Forward TOF

Update on a photocathode choice, and waveform digitizing electronics performance

J. Va'vra, SLAC

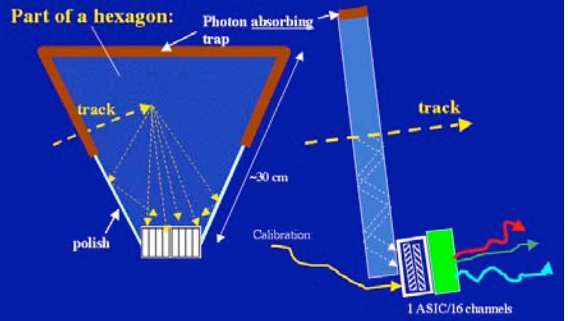
Content of this talk

- **DIRC-like TOF: would more a red photocathode help ?**
- **Pixel-type TOF: New timing measurements with the TARGET chip**

  - Is there a new trick in timing ?

DIRC-like TOF

DIRC-like TOF:



- Bad part:

a) Must be sensitive to single photoelectrons

b) Detector has to work at high gain (>5x10^5).

c) Detector operates at higher rate. Therefore, the rate and aging problems are a concern.

e) Chromatic effects could be important for large photon paths.

f) More complicated data analysis.

g) Quartz radiator needs a complicated & perfect photon trap.

- Good part:

a) Small number of photo-detectors

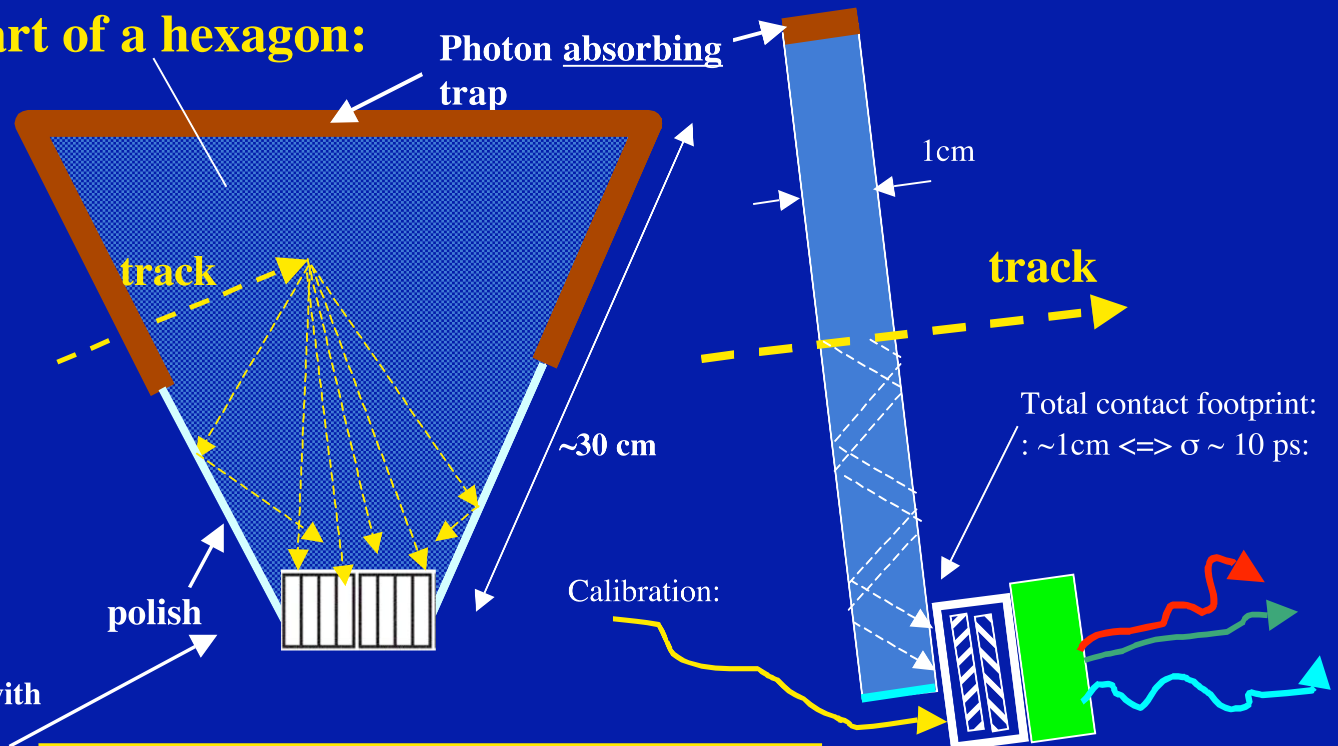
b) Thin & uniform radiator in front of the calorimeter

“DIRC-like” TOF detector

J.V., http://www.slac.stanford.edu/~jjv/activity/Vavra_Forward_TOF_geometry.pdf, Perugia, June 2009

Part of a hexagon:

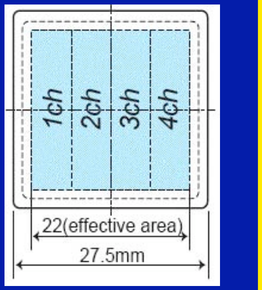
- Not all photons are of “equal” quality. Some we want to throw away because they are affected by the chromatic broadening.
- We do not want photons to rattle around for too long
- This design requires a high gain operation to detect single photons



1 ASIC/16 channels

Hamamatsu MCP-PMT (SL-10) with strips and a protection foil:

ϕ 10 μm holes



Time-of-Proparation:

$$TOP(\Phi, \theta_c, \lambda) = [L_{\text{photon path}})]/[v_g(\lambda)]$$

A direct photon is accepted only if:

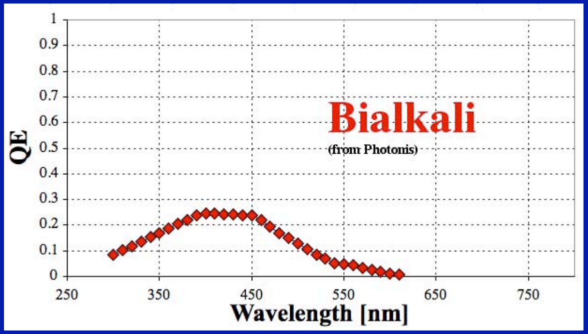
$$TOP_i^{\text{measured}} - TOP_i^{\text{expected}} < Cut$$

Even 3 photons will do as long as they are “good” photons

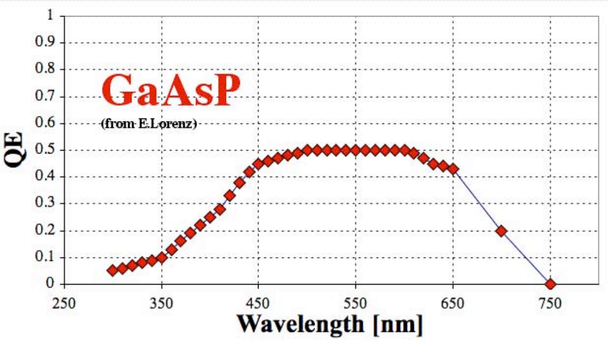
Number of photoelectrons in quartz for various photocathodes

J. V., TOF_counter_Npe.xls

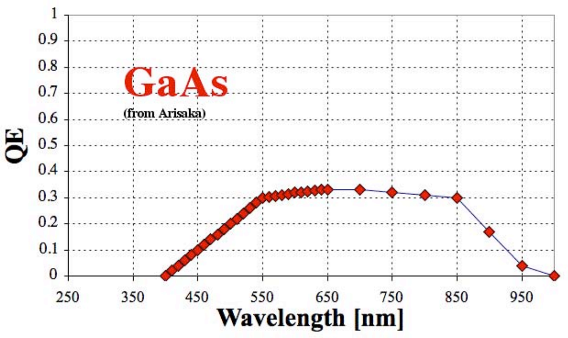
$$\boxed{Npe = 370\, L \int \varepsilon(E) \sin^2 \theta_c \, dE}$$



Npe ~ 40/cm



Npe ~ 70/cm



Npe ~ 42/cm

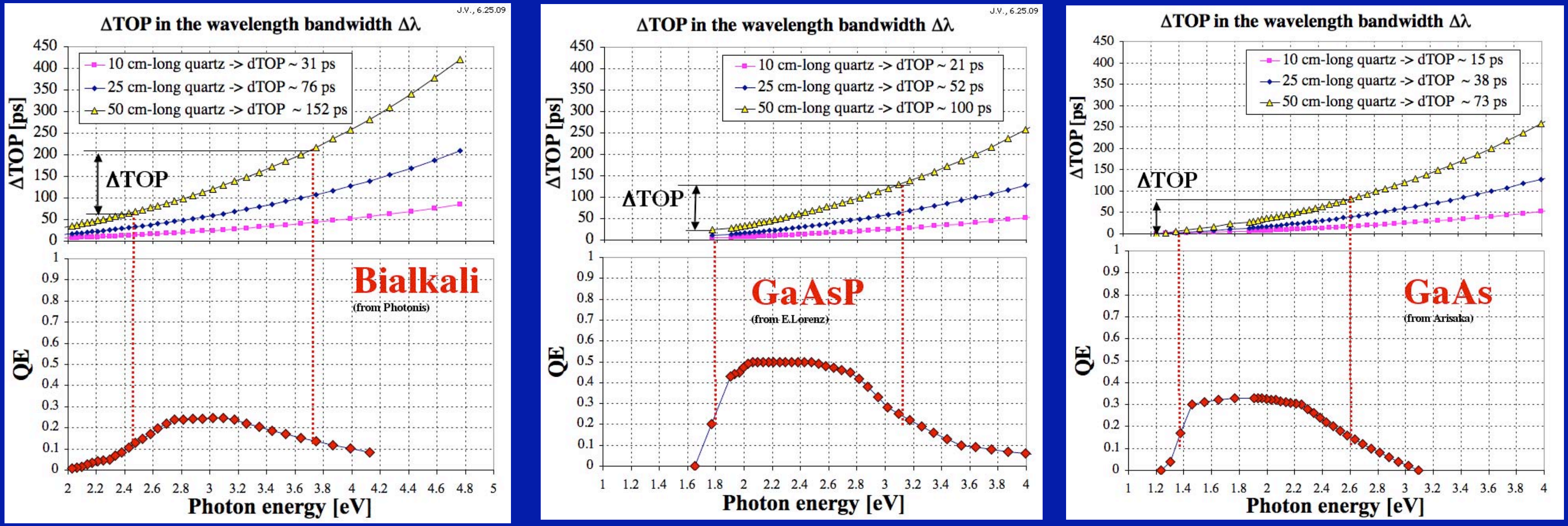
- **The photon yield goes as $1/\lambda^2$ => Going red means that one needs a higher QE to offset the loss due to the $1/\lambda^2$ effect.**
- **It turns out that GaAsP gives largest number of photoelectrons.**

How important is the chromatic broadening ?

J. V., Q.E.&Tr&n - overall.xls

$$TOP(\Phi, \theta_c, \lambda) = [L_{total\ photon\ path}(\Phi, \theta_c)/[c/n_g(\lambda)], \text{ where } n_g = n_{phase} - \lambda * dn_{phase}/d\lambda$$

Determine ΔTOP three photon path lengths in quartz: 10, 25 and 50 cm:



ΔTOP in the wavelength bandwidth ΔE

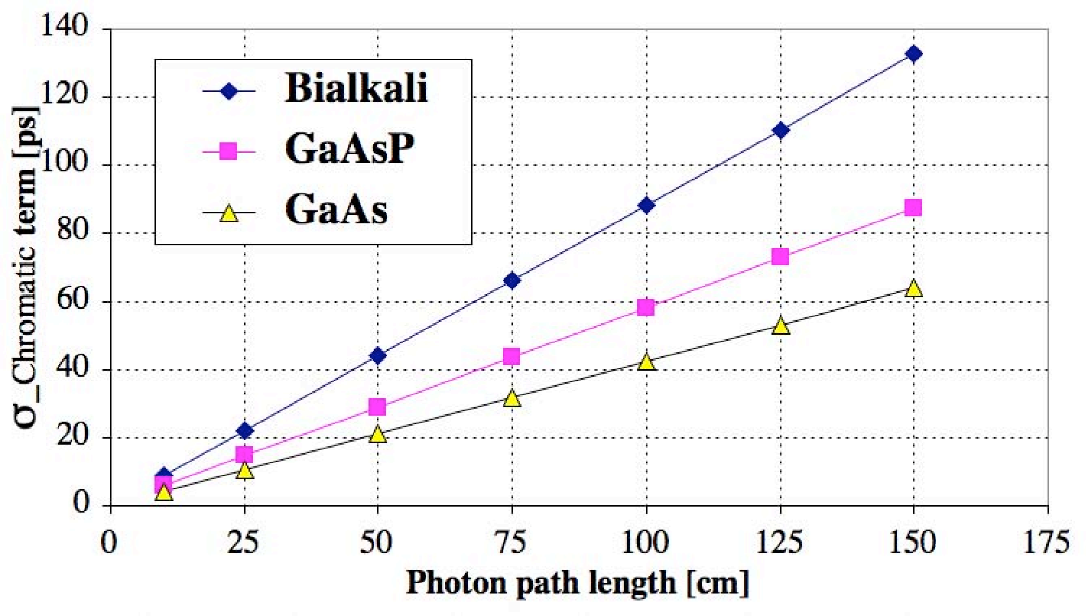
- **ΔTOP gets smaller as one goes more red.**

Chromatic term in timing resolution

J. V., TOF_counter_Npe.xls

$$\boxed{\sigma_{Chromatic} \sim \Delta TOP/\sqrt{12}}$$

Chromatic term for different colors:



- Going more red reduces $\sigma_{Chromatic}$ significantly for longer photon paths.

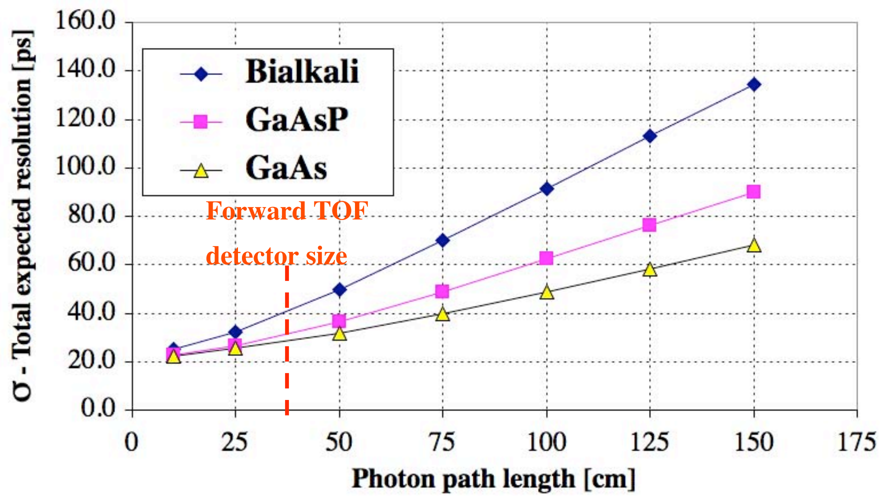
Large “DIRC-like” TOF detector

J. V., TOF_counter_Npe.xls

$$\sigma_{Total} \sim \sqrt{}\,[\sigma^2_{Electronics} + (\sigma_{Chromatic} / \sqrt{}(\varepsilon_{Geometrical\_loss} * N_{pe}))^2 + (\sigma_{TTS} / \sqrt{N_{pe}})^2 + \sigma^2_{Track} + + \sigma^2_{detector\ coupling\ to\ bar} + \sigma^2_{to}]$$

$\sigma_{Electronics}$ - electronics contribution ~ 10 ps
$\sigma_{Chromatic}$ - chromatic term = f (photon path length) ~ 5-45 ps for path lengths 10-50 cm
σ_{TTS} - transit time spread ~ 35 ps
σ_{Track} - timing error due to track length L_{path} (poor tracking in the forward direction) ~ 5-10 ps
$\sigma_{detector\ coupling\ to\ bar}$ - timing error due to detector coupling to the bar ~ 10 ps
$\sigma_{t\ o}$ - start time dominated by the SuperB crossing bunch length ~ 15 ps
$\varepsilon_{Geometrical\_loss}$ - loss due to a geometrucal acceptance (“reject” bad photons) ~ 10%

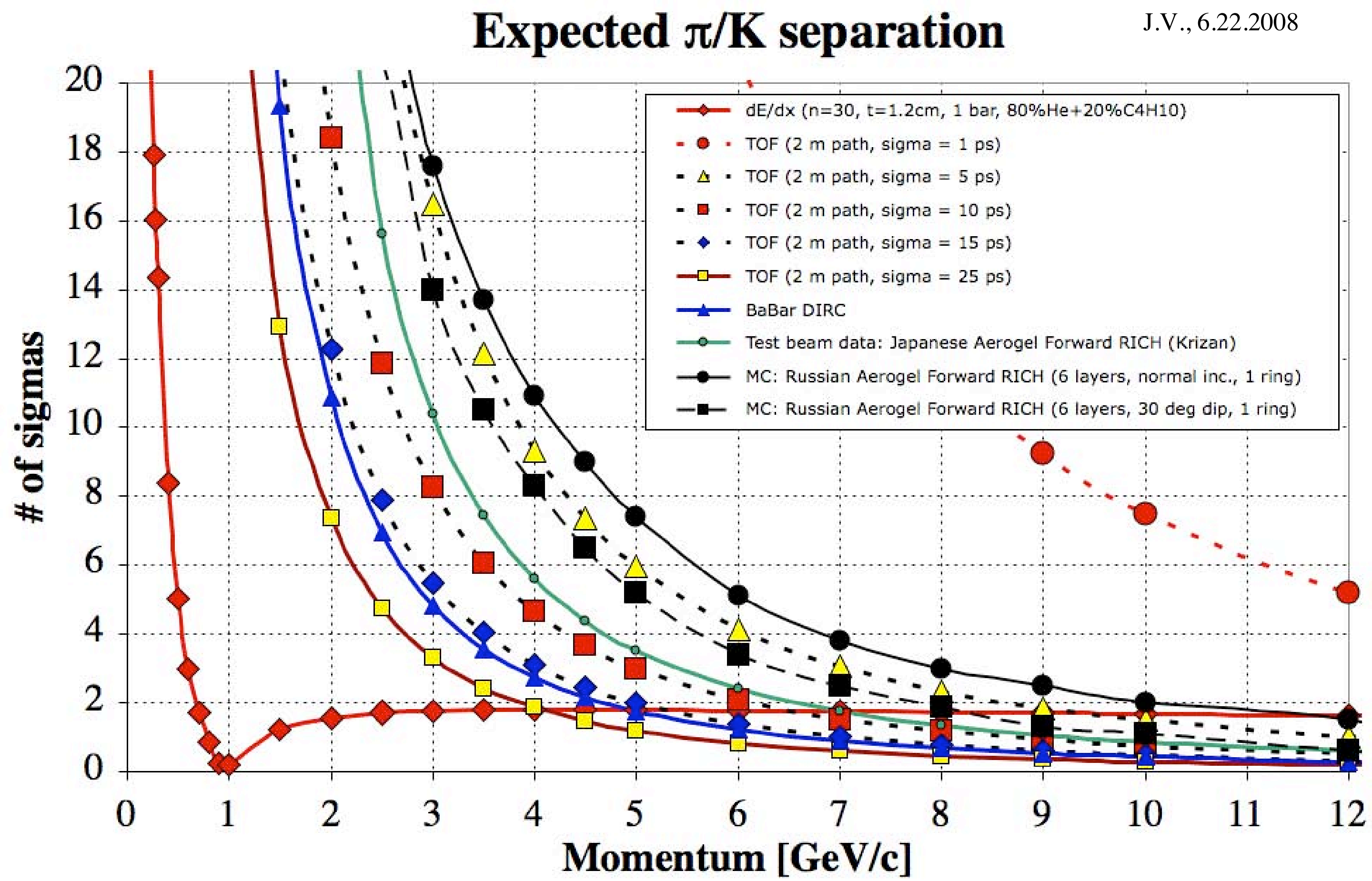
Expected final resolution:



- **Bialkali photocathode will have σ_{ave}~ 30ps, with GaAsP ~ 25ps. Is it worth it ? Perhaps not.**
- **For L_{path} > 15 cm, red-sensitive photocathodes start yielding better results.**

Comparison of PID methods in SuperB geometry

J. V., dE_dx = f(beta_gamma) study.xls

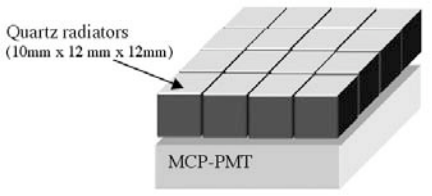


Expected π/K separation

J.V., 6.22.2008

- **If the DIRC-like TOF will achieve σ ~ 30ps, a practical detector with this photocathode will be useful up to ~ 2.5 GeV/c.**

Pixilated TOF:



Pixilated TOF

- Bad part:

a) Large number of photo-detector needed.

b) Too much mass in front of the calorimeter.

c) Low gain operation => worse S/N ratio

- Good part:

a) Low gain operation (~$2x10^4$) - small rate of aging.

b) Detector "does not" see single photoelectron background. The detector is sensitive only to tracks. Therefore the detector operates at much lower rates. Therefore, the rate and aging problems are easier to solve.

c) Simple data analysis.

d) The chromatic effects are not important at all.

Further testing results using the Target ASIC chip with a TOF prototype

Can one get a good timing resolution even with a slow sampling rate of ~2.5 GSs/s and a chip with a front end BW of ~ 0.25 GHz ?

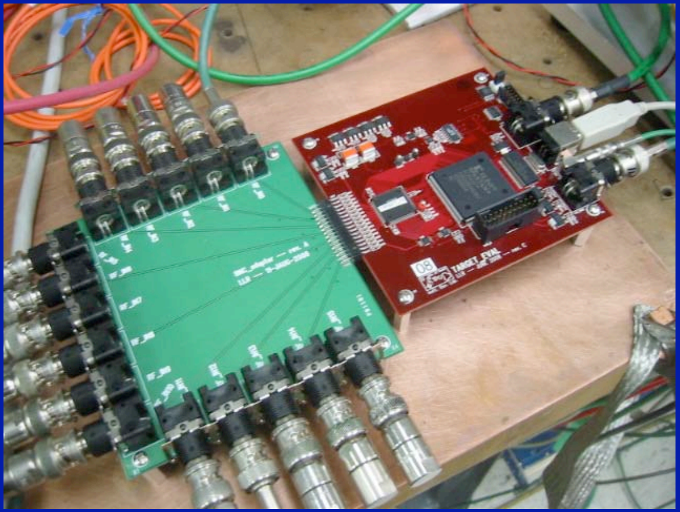
Comments:

- Apparently the answer no, judging by the fact that the entire world is pushing more than 4 GSa/s.
- After my last SuperB presentation, Dominique told me that I must have some trick, which CERN people are apparently missing…
- Gary Varner told me, when I explained to him my new timing scheme: hm, interesting, I did not think about this before.

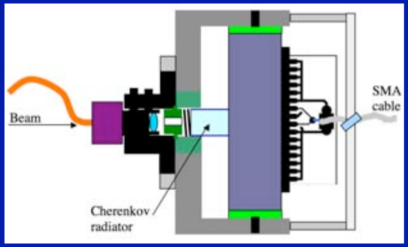
So, what is the new scheme ?

Target chip & TOF counter bench tests with the laser

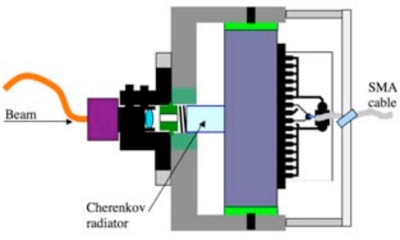
TARGET chip developed by G. Varner:



TOF 1:



TOF 2:

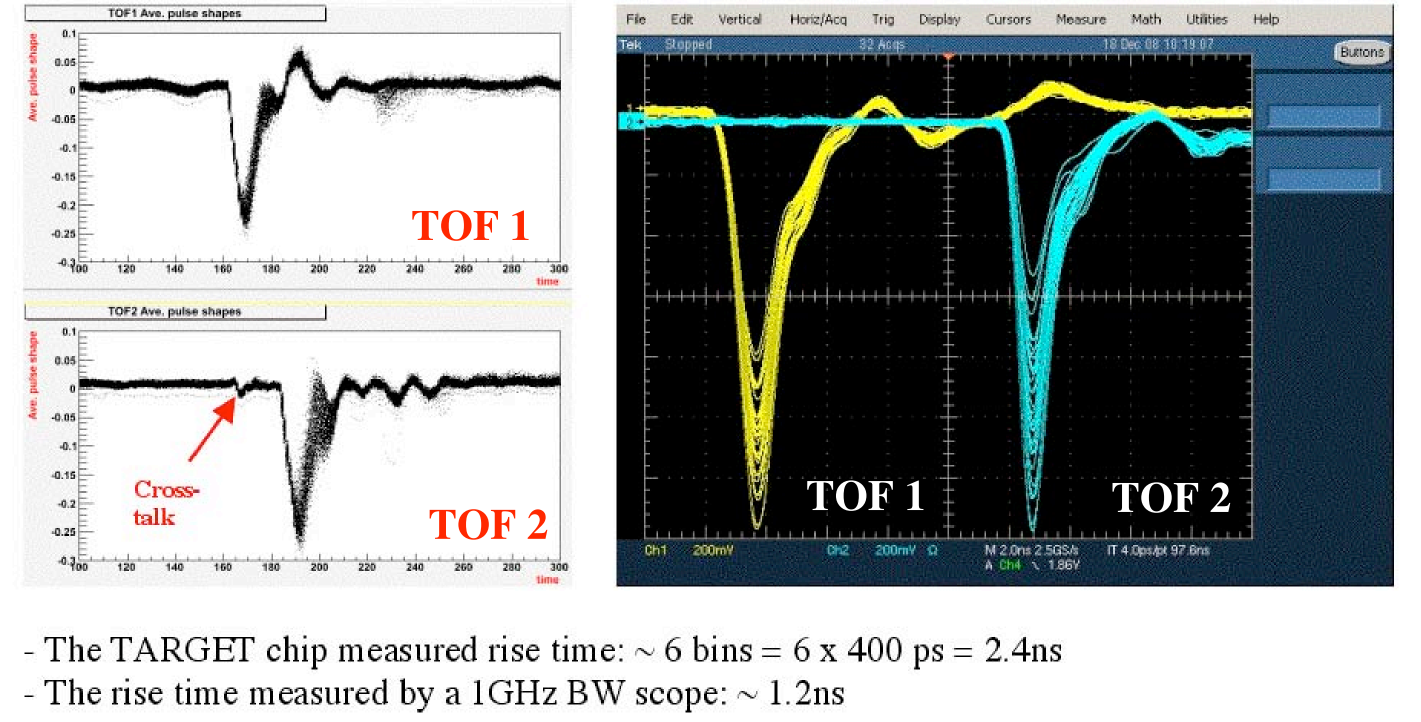


- Light source: PiLas laser diode
- Two Photonis MCP-PMTs used in the Fermilab test beam setup.
- **Low gain** of 2-3x10^4.
- **Fast detector** & **fast** HPK **~1.5 GHz BW amplifier** (gain of 63x).
- Target chip sampling speed only ~ 2.5 GSa/s (sampling every 400 ps), **with very slow front end (~ 0.25 GHz BW).**

\- **This leads to the saturation of the leading edge, and this is the trick.**

=> Therefore the timing becomes easier & spline interpolation more precise

1 GHz BW scope vs. Target chip



- Comparison of the reconstructed pulses from the TARGET chip and 1GHz BW scope:

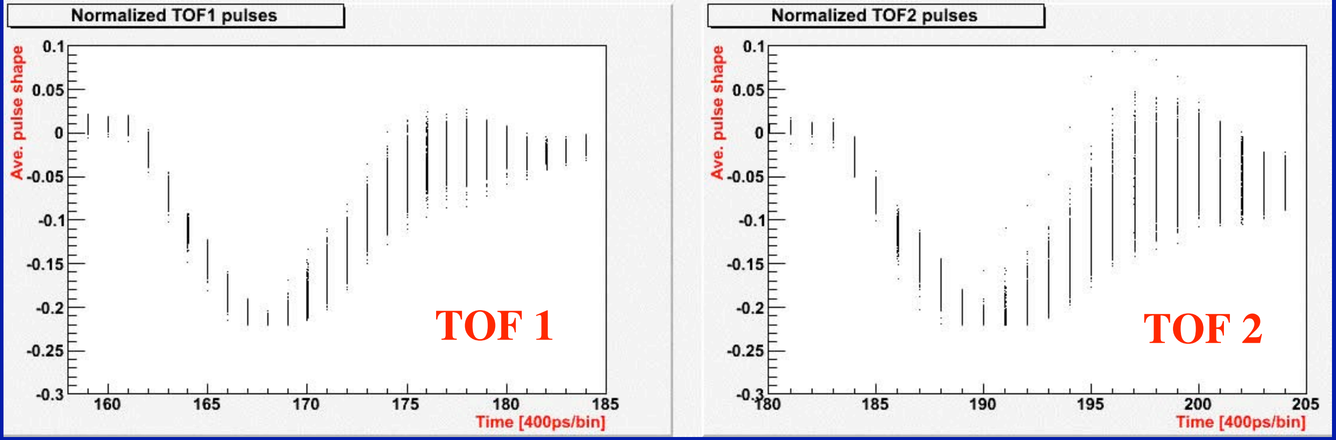
- The TARGET chip measured rise time: ~ 6 bins = 6 x 400 ps = 2.4ns
- The rise time measured by a 1GHz BW scope: ~ 1.2ns

- I call the new timing method as:

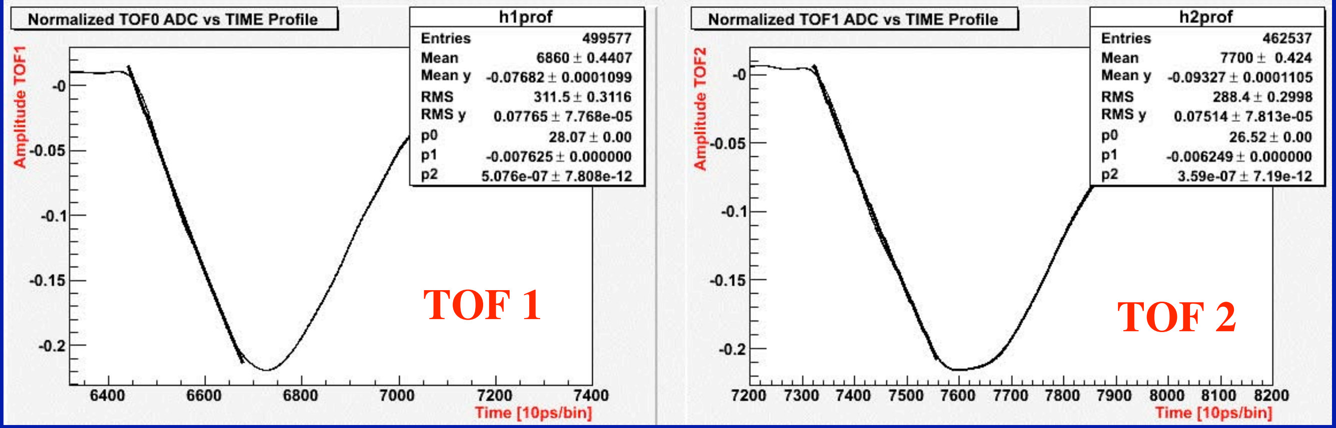
“Mismatched BW timing method”.

Timing method: Reference pulse timing algorithm

Create an average waveform using pulses normalized to amplitude:



Create profile of the average waveform and fit the leading edge with a polynomial function:

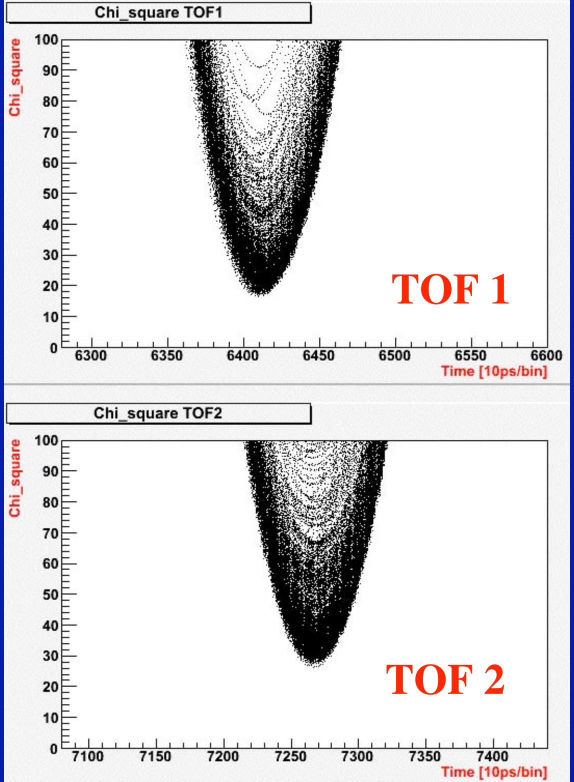


- Use a **spline interpolation** to get a new binning: 10ps/bin.

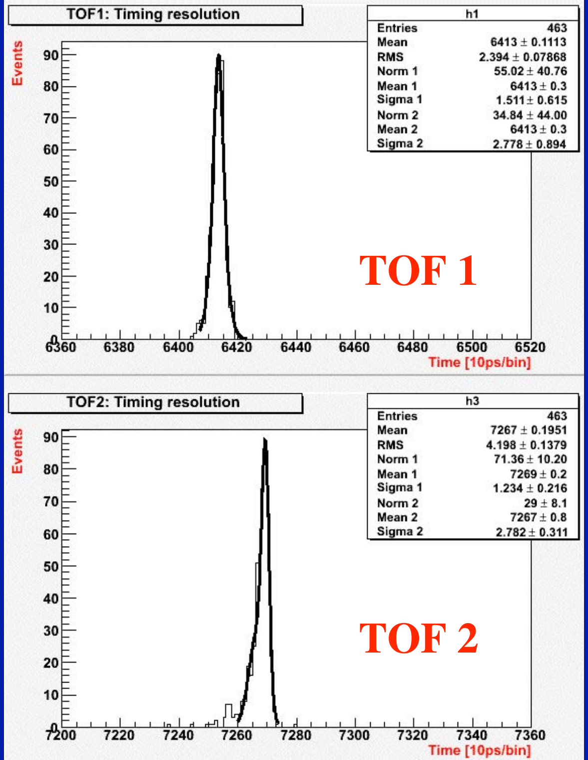
Find an optimum timing point

Reference pulse "marches" through
a given pulse and finds a minimum chi-sq.:

Used
normalized
pulses:



Timing between the trigger and each counter:

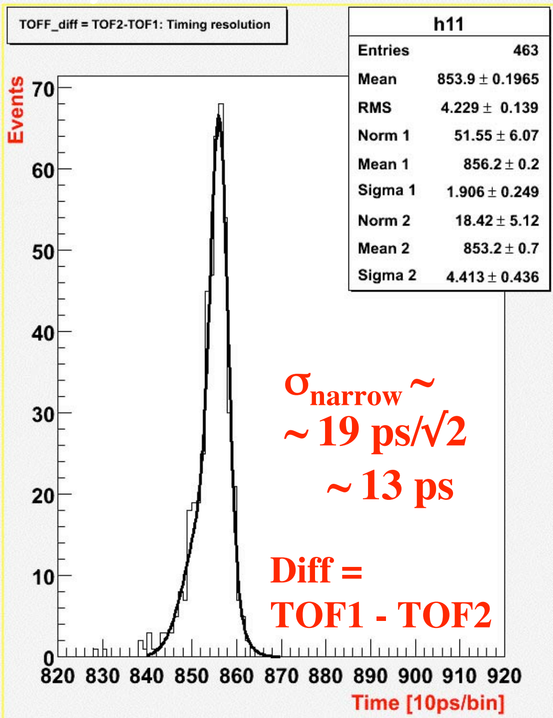


- **Tune the optimum number of bins** used in the chi-sq. calculation.

The optimum is to go beyond the leading edge width: 200 (analysis 2a) -> 300 bins (analysis 2b).

Final result with TARGET chip

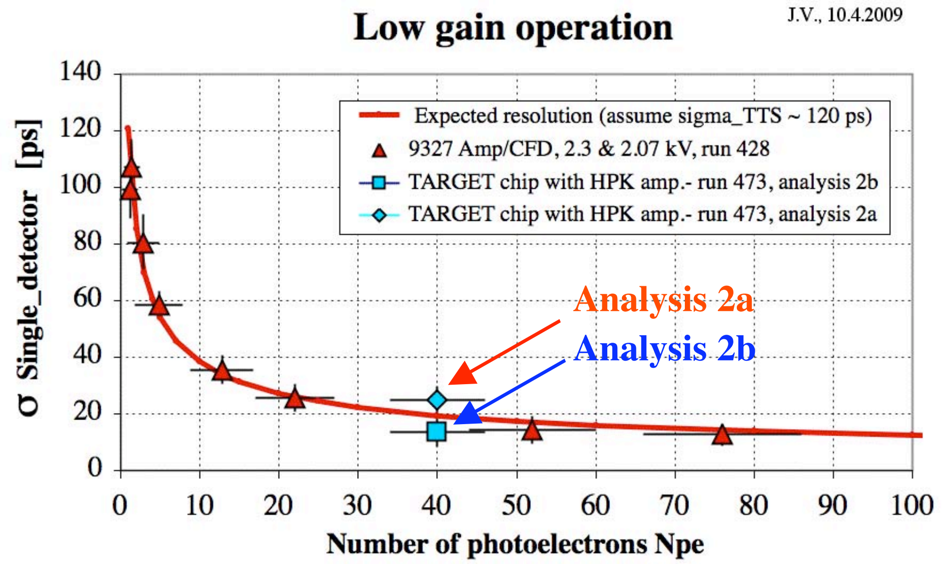
Results with the Target chip:
(analysis 2b)



σ_{narrow} ~
~ 19 ps/√2
~ 13 ps

Diff =
TOF1 - TOF2

Comparison with the same laser test with the Ortec 1GHz BW CFD/TAC/ADC electronics:



Analysis 2a
Analysis 2b

Note: σ_{TTS} ~ 120 ps because of the low gain

- Set **Npe ~ 40** pe per laser pulse (equivalent to beam with 1cm-long quartz radiator).
- **A combination of <u>fast detector</u> and <u>fast amplifier</u> & <u>low TARGET chip BW</u> gives equal or better result than a 1 GHz BW Ortec CFD/TAC/ADC electronics !?!?!**