Homework n.4 a.a. 2023-2024

INTRODUCTION:

A part of data collected by the KLOE experiment is provided, corresponding to a run (~1 hour of data taking) with an integrated luminosity of $\mathcal{L}$=200 nb^{-1} (download the file from e-learning, the data format is described below, in the last slide).

The data have been already filtered by the KLOE event classification algorithm as "neutral kaon stream" that mostly select events from the process:

$\phi \rightarrow K_S K_L$ with at least one of the two kaons decaying in the volume of the detector (~ 4m diameter).

Additional information:

$\sigma(e^+e^- \rightarrow \phi) \cong 3\ \mu b$; $BR(\phi \rightarrow K_S K_L) \cong 0.34$;

Assuming the ϕ meson produced at rest, the angular distribution of $K_S K_L$ pair produced is $dN/d\Omega \propto \sin^2(\theta)$.

HOMEWORK:

Apply a sequence of cuts to the data to identify the decay $K_S \to \pi^0\pi^0$:

- evaluate the number $N(K_S \to \pi^0\pi^0)$ of signal events after the sequence
- provide a table with the cut-flow: list each cut and the number of candidate events surviving after each cut.

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- provide a table with the cut-flow: list each cut and the number of candidate events surviving after each cut.

- evaluate the ratio $N(K_S \to \pi^+\pi^-)/N(K_S \to \pi^0\pi^0)$
  (at this stage ignore the evaluation of the efficiencies, that will be the subject of another exercise)

HINTS

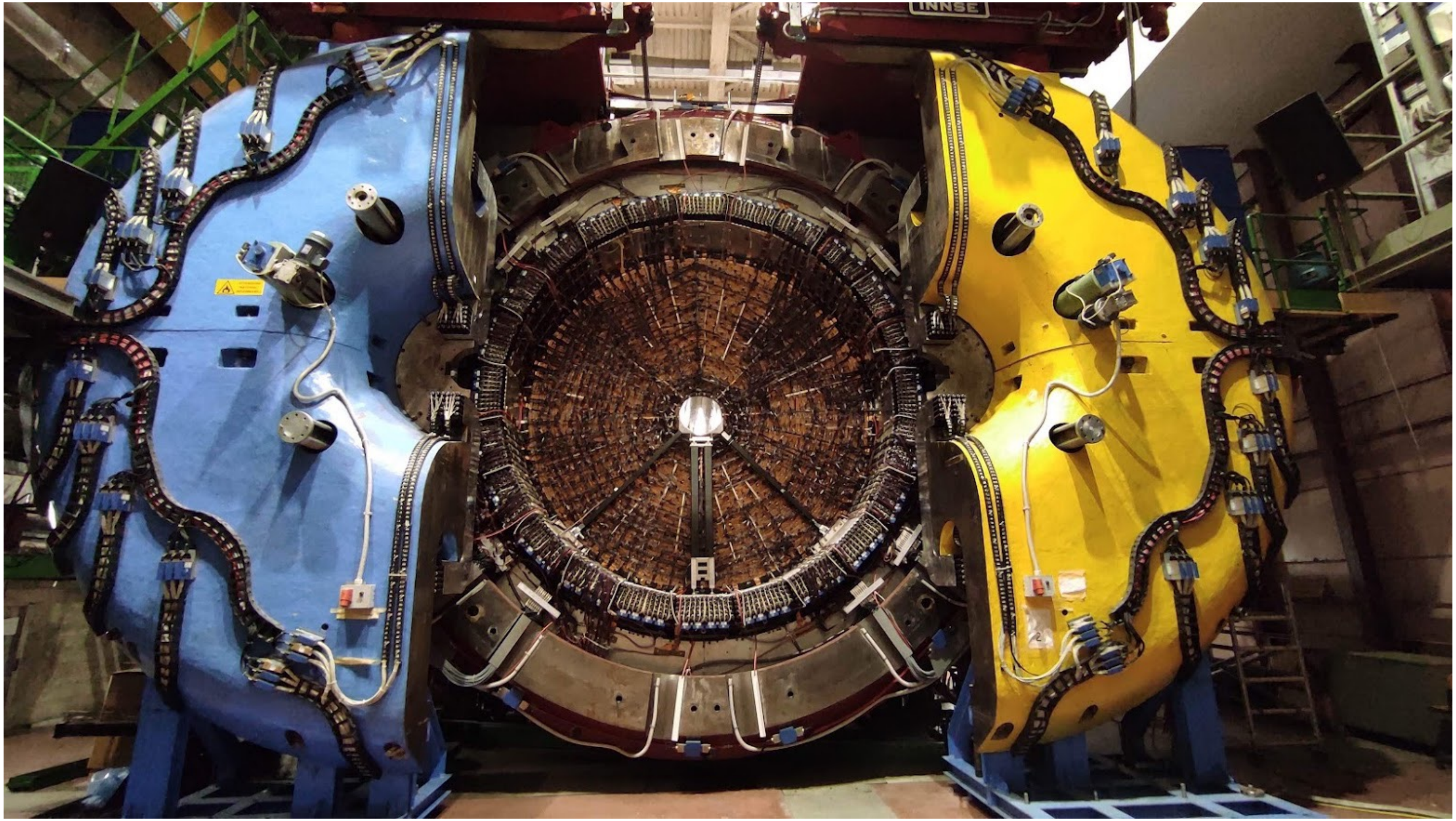
IN ADDITION TO THE SEQUENCE OF CUTS CHOSEN TO SELECT THE SIGNAL CONSIDER THE FOLLOWING SUGGESTIONS:

To reduce the background for the $K_S \to \pi^0\pi^0$ signal, consider only calorimeter clusters with energy 20 MeV< E_{cl}<300 MeV and polar angle θ> 21° .

For $K_S \to \pi^+\pi^-$ decays choose a fiducial volume (FV) around the interaction point (IP) (typically $|z(vtx)|<5$ cm ; $R_\perp(vtx)<4$ cm) such that its geometrical acceptance for the signal is ~100%, avoiding the background from e.g. regeneration on the beam pipe walls.

Identify a K_L interaction in the calorimeter ("KL-crash") and use it as a "K_S – tagging" . The detection of a K_L guarantees the presence on the other side of a K_S with given momentum and direction. To reduce background consider E_{cl}(KL-crash)>150 MeV and 2-body decay kinematics, e.g. $\vec{P}_L = \vec{P}_S - \vec{P}_\phi$.

KLOE detector opened in the assemply hall



KLOE detector closed and in postion at the DAFNE e^+e^- collider

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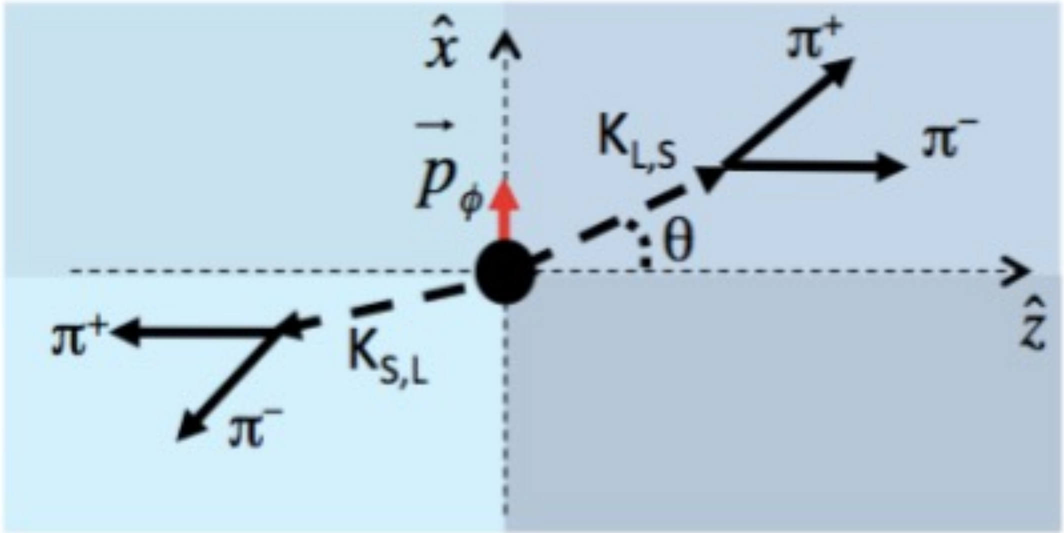
KLOE



view in the (x,z) plane
(the horizontal plane).

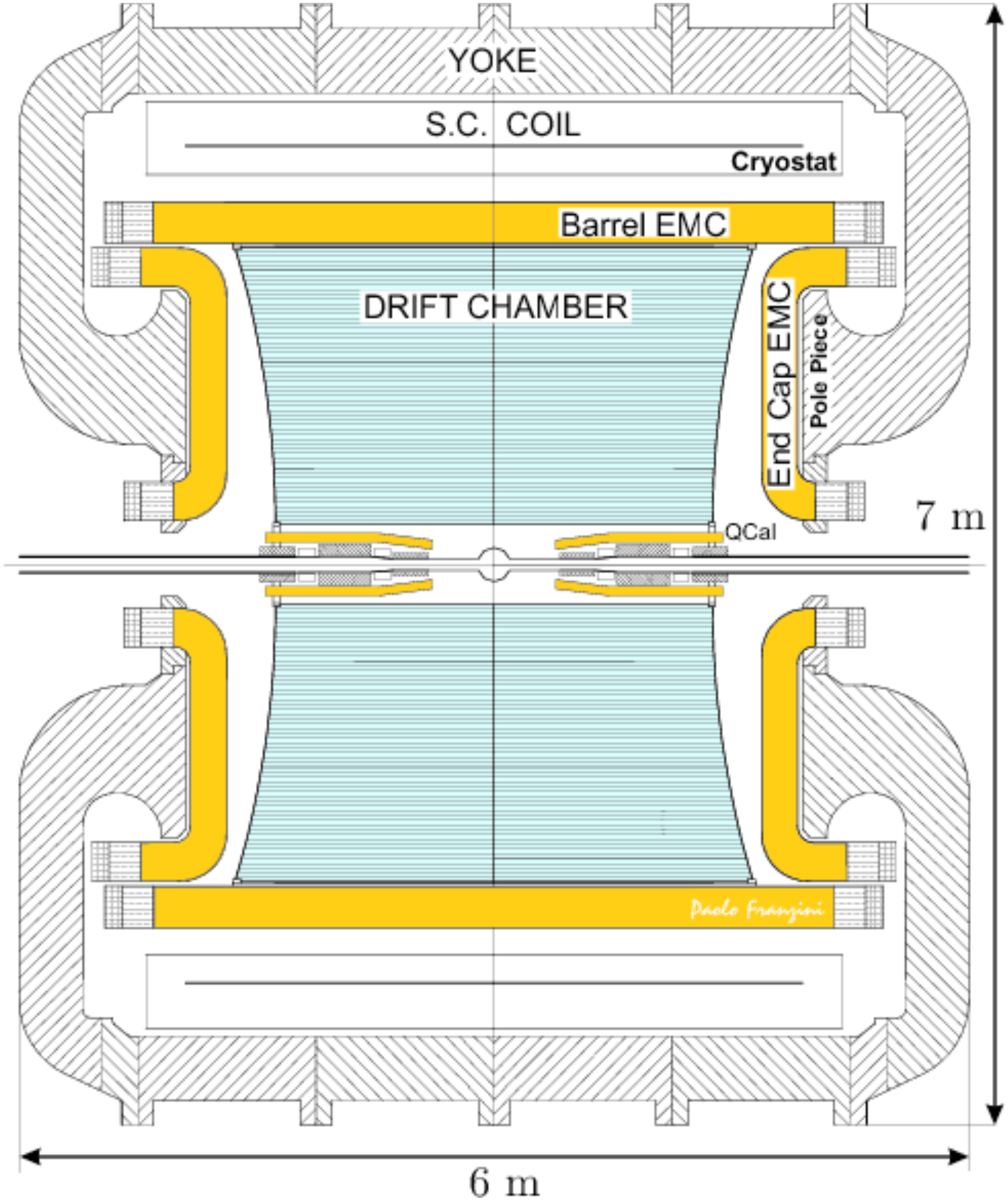
Specific KLOE case determines the detector overall dimensions:

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

$p(K_0) = 110.6$ 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



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: $\approx$ 30 hits with 200 μm space resolution each.

transverse momentum resolution:

$$\frac{\sigma(P_\perp)}{P_\perp} \approx 0.4\%$$

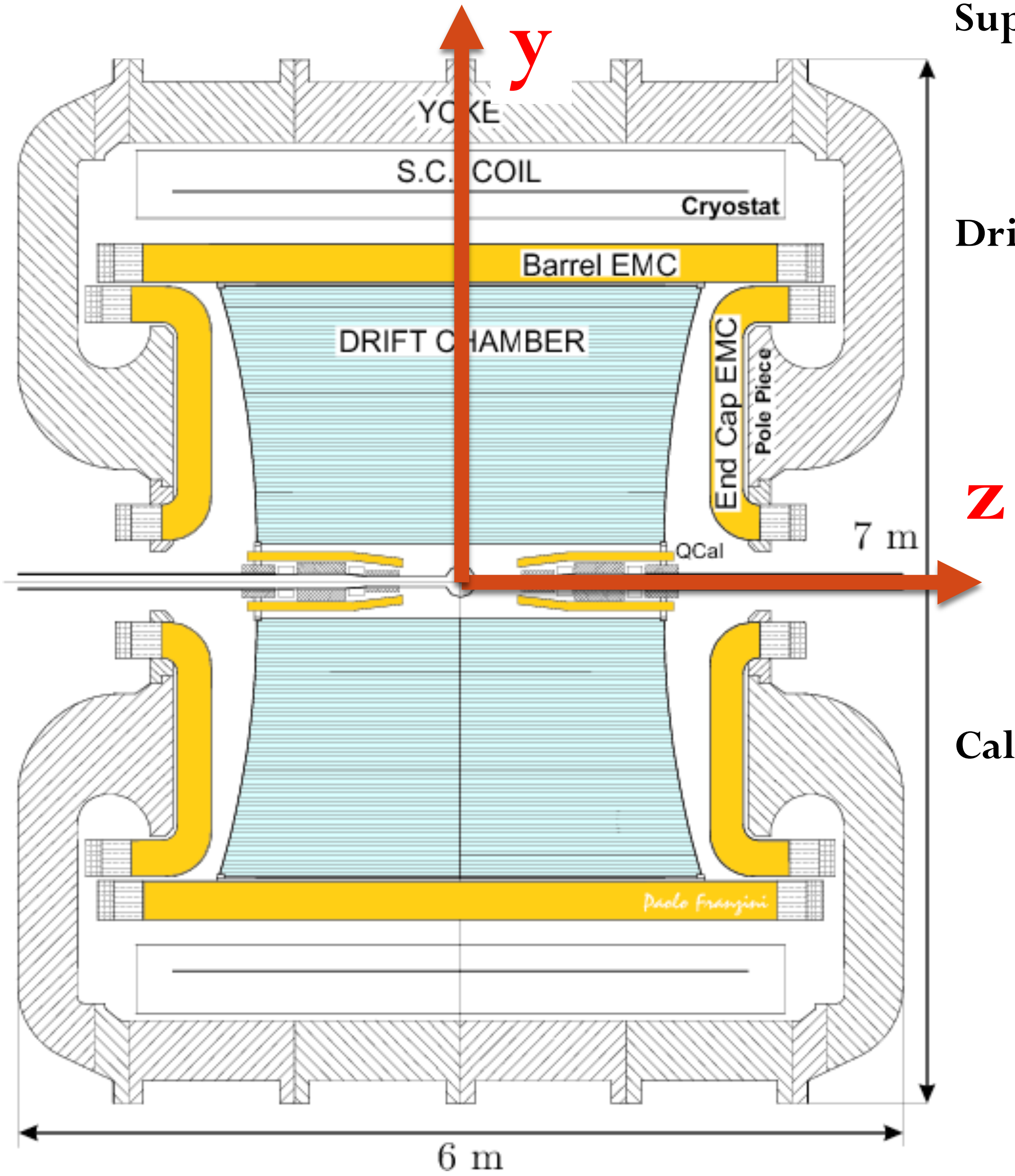
Calorimeter

Lead-Scintillating fibers calorimeter

Read-out through 4880 PMTs

Energy and time resolutions (record for a sampling calorimeter):

$$\frac{\sigma(E)}{E} \cong \frac{5.7\%}{\sqrt{E(GeV)}} \quad ; \quad \sigma(t) \cong \frac{54\,ps}{\sqrt{E(GeV)}} \oplus 100\,ps$$



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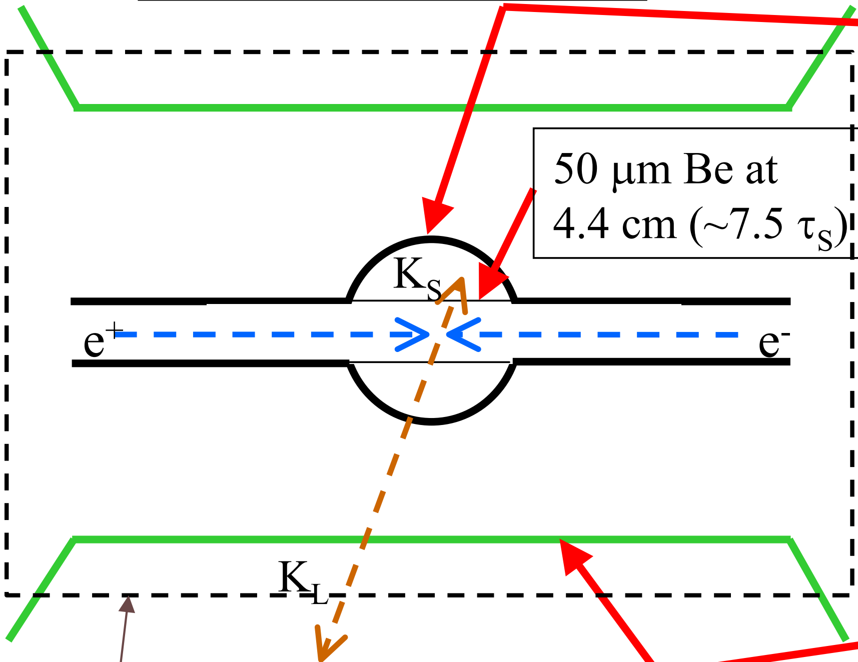
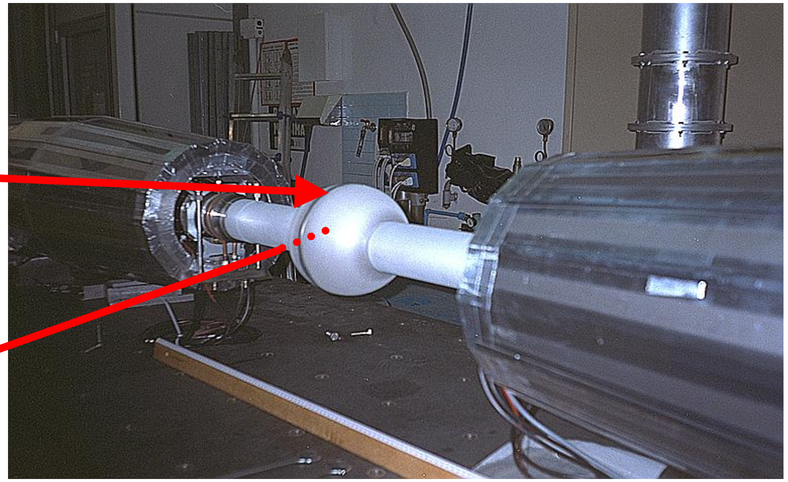
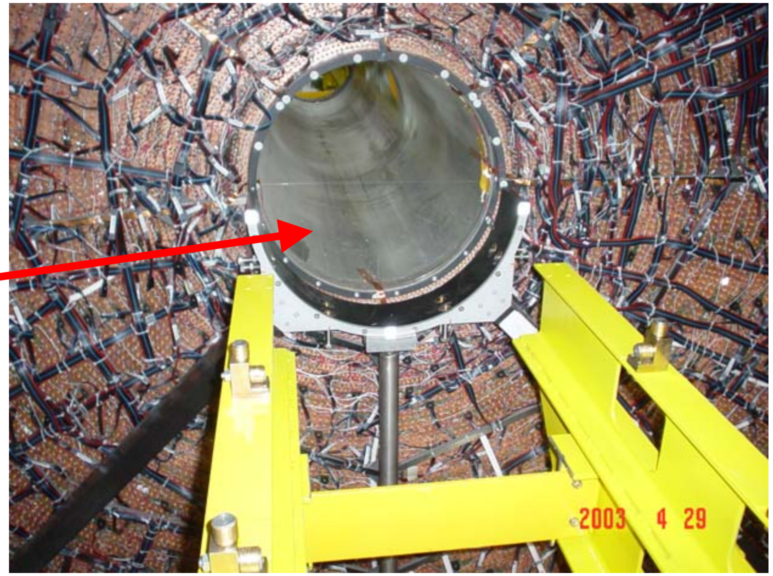
Beam pipe in KLOE

500 μm Be-Al 60-40%
at 10 cm (~17 τ_S) from IP

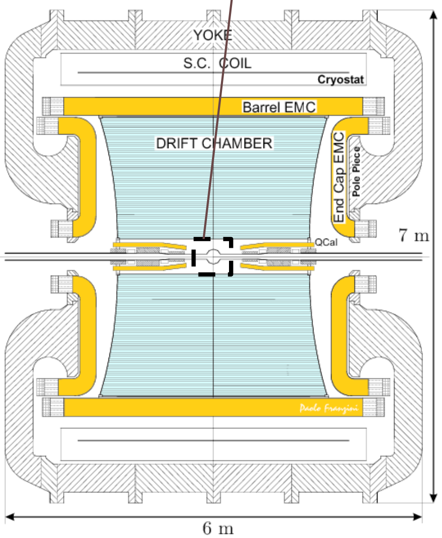


50 μm Be at
4.4 cm (~7.5 τ_S) from IP

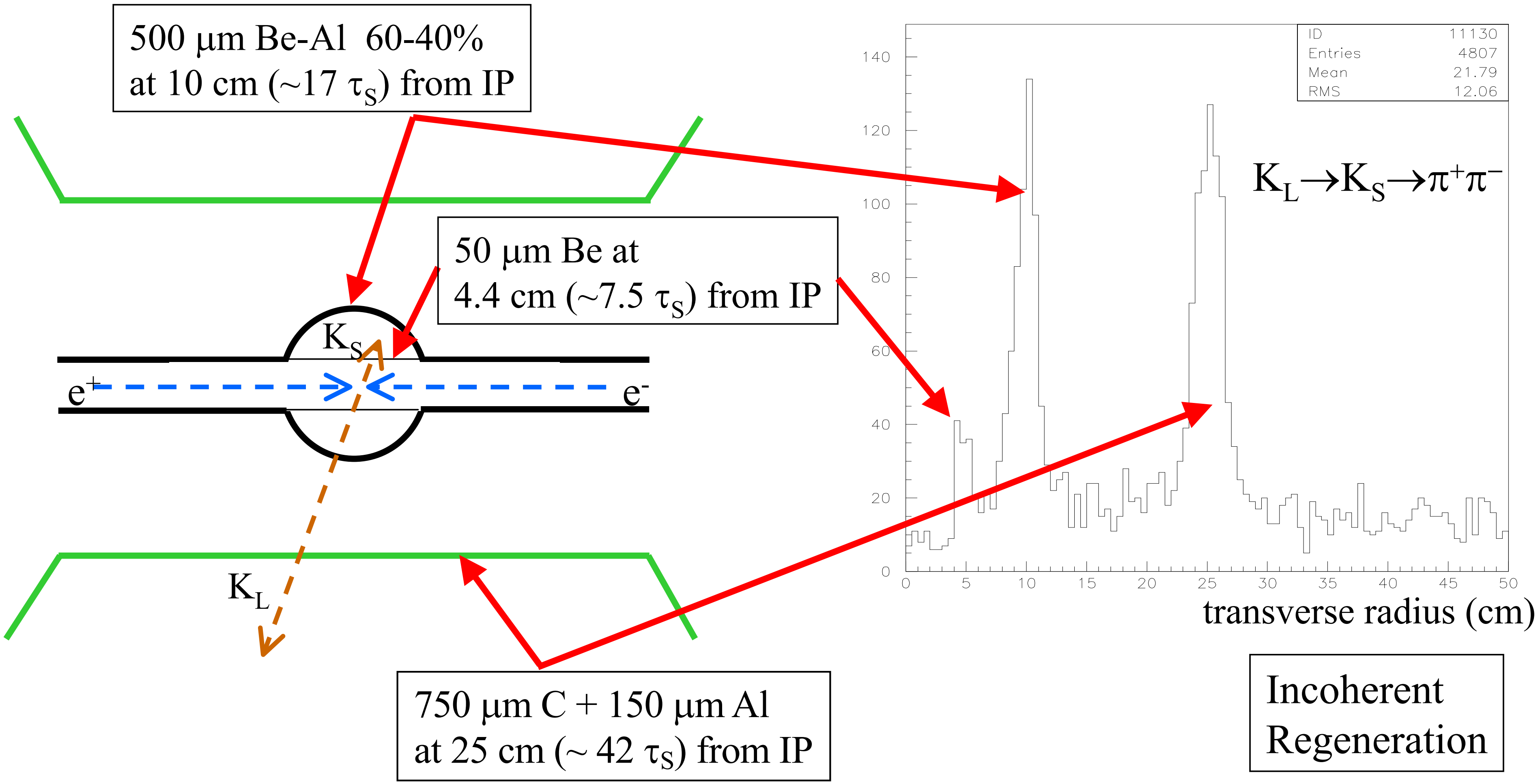




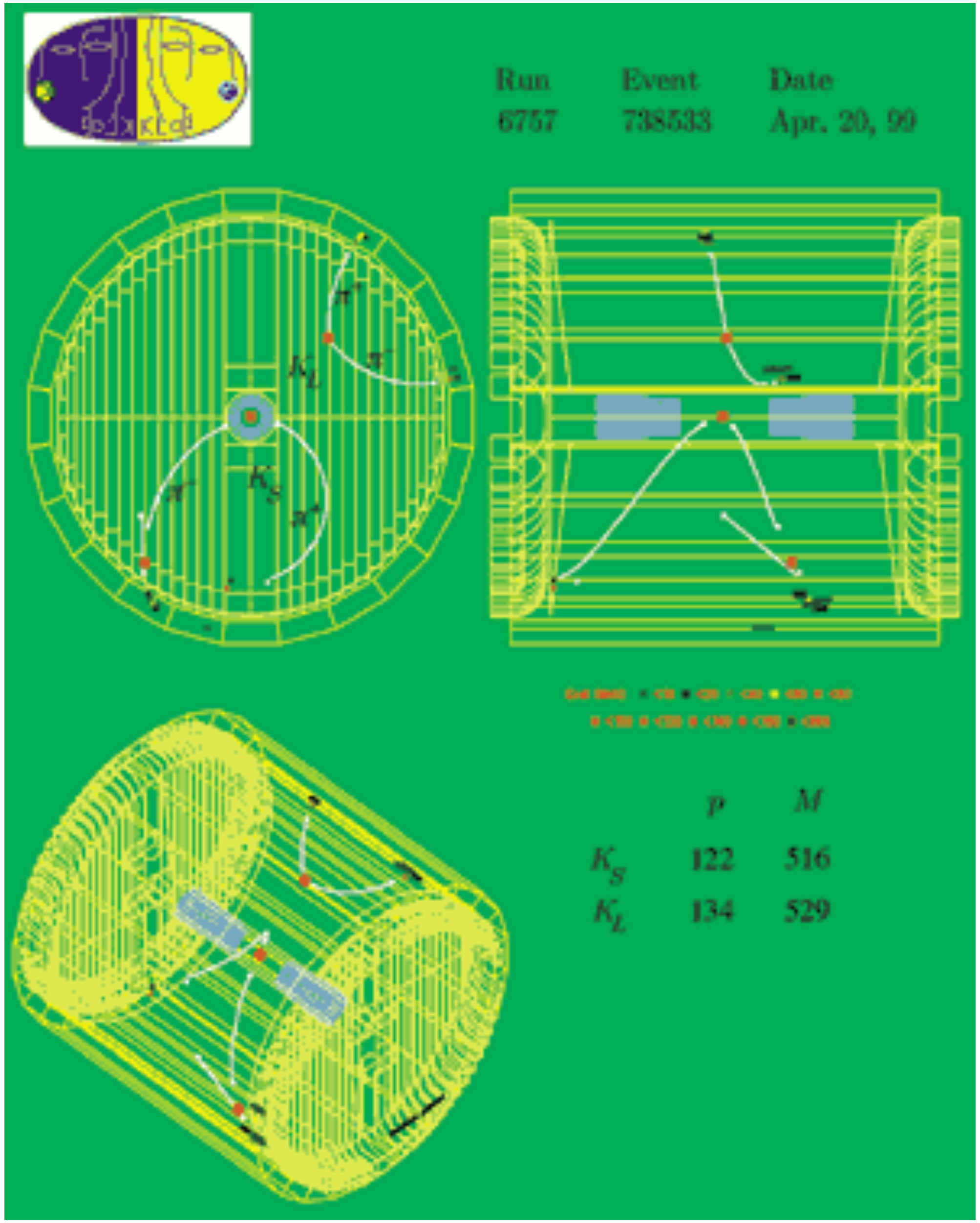
750 μm C + 150 μm Al
at 25 cm (~ 42 τ_S) from IP



Regenerators in KLOE



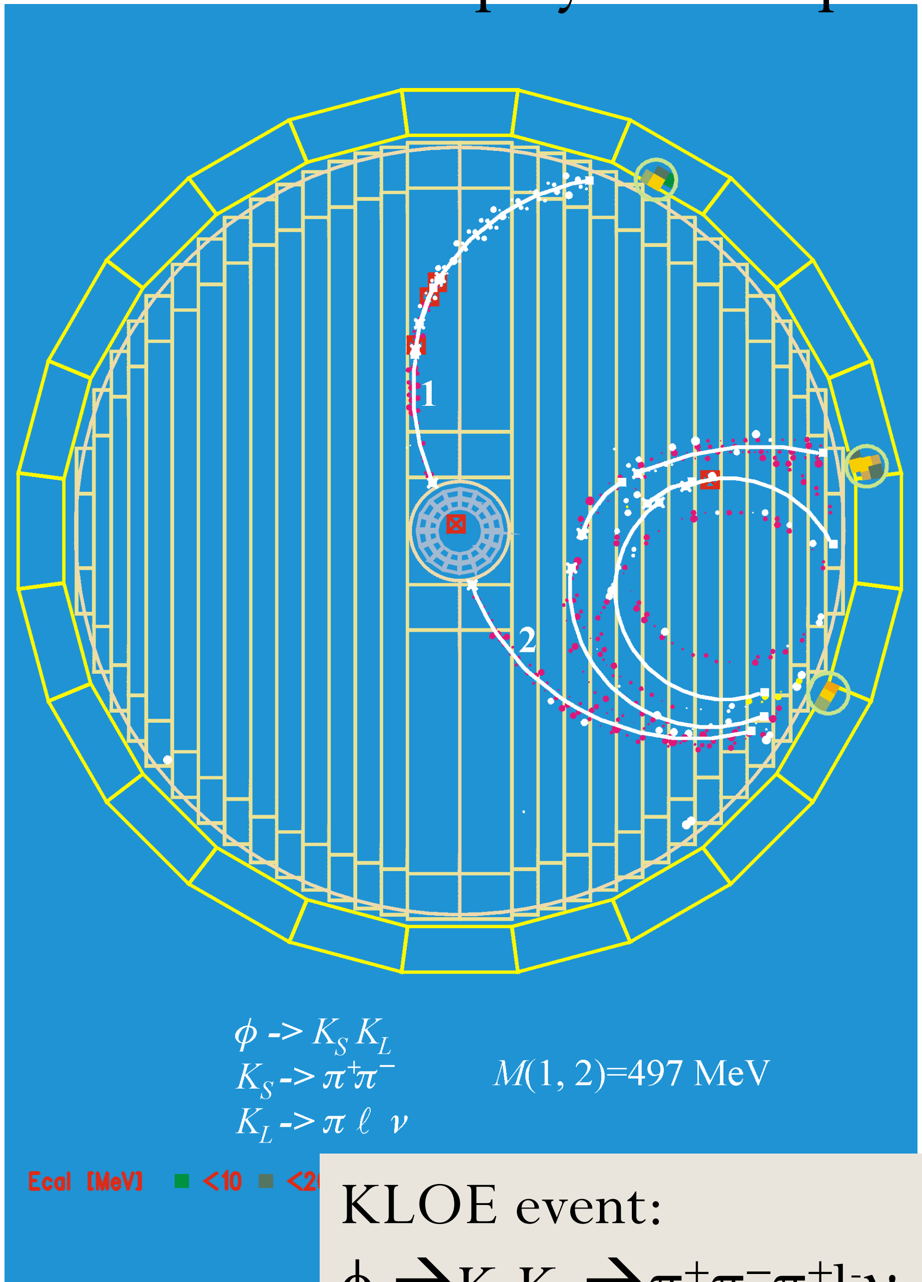
Event display – examples (1)



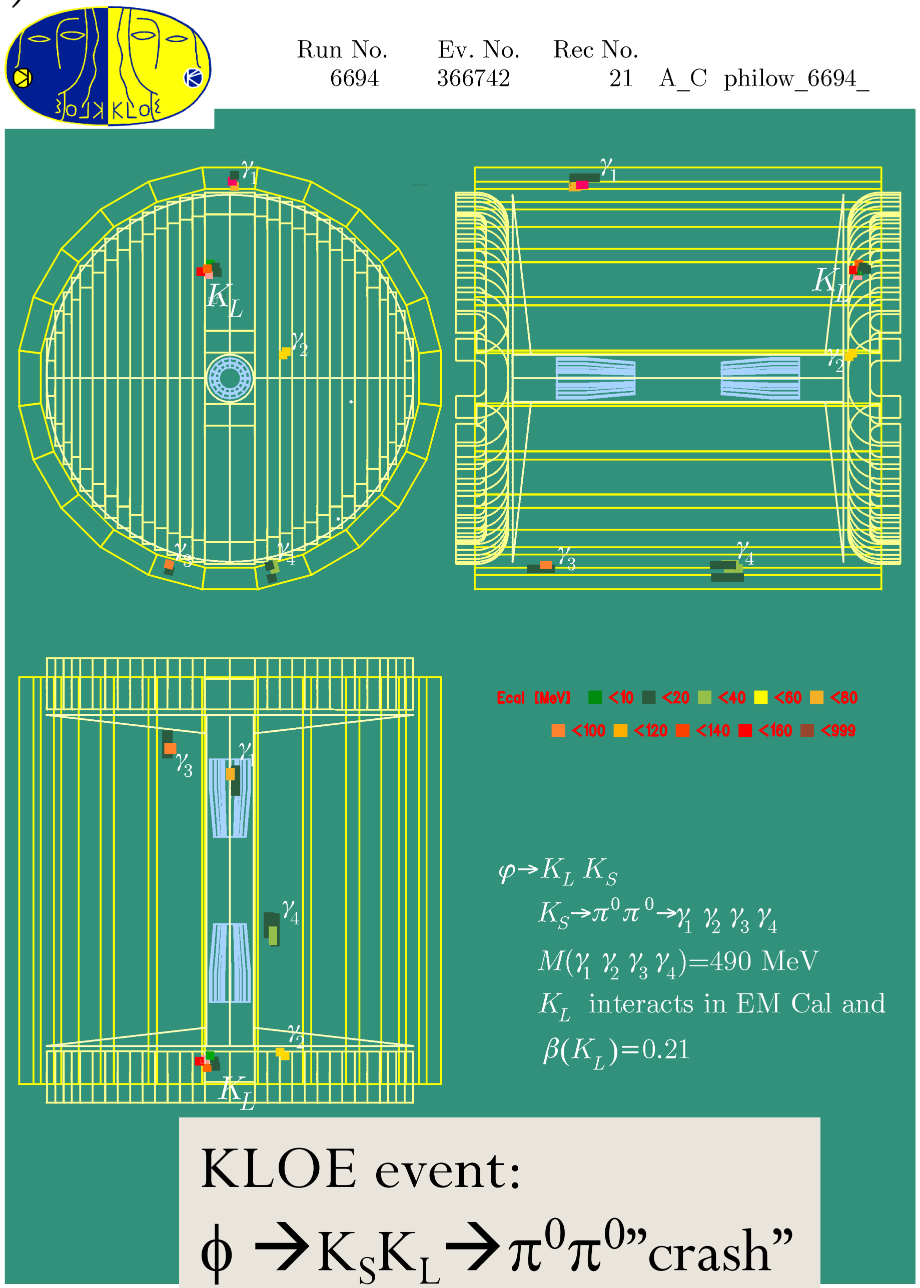
KLOE event:

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

Event display – examples (2)



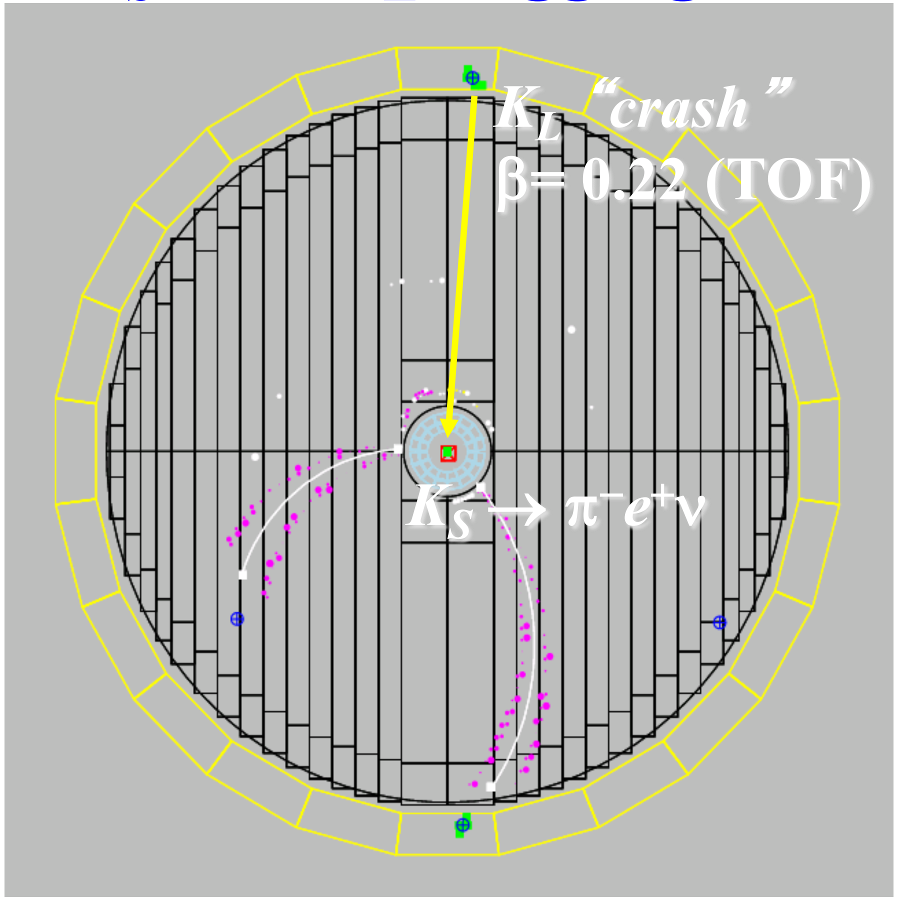
KLOE event:
$\phi \rightarrow K_S K_L \rightarrow \pi^+\pi^-\pi^+ l^- \nu$

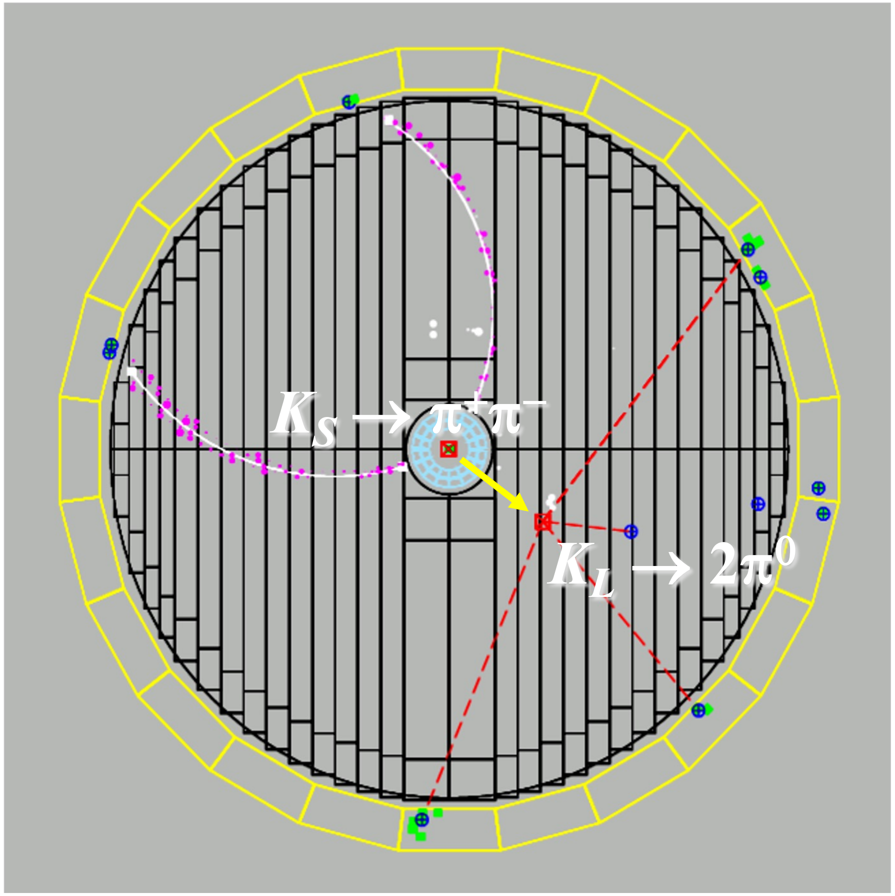


KLOE event:
$\phi \rightarrow K_S K_L \rightarrow \pi^0 \pi^0$"crash"

Event display – examples (3)

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 $K_S \to \pi^+\pi^-$ vertex at IP

Efficiency ~ 70% (mainly geometrical)

K_L angular resolution: ~ 1°

K_L momentum resolution: ~ 2 MeV

DATA format

1 event

1 event

1 event

1 event

....

0	0	0.035869	0.079946	0.548119	-15.995125	-0.156951	-0.765283	1019.750977	0	0
2	1	0.180338	0.166126	0.816596	151.192932	-61.700985	54.802067	-209.739105	142.082977	5.926435
0	0	0.035869	0.079946	0.548119	-15.995125	-0.156951	-0.765283	1019.750977	0	0
1	1	-205.31308	-12.200912	4.015152	7.252731	214.829895	0	0	0	0
1	2	-31.037476	202.937012	123.875343	8.16227	126.973534	0	0	0	0
1	3	-68.547661	89.140495	-189.911667	31.578369	6.145964	0	0	0	0
1	4	-86.098663	73.258659	-185.074326	38.752144	13.187425	0	0	0	0
1	5	-165.094727	-118.636337	133.023621	47.401321	7.105018	0	0	0	0
2	1	0.511572	0.067841	1.507393	-124.688904	-169.867401	4.889555	140.067444	133.100037	96.255516
0	0	0.035869	0.079946	0.548119	-15.995125	-0.156951	-0.765283	1019.750977	0	0
1	1	-57.410442	21.75717	175.496567	5.889347	393.982239	0	0	0	0
1	2	54.01231	4.012296	-175.383377	6.078804	214.234085	0	0	0	0
1	3	34.10471	37.743622	-173.41066	6.323677	226.238037	0	0	0	0
1	4	112.093002	11.276959	-176.34967	7.03524	4.597826	0	0	0	0
1	5	-117.105995	128.155563	171.574554	8.612904	5.187032	0	0	0	0
2	1	-0.673846	17.879251	-5.96976	-23.862055	-39.697712	158.070496	7.350477	-37.824757	-70.982933
0	0	0.035869	0.079946	0.548119	-15.995125	-0.156951	-0.765283	1019.750977	0	0
1	1	-86.65889	-19.226862	-176.641495	5.534523	169.180695	0	0	0	0
1	2	-74.433548	-112.078461	170.878922	7.298756	66.885292	0	0	0	0
1	3	59.36533	-52.221588	174.544235	11.929249	68.045532	0	0	0	0
1	4	154.940964	133.01506	66.629776	12.044724	116.128792	0	0	0	0
1	5	-104.134201	174.772659	103.915047	12.729015	104.712448	0	0	0	0
1	6	-149.680542	139.828247	50.176979	12.822372	69.41761	0	0	0	0
1	7	85.812004	-143.801208	173.632889	14.314499	90.73526	0	0	0	0

The first column indicates the block number.
Each event has 2 or 3 blocks: header info (0), calorimeter clusters info (1), and vertices with 2 tracks info (2).

DATA format

Meaning of the variables in each block:

block #	-	x_Phi (cm)	y_Phi (cm)	z_Phi (cm)	Px_Phi (MeV/c)	Py_Phi (MeV/c)	Pz_Phi (MeV/c)	sqrt(s) (MeV)		
0	0	0.035869	0.079946	0.548119	-15.995125	-0.156951	-0.765283	1019.750977	0	0
block #	cluster #	x_cl (cm)	y_cl (cm)	z_cl (cm)	time_cl (ns)	Energy_cl (MeV)				
1	1	-205.31308	-12.200912	4.015152	7.252731	214.829895	0	0	0	0
1	2	-31.037476	202.937012	123.875343	8.16227	126.973534	0	0	0	0
1	3	-68.547661	89.140495	-189.911667	31.578369	6.145964	0	0	0	0
1	4	-86.098663	73.258659	-185.074326	38.752144	13.187425	0	0	0	0
1	5	-165.094727	-118.636337	133.023621	47.401321	7.105018	0	0	0	0
block #	vertex #	x_vtx - x_Phi (cm)	y_vtx - y_Phi (cm)	z_vtx - zPhi (cm)	Px_trk 1 (MeV/c)	Py_trk 1 (MeV/c)	Pz_trk 1 (MeV/c)	Px_trk 2 (MeV/c)	Py_trk 2 (MeV/c)	Pz_trk 2 (MeV/c)
2	1	0.511572	0.067841	1.507393	-124.688904	-169.867401	4.889555	140.067444	133.100037	96.255516

Block 0 contains information about the effective IP position, total momentum and sqrt(s) evaluated from Bhabha scattering events acquired in the same run;
they are average quantities valid for all events in the run.

Block 1 contains information about position, time and energy of each calorimeter cluster in the event.
A cluster is a group of contiguous hit cells, each cell is read-out by a PMT at each end.

Block 2 contains information about the position of each vertex in the event formed by two tracks of opposite curvature reconstructed with the drift chamber (DC). For each vertex the momenta of the two tracks is also provided. The numbering of the two tracks (trk1 and trk2) is arbitrary.
For user convenience, the provided vertex coordinates have already the IP average position (x_phi, y_Phi and z_Phi of block 0) subtracted.