Sapienza Università di Roma

Dipartimento di Fisica

Scuola di dottorato "Vito Volterra"

XXI ciclo

Studio del processo $e^+e^-\rightarrow\omega\pi^0$ intorno alla risonanza ϕ con il rivelatore KLOE

Dottorando:
Antonio De Santis

Tutor:
Antonio Di Domenico

Coordinatore:
Enzo Marinari

Analysis outlook

We have measured the cross section $e^+e^- \to \omega\pi^0$ in two different final states:

- $\pi^+\pi^-\pi^0\pi^0$
- $\pi^0\pi^0\gamma$

Using the ratio of the cross section for the non resonant process at ϕ mass we measure the dominant BR's for ω meson

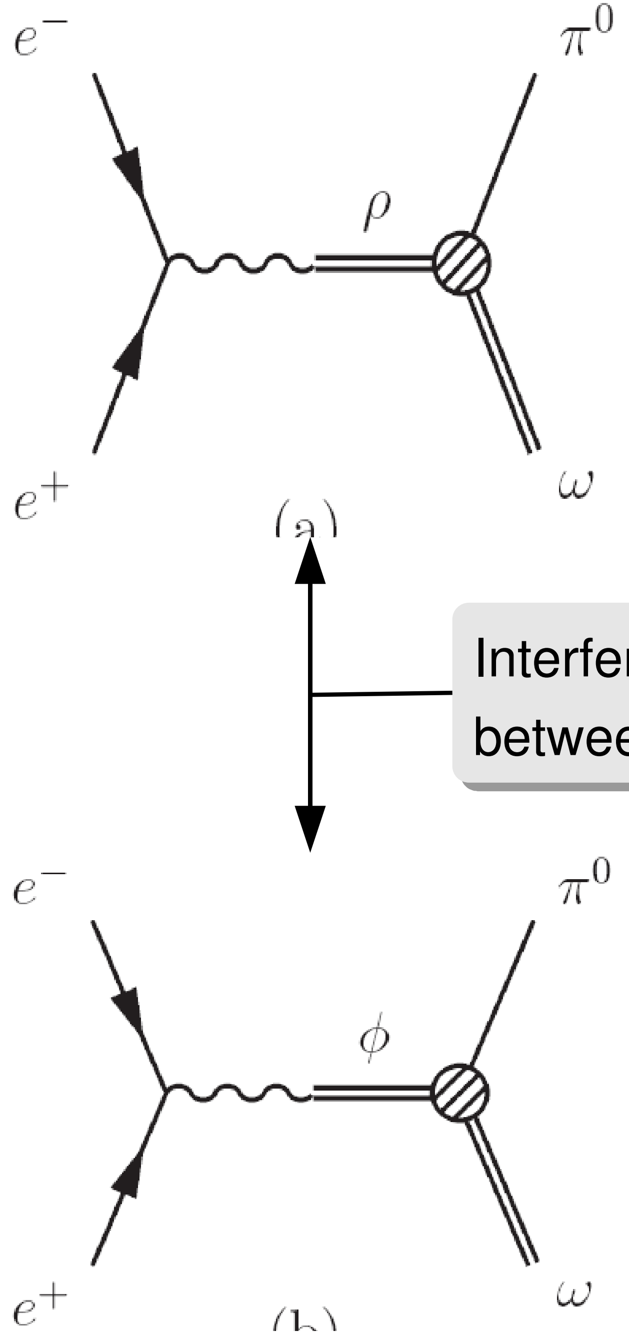
Using the results on cross section parameters for the $\pi^+\pi^-\pi^0\pi^0$ final state we measure the $BR(\phi\to\omega\pi^0)$

$$\frac{\sigma(ee\to\omega\pi^0\to\pi^0\pi^0\gamma)}{\sigma(ee\to\omega\pi^0\to\pi^+\pi^-\pi^0\pi^0)}$$

$$\frac{BR(\omega\to\pi^0\gamma)}{BR(\omega\to\pi^+\pi^-\pi^0)}$$

$$BR(\phi\to\omega\pi^0)=\frac{\sigma_0(m_\phi)|Z|^2}{\sigma_\phi}$$

General consideration on $e^+e^- \to \omega\pi^0$



ρ^0 775 MeV
$I^G(J^{PC}) = 1^+(1^{--})$

G-Parity conserving

π^0 135 MeV
$I^G(J^{PC}) = 1^-(0^{-+})$

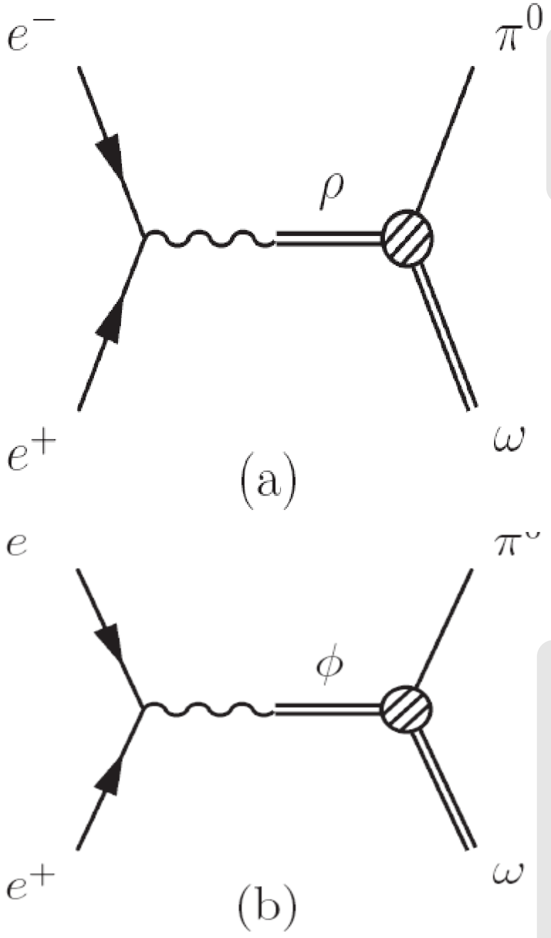
ω 782 MeV
$I^G(J^{PC}) = 0^-(1^{--})$

Interference due to flavor mixing between ϕ and ρ meson

ϕ 1020 MeV
$I^G(J^{PC}) = 0^-(1^{--})$

G-Parity violating
OZI suppressed

Cross section for $e^+e^-\rightarrow\omega\pi^0$



Cross section assuming only ρ / ρ' contribution(a)

Interference weighted by the ϕ meson propagator(b)

$$\sigma(E) = \boxed{\sigma_0(E)}\left|1 - \boxed{Z\frac{m_\phi \Gamma_\phi}{D_\phi}}\right|^2$$

The interference parameter is linked to the "coupling constant" $g_{\phi\omega\pi}$ and $g_{\rho\omega\pi}$

Those quantity can be calculated in VMD approximation or using more complex model (χ^{PT} or effective lagrangian method). Precise measurement allows for constraint in parameter space and testing of different models.

PRD 77(2008)014010

BR(w->p0g)

The value reported by PDG (8.91±0.24)% has been criticized for many reason:

• SU(3) consideration → $g_{\omega\pi\gamma}$ / $g_{\phi\pi\gamma}$ = 18±1 [exp] vs 12 [the] while in other V→Pγ processes the agreement is at level of 1σ

• Global fit of e^+e^- vs tau data in a_μ determination: significant deviation from PDG value found

EPJC 55(2008)199

This quantity is used in the analysis of η' wave function as normalization amplitude. The gluonium content is found at 3s level.

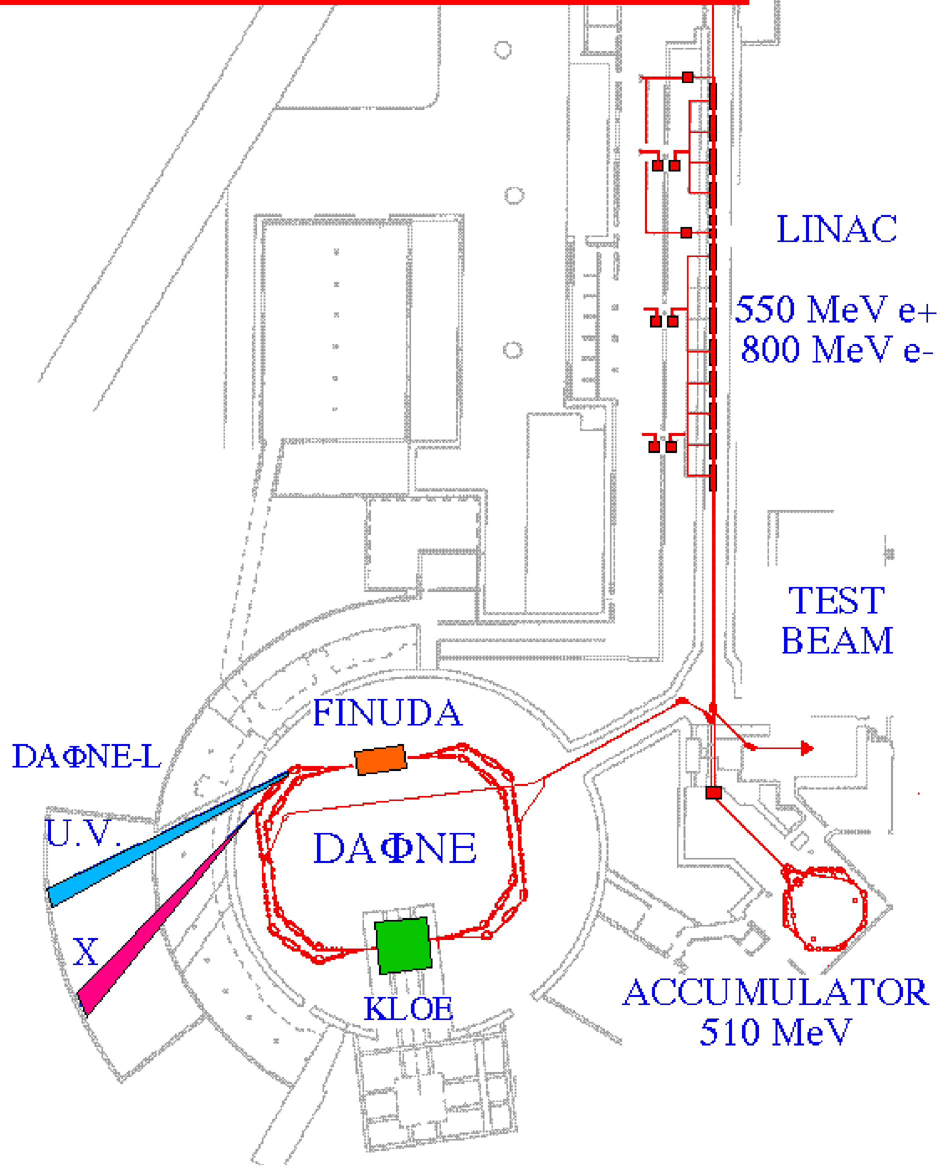
PLB 648(2007)267

Precise measurement of this BR is crucial to answer to this question

The KLOE experiment

DAΦNE: the Frascati ϕ-factory

$L_{design} = 5\times10^{32}$ cm^{-2} s^{-1}



e^+e^- collider @ $\sqrt{s}$ = 1019.4MeV

double rings: e^+, e^-

crossing angle: 12.5 mrad

bunch crossing Δt = 2.7 ns

Continuous injection

<u>2004/05 performances:</u>

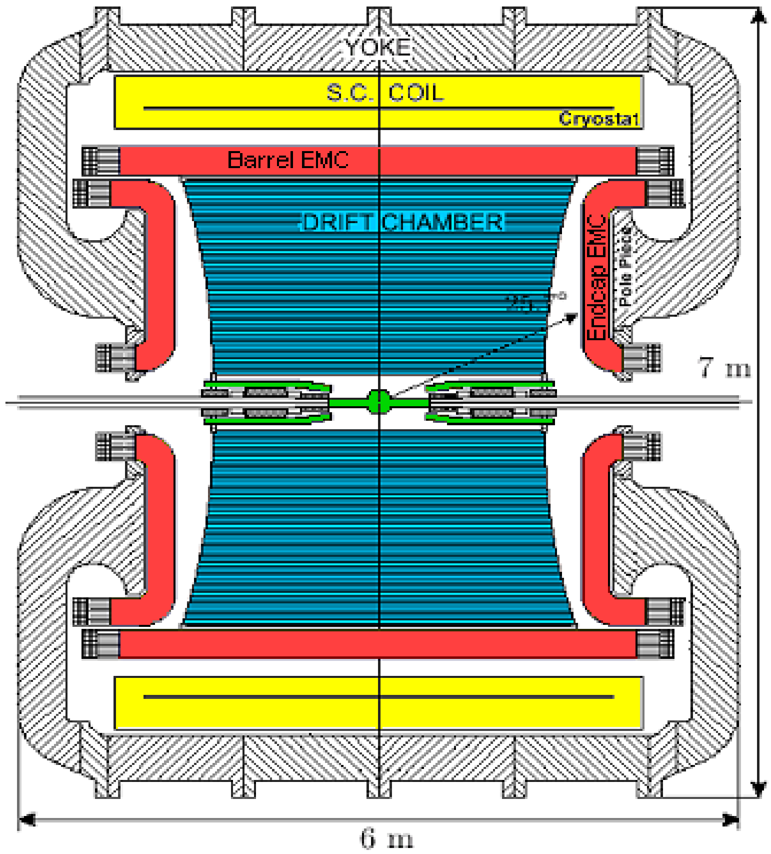
110 $e^+ + e^-$ bunches

$I^-_{peak} = 1.92$ A, $I^+_{peak} = 1.39$ A

$L_{peak} = 1.26 \times 10^{32}$ cm^{-2} s^{-1}

L_{avg} (month) $\cong$ 80 pb^{-1}

The KLOE experiment



Be beam pipe (0.5 mm), r =10 cm

QCAL (32 PMT's)

Drift chamber (4 m Ø × 3.3m) 90% He + 10% IsoB, carbon fiber walls;

12582 sense wires

Sampling electomagnetic calorimeter;

Lead – Sci-fiber 4880 PMT's, 98% of solid angle coverage

Superconducting coil B = 0.52 T

DCH

$\sigma_p/p \cong 0.4\ \%$ (tracks $\theta>45°$)

$\sigma_x^{hit} \cong 150\ \mu m$ (xy), 2 mm (z)

$\sigma_x^{vertex} \sim 1$ mm

EMC

$\sigma_E/E \cong 5.7\% / \sqrt{E(GeV)}$

$\sigma_{\Delta\tau} \cong 54\ ps / \sqrt{E(GeV)} \oplus 50\ ps$

Dataset used

Int luminosity *on-peak* 450 pb^{-1}

Int luminosity *off-peak* 150 pb^{-1}

Luminosity measured with

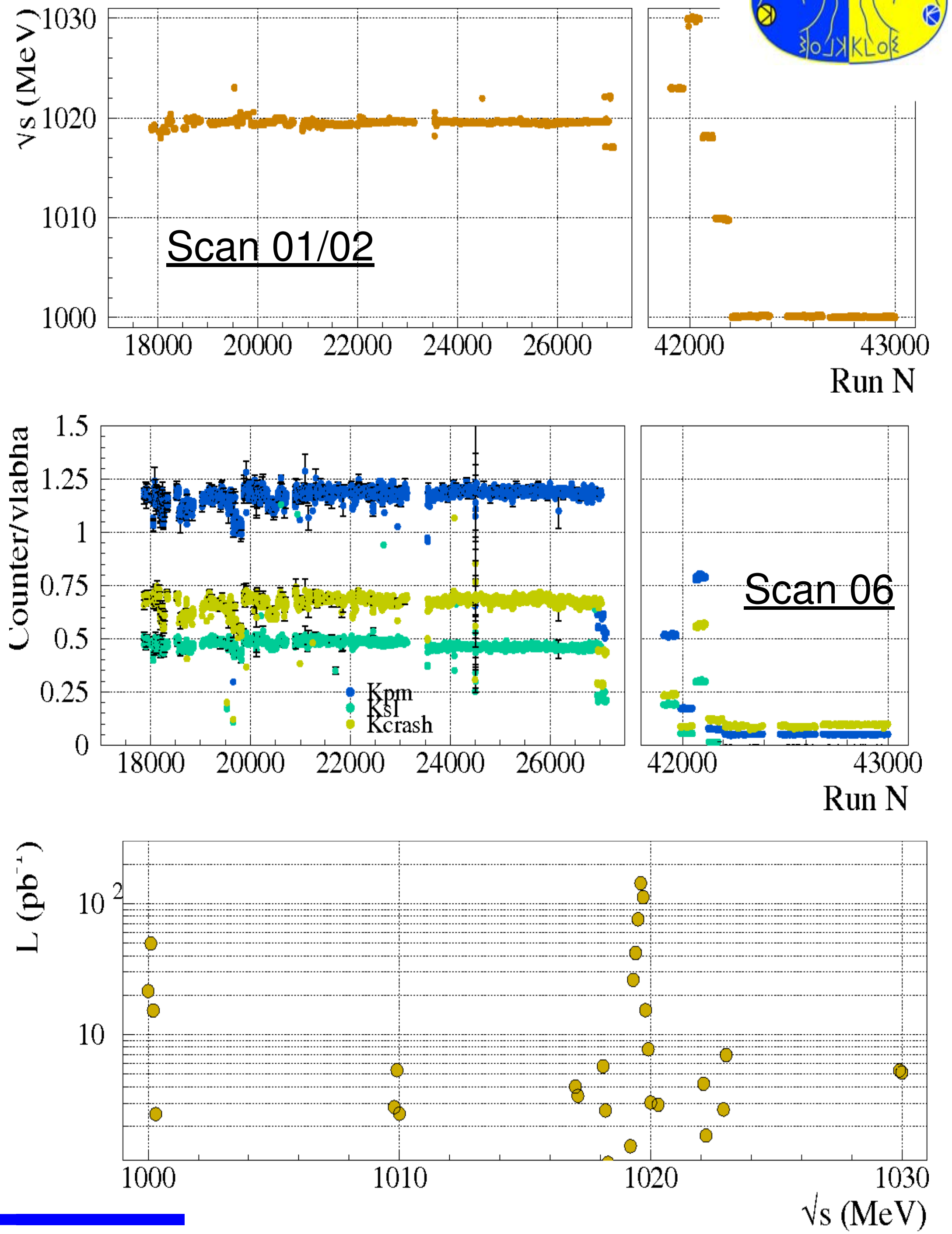
Very Large angle Bhabha events

MC sample luminosity:

- Signal 3000: pb^{-1}
- ϕ-backgrounds (1): 600 pb^{-1}
- ϕ-backgrounds (2): 3000 pb^{-1}
- Other continuum backgrounds: 3000 pb^{-1}

(1) Dominant ϕ decays (KK,rp)

(2) Radiative ϕ decays ($\eta\gamma$,$\pi\gamma$,etc)



Luminosity

In order to use the correct luminosity for the energy outside the ϕ resonance peak we have used directly “very large angle Bhabha” events.

Energy (MeV)	$\sigma(e^+e^- \rightarrow e^+e^-)_{(vla)}$ (nb)
1000	448.40
1010	439.95
1020	431.51
1030	423.06

Dataset has been sliced in bins of 100 keV width.

In the region around the ϕ *peak* we have used these bins.

For the *off-peak* data we have packed them using the luminosity weighted energy:

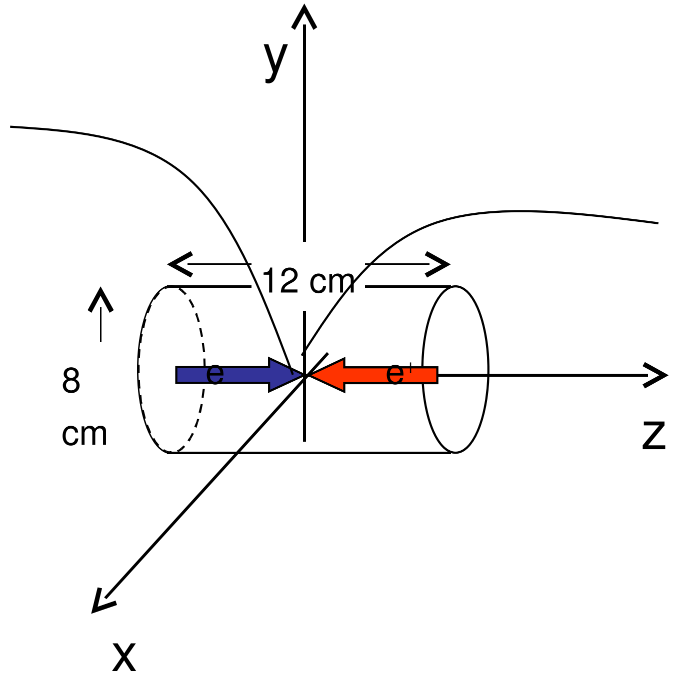
$$E_k = \frac{\sum_j E_{jk} L_{jk}}{\sum_j L_{jk}}$$

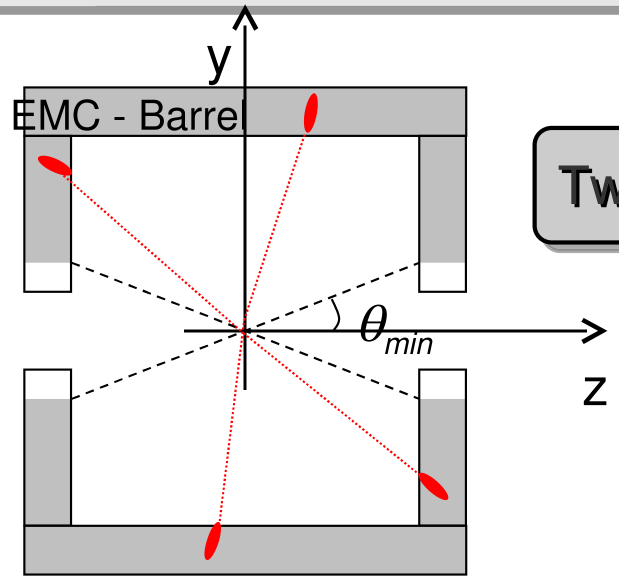
~6% variation along the scale

$$\omega\pi^{0} \rightarrow \pi^{+}\pi^{-}\pi^{0}\pi^{0}$$

$\omega\pi^0 \rightarrow \pi^+\pi^-\pi^0\pi^0$: Sample selection

- Only one vertex at Interaction Point
- Only two tracks connected at vertex
- Four neutral cluster with:
  - E_{clu} greater than 10 *MeV*
  - *ToF* compatible with prompt γ (Tw $=4\sigma_t$)
  - $22° < \theta < 158°$





Tw: $|T_{clu} - R_{clu}/c| < 4\sigma_t$

Global kinematic fit

Inputs:

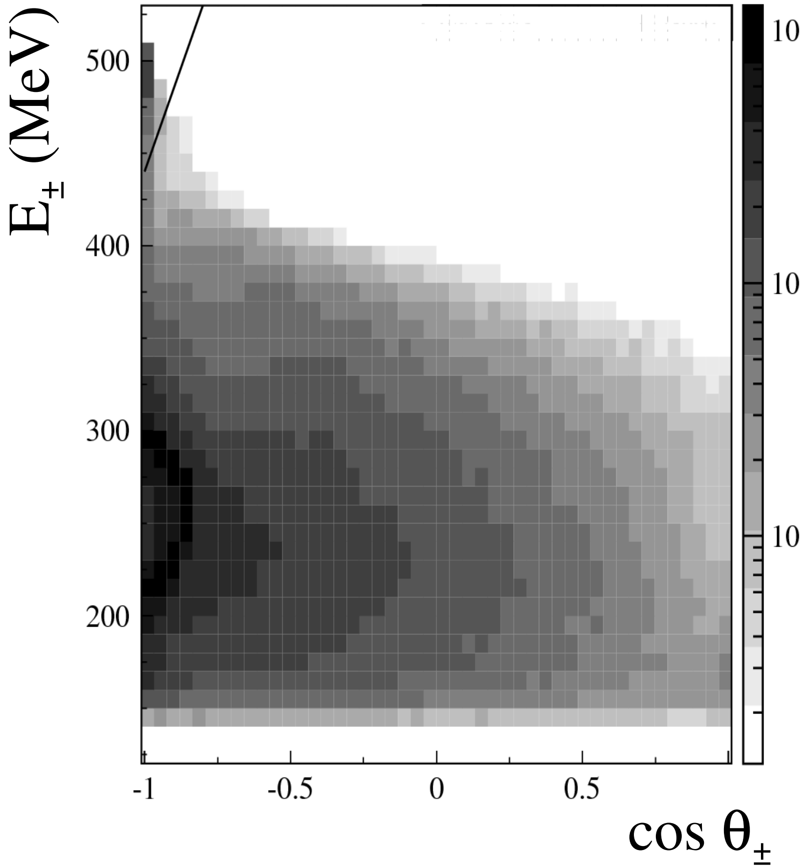
Cluster energy (E_{clu})	$\Delta E_{clu} = \frac{0.06}{\sqrt{E_{clu}(\mathrm{GeV})}}$ MeV
Cluster position ($\vec{R}_{clu}$)	$\Delta \vec{R}_{clu} = 1.2$ cm
Cluster time (T_{clu})	$\Delta T_{clu}(\frac{0.057}{\sqrt{E_{clu}(GeV)}} \oplus (0.140))$ ns
Track curvature ($\mathcal{C}_{trk}$)	$\Delta \mathcal{C}_{trk} \sigma_{trkfit}(\mathcal{C}_{trk}))$
Polar angle of the track ($\cot(\vartheta_{trk})$)	$\Delta \cot(\vartheta_{trk}) \sigma_{trkfit}(\cot(\vartheta_{trk}))$
Azimuthal angle of the track (φ_{trk})	$\Delta \varphi_{trk} \sigma_{trkfit}(\varphi_{trk})$
Vertex position ($\vec{R}_{vtx}$)	$\Delta \vec{R}_{vtx} \sigma_{vtxfit}(\vec{R}_{vtx})$
Four-momentum of the ϕ (P_ϕ)	$\Delta E_\phi = 0.3$ MeV; $\Delta P_x(\phi) = 0.005$ MeV

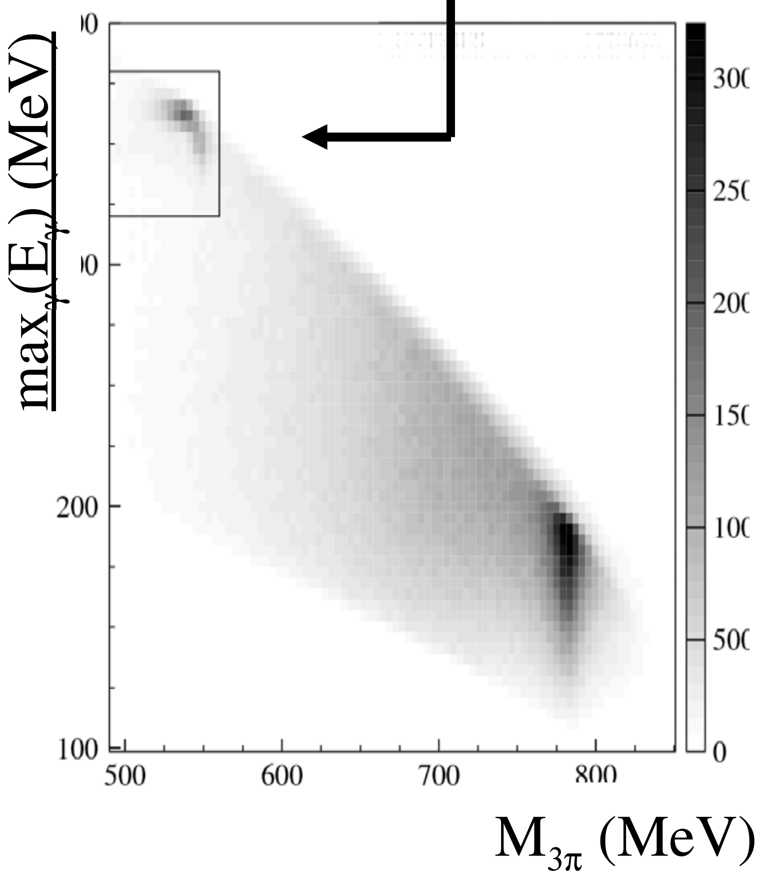
Constraints:

$$T_\gamma - R_\gamma / c = 0 \qquad P_\varphi - p_{\pi^+} - p_{\pi^+} - \sum_\gamma p_\gamma = 0$$

$\omega\pi^0 \rightarrow \pi^+\pi^-\pi^0\pi^0$: Background rejection

- $\Delta m_\pi / m_\pi < 3\sigma$
- bhabha-filter
- η-filter

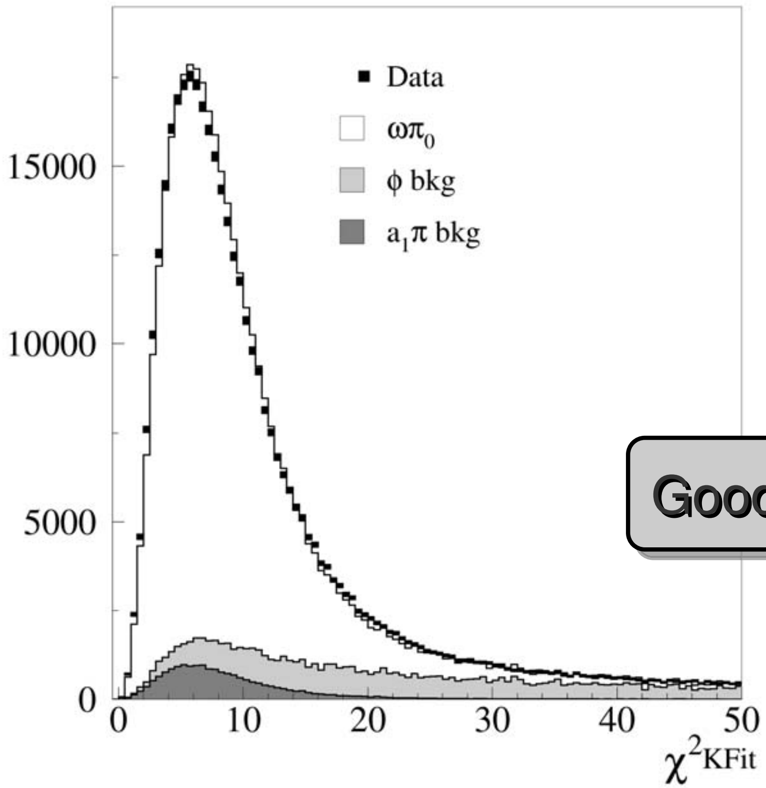


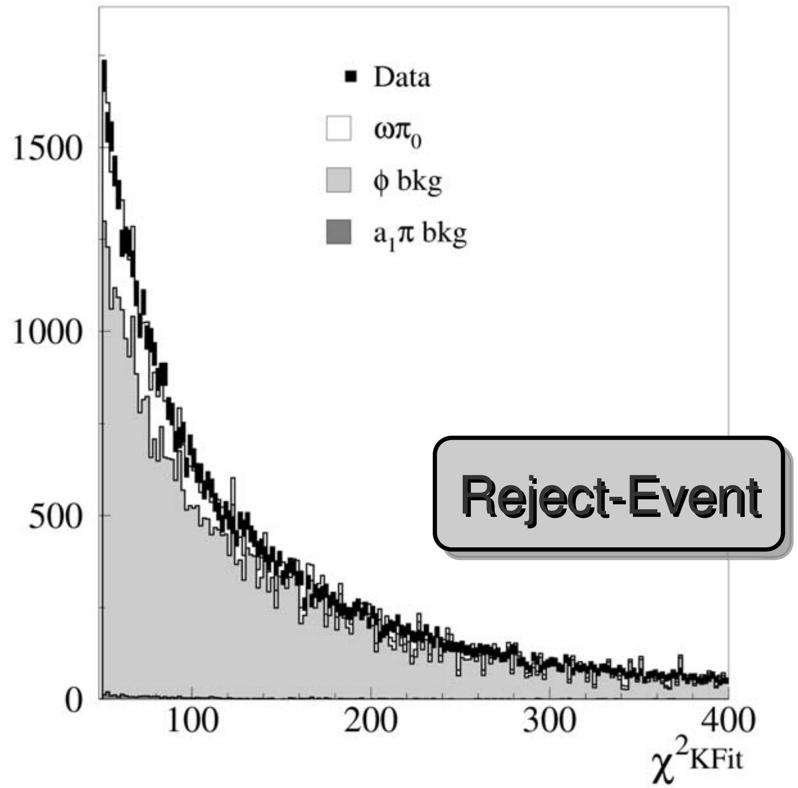


Bhabha-filter is applied on both tracks.

η-filter has been implemented to reject events due to cluster splitting/machine background.

$\omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$: Data-MC comparison

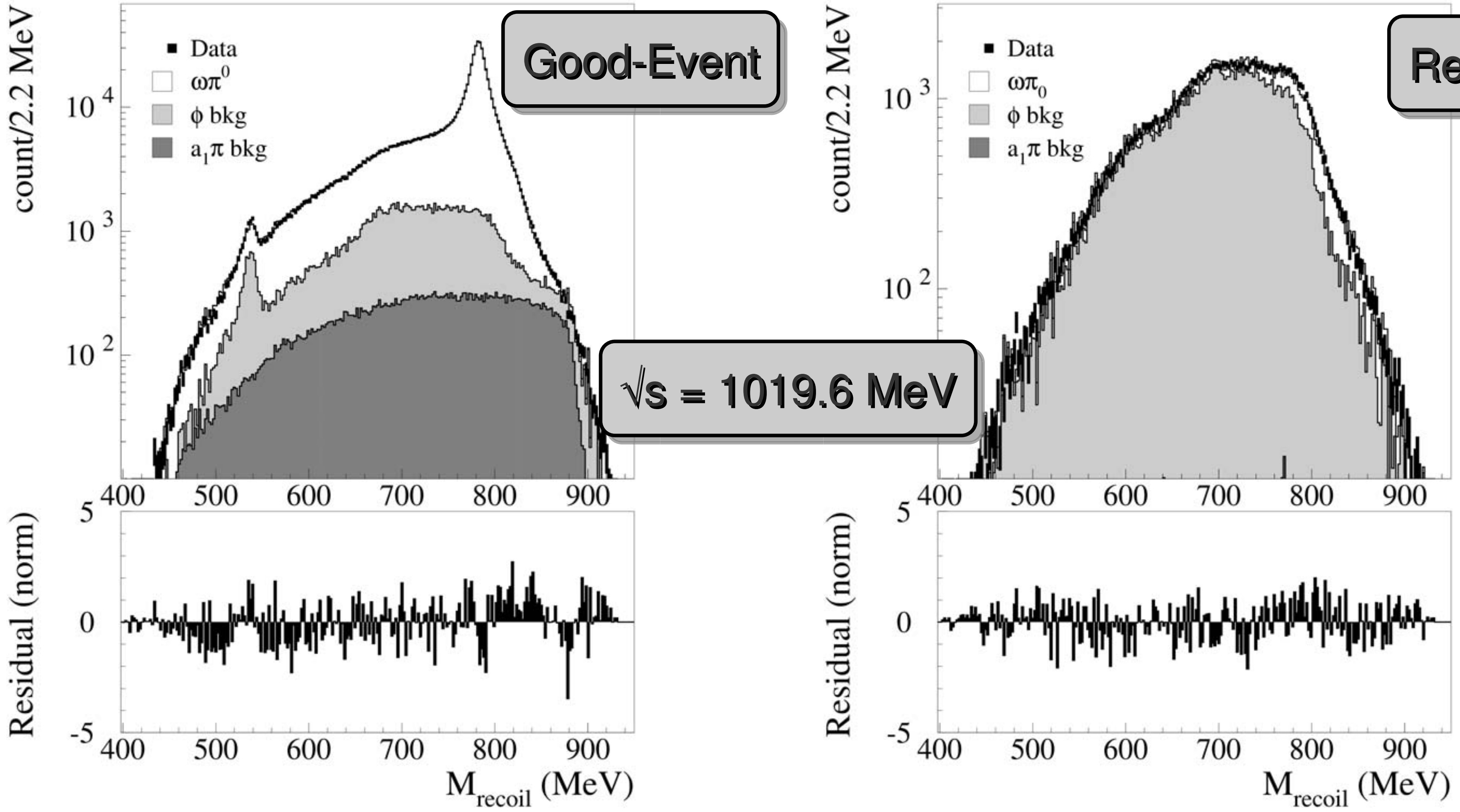




According to χ^2 value data are divided in two categories: **Good** and **Reject** event. Both used in the fit. In the fit we have included three MC component

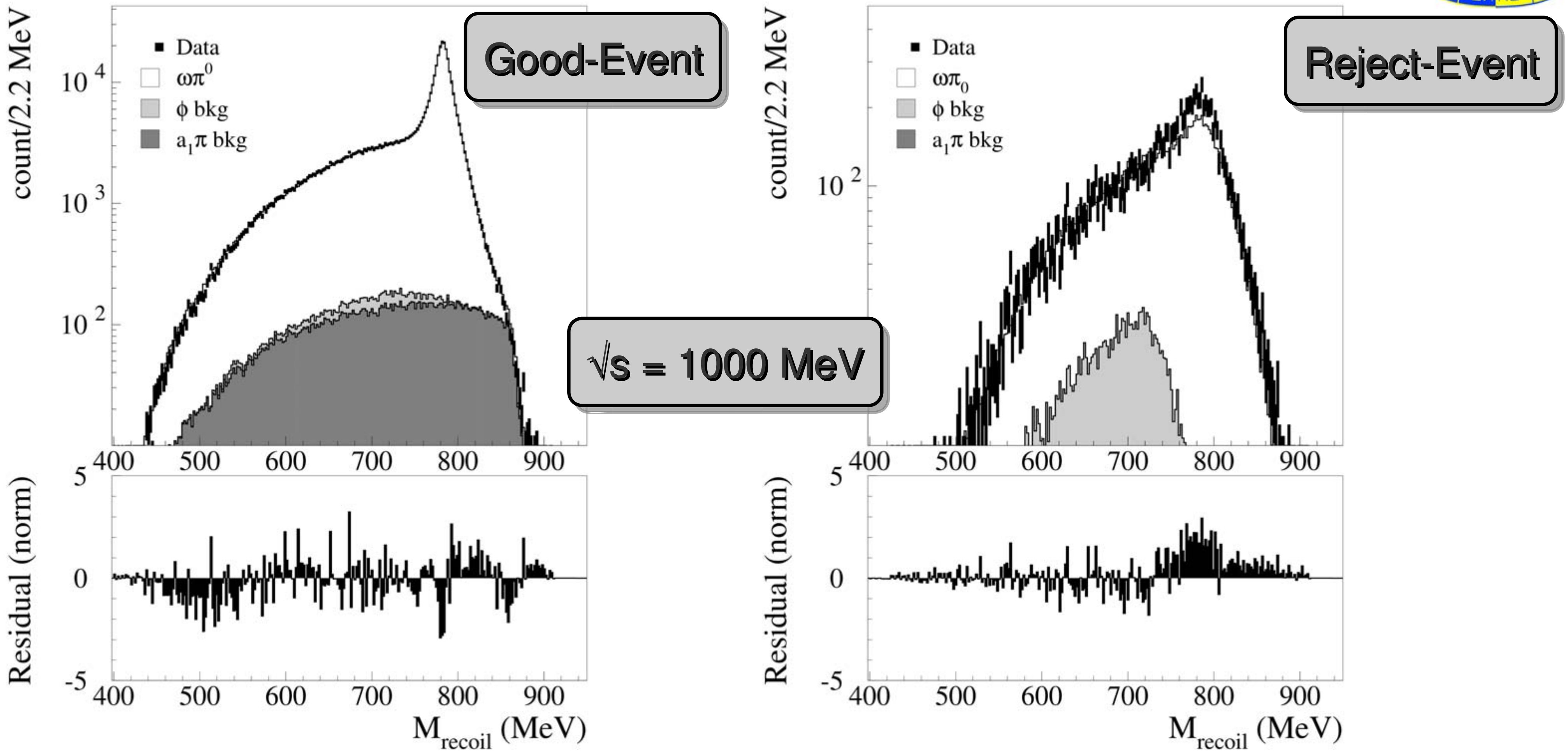
- MC signal
- MC ϕ background
- MC $a_1\pi$ background

$\omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$: Data-MC comparison



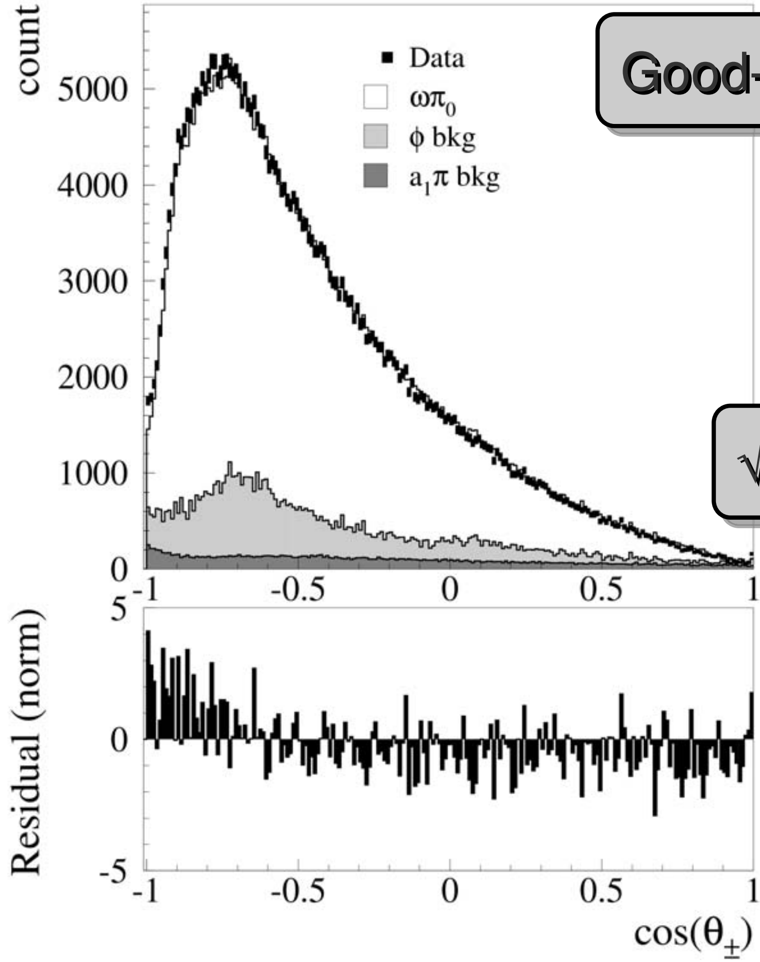
Recoil mass distribution. The standard distribution used in the fit

$\omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$: Data-MC comparison

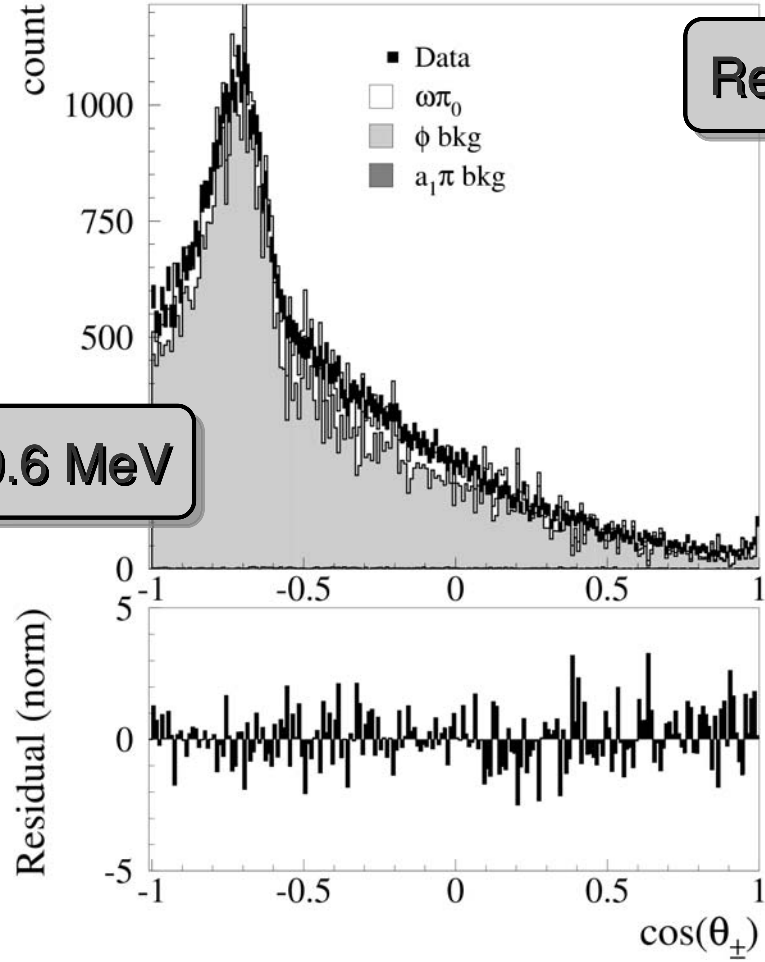


Recoil mass distribution. The standard distribution used in the fit

$\omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$: Data-MC comparison

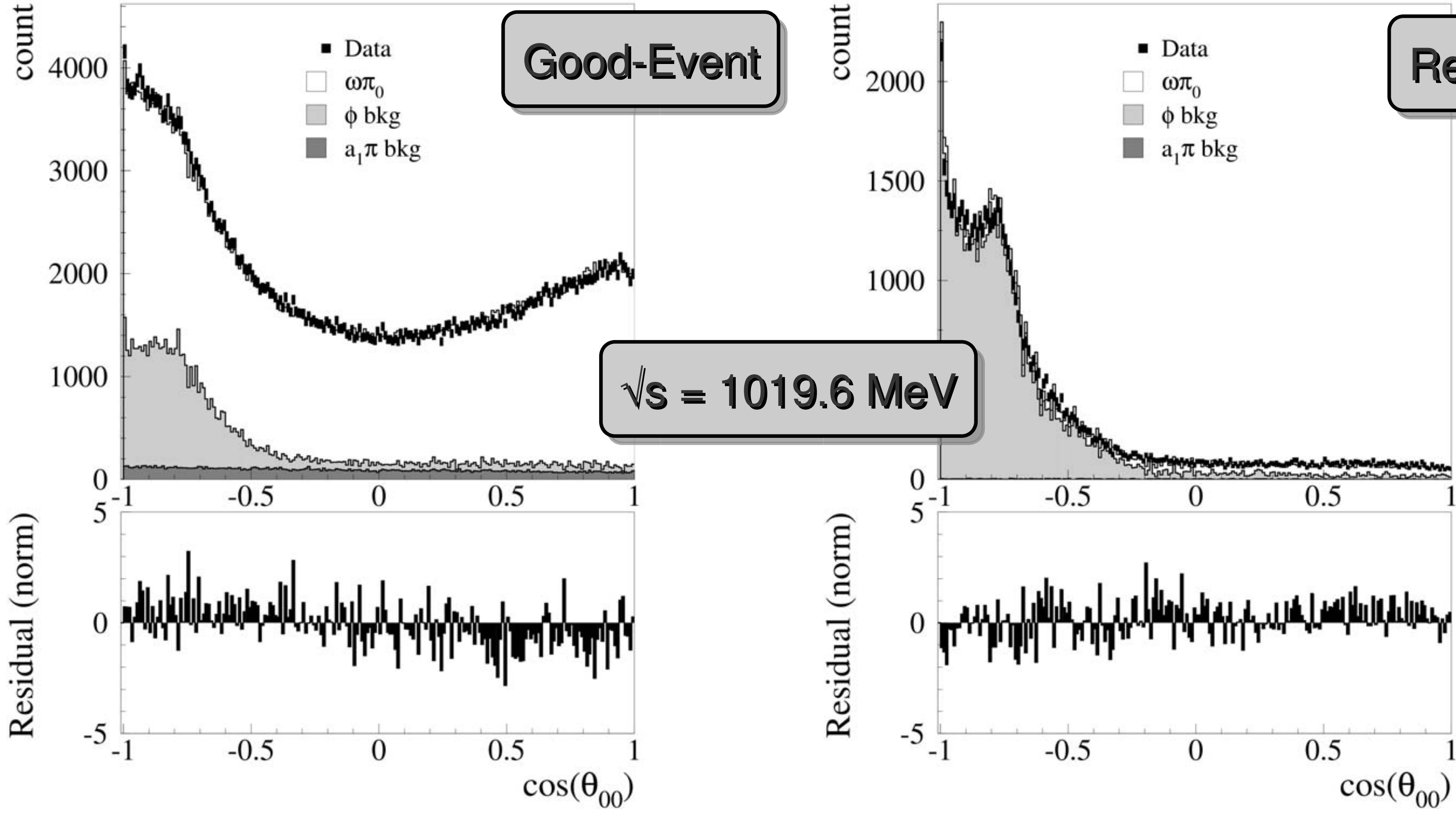


$\sqrt{s}$ = 1019.6 MeV



Angle between charged tracks. Scale factor for the three MC components has been determined with the fit to the recoil mass.

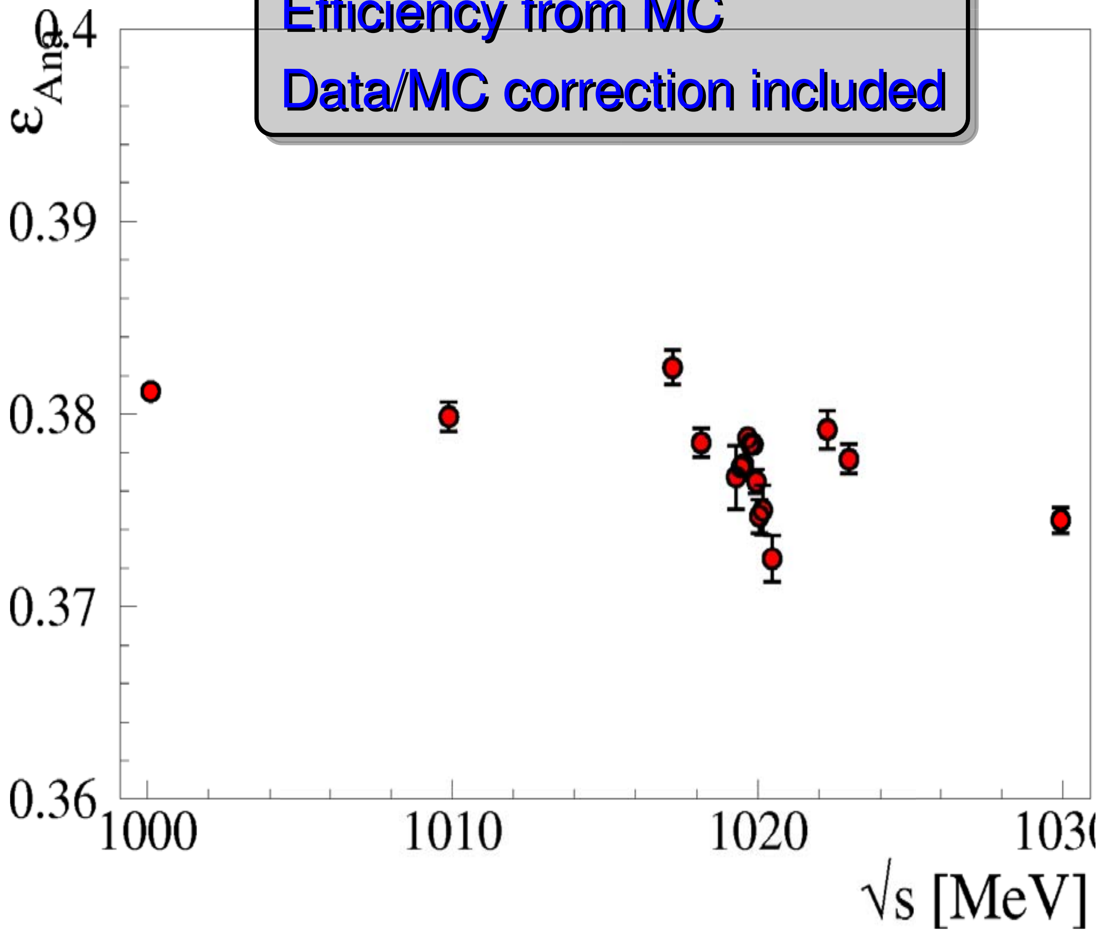
$\omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$: Data-MC comparison



Angle between reconstructed π^0's. Scale factor for the three MC components has been determined with the fit to the recoil mass.

$\omega\pi^0 \rightarrow \pi^+\pi^-\pi^0\pi^0$: *Efficiency*

- Tracking and vertexing efficiency correction included
- Clustering efficiency correction curves included
- ISR reshape included
- Machine Background



Efficiency from MC

Data/MC correction included

Fluctuation are due to the sum of different data tacking period in the same √s bin

$\omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$: Absolute scale systematics

Resolution and reconstruction effect included as systematics to the absolute normalization.

Theoretical uncertainty for Bhabha event generator also included

FSR effect calculated using PHOTOS

Source	$\delta_\varepsilon/\varepsilon$
Cosmic Veto	0.3 %
ϑ_γ and E_γ	0.3 %
Analysis cuts	0.3 %
FSR	0.2 %
Luminosity	0.5 %
Total	0.75 %

Added in quadrature to each point

$\sigma(e^+e^-\to\omega\pi^0\to\pi^+\pi^-\pi^0\pi^0, E)$

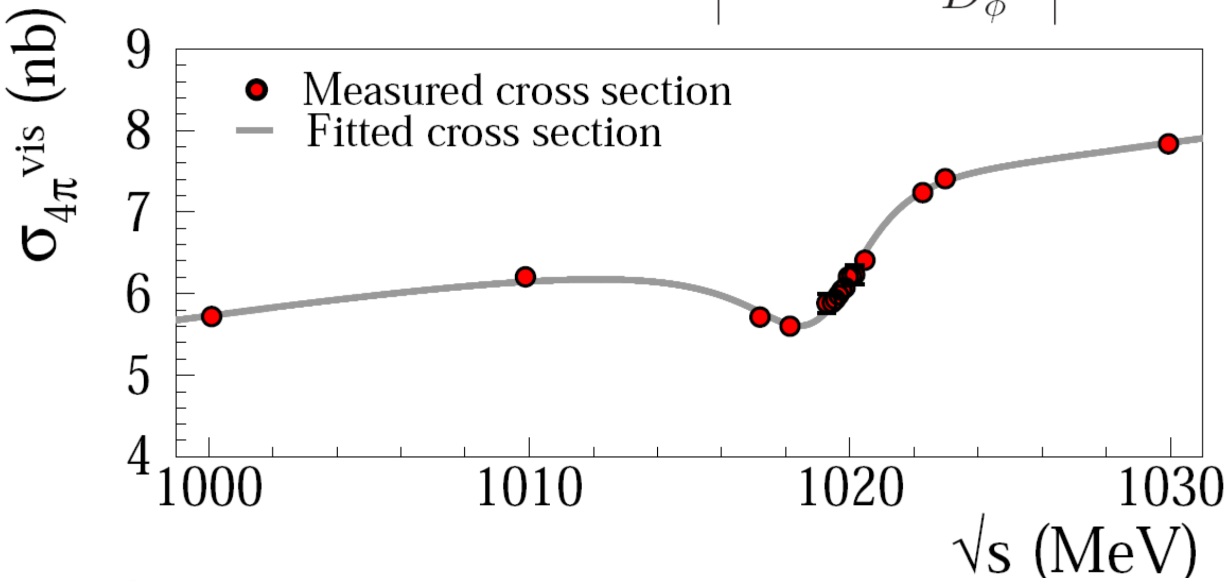
Radiative correction included
Beam Energy Spread included

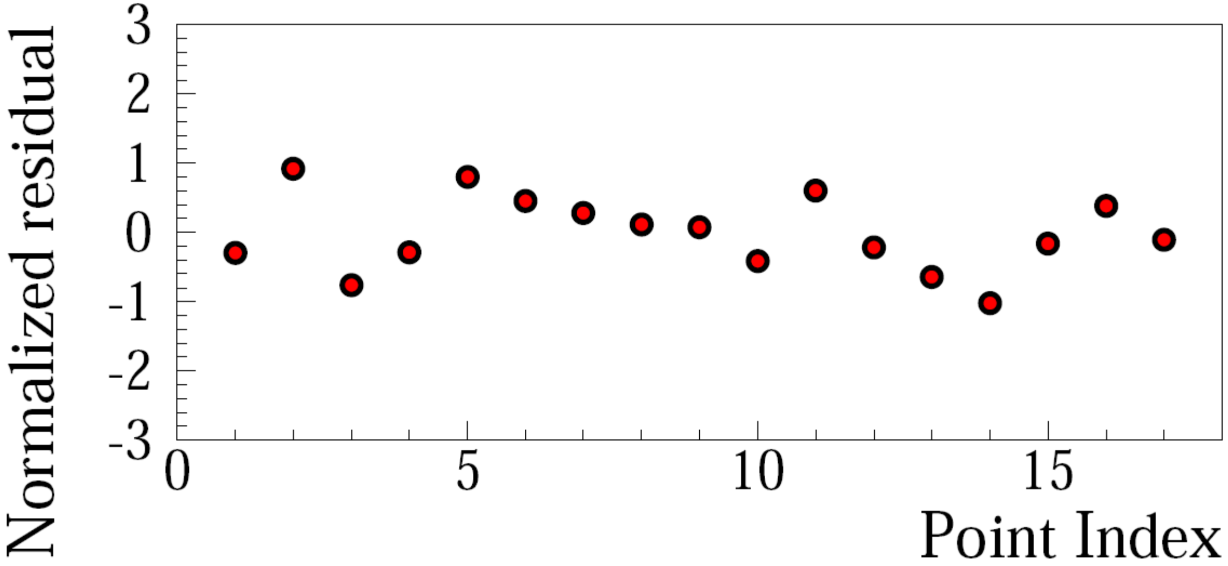
Fit parameters - $P(\chi^2_{fit})$=98%			
$\sigma_0^{4\pi}$ (nb)	7.89	$\pm$	0.06
$\Re(Z)$	0.109	$\pm$	0.007
$\Im(Z)$	-0.103	$\pm$	0.004
σ' (nb/MeV)	0.063	$\pm$	0.003

correlation matrix

ρ (%)	$\Re(Z)$	$\Im(Z)$	σ'
σ_0	−34	−81	79
$\Re(Z)$		6	−46
$\Im(Z)$			−45

$$\sigma^{4\pi}(\sqrt{s}) = \sigma^{4\pi}_{nr}(\sqrt{s}) \cdot \left|1 - Z_{4\pi}\frac{M_\phi\Gamma_\phi}{D_\phi}\right|^2$$



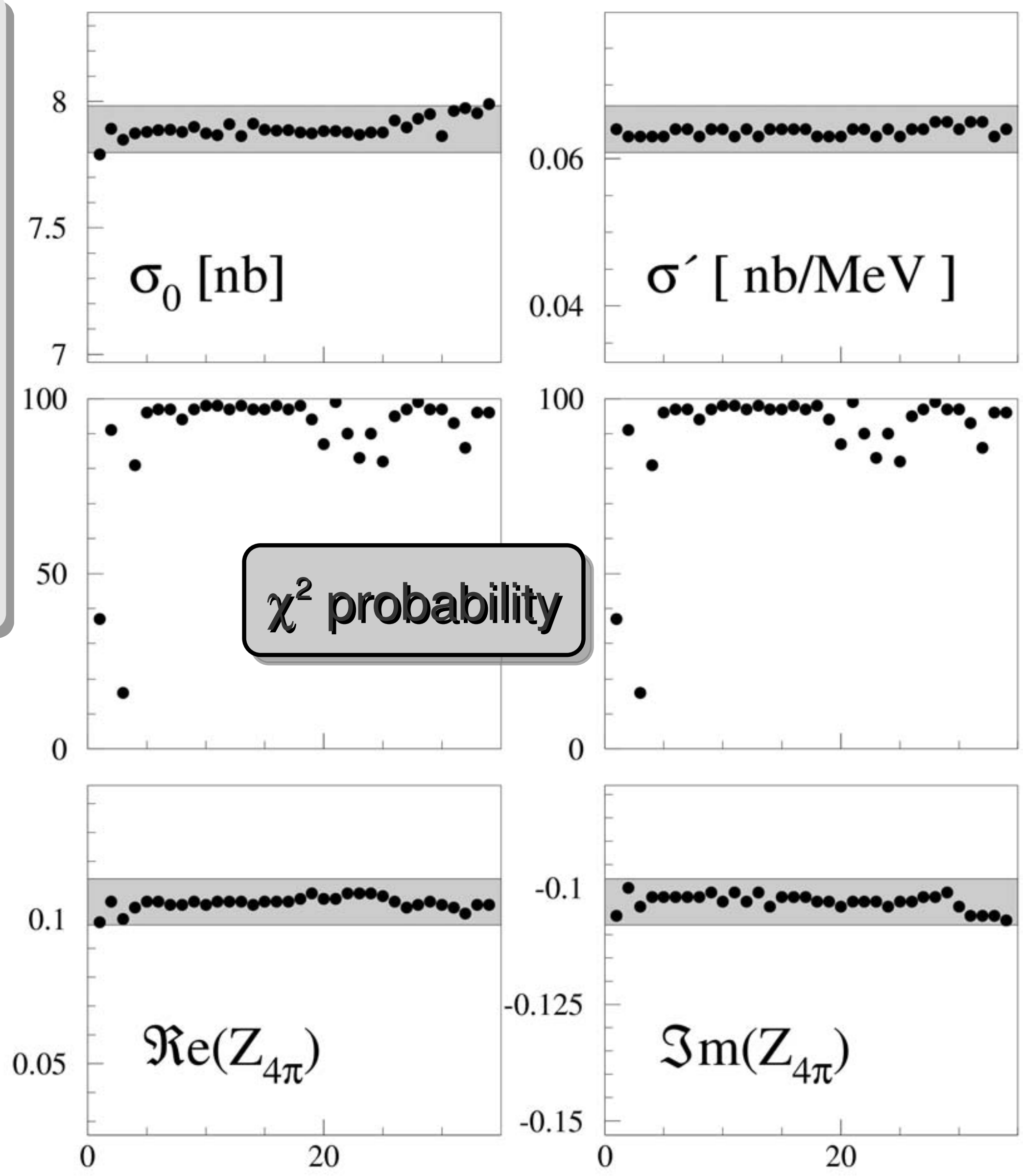


$\omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$: Cross section systematics

Complete set of variation considered

Required minimum fit probability (10%)

- Cluster time
- Cluster energy
- Cluster position
- χ^2 cut (background composition)
- Fit distribution
- Tracking and vertexing efficiency



Final results

σ_0	7.89	±	0.06	±	0.07
$\Re(Z)$	0.109	±	0.006	±	0.004
$\Im(Z)$	0.103	±	0.004	±	0.003
σ'	0.063	±	0.003	±	0.001

$$\omega\pi^0 \rightarrow \pi^0\pi^0\gamma$$

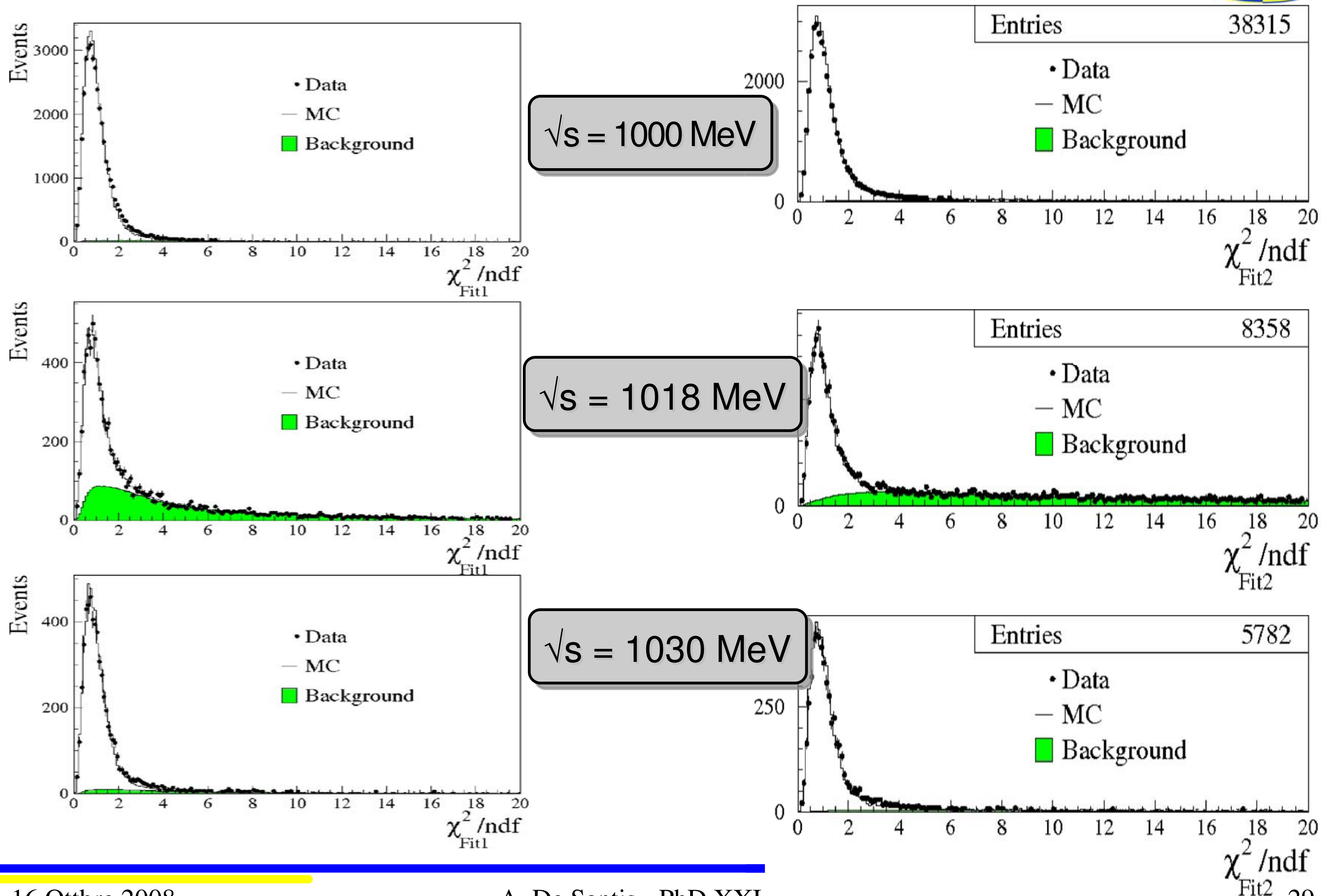
$\omega\pi^0 \to \pi^0\pi^0\gamma$

- Sample selection → 5 clusters
  - neutral (KLOE TCLO km129)
  - in Time Window ($|T_\gamma - R_\gamma/c| < \min(5\sigma_t, 2\text{ ns})$)
  - $E_\gamma < 7$ MeV
  - $\cos(\theta_\gamma) < 0.92$ (~23°)
  - $E\gamma_1 + E\gamma_2 < 900$ MeV
- Photons pairing:
  - 1^{st} kinematic fit (ToF and Energy momentum conservation)
  - parametrization of photon energy resolution (MC)
  - photon pairing into π^0 minimizing a χ^2 defined with the previous resolution
- 2^{nd} kinematic fit (ToF, Energy momentum conservation and π^0 masses)
- $\chi^2(2^{nd})/N_{dof} < 5$
- $|\Delta M_{\pi 0}| < 5\sigma_M$

Acceptance (Step1)

Bkg Rej (Step2)

$\omega\pi^0 \rightarrow \pi^0\pi^0\gamma$ Data-MC



$\omega\pi^0 \to \pi^0\pi^0\gamma$

$\phi \to S\gamma$ and $\phi \to \omega\pi^0$ are assumed uncorrelated (int ~2% KN212)

Sig ID (Step3)

Signal identification performed requiring $750 < M_{\pi\gamma} < 830$ MeV

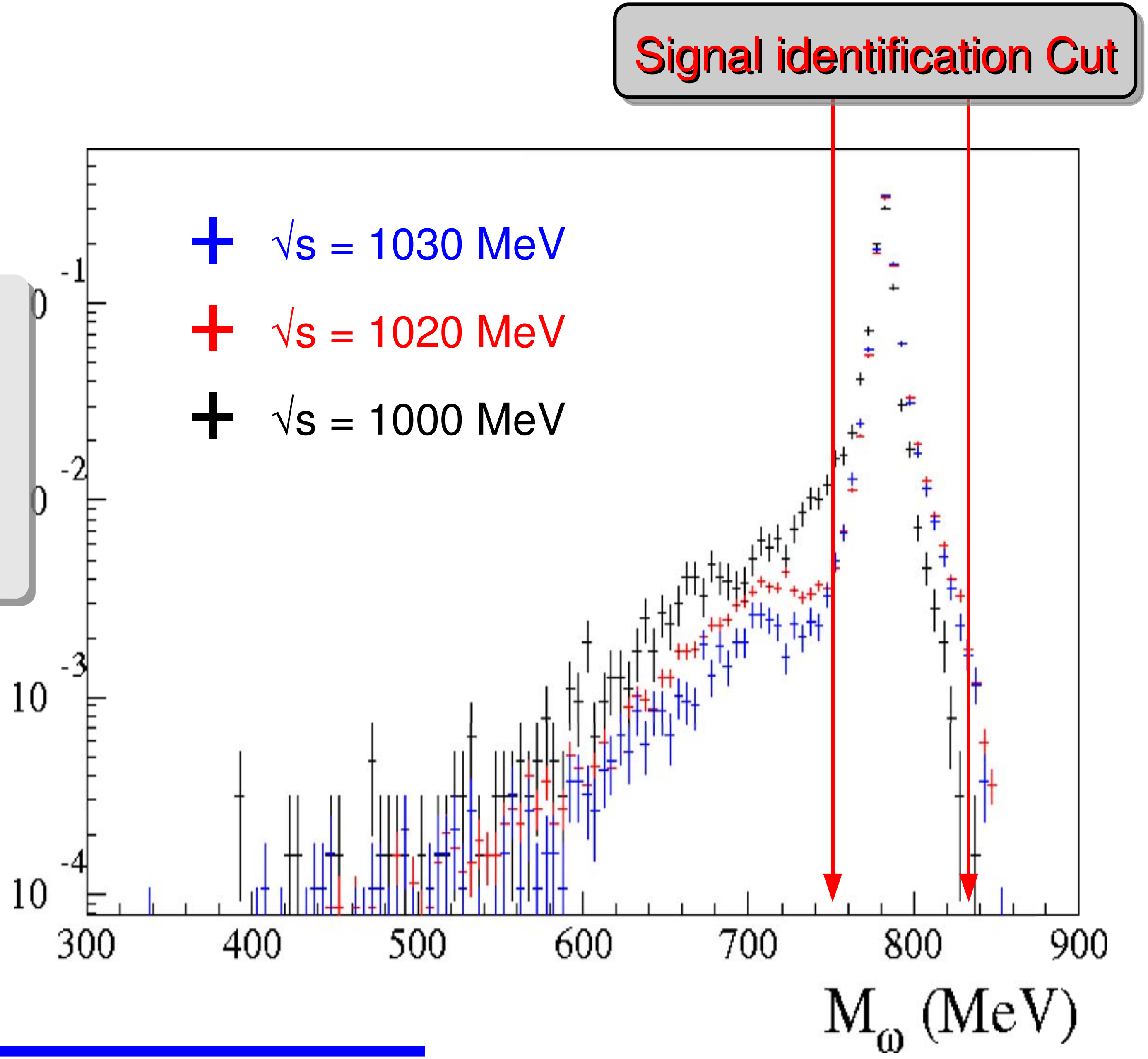
Background contribution estimated from MC distribution normalized with scale factor calculated using the MC/Data luminosity ratio (tested on different background enriched distribution) .

Dominant Background sources

Background	S/B (no cuts)	S/B (selection)	S/B (bkg rej)
$\eta\pi^0\gamma$	8.5	8.8	18.9
$\eta\gamma \to \pi^0\pi^0\pi^0\gamma$	0.1	0.5	3.9
$\eta\gamma \to \gamma\gamma$	0.1	18.8	32.3

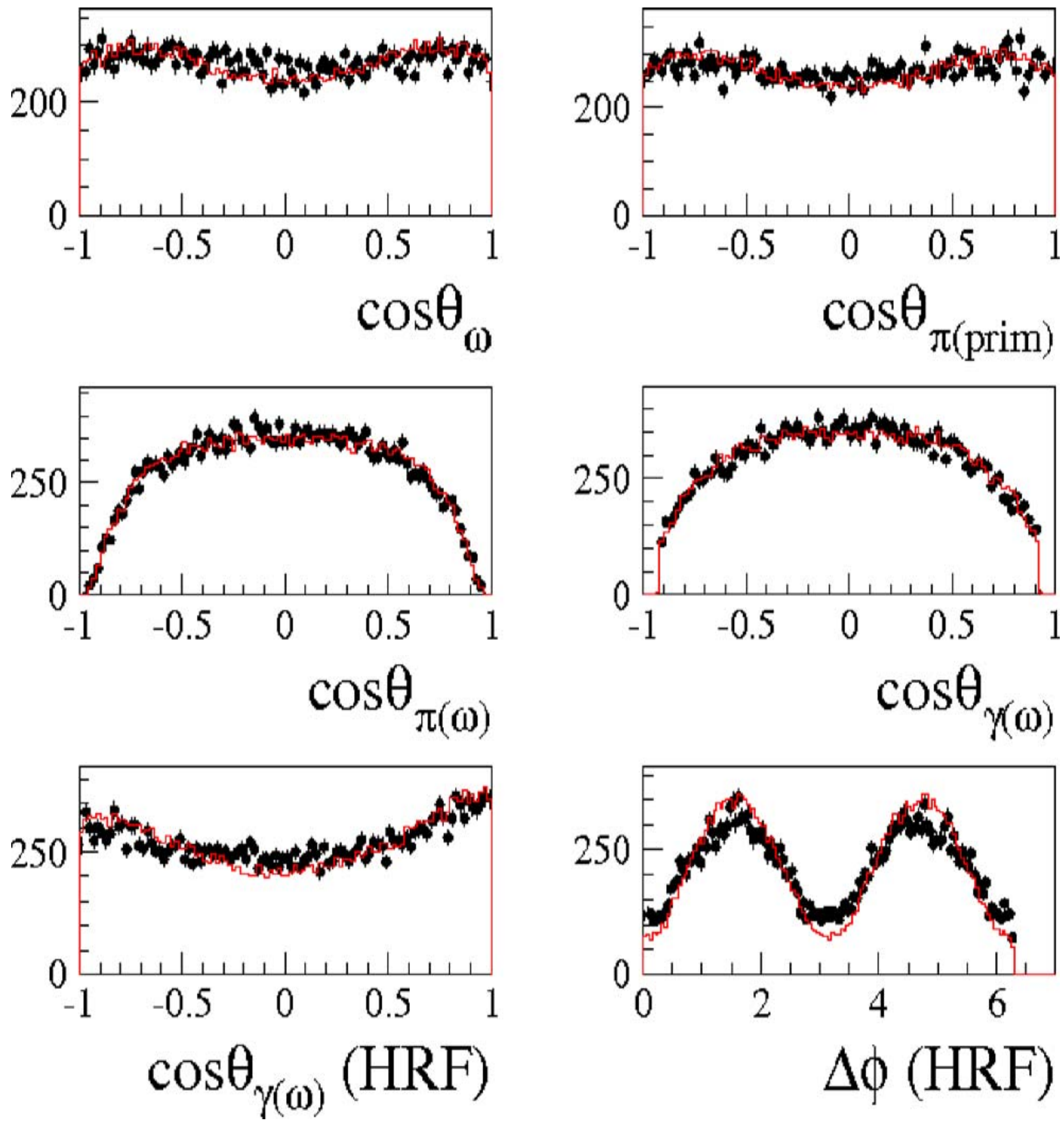
$\omega\pi^0 \rightarrow \pi^0\pi^0\gamma$

The ω tail depends on the center of mass energy.



$\omega\pi^0 \rightarrow \pi^0\pi^0\gamma$ Data-MC comparison

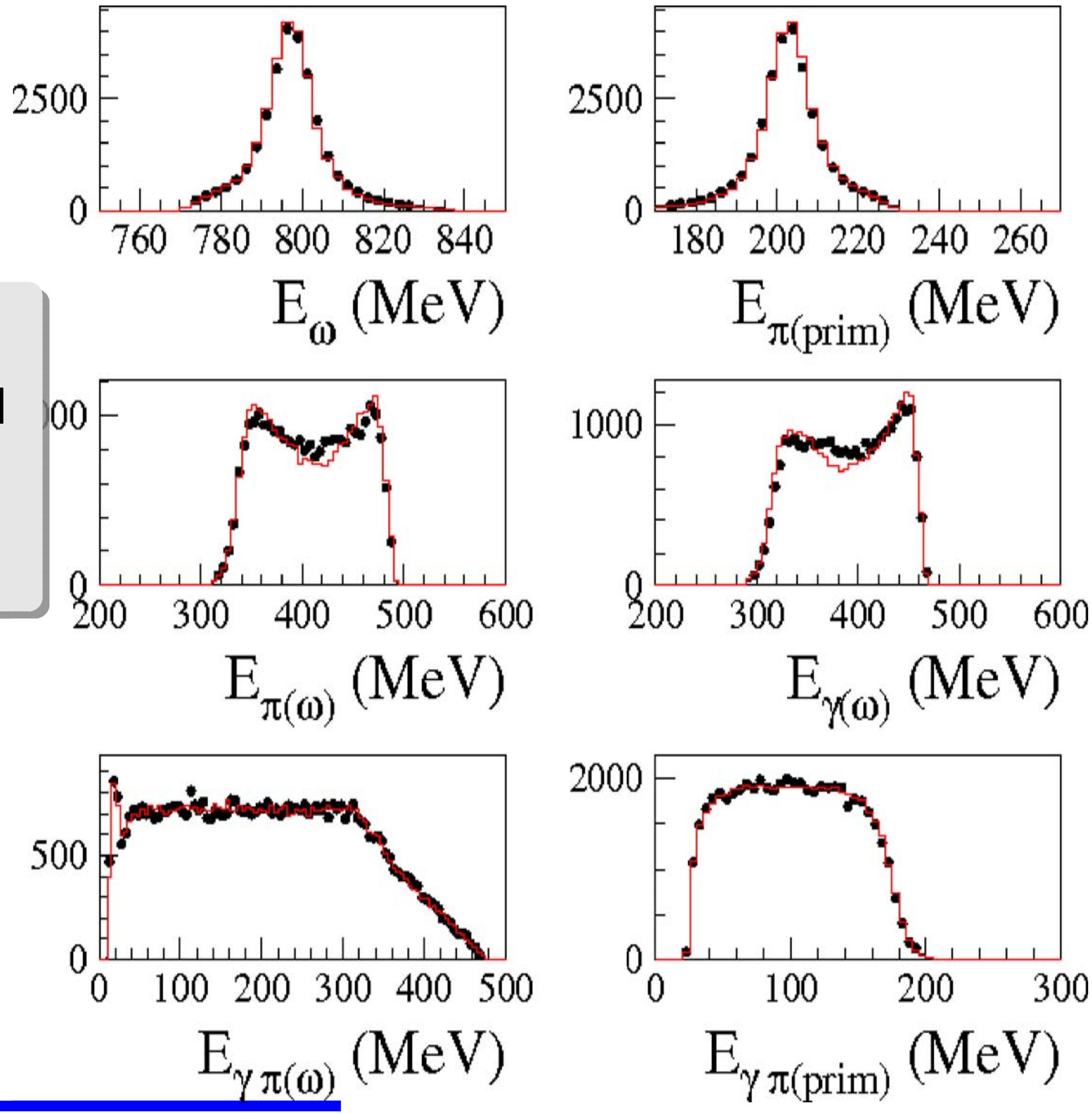
Data-MC comparison after ω identification and residual background subtraction. Angular distributions



$\omega\pi^0 \rightarrow \pi^0\pi^0\gamma$ Data-MC comparison

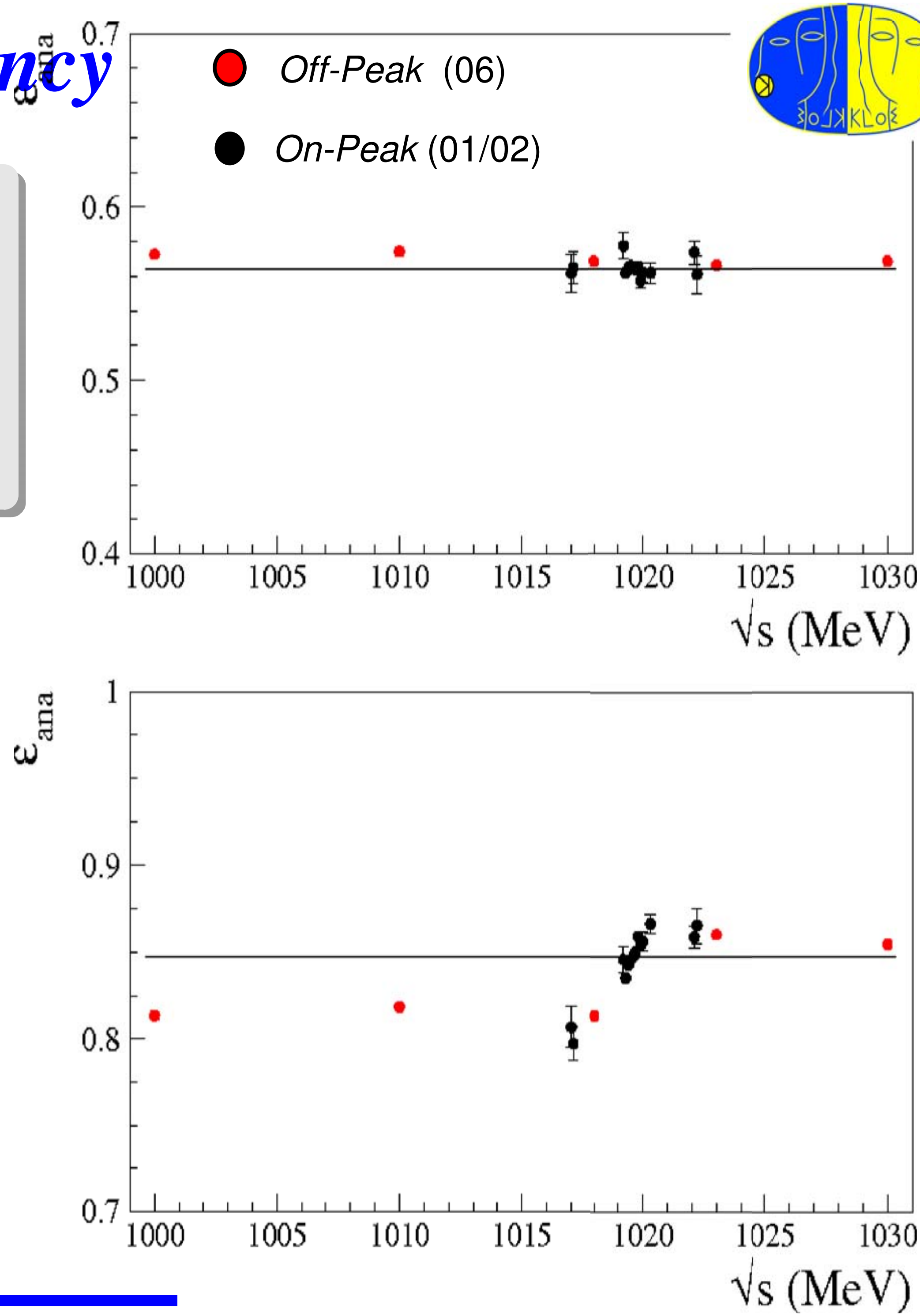
Data-MC comparison after ω identification and residual background subtraction.

Energy distributions



$\omega\pi^0 \rightarrow \pi^0\pi^0\gamma$ Efficiency

Analysis efficiency after the preselection and background rejection (Step1+2)



Analysis efficiency after the Mω cut (step 3)

$\sigma(e^+e^-\to\omega\pi^0\to\pi^0\pi^0\gamma)$

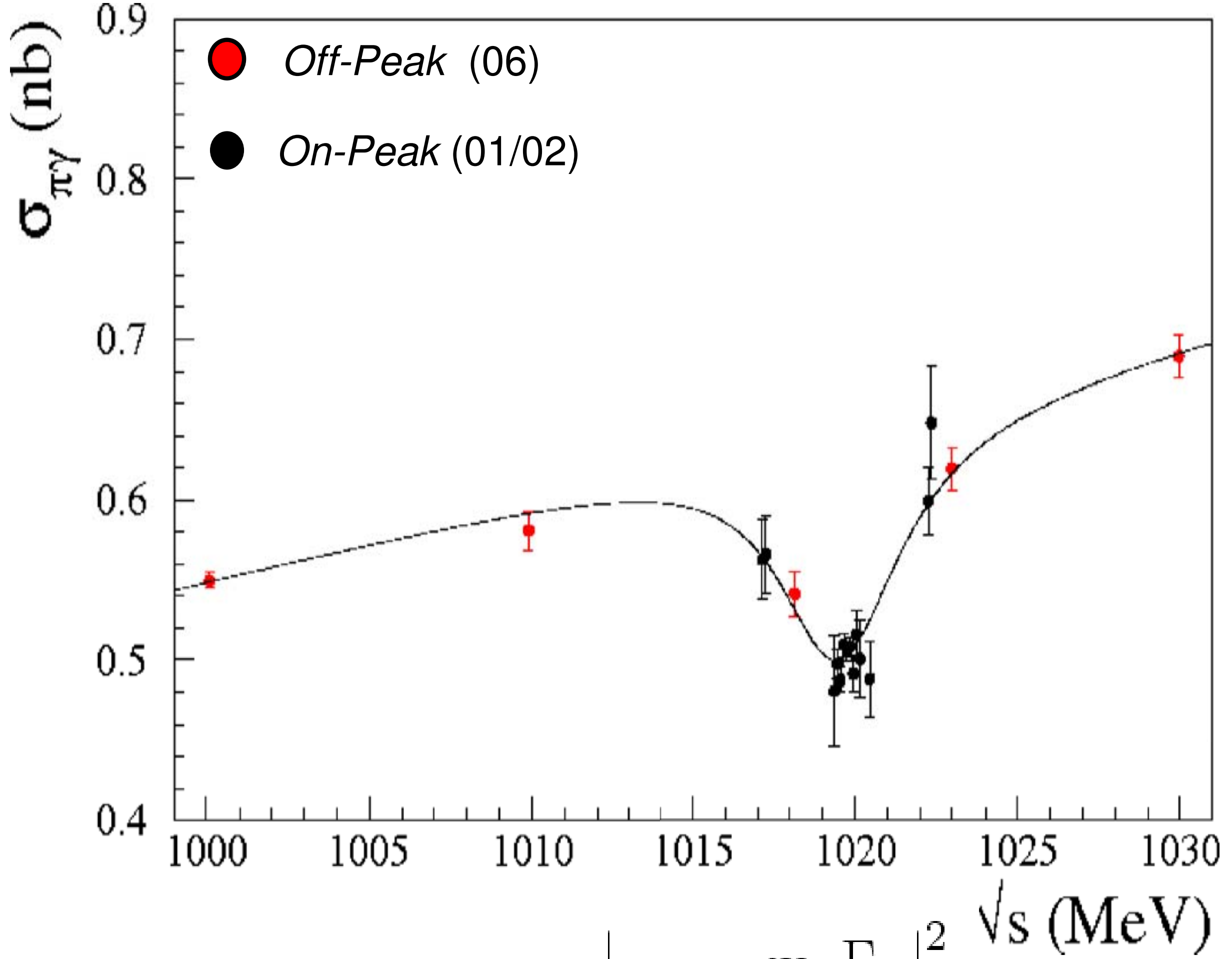
Radiative correction included

Beam Energy Spread included

Parameter $(e^+e^-\to\pi^0\pi^0\gamma)$	
$\sigma_0^{\pi\pi\gamma}$ (nb)	0.724 ± 0.011
$\Re(Z_{\pi\pi\gamma})$	0.011 ± 0.016
$\Im(Z_{\pi\pi\gamma})$	-0.154 ± 0.004
$\sigma'_{\pi\pi\gamma}$ (nb/MeV)	$0.0053\pm0.0.0005$

correlation matrix

$\rho(\%)$	$\Re(Z)$	$\Im(Z)$	σ'
σ_0	−30	−86	87
$\Re(Z)$		14	−44
$\Im(Z)$			−63



$$\sigma(E)=\sigma_0(E)\left|1-Z\frac{m_\phi\Gamma_\phi}{D_\phi}\right|^2$$

$\omega\pi^0 \to \pi^0\pi^0\gamma$ Systematics

	σ_0 (nb)	$\Re(Z)$	$\Im(Z)$	σ' (nb/MeV)	χ^2 / Ndof
Default	**0.724(11)**	**0.011(15)**	**-0.154(7)**	**0.0053(5)**	**13.1/15**
χ^2	0.720(11)	0.004(15)	-0.155(7)	0.0054(5)	9.9/15
Mω	0.730(11)	0.005(15)	-0.156(7)	0.0059(5)	8.2/15
Eg	0.727(10)	0.010(15)	-0.155(7)	0.0055(5)	11.0/15
E scale	0.722(10)	0.004(14)	-0.155(7)	0.0054(5)	9.7/15
Bkg	0.724(11)	0.012(14)	-0.157(7)	0.0053(5)	13.9/15
√s scale	0.723(11)	0.022(15)	-0.151(7)	0.0052(5)	12.3/15
ISR tail	0.728(11)	0.010(15)	-0.158(7)	0.0052(5)	12.5/15
Mππ	0.728(10)	0.006(14)	-0.153(7)	0.0053(5)	11.3/15
Interf	0.724(11)	0.019(18)	-0.158(7)	0.0053(6)	13.0/15
All	**±0.003**	**±0.006**	**±0.004**	**±0.0002**	

Combined

ω's BR

Parameter	$e^+e^- \to \pi^+\pi^-\pi^0\pi^0$	$e^+e^- \to \pi^0\pi^0\gamma$
σ_0 (nb)	$7.89 \pm 0.06 \pm 0.07$	$0.724 \pm 0.010 \pm 0.003$
$\Re e(Z)$	$0.106 \pm 0.007 \pm 0.004$	$0.011 \pm 0.015 \pm 0.006$
$\Im m(Z)$	$-0.103 \pm 0.004 \pm 0.003$	$-0.154 \pm 0.007 \pm 0.004$
σ' (nb/MeV)	$0.064 \pm 0.003 \pm 0.001$	$0.0053 \pm 0.0005 \pm 0.0002$

$$\frac{\sigma_0(\omega \to \pi^0\gamma)}{\sigma_0(\omega \to \pi^+\pi^-\pi^0)} = 0.0918 \pm 0.0016$$

Phase space correction (1.023)

$$\frac{\Gamma(\omega \to \pi^0\gamma)}{\Gamma(\omega \to \pi^+\pi^-\pi^0)} = 0.0897 \pm 0.0016$$

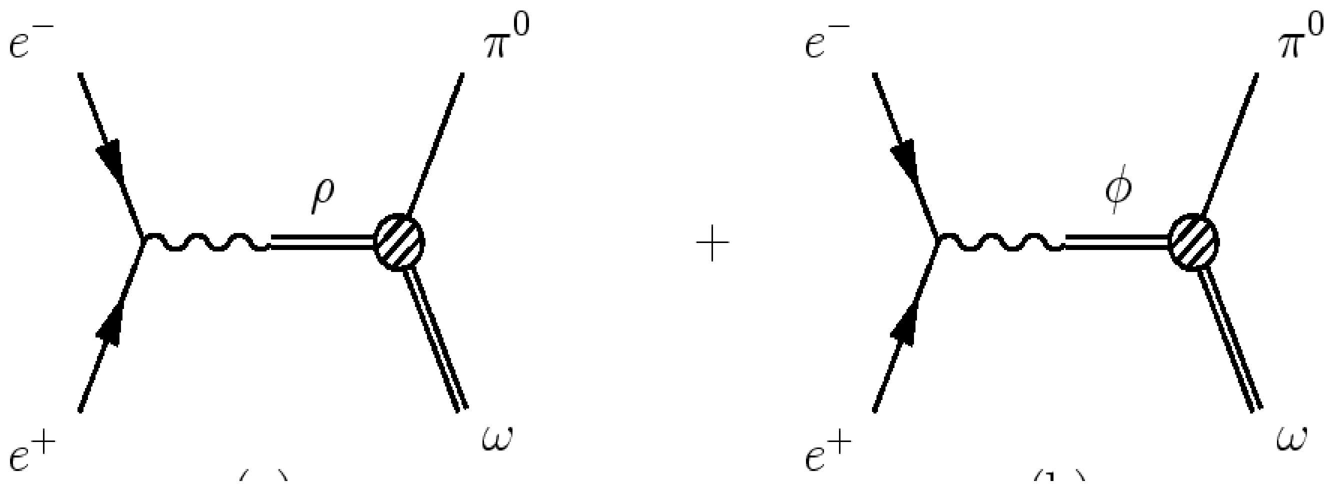
Unitarity imposed

Δ = 1.66%

$$BR(\omega \to \pi^+\pi^-\pi^0) = (90.24 \pm 0.19)\%$$
$$BR(\omega \to \pi^0\gamma) = (8.09 \pm 0.14)\%$$

$BR(\phi \to \omega\pi^0)$

In the 4π final state only two diagram contribute.
Using our results we extract the amplitude for the $\phi \to \omega\pi^0$ process

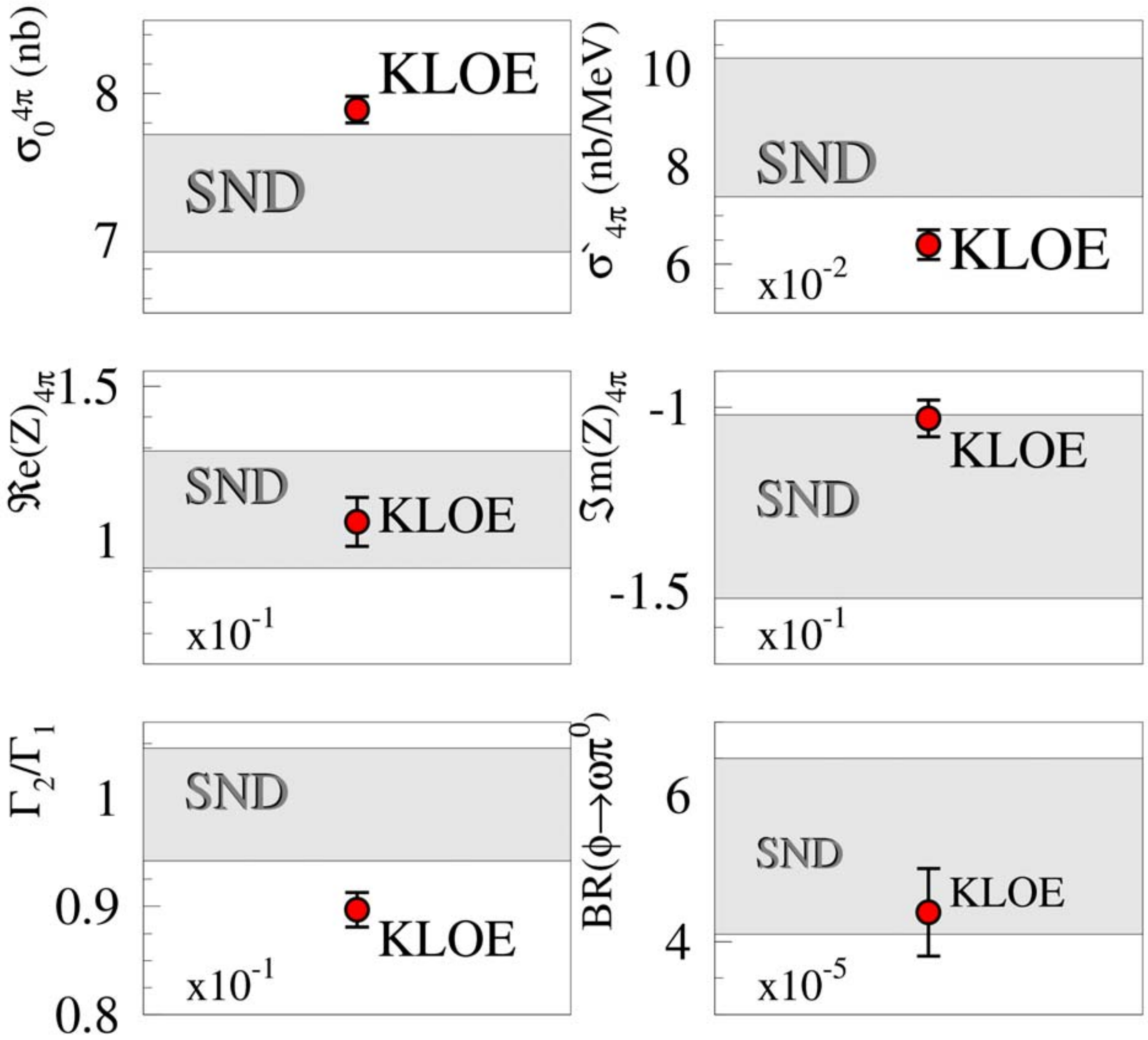


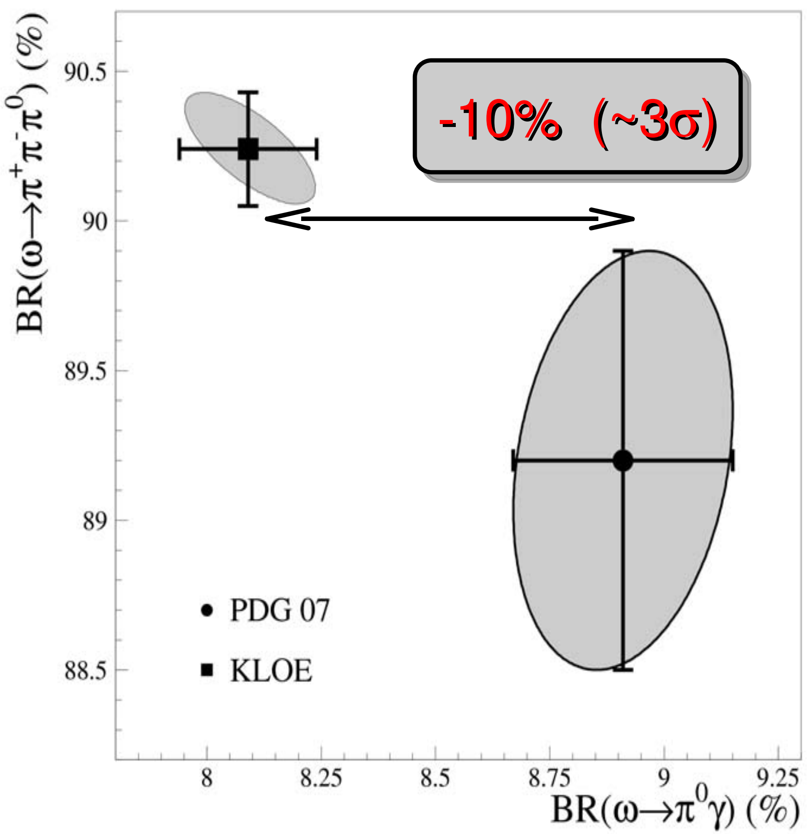
$$BR(\phi \to \omega\pi^0) = \frac{\sigma_0(m_\phi)|Z|^2}{\sigma_\phi}$$

Using KLOE results (correlation included)

$$BR(\phi \to \omega\pi^0) = (4.6 \pm 0.6) \times 10^{-5}$$

Graphical summary





Precision improved by factor 2
Neutral BR changed of ~10%

Conclusions

- Precision improved by a factor of two with respect to published results
- BR($\omega \rightarrow \pi^0 \gamma$) changed of 10% (3$\sigma$'s)
- Highly reliable MC developed for KLOE collaboration
  (e.g. neutral kaon interferometry study)

- Work **Accepted** by PLB for publication

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Study of the process $e^+e^- \to \omega\pi^0$ in the ϕ-meson mass region with the KLOE detector

KLOE Collaboration

F. Ambrosino [c,d], A. Antonelli [a], M. Antonelli [a], F. Archilli [h,i], P. Beltrame [b], G. Bencivenni [a], S. Bertolucci [a], C. Bini [f,g], C. Bloise [a], S. Bocchetta [j,k], F. Bossi [a], P. Branchini [k], P. Campana [a], G. Capon [a], T. Capussela [a], F. Ceradini [j,k], P. Ciambrone [a], F. Crucianelli [f], E. De Lucia [a], A. De Santis [f,g,*], P. De Simone [a], G. De Zorzi [f,g], A. Denig [b], A. Di Domenico [f,g], C. Di Donato [d], B. Di Micco [j,k], M. Dreucci [a], G. Felici [a], M.L. Ferrer [a], S. Fiore [f,g], P. Franzini [f,g], C. Gatti [a], P. Gauzzi [f,g], S. Giovannella [a], E. Graziani [k], W. Kluge [b], G. Lanfranchi [a], J. Lee-Franzini [a,l], D. Leone [b], M. Martini [a,e], P. Massarotti [c,d], S. Meola [c,d], S. Miscetti [a], M. Moulson [a], S. Müller [a], F. Murtas [a], M. Napolitano [c,d], F. Nguyen [j,k], M. Palutan [a], E. Pasqualucci [g], A. Passeri [k], V. Patera [a,e], F. Perfetto [c,d], P. Santangelo [a], B. Sciascia [a], A. Sciubba [a,e], A. Sibidanov [a], T. Spadaro [a], M. Testa [f,g], L. Tortora [k], P. Valente [g], G. Venanzoni [a], R. Versaci [a,e], G. Xu [a,m]

[a] Laboratori Nazionali di Frascati dell'INFN, Frascati, Italy
[b] Institut für Experimentelle Kernphysik, Universität Karlsruhe, Germany
[c] Dipartimento di Scienze Fisiche dell'Università "Federico II", Napoli, Italy
[d] INFN Sezione di Napoli, Napoli, Italy
[e] Dipartimento di Energetica dell'Università "La Sapienza", Roma, Italy
[f] Dipartimento di Fisica dell'Università "La Sapienza", Roma, Italy
[g] INFN Sezione di Roma, Roma, Italy
[h] Dipartimento di Fisica dell'Università "Tor Vergata", Roma, Italy
[i] INFN Sezione di Roma Tor Vergata, Roma, Italy
[j] Dipartimento di Fisica dell'Università "Roma Tre", Roma, Italy
[k] INFN Sezione di Roma Tre, Roma, Italy
[l] Physics Department, State University of New York at Stony Brook, USA
[m] Institute of High Energy Physics of Academica Sinica, Beijing, China

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ABSTRACT

We have studied the $e^+e^- \to \omega\pi^0$ cross section in the $\sqrt{s}$ interval 1000–1030 MeV using the $\pi^+\pi^-\pi^0\pi^0$ and $\pi^0\pi^0\gamma$ final states with a sample of ~ 600 pb^{-1} collected with the KLOE detector at DAΦNE. By fitting the observed interference pattern around M_ϕ for both final states, we extract the ratio of the decay widths $\Gamma(\omega \to \pi^0\gamma)/\Gamma(\omega \to \pi^+\pi^-\pi^0) = 0.0897 \pm 0.0016$ and derive the branching fractions $\mathrm{BR}(\omega \to \pi^+\pi^-\pi^0) = (90.24 \pm 0.19)\%$, $\mathrm{BR}(\omega \to \pi^0\gamma) = (8.09 \pm 0.14)\%$. The parameters describing the $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$ reaction around M_ϕ are also used to extract the branching fraction for the OZI and G-parity violating $\phi \to \omega\pi^0$ decay: $\mathrm{BR}(\phi \to \omega\pi^0) = (4.4 \pm 0.6) \times 10^{-5}$.

1. Introduction

At low energy, below 1.4 GeV, the $e^+e^- \to \omega\pi^0$ cross section is largely dominated by the non-resonant processes $e^+e^- \to \rho/\rho' \to \omega\pi^0$. However, in the region around M_ϕ, a contribution from the OZI and G-parity violating decay $\phi \to \omega\pi^0$ is expected. This strongly suppressed decay ($\mathcal{O}(10^{-5})$) can be observed via interference with the non-resonant process, showing up as a dip in the total cross section dependence from $\sqrt{s}$.

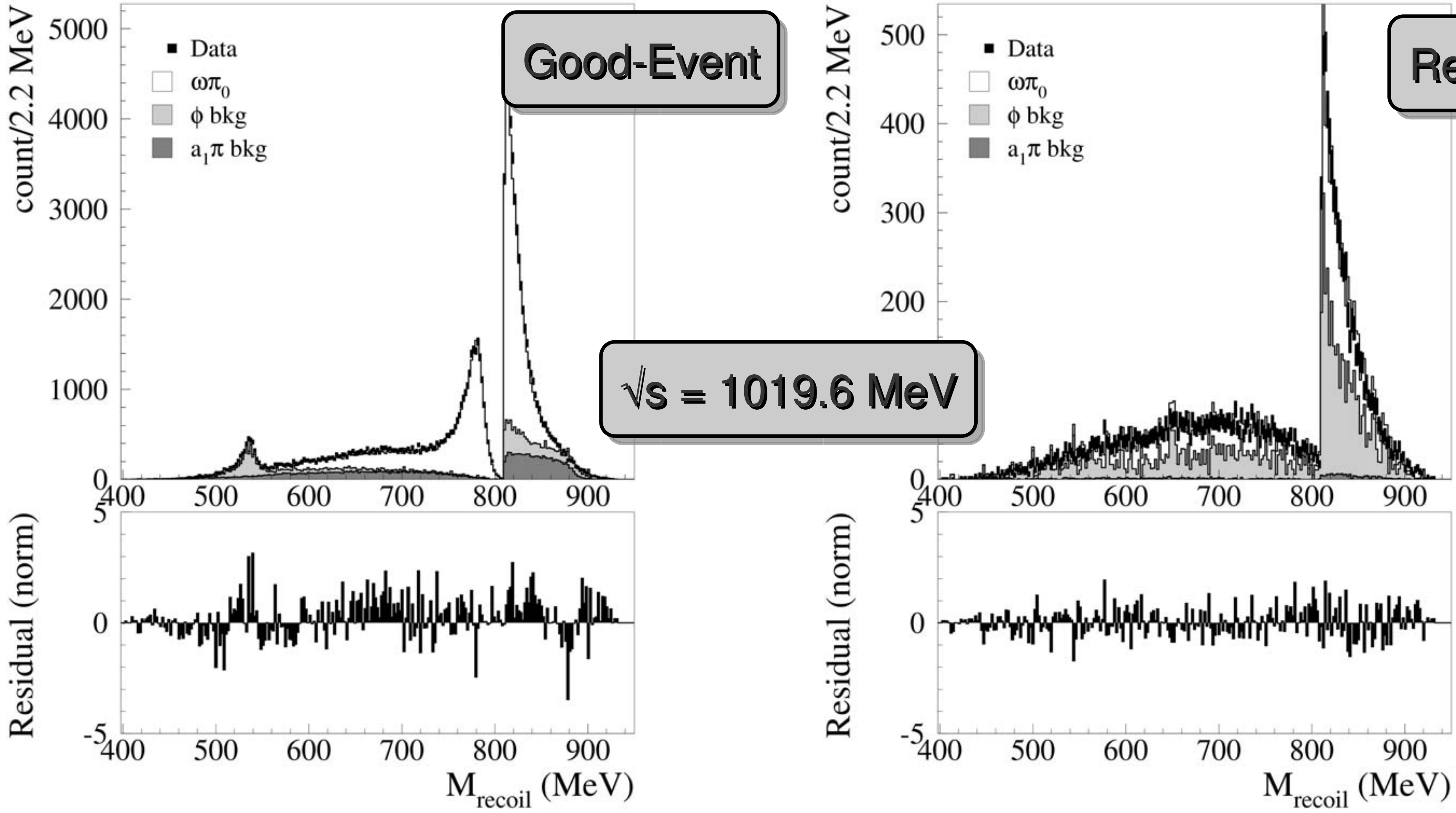
The $e^+e^- \to \omega\pi^0$ cross section as a function of $\sqrt{s}$ is parametrized as [1]:

* Corresponding author.
E-mail addresses: antonio.desantis@roma1.infn.it (A. De Santis), simona.giovannella@lnf.infn.it (S. Giovannella).

0370-2693/$ – see front matter
doi:10.1016/j.physletb.2008.09.056

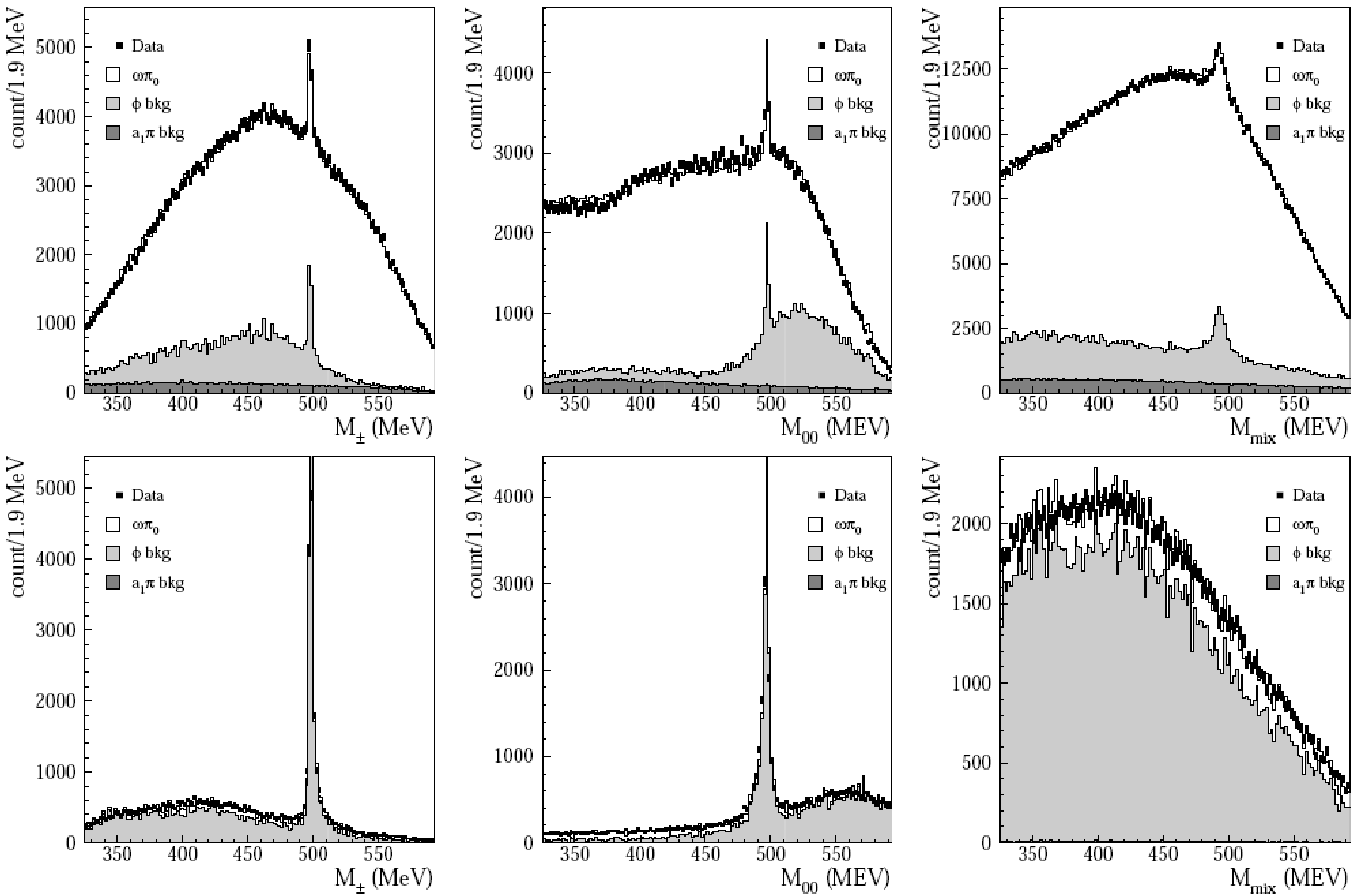
SPARE

$\omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$: Data-MC comparison



Recoil mass distribution when at least one of the two combination is above 810 MeV ($a_1\pi$ region). Scale factor for the three MC components has been determined with the fit to the recoil mass.

$\omega\pi^0 \rightarrow \pi^+\pi^-\pi^0\pi^0$: Data-MC comparison



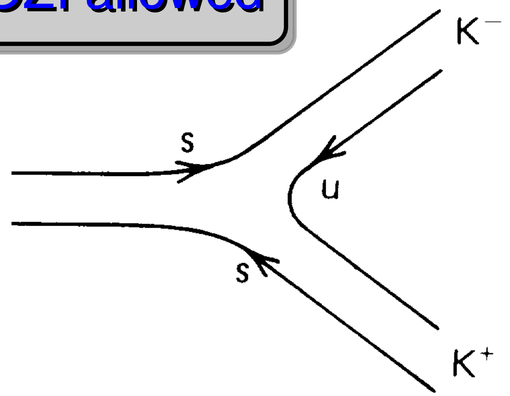
OZI rule

The "OZI" rule: in the 1960's it was noted that the ϕ meson decayed (strongly) into kaons more often than expected from phase space consideration ($\Delta m(\phi \to \pi^+\pi^-\pi^0)$ / $\Delta m(\phi \to KK)$ ~ 20)

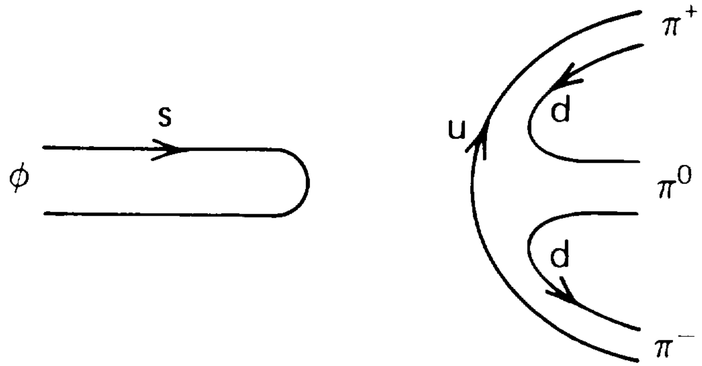
ϕ 1020 MeV

$I^G(J^{PC}) = 0^-(1^{-}\ )$

OZI allowed



OZI suppressed



Okubo, Zweig, and Iizuka (OZI) independently suggested a rule: disconnected quark diagrams are suppressed relative to connected ones".

Default

Evidenced 1

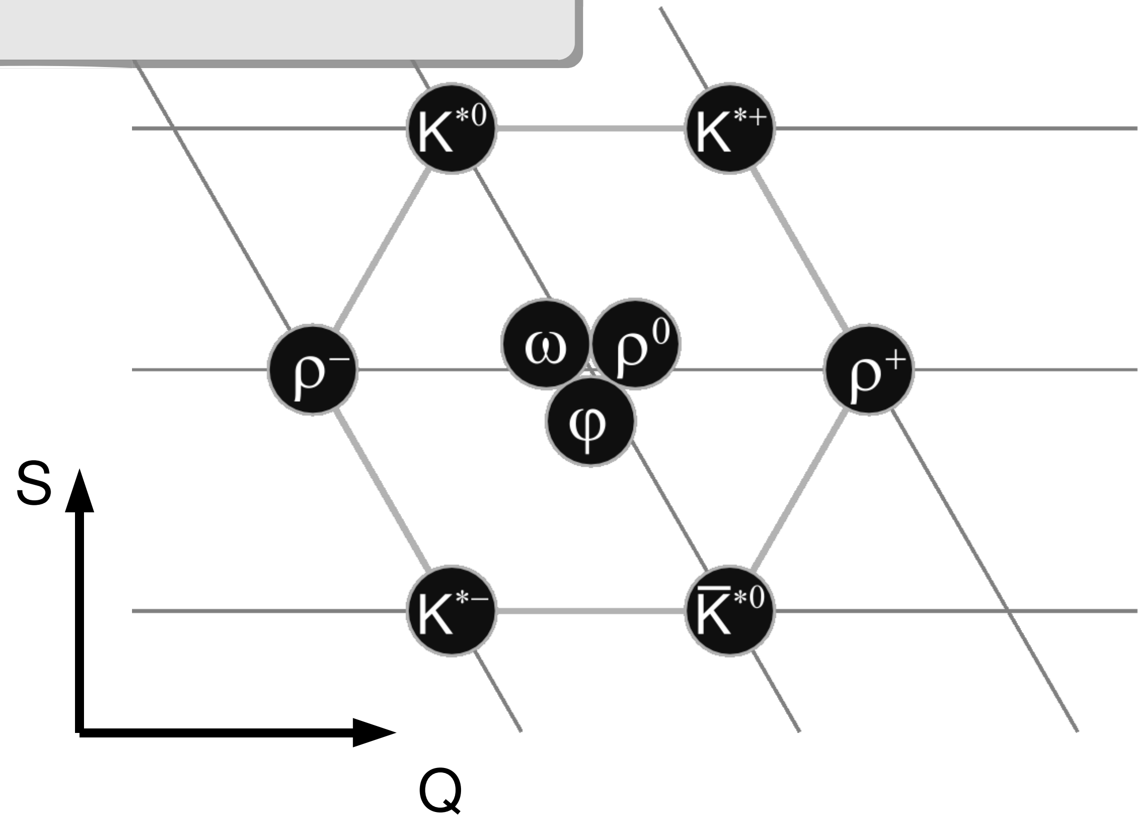
Evidenced 1

Description

Long text format

SU(3) quark model

In $SU(3)_f$ vector meson nonet the three vector f/r0/w could mix.



η/η' mixing

KLOE PLB 648 (2007)

- $\phi \to \eta'\gamma \quad \eta' \to \pi^+\pi^-\eta \quad \eta \to 3\pi^0$
- $\phi \to \eta'\gamma \quad \eta' \to \pi^0\pi^0\eta \quad \eta \to \pi^+\pi^-\pi^0$
- $\phi \to \eta\gamma \quad \eta \to 3\pi^0$

Allowing also for gluonium content in η' we fit the following ratios of BR:

$$\frac{\Gamma(\eta' \to \rho\gamma)}{\Gamma(\omega \to \pi^0\gamma)} = C_{M2} Z_{NS} \left(\sin(\varphi_G)\cos(\varphi_P)\right)^2$$

$$R_\phi = \cot^2(\varphi_P)\cos^2(\varphi_G)\left(1 - C_V \frac{Z_{NS}}{Z_N}\frac{1}{\sin(2\varphi_P)}\right)^2\left(\frac{p_{\eta'}}{p_\eta}\right)^3$$

$$\frac{\Gamma(\eta' \to \gamma\gamma)}{\Gamma(\pi^0 \to \gamma\gamma)} = C_{M1}\left(5\cos(\varphi_G)\sin(\varphi_P) + \sqrt{2}\frac{f_q}{f_s}\cos(\varphi_G)\cos(\varphi_P)\right)^2$$

$$\frac{\Gamma(\eta' \to \omega\gamma)}{\Gamma(\omega \to \pi^0\gamma)} = C_{M3}\left(Z_{NS}\sin(\varphi_G)\cos(\varphi_P) + 2C_V Z_S \sin(\varphi_G)\sin(\varphi_P)\right)^2$$

$$R_\phi = \frac{BR(\phi \to \eta'\gamma)}{BR(\phi \to \eta\gamma)} = 4.77 \pm 0.09 \pm 0.19$$

$$|\eta'\rangle = X_{\eta'}\frac{1}{\sqrt{2}}|u\bar{u} + d\bar{d}\rangle + Y_{\eta'}|s\bar{s}\rangle + Z_{\eta'}|glue\rangle$$

$$|\eta\rangle = \cos\varphi_P \frac{1}{\sqrt{2}}|u\bar{u} + d\bar{d}\rangle + \sin\varphi_P|s\bar{s}\rangle$$

$$X_{\eta'} = \cos\varphi_G \cos\varphi_P$$

$$Y_{\eta'} = \cos\varphi_G \sin\varphi_P$$

$$Z_{\eta'} = \sin\varphi_G$$ $\leftrightarrow$ **Gluonium content**

$$C_V = \frac{m_s}{\bar{m}}\tan(\varphi_V)$$

$$C_{M1} = \frac{1}{9}\left(\frac{m_{\eta'}}{m_{\pi^0}}\right)^3$$

$$C_{M2} = \frac{3}{\cos(\varphi_V)}\left(\frac{m_{\eta'}^2 - m_\rho^2}{m_\omega^2 - m_\pi^2}\frac{m_\omega}{m_{\eta'}}\right)$$

$$C_{M3} = \frac{1}{3}\left(\frac{m_{\eta'}^2 - m_\omega^2}{m_\omega^2 - m_\pi^2}\frac{m_\omega}{m_{\eta'}}\right)$$

Gluonium in η'

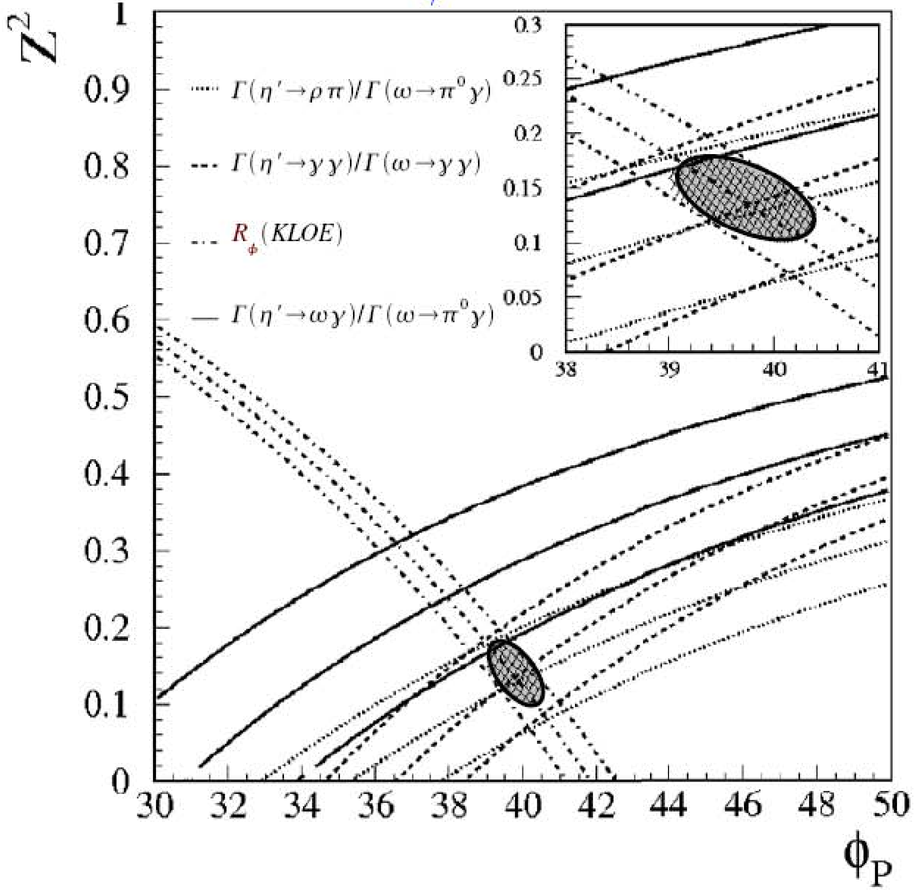
KLOE PLB 648 (2007)

Using as input for the experimental quantity PDG values and our value R_ϕ

$\varphi_P = (39.7 \pm 0.7)^\circ$

$Z^2_G = 0.14 \pm 0.04$

Results obtained with (Z_N Z_{NS}) evaluated assuming **$Z^2_G = 0$** [1].



Further checks:

- **Value stable w.r.t. Z_N / Z_{NS}**
- **Using parameters Z_N / Z_{NS} from [2]**

  (evaluated allowing for gluonium content $Z^2_G \neq 0$) **we obtain $Z^2_G = 0.12$ with same accuracy (still 3σ evidence).**

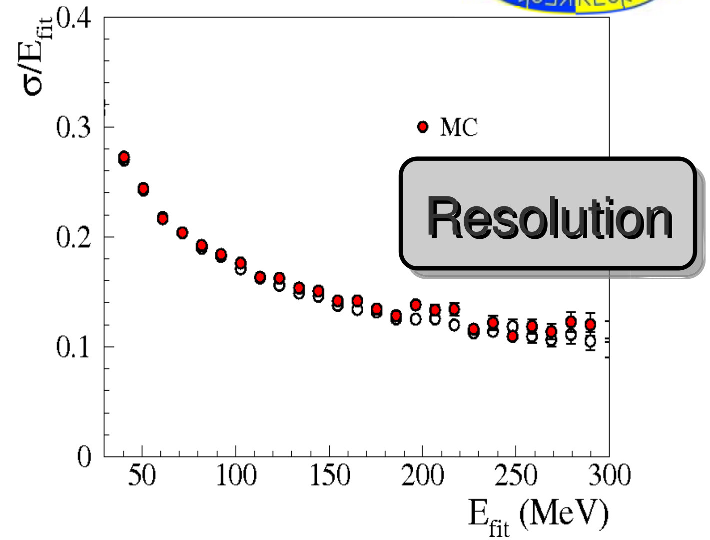
- **A global fit with all parameters is in progress**

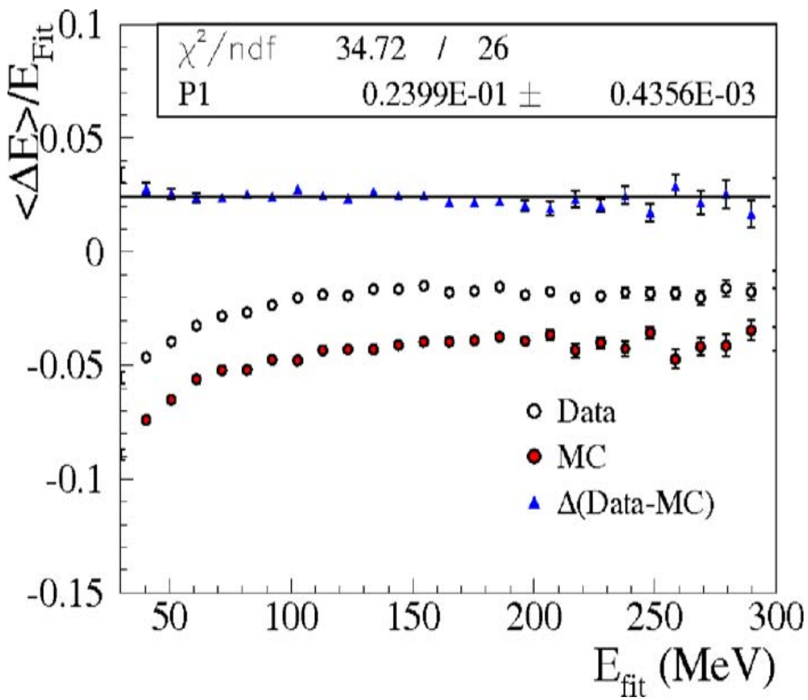
[1] PLB 503 (2001)
[2] JHEP 05 (2007)

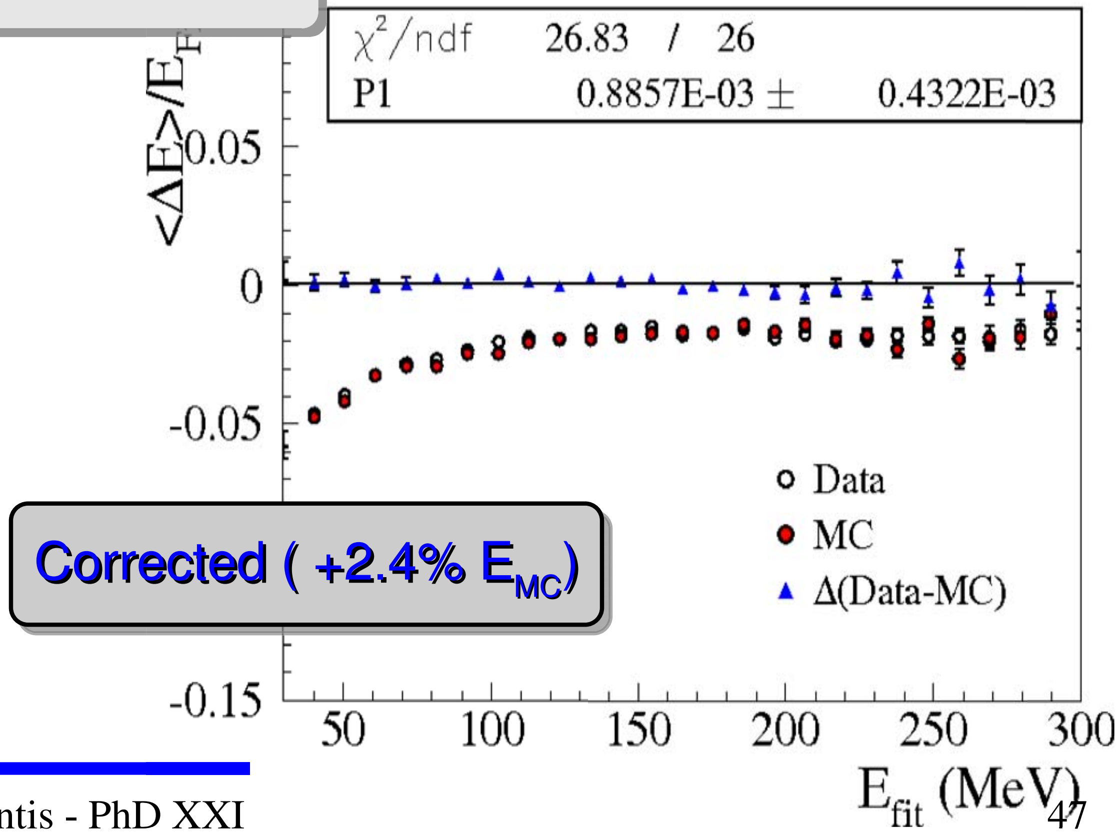
$\omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$: MC energy scale

To analyse the MC energy scale for EMC we have
fitted the kinematic fit pulls ($E_{rec} - E_{fit}$) with simple gaussian for different value of fitted energy

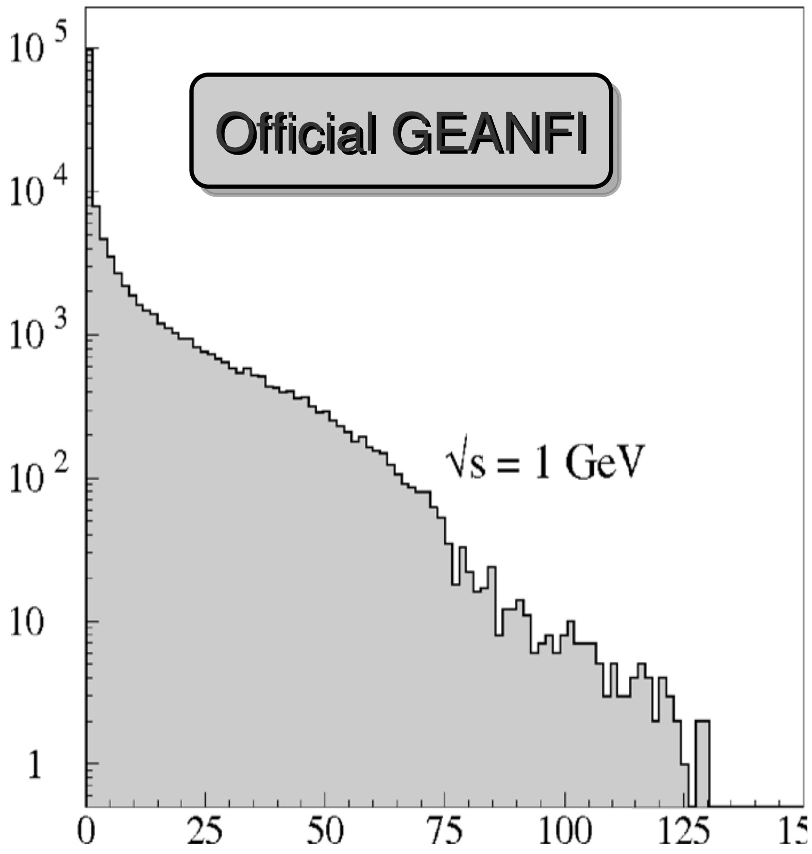
A difference in the scale calibration of 2.4% has been found

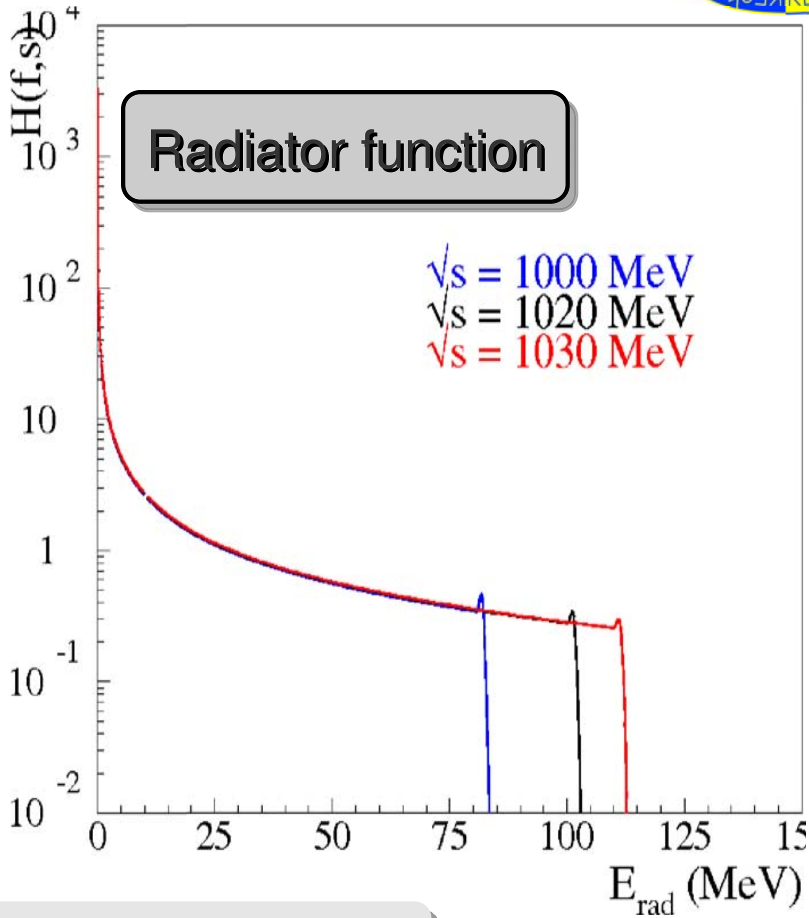






$\omega\pi^0 \rightarrow \pi^+\pi^-\pi^0\pi^0$: ISR Tail





In GEANFI (Official release) the radiative correction (ISR) is badly implemented:

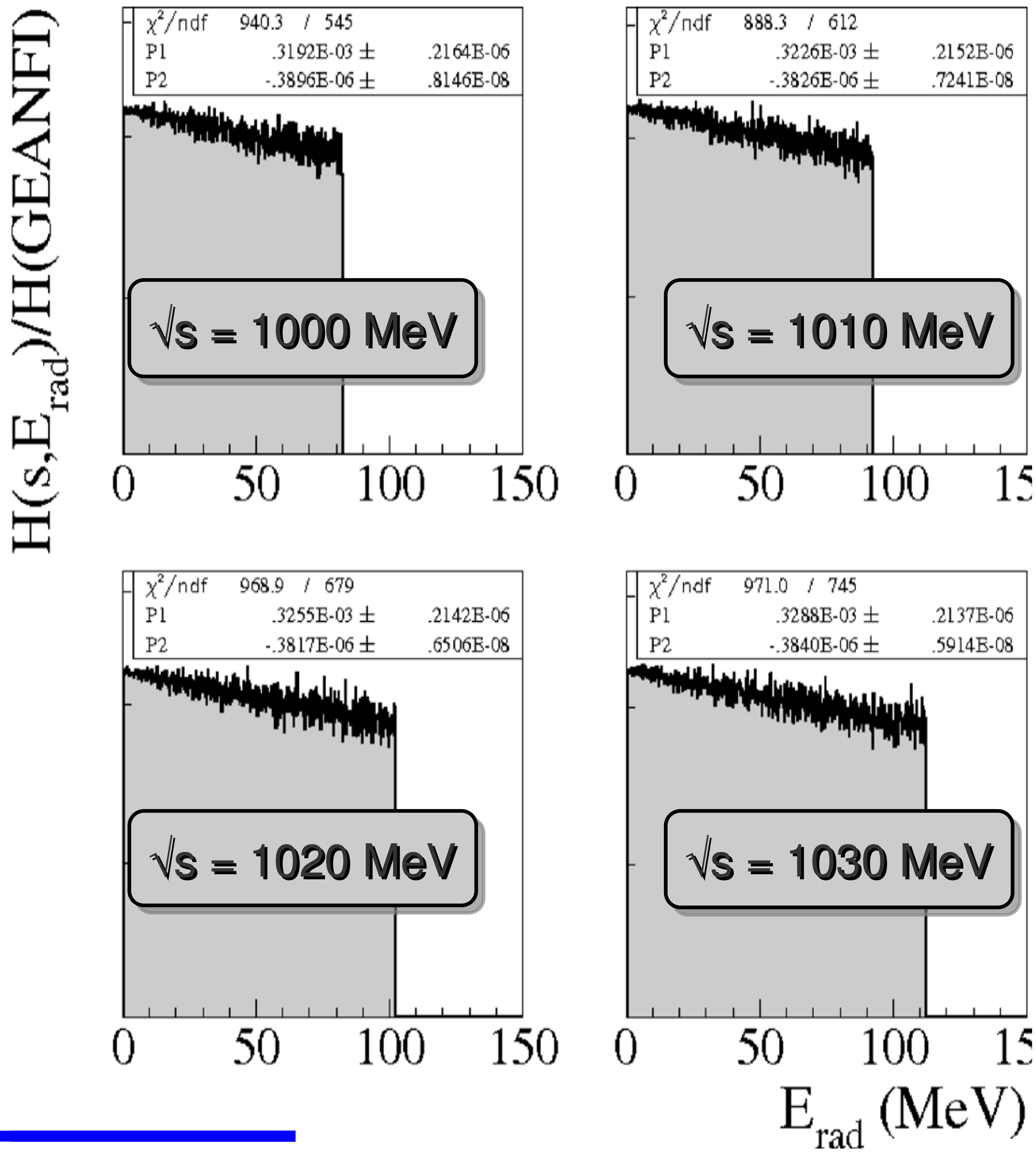
- Maximum radiated energy is fixed (130 MeV)
- Tail not from standard radiator function

Max Radiated energy variation with CoM energy

$\omega\pi^0 \rightarrow \pi^+\pi^-\pi^0\pi^0$: ISR Tail

To correct this effect (~% of the total number of events) we use the ratio of the GEANFI shape and the radiator used in the cross section fit.

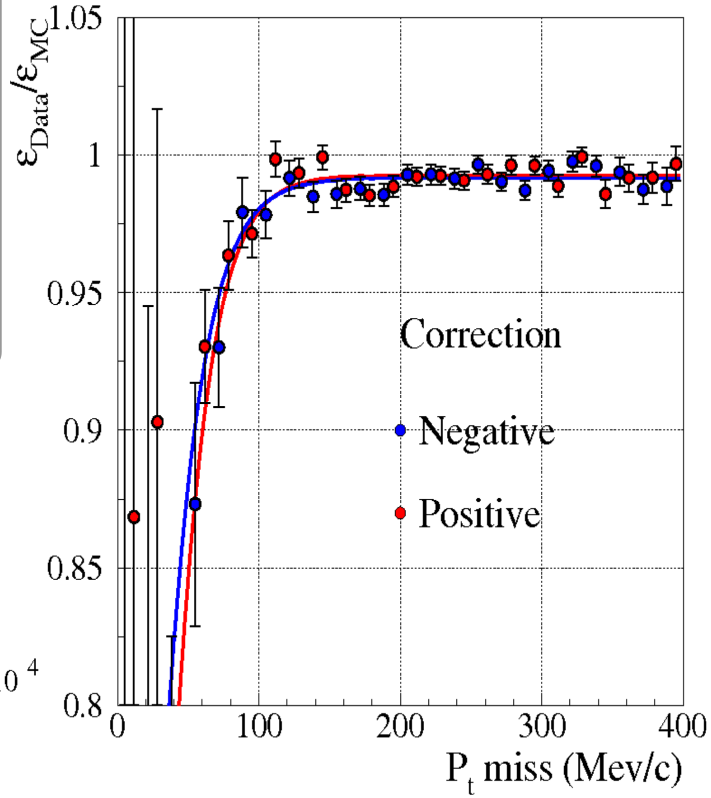
Minimal effect on the global efficiency, small effect on the shape when fitting.



$\omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$: Data/MC tracking efficiency

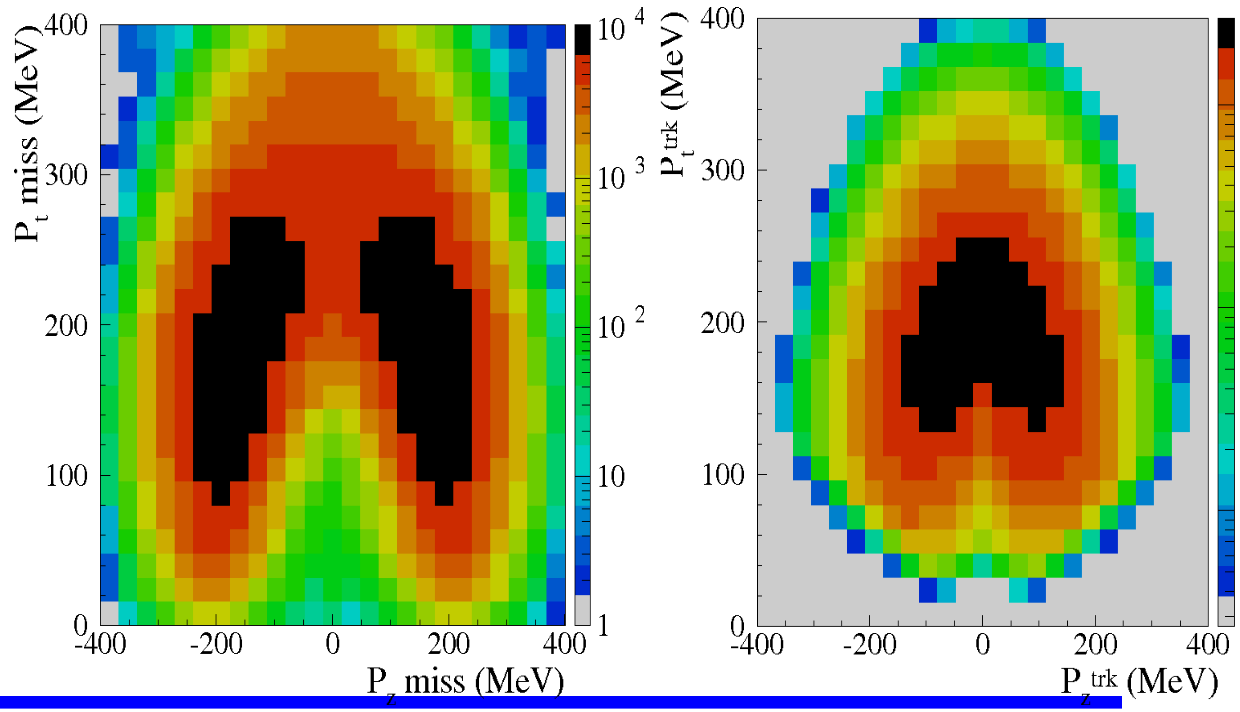
Tracking efficiency (KM343) has been determined both for on-peak and off-peak data using UFO stream [DBV-26]

For on-peak the resulting correction is smaller



Control sample

Signal shape



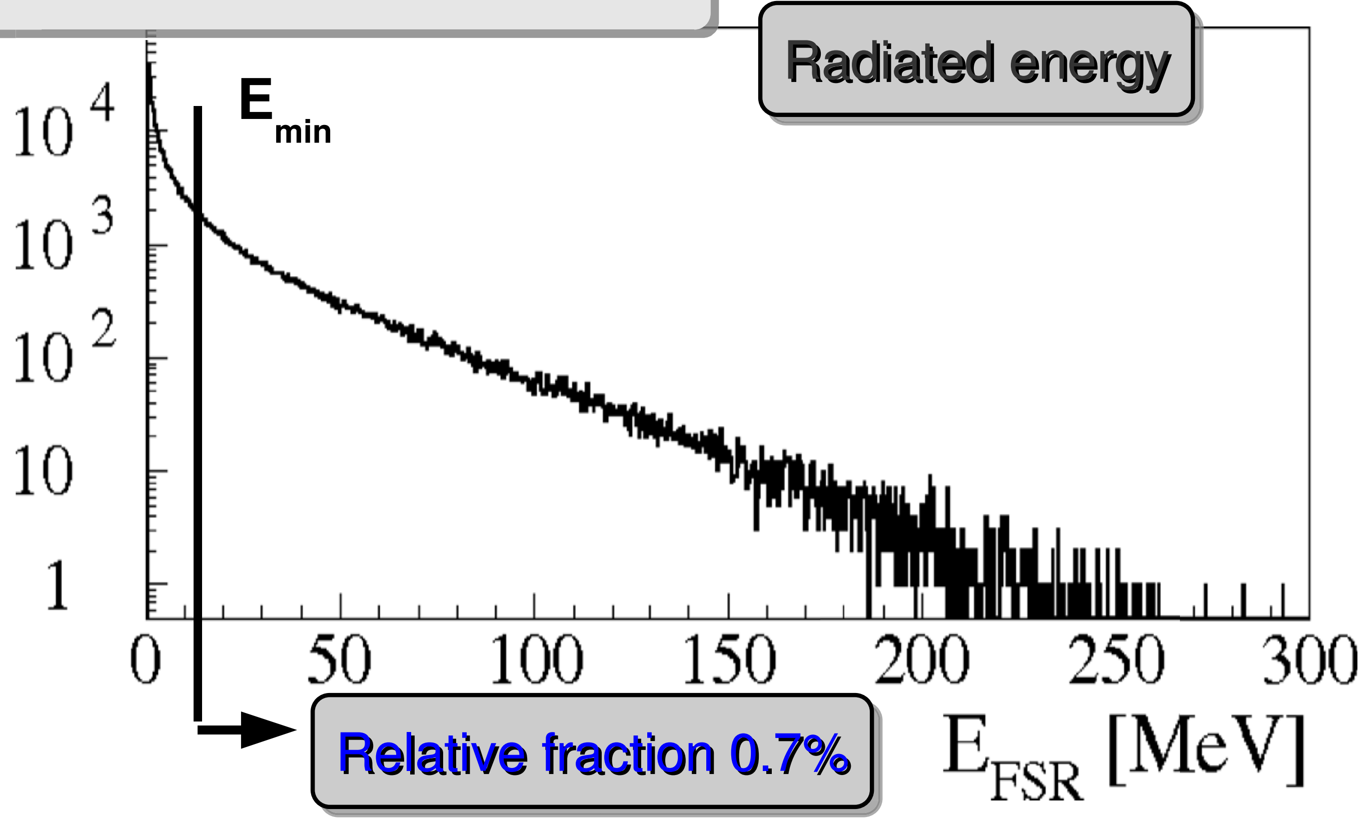
Each slice in Pz of the distribution for Pt-Pz has been fitted with:

$$C_\epsilon = A\left(1 - \frac{1}{1+e^{(X-X_0)/\delta}}\right)$$

FSR

The FSR tail has been obtained with PHOTOS

Variation of the acceptance efficiency assumed as systematics to the absolute normalization (0.7% of the total events has one photon over threshold)



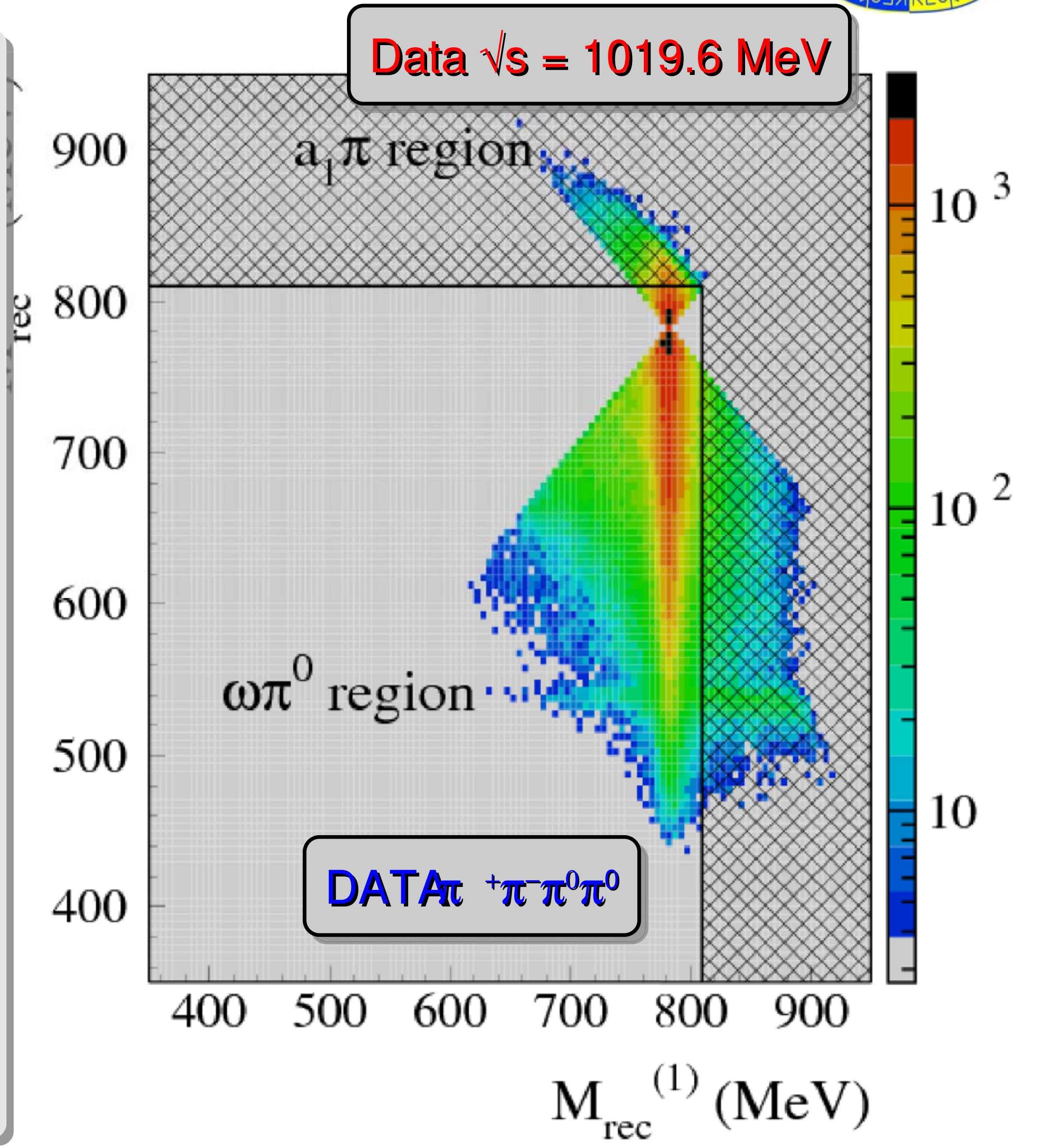
$$\omega\pi^0 \rightarrow \pi^+\pi^-\pi^0\pi^0$$

Sidebands for $a_1\pi \to \pi^+\pi^-2\pi^0$

To select a subsample enriched of $a_1\pi$ candidate we choose in the the plane $M_{recoil}(2)$ vs $M_{recoil}(1)$ events in witch at least one of the reconstructed recoiling masses is greater than 810 MeV ($a_1\pi$ region).

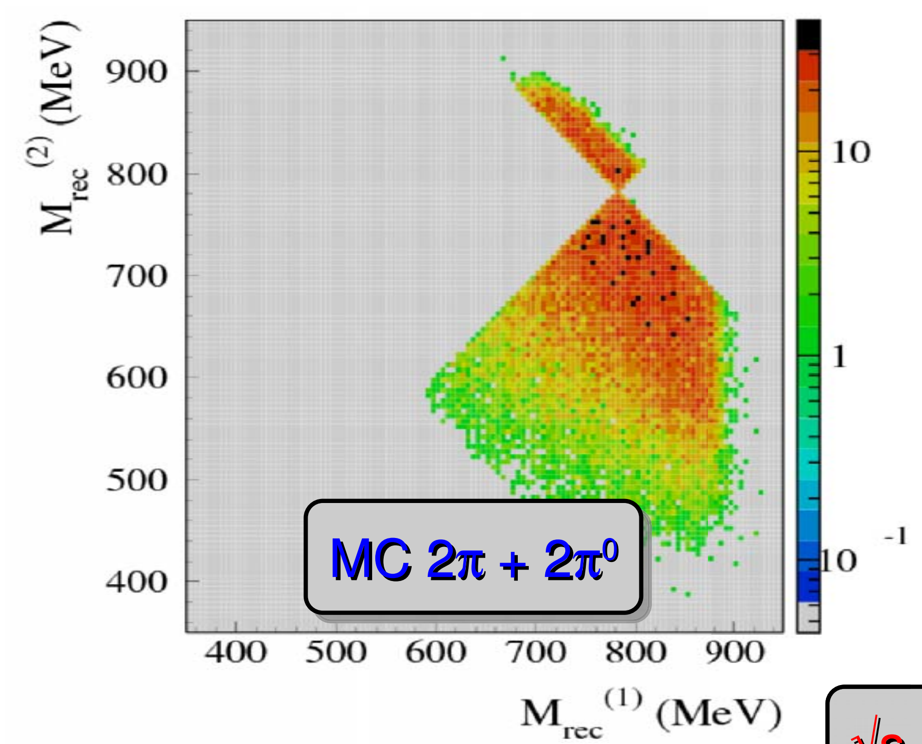
$N_{evt}(a_1\pi$ region) ~ 6÷12 % (off/on peak)

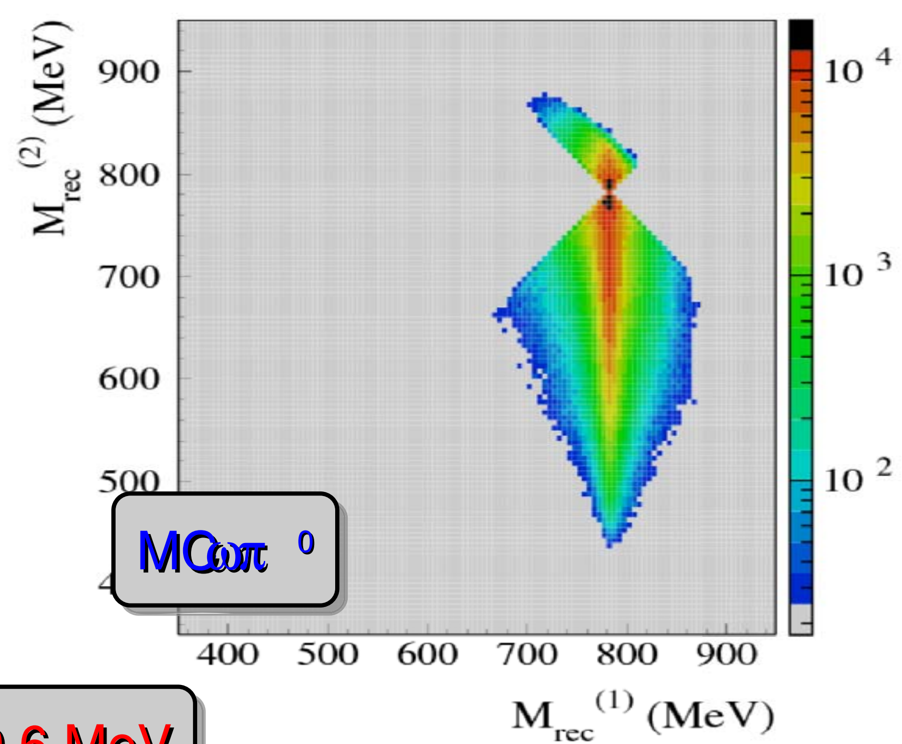
Notes:
The value of M_{recoil} are ordered according to the absolute difference from M_ω



Signal distribution

To evaluate the contribution of $a_1\pi$ we have produced a dedicated MC for all runs used in the analysis (01/02 and 06) including also the run condition simulation via background insertion.





$\sqrt{s}$ = 1019.6 MeV

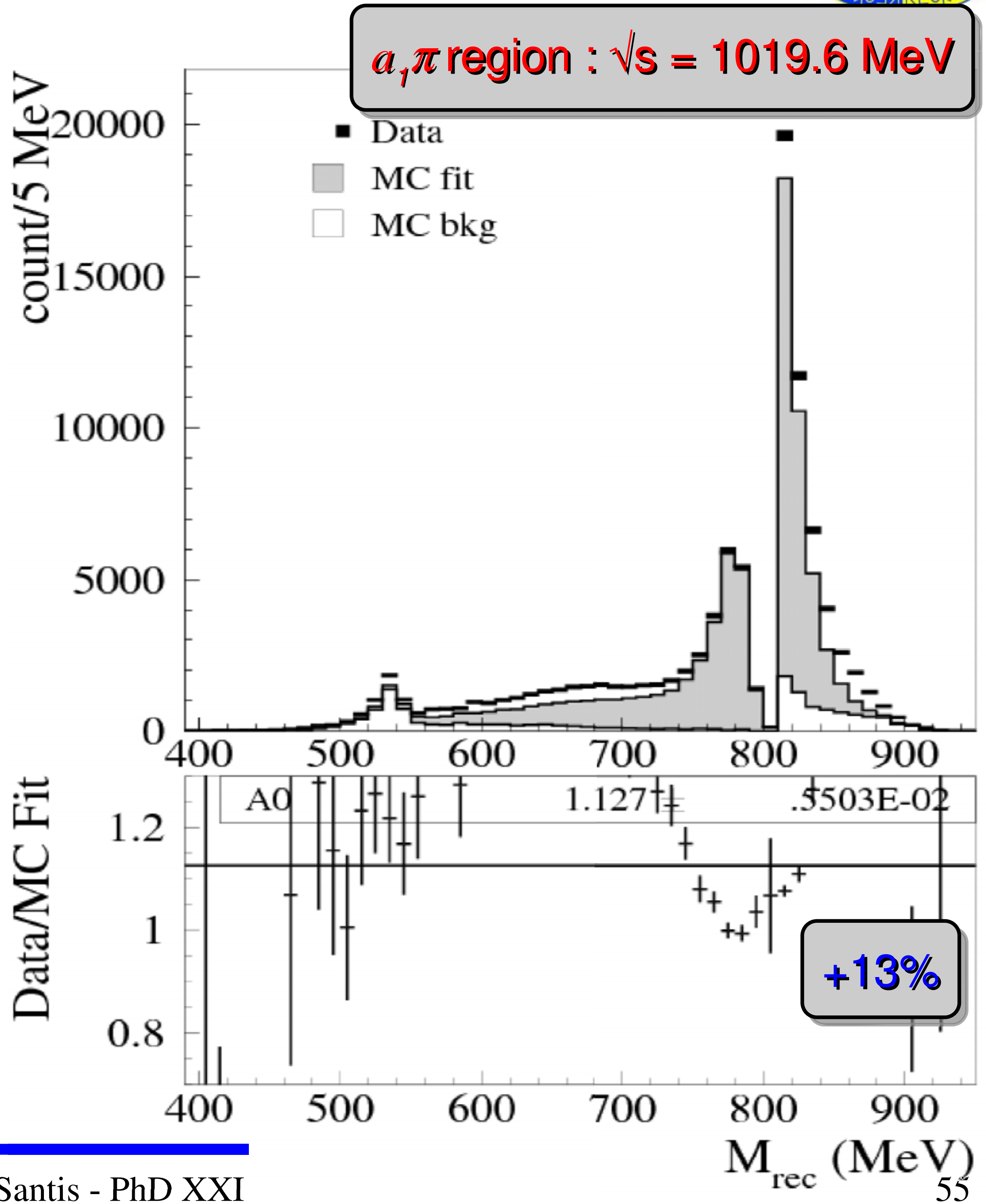
Data-MC comparison in Sideband: OLD

Comparing Data and MC sample selected in "$a_1\pi$ region" using the scale factor for signal and ϕ backgrounds determined with the standard fit (w/o $a_1\pi$ contribution) we observe large disagreement.

The ratio between Data and MC-fit is not flat. This implies that the lacking background has some structure that will help in the fit.

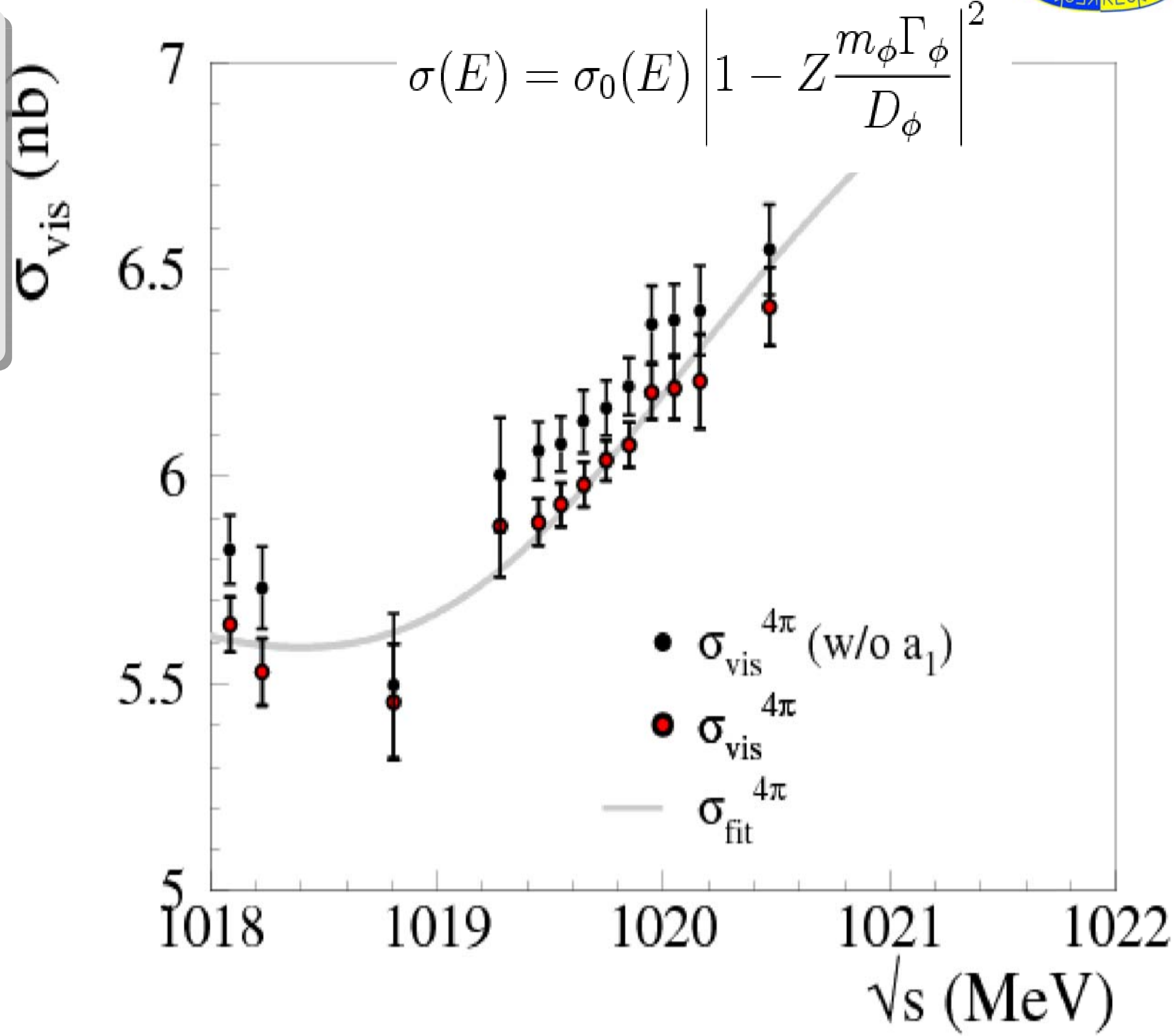
Notes:

M_{rec} is the combinatorial distribution of the two values of M_{recoil}



$\sigma(e^+e^- \to \omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0)(E)$

The cross section variation is almost flat along √s



Systematics of $e^+e^- \to \omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$

Systematics has been calculated by summing in quadrature the r.m.s. obtained for each set of variations considered:

$$\delta_X^{syst} = \sqrt{\sum_{cause} \left(rms_{cause}(X)\right)^2}$$

$$X \equiv \{\sigma_{0,} \Re(Z), \Im(Z), \sigma'\}$$

Contributors

Cause	σ_0 (nb)	$\Re(Z)$	$\Im(Z)$	σ' (nb/MeV)
E_{clu}^{min}	0.023	0.0008	0.0006	0.0005
ϑ_{clu}^{min}	0.047	0.0013	0.0017	0.0007
σ_t	0.046	0.0033	0.0025	0.0005
$\chi^2_{Kfit} cut$	0.013	0.0020	0.0007	0.0005
$\varepsilon_{trk/vtx}$	0.017	0.0004	0.0010	0.0004
Fit distribution	0.005	0.0011	0.0006	0.0005
Total	0.073	0.0043	0.0034	0.0013

$\omega\pi^0 \to \pi^0\pi^0\gamma$

Combined

ω's BR: combined fit

Parameter $(e^+e^- \to \omega\pi^0)$	
$\sigma_0^{4\pi}$ (nb)	7.86 ± 0.05
$\Re(Z_{4\pi})$	0.108 ± 0.006
$\Im(Z_{4\pi})$	-0.102 ± 0.004
$\sigma'_{4\pi}$ (nb/MeV)	0.062 ± 0.003
$\Re(Z_{\pi\pi\gamma})$	0.005 ± 0.013
$\Im(Z_{\pi\pi\gamma})$	-0.157 ± 0.005
Ratio	0.0933 ± 0.0008
$\sigma_0^{\pi\pi\gamma}$ (nb)	0.733
$\sigma'_{\pi\pi\gamma}$ (nb/MeV)	0.0058

Non resonant cross section assumed proportional

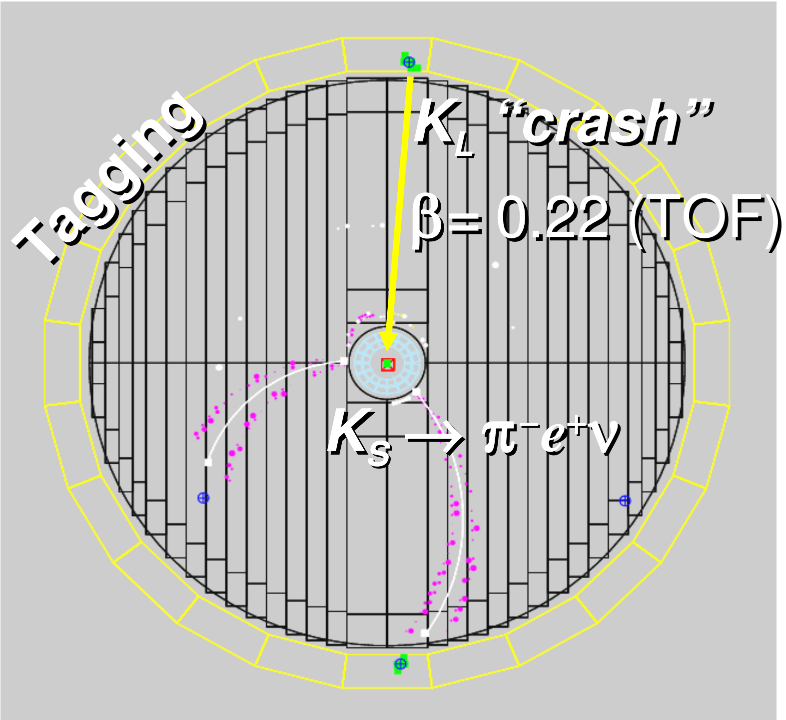
Errors are from fit (no syst)

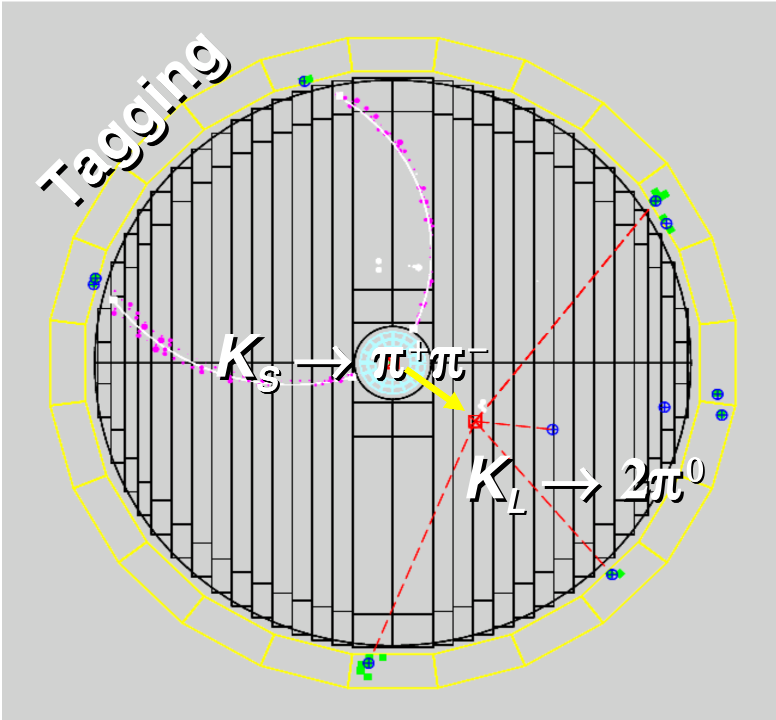
Good agreement wrt separated fit

K neutri in una ϕ-factory: tagging

$e^+e^- \to \phi$ $\sigma_\phi \sim 3.2\ \mu b$ $BR(\phi \to K_S K_L) = 34.1\%$

Tot 3×10^9 coppie di K neutri prodotti nello stato quantico $J^{PC} = 1^{--}$





K_S identificato dall'interazione nel EMC di un K_L

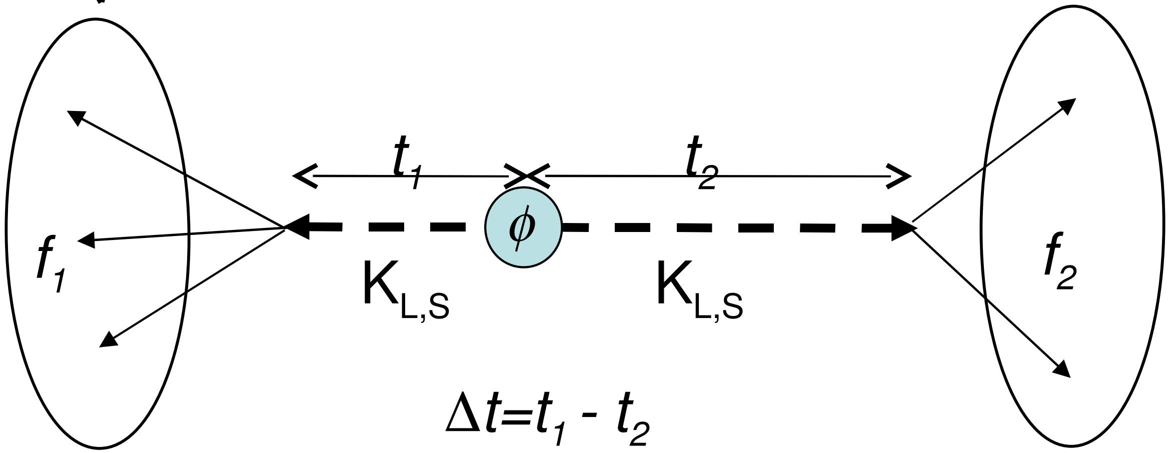
Efficienza ~ 30%

K_L identificato dal decadimento $K_S \to \pi^+\pi^-$ all'IP.

Efficienza ~ 70%

K_0 in una ϕ-factory: evoluzione temporale

$$|i\rangle = \frac{1}{\sqrt{2}}\left(|K_S(\vec{p})\rangle |K_L(-\vec{p})\rangle - |K_L(\vec{p})\rangle |K_S(-\vec{p})\rangle \right)$$



La scelta della coppia di particolari stati finali f_1,f_2 permette di accedere a grandezze sperimentali diverse.

$$ex. \quad \left(\frac{\varepsilon'}{\varepsilon}\right)_{\not{C}\not{P}} \Rightarrow f_1; f_2 \equiv \pi^+\pi^-; \pi^0\pi^0$$