The KLOE Calorimeter Trigger

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KLOE Collaboration

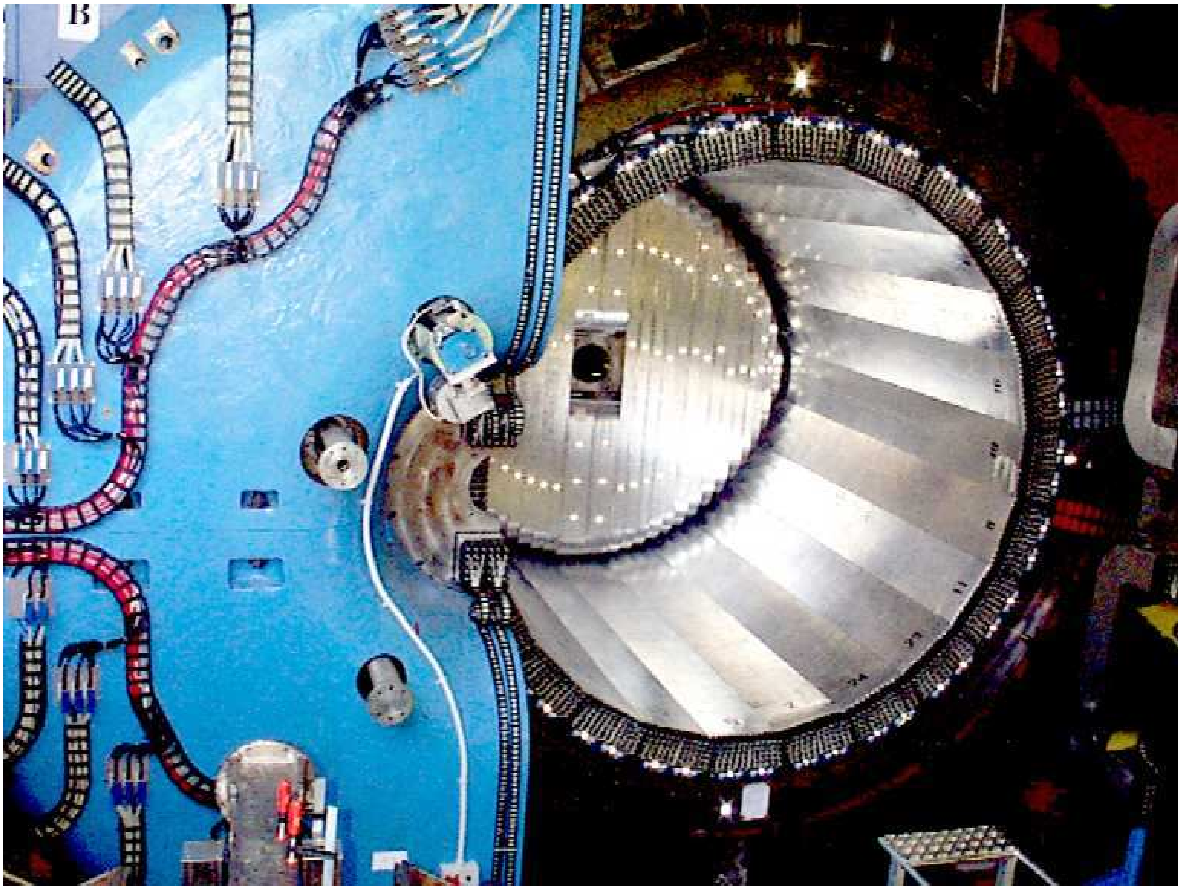
The experiment

KLOE aims to $\sigma(\Re e\,(\varepsilon'/\varepsilon)) \sim 10^{-4}$ with the double ratio method

$$\mathcal{R} = \frac{\Gamma(K_L \to \pi^0\pi^0)}{\Gamma(K_S \to \pi^0\pi^0)} \cdot \frac{\Gamma(K_S \to \pi^+\pi^-)}{\Gamma(K_L \to \pi^+\pi^-)} \simeq 1 - 6\Re e \frac{\varepsilon'}{\varepsilon}$$

The detector has $\sim$ 4 m diameter and $\sim$ 4 m length:

- Superconducting Coil of 6 kG
- Lead-Scintillating Fiber Calorimeter with 13% energy sampling fraction and 5000 PMs readout



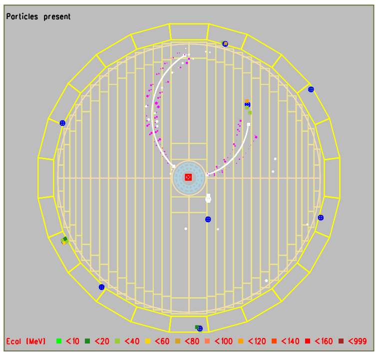
$\longrightarrow$ the measured performances are :

$$\frac{\delta E}{E} = \frac{5.7\%}{\sqrt{E(GeV)}}; \qquad \delta t = \frac{54ps}{\sqrt{E(GeV)}} + 147ps$$

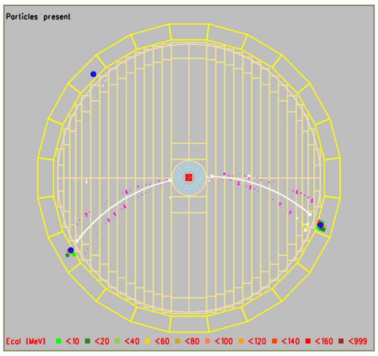
- Helium Drift Chamber all-stereo cell geometry with 12500 sense wires

Trigger requirements

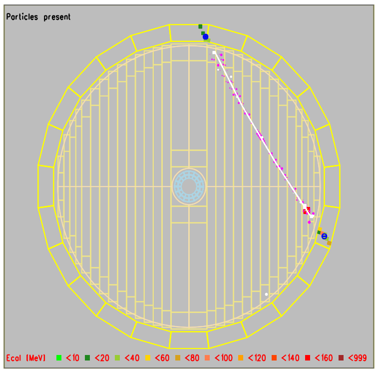
- Equalized trigger efficiencies on $\pi^+\pi^-$ and $\pi^0\pi^0$ decays of K_{L} and K_{S} :
  $\longrightarrow \mathcal{R} = \frac{N_L^0 N_S^{\pm}}{N_S^0 N_L^{\pm}} \cdot (1 + \varepsilon_S^0 - \varepsilon_S^{\pm} + \varepsilon_L^{\pm} - \varepsilon_L^0)$
- High efficiency $\longrightarrow$ small $\sigma(\varepsilon) = \sqrt{\varepsilon(1-\varepsilon)/N}$



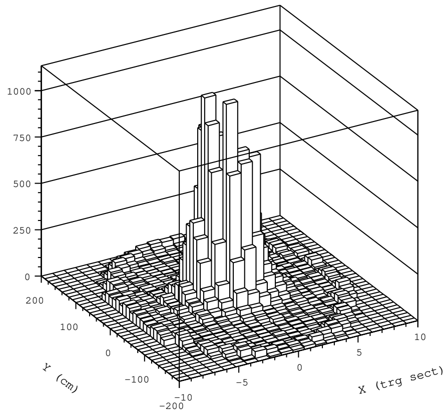
Phi physics rate: ~2 kHz



Bhabha rate: 3.5 kHz



Cosmic rays rate: 2.6 kHz

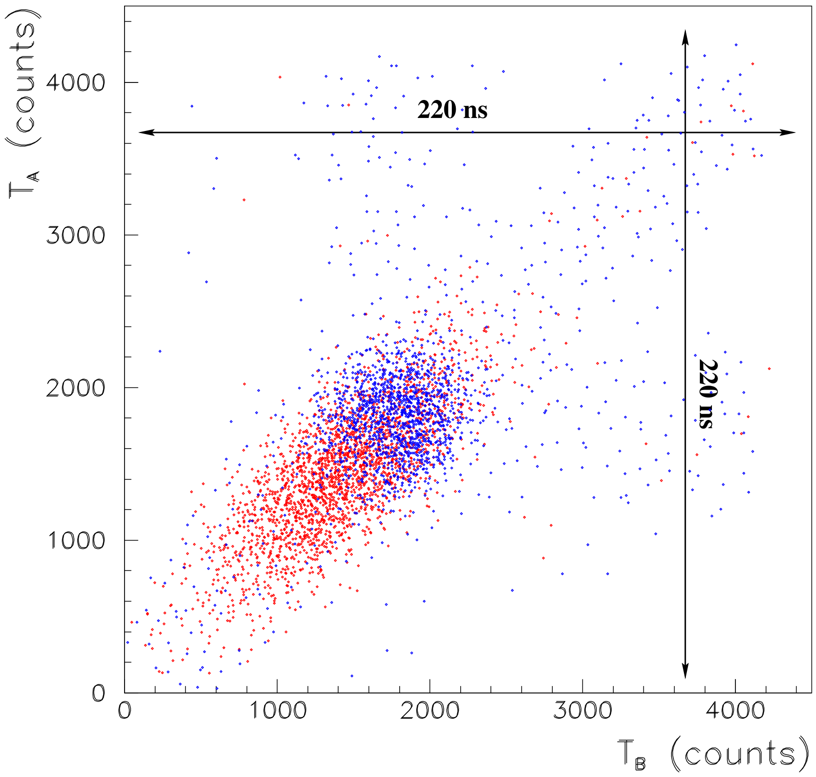


Machine Background rate: O(MHz)

- DAQ max throughput: 50 Mbytes/sec ($\sim$10 kHz)
  $\longrightarrow$ rejection capability on "non-ϕ events"
- 2.7 ns interbunch spacing $\longrightarrow$ continuous mode operation

… and technical solution

- Two independent chains:
  1) EmC trigger: based on multiplicity of fired calorimeter sectors
  2) DC trigger: based on multiplicity of hit drift chamber wires
- Two level scheme:
  1) Fast L1 (within 200 ns) to start calorimeter TDC's
  2) Slower L2 confirmation after $\simeq 2\mu$s (drift time in the chamber cells)



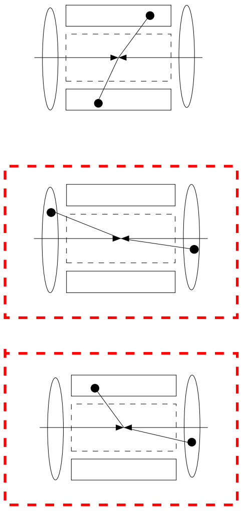
- L1 synchronized with machine RF/4 and distributed with 50 ps precision

Triggering with the calorimeter

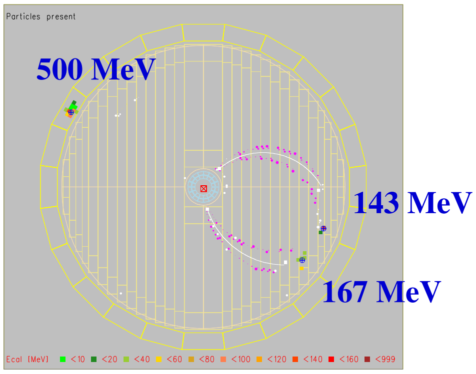
Two energy deposits are required in a 70 ns time window.

Each sector discriminates signals on two thresholds at the same time:

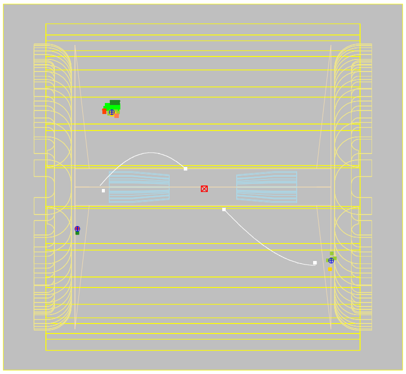
- A low threshold (LET = 50 MeV on barrel, 85 MeV on the endcaps), in order to trigger on particles from ϕ decays in the following topologies



Ks $\longrightarrow$ $\pi^+ \pi^-$ + Kl interacting in the calorimeter

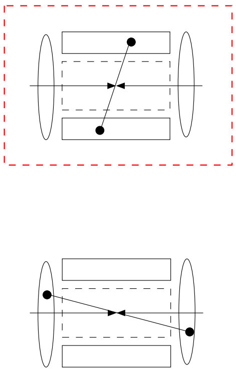


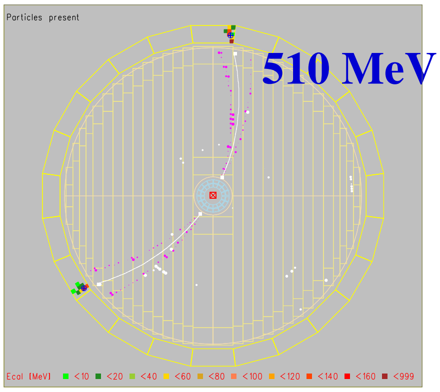
front view



side view

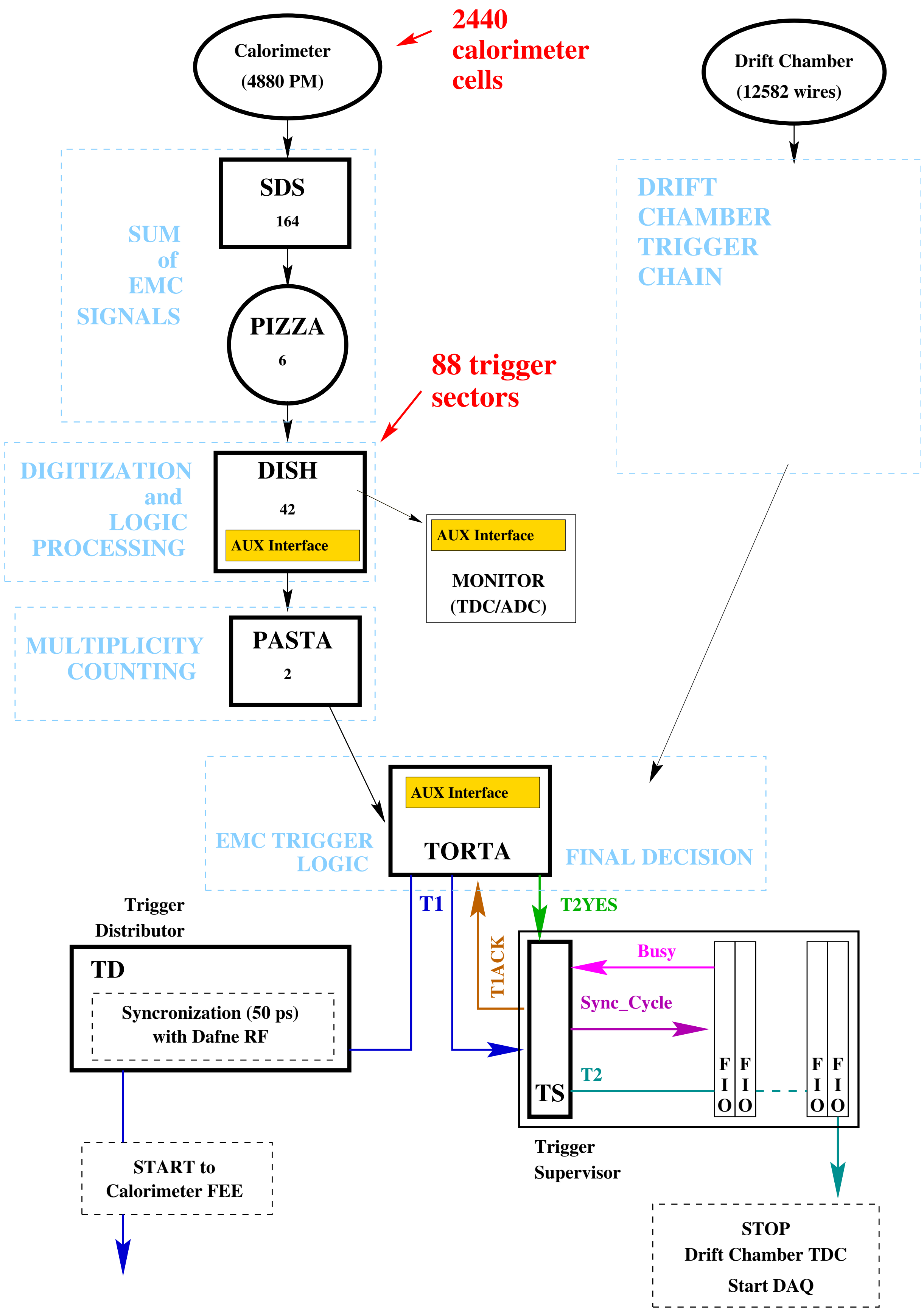
- A high threshold (BBT = 300 MeV) in order to identify and reject/downscale Bhabha events





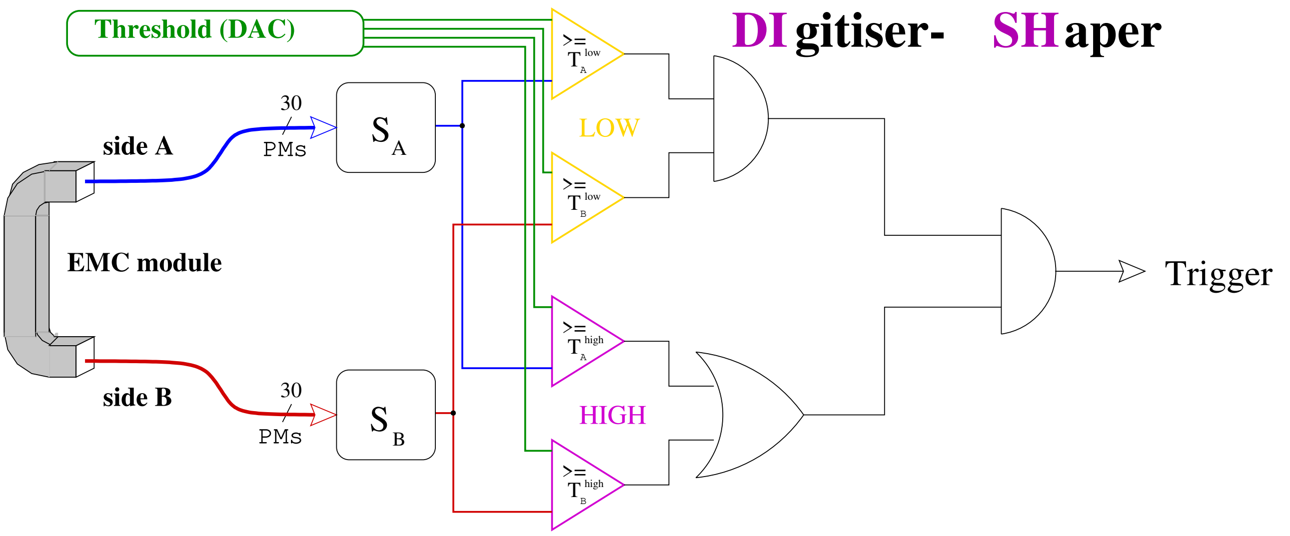
Bhabha event on barrel

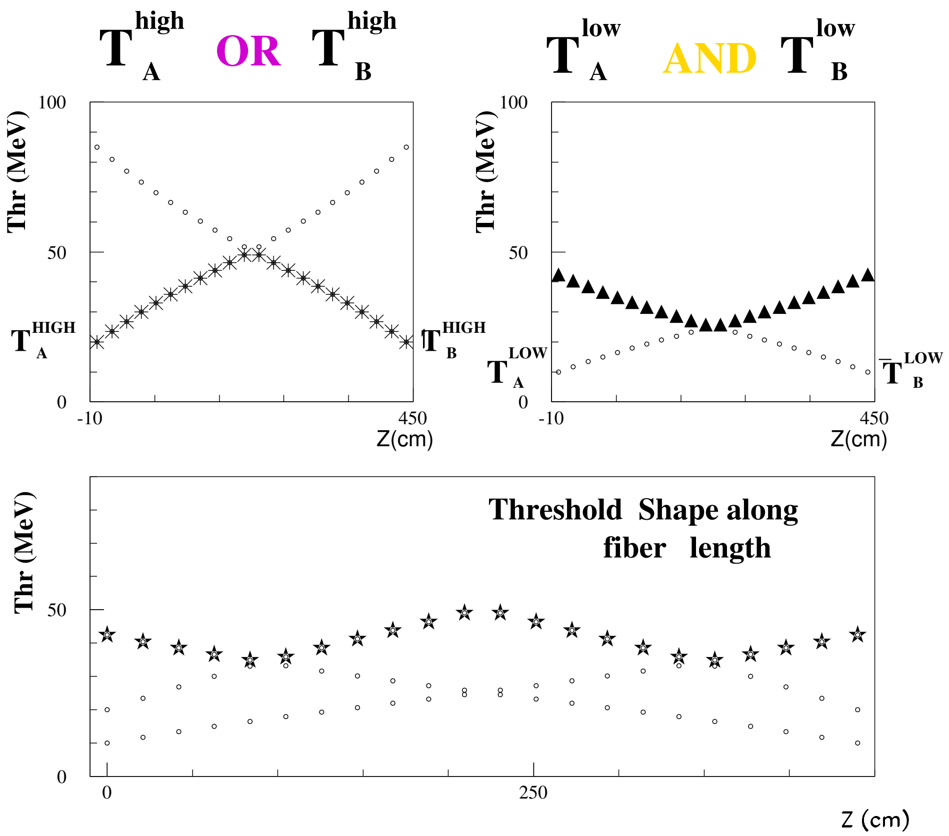
Hardware Architecture



Signal generation (DISH)

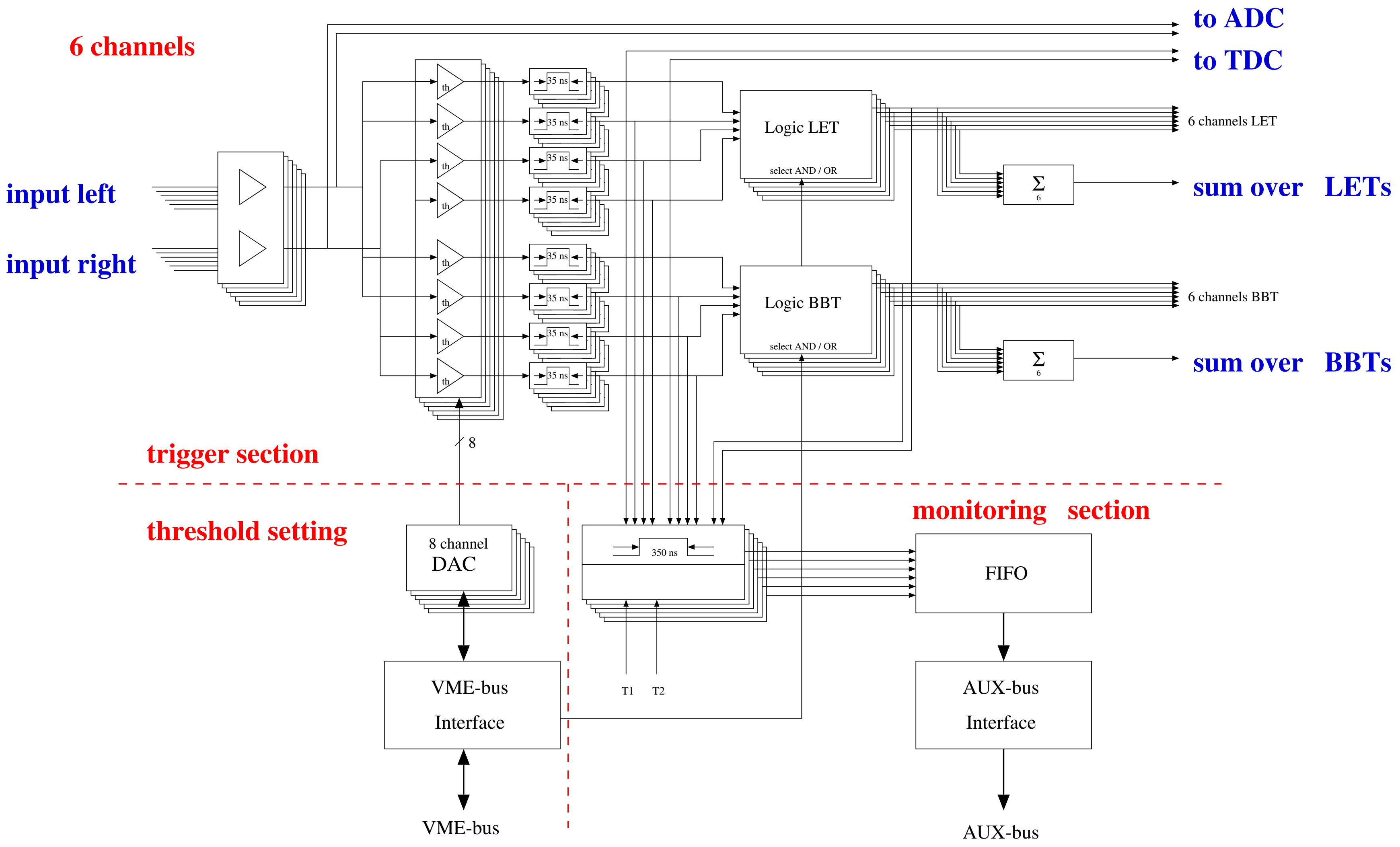
- Each trigger channel discriminates the two input signals, coming from side A and B of the calorimeter with 8 comparator:
  4 produce the LET signal, and 4 the BBT one.





$$(T_A^{low} \ .AND. \ T_B^{low}) \ .AND. \ (T_A^{high} \ .OR. \ T_B^{high})$$

DISH scheme

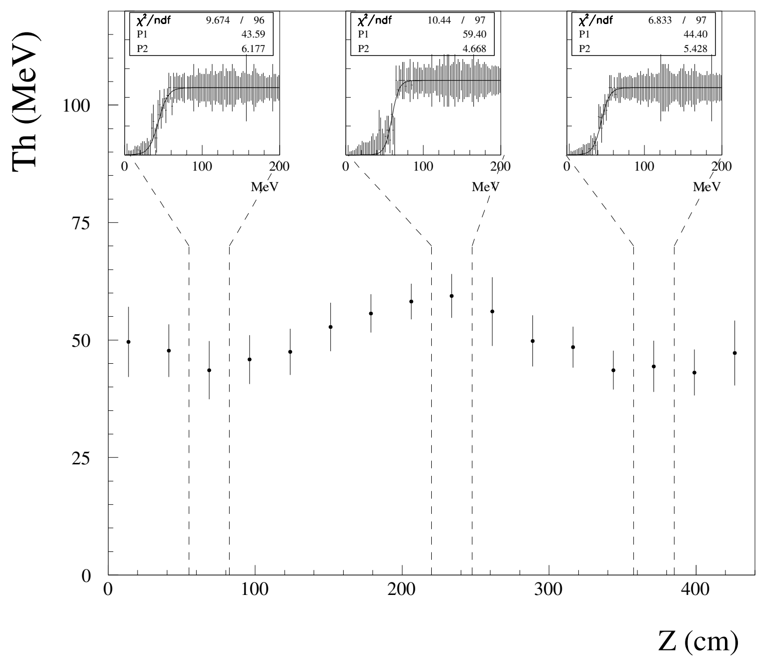


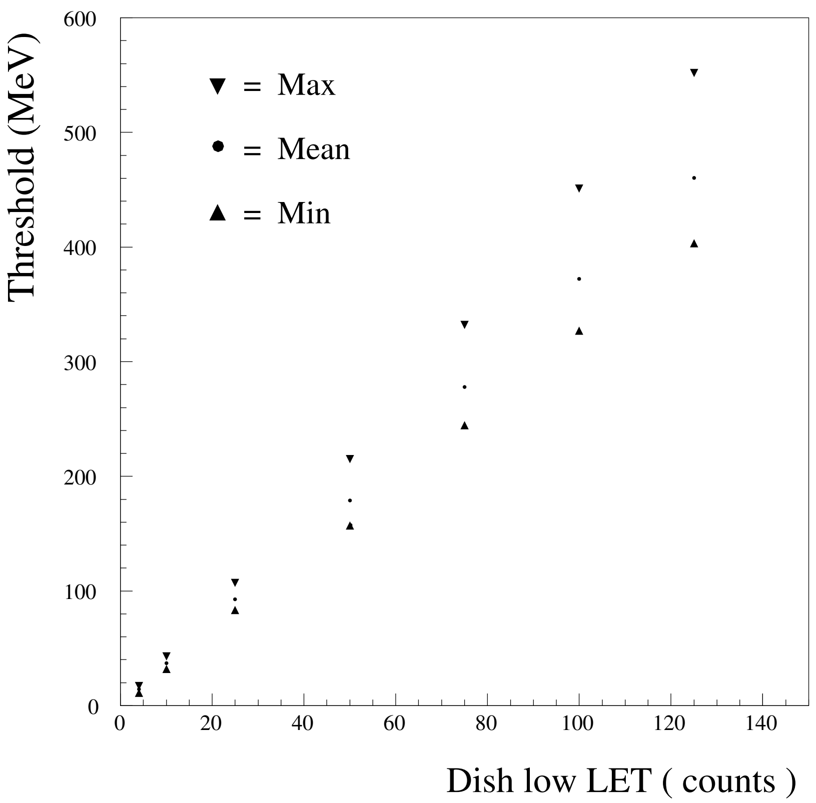
6 channels
input left
input right
th
35 ns
Logic LET
select AND / OR
Logic BBT
select AND / OR
to ADC
to TDC
6 channels LET
Σ
6
sum over LETs
6 channels BBT
sum over BBTs
8
trigger section
threshold setting
8 channel
DAC
VME-bus
Interface
VME-bus
350 ns
T1
T2
monitoring section
FIFO
AUX-bus
Interface
AUX-bus

Threshold calibration

The threshold profile is measured by correlating the reconstructed sector energy with the corresponding trigger response, in z slices.

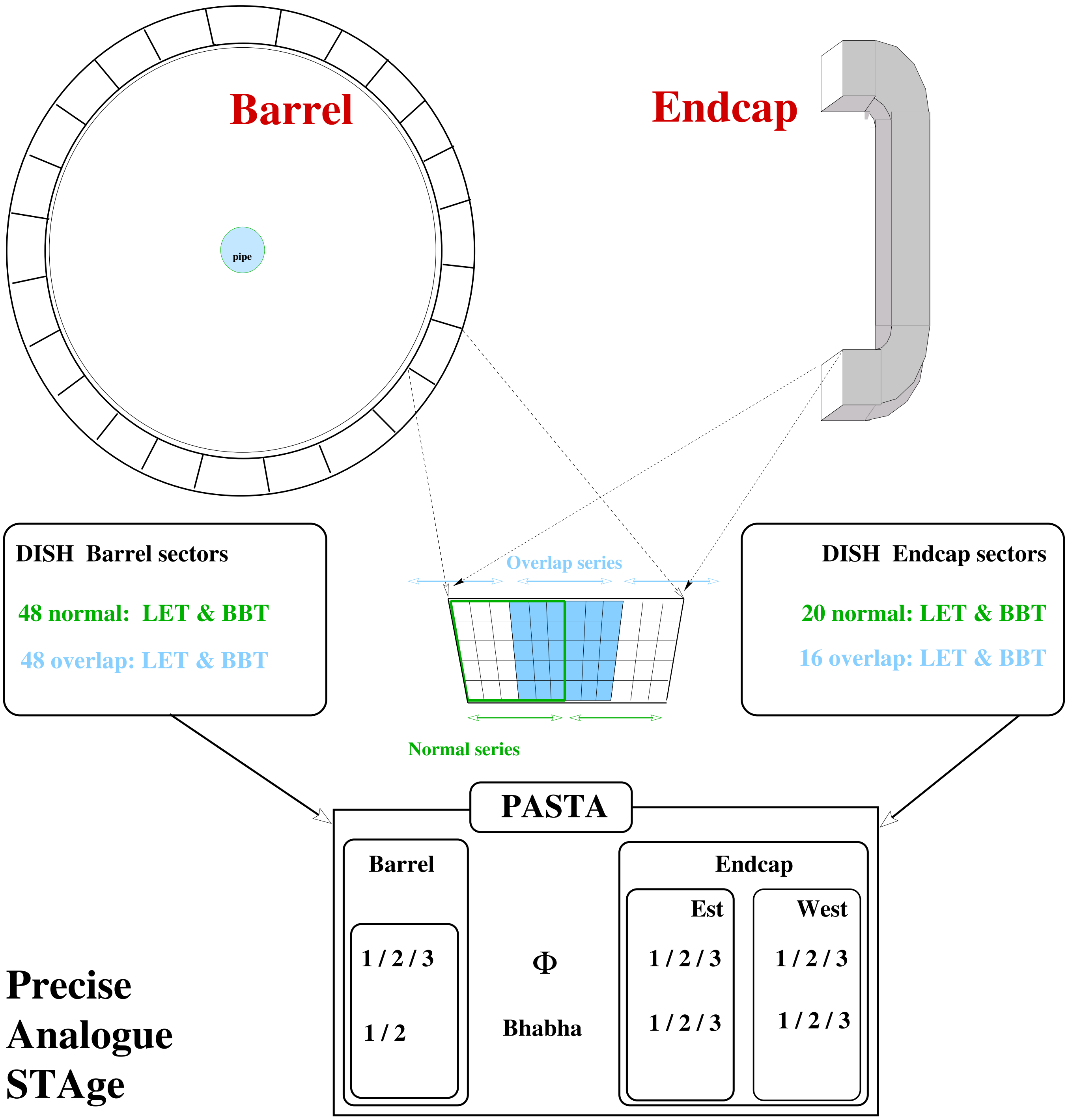
The threshold spread along z is compatible with the energy resolution in the 40-100 MeV range (30% - 20%)





A calibration curve has been obtained spanning the range of all possible DISH settings

Multiplicity counting (PASTA)



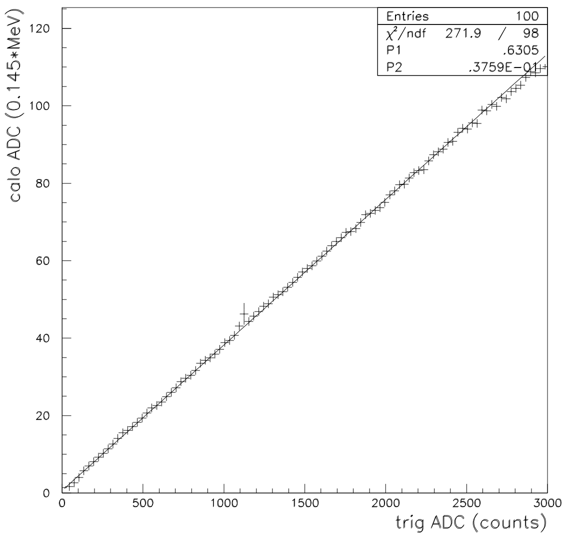
→ DISH boards provide signals proportional to the number of active trigger channels

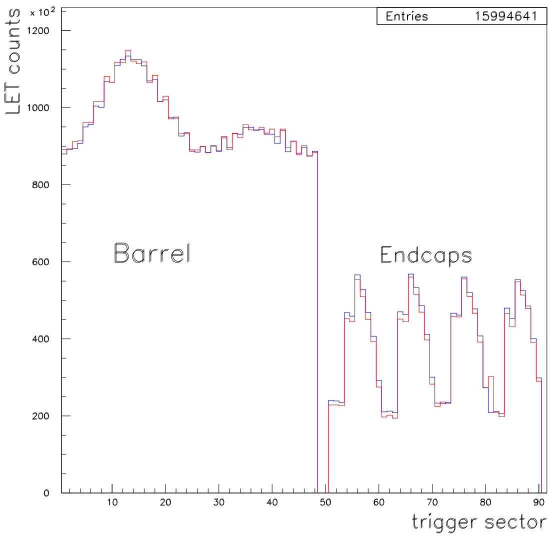
→ PASTA board uses these signals to count the number of "ϕ tagged" (LET) and "Bhabha tagged" (BBT) particles, separately for Barrel and Endcaps, merging the information coming from two series of overlapping trigger sectors.

Online hardware monitoring

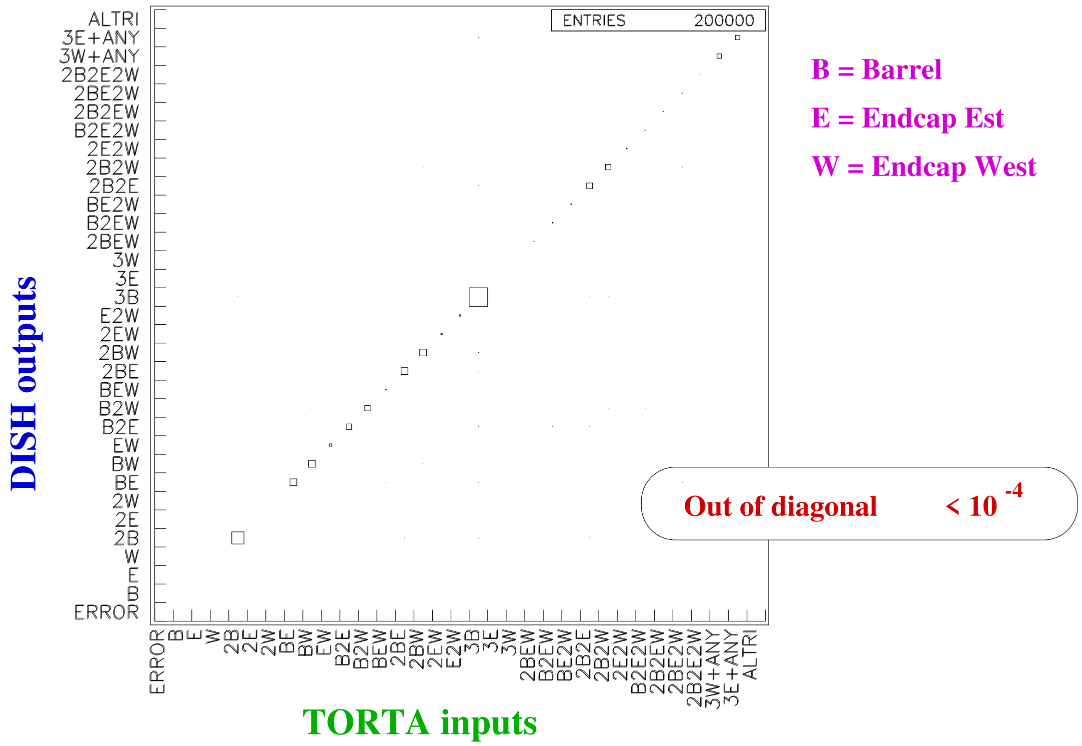
1) PIZZA sum stage:
calorimeter ADC signals versus the trigger ADC at DISH inputs

2) Trigger sector's hardware:
LET occupancy (blue) versus the illumination of calorimeter cells (red)





3) Consistency check on the multiplicity counting stage:
multiplicities at the TORTA input are correlated with the ones calculated starting from DISH outputs



B = Barrel

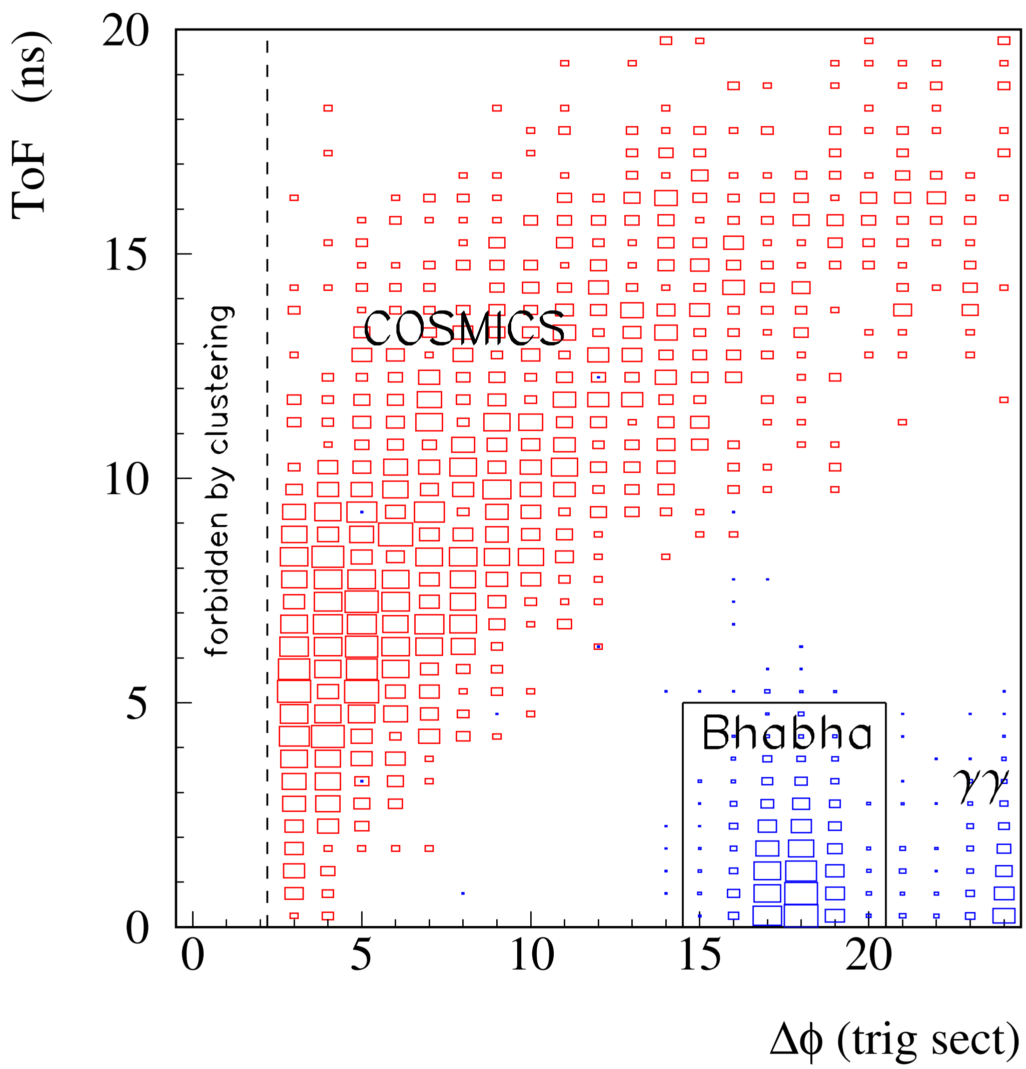
E = Endcap Est

W = Endcap West

Luminosity monitor

BHABHA SELECTION:

- 2 BBT sectors on the barrel;
- Angular distance: $15 \leq \Delta\phi \leq 22$ trigger sectors;
- Time of flight difference on trigger TDC's: $\Delta t \ \leq \ 5$ ns.

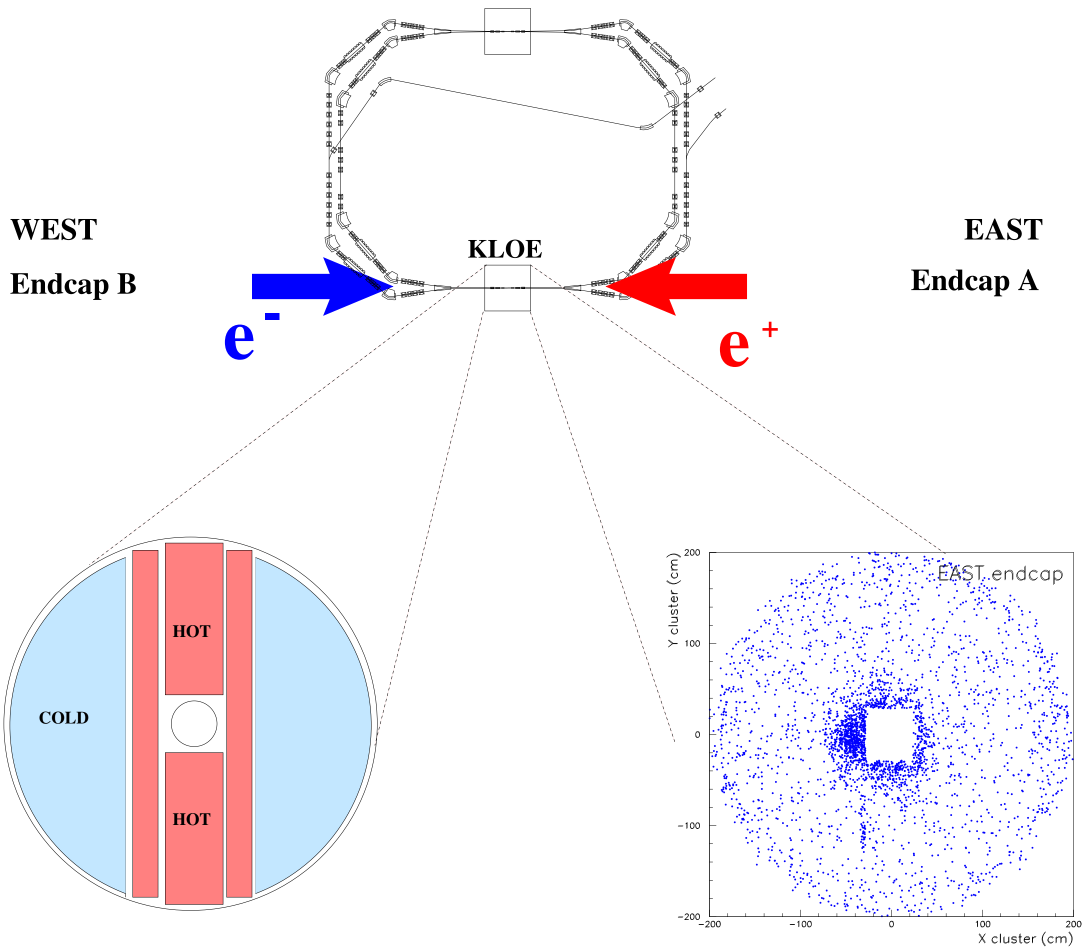


PERFORMANCES:

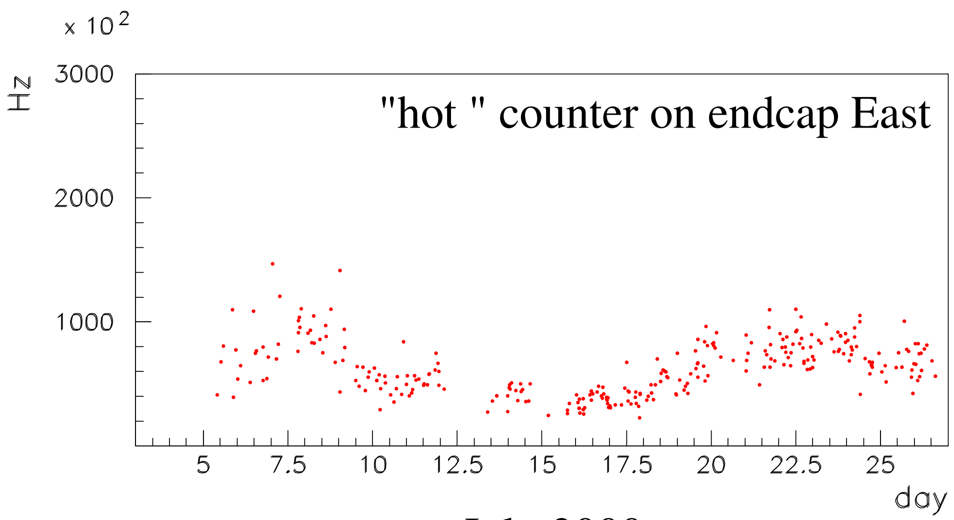
- Fast and reliable response → one luminosity measurement per minute at 10^{31} cm^{-2}s^{-1} with $\sigma_{STAT} = 5\%$;
- $\mathcal{L}_{TRIG} - \mathcal{L}_{OFFLINE} \sim 10\%$;
- Rejection power on cosmics $> 10^5$ (~ 4 mHz residual rate);
- Machine background contamination $\leq 5\%$.

Machine background monitor

The distribution of clusters with $E > 100$ MeV shows that machine background peaks around the beam pipe, particularly toward the centre of DAΦNE orbit



Bhabha trigger channels on the endcaps (veto not needed if $\mathcal{L} < 10^{32}$ cm^{-2}s^{-1}) are currently used to monitor single rates with a 100 MeV threshold



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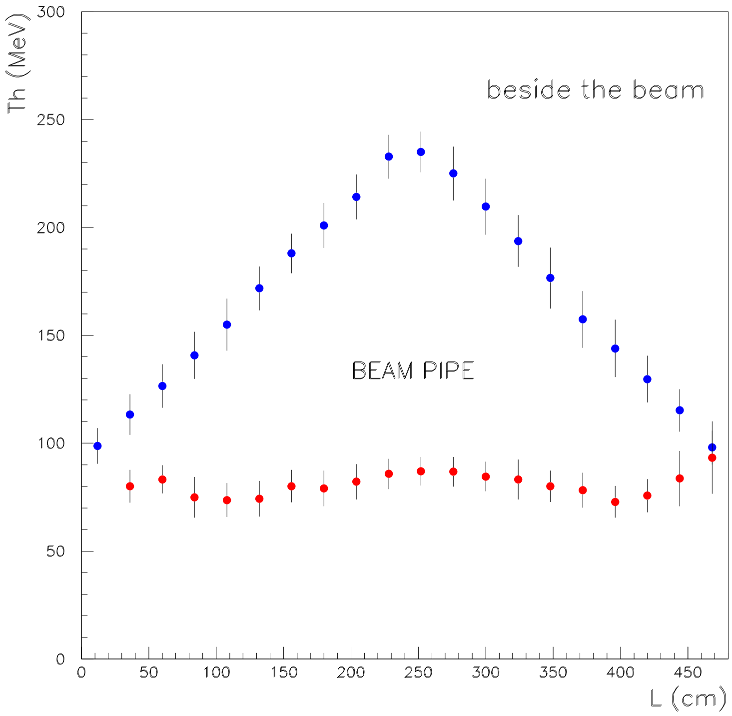
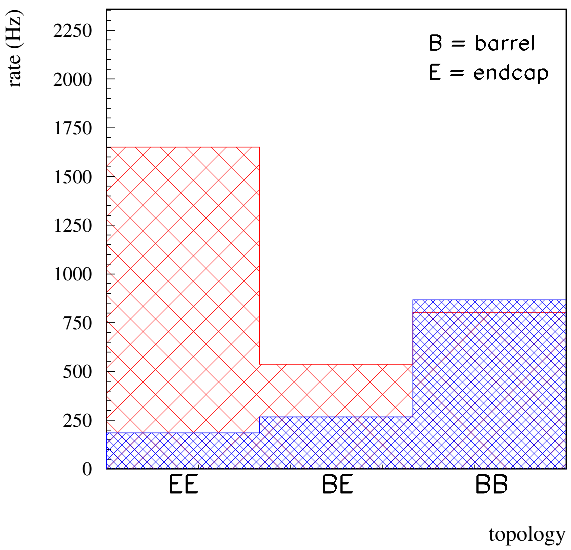
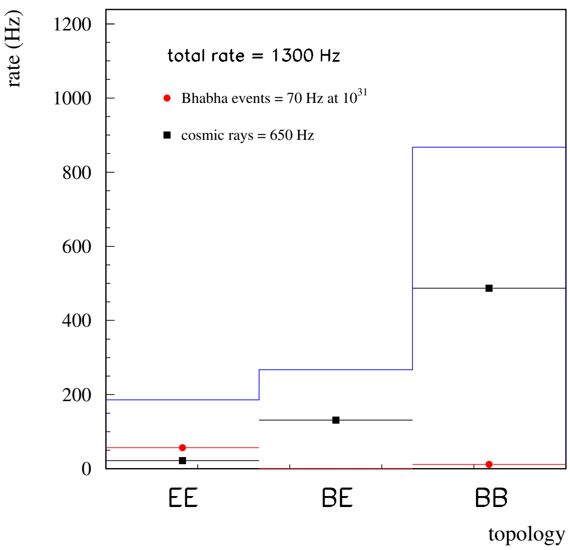
Machine background rejection



Close to the beam pipe higher thresholds have been set in order to reject accidental coincidences of the two endcaps

In the present running condition ($I^-/I^+ \simeq 500$ mA; $\mathcal{L} \simeq 10^{31}$ cm^{-2}s^{-1}) the unbalanced threshold map reduces the trigger rate from ~ 3000 Hz down to ~ 1300 Hz (calorimeter trigger only), composed by:
a) **650 Hz** of cosmic rays, b) 70 Hz of Bhabha's, c) 30 Hz of ϕ decays + d) 550 Hz machine background

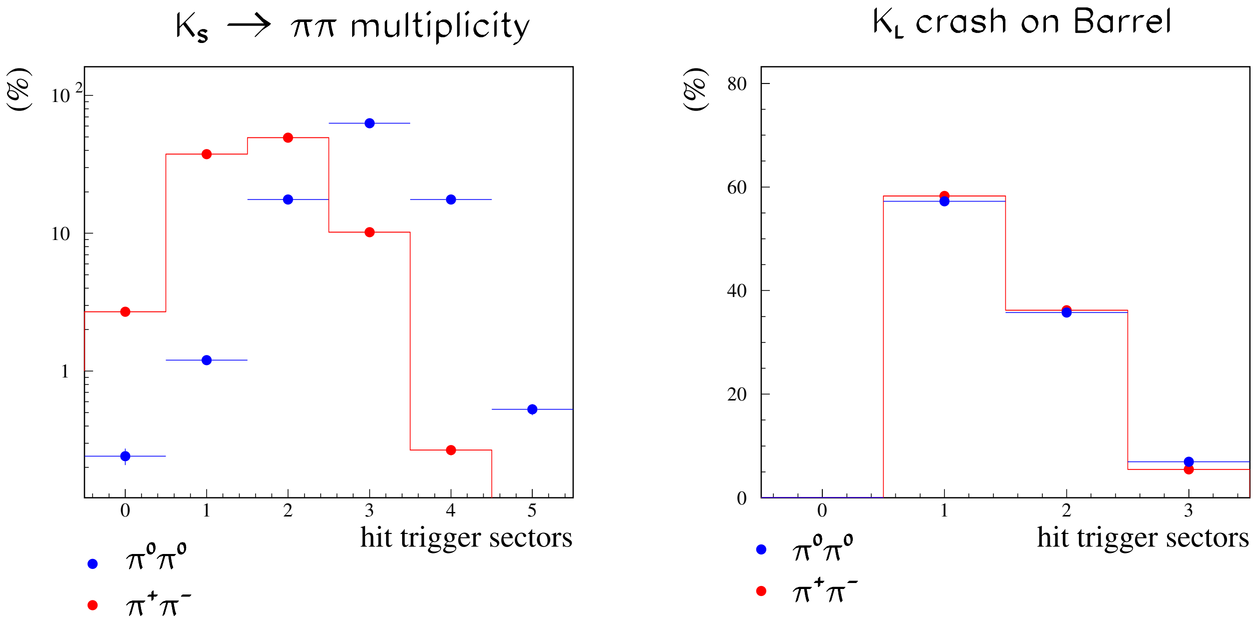




Trigger efficiency on K_S decays

$K_S \to \pi\pi$ events are tagged by a K_L interacting in the calorimeter barrel with $E > 100$ MeV.
K_L fires at least 1 sector, the trigger efficiency is therefore (2 sectors required !):

$$\varepsilon(K_S \to \pi\pi, K_L\mathrm{crash}) = 1 - P_L(1) \cdot P_S(0)$$



The following efficiencies have been measured for K_L and K_S:

$P_S(0) = 0.24 \pm 0.03\%$ $(\pi^0\pi^0)$
$P_S(0) = 2.69 \pm 0.07$ % $(\pi^+\pi^-)$

$P_L(1) = 55.0 \pm 0.3$ %

As a result:

- $\epsilon_{trig} = (99.87 \pm 0.02)$ % for $\pi^0\pi^0$
- $\epsilon_{trig} = (98.52 \pm 0.04)$ % for $\pi^+\pi^-$

Trigger efficiency on K_L decays

- The probability $P(i)$ of having " i " sectors fired ($i = 0, 1, 2$) on each subdetector (B = barrel, W = endcap west, E = endcap east) is:

$$P(0) = S(0)L(0);\ P(1) = S(0)L(1) + S(1)L(0), ...$$

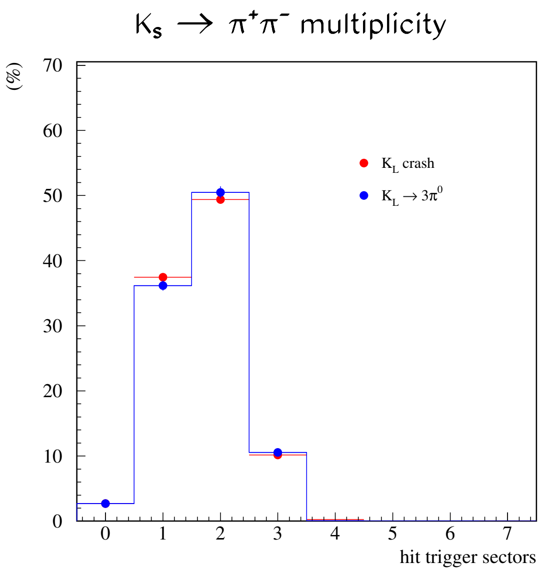
where $S(i)$ and $L(i)$ are extracted from the "unbiased" multiplicity distributions of K_S and K_L

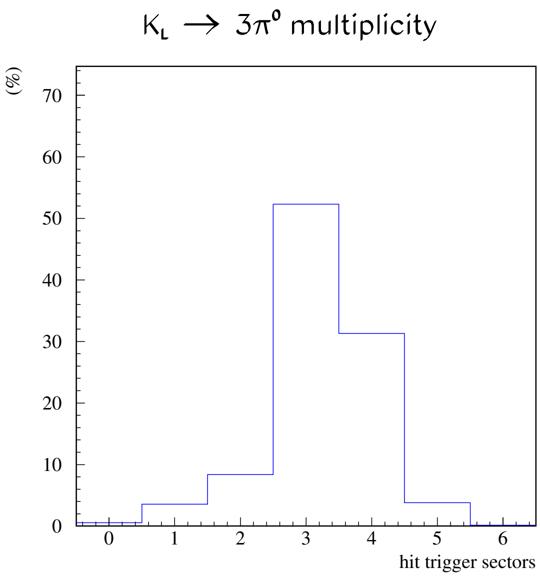
- The fraction of lost events $1 - \epsilon_{trig}$ is:

$$B(0)W(0)E(0)+$$
$$B(1)W(0)E(0) + B(0)W(1)E(0) + B(0)W(0)E(1)$$

For $K_L \to 3\pi^0$ (tagged by $K_S \to \pi^+\pi^-$)

$$\epsilon_{trig} = 99.0 \pm 0.5\%$$





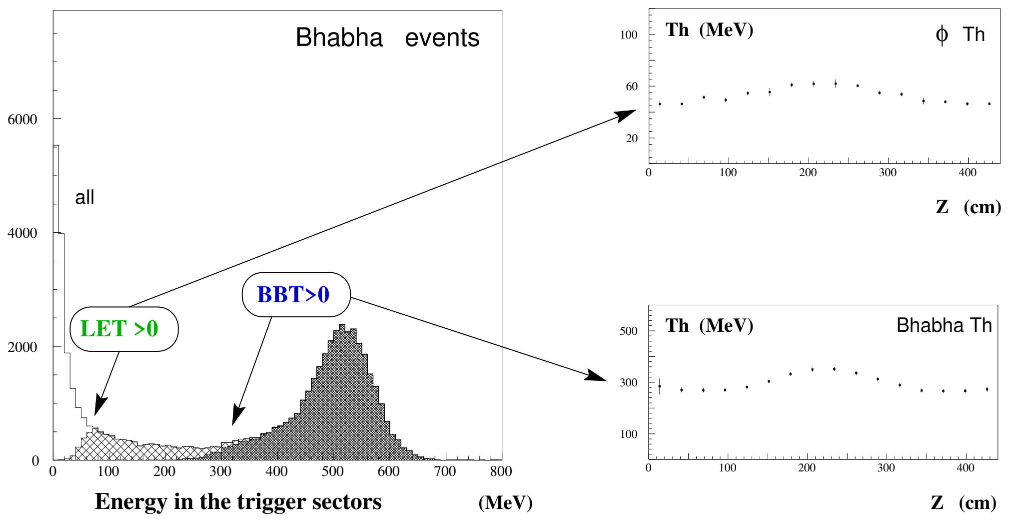
Conclusions

- The KLOE calorimeter trigger selects with high efficiency the neutral kaon decays
- It also produces a fast signal for starting the calorimeter FEE within 300 ns from the interaction
- Despite high backgrounds, the S/B ratio is kept at a reasonable level
- A highly redundant monitoring system allows for an efficient online control of the detector hardware, providing at the same time reliable measurements of the machine luminosity and the background levels

Bhabha and Cosmic Vetoes

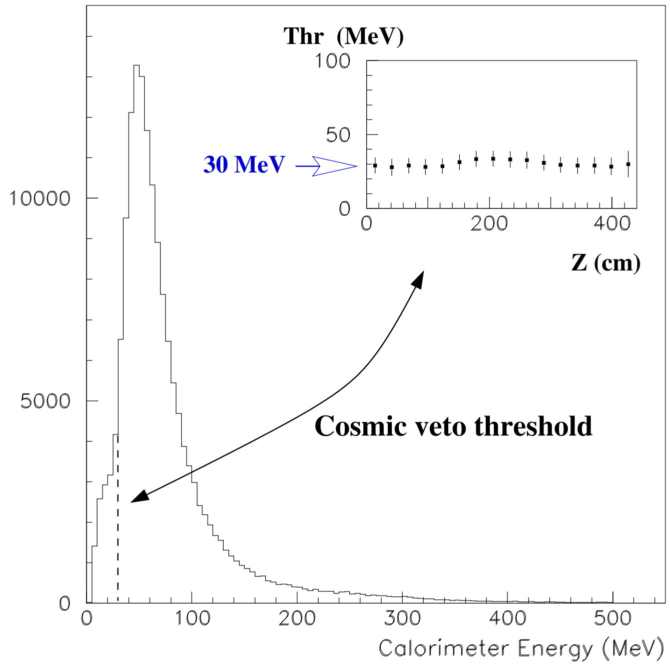
$$BHABHA\_VETO \;=\; B2B \;+\; E1B * W1B$$

$\longrightarrow$ Efficiency $\sim 96\%$.

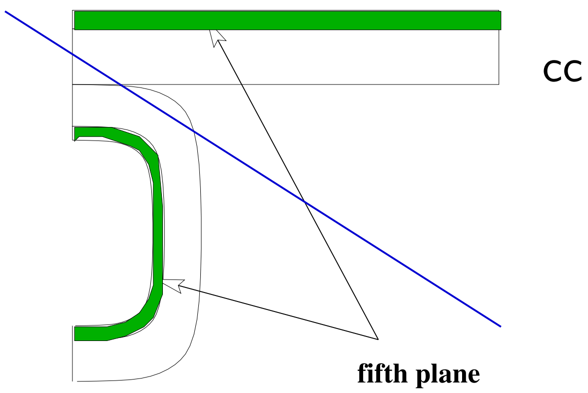


$$COSMIC\_VETO \;=\; B2C \;+\; B1C * (E1C + W1C)$$

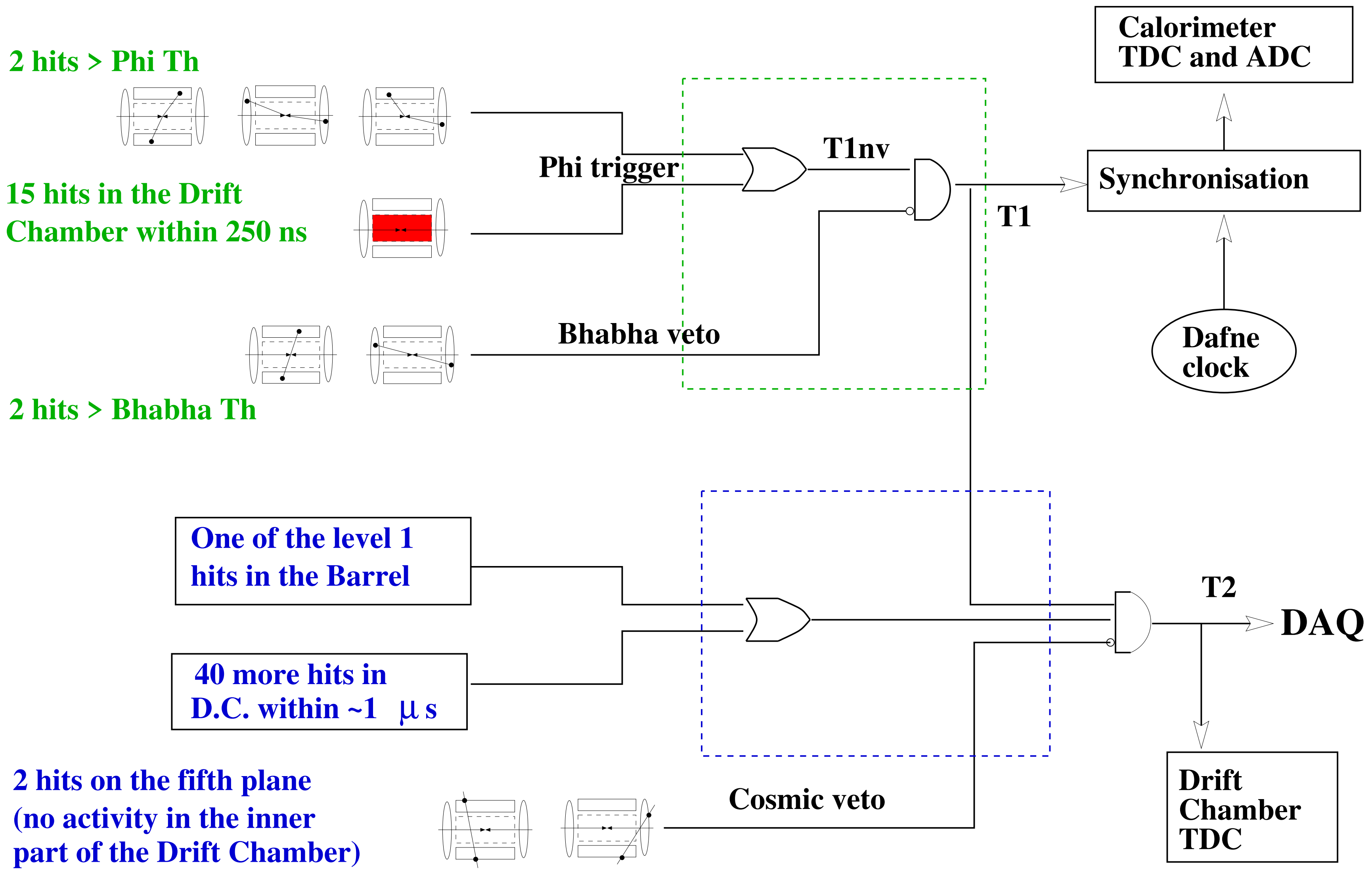
$\longrightarrow$ Efficiency $\sim 75\%$ (2.7 kHz $\longrightarrow$ 0.68 kHz)



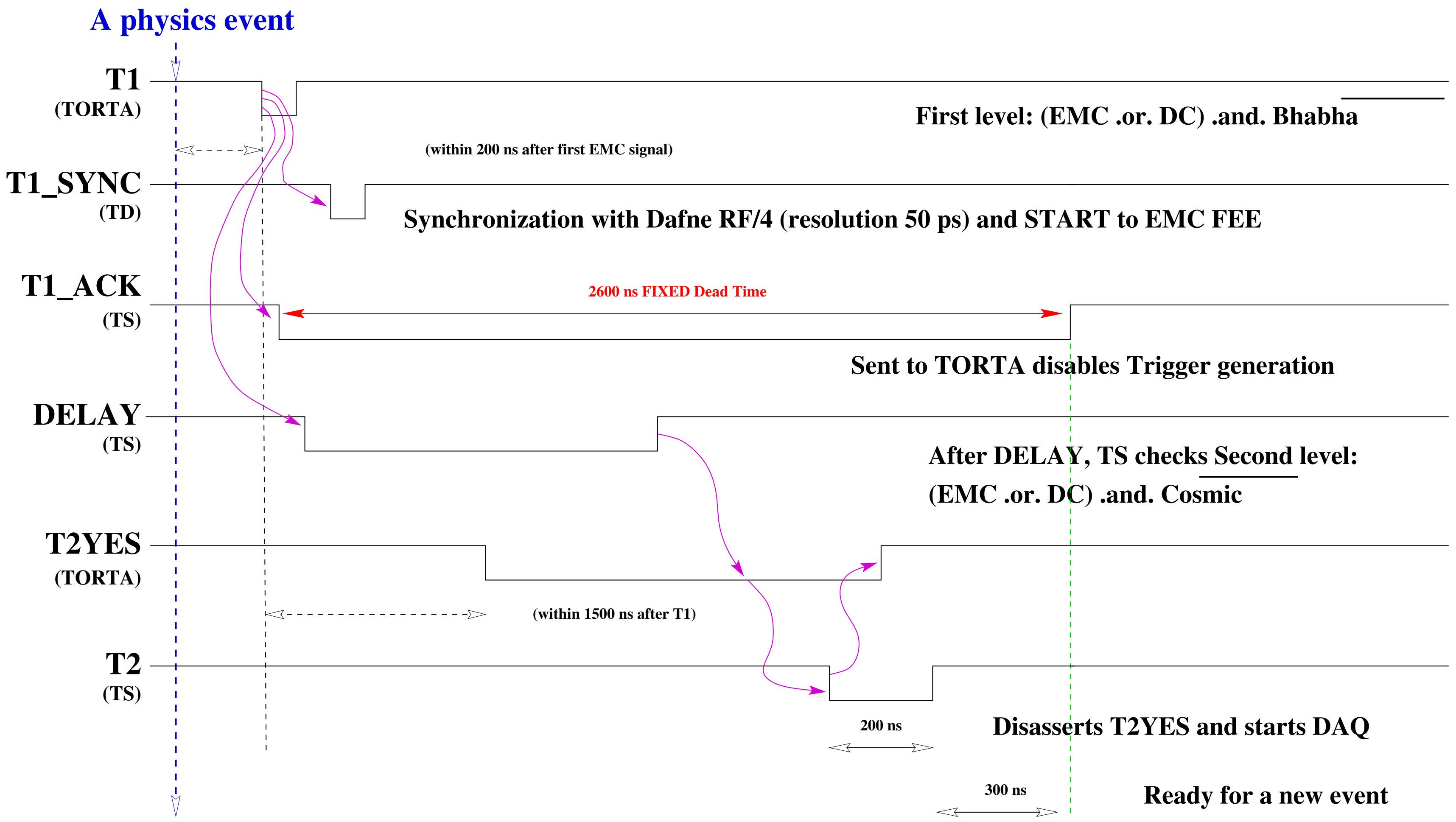
The ~25% cosmic veto inefficiency is dominated by the geometry of the apparatus



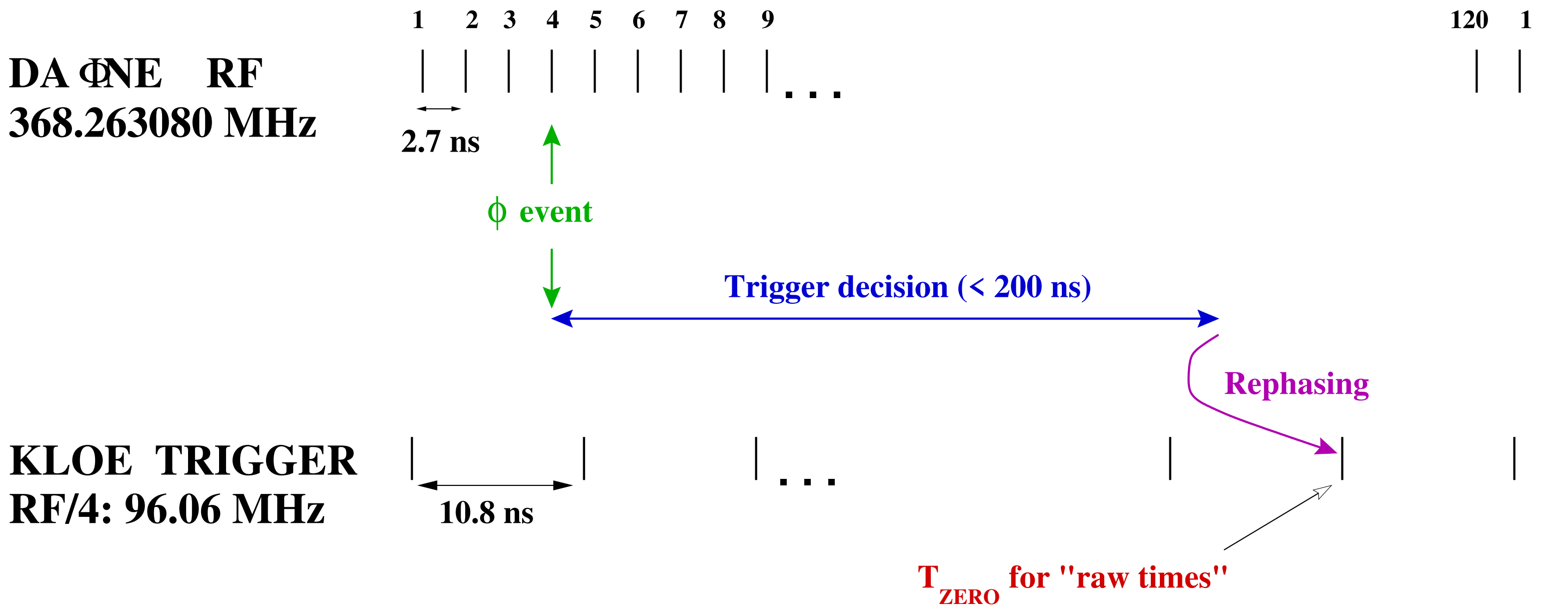
Trigger Scheme



Trigger timing



Rephasing



1 2 3 4 5 6 7 8 9 120 1
DA ΦNE RF
368.263080 MHz
. . .
2.7 ns
ϕ event
Trigger decision (< 200 ns)
Rephasing
KLOE TRIGGER
RF/4: 96.06 MHz
. . .
10.8 ns
T ZERO for "raw times"