Why we should consider the red photocathodes

J. Va'vra, SLAC

Goal of this talk

1st Workshop on Photo-cathodes: 300nm-500nm

July 20-21, 2009: University of Chicago
3rd Floor Conference Room (HEP323); 5620 S. Ellis Ave

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Welcome and Introduction

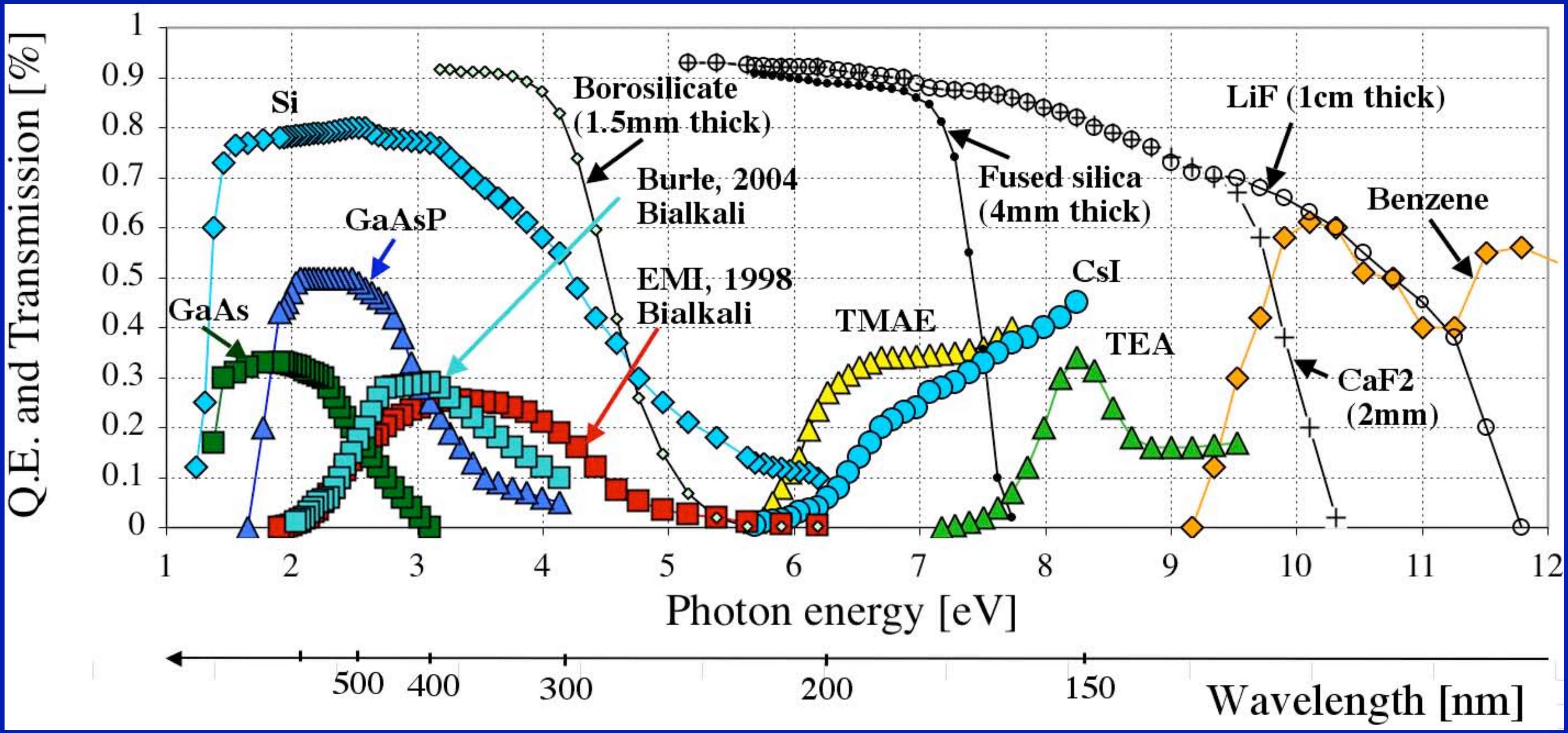
8:30 - 8:33	Welcome	Henry Frisch (Chicago/ANL)
8:33 - 8:45	Goals of the Workshop	Klaus Attenkofer (ANL)

- I will try to convince you that the range should be extended to ~950 nm.

Content

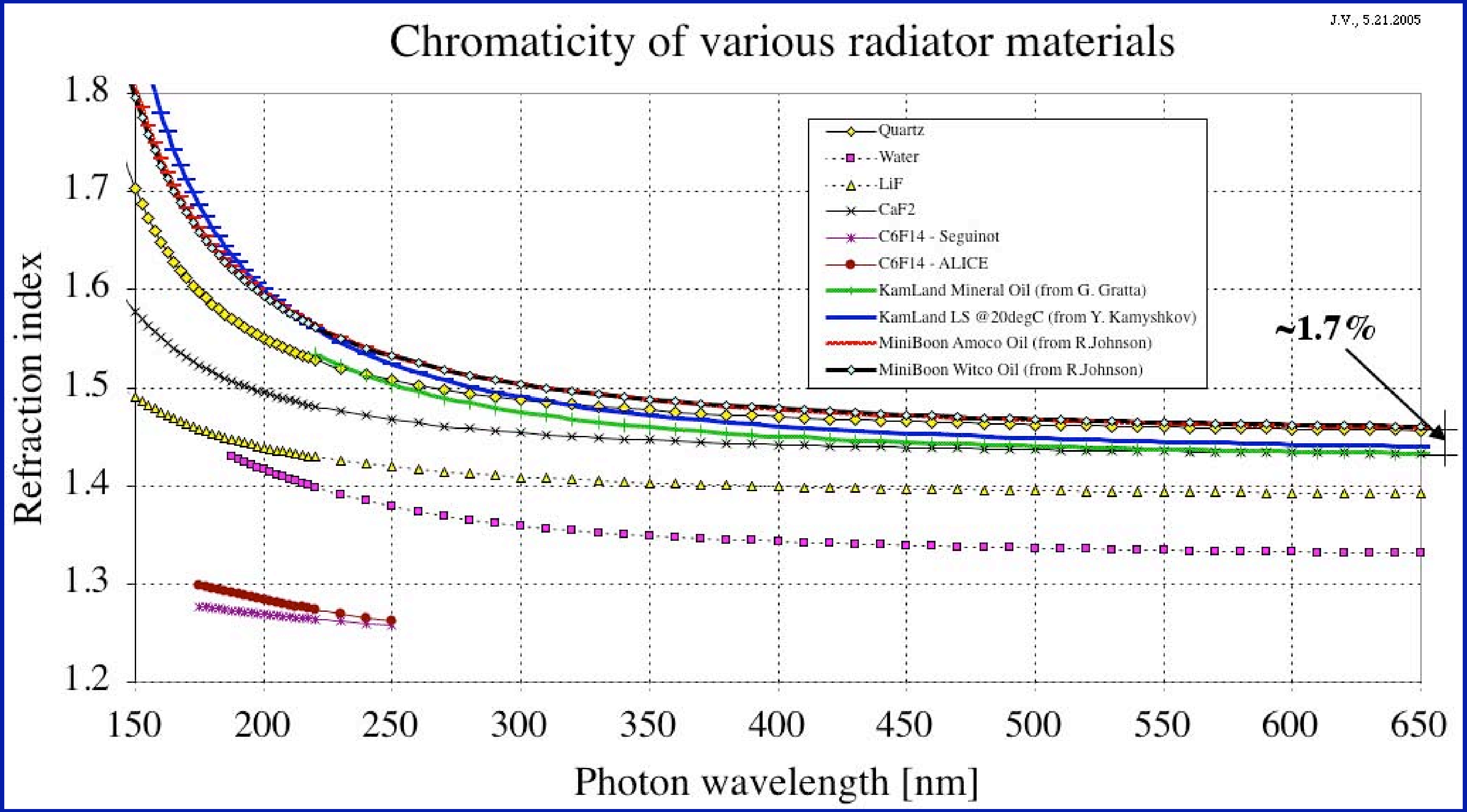
- **Would these detectors benefit from red photocathodes ?:**
  - "Pixilated" TOF detector
  - "DIRC-like" or "TOP-like" TOF detector
  - FDIRC PID detector
  - TOP PID detector
- **Bialkali vs. (GaAs or GaAsP)**

Typical photocathodes



- **Photocathodes of interest: Bialkali, GaAs, and GaAsP. Which one ? Or, should one pay more attention to Si ?**

Refraction index = f (wavelength)

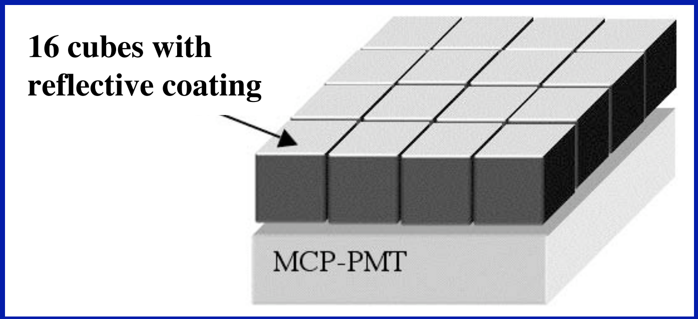


- **Important to estimate the chromatic contribution to timing resolution.**

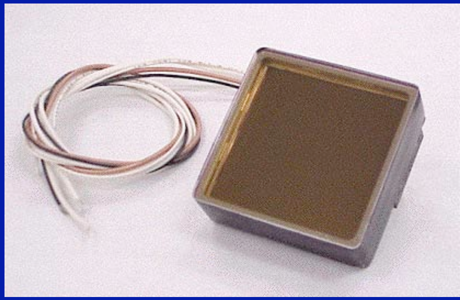
"Pixilated" TOF counter running at low gain

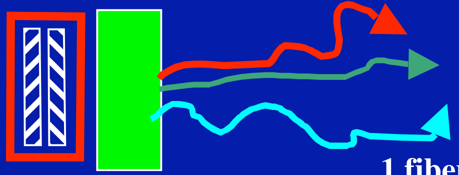
J.Va'vra, http://www.slac.stanford.edu/~jjv/activity/Vavra_Forward_TOF_geometry.pdf, Perugia, June 2009

Quartz cubes radiators:



Photonis MCP-PMT, 10µm holes, 64 pixels



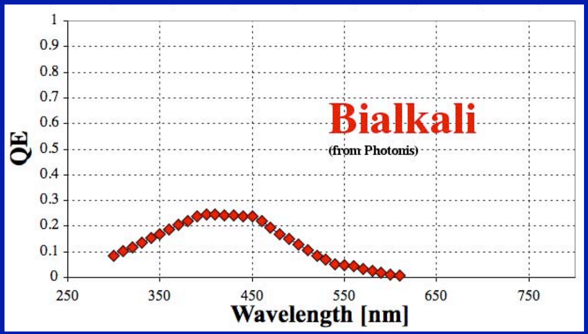


Arguments in favor:
- low gain of ~2x10^4.
- good results in beam
- use all photons
- less complicated analysis
- smaller aging rate ?

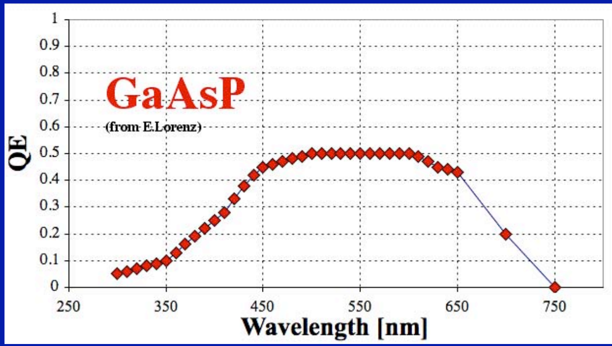
- **This design is extrapolation from a design used in the Fermilab test. Which photocathode to use ?**

Number of photoelectrons in quartz ?

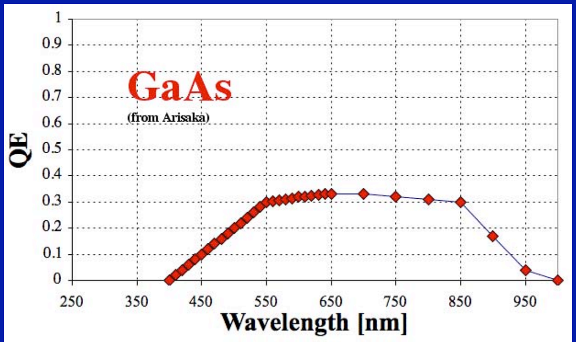
$$Npe = 370\ L \int \varepsilon(E) \sin^2 \theta_c \, dE$$



Npe ~ 40/cm



Npe ~ 70/cm



Npe ~ 42/cm

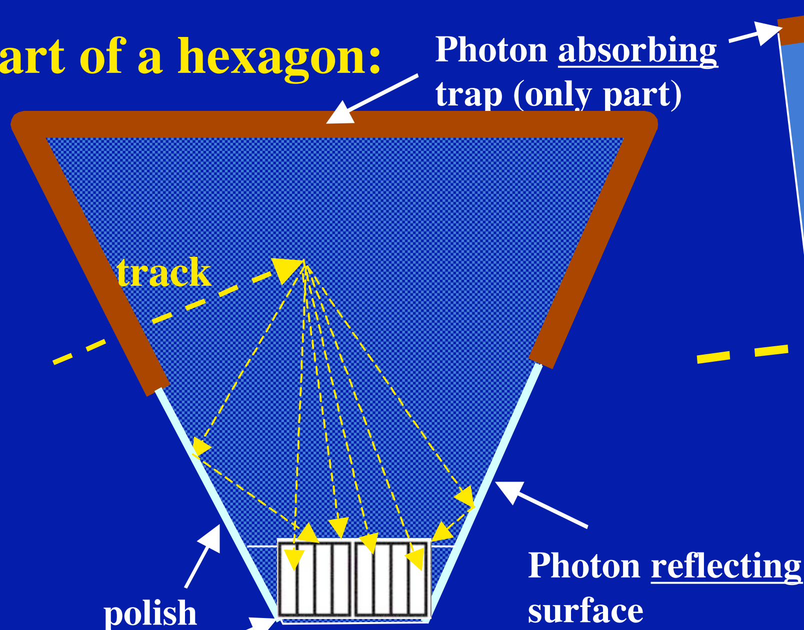
- The photon yield goes at $1/\lambda^2$.
- Going red means that one needs higher QE.
- GaAsP gives largest number of photoelectrons.

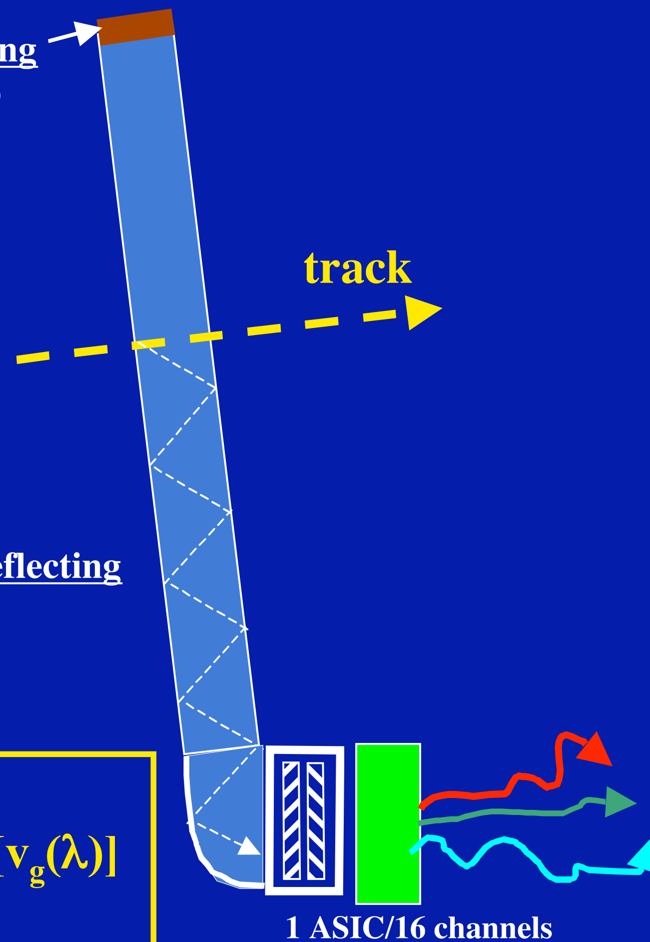
"DIRC-like" or "TOP-like" TOF detector ?

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

Part of a hexagon:

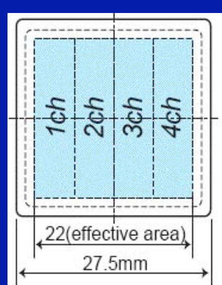
- Not all photons are of "equal" quality. Some we want to throw away because they are affected by the chromatic broadening.
- We do not want photons to rattle around for too long
- This design requires a high gain operation to detect single photons





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

ϕ 10 μm holes



Time-of-Proparation:

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

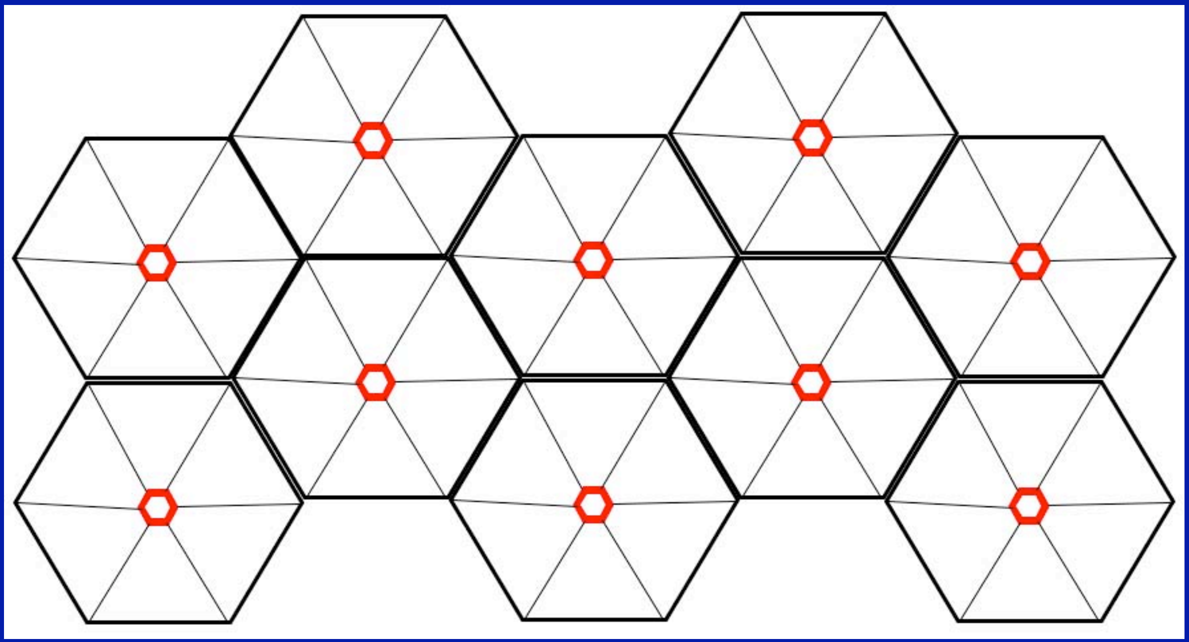
A direct photon is accepted only if:

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

Even 5 photons will do

Large “DIRC-like” TOF detector ?

J.Va’vra, http://www.slac.stanford.edu/~jjv/activity/Vavra_DOE_talk.pdf, Washington, July 2009

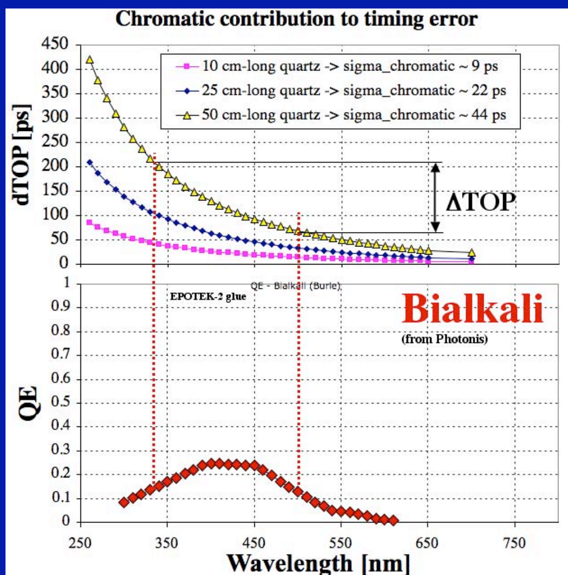


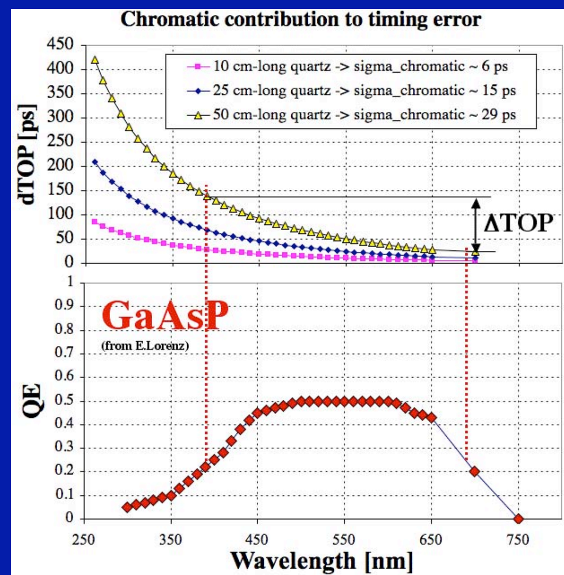
- **Large detector made of many small segments.**

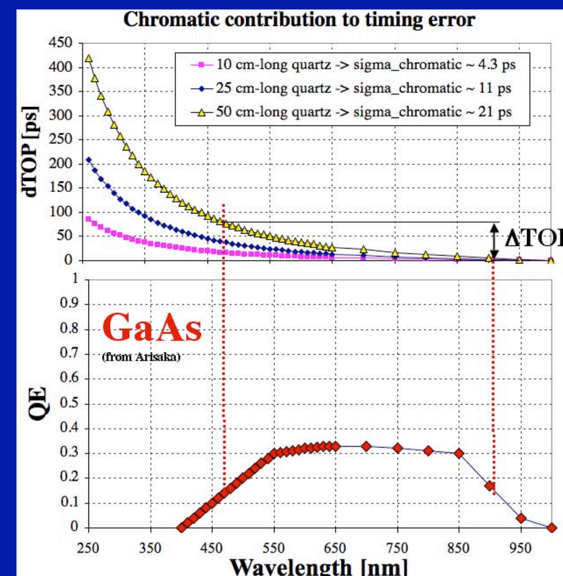
How important is the chromatic broadening ?

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

Determine TOP spread for three photon path lengths: 10, 25 and 50 cm:





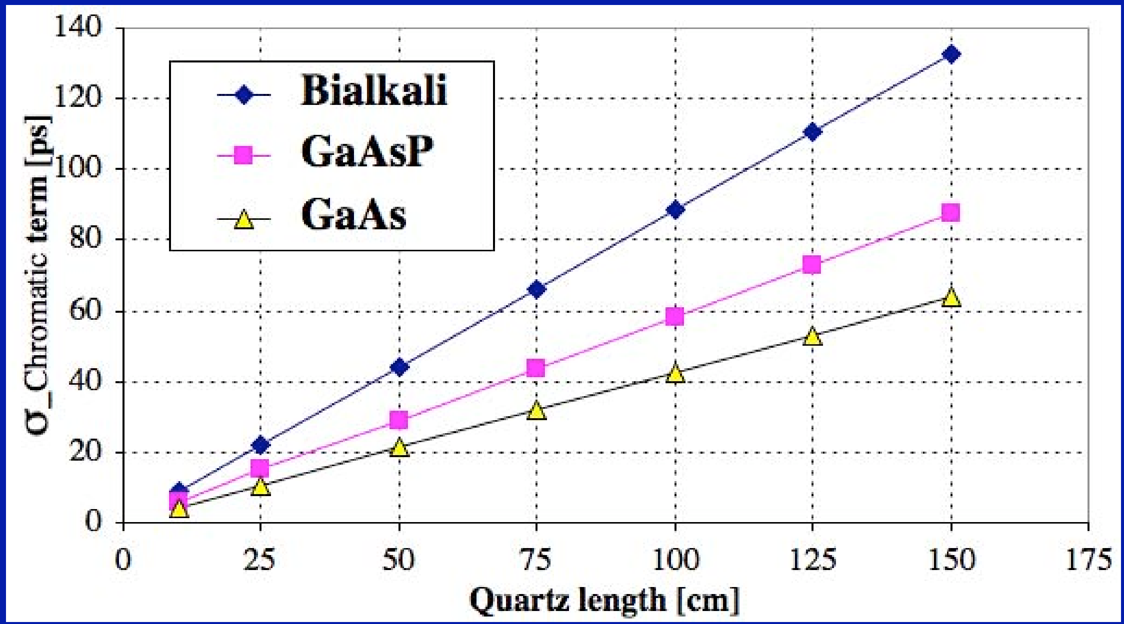


- **TOP-range gets smaller as one goes more red.**

Chromatic term in timing resolution

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

Chromatic term for different colors:



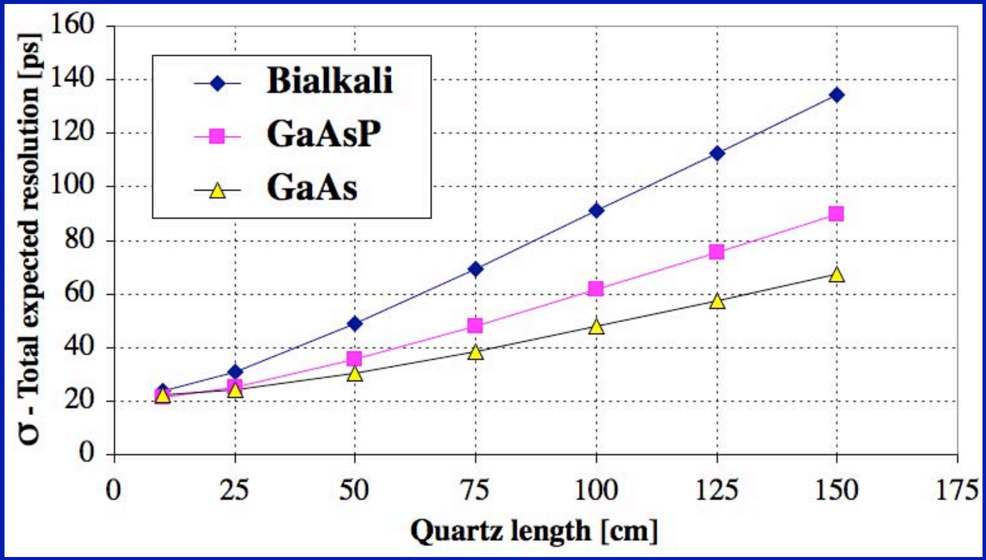
- Going more red reduces $\sigma_{Chromatic}$ significantly

Large "DIRC-like" TOF detector

$\sigma_{Total} \sim \sigma_{Electronics} \otimes \sigma_{Chromatic}/\sqrt{Npe} \otimes \sigma_{TTS}/\sqrt{Npe} \otimes \sigma_{T0}$

Example #1: $\sigma_{TTS} \sim 35$ ps , $\sigma_{Electronics} \sim 10$ ps , $\sigma_{T0} \sim 15$ ps (specific to a long bunch at SuperB), Npe (Bialkali) ~ 40/cm, Npe (GaAsP) ~ 70/cm, Npe (GaAs) ~ 42/cm, $\varepsilon_{Geometrical\_loss} \sim 1/5$

Expected resolution:



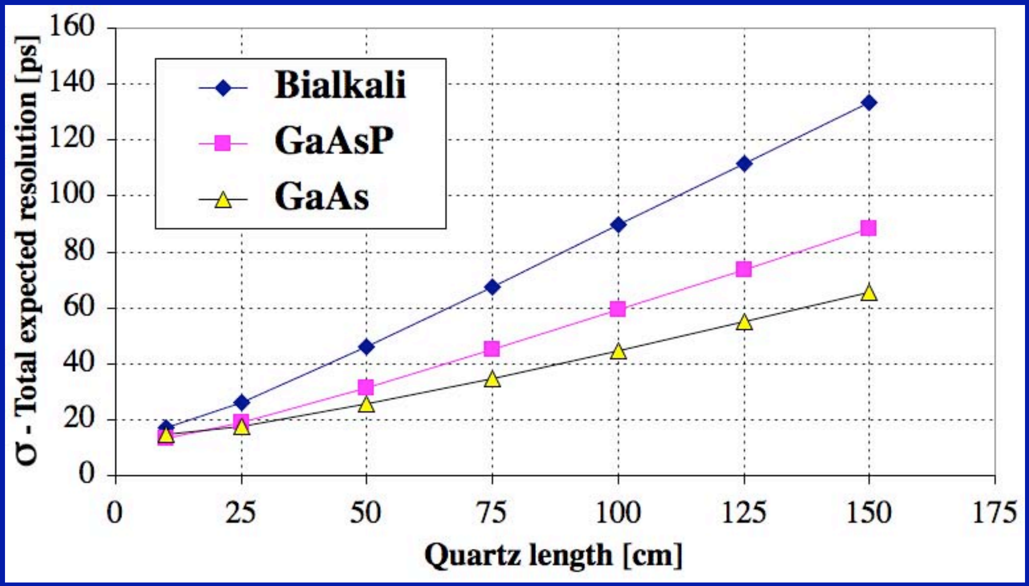
- **For L_{quartz} > 20 cm, red-sensitive photocathodes yield better results.**

Large "DIRC-like" TOF detector

$\sigma_{Total} \sim \sigma_{Electronics} \otimes \sigma_{Chromatic} /\sqrt{Npe} \otimes \sigma_{TTS} /\sqrt{Npe} \otimes \sigma_{T0}$

Example #2: σ_{TTS} (HPK SL-10) ~ 35 ps , $\sigma_{Electronics}$ ~ 5 ps , σ_{T0} ~ 5 ps,
Npe (Bialkali) ~ 40/cm, Npe (GaAsP) ~ 70/cm, Npe (GaAs) ~ 42/cm, $\varepsilon_{Geometrical\_loss}$ ~1/5

Expected resolution:

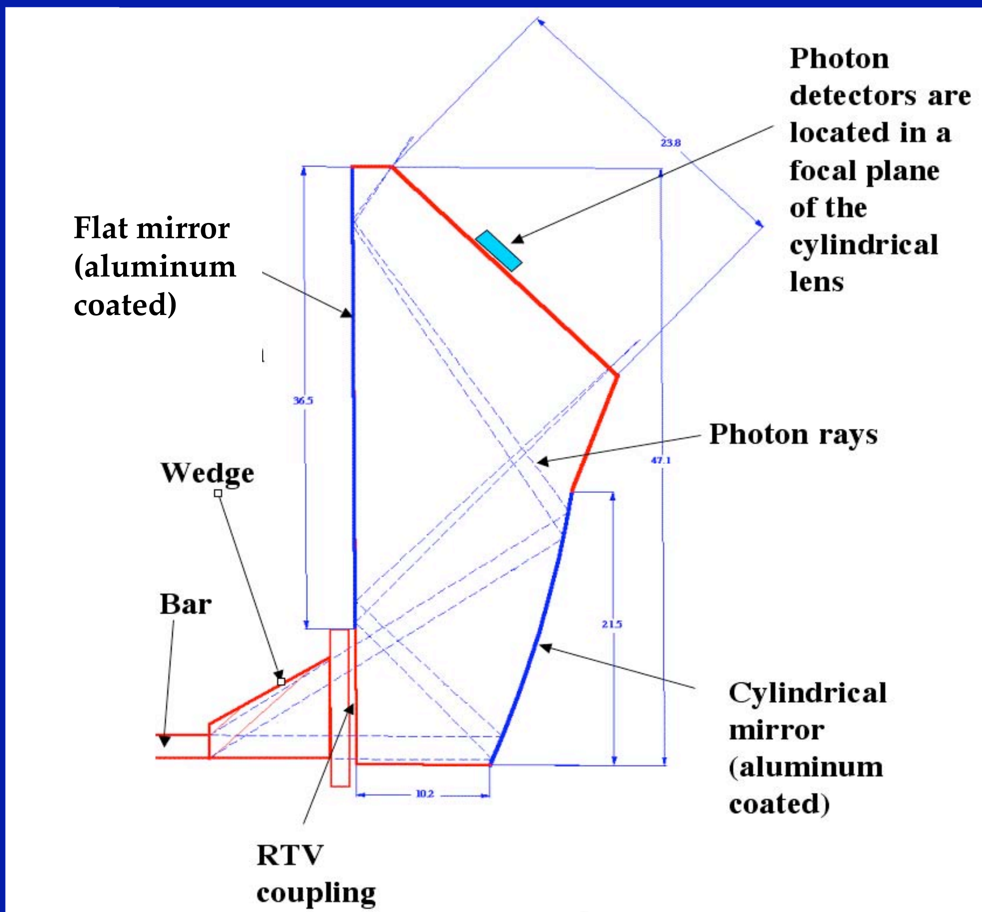


- **For L_{quartz} > 10-15 cm, red-sensitive photocathodes yield better results.**

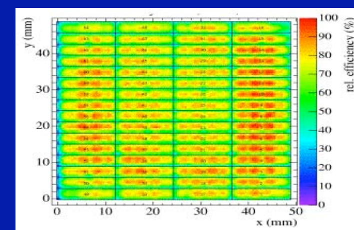
FDIRC for SuperB

J.Va'vra, LDRD proposal, SLAC, June 2009

FDIRC PID detector: measure x & y & TOP



Pixilization of H-9500 multi-anode PMT:



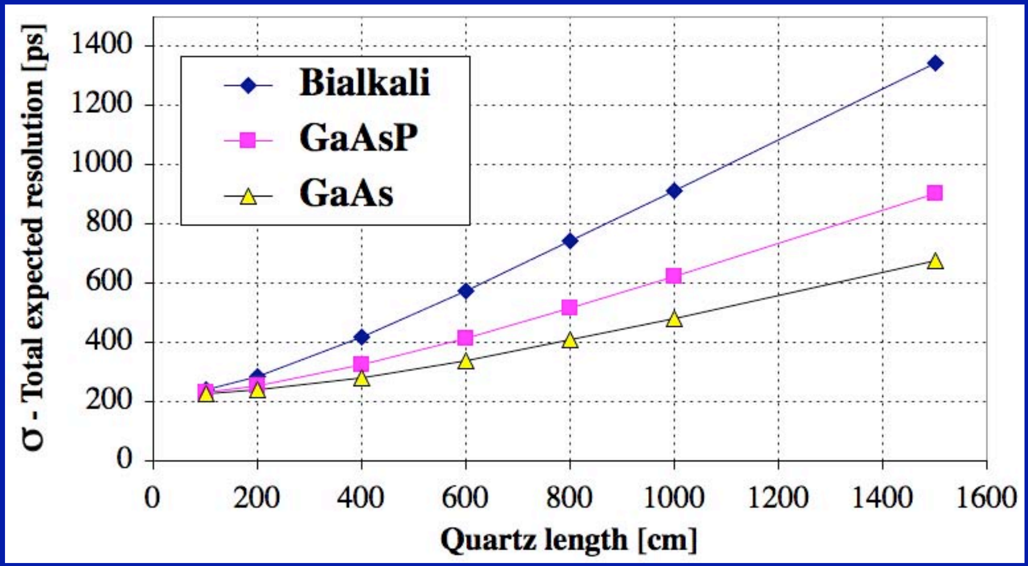
- **Preliminary optical design of the FDIRC (dimensions are in cm).**
- **Photon detectors: H a mamatsu multi-anode H-9500 multi-anode PMTs, modified to have 3mm x 12mm pixel sizes, where smaller size samples vertical direction.**
- **Electronics:ASIC-based waveform sampling electronics such as proposed by University of Hawaii, or a 100ps resolution TDC system proposed by the Orsay lab, France.**

FDIRC PID detector

$$\sigma_{Total} \sim \sigma_{Electronics} \otimes \sigma_{Chromatic} /\sqrt{Npe} \otimes \sigma_{TTS} /\sqrt{Npe} \otimes \sigma_{T0}$$

<u>Example #3:</u> **σ_{TTS}(H-9500 MaPMT) ~ 200 ps , $\sigma_{Electronics}$ ~ 100 ps , σ_{T0} ~ 15 ps,**
Npe (Bialkali) ~ 40/cm, Npe (GaAsP) ~ 70/cm, Npe (GaAs) ~ 42/cm

Expected resolution:



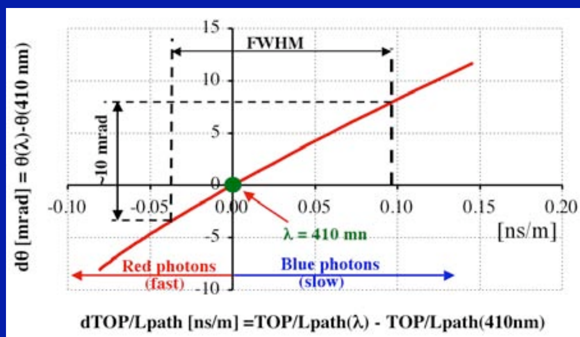
- **For L_{quartz} > 2-3 meters, red-sensitive photocathodes yield much better results.**
- **Important thing here is that a range of TOP gets reduces going red.**

Chromatic correction by timing in FDIRC

SLAC-PUB-12803 and Nucl.Instr.&Meth. A595(2008)104-107.

Chromatic correction:

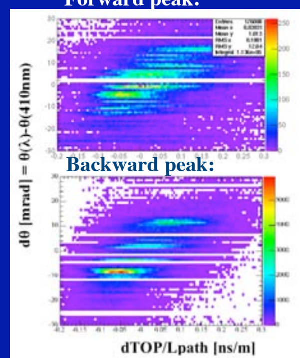
(ΔCherenkov angle ~ const * $\Delta TOP/L_{path}$)



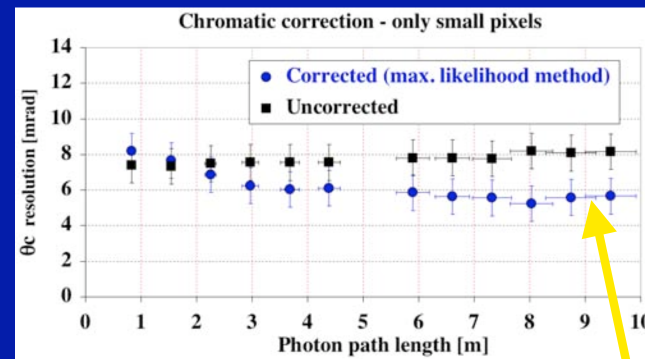
Data:

(at θ_{dip} = 90^o)

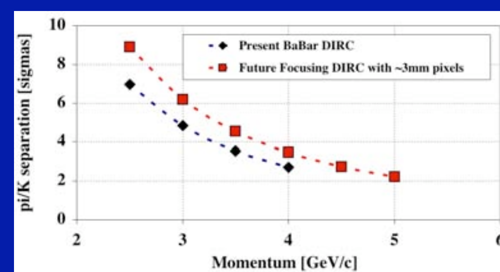
Forward peak:



Beam test result for 3mm pixels:



FDIRC PID performance prediction fro SuperB based on 3mm pixels and chromatic correction by timing:



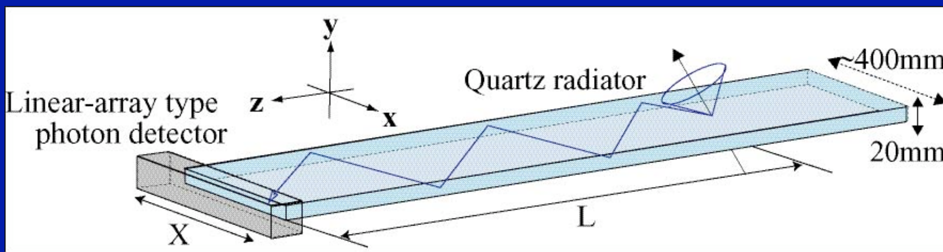
π/K separation: ~3.5σ at 4 GeV/c:

- **Bialkali:** Chromatic error corrected by timing.
- **This is the first RICH detector to do it !!**
- **GaAs or GaAsP:** timing correction may not be not necessary to get the same result => **one could simplify electronics (no need for ADC for instance)**

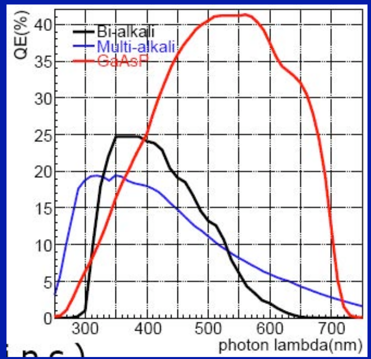
TOP PID detector

K. Inami, TIPP conference, Tsukuba, Japan 2009

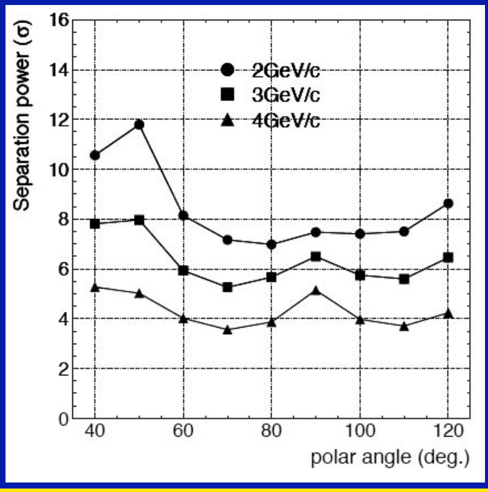
TOP PID detector: measure x & TOP



HPK SL-10



Beam test result with GaAsP & a filter λ >400nm:



π/K separation: ~3.5σ at 4 GeV/c and θ_{dip} ~ 70°

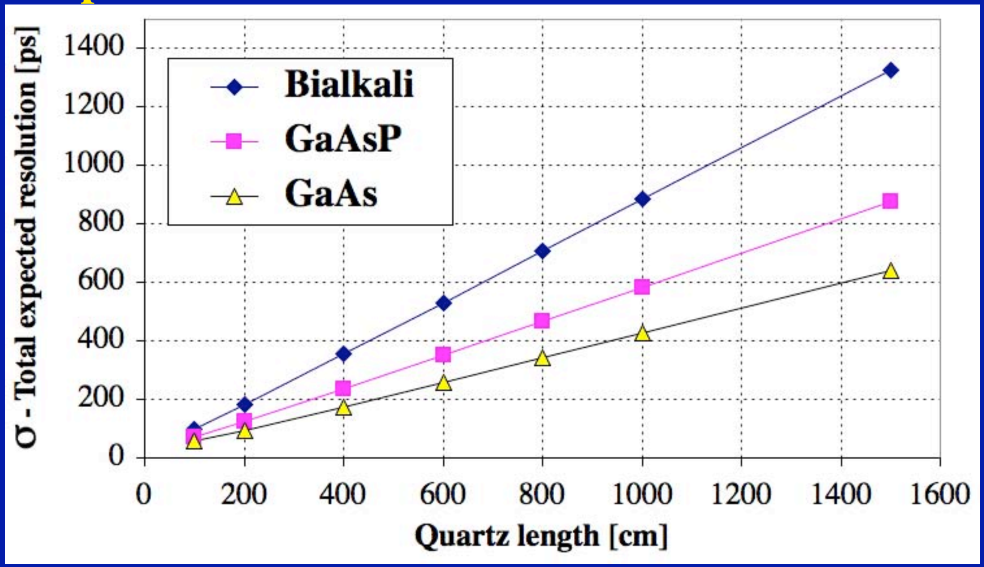
- **They are developing a GaAsP photocathode with foil protection against the photocathode aging**
- **Photon detector type:** **HPK MCP-PMT SL-10.**
- **Electronics: CFD/TDC.**

TOP PID detector

$\sigma_{Total} \sim \sigma_{Electronics} \otimes \sigma_{Chromatic} /\sqrt{Npe} \otimes \sigma_{TTS} /\sqrt{Npe} \otimes \sigma_{T0}$

Example #4: σ_{TTS}(HPK SL-10) ~ 35 ps , $\sigma_{Electronics}$ ~ 10 ps , σ_{T0} ~ 15 ps,
Npe (Bialkali) ~ 40/cm, Npe (GaAsP) ~ 70/cm, Npe (GaAs) ~ 42/cm

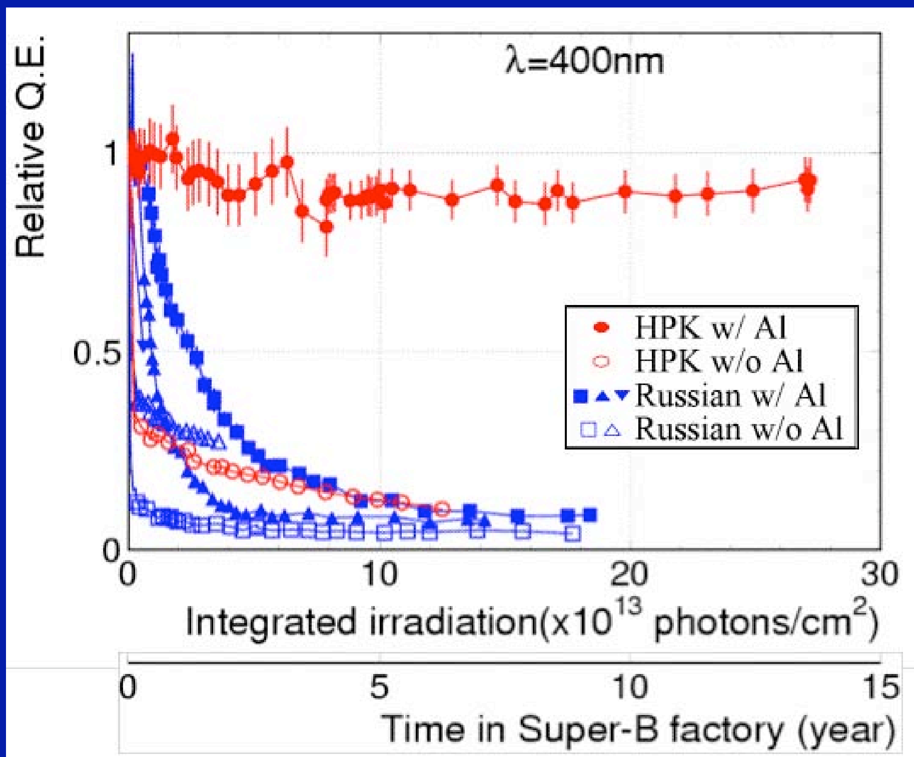
Expected resolution:

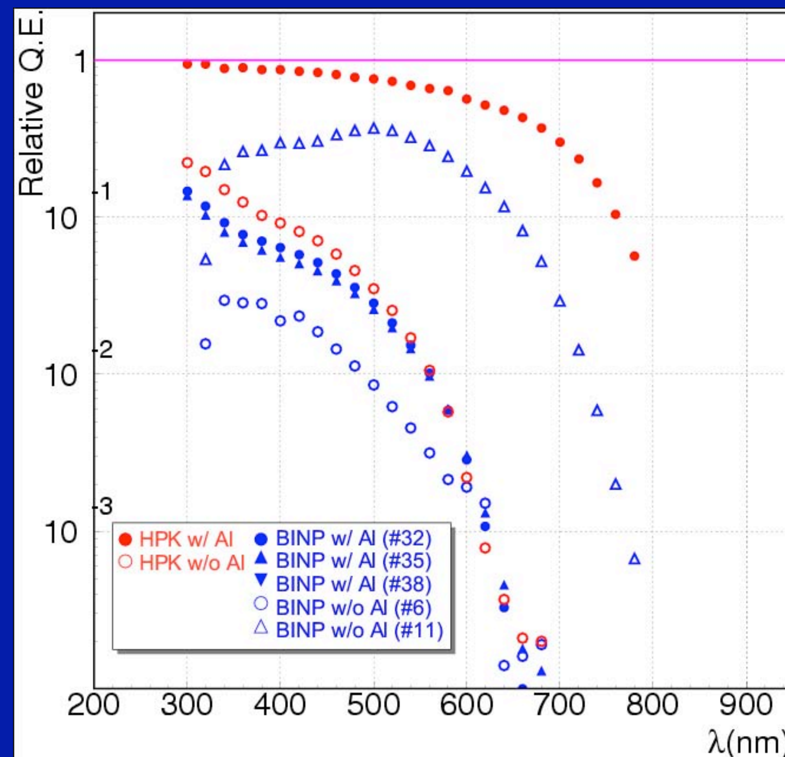


- For L_{quartz} > 2-3 meters, red-sensitive photocathodes yield much better results.
- They could do the same chromatic correction as the FDIRC can do, that is until they have decided to segment a mirror into 4-segments.

Aging - Q.E. vs wavelangth

K. Inami, Nagoya, TIPP conference, Japan, 2009





- **Red wavelengths suffer most**

Conclusion

- For TOF detectors with small radiators, GaAsP would produce twice as many photoelectrons compared to Bialkali
- For "DIRC-like" the benefit of red photocathodes is clear for photon propagation length longer than 10 cm
- For FDIRC and TOP there is a clear benefit going red as well.