

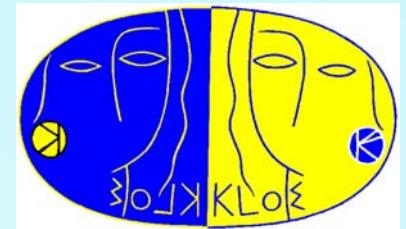
*Les Rencontres
de Moriond QCD
March 20, 2006*



*Measurement of the
Pion Form Factor with KLOE
and Study of the
Reaction $f_0(980) \rightarrow \pi^+ \pi^-$*

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1

Measurement of the Pion Form Factor with KLOE

Phys. Lett. B606 (2005) 12

Hadronic Cross Section & Myon-Anomalie

Motivation:

High Precision Test of the Standard Model

→ Anomalous magnetic moment of the muon

Myon-Anomaly $a_\mu = (g_\mu - 2)/2 = \alpha/2\pi + \dots$

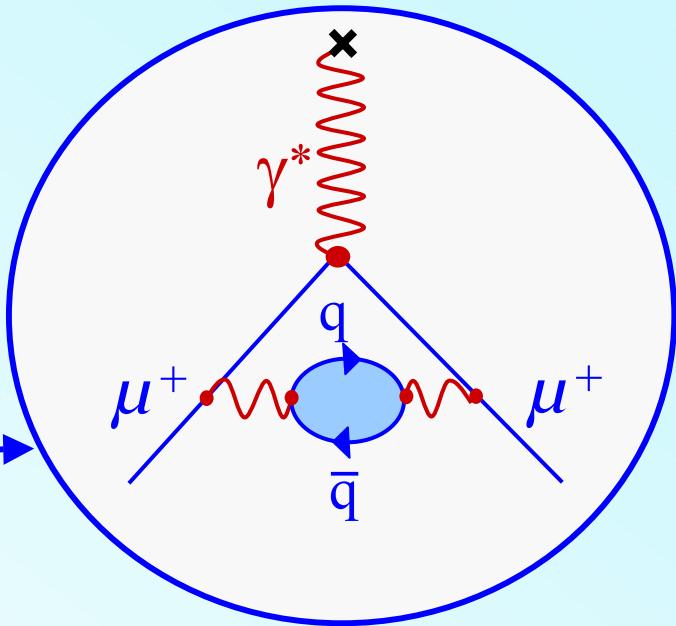
$$a_\mu^{theor} = a_\mu^{QED} + a_\mu^{had} + a_\mu^{weak} + a_\mu^{new}$$

→ Fine structure constant at Z^0 -mass $\alpha_{QED}(M_Z)$

2nd largest contribution, $pQCD$ not applicable

Error of hadronic contribution dominates total error of a_μ !

Hadronic Vacuum Polarization



Dispersion-Relation

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

- $K(s)$ = analytic kernel-function,
- above typically 2...5 GeV, use $pQCD$

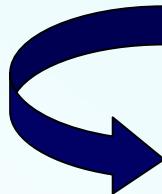
Pion Form Factor $\sigma(e^+ e^- \rightarrow \pi^+ \pi^-)$

< 1 GeV contributes to ca. 70% !

Alternative: Spectral function from decay ($\tau \rightarrow \nu_\tau$ Hadrons) taking into account isospin breaking corrections

Radiative Return

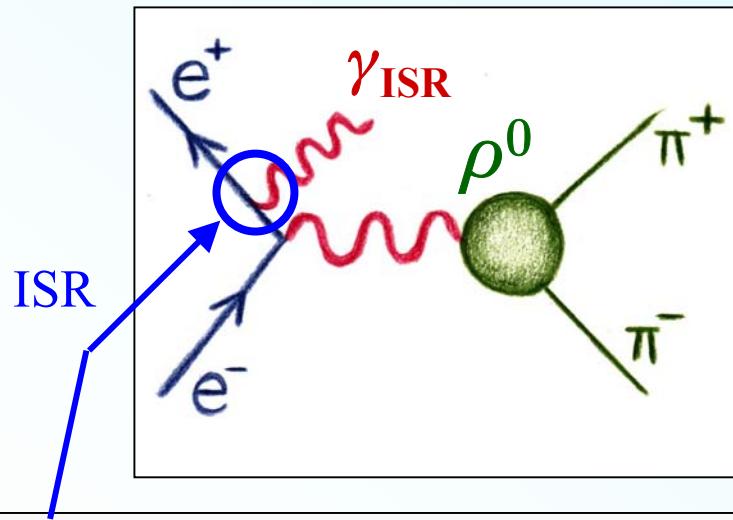
Particle factories, as the **ϕ -factory DAΦNE**, are designed for a fixed center-of-mass energy: $\sqrt{s} = m_\phi = 1.02$ GeV in the case of DAΦNE
Energy-scan to measure the cross section is not possible!



New and completely complementary ansatz:

Consider events with **Initial State Radiation (ISR)**

Possible due to the high integrated luminosities obtained: 2.5fb^{-1}



'Radiative Return' to $\rho(\omega)$ -resonance:
 $e^+ e^- \rightarrow \rho(\omega) + \gamma \rightarrow \pi^+ \pi^- + \gamma$

$$\frac{d\sigma_{\pi\pi\gamma}}{dM_{\pi\pi}^2} = \frac{d\sigma(e^+ e^- \rightarrow \pi^+ \pi^- \gamma_{\text{ISR}})}{dM_{\pi\pi}^2}$$

$$\text{for } (2m_\pi)^2 < M_{\pi\pi}^2 < s$$

MC-Generator PHOKHARA = NLO
J. Kühn, H. Czyż, G. Rodrigo
Radiator-Function $H(s)$

$$M_{\pi\pi}^2 \frac{d\sigma_{\pi\pi\gamma}}{dM_{\pi\pi}^2} = \sigma_{\pi\pi}(s) \times \mathbf{H}(s)$$

Selection $\pi^+\pi^-\gamma_{ISR}$

Pion tracks at large angles

$$50^\circ < \theta_\pi < 130^\circ$$

a) Photons at small angles

$$\theta_\gamma < 15^\circ \text{ and } \theta_\gamma > 165^\circ$$

→ No photon tagging

$$\vec{p}_\gamma = -\vec{p}_{\text{miss}} = -(\vec{p}_+ + \vec{p}_-)$$

- High statistics for *ISR* photons
- Negligible contribution of *FSR*
- Reduced overall background

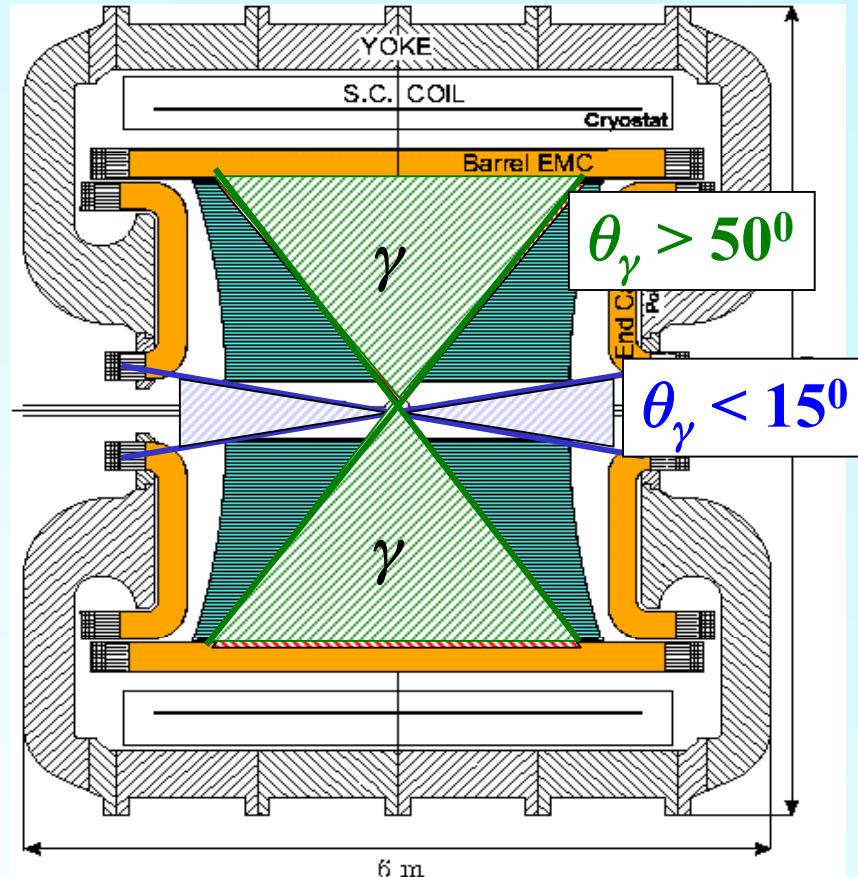
b) Photons at large angles

$$50^\circ < \theta_\gamma < 130^\circ$$

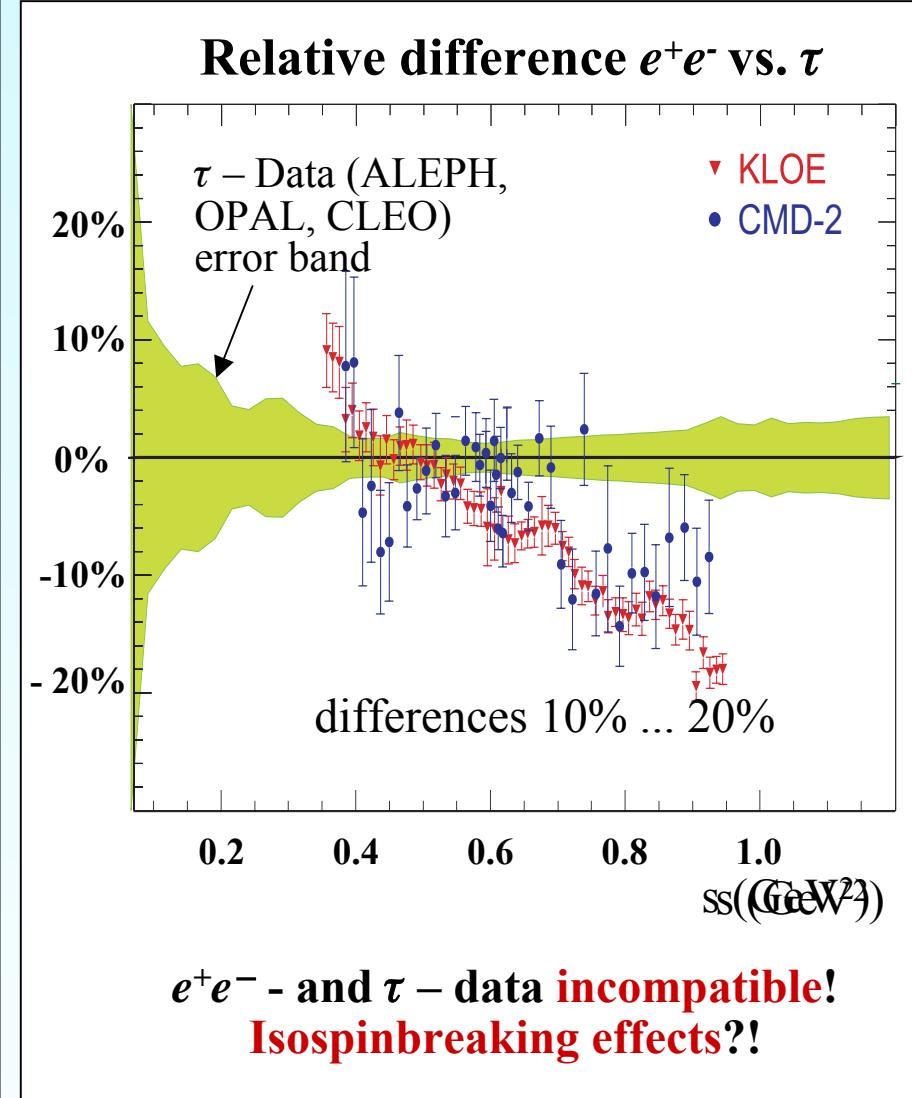
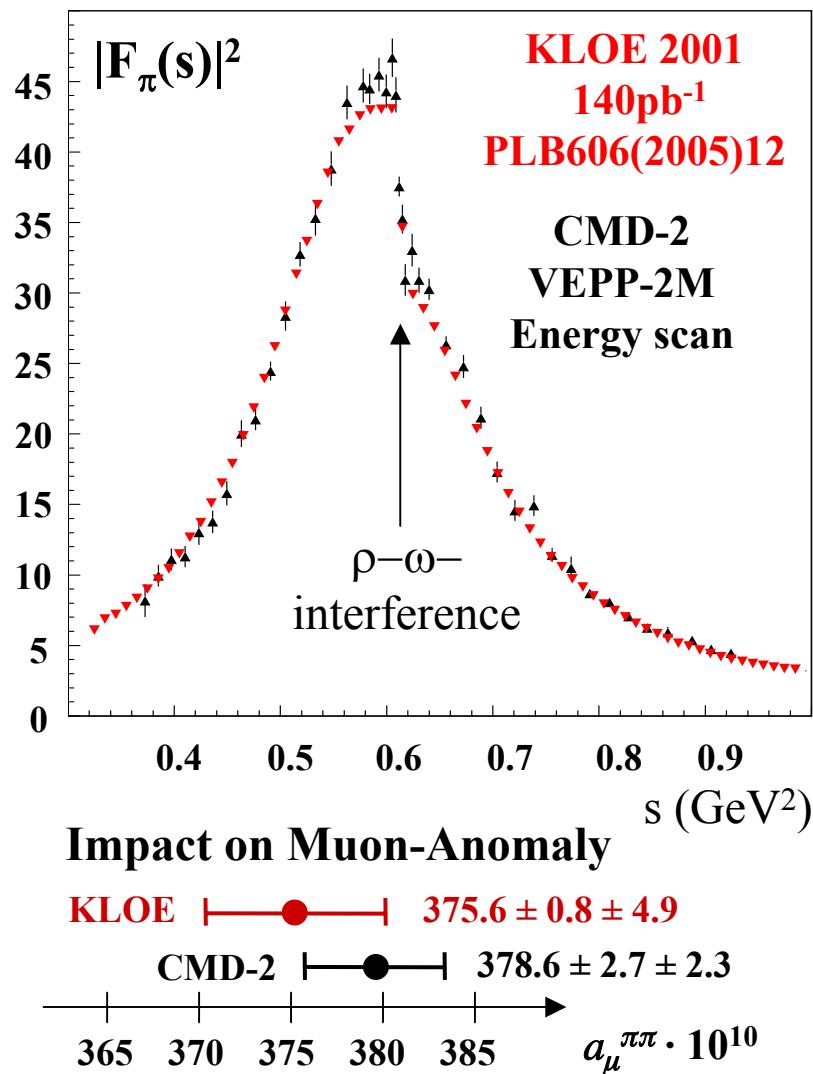
→ Photon tagging possible

- Measurement of threshold region
- Increased contribution of *FSR*
- Contribution $\phi \rightarrow f_0(980) \gamma \rightarrow \pi^+\pi^-\gamma$

The KLOE Detector

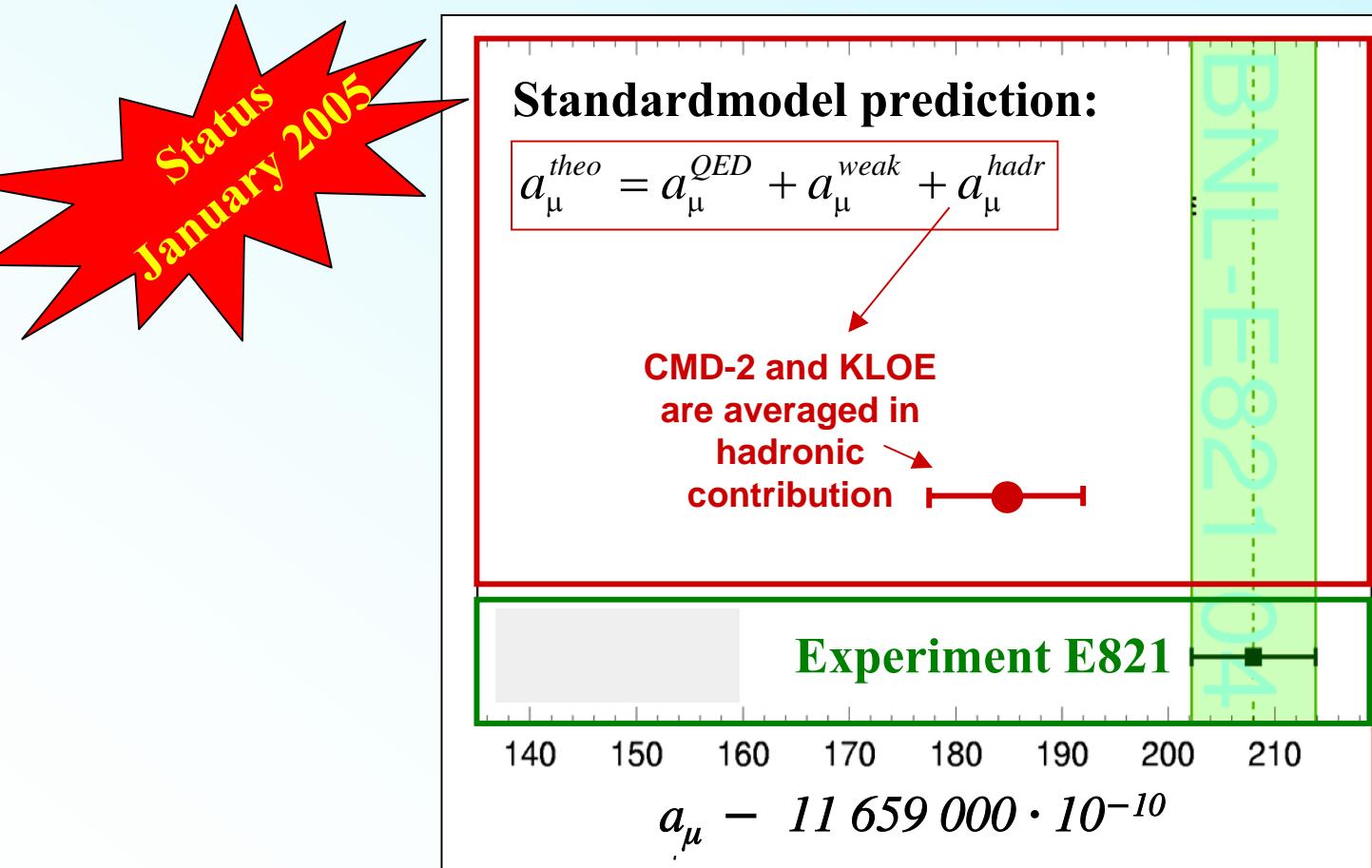


Reminder: Result Small Photon Angles



Reminder: Theory vs. Experiment a_μ

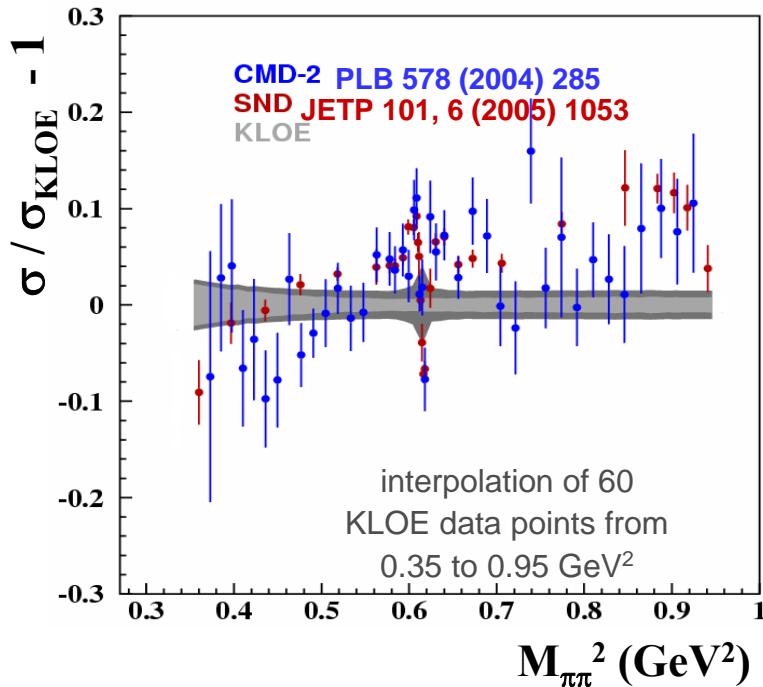
KLOE- and CMD-2 measurements of the pion form factor are used for a new evaluation of the hadronic contribution of the **muon anomaly**.



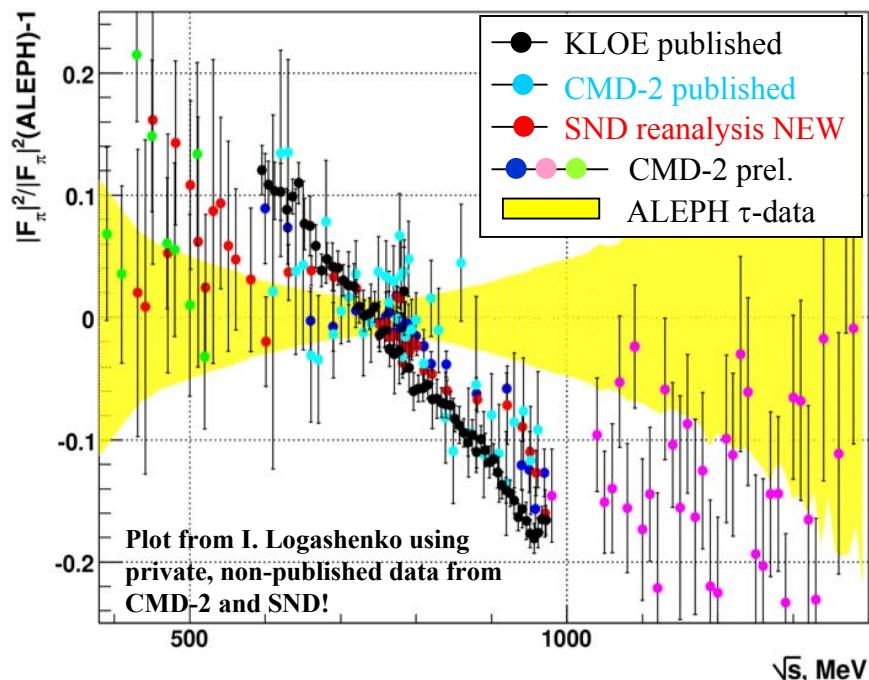
Comparison with E821-measurement of a_μ shows 2.7σ deviation btw. theory and experiment.

Comparison with τ - and recent e^+e^- - Data

Published SND data (VEPP-2M) in agreement with τ -data at high masses



'New' preliminary SND data after reanalysis
Wrong radiative corrections in publ. data

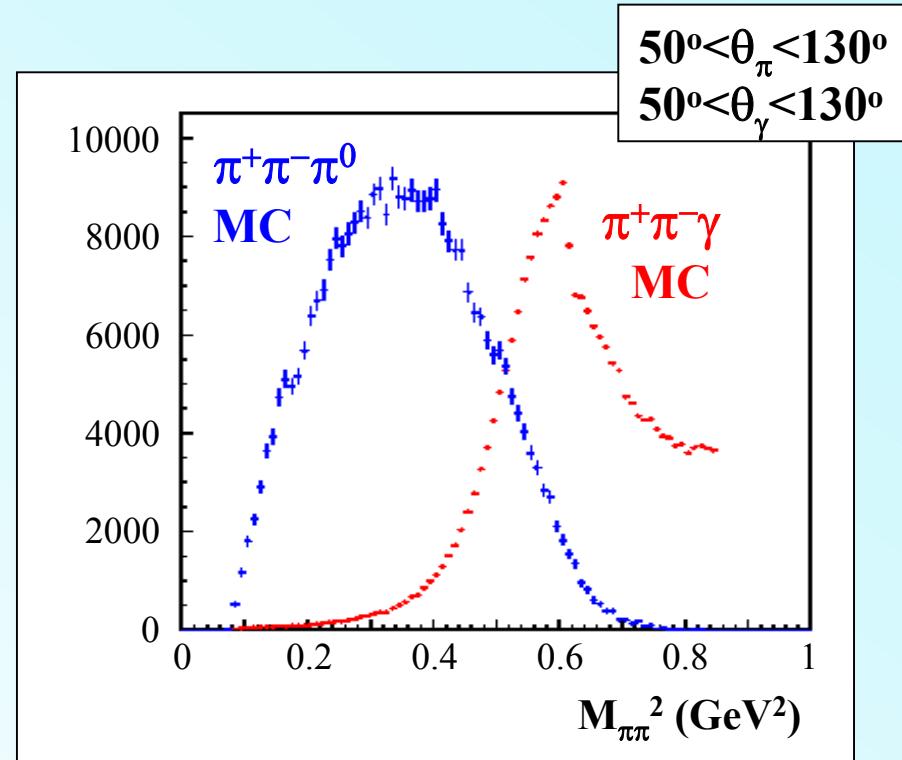


- All recent e^+e^- experiments see large deviations with τ -data above ρ peak
- Some disagreement btw. KLOE and CMD-2/SND seen
- All recent e^+e^- experiments agree now within 0.5σ in the 2π -contribution to a_μ^{had}
- Recent preliminary τ -analysis from BELLE in agreement with e^+e^- (hep-ex/0512071)?!

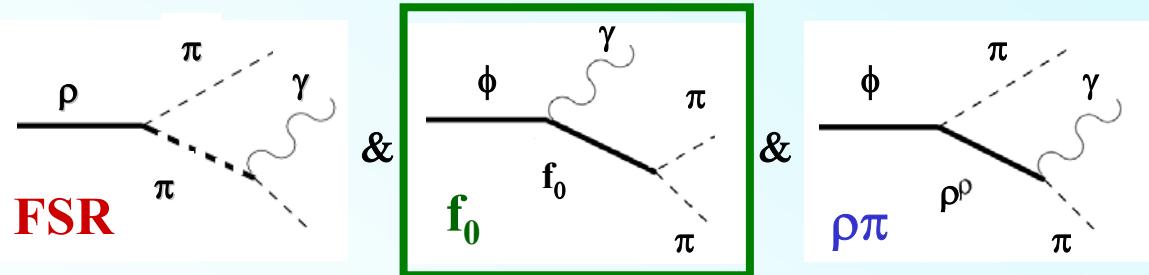
Analysis 2002 Data: Large Photon Angles

PRO & CONTRA

- ✓ important cross-check
- ✓ the **threshold region** is accessible
ca. 20% contribution to a_{μ}^{hadr}
- ✓ **photon tagging** is possible
(4-momentum constraints)
- ✓ lower signal statistics
- ✓ **large** $\phi \rightarrow \pi^+\pi^-\pi^0$ background
- ✓ **large FSR** (charge asymmetry!)
- ✓ **irreducible bkg.** from ϕ decays

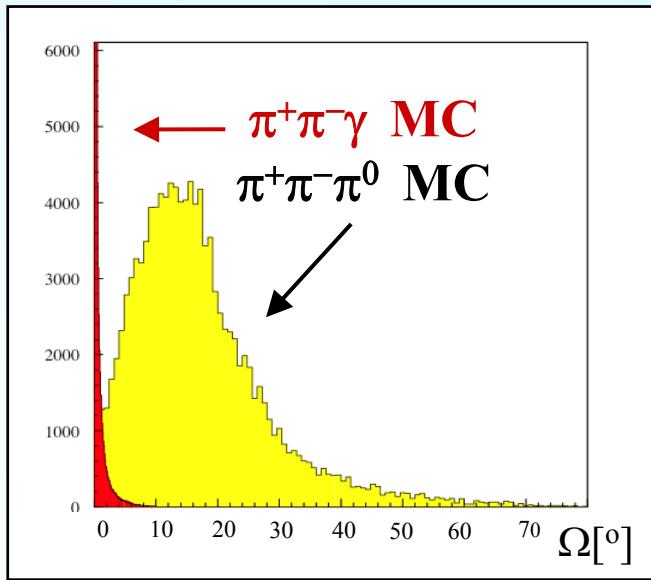


Threshold region non-trivial
due to irreducible FSR-effects,
which have to be cut from MC
using phenomenological models
(interference effects unknown)

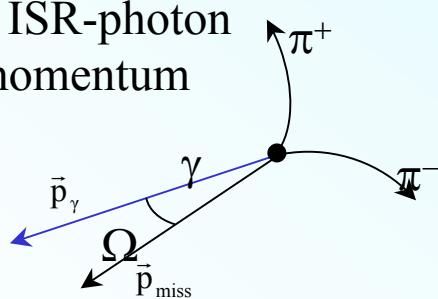


Signal for $f_0(980) \rightarrow \pi^+\pi^-$ analysis → later!

Analysis 2002 Data: Large Photon Angles



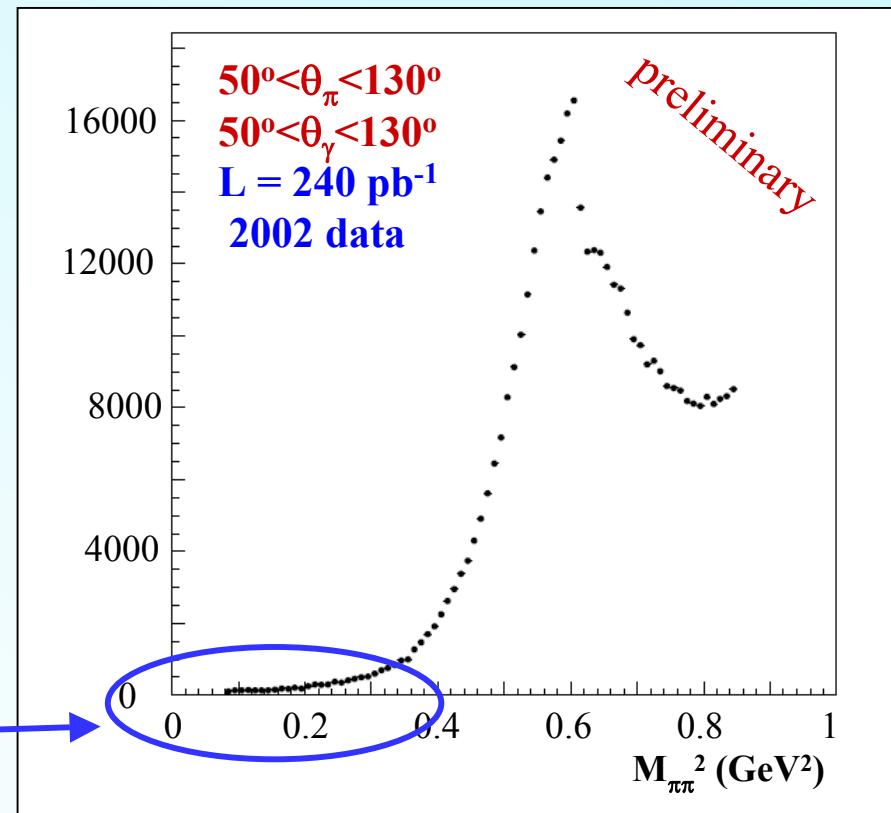
- Angle Ω btw. ISR-photon and missing momentum



**Threshold region becomes accessible in large angle analysis
Kinemat. forbidden at small ISR angle**

Dedicated selection cuts to cut huge background:

- Kinematic fit in $\pi^+\pi^-\pi^0$ hypothesis
- Kinematic cut exploiting high momentum resolution of KLOE tracking detector



DAΦNE - Run Off - Resonance

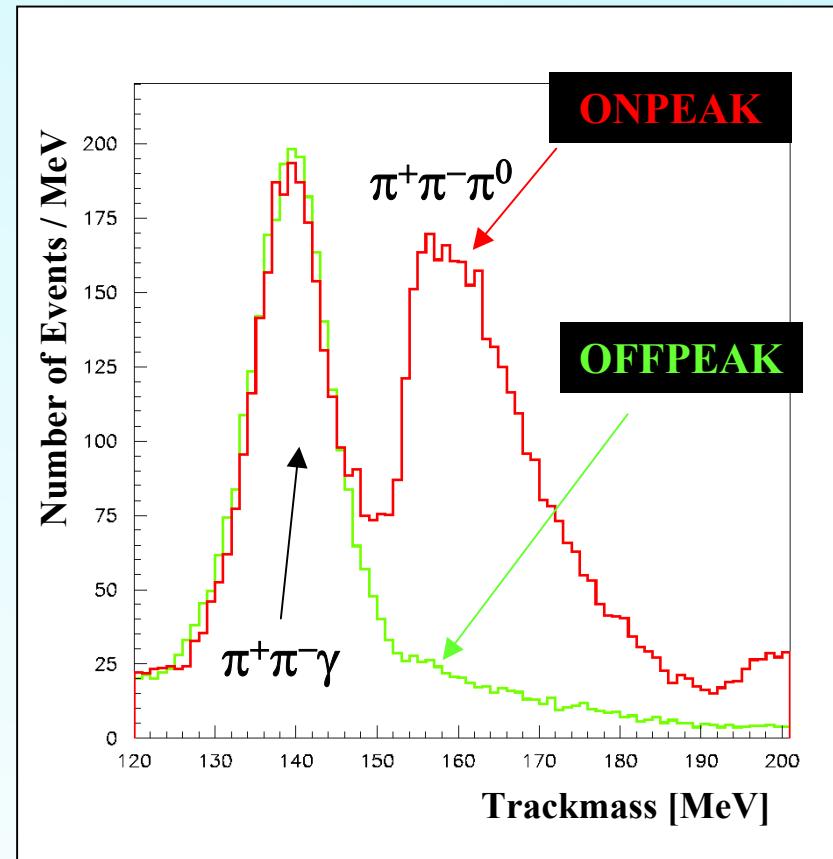
Radiative Return measurements at large ISR-photon angles are limited by
reducible and irreducible background from ϕ -decays

Off-Peak-Program:

- 1) Run for 3 months at $\sqrt{s} = 1.00$ GeV
250 pb⁻¹ off-peak collected (ended on March 16, 2006):

→ the ultimate background-free data sample for Radiative Return
→ background-free $\gamma\gamma$ – physics program

- 2) ϕ - scan with 4 scanning points at $\sqrt{s} = 1.030, 1.023, 1.018, 1.010$ GeV integrated luminosity 10pb⁻¹ each
→ study the model-dependence in description of $f_0(980)$





2

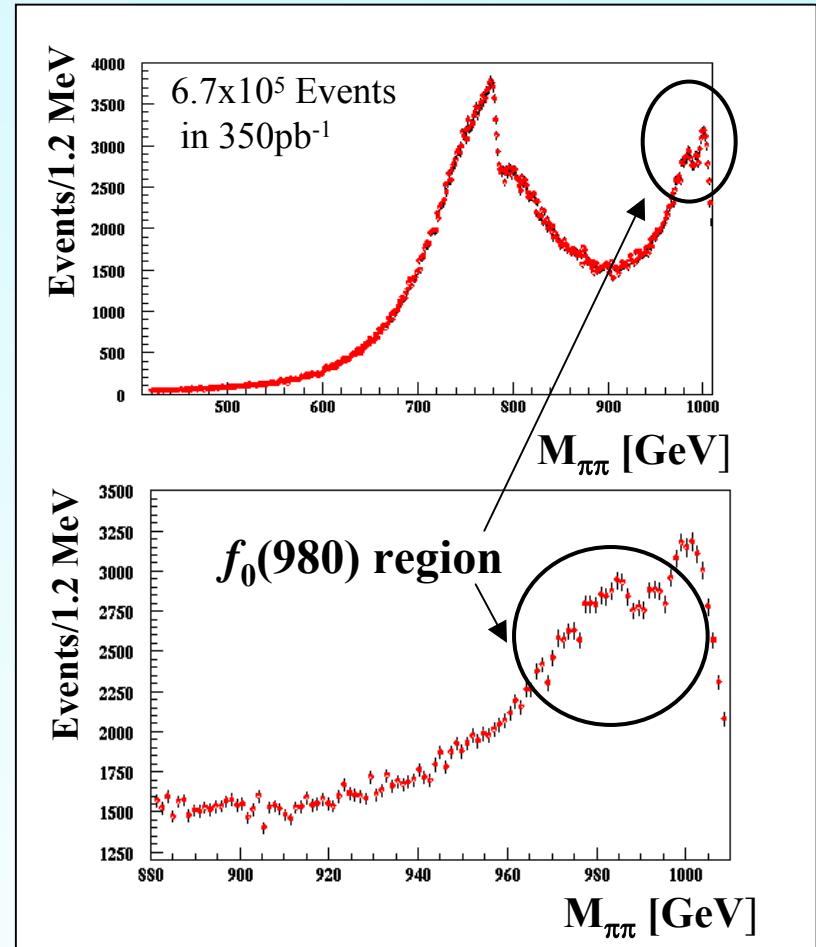
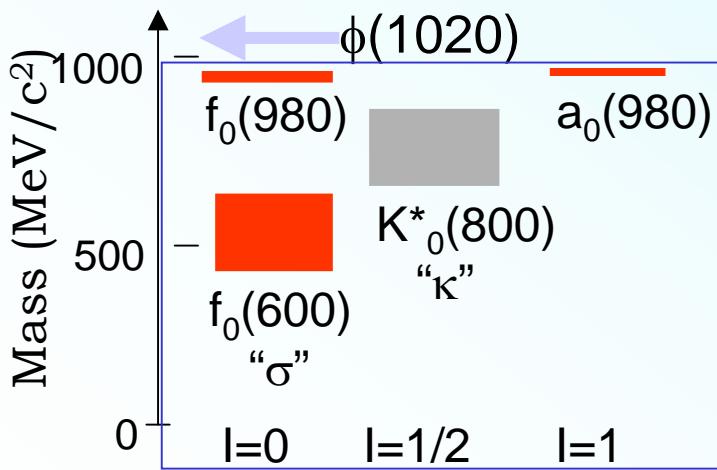
Study of the Reaction $f_0(980) \rightarrow \pi^+ \pi^-$

Phys. Lett. B634 (2006) 148

Signal $\phi \rightarrow f_0(980) \gamma \rightarrow \pi^+ \pi^- \gamma$

Produce scalar mesons $f_0(980)$, $a_0(980)$ in radiative ϕ -decays
 $\phi \rightarrow f_0(980) \gamma \rightarrow \pi^+ \pi^- \gamma$ with large background from ISR (Rad. Return) and FSR

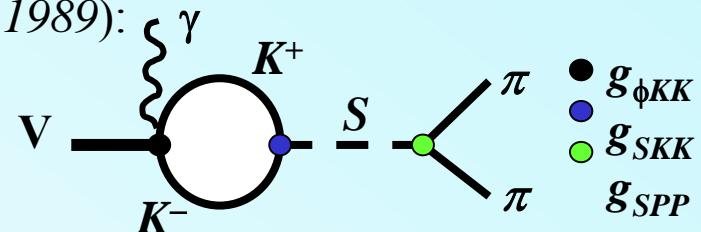
- In radiative ϕ -decays there is a high sensitivity to distinguish btw. different models for the nature of the scalars:
 not easily interpreted as conventional $q\bar{q}$
 probably $q\bar{q}q\bar{q}$ (Jaffe '77)
 $K\bar{K}$ (Weinstein-Isgur '90)
- Can broad $f_0(600)$ “ σ “ be seen in spectrum?



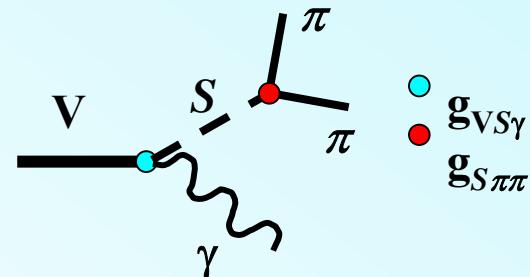
Scalar Amplitude Description

We use three different approaches in the description of the scalar amplitude.
Check these phenomenological models by fitting the mass spectrum:

1. **Kaon-loop KL** (*Achasov-Ivanchenko, NPB315 1989*):
 for each scalar meson S there are three free parameters of the fit: $\mathbf{g}_{S\pi\pi}$, \mathbf{g}_{SKK} , \mathbf{M}_S



2. **No-Structure NS** (by *G.Isidori and L.Maiani*):
 a modified BW + a polynomial continuum:
 $\mathbf{g}_{\phi S\gamma}$, $\mathbf{g}_{S\pi\pi}$, \mathbf{g}_{SKK} , \mathbf{M}_S
 + continuum parameters



3. **Scattering Amplitudes SA**

(*M.E.Boglione, M.R.Pennington, Eur. Phys., J. C30 (2003)*)

$$A \propto (a_1 + b_1 m^2 + c_1 m^4) T(\pi\pi \rightarrow \pi\pi) + \\ (a_2 + b_2 m^2 + c_2 m^4) T(\pi\pi \rightarrow KK)$$

→ extract **pole residual \mathbf{g}_ϕ**

Scalar Fit Procedure

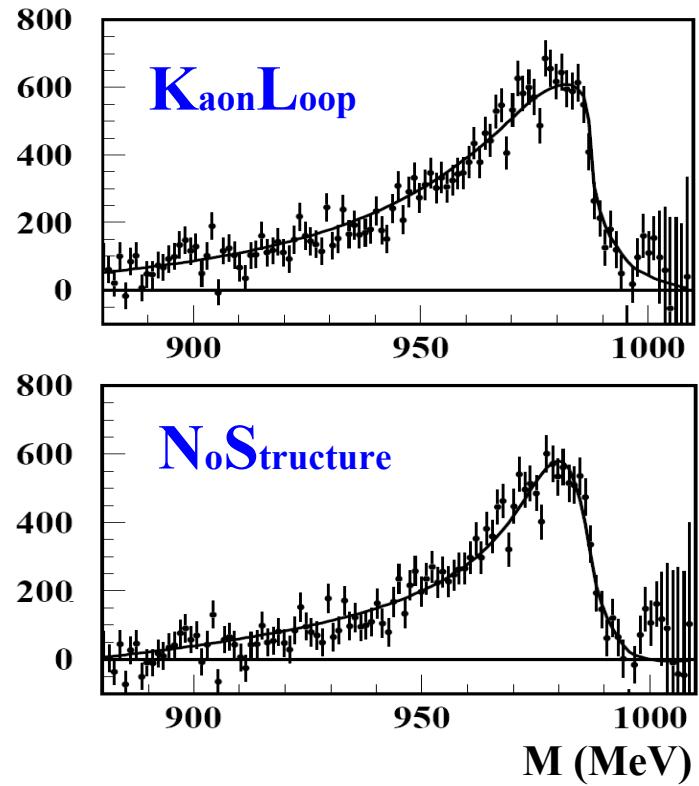
**Fit : ISR + FSR + scalar $f_0(980)$
 ± interference (scalar+ FSR)
 + background($\rho\pi \rightarrow \pi\pi\gamma$)**

491 bins à 1.2 MeV, $M_{\pi\pi} = 420 - 1009$ MeV

- Good description in both cases KL and NS of signal and background by the fit
- Negative interference btw. $f_0(980)$ -FSR
- $R > 2$ in both fit cases indicating a strong coupling of $f_0(980)$ to strangeness
- The introduction of a $f_0(600)$ does not improve the fit quality

Parameter	KL	NS
M_{f_0} (MeV)	980-987	973-981
$g_{f_0 K^+ K^-}$ (GeV)	5.0-6.3	1.6-2.3
$g_{f_0 \pi^+ \pi^-}$ (GeV)	3.0-4.3	0.9-1.1
$R = g_{f_0 K^+ K^-}^2 / g_{f_0 \pi^+ \pi^-}^2$	2.2-2.8	2.6-4.4
$g_{\phi f_0 \gamma}$ (GeV)	-	1.2-2.0

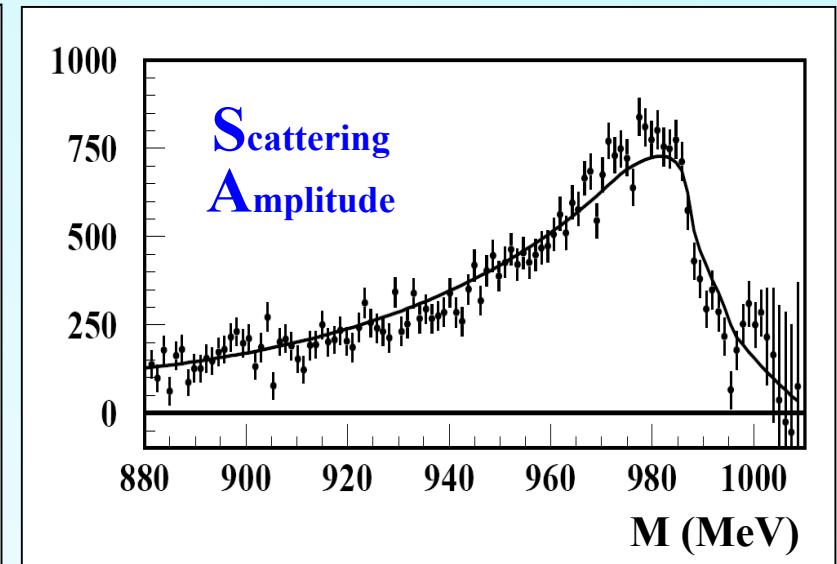
**Scalar spectra after subtraction of non-scalar part:
 look for an excess of events**



Scalar Fit Procedure

Scattering Amplitude SA gives only a marginal agreement:

Fit results worse in SA approach					
χ^2 ($p(\chi^2)$)			577/477 (0.1%)		
a_1	11.9	a_2	-14.7	m_{ρ^0} (MeV)	774.4 ± 0.2
b_1	3.3	b_2	-15.3	Γ_{ρ^0} (MeV)	142.8 ± 0.3
c_1	-15.1	c_2	35.8	$\alpha (\times 10^{-3})$	1.74 ± 0.05
m_0	0.	λ	-1.63	$\beta (\times 10^{-3})$	-100 ± 18
			$a_{\rho\pi}$	0 ± 2	
$\Gamma(\phi \rightarrow \gamma f_0(980)) = \frac{\pi^2}{2} g_\phi^2 \frac{m_\phi^2 - m_{f_0}^2}{m_\phi^3}$					



$$g_\phi = 6.6 \times 10^{-4} \rightarrow \text{BR} (\phi \rightarrow f_0 \gamma) \times \text{BR} (f_0 \rightarrow \pi^+ \pi^-) \sim 3 \times 10^{-5}$$

→ BR considerably lower than in KL and NS model

→ similar conclusion already from Boglione Pennington analysis EPJ C30 (2003) 503 of $\pi^0 \pi^0 \gamma$ data (KLOE,SND)

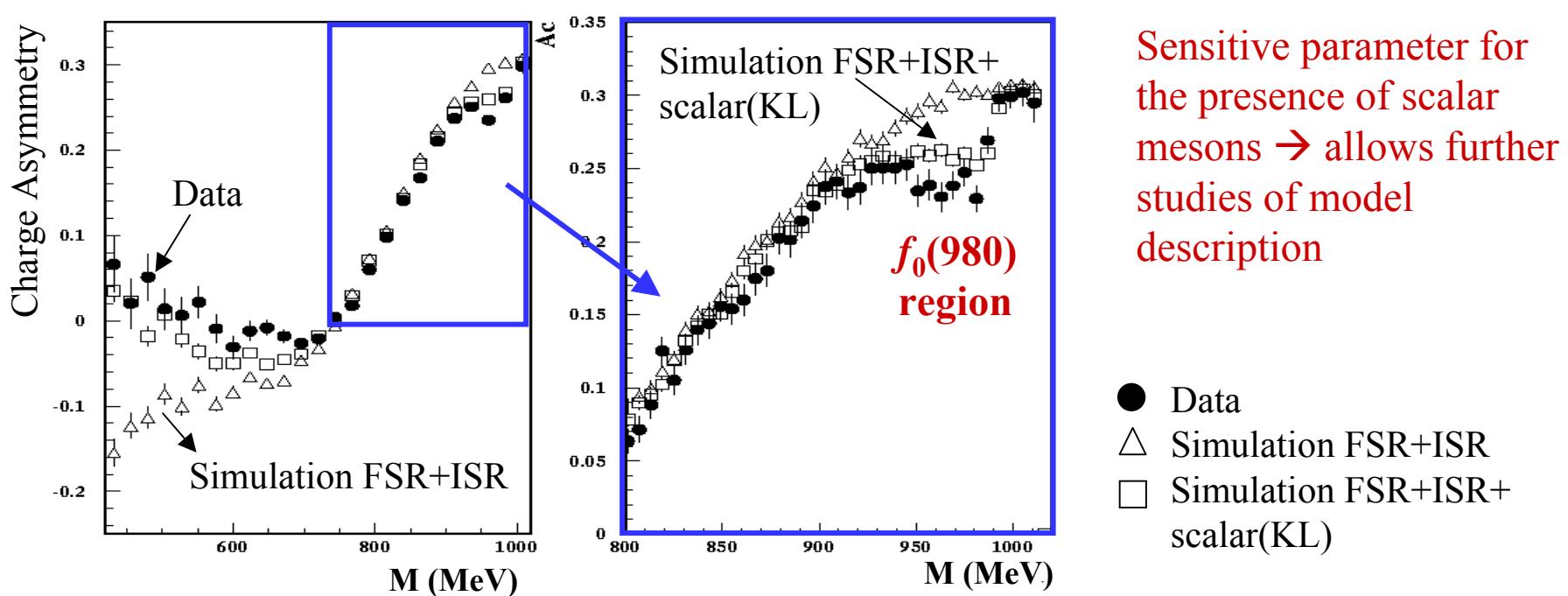
→ PLB 537 (2002) 21

Forward - Backward - Asymmetry

Define the forward-backward-asymmetry

$$A_{FB}(M_{\pi\pi}) = \frac{N(\theta^+ > 90^\circ) - N(\theta^+ < 90^\circ)}{N(\theta^+ > 90^\circ) + N(\theta^+ < 90^\circ)} (M_{\pi\pi})$$

Asymmetry is a consequence of different C-Parity of $\pi^+\pi^-$ for ISR- and FSR-amplitude



- Clear signal ~ 980 MeV in charge asymmetry
- Huge effect at low masses below ρ peak, can be described by $f_0(980)$ only

3

Conclusions



Conclusions

- Radiative Return suited for precision cross section measurements
 - Pion form factor @ 1%, reanalysis using 2002 data
 - Complementary analysis allows to cover the threshold region in the 2π -channel, of utmost importance for muon anomaly
- First precision measurement of the decay $\phi \rightarrow f_0(980) \gamma \rightarrow \pi^+ \pi^- \gamma$
 - Sensitivity to distinguish btw. different models for scalar amplitude: KaonLoop- and NoStructure-models describe well mass spectrum
 - No $f_0(600)$ contribution needed in mass spectrum
- Factor 4 more data on tape (2.5fb^{-1})
 - Will allow further precision studies in hadronic physics
 - Understand the real nature of the scalar particles $f_0(980)$, $a_0(980)$
 - Off-Peak-Run (250pb^{-1}) and ϕ -scan just completed