# Status of the CMD-3 Experiment at VEPP-2000

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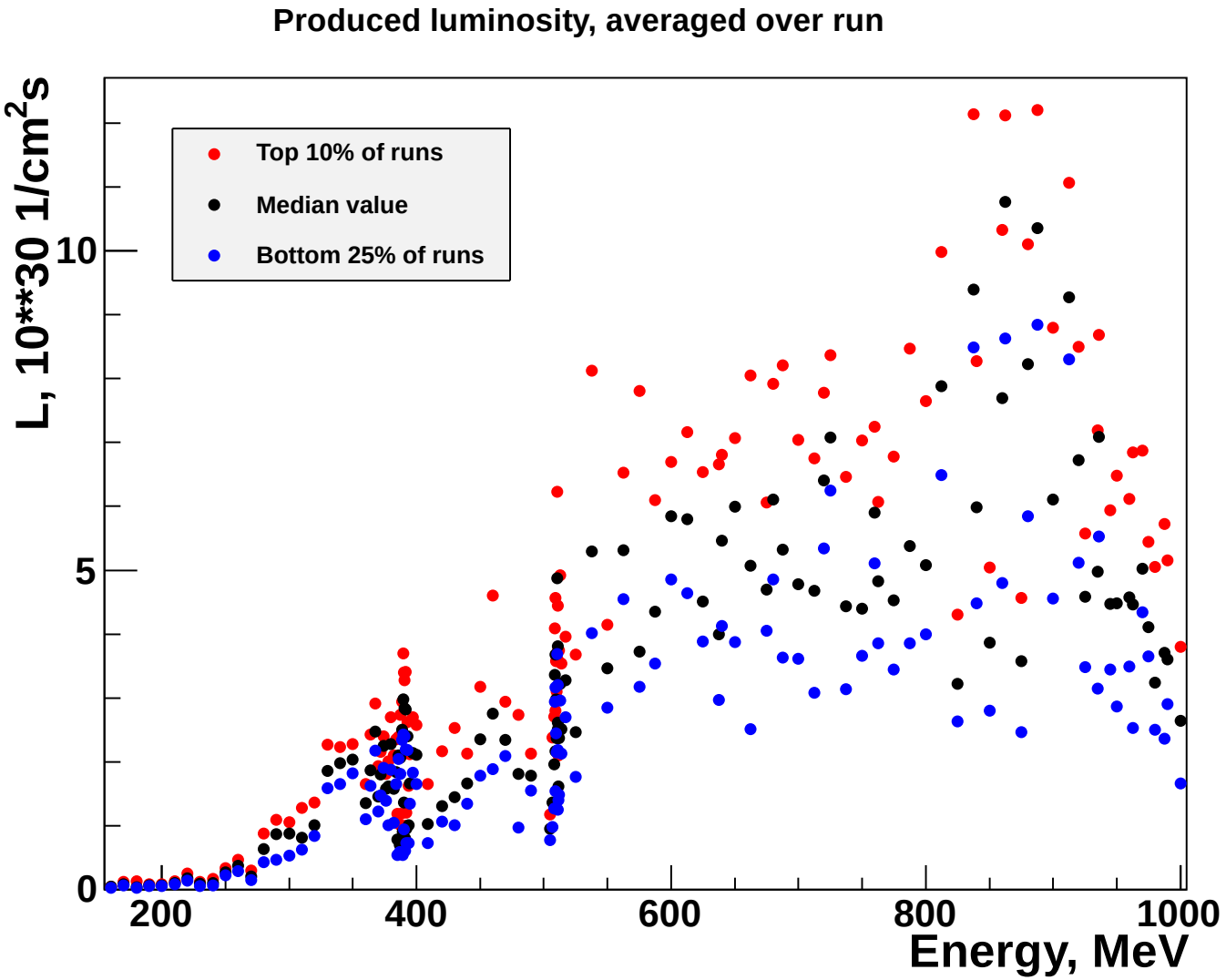
## Outline

1. General
2. PID at low energies
3. $e^+e^- \to 6\pi$
4. Conclusions

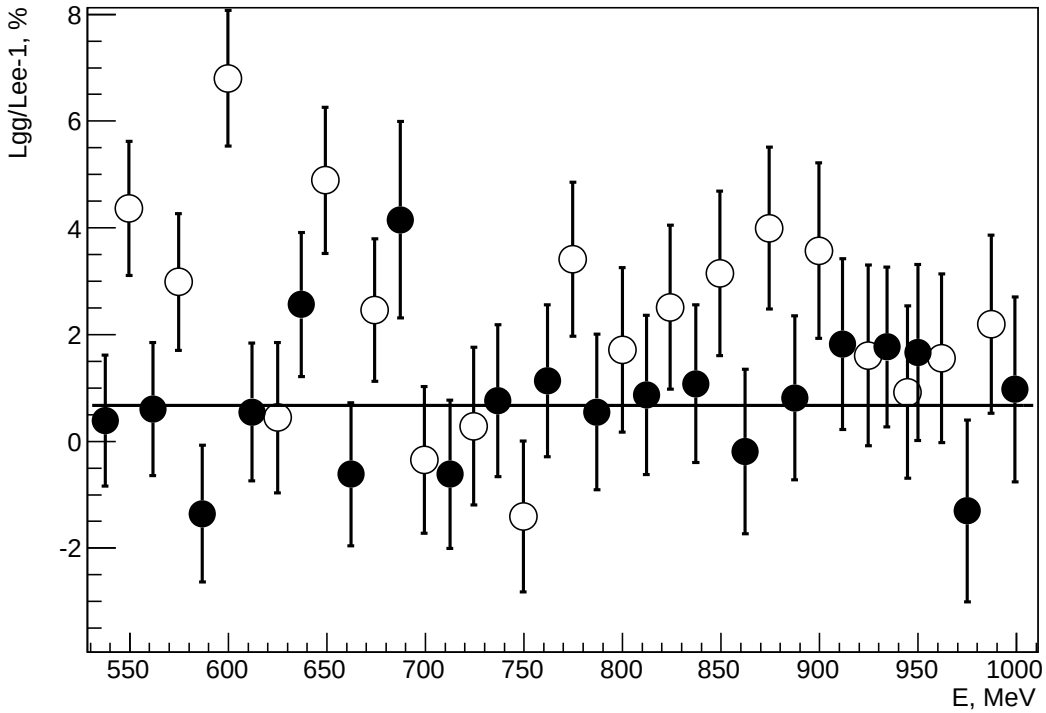
## General

- Since 2010, when data taking started, CMD-3 collected:
  3.1 pb$^{-1}$ at the $\phi$, 33 pb$^{-1}$ from $\phi$ to 2 GeV, 5.2 pb$^{-1}$ below the $\phi$
- The maximum luminosity is $2 \cdot 10^{31}$ cm$^{-1}$s$^{-1}$ at 1.7-1.8 GeV,
  falling much slower with decreasing energy than before the round beams
- At high energies lumi is limited by a deficit of positrons and
  maximum energy of the booster (900 MeV now)
- We are now running at $2 \times 160$ MeV, the smallest $\sqrt{s}$ ever,
  another 2-3 months at the $\omega$ and $\phi$
- A long shutdown for 1-1.5 years to increase the booster energy to 1 GeV
  and commission the new injection complex to reach $10^{32}$ cm$^{-1}$s$^{-1}$

# Luminosity vs. Energy

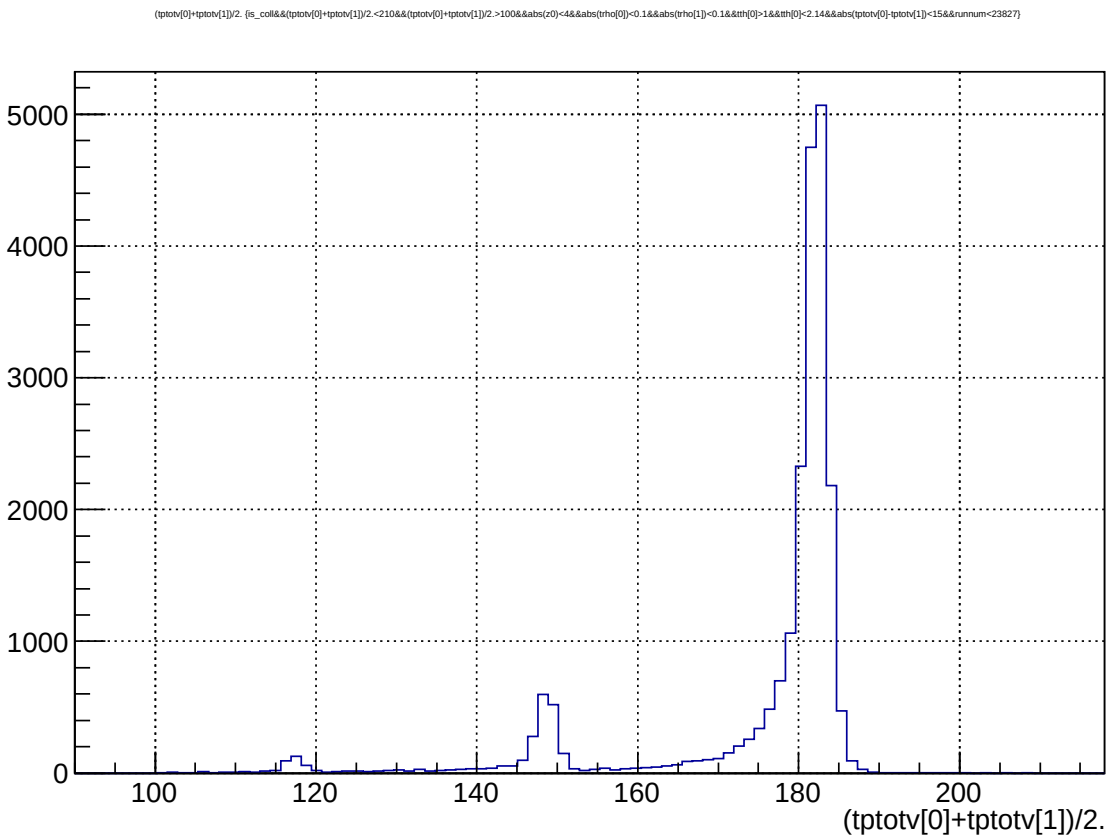


# Luminosity Measurement



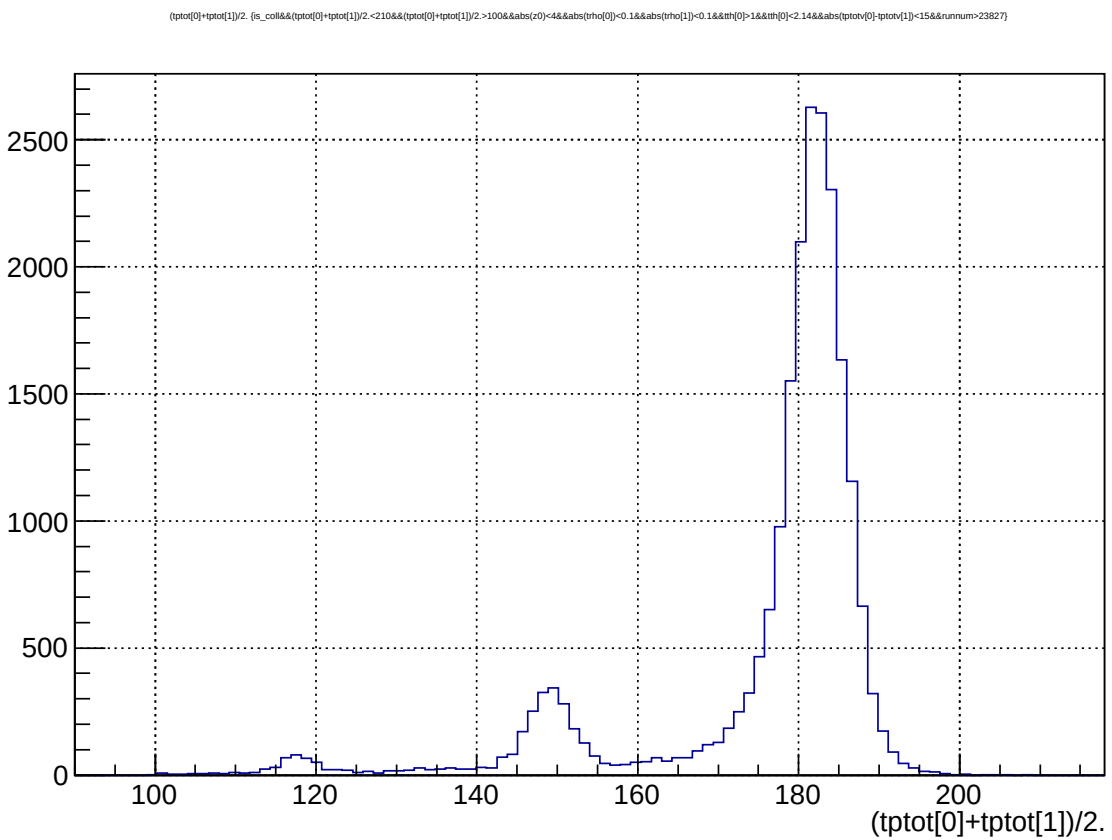

Luminosity measured by $e^+e^- \to e^+e^-$ and $e^+e^- \to \gamma\gamma$ at large angles agrees

# PID by Momentum at Low Energies – I



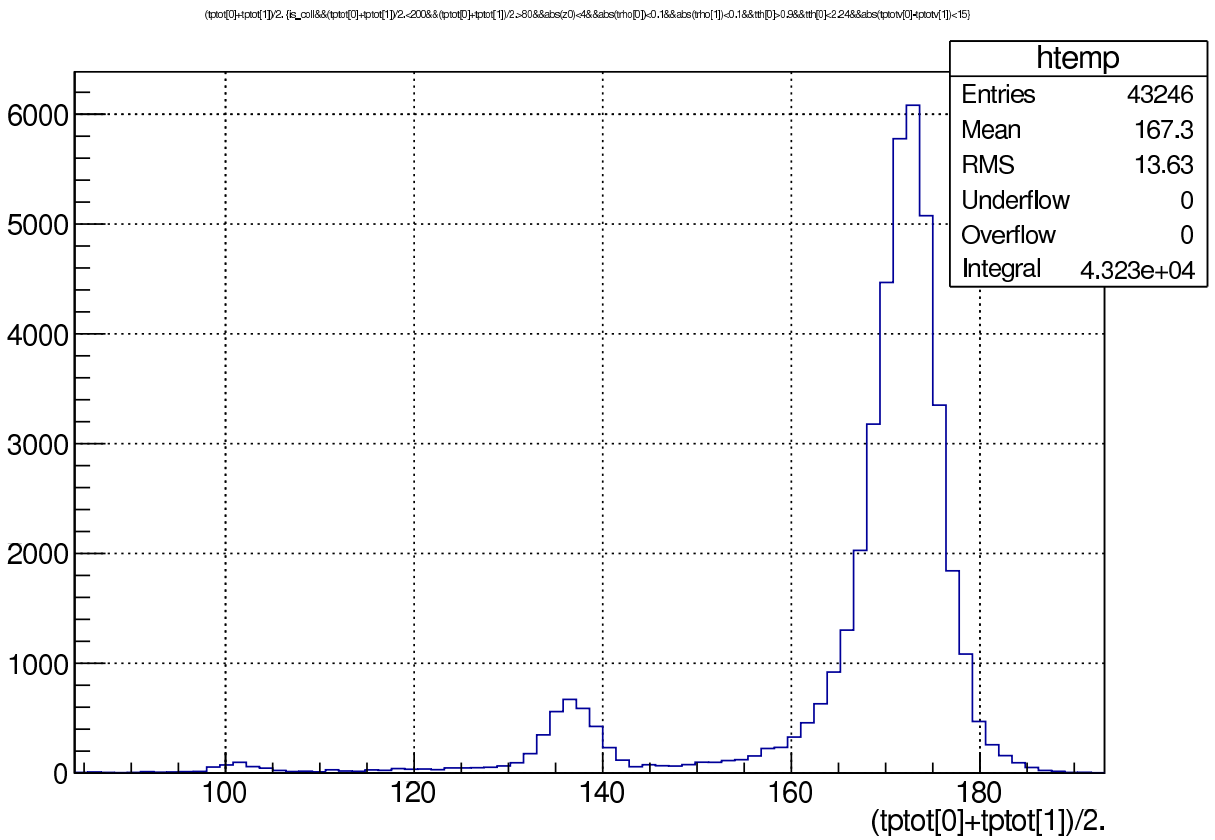

$\sqrt{s} = 360$ MeV, 1.3T

# PID by Momentum at Low Energies – II



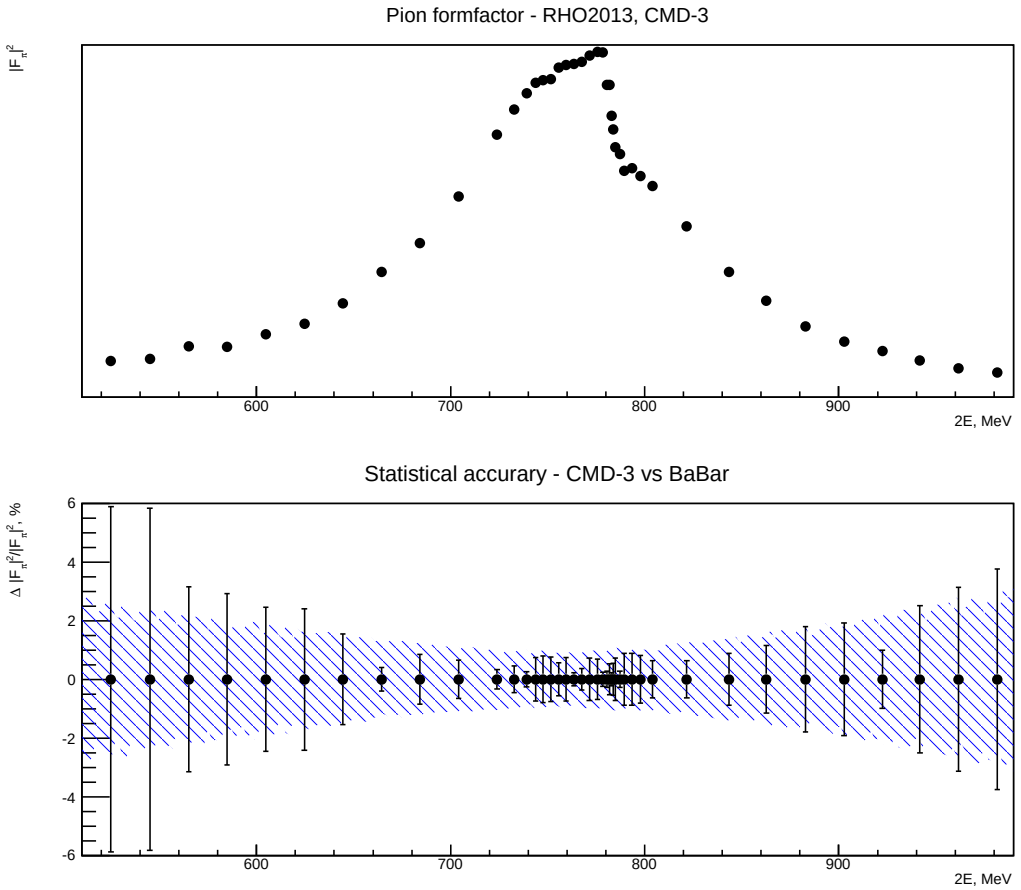

$\sqrt{s} = 360$ MeV, 0.65T, $\mathcal{L} \sim 2 \cdot 10^{29}$ cm$^{-1}$s$^{-1}$ or $\times 6$ than at 1.3T

# PID by Momentum at Low Energies – III



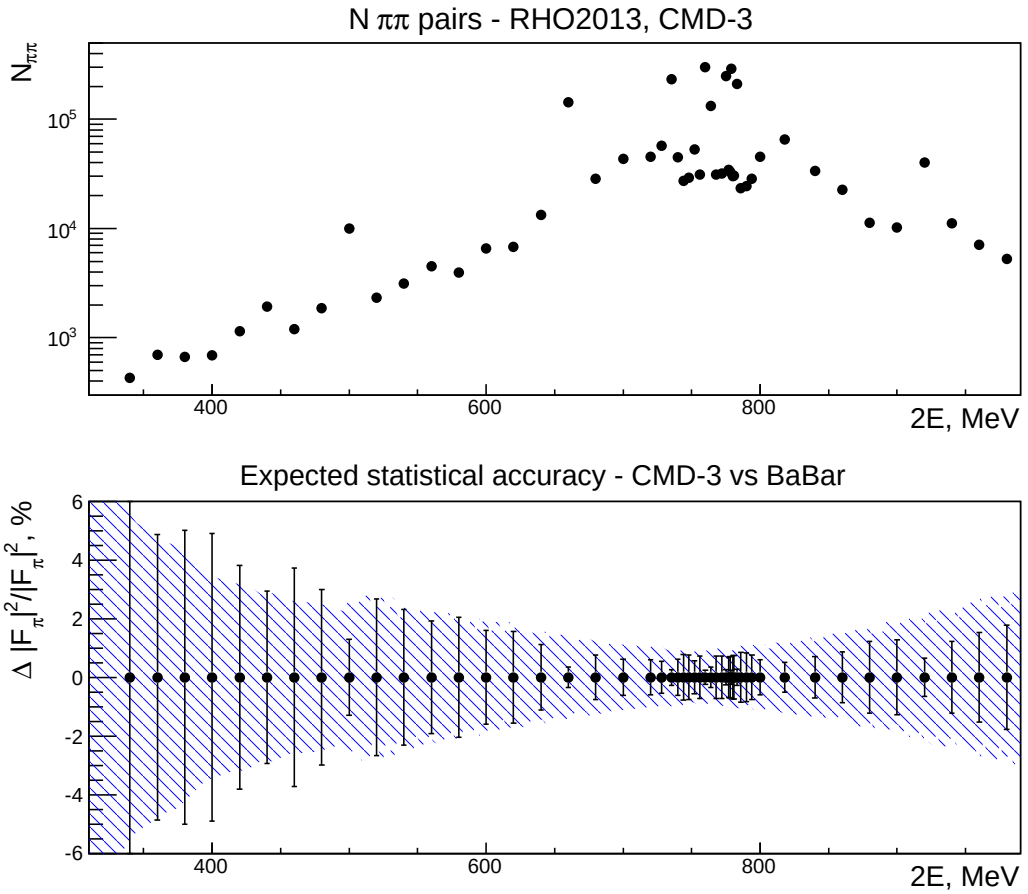

$\sqrt{s} = 340$ MeV, 0.65T

# Pion Form Factor – I




$\pi^+\pi^-$ events are selected by energy deposition in the calorimeter,
at low energies accuracy will be much better from PID by momentum

# Pion Form Factor – II

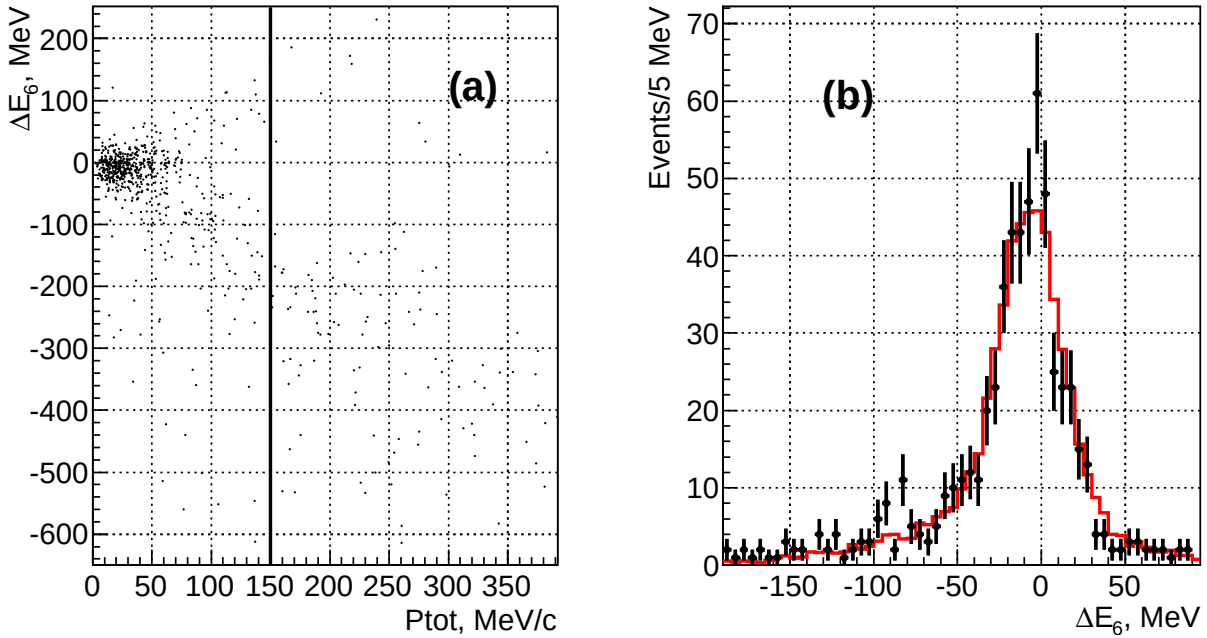



The total number of $\pi^+\pi^-$ events ($4\pi$ solid angle) and the expected $1/\sqrt{N_{\pi\pi}}$ for $1.1 < \theta < \pi - 1.1$

## $e^+e^- \to 3\pi^+3\pi^-$ – I

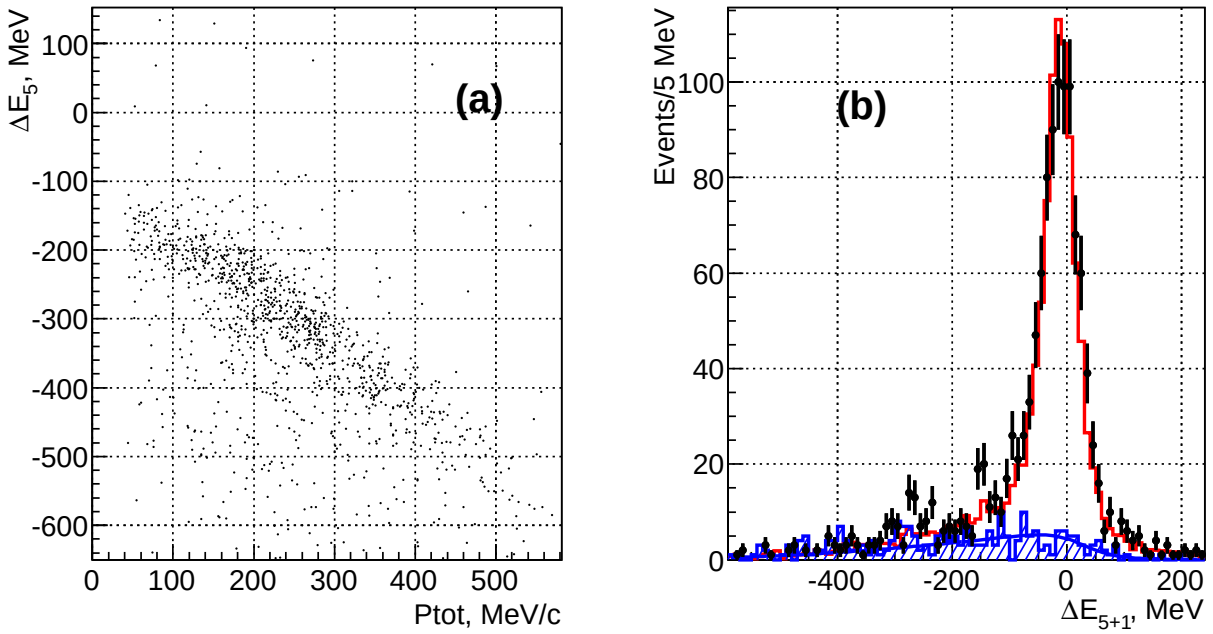
- The very first physical publication of CMD-3 on $e^+e^- \to 3\pi^+3\pi^-$ in arxiv:1302.0053, PLB
- A scan from 1500 to 2000 MeV with a $\sqrt{s} = 25$ MeV step and a finer scan of the near-$N\bar{N}$ threshold used, $\int Ldt$ =22 pb$^{-1}$
- About 8k five- and six-track events selected (5069 and 2887 events, respectively)
- Very few candidates below 1.5 GeV

# $e^+e^- \to 3\pi^+3\pi^- - \mathrm{II}$




6-track events: $\mathrm{Etot} = \sum_{i=1}^{6} \sqrt{p_i^2 + m_\pi^2}$, $\mathrm{Ptot} = |\sum_{i=1}^{6} \vec{p}_i|$, $\Delta E_6 = \mathrm{Etot} - \sqrt{s}$

# $e^+e^- \to 3\pi^+3\pi^-$ – III




5-track events: $\text{Etot} = \sum_{i=1}^{5} \sqrt{p_i^2 + m_\pi^2}$, $\text{Ptot} = |\sum_{i=1}^{5} \vec{p}_i|$,

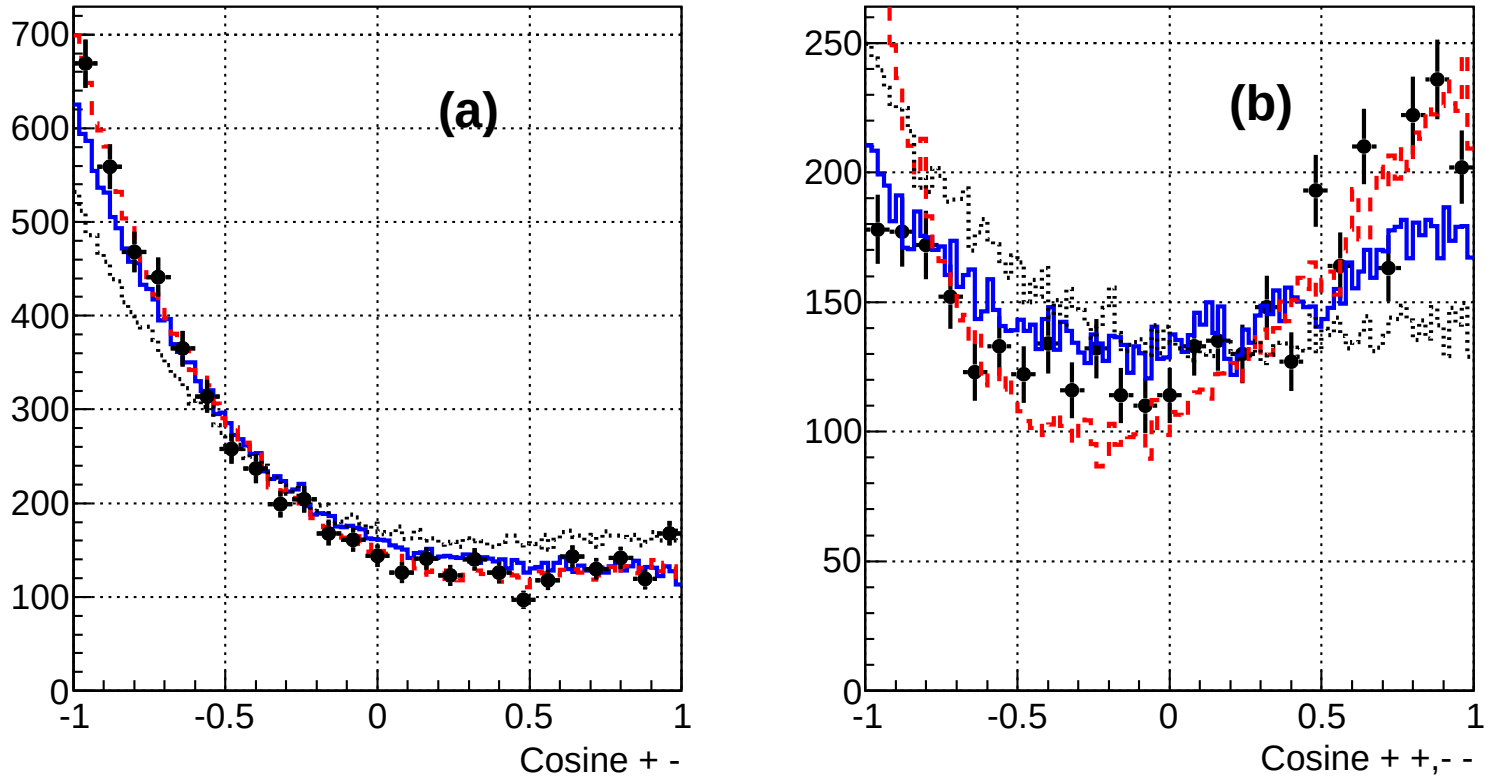
$\Delta E_5 = \text{Etot} - \sqrt{s}$, $\Delta E_{5+1} = \text{Etot} + \sqrt{Ptot^2 + m_\pi^2} - \sqrt{s}$

## $e^+e^- \to 3\pi^+3\pi^-$ – IV

We study dynamics, pure phase space doesn't work,
three models with $J^{PC} = 1^{--}$, each with one $\rho^0$/event:

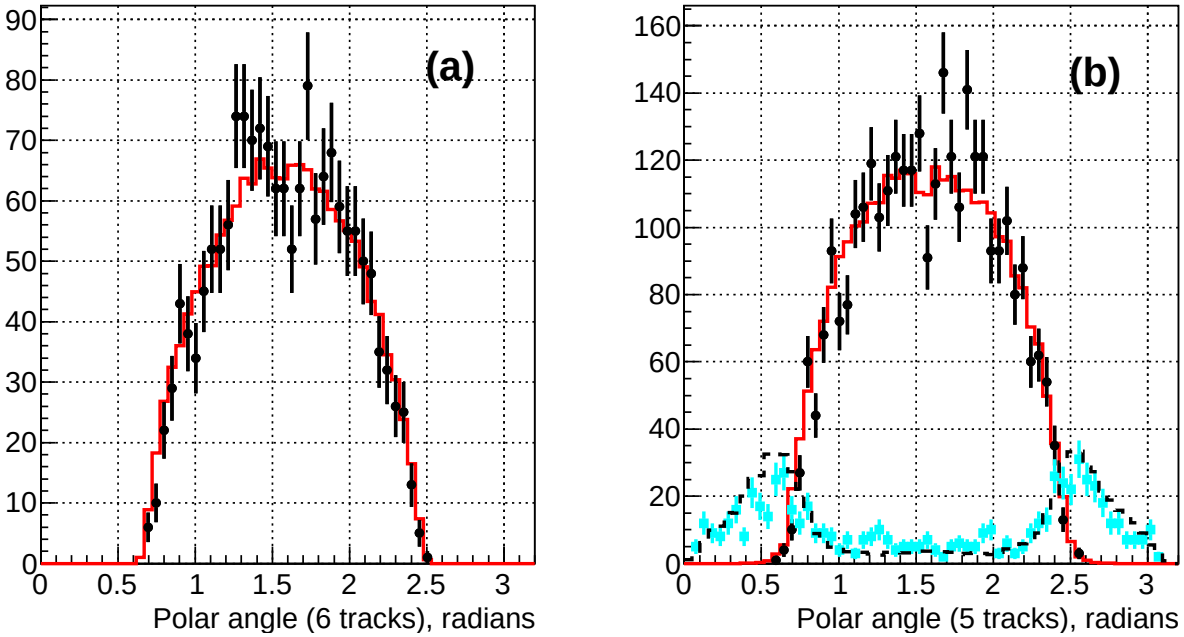
- $\rho(1450)(\pi^+\pi^-)_{\rm S-wave} \to a_1(1260)^{\pm}\pi^{\mp}\pi^+\pi^- \to \rho^0 2(\pi^+\pi^-) \to 3(\pi^+\pi^-)$
- $\rho(770)(2\pi^+2\pi^-)_{\rm S-wave} \to 3(\pi^+\pi^-)$
  3 options for $2\pi^+2\pi^-$: phase space, $f_0(1370)$, $f_0(1500)$
- $\rho(770)f_2(1270) \to 3(\pi^+\pi^-)$

## $e^+e^- \to 3\pi^+3\pi^- - \mathrm{V}$



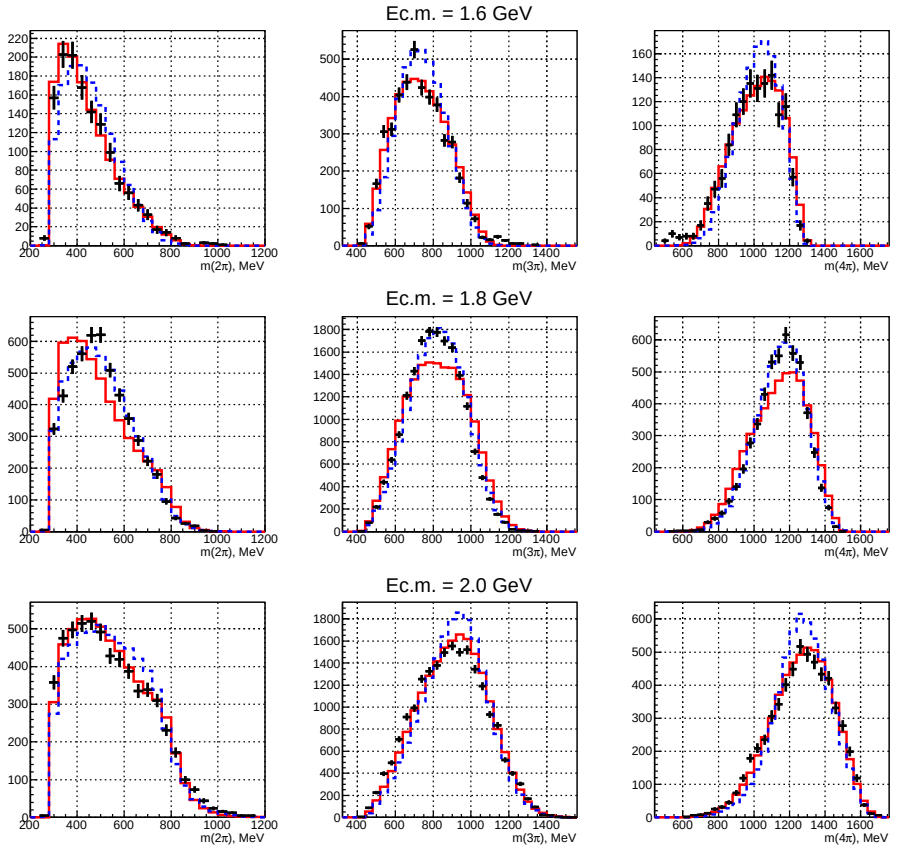

Cosines of the angle between two pions:
(a) opposite-sign charge, (b) same-sign charge

## $e^+e^- \to 3\pi^+3\pi^-$ – VI

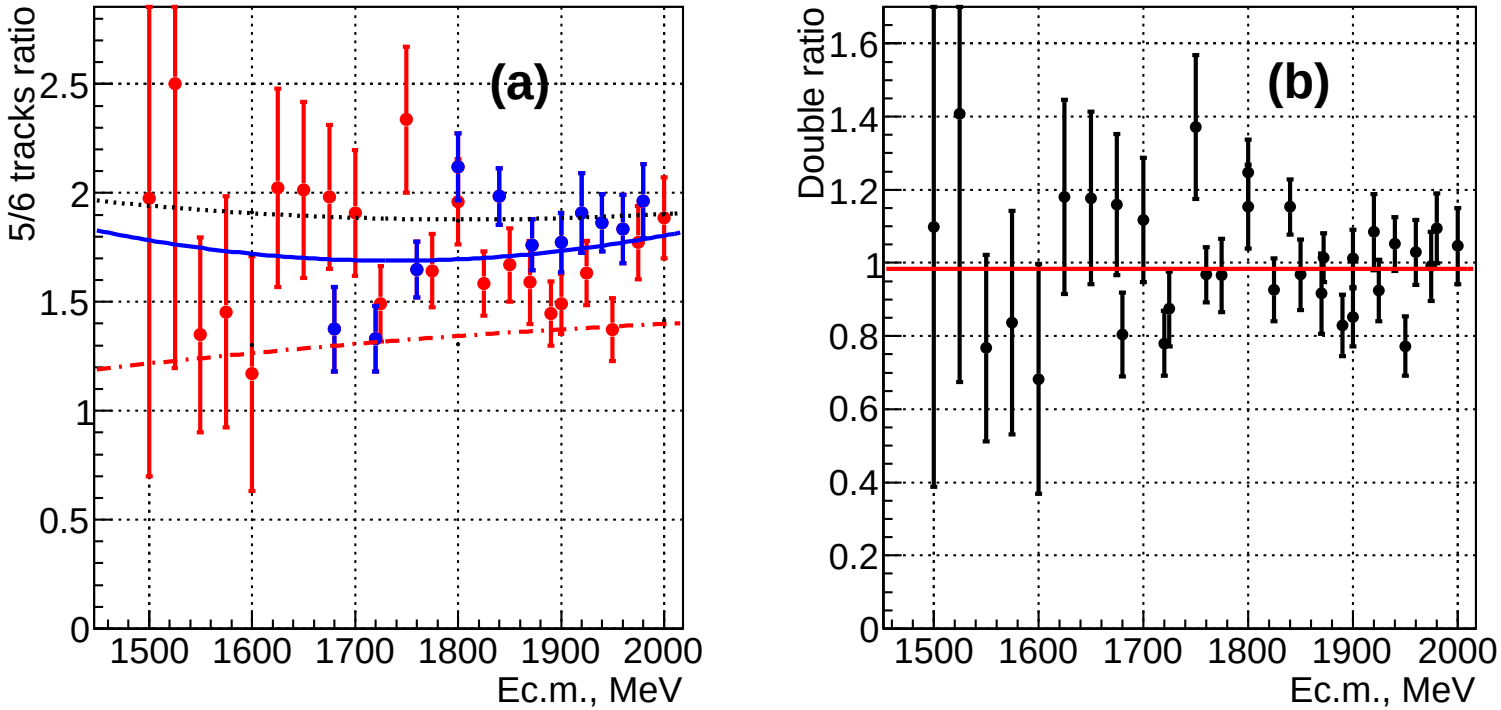



Polar angle distribution;
(a) – 6 tracks, (b) – 5 tracks, squares – a missing track

# $e^+e^- \to 3\pi^+3\pi^- - \mathrm{VII}$

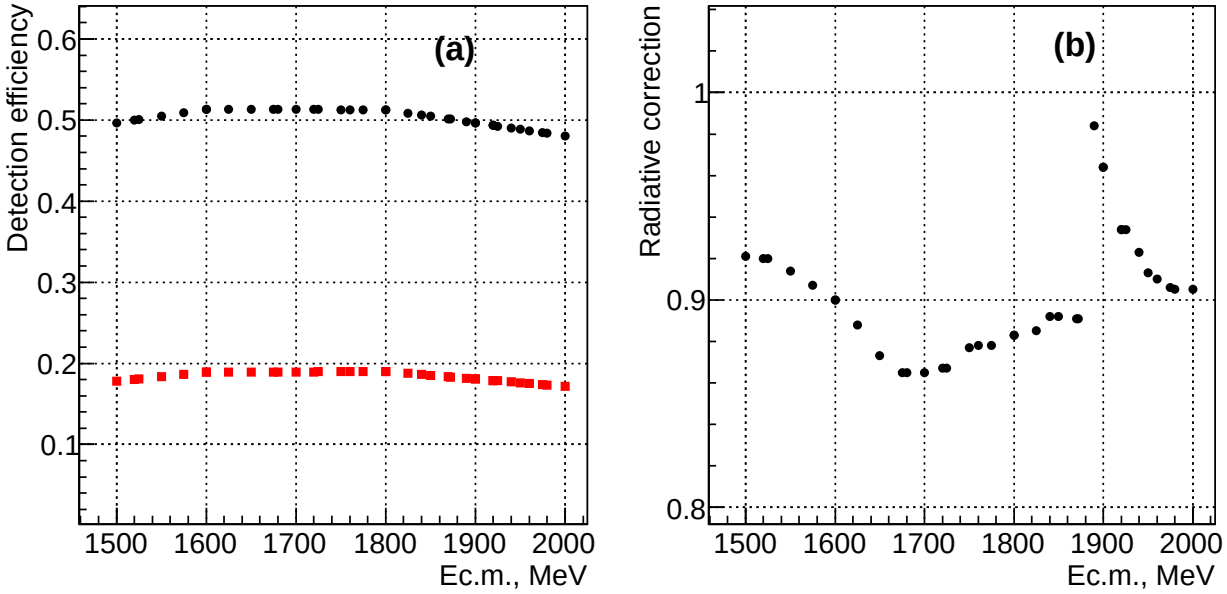


# $e^+e^- \to 3\pi^+3\pi^-$ – VIII




(a) Ratio $R_{56}$ of 5-tr. to 6-tr. events, (b) $R_{56}^{data}/R_{56}^{MC2}$

## $e^+e^- \to 3\pi^+3\pi^-$ – IX




(a) Efficiency for 6-track (squares) and (5+6)-track (circles) events,
(b) Radiative correction

## $e^+e^- \to 3\pi^+3\pi^- - X$

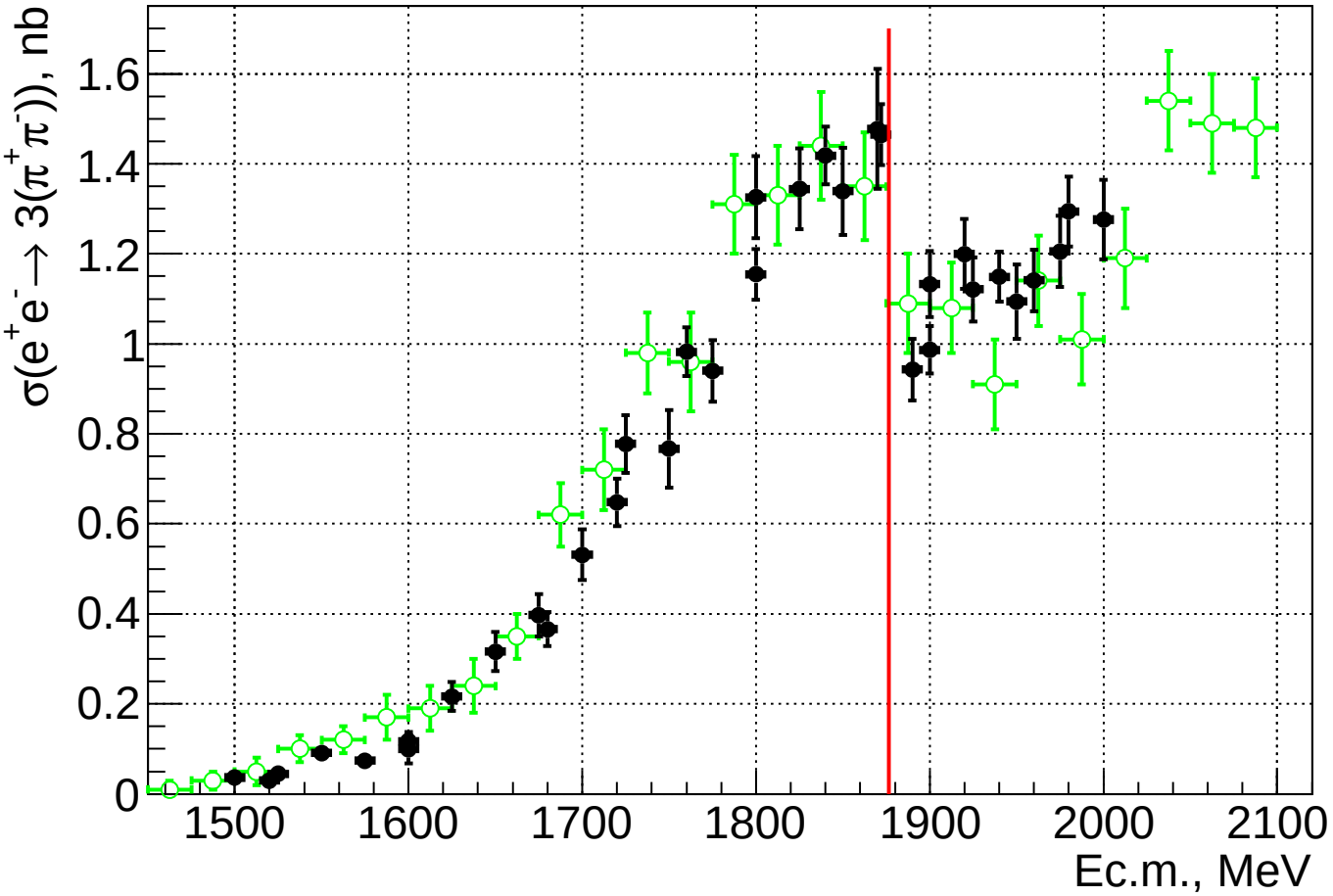
Systematic uncertainties for $\sigma(e^+e^- \to 3\pi^+3\pi^-)$

| Source | CMD-3, % | BaBar, % |
|---|---|---|
| Model | 4 | 3 |
| Selection | 3 | $2 \bigoplus 3$ |
| Lumi | 2 | 3 |
| Background (6 tr.) | 1 | 3 |
| Background (5 tr.) | 3 | – |
| $\Delta\sqrt{s}/\sqrt{s}(\sim 5 \cdot 10^{-3})$ | 1 | – |
| Rad. corr. | 1 | 1 |
| Total | 6 | 6 |

CMD-3: R.R. Akhmetshin et al., arxiv:1302.0053, Phys. Lett. B

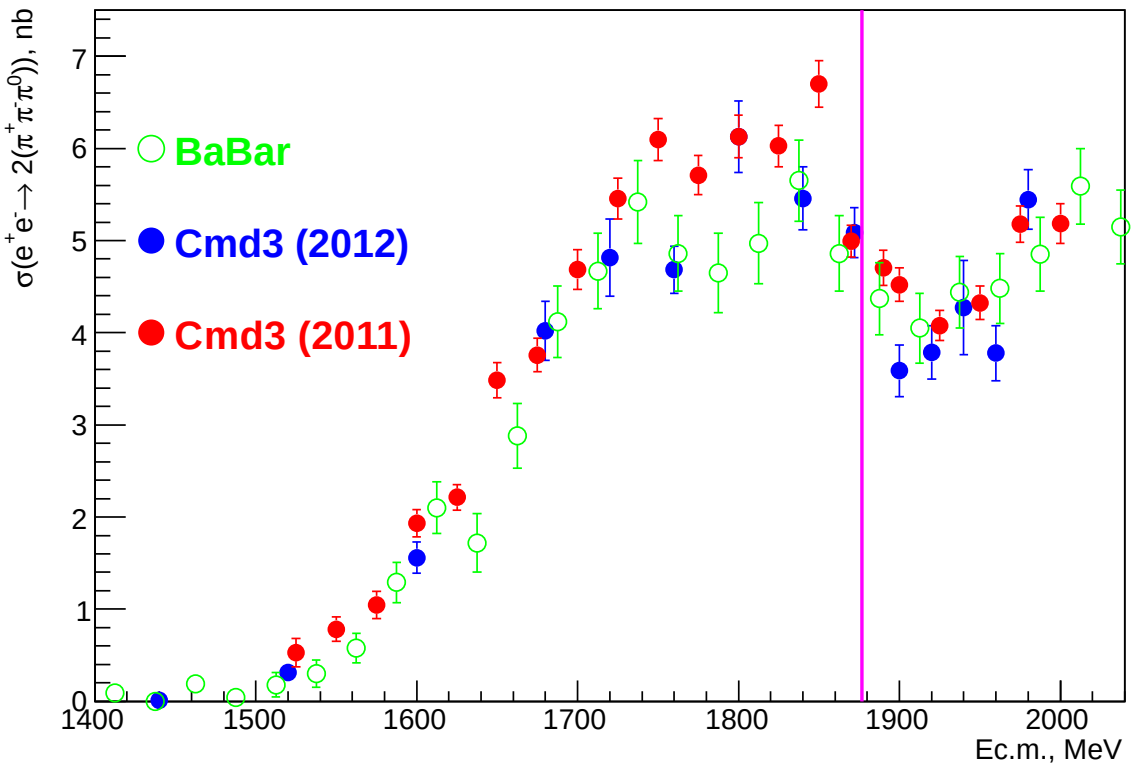
BaBar: B. Aubert et al., Phys. Rev. D 73, 052003 (2006)

## $e^+e^- \to 3\pi^+3\pi^-$ – XI




$\sigma(e^+e^- \to 3(\pi^+\pi^-))$, black - CMD-3, green - BaBar

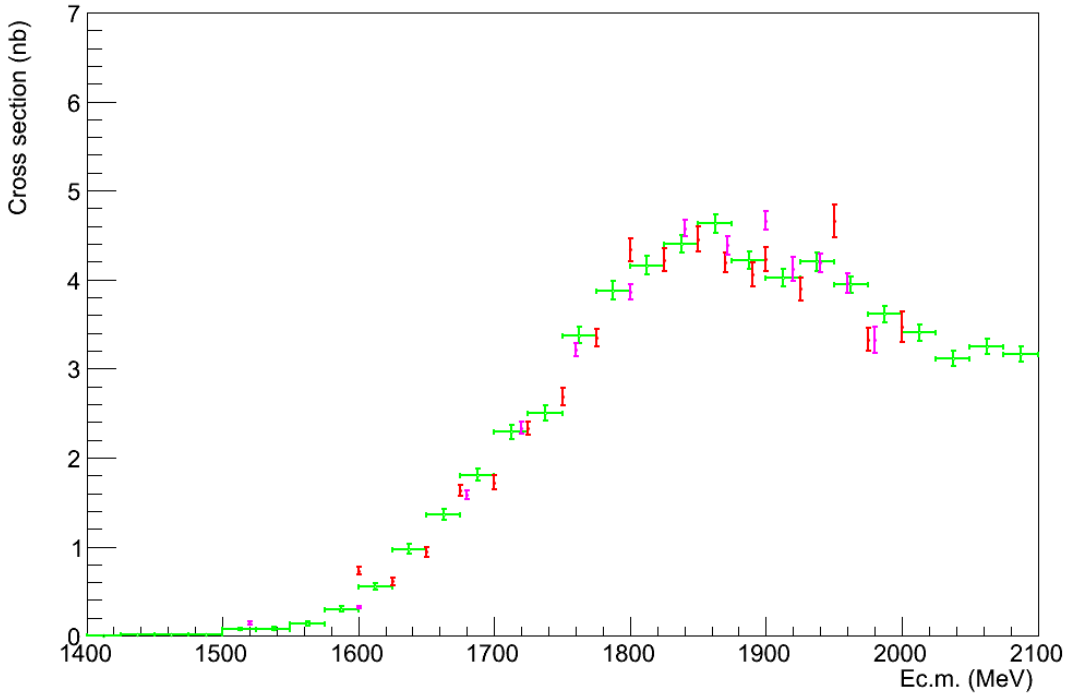
## $e^+e^- \to 2\pi^+2\pi^-2\pi^0$




2011 – all reconstructed or a $\pi^\pm$ or $\pi^0$ lost

2012 – all reconstructed only

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




Red and lilac – CMD-3, green – BaBar

## Conclusions

- VEPP-2000 operates successfully in the mode of round beams, Luminosity is $\sim 5$ times higher than before from $\omega$ to 1.4 GeV, $2 \cdot 10^{31}$ cm$^{-1}$s$^{-1}$ achieved at 1.7-1.8 GeV
- Two updated detectors, CMD-3 and SND, are taking data and perform fairly well. Work on calibrations, software is in progress
- With collected $\int Ldt$ CMD-3 has the stat. accuracy of cross sections for most of the multihadronic processes the same or better than at BaBar
- Analysis is in progress for $e^+e^- \to \pi^+\pi^-$, $K^+K^-$, $\pi^+\pi^-\pi^0$, $2\pi^+2\pi^-$, $\pi^+\pi^-2\pi^0$, $K^+K^-\pi^+\pi^-$, $3\pi^+3\pi^-$, $2\pi^+2\pi^-2\pi^0$, $p\bar{p}$
- First analysis of the $3\pi^+3\pi^-$ dynamics will soon be published
- We hope to have $\mathcal{L} \sim 10^{32}$ cm$^{-1}$s$^{-1}$ at VEPP-2000 in 2015