Studies with Initial State Radiation at BABAR

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(for BaBar collaboration)

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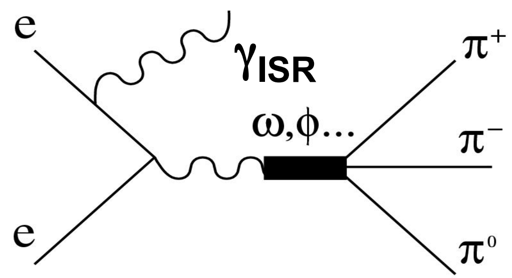
Outline

- Short introduction
- Overview of results obtained up to now
- Preliminary results for $K^+K^-\pi^+\pi^-$, $K^+K^-\pi^0\pi^0$, $K^+K^-K^+K^-$
- Conclusion

PEP-II and BaBar were designed for B-physics, but they are excellent machine and detector for ISR study ! About 500 fb^{-1} are available for analysis.

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

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



Motivation

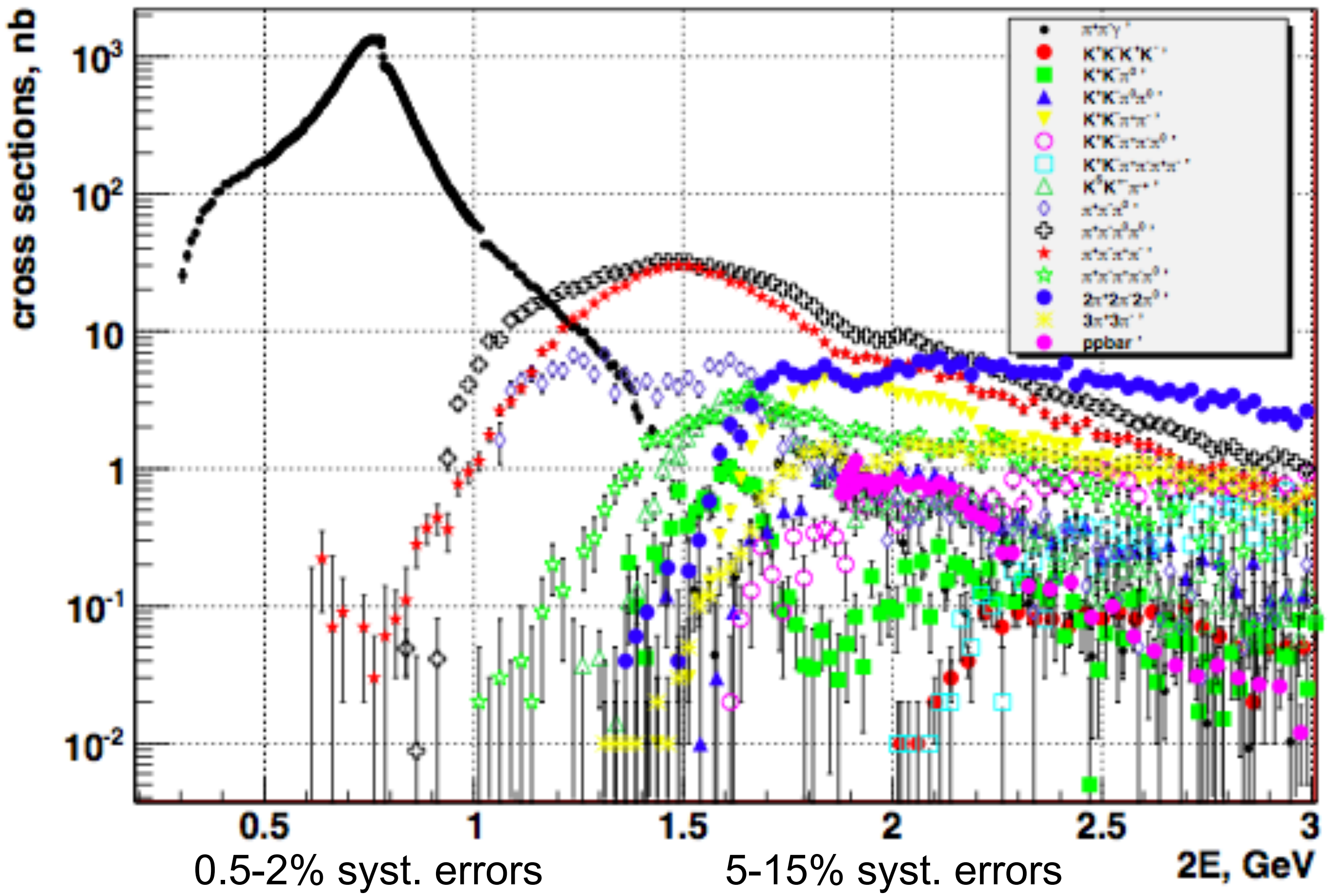
- Low energy e^+e^- cross section dominates in hadronic contribution to a_μ = (g-2)/2 of muon
- Direct e^+e^- data in 1.4 - 2.5 GeV region have very low statistic
- Hadron spectroscopy at low masses and charmonium region

- ISR at BaBar gives competitive statistic
- BaBar has excellent capability for ISR study
- All major hadronic processes are under study

$e^+e^- \to 2\mu\gamma$, $2\pi\gamma$, $2K\gamma$, $2p\gamma$, $2\Lambda\gamma$, $2\Sigma\gamma$, $\Lambda\Sigma\gamma$, $\Lambda_c\Lambda_c\gamma$
$e^+e^- \to 3\pi\gamma$
$e^+e^- \to 2(\pi^+\pi^-)\gamma$, $K^+K^-\pi^+\pi^-\gamma$, $K^+K^-\pi^0\pi^0\gamma$, $2(K^+K^-)\gamma$
$e^+e^- \to 2(\pi^+\pi^-)\pi^0\pi^0\gamma$, $3(\pi^+\pi^-)\gamma$, $K^+K^-2(\pi^+\pi^-)\gamma$
$e^+e^- \to \pi^+\pi^-\pi^0\pi^0\gamma$, $\pi^+\pi^-\pi^0\pi^0\pi^0\gamma$, $\pi^+\pi^-\pi^0\eta\gamma$ ...
$e^+e^- \to K^+K^-\pi^0\gamma$, $K^+K^-\eta\gamma$ ($KK^*\gamma$, $\phi\pi^0\gamma$, $\phi\eta\gamma$ ...)
$e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^0/\eta\gamma$, $K^+K^-\pi^+\pi^-\pi^0/\eta\gamma$

Are being updated to full BaBar data with ~500fb^{-1}

BaBar measurements summary



To calculate R in the energy range 1-2 GeV the processes
$\pi^+\pi^-3\pi^0$, $\pi^+\pi^-4\pi^0$, K^+K^-, K_SK_L, $K_SK_L\pi\pi$, $K_SK^+\pi^-\pi^0$
must be measured. Work is in progress.

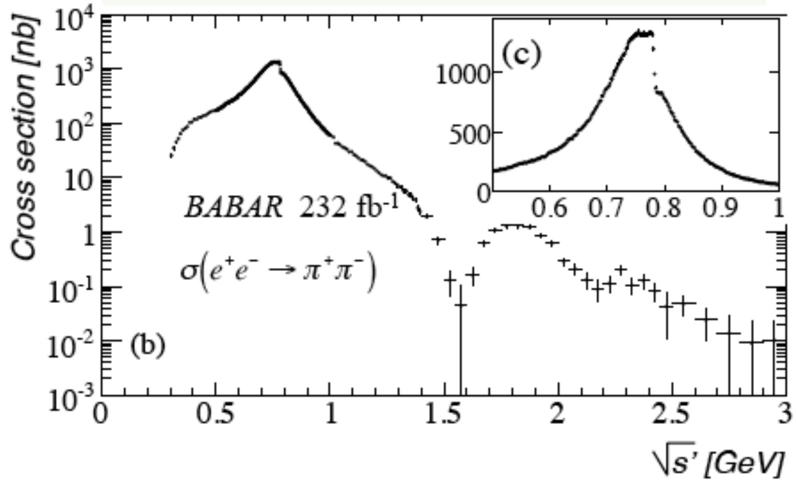
$e^+ e^- \rightarrow \pi^+ \pi^-$ cross section (1)

- ISR γ detected ==> powerful background rejection
- Kinematic fit including 1 additional γ : NLO
- All efficiencies (trigger, filter, tracking, PID, fit) from the same data
- Measure ratio of $\pi\pi$ to $\mu\mu$ to cancel :

  ee Luminosity, additional ISR, vacuum polarization, ISR γ efficiency

Total systematic uncertainties in the ρ region 0.5%

Phys. Rev. Lett. 103, 231801(2009)



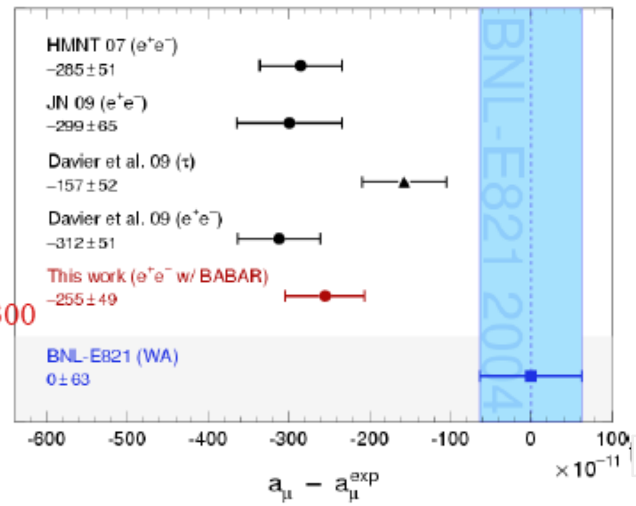
a_μ : where we stand:

$a_\mu^{\pi\pi}$ from SND & CMD-2

$a_\mu^{\pi\pi}$ from tau

ee average including KLOE '08

ee average including BABAR arXiv:0908.4300

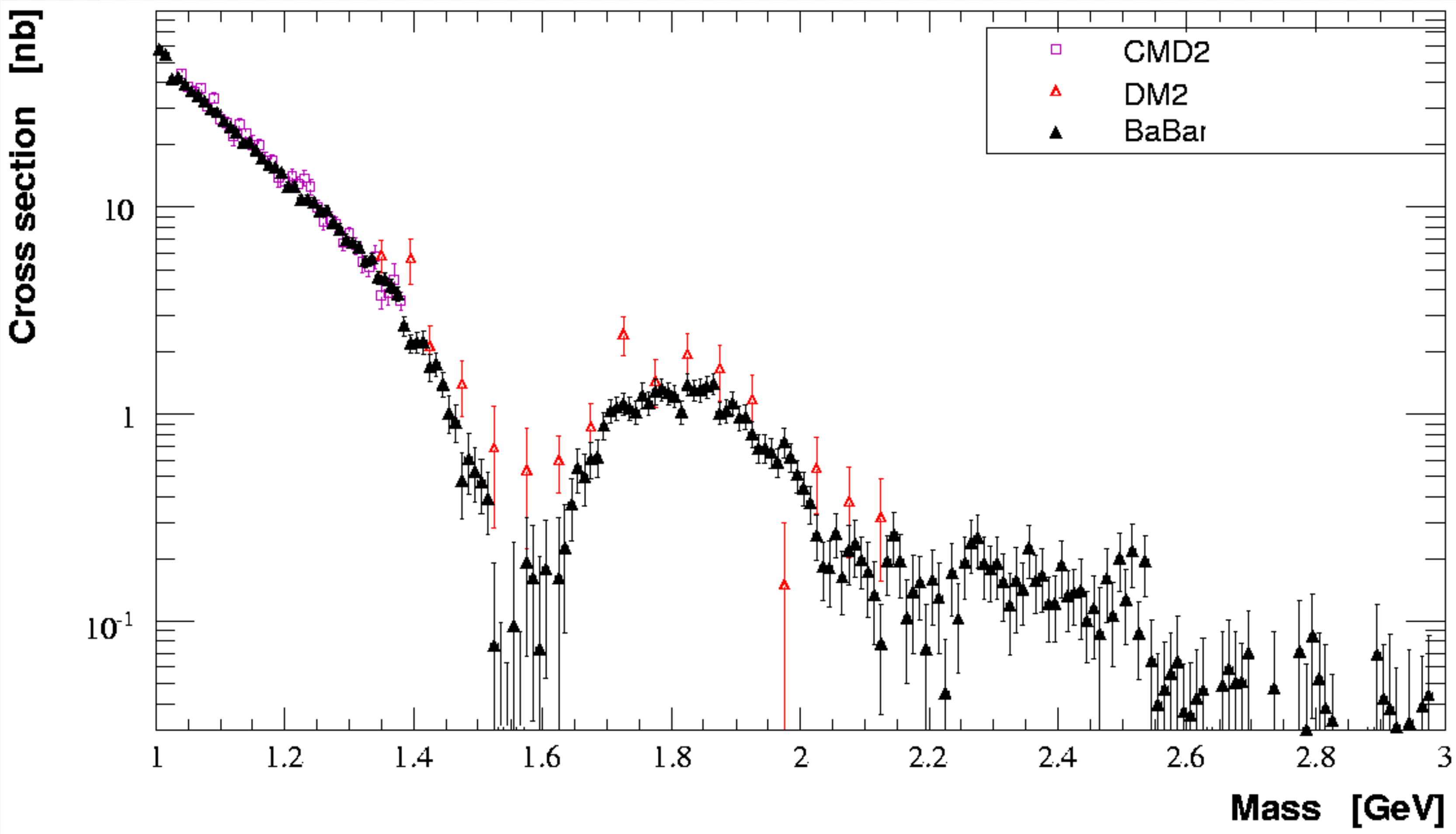


new deviation :

$a_\mu^{exp} - a_\mu^{SM} = (-25.5 \pm 8.0) \times 10^{-10}$

still above 3σ!

$e^+ e^- \rightarrow \pi^+ \pi^-$ cross section (2)



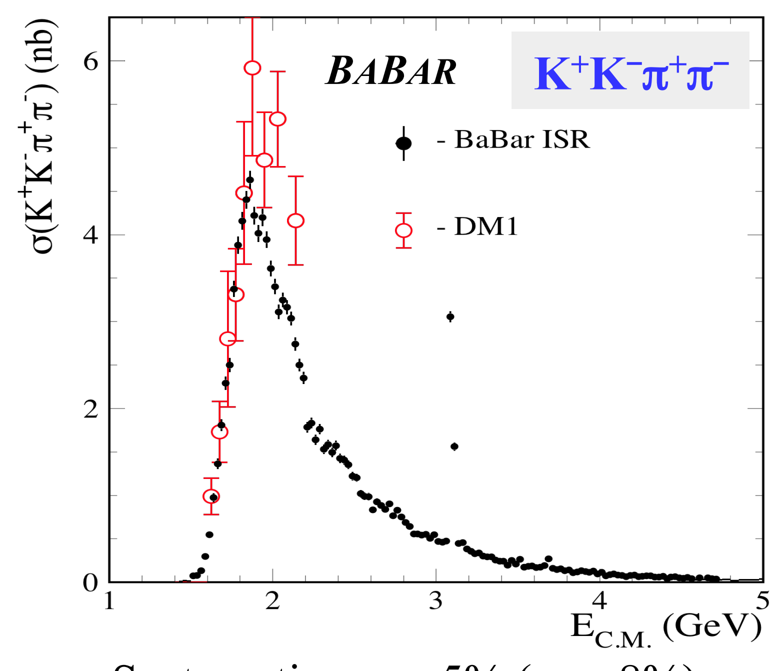
Good agreement with VEPP-2M data, DM2 data have large systematic errors.
Can we understand all structures in the cross section?

$e^+e^- \rightarrow K^+K^-\pi^+\pi^-, K^+K^-\pi^0\pi^0$

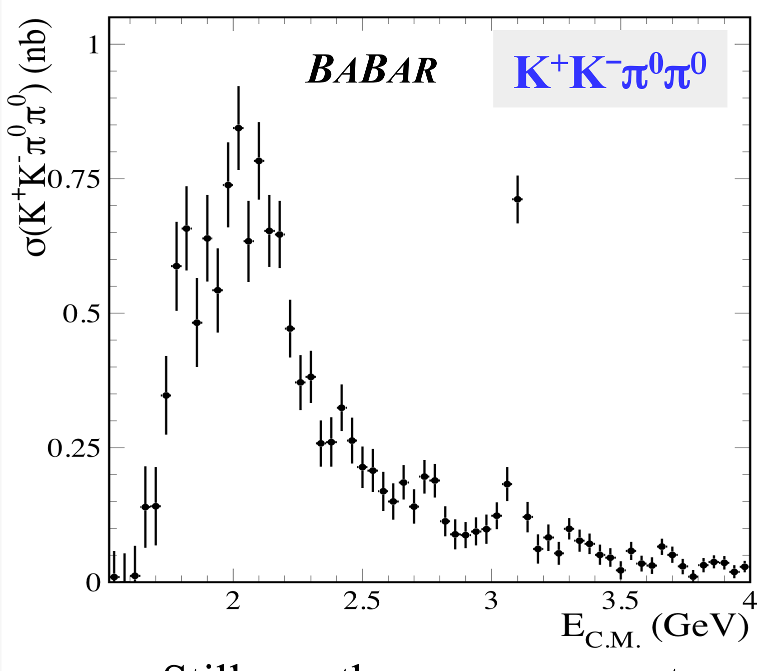
Our previous publications PRD-RC 74 (2006) 091103
PRD 76 (2007) 012008

Motivation for new study:

- Factor 2 **more statistics** with respect to published results – 454 fb^{-1}
- Search for **$\phi(1020)f_0(980)$ final state** and Y(2175) update
- Improve BR of **J/ψ and $\psi(2S)$**
- Search for **new states**

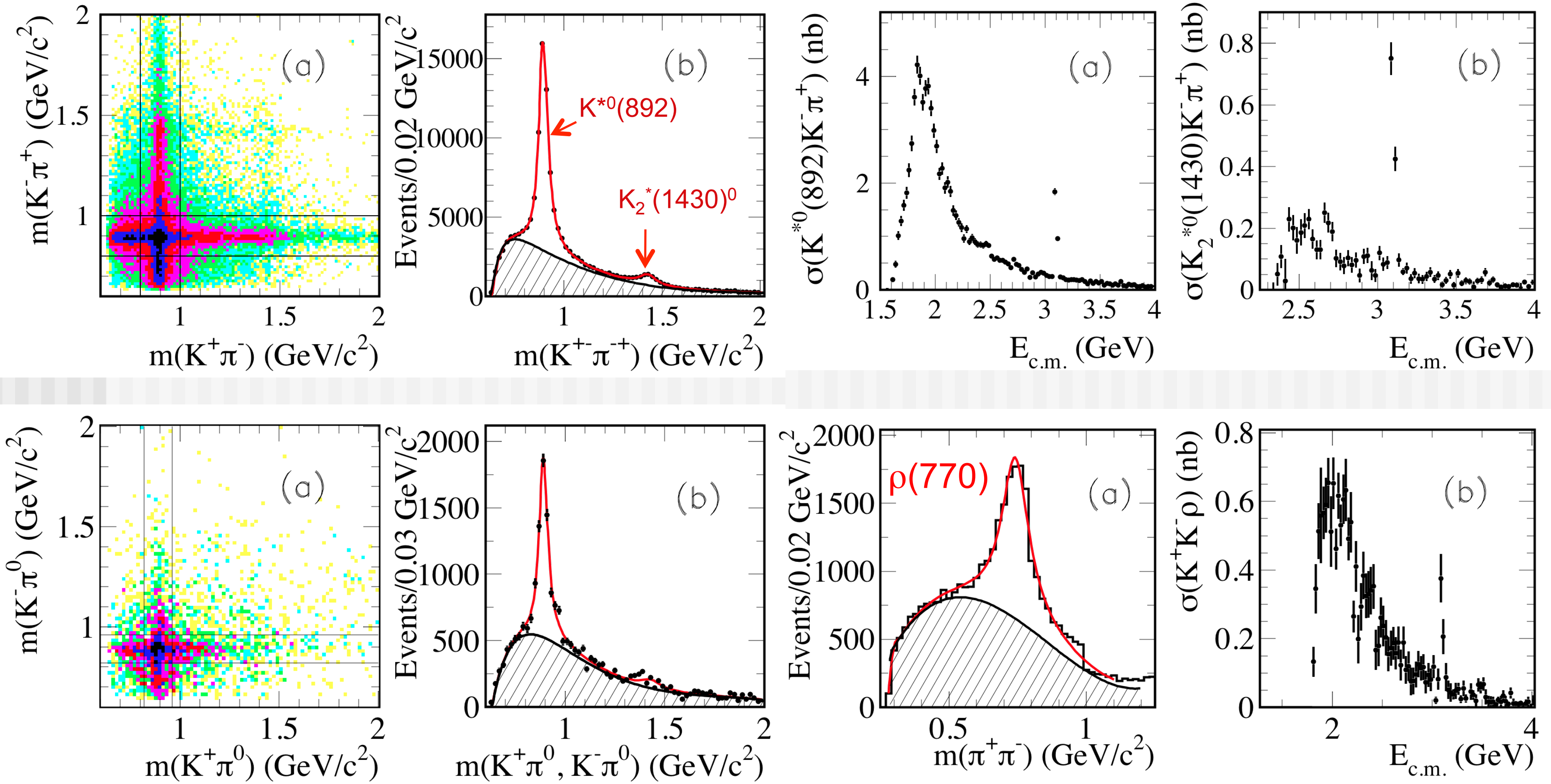


- Systematic error 5% (was 8%)
- Error dominated by acceptance



- Still no other measurements
- Systematic error 7% (was 11%)

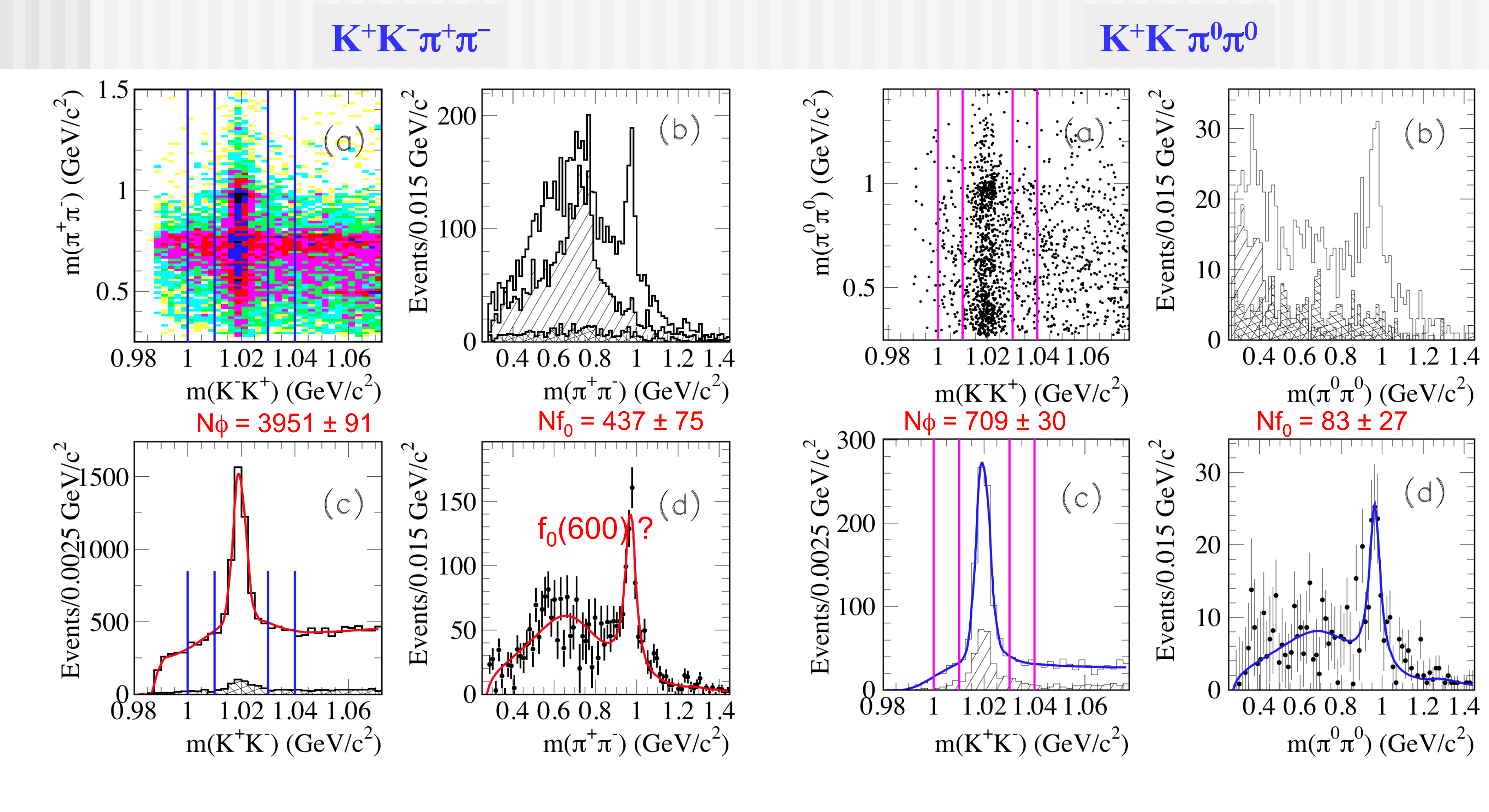
Kaon substructures for $K^+K^-\pi^+\pi^-$, $\pi^0\pi^0$



Cross section dominates by $K^{*0}(892)K\pi$ final state.
Only ~1% of events associated with $K^{*0}\overline{K^{*0}}$!!
But $K^{*0}(892)K_2^*(1430)^0$ + c.c. is seen.

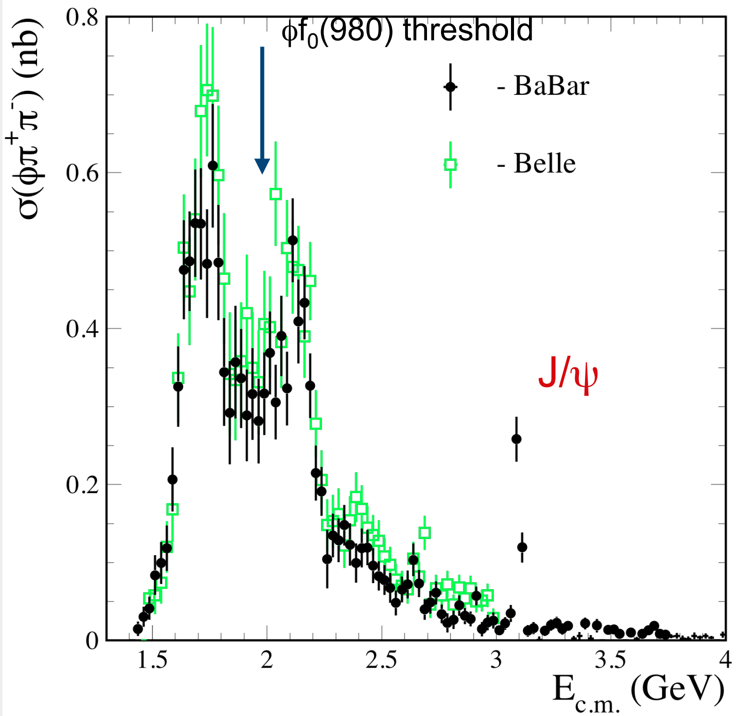
Also $K_1(1270,1400) \rightarrow K^*(892)K$, $K^*(892)\pi$ are seen
ρ's are from $K_1(1270)$, $K_1(1400)$ $\rightarrow$ $K\rho$ decay

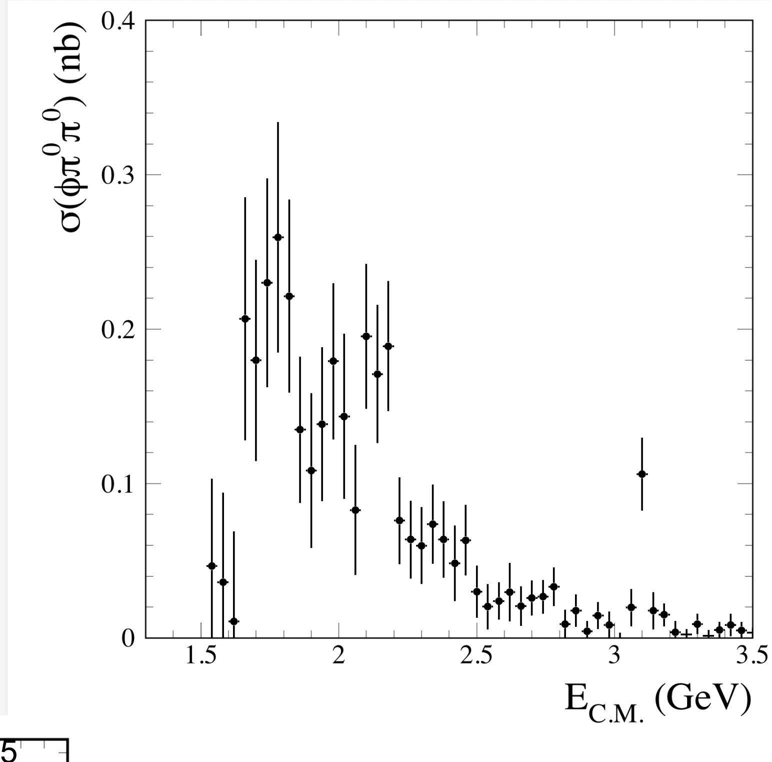
Selection of $\phi(1020)\pi^+\pi^-$, $\pi^0\pi^0$

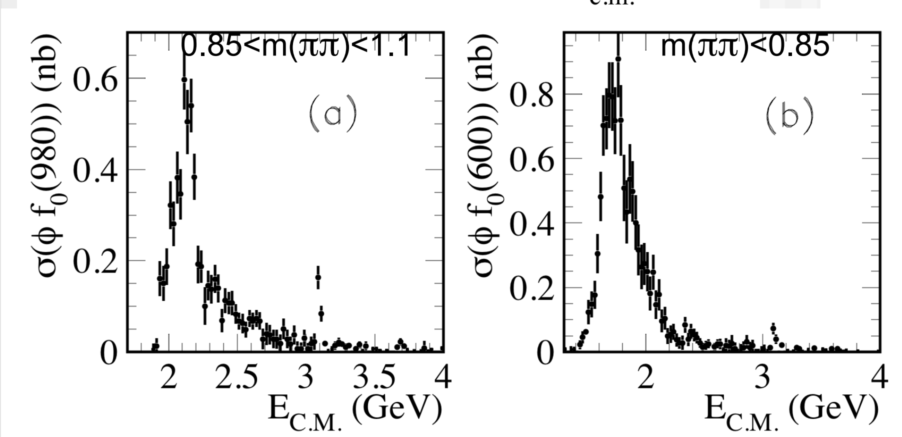


The $f_0(980)$ parameters are not shifted from PDG values – f_0-$\pi\pi$ interference is small because of kinematics.

Cross sections for $e^+e^- \to \phi\,\pi^+\pi^-$, $\phi\,\pi^0\pi^0$

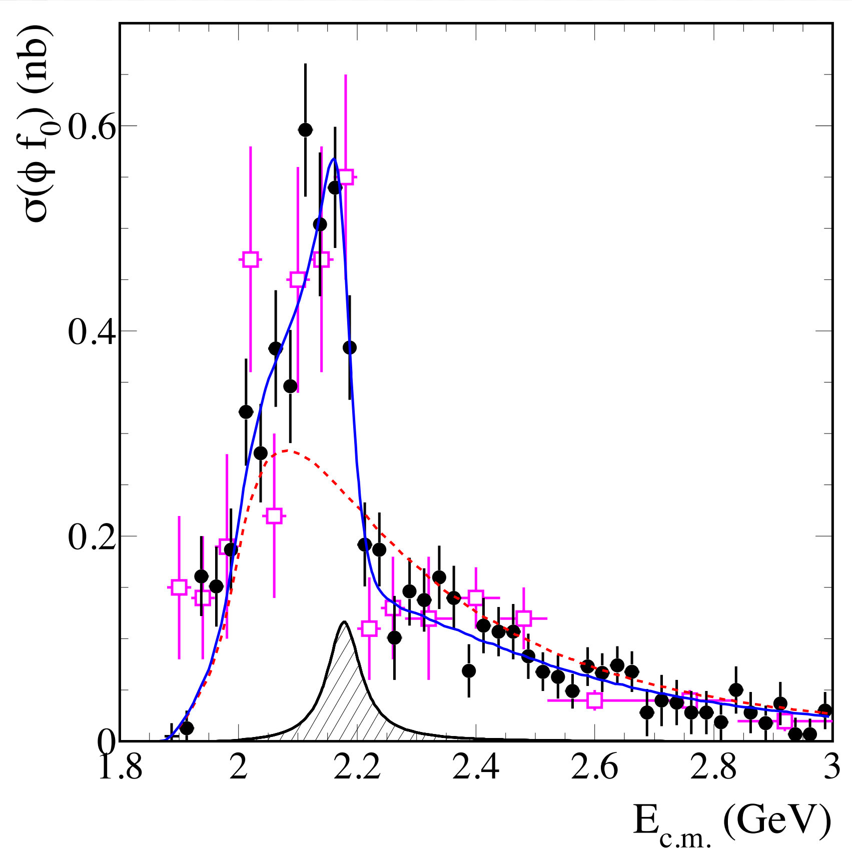






Cut $m(\pi\pi)<0.85$ completely removes structures above E_{cm} = 2 GeV !!
And confirms Y(2175) structure if $0.85<m(\pi\pi)<1.1$ GeV/c2 (next slide)

Cross section for $e^+e^- \to \phi\ f_0(980)$, Y(2175)



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

$\sigma_0^x = 0.104 \pm 0.025$ nb
$m_x = 2.179 \pm 0.009$ GeV/c²
$\Gamma_x = 0.079 \pm 0.017$ GeV

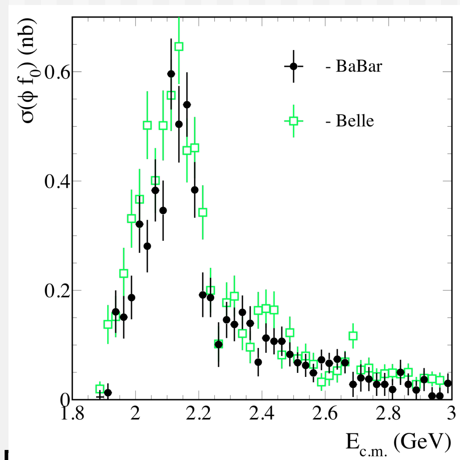
$$\sigma_0 = \frac{12\pi\Gamma_{ee}B_f}{m^2C}$$

$\Gamma_{ee} \bullet B_{\phi\ f0} = (2.3 \pm 0.4 \pm 0.3)$ eV

2 ln (L_0/L_x) = sqrt (150 – 64) ~ 9.3 σ

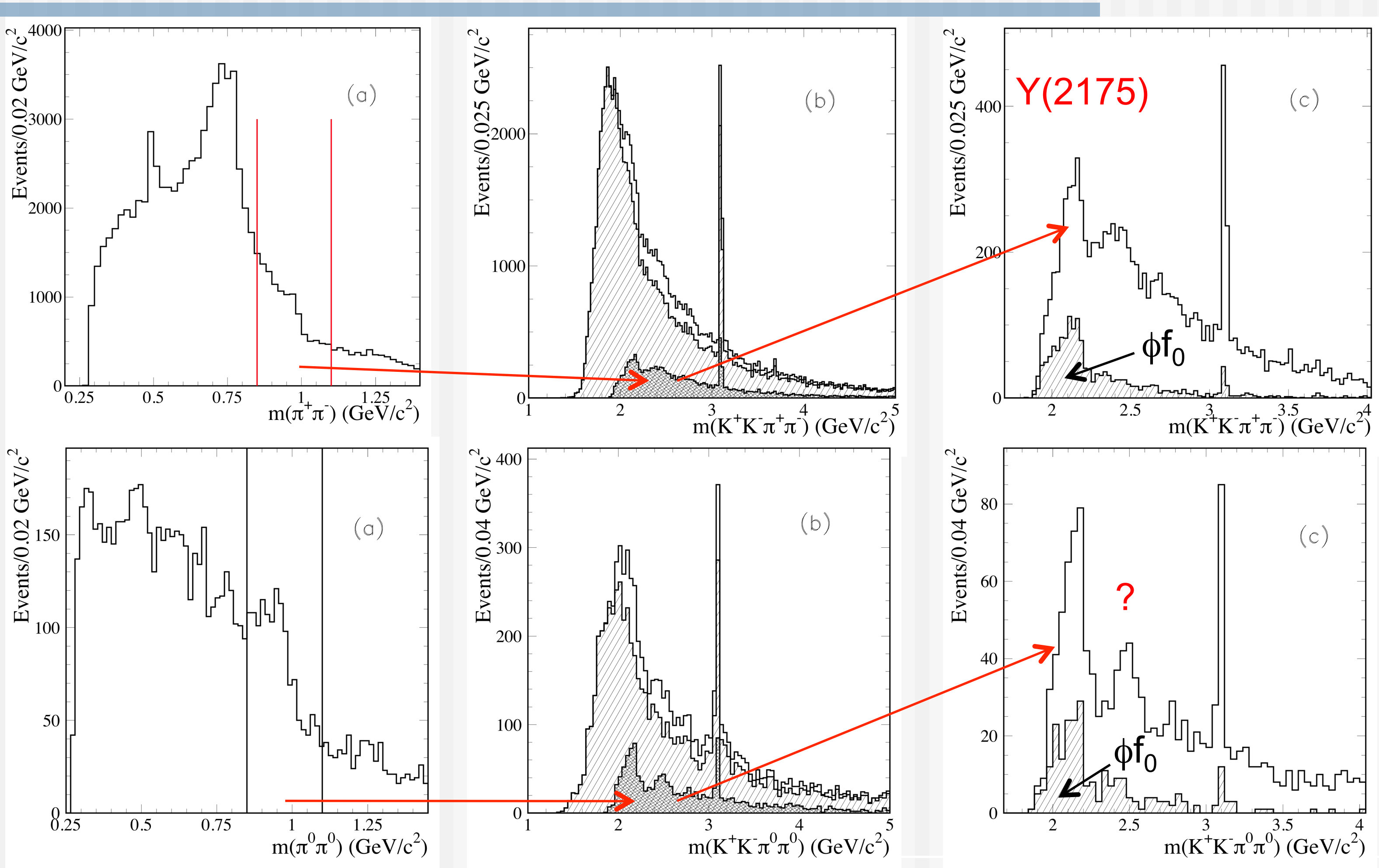
XS is corrected by:
$Br(\phi \to K^+K^-) = 0.491$
$Br(f_0 \to \pi^+\pi^-) = 2/3$
$Br(f_0 \to \pi^0\pi^0) = 1/3$

A fit with free interference phase with continuum



Good overall agreement with 670 fb^{-1} Belle data for $K^+K^-\pi^+\pi^-$ channel

Evidence of Y (2175) in K+K-f_0 final state



Raw ππ mass
No background subtraction

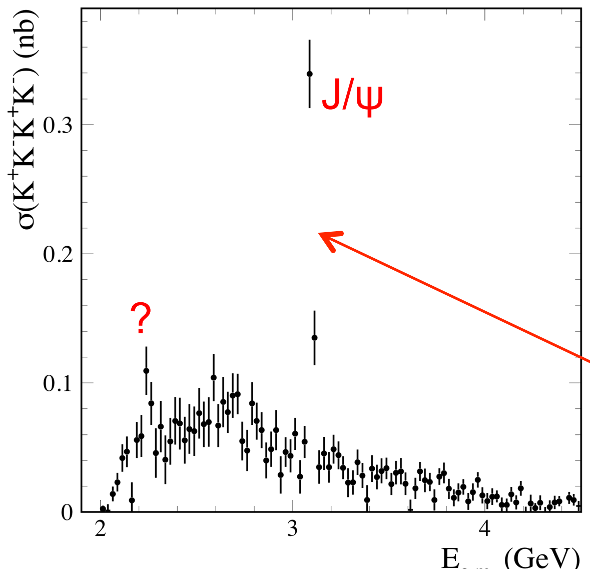
Possible nature of Y(2175):

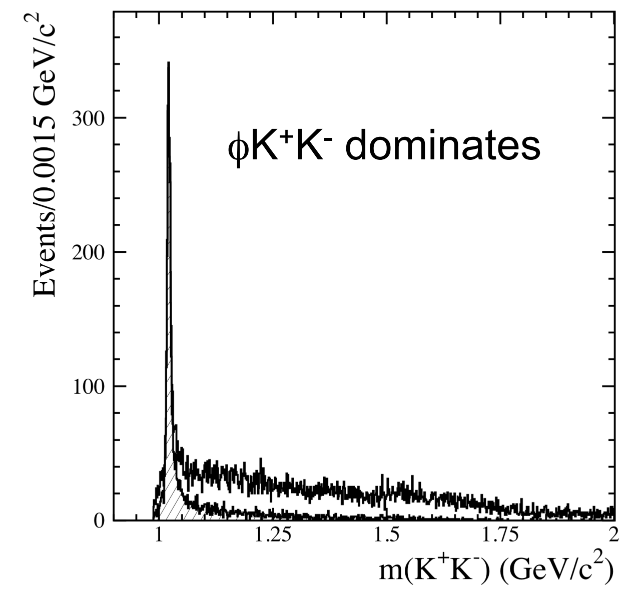
1 – ssss, 2 – ϕ'' but no BR $\phi\pi\pi$,

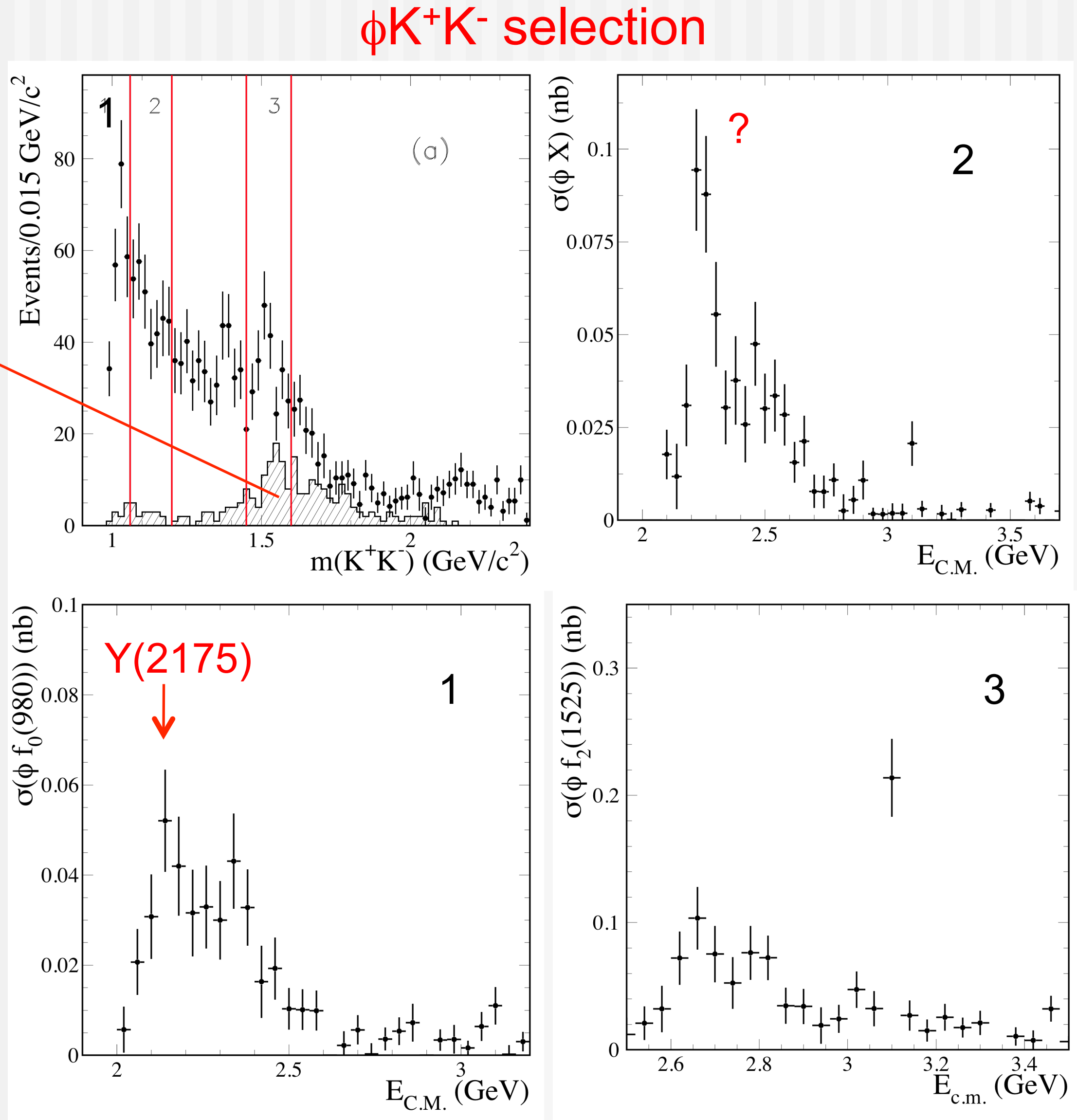
3- Y(2175) is similar to Y(4260): Y(4260) = $J/\Psi\ f_0$, Γ_{ee}=5.5 eV

Y(2175)= ϕf_0, Γ_{ee}=2.5 eV

$e^+e^- \rightarrow K^+K^-K^+K^-$







J/ψ region for $K^+K^-\pi^+\pi^-$, $K^+K^-\pi^0\pi^0$, $K^+K^-K^+K^-$

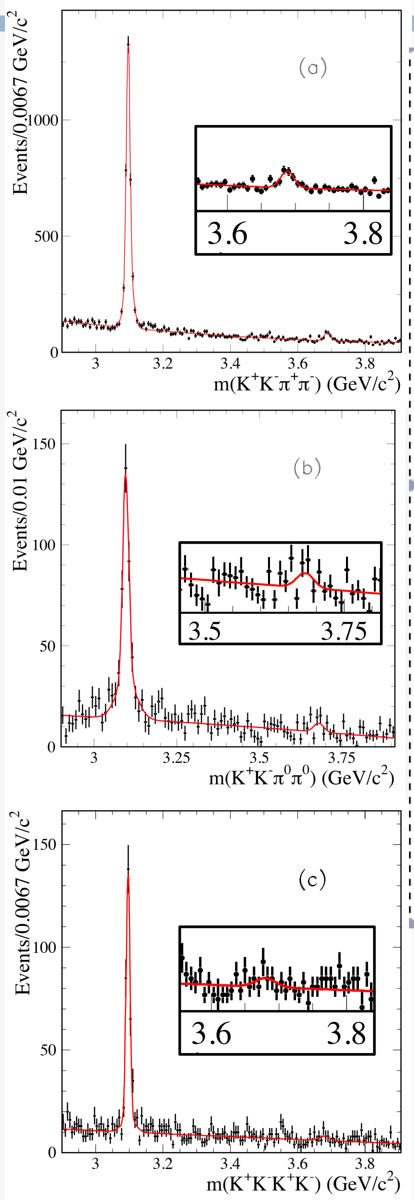


TABLE XIII: Summary of the J/ψ and $\psi(2S)$ branching fraction values obtained in this analysis.

Measured Quantity	Measured Value (eV)	J/ψ or $\psi(2S)$ Branching Fraction (10^{-3}) This work	PDG2009
$\Gamma_{ee}^{J/\psi}\cdot\mathcal{B}_{J/\psi\to K^+K^-\pi^+\pi^-}$	37.94±0.81±1.10	6.84±0.15±0.27	6.6 ±0.5
$\Gamma_{ee}^{J/\psi}\cdot\mathcal{B}_{J/\psi\to K^+K^-\pi^0\pi^0}$	11.75±0.81±0.90	2.12±0.15±0.18	2.45 ±0.31
$\Gamma_{ee}^{J/\psi}\cdot\mathcal{B}_{J/\psi\to K^+K^-K^+K^-}$	4.00±0.33±0.29	0.72±0.06±0.05	0.76 ±0.09
$\Gamma_{ee}^{J/\psi}\cdot\mathcal{B}_{J/\psi\to K^{*0}\bar{K}_2^{*0}}\cdot\mathcal{B}_{K^{*0}\to K^+\pi^-}\cdot\mathcal{B}_{\bar{K}_2^{*0}\to K^-\pi^+}$	8.59±0.36±0.27	6.98±0.29±0.21	6.0 ±0.6
$\Gamma_{ee}^{J/\psi}\cdot\mathcal{B}_{J/\psi\to K^{*0}\bar{K}^{*0}}\cdot\mathcal{B}_{K^{*0}\to K^+\pi^-}\cdot\mathcal{B}_{\bar{K}^{*0}\to K^-\pi^+}$	0.57±0.15±0.03	0.23±0.06±0.01	0.23 ±0.07
$\Gamma_{ee}^{J/\psi}\cdot\mathcal{B}_{J/\psi\to\phi\pi^+\pi^-}\cdot\mathcal{B}_{\phi\to K^+K^-}$	2.19±0.23±0.07	0.81±0.08±0.03	0.94 ±0.09
$\Gamma_{ee}^{J/\psi}\cdot\mathcal{B}_{J/\psi\to\phi\pi^0\pi^0}\cdot\mathcal{B}_{\phi\to K^+K^-}$	1.36±0.27±0.07	0.50±0.10±0.03	0.56 ±0.16
$\Gamma_{ee}^{J/\psi}\cdot\mathcal{B}_{J/\psi\to\phi K^+K^-}\cdot\mathcal{B}_{\phi\to K^+K^-}$	2.26±0.26±0.16	1.66±0.19±0.12	1.83 ±0.24 [a]
$\Gamma_{ee}^{J/\psi}\cdot\mathcal{B}_{J/\psi\to\phi f_0}\cdot\mathcal{B}_{\phi\to K^+K^-}\cdot\mathcal{B}_{f_0\to\pi^+\pi^-}$	0.69±0.11±0.05	0.25±0.04±0.02	0.18 ±0.04 [b]
$\Gamma_{ee}^{J/\psi}\cdot\mathcal{B}_{J/\psi\to\phi f_0}\cdot\mathcal{B}_{\phi\to K^+K^-}\cdot\mathcal{B}_{f_0\to\pi^0\pi^0}$	0.48±0.12±0.05	0.18±0.04±0.02	0.17 ±0.07 [c]
$\Gamma_{ee}^{J/\psi}\cdot\mathcal{B}_{J/\psi\to\phi f_x}\cdot\mathcal{B}_{\phi\to K^+K^-}\cdot\mathcal{B}_{f_x\to\pi^+\pi^-}$	0.74±0.12±0.05	0.27±0.04±0.02	0.72 ±0.13 [d]
$\Gamma_{ee}^{\psi(2S)}\cdot\mathcal{B}_{\psi(2S)\to K^+K^-\pi^+\pi^-}$	1.92±0.30±0.06	0.81±0.13±0.03	0.75 ±0.09
$\Gamma_{ee}^{\psi(2S)}\cdot\mathcal{B}_{\psi(2S)\to K^+K^-\pi^0\pi^0}$	0.60±0.31±0.03	0.25±0.13±0.02	no entry
$\Gamma_{ee}^{\psi(2S)}\cdot\mathcal{B}_{\psi(2S)\to K^+K^-K^+K^-}$	0.22±0.10±0.02	0.09±0.04±0.01	0.060±0.014
$\Gamma_{ee}^{\psi(2S)}\cdot\mathcal{B}_{\psi(2S)\to\phi\pi^+\pi^-}\cdot\mathcal{B}_{\phi\to K^+K^-}$	0.27±0.09±0.02	0.23±0.08±0.01	0.117±0.029
$\Gamma_{ee}^{\psi(2S)}\cdot\mathcal{B}_{\psi(2S)\to\phi f_0}\cdot\mathcal{B}_{\phi\to K^+K^-}\cdot\mathcal{B}_{f_0\to\pi^+\pi^-}$	0.17±0.06±0.02	0.15±0.05±0.01	0.068±0.024 [e]

[a] $\mathcal{B}_{J/\psi\to\phi KK}$ obtained as $2\cdot\mathcal{B}_{J/\psi\to\phi K^+K^-}$.
[b] Not corrected for the $f_0\to\pi^0\pi^0$ mode.
[c] Not corrected for the $f_0\to\pi^+\pi^-$ mode.
[d] We compare our ϕf_x, $f_x\to\pi^+\pi^-$ mode with $\phi f_2(1270)$.
[e] $\mathcal{B}_{\psi(2S)\to\phi f_0}$, $f_0\to\pi^+\pi^-$

Small systematic errors allow BaBar to improve BF for major decay modes.

Conclusions

1. ISR method is developed at Babar as a practical tool to study e+e- annihilation in wide CM energy range.

2. Numerous number of e+e→ hadrons process are studied at Babar including productions of pions, kaons, baryons, D-mesons, new states Y(4260), Y(2175), …

3. Babar data significantly contribute to $(g\text{-}2)_\mu$ calculation. Most of the channels have best to date accuracy.

4. Decay parameters of many vector mesons are improved ρ_S, ω_S, ϕ_S, J/ψ, $\psi(2S)$, …

5. We present new (preliminary) study of $K^+K^-\pi^+\pi^-$, $K^+K^-\pi^0\pi^0$, $K^+K^-K^+K^-$ channel production via ISR.

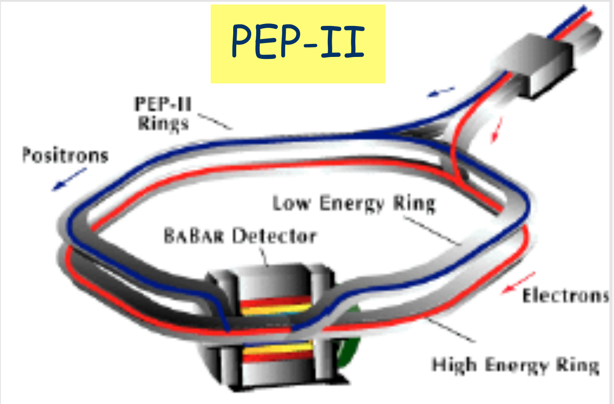
6. We confirm Y(2175) evidence with ~9 standard deviation significance and improve measurement of its parameters.

6. Some of the observed structures still have no proper theoretical explanation… PWA is needed to learn more..

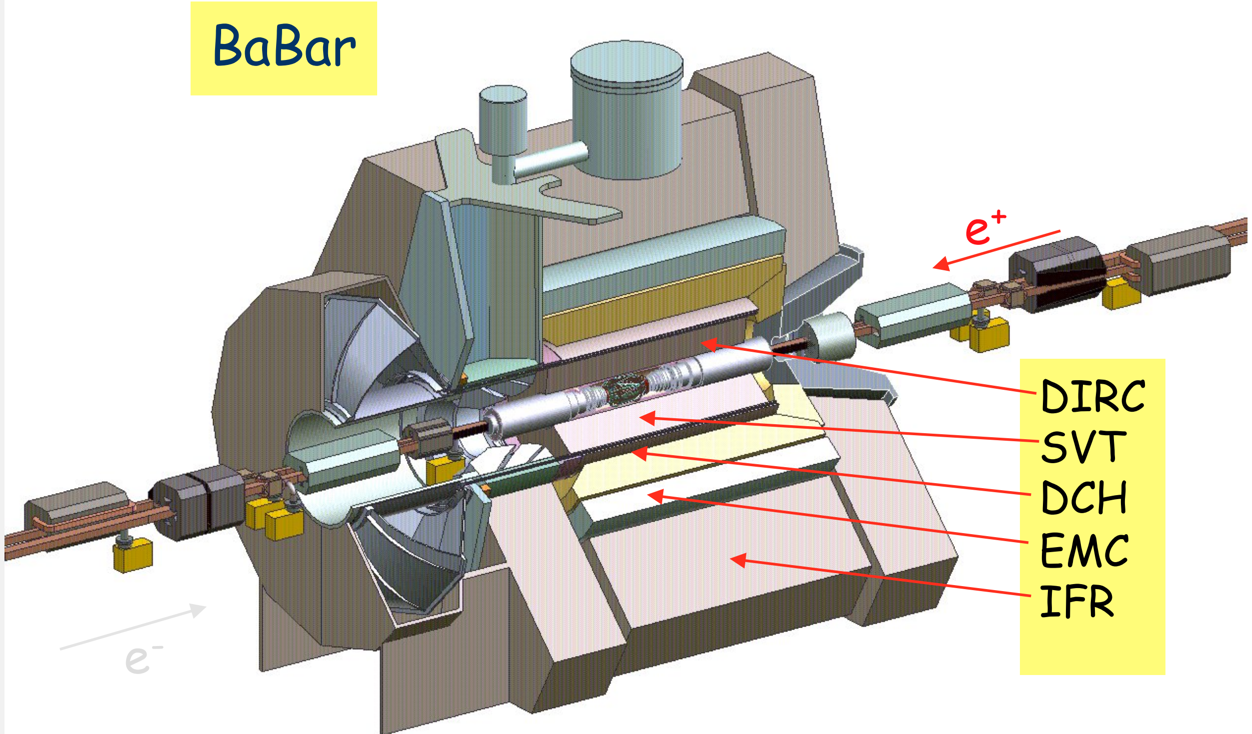
7. More data are in hand and new results are coming…

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
$\Delta L = 500\ fb^{-1}$
$N(B) = 10^9$



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

θ - photon polar angle in c.m.