~~CP~~ at DAΦNE,

The Frascati Φ Factory,

with KLOE

A. Calcaterra

Physics

- ~~CP~~ measurements ($K^0, K^{\pm}$)
- √ • ~~CPT~~ studies
- √ • Tests of chiral theories
- √ • "Rare" kaon decays
- √ • Hadron Spectroscopy
- √ • Total σ measurements

The DAΦNE storage rings

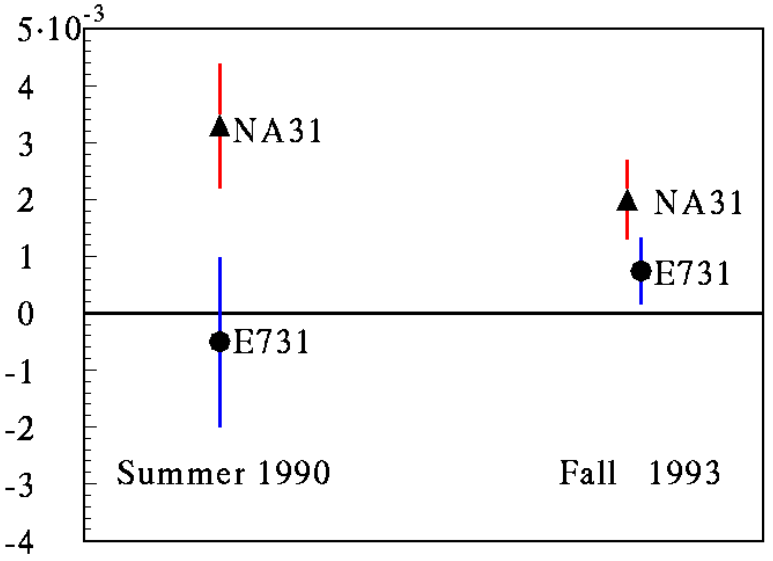
- √ • Requirements
- √ • The Frascati design

√ topics **not** covered in this talk

The KLOE detector

- Control of systematics
- Charged tracking
- Calorimetry
- Results from prototypes

A look at the data



E731: Phys. Rev. Lett.70(1993)1199,1203
NA31: Phys. Lett. B317(1993)233

Both collaborations have used the method of Double Ratio (DB):

$$\frac{N(K_L \to 2\pi^{\pm}) / N(K_S \to 2\pi^{\pm})}{N(K_L \to 2\pi^{0}) / N(K_S \to 2\pi^{0})} = 1 + 6 \cdot \Re(\varepsilon'/\varepsilon)$$

to give measurements of $\Re(\varepsilon'/\varepsilon)$ that are closer to each other than in 1990

Spelling out numbers

E731: $\Re(\varepsilon'/\varepsilon) = (0.74 \pm 0.59) \cdot 10^{-3}$

NA31: $\Re(\varepsilon'/\varepsilon) = (2.0 \pm 0.7) \cdot 10^{-3}$

The goal for DAΦNE:

$\delta(\Re(\varepsilon'/\varepsilon)) \rightarrow 3 \cdot 10^{-4}$ "fast"

$\rightarrow 10^{-4}$ "final"

DAΦNE **is** a $K^0_L K^0_S$ factory!

$$\frac{\delta\ DB.R.}{DB.R.} = \sqrt{\left(\frac{\Delta N(K_L \rightarrow \pi^+\pi^-)}{N(K_L \rightarrow \pi^+\pi^-)}\right)^2 + \left(\frac{\Delta N(K_L \rightarrow \pi^0\pi^0)}{N(K_L \rightarrow \pi^0\pi^0)}\right)^2}$$

$$\cong \sqrt{\frac{3}{2} \cdot \frac{1}{N(K_L \rightarrow 2\pi^0)}}$$

So, how many events do we need?

The DAΦNE goals

The DAΦNE first goal above implies a "fast" generation and analysis of ~$5 \cdot 10^5$ $K_L \rightarrow \pi^0\pi^0$ events. For the "final" goal more than $5 \cdot 10^6$ such events will have to be dealt with. Now:

- The expected turn-on luminosity of DAΦNE is of ~10^{32} cm^{-2} s^{-1}
- The e^+e^- cross section at the Φ peak is of ~4 μb

Taking also into account all relevant B.R.'s, this means that we expect to treat ~several *billions* of events in one year of data taking:

A very uncommon effort in HEP !

The DAΦNE Storage rings

- Goal: $5 \cdot 10^9$ Φ mesons in the first year

$$\mathcal{L}_{min} = 10^{32}\ cm^{-2}s^{-1}$$

$$\mathcal{L}^{VEPP\text{-}2M} = 5 \cdot 10^{30}$$

- $\mathcal{L} = const. \cdot \dfrac{\xi_x \cdot \xi_y \cdot \varepsilon \cdot f \cdot (1+\kappa)}{\beta_y^*}$

High $\mathcal{L}$ needs: f↑ ξ↑ β↓ ε↑

"Phenomenological" limit

A "difficult" machine:
Large aperture
Low $\mathcal{L}$ lifetime

A conservative design

- Moderate Luminosity single-beam design

- High collision frequency

A small footprint machine is a good idea, but one must confront the decrease in event rate due to a small detector.

A long, multibunch machine with two rings seems to be the most promising idea.

Avoid parasiting crossings (if necessary) with crabbing cavities.

Some DAΦNE numbers

Design $\mathcal{L}$ ($cm^{-2}s^{-1}$)	$1.3 \rightarrow 5 \cdot 10^{32}$
Design $\mathcal{L}$/bunch ($cm^{-2}s^{-1}$)	0.043
Bunches / beam	$30 \rightarrow 120$
Particles / bunch	$9 \cdot 10^{10}$
Circumference (m)	97.7
Rings	2
Interaction Regions	2
Crossing type	Horiz.angle
Crossing half angle (mr)	$10 \rightarrow 15$
Total current τ (min)	230
Beam-Beam τ (min)	1500
Horizontal β at IP (cm)	450
Vertical β at IP (cm)	4.5
Horiz. beam size (mm)	2
Vert. beam size (μm)	20
RMS bunch length (mm)	30
Radiation loss/turn (keV)	9.3
Horiz.emittance (mm·mr)	1
Tune shift parameter ξ	0.04
Mom. compaction α	0.05

~~CP~~ at a Φ-factory

Due to the **coherent** production of $K_L K_S$, several tools, other than the Double Ratio, are available at a Φ factory, that are **not** at a hadron machine:

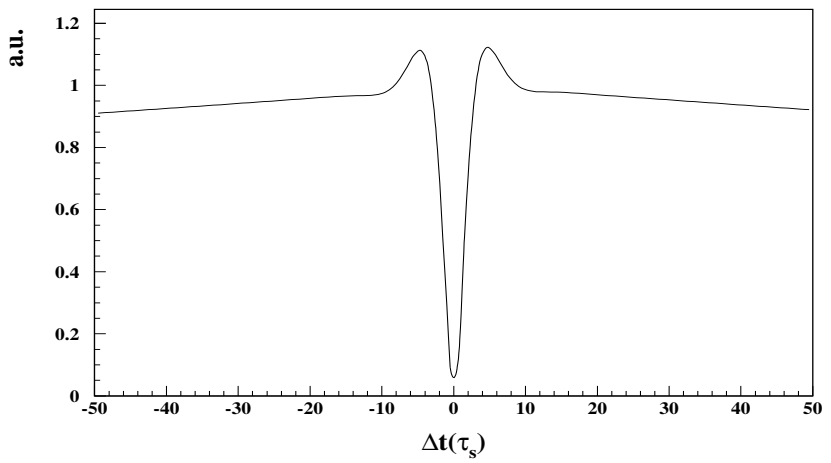
- Some integrated ratios of different channels can be measured:

$$\frac{N(4\pi^{\pm})}{N(4\pi^{0})} \cdot \left[\frac{BR(K_S \to 2\pi^{0})}{BR(K_S \to 2\pi^{\pm})}\right]^2 = 1 + 6\Re(\varepsilon'/\varepsilon)$$

$$\frac{N(4\pi^{\pm})}{N(2\pi^{\pm},2\pi^{0})} \cdot \frac{BR(2\pi^{\pm}) \cdot BR(2\pi^{0})}{\left[BR(K_S \to 2\pi^{\pm})\right]^2} = 1 + 3\Re(\varepsilon'/\varepsilon)$$

- Asymmetry in decay paths:

1. Take all events $\Phi \rightarrow \pi^+\pi^-\pi^0\pi^0$
2. Define $\Delta d = d_{+-} - d_{00}$
3. Plot Δd in units of the K_S lifetime:



- $\Re(\varepsilon'/\varepsilon) \propto I(\Delta d) - I(-\Delta d)$ out of the interference region

The shape of the depression at $\Delta d=0$ gives information on $\Im(\varepsilon'/\varepsilon)$

~~CP~~ in $K^{\pm}$ decays

- No mass matrix mixing: **a direct measurement of ε′ is possible**

- Theoretical calculations are more uncertain than for K_S's

  The most favorite channels (no ΔI=1/2 rule) are:

- "τ" decay mode: $K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$
- "τ′" decay mode: $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$

What can be measured?

1.Rate differences:

$$\delta_\tau = \frac{\Gamma(\tau^+) - \Gamma(\tau^-)}{\Gamma(\tau^+) + \Gamma(\tau^-)} \quad , \delta_{\tau'}$$

$$R = \frac{\Gamma(\tau^+) / \Gamma(\tau^-)}{\Gamma(\tau'^+) / \Gamma(\tau'^-)}$$

expected at the level of $10^{-5} \div 10^{-4}$ .....***hard!***

2.$K \to 3\pi$ Dalitz plot slopes. Theoretical expectations for

$$g(\tau^+) - g(\tau^-) \,/\, g(\tau^+) + g(\tau^-)$$

ranged once[1] as high as 10^{-3}...maybe a 3σ signal is within reach?

[1]A.A.Bel'kov et al., Phys.Lett.B232(1989)118, using first NA31 results

Enter Systematics...

The cleanest way to select events for

$$\frac{N(K_L \to +-) / N(K_S \to +-)}{N(K_L \to 00) / N(K_S \to 00)}$$

is to use tags:

K_S tag: K_{l3} , $K_L \to \pi^+\pi^-\pi^0$

$\varepsilon_{tag} \cong 78\ \%$, tagged $K_S \cong 4 \cdot 10^8$

K_L tag: $K_S \to \pi^+\pi^-$ and $\pi^0\pi^0$

$\varepsilon_{tag} \cong$ 66% if only $\pi^+\pi^-$
100% if both

Precise reconstruction of neutral decay vertices is **imperative**

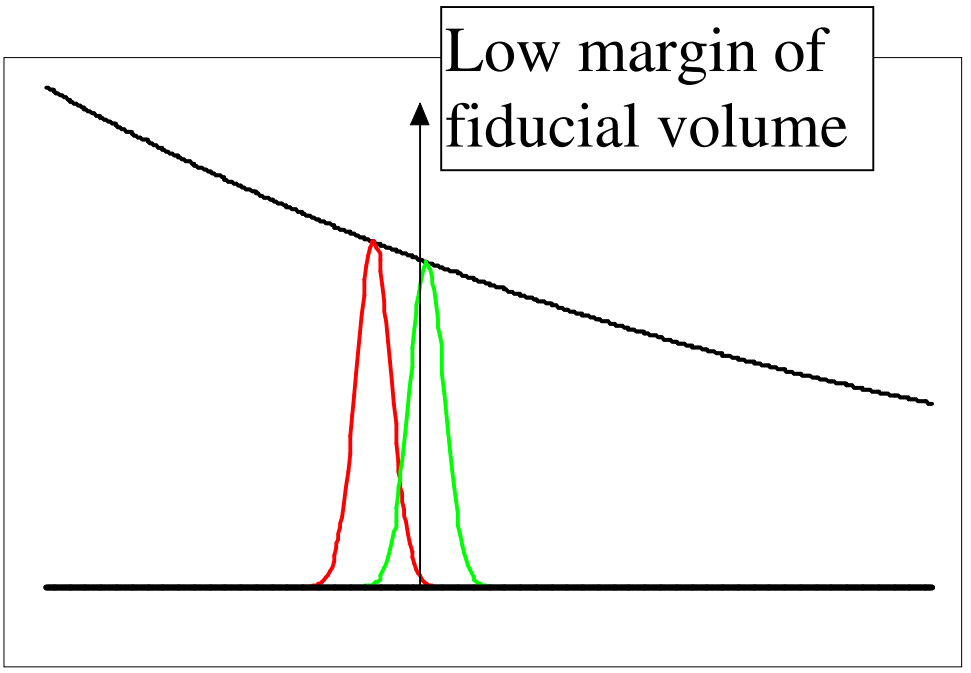
In the Double Ratio above, tagging efficiencies cancel completely, but not the others:

1. Geometric acceptances are not the same: the σ's in vertex recostruction will differ for $K_L \rightarrow \pi^+\pi^-$ or $\pi^0\pi^0$, affecting event counts in any given fiducial volume.
2. Detection and reconstruction efficiencies also differ.
3. Background subtraction is hard, particularly for K_L decays.

Nevertheless:

σ_{syst} must be kept down at the 2-3·10^{-5} level

Smearing losses



$$N_{meas} = N_{true} - N(in \rightarrow out) + N(out \rightarrow in)$$

Vertices ~2σ away from a boundary of the fid.volume are found with same σ and ε, but the underlying distribution is **not a constant**, so:

N(out→in) **syst. >** N(in→out)

The above bias is proportional to the derivative of the (exponential) distribution function, to the detection / reconstruction efficiency and to the σ^2 of the resolution function.

The counting biases will be different for decays $K_L \to \pi^+\pi^-$ and $\pi^0\pi^0$, so one must fight each one separately:

For K_S: (λ=6mm)

r(fid.volume) = 6 cm

σ_r < 1cm is enough

For K_L: (λ=3.5m)

20cm < r_{FV} < 150cm

$\delta N/N \leq 10^{-5} \Rightarrow \sigma \leq$ a few mm

Detection efficiencies

- Easier/less critical for K_S

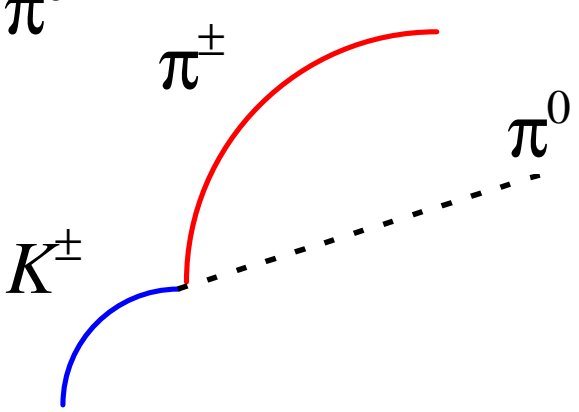
- Two methods are available for K_L:

  1) for both charged and neutral decays, calibrate the distribution of fitted vertices with:

  $$dN/dr = \exp(-r/\lambda_L)$$

  and fix the point at r=0 to be equal to the K_S det.efficiency

  2) for π^0 efficiency, use $K^\pm \rightarrow \pi^\pm\pi^0$



Background subtraction

$$N_{good} = N_{tot} - N_{bkg}$$

$$\Delta N_{good} = \sqrt{N_{tot} + (\Delta N_{bkg})^2}$$

$$\Delta N_{bkg.} \leq 0.5 \cdot \Delta N_{stat}$$

So if one knows the background to a relative precision α,

$$\alpha \cdot N_{bkg} = \Delta N_{bkg} \leq \sqrt{N_{tot}/2}$$

$$\Downarrow$$

$$\text{Re jection} \leq \frac{\text{BR(signal)}}{\text{BR(bckg)}} \cdot \frac{1}{2\alpha\sqrt{\text{N}_{\text{tot}}}}$$

Background subtraction

Signal	*Background*	*Relative BR*	*Rejection*
$K_L \to \pi^0\pi^0$	$K_L \to \pi^0\ \pi^0\ \pi^0$	**240**	$\mathbf{1.2 \cdot 10^{-5}}$
$K_L \to \pi^+\pi^-$	$K_L \to \pi\mu\nu$	**135**	$\mathbf{1.6 \cdot 10^{-5}}$
$K_L \to \pi^+\pi^-$	$K_L \to \pi e\nu$	**190**	$\mathbf{1.1 \cdot 10^{-5}}$
$K_L \to \pi^+\pi$	$K_L \to \pi^+\ \pi^-\ \pi^0$	**60**	$\mathbf{5 \cdot 10^{-5}}$

(background knowledge assumed at 15% level)

- hermetic E.M. calorimeter coverage (1,4)
- Energy resolution $\leq 5\%/\sqrt{E_{GeV}}$ (1)
- Some Particle ID capability (2,3)
- High efficiency for low E photons to fight combinatorial bkgr. in (1)

Tracking needs

The KLOE D. C. must yield, in a big (λ_D of K_L = 350 cm) volume of R=2m and total length=3.3m, excellent efficiency and resolution:

$$\delta_{x,y} = \mathbf{200\ \mu m},\ \delta_z = \mathbf{2\ mm}$$
$$\delta_{Pt} = \mathbf{0.5\%} \cdot \mathbf{P_t}$$
$$\delta(\tan\theta) = \mathbf{5 \cdot 10^{-4}}$$
$$\delta(M_{\pi\pi}) = \mathbf{1\ MeV/c^2}$$

Even with:

- low momenta, particularly for π_s from CP conserving K_L decays
- decaying π_s ~30% of all tracks
- K_L vertices far from the beam line

many tracks ~ parallel to z-axis

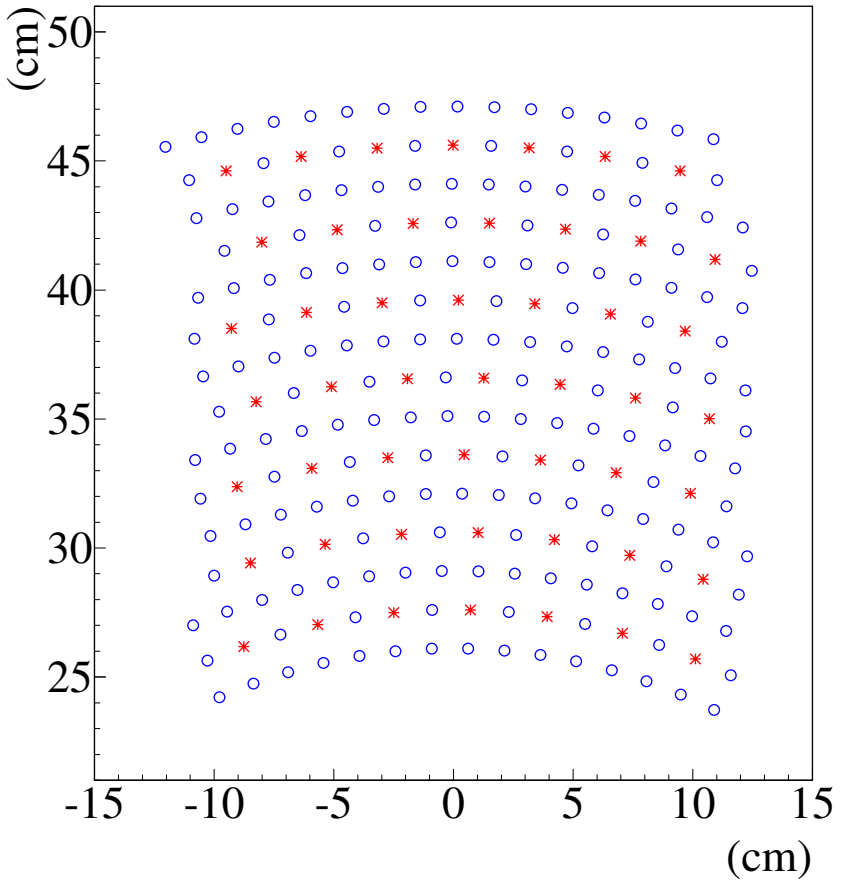
Results from test beam in a small 50-cells prototype

ns

distance from sense wire (cm)

- using the 90-10 He-C_4H_{10} mixture, the drift velocity is ***not saturated***

Typical cells in the KLOE d.c.



- Almost square, 3·3 cm^2
- 3:1 ratio of field:sense wires
- 90:10 He-C_4H_{10} gas mixture
- $v_{drift} \cong 20$ μm/ns, small Lorenz angle

Calorimetry needs

1. **Hermetic** coverage of a vast surface (~65 m^2) to reject most of $K_L \rightarrow 3\pi^0 \rightarrow 6\gamma$'s by photon counting.
2. Good E-resolution: $\mathbf{5\%/\sqrt{E_{GeV}}}$ for further rejection of $K_L \rightarrow 3\pi^0$.
3. Reconstruction of the neutral vertex $K_L \rightarrow 2\pi^0 \rightarrow 4\gamma$'s to an accuracy of **a few mm**.
4. Some PID capability for additional rejection of K_{l3} events

The choice is a Pb-SciFi sandwich, able to measure the TOF of photons with an accuracy of $\mathbf{\sim 50ps/\sqrt{E_{GeV}}}$. Knowing the K_L line of flight, the 4 photon TOFs will overconstrain the K_L vertex with the needed spatial accuracy.

Conclusions

- The performances of a He-operated drift chamber have been satisfactorily tested in small prototypes. A full scale D.C. has been built[1] in Lecce and successfully tested at CERN with final electronics: results should be available quite soon. The actual KLOE D.C. is under construction: wiring will start in a few weeks.

- Beam tests[2] of the first modules of the KLOE calorimeter have shown the expected energy resolution and timing properties. Construction of all modules is well under way.

[1] F.Grancagnolo in Proc. of the 7th Wien Wire Chamber Conference, Feb 1995
[2] A. Antonelli et al., NIM A351(1995)352.