FTOF detector: forward particle identification using Cherenkov light

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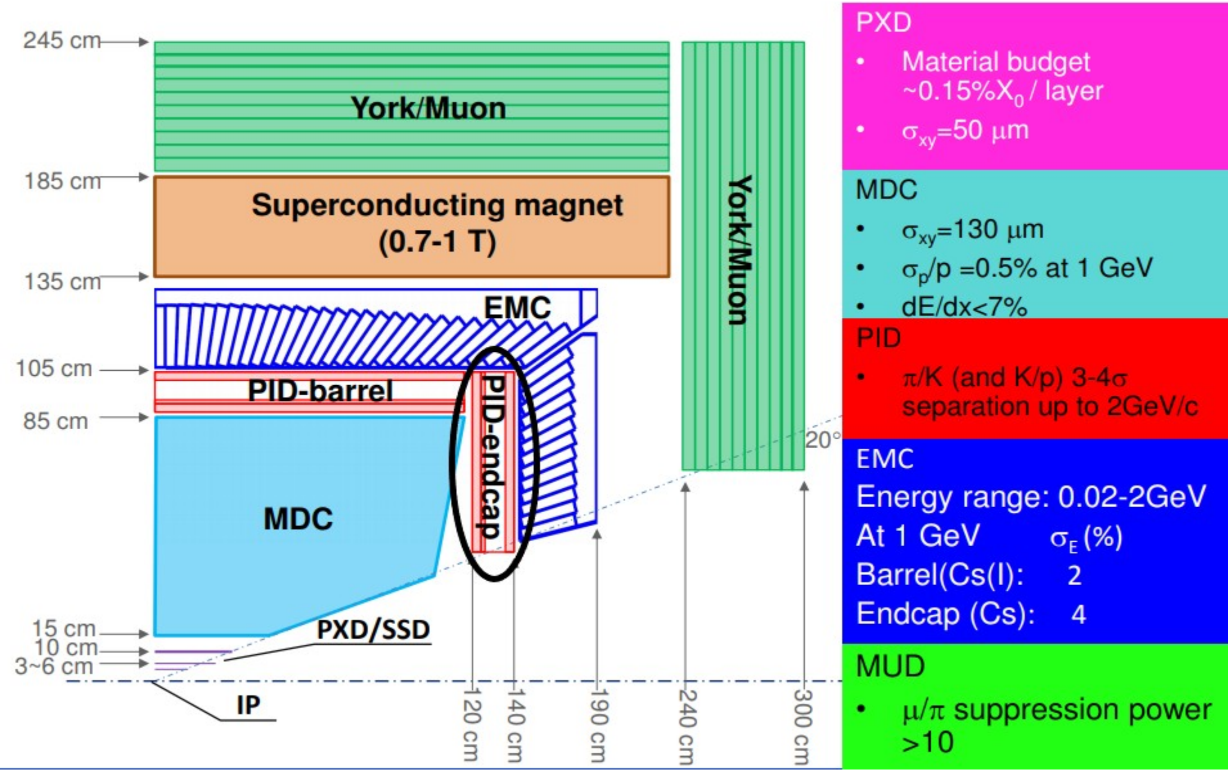
fTOF Detector for HIEPA



Main goals

- **p/K/π separation up to 2 GeV**
- Beam crossing **time stamp**

Constraints:

- **Compact, fast, low-material, radiation resistant** detector

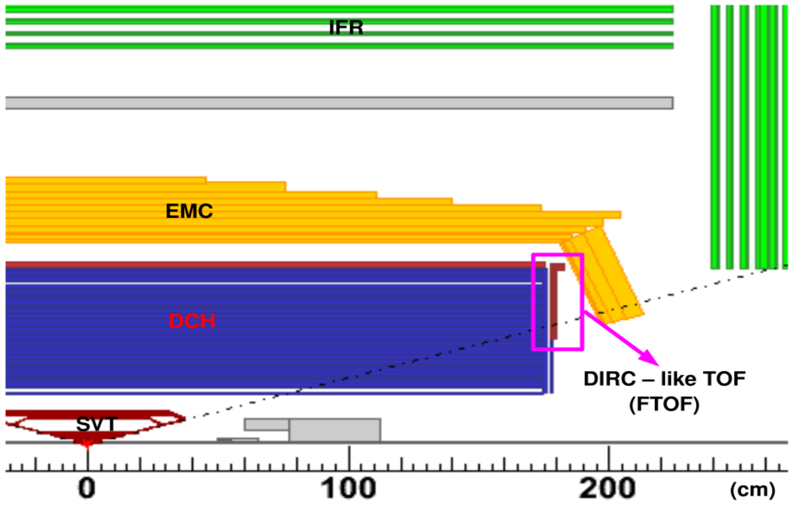
Principle

- Quartz Cherenkov radiators conduct light to photon detectors using total internal reflection

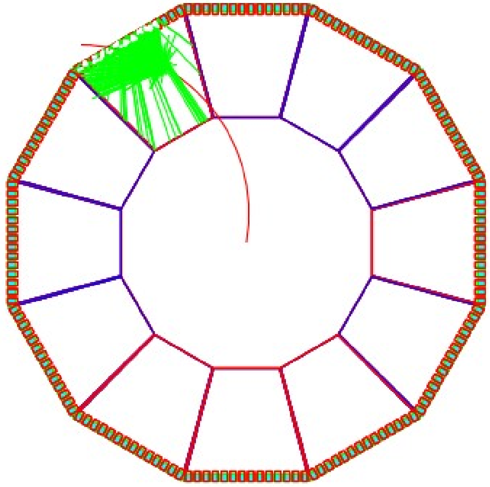
DIRC-like TOF for SuperB project

Original idea was proposed for Italian SuperB project: DIRC-like TOF detector for PID in forward region

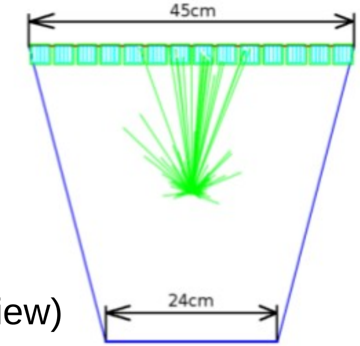
SuperB detector design



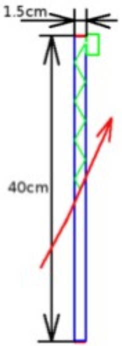
TOF endcap ring (beam view)



Trapeze sectors with 14 MCPPMTs



(beam view)

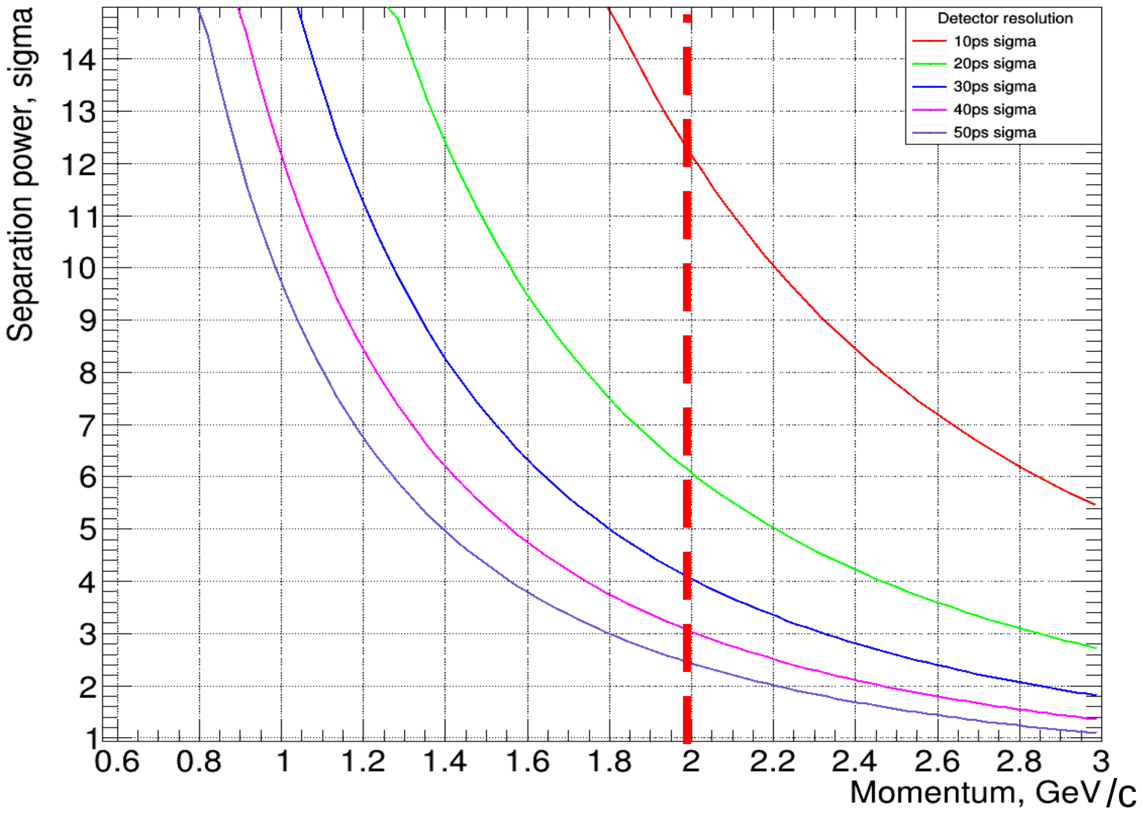


(side view)

- >10 photons / track → time resolution per photon around 100 ps
- 12 thin (15 mm thick) quartz tiles
- Cherenkov light detected by fast MCPPMTs
- WaveCatcher electronics

K/π separation

$$separation\ power = \frac{|\Delta t|}{\sigma}$$

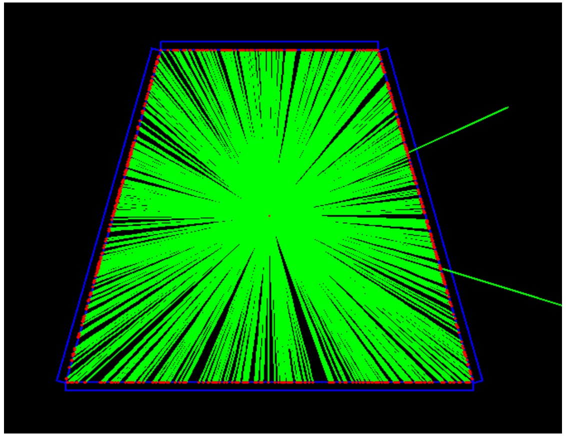


- Kaon/pion separation power as function of particles' momentum for different detector resolution

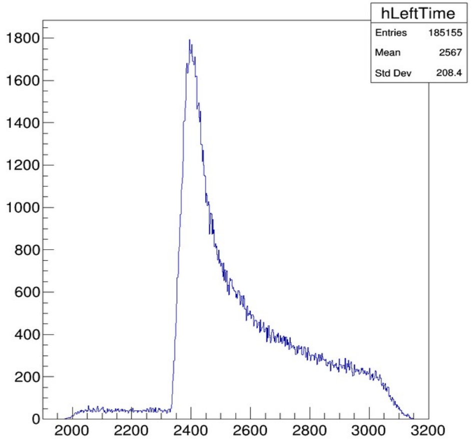
- Time resolution of **~30 ps** needed to achieve **4σ** K/π separation on **130 cm** flight length for momentum of **2 GeV/c**

Optimization of time resolution: sector size

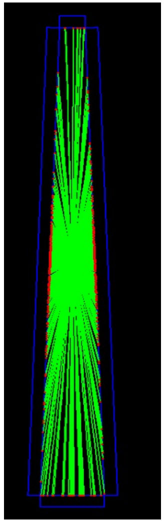
Photon arrival time



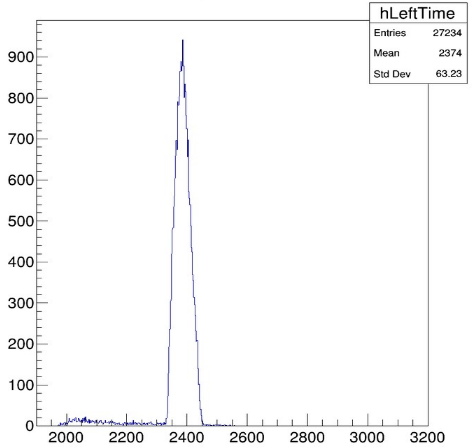
12 big sectors (SuperB)



Time, ps



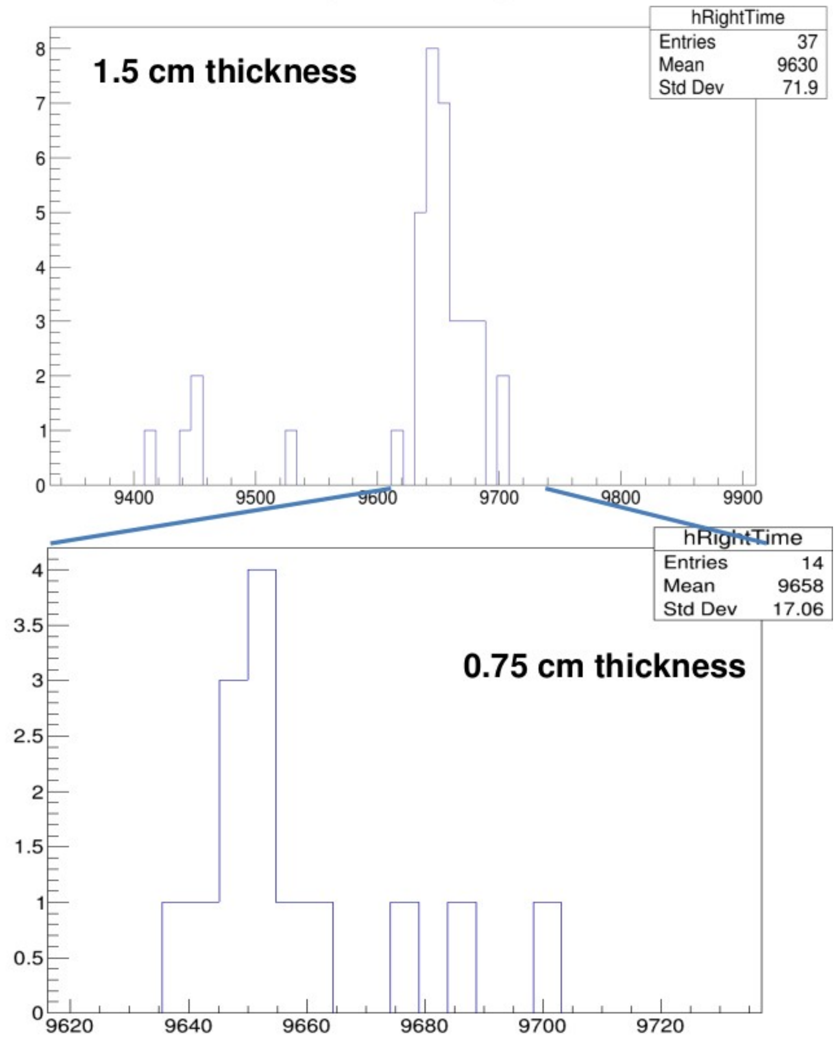
100 small sectors



Time, ps

- Narrower time distribution of collected light

Optimization of time resolution: sector thickness



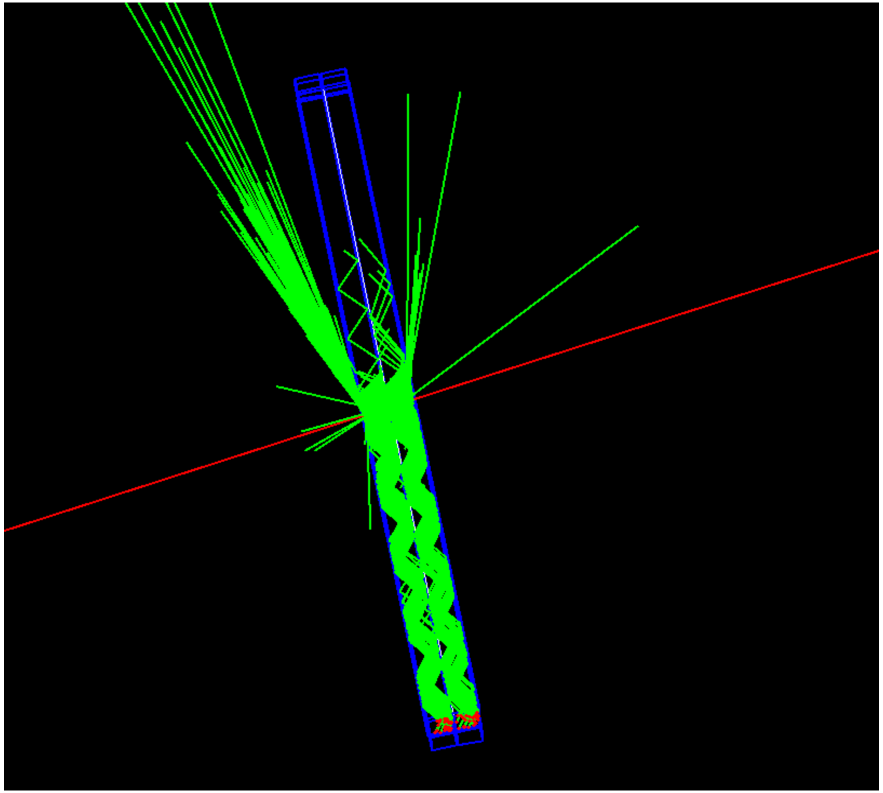
- Reduce spread of photon arrival time by reducing a sector thickness (right/left sides blackened)

- Twice as narrow distribution, but also twice less light

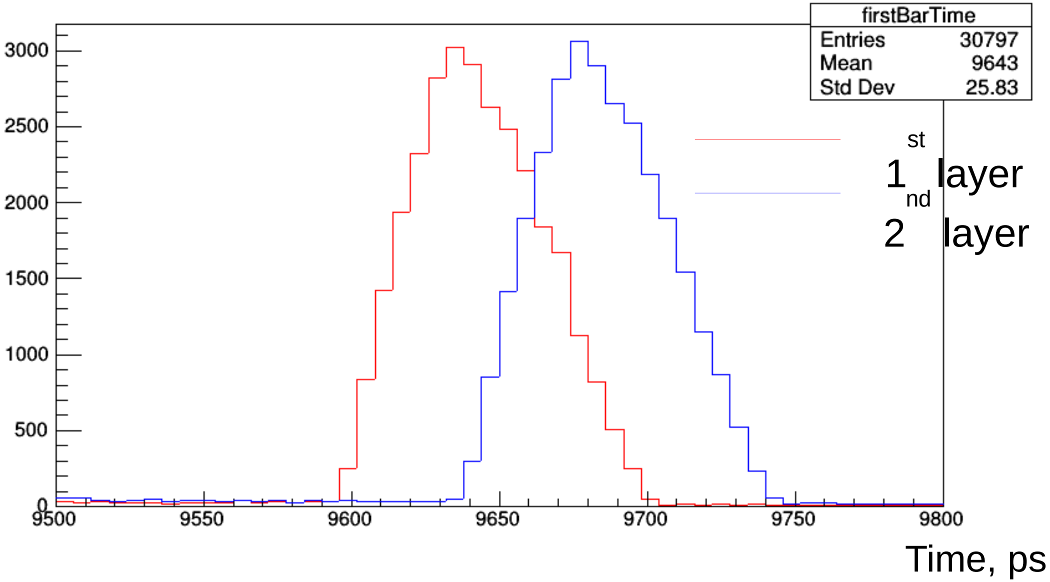
Optimization of time resolution: sector thickness

- Restore (or improve) initial amount of light retaining the improved time resolution by **using multilayers**

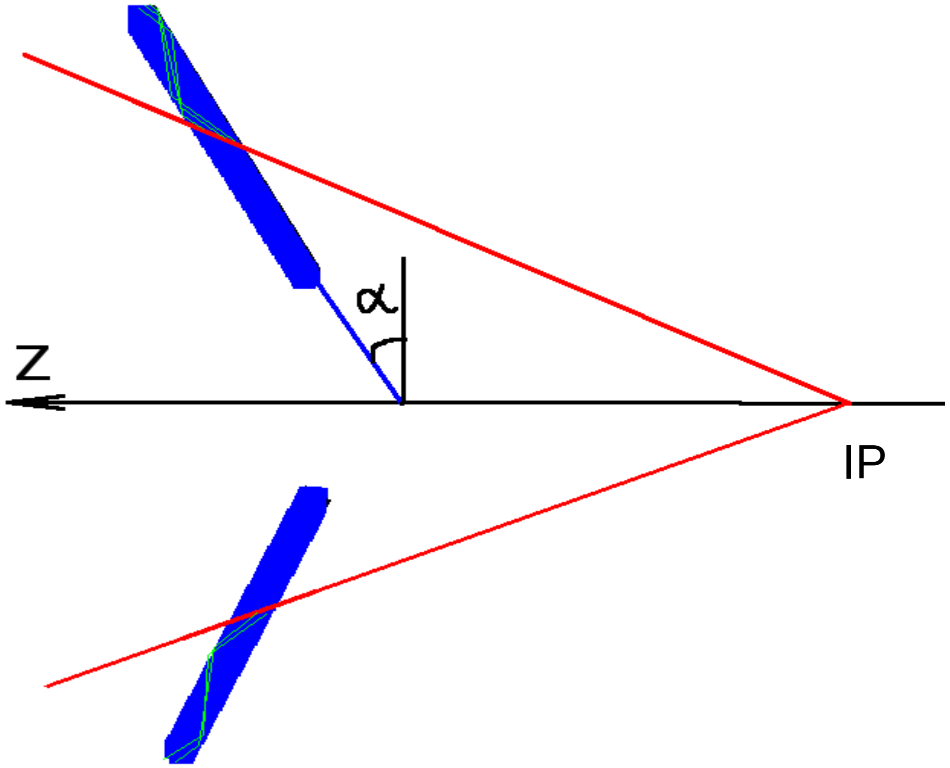
Two layers of quartz optically separated from each other



Time arrival of detected photons



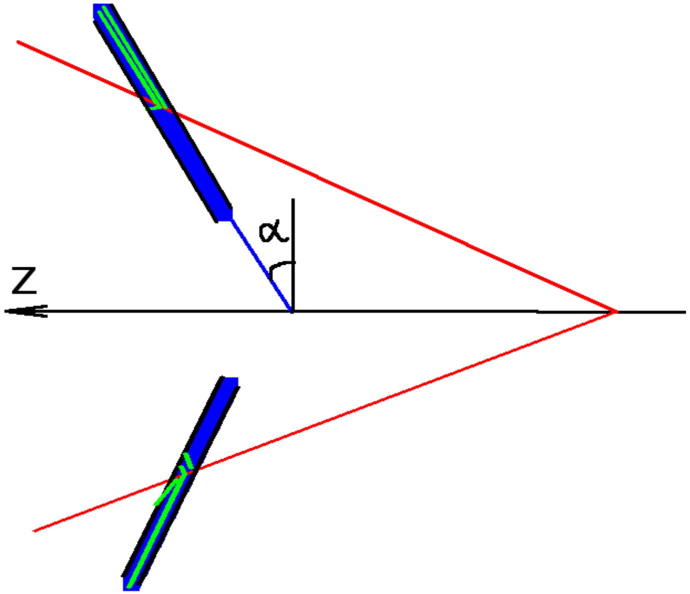
Further geometry optimization: tilted sectors



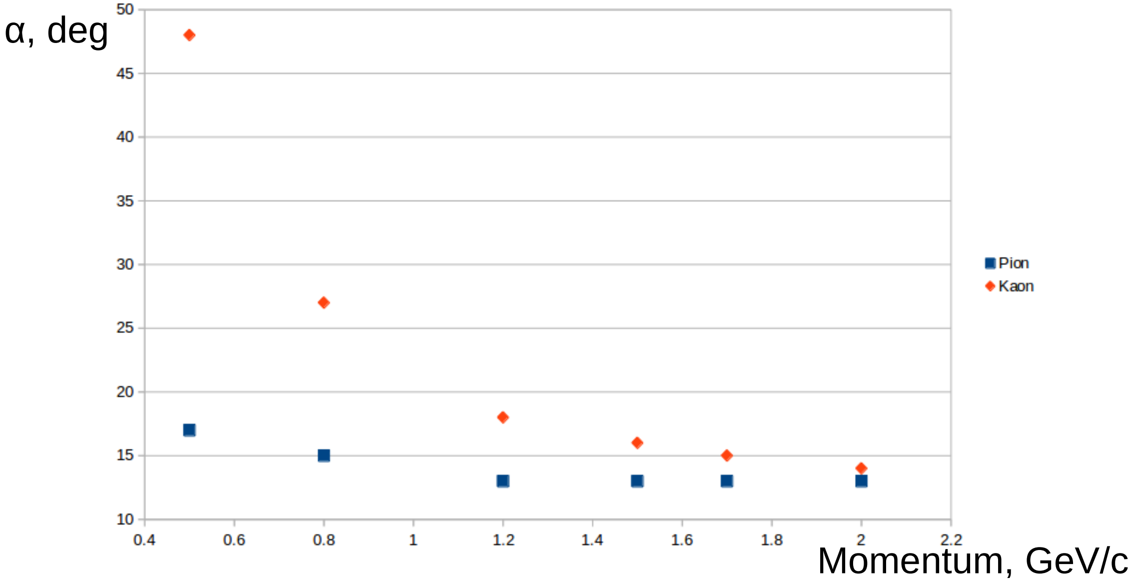
- **Tilted geometry** with an angle **α**
- Decrease number of side reflections
- Reduce time of propagation spread
- Reduce light loss caused by surface imperfections
- Reduce time spread caused by Cherenkov light from δ-electrons
- Allows optimal implementation of **threshold-based particle identification**
- Single-type geometry to allow all possible tilting angles

Threshold-based particle identification

- Given α values favour the light propagating directly to the photon detector without reflection – “direct” photons
- Threshold of Cherenkov light emission is different for K and π having the same momentum
- Using **photo absorbers on sector side surfaces** – detecting only direct photons – allows to **improve time properties** of the signal and to use **threshold-based particle identification**
- This complementary information does not depend on time resolution of photon detectors



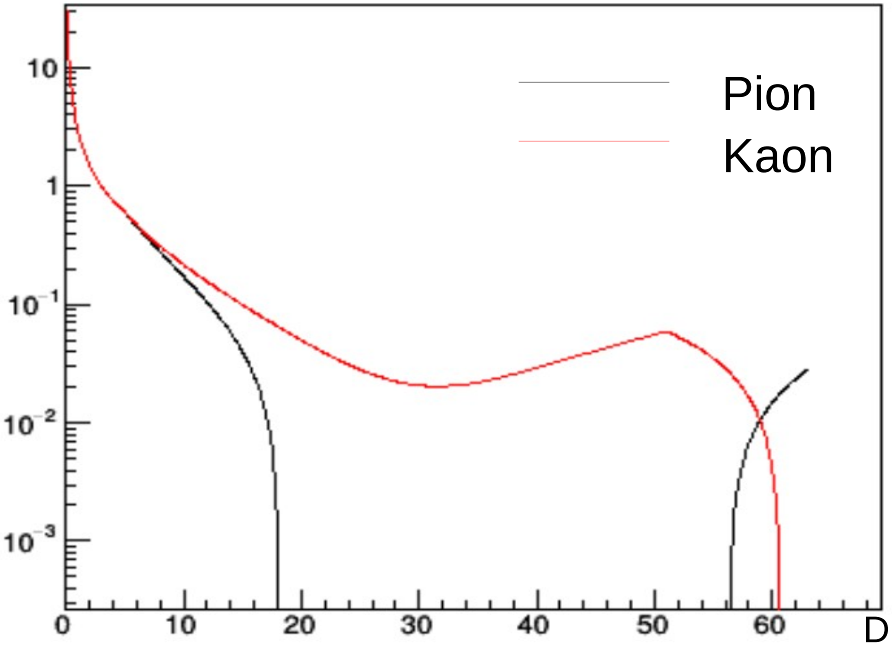
Angle α of propagation without reflections for K and π



Threshold-based particle identification

- Performance illustration for the sector with blackened sector side surfaces and
- thickness of 3 cm tilted at α = 23 degrees for K and π with p = 1 GeV/c

Geometrical factor for the amount of the detected photons vs distance from photodetector (cm). It doesn’t include light yield dependent on momentum and detection efficiency.

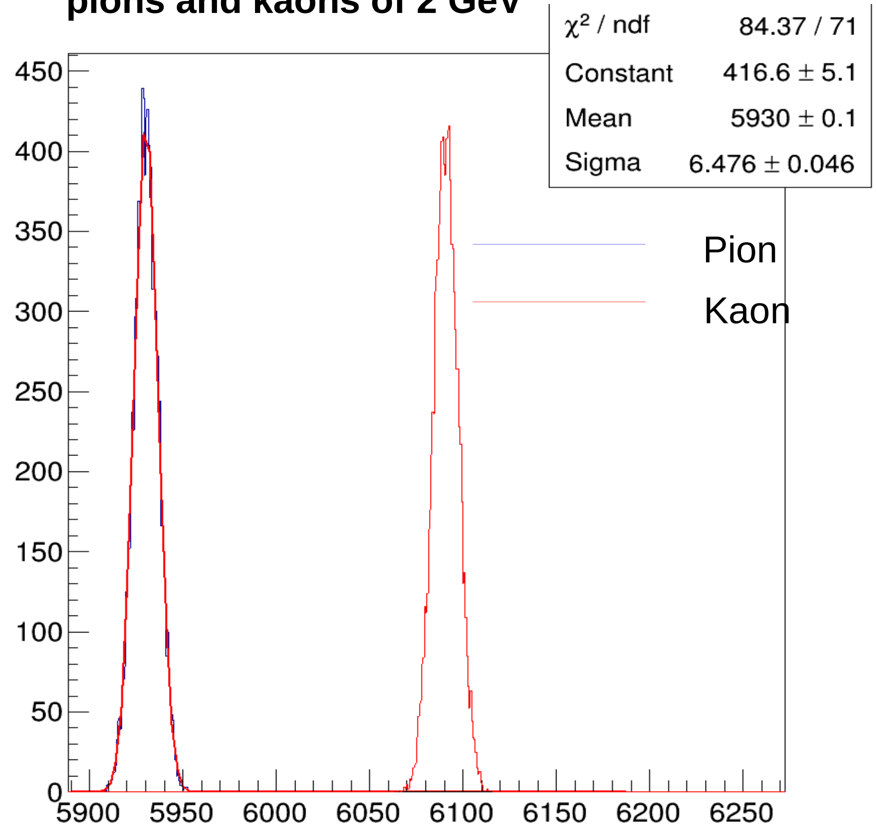


Distance from PD, cm

- **Threshold-based separation** between K and π possible in a region between **18 cm and 60 cm**
- For the **distances below 18 cm** spread in photon time of arrival is reduces and **time-of-flight measurement** performance is better

Identification of particles close to photon detectors

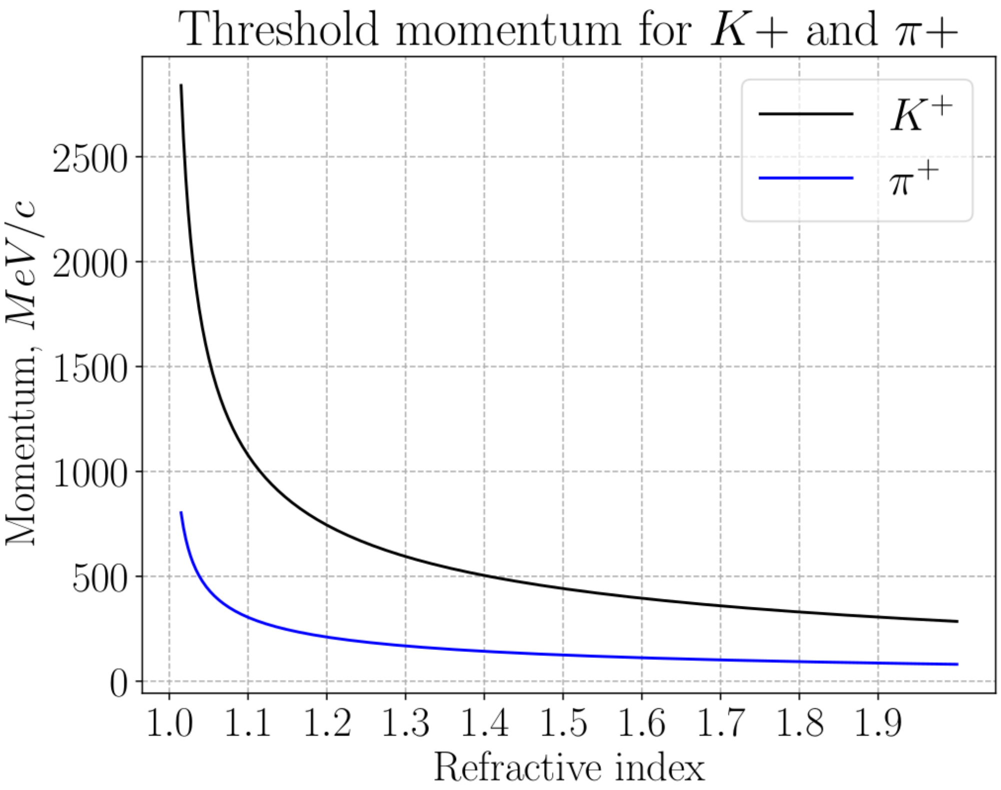
Time arrival of detected photons for pions and kaons of 2 GeV



- In the region **near photon detectors** a significant amount of light is detected for both K and π
- Difficult to use threshold-based particle identification
- In this case **TOF measurement** can be used for separation
- On average **~500 photons detected from every particle**, each with σ = 150 ps time resolution, **reliable K/π separation at p = 2 GeV/c**

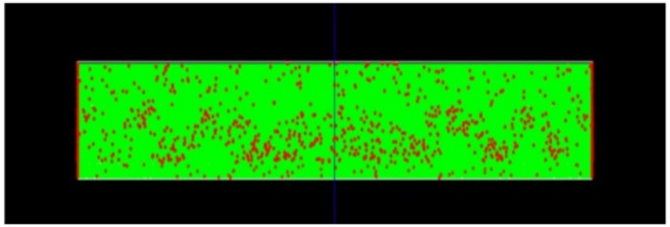
Refraction index variation

- Threshold-based particle identification can be further optimized by simultaneously using materials with adjusted refractive indices n

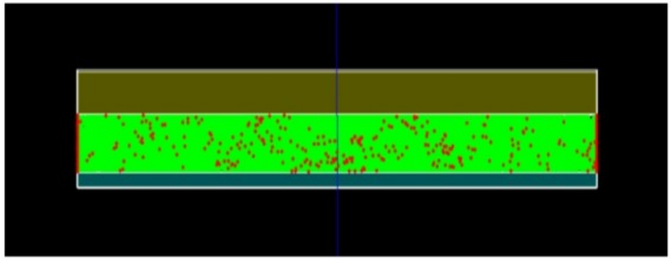


The “sandwich” of layers with n = 1.04, 1.1, 1.04

Particle is over thresholds in all the layers



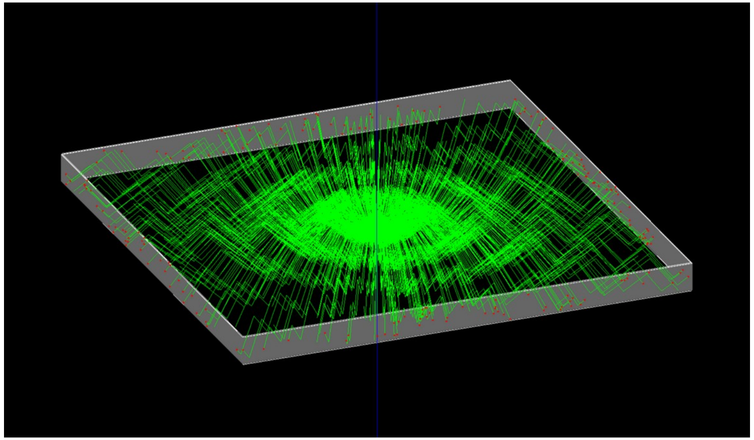
Particle is over thresholds in middle layer only



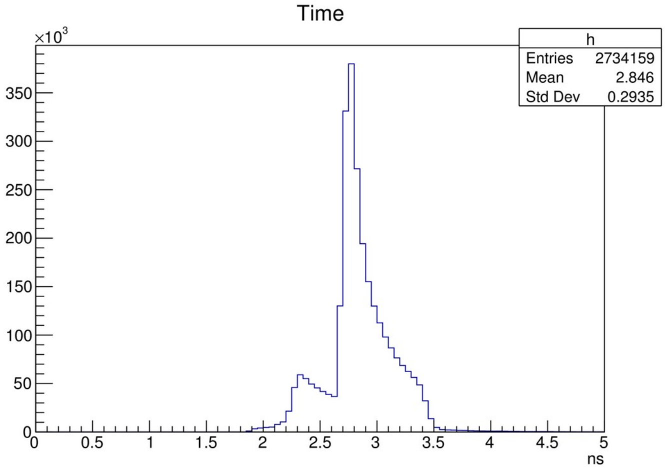
Results of Vlad Orlov

WLS tubes light collection

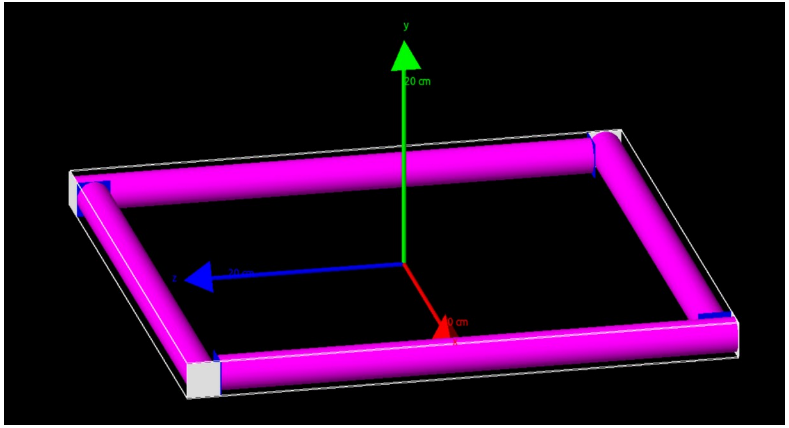
Direct idealistic light collection

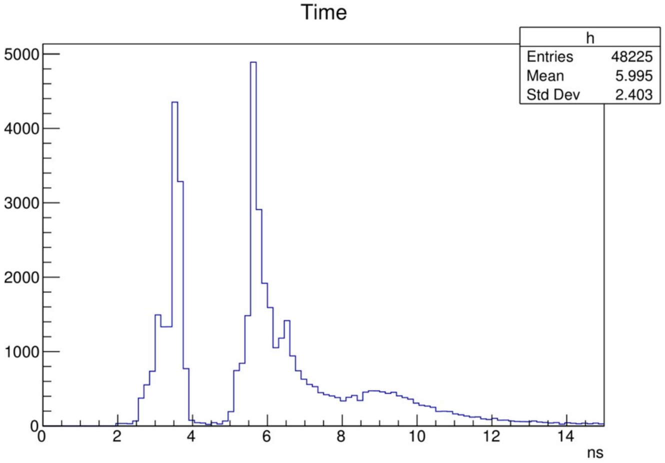


Photon arrival time



Light collection with idealistic photodetector on the end of the WLS tube





- To minimize the amount of photon detectors wavelength shifting tubes can be used

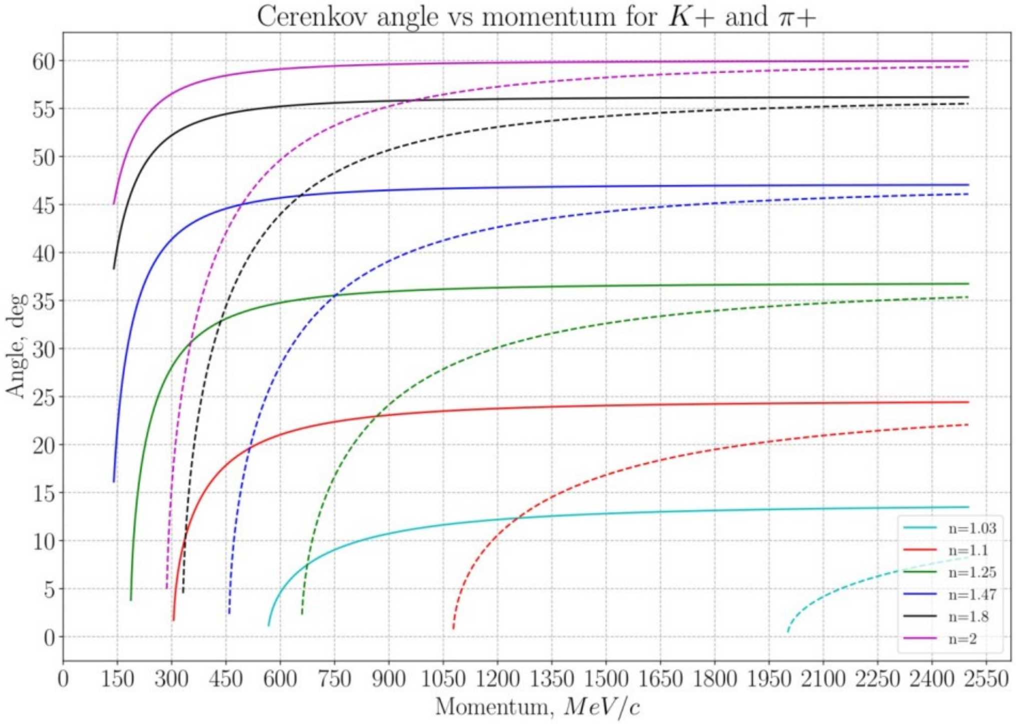
Results of Vlad Orlov

Summary

- **FTOF detector** initially proposed for the SuperB project is reconsidered for the forward particle identification at future high-luminosity tau-charm factory
- **New detector geometries** are considered to improve time properties of the signal
- **Combining TOF measurement and Cherenkov light threshold information** is promising to improve PID performance
- Using **Cherenkov light radiators with different refractive index n** complementary to quartz allows further optimization
- New SiPM photodetectors are considered as an alternative to MCPPMT

Backup

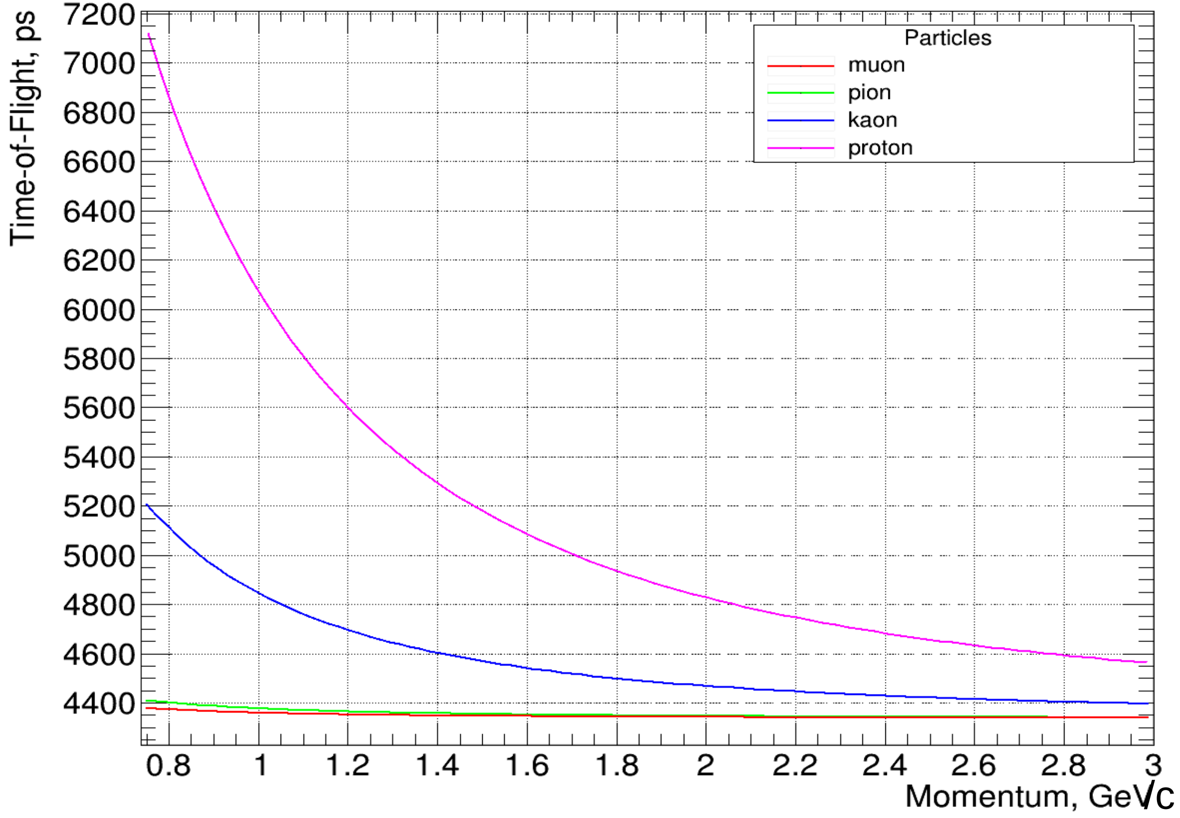
Threshold momentum



n	β	$\pi^+, MeV/c$	$K^+, MeV/c$	200-700 nm	400-700 nm
1.01	0.990	984.451	3482.129	32	9
1.02	0.980	694.387	2456.135	63	19
1.03	0.971	565.566	2000.480	94	28
1.04	0.962	488.593	1728.215	123	37
1.05	0.952	435.943	1541.988	152	45
1.06	0.943	396.993	1404.215	180	54
1.07	0.935	366.655	1296.907	207	62
1.08	0.926	342.149	1210.225	233	70
1.09	0.917	321.809	1138.278	259	77
1.10	0.909	304.567	1077.292	284	85
1.20	0.833	210.410	744.246	500	150
1.30	0.769	168.023	594.317	668	200
1.40	0.714	142.448	503.857	802	240
1.50	0.667	124.835	441.558	909	272
1.60	0.625	111.745	395.258	998	299
1.70	0.588	101.522	359.097	1071	321
1.80	0.556	93.254	329.852	1132	339
1.90	0.526	86.392	305.578	1184	355
2.00	0.500	80.581	285.025	1228	368

Results of Vlad Orlov

Time-Of-Flight Technique



Particles’ time-of-flight as function of momentum for different particles (L = 130 cm)

- Time of flight for distance L, momentum p and mass m:

$$t = \frac{L}{c}\sqrt{1 + \left(\frac{mc}{p}\right)^2}$$

- The difference in time of flight (K /π):

$$\Delta t = \frac{Lc}{2p^2}({m_K}^2 - {m_\pi}^2)$$

Likelihood based particle selector

In Likelihood based selector we construct out measured qualities variable which can be likelihood ratio defined by this equation:

$$R_{LH} = \frac{LH_1}{LH_1 + LH_2} = \frac{1}{1 + LH_2 / LH_1}$$

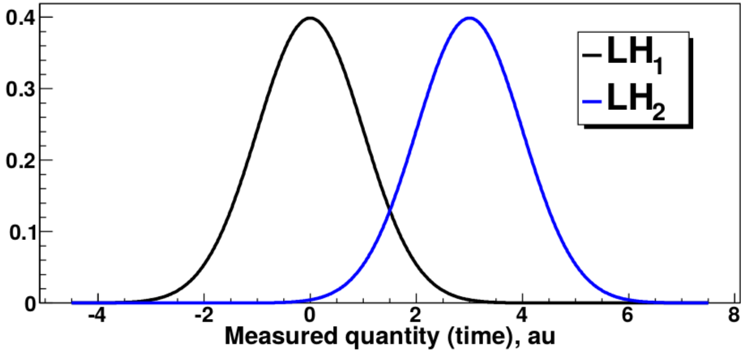
Where LH_1 and LH_2 - likelihoods of the hypothesis (1) and (2) respectively.

In our case is particle K-meson or π-meson.

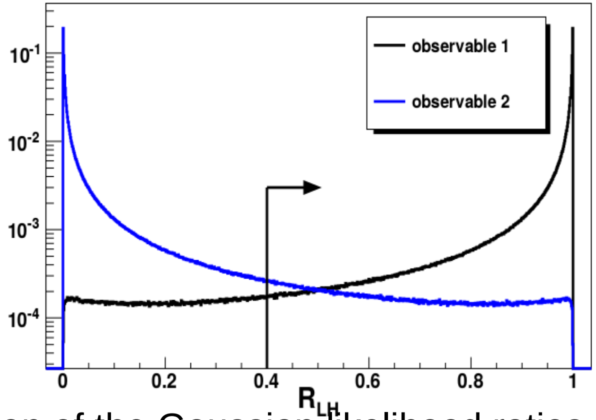
Considering probability density function (PDF) of the measurements are Gaussian, the likelihood can be written like this both for **time-of-flight** and **number of photoelectrons** (for threshold counting):

$$LH = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(\frac{-\left(t - t_{\exp}(P, L, m, \{x, y, \phi, \theta\}_i)\right)^2}{2\sigma^2} \right)$$

$$LH = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(\frac{-\left(n - n_{\exp}(P, L, m, \{x, y, \phi, \theta\}_i)\right)^2}{2\sigma^2} \right)$$



Likelihood distribution for two different observable separated apart by 3 σ. For convenience we centered at 0 and 3 the LH_1 and LH_2 respectively, σ = 1.



Distribution of the Gaussian likelihood ratios R_{LH} for different observable.