KLOE results on Scalar Mesons (II)

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For the **KLOE** collaboration

1. Status of $\eta\pi^0\gamma$ analysis: 400 pb^{-1} sample
2. Search of the decay $f_0(980)\rightarrow\pi^+\pi^-$ on $\pi^+\pi^-\gamma$ events with a photon at large angle

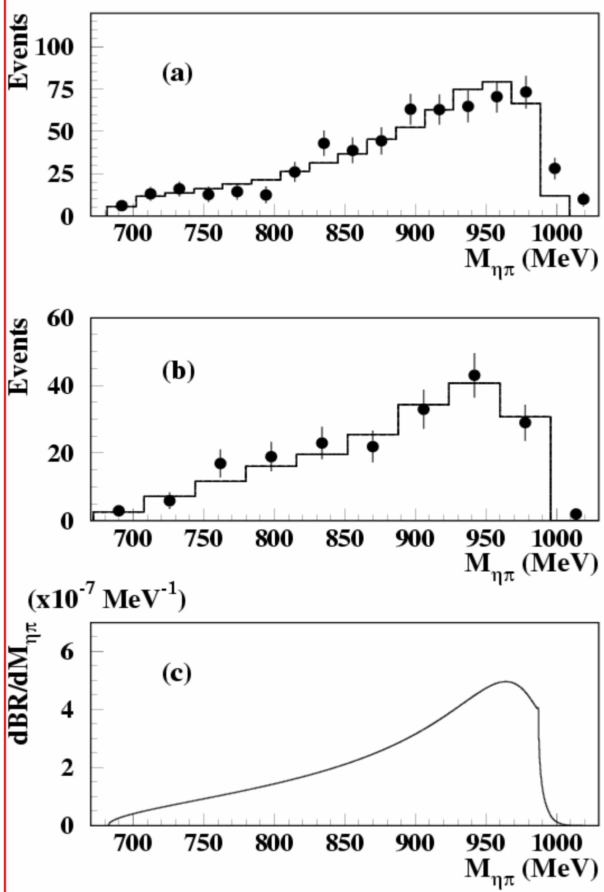
All results are PRELIMINARY (not yet published)

1. Status of $\eta\pi^0\gamma$ analysis

The analysis is done on 2 samples:

(s.1) $\eta \rightarrow \gamma\gamma$ BR=39.43%

(s.2) $\eta \rightarrow \pi^+\pi^-\pi^0$ BR=22.6%



2000 data ($L = 16\ pb^{-1}$) $\rightarrow$ 916 – 309 cand. (s.1)

$\rightarrow$ 197 – 4 cand. (s.2)

We obtained:

$$BR(\phi \rightarrow \eta\pi^0\gamma)_{(s.1)} = (8.51 \pm 0.51 \pm 0.57) \times 10^{-5}$$

$$BR(\phi \rightarrow \eta\pi^0\gamma)_{(s.2)} = (7.96 \pm 0.60 \pm 0.40) \times 10^{-5}$$

KLOE Collab. Phys.Lett.B536 (2002)

The combined fit:

$$A = A(\phi \rightarrow a_0(980)\gamma \rightarrow \eta\pi^0\gamma) + A(\phi \rightarrow \rho\pi \rightarrow \eta\pi^0\gamma):$$

1. the data are well described by the "Kaon loop approach".
2. $\phi \rightarrow \rho\pi \rightarrow \eta\pi^0\gamma$ contribution is negligible as expected

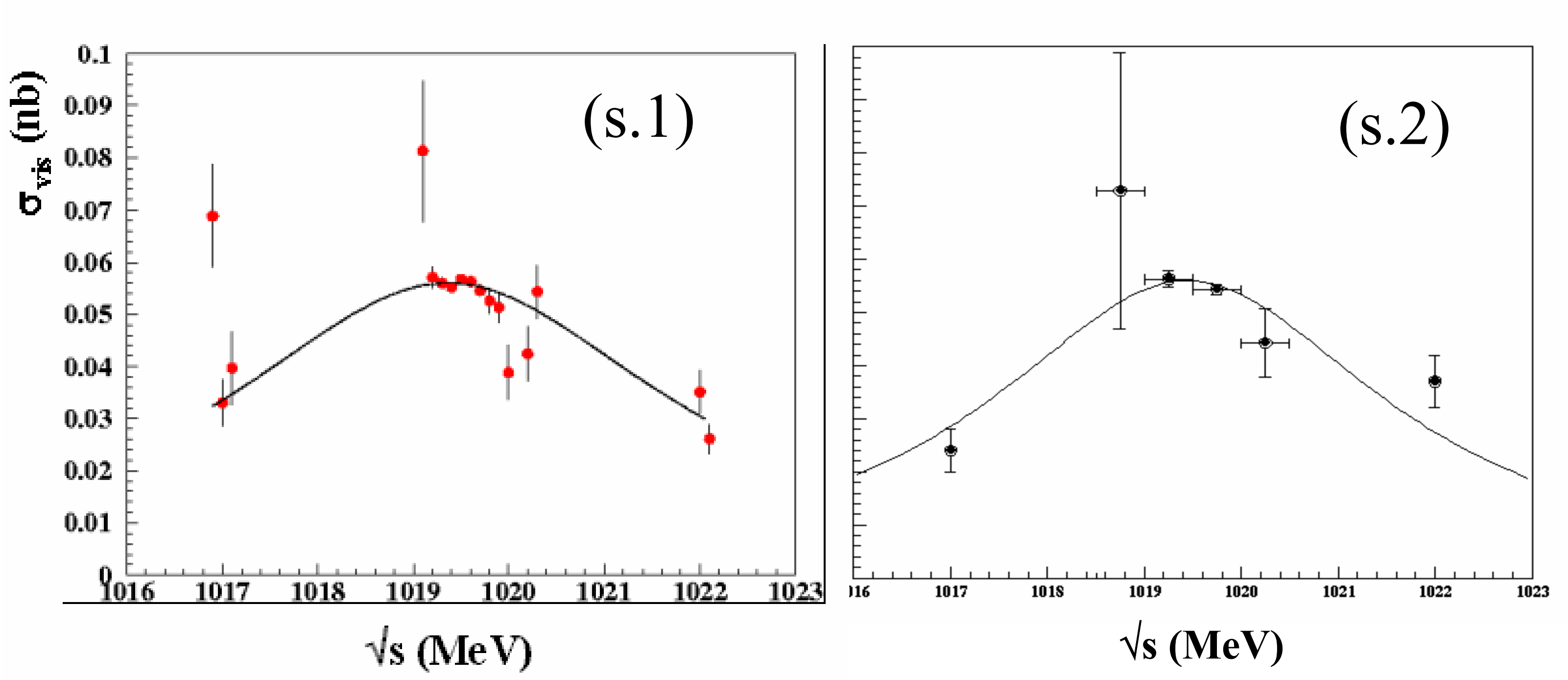
New data set:

$L = 395\ pb^{-1}$ @ ϕ peak + ~$10\ pb^{-1}$ off-peak [1017, 1022 MeV]

s.1 ($\eta \rightarrow \gamma\gamma$) ➔ 2.2×10^4 events

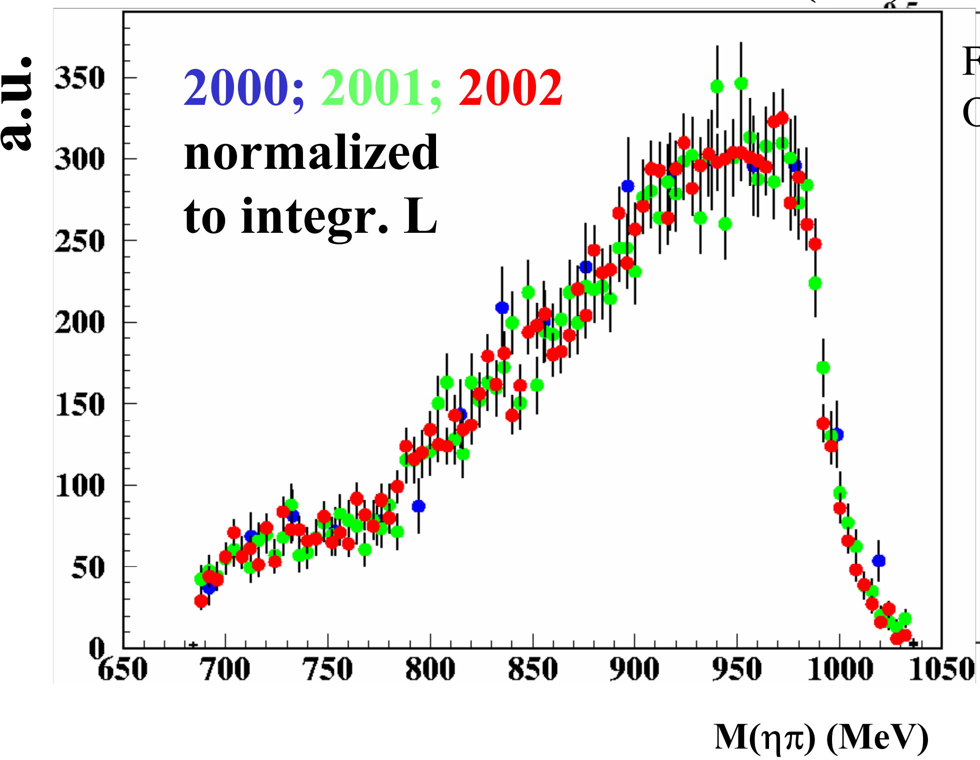
s.2 ($\eta \rightarrow \pi^+\pi^-\pi^0$) ➔ 4180 events

√s dependence for the 2 samples: "nice" resonant behaviour

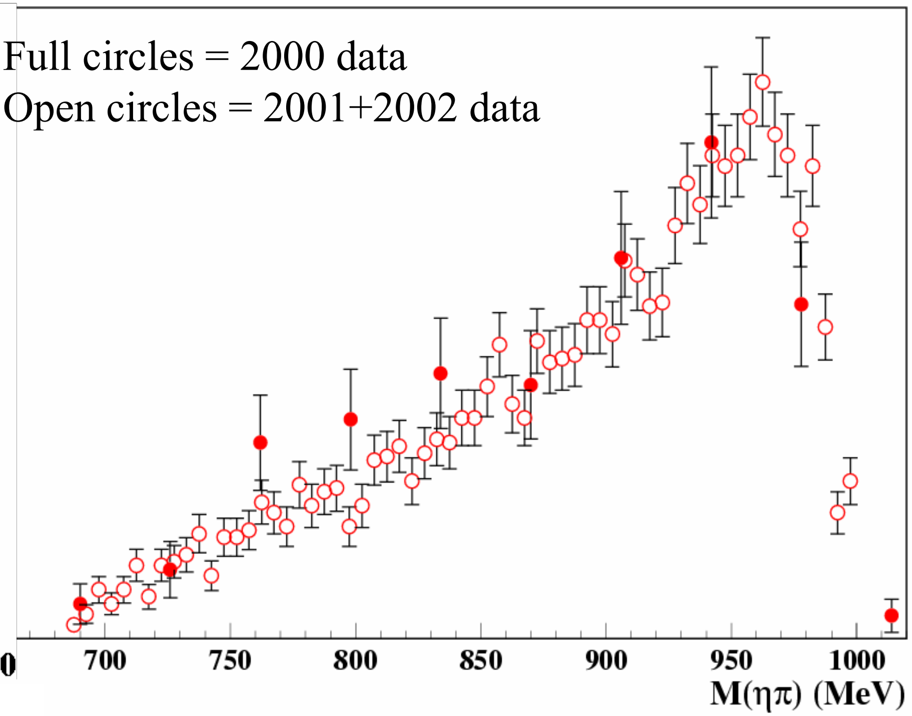


Comparison of “old” and “new” samples normalized to luminosity only:

(s.1)



(s.2)



Fit of new data:

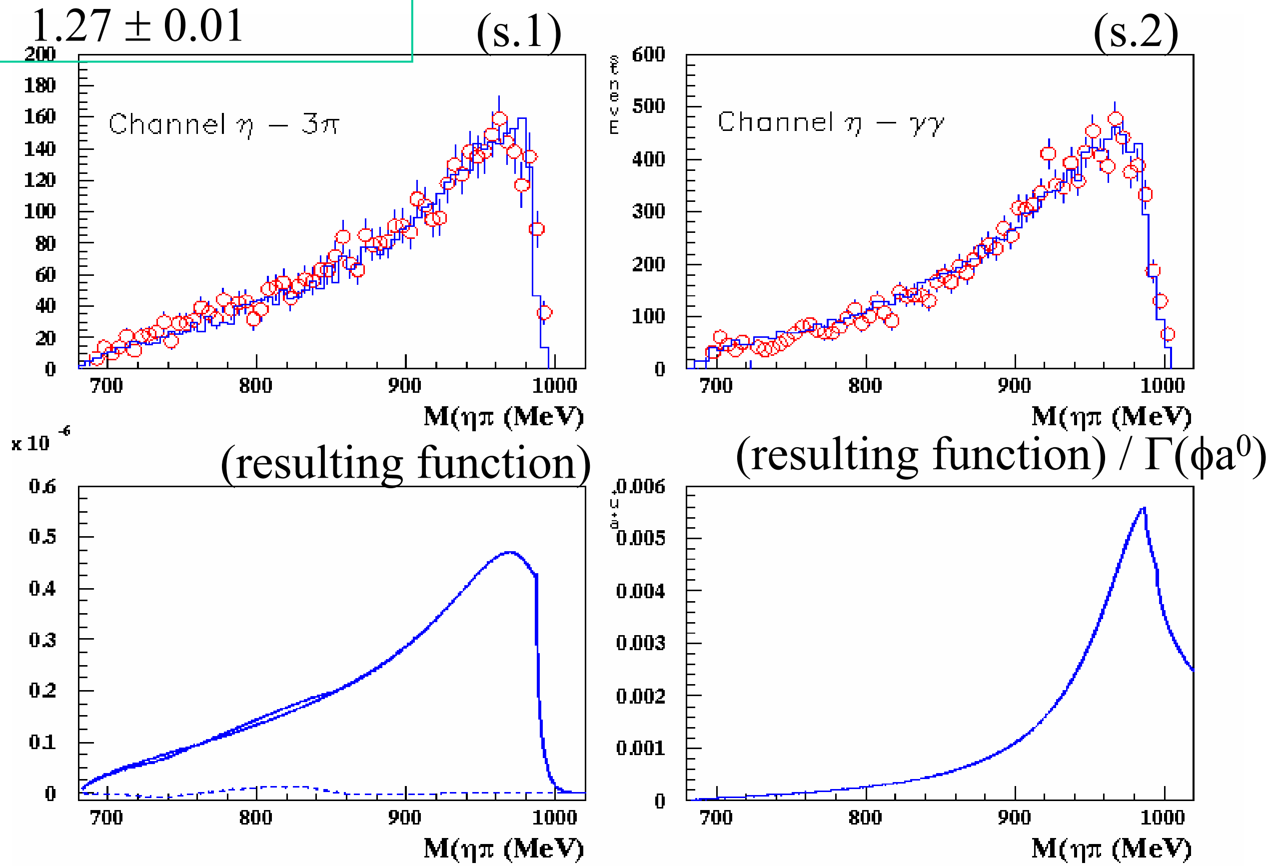
First attempt: repeat the same fit with a factor 20 statistics more. Now we are sensitive to the $\rho\pi$ term. A phase δ is introduced for the interference term [*Achasov and Kisilev Phys.Rev.D68:014006,2003*]

Good combined fit $\chi^2 = 196 / 128$ points (5 parameters)

BUT $\rho\pi$ contribution → 0 $(BR(\phi \rightarrow \rho\pi \rightarrow \eta\pi^0\gamma) < 5 \times 10^{-7})$

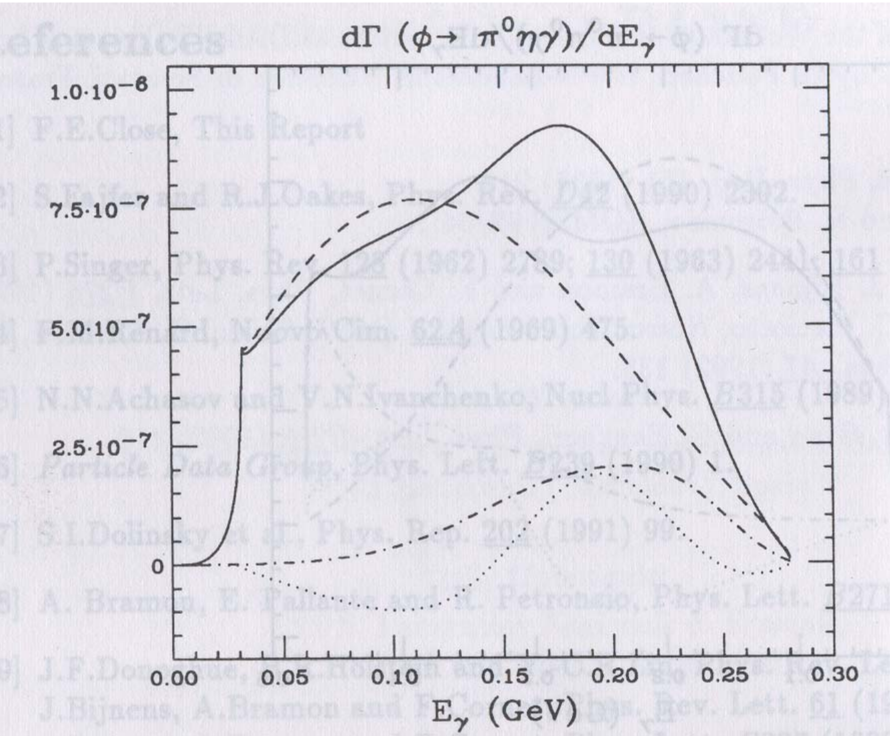
$BR(\phi \rightarrow \rho\pi \rightarrow \eta\pi^0\gamma) \sim 5 \times 10^{-6}$ [*Bramon,Grau,Pancheri PLB283 (1992) 416*]

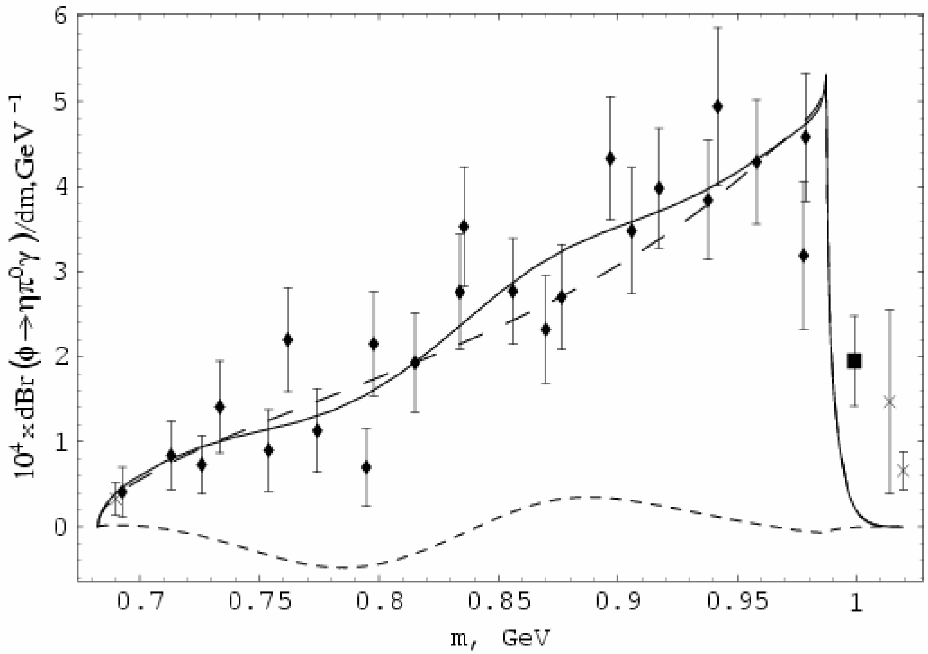
$M(a_0)$	=	987.0 ± 0.4 MeV
$g^2(a_0KK)/4\pi$	=	0.434 ± 0.007 GeV^2
R	=	1.27 ± 0.01



→ Either *the $\rho \rightarrow \eta\gamma$ is overestimated* OR *scalar shape is not correct*

The $\rho\pi - a_0$ interference term has a waving behaviour



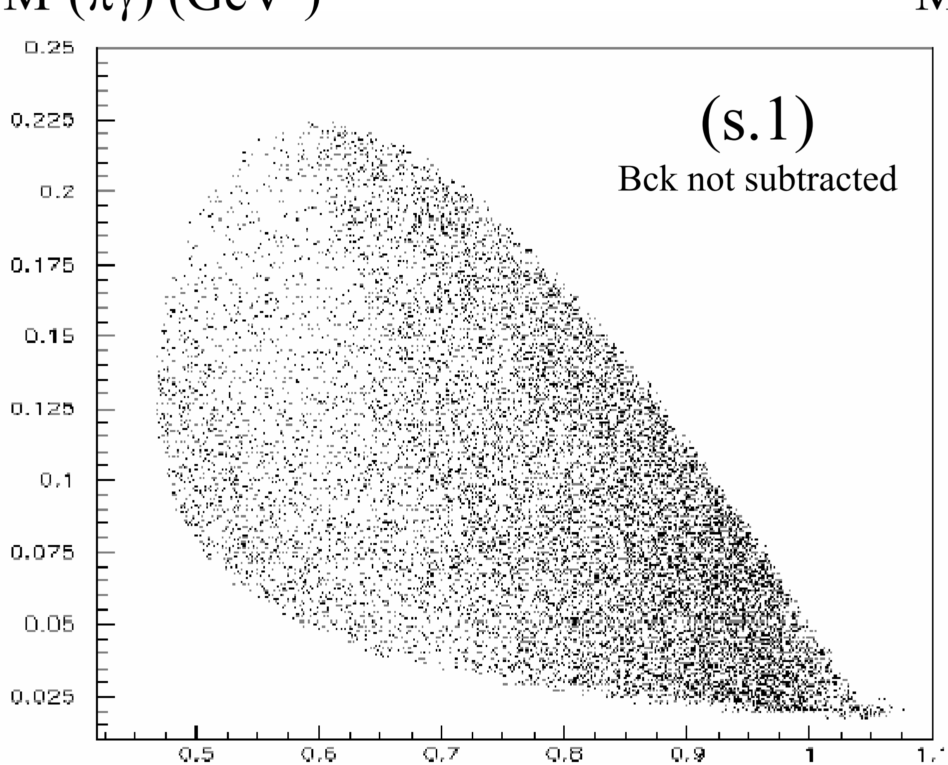


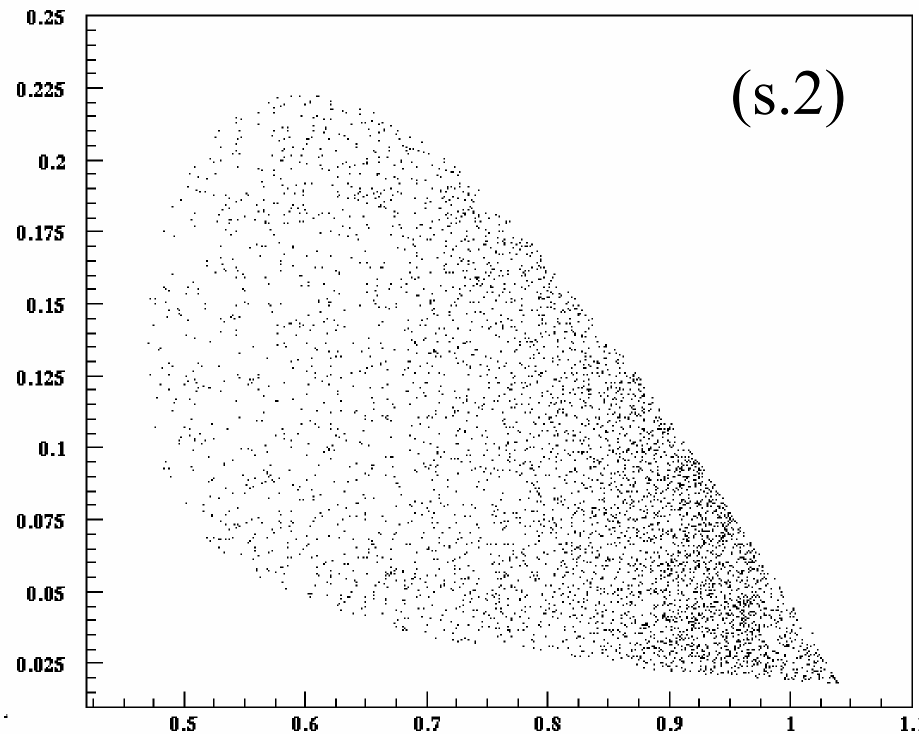
[Bramon,Grau,Pancheri DPH]
Dashed = a_0
Dashed-Dotted = $\rho\pi$
Dotted = interference

[Achasov,Kisilev PRD68:014006,2003]
Dashed = a_0
Dotted = $\rho\pi$
Points = KLOE data 2000 (16 pb^{-1})

Outlook:

1. Still some work on efficiency / resolutions to be done;
2. Higher statistics → Dalitz plot analysis;
3. Try new approach for the scalar sector (Isidori-Maiani);
   $\eta\pi\gamma$ good starting point for scalar analyses (less severe bckg)



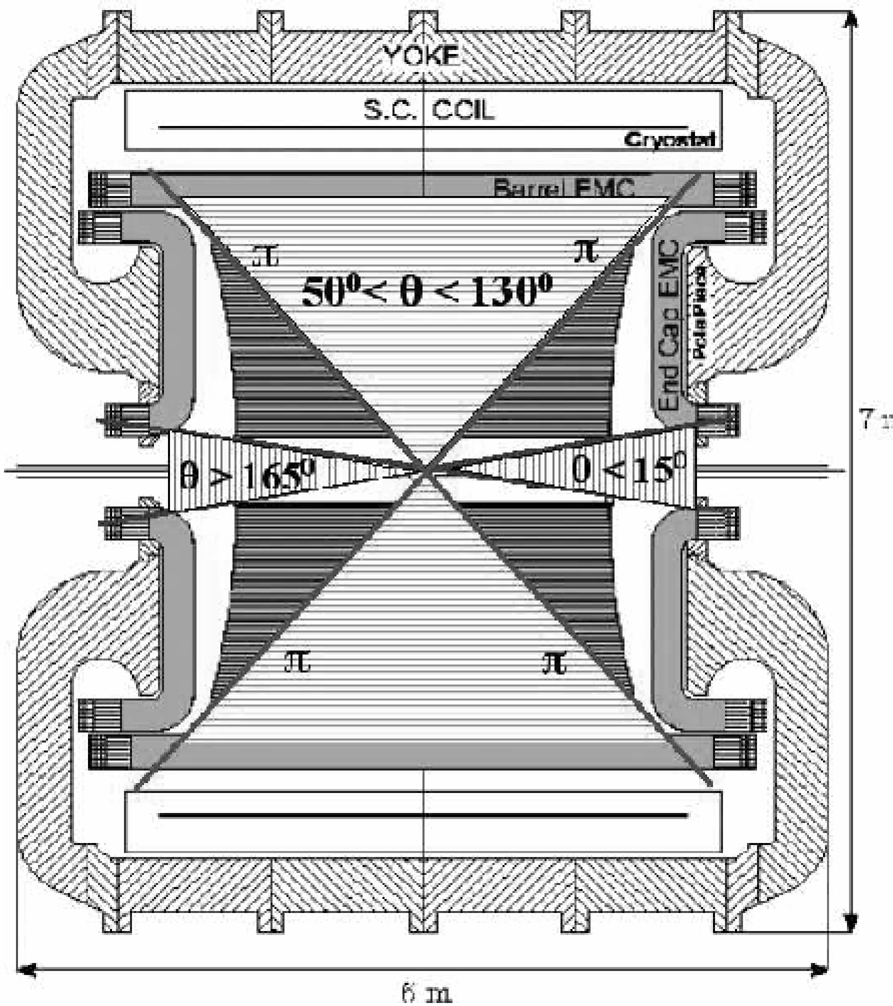


2. Search of the decay $f_0(980) \rightarrow \pi^+\pi^-$ on $\pi^+\pi^-\gamma$ events with a photon at large angle

KLOE $\pi^+\pi^-\gamma$ analyses:

1. Photon at "small" angle
   1.1×10^4 evts / pb^{-1}
   dominated by ISR
   ➔ $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ ➔ g-2
   hep-ex/0407048

2. Photon at "large" angle
   0.2×10^4 evts / pb^{-1}
   ➔ ISR + FSR + "scalar" + $\rho\pi$
   ➔ Search of $f_0\gamma$ contribution
   ➔ Upper limit $\eta \rightarrow \pi^+\pi^-$

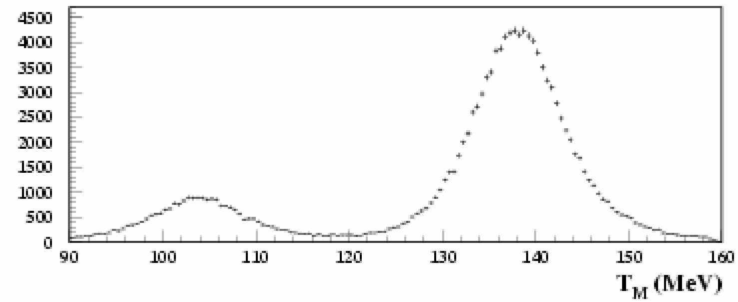


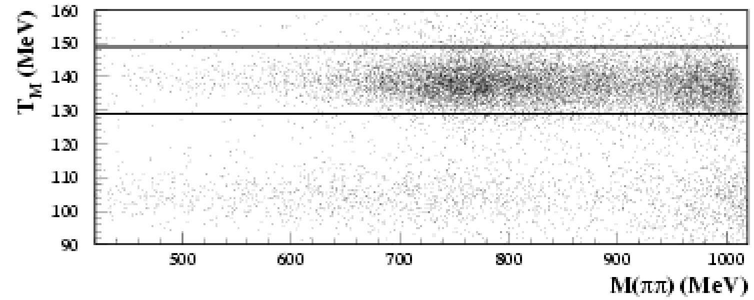
Event selection main ingredients:

$\pi^+\pi^-\gamma$ events respect to:

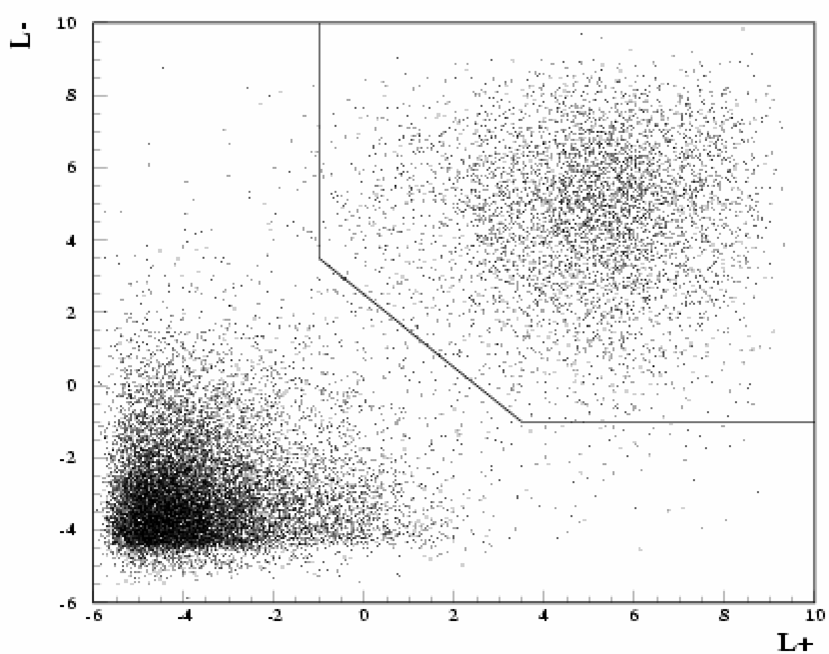
- $e^+e^-\gamma$ events
- $\mu^+\mu^-\gamma$ events
- $\pi^+\pi^-\pi^0$ events

(Track Mass)

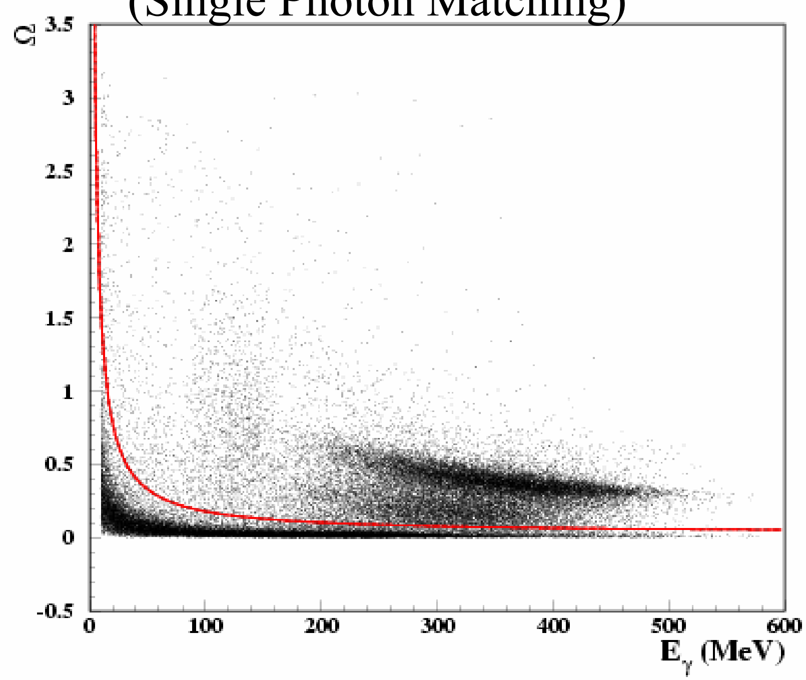




(Likelihood: Tof and Shower shape)

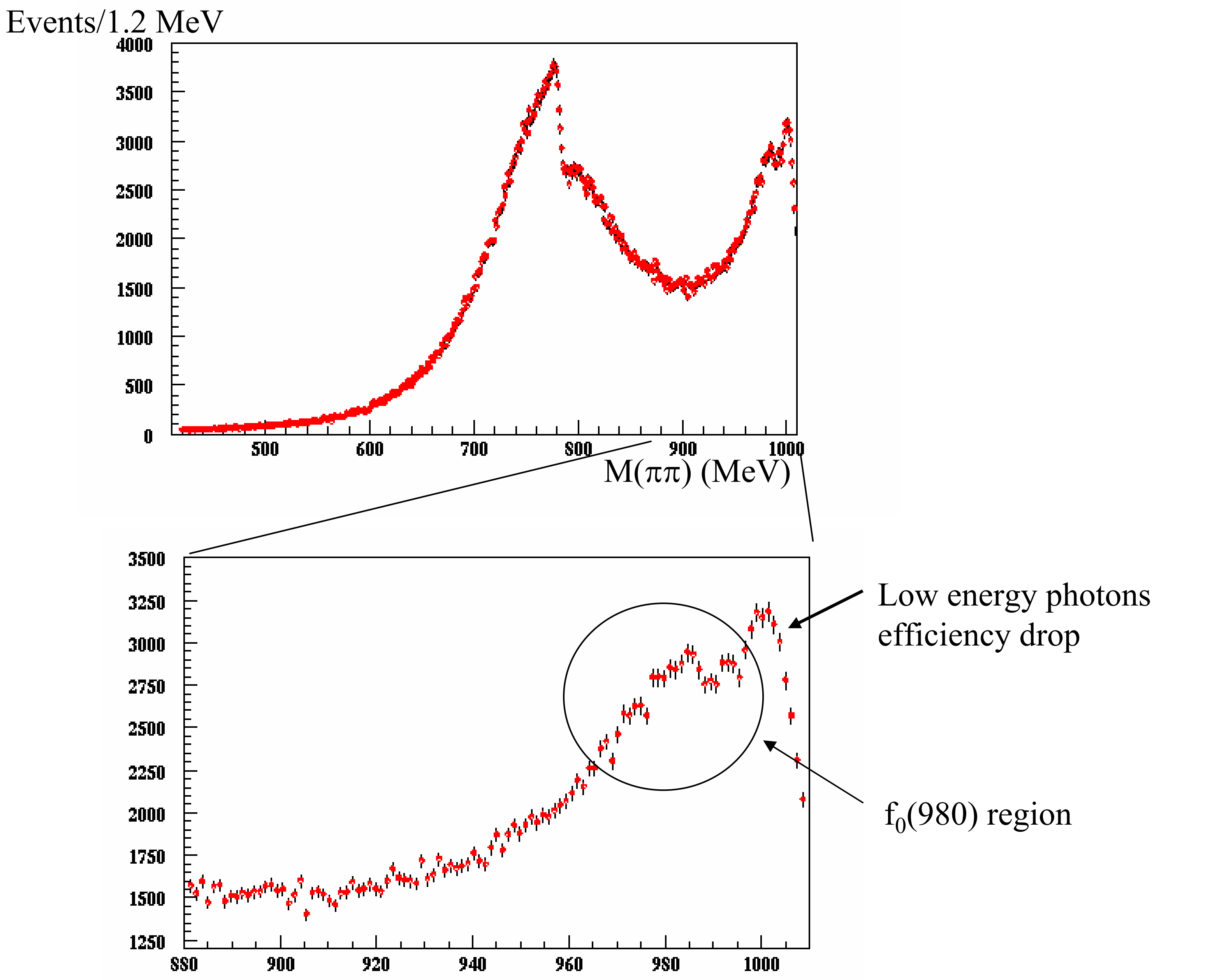


(Single Photon Matching)



The data sample: 676000 events from 2001+2002 data (350 pb^{-1})

The $M(\pi\pi)$ spectrum:



Fit of the spectrum

$$\frac{d\sigma}{dM} \propto \left| A(ISR) + A(FSR) + A(f_0) + A(\rho\pi) \right|^2$$

Where:

M = invariant mass of $\pi^+\pi^-$

ISR = initial state radiation (radiative return to ρ , ω)

FSR = final state radiation

→ f_0 = amplitude ($\phi \rightarrow f_0(980)\gamma \rightarrow \pi^+\pi^-\gamma$)

$\rho\pi$ = amplitude ($\phi \rightarrow \rho^{\pm}\pi^{\pm} \rightarrow \pi^+\pi^-\gamma$)

1. $45 < \theta_\gamma < 135^o$ → ISR reduced AND not "interfering"
2. FSR + f_0 interference expected (either + or -)
3. $A(\rho\pi)$ "small" and relevant only in the low M region

Ingredients of the fit:

1. FSR completely fixed [*Achasov, Gubin, Solodov PRD55(1997)2672*
Bramon,Colangelo, Greco PLB (1992)]

2. $\rho\pi$ completely fixed ($\rho^{\pm}\rightarrow\pi^{\pm}\gamma$ coupling known at ~ 10%)
[*Bramon,Grau,Pancheri PLB283 (1992) 416*
Achasov,Gubin, PRD56 (1997)4084]

3. ISR pion form factor needed: [*Kuhn,Santamaria ZPC48 (1990) 455*]
parametrization $\rho + \omega + \rho'$

$$F_{\pi}(Q^2) = \frac{\left(BW_{\rho}\left(\frac{1+\alpha BW_{\omega}}{1+\alpha}\right) + \beta BW_{\rho'} \right)}{(1+\beta)}$$

the ρ shape is given by

$$BW(Q^2) = \frac{m_{\rho}^2}{m_{\rho}^2 - Q^2 - i\sqrt{Q^2}\Gamma_{\rho}(Q^2)}$$

$$\Gamma(Q^2) = \Gamma_{\rho}\frac{m_{\rho}^2 p^3}{Q^2 p_{\rho}^3}$$

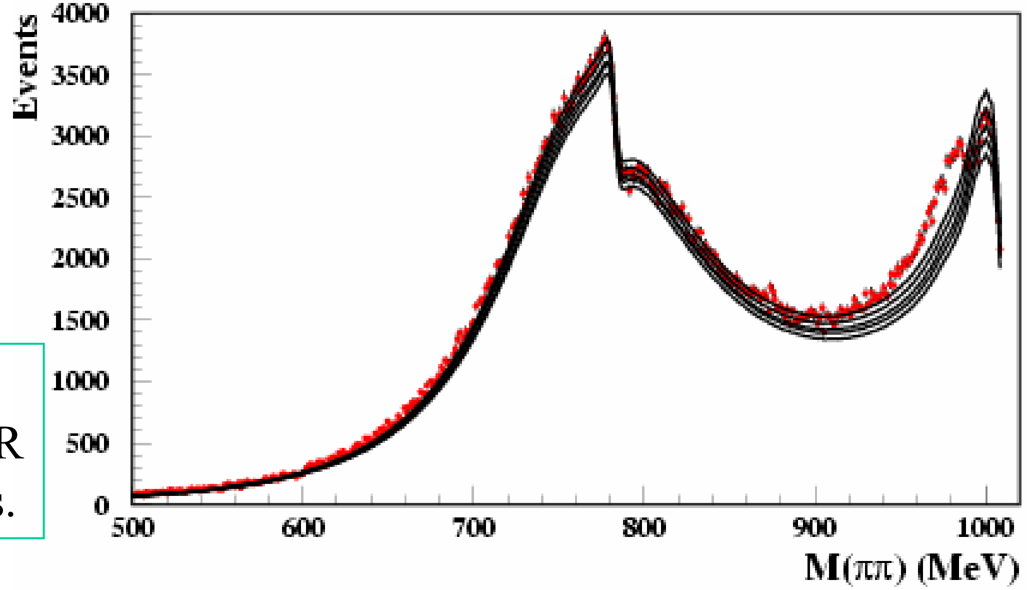
Radiative corrections are included based on the EVA Montecarlo

4. $f_0(980)$ "Kaon-loop approach" [*Achasov,Ivanchenko NPB315 (1989) 465*]
FSR / f_0 interference [*Achasov, Gubin PRD57 (1998) 1987*]

Is it possible to subtract the FSR+ISR background ?

NO

The knowledge of the ISR background is not good enough for that.



Absolute comparison between the experimental spectrum (red) and FSR+ISR Predictions based on available parameters.

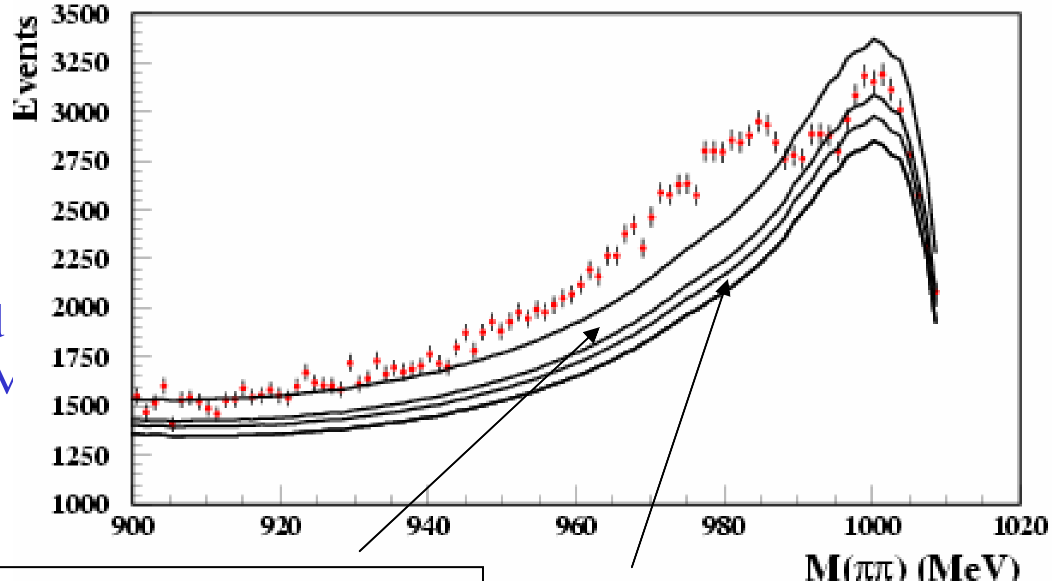
Free parameters of the fit are:

$M(\rho^0)$, $\Gamma(\rho^0)$, α, β

$M(f_0)$, $g(f_0KK)$, $g(f_0\pi\pi)$

β "effective background" has to be fitted

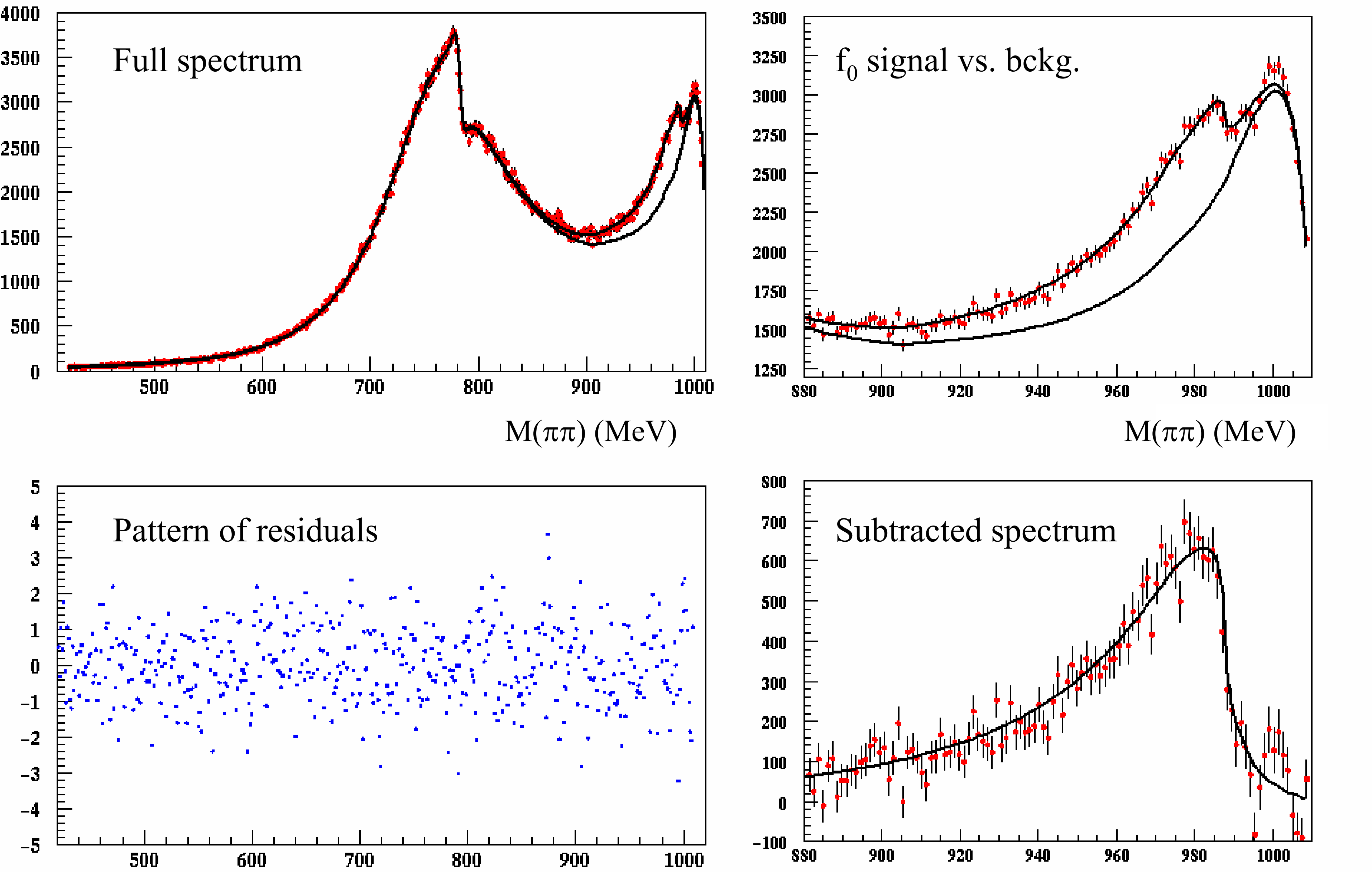
Based on points in the region 990-1010 M



Aleph $\beta = -0.087 : -0.101$

CMD-2 $\beta = -0.065 : -0.075$

Result of the fit: χ^2 = 539 / 488 points for NEG interference: 7 free parameters



Parameters

parameter	Fit result	Systematic (Maximal Variations)
$g^2_{fKK}/4\pi$	3.25 ± 0.50 GeV^2	± 1.1 GeV^2
R	2.81 ± 0.03	± 0.40
$M(f_0)$	983.4 ± 0.3 MeV	± 3.5 MeV
$M(\rho_0)$	773.3 ± 0.1 MeV	
$\Gamma(\rho_0)$	144.1 ± 0.1 MeV	
$\beta(\times 10^{-3})$	-122 ± 1	
$\alpha(\times 10^{-3})$	16.7 ± 0.1	

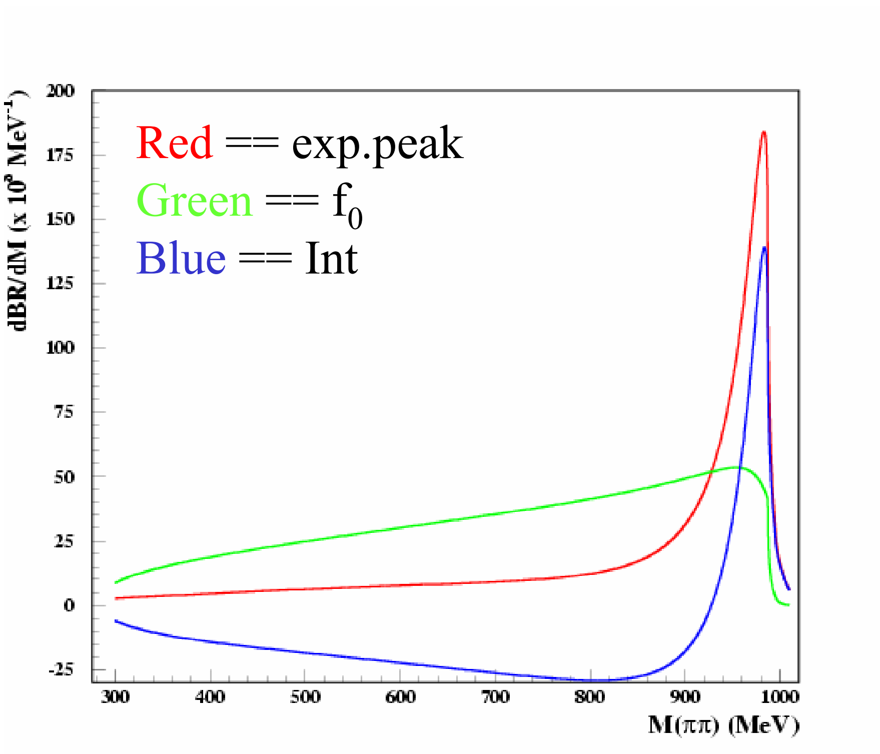
Background parameters are all reasonable

$M(f_0)$ well within the latest PDG estimate (980 ± 10 MeV)

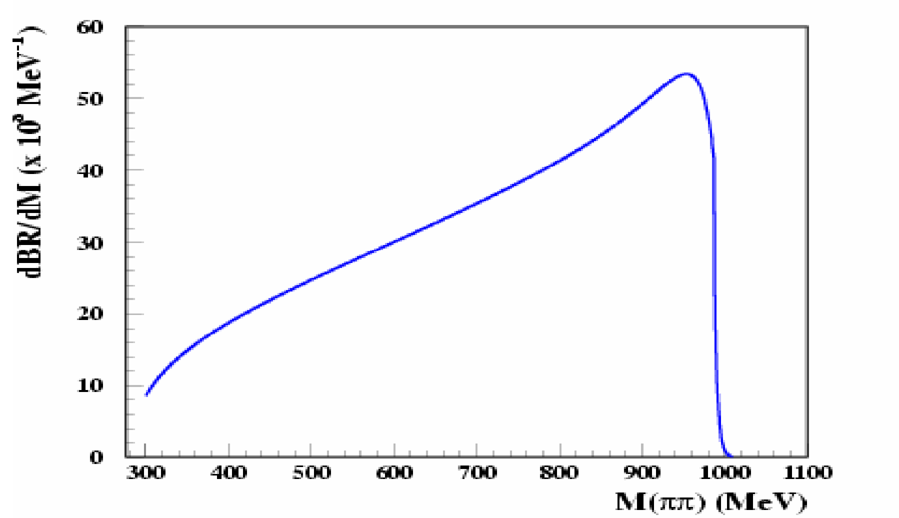
Limiting feature of this analysis:
the signal is small AND close to the spectrum edge

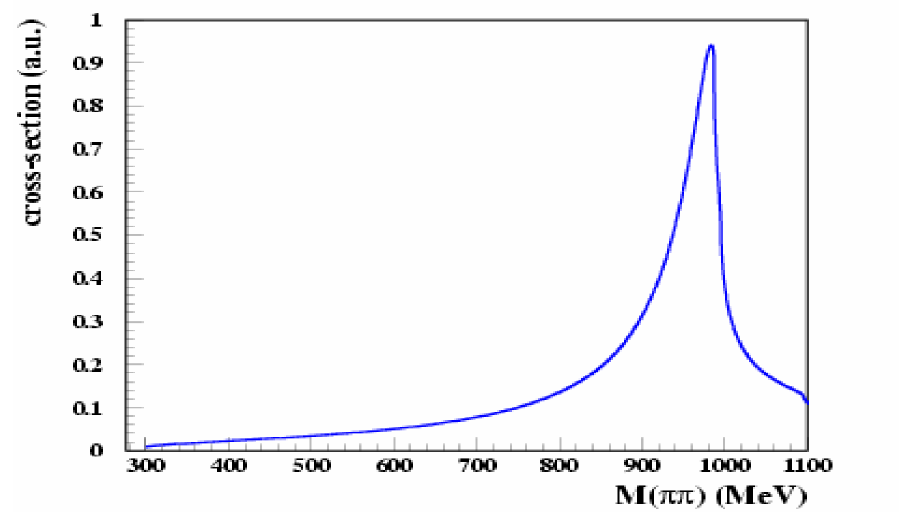
The $f_0(980)$ line-shape:

1) The peak is the result of a "*strong cancellation*" between the f_0 and the interference term



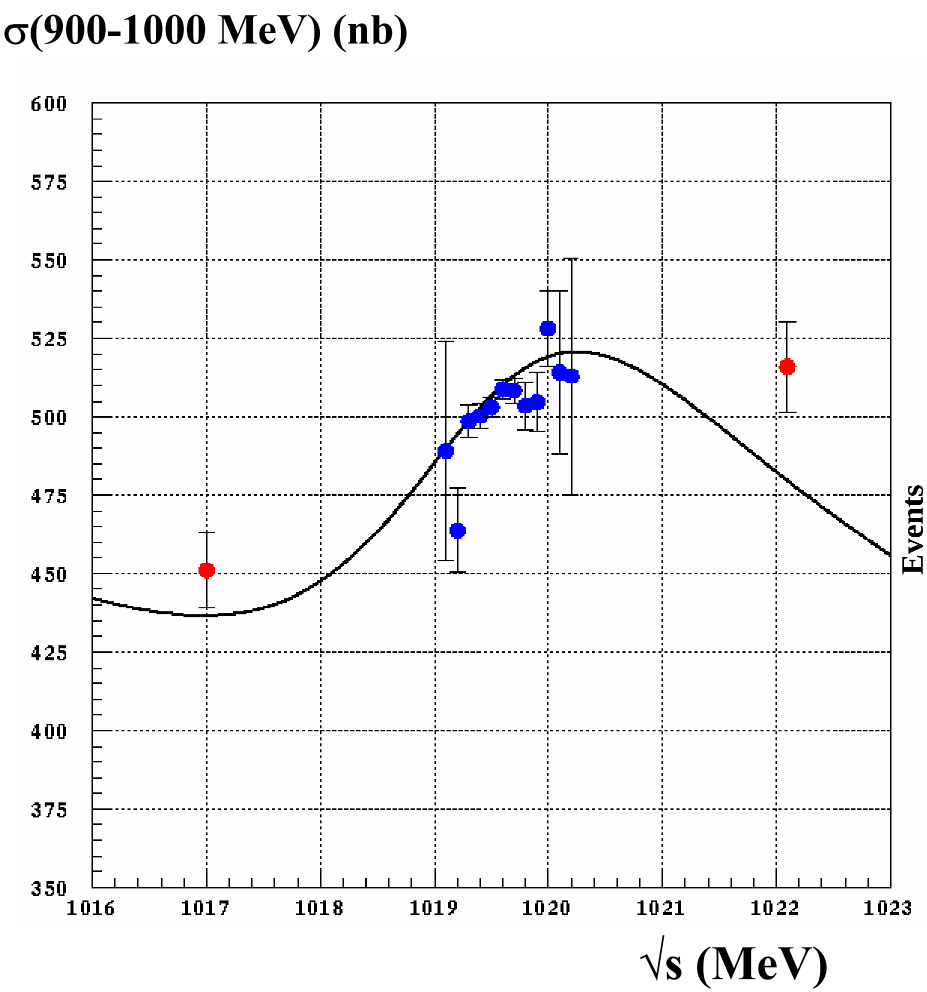
2) Take out the φ – based features:
$F'(M) = F(M) / [\, g(M)\, (s - M^2)\,]$
➔ "narrow f_0" (FWHM ~ 80 MeV)
➔ asymmetric shape (due to kaon Thresholds (Flatte' effect))

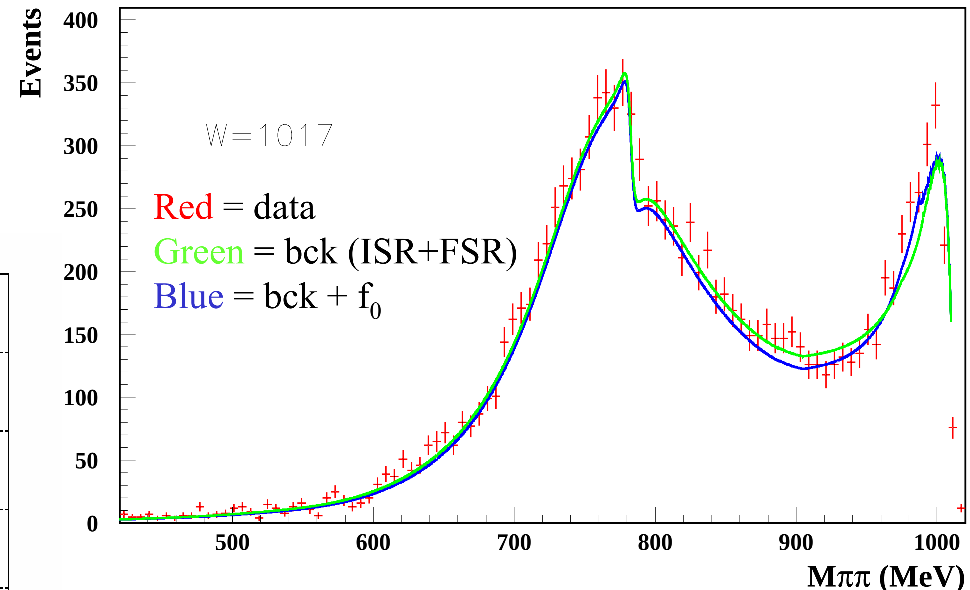


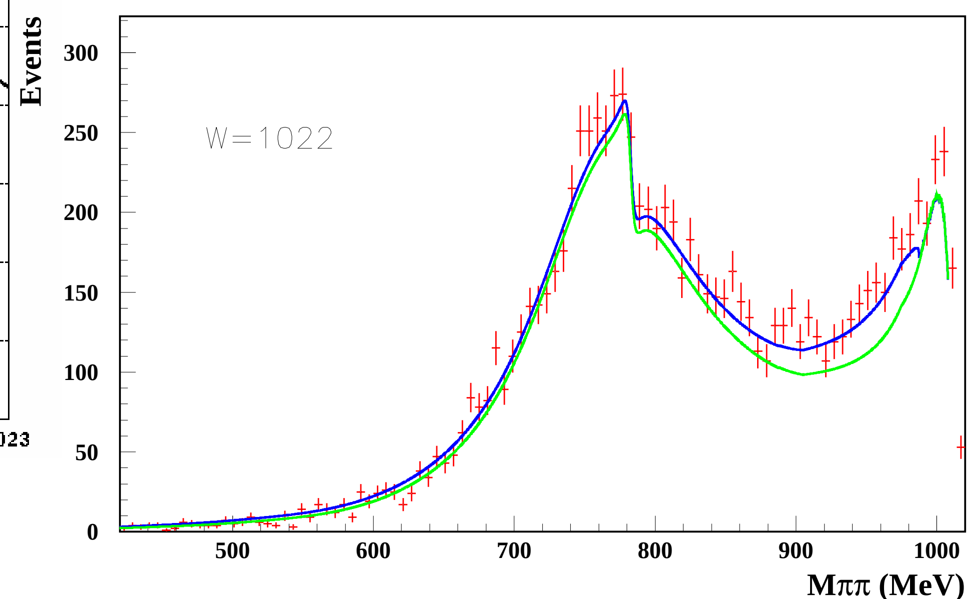


3) How big is the signal ?
Equivalent B.R.($\phi \rightarrow f_0(980)\gamma \rightarrow \pi^+\pi^-\gamma$)
from the integral of (Green) = 2.1×10^{-4}

√s dependence vs extrapolation from peak data (fit results)







Fit using the prescription from M.E.Boglione and M.Pennington

[*M.E.Boglione, M.Pennington, Eur.Phys.J. C30,503 (2003)*]

$$\frac{g(fKK)g(f\pi\pi)\exp(i\delta(M))}{D_f(M)}$$

$$\updownarrow$$

$$T_{12} \times (\text{polyn. in } M^2)$$

Where:

g(fKK) g(fππ) f_0 couplings;

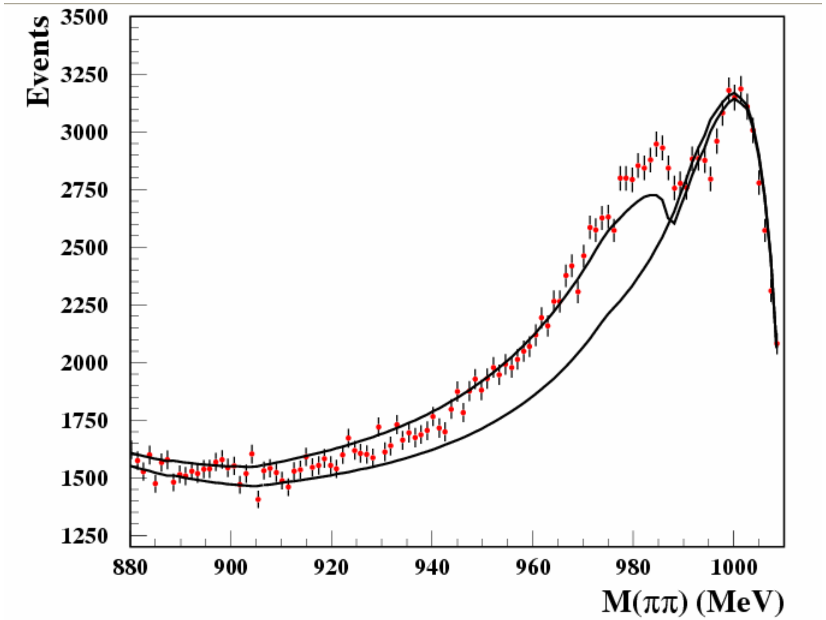
exp(iδ(M)) ππ phase shift

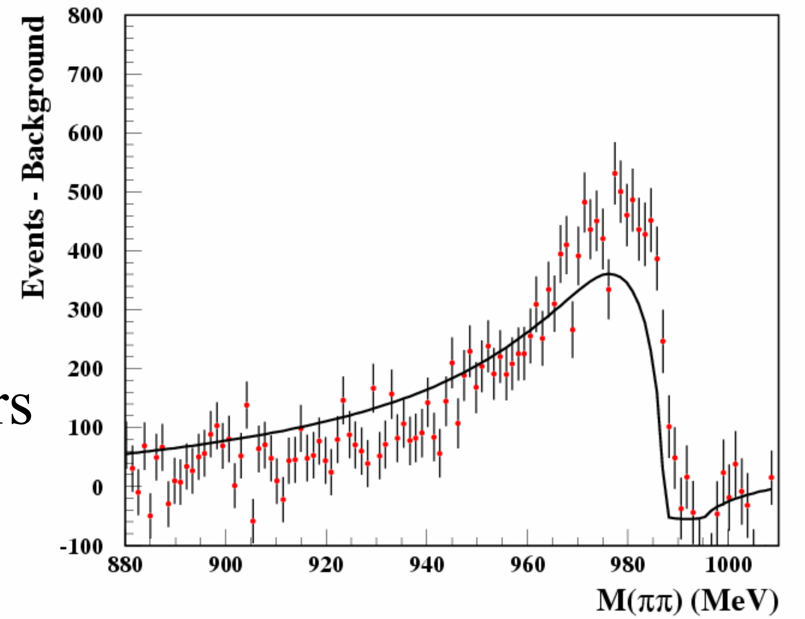
$D_f(M)$ f_0 propagator

T_{12} T(KK→ππ)

assumed no contribution from T(ππ→ππ)

Fit with POS interference is the best one fit: χ^2 = 779 / 488 points 7 free parameters (3rd degree polynomial)





Charge asymmetry

$\pi^+\pi^-$ system: odd terms (green) and even terms (brown)

A(ISR) ➔ C-odd

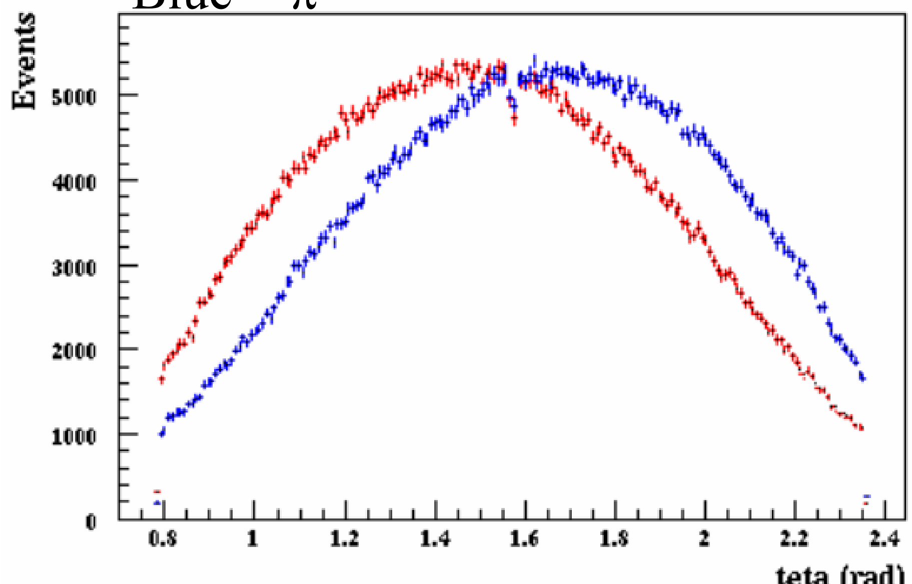
A(FSR) ➔ C-even

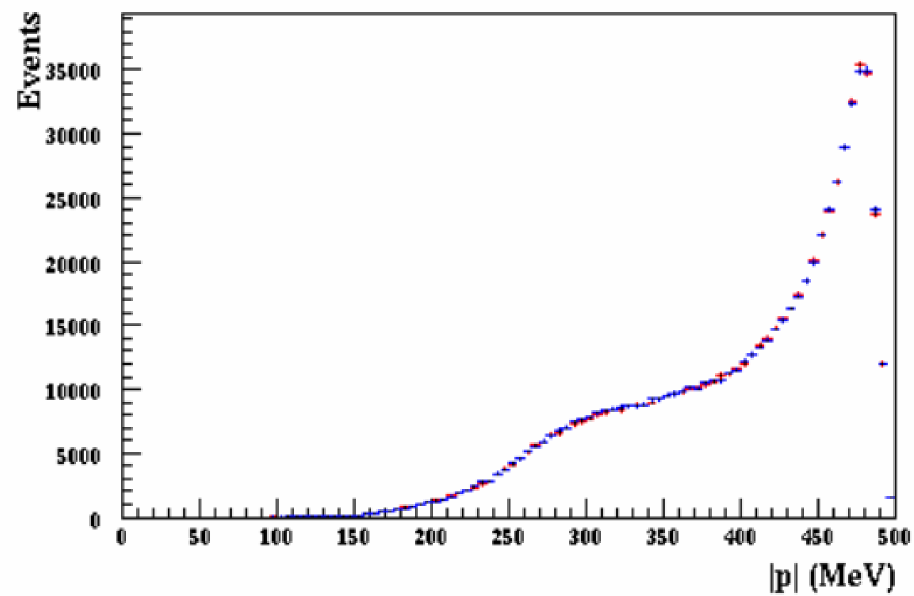
A(f0) ➔ C-even

$$|A(tot)|^2 = |A(ISR)|^2 + |A(FSR)|^2 + |A(f_0)|^2 + 2Re[A(ISR)\,A(FSR)] + 2Re[A(ISR)\,A(f_0)] + 2Re[A(FSR)\,A(f_0)]$$

Red = π^+

Blue = π^-



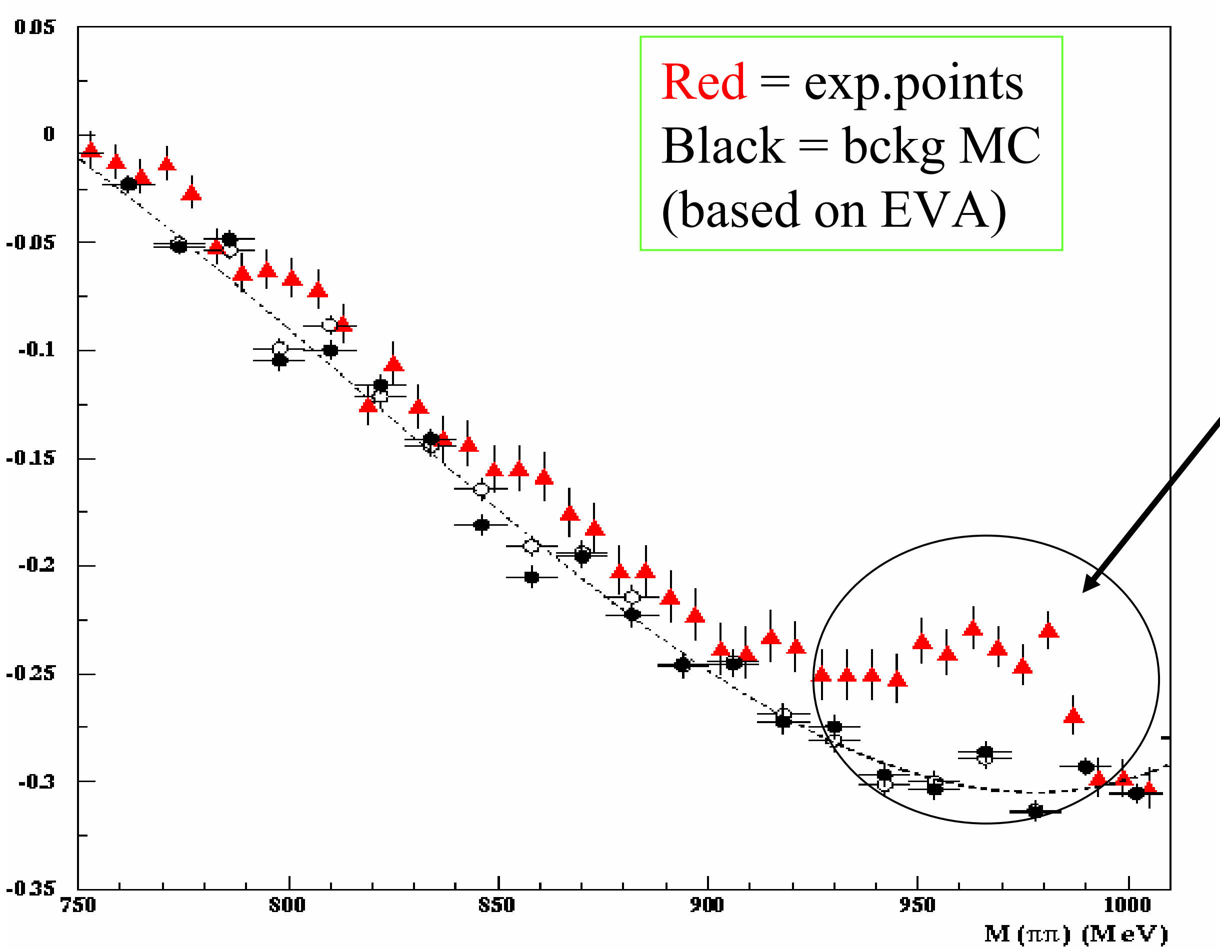


➔ Asymmetry in $\pi^+\pi^-$ θ angle: **A = (N(θ^+>90) – N(θ^+<90)) / sum**

Look at **M** dependence of **A**

M dependence: **data** vs **FSR+ISR prediction**:

MC is based on EVA:
FSR+ISR (LO) +interference



f_0(980) gives this "bump"
2Re[A(ISR) A(f0)]

Main points:

- ➔ $\eta\pi\gamma$ fit is in "trouble" with high statistics;
- ➔ clear evidence of $f_0(980)$ signal in the $\pi^+\pi^-\gamma$ sample;
  - → event spectrum
  - → charge asymmetry
- ➔ Experimentally solid results.

$$\left(\frac{d\sigma}{dM}\right)_{f0} = \frac{\alpha^2}{24\pi s^2\sqrt{s}}\left(\frac{g_{f0\pi\pi}}{f_\phi}\right)^2 \frac{m_\phi^4|g(M)|^2}{|D_\phi(s)|^2|D_{f0}(M)|^2}(s-M^2)f(x)\left(a+\frac{a^3}{3}\right)\frac{M}{m_\phi}H_{rad}(s)$$

$$\left(\frac{d\sigma}{dM}\right)_{int} = \frac{\alpha^3}{s\sqrt{s}}\left(\frac{g_{\rho\pi\pi}\, g_{f0\pi\pi}}{f_\phi f_\rho}\right)\times \mathrm{Re}\left[\frac{m_\phi^2 m_\rho^2 g(M)\exp(i\delta_B(m))}{\sqrt{4\pi\alpha}D_\phi(s)D_\rho^*(s)D_{f0}(M)}\left(1-\frac{3\Gamma(\phi\to ee)\sqrt{s}}{\alpha D_\phi^*(s)}\right)\right]\times$$

$$\left[f(x)+\frac{\xi}{2}\ln\frac{1-f(x)}{1+f(x)}\right]\left(a+\frac{a^3}{3}\right)H_{rad}(s)$$

$$\delta_B(M) = B\ [\, M^2 - 4\, M_\pi^{\,2}\,]^{1/2}$$
$$B = (\, 84 \pm 8\,)\,^{o} / \mathrm{GeV}$$

Free parameters are:

$M(\rho^0)$, $\Gamma(\rho^0)$, α, β

$M(f_0)$, $g(f_0KK)$, $g(f_0\pi\pi)$

Comments:

No scale parameter: absolute prediction;

β is poorly known ➔ has to be left free

Scalar sector: only $f_0(980)$; σ not included

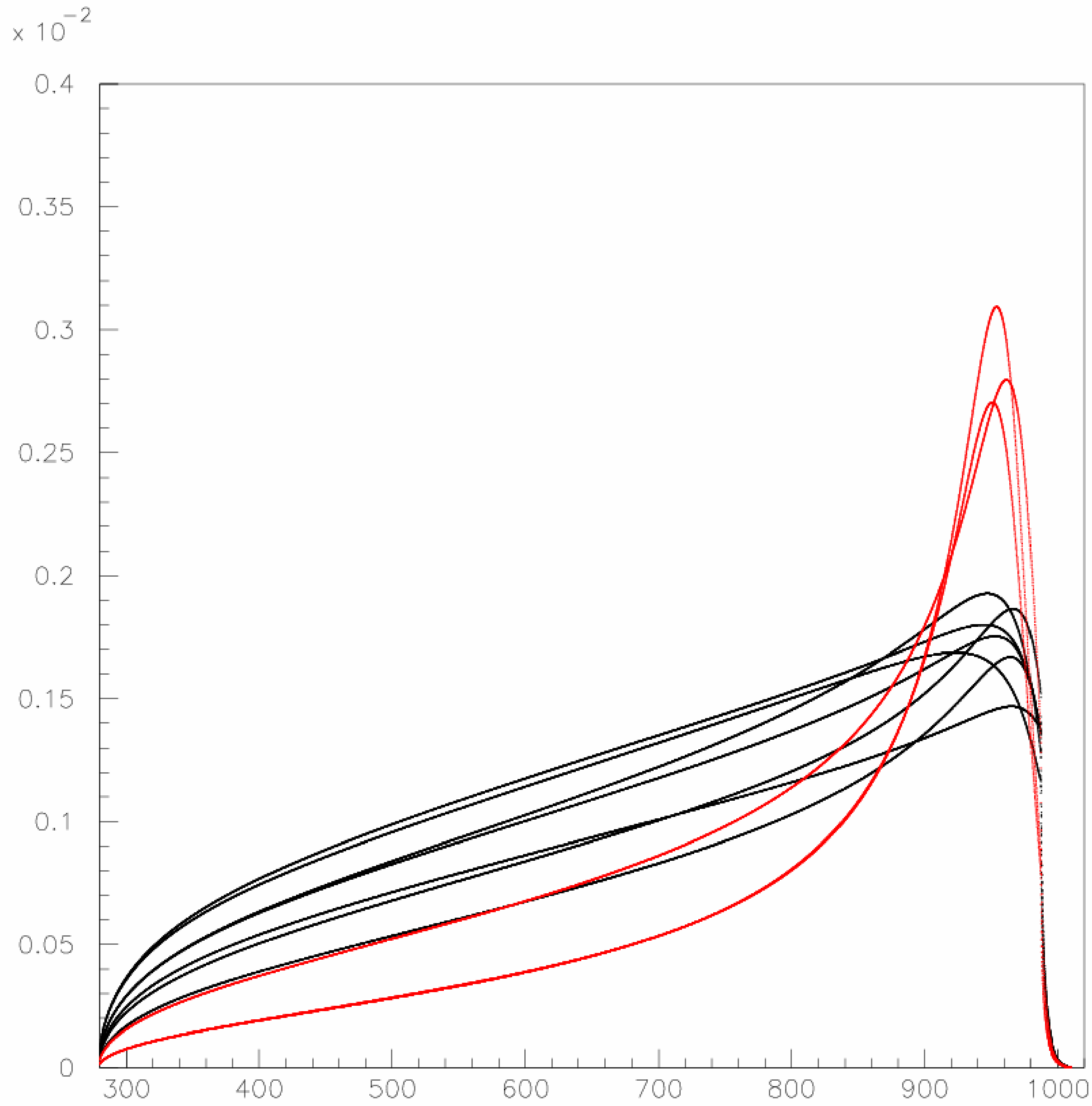
Fit stability Tests

Test of reproducibility: 2001 data vs 2002 data only:

Sample	$g^2_{f0KK}/4\pi$ (GeV^2)	R	m_{f0}(MeV)	χ^2	BR(10^{-4})
2001	2.90	2.66	984.1	473	1.95
2002	3.69	2.92	983.4	507	2.16
full	3.48 ± 0.63	2.84 ± 0.09	983.6 ± 0.6	539	2.12

	$g^2_{f0KK}/4\pi$ (GeV)^2	R	m_{f0}(MeV)	**B.R.**
Abs.Scale ± 2%	±0.3	±0.02	±0.2	
γ eff cut ±2 MeV	±0.2	±0.15	±2.6	
$\sqrt{s}$ ±0.5 MeV	±0.3	±0.28	±1.2	
B ± 1 σ	±0.2	±0.17	±2.1	
Fit bounds	±0.8	±0.18	±1.4	
Binning	±0.1	±0.01	±0.1	
				$\pm 0.4 \times 10^{-4}$

Limiting feature of this analysis:
the signal is small AND close to the spectrum edge



x 10^-2
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
300
400
500
600
700
800
900
1000

Polar angle distributions: data vs. MC

Check of $(1+\cos^2\theta)$

Red = data
Blue = MC

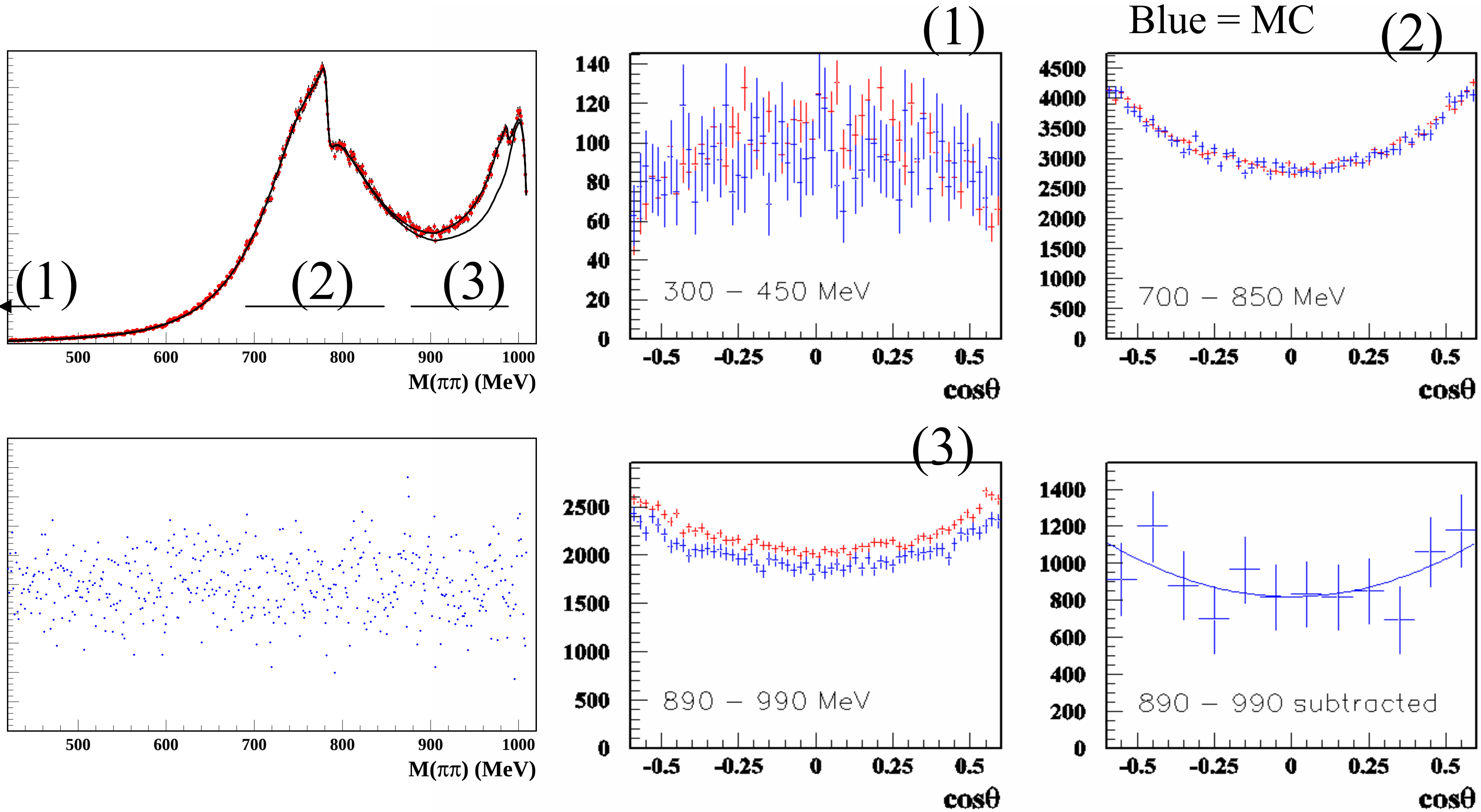
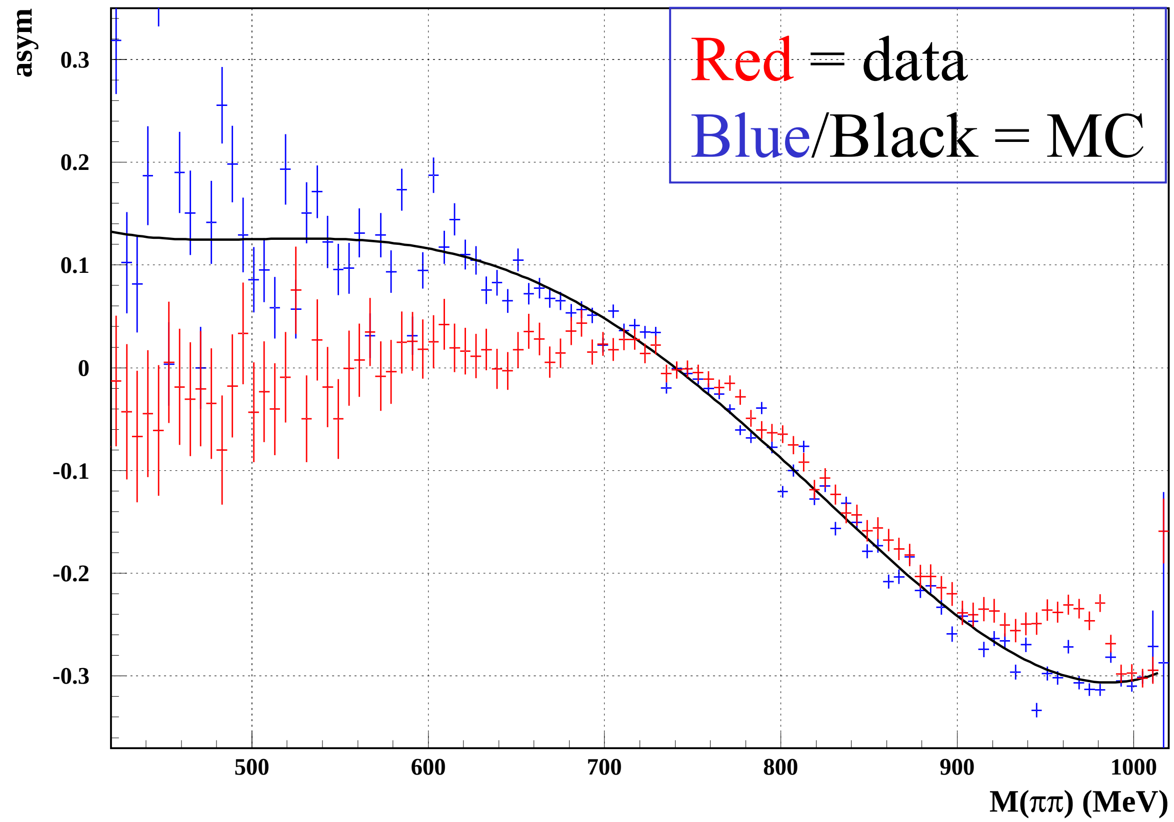


Fig.7 Polar angle distributions of on-peak data (red) and background ISR+FSR Montecarlo (blue) in 3 *M* regions. The angular subtracted angular distribution of the events in the *f0* region is shown in plot 4 with a $(1+\cos^2\theta)$ curve superimposed.



asym
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
500
600
700
800
900
1000
M(ππ) (MeV)
Red = data
Blue/Black = MC

Simple considerations on the charge asymmetry:

N = S + B (functions of M)

Where S = signal events,

B = background events

A = (ΔS + ΔB)/(S+B) = (ΔB/B) B/(S+B) + (ΔS/S) S/(B+S)

(ΔB/B) known from ISR+FSR Montecarlo

B , S known from cross-section fit

(ΔS/S) only unknown

If **(ΔS/S)** = (ΔB/B) ➔ no peak is found in A

If **(ΔS/S)** ≠ (ΔB/B) ➔ a peak is found in A

➔ Excess of events at f0 peak has 0 or >0 charge asymmetry