Geant4 simulation of the DIRC-like forward TOF detector

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Outlook

- Master formulae for time resolution
- From fDIRC to fTOF simulation
- Geant4 simulation
- Electronic readout simulation
- Studying Chromatic, Transit Production and Photon Track contributions to the timing error
- Conclusions
- Work with Kiev Taras Shevchenko University, Collaborative tools

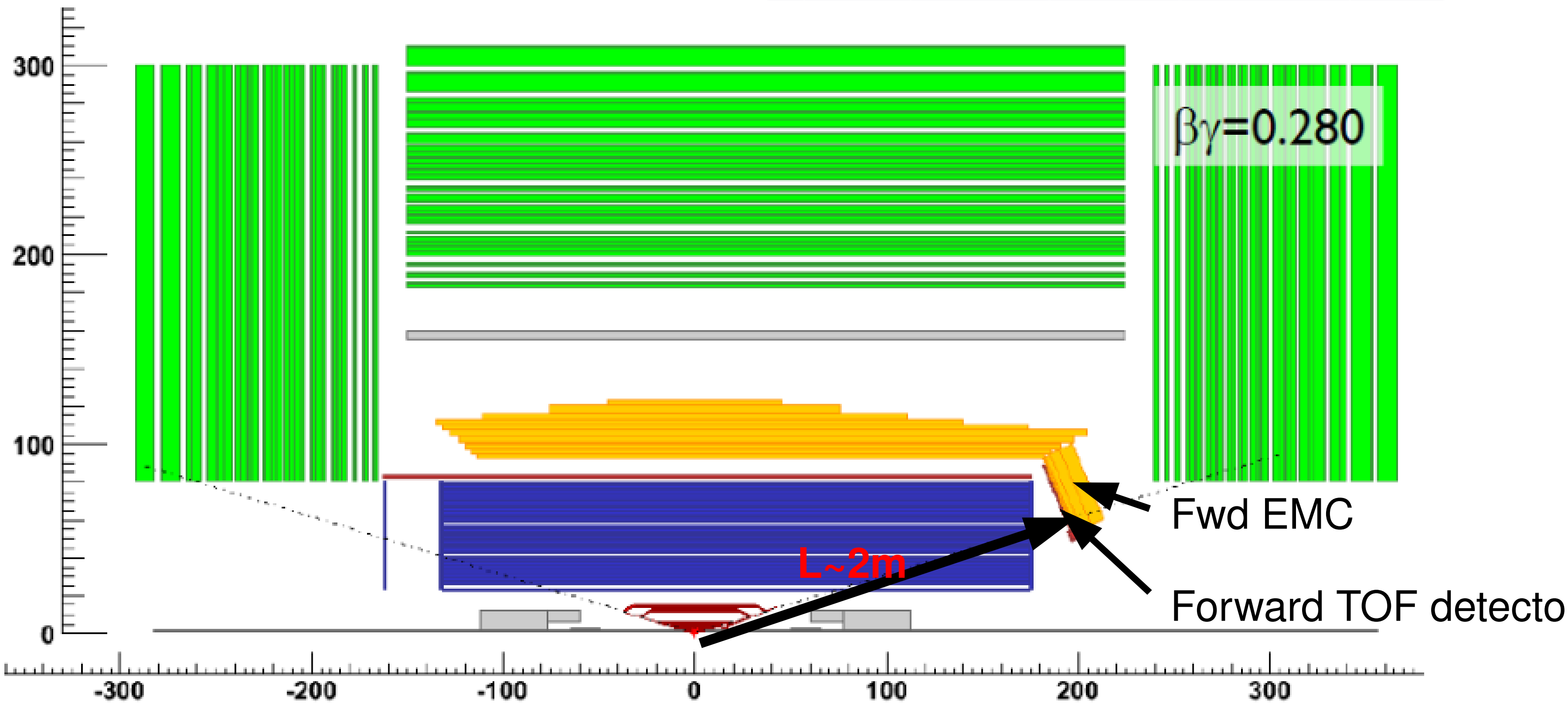
1) Université Paris-Sud 11, LAL-ORSAY, France

2) Kiev Taras Shevchenko University, Ukraine

Master formula 1 for time resolution

Two particles hypothesis with masses m_1, m_2, with same momentum p flying over a distance L, have a Δt time flight difference given by:

$$\Delta t = \frac{Lc}{2p^2}\left(m_1^2 - m_2^2\right)$$



Main requirements:

→ 20 – 25 ps time resolution enough to make 3 - 4 'sigma' K/pi separation @ 3GeV with L = 2 m

→ To avoid degrading significantly the EMC resolution, any fPID detector should have a small radiation length.

Master formula 2 for time resolution

The (**$\text{time}_{measured}$** – **$\text{time}_{expected}$**)/error ratios (one for each particle hypothesis) define likelihood values which are then used to construct LH-based PID selectors

The accuracy of the **$\text{time}_{expected}$** term is related to the precision with which flight length and momentum are measured. These can be studied with FastSim

$$\mathbf{Time_{measured}} = \text{Time}_{stop} - \text{Time}_{start}$$

Precision on the Time_{start} dominated by time of the bunch crossing $\sigma_{T0} \simeq 15\text{ps}$

In the following we study time_{stop} which is given by the TOF detector.

Master formula 2 by J.Vavra for time resolution

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%

Master formula 2 for $time_{stop}$ resolution

$$\sigma^{stop} = \sqrt{\left(\left(\frac{\sigma_{Electronics}}{N_{channel}}\right)^2 + \left(\frac{\sigma_{Chromatic}}{N_{pe}}\right)^2 + \left(\frac{\sigma_{TTS}}{N_{pe}}\right)^2 + \left(\frac{\sigma_{TransitProduction}}{N_{pe}}\right)^2 + \left(\frac{\sigma_{PhotonTrack}}{N_{pe}}\right)^2\right)}$$

$N_{channel}$ = 16 readout channels

N_{pe} Number of photo electrons

$\sigma_{PhotonTrack}(for\ \lambda = 450\mathrm{nm}) = 90\mathrm{ps}$ Timing spread due to different photon path length.

Kaon hit in center of the barrel

$\sigma_{TransitProduction} = 11.7\mathrm{ps}$ Cerenkov light produced all along the way in the quartz detector. For instance, for K @ 3 GeV the transit time at 1.2cm thick detector is 40.6 ps .

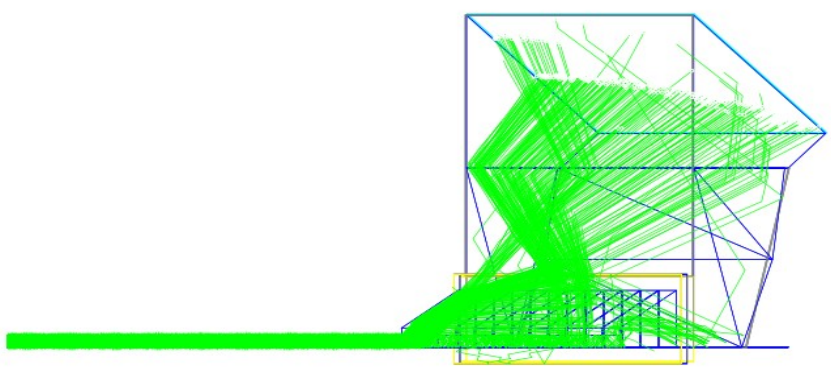
From simulation of the fDIRC to simulation of the DIRC-like fTOF

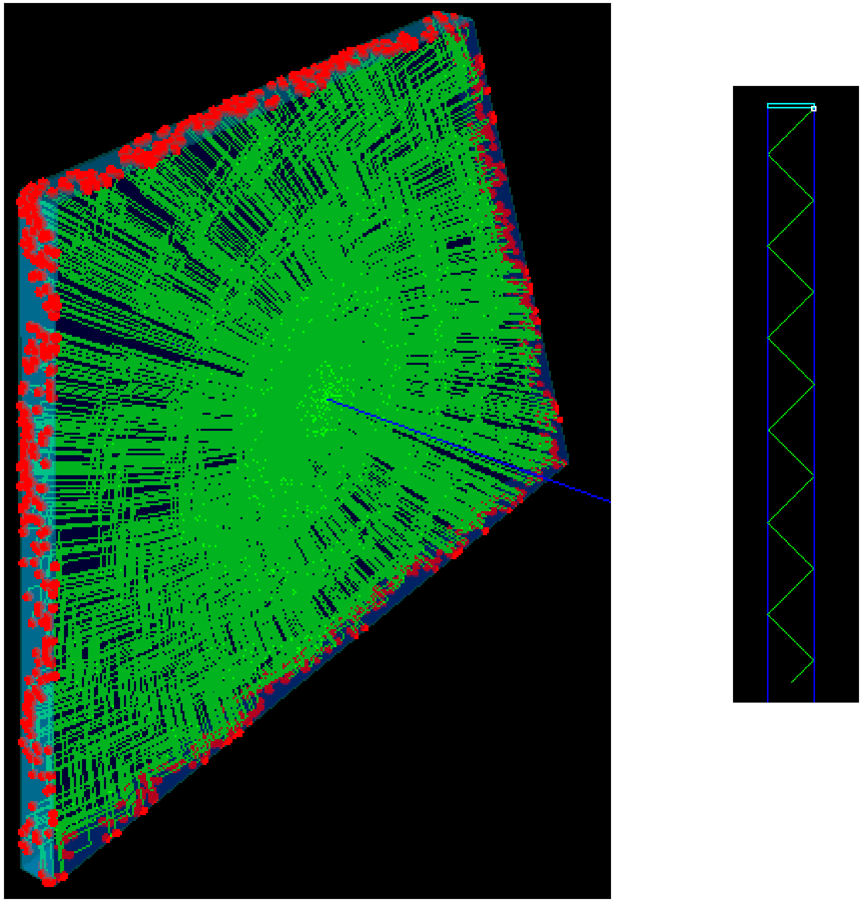
Starting point: the standalone Geant4 simulation of the focusing DIRC.

Material properties, physical and boundary processes are same for focusing DIRC and forward TOF. Only geometry has to be changed.

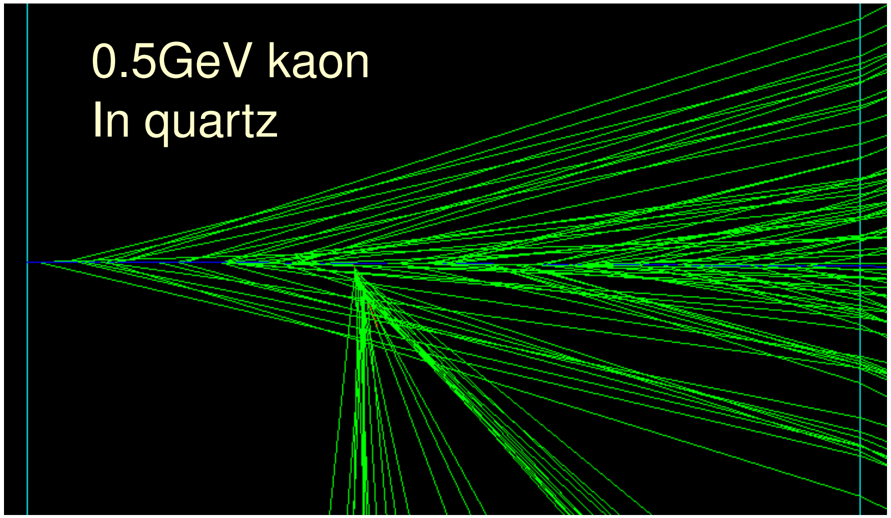
Geant4 simulation of the fTOF

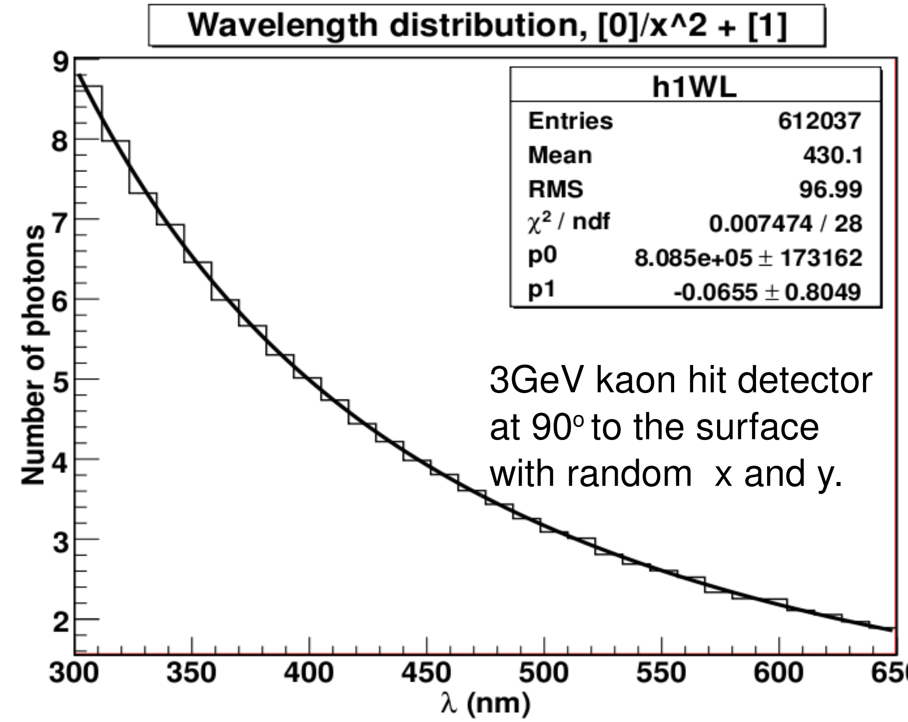
Geant4 simulation of the fDIRC





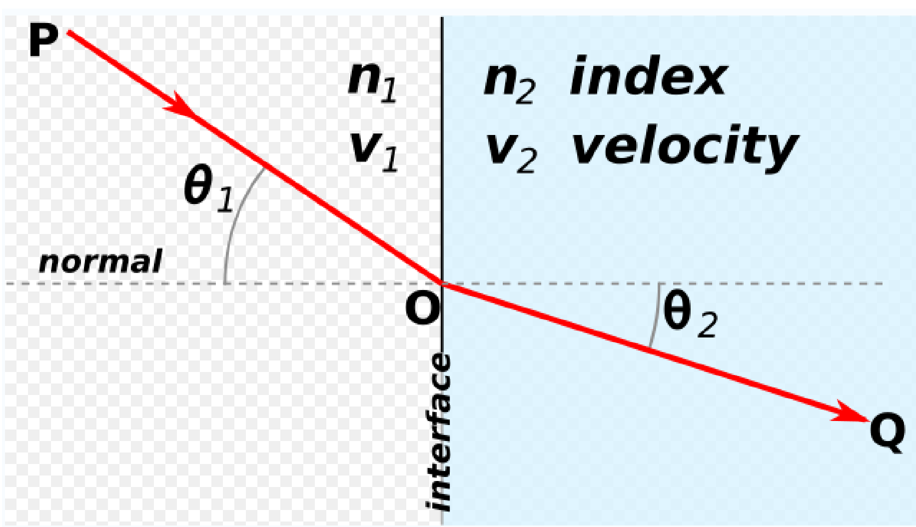
Simulation of the Cerenkov effect in Geant4



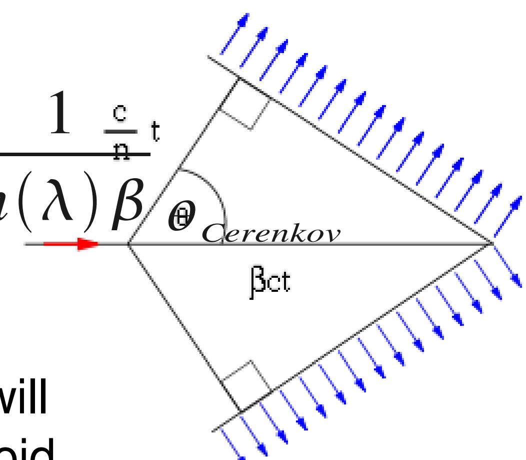


→ Cerenkov photons emitted all along the way particle cross detector

→ Spectrum of the emitted photons goes like 1/(Lambda^2)



$$\cos(\theta_{Cerenkov}) = \frac{1}{n(\lambda)\beta}$$



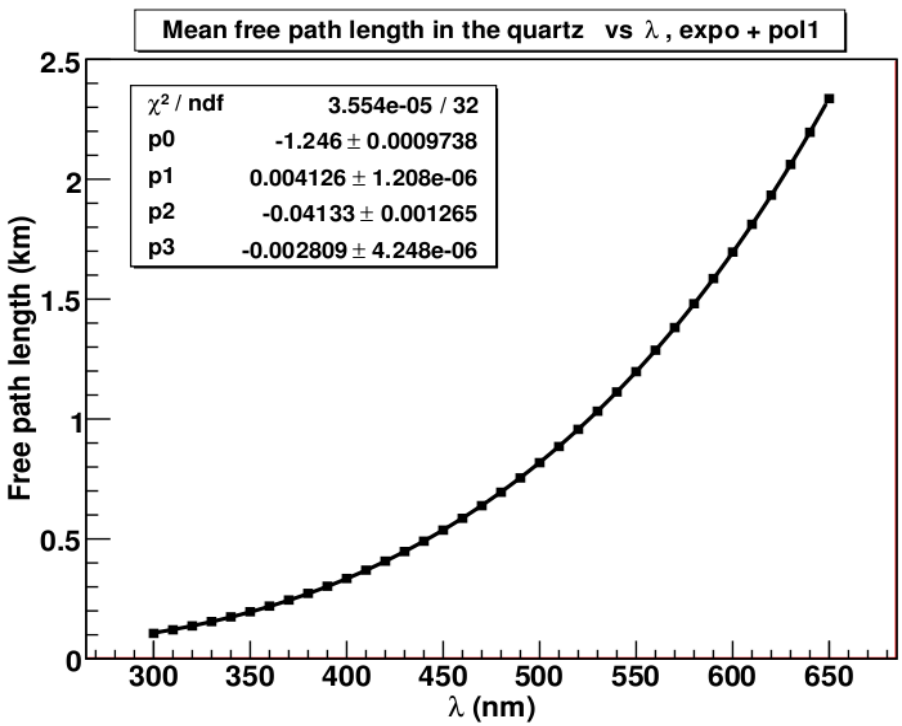
$$\frac{\sin(\theta_1)}{\sin(\theta_2)} = \frac{n_2}{n_1}$$

Photons from kaon with momentum 1GeV will leave detector. By putting mirrors we can avoid this effect

Simulation of the optical properties of the quartz

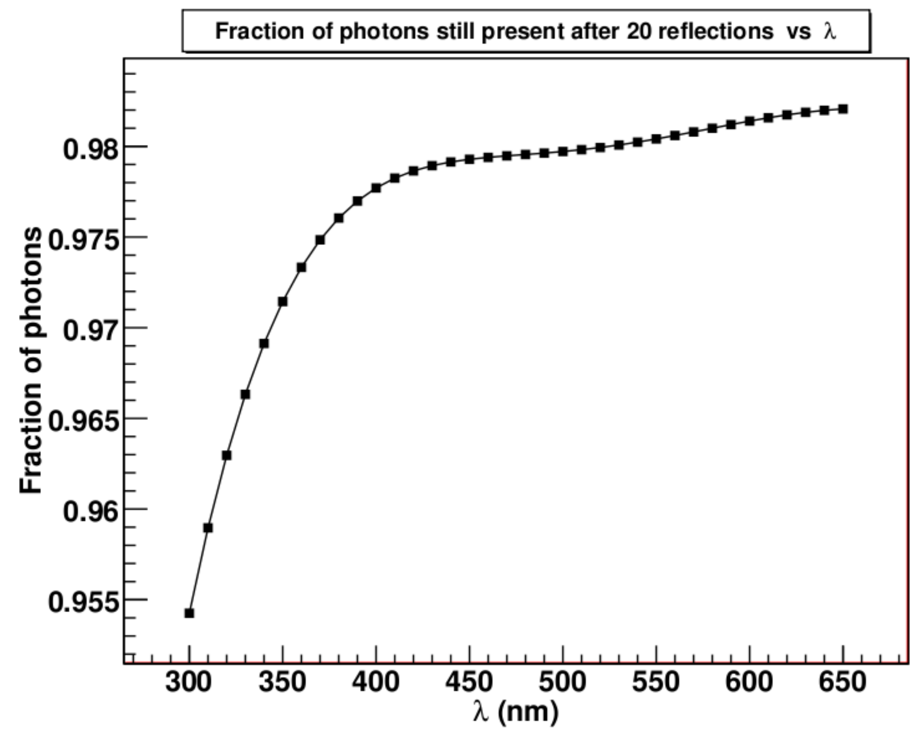
Effects which could reduce the photon rate

Absorption in quartz bar

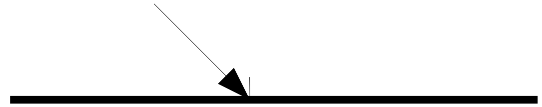


Free path length is in km in this plot

This effect is negligible small, Characteristic photon path length is around 50cm in fTOF.



Each time photon deflect from boundary non zero probability to hit dust exist.



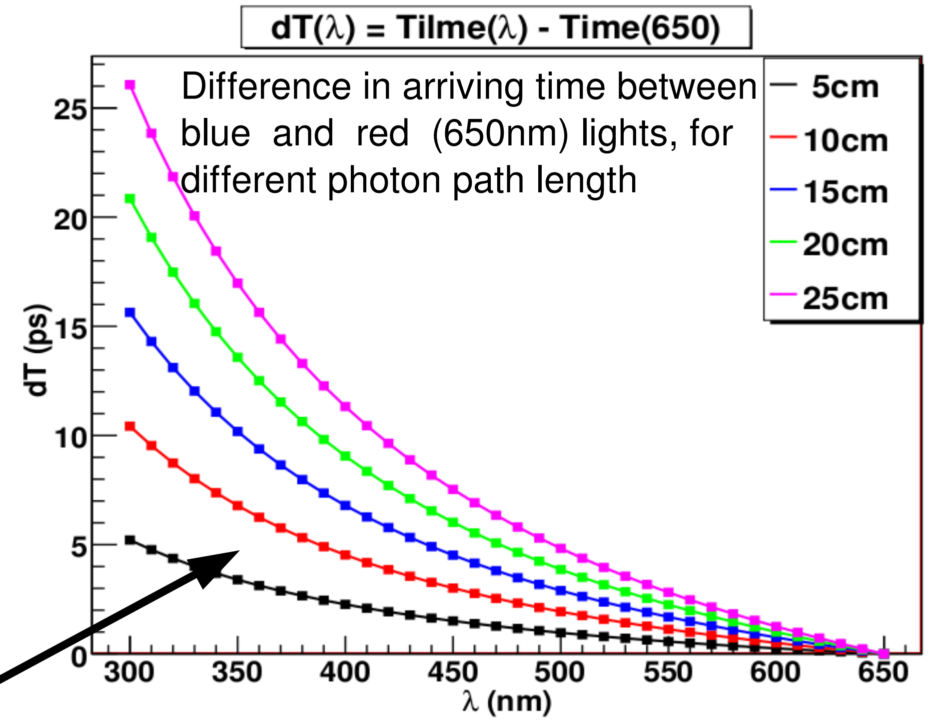
dust

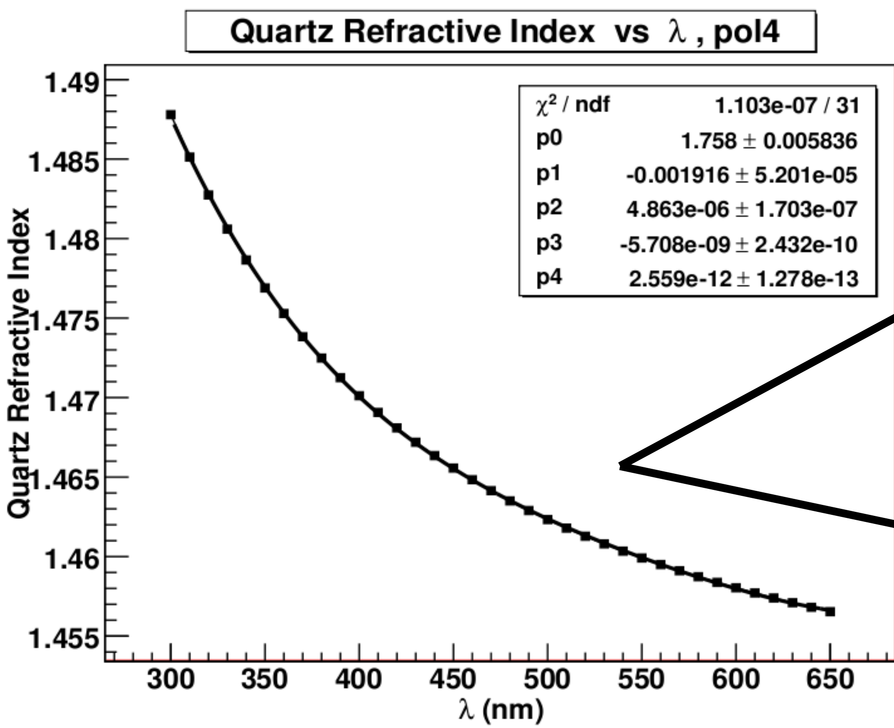
Less than 5% of the photons lost after 20 reflexions regardless of their wavelength.

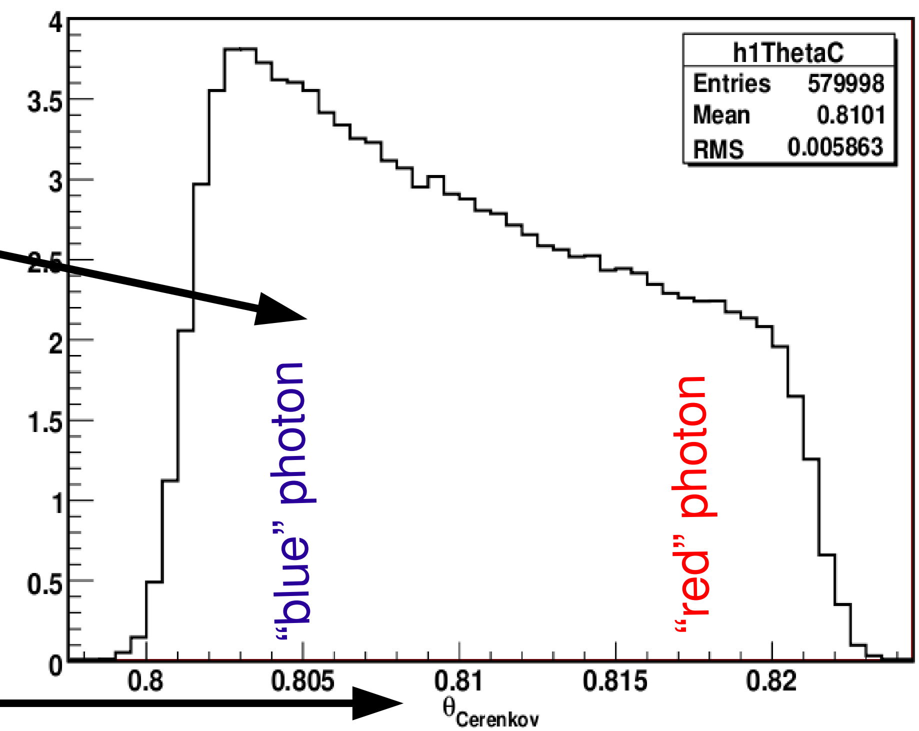
Simulation of the optical properties of the quartz

Speed of propagation of the photons in quartz is the function of their wavelength !!!!

Time spread due to this known as Chromatic effect



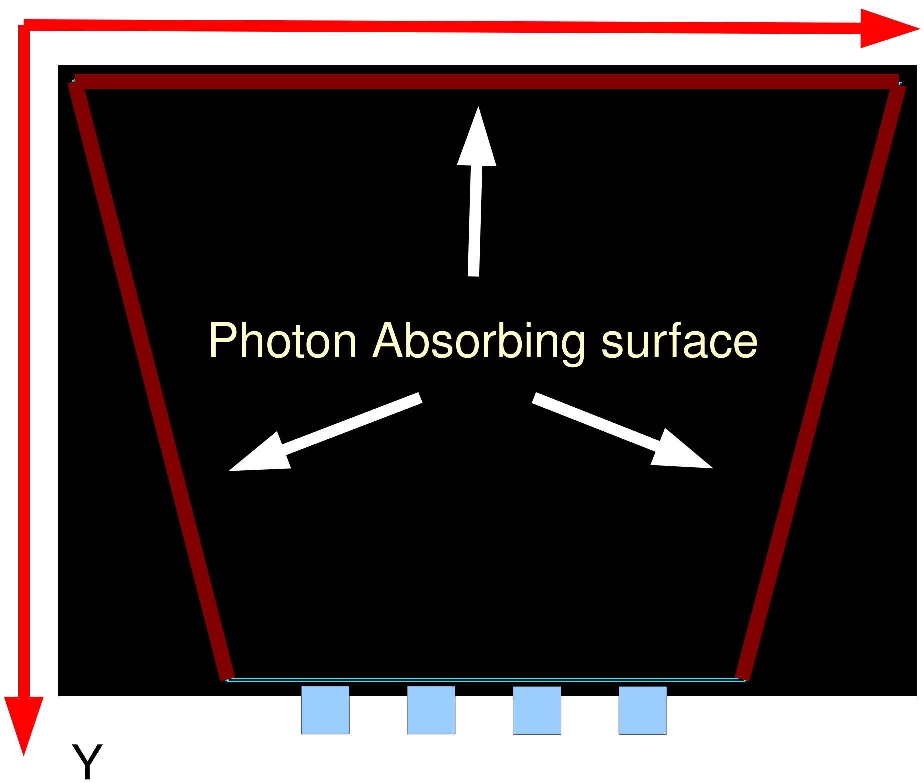




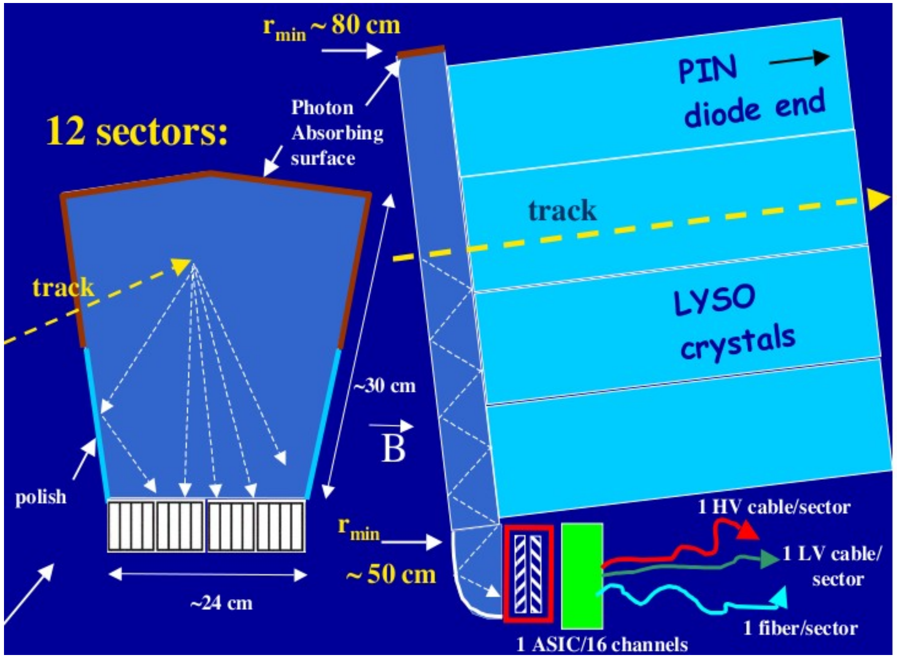
$$\cos(\theta_{Cerenkov}) = \frac{1}{n(\lambda)\beta}$$

Geometry of fTOF in Geant4

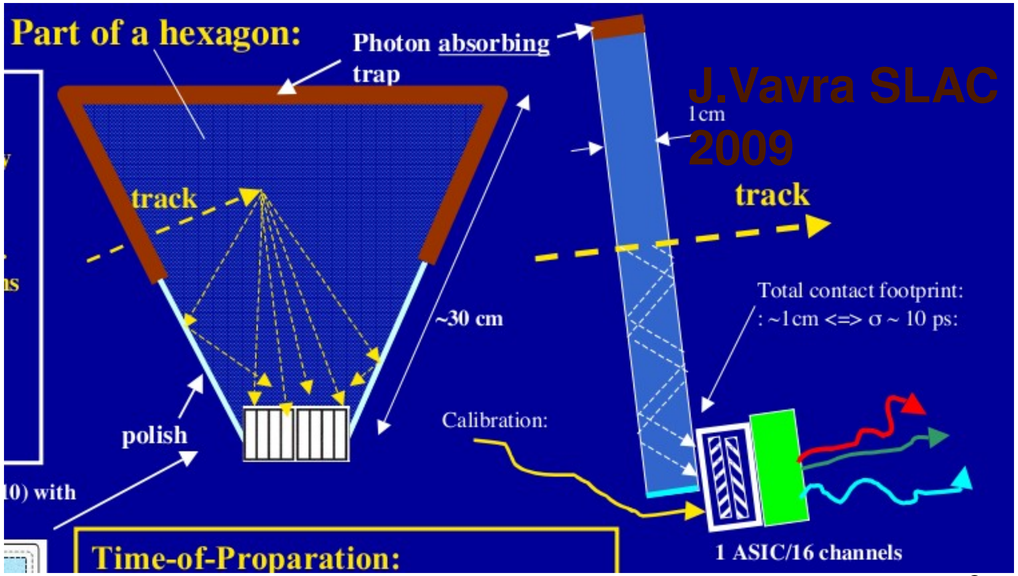
For the moment just this geometry was studying



Detector is trapezoid, with size:
L – length 30 cm
Xmin – length 25.9 cm
Xmax – length 41.4 cm
Thickness – 12.0 mm
4 MCP – PMTs

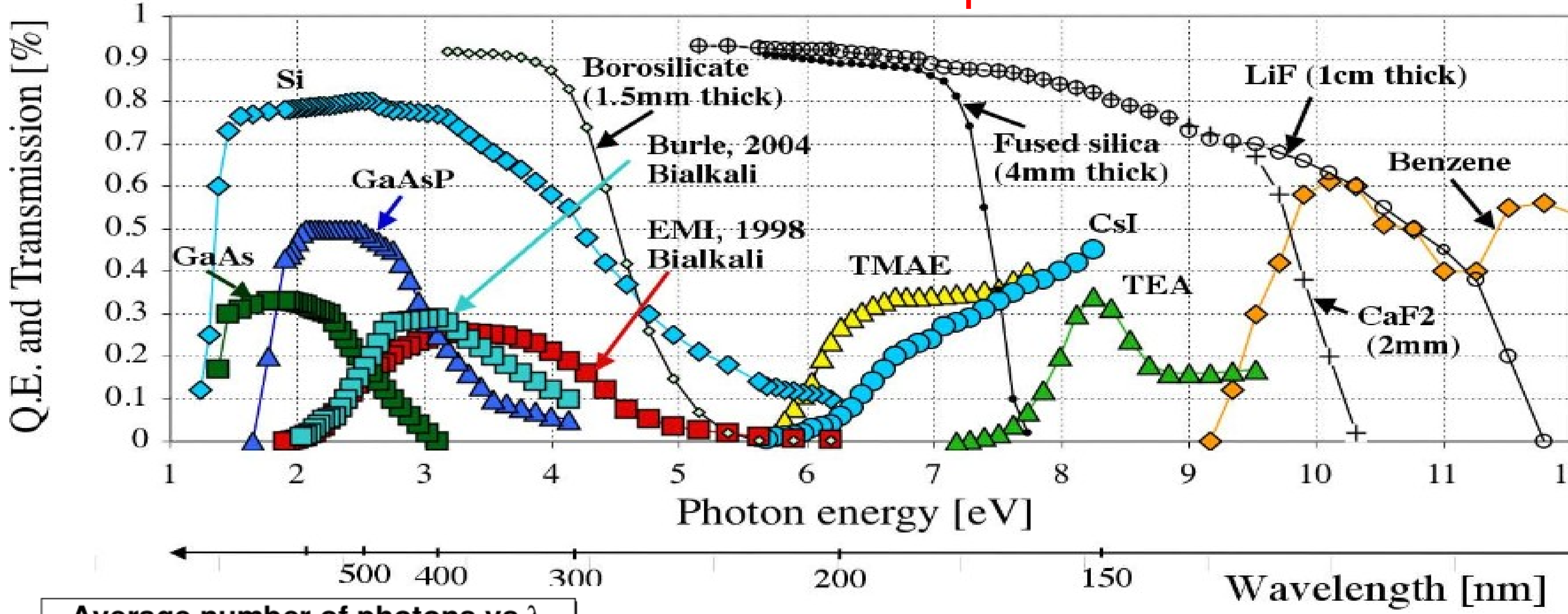


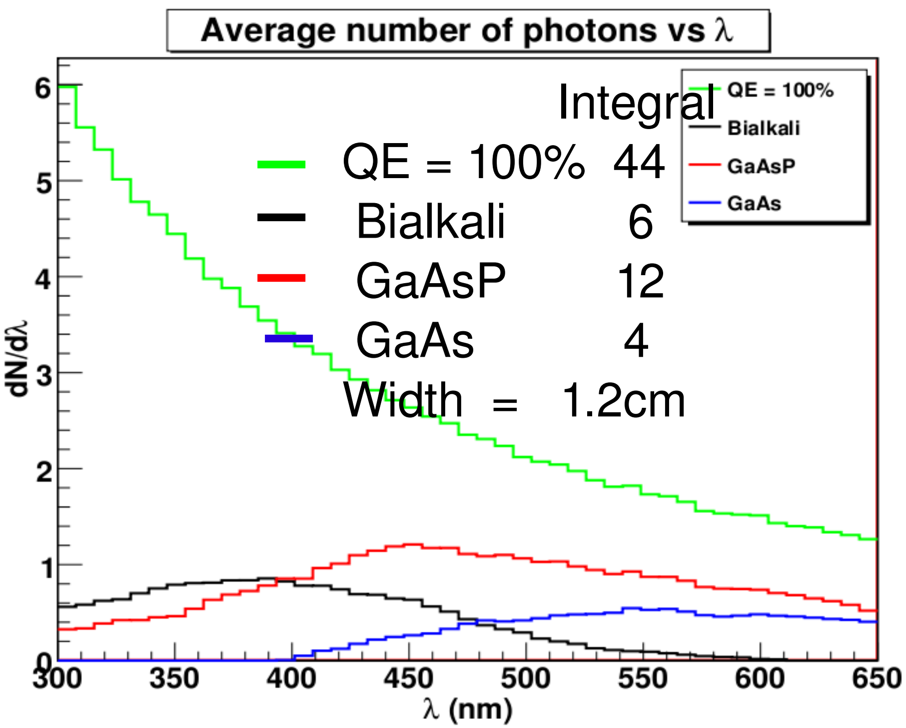
J.V.,http://www.slac.stanford.edu/~jjv/activity/Vavra_Forward_TOF_geometry.pdf, Perugia, June 2009



A simple geometry simulated so far; next step with be to compare different ones.

Simulation of the different photocathodes

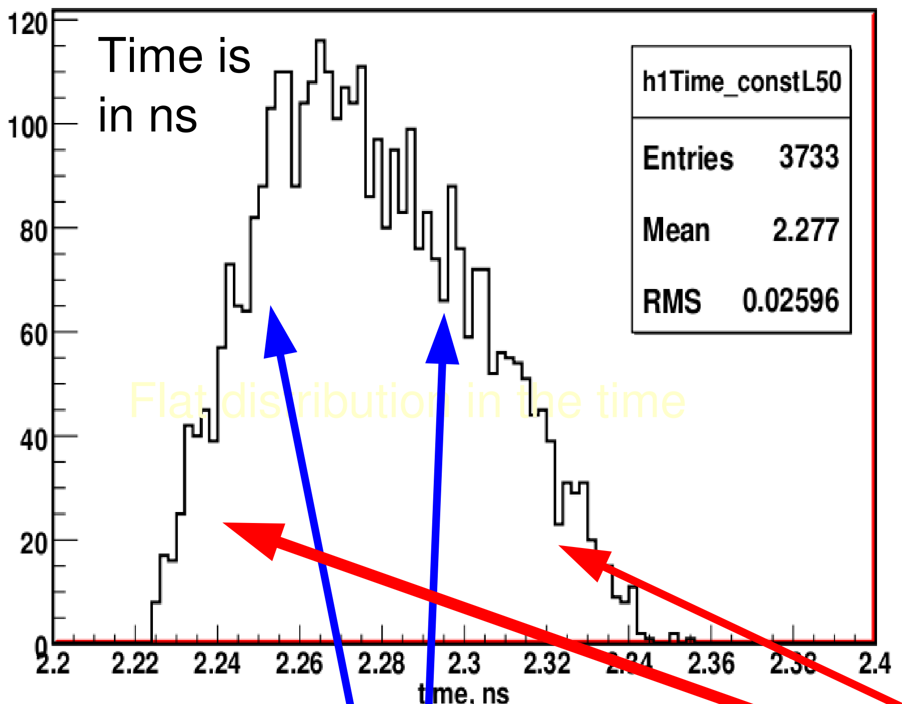




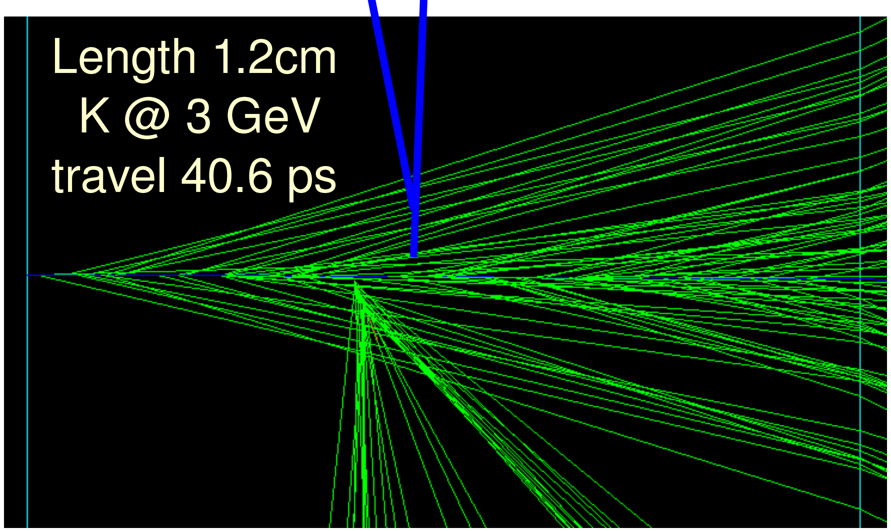
3GeV kaon hit detector at 90^{o} to surface with randomly generated x and y.

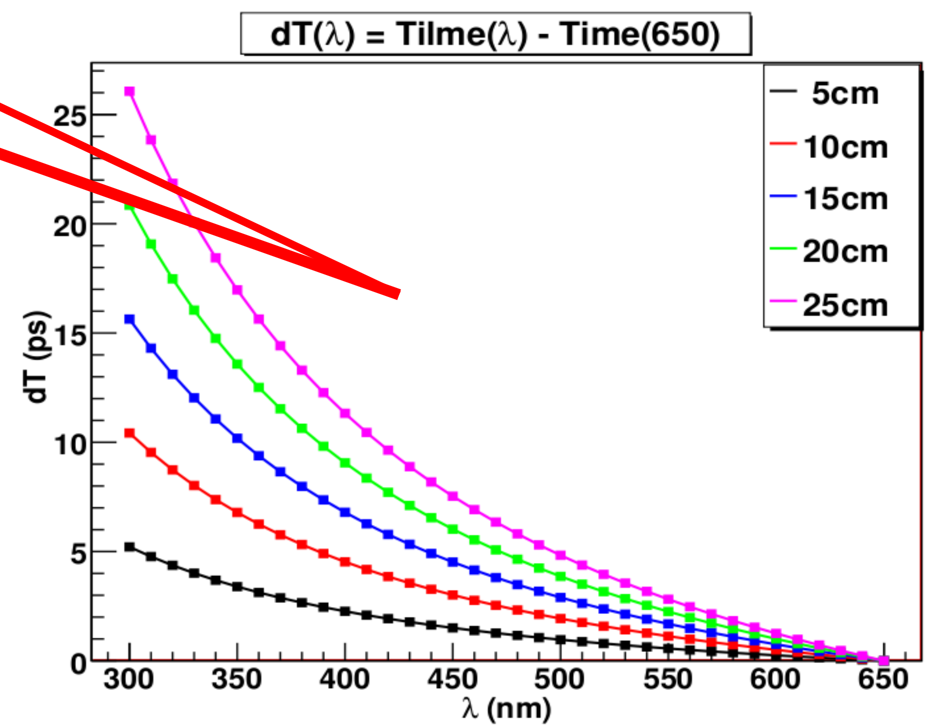
Convolution between chromatic and transit production terms

time for 249.7mm<photon path length < 250.3mm



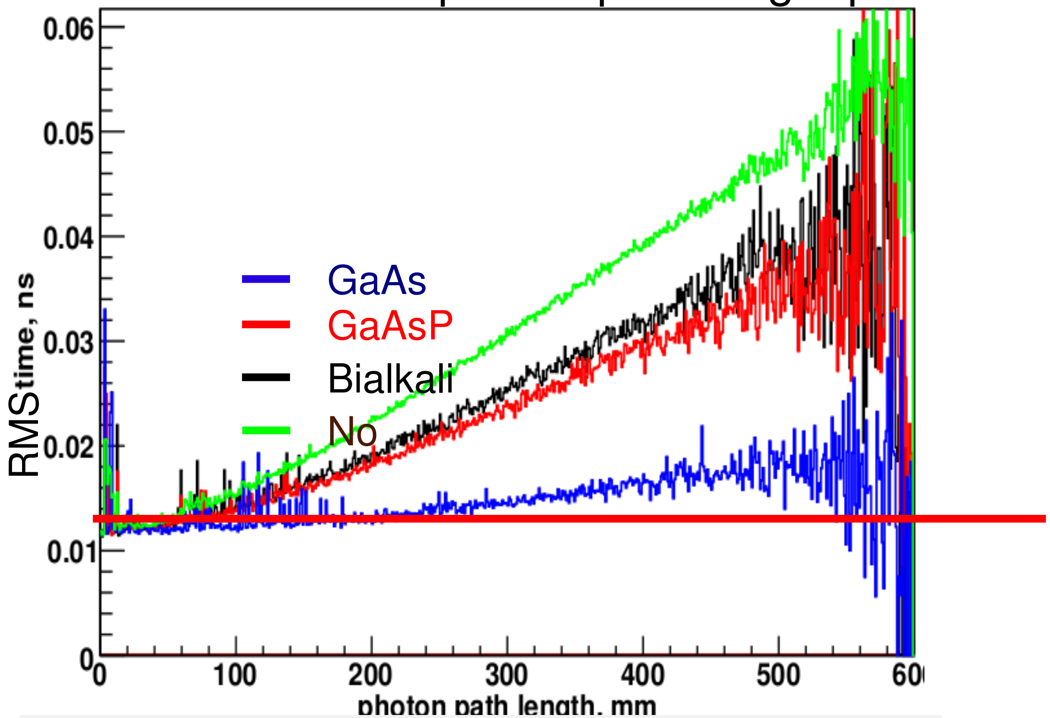
To study chromatic transit production and photon track terms, simulation of the TTS and electronics is not needed





Convolution between chromatic and transit production terms

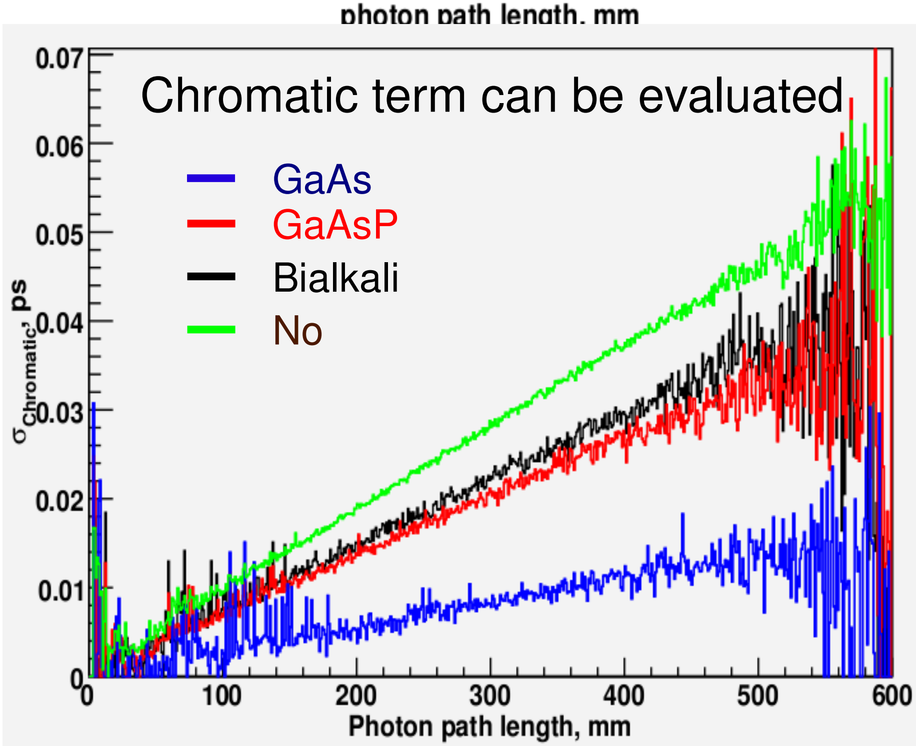
RMS of the time vs photon path length profile



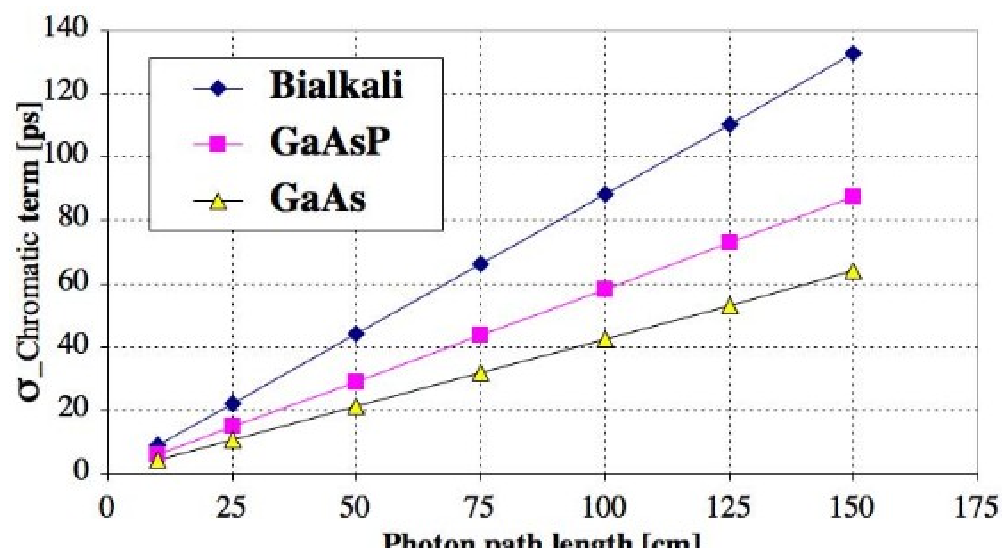
$$RMS = \sqrt{\sigma^2_{Chromatic} + \sigma^2_{TransitProduction}}$$

Constant pedestal correspond to

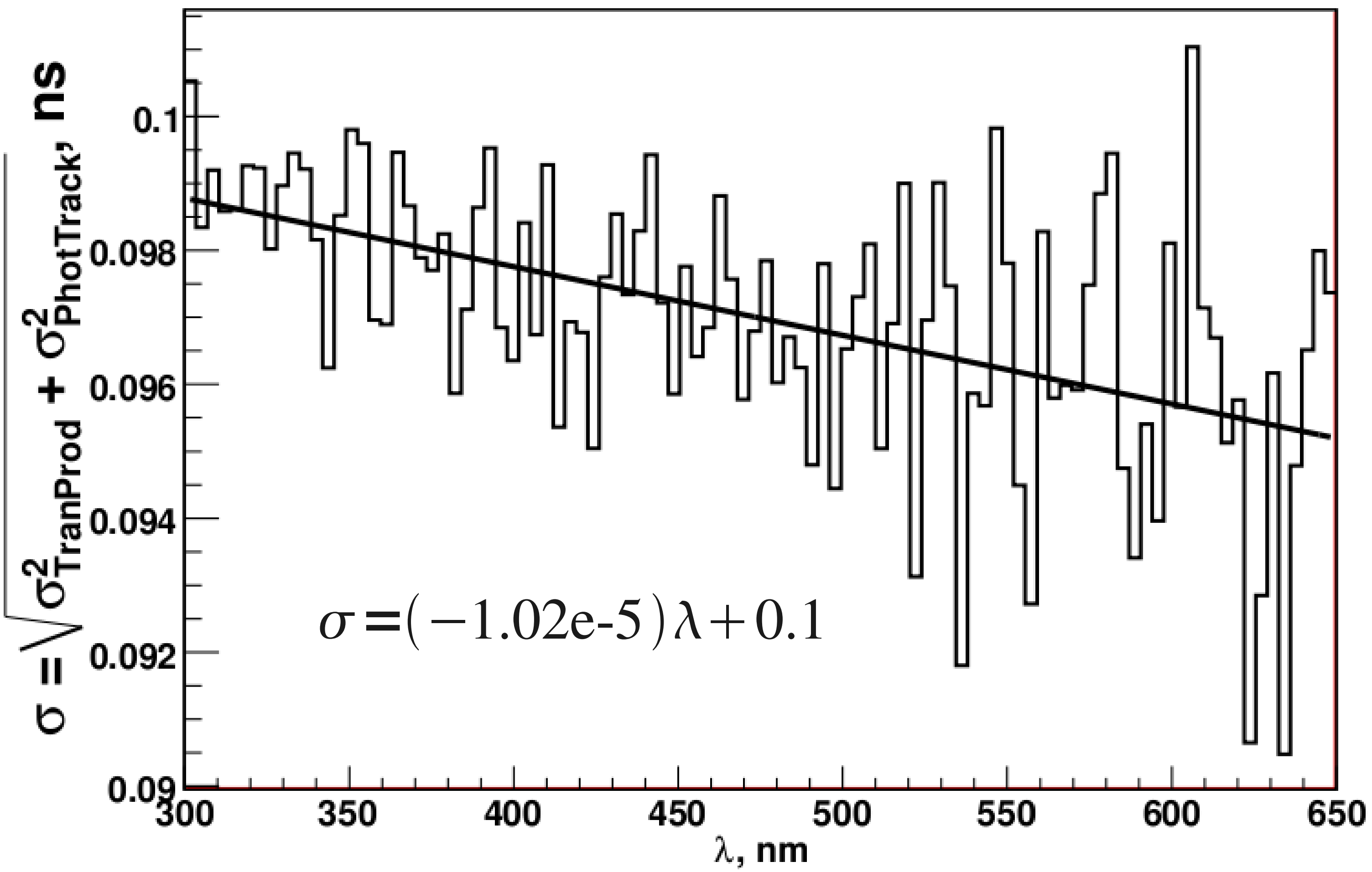
$Sigma_{transitProduction}$ = 40.6ps/sqrt(12) = 11.7 ps



$$\sigma_{Chromatic} = \sqrt{(RMS^2 - \sigma^2_{transitProduction})}$$

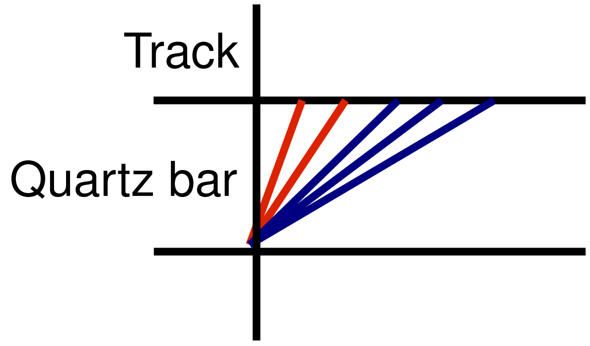


Convolution between the Transit Production and Photon Track terms



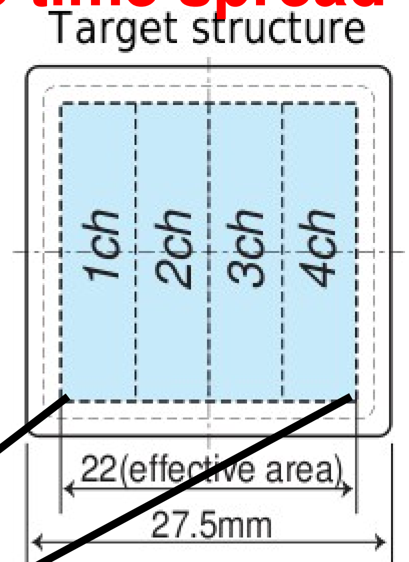
$\sigma_{PhotonTrack}(450\text{nm}) = 90\text{ps}$

We can correct it



"blue" photons have more spread path length

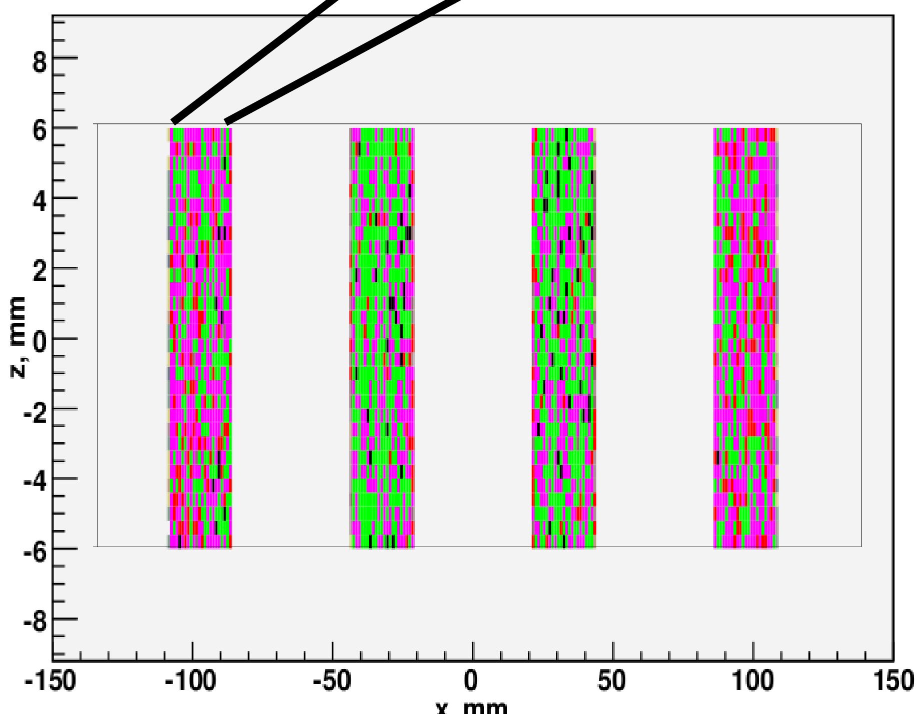
Simulation of the time spread due to TTS and electronics



The design currently studied has, effective surface 2.2*4 mm = 8.8 cm (34 % from total)

Position resolution is about size of the channel ~ 5.5 mm

Position of the PMTs



This is how we simulate sensitive surface.

Different geometries of connectors between quartz bar and PMTs have to be studied

Connectors with a more complicated geometry would allow the effective surface to be increased.

How PMTs should be placed?

Simulation of the time spread due to TTS and electronics

Time of each photoelectron smeared by TTS = 35ps

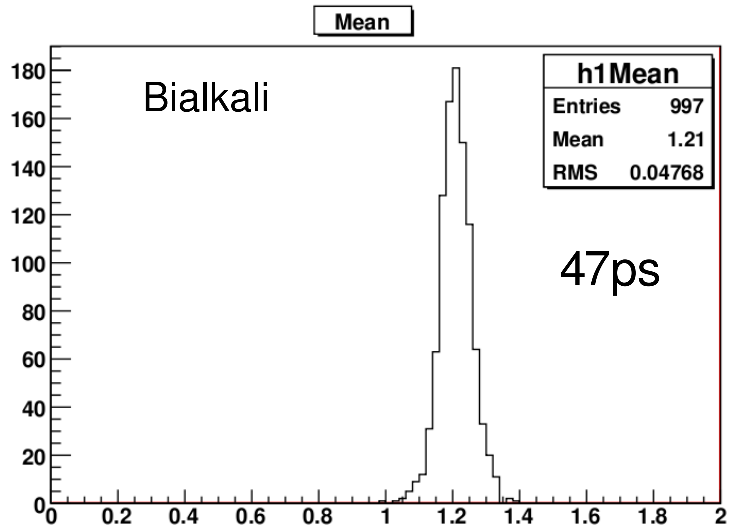
Each channel has its own 10ps time spread, which affect all photoelectrons in same channel.

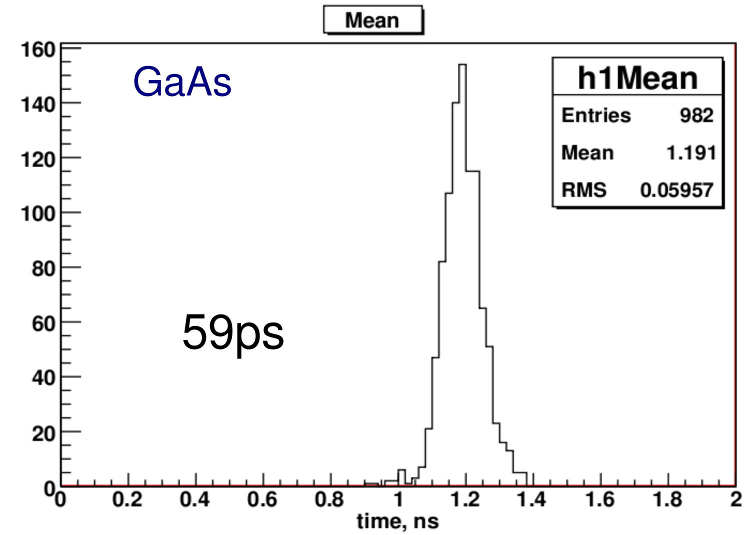
In general we have only one photon per channel, but if two photons enter same channel the actual measurement is a time average.

Taking into account measurements from all channels and their weight (number of photons) the average time $time_{average}$ is evaluated.

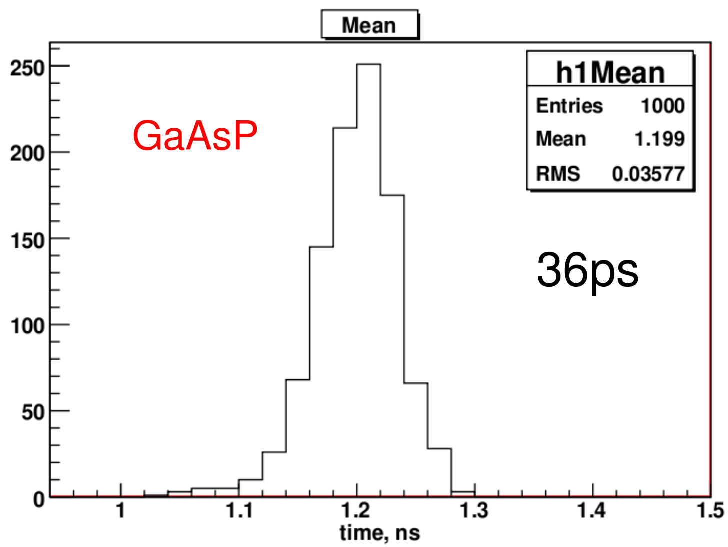
Next slide shows a study of the $time_{average}$ RMS

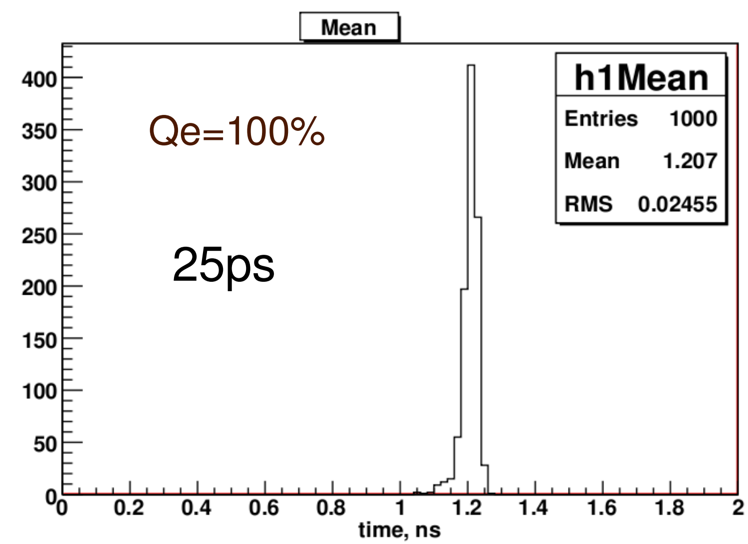
Studying RMS of the time$_{avarage}$ for Kaon at 3GeV which hit in the center of the detector perpendicular to the surface



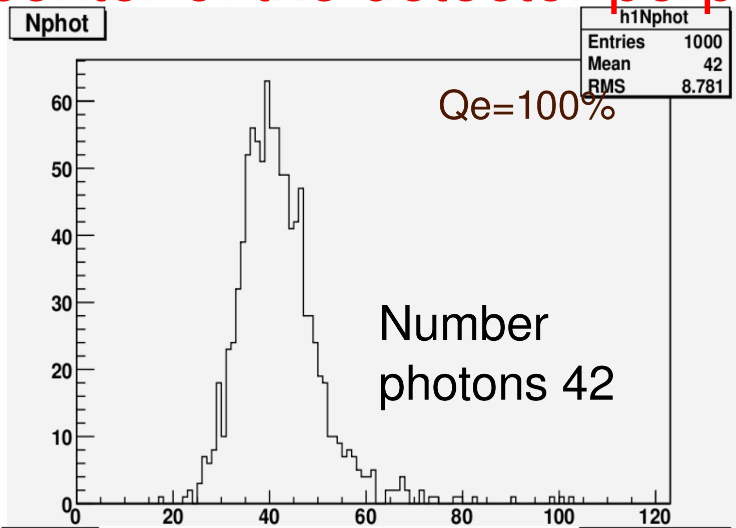


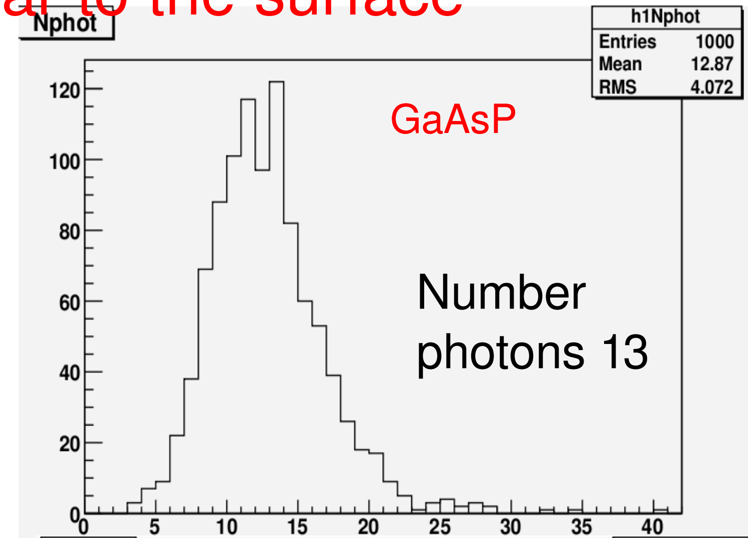
All times are in ns

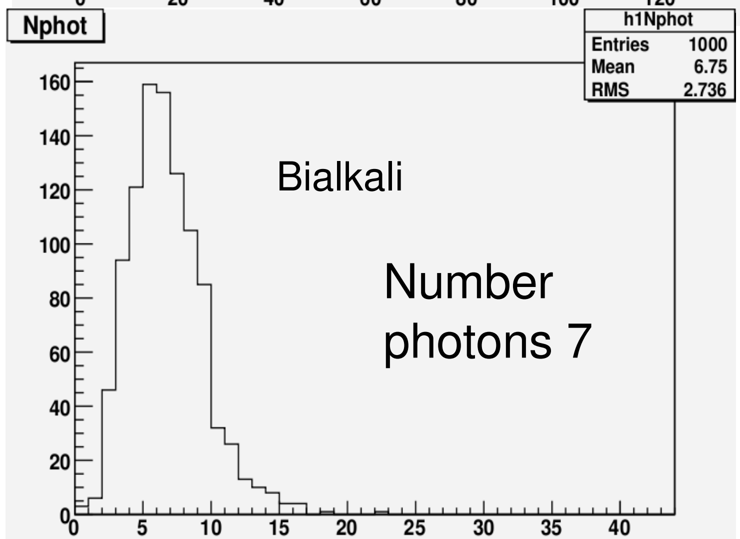


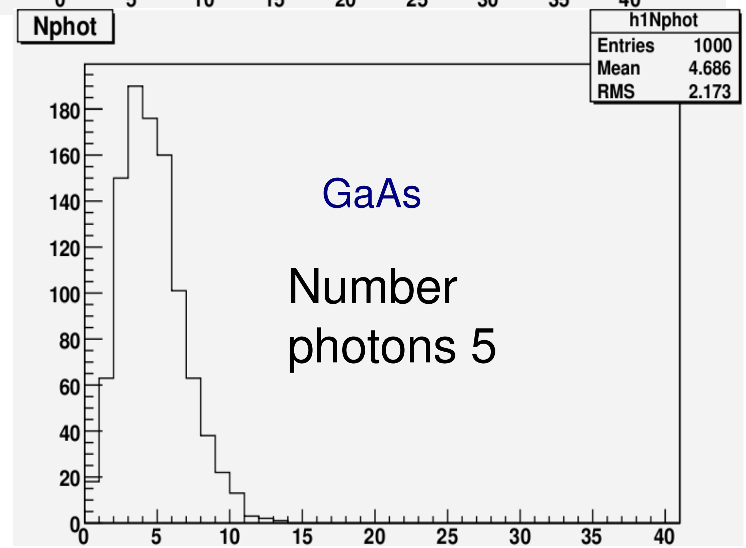


Numbers of photons studying for Kaon at 3GeV which hit in the center of the detector perpendicular to the surface









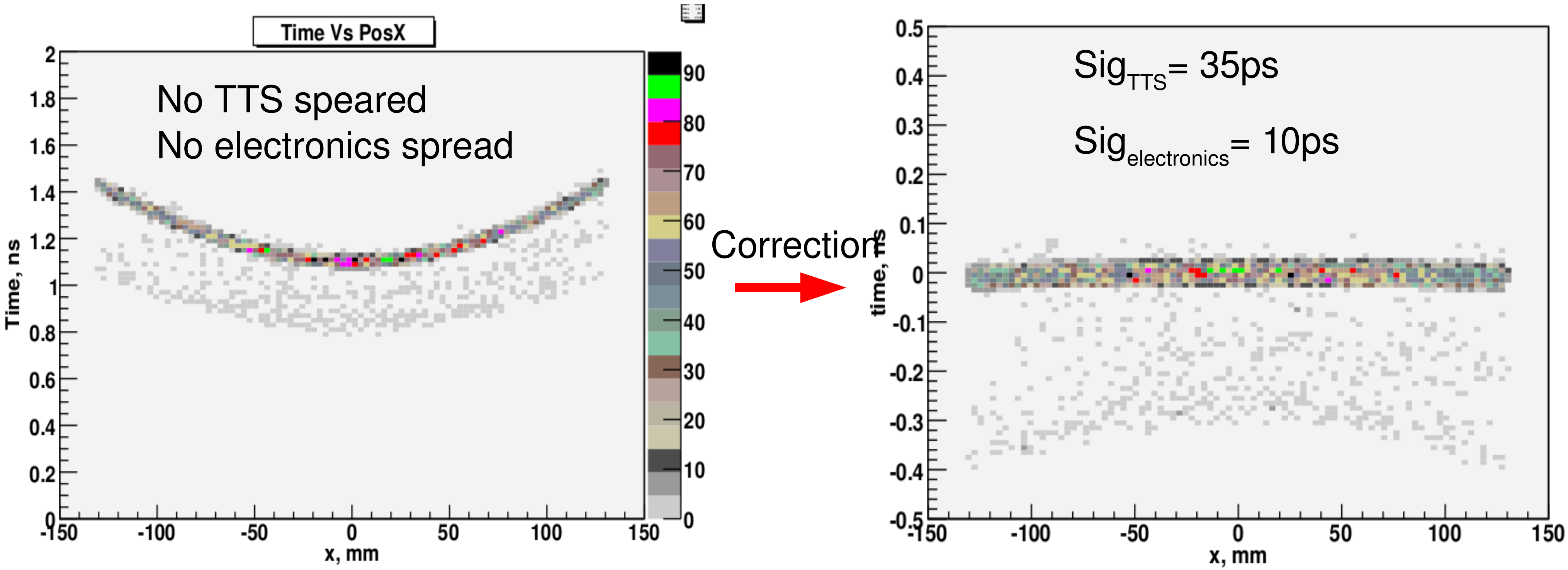
Number of photons is very important parameter. How can we increased it ?

By increasing thickness of the detector

By increasing number of readout channels

By changing geometry of the connector between quartz bar and PMTs

We can correct $Sig_{PhotonTrack}$



$$\sigma_{PhotonTrack}(450) = 90ps \quad \xrightarrow{\text{Correction}} \quad \sigma_{PhotonTrack}(450ns) \; ???$$

This job has to be done

Conclusion

For kindly providing the G4 package after the SLAC workshop
Many thanks to Doug Roberts

- Geant4 simulation of the fTOF detector study started
- Study the effect of the Chromatic, Transit Production and Photon Track terms
- Studying effect of different photocathodes on time resolution
- Collaborative work with Kiev Taras Shevchenko University, Ukraine

To do list

- Add connectors between quartz bar (TOF) and PMTs in to the simulation
    - Study different geometries
- Study effect from different thickness
- More realistic simulation of the electronics have to be done
- Study of different geometries of the detector in general

Collaborative tools

We started to collaborate with Kiev Taras Shevchenko University

Dedicated please for simulation of the fTOF

https://ftof.bezsh.org.ua/

login: guest   password: welcome

Wiki — show changes — Trac + svn — Forum

logged in as burmist | Logout | Preferences | Help/Guide | About Trac

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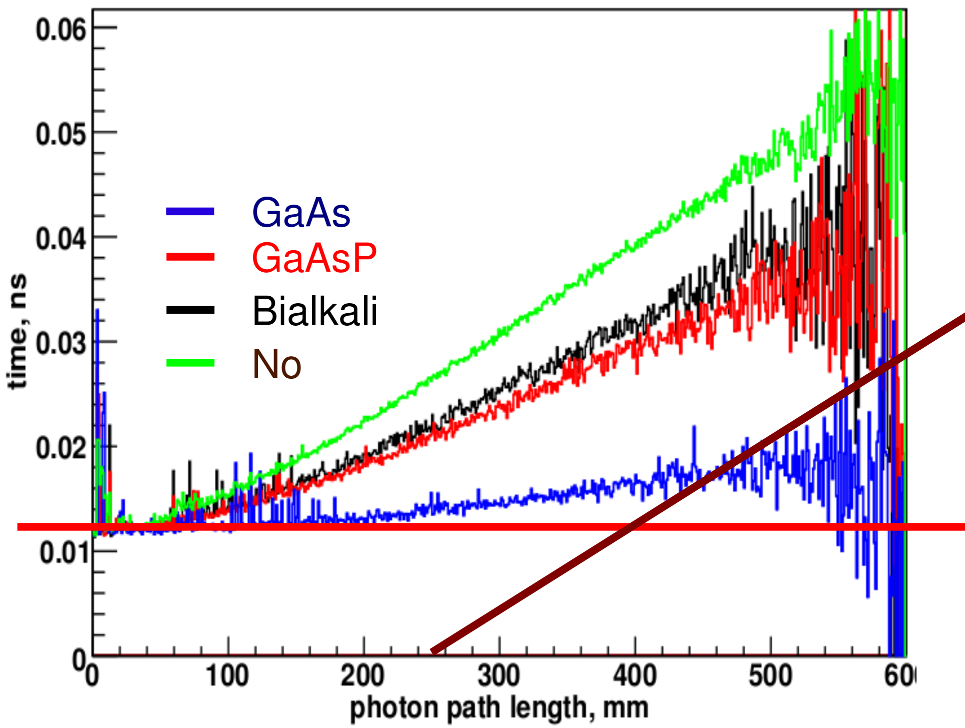
WELCOME to fTOF subproject page

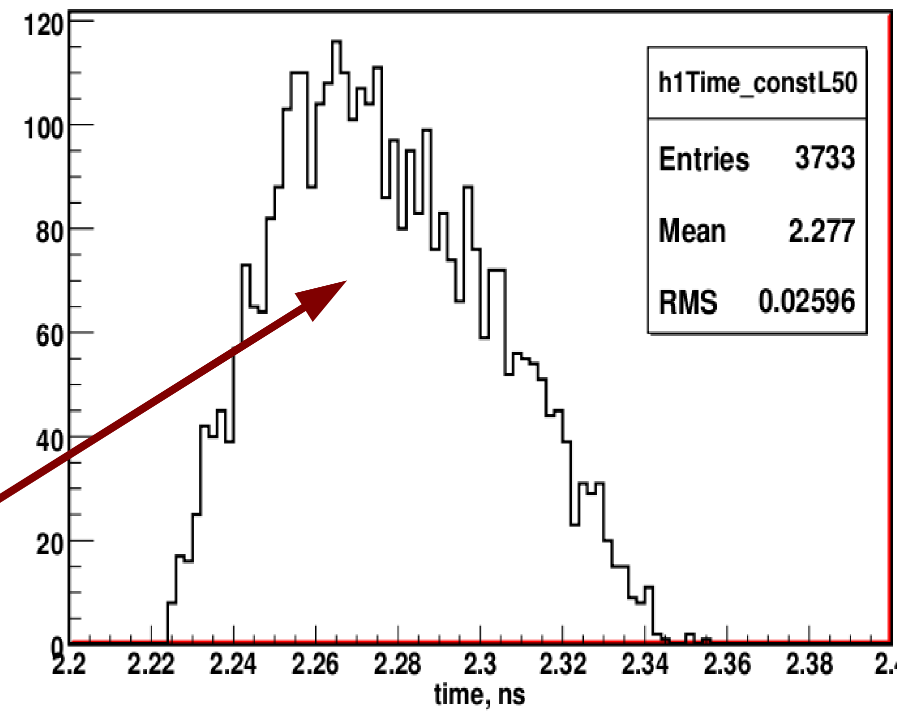
This is a small part of HEP project SuperB http://web.infn.it/superb/ (old web server - http://www.pi.infn.it/SuperB/)
Some more information can be found here: http://www.slac.stanford.edu/~burmist/TOFinfo/

Backup

Convolution between Chromatic and Transit Production terms

$$\sigma_{res} = \sqrt{(\sigma^2_{TransitProduction} + \sigma^2_{Chromatic})}$$

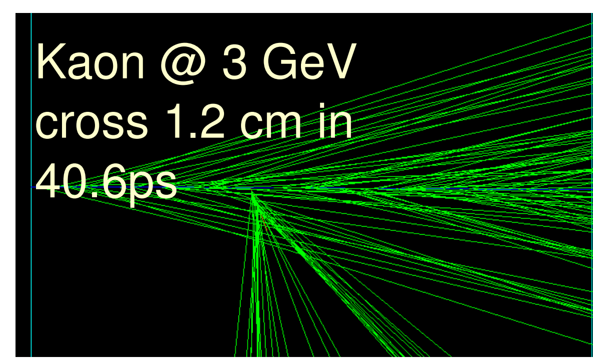




RMS of the time vs photon path length profile

Constant pedestal ~ 11.7 ps correspond to photon produced all over the way

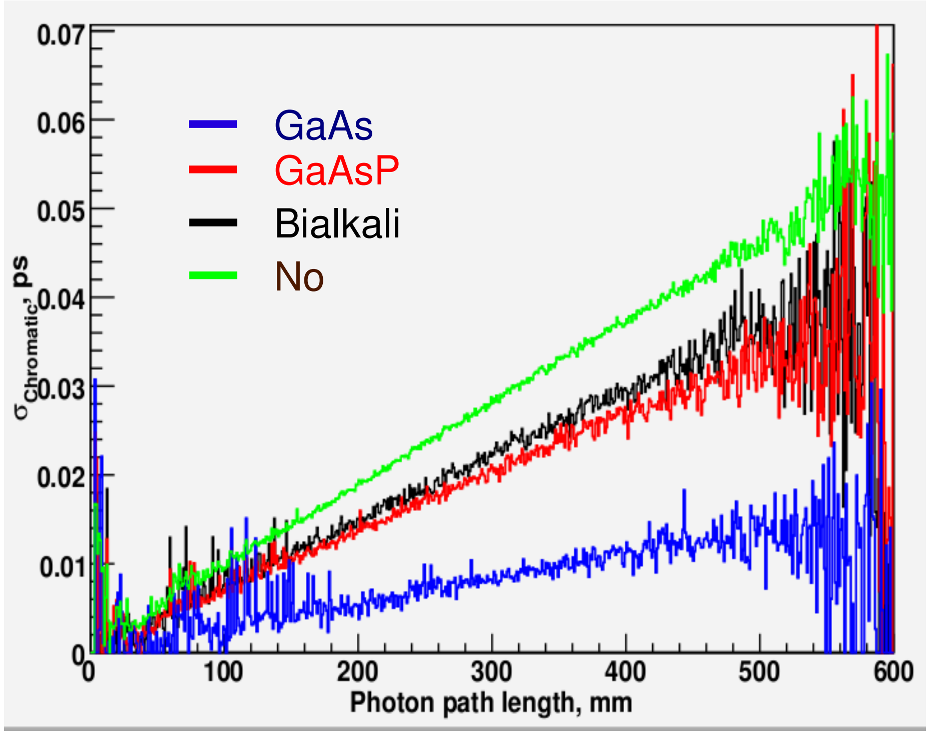
What we see on this plot is convolution between $Sig_{TransitProduction}$ and $Sig_{Chromatic}$.

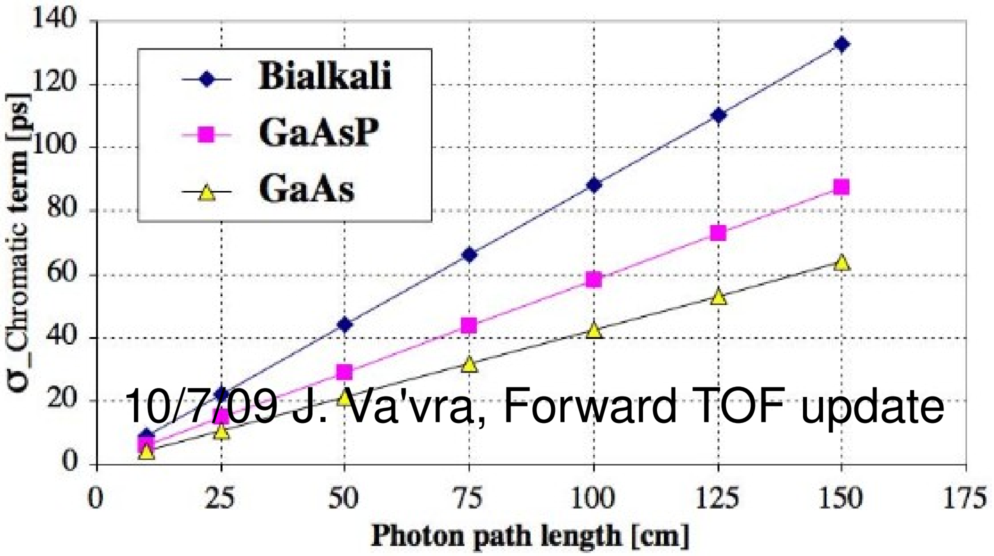


Extraction of the Chromatic term

Chromatic term can be evaluated like this

$$\sigma_{Chromatic} = \sqrt{(\sigma_{res}^{2} - \sigma_{TransitProduction}^{2})}$$





GaAs has the smaller error from chromatic term since it selects more “red” photons.

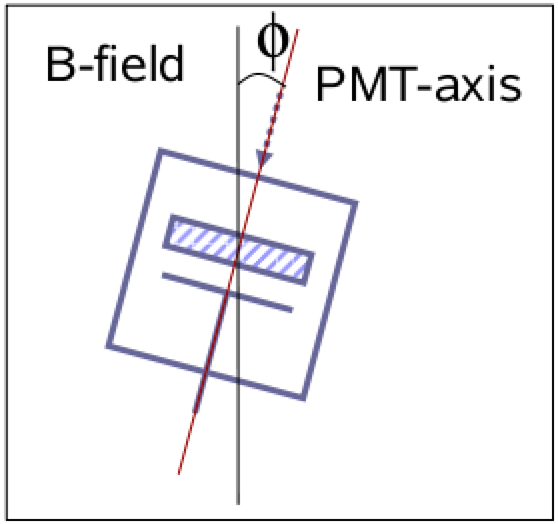
To get the code from svn and run simple example

Programs which you need to install fTOF

1) svn
2) Geant4 (geant4.9.2.p02)
3) root
4) Java (for visualization with HepRep)

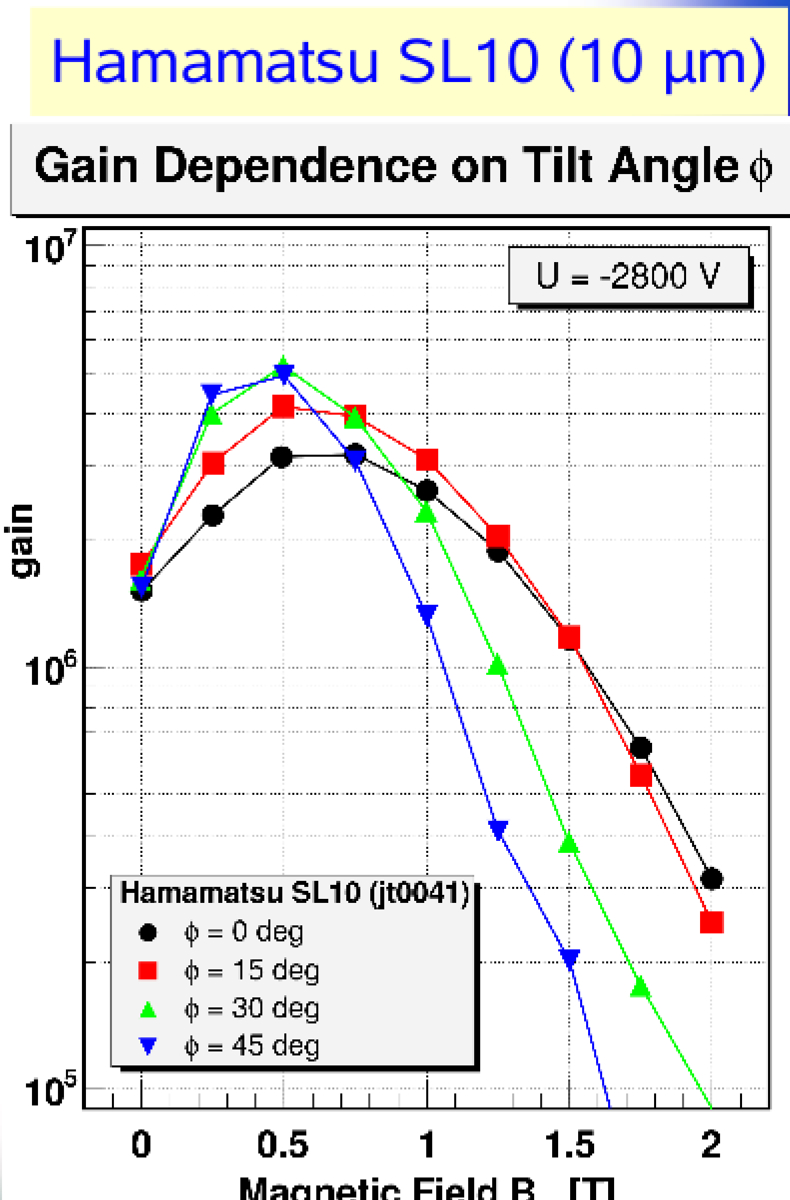
1) Load the code > svn - - username user https://www.bezsh.org.ua/svn/fTOF/trunk
2) make
3) run executable with vis.mac files (Geant0.heprep and Geant1.heprep should appear)

Gain Dependence on B-Field Direction, define how PMT have to be connected to the quartz bar



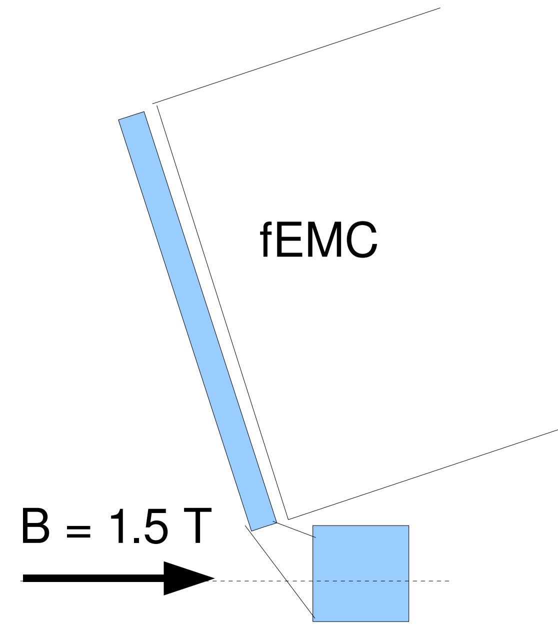
ϕ = angle between magnetic field direction and PMT-axis

Significant gain drop at large magn. fields and ϕ-angles



PMT should work with gain 10^6

Phi have to be 0 deg



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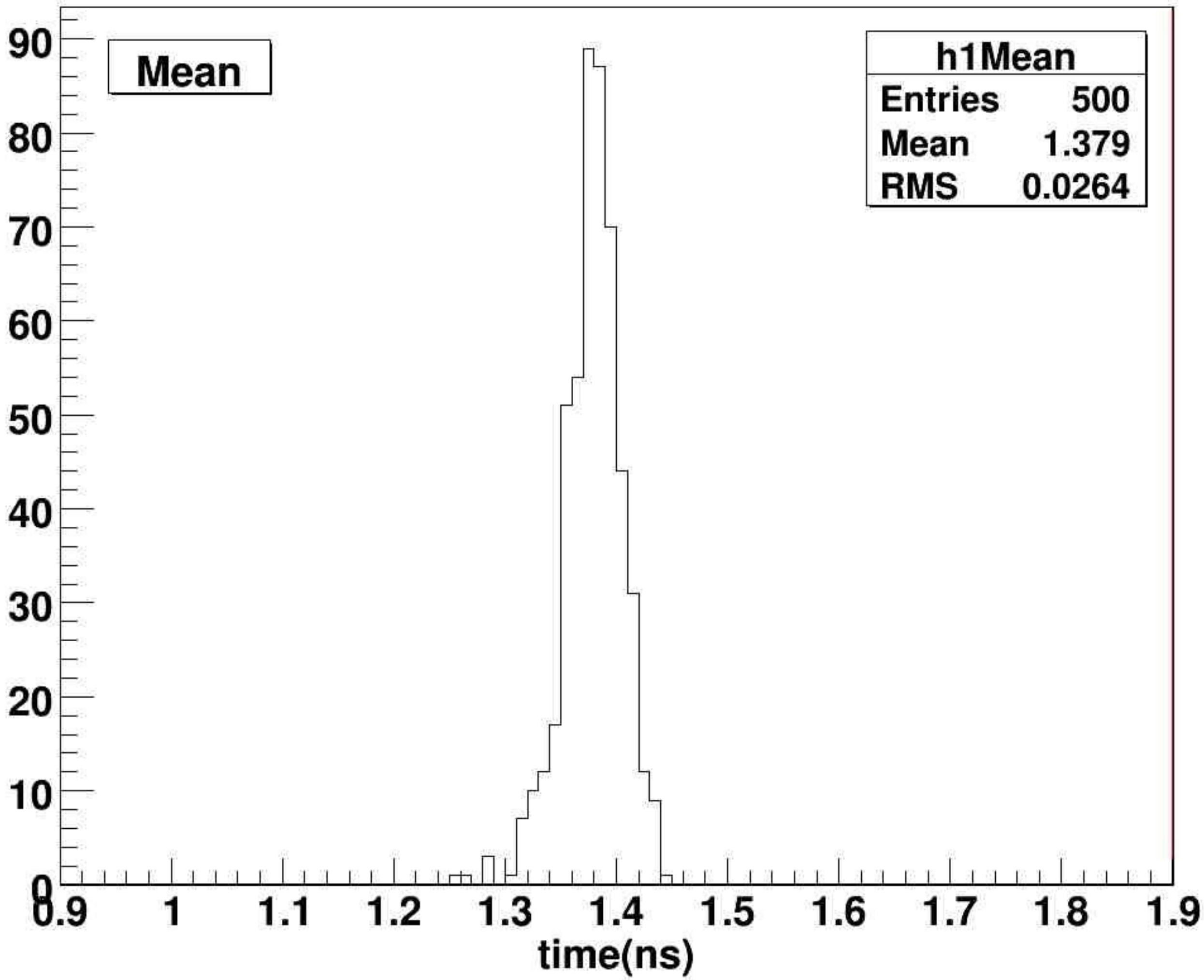
Results we get for now



Sig_electronics = 10ps

Sig_T0 = 15ps

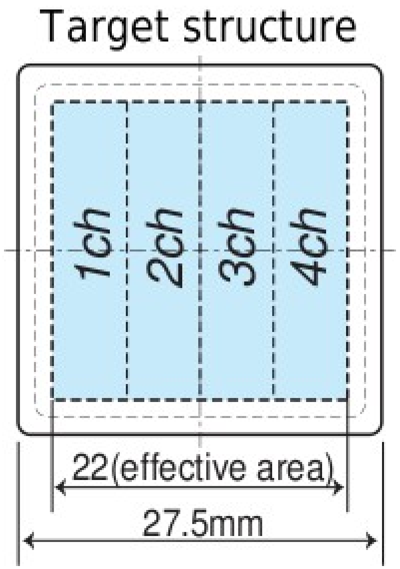
Sig_TTS = 35ps

photocathode - GaAsP

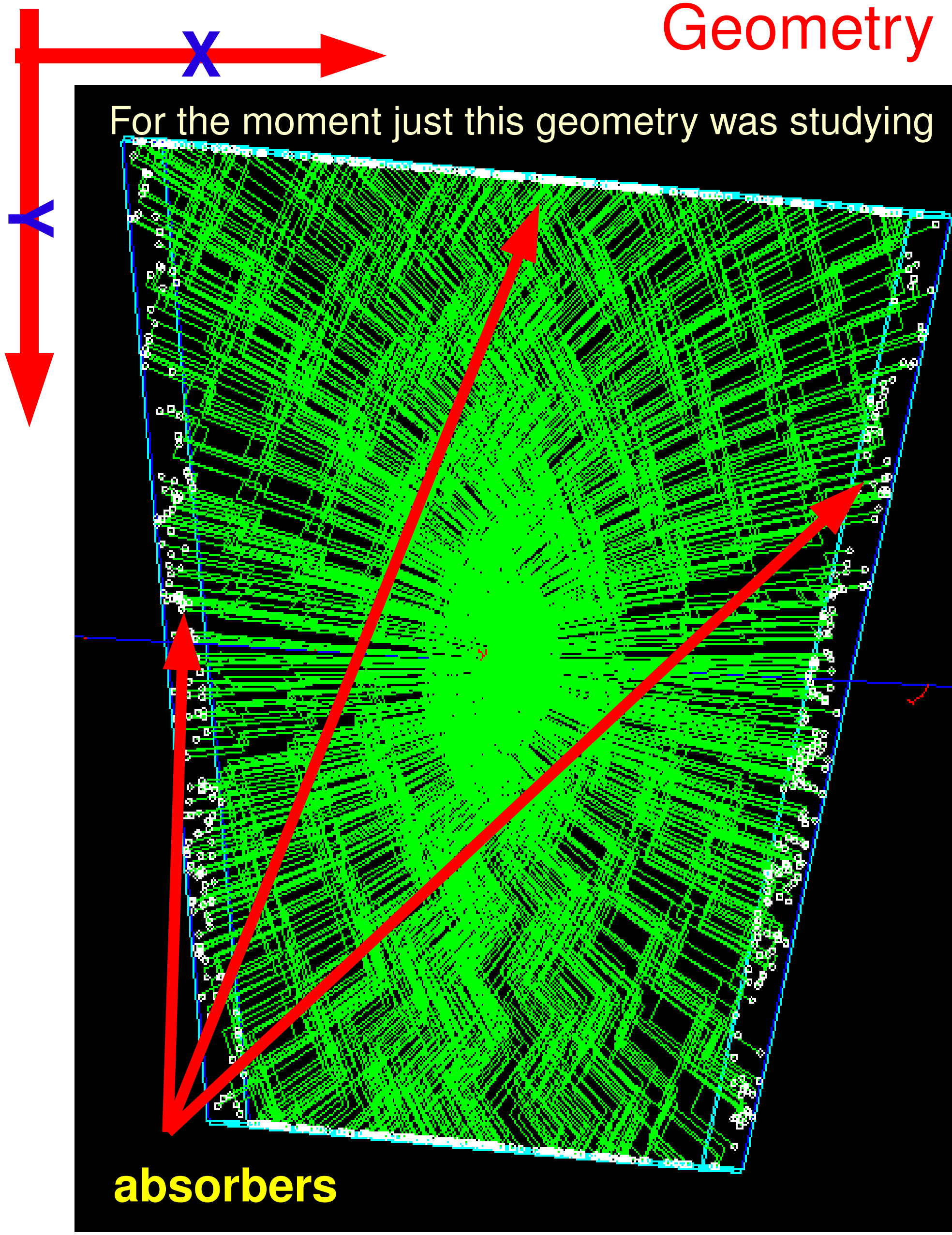
thickness = 20.0mm

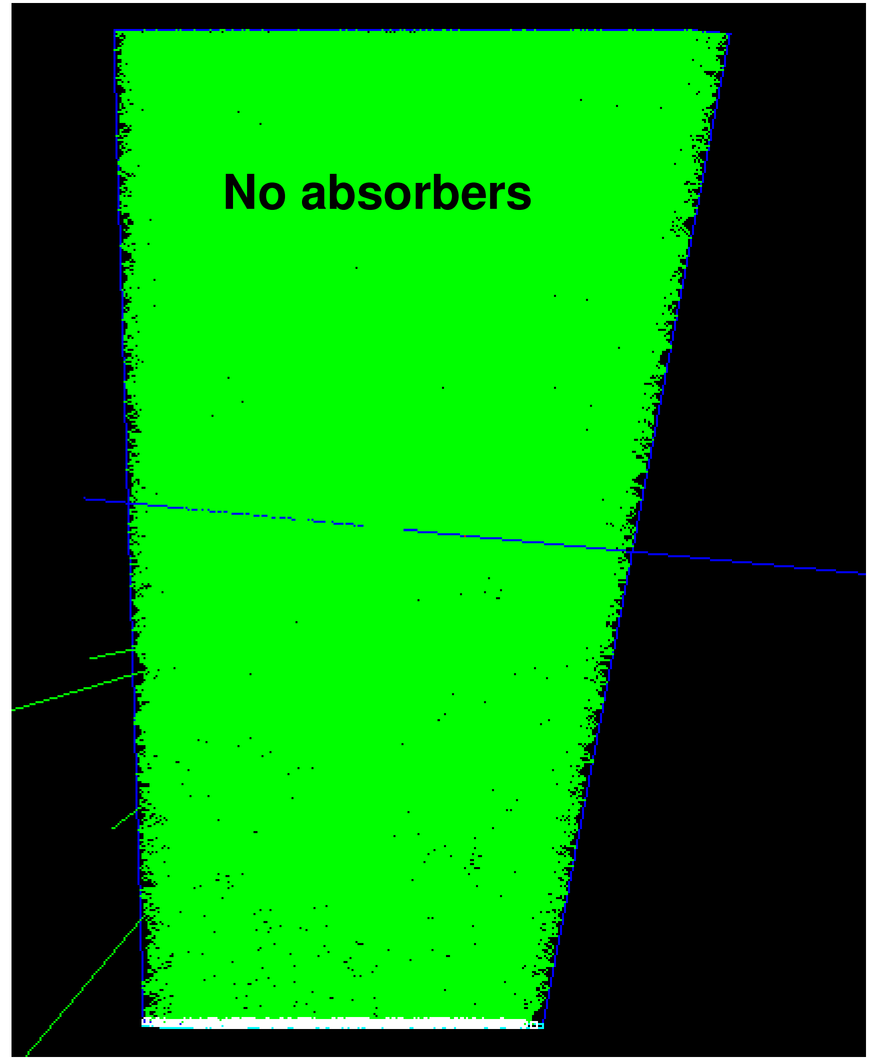
The RMS and mean was extracted from histogram with no FIT

Sig_electronics – effect all photons **(should effect just one channel)**


Target structure
1ch
2ch
3ch
4ch
22(effective area)
27.5mm

Geometry of fTOF in Geant4





Detector is trapezoid, with size:

Y – length 30 cm

Xmin – length 25.9 cm

Xmax – length 41.4 cm

Thickness – 12.0 mm

Sizes with some changes taken from this presentation of J.Vavra

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