Photon detectors

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SLAC

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  - Burle MCP-PMTs with 25 and 10 μm dia. holes
- **Gaseous-based detectors:**
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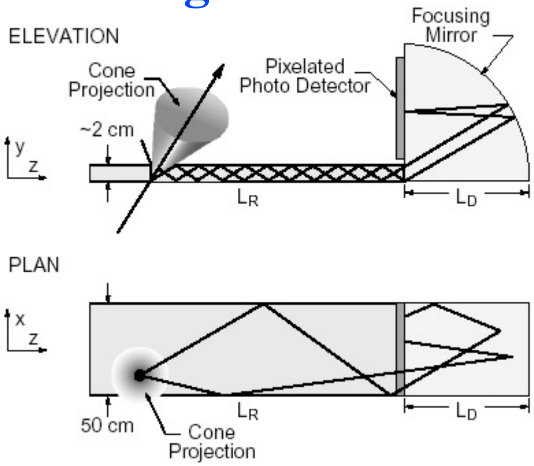
What detector do we want ?

Present prototype:

Future Fast Focusing DIRC:



- **We want to measure x, y and TOP (time-of-propagation) for each photon.**
- **We need a single photon timing resolution at a level of σ ~100-150ps, to be able to perform the TOP measurement and correct the chromatic error contribution to the Cherenkov angle.**
- **We need to operate at 15kG for the Super B-factory, or even at higher field, if the device would find a use at ILC.**
- **We want to have a highly pixilated detector. We started with a square pixel size of ~6x6mm. Now we aim for a rectangular size of ~2x8mm.**
- **The detector should have a good aging performance.**

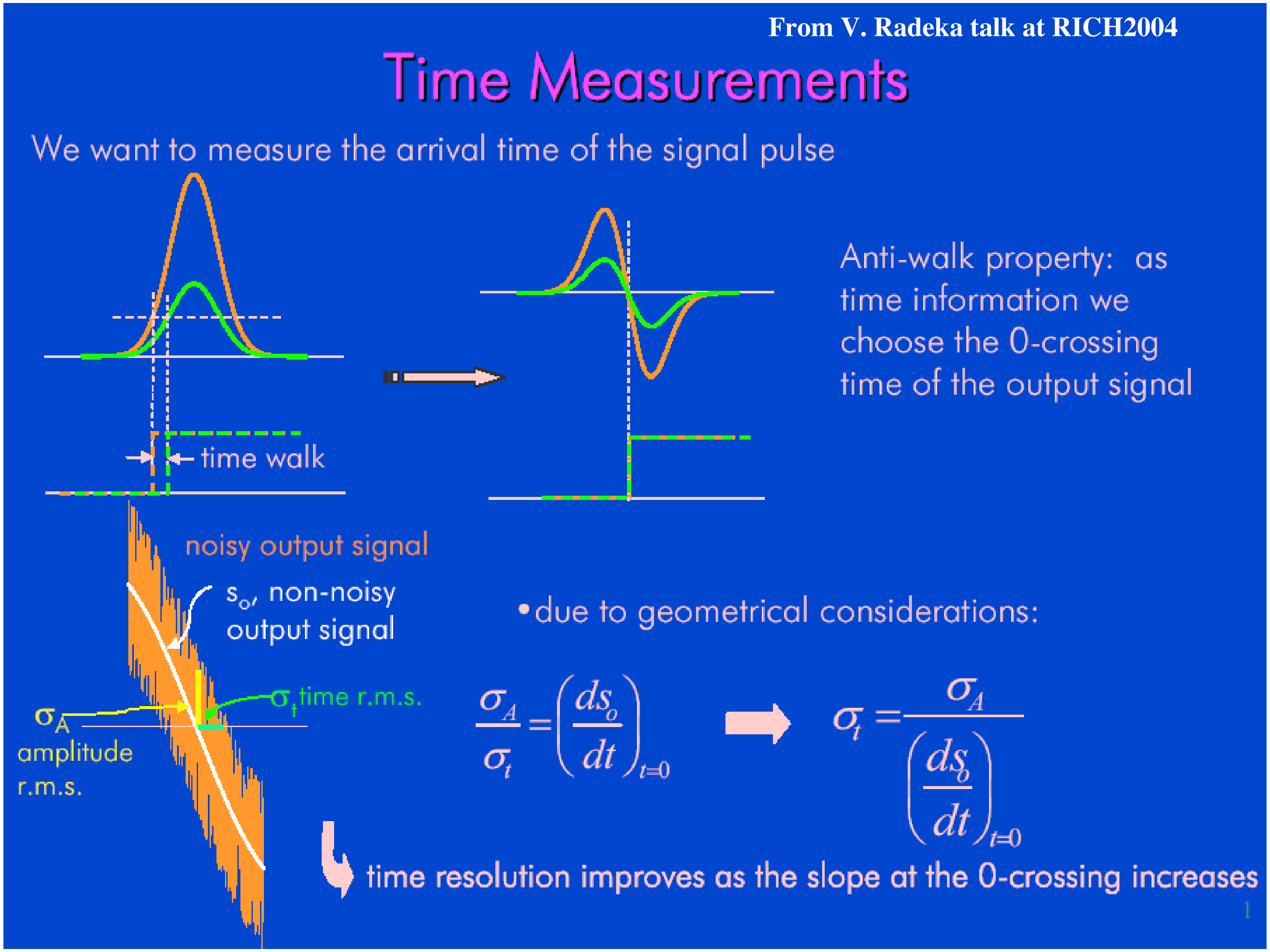
Single photoelectron timing resolution at B = 0 kG

High Resolution Timing

- **We have tried these timing techniques:**
  - Leading edge discriminator + single TDC + ADC correction
  - Constant fraction discriminator (CFD) + single TDC
  - Two leading edge discriminators with two TDCs per channel

  Note: There is no evidence that one method is better than the others. We have chosen the CFD method for the Focusing DIRC prototype. But, in retrospect, I think that for alarge scale system, the "double-threshold + two TDCs" might be a better.
- **Amplifier rise time must be comparable to the photon detector's rise time, and both have to be fast.**
- **Need to have expensive tools:**
  - PiLas laser diode with 35ps FWHM timing capability
  - Fast SiPMT to verify its correct timing operation
  - 2D-scanning setup to measure a PMT response across its face

Speed of the amplifier & detector is essential for good timing



From V. Radeka talk at RICH2004

Time Measurements

We want to measure the arrival time of the signal pulse

Anti-walk property: as time information we choose the 0-crossing time of the output signal

- due to geometrical considerations:

$$\frac{\sigma_A}{\sigma_t} = \left(\frac{ds_o}{dt}\right)_{t=0} \Rightarrow \sigma_t = \frac{\sigma_A}{\left(\frac{ds_o}{dt}\right)_{t=0}}$$

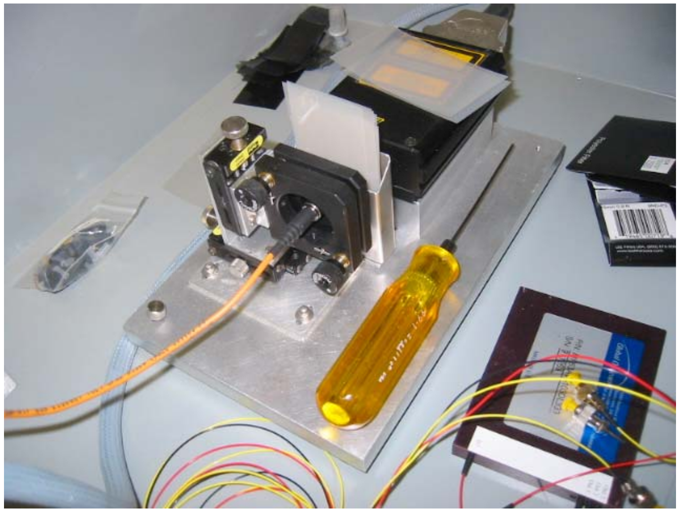
time resolution improves as the slope at the 0-crossing increases

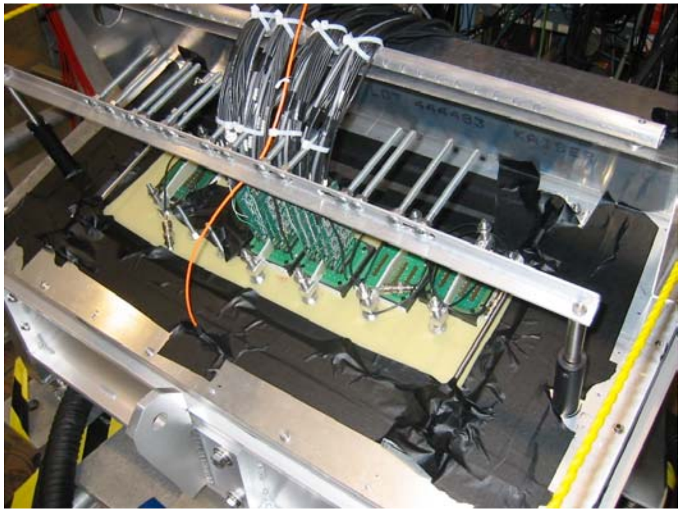
Examples of two amplifiers

- **Elantek amplifier:**
  - Gain ~130x, MCP-PMT with 25µm holes connected
  - $\sigma_A \sim$ 5mV
  - $(ds_o/dt)_{t=0} \sim$ 0.3V/1ns
  - $\sigma_t \sim (5 \times 10^{-3}/0.3) * 1$ns ~15-20ps
- **Ortec VT-120A amplifier:**
  - Gain ~200x, MCP-PMT with 10µm holes connected
  - $\sigma_A \sim$ 5mV
  - $(ds_o/dt)_{t=0} \sim$ 1.2V/1ns
  - $\sigma_t \sim (5 \times 10^{-3}/1.2) * 1.0$ns ~ 4-5ps

- **Both amplifiers will do the excellent job from noise point of view.**
- **However, the Ortec VT-120A amp is much better match for the speed of the MCP-PMT with 10 µm holes.**

PiLas laser diode and fiber optics

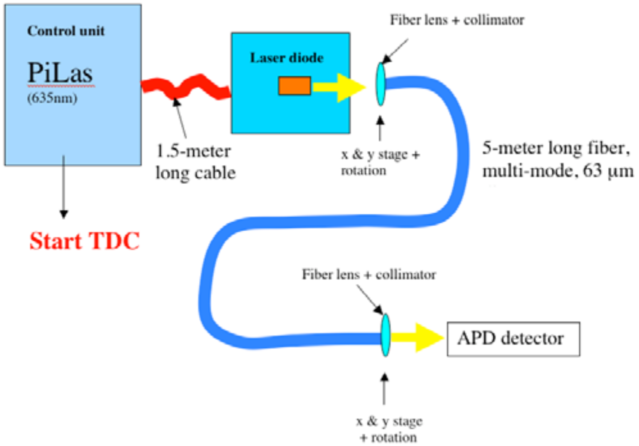




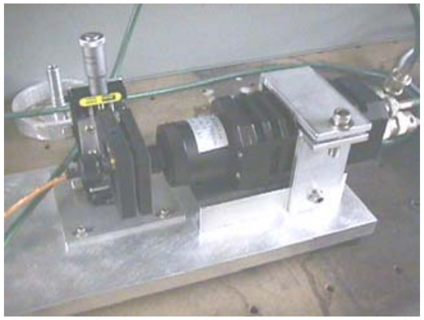
- **Achieved σ ~ 40-70ps with:**

  - 635, 430 and 407nm wavelengths
  - 63μm dimeter multi-mode fiber
  - 5 & 10 m fiber lengths
  - 1-to-3 fiber splitter
  - "Home-made" alignment with the x&y small stage
  - Mylar attenuators to get single photons
  - CFD discriminator or TDC/ADC electronics

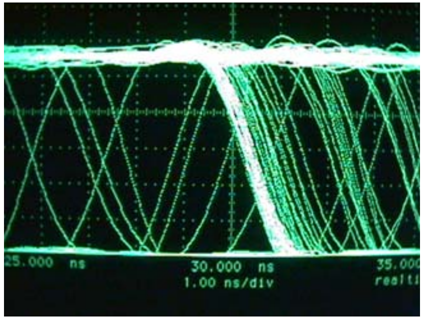
Use a SiPMT detector to verify that the PiLas laser diode



SiPMT:

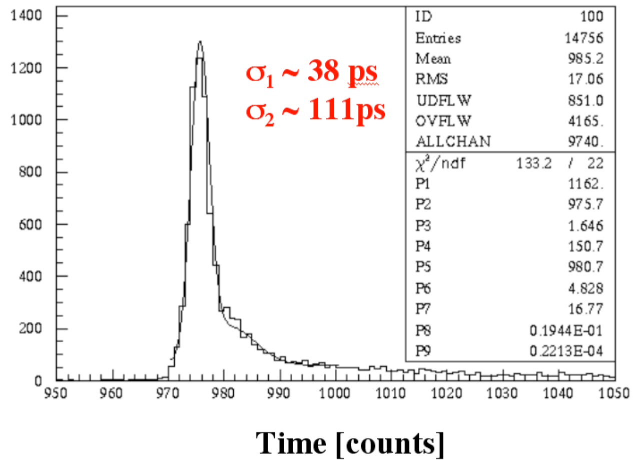


CFD analog out, 1ns/div:



Use this one in this test

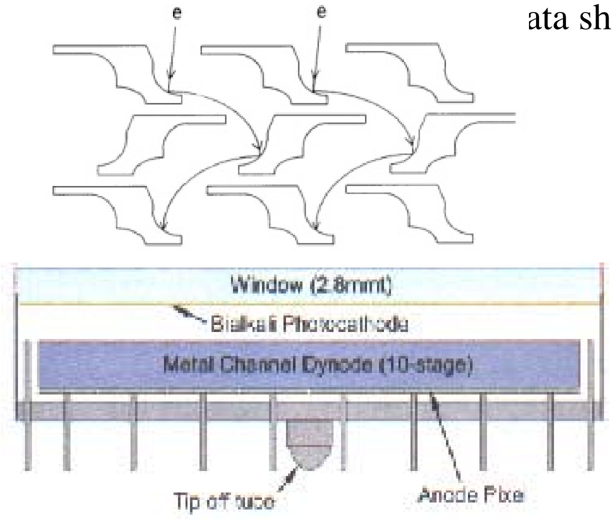
Parameter	PiLas 043G	PiLas 063G	Hamamatsu
Wavelength	430 nm	635 nm	394 nm
Tolerance [nm]	± 10	± 5	
Spectral width [nm]	< 7	< 7	
FWHM of light pulse spread	< 60 ps	~35 ps	34 ps
Light pulse jitter relative to trigger	~2 ps	~2 ps	±10 ps
Peak power [mW]	> 140	> 200	



- Detector: 100 μm dia. GaP SiPMT (APD) operating in a Geiger mode with active quenching. APD developed by Sopko & Prochazka, CVUT Prague. The authors quote this timing resolution: $\sigma_{diode} \sim$ (FWHM = 58/2.35) ~ 25 ps for the single photoelectron regime. Therefore, we expect: $\sigma_{PiLas} \sim \mathrm{sqrt}(\sigma_{result}^2 - \sigma_{APD}^2 - \sigma_{electronics}^2) \sim \mathrm{sqrt}(38^2 - 25^2 - 17^2)$ **~23 ps**; PiLas data sheet quotes: (35/2.35) **~15ps**) - **a small inconsistency due to some systematic error** (PiLas power set to ~11% might be too low).
- Electronics chain in this test: SLAC CFD, 30mV threshold, CFD analog output to the LeCroy 2228ATDC (25ps/count).

Hamamatsu H-8500 Flat panel MaPMT

ata sheet + SLAC measurements + my interpretation

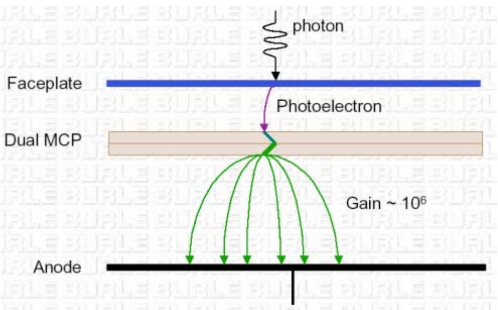


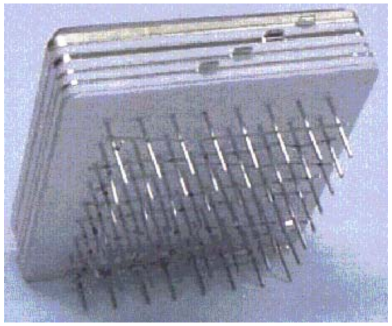
Hamamatsu data on H8500 Flat Panel MaPMT (some SLAC measurements included)

Parameter	**Value**
Photocathode type	Bialkali
Number of dynodes	12
Total average gain @ -1kV	~10^6
Geometrical collection efficiency of the 1-st dynode	70-80%
Geometrical packing efficiency	97%
Fraction of late photoelectron arrivals (SLAC estimate)	~5%
Total fraction of "in time" photoelectrons detected	**65-75%**
SLAC measurement of single electron resolution (σ_{narrow})	~140ps
Matrix of anode pixels	8 x 8
Number of anode pixels	64
Pixel size	6mm x 6mm

Burle 85011 MCP-PMT parameter list

Burle Co. data sheet + SLAC measurements + my interpretation





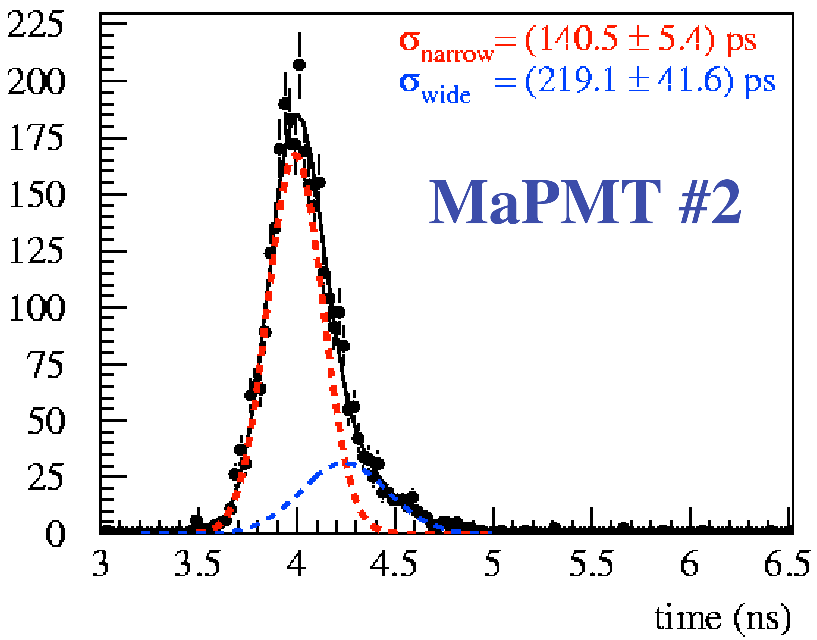
Burle data on 85011 MCP-PMT (some SLAC measurements included)

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	~5×10^5	~5×10^5	~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

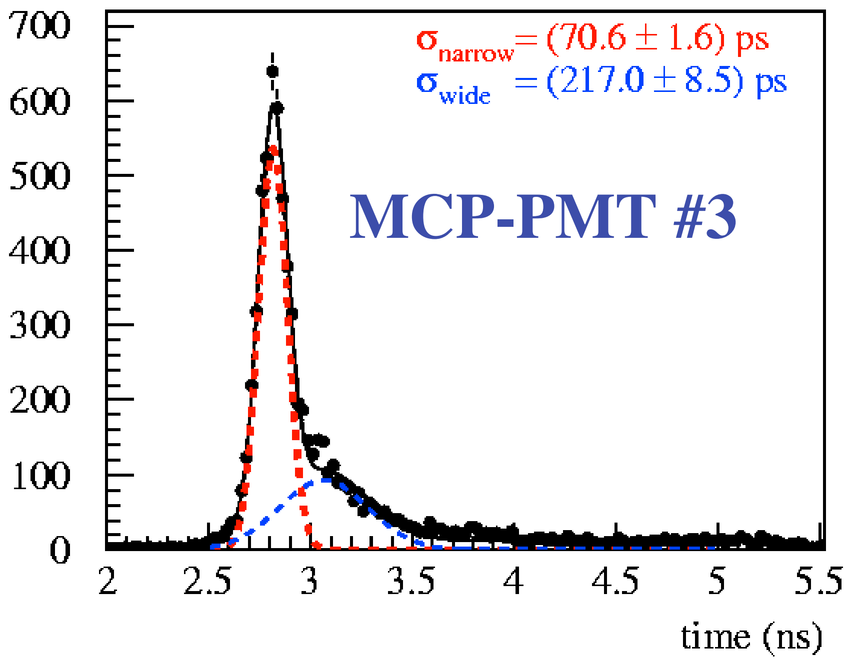
← !!

Timing studies in MaPMT and MCP-PMT

Hamamatsu Flat Panel H8500 PMT:



Burle 85011-501 MCP-PMT:

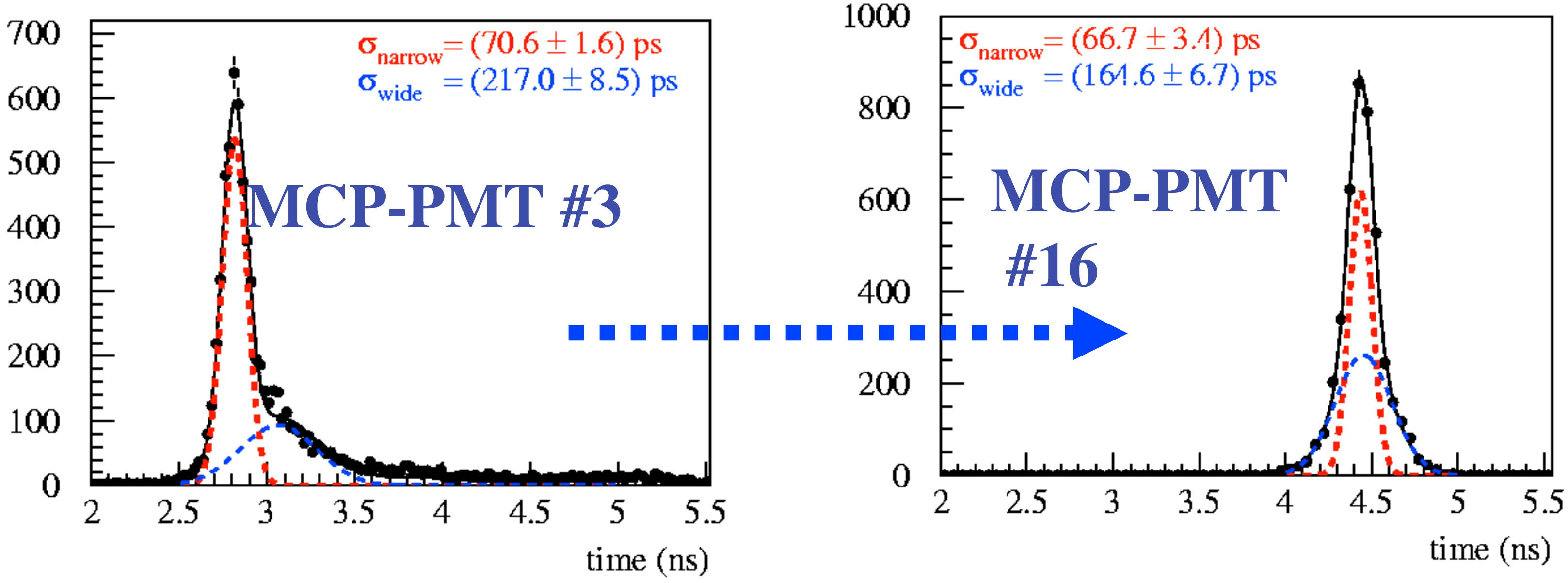


- Double Gaussian fit
- **Burle MCP-PMT #3 has a very long tail due to recoil electrons from the MCP top surface. The tail contains ~20% of all events !!! The MCP-to-cathode distance is 6-7mm.**
- Electronics chain used in this test: Final SLAC amplifier, final SLAC CFD providing the analog output to LeCroy 2228A TDC (25ps/count).
- Light source: Use the 635nm PiLas laser diode in a single photoelectron mode.

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

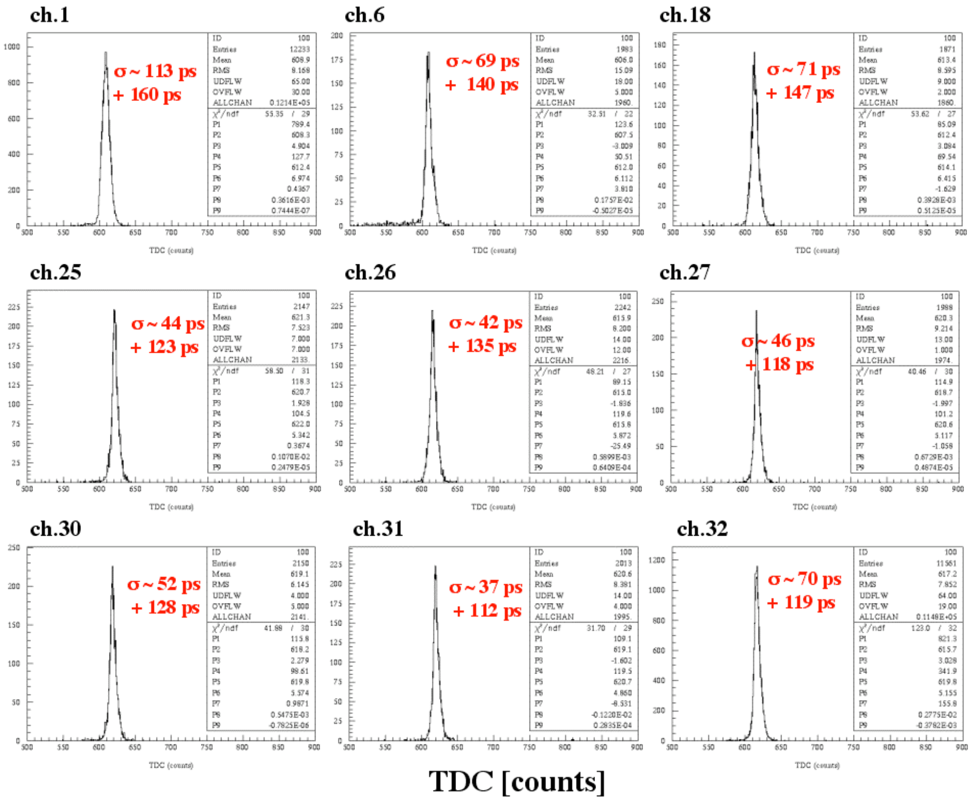


- Double Gaussian fits.
- **The reduction of the MCP-to-Cathode distance to 0.75mm limits the rate of recoiling photoelectrons from the MCP surface, which reduces the tail in the timing spectrum. These electrons are, however, lost from the detection efficiency, but the spectrum is more Gaussian. Nevertheless, 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

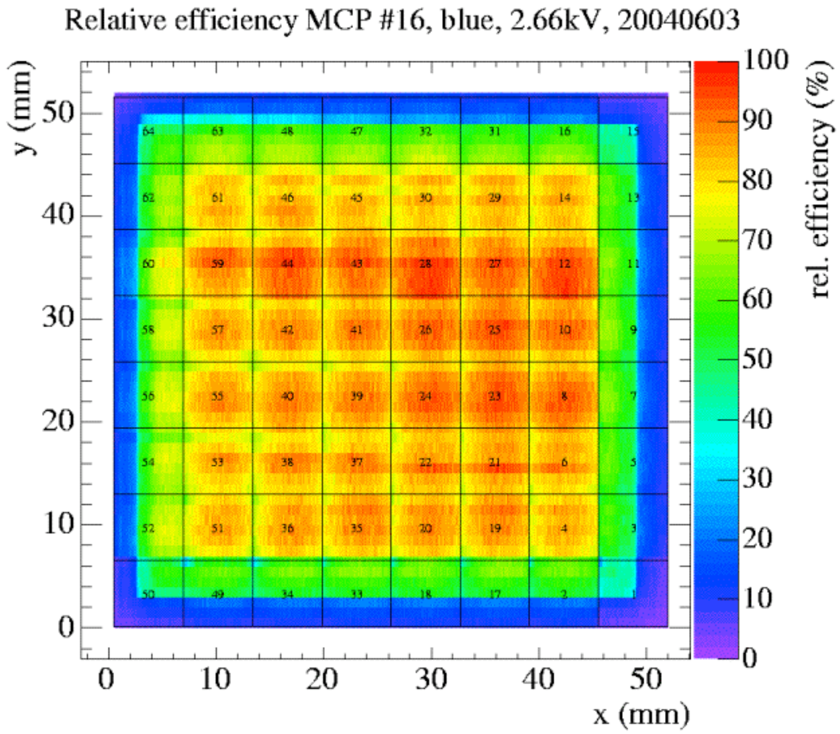


- Double Gaussian fits.
- **No tail in this type of MCP-PMT.**
- **Some pixels are better than others. Not clear why.**

However, the new tube is inefficient around the edges

New design (85011-430):

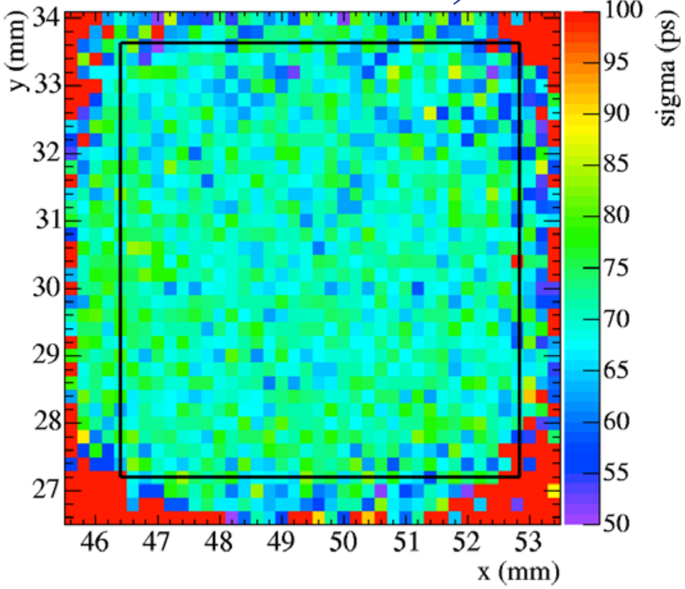
MCP-to-Cathode distance = 0.75 mm



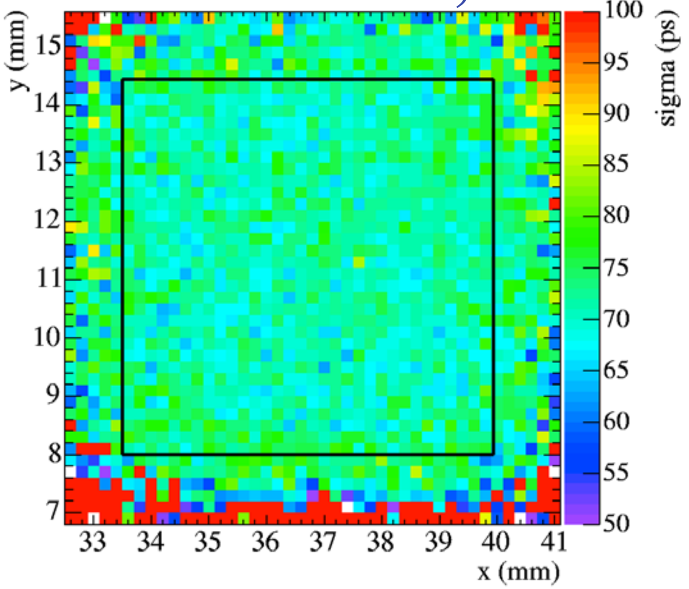
- The efficiency drops to zero half way through all edge pads.
- This inefficiency is related to the electrostatic design near the edges.
- Perhaps, one can have a small light collector around the boundary

Compare timing distribution on two different pads with the Phillips 7186 TDC

MCP-PMT #16, Pad 14:



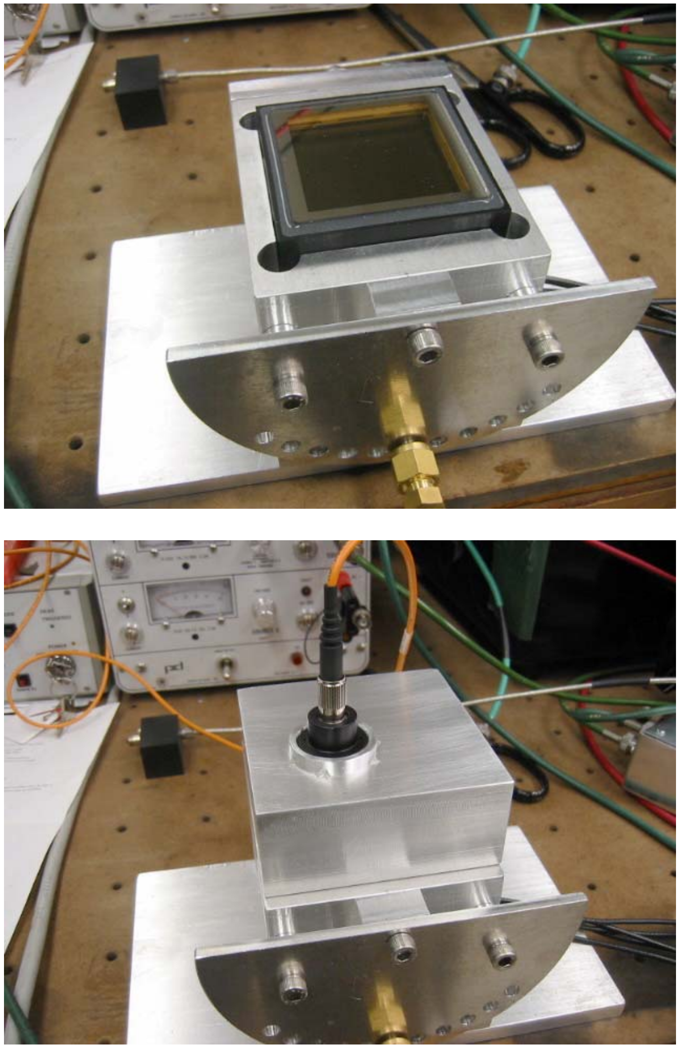
MCP-PMT #16, Pad 24:



- **Single Gaussian fit** to the timing distribution generated in each laser head location.
- **Measure typically σ = 70-80ps in the central pad region, slightly worse near the boundary.**
- Worse timing resolution around edges is due to the charge sharing, causing lower pulse height, and possibly a cross-talk from hits in neighboring pads.
- 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 photoelectron timing resolution at B = 15 kG

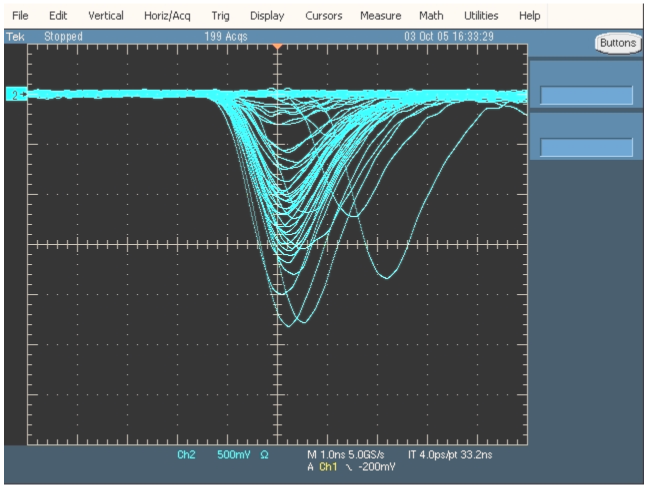
Burle MCP-PMT with 10μm holes

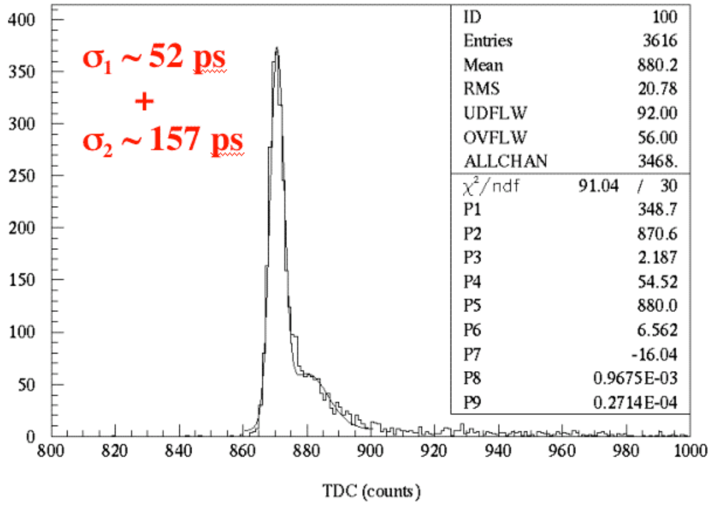


- 4-pixel MCP-PMT 85001-501 P01 tube for the initial tests.
- PMT has two MCPs with 10 μm dia. holes
- Cathode-to-MCP distance ~6mm
- According to Burle, this particular 10μm MCP should produce a gain of ~10^6 at –2.2kV.
- Setup had a capability to measure sensitivity to angles in 5^o steps between the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

Choice of amplifier and timing results at B = 0 kG

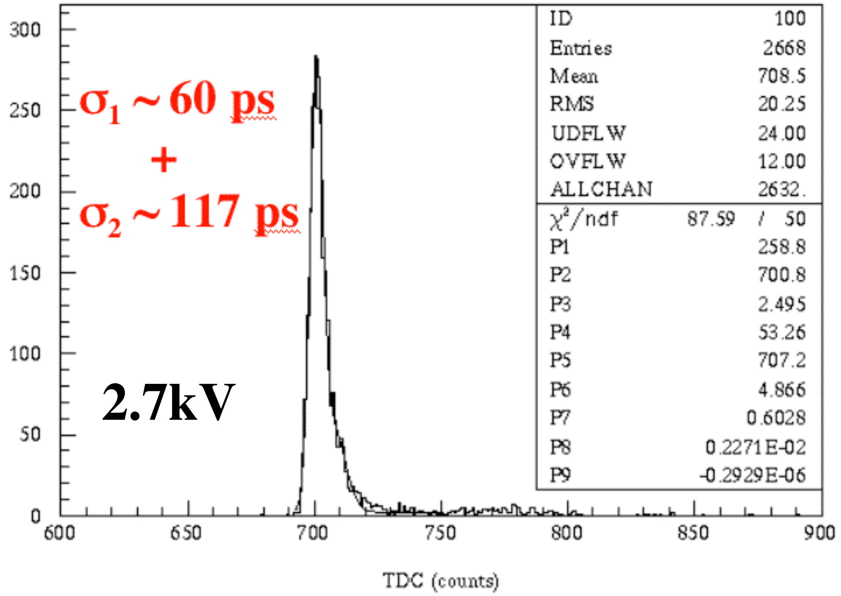
500mV/div, 1ns/div, 2.2kV:

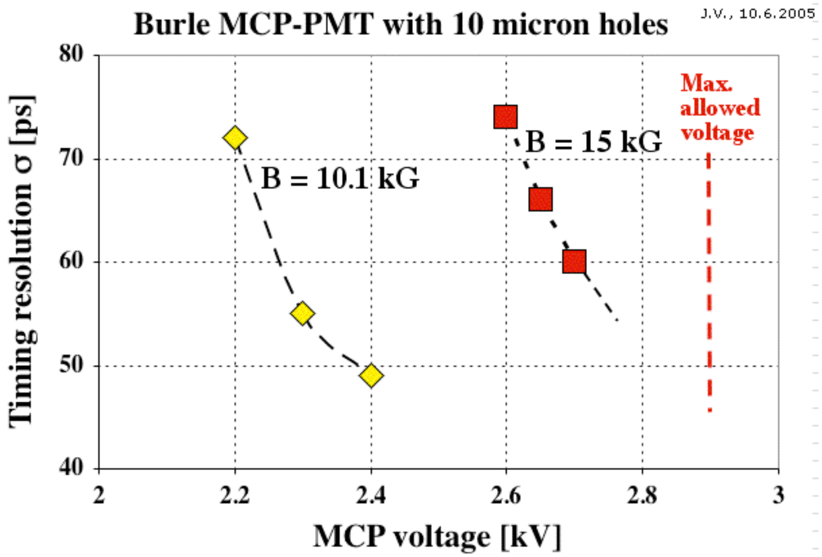




- **Ortec VT-120A amplifier**, gain of 200x, $(ds_o/dt)_{t=0} \sim 1.2V/1ns$
- **Philips CFD** discriminator and LeCroy TDC with 25ps/count.
- **Elantek** 130x amplifier with 1.5ns risetime gives a smaller pulse height.
- **The detector controls the choice of amplifier:** If the amplifier is too slow compared to the detector, one reduces the maximum peak amplitude for a given gain. On the other hand, if the amplifier is much faster than the detector, one increases the noise.

Timing results at B = 15 kG



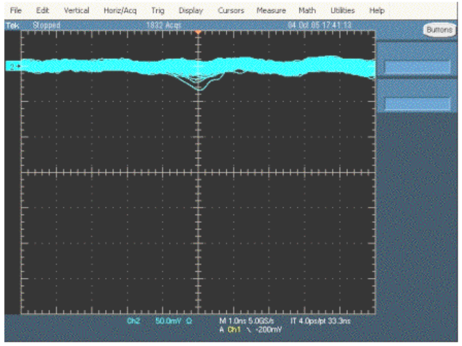


- **Ortec VT-120A amp**
- **Initially, there was some confusion what the maximum allowed voltage. Burle initially thought that it is -2.4kV. After I have “overvoltaged” the tube to -2.7kV to get a decent timing result at 15kG, Burle corrected the max voltage value to -2.85kV. I could have gone higher….**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

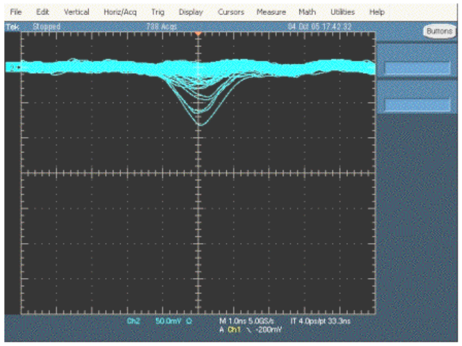
Sensitivity to MCP voltage at B = 15kG

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

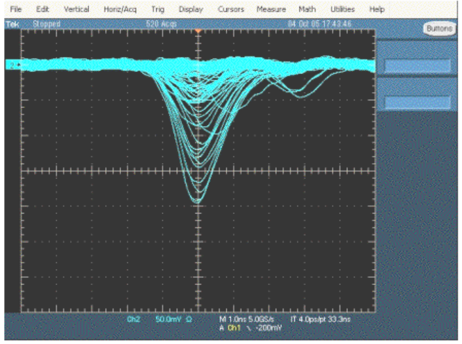
V = **-2.4 kV**, B = **15 kG,** 50mV/div, 1ns/div



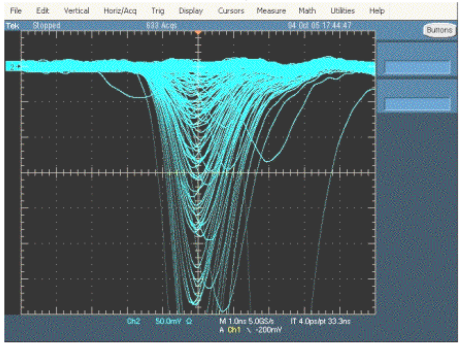
V = **-2.5 kV**, B = **15 kG,** 50mV/div, 1ns/div



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



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

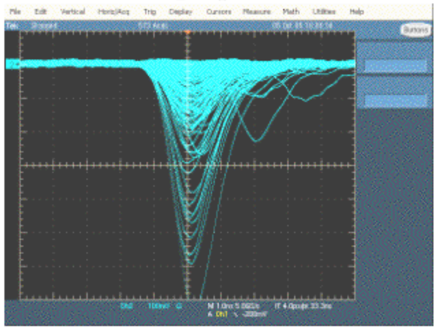


- **The necessary voltage to get a good timing resolution is 2.7-2.8kV.**

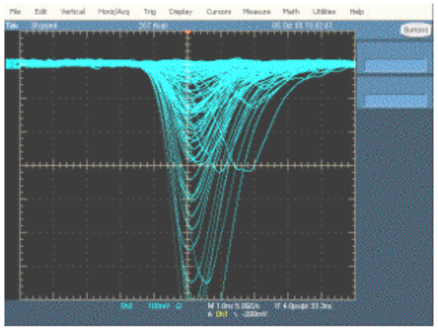
Sensitivity to angular rotation at B = 15kG

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

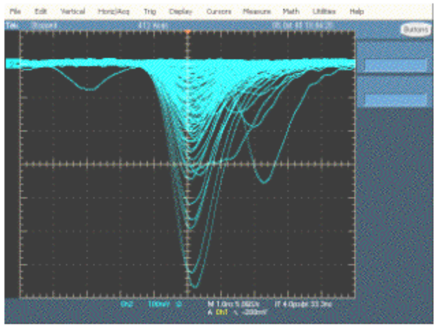
$\Theta = 0^{\circ}$ (face perp. to field)



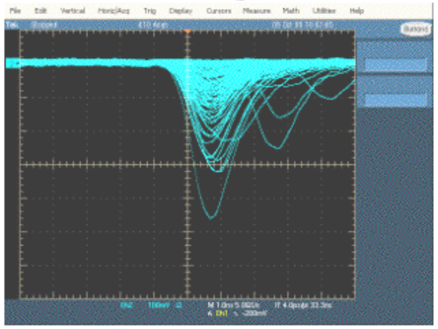
$\Theta = +3^{\circ}$ (tilt to left)



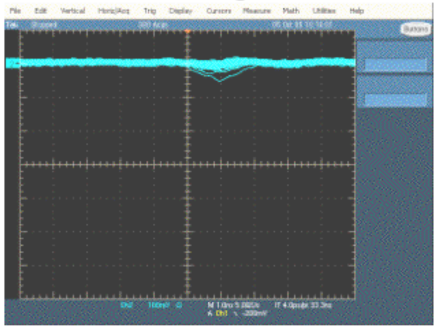
$\Theta = -3^{\circ}$ (tilt to right)



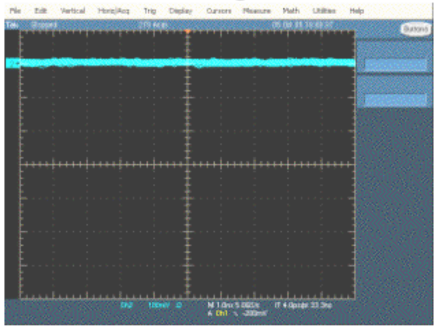
$\Theta = -10^{\circ}$ (tilt to right)



$\Theta = -15^{\circ}$ (tilt to right)



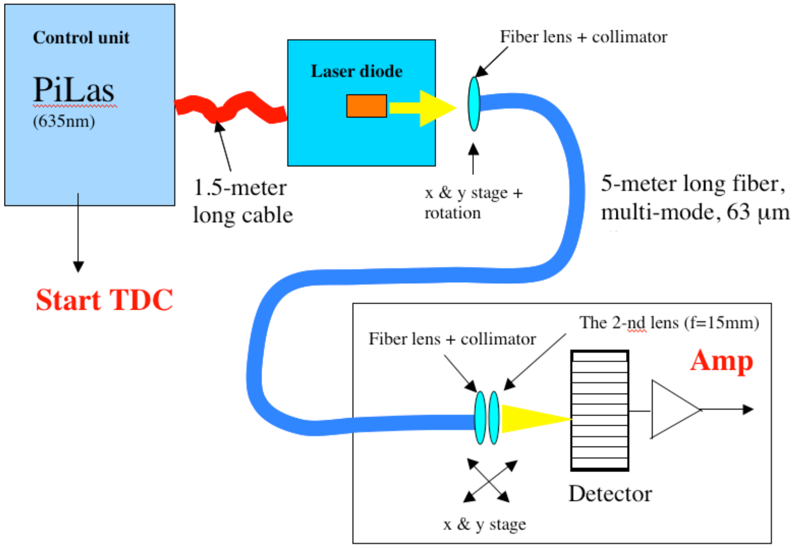
$\Theta = -20^{\circ}$ (tilt to right)

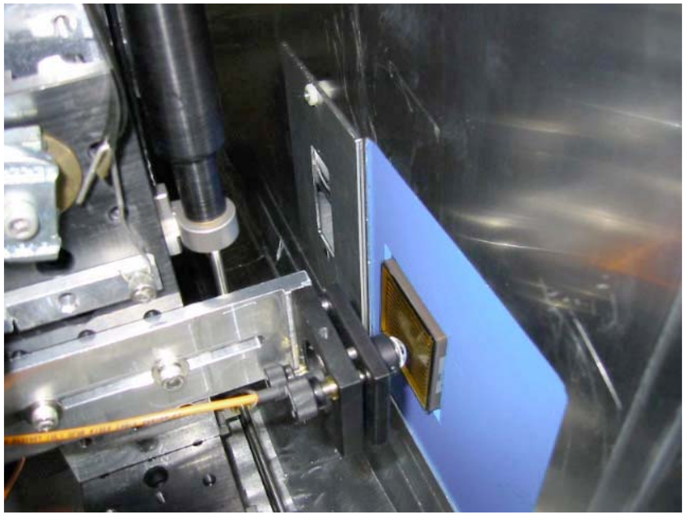


- **The MCP can be tilted by 3-5^{o} before pulse height is affected. At 10^{o}, one sees a clear reduction of pulse height, but the tube can still be used. At 15^{o} and above, the response is killed entirely.**

Single photoelectron spatial response at B = 0 kG

Scanning setup to measure the PMT spatial response





- **x&y stage for the fiber final focus :**
  Stepper motor moves the end of the fiber equipped with a lens, resulting in the spot size of ~150 μm. The linear motor is set typically to:
  x-step ~ 100μm & y-step ~ 1mm.
- **Light source:**
  - PiLas laser diode operating in single photoelectron mode.
  - 635 & 430 nm (on loan) & 407 nm (now).
  - Fiber is 63μm dia. multi-mode fiber, equipped with lenses at both ends.
- **Analysis:**
  - **A hit is accepted into the efficiency definition if it is within a time window, and it is on the same pad as the laser head is pointing to.**
  - **To get a relative efficiency we normalize to the 2 inch dia. Photonis XP 2262B PMT** (or the DIRC PMT, ETL 9125FLB17).
  - DAQ trigger rate: 20kHz.

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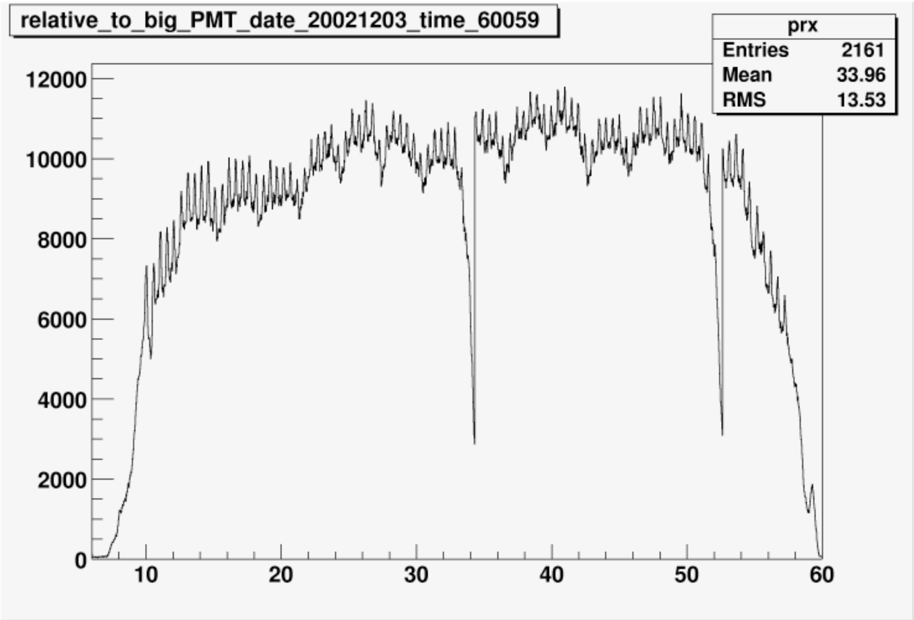
Resolution of the scanning system Hamamatsu Flat Panel H8500 MaPMT #2:

Micro-structure of the dynode electrodes:

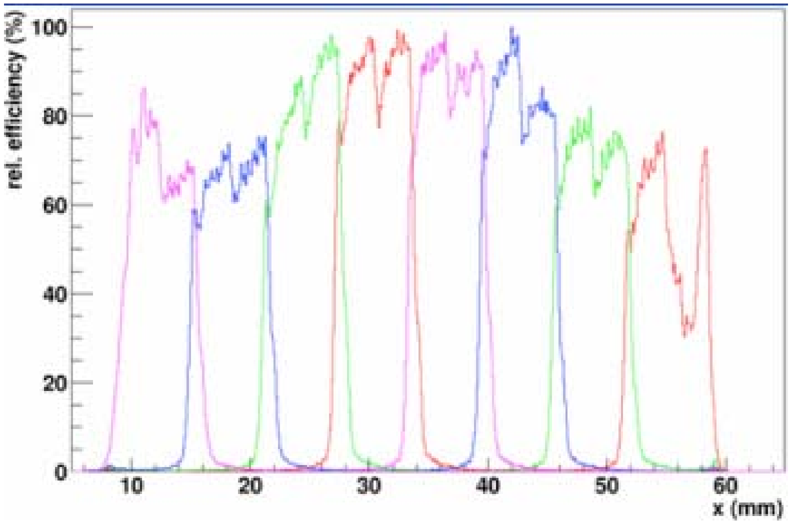


- **<u>Resolution:</u>** Clearly see the details of the dynode electrode structure. **Spatial resolution of the system is less than 100 µm, for a step size of 25µm.**
- <u>Electronics chain used in this test:</u>

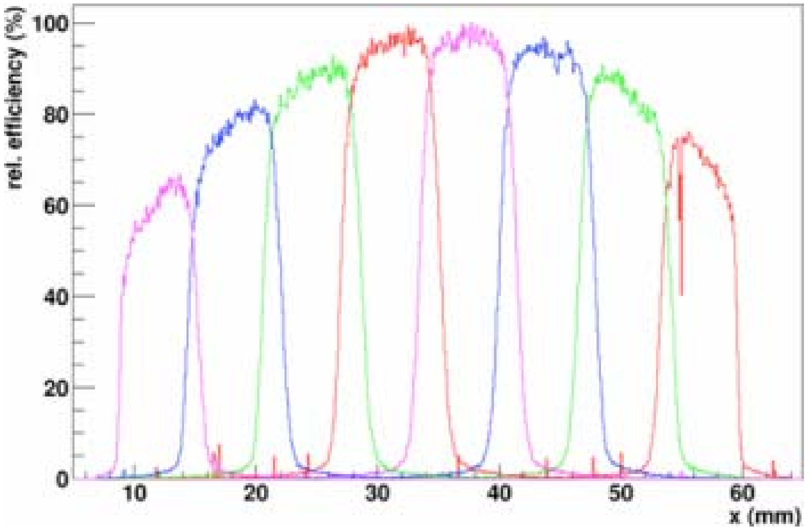
  Final SLAC amplifier, LeCroy 4413 discriminators with 100mV threshold, LeCroy 3377 TDCs with 0.5ns/count.

An example of the relative response along a line scan across eight pads

Hamamatsu Flat Panel H8500 PMT #2:



Burle 85011-501 MCP-PMT #3:



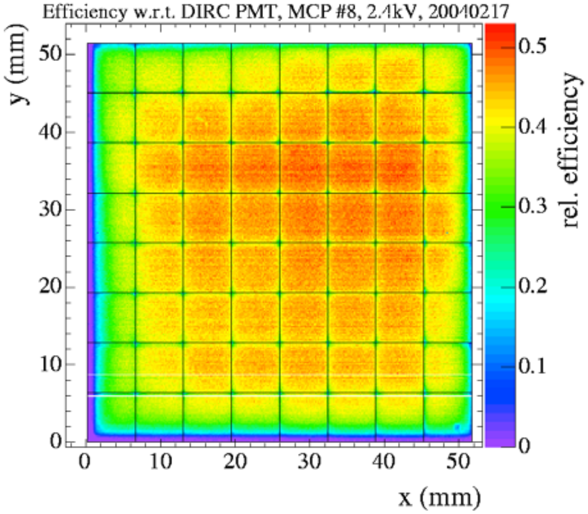
- **The Hamamatsu MaPMT uniformity is ~1:2.5 and the Burle MCP-PMT uniformity is ~1:1.5, in this example.**
- Electronics chain used in this test:

  Final SLAC amplifier, LeCroy 4413 discriminators with 100mV threshold, LeCroy 3377 TDCs with 0.5ns/count.

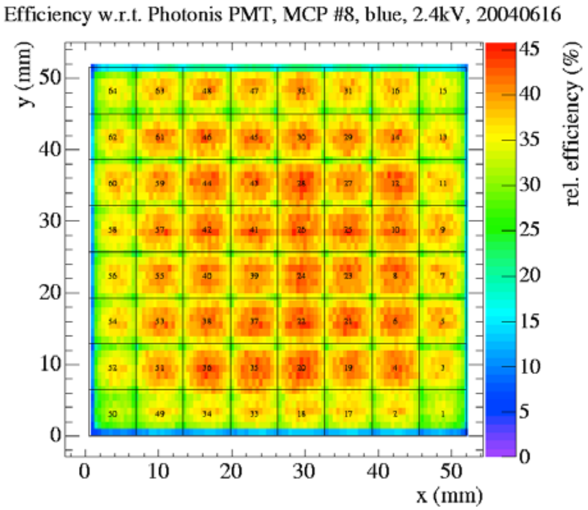
Burle MCP-PMT #8 relative detection efficiency

(Normalized to the Photonis XP 2262B PMT)

635nm:



430nm:



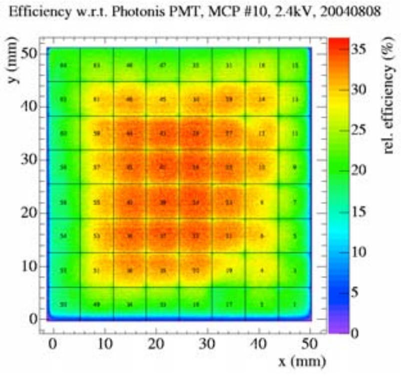
- At **635nm**, which is close to the end of the Bialkali Q.E. range, the relative efficiency scaling to the Photonis PMT is not very reliable.
- At **430nm**, the relative efficiency is 50-60% relative to the Photonis PMT, if we include the late arrivals. This is approximately expected based on the MCP design (to be compared with the geometrical MCP collection efficiency (cathode-to-top MCP) of 60-65%, shown on page 6).
- Electronics chain used in this test:

  Final SLAC amplifier, LeCroy 4413 discriminators with 100mV threshold, LeCroy 3377 TDCs with 0.5ns/count
- Light source: PiLas laser diodes operating in the single photoelectron mode (635nm & 430nm).

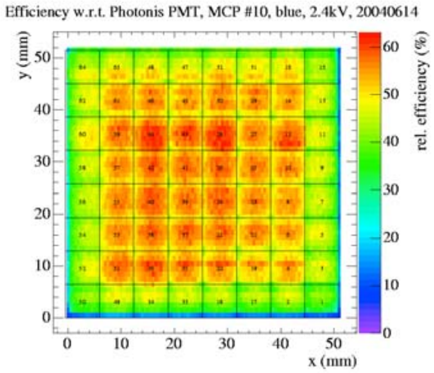
Relative response across the MCP-PMT face

Burle MCP-PMT #10

635 nm:

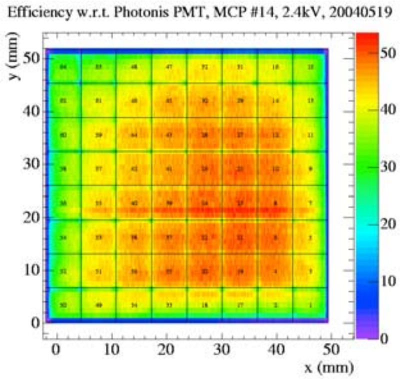

Efficiency w.r.t. Photonis PMT, MCP #10, 2.4kV, 20040808

430nm:

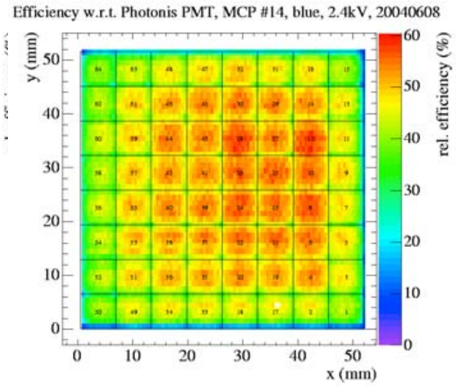

Efficiency w.r.t. Photonis PMT, MCP #10, blue, 2.4kV, 20040614

Burle MCP-PMT #14

635 nm:

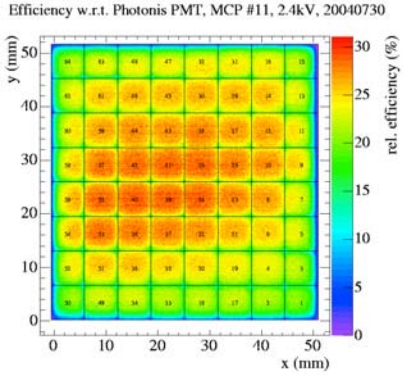

Efficiency w.r.t. Photonis PMT, MCP #14, 2.4kV, 20040519

430nm:

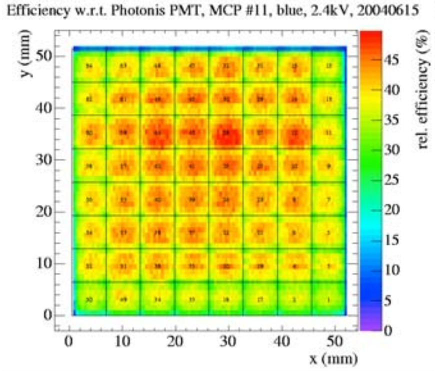

Efficiency w.r.t. Photonis PMT, MCP #14, blue, 2.4kV, 20040608

Burle MCP-PMT #11

635 nm:

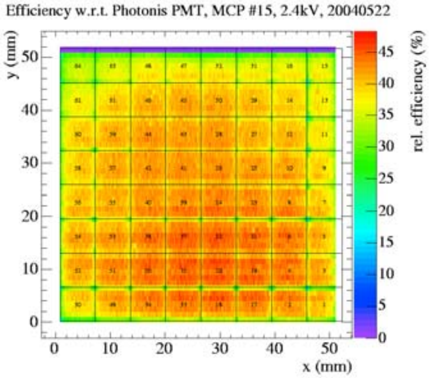

Efficiency w.r.t. Photonis PMT, MCP #11, 2.4kV, 20040730

430nm:

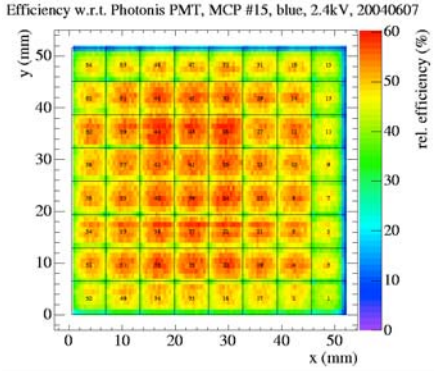

Efficiency w.r.t. Photonis PMT, MCP #11, blue, 2.4kV, 20040615

Burle MCP-PMT #15

635 nm:


Efficiency w.r.t. Photonis PMT, MCP #15, 2.4kV, 20040522

430nm:

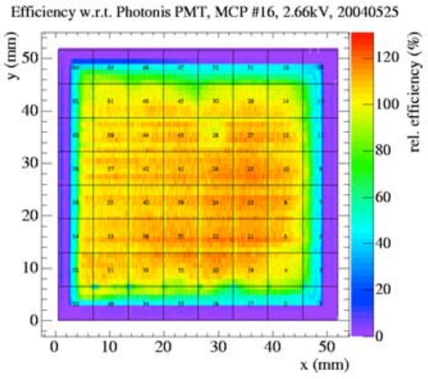

Efficiency w.r.t. Photonis PMT, MCP #15, blue, 2.4kV, 20040607

- Typical relative efficiency is 50-60% of the 2 inch dia. Photonis XP 2262B PMT at 430nm. The efficiency drops to 30-50% around the edges at 430nm.

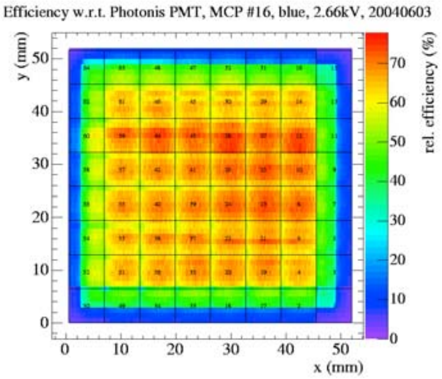
Relative response across the MaPMT face

Burle MCP-PMT #16

635 nm:

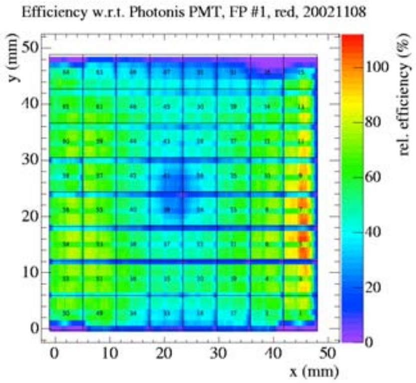

Efficiency w.r.t. Photonis PMT, MCP #16, 2.66kV, 20040525

430nm:

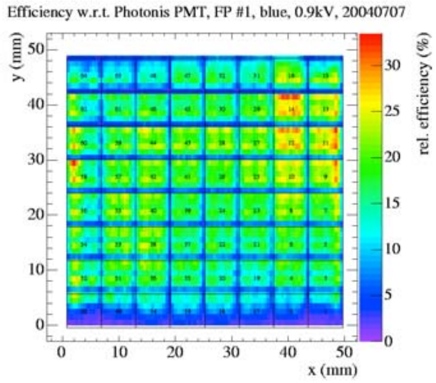

Efficiency w.r.t. Photonis PMT, MCP #16, blue, 2.66kV, 20040603

Hamamatsu MaPMT #1

635 nm:

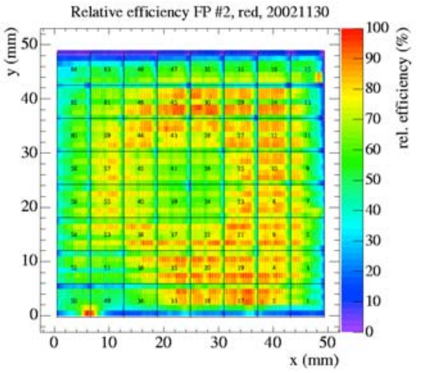

Efficiency w.r.t. Photonis PMT, FP #1, red, 20021108

430nm:

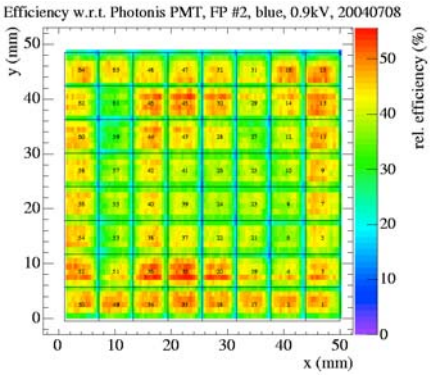

Efficiency w.r.t. Photonis PMT, FP #1, blue, 0.9kV, 20040707

Hamamatsu MaPMT #2

635 nm:

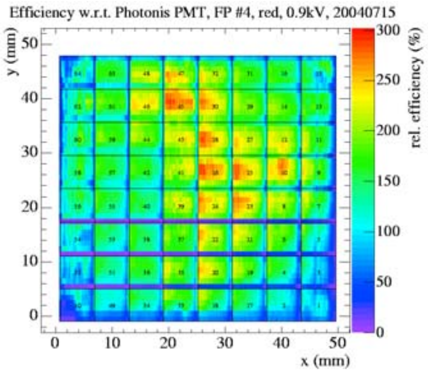

Relative efficiency FP #2, red, 20021130

430nm:

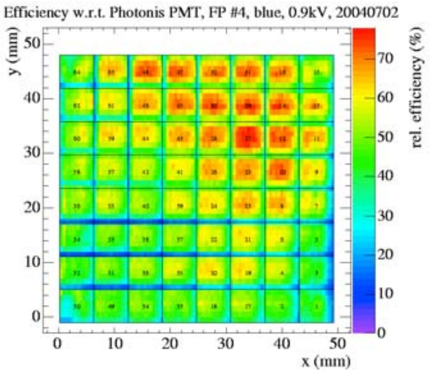

Efficiency w.r.t. Photonis PMT, FP #2, blue, 0.9kV, 20040708

Hamamatsu MaPMT #4

635 nm:


Efficiency w.r.t. Photonis PMT, FP #4, red, 0.9kV, 20040715

430nm:


Efficiency w.r.t. Photonis PMT, FP #4, blue, 0.9kV, 20040702

- **MCP-PMT #16 has large inefficiency around edges (it has the MCP-to-cathode distance of 0.75 mm).**
- **Hamamatsu Flat Panel MaPMT relative efficiency is 50-70% of the Photonis XP 2262B PMT at 430nm. The efficiency drops to 30-50% around the edges at 430nm.**

Aging of MCP-PMT

Aging of MCP-PMT

- **Aging due to damage of the photocathode by ion bombardment.**
- **Burle claims a ~50% loss after of ~10 C/25cm^2 area of MCP-PMT.**
- **Example:** DIRC single photon background rate is: ~200 kHz per 1” dia PMT at a luminosity of **~10^{34}cm^{-2}sec^{-1}**. If I assume that ~1/3 comes from the bar, we run ~6 months/year, then after 10 years, I get about ~**10^{13} pe$^-$/cm^2. This translates to ~ 1-2 C/25cm^2, if we would have the MCP-PMTs in the present DIRC. The rate** is dominated by the LUMI-term, caused by the radiative Bhabhas striking beam components.
- **Nobody knows how to scale things for the Super B factory with a luminosity of > 10^{35}cm^{-2}sec^{-1}, however, it is clear that one has to pay attention to this problem.**

Coherent resonance effects ?

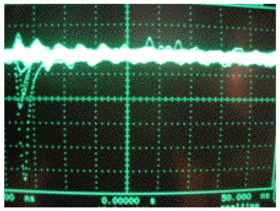
(observed in the prototype)

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

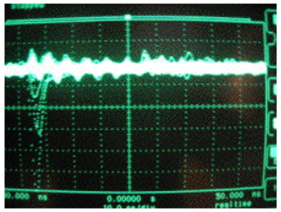
Coherent excitation resonance effects

- Scope setting: 10ns/div/ 100mV/div

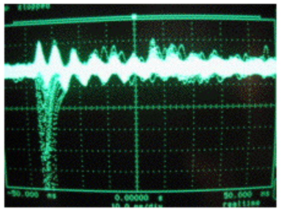
PiLas at 10%



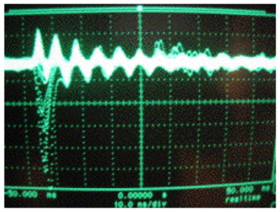
PiLas at 13%



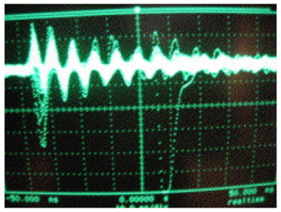
PiLas at 25%



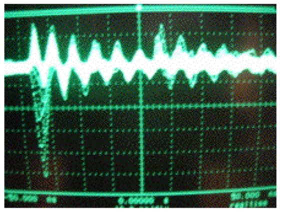
PiLas at 30%



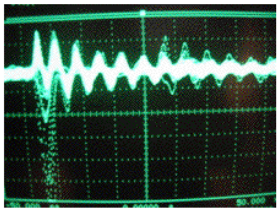
PiLas at 40%



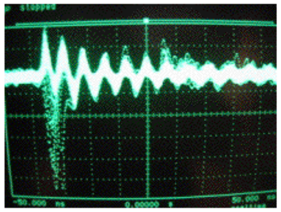
PiLas at 45%



PiLas at 55%



PiLas at 65%

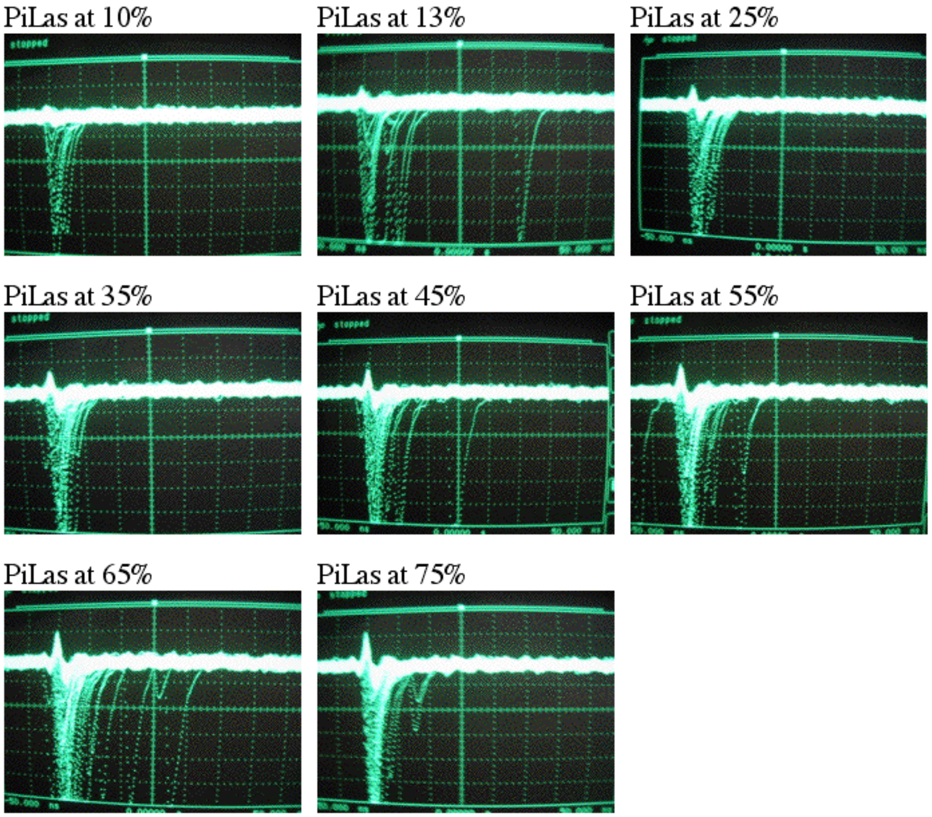


During the run we typically get 3-4 Cherenkov photons, which do not arrive at the same time, so we probably do not suffer from this problem. However, this needs to be fixed.

- **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:



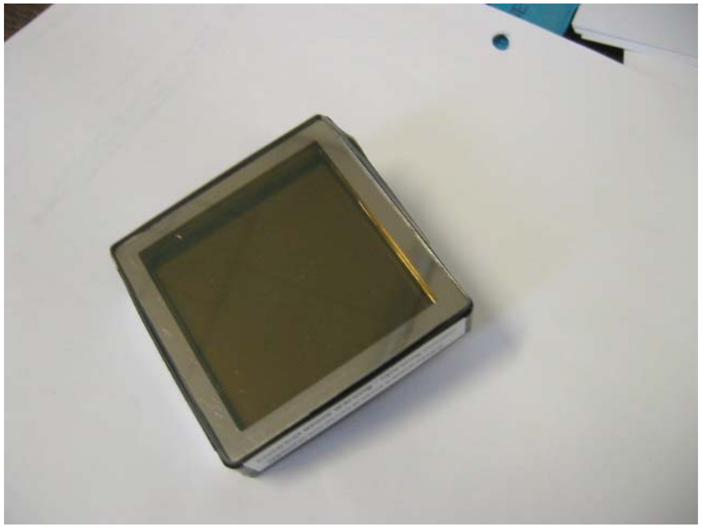
- **The effect does not exist with the Hamamatsu MaPMTs (the same amplifier, the same LV PS, the same grounding).**

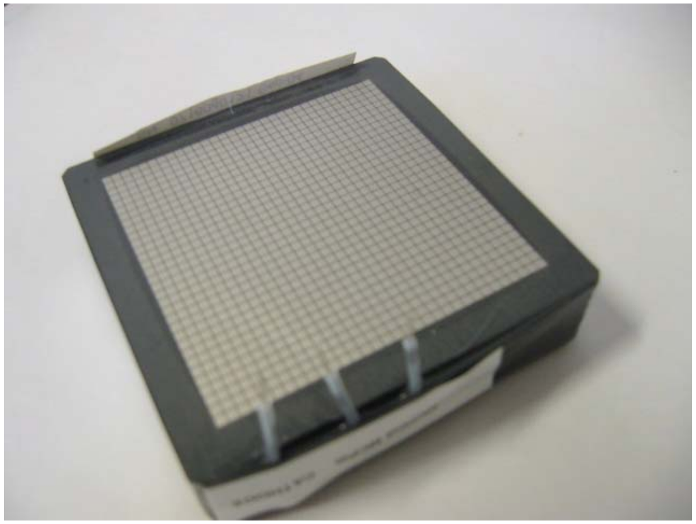
Future developments with the non-gaseous detectors

R&D related to Focusing DIRC

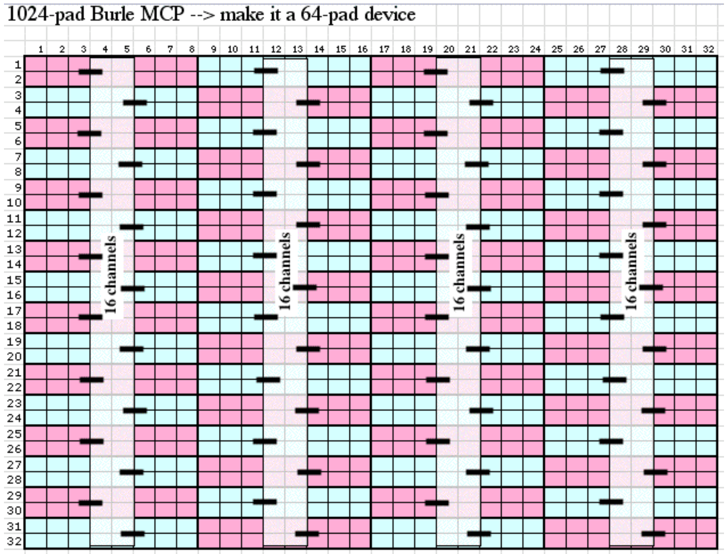
- **Develop rectangular pads of 2mm x 8mm, or 3mm x 12mm in size.**
- **Suppress the timing tails by reducing the gap between the photocathode and MCP surface.**
- **Do more tests with 10μm dia. hole MCP-PMTs in the magnet and estimate better the max possible field.**
- **Test the timing with a gaseous MCP + Micromegas photon detector equipped with the Bialkali photocathode.**
- **SiPMTs ?**
- **Rate and aging tests.**

New 1024-pixel Burle MCP 85021-600



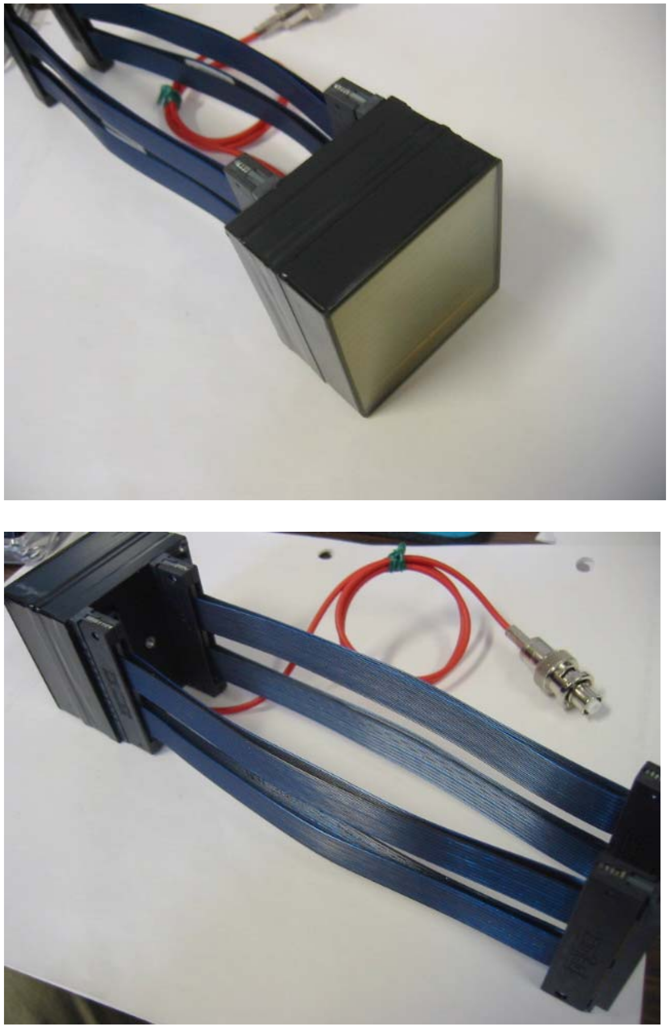


A proposal how to connect pads:

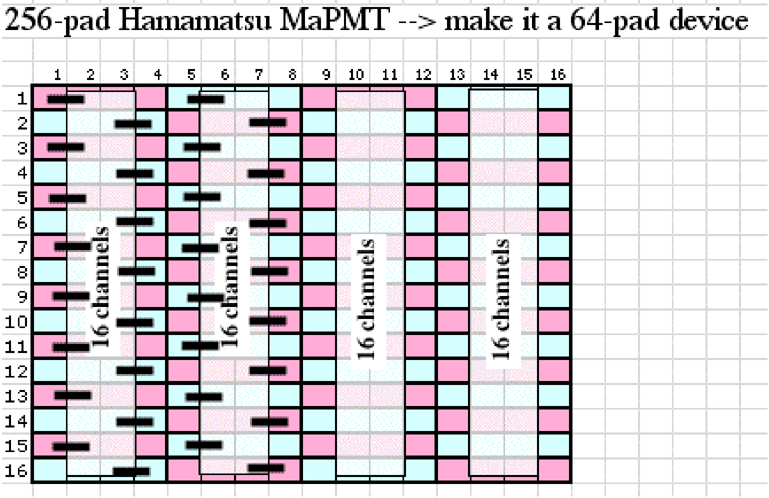


- **Large rectangular pad: 2x8 little ones**
- Small margin around boundary
- 1024 pixels (32 x 32 pattern)
- Small pixel size: ~1.4mm x 1.4mm
- Pitch: 1.6 mm

New 256-pixel Hamamatsu MaPMT H-9500

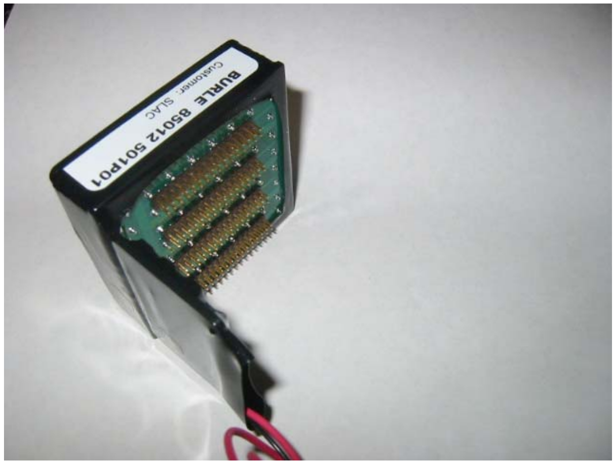


A proposal how to connect pads:



- **Large rectangular pad: 1x4 little ones**
- 256 pixels (16 x 16 pattern).
- Pixel size: 2.8 mm x 2.8 mm
- Pitch of 3.04 mm.
- Very neat connections

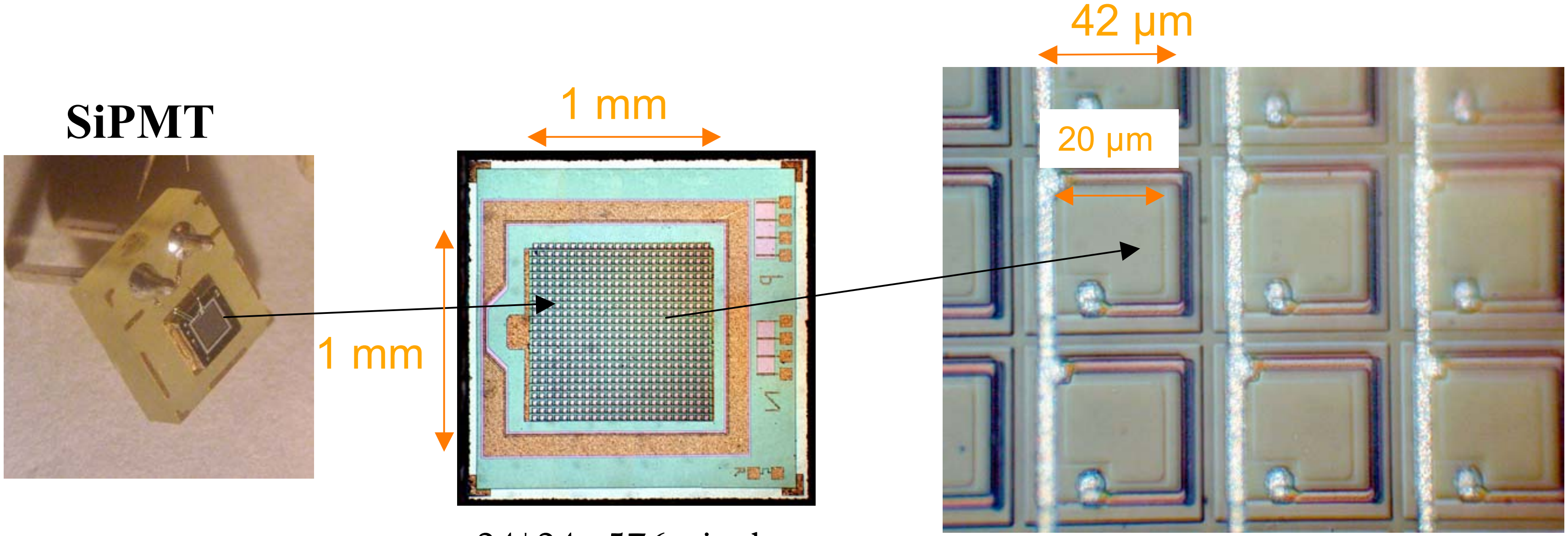
“Open area” Burle MCP 85012-501



- Small margin around the boundary
- 10 & 25 μm MCP hole diameter
- 64 pixel devices
- Pad size: 6 mm x 6 mm.
- The MCP-PMT still has 6-7mm cathode-to-MCP distance, thus making a long tail in the timing distribution
- Can change the resistor chain. Will study if the tail can be supressed by a choice of the MCP operating voltages.
- Elantek amplifier may not work with a 10μm MCP-PMT.

Silicon PhotoMultiplier (SiPM)

(R. Mirzoyan, Max-Planck Inst., IEEE 2005)



24*24=576 pixels

Pixels of the SiPM

Each pixel = binary device ⇨ SiPM = analogue detector

- **Need a rectangular pixel of 2mm x 8 mm for the Focusing DIRC.**
- **Active area presently 25-80 %**
- **Dark count rate/mm^2: 10^5-10^6 counts/sec at room temperature**
- **Single pixel recovery time ~1 sec.**
- **A high breakdown probability limits the photon efficiency to ~30% only.**

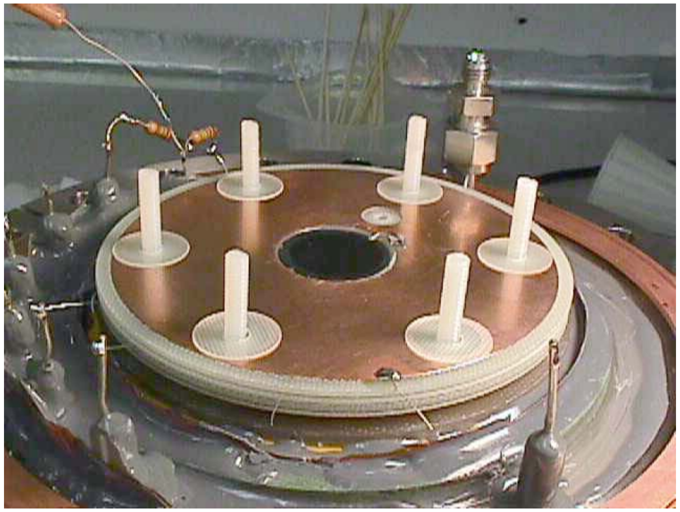
Gaseous Micropattern detectors

Can they play a role among the fast detectors ?

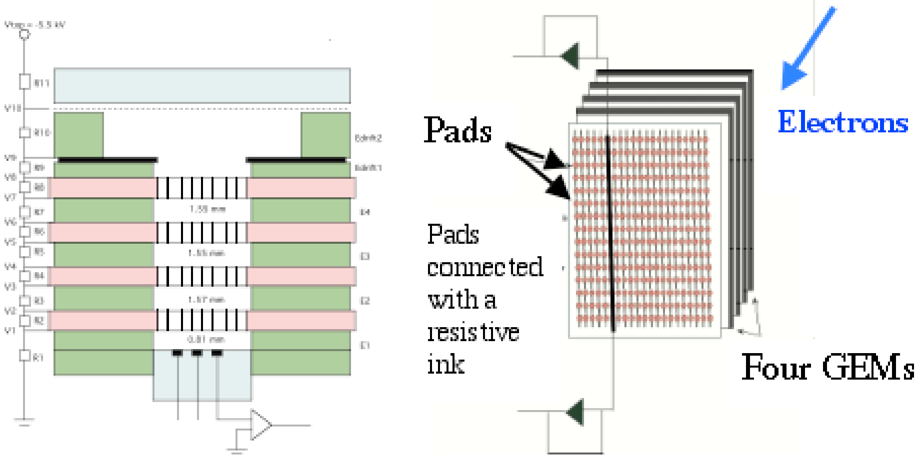
Yes, if one can demonstrate three things:
(a) longevity of the Bialkali photocathode in the gas,
(b) high gain operation, and (c) good timing
resolution.

Modular setup to test various detector ideas

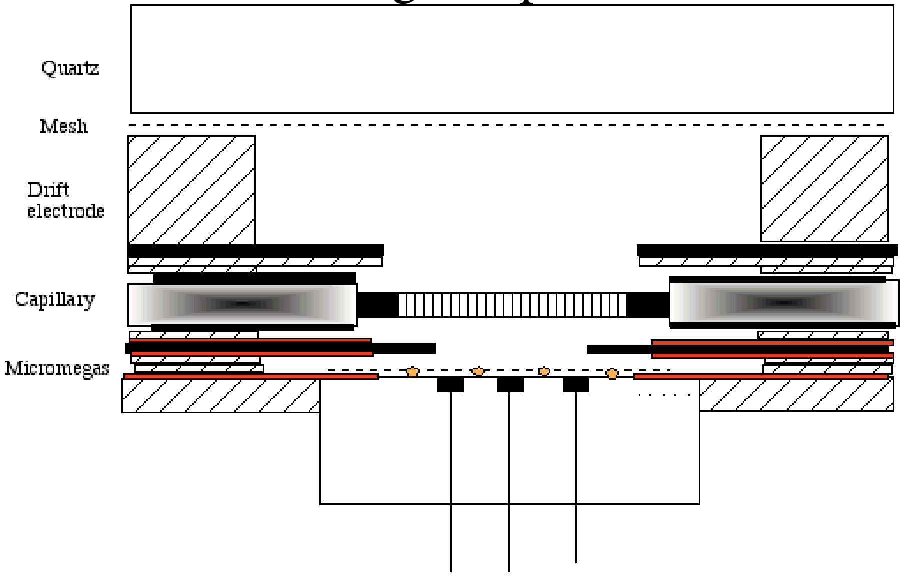
Modular ring structure:



Quadruple-GEM + pads:



MCP + Micromegas + pads:

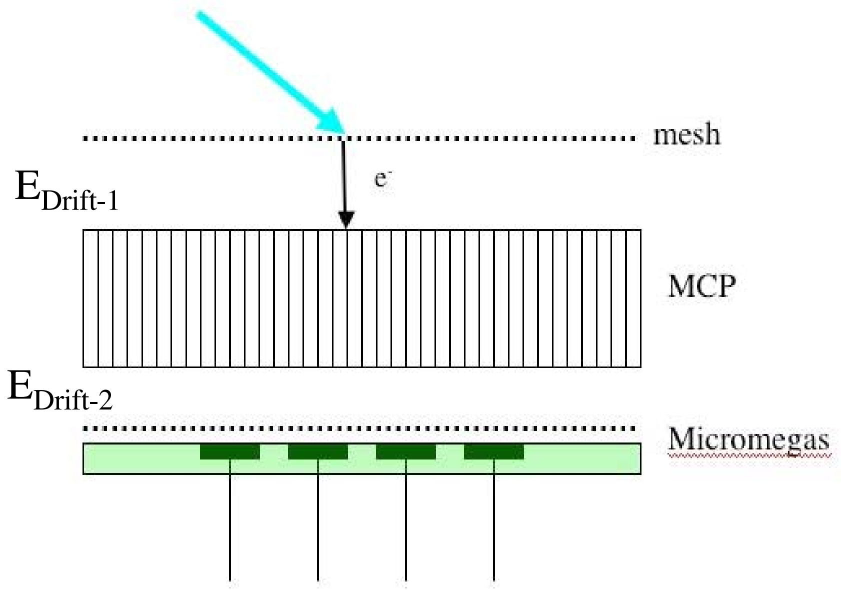


Geometries tested:

- Quadruple-GEM + pads
- Tripple MCP + pads
- GEM + Micromegas + pads
- MCP + Micromegas + pads

Micromegas + MCP with a pad readout

J.Va'vra & T. Sumiyoshi, Nucl.Instr.&Meth. A, 435(2004)334.



<u>An example of running conditions:</u>

$E_{Drift-1}$ ~350V/cm
E_{MCP} ~10kV/cm
$E_{Drift-2}$ ~1.25kV/cm
$E_{Micromegas}$ ~50kV/cm
Ave. total gain ~$2x10^5$

<u>Gain distribution in final application:</u>

$G_{Micromegas}$ ~$2x10^3$, G_{MCP} ~100
$V_{Micromegas}$ ~500V, dV_{MCP} ~1200V

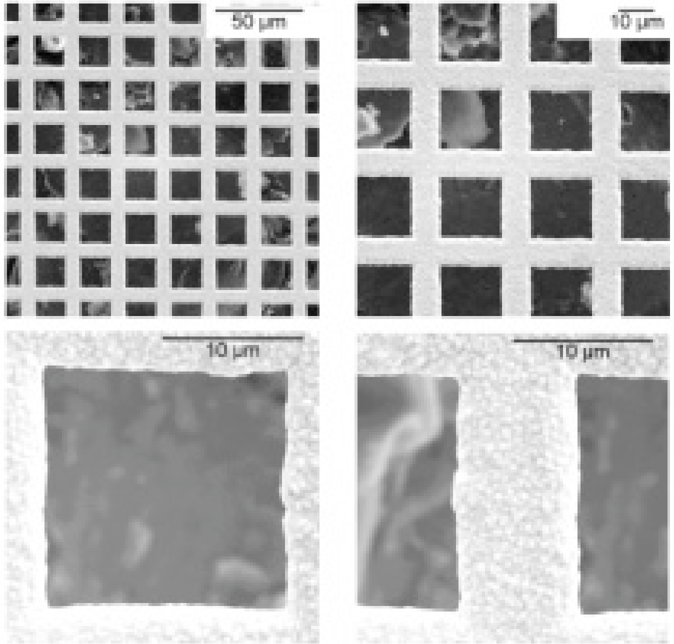
<u>Photocathode:</u>

Metal mesh + Xenon UV light

- **Works well in the single electron mode**

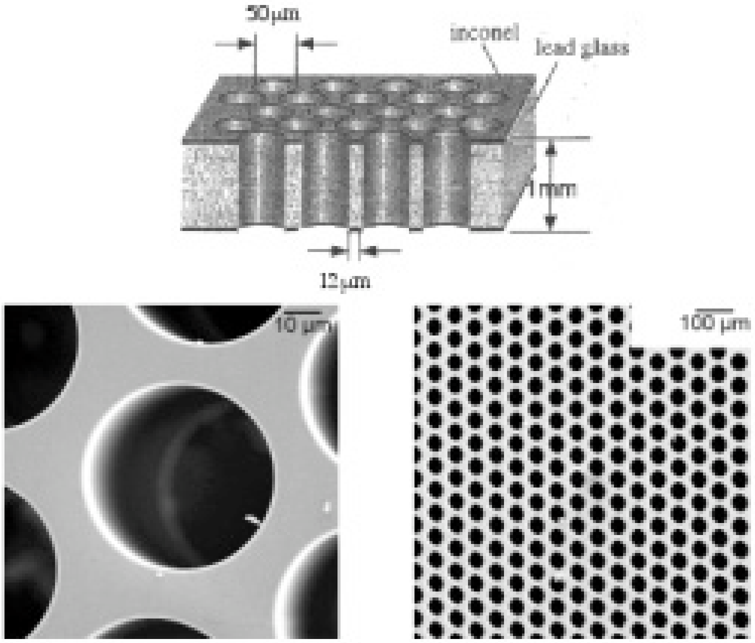
Mesh and MCP can be made “very clean”

s.s. electro-mesh:



1000 lpi mesh density (lines per inch)
A square hole dimension: ~17 x 17 µm²
A sidewall width: ~9 µm
Made by: BuckBee-Mears Co.

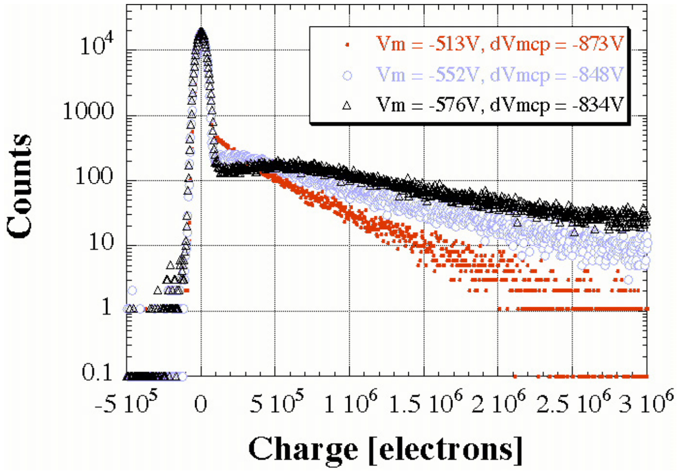
MCP:



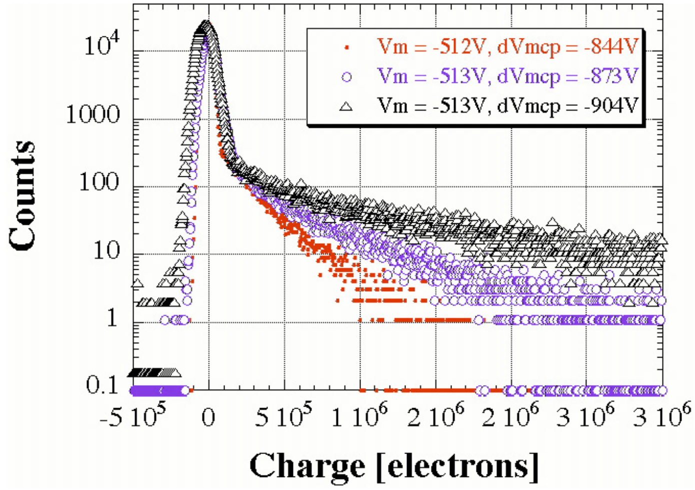
A hole diameter: ~50 µm
A sidewall width: ~12 µm
Thickness: ~1mm
Made by: Hamamatsu

A good single photoelectron response

Vary Micromegas gain mainly:

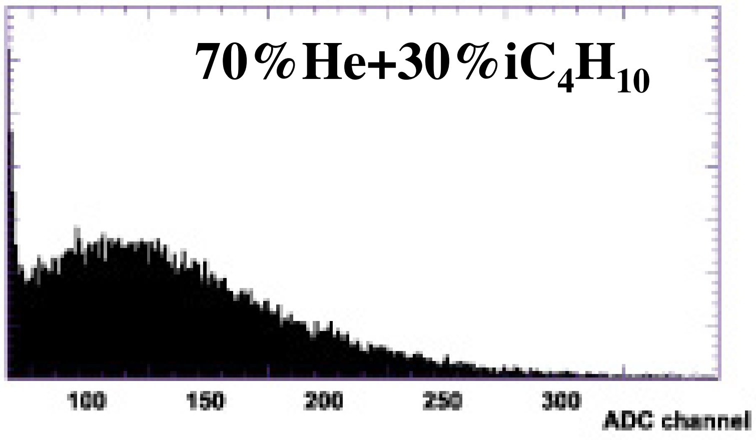


Vary only the MCP gain:



- Very stable operation even at very high gain in 89.1% He + 10.9% iC4H10 gas.
- Observe a slight turnover in the pulse height spectrum.
- For comparison:

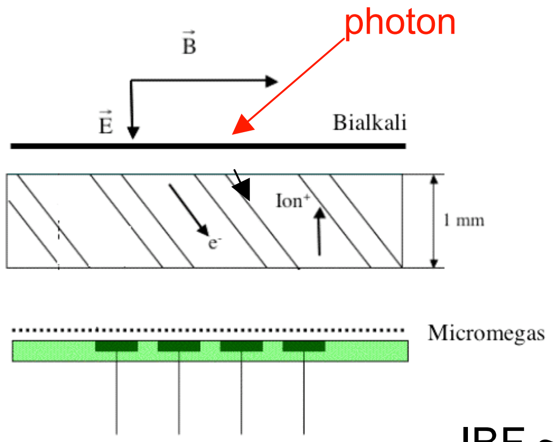
Giomataris has observed a clear turnover with ~30% of iC_4H_{10} in the Micromegas alone:



MCP with inclined holes + Micromegas

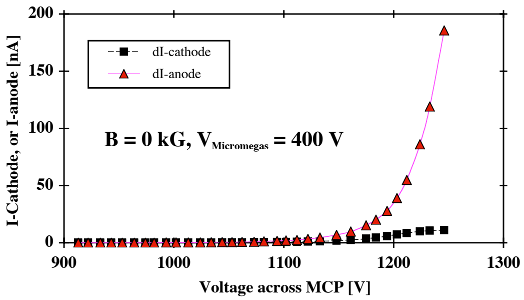
J.Va'vra & T. Sumiyoshi, NIM A, 435(2004)334 & RICH2004

MCP: 1" dia, 1mm thick, 50micron holes



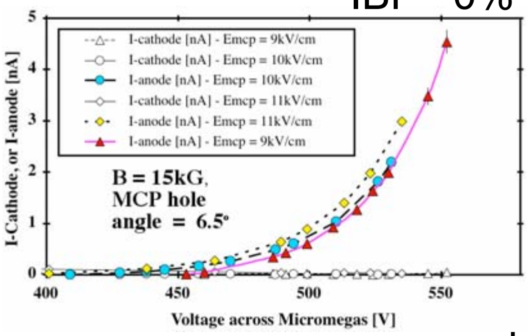
MCP with straight holes, B=0kG:

IBF ~10%



MCP with inclined holes, B=15kG:

IBF ~0%

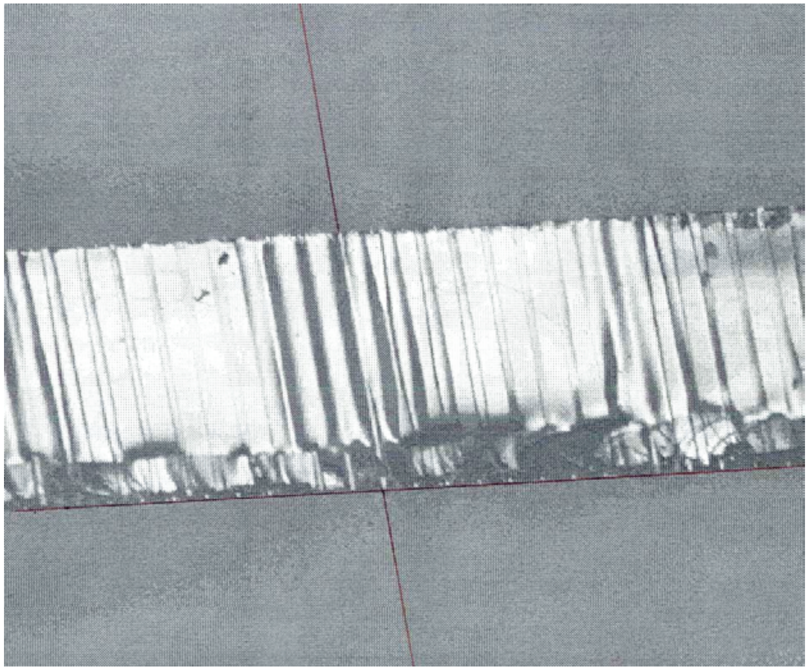


IDEA:

Block the ion backflow (IBF) by inclined MCP holes in a magnetic field

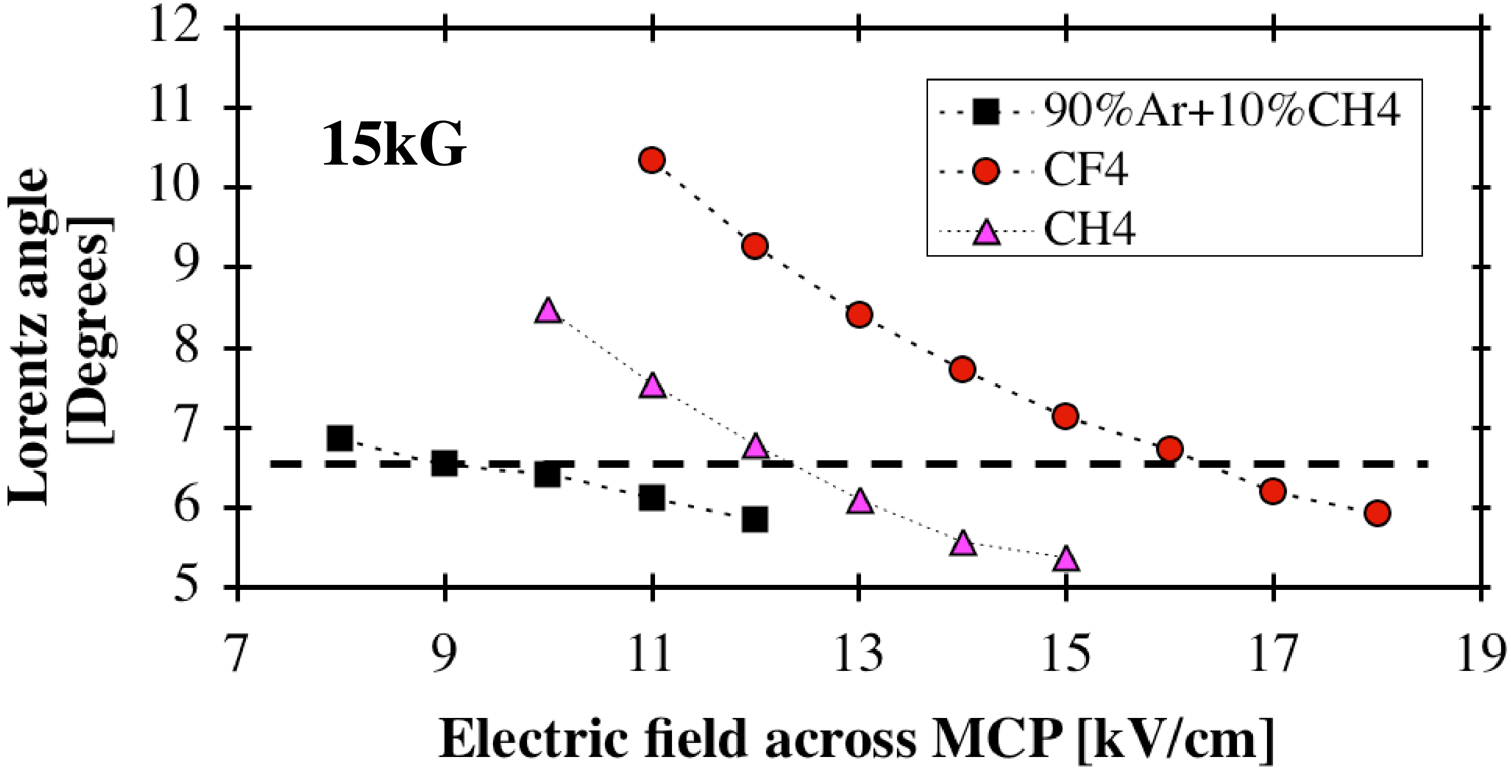
- **IBF reduction by aligning the MCP holes with the electron's Lorenz angle.**
- **Electrons drift & amplify along the MCP hole; ions are caught on the MCP walls.**
- **The measured IBF with inclined holes is negligible (consistent with a pA noise). The measured IBF with MCP with the straight holes at a level of ~10% !!**
- **No data on electron collection eff.**
- **No charging effects observed, which would indicate that the electric field would align with the MCP hole direction. If that would happen, the idea would not work.**

Inclined MCP holes



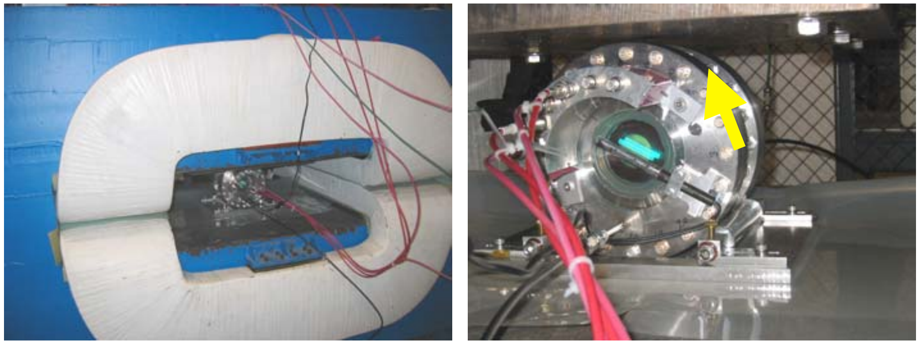
- In this test, use Hamamatsu MCP with a 50μm hole diameter and an angle of 6.5^o.
- The picture shows a cut through the MCP to verify the angle.
- The inclined holes are a standard MCP technology as all vacuum-bases MCP-PMTs use them to limit the ion damage of the photocathode

Lorenz angle calculation at 15 kG

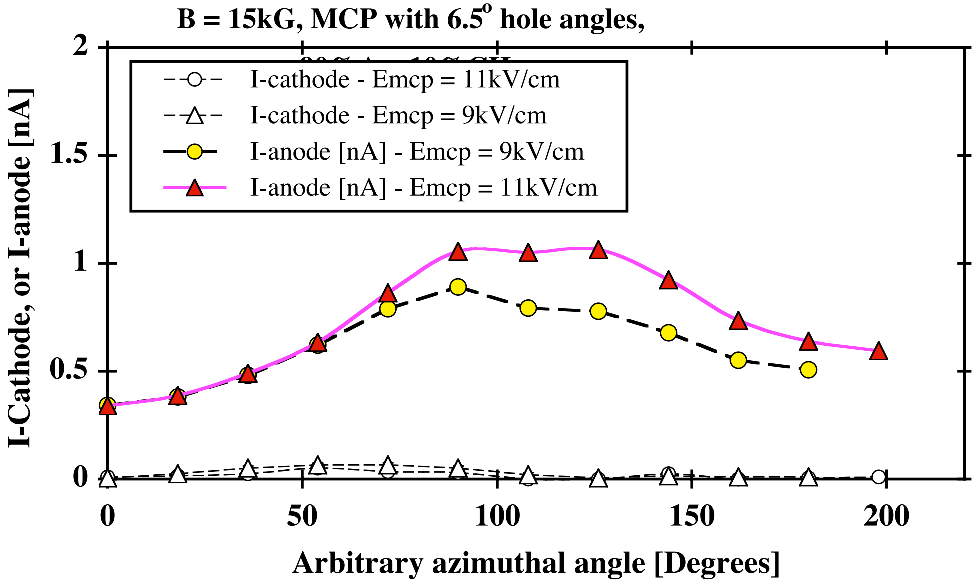


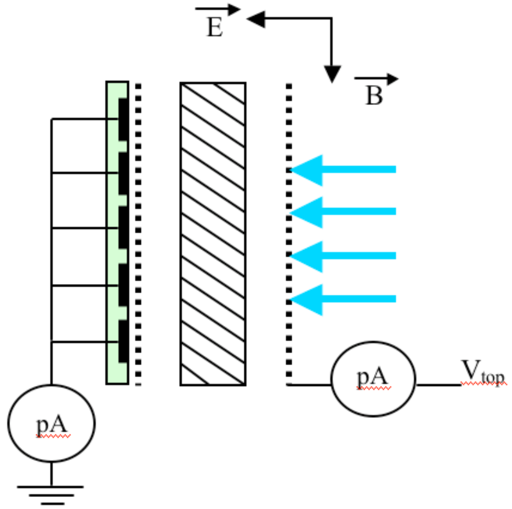
- **The MCP angle is fixed by a choice of gas and MCP gain.**
- Use Magboltz program (version 7.1).

Experimental setup in the magnet

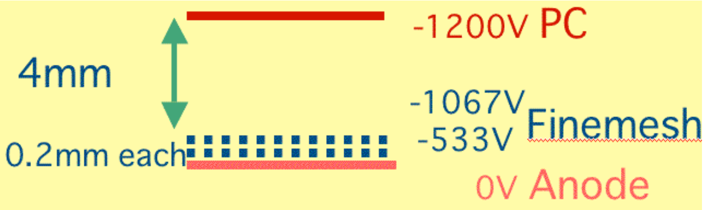


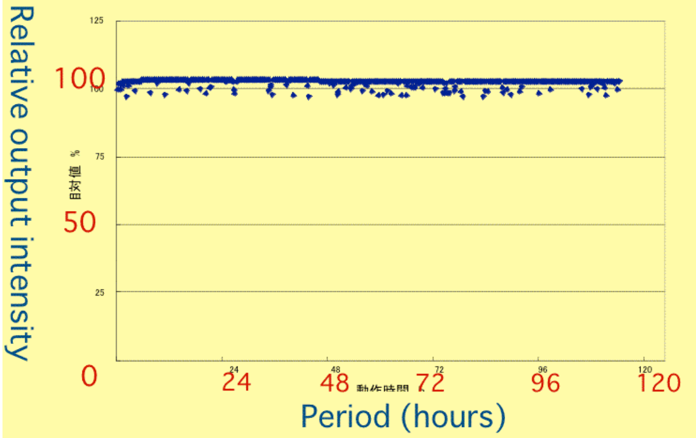
- 15kG
- $90\% Ar + 10\% CH_4$ gas
- Mercury UV lamp
- MCP needs to be rotated to the optimum azimuth. Indeed, one measures nearly zero cathode backflow current, i.e., consistent with a picoammeter noise) at the azimuth angle where the electron transfer is at maximum (aligned with the electron Lorenz angle).





Hamamatsu Bialkali GPM R&D work





Sumiyoshi, Va'vra, Tokanai & Hamamatsu

- Hamamatsu built a double-mesh Micromegas structure w bialkali pc.
- Works both in $90\%Ar+10\%CH_4$ or $90\%Ar+10\%CF_4$.
- No detorioration of the photocathode observed within 5 days
- Gain of ~$6x10^3$, limited by secondary effects. Not sufficient for single-photon detection.
- **Work with MCP & Bialkali photocathode is in progress.**

Discussion of the gaseous detectors

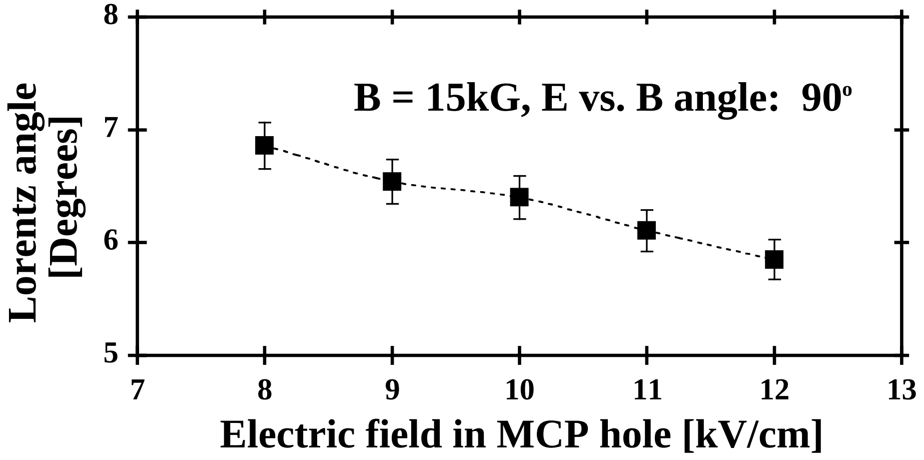
- The micro-pattern gas detectors have **good aging rate, and can handle high rates** (ions travel a short distance).
- Gaseous detectors could work easily up to **60 kG.** Vacuum MCP-PMT will not work much above **B~15kG** at present.
- Gaseous detectors can use rather large MCP hole diameter of **~50μm.**
- One could presumably make a **large size photon detector** using a mosaic of MCPs.
- **Higher geometrical efficiency** compared to the vacuum-based MCP-PMTs, at least in principle. Vacuum MCP-PMT has **~50%** geometrical efficiency at best.
- **Timing:** Giamataris has achieved **σ ~300ps** with a Micromegas covered with CsI with just a leading edge disriminator. Adding a MCP will make it worse. The question how much. Needs to be measured.
- **We have invented a simple method to block the ion flow to the cathode.** Needs to be studies in more detail using a good simulation code.

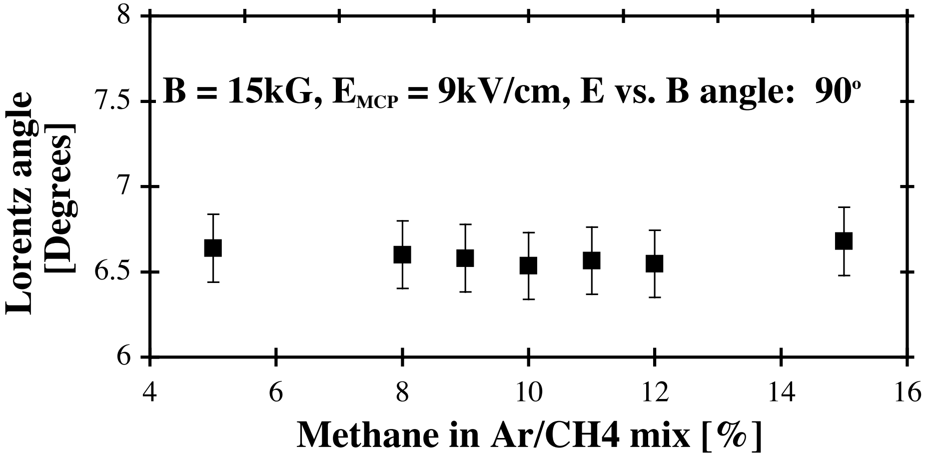
Conclusion

- **A single photon timing resolution at a level of $\sigma \sim$ 50-100ps is much closer to a reality compared to a situation when we started.**
- **But, much more has to be done.**

Backup slides

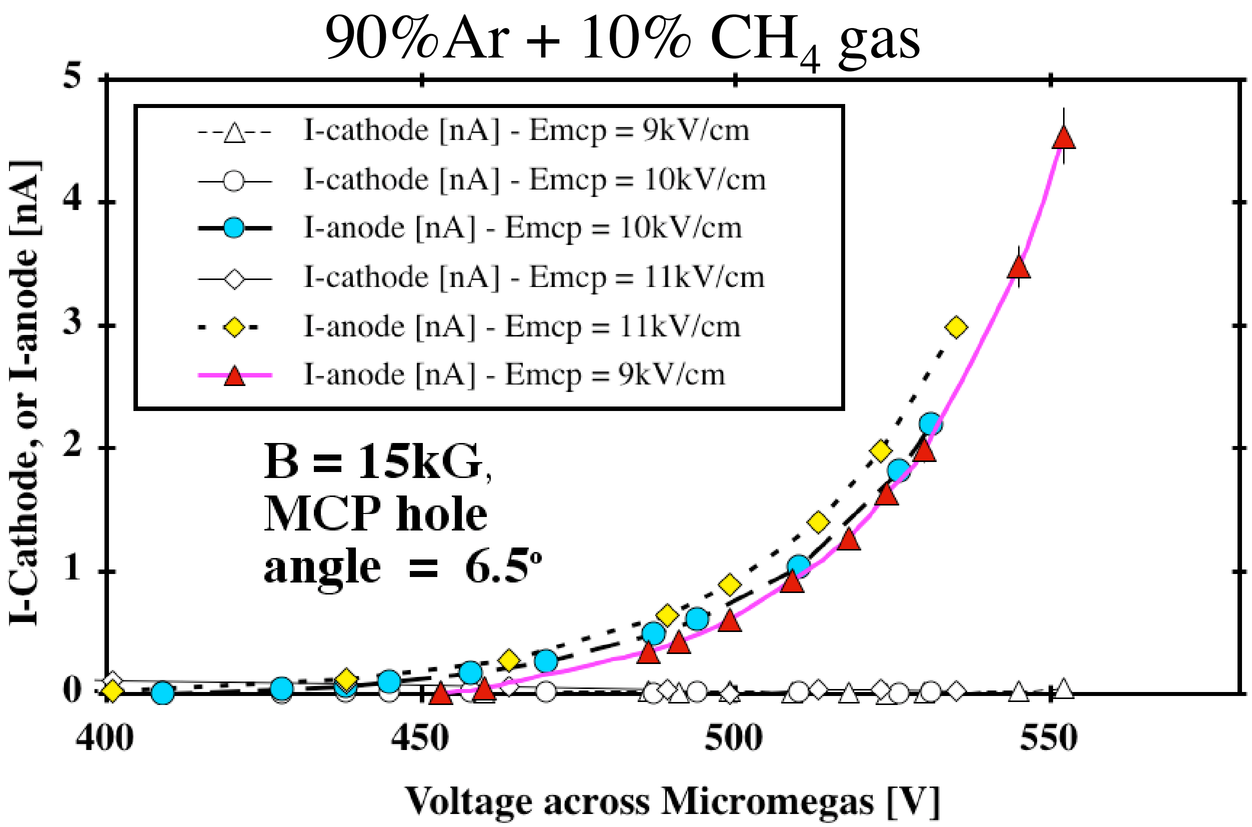
Lorenz angle calculation at 15 kG





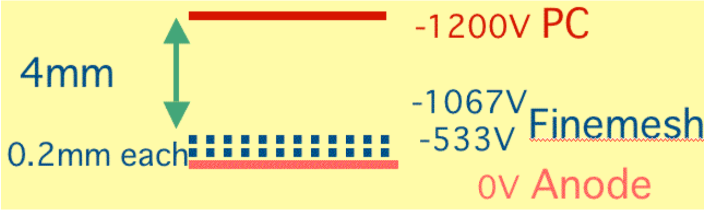
- **The MCP angle is fixed by a choice of gas and MCP gain.**
- With 90%Ar+10%CH_4 gas & E = 9kV/cm & B = 15kG:
  v_{along_E} = 36.75 μm/ns
  v_{along_B} = 4.21 μm/ns
  $\sigma_{long\_along\_E}$ ~ 106 $\mu m^2/ns$
  $\sigma_{transv\_along\_B}$ ~ 245 $\mu m^2/ns$
- Very high diffusion => expect losses along the MCP hole walls
- Use Magboltz program (version 7.1). Thanks to Steve Biagi for always making sure that (a) I do it right, and (b) use the latest version of the program.

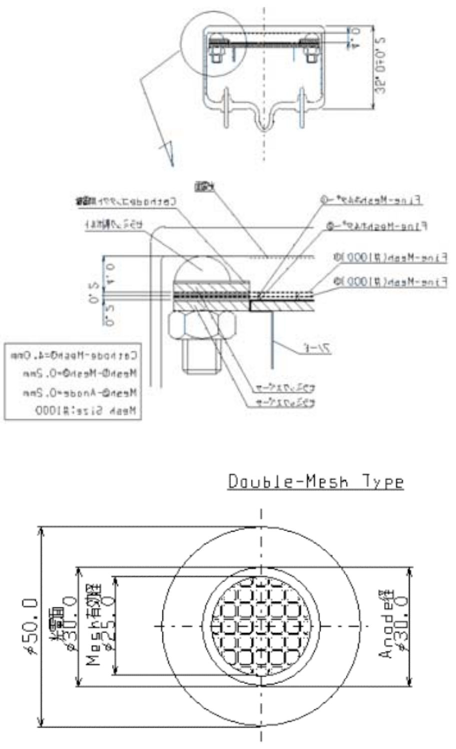
Ion backflow at optimum azimuth is negligible

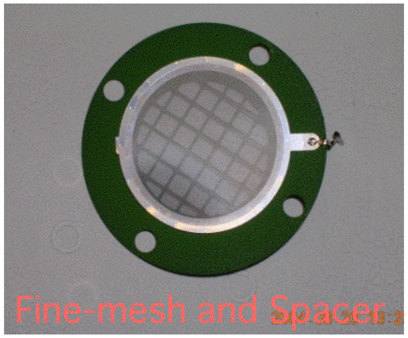


- **The magnitude of the ion backflow at optimum azimuth is zero, consistent with a picoammeter noise.**

Hamamatsu work with the gaseous photodetectors with Bialkali photocathode

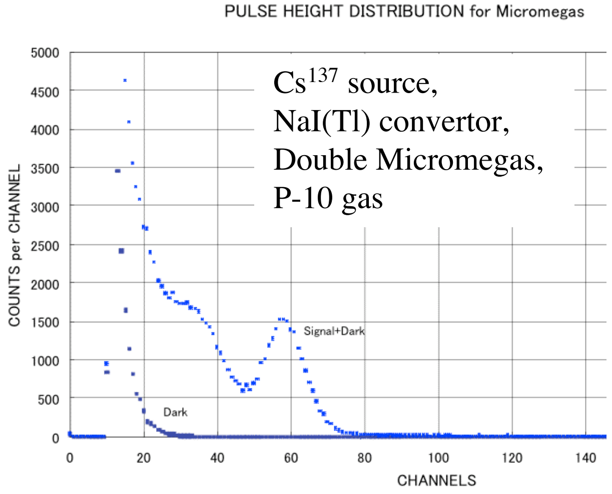





Fine-mesh and Spacer

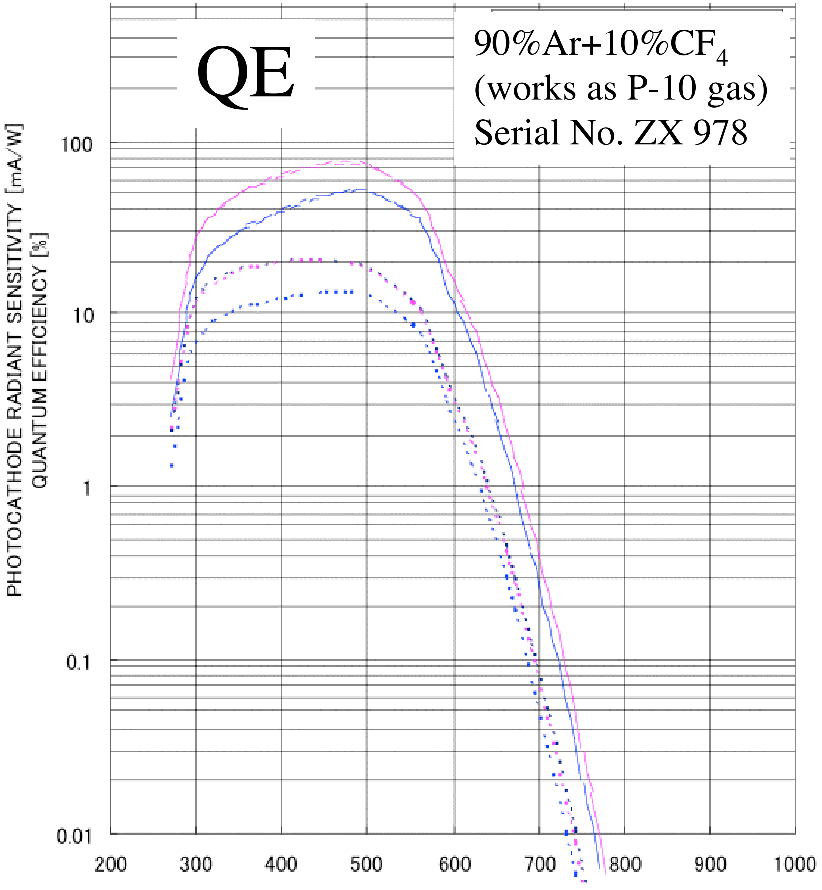
- **So far, they built successfully a Double-mesh Micromegas.**
- Works both in 90%Ar+10%CH_4 or 90%Ar+10%CF_4 gases.
- Gain of ~6x10^3 reached with a coarser mesh.
- Coarser mesh yields higher gain (Gain ~ 6x10^3 for 34μm pitch, and Gain ~2x10^3 for 25μm pitch).
- **Not yet good enough for the single electron operation with a good timing resolution.**
- **The Micromegas+MCP with inclined holes will be done next.**

Results with Double Micromegas and Bialkali photocathode in 90%Ar+10%CH_4 gas


PULSE HEIGHT DISTRIBUTION for Micromegas

Cs^{137} source,
NaI(Tl) convertor,
Double Micromegas,
P-10 gas

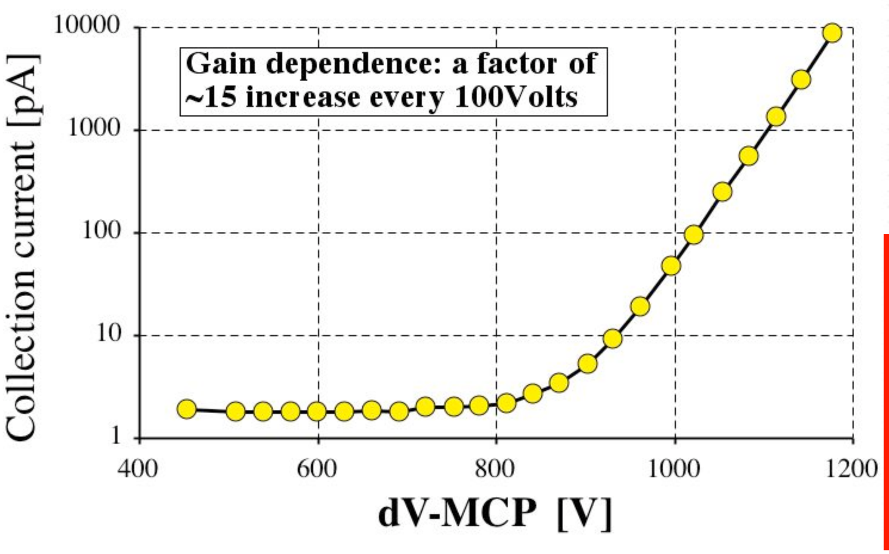
- **Connect the NaI(Tl) crystal to the Double-mesh Micromegas photo-detector operating in the P-10 gas, and with a Cs^{137} source obtain the result shown above.**
- **QE of Bialkali photocathode in 90%Ar+10%CF_4 gas (the P-10 gas gives similar results):**
  - **a) 20.8% in vacuum,**
  - **b) 13% in the gas,**
  - **c) 20.0% in vacuum again.**

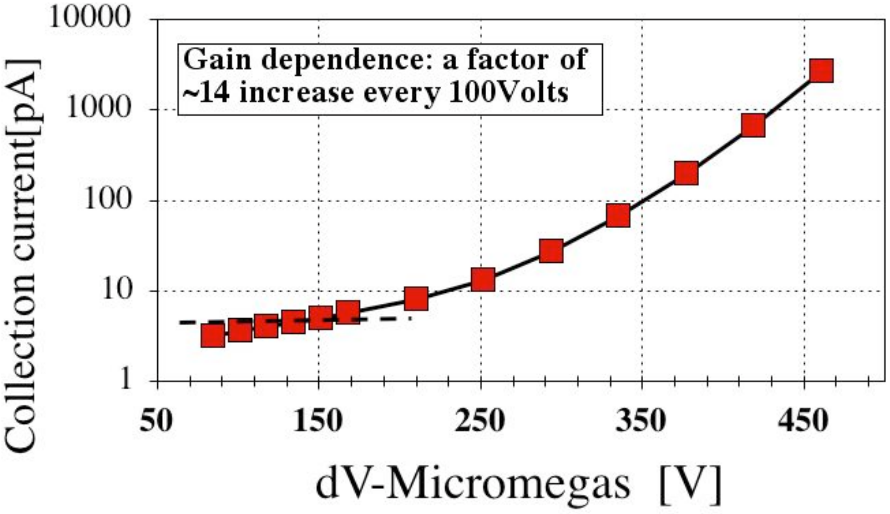

QE

90%Ar+10%CF_4
(works as P-10 gas)
Serial No. ZX 978

Wavelength

Total gas gain in 94.5%He+5.5%CH_4 gas at 1 bar





- **A factor of ~15 of gain increase every 100 Volts across either the Capillary or the Micromegas in this gas.**

- **Use a Mercury UV lamp to do this measurement.**

Comments on the timing resolution

- **Measurement to produce single electrons off the s.s. mesh using a PiLas laser diode (430nm) was not successful. So, I do not have a direct result, unfortunately.**
- **<u>However, perhaps, one could argue theoretically as follows:</u>**

  - Let's assume that the MCP has an average gain of 50.

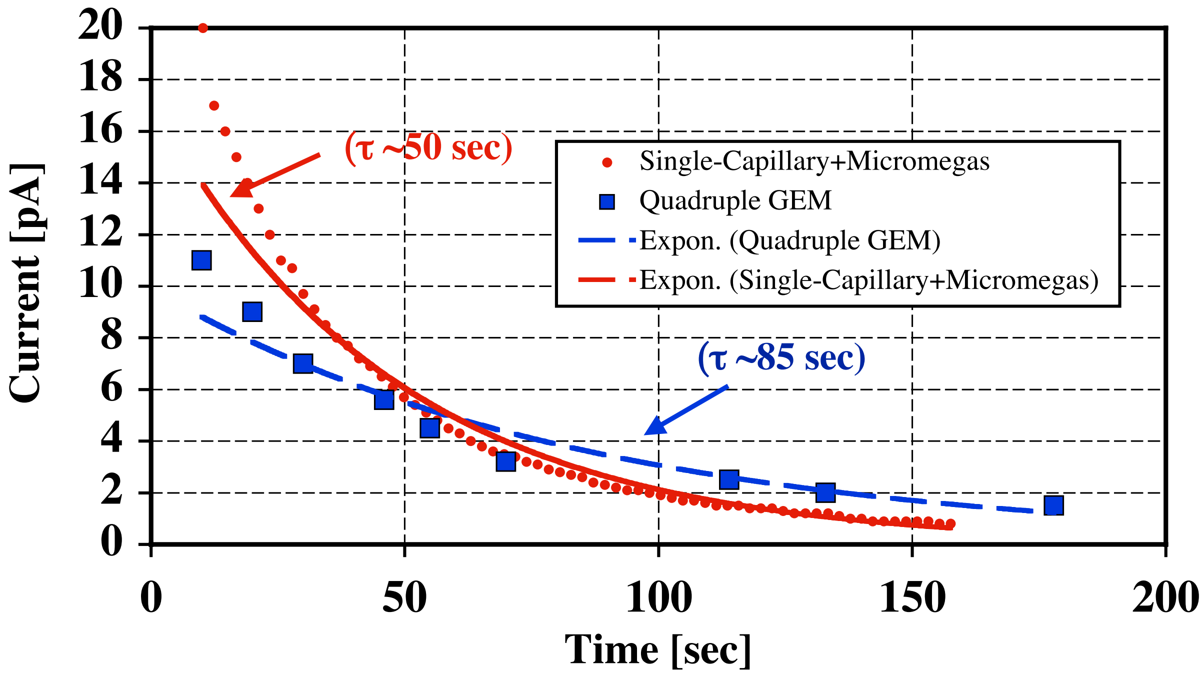
  - I will use this simple formula: $\mathbf{\Delta t \sim (1/\sqrt{N})\, \tau_{coll}/v_{drift}}$

  where N = 50, $\tau_{coll} = 1/\alpha$ is mean free path (α is Townsend coeff.) and v_{drift} is electron drift velocity in the Micromegas at ~50kV/cm.

  - Using the Magboltz-Monte program, one obtains Δt < 100ps for a 90%He+10%CH_4 gas.

  - However, in addition, there are avalanche fluctuations, which will make it worse. The MCP will also add tails to the timing distribution.

How quickly is the ion removed from the insulator ?



The remnant charge is removed from the insulators of the detector (Kapton or Glass) with a time constant ~85sec for "Quadruple-GEM", vs. ~50sec for the "Single Capillary + Micromegas detector".
Use a Mercury UV lamp (detector draws ~ 350nA). At that point switch lamp off and measure a discharge time constant of the decaying photocurrent.