ISR Physics at Babar

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For the Babar Collaboration

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BABAR™

OUTLINE OF THE TALK

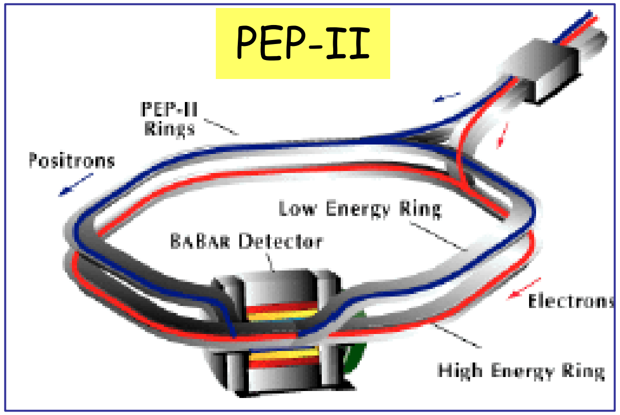
I Introduction
  1. PEP-II collider
  2. Babar detector
  3. ISR method

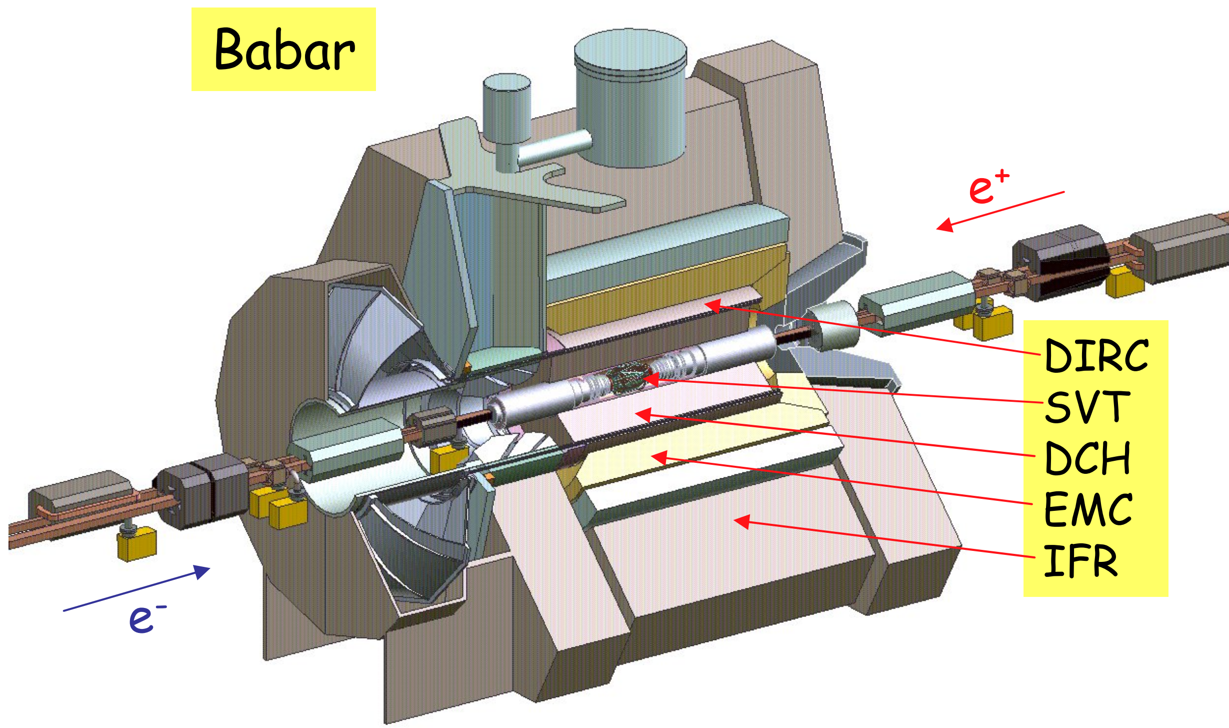
II Physical results
  1. Production of mesons
  2. Production of baryons
  3. Physics of resonances

III Perspectives, conclusions

PEP-II e+e- collider, Babar detector

$E_+ = 3.1$ GeV, $E_- = 9$ GeV

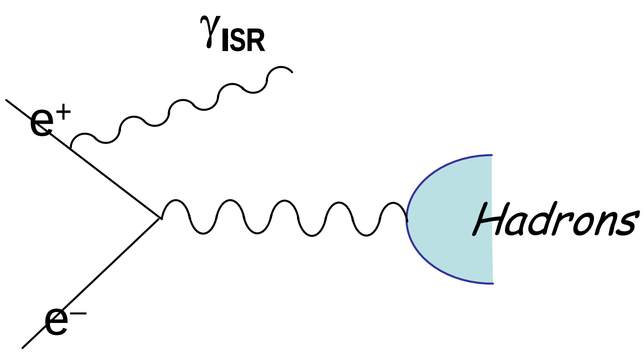




$E_{CM} = M(\Upsilon(4S)) = 10.6$ GeV
2000 - 2008 yrs
$L_{ins} = 10\ nb^{-1}/sec$
$IL = 500\ fb^{-1}$
$N(B) = 10^9$

ISR approach

ISR – Initial State Radiation or Radiative Return



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

H is radiation function

$$H(s,x,\theta) = \frac{\alpha}{\pi x}\left(\frac{2-2x+x^2}{\sin^2\theta} - \frac{x^2}{2}\right),\ x = \frac{2E_\gamma}{\sqrt{s}}$$

Mhadr < $\sqrt{s}$

$L_{ISR} \sim 0.3\%\ L_0$,
with $L_0 \sim 0.5\ ab^{-1}$ ---> $L_{ISR} \sim 1.5\ fb^{-1}$!

Advantages of ISR

1. Full energy range from $2m_\pi$ up to $\sqrt{s}$ is available
2. Detection efficiency is flat over cos(θ) and mass beginning from the threshold
3. No large radiative corrections

But:

1. Low luminosity < 1 % L_0

Advantages of e+e-

1. Good energy resolution
2. Effective study of narrow resonances

But:

1. No efficiency at small angles θ < 0.2

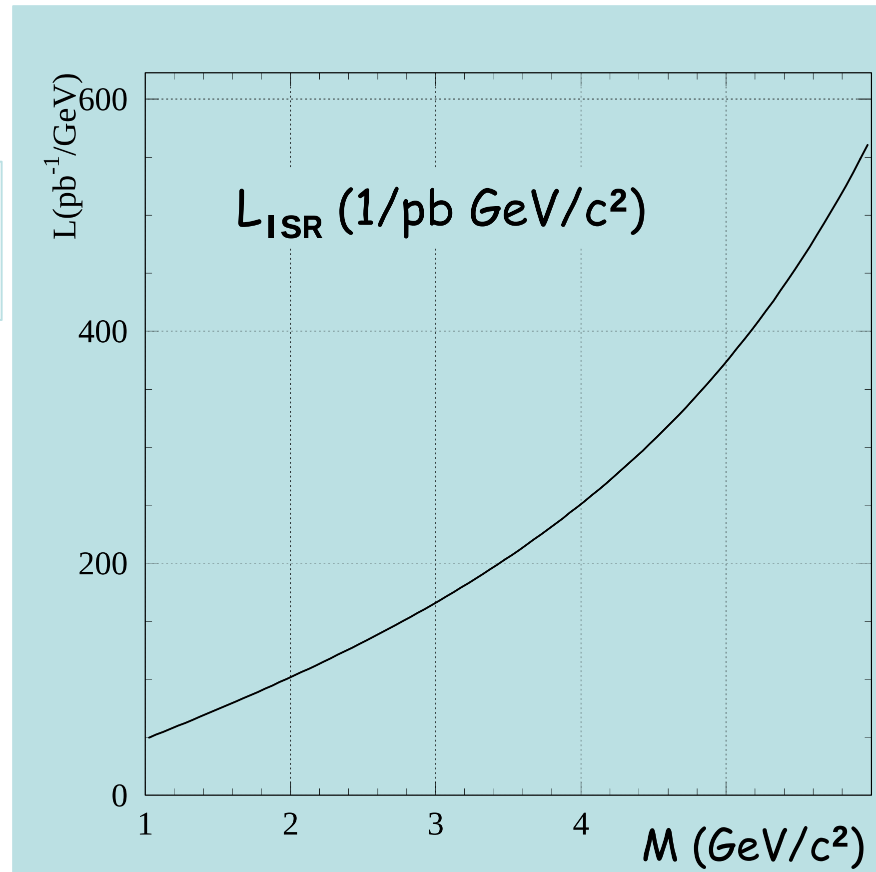
ISR luminosity, $\theta<20^0$

$$\frac{dN}{dm} = \varepsilon\ R\ \sigma\ (m)\frac{dL}{dm},$$

$$\frac{dL}{dm} = \frac{\alpha}{2\pi}((2-2x+x^2)\ln\frac{1+c}{1-c} - x^2 c)\frac{2m}{c}L_o,$$

ε – det.effic., R – rad.corr.

$$c = \cos(20^0),\ x = \frac{\omega}{E},\ L_0 = 454\ fb^{-1},$$



In mass range 4-5 GeV/c^2
IL=300 pb^{-1},
If cos(θ)=1, ΔL->1.5 fb^{-1},

Two ISR kinematics

I

With detected ISR photon:

$\theta_\gamma > \sim 15^0$ $\varepsilon \sim 0.15$

1   e+e- -> $n\pi$, nK, $n\pi n$K

2   e+e- -> baryons

List of reactions studied:

e^+e^- ->

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

K+K- $\pi+\pi-$, K+K- $\pi0\pi0$, 2K+2K- ,

K+K$-\pi0$, KSK$-\pi+$, K+K$-\eta$,

$3\pi+3\pi-$, $2\pi+2\pi-\pi0\pi0$, K+K-$2\pi+2\pi-$

$2\pi+2\pi-\pi0$, $2\pi+2\pi-\eta$,

KK $\pi+\pi-\pi0$, KK $\pi+\pi-\eta$,

$\pi+\pi-$, K+K$-$, $\pi+\pi-3\pi0$, ...

pp, $\Lambda\Lambda$, $\Lambda\Sigma^0$, $\Sigma^0\Sigma^0$,

II

ISR photon is not detected,

$\theta_\gamma < 10^0$, $\varepsilon \sim 0.8$, but M > 4 GeV/c²

1 e+e- -> D Dbar

2 e+e- -> Y(4260)

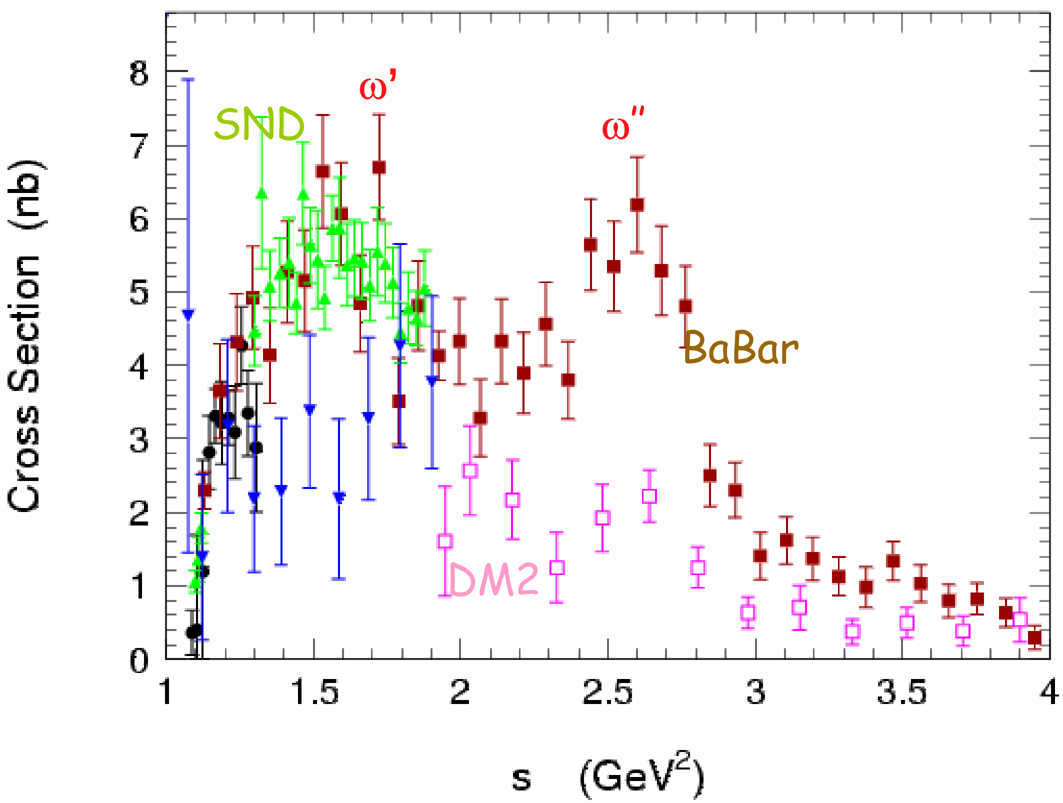
List of reactions studied:

e^+e^- ->

DD, DD*, D*D*

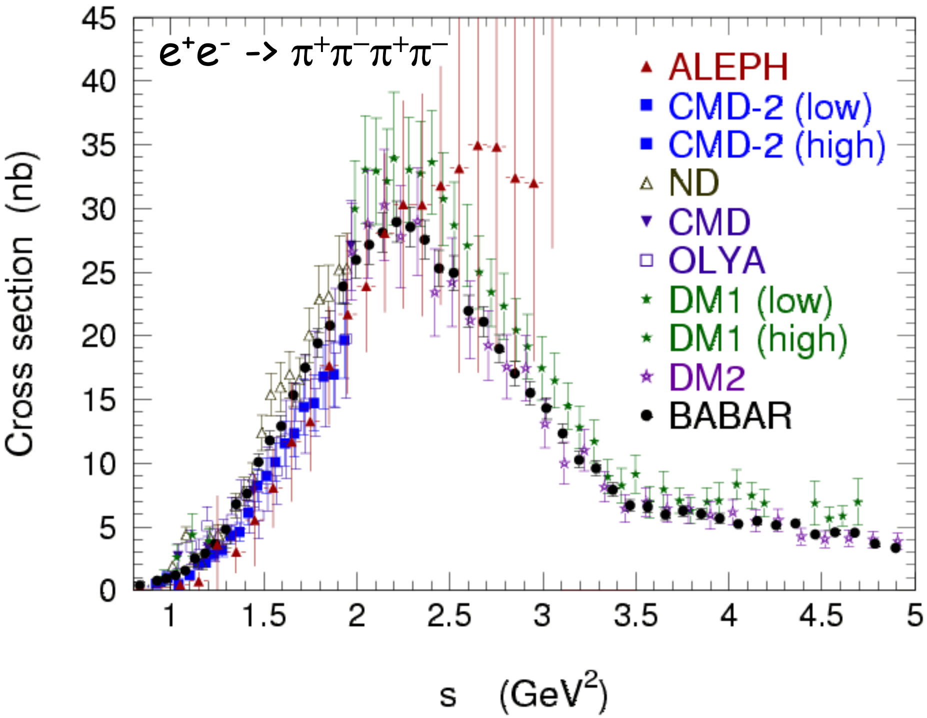
Y(4260) -> J/ψ $\pi^+\pi^-$

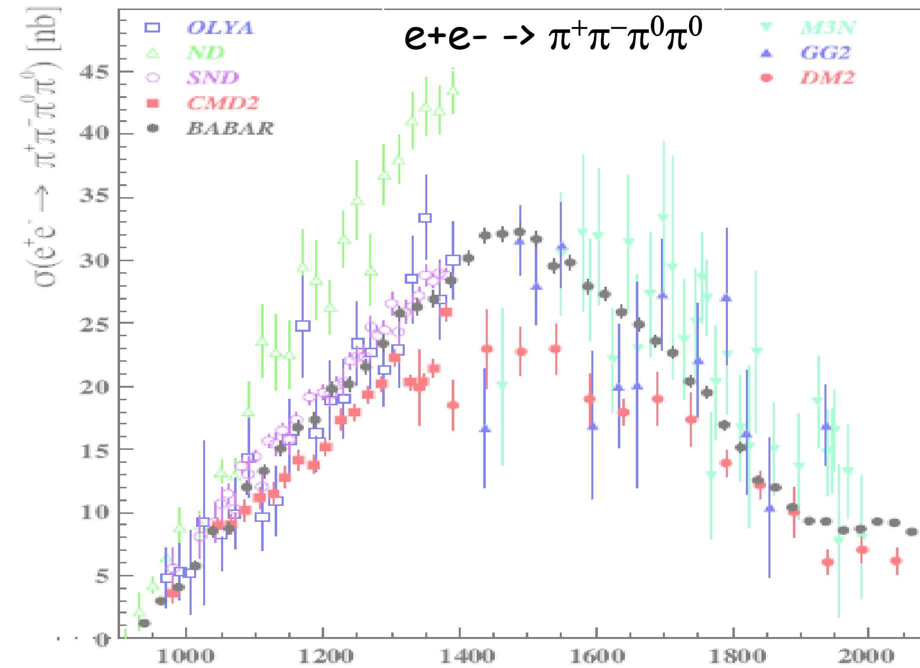
$e^+e^- \to \pi^+\pi^-\pi^0$, PRD, 70, 072004, (2004)

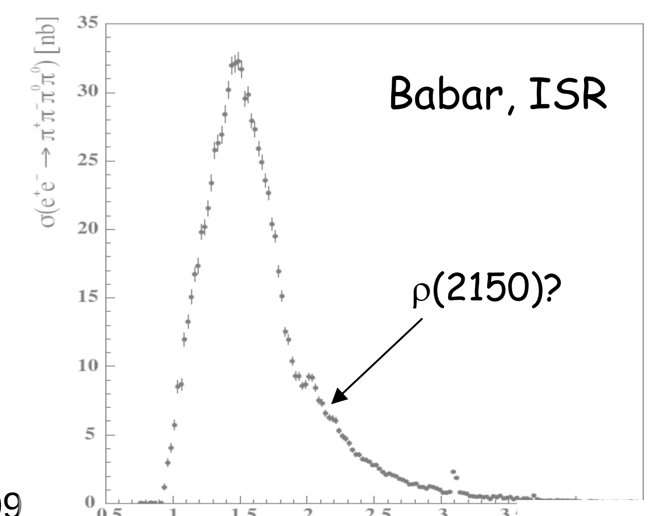


1. Huge discrepancy Babar with DM2,
2. ω'' is seen,
3. contribution into a_μ is by 40% higher

$e+e- \rightarrow 4\pi$, PRD, 71, 052001, (2005)

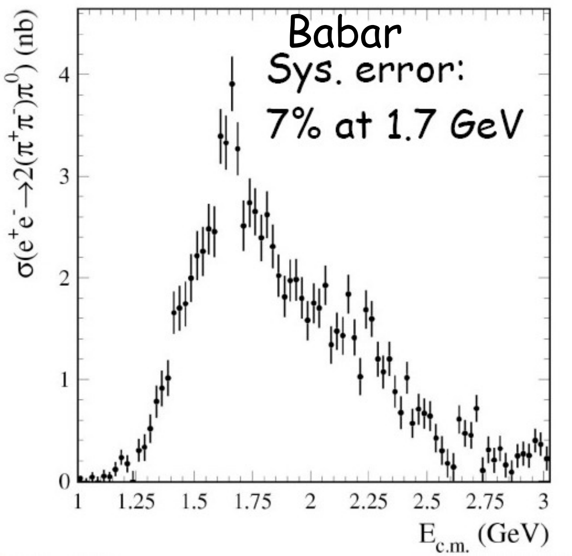


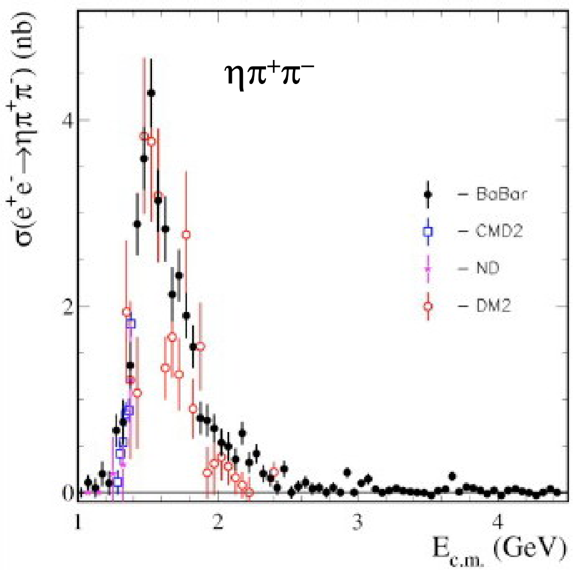


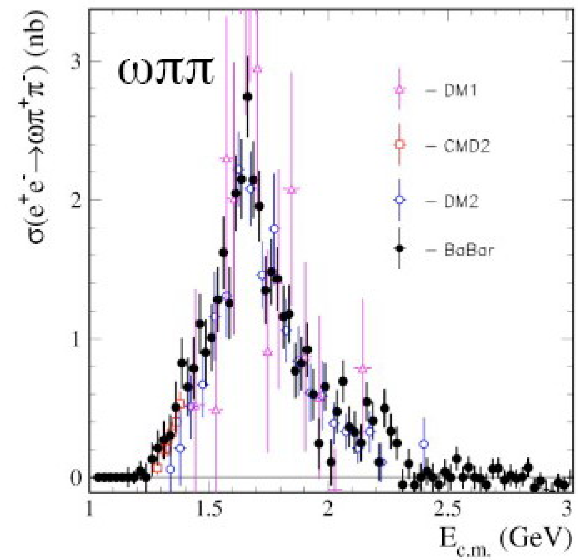


1. Greatest contribution into a_μ, α_{QED} above 1 GeV,
2. Greatest improvement above 1.4 GeV,
3. Sub-structures: $\omega\pi^0$, πa_1, $\rho^+\rho^-$, $\rho^0 f^0$

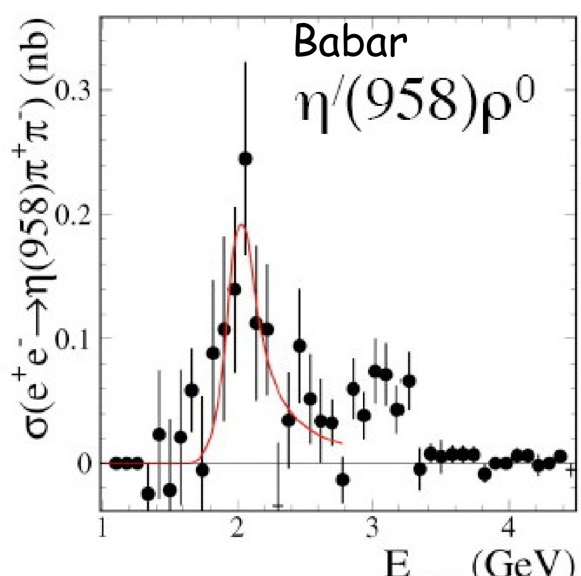
$e^+e^- \to 5\pi\ (2(\pi^+\pi^-)\pi^0)$, PRD, 76, 092005, (2007)

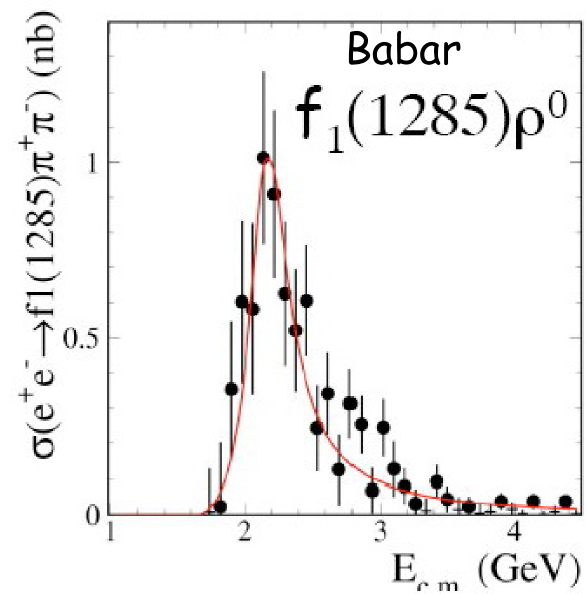




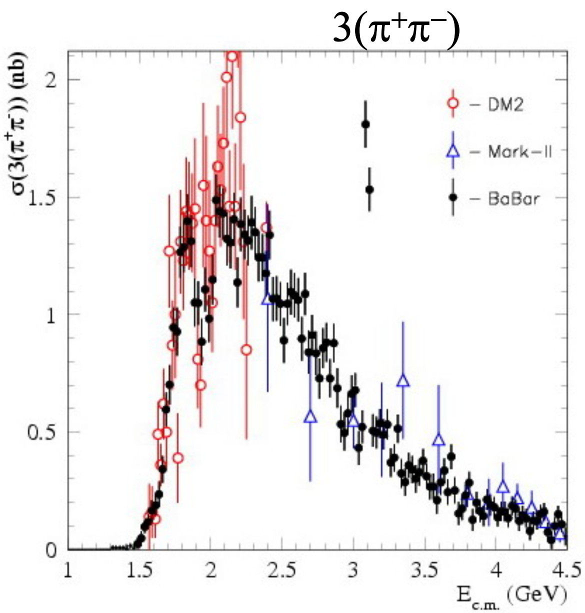


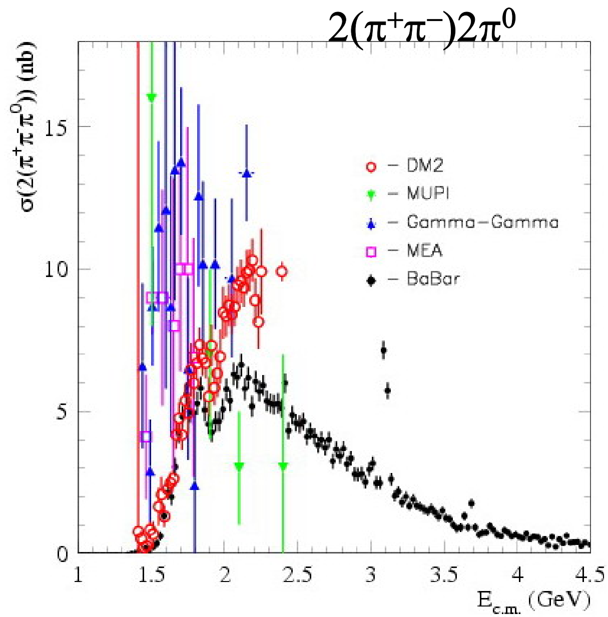
Sub-structures:
ωf^0,
$\eta^/(958)\rho^0 - \rho^{///}(2150)$?
$f_1(1285)\rho^0$

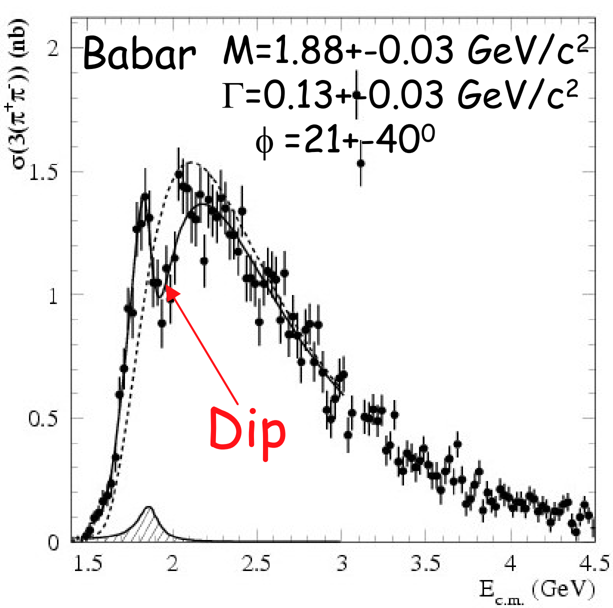


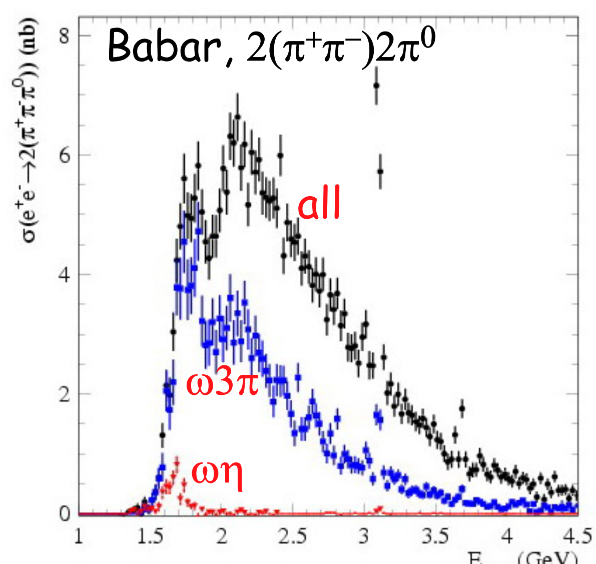


e+e- -> 6π, PRD, 73, 052003, (2006)









Sub-structures in 3(π+π-):

ρ(770) 4π

Sub-structures in 2(π+π–)2π^0:

ω(783) 3π

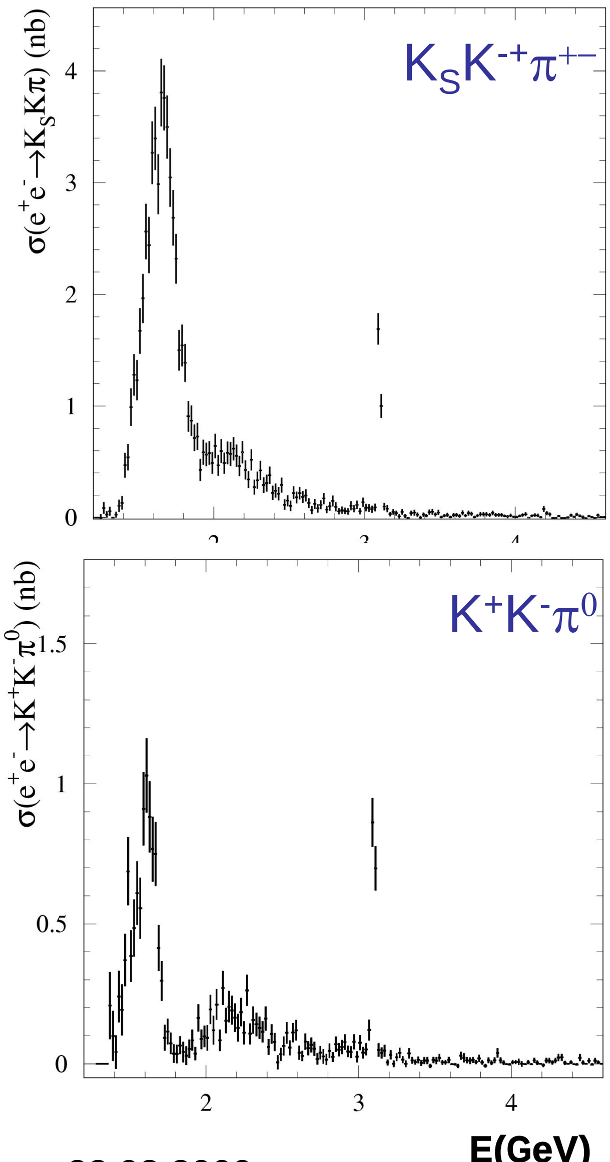
ω(783) η – $\omega^{//}$?

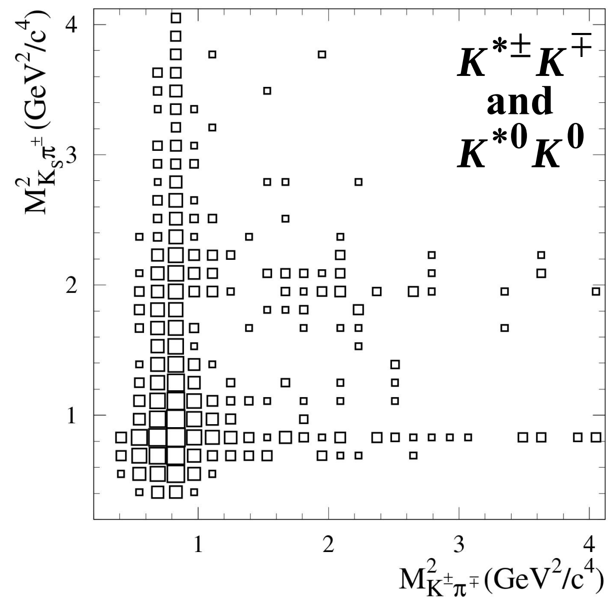
f_0(980) - $\pi^0\pi^0$

f_0(1370) - $\pi^0\pi^0$

f_2(1270) - $\pi^0\pi^0$

e+e- -> 2Kπ, ($K^+K^-\pi^0$, $K_SK^{-+}\pi^{+-}$) PRD, 77, 092002, (2008)

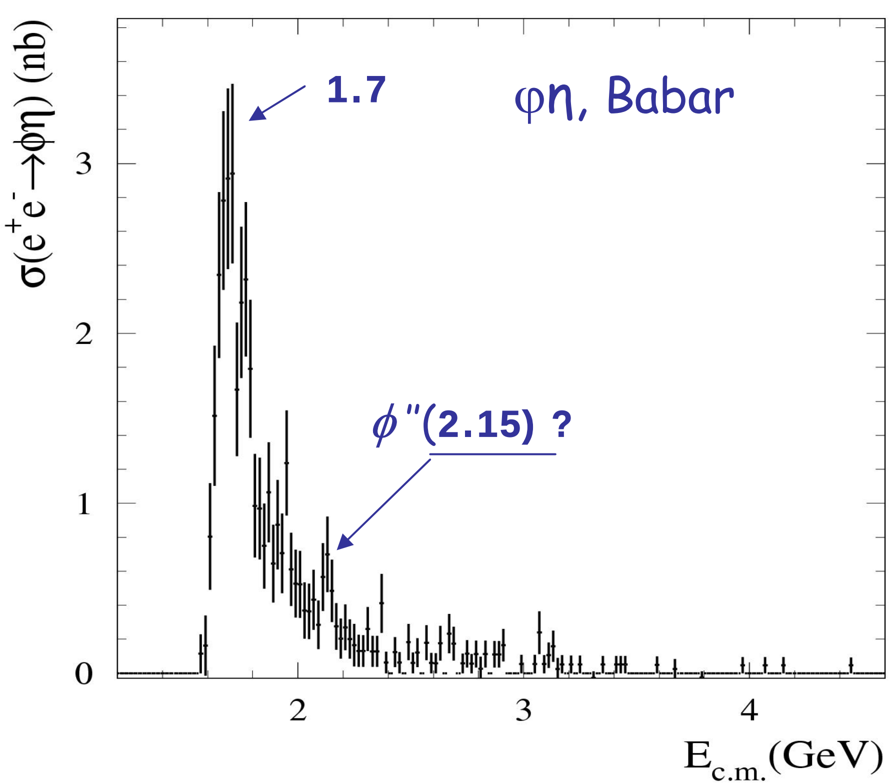


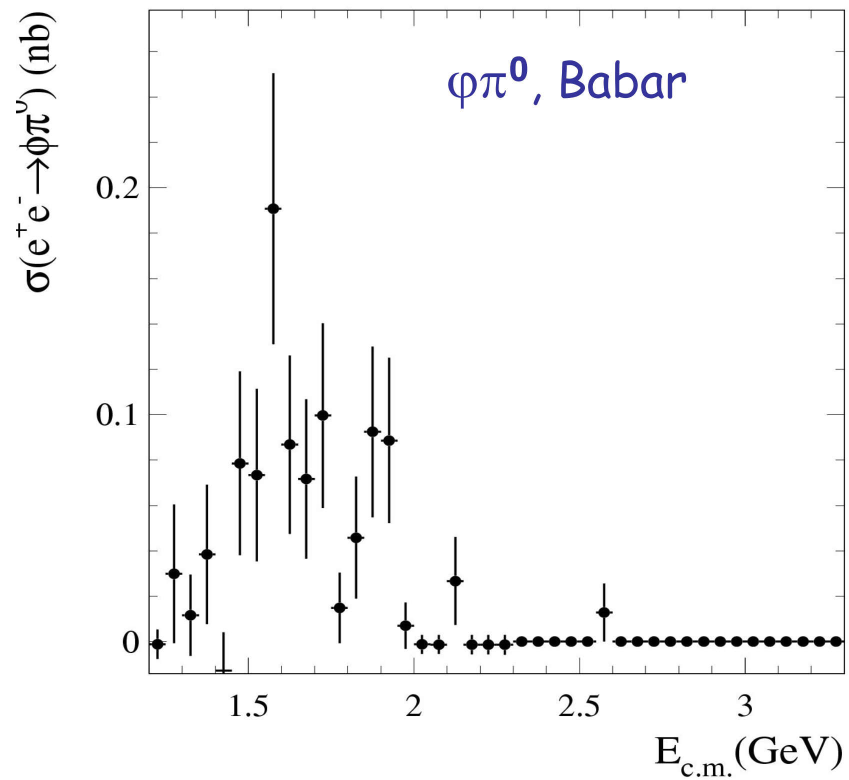


Sub-structures:
K*(980)K,
K_2*(1430)K,
$\phi\eta$,
$\phi\pi^0$,

φ(1680) parameters:	PDG
m=1723±20 MeV,	1680±20
Γ = 371±75 MeV,	150±50
Γ_{ee}= 580±60 ev,	
Bφη/BK*K~ 1/3	

e+e- -> $\varphi\eta$, $\varphi\pi^0$, PRD, 77, 092002, (2008)



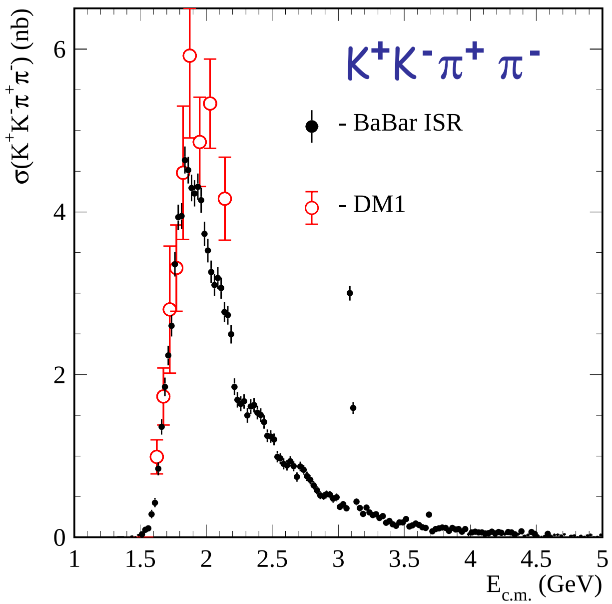


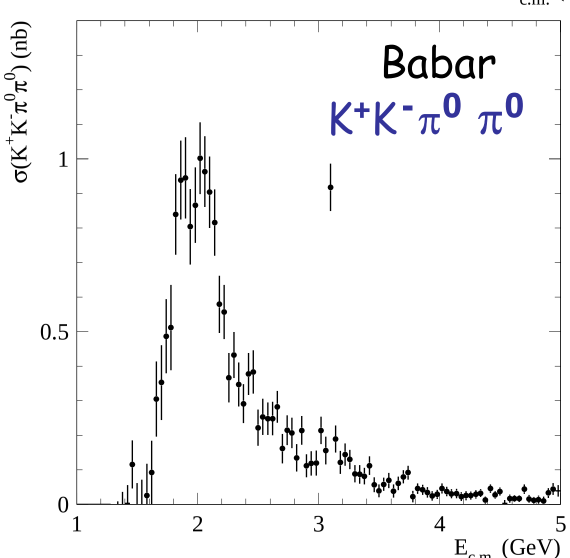
$e^+e^- \to \varphi\eta$ is good channel for study of excited φ-state. $\varphi\eta$ dominates in $KK\eta$**.**

$e^+e^- \to \varphi\pi^0$ is suitable for search of exotic isovector resonances because of OZI suppression.

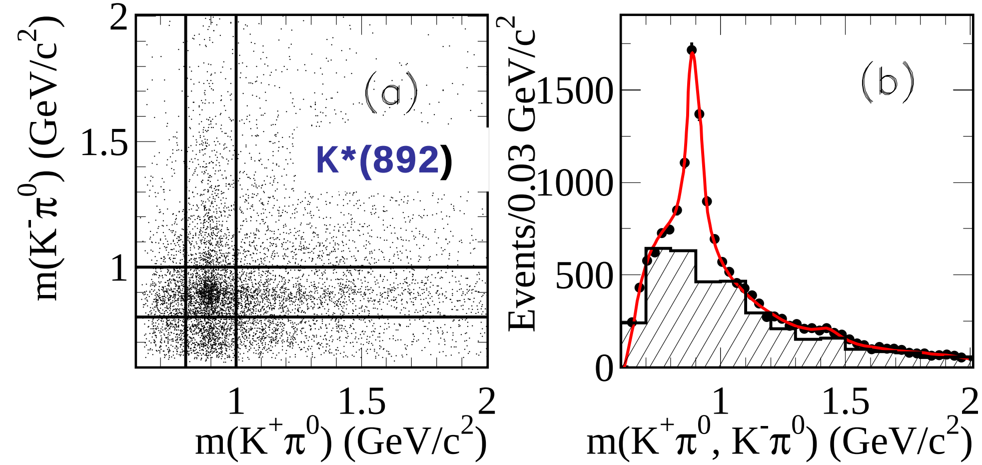
General fit to $\varphi\eta$, $\varphi\pi^0$, **K*(980)K** data gives parameters of excited vector mesons ρ', ρ'', ρ''', φ', φ''.

e+e- ->2K2π, ($K^+K^-\pi^+\pi^-$, $K^+K^-\pi^0\pi^0$), PRD, 76, 012008, (2007)

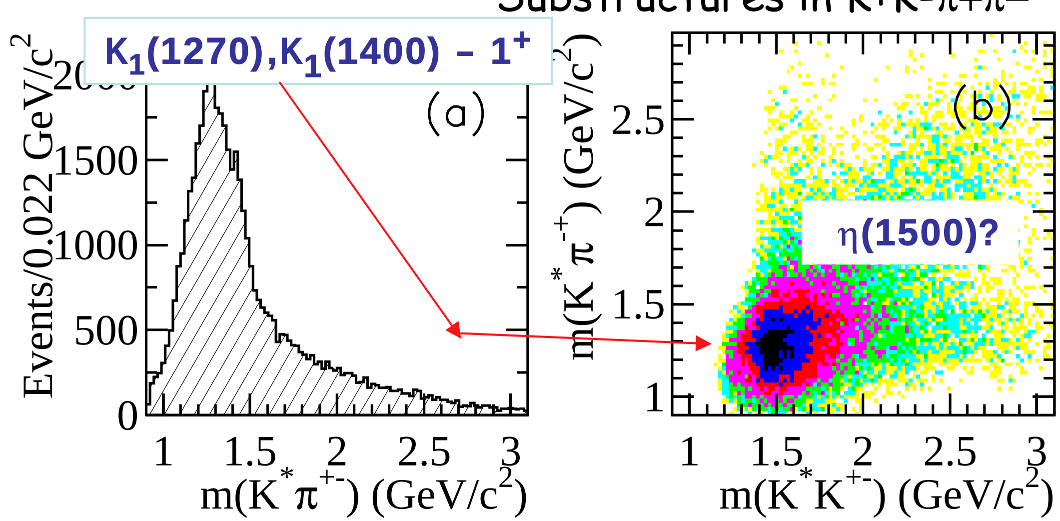




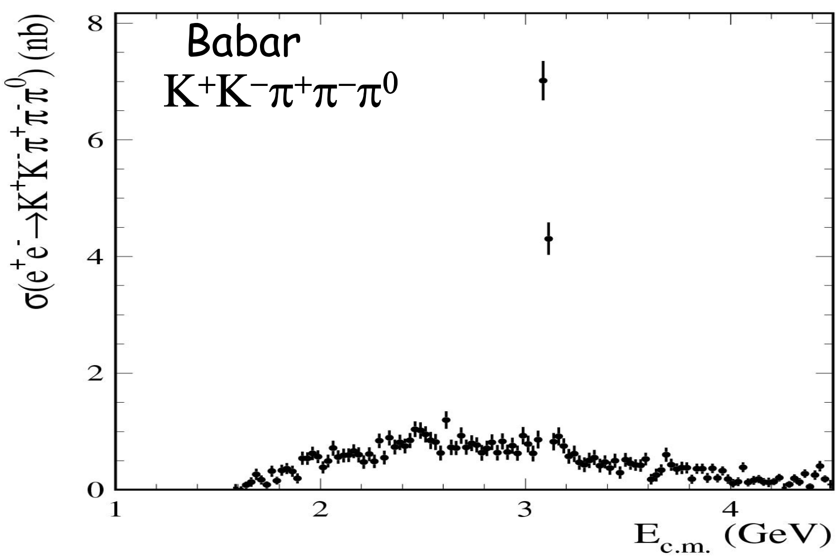
Substructures in K+K-$\pi^0\pi^0$

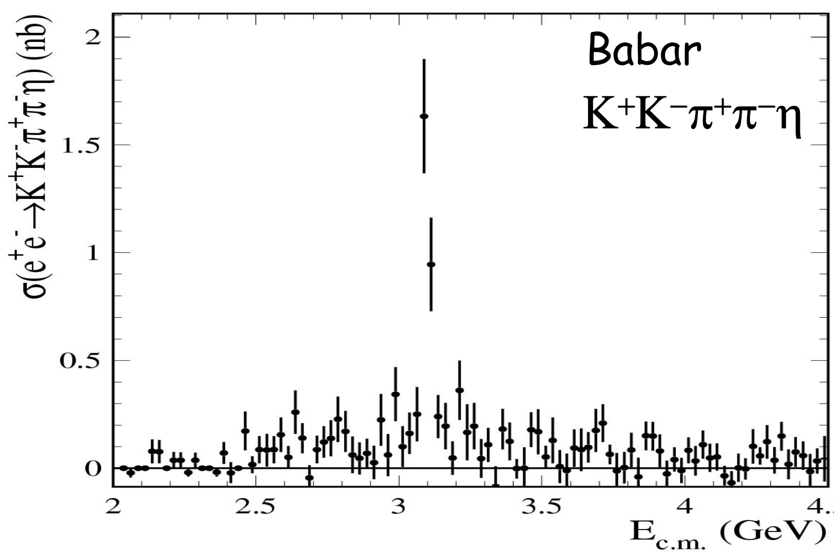


Substructures in K+K-π+π−

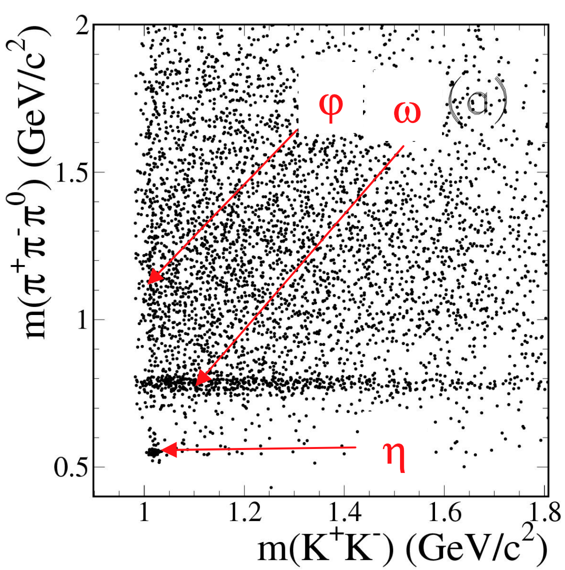


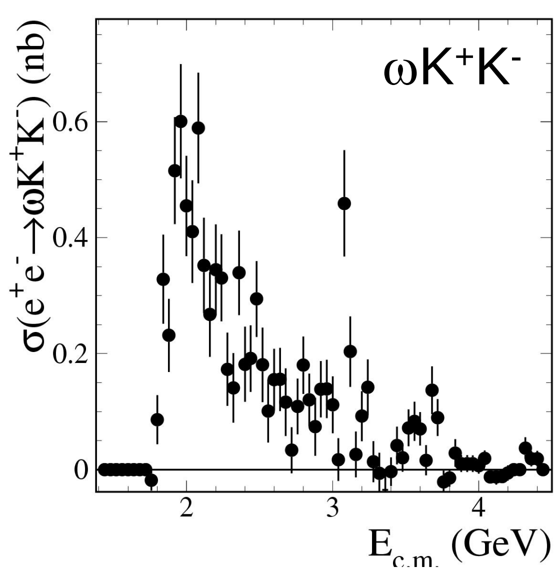
e+e- ->2K3π, ($K^+K^-\pi^+\pi^-\pi^0$, $K^+K^-\pi^+\pi^-\eta$), PRD, 76, 092005, (2007)

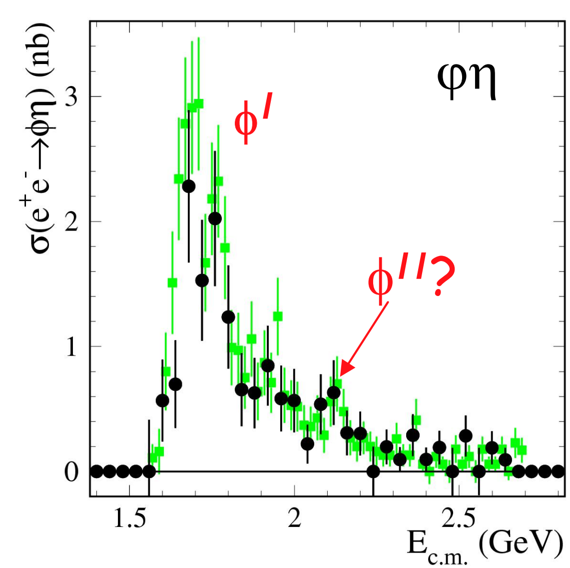




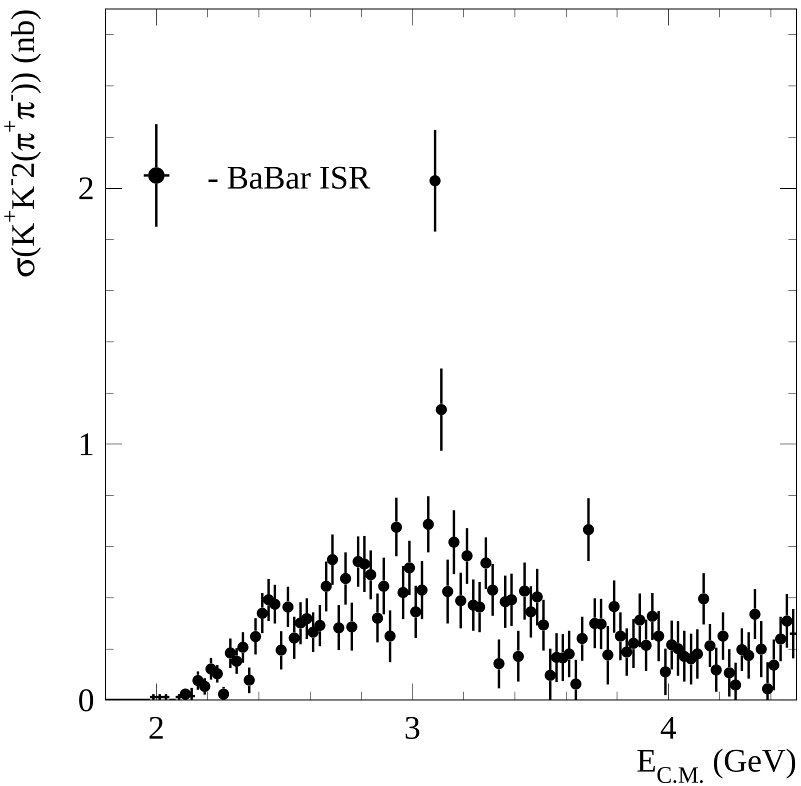
<- Sub-structures ->



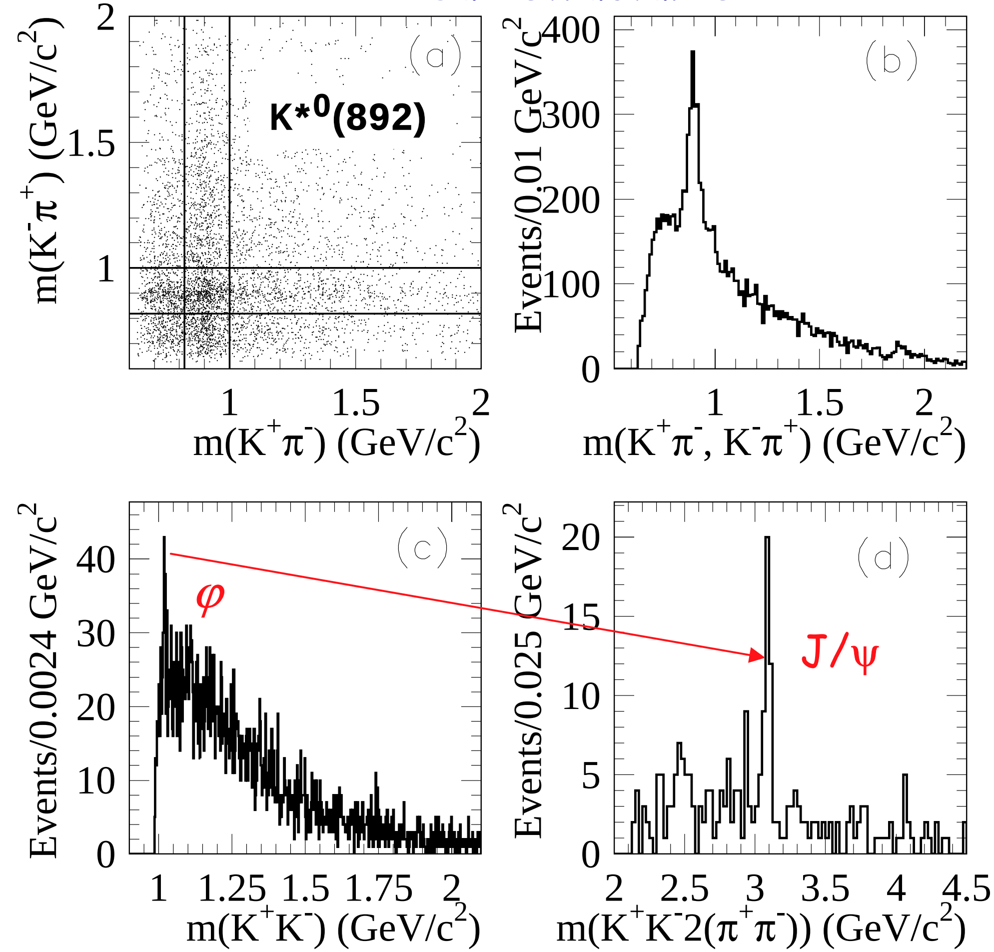




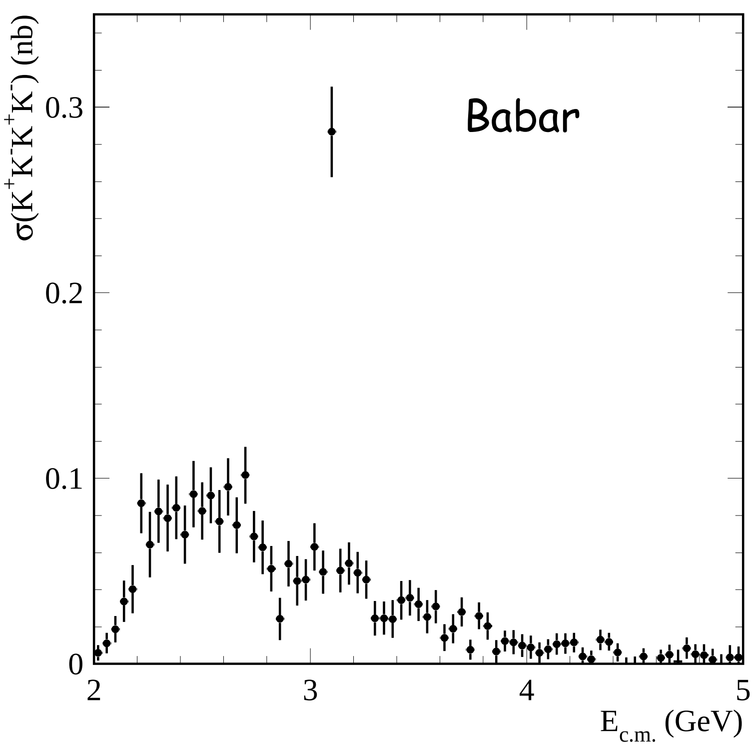
e+e- ->2K4π, $(K^+K^-\pi^+\pi^-\pi^+\pi^-)$, PRD, 73, 052003, (2006)

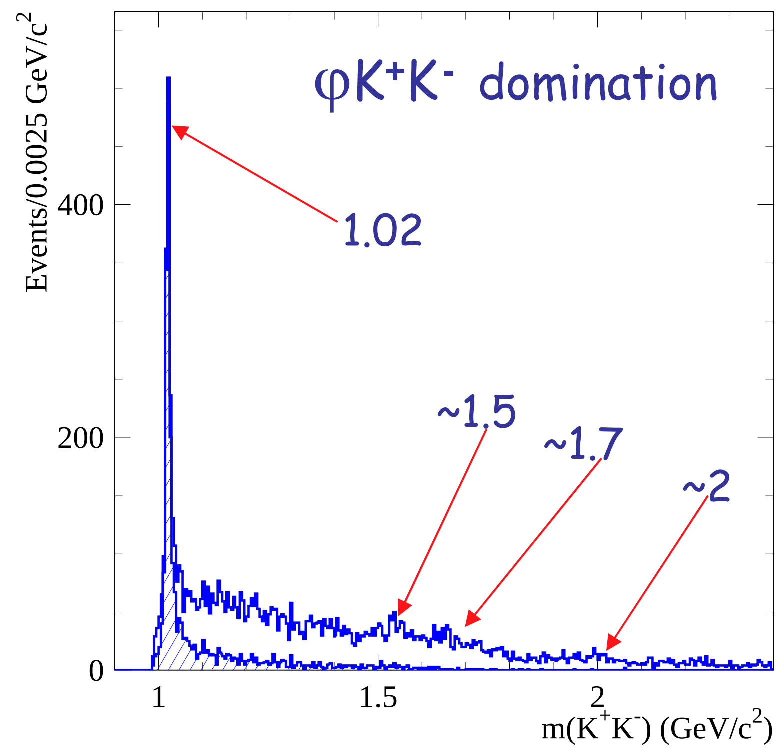


Sub-structures



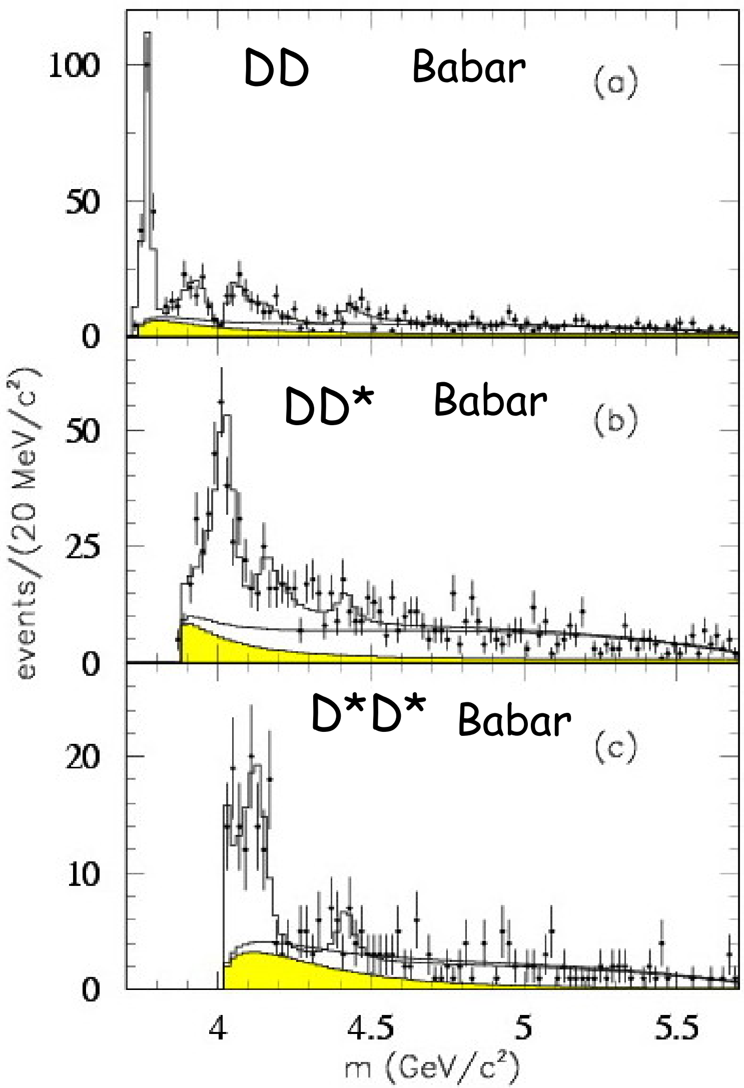
$e^+e^- \to 4K$, $(K^+K^-K^+K^-)$, PRD, 71, 052001, (2005)

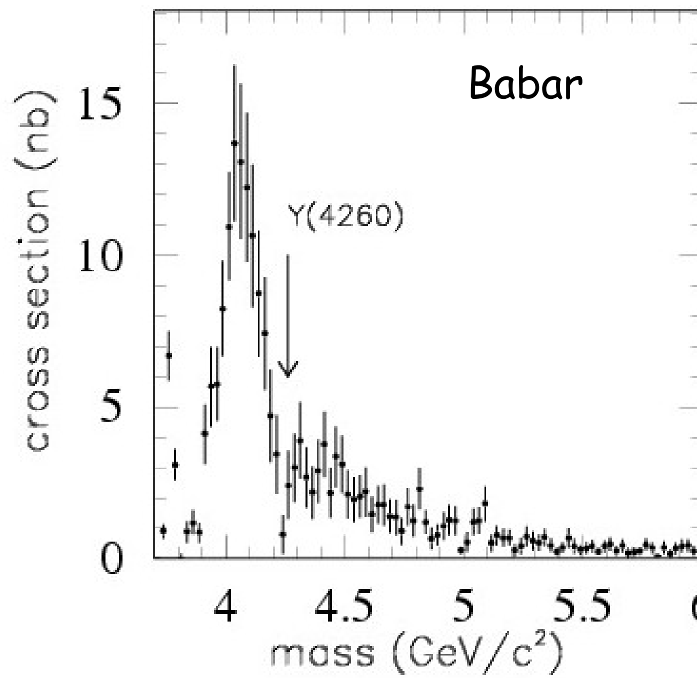




e+e- -> DD, DD*, D*D*, PRD, 79, 092001, (2009)

ISR kinematics – $\theta_\gamma \sim 0$,





RESULTS:

BF_{rel} Ψ(4040)->~0.17(DD);~0.71(DD*);~0.12(D*D*)
BF_{rel} Ψ(4160)->~0.02(DD);~0.25(DD*);~0.73(D*D*)
BF_{rel} Ψ(4415)->~0.11(DD);~0.13(DD*);~0.76(D*D*)
G(3900) is seen, M=3943+-20,Γ=52+-10,
Y(4260) is not seen, BF(Y->DD)<BF(Y->J/ψ $\pi+\pi-$)

Baryon Form factors (B = p, Λ, Σ_0. $\Lambda\Sigma_0$)

Differential cross section **(m=BB inv. mass):**

$$\sigma(e^+e^- \to B\overline{B}) = \frac{\alpha^2\beta C^2}{4m^2}\left(|G_M|^2(1+\cos^2\theta) + \frac{4m_B^2}{m^2}|G_E|^2(1-\cos^2\theta)\right)$$

Total cross section: $$\sigma(e^+e^- \to B\overline{B}) = \frac{4\pi\alpha^2\beta}{3m^2}\left(|G_M|^2 + \frac{2m_B^2}{m^2}|G_E|^2\right)$$

Effective form factor: $$|F|^2 = \frac{|G_M|^2 + |G_E|^2/2\tau}{1+1/2\tau}, \quad \tau = \frac{m^2}{4m_B^2}$$

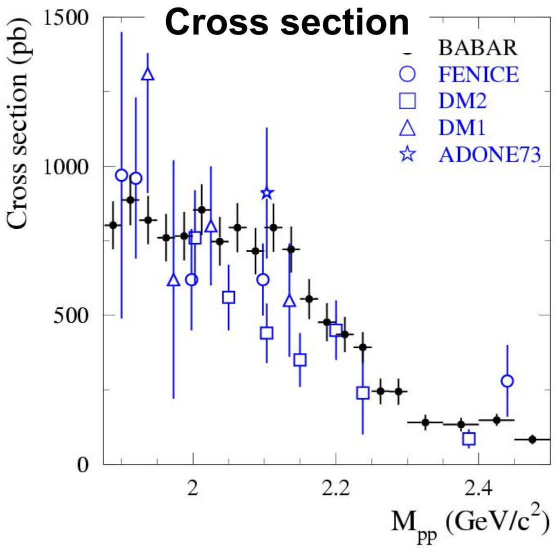
to pointlike cross section
-the ratio of real cross section

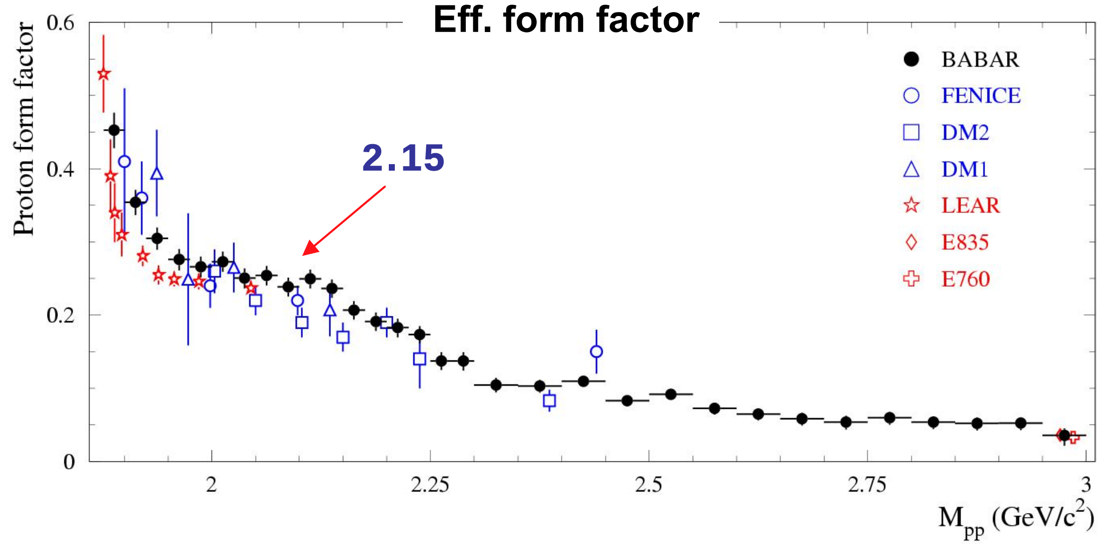
At the threshold $s=4m_B^2$ -> $|G_E| = |G_M|$
Only S-wave

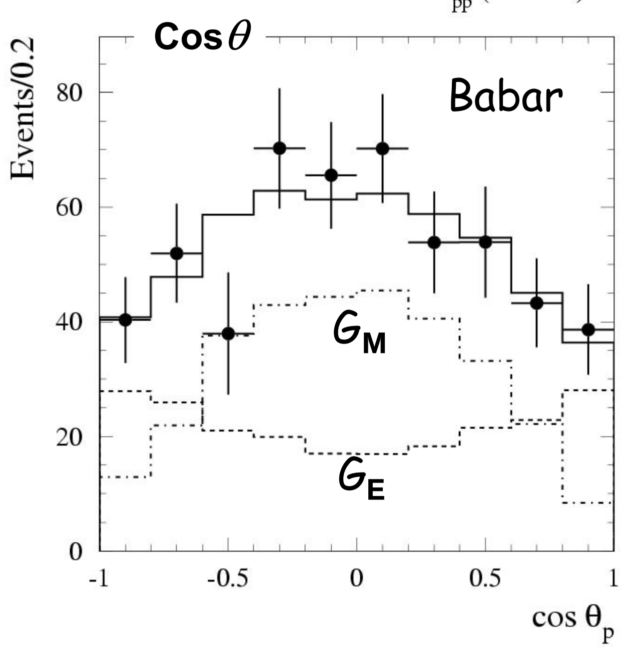
Two measurable values:
1 - effective FF, 2 - G_E/G_M

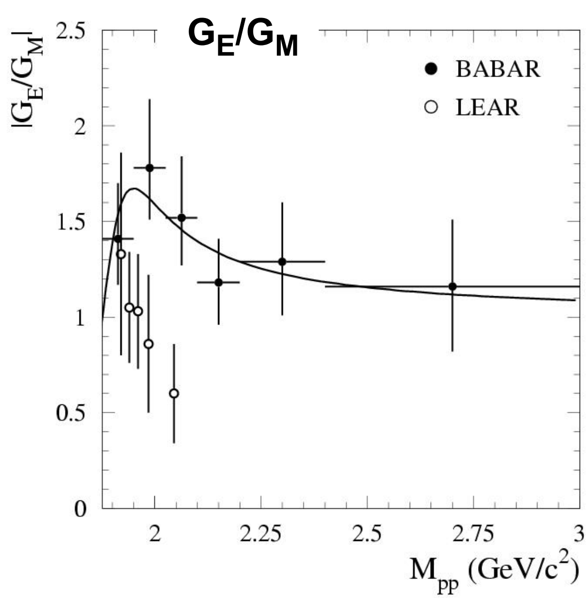
Nonzero phase ϕ between complex form factors G_E and G_M leads to transverse polarization ζ of outgoing baryons: $|\zeta| \sim \alpha \sin\phi$, α~0-0.5

$e^+e^- \to p\bar{p}$, PRD, 73, 012005, (2006)







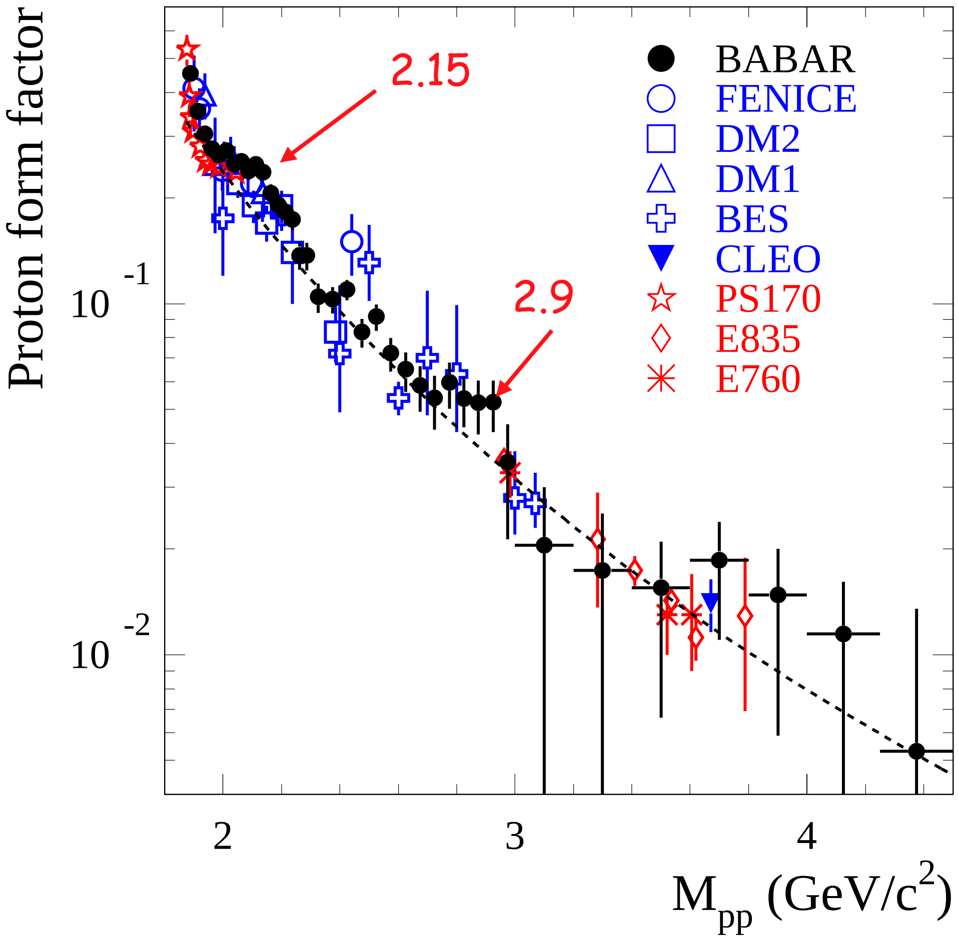


What is new:

1 – $G_E/G_M > 1$

2 – a structure at 2.15 GeV/c^2 - $\rho^{///}$?

QCD fit for proton FF data, PRD, 73, 012005, (2006)

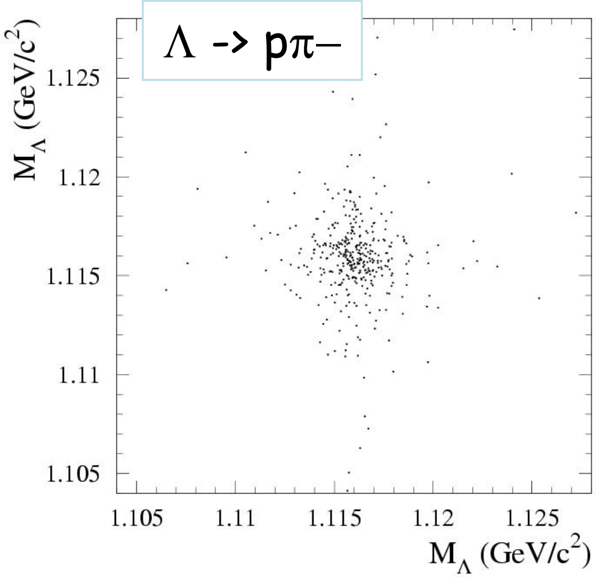


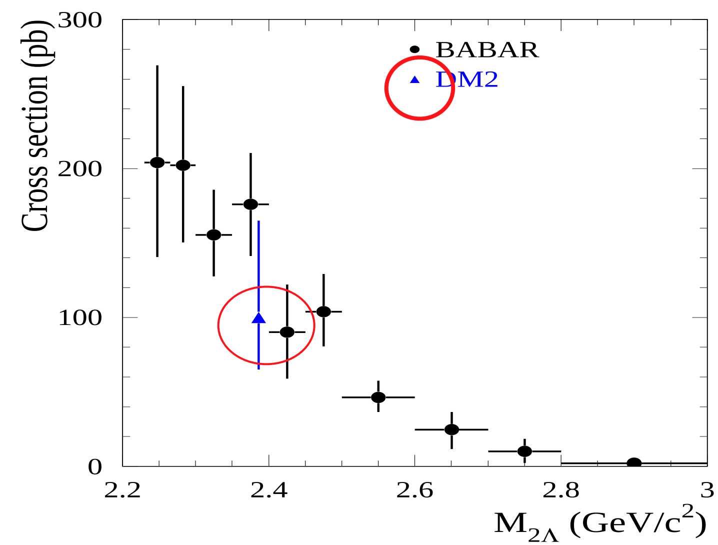
Asymptotic fit for baryon FFs

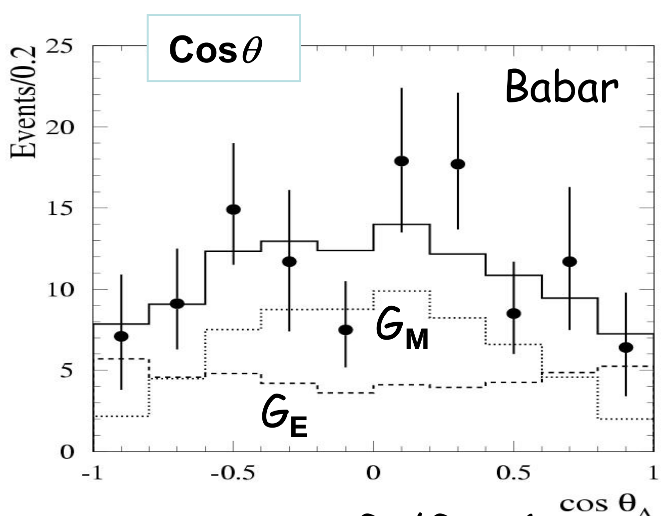
$$F_{pp} \sim \frac{\alpha_s^{\,2}(m)}{m^4} \sim \frac{C}{m^4 \ln^2(m^2/\Lambda^2)}$$

JETP Lett. 25 510 (1977)

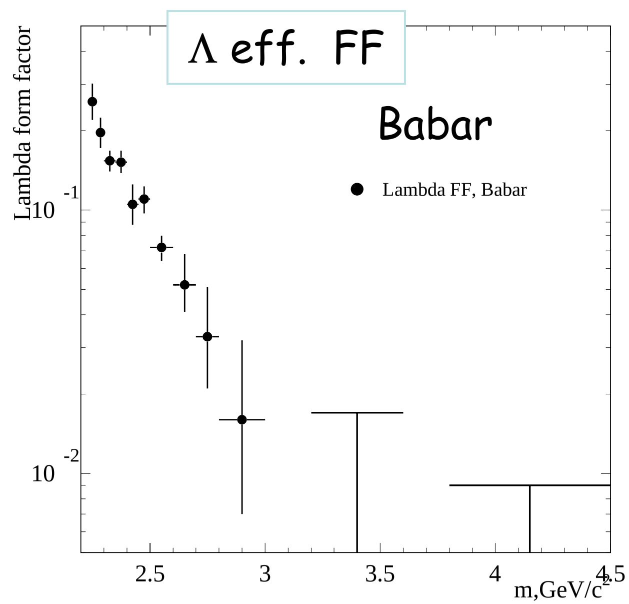
$e^+e^- \to \Lambda\bar{\Lambda}$, PRD, 76, 092006, (2007)







G_E/G_M ~1



What is new:

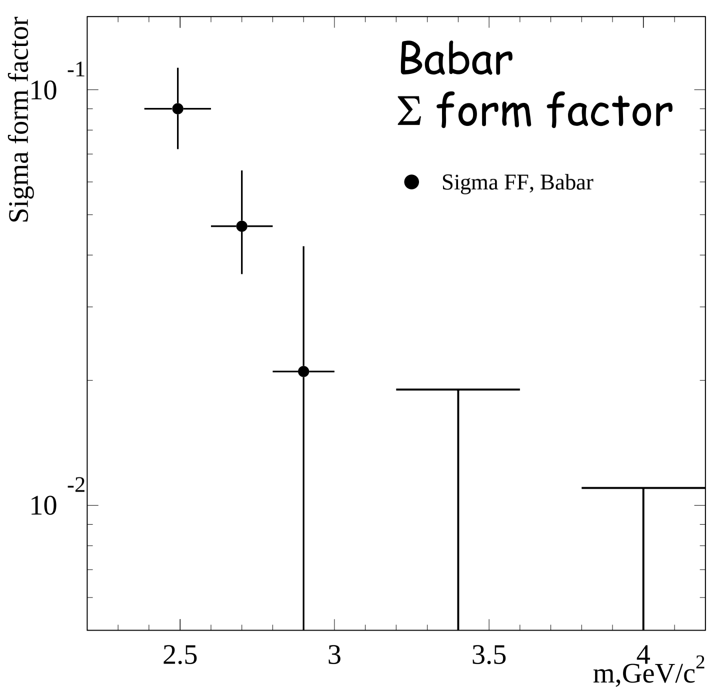
1 –FF vs energy

2 - G_E/G_M ~1

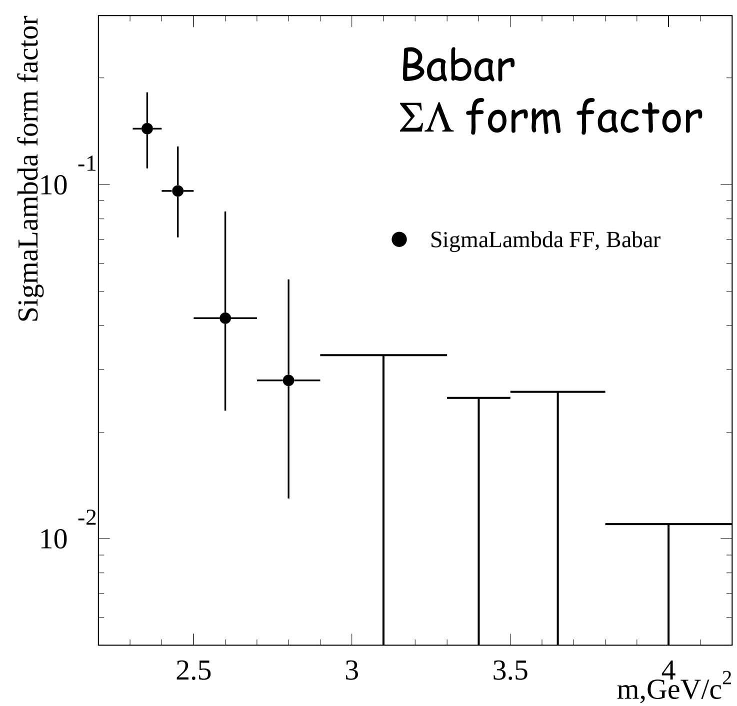
3 – Λ polarization

e+e- -> $\Sigma_0 \bar{\Sigma}_0$, $\Lambda_0 \bar{\Sigma}_0$ ($\bar{\Lambda}_0 \Sigma_0$), PRD, 76, 092006, (2007)

Σ_o -> $\Lambda\gamma$, Λ -> p π,
E_γ > 30 MeV,
$\Lambda\Lambda\gamma\gamma\gamma$ kinematic fit

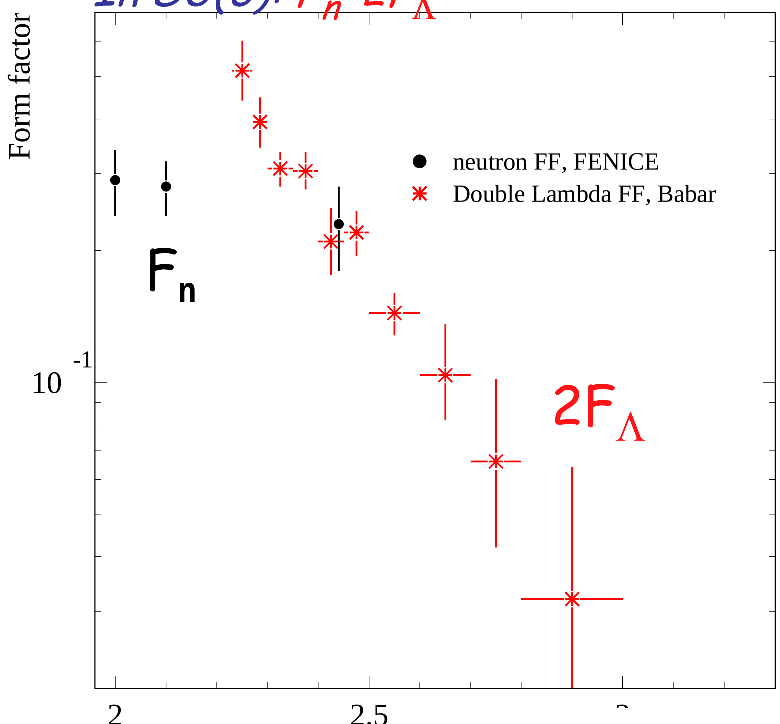


$\Sigma^0 \to \Lambda\gamma$, $\Lambda \to p\pi$-
$\Lambda\Lambda\gamma\gamma$ fit

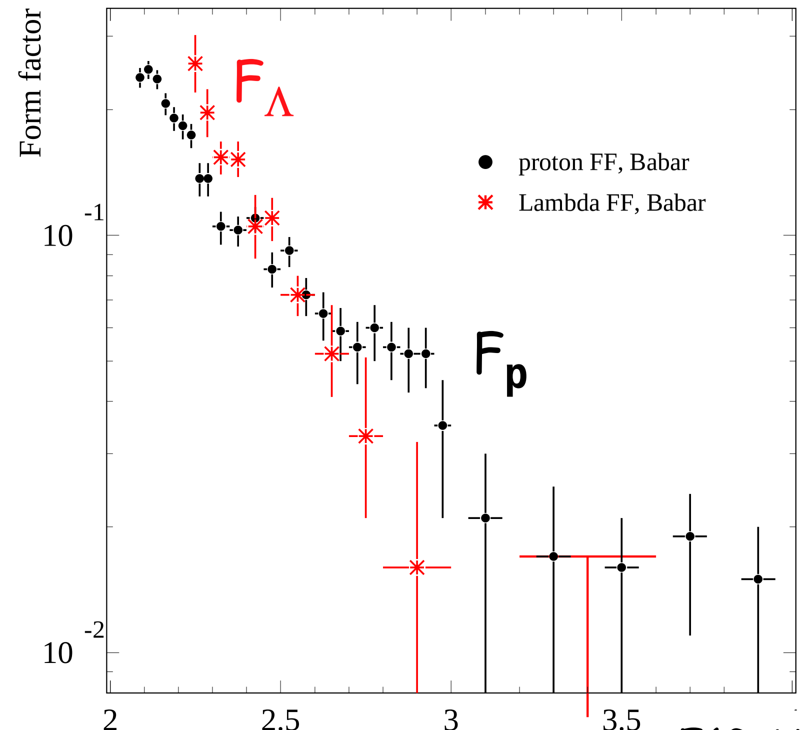


Some conclusions from Babar FFs (p, Λ, Σ^0, $\Lambda\Sigma^0$)

A comparison between neutron and doubled Λ form factor data
In SU(3): $F_n = 2F_\Lambda$



A comparison between proton and Λ form factors (Babar data)
Prediction $\Lambda/p = -0.24$



V.Chernyak prediction for asymptotic form factors:
$\Lambda/p=-0.24$, $\Sigma_0/p=0.29$, $\Lambda\Sigma_0/p=0.54$, $n/p=-0.47$
Z.Ph. C42 569 (1989)

We have strong disagreement at m<2.5 GeV/c^2. The higher mass – the less disagreemnt with QCD.

Babar ISR resonance physics results

New vector states, found by Babar in ISR:
Y(4260), Y(2175), Y(4320)

Exotic?

ϕ'' (KKpp, $\phi\eta$) ?, Exot.?

ρ''' (4π, $\eta\rho$, pp) ?

6π, pp thresh.

Candidates for new states:
Y(4500), X(2150), X(1880), G(3900)

'Old' states, improved parameters:
$\rho'(1450)$, $\rho''(1700)$, $\omega'(1420)$, $\omega''(1650)$, $\phi'(1680)$,
J/ψ, ψ', $\psi(4040)$, $\psi(4160)$, $\psi(4400)$

J/Ψ and $\Psi(2s)$ decay in ISR

With ΔL=454 fb^{-1} → $N_{J/\Psi} = 1.6\ 10^7$, $N_{\Psi(2S)} = 0.6\ 10^6$ ev.

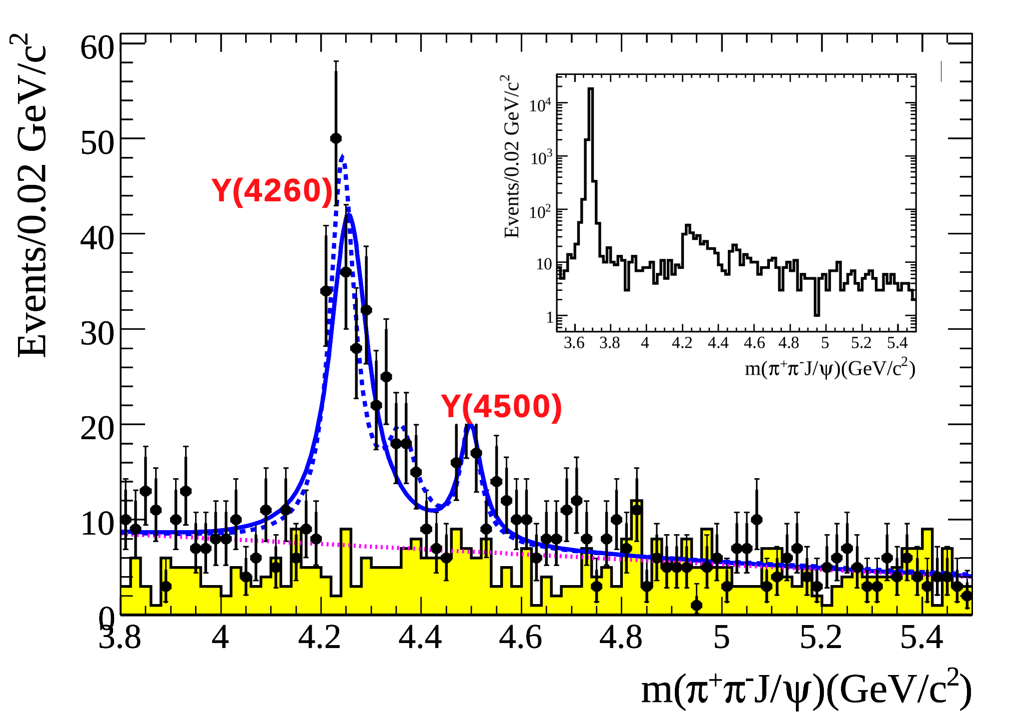
More than 10 decays are observed for the first time:

- $J/\psi \to K^+K^-\pi^+\pi^-\eta$
- $J/\psi \to K^+K^-p^0p^0$
- $J/\psi \to K^{*0}K^{*0}$
- $J/\psi \to K^*K_2(1770)$
- $J/\psi \to \phi\pi^0\pi^0$
- $J/\psi \to \phi\ f_2$
- $J/\psi \to \pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$
- $J/\psi \to \omega\ \pi^+\pi^-\pi^0$
- $\Psi(2S) \to \pi^+\pi^-\pi^+\pi^-\eta$
- $\Psi(2S) \to K^+K^-\pi^+\pi^-\eta$
- $\Psi(2S) \to K^+K^-\pi^+\pi^-\pi^+\pi^-$
- $\Psi(2S) \to \pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$

BF ~ 10^{-3}

And for similar number of decays the BFs are improved.

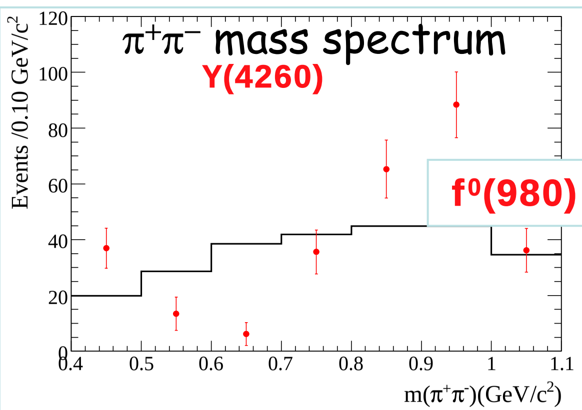
Observation of 1^{--} Y(4260) state, decaying into $J/\psi\ \pi^+\pi^-$.

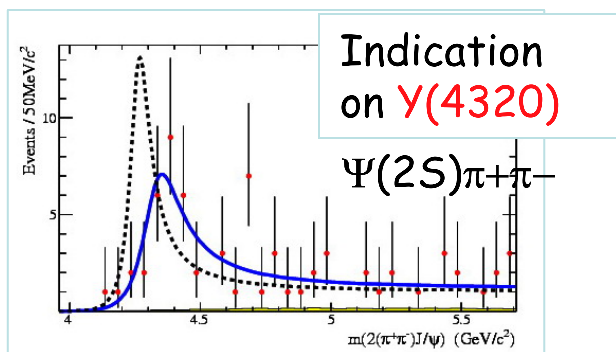


ISR kinematics – $\theta_\gamma \sim 0$,

Main results:

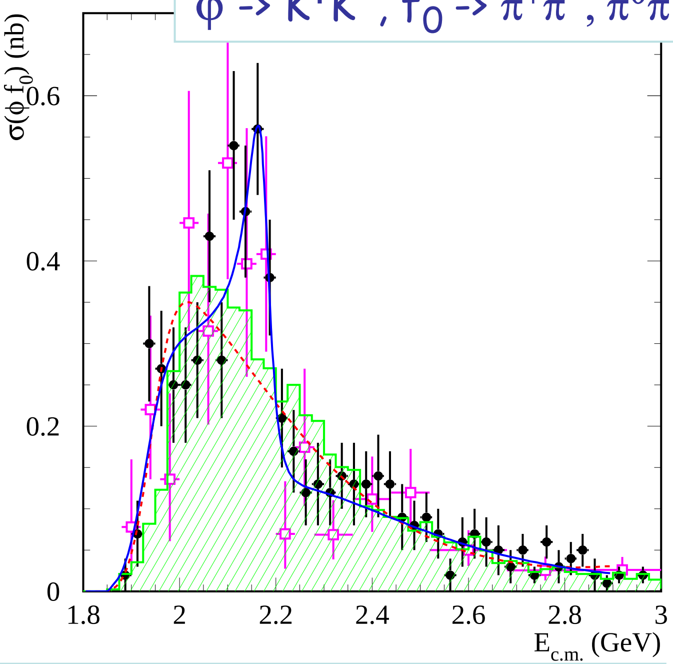
1. M_Y=4254+-6 MeV, Γ_Y=92+-15 MeV, $B(J/\psi\ \pi+\pi-)\Gamma_{ee}$=7.5+-1.1 eV,
2. Compare with: $\Gamma_{ee}(\psi(4040), \psi(4160), \psi(4415))$ ~ 600-800 eV
3. Y(4260)-is the good candidate for exotic state like ~ccqq, QQ,qqg
4. Evidence for Y(4500): M=4498+-11+4-2 MeV/c², Γ=56+-35+24-12 MeV/c²



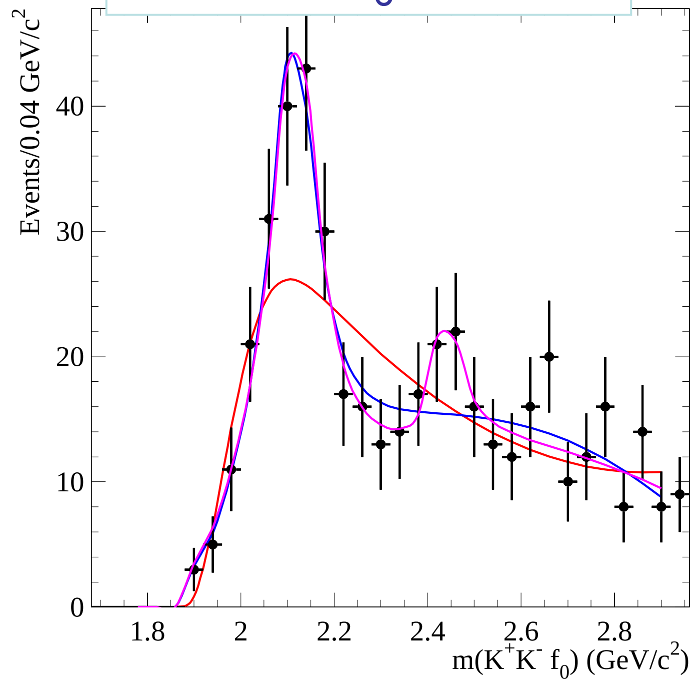


Evidence of Y (2175) state

$e^+e^- \to \varphi f^0(980)$
$\varphi \to K^+K^-$, $f_0 \to \pi^+\pi^-, \pi^0\pi^0$



$e^+e^- \to K^+K^-f_0$ $f^0 \to \pi^0\pi^0$



Possible nature of Y(2175):
1 – ssss, 2 – φ'',
3- Y(2175) is similar to Y(4260):
Y(4260) -> $J/\Psi\ f_0$, Γ_{ee}=5.5 eV
Y(2175)-> φf_0, Γ_{ee}=2.5 eV

M=2175±18 MeV
Γ=58±25 MeV
$B_{\varphi f0}\ \Gamma_{ee}$ =
=2.5+-0.8+-0.4 eV

Y(2175) is confirmed by Belle and BES.
Babar update is coming soon.

Significance and perspectives

1. Measurements of e+e- -> hadrons processes are very important for tests of Standard model with muon anomaly $a_\mu=(g-2)/2$ and fine structure constant at Z-mass $\alpha_{em}(s=M_Z^2)$
2. Isovector part of the hadronic cross sections e+e- -> H (T=1) and corresponding τ-lepton decays $\tau \to H \nu$ can be used for test of the CVC hypothesis.
4. Most of reactions, studied by Babar, use only half of available statistics. Many important processes are still not analysed. This is the perspective field for future work.
5. Super BF with 2 orders higher luminosity promise a great future for ISR – new level of precision!

Conclusions

1. ISR method is developed at Babar for study e+e- annihilation in wide range from $2m_\pi$ to 7 GeV/c^2
2. Numerous number of e+e→ hadrons processes are studied at Babar including production of pions, kaons, baryons, D-mesons, …
3. Parameters of many vector mesons are improved ρ_S, ω_S, ϕ_S, J/ψ, $\psi(2S)$, …
4. New states are found with ISR incl. Y(4260), Y(2175), …