

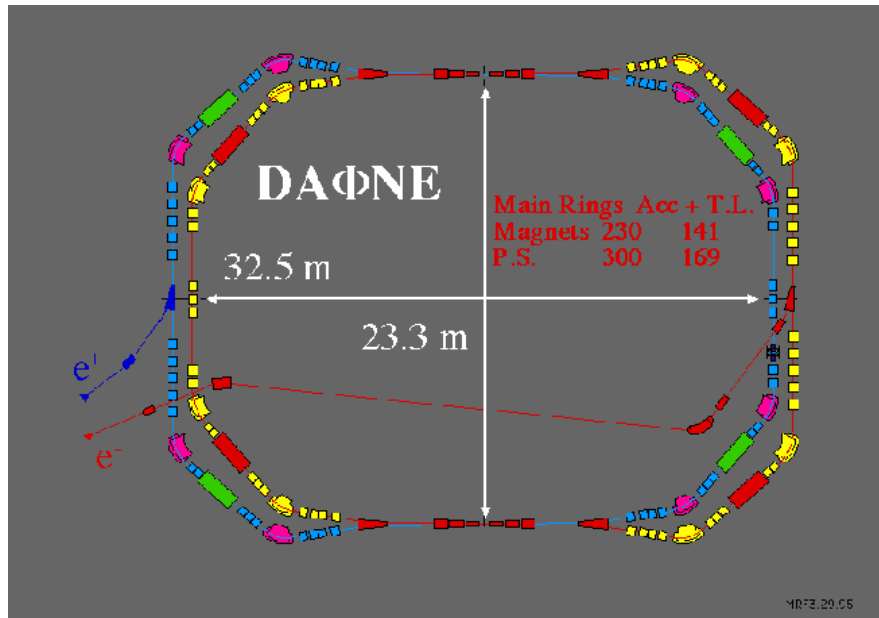
Studio dei mesoni K neutri a KLOE

Claudio Gatti

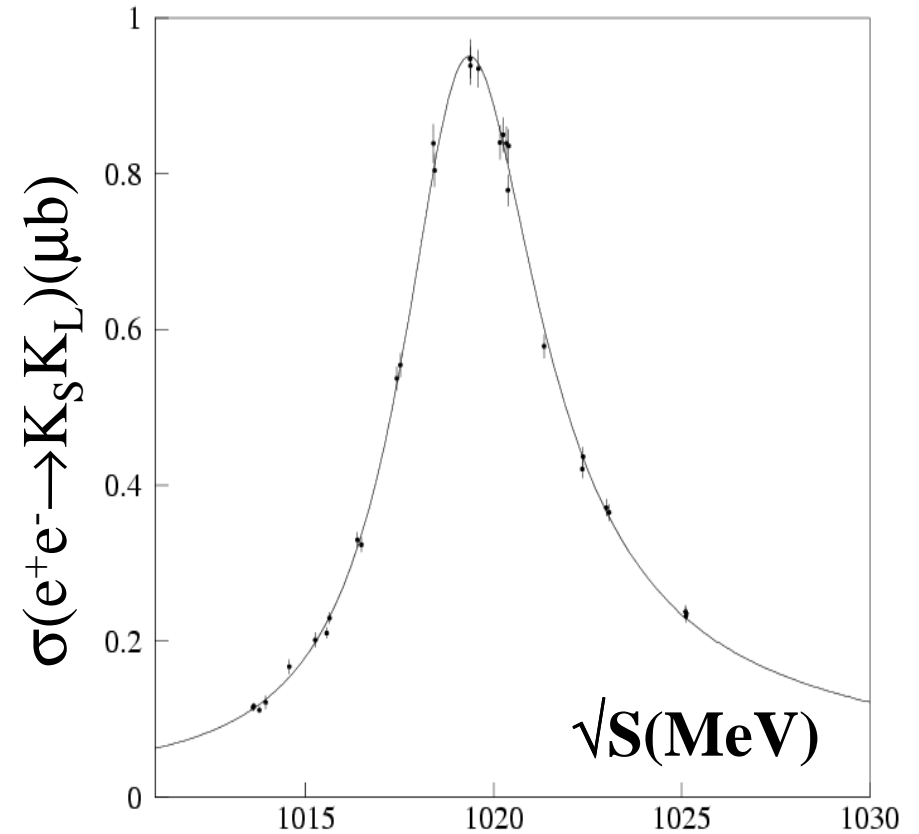


Roma 16/1/04

DAΦNE

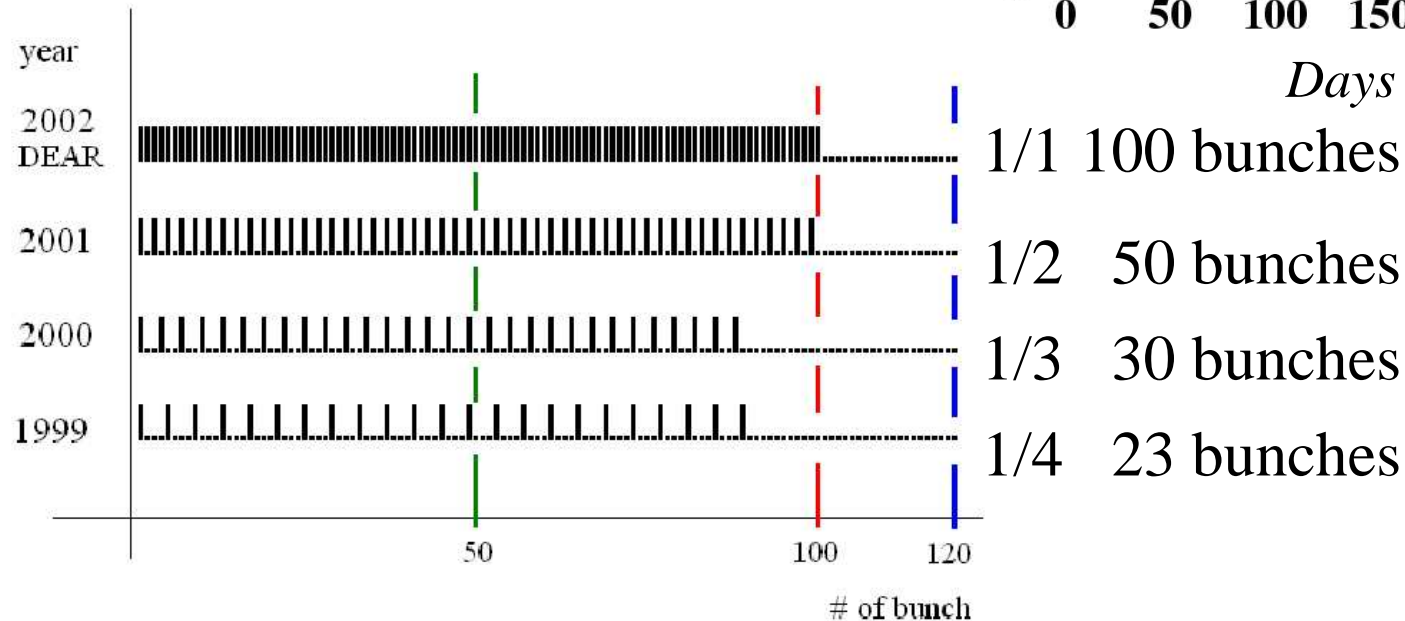
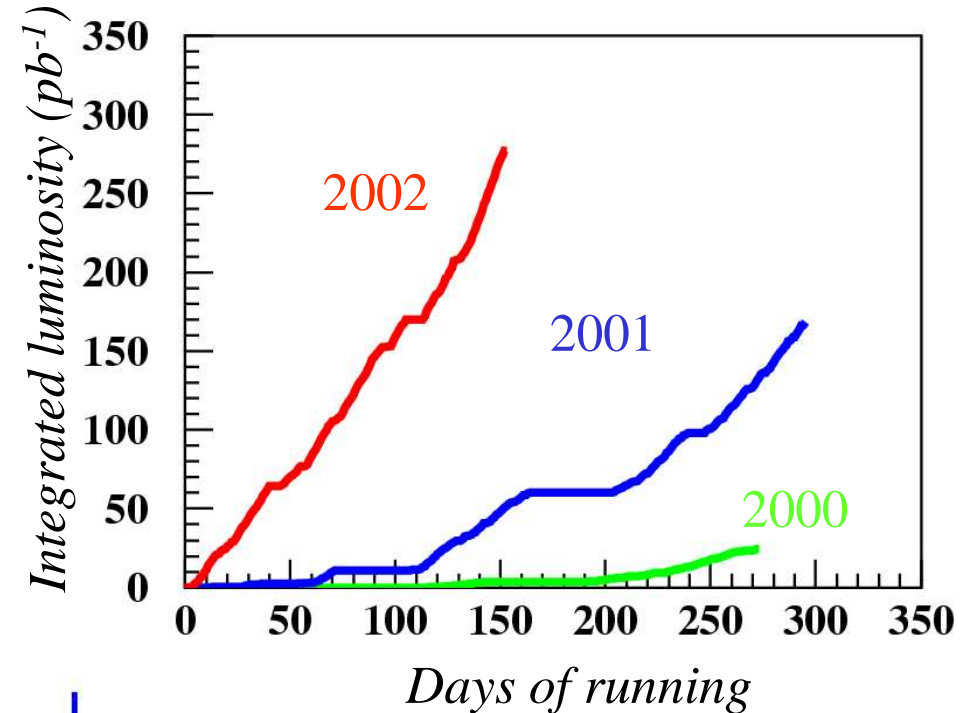


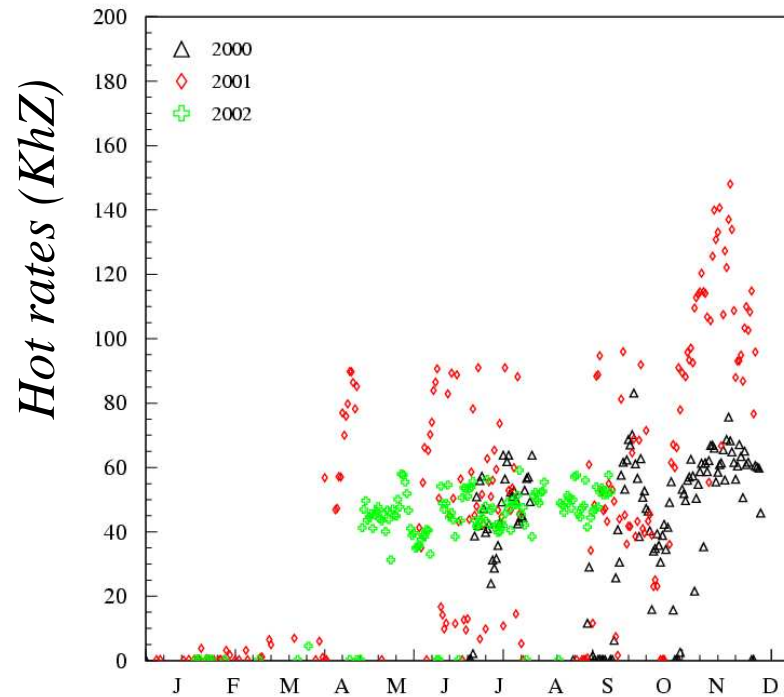
$\sqrt{S}(\text{GeV})$	1.02
$T_{\text{bunch}}(\text{ns})$	2.715
N_{bunch}	120 + 120
$I_{\text{TOT}} e^+/e^- (\text{A})$	5/5
Peak Luminosity ($\text{cm}^{-2}\text{s}^{-1}$)	5×10^{32}



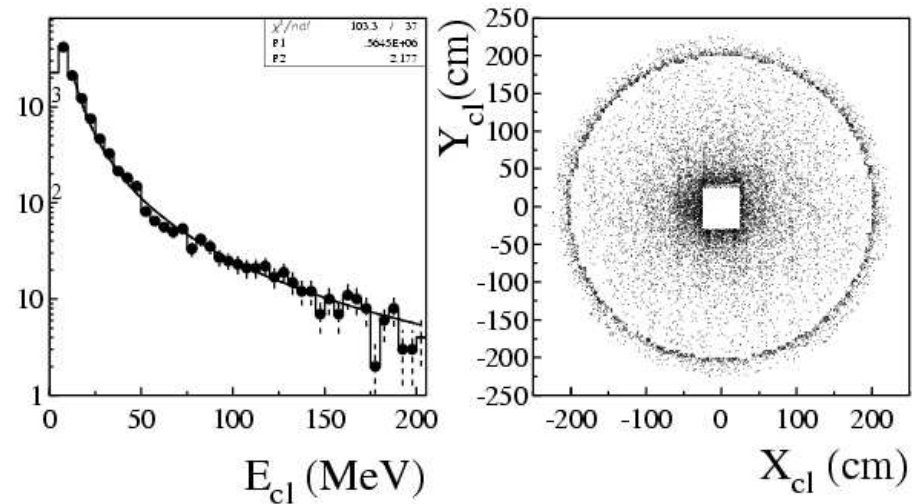
Daφne 1999-2002

N_{bunch}	49 + 49
$I_{\text{TOT}} e^+/e^-$ (A)	0.8/1.1
Peak Luminosity ($\text{cm}^{-2}\text{s}^{-1}$)	8×10^{31}
Luminosity per day (pb^{-1})	4.8 (best)
Luminosity Lifetime (h)	0.6



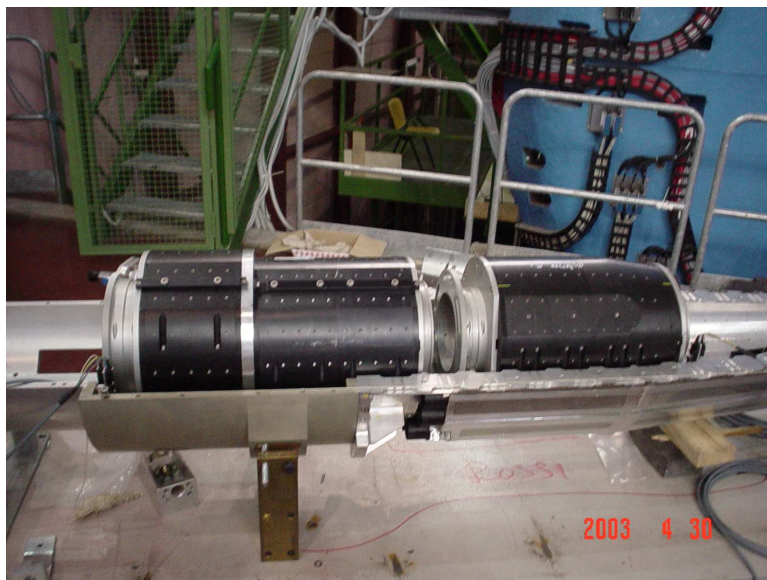


Fondo macchina

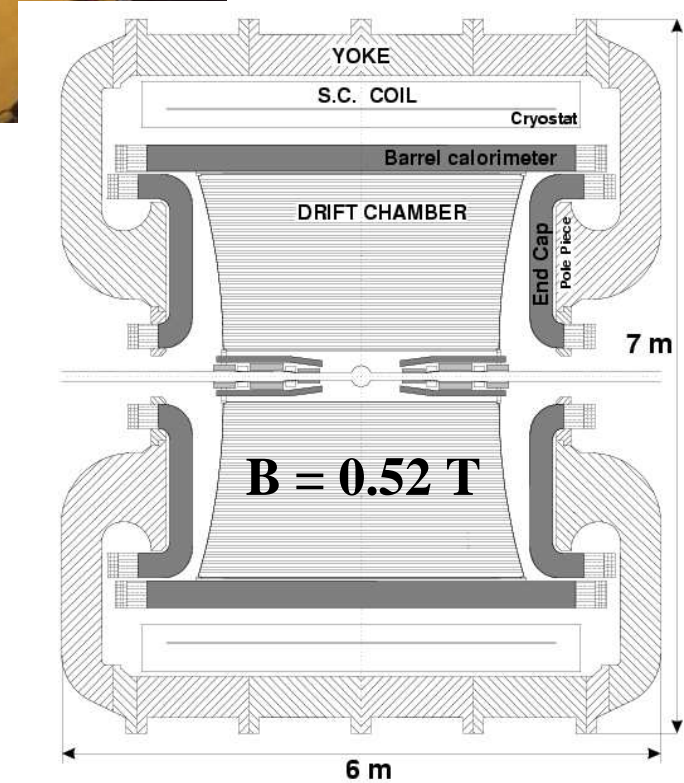
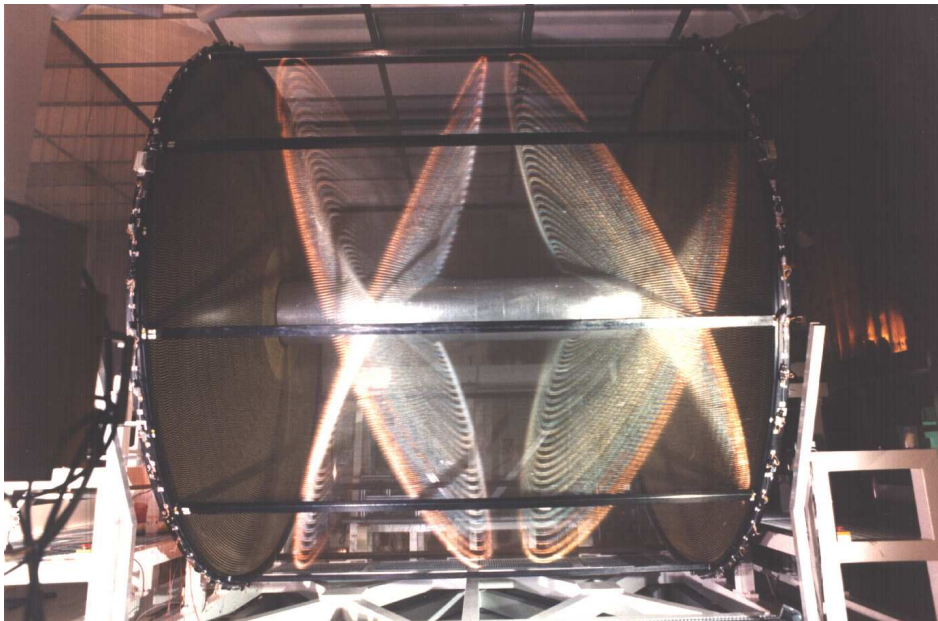
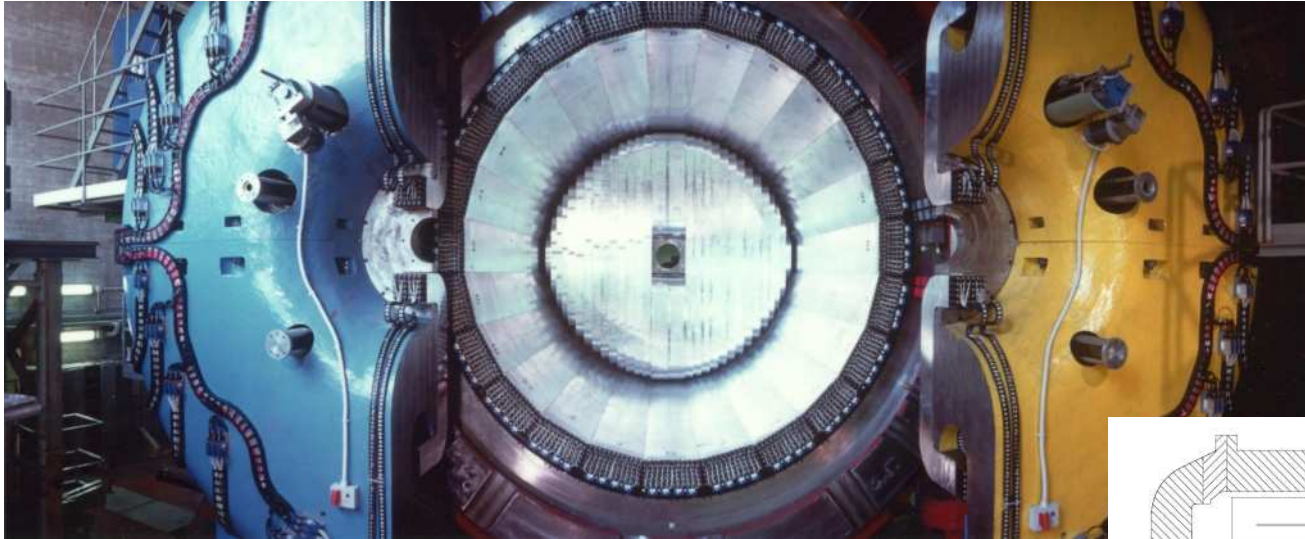


Daφne: obiettivi

N_{bunch}	110+ 110
$I_{\text{TOT}} e^+/e^-$ (A)	2/2
Peak Luminosity ($\text{cm}^{-2}\text{s}^{-1}$)	2×10^{32}
Luminosity per day (pb^{-1})	10
L_{TOT} (fb^{-1})	2
Luminosity Lifetime (h)	1.2

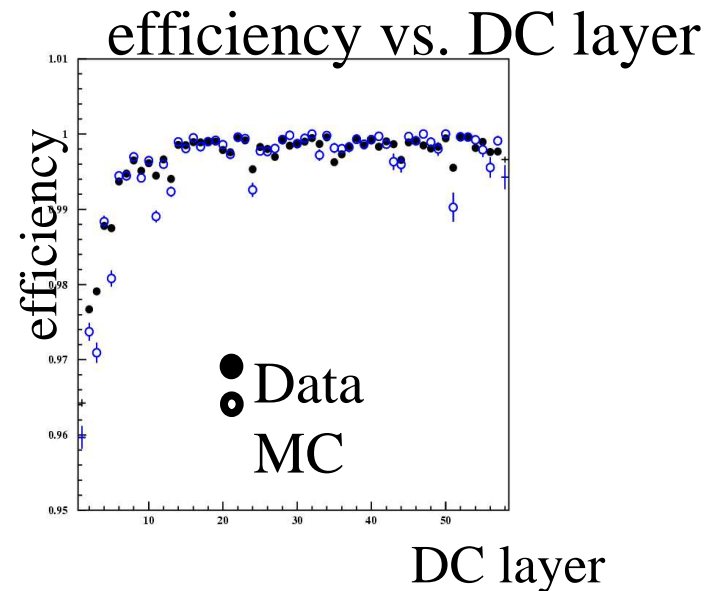
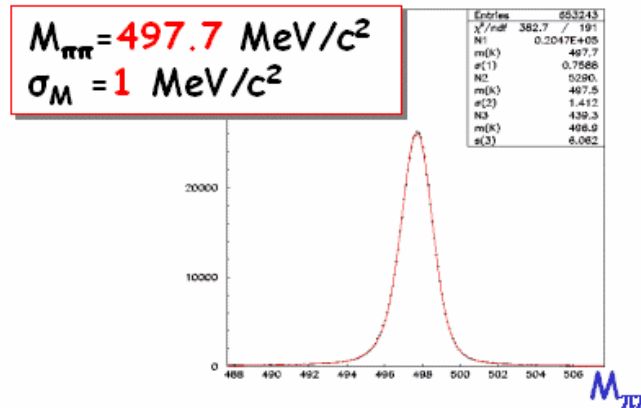
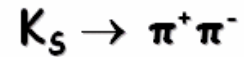
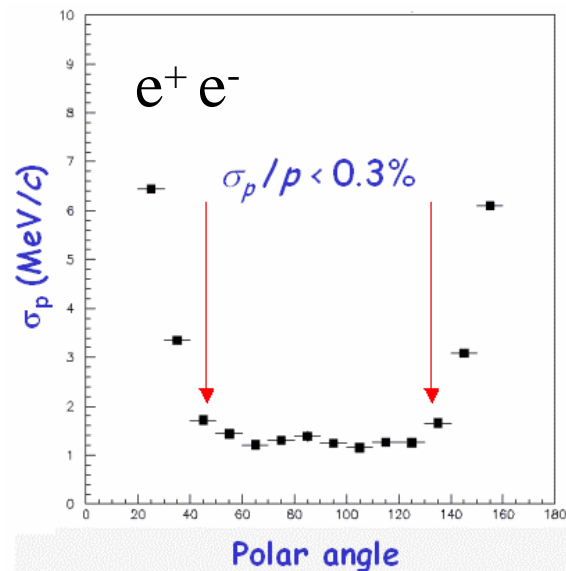
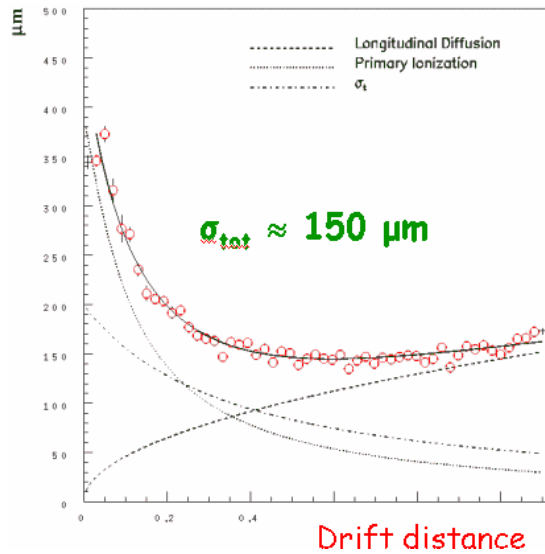


Il rivelatore KLOE



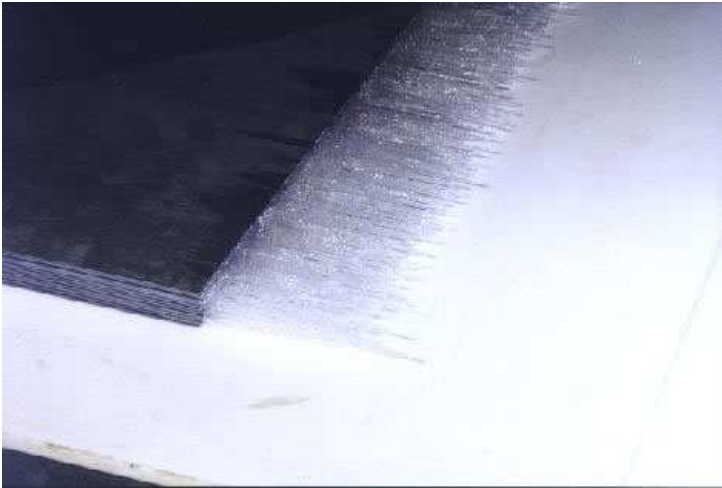
Camera

- 90% He 10% iC₄H₁₀
- ~ 12600 celle (2×2 e 3×3 cm²)
- geometria stereo ($\sigma_z \sim 2$ mm)

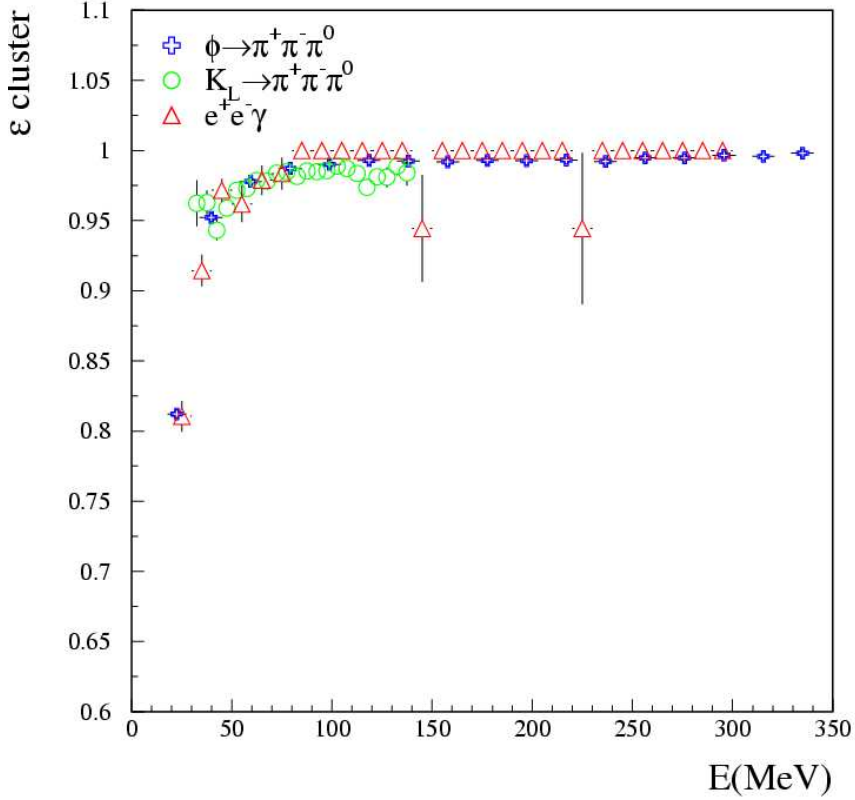
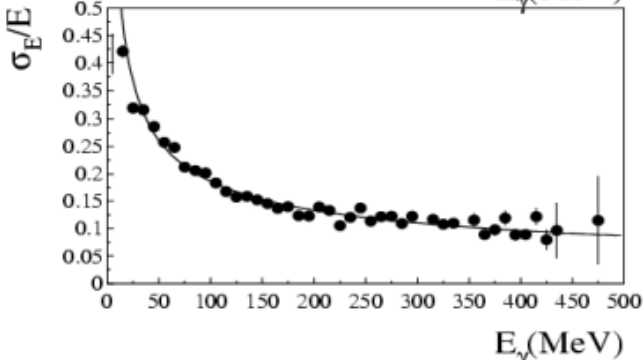
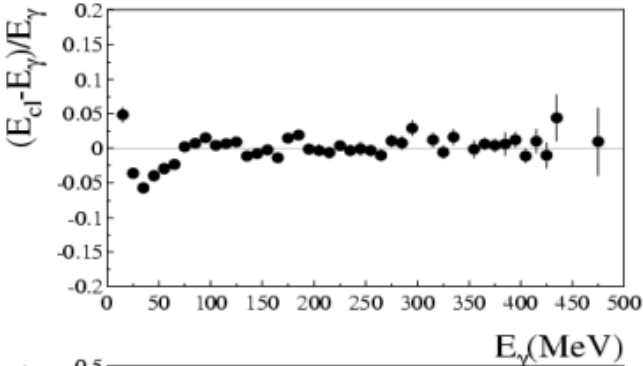


Calorimetro

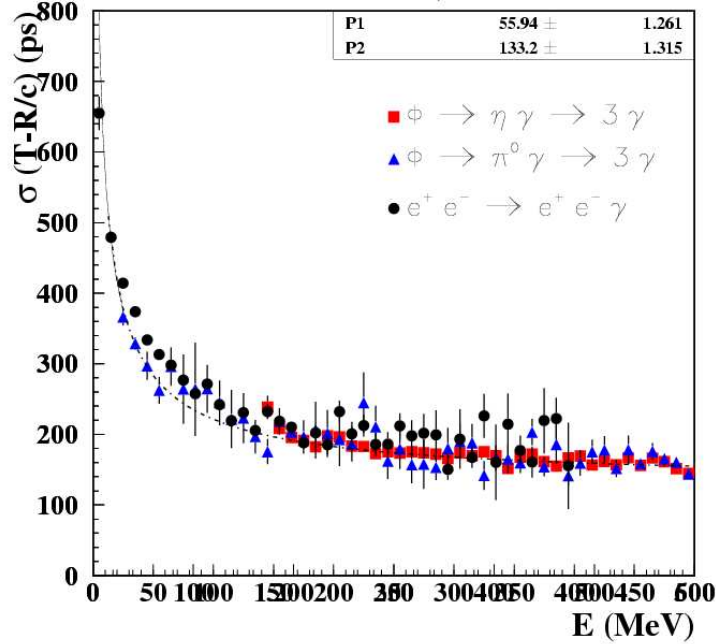
- Emc: piombo fibre scintillanti
- lettura con PM: (4.4×4.4 cm²)
- spessore 15 x₀ (x₀ ~ 1.5 cm)



$$\frac{\sigma(E)}{E} = \frac{5.7\%}{\sqrt{E(\text{GeV})}}$$



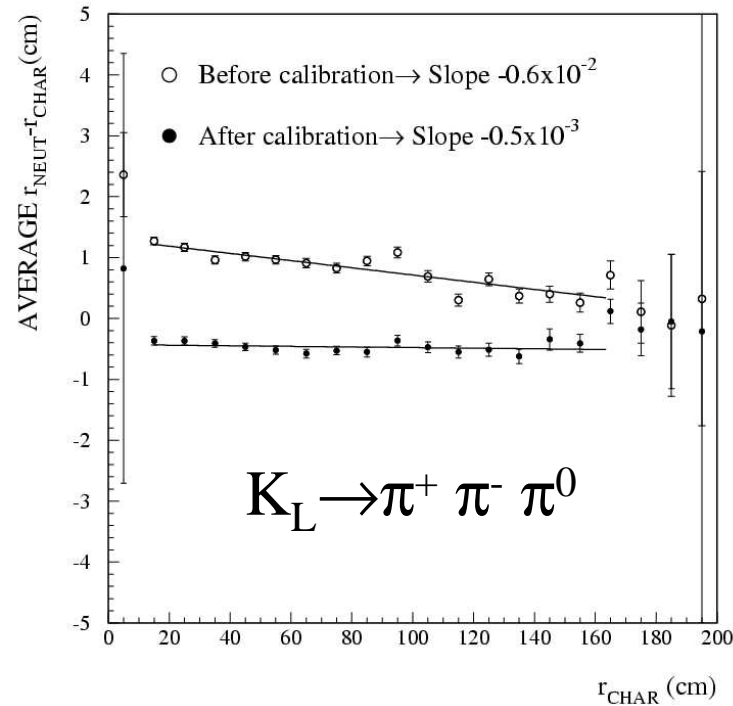
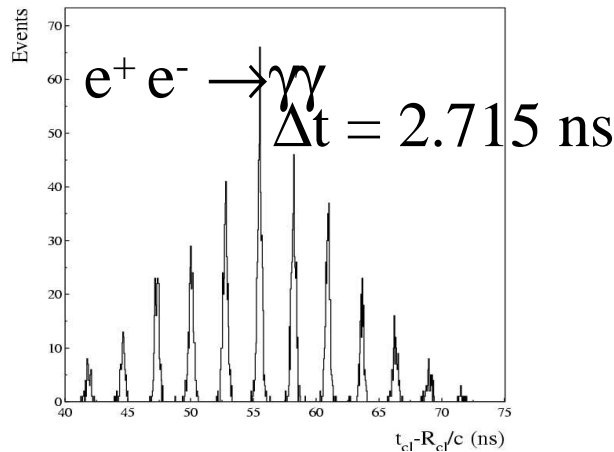
Time resolution



- Lettura dei tempi ai due estremi: t_A e t_B
- $t = (t_A + t_B)/2$
- $S = v_f (t_A - t_B)/2$

$$\sigma(t) = \frac{54 ps}{\sqrt{E(GeV)}} \oplus 50 ps \quad \sigma(S) \approx 1 cm$$

Scala temporale



K a KLOE

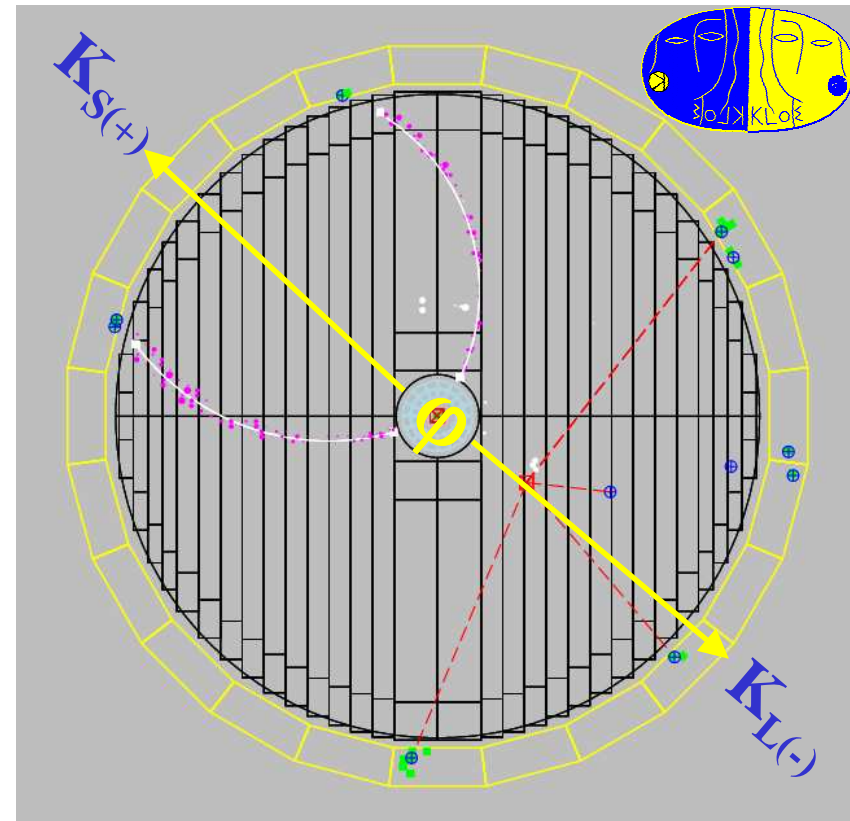
I decadimenti a riposo della ϕ permettono di selezionare fasci puri di K monocromatici ($p \sim 110$ MeV/c):

1. Decadimenti rari dei K.
2. Branching ratios assoluti:

$$BR = \frac{N^{\text{found}}}{N^{\text{tag}}} \times \frac{1}{\epsilon}$$

3. Vite medie dei K: meta' dei K^0 decadono prima del EmC. K^\pm decadono tutti prima.

$$\frac{\lambda_L}{L_{\text{eff}}} \approx 2 \quad \frac{\lambda_{\pm}}{L_{\text{eff}}} \ll 1 \quad \beta \approx 0.2$$



$$\lambda_L \sim 340 \text{ cm}$$

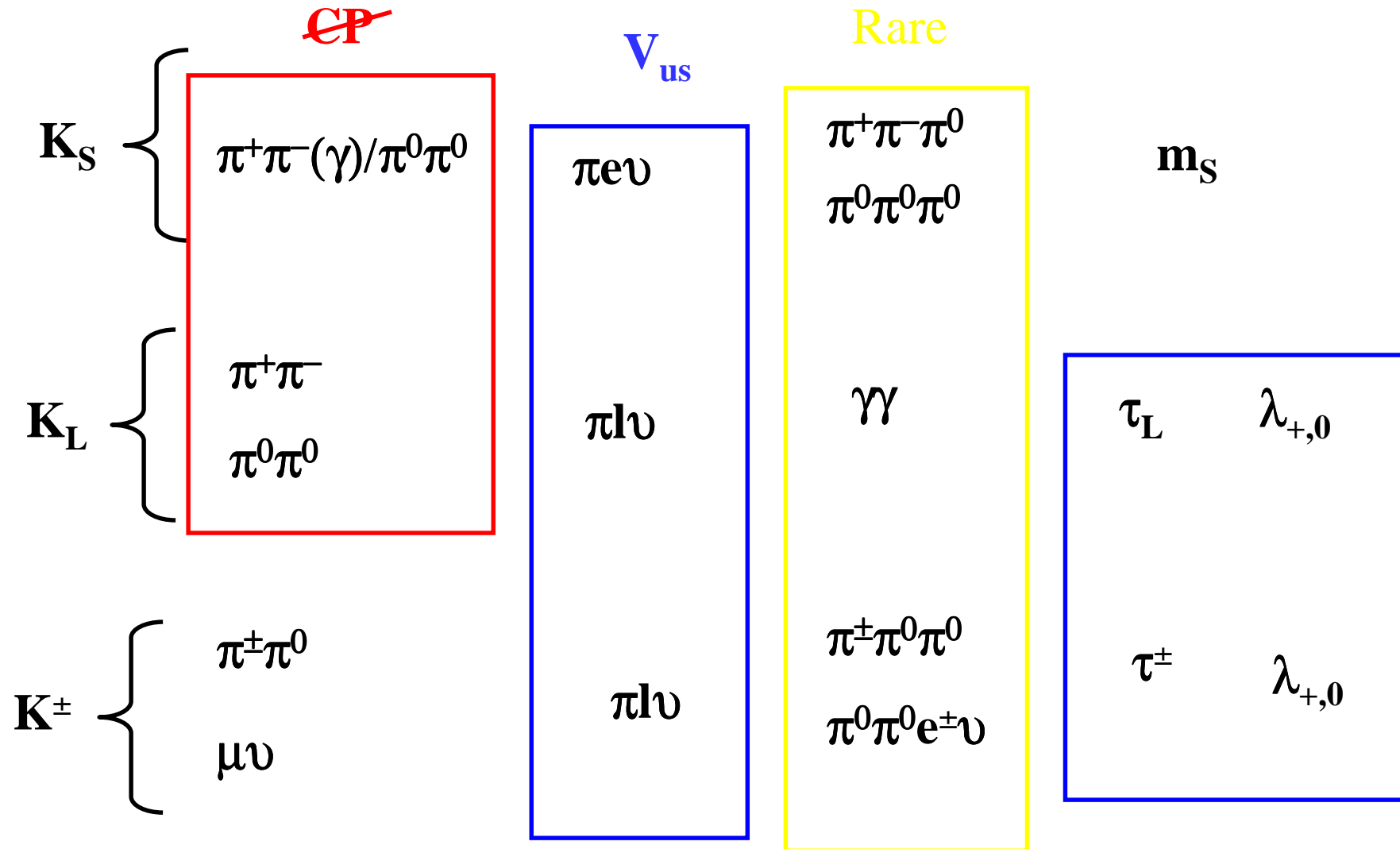
$$\lambda_S \sim 0.6 \text{ cm}$$

$$\lambda_{\pm} \sim 95 \text{ cm}$$

$$K^+K^- \quad 1.5 \times 10^6/\text{pb}^{-1}$$

$$K_L K_S \quad 10^6/\text{pb}^{-1}$$

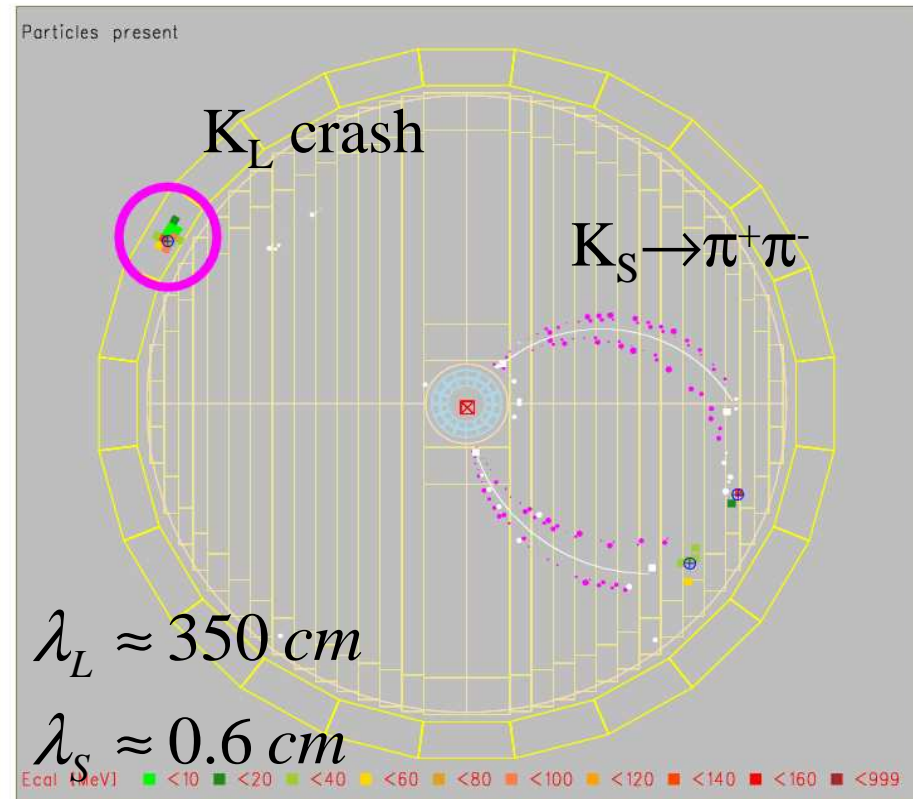
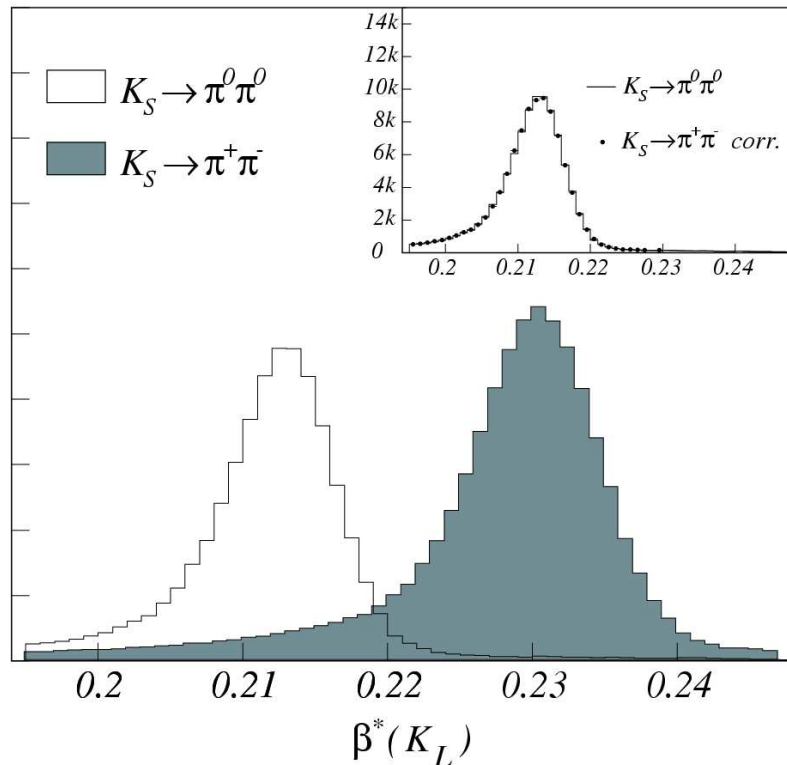
Fisica dei K a KLOE: misure in corso



K_L crash

K_L crash (30%):

- Un cluster sul barrel
- $E_{clu} > 100$ MeV
- $0.17 < \beta^* < 0.28$ (velocità del K_L nel CMS della ϕ misurata dal tempo e posizione del cluster)



$$\sigma(P_S) \sim 2 \text{ MeV}$$

Il tempo iniziale dell'evento non e' noto.
 La distribuzione della velocità β^*
 dipende dalla stima del T0 \Rightarrow tag bias.

BR($K_S \rightarrow \pi^+ \pi^-(\gamma)$) / BR($K_S \rightarrow \pi^0 \pi^0$) e $\delta_0 - \delta_2$

$$A_{+-} = \sqrt{\frac{2}{3}} A_0 e^{i\delta_0} + \sqrt{\frac{1}{3}} A_2 e^{i\delta_2}$$

$$A_{00} = -\sqrt{\frac{1}{3}} A_0 e^{i\delta_0} + \sqrt{\frac{2}{3}} A_2 e^{i\delta_2}$$

$$A_{+0} = \sqrt{\frac{3}{2}} A_2 e^{i\delta_2}$$

Nel limite di esatta simmetria di isospin, i phase shifts possono essere estratti dai decadimenti $K \rightarrow \pi\pi$.

$\delta_0 - \delta_2 = (56.7 \pm 3.8)^\circ$ dai BR nel PDG
 $\rightarrow \pm 8^\circ$ (Cirigliano et al.)

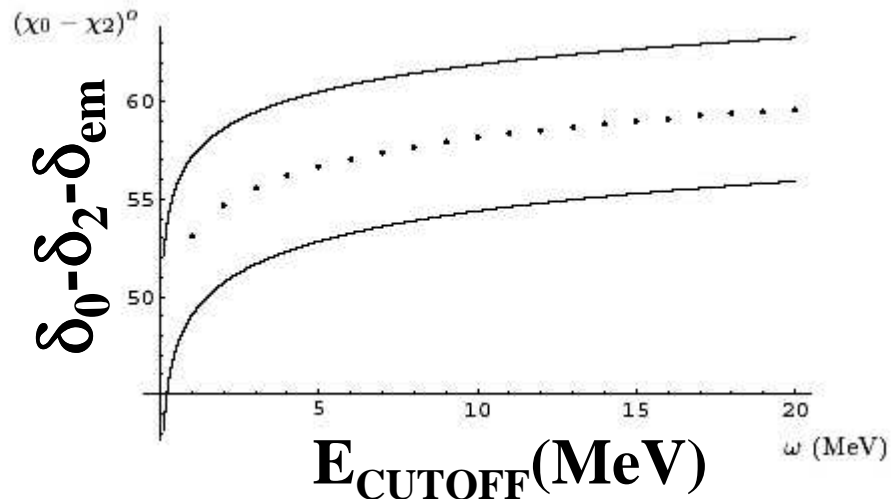
Atteso $\delta_0 - \delta_2 = (47.7 \pm 1.5)^\circ$
 da G. Colangelo et al.

In presenza di rottura di simmetria di isospin (EM):

$$EM \Rightarrow (A_I + \partial A_I) \cdot e^{i(\delta_I + \gamma_I)}$$

$$\delta_0 - \delta_2 \Rightarrow \delta_0 - \delta_2 - \delta_{em}$$

$$\delta_{em} \approx 3.2^\circ \text{ (Cirigliano et al.)}$$



I dati devono essere analizzati includendo le correzioni EM.

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

Almeno 3 clusters neutri.
Misura quasi inclusiva, poco sensibile ad accidentali ed inefficienze

$$E_{cl} \geq 20 \text{ MeV}$$

$$|\cos \theta_{cl}| \leq 0.9$$

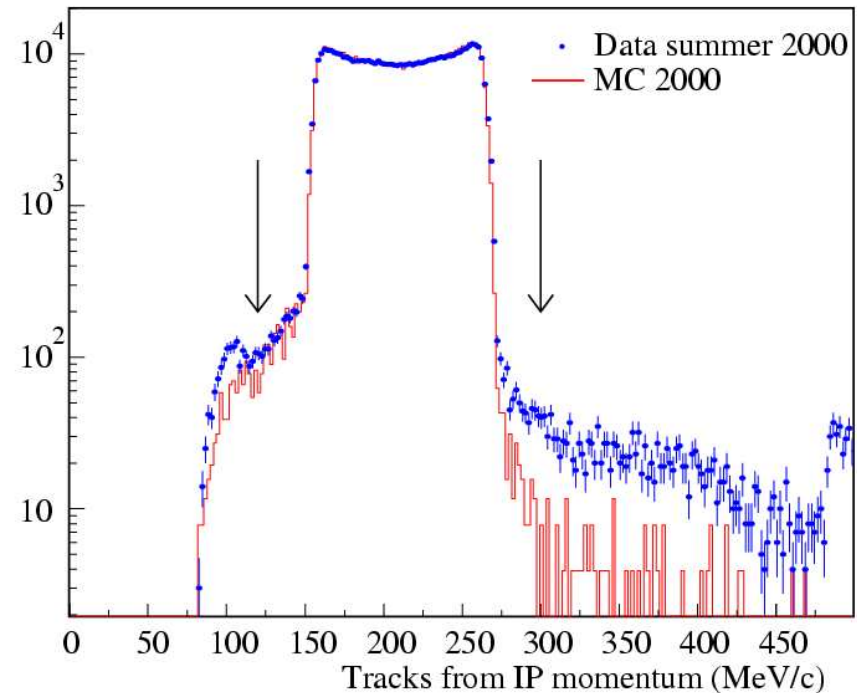
$$\varepsilon \sim 90\%$$

N. clusters	%
<2	1.3
2	8.6
3	33.2
4	56.6
>4	0.3

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

Poco BKG
2 TRK's dall' IP estrapolate all'EmC:
 $120 \text{ MeV} < p_{\text{TRK}} < 300 \text{ MeV}$

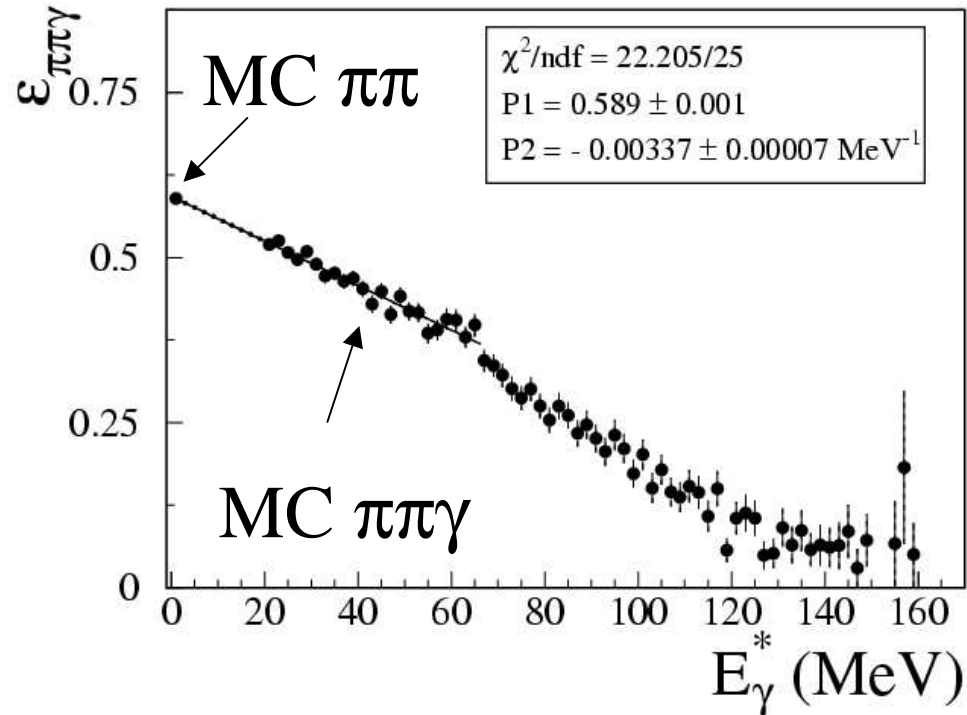
$$\varepsilon \sim 60\%$$



$K_S \rightarrow \pi^+ \pi^- (\gamma)$

L'efficienza e' corretta per la presenza del fotone irraggiato. La correzione totale e' del 0.3%.

Y2000: ~17 pb⁻¹



$$\frac{BR(K_S \rightarrow \pi^+ \pi^- (\gamma))}{BR(K_S \rightarrow \pi^0 \pi^0)} = (2.236 \pm 0.003_{stat} \pm 0.015_{syst})$$

Phys Lett B538 (2002)

$$\delta_0 - \delta_2 - \delta_{em} = (47.8 \pm 2.8)^\circ$$

Errore stat. gia' 0.1%. Sist. (0.7%) dominato da tag bias: nuova finestra β^* , nuova definizione di Kl-crash ... , con 20 volte la statistica e' possibile selezionare campioni sempre piu' 'puliti'.

$K_S \rightarrow \pi e \nu$

Asimmetria di carica

Mai misurata prima nel K_S

$$A = \frac{N^+ - N^-}{N^+ + N^-}$$

$$A_S = 2 \operatorname{Re} \varepsilon_K + 2 \operatorname{Re} \delta_K - 2 \operatorname{Re} y + 2 \operatorname{Re} x_-$$

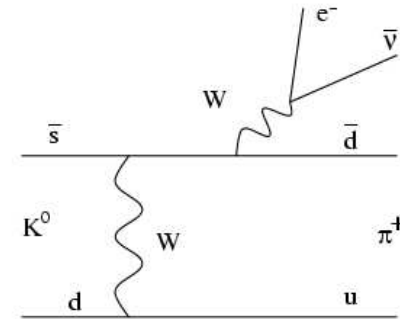
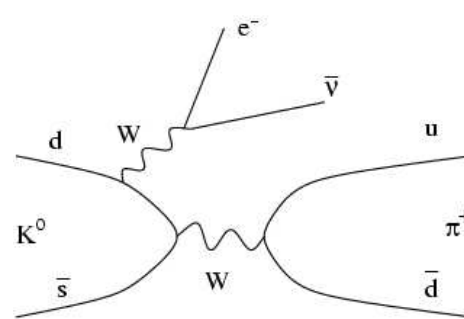
$$A_L = 2 \operatorname{Re} \varepsilon_K - 2 \operatorname{Re} \delta_K - 2 \operatorname{Re} y - 2 \operatorname{Re} x_-$$

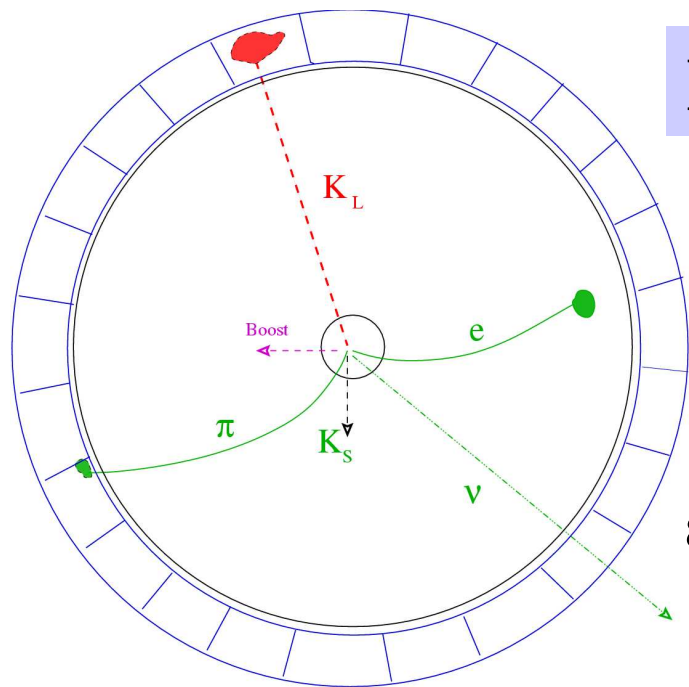
~~CPT~~

$\Delta S = \Delta Q$

$$\operatorname{Re} x_+ = \frac{1}{2} \frac{\Gamma_S^{\pi e \nu} - \Gamma_L^{\pi e \nu}}{\Gamma_S^{\pi e \nu} + \Gamma_L^{\pi e \nu}}$$

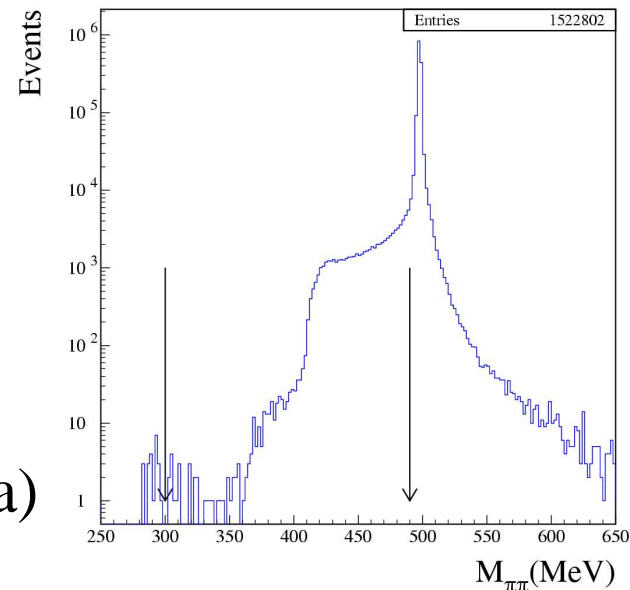
$$|x_+| \approx 10^{-7}$$





$K_S \rightarrow \pi e \nu$

$\epsilon \sim 30\%$ (accettanza)



BKG: $K_S \rightarrow \pi\pi \rightarrow \pi\mu$ (5%)

2 tracce dall'IP estrapolate all' EmC:

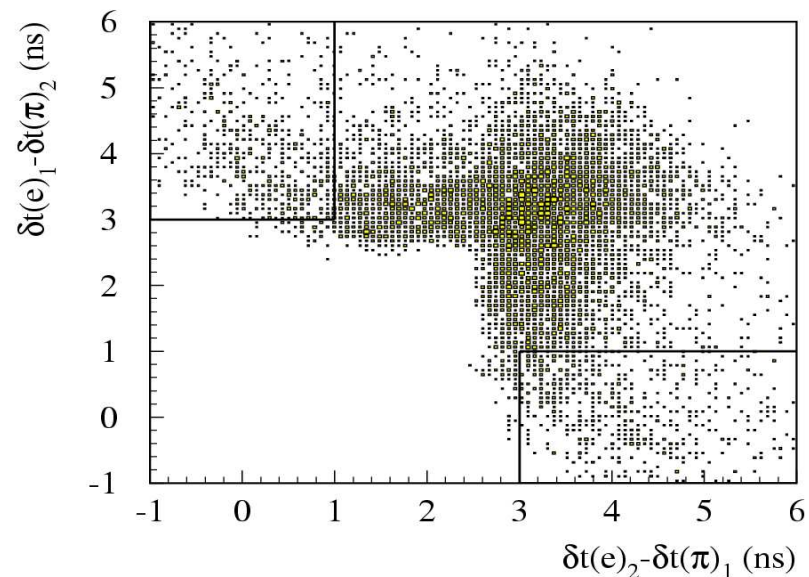
1 VTX : $|Z| < 10$ cm $\rho < 4$ cm

$300 \text{ MeV} < M_{\pi\pi} < 490 \text{ MeV}$

$$\delta_t(m) = t_{cl} - \frac{L}{c\beta(m)}$$

$$d\delta_{t,\pi e} = \delta_t(m_\pi)_1 - \delta_t(m_e)_2$$

$$d\delta_{t,e\pi} = \delta_t(m_e)_1 - \delta_t(m_\pi)_2$$



Conteggio degli eventi Y2001

- Per un neutrino mancante: $E_{\text{miss}} - cP_{\text{miss}} = 0$.
- Ipotesi di massa dal ToF.
- Fit ottenuto usando istogrammi del MC per segnale e fondo.

Phys. Lett. B535

$$BR(K_S \rightarrow \pi e \nu) = (6.91 \pm 0.34_{\text{stat}} \pm 0.15_{\text{syst}}) \times 10^{-4}$$

Preliminare 2001

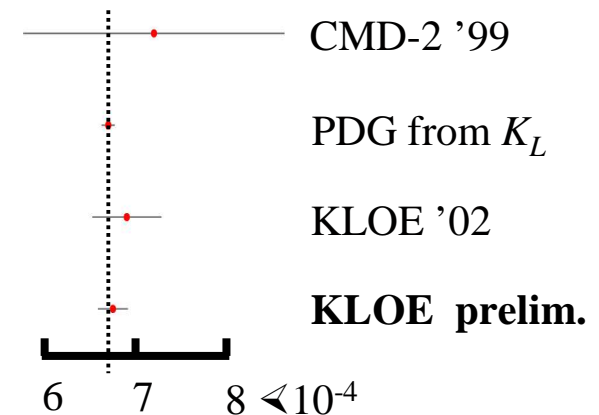
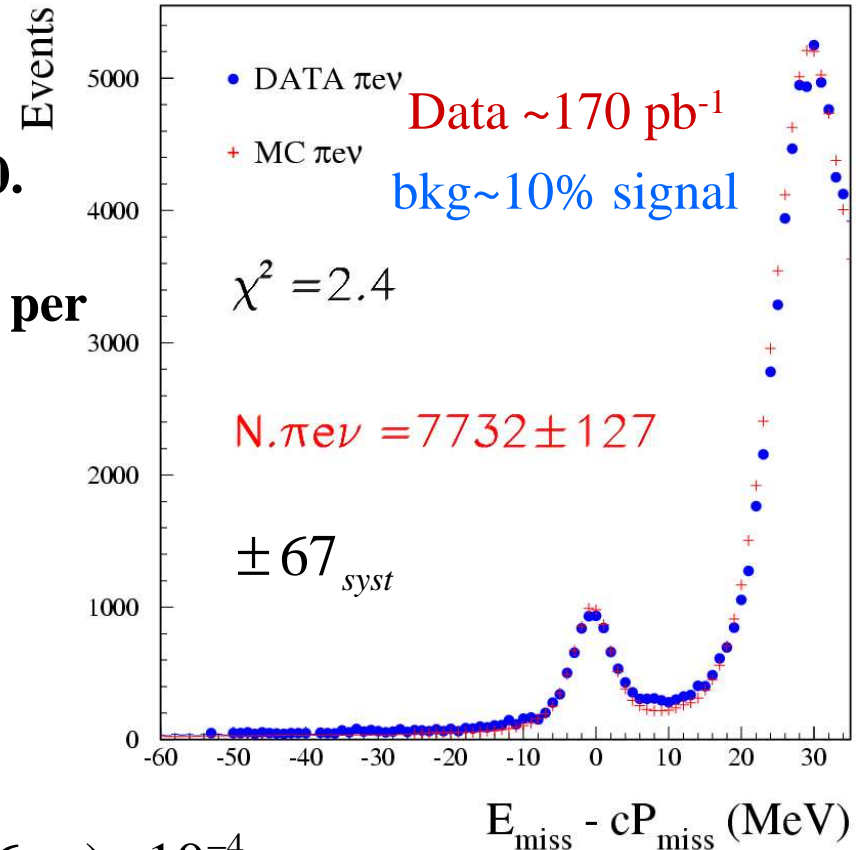
$$BR(K_S \rightarrow \pi^- e^+ \nu) = (3.44 \pm 0.09_{\text{stat}} \pm 0.06_{\text{syst}}) \times 10^{-4}$$

$$BR(K_S \rightarrow \pi^+ e^- \bar{\nu}) = (3.31 \pm 0.08_{\text{stat}} \pm 0.05_{\text{syst}}) \times 10^{-4}$$

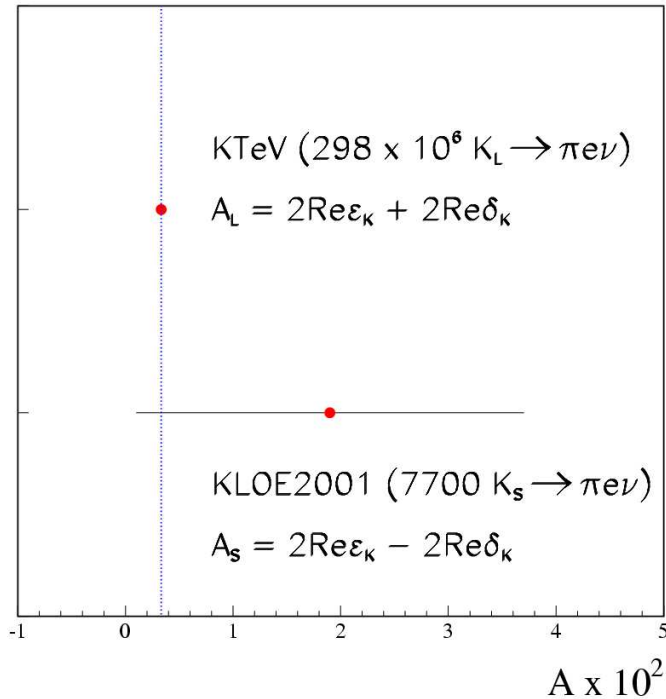
$$BR(K_S \rightarrow \pi e \nu) = (6.76 \pm 0.12_{\text{stat}} \pm 0.10_{\text{syst}}) \times 10^{-4}$$

$$A_S = (1.9 \pm 1.7_{\text{stat}} \pm 0.6_{\text{syst}}) \times 10^{-2}$$

$$\text{Re } x_+ = (2.2 \pm 5.3_{\text{stat}} \pm 3.5_{\text{syst}}) \times 10^{-3}$$



Asimmetria



$$\Delta S = \Delta Q$$

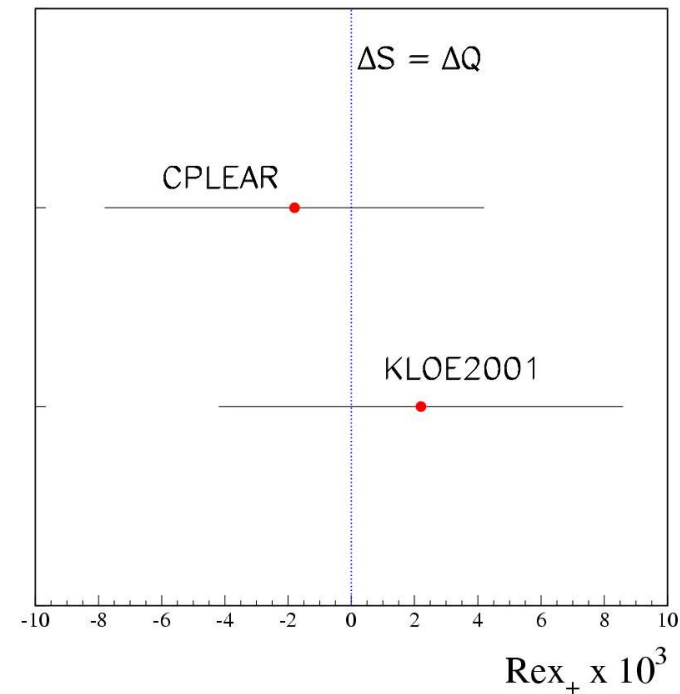
Confrontabile con CPLEAR.
Possibile dimezzare l'errore con 400 pb^{-1} .
Poi errore dominato dal K_L

Preliminare 2001

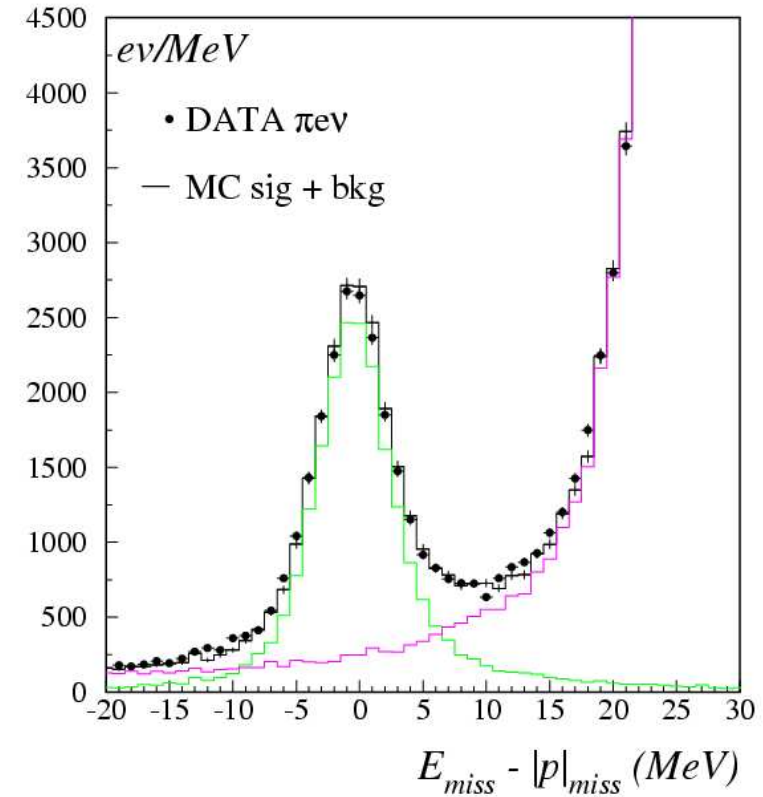
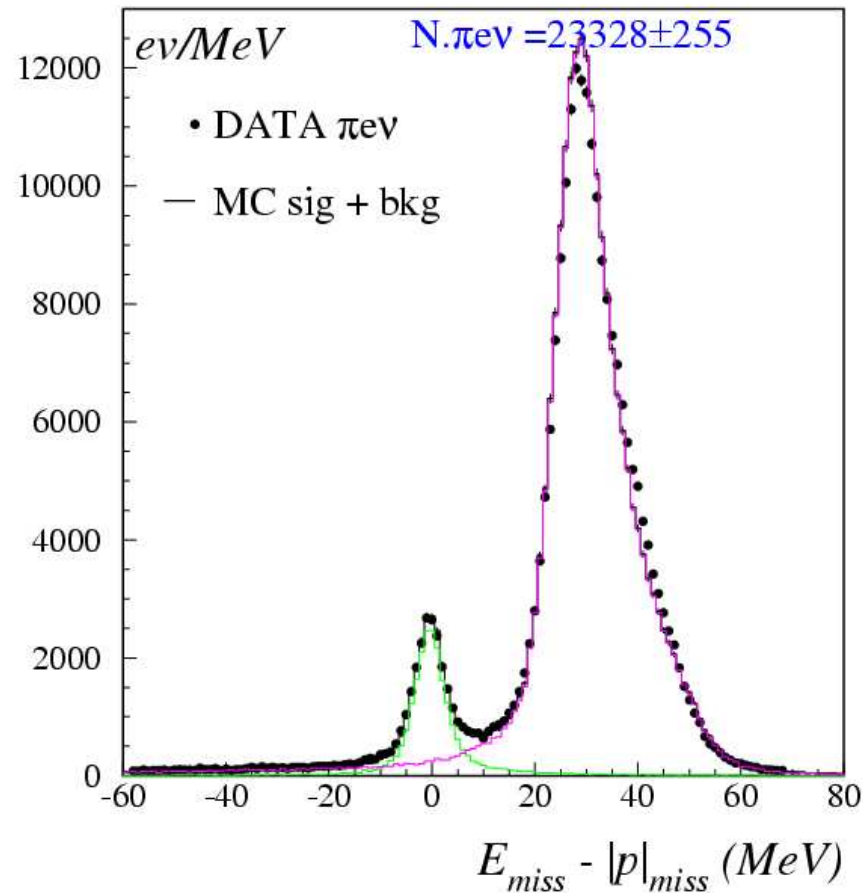
$$\delta_K = \frac{A_S - A_L}{4} \quad \text{CPT}$$

CPLEAR: $\sigma(\delta) = 3 \times 10^{-4}$

KLOE con 2 fb^{-1} $\sigma(\delta) \sim 8 \times 10^{-4}$



Preliminare 2001+2002



- inclusi eventi $K \rightarrow \pi e\nu \gamma$ MC
- parametrizzata la risposta temporale nel EmC
- $\delta BR/BR < 1\%$ $\delta A/A < 1\%$

$K_S \rightarrow 3\pi^0$

$$BR(K_S \rightarrow 3\pi^0)_{th} = BR(K_L \rightarrow 3\pi^0) \frac{\tau_S}{\tau_L} |\epsilon|^2 \approx 2 \times 10^{-9} \quad \text{CP}$$

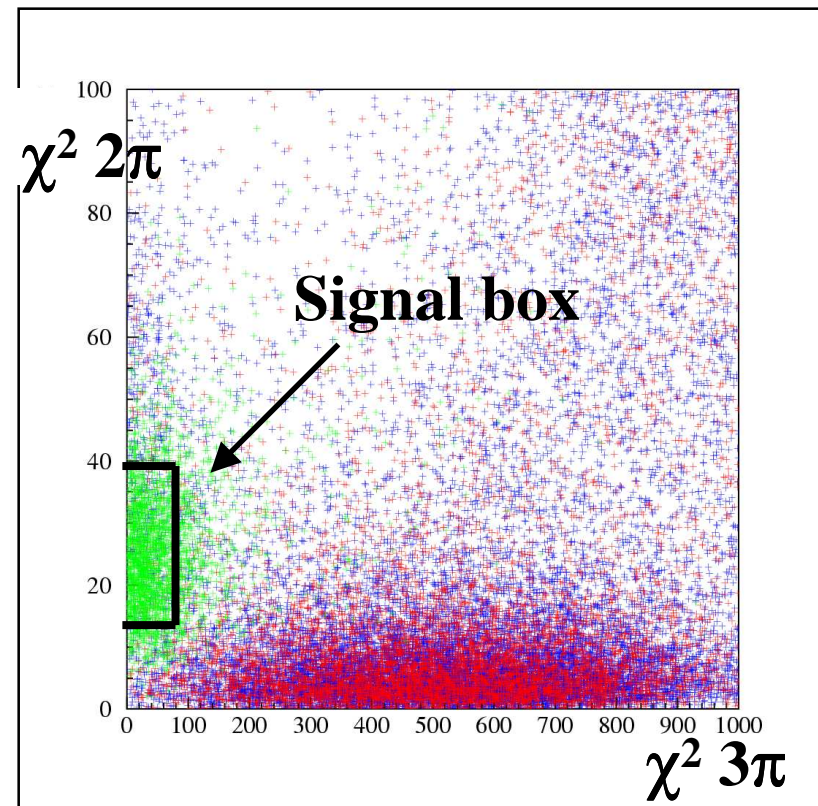
- 450 pb⁻¹ analizzati
- N_{ev} = 5
- N_{BKG} = 3 ± 2

NA48: da interferenza K_L K_S (CPT)

BR(K_S → 3π⁰) < 3.0 × 10⁻⁷ 90% CL

Preliminare KLOE

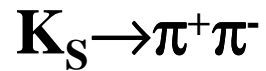
BR(K_S → 3π⁰) < 2.2 × 10⁻⁷ 90% CL



Con L_{int} ~ 2 fb⁻¹ ⇒ 1 evento aspettato

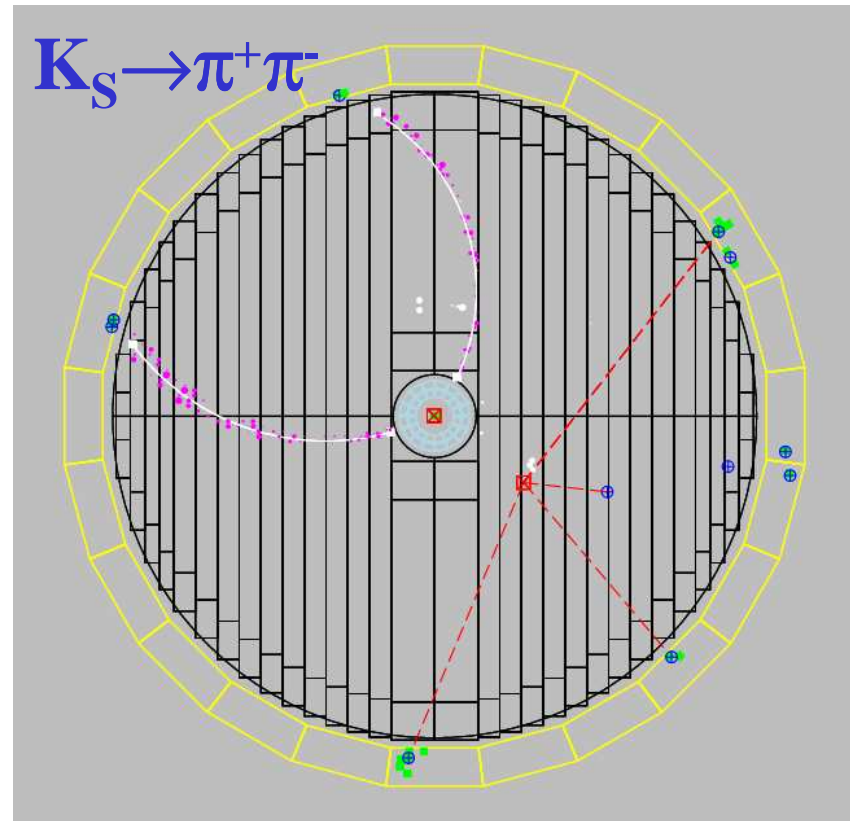
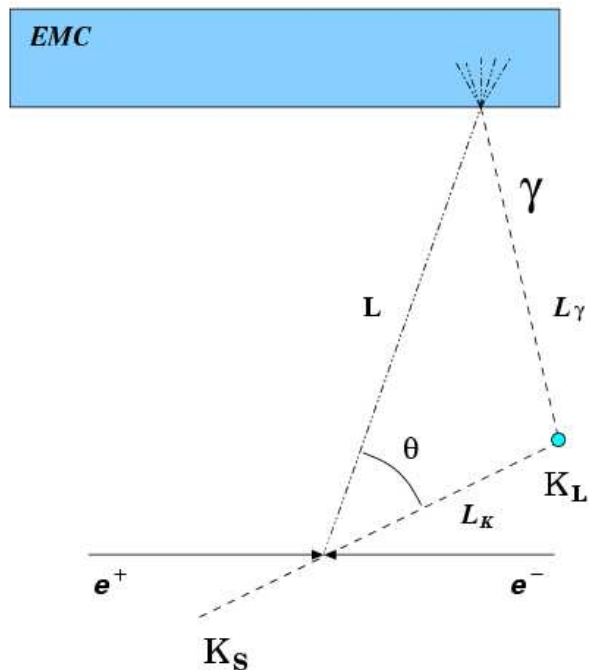
K_L tag

- Identificazione di un decadimento



- $\sigma(P_L) \sim 2 \text{ MeV}$

Vertice neutro

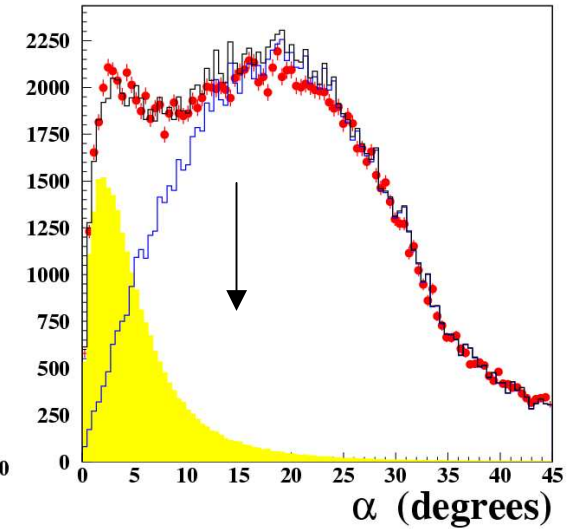
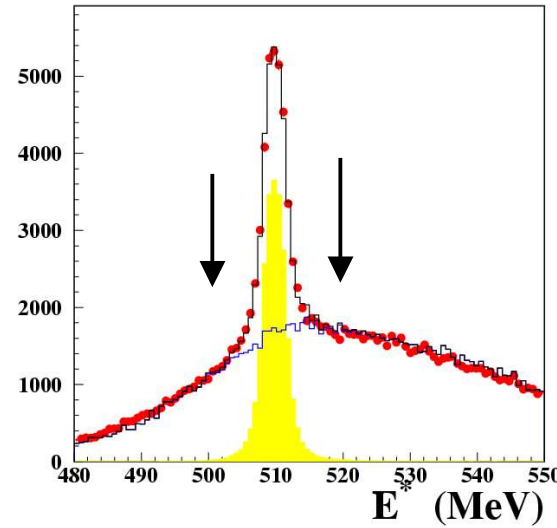


$$\begin{cases} \vec{L} = \vec{L}_K + \vec{L}_\gamma \\ L_K / \beta_K + L_\gamma = ct_{clu} \end{cases}$$

$$\sigma_L \approx 2 \text{ cm}$$

$K_L \rightarrow \gamma\gamma$

- test χ^{PT} e $\text{BR}(K_L \rightarrow \mu\mu)$
- 362 pb^{-1}
- 27000 eventi $\gamma\gamma$
- 10^7 eventi $3\pi^0$



$$R = \text{BR}(K_L \rightarrow \gamma\gamma) / \text{BR}(K_L \rightarrow 3\pi^0)$$

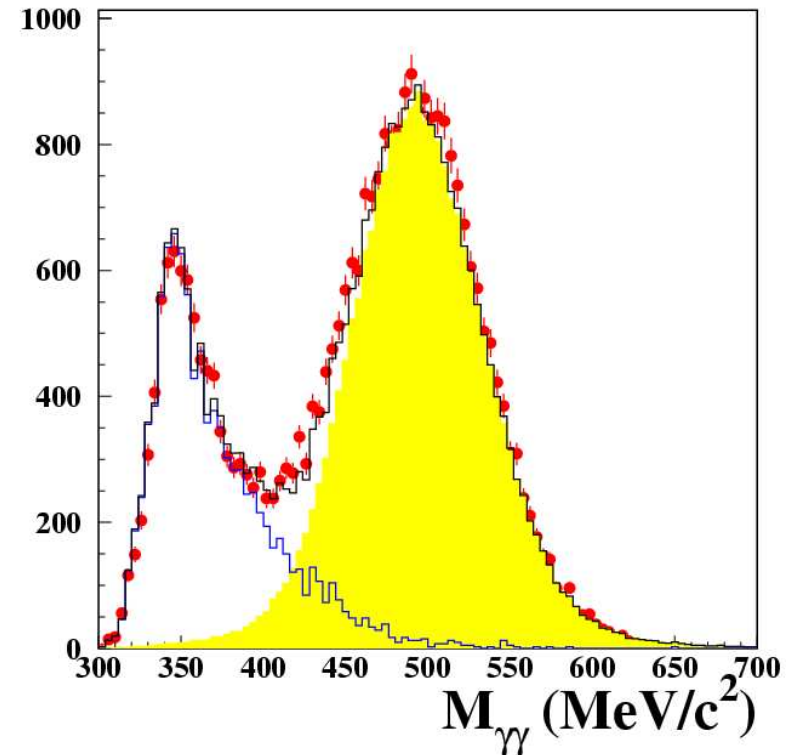
NA48 R=

$$(2.81 \pm 0.01_{\text{stat}} \pm 0.02_{\text{syst}}) \cdot 10^{-3}$$

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KLOE R=

$$(2.79 \pm 0.02_{\text{stat}} \pm 0.02_{\text{syst}}) \cdot 10^{-3}$$

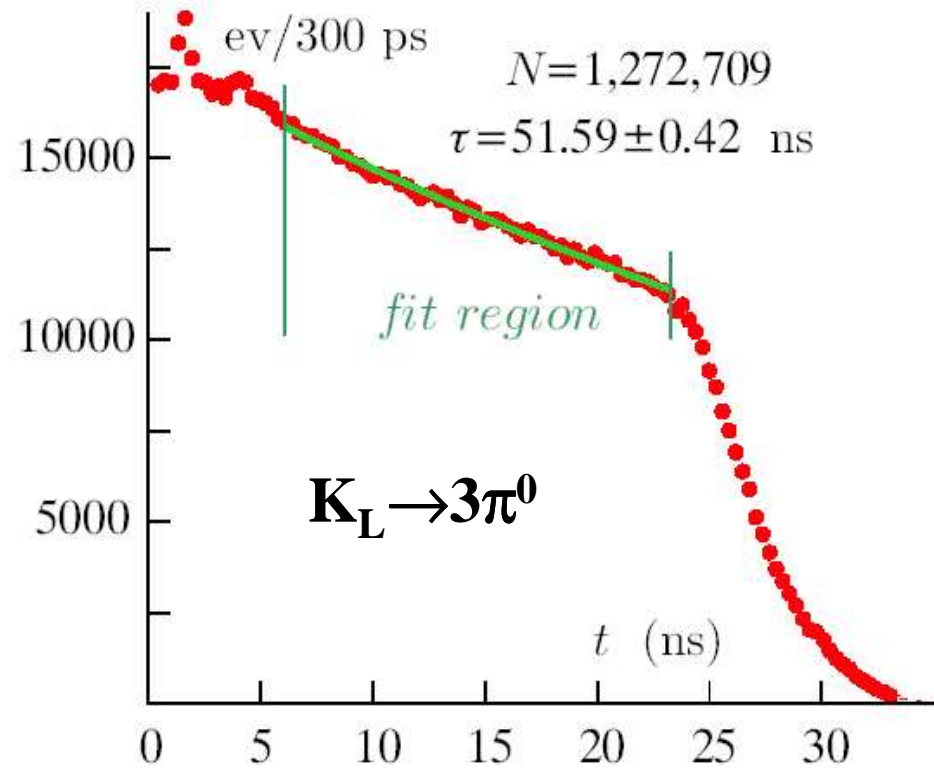


$K_L \rightarrow \gamma\gamma : \tau_L$

Vita media del K_L da un campione di eventi $K_L \rightarrow 3\pi^0$. Usata per fare un controllo sull'efficienza nell'analisi del $K_L \rightarrow \gamma\gamma$.

$$\tau_L = (51.6 \pm 0.4) \text{ ns} \quad \text{KLOE}$$

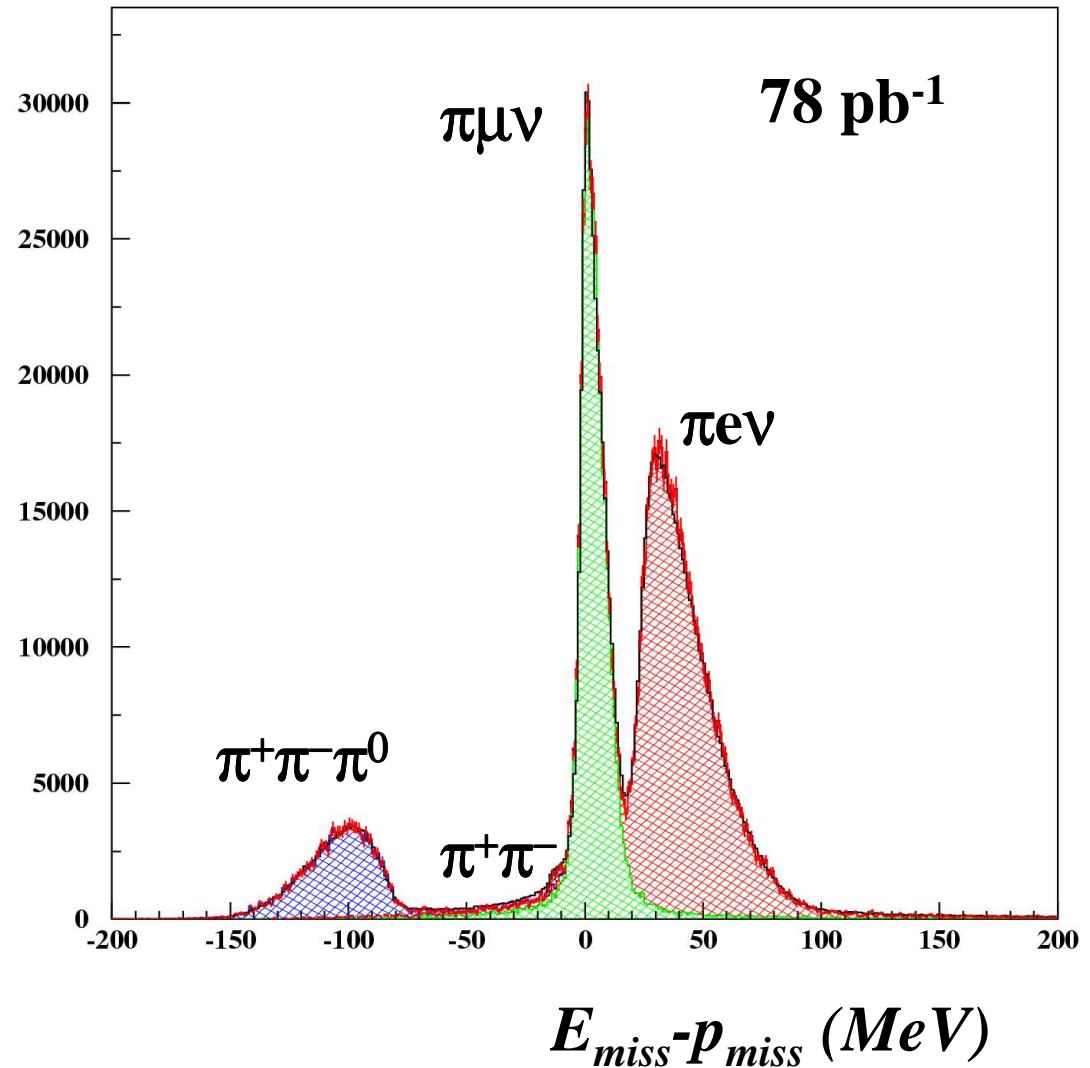
$$\tau_L = (51.7 \pm 0.4) \text{ ns} \quad \text{PDG}$$



Si puo' raggiungere $\delta\tau \sim 0.1$ ns

$K_L \rightarrow \text{carichi}$

- Fit alla distribuzione $E_{\text{miss}}-p_{\text{miss}}$ (ipotesi $\pi\mu$) con spettri MC.
- Misura simultanea di tutti i BR's assoluti ($\pi^+\pi^-$ fissato).
- Con $\sim 80 \text{ pb}^{-1}$ $\delta\text{BR}/\text{BR} < 1\%$
- Sistematiche: TRK, tag bias (trigger) ... (1%)
- Inclusi generatori MC $\pi\mu\nu\gamma$ $\pi e\nu\gamma$.



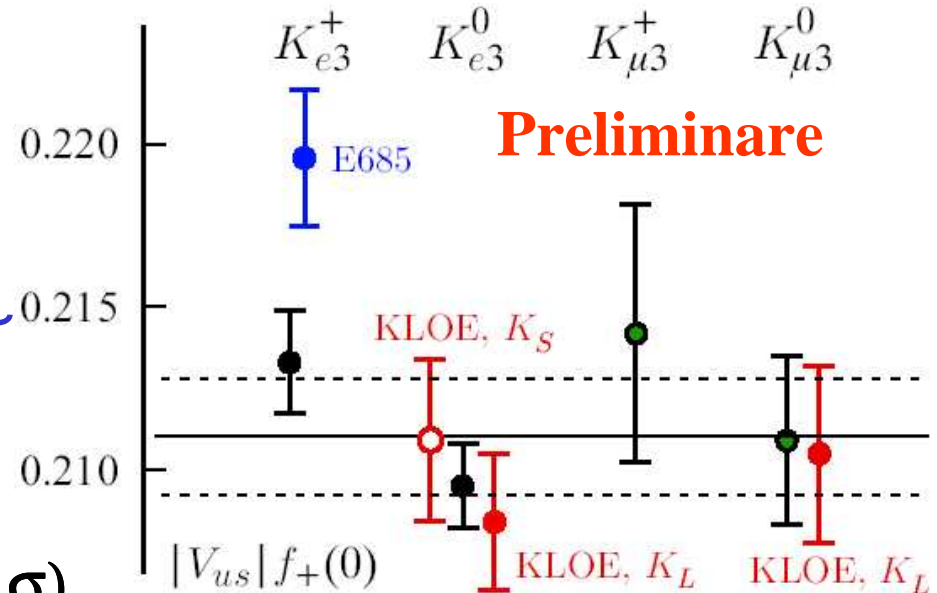
Prospettive per V_{us}

Introdotta nel 1963, conosciuta all' 1%

Per i K_{e3} :

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

$$|V_{ud}|^2 + |V_{us}|^2 = 0.9978 \pm 0.0016 \quad (1.4 \sigma)$$



- Misura di BR's assoluti al 0.2%. Con $\sim 400 \text{ pb}^{-1}$, tenendo conto delle efficienze, si hanno $\sim 1-3 \times 10^6$ decadimenti semileptonici di ogni tipo (neutri e carichi). (vedi $K_L \rightarrow \text{carichi}$ e $K_S \rightarrow \pi e \nu$)
- Misura di τ_L al 0.1%. (vedi $K_L \rightarrow 3\pi^0$)
- λ^+ λ^0

Interferenza



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

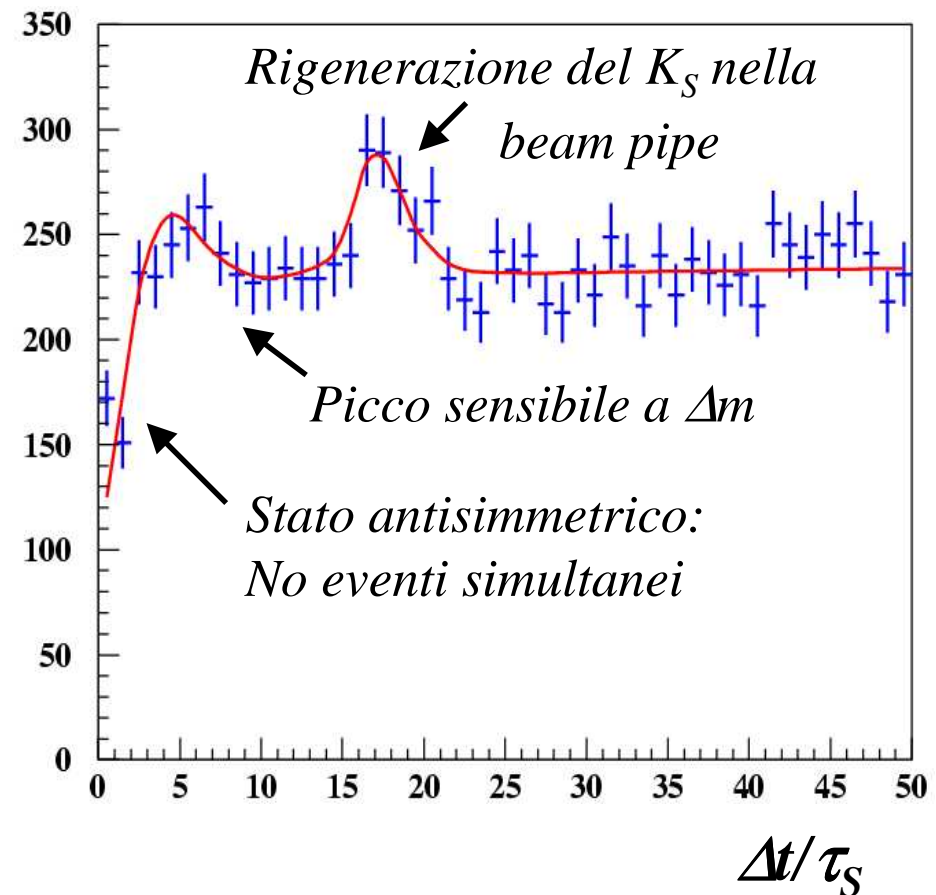
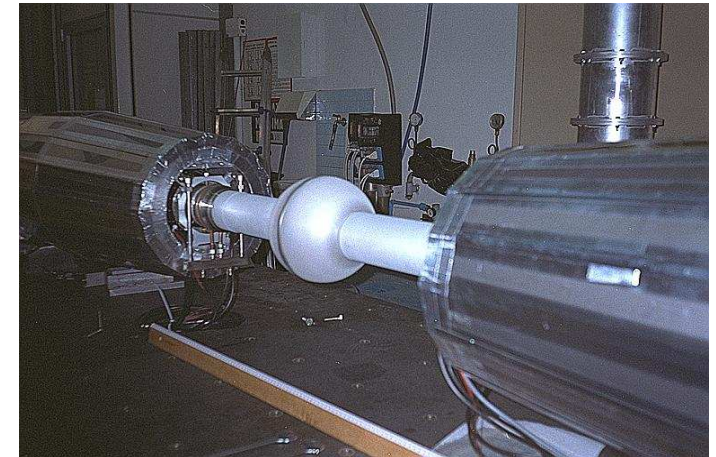
$$\sigma(\Delta t) \sim 1\tau_S$$

Preliminare KLOE:

Con 340 pb^{-1} , fit tenendo fissi Γ_S e Γ_L (PDG):

$$\Delta m = (5.64 \pm 0.37) \times 10^{-11} \hbar \text{ s}^{-1}$$

$$\text{PDG } (5.301 \pm 0.016) \times 10^{-11} \hbar \text{ s}^{-1}$$



Conclusioni

Con i primi $\sim 450 \text{ pb}^{-1}$:

- $R(K_S \rightarrow +-/00)$ al 0.7% tenendo conto del fotone irradiato.

Risolto $(\delta_0 - \delta_2)$? Cirigliano et al. (2003) trovano nuove correzioni ...

- $K_S e3$: BR al 2% ($\rightarrow 1\%$) e prima misura della asimmetria di carica. V_{US} !
- alcuni canali rari: (S) $3\pi^0$, $\pi^+\pi^-\pi^0$, (L) $\gamma\gamma$.
- la massa del K_S (errore $\sim 20 \text{ KeV}$)
- Un controllo sui decadimenti $K_L \rightarrow 3\pi^0$ mostra potenzialita' per τ .
- Infine tutti BR's assoluti del K_L in carichi ...
- $(\tau + \text{BR}(\text{semilept.})) \Rightarrow V_{US}$.

Kloe ripartira' nei prossimi mesi (marzo) per raccogliere $\sim 2 \text{ fb}^{-1}$ corrispondenti a $2 \times 10^9 K_S K_L$.

CP:stato

$$1 - 6 \operatorname{Re} \left(\frac{\varepsilon'}{\varepsilon} \right) = \frac{BR(K_S \rightarrow \pi^+ \pi^-)}{BR(K_S \rightarrow \pi^0 \pi^0)} \cdot \frac{BR(K_L \rightarrow \pi^0 \pi^0)}{BR(K_L \rightarrow \pi^+ \pi^-)}$$

Dati 2001+2002

$$BR(K_L \rightarrow \pi^+ \pi^-) = N_{\pi\pi} / \varepsilon N_S$$

- $\sim 90 \text{ ev/pb}^{-1}$ circa 40000 ev
- $\delta BR/BR \sim 2\%$ (in accordo con PDG)

$$BR(K_L \rightarrow \pi^0 \pi^0) / BR(K_L \rightarrow \pi^0 \pi^0 \pi^0)$$

- $\sim 70 \text{ ev/pb}^{-1}$ circa 30000 ev
- $\delta R/R \sim 2\%$

Necessaria una statistica $\times 10$ per avere un errore minore di 10^{-3} su $\operatorname{Re}(\varepsilon'/\varepsilon)$.

Correzioni radiative

Generatori MC per:

$K^0 e 3\gamma$, $K^0 \mu 3\gamma$, $\pi^+ \pi^- \gamma$

$K^\pm e 2\gamma$, $K^\pm \mu 2\gamma$, $\pi^\pm \pi^0 \gamma$

$K^\pm e 3\gamma$, $K^\pm \mu 3\gamma$

Ad esempio $\pi^+ \pi^- \gamma$

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

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

Importanza ad esempio per V_{US}

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

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

