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Light meson production in e^+e^- annihilation at *BABAR*

Gianluigi Cibinetto
INFN Ferrara
on behalf of the BaBar collaboration

Outline

- Introduction

- Precise measurement of the $e^+e^- \rightarrow \pi^+\pi^-(\gamma)$ cross section using initial-state radiation.

  PRL 103, 31801 (2009)
  PRD 86, 032013 (2012)

- Precision measurement of the $e^+e^- \rightarrow K^+K^-(\gamma)$ cross section using initial-state radiation.

  PRD 88, 032013 (2013)

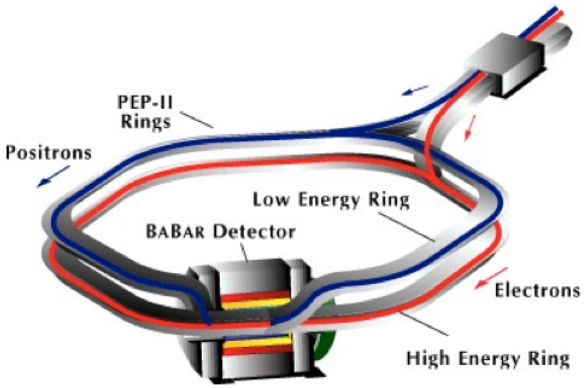
- Summary and conclusions.

The BaBar experiment at SLAC

main purpose: B-physics $\rightarrow$ CP violation

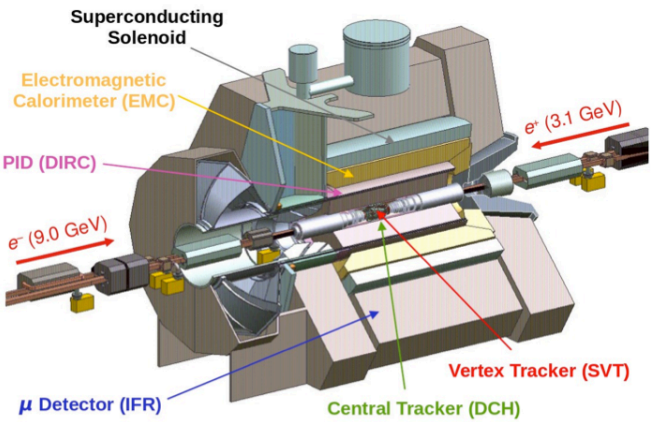
PEP-II

- asymmetric e^+e^--collider
- $\sqrt{s} = 10.58\,\mathrm{GeV} \Rightarrow \Upsilon(4S)$
  $\Rightarrow$ above $B\bar{B}$-threshold



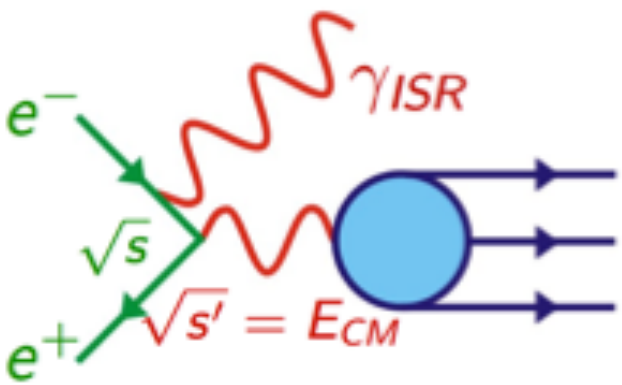
BABAR detector

- multi-purpose detector
- data taking: 1999 – 2008:
- $\mathcal{L}_{int} = 531\,\mathrm{fb}^{-1}$
  $\mathcal{L}_{int}(\Upsilon(4S)) = 454\,\mathrm{fb}^{-1}$
  $\approx 4.7 \cdot 10^8$ $B\bar{B}$ pairs



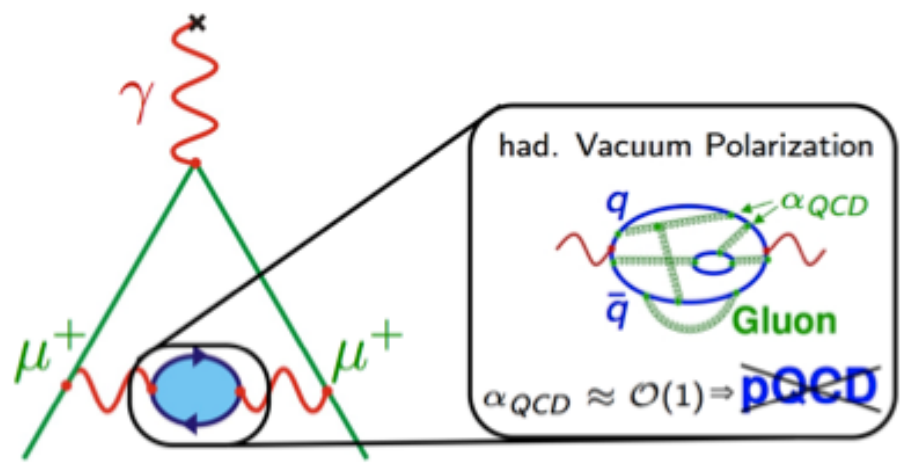
In addition

- Initial-State-Radiation (ISR) Physics

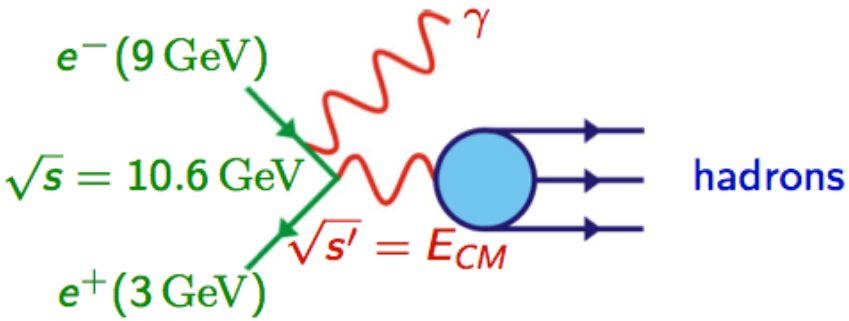


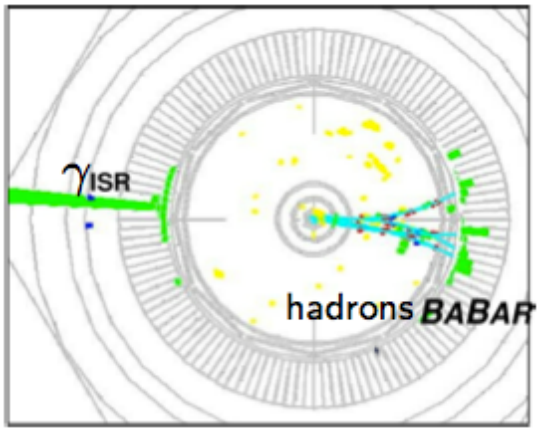
$a_\mu^{had,VP}$

- higher energy γ_{ISR} ⇒ lower c.m.s. energy
- produce vector states with $J^{PC} = 1^{--}$
- measure σ_{had}



The ISR method at BaBar



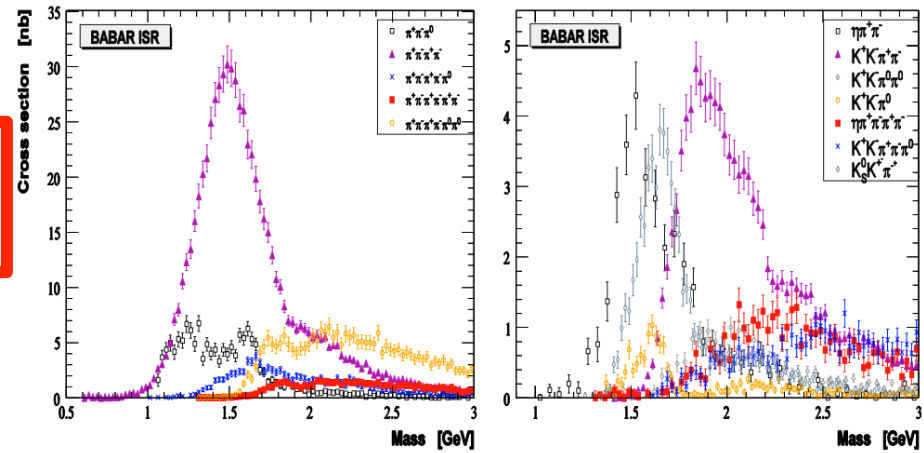


- High energy (E* γ >3 GeV) detected at large angle
  → defines $\sqrt{s'} = E_{CM}$ and provides strong background rejection
- Event topology: ISR photon back-to-back to hadrons
  → high acceptance, large boost to hadrons (measurements from threshold and easier PID)
- Final state can be hadronic or leptonic (QED)
  → $\mu + \mu - \gamma(\gamma)$ events used to get ISR luminosity
- Kinematic fit including ISR photon
  → removes multihadronic background; improves mass resolution (a few MeV)
- Continuous measurement from threshold to 3-5 GeV CM energy
  → reduced systematic uncertainties compared to multiple data sets with different colliders and detectors

The BaBar ISR program

- **published:**

$K^+ K^-$	PRD 2013
$\pi^+\pi^-$	PRL 2009; PRD 2012
$\pi^+\pi^-\pi^0$	PRD 2004
Φ $f^0(980)$	PRD 2006; PRD 2007
$p\bar{p}$	PRD 2006; PRD 2013
$\Lambda\Lambda$, $\Lambda\Sigma^0$, $\Sigma^0\Sigma^0$	PRD2007
$2(\pi^+\pi^-)$, $K^+K^-\pi^+\pi^-$, $K^+K^-2\pi^0$, $2(K^+K^-)$	PRD 2007; PRD 2012
$K^0_S K^{+-}\pi^{-+}$, $K^+K^-\pi^0$, $K^+K^-\eta$	PRD 2005;PRD 2008
$2(\pi^+\pi^-)\pi^0$, $2(\pi^+\pi^-)\eta$, $K^+K^-\pi^+\pi^-\pi^0$, $K^+K^-\pi^+\pi^-\eta$	PRD2007
$3(\pi^+\pi^-)$, $2(\pi^+\pi^-\pi^0)$, $2(\pi^+\pi^-)K^+K^-$	PRD 2006

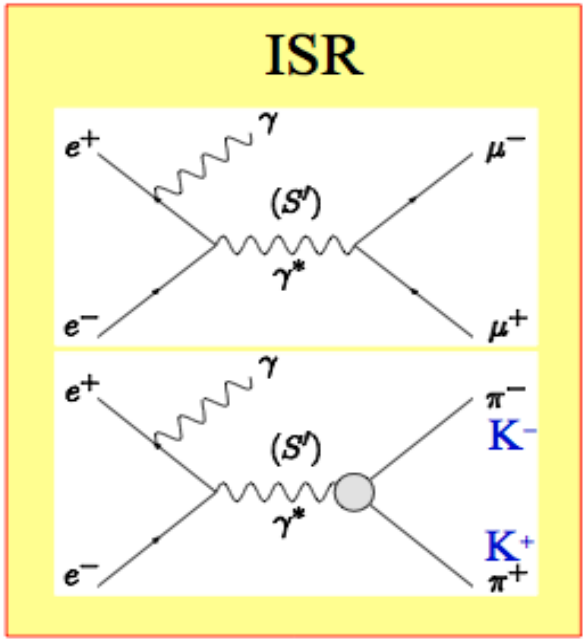


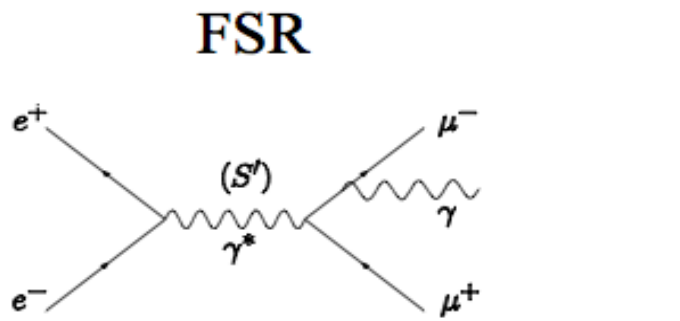
- **in progress:**

$\pi^+\pi^-2\pi^0$, $K^0_S K^0_L$, $K^0_S K^0_L \pi^+\pi^-$, $K^0_S K^{+-}\pi^{-+}\pi^0$, $K^0_S K^{+-}\pi^{-+}\eta$

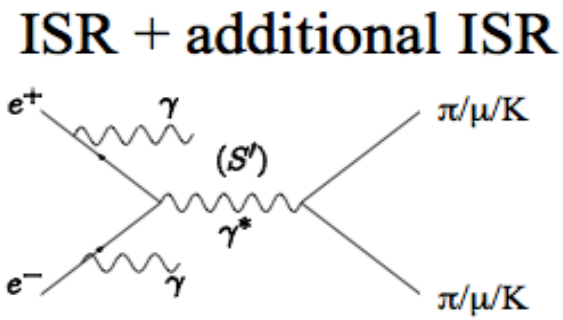
Relevant processes for the ππ and KK measurements

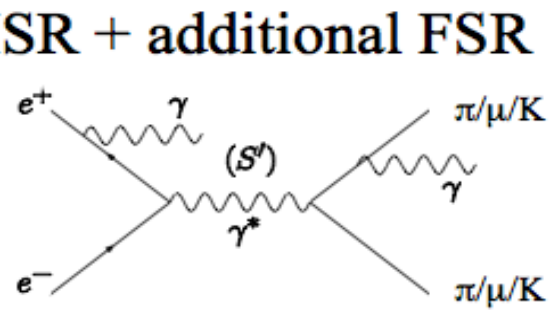
- $e^+e^- \to \mu^+\mu^-\gamma_{ISR}$ (γ add.), $\pi^+\pi^-\gamma_{ISR}$ (γ add.) and $K^+K^-\gamma_{ISR}$ (γ add.)





LO FSR negligible for ππ and KK at s~(10.6 GeV)^2





QED test with $\mu\mu\gamma$ sample

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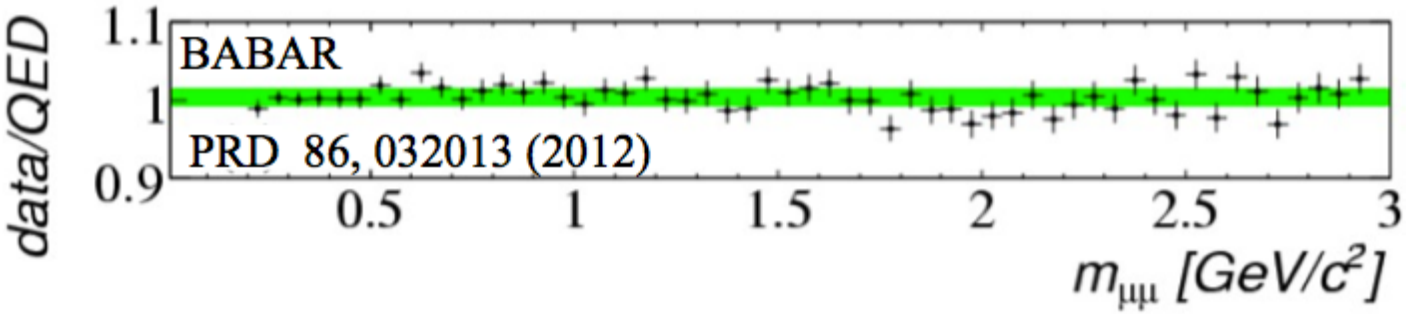
- Absolute comparison of μμ mass spectra in data and in simulation
- Simulation corrected for data/MC efficiencies
- AfkQed generator corrected for incomplete NLO using Phokhara



$$\frac{\sigma^{data}_{\mu\mu\gamma(\gamma)}}{\sigma^{NLO\ QED}_{\mu\mu\gamma(\gamma)}} = 1 + (4.0 \pm 1.9 \pm 5.5 \pm 9.4) \times 10^{-3} \qquad (0.2 - 3GeV)$$

ISR γ efficiency 3.4 syst.
trig/track/PID 4.0

BABAR e⁺e⁻ luminosity

$\pi\pi(\gamma_{FSR})$ cross section

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$$\frac{dN_{\pi\pi\gamma(\gamma)}}{d\sqrt{s'}} = \frac{dL^{eff}_{ISR}}{d\sqrt{s'}}\,\varepsilon_{\pi\pi\gamma(\gamma)}(\sqrt{s'})\,\sigma^0_{\pi\pi(\gamma)}(\sqrt{s'})$$

Unfolded spectrum

Acceptance from MC + data/MC corrections

Effective ISR luminosity from μμγ(γ) analysis (similar equation + QED)

- $\pi\pi$ mass spectrum unfolded (B. M. arXiv:0907.3791) for detector response
- Additional ISR almost cancels in the procedure ($\pi\pi\gamma(\gamma)$ / $\mu\mu\gamma(\gamma)$ spectra ratio)
- Correction data/MC $(2.5 \pm 1.0) \times 10^{-3}$
- ISR luminosity from $\mu\mu\gamma(\gamma)$ in 50-MeV energy intervals (small compared to variation of efficiency corrections)
- Total systematic uncertainty of 0.5% in the ρ region (dominant for a_μ)

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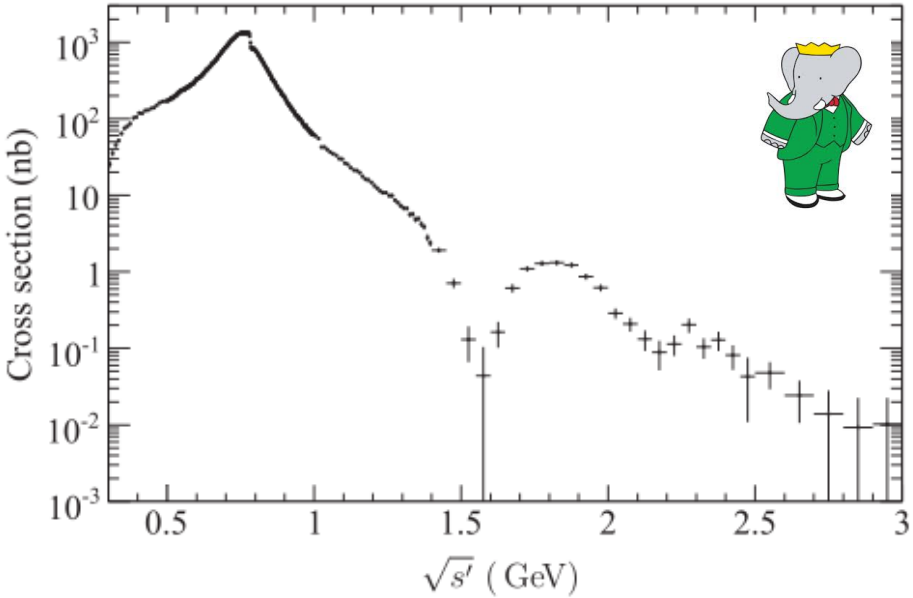
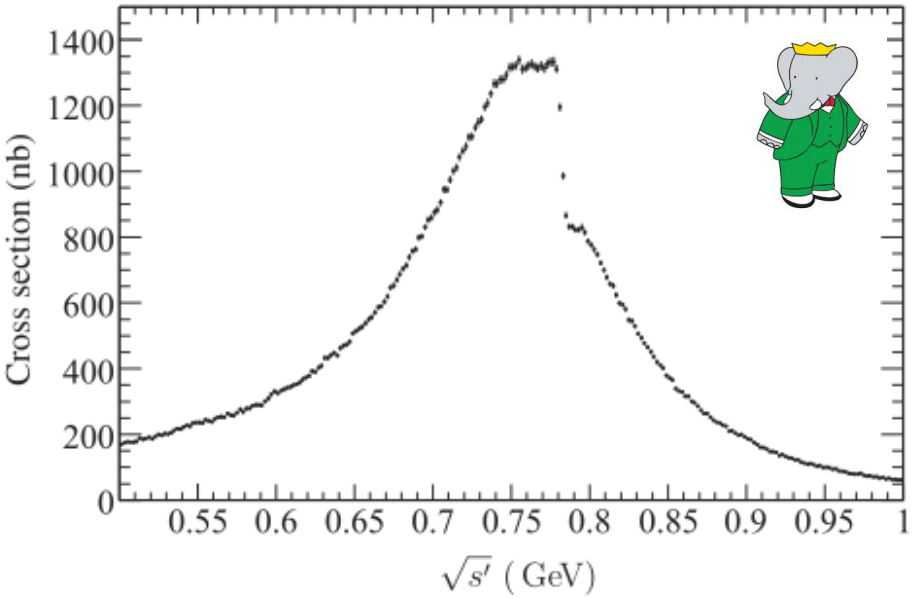
$\pi^+\pi^-$ cross section



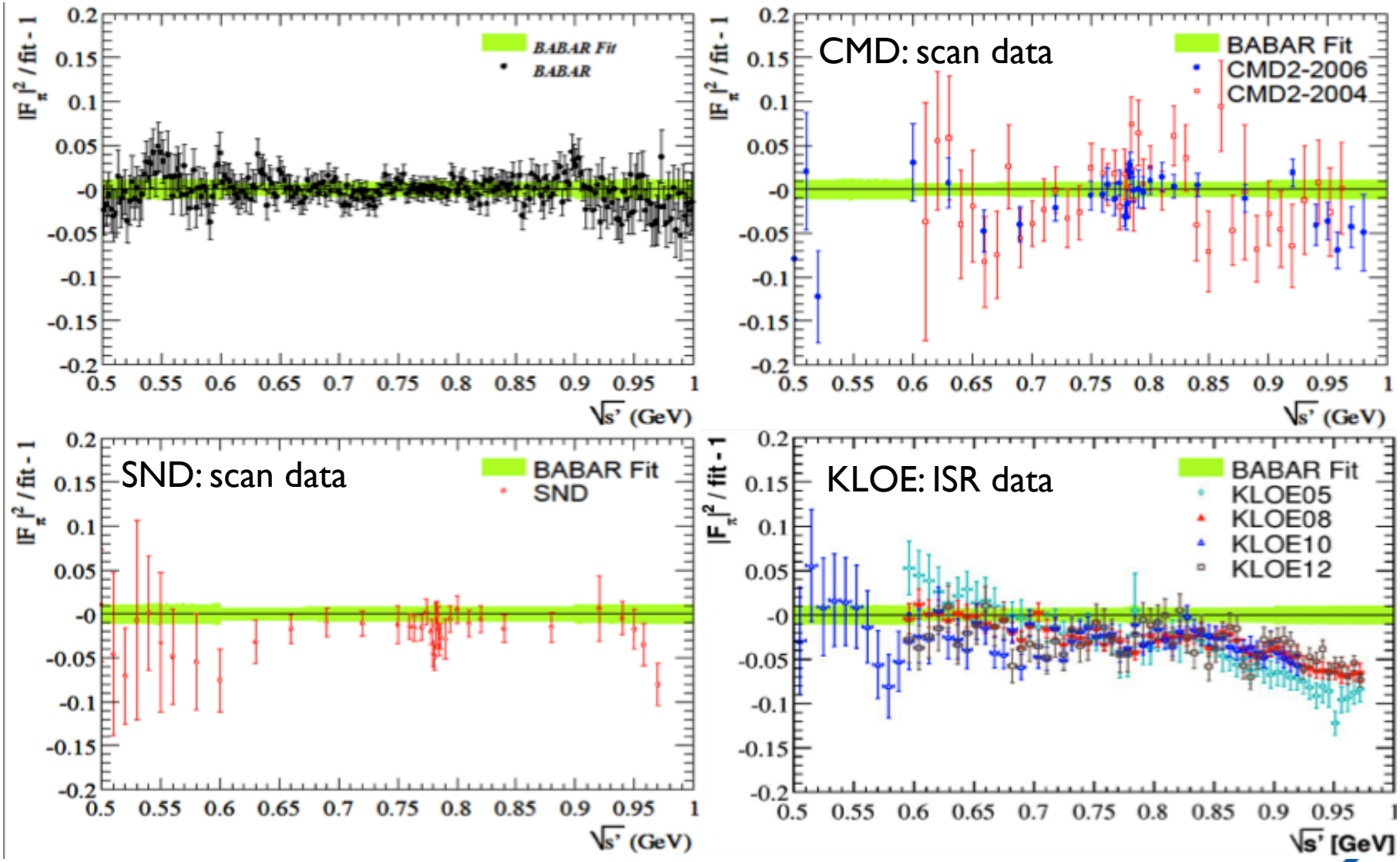


- ρ peak
- $\rho - \omega$ interference
- Dip at 1.6 GeV: excited ρ states
- Dip at 2.2 GeV
- Contribution to a_μ^{had}: 75%!

Systematic Uncertainties

BABAR: 0.5%
CMD2: 0.8%
SND: 1.5%
KLOE: 0.8%

BABAR fit vs. e^+e^- data (stat + syst errors included)



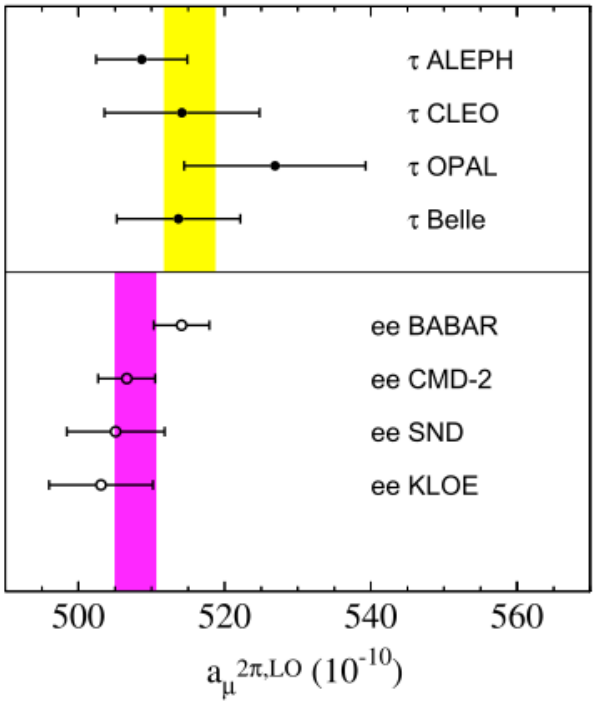
Computing $a_\mu^{\pi\pi}$

$$a_\mu^{\pi\pi(\gamma),LO} = \frac{1}{4\pi^3}\int_{4m_\pi^2}^{\infty} ds\, K(s)\, \sigma^0_{\pi\pi(\gamma)}(s)$$

where $K(s)$ is the QED kernel.

0.28–1.8 (GeV)

BABAR	$(514.1 \pm 3.8) \times 10^{-10}$
previous e^+e^- combined	$(503.5 \pm 3.5) \times 10^{-10}$ *
+ BABAR	$(508.4 \pm 2.9) \times 10^{-10}$ *
+ KLOE 10	$(507.8 \pm 2.7) \times 10^{-10}$ *
τ combined	$(515.2 \pm 3.5) \times 10^{-10}$ *



Deviation between BNL measurement and theory prediction reduced using BABAR $\pi^+\pi^-$ data

a_μ [exp] – a_μ [SM] =**(19.8 ± 8.4)**$\times 10^{-10}$ (2.4σ)

$\pi^+\pi^-$ from BABAR only

* arXiv:0906.5443; 0908.4300; 1010.4180 M. Davier et al.

Analysis of $e^+e^- \rightarrow K^+ K^-(\gamma)$ (PRD 88, 032013 (2013))

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- procedures similar to $\pi\pi$ analysis
- efficiencies obtained from full simulation (AfkQed) and data/MC corrections, geometrical acceptance and second-order corrections using Phokhara
- unfolding background-subtracted mass spectra
- ISR effective luminosity from $\mu\mu\gamma(\gamma)$: $KK/\mu\mu$ ratio
- mass-dependent systematic uncertainties, best in ϕ region (0.7%)
- Performed
  - cross section measurement
  - form factor phenomenological fits
  - contribution to a_μ

Results on the $e^+e^- \to K^+K^- (\gamma)$ bare cross section with FSR included (small)

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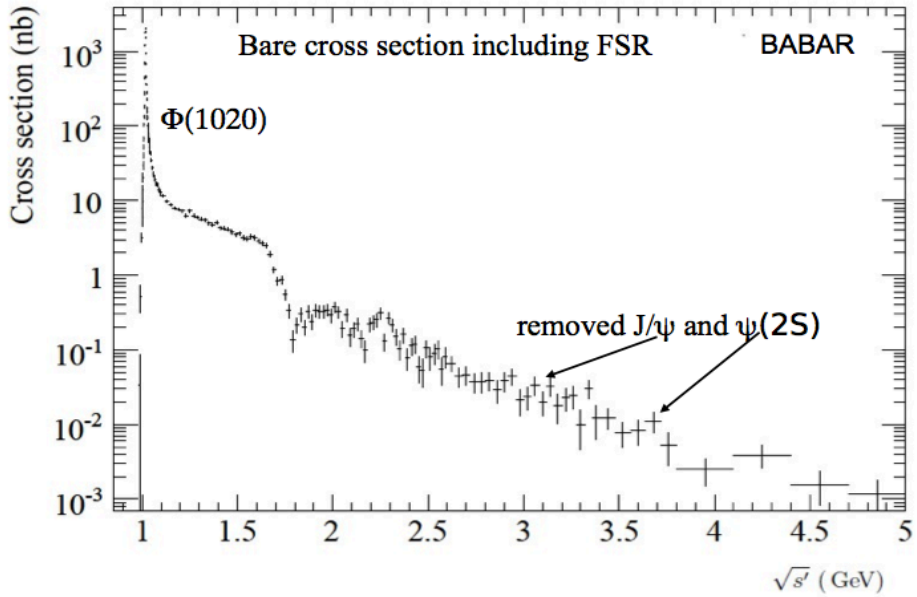
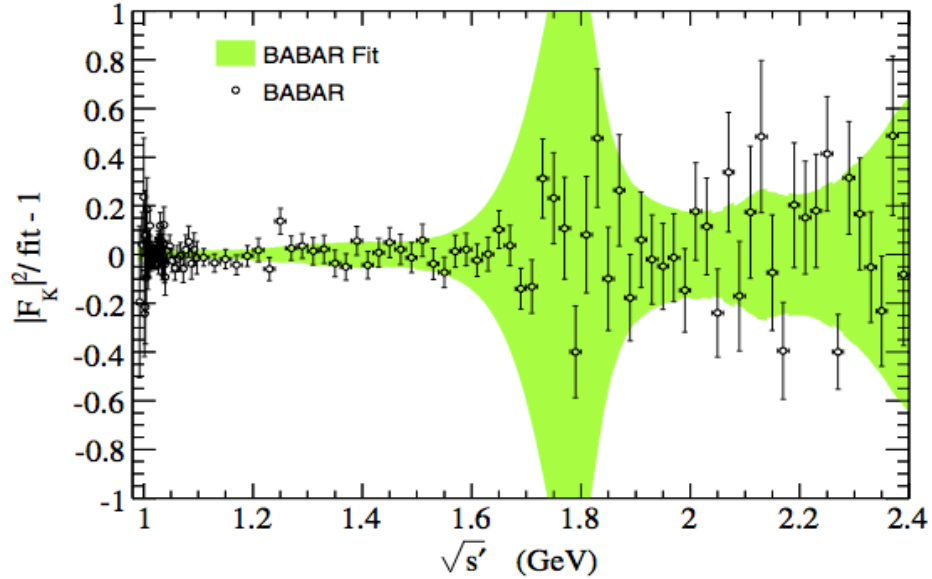
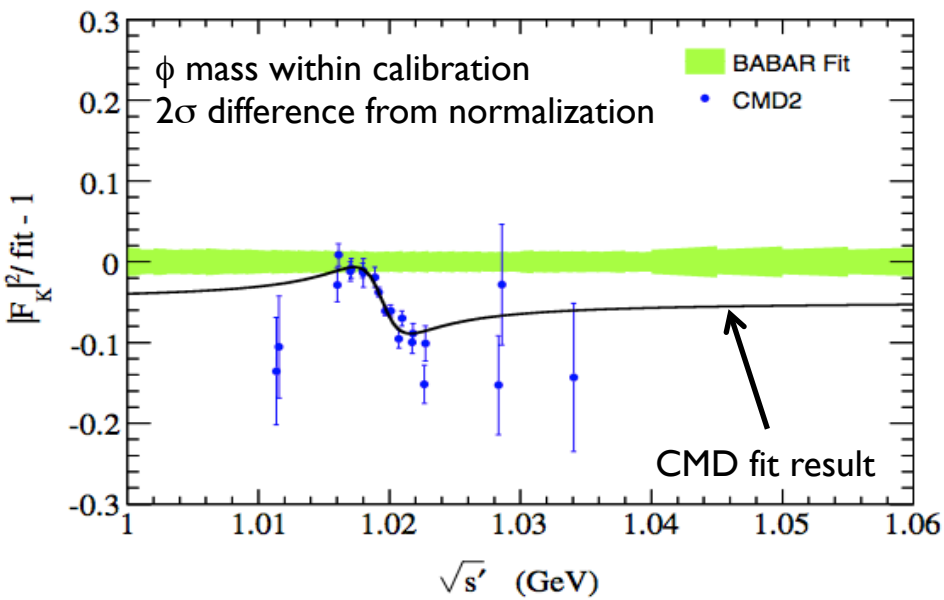
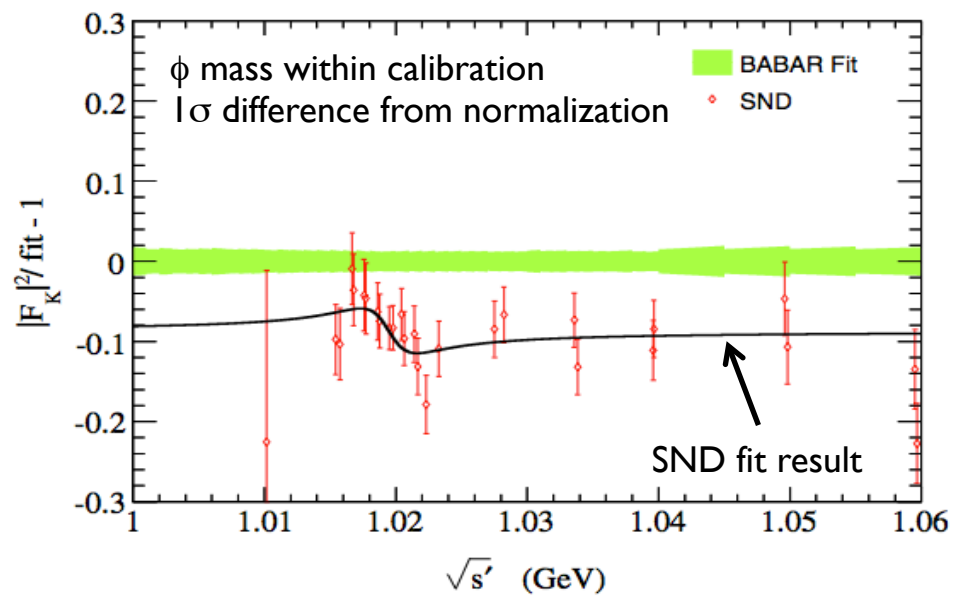


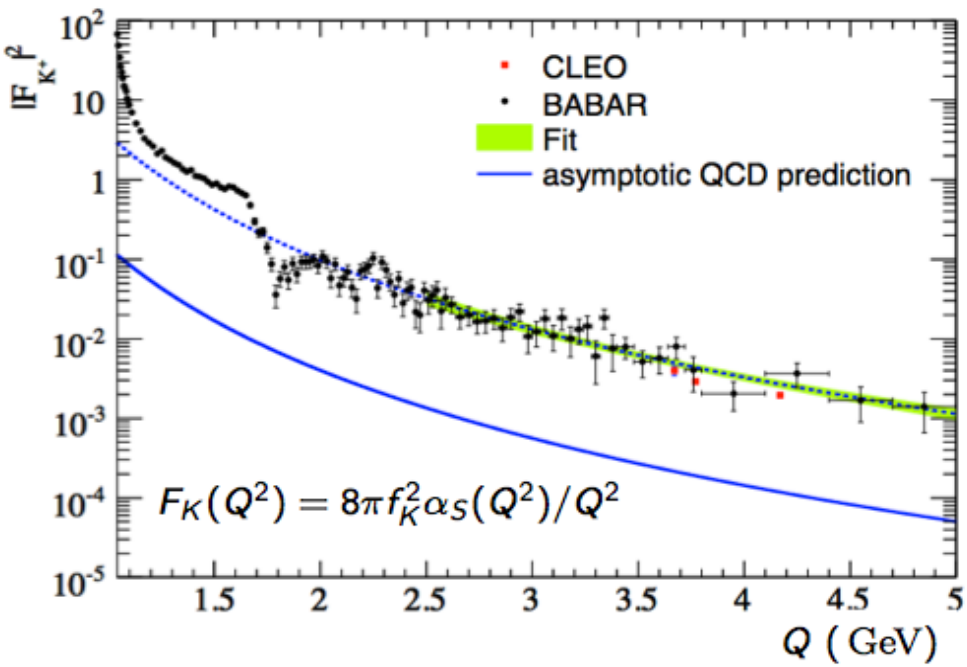






Charged kaon form factor at large Q^2

- Predictions based on QCD in asymptotic regime (Chernyak-Zhitnitsky JETP Lett. (1977); Brodsky-Lepage Phys. Lett. B (1979))
  - power law $F_K \sim \alpha_S(Q^2)\, Q^{-n}$ with n=2
  - but data on $|F_K|^2$ a factor ~20 above prediction!
  - no trend in data up to 25 GeV^2 for approaching the asymptotic QCD prediction



fit function:
$A\alpha_s^2(s)/Q^n$

the fit returns
n=2.04 ± 0.22
(χ^2/DF = 23.4/32)

Impact of BABAR data for g-2: K^+K^-

BABAR:

$a_\mu^{KK,LO}$ [0.98-1.8] GeV = (22.93 ± 0.18 (stat) ± 0.22 (syst)) 10^{-10} (1.3%)

DHMZ arXiv:1010.4180 : update of all results before BABAR

$a_\mu^{KK,LO}$[0.98-1.8]GeV = (21.63 ± 0.27 (stat) ± 0.68 (syst))10^{-10} (3.4%)

BaBar more precise than previous world average by a factor of ~2.6

Summary and conclusions

- By means of ISR analyses BABAR carried out an extensive and consistent program to measure precise cross sections for the dominant channels of $e^+e^- \rightarrow$ hadrons from threshold to 1.8 GeV.

- A few more analyses are in progress.

- BABAR results have a large impact on the precision of hadronic vacuum polarization (HVP) contribution to the value of muon g-2 calculation.

- In addition to HVP there are other applications of these data for QCD tests with finite energy sum rules, complementing similar studies performed using hadronic τ decays.

- Also (not covered in this talk) BABAR ISR results provide input on hadron spectroscopy, resonance dynamics and measurements of baryon form factors.

Thanks