Processes with radiative return

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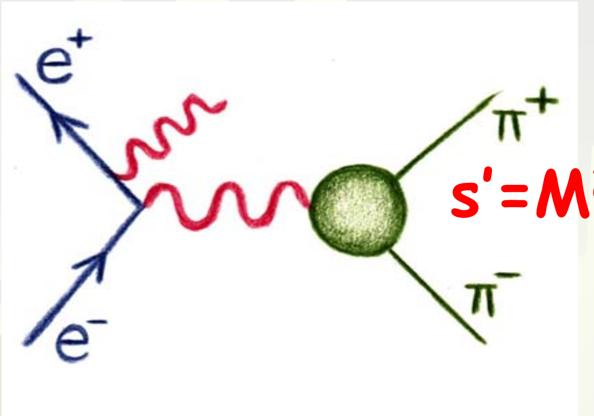
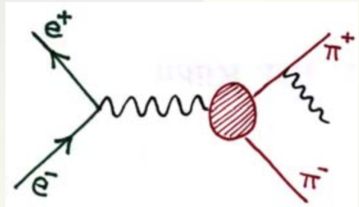
There are many reasons to measure total and partial cross sections of the $e^+e^- \rightarrow$ hadrons annihilation in a wide range and with high accuracy:

- Determination of the fundamental parameters which requires the integrals from the cross sections, like muon $(g_m\text{-}2)$, $\alpha(M_Z)$ and others;
- Study of the u,d,s quarks interactions;
- Tests of models and input for ChPT and other theories;
- Light meson spectroscopy;
- Search for exotic states like glueballs and hybrids;
- Tests of CVC relations between e^+e^- and τ decays



$s' = M^2_{\pi\pi}$



The idea is quite old*, but lately became popular due to the high luminosity meson factories.

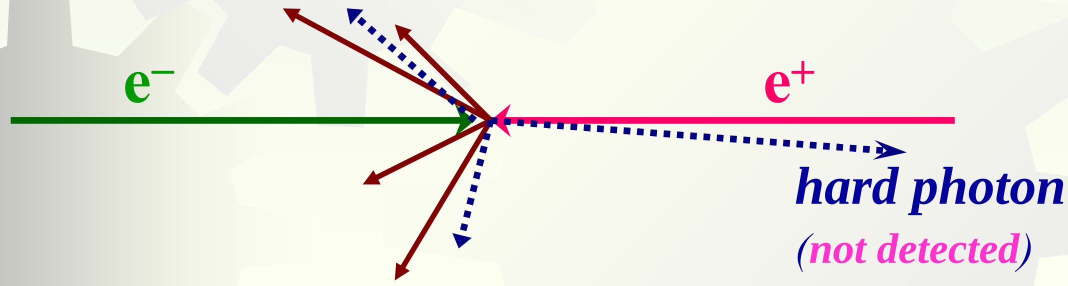
Many talks on this subject at the conferences were presented by KLOE, BaBar and Belle.

*) ***V.N.Baier and V.S.Fadin, Phys.Let. B 27 (1968) 223***

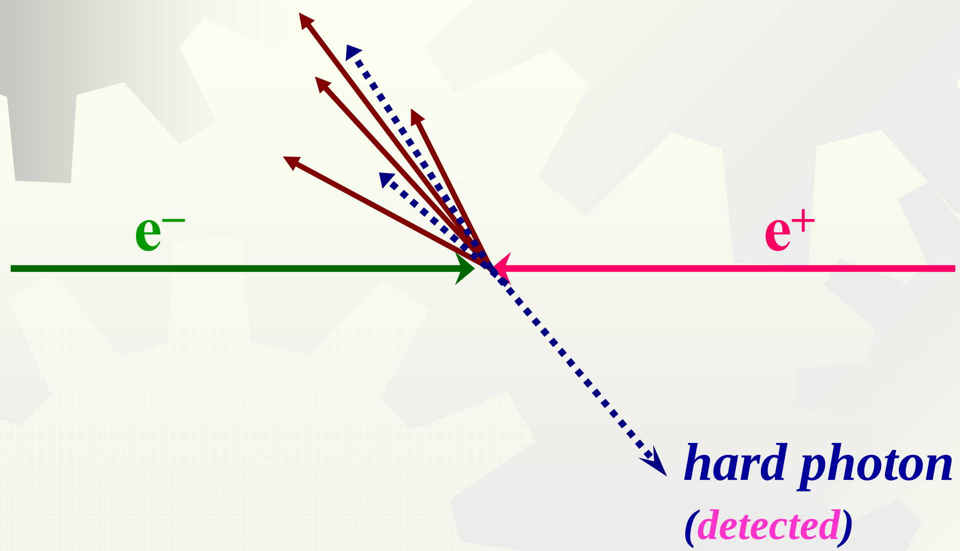
M.S.Chen, P.Zerwas, Phys. Rev. D 11 (1975) 58

M.Benayoun, S.I.Eidelman, V.N.Ivanchenko, Z.K.Silagadze, Mod.Phys.Lett. A14 (1999) 2605.

Two approaches

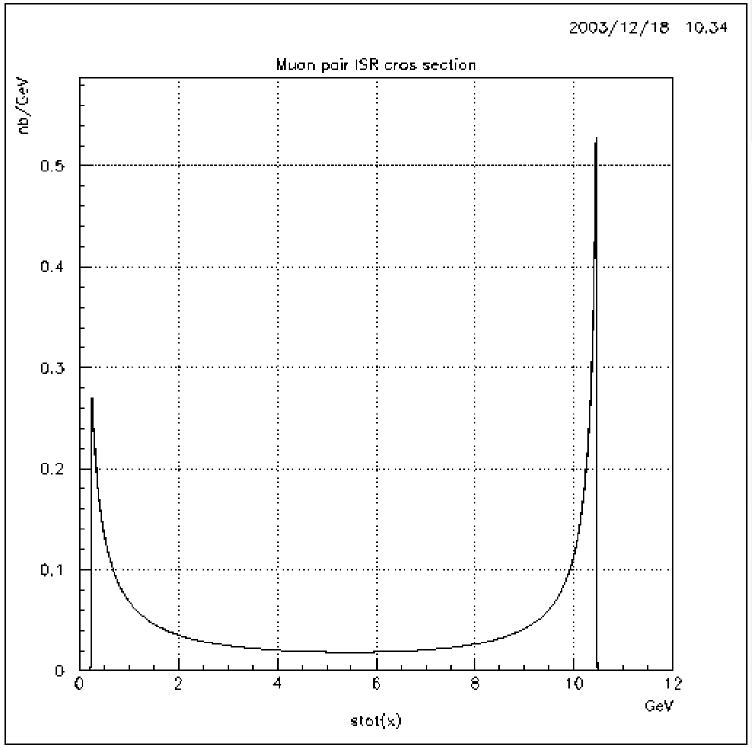


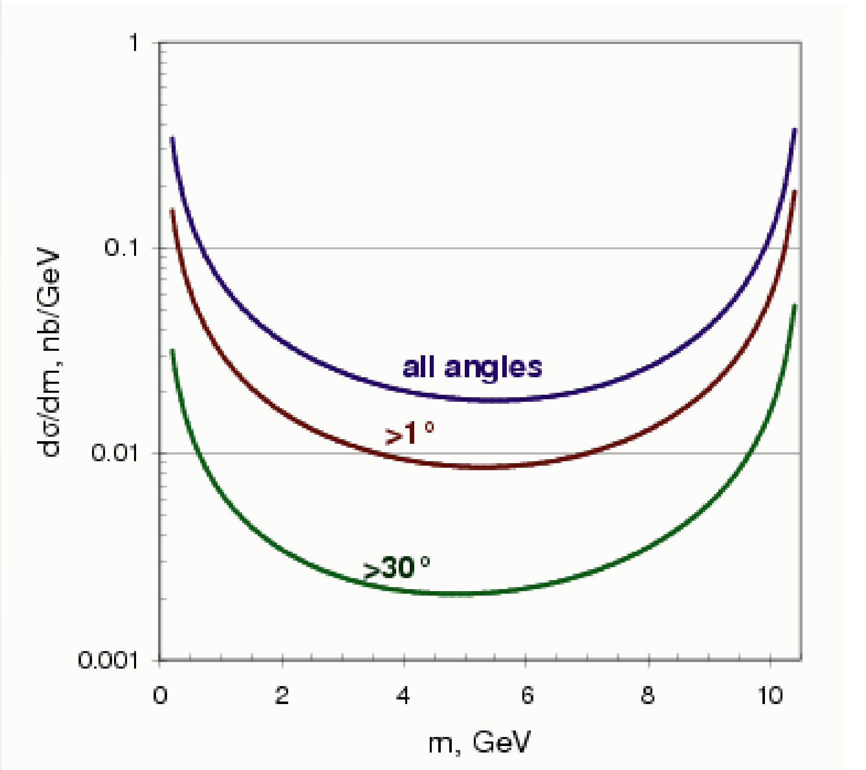
higher cross section,
but
partial reconstruction,
higher background,
good for high mass range



full reconstruction,
low background
but
lower cross section, full
mass range is available

$e^+e^- \to \mu^+\mu^-\gamma$



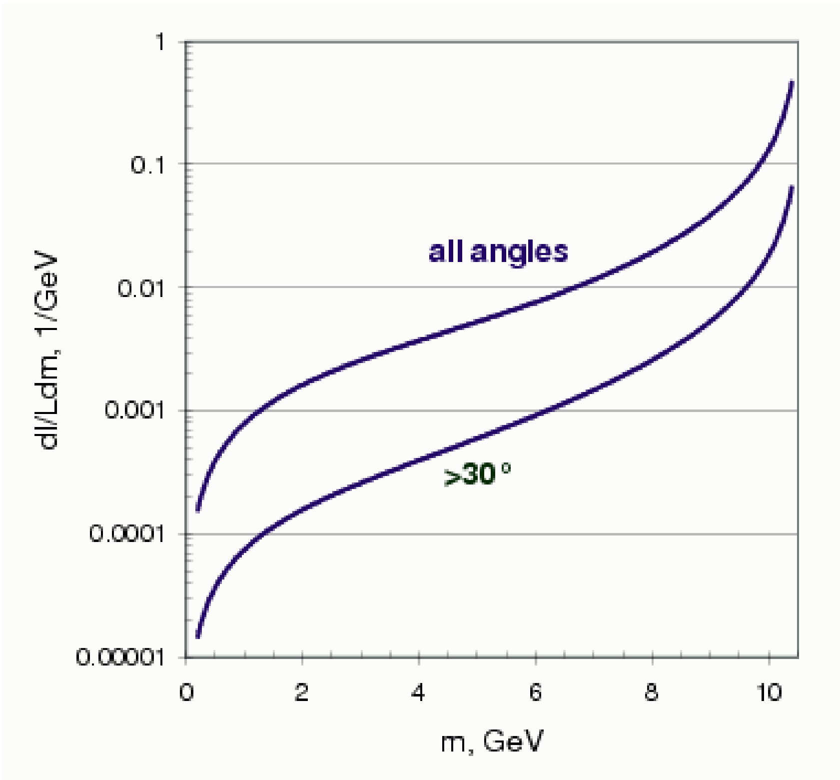


$$m^2\frac{d\sigma}{dm^2}=\frac{4\alpha^3}{3s}R(m^2)\left[\frac{s^2+m^4}{s(s-m^2)}(\ln\frac{s}{m_e^2}-1)\right]$$

$$\frac{d\sigma}{dm}=\frac{0.4035[nb\cdot GeV^2]}{s[GeV^2]}\frac{R(m^2)}{m}\left[\frac{s^2+m^4}{s(s-m^2)}(\ln\frac{s}{m_e^2}-1)\right]$$

$R = \sigma_{study}/\sigma(e^+e^- \to \mu^+\mu^-)$

Differential luminosity



$$\frac{dl}{Ldm} = \frac{2\alpha m}{\pi s}\left\{\frac{s+m^4}{s(s-m^2)}\left(\ln\frac{s}{m_e^2}-1\right)\right\}$$

The rate at $L=10^{35} cm^{-2}s^{-1}$:

$f_{\mu\mu\gamma}$ ~ 30 Hz;

$f_{\tau\tau\gamma}$ ~ 15 Hz

f_{hadr} ~ 80 Hz

E_γ > 1GeV

Comparison to VEPP-2000 project, e^+e^- up to 2 GeV

$$\frac{dl}{Ldm} = \frac{2\alpha m}{\pi s}\left\{\frac{s+m^4}{s(s-m^2)}(\ln\frac{s}{m_e^2}-1)\right\}$$

(under construction at BINP)

	S-KEKB	VEPP-2000
Luminosity, $cм^{-2}\,s^{-1}$	10^{35}	10^{32}
Integrated lum. (per 10^7 s)	1000 fb^{-1}	1 fb^{-1}
Integrated in the range [1-2] GeV	1 fb^{-1}	1 fb^{-1}

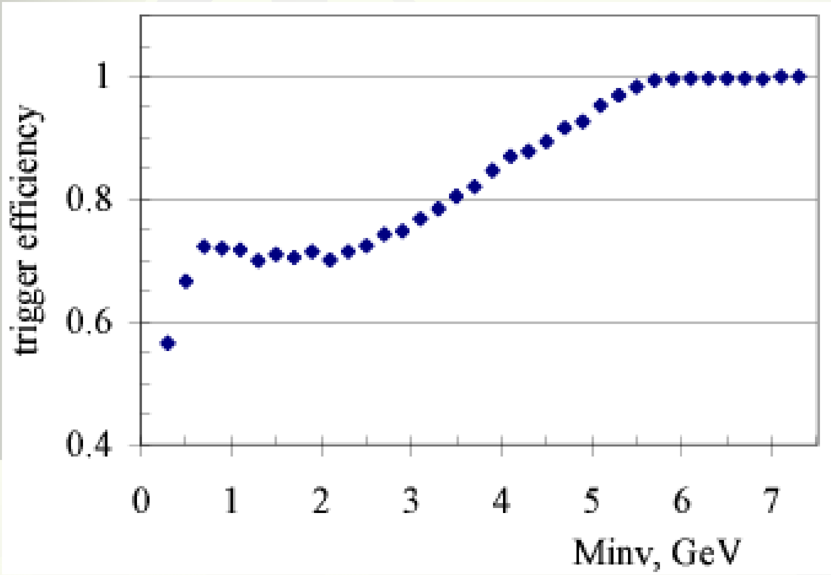
Number of events of the vector meson production at 3 ab^{-1}

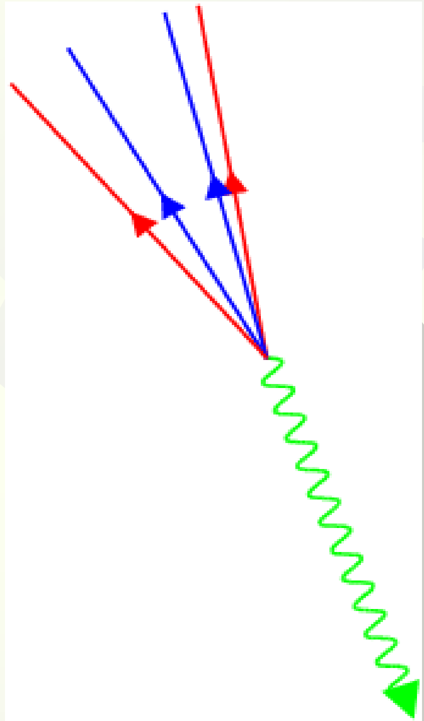
ϕ	5.5×10^7
ψ	8.4×10^7
ψ(2S)	2.9×10^7
ψ(3770)	3.6×10^6
Υ(1s)	4.8×10^7
Υ(2s)	4.4×10^7
Υ(3s)	9.0×10^7

- Thus, the ISR approach is competitive to conventional collider experiments.
- The advantage of ISR is that the whole energy range is measured simultaneously , in the same run, at the same apparatus status while at the conventional approach the status of the detector and collider may vary during long time energy scan.
- A disadvantage – more complicated interpretation of the data and specific event geometry.

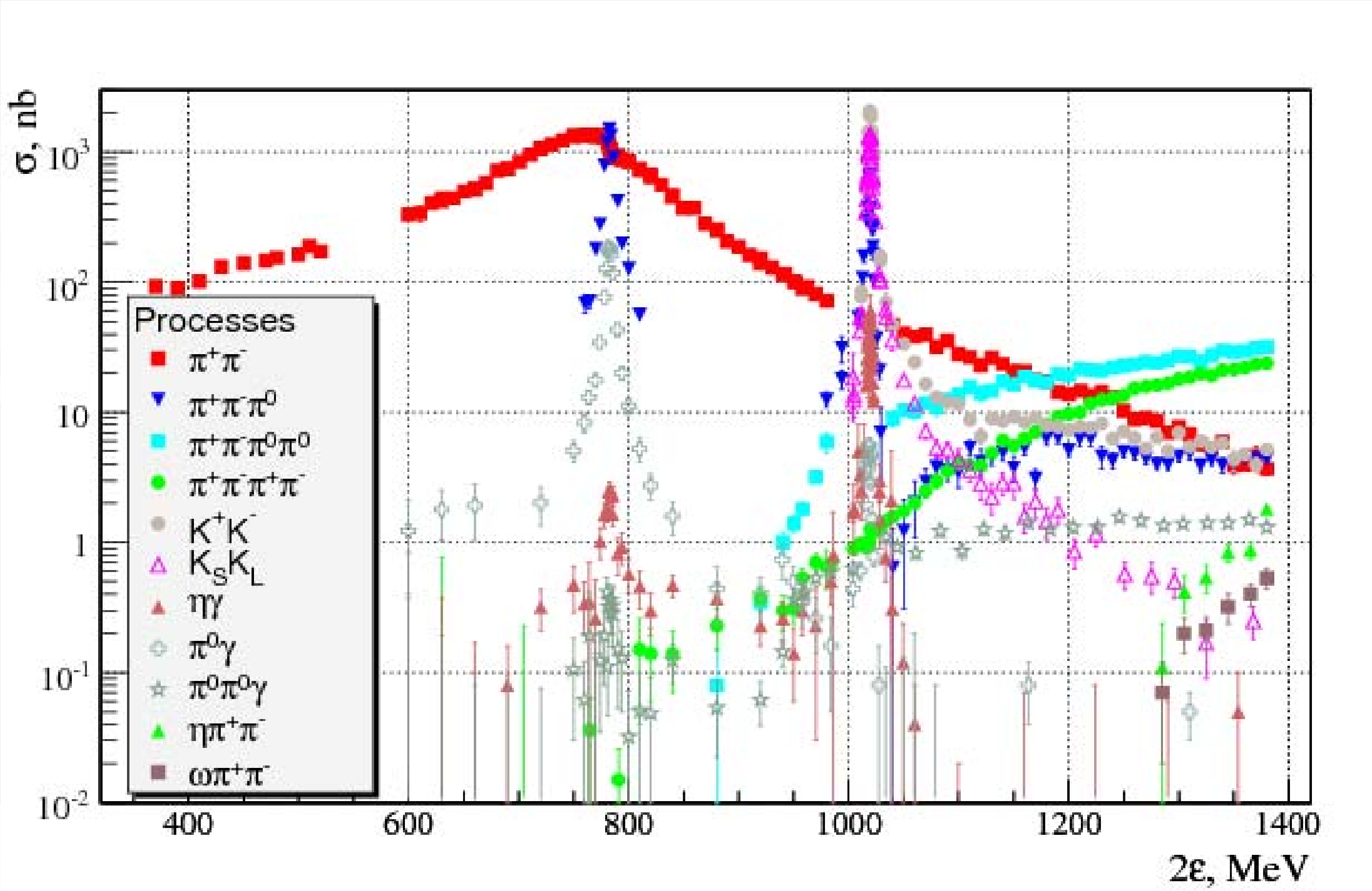
Trigger

In the current trigger ISR events with the small invariant mass are suppressed by Bhabha veto.

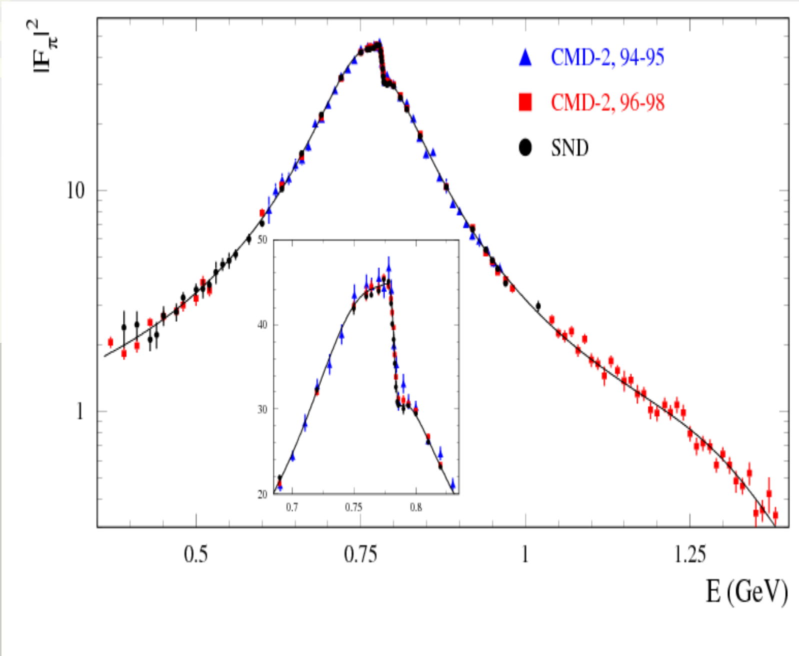


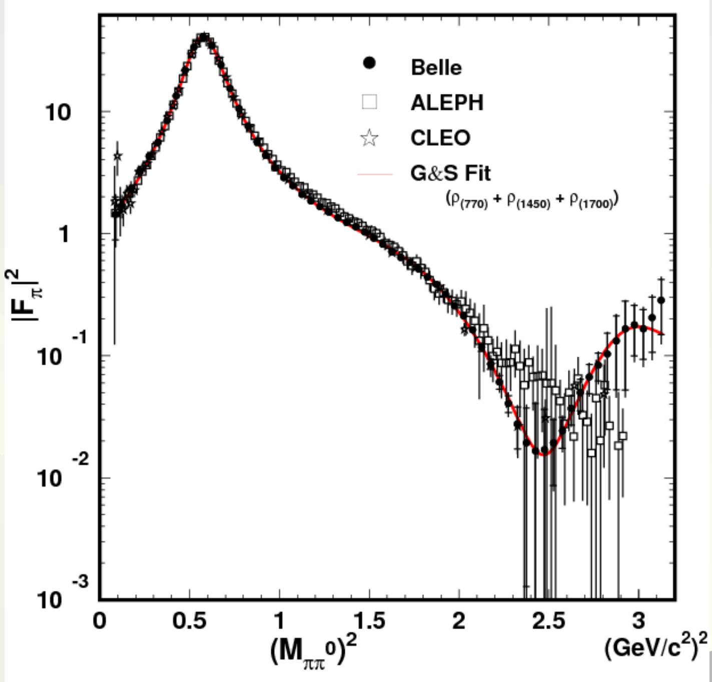


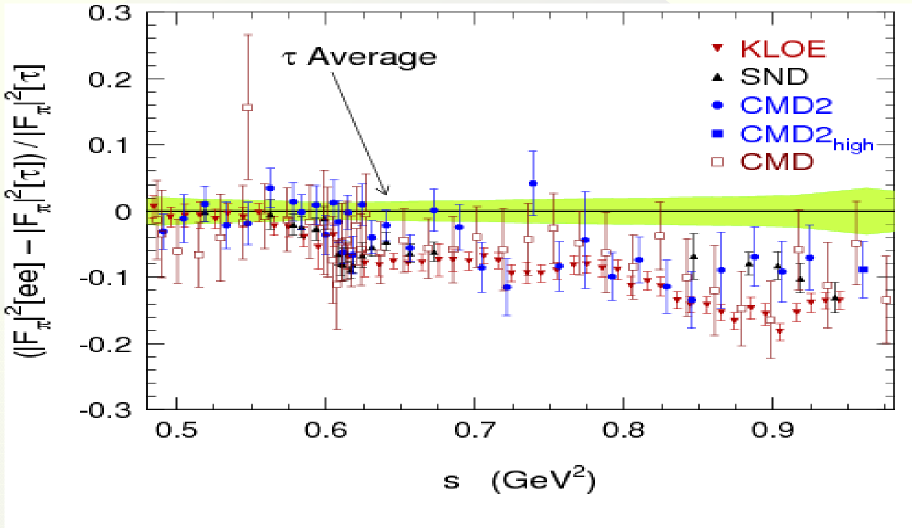
There should be trigger with coincidence of high energy cluster without track + tracks in the opposite side.



After 20 years of the VEPP-2M collider operation, a lot of experimental data were accumulated. However, even here puzzles exist…


$|F_\pi|^2$
CMD-2, 94-95
CMD-2, 96-98
SND
10
1
0.5
0.75
1
1.25
E (GeV)


Belle
ALEPH
CLEO
G&S Fit
$(\rho_{(770)} + \rho_{(1450)} + \rho_{(1700)})$
$|F_\pi|^2$
$(M_{\pi\pi^0})^2$
$(GeV/c^2)^2$

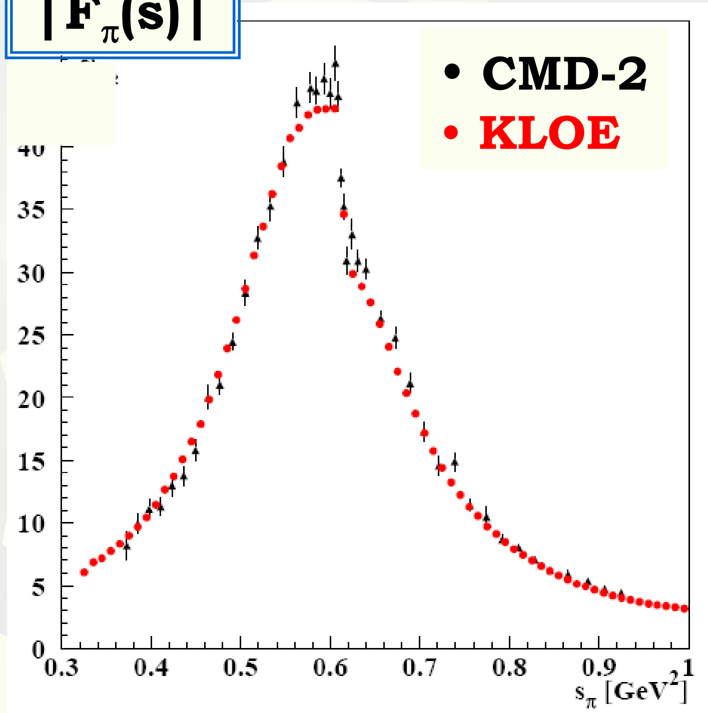

τ Average
KLOE
SND
CMD2
$CMD2_{high}$
CMD
$(|F_\pi|^2[ee] - |F_\pi|^2[\tau]) / |F_\pi|^2[\tau]$
s (GeV^2)

2π contribution to a_μ^{hadr}

- We have evaluated the dispersion integral for 2π channel in the energy range $0.35 < s_{\pi\pi} < 0.95$ GeV^2

$$a_\mu^{\pi\pi} = \frac{1}{4\pi^3} \int_{0.35\text{GeV}^2}^{0.95\text{GeV}^2} ds\, \sigma(e^+e^- \to \pi^+\pi^-)\, K(s)$$

$a_\mu^{\pi\pi} = (388.7 \pm 0.8_{stat} \pm 3.5_{syst} \pm 3.5_{theo})\ 10^{-10}$



s_π [GeV^2]

- Comparison with CMD-2 in the energy range $0.37 < s_{\pi\pi} < 0.97$ GeV^2

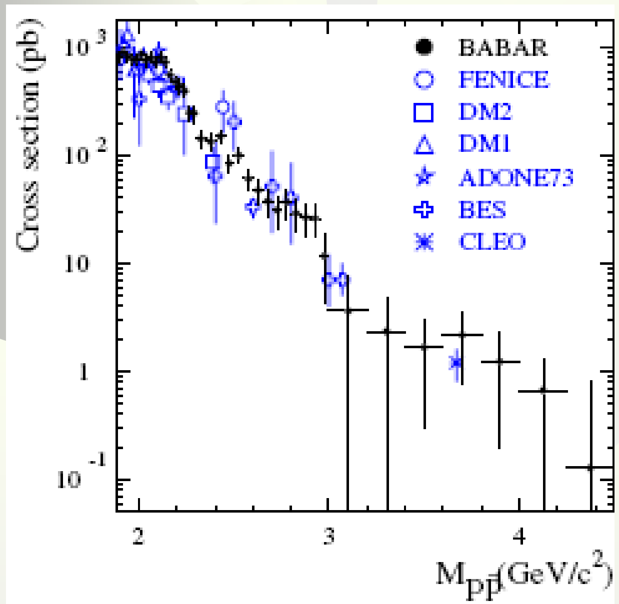
KLOE	$(375.6 \pm 0.8_{stat} \pm 4.8_{syst+theo})$	**1.3% Error**
CMD-2	$(378.6 \pm 2.7_{stat} \pm 2.3_{syst+theo})$	**0.9% Error**

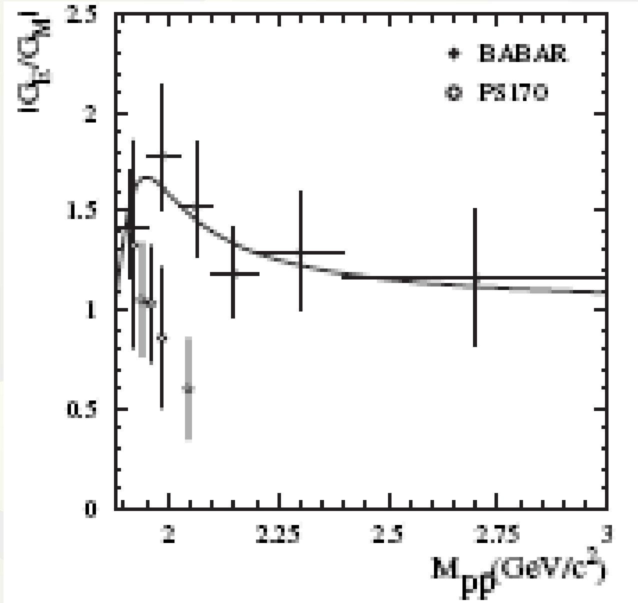
At large values of s_π ($>m_\rho^2$) KLOE is consistent with CMD-2 and the deviation from τ-data is confirmed.

BaBar

$$e^+e^- \to p\bar{p}$$

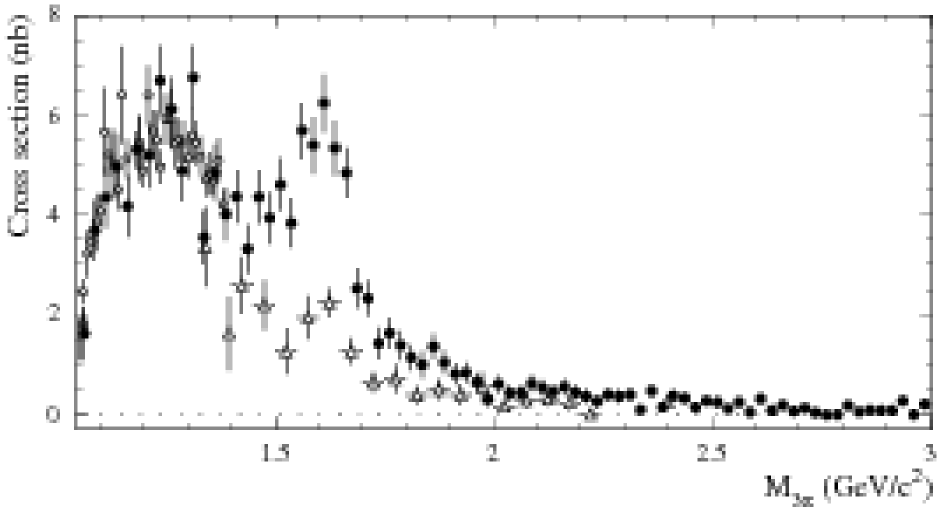
$$\sigma_{p\bar{p}}(m) = \frac{4\pi\alpha^2\beta C}{3m^2}\left[\,|G_M(m)|^2 + \frac{2m_p^2}{m^2}|G_E(m)|^2\,\right]$$

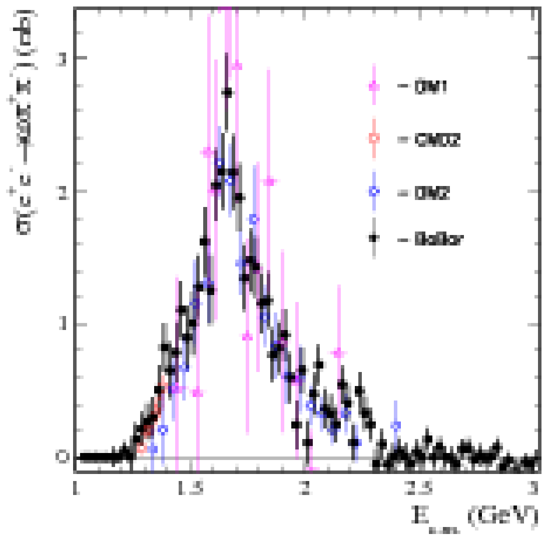




- **Phys.Rev. D73, 012005 (2006):** $e^+e^- \to pp$

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



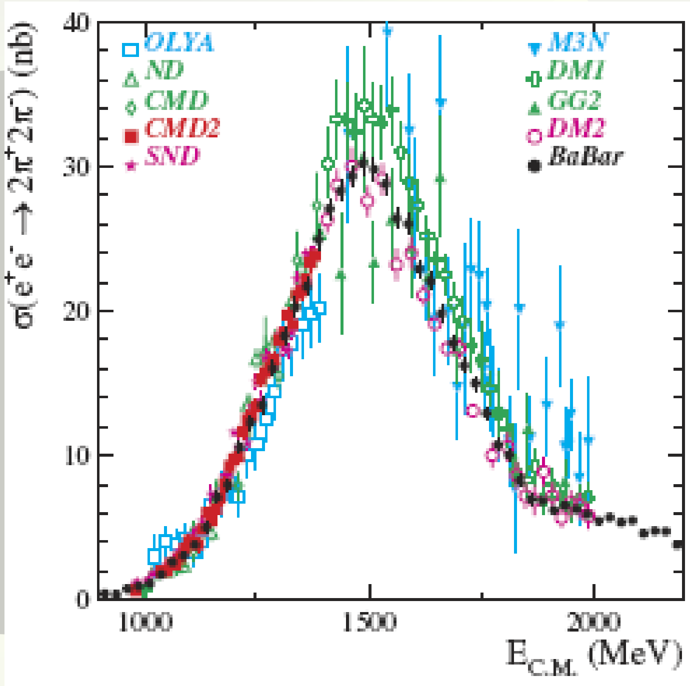


$\pi^+\pi^-\pi^0$: BaBar and SND agree. BaBar's points much higher than at DM2

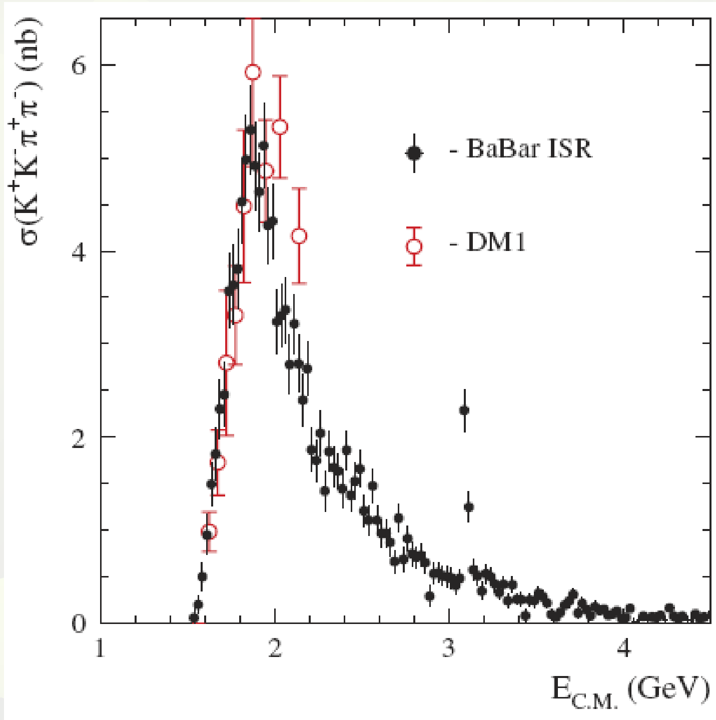
Two ω' observed in $\pi^+\pi^-\pi^0(\rho\pi)$ and $2(\pi^+\pi^-)\pi^0(\omega\pi^+\pi^-)$

BaBar

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

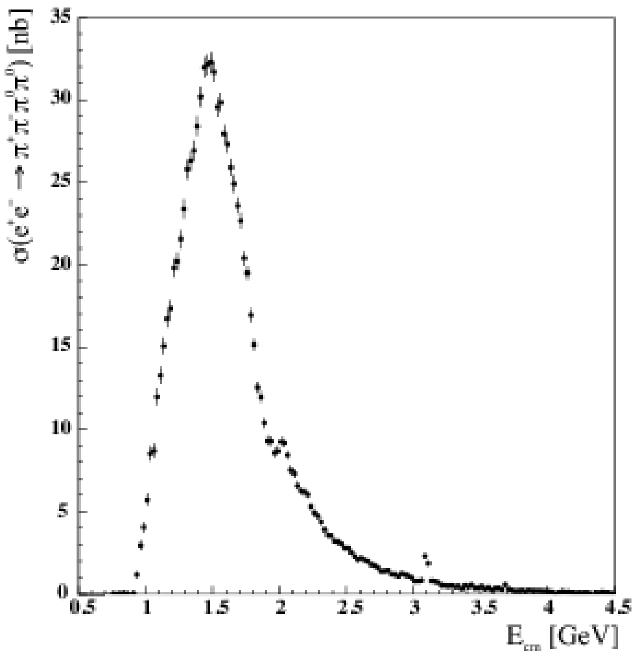


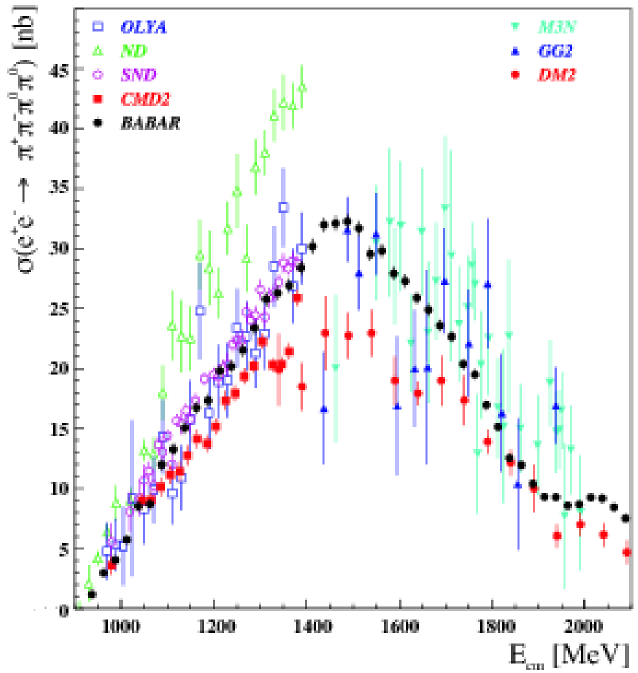
$e^+e^- \to K^+K^-\pi^+\pi^-$



BaBar

$\pi^+\pi^-2\pi^0$ Mode



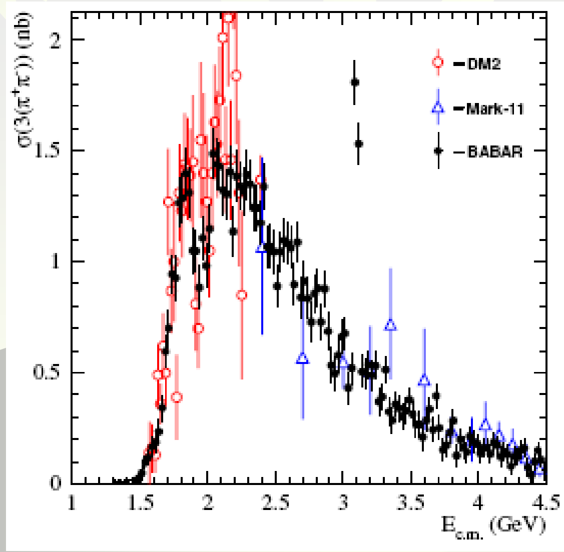


One broad state seen!

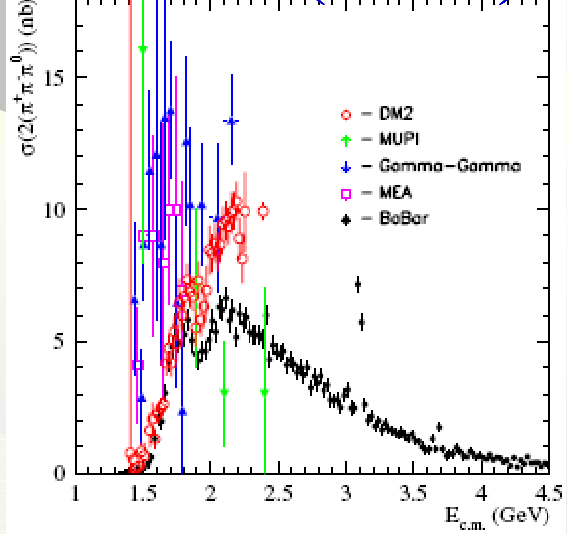
Separation of different channels needed

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

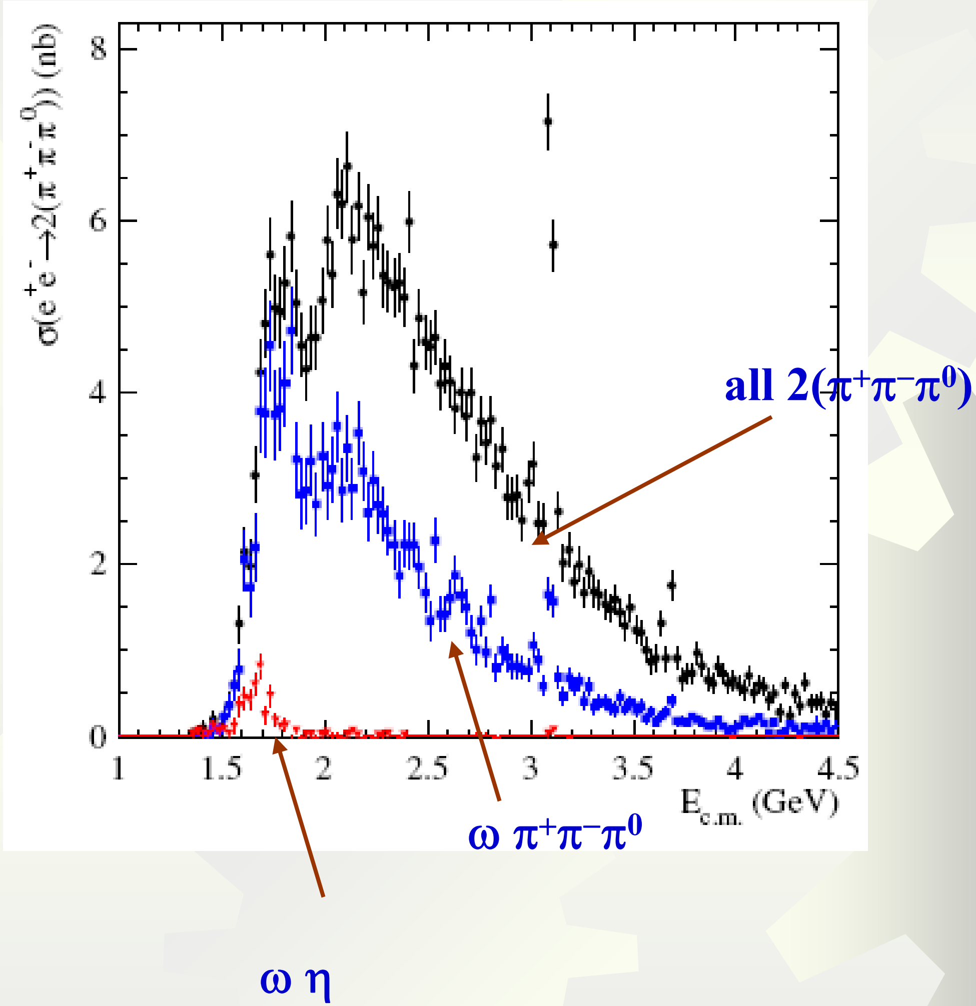
BaBar



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



$e^+e^- \to 6\pi$

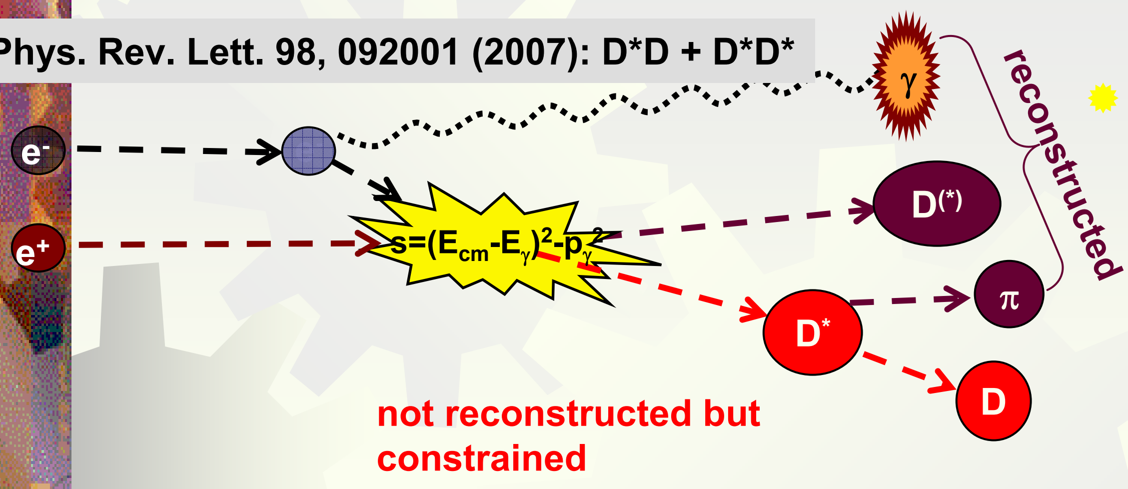


By now Belle obtained new results on charmonium production using ISR events with/without hard photon detection.

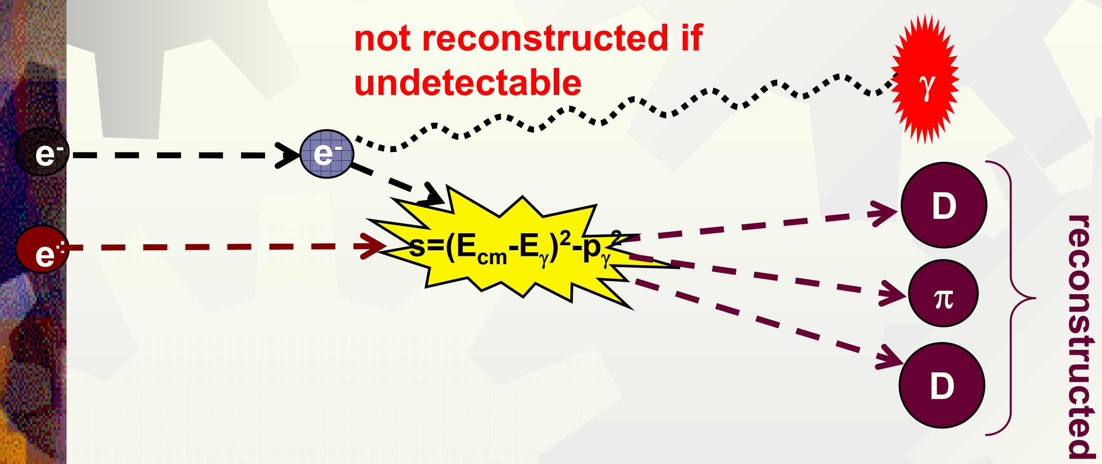
Still not much done on exclusive ISR processes.

$e^+e^- \to D^{(*)}D^{(*)}(\pi)$ at $\sqrt{s} \sim 4–5$ GeV via ISR

Phys. Rev. Lett. 98, 092001 (2007): D*D + D*D*



Phys. Rev. D77, 011103 (2008): DD
arXiv:0708.3313 : DDπ

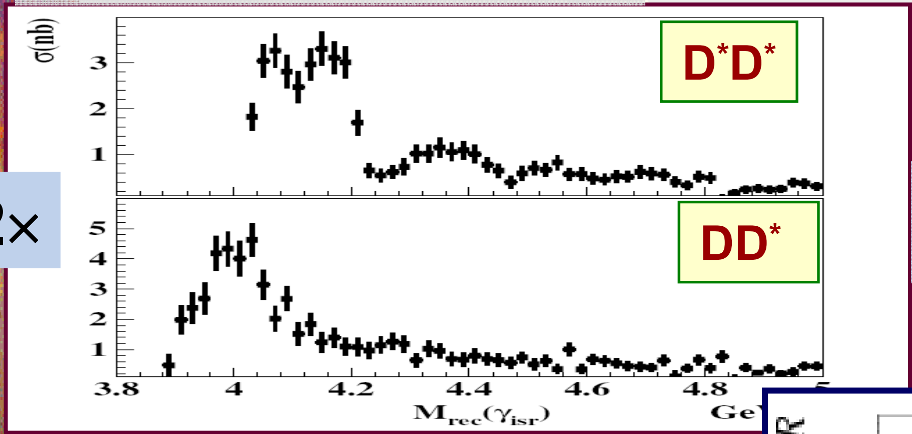


- Different reconstruction methods used for different hadronic final states:
  - DD^* & D^*D^* – partial reconstruction of D* + detection of ISR photon (if ISR photon is outside the acceptance, D^*'s have tiny reconstruction efficiency)
  - DD & $D^0 D^- \pi^+$ – full reconstruction of hadronic part; ISR photon detection is not required (but used if in the detector acceptance)

Decomposition of inclusive cross-section

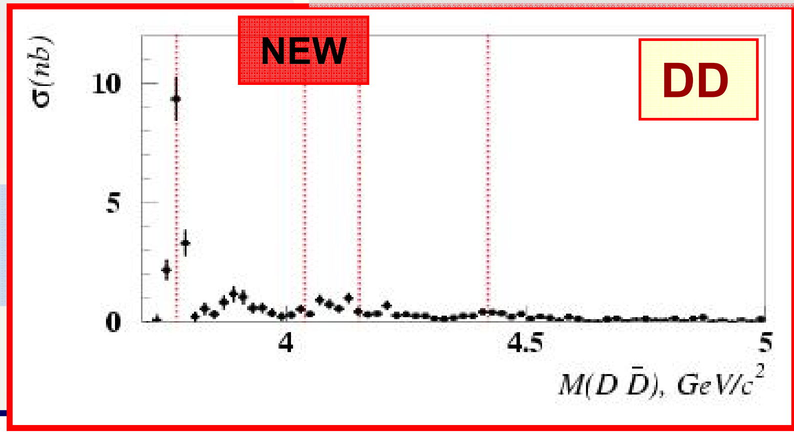
Phys. Rev. Lett. 98, 092001 (2007)

2×



+

Phys. Rev. D77, 011103 (2008)



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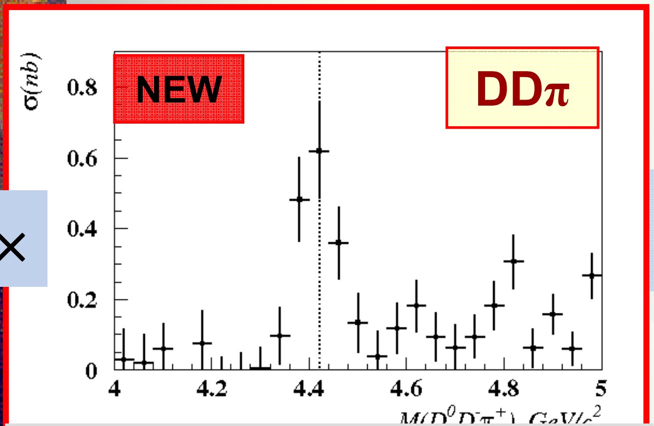
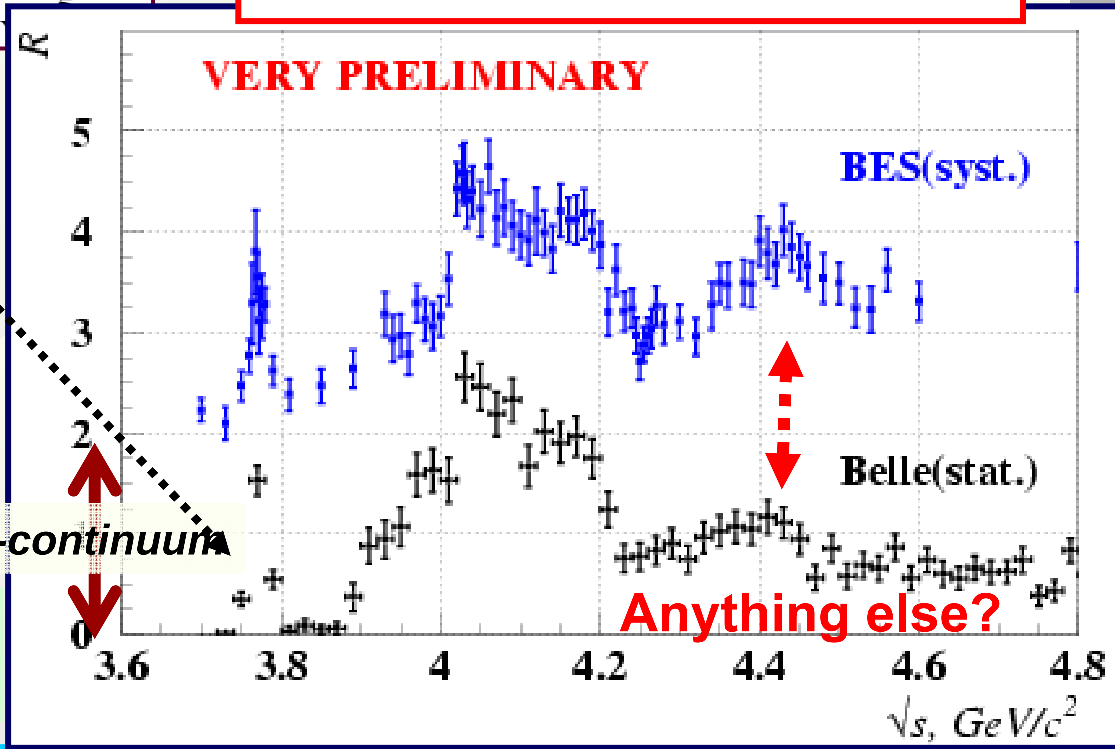
2×



arXiv:0708.3313, accepted by PRL

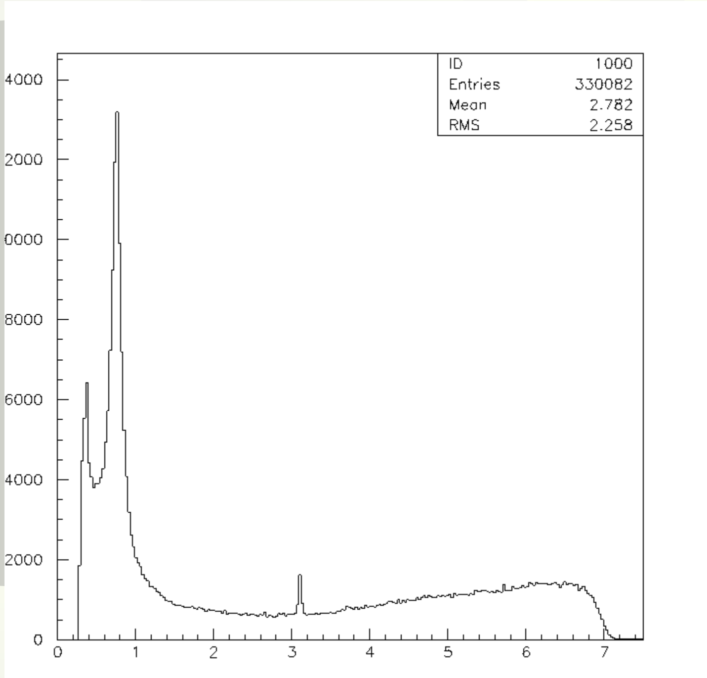
=



These 4 final states almost saturate inclusive cross section

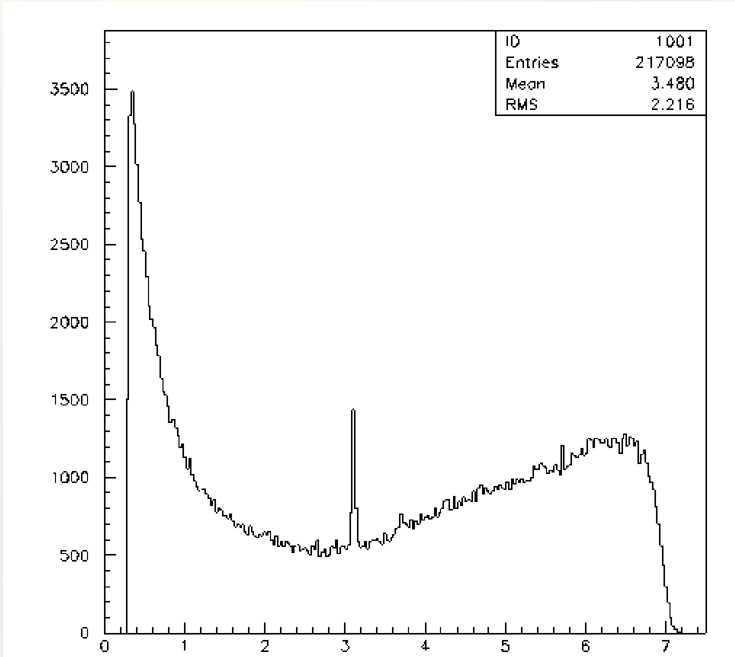
Two particle events – exclusive approach

All events



M_{inv}(2tr), GeV

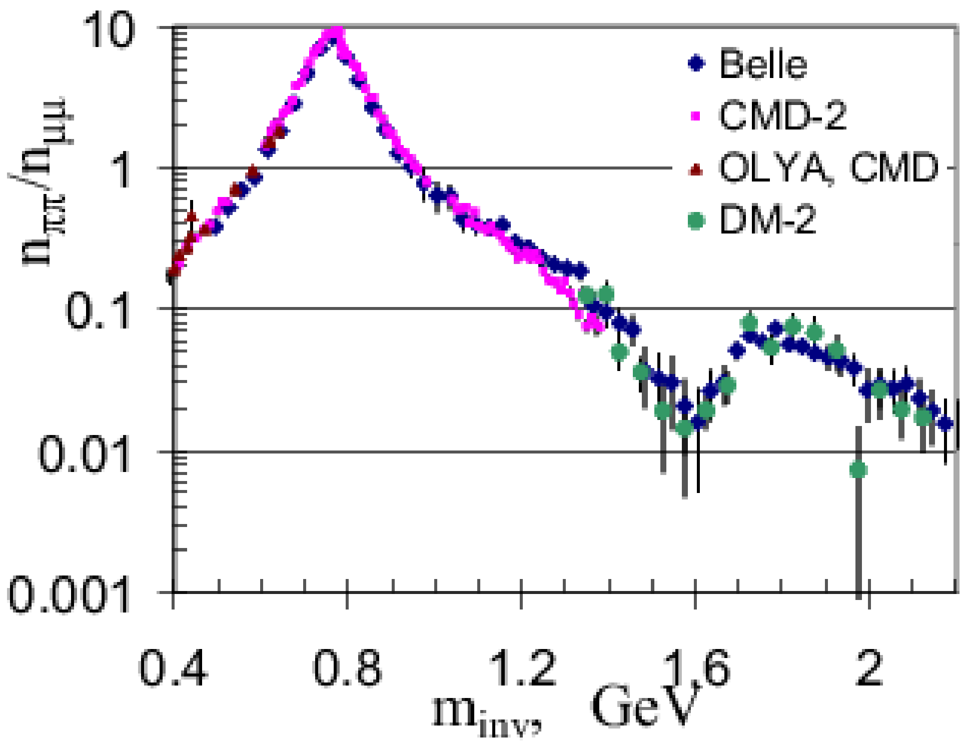
$\mu^+\mu^-$, $(L1_{\mu/\pi}, L2_{\mu/\pi} > 0.5)$

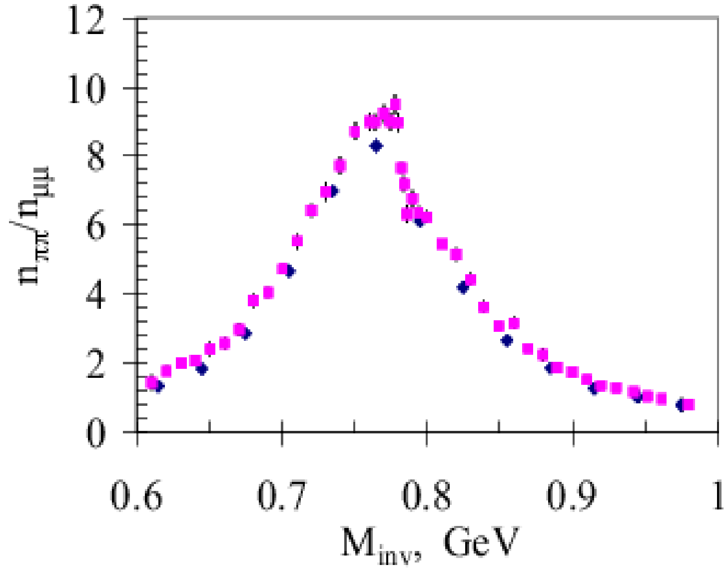


M_{inv}(2tr), GeV

$N_{\pi\pi}/N_{\mu\mu}$ ratio

By a simple separation procedure the number of $\pi\pi$ and $\mu\mu$ events are obtained and ratio is calculated (just demonstration, not for usage!)





The difference ~5% can be caused by the different trigger efficiency for pion and muon events. This is a measure of systematics.

PRL **94,** 021801 (2005) PHYSICAL REVIEW LETTERS week ending 21 JANUARY 2005

Evidence for the Decay $\Sigma^+ \rightarrow p\mu^+\mu^-$

H. K. Park,[8] R. A. Burnstein,[5] A. Chakravorty,[5] Y. C. Chen,[1] W. S. Choong,[2,7] K. Clark,[9] E. C. Dukes,[10] C. Durandet,[10] J. Felix,[4] Y. Fu,[7] G. Gidal,[7] H. R. Gustafson,[8] T. Holmstrom,[10] M. Huang,[10] C. James,[3] C. M. Jenkins,[9] T. Jones,[7] D. M. Kaplan,[5] L. M. Lederman,[5] N. Leros,[6] M. J. Longo,[8,*] F. Lopez,[8] L. C. Lu,[10] W. Luebke,[5] K. B. Luk,[2,7] K. S. Nelson,[10] J.-P. Perroud,[6] D. Rajaram,[5] H. A. Rubin,[5] J. Volk,[3] C. G. White,[5] S. L. White,[5] and P. Zyla[7]

(HyperCP Collaboration)

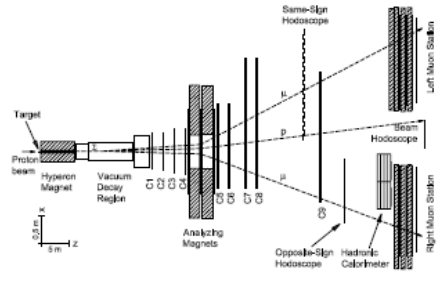
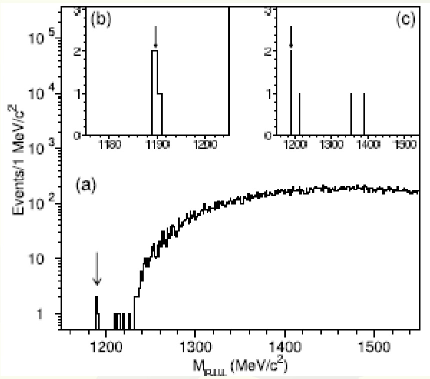
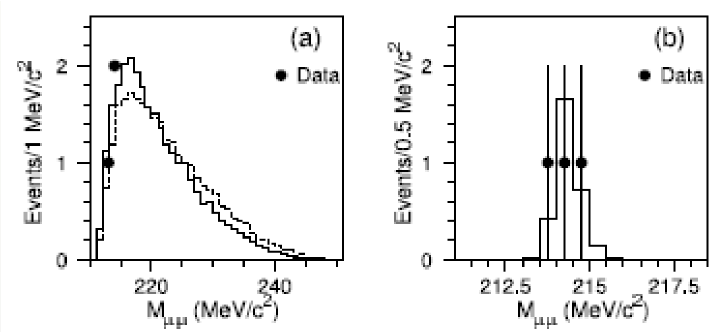


FIG. 2. Plan view of the HyperCP spectrometer.

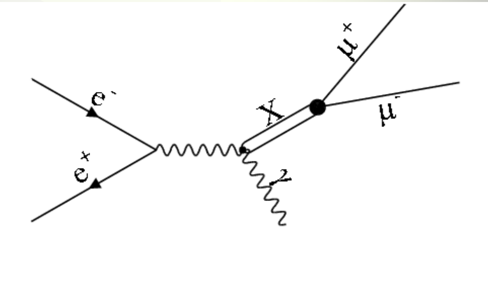




PHYSICAL REVIEW D **73,** 035002 (2006)

Sgoldstino interpretation of HyperCP events

D. S. Gorbunov* and V. A. Rubakov



Conclusion

- At the luminosity more than $10^{35} cm^{-2} s^{-1}$ the ISR approach becomes competitive to the conventional experiments at the existing and planned low energy colliders.
- The ISR is complementary to the conventional method. A measurement of some hadron cross sections by both methods should reduce systematic uncertainties.
- For CVC tests, it is important to perform both studies, tau decay and corresponding $e^- e^+ \to$ hadrons cross section at the same experimental setup.
- ISR should provide the widest and very important field of studies.