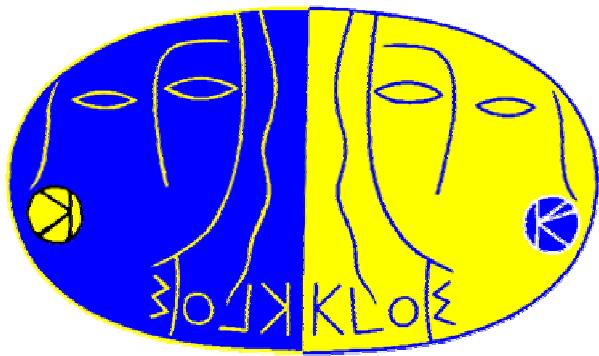


Status of KLOE



E. De Lucia

for the KLOE Collaboration

LNF Scientific Committee

Dec 1st 2003

Outline:

- ◊ MC summary
- ◊ Neutral kaons
- ◊ Charged kaons
- ◊ ϕ decays
- ◊ Hadronic cross section
- ◊ Conclusions

MC production for 2001-2002 analysis

Ambitious program for MC development and production

✓ Comprehensive upgrades

Both MC executable and production procedure affected:

- ◊ Improved detector simulation
- ◊ Inclusion of accidental activity from machine background
- ◊ MC DST's to provide transparent user interface

✓ Each run in data set individually simulated

- ◊ \sqrt{s} , p_ϕ , x_ϕ , background, dead wires, trigger thresholds

✓ Simulated event samples statistically comparable to data

$\phi \rightarrow \text{all}$ 450 pb^{-1} at 1:5 Lum scaled 255 Mevents

$\phi \rightarrow K_S K_L$ 450 pb^{-1} at 1:1 Lum scaled 410 Mevents

MC production status

Generation	Events requested	Time (CPU days)	Size (TB)
$\phi \rightarrow \text{all}$	255M 450 pb ⁻¹ , 1:5	1100 (375 ms/ev)	6.9
e ⁺ e ⁻ → ππγ PHOKHARA 3.0	36M 140 pb ⁻¹ , 5:1	110 (264 ms/ev)	0.8
$\phi \rightarrow K_S K_L$	410M 450 pb ⁻¹ , 1:1	1800 (375 ms/ev)	11.0

Radiative ϕ decays, radiative bhabhas and $\phi \rightarrow 3\pi$ presently under generation

Kaon physics at KLOE

$K_S \rightarrow \pi e \nu$

Phys. Lett. B537 21 (2002)

Preliminary update with 2001-2002 data

$K_S \rightarrow \pi^0 \pi^0 \pi^0$

Preliminary results

$K_L \rightarrow \gamma\gamma / K_L \rightarrow 3\pi^0$

Phys. Lett. B566 61 (2003)

τ_{KL} from $K_L \rightarrow 3\pi^0$

Preliminary results

$K_L \rightarrow$ charged

Preliminary results

$K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$

hep-ex/0307054 *submitted to Phys. Lett. B*

$K^\pm \rightarrow \mu\nu$

Preliminary results

$K^\pm \rightarrow \pi^\pm \pi^0$

$K^\pm \rightarrow \pi^0 \pi^0 e^\pm \nu$

Preliminary results

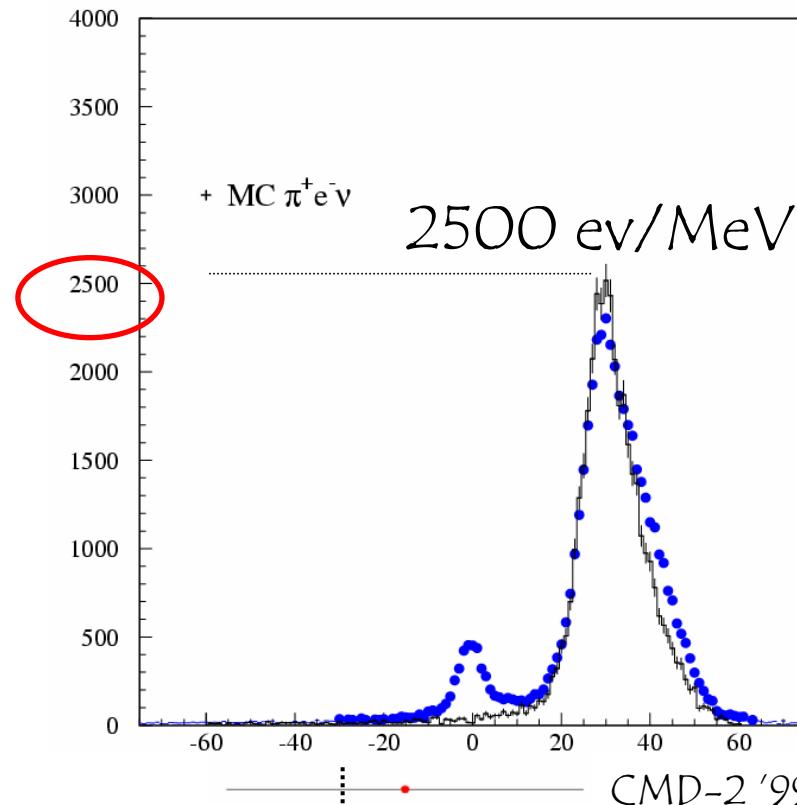
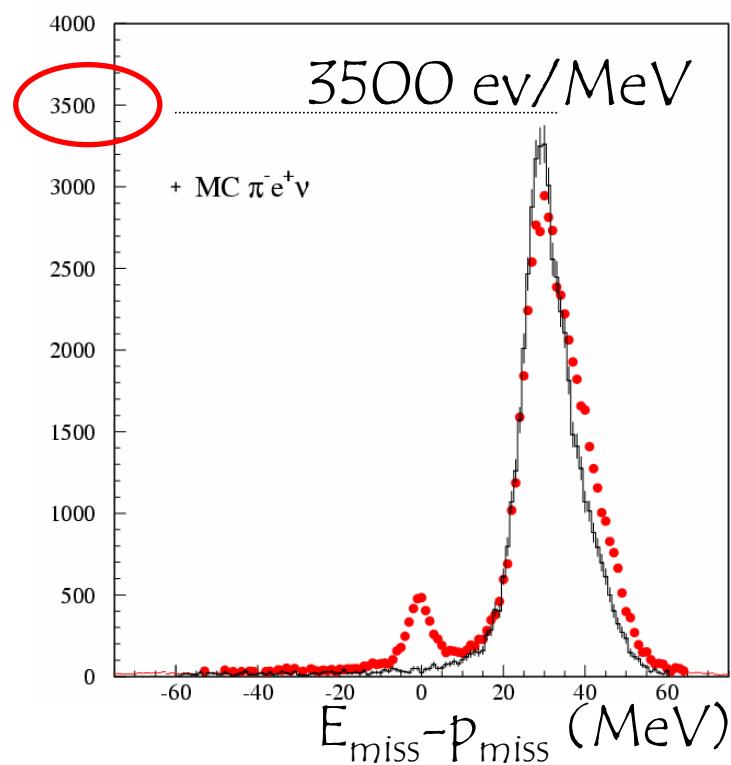
V_{us}

Prospects & preliminary results

1) Neutral Kaons

$K_S \rightarrow \pi^- e^+ \nu, \pi^+ e^- \nu$: situation June '03

Different efficiencies and systematic uncertainty from shape

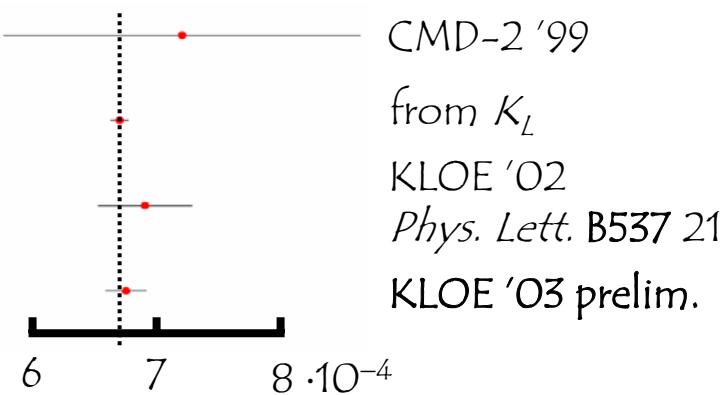


KLOE preliminary (170 pb⁻¹ '01 data)

$$\text{BR}(\pi^- e^+ \nu) = (3.46 \pm 0.09 \pm 0.06) \cdot 10^{-4}$$

$$\text{BR}(\pi^+ e^- \nu) = (3.33 \pm 0.08 \pm 0.05) \cdot 10^{-4}$$

$$\text{BR}(\pi^\mp e^\pm \nu) = (6.81 \pm 0.12 \pm 0.10) \cdot 10^{-4}$$



Radiative corrections

- ✓ New MC generators for $\pi\pi$ and K_{e3} decays including radiated photon, without any cutoff on the energy.
- ✓ The fraction of events in the tail is in agreement with present experimental knowledge:

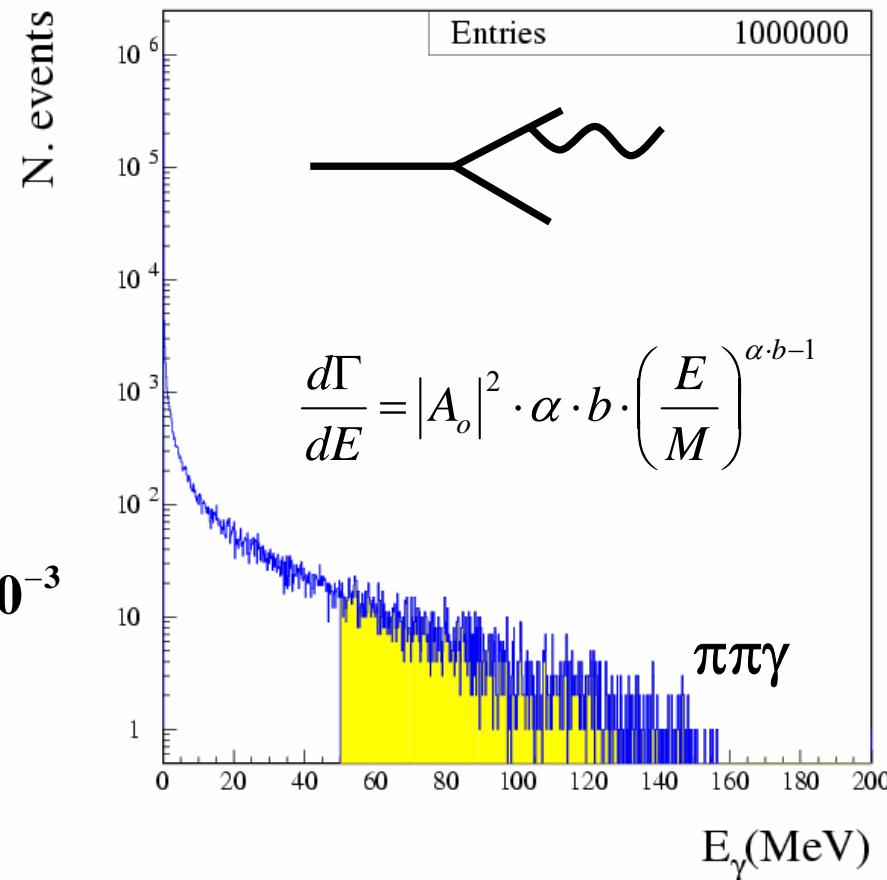
$$N(E_\gamma > 50 \text{ MeV}) / N_{\text{TOT}} = 2.6 \times 10^{-3}$$

$$\frac{K_S \rightarrow \pi\pi\gamma (> 50 \text{ MeV})}{K_S \rightarrow \pi\pi} = (2.59 \pm 0.07) \times 10^{-3}$$

- ✓ Radiative corrections needed for V_{us} :

$$\Gamma(K_{e3}) \rightarrow \Gamma(K_{e3}) \cdot (1 + \delta) \quad \delta = \pm 1\%$$

$$|V_{us}|^2 |f_+(\mathbf{0})|^2 \propto \Gamma(K_{e3})$$



π^- vs π^+

"Pezzetto"

π^- and π^+ have:

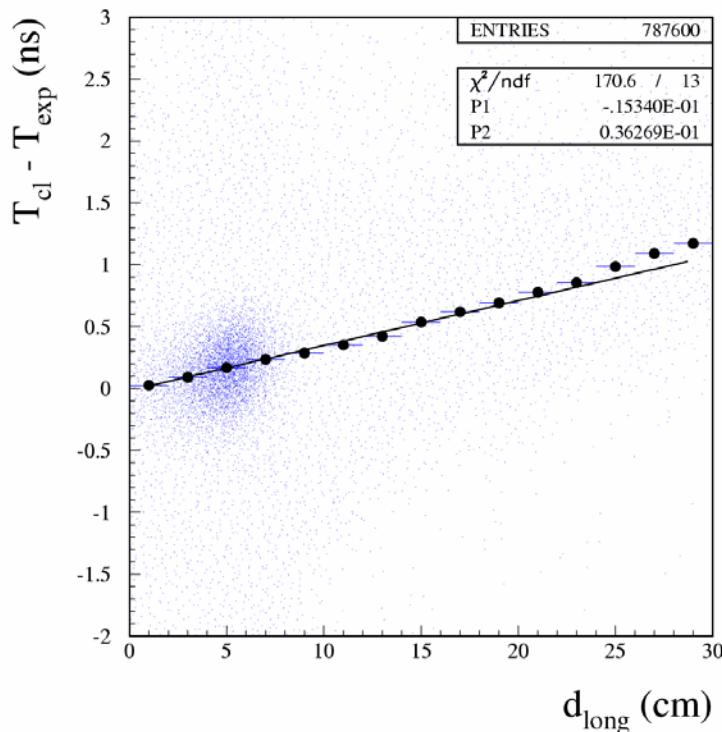
- ❖ different paths in the calorimeter
- ❖ different time delays for fixed path \Rightarrow ID from TOF
- ❖ DATA and MC were not in agreement
 \rightarrow fix

Parametrization of these effects using
DATA and MC control samples

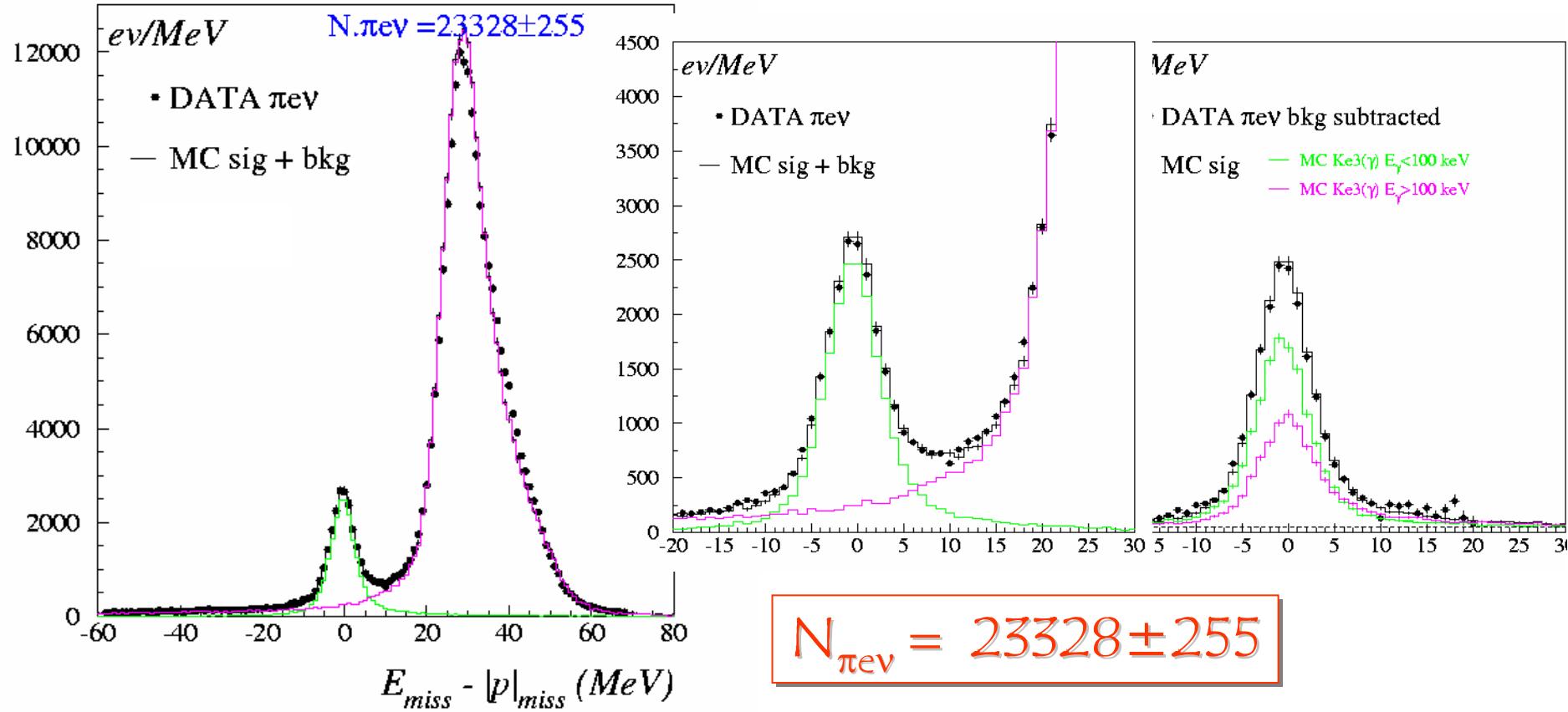
$$\Delta t(ns) = a(ns) + b(ns/cm)R_{centroide}$$

~ 1 ns effect compared to 8 ns TOF

slice det barr $P_{TRK} = 200.$ (MeV) data part π^+



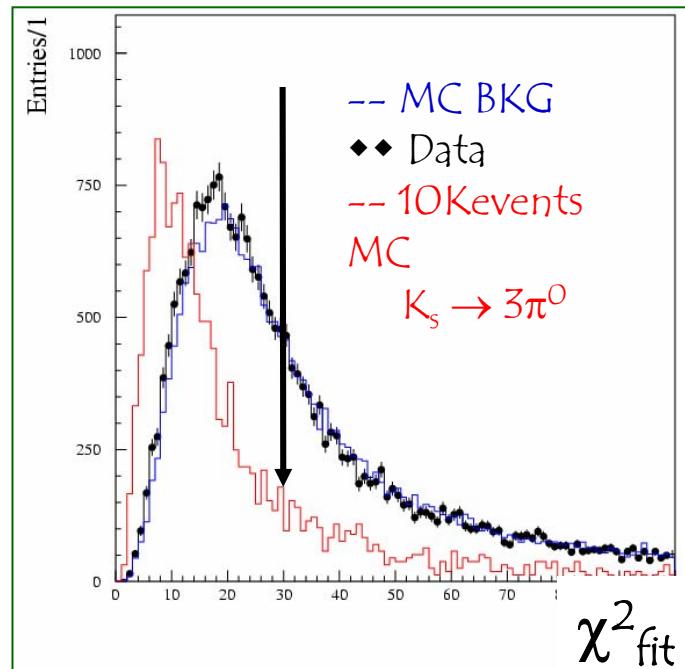
$K_S \rightarrow \pi^- e^+ \nu, \pi^+ e^- \nu$: present situation



- ◊ improved agreement between DATA/MC shape
- ◊ lower discrepancies between different charges
- ◊ fit stability vs $(E_{\text{miss}} - |p|_{\text{miss}})$ range: ΔN_{sig} below statistical accuracy
1% fractional error on counts implies :
0.5% fractional error on V_{us} and 0.01 absolute error on A

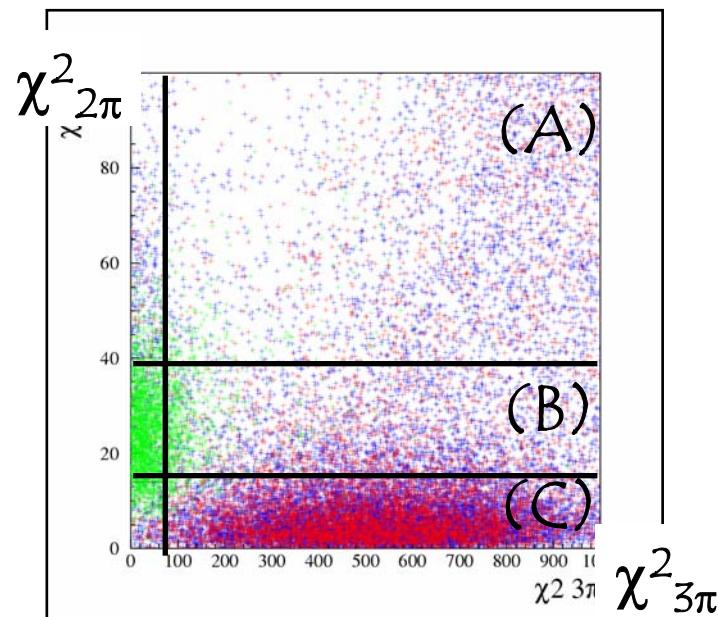
Search for $K_s \rightarrow 3\pi^0$

- ◆ 450 (400) pb^{-1} data (MC) sample analyzed
- ◆ Preselection:
 - K_L interacting in EMC "K_{crash}" ($\epsilon \approx 30\%$)
 - 6 neutral clusters with $E > 7 \text{ MeV}$, $\Delta t < 3.5\sigma_t$, $\theta > 22.5^\circ$ ($\epsilon \approx 58\%$)
- ◆ Normalization: $K_{\text{crash}} + 4\gamma \rightarrow 23.6 \times 10^6$
- ◆ Starting sample of $6\gamma \rightarrow 39728$



Analysis steps

- Kinematic fit on K_s side constraining to the expected K_L momentum from K_{crash}
- To increase signal/noise ratio we construct two pseudo- χ^2 to disentangle between:
 - 1) $K_s \rightarrow 2\pi^0 + \text{accidental/splitting}$ ($\chi^2_{2\pi}$)
 - 2) $K_s \rightarrow 3\pi^0$ events ($\chi^2_{3\pi}$)



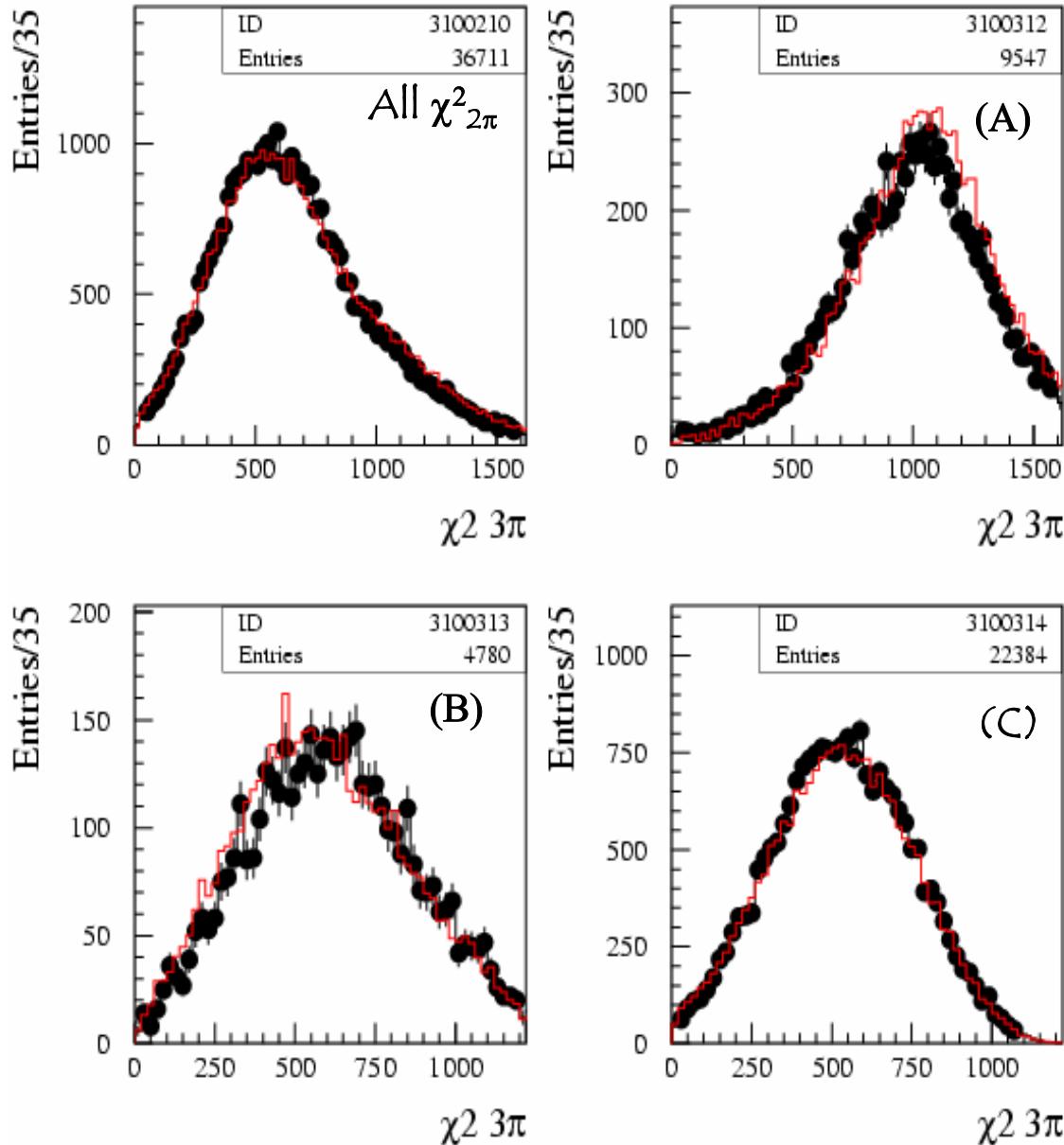
Data-MC comparison of $\chi^2_{3\pi}$ projections

- MC calibration performed without cutting on χ^2_{fit}

- $\approx 3\%$ "fake" K_{crash} found (dominated by $K_s \rightarrow \pi^+ \pi^-$, $K_L \rightarrow 3\pi^0$)

→ Track veto needed

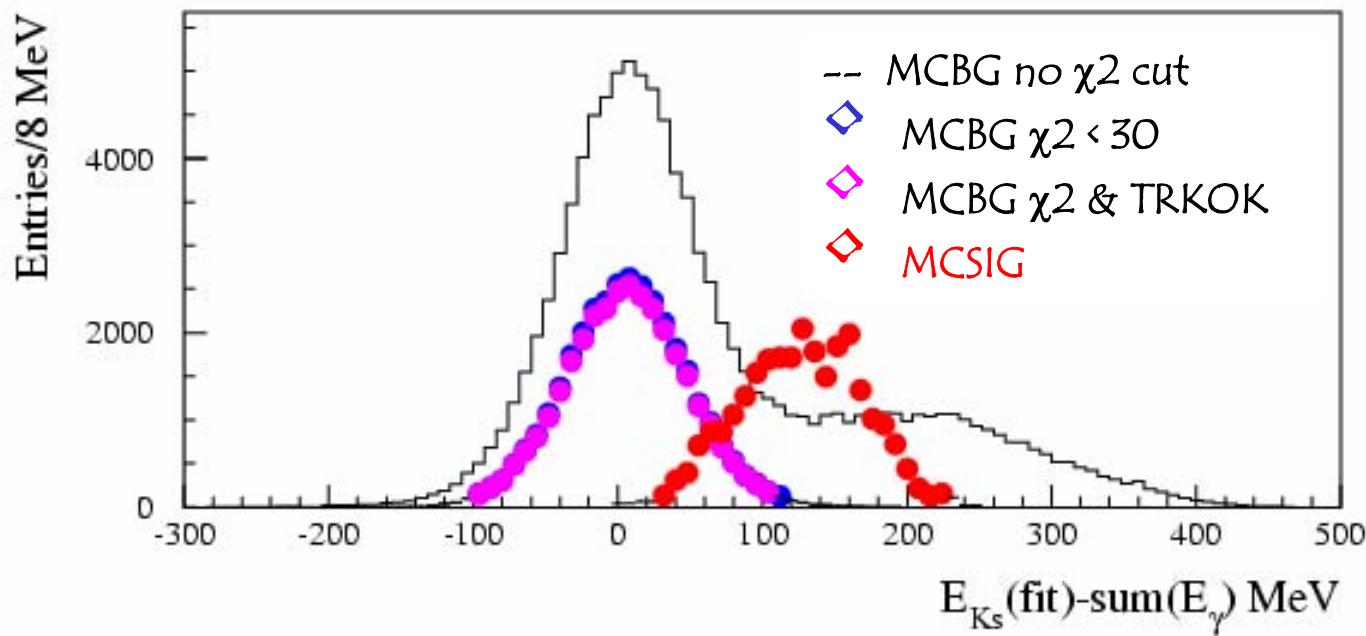
- $\chi^2_{\text{fit}} < 30$
- TRACK Veto:
Rejecting events with tracks coming from interaction region: $p(\text{PCA}) < 4 \text{ cm}$
 $Z(\text{PCA}) < 10 \text{ cm}$



Last kinematic cut

After finding the 4 γ satisfying the $K_s \rightarrow 2\pi^0$ kinematics (by $\chi^2_{2\pi}$) we evaluate the residual energy on the K_s side:

$$\Delta E(K_s) = E_{K_s}(\text{KineFit}) - \sum E_\gamma$$



- Cutting all events with $\Delta E(K_s) < 10$ MeV we retain full efficiency on $K_s \rightarrow 3\pi^0$
- $\epsilon(K_s \rightarrow 3\pi^0) (\text{Acc} * S_{\text{box}} * \text{Trk}_{\text{Veto}} * \Delta E) = 26\%$ after K_{crash} tagging

Search for $K_s \rightarrow 3\pi^0$: preliminary result

OBSERVED candidates
EXPECTED bkg

5
 3.1 ± 1.9

VERY PRELIMINARY

Using for upper limit a conservative BKG estimate $\mu - 1\sigma \rightarrow N < 7.6$
Normalizing to $BR(K_s \rightarrow 2\pi^0)$

KLOE preliminary

$BR(K_s \rightarrow 3\pi^0) < 2.2 \times 10^{-7}$ @ 90% CL

NA48 indirect search (fitting interference with $K_L \rightarrow 3\pi^0$)

$BR(K_s \rightarrow 3\pi^0) < 1.4 \times 10^{-6}$ @ 90% CL

$BR(K_s \rightarrow 3\pi^0) < 3.0 \times 10^{-7}$ @ 90% CL (assuming CPT)

- ❖ Upper limit can still be improved selecting a better S_{BOX} and ΔE cut using MC
- ❖ Efficiency and systematic errors still under scrutiny

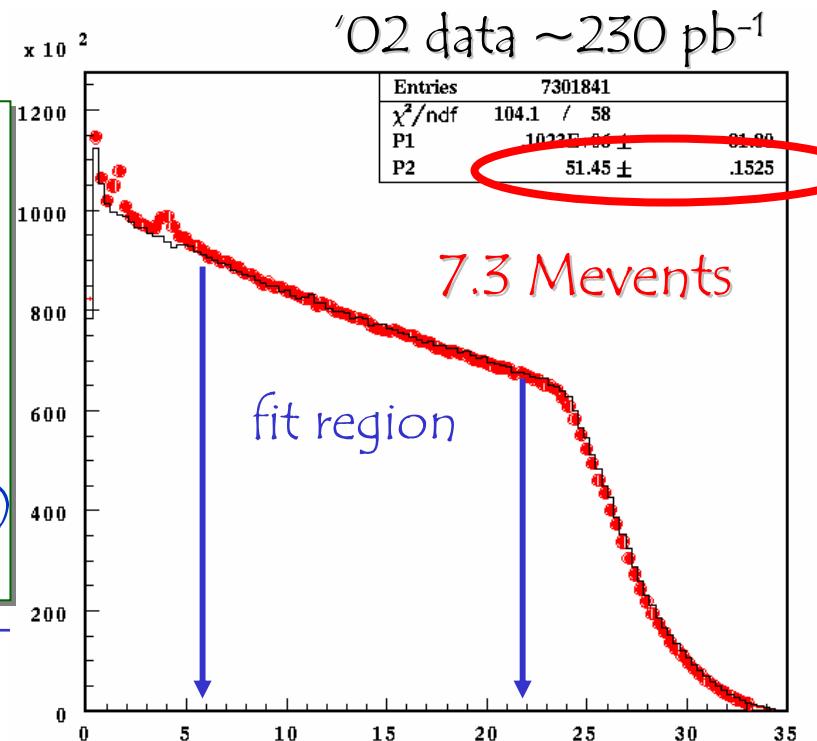
τ_{KL} from $K_L \rightarrow \pi^0\pi^0\pi^0$

Towards $\Gamma(K_L)$ and V_{us} measurement

Selection

- tag with $K_S \rightarrow \pi^-\pi^+$
- at least 3 neutral cluster in EMC
- neutral vertex reconstruction and $3\pi^0$

selection as for $\Gamma(K_L \rightarrow \gamma\gamma) / \Gamma(K_L \rightarrow \pi^0\pi^0\pi^0)$



$$\tau(\text{KLOE}) = (51.45 \pm 0.15_{\text{stat}}) \text{ ns}$$

$$\tau(\text{PDG}) = (51.7 \pm 0.4) \text{ ns}$$

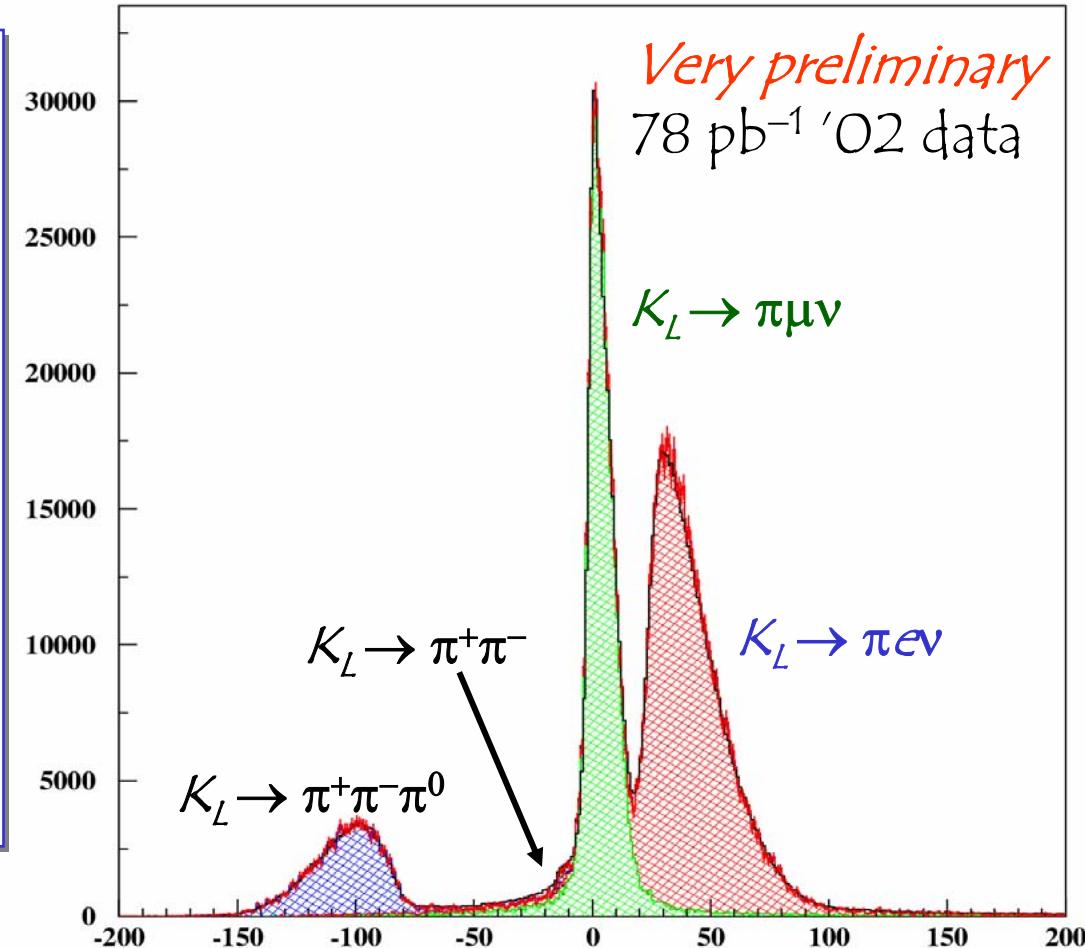
$$\tau(\text{Vosburg, '72}) = (51.54 \pm 0.44) \text{ ns} \quad 0.4 \text{ Mevents}$$

- ❖ With 400 pb^{-1} we can reach a statistical accuracy of 0.2%
- ❖ Systematics to be evaluated

$K_L \rightarrow$ charged particles

- ✓ tracking efficiencies from $K_L \rightarrow \pi^+\pi^-\pi^0$ and K_{e3} samples
 - ✓ tag bias checked:
 - ◊ stability vs different tags
 - ◊ stability vs decay volume
 - ✓ shapes:
 - ◊ $K_{e3}\gamma$ generator
 - ◊ resolutions checked with independent method (PID)
- insert $K_{\mu 3}\gamma$ generator
 → finalize systematics

BR	KLOE
$K_L \rightarrow \pi^+\pi^-\pi^0$	0.132 ± 0.002
$K_L \rightarrow \pi\mu\nu$	0.271 ± 0.002
$K_L \rightarrow \pi e\nu$	0.384 ± 0.002

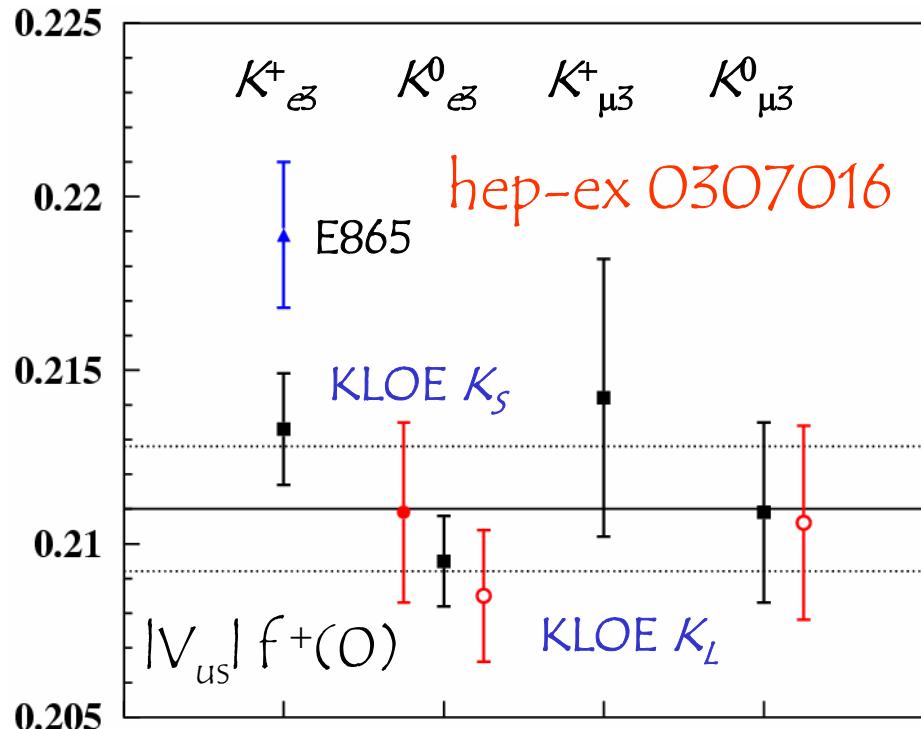


Lesser of $P_{\text{miss}} - E_{\text{miss}}$ in $\pi\mu$ or $\mu\pi$ hyp. (MeV)

BR($K_L \rightarrow \pi^+\pi^-$), similar analysis:
 KLOE $(2.04 \pm 0.04) \times 10^{-3}$
 PDG '02 $(2.084 \pm 0.032) \times 10^{-3}$

Errors are statistical only! (including MC statistics)

V_{us} from $K_{\ell 3}$ decays



For K_{e3} modes:

$$\frac{\delta |V_{us}|}{|V_{us}|} = \underbrace{\frac{1}{2} \left(\frac{\delta \text{BR}}{\text{BR}} \right)}_{\text{exp}} \oplus \underbrace{\frac{1}{2} \left(\frac{\delta \tau}{\tau} \right)}_{\text{exp}} \oplus \underbrace{\frac{1}{20} \left(\frac{\delta \lambda_+}{\lambda_+} \right)}_{\text{th}} \oplus \underbrace{\frac{f_+(0)}{\delta f_+(0)}}_{\text{th}}$$

$$|V_{us}| = 0.2201 \pm 0.0019_{\text{exp}} \pm 0.0018_{\text{th}}$$

Old data (Chiang '72) or PDG fit values
Inclusiveness for $K_{e3}\gamma$ and $K_{\mu 3}\gamma$?

KLOE preliminary $K_s \rightarrow \pi \nu \bar{\nu}$ 170 pb⁻¹
Consistent with previous measurements

KLOE preliminary $K_L \rightarrow \pi \ell \nu$ 78 pb⁻¹
Also confirms previous measurements

KLOE will have $\text{BR}(K^{+}_{e3})$ by Spring

KLOE will measure *all* BR's to 0.1% level and can also significantly improve λ_+ , λ_0 , τ_L

$1.2\% \oplus 0.2\% \oplus 0.3\%$	$K^+ e 3$
$0.7\% \oplus 0.8\% \oplus 0.3\%$	$K^0 e 3$

A first look at interference

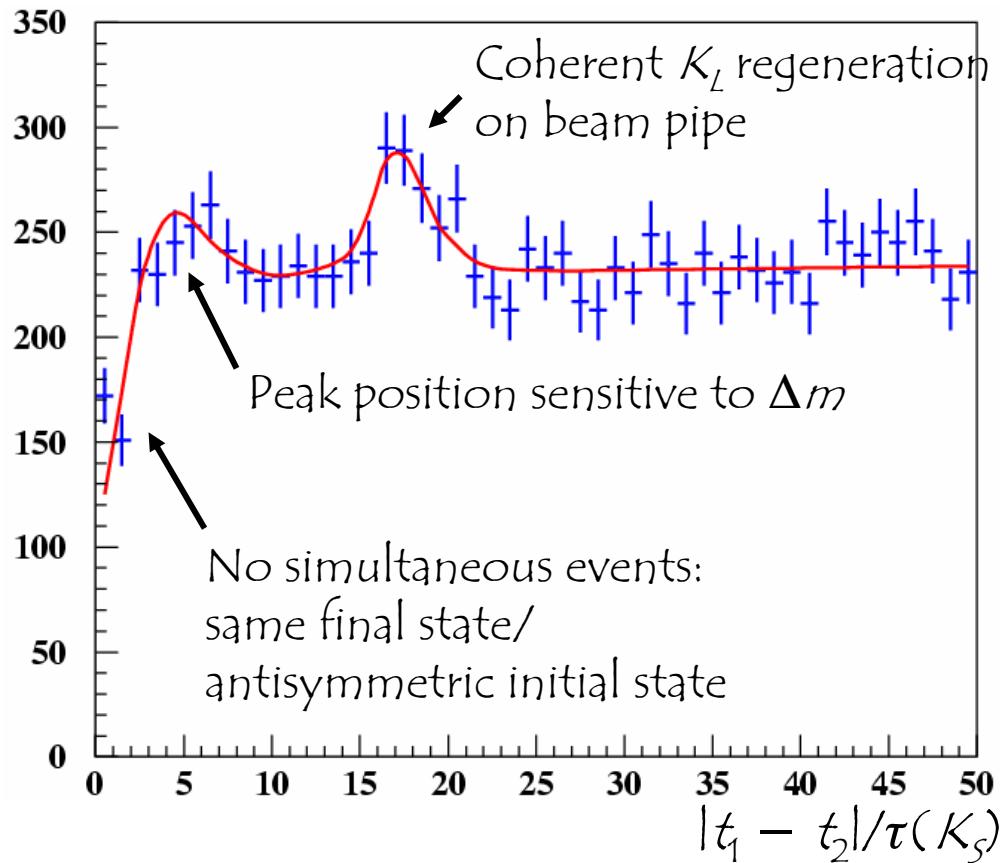
$$K_S K_L \rightarrow \pi^+ \pi^- \pi^+ \pi^- : |A(\Delta t)|^2 \propto e^{-\Gamma_L |\Delta t|} + e^{-\Gamma_S |\Delta t|} - 2e^{-(\Gamma_S + \Gamma_L) |\Delta t|/2} \cos(\Delta m \Delta t)$$

KLOE preliminary
340 pb⁻¹ '01 + '02 data

Fit with PDG values for Γ_S , Γ_L
 $\chi^2/\text{d.o.f.} = 43.7/47$

$\Delta m = (5.64 \pm 0.37) \times 10^{-11} \text{ } \hbar \text{ s}^{-1}$
PDG '02: $(5.301 \pm 0.016) \times 10^{-11} \text{ } \hbar \text{ s}^{-1}$

First observation of quantum
interference in relative decay-
time distribution of K_S , K_L



2) Charged Kaons

Event selection

1) Tag on one side with $K \rightarrow \mu\nu$ or $K \rightarrow \pi\pi$

Preselection:

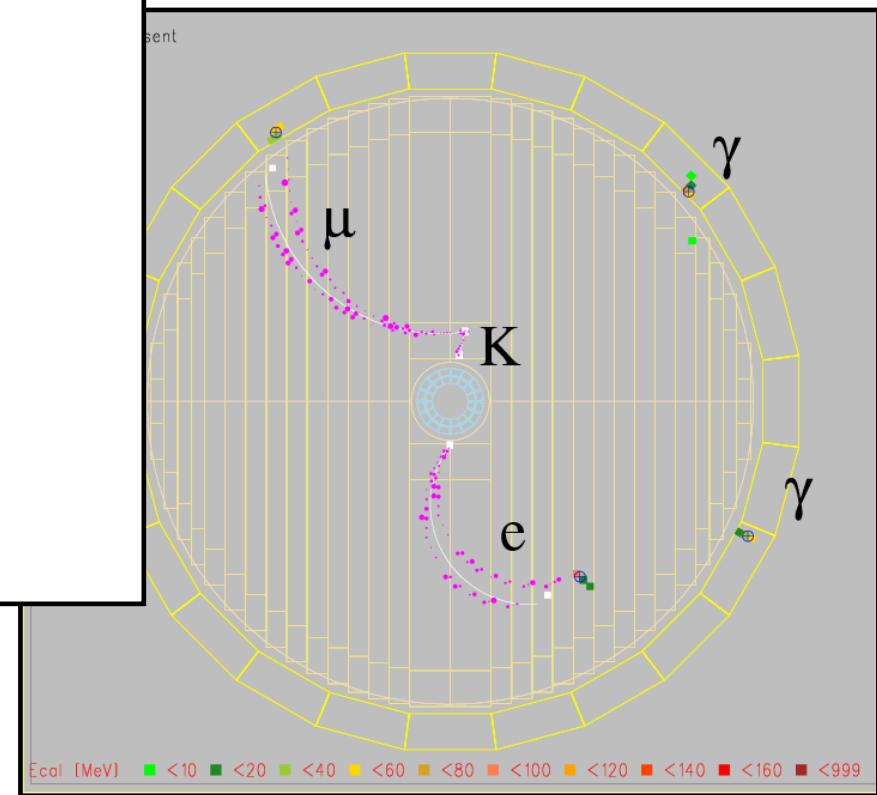
- $|z_{PCA}| < 20\text{cm}$
- $\rho_{PCA} < 10\text{cm}$
- $p_K \in (70, 130) \text{ MeV}$

Selection:

- $\rho_{VTX} \in (40, 150) \text{ cm}$
- $d\vec{p} \in (-320, -120) \text{ MeV}$
- $p^*(m_\pi) \in (180, 270) \text{ MeV}$

2) Require self-triggering tag

3) Look for signal on the other side



*Study tag bias for absolute BR's and differences between
 $K \rightarrow \mu\nu$ and $K \rightarrow \pi\pi$ tags*

$K^\pm \rightarrow \mu^\pm \nu$ Tag Bias

- DC selection (p^* , m_μ mass hypothesis)
- Trk-to-Clu for μ track
- μ -cluster fires 2 trigger sectors (self-triggering)

Tag K^+ Signal K^-

$K^- \rightarrow \mu^- \nu$	$-1.3 \pm 0.4 \%$
$K^- \rightarrow \pi^0 e^- \nu$	$+0.1 \pm 0.4 \%$
$K^- \rightarrow \pi^0 \mu^- \nu$	$+1.3 \pm 0.4 \%$
$K^- \rightarrow \pi^- \pi^0$	$-0.9 \pm 0.4 \%$
$K^- \rightarrow \pi^- \pi^0 \pi^0$	$+4.5 \pm 0.4 \%$
$K^- \rightarrow \pi^- \pi^+ \pi^-$	$+19.1 \pm 0.4 \%$

Tag K^- Signal K^+

$K^+ \rightarrow \mu^+ \nu$	$-1.0 \pm 0.4 \%$
$K^+ \rightarrow \pi^0 e^+ \nu$	$+0.9 \pm 0.4 \%$
$K^+ \rightarrow \pi^0 \mu^+ \nu$	$+1.3 \pm 0.4 \%$
$K^+ \rightarrow \pi^+ \pi^0$	$-1.9 \pm 0.4 \%$
$K^+ \rightarrow \pi^+ \pi^0 \pi^0$	$+6.6 \pm 0.4 \%$
$K^+ \rightarrow \pi^+ \pi^+ \pi^-$	$+17.7 \pm 0.4 \%$

each MC sample: 4 pb⁻¹ for 20 pb⁻¹ of Data

$K^\pm \rightarrow \pi^\pm \pi^0$ Tag Bias at the same level

K[±] two-body decays

Two different strategies for BR's measurements have been developed

1) event counting:

$$\text{absolute BR}(K^\pm \rightarrow \mu^\pm \nu)$$

2) fit the distribution of the momentum of the secondary track (p^*) in the kaon rest frame:

- ◊ absolute BR($K^\pm \rightarrow \mu^\pm \nu$)
- ◊ absolute BR($K^\pm \rightarrow \pi^\pm \pi^0$)
- ◊ $\text{BR}(K^\pm \rightarrow \pi^\pm \pi^0)/\text{BR}(K^\pm \rightarrow \mu^\pm \nu)$

$K^\pm \rightarrow \mu^\pm \nu$ absolute BR

Tag

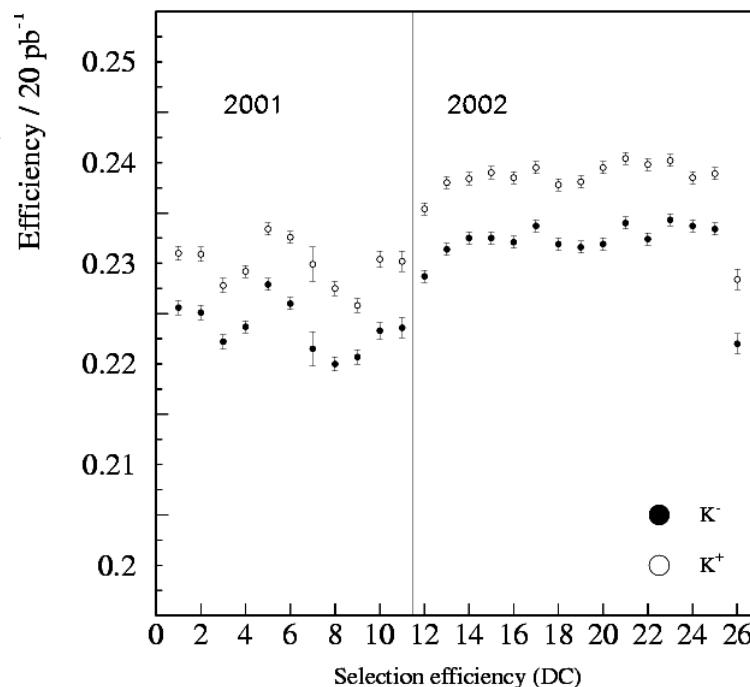
- "recover" K from EvCl2 (TagDecay)
- $p^*(m_\mu)$: 3σ cut
- Trk-to-clu for μ -track
- 2 trigger sectors fired by the μ (self-trigger)

Signal (DC only)

- Look for K (TagDecay preselection)
- 2-tracks vertex
- $\rho_{\text{VTX}} \in (40,150)$ cm
- $p^*(m_\mu)$: 3σ cut

Efficiency measured directly from data

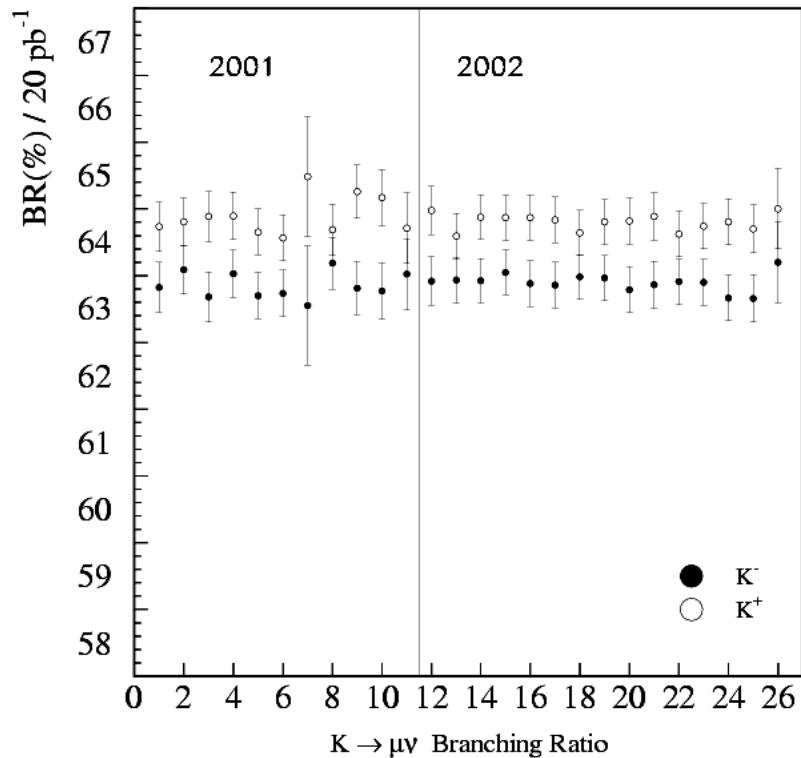
- Tag in one side
- One " μ -cluster" besides the tag one:
 - 0 cluster with $E_{\text{CLU}} \in (E_A, E_B)$ MeV
 - 1 cluster with $E_{\text{CLU}} \in (E_B, E_C)$ MeV
- taking into account for differences between DATA/MC



$K^\pm \rightarrow \mu^\pm \nu$ absolute BR

- + Cosmic veto/T3 efficiency: 0.2%

2001-2002 Data/MC	$K^+ \text{ (%)}$	$K^- \text{ (%)}$
$N_{\text{SIG}}/N_{\text{TAG}}$ (Stat)	0.051	0.053
Efficiency (Stat)	0.059	0.062
Correlation (Stat MC)	0.050	0.051
Tag Bias (Stat MC)	0.076	0.076
Cosmic veto/T3 (Stat)	0.030	0.030
Total	0.12	0.13



- + Systematics still under study, all necessary because

- + $\text{BR}(K^+ \rightarrow \mu^+ \nu)$ and $\text{BR}(K^- \rightarrow \mu^- \nu)$ have a statistical error of 0.12%
- + difference consistent with nuclear interaction cross section

K^\pm two-body decays: fit p^* distribution

Selection

- ❖ Self-tag on one side
- ❖ Vertex with 2 tracks in DC on the signal side

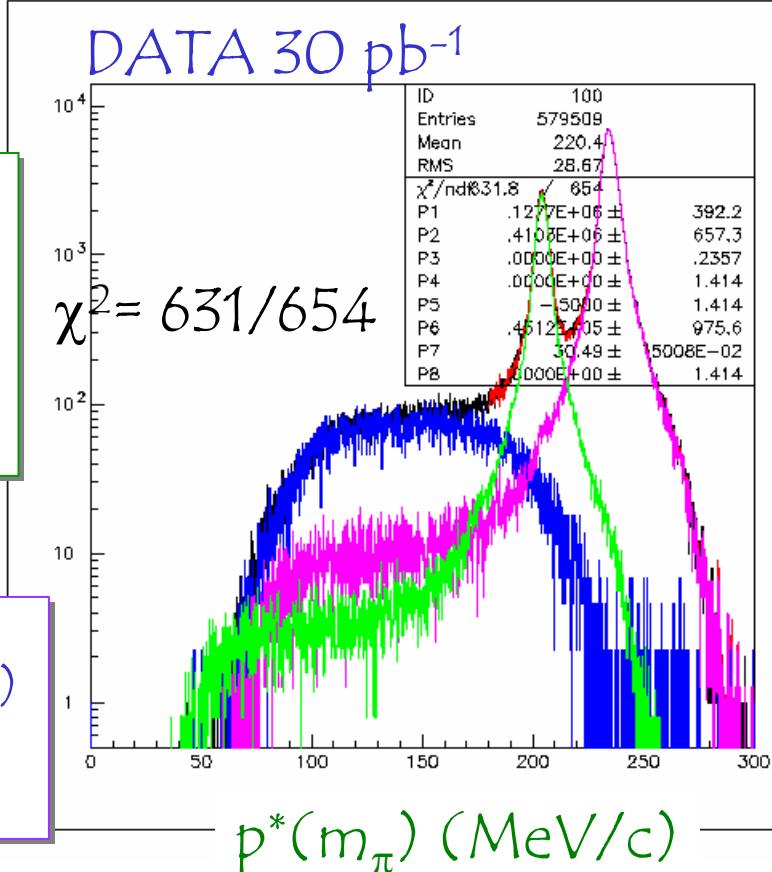
Fit procedure

- 1) the shape of $\pi\pi^0$ and $\mu\nu$ peaks from the two "μ-cluster" sample
- 2) MC shape for 3-body decays

Efficiencies for $\pi\pi^0$:

$$\varepsilon_K = (41.84 \pm 0.23_{\text{syst}}) \% \quad (2001-2002)$$

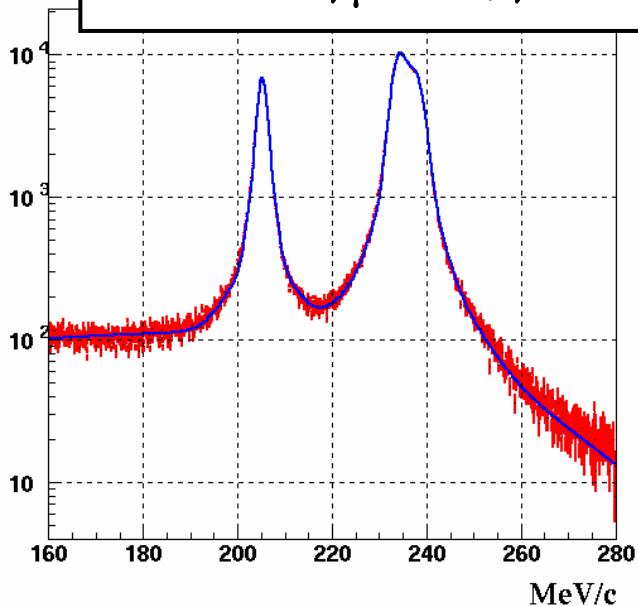
ε_{VTX} on going work



$$BR(K^\pm \rightarrow \pi^\pm \pi^0) / BR(K^\pm \rightarrow \mu^\pm \nu)$$

$$R \left(\frac{K \rightarrow \pi\pi^0}{K \rightarrow \mu\nu} \right) = \left(\frac{K \rightarrow \pi\pi^0}{K \rightarrow \mu\nu} \right)_{\text{exp.window}} \times K_{\text{trg}} \times K_{\text{fit.}} \times K_{\text{sel.}} \times K_{\text{cos}}$$

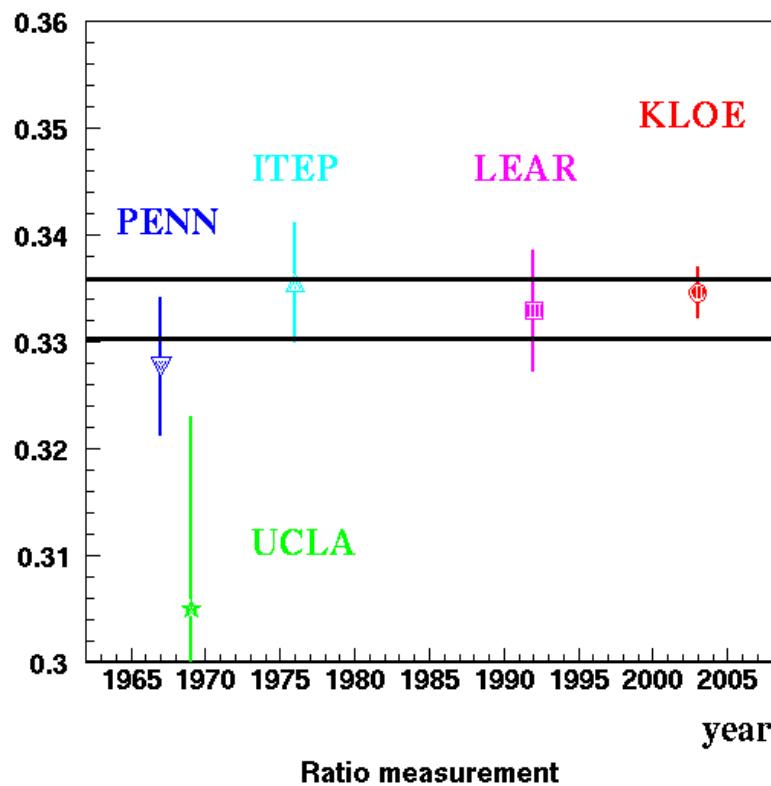
- ❖ π - hypothesis for secondary particles
- ❖ Selected π - window : 190 – 220 MeV/c
- ❖ Selected μ - window : 220 – 260 MeV/c



- ◆ K_{trigger} – trigger efficiency, extracted from data
- ◆ K_{fit} – efficiency of signals and background rejection, based on MC data and performed of data,
- ◆ K_{sel} – selection efficiency, from MC and data
- ◆ $K_{\text{veto cos}}$ – efficiency of cosmic veto rejection, data

$$BR(K^\pm \rightarrow \pi^\pm \pi^0) / BR(K^\pm \rightarrow \mu^\pm \nu)$$

$$\frac{BR(K^\pm \rightarrow \pi^\pm \pi^0)}{BR(K^\pm \rightarrow \mu^\pm \nu)} = 0.3346 \pm 0.0003(\text{stat.}) \pm 0.0022(\text{syst.}) = \\ 0.3346 \times (1 \pm 0.0009(\text{stat.}) \pm 0.0065(\text{syst.}))$$



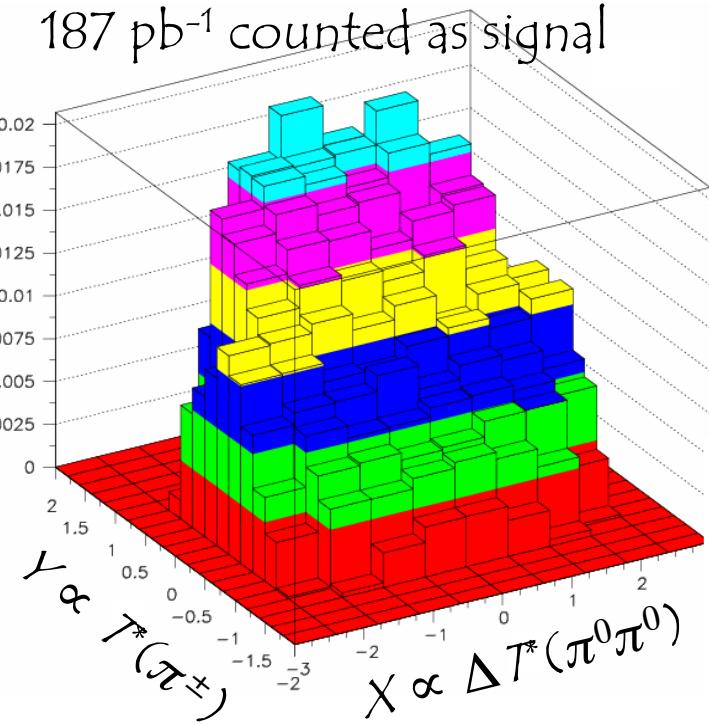
- Preliminary
- ❖ Both triggers employed
 - ❖ New checks on Ktrg and Kcos
 - ❖ Result is in good agreement with world data
 - ❖ Statistical error negligible due to the huge sample of kaon decays (more than 6.5 M; 2002 Data).
 - ❖ Systematic error (0.65 %) dominates
 - ❖ Result can be updated by further investigation of MC/DATA uncertainties
 - ❖ Include calculation of $K \rightarrow \mu\nu\gamma$ decay

$$K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$$

- Asymmetries in K^\pm rates ($\sim 10^{-8}$) and Dalitz slopes ($\sim 10^{-5}$) signal direct CP viol.
- Dalitz slopes give information on $\Delta l = 1/2, 3/2$ amplitudes for $K \rightarrow 3\pi$ decays

441 pb⁻¹ '01+'02 data

187 pb⁻¹ counted as signal



Preliminary fit to Dalitz plot
 $F(X,Y) = 1 + gY + hY^2 + kX^2$

$$\text{BR}(K^\pm \rightarrow \pi^\pm \pi^0 \pi^0)$$

PDG '02 fit $(1.73 \pm 0.04)\%$

KLOE preliminary hep-ex/0307054

$(1.810 \pm 0.013 \pm 0.017)\%$ *Submitted to PLB*

	KLOE	PDG
g	$0.586 \pm 0.010 \pm 0.012$	0.652 ± 0.031
h	$0.030 \pm 0.010 \pm 0.013$	0.057 ± 0.018
k	$0.0055 \pm 0.0026 \pm 0.0018$	0.0197 ± 0.0054

$$K^\pm \rightarrow \pi^0 \pi^0 e^\pm \nu (K_{e4}')$$

◊ Test of $\Delta l = 1/2$ rule:

$$\Gamma(K_{\ell 4}^\pm) = 2\Gamma(K_{\ell 4}') = 1/2\Gamma(K_{\ell 4}^0)$$

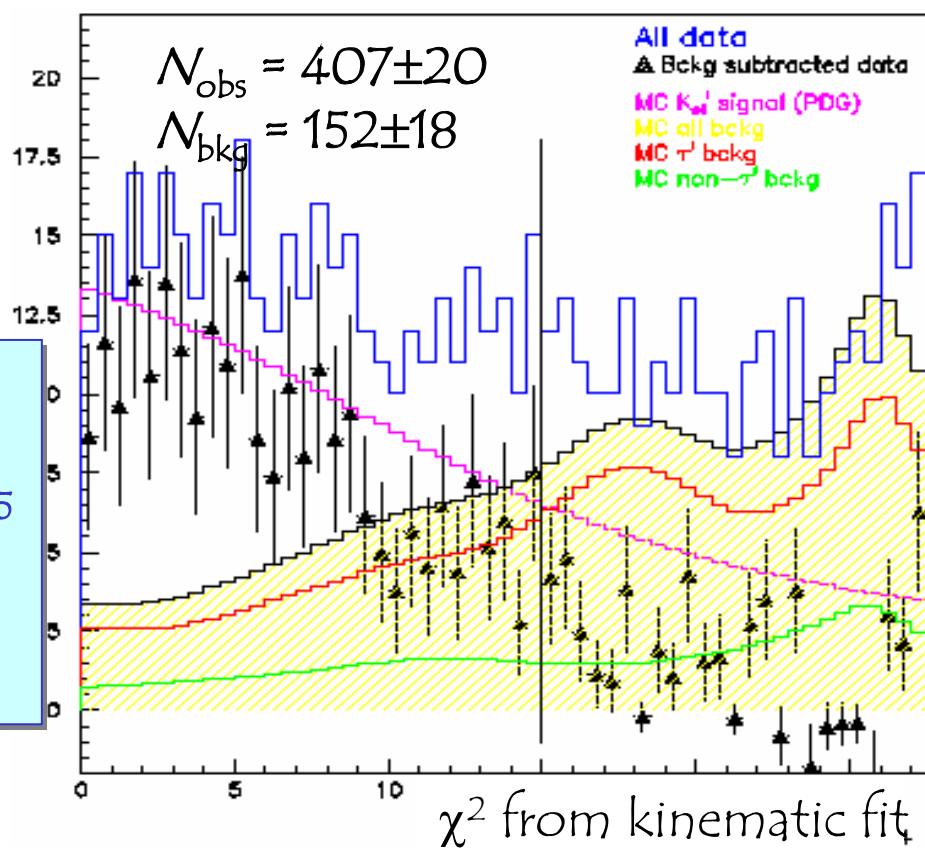
$$|F(K_{\ell 4}^\pm)| = |F(K_{\ell 4}')|$$

◊ For $K_{\ell 4}'$, $m_\ell = 0$:

$$\Gamma = C_F |F|^2 |V_{us}|^2 \Rightarrow F \text{ form factor}$$

$K_{\ell 4}^\pm$	$K^\pm \rightarrow \pi^+ \pi^- \ell^\pm \nu$
$K_{\ell 4}'$	$K^\pm \rightarrow \pi^0 \pi^0 \ell^\pm \nu$
$K_{\ell 4}^0$	$K_L \rightarrow \pi^0 \pi^0 \ell^\pm \nu$

KLOE preliminary
 (441 pb⁻¹ '01 + '02 data)
 $BR(K_{e4}') = (2.43 \pm 0.20 \pm 0.22) \times 10^{-5}$
 PDG fit: $(2.1 \pm 0.4) \times 10^{-5}$
 Barmin 88: $(2.54 \pm 0.89) \times 10^{-5}$



ϕ radiative decays and $\sigma(e^+e^- \rightarrow hh)$ at KLOE

$\phi \rightarrow f_0\gamma, a_0\gamma$

$\phi \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma$

$\phi \rightarrow f_0\gamma \rightarrow \pi^+\pi^-\gamma$

Phys. Lett. B536 209 (2002), B537 21 (2002)

Preliminary update with 2001-2002 data

Preliminary results

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

$\eta \rightarrow 3\pi^0$

$\eta \rightarrow \pi^+\pi^-\gamma$

$\eta \rightarrow \pi^0\gamma\gamma$

Preliminary results

$\eta \rightarrow 3\gamma$

hep-ex/0307042 to be submitted

$\text{BR}(\eta \rightarrow 3\gamma) \leq 1.6 \times 10^{-5}$ 95% CL

$\sigma(e^+e^- \rightarrow \text{hadrons})$

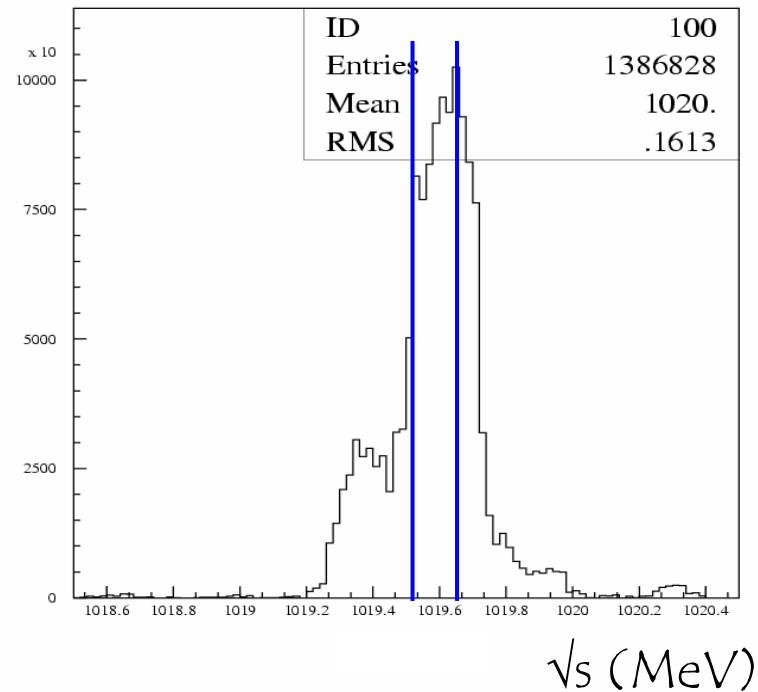
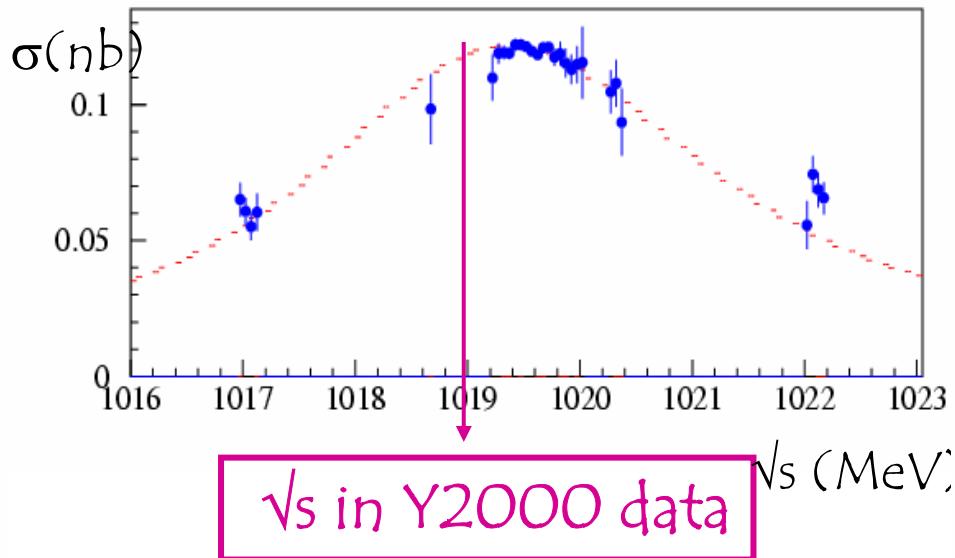
hep-ex/0307051 update

3) $\phi \rightarrow f_0\gamma$

$\phi \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma$ update : sample selection

2001 + 2002 data:

$\phi \rightarrow \pi^0\pi^0\gamma$ visible x-section



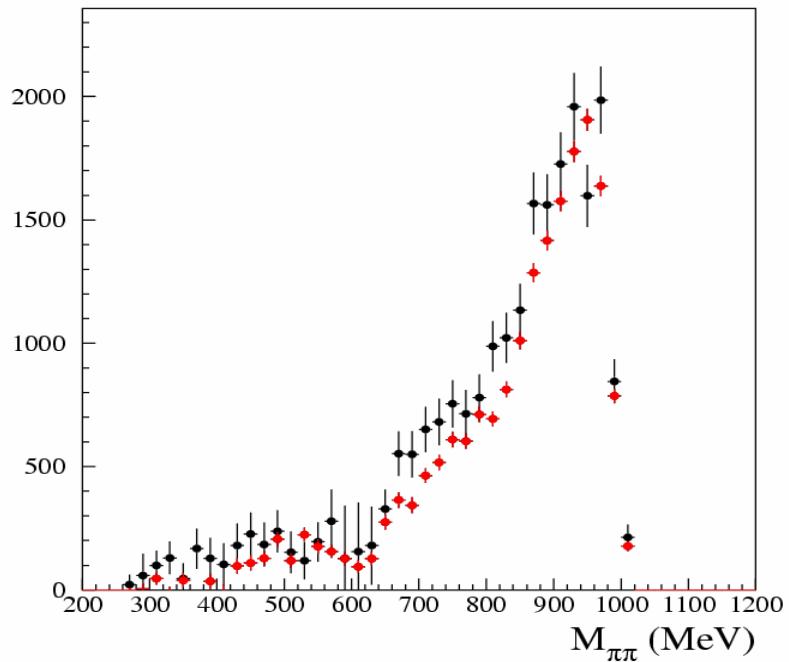
- ◊ Not negligible dependence on \sqrt{s}
- ◊ Very few events @ Y2000 \sqrt{s} value
- ◊ Analysis repeated selecting a \sqrt{s} region symmetric wrt peak (σ_0)

$$1019.55 < \sqrt{s} < 1019.65$$

$$L_{\text{int}} = 147 \text{ pb}^{-1}$$

$\phi \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma$: '01+'02 data @ $\sqrt{s}=1019.6$

$M_{\pi\pi}$ spectra, normalized to L_{int}



✓ $N_{\pi\pi\gamma} = 18511 \pm 184$

✓ $BR = (0.98 \pm 0.01_{stat}) \times 10^{-4}$

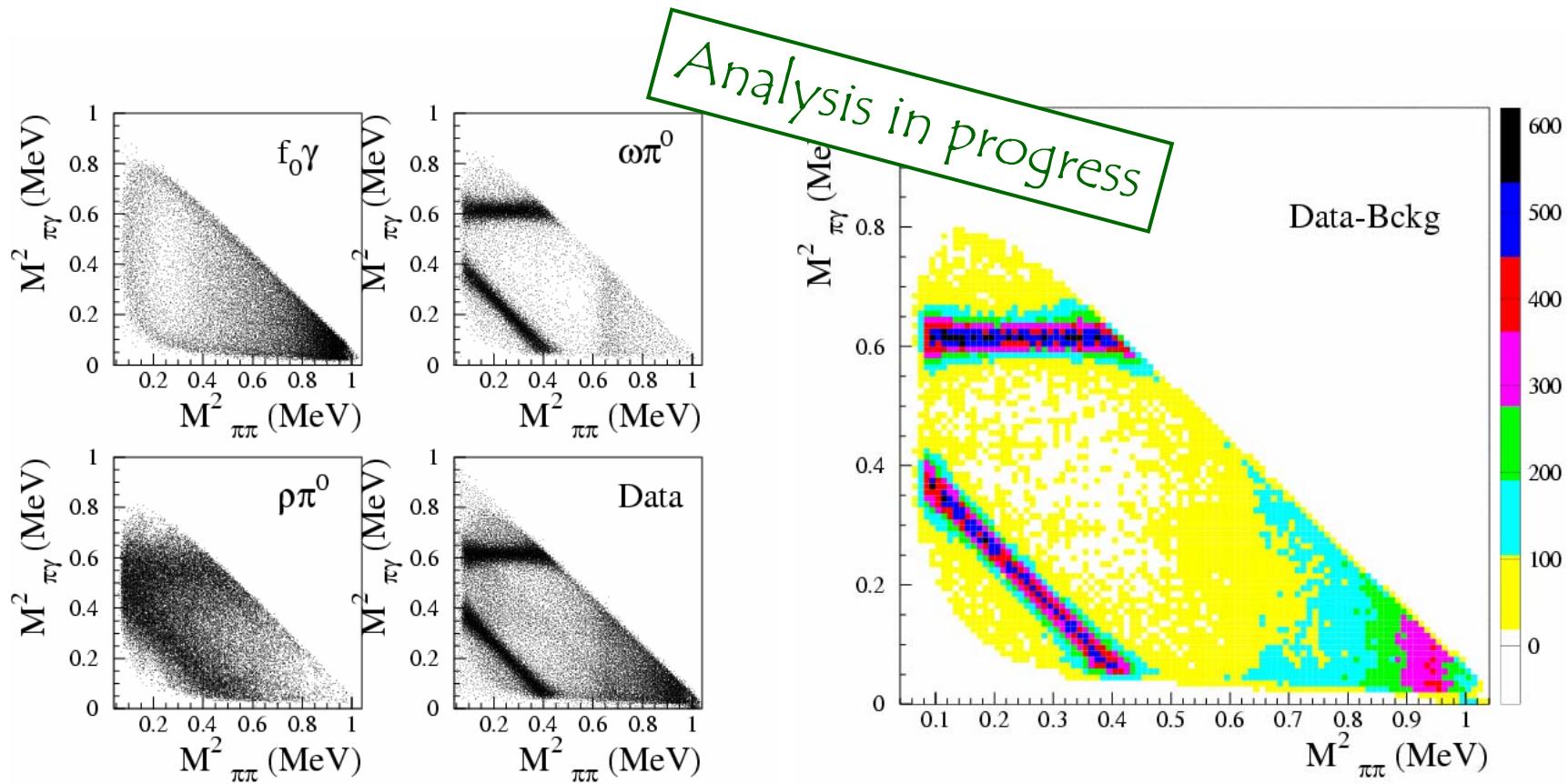
The central value is $\sim 10\%$ lower than Y2000

[$BR_{2000} = (1.09 \pm 0.03 \pm 0.05) \times 10^{-4}$]

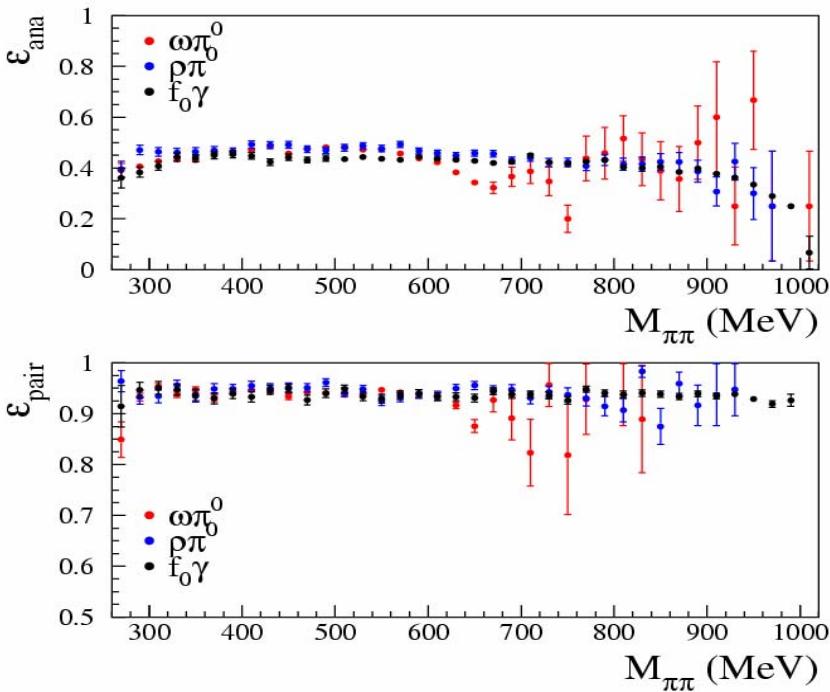
- Work in progress in order to understand this discrepancy
- Perform the analysis for all available \sqrt{s} values in order to extract the BR by fitting the line shape

A first look at $\phi \rightarrow \pi^0\pi^0\gamma$ Dalitz plot

- ❖ The large statistics allows now to perform a **Dalitz plot fit** to extract all contributions and the interference
- ❖ Photon's pairing is a crucial point of the Dalitz plot analysis.



Pairing procedure



- In order to be process independent, we developed a **pairing procedure** which parametrizes the π^0 mass resolution as a function of γ 's energy resolution after kinematic fit:

$$\sigma_M/M = 0.5 (\sigma_{E_1}/E_1 \oplus \sigma_{E_2}/E_2)$$

- To improve the overall efficiency, the difference between the two best selection χ^2 is exploited.

Cutting at $\Delta\chi^2 > 1$:

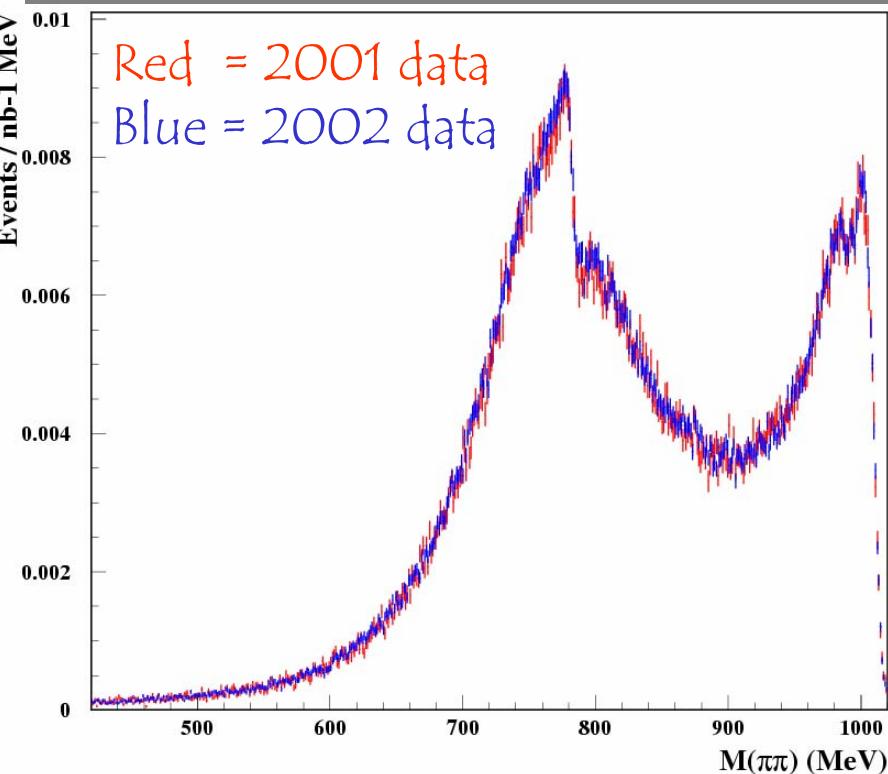
- the analysis efficiency for signal decreases of $\sim 20\%$ ($\epsilon_{\text{tot}} \sim 45\%$)
- the pairing efficiency becomes : $\epsilon_{\text{pair}} \sim 94\%$, flat in $M_{\pi\pi}$

Search for $f_0(980) \rightarrow \pi^+ \pi^-$ in $\pi^+ \pi^- \gamma$

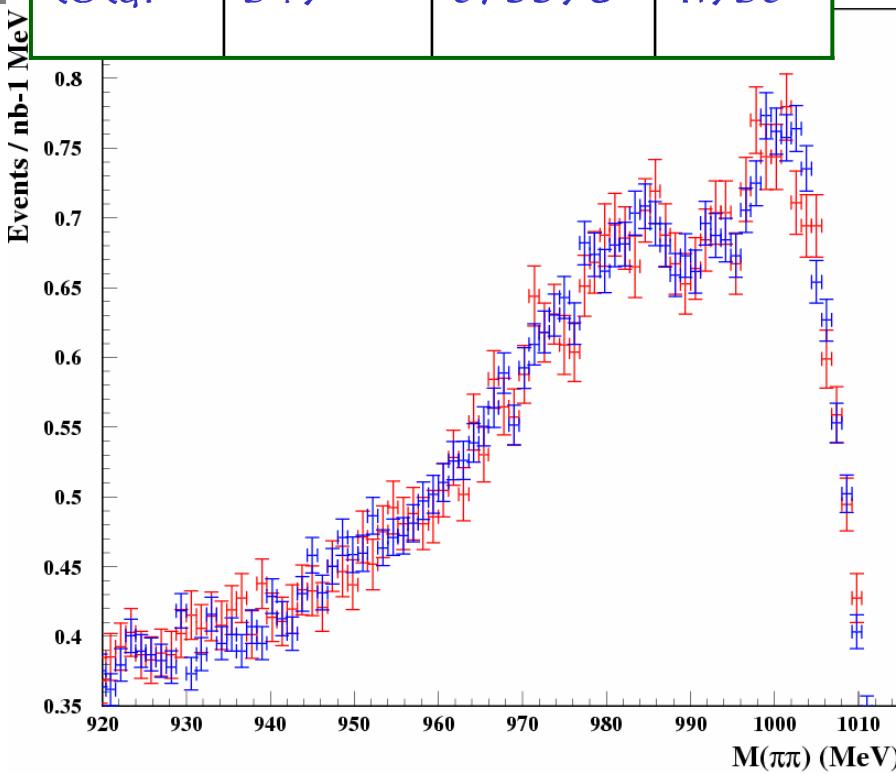
Selection

- ◊ 2 tracks from I.R.
- ◊ 1 photon at $\theta > 45^\circ$

$M(\pi^+ \pi^-)$ spectrum
normalized to L $\Rightarrow f_0$ signal
(ISR+FSR large contribution in signal region)



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

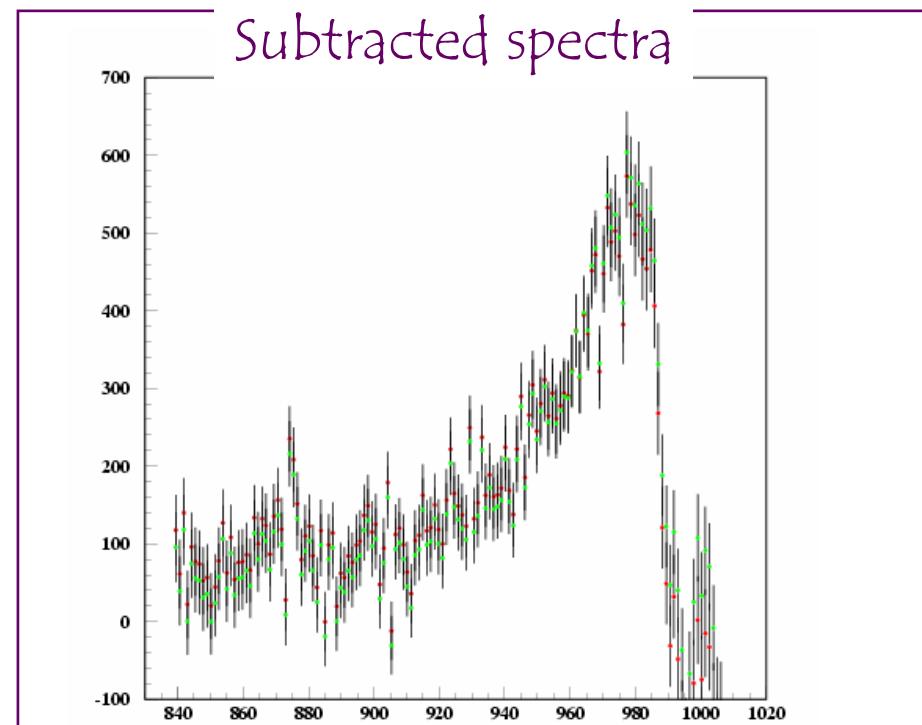
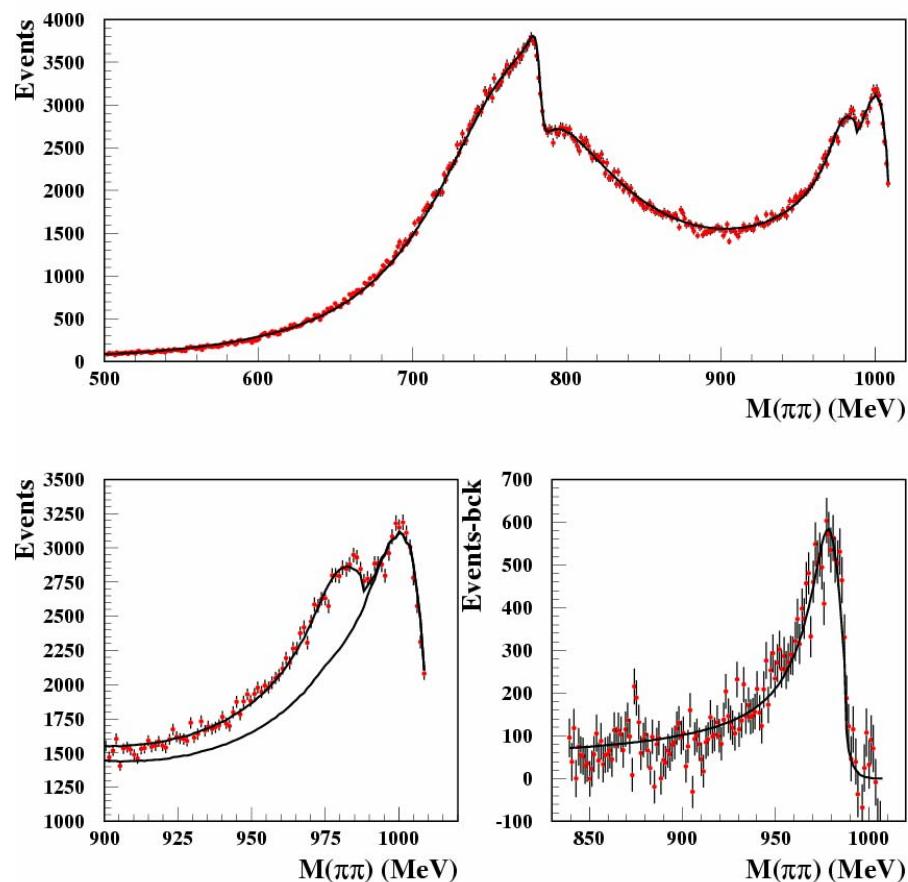


Search for $f_0(980) \rightarrow \pi^+\pi^-$: the fit

- ◊ 7 free parameters
- ◊ BCK: $M(\rho^0)$, $\Gamma(\rho^0)$, α , β
- ◊ signal: $g^2_{FOKK}/4\pi$, R , $M(f_0)$
- ◊ 3 interference schemes: +, no, -

$$\Rightarrow FF_\pi = \frac{BW(\rho)[1+\alpha BW(\omega)]}{1+\alpha} + \frac{\beta BW(\rho')}{1+\beta}$$

Best fit is with no interf. $\rightarrow \chi^2 = 688 / 483$ d.o.f.



The shape of the subtracted spectrum is almost independent on the background parameters

4) η decays

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

Study of Dalitz plot gives $u-d$ quark mass difference and sheds light on isospin-breaking mechanisms

Fit with a, b, d free parameters,
 c, e fixed to zero

$$\chi^2/N_{\text{dof}} = 33/38$$

KLOE

$$a = -1.05 \pm 0.01 + 0.02/0.$$

$$b = 0.020 \pm 0.03 + 0.0/-0.08$$

$$d = 0.05 \pm 0.03 + 0.0/-0.01$$

PDG

$$-1.08 \pm 0.014$$

$$0.034 \pm 0.027$$

$$0.046 \pm 0.031$$

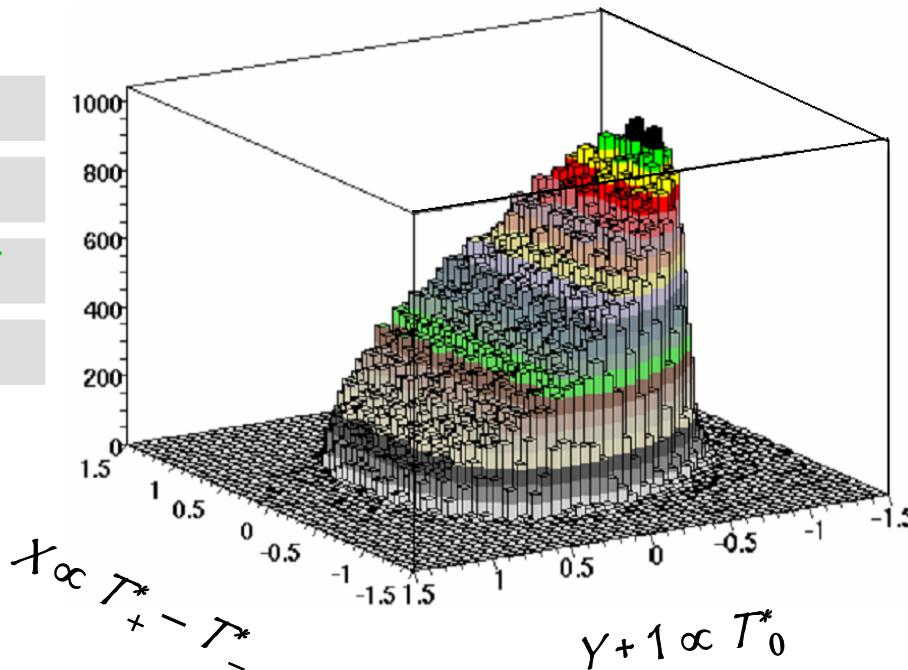
When treated as free parameters:

$$c = -0.008 \pm 0.010$$

$$e = 0.01 \pm 0.03$$

Will limit C violation in $\eta \rightarrow 3\pi$

KLOE preliminary, $\sim 100 \text{ pb}^{-1}$
 $352K \eta \rightarrow \pi^+ \pi^- \pi^0$ events



Expansion of Dalitz plot:

$$A(X, Y) \propto 1 + aY + bY^2 + cX + dX^2 + eXY$$

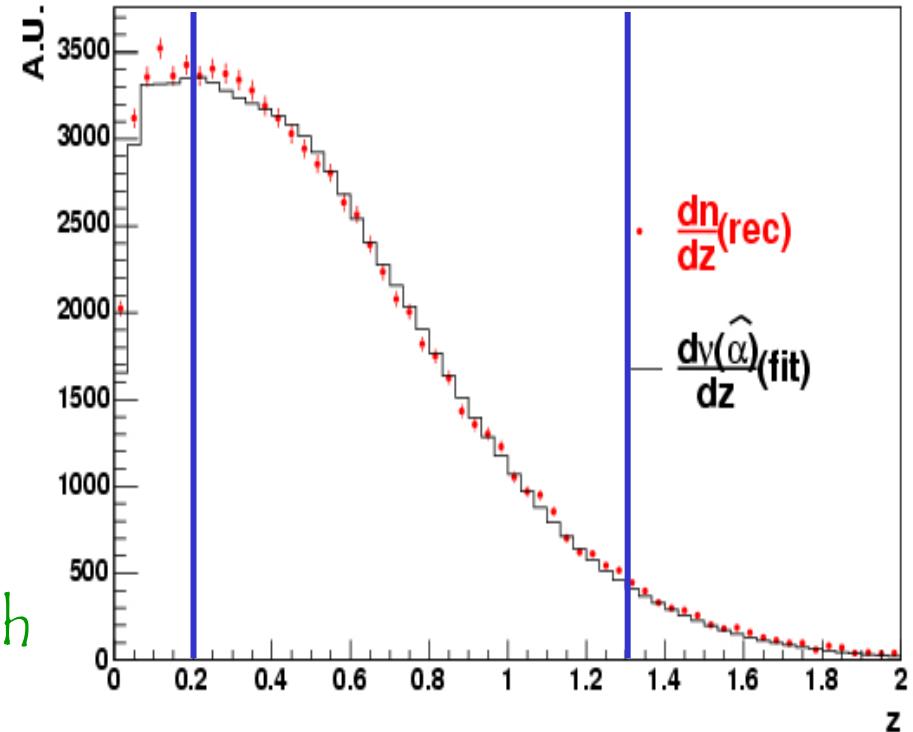


Dalitz Plot parameter definition:

$$|A|^2 \propto 1 + 2\alpha z$$

$$z = \frac{2}{3} \sum_{i=1}^3 \left(\frac{3E_i - m_\eta}{m_\eta - 3m_{\pi^0}} \right)^2 = \frac{\rho^2}{\rho_{\max}^2}$$

- ◊ Important the convolution with energy resolution function
- ◊ From very preliminary study on 1/10 available statistics
0.014 accuracy on α



Alde (1984)	-0.022 ± 0.023
Crystal Barrel (1998)	-0.052 ± 0.020
Crystal Ball (2001)	-0.031 ± 0.004

Therefore with all statistics we can reach Crystal Ball accuracy

$\eta \rightarrow \pi^+ \pi^- \gamma$

- ◊ $M_{\pi\pi}$ spectrum sensitive to box anomaly
- ◊ Charge asymmetry related to C violation
- ◊ Most recent BR measurement dates 1973

$$R_\eta = \frac{BR(\eta \rightarrow \pi^+ \pi^- \gamma)}{BR(\eta \rightarrow \pi^+ \pi^- \pi^0)}$$

KLOE preliminary, 95.7 pb⁻¹ ('01)

$$R_\eta = 0.202 \pm 0.002 \pm 0.002$$

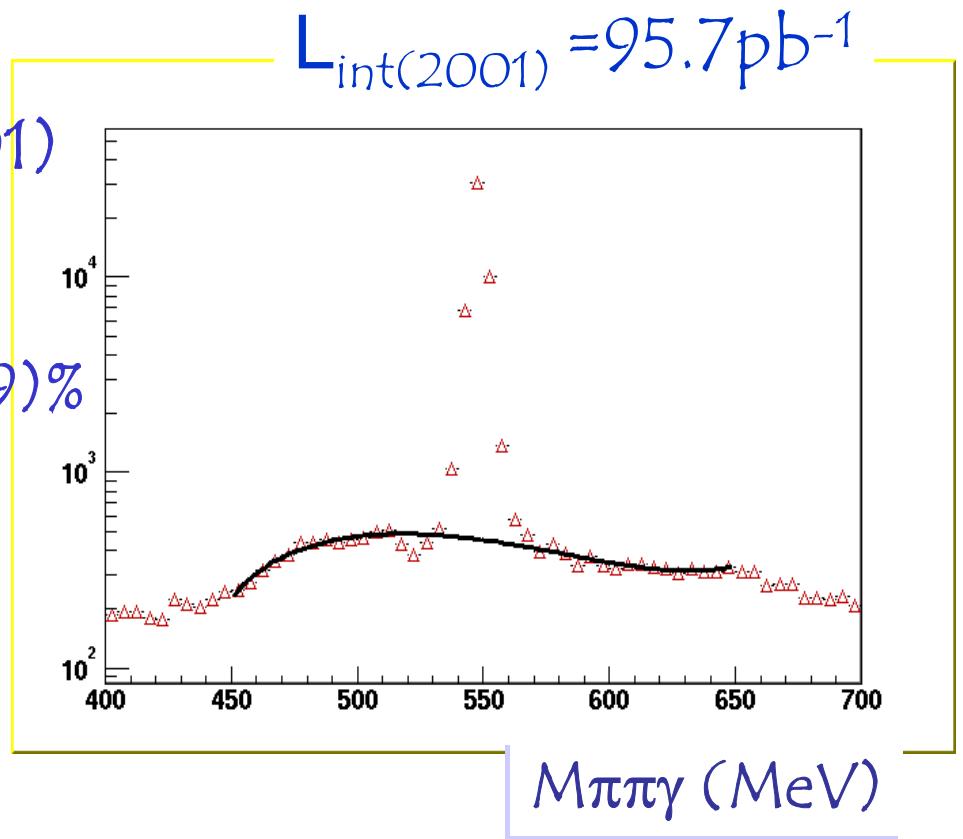
$$BR(\eta \rightarrow \pi^+ \pi^- \gamma) = (4.56 \pm 0.04 \pm 0.09)\%$$

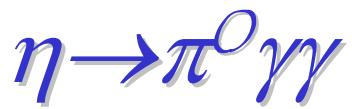
$$A_S = (0.8 \pm 0.4) \times 10^{-2}$$

$$R_\eta^{\text{PDG}} = 0.207 \pm 0.004$$

$$BR^{\text{PDG}}(\eta \rightarrow \pi^+ \pi^- \gamma) = (4.68 \pm 0.11)\%$$

$$A_S^{\text{PDG}} = (0.9 \pm 0.4) \times 10^{-2}$$





This decay is a window on rather high order corrections in ChPT

- Leading term $O(p^2)$ is absent
- tree-level amplitude $O(p^4)$ is also zero
- loop contributions $O(p^4)$ plays a very minor role:

$$\Rightarrow \Gamma^{(4)}(\eta \rightarrow \pi^0 \gamma\gamma) = 4 \div 7 \times 10^{-3} \text{ eV}$$

- chiral expansion starts from $O(p^6)$

— Experimental status —

- GAMS-2000 (1981): $(\pi^- p \rightarrow \eta n)$
 $6 \times 10^5 \eta$ produced ; 38 evts.
- GAMS-2000 reanalysis (1984):
- SND (2001): $2.6 \times 10^5 \phi \rightarrow \eta \gamma$;
- Crystal Ball (preliminary)
 $2 \times 10^7 \eta$ produced; 120 ± 40 evts. \Rightarrow

$$Br(\eta \rightarrow \pi^0 \gamma\gamma) = (9.5 \pm 2.3) \times 10^{-4}$$

$$Br(\eta \rightarrow \pi^0 \gamma\gamma) = (7.1 \pm 1.4) \times 10^{-4}$$

$$Br(\eta \rightarrow \pi^0 \gamma\gamma) < 8.4 \times 10^{-4} @ 90\% \text{ C.L.}$$

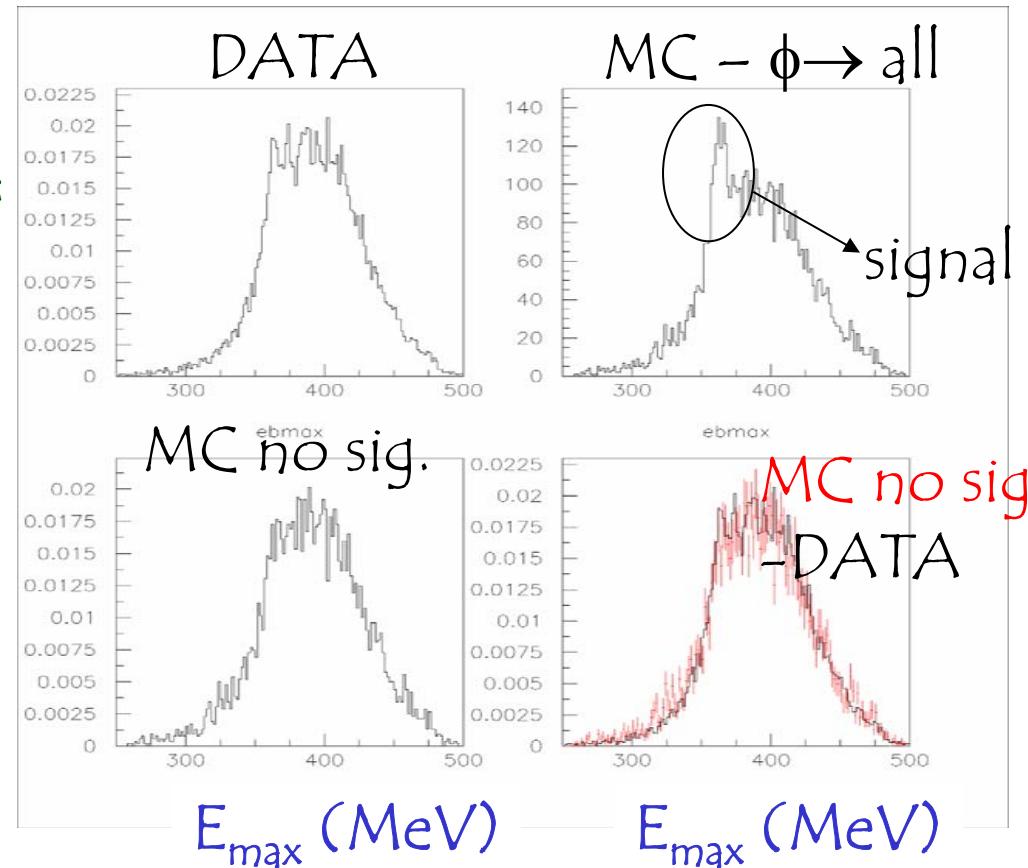
$$Br(\eta \rightarrow \pi^0 \gamma\gamma) = (2.7 \pm 0.9) \times 10^{-4}$$

KLOE: with 2001 + 2002 statistics $\Rightarrow \sim 2 \times 10^7 \eta$ produced
(same as Crystal Ball)

$\eta \rightarrow \pi^0 \gamma\gamma$: DATA - MC comparison

Background is the crucial point:

- ◊ f_0 , a_0 and $\omega\pi^0$ "easily" reduced
- ◊ $\phi \rightarrow \eta\gamma \rightarrow \pi^0\pi^0\pi^0\gamma$
 - 1) with lost photons
 - 2) with merged clusters



No clear signal of $\eta \rightarrow \pi^0 \gamma\gamma$ because $\eta \rightarrow \pi^0 \pi^0 \pi^0$ background simulates signal

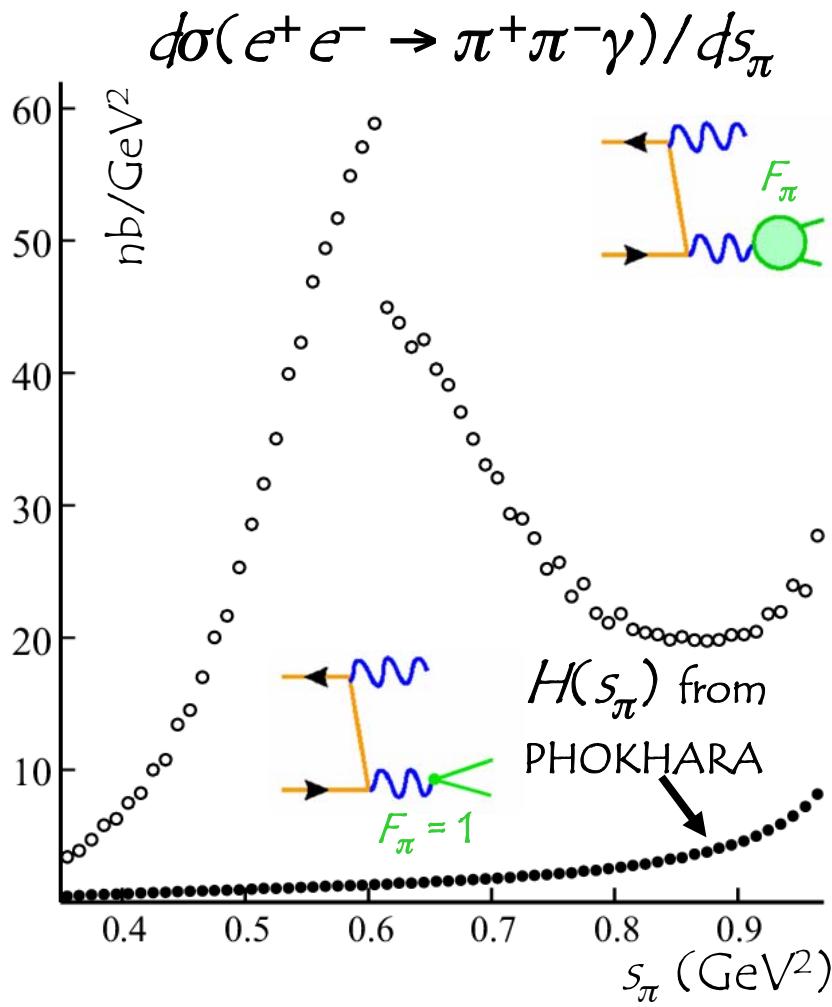
A dedicated study to identify merged clusters is in progress.
MC shows its use could improve S/B by factor 1.5

5) $\sigma(e^+e^- \rightarrow \text{hadrons})$

$\sigma(e^+e^- \rightarrow \text{hadrons})$

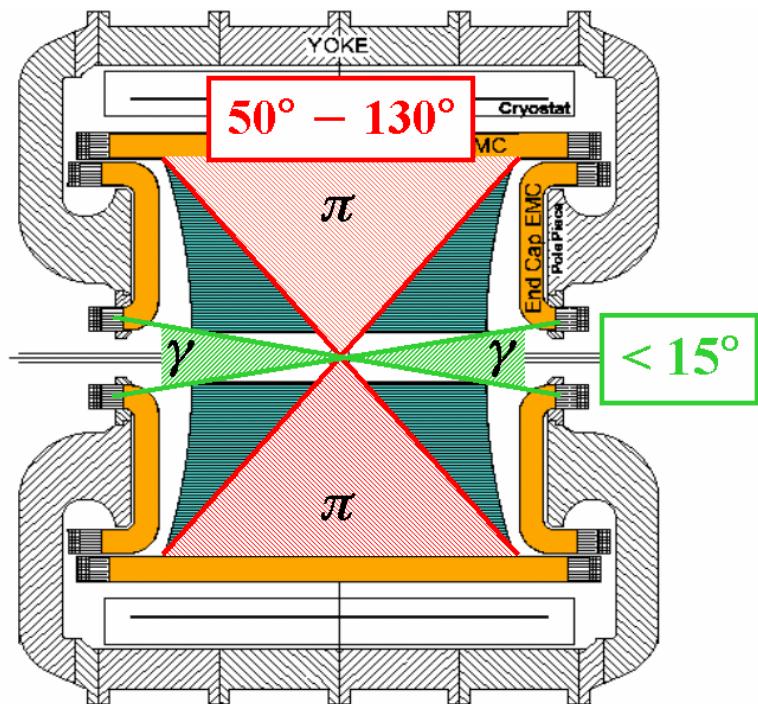
KLOE preliminary: 140 pb⁻¹ '01 data, 1.5M events

hep-ex/0307051



Angular cuts ensure:

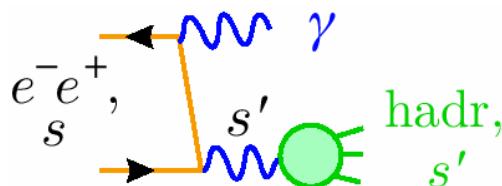
- ◊ High statistics for ISR events
- ◊ Very low contribution from FSR-only events
- ◊ Reduced background contamination



$\sigma(e^+e^- \rightarrow \text{hadrons})$

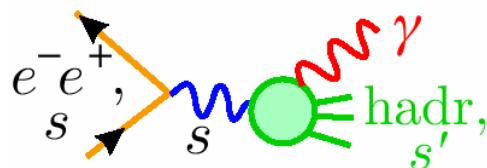
ISR:

$$M_{\pi\pi}^2 = s'$$



FSR:

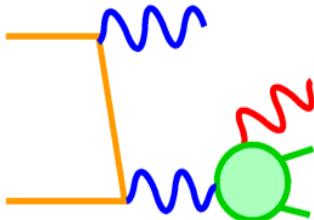
$$M_{\pi\pi}^2 = s' \neq s$$



the radiator H assumes $M^2(\gamma^*) = M^2(\pi\pi)$
 but $M^2(\pi\pi) \neq M^2(\pi\pi\gamma_{\text{FSR}}) = M^2(\gamma^*)$

$$\sigma(\pi\pi) = \frac{d\sigma(\pi\pi\gamma)/ds_\pi}{H(s_\pi)}$$

For g_μ we need the inclusive cross section: $e^+e^- \rightarrow \pi^+\pi^-(\gamma), \gamma$ from FSR



resume ISR+FSR events eliminated by kinematic cuts

Now evaluating this correction with PHOKHARA v3.0
 in which the FSR photon is flagged

Summary of systematic errors

Experimental

Trigger + TV: 0.2%

Tracking: 0.3%

Vertex: 0.7%

Likelihood: 0.1%

Filfo: 0.6%

Trkmass: 0.2%

Acceptance: 0.3%

Bckg subtr: 0.5%

Total: 1.2%

← 2%
← 1%

Theory

- ◊ Vacuum Polarization in Babayaga has been checked by the Pavia group at 0.1% level
- ◊ Comparison of Babayaga with other generators

Bhagenf (460.8 \pm 0.1_{STAT}) nb

Babayaga 3.5 (459.4 \pm 0.1_{STAT}) nb

BHWIDE (456.2 \pm 0.1_{STAT}) nb

VEPP-2000 (455.3 \pm 0.1_{STAT}) nb

Radiator H: 0.5%

Vacuum Polarization: 0.1%

Luminosity: 0.6%

Total: 0.8%

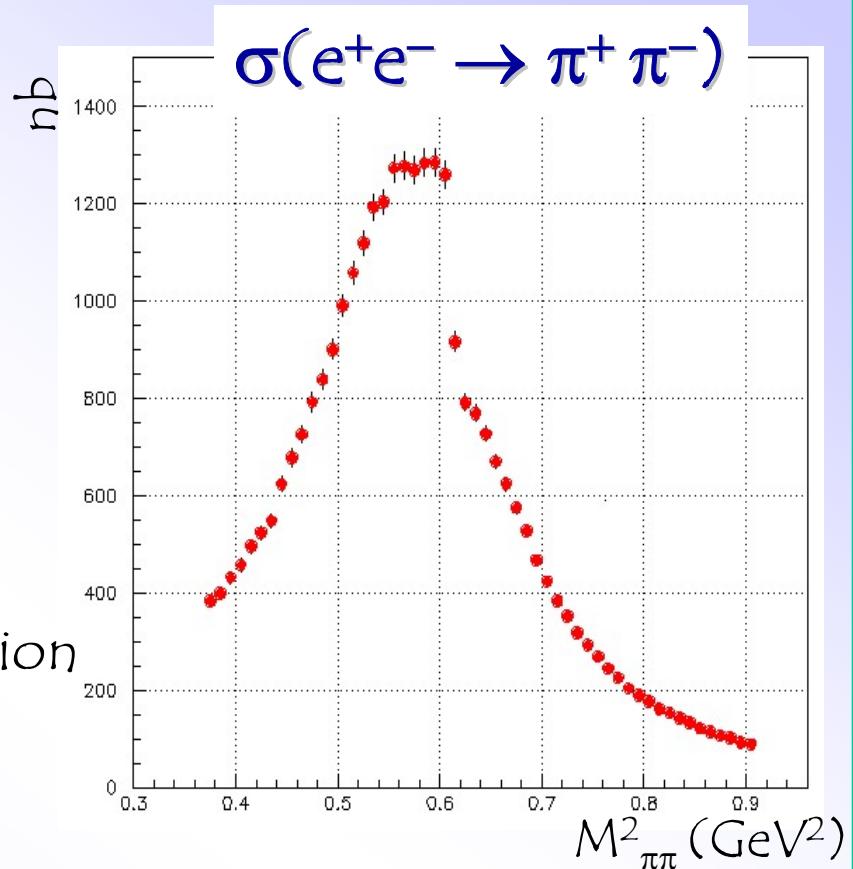
It will go to 1%

Additional error of 1% due to the treatment of FSR which should diminish drastically because total effect in only 3%

Results for a_μ^{had}

$$a_\mu^{\pi\pi} \propto \int ds \sigma(e^+ e^- \rightarrow \pi^+ \pi^-) K(s)$$

bare cross section integrated in the region
 $0.37 \text{ GeV}^2 < M_{\pi\pi}^2 < 0.93 \text{ GeV}^2$



KLOE result: $a_\mu^{\pi\pi} (0.37-0.93) = 378.4 \pm 0.8_{\text{stat}} \pm 4.9_{\text{syst}} \pm 3.0_{\text{theo}} \pm 3.8_{\text{FSR}}$

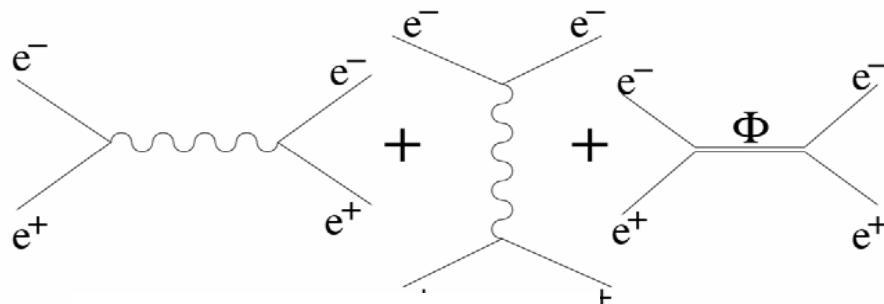
0.2%	1.2 %	0.8%	1%
0.2%	1.0%	0.8%	

It will go to →

Published CMD-2 result: $a_\mu^{\pi\pi} (0.37-0.93) = 378.6 \pm 2.7_{\text{stat}} \pm 2.3_{\text{syst+theo}}$

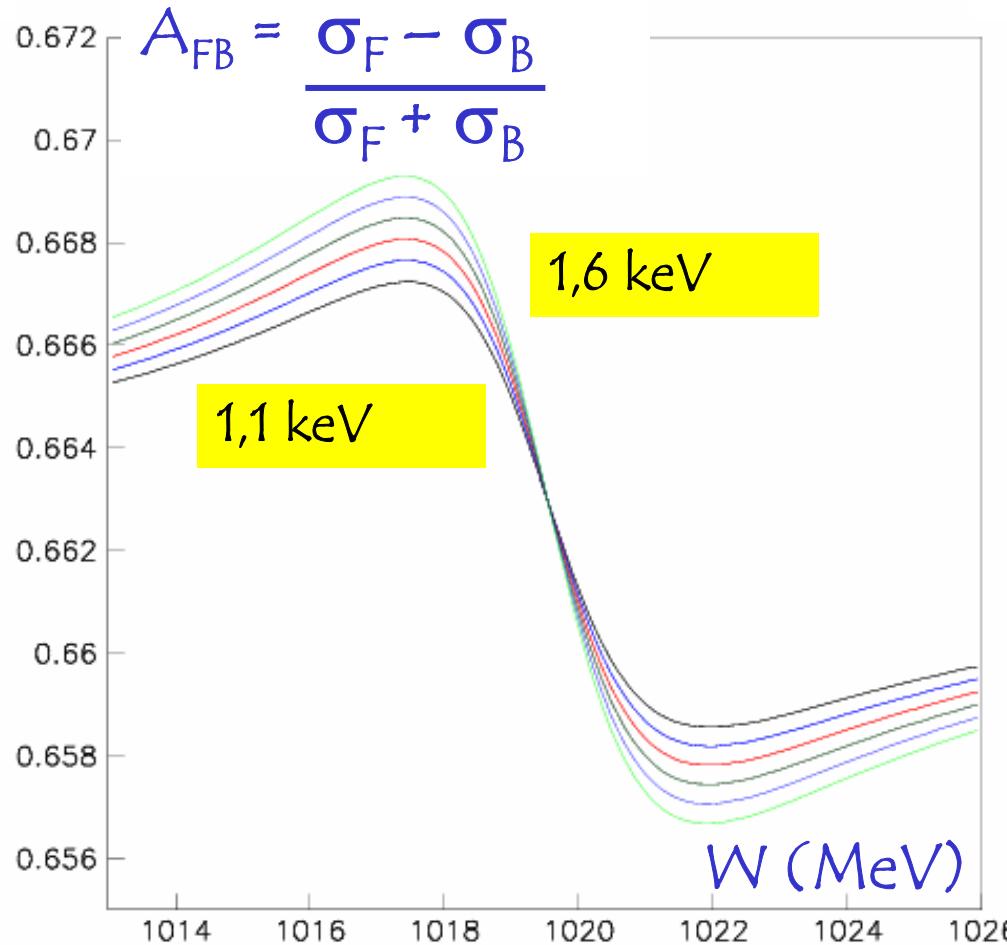
$$6) \Gamma(\phi \rightarrow e^+e^-)$$

Forward backward asymmetry A_{FB}



$$A = A_{st} + A_\Phi$$

$$\sigma = \sigma_{st} + \sigma_\Phi + l$$



- ❖ Enhanced sensitivity to Γ_{ee} with respect to σ_{ee}
- ❖ Luminosity not needed
- ❖ Partial cancellations (eff, bkg, syst.)
- ❖ Γ_{ee} depends on absolute asymmetry difference

Selection and fit result

Selection:

- ◊ $W'/W > 0.95$
- ◊ $53^\circ < \theta < 127^\circ$

Fit function :

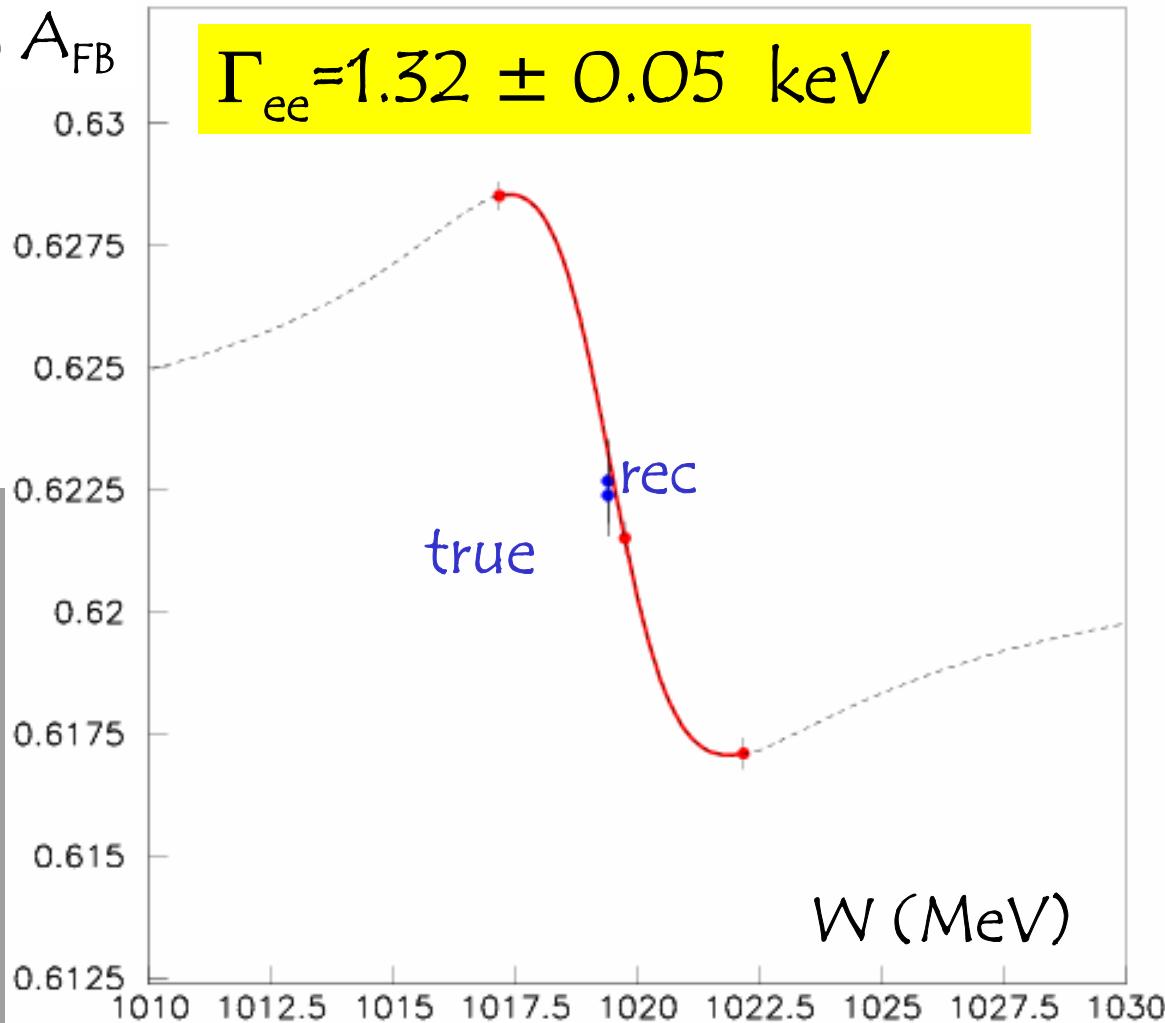
born + rad + bes (d.p.)

Red - Data sample:

scan 2002, 3 energy points, 7 pb^{-1} each

Blue - Monte Carlo:

Geanfi (no interfer, Babayaga generator)



Systematics

- ◊ 3 mrad θ_{rec} resolution $\sim 10^{-2}$ keV
- ◊ Γ_{tot} uncertainty $\sim 10^{-2}$ keV
- ◊ eff uncertainty $\sim 10^{-3}$ keV
- ◊ bkg uncertainty $\sim 10^{-3}$ keV
- ◊ ω exchange contribution $\sim 10^{-3}$ keV
- ◊ radiative cut $\sim 1.7 \cdot 10^{-2}$ keV

KLOE	$1.32 \pm 0.05 \pm 0.02$
CMD-2 (1999)	$1.32 \pm 0.02 \pm 0.04$
CMD-2 (2003 reanalysis) $\rightarrow 1.36$	

From muons we expect same statistical accuracy

Conclusions

Recently completed ambitious new MC production campaign

- ✓ culmination of 1 year of effort
- ✓ vastly improved simulation with background insertion and MC DST's
- ✓ of fundamental importance for recent improvements on results of various analyses

Conclusions

KLOE is gathering the fruit of its unique physics program

- ✓ Precision measurements of relatively rare processes,
first observations & new upper limits
- ✓ More and more KLOE measurements are the best

*This demonstrates the importance of the KLOE
program in shedding light on a long list of physics
topics*

*We are waiting anxiously for
much more data*