Recent results on hadron production via ISR at BABAR

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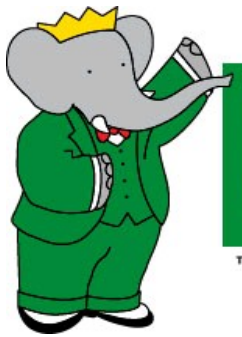
for the BABAR collaboration

22nd of July 2010



BABAR™

Institut für Kernphysik
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

motivation

$\vec{\mu} = g \cdot e\hbar/2mc \cdot \vec{S}$

with g: gyromagnetic factor

$g = 2$ Dirac-Theory (spin-1/2-particles)

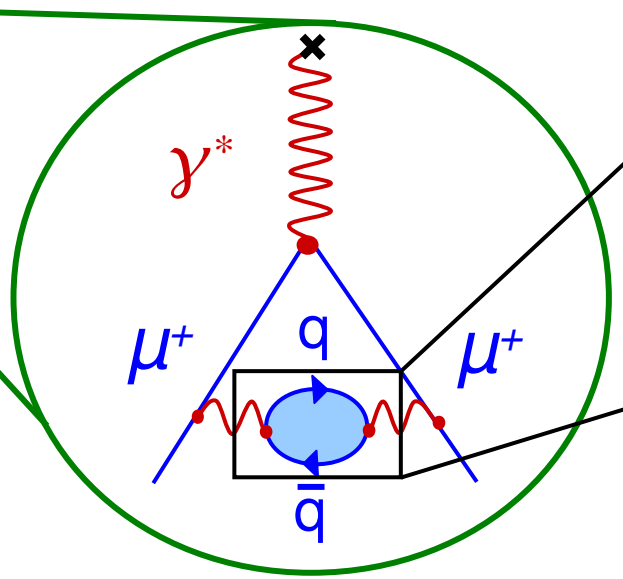
$g \neq 2$ Quantum Field Theory

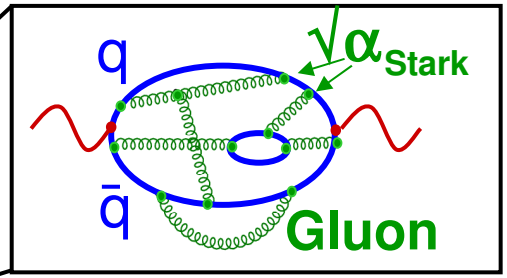
$a_\mu^{exp} = (11{,}659{,}208.9 \pm 6.3) 10^{-10}$

muon anomaly

$a_\mu = (g_\mu - 2) / 2$

$$a_\mu^{\text{theory}} = a_\mu^{\text{QED}} + a_\mu^{\text{weak}} + a_\mu^{\text{had}}$$





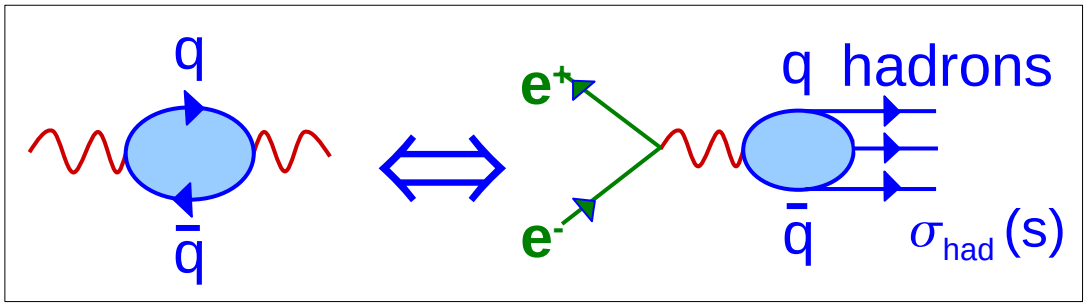
$\alpha_{strong} \approx O(1) \Rightarrow$ ~~pQCD~~

strong interaction:

- had. Vacuum Polarization (VP): production of quark-antiquark-pairs in virtual loops
- Light-by-Light Scattering (LbL)

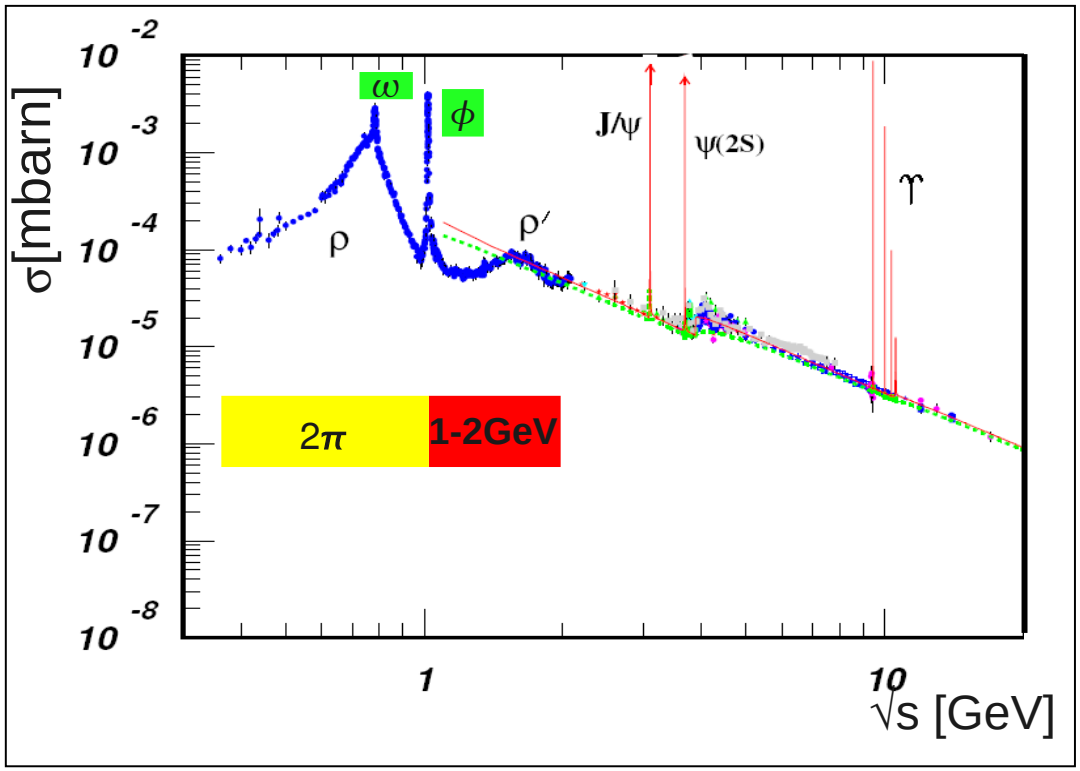
dispersion relation for a_μ^{hadr}

optical theorem:



dispersion integral:

$$a_\mu^{had} = \frac{1}{4\pi^3}\int_{4m_\pi^2}^{\infty} ds\, K(s)\, \sigma_{had}(s)$$



$K(s) \sim 1/s$

→ ***contributions at low energies very important (~1/s²)***

hadronic contribution to a_μ:
Sum of all exclusive hadronic e^+e^- cross-sections

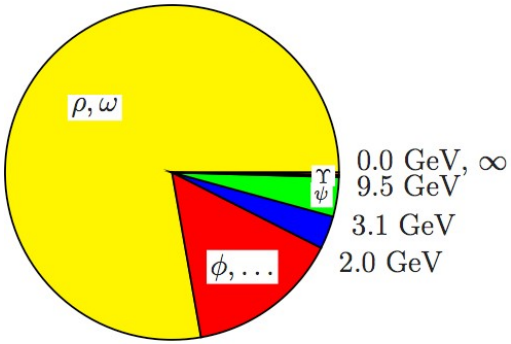
M. Davier *et al.*, EPJC71:1515 (2011):

$a_\mu^{exp} - a_\mu^{theo} = (28.7 \pm 8.0) \cdot 10^{-10}$ (significance: **3.6σ**) → Hint for physics beyond the SM?

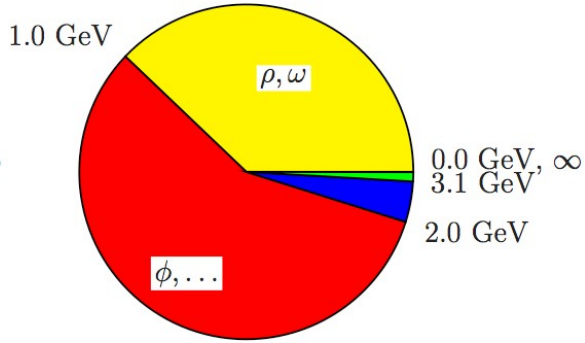
impact on a_μ^{had}

Contributions of different energy regions to the dispersion integral:

F. Jegerlehner, A. Nyffeler, *Physics Reports 477 (2009) 1*

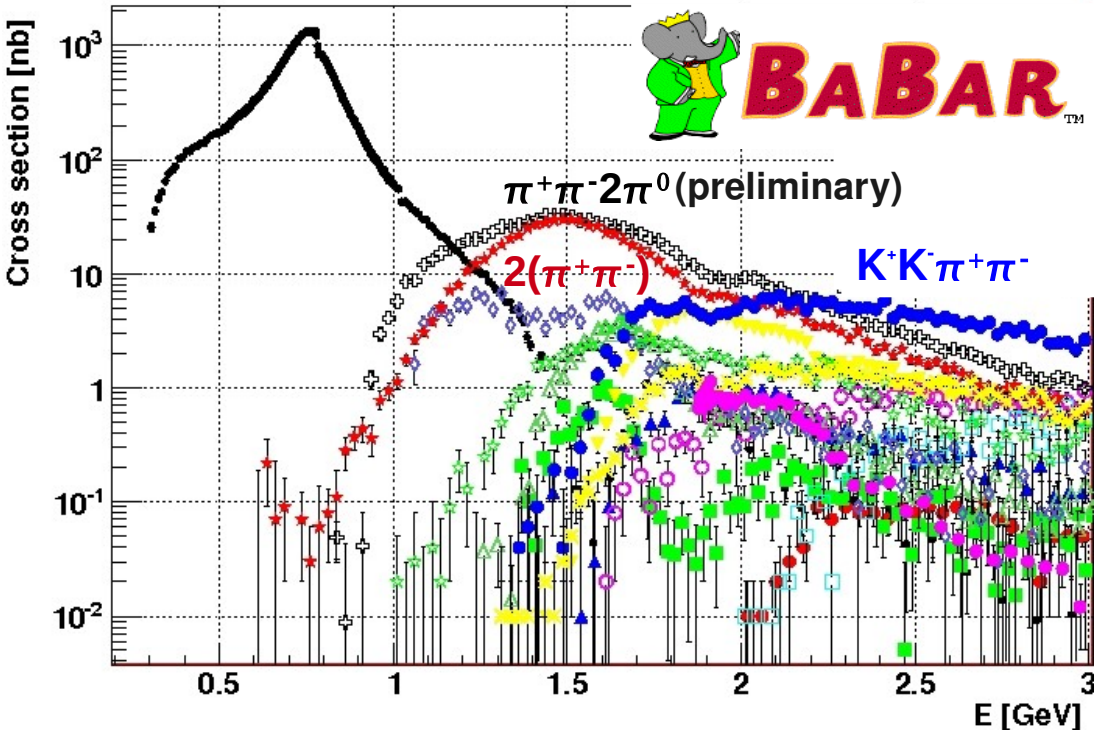


contributions



(uncertainty)^2

⇨ precise measurements below 2 GeV are needed

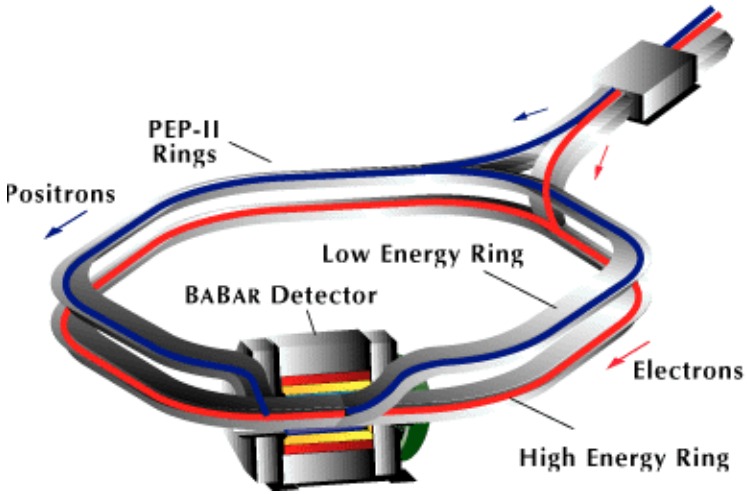


⇨ channels with higher multiplicity important!!

Why update?

- increase statistics
- systematics better understood
- use data for bkg subtraction
- radiative corrections

B-Factory PEP-II & BABAR detector

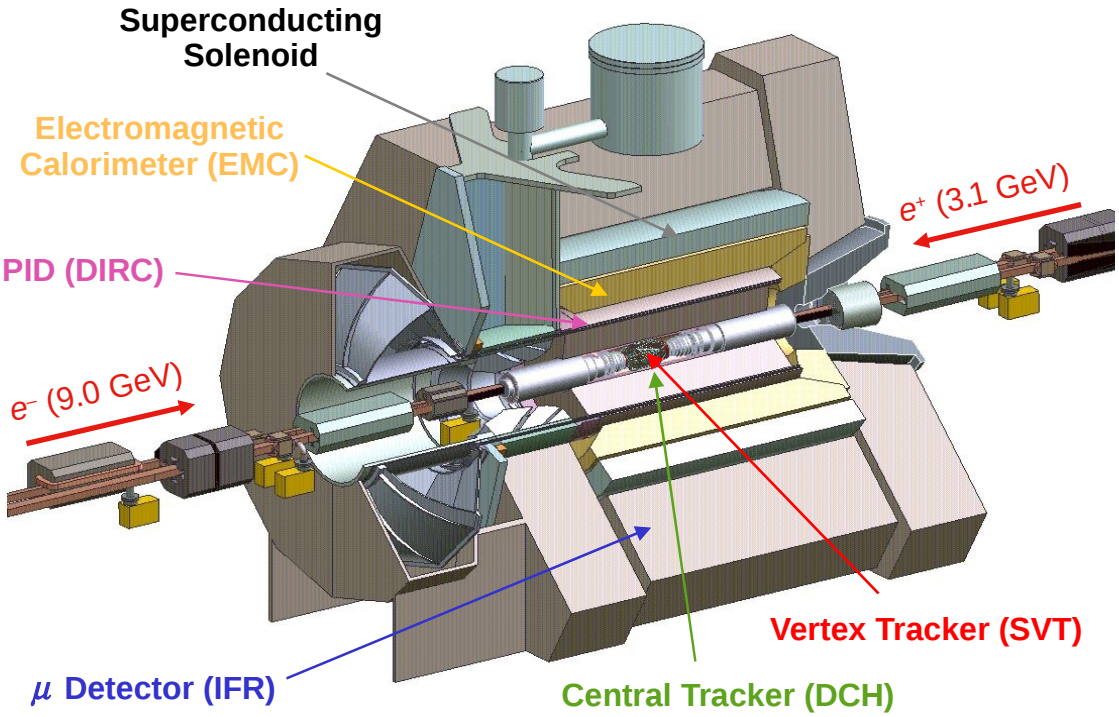


- asymmetric e^+e^- - collider:

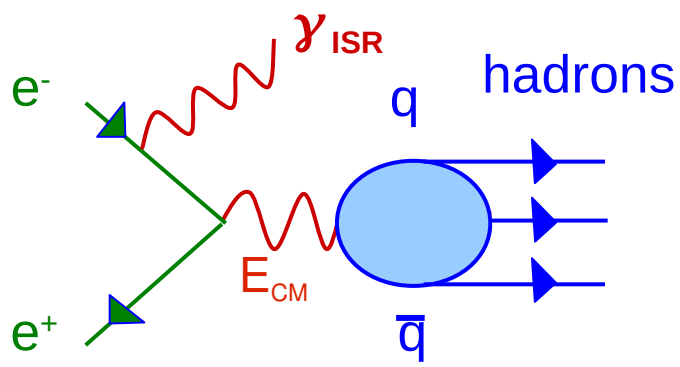
  9 GeV (e^-) and 3.1 GeV (e^+)
  $\rightarrow \sqrt{s}$=10.58 GeV $\rightarrow \Upsilon(4S)$-resonance
- main purpose: analysis of decays of B-meson pairs

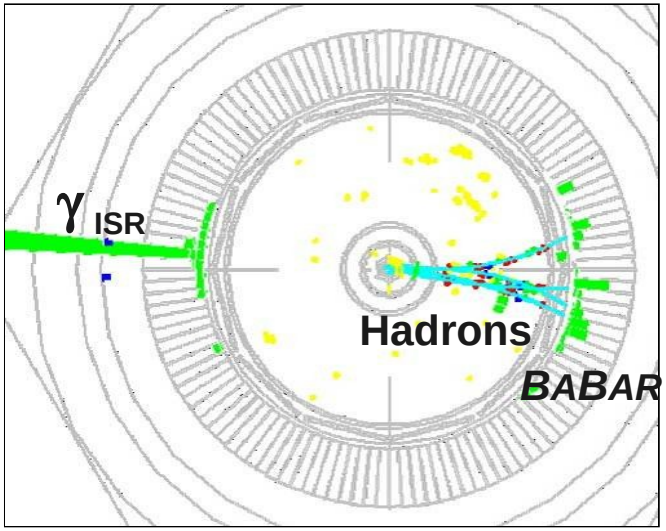
  $\Upsilon(4S) \rightarrow B^0\overline{B}^0$ or B^+B^-

- data taken from 1999-2008
- integrated luminosity: 531 fb^{-1}
  454 fb^{-1} on $\Upsilon(4S)$



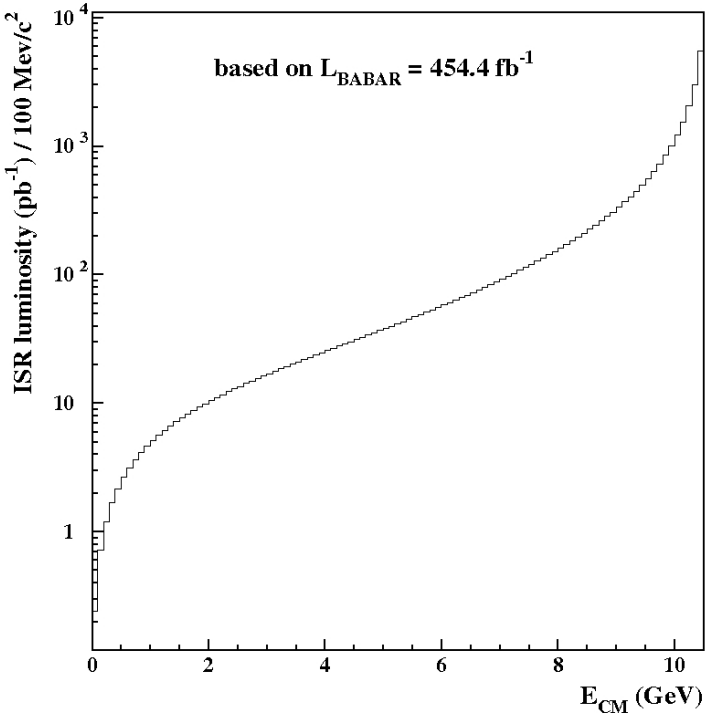
ISR events at BABAR





selection criteria:

- Photon > 3 GeV
- Typical topology: $\gamma_{ISR} \leftrightarrow$ hadrons
  - ➔ high acceptance
- Very good energy resolution (6-15 MeV)
  due to kinematic fit (including γ_{ISR})
- Boost in laboratory system
  $\rightarrow$high efficiency at threshold!
- Continuous measurement from threshold until 4.5 GeV/c^2
  $\rightarrow$reduced point-to-point uncertainty
- simultaneous measurement of the muon cross section
  (fully calculable by QED) provides crucial test for ISR lumi



exclusive ISR measurements at BABAR

published:

- 2 mesons: $e^+e^- \to \pi^+\pi^-$ PRL 103 (2009) 231801
- 2 mesons: $e^+e^- \to \phi\ f_0(980)$ PRD 74 (2006) 091103 & PRD 76 (2007) 012008
- 3 mesons: $e^+e^- \to \pi^+\pi^-\pi^0$ PRD 70 (2004) 072004
- 3 mesons: $e^+e^- \to K^+K^-\eta$, $K^+K^-\pi^0$, $K^0_S K^\pm\pi^\mp$ PRD 77 (2008) 092002
- 4 mesons: $e^+e^- \to 2(\pi^+\pi^-)$, $K^+K^-\pi^0\pi^0$, $K^+K^-\pi^+\pi^-$, $2(K^+K^-)$ PRD 71 (2005) 052001, PRD 76 (2007) 012008
- 5 mesons: $e^+e^- \to 2(\pi^+\pi^-)\pi^0$, $2(\pi^+\pi^-)\eta$, $K^+K^-\pi^+\pi^-\pi^o$, $K^+K^-\pi^+\pi^-\eta$ PRD 76 (2007) 092005
- 6 mesons: $e^+e^- \to 3(\pi^+\pi^-)$, $2(\pi^+\pi^-\pi^0)$, $2(\pi^+\pi^-)K^+K^-$ PRD 73 (2006) 052003
- 2 baryons: $e^+e^- \to p\bar{p}$ PRD 73 (2006) 012005
- 2 baryons: $e^+e^- \to \Lambda\bar{\Lambda}$, $\Lambda\bar{\Sigma}^0$, $\Sigma^0\bar{\Sigma}^0$ PRD 76 (2007) 092006

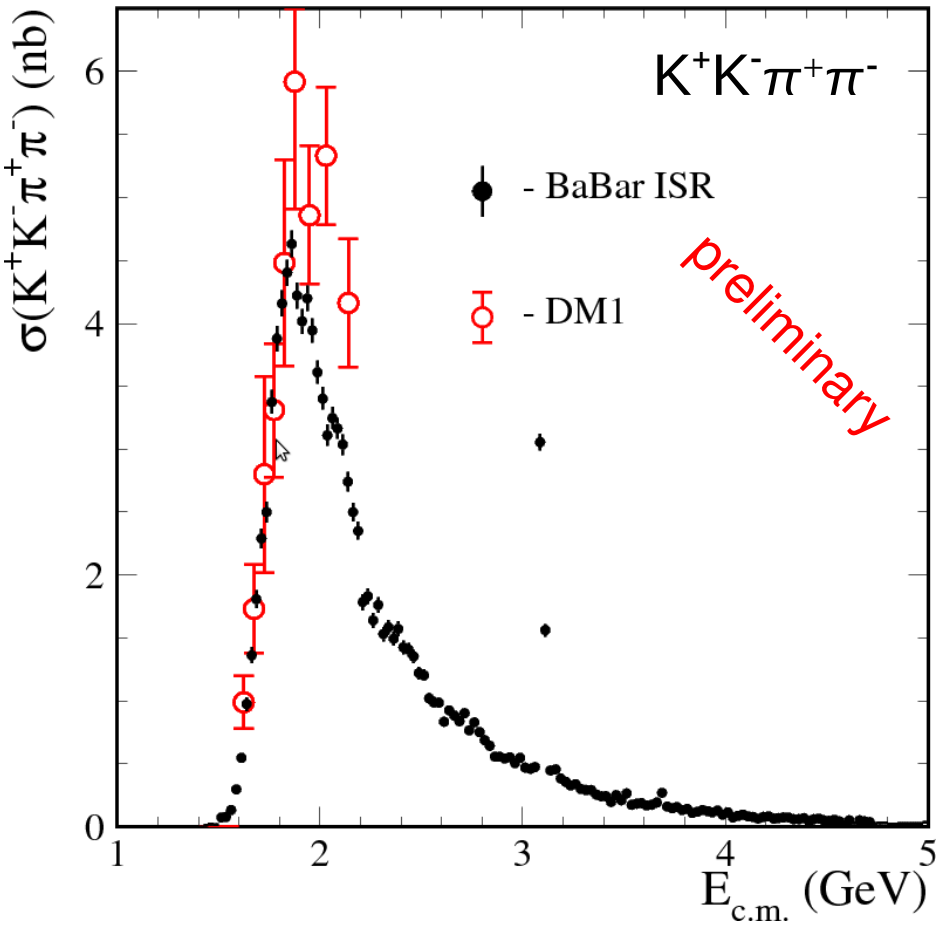
ongoing analyses:

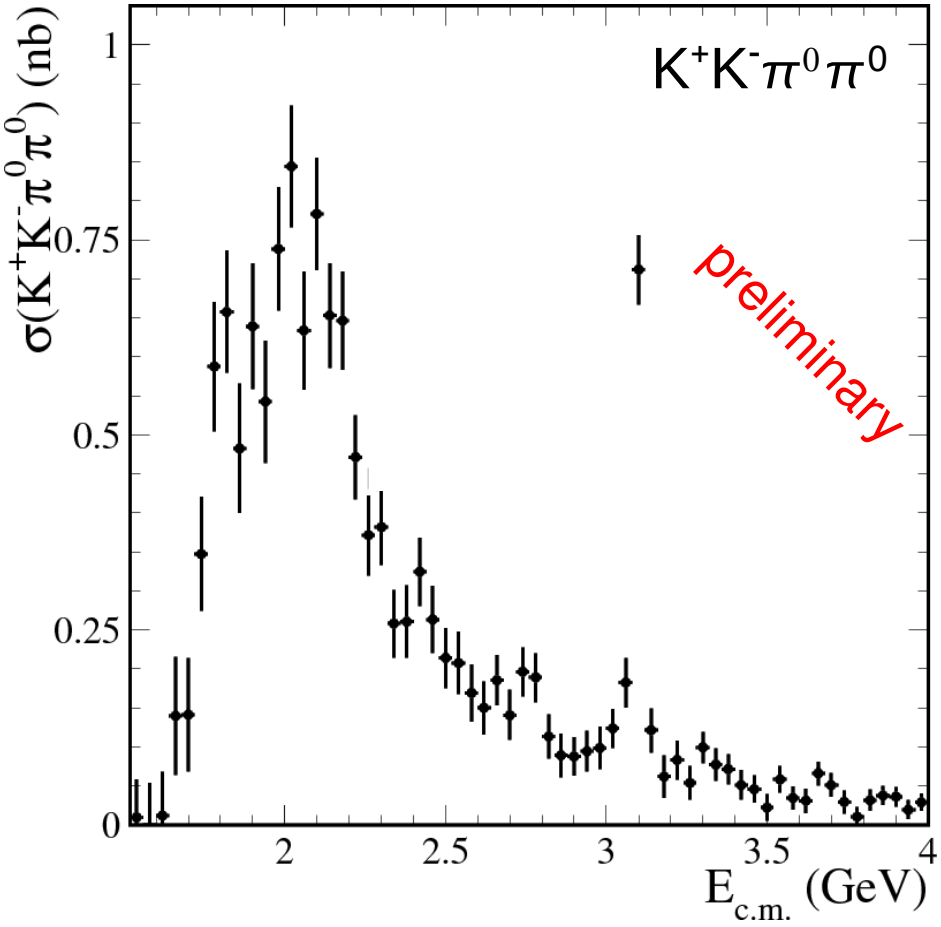
- 2 mesons: $e^+e^- \to K^+K^-$, K_SK_L
- 4 mesons: $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$
- about to be published: $e^+e^- \to 2(\pi^+\pi^-)$, $K^+K^-\pi^0\pi^0$, $K^+K^-\pi^+\pi^-$, $2(K^+K^-)$

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

preliminary results (submitted to PRD)
(**arXiv:1103.3001v1**)
our previous publication, based on part of the data:
B. Aubert *et al.* (BaBar Collaboration),
Phys. Rev. D76, 012008 (2007).

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

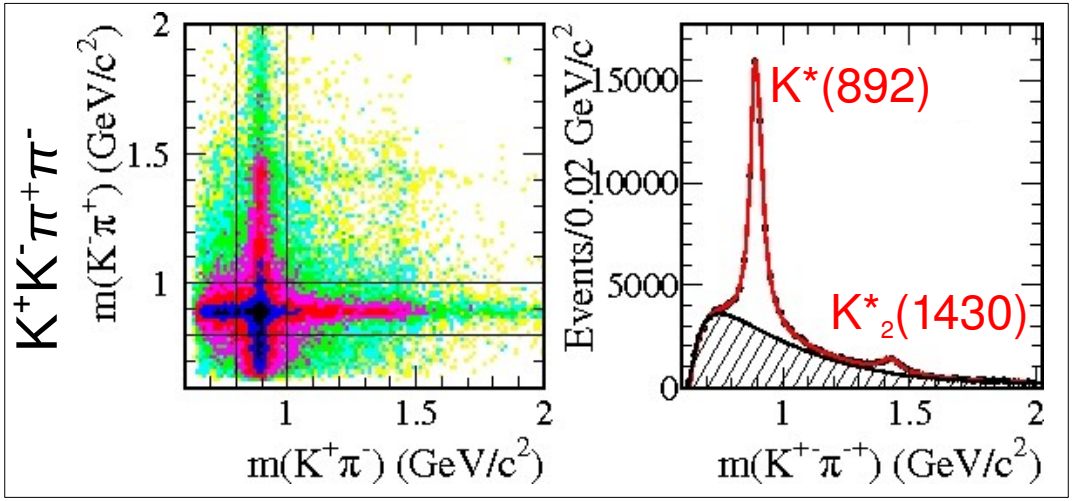


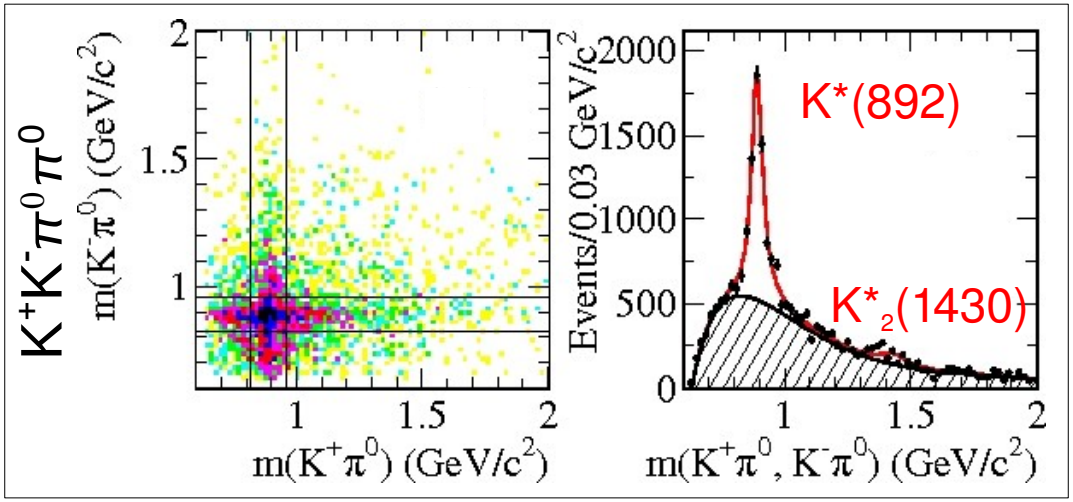


- syst. uncertainty: 4-11%
- resolution: 4.2 - 5.5 MeV
- J/ψ clearly visible

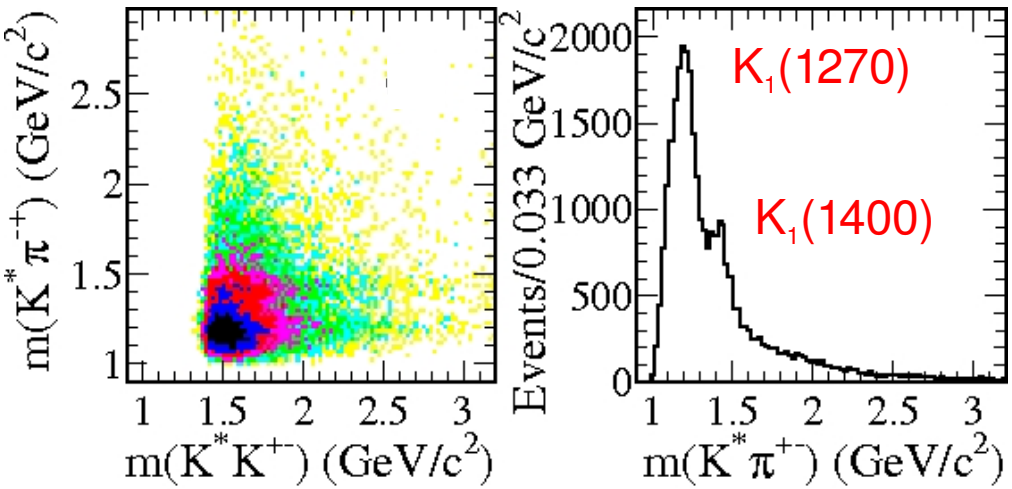
- syst. uncertainty 7-16%
- resolution: 8.8 - 11.2 MeV
- J/ψ clearly visible

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





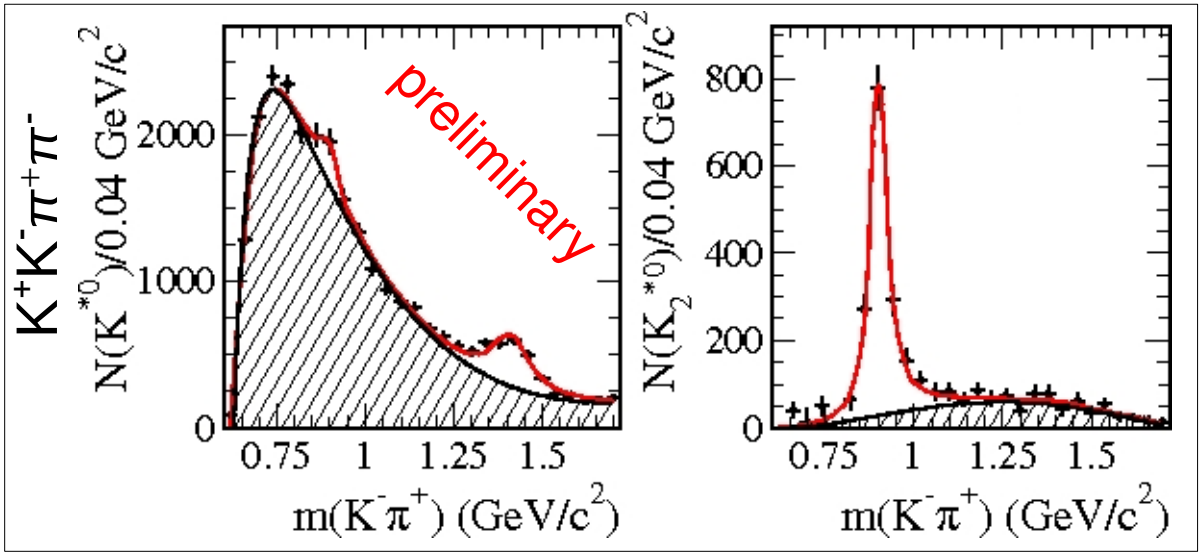
charged combinations from K*(892)^0 bands



Cross section dominated by K*(892)Kπ final state:
$K_1(1270, 1400) \to K^*(892)\pi$ and
$K_1(1270, 1400) \to K\rho(770)$ are seen

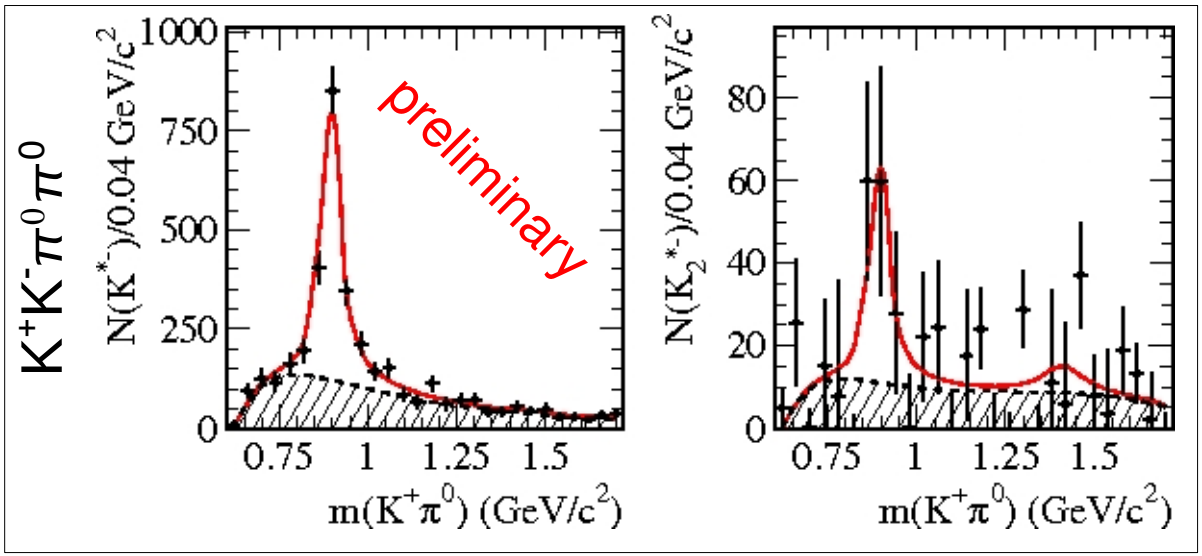
$e^+e^- \to K^+K^-\pi\pi$

cross section dominated by K*(892)Kπ final state! … BUT...



Count number of K*(892)^0 and K*(1430)^0 by fitting $K^+\pi^-$ mass in every 40 MeV bin of $K^-\pi^+$ mass

⇒ less than 1% K*(892)^{0}K*(892)^0

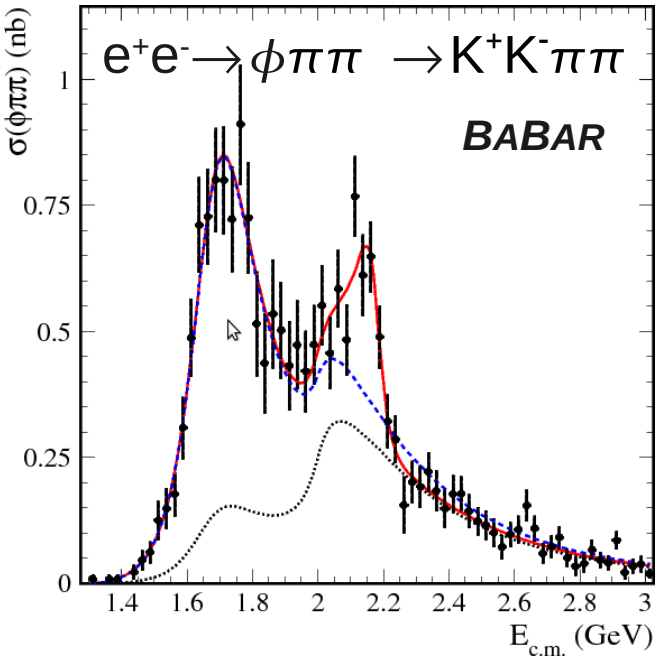


Count number of K*(892)$^+$ K*(1430)$^+$ by fitting 40 MeV bins of $K^-\pi^0$ mass

⇒ 30% K*(892)$^\pm$K*(892)$^\mp$

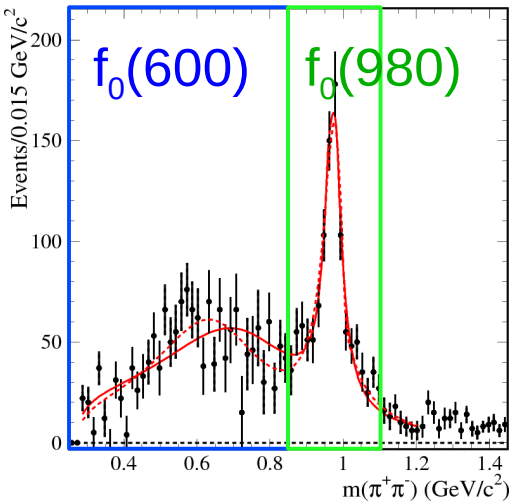
$e^+e^- \to K^+K^-\pi\pi$

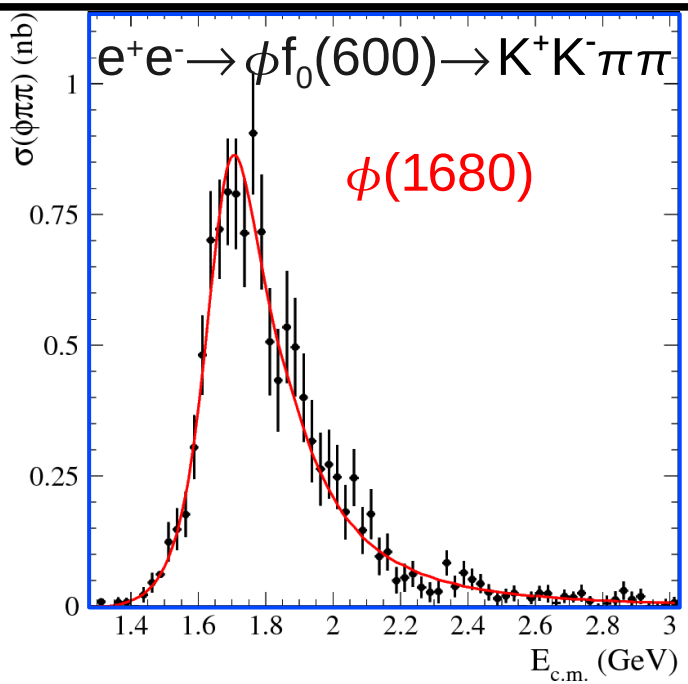
events including a ϕ:

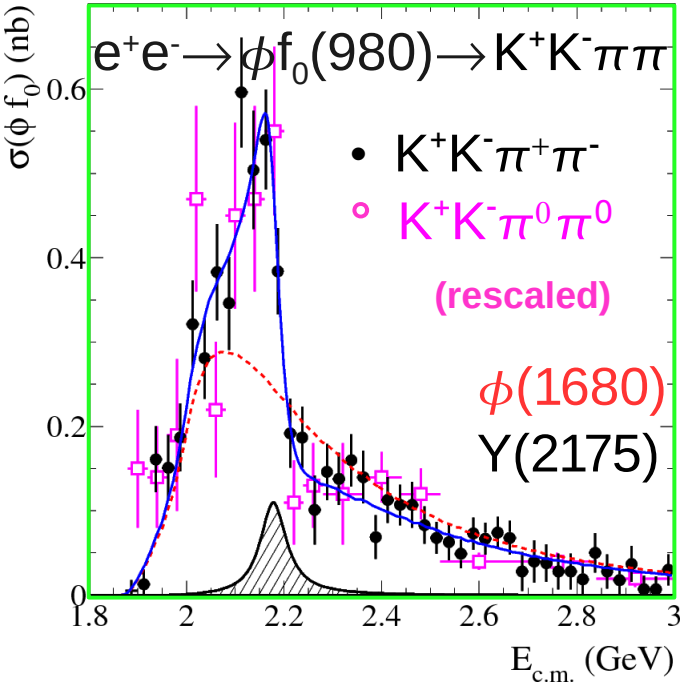


preliminary

$\pi\pi$ S-wave:







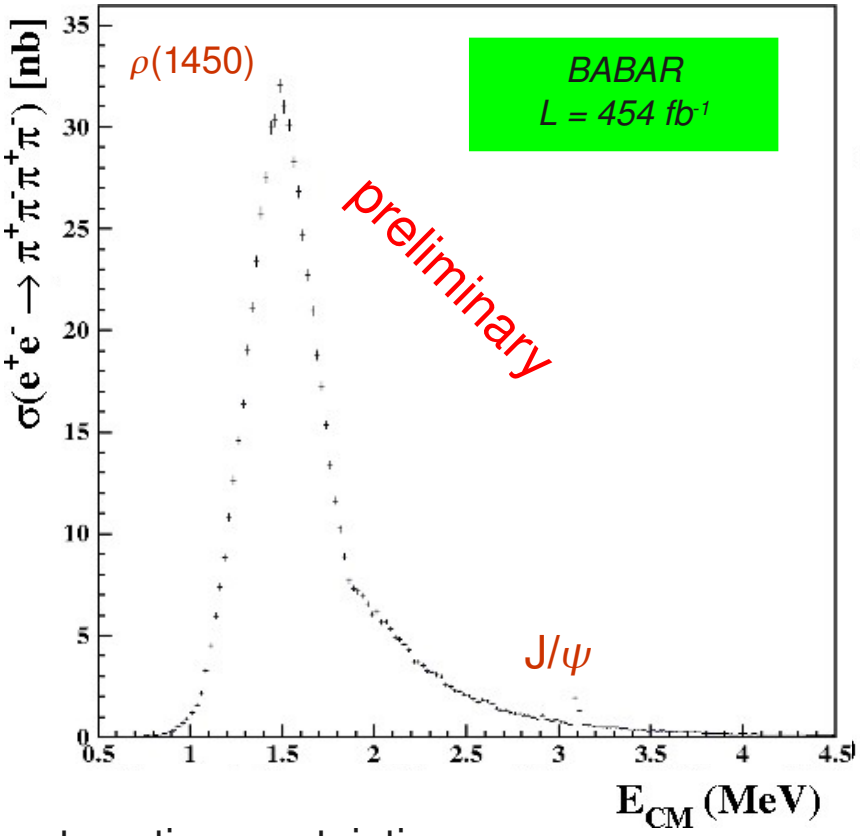
- min. 2 peaks!
- new resonance with $J^{PC} = 1^{--}$?
  mass: 2175 MeV/c^2; width: 58 MeV
- not a radial excitation:
  - width too small
  - should also decay in $f_0(600)$ as $\phi(1680)$
- strangeness partner of Y(4260)?
- hybrid-candidate

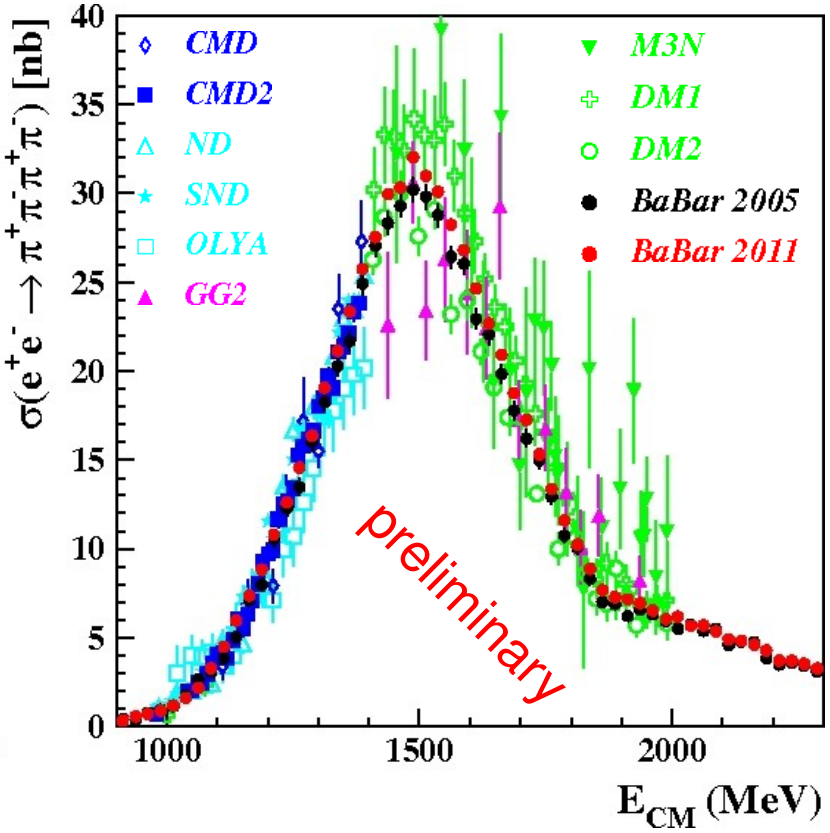
$e^+e^- \to \pi^+\pi^-\pi^+\pi^-$

preliminary result

supersedes our previous publication,
based on part of the data:
B. Aubert *et al.* (BaBar Collaboration),
Phys. Rev. D71, 052001 (2005).

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





- systematic uncertainties:
  - 2.4% in peak (1.1 GeV - 2.8 GeV)
  - 11% (0.6 GeV - 1.1 GeV)
  - 4% (2.8 GeV - 4.0 GeV)
- hint for $\rho(1450)$, J/ψ
- $a_\mu^{had}(4\pi) = (13.64 \pm 0.03 \pm 0.36) \cdot 10^{-10}$

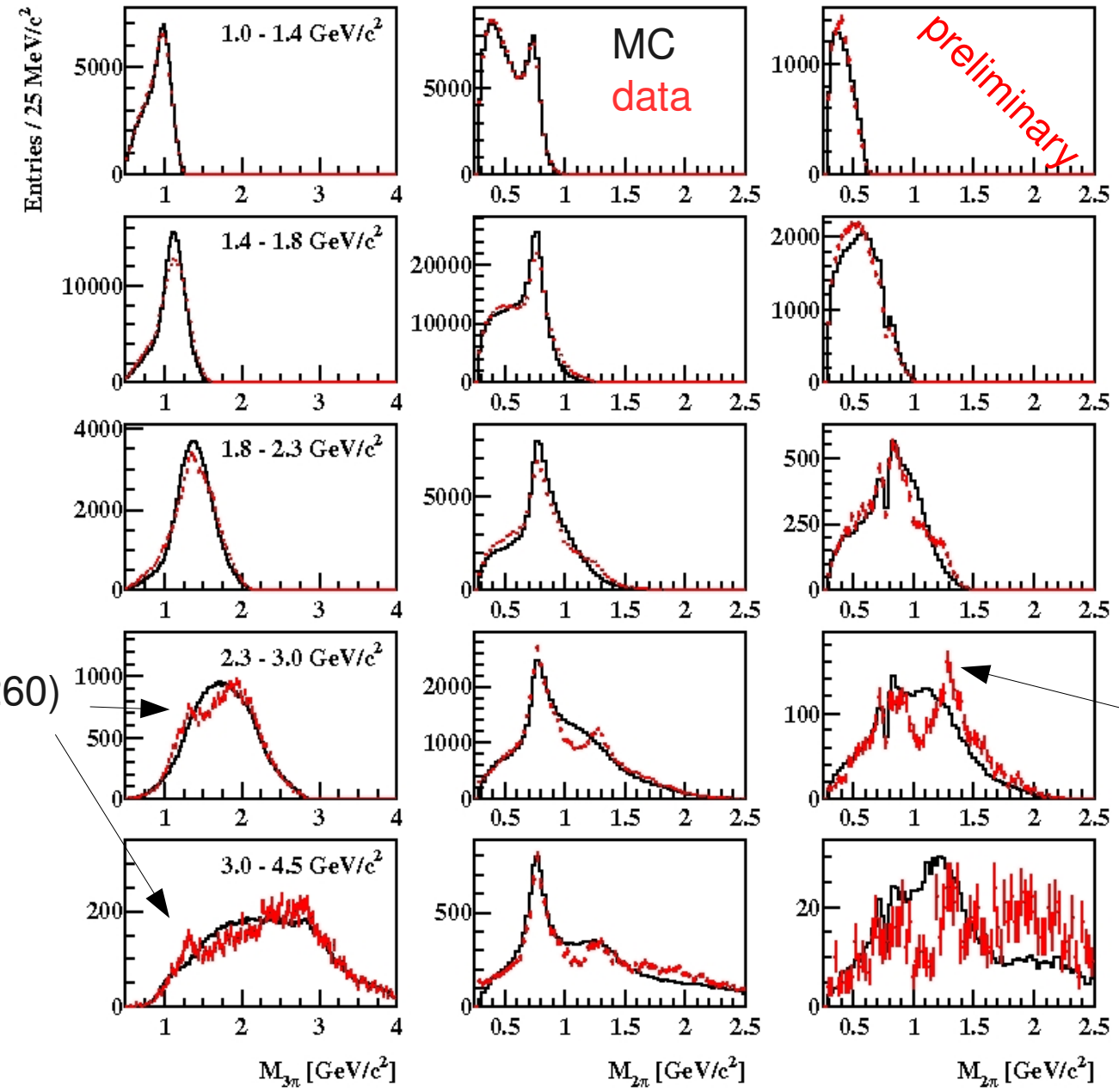
< 1.4 GeV: agreement with previous BaBar results, SND (syst. uncertainty 10%) and new CMD-2 data

> 1.4 GeV: higher in precision (DM2, 20%)

$a_{\mu\ world}^{had}(4\pi) = (13.31 \pm 0.10 \pm 0.43 \pm 0.29) \cdot 10^{-10}$

[in energy region 0.625 GeV < E_{CM} < 1.8 GeV]

intermediate resonances



$a_1(1260)$

4 entries per event
strong ρ^o contribution
$\rho^o\rho^o$ is forbidden!
For 4π mass > 1.4 GeV:
$1/4^{th}$ of entries are in ρ^o peak
ρ^o in each event!

diagrams in third column:
two π have ρ^o mass &
other π's mass is plotted

$f_2(1270)$? -> PWA needed

preliminary

$|M_{other}(2\pi)-M(\rho^o)| < 25$ MeV/c^2

summary

Measurement of hadronic cross sections via **ISR** is a very **productive field** in addition to B-physics **at BABAR**

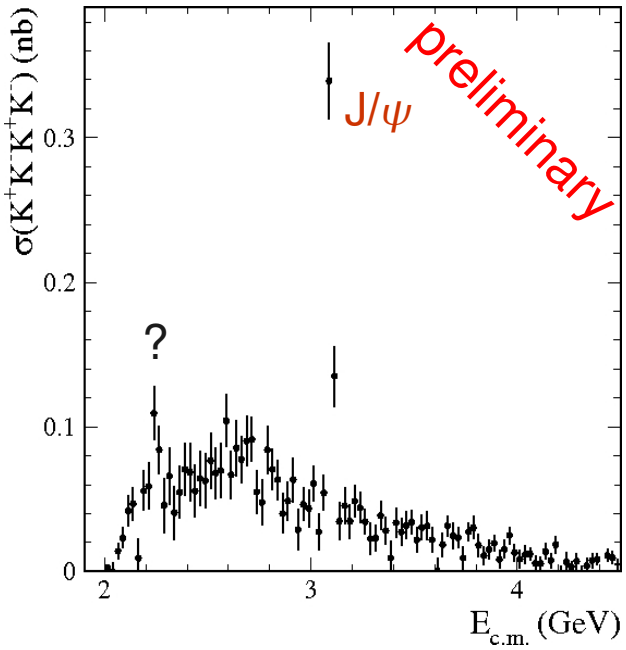
ISR Physics:

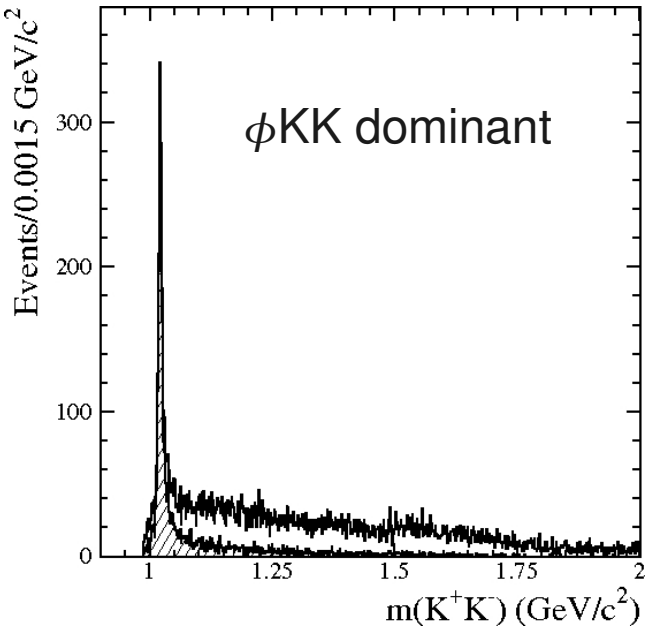
- Measurements from threshold up to 5 GeV/c^2
- Many measurements for the first time with high accuracy
- Important for theoretical predictions of (g_μ - 2)

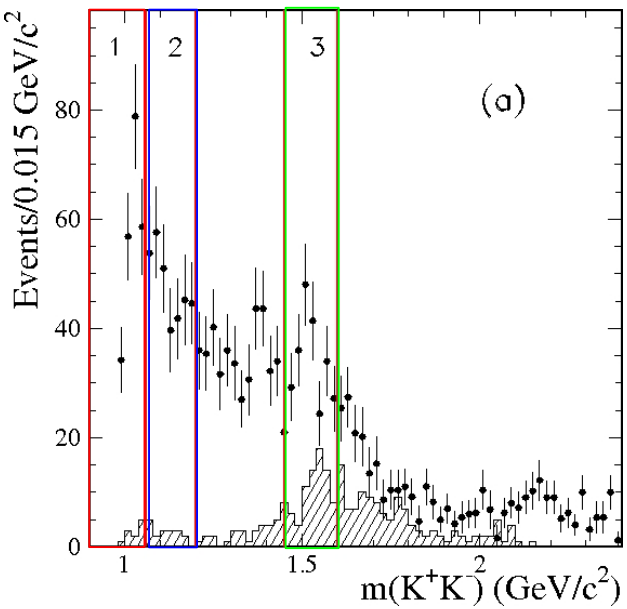
  $\rightarrow$ Hint for new physics? (3.6 σ)
- Implications on the running of $\alpha_{QED}(M_Z^2)$ and predictions for the Higgs mass
- Hadron spectroscopy

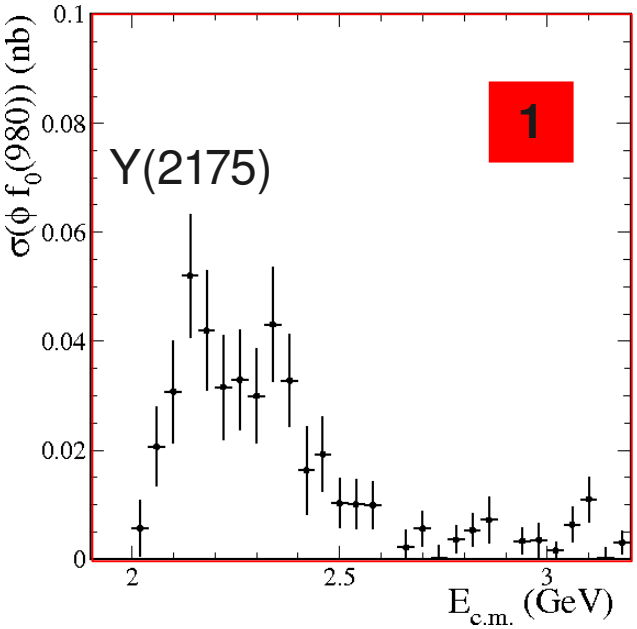
Backup

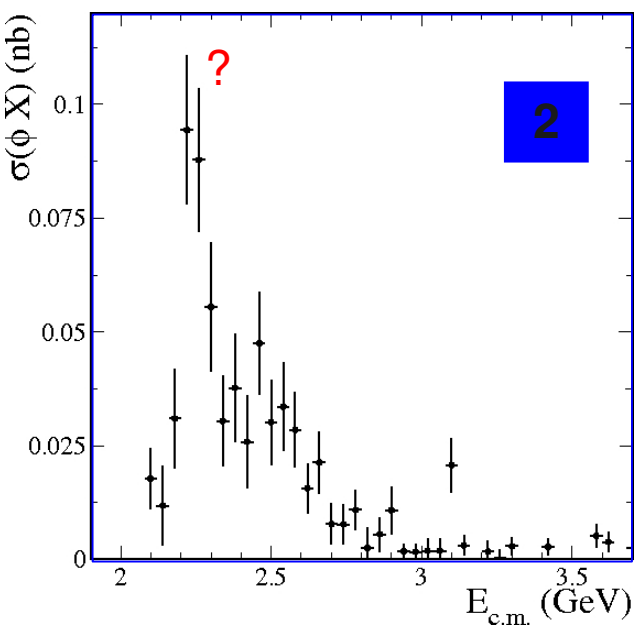
$e^+e^- \to K^+K^-K^+K^-$

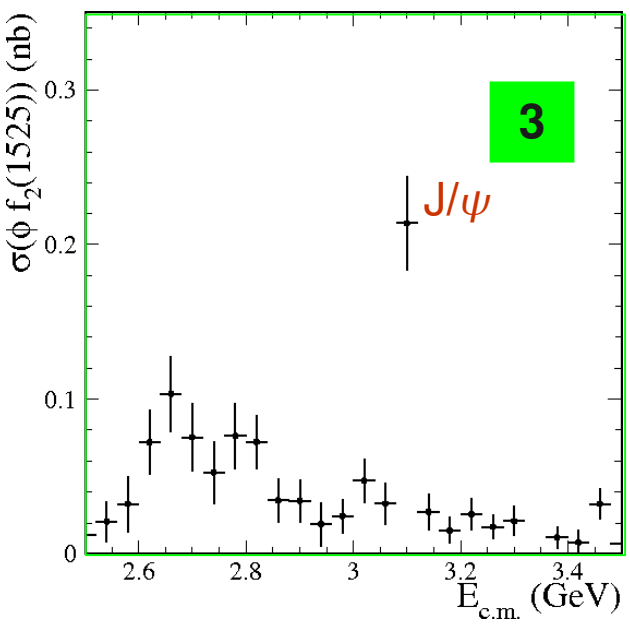

preliminary
J/ψ
?
σ(K⁺K⁻K⁺K⁻) (nb)
E_c.m. (GeV)


φKK dominant
Events/0.0015 GeV/c²
m(K⁺K⁻) (GeV/c²)

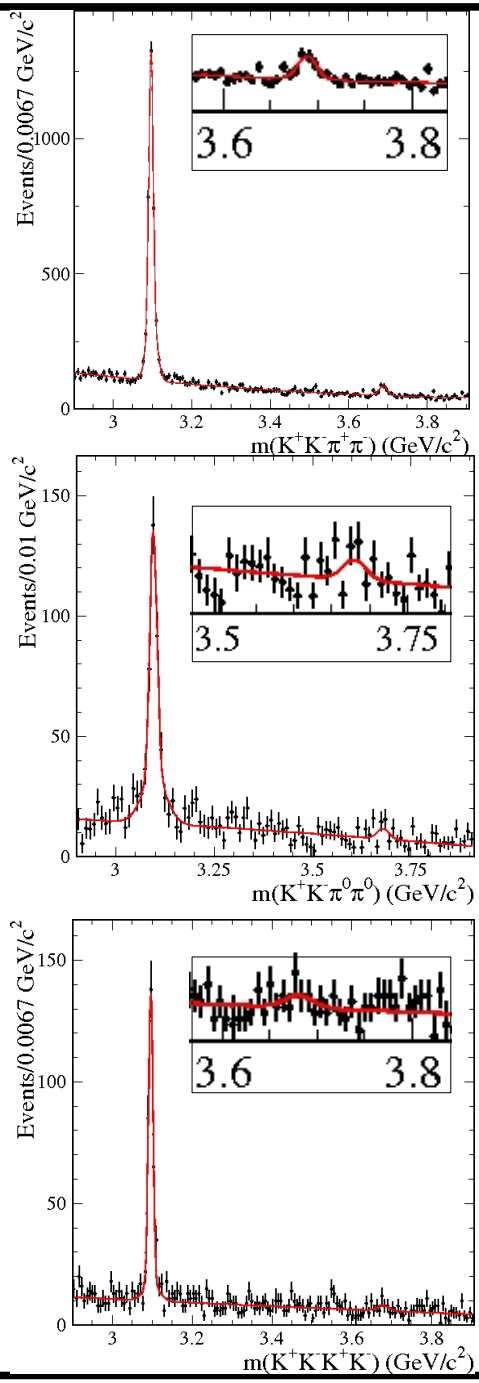

1
2
3
(a)
Events/0.015 GeV/c²
m(K⁺K⁻) (GeV/c²)


Y(2175)
1
σ(φ f₀(980)) (nb)
E_c.m. (GeV)


?
2
σ(φ X) (nb)
E_c.m. (GeV)


3
J/ψ
σ(φ f₂(1525)) (nb)
E_c.m. (GeV)

charmonium Branching Fractions



preliminary

Measured Quantity	Measured Value (eV)	J/ψ or $\psi(2S)$ Branching Fraction (10^{-3}) This work	PDG2010
$\Gamma_{ee}^{J/\psi}\cdot\mathcal{B}_{J/\psi\to K^+K^-\pi^+\pi^-}$	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
$\Gamma_{ee}^{J/\psi}\cdot\mathcal{B}_{J/\psi\to K^{*0}\overline{K}_2^{*0}}\cdot\mathcal{B}_{K^{*0}\to K^+\pi^-}\cdot\mathcal{B}_{\overline{K}_2^{*0}\to K^-\pi^+}$	8.59±0.36±0.27	6.98±0.29±0.21	6.0 ±0.6
$\Gamma_{ee}^{J/\psi}\cdot\mathcal{B}_{J/\psi\to K^{*0}\overline{K}^{*0}}\cdot\mathcal{B}_{K^{*0}\to K^+\pi^-}\cdot\mathcal{B}_{\overline{K}^{*0}\to K^-\pi^+}$	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] $\mathcal{B}_{J/\psi\to\phi\overline{K}K}$ 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 $\phi f_x, f_x\to\pi^+\pi^-$ mode with $\phi f_2(1270)$.
[e] $\mathcal{B}_{\psi(2S)\to\phi f_0}, f_0\to\pi^+\pi^-$

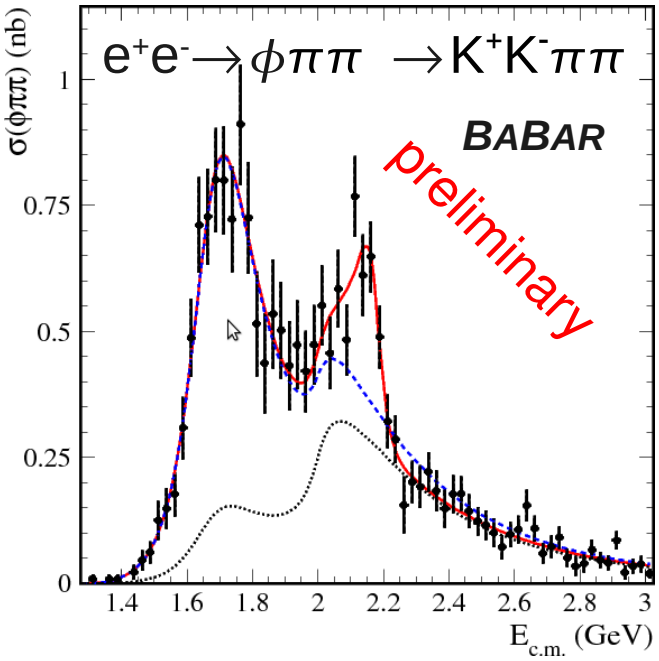
small systematic uncertainties at BaBar

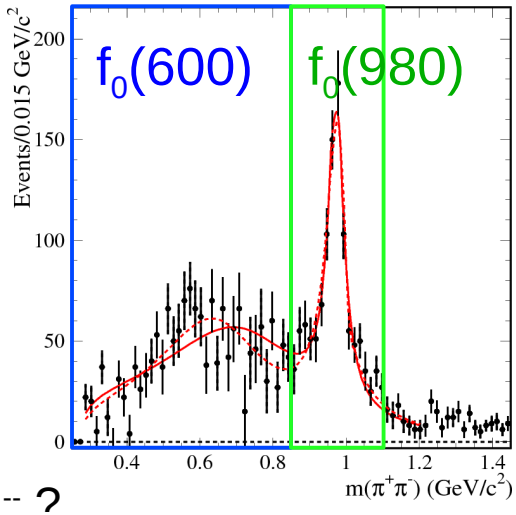
⇩

improve BFs of many decay modes

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

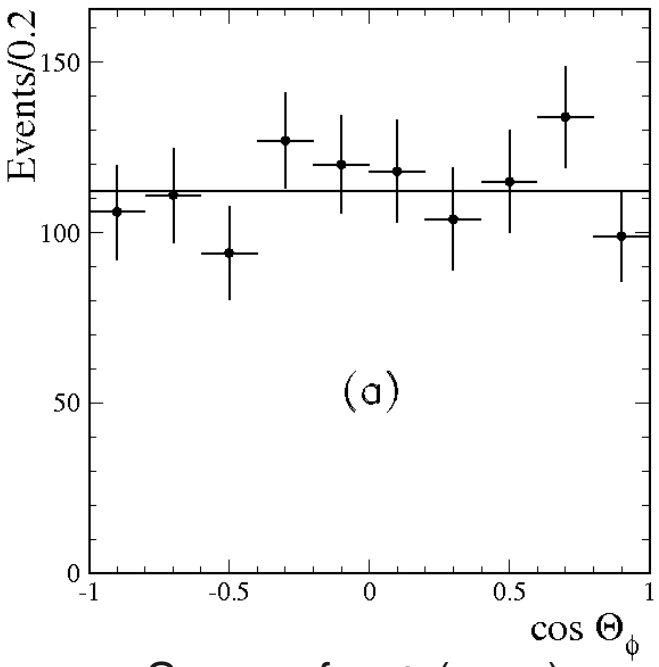
events including a ϕ:



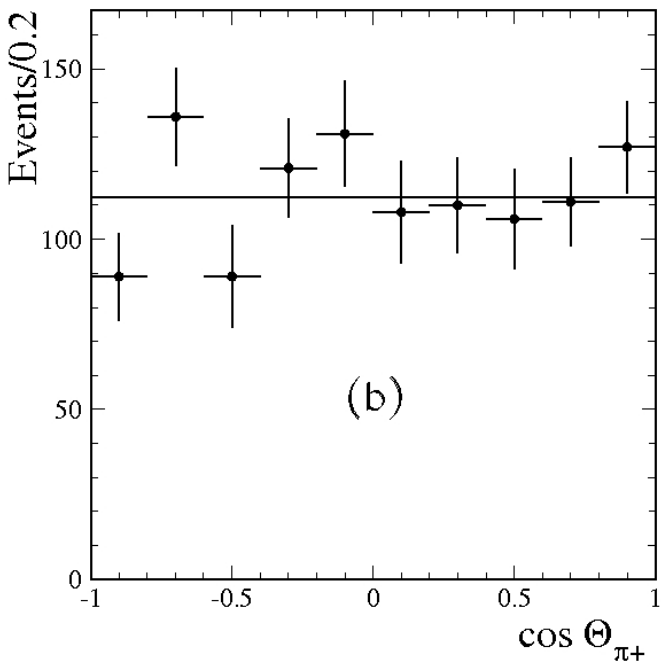


- min. 2 peaks!
- new resonance with $J^{PC} = 1^{--}$?
  mass: 2175 MeV/c^2; width: 58 MeV

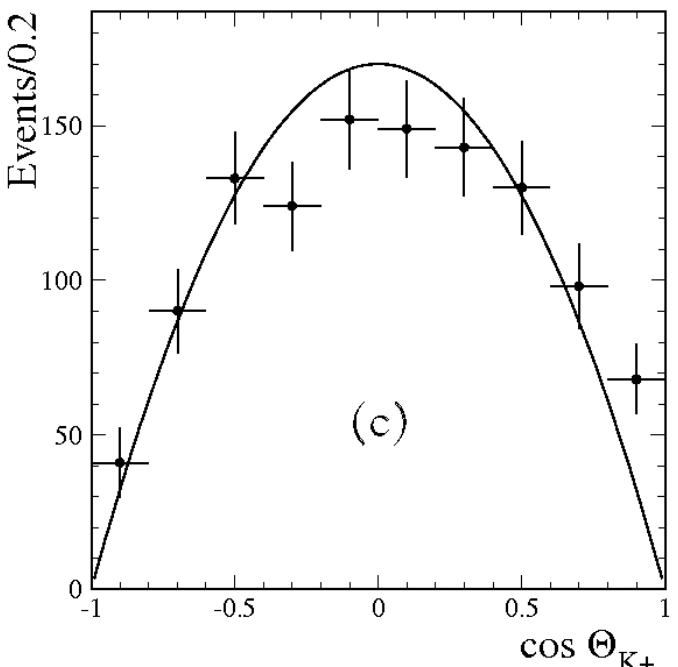
$e^+e^- \to \phi\pi\pi \to K^+K^-\pi\pi$



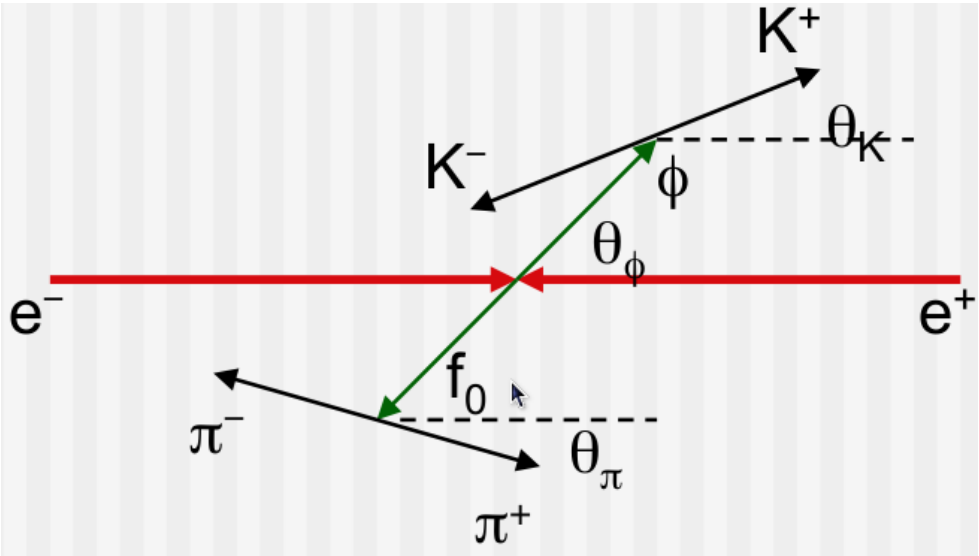
S-wave for ϕ ($\pi^-\pi^+$)



S-wave for $\pi^-\pi^+$ from f_0



P-wave for KK from ϕ



ϕ and $\pi^-\pi^+$ system are in S-wave
Pions in $\pi^-\pi^+$ system are in S-wave
Kaons from ϕ are in P-wave (as expected)

anomaly of magnetic moment of muon

$$\vec{\mu} = g \cdot e\hbar/2mc \cdot \vec{S}$$

with g: gyromagnetic factor

$g = 2$ Dirac-Theory (spin-1/2-particles)

$g \neq 2$ Quantum Field Theory

muon anomaly

$$a_\mu = (g_\mu - 2) / 2$$

$$a_\mu^{\text{theory}} = a_\mu^{\text{QED}} + a_\mu^{\text{weak}} + a_\mu^{\text{had}}$$

anomaly of magnetic moment of muon

$\vec{\mu} = g \cdot e\hbar/2mc \cdot \vec{S}$

with g: gyromagnetic factor

$g = 2$ Dirac-Theory (spin-1/2-particles)

$g \neq 2$ Quantum Field Theory

muon anomaly

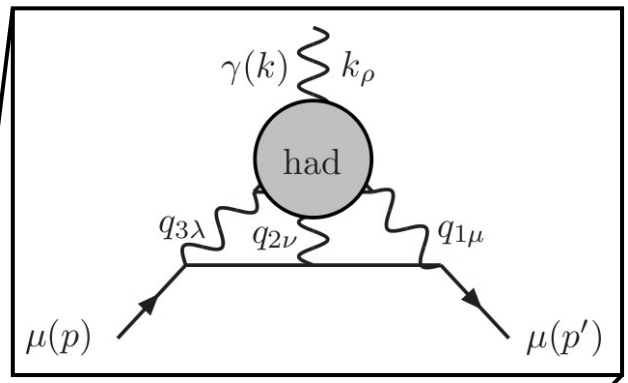
$a_\mu = (g_\mu - 2) / 2$

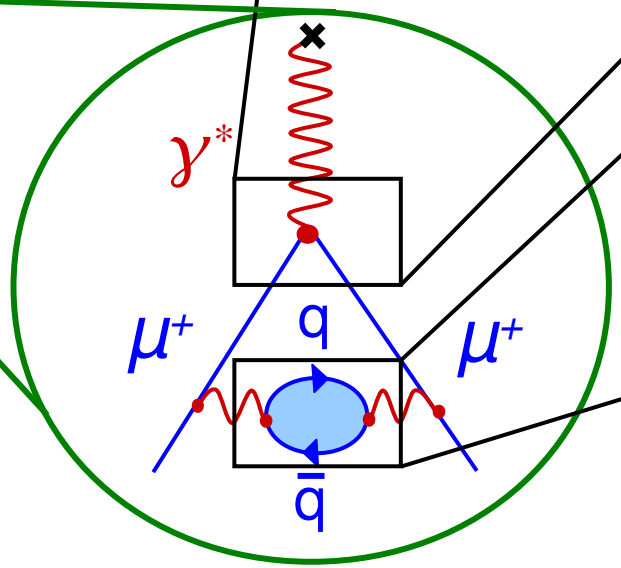
$$a_\mu^{\text{theory}} = a_\mu^{\text{QED}} + a_\mu^{\text{weak}} + a_\mu^{\text{had}}$$

strong interaction:

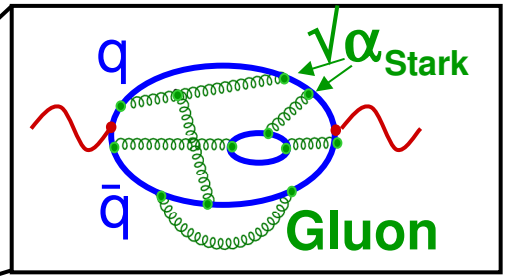
- had. Vacuum Polarization (VP): production of quark-antiquark-pairs in virtual loops
- Light-by-Light Scattering (LbL)

LbL





hadronic VP



$\alpha_{\text{strong}} \approx O(1) \Rightarrow$ ~~pQCD~~

typical analysis path $\sigma(e^+e^- \to \text{had})$

$dN(\text{had},\gamma_{ISR}) / dE_{CM}$
with acceptance cuts

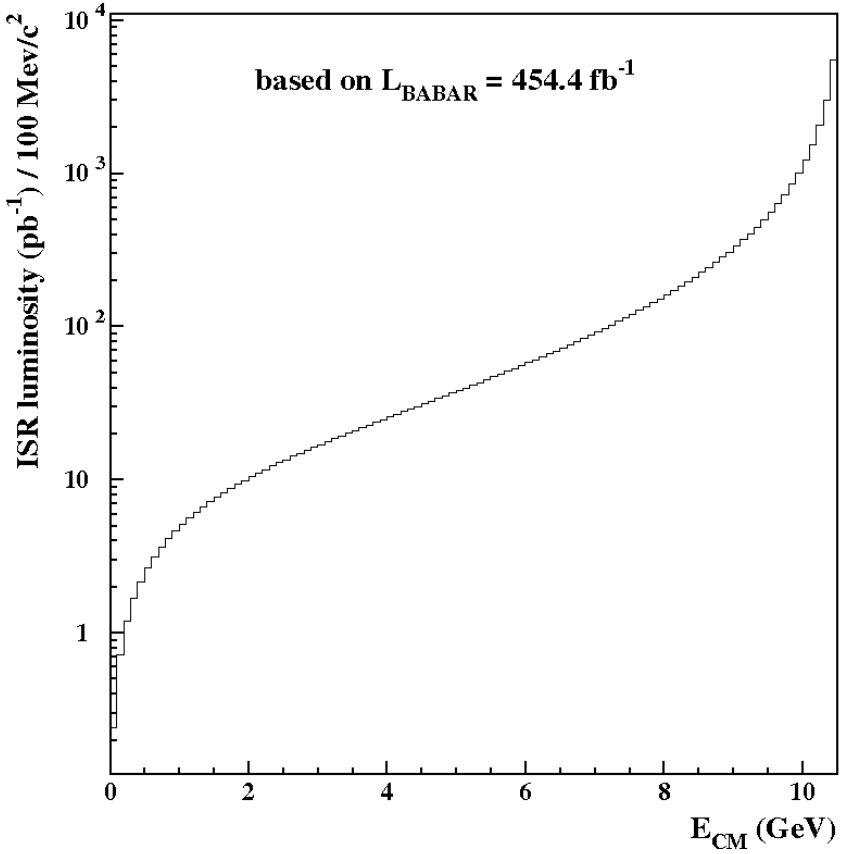
heart of analysis:
efficiencies (data-MC diff.),
background in dependence of E_{CM}

normalise with **luminosity**
and **radiator function**

cross checked with $\mu\mu\gamma$

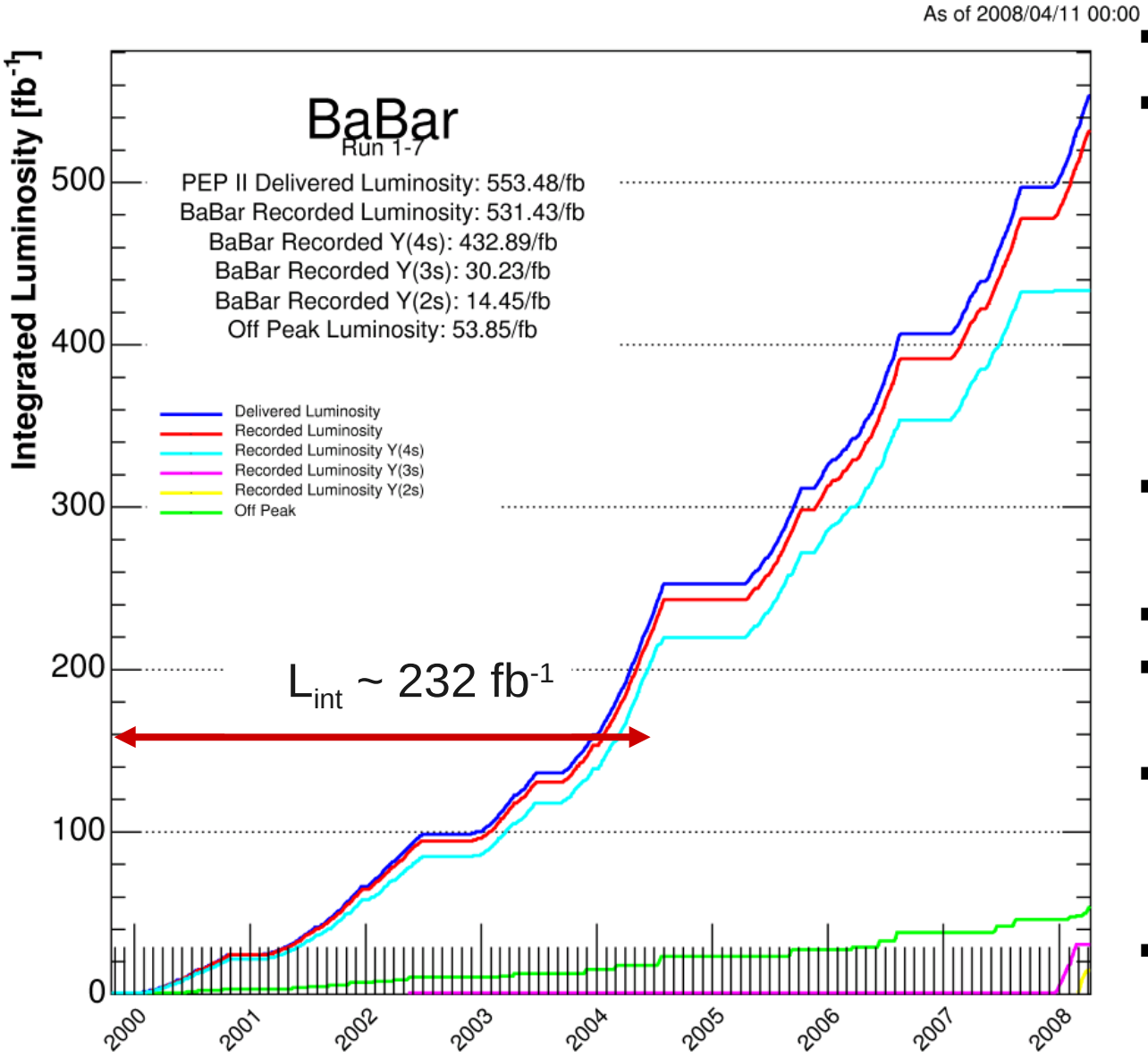
Analysis

cross section
$\sigma(e^+e^- \to \text{had})$



Input from theory:
probability to emit an ISR photon

Integrated Luminosity with BaBar



- L_{int} ~ 531 fb^{-1} over all
- especially:
  - Y(4S) ~ 433 fb^{-1}
  - Y(3S) ~ 30 fb^{-1}
  - Y(2S) ~ 14 fb^{-1}
  - Off-peak data ~ 54 fb^{-1}
  - Scan above Y(4S)
- ~600 x 10^6 B-pair

  $\rightarrow$main interest in B-physics!
- Huge Charm-production
- ~900 x 10^6 τ-pairs

- 1 day measurement with BaBar corresponds to the complete data taken with ARGUS (>10 y)
- KEK-B L_{int}~ 890 fb^{-1} $\rightarrow$1 ab^{-1}