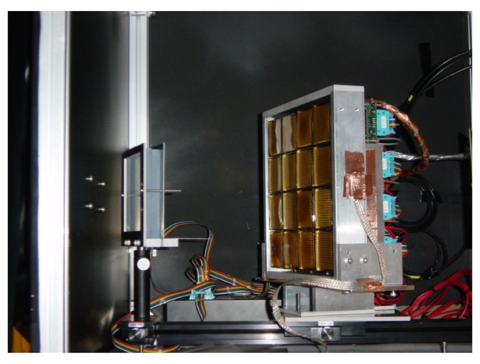
Design optimization of the proximity focusing RICH with multiple layer aerogel radiator using a maximum-likelihood analysis of Cherenkov rings

Rok Pestotnik[a], Toru Iijima[b], Peter Križan[a,c], Samo Korpar[a,d]

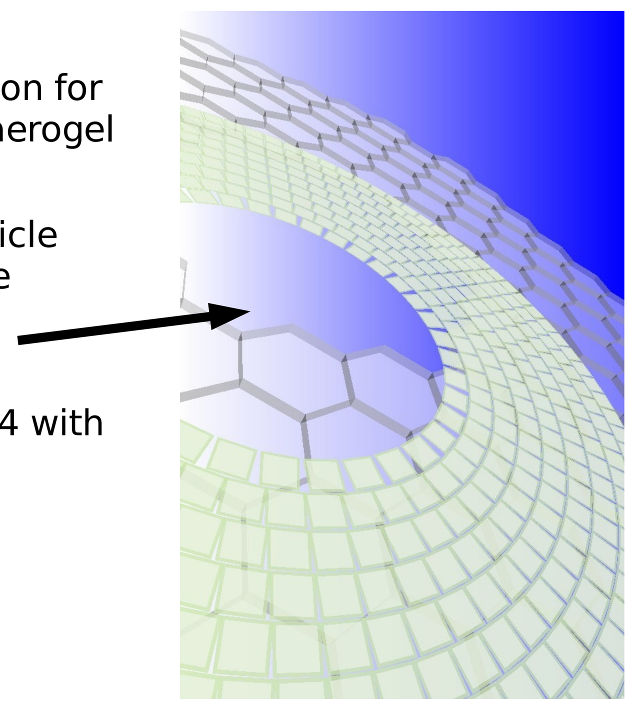
[a]Jožef Stefan Institute, Ljubljana, Slovenia
[b]Nagoya University, Nagoya, Japan
[c] Faculty of Mathematics and Physics, University of Ljubljana, Slovenia
[d]Faculty of Chemistry and Chemical Engineering, University of Maribor, Slovenia



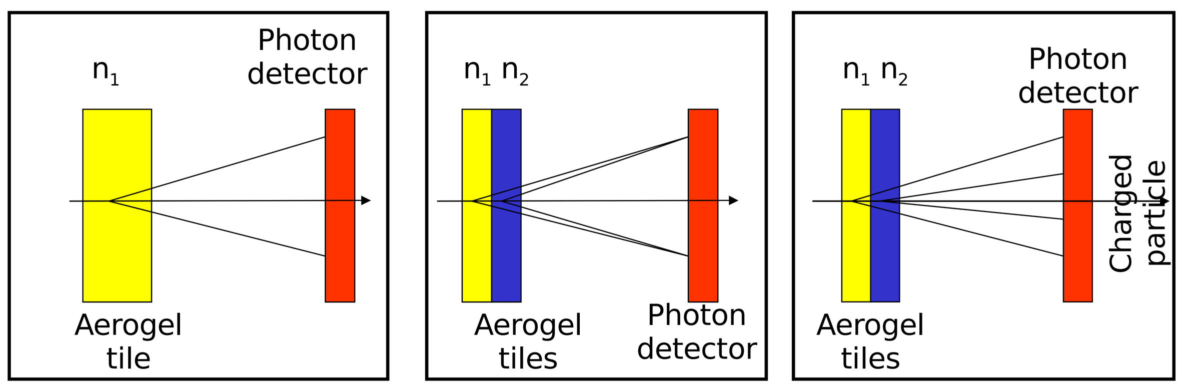
The use of a sequence of different aerogel radiators in a proximity focusing Cherenkov ring imaging detector has been shown to improve the resolution of the Cherenkov angle. In order to obtain further information on the capabilities of such a detector, a maximum-likelihood analysis has been performed on simulated data, with the simulation being appropriate for the upgraded Belle detector. The dependence of the efficiencies for identification of pions and kaons on momentum, incident angle and background level are presented for different combinations of aerogel radiators.

Motivation

- Study of kaon pion separation for different configurations of aerogel proximity focusing RICH
- Optimize design of the particle identification device for the forseen upgraded Belle spectrometer.
- Monte Carlo study in Geant4 with a rectangular detector segmentation

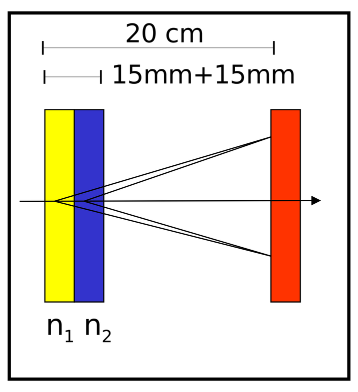


Detector configurations



Single radiator **Focusing type** **Defocusing type**

Properties of the simulated detector



Aerogel radiator
- Refractive index:
  - focusing n_1=1.043 n_2=1.05
  - defocusing n_1=1.05 n_2=1.03
  - reference single n_1=1.05
- Rayleigh trans. length @400 nm : 40 mm

Photon detector:
- Pad size : 6 mm
- Bialkali photocathode, detection eff. decreased by 50% (inactive region, collection eff.)
- Binary detection
- σ_Θ and N_{det} as in the test beam results
- $\sigma_\Theta = \sigma_{emp} \oplus \sigma_{pad} \oplus \sigma_{rest}$ σ_{rest} = 8 mrad
- Additional background hits generated uniformly over the photon detector at the level measured in the test beam:
  - 125 ph./m²/event

Perpendicular charged particle **incidence**

Simulation and reconstruction

Hit Simulation using Geant4

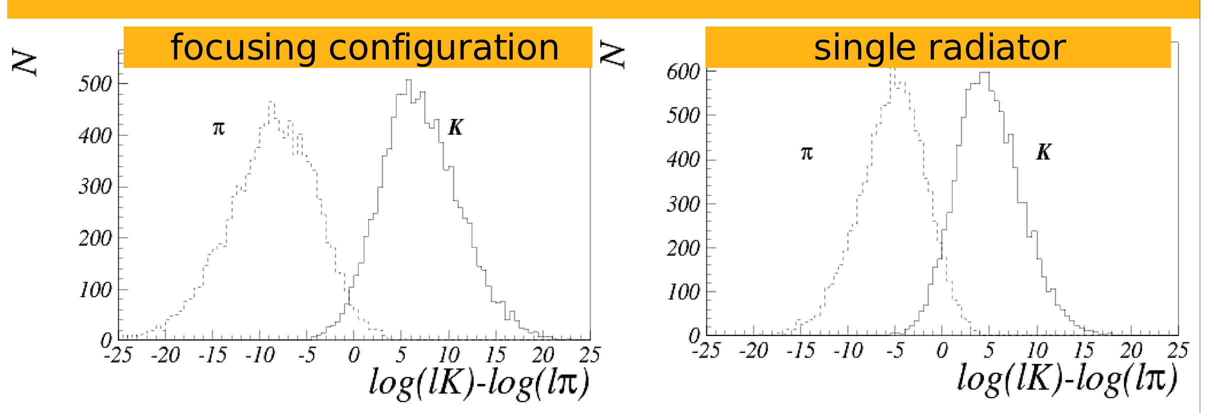
- Particle tracking through proximity focusing aerogel RICH
- Cherenkov photon generation in the aerogel and the quartz window of the photon detector
- Rayleigh scattering of the photons in the aerogel
- Photon tracking through the quartz window of the photon detector
- Photon detection in the active area

Reconstruction

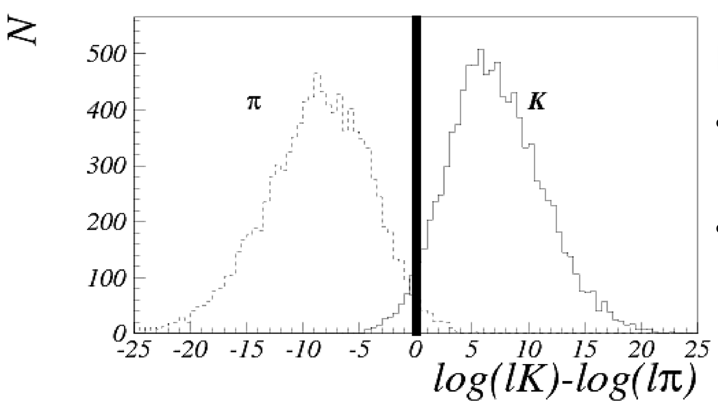
Calculation of:
- track parameters
- Cherenkov angle for a pair track - detector position
- the expected hit distribution for different particle hypotheses
- the likelihood function

The likelihood difference L_K-L_π

the difference of log likelihood for K and π hypothesis at 4GeV/c

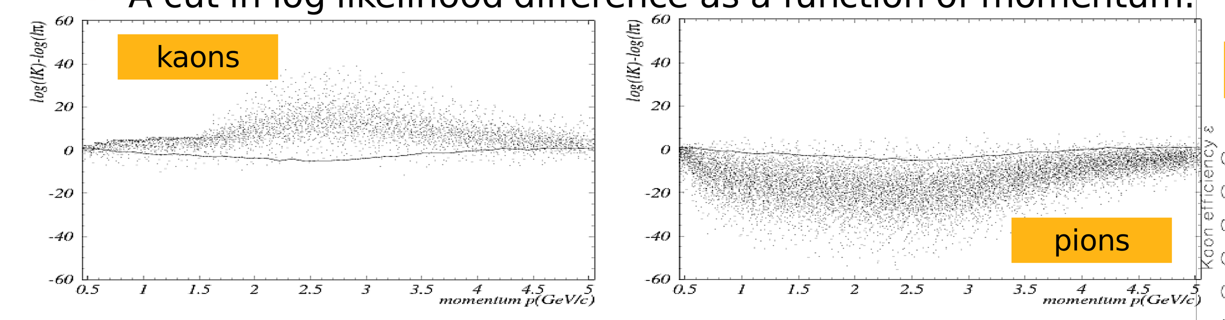


Efficiency and fake probabilities

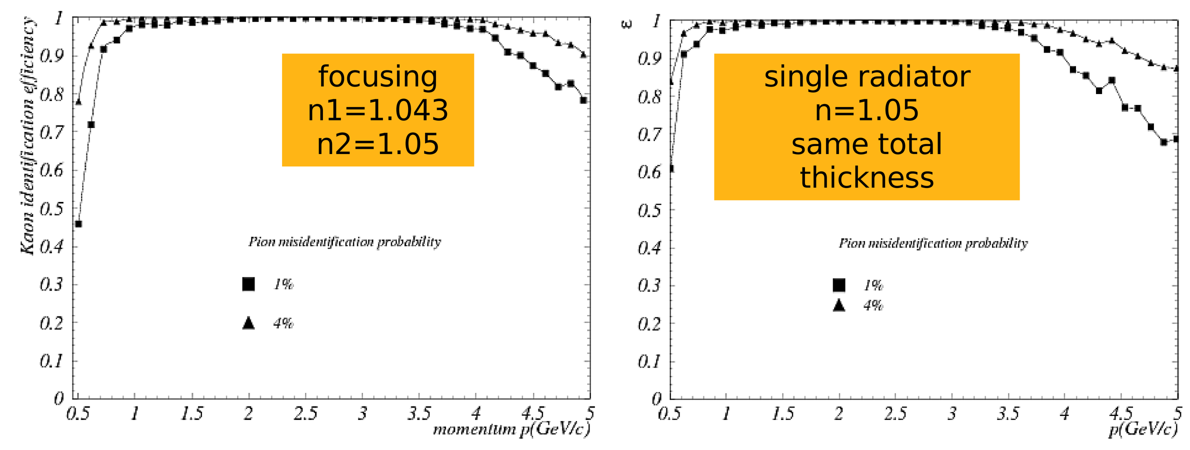


For each momentum bin
- fix fake rate probability π→K
- calculate efficiency for K

- A cut in log likelihood difference as a function of momentum.

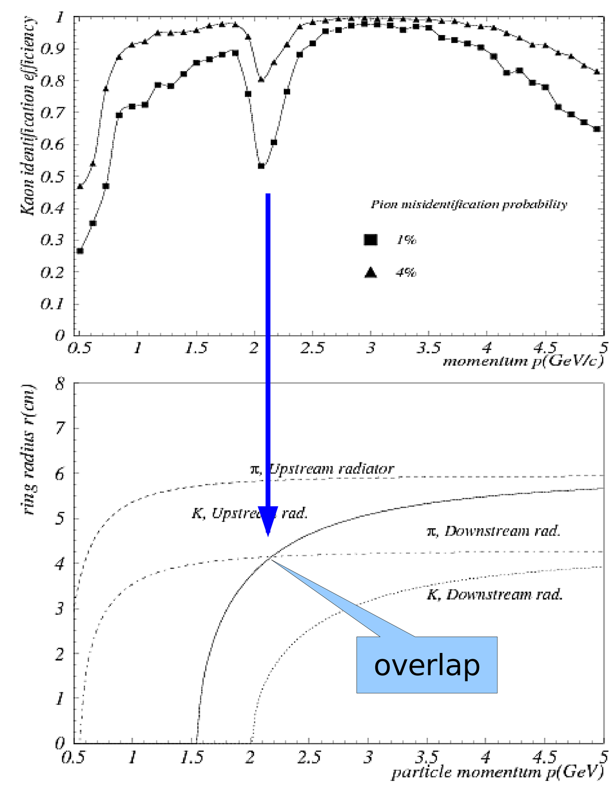


K identification efficiency focusing configuration



kaon identification efficiency as a function of momentum for two pion misidentification probabilities: 1% and 4%

K identification efficiency defocusing configuration

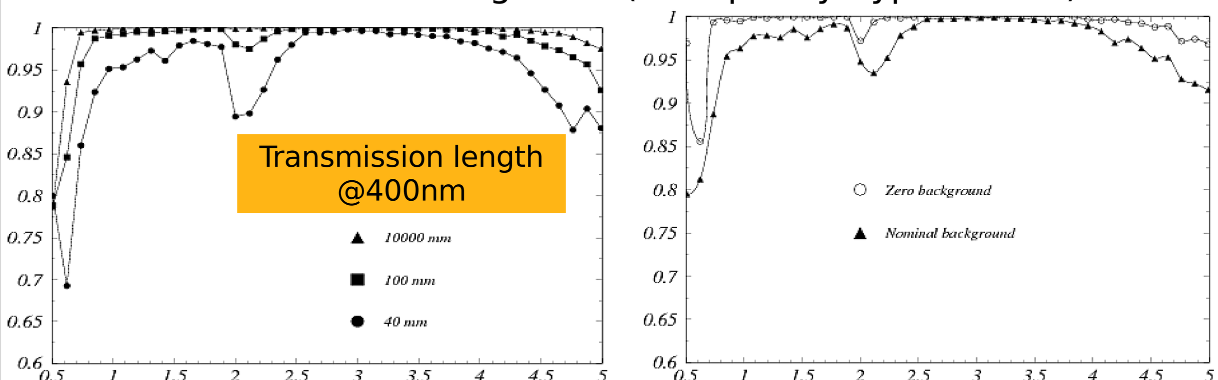


- The kaon identification efficiency as a function of momentum for two pion misidentification probabilities:

  1% and 4%

- Dip in the efficiency at around 2GeV/c where Cherenkov rings from different radiator layers overlap

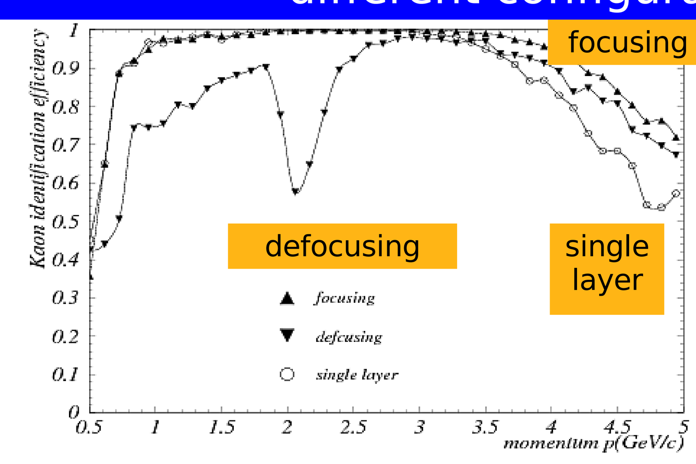
The dip dissapears in the limits of either perfect aerogel transmission or zero background (both purely hypothetical)



Improvement with a perfect aerogel transmission

Performance depends on the background level

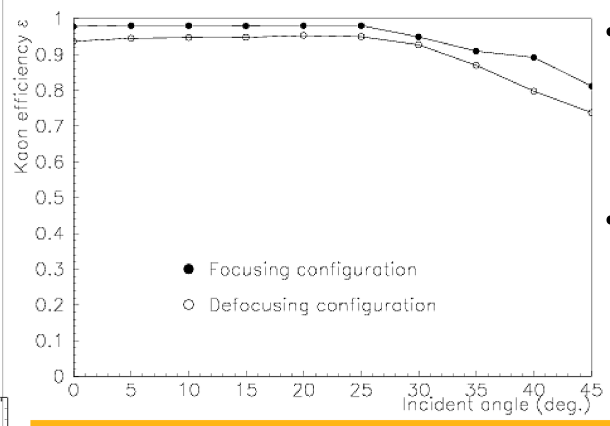
Kaon identification efficiency: Comparison of different configurations



- Improvement for higher momenta by dual radiators
- defocusing configuration has a lower efficiency at low momenta

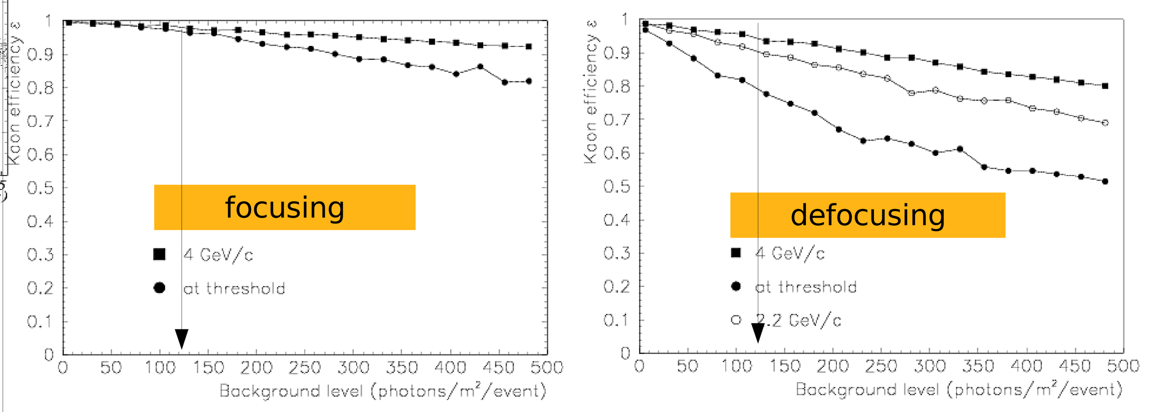
Variation of parameters

Incident angle



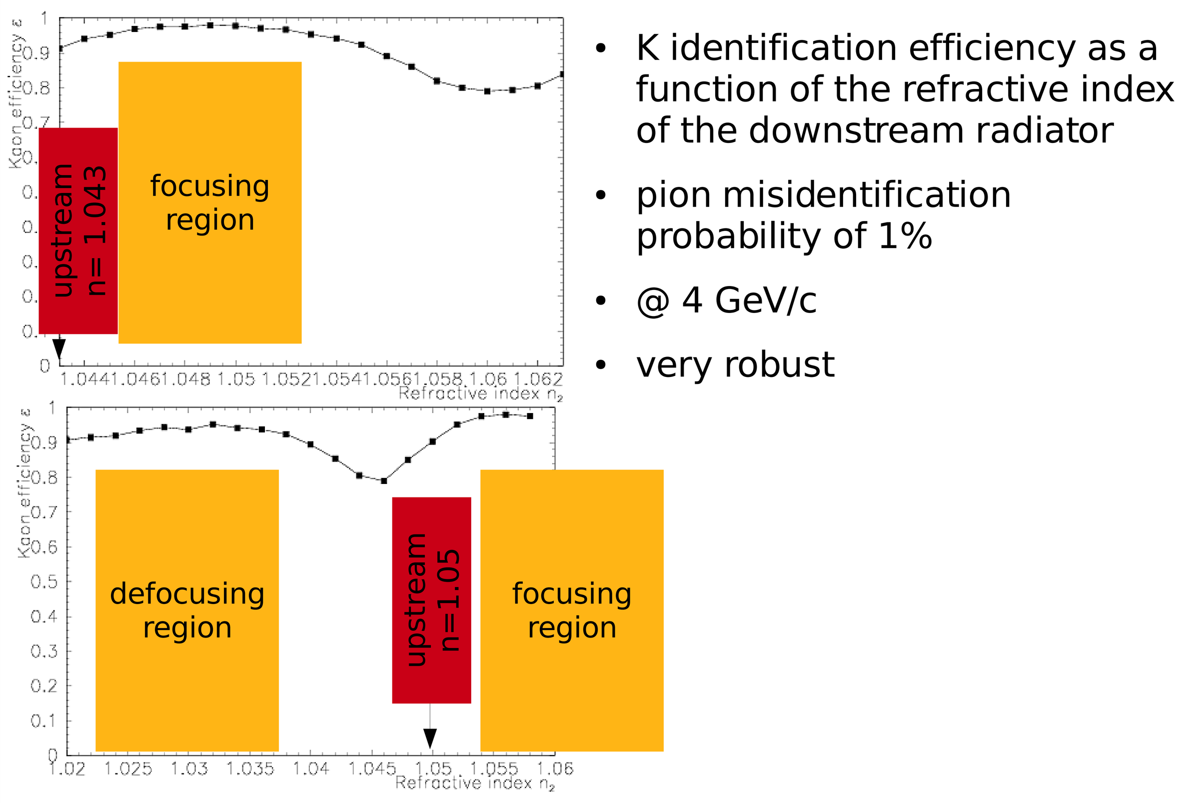
- K identification efficiency as a function of incident angle for focusing and defocusing configuration @ 4GeV/c
- pion misidentification probability of 1%

Background Level



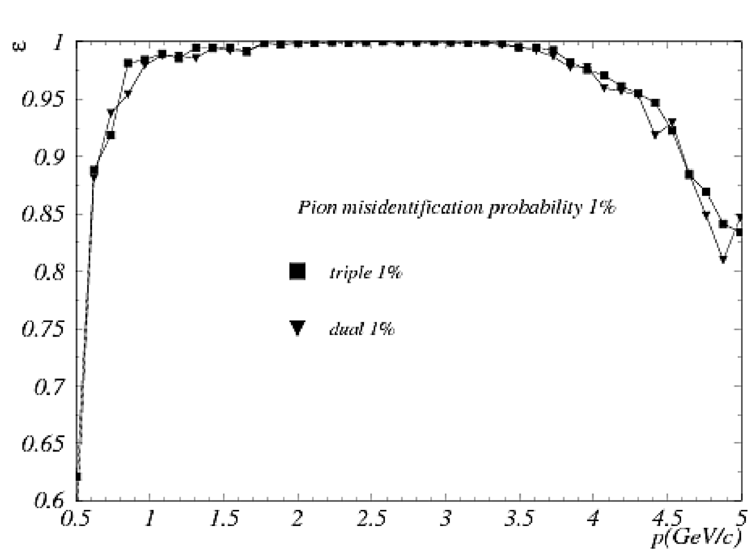
- K identification efficiency @ 4GeV/c as a function of the background level for 1% pion misidentification probability

Refractive index



- K identification efficiency as a function of the refractive index of the downstream radiator
- pion misidentification probability of 1%
- @ 4 GeV/c
- very robust

Triple vs. dual radiator



Focusing configuration

n_1=1.043 d_1=10mm

n_2=1.0475 d_2=10mm

n_3=1.053 d_3=10mm

No considerable improvement compared to dual focusing combination

n_1=1.043 d_1=15mm

n_2=1.050 d_2=15mm

Conclusions

- Study of kaon-pion separation for different detector configurations was carried out.
- The data were simulated using GEANT4 and reconstructed using maximum likelihood method for different detector configurations:
  - single, dual layer (focusing, defocusing), triple layer (focusing)
- Dual layer configuration improves the identification in the higher momentum region (above 3GeV/c)
- Focusing configuration seems to perform better than defocusing, which has a dip in the efficiency, where the rings for pion and kaon hypothesis from different radiators overlap
- We have studied the influence on performance as a function of several parameters, little sensitivity was found
- Triple radiator configuration does not improve the performance significantly

Likelihood function

$$L = \prod_{\text{all pixels}} p_i = \prod_{\text{not hit } i} e^{-n_i} \cdot \prod_{\text{hit } i} (1-e^{-n_i})$$

$$\ln L = -\sum_{\text{not hit } i} n_i + \sum_{\text{hit } i} \ln(1-e^{-n_i})$$

$$\ln L = -\sum_{\text{not hit } i} n_i - \sum_{\text{hit } i} n_i + \sum_{\text{hit } i} n_i + \sum_{\text{hit } i} \ln(1-e^{-n_i})$$

$$\ln L = -N + \sum_{\text{hit } i} n_i + \sum_{\text{hit } i} \ln(1-e^{-n_i})$$

N ... the number of expected hits on the detector

- The summation runs only over the hit pixels
- We assumed the tracks are isolated, so that the rings do not overlap
- Likelihood function should be evaluated for each hypothesis

* R.Forty, NIM A433 (1999) p.257

Hit probability for a hypothesis

Number of photons hitting a pixel obeys Poisson distribution $P_i = \frac{e^{-n_i} n_i^{m_i}}{m_i!}$

n_i expected number of photons in the pad i

m_i measured number of photons in the pad i

average $n_i = n_s^i + n_b^i$ $n_s^i = \sum_r n_{s,r}^i$ contribution from different radiators

$$n_{s,r}^i = \varepsilon_i n_{t,r} \int_{\Omega_i} S_r(\theta_r, \phi_r) d\theta_r d\phi_r, \qquad S_r(\theta_r, \phi_r) = \frac{1}{2\pi} \frac{1}{\sqrt{2\pi}\sigma_{\theta_r}} e^{-\frac{(\theta_r - \theta_r^h)^2}{2\sigma_{\theta_r}^2}}$$

ε_i ... detection efficiency

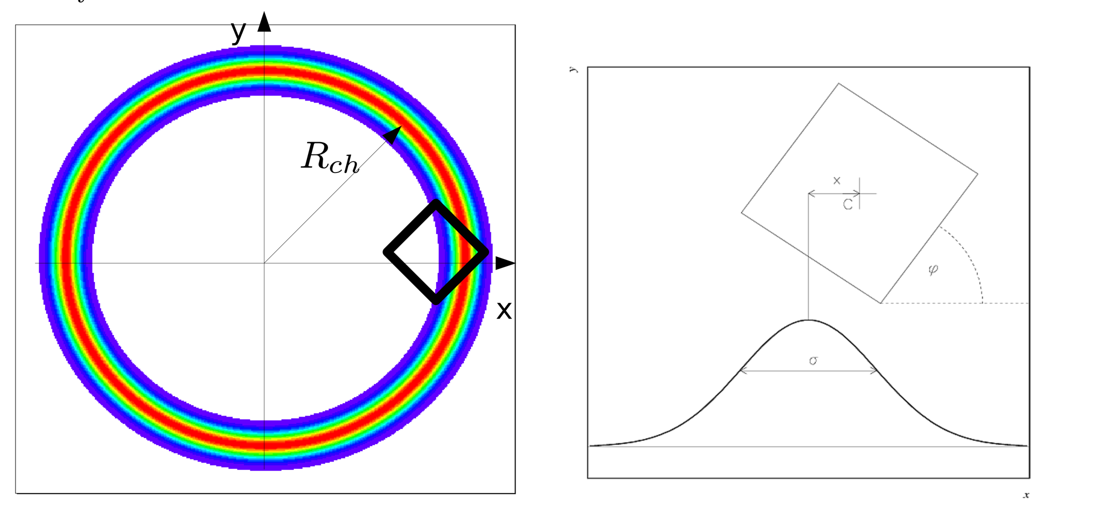
$n_{t,r}$ ... the total number of photons emitted in the radiator

$$p_i = \begin{cases} e^{-n_i} & \text{for } m_i = 0, \\ 1 - e^{-n_i} & \text{for } m_i > 0. \end{cases}$$

number of hits in the binary detection device

Evaluation of the pad contribution

$$\int_{\Omega_i} S_r(\theta_r, \phi_r) d\theta_r\, d\phi_r = \int_S S_r(x,y) dx\, dy \approx \int_S S_r(r)\, dr$$



For pad size << R_{ch} the integral can be evaluated analytically