

Recent results from KLOE at DA Φ NE

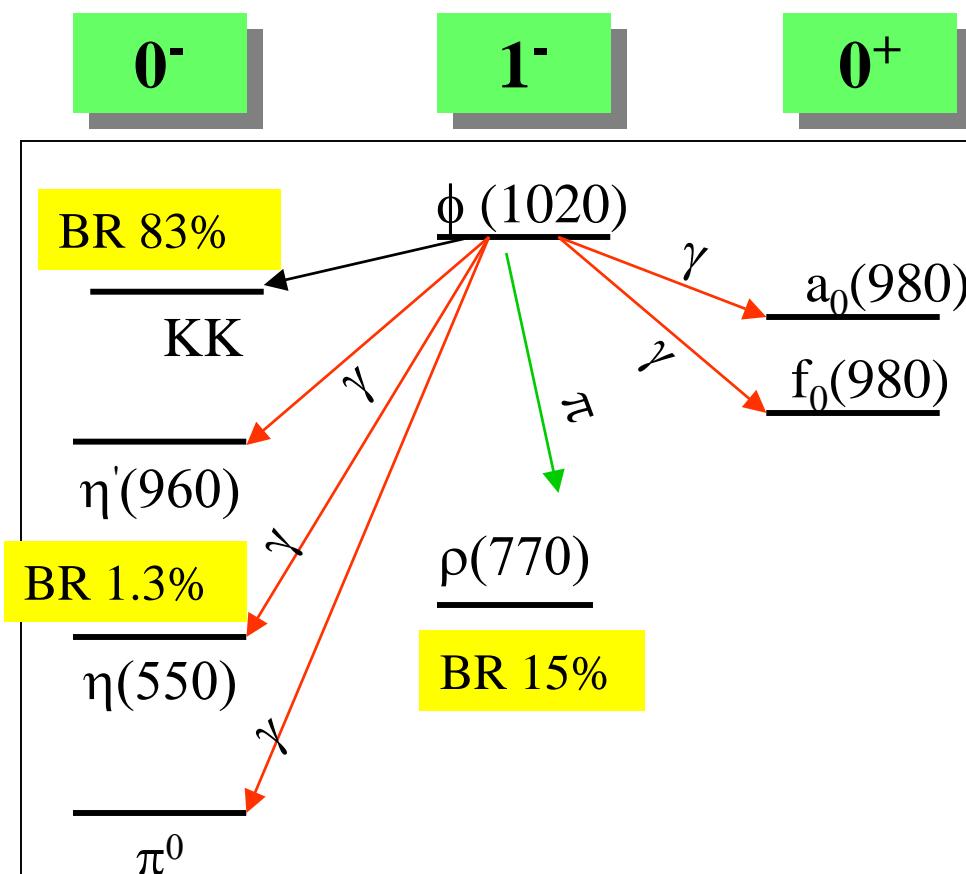
**M. Palutan, INFN/Frascati,
for the KLOE collaboration**

Padova, 24th March, 2004

KLOE: Physics at a ϕ -factory



A ϕ -factory is a collider e^+e^- running at $\sqrt{s} = M_\phi$



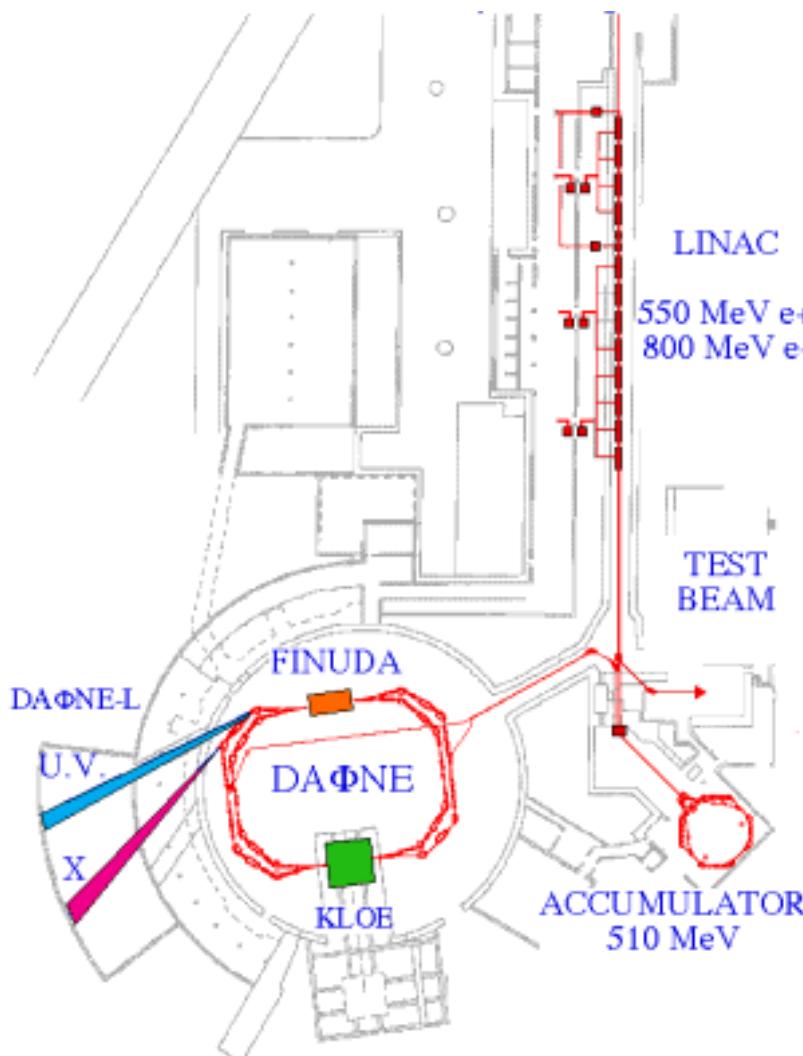
Main focus on KAON physics

- CP double ratio/interferometry
- CPT test with **semileptonic** K_s, K_L charge asymmetries
- V_{us} , kaon form factors from semileptonic $K_{S,L}, K^\pm$ decays
- Rare $K_{S,L}$ decays
($K_S \rightarrow 3\pi^0, \pi^+\pi^-\pi^0$, $K_L \rightarrow \gamma\gamma\dots$)

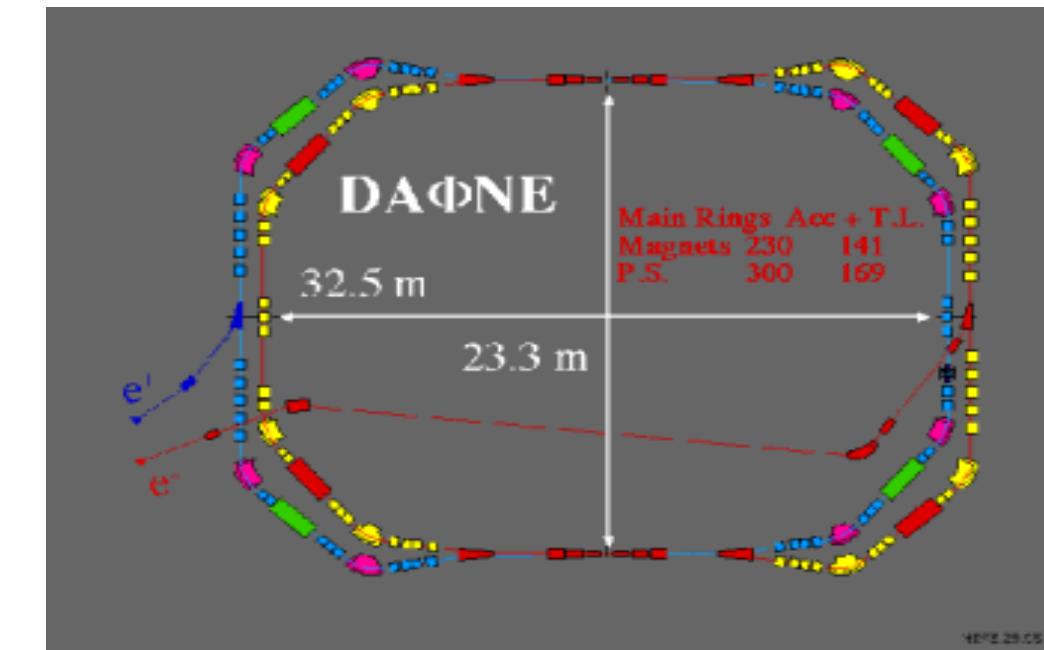
Non Kaon Physics

- radiative ϕ decays (scalars, pseudoscalars + photon)
- $\rho\pi$ final states
- **hadronic cross section**

DAΦNE: the Frascati ϕ -factory

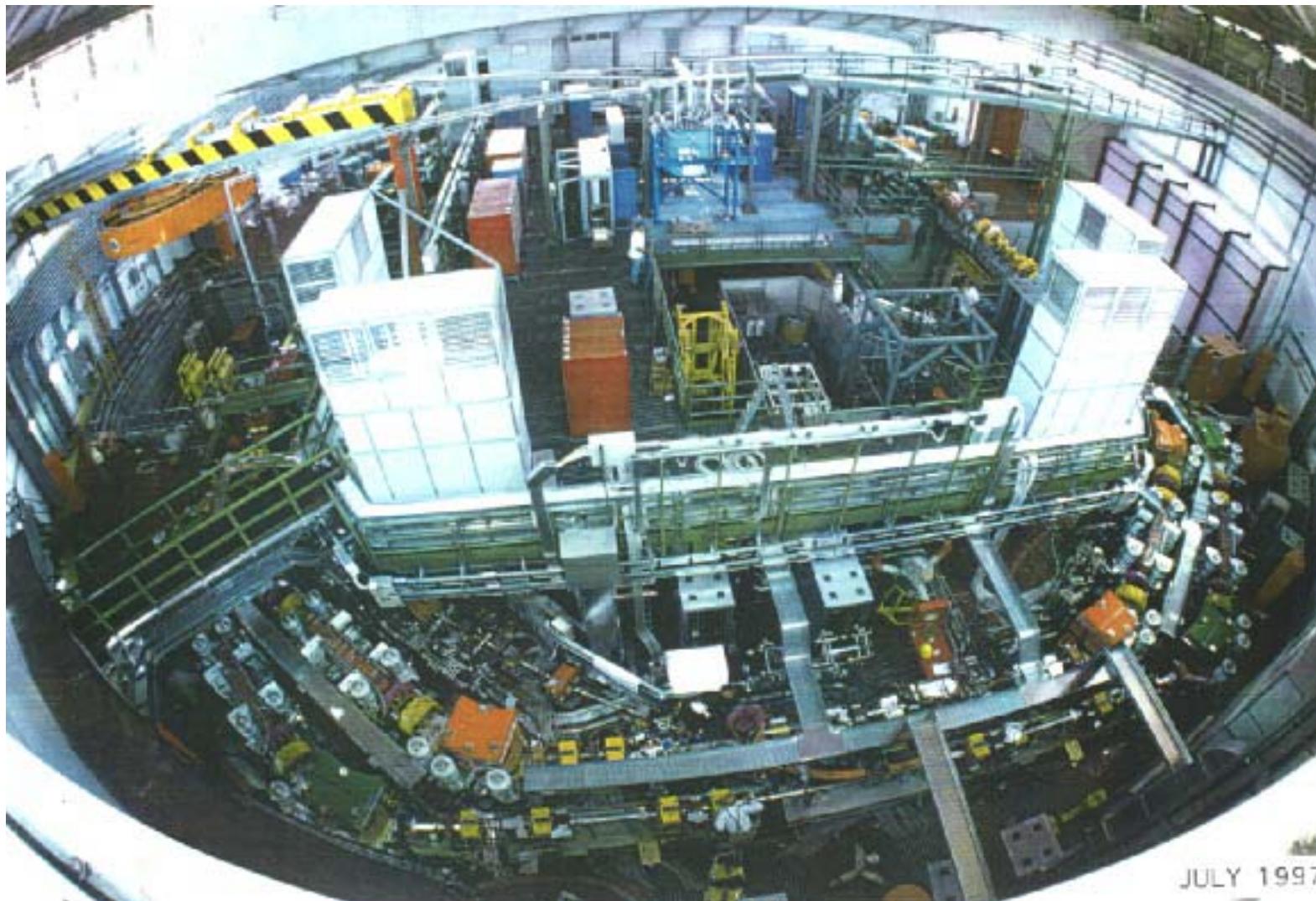


- e^+e^- collider @ $\sqrt{s} = M_\phi = 1019.4 \text{ MeV}$
- 2 interaction regions (KLOE – DEAR/FINUDA)
- Separate e^+ , e^- rings to minimize beam-beam interactions
- Crossing angle: 12.5 mrad ($p_x(\phi) \sim 13 \text{ MeV}$)



Recent results from KLOE at DAΦNE – M. Palutan – Padova, 24 March 2004

DAΦNE: the Frascati ϕ -factory



Recent results from KLOE at DAΦNE – M. Palutan – Padova, 24 March 2004

DAΦNE: the Frascati ϕ -factory

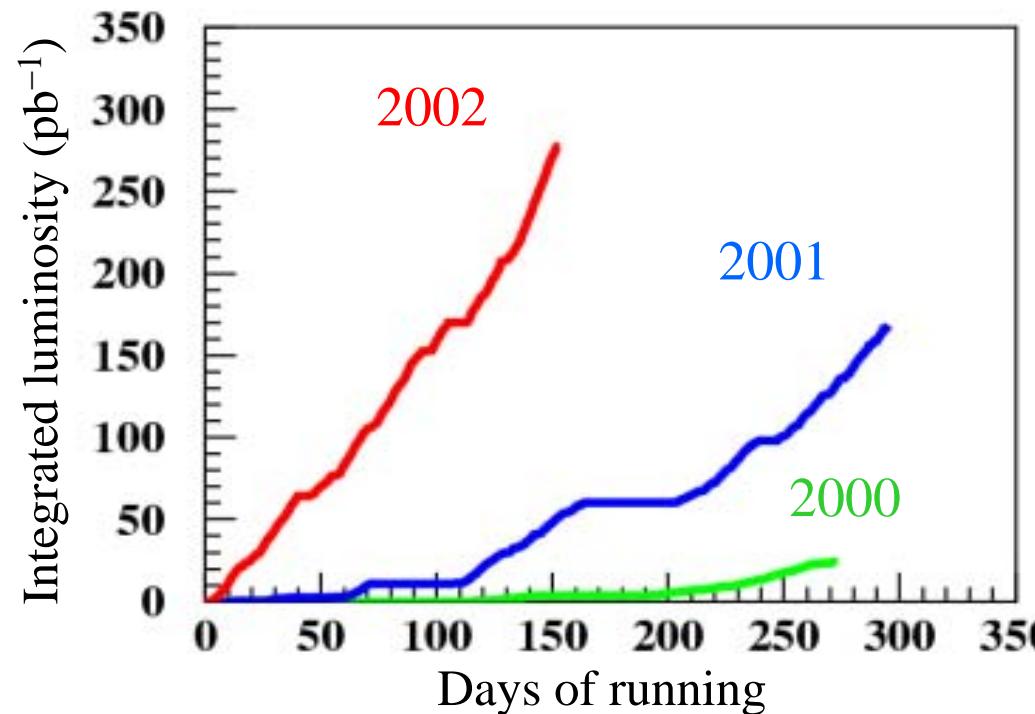


DAΦNE Parameters	Design	2002 (KLOE)	2004 (KLOE)
Number of bunches	120+	49+49	110+11
Lifetime (mins)	120	40	70
Bunch current(mA)	40	20	20
L_{bunch} ($\text{cm}^{-2}\text{s}^{-1}$)	4.4	1.5	1.8
L_{peak} ($\text{cm}^{-2}\text{s}^{-1}$)	$5.9 \cdot 10^{30}$	$6.8 \cdot 10^{30}$	$2.0 \cdot 10^{30}$
	$\cdot 10^{32}$	10^{32}	10^{32}

Injection during data-taking :

- 3 fillings per hour
- $\times 2 \int L dt$

KLOE data taking: 2000-2002



2000: **25 pb⁻¹**

$80 \cdot 10^6 \phi$ decays

*First
published
results*

2001: **176 pb⁻¹**

$550 \cdot 10^6 \phi$ decays

*Analysis
in
progress*

2002: **296 pb⁻¹**

$920 \cdot 10^6 \phi$ decays

2002 run:

- Best value of L_{peak} : $7.8 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$
- Best $\int L dt$ in one day: 4.5 pb^{-1}

KLOE data taking: 2004



New KLOE IR installed
July 2003



- The new interaction region has modified optic in order to decrease the IP beta-functions and lattice chromaticity, optimise background rejection and provide variable quadrupole rotation to operate at different magnetic fields in the solenoids.
- Injection efficiency improved
- Wiggler magnets have been modified, in order to increase dynamic aperture and lifetime

Goals for 2004:

$L_{\text{peak}} = 2 \cdot 10^{32} \text{ cm}^{-2}\text{s}^{-1}$

$L_{\text{int}} / \text{day} = 10 \text{ pb}^{-1}$

$L_{\text{int}} / \text{year} > 1 \text{ fb}^{-1}$

Kaons production



The ϕ decay at rest provides **monochromatic** and **pure** beam of kaons

- The KK pairs in the final state have the same ϕ quantum numbers, *i.e.* are produced in a pure $J^{PC} = 1^{--}$ status

$$\mathbf{K}_S (\mathbf{K}^+) \xleftarrow{\Phi} \mathbf{K}_L (\mathbf{K}^-) \quad \text{purity} \approx 10^{-10}$$
$$|i\rangle \propto \frac{1}{\sqrt{2}} (|K_L, \mathbf{p}\rangle |K_S, -\mathbf{p}\rangle - |K_L, -\mathbf{p}\rangle |K_S, \mathbf{p}\rangle)$$

- **Tagging:** observation of $K_{S,L}$ signals presence of $K_{L,S}$
 - precision measurement of absolute BR's
 - interference measurements of $K_S K_L$ system

$K^+ K^-$
 $1.5 \times 10^6 / pb^{-1}$
 $p^* = 127 \text{ MeV/c}$
 $\lambda_{\pm} = 95 \text{ cm}$

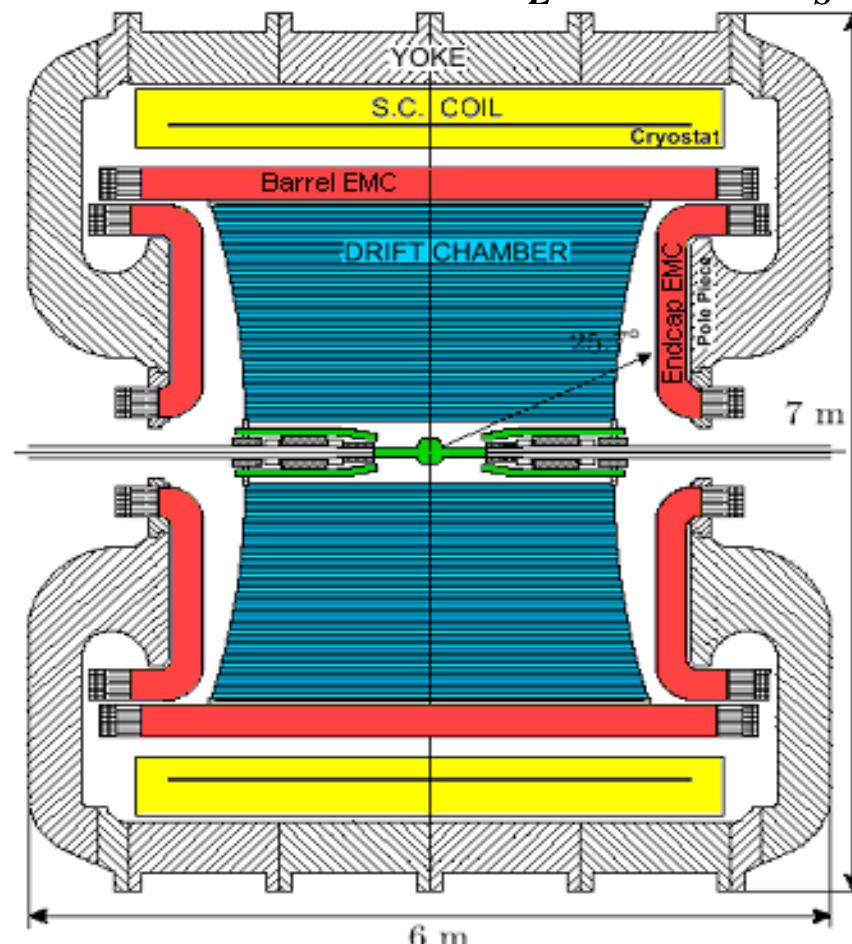
$K_L K_S$
 $10^6 / pb^{-1}; p^* = 110 \text{ MeV/c}$
 $\lambda_S = 6 \text{ mm}$ K_S decays near interaction point
 $\lambda_L = 3.4 \text{ m}$ Large detector to keep reasonable acceptance for K_L decays ($\sim 0.5 \lambda_L$)

The KLOE detector



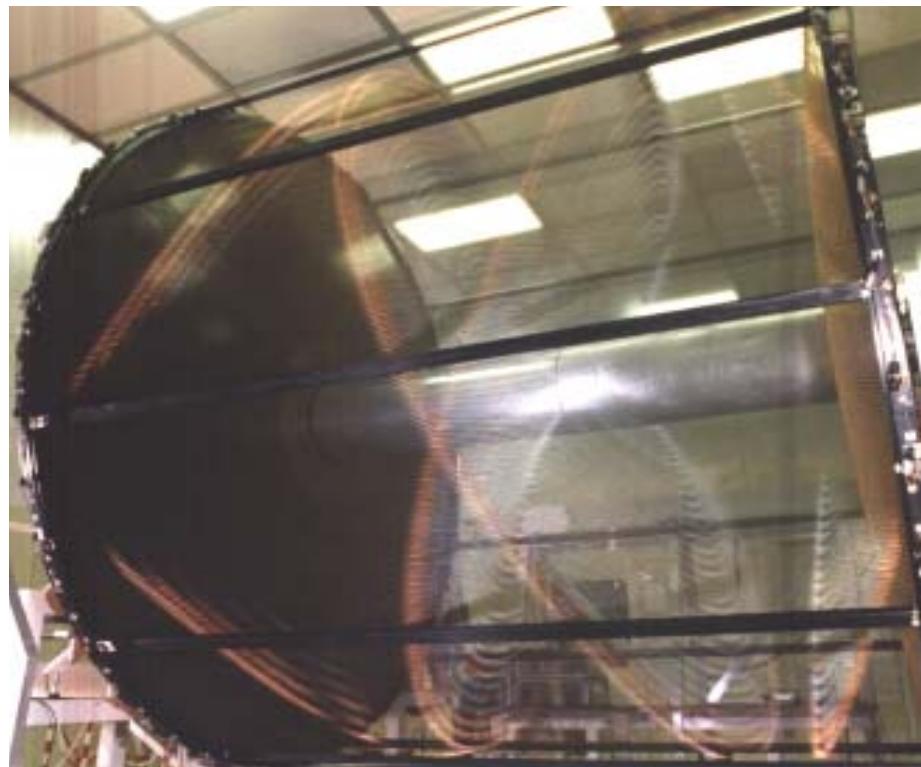
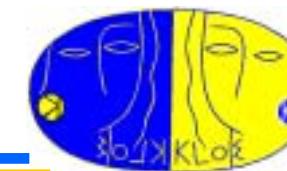
The KLOE design was driven by the measurement of direct CP through the double ratio:

$$R = \Gamma(K_L \rightarrow \pi^+ \pi^-) \Gamma(K_S \rightarrow \pi^0 \pi^0) / \Gamma(K_S \rightarrow \pi^+ \pi^-) \Gamma(K_L \rightarrow \pi^0 \pi^0)$$

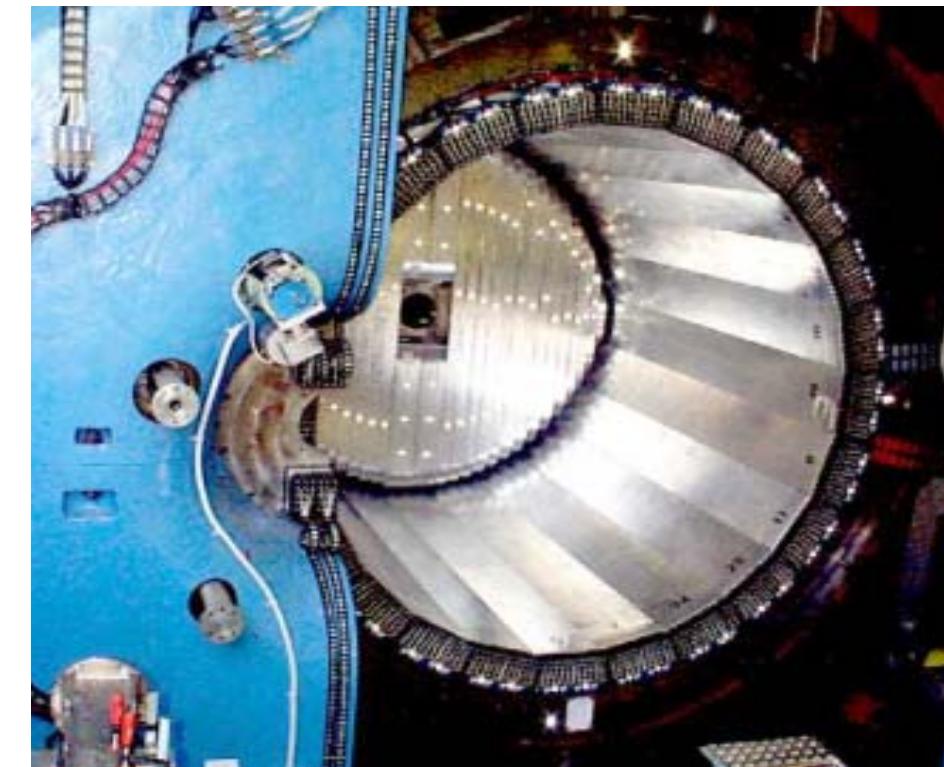


- **Be beam pipe** (spherical, 10 cm Ø, 0.5 mm thick) + **instrumented permanent magnet quadrupoles** (32 PMT's)
- **Drift chamber** (4 m Ø × 3.75 m, CF frame)
 - Gas mixture: 90% He + 10% C₄H₁₀
 - 12582 stereo–stereo sense wires
 - almost squared cells
- **Electromagnetic calorimeter**
 - lead/scintillating fibers (1 mm Ø), 15 X₀
 - 4880 PMT's
 - 98% solid angle coverage
- **Superconducting coil** ($B = 0.52$ T)

Detector performances



$\sigma_p/p = 0.4\%$ (tracks with $\theta > 45^\circ$)
 $\sigma_x^{\text{hit}} = 150 \mu\text{m}$ (xy), 2 mm (z)
 $\sigma_x^{\text{vertex}} \sim 1 \text{ mm}$
 $\sigma(M_{\pi\pi}) \sim 1 \text{ MeV}$



$\sigma_E/E = 5.7\% / \sqrt{E(\text{GeV})}$
 $\sigma_t = 54 \text{ ps} / \sqrt{E(\text{GeV})} \oplus 50 \text{ ps}$
 $\sigma_{\text{vtx}}(\gamma\gamma) \sim 1.5 \text{ cm}$ (π^0 from $K_L \rightarrow \pi^+\pi^-\pi^0$)

Kaon physics at KLOE



this talk:

- Neutral kaons tagging
- $K_S \rightarrow \pi^0 \pi^0 \pi^0$ preliminary results
- $K_S \rightarrow \pi e \nu$ *Phys. Lett.* **B537** 21 (2002), preliminary update
- K_L semileptonic decays in progress
- K^\pm semileptonic decays in progress

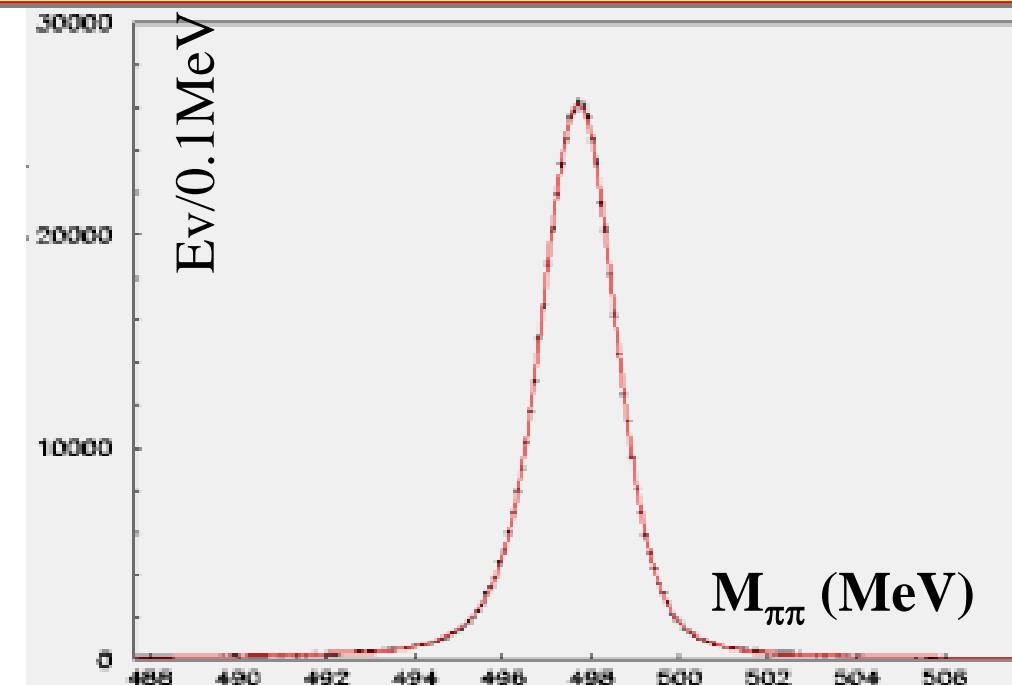
other topics:

- | | |
|--|---|
| $K_S \rightarrow \pi^+ \pi^- (\gamma)$ / $K_S \rightarrow \pi^0 \pi^0$ | <i>Phys. Lett.</i> B538 21 (2002) |
| K_S mass | KLOE Note 181 (http://www.lnf.infn.it/kloe) |
| $K_L \rightarrow \gamma \gamma$ / $\pi^0 \pi^0 \pi^0$ | <i>Phys. Lett.</i> B566 61 (2003) |
| $K_S K_L$ interference | in progress |
| $K^\pm \rightarrow \pi^\pm \pi^0$ / $K^\pm \rightarrow \mu^\pm \nu$ | in progress |
| $K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$ | preliminary results, hep-ex/0307054 |
| $K^\pm \rightarrow \pi^0 \pi^0 e^\pm \nu$ | in progress |

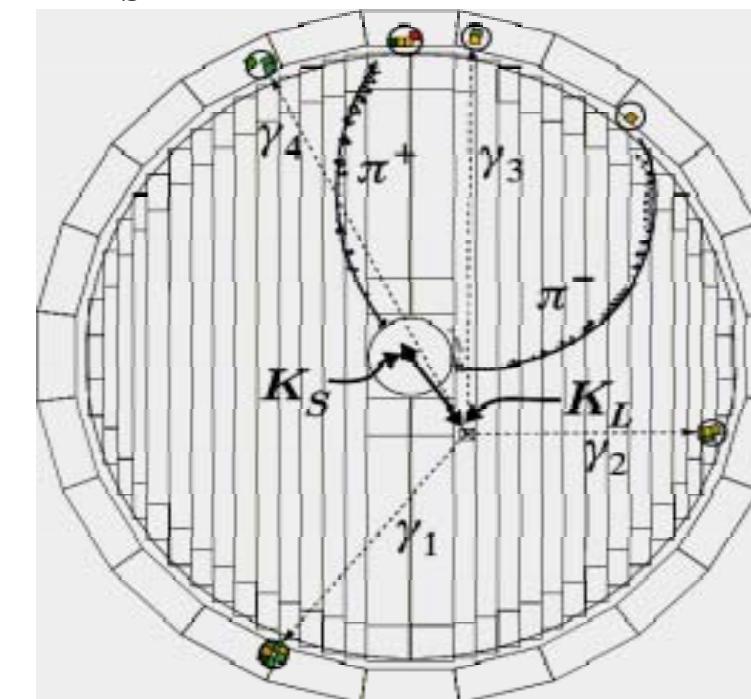
Neutral kaons tagging: K_L “beam”



- K_L tagged by $K_S \rightarrow \pi^+\pi^-$ vertex at IP
- DC resolution on $\pi^+\pi^-$ invariant mass $\sigma_M \sim 1$ MeV
- Tagging efficiency $\epsilon_{tag,total} \sim 70\%$ (mainly geometrical) $\Rightarrow 2.2 \cdot 10^8$ tagged K_L



$$K_S \rightarrow \pi^+\pi^- \quad K_L \rightarrow 2\pi^0$$



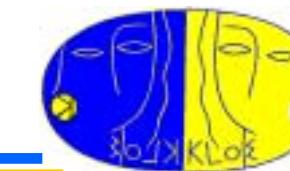
Kinematic closure of the event

$$(p_L = p_\phi - p_S):$$

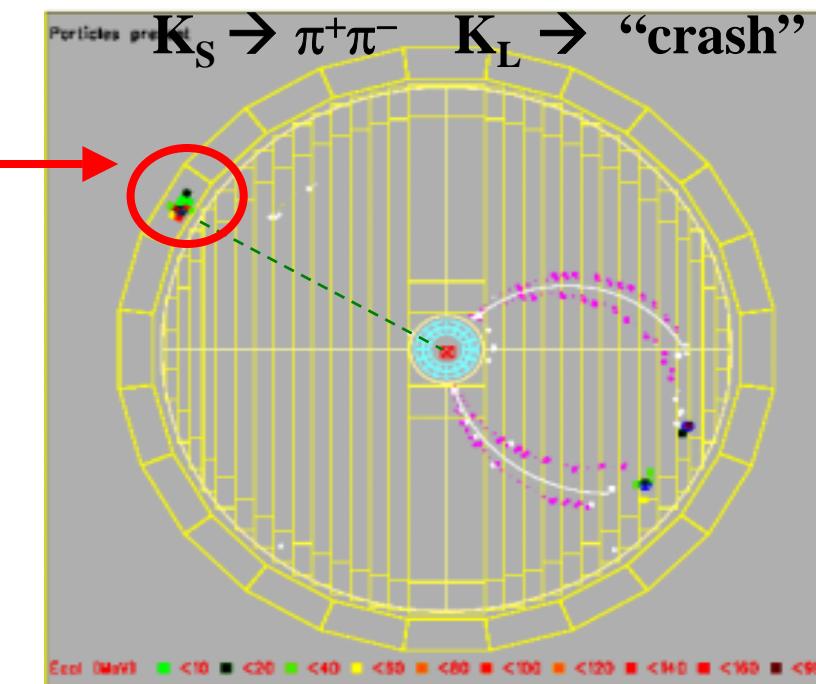
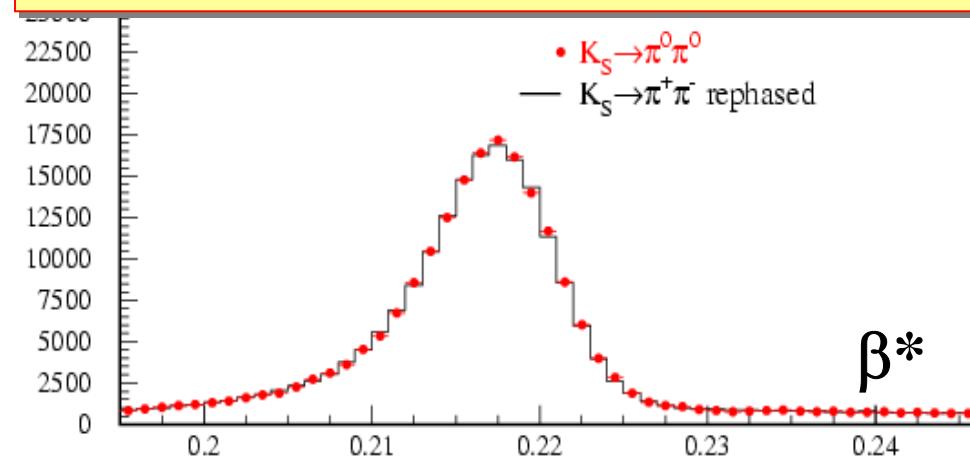
K_L angular resolution: $\sim 1^\circ$

K_L momentum resolution: ~ 1 MeV

Neutral kaons tagging: K_S “beam”



- Clean K_S tagging by time-of-flight identification of K_L interactions in the calorimeter
- K_L velocity in the ϕ rest frame
 $\beta^* \sim 0.218$
- Tagging efficiency $\varepsilon_{tag,total} \sim 30\% \Rightarrow 1.5 \cdot 10^8$ tagged K_S



Kinematic closure of the event

$$(\mathbf{p}_S = \mathbf{p}_\phi - \mathbf{p}_L)$$

K_S angular resolution: $\sim 1^\circ$ (0.3° in ϕ)

K_S momentum resolution: ~ 1 MeV

$K_S \rightarrow \pi^0 \pi^0 \pi^0$ – Test of CP and CPT



- Observation of $K_S \rightarrow 3\pi^0$ signals CP violation in mixing and/or in decay:

SM prediction: $\Gamma_S = \Gamma_L |\varepsilon|^2$, giving $\text{BR}(K_S \rightarrow 3\pi^0) = 1.9 \cdot 10^{-9}$

Present published results: $\text{BR}(K_S \rightarrow 3\pi^0) < 1.4 \cdot 10^{-5}$ (90% CL)

- Uncertainty on $K_S \rightarrow 3\pi^0$ amplitude limits precision of CPT test:

from unitarity (Bell-Steinberger)

$$(1 + i \tan\phi_{SW}) \text{Re } \varepsilon - \sum_f A^*(K_S \rightarrow f) A(K_L \rightarrow f) / \Gamma_S = (-i + \tan\phi_{SW}) \text{Im } \delta$$
$$(\varepsilon_{S,L} = \varepsilon \pm \delta)$$

- A limit on $\text{BR}(K_S \rightarrow 3\pi^0)$ at 10^{-7} level translates into a 2.5-fold improvement on the accuracy of $\text{Im } \delta$ ($5 \cdot 10^{-5} \rightarrow 2 \cdot 10^{-5}$), *i.e.*

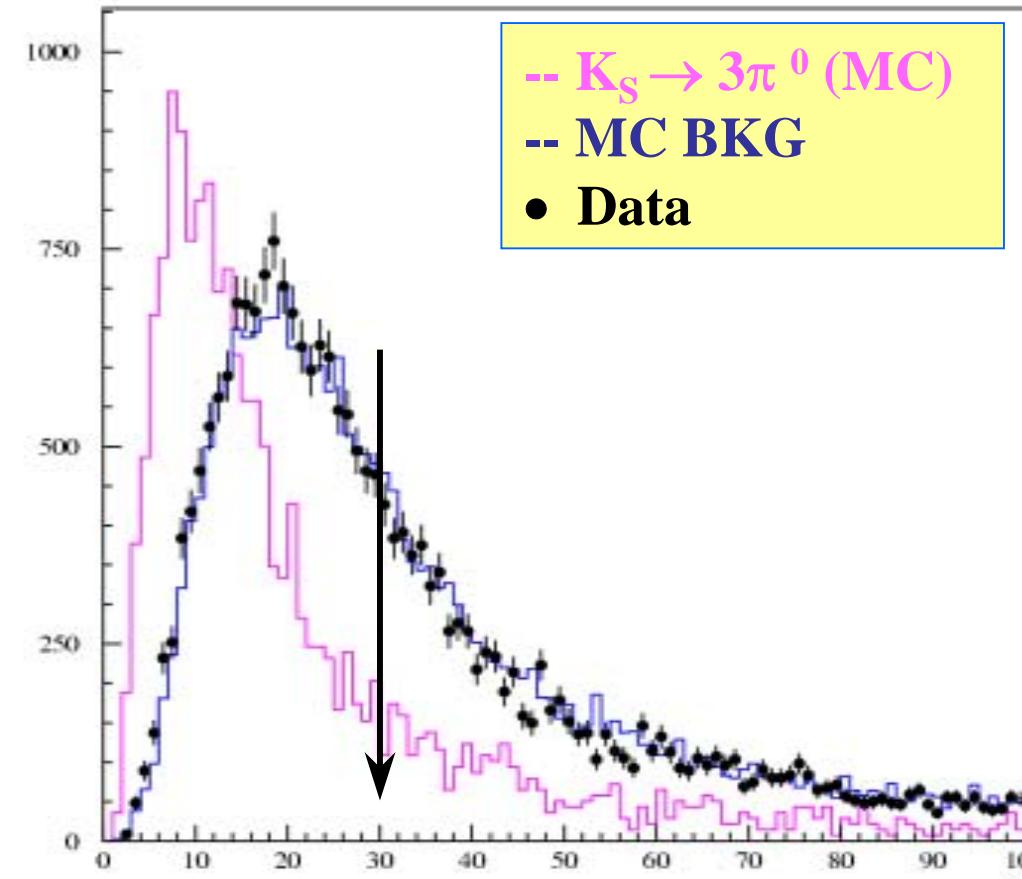
$$\frac{\delta(M_{K0} - M_{K0})}{M_K} \sim 5 \cdot 10^{-19}$$

($\Gamma_{K0} = \Gamma_{K0}^-$ assumed)

Search for $K_S \rightarrow \pi^0\pi^0\pi^0$



- ◆ K_S 's tagged by K_{crash} identification ($1.5 \cdot 10^8$ events)
- ◆ 6 photons (neutral clusters, TOF consistent with $\beta = 1$)
- ◆ No charged tracks from IP
- ◆ Kinematic fit:
 - Impose K_S mass and energy-momentum conservation, $\beta = 1$ for each γ
 - Estimate $E_\gamma, \mathbf{r}_\gamma, t_\gamma, \sqrt{s}, p_\phi$



Rejection power of χ^2_{fit} not sufficient to eliminate main background due to $K_S \rightarrow \pi^0\pi^0 + 2 \text{ fake } \gamma$'s

χ^2_{Fit}

Search for $K_S \rightarrow \pi^0\pi^0\pi^0 - 2\pi^0$ vs $3\pi^0$

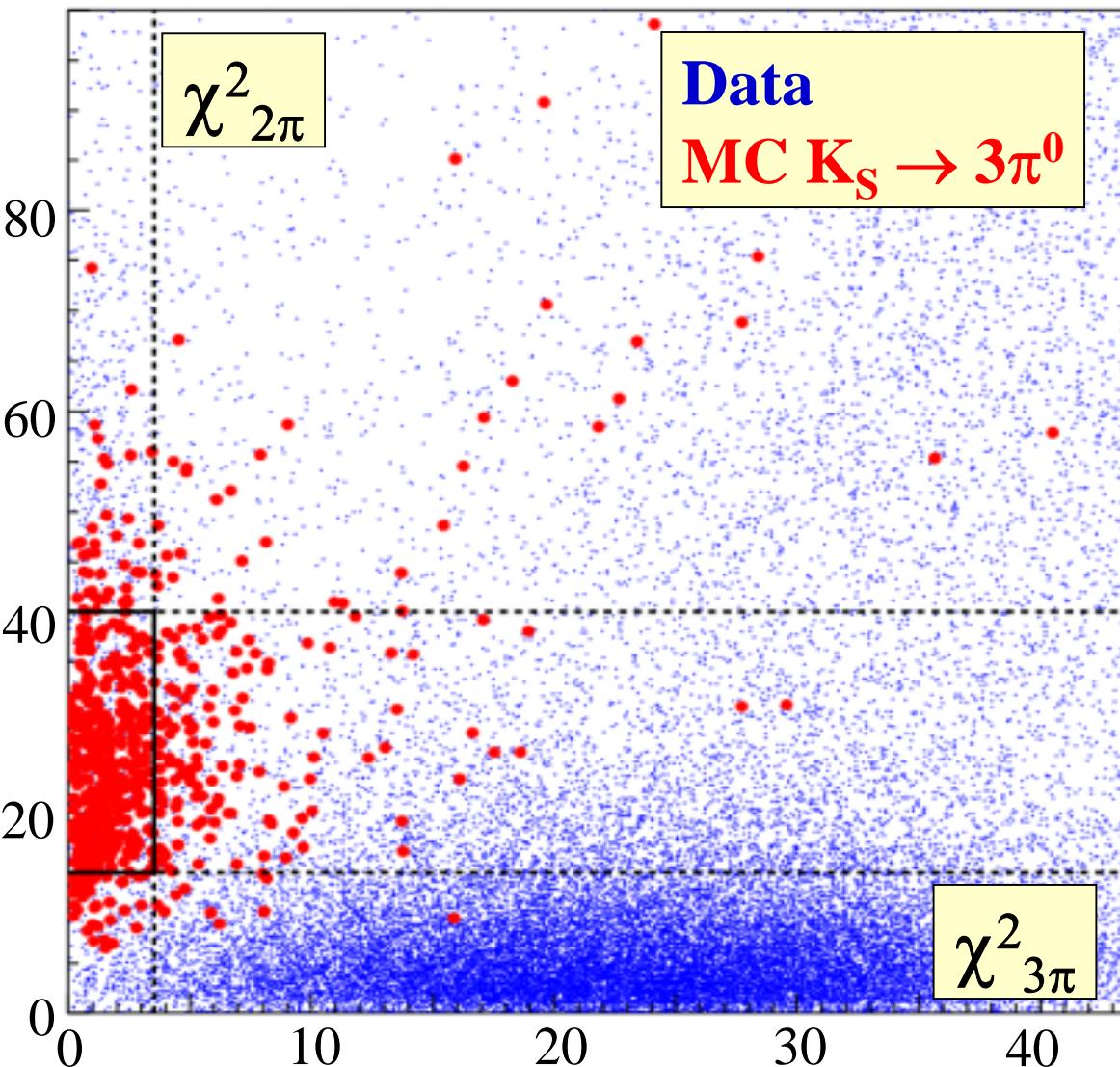


To reject background compare
 3π vs 2π hypotheses :

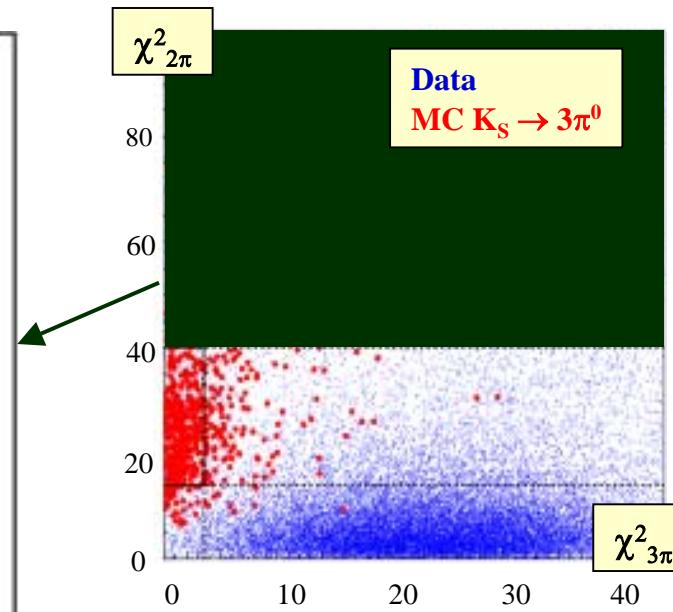
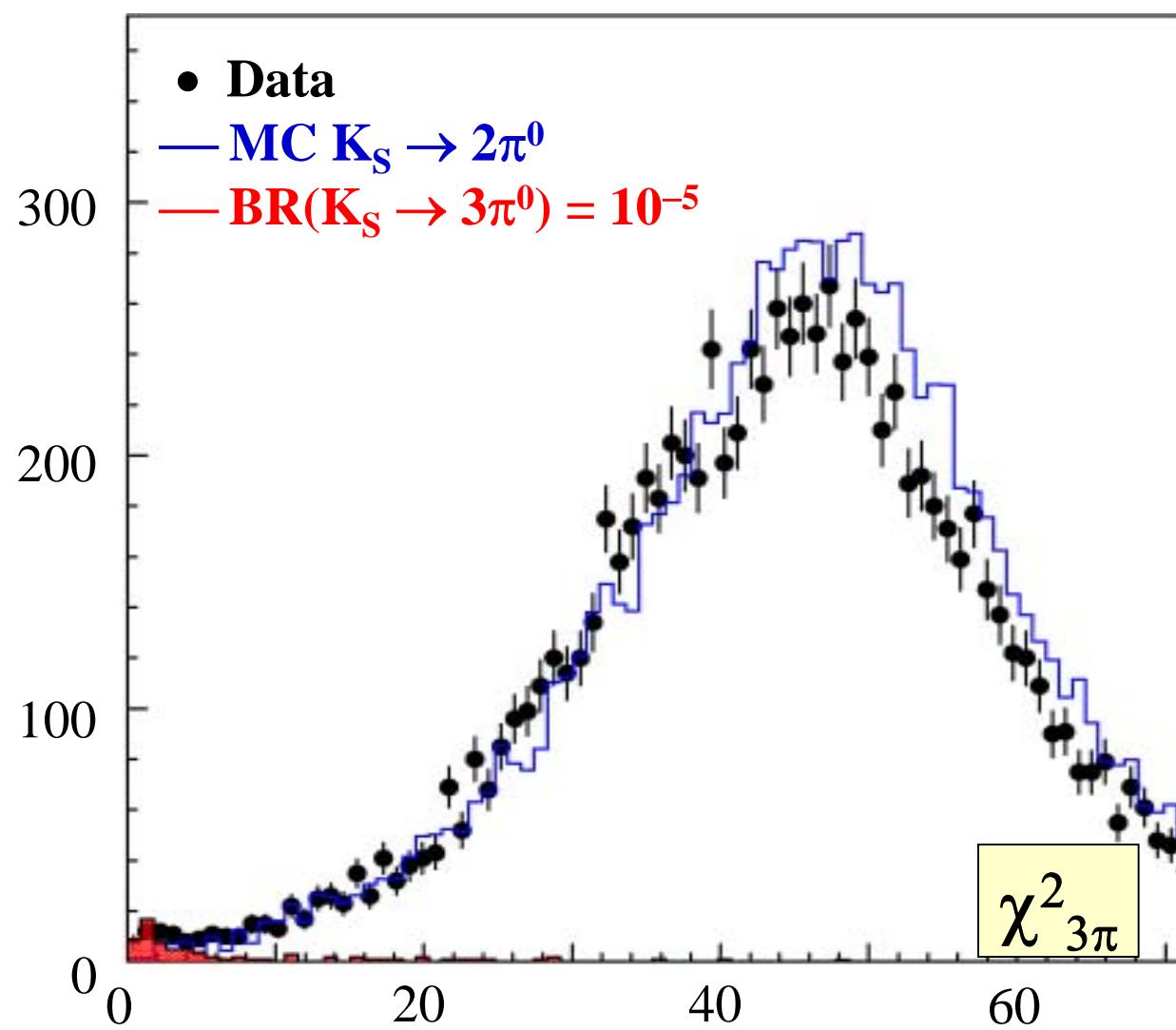
$\chi^2_{3\pi}$ – pairing of 6 γ clusters
with best π^0 mass estimates

$\chi^2_{2\pi}$ – pairing of 4 γ 's out of
6: π^0 masses, $E(K_S)$, $P(K_S)$,
c.m. angle between π^0 's

**Definition of the signal box
obtained from analysis of 6-
pb⁻¹-equivalent MC
subsample**

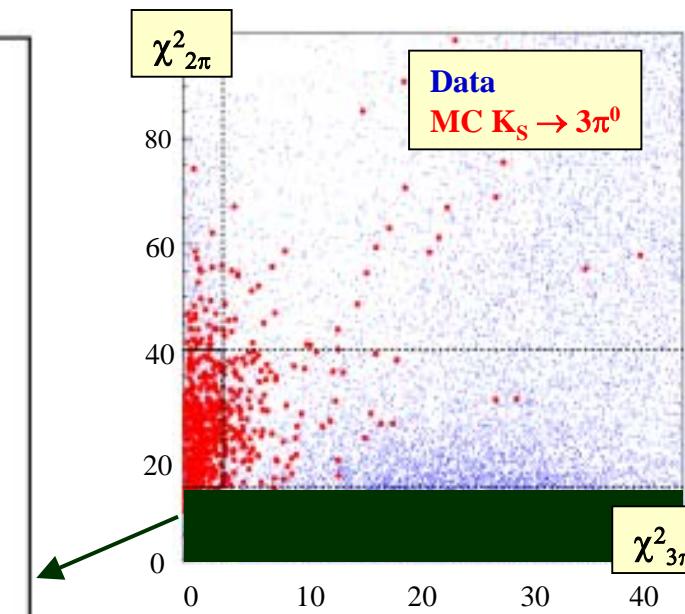
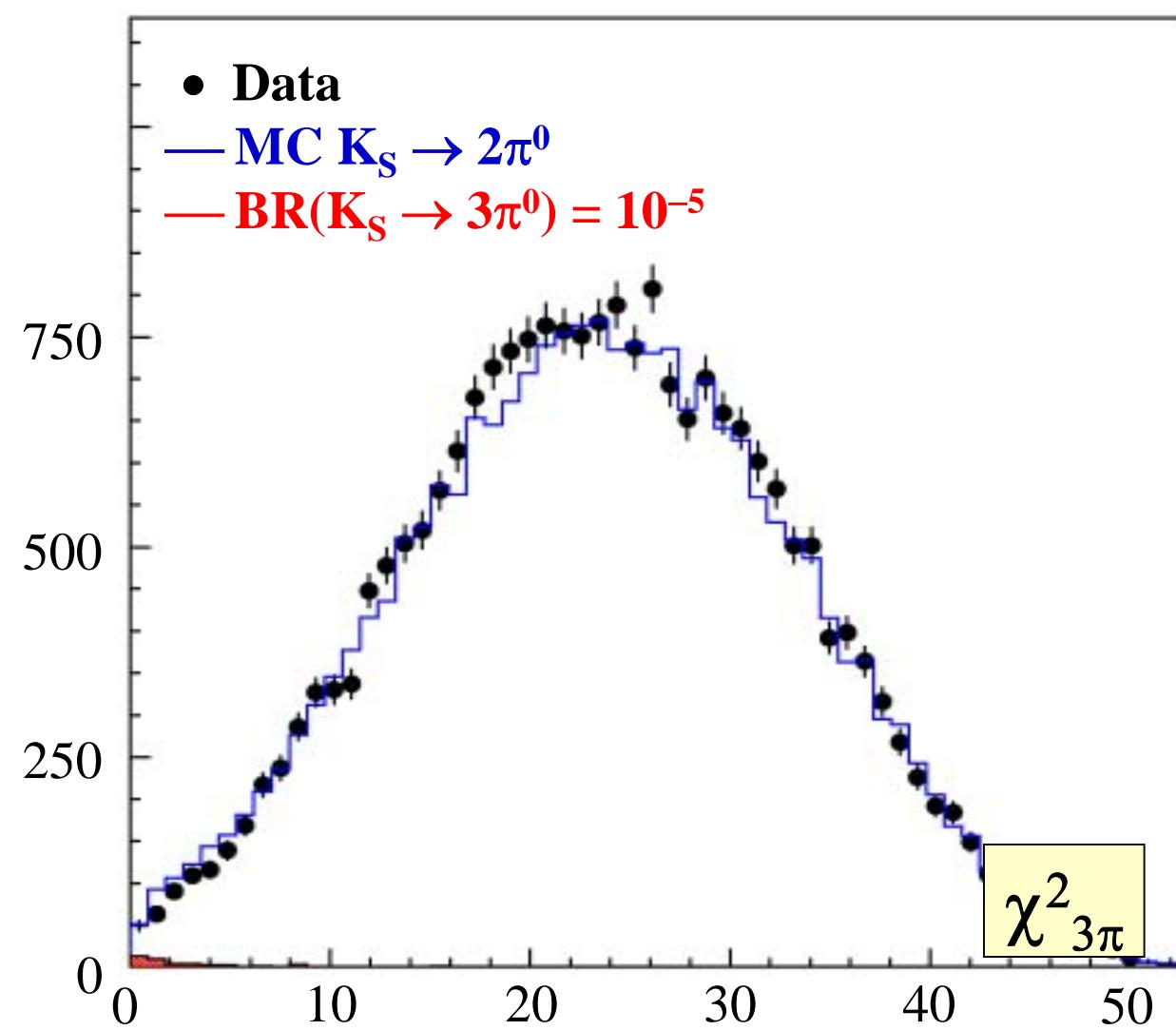
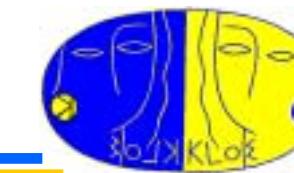


Search for $K_S \rightarrow \pi^0\pi^0\pi^0$ - sidebands



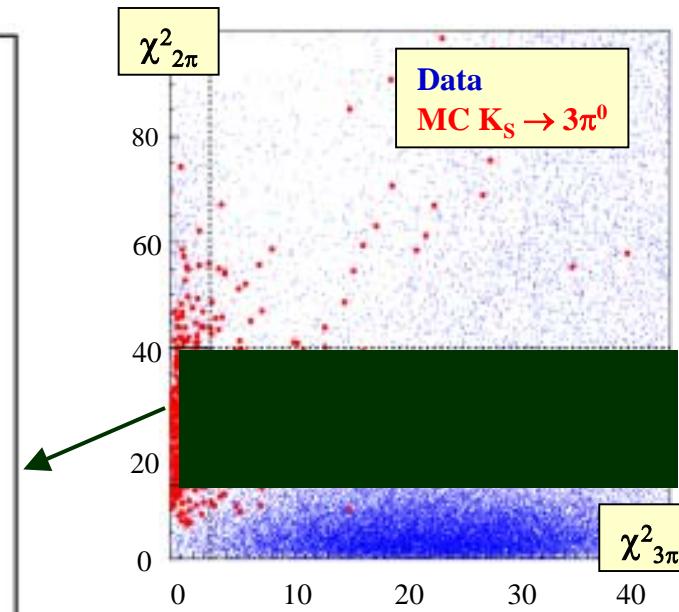
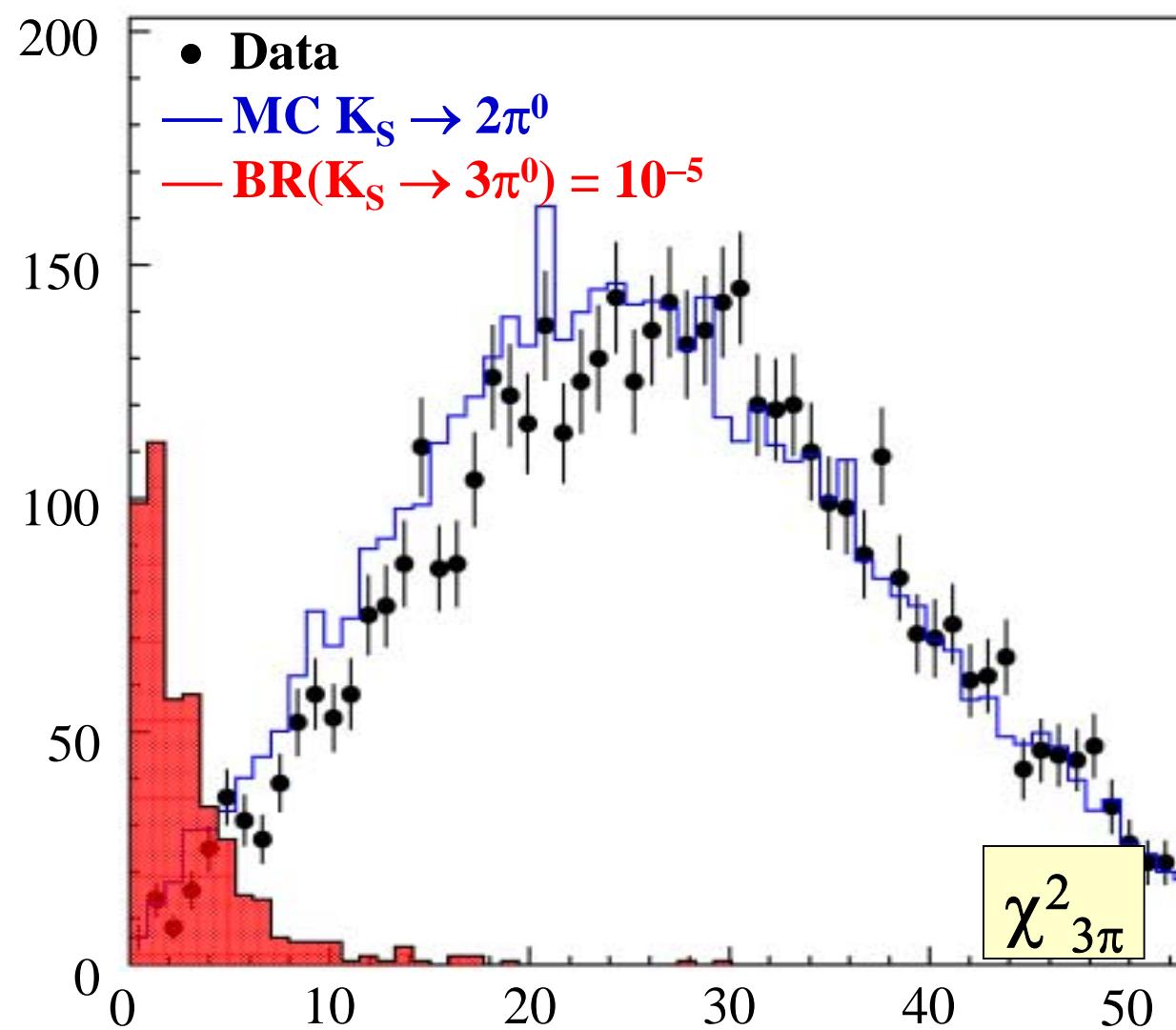
$K_S \rightarrow 3\pi^0$ decay switched on during MC production of 450 pb⁻¹ equivalent data, with BR equal to the present upper limit

Search for $K_S \rightarrow \pi^0\pi^0\pi^0$ - sidebands



**Absolute BKG
normalization
better than 10%
in all control boxes**

Search for $K_S \rightarrow \pi^0\pi^0\pi^0$ – signal region



$K_S \rightarrow \pi^0 \pi^0 \pi^0$ – Preliminary results



- ♦ UL optimized by varying in MC: Signal-Box definition, cut on χ^2_{fit} and residual K_s energy ($\Delta E = M_\Phi/2 - \sum E_\gamma$). We find:

- $N_{\text{sel}}(\text{data}) = 4$ events selected as signal, with efficiency $\varepsilon_{3\pi} = 22.6\%$
- $N_{\text{sel}}(\text{bkg}) = 3 \pm 1.4_{\text{stat}} \pm 0.2_{\text{syst}}$ bkg events expected from MC

- ♦ Folding the proper BKG uncertainty we get: $N_{3\pi} < 5.8$ with a 90% CL
- ♦ Normalize to $K_S \rightarrow \pi^0 \pi^0$ count in the same data set (38x10⁶, $\varepsilon_{2\pi} = 92\%$)

$$\text{BR}(K_S \rightarrow \pi^0 \pi^0 \pi^0) = \frac{N_{3\pi} / \varepsilon_{3\pi}}{N_{2\pi} / \varepsilon_{2\pi}} \text{BR}(K_S \rightarrow \pi^0 \pi^0) < 2.1 \cdot 10^{-7},$$

preliminary

This translates to: $|n_{000}| = \left| \frac{A(K_S \rightarrow \pi^0 \pi^0 \pi^0)}{A(K_L \rightarrow \pi^0 \pi^0 \pi^0)} \right| < 2.4 \cdot 10^{-2}$

$K_S \rightarrow \pi e \bar{\nu}$ decay – Test of CPT



Sensitivity to CPT violating effects through charge asymmetry:

$$A_{S,L} = \frac{\Gamma(K_{S,L} \rightarrow \pi^- e^+ \bar{\nu}) - \Gamma(K_{S,L} \rightarrow \pi^+ e^- \bar{\nu})}{\Gamma(K_{S,L} \rightarrow \pi^- e^+ \bar{\nu}) + \Gamma(K_{S,L} \rightarrow \pi^+ e^- \bar{\nu})}$$

$\langle \pi^+ e^- \bar{\nu} H_W K^0 \rangle = a + b$	b=d=0 if CPT holds
$\langle \pi^- e^+ \bar{\nu} H_W K^0 \rangle = a^* - b^*$	
$\langle \pi^- e^+ \bar{\nu} H_W K^0 \rangle = c + d$	c=d=0 by $\Delta S = \Delta Q$ rule
$\langle \pi^+ e^- \bar{\nu} H_W K^0 \rangle = c^* - d^*$	

$K \rightarrow \pi e \bar{\nu}$ amplitudes

$$A_S = 2(\operatorname{Re} \varepsilon_K + \operatorname{Re} \delta_K + \operatorname{Re} b/a - \operatorname{Re} d^*/a)$$

$$A_L = 2(\operatorname{Re} \varepsilon_K - \operatorname{Re} \delta_K + \operatorname{Re} b/a + \operatorname{Re} d^*/a)$$

\mathcal{CP}

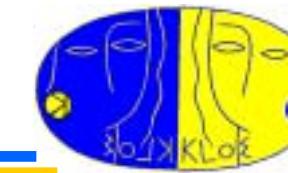
CPT in
mixing

CPT in
decay

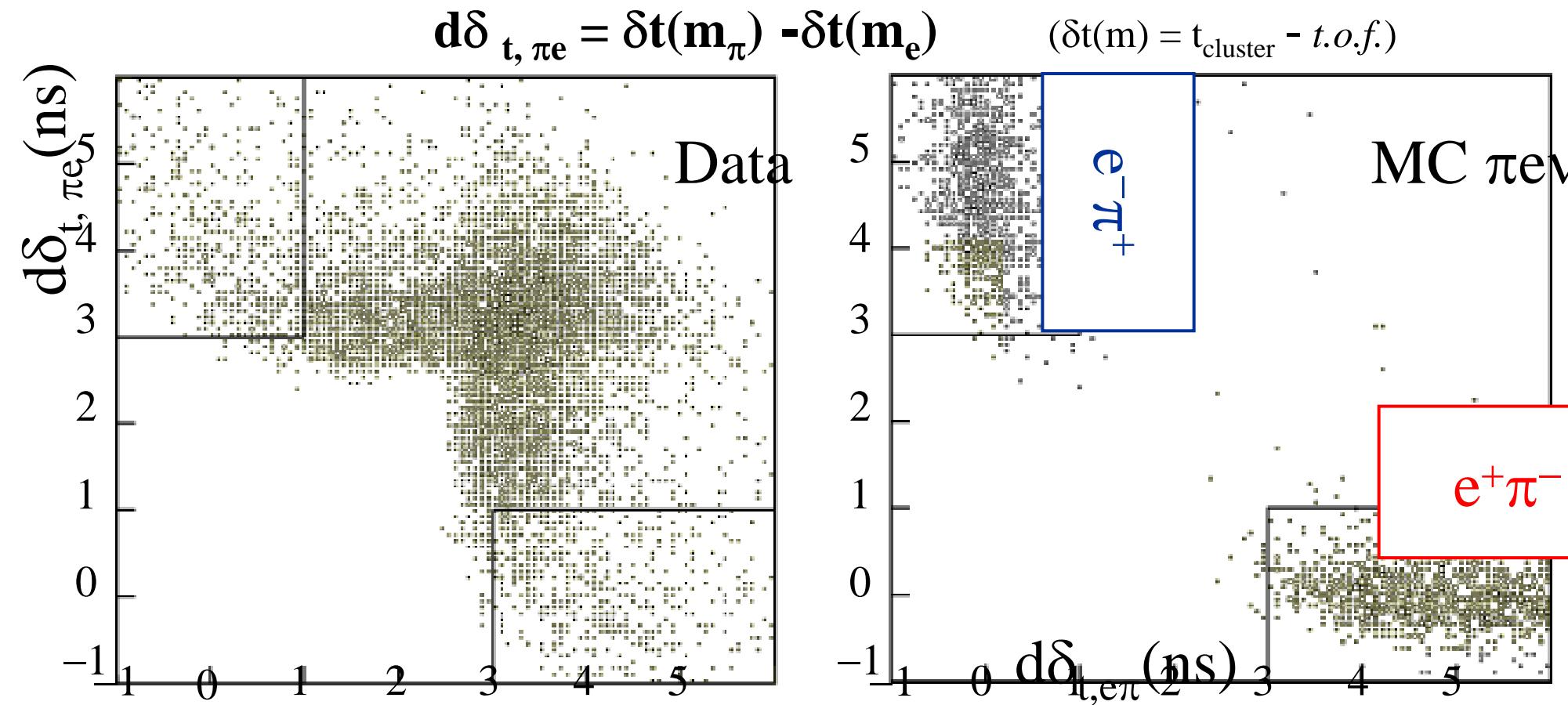
$\Delta S \neq \Delta Q$
and CPT

$A_S - A_L \neq 0$
implies
~~CPT~~

$K_S \rightarrow \pi e\nu$ decay – Analysis outline



- ◆ K_{crash} tag + 2 tracks from IP with $M_{\pi\pi} < 490$ MeV (reject $K_S \rightarrow \pi\pi(\gamma)$)
- ◆ **TOF identification:** compare π -e expected flight times, reject $\pi\pi, \pi\mu$ bkg



$K_S \rightarrow \pi e \bar{\nu}$ decay – Events counting

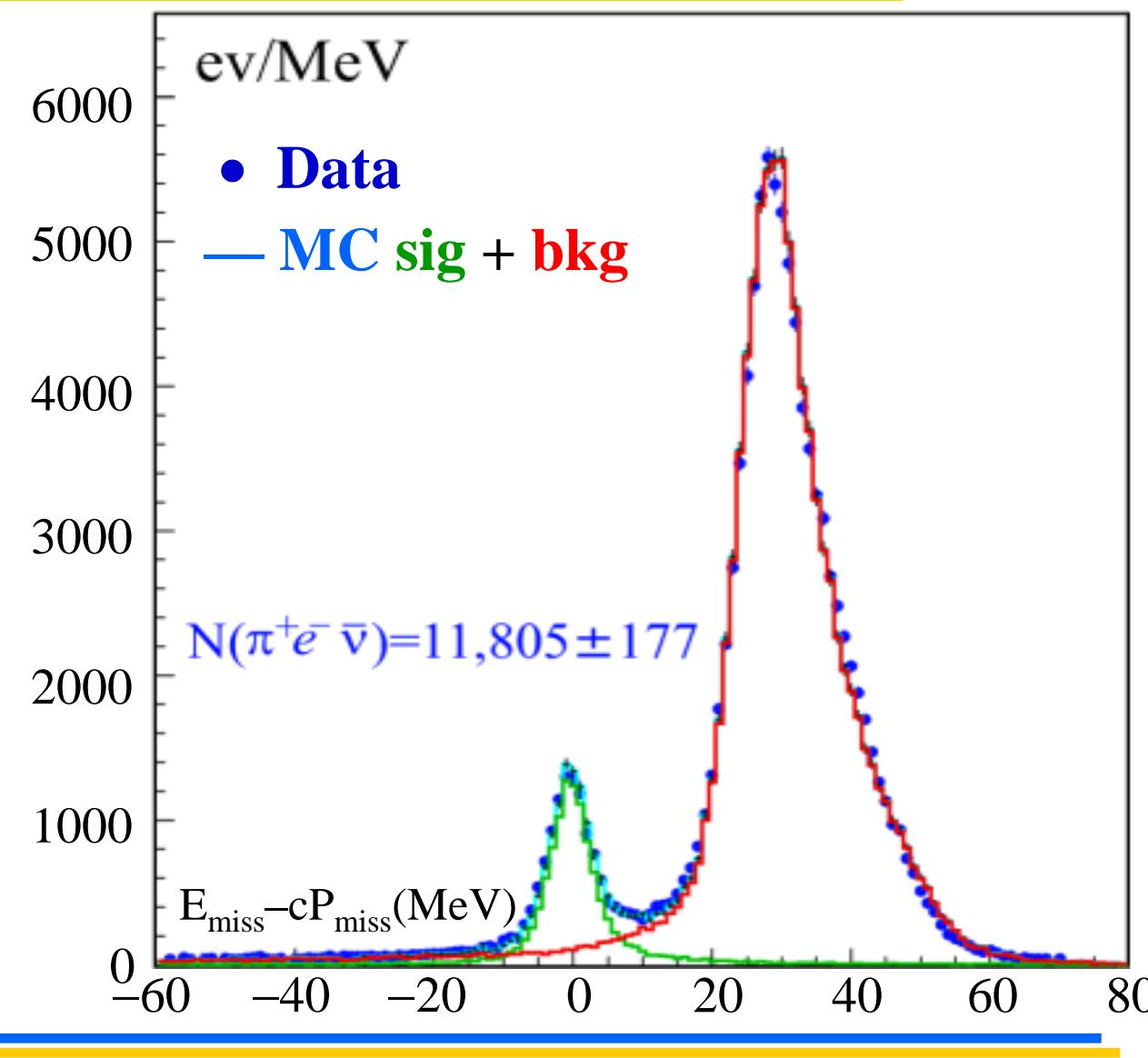


Kinematic closure: use K_L to obtain K_S momentum P_K and test for presence of neutrino:

$$E_{\text{miss}} = \sqrt{M_K^2 + P_K^2} - E_\pi - E_e$$

$$P_{\text{miss}} = |P_K - P_\pi - P_e|$$

Determine number of signal counts by fitting data to a linear combination of MC spectra for signal and background



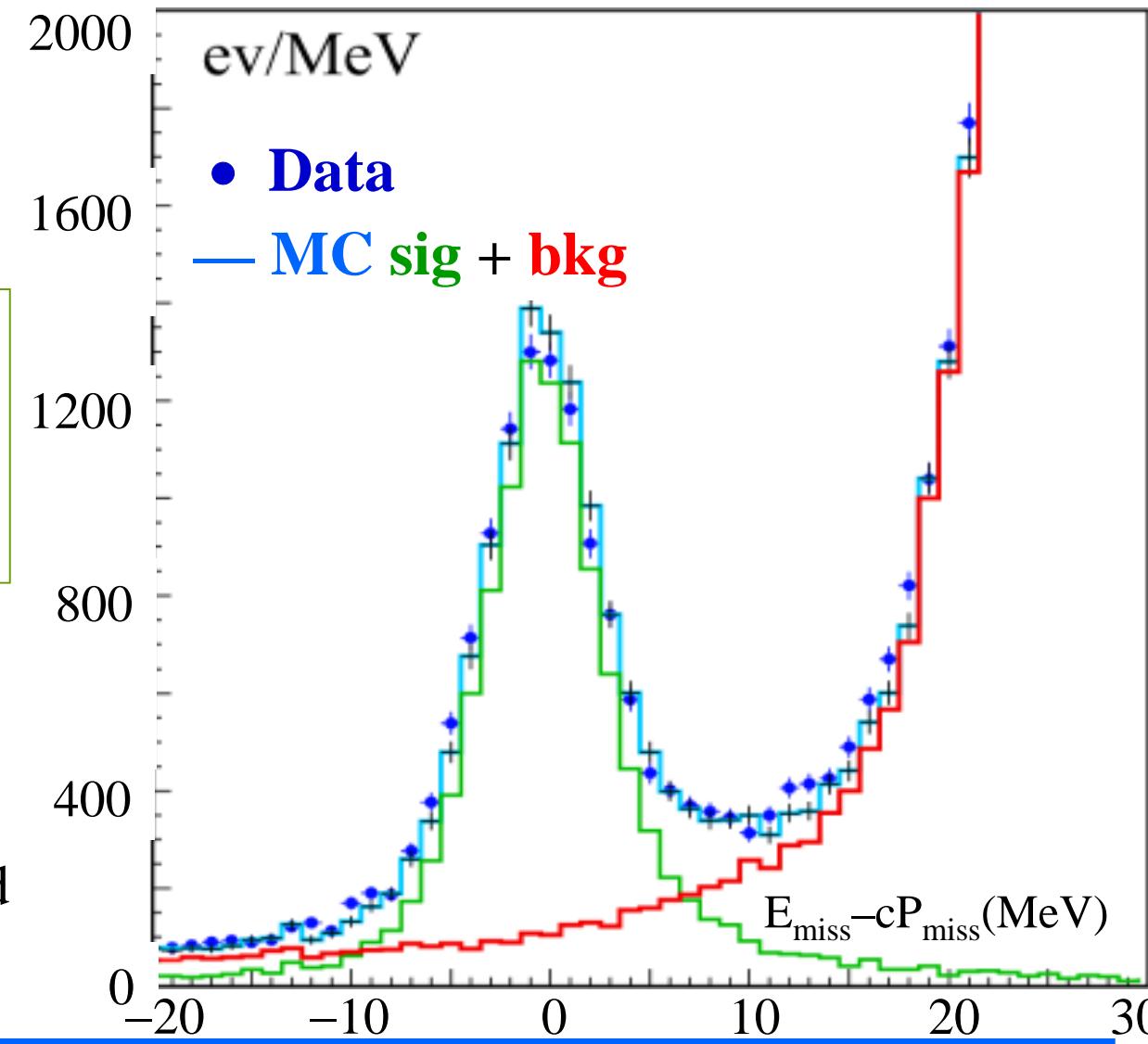
$K_S \rightarrow \pi \nu$ decay – Events counting



Signal spectrum clearly sensitive to the presence of a photon in the final state

Include radiative effects through an IR-finite treatment in MC (no energy cutoff)

Normalize signal counts to $K_S \rightarrow \pi\pi(\gamma)$ counts in the same data set (use PDG03 for $\text{BR}(K_S \rightarrow \pi\pi(\gamma))$, dominated by KLOE measurement)



K_S→πeν decay – BR and A_S



Selection efficiency (given the tag) is evaluated by charge, using data control sample of K_L → πeν decaying close to IP:

$$\varepsilon(\pi^- e^+) = (24.1 \pm 0.1 \pm 0.2)\% ; \quad \varepsilon(\pi^+ e^-) = (23.6 \pm 0.1 \pm 0.2)\%$$

$$BR(K_S \rightarrow \pi^- e^+ \nu) = (3.54 \pm 0.05_{\text{stat}} \pm 0.05_{\text{syst}}) 10^{-4}$$

$$BR(K_S \rightarrow \pi^+ e^- \nu) = (3.54 \pm 0.05_{\text{stat}} \pm 0.04_{\text{syst}}) 10^{-4}$$

$$\boxed{BR(K_S \rightarrow \pi e \nu) = (7.09 \pm 0.07_{\text{stat}} \pm 0.08_{\text{syst}}) 10^{-4}}$$

(Published result: $(6.91 \pm 0.34_{\text{stat}} \pm 0.15_{\text{syst}}) 10^{-4}$, KLOE '02)

preliminary

evaluation of the
systematics near
completion

$$\boxed{A_S = (-2 \pm 9_{\text{stat}} \pm 6_{\text{syst}}) 10^{-3} \quad (\text{never measured before})}$$

($A_L = (3.322 \pm 0.058 \pm 0.047) 10^{-3}$, KTeV 2002)

future:

next year run

$$2 \text{ fb}^{-1} \rightarrow \sigma(A_S) \sim 3 \cdot 10^{-3}$$

CPT test

$$\sigma(\text{Re}\delta_K) = \frac{1}{4} \sigma(A_S) = 3 \cdot 10^{-4} \rightarrow 20 \text{ fb}^{-1}$$

Unitarity test of CKM matrix – V_{us}



- Most precise test of unitarity possible at present comes from 1st row:

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 \sim |V_{ud}|^2 + |V_{us}|^2 \equiv 1 - \Delta$$

- Can test if $\Delta = 0$ at few 10^{-3} : PDG02 $\Delta = 0.0042 \pm 0.0019$

from super-allowed $0^+ \rightarrow 0^+$ Fermi transitions, n β -decays: $2|V_{ud}|\delta V_{ud} = 0.0015$

from semileptonic kaon decays (PDG 2002 fit): $2|V_{us}|\delta V_{us} = 0.0011$

- $|V_{us}|$ is extracted from K_{l3} partial decay width:

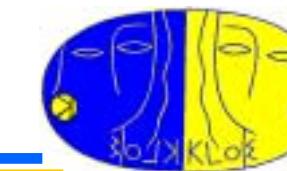
$$\Gamma_i(K \rightarrow \pi l \nu(\gamma)) = N_i |V_{us}|^2 |f_+^i(0)|^2 I_i(\lambda_+, \lambda_0, \alpha) S_{ew}$$

- where i runs over the four modes $K^{\pm,0}(e3), K^{\pm,0}(\mu3)$

$$\bullet N_i = \frac{G_F^2 M_{Ki}^5}{192\pi^3} C_i^2 \quad [Ci=1(2^{-1/2}) \text{ for neutral (charged kaon decays)}]$$

- $f_+^i(0)$ form factor, $I(\lambda)$ phase space integral, S_{ew} short distance corrections (1.0232)

$\Gamma(K \rightarrow \pi l \nu) : \text{EM effects}$



A precise determination of V_{us} needs inclusion of **EM** effects (few 10^{-2})

$$\Gamma_i(K \rightarrow \pi l \nu(\gamma)) = N_i |V_{us}|^2 S_{ew} |f_+^i(0)|^2 I_i(\lambda_+, \lambda_0, \alpha)$$

- $I_i(\lambda_+, \lambda_0, \alpha) = I(\lambda_+, \lambda_0, 0) (1 + \Delta I_i(\lambda_+, \lambda_0))$ phase space corr. due to γ radiation
- $f_+^i(0) = f_+^{K0\pi^-}(0) (1 + \delta^i_{SU(2)}) (1 + \delta_{e2p2})$ isospin breaking effects both of strong and electromagnetic origin
- $f_+^{K0\pi^-}(0)$ form factor at zero momentum transfer: pure theory calculation (χ PT)
- **Relative uncertainty:**

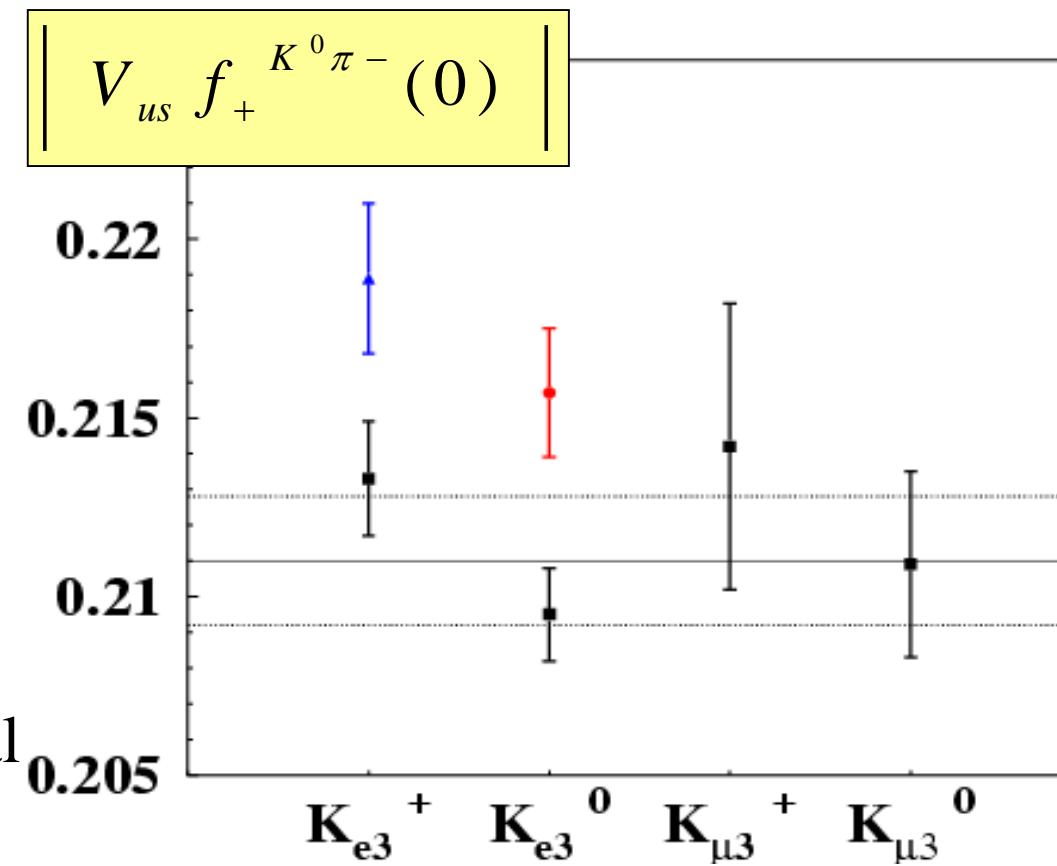
$$\frac{\delta|V_{us}|}{|V_{us}|} = 0.5 \frac{\delta\Gamma}{\Gamma} \oplus 0.05 \frac{\delta\lambda_t}{\lambda_t} \oplus \frac{\delta f_+^{K0\pi^-}(0)}{f_+^{K0\pi^-}(0)}$$
$$0.5\% \oplus 0.3\% \oplus 1\%$$

$K_s \rightarrow \pi e \bar{\nu}$ decay – $V_{us} f_+^{K\pi}(0)$



Compare **our K_s measurement** of $V_{us} f_+^{K\pi}(0)$ with:

- PDG02 fit results for $\Gamma(K^+ \rightarrow \pi^0 l^+ \bar{\nu})$ and $\Gamma(K_L \rightarrow \pi^- l^+ \bar{\nu})$ (radiation effects not known)
- $\Gamma(K^+ \rightarrow \pi^0 e^+ \bar{\nu})$ from E865 experiment
- CKMwg prescription is used to extract $V_{us} f_+^{K\pi}(0)$ from the partial decay width



Our preliminary result agrees better with latest K^+ data, while showing a appreciable deviation from old K^0_{e3}

$K_S \rightarrow \pi e\nu$ decay – V_{us} determination

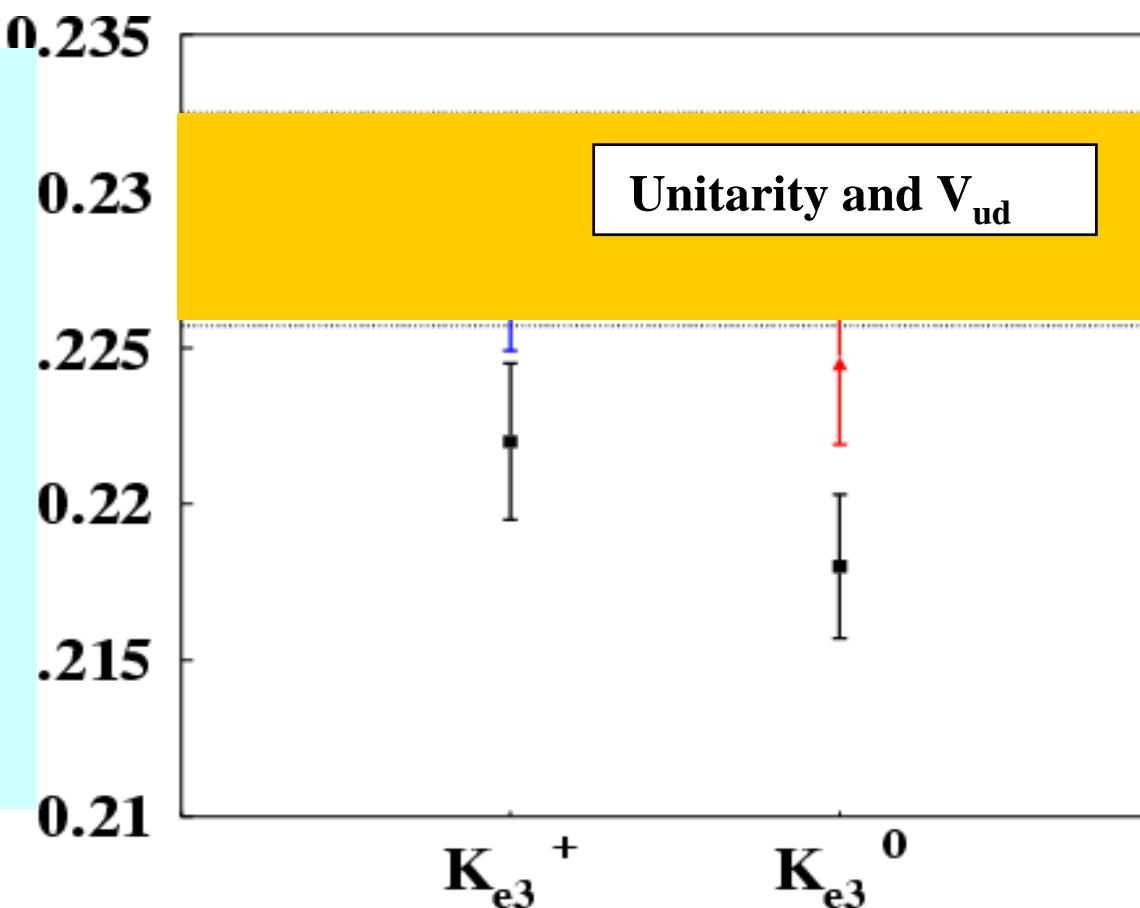


PDG02, CKMwg use

$$f_+^{K^0\pi^-}(0) = 0.961 \pm 0.008$$

from **Leutwyler, Roos**
Z.Phys. C 25 1984

- p^4 contr. in χ PT
- confirmed by a lattice calculation
(Isidori et al., [hep-ph 0403217](#))



A recent determination of $f_+(0)$ (**Cirigliano et al.** [hep-ph 0401173](#)) differs by +2%; the same authors suggest to use experimental ratio $\Gamma(K^0 e_3)/\Gamma(K^+ e_3)$ to improve the theoretical estimate of $f_+^{K\pi}$

K_L decays – Present knowledge



Knowledge of 4 main K_L BR's at present dominated by 3 measurements:

$$\frac{\Gamma(K_L \rightarrow \pi^0\pi^0\pi^0)}{\Gamma(K_L \rightarrow \pi e \nu)} \text{ and } \frac{\Gamma(K_L \rightarrow \pi^0\pi^0\pi^0)}{\Gamma(K_L \rightarrow \pi^+\pi^-\pi^0)}, \text{ with } \sim 2\% \text{ relative uncertainty [NA31]}$$

$$R_{\mu/e} = \frac{\Gamma(K_L \rightarrow \pi\mu\nu)}{\Gamma(K_L \rightarrow \pi e \nu)} = 0.702 \pm 0.011 \text{ [Argonne HBC 1980]}$$

3- σ discrepancy ($\sim 4\%$) between measurement and expectation for R_{μ/e}:

R_{μ/e} = 0.671 ± 0.002, direct measurement for K⁺, from KEK-E246 2001

R_{μ/e} calculable from the slopes λ₊ and λ₀ of vector and scalar form factors:

0.670 ± 0.002, if λ₀ = 0.0183 ± 0.0013, from ISTRA+ 2003

0.668 ± 0.006, if λ₀ = 0.017 ± 0.004, from one-loop χPt

K_L decays – Status and objectives

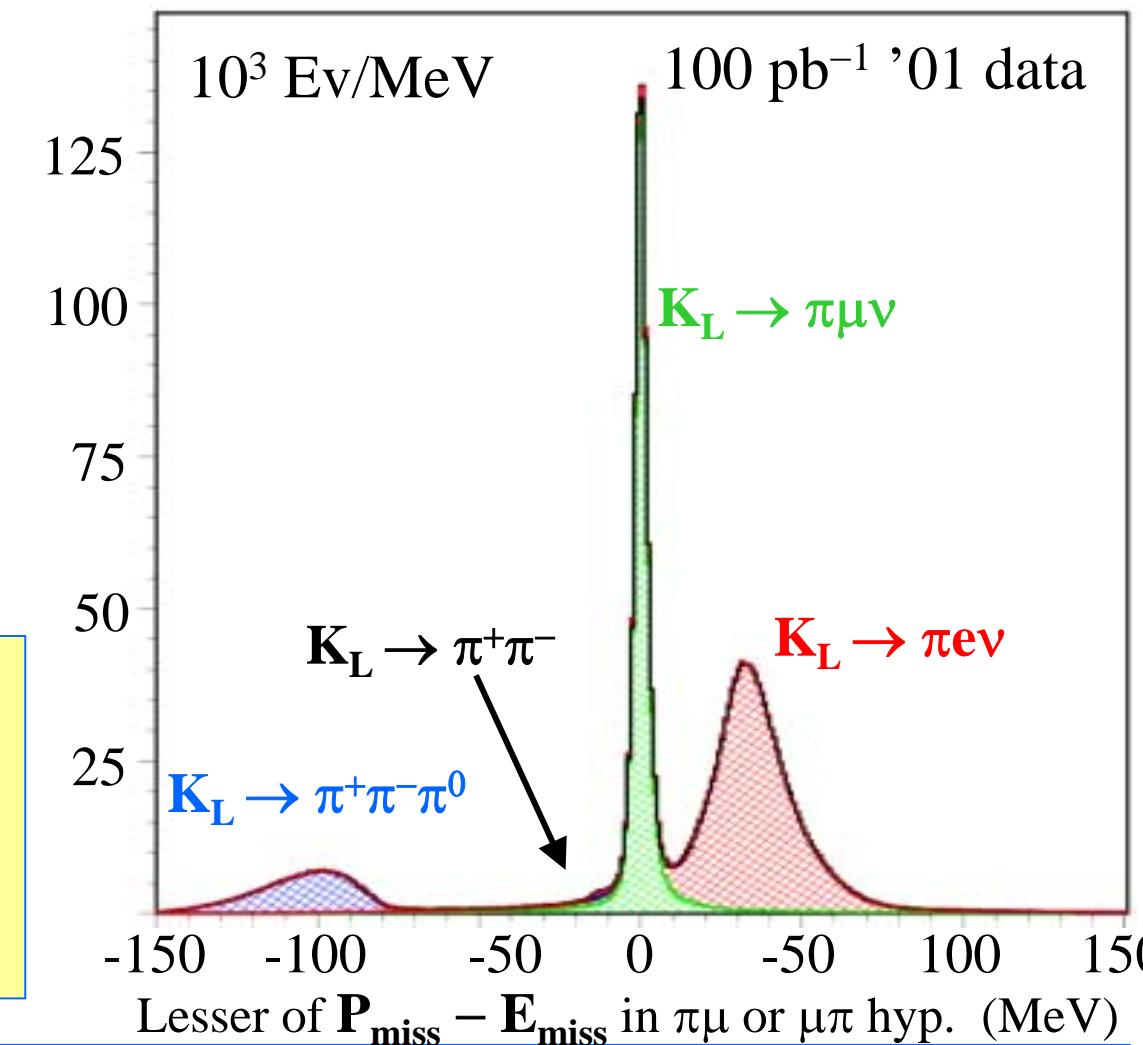


Have to precisely measure **absolute** branching ratios, with rel. accuracy < 1%

- ◆ K_L decay vertex in a fiducial volume in DC (given a $K_S \rightarrow \pi^+\pi^-$ tag)
- ◆ **Kinematic identification using reconstructed momenta**

450 pb⁻¹ $\Rightarrow 3 \cdot 10^6 K_{e3}$ events

- ◆ In progress:
 - New detailed MC with radiation and $\pi-\mu-K_L$ response
 - Selection efficiency as a function of K_L vertex position and momenta of decay products





MC simulation

Simulated event samples statistically comparable to data

$\phi \rightarrow \text{all}$ 452 pb^{-1} at 1:5 scale $\sim 300\text{M}$ events

$\phi \rightarrow K_S K_L$ 452 pb^{-1} at 1:1 scale $\sim 500\text{M}$ events

Each run in data set individually simulated

\sqrt{s} , \mathbf{p}_ϕ , \mathbf{x}_ϕ , background, dead wires, trigger thresholds...

Inclusion of accidental activity from machine background

extracted from $e^+e^- \rightarrow \gamma\gamma$ events in data set

inserted run-by-run to match temporal profile of bkg in data

Tuning of calorimeter response simulation on μ, π, K_L

**Suite of new generators introduced, particular emphasis on
radiative processes**

Generators for radiative K decays



Motivation: acceptance evaluation with accuracy better than 1%, shape of kinematic variables (*e.g.* $E_{\text{miss}}\text{-}p_{\text{miss}}$ spectrum)

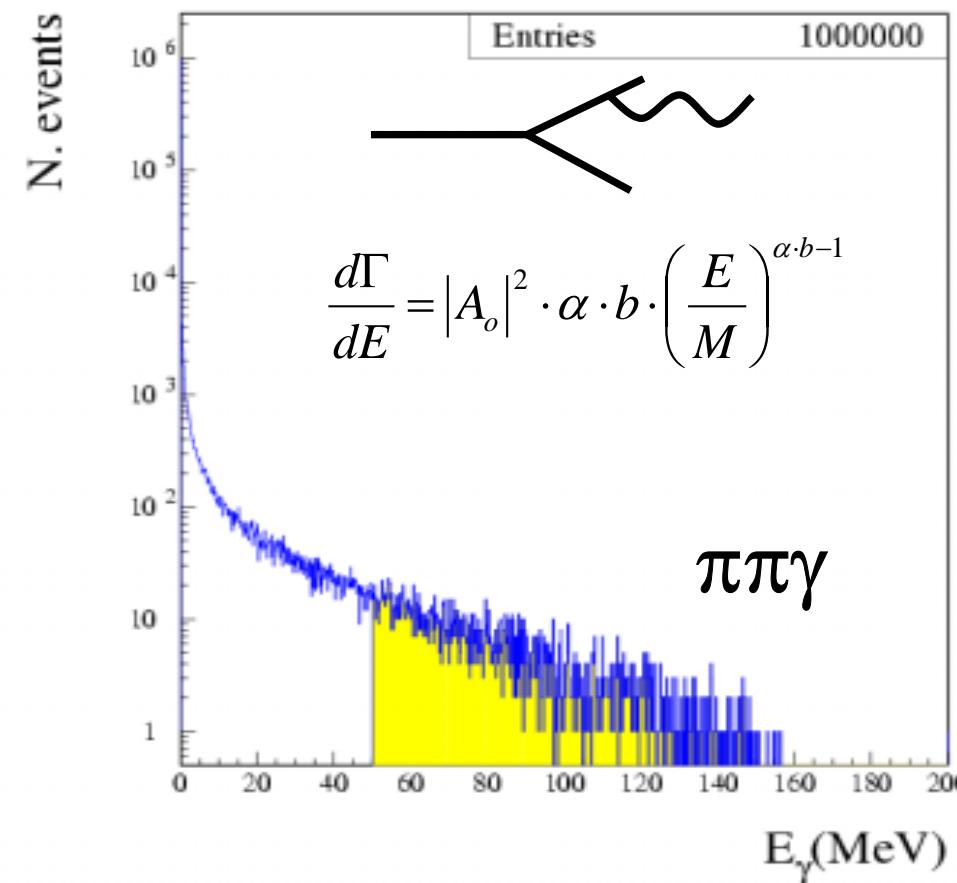
New MC generators for $\pi\pi$ and K13 decays
including radiated photon, without any cutoff on the energy. The fraction of events in the tail is in agreement with present experimental knowledge:

$$\frac{BR(K_L \rightarrow \pi e \nu \gamma, E_\gamma > 30 \text{ MeV} \theta_{e\gamma} > 20^\circ)}{BR(K_L \rightarrow \pi e \nu)} =$$

$kTeV$	$(0.908 \pm 0.015) \times 10^{-2}$
<i>Bijnens et al</i>	0.93×10^{-2}
<i>MC</i>	0.93×10^{-2}

$$\frac{BR(K_S \rightarrow \pi\pi\gamma, E_\gamma > 50 \text{ MeV})}{BR(K_S \rightarrow \pi\pi)} =$$

<i>E731</i>	$(2.56 \pm 0.09) \times 10^{-3}$
<i>MC</i>	2.6×10^{-3}

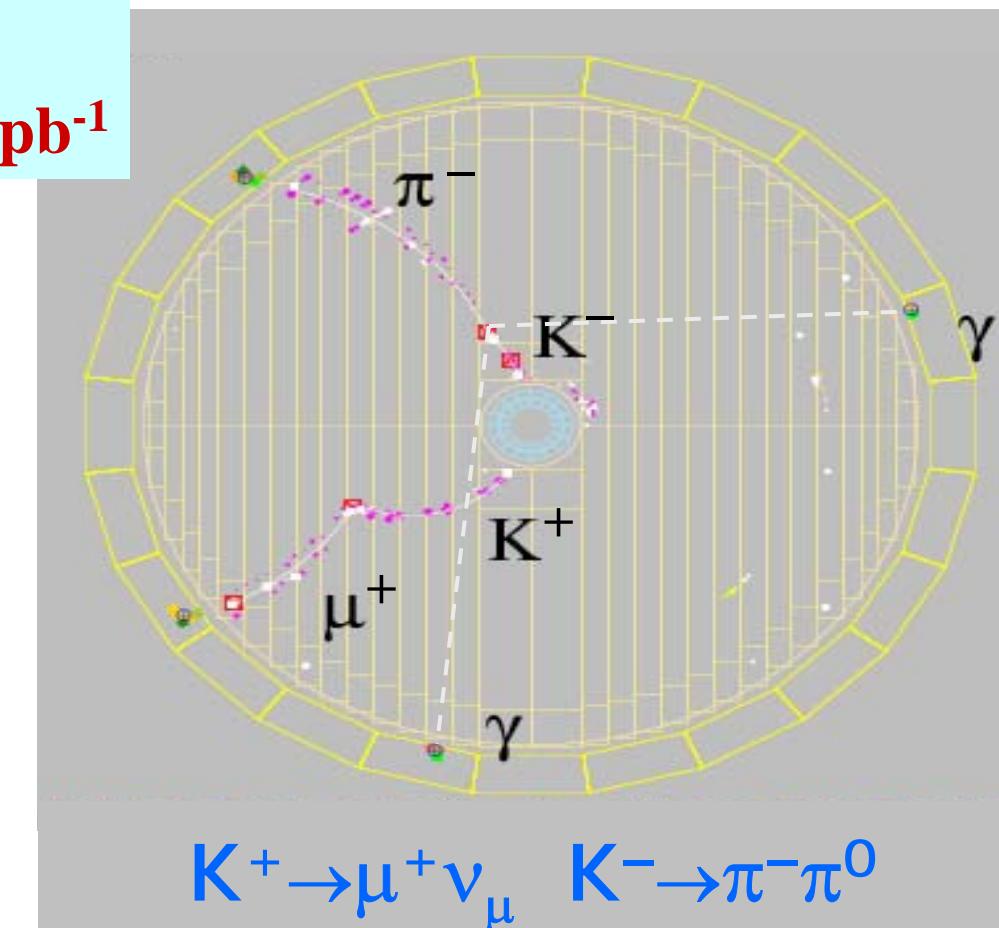
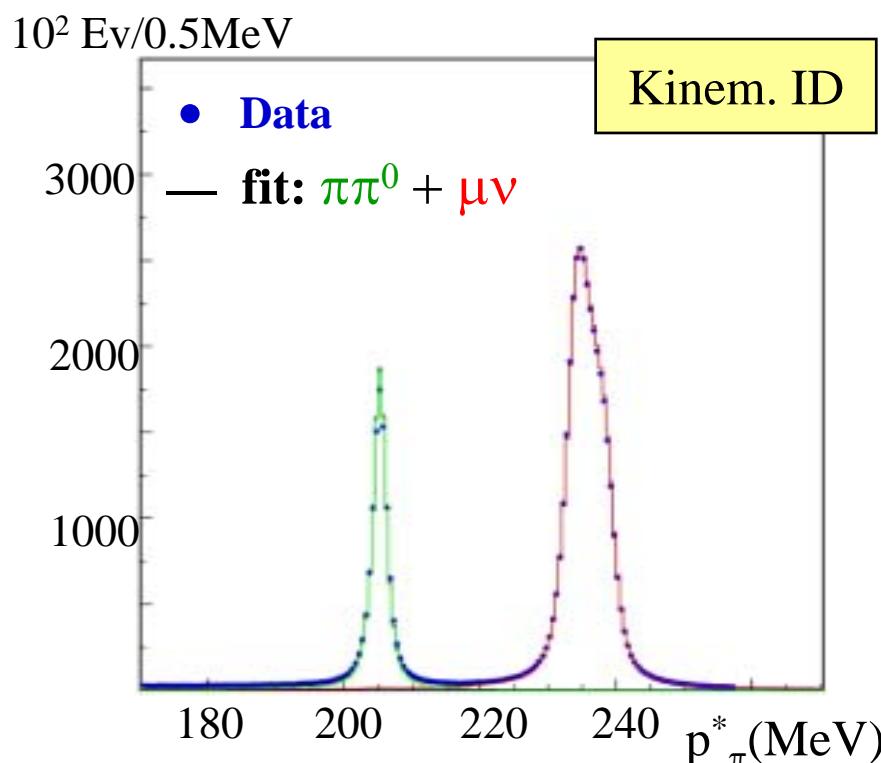


Charged kaons – Tagging



Measurement of absolute BR's: K^+ beam tagged from $K^- \rightarrow \pi^-\pi^0, \mu^-\nu$

- Two-body decays identified as peaks in the momentum spectrum of secondary tracks in the kaon rest frame: **6•10⁵ tags/pb⁻¹**



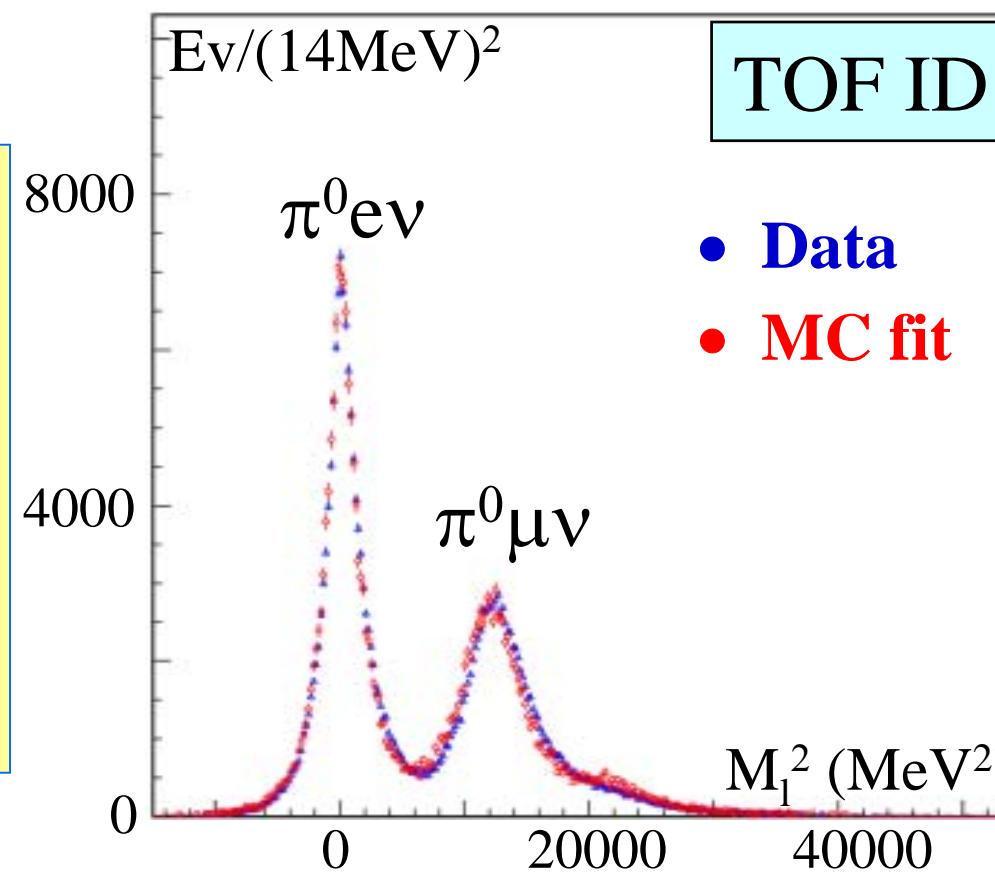
Charged kaons – $K^\pm \rightarrow l_3$ decays



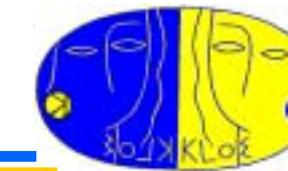
- ◆ After tag a dedicated reconstruction of K^\pm tracks is performed, correcting for charged kaon dE/dx in the DC walls

- 1-prong kaon decay vertex in a given fiducial volume in DC
- Reject two-body decays by cutting on P_π^*
- π^0 search: 2 neutral clusters in EmC, with tof matching the K decay vertex
- Obtain charged daughter mass spectrum from TOF measurement.
$$t_{\text{decay}} = t_l - L_l \cdot (E_l/p_l c^2) = \langle t_\gamma - L_\gamma/c \rangle$$

450 pb⁻¹ $\Rightarrow 3 \cdot 10^5$ K_{e3} events



“Non-kaon” physics at KLOE



this talk:

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

preliminary results, hep-ex/0307051

other topics:

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

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

$\eta \rightarrow \gamma\gamma\gamma$

hep-ex/0402011, submitted to PLB

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

in progress

$\phi \rightarrow \eta'\gamma$

Phys. Lett. **B541** 45 (2002)

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

Phys. Lett. **B561** 55 (2003)

a_μ – SM prediction vs experiment



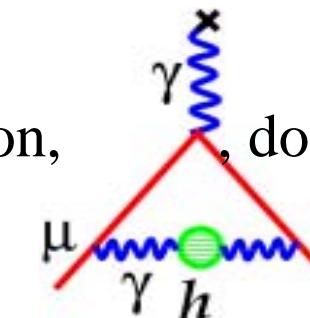
Updated measurement from E821@BNL, averaging results for μ^+ and μ^- :

$$a_\mu = (11\ 659\ 208 \pm 6) \cdot 10^{-10}$$

Contributions to the SM prediction:
(10^{-10} units)

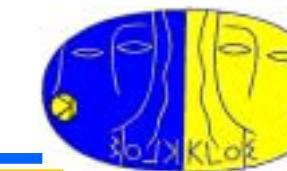
$$\begin{aligned} a_\mu(\text{QED}), & \quad 11\ 658\ 470.4 \pm 0.3 \\ a_\mu(\text{weak}), & \quad 15.4 \pm 0.2 \\ a_\mu(\text{hadronic}), & \quad \sim 700 \end{aligned}$$

Uncertainty on lowest-order hadronic vacuum polarization,



Hadronic correction to the γ propagator not calculable by p-QCD for low M_{γ^*}

a_μ – SM prediction vs experiment



Dispersion integral relates $a_\mu^{\text{had}}(\text{vac-pol})$ to $\sigma(e^+e^- \rightarrow \text{hadrons})$



$$a_\mu^{\text{had,lo}} = \frac{1}{4\pi^3} \int_{4m_\pi^2}^\infty \sigma_{e^+e^- \rightarrow \text{hadr}}(s) K(s) ds$$

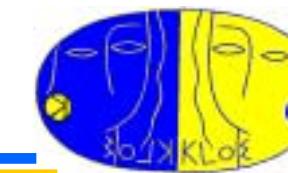
Process $e^+e^- \rightarrow \pi^+\pi^-$ @ $\sqrt{s} < 1$ GeV contributes as much as 66% to a_μ^{had}

So far, estimates of a_μ^{had} from:

- measuring $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ vs \sqrt{s} at an e^+e^- collider, varying the beam energy (CMD2, 0.9% rel. uncertainty)
- using the spectral function from $\tau^\pm \rightarrow \pi^\pm \pi^0 \nu_\tau$ (LEP, CESR data)

However, $a_\mu(e^+e^-) - a_\mu(\tau) \sim 20 \cdot 10^{-10}$

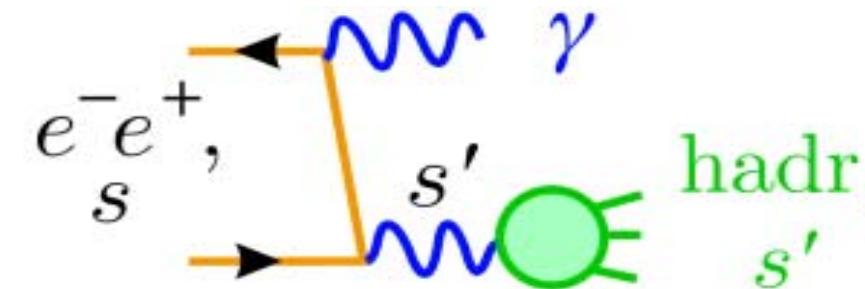
$\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ from $\pi\pi\gamma$ events



Measure $\sigma(e^+e^- \rightarrow \pi^+\pi^-\gamma)$ at fixed \sqrt{s}

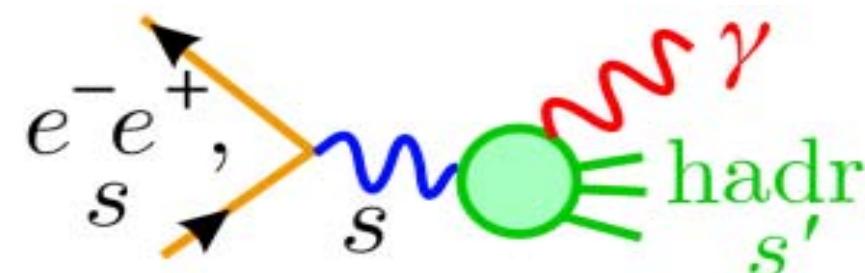
Exploit ISR to extract $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ for $\sqrt{s'}$ from $2m_\pi \rightarrow \sqrt{s}$

$$(s' = s - 2 E\gamma \sqrt{s})$$

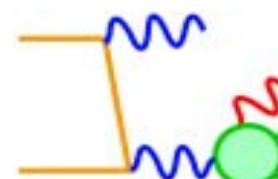


Have to watch out for **hard FSR**:

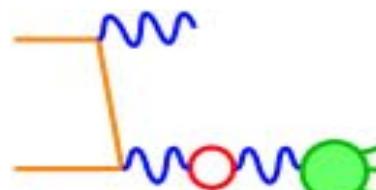
- Rate \sim same order as ISR signal
- FSR causes events with $M_{\gamma^*} = \sqrt{s}$ to be assigned to lower $\sqrt{s'}$ values



Have to properly include radiative corrections,



Must remove vacuum polarization,



$\sigma(\pi\pi\gamma)$ – Analysis scheme



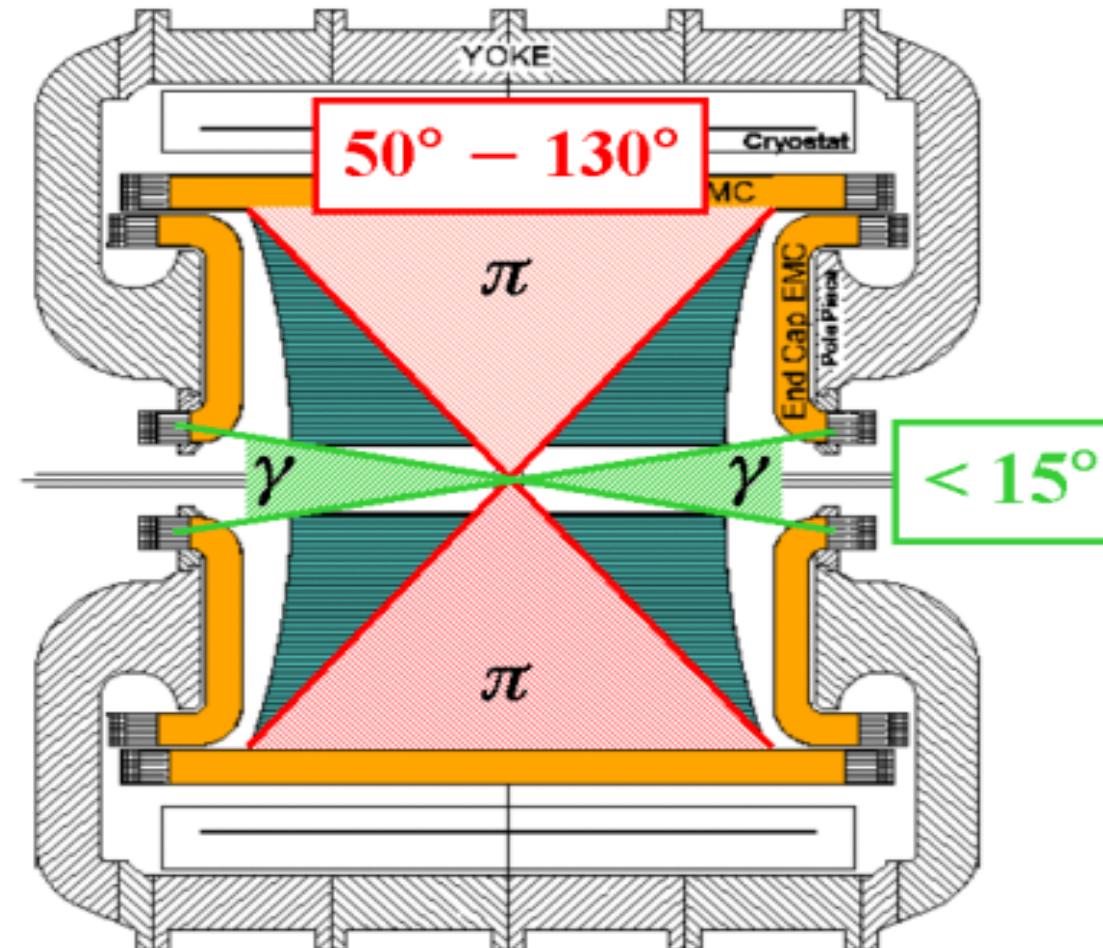
Two **high- θ** tracks from a vertex close to IP

Compute photon momentum,
without explicit γ detection:

$$p_\gamma = p_{e+} + p_{e-} - p_{\pi+} - p_{\pi-}$$

Select signal with a **small- θ photon**,
to enhance ISR: $d\sigma_{\text{ISR}}/d\Omega \sim 1/\sin^2\theta$

- relative contribution of **hard FSR** below the % level over entire $M_{\pi\pi}$ spectrum
- no acceptance $M_{\pi\pi} < 600$ MeV
- Reduce background



Residual background from $\pi^+\pi^-\pi^0$, $e^+e^-\gamma$, $\mu^+\mu^-\gamma$

$\sigma(\pi\pi\gamma)$ – Preliminary result



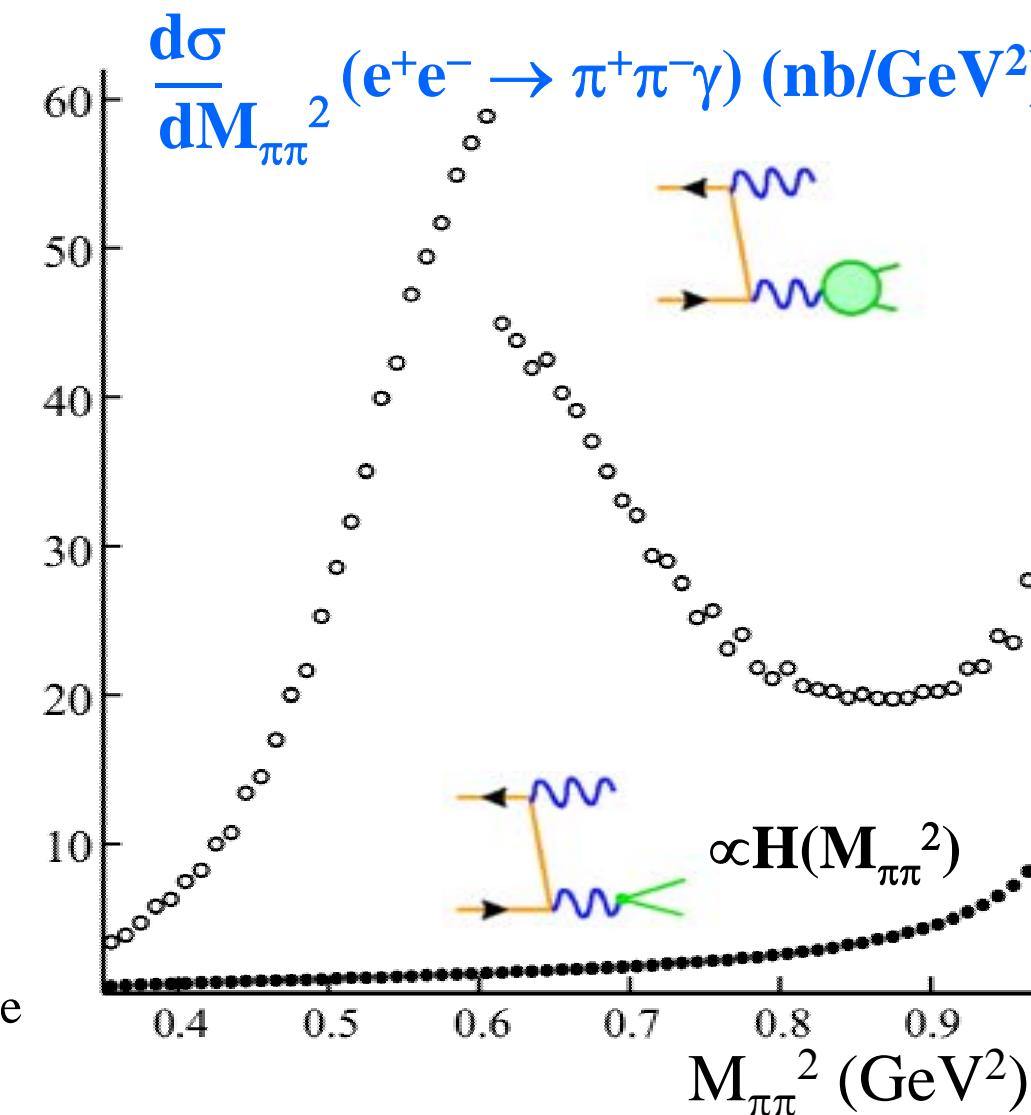
Luminosity from $e^+e^-(\gamma)$ counts, $55^\circ < \theta_e < 125^\circ$, σ calculated at 0.5%, experimental accuracy 0.3%

Experimental $M_{\pi\pi}^2$ resolution unfolded in all spectra shown

Radiator function $H(M_{\pi\pi}^2)$, defined as:

$$\frac{d\sigma(\pi\pi\gamma, M_{\pi\pi}^2)}{dM_{\pi\pi}^2} = H(M_{\pi\pi}^2) \sigma(\pi\pi, M_{\pi\pi}^2),$$

with inclusion of radiative effects, from QED MC calculation (PHOKHARA generator, including nl, nnl corrections, Karlsruhe Theory Group, Kühn et al.)



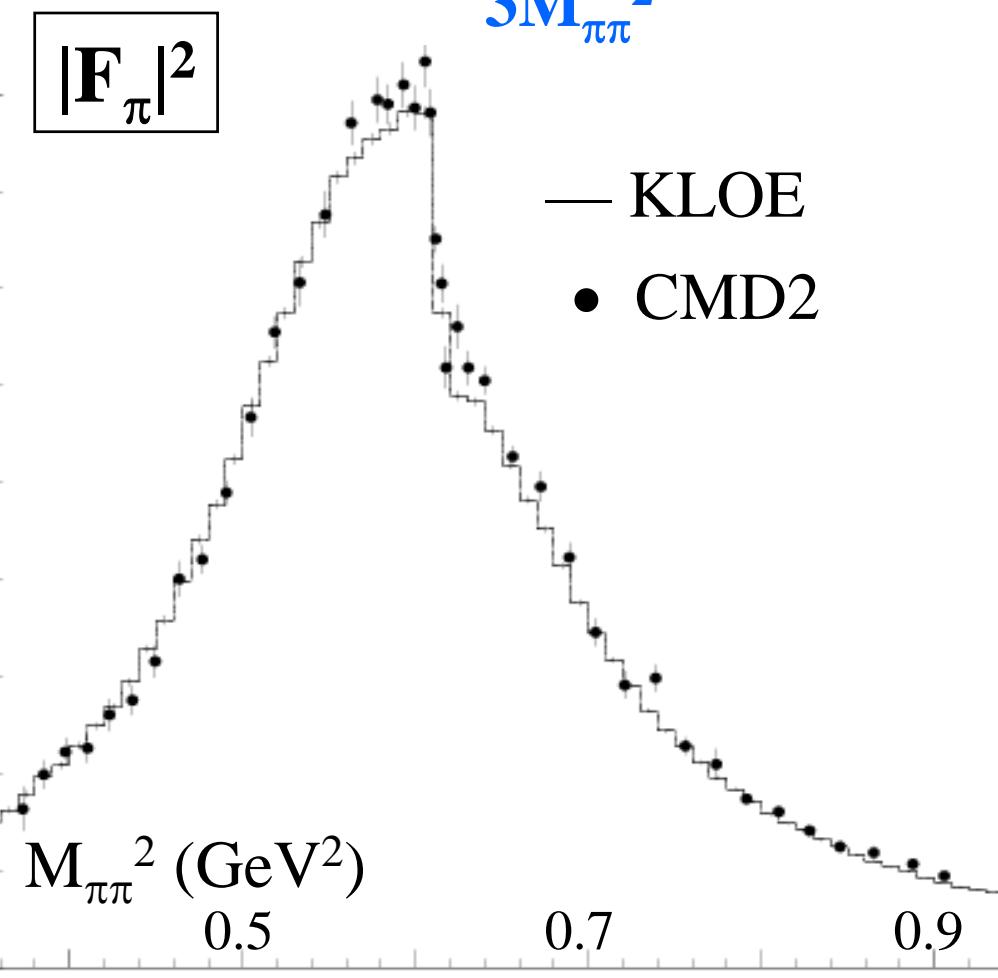
a_μ – Preliminary results



Calculating the dispersion integral,

$$a_\mu^{\text{had-}\pi\pi}(0.35 < M_{\pi\pi} < 0.95 \text{ GeV}^2) = (389.2 \pm 0.8_{\text{stat}} \pm 4.7_{\text{syst}} \pm 3.9_{\text{theo}}) 10^{-10}$$

$$\sigma(e^+e^- \rightarrow \pi^+\pi^-) = \frac{\pi \alpha^2}{3M_{\pi\pi}^2} \beta^3 |F_\pi(M_{\pi\pi})|^2$$



- Comparison with CMD2:

$$a_\mu^{\text{had-}\pi\pi}(0.37 < M_{\pi\pi} < 0.93 \text{ GeV}^2) =$$

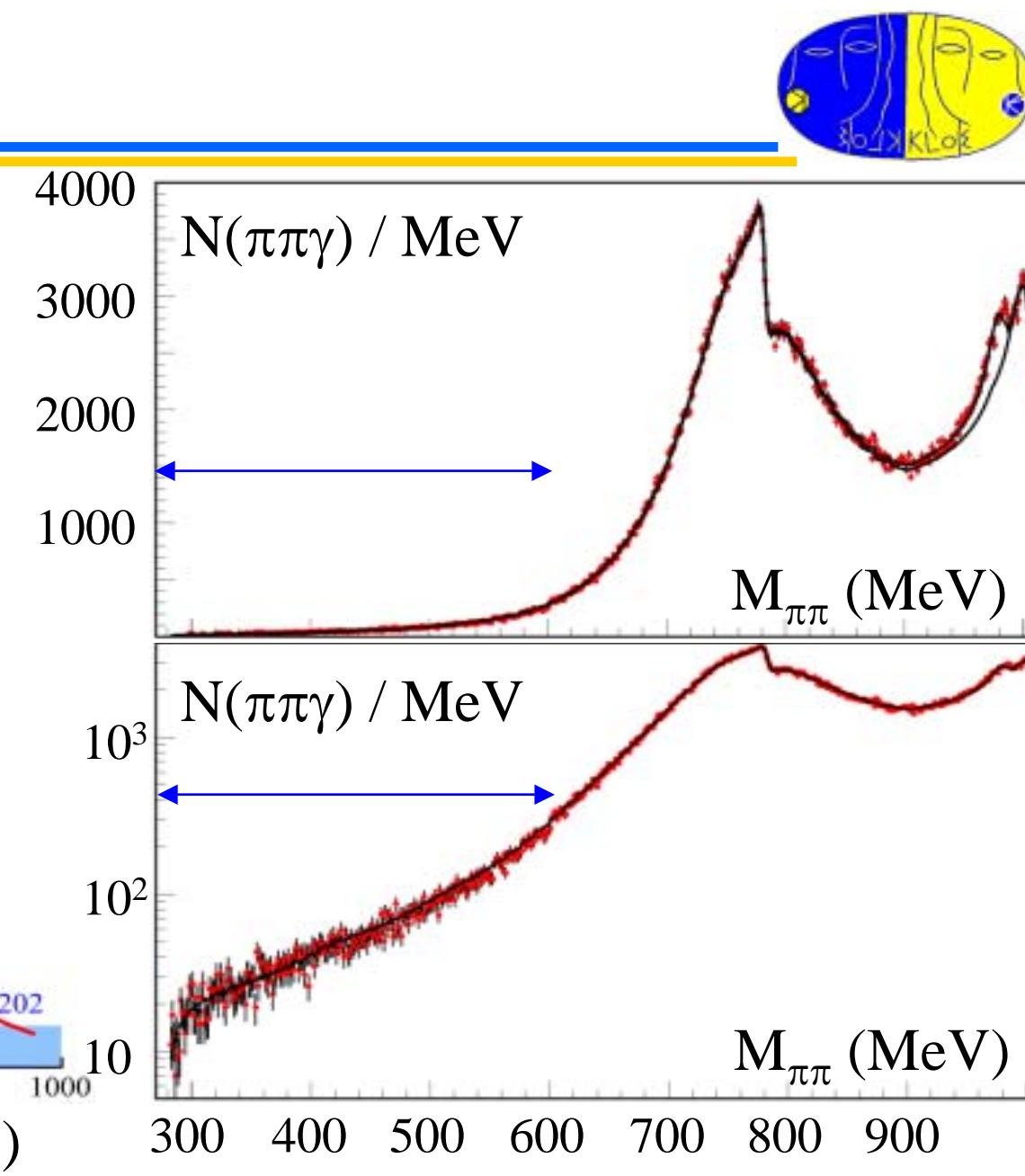
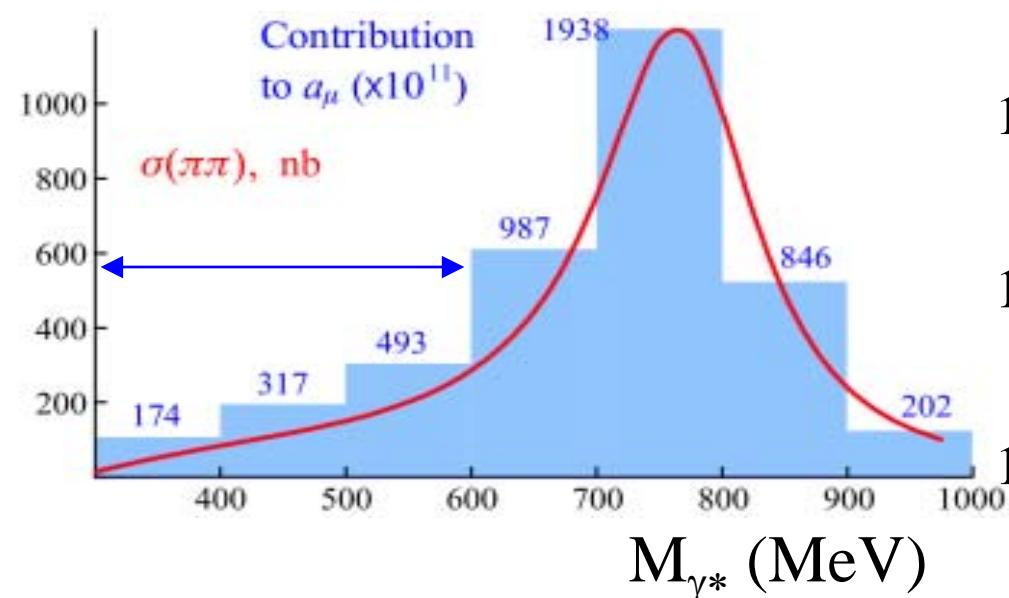
KLOE ($376.5 \pm 0.8_{\text{stat}} \pm 5.9_{\text{syst+theo}}$) 10^{-10}	
CMD2 ($378.6 \pm 2.7_{\text{stat}} \pm 2.3_{\text{syst+theo}}$) 10^{-10}	

- Measurements are in agreement
- $e^+e^- - \tau$ discrepancy is confirmed

a_μ – Prospects

Measure $\sigma(\pi\pi)$ in the region close to threshold, $M_{\pi\pi} < 600$ MeV, responsible for $\sim 20\%$ of a_μ^{had}

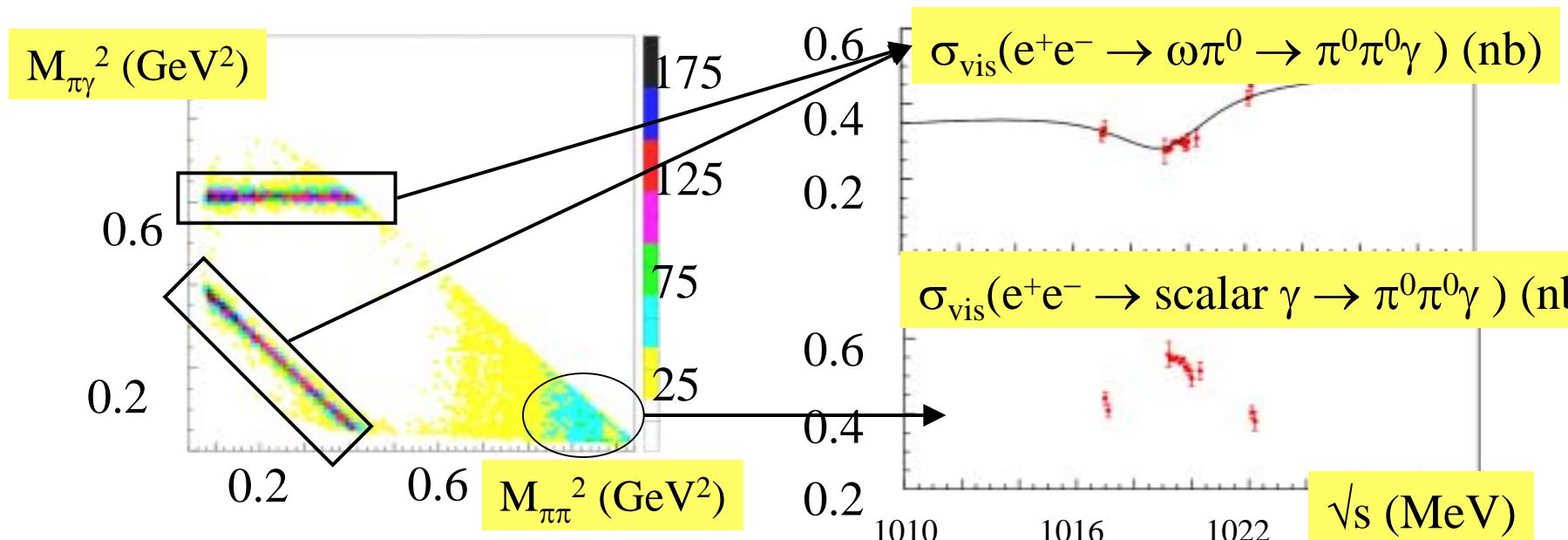
This region currently excluded by angular selection



$\phi \rightarrow \text{scalar} + \gamma$



- $\pi^+\pi^-\gamma$ at large θ_γ angle
 - first hints of an $f_0(980)$ signal
 - Study interference pattern between FSR and $\phi \rightarrow f_0\gamma$
- $\pi^0\pi^0\gamma$ high stat. sample for $\phi \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma$
 - high stat: Dalitz plot to separate not resonant vs resonant contribution
 - interference between $\phi \rightarrow S\gamma$ and VDM production



Recent results from KLOE at DAΦNE – M. Palutan – Padova, 24 March 2004

$\phi \rightarrow \text{pseudoscalar} + \gamma$



~ 20 million η 's produced

Search for forbidden η decays:

C violating: $\text{BR}(\eta \rightarrow \gamma\gamma\gamma) < 1.7 \cdot 10^{-5}$, 90% CL, hep-ex/0402011
(best world limit)
CP, P violating: $\text{BR}(\eta \rightarrow \pi^+\pi^-) < 9 \cdot 10^{-6}$, 90% CL, in progress

Precision studies of meson dynamics:

Dalitz plot analyses of $\eta \rightarrow 3\pi$, $\eta \rightarrow \pi^0\gamma\gamma$, and $\eta \rightarrow \pi^+\pi^-\gamma$

Pseudoscalar mixing angle measurements, $\phi \rightarrow \eta'\gamma$ decays:

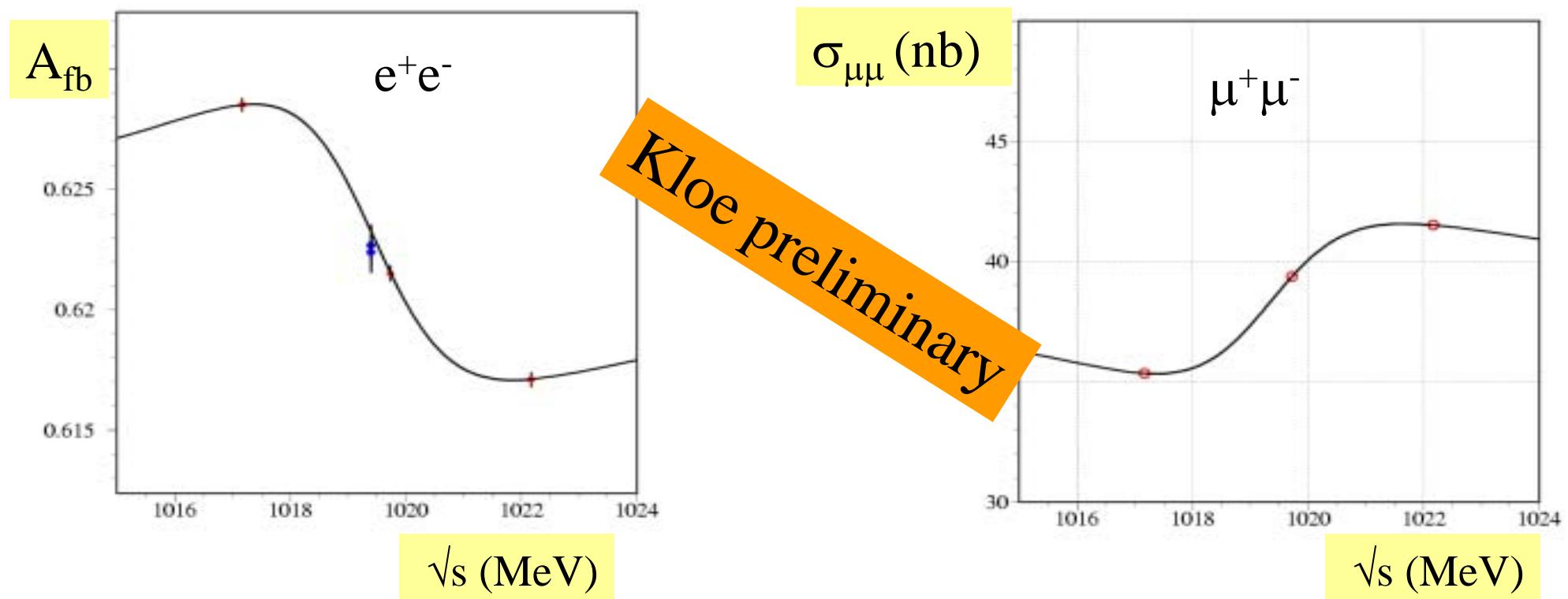
Analysis of $\pi^+\pi^-3\pi^0\gamma$ final states from decay chain $\eta' \rightarrow \eta\pi\pi$, $\eta \rightarrow 3\pi$

$\text{BR}(\phi \rightarrow \eta'\gamma) = (6.04 \pm 0.10_{\text{stat}} \pm 0.36_{\text{syst}}) \cdot 10^{-5}$, confirming previous KLOE result
Can extract mixing angle, uncertainty at 1-degree level

ϕ -meson properties



- Combined line-shape fit in principal decay channels
- Measurement of $\Gamma(\phi \rightarrow e^+e^-)$ from FB asymmetry vs \sqrt{s}
- Measurement of $\Gamma(\phi \rightarrow \mu^+\mu^-)$ from $\sigma_{\mu\mu}$ vs \sqrt{s}



Recent results from KLOE at DAΦNE – M. Palutan – Padova, 24 March 2004

Conclusions



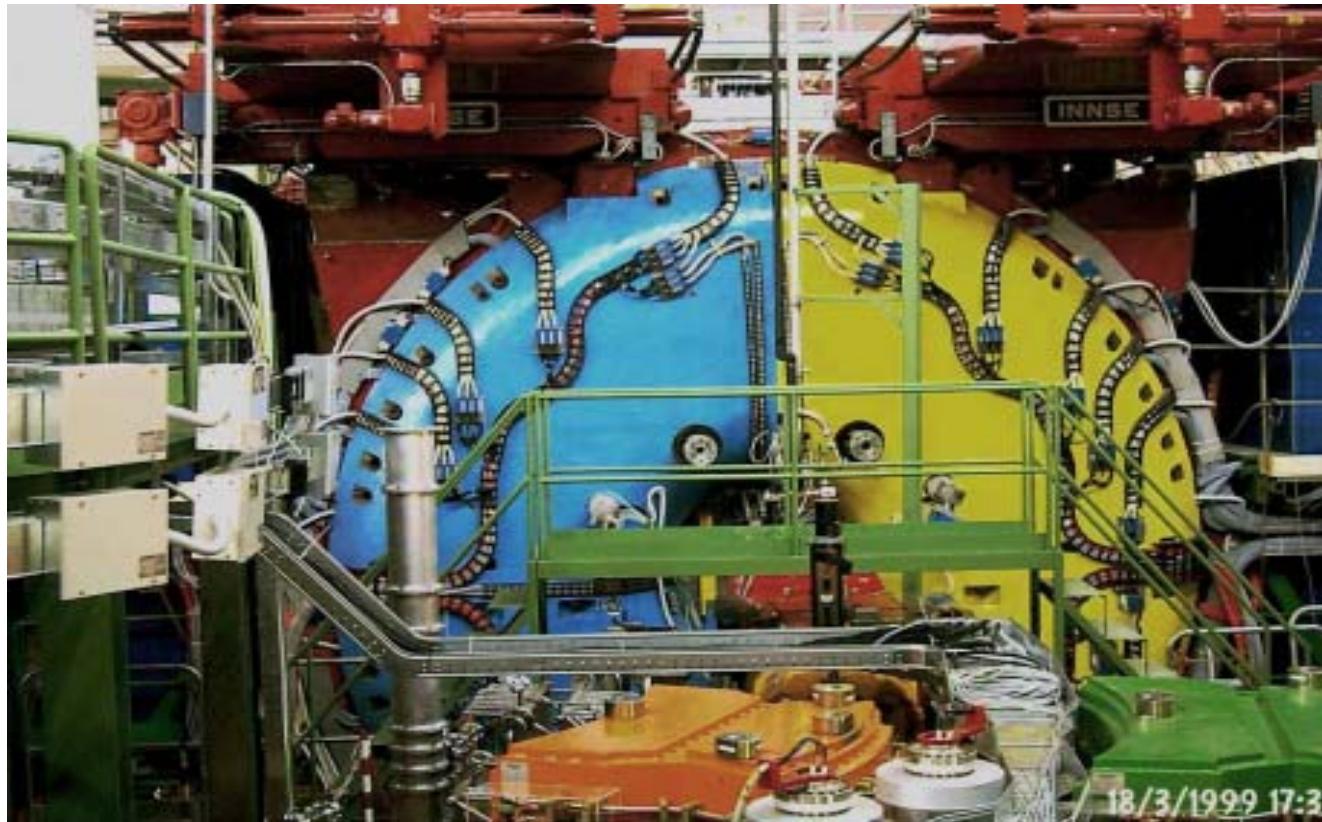
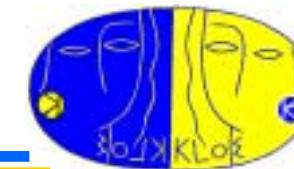
KAON physics:

- ◆ Sensitivity to K_s BR's at the 10^{-7} level (preliminary UL for $K_s \rightarrow 3\pi^0$)
- ◆ Measurement of K_{e3} mode at the % level, 10^{-2} accuracy on A_S
- ◆ Measurement of BR's for semileptonic K_L and K^+ decays in progress
 - Huge statistics, uncertainty will be limited by systematics
 - Will clarify situation concerning V_{us}

Non KAON physics:

- ◆ Analysis of $\sigma(\text{had})$ at small angles almost completed (draft in preparation):
measurement of a_μ^{had} with $6 \cdot 10^{-10}$ total error, $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ at 1.6%
 - Large angles meas. in progress: a_μ^{had} contribution for $M_{\gamma^*} < 600$ MeV
- ◆ A lot of measurement in progress on light scalar, pseudoscalar mesons and on determination of lineshape and Γ_{ll}

April 13th: KLOE restart



Start new long data taking with higher luminosity: $>1 \text{ fb}^{-1}$
Interferometry measurements
Measure *CPV* parameters in K_L decays

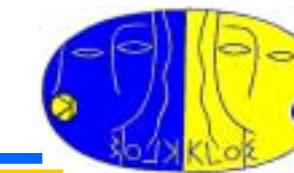


Spare slides

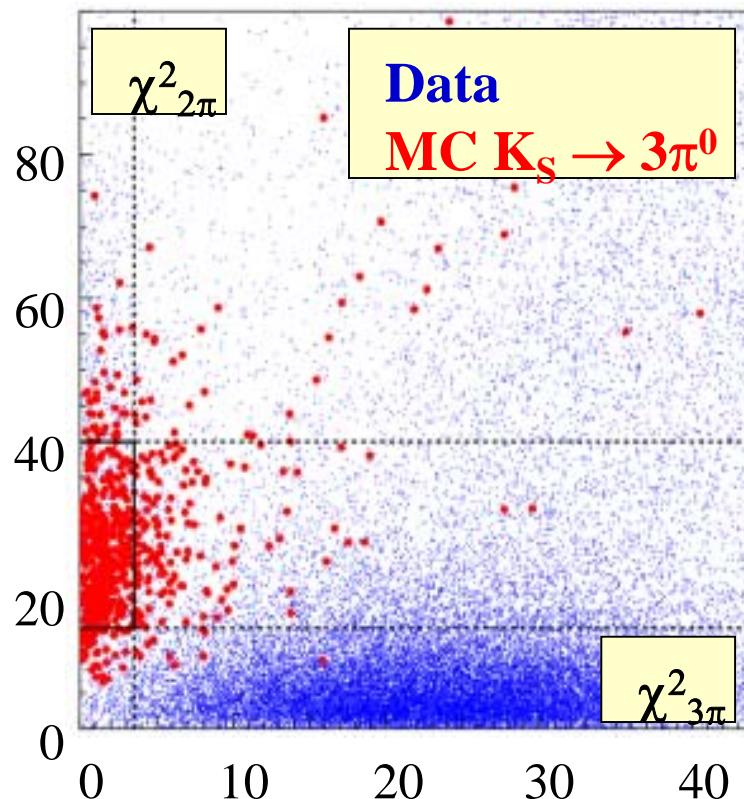


Recent results from KLOE at DAΦNE – M. Palutan – Padova, 24 March 2004

$K_S \rightarrow \pi^0 \pi^0 \pi^0$ - MC reliability



Data-MC comparison, MC statistics ~3 times that of data



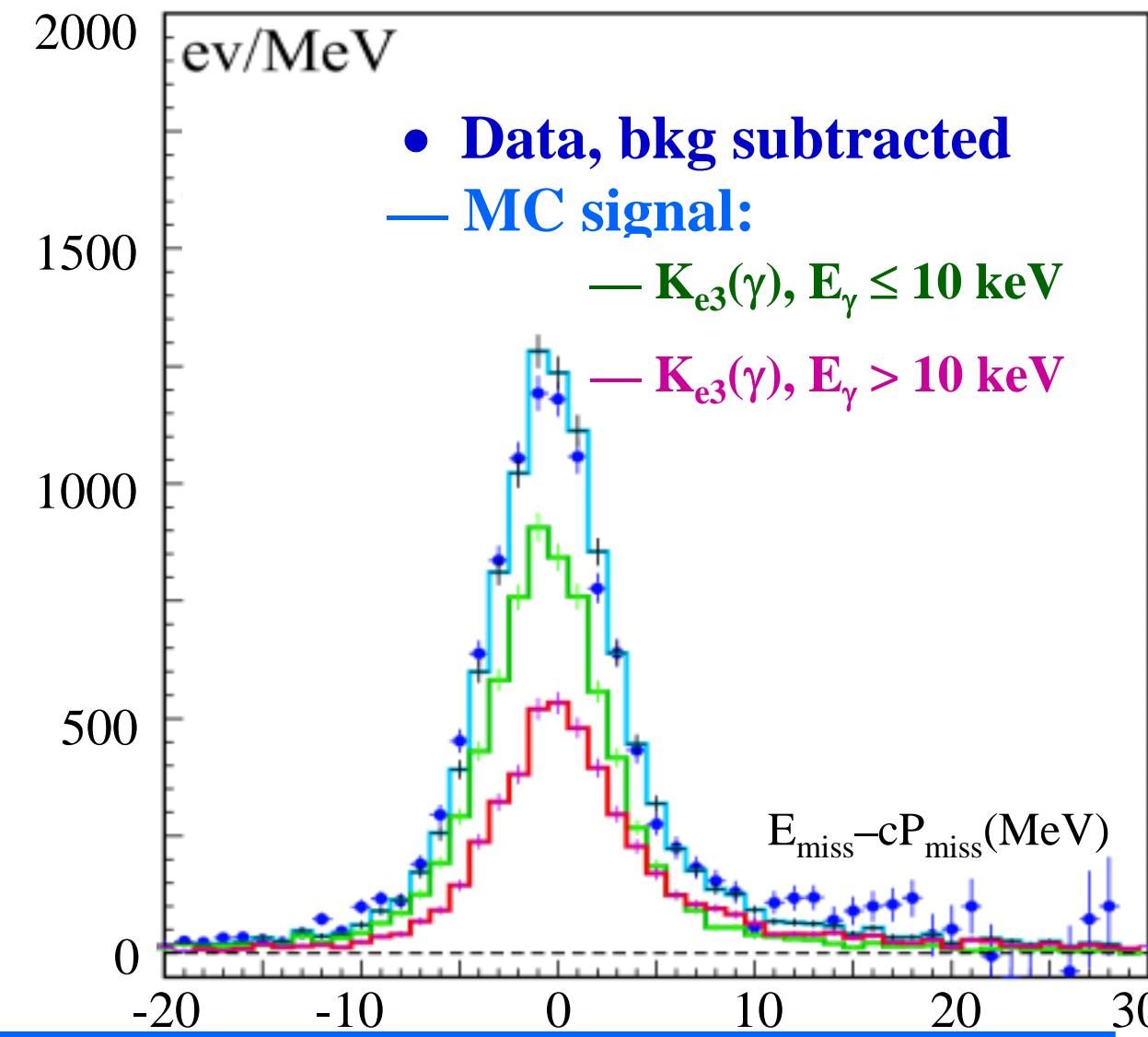
Zone	data	MC
SBOX	337 ± 18	309.5 ± 16.3
UP	493 ± 22	479.8 ± 21.2
DOWN	382 ± 19	426.5 ± 14.4
CSbox	5502 ± 74	5595.1 ± 51.0
Cup	11249 ± 106	11744.1 ± 74.0
Cdown	24396 ± 156	23844.9 ± 103.8

$K_S \rightarrow \pi \nu \bar{\nu}$ decays – Impact of radiation



Signal spectrum clearly sensitive to the presence of a photon in the final state

Include radiative effects through an IR-finite treatment in MC (no energy cutoff)



A first glance at interference



$K_S K_L \rightarrow \pi^+ \pi^- \pi^+ \pi^-$:

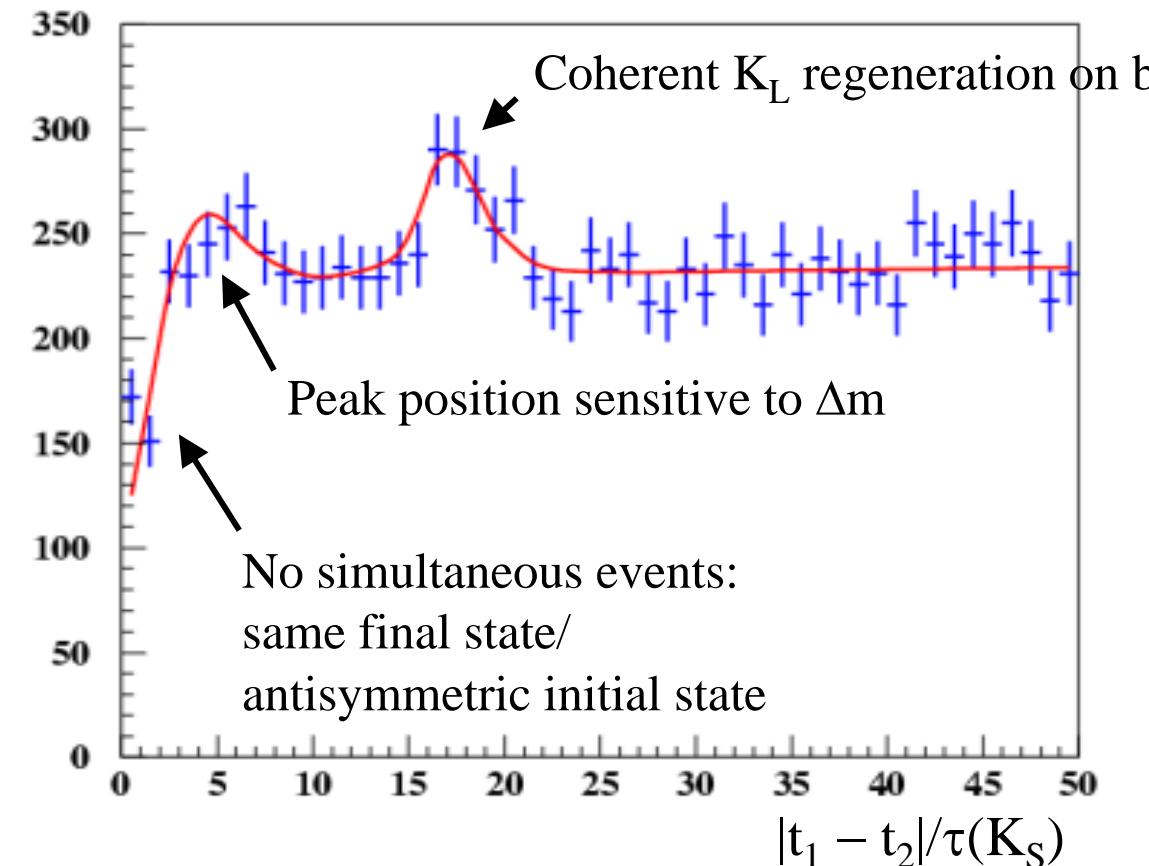
$$|A(\Delta t)|^2 \propto e^{-\Gamma_L |\Delta t|} + e^{-\Gamma_S |\Delta t|} - 2e^{-(\Gamma_S + \Gamma_L) |\Delta t|/2} \cos(\Delta m \Delta t)$$

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

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

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

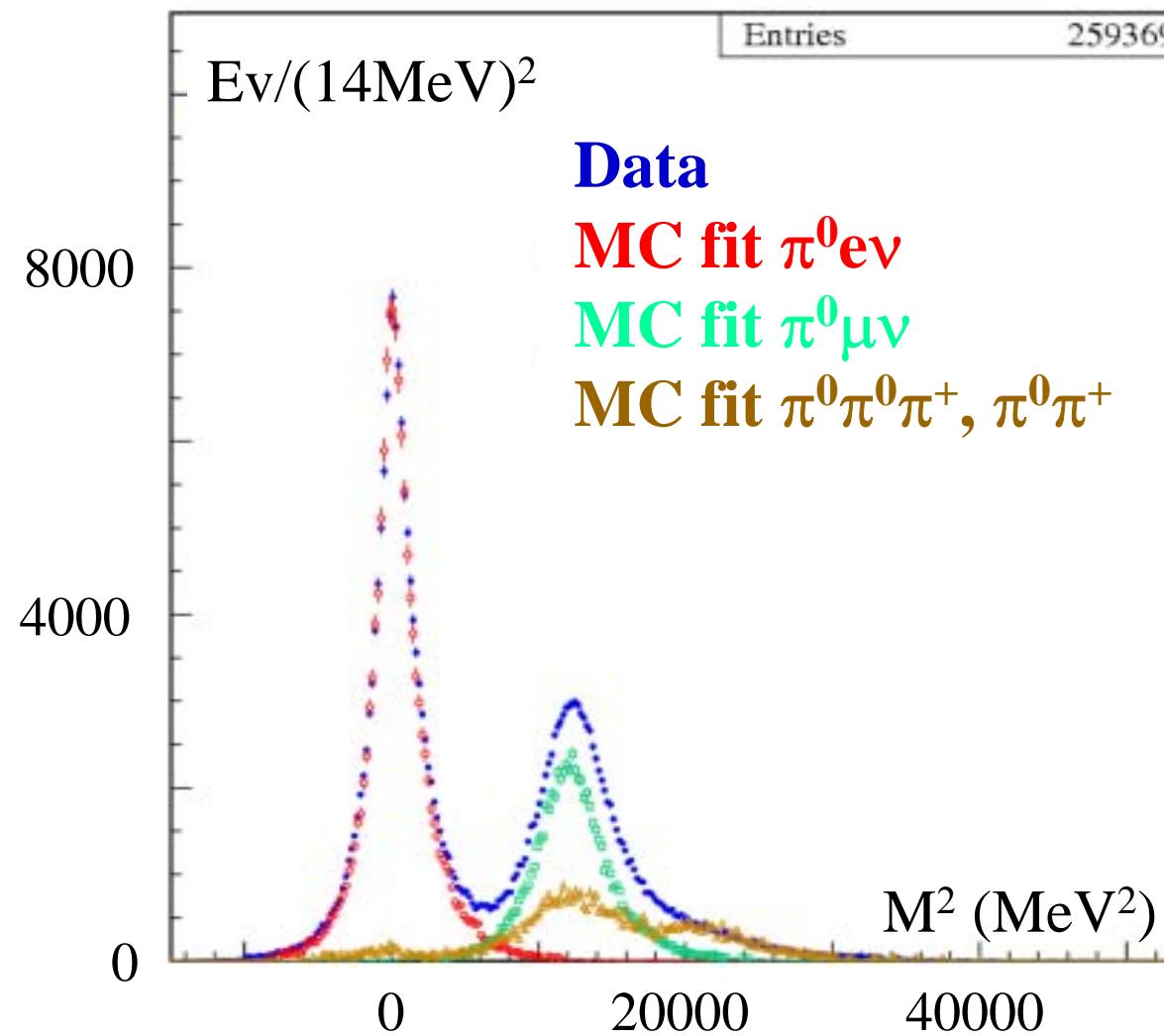
**First observation of quantum
interference in relative decay-
time distribution of K_S , K_L**



Selection of K_{l3}^\pm decays



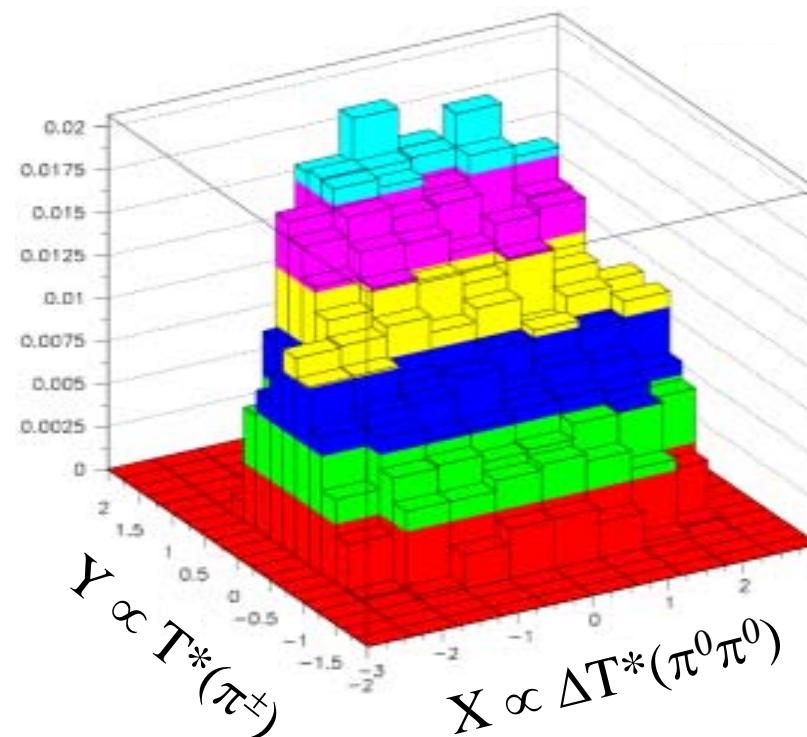
- Tagging of a K^+ beam from identification of $K^- \rightarrow \mu^- \nu$
- 1-prong kaon decay vertex in a given fiducial volume in DC
- Reject fraction of two-body decays by cutting on P_π^*
- π^0 search: 2 neutral clusters in EmC, with γ TOF wrt K decay vertex
- Obtain K_{l3} counts from spectrum of $M^2(\text{TOF}, L, p)$ of charged decay product



Analysis of $K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$ decays



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



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

BR($K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$)

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

KLOE preliminary hep-ex/0307054

441 pb⁻¹ '01+'02 data

187 pb⁻¹ for signal counting

$(1.781 \pm 0.013 \pm 0.016)\%$

	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

Measurement of $\sigma(\pi\pi\gamma)$ – Bkg rejection



In the accepted angular region:

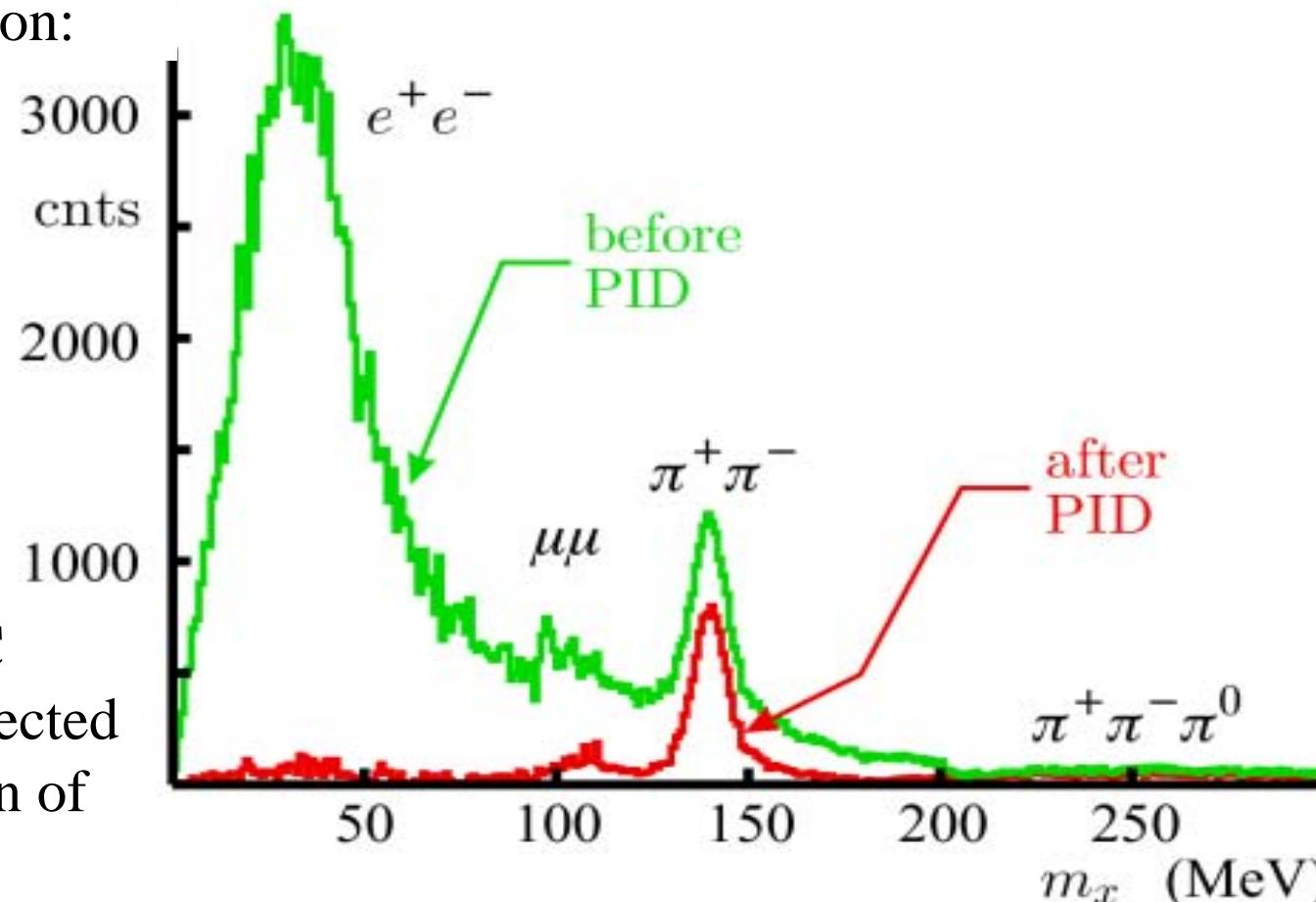
$\pi^+\pi^-\gamma$	$\sigma \sim 20 \text{ nb}$
$e^+e^-\gamma$	$\sigma \sim 400 \text{ nb}$
$\pi^+\pi^-\pi^0$	$\sigma \sim 50 \text{ nb}$
$\mu^+\mu^-\gamma$	$\sigma \sim 10 \text{ nb}$

0) Preliminary cut on M_{miss} ,
to reject $\pi^+\pi^-\pi^0$ events

1) PID obtained using EMC
clusters geometrically connected
to tracks: TOF + distribution of
energy release

2) For a $x^+x^-(\gamma)$ final state, calculate m_x from:

$$[\sqrt{s} - E_+(m_x) - E_-(m_x)]^2 - |\mathbf{p}_+ + \mathbf{p}_-|^2 = 0$$



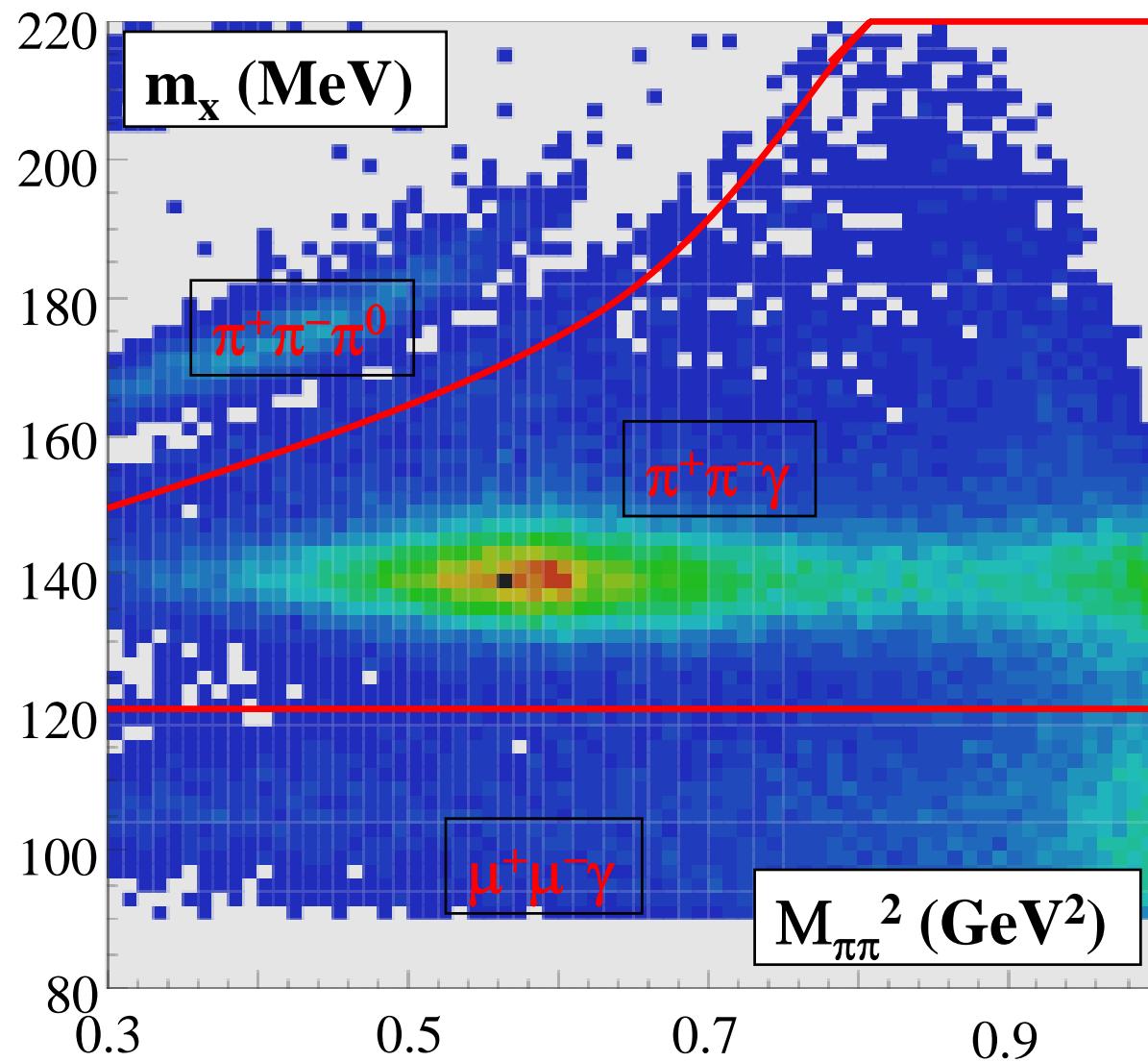
Measurement of $\sigma(\pi\pi\gamma)$ – Bkg rejection



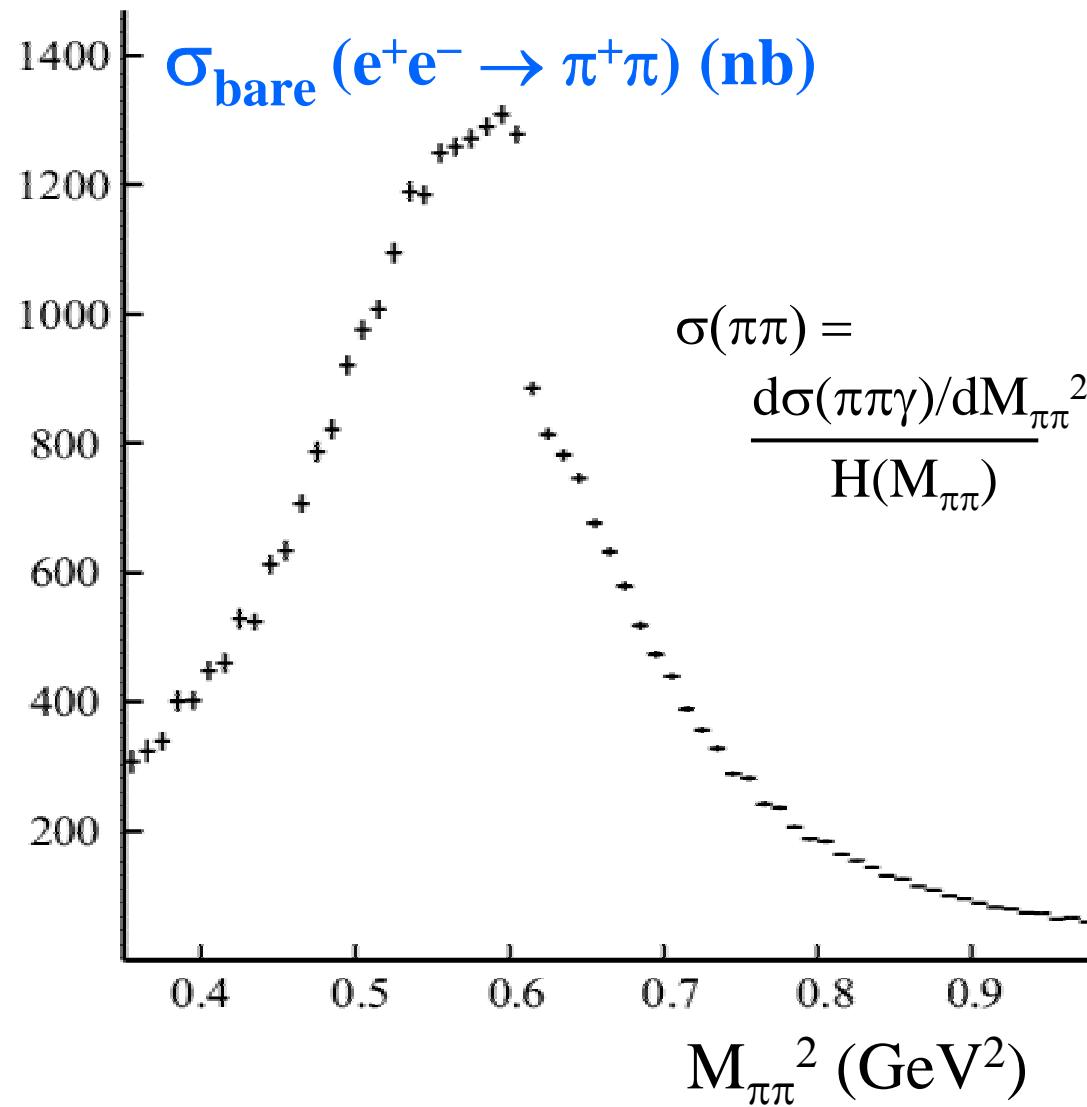
Cut in the m_x vs $M_{\pi\pi}$ plane

Choose to be inclusive of additional radiation at $M_{\pi\pi}^2 > 0.6 \text{ GeV}^2$, to allow consistency checks of MC calculation of FSR

- Background below 3% for $M_{\pi\pi}^2 > 0.4 \text{ GeV}^2$
- Estimate and subtract residual background by fitting data to a linear combination of signal and bkg MC distributions



a_μ – Preliminary results – $\sigma_{\text{bare}}(\pi\pi)$



News on $\pi^+\pi^-\gamma$ analysis



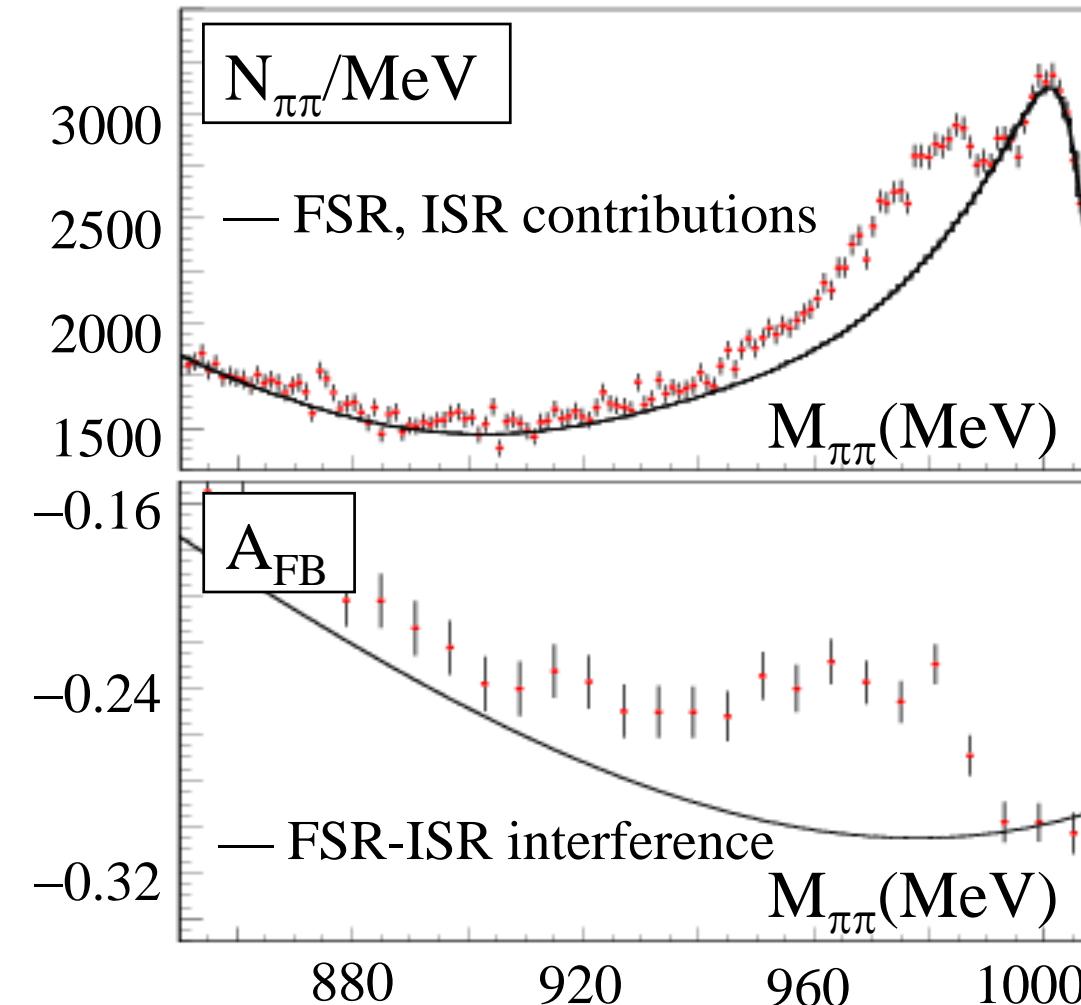
Large-angle events, study of the decay $\phi \rightarrow \gamma f_0 \rightarrow \pi^+\pi^-\gamma$

$\pi^+\pi^-$ system C-odd in ISR events, C-even in FSR events and scalar decays

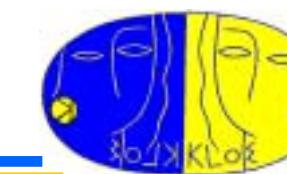
FB asymmetry measures ISR-FSR and ISR-scalar interference:

$$A_{FB} = \frac{N_{\pi^+}(\theta > 90^\circ) - N_{\pi^+}(\theta < 90^\circ)}{N_{\pi^+}(\theta > 90^\circ) + N_{\pi^+}(\theta < 90^\circ)}$$

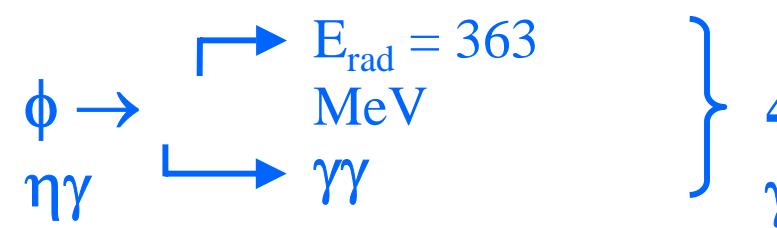
Preliminary evidence for an f_0 contribution



Search for $\eta \rightarrow \gamma\gamma\gamma$



Violates C, $\text{BR} < 5 \times 10^{-4}$ at 95% CL PDG '02 (GAMS2000)



Require 4 γ with fiducial cuts on E, θ

Reclustering to eliminate 3 γ background

Kinematic fit

$m(\pi^0)$ veto eliminates $e^+e^- \rightarrow \omega\pi^0$ and 5 γ background

hep-ex/0402011, submitted to PL

410 pb⁻¹ '01 + '02 data

$\text{BR}(\eta \rightarrow 3\gamma) \leq 2.2 \times 10^{-5}$ 95% CL

