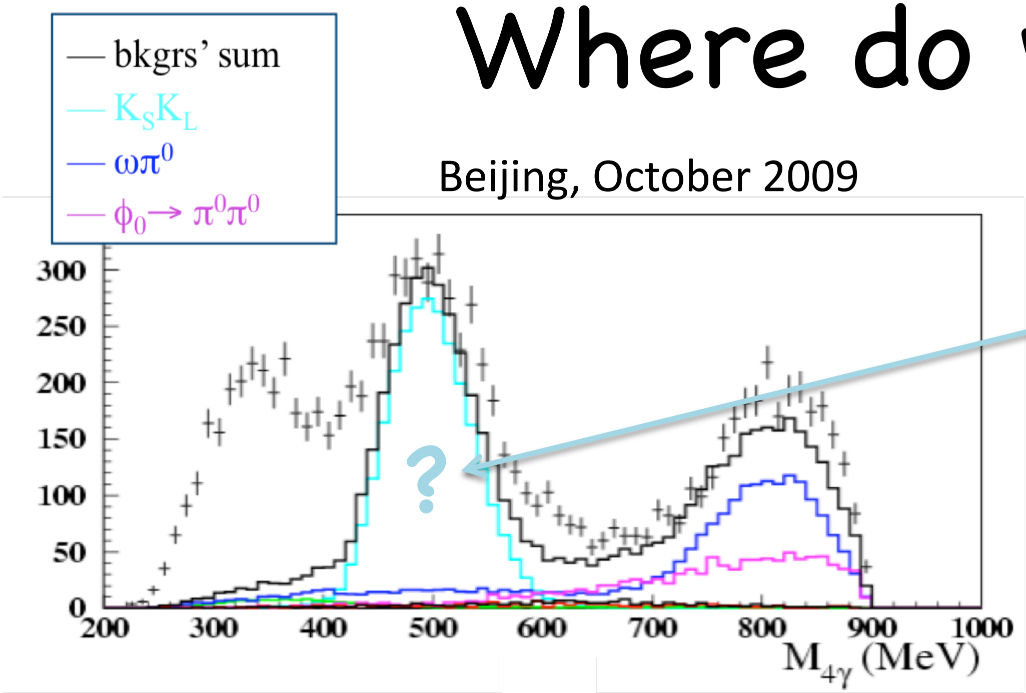
$\gamma\gamma \rightarrow \pi^0\pi^0$ production with $e^+ e^-$ colliding beams @ $\sqrt{s}$=1 GeV

Frascati, 2/9th/2010

Where do we start from?

Beijing, October 2009

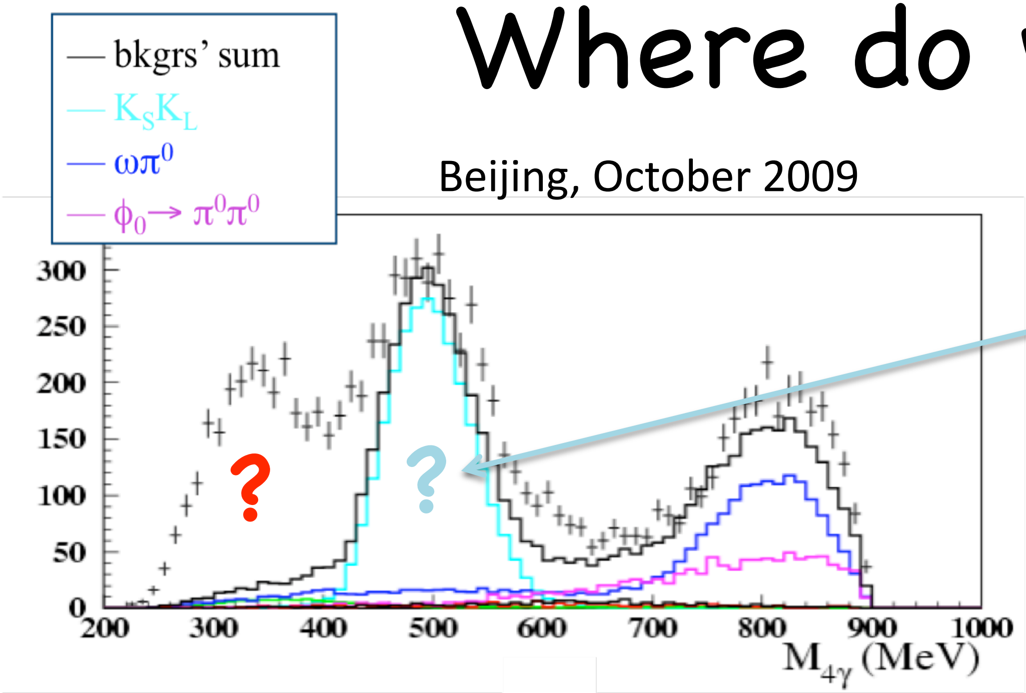


	ϵ	σ (nb)	$n = \epsilon L \sigma$	$n/10188$
$K_S K_L$	5.60×10^{-3}	2.0	2 682	0.26
$\eta \to 3\pi^0$	1.79×10^{-3}	0.33	142	0.014
$\omega\pi^0$	1.55×10^{-2}	0.55	2 045	0.2
$f_0 \to 2\pi^0$	2.58×10^{-2}	0.17	1 052	0.10
$a_0 \to \eta\pi^0$	4.55×10^{-3}	0.11	120	0.012
$e^+e^- \to \gamma\gamma$	1.92×10^{-5}	360	166	0.016
$\eta \to \gamma\gamma$	1.57×10^{-4}	0.39	15	0.0014

ISSUES:

- Systematic study of efficiency from MC
- Correction of scale energy (Data-MC comparison)
- Measure of $K_S K_L$ cross section

Where do we start from?



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ISSUES:

- Systematic study of efficiency from MC
- Correction of scale energy (Data-MC comparison)
- LSB
- Measure of K_SK_L cross section
- **Fit to data!**

Monte Carlo simulation

- Generation of $e^+e^- \to e^+e^- \sigma \to e^+e^-\pi^0\pi^0$ events using:

  M_σ=541 MeV, Γ_σ=504 MeV (*BES2*) # 50000

  M_σ=513 MeV, Γ_σ=335 MeV (*CLEO*) # 40000

  M_σ=478 MeV, Γ_σ=324 MeV (*E791*) # 40000
- e^+ and e^- in the cone $10^0 < \vartheta > 170^0$
- GEANFI simulation of the detector response

Chosen because of wider $m_{4\gamma}$ interval

We use official ALLPHYS MC production for main background processes:

- $e^+e^- \rightarrow$ KsKl
- $e^+e^- \rightarrow \eta\gamma \rightarrow 3\pi^0\gamma$
- $e^+e^- \rightarrow \omega\pi^0$
- $e^+e^- \rightarrow f_0\ \gamma$
- $e^+e^- \rightarrow a_0\ \gamma$
- $e^+e^- \rightarrow \gamma\gamma$

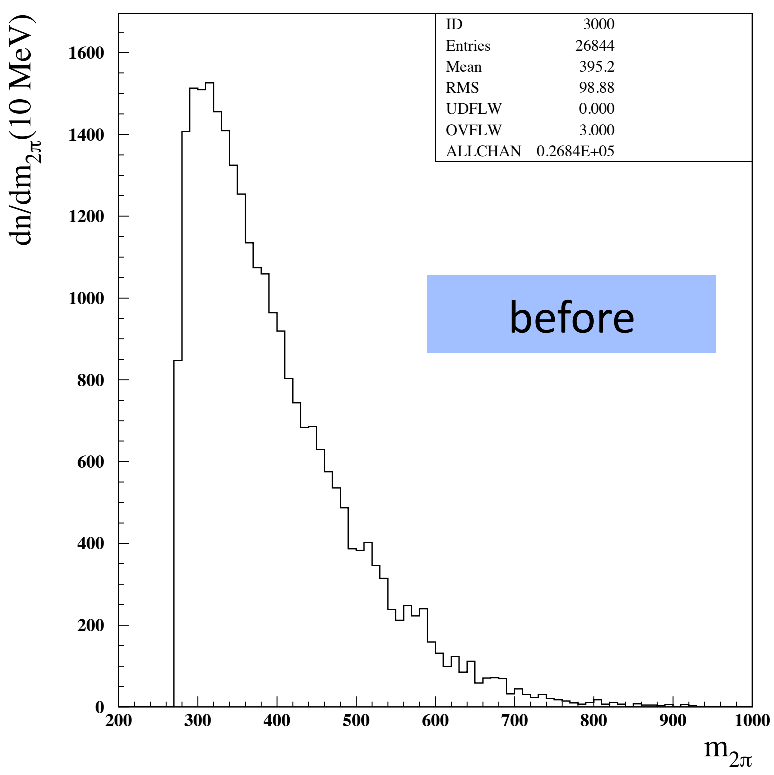
Gaussian smearing

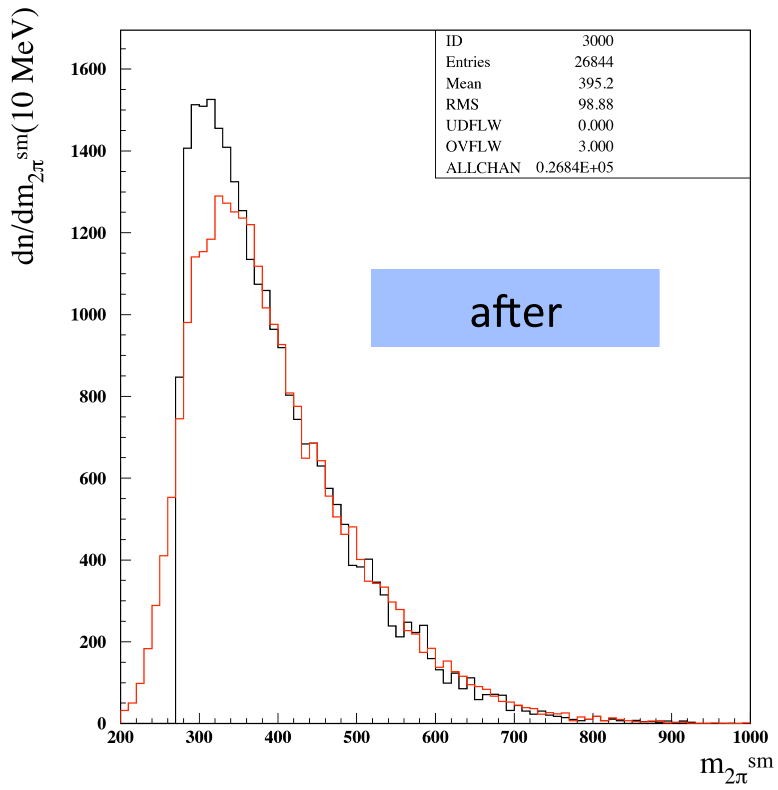
MC genarates $m_{2\pi}$

The variable we use before cluster reconstruction is

$$m^{sm}_{2\pi^0} = m_{2\pi^0}(1 + rgau \times Res(m_{2\pi^0}))$$

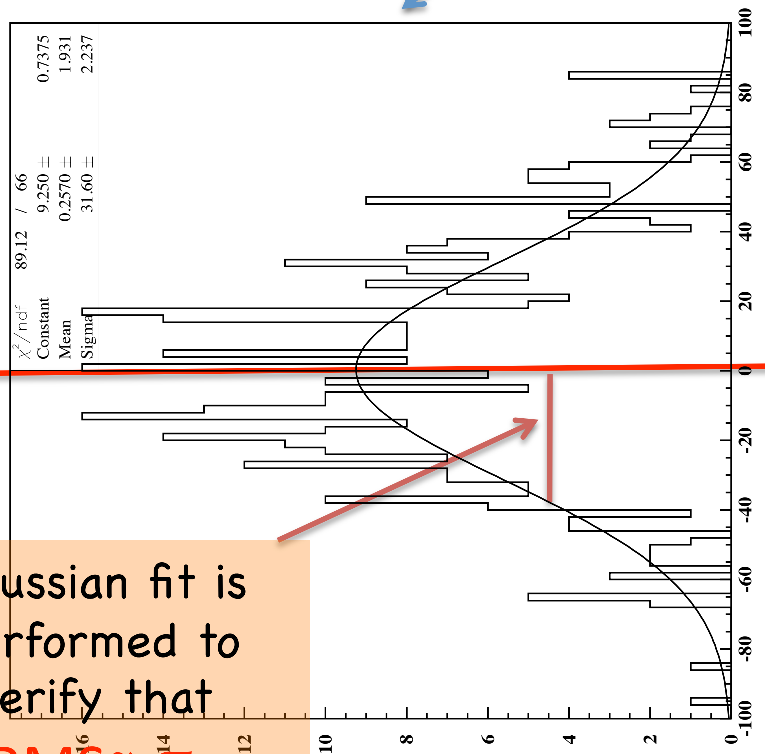
Gaussian distributed random number

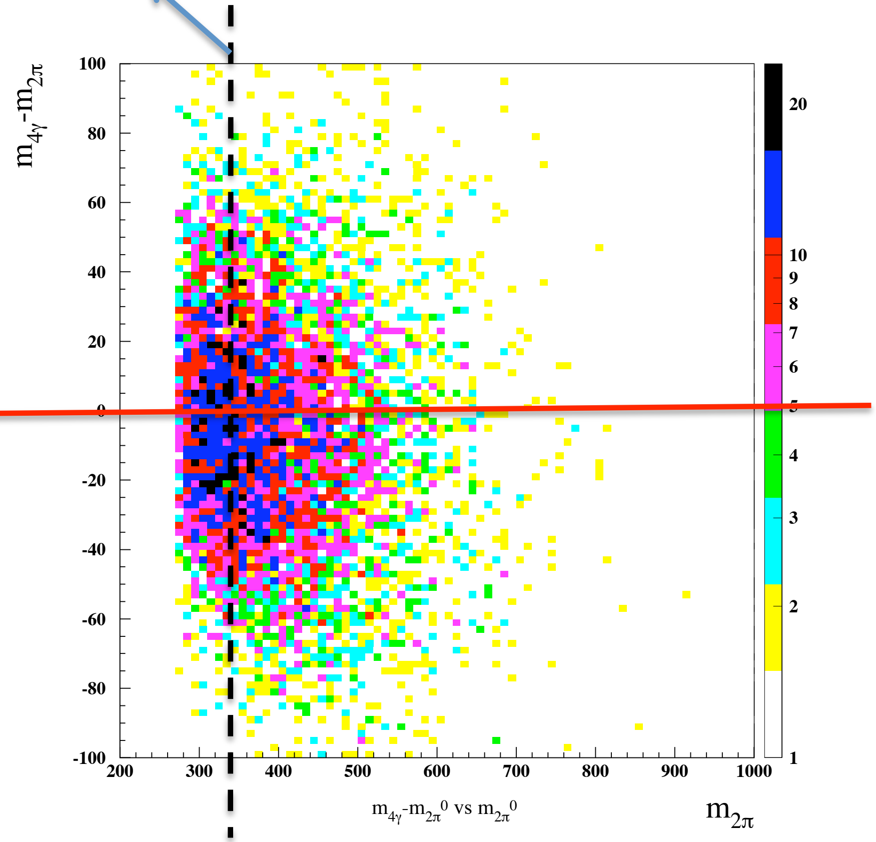




Resolution function: scatter plot ($m_{4\gamma} - m_{2\pi}$) vs $m_{2\pi}$

For each bin in $m_{2\pi}$ we consider a slice projected onto ($m_{4\gamma} - m_{2\pi}$) axis





Gaussian fit is performed to verify that

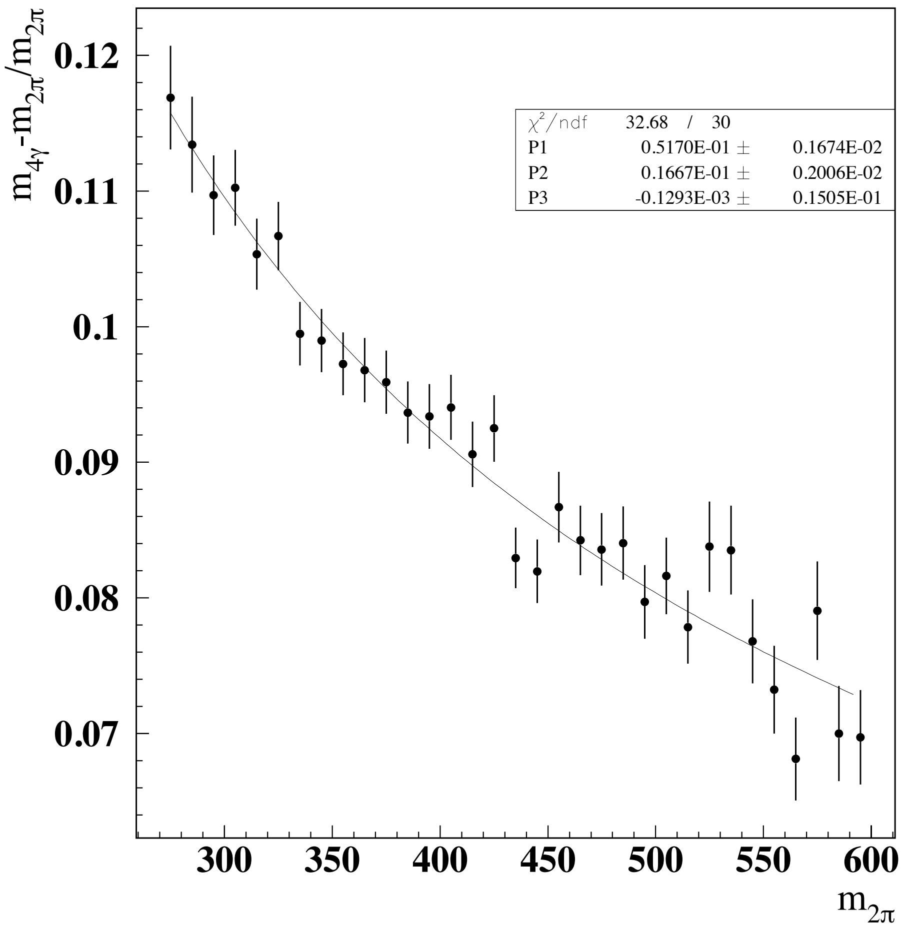
RMS ≅ σ

Resolution function: fit result

We plot $\sigma(m_{2\pi})/m_{2\pi}$ VS $m_{2\pi}$ and fit with the function

$$f(x) = \frac{A}{\sqrt{x}} + \frac{B}{x^2} + C$$

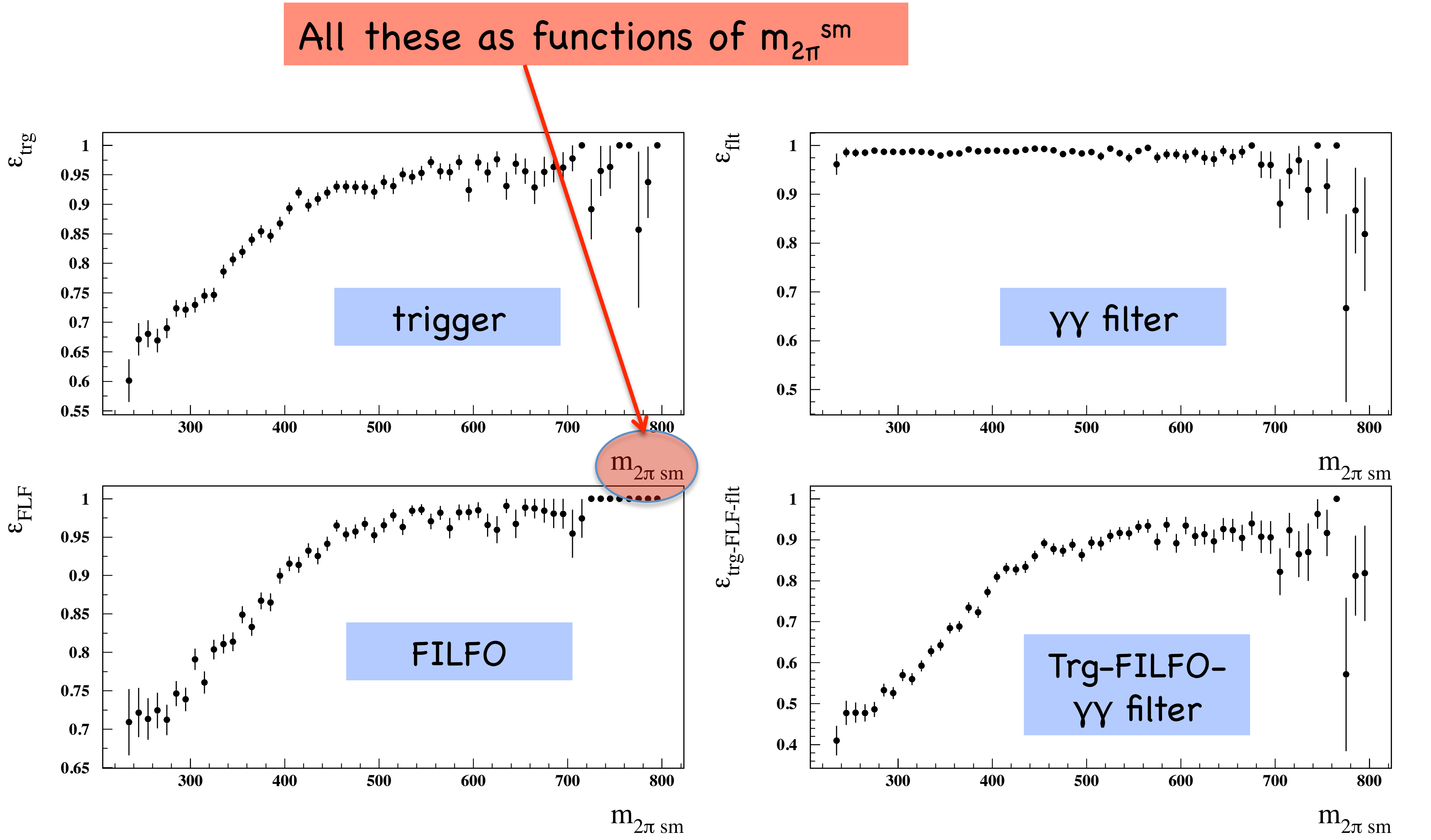
f(x) is our resolution function



Preselection filters

- Trigger
- Bkg rejection filter FILFO
- $\gamma\,\gamma$ filter asking for:
  - at least 2 prompt neutral clusters
  - All clusters with E>15 MeV and $20^0<\vartheta<160^0$
  - at least one cluster with E>50 MeV
  - $R=(E_1+E_2)/E_{tot}>0.3$
  - $100<E_{tot}<900$ MeV

Filters (trg-FILFO-γγfilter) efficiencies



4 γ reconstruction

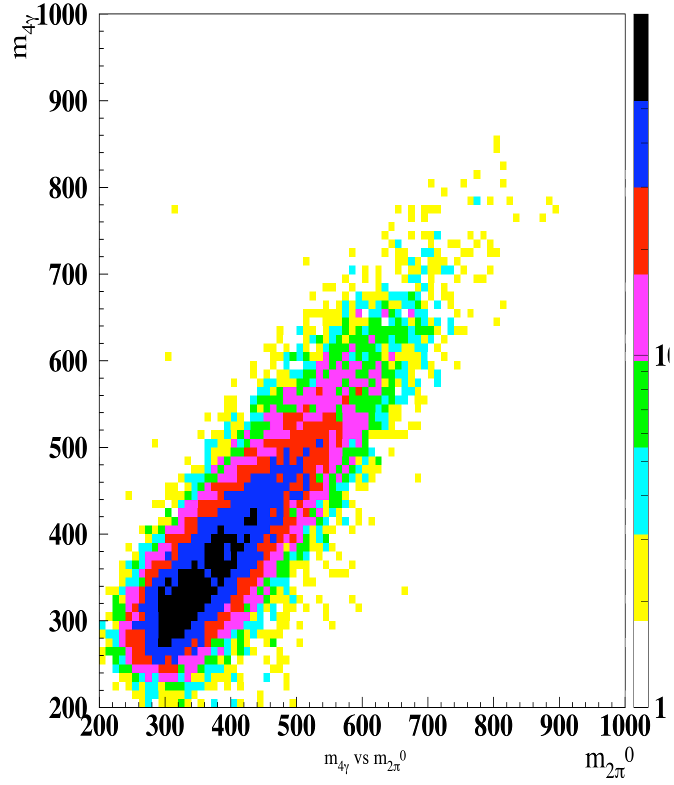
What we do:

- ask at least 4 neutral prompt clusters, with E≥15 MeV and 20° < ϑ > 160°
- perform recover splitting
- choose and pair 4 γ minimizing

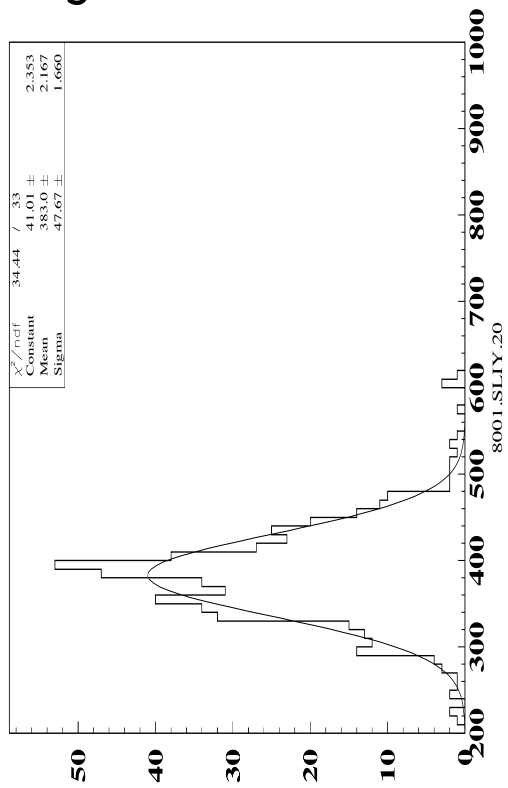
$$\chi^2_{\pi^0\pi^0} = \frac{(m_{\pi^0} - m_{\gamma 1\gamma 2})^2}{\sigma^2_{\gamma 1\gamma 2}} + \frac{(m_{\pi^0} - m_{\gamma 3\gamma 4})^2}{\sigma^2_{\gamma 3\gamma 4}}$$

Switching from $m_{2\pi}^{sm}$ to $m_{4\gamma}$

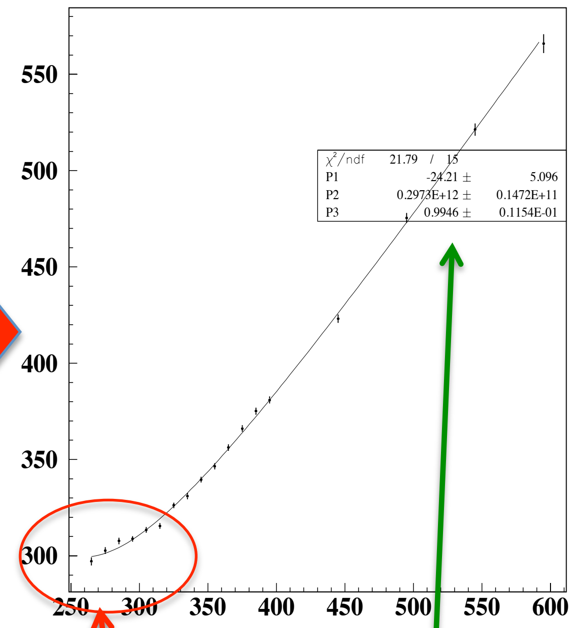
$m_{4\gamma}$ vs $m_{2\pi}^{sm}$



Slice with gaussain fit



$m_{4\gamma} = f(m_{2\pi}^{sm})$



C≅1,B<<1
Almost linear

Fit function:

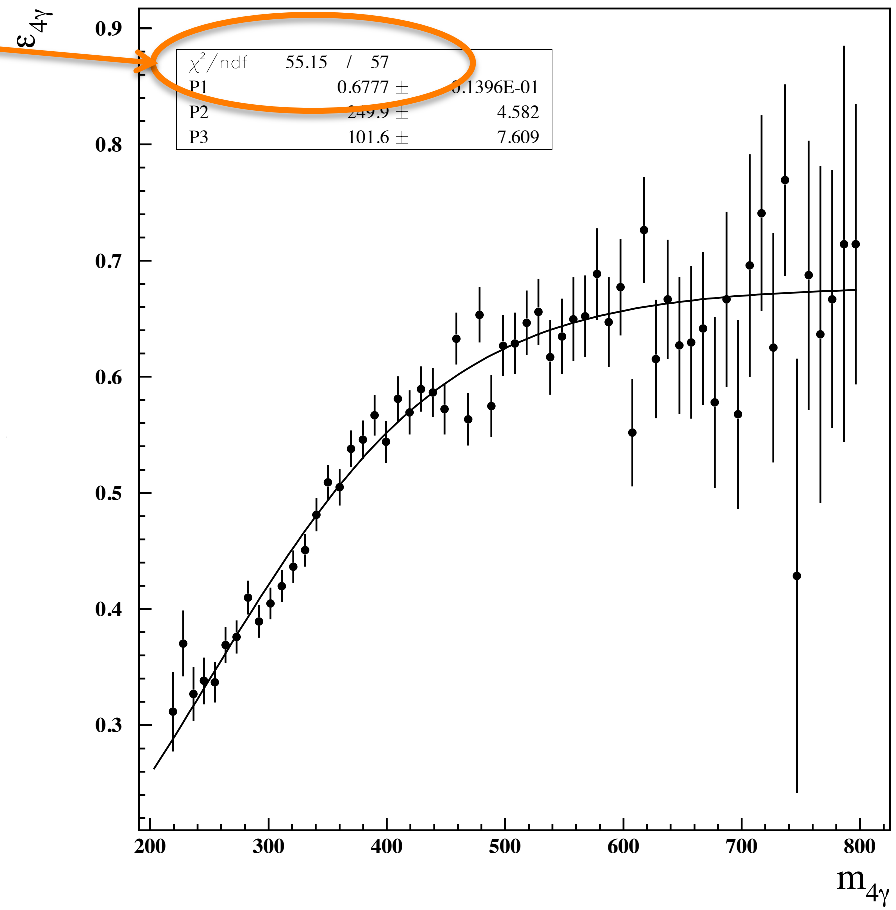
$$f(x) = A + \frac{B}{x^4} + Cx$$

Effects due to low energy wrongly reconstructed γ

Total preselection efficiency

X^2/ndf = 55.15/57

$$f(x) = \frac{A}{1 + \exp(-\frac{x}{C})}$$



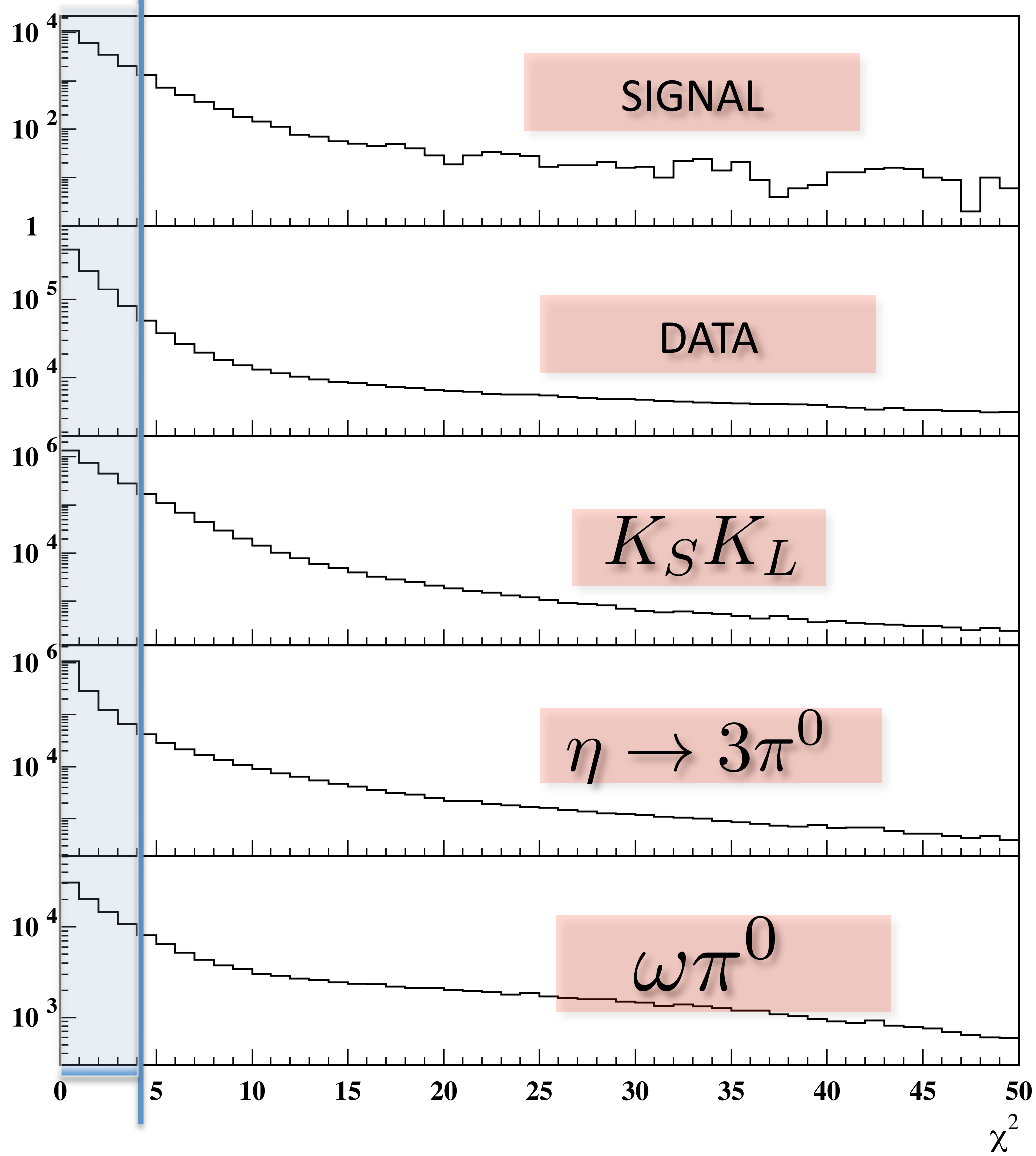
Analysis cuts

We require:

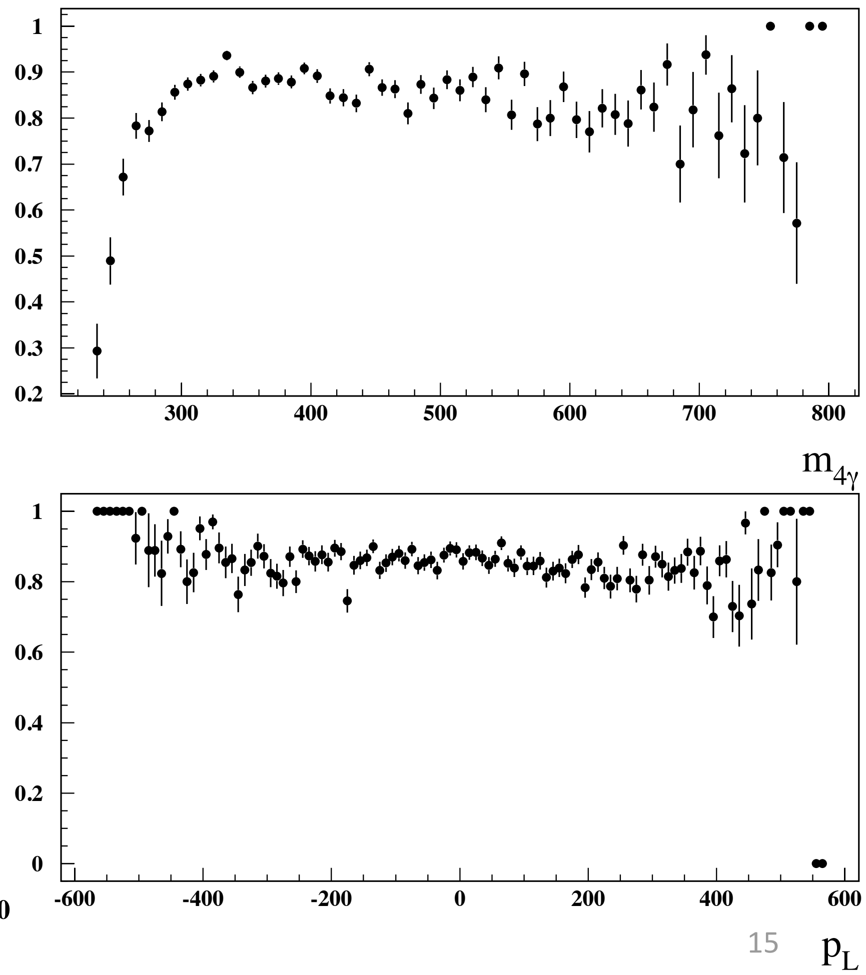
- $\chi^2_{\pi\pi} < 4$
- 4 and only 4 neutral prompt clusters
- no tracks in the Drift Chamber
- $R = \Sigma_\gamma E_\gamma / E_{tot} > 0.8$
- $E_{\gamma 3} + E_{\gamma 4} > 60$ MeV
- $E_{\gamma 1} < 450$ MeV & $E_{\gamma 2} < 400$ MeV
- $\Sigma_\gamma p_T < 80$ MeV

Analysis cuts 1:

$$\chi^2_{\pi^0\pi^0} < 4$$

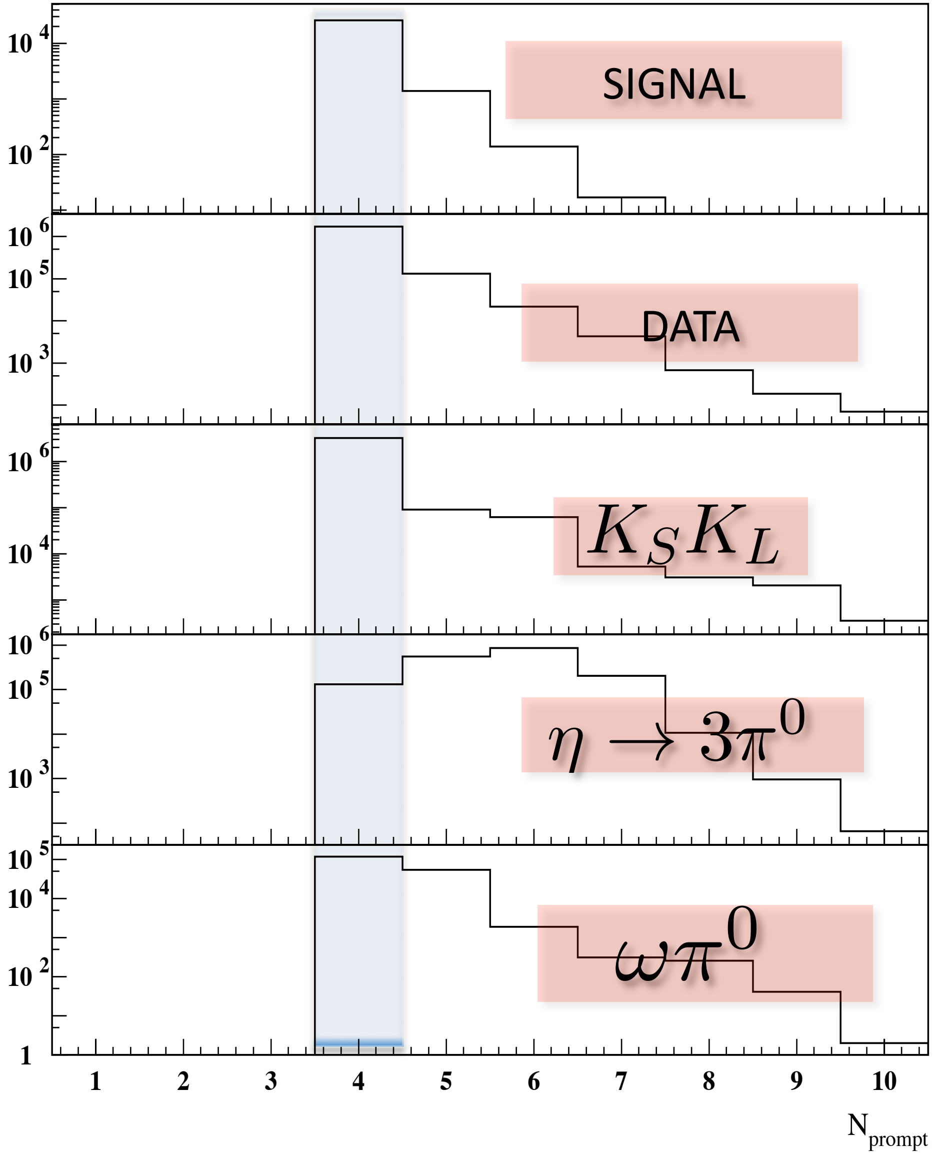


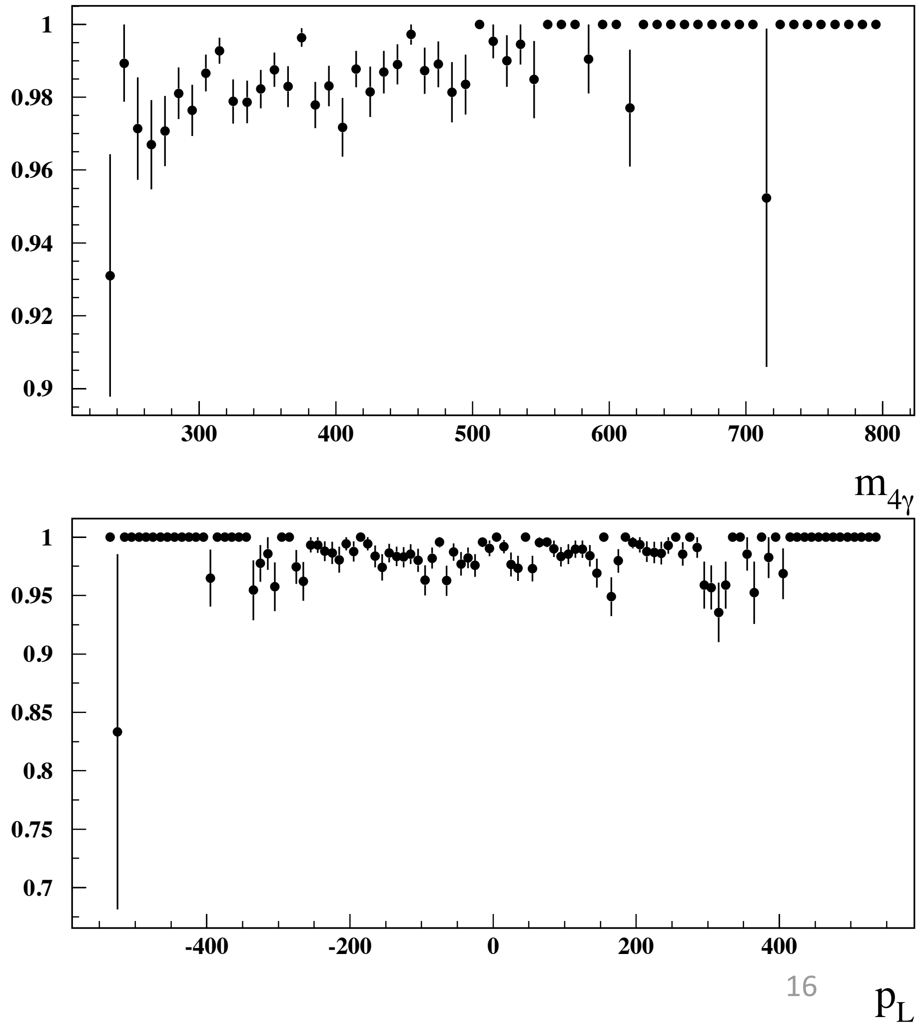
Signal efficiency



Analysis cuts 2

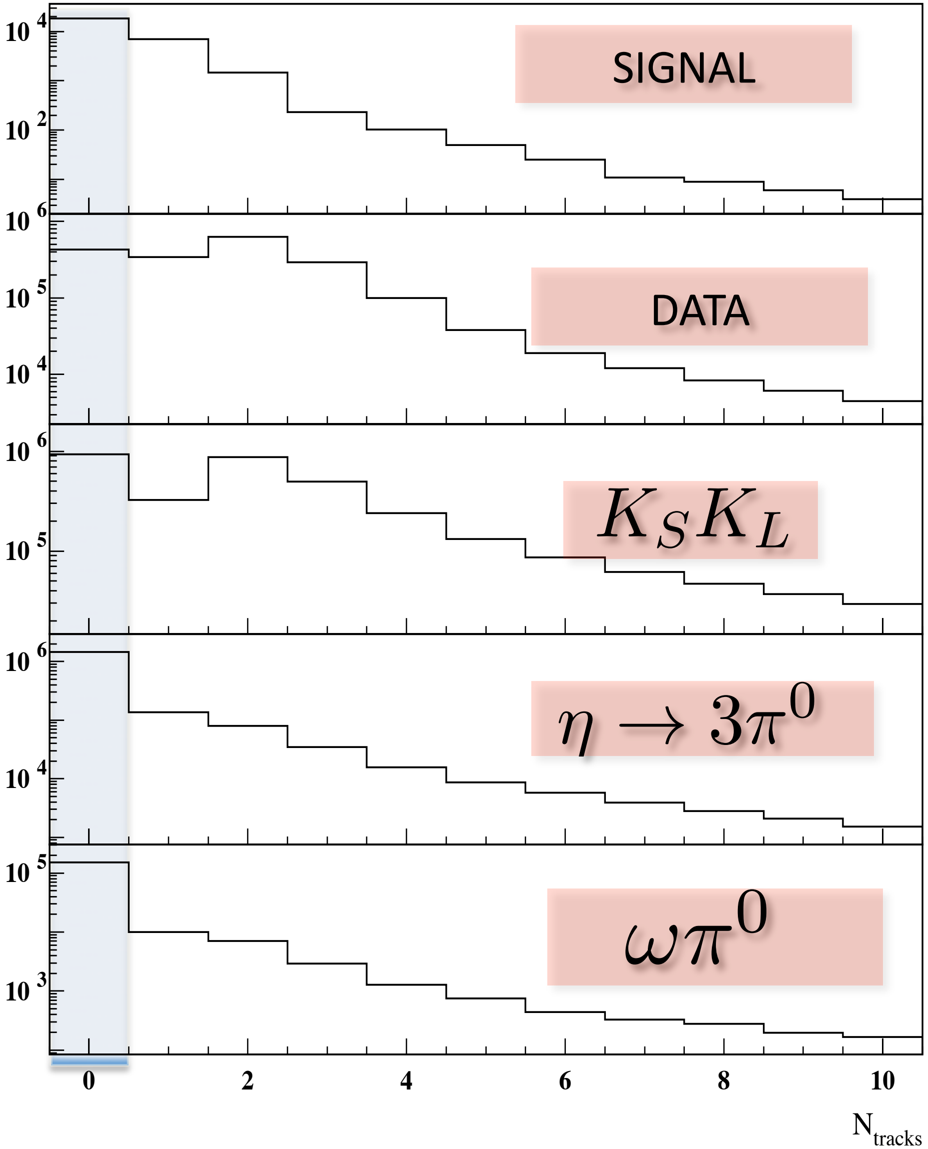
Only 4 γ prompt



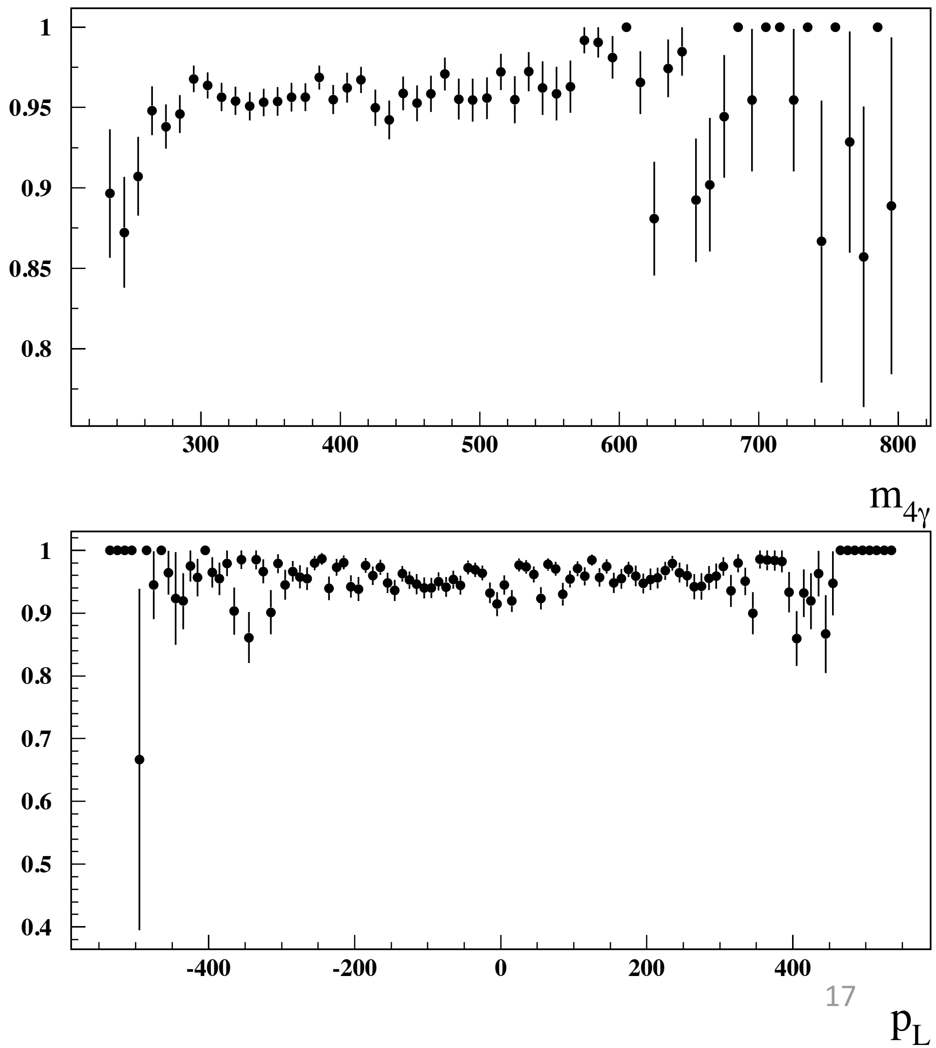


Analysis cuts 3

No tracks

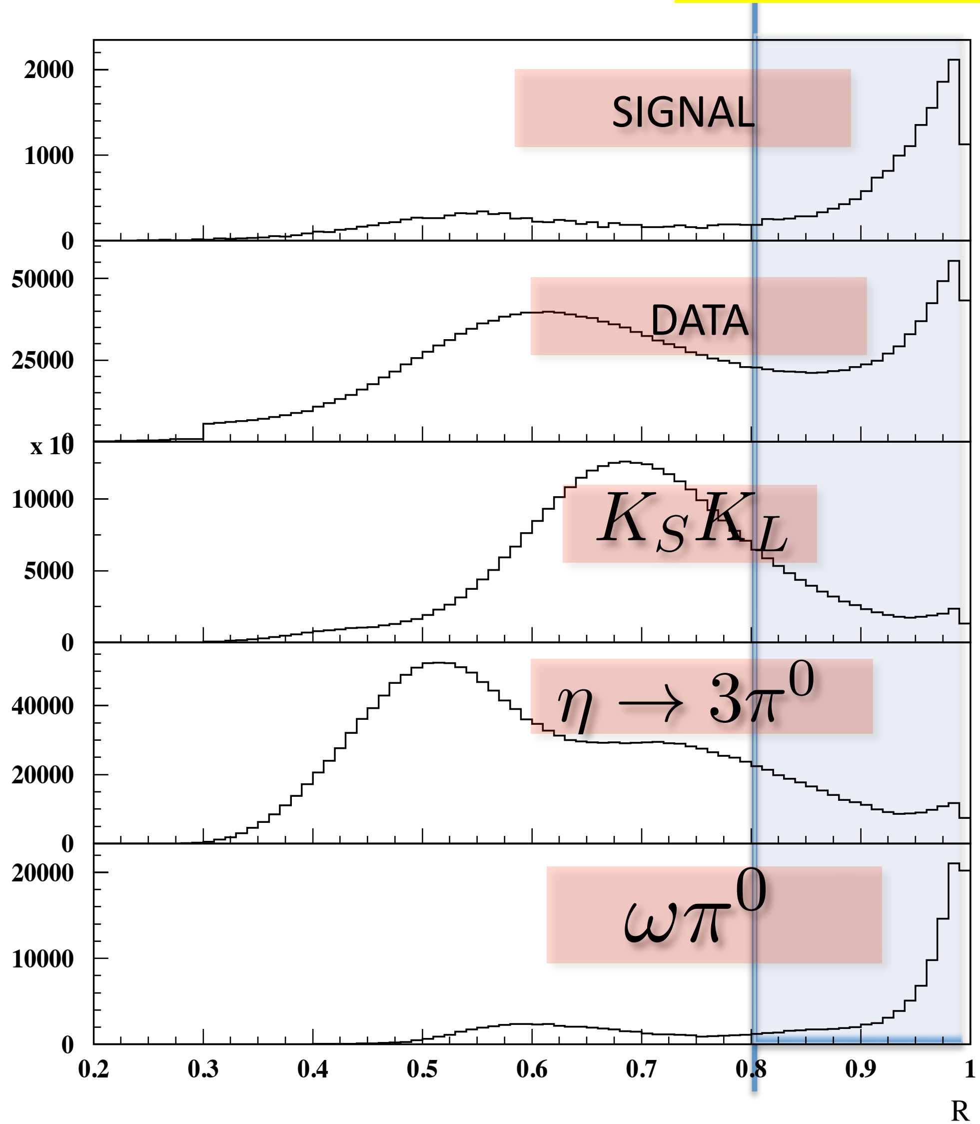


Signal efficiency

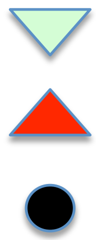


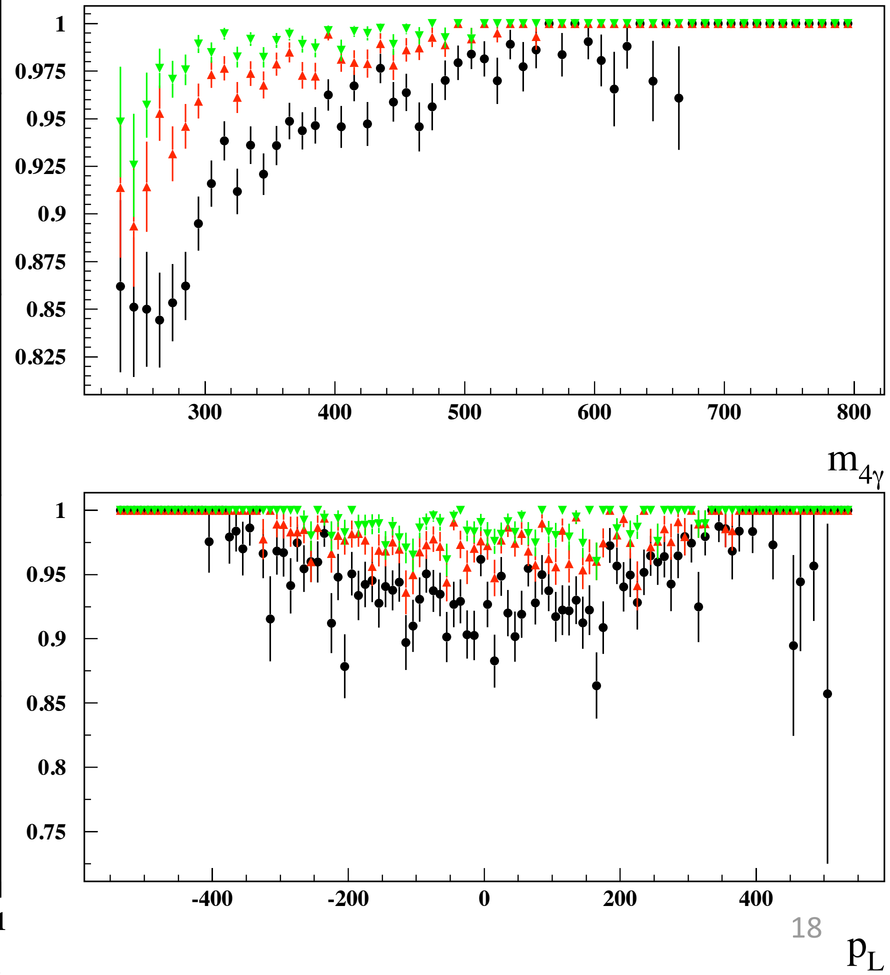
Analysis cuts 4:

$$R = \frac{\sum_i^4 E_{\gamma_i}}{E_{tot}} > a$$



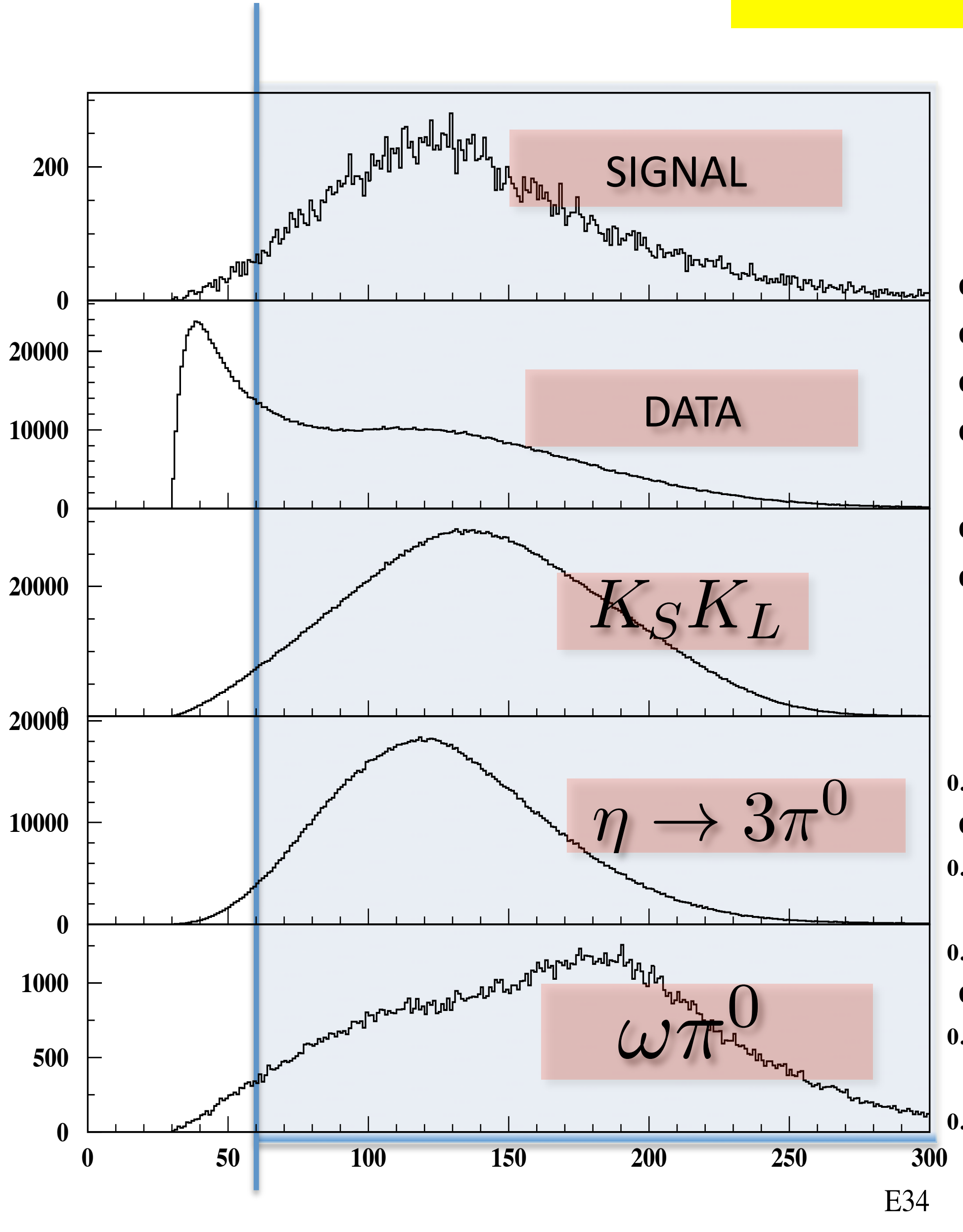
Signal efficiency

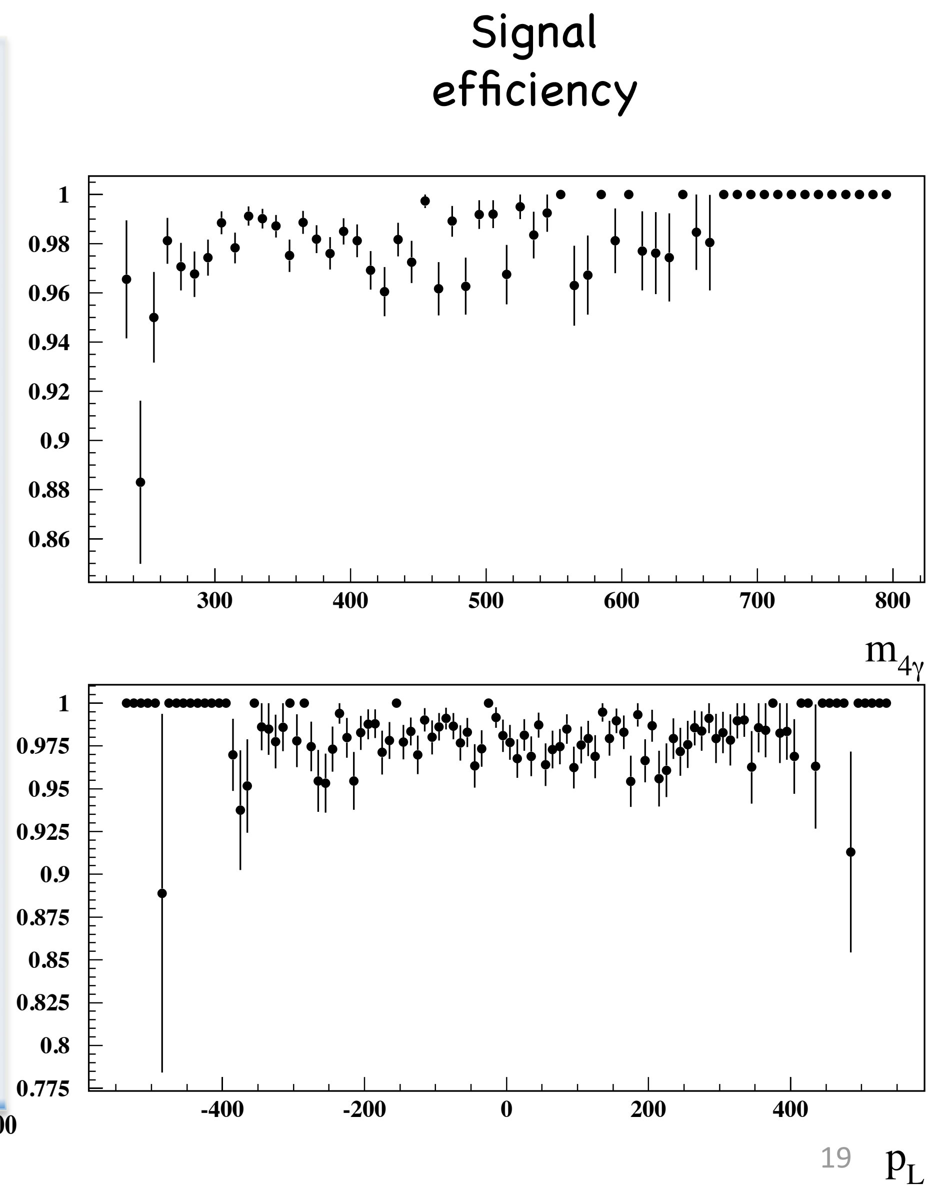




Analysis cuts 5:

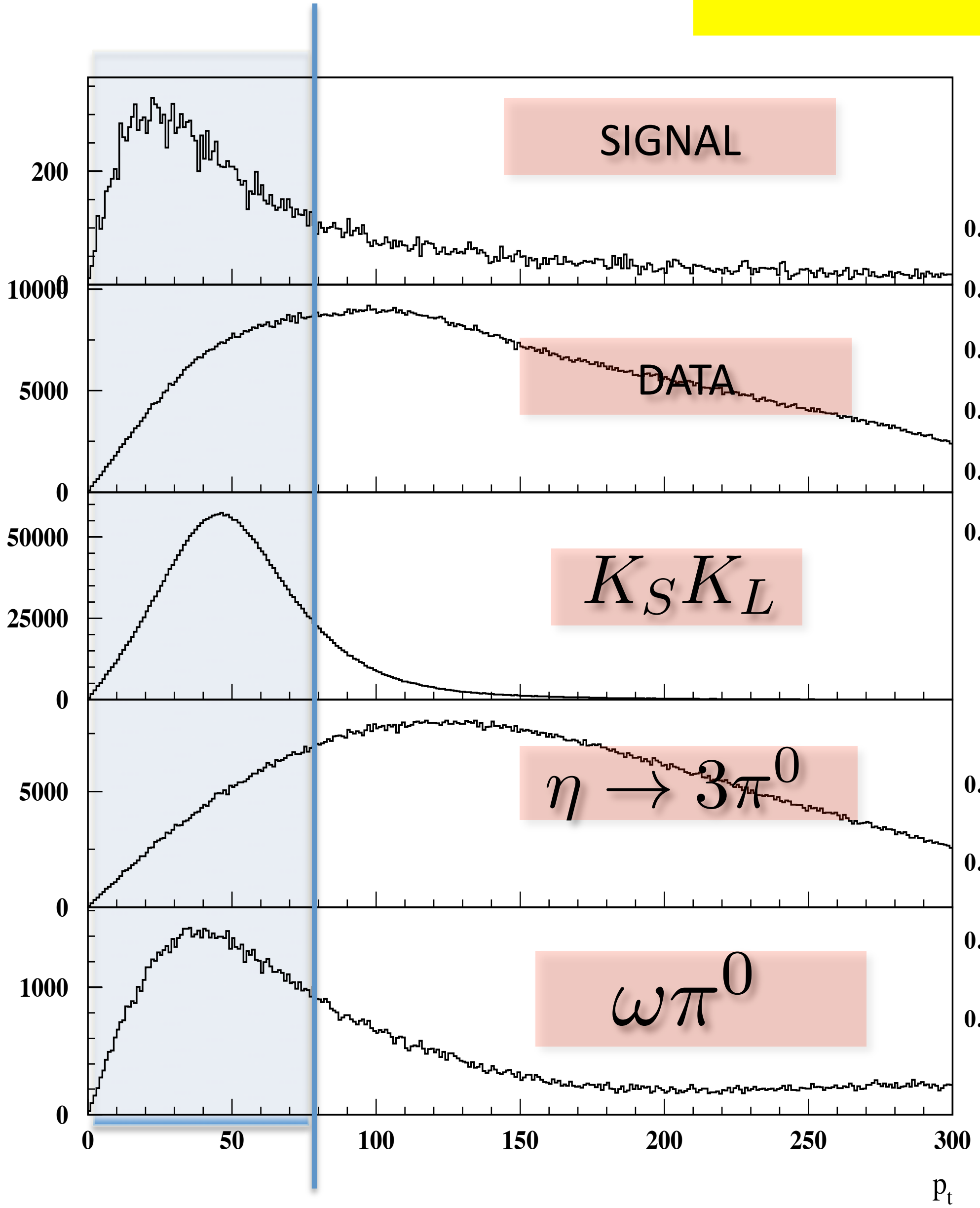
$E_{\gamma 3} + E_{\gamma 4} > 60$ MeV



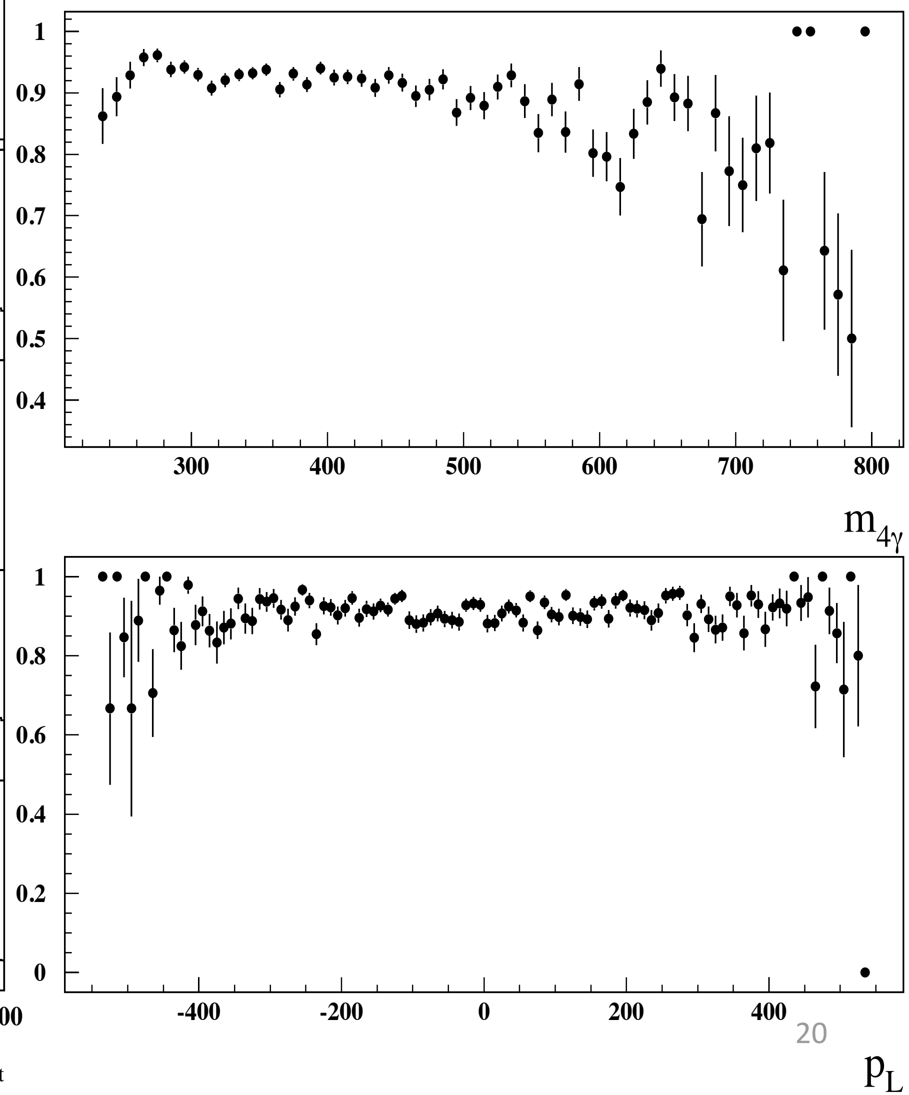


Analysis cuts 6:

$$\sum p_T < 80 \text{ MeV}$$

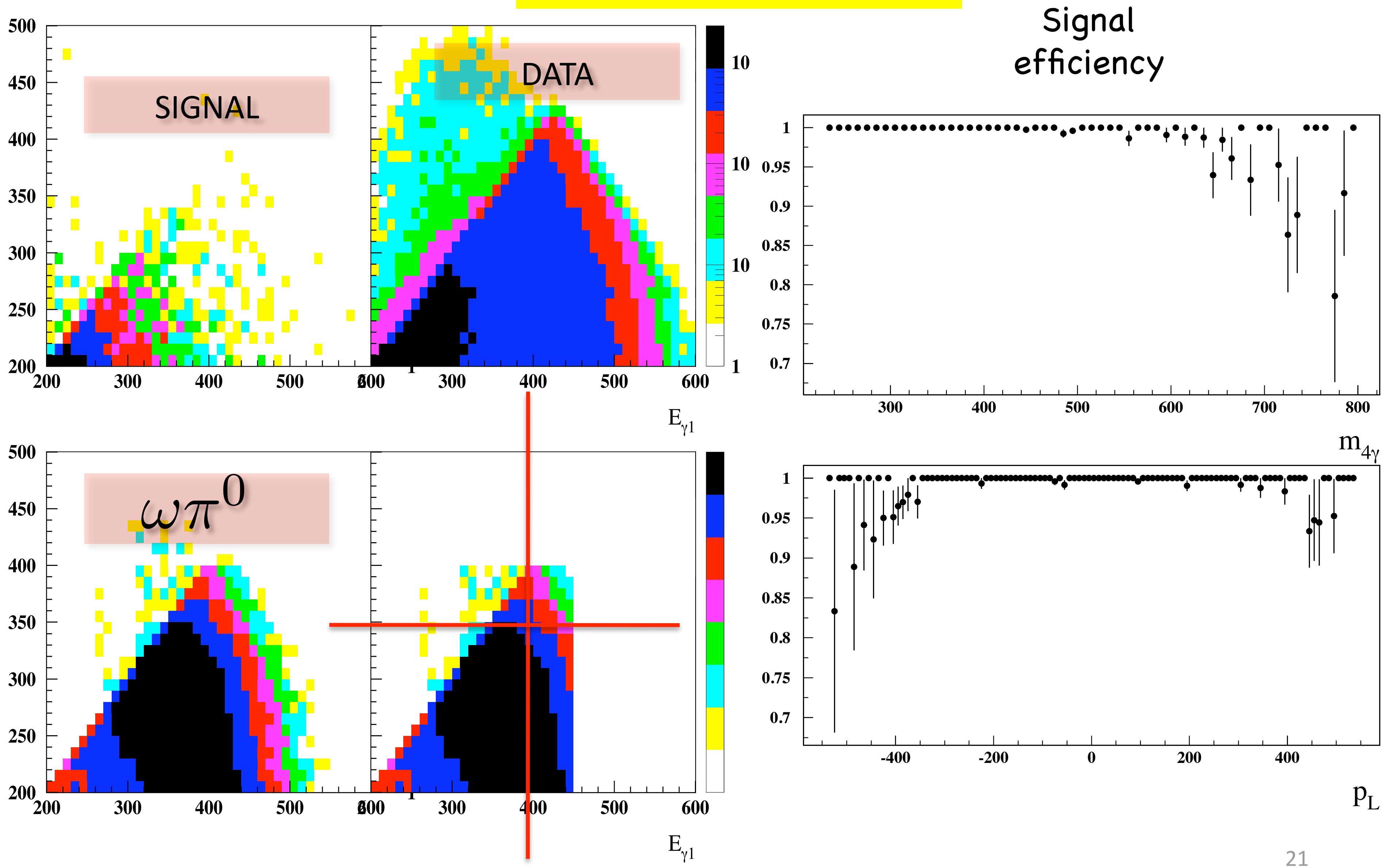


Signal efficiency



Analysis cuts 7:

$E_{\gamma1}$ < 450 MeV &
$E_{\gamma2}$ < 400 MeV

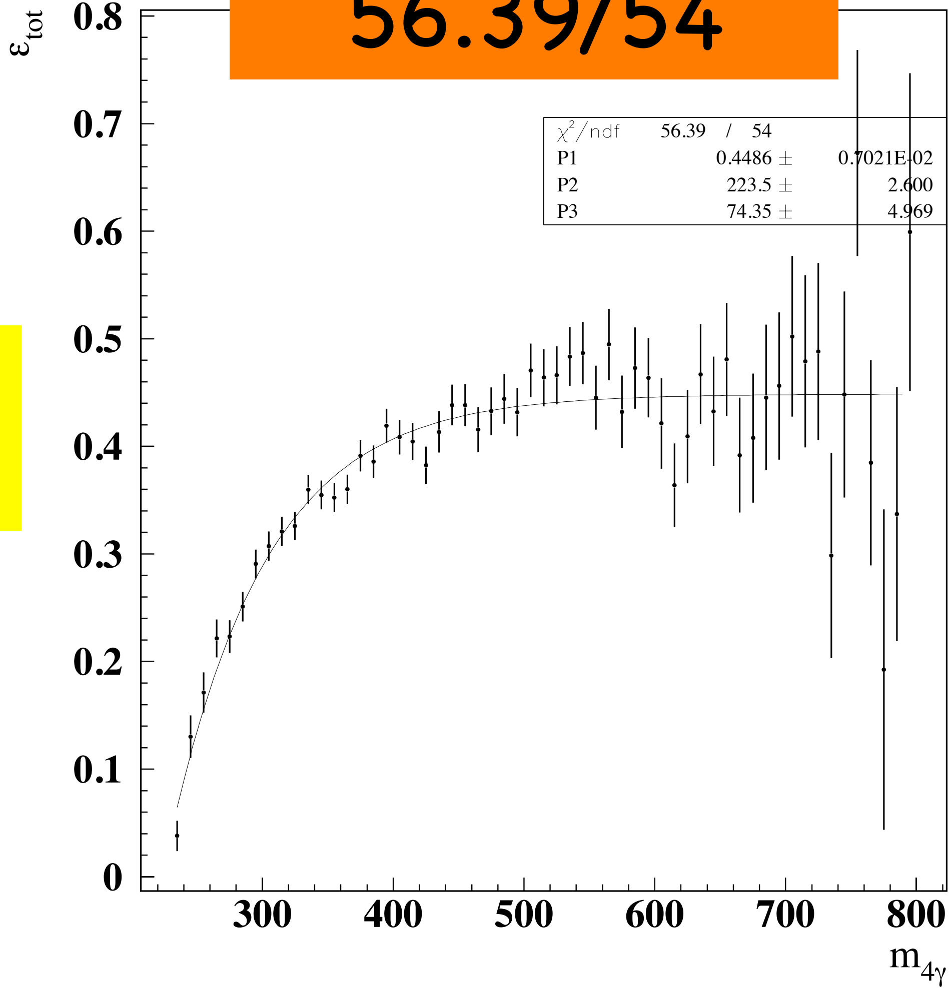


Global efficiency

χ^2/ndf = 56.39/54

Fitted with the function

$$f(x) = A(1 - \exp(-\frac{x - x_0}{C}))$$



MC signal and bkg reduction factors

	$e^+e^-\sigma$	K_SK_L	$\eta \to 3\pi^0$	$f_0\gamma$	$a_0\gamma$	$\omega\pi^0$	$\gamma\gamma$
MC	26844	19887800	6423710	131849	97205	933541	80601500
trigger	0.835						
FILFO	0.870						
filtro $\gamma\gamma$	0.984						
$\geq 4\gamma$	0.688						
preselection	0.491	0.160	0.273	0.160	0.237	0.189	2×10^{-4}
$\chi^2_{pair} < 4$	0.853	0.841	0.875	0.466	0.654	0.432	0.133
only 4γ	0.985	0.951	0.074	0.736	0.340	0.675	0.872
no tracks	0.955	0.280	0.833	0.881	0.843	0.865	0.632
$R > 0.8$	0.940	0.196	0.157	0.805	0.355	0.722	0.737
$E_{\gamma 3 \gamma 4}$	0.979	0.972	0.979	0.962	0.982	0.971	0.329
$\sum p_T < 80$ MeV	0.911	0.843	0.185	0.535	0.344	0.490	0.561
$E_{\gamma 1 \gamma 2}$	0.998	0.999	0.999	0.973	0.988	0.952	0.625
tot cuts	0.698	3.31×10^{-2}	6.57×10^{-3}	0.165	0.019	0.086	0.010
efficiency	0.344	5.6×10^{-3}	1.8×10^{-3}	0.026	4.5×10^{-3}	1.55×10^{-2}	1.9×10^{-6}

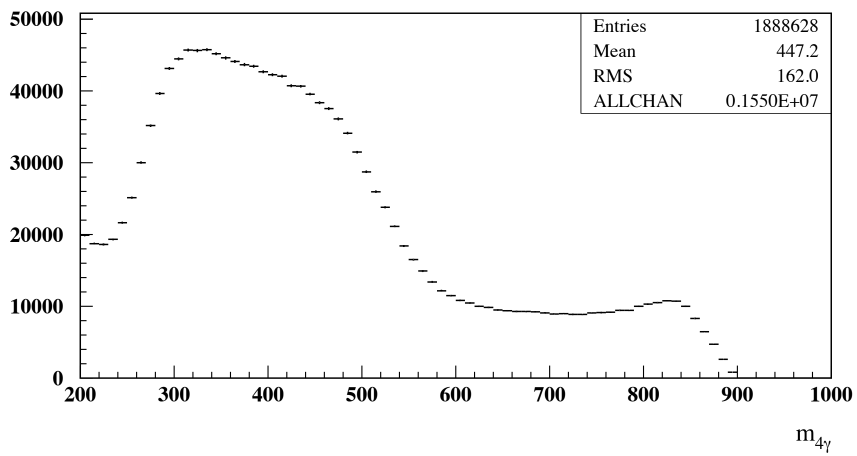
Data reduction factors

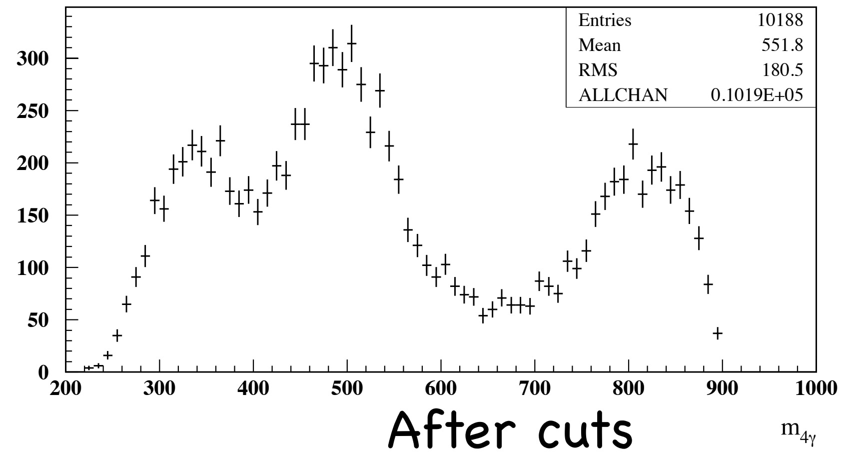
radiative stream	3.767×10^{8}	
$\gamma\gamma$ filter & ≥ 4 prompt	3.257×10^{6}	
recover splitting	1888628	
$\chi^2_{pair} < 4$	898356	0.476
only 4γ	1728217	0.915
no tracks	425079	0.225
$R > 0.8$	643975	0.341
$E_{\gamma 3 \gamma 4}$	1346737	0.713
$E_{\gamma 1 \gamma 2}$	1694786	0.897
$\sum p_T < 80$ MeV	466917	0.247
tot cuts	10188	5.39×10^{-3}

Data collected @ √s=1 GeV
17/12/2005 – 16/3/2006

$$(\mathcal{L} = 239.6 \text{ pb}^{-1})$$

Before cuts

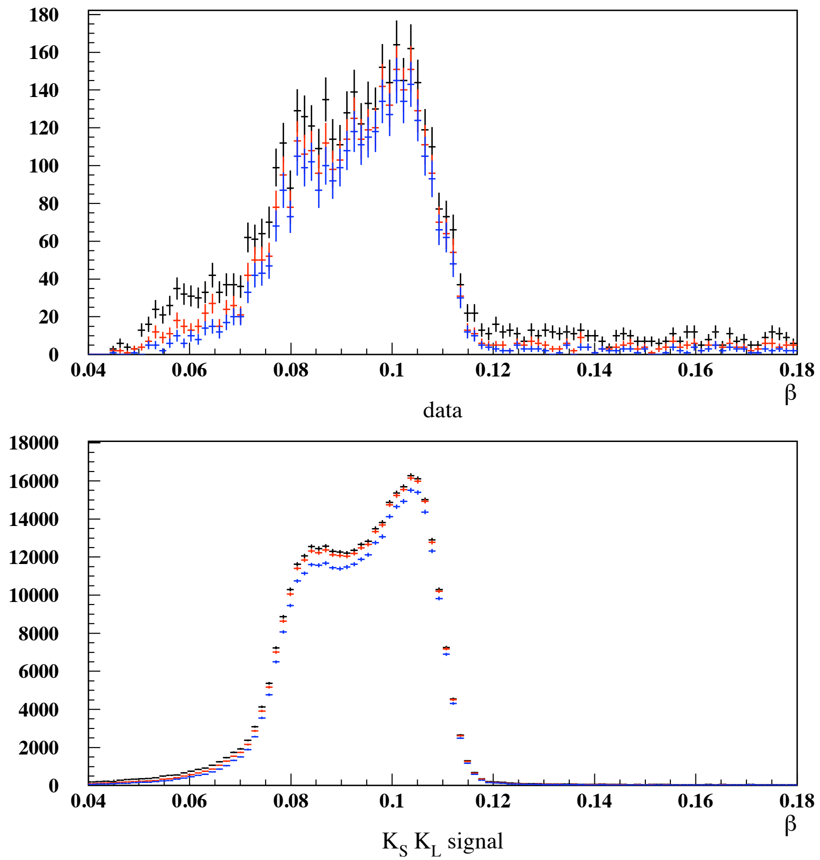




After cuts

Study of the energy scale: K_S mass peak

$\beta_{delayed}$ distribution for data and MC



Analysis cuts:

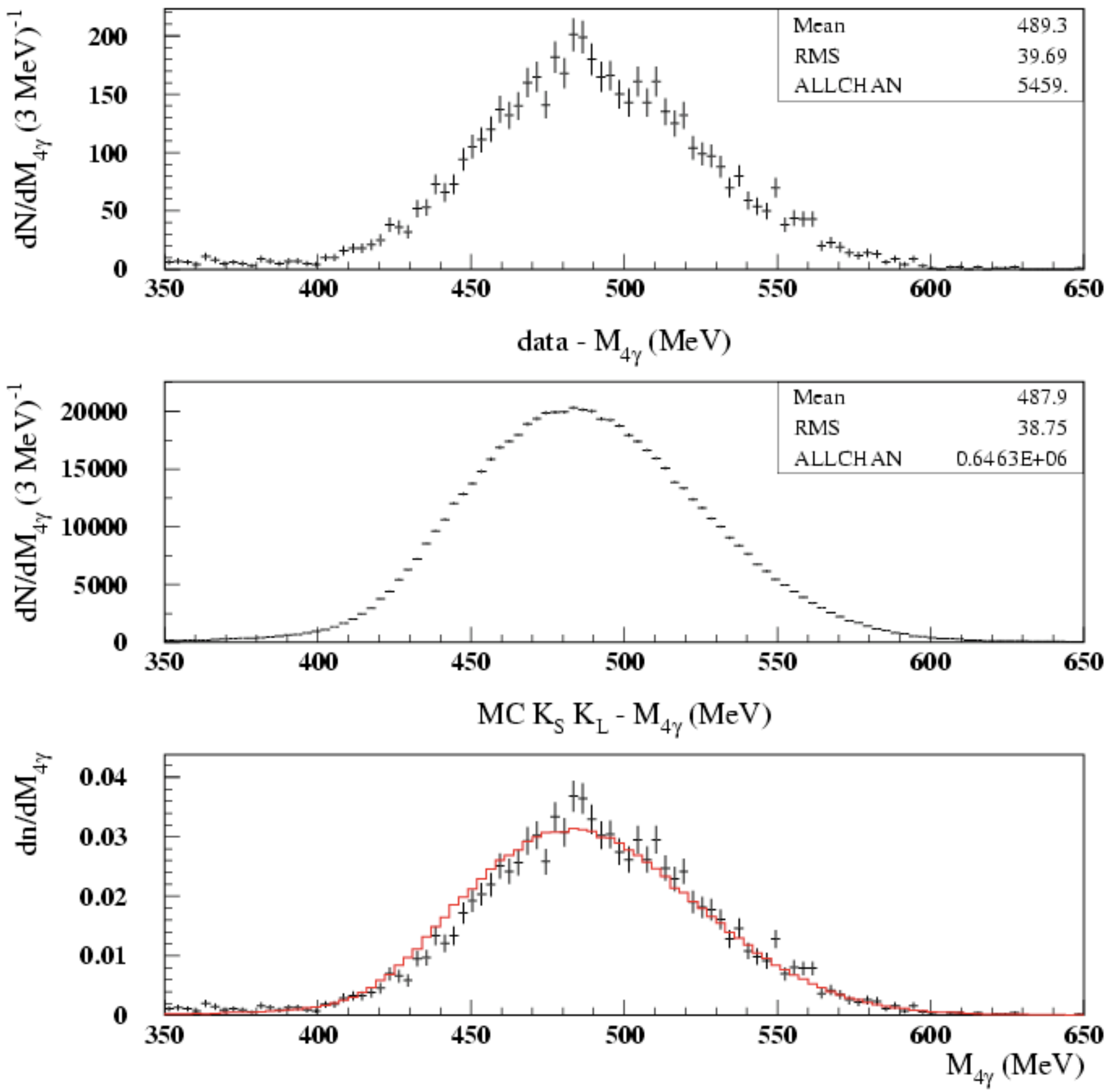
- χ^2 pair < 4
- 350 < $m_{4\gamma}$ < 650 MeV
- # prompt = 4
- no tracks
- 1 & only 1 delayed cluster
- $E_{delayed}$ > 15 (30) (60) MeV
- 0.06 < $\beta_{delayed}$ < 0.13

● $E_{delayed}$ > 15 MeV

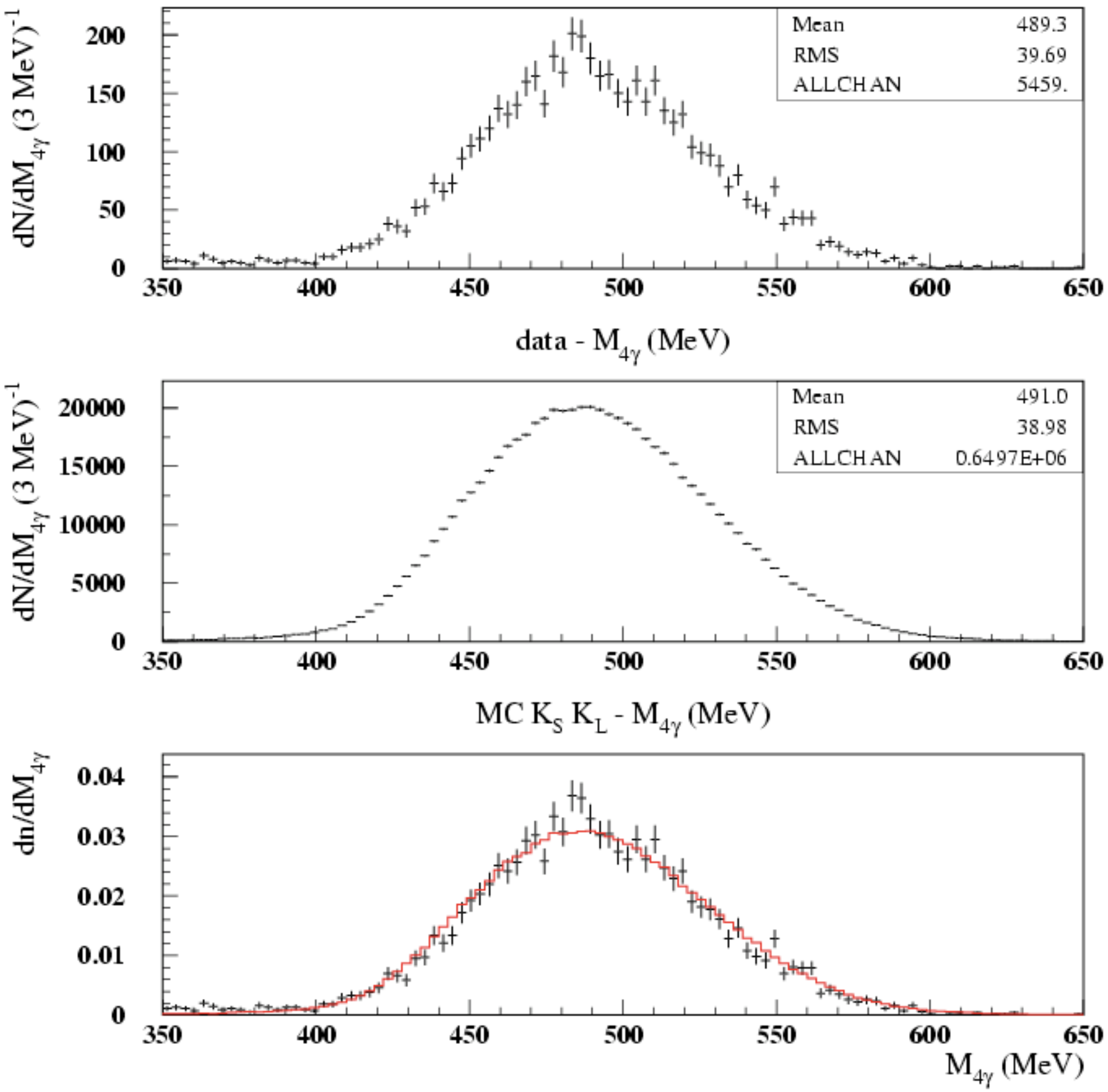
● $E_{delayed}$ > 30 MeV

● $E_{delayed}$ > 60 MeV

K_S mass peak: before the cure



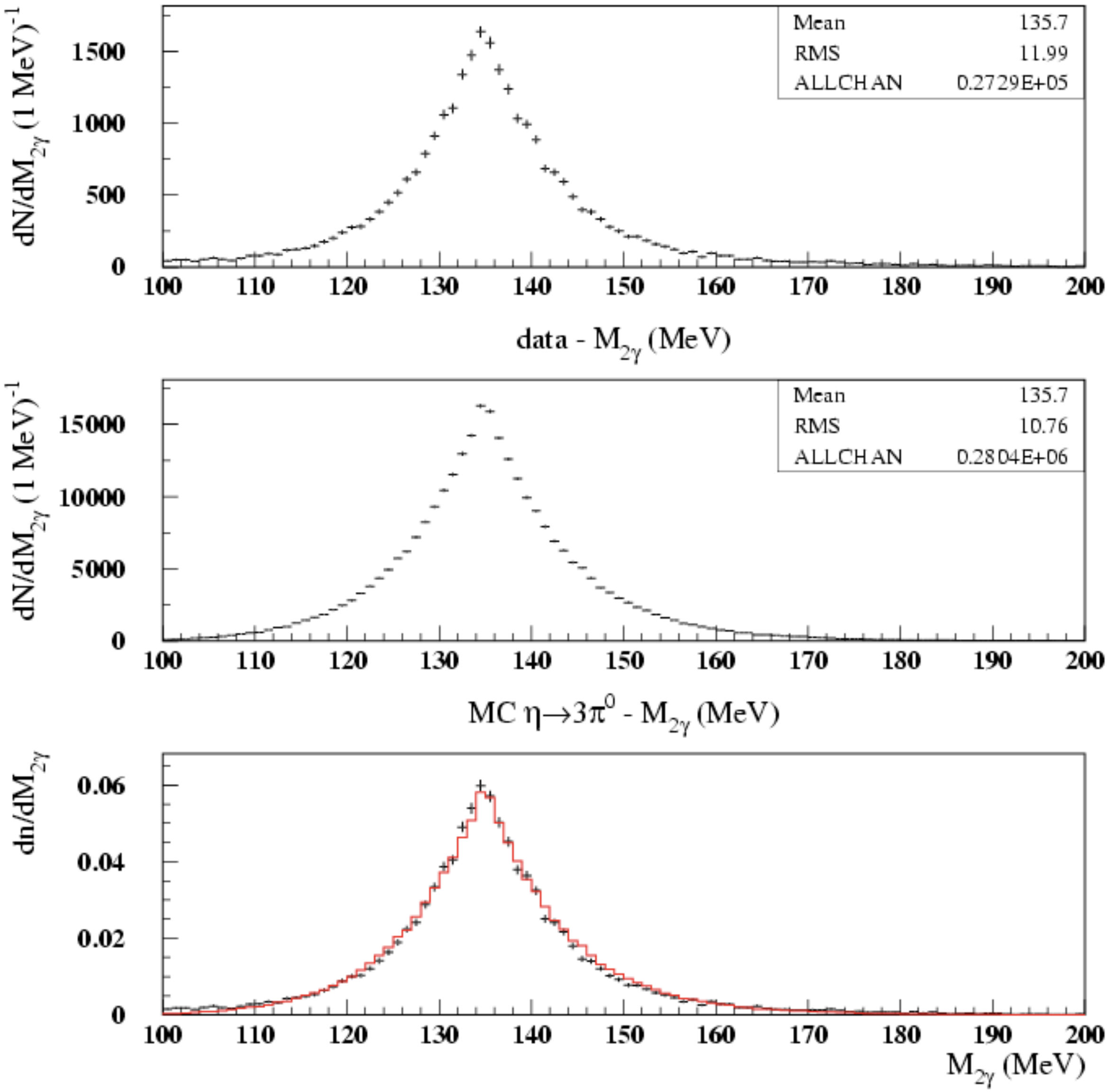
K_S mass peak: after the cure



on MC only:

for all prompt neutral clusters
E = 1.008*Eclu

π^0 mass peak: after the cure

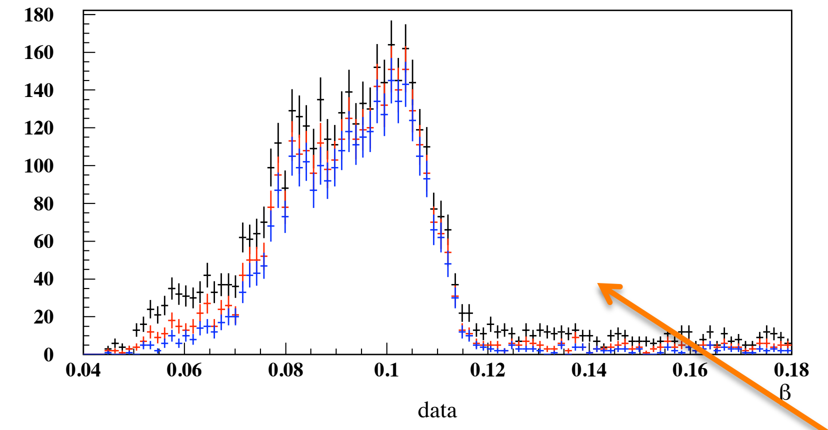


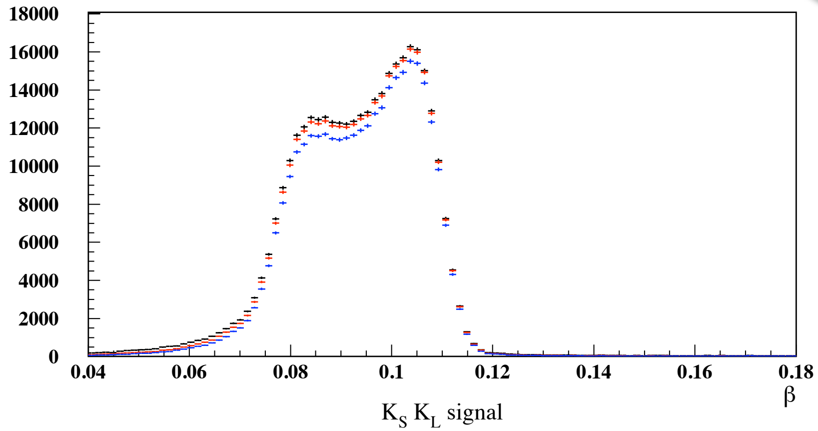
on MC only:

for all prompt neutral clusters
E = 1.008*Eclu

KsKl cross section @ √s=1 GeV

$\beta_{delayed}$ distribution for data and MC





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- no tracks
- 1 & only 1 delayed cluster
- $E_{delayed}$ > 15 (30) (60) MeV
- 0.06 < $\beta_{delayed}$ < 0.13

● $E_{delayed}$ > 15 MeV

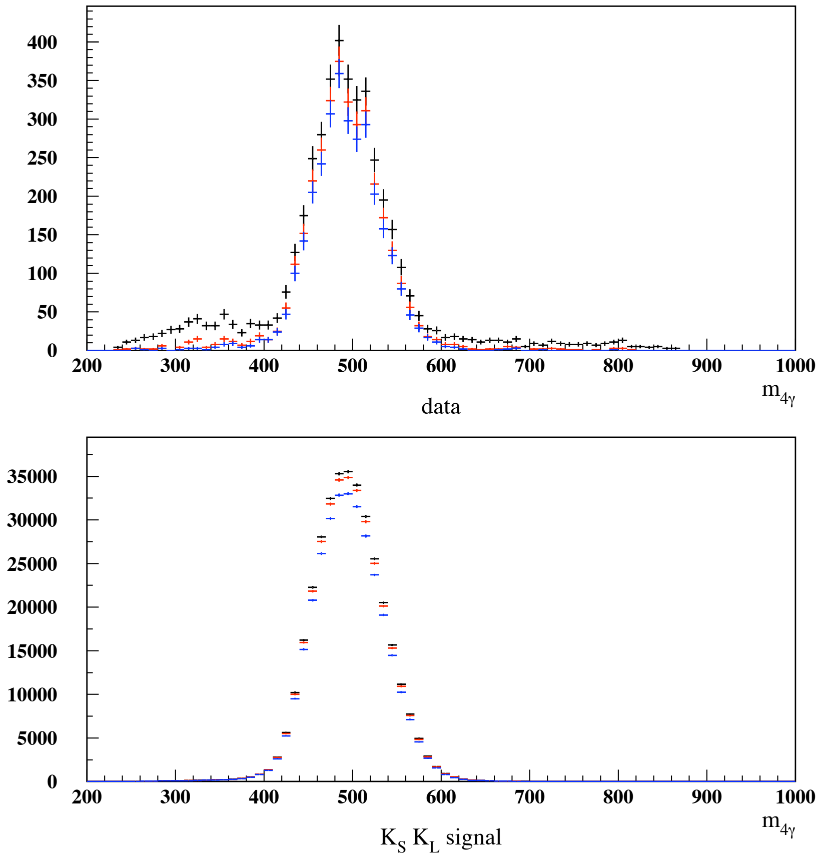
● $E_{delayed}$ > 30 MeV

● $E_{delayed}$ > 60 MeV

The stronger the cut, the narrower the peak

KsKl cross section @ $\sqrt{s}$=1 GeV

$m_{4\gamma}$ distribution for data and MC



Analysis cuts:

- X^2 pair < 4
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- no tracks
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- $E_{delayed}$ > 15 (30) (60) MeV
- 0.06 < $\beta_{delayed}$ < 0.13

● (black) $E_{delayed}$ > 15 MeV

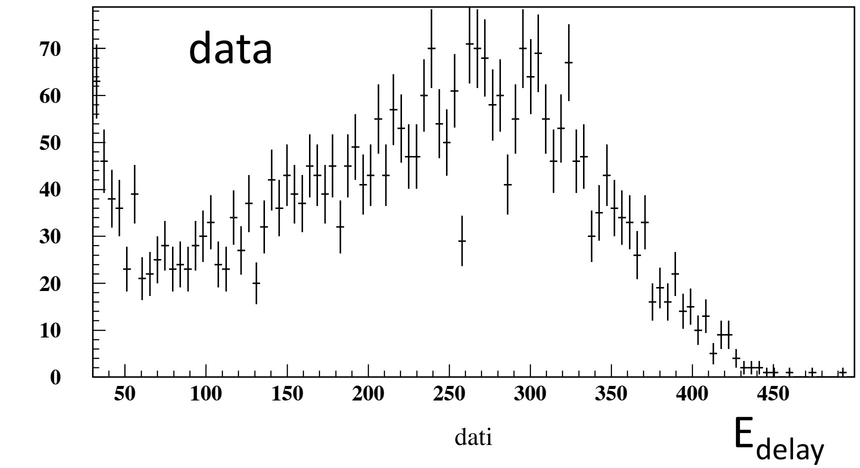
● (red) $E_{delayed}$ > 30 MeV

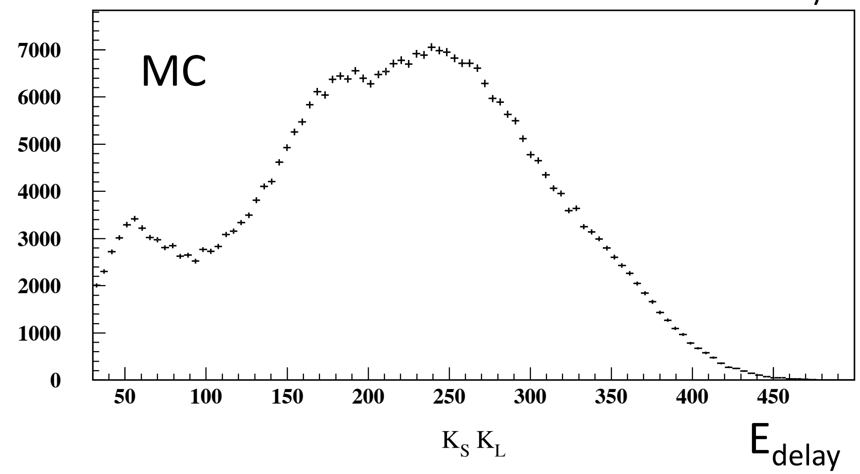
● (blue) $E_{delayed}$ > 60 MeV

Unfortunately the cut $E_{delayed}$ > 15 (30) (60) MeV is not really safe…

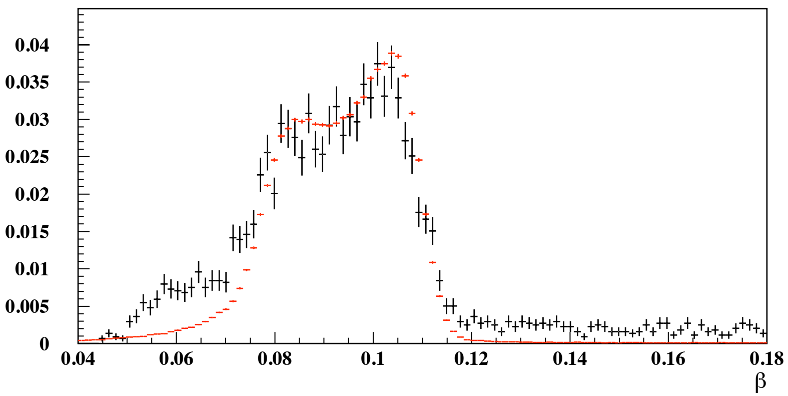
Data and MC are not in so good agreement

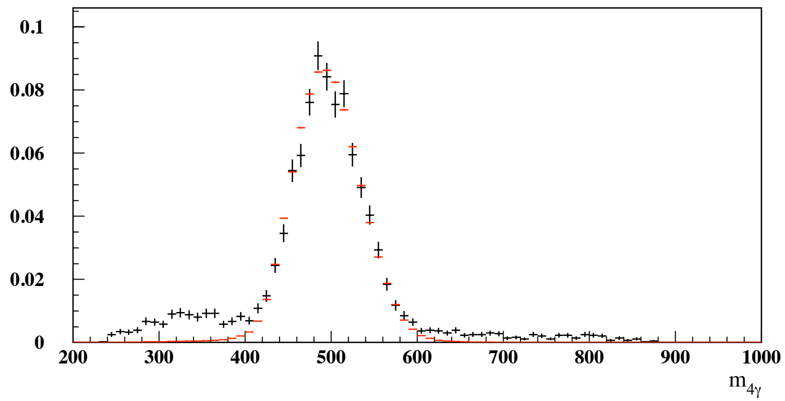
Waiting for better solution we adopt the weaker cut, namely $E_{delayed}$ > 15





KsKl cross section @ √s=1 GeV





Data

MC

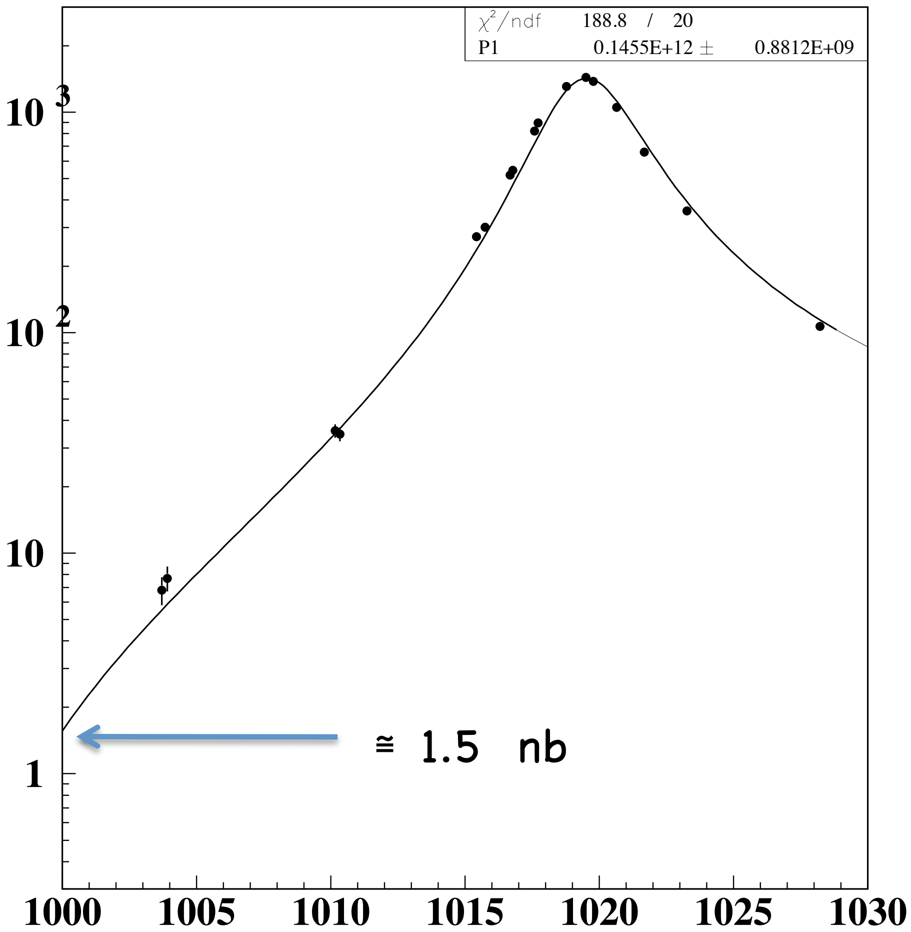
	data	$K_S K_L$
radiative stream	3.767×10^8	
MC		19887800
preselection	1888628	709532
$\chi^2_{pair} < 4$	0.008	1
$350 < m_{4\gamma} < 650$ MeV	6.36×10^{-3}	0.994
only 4γ	0.008	1
no tracks	0.008	1
only 1 delayed	5.50×10^{-3}	0.514
$E_{\text{delayed}} > 15$ MeV	8.08×10^{-3}	1
$0.06 < \beta_{\text{delayed}} < 0.13$	3.73×10^{-3}	0.885
tot cuts	3873	348817
efficiency ϵ		1.75×10^{-2}

$$\sigma = \frac{n}{\mathcal{L}\epsilon}$$

$$(\mathcal{L} = 239.6 \text{ pb}^{-1})$$

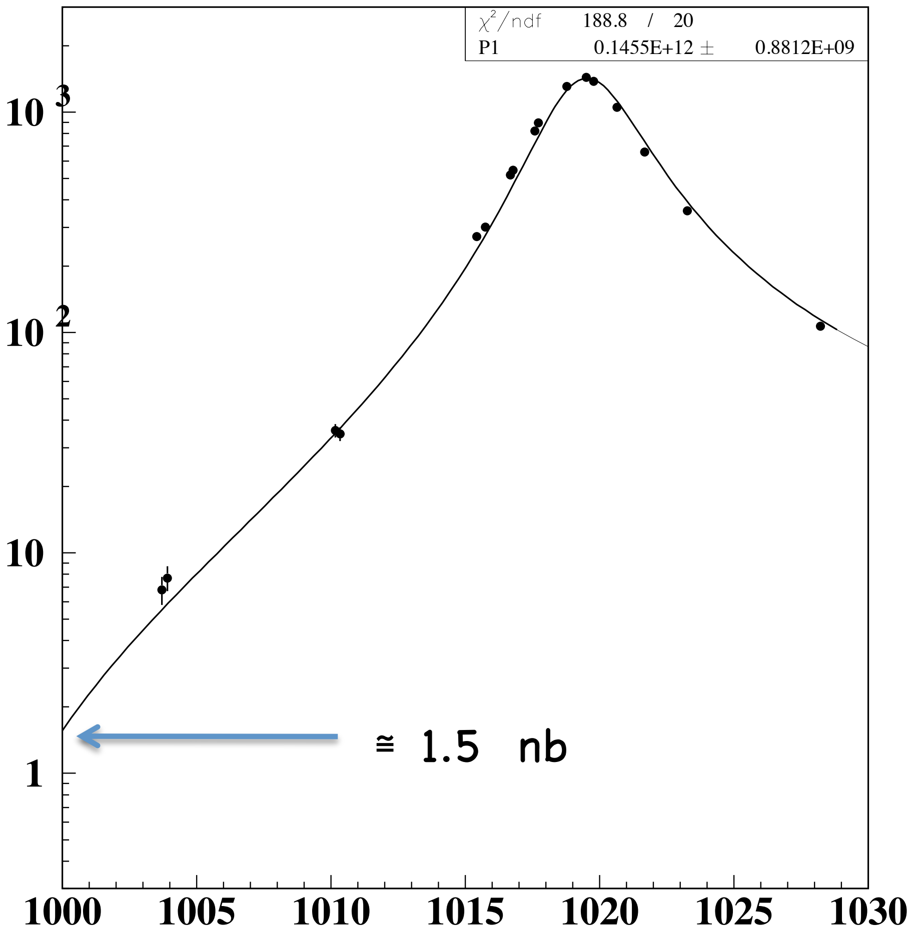
≅ 1 nb

SND data fit



Without radiative correction

SND data fit



In any case, it seems to be lower than 2 nb

Without radiative correction

Ideas about the fit

Fit the data spectrum with:

• normalized background distributions weighted by their efficiencies

• a signal distribution generated according to

$$\frac{d\sigma_{\pi\pi}}{dw} = \left[16\pi\Gamma_{\gamma\gamma}\frac{\Gamma_{\pi\pi}}{\Gamma}\left(\frac{2\alpha}{\pi}\ln\frac{E}{m_e}\right)^2\right] \times$$

$$\frac{1}{w^3}\left[\left(2+\frac{w^2}{4E^2}\right)^2\ln\frac{2E}{w} - \left(1-\frac{w^2}{4E^2}\right)\left(3+\frac{w^2}{4E^2}\right)\right]\frac{M^2\Gamma(w)}{(w^2-M^2)^2+M^2\Gamma^2(w)}$$

wich has to be convoluted with the resolution function end wieghted by the efficiency

A deeper look on the signal function

$$\frac{d\sigma_{\pi\pi}}{dw} = \frac{16\pi}{w^2}\frac{M^2\Gamma_{\gamma\gamma}\Gamma(w)}{(w^2-M^2)^2+M^2\Gamma^2(w)}\times$$

$$\left(\frac{2\alpha}{\pi}\ln\frac{E}{m_e}\right)^2\frac{1}{w}\left[\left(2+\frac{w^2}{4E^2}\right)^2\ln\frac{2E}{w}-\left(1-\frac{w^2}{4E^2}\right)\left(3+\frac{w^2}{4E^2}\right)\right]$$

A deeper look on the signal function

$$\frac{d\sigma_{\pi\pi}}{dw} = \frac{16\pi}{w^2}\frac{M^2\Gamma_{\gamma\gamma}\Gamma(w)}{(w^2-M^2)^2+M^2\Gamma^2(w)} \times$$

Relativistic BW

$$\left(\frac{2\alpha}{\pi}\ln\frac{E}{m_e}\right)^2 \frac{1}{w}\left[\left(2+\frac{w^2}{4E^2}\right)^2 \ln\frac{2E}{w} - \left(1-\frac{w^2}{4E^2}\right)\left(3+\frac{w^2}{4E^2}\right)\right]$$

A deeper look on the signal function

Relativistic BW

$$\frac{d\sigma_{\pi\pi}}{dw} = \frac{16\pi}{w^2} \frac{M^2 \Gamma_{\gamma\gamma} \Gamma(w)}{(w^2 - M^2)^2 + M^2 \Gamma^2(w)} \times$$

$$\left(\frac{2\alpha}{\pi} \ln \frac{E}{m_e} \right)^2 \frac{1}{w} \left[\left(2 + \frac{w^2}{4E^2} \right)^2 \ln \frac{2E}{w} - \left(1 - \frac{w^2}{4E^2} \right) \left(3 + \frac{w^2}{4E^2} \right) \right]$$

Low function

A deeper look on the signal function

Relativistic BW

$$\frac{d\sigma_{\pi\pi}}{dw} = \frac{16\pi}{w^2} \frac{M^2 \Gamma_{\gamma\gamma} \Gamma(w)}{(w^2 - M^2)^2 + M^2 \Gamma^2(w)} \times$$

$$\left(\frac{2\alpha}{\pi} \ln \frac{E}{m_e}\right)^2 \frac{1}{w} \left[\left(2 + \frac{w^2}{4E^2}\right)^2 \ln \frac{2E}{w} - \left(1 - \frac{w^2}{4E^2}\right)\left(3 + \frac{w^2}{4E^2}\right)\right]$$

Low function

and, for a broad resonance,

$$\Gamma(w) = \Gamma \frac{M}{w} \frac{p*}{p*_0} = \Gamma_0 \sqrt{\frac{1 - 4m_\pi^2/w^2}{1 - 4m_\pi^2/M^2}}$$

Conclusions

- Efficiency from MC signal has been studied: it is almost flat in $m_{4\gamma}$ and it results

$$\int \varepsilon(m_{4\gamma})dm_{4\gamma} \cong 0.344$$

- Cuts have been varied in order to optimize $\varepsilon_{signal}/\varepsilon_{bkg}$
- MC energy scale has been adjusted @ Ks peak

Conclusions and what we have to do

- adjust energy scale @ ω
- verify that cuts efficiencies are generator-indipendent
- determine KsKl cross section (taking in acconunt radiative correction in the SND data fit?)
- PERFORM FIT TO DATA!

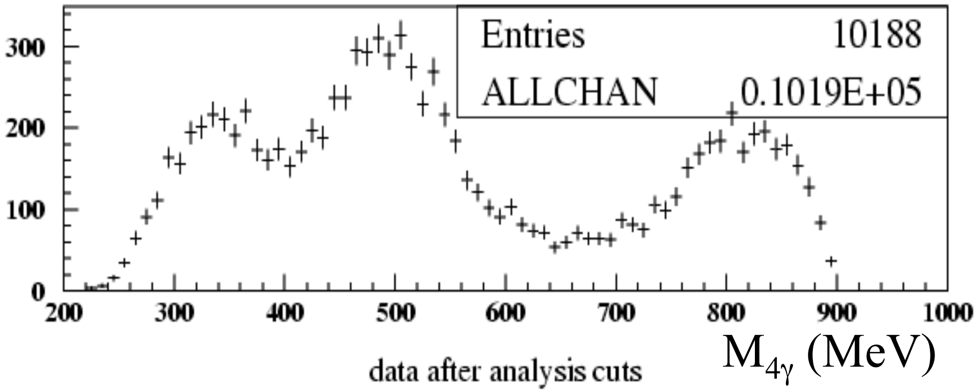
Checks on accidental clusters, fake triggers…

there is the concern to look at low mass values, without closing the kinematics → dedicated care of background clusters? Done!

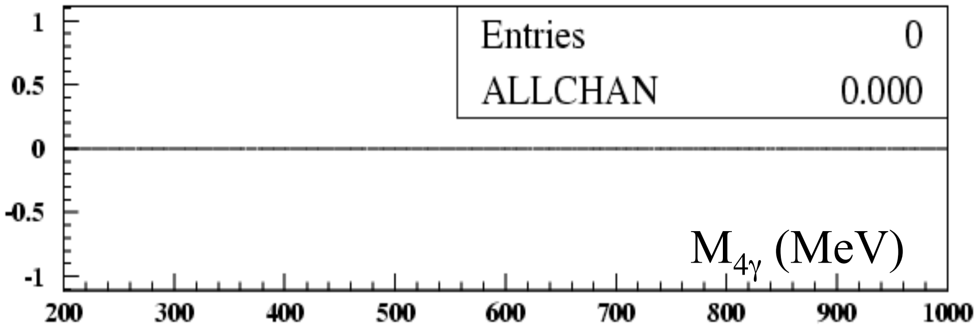
thanks to discussions with M. Moulson and S. Giovannella, we selected a "clean sample of garbage" → events with LSB clusters able to provide the trigger, and applied the selection on these accidental clusters

from 8.1×10^7 events, only 1.9×10^5 (~ 0.23%) are triggered by accidental clusters, how many survive analysis cuts?

Checks on accidental clusters, fake triggers…



data after analysis cuts

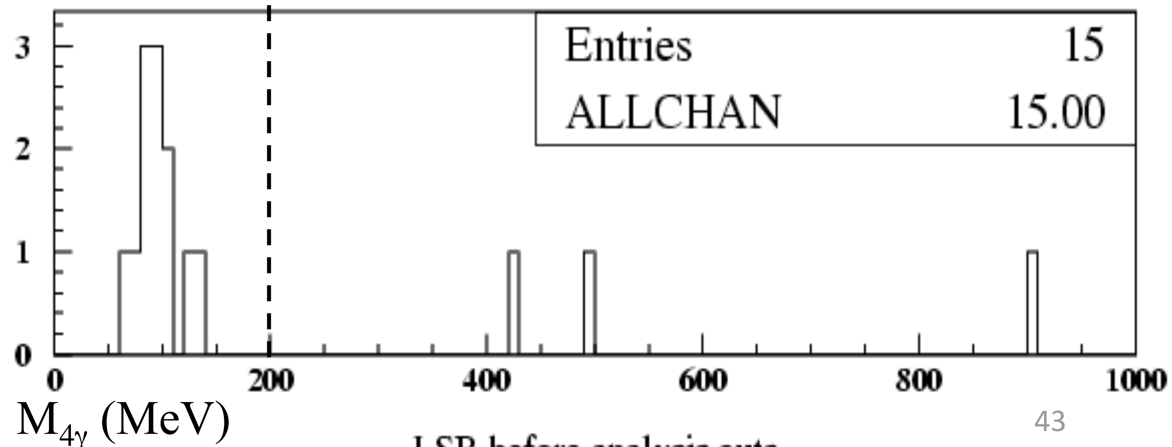


LSB after analysis cuts

1) no LSB event survives analysis cuts

2) before analysis cuts, but requiring at least 4 prompt and neutral clusters, there are 15 events, most at low M values, as expected

3) but only 3 of these may enter the mass spectrum of interest



LSB before analysis cuts

Federico N., General Meeting November 9, 2009