Study of Scalar Mesons in $\pi^+\pi^-\gamma$ events with the KLOE detector

(0) Motivations of this analysis
(1) Event Selection
[see C.Bini, S.Ventura, KLOE Memo 284]
(2) The data sample: what we measure
(3) Fit to the data
(4) Interpretation of the results
(5) Conclusions (=answers to (0))

(0)Motivations of this analysis:

Look for $f_0(980) \rightarrow \pi^+\pi^-$ signal

Extraction of the "coupling" of the $f_0(980)$ to the $\phi(1020)$: s-quark content of f_0

Any further meson ($f_0(600)=\sigma$) is needed to describe the spectrum ?

Comparison between different approaches for the $\phi \rightarrow$ scalar + γ amplitude descriptions

(1)Event selection

- Vertex in I.R. (r_{xy}< 8 cm, |Z|< 10 cm)with 2 opposite charge tracks 45º < θ < 135º;

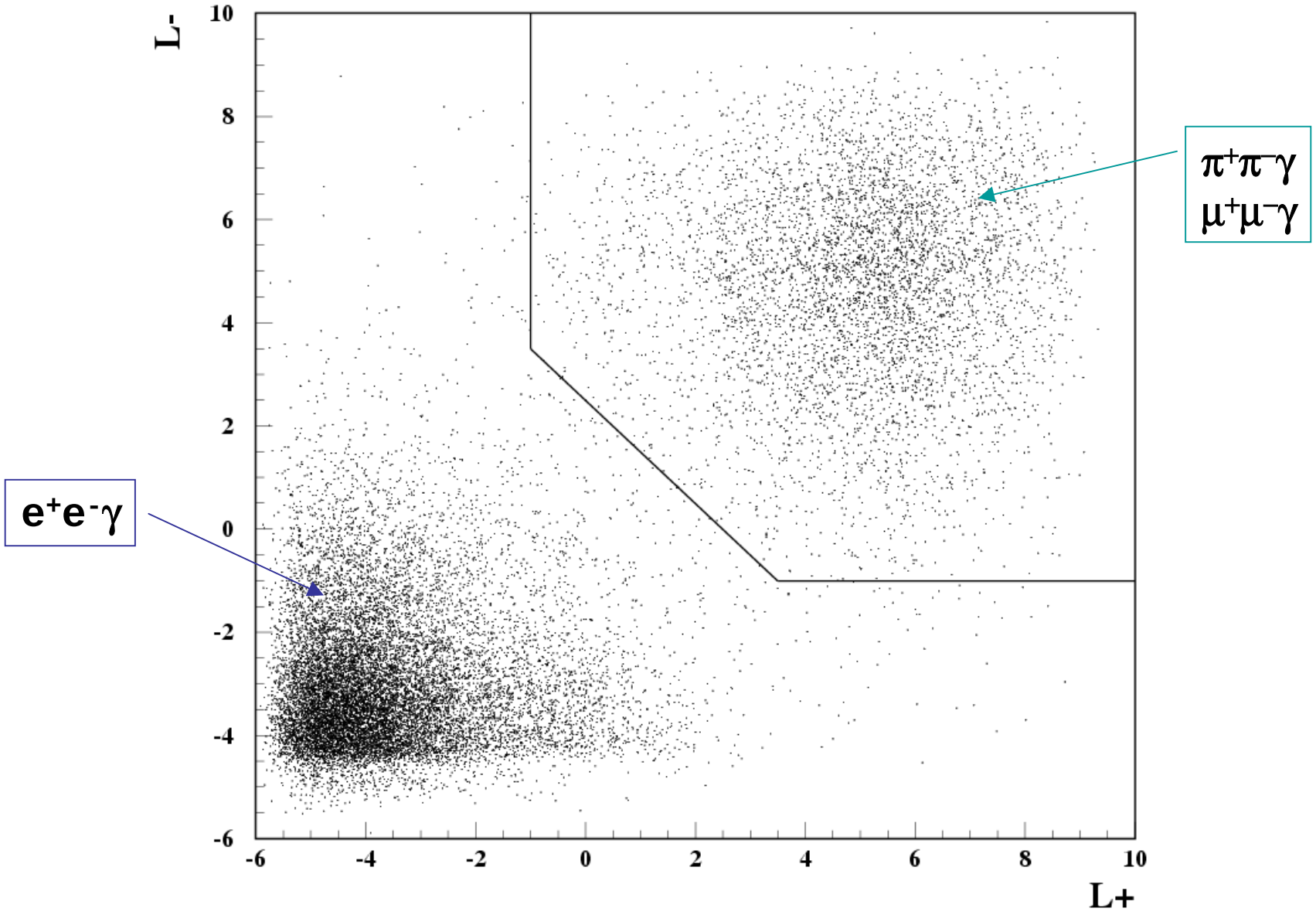
(2)Both tracks extrapolated to calorimeter
TCA + Likelihood (in AND);
➔[*reduce $e^+e^-\gamma$*]

(3)$P_{miss}=P_\phi-P_{t1}-P_{t2}$; 45º < θ($P_{miss}$) < 135º;
➔[*photon at "large angle" reduce ISR*]

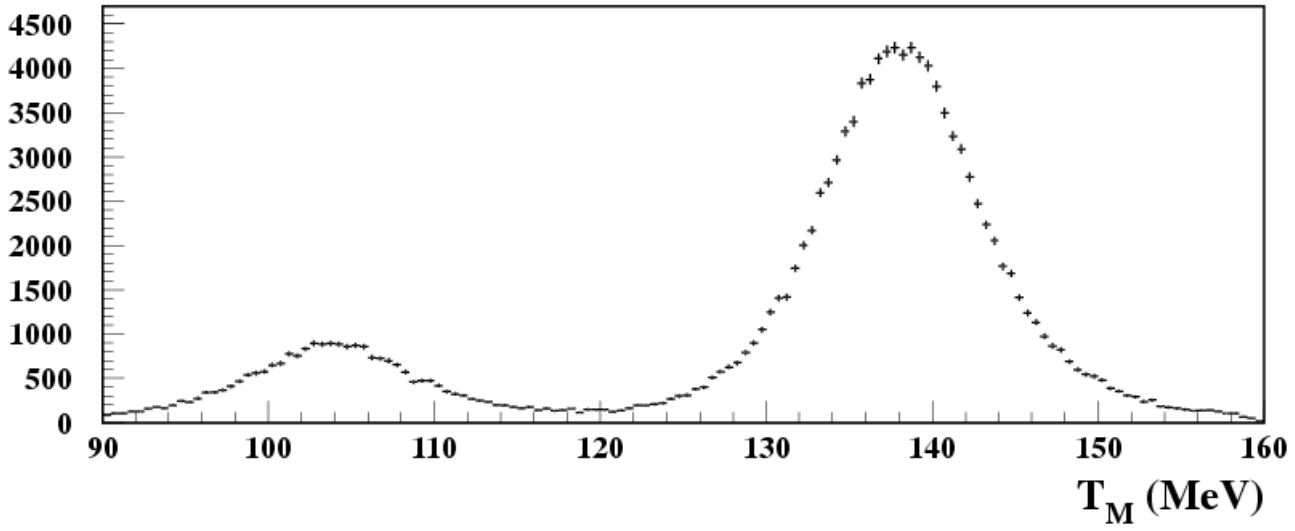
(4)Trackmass: 129 < M_T < 149 MeV;
➔[*reduce $\mu^+\mu^-\gamma$ and $\pi^+\pi^-\pi^0$*]

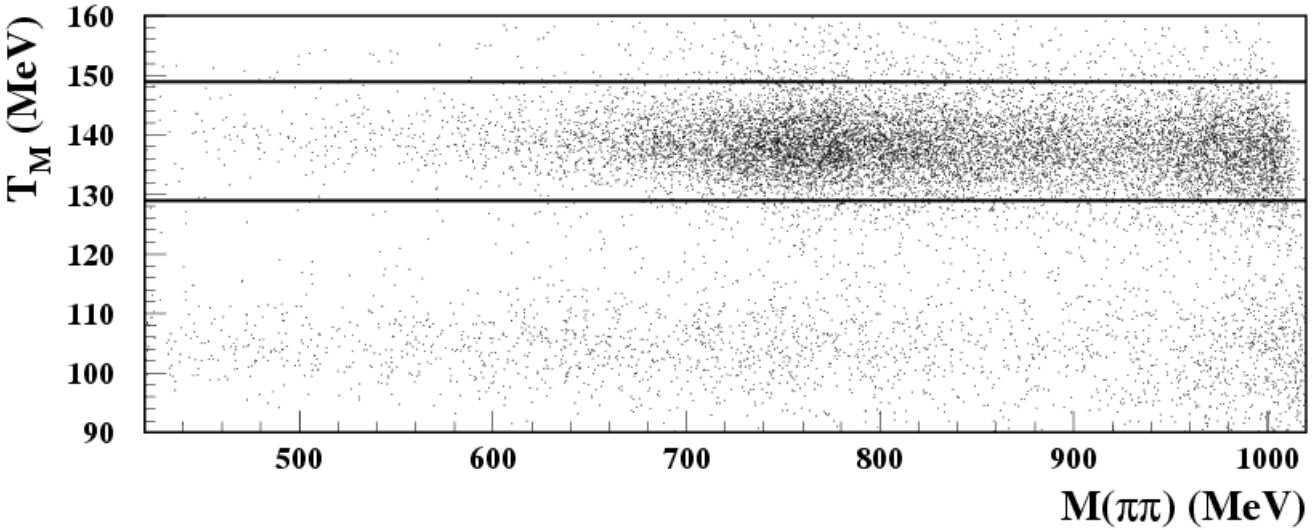
(5)Request of the photon: a neutral cluster with
$\Omega \propto \arccos(p_{cl}\cdot P_{miss}) < 0.03 + 3/E_\gamma$(MeV) rad;
➔[*further reduction of $\pi^+\pi^-\pi^0$ and of $\pi^+\pi^-$*]

Cut on the likelihood variables (AND)

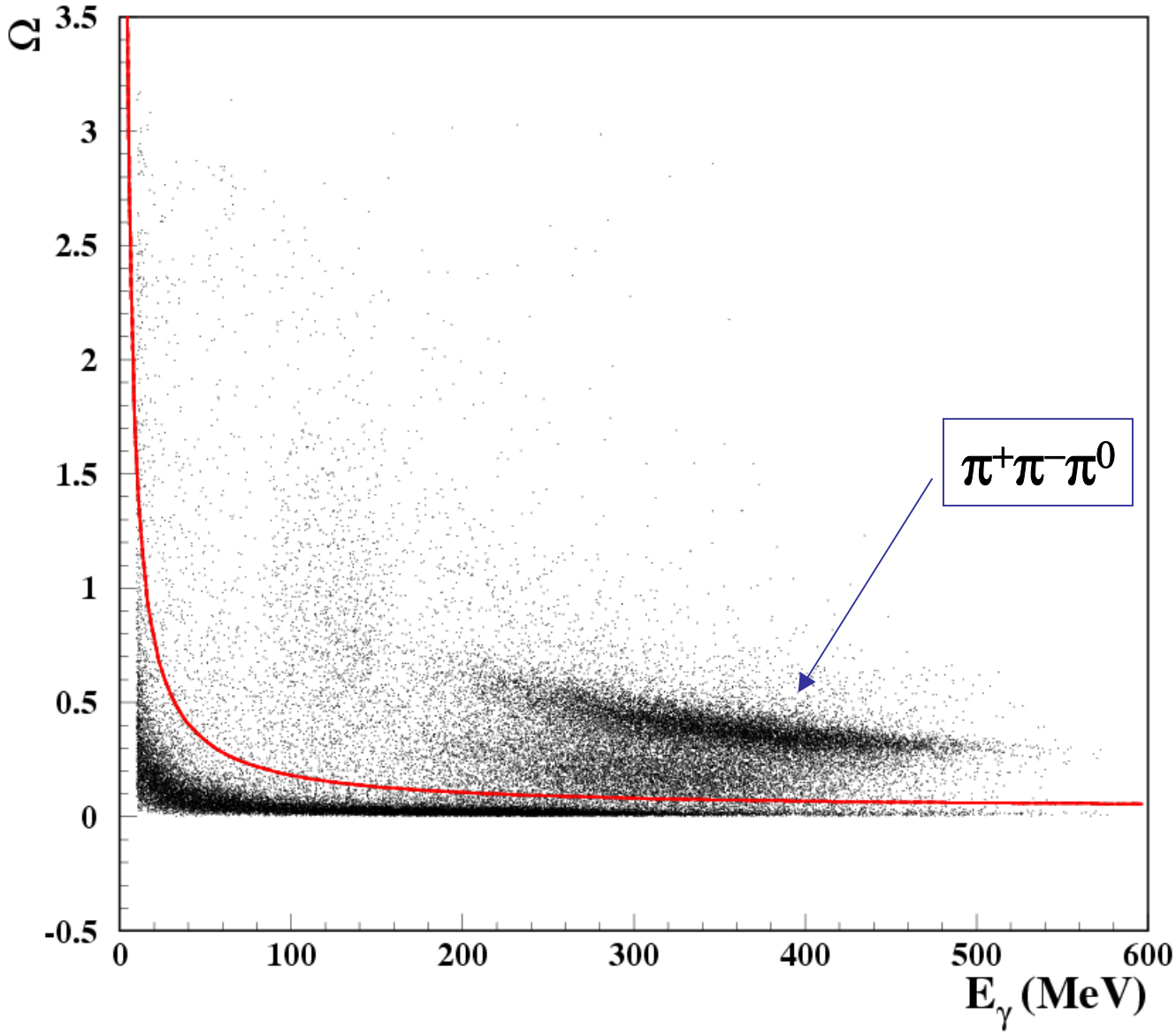


Cut on the trackmass variable





Cut on the Ω variable

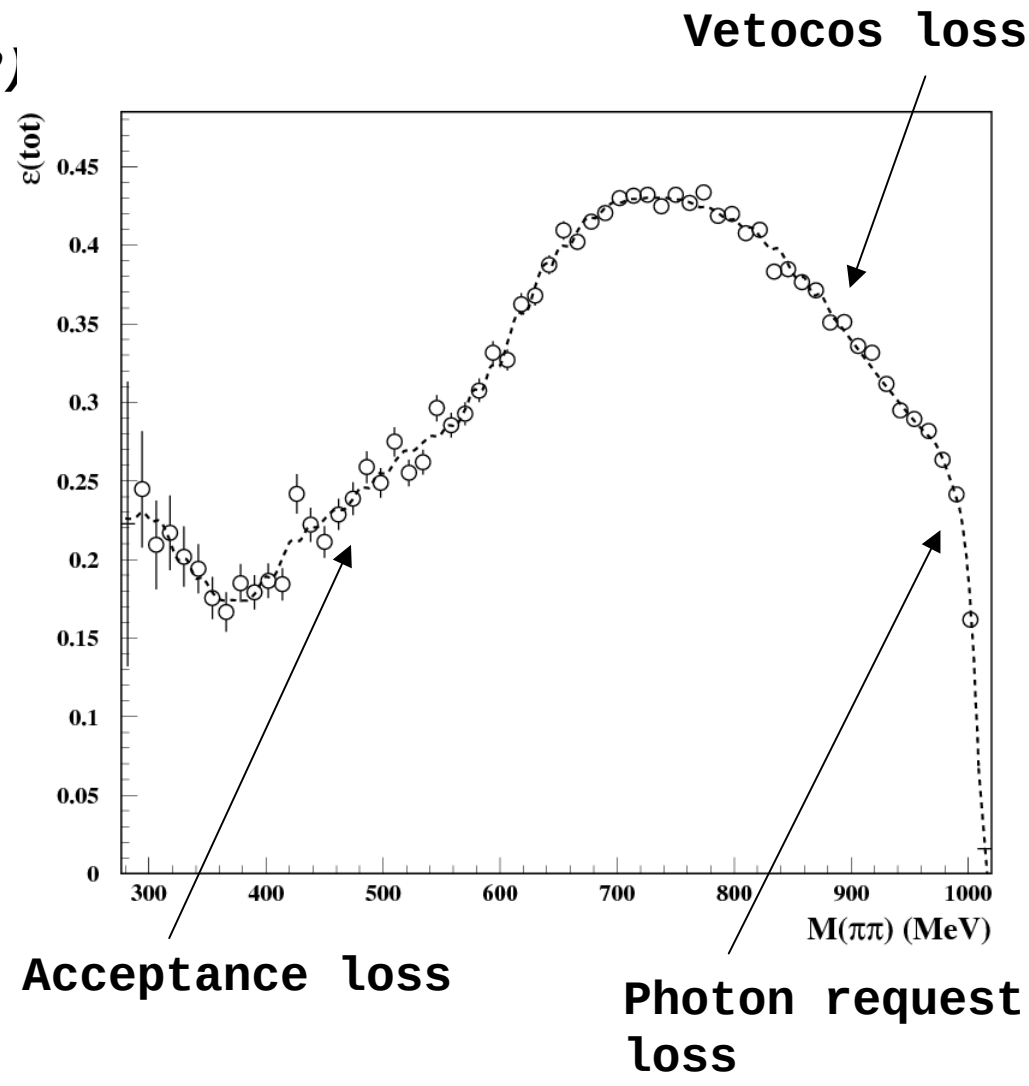


Efficiency:

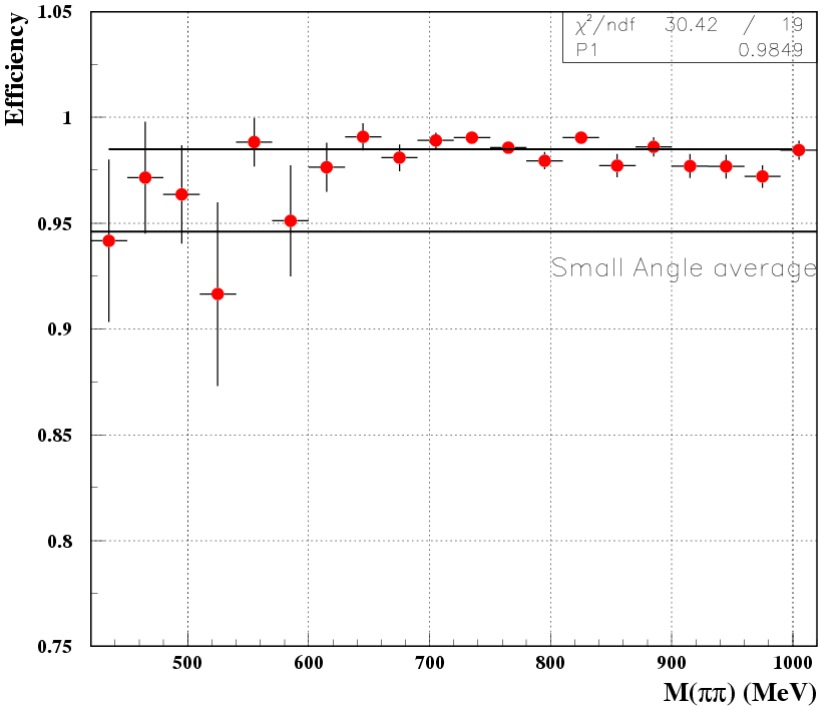
MC stream ppphvlag (ISR+FSR)
Sample size ~ data

All selection chain apart from:
Filfo
Vetocos
TCA+Likelihood
(taken from data)

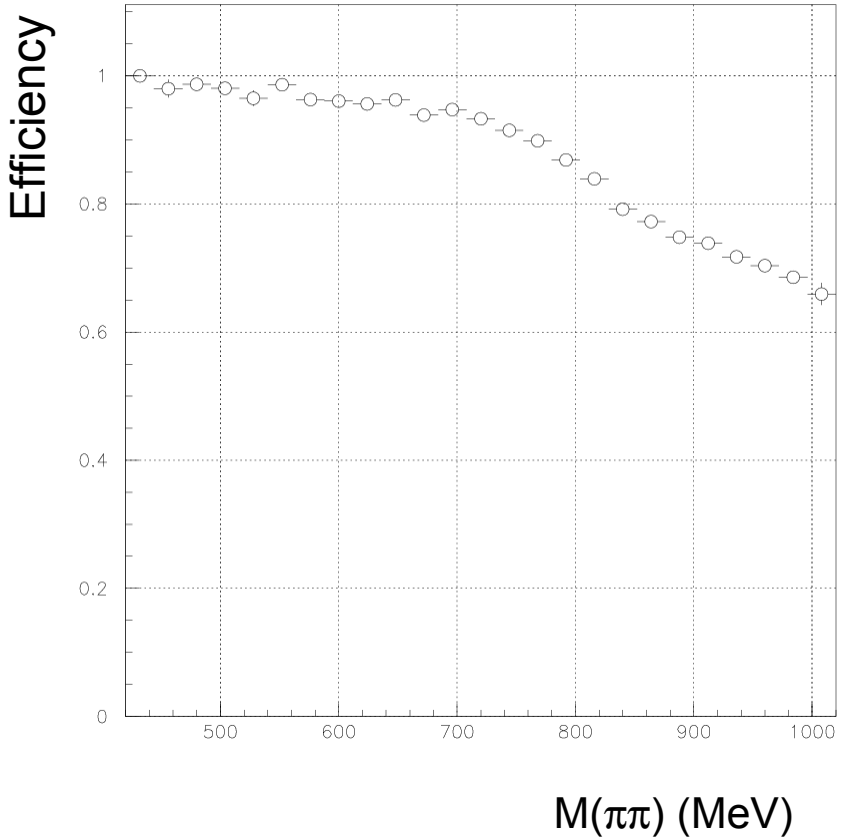
Corrections from:
tracking efficiency
photon efficiency
(1-exp(-E/a)) a~8 MeV



Filfo efficiency: negligible dependence on the machine bck thanks to the photon



Vetocos efficiency from pre-scaled events: very important correction.

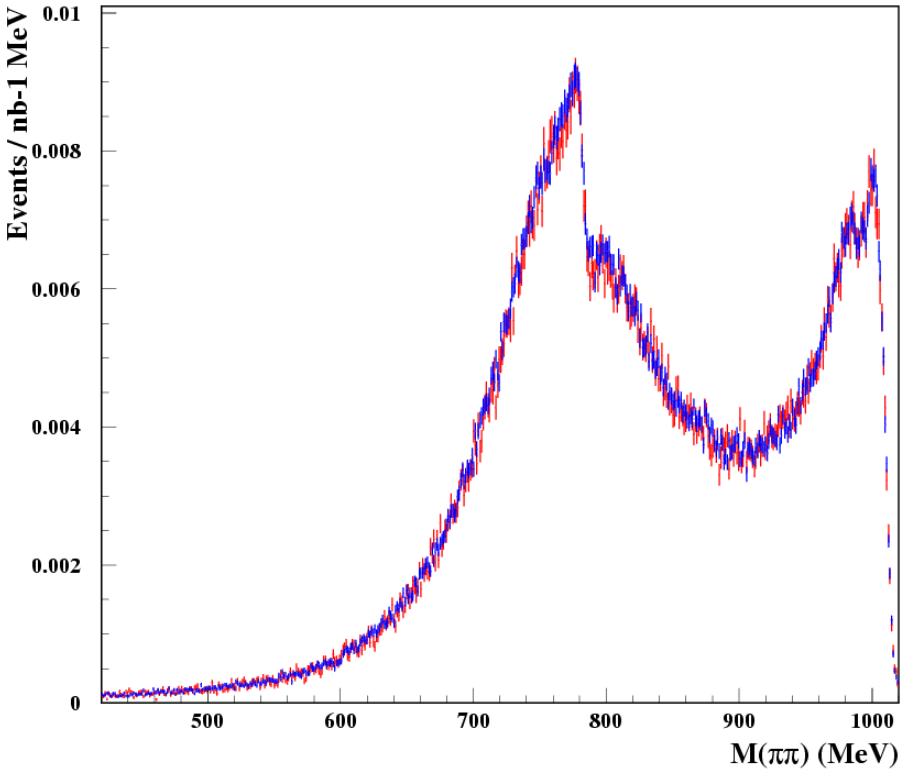


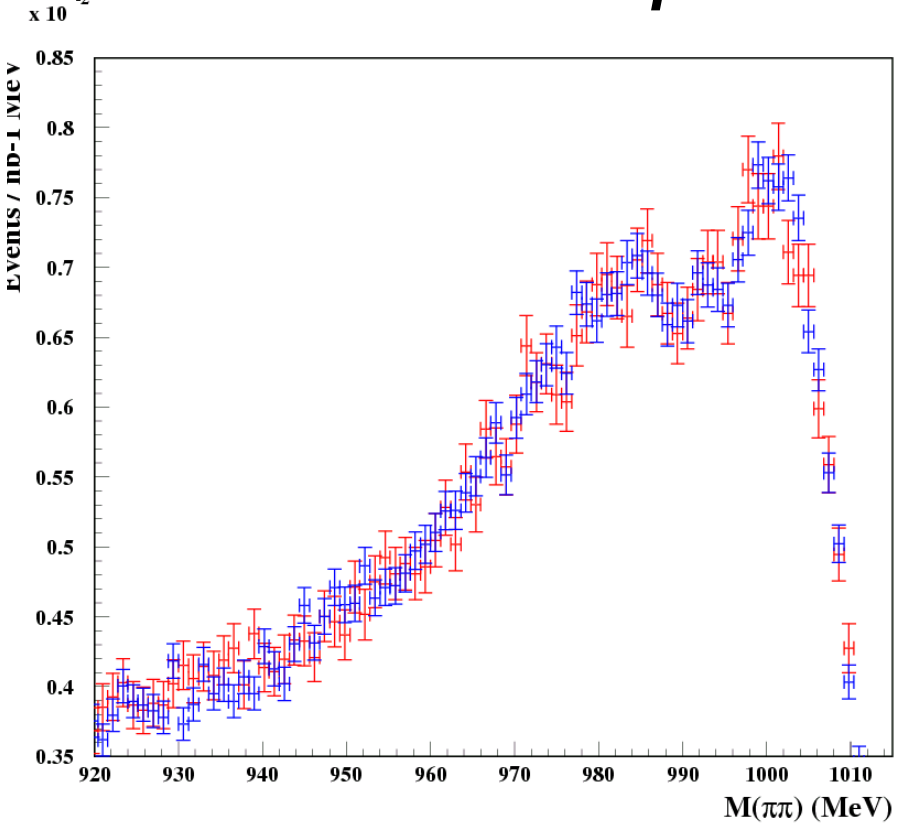
(2)The data sample

sample	Lumin. (pb^{-1})	#events	Rate (nb)
2001	115	221178	1.923
2002	234	454412	1.942
total	349	675590	1.936

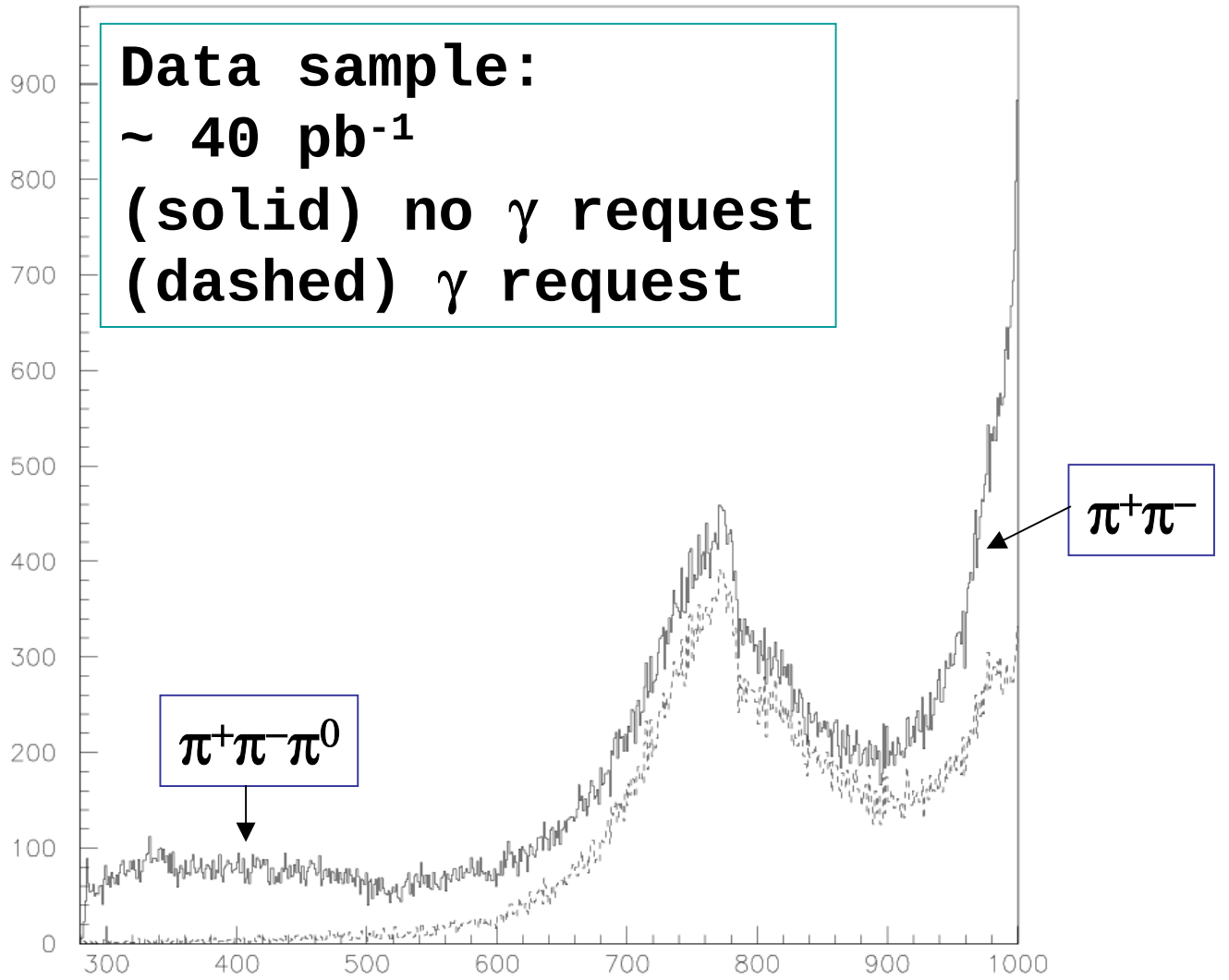
M(ππ) spectrum: [410 – 1020 MeV]

Comparison between 2001 and 2002 spectra

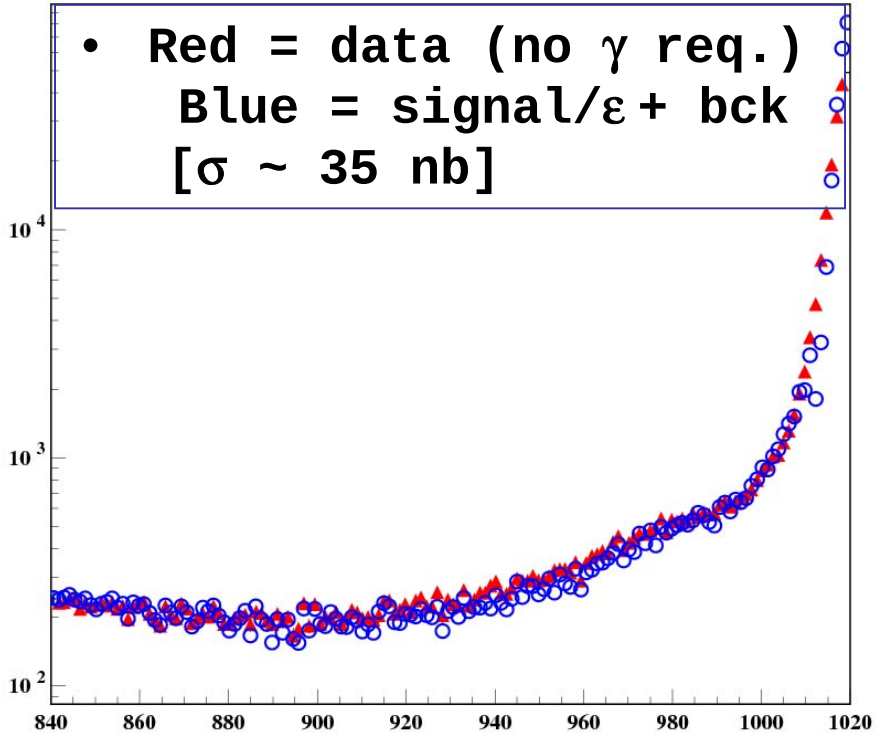


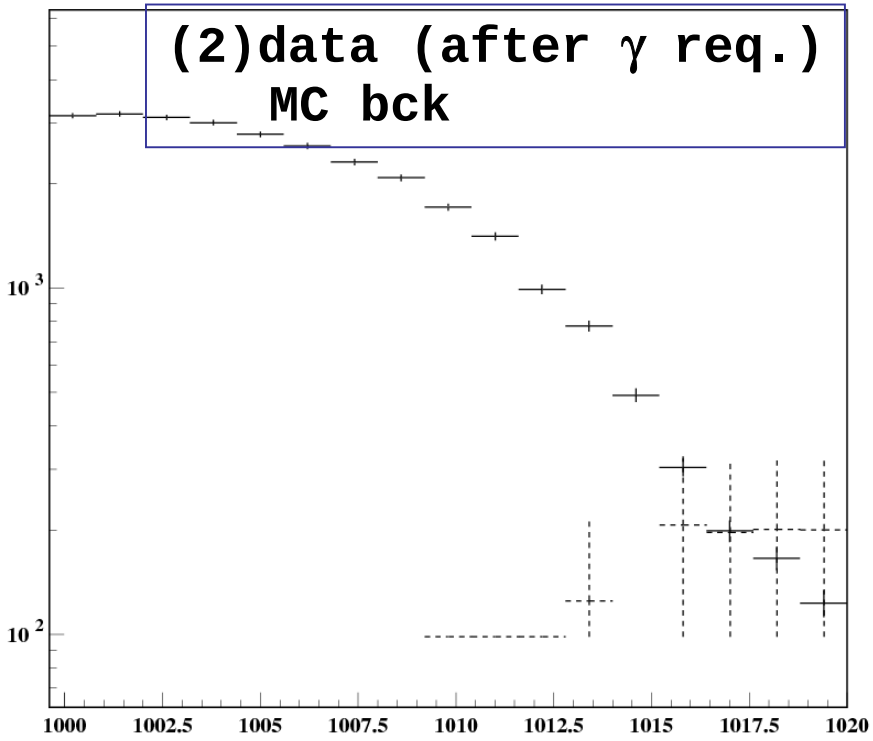


What happens if the photon is not explicitely required ?

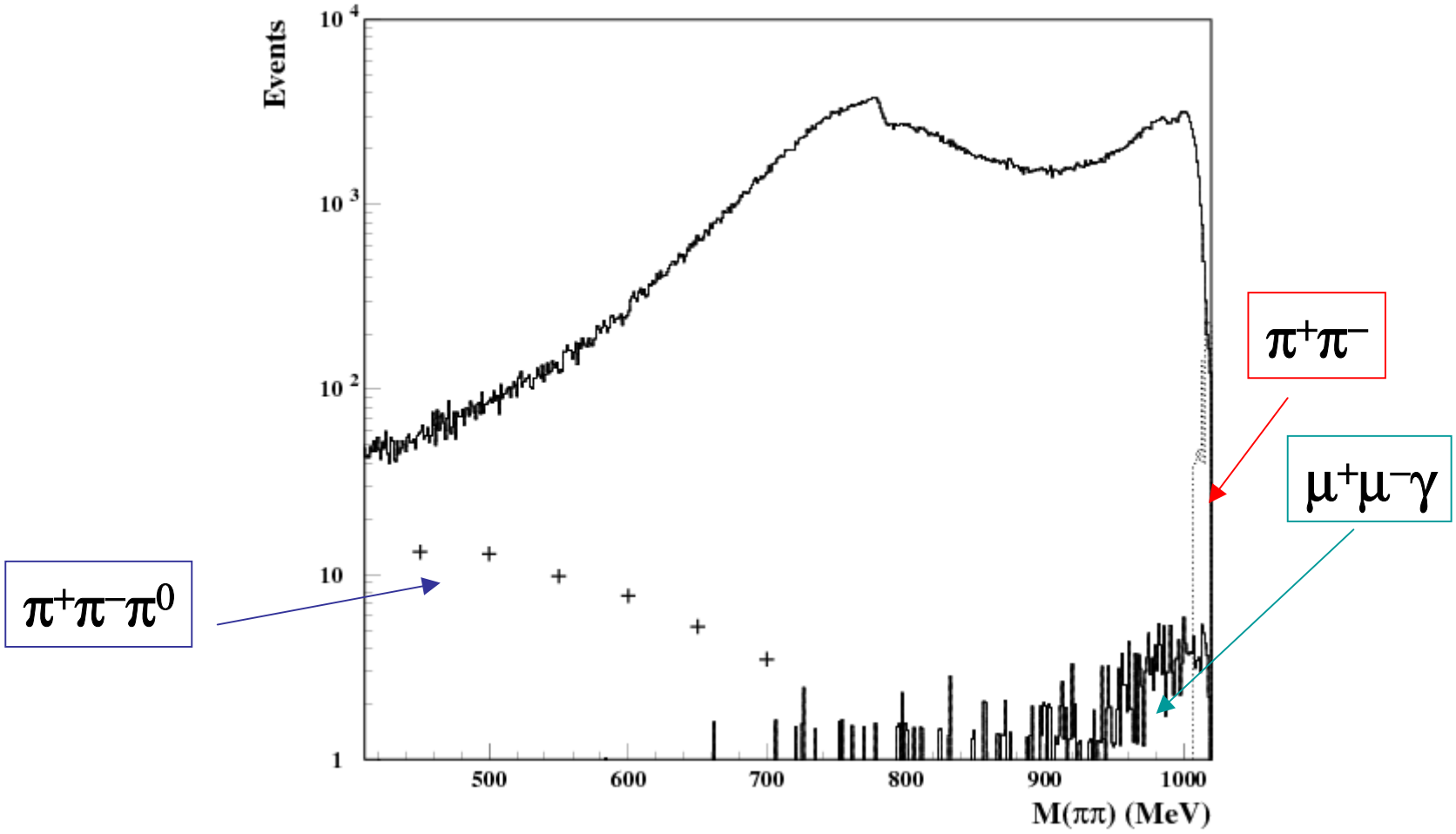


Generation and reconstruction of $e^+e^- \rightarrow \pi^+\pi^-$ with no radiation (and no BES):
(1)Do they explain the huge background when no γ is requested ?
(2)How much bckg after γ request ?





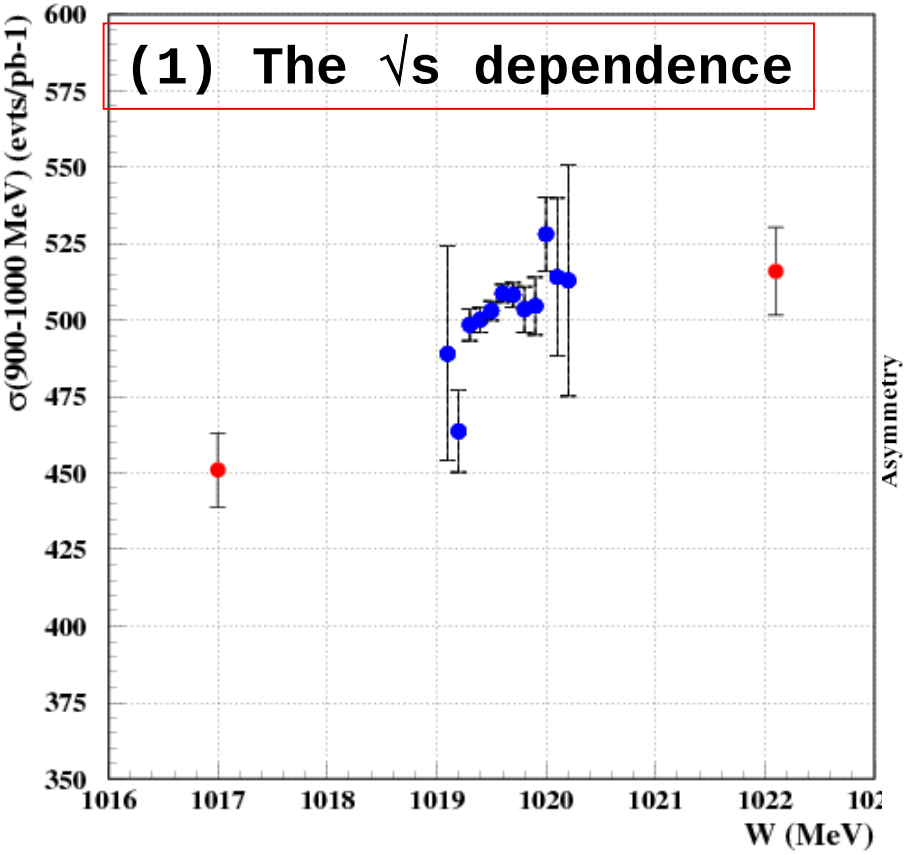
Estimated backgrounds:



Other variables that can be studied:

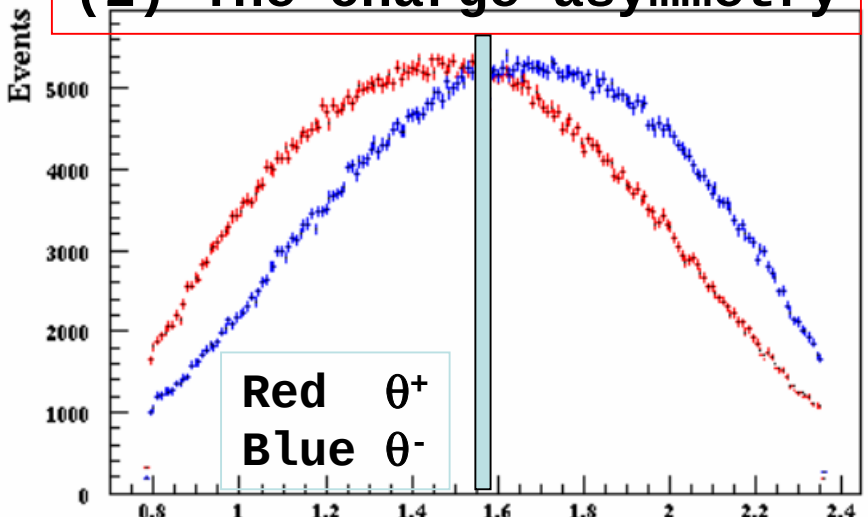
- The s dependence
- The charge asymmetry

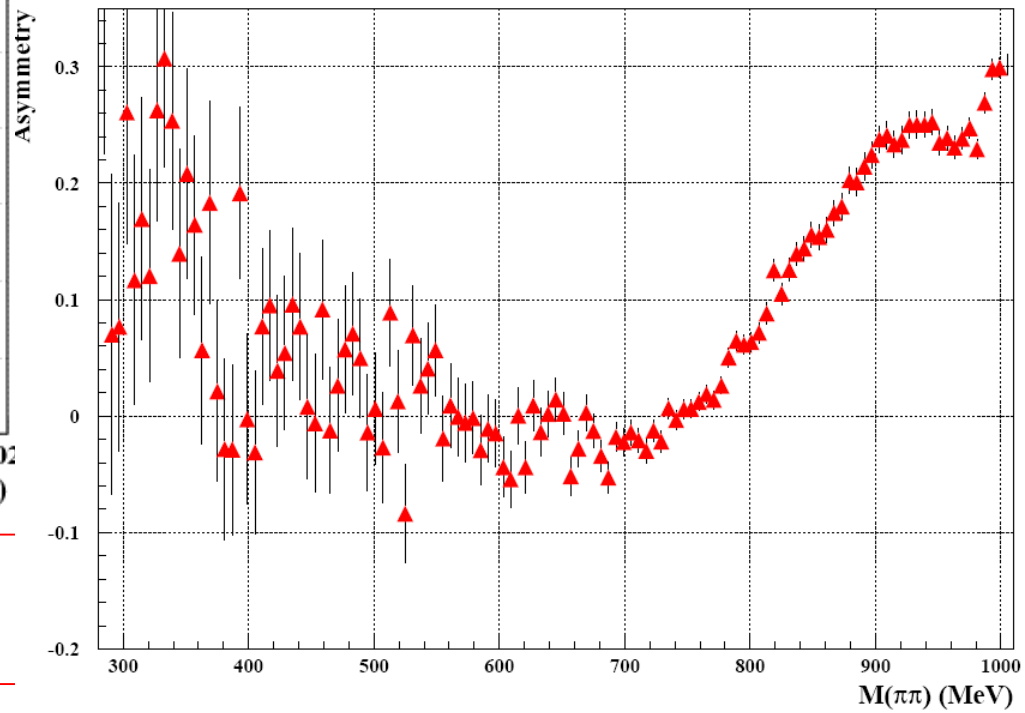
(1) The √s dependence



Asym=N(θ⁺>90)-N(θ⁺<90)/sum vs. M(ππ)

(2) The charge asymmetry





(3)Fit to the data

Strategy: fit of the full m spectrum with:

$$\frac{dN}{dm} = \left\{ \begin{array}{l} \left(\frac{d\sigma}{dm}\right)_{ISR} + \left(\frac{d\sigma}{dm}\right)_{FSR} + \left(\frac{d\sigma}{dm}\right)_{\rho\pi} + back(\pi^+\pi^-\pi^0 + \mu^+\mu^-\gamma) \\ + \left(\frac{d\sigma}{dm}(|\mathrm{A}|^2)\right)_{Scalar} + \left(\frac{d\sigma}{dm}(\mathrm{A})\right)_{\mathrm{int}.Scalar+FSR} \end{array} \right\} \times \varepsilon(m) \times \mathrm{L}$$

A is the $\phi \rightarrow$ Scalar + γ amplitude:

$$\mathrm{A}(\phi \rightarrow S\gamma \rightarrow \pi^+\pi^-\gamma) = -\frac{esm_\phi^2}{4 f_\phi D_\phi(s)}\{\mathrm{M}\}$$

M is the "model". We have considered:

KL = Kaon-loop model
[N.N.Achasov et al]

NS = No Structure model
[G.Isidori, L.Maiani]

$$M_{KL} = \frac{2 g_{f\pi^+\pi^-} g(m^2) e^{i\delta_m(\theta)}}{D_f^{(1)}(m^2)(s-m^2)}$$

$$M_{NS} = \left[\frac{g_{f\pi^+\pi^-} g_{\phi f\gamma}}{D_f^{(2)}(m^2)} + \frac{c_0}{m_\phi^2} + c_1 \frac{m^2 - m_f^2}{m_\phi^4} \right] e^{i\lambda}$$

Parameters:

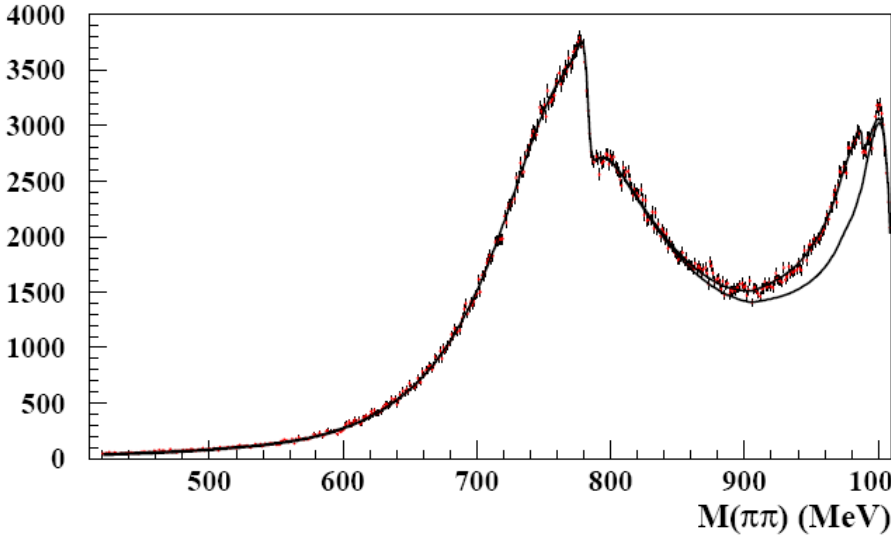
(KL) $m(f_0)$, g_{fKK} , $g_{f\pi^+\pi^-}$

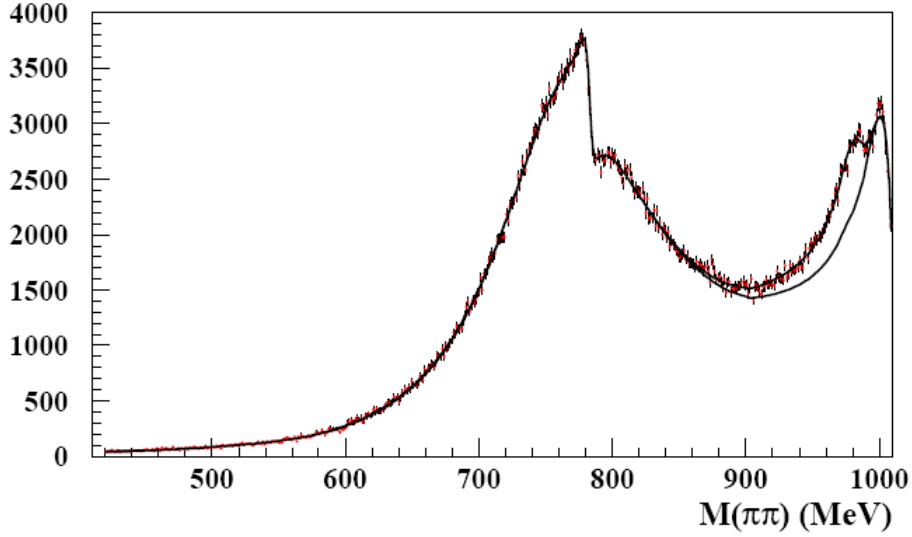
(NS) $m(f_0)$, $\Gamma(f_0)$, $g_{f\pi^+\pi^-} \times g_{\phi f\gamma}$, c_0 , c_1 , λ

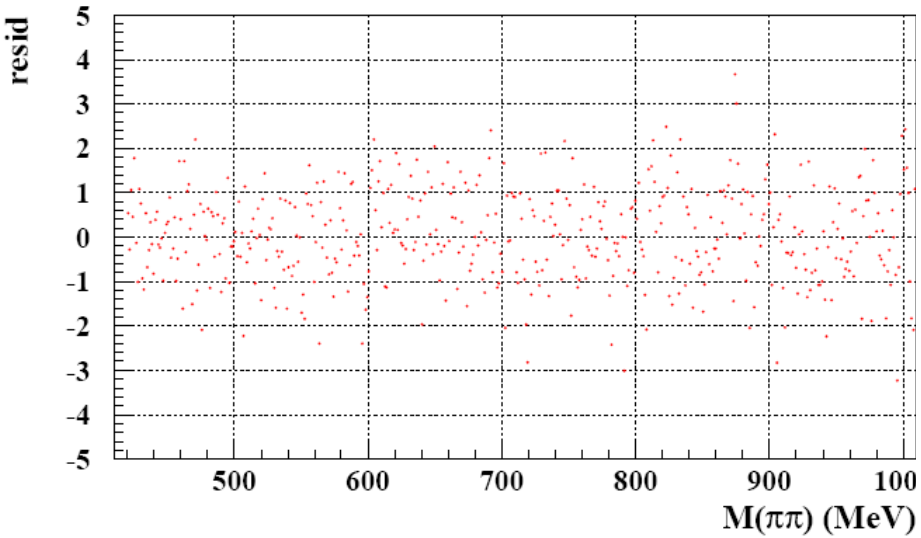
\+ for the "background" $M(\rho^0)$ $\Gamma(\rho^0)$ α β $a_{\rho\pi}$

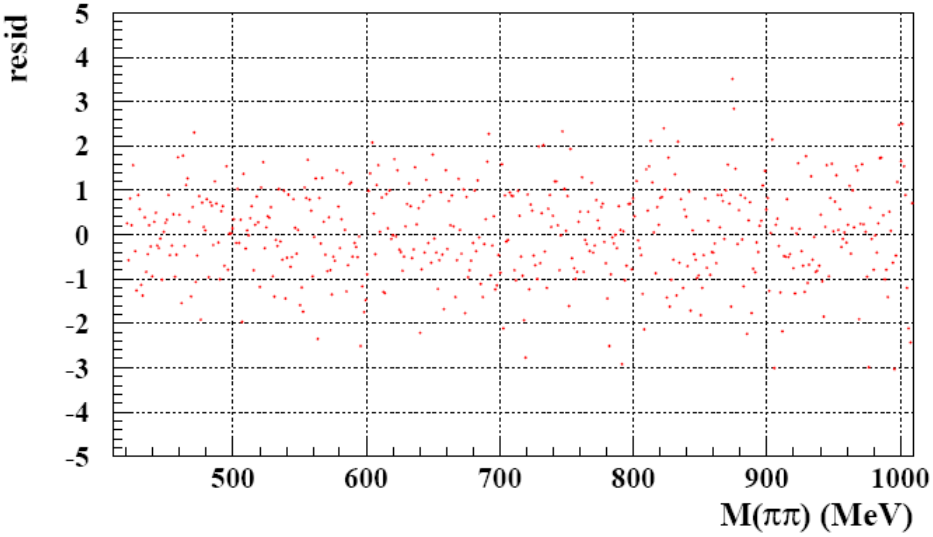
KL fit
χ^2 = 541/481
P(χ^2)= 3.0%

NS fit
χ^2 = 540/478
P(χ^2)= 2.6%

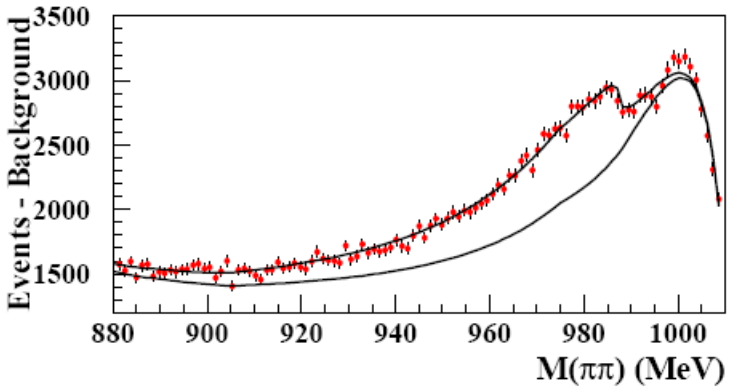


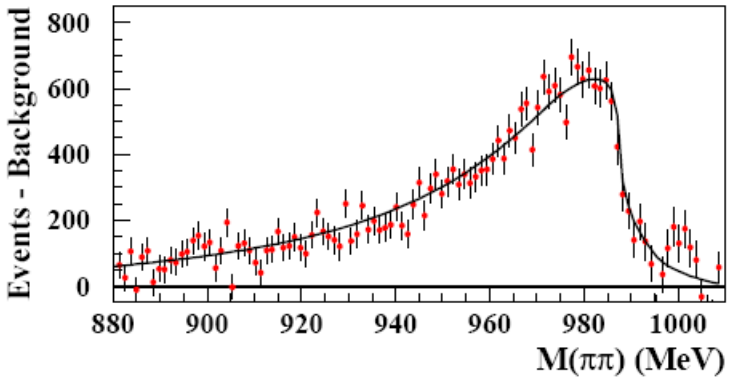


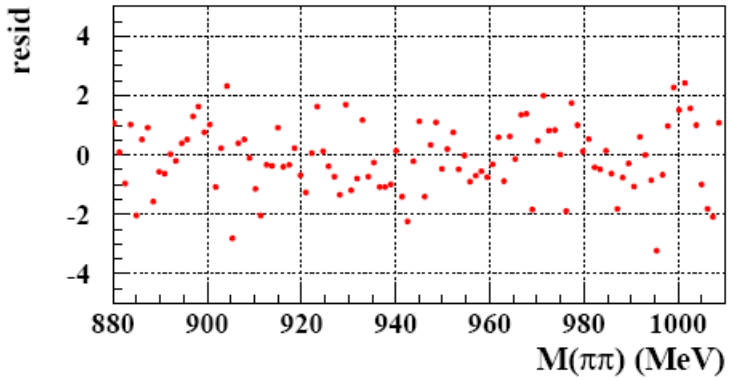




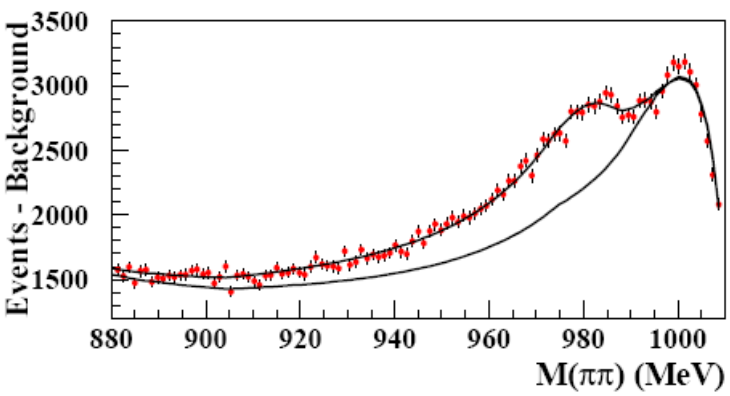
KL fit

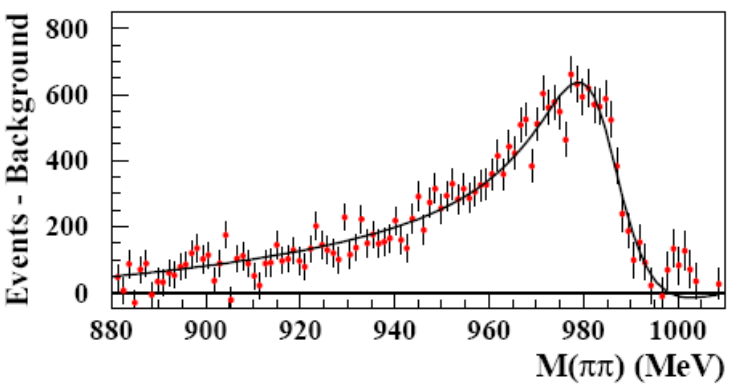

Events - Background
3500
3000
2500
2000
1500
880
900
920
940
960
980
1000
M(ππ) (MeV)

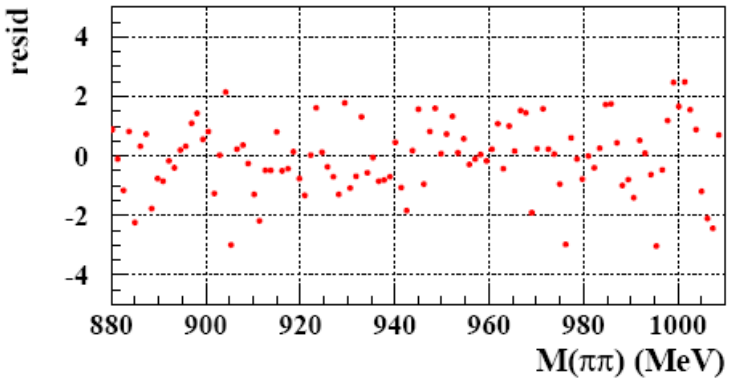

Events - Background
800
600
400
200
0
880
900
920
940
960
980
1000
M(ππ) (MeV)


resid
4
2
0
-2
-4
880
900
920
940
960
980
1000
M(ππ) (MeV)

NS fit


Events - Background
3500
3000
2500
2000
1500
880
900
920
940
960
980
1000
M(ππ) (MeV)


Events - Background
800
600
400
200
0
880
900
920
940
960
980
1000
M(ππ) (MeV)


resid
4
2
0
-2
-4
880
900
920
940
960
980
1000
M(ππ) (MeV)

Fit results: values of the parameters

"background" parameters

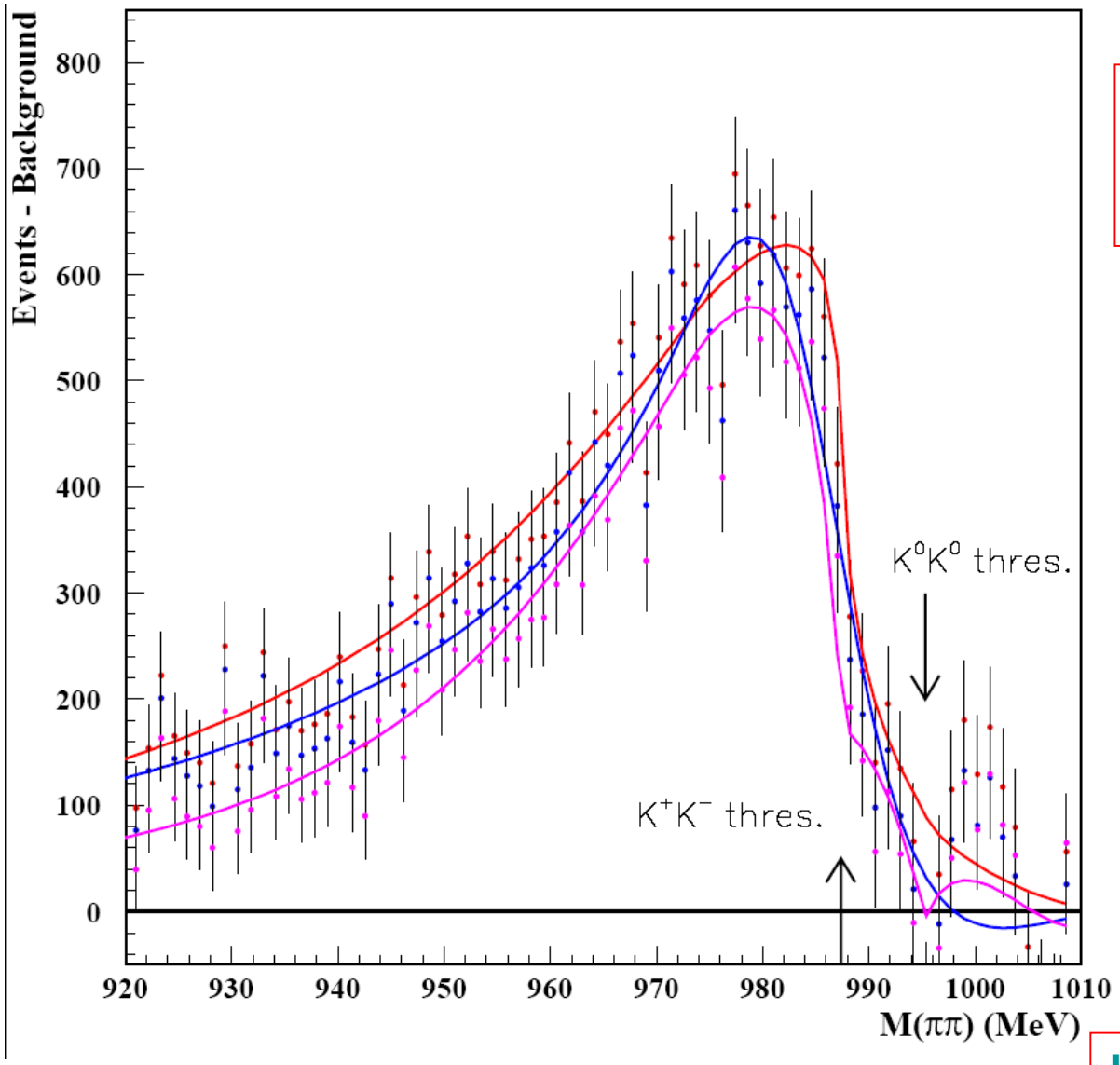
"signal" parameters

	KL	NS
χ^2/dof	541 / 481	540 / 478
M(ρ^0) (MeV)	773.3 ± 0.2	773.7 ± 0.3
$\Gamma(\rho^0)$ (MeV)	144.1 ± 0.3	145.0 ± 0.5
α ($\times 10^{-3}$)	1.68 ± 0.05	1.70 ± 0.05
β ($\times 10^{-3}$)	-122 ± 2	-126 ± 2
$a_{\rho\pi}$	Compatible with 0 and with 1	
M(f_0) (MeV)	983.7±0.6	984.6±0.5
$\Gamma(f_0)$ (MeV)		21.3±1.1
$g^2_{fKK}/4\pi$ (GeV^2)	3.4±0.6	
$R=g^2_{fKK}/g^2_{f\pi+\pi-}$	2.82±0.08	
$g_{f\pi+\pi-}\times g_{\phi f\gamma}$		1.58±0.05
c0		7.8±0.3
c_1		8.0±0.2
λ		0.80±0.32

Study of systematic uncertainties on the fitted parameters: KL fit

	$g^2_{f0KK}/4\pi$ $(GeV)^2$	R	m_{f0} (MeV)
Fit cond. (bin,ranges)	±1.0	±0.18	±1.2
Abs.Scale ± 2%	±0.3	±0.02	±0.2
γeff cut ± 2 MeV	±0.2	±0.15	±2.6
vs ± 0.5 MeV	±0.3	±0.28	±1.2
θ ± 1 std.d.	±0.2	±0.17	±2.1
STAT	± 0.6	± 0.08	± 0.6

The f_0 peak: compare different fits.



Red = KL
Blue = NS
Pink = "BP"

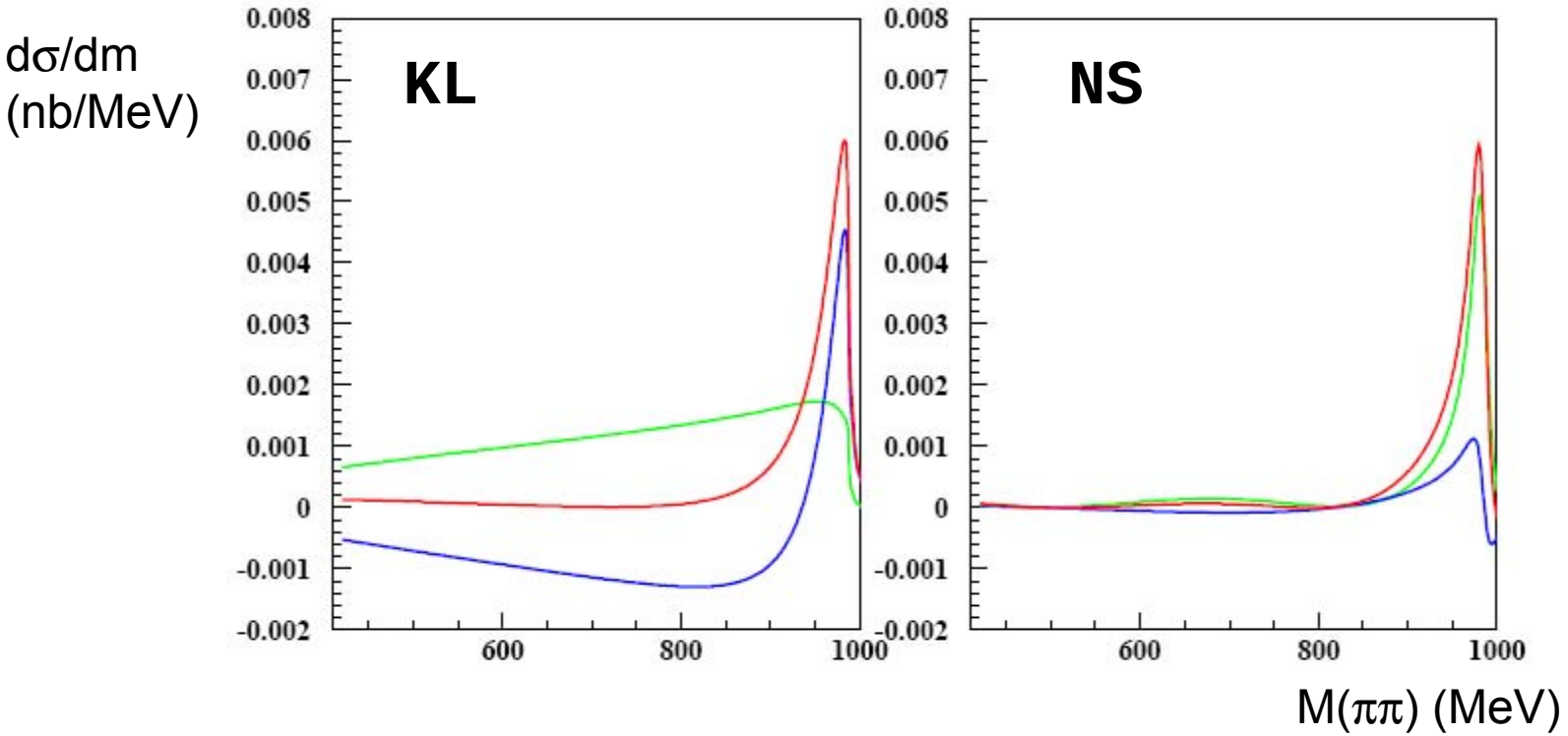
(4)Interpretation of the results

(4.1) Line-shapes:

Red = signal

Green = direct

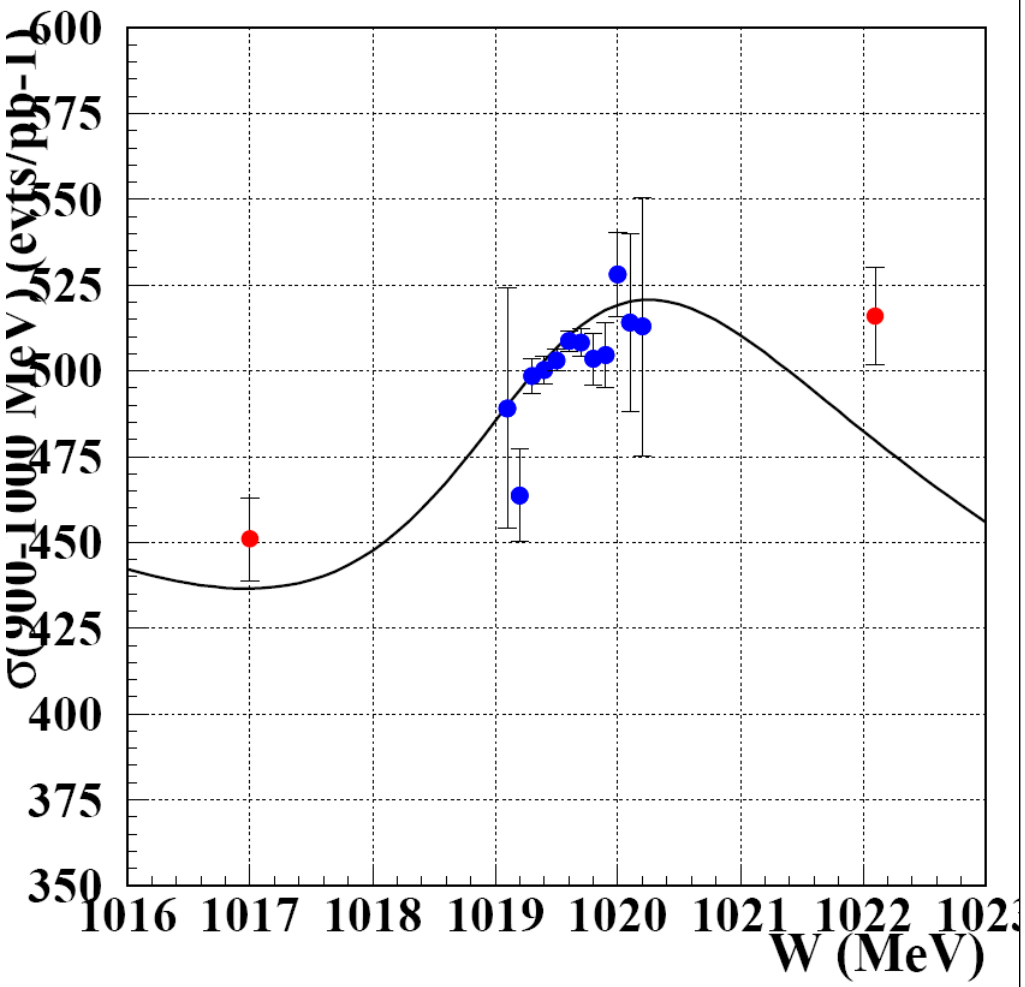
Blue = interference

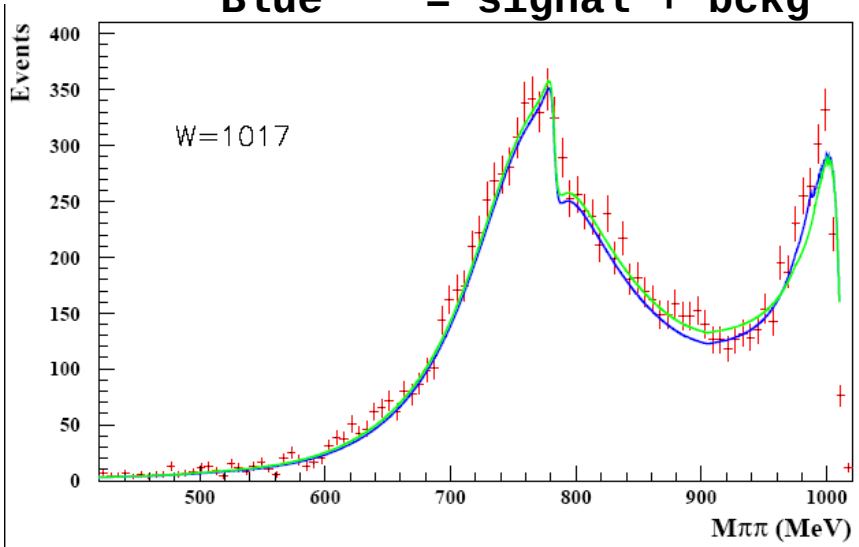


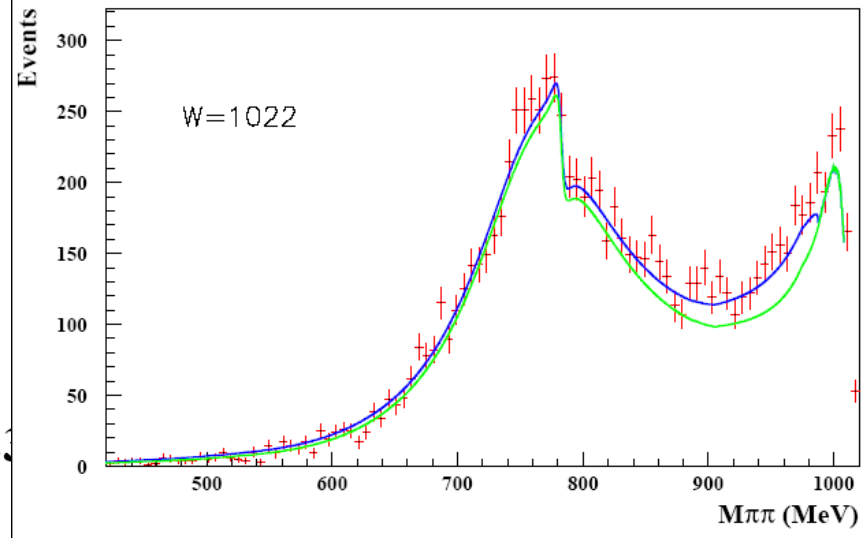
(4.2) Off-peak data:

Extrapolate to off-peak data using KL fit parameters.

Green = bckg only
Blue = signal + bckg







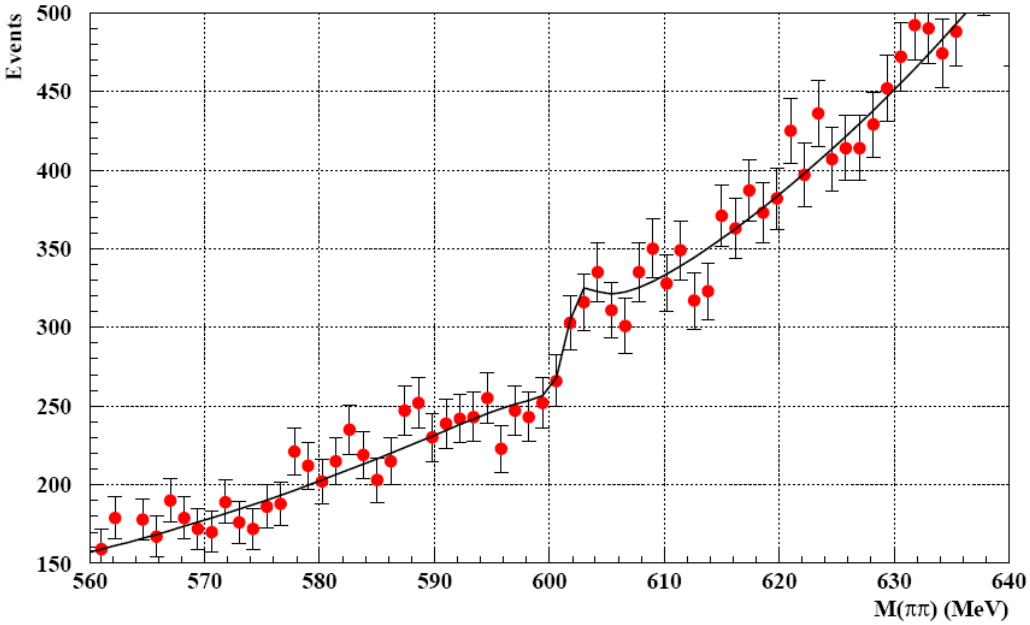
(4.3) Is there any σ?
"Easy" to implement in the KL frame

$$\frac{g_{fKK}\,g_{f\pi+\pi-}}{D_f(m)} \rightarrow \sum_{R,R'}\left(g_{RKK}\,G^{-1}_{RR'}\,g_{R'\pi+\pi-}\right)$$

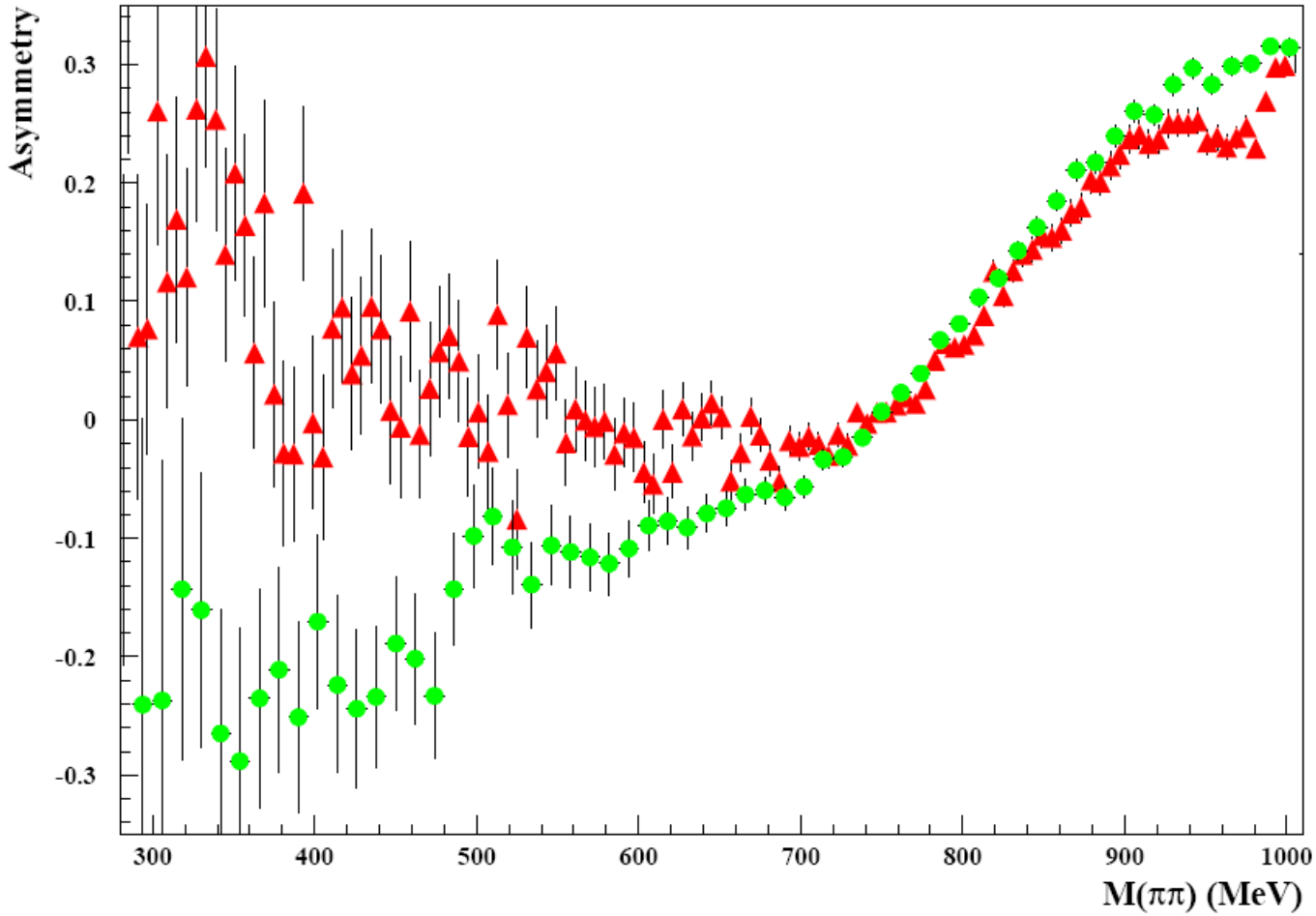
$$G_{RR'}(m) = \begin{pmatrix} D_f(m) & -\Pi_{f\sigma}(m) \\ -\Pi_{\sigma f}(m) & D_\sigma(m) \end{pmatrix}$$

4 extra parameters:
$M(\sigma)$, $g_{\sigma KK}$, $g_{\sigma\pi+\pi-}$, $C_{f\sigma}$

First try:
- **f_0 param. slightly changed**
- **bckg param. unchanged**
- **narrow and weakly coupled σ "found" around 600 MeV**



(4.4) The charge asymmetry
Compare with pure ISR+FSR simulation



Red = data
Green = MC

(4.5) The coupling of the f_0 to the ϕ

KL Fit:

g_{fKK} = 6.4 GeV
$g_{f\pi+\pi-}$ = 3.9 GeV

Compare with KLOE $\pi^0\pi^0\gamma$ and $\eta\pi^0\gamma$ analyses

"BR" = 21.5 × 10^{-5}

NS Fit:

$g_{f\pi+\pi-} \times g_{\phi f\gamma}$ = 1.58
Γ_f = 21 MeV
➔ $g_{f\pi+\pi-}$ = 0.9 GeV
➔ $g_{\phi f\gamma}$ = 1.8 GeV^{-1}

"BR" = 6.9 × 10^{-5}

$$\text{"BR"} = \frac{1}{\sigma(\phi)} \int \left(\frac{d\sigma}{dm} (|A|^2) \right)_{scalar} dm$$

$$\Gamma(f_0 \to \pi^+\pi^-) = \frac{g^2_{f\pi\pi} p_{12}(m_f)}{8\pi m_f^2}$$

Meson	$g_{\phi M\gamma}$ (GeV^{-1})
π^0	0.12
η	0.66
η'	0.70
f_0	1.8
a_0	1.3

(5) Conclusions

Clear evidence of $f_0(980) \rightarrow \pi^+\pi^-$ signal: we are able to describe it;

The coupling of the $f_0(980)$ to the $\phi(1020)$ is "large" (even in the NS approach);

No σ is needed: higher statistics (2 fb^{-1}) can clarify "narrow structures";

Comparison between different models: no one "wins".

STOP here now.

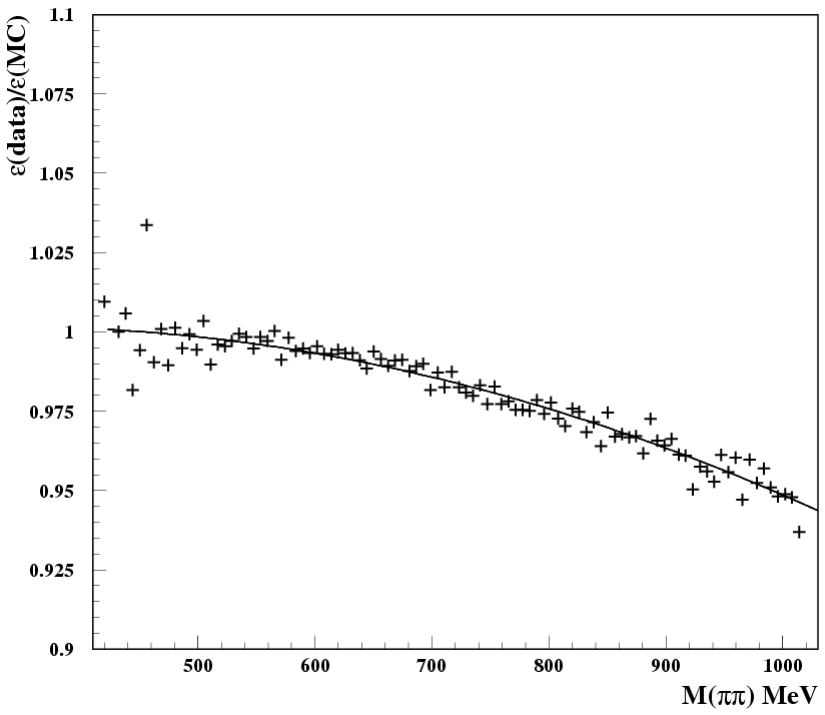
THEN a step forward for a “precision” analysis with 2-2.5 fb^{-1} :

(1)Big work on simulation (it is starting now a new *phokhara*);

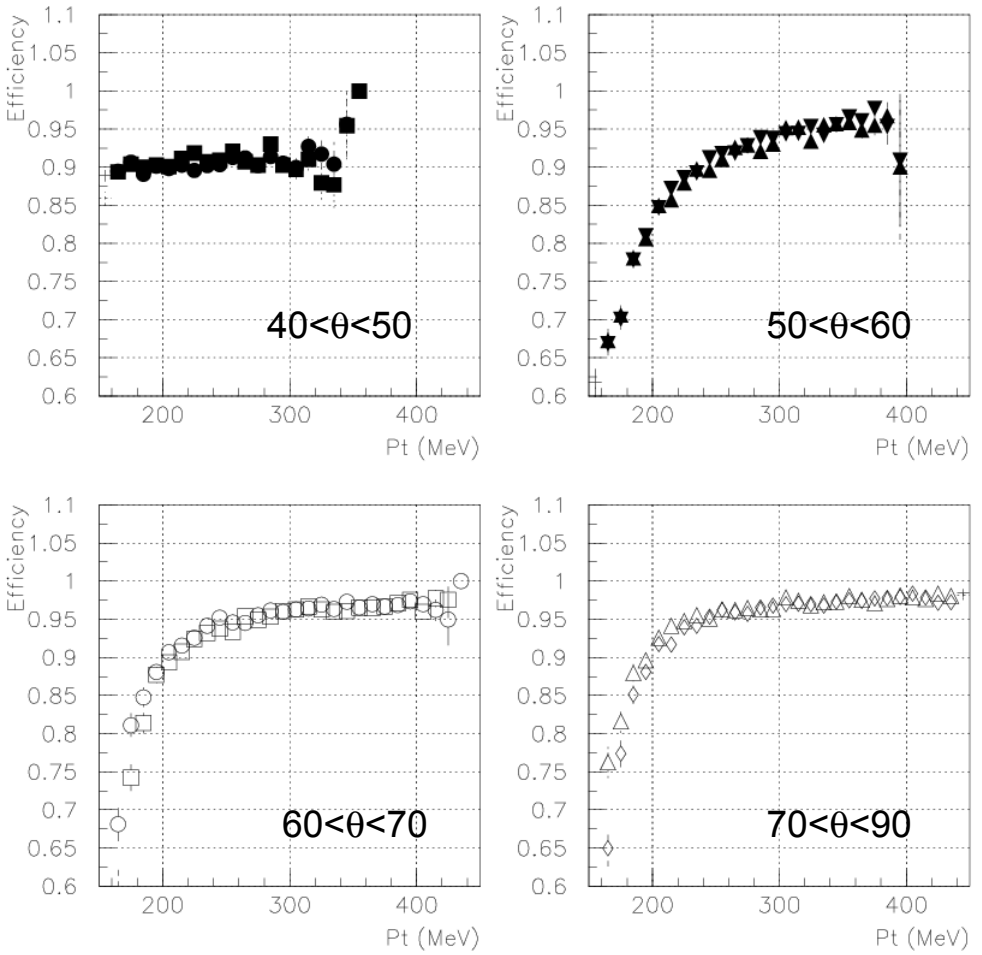
(2)Refine the $\varepsilon_\gamma(m)$ knowledge;

(3)Run @ $M(\phi)$–10 MeV probably “unavoidable” (a study is in progress).

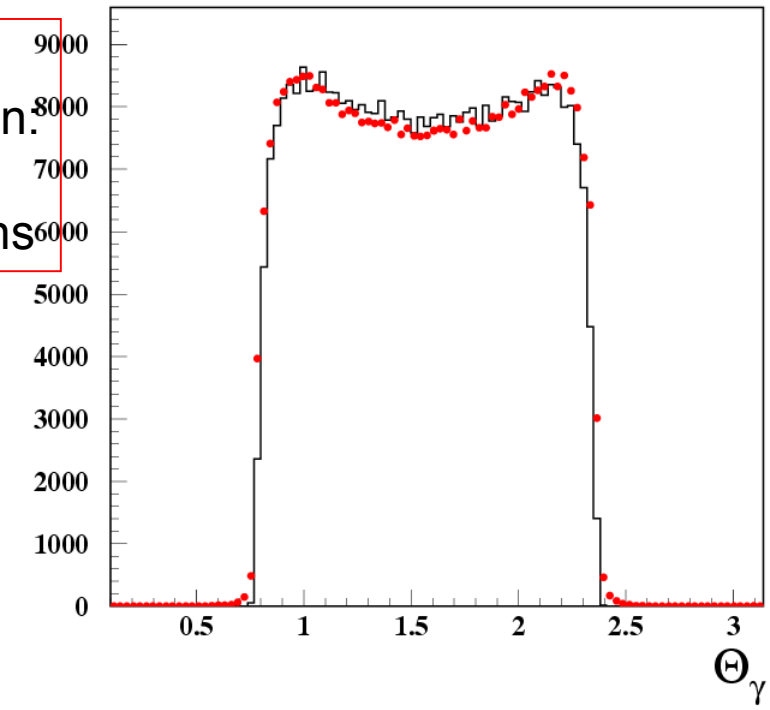
Trkmass efficiency: data/MC ratio

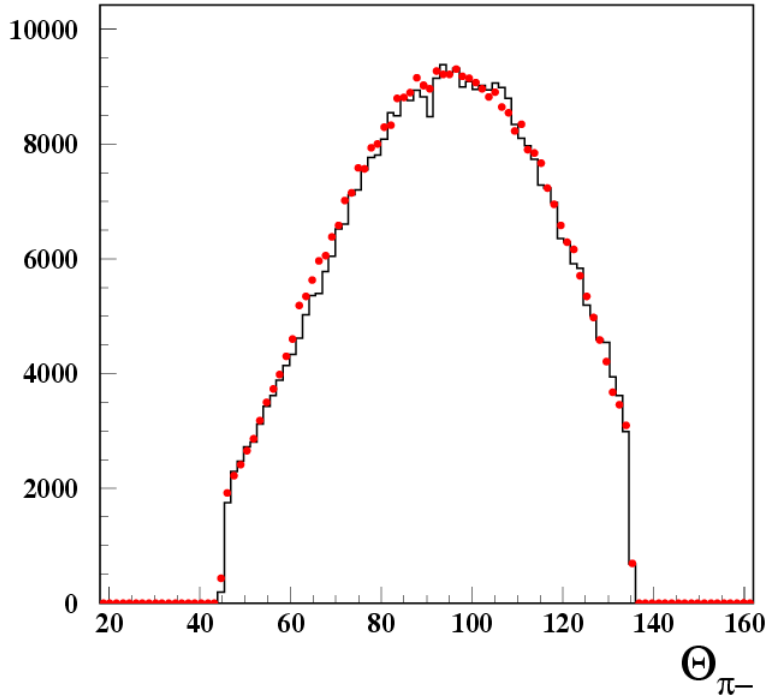


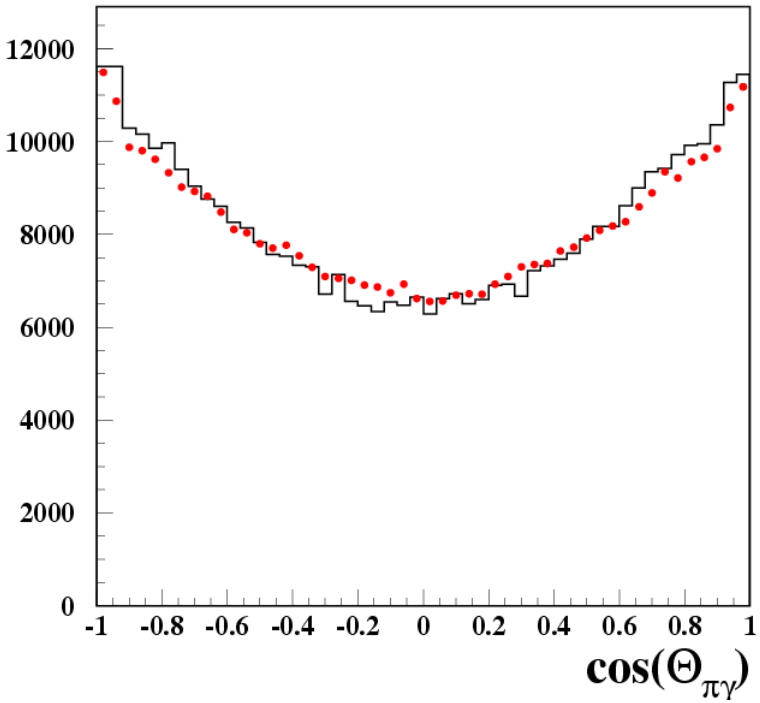
TCA + likelihood efficiency from a $\pi^+\pi^-\pi^0$ control sample

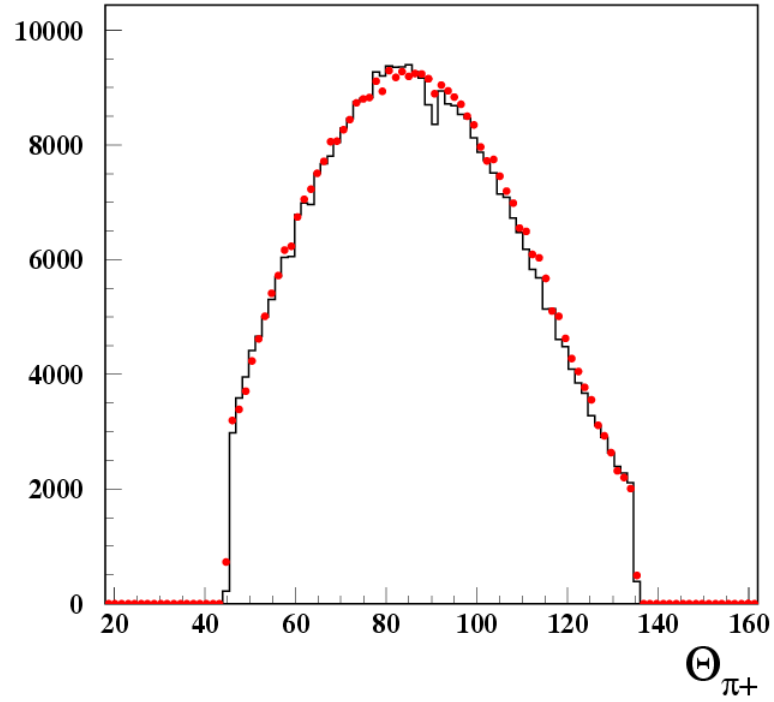


Data-MC comparison: Angular distributions









Data-MC comparison: Ω distributions