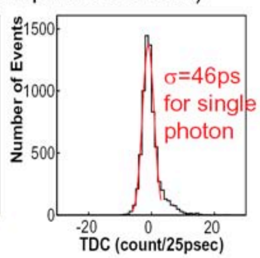


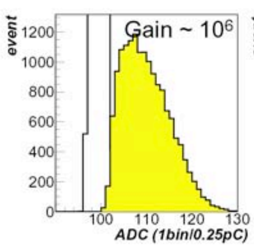


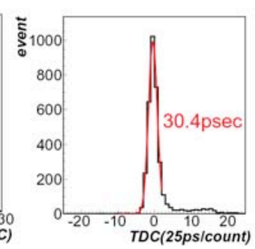
- Hamamatsu R3809U-50 (multi-alkali photo-cathode)

MCP hole 10μmφ



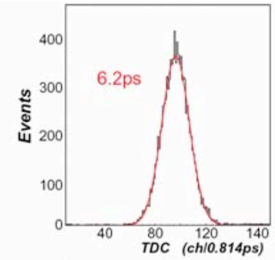




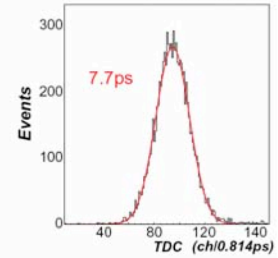


Resolution results:

- With 10mm quartz radiator
  - +3mm quartz window
  - Number of photons ~ 180
  - Time resolution = 6.2ps
  - Intrinsic resolution ~ 4.7ps



- Without quartz radiator
  - 3mm quartz window
  - Number of photons ~ 80
    - Expectation ~ 20 photo-electrons
  - Time resolution = 7.7ps



- Readout electronics
  - $\sigma_{elec.}$: 8.8ps → 4ps
  - Time-correlated Single Photon Counting Modules (SPC-134, Becker & Hickl GMbH's)
    - CFD, TAC and ADC
    - Channel width = 813fs
    - Electrical time resolution = 4ps RMS

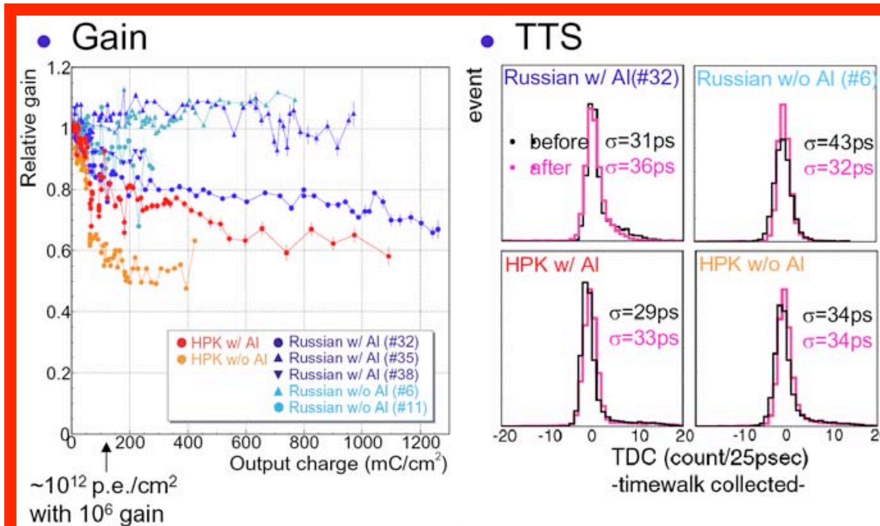
- MCP-PMT
  - TTS: ~46ps → ~30ps
  - 10μm hole → 6μm hole
    - R3809U-50-25X → -11X

MCP-PMT aging with & without film protection

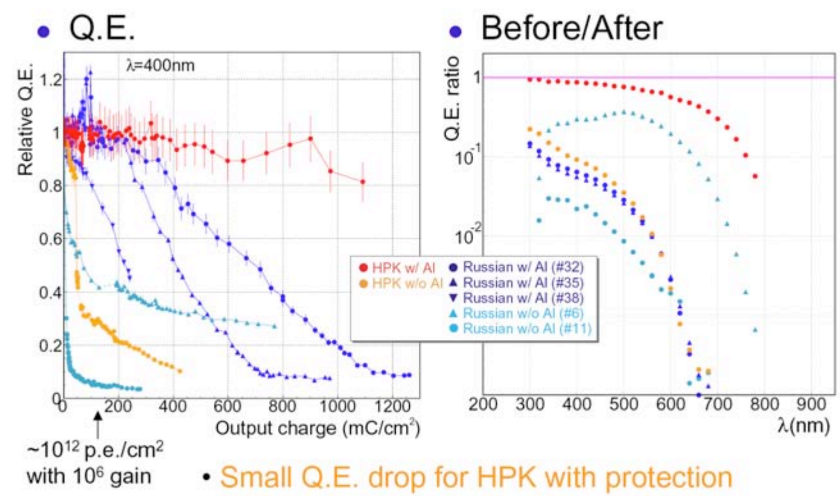
K.Inami, Nagoya Univ., Japan - SNIC conf. at SLAC, April 2006

Aging:

- **With a thin Al film protection, the relative Q.E. and gain stays OK beyond ~1C/cm²**
- **TTS is not affected**
- **The Al film costs a loss of factor of two in the transfer efficiency**

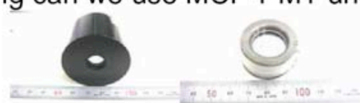


TTS is stable within the gain drops.

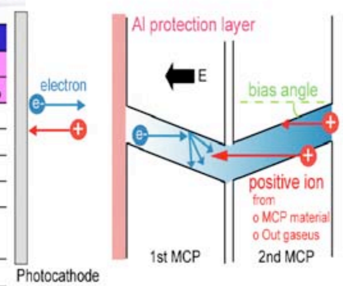


- Small Q.E. drop for HPK with protection
- Fast degradation for longer wavelength

- How long can we use MCP-PMT under high hit rate?



	HPK (x2)		Russian (x5)	
Al protection	O	X	O	X
Correction eff.	37%	65%	40-60%	55-60%
Effective area	11mmφ		18mmφ	
Gain	1.9×10^6	1.5×10^6	$3\text{-}4 \times 10^6$	
TTS	34ps	29ps	30-40ps	
Photo-cathode	Multi-alkali (NaKSbCs)			
Quantum eff. at 400nm	21%	19%	16-20%	
Bias angle	13deg		5deg	



- Light load by LED pulse (1~5kHz)
  - 20~100 p.e. /pulse (monitored by normal PMT)

Time Resolution with GaAsP

T. Ijima, RICH 2004

- TTS may be worse due to thicker photo cathode

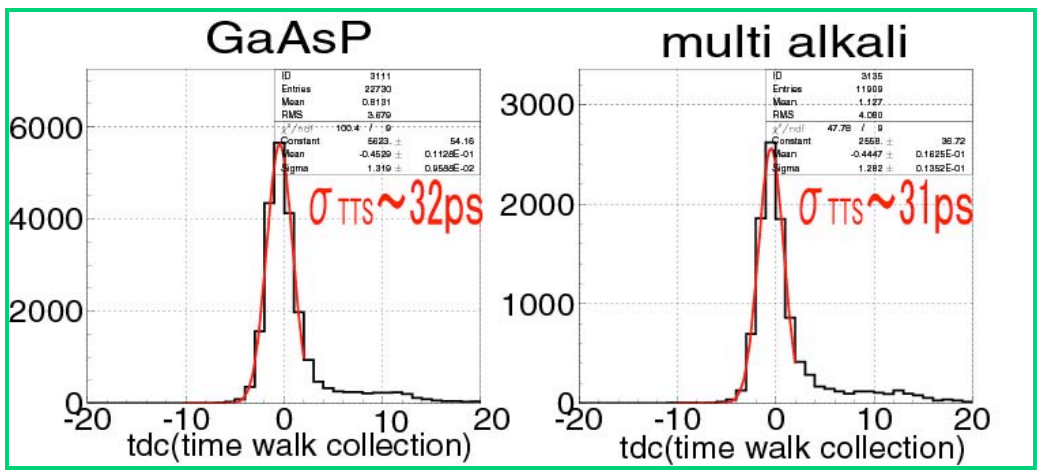
GaAsP:~μm <=> multi(bi)-alkali:~100A

Structure of measured MCP-PMT	
MCP channel diameter	ϕ 6μm
# of MCP	2 stage
anode	single anode
effective area	ϕ 11mm

GaAsP

multi alkal

Same time response has been observed.



Conclusion

- **We achieved a single photon timing resolution of $\sigma \sim 30$-35 ps with a <u>multi-pixel</u> Burle MCP-PMT photon detectors with 10μm holes.**
- **We achieved a multi-photon timing resolution of $\sigma \sim 8$-10 ps with a <u>multi-pixel</u> MCP-PMT photon detectors for $N_{pe} > 20$-25 photoelectrons.**
- **Calibration requirements are non-trivial but probably achievable with proper planning.**
- **But, much more has to be done.**