Study of physics of strong interaction at low energies in experimenta at e+e- collider VEPP-2000

(Some hadronic cross sections measurements with the CMD-3 detector)

Fedotovich G.V.

On behalf of CMD-3 collaboration
Budker Institute of Nuclear Physics
Novosibirsk State University

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Nalchik, BNA-50

Outline

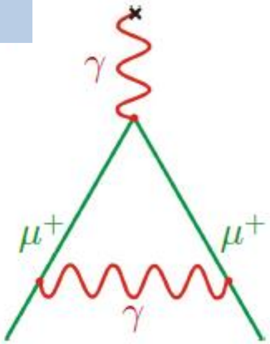
- Collider and detector
- Experiment
- Short recent results
- Summary and perspectives

Motivation

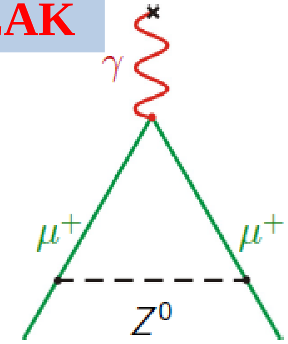
Muon anomaly, $a_m = (g-2)_m/2$

$$a_\mu^{theory(SM)} = a_\mu^{QED} + a_\mu^{weak} + a_\mu^{had}$$

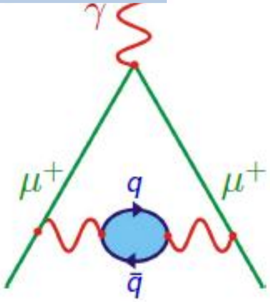
QED



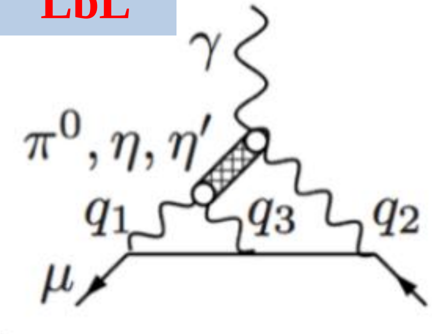
WEAK



HADRONIC



LbL



$$a_\mu^{had} = \frac{\alpha^2}{3\cdot\pi^2}\int_{4m_\pi^2}^{\infty} ds \cdot \frac{K(s)}{s}\cdot R(s)$$

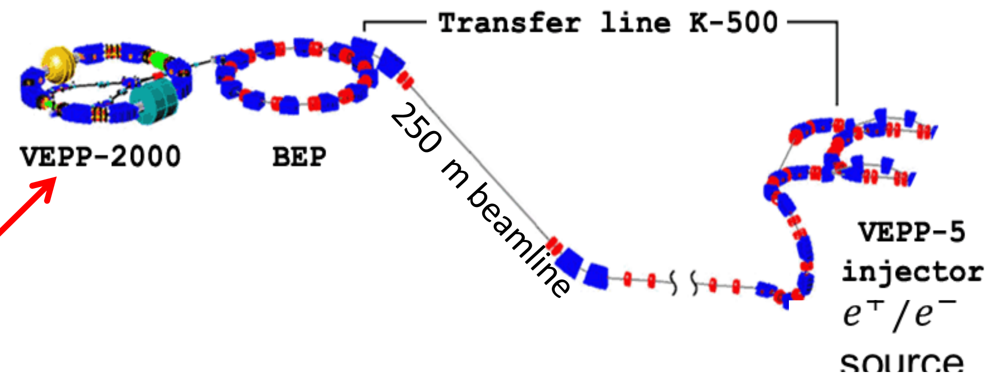
$$R(s) = \frac{\sigma(e^+e^- \to \gamma^* \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

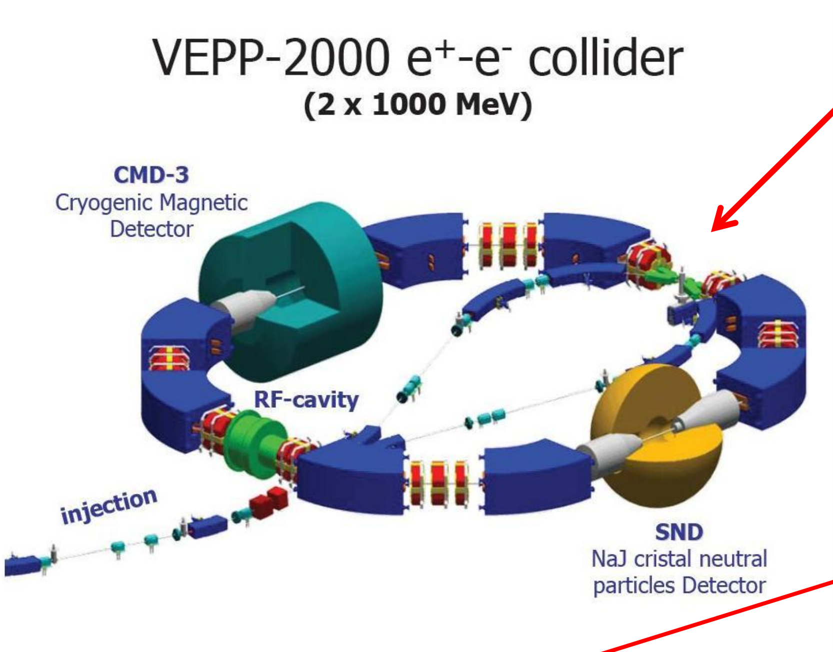
M. Davier et al.,EPJC71(2011)1515

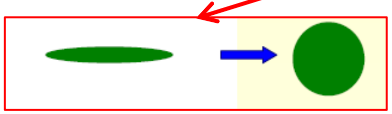
$$a_\mu^{EXP} - a_\mu^{SM} = 3.6\sigma$$

Experimental input is needed! The major contribution to (g-2)/2 coming from VEPP-2000 energy range gives 92% and determines its uncertainty

VEPP-2000 collider, in operation since 2010







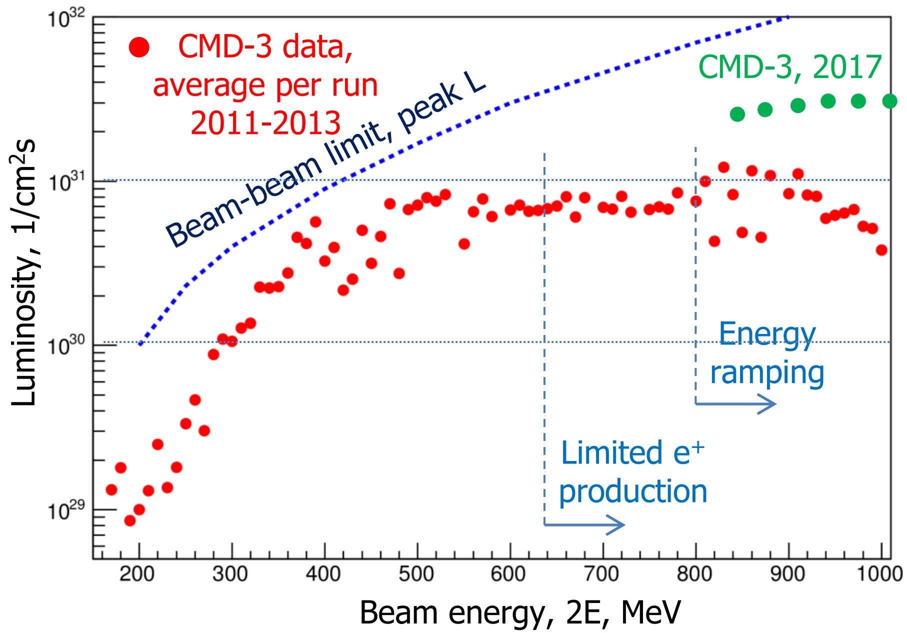
VEPP-2000 parameters:

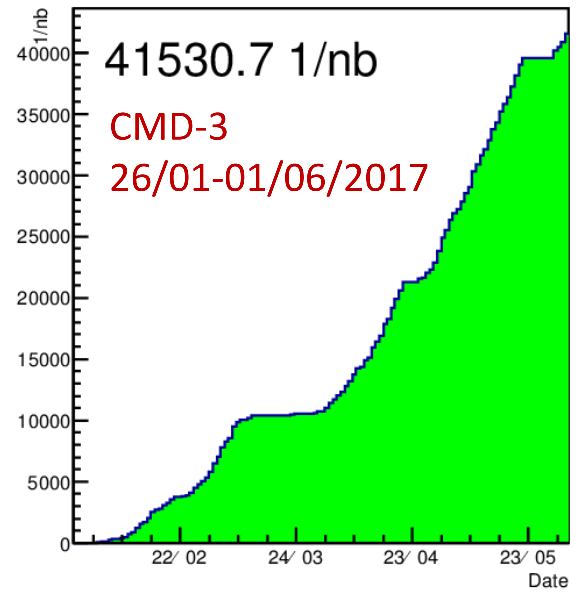
- c.m. energy E=0.3-2.0 GeV
- round beam optics
- Luminosity at E=2 GeV 10^{32} cm^{-2} sec^{-1} (project).

Now (May, 2017)

E=1.8 GeV, L $\approx$ 2-3$\times 10^{31}$ cm^{-2} sec^{-1}

2017 data taking





In 2011-2013, the luminosity was limited by a deficit of positrons (from $E > 650$ MeV) and limited energy of the booster (from $E > 825$ MeV).

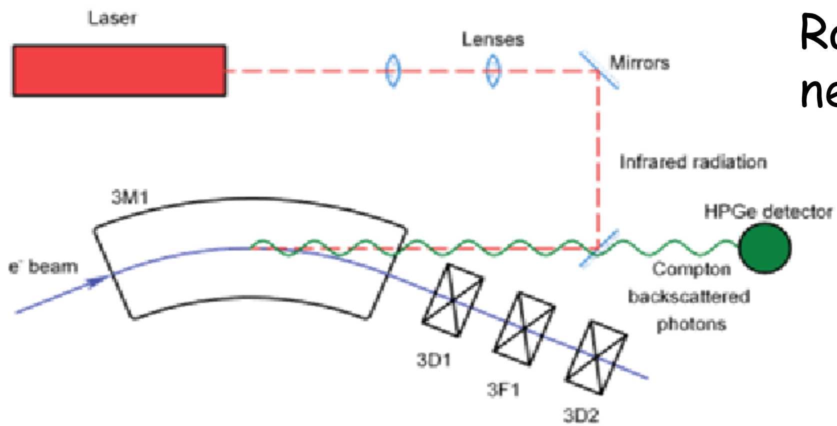
In 2017: big improvement in luminosity at high energy, still way to go

About 40 pb-1 collected

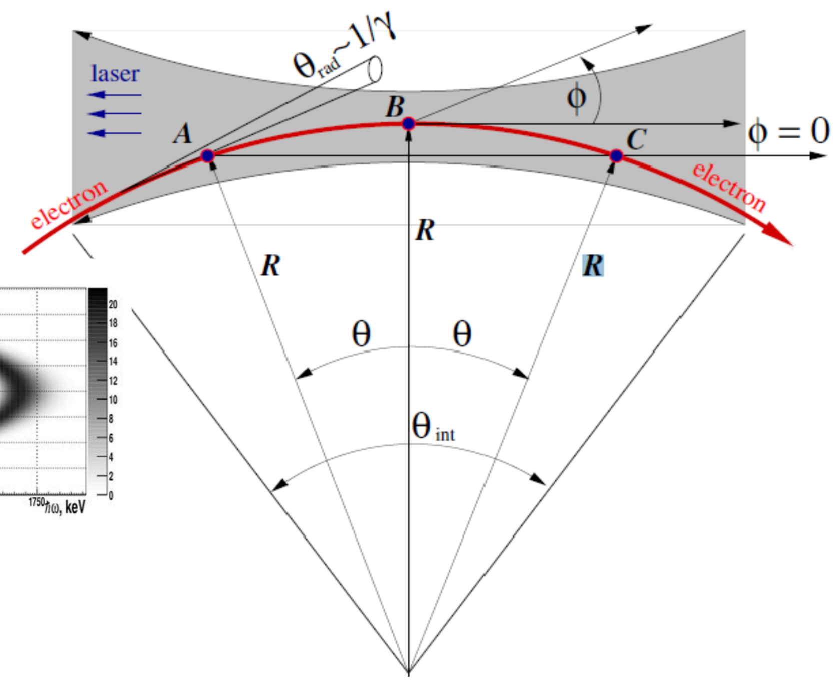
2.007 GeV ($e^+e^- \to D^{0*}$)	$4\ 1/pb$
$p\bar{p}$ and $n\bar{n}$ threshold	$14\ 1/pb$
Overall:	
$1.65 - 2.007$ GeV	$41.5\ 1/pb$

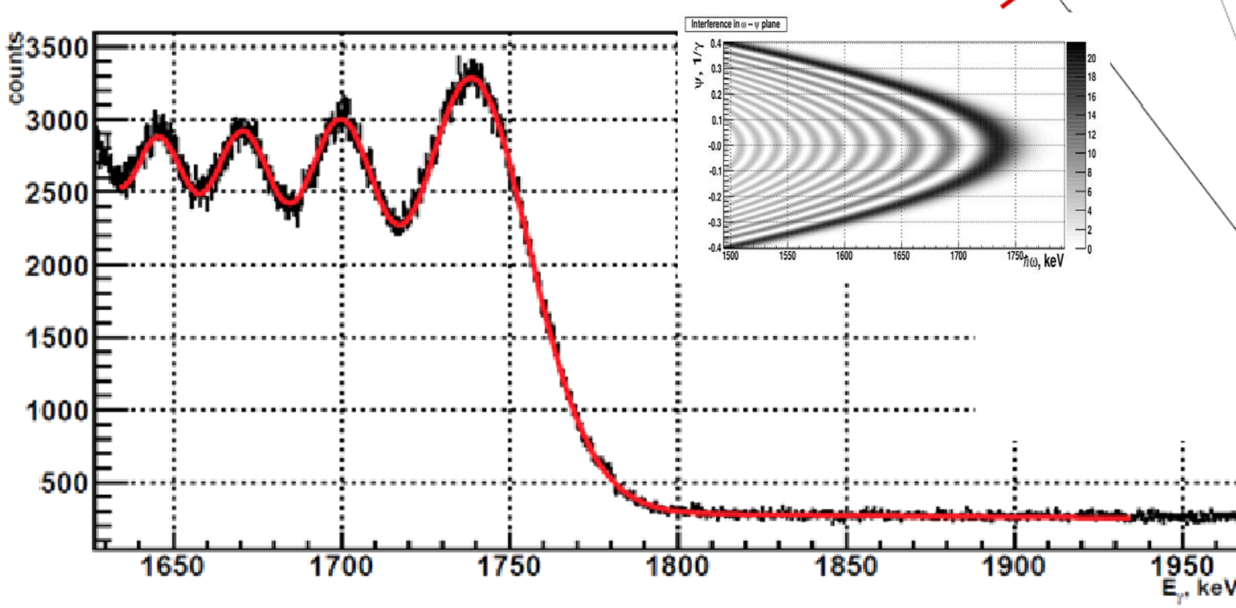
Energy measurement

Starting from 2012, energy is monitored continuously using Compton backscattering techniques



Radiation coming from A and C points near angle θ = 0 is undergone interference

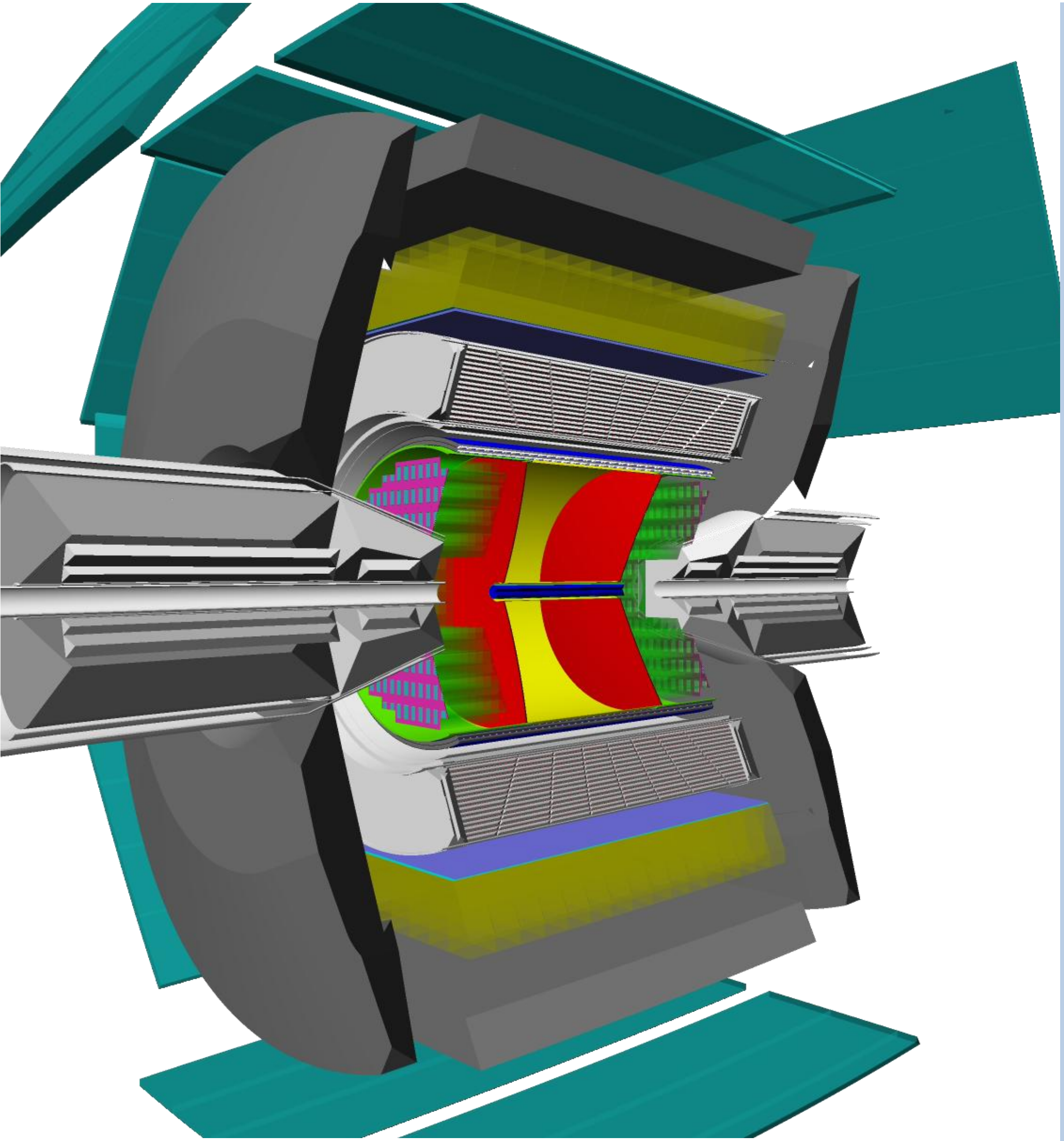




E = 993.662 ± 0.016 MeV

E.V. Abakumova et al.,Nucl.Instrum.Meth. A744 (2014) 35-40

CMD-3 detector



DC – 1218 hexagonal cells with sensitive wires, W-Re alloy, 15 ⌠ in diameter, spatial resolution < 100⌠.

Z-chamber – start FLT, precise determine z-coordinate ~ 500 ⌠ (detector acceptance)

LXe calorimeter thickness 5,1X_0, 196 towers & 1286 strips. Spatial resolution 1 – 2 mm, measurement of conversion point for g's measurement of shower profile

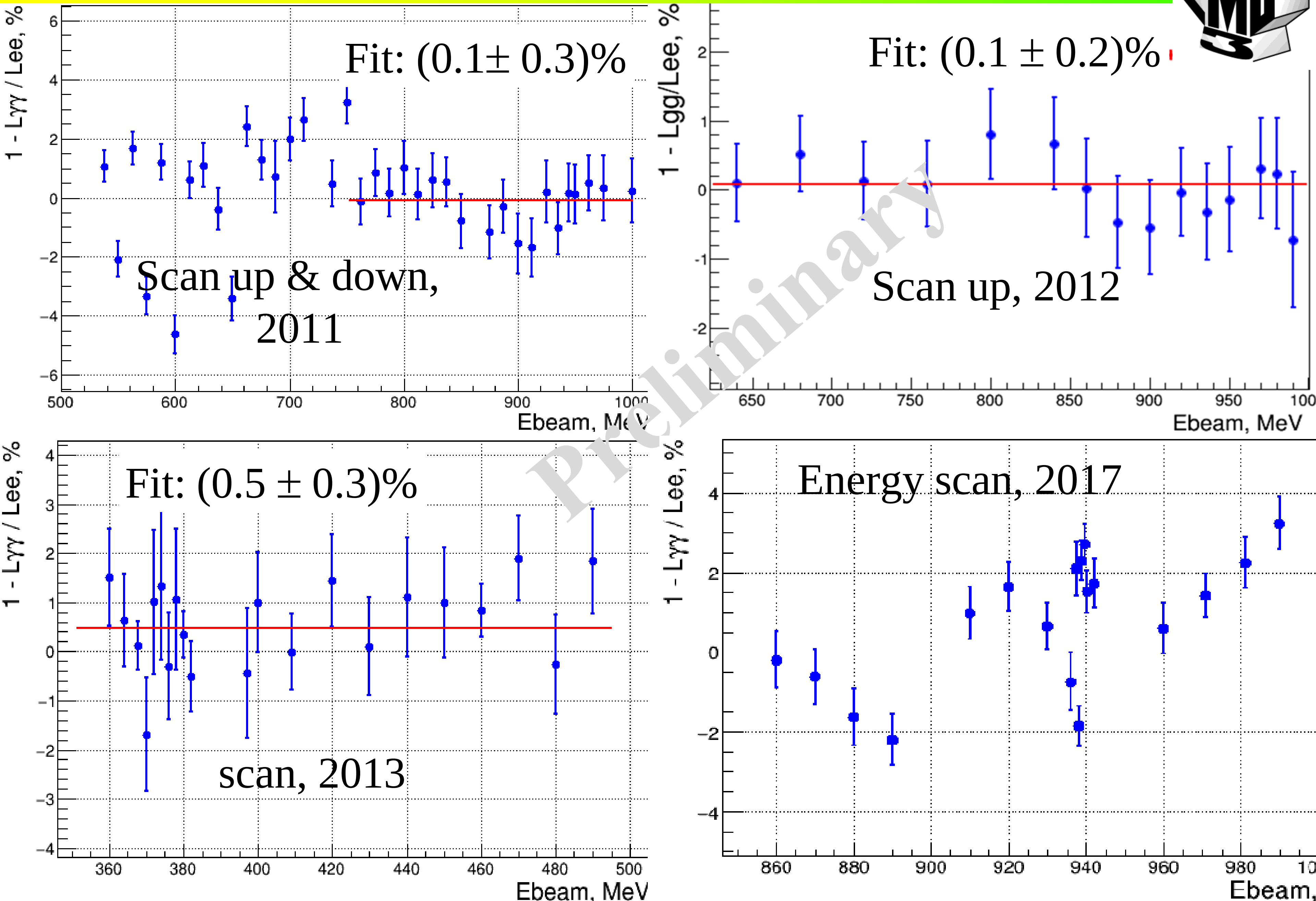
TOF – 16 counters, time resolution ~ 1ns particle id (mainly p, n)

Calorimeter with CsI crystals (<3,5 t), 8 octants, number of crystals - 1152, 8 X_0.

MR system – 8 octants (cosmic veto, ~ 1ns)

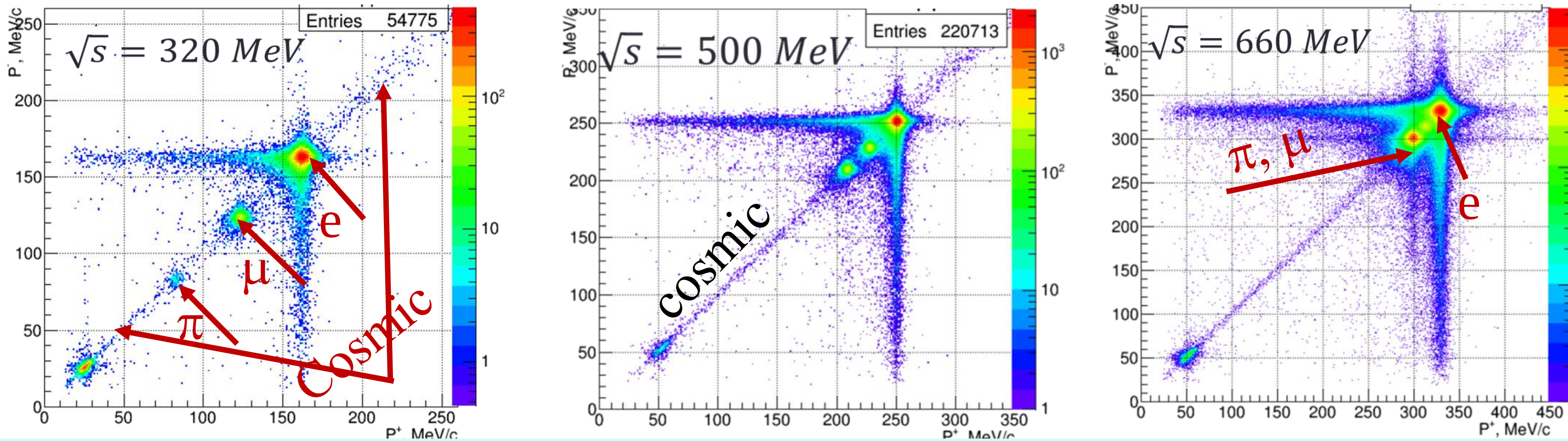
Design magnetic field - 1,5 T (current value 1.3 T)

Luminosity determination



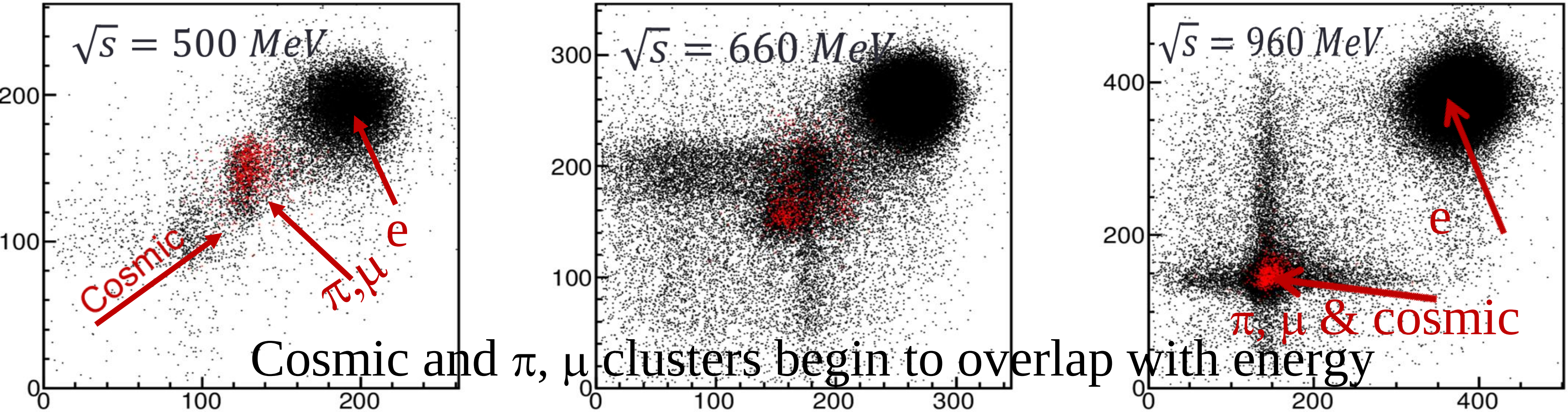
Luminosity determination (e+e- & $\gamma\gamma$)

e, μ, π separation based on momentum in DC



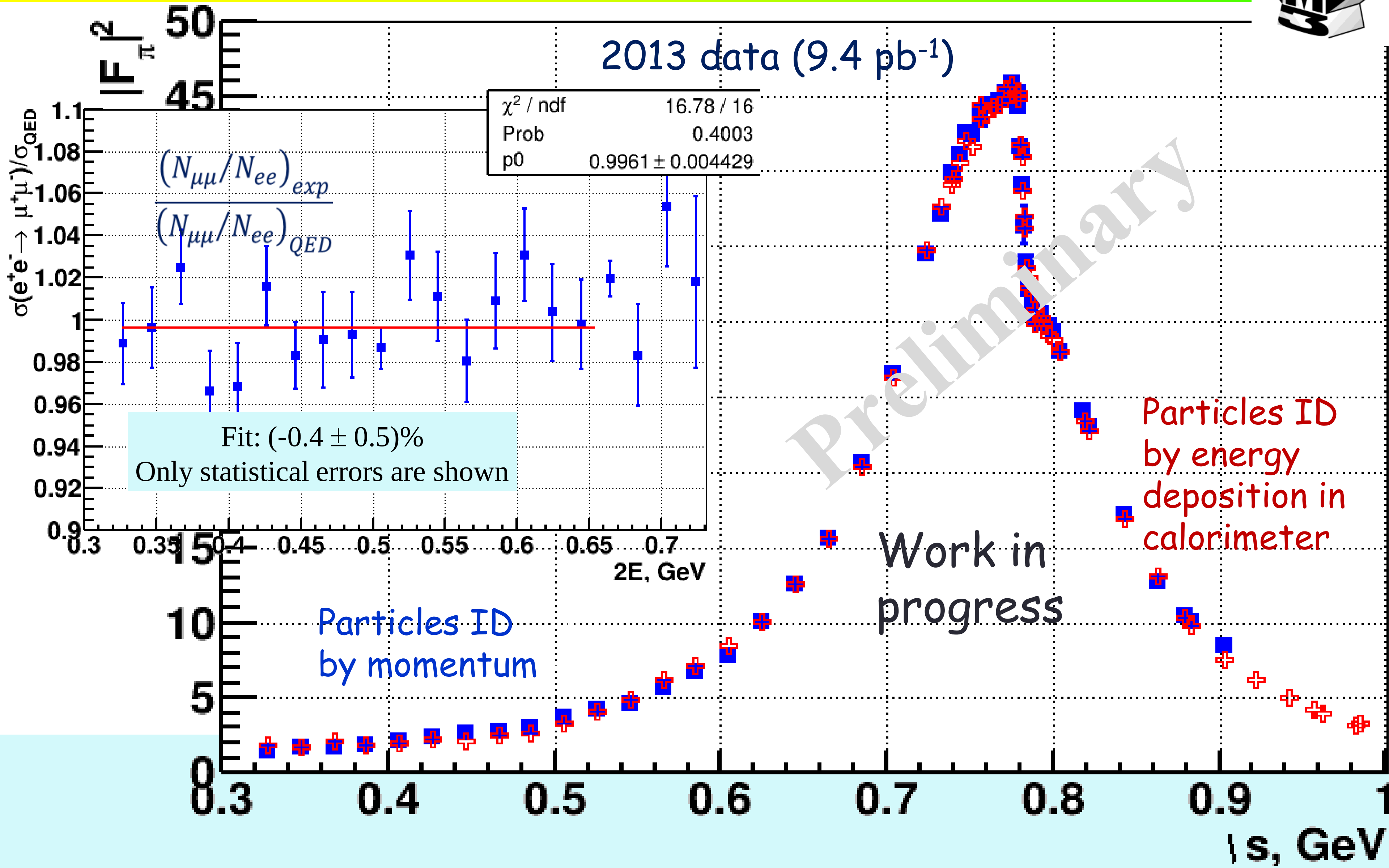
e, μ, π separation based on energy deposition in calorimeter

red dots – simulated muons



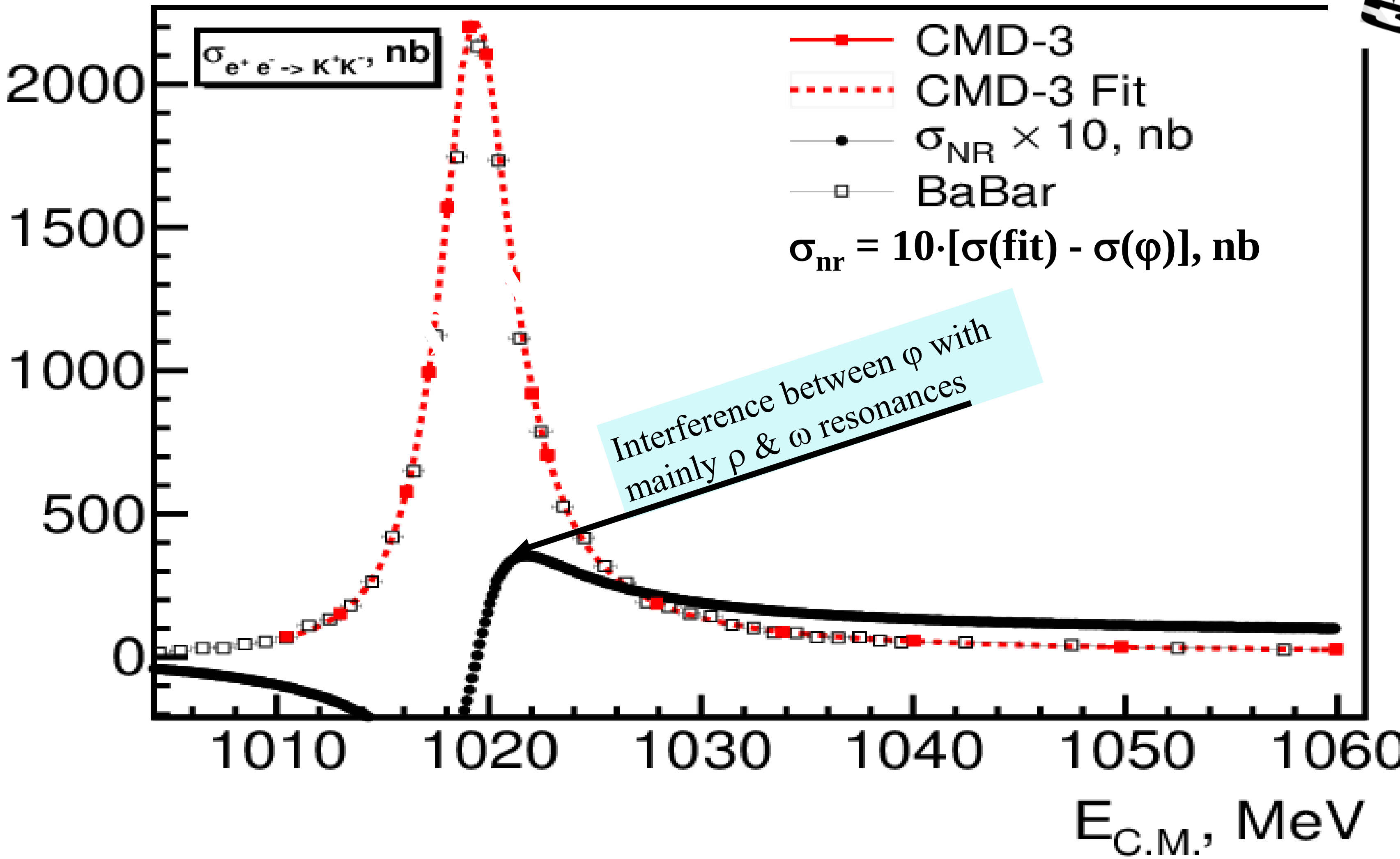
Cosmic and π, μ clusters begin to overlap with energy

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



2013 data (9.4 pb^{-1})
$|F_\pi|^2$
$\sigma(e^+e^- \to \mu^+\mu^-)/\sigma_{QED}$
$\frac{(N_{\mu\mu}/N_{ee})_{exp}}{(N_{\mu\mu}/N_{ee})_{QED}}$
χ^2 / ndf 16.78 / 16
Prob 0.4003
p0 0.9961 ± 0.004429
Fit: (-0.4 ± 0.5)%
Only statistical errors are shown
2E, GeV
Preliminary
Particles ID by energy deposition in calorimeter
Work in progress
Particles ID by momentum
√s, GeV

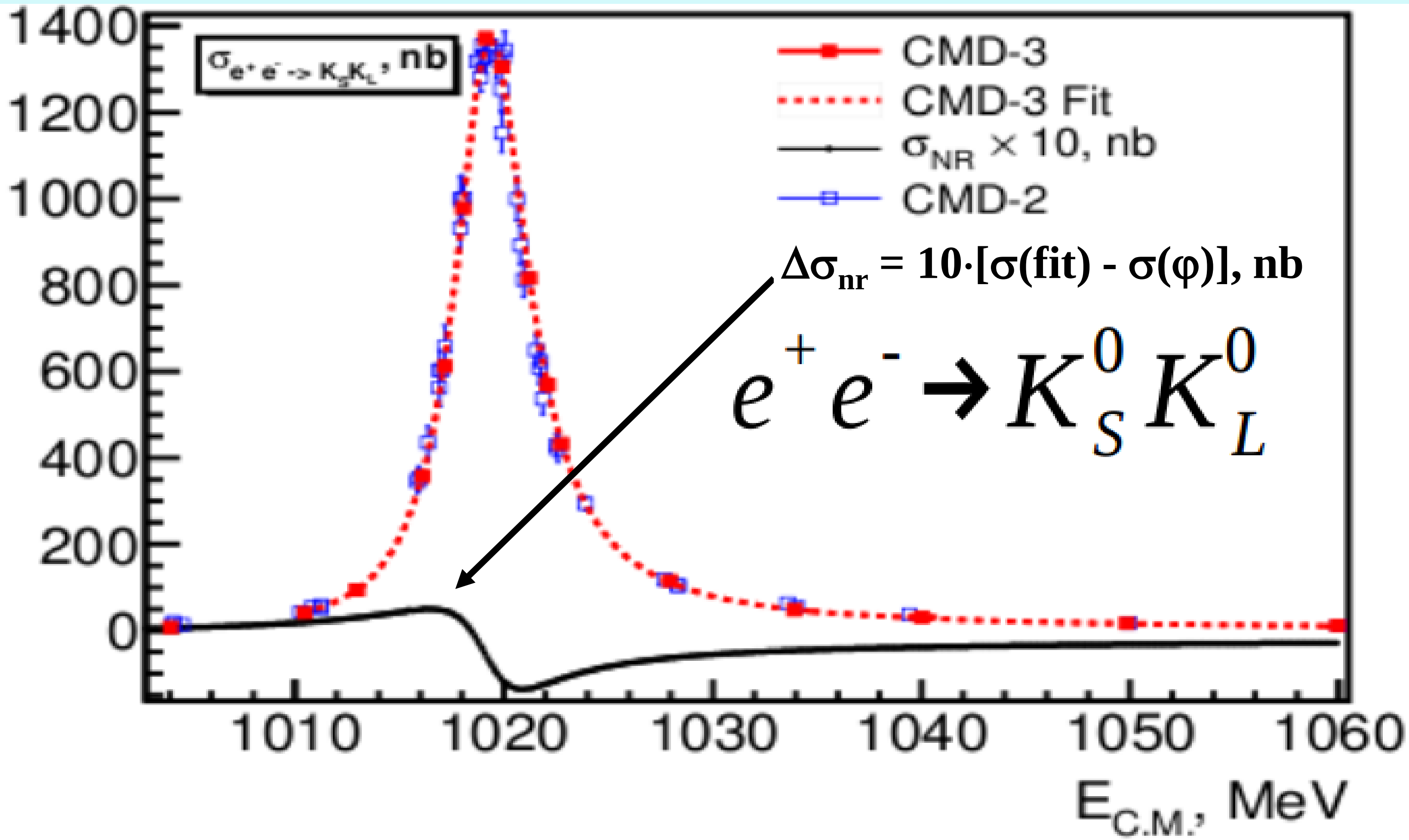
Study of the process $e^+e^- \to K^+K^-$



The measured cross section of the process e+e- → K^+K^- together with the results from BaBar is shown near φ-meson mass energy. The systematic error is about 2.5%

$e^+e^- \to K_L K_S$

This process is studied using decay $K_s \to \pi^+\pi^-$



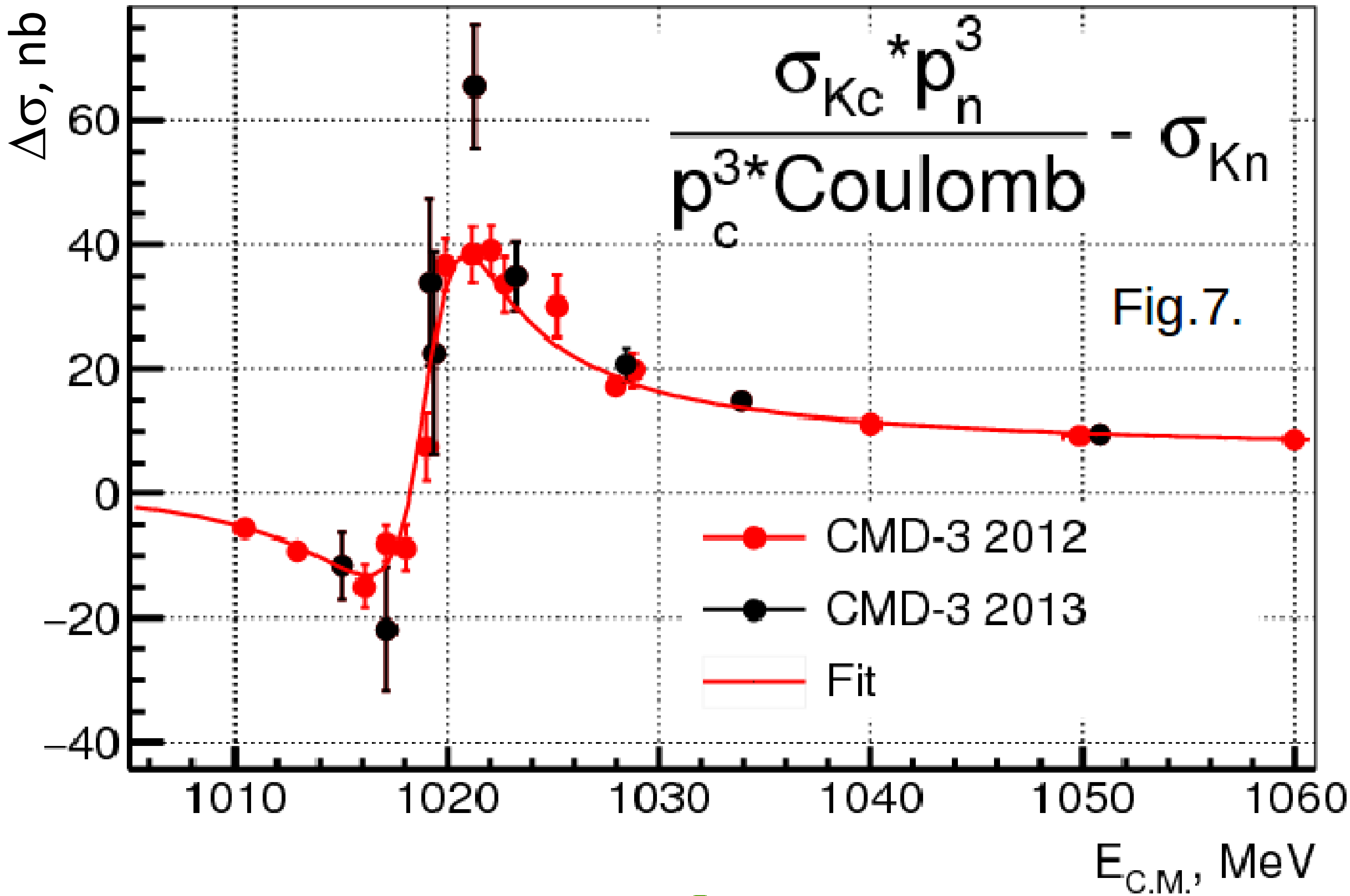
In E_{cm} = 1004 – 1060 MeV: 25 energy points. Collected luminosity ~5.9 pb^{-1}

Systematic error is 2 – 3 %

Published in **Phys.Lett. B760 (2016) 314-319**

The difference of charged and neutral cross-sections normalized to phase space difference as well as Coulomb interaction of charged kaons in final state.

$$\sigma(K^+K^-) \sim |A_{I=0}(\omega,\varphi) + A_{I=1}(\rho)|^2$$
$$\sigma(K_SK_L) \sim |A_{I=0}(\omega,\varphi) - A_{I=1}(\rho)|^2$$



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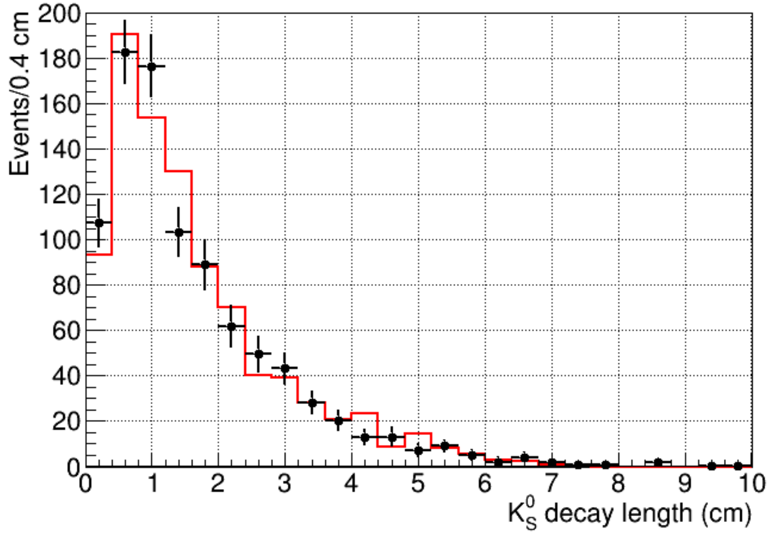
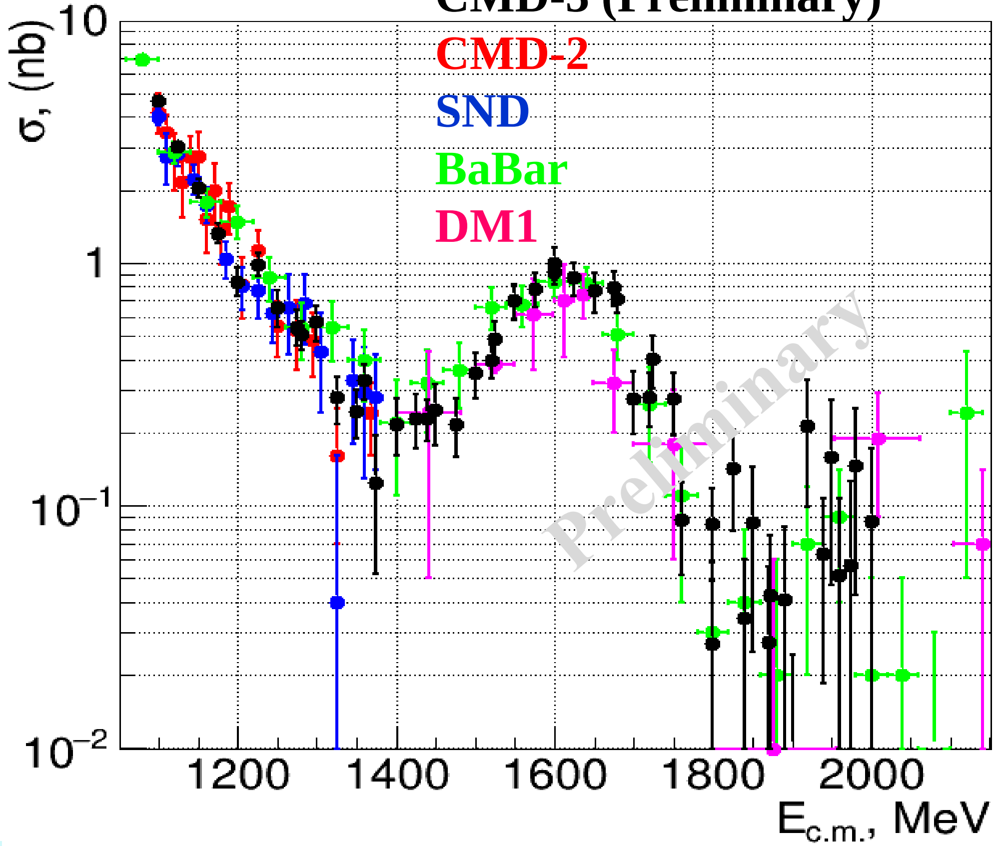




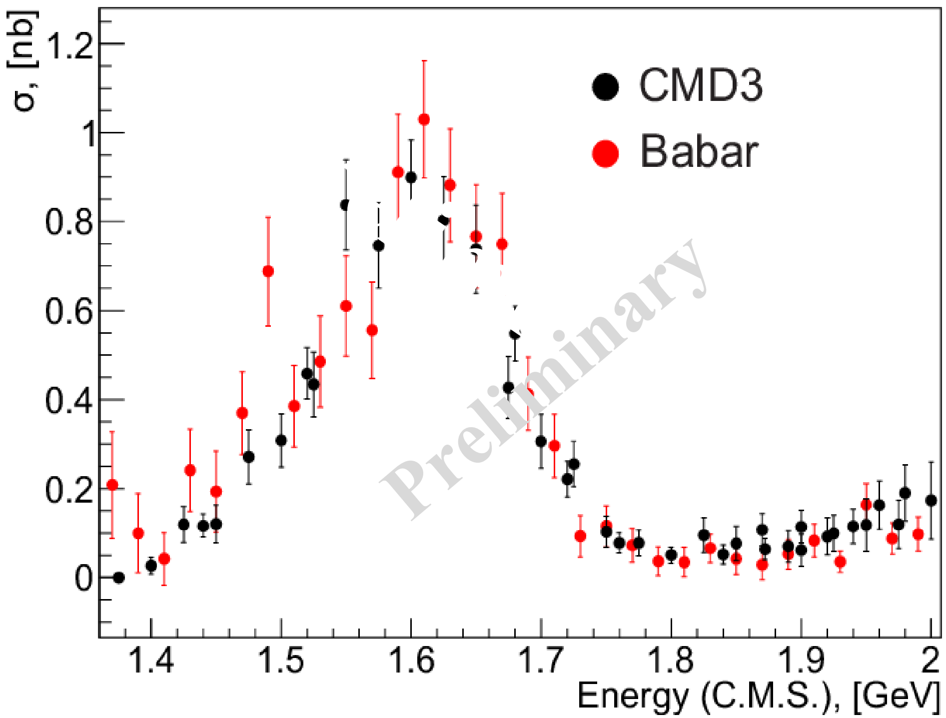
Good agreement with all previous results

In E_{cm} = 1100 – 2000 MeV: 54 energy points

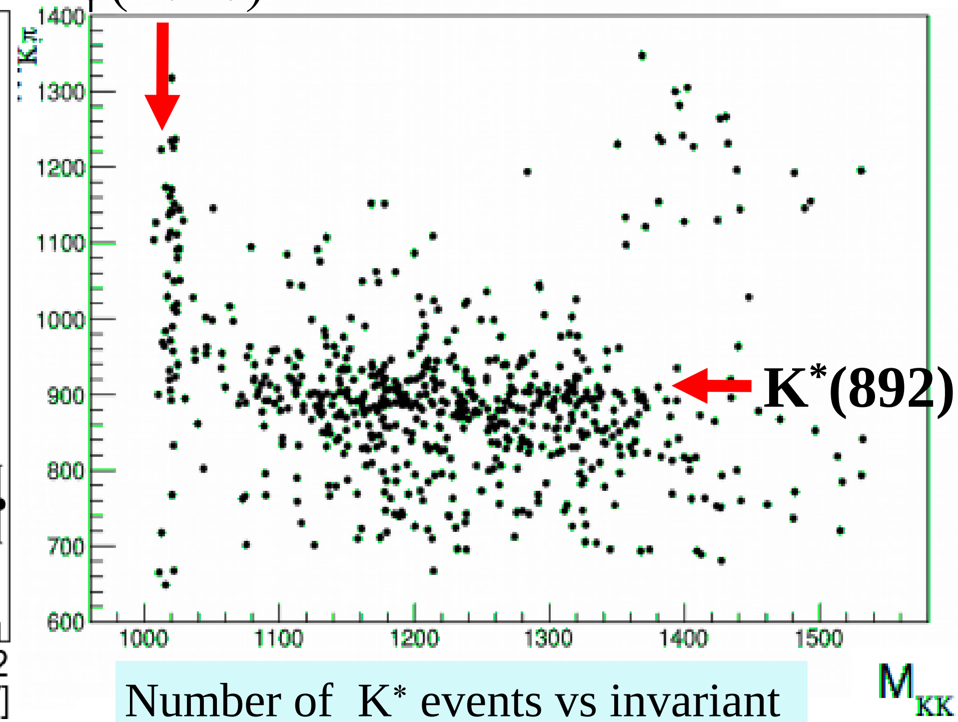
Accumulated luminosity about 32.1 pb^{-1}

1889 events with fully reconstructed $K_S \to \pi^+\pi^-$

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



Cross section, very preliminary

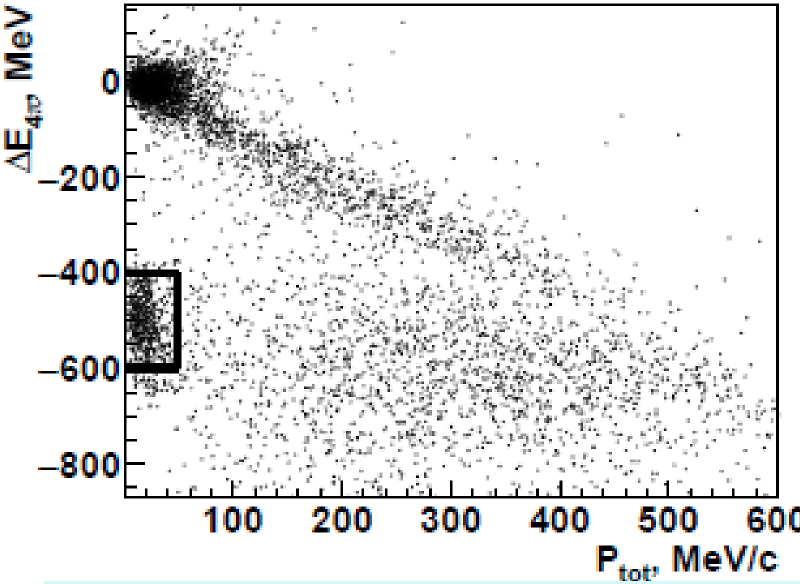


Number of K^* events vs invariant mass of K^+K^-

- Analysis is based on the integrated luminosity34 pb^{-1}
- It is consistent with BaBar but more precise
- Number of selected signal events was found to be 940 ± 57.
- The main physical background comes from the processes: e+e- → $K^+K^-\pi^0\pi^0$, $\pi^+\pi^-\pi^0$

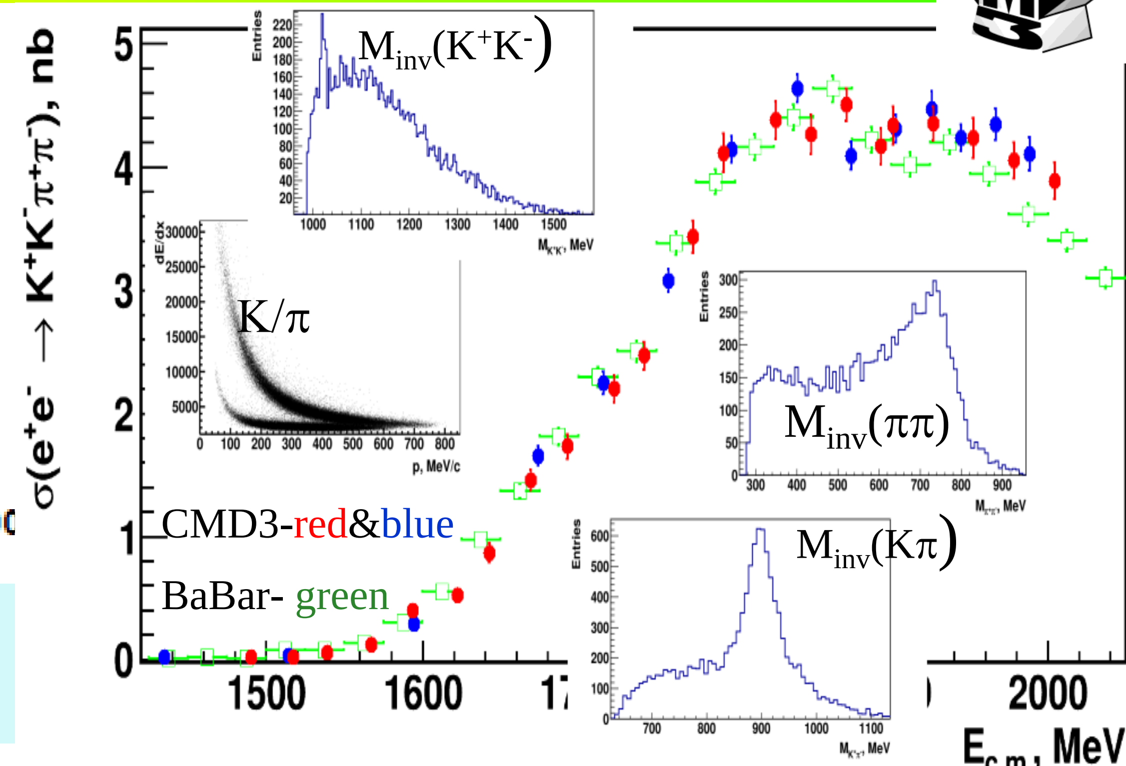
- Two intermediate states are clearly seen: $\varphi\pi^\circ$ and K*(892)K mechanism
- Detection efficiency according to SIM was around 12% ~ 18% with energy
- The current systematic uncertainty we estimated as 10%

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



$\Delta E = E_1 + E_2 + E_3 + E_4 - 2E_{beam}$

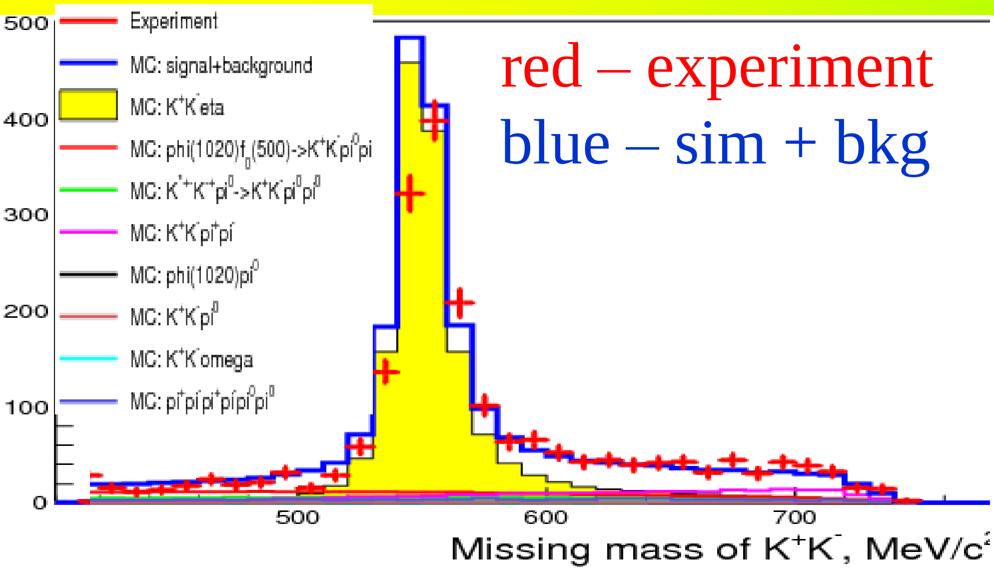
$\mathbf{P}_{tot} = |\mathbf{P}_1 + \mathbf{P}_2 + \mathbf{P}_3 + \mathbf{P}_4|$

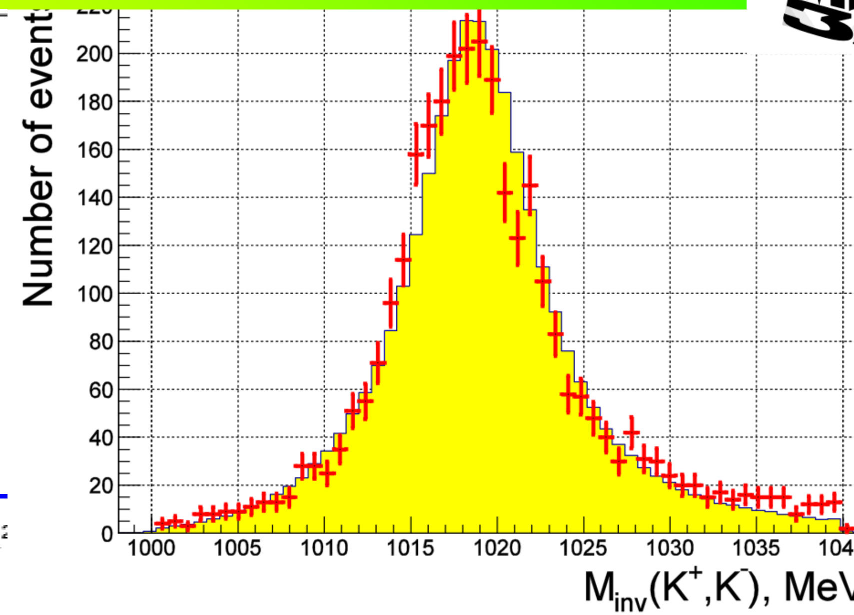


- CMD-3 studies uses 22 pb^{-1} between 1.5 and 2 GeV, more than 20000 events with 3 and 4 tracks were selected for analysis;
- Ionisation losses in DC dE/dx provide good K/π separation;
- Analysis of $\pi^+\pi^-$, $K^\pm\pi^\mp$, K^+K^- inv. Masses clear shows signals from π^0, $K^{*0}(892)$ and $\phi(1020)$;
- Many different mechanisms seen: $K_1(1270)K \to K2\pi K$, $K^*(892)K\pi$,
  $K_1(1400)K \to K^*(892)\pi K$, $\varphi\pi^+\pi^-$.

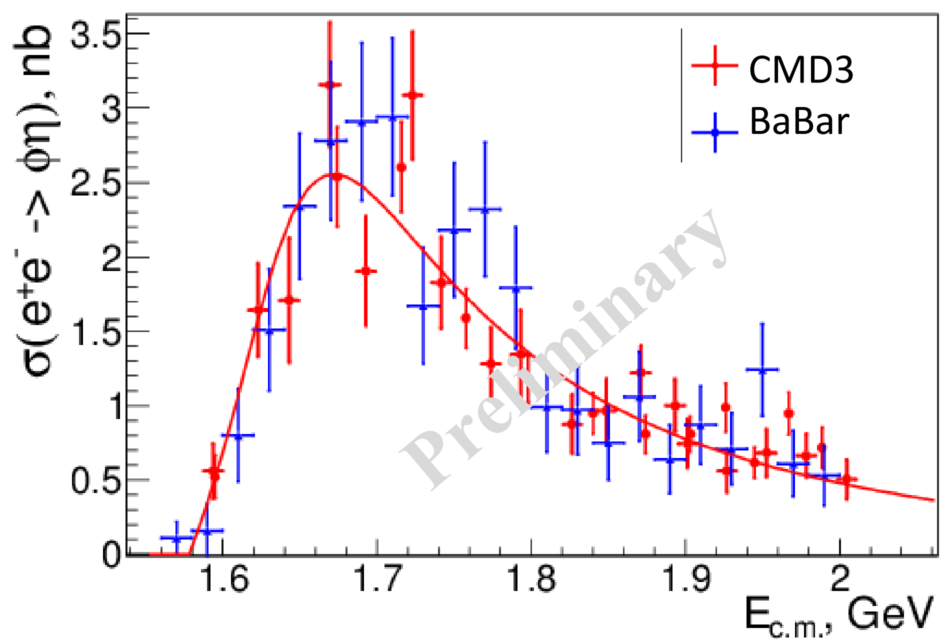
Recently published in Phys.Lett. B756 (2016)153-160

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

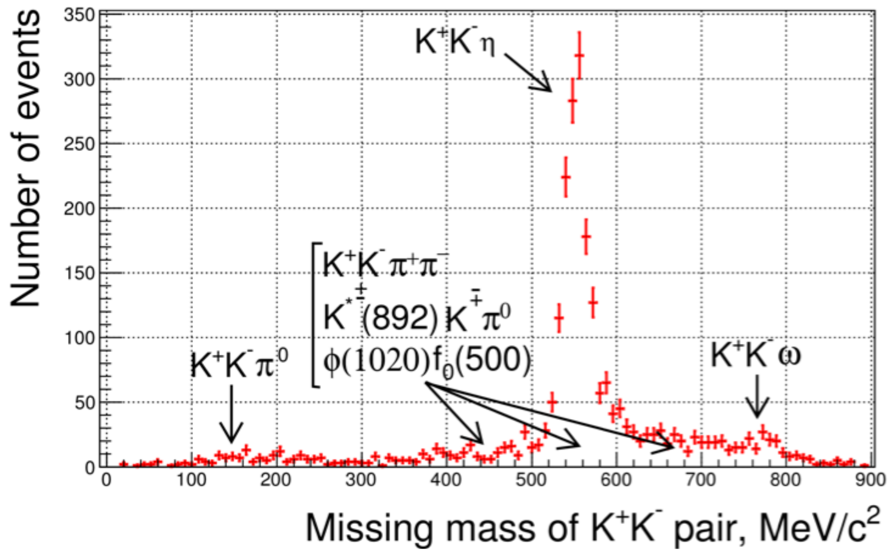


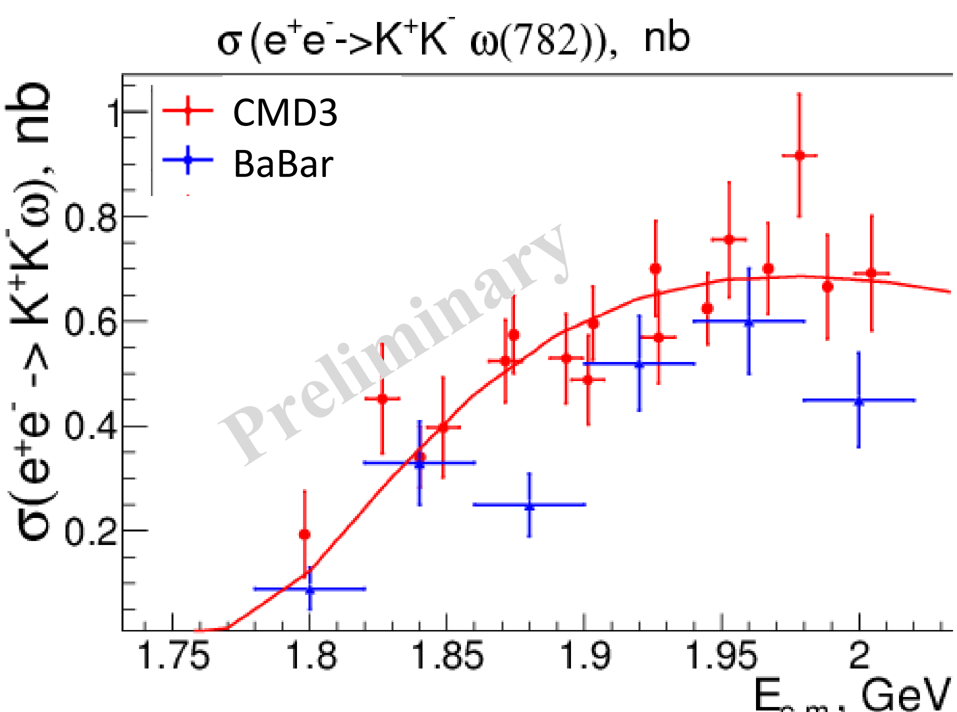


- A data sample of 22 pb^{-1} collected in 2011-2012 is used to energy points between 1.57 - 2.0 GeV
- Analysis: dominant $\varphi\eta$ signal, studies of nonresonance $K^+K^-\eta$ is needed
- Background with numerous physical components is seen
- The data sample includes 1268 ± 43 signal events



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





- A data sample of 12 pb^{-1} collected in 2011-2012 is used to study $e^+e^- \to K^+K^-\omega$;
- Selected number of signal events 899 ± 37
- XS was measured at 16 energy points between 1.84 - 2.0 GeV
- Analysis emphasizes the dominant $K^+K^-\omega$ signal, studies of the hadronic continuum $K^+K^-\omega$ is needed

Summary and nearest perspectives

- VEPP-2000 successfully operated at $\sqrt{s}$ = $2m_\pi$ -2 GeV with $L_{max} = 2x10^{31}$ cm^{-2}s^{-1} and collected about 60 pb^{-1} per detector (2011 – 2013).

- Cross sections measured have the same or better statistical precision with respect to previous CMD-2 experiments.

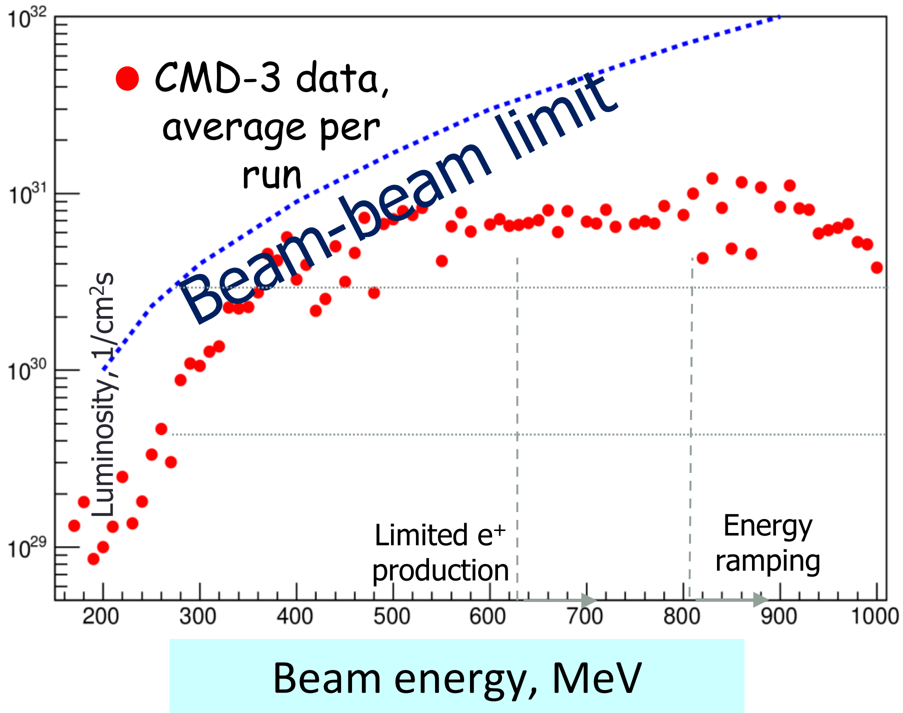
- CMD-3 results will provide high accuracy, compatible or better than ISR measurements, the tentative goals are 0.3% (0.5%) for $\pi^+\pi^-$ and ~3% for multibody modes.

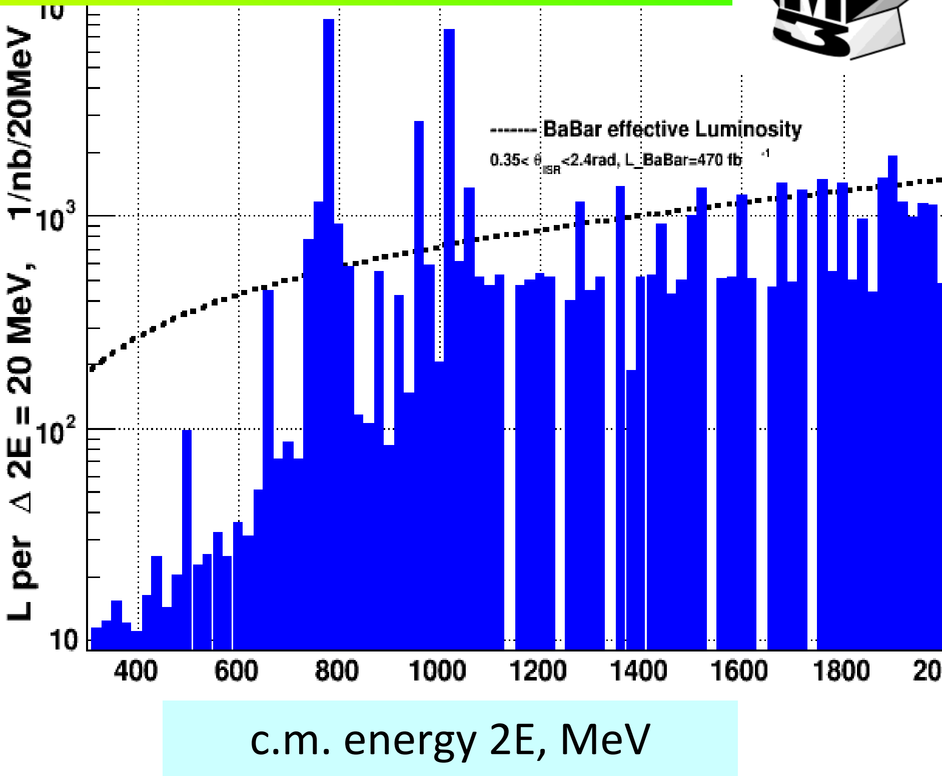
- VEPP-2000 upgrade is completed with new positron injection facility, which will increase luminosity at least by factor of 10 (~3 - 5 times at the moment).

- We star analysis processes with Ks in final states: $K_S K^{0*} \rightarrow K_S K^{\pm}\pi^{- +}$, $K^{*\pm}K^{- +} \rightarrow K_S\pi^{\pm}K^{- +}$, $K^{*\pm}K^{*- +} \rightarrow K_S\pi^{\pm}K^{- +}\pi^0$ and so on

- We plan to get data with integrated luminosity of about 1-2 fb^{-1} in 5 years, which should provide new precise results on multihadron production.

Collected luminosity





Today the peak luminosity is limited by a deficit of positrons (650 MeV) and limited energy of the booster (higher 825 MeV).

After upgrade (completed) we expect increasing of luminosity by a factor of 10 at maximum beam energy.

Collected L ~ 60 pb^{-1} per detector

8.3 pb^{-1}	ω-region
9.4 pb^{-1}	region below 1 GeV (except ω)
8.4 pb^{-1}	φ-region
34.5 pb^{-1}	region higher than φ

VEPP-2000 physical results, (journal articles)

1. e+e- → $\pi^0\pi^0\gamma$, Phys.Rev.D, (2013)
2. e+e- → 6π, Phys.Lett.B,(2013)
3. e+e- → nn, Phys.Rev.D,(2014)
4. e+e- → NN 6π, JETP Lett.,(2014)
5. e+e- → $\eta\gamma$, Phys.Rev.D,(2014)
6. e+e- → η', Phys.Lett.B,(2015)
7. e+e- → η,η', Phys.Rev.D,(2015)
8. e+e- → $\eta\pi^+\pi^-$, Phys.Rev.D,(2015)
9. e+e- → $\pi^+\pi^-\pi^0$, JETP,(2015)
10. e+e- → K^+K^-, Yad.Fizika, (2015)

11. e+e- → η, JETP Lett.,(2015)
12. e+e- → K^+K^-, Phys.Rev.D,(2016)
13. e+e- → $\omega\eta\pi^0$, Phys.Rev.D,(2016)
14. e+e- → $\omega\eta$, Phys.Rev.D,(2016)
15. e+e- → $\pi^0\gamma$, Phys.Rev.D,(2016)
16. e+e- → $K^+K^-\pi^+\pi^-$, Phys.Lett.B,(2016)
17. e+e- → pp, Phys.Lett.B,(2016)
18. e+e- → K_SK_L, Phys.Lett.B,(2016)
19. e+e- → $\pi^0\pi^0\gamma$, Phys.Rev.D, (2016)