Study of the processes $e^+e^- \to K^+K^-\pi^+\pi^-$, $K^+K^-\eta$ with the CMD-3 detector at e^+e^- collider VEPP-2000

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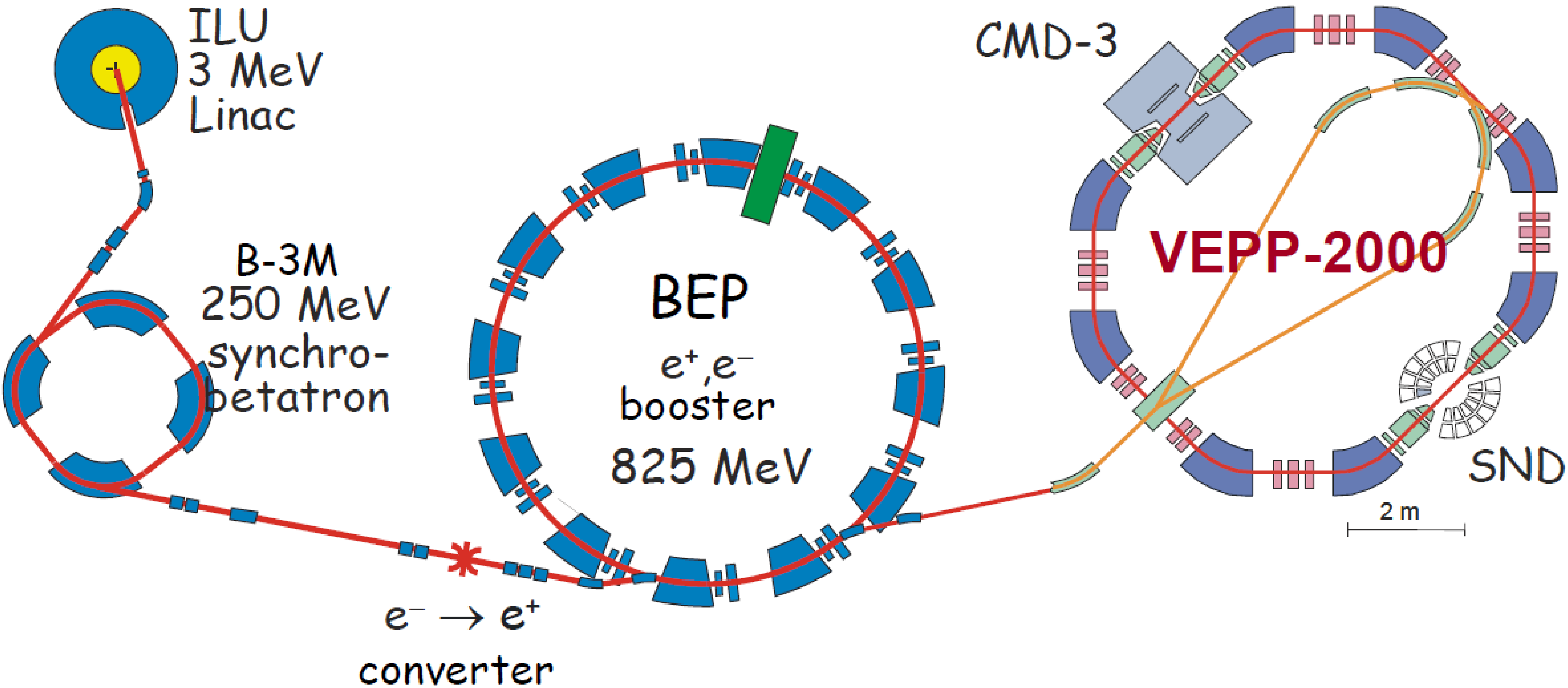
Outline

- VEPP-2000
- CMD-3
- $e^+e^- \to K^+K^-\pi^+\pi^-$
- $e^+e^- \to K^+K^-\eta$
- Conclusion

VEPP-2000

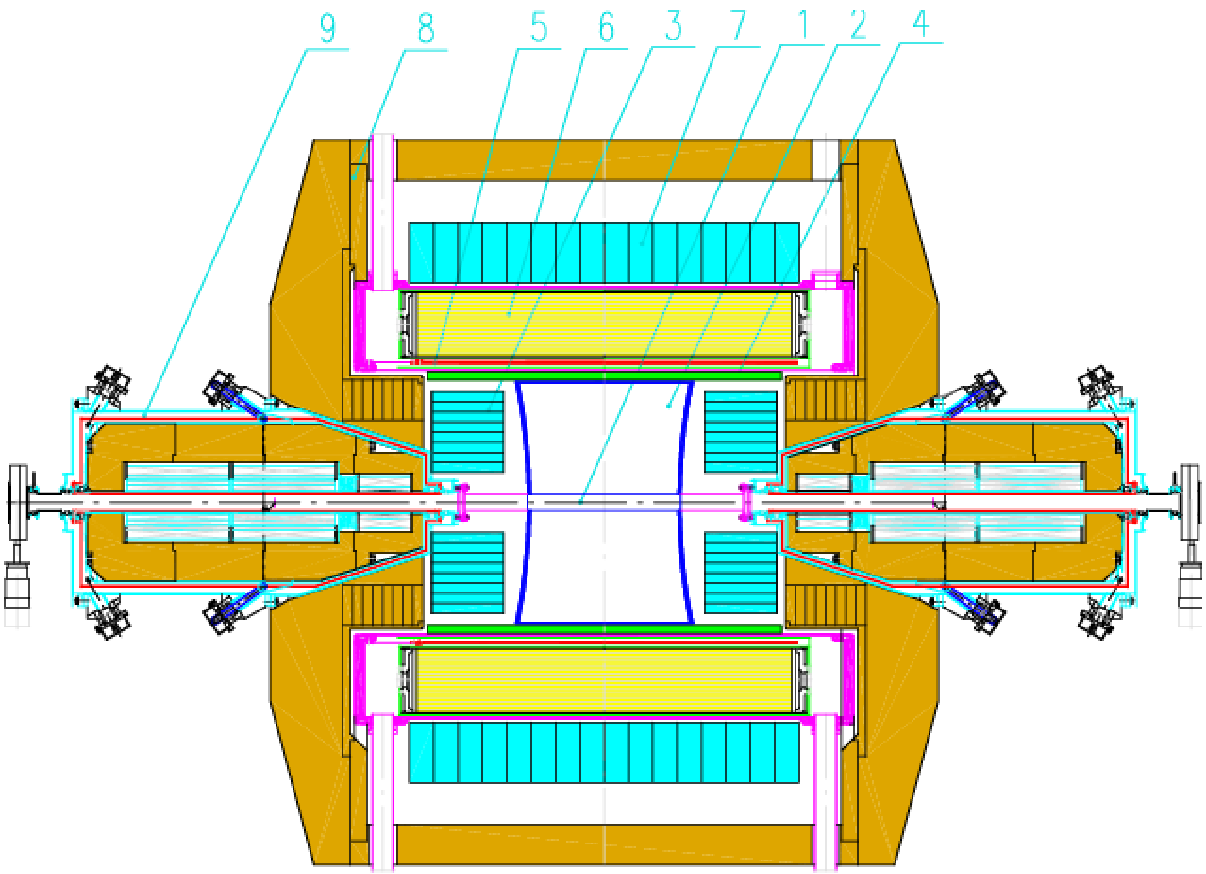


Maximum c.m. energy is 2 GeV, design luminosity is $L = 10^{32} 1/cm^2 s$ at $\sqrt{s} = 2$ GeV

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 – end-cap electromagnetic BGO calorimeter,
4 – Z – chamber,
5 – CMD SC solenoid(1.3 T),
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 1.5×10^{-10}

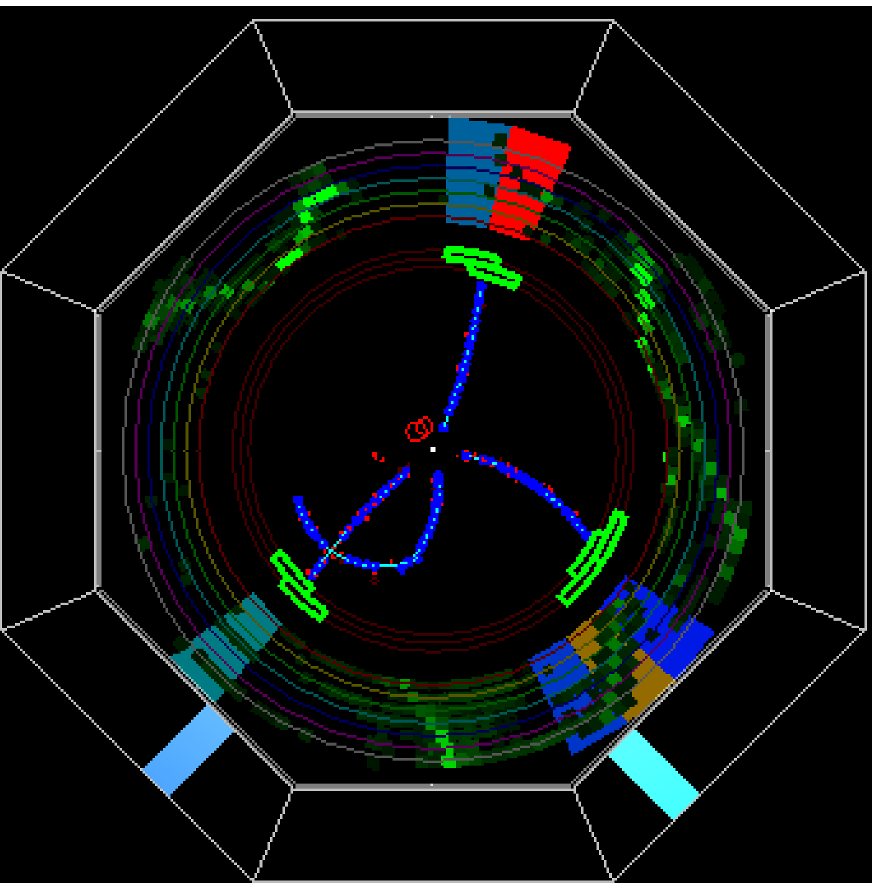
LO hadronic contribution $(694.1 \pm 4.3) \times 10^{-10}$ HLMNT 11

$KK2\pi$ c.m. energy region below 2 GeV $(3.31 \pm 0.58) \times 10^{-10}$, based on BaBar. arXiv:1105.3149

$e^+e^- \to K^+K^-\pi^+\pi^-$

Event selection

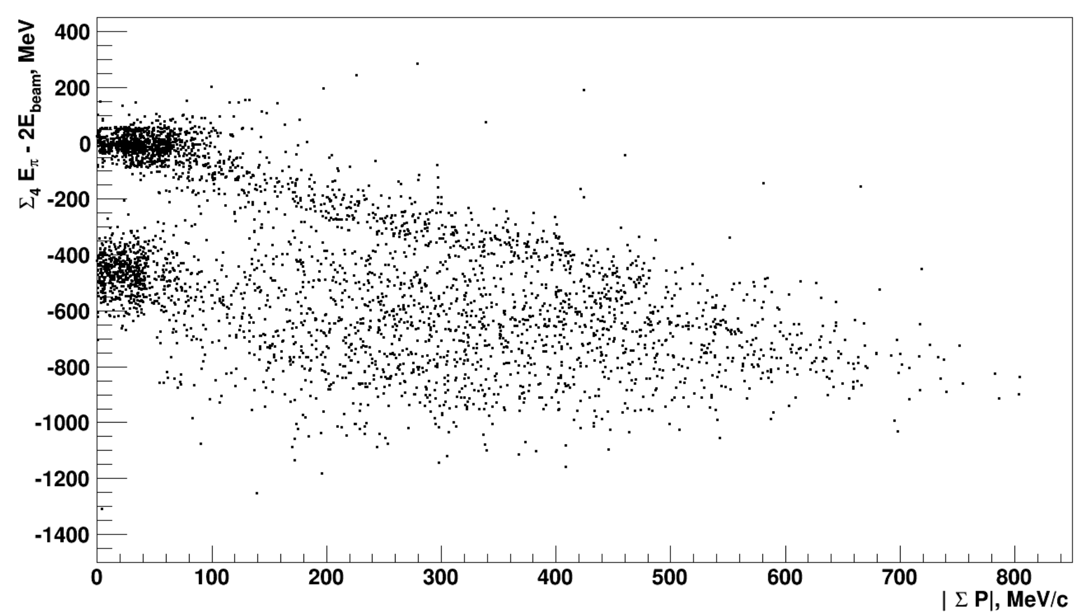
Display of $K^+K^-\pi^+\pi^-$ event in CMD-3



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.

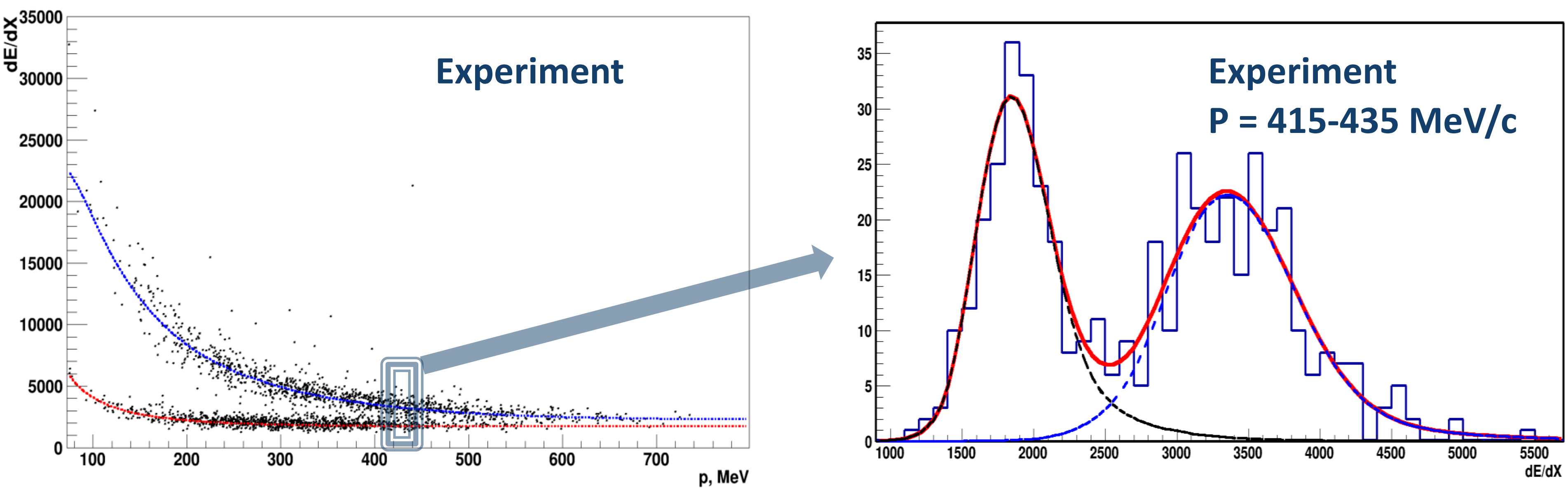
Probability density function with momentum and dE/dx as parameters is constructed for kaons f_K(p,dE/dx) and pions f_π(p,dE/dx).

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

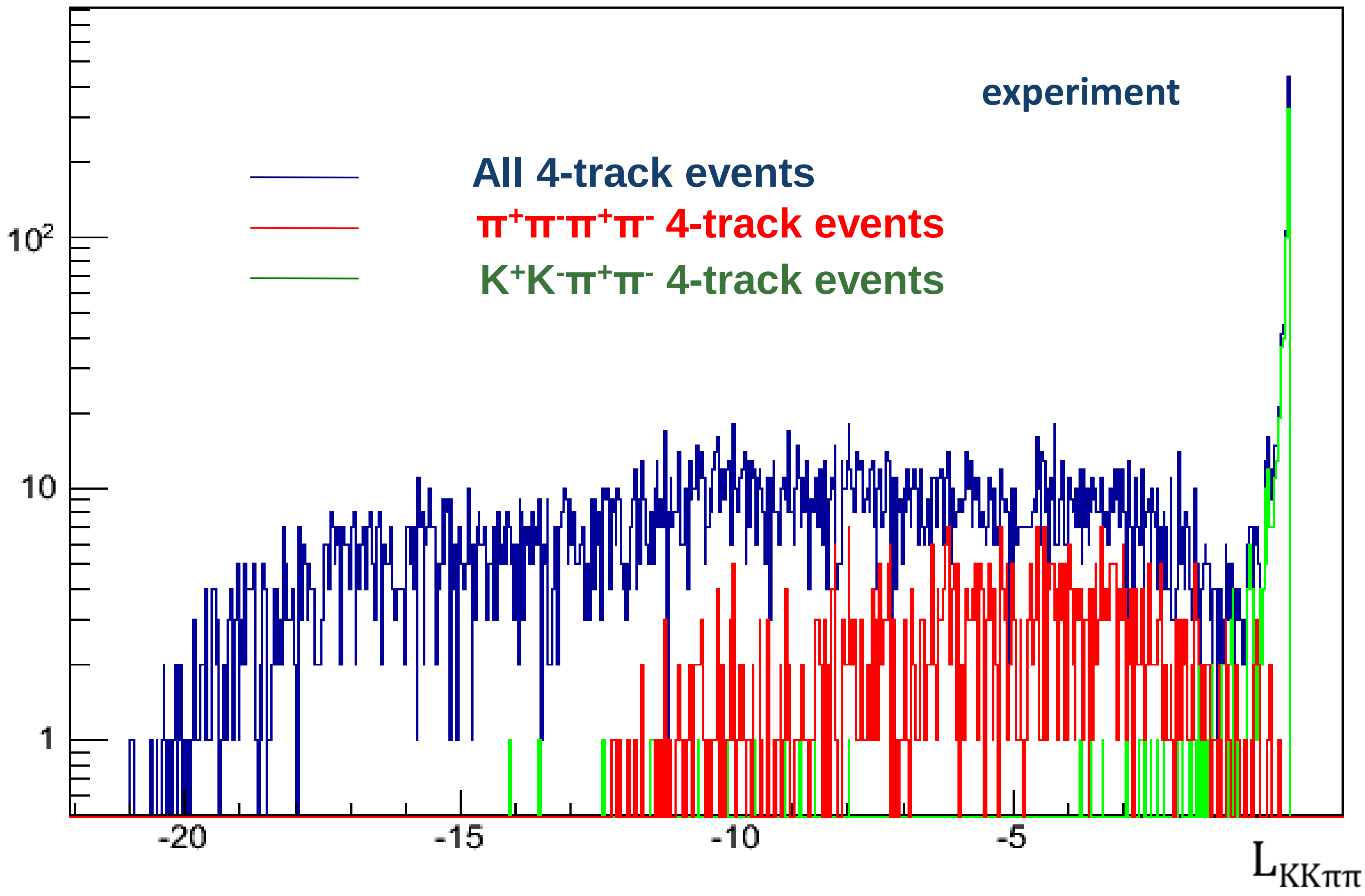
$$L_{KK\pi\pi}\left(p,\frac{dE}{dX},ai\right) = Ln\left(\prod_i \frac{f_{ai}\left(p_i,\frac{dE}{dX_i}\right)}{f_\pi\left(p_i,\frac{dE}{dX_i}\right)+f_K\left(p_i,\frac{dE}{dX_i}\right)}\right),$$

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.

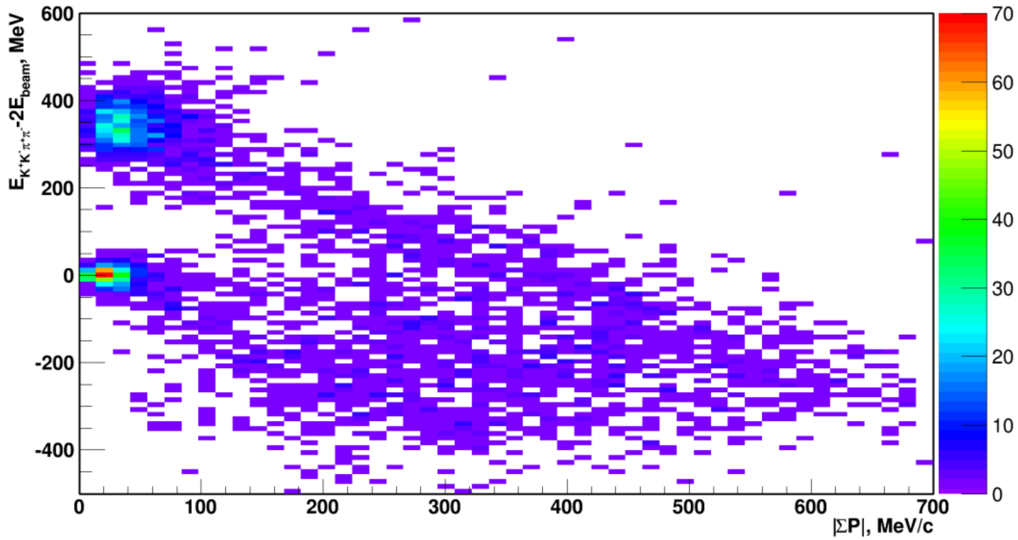


Using $L_{KK\pi\pi}$ for background rejection

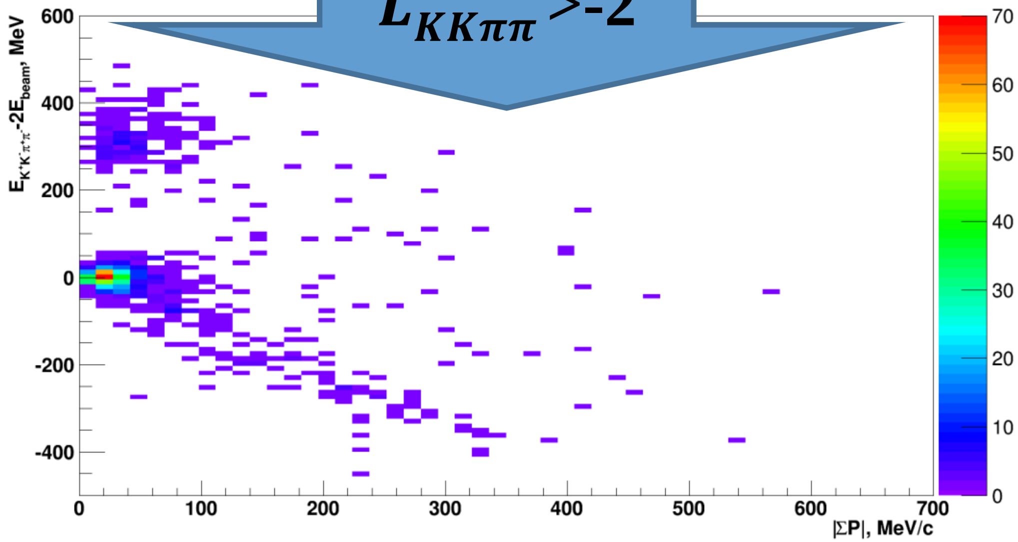


$L_{\pi\pi\pi\pi}$, $L_{KKK\pi}$, $L_{\pi\pi\pi K}$, L_{KKKK} are constructed in the same way.

Four-track events



$L_{KK\pi\pi}$ >-2



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

Conditions:

$| \Sigma E - 2^* E_{beam} | < 100$ MeV

$|\Sigma \overrightarrow{P}| < 100$ MeV/c

$L_{KK\pi\pi} > -2$

Cut on likelihood value allows to suppress background by a factor of 20. It was obtained from simulation of processes $e^+e^- \to K_s K \pi$, $\pi^+\pi^+\pi^-\pi^-\gamma$, $\pi^+\pi^+\pi^-\pi^-\pi^0\pi^0$, $\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\gamma$.

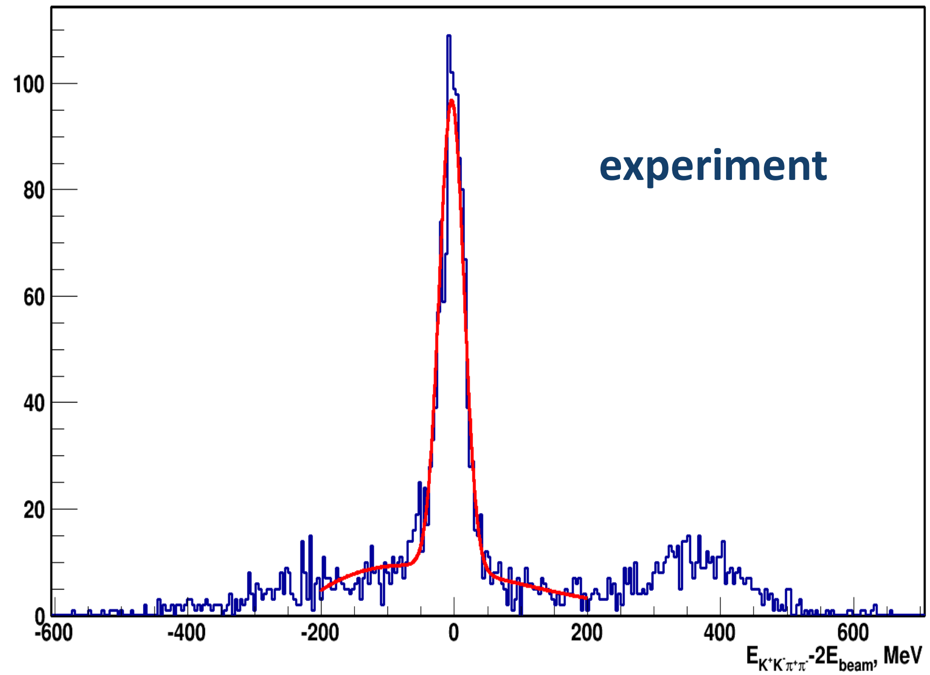
Events with one missing track in DC

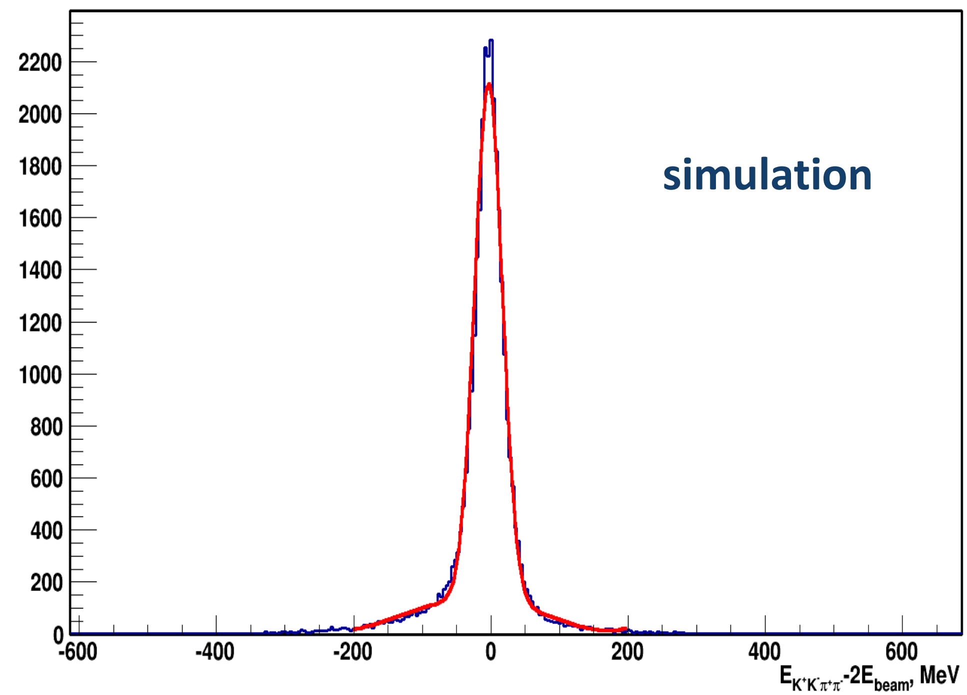
Likelihood function $L_{KK\pi\pi}$ for three-track events is constructed in the same way, as it was done for $L_{KK\pi\pi}$ with four tracks.

Momentum of fourth particle is determined by momentum conservation law.

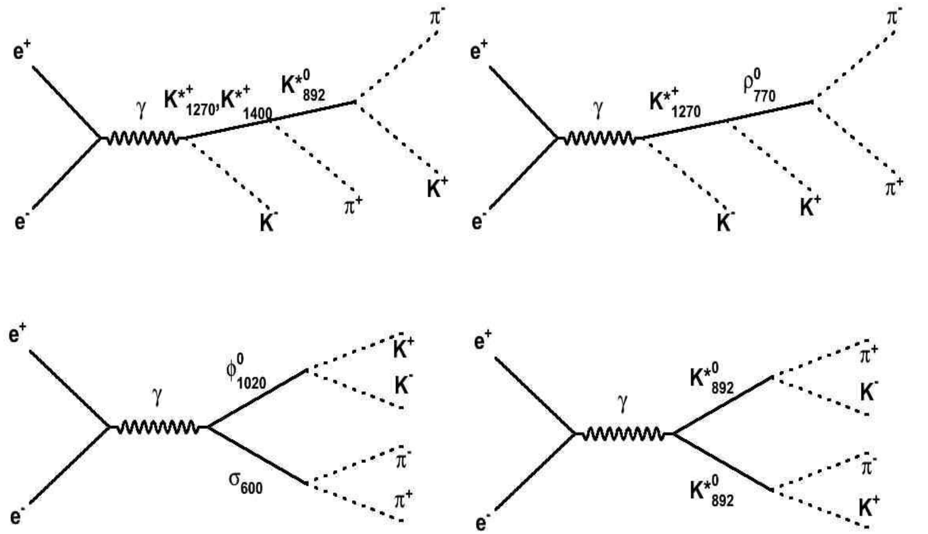
Total energy of four particles minus double beam energy is plotted in histogram.

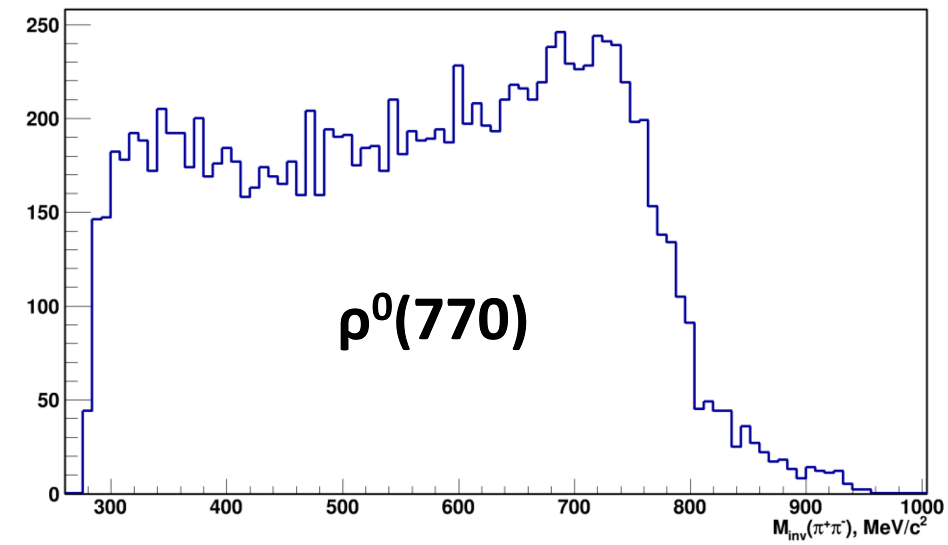
Histogram is fitted by Gaussian function with quadratic background subtracted.

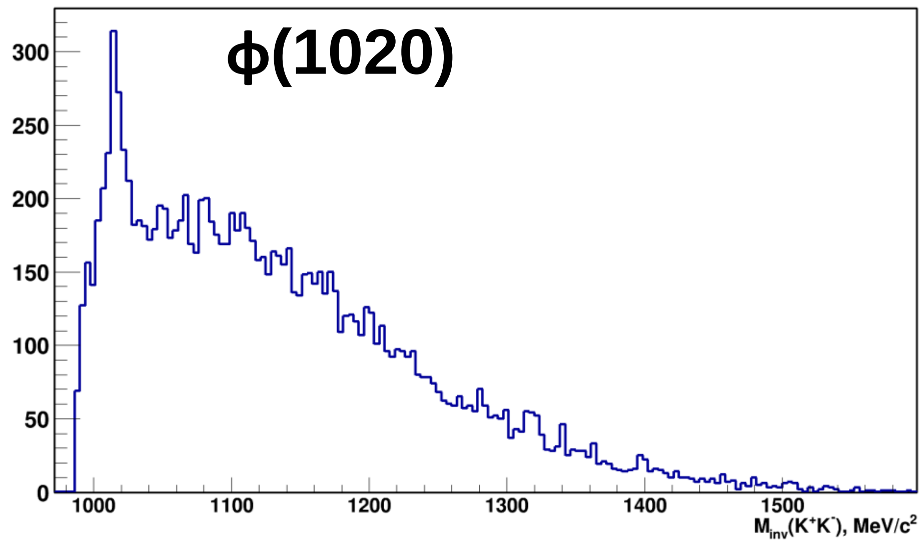


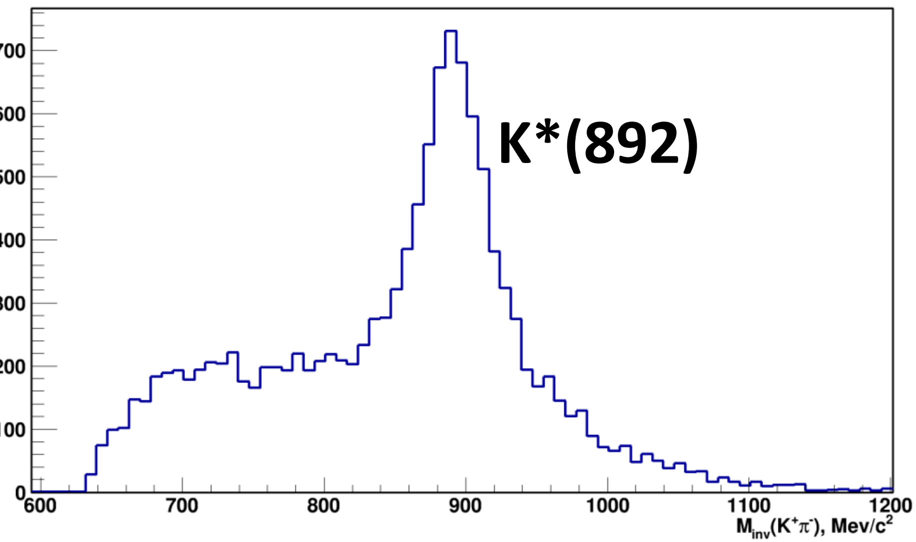


Dynamics


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


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):

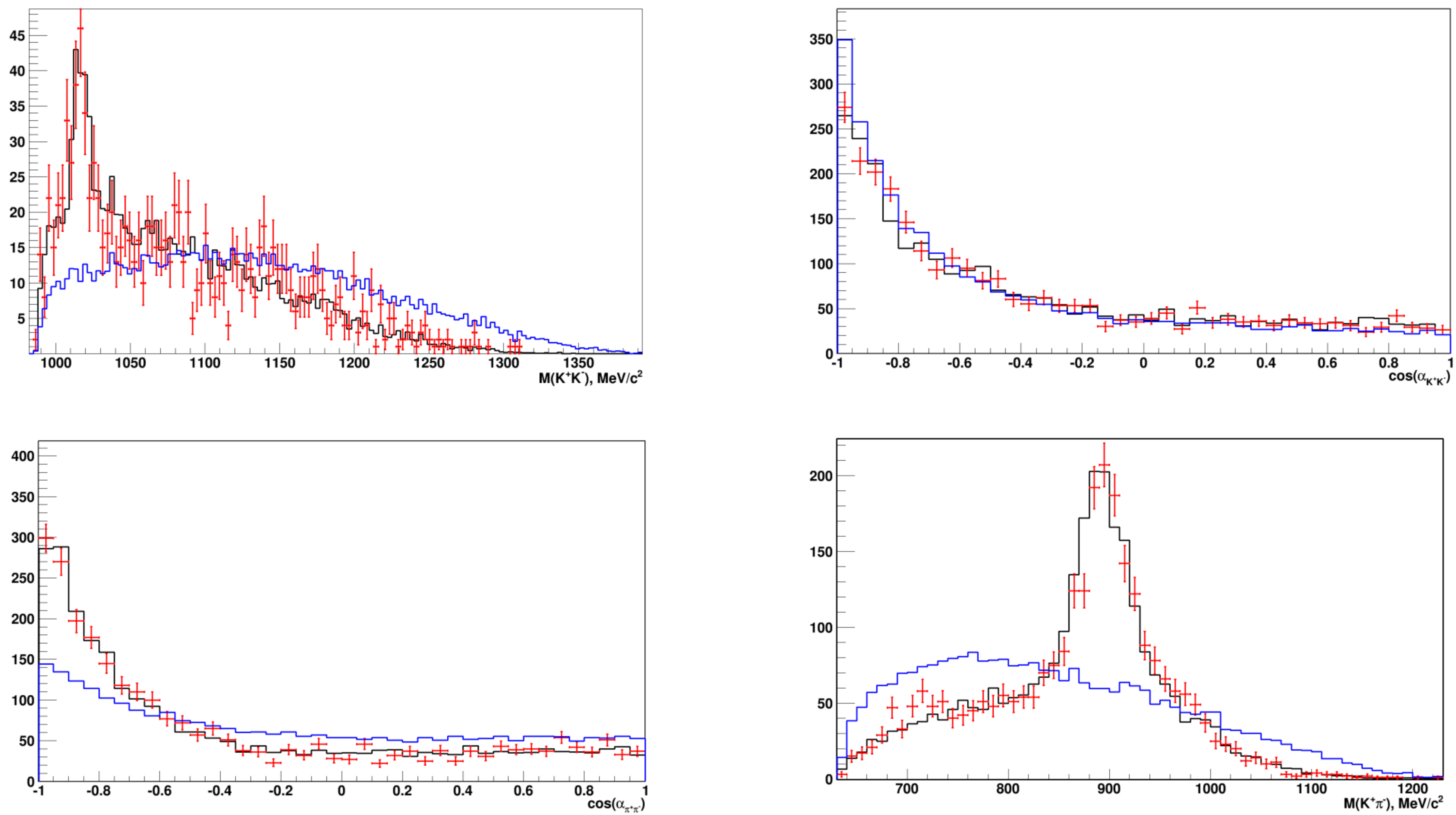
K*(892) K_bar*(892)
$\phi(1020)f_0(600)$
$\rho(770)\ (K+K-)_{Swave}$
$(K_1(1410)\ K)_{Swave} \rightarrow K^*(892)\ \pi\ K$, $(K_1(1270)\ K)_{Swave} \rightarrow K^*(892)\ \pi\ K$
$(K_1(1270)\ K)_{Swave} \rightarrow \rho(770)\ K\ K$

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

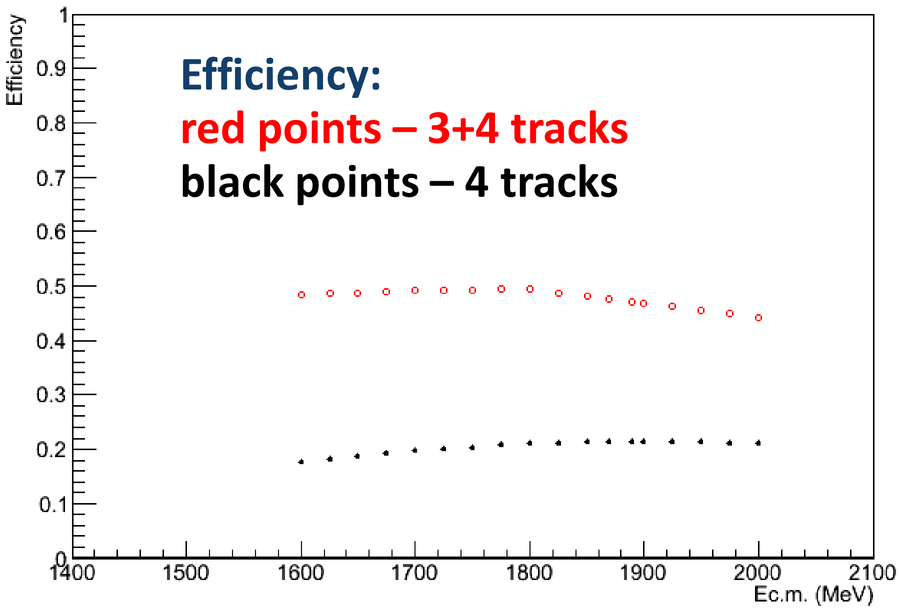
Calculation of the cross section $e^+e^- \to K^+K^-\pi^+\pi^-$

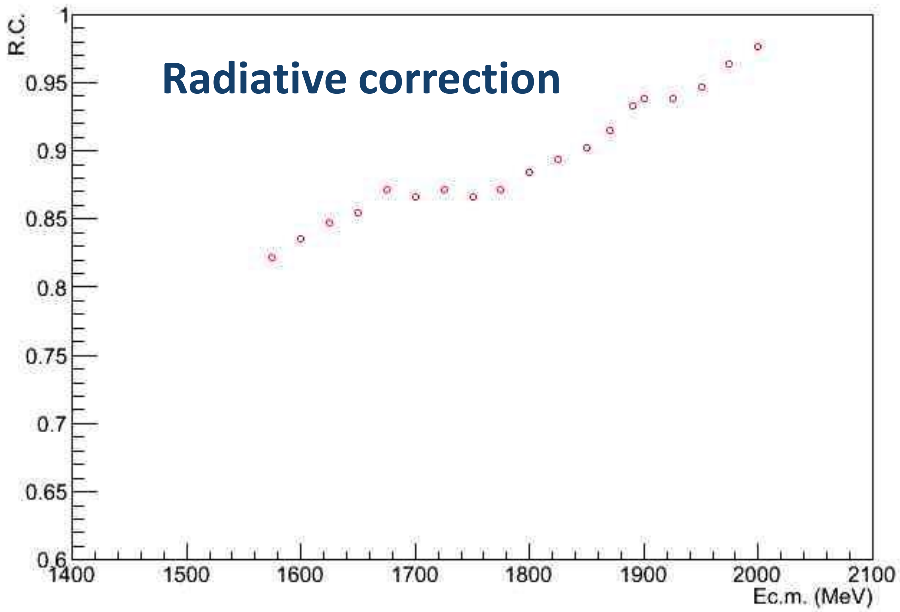
$$\sigma = \frac{N_3 + N_4}{L * \varepsilon * (1-\delta) * \xi}$$

$$\xi = \frac{P_{1exp}^4 + 4 * P_{1exp}^3 * (1 - P_{1exp})}{P_{1mc}^4 + 4 * P_{1mc}^3 * (1 - P_{1mc})}$$

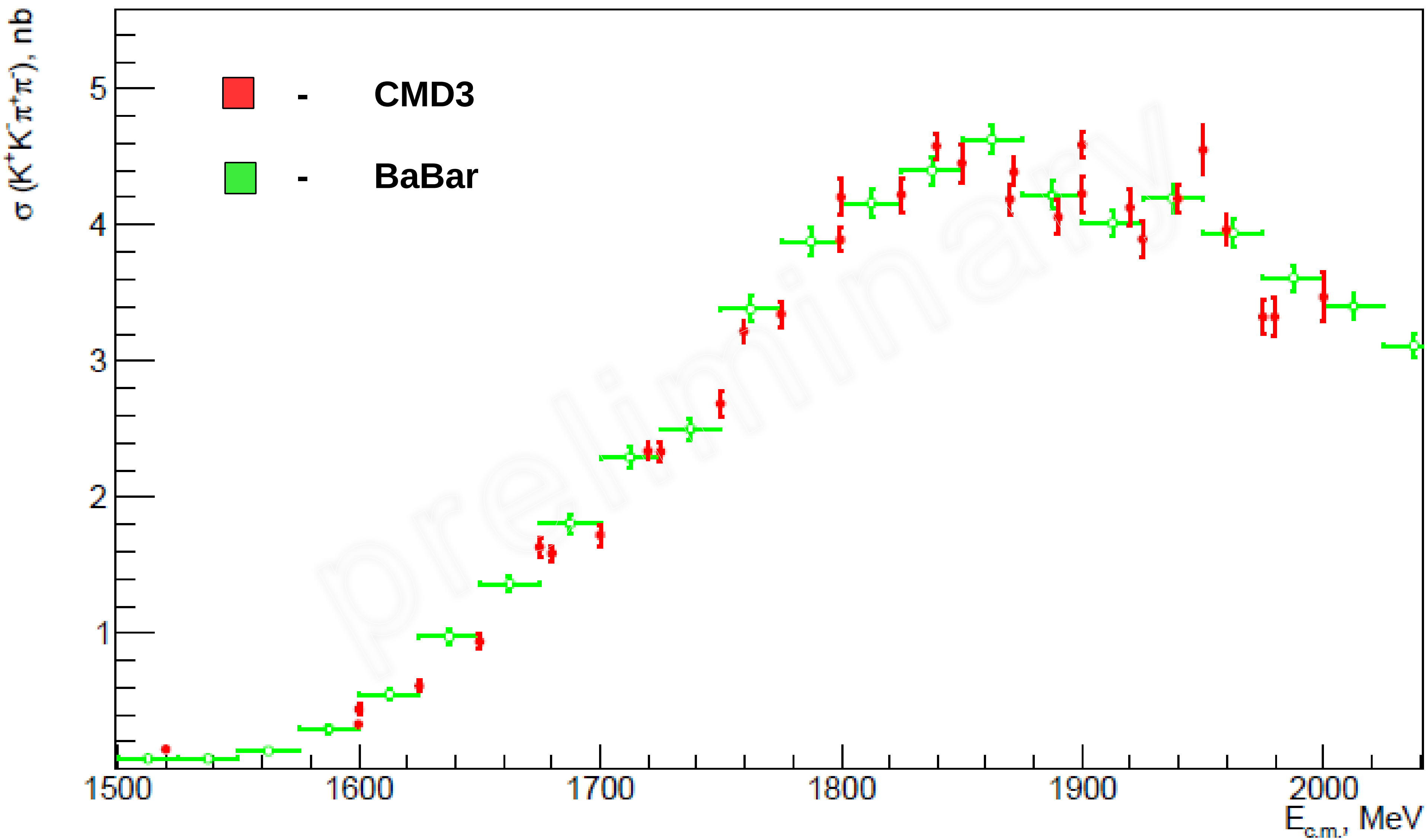
N_4 — number of four-track events,
N_3 — number of three-track events,
L — integrated luminosity,
ε — detection efficiency,
δ — radiative correction,
ξ— corrections, taking into account difference between simulation and experiment,
P_1 — probability to detect one track in DC.

$$\varepsilon = \frac{N_3^{mc} + N_4^{mc}}{N_{all}^{mc}} \quad N_4 = {P_1}^4 * N_{all}, \quad N_3 = 4 * {P_1}^3 * (1 - P_1) * N_{all} \quad P_1 = \frac{4 * N_4}{4 * N_4 + N_3}$$





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



$e^+e^- \to \phi\eta \to K^+K^-\eta$

Process $e^+e^- \to K^+K^-\eta$

- Process $e^+e^- \to K^+K^-\eta$ was studied in BABAR experiment in $\eta \to 2\gamma$ channel (~480 events), and in the channel $\eta \to \pi^+\pi^-\pi^0$(~250 events).
- It is established that the process basically goes through ϕη intermediate channel, and the non-resonant cross section $\sigma(e^+e^- \to K^+K^-\eta)$ is suppressed by a factor of 15, so we measure cross section $\sigma(e^+e^- \to \phi\eta \to K^+K^-\eta)$.
- Analysis is based on integrated luminosity about 21 pb^{-1} in center of mass energy range $\sqrt{s} \in$ 1.57 -2.0 GeV.
- Main decay modes: $Br(\eta \to 2\gamma) \approx 39.31\%$, $Br(\eta \to 3\pi^0) \approx 32.57\%$, $Br(\eta \to \pi^+\pi^-\pi^0) \approx 22.74\%$.
- In this analysis, we use only the tracks of charged kaons in DC, without using of information about the neutral particles. It allows to significantly increase the statistics and facilitate data analysis.
- To perform the analysis, matrix elements were written: $e^+e^- \to K^+K^-\eta$, $e^+e^- \to K^+K^-\pi^0$ (using intermediate channel K^*K, $\phi\pi^0$ and other), $e^+e^- \to \phi f_0(600)$.

Selection criteria

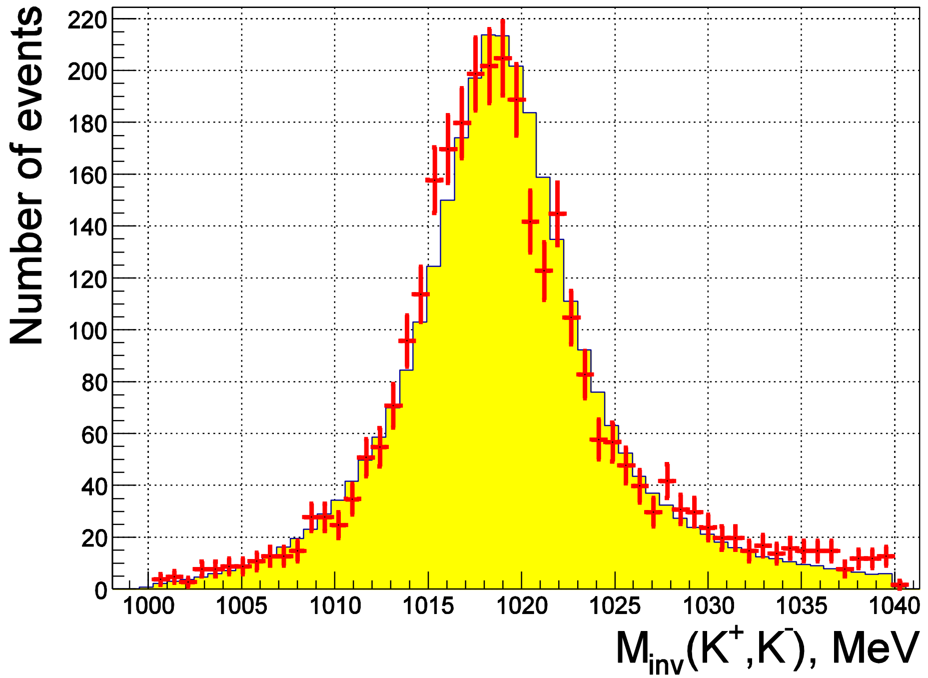
- Two tracks in DC from interaction e^+e^- point
- Total charge = 0
- Momentum of particle ∈ 40,550 MeV/c
- Ionization losses must conform to Ionization losses of kaons.
- 1000 MeV < $M_{inv}(K^+K^-)$ < 1050 MeV
- Constraints on the angle between kaons

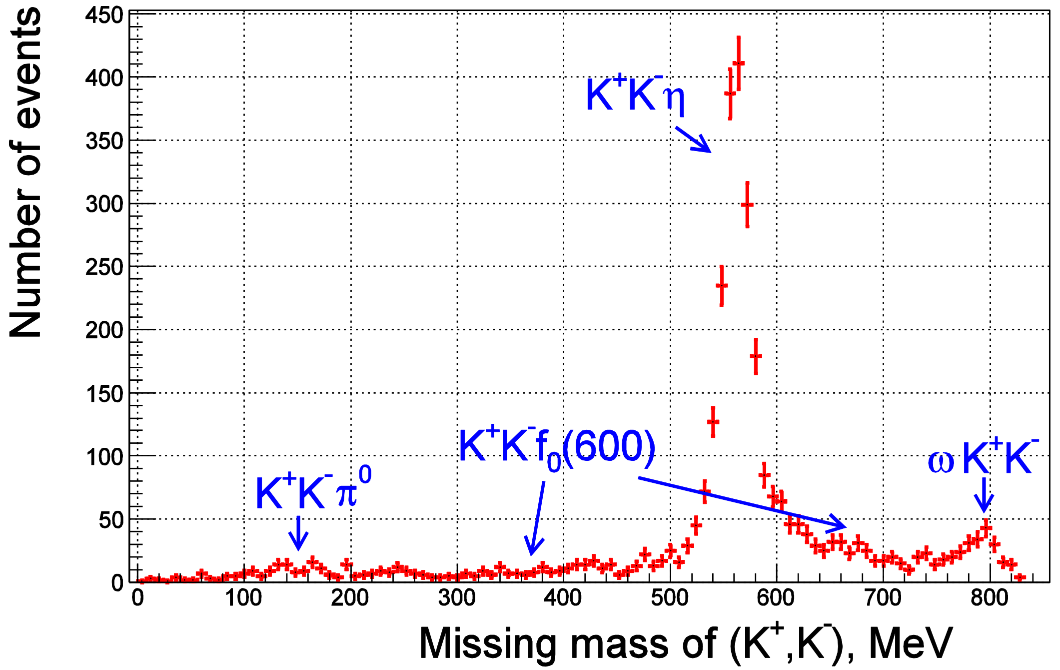
So we have two “kaons”

The total energy of particles system defined as:

$$E_{tot} = \sqrt{\overrightarrow{P_{K^+}}^2 + m_{K^+}{}^2} + \sqrt{\overrightarrow{P_{K^-}}^2 + m_{K^-}{}^2} + \sqrt{(\overrightarrow{P_{K^-}} + \overrightarrow{P_{K^+}})^2 + m_\eta{}^2} - 2 \cdot Ebeam.$$

K^+K^- invariant mass and missing mass

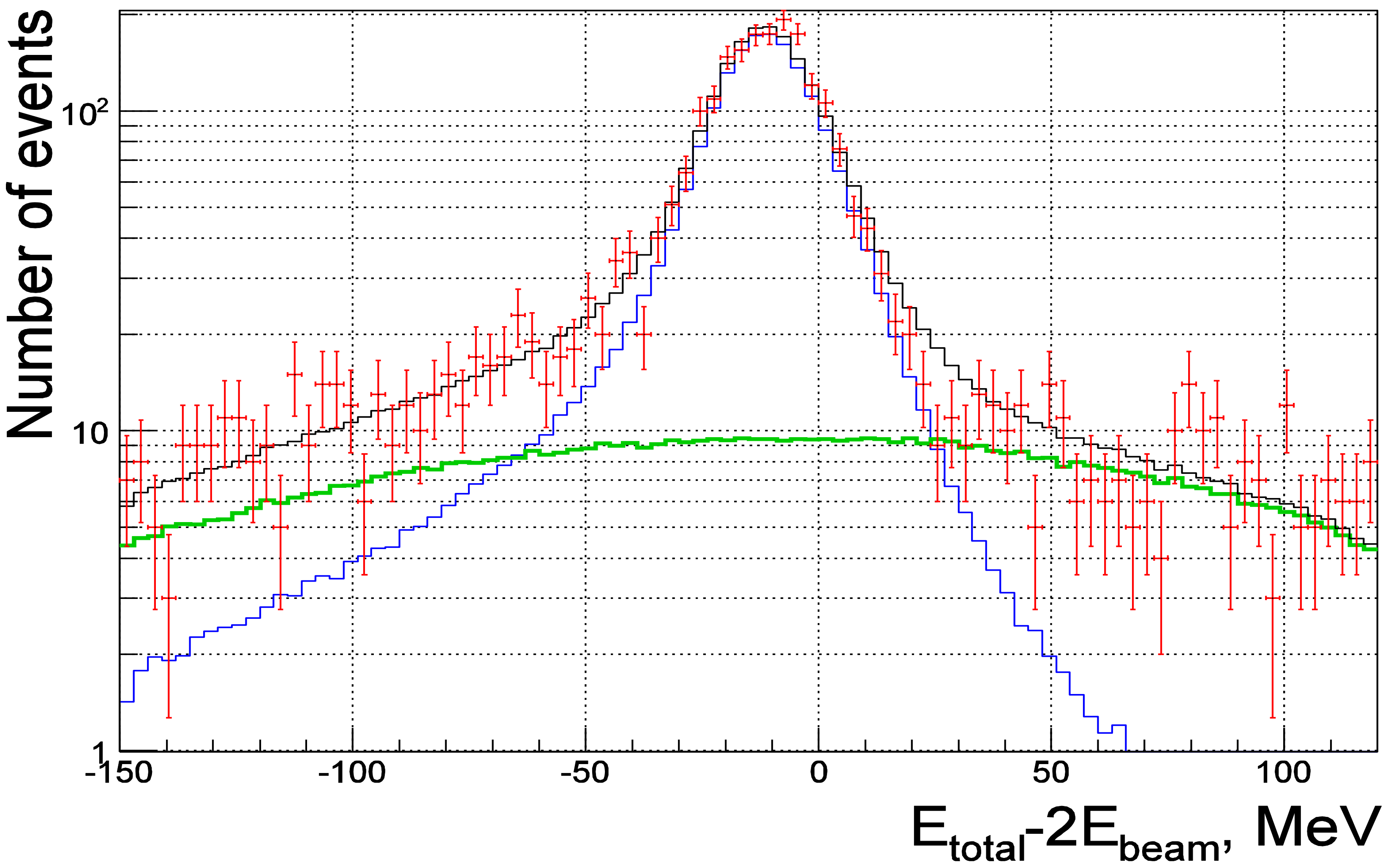




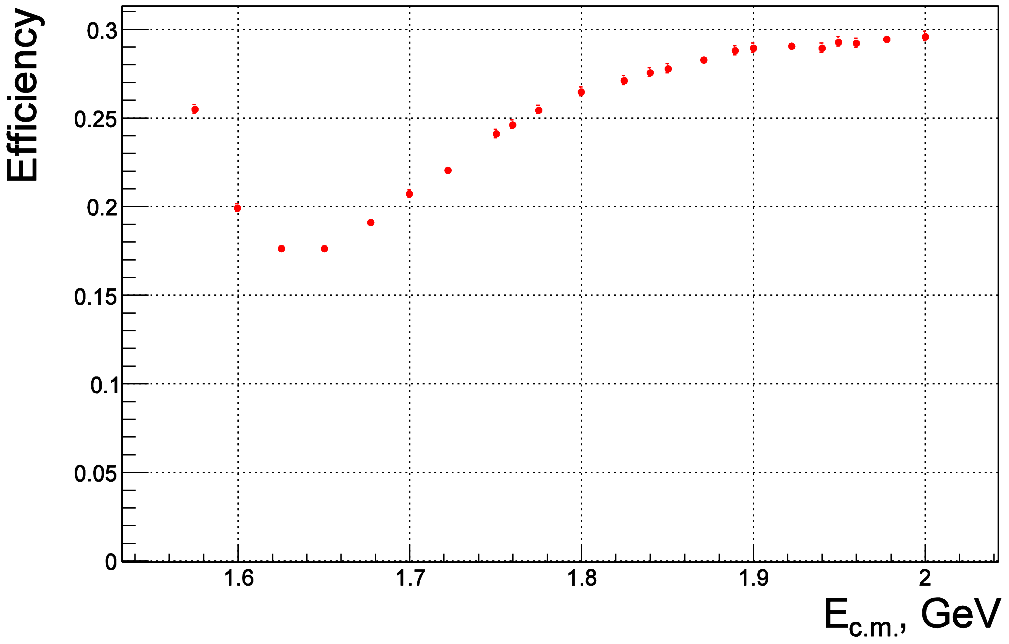
Energy of $K^+K^-\eta$ system

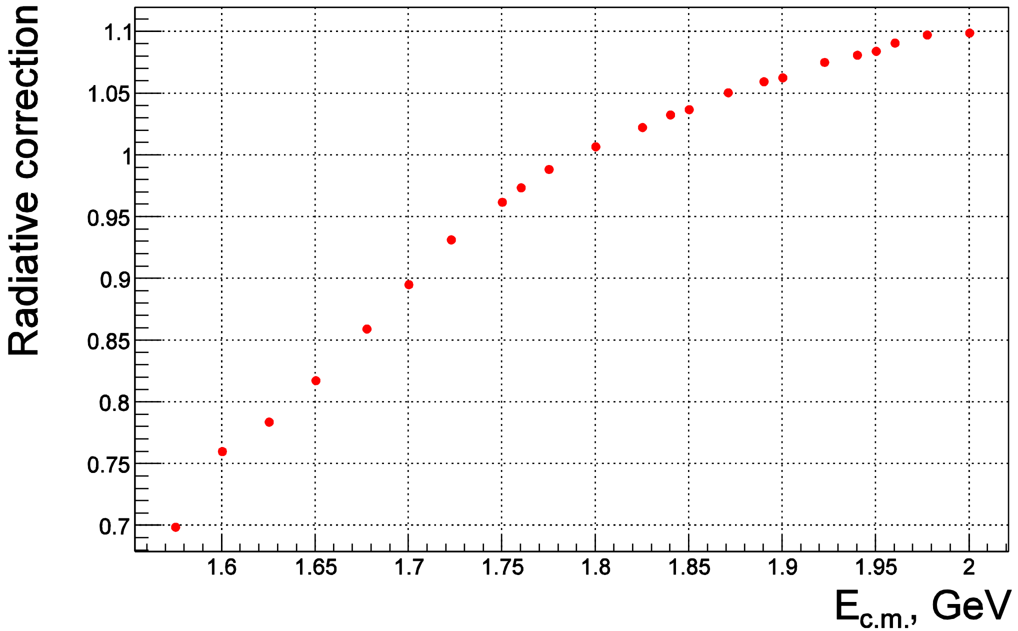
All energy points are combined.

Red points corresponds to experiment, blue histogram – simulation of $K^+K^-\eta$, green histogram – simulation of background, black – simulation of background and signal.



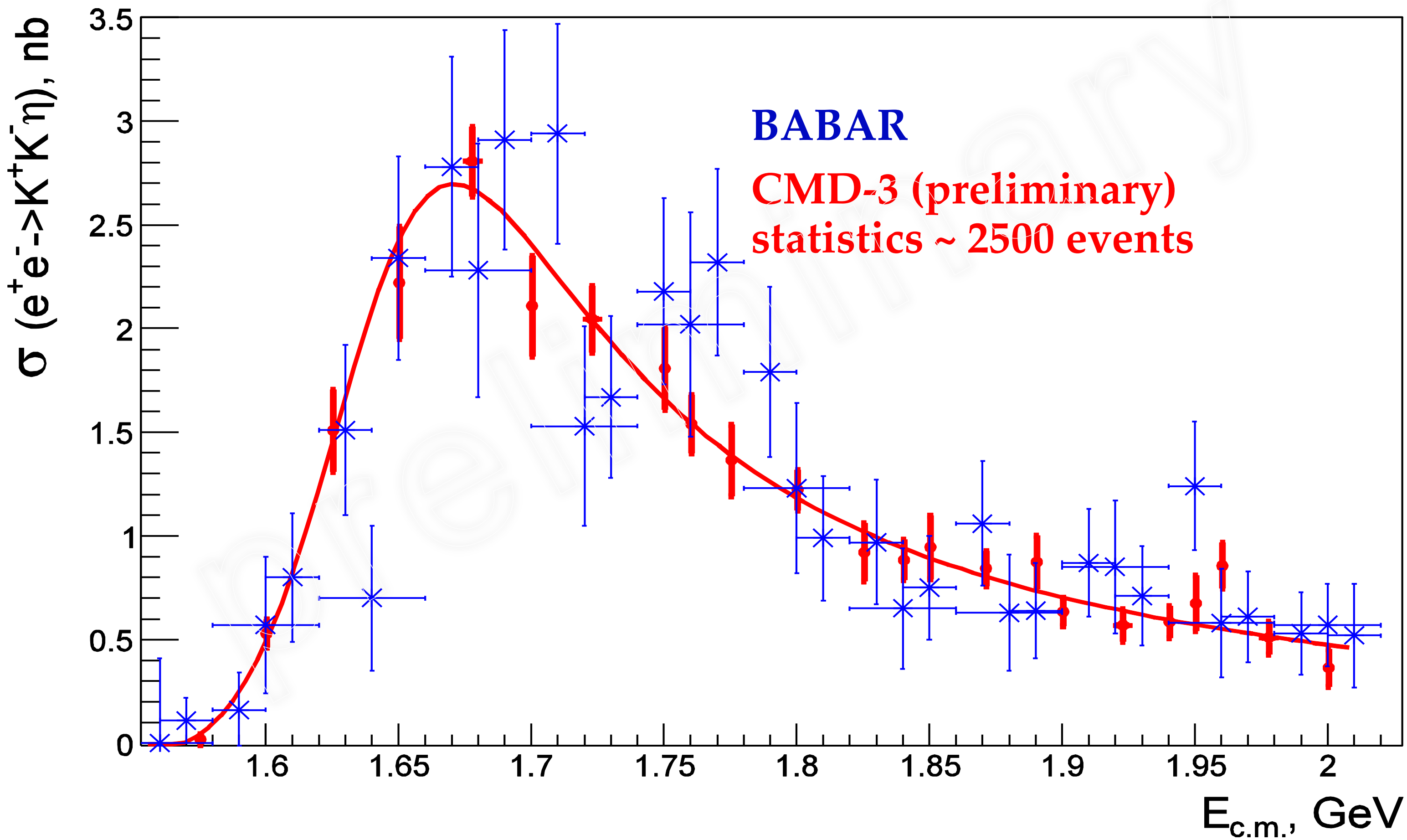
Radiative correction and efficiency





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

$$\sigma(s) = \frac{N_{exp} \cdot Corr}{L(s)\varepsilon_{MC}\varepsilon_{trig}\left(1+\delta_{rad}(s)\right)Br(\phi \to K^+\ K^-)}$$



Approximation of cross section

$$\sigma_{\varphi\eta}(s)=12\pi P_{\varphi\eta}(s)\left|\frac{A^{n.r.}}{s}+\sqrt{B^{\varphi'}{}_{\varphi\eta}\Gamma^{\varphi'}{}_{ee}}\,\frac{\sqrt{\frac{\Gamma_{\phi'}}{P_{\varphi\eta(M^2{}_{\varphi'})}}}e^{i\Psi}}{M^2{}_{\varphi'}-s-i\sqrt{s}\Gamma_{\phi'}}\right|^2$$

Parameter	BABAR	CMD-3
$B^{\varphi'}{}_{\varphi\eta}\Gamma^{\varphi'}{}_{ee}$, eV	76.1±16.1	77.8±8
$M_{\phi'}$, GeV	1675.0±10.9	1667.0±5.5
$\Gamma_{\phi'}$, GeV	141.1±34.0	153.1±19.0

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 7%.
- Cross section of the process $e^+e^- \to K^+K^-\eta$ was measured in the energy region 1.57-2 GeV with statistical error about 7-10% (number of events is about 2500) and systematic uncertainty is estimated as 10%.
- New positron injection complex will increase luminosity up to 10^{32} $cm^{-2}s^{-1}$ on 2E=2 GeV and it is commissioned now. After that experiments will be continued and statistics will be increased by a factor of 10.

Thank you for attention!