

Measurement of hadronic cross sections at CMD-3

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The CMD-3 experiment at the VEPP-2000 collider in Novosibirsk carries out a comprehensive study of the exclusive production of hadrons in e^+e^- annihilation in the center-of-mass energy range from the threshold to $\sqrt{s} < 2$ GeV.

Previously, the comprehensive measurement was performed by CMD-2 and SND at VEPP-2M collider (1993-2000, up to 1.4 GeV), and by BaBar and KLOE using initial-state-radiation (ISR) method.

VEPP-2000 now collected the world-largest $e^+e^- \rightarrow \text{hadrons}$ data sample below 2 GeV (except ϕ -meson energy range).

VEPP-2000 collider

The experiments are carried out at VEPP-2000 e^+e^- collider at Budker Institute of Nuclear Physics (Novosibirsk, Russia):

- perimeter 24 m, 1x1 bunch, "round" beams
- $2E = 0.32 - 2.0$ GeV, $L = 10^{31} \div 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
- beam energy is monitored using Compton backscattering
- two interaction points with CMD-3 and SND detectors

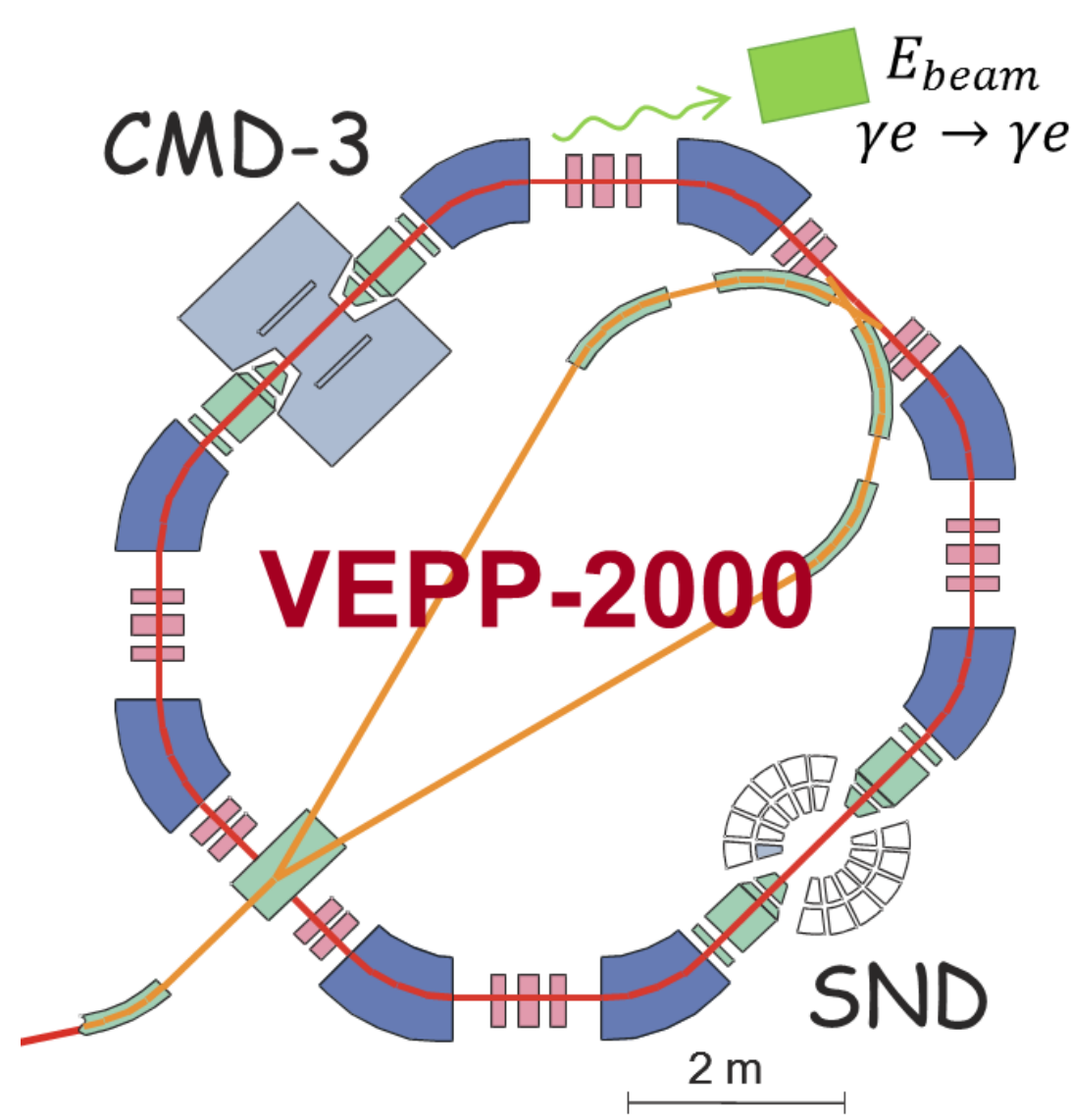


Figure 1: VEPP-2000 collider

CMD-3 detector

The Cryogenic Magnetic Detector (CMD-3) consists of drift chamber, Z-chamber, 13.5X₀ electromagnetic calorimeter (LXe and CsI in barrel, BGO in endcap), time-of-flight system and muon system.

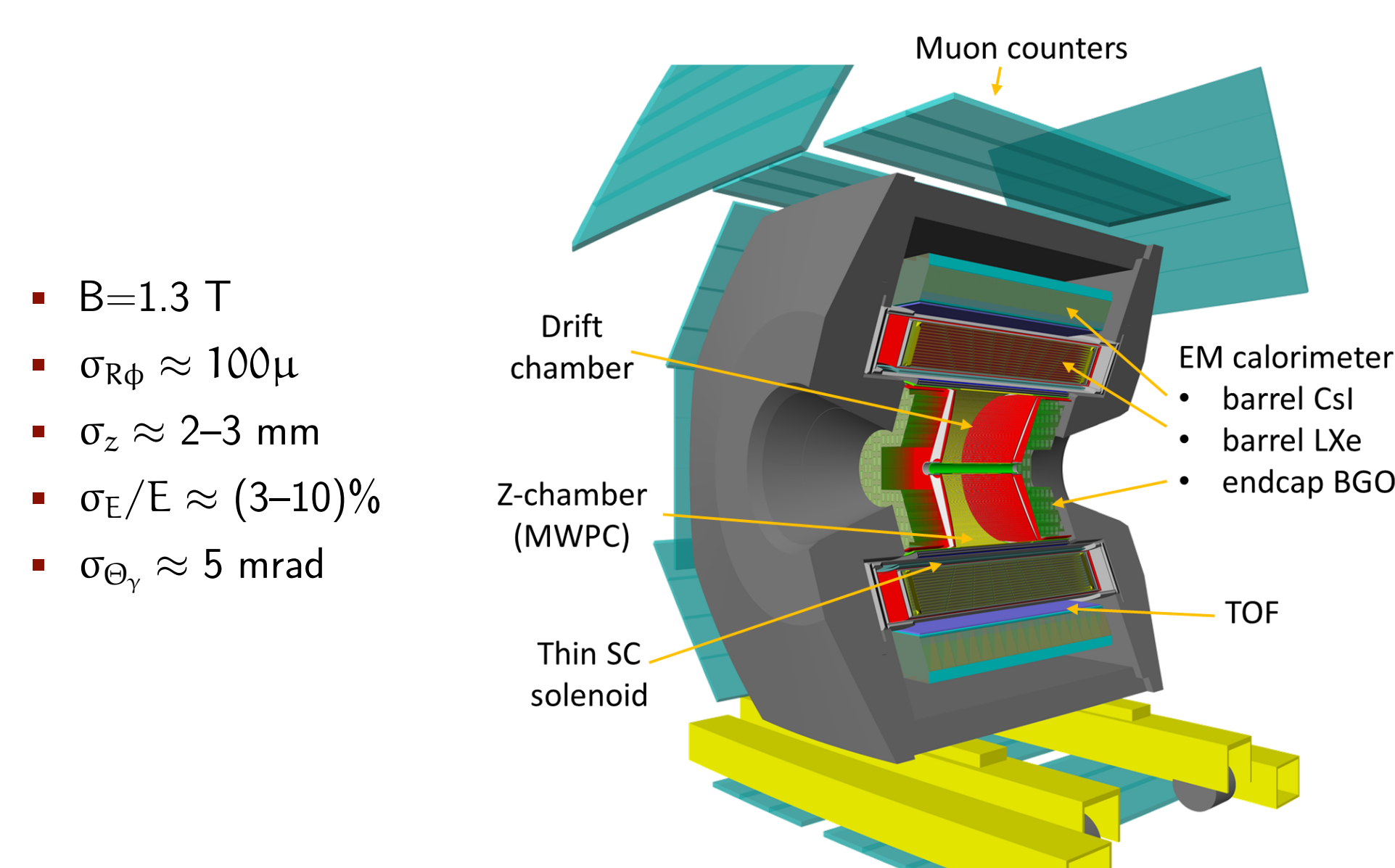


Figure 2: CMD-3 detector and its parameters

The full energy range of VEPP-2000 was scanned in 2011-2013 and, after collider upgrade, in 2017-2019. Total collected luminosity integral is about 250 pb⁻¹.

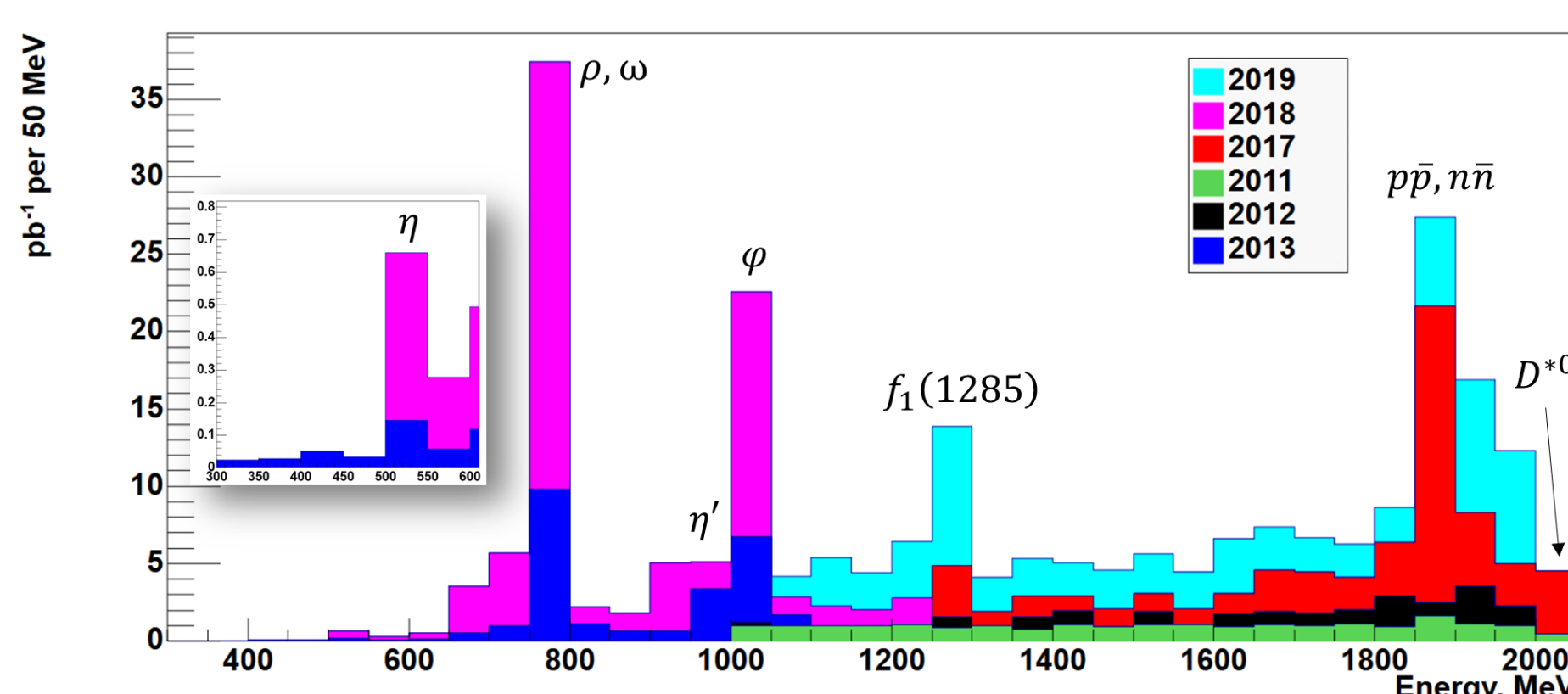


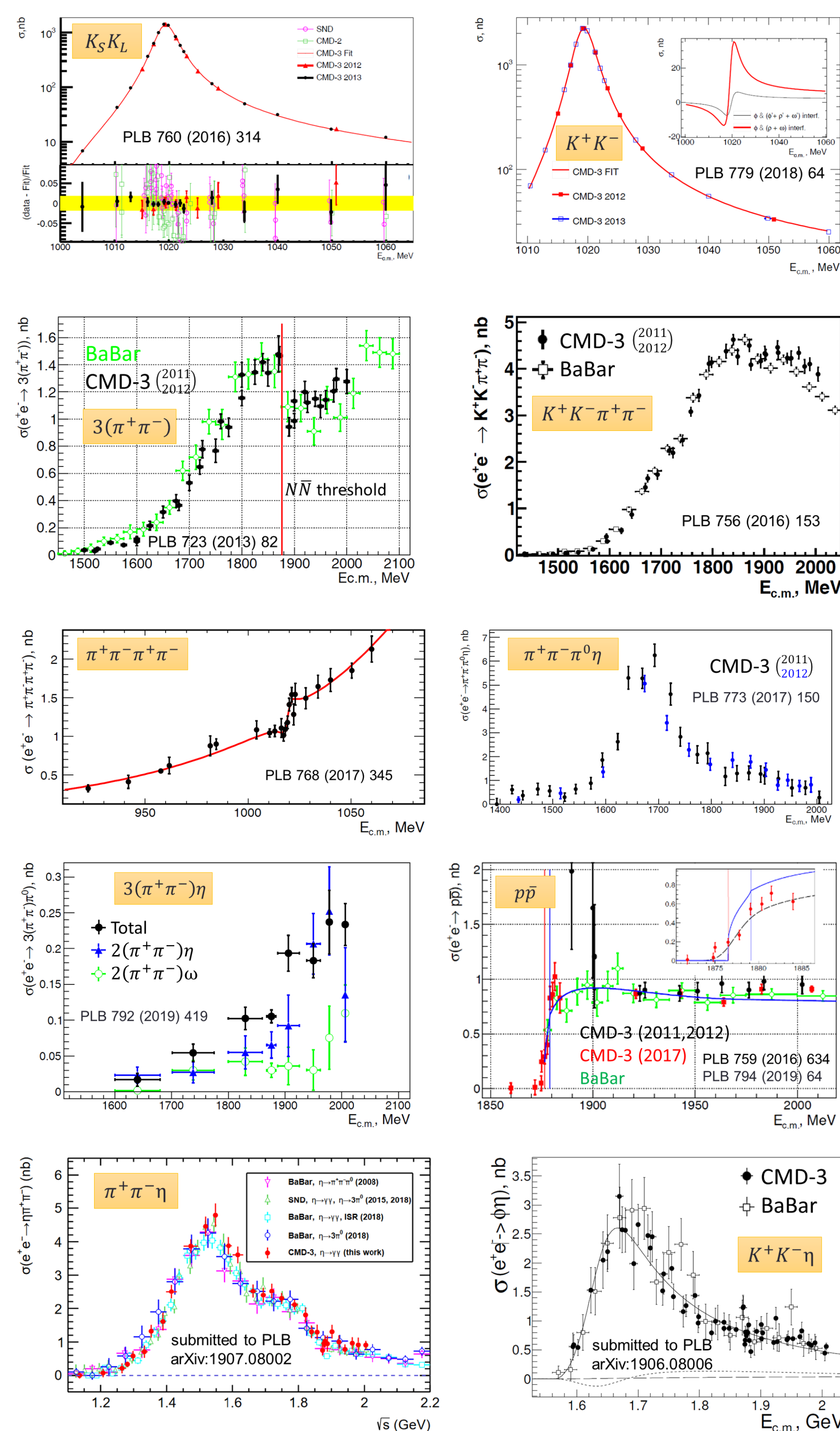
Figure 3: Data, collected by CMD-3 detector

Exclusive $e^+e^- \rightarrow \text{hadrons}$

List of final states considered

Signature	Final states (preliminary, published)
2 charged	$\pi^+\pi^-$, K^+K^- , $K_S K_L$, $p\bar{p}$
2 charged + γ 's	$\pi^+\pi^-\gamma$, $\pi^+\pi^-\pi^0$, $\pi^+\pi^-2\pi^0$, $\pi^+\pi^-3\pi^0$, $\pi^+\pi^-4\pi^0$, $\pi^+\pi^-\eta$, $\pi^+\pi^-\pi^0\eta$, $\pi^+\pi^-2\pi^0\eta$, $K^+K^-\pi^0$, $K^+K^-2\pi^0$, $K^+K^-\eta$, $K_S K_L \pi^0$, $K_S K_L \eta$
4 charged	$2(\pi^+\pi^-)$, $K^+K^-\pi^+\pi^-$, $K_S K_S \pi^+\pi^-$
4 charged + γ 's	$2(\pi^+\pi^-)\pi^0$, $2\pi^+2\pi^-2\pi^0$, $\pi^+\pi^-\eta$, $\pi^+\pi^-\omega$, $2\pi^+2\pi^-\eta$, $K^+K^-\omega$, $K_S K_S \pi^+\pi^0$
6 charged	$3(\pi^+\pi^-)$, $K_S K_S \pi^+\pi^-$
6 charged + γ 's	$3(\pi^+\pi^-)\pi^0$
Neutral	$\pi^0\gamma$, $2\pi^0\gamma$, $3\pi^0\gamma$, $\eta\gamma$, $\pi^0\eta\gamma$, $2\pi^0\eta\gamma$
Other	$n\bar{n}$, $\pi^0 e^+e^-$, ηe^+e^-
Rare decays	η' , $D^*(2007)^0$

Published CMD-3 results on $e^+e^- \rightarrow \text{hadrons}$ exclusive cross sections. Most of the results are based on data, collected in 2011-2013 (about 25% of full sample, collected by today).



Study of dynamics. With high statistics we are able to perform amplitude analysis (based on multidimensional unbinned likelihood fit) and study the intermediate dynamics of particular decay.

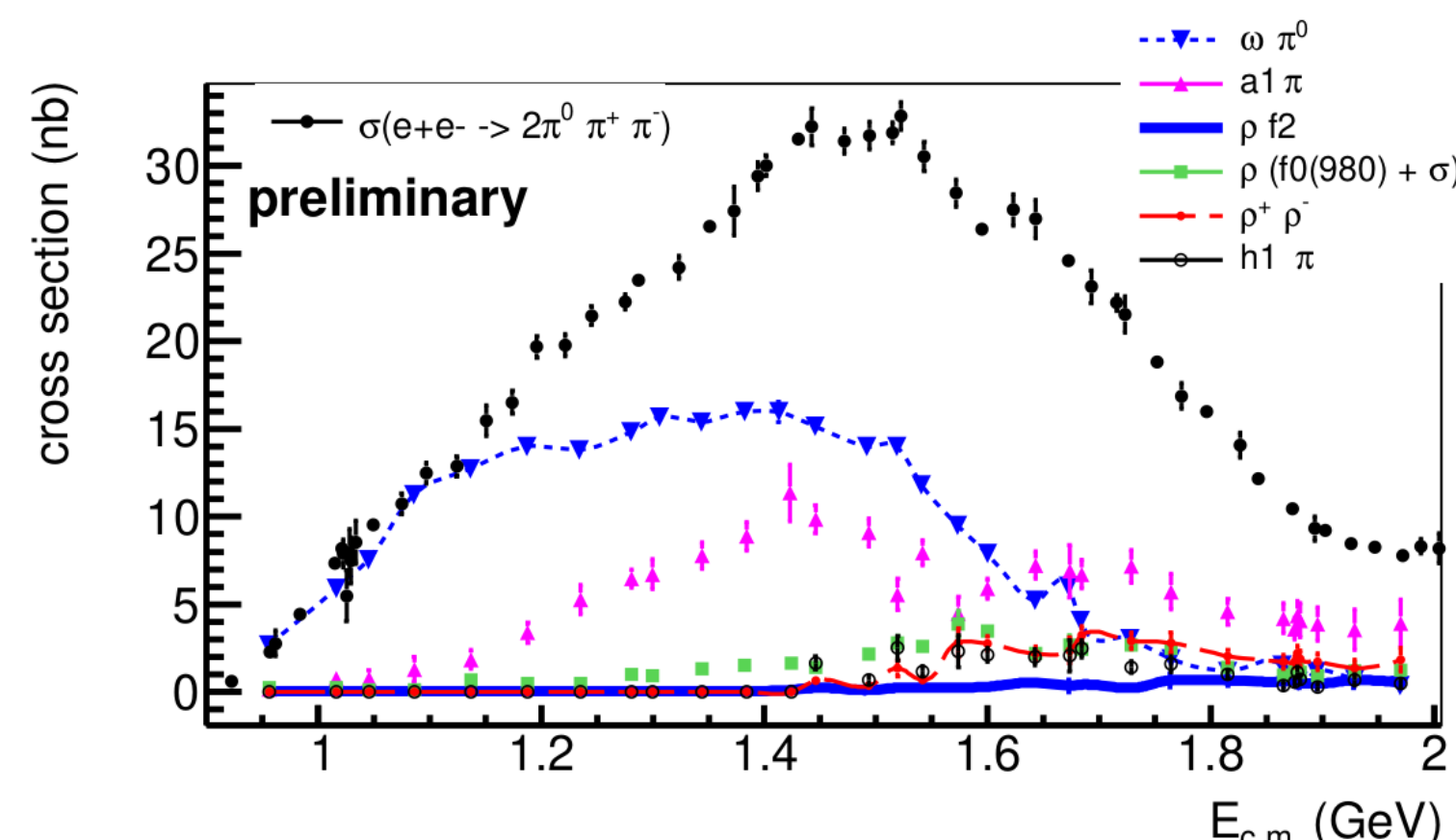


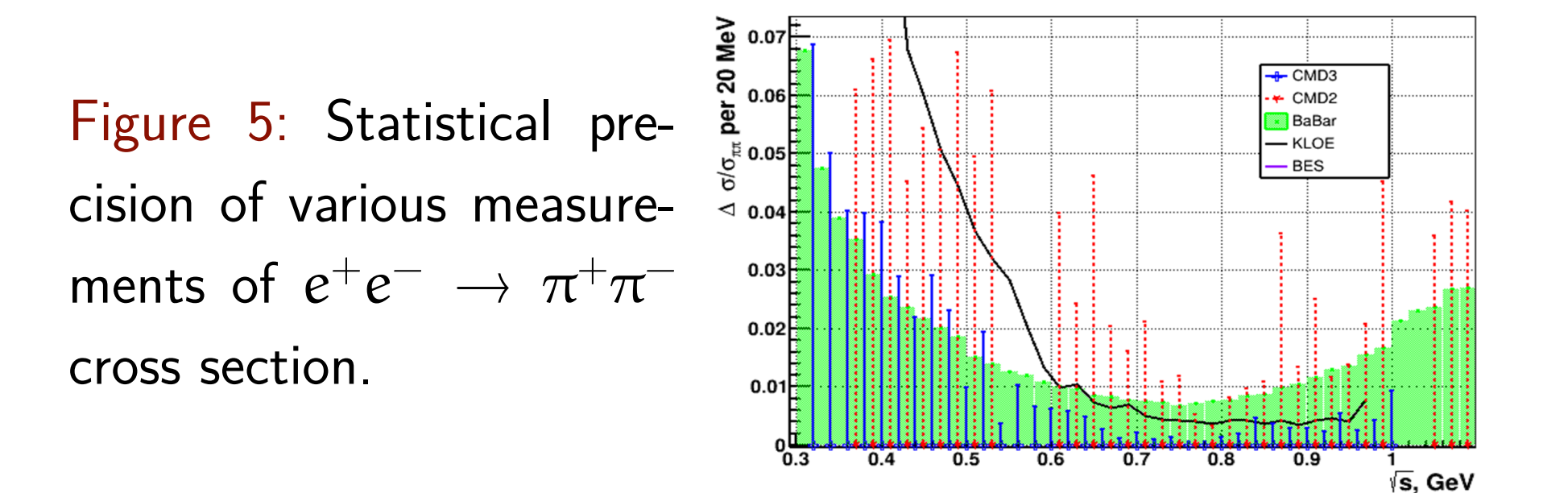
Figure 4: Preliminary analysis of intermediate dynamics of four-pion production in e^+e^- annihilation

Connection to $(g-2)_\mu$

The hadronic contribution to muon (g-2) is calculated via dispersion integral using $e^+e^- \rightarrow \text{hadrons}$ cross-section:

$$a_\mu(\text{had}; \text{LO}) = \frac{\alpha^2}{3\pi^2} \int \frac{ds}{s} R(s) K(s), \quad R(s) = \frac{\sigma(e^+e^- \rightarrow H)}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}$$

The dominant contribution to the value and uncertainty of the integral comes from VEPP-2000 energy range. About 3/4 of the total contribution comes from $e^+e^- \rightarrow \pi^+\pi^-$ final state. High precision measurement was done by CMD-2 and SND (energy scan) and KLOE and BaBar (ISR). There is tension between their results beyond claimed errors. The CMD-3 analysis is in progress.



NN threshold

The energy range around $p\bar{p}$ and $n\bar{n}$ production thresholds was scanned with small energy steps. A very fast rise (~ 1 MeV width) of $p\bar{p}$ cross section was observed. A sharp drop was observed in $3(\pi^+\pi^-)$ and $K^+K^-\pi^+\pi^-$ cross sections.

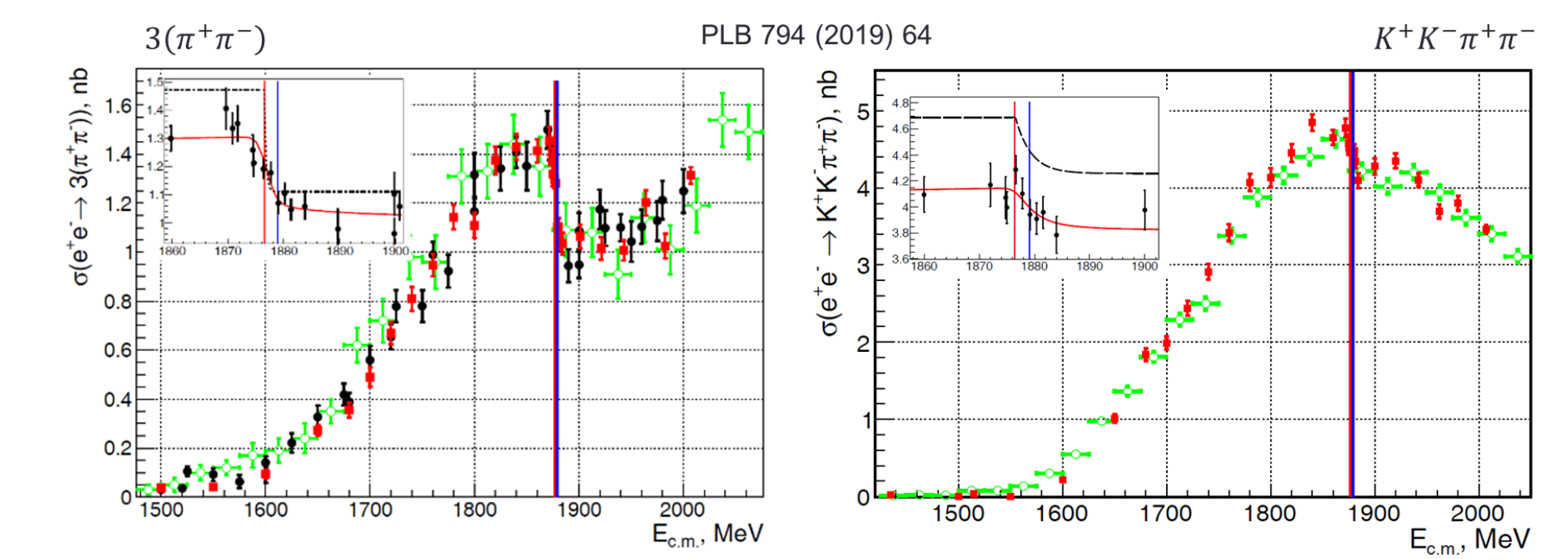
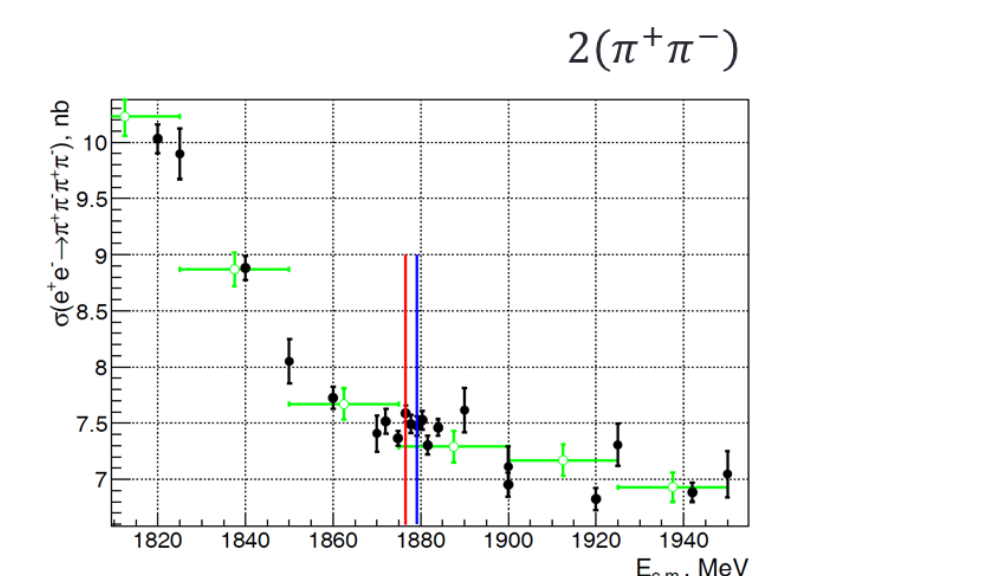


Figure 6: Fine structure of $e^+e^- \rightarrow \text{hadrons}$ production at NN threshold

Surprisingly, no drop was observed in $2(\pi^+\pi^-)$.



Search for rare decays

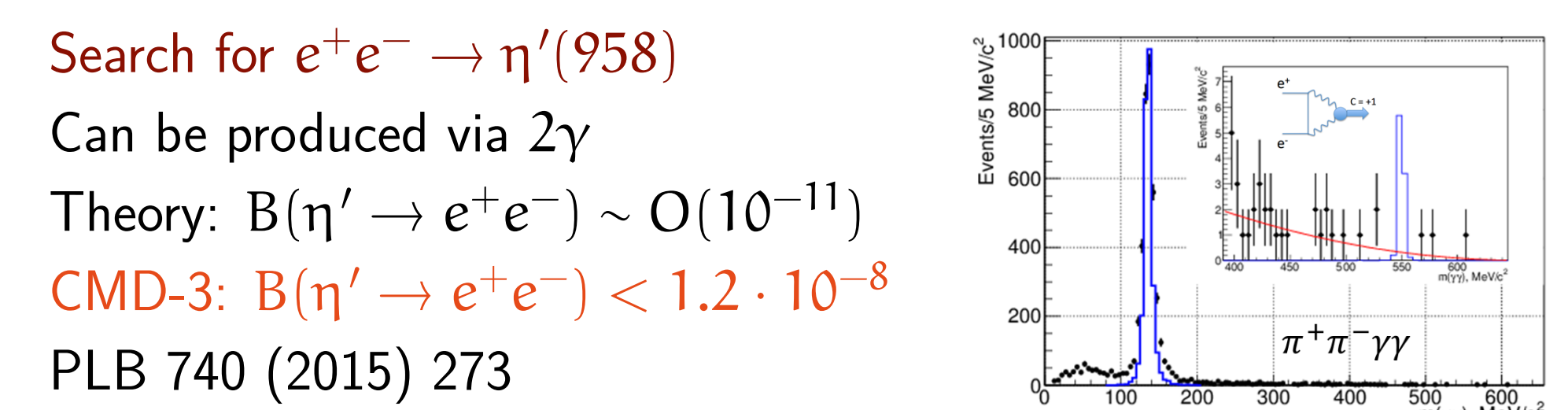
Search for $e^+e^- \rightarrow \eta'(958)$

Can be produced via 2γ

Theory: $B(\eta' \rightarrow e^+e^-) \sim O(10^{-11})$

CMD-3: $B(\eta' \rightarrow e^+e^-) < 1.2 \cdot 10^{-8}$

PLB 740 (2015) 273



Search for $e^+e^- \rightarrow D^{*0}(2007)$

Motivation: JHEP 1511 (2015) 142

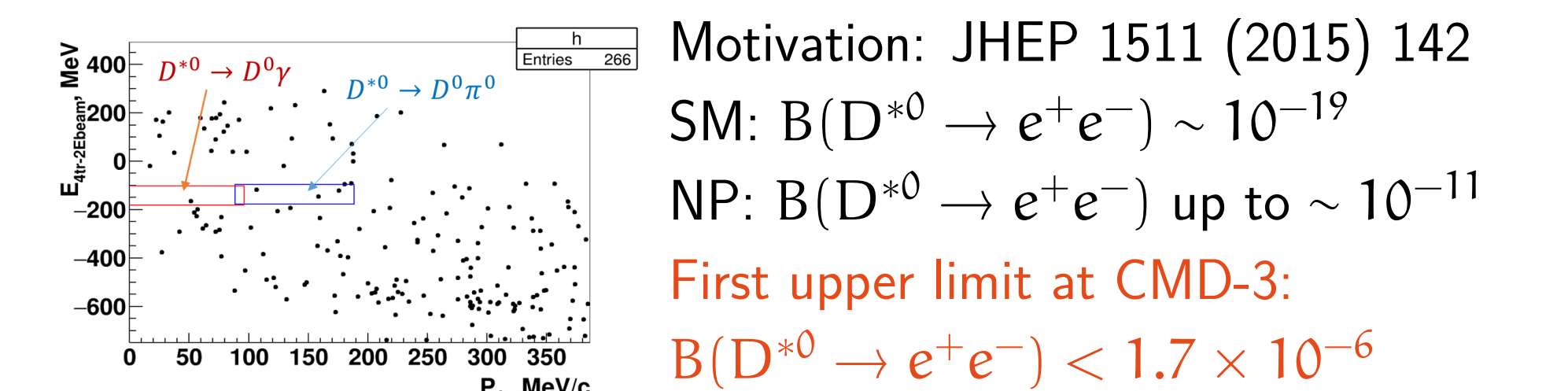
SM: $B(D^{*0} \rightarrow e^+e^-) \sim 10^{-19}$

NP: $B(D^{*0} \rightarrow e^+e^-)$ up to $\sim 10^{-11}$

First upper limit at CMD-3:

$B(D^{*0} \rightarrow e^+e^-) < 1.7 \times 10^{-6}$

preliminary, 90% CL



Conclusion

- CMD-3 has collected about 250 pb⁻¹ of $e^+e^- \rightarrow \text{hadrons}$ data so far in $0.32 < \sqrt{s} < 2.0$ GeV energy range with the plan to collect 0.5-1.0 fb⁻¹ in the next few years.
- The data analysis is in progress. Results on cross section and dynamics for several exclusive modes of hadron production have been published.
- Results of experiments at VEPP-2000 are important for reaching better precision of calculation of hadronic contribution to muon (g-2).

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