Operation and performance of the ASHIPH counters at the KEDR detector.

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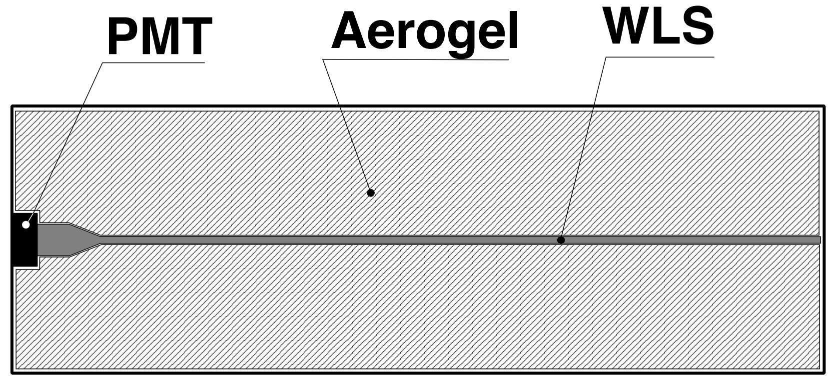
Outline:

1. ASHIPH method
2. System of ASHIPH counters for the KEDR detector
3. Efficiency of the system
4. Summary

KEDR physical plans for next few years

- D-mesons mass measurement
- $R=\sigma(e^+e^- \to hadr)/\sigma(e^+e^- \to \mu^+\mu^-)$ measurement in wide energy range $W=1.8 \div 9$ GeV
- Branchings:
  - J/Ψ ->hadrons
  - Ψ' -> hadrons
  - …
- ϒ-mesons: Masses, widths
- γγ-physics

ASHIPH method



Cherenkov light from aerogel is collected by WLS placed in the middle of the counters and guided to PMT photocathode.

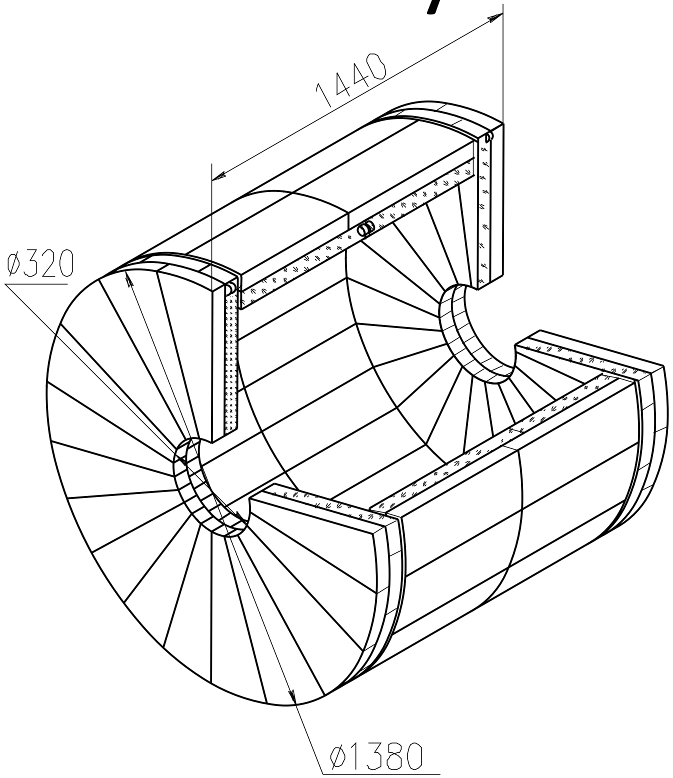
This method permit us to make:

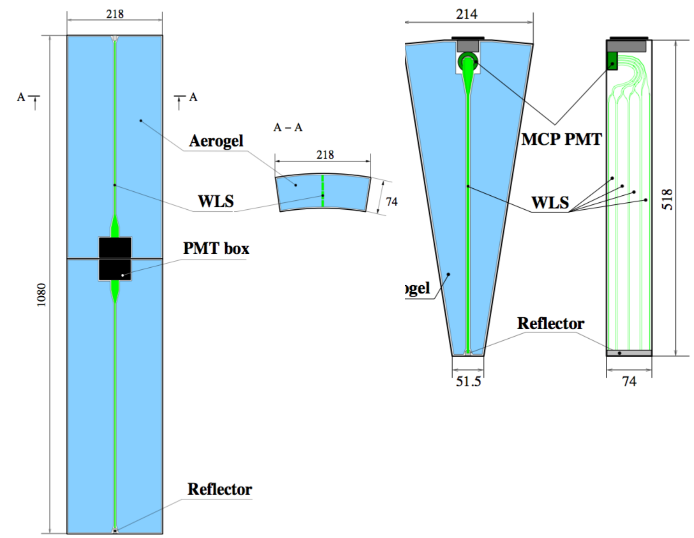
- Large system for the KEDR detector (1000 liters of aerogel, n=1.05, 0.97x4π) with small number of the PMTs and photocathode surface (160 MCP PMTs with PC Ø18mm)
- Small system for the SND detector (9 liters of aerogel, n=1.13, 0.6x4π, 9 MCP PMTs with PC Ø=18mm, 35mm thickness)

ADVANTAGES:

- ***Small amount of material***
- ***Rather cheap system***
- ***Valuable PID system in very limited space***

ASHIPH system for the KEDR detector





- 1000 liters of aerogel with n=1.05.
- π/K-separation in momentum range 0.6-1.5GeV/c.
- 160 counters arranged in two layers in such way that tracks bended in the KEDR magnetic field cross WLS and PMT box only in one layer
- 160 MCP PMT with multialkali PC Ø18mm able to work in magnetic field (~2T)
- WLS is based on PMMA with BBQ dope (150mg/kg)

Operation in the KEDR detector

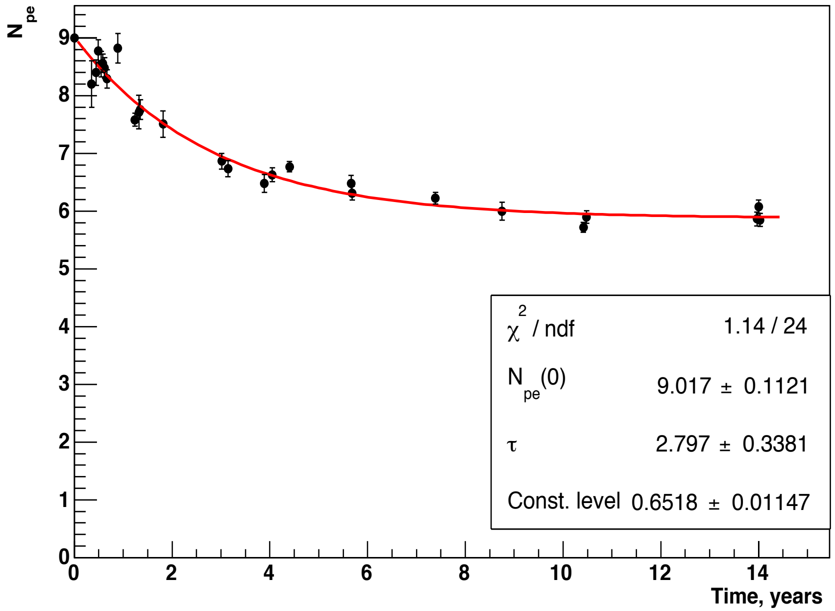
- HV system:
  - 6 HV transformers H40N (EMCO: 4000V, 3.75mA, 15W) in one standard KAMAK 4M module are developed in BINP.
  - 10 modules of active HV dividers (16 channels per each) from PNPI provide tuning of voltage for each counters in dynamic range from 2500 to 4000V.
- DAQ system
  - The counters are read out by 28 A6 boards with flash ADCs in the KLUKVA standard developed at the BINP.
  - A6 has 6 channel with 10-bits ADC which makes measurements each 60ns and save 5 of them in pipe-line register.
  - The register is blocked when the detector trigger system generate positive decision to read out data from system.
- Slow control system
  - The system monitors dark count rates of PMTs and provides HV power control.
  - In case of emergency each counter is switched of by active HV divider individually.
  - Control for gain stability and counters efficiency is performed twice per week during calibration runs with LED and cosmic particles.

(All systems were developed and produced in BINP)

Long term stability

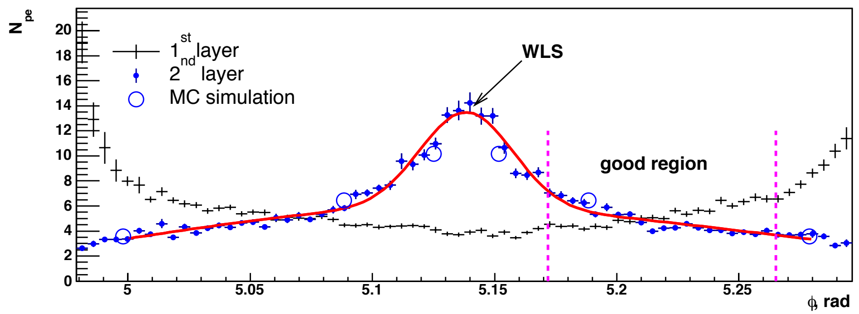
- Since 2000 the stability of ASHIPH counters has been studied.
- 80 counters (first layer) of the KEDR ASHIPH system were under operation in detector from 2003 to 2011. Due to problems with PMT holders in magnetic field the system had poor geometrical and light collection efficiencies.
- The sources of amplitude decrease were studied with 80 counters.:
  - QE PMT – 18%
  - LC(Aerogel) – 22%
  - PMT-WLS –up to 30%

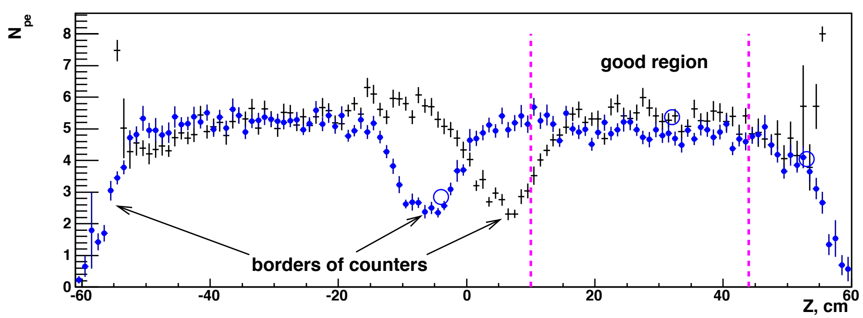
    (optical coupling)

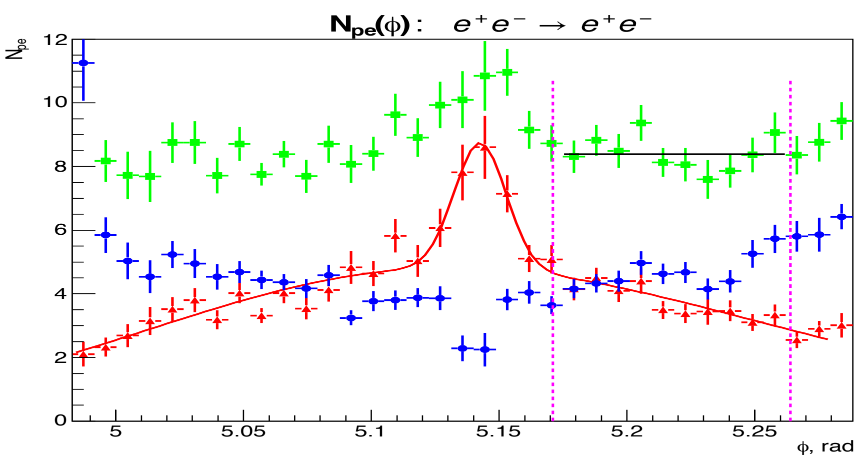


Dynamic of the amplitude dependence on time is explained by slow aerogel degradation which goes to some stable level.

Alignment of the system





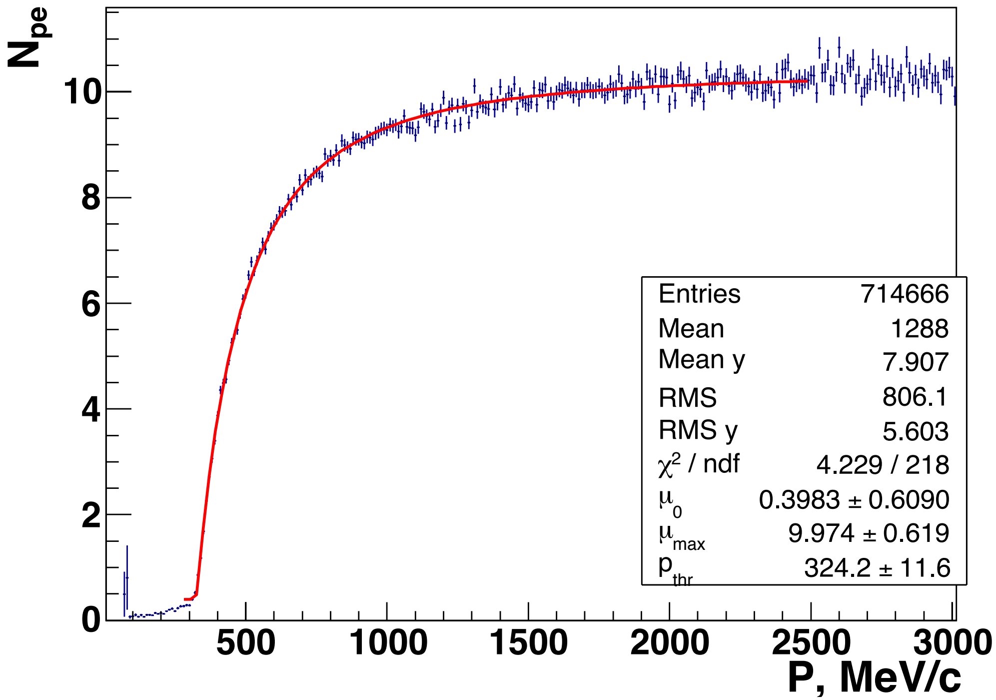


- Shifts, tilts and rotations were determined by cosmic tracks with accuracy of 0.5mm and 1mrad correspondingly.
- Amplitude dependences of the signal on ϕ and Z are in good agreement with MC simulation of light collection in the counters.
- To compare different approaches of system efficiency calculation "good region" was chosen. WLS and counter edges were excluded.
- Uniformity of signal in "good region":
  - Single layer – 30%
  - Double layer – 10%

Momentum dependence of the amplitude

Barrel part of the system

$N_{pe}(p)$



- $P_{thr}(\mu)$=324±11MeV/c -> n=1.051±0.004
- N_{pe} from relativistic muons:
  - 1st layer - 4.9ph.e
  - 2nd layer - 4.7ph.e
  - 2 layers - 9.6ph.e
- $N_{pe}(e^+e^- \to e^+e^-)$:
  - 1st layer - 6.0ph.e
  - 2nd layer - 4.7ph.e
  - 2 layers - 10.8ph.e

Main sources of under threshold signal:

- P_μ <110MeV/c – only scintillation in PTFE
- P_μ >110MeV/c – + Cherenkov light from PTFE
- P_μ > 130MeV/c – + Cherenkov light from δ-electrons in aerogel

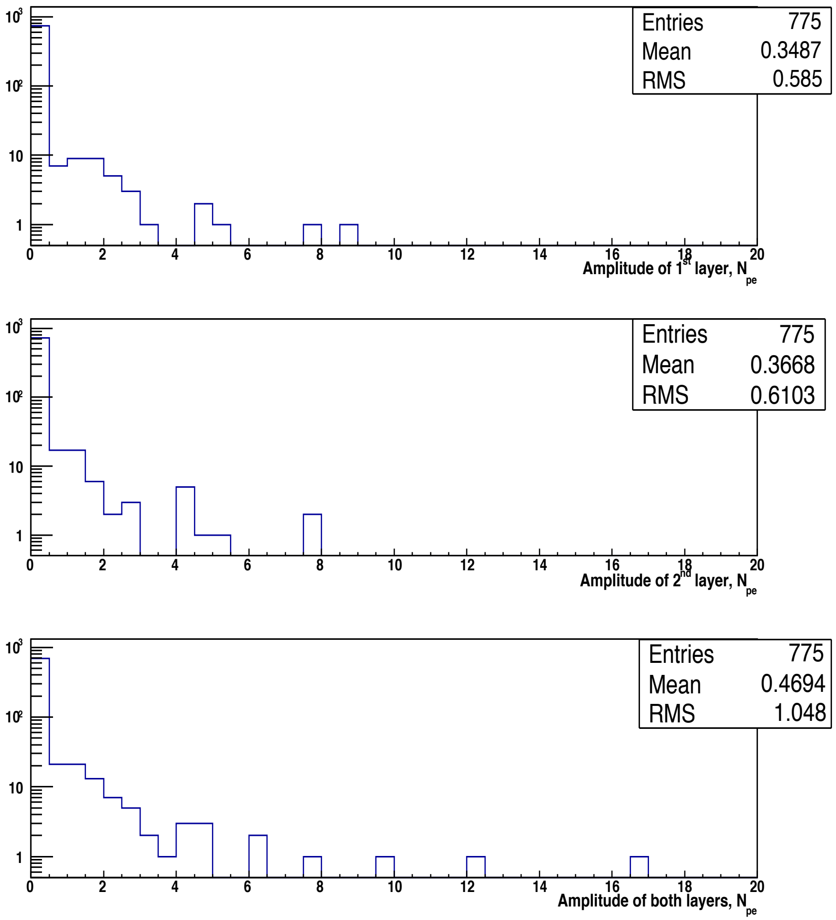
Efficiency calculation

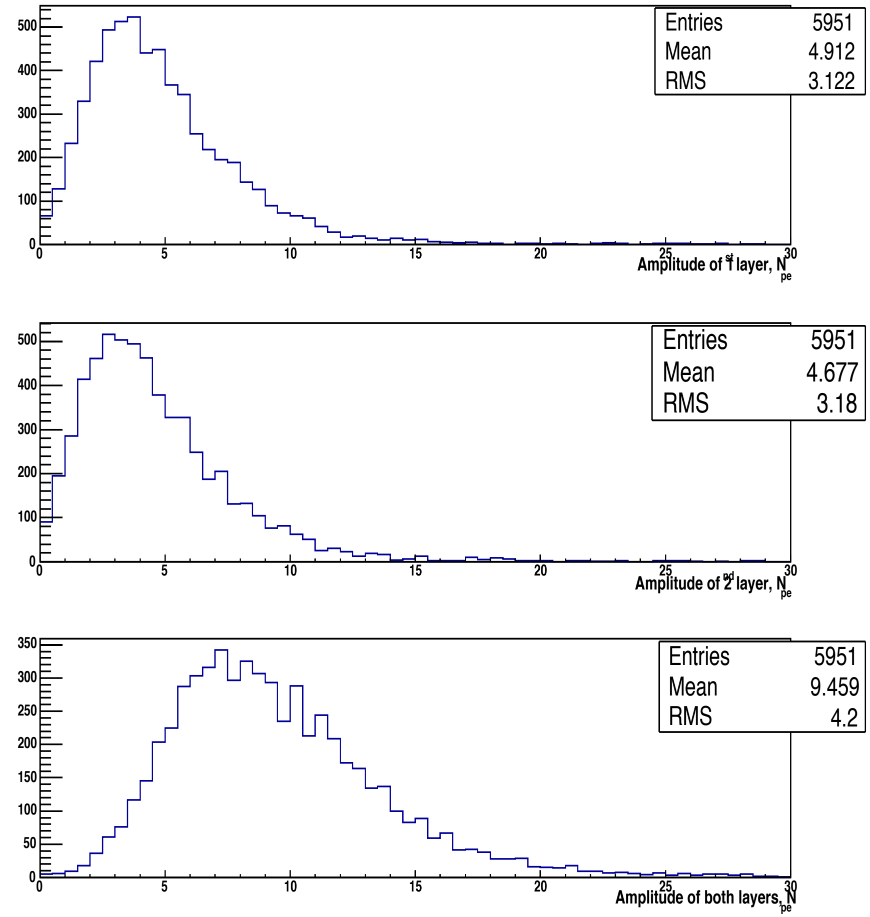
- To calculate registration efficiency for kaons and pions with $P_{K,\pi}$ muons with corresponding velocity were chosen ($P_\mu = P_K*[m_\mu/m_{K,\pi}]$):
  - 950 < P_K < 1450 MeV/c: -> 200< P_μ < 300 MeV/c   0.885<β<0.944
  - 950 < P_π < 1450 MeV/c: -> 700< P_μ < 1100 MeV/c   0.989<β<0.995
- The several approaches of efficiency measurement of double layer system were studied:
  - AND   :   relativistic particle have to give a signal in both layers of the system
  - OR   :   relativistic particle have to give a signal at least in one layer of the system
  - THICK :   sum of the amplitudes in both layers have to be more than threshold

In any case it is necessary to exclude amplitude from WLS

It depends on the goal of experiment which of them should be used!

Amplitude spectrums

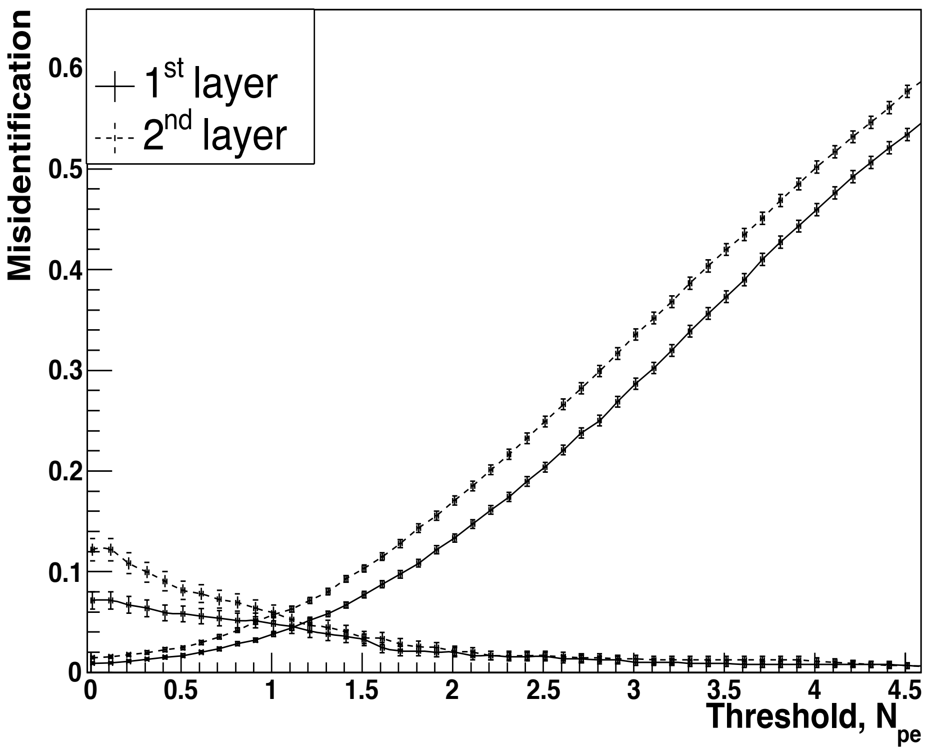


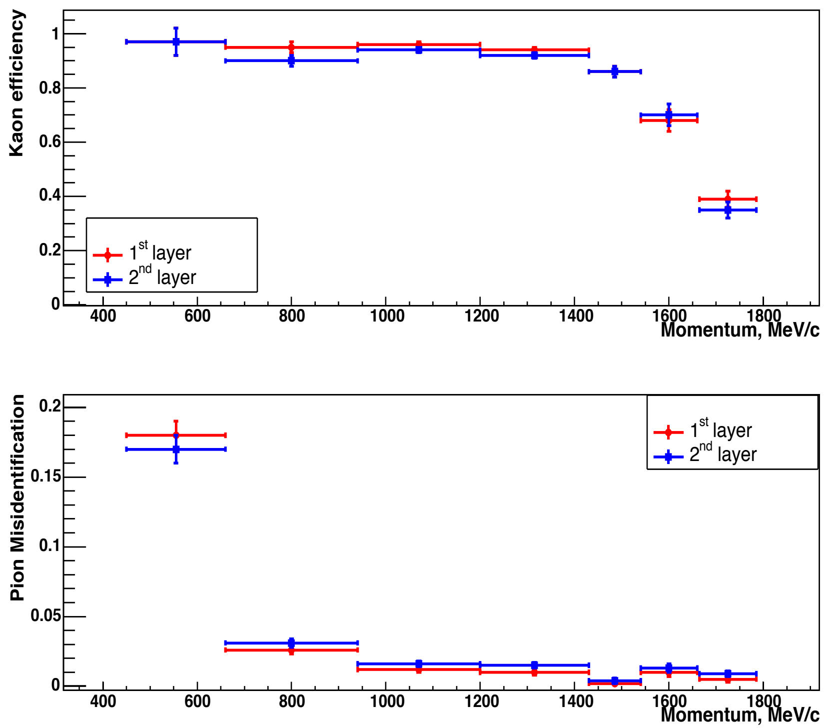


<<Kaons>> : $0.885<\beta<0.944$

<<Pions>> : $0.989<\beta<0.995$

Single layer efficiency

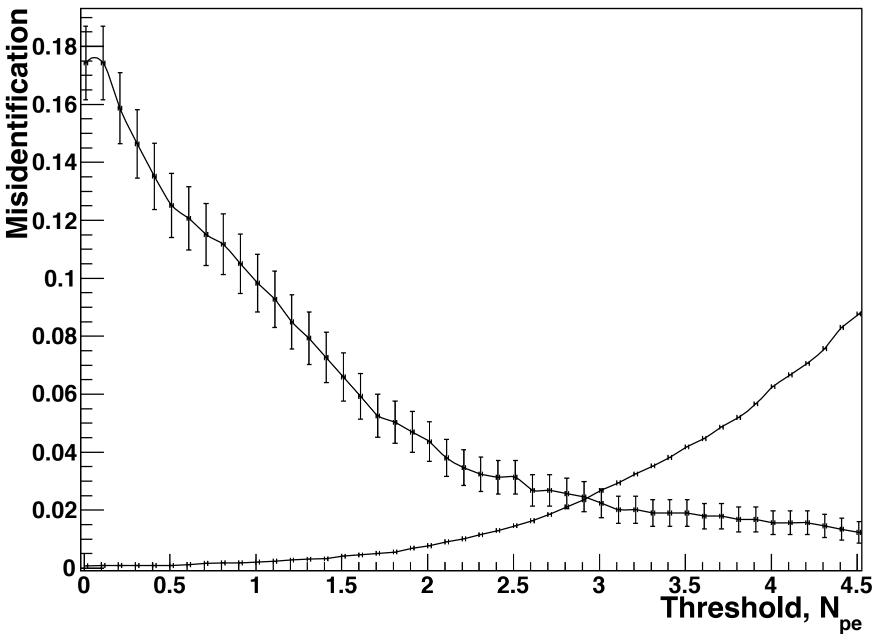




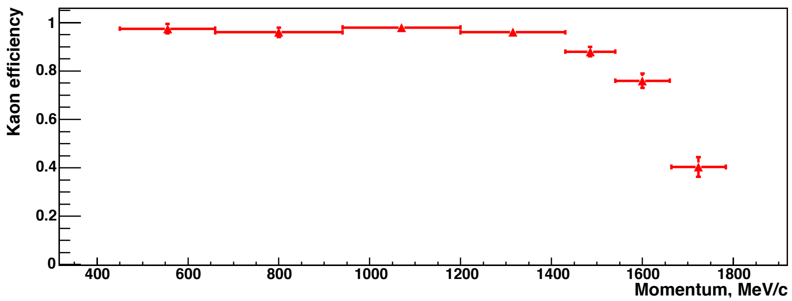
940MeV/c < $P_{\pi,K}$< 1430MeV/c

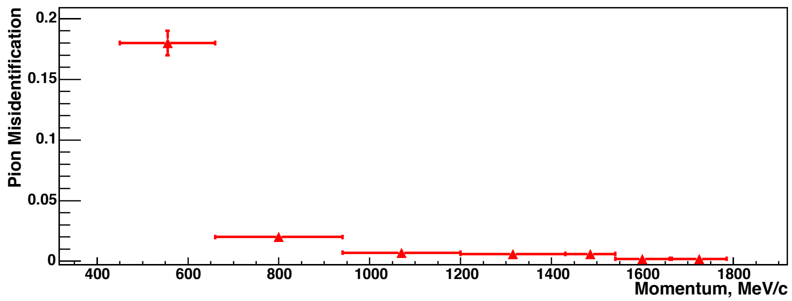
Threshold 0.5 ph.e.

Double layer efficiency (THICK counter)



940MeV/c < $P_{\pi,K}$< 1430MeV/c



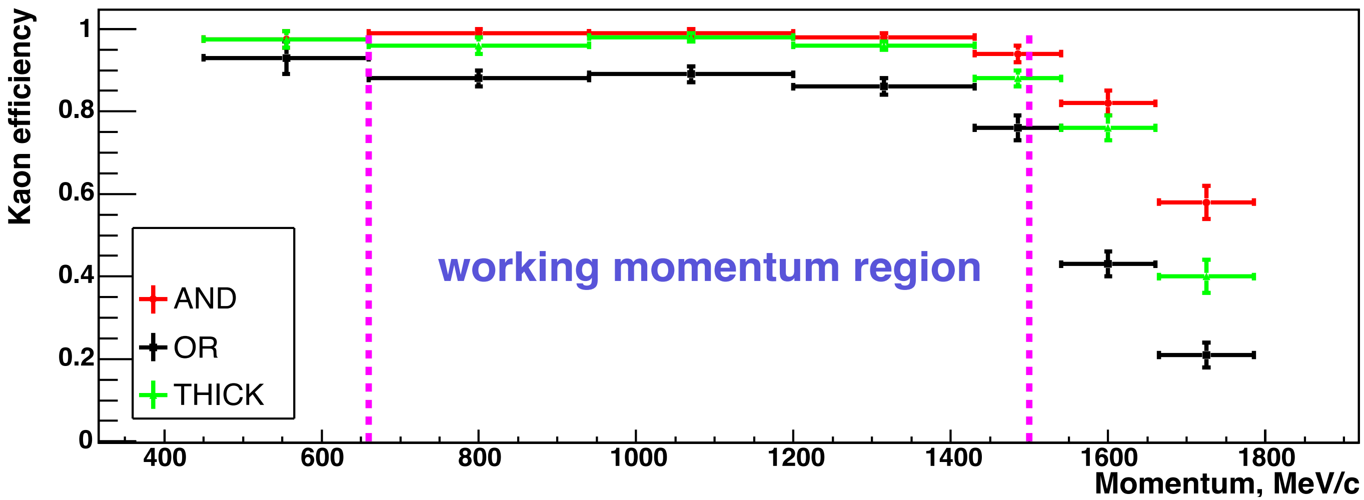


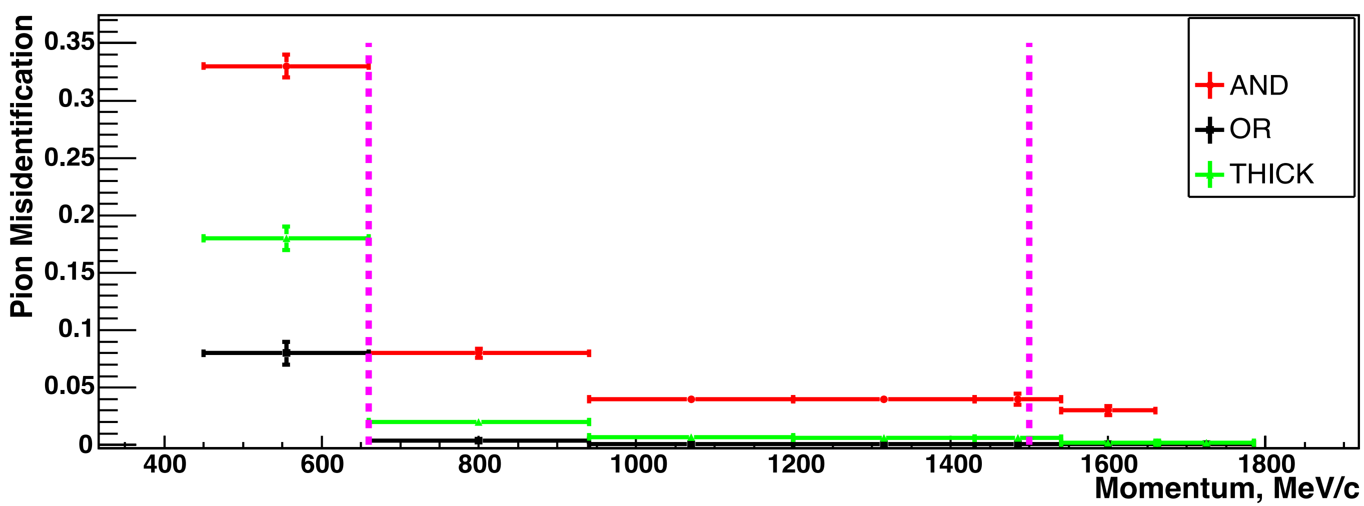
Threshold 2.0 ph.e.

Alvantages:

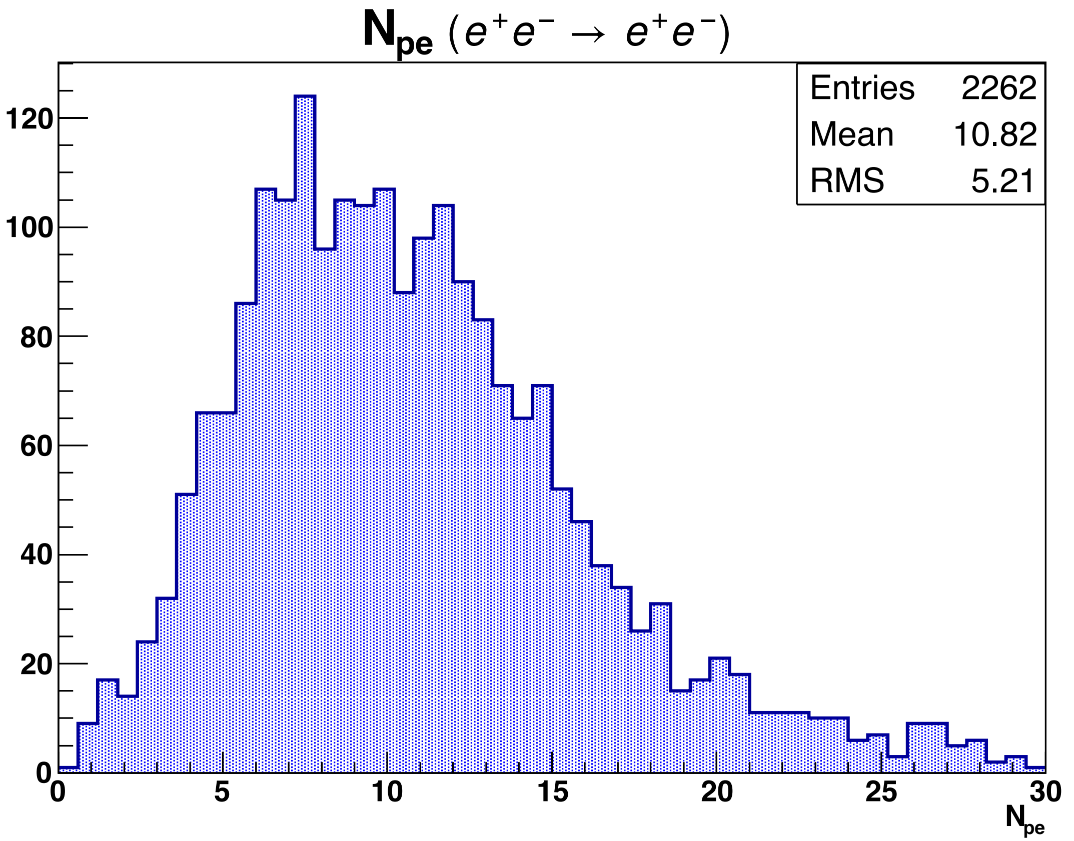
- More uniform signal from different parts of the system
- It is possible to set large threshold to suppress noises etc.

Two layer system efficiency (approach comparison)





e^+e^-->e^+e^- suppression



Amplitude spectrum of the THICK system

- For one layer suppression factor:
  - 50 for barrel
  - 70 for endcap
- For double layer (THICK):
  - 2200 for barrel
  - 2500 for endcap

Summary

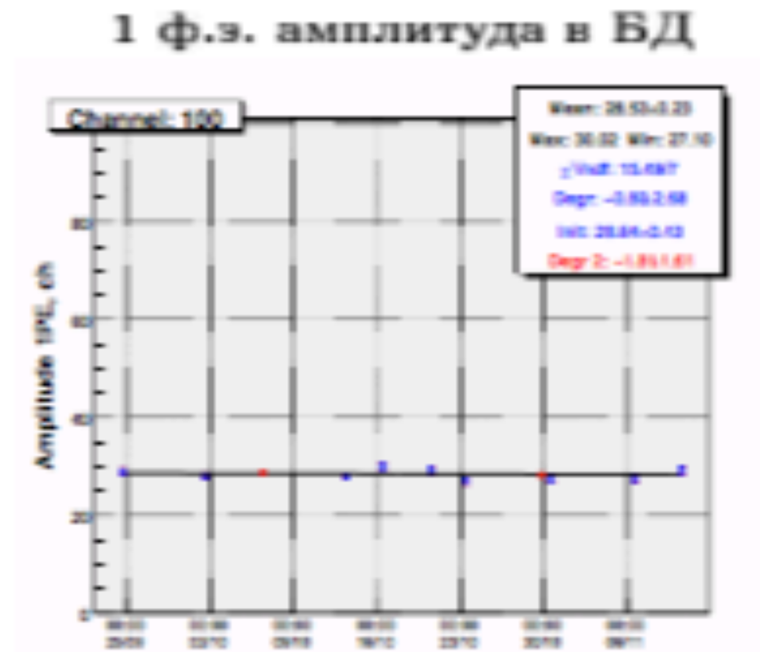
- The ASHIPH technique of Cherenkov light collection was developed in BINP. It allowed us to decrease significantly the photocathodes area and amount of material before the calorimeter.
- The fully installed ASHIPH system began its operation at the KEDR detector in 2014.
- The first results on the full system efficiency for particles of different momenta has been obtained.
  - 1. Average number of photoelectrons for relativistic cosmic muons (>1GeV/c) that cross both counter layers:
    - 9.6± 0.4
  - 2. BhaBha electrons:
    - 10.8 ± 0.2
  - 3. Detection efficiency for muons with ($700<P_{\mu}<1100$MeV/c) is ($1-(7\pm 1)\cdot 10^{-3}$) for threshold on the amplitude sum equal to 2.0 photoelectron.
  - 4. Detection efficiency for under-threshold muons ($200<P_{\mu}<300$MeV/c) in the same approach is 0.03±0.01.
  - These data correspond to π/K-separation better than 4 sigma in the momentum range from 0.95 to 1.45 GeV/c.

The End

BACKUP

Calibration of PMT’s gain in ASHIPH system of the KEDR detector

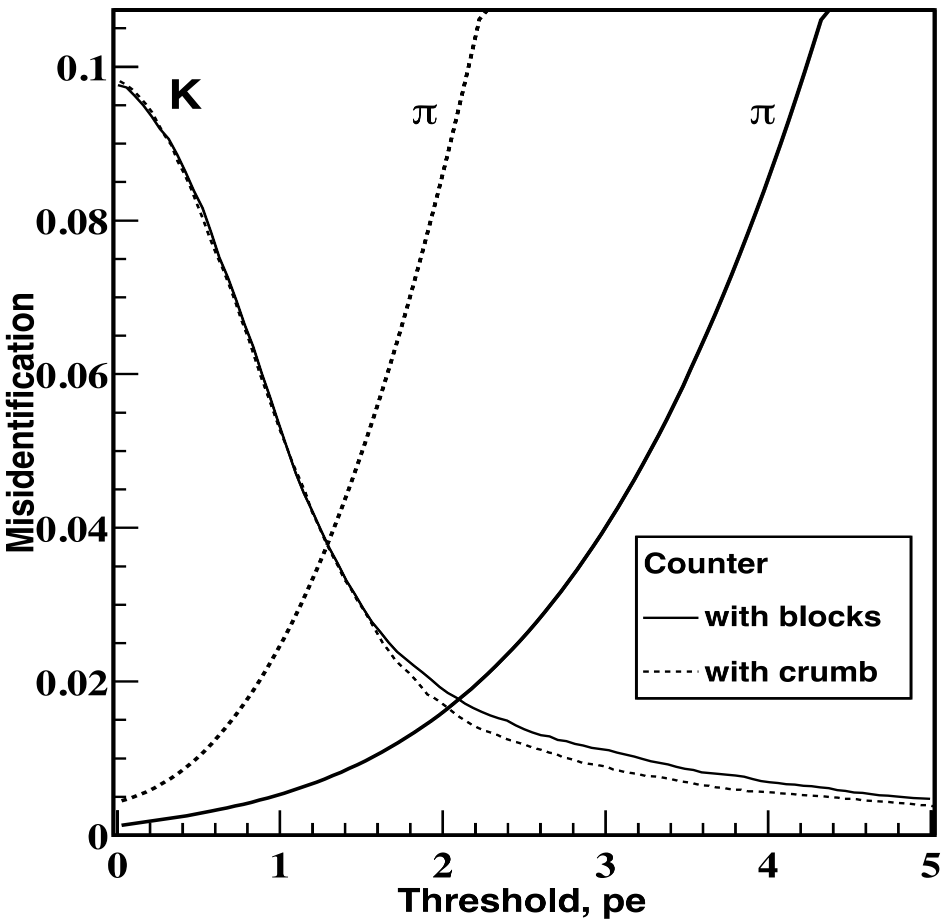
Single photoelectron spectrum



Stability of 1 ph.e. amplitude in time

Prototype investigation

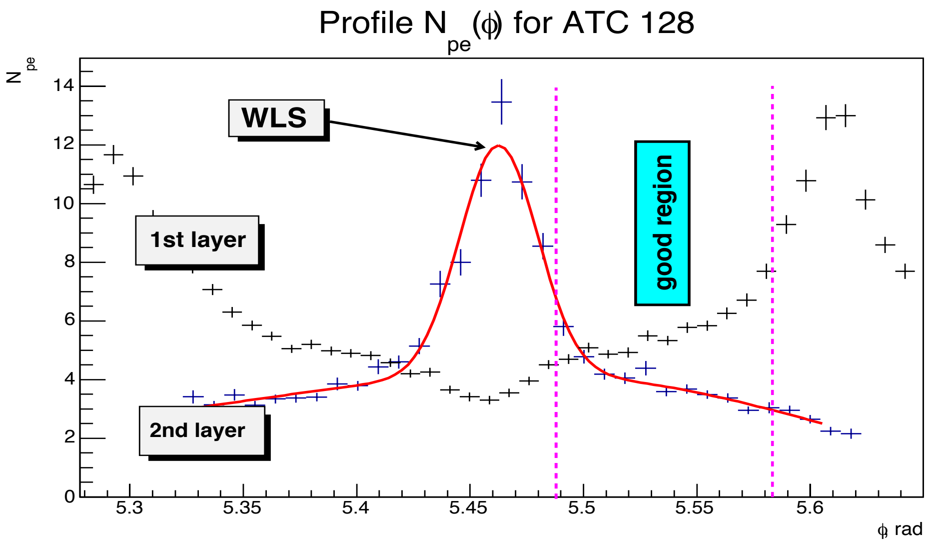
P=1.2GeV/c

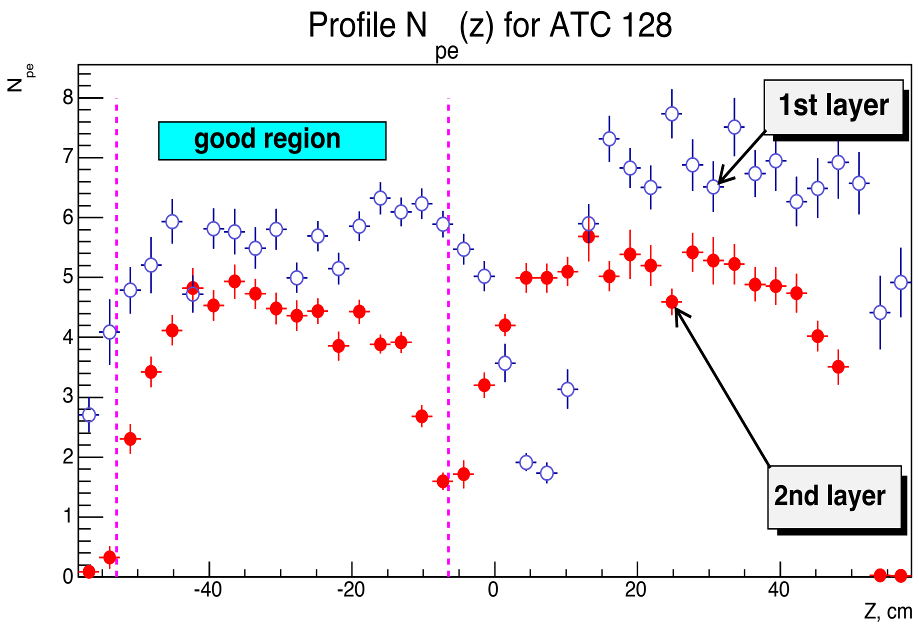


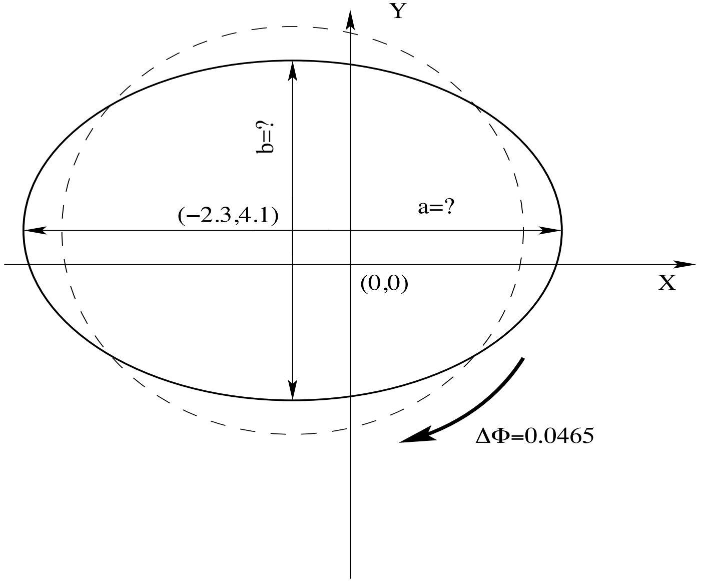
P, GeV/c	Pion suppress.	Kaon eff.	Sepparation
0.86	900	94%	4.7σ
1.2	1300	90%	4.5σ

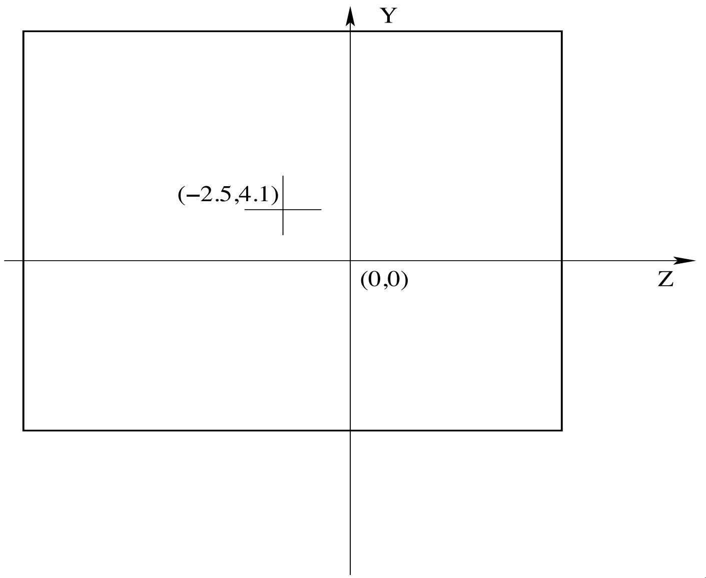
A.Yu.Barnyakov et al. NIM A478 (2002) 353-356

ATC system alignment

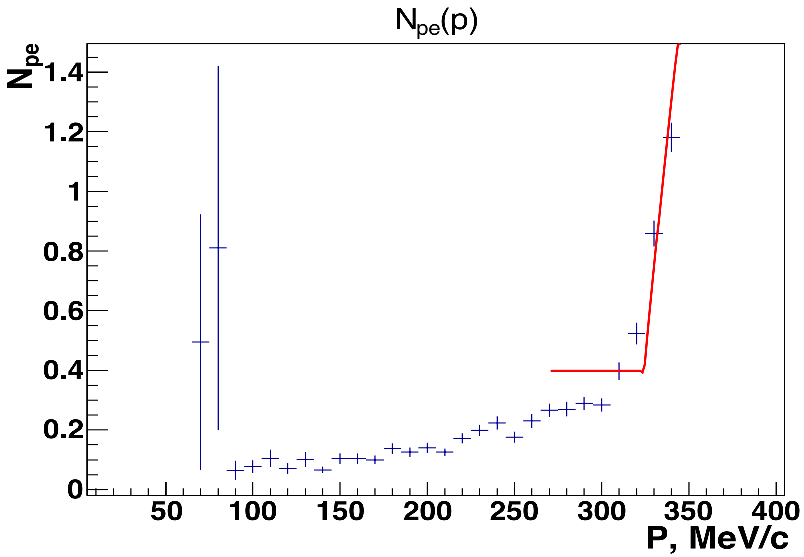


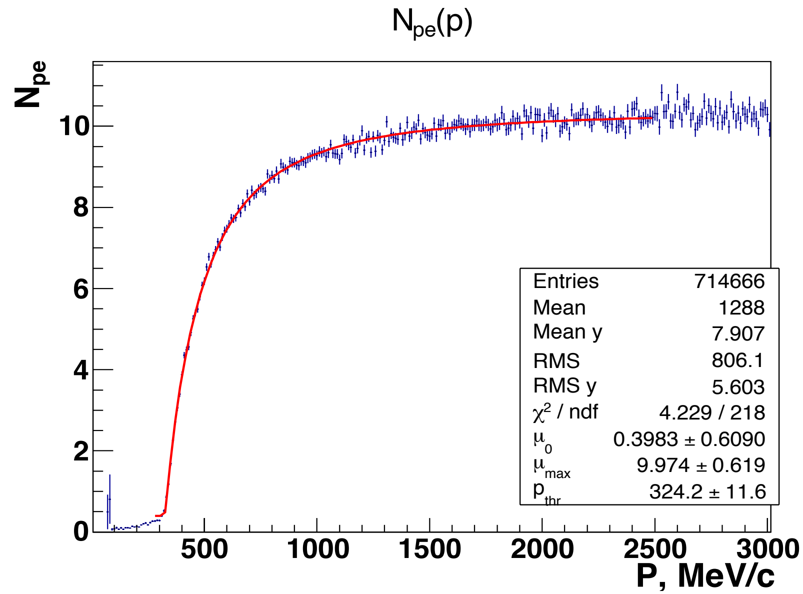




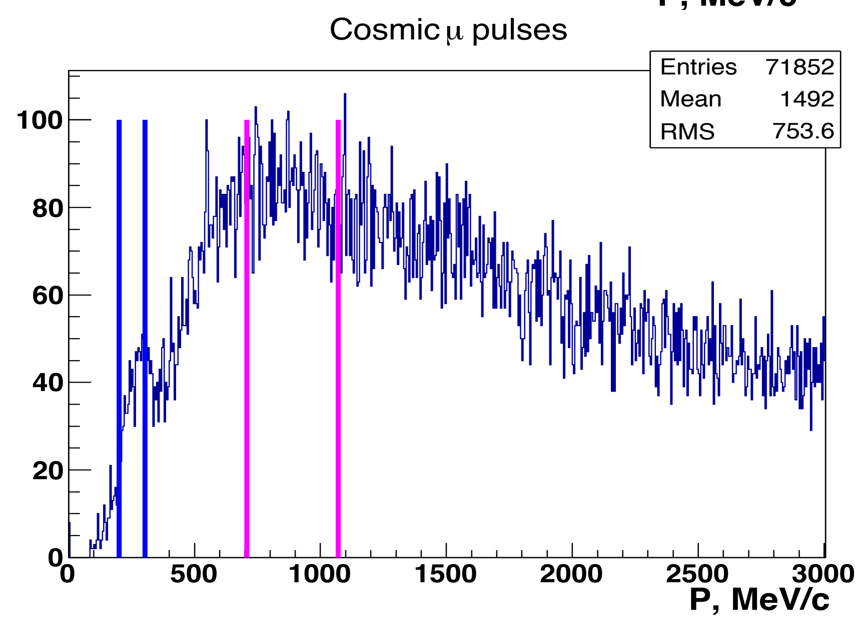


Amplitude versus momentum

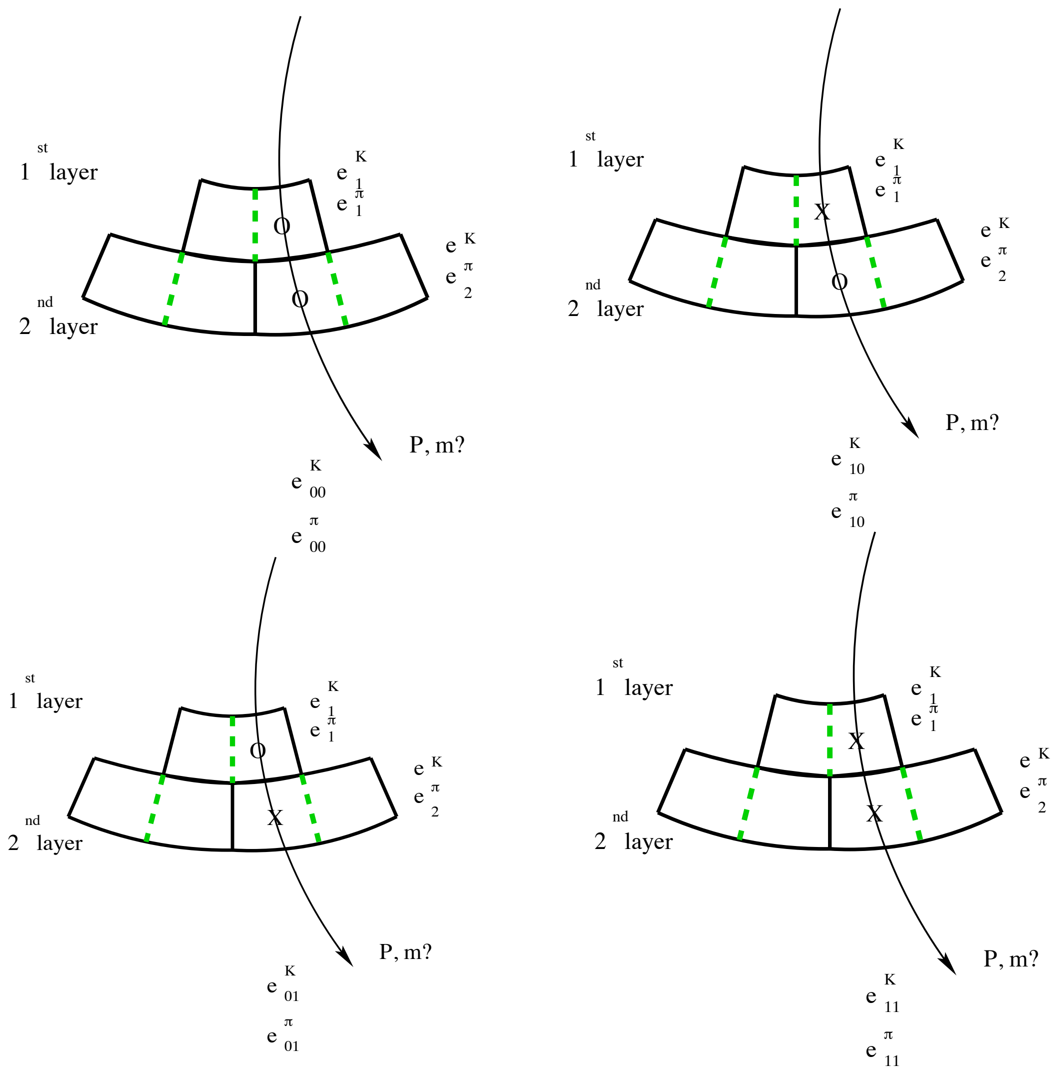




- Main sources of under threshold signal:
- P_μ<110MeV/c – only scintillation in PTFE
- P_μ >110MeV/c – Cherenkov light from PTFE
- P_μ > 130MeV/c – Cherenkov light from δ-electrons in aerogel



Two layer system: correlated events



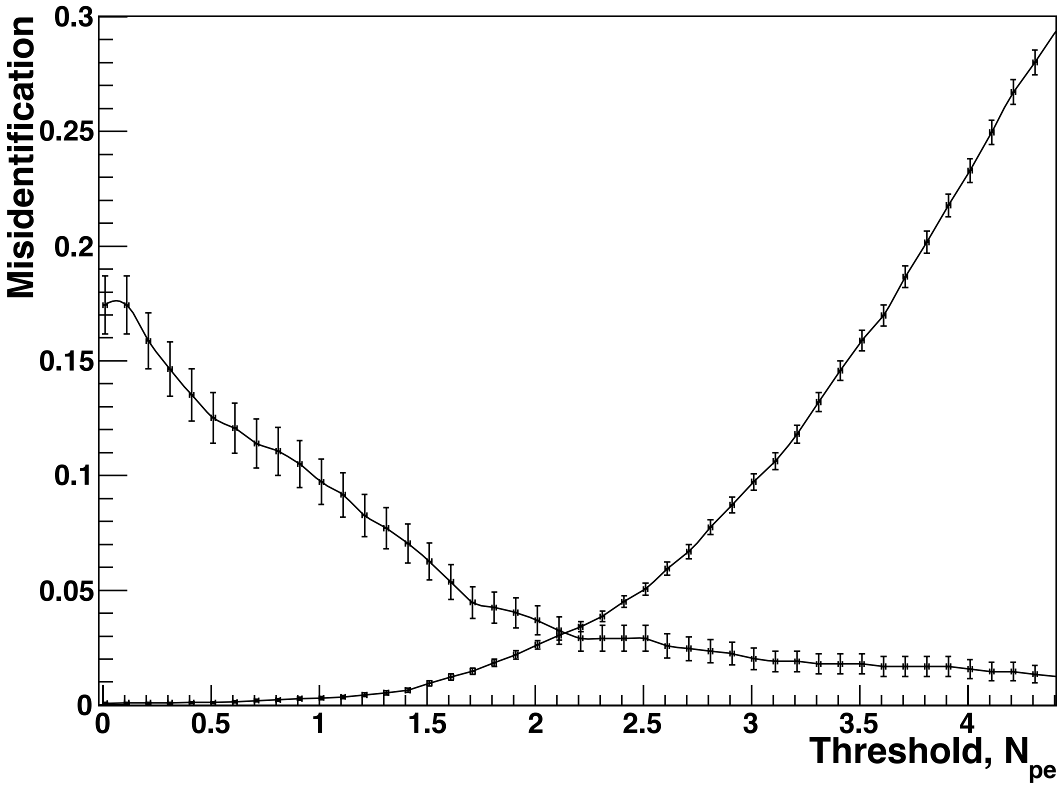
P_K=940 – 1430 MэB/c N_K=775, ε_1=0.06 ε_2=0.11	
ε_{00}=0.85	ε_{10}=0.04
ε_{01}=0.09	ε_{11}=0.018

$N_K*\varepsilon_1*\varepsilon_2/N_K*\varepsilon_{11}=5/14$

P_π=940 – 1430 MэB/c N_π=5951, ε_1=0.996 ε_2=0.994	
ε_{00}=8.4e-4	ε_{10}=5.3e-3
ε_{01}=3.2e-3	ε_{11}=0 .994

$N_\pi*(1-\varepsilon_1)*(1-\varepsilon_2)/N_\pi*\varepsilon00=0.14/5$

Two layer system: «OR»



940MэB/c < $P_{\pi,K}$< 1430MэB/c

«Pion» -- if the signal is in one layer at least.

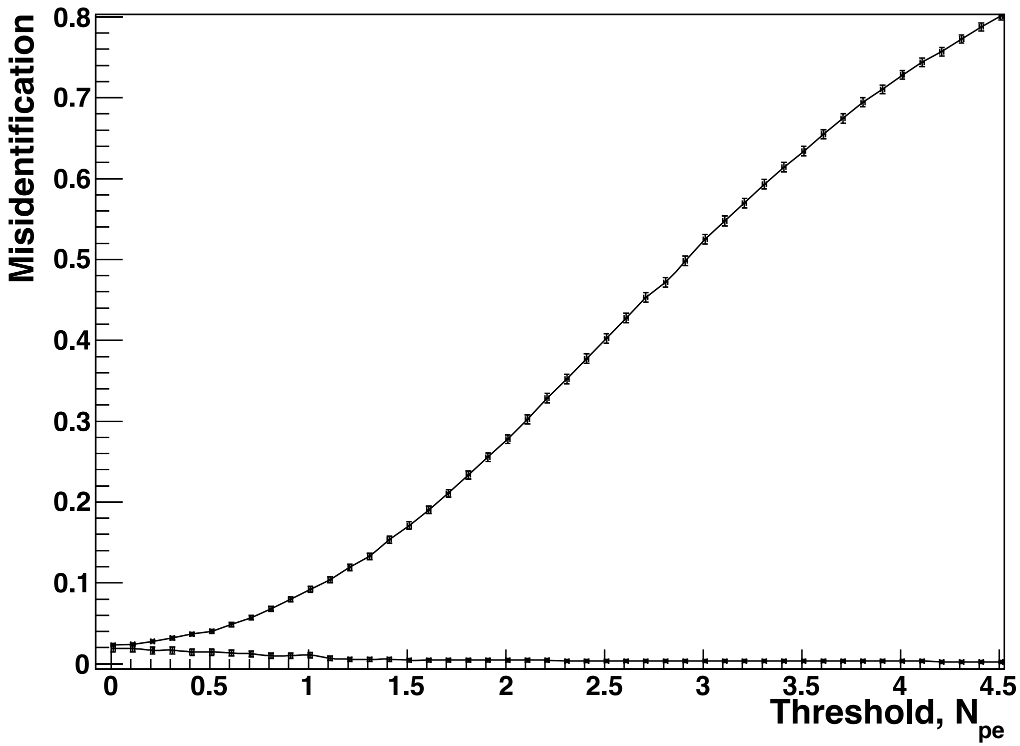
«Kaon» – if the signal is absent in both layers

$\varepsilon_K=\varepsilon_{00}^K$

$1-\varepsilon_\pi=1-\varepsilon_{00}^\pi$

Kaons -> 200< P_μ < 300 MeV/c : 0.885<β<0.944
Pions -> 700< P_μ < 1100 MeV/c : 0.989<β<0.995

Two layer system : «AND»



«Pion» --if the signal is in both layers.

«Kaon» – if the signal is absent in one layer at least.

$\varepsilon_K = 1 - \varepsilon_{11}^K$

$1 - \varepsilon_\pi = 1 - \varepsilon_{11}^\pi$

940MeV/c < $P_{\pi,K}$ < 1430MeV/c

Kaons -> 200< P_μ < 300 MeV/c : 0.885<β<0.944
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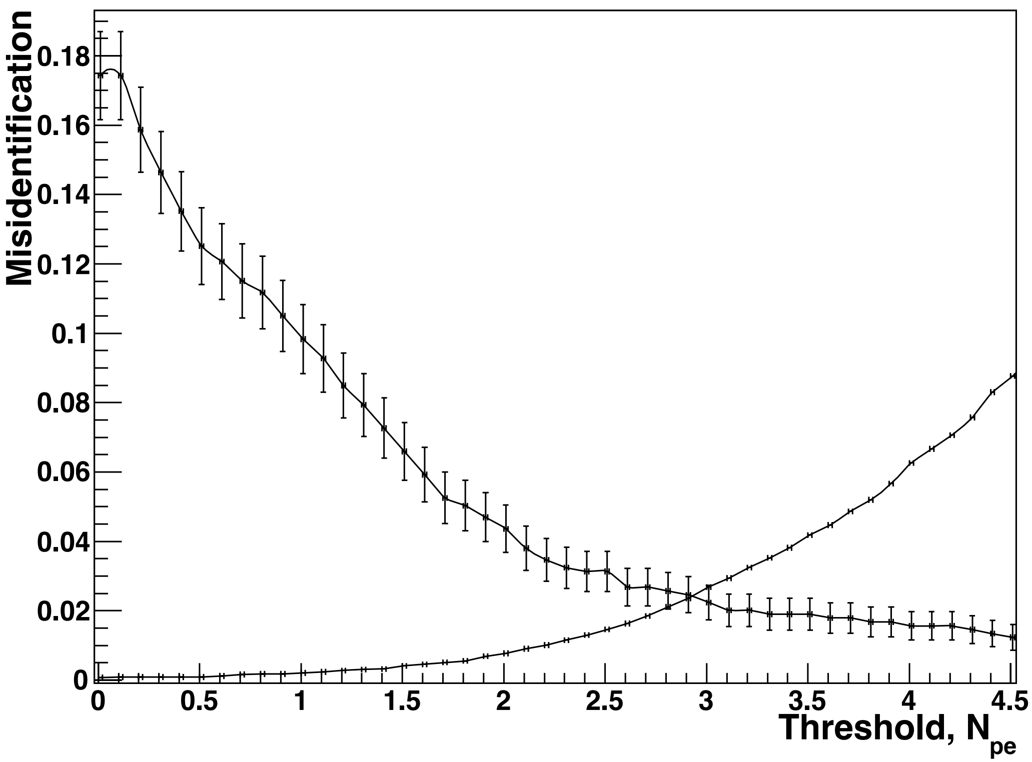
Two layer system: “THICK”



940MeV/c < $P_{\pi,K}$< 1430MeV/c

Sum amplitude for the track is determined.

«Kaon» – if the amplitude is less than threshold.

«Pion» – if the amplitude is higher than threshold.

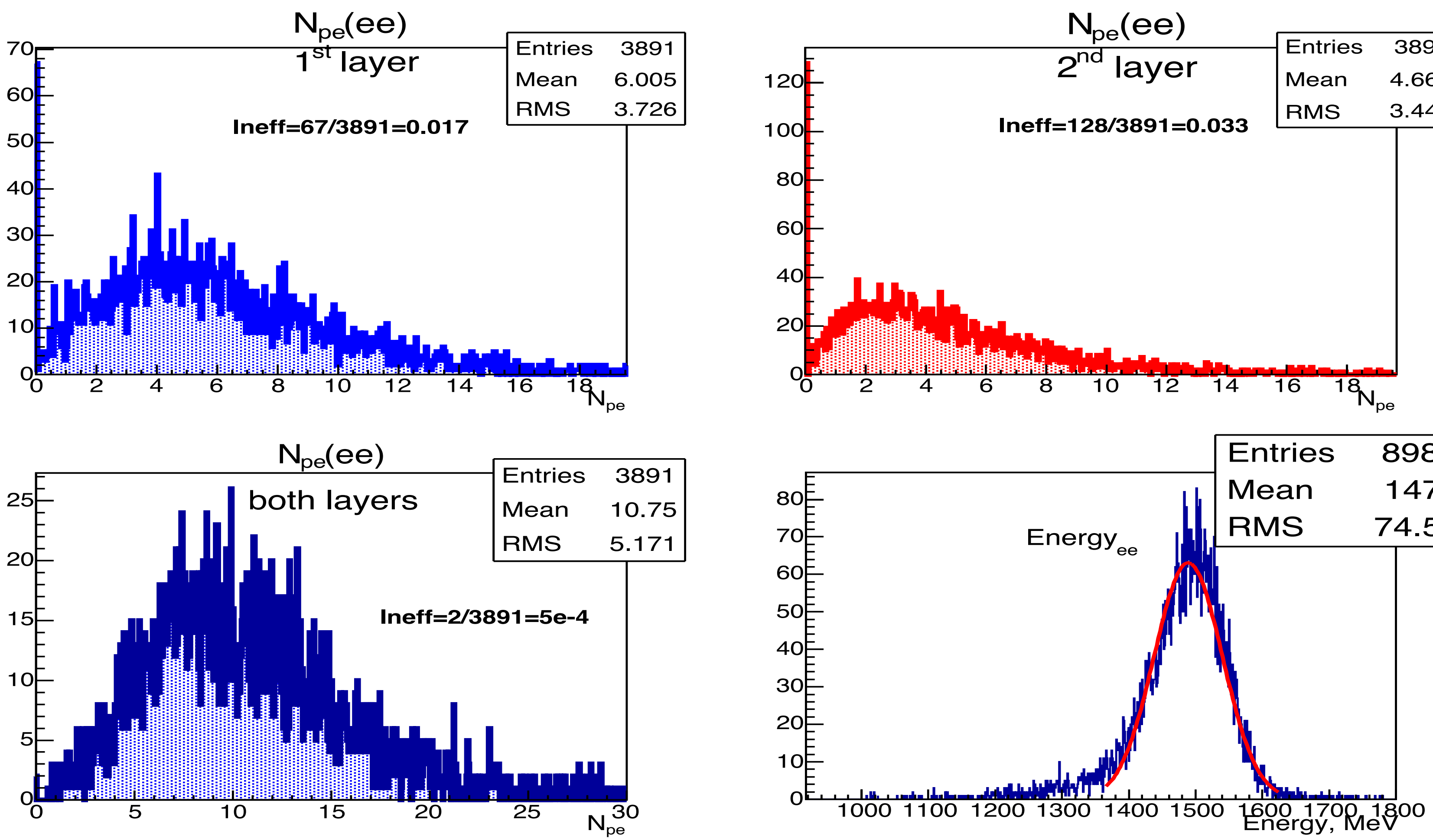
.

Kaons -> 200< P_{μ} < 300 MeV/c : 0.885<β<0.944
Pions -> 700< P_{μ} < 1100 MeV/c : 0.989<β<0.995

Two layer system: efficiency

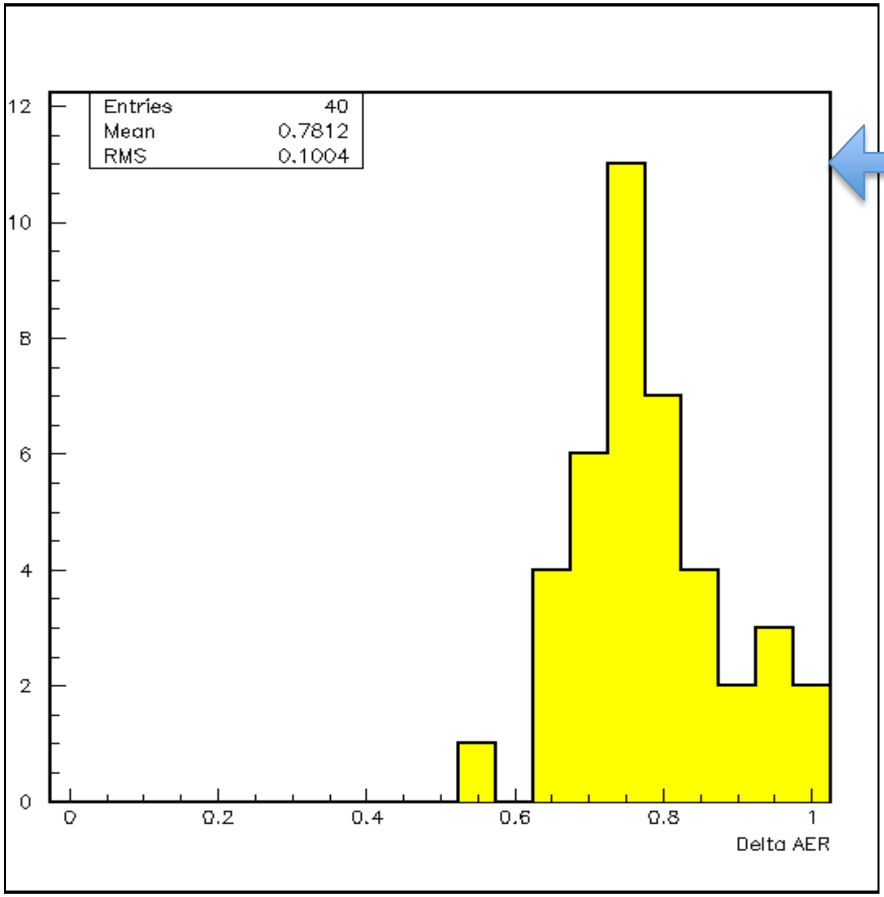
$P_{\pi,K}$	«AND» threshold 0.5ph.e.			«OR» threshold 0.5фэ			«THICK» threshold 2.0ph.e.		
ГэВ/с	ε_K	$1-\varepsilon_\pi$	σ	ε_K	$1-\varepsilon_\pi$	σ	ε_K	$1-\varepsilon_\pi$	σ
0.45-0.66	>0.975	0.33±0.01	2.4	0.93±0.04	0.08±0.01	2.9	>0.975	0.18±0.01	2.9
0.66-0.94	0.99±0.01	0.08±0.004	3.7	0.88±0.02	$(4\pm1)\cdot10^{-3}$	3.8	0.96±0.02	0.021±0.003	3.8
0.94-1.2	0.99±0.01	0.04±0.003	4.1	0.89±0.02	$(1.\pm0.6)\cdot10^{-3}$	4.3	0.98±0.01	$(7\pm1)\cdot10^{-3}$	4.5
1.2-1.43	0.98±0.01	0.04±0.003	3.9	0.86±0.02	$(7\pm5)\cdot10^{-4}$	4.3	0.96±0.01	$(6\pm1)\cdot10^{-3}$	4.2
1.43-1.55	0.94±0.02	0.04±0.005	3.4	0.76±0.03	$(7\pm7)\cdot10^{-4}$	3.9	0.88±0.02	$(6\pm2)\cdot10^{-3}$	3.7
1.55-1.65	0.82±0.03	0.03±0.004	3.0	0.43±0.03	$<7\cdot10^{-4}$	3.0	0.76±0.03	$(2\pm1)\cdot10^{-3}$	3.7
1.65-1.79	0.58±0.04	$(1\pm1)\cdot10^{-3}$	2.3	0.21±0.03	$(1\pm1)\cdot10^{-3}$	2.4	0.40±0.04	$(2\pm1)\cdot10^{-3}$	2.6

Registration efficiency: $e^+e^- \to e^+e^-$



P>1.3ГэВ/с && EMC>1ГэВ && abs(Z)<55

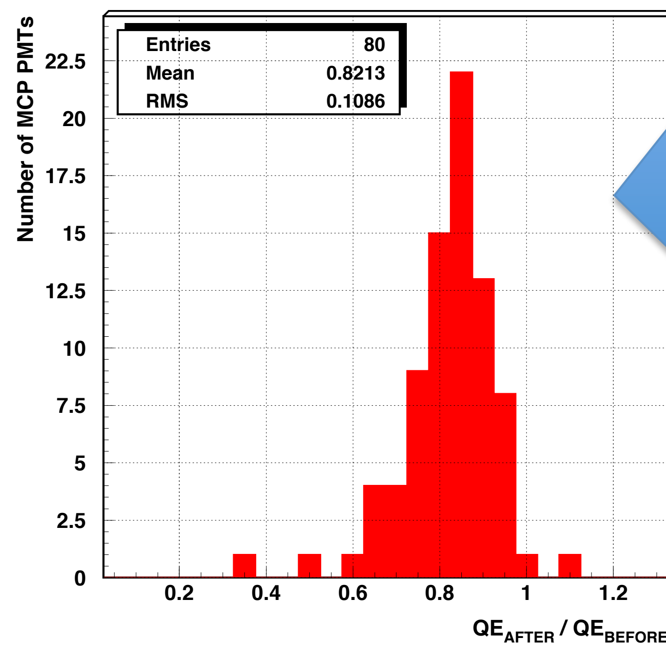
Reasons of degradation of ASHIPH counters



All counters of the 1st layer were inspected for the reasons of degradation, repaired and upgraded during the stop of the KEDR experiment in 2011-2013

The main reasons of the signal degradation

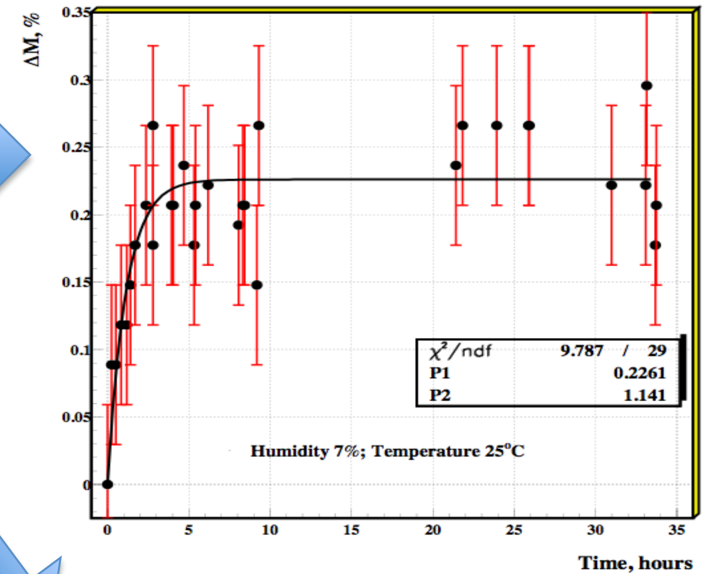
- Aerogel 0-45%. In average:
  - 22% for endcap
  - 34% for barrel
- QE of PMT 0-50%. In average 18%
- Magnetic field:
  - Tilt PMTs in endcap 4-6° (up to 20%)
  - Tilt PMTs in barrel 15-17° (up to 30%)
  - Broken optical contacts 0-54%. In average 9.5%

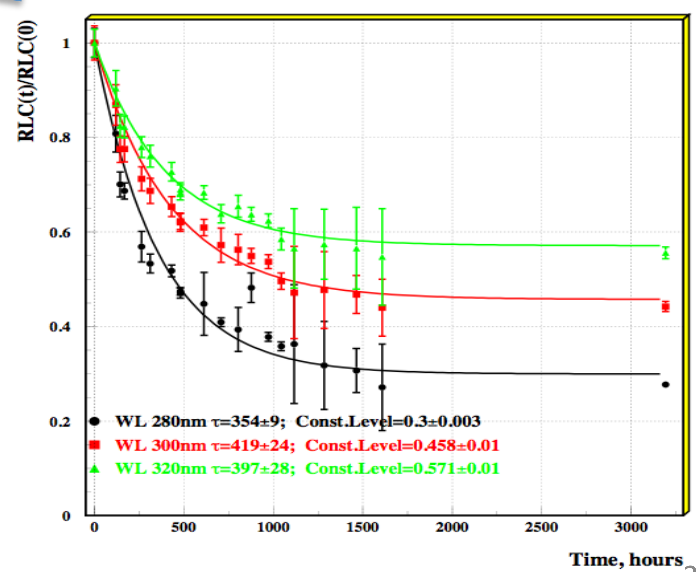


Details on MCP PMT in oral presentation of M. Barnyakov in the evening session

Aerogel degradation due to water adsorption

- Aerogel internal surface in 10^6 times greater than external. Adsorption of water is very fast process (1-2 hours).
- Degradation of light absorption length is very slow process (1-2 months) after water absorption.
- The time and level of the degradation are depend on impurities in aerogel from raw materials and production procedure (Fe, Mn, Cr, etc.).



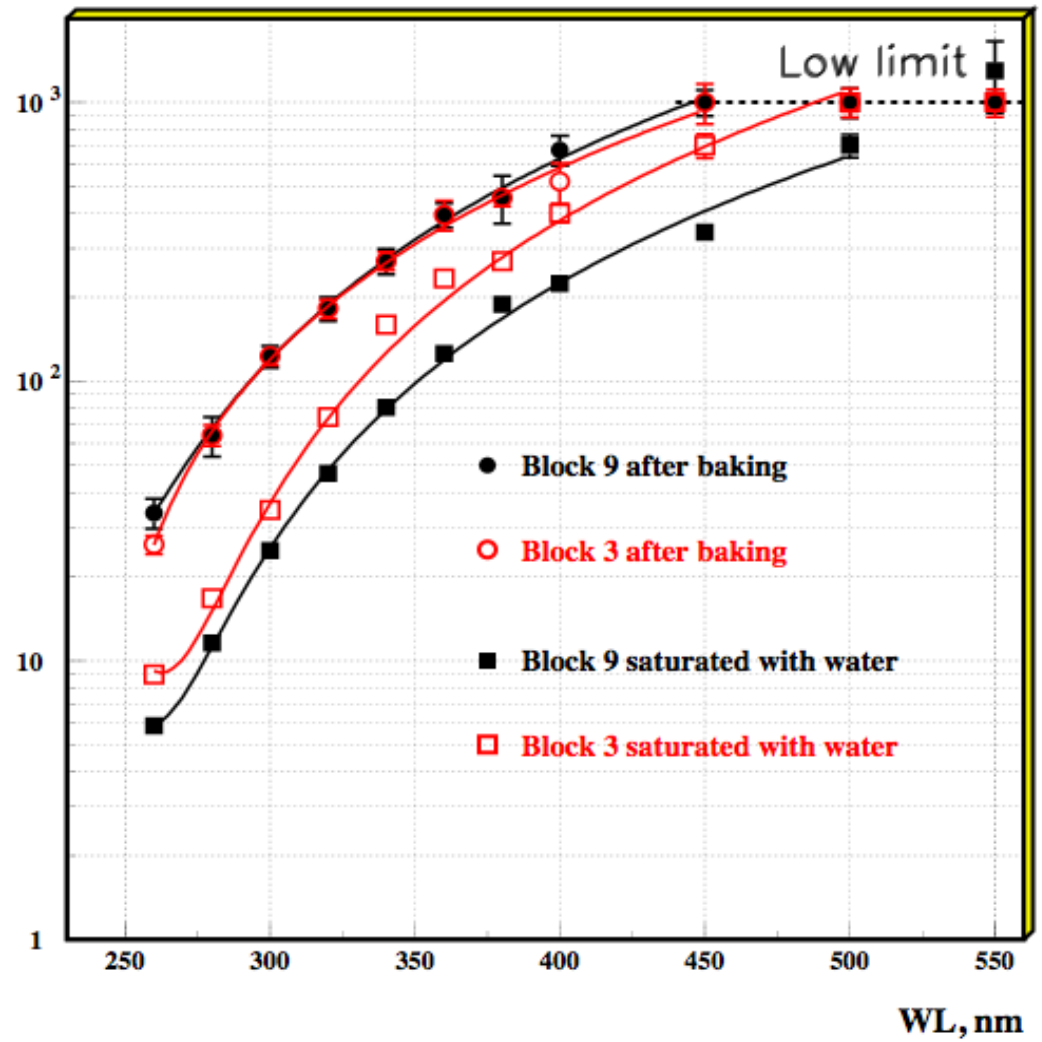


Concentration of metals in aerogel, ppb				
Fe	Cu	Mn	Cr	Ni
500	56	7	26	

Aerogel light absorption length

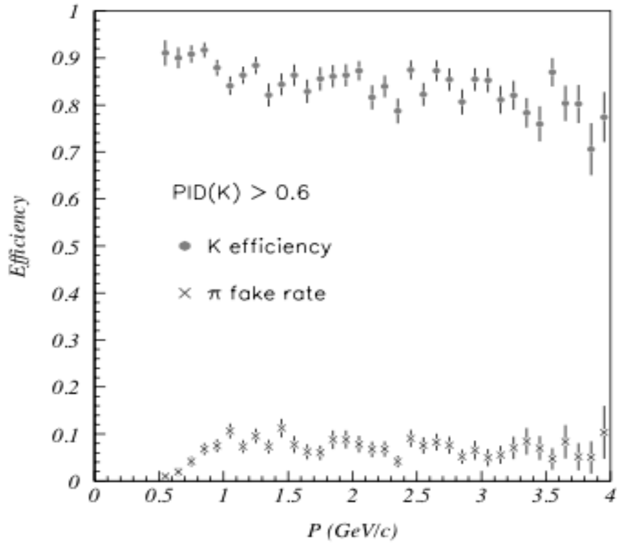
- Refractive index (n-1) and light scattering length depends on adsorbed water and are changed less than 10% after water adsorption of 2-4% of aerogel mass.
- Light absorption length (L_{abs}) in different aerogel samples after baking is the same, but after water impregnation is very different
- It is possible to make aerogel selection after water impregnation
- One atom Fe is able to attract 6 molecules of water
- To achieve maximum degradation of L_{abs} enough to adsorb 1ppm of water

(NIM A598 (2009) 166-168)

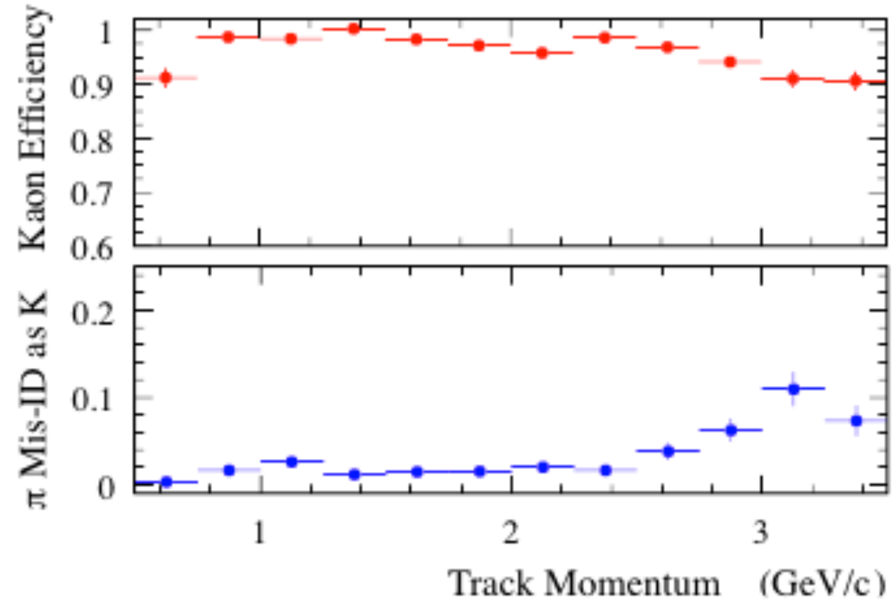


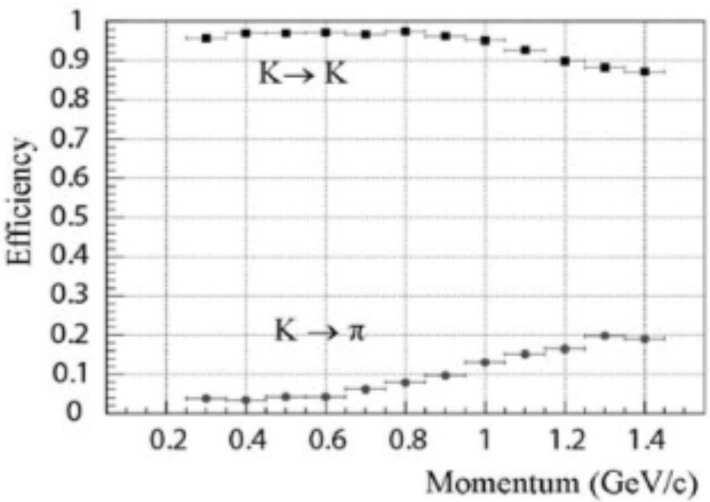
Comparison different PID systems

Belle: ACC



BaBar:DIRC





BES-III:TOF

- BaBar:DIRC – at P=1.2GeV/c -- separation ~4σ [D0 → K+π−]
- Belle:ACC – при P=1.2GeV/c – separation ~2.6σ [D*+ → D0(Kπ)π^+]
- BESIII:TOF – at P<0.9GeV/c – separation ~3σ [calculation and simulation]
- KEDR: ASHIPH – at P=1.2GeV/c –separation ~4.3σ [cosmic muons]