RICH with multiple aerogel layers of different refractive index

Samo Korpar
University of Maribor and Jožef Stefan Institute, Ljubljana

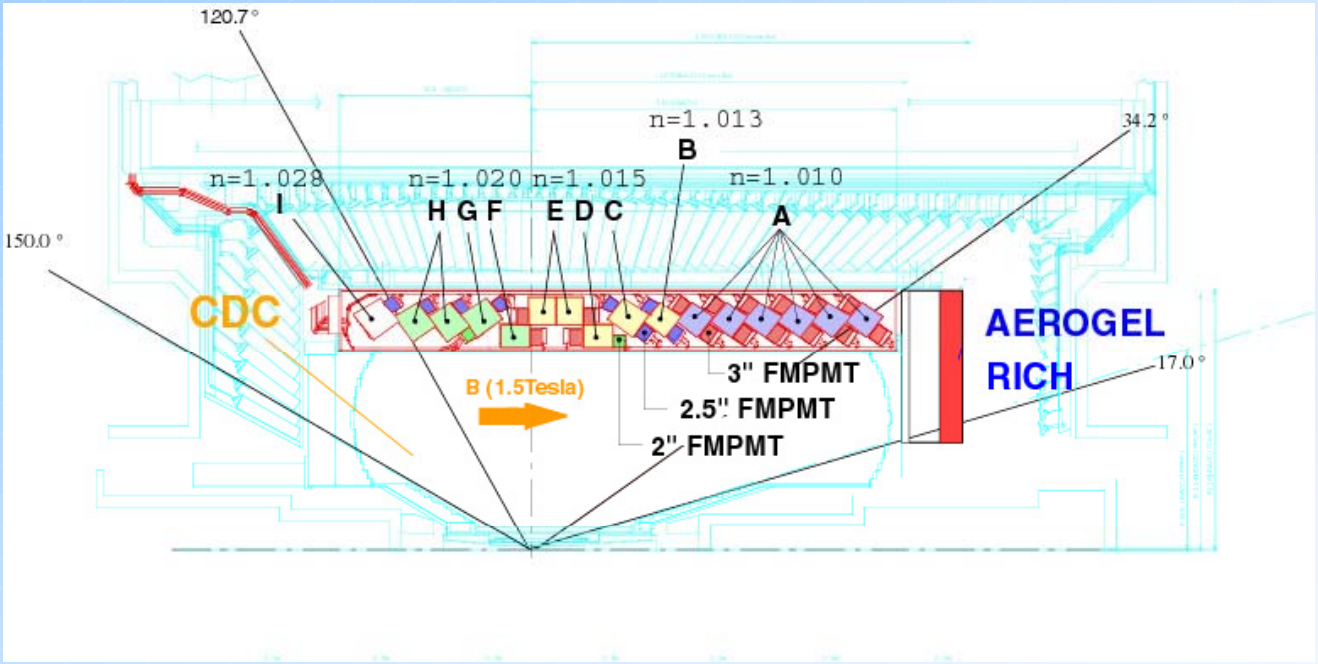
November 30 - December 5, 2004
RICH2004

I. Adachi, S. Fratina, T. Fukushima, A. Gorišek, T. Iijima, H. Kawai, M. Konishi, Y. Kozakai, P. Križan, T. Matsumoto, S. Nishida, S. Ogawa, S. Ohtake, R. Pestotnik, S. Saitoh, T. Seki, A. Stanovnik, T. Sumiyoshi, Y. Uchida, Y. Unno, S. Yamamoto

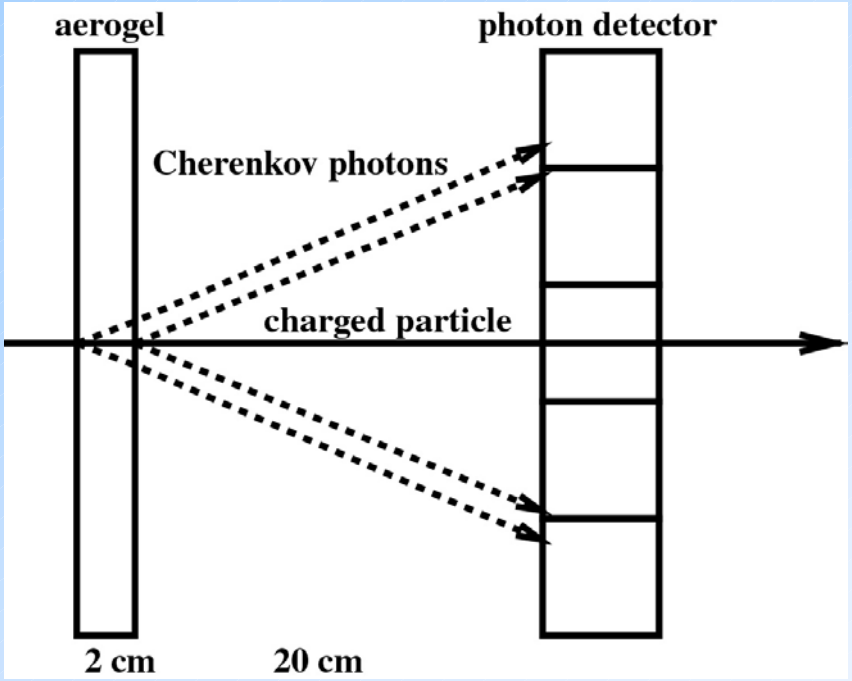
- Belle PID upgrade - requirements
- beam test setup
- limitation of proximity focusing aerogel RICH
- dual refractive index configurations - concept
- tests of different configurations
- summary

Belle PID UPGRADE

requirement: ~ 4σ K/π separation @ 1-4 GeV/c



- proximity focusing aerogel RICH in forward direction



- n ~ 1.05
- $\vartheta_C(\pi)$ = 310 mrad @ 4 GeV/c
- $\vartheta_C(\pi) - \vartheta_C(K)$ = 23 mrad @ 4 GeV/c
- pion threshold 0.44 GeV/c
- distance from aerogel entrance window to photon detector 200 mm
- track incidence angles ~ 17° - 34°

BEAM TESTS

At KEK-PS

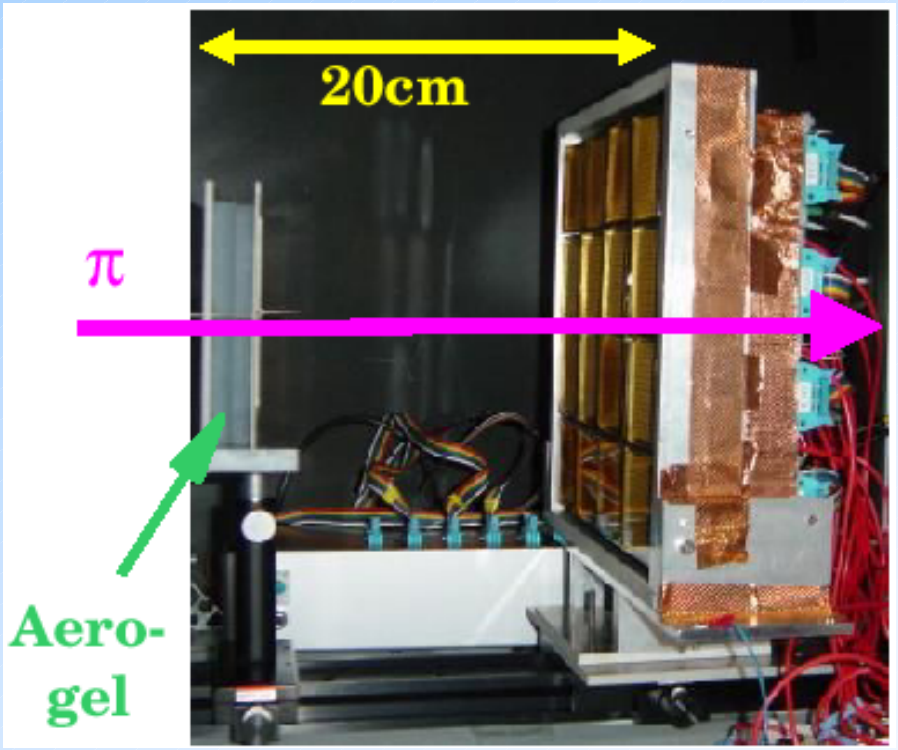
- march 2004 π2 (0.5-4 GeV/c)
- june 2004 T1 (0.5-2 GeV/c)

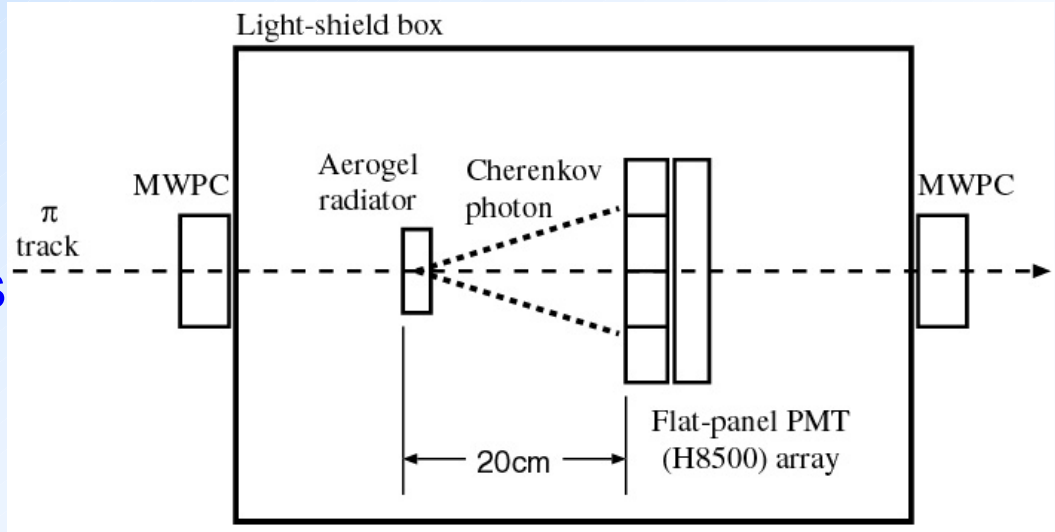
Photon detector

- 4x4 array Hamamatsu H8500
- 1024 channels
- 52.5 mm pitch (84% eff. area)

- two MWPCs for tracking

- different aerogel configurations tested





SINGLE PHOTON CHERENKOV ANGLE RESOLUTION

Two main contributions to single photon resolution (n=1.05, d=1cm)

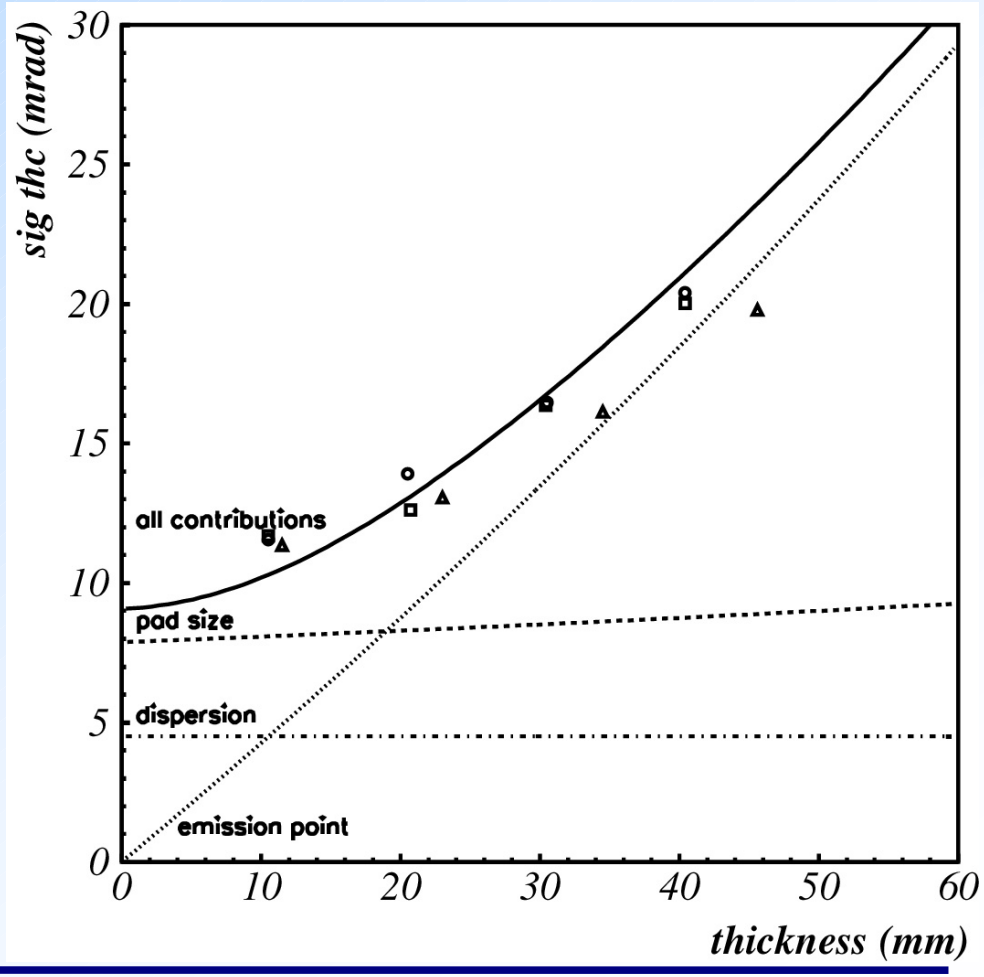
$$\sigma^2_{\vartheta_c} \approx \sigma^2_a + (Ad)^2$$

- pad size a (~6mm)

$$\sigma_a = \frac{\cos^2\vartheta_c\, a}{\sqrt{12}\left(l - \frac{1}{2}d\right)} \approx 8mrad$$

- aerogel thickness d

$$\sigma_d = \frac{\cos\vartheta_c \sin\vartheta_c\, d}{\sqrt{12}\left(l - \frac{1}{2}d\right)} \approx \frac{4mrad}{cm}\, d$$



OPTIMAL AEROGEL THICKNESS

Single track Cherenkov angle resolution

$$\sigma_{track} = \frac{\sigma_{\vartheta_c}}{\sqrt{N}}$$

- with no attenuation (N=Bd)

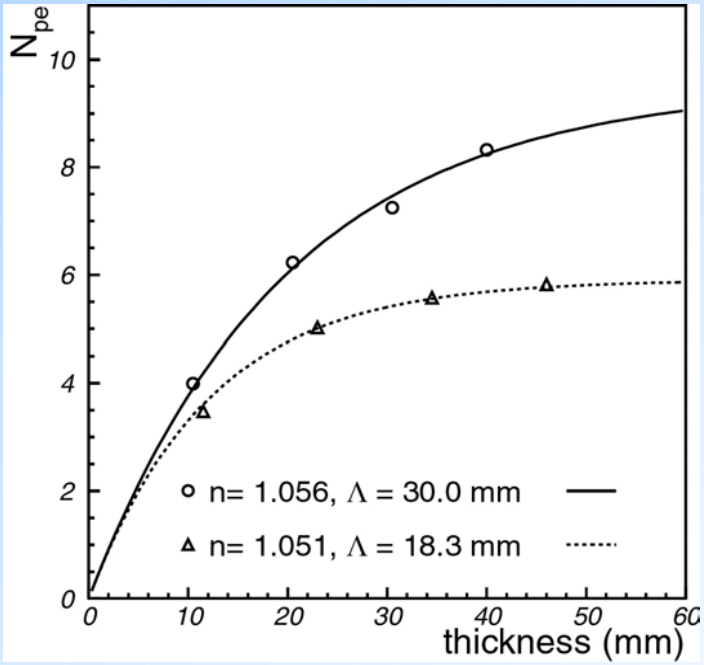
$$\sigma^2_{track} \approx \frac{\sigma_a^2 + (Ad)^2}{Bd}$$

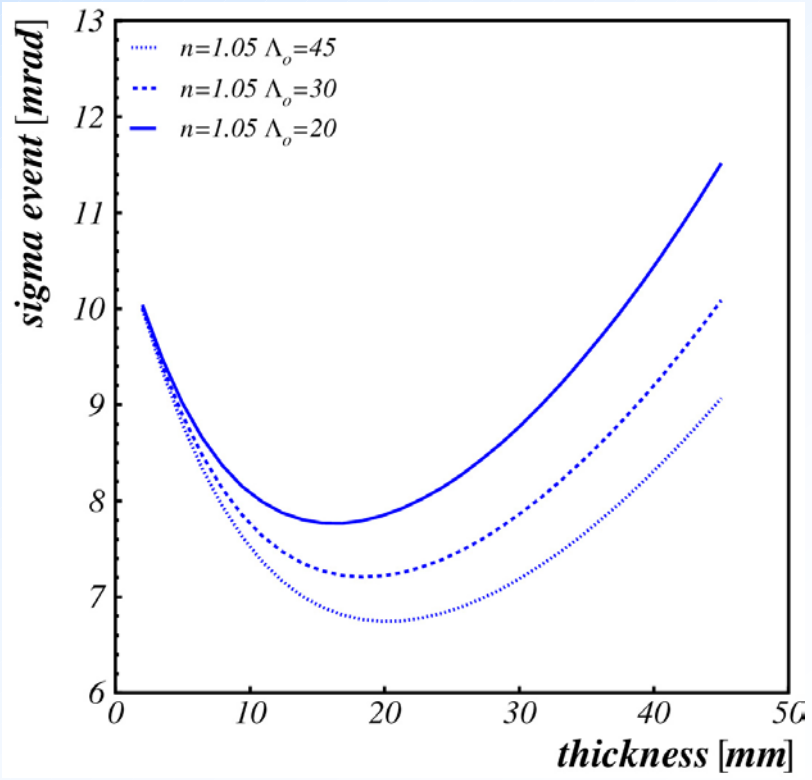
- minimum at

$$d_{min} = \frac{\sigma_a}{A} \approx 2cm$$

- minimum sigma (data)

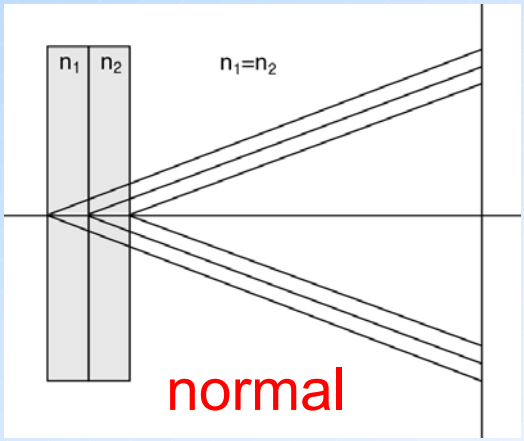
$$\sigma_{track} \approx \frac{14\,mrad}{\sqrt{6}} = 5.7mrad$$





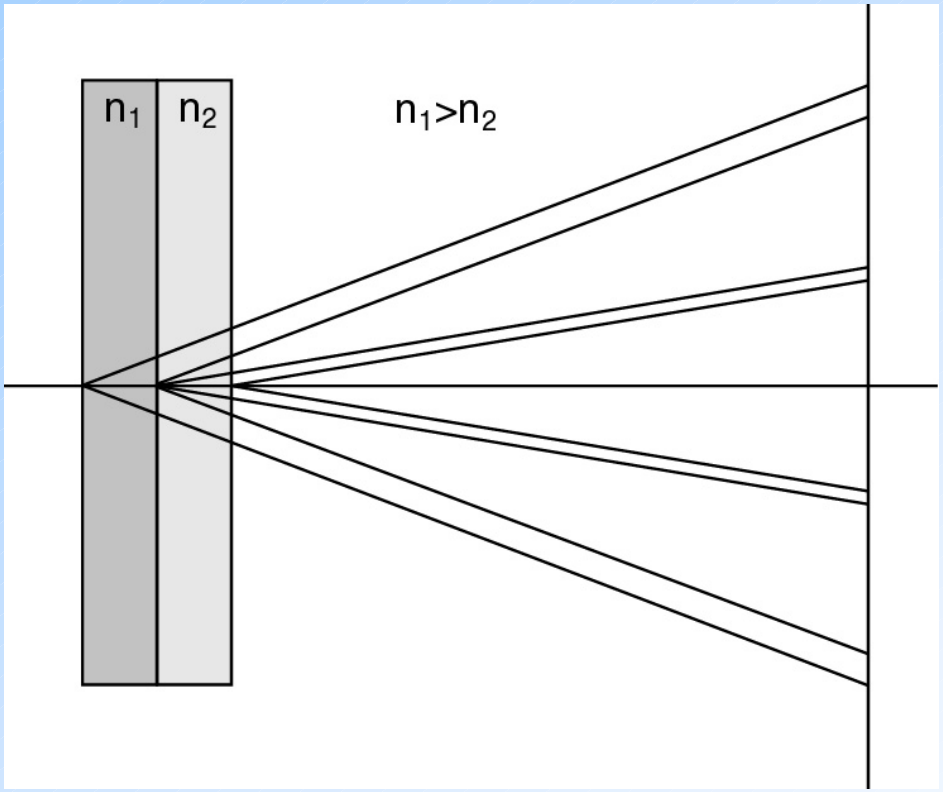
DUAL REFRACTIVE INDEX CONFIGURATIONS

How to increase number of photons without degrading the resolution?



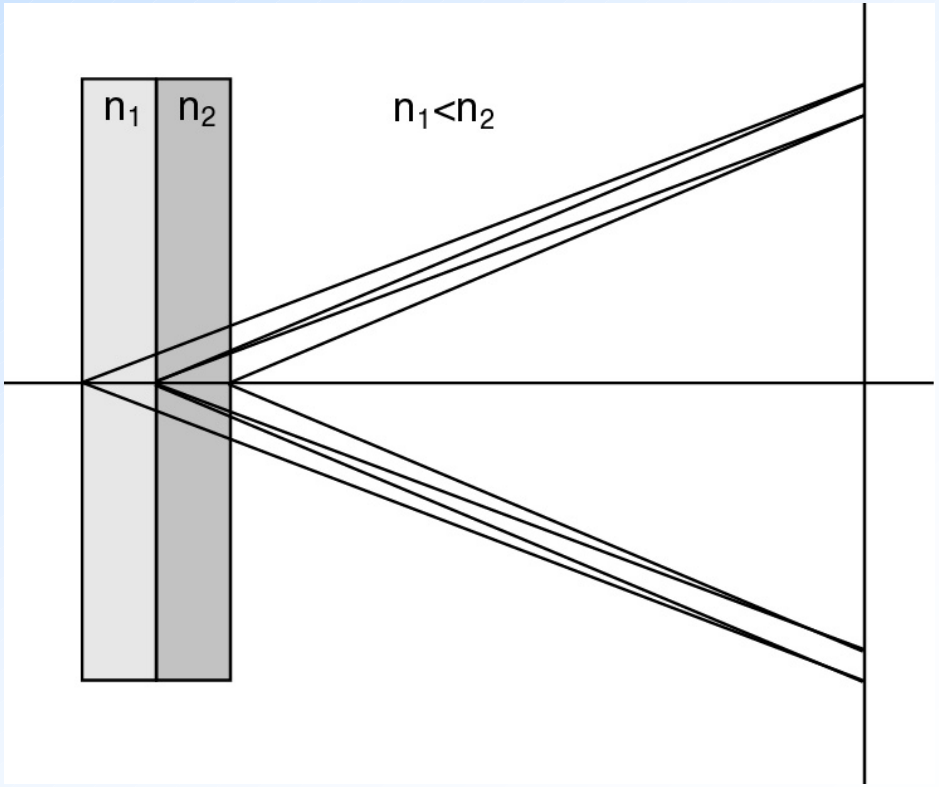
- measure two separate rings

"defocusing" configuration



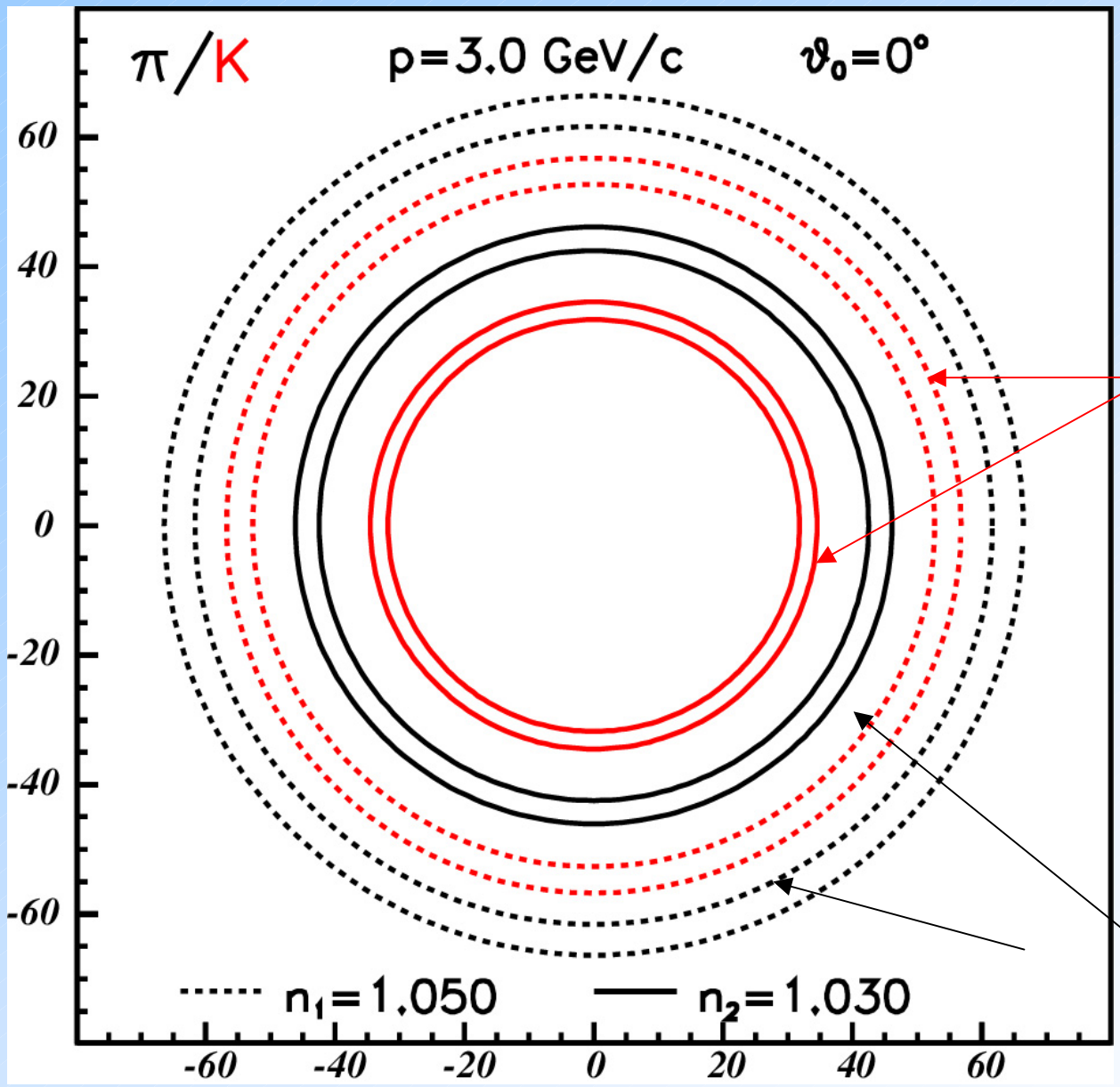
- measure overlapped rings

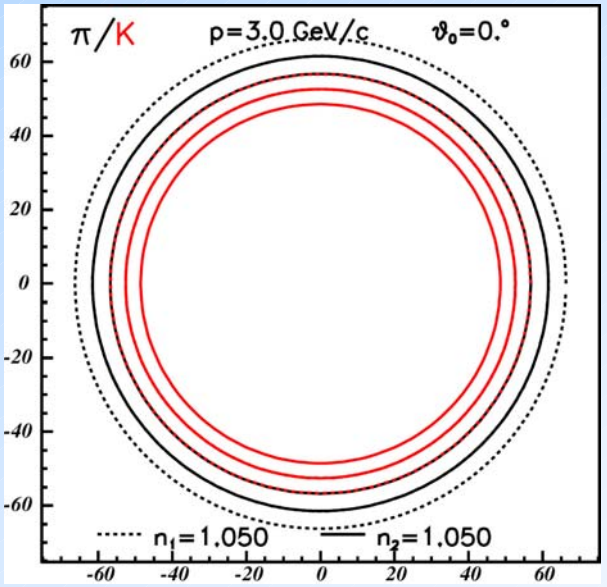
"focusing" configuration



Samo Korpar
University of Maribor and Jožef Stefan Institute

DEFOCUSING CONFIGURATION @ 3 GeV/c





normal

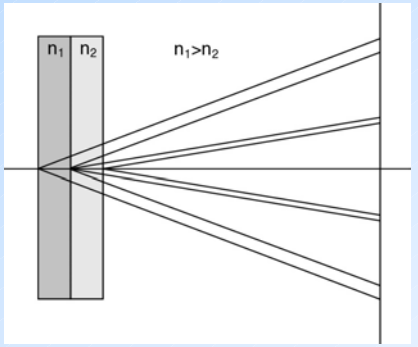
kaon

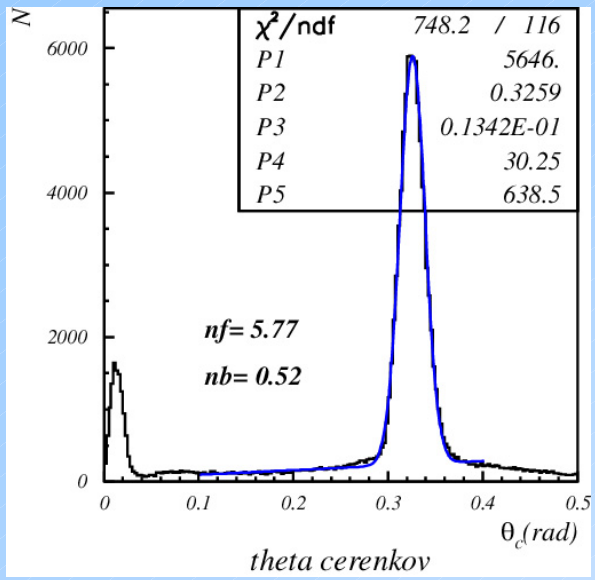
pion

- layer thickness 15mm
- n_1- n_2= 0.02

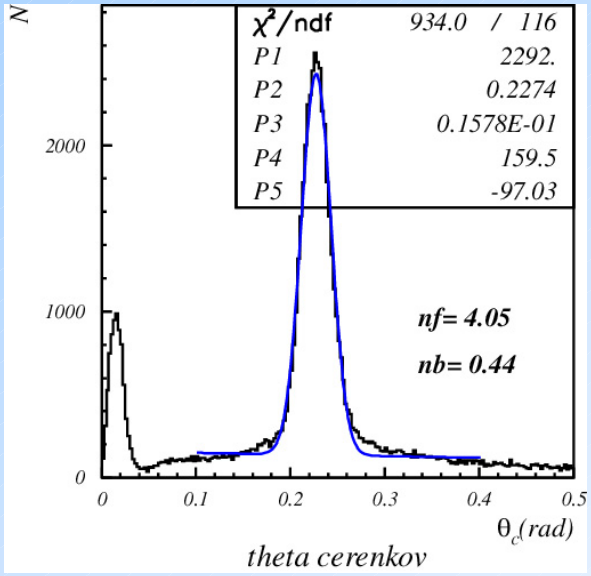
Samo Korpar
University of Maribor and Jožef Stefan Institute

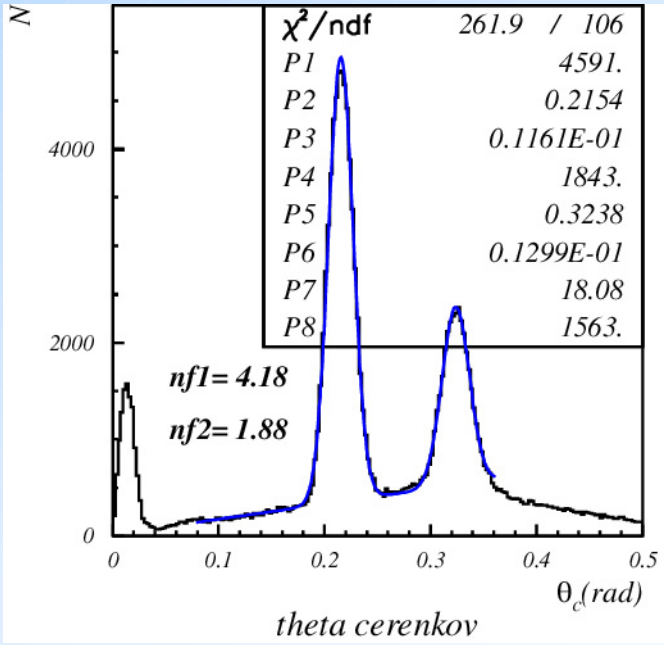
DEFOCUSING CONFIGURATION @ 3 GeV/c, data

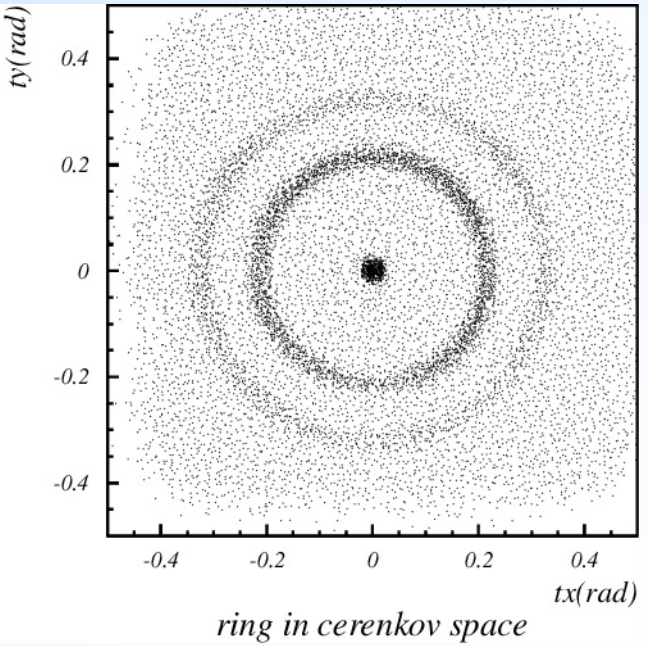




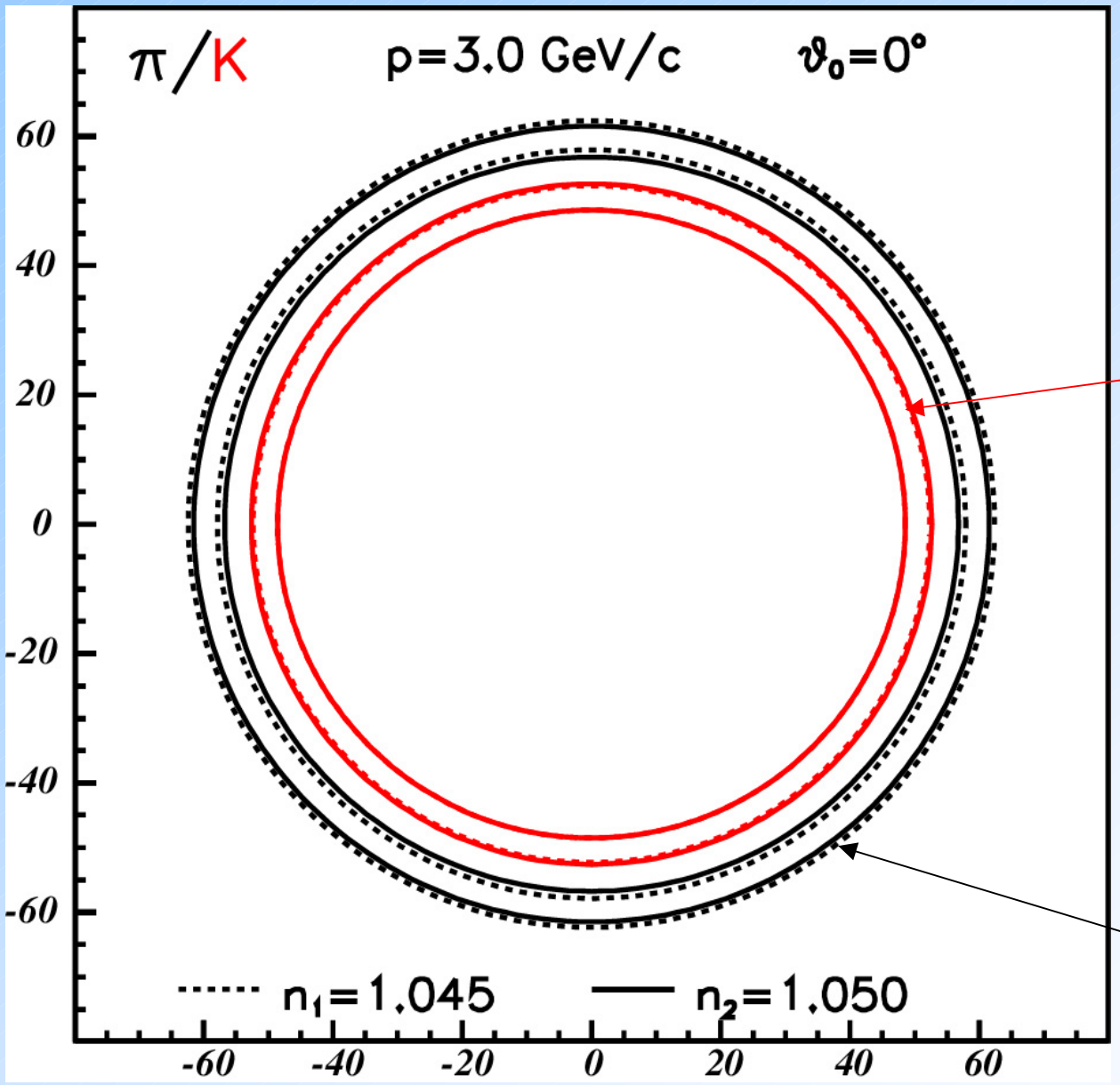
- two well separated rings
- decrease of n1 peak due to absorption





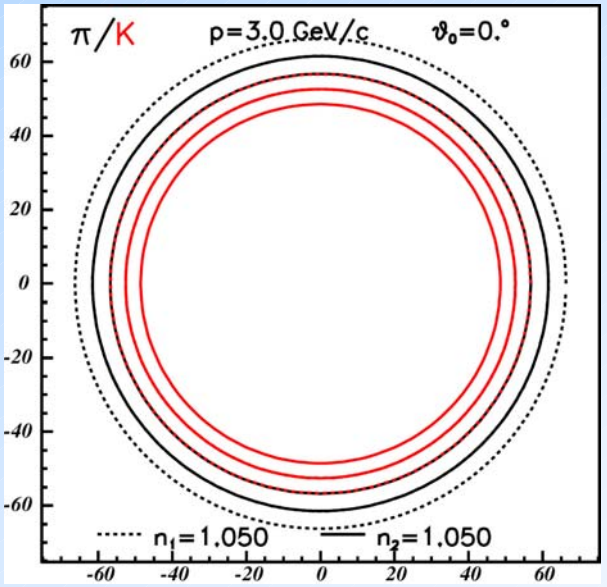


FOCUSING CONFIGURATION @ 3 GeV/c



kaon

pion

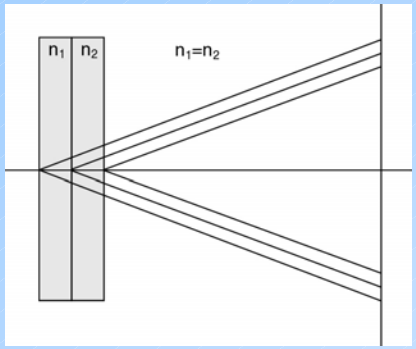


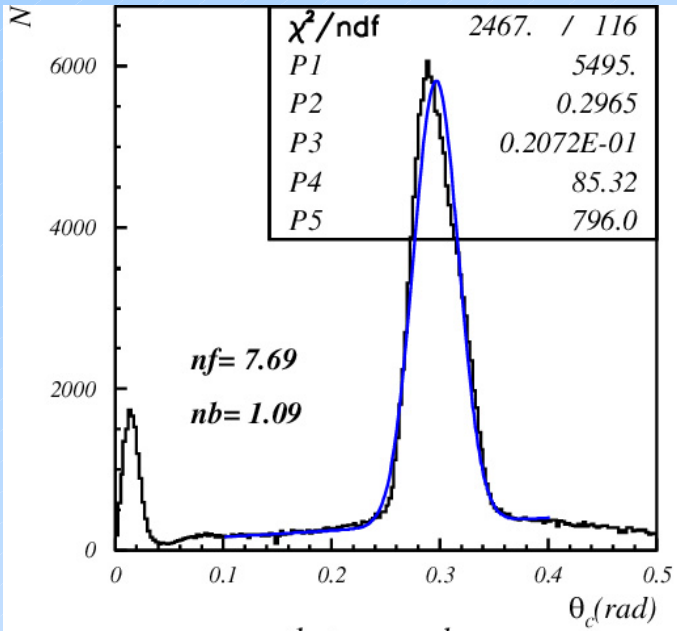
normal

- layer thickness 15mm
- $n_2 - n_1 = 0.005$

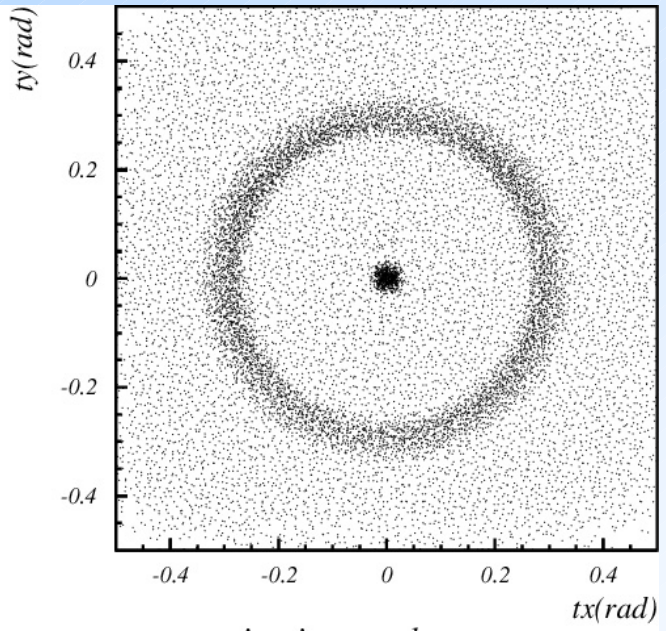
FOCUSING CONFIGURATION - data

- 4cm aerogel
- MD2-5
- RUN 192



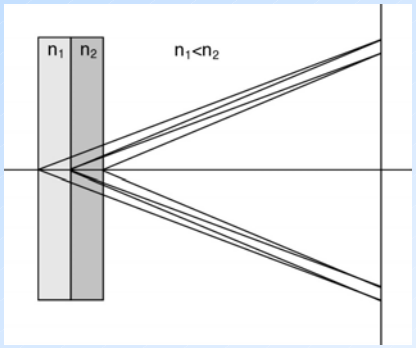


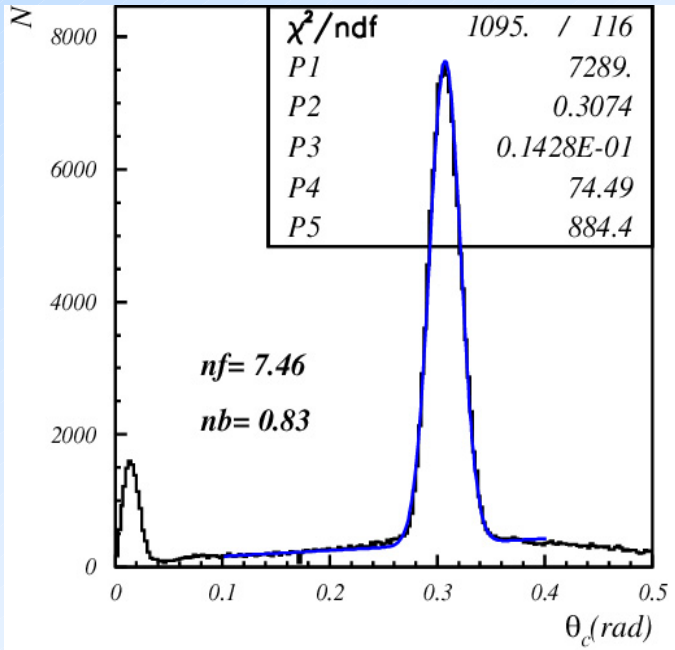
theta cerenkov

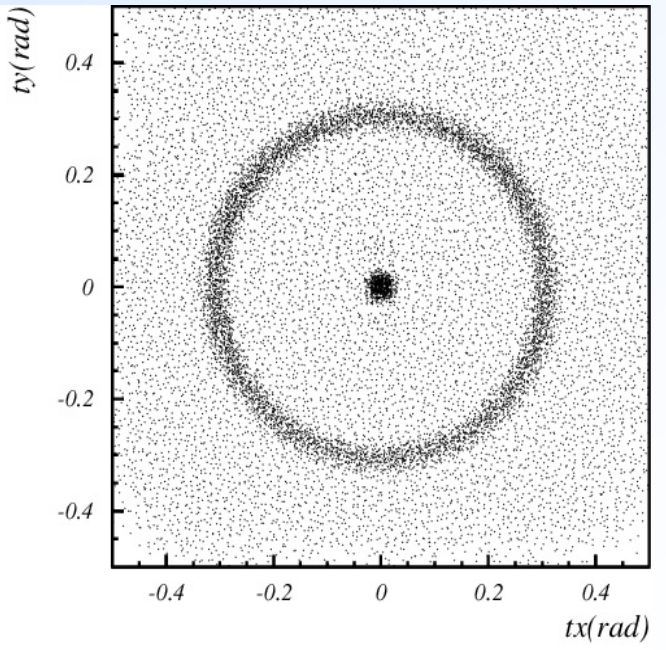


ring in cerenkov space

- 2+2cm aerogel
- MD-6,9,4,5
- RUN 213



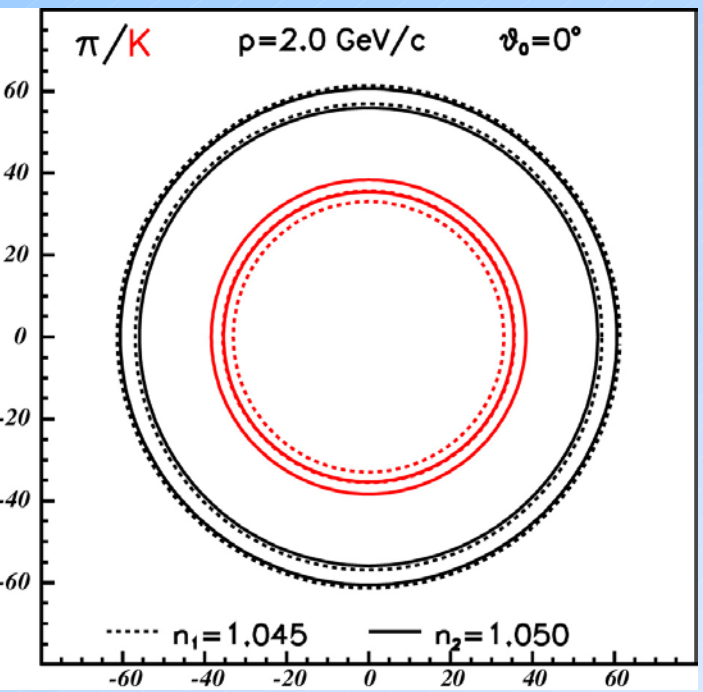


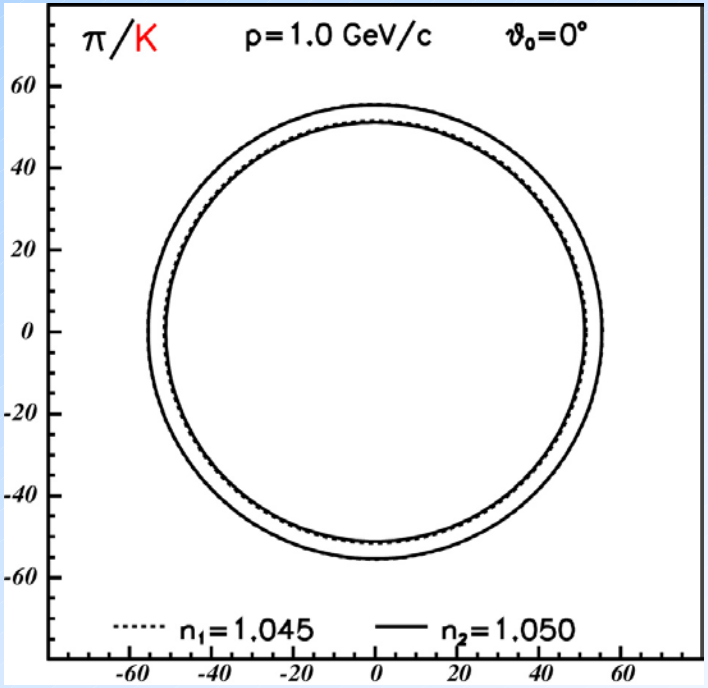


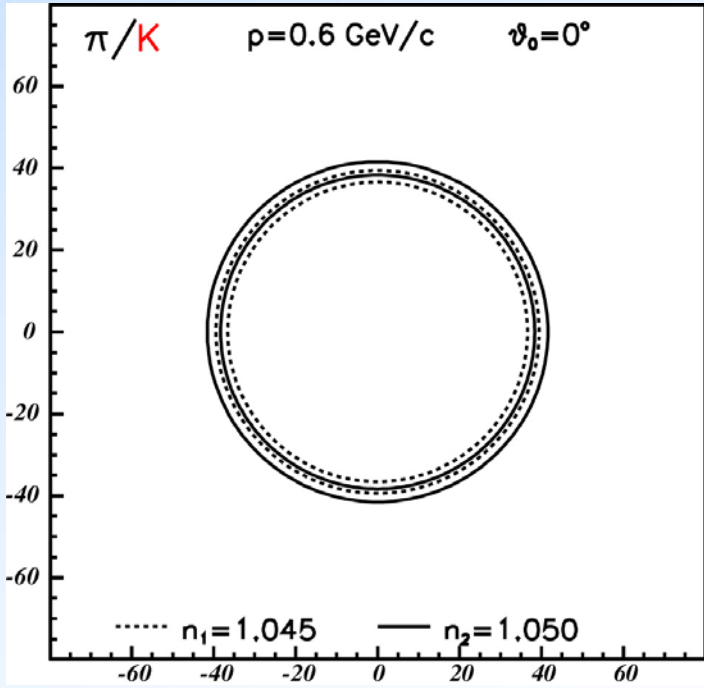
Samo Korpar
University of Maribor and Jožef Stefan Institute

FOCUSING CONFIGURATION - low momentum

- overlapping of rings for low momentum tracks



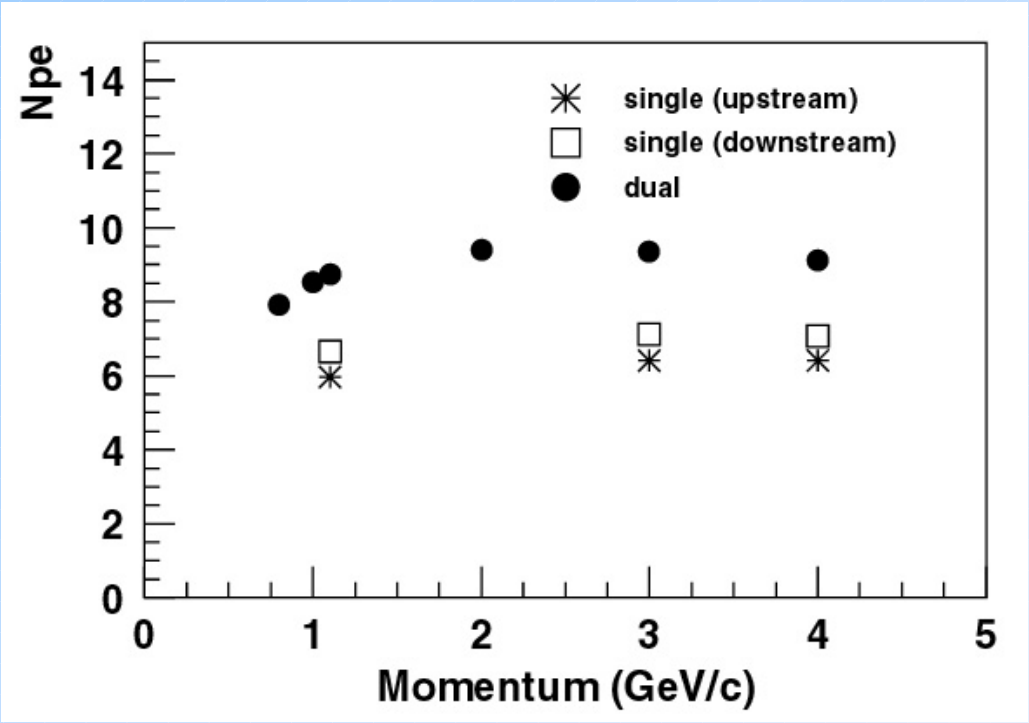




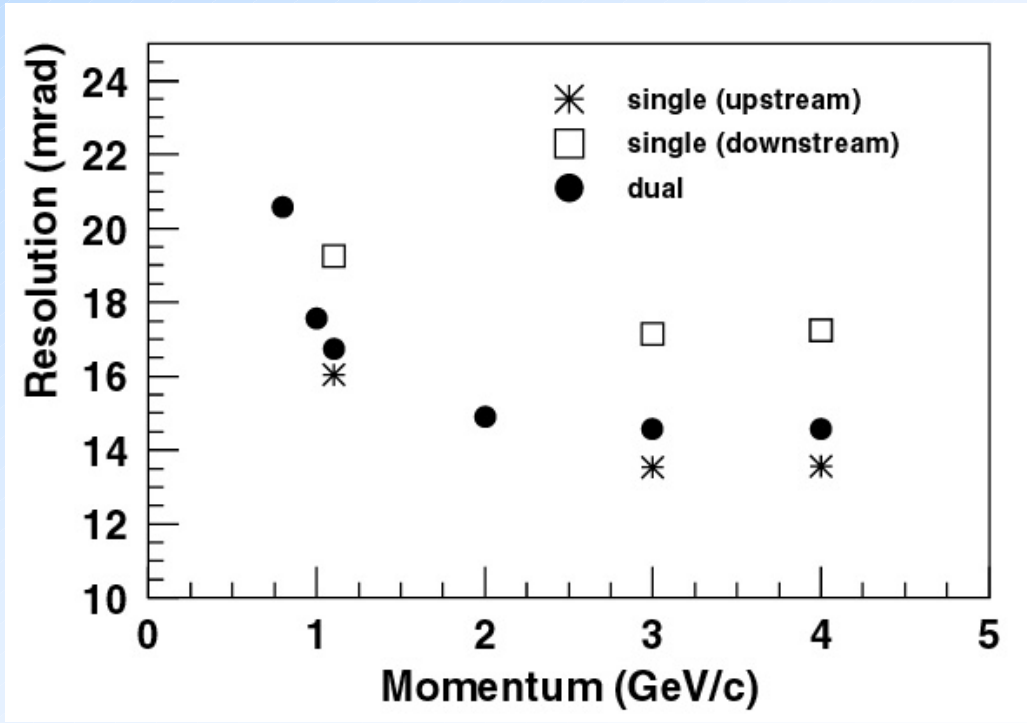
Good overlapping down to 0.6 GeV/c

FOCUSING CONFIGURATION - momentum scan, data

- number of detected hits as function of momentum

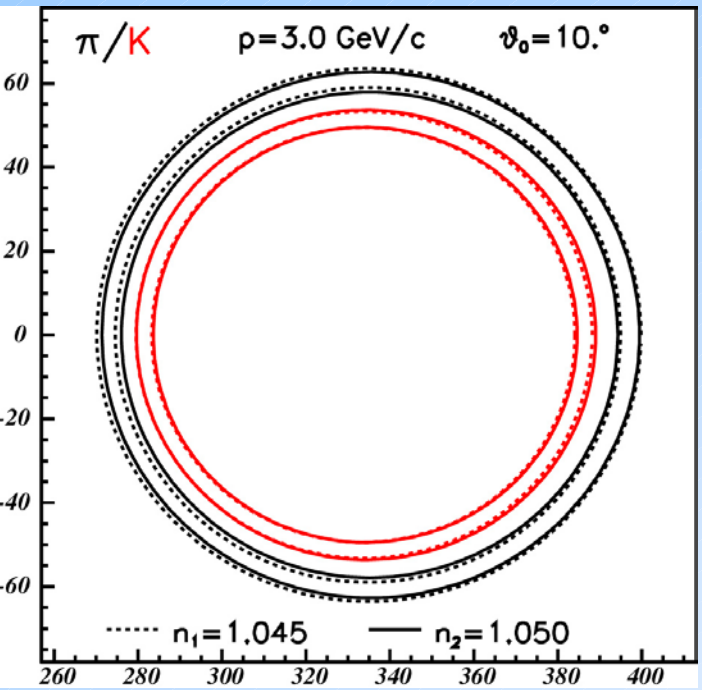


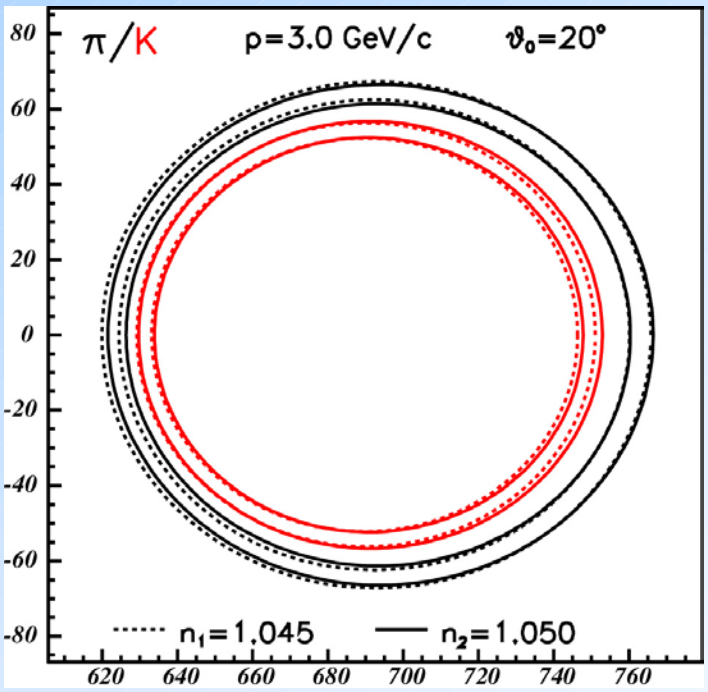
- single photon resolution as function of momentum

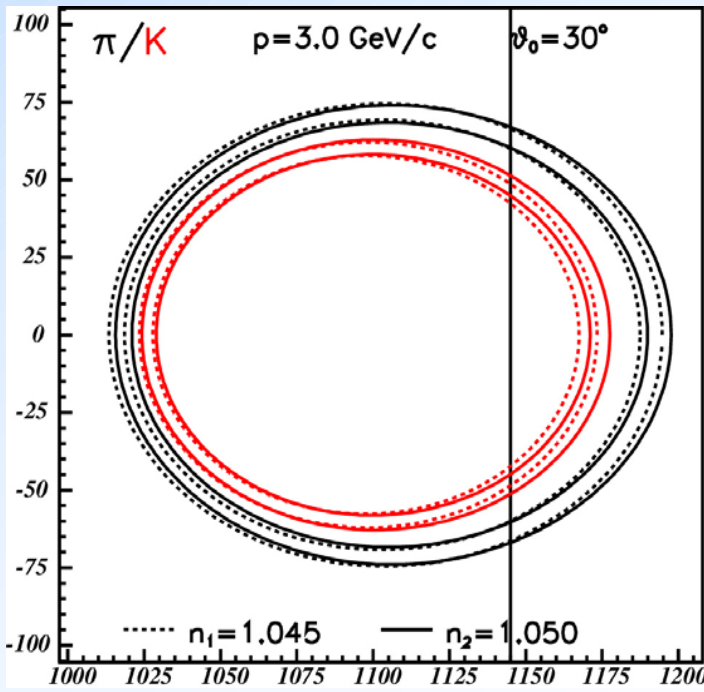


FOCUSING CONFIGURATION - different incidence angles

- overlapping of rings for inclined tracks
- expected range ~ 17°-34°



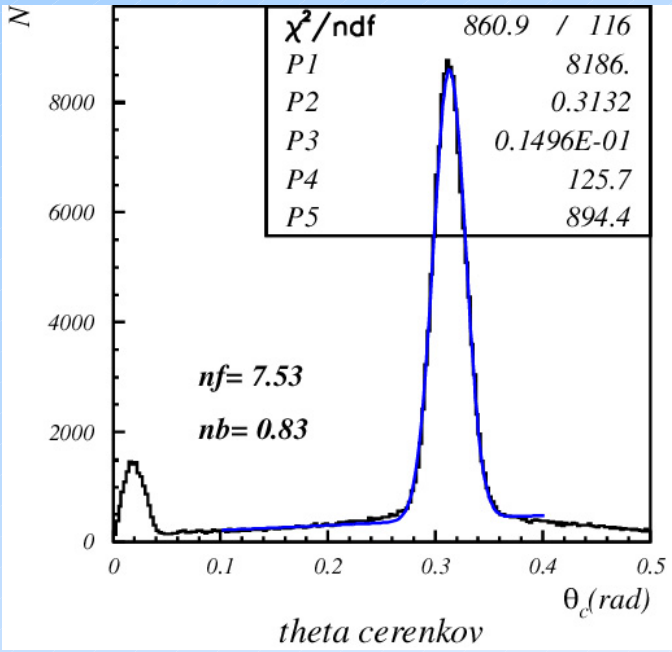


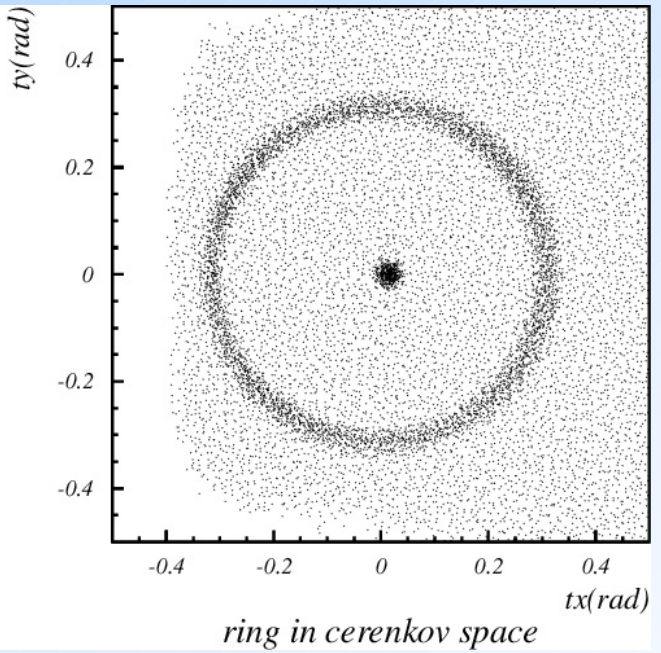


Good overlapping up to 30°

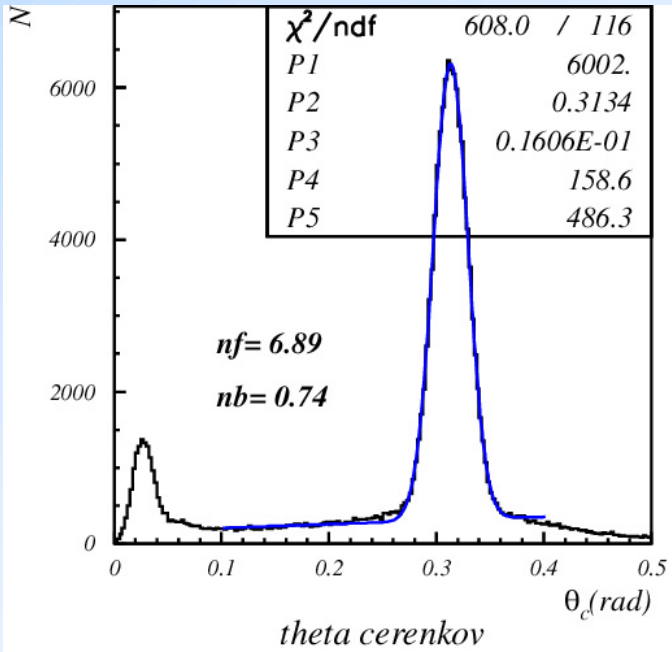
FOCUSING CONFIGURATION - inclined tracks, data

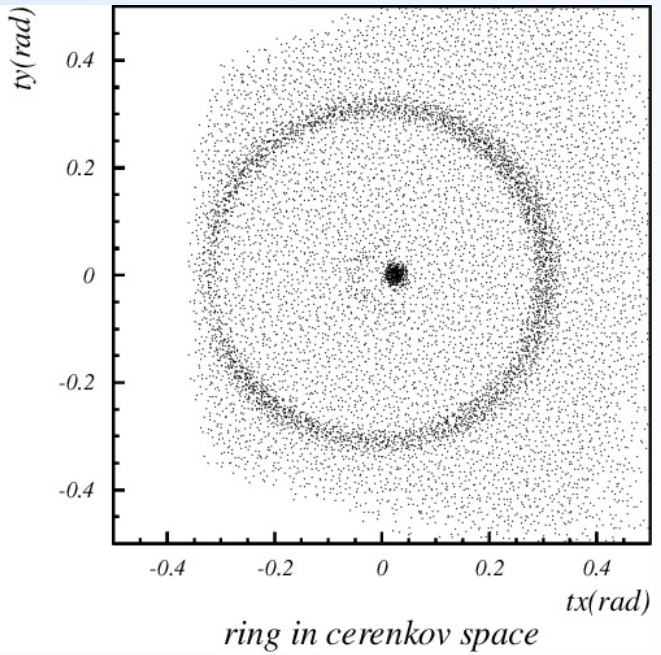
- 2+2cm aerogel
- MD-6,9,4,5
- RUN 210
- angle 20°



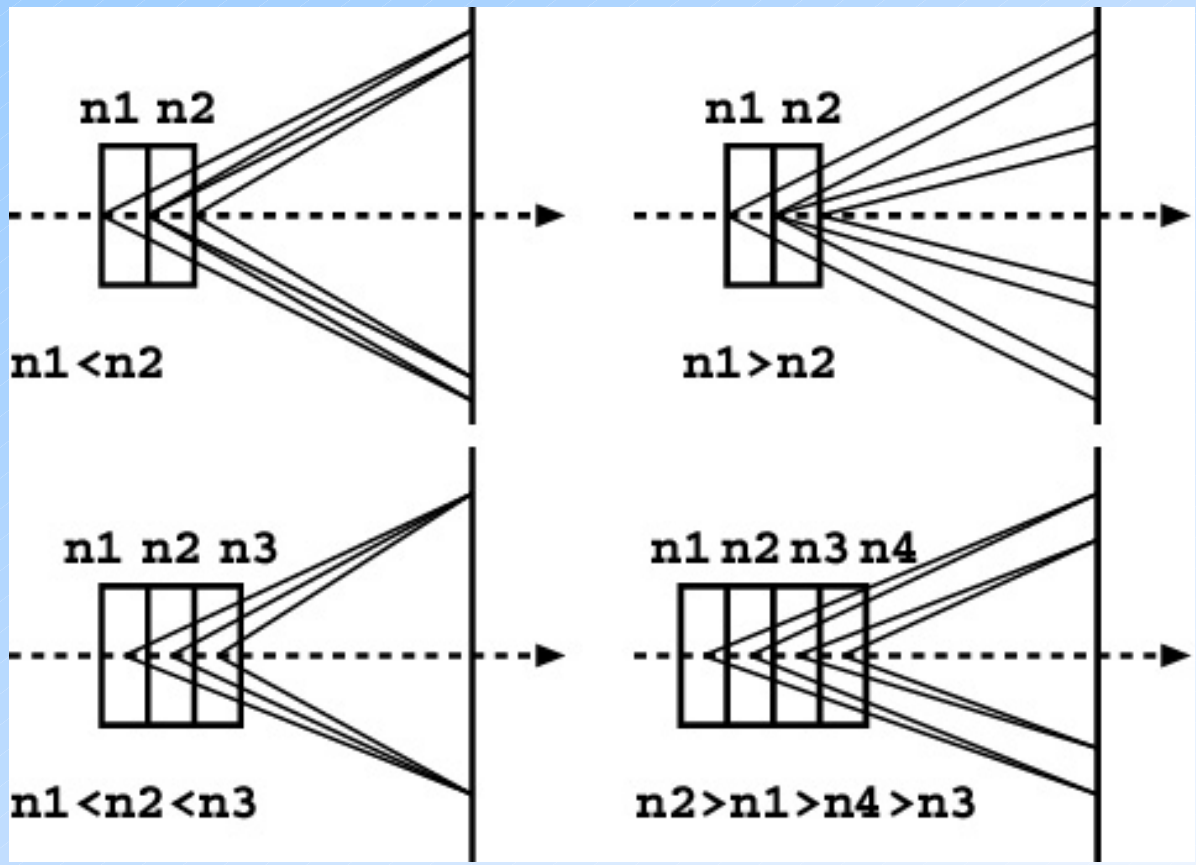


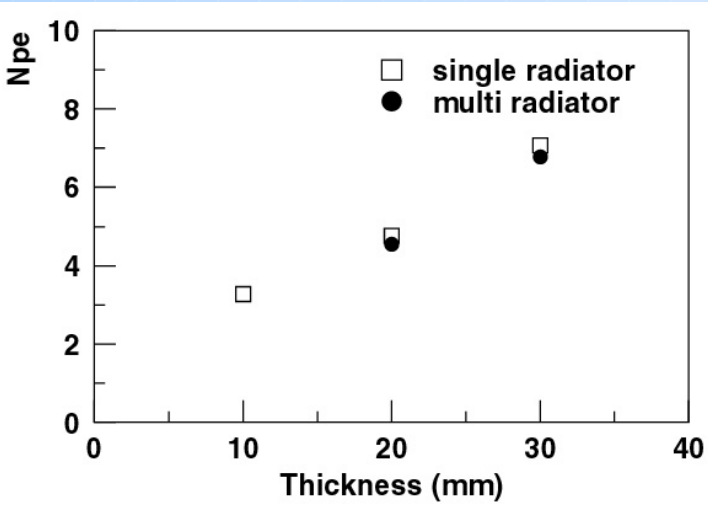
- 2+2cm aerogel
- MD-6,9,4,5
- RUN 216
- angle 30°

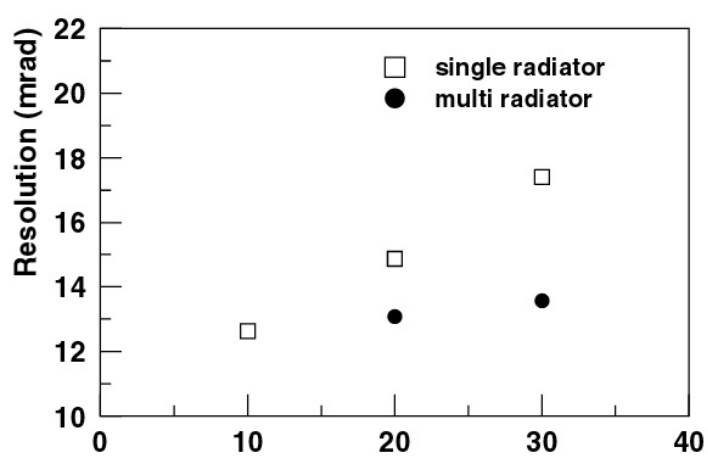


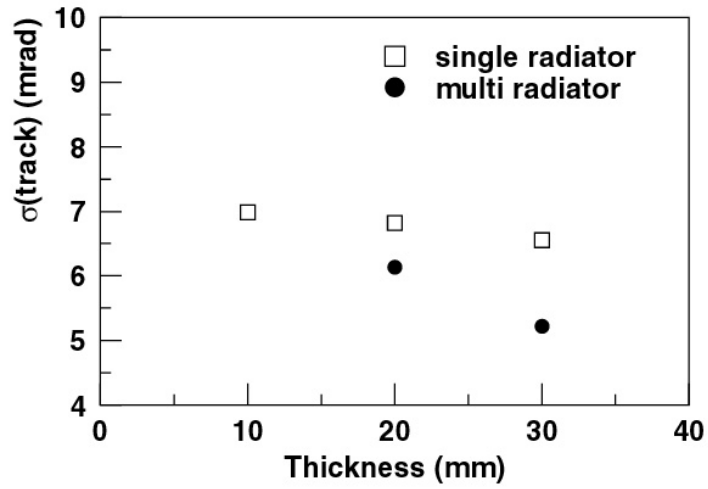


POSSIBLE MULTILAYER EXTENSIONS









PID CAPABILITY: LIKELIHOOD CALCULATION

- distribution of Cherenkov photons from both radiators and uniform background can be approximated by

$$n_{cf}(\vartheta,\varphi,m)\approx\frac{1}{2\pi}\left(\frac{1}{\sqrt{2\pi}\,\sigma_1}e^{-\frac{(\vartheta-\vartheta_1(m))^2}{2\sigma_1^2}}+\frac{1}{\sqrt{2\pi}\,\sigma_2}e^{-\frac{(\vartheta-\vartheta_2(m))^2}{2\sigma_2^2}}\right)$$

$$n_{bf}(\vartheta,\varphi,m)\propto\vartheta$$

- likelihood function

$$L(m)=\prod_{no\ hit\ i}e^{-\bar{n}_i(m)}\prod_{hit\ i}(1-e^{-\bar{n}_i(m)})$$

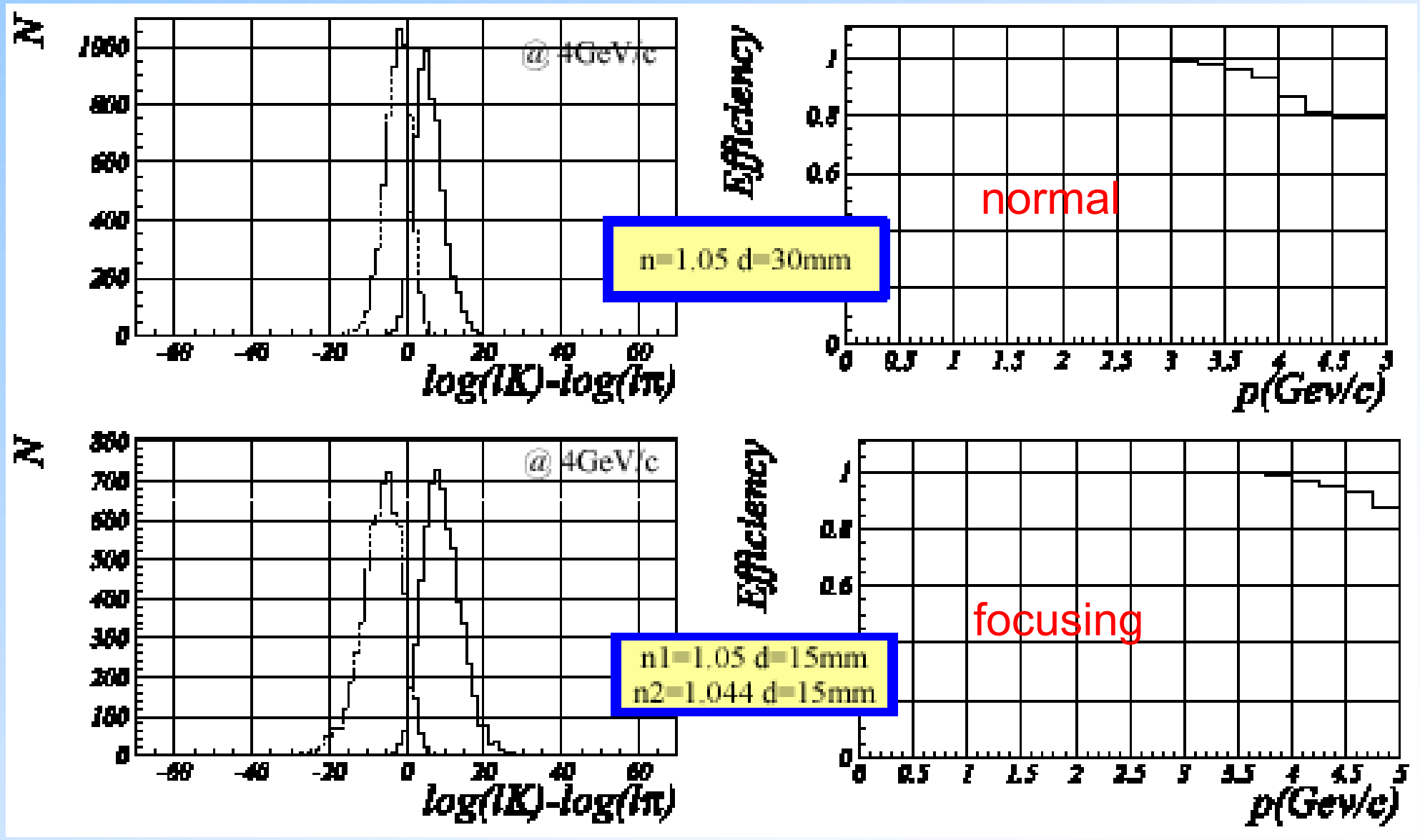
$$\ln L(m)=-\sum_{no\ hit\ i}\bar{n}_i(m)+\sum_{hit\ i}\ln(1-e^{-\bar{n}_i(m)})=$$

$$=-\bar{N}(m)+\sum_{hit\ i}(\bar{n}_i(m)+\ln(1-e^{-\bar{n}_i(m)}))$$

- average number of photons is needed only for pixels with hit

PID CAPABILITY - MC results, focusing configuration

- distribution of log likelihood difference for pions and kaons
- kaon efficiency as a function of momentum at 5% pion fake rate



SUMMARY

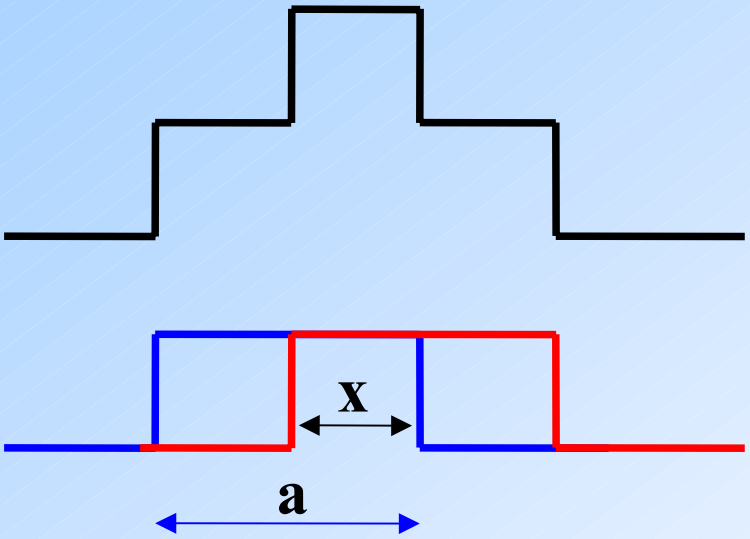
- A proximity focusing RICH with ~ 20 cm radiator to photon detector distance has an optimal radiator thickness of ~ 2 cm, increasing the thickness results in degradation of Cherenkov angle resolution per track.
- Way out: use of multi layer radiator with varying refractive index
- We have tested both configurations, dual and multiple radiators
- Results are very promising
- More studies are needed to decide which configuration we should use for the Belle PID upgrade

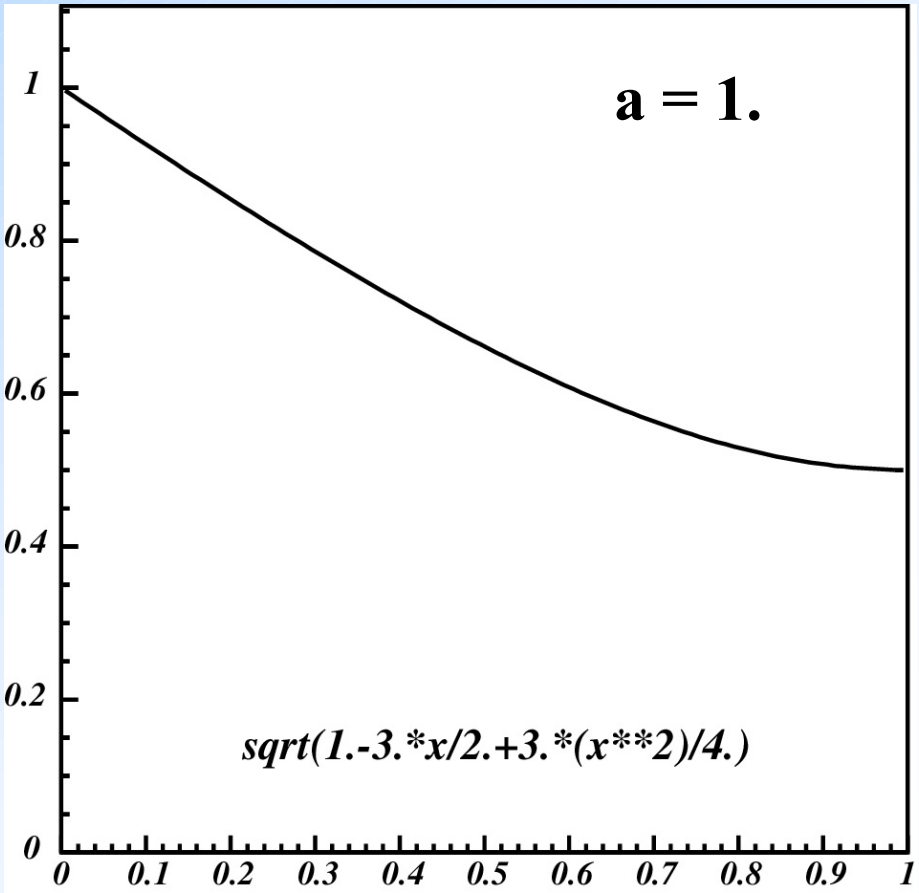
BACKUP SLIDES

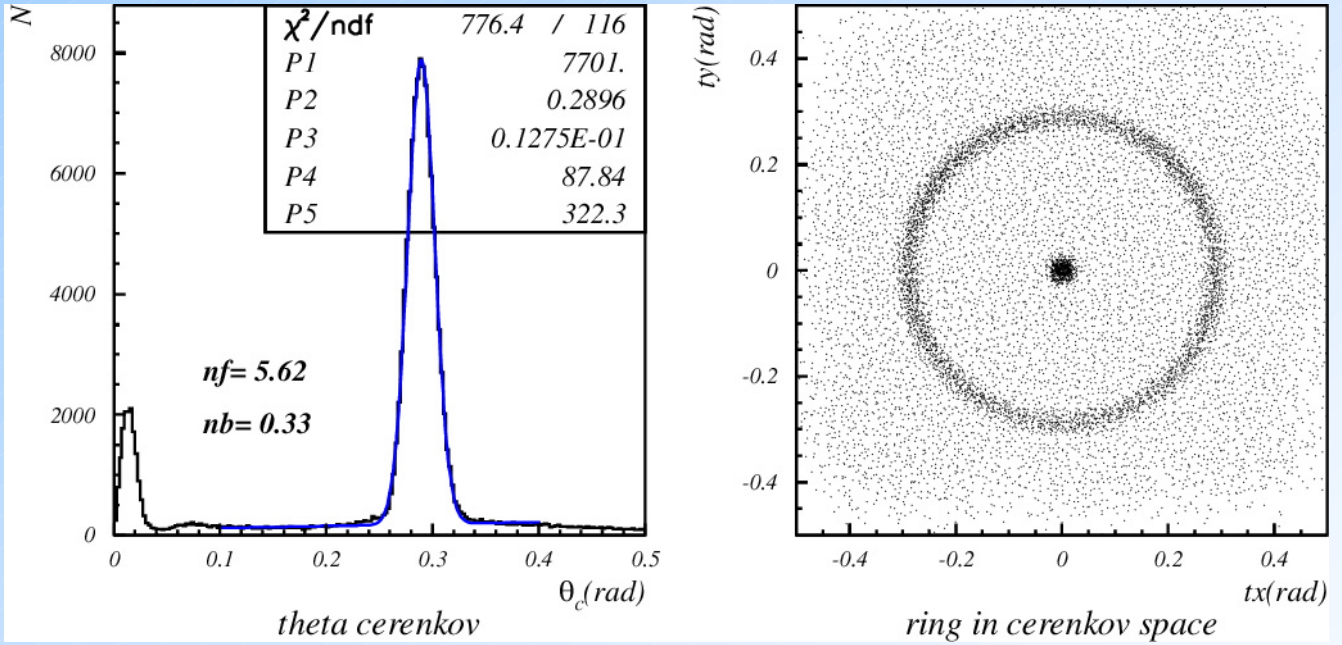
RESOLUTION: simple model

- overlapping of two uniform distributions

$$\sigma^2 = \frac{a^2}{3}\left(1 - \frac{3}{2}\frac{x}{a} + \frac{3}{4}\left(\frac{x}{a}\right)^2\right)$$

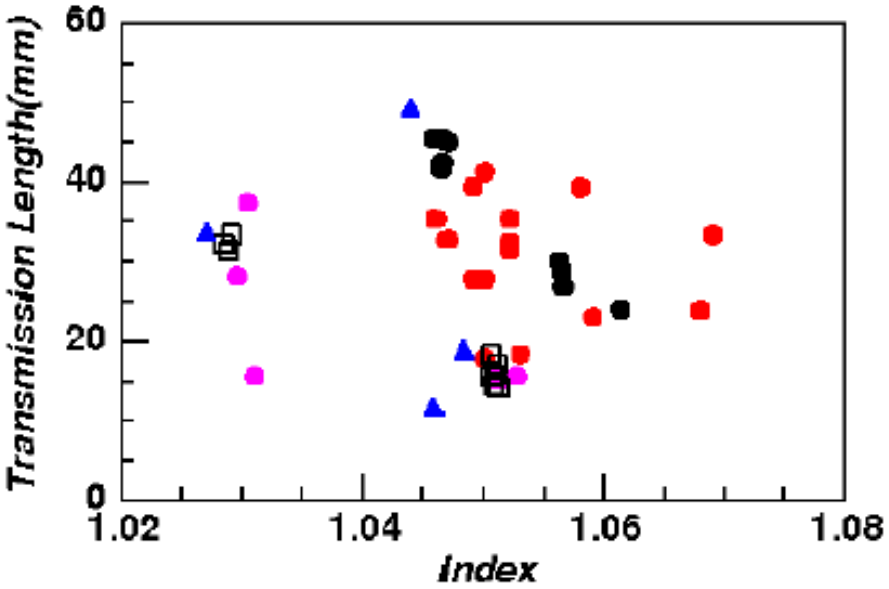






Samo Korpar
University of Maribor and Jožef Stefan Institute

AEROGEL SAMPLES

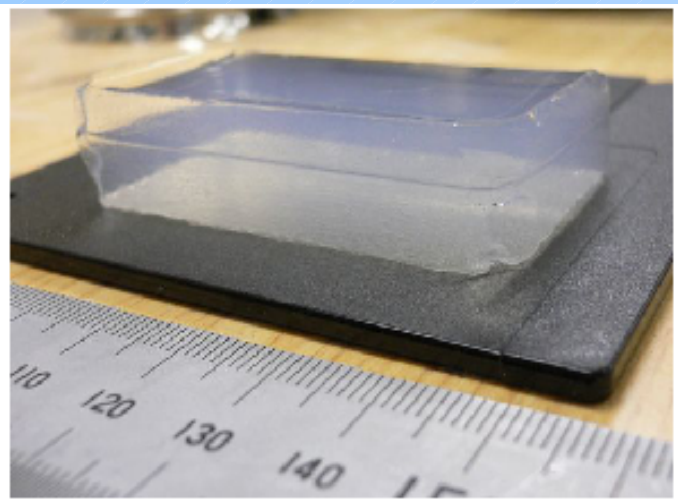


Aerogels with high transmission length (~40mm) and index of n =1.05 are now available.

already tested at 2001 beam test

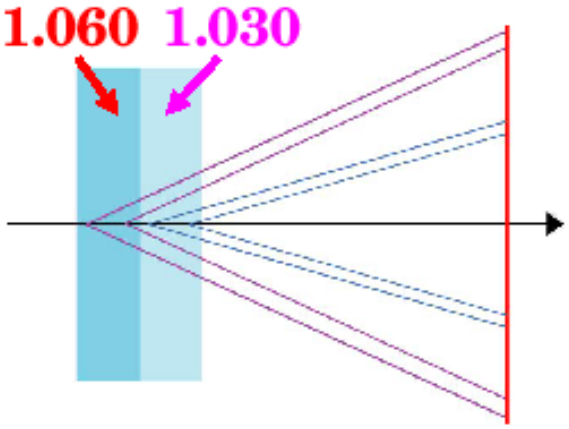
Aerogels with up to n=1.07 have been produced.

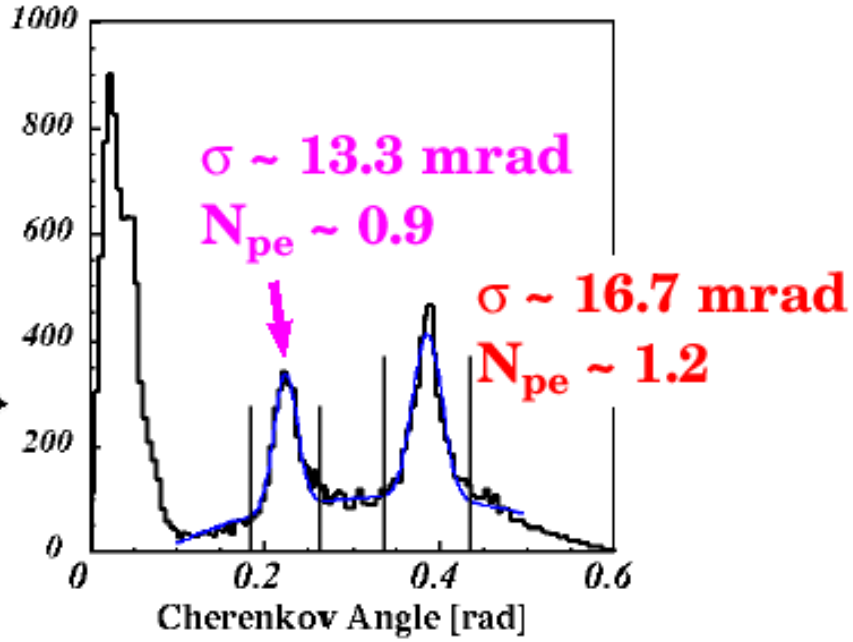
- **Novosibirsk**
- **Matsushita(2002,Methyl-alcohol)**
- **Matsushita(2002,DMF)**
- **Chiba(2003)**
- **Matsushita(2001)**



- **Two layers are chemically attached in one sample.**
- **Two layers have different indices.**
- **Easy to handle in the construction.**
- **Less sensitive to surface effect.**

Defocusing type



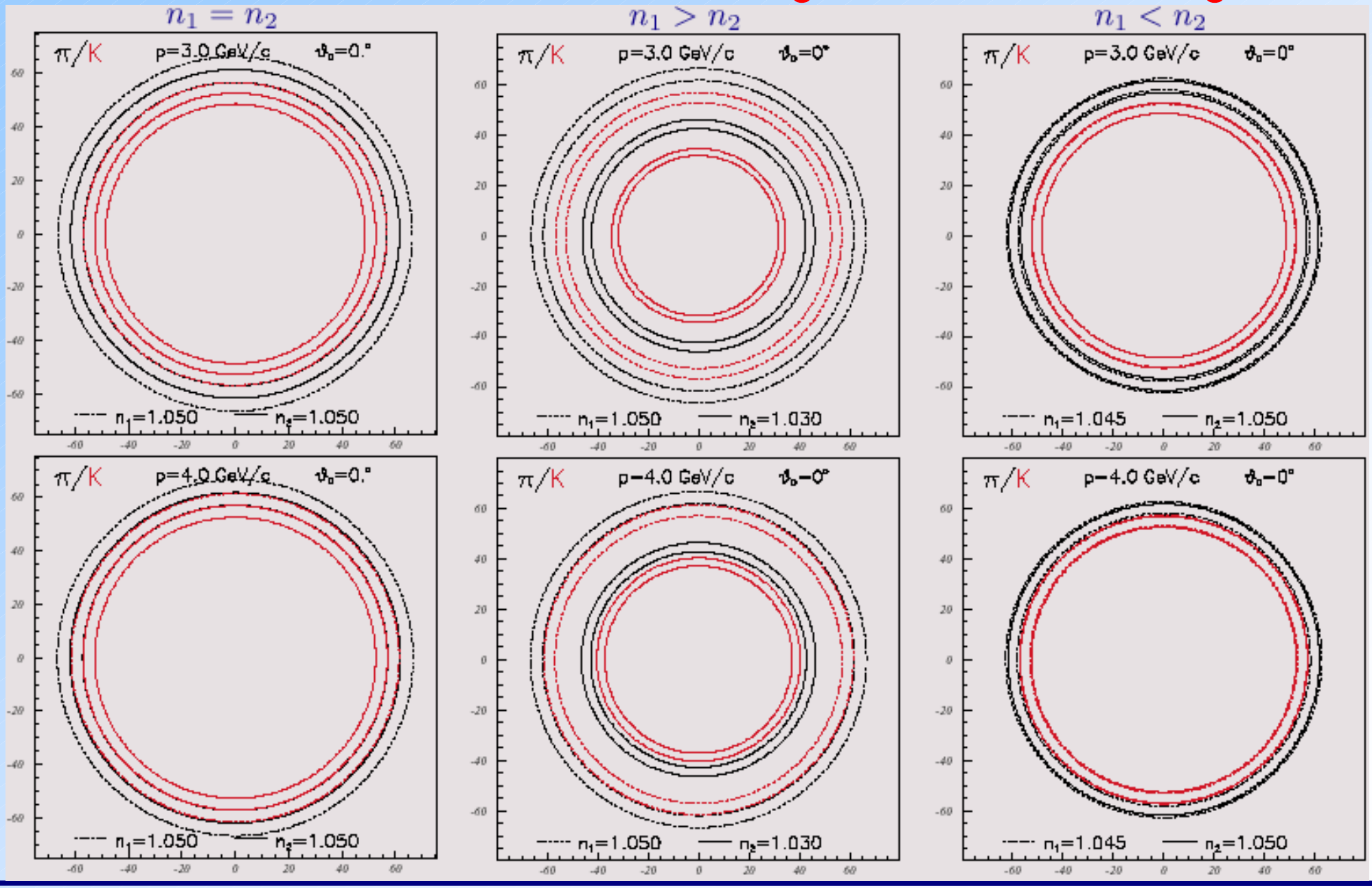


- **Two Cherenkov rings are observed.**
- **Low photon yield (due to worse transmission length)**
- **Performance should be studied in future (e.g. comparison with separate radiators).**

RING AREAS @ 3 & 4 GeV/c

- layer thickness 15mm

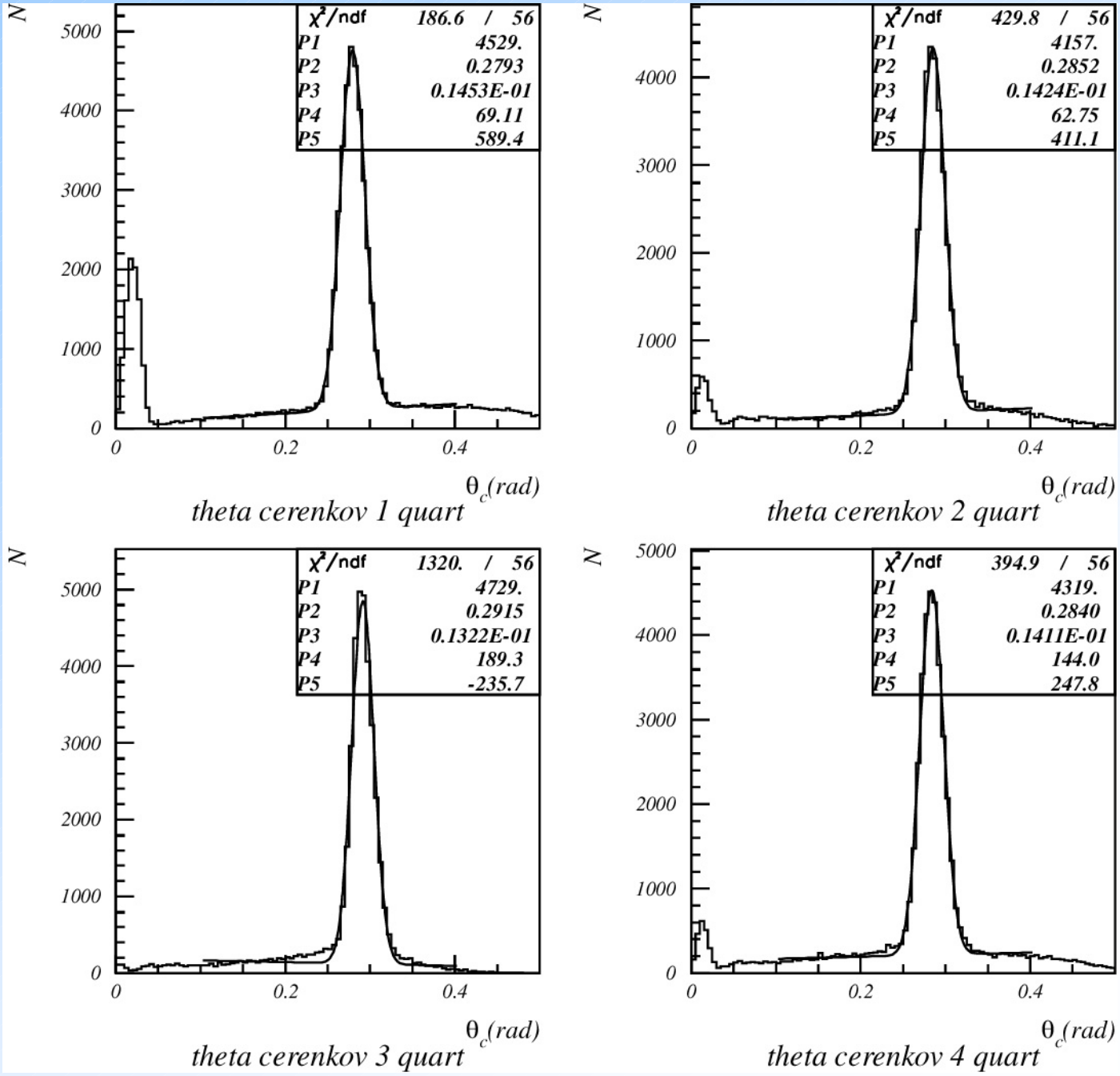
normal $n_1 = n_2$ | defocusing $n_1 > n_2$ | focusing $n_1 < n_2$



Samo Korpar
University of Maribor and Jožef Stefan Institute

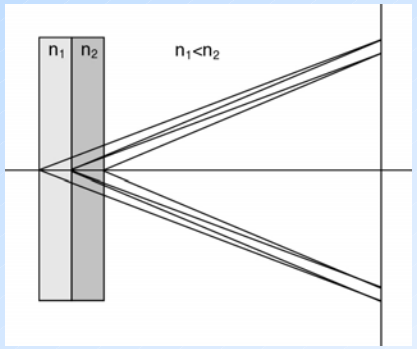
FOCUSING CONFIGURATION: angle, different parts of ring

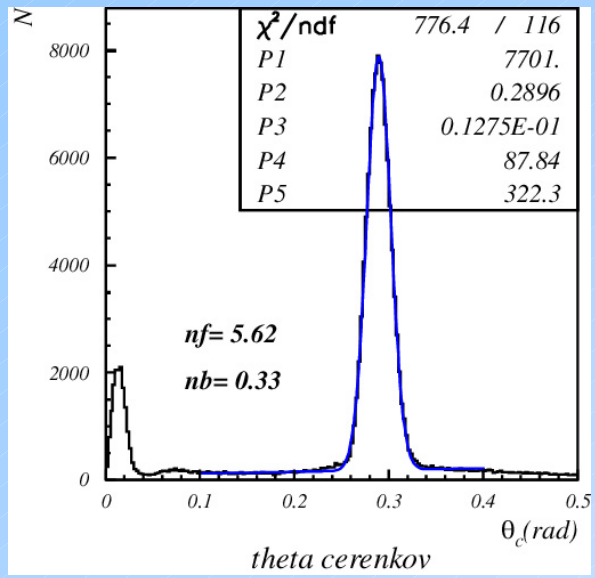
- 2+2cm aerogel
- MD-6,9,4,5
- RUN 210
- angle 20°

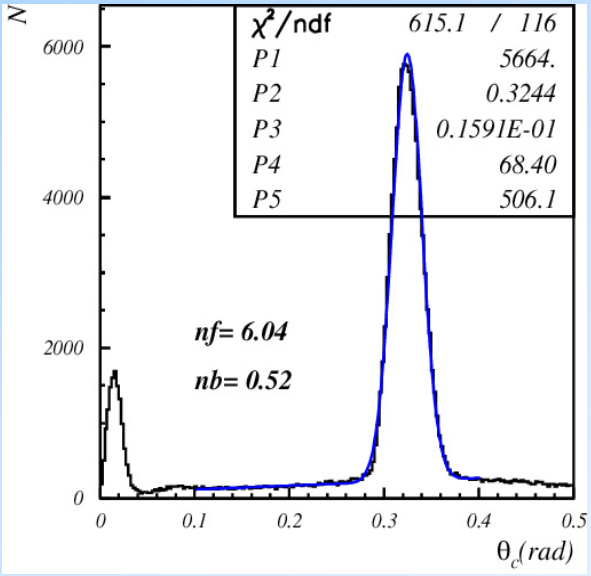


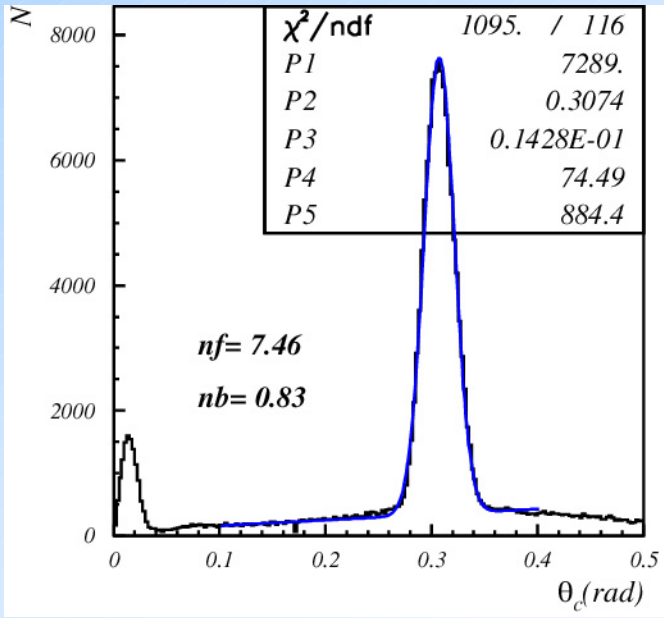
Samo Korpar
University of Maribor and Jožef Stefan Institute

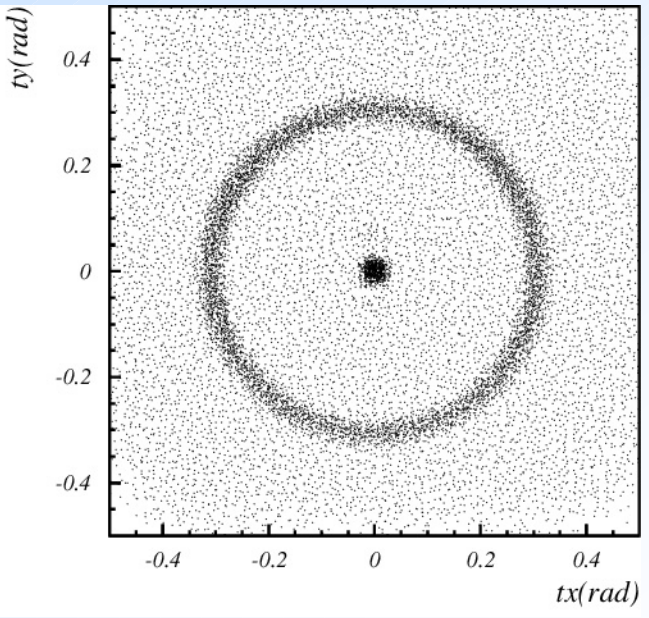
FOCUSING CONFIGURATION @ 3 GeV/c, data







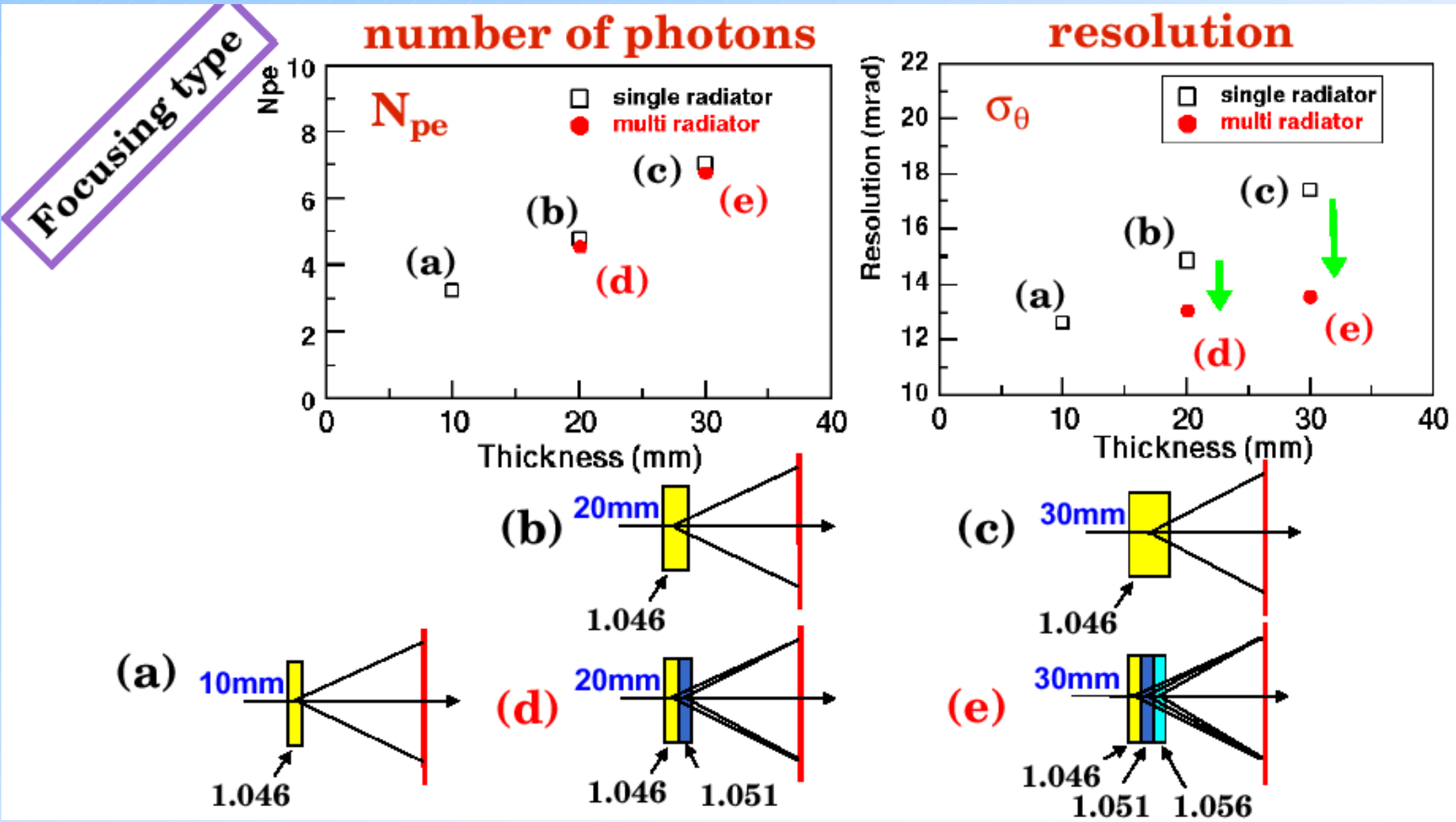




Samo Korpar
University of Maribor and Jožef Stefan Institute

MULTILAYER FOCUSING COMBINATION - data

Focusing type



Samo Korpar
University of Maribor and Jožef Stefan Institute