Cross section measurement of the process $e^+e^- \to K^+K^-\pi^+\pi^-$ at the VEPP-2000 e^+e^- collider with the CMD-3 detector

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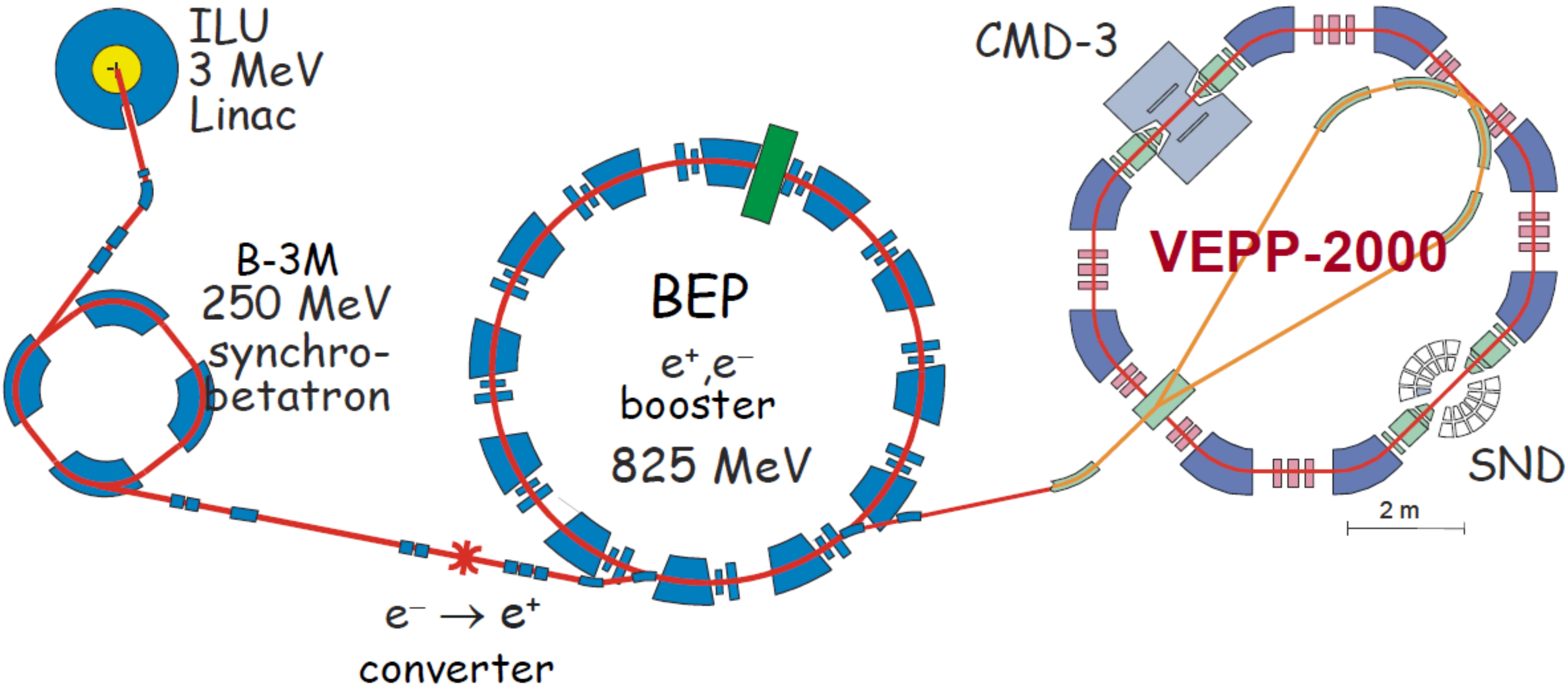
Outline

- **VEPP-2000**
- **CMD-3**
- $e^+e^- \longrightarrow K^+K^-\pi^+\pi^-$
- **Conclusion**

VEPP-2000

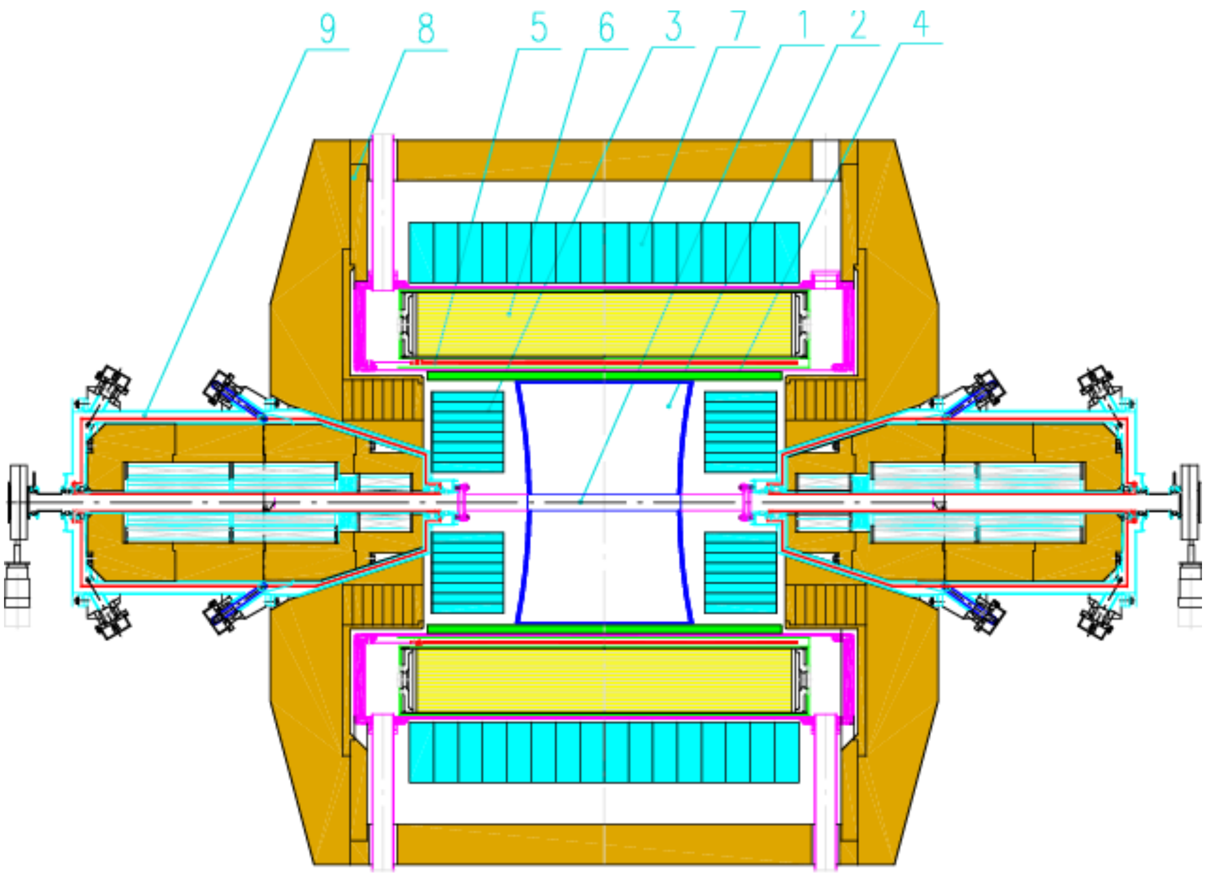


Maximum c.m. energy is 2 GeV, design luminosity is $L = 10^{32} 1/cm^2s$ at $\sqrt{s} = 2$ GeV

Unique optics, "round beams", allows to reach higher luminosity

Experiments with two detectors, CMD-3 and SND, started by the end of 2010

CMD-3 detector



1 – beam pipe,
2 – drift chamber,
3 – electromagnetic BGO calorimeter,
4 – Z – chamber,
5 – CMD SC solenoid(1.3 Tl),
6 – electromagnetic LXe calorimeter,
7 – electromagnetic CsI calorimeter,
8 – yoke,
9 – VEPP-2000 solenoid,
(not shown) muon range system and TOF system

~ 22 pb^{-1} has been collected in the center-of-mass energy region from 1.5 to 2 GeV

Motivation

- Study intermediate states

- Measure parameters of intermediate mesons

- Calculation of hadronic contribution to anomalous magnetic moment of muon

ArXiv:1010.4180,arXiv:1105.3149

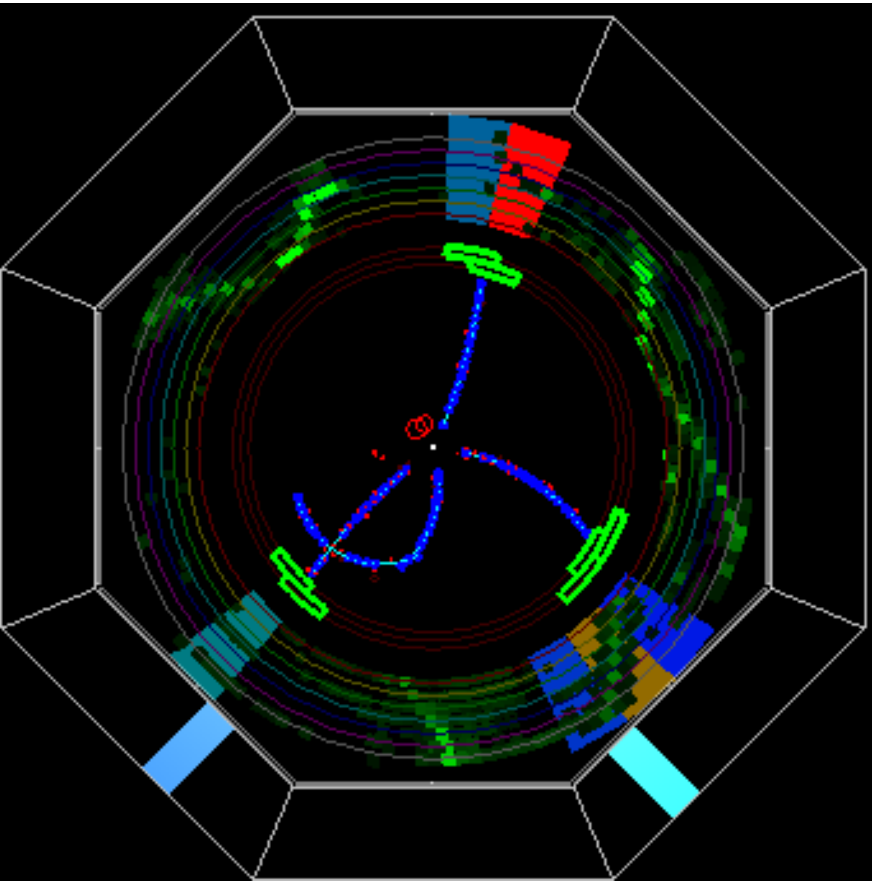
New (g-2) experiments at FNAL and J-PARC have plans to improve the precision by a factor of four to the level $1.5\text{x}10^{-10}$

LO hadronic contribution (694.1 ±4.3) x 10^{-10} HLMNT 11

KK2π c.m. energy region below 2 GeV (3.31 ± 0.58) x 10^{-10} , based on BaBar. arXiv: 1105.3149

Event selection

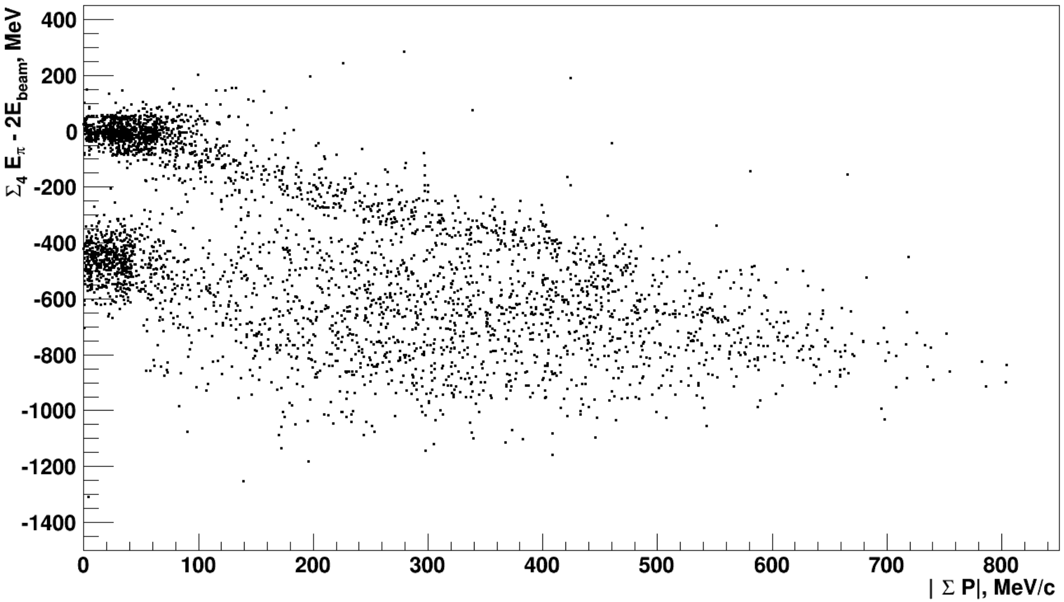
Display of $K^+K^-\pi^+\pi^-$ event in CMD-3



When all four particles have tracks in DC, energy-momentum conservation is used to extract $e^+e^- \to K^+K^-\pi^+\pi^-$ events.

Momentum of charged particle is reconstructed from the track curvature in DC.

Particle type is identified using information about ionization losses (dE/dX) in DC.



K/π separation based on dE/dx in DC

Particle separation is based on minimization of the maximum likelihood function.

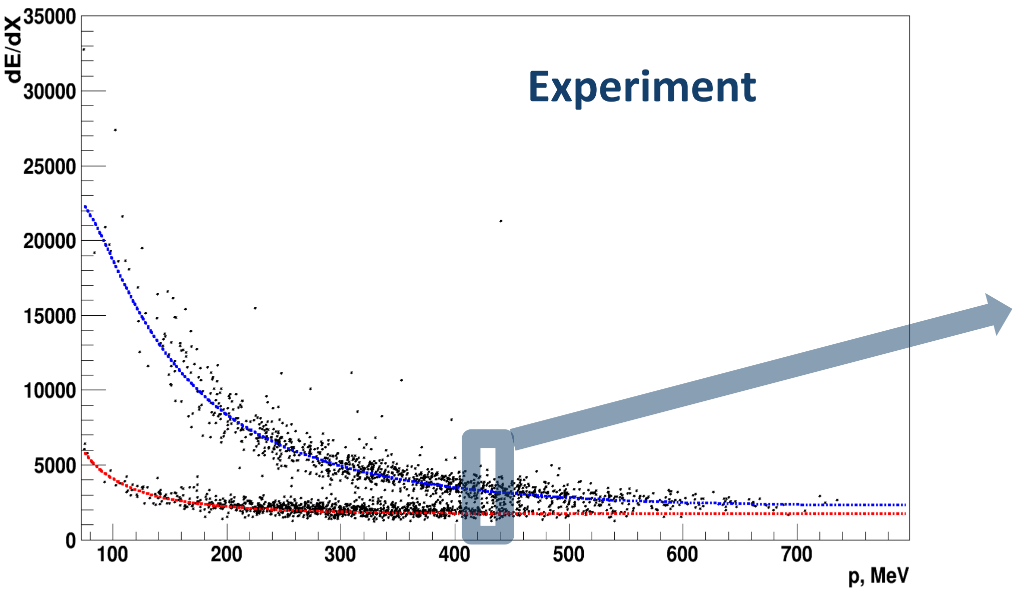
Probability density function with momentum and dE/dx as parameters is constructed for kaons f_K(p,dE/dx) and pions f_π(p,dE/dx).

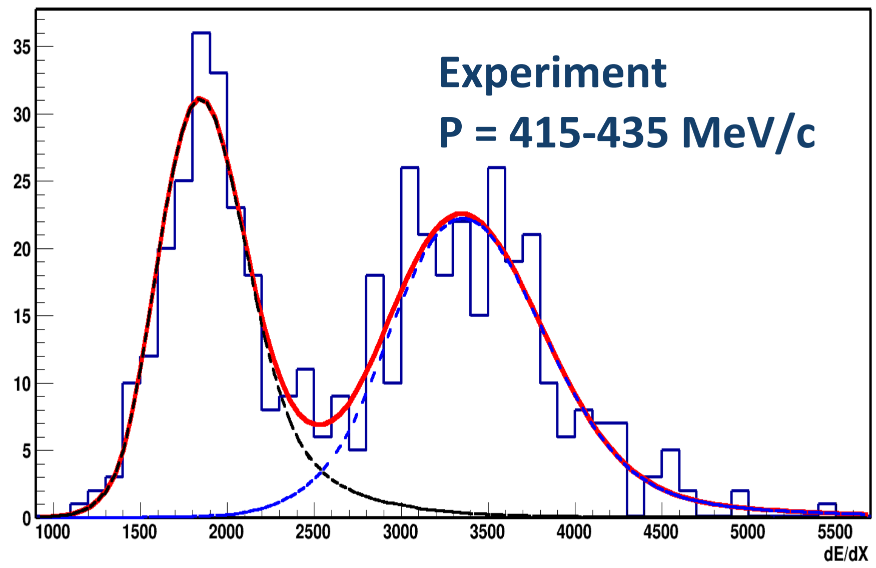
Likelihood function $L_{KK\pi\pi}$ is probability that a four-track event is $K^+K^-\pi^+\pi^-$ and defined as:

$$L_{KK\pi\pi}\left(p,\frac{dE}{dX},ai\right) = Ln\left(\prod_i \frac{f_{ai}\left(p_i,\frac{dE}{dX_i}\right)}{f_\pi\left(p_i,\frac{dE}{dX_i}\right)+f_K\left(p_i,\frac{dE}{dX_i}\right)}\right),$$

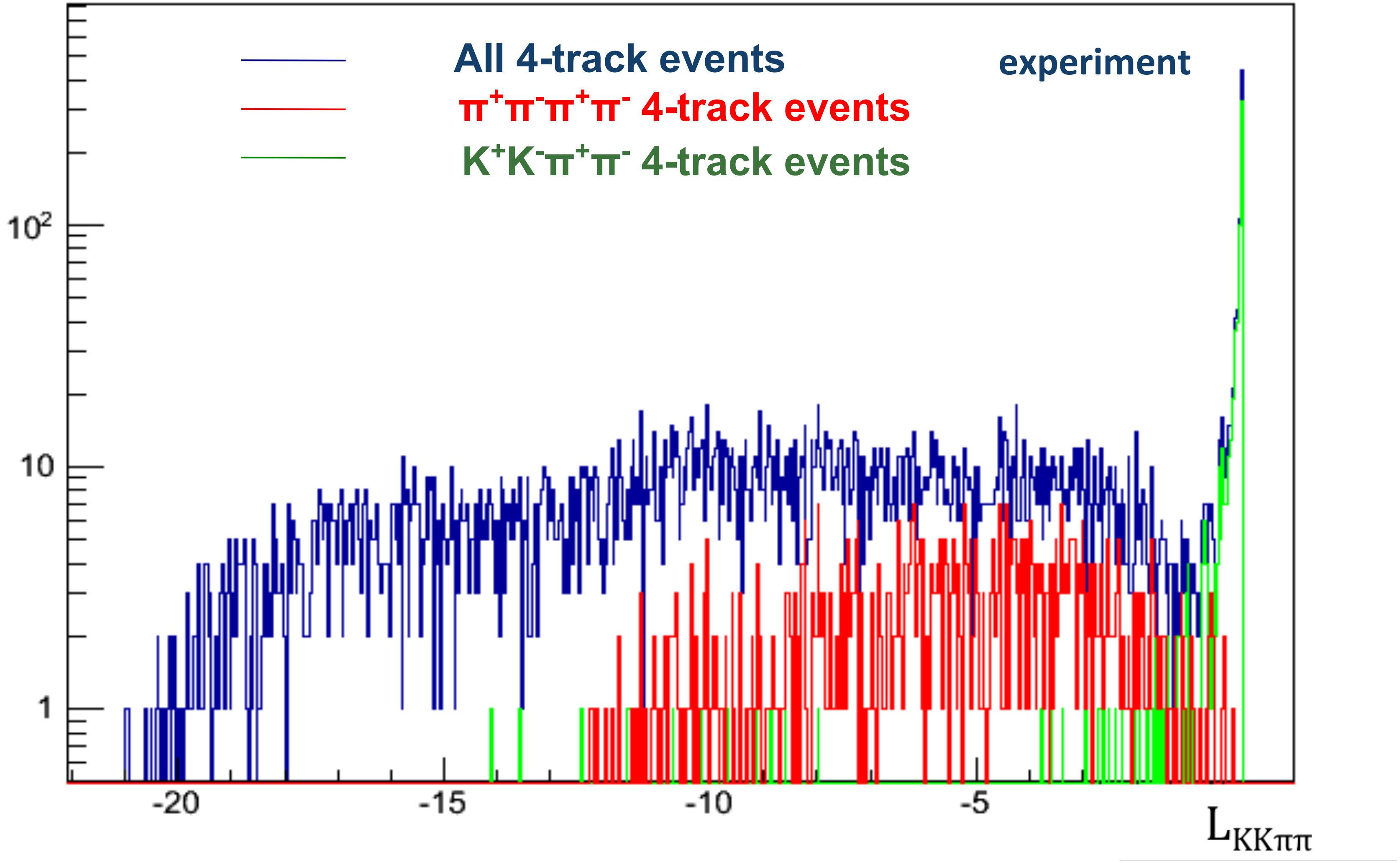
i – track index, alpha_i (α_i) – type of particle for i-track.

$L_{KK\pi\pi}$ maximum corresponds to the most probable alpha_i (α_i) combination.

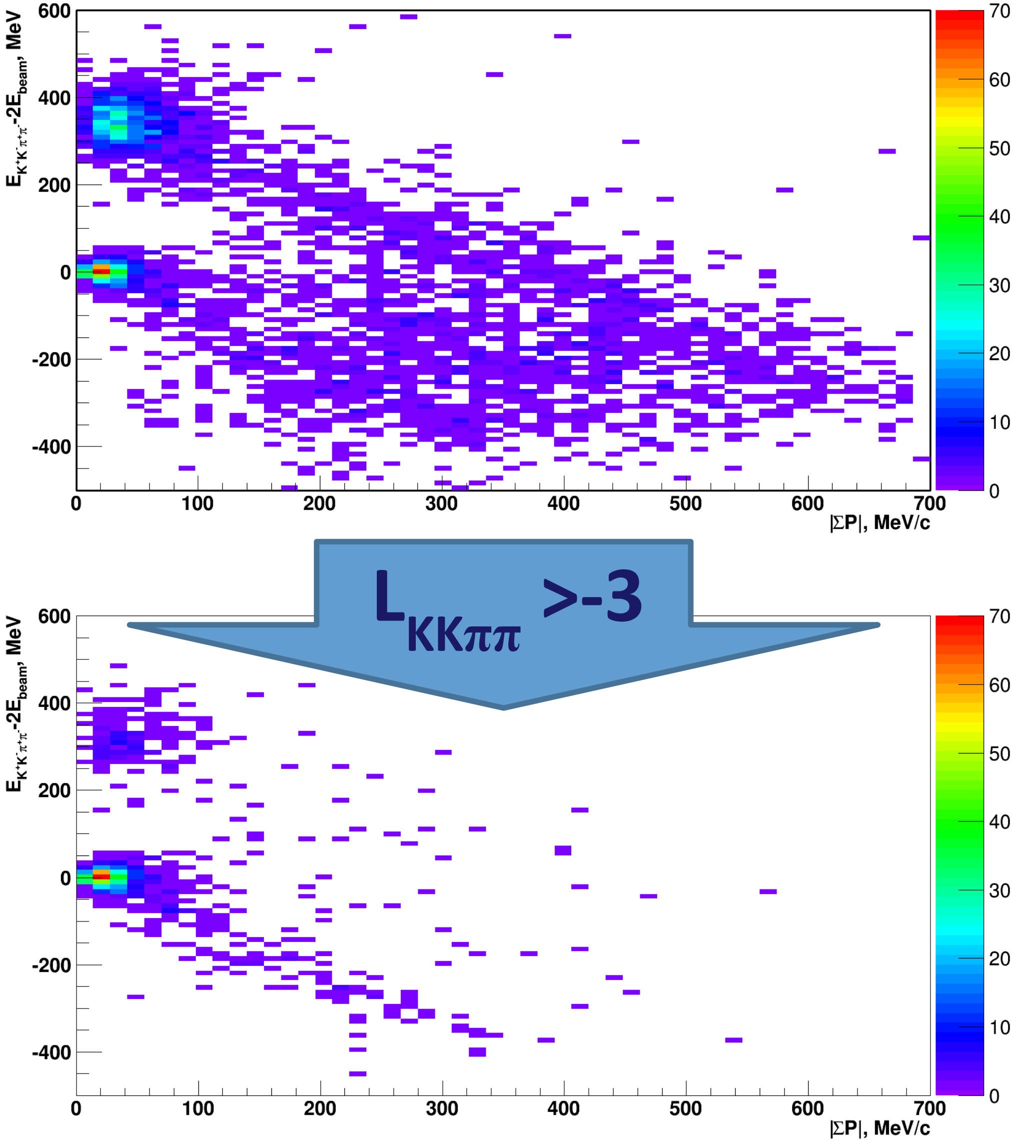




Using $L_{KK\pi\pi}$ for background rejection



Four-track events



Energy vs momentum histograms are presented for four-track events.

Conditions:

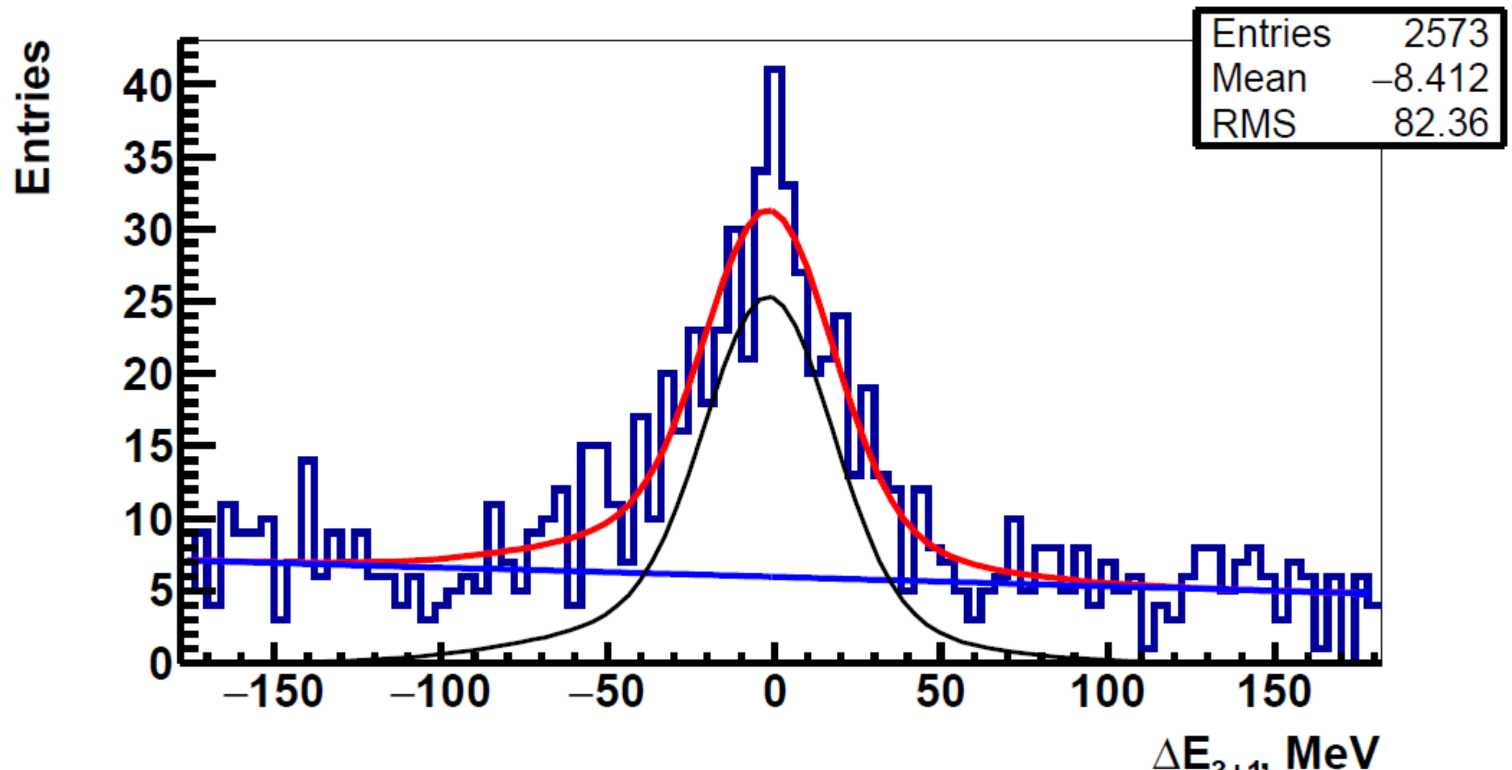
$|\sum E - 2*E_{beam}|<80$ MeV
$|\sum P|<80$ MeV/c
$L_{KK\pi\pi}>-3$

Cut on likelihood value allows to suppress background by factor of 10. It was obtained from simulation of background processes.

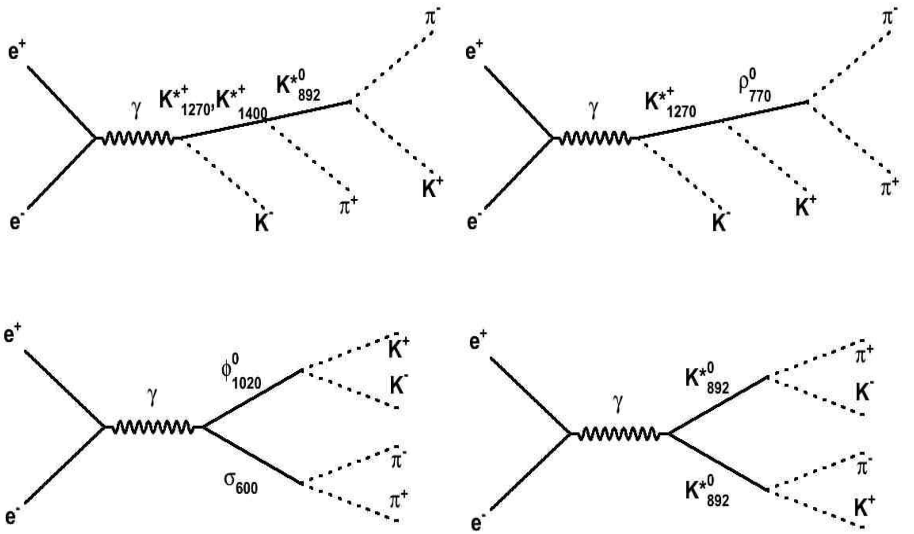
Events with one missing track in DC

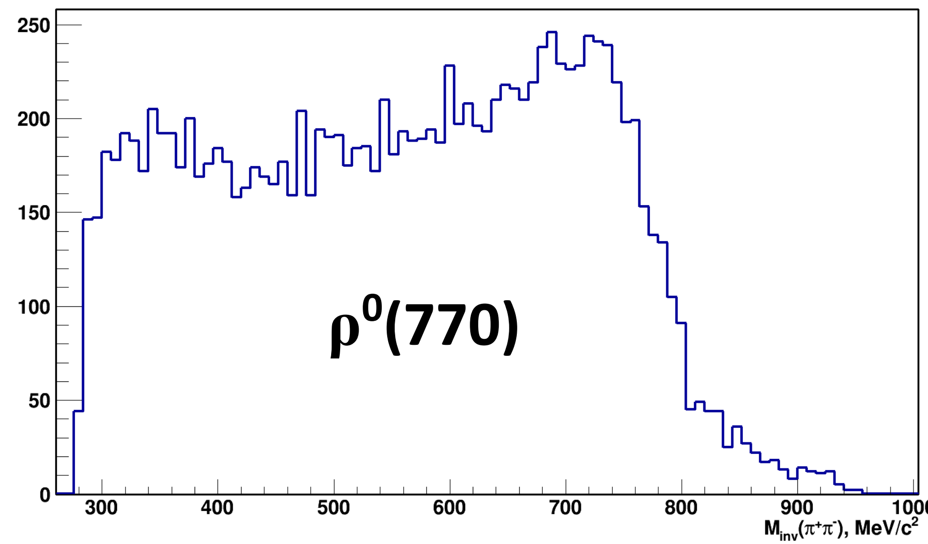
Likelihood function $L_{KK\pi\pi}$ for three track events is constructed in the same way, as it was done for $L_{KK\pi\pi}$ for four track events.
Momentum of fourth particle is determined by momentum conservation law.

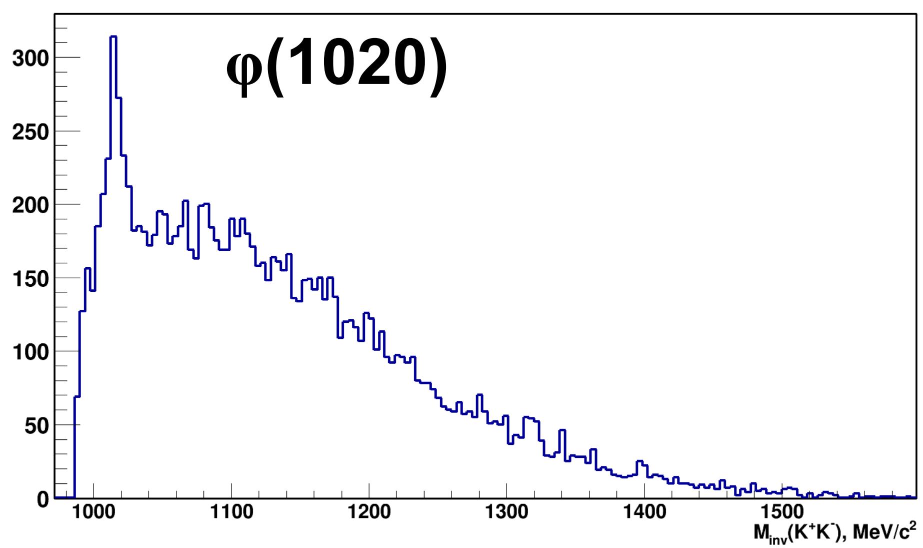
Events with a missing particle mainly appear due to the limited DC acceptance, in addition, some tracks are not reconstructed due to a DC inefficiency.

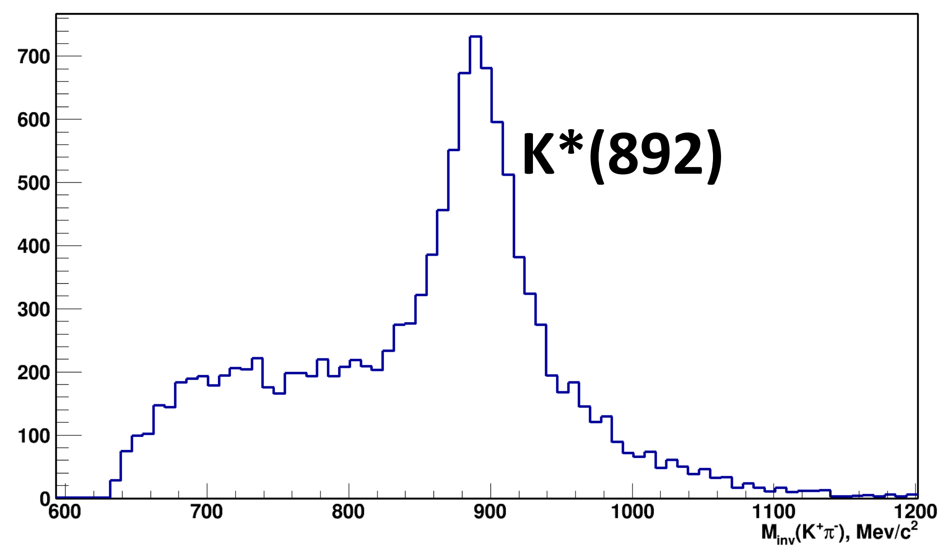


Dynamics


e+
e-
γ
K*+1270, K*+1400
K*0892
π-
K+
K-
π+
ρ0770
φ01020
σ600


ρ0(770)
Minv(π+π-), MeV/c2


φ(1020)
Minv(K+K-), MeV/c2


K*(892)
Minv(K+π-), Mev/c2

Simulation

Effective matrix elements have been written for main two-particle intermediate states, which have been chosen according to BaBar results (J.P. Lees et al., Phys. Rev. D86 012008 (2012):

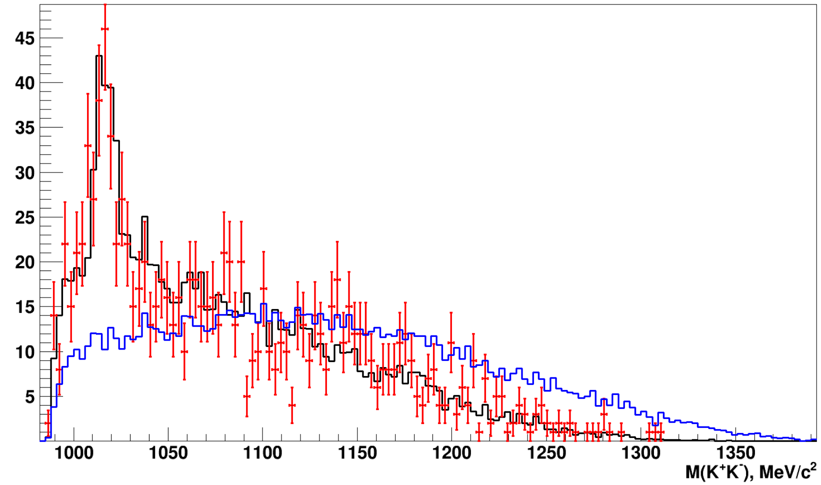
K*(892) K_bar*(892)
$\phi(1020)f_0(600)$
$\rho(770)\ (K+K-)_{Swave}$
$(K_1(1410)\ K\ )_{Swave} \rightarrow K^*(892)\ \pi\ K$, $(K_1(1270)\ K\ )_{Swave} \rightarrow K^*(892)\ \pi\ K$
$(K_1(1270)\ K\ )_{Swave} \rightarrow \rho(770)\ K\ K$

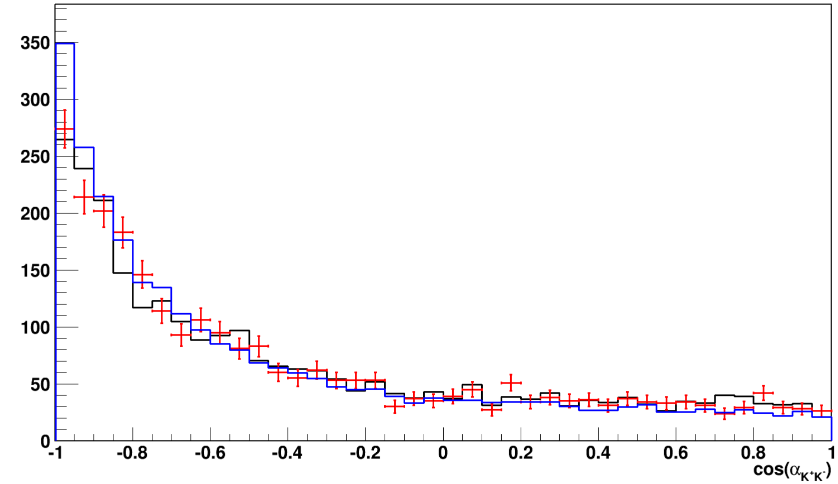
Maximum likelihood function is given by:

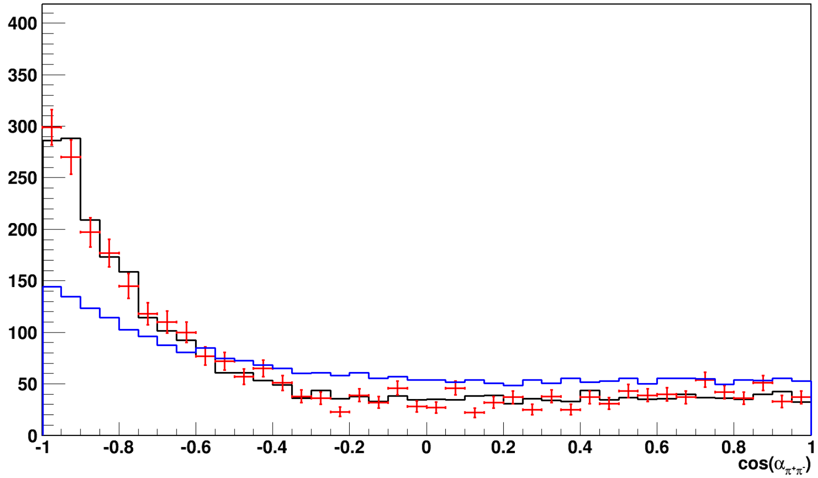
$$L = \prod_i M_i^{\,2}(\vec{\alpha}, P_{iK^+} P_{iK^-} P_{i\pi^+} P_{i\pi^-}) \,,$$

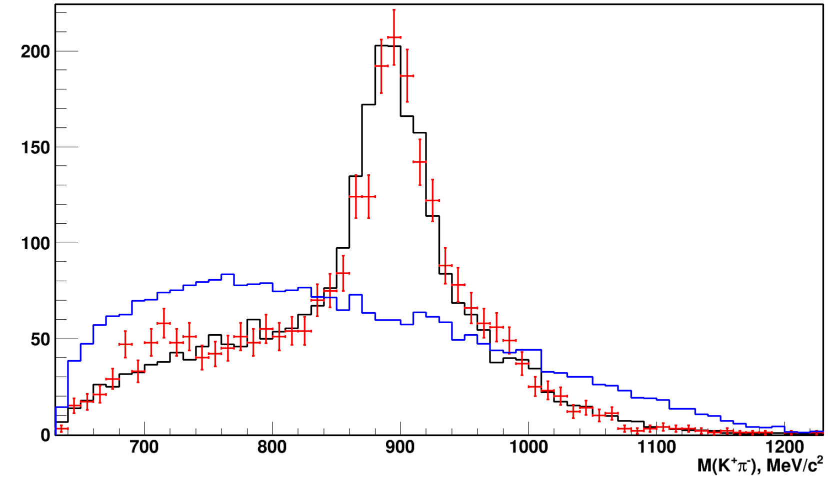
where the multiplication is over the experimental events.
Normalization of the matrix element is performed using simulation events.
Events are simulated by four-particle phase space, pass through the detector using GEANT4 package and reconstructed with the same software as experimental data.

Simulation vs Experiment









Comparison of the experimental angular and momentum distributions with simulation.

RED – EXPERIMENT, BLACK – SIMULATION, BLUE - PHASE SPACE

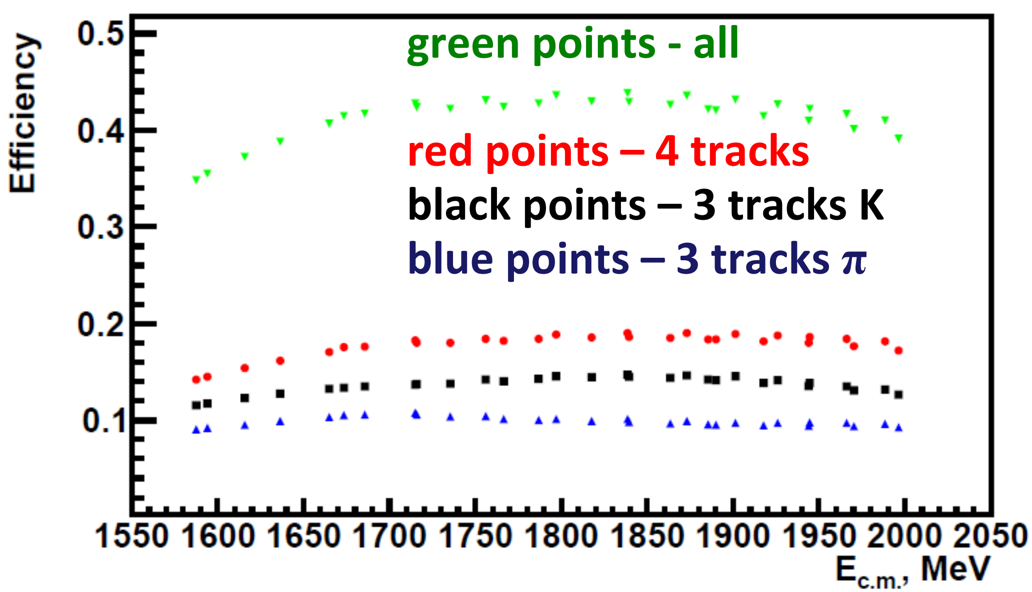
Calculation of the cross section $e^+e^- \to K^+K^-\pi^+\pi^-$

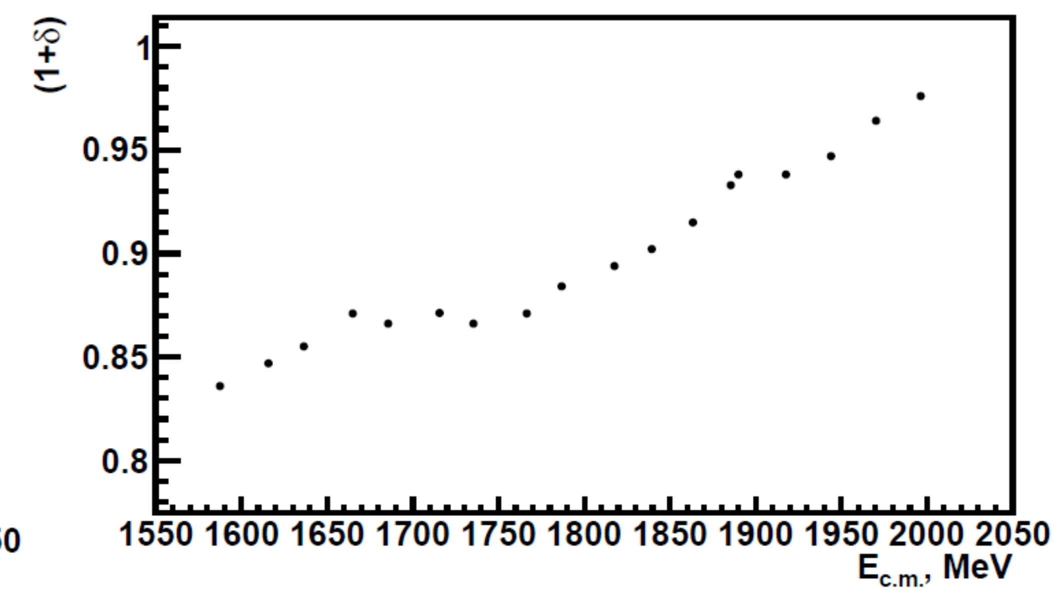
$$\sigma_{4tr} = \frac{N_{4tr}}{\epsilon_{4tr} L_{int} (1+\delta) \xi_{4tr}}$$

$$\sigma_{3tr} = \frac{N_{3tr}}{\epsilon_{3tr} L_{int} (1+\delta) \xi_{3tr}}$$

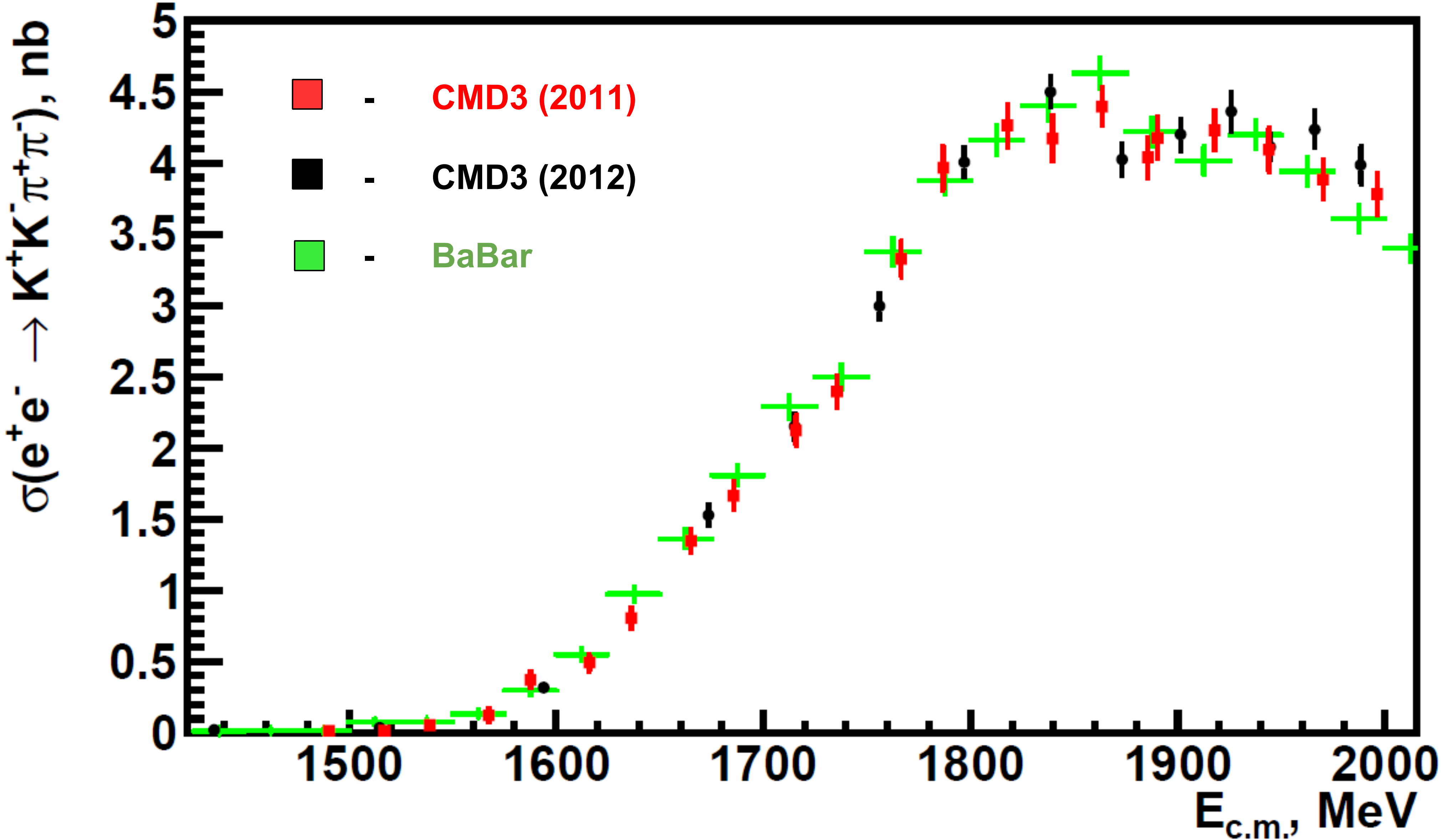
N_4 — number of four-track events,
N_3 — number of three-track events,
L — integrated luminosity,
ε — detection efficiency,
δ — radiative correction,
ξ— corrections, taking into account difference between simulation and experiment.

The cross section $\sigma(e^+e^- \to K^+K^-\pi^+\pi^-)$ is calculated as a weighted average of the cross sections for different set of events σ_{4tr} and σ_{3tr}.



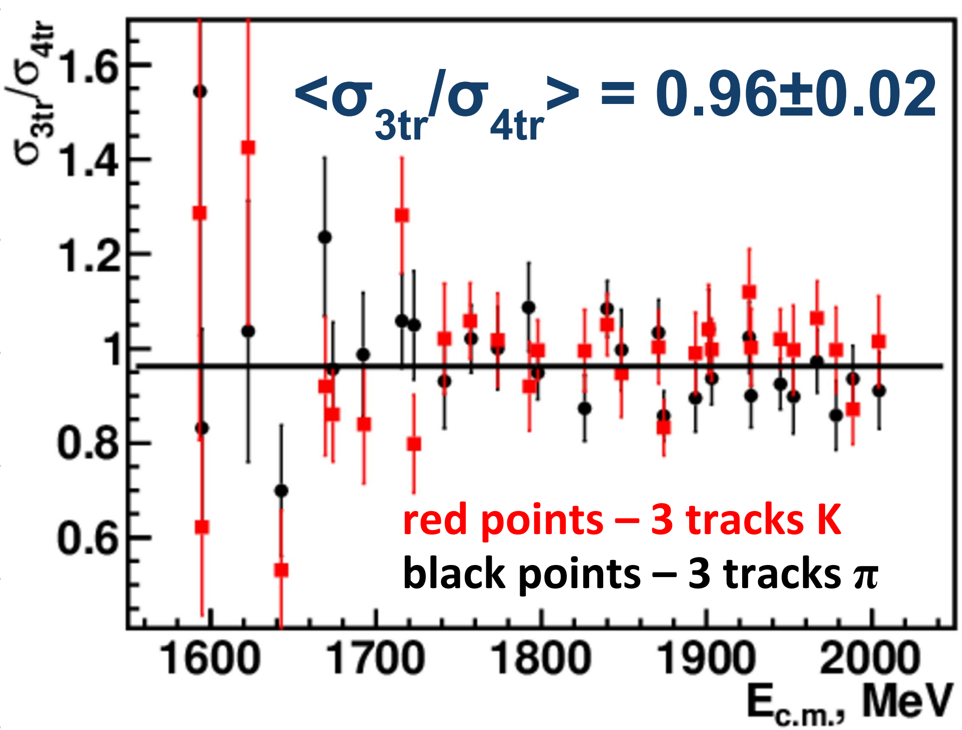


Cross section of the process $e^+e^- \to K^+K^-\pi^+\pi^-$



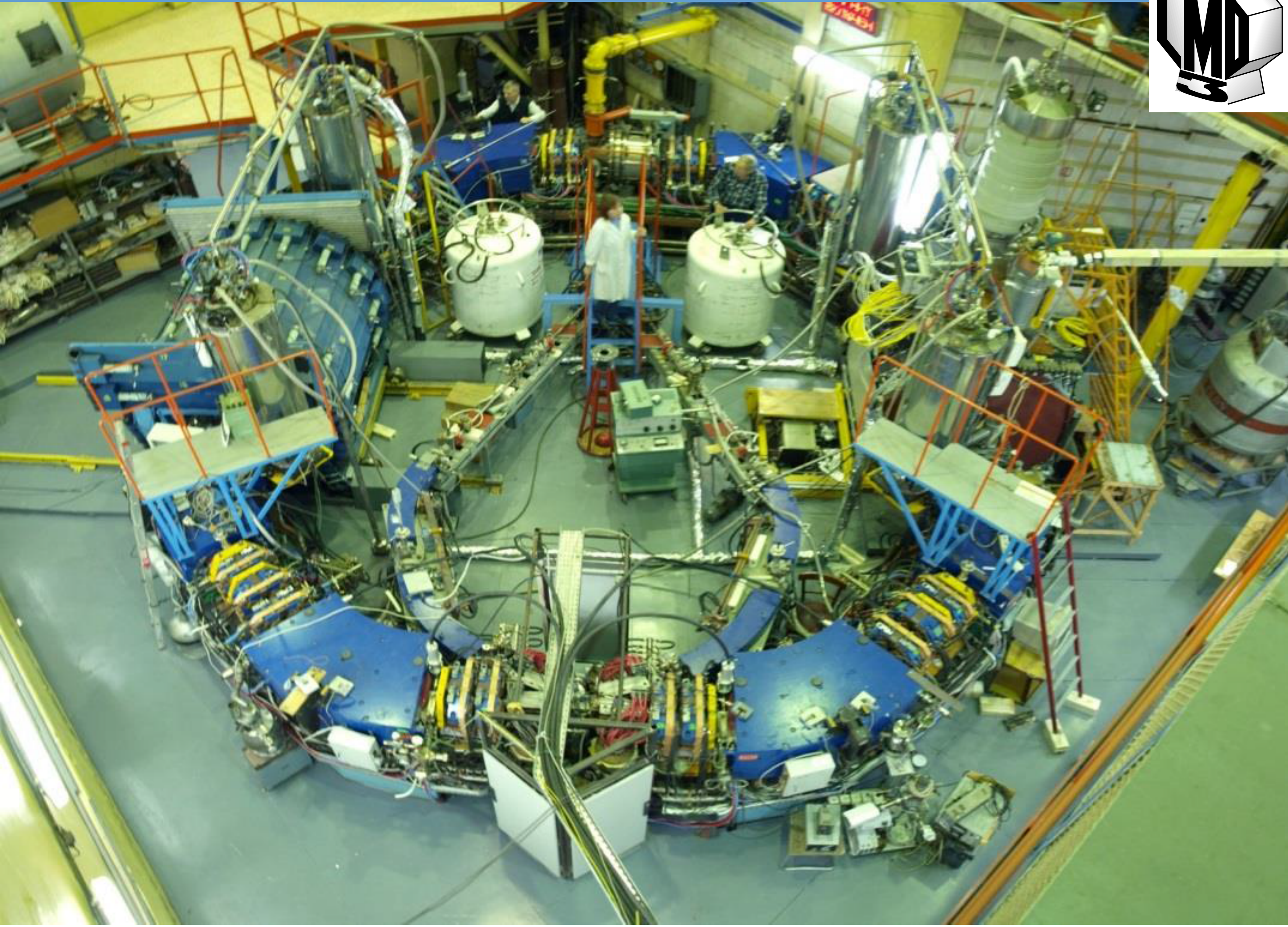
Systematic uncertainties

Source	Systematic uncertainty
The determination of the integrated luminosity	1%
Associated with the operation of the CMD-3 detector	1.2%
Background subtraction	1.5%
The selection criteria	2.6%
The model dependency	5%
Total	**6%**



Conclusion

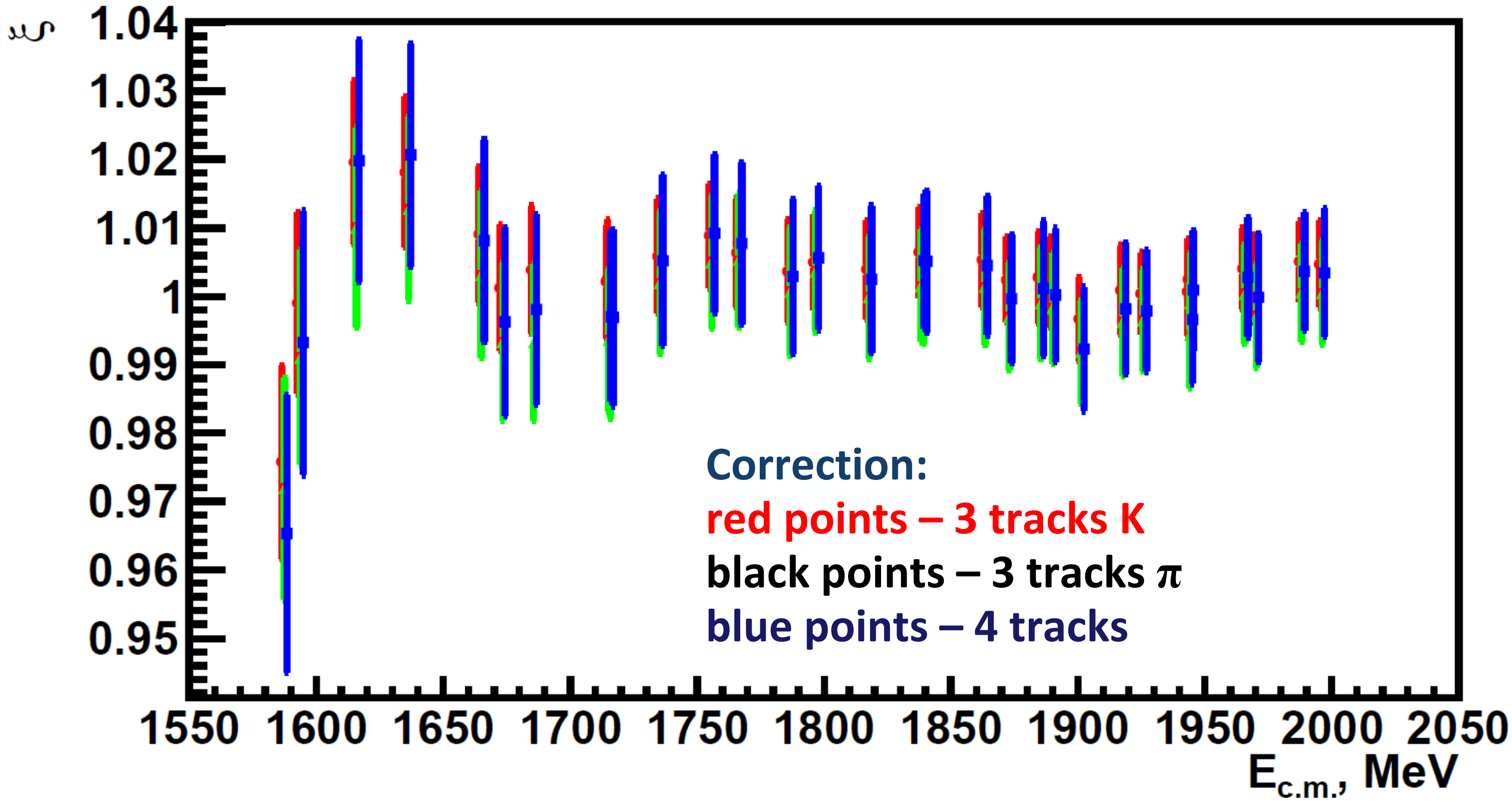
- **22 pb^{-1} was collected in 1.5-2 GeV c.m. energy region.**
- **Method of π/K separation using ionization losses in Drift Chamber was developed.**
- **Cross section of the process $e^+e^- \to K^+K^-\pi^+\pi^-$ was measured in the energy region 1.5-2 GeV with statistical error about 4-10% (number of four track events is about 12000, three track events - about 15000) and systematic uncertainty is estimated as 6%.**
- **New positron injection complex will increase VEPP-2000 collider luminosity up to 10 times and it is commissioned now. Experiments will be continued and statistics will be increased at least by a factor of 10.**

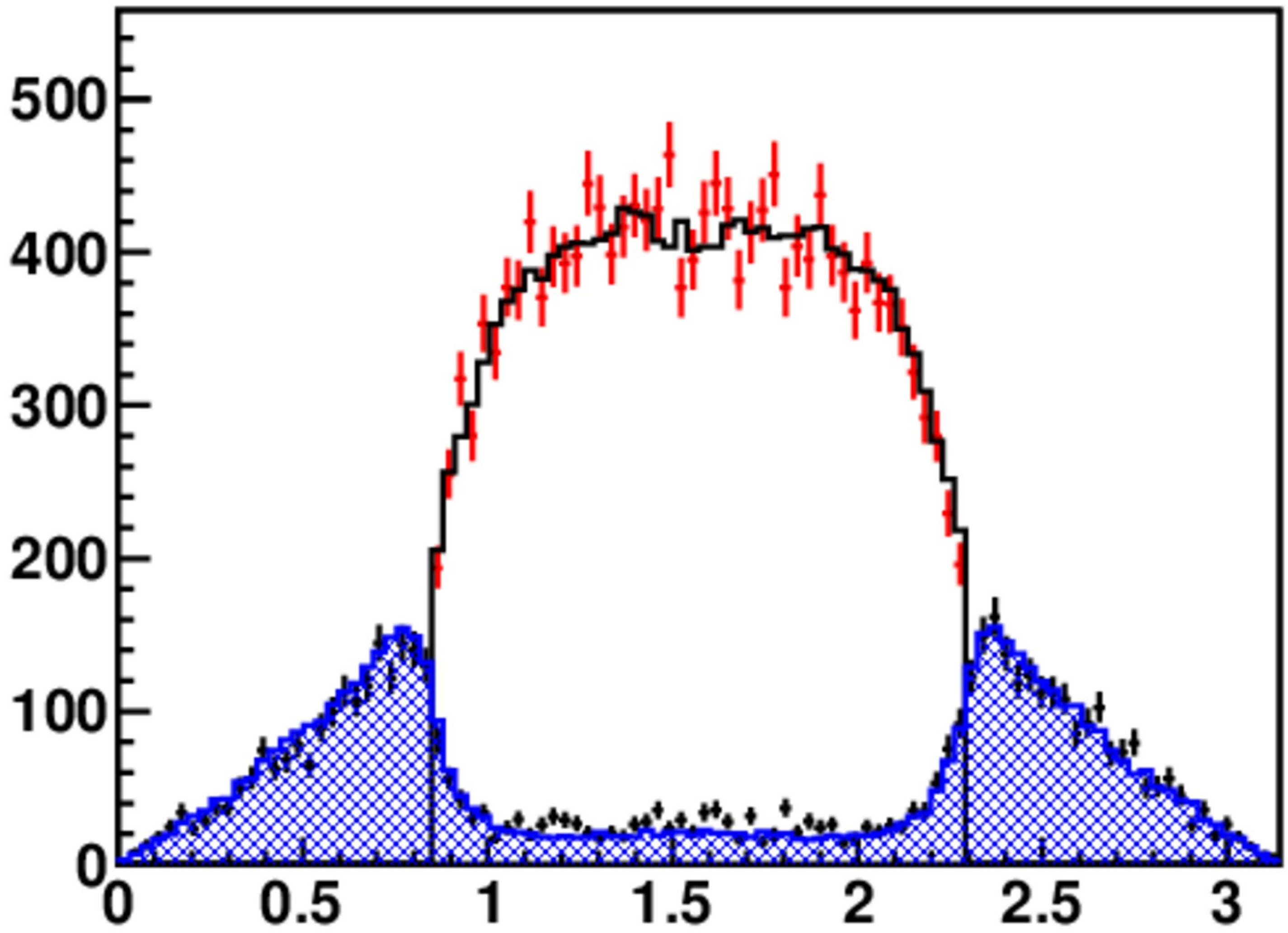


Correction of difference of track efficiency between simulation and experiment

$$\varepsilon_{1tr} = 1/(1 + \frac{N_{3tr}}{2 \cdot N_{4tr}})$$

$$\xi_{4tr} = \frac{(\varepsilon^{exp}_{1tr\ K})^2(\varepsilon^{exp}_{1tr\ \pi})^2}{(\varepsilon^{mc}_{1tr\ K})^2(\varepsilon^{mc}_{1tr\ \pi})^2} \qquad \xi^{\pi}_{3tr} = \frac{(\varepsilon^{exp}_{1tr\ K})^2\varepsilon^{exp}_{1tr\ \pi}(1-\varepsilon^{exp}_{1tr\ \pi})}{(\varepsilon^{mc}_{1tr\ K})^2\varepsilon^{mc}_{1tr\ \pi}(1-\varepsilon^{mc}_{1tr\ \pi})}$$




500
400
300
200
100
0
0
0.5
1
1.5
2
2.5
3