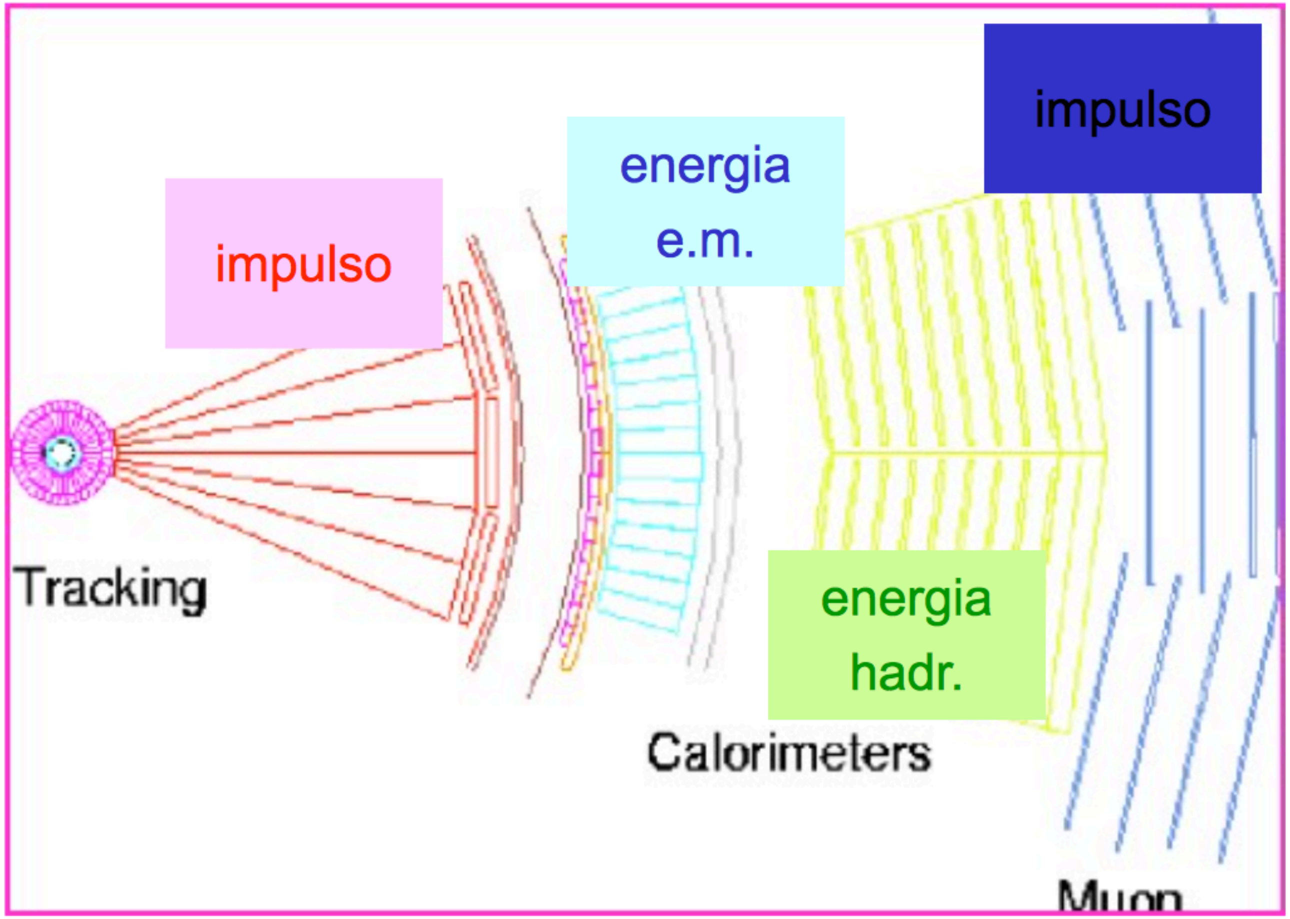
	p_c	E_{em}	E_h	p_μ
• $e^\pm$:	si	si	no	no;
• γ :	no	si	no	no;
• $\pi^\pm$:	si	mip	si	no;
• n :	no	mip	si	no;
• $\mu^\pm$:	si	mip	mip	si;
• ν :	no	no	no	no;

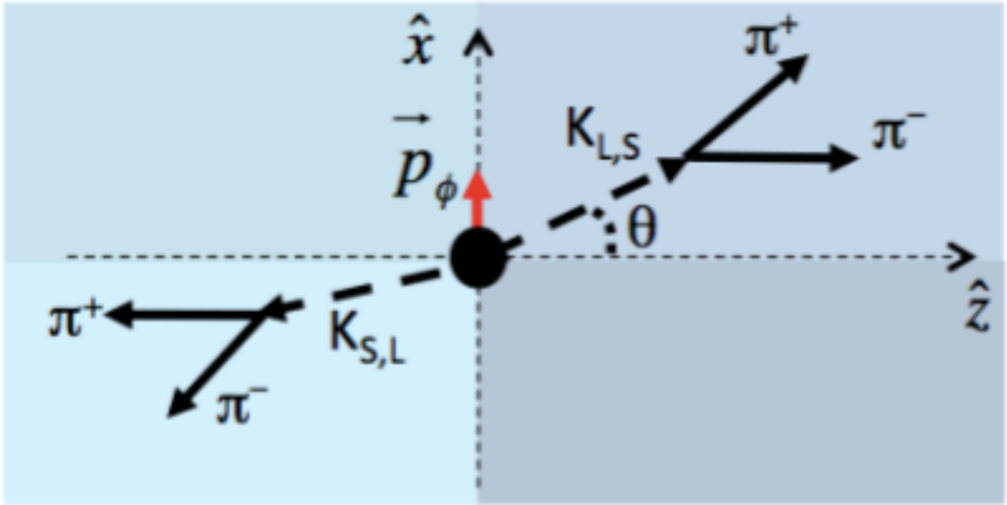
- ν da apparente sbilanciamento dell'evento (ermeticità).



KLOE - I

- e^+e^- collisions at $\sqrt{s} = 1.02$ GeV $= M_\phi$
- Low multiplicity events well suited for "exclusive" analyses.
- Particles to detect (momentum range 50 ÷ 500 MeV):
  - Pions
  - Photons
  - Electrons
  - Muons
  - Charged kaons from $\phi \rightarrow K^+K^-$ (momentum = 130 MeV)
  - Neutral Kaons (see later)
- At these low momenta, there are not "hadronic showers", a pion is similar to a muon. On the other hand, electrons and photons are "e.m. showers".
- Strategy:
  - A tracking chamber in magnetic field to measure charged particles momenta (with some charged kaon discrimination through dE/dx measurement);
  - A calorimeter on its back to measure photons, and to help in the discrimination between pions, muons and electrons through time-of-flight;

KLOE - II



Specific KLOE case determines the detector overall dimensions:

$$\phi \to K_0\overline{K}_0 \to K_S K_L$$

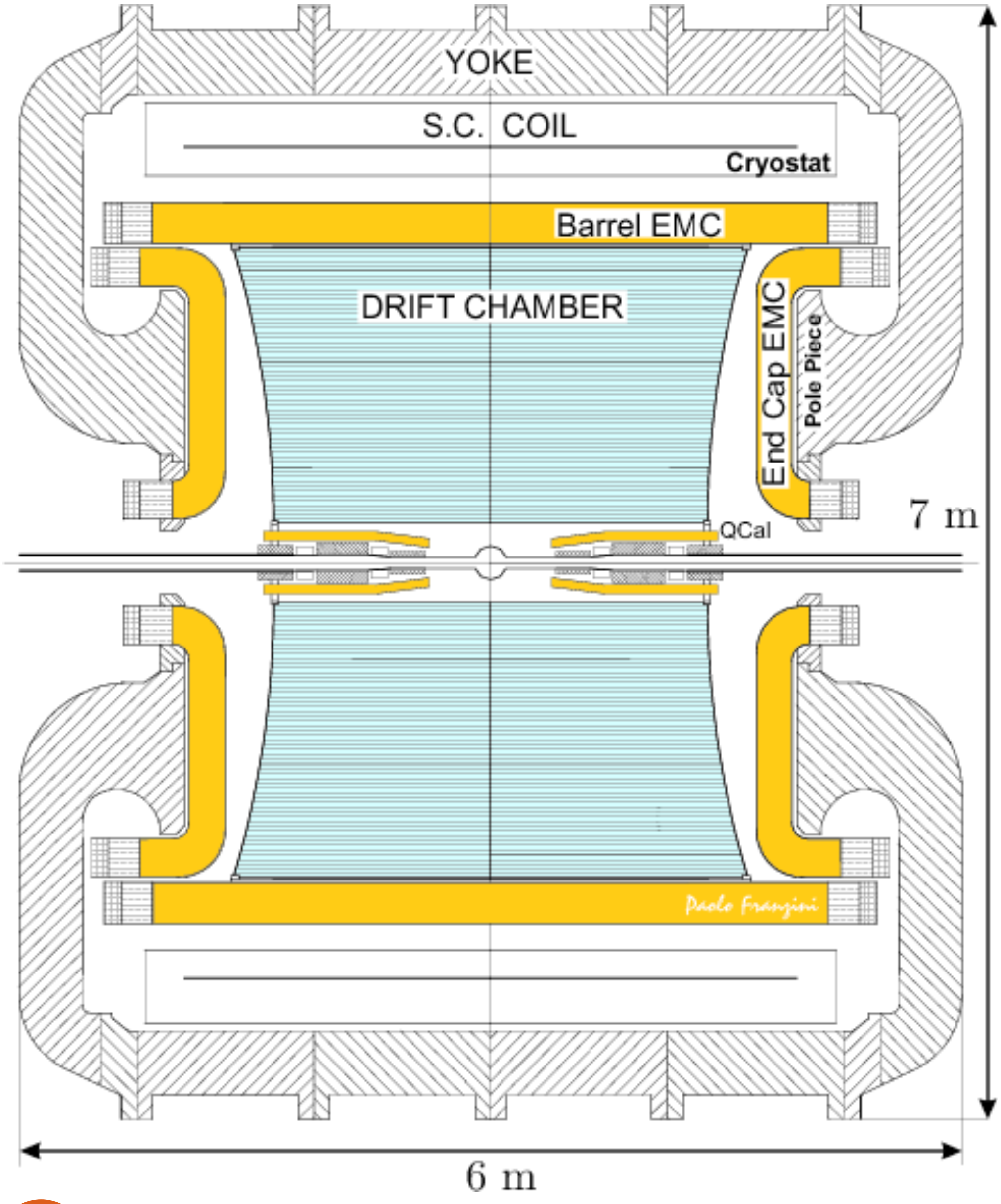
$p(K_0) = 110.6$ MeV/c

$\tau(K_S) = 0.8954 \times 10^{-10}$ s ➔ $l(K_S) = \tau(K_S)\ \beta\gamma\ c = 6$ mm

$\tau(K_L) = 5.116 \times 10^{-8}$ s ➔ $l(K_L) = \tau(K_L)\ \beta\gamma\ c = 3.4$ m

A>50% (acceptance on K_L) if R>2.3 m

$$A = \int_0^R f(r)dr = \frac{1}{l(K_L)}\int_0^R e^{-r/l(K_L)}dr = 1 - e^{-R/l(K_L)}$$



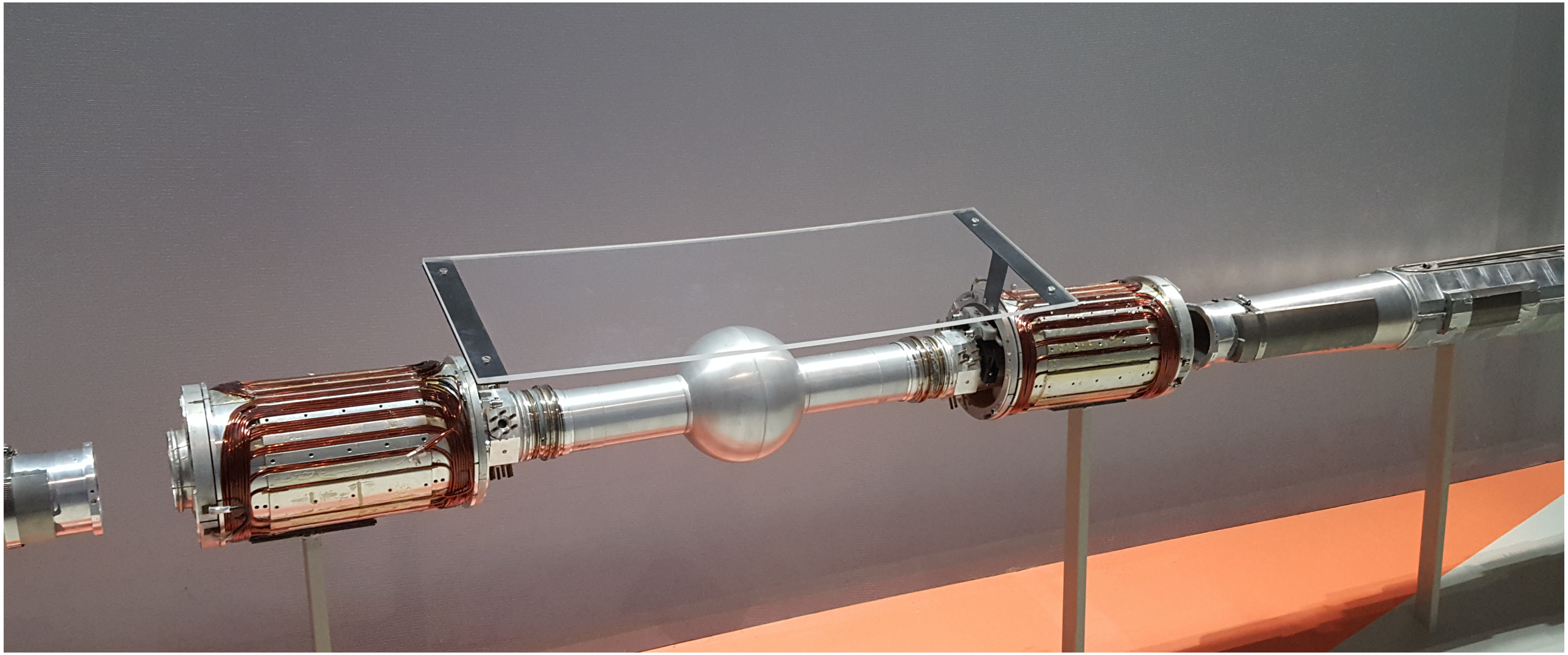
SuperConducting Coil + Return Yoke
- $B \approx 0.5\,T$
- typical curvature radii
- $R = p_T/0.3B = 33 \div 330$ cm

Drift chamber
- $\approx 10^4$ wires in stereo configuration
- momentum measurement down to
  - 50 MeV
- typical track: ≈ 30 hits with 200 μm
- space resolution each.

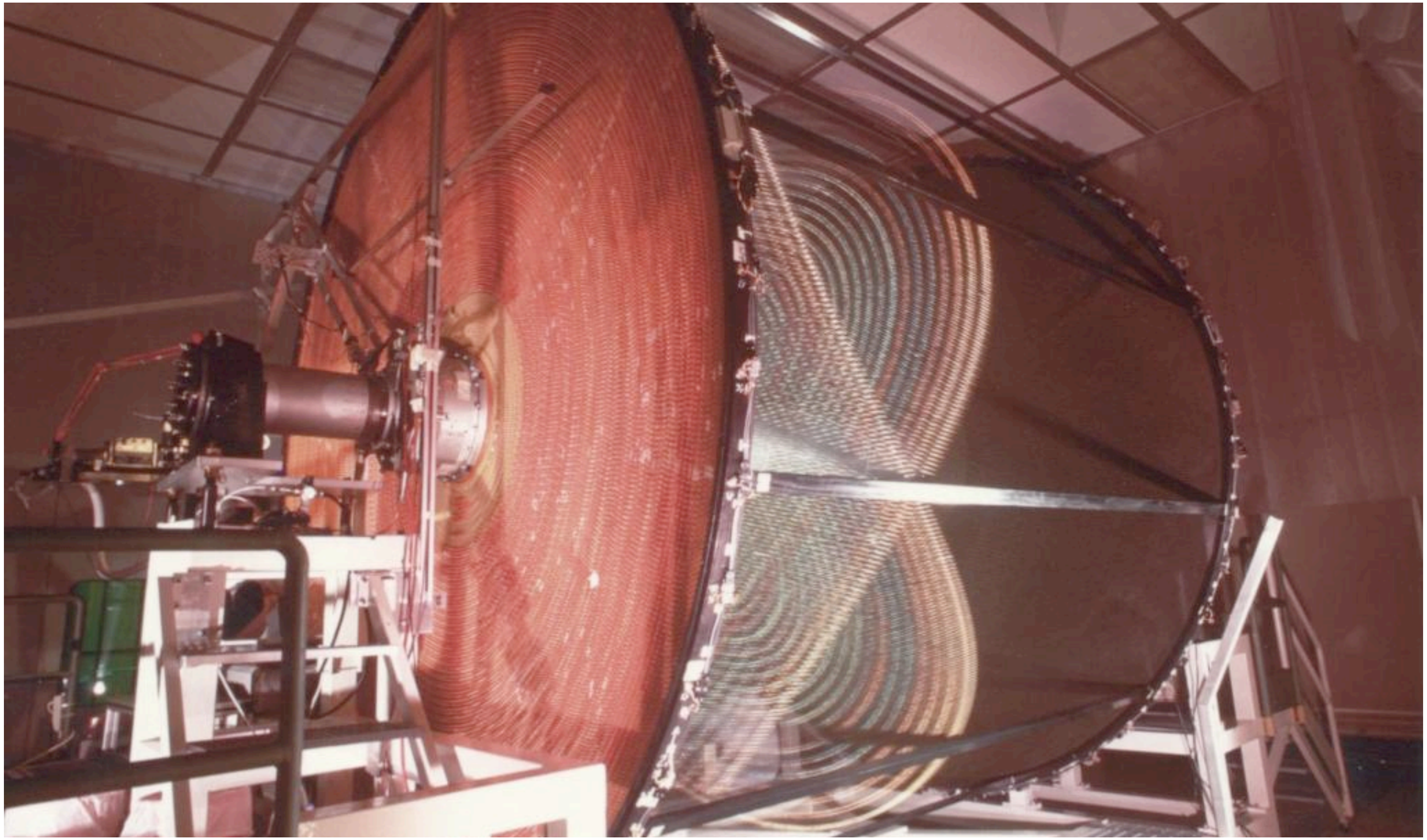
Calorimeter
- Lead-Scintillating fibers calorimeter
- Read-out through 4880 PMTs
- Energy resolution (record for
- a sampling calorimeter)

$$\frac{\sigma(p_T)}{p_T} \approx 0.4\%$$

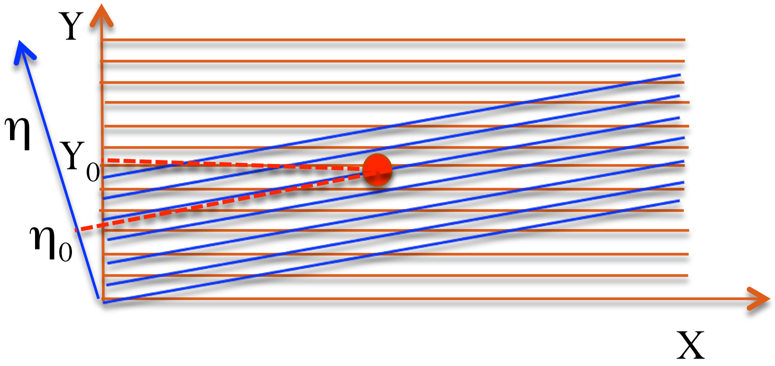
$$\frac{\sigma(E)}{E} \approx \frac{5.7\%}{\sqrt{E(GeV)}}$$



The KLOE drift chamber



Stereo wires



Measurement of two coordinates in the two views:

$$Y = Y_0$$
$$\eta = \eta_0$$

Each measurements is a line in the X-Y plane:

$$Y = Y_0$$
$$Y = \eta_0/\cos\theta + tg\theta\, X$$

Risolvo il sistema e ottengo ($\sin\theta \approx \theta$, $\cos\theta \approx 1$)

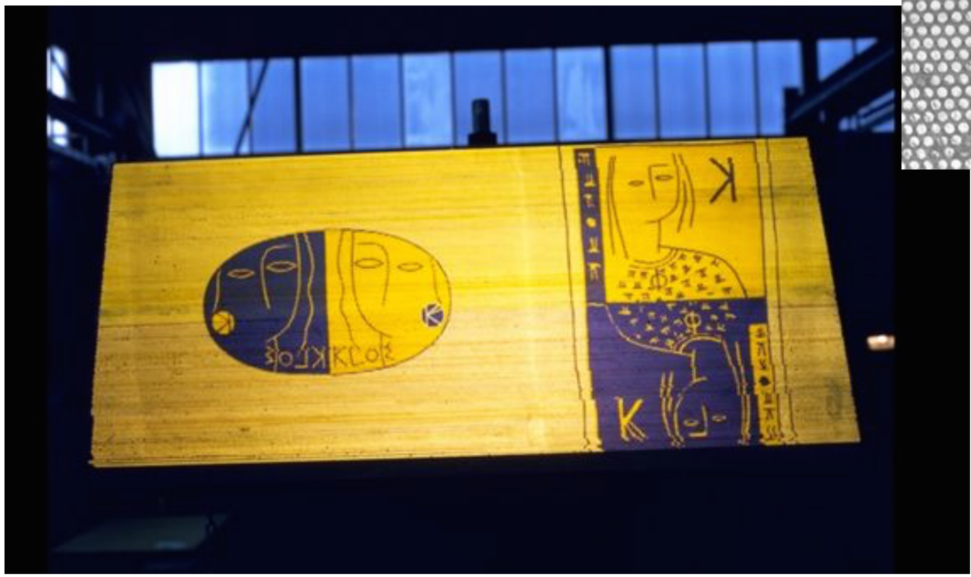
$$X = (Y_0\cos\theta - \eta_0)/\sin\theta \approx (Y_0 - \eta_0)/\theta$$

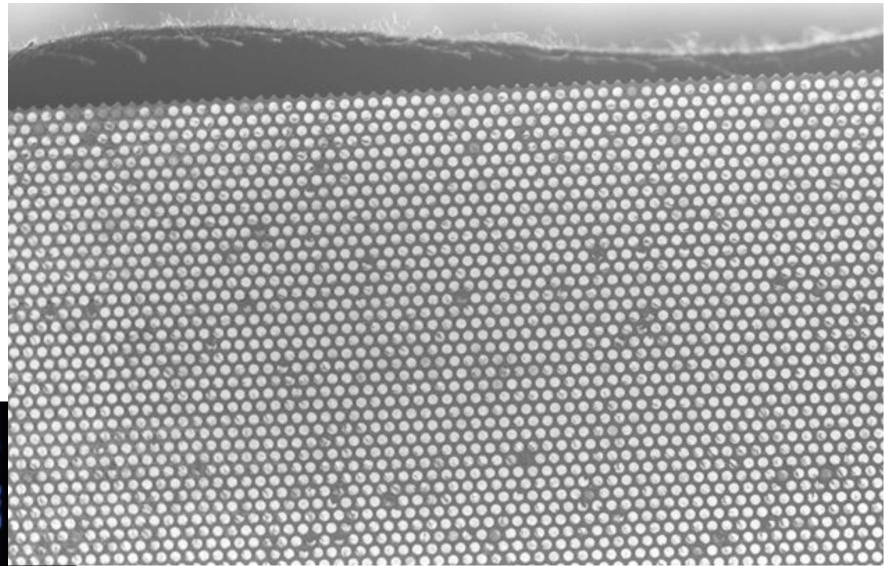
NB: given $\sigma(Y_0)$ and $\sigma(\eta_0)$

➔ $\sigma(X) = \sigma(Y_0)\sqrt{2}/\theta$

The KLOE calorimeter

The KLOE calorimeter





KLOE calorimeter: Time-of-flight

Time resolution for scintillators:

τ is the scintillator decay time;

N_{pe} is the number of photoelectrons/MeV

N is the total number of photoelectrons

$= N_{pe} \times E(\mathrm{MeV})$

tts = Transite Time Spread (PMT, guides,..)

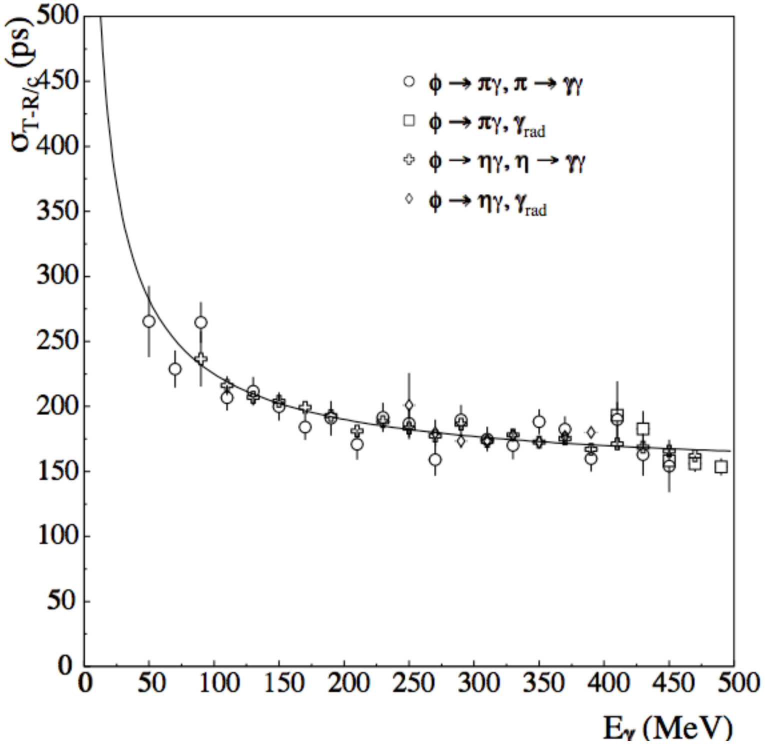
$$\sigma(t) = (\tau + tts)/\sqrt{N} \approx const/\sqrt{E}$$

In KLOE:

$\tau \approx 2$ ns

Npe ≈ 2/MeV

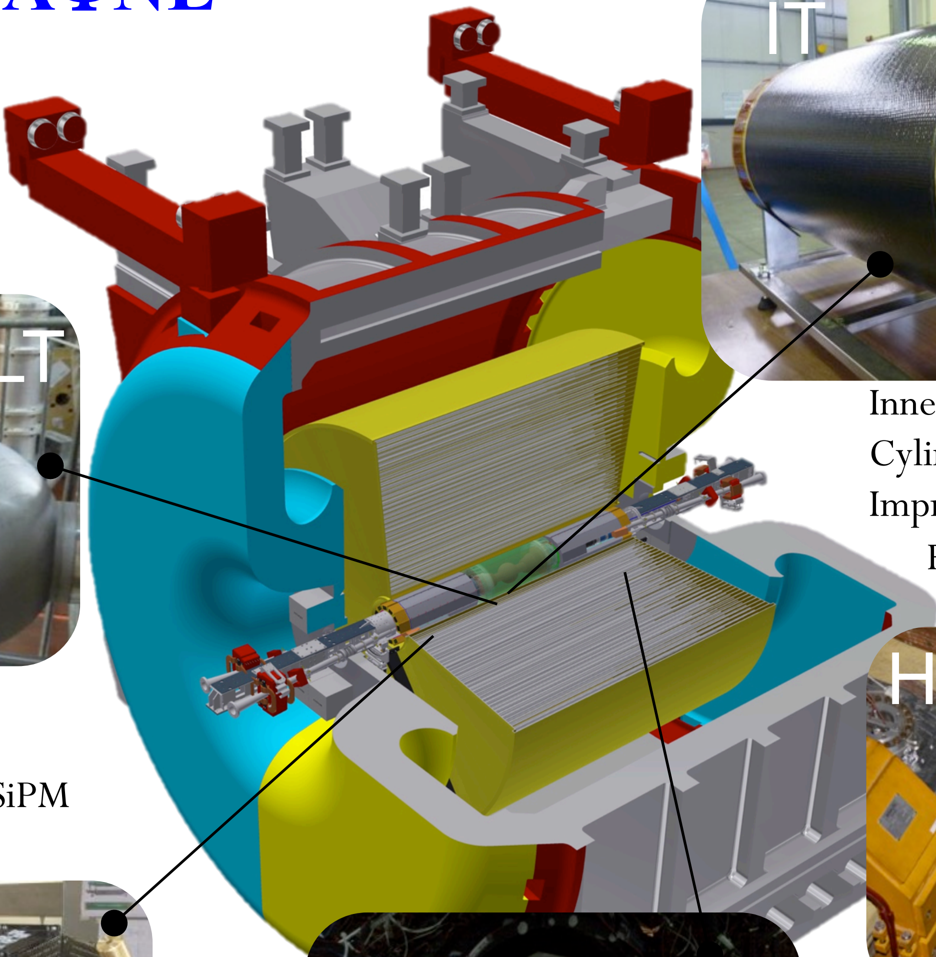
tts ≈ 0.3 ns



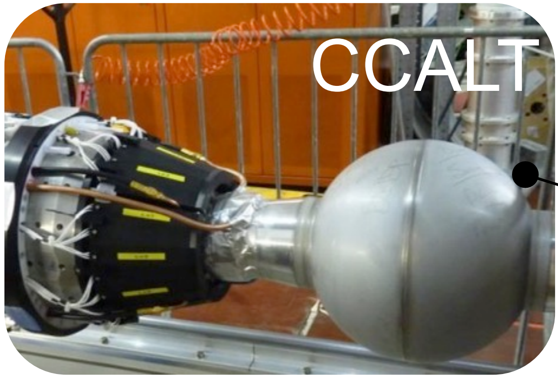
$$\sigma_t = 54 \text{ ps}/\sqrt{E \text{ (GeV)}} \oplus 140 \text{ ps}$$

Spread in the “start” time

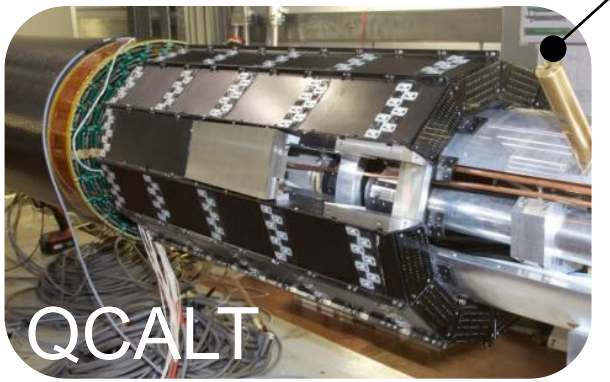
KLOE-2 at DAΦNE

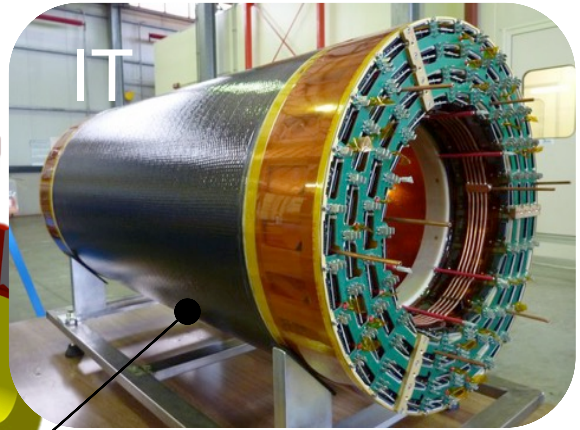


LYSO Crystal w SiPM
Low polar angle

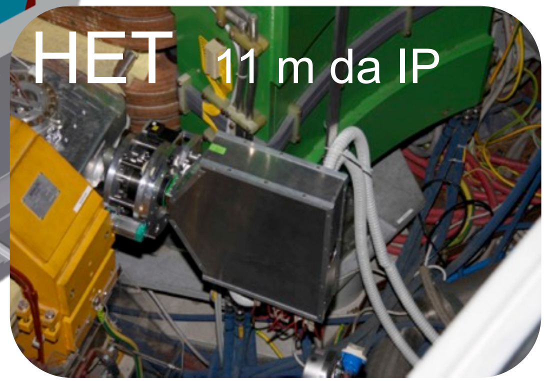


Tungsten / Scintillating Tiles w SiPM
Quadrupole Instrumentation



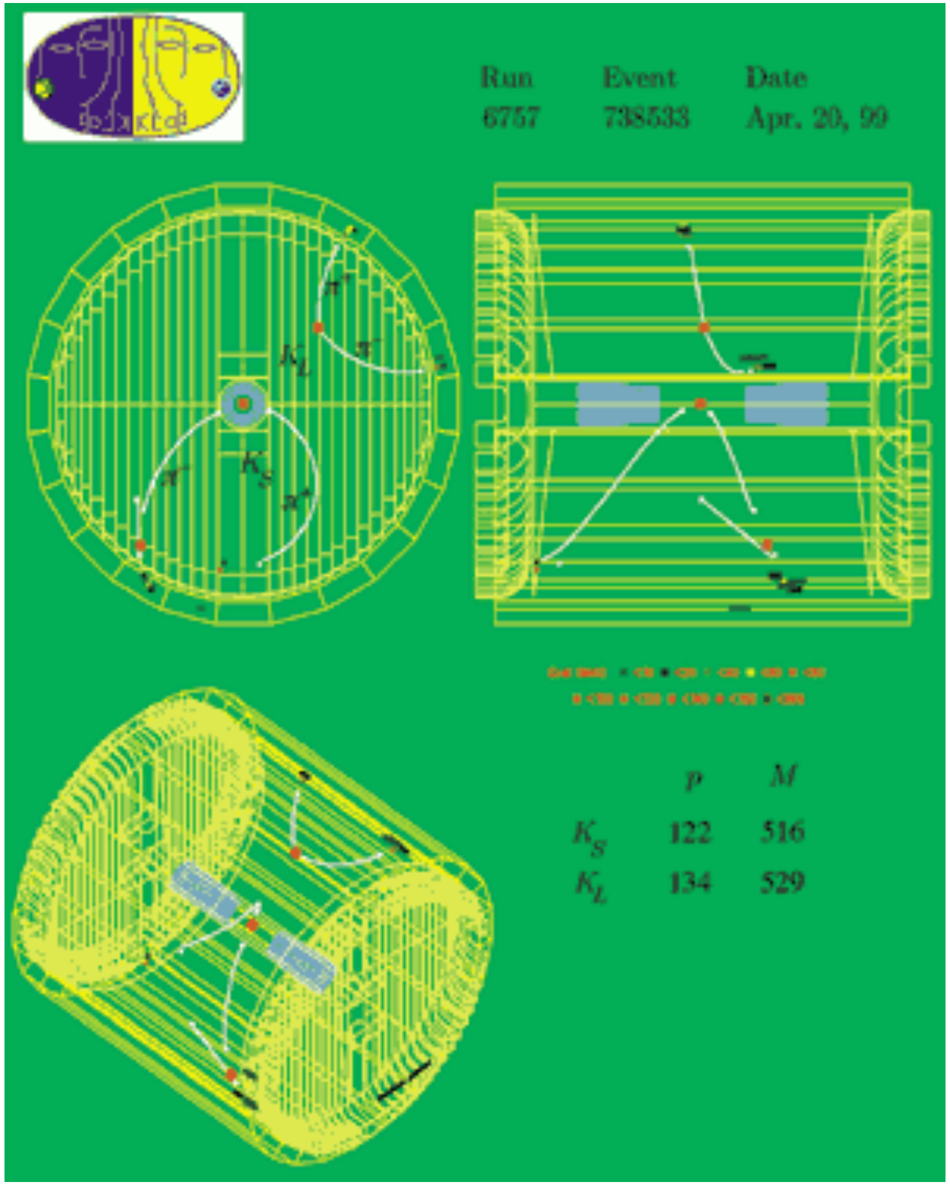


Inner Tracker – 4 layers of
Cylindrical GEM detectors
Improve track and vtx reconstr.
First CGEM in HEP expt.



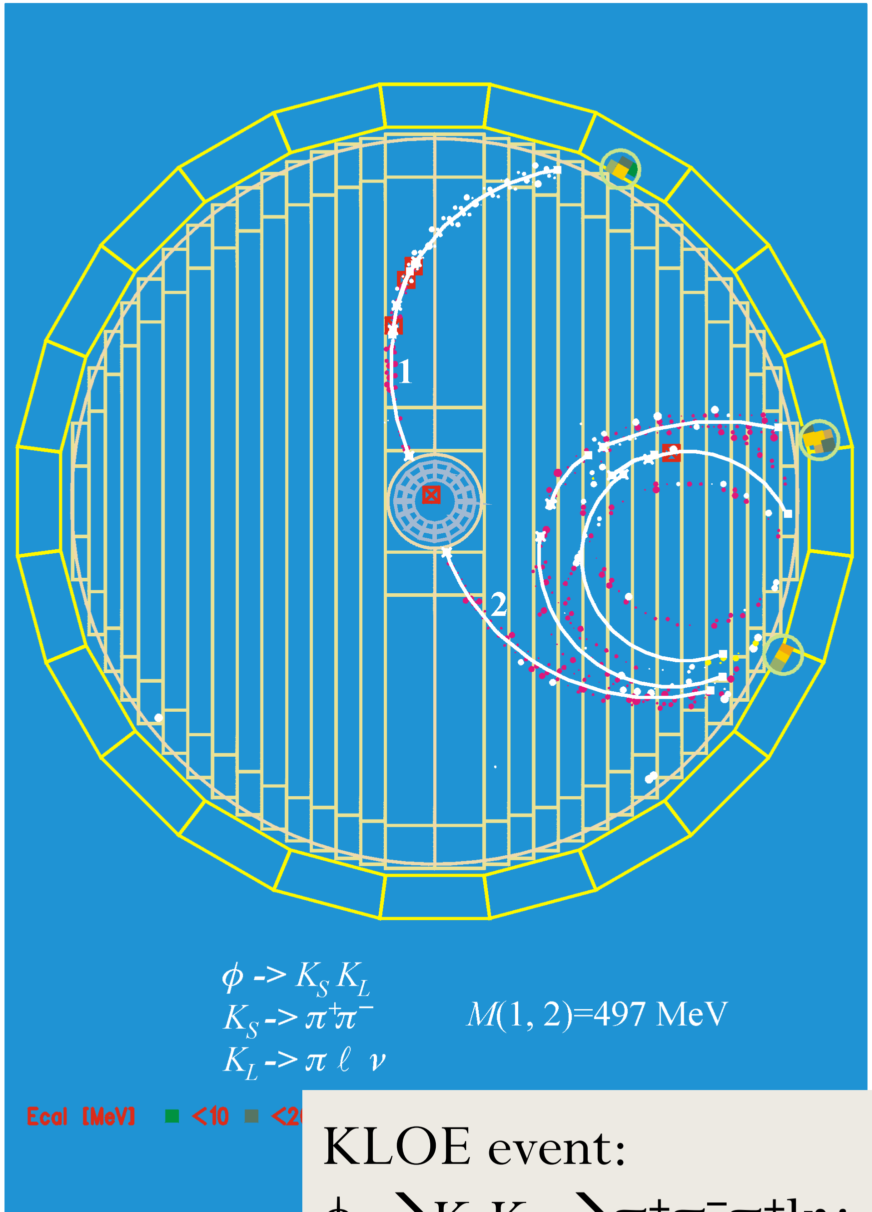
Scintillator hodoscope +PMTs

calorimeters LYSO+SiPMs at
~ 1 m from IP



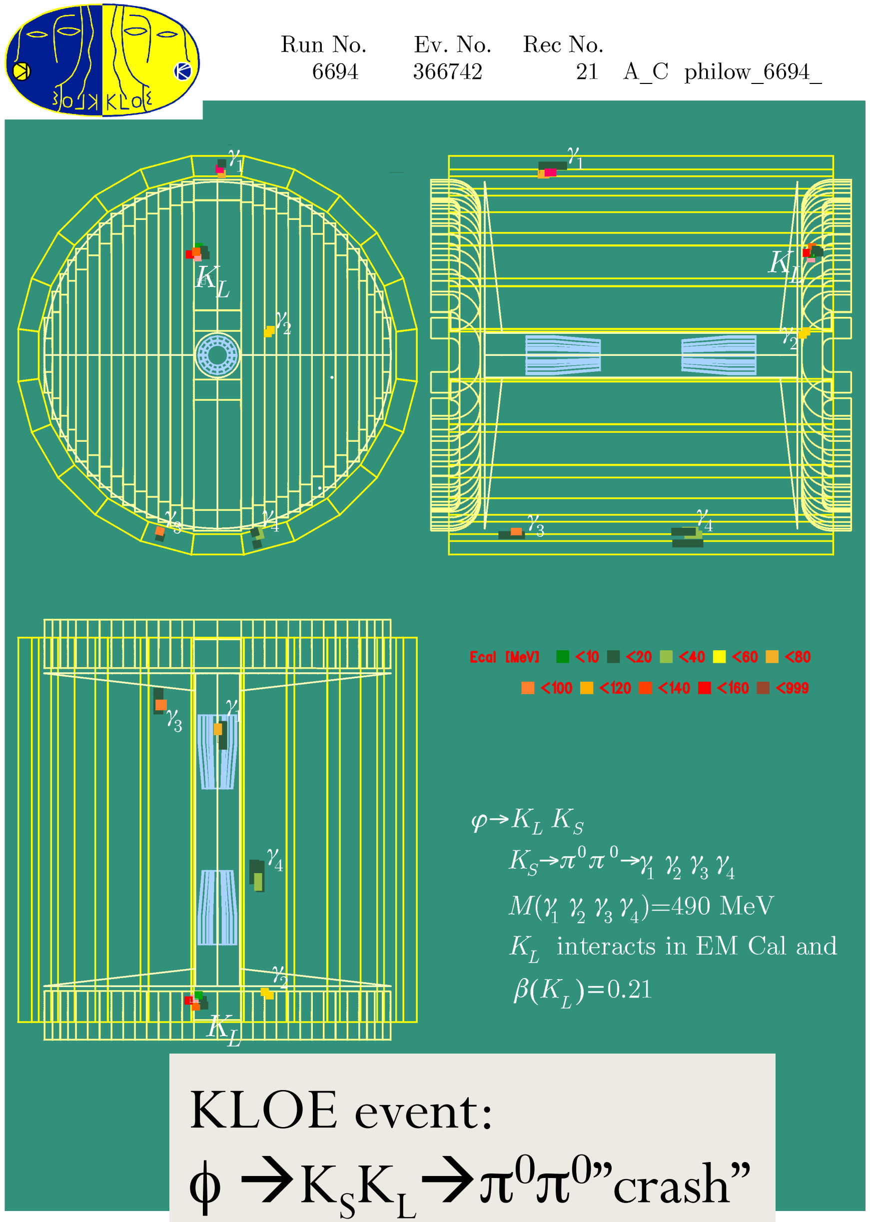
KLOE event:

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



KLOE event:

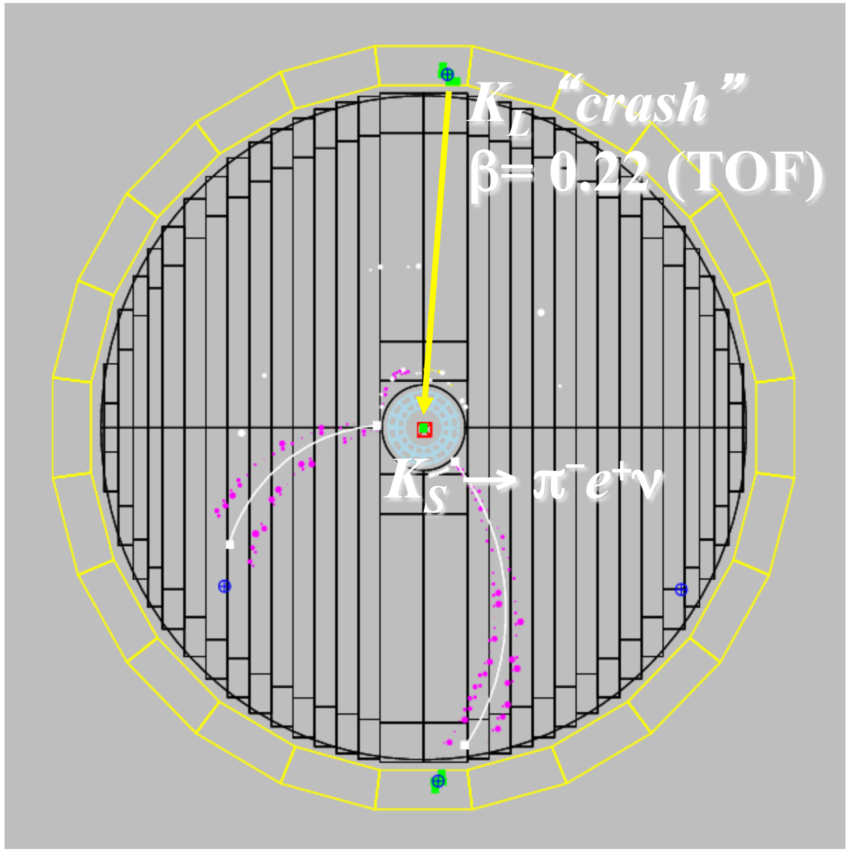
$\phi \rightarrow K_S K_L \rightarrow \pi^+\pi^-\pi^+ l^- \nu$

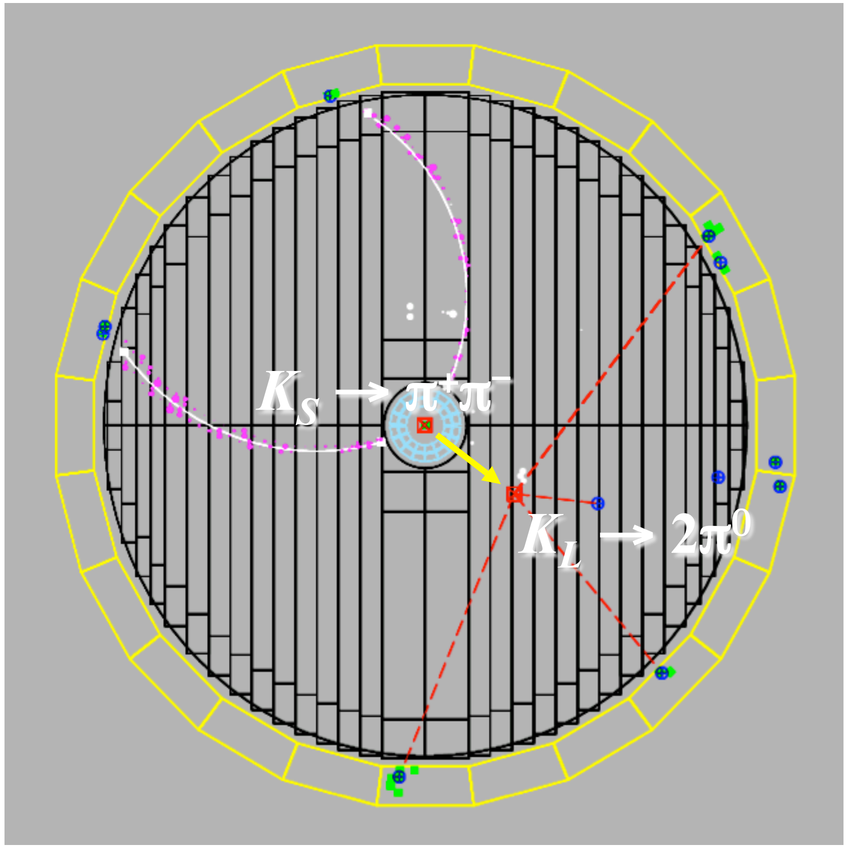


KLOE event:

$\phi \rightarrow K_S K_L \rightarrow \pi^0\pi^0$"crash"

K_S and K_L Tagging at KLOE





***K_S* tagged by *K_L* interaction in EmC**
Efficiency ~ 30% (largely geometrical)
K_S angular resolution: ~ 1° (0.3° in ϕ)
K_S momentum resolution: ~ 2 MeV

***K_L* tagged by *K_S* → $\pi^+\pi^-$ vertex at IP**
Efficiency ~ 70% (mainly geometrical)
K_L angular resolution: ~ 1°
K_L momentum resolution: ~ 2 MeV

Resolution of energy measurements through e.m. calorimetry

- In general the energy resolution of an e.m. calorimeter is given in terms of $\sigma(E)/E$.
- Main contributions:
  - $a/\sqrt{E}$ ➔ due to statistics: sampling fluctuations and/or number of photoelectrons fluctuations;
  - b/E ➔ tipically due to the fluctuations of a constant contribution to the energy (e.g. pedestal, electronic noise,…)
  - c ➔ constant term: due to systematics, calibration, containment.
- All three terms contribute. Normally c dominates at high energies, and a at low/intermediate energies. b is present only in specific cases.

Electromagnetic calorimetry

Table 31.8: Resolution of typical electromagnetic calorimeters. E is in GeV.

Technology (Experiment)	Depth	Energy resolution	Date
NaI(Tl) (Crystal Ball)	$20X_0$	$2.7\%/\mathrm{E}^{1/4}$	1983
$Bi_4Ge_3O_{12}$ (BGO) (L3)	$22X_0$	$2\%/\sqrt{E} \oplus 0.7\%$	1993
CsI (KTeV)	$27X_0$	$2\%/\sqrt{E} \oplus 0.45\%$	1996
CsI(Tl) (BaBar)	$16–18X_0$	$2.3\%/E^{1/4} \oplus 1.4\%$	1999
CsI(Tl) (BELLE)	$16X_0$	1.7% for $E_\gamma > 3.5$ GeV	1998
$PbWO_4$ (PWO) (CMS)	$25X_0$	$3\%/\sqrt{E} \oplus 0.5\% \oplus 0.2/E$	1997
Lead glass (OPAL)	$20.5X_0$	$5\%/\sqrt{E}$	1990
Liquid Kr (NA48)	$27X_0$	$3.2\%/\sqrt{E} \oplus 0.42\% \oplus 0.09/E$	1998
Scintillator/depleted U (ZEUS)	$20–30X_0$	$18\%/\sqrt{E}$	1988
Scintillator/Pb (CDF)	$18X_0$	$13.5\%/\sqrt{E}$	1988
Scintillator fiber/Pb spaghetti (KLOE)	$15X_0$	$5.7\%/\sqrt{E} \oplus 0.6\%$	1995
Liquid Ar/Pb (NA31)	$27X_0$	$7.5\%/\sqrt{E} \oplus 0.5\% \oplus 0.1/E$	1988
Liquid Ar/Pb (SLD)	$21X_0$	$8\%/\sqrt{E}$	1993
Liquid Ar/Pb (H1)	$20–30X_0$	$12\%/\sqrt{E} \oplus 1\%$	1998
Liquid Ar/depl. U (DØ)	$20.5X_0$	$16\%/\sqrt{E} \oplus 0.3\% \oplus 0.3/E$	1993
Liquid Ar/Pb accordion (ATLAS)	$25X_0$	$10\%/\sqrt{E} \oplus 0.4\% \oplus 0.3/E$	1996