Spectroscopy of low mass resonances and R measurement with Initial State Radiation (ISR) at BaBar

Evgeny P. Solodov

The goal of the talk is to show the statistical power of ISR events produced at $\Upsilon(4S)$ for measuring hadronic processes at lower energies with present BaBar data

- **How ISR works**
- **Event selection and Data**
- **Preliminary spectra from $e^+e^- \to \mu^+\mu^-\gamma,\ \pi^+\pi^-\gamma,\ K^+K^-\gamma$**
- **Preliminary spectra from $e^+e^- \to \pi^+\pi^-\pi^0\gamma$**
- **Preliminary spectra from $e^+e^- \to 4\pi\gamma,\ N\pi\gamma$**
- **Conclusion**

How ISR works

M.Benayoun, S.I.Eidelman, V.N.Ivanchenko, Z.K.Silagadze. "Spectroscopy at B-factories using hard photon emission", Modern Phys.Lett. A. Vol.14, No.37(1999)2605-2614

V.Ivanchenko. "Spectroscopy at BaBar using hard photon emission". BaBar internal documentations

Vuko Brigljevic (LLNL). "Study of $e^+e^- \to \phi\gamma$ events. " BaBar internal documentations

X.C.Lou (UT Dallas), W.Dunwoodie (SLAC). "Production of the $\Psi(2S)$ via Initial State Radiation at the $\Upsilon(4S)$ Energy". BaBar internal documentations.

$$\frac{d\sigma(s,x)}{dx} = W(s,x) \cdot \sigma_0(s(1-x)),$$

$$W(s,x) = \frac{2\alpha}{\pi x} \cdot (2ln\frac{\sqrt{s}}{m_e} - 1) \cdot (1 - x + \frac{x^2}{2}), \quad s = 4E^2, \quad x = \frac{E_\gamma}{E}$$

For $\sqrt{s} = m_{\Upsilon(4S)}$,

$$\sigma(e^+e^- \to \Upsilon(1S)\gamma) = 0.021\ nb,$$
$$\sigma(e^+e^- \to J/\Psi\gamma) = 0.034\ nb,$$
$$\sigma(e^+e^- \to \phi\gamma) = 0.024\ nb,$$
$$\sigma(e^+e^- \to \rho\gamma) = 0.160\ nb.$$

Acceptance for detection of ISR photon (BaBar) $10 - 15\%$.

How to obtaine e^+e^- cross section from ISR final state ?

All ISR final states are 1^{--}, but in case of $e^+e^- \to \gamma\gamma^*$ virtual photon spin is not directed to its momentum

The final state invariant mass determines the virtual photon energy

$$s' = m^2_{inv} = s(1-x)$$

The e^+e^- cross section can be obtained as:

$$d\sigma_f(s') = \frac{\frac{dN_{f\gamma}}{dm^f_{inv}} \cdot \epsilon_{\mu\mu} \cdot (1+\delta^{\mu\mu}_{rad})}{\frac{dN_{\mu\mu\gamma}}{dm^{\mu\mu}_{inv}} \cdot \epsilon_f \cdot (1+\delta^f_{rad})} \cdot \sigma_{e^+e^-\to\mu+\mu-}(s')ds'$$

$\epsilon_{\mu\mu}$, ϵ_f are detection efficiencies, $1+\delta^{\mu\mu}_{rad}$, $1+\delta^f_{rad}$ are rad. corrections for final state radiation.

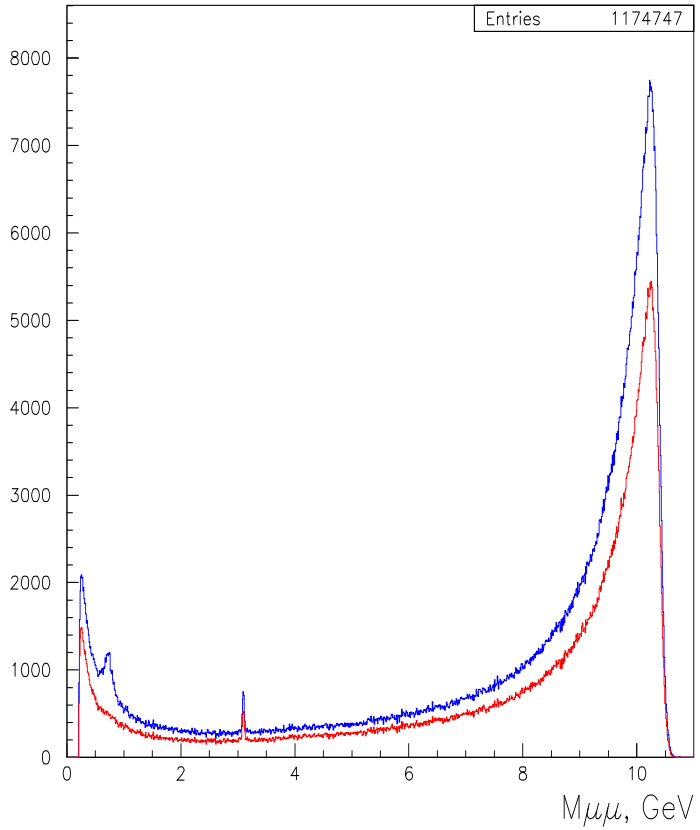
All ISR and virtual photon properties are the same for $\mu\mu$ and f and canceling in the ratio !

Primary Event Selections and data analyzed

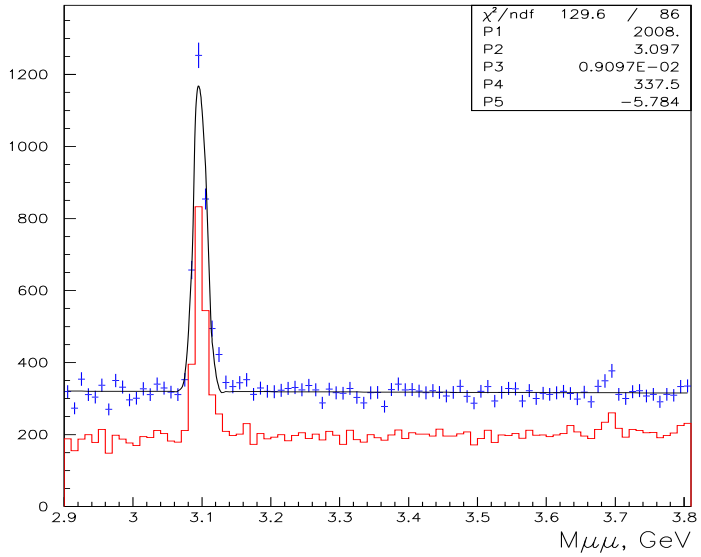
Steps are:

- **Filter skips simple events and leaves 15% of them**
- **Look for "good tracks" from interaction point**
- **Hard photon search in Pmis direction**
  - **For all charged tracks (total charge = 0) and E_γ^{ISR} >0.2 GeV**
  - **For charged tracks and photons with E_γ >0.1 GeV, assuming hardest with E_γ >1 GeV is ISR**
- **Store info about all tracks and photons with PID (100 ev/sec)**
- **22 fb^{-1} of BaBar data were looked through**

Selection of $e^+e^- \to \mu^+\mu^-\gamma$ events



Invariant mass of $\mu\mu$ (uncorrected raw data)



From PDG

$Br(J/\Psi \to \mu^+\mu^-) = 6.01 \pm 0.19\%$

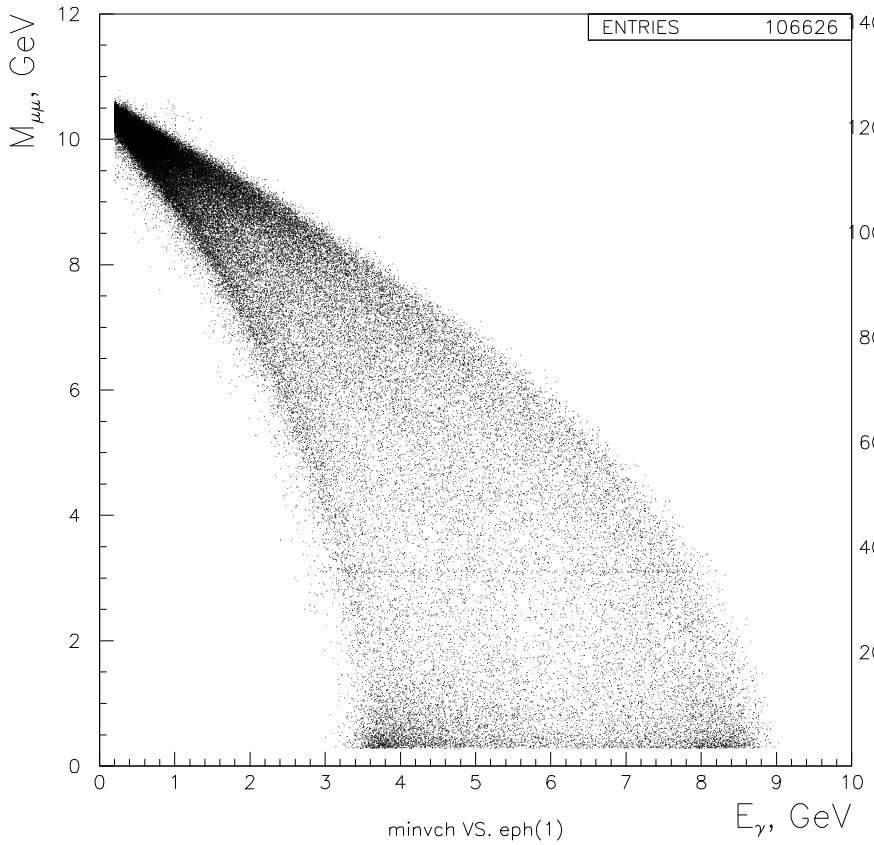
$m_{J/\Psi} = 3.09687 \pm 0.00004$

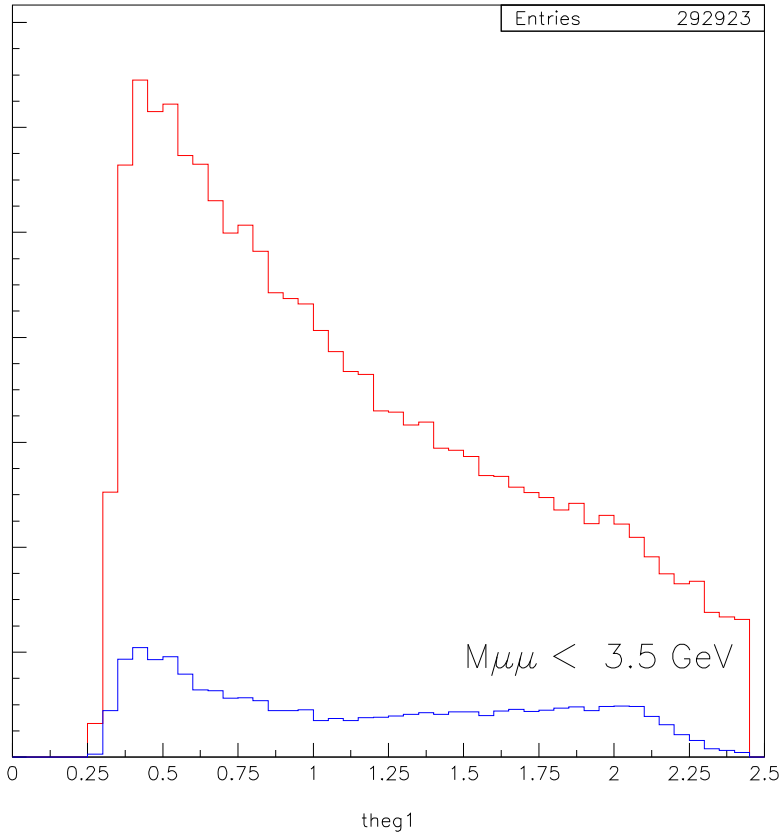
With 22 fb^{-1}

$N(J/\Psi \to \mu^+\mu^-) \approx 2000$ $(\pm 3\%(stat))$

$m_{J/\Psi} = 3.09 * * \pm 0.0004$

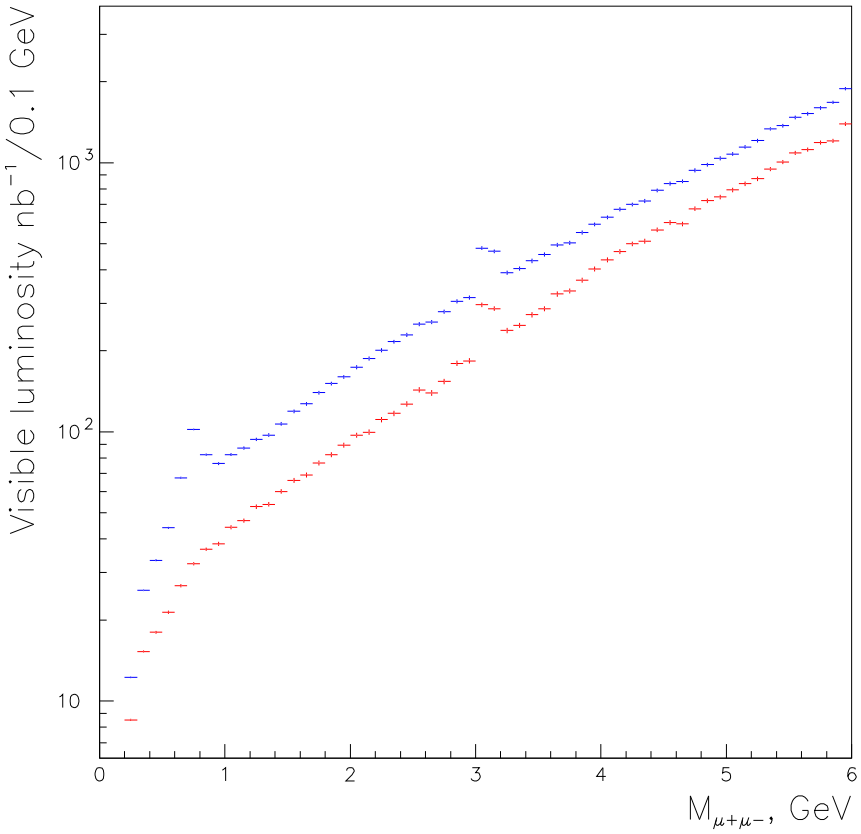
More about ISR photon ($\mu^+\mu^-\gamma$ events)





Luminosity for ISR processes by $\mu^+\mu^-\gamma$ events

$$\frac{dL}{dE_{\gamma^*}} = \frac{\frac{dN_{\mu\mu\gamma}}{dE_{\gamma^*}}}{\epsilon_{\mu\mu}\cdot(1+\delta^{\mu\mu}_{rad})\cdot\sigma_{e^+e^-\to\mu^+\mu^-}(E_{\gamma^*})}, \qquad E_{\gamma^*} = m^{\mu\mu}_{inv}$$



No corrections are applied

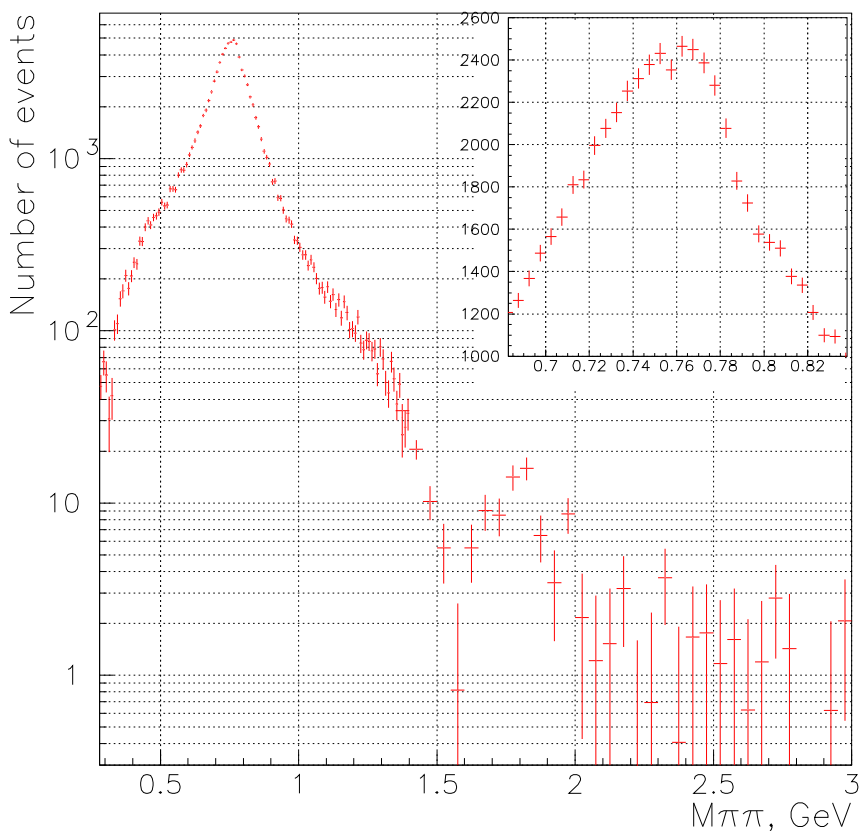
The luminosity integral in 1.5-2.5 GeV range is $\approx 2pb^{-1}$!

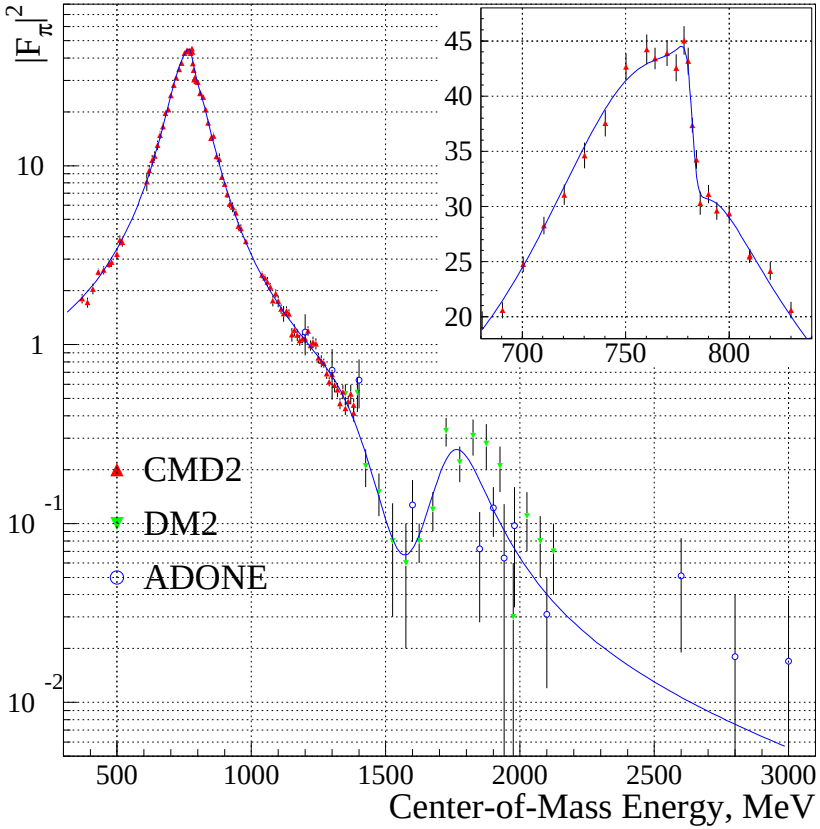
The effective BaBar luminosity in this range is $\approx 1 - 3 \cdot 10^{29} cm^2 s^{-1}$

DM2 at DCI has collected $1.6pb^{-1}$ in this range

Pion Form Factor: Can ISR compete with direct e^+e^- ?

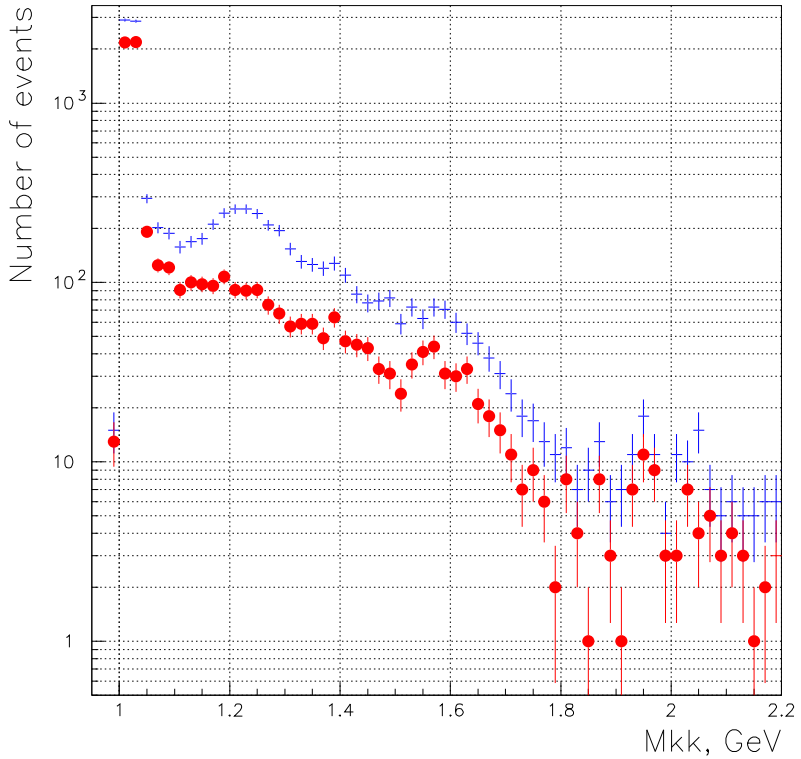
Uncorrected raw BaBar data



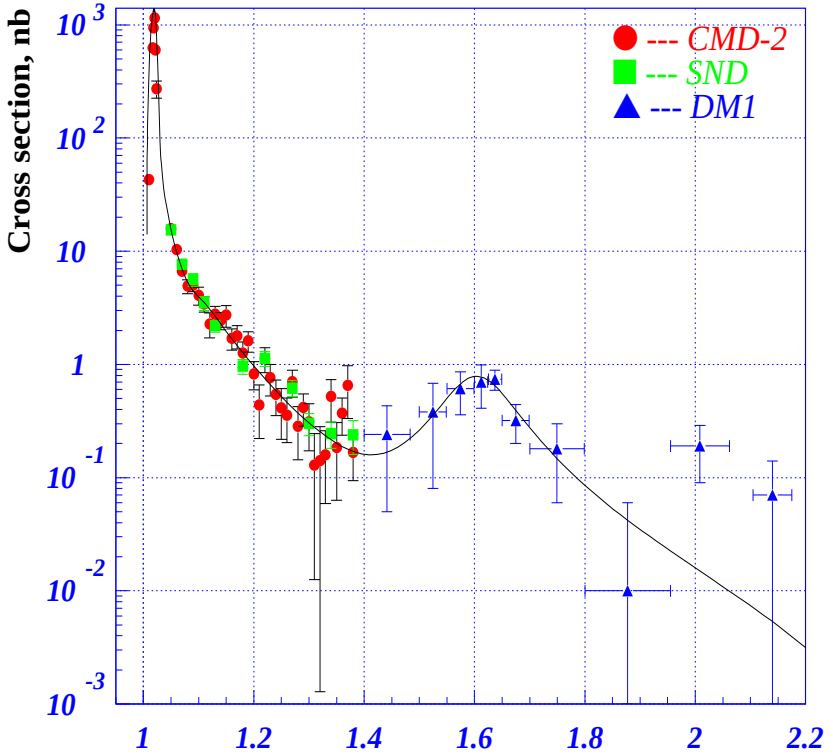


Kaon Form Factor: Can ISR compete with direct e^+e^- ?

Uncorrected raw BaBar data



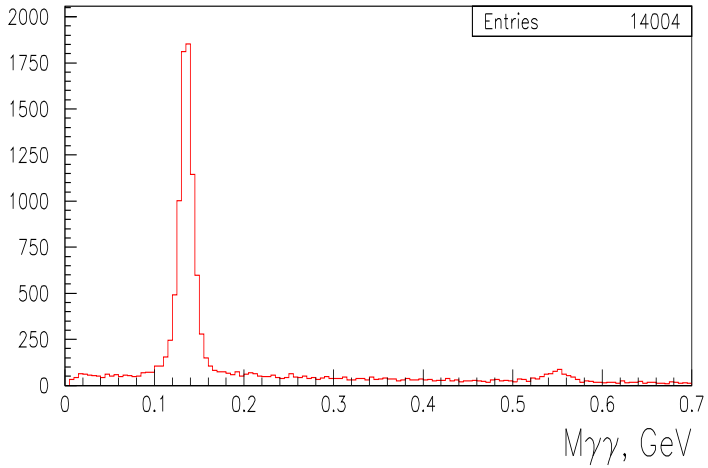
Data from $e^+e^- \to K_S K_L$



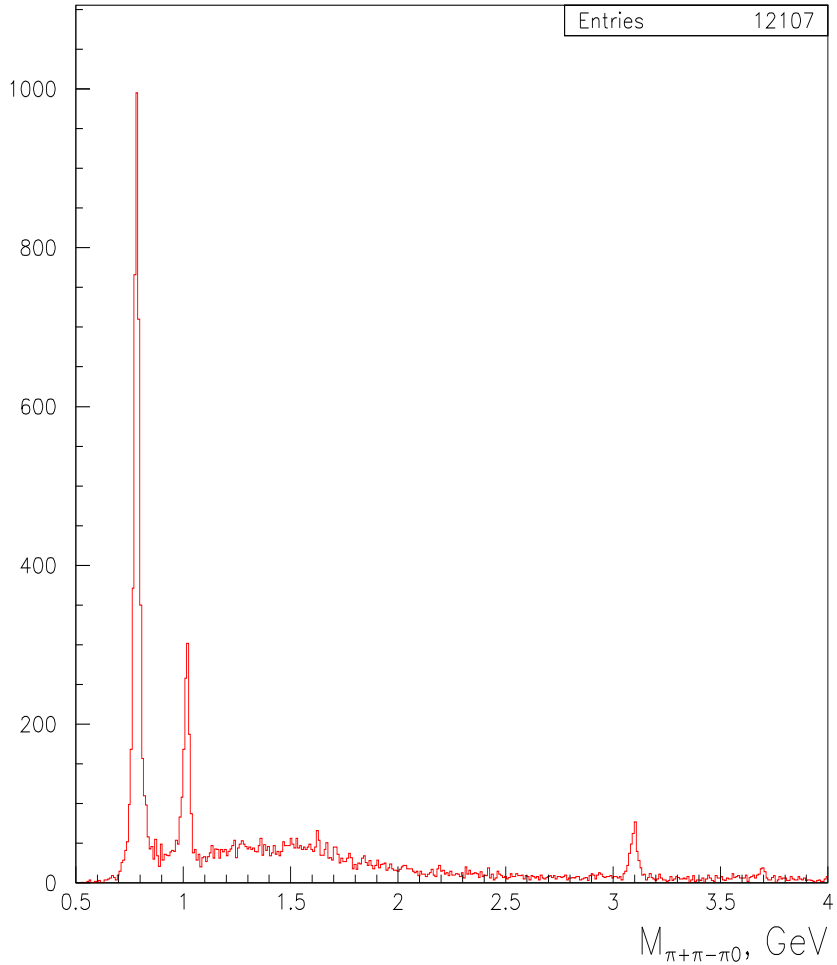
Study of the reaction $e^+e^- \to \pi^+\pi^-\pi^0\gamma$

Selections applied:

- $N_{track} = 2$
- $N_{photon} = 3, 4$
- No response from μ, K, P selectors
- π^0 selection by $|M_{\gamma\gamma} - M_{\pi^0}| < 0.05$
- η selection by $|M_{\gamma\gamma} - M_{\eta}| < 0.05$
- Background subtraction by events out of the peaks



Uncorrected raw BaBar data



Study of the reaction $e^+e^- \to \gamma K K^* \to \gamma K^+ K^- \pi^0$

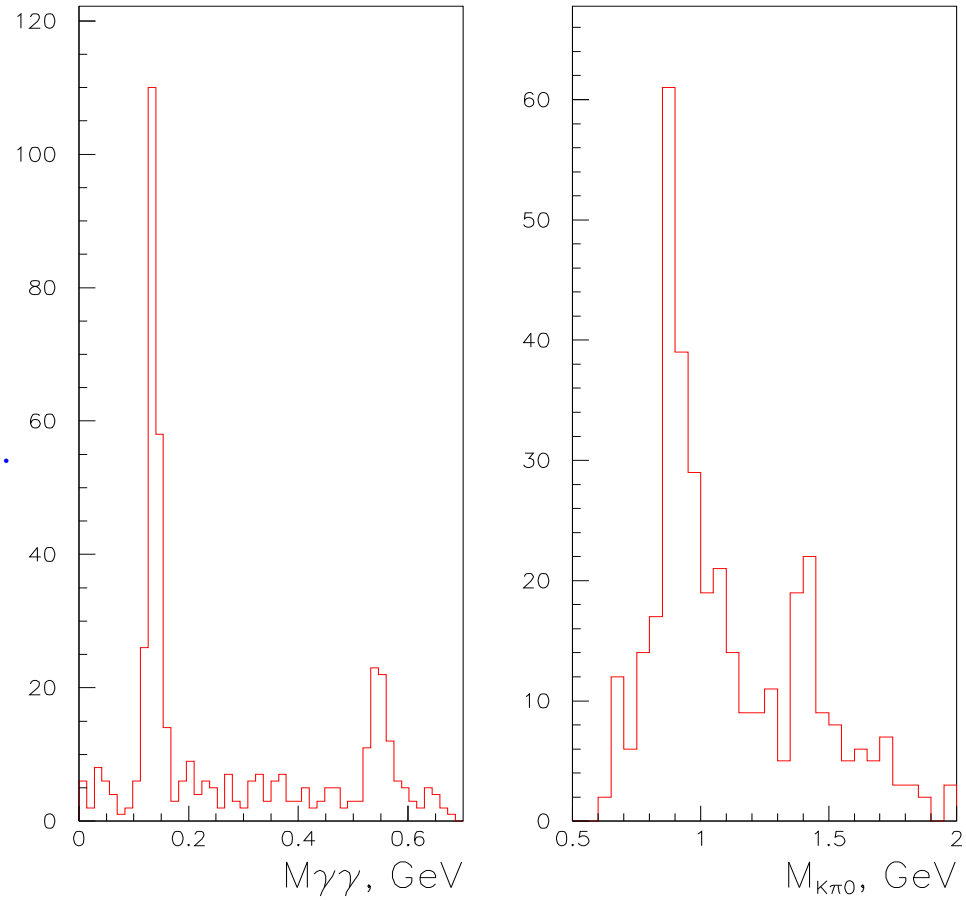
Selections applied:

- $N_{track} = 2$, $N_{photon} = 3$
- No response from μ, P selectors
- Both tracks selected as kaons
- π^0 select $|M_{\gamma\gamma} - M_{\pi^0}| < 0.045$
- η select $|M_{\gamma\gamma} - M_{\eta}| < 0.05$

$K^*(892)$,$K^*(1400)$ are seen in $K\pi^0$.
60 events of $\phi(1680)$ and
20 events from J/Ψ are also seen.

What else?

Uncorrected raw BaBar data

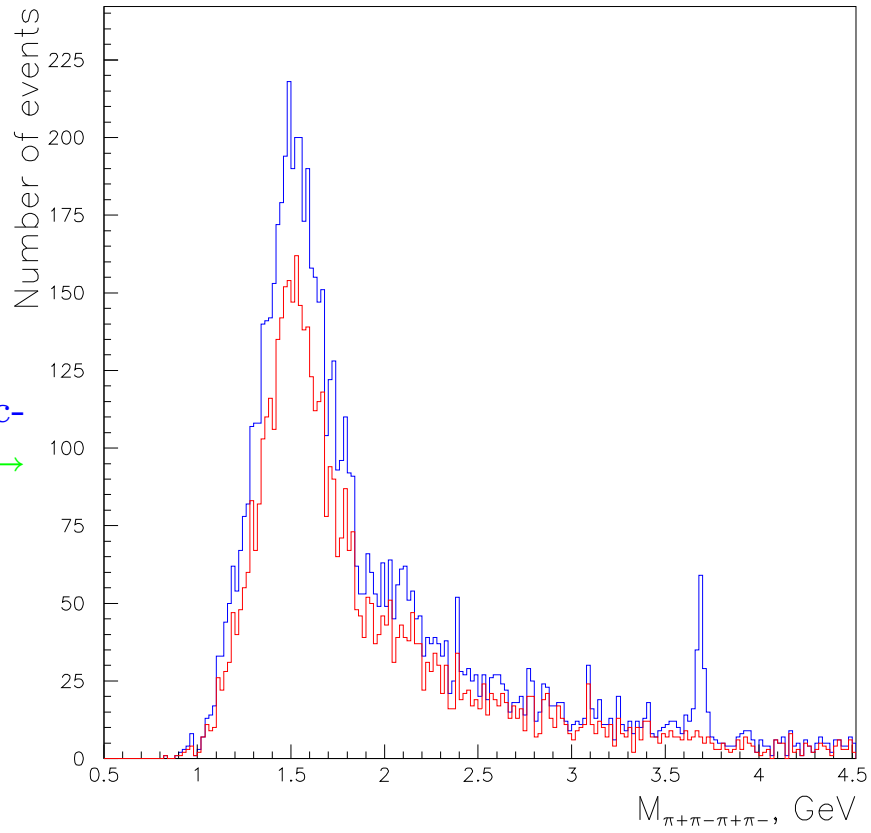


Study of the reaction $e^+e^- \to \gamma\pi^+\pi^-\pi^+\pi^-$

Uncorrected raw BaBar data

Selections applied:

- $N_{track} = 4$
- $N_{photon} = 1$
- $11.6 < E_{tot} < 13.0 GeV$
- No response from K selectors
- OR no response from μ and K selectors (eliminate peak from $\Psi(2S) \to J/\Psi(1S)\pi^+\pi^- \to \mu^+\mu^-\pi^+\pi^-$)

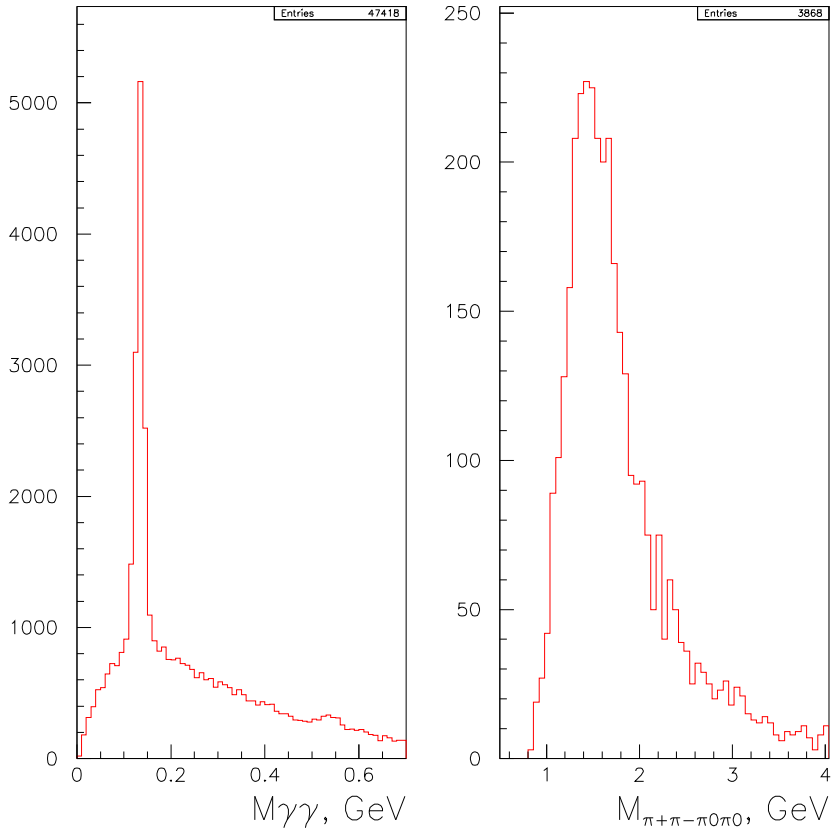


Study of the reaction $e^+e^- \to \gamma\pi^+\pi^-\pi^0\pi^0$

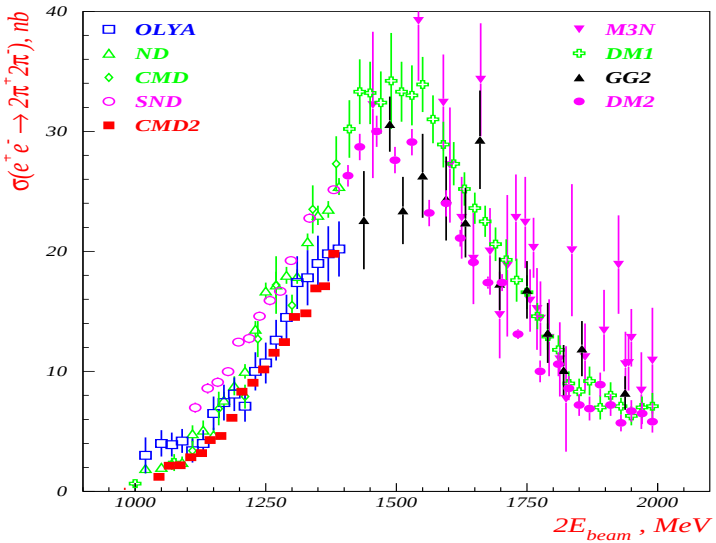
Selections applied:

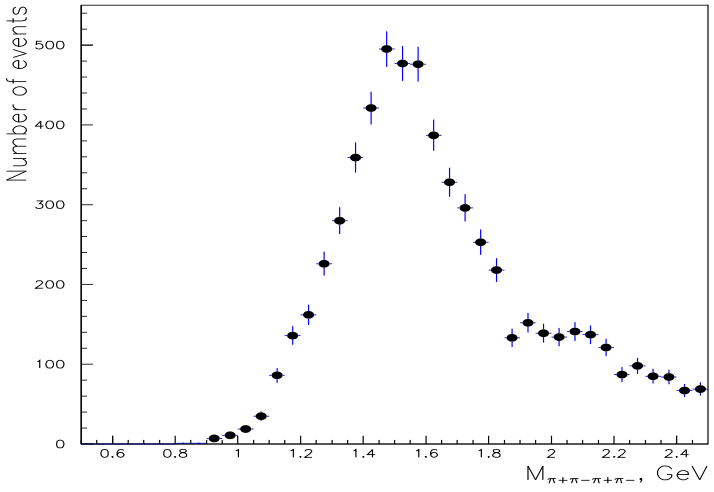
- $N_{track} = 2$
- $N_{photon} = 5$
- $11.6 < E_{tot} < 13.0 GeV$
- No response from μ, K, P selectors
- π^0 selection by $|M_{\gamma\gamma} - M_{\pi^0}| < 0.035$ in any combination

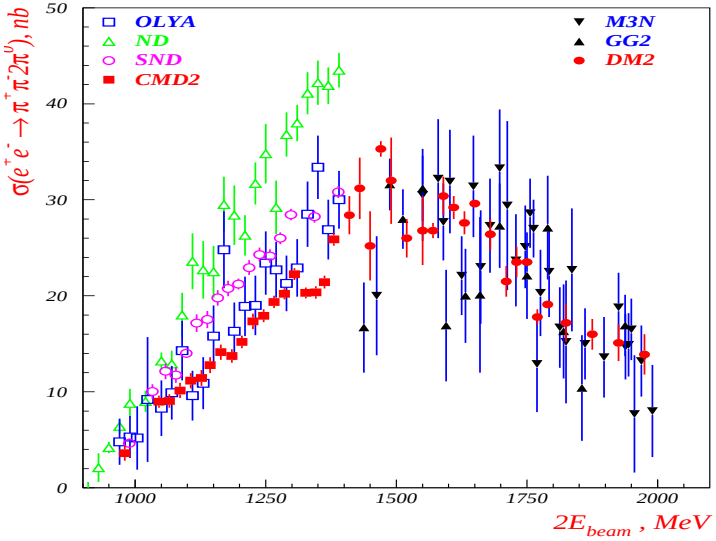
Uncorrected raw BaBar data

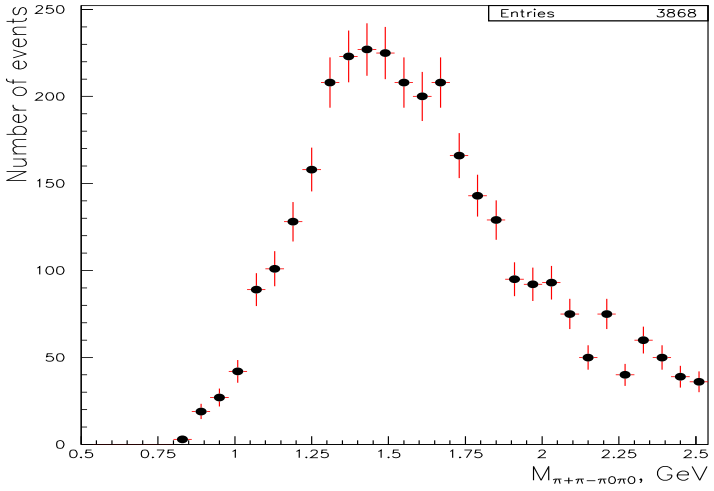


Comparison of BaBar data with $e^+e^- \to 4\pi$

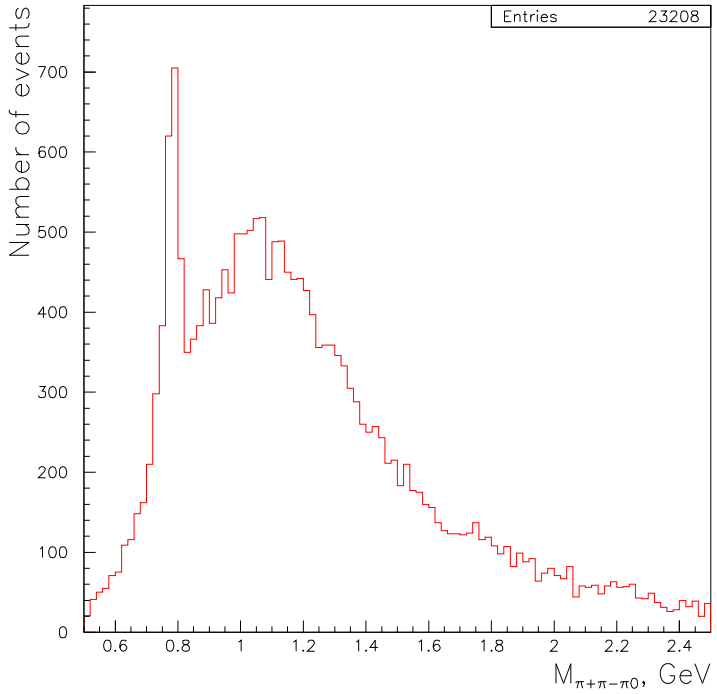


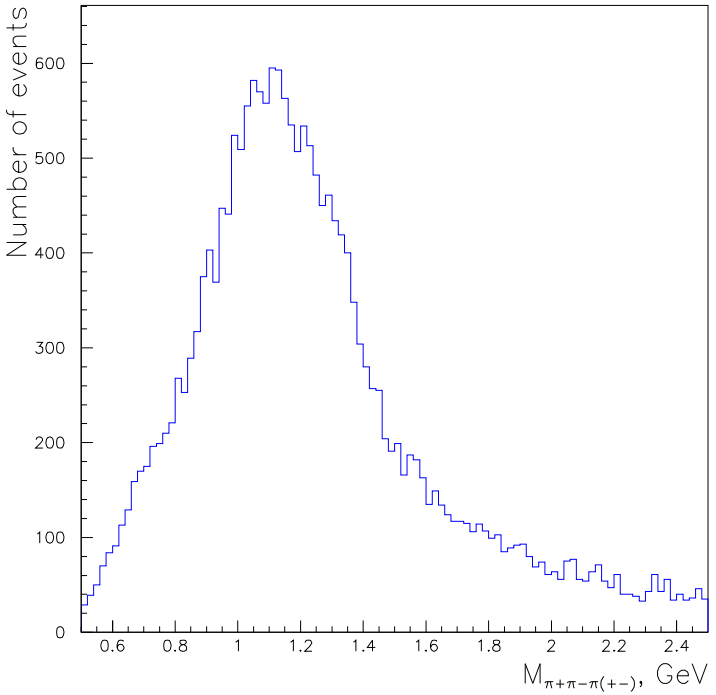






3 pion invariant mass spectra from $e^+e^- \to \gamma 4\pi$





$\omega(780)\pi$ and $a_1(1260)\pi$ states should be dominant as reported by CMD-2

Multihadron reactions from ISR events at BaBar

- Good resolutions and PID of BaBar allow to select and study multi-hadron events
- $K^+K^-\pi^+\pi^-\gamma$, $2(\pi^+\pi^-)\pi^0\gamma$, $6\pi(charged)\gamma$, $2(\pi^+\pi^-\pi^0)\gamma$ and $3(\pi^+\pi^-)\pi^0\gamma$ processes were selected with few thousands events each - EXCLUSIVLY!
- Normalization to $\mu^+\mu^-\gamma$ (acceptances are needed!) will provide cross sections for these processes in 1-5 GeV range
- Important "preview" to internal structure and meson spectroscopy can be done with present data
- Factor of 10 ! is expected in nearest 2-3 years

Conclusion

- BaBar provides good data for study ISR processes (exclusively!).
- The selection of low mass 1^{--} resonances has been demonstrated. Additional information about meson structure can be obtained.
- Available BaBar data in 1.4-3.0 GeV mass energy range are comparable with ones from DCI and ADONE machines. But study of $P\bar{P}$ (and even more $N\bar{N}$) looks difficult
- If luminosity and efficiencies can be under control with 2-3% accuracy - BaBar can provide good data for R calculation.

To Do

- To develop kinematic fits for all interesting final states
- To learn how to calculate luminosity ($\mu^+\mu^-$ acceptance, efficiency)
- To run MC (is it available for ISR?) and get efficiencies (also exclusively!)
- Study systematics...