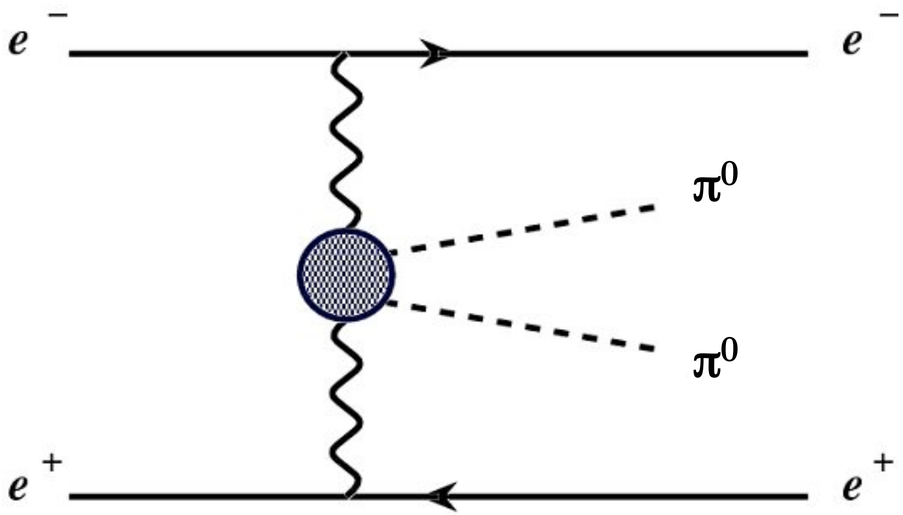
Search for $e^+e^- \to e^+e^-\pi^0\pi^0$



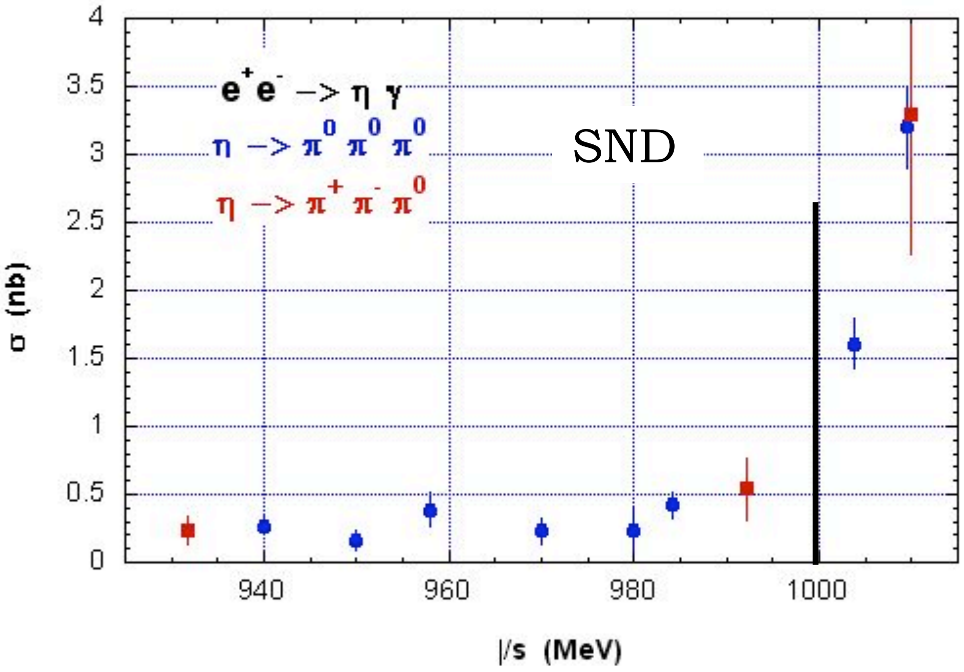
Samples

1. **DATA: 239.6 pb^{-1} from 2006, Off-Peak**
2. **ALL_PHYS Monte Carlo $K_S K_L$: 19 887 800 events**
3. **ALLRAD Monte Carlo $\eta \rightarrow 3\pi^0$: 6 423 710 events**
4. **OMEGA_PI Monte Carlo $e^+e^- \rightarrow \omega\pi^0$: 933 540 events**
5. **ALLRAD Monte Carlo $f_0 \rightarrow 2\pi^0$: 131 849 events**
6. **ALLRAD Monte Carlo $a_0 \rightarrow \eta\pi^0$: 97 205 events**
7. **GG04 Monte Carlo $e^+e^- \rightarrow 2\gamma$: 81 601 500 events**

All these must fulfill the GGfilter - D.Capriotti, F.N. & G.Venanzoni KLOE Memo 346

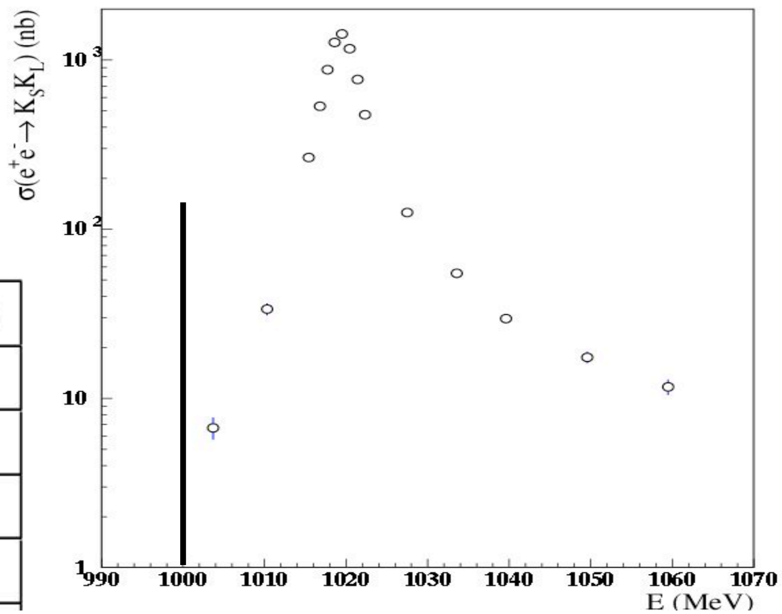
- at least 2 prompt neutral clusters with energy > 15 MeV, acceptance 20°-160°
- the most energetic neutral prompt cluster with energy > 50 MeV
- total calorimetric energy $200\text{MeV} < E_{calo} < 900\text{MeV}$
- $R = (\sum E_{prompt}) / E_{calo} > 0.3$

Cross section of background processes

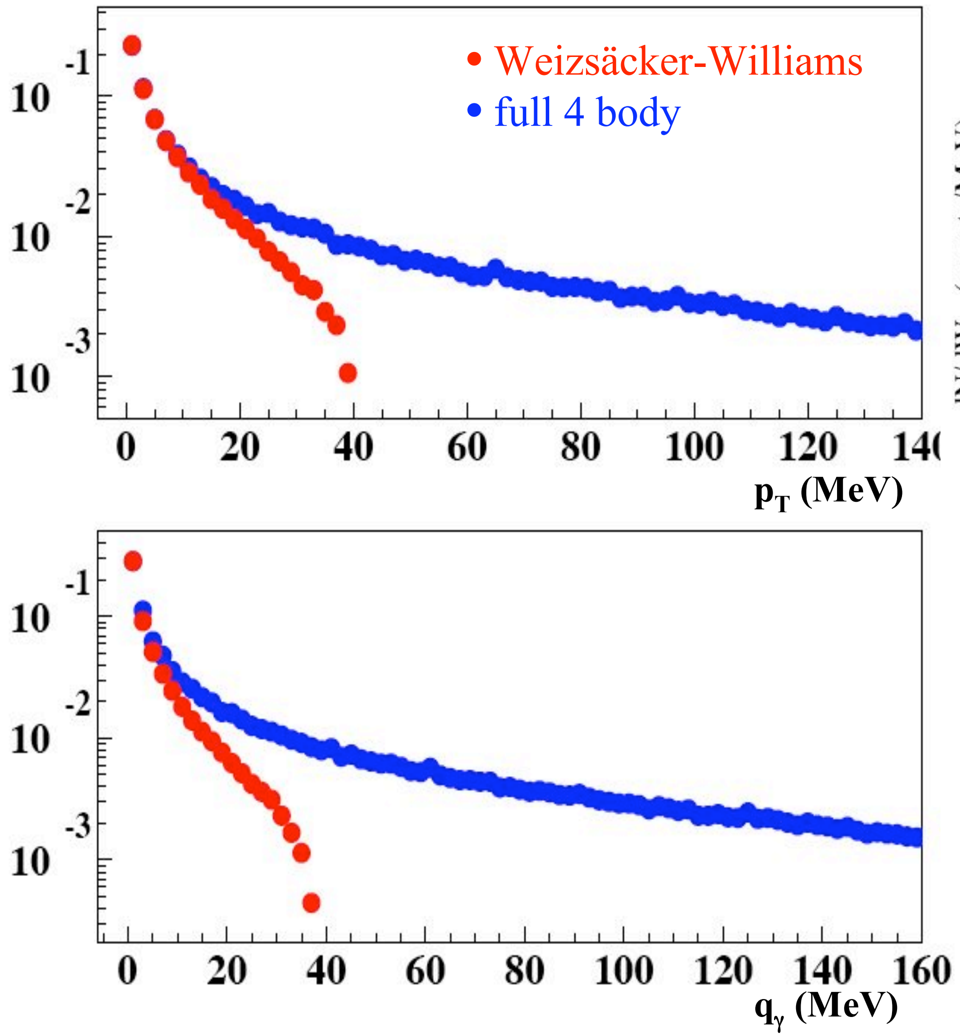


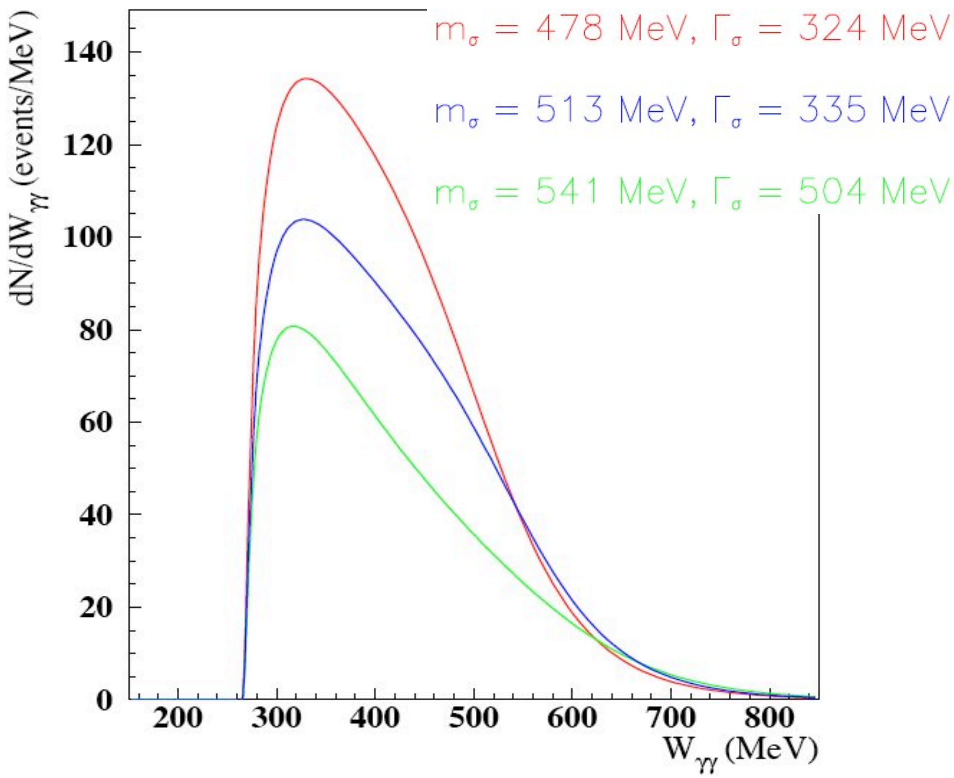
f0 cross section assumed to be 0.15 nb, and a0 cross section rescaled to give the ratio of BR's measured by KLOE

	$\sigma\ (nb)$
$e^+e^- \to \eta\gamma \to \pi^0\pi^0\pi^0\gamma$	0.35
$e^+e^- \to K_S K_L$	2.0
$e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$	0.55
$e^+e^- \to \gamma\gamma$	420.



Signal simulation

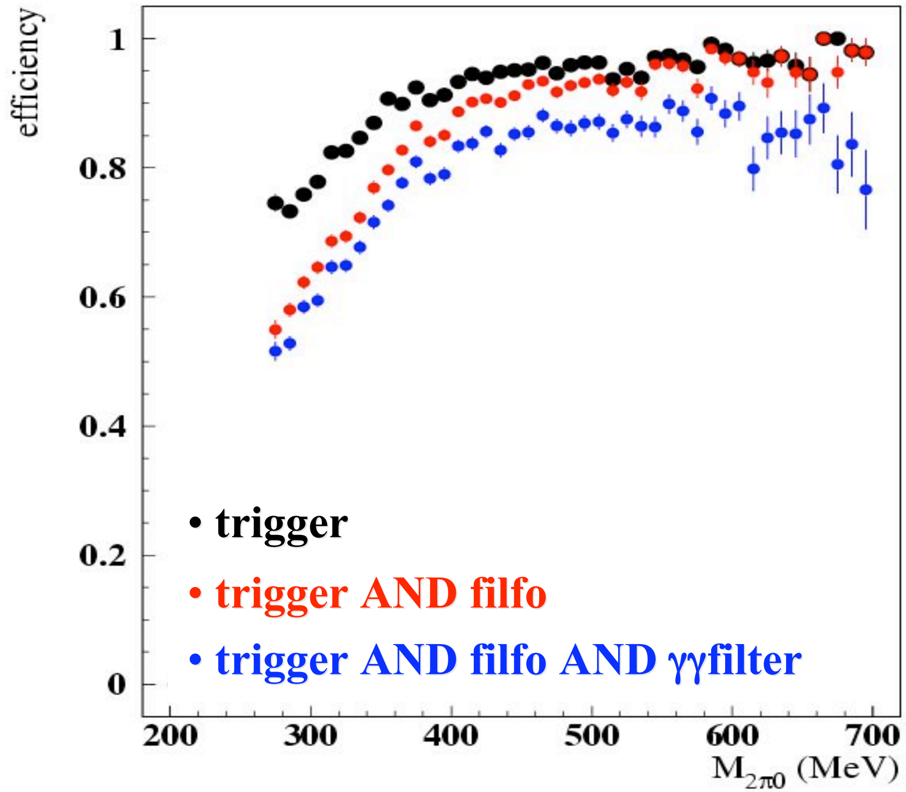




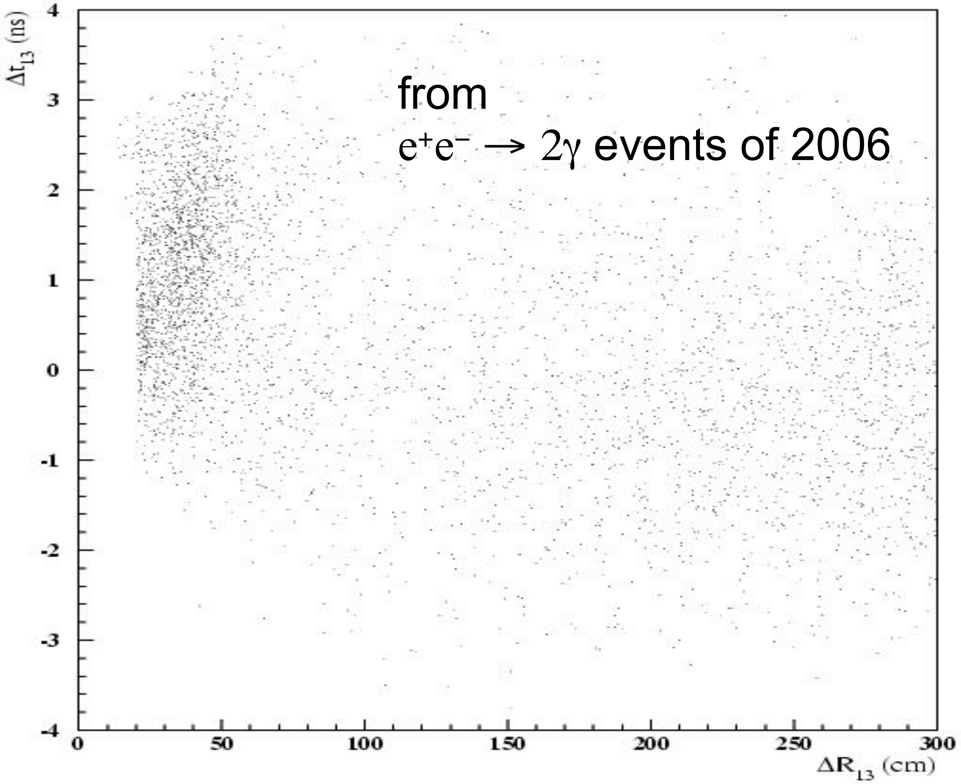
Signal efficiencies

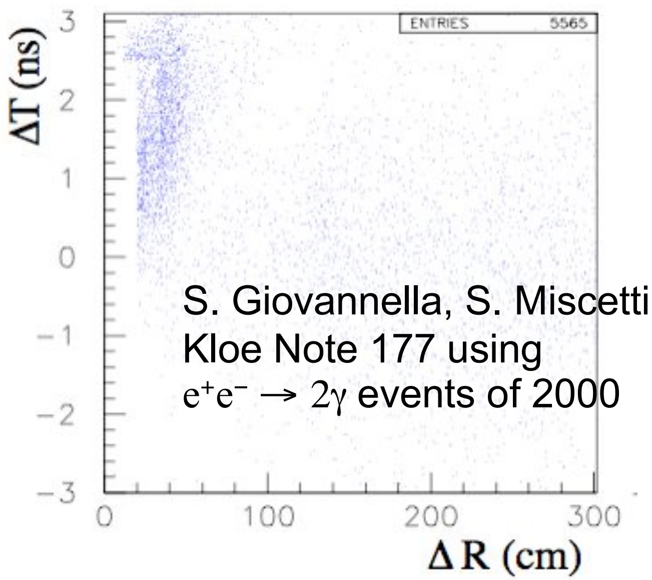
	CLEO σ events	efficiency (%)
generated	40000	
TRIGGER	35241	88
FILFO	36873	92
TRG∩FLF	32114	80

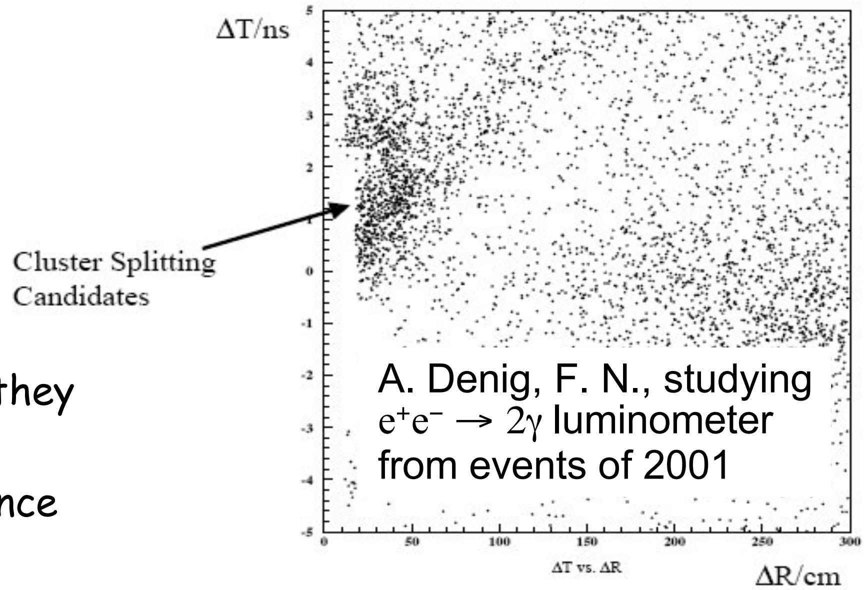
$$\frac{N(ggfilter \mid TRG \cap FLF)}{N(TRG \cap FLF)} = 91.7\%$$



Recover splitting







a procedure of recover splitting has to be applied,
otherwise overwhelmed by $e^+e^- \to 2\gamma$ (~ 400 nb),
and we are looking for O(10)-O(100) pb cross section

"soft" recover splitting: if 2 clusters are within 50 cm they are merged - not looking at any pair else
"hard" recover spliiting: all cluster pairs withing a distance accounting for energy are merged

Identification of the π^0 signal

after recover splitting, the candidate 4 photons are obtained by minimizing

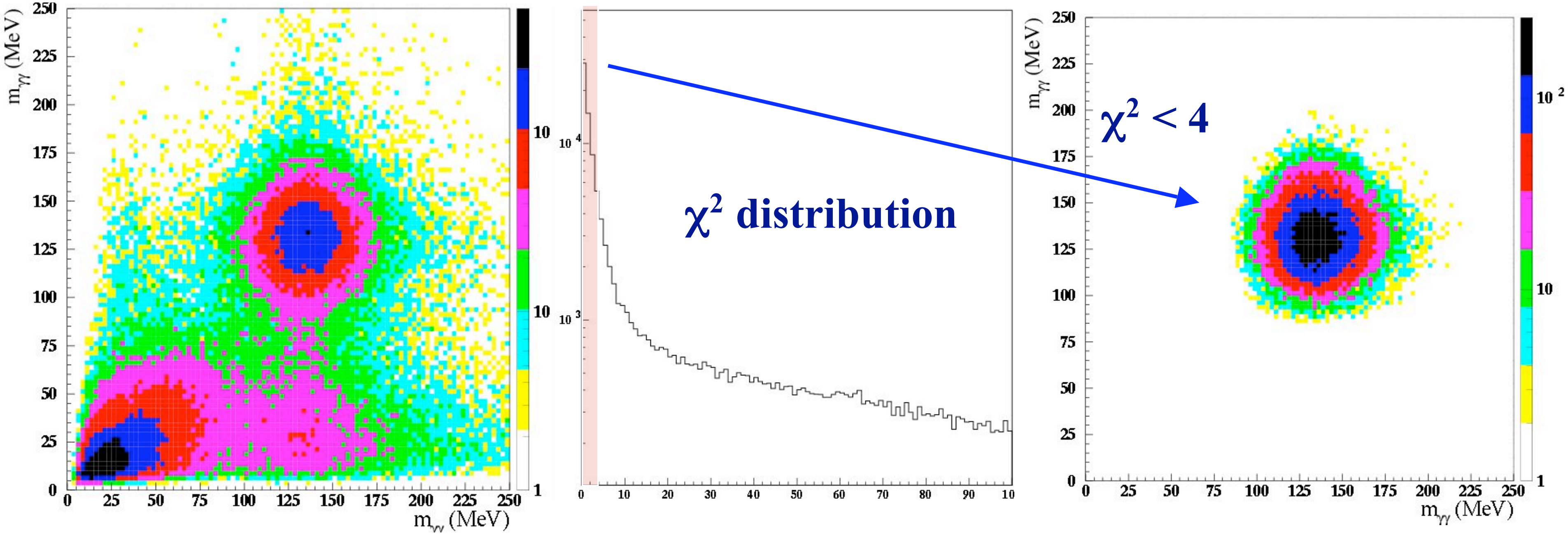
$$\chi^2_{pair} = \left(\frac{M_{ij} - m_{\pi 0}}{\sigma(E_i, E_j)}\right)^2 + \left(\frac{M_{lk} - m_{\pi 0}}{\sigma(E_l, E_k)}\right)^2$$

$$\frac{\sigma(E_i, E_j)}{M_{ij}} = \frac{1}{2}\left(\frac{\sigma_{E_i}}{E_i} \oplus \frac{\sigma_{E_j}}{E_j}\right)$$

$$\frac{\sigma_E}{E} \sim \frac{0.06}{\sqrt{E(GeV)}}$$

$$M_{ij}^2 = 2E_iE_j(1-\cos\theta_{ij})$$

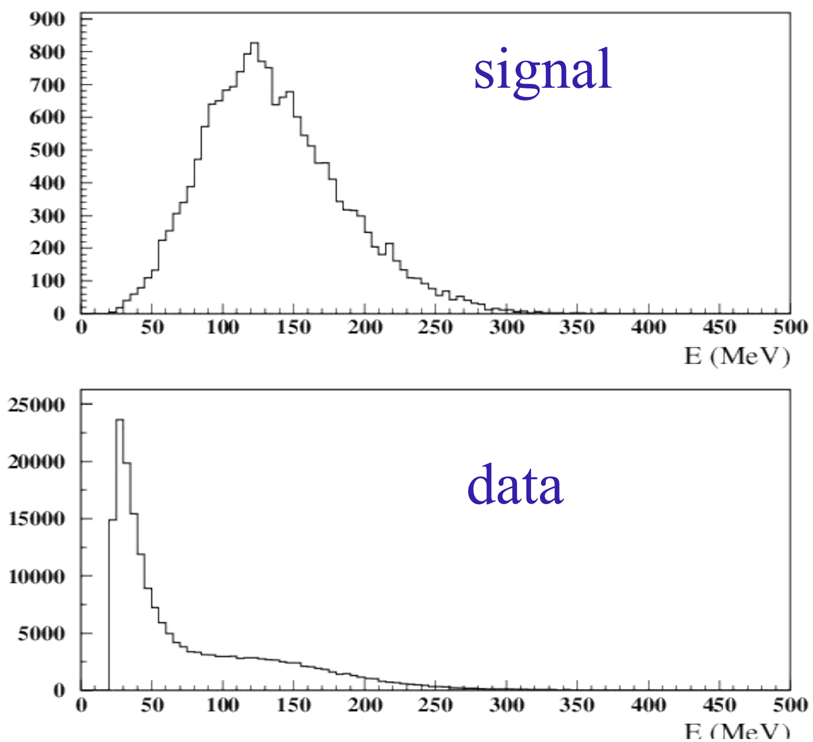
$m_{\gamma 1 \gamma 2}$ vs. $m_{\gamma 3 \gamma 4}$



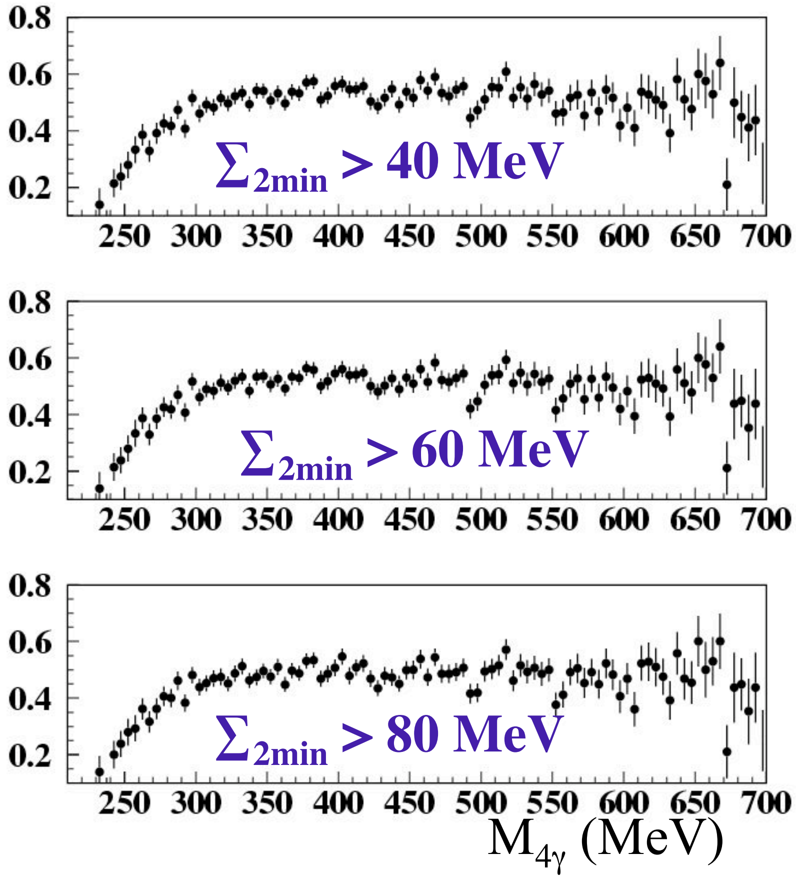
Choice of the cuts

Σ_{2min}: sum of the energies of the two least energetic clusters

Σ_{2min}

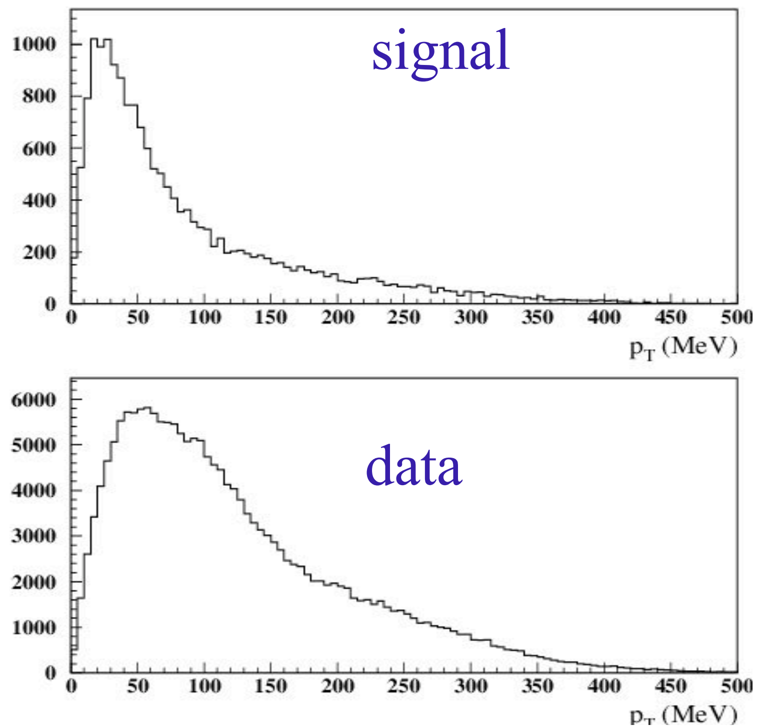


Efficiency vs. 4γ invariant mass (MC signal)

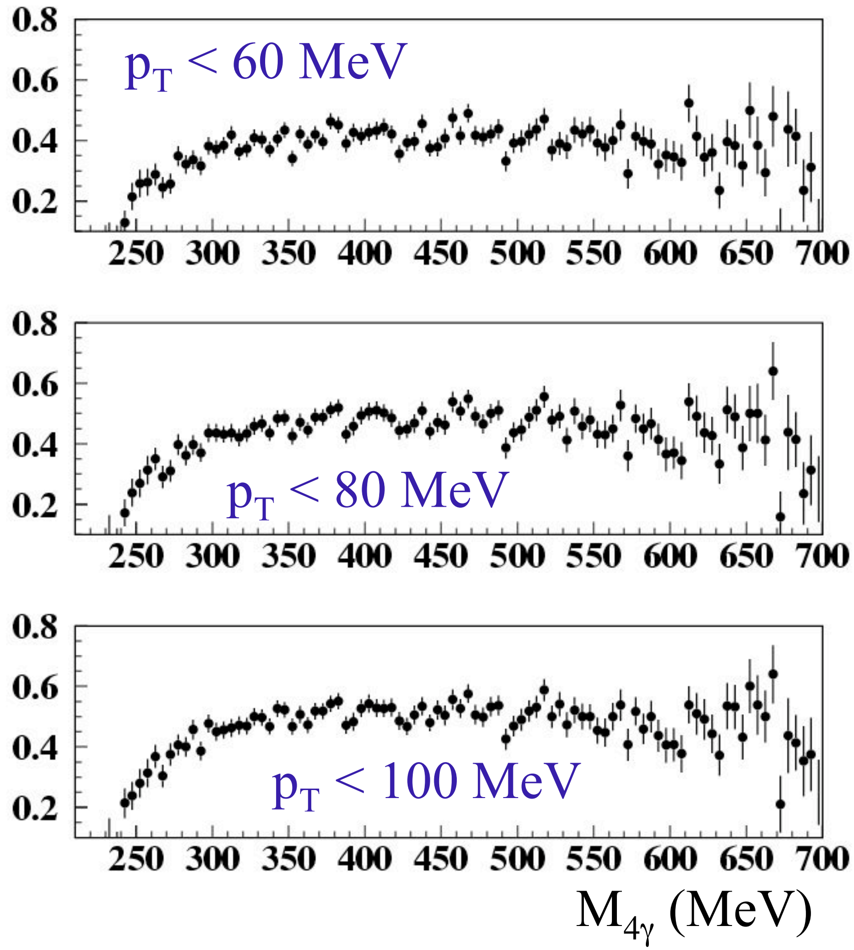


Choice of the cuts

transverse momentum p_T (MeV)



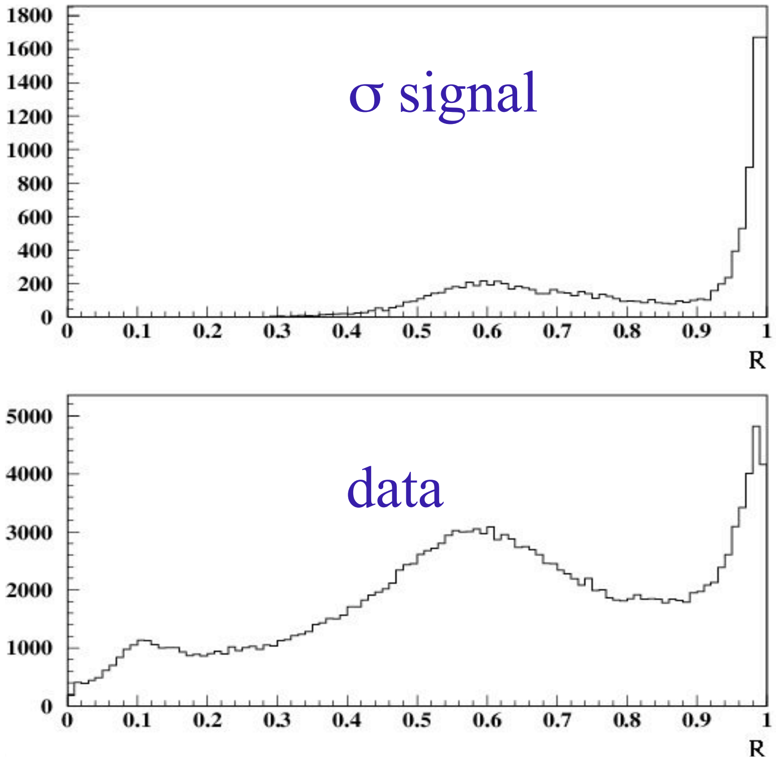
Efficiency vs. 4γ invariant mass (MC signal)

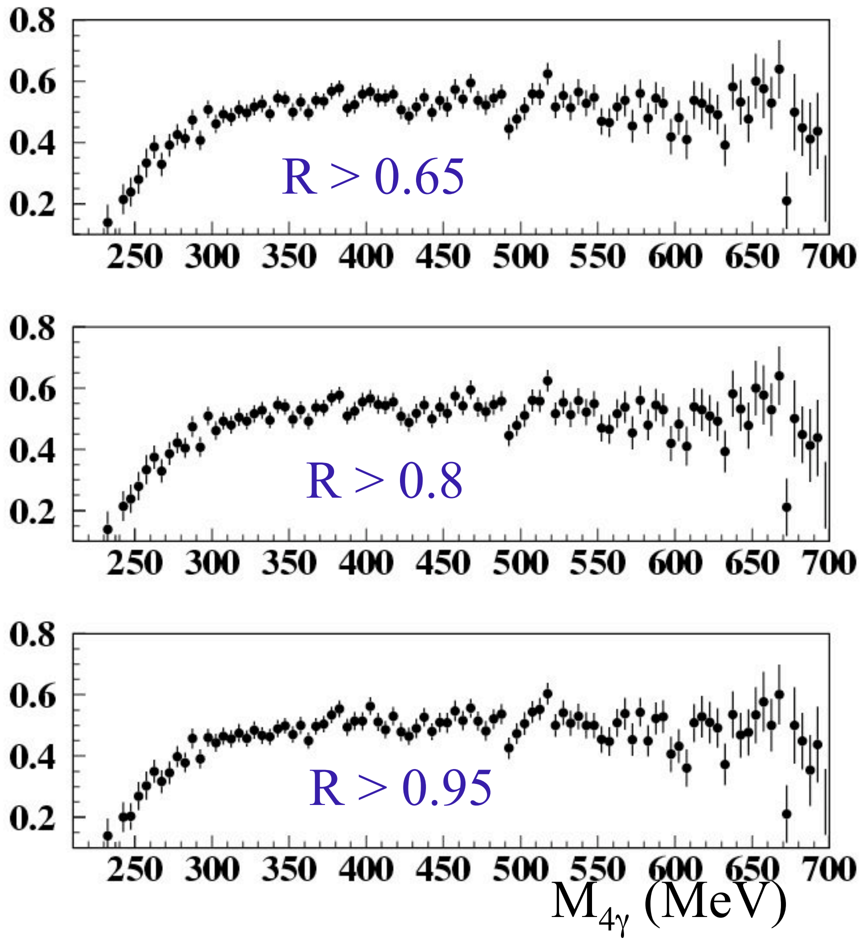


Choice of the cuts

Calorimetric fraction

$$R = \frac{\sum_{i=1}^{4} E_i}{E_{calo}}$$





Analysis cuts efficiency

4 prompt neutral clusters

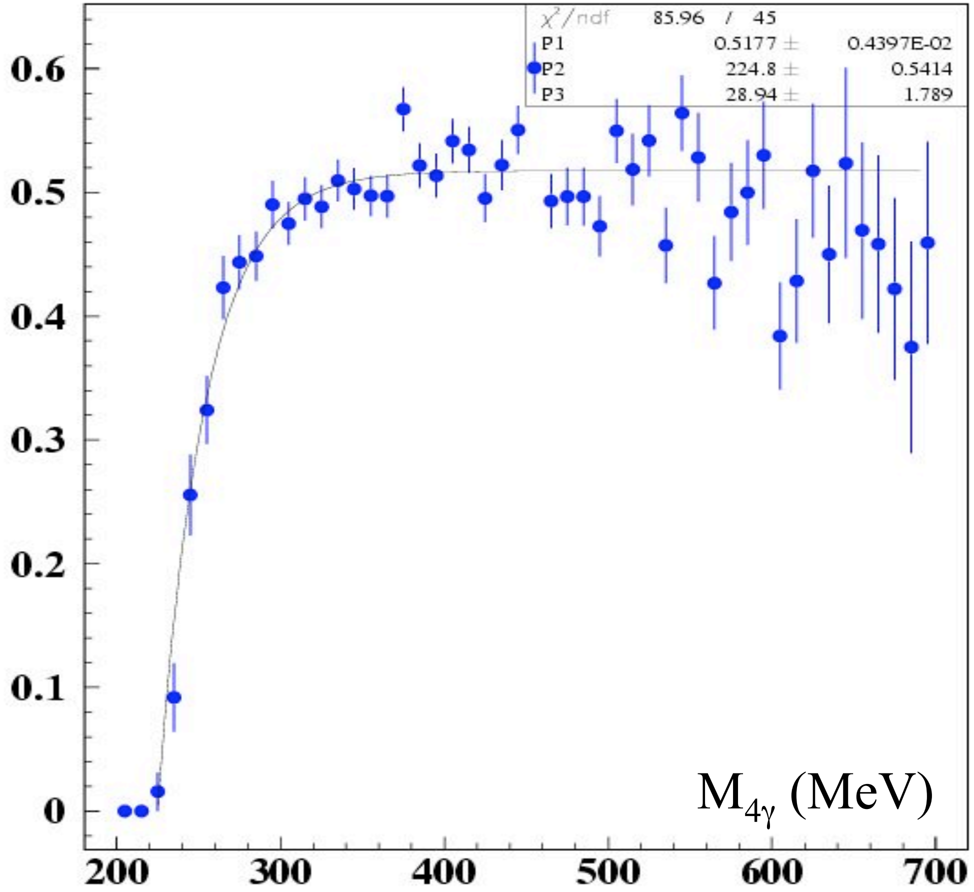
$\chi^2 < 4$

$R > 0.8$

$\sum_{2min} > 60$ MeV

$p_T < 80$ MeV

no tracks



the strategy is to subtract background events and to fit the resulting spectrum with an analytical function, folded with efficiency corrections and resolution function, NOT to fit anymore with σ inside to be "blind" with respect to σ details

Background shapes

4 prompt neutral clusters

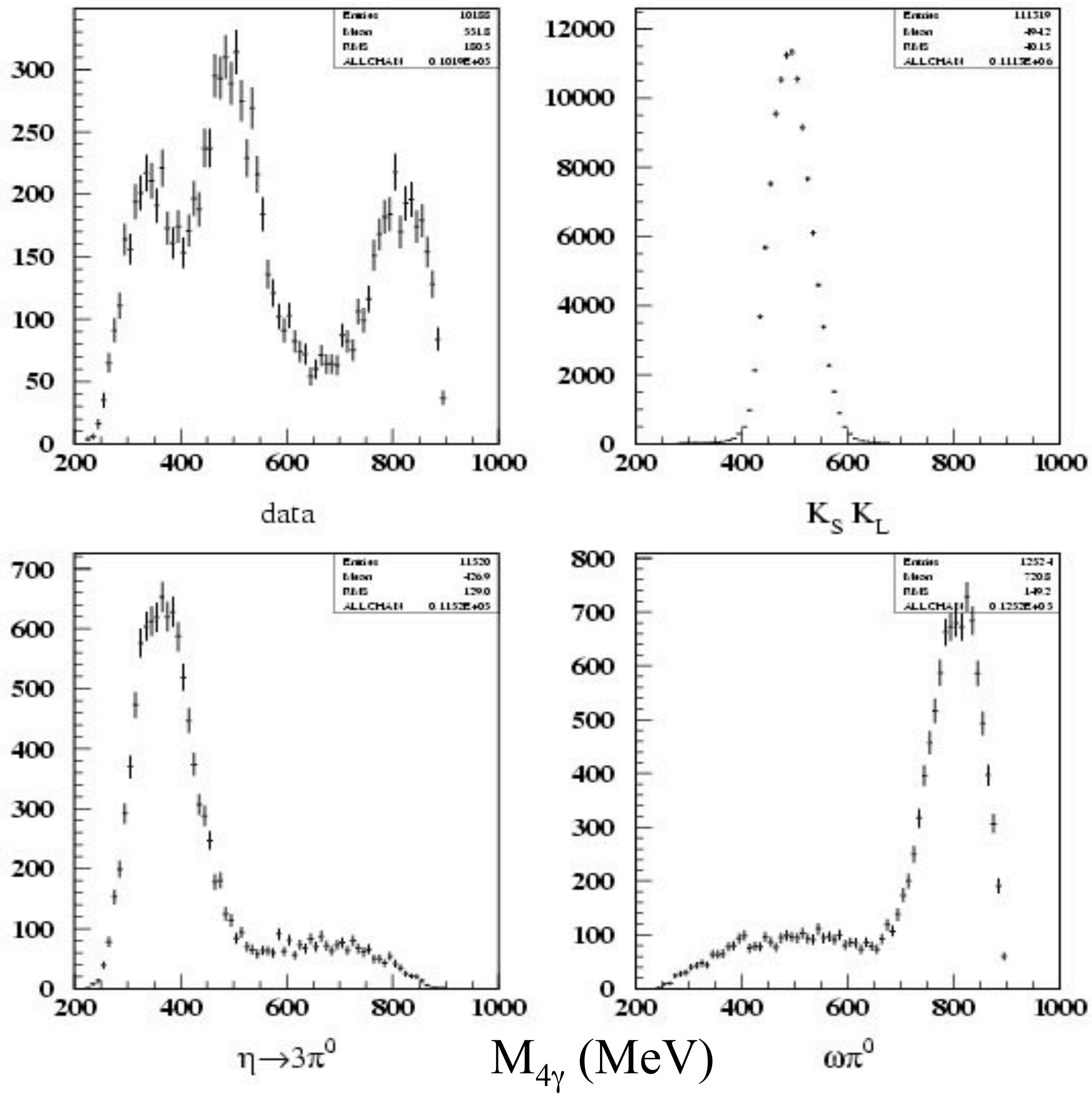
$\chi^2 < 4$

$R > 0.8$

$\sum_{2min} > 60$ MeV

$p_T < 80$ MeV

no tracks



Background (and signal) shapes

4 prompt neutral clusters

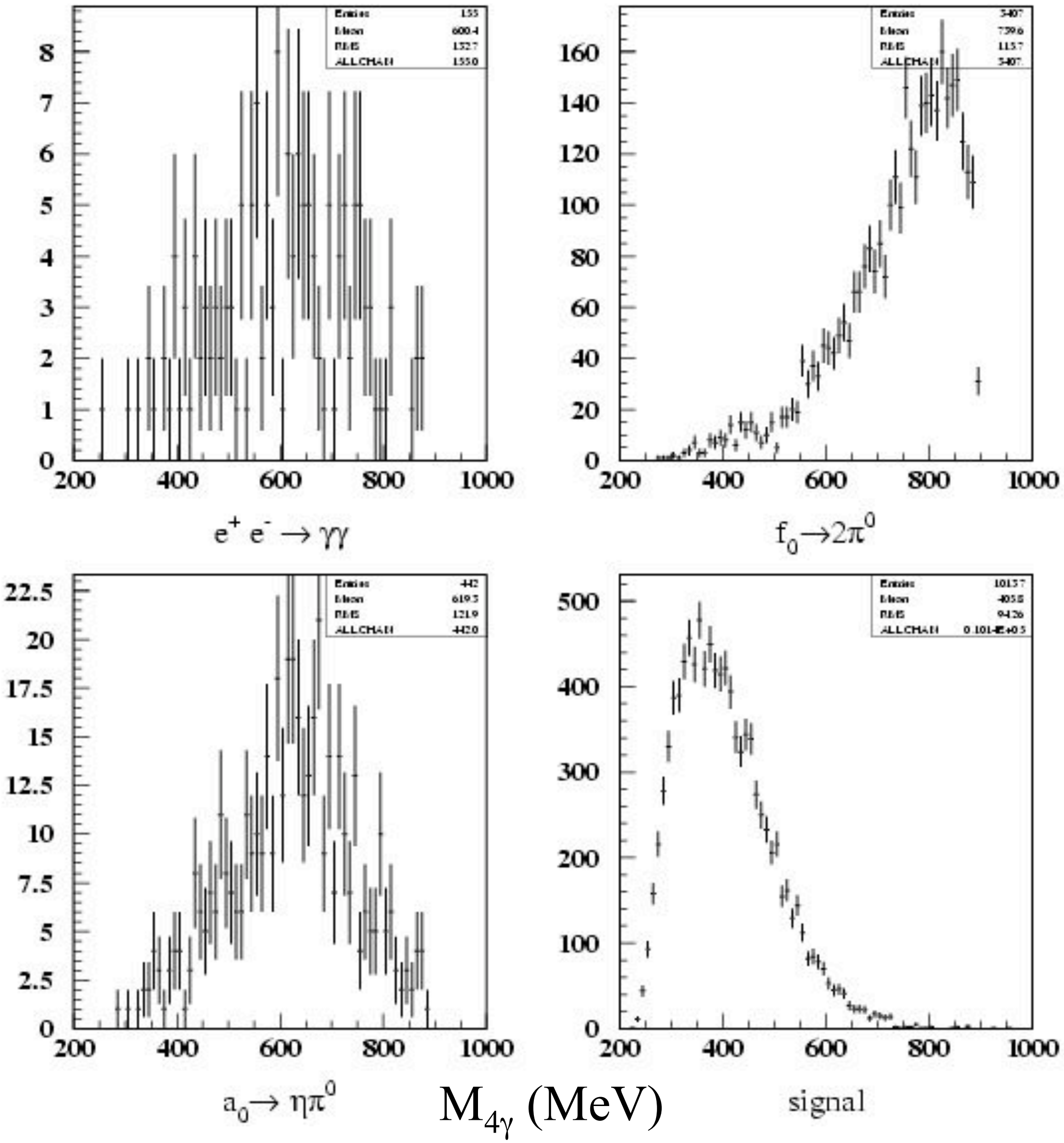
$\chi^2 < 4$

$R > 0.8$

$\sum_{2min} > 60$ MeV

$p_T < 80$ MeV

no tracks



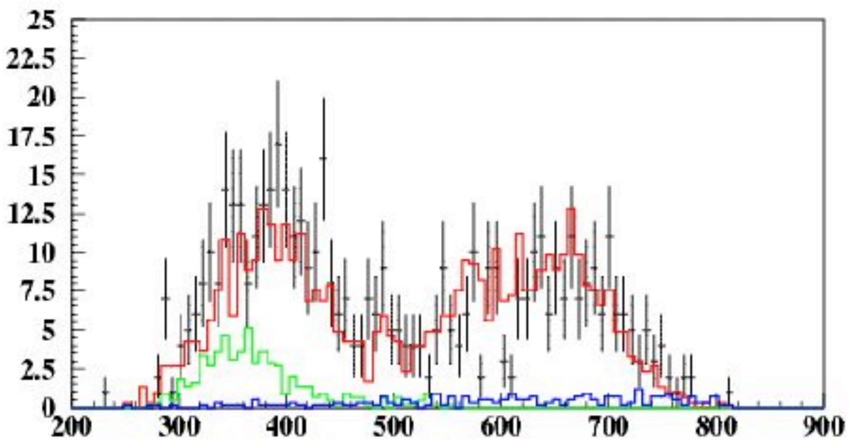
Check of $\eta \to 3\pi^0$

	Weight	Error
$e^+e^- \to \eta\gamma \to \pi^0\pi^0\pi^0\gamma$	0.833	0.075
$e^+e^- \to K_S K_L$	0.113	0.041
$e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$	0.053	0.036

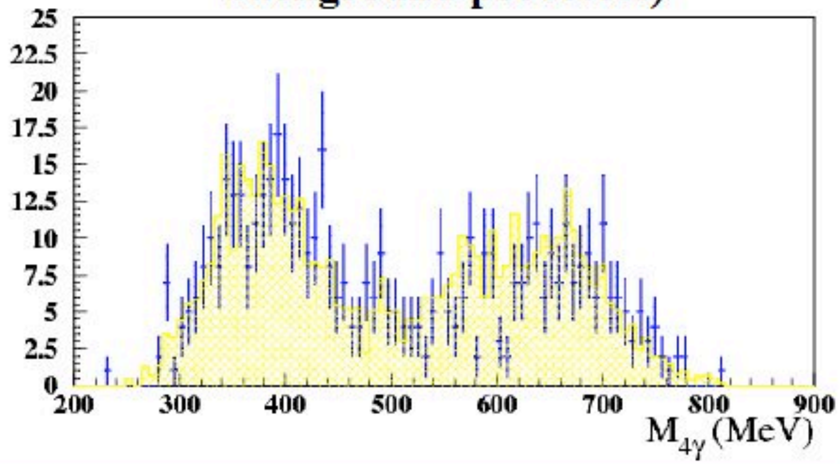
only 6 prompt neutral clusters

$\chi^2 = 69/97$ from fit

M4γ distribution ($K_S K_L$, $\eta \to 3\pi^0$, $\omega\pi^0$)



M4γ distribution (sum of background processes)



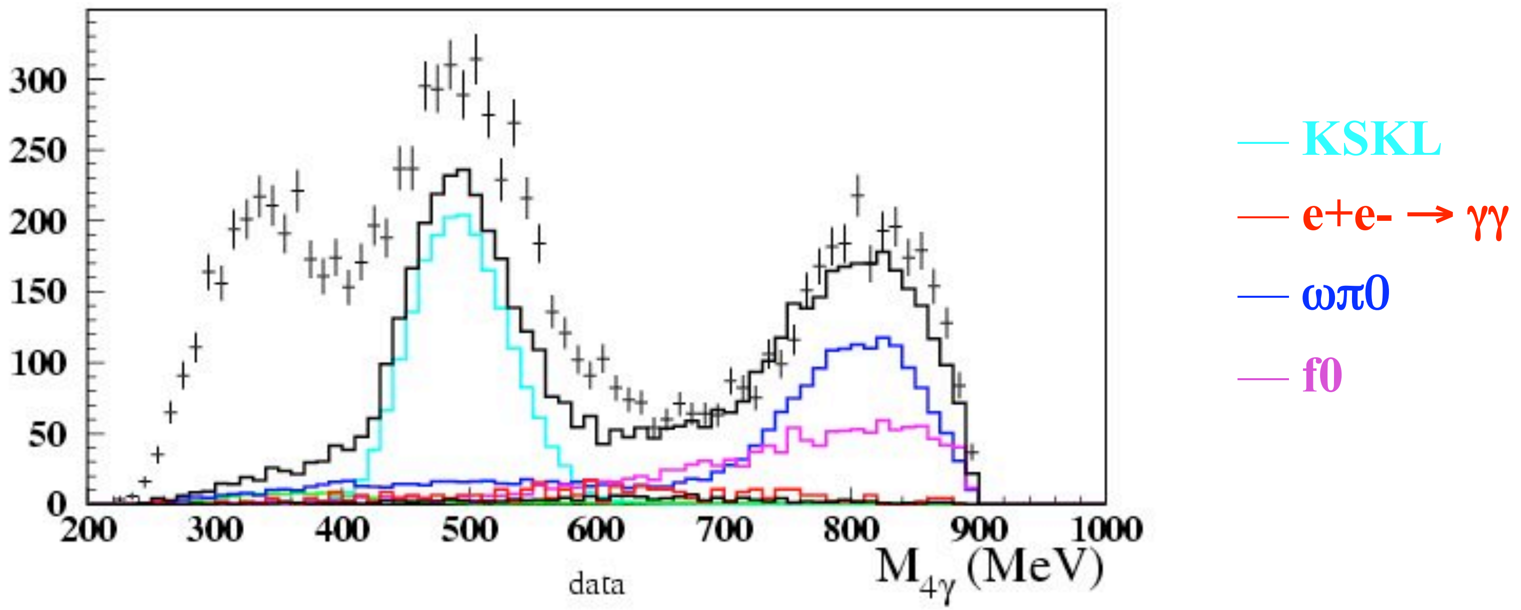
$\sigma(e^+e^- \to \phi \to \eta\gamma \to \pi^0\pi^0\pi^0\gamma) = 338 \pm 33$ pb at 1 GeV

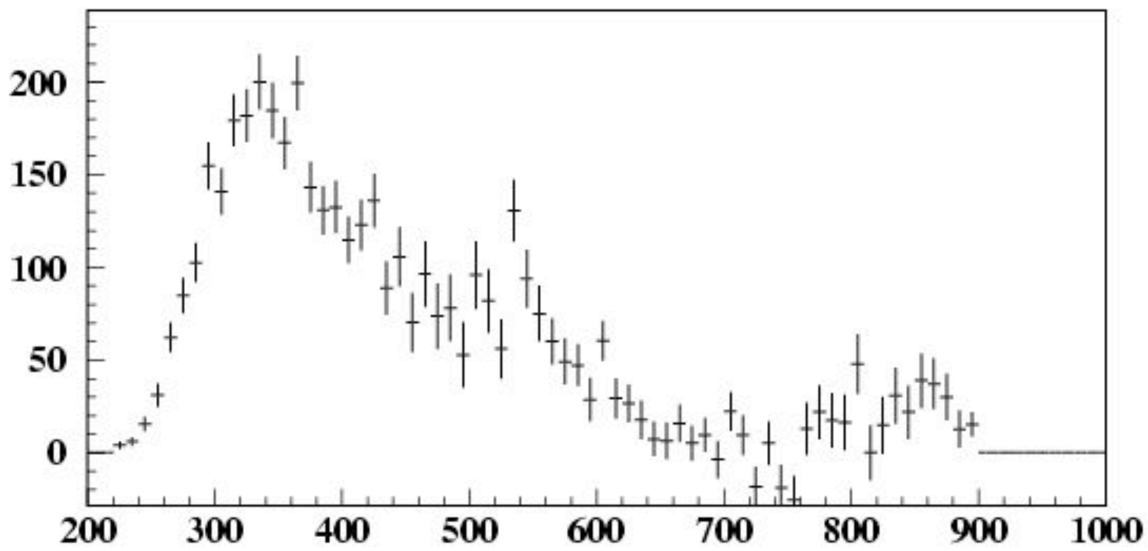
consistent with SND measurement

Analysis with "soft" recover and γ @ 20°

	N_{MC}	N^0_{MC}	ϵ	σ (nb)	$n = \epsilon L \sigma$	$n/10188$
$K_S K_L$	111 319	19 887 800	5.6×10^{-3}	2.0	2682	$0.26 \rightarrow 0.197$
$\eta \rightarrow 3\pi^0$	11 520	6 423 710	1.79×10^{-3}	0.33	142	0.014
$\omega\pi^0$	14 485	933 541	1.55×10^{-2}	0.55	2045	0.2
$f_0 \rightarrow 2\pi^0$	3 407	131 894	2.58×10^{-2}	0.17	1052	$0.10 \rightarrow 0.124$
$a_0 \rightarrow \eta\pi^0$	442	97 205	4.55×10^{-3}	0.11	120	$0.012 \rightarrow 0.0144$
$e^+e^- \rightarrow \gamma\gamma$	155	80 601 500	1.92×10^{-5}	360	166	$0.016 \rightarrow 0.033$

Analysis with "soft" recover and γ @ 20°

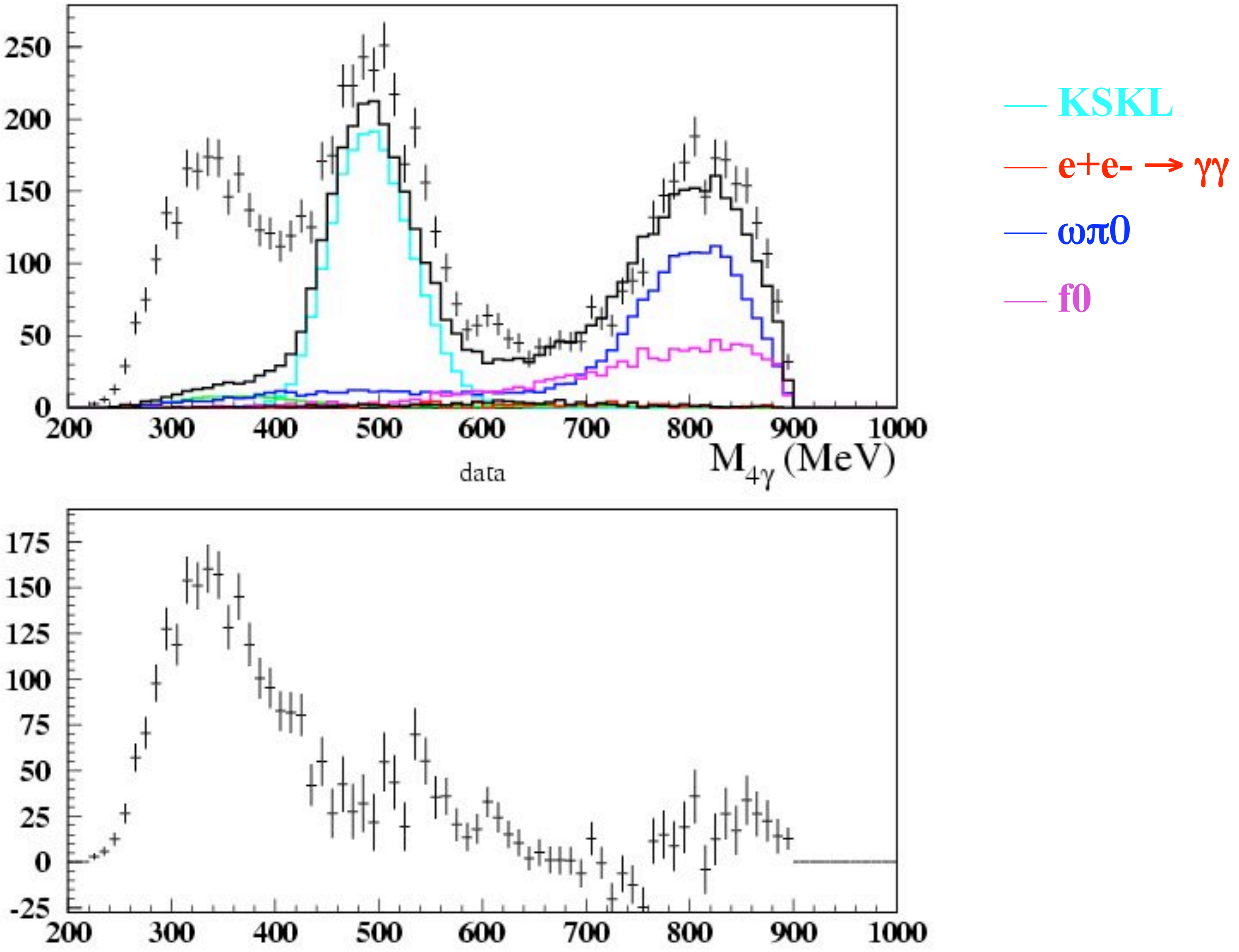




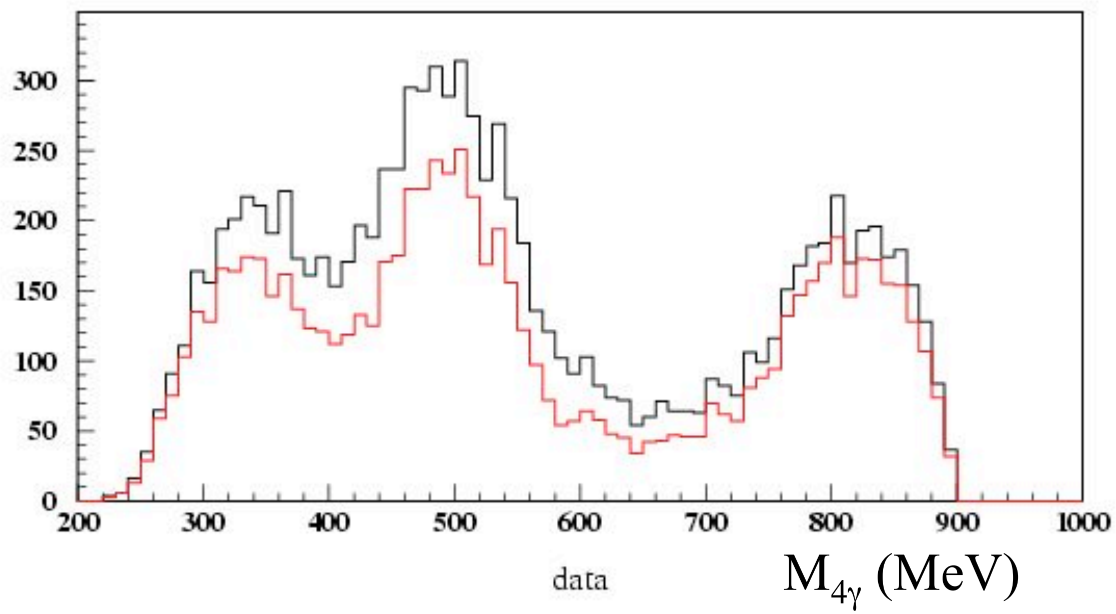
Analysis with “soft” recover and γ @ 23°

	N_{MC}	N^0_{MC}	ϵ	σ (nb)	$n = \epsilon L\sigma$	$n/7924$
$K_S K_L$	104 118	19 887 800	5.24×10^{-3}	2.0	2509	$0.317 \rightarrow 0.238$
$\eta \rightarrow 3\pi^0$	12 386	6 423 710	1.93×10^{-3}	0.33	153	0.019
$\omega\pi^0$	13 132	933 541	1.41×10^{-2}	0.55	1854	0.234
$f_0 \rightarrow 2\pi^0$	3 136	131 894	2.38×10^{-2}	0.17	969	0.122
$a_0 \rightarrow \eta\pi^0$	410	97 205	4.22×10^{-3}	0.11	111	0.014
$e^+e^- \rightarrow \gamma\gamma$	84	80 601 500	1.04×10^{-5}	360	82	0.01

Analysis with “soft” recover and γ @ 23°



Comparison 20° vs. 23°



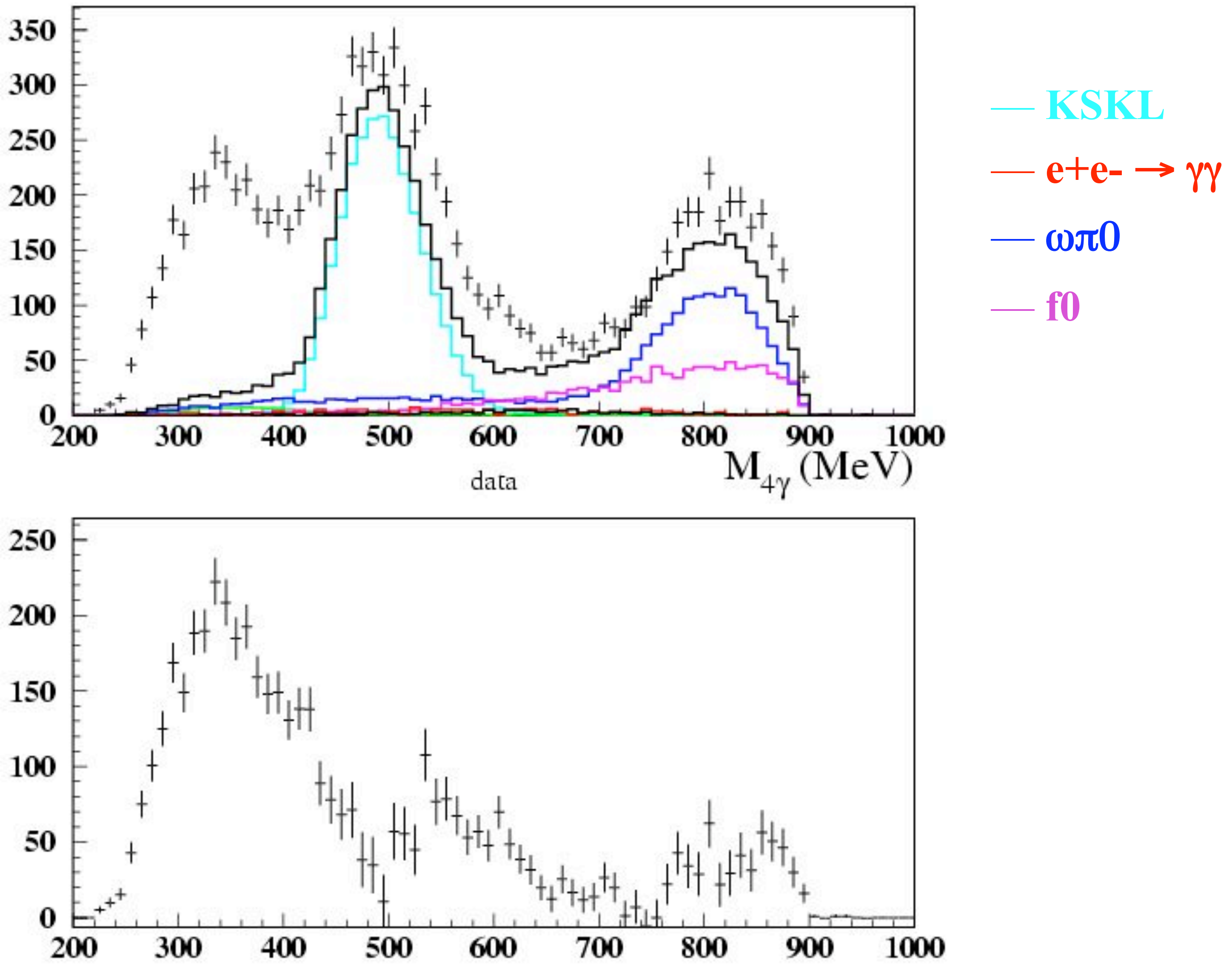
- the ratio between KSKL peak and signal bump remains the same
- region around 800 MeV ($\omega\pi0$ and f0) is apparently unaffected

Analysis with "hard" recover and γ @ 20°

	N_{MC}	N^0_{MC}	ϵ	σ (nb)	$n = \epsilon L \sigma$	$n/10768$
$K_S K_L$	110 955	19 887 800	5.58×10^{-3}	2.0	2673	0.248
$\eta \to 3\pi^0$	9 960	6 423 710	1.55×10^{-3}	0.33	123	0.0114
$\omega\pi^0$	14 290	933 541	1.53×10^{-2}	0.55	2017	0.187
$f_0 \to 2\pi^0$	3 365	131 894	2.55×10^{-2}	0.17	1039	0.097
$a_0 \to \eta\pi^0$	440	97 205	4.53×10^{-3}	0.11	119	0.011
$e^+e^- \to \gamma\gamma$	164	80 601 500	2.03×10^{-5}	360	176	0.016

- 6% difference in the # of events between "soft" and "hard"
- eta -> 3p0 reduces by ~ 20%

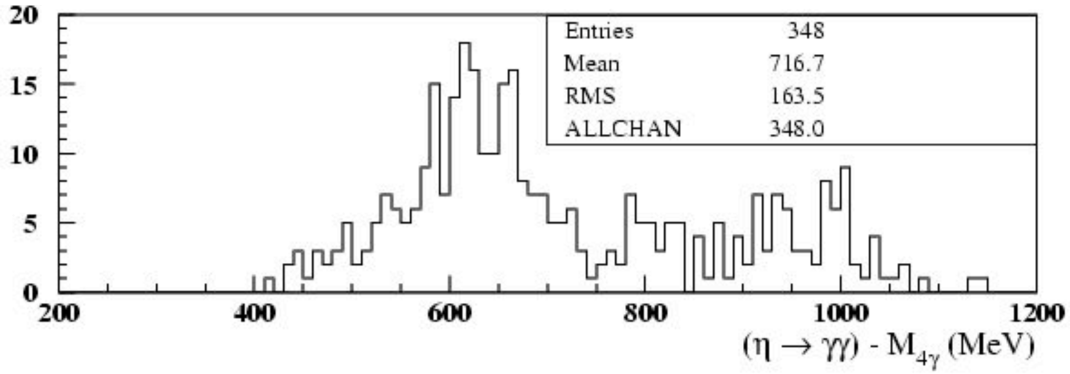
Analysis with "hard" recover and γ @ 20°



Where we are

- the structure where $\gamma\gamma \rightarrow \pi0\pi0$ events are expected is confirmed with 20 times the statistics analyzed in the past

- some bumps are not yet explained, but for the region ~ 550-600 MeV, we are processing right now eta -> gg events that have been neglected in the past, but that can play a role with increased accuracy



- perhaps some analysis cuts may be loosened

Conclusions

- the bump is confirmed, with increasing statistics (20 times) you unavoidably get sensitive to effects obscured by statistical fluctuations
- some systematic checks addressed (splitting and γ polar angle)
- we are writing documentation and we wish to undergo the usual refereeing procedure