Measurements of e+e- → hadrons cross sections with CMD-3 at VEPP-2000

Fedotovich G.V., Shemyakin D.N.
(on behalf of the CMD-3 Collaboration)

Outline

Introduction
Collider & Detector
Preliminary Results
Conclusion

Introduction

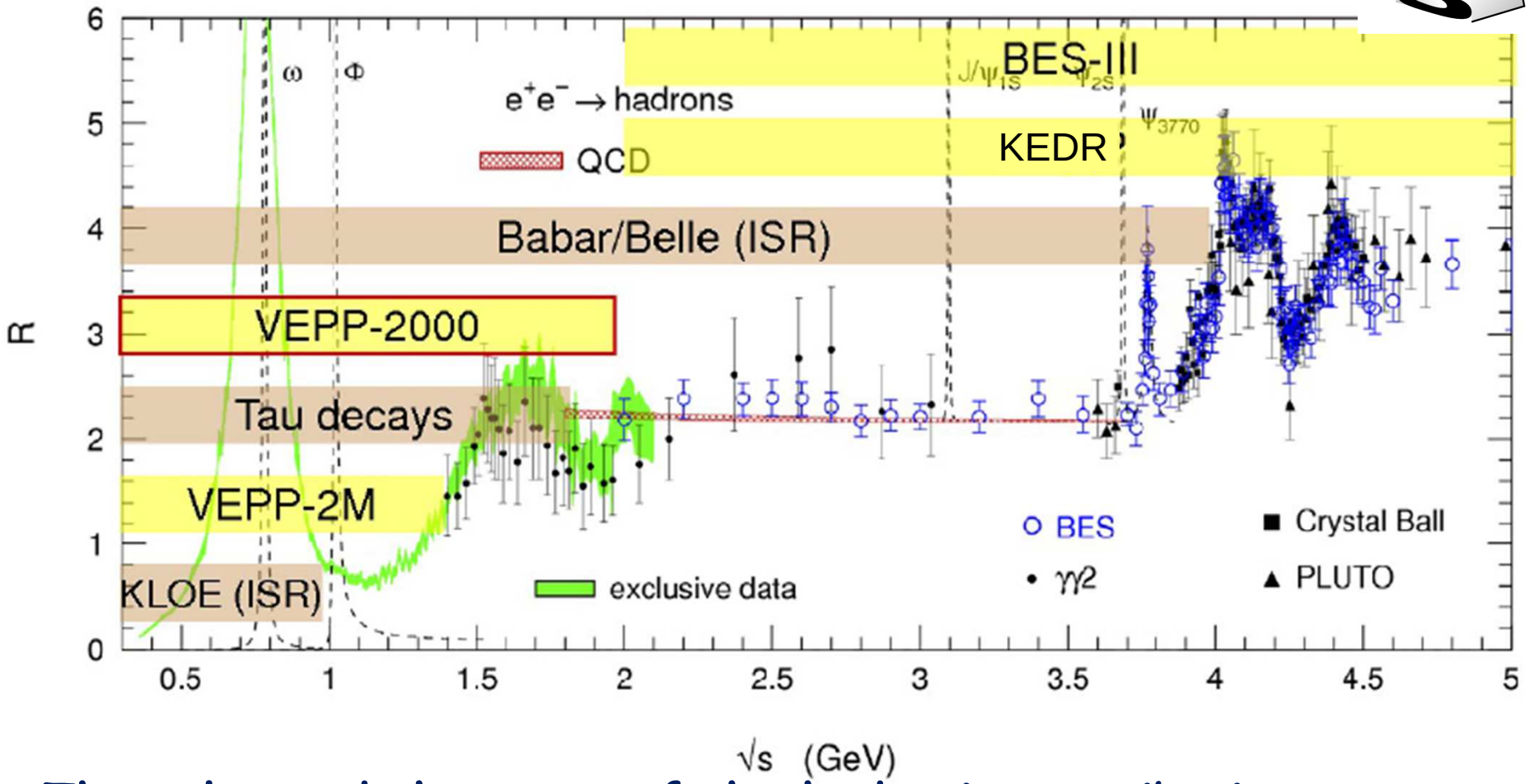
Measurement of the cross section e+e- →hadrons
in the low energy range up to 2 GeV is interesting for:

- measurement of parameters of light vector mesons ρ, ω, φ, φ′, ρ′, ρ″, ω′, ω″
- search of exotics (light hybrids and glueballs)
- CVC test in comparison with spectral functions of tau decays

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

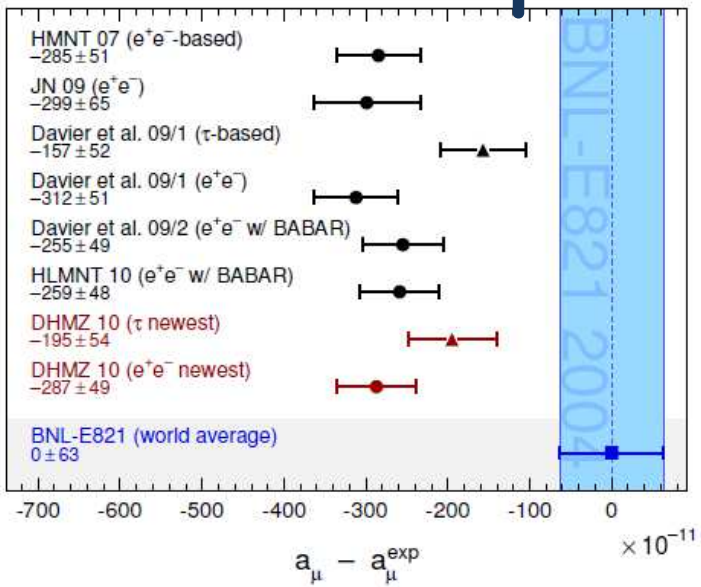
It is essential for the interpretation of precision measurements of the (g-2) of muon - good test of SM

R(s) measurements at low s



The value and the error of the hadronic contribution to muon (g-2) are dominated by low energy R(s) (<2GeV give 92%).

SM prediction for muon g-2



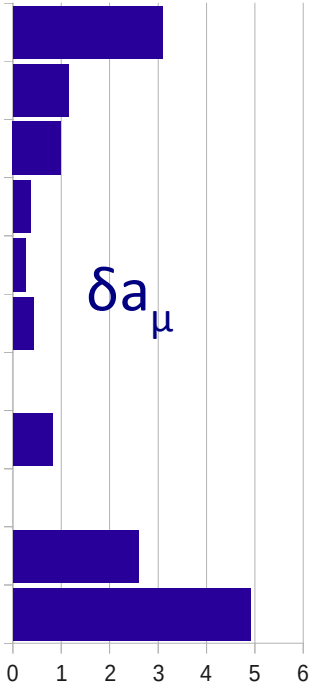
$a_\mu^{exp} = (g-2)_\mu/2 = (11\,659\,208.9 \pm 6.3) \times 10^{-10}$

$a_\mu^{th} = a_\mu^{QED} + a_\mu^{EW} + a_\mu^{hadr}$

Δ(Exp. − Theor.) ~3-3.6σ

QED	**11 658 471.808 ±0.015**	**T. Kinoshita and M. Nio, Phys. Rev. D 73, 013003**
EW	**15.4 ±0.2**	**A. Czarnecki et al., Erratum-ibid. D73 (2006) 119901**
NLO hadronic	**−9.8 ± 0.1**	**HLMNT 11 , J. Phys. G 38, 085003 (2011).**
LO hadronic	**694.9 ±4.3**	**HLMNT 11 , J. Phys. G 38, 085003 (2011).**

Main channels which contribute to precision at √s<1.8 GeV **M. Davier et al.,Eur.Phys.J. C71 (2011) 1515**

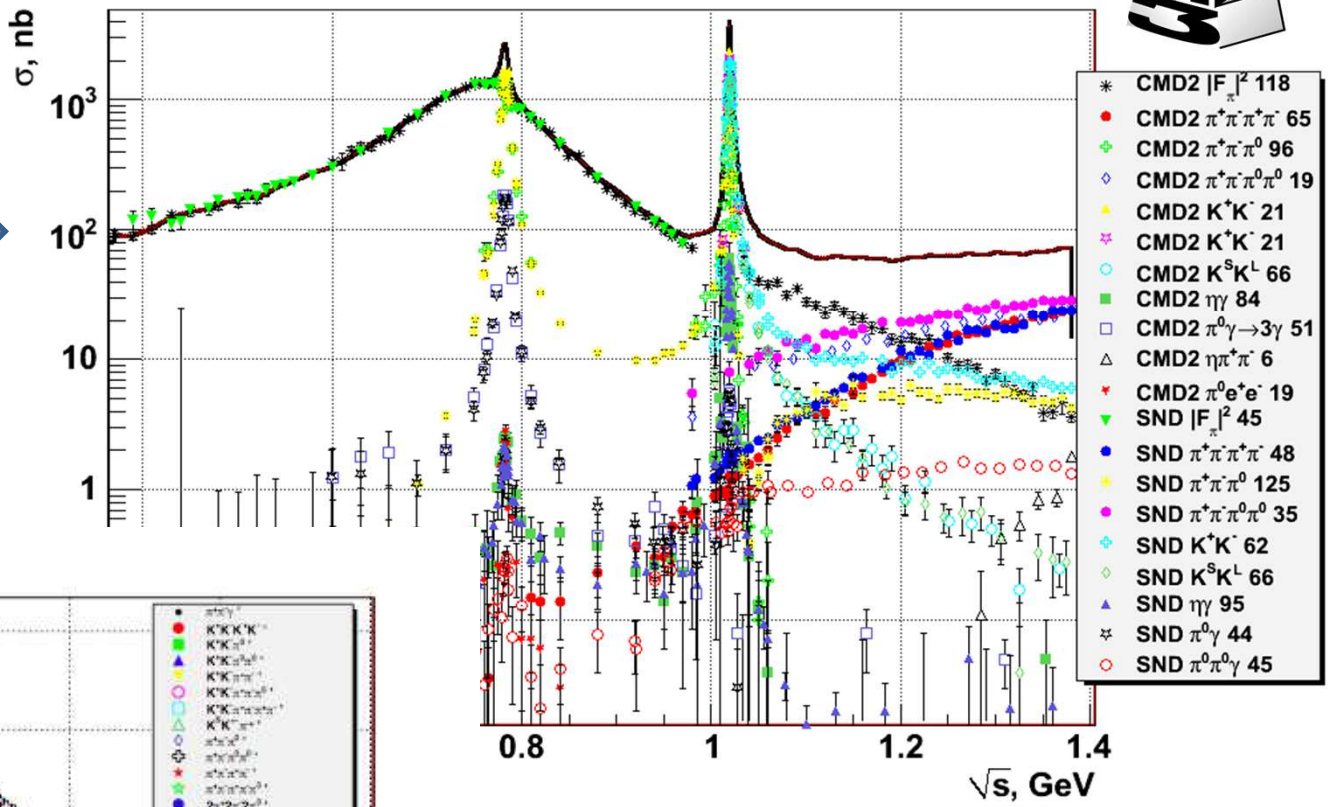


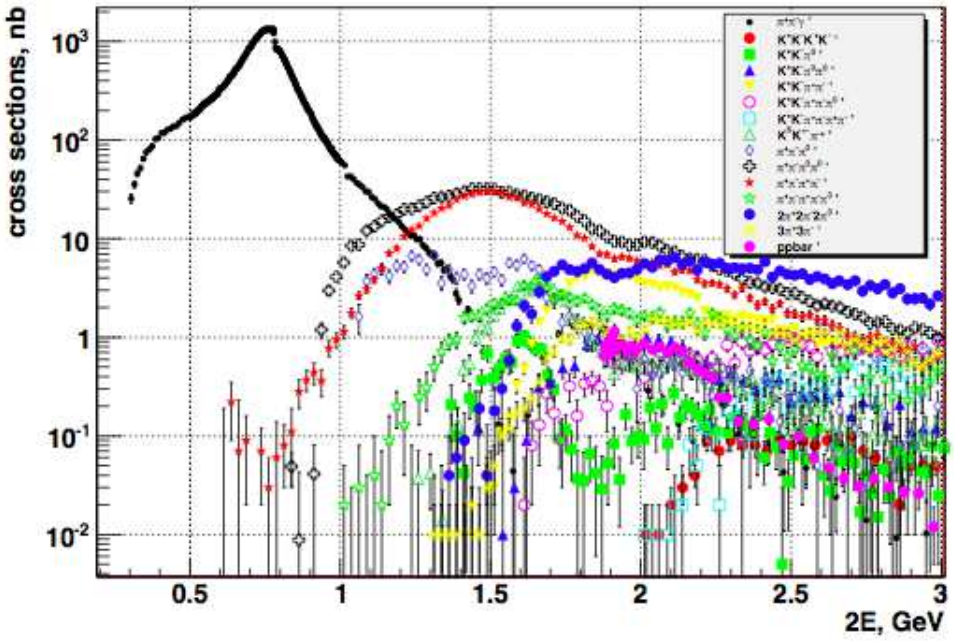
π+π−	**505.65 ± 3.09**
π+π−2π0	**18.62 ± 1.15**
π+π−π0	**47.38 ± 0.99** (mostly from omega region)
2π+2π−	**13.64 ± 0.36** (BaBar)
K+K-	**22.95 ± 0.26** (BaBar)
Isospin relations:	**5.98 ± 0.42** for not measured KKπ, KK2π, 2π4π0, 2π3π0
	(**12.46 ± 0.76** for √s<2 GeV **HLMNT 11 , J. Phys. G 38, 085003 (2011)**)
Rqcd[2-11GeV]	**41.19 ± 0.82**
LBL	**10.5 ± 2.6**
Th. TOTAL	**11 659 180.2 ± 4.9**

New g-2 experiments at FNAL and J-PARC have plans to reduce error to 1.5x10^{-10}

Exclusive cross-sections

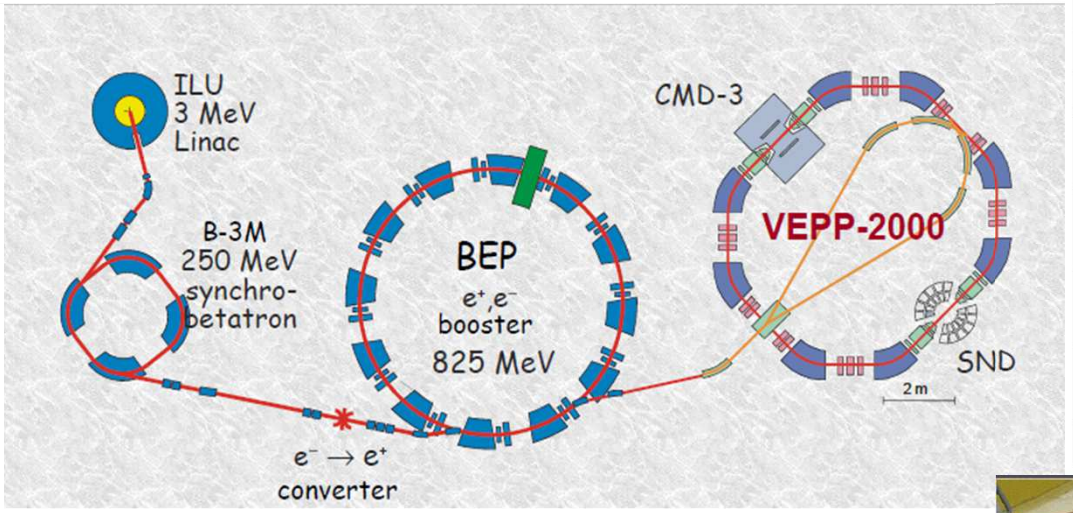
CMD-2 and SND data





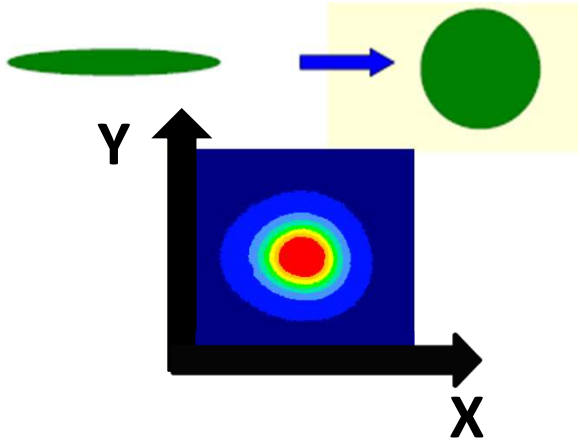
BaBar data

VEPP-2000 e^+e^- collider

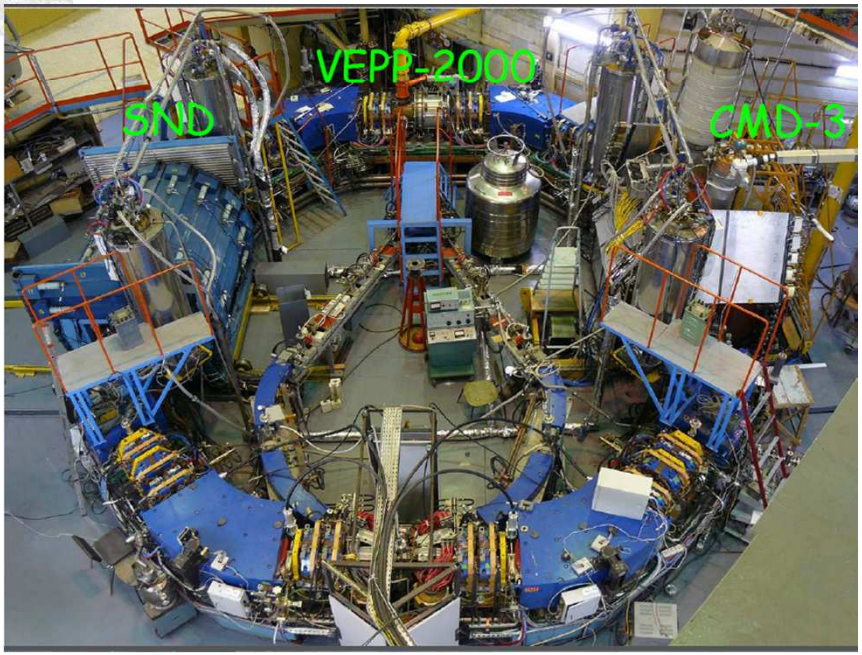


	VEPP-2M	VEPP-2000	
E (MeV)	510	510	900
Π (cm)	1788	2235	2235
$\mathcal{I}^+, \mathcal{I}^-$ (mA)	40	34	200
$\varepsilon \cdot 10^5$ (cm · rad)	3	0.5	1.6
β_x (cm)	40	6.3	6.3
β_z (cm)	5	6.3	6.3
ξ_x	0.016	0.075	0.075
ξ_z	0.050	0.075	0.075
$\mathcal{L}(\mathrm{cm}^{-2}\mathrm{s}^{-1})$	$3 \cdot 10^{30}$	$1 \cdot 10^{31}$	$1 \cdot 10^{32}$

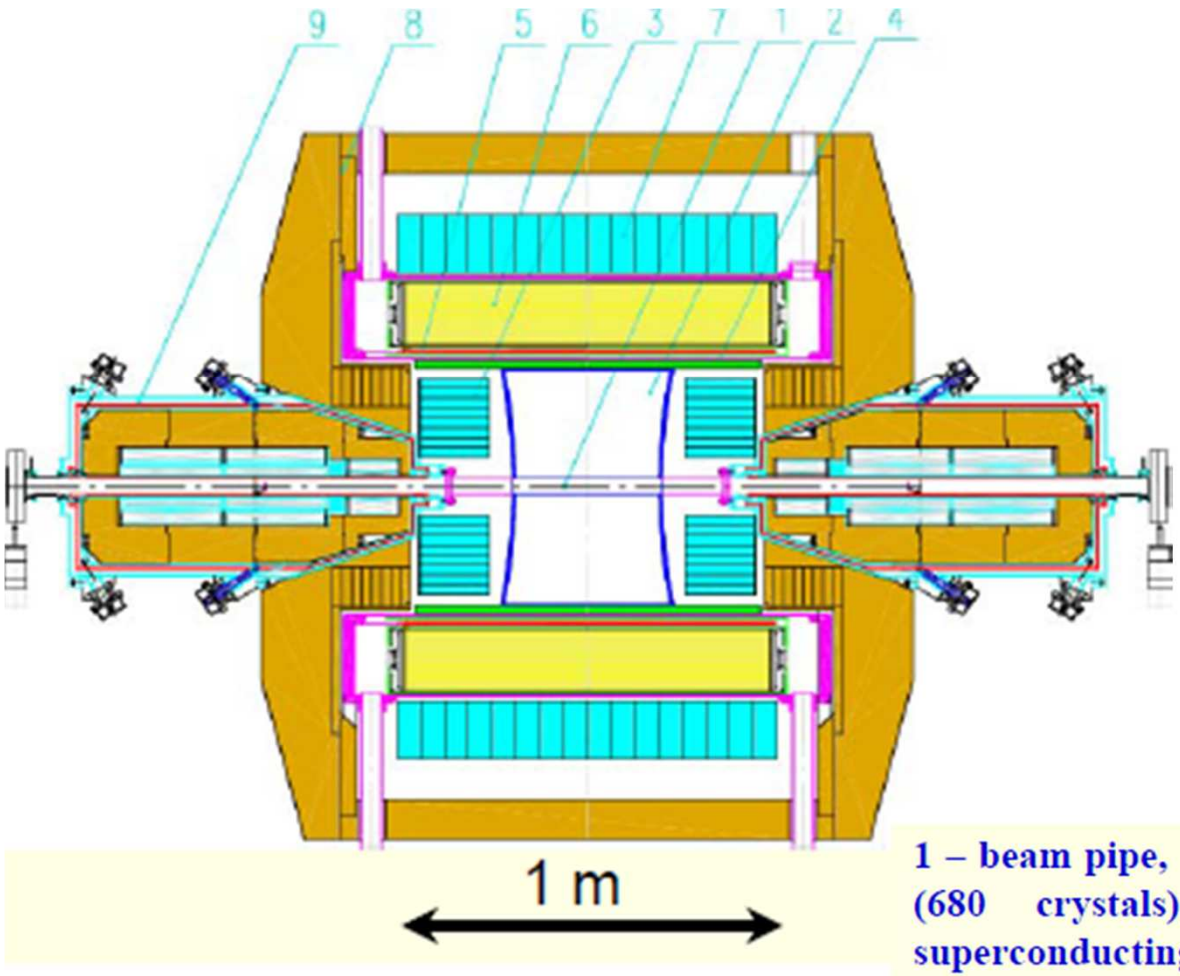
Main idea: Round Beams

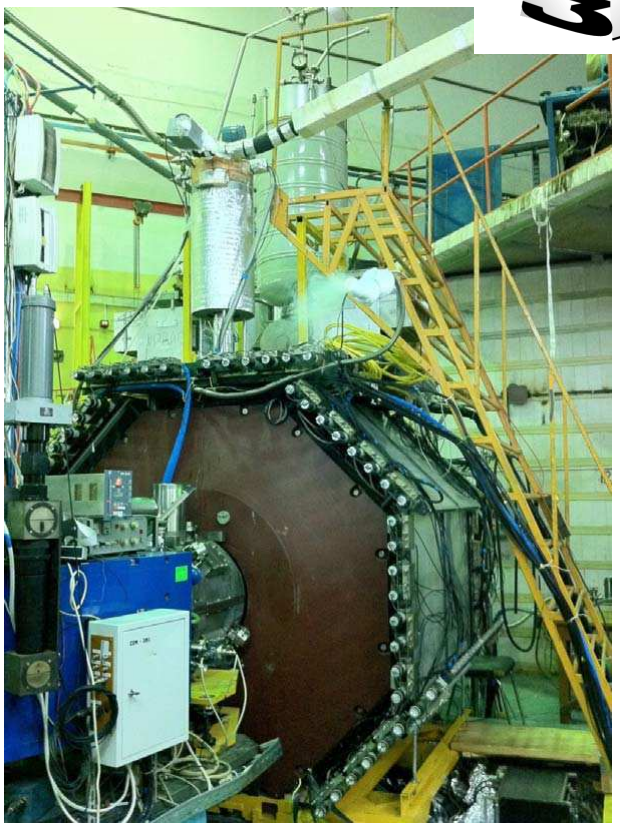


$$L = \frac{\pi\gamma^2 \xi_x \xi_y \varepsilon_x f}{r_e^2 \beta_y^*}\left(1+\frac{\sigma_y}{\sigma_x}\right)^2 \quad \Rightarrow \quad L = \frac{4\pi\gamma^2 \xi^2 \varepsilon f}{r_e^2 \beta^*}$$



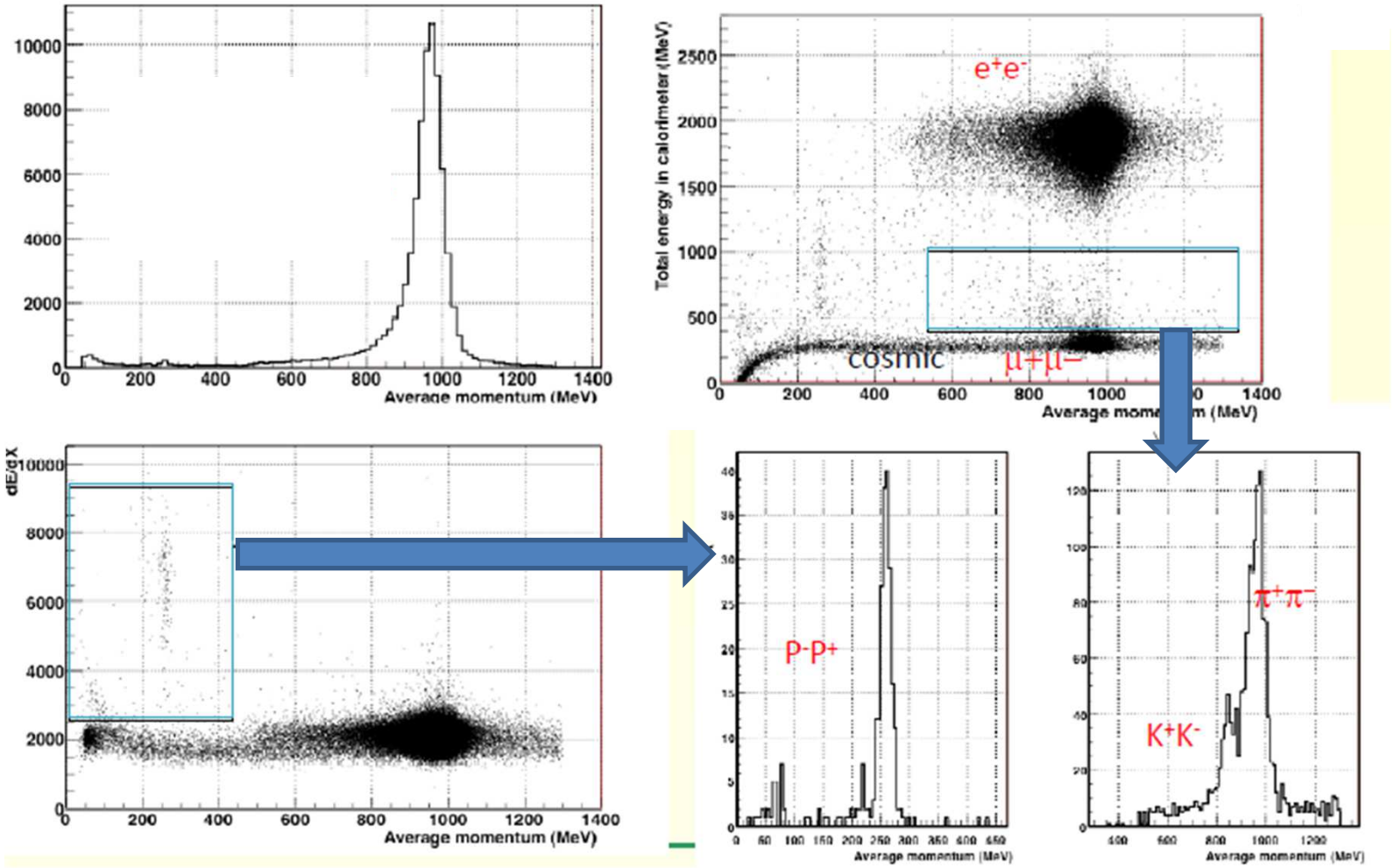
CMD-3 Detector



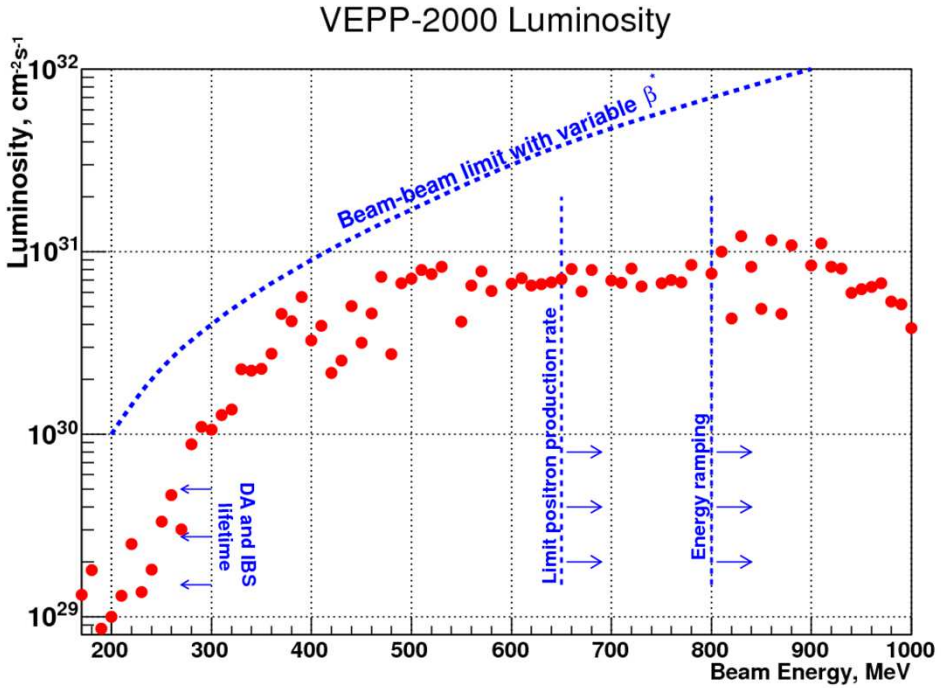


1 – beam pipe, 2 – drift chamber, 3 – BGO calorimeter (680 crystals), 4 – Z–chamber, 5 – CMD-3 superconducting solenoid, 6 – calorimeter LXe (400 liters), 7 – calorimeter CsI (1152 crystals), 8 –iron yoke, 9 – solenoids of VEPP-2000, (not shown) muon range system (scintillation counters) and TOF system.

Collinear Events @ CMD-3 ($E_{c.m.}$ = 1.95 GeV)

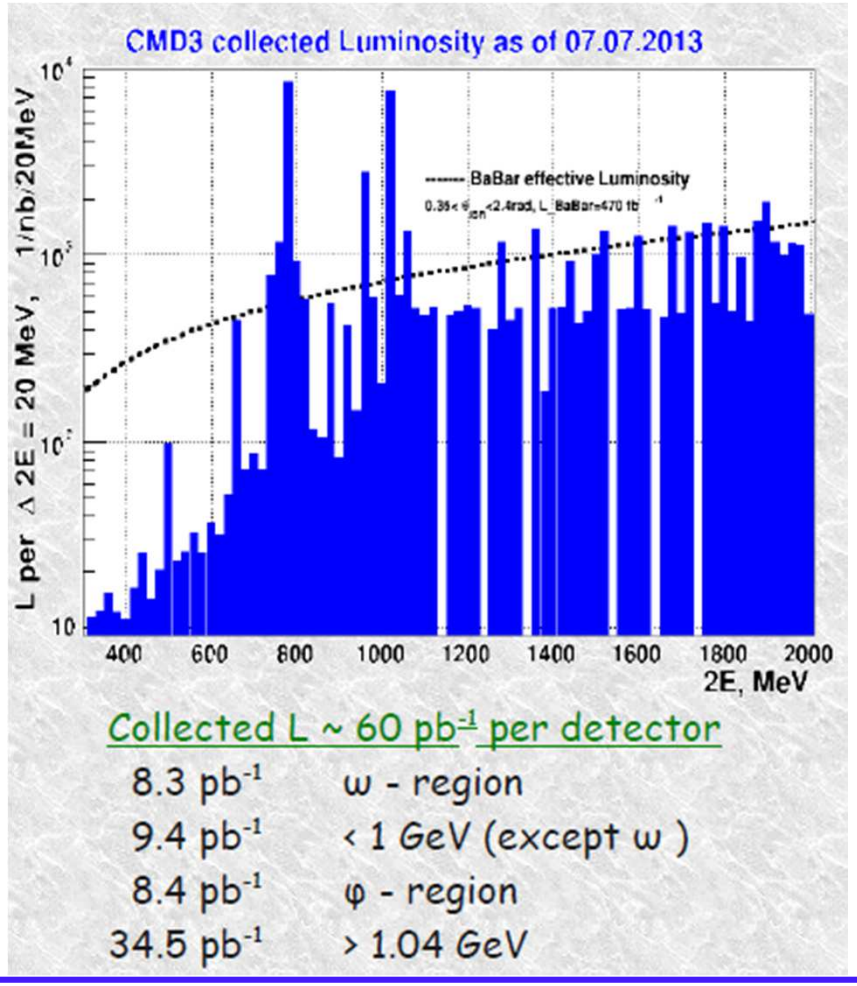


Collected Luminosity



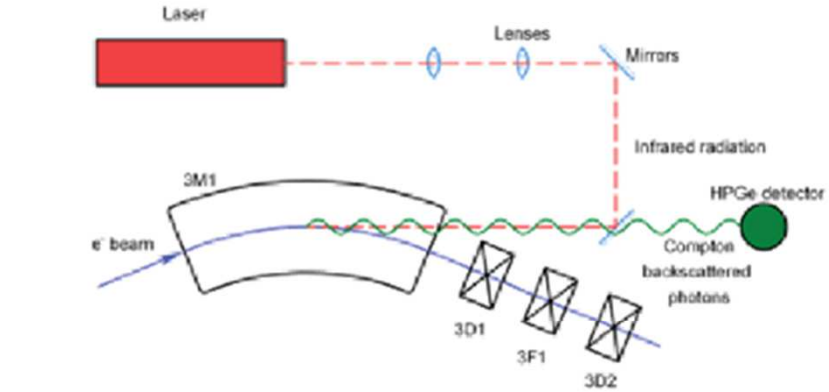
The maximum luminosity is $2 \cdot 10^{31}$ $cm^{-2}s^{-1}$ at 1.7-1.8 GeV, falling much slower with decreasing energy than before the round beams

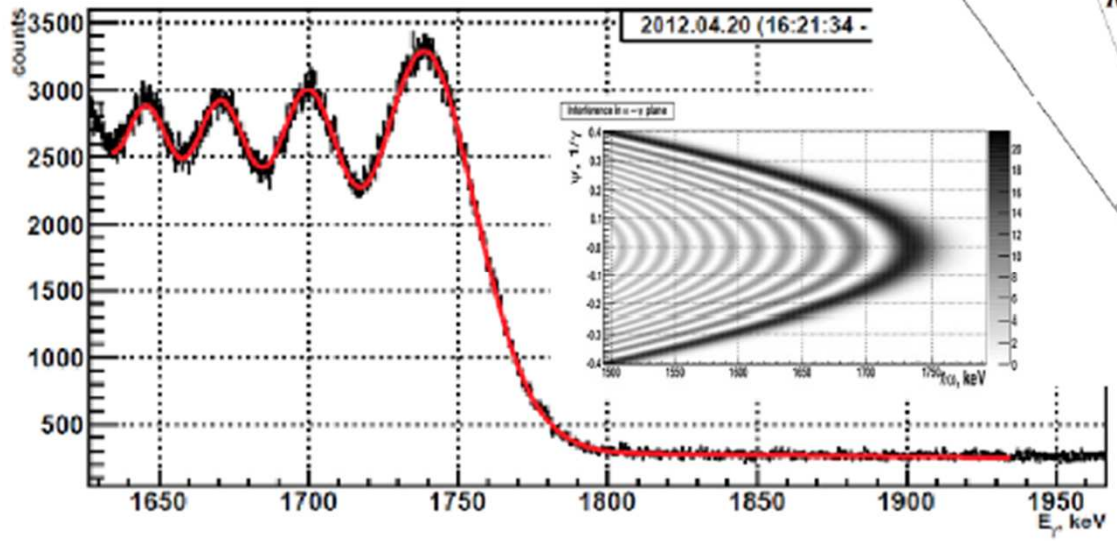
At high energies luminosity is limited by a deficit of positrons and maximum energy of the booster (800 MeV now)

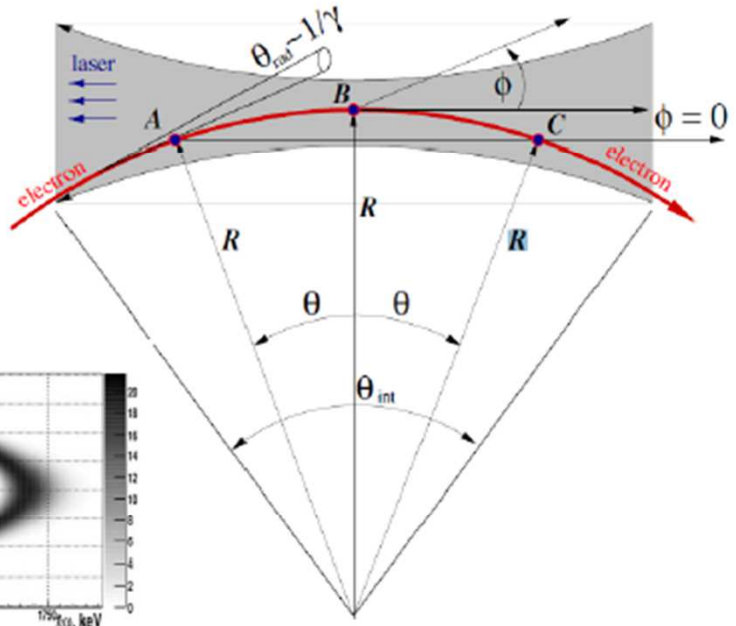


In 2013 we reached 2 × 160 MeV, the smallest energy ever measured at ee colliders

Energy measurement by Compton back scattering







E = 993.662 ± 0.016 МэВ

Nucl. Inst. Meth. A744 (2014) 35-40

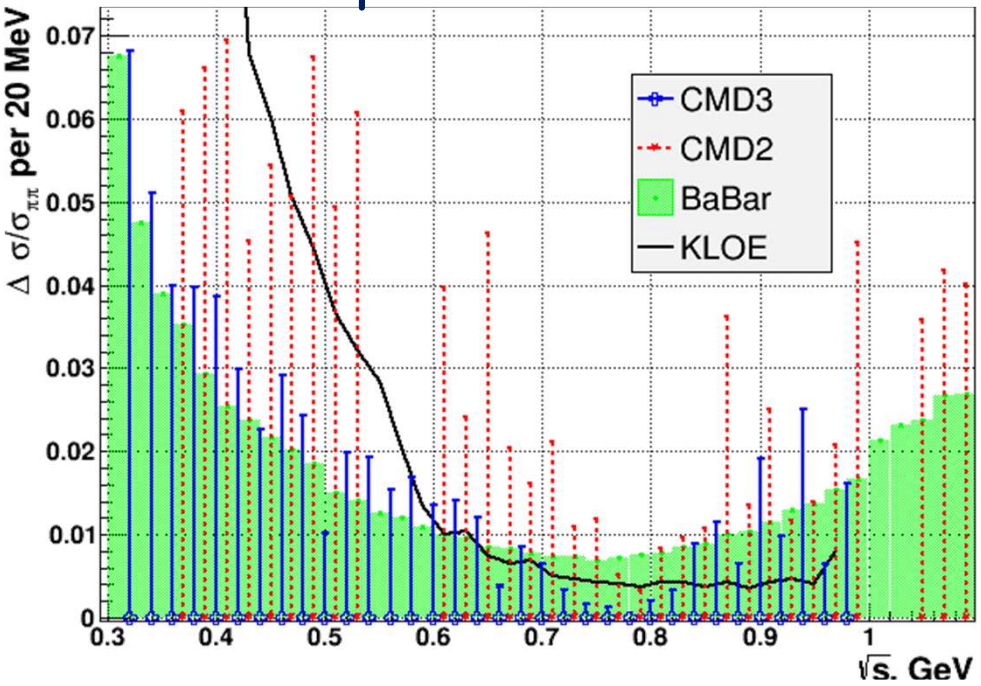
e+e- → π+π- by CMD3

Clean collinear events (mostly without background)

Plans to reduce systematic error from 0.6% -> 0.3%:

- Event separation will be checked by different methods 0.2%
- Better test of Radiative corrections 0.2% -> 0.1%
- Determination of fiducial volume controlled independently by LXe and ZC subsystems (0.1%)

Statistical precision of cross section measurement

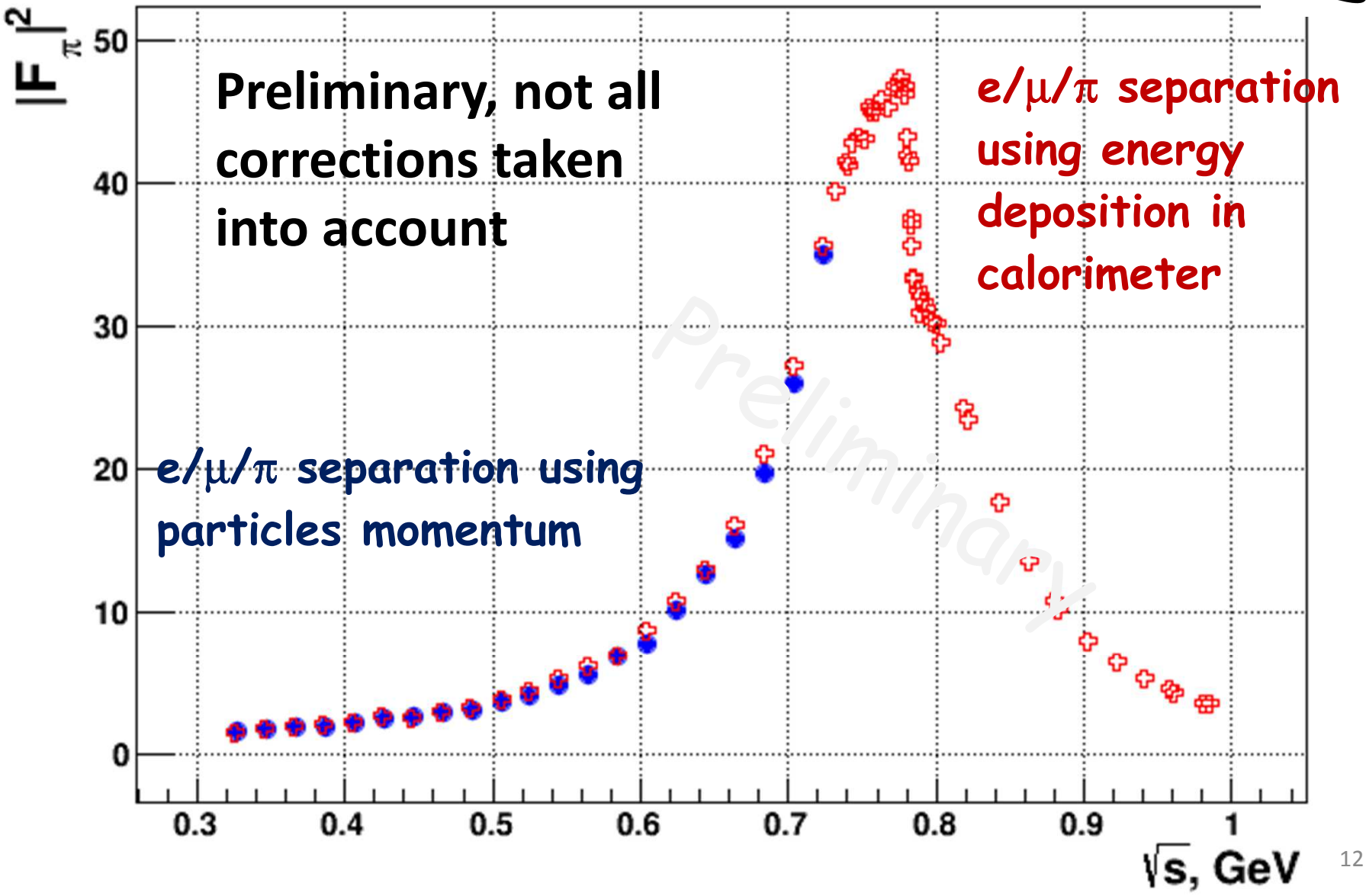


Collected L ~ 60 pb^{-1} per detector

8.3 pb^{-1}	ω - region
9.4 pb^{-1}	< 1 GeV (except ω)
8.4 pb^{-1}	φ - region
34.5 pb^{-1}	> 1.04 GeV

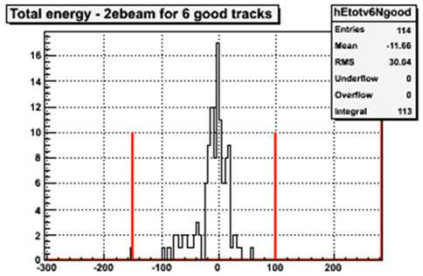
e+e- → π+π- by CMD3

$|F_\pi|^2$

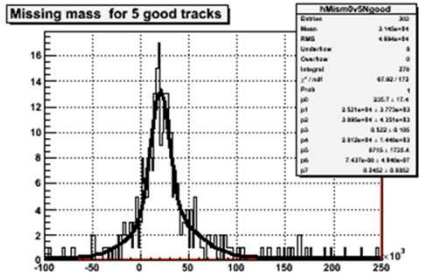


Process $e^+e^- \to 3(\pi^+\pi^-)$

We have very clean selection of 6 and 5 pions

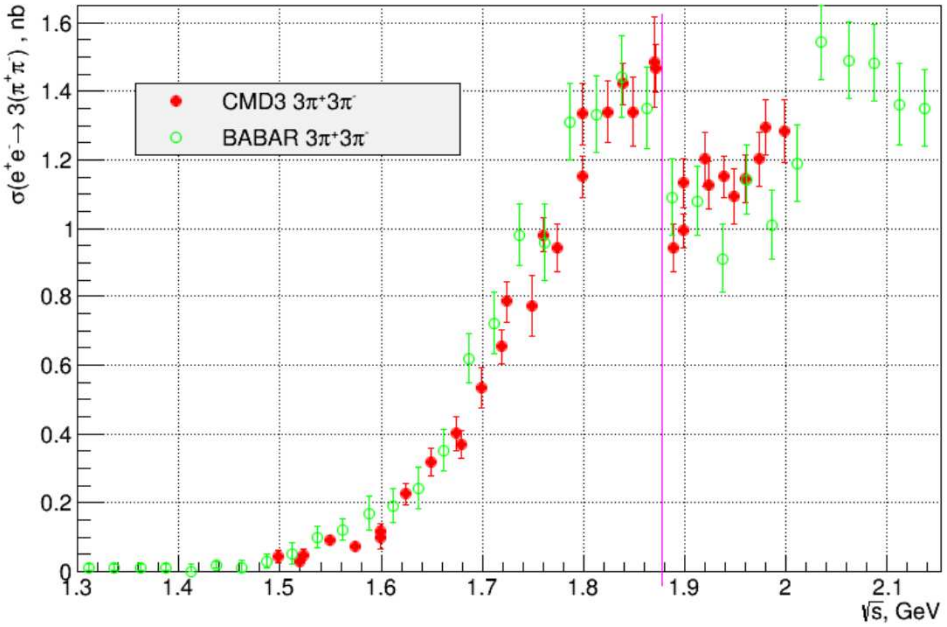


$E_{6\pi}$-$2E_{beam}$ (MeV)

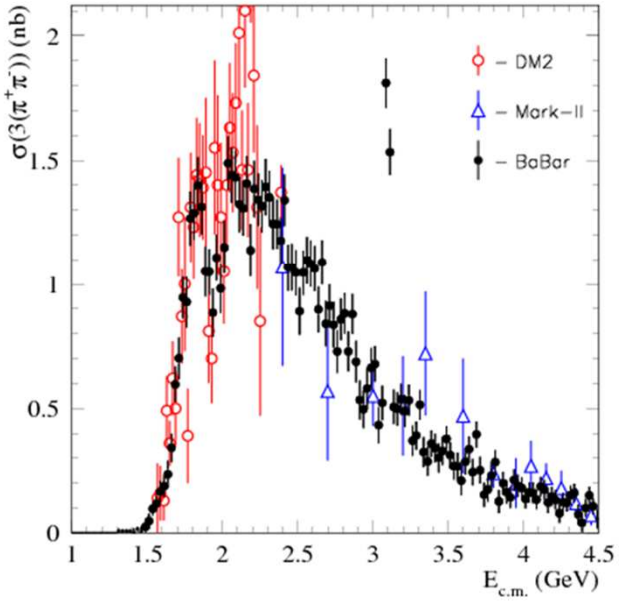


M_{miss}^2 (MeV^2)

Phys.Lett. B723 (2013) 82-89



Other data for e+e- -> 3(π+π-)



We study dynamics, pure phase space doesn't work, three models with JPC = 1^{--}, each with one ρ^0/event:

- $\rho(1450)(2\pi^+2\pi^-)_{S-wave} \to a_1(1260)^{\pm}\pi\pi\pi^+\pi^- \to \rho^0 2(\pi^+\pi^-) \to 3(\pi^+\pi^-)$
- $\rho(770)(2\pi^+2\pi^-)_{S-wave} \to 3(\pi^+\pi^-)$

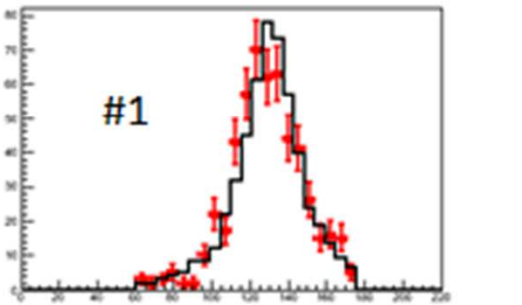
3 options for $2\pi^+2\pi^-$: phase space, $f^0(1370)$, $f^0(1500)$

- $\rho(770)f_2(1270) \to 3(\pi^+\pi^-)$

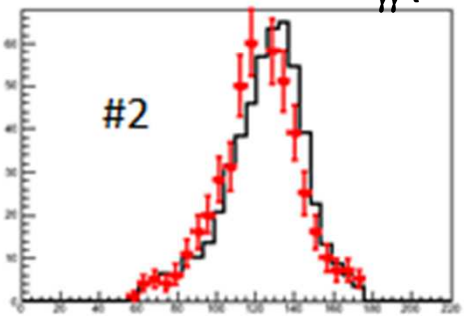
The best description is with one ρ(770) and 4 pions in S-wave

Process $e^+e^- \to 2(\pi^+\pi^-\pi^0)$

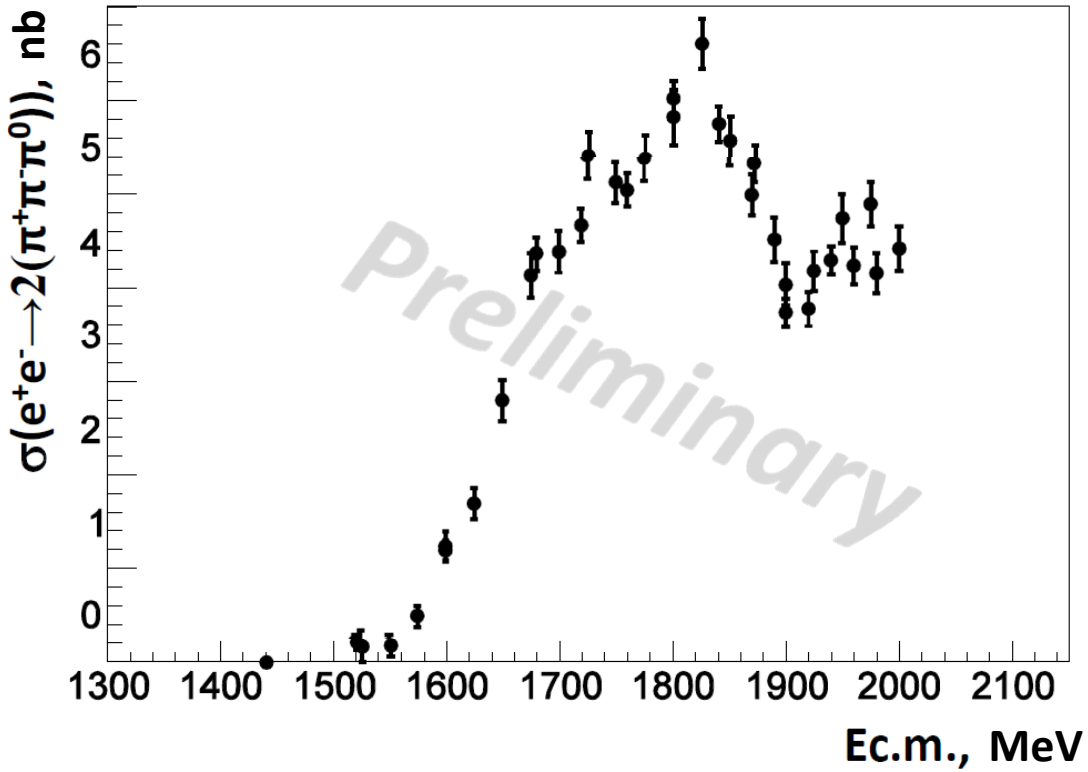
We have relatively clean selection of 2 and 1 π^0 in addition to four charged tracks



$M_{\gamma\gamma}$ (MeV)



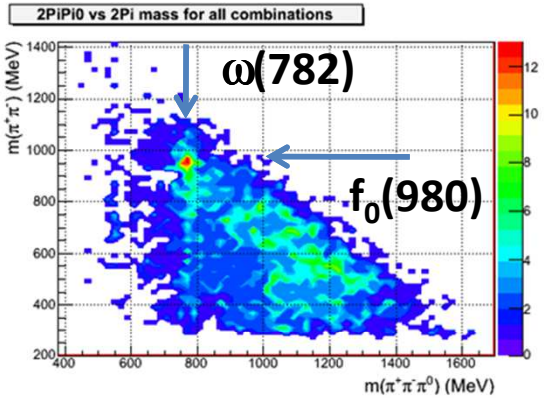
$M_{\gamma\gamma}$ (MeV)

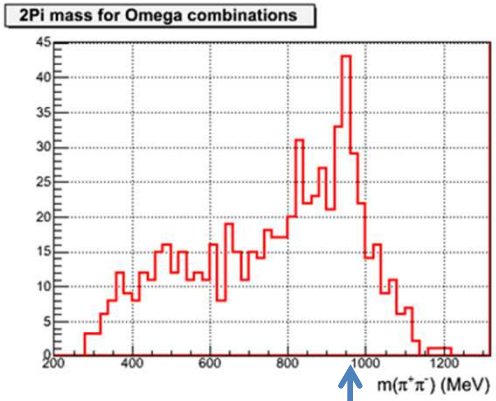


many intermediate states are seen, systematic errors are under study.

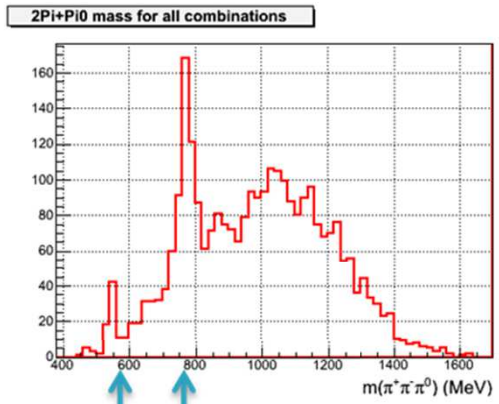
Look at the Process $e^+e^- \to 2(\pi^+\pi^-)\pi^0$

Example of $\omega f^0(980)$ signal in $\omega\pi^+\pi^-$ final state.

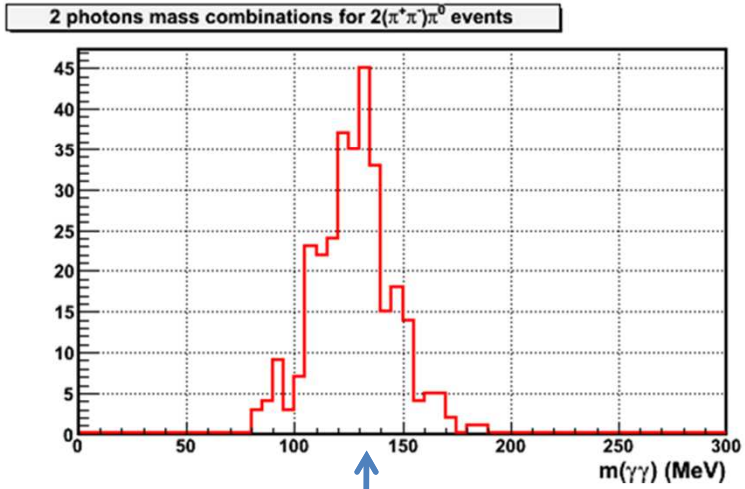




$f_0(980)$



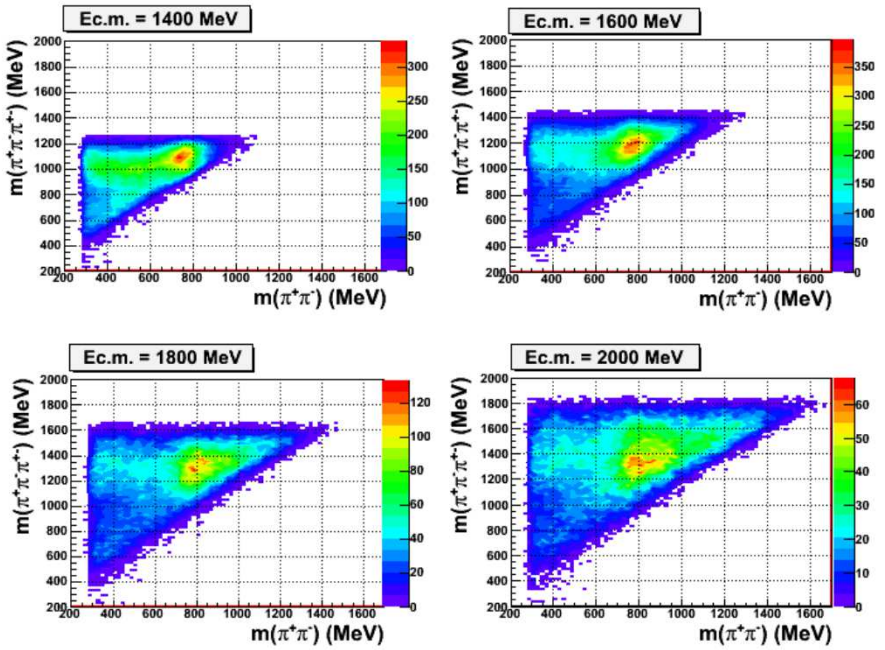
$\eta(545)$ $\omega(782)$

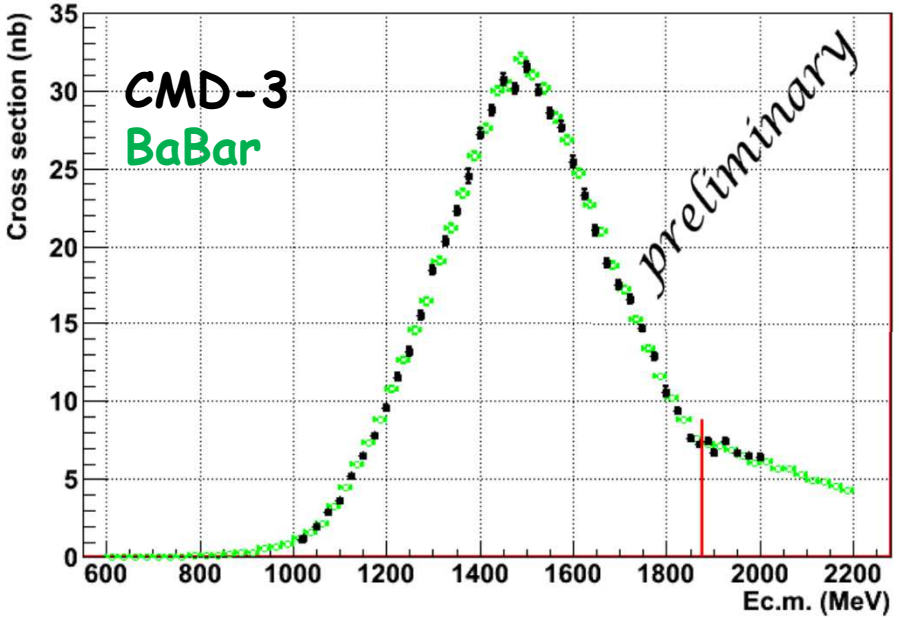


π^0

Detailed analysis is coming…

Process $e^+e^- \to 2(\pi^+\pi^-)$

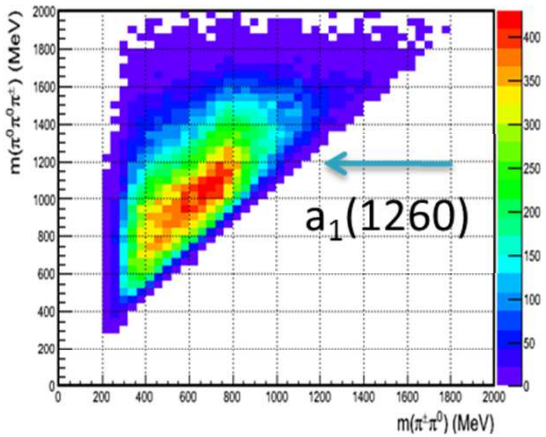


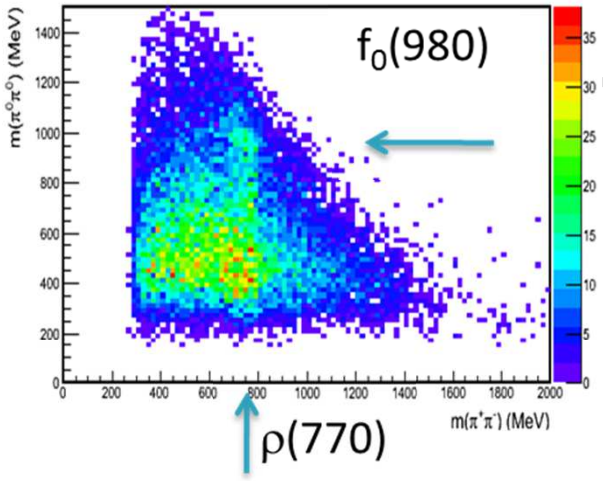


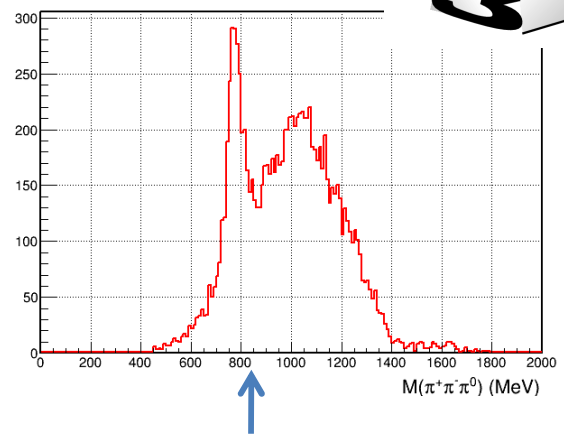
We confirm a1(1260)π dominance. Some other states (ρ(770)f0(600), ρ(770)f0(980)) are seen.

Statistical errors are at the level of 1-2% per point. Analysis of systematic errors is in progress.

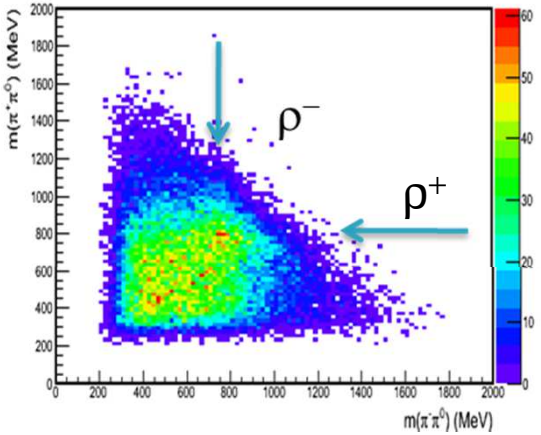
Study of $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$







$\omega(782)$

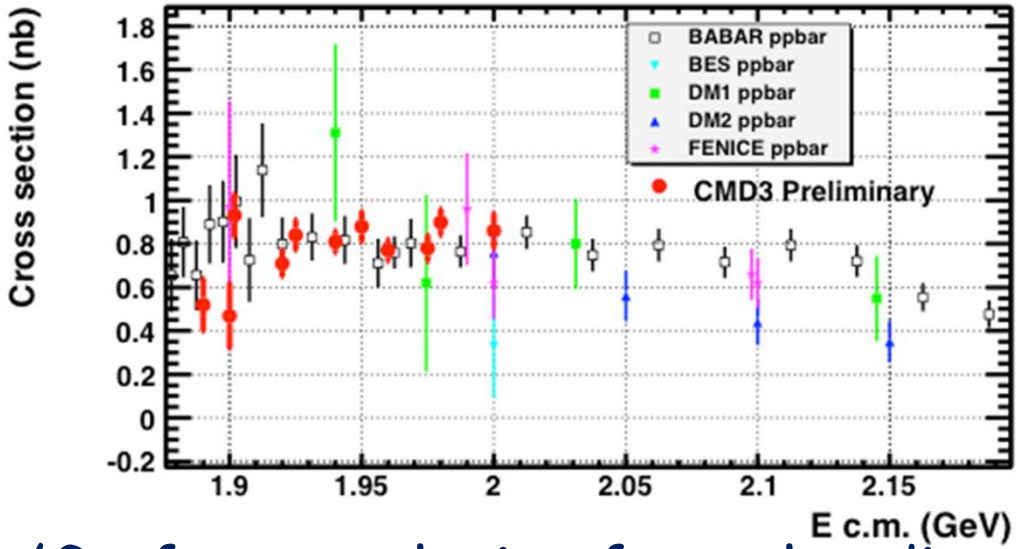


In addition to dominant $\omega\pi^0$ and $a_1\pi$ we see $\rho^+\rho^-$, $\rho(770)f^0(600)$?, $\rho(770)f^0(980)$

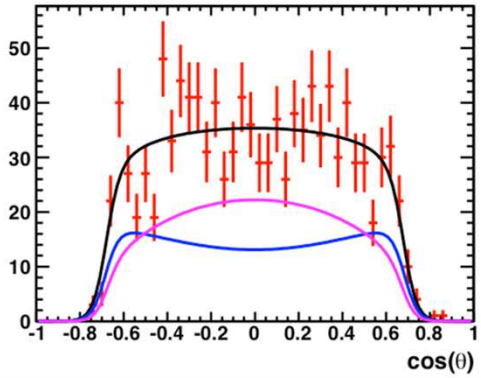
We have statistical errors at the level of 1-2% per point.
Systematic errors are under study.

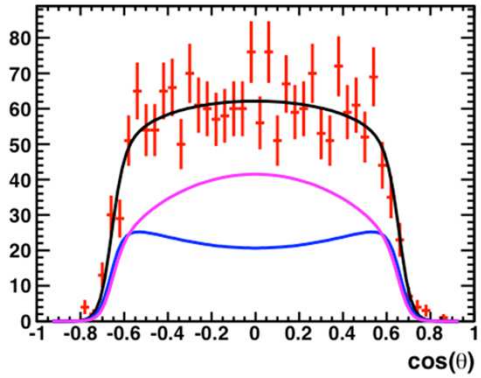
Preliminary results on $e^+e^- \to \overline{p}p$

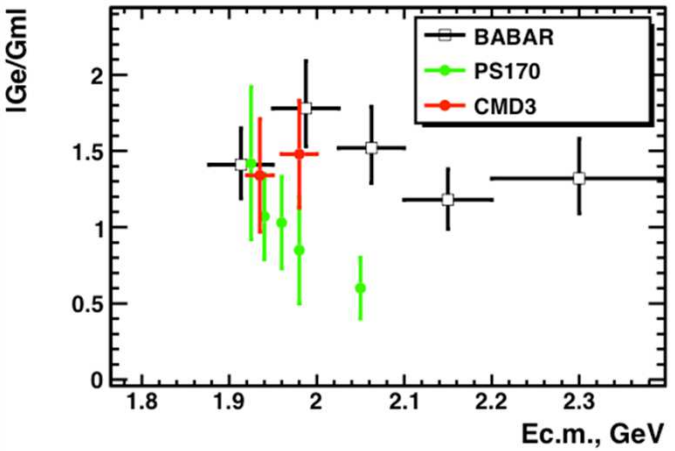
Cross section



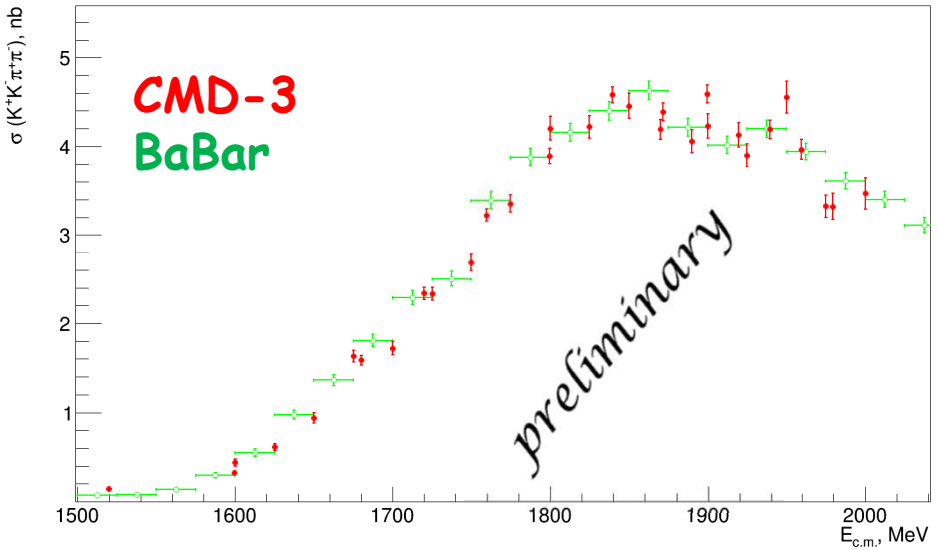
Ratio G_E/G_M from analysis of angular distributions

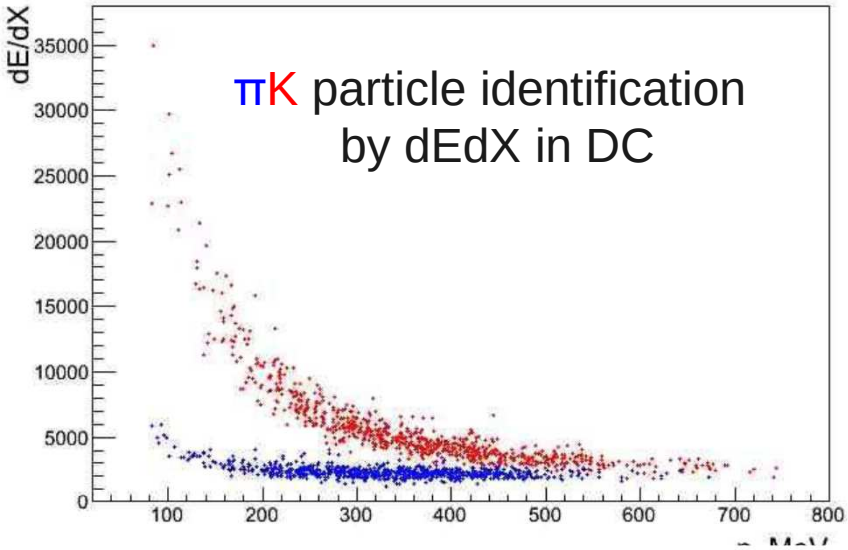






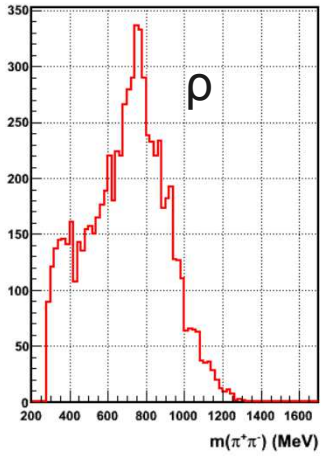
Process $e^+e^- \to K^+K^-\pi^+\pi^-$

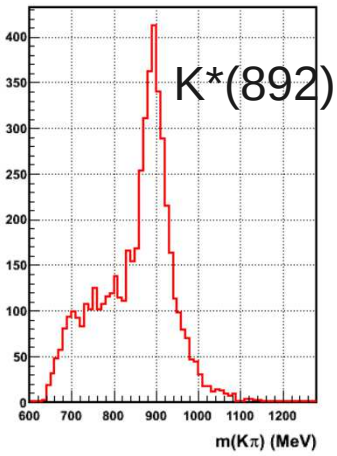




Rich dynamics seen, many intermediate states:

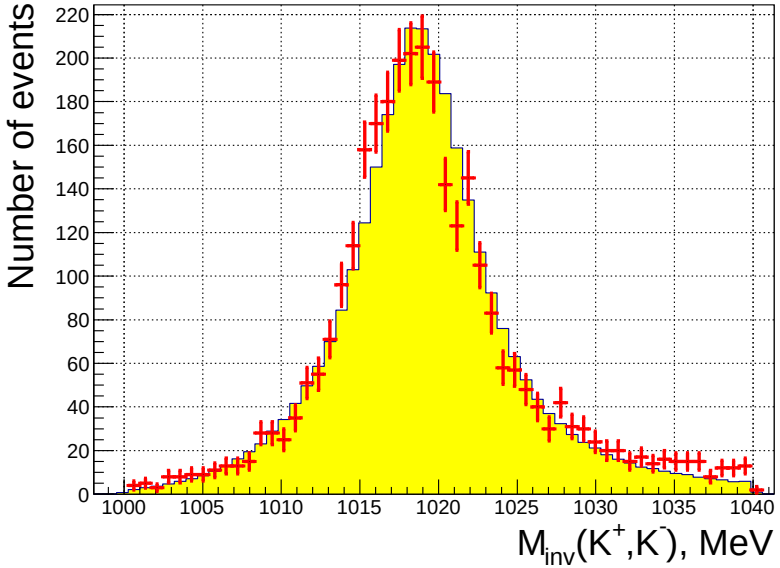
K_1(1270)K->K*(892)Kπ
K_1(1400)K->K*(892)Kπ
K_1(1270)K->ρKK
K*(892)K*(892), φππ

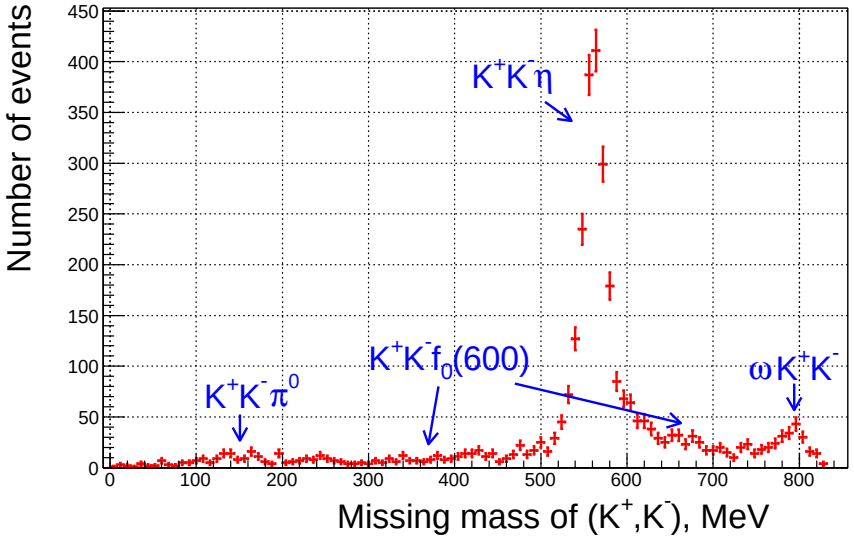


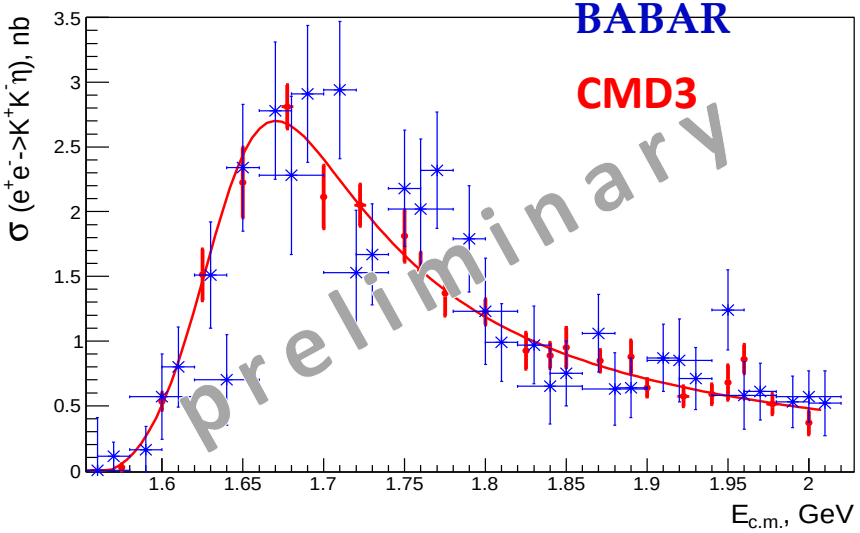


Processes $e^+e^- \to K^+K^-\eta$

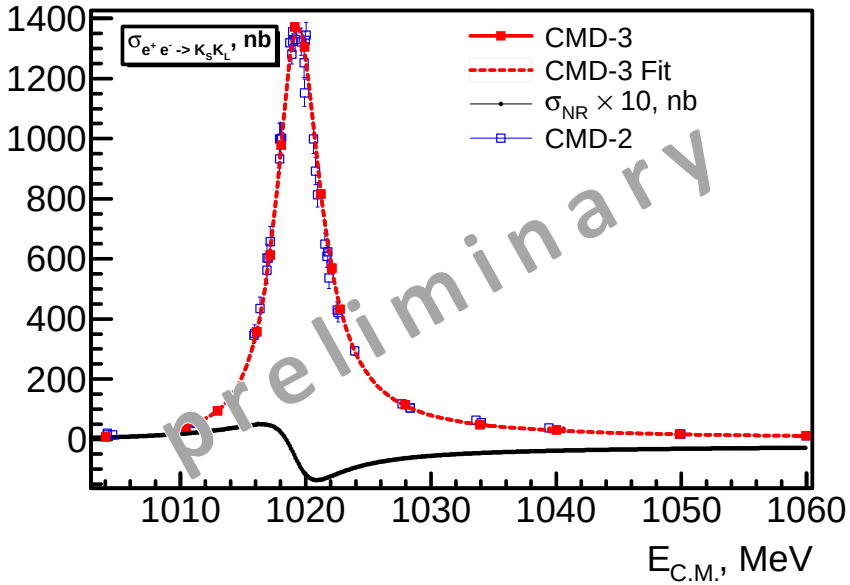
K^+K^- invariant mass and missing mass

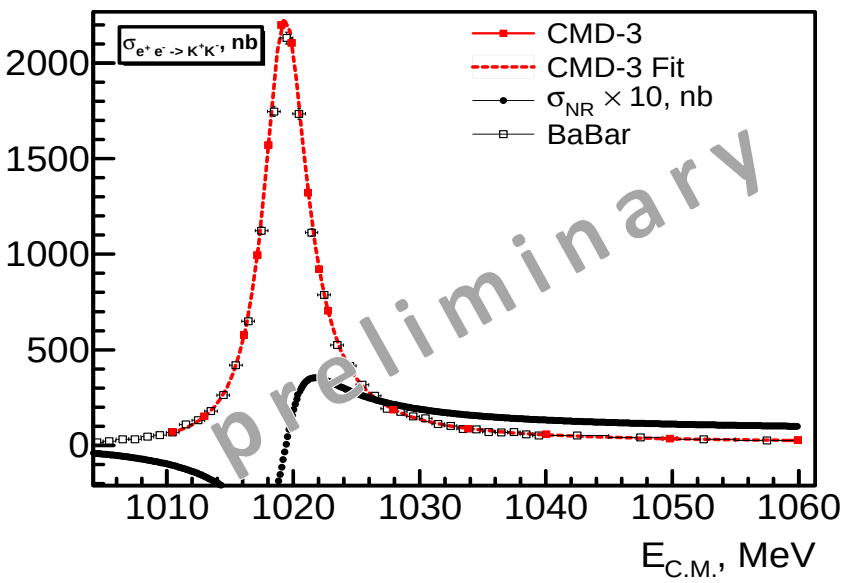


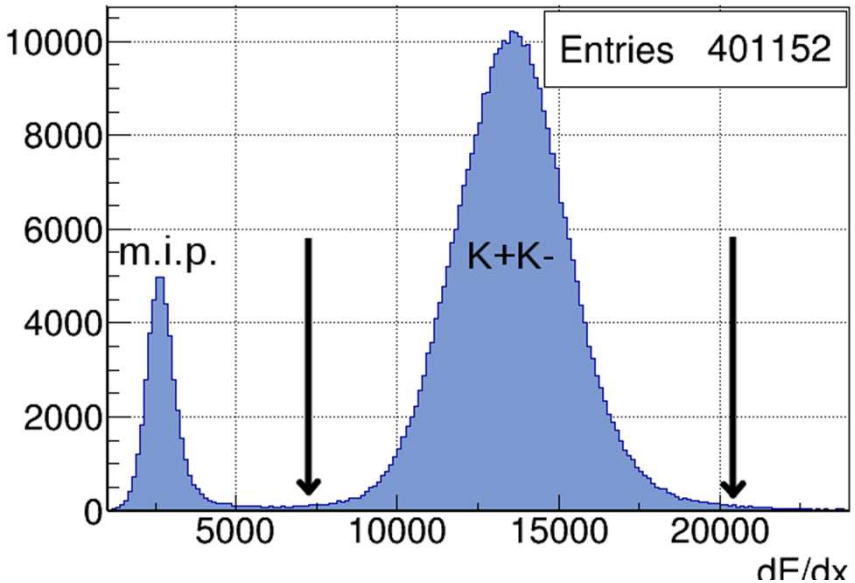


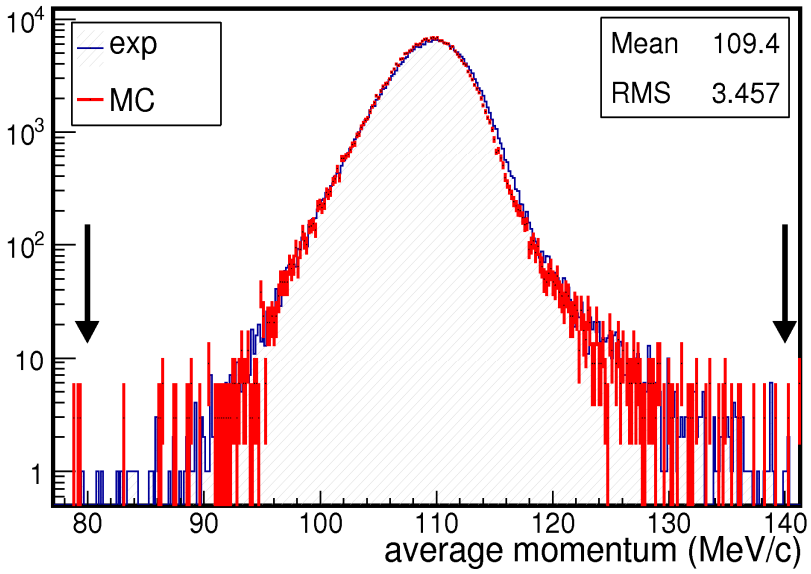


Processes $e^+e^- \to K^+K^-, K_sK_L$









Conclusion

- ✓ New accelerator concepts used at the VEPP-2000 collider were successfully proved. First three experimental runs generated considerable amount of data which analysis is in progress now. The second detector, SND, with very good photon detection collected similar statistics and has a lot of various results on hadronic cross sections, particularly on channels with neutrals.

- ✓ The last experimental run ended in the middle of July 2013. Then a long shutdown for ~1.5 years to increase the booster energy to 1 GeV and commission the new injection complex to reach 10^{32} $cm^{-2}s^{-1}$

- ✓ Hopefully, in the next 5-10 years the VEPP-2000 will produce the integrated luminosity ~ 1 fb^{-1} which should provide new precise interesting results on the hadron production in e^+e^- annihilation.

Thank You