(2004-2014)

MCP gain choices for TOF and Focusing DIRC (FDIRC) prototypes for SuperB

J. Va’vra, SLAC

- Around 2002 we started to think about SuperB experiment => this created a support for this activity.
- In the same period, Burle Planacon 64-pixel MCP-PMTs and Hamamatsu H-8500 MaPMTs were available.
- At one point I had ~14 Planacon MCPs and ~13 MaPMTs in my hands, so it was a non-trivial effort.

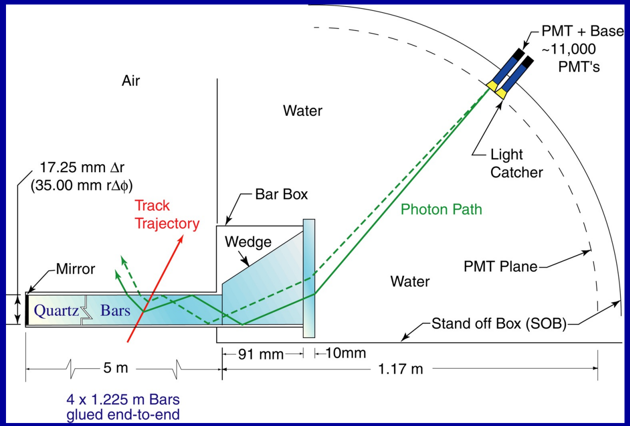
BaBar DIRC ---> SuperB FDIRC (2004-2015)

SuperB TDR: ArXiv 1306.5655, 2013

100x higher luminosity

BaBar DIRC

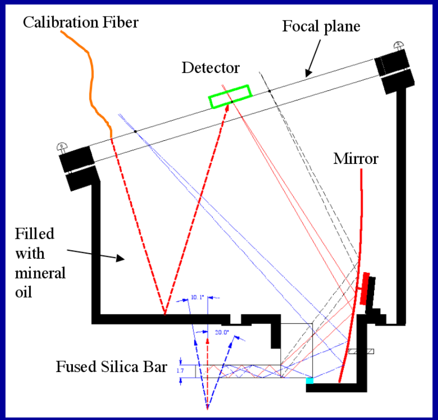
(water filled, ~11,000 PMTs)



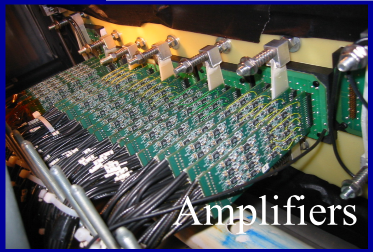
- **No. of pixels: ~11,000**
- **σ_{time}~1.7 ns /photon**

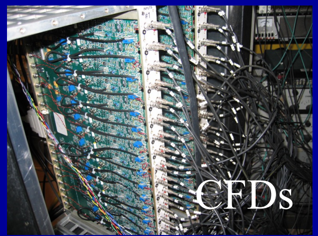
1-st FDIRC prototype

(oil filled, four MCPs. 2 MaPMTs)



SLAC electronics:



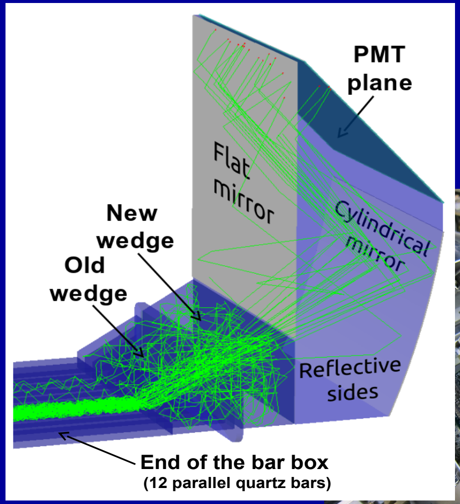


- **No. of pixels: ~384**
- **σ_{time} ~150-200 ps /photon**

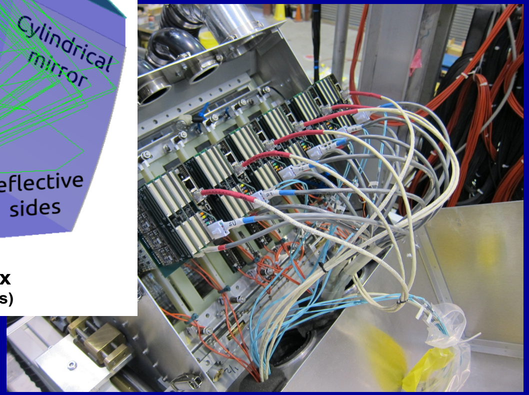
Final FDIRC prototype

(solid Fused Silica, eight H-8500 MaPMTs)

- **No. of pixels: ~384**
- **σ_{time} ~150-200 ps /photon**
- **25x smaller volume => smaller background**
- **10x faster than BaBar DIRC**



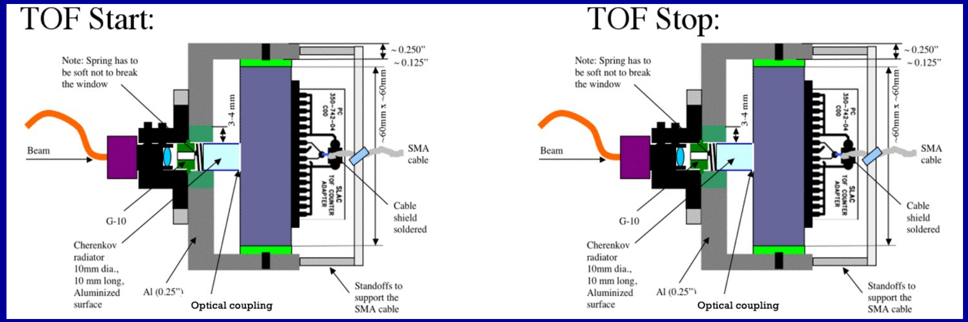
G. Varner's
IRS-2 electronics:



- **Final FDIRC optical concept was used in the GLUEX experiment at JLAB.**
- **We were also de facto debugging the waveform digitizing electronics for Belle-II.**

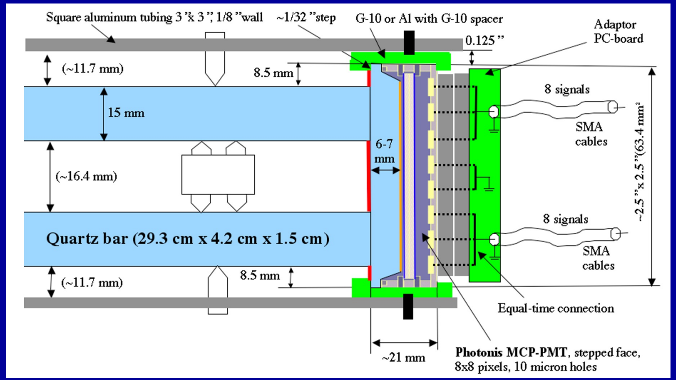
TOF R&D for SuperB (2003-2012)

Two prototypes:



NIM A 606 (2009) 404

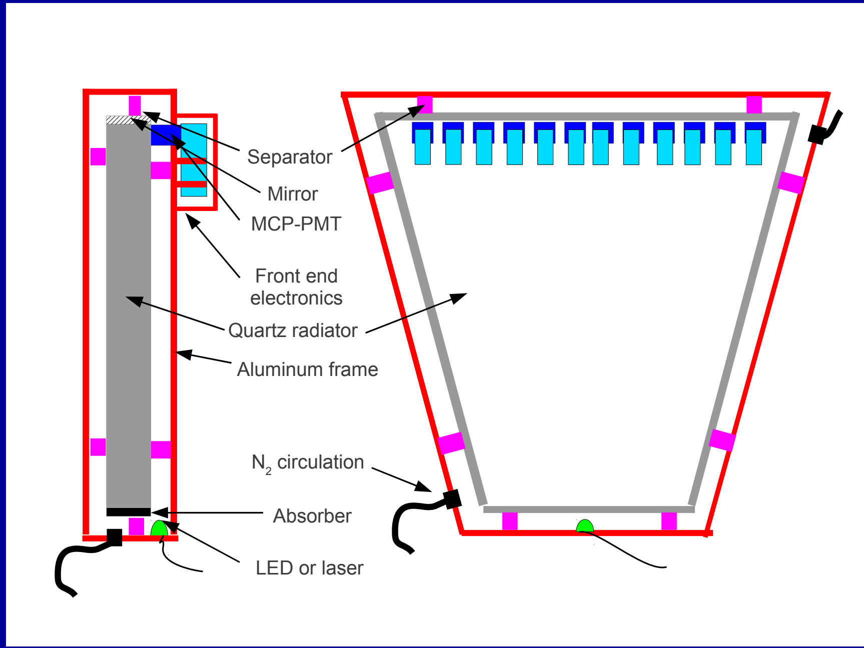
Coupled to:
Hamamatsu C5594, Ortec VT-120 or Ortec 9327 amp/CFD disc, etc.



NIM A 695 (2012) 83

Coupled to:
Miteg amplifiers

Final proposal for SuperB:

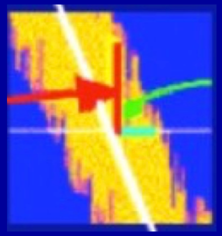


SuperB TDR: ArXiv 1306.5655, 2013

Timing resolution for leading edge timing

A simple well-known formula:

$$\sigma_{time} = \sigma_{noise} / (dS/dt)_{threshold} \sim t_{risetime} / (S/N)$$



$S/N = S / \sigma_{noise}$
S = Signal amplitude
$(dS/dt)_{threshold} \sim S/ t_{risetime}$

- **To get good timing one needs a good S/N ratio => One wants to push the gain up.**
- **The signal must trigger a threshold to increase efficiency => One wants to push the gain up.**
- **Noise should be reduced. To reduce the amplifier noise level N, lower BW amplifier helps.**
- **High gain we may trigger MCP after-pulsing due to positive ions.**
- **High gain increases cross-talk and and may worsen ringing in MCP.**
- **High gain worsens aging.**

- **One must find a delicate balance among all these variables. Empirically.**

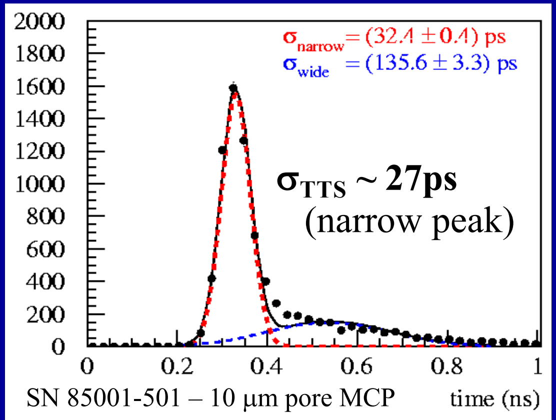
Single photoelectron TTS at high MCP gain

Va'vra, logbook 3, p. 27, 28 & 37, 2006 and NIMA A 572 (2007) 459
vs. J. Milnes et al., NIMA 1056 (2023) 168631

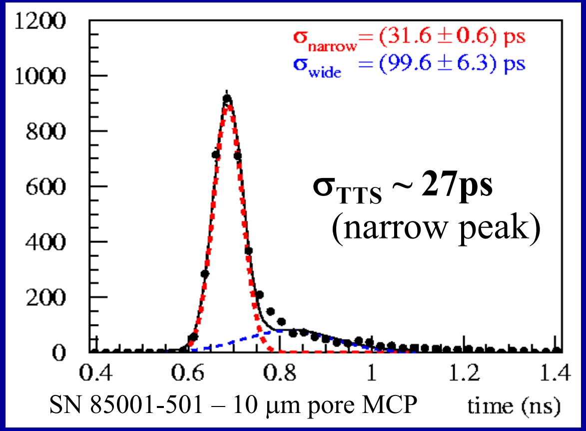
1) J. Va'vra:

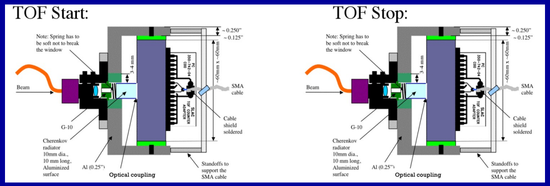
2006:

With Hamamatsu C5594-44 amplifier
1.5 GHz BW, 63x gain, 2.8kV



With Ortec VT-120A amplifier
~0.4 GHz BW, 200x gain + 6dB, 2.8kV



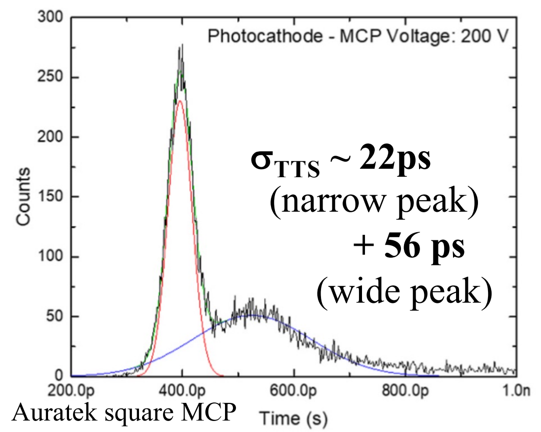


- **MCP Gain ~10^6, Npe = 1**
- Planacon MCP
- 10 μm MCP hole diameter
- $\sigma_{TTS} \sim \sqrt{(32^2 - \sigma_{Laser}^2 - \sigma_{Electronics}^2)} \sim 27$ ps
- σ_{Laser} ~15 ps, Pilas 635 nm
- $\sigma_{Electronics}$ ~15-20 ps
- Philips 715 CFD, LeCroy TDC 2248

2) J. Milnes:

2022:

No amplifier:

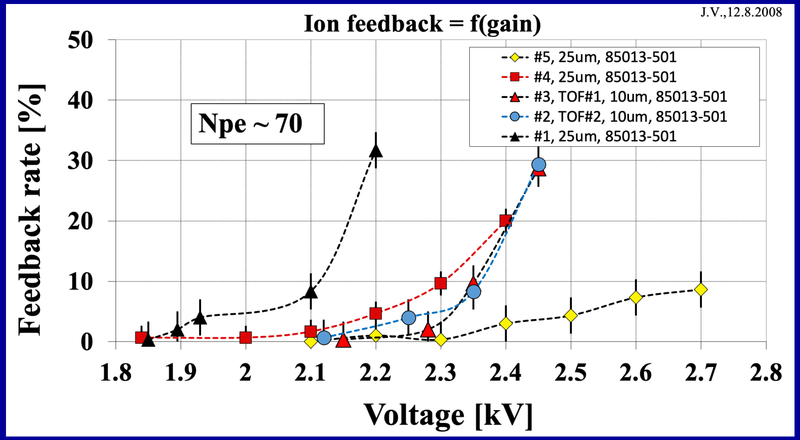


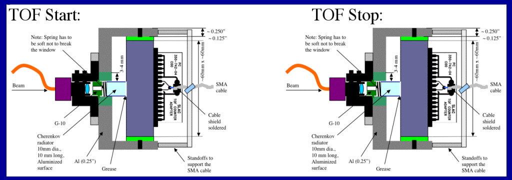
- **MCP Gain ~2×10^6, Npe = 1**
- Photek 256-pixel Auratek square MCP
- 6 μm MCP hole diameter
- Photek 405 nm LPG-405: ~ 40 ps FWHM
- LeCroy Wavemaster 808Zi-A (8 GHz, 40 GS/s)

- **One can get excellent TTS resolution with MCP operating at high gain.**

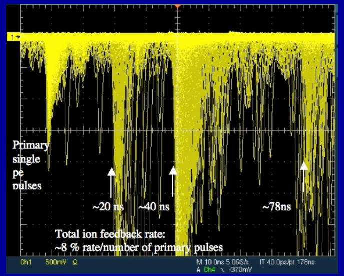
Ion feedback in early Burle MCP-PMT

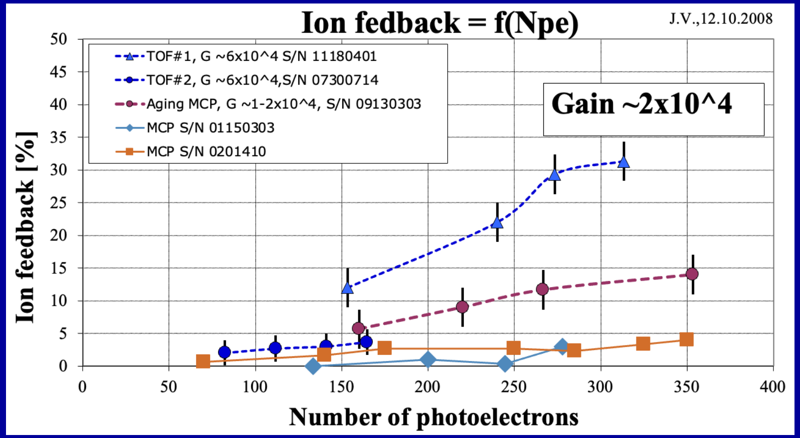
J. Va'vra, logbook 6, 2008, MCP_ion_feedback.xlsx

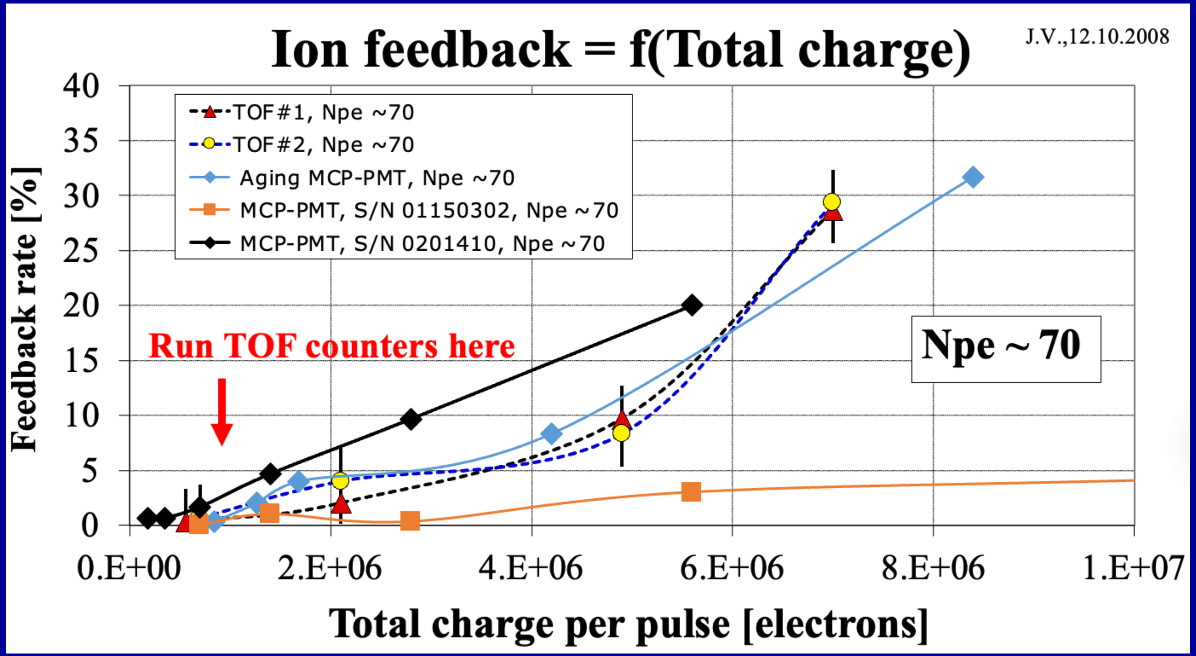




Peaks on storage scope correspond to different ions (H^+, He^+…) :







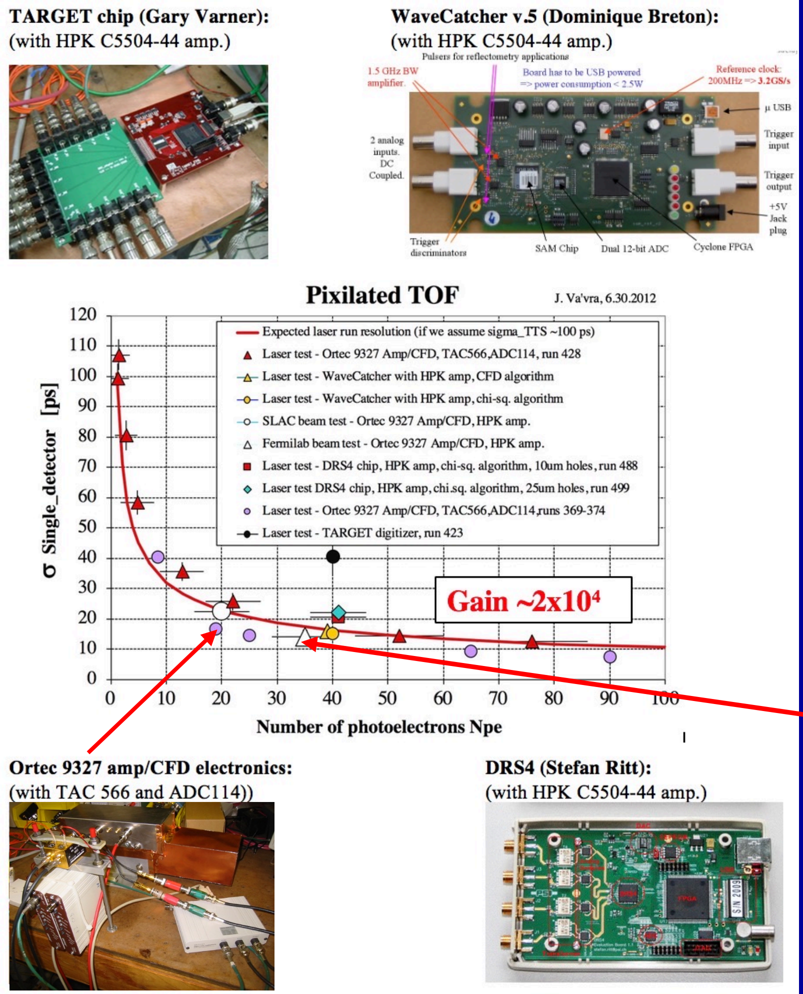
- I decided to limit the gain to $<10^6$ to minimize the ion feedback. Both TOF counters run with a total charge of ~$8x10^5$ (gain ~$2x10^4$ & Npe ~40; to get Npe ~40, I used 1cm long quartz radiator).
- (MCP could deteriorate if a vacuum leak develops or outgassing by electron bombardment of pores.)

Can one achieve a good timing resolution at low gain ?

J. Va'vra, MCP logbook #7, p.120, 2012, NIMA 629 (2011)123, and NIMA 606 (2009) 404

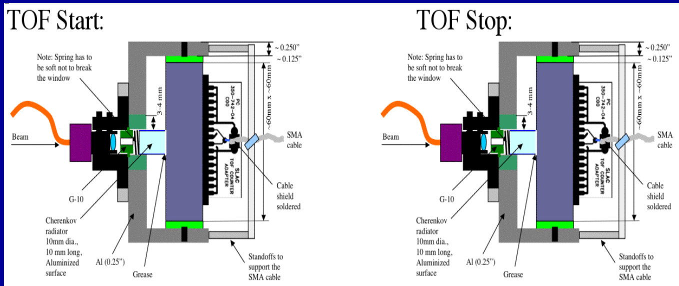
2012:

Laser and beam tests with various electronics concepts:

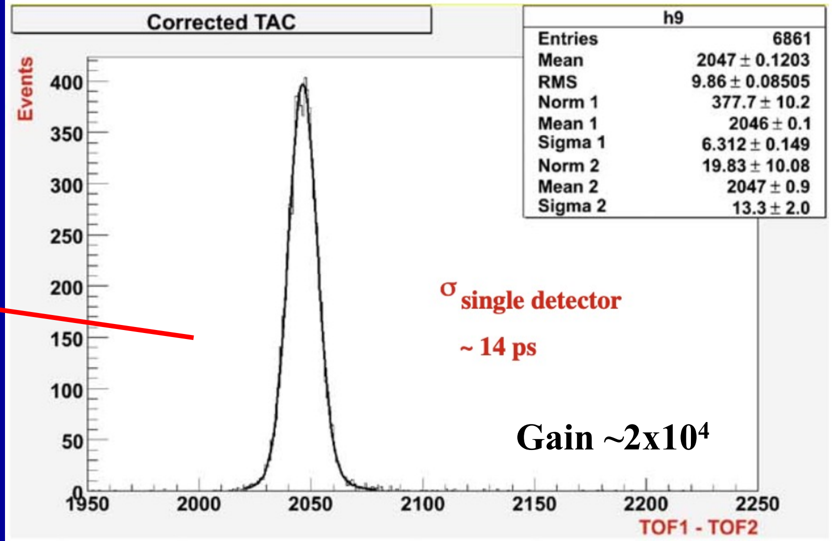


2 Burle old Planacon 10μm MCP-PMT 85013-501:

(4 pixels ganged together, others grounded)



Fermilab beam test at low gain (with Ortec electronics):



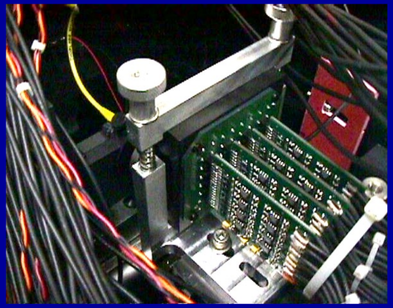
- **We did reach a timing resolution of ~14ps even at low gain of ~2x10^4, if Npe ~40.**
- **Ortec 9327 analog Amp/CFD electronics was the best method.**

Cross-talk in early version of Planacon MCP 85011-501

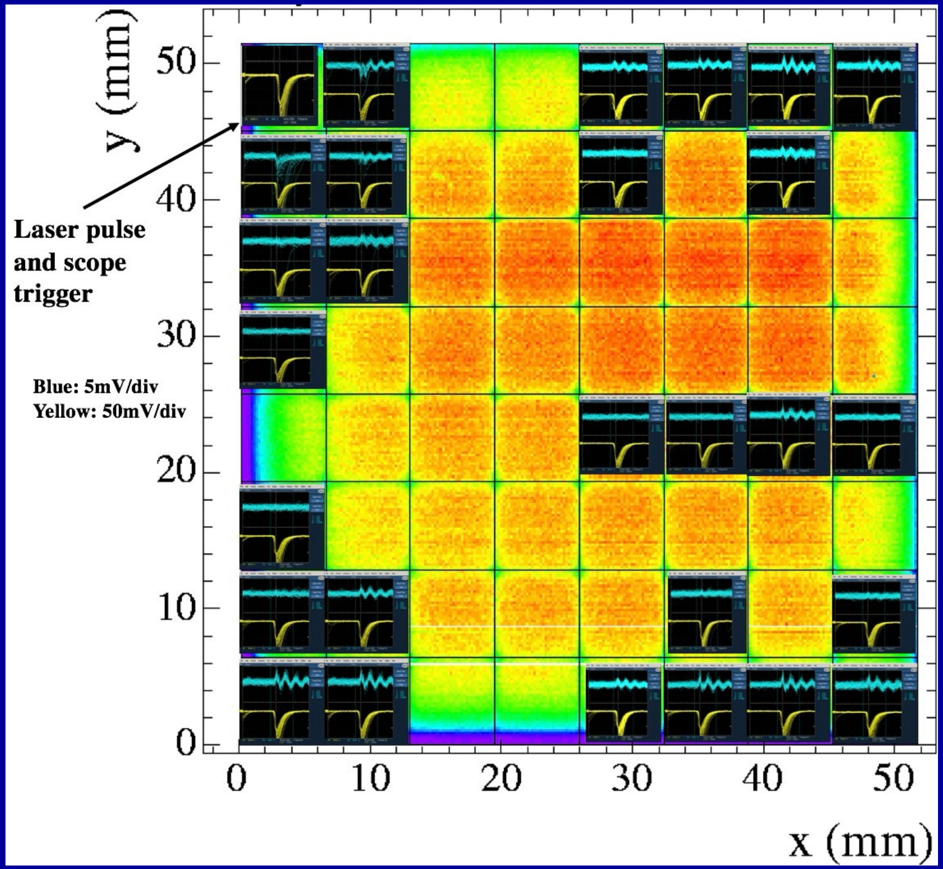
J.Va'vra, MCP-PMT logbook #1, p.86, 2003

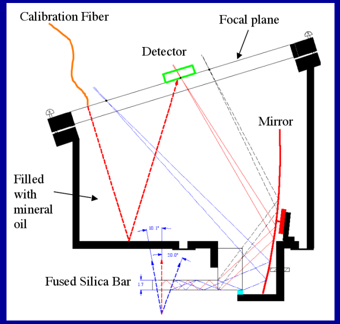
2003:

SLAC amplifier based on Elantec chip:



4 ns/div
&
50 mV/div
&
5 mV/div





Electronics used in this test:
Voltage gain in this test:
Total voltage gain of 130x =
Elantek 2075 amp. 13x + Phillips amp. 10x

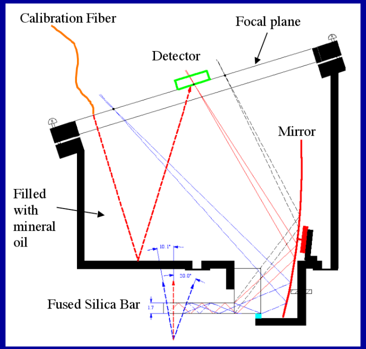
- **The cross-talk was very complicated geometrically due to design of the backplane.**
- **Such crosstalk affects the leading edge of unrelated pulses, thus affects multi-pixel timing quality.**
- **Note: Photonis has solved this ~15 years later by redesigning the backboard.**

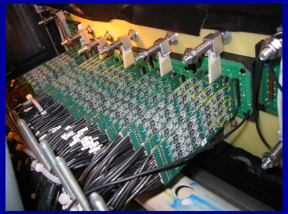
Ringing observed in the 1-st FDIRC while in the beam

J. Va'vra, FDIRC logbook "Beam_test_Focusing_DIRC_3.pdf", p.53, 2006, and J. Phys.: Conf. Ser. 1498 012013

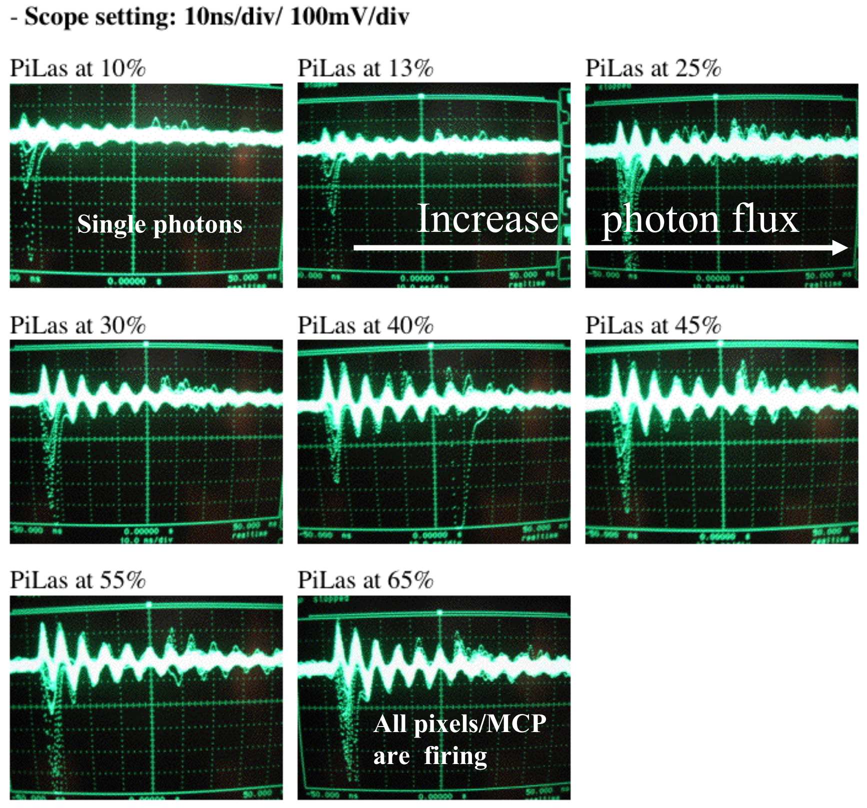
2006:

1-st FDIRC prototype:





Early version of Planacon MCP-PMT 85011-501:



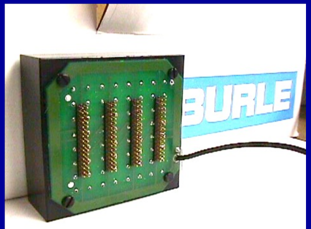
- **If MCP is subject to many pulses at the same time, the crosstalk adds up, and it causes ringing.**
- **Amplitude of ringing increases with number of photons hitting MCP. High gain makes it worse.**
- **Taking all things into account, I have decided to operate FDIRC MCPs at a gain of 3-5x10^5.**

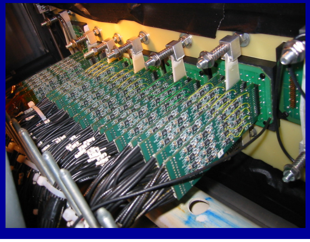
Analog electronics to run the 1-st FDIRC prototype at low gain

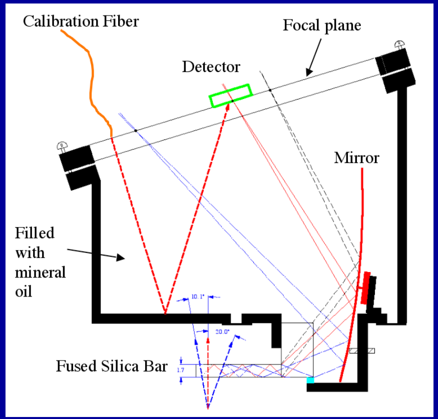
2005:

To develop amplifier & CFD: **G. Mazaheri** & J. Va'vra, logbook2, 2005, NIMA 553 (2005) 96

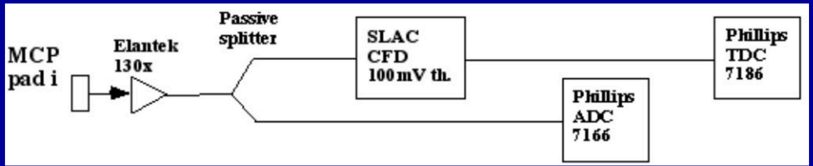
Burle Planacon:





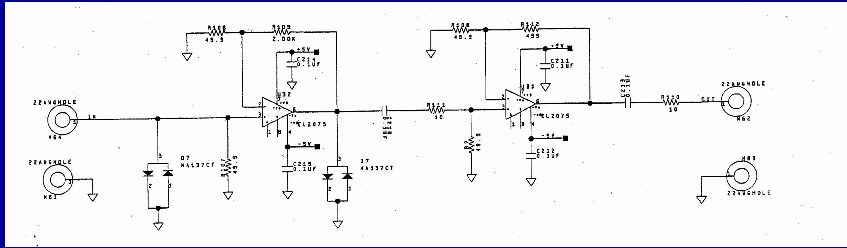


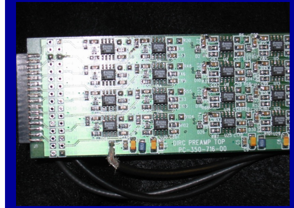
Simple electronics:



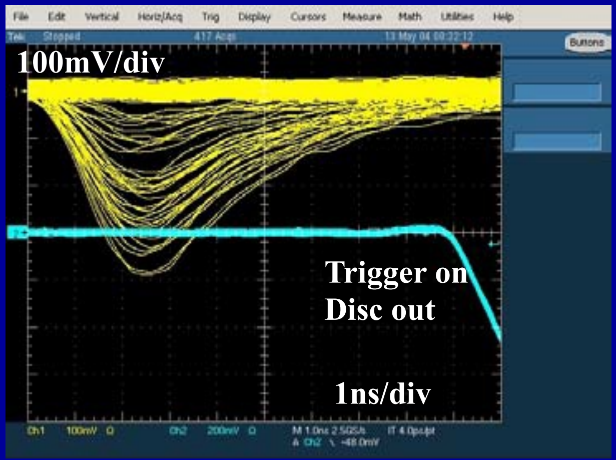
SLAC-made Amplifier based on Elantek 2075:

Total voltage gain of ~130x, and a rise time of ~1.5ns.

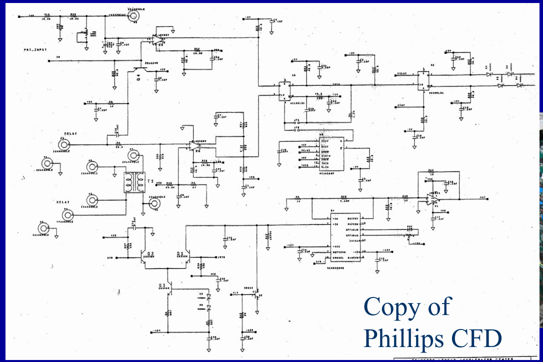


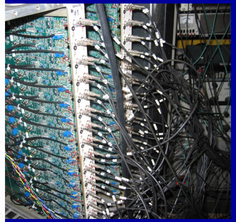


Amplified single photons – laser @ 2.4 kV:



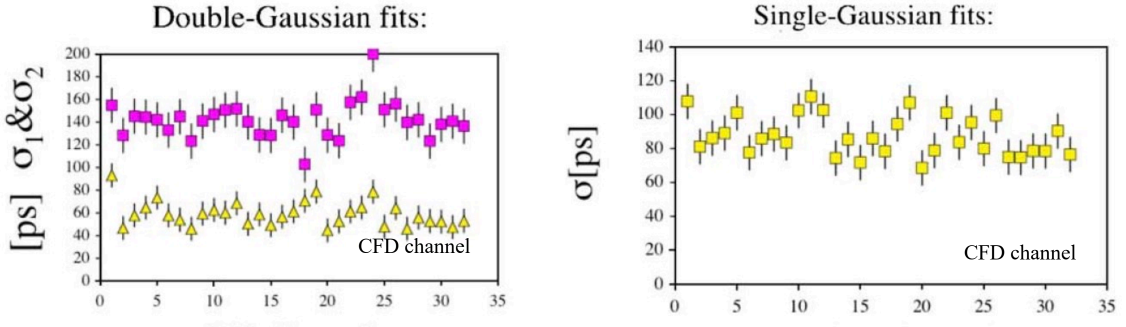
SLAC-made CFD (32 ch./board):





Single photo-electron timing resolutions with Planacon MCP with small photocathode-MCP gap of ~0.75mm:

(Burle Planacon stepped face MCP used in this test had 25 μm pores)

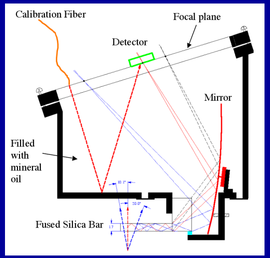


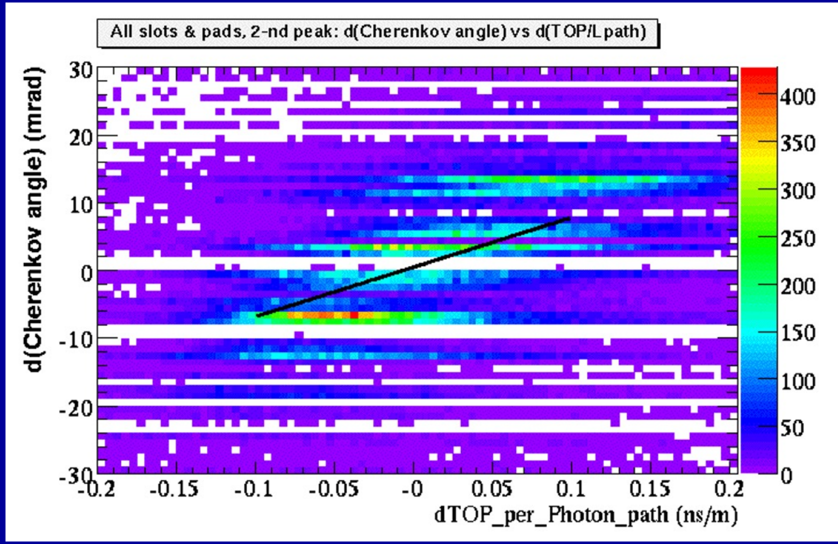
- **Results were very good.**
- **Analog electronics allowed to understand every channel. This feature was crucial for success of FDIRC.**

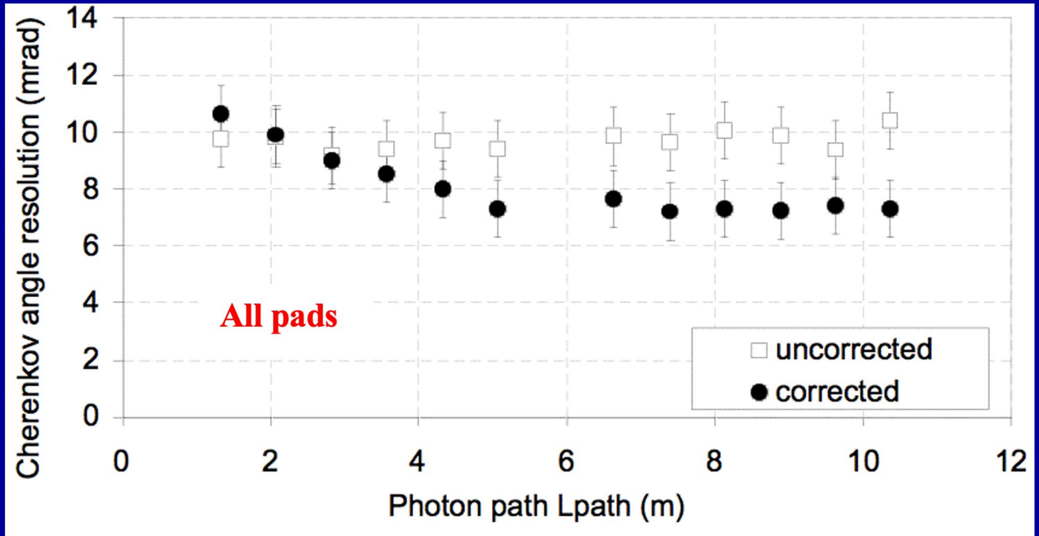
The 1-st FDIRC prototype was the very first RICH detector to correct the chromatic error by timing

2008:

NIM A 595 (2008) 104



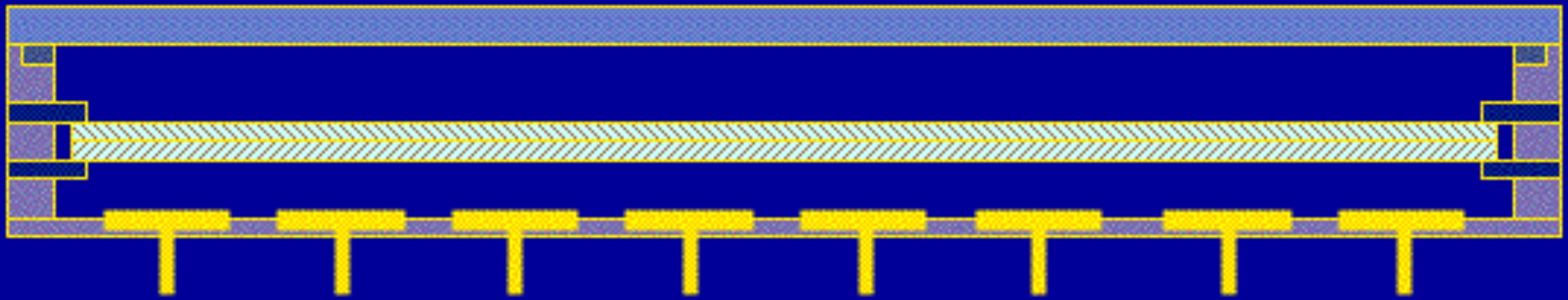




Note: dTOP = $TOP_{measured}$ - $TOP_{expected}$

- **The chromatic error is caused by different colors in the Cherenkov spectrum. Red photons propagate faster than blue photons. While the red photons have a small path handicap from the production point to the detector, their group velocity is larger, so they arrive at the detector before the blue photons, resulting in an easily measured time dispersion of up to a few nanosecond over the full range of L_{path} in DIRC bar.**
- **The final FDIRC improved this with higher accuracy.**

Conclusion



- **Initially, I thought that MCP is a simple detector.**
- **Now, I do not think so. This is because MCPs use insulators (glass, ALD coating, ceramic).**
- **One deals with rate dependent effects, ion feedback, aging, outgassing, possible leaks, etc.**
- **Considering all variables, I would run MCPs at <u>as low gain as possible</u> to achieve your goal.**