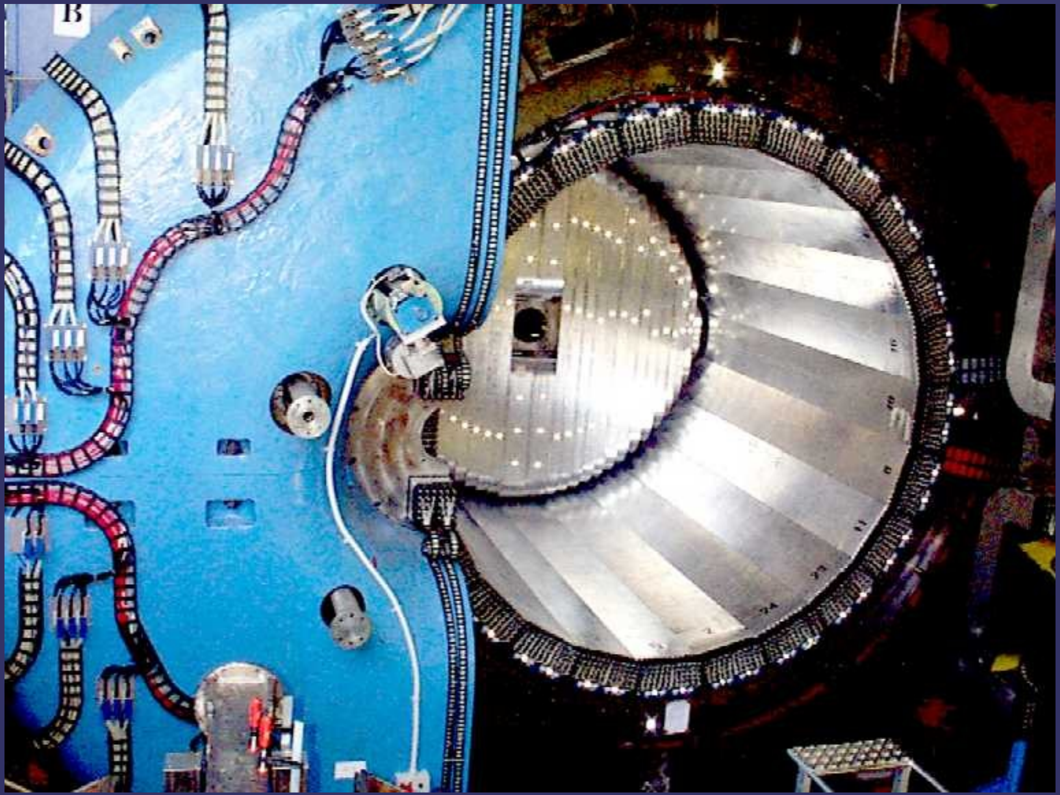
KLOE CALORIMETER

INSTR'08
Novosibirsk
4 March 2008



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(ИНФН РИМ ТРИ)

Outline

- The KLOE experiment;
- Calorimeter description;
- Calibration;
- Performances;
- Physics results

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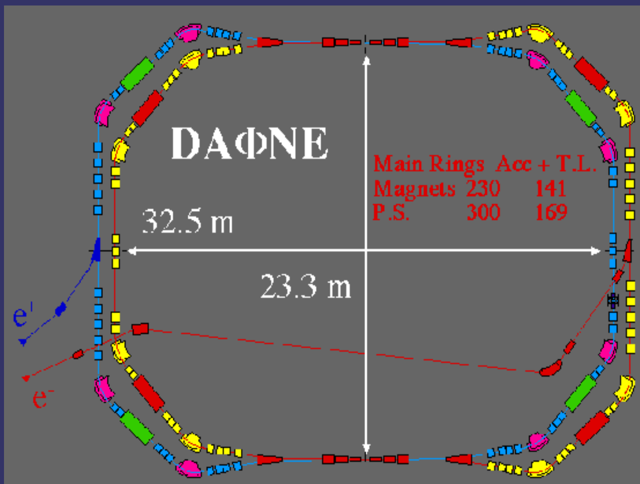
DAΦNE and KLOE

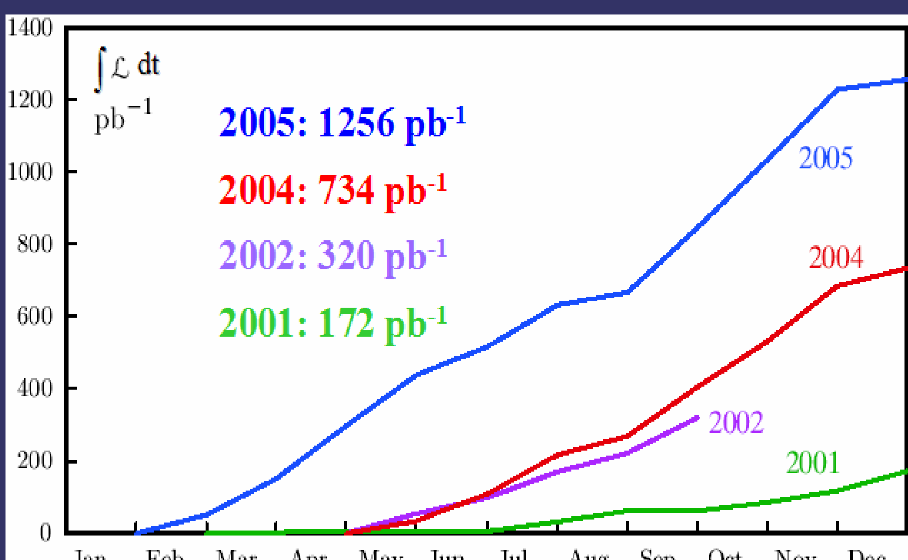
High luminosity e^+e^- collider



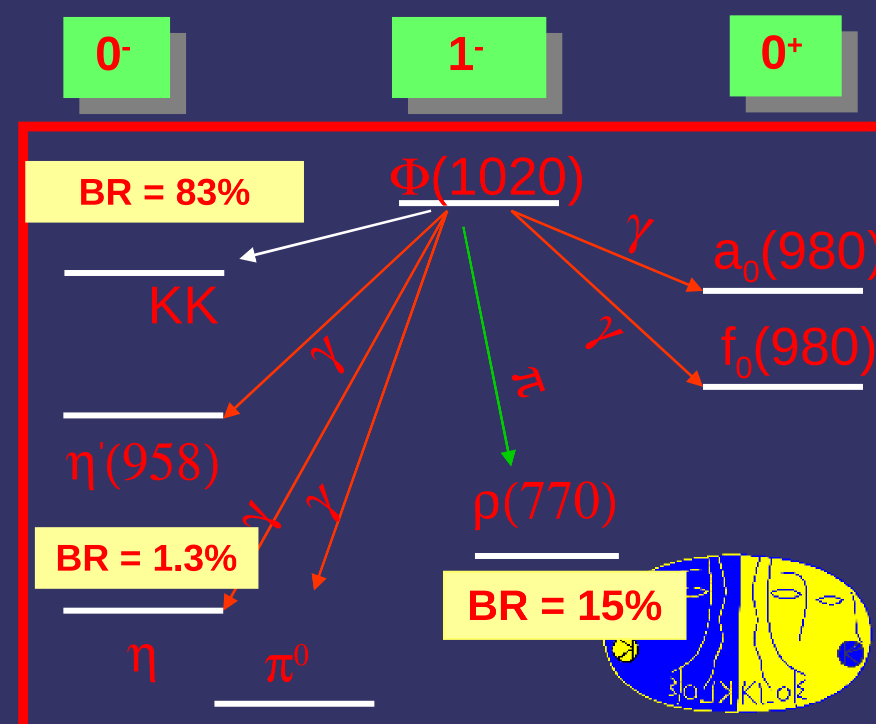
- $\sigma(e^+e^- \to \phi) \sim 3\ \mu\beta$ $\sqrt{s} = m(\phi) = 1\,019.4$ MeV
- Independent e^+e^- rings to reduce beam-beam interactions
- crossing angle: 25 mrad, $p_x(\phi)$ ~12.6 MeV/c
- Bunch crossing every 2.7 ns
- injection during acquisition

Collected luminosity (2.5 fb^{-1})

- $L_{peak} = 1.4 \times 10^{32}\ cm^{-2}s^{-1}$ $L_{int}/day = 8.5\ pb^{-1}$



Main ϕ decays



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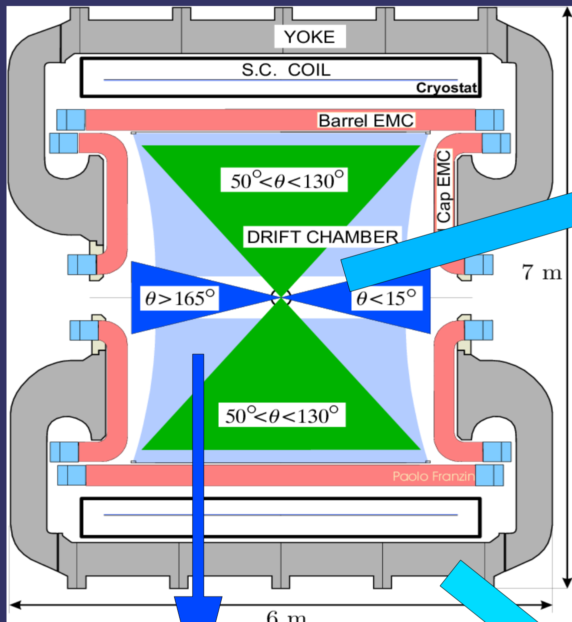
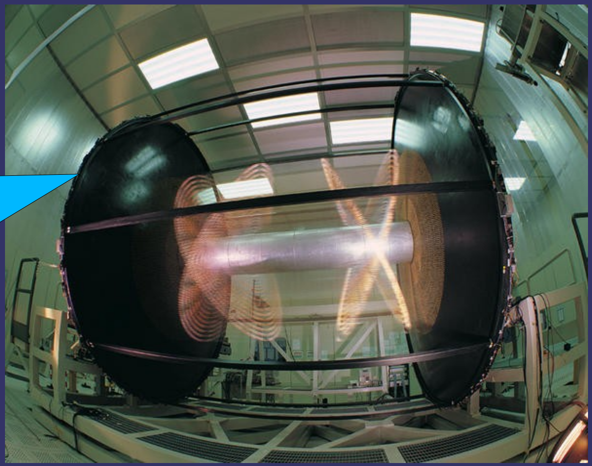
The KLOE Detector

Detector scheme





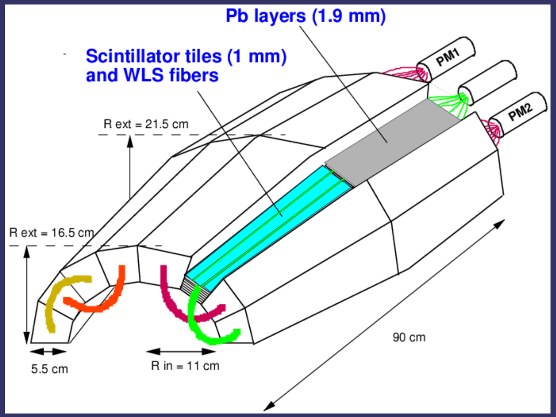
Cylindrical Drift Chamber

Stereo wires structure to re-construct longitudinal position

52140 wires – 12582 drift cell
90% He 10% iC_4H_{10}

$\sigma_{vtx} = 1$ mm $\sigma_{pt}/p_t = 0.5\%$
$\sigma_{r,\phi} = 200$ μm $\sigma_z = 2$ mm

Small angle calorimeter



Efficiency 20 – 90 % E_{ne} 26-125 MeV
$\sigma_t = 240$ ps/√E (GeV)
covered angle 23°

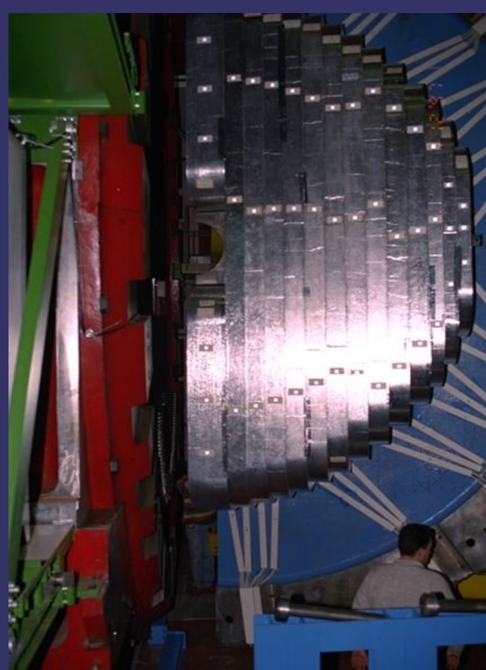
Magnetic yoke before installation.

0.5 T magnetic field
Cryogenic coil working at 4.2 °K
Coil current 2300 A

The KLOE Calorimeter

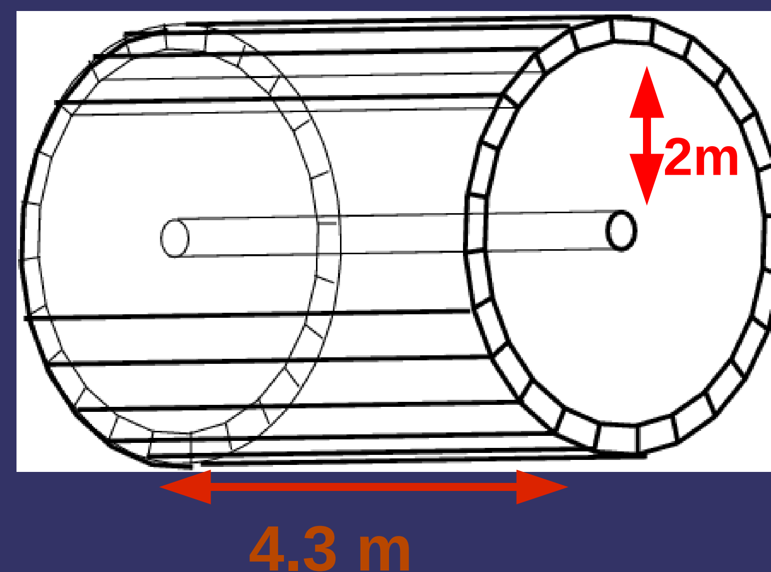
Barrel

End-cap half module



- 1 barrel + 2 end-caps
- Barrel 24 modules
- End-caps 30 modules
- 98% solid angle coverage

Calorimeter size



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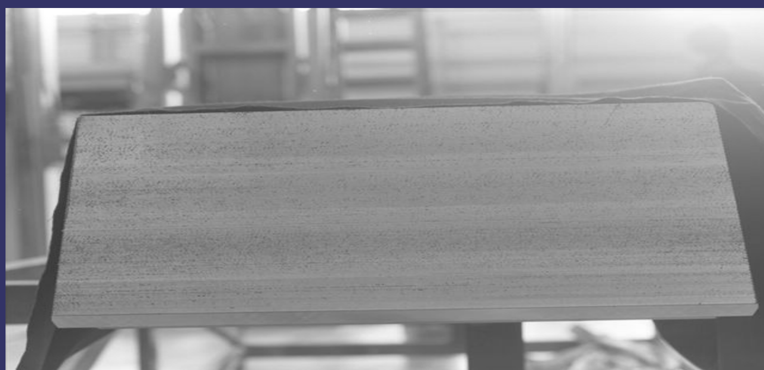
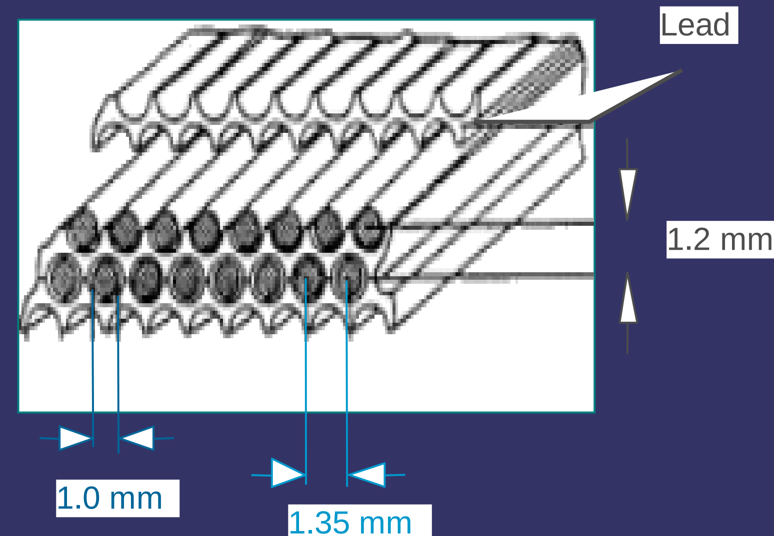
Module structure

Spaghetti calorimeter: Lead scintillating fibers structure

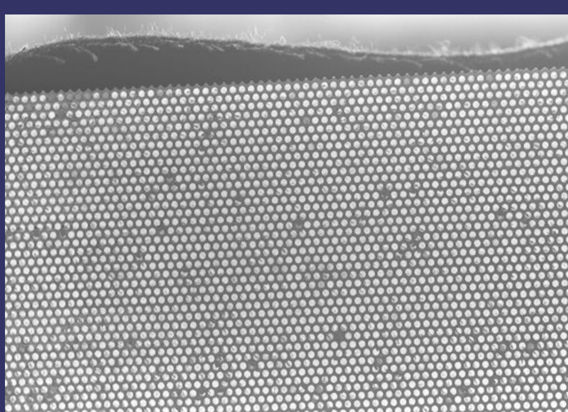
1 Module



Fiber structure scheme

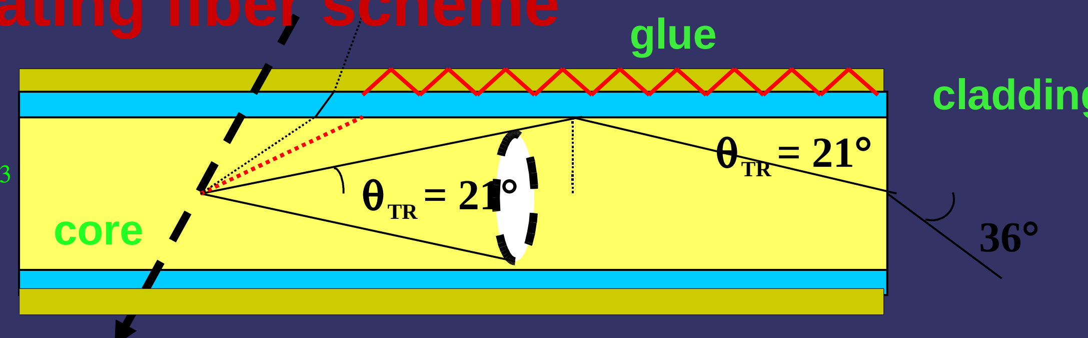


Detail of the calorimeter PM side surface



Scintillating fiber scheme

polystyrene
$\rho = 1.050$ g/cm^3

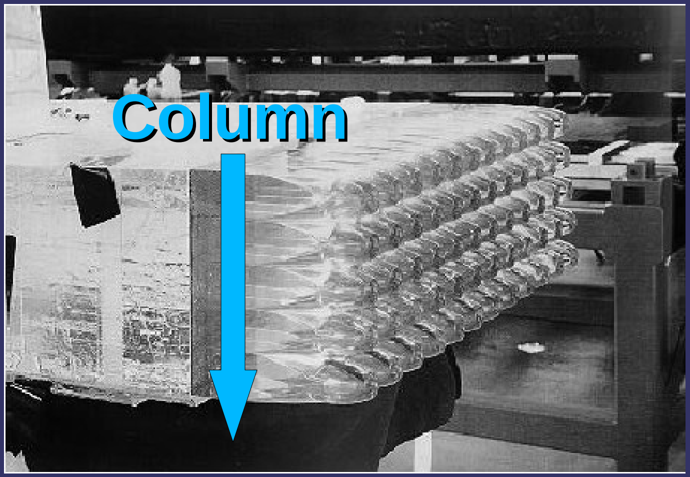


n(core=polystyrene) = 1.60
n(cladding=PMMA) = 1.49
n(glue) ~ n(core)
λ(attenuation length) = 4.5 m

Diameter 1 mm
emitting light:
blue-green region
λ_{peak}~460 nm

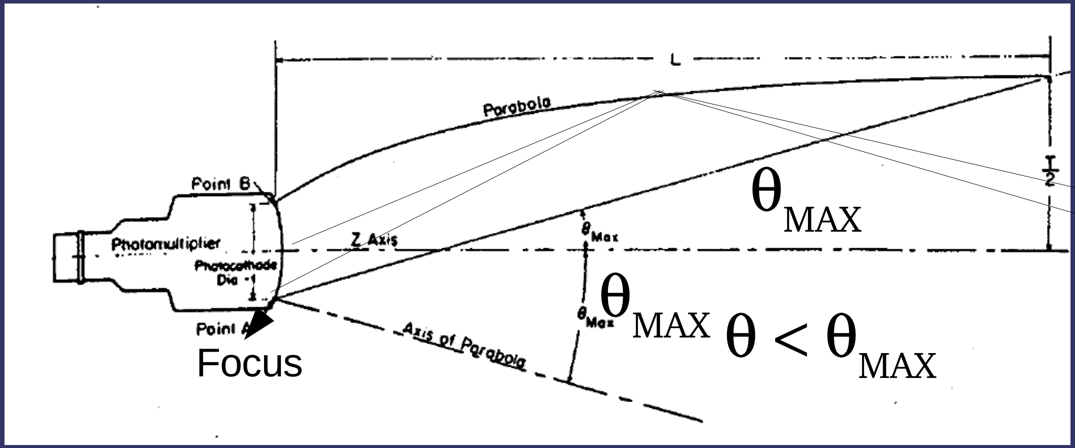
Fibers used: *Kuraray SCSF-81*
Pol.Hi.Tech. 00046 **15.000 km** of fibers

READ OUT SYSTEM



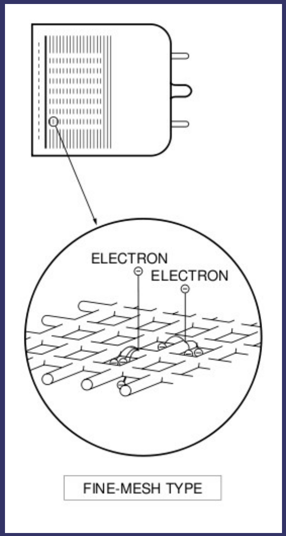
Plexiglas light guides (n=1.6)
Length 20 cm

Read out cell 4.4 x 4.4 cm^2
Geometry: Winston cone.



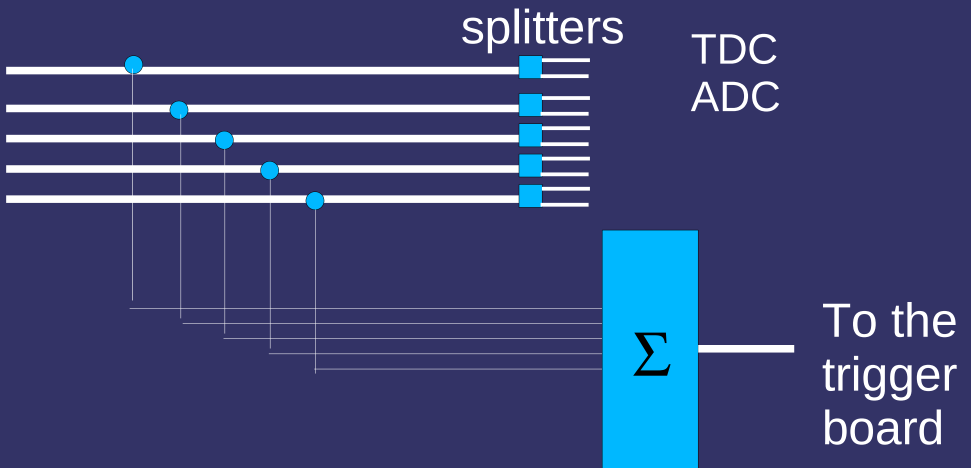
Fine-mesh photo multipliers (1.5')
Hamamatsu **R5960**
Working field: B = 0.1 – 0.2 T, 0° < θ < 30°

Fine-mesh
dynode



Splitting and summing circuit (SDS)

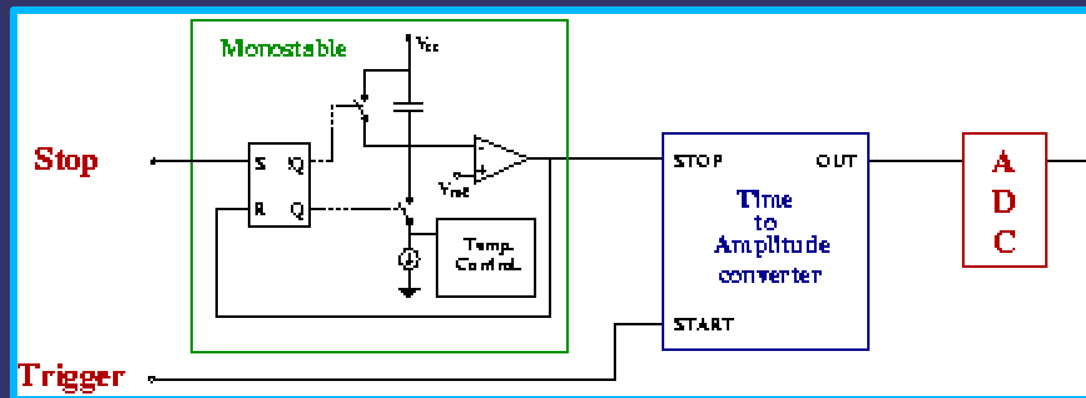
PMT signal 1 column



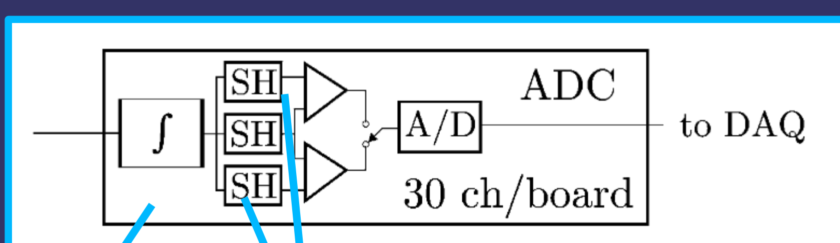
TDC and ADC scheme

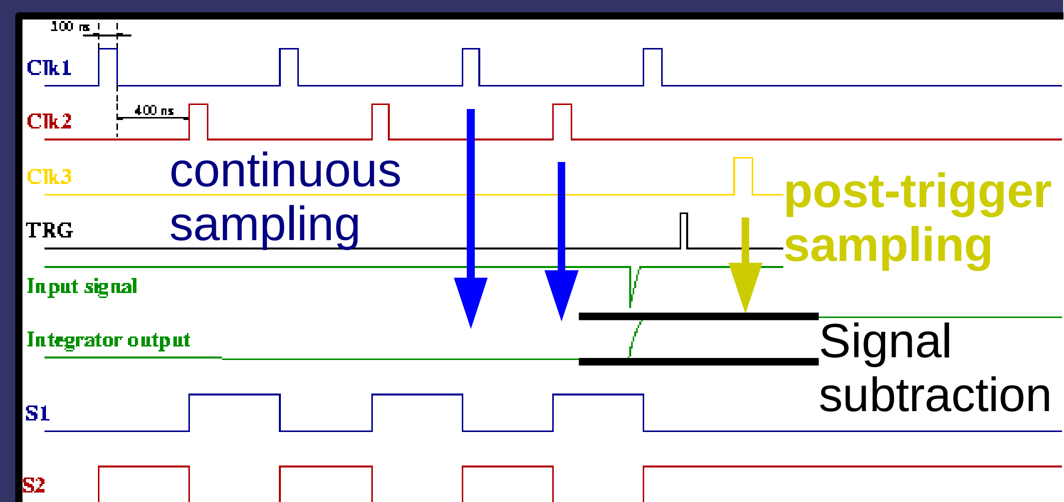
The signal precedes the trigger of ~ 220 ns (monostable is used to delay discriminated signal)

TDC full scale 220 ns (need to acquire low β Kaons)



To avoid a too long delay line the ADC works in continuing acquisition.



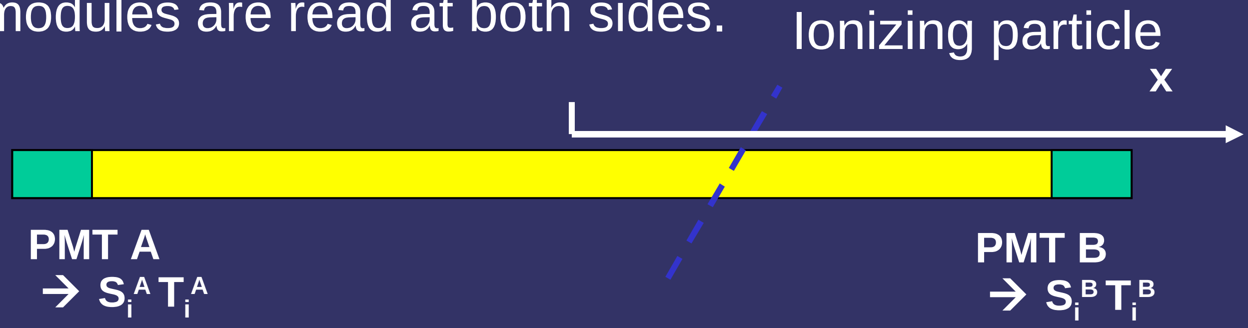


Large decay time integrator

Continuous signal sampler with a 900 ns period.

Energy and time measurement

The modules are read at both sides.



$T^{A,B}$ time at side A,B

$S^{A,B}$ charge collected at A,B

$$E_i^{A,B} = \frac{S_i^{A,B} - S_{o,i}^{A,B}}{S_{M,i}^{A,B}} \times \kappa_E$$

Pedestal charge (determined with fake trigger signals at each triplet)

MIP charge measured with a dedicated cosmic rays run at the beginning of DATA taking.

Absolute calibration constant determined using $e^+e^- \rightarrow \gamma\gamma$ (510 MeV clusters) run by run (24000 events).

$$E_i(MeV) = \frac{E_i^A A_i^A(x) + E_i^B A_i^B(x)}{2}$$

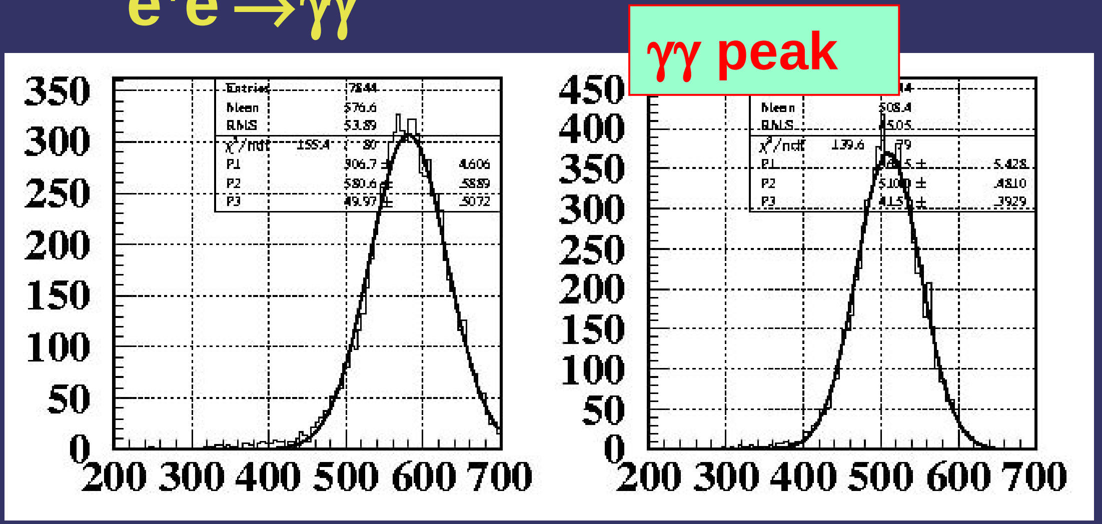
Attenuation factor (determined using cosmic rays run at the beginning of DATA taking period)

Triplet: calibration runs performed each 3-4 days of data taking

Energy scale calibration

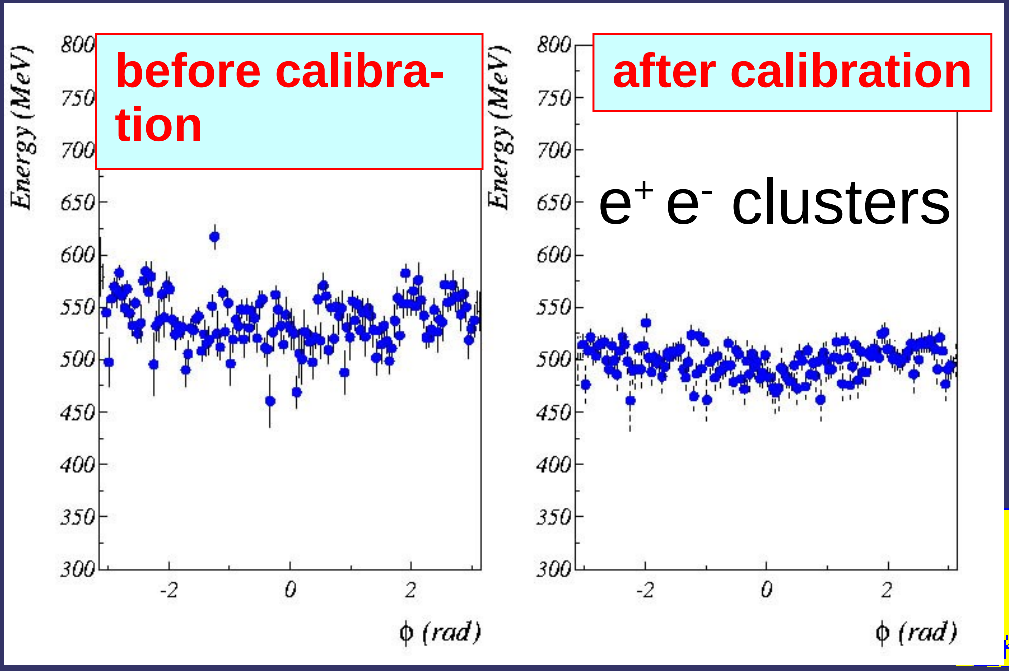
$e^+e^- \to \gamma\gamma$

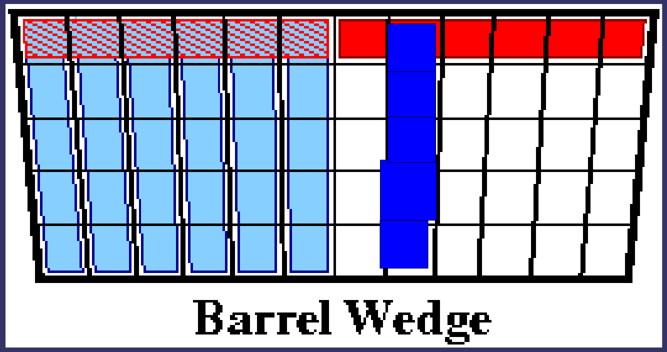
The k_E constant is evaluated each 200 nb^{-1} of data by imposing $M_\phi/2$ on the $\gamma\gamma$ peak. Error is ~1% on barrel and 2% on endcaps.



$e^+e^- \to e^+e^-$

Run by run PM gain variations are corrected on a **column-by-column** basis requiring uniform response to e^+ e^- clusters from Bhabha events.

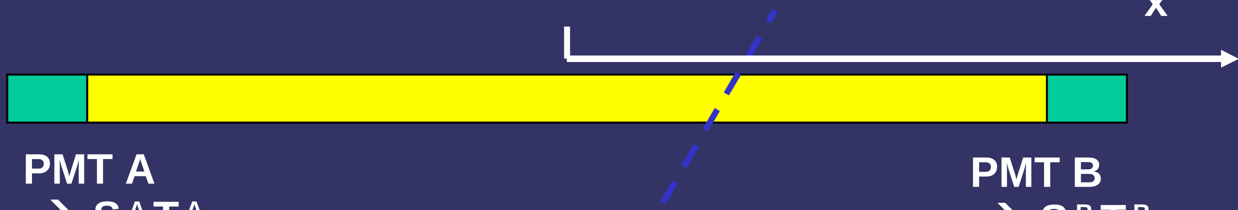




Time measurement 1/2

The modules are read at both sides.

Ionizing particle



PMT A
→ $S_i^A T_i^A$

PMT B
→ $S_i^B T_i^B$

$T^{A,B}$ TDC counts at side A,B
$S^{A,B}$ charge collected at A,B

TDC scale

TDC offset

Module length

$$t_i^{A,B}[\mathrm{ns}] = c_i^{A,B}\,(T_i^{A,B} - T_{0,i}^{A,B})\ [\mathrm{tdc\ counts}]$$

$$t_i = \frac{t_i^A + t_i^B}{2} - \frac{t_{0,i}^A + t_{0,i}^B}{2} - \frac{L}{2v} - t_o^G$$

$$z_i(\mathrm{cm}) = \frac{v}{2}\left[(t_i^A - t_i^B) - (t_{0,i}^A - t_{0,i}^B)\right]$$

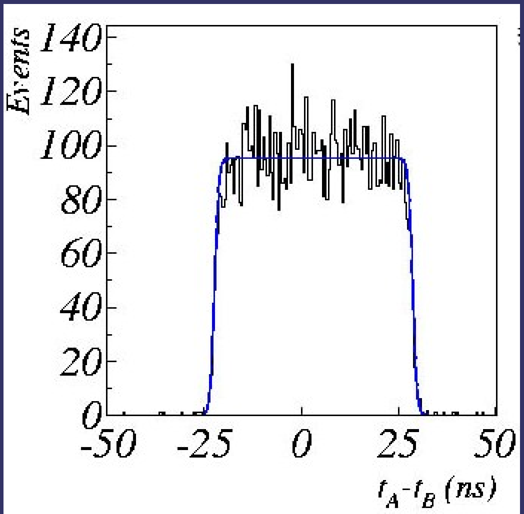
Measured using t-r/c run by run

Light velocity in fiber (calibrated using cosmics at each triplet)

TDC time offset: calibrated cell by cell using cosmic rays at each triplet, and on a column basis using $e^+e^- \to \gamma\gamma$

Allows to reconstruct Z

Distribution from triggered cosmic rays



1st step
Determination of $t_0^A - t_0^B$ from mean of this distribution
Determination of v from width (+ module length)

Time calibration cosmic rays

Using the cosmic rays data-set

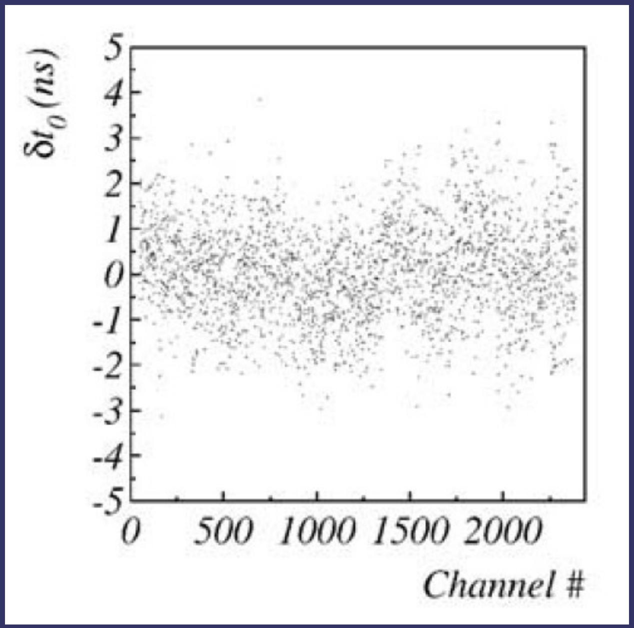
- Select cosmic rays >7 GeV/c
- use all cells connected to the 2 clusters to find *cos*θ of the track.
- assume the particle is moving downward at light velocity for each cell

$$t_i = t_{i,0} + Y_i / v_y \qquad (v_y = c \cdot \cos\theta)$$

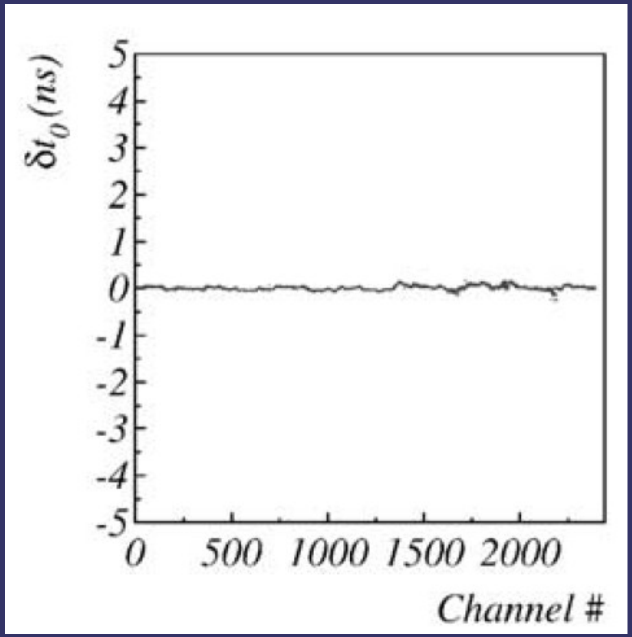
get $\mathbf{t_{i,0}}$ residual

- use average cell residuals over the run to correct next iteration
- 10 iterations.
- Final stat. error on $t_{i,0}$ is 50 ÷ 80 ps according cell illumination

At 1st iteration



At last iteration

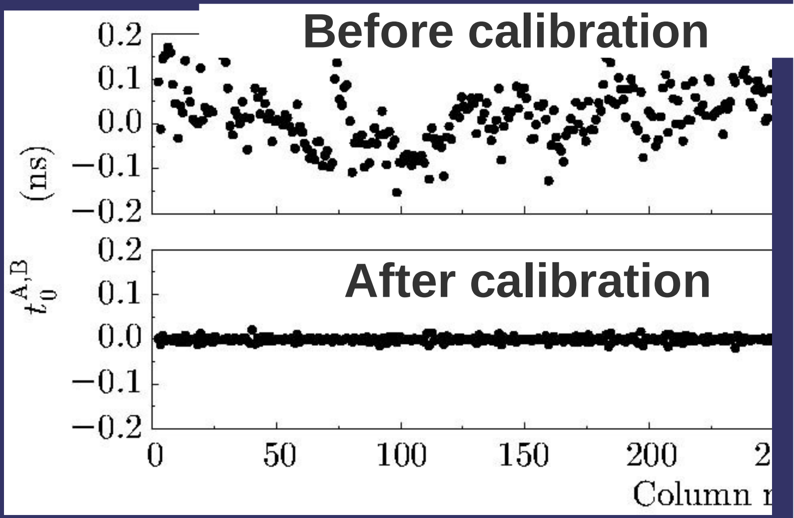


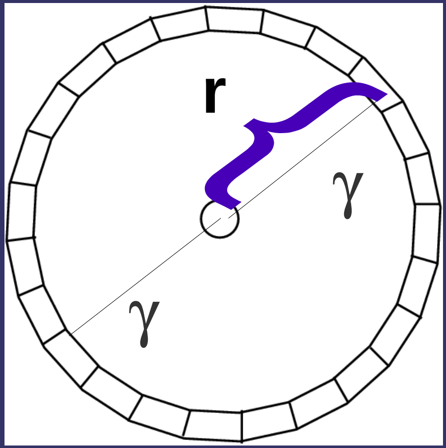
Time calibration $e^+ e^- \rightarrow \gamma\gamma$

Calibration performed run by run on a **column by column** basis imposing time of flight of photons to inter-calibrate time response t^A_0, t^B_0

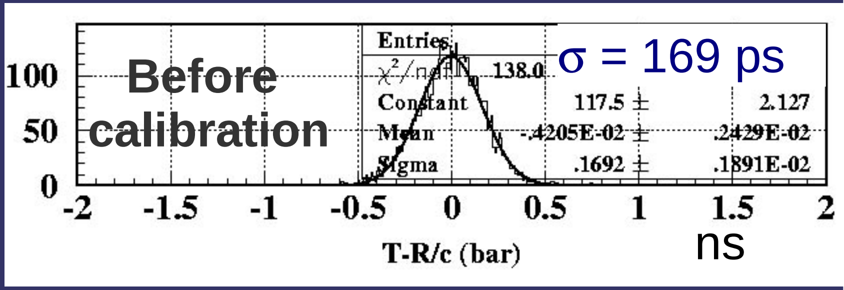
1) t - R/c for each γ cluster is computed;
2) the residual is applied as a correction for next iteration;
3) convergence obtained after 3 iterations;
4) statistical error at level of ±20 ps;
5) Allow compensation of calibration drifts before cosmics recalibration.

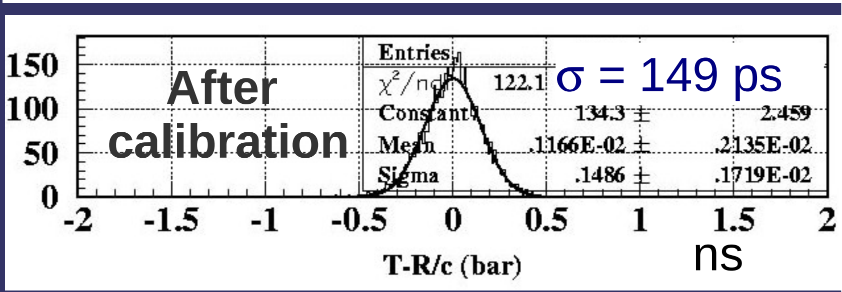
column by column t_0



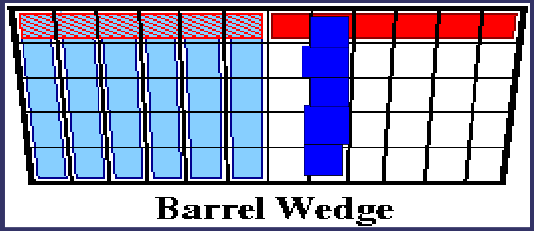


Distribution on the whole barrel





The correction is applied to all cells of the same column



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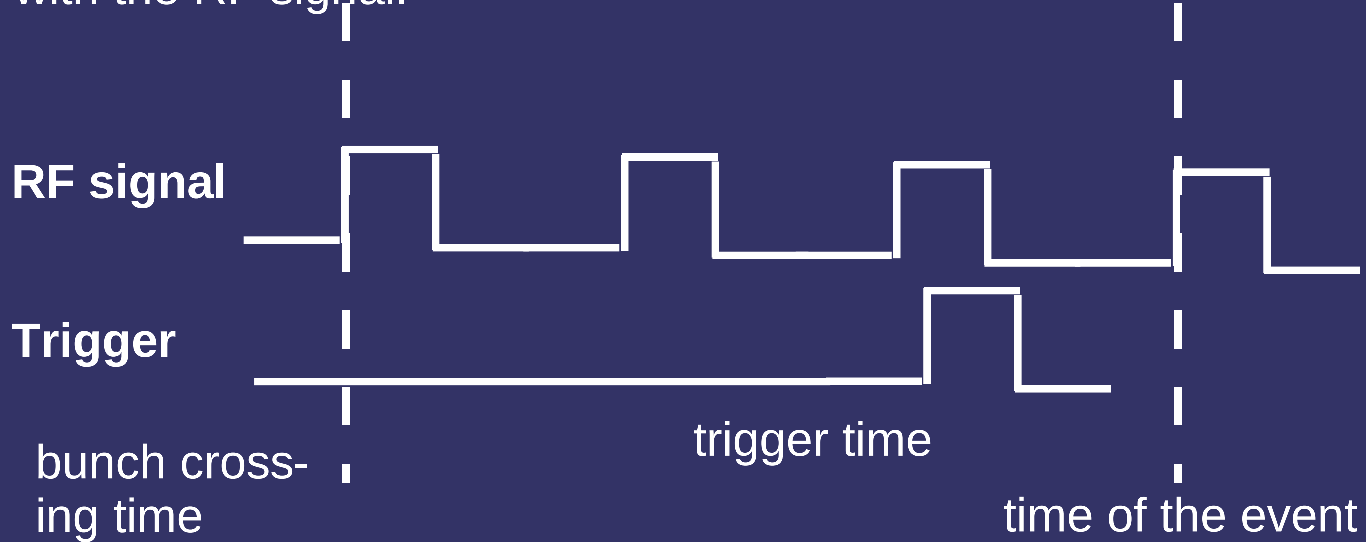
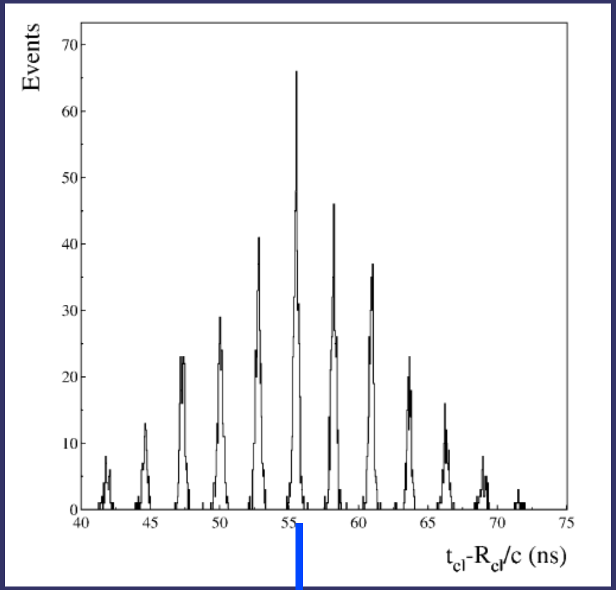
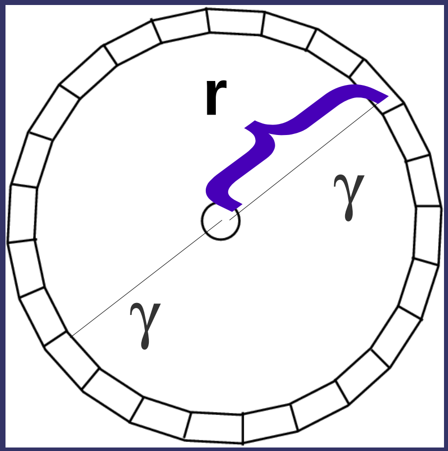
t^G_0 determination $e^+ e^- \to \gamma\gamma$

In order to not spoil time resolution trigger is synchronized with the RF signal.





Set t^G_0, correct bunch crossing is determined at analysis level.

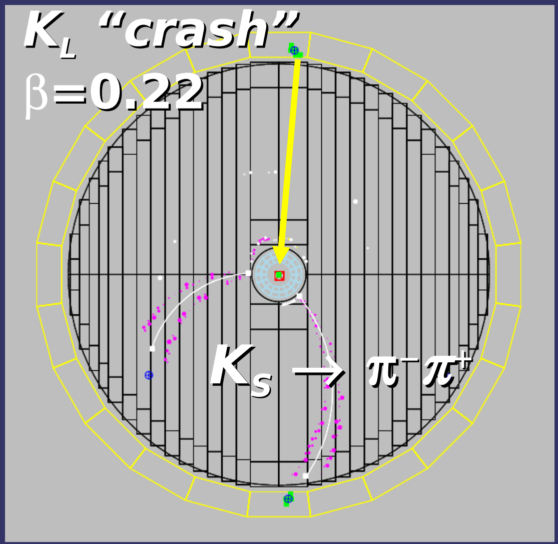


After all corrections

$t - r/c = nT_{RF}$

$n = Int[(t-r/c)/T_{RF}]$

T_{RF} = 2.715 ns



After all corrections

$t - l_{trk}/v_\pi = nT_{RF}$

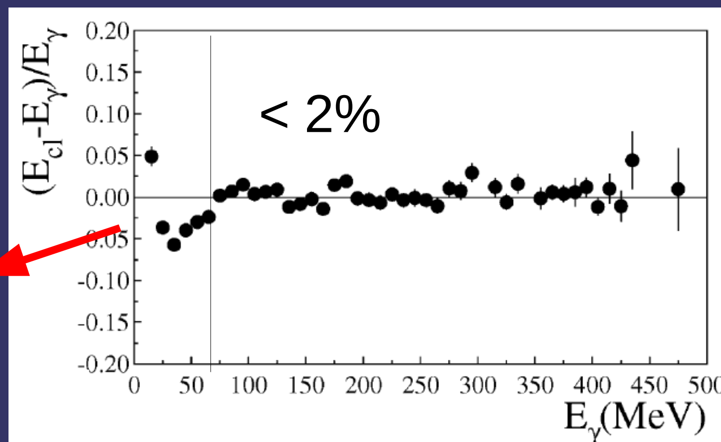
$n = Int[(t-l_{trk}/v_\pi)/T_{RF}]$

Calorimeter performances

Energy response measured using $e^+e^- \rightarrow e^+e^-\gamma$

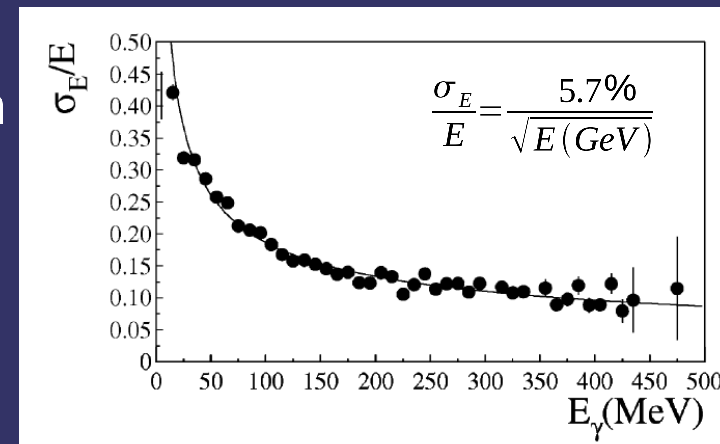
γ energy E_γ from e^+e^- momenta.

Linearity



5% near threshold (corrected at analysis level)

Energy resolution

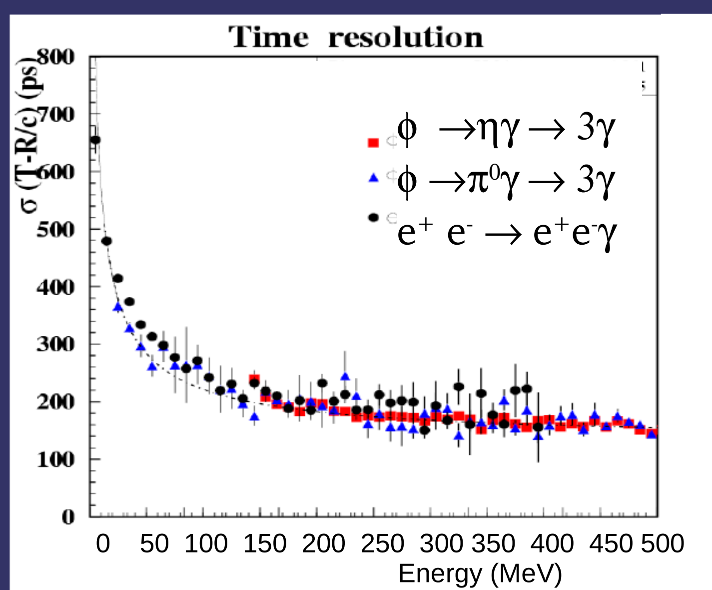


E_γ computed from kinematic fit

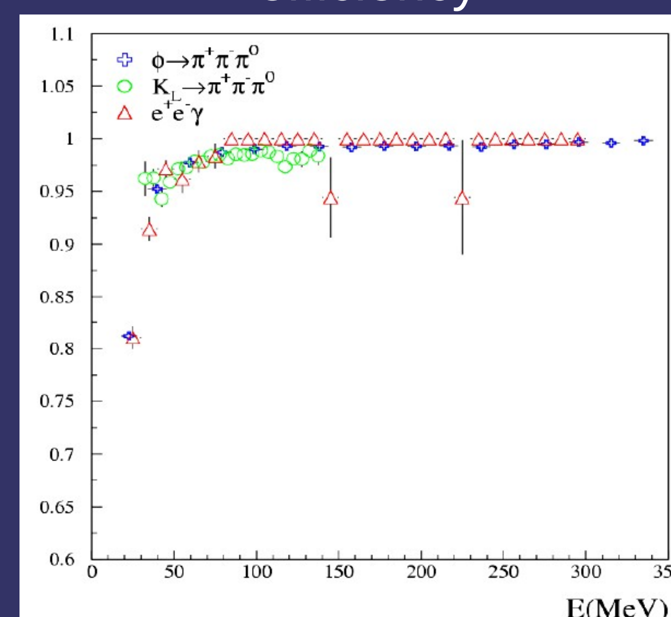
$$\sigma_t = \frac{54\ ps}{\sqrt{E(GeV)}} \oplus 140\ ps$$

50 ps inter-calibration

130 ps bunch length and coincidence jitter.



efficiency



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Analysis technique full neutral events at IP

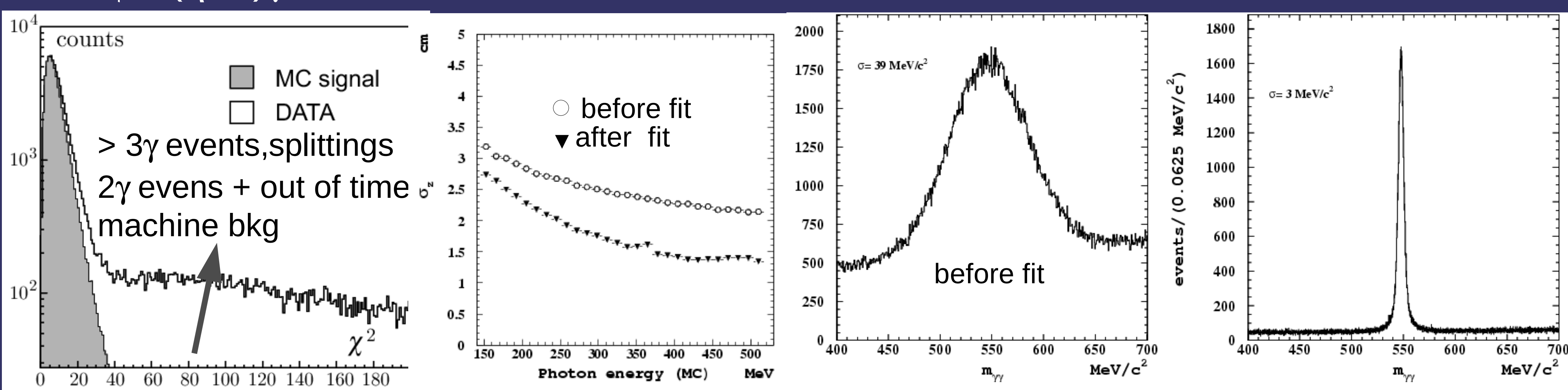
- Excellent time resolution and azimuthal angular resolution 5 mrad (~1 cm / 200 cm ~)
- ϕ momentum measured run by run from ~ 40000 Bhabha events (60 keV stat. error on $\sqrt{s}$– absolute calibration performed using m_ϕ from CMD-2)

constrained fit

Photon TOF
Energy momentum conservation

- χ^2 Powerful discriminating variable
- Fitted energy – insensitive to the calorimeter energy scale ($\sigma_{Efit} \sim 1/20\ \sigma_E$)
- Longitudinal cluster position improved by a factor 2

$\phi \to (\eta,\pi^0)\gamma$



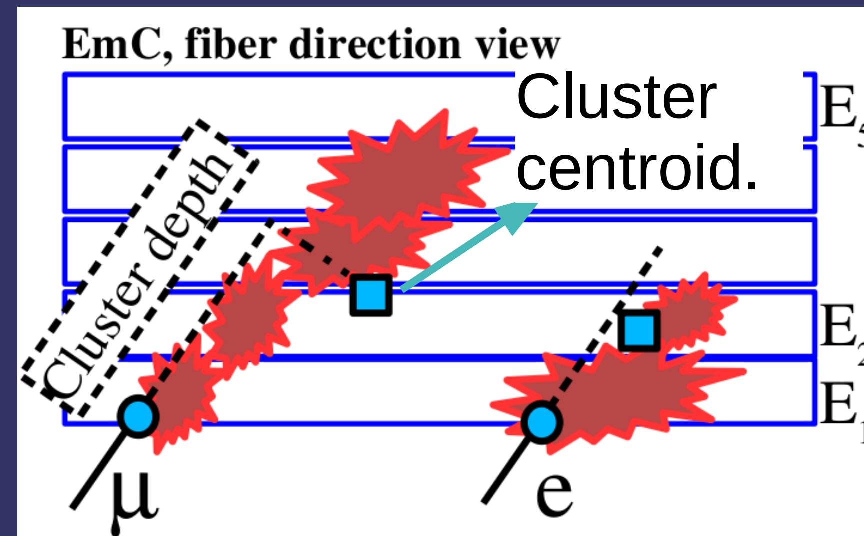
JHEP-12 (2007) 073 :

$$m_\eta = 547.874 \pm 0.007 \pm 0.029\ \text{MeV}$$

$< 10^{-5}$ syst. error calorimeter energy scale and linearity

3×10^{-5} syst. error from module position knowledge

PID capability e/μ discrimination



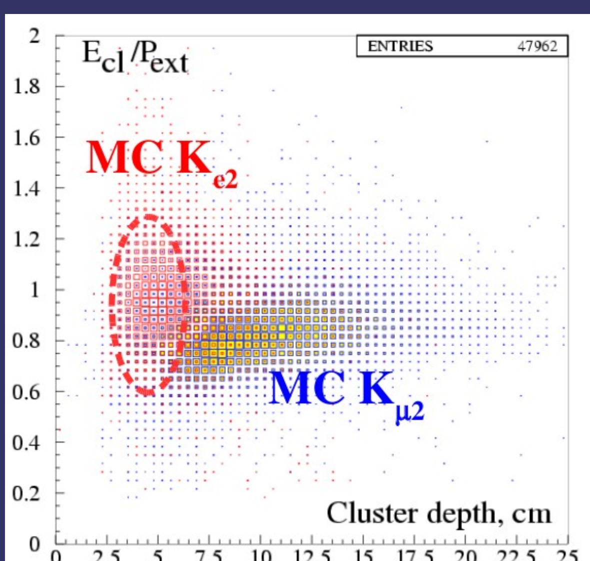
Lepton flavor violation

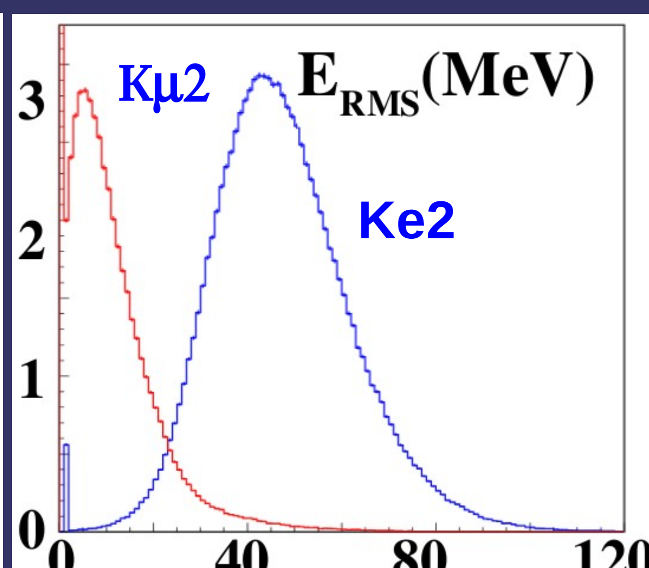
$K^{\pm} \to e^{\pm}\nu / \mu^{\pm}\nu \sim 2.5 \times 10^{-5}$

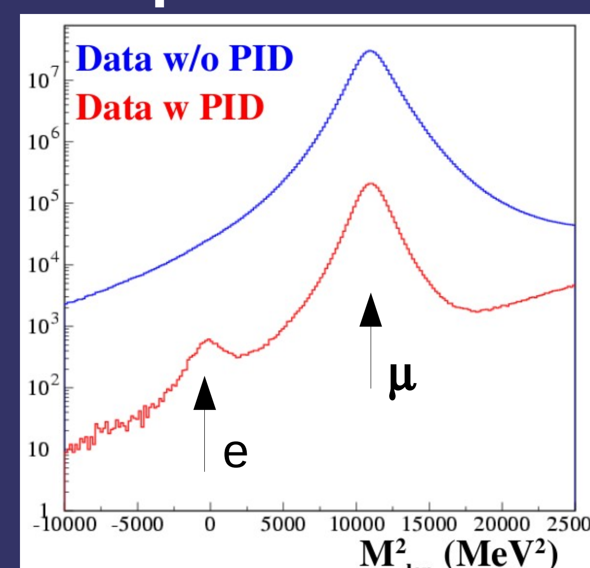
Cluster shaping variables exploring different interaction length in calorimeter.

P_μ < 500 MeV (stop in calorimeter)

Lepton mass







PID rejection power: 100

PID capability μ/π discrimination

Neural network construction using the following inputs:

$$\Delta T = T_{clu} - \frac{L_{trk}\sqrt{p_{trk}^2 + m_\mu^2}}{c p_{trk}}$$

Expected time in μ hypothesis

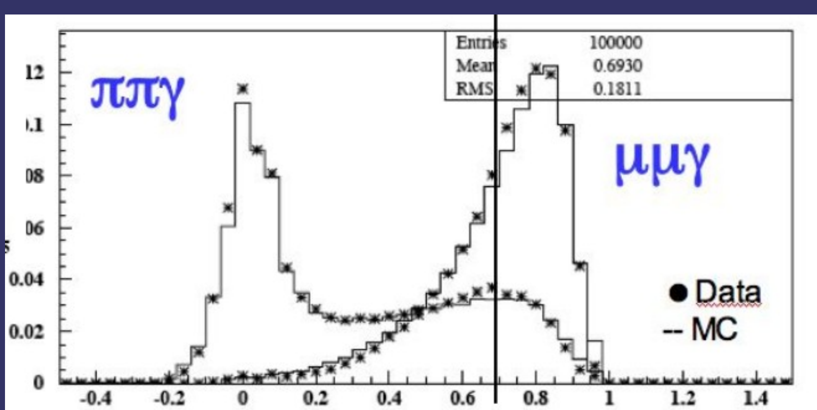
$$|\vec{r}_{clu} - \vec{r}_{ext}|$$

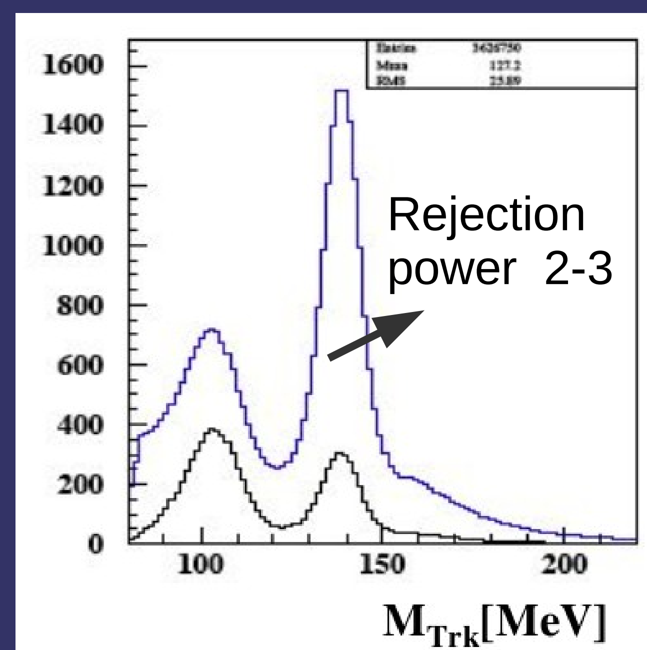
Expected cluster position in μ hypothesis

$$\frac{E_{clu}}{\sqrt{p_{trk}^2 + m_\mu^2}}$$

Expected energy in μ hypothesis

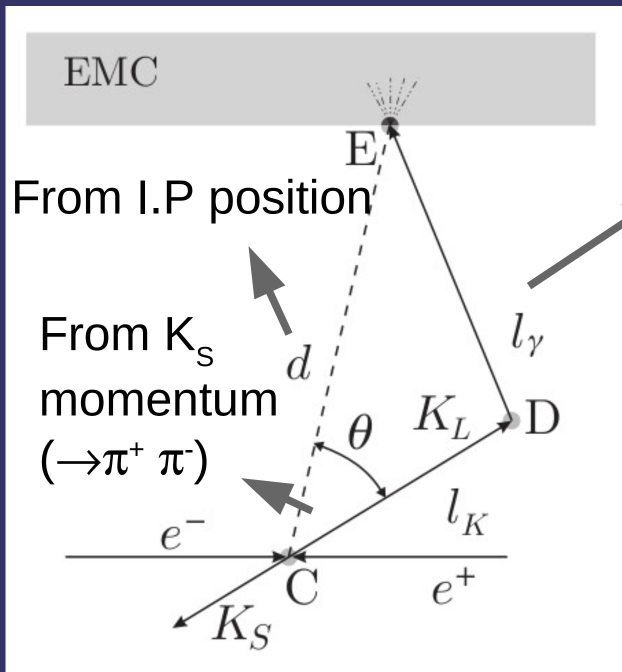
$e^+ e^- \rightarrow \mu^+ \mu^- \gamma$/ $e^+ e^- \rightarrow \pi^+ \pi^- \gamma$



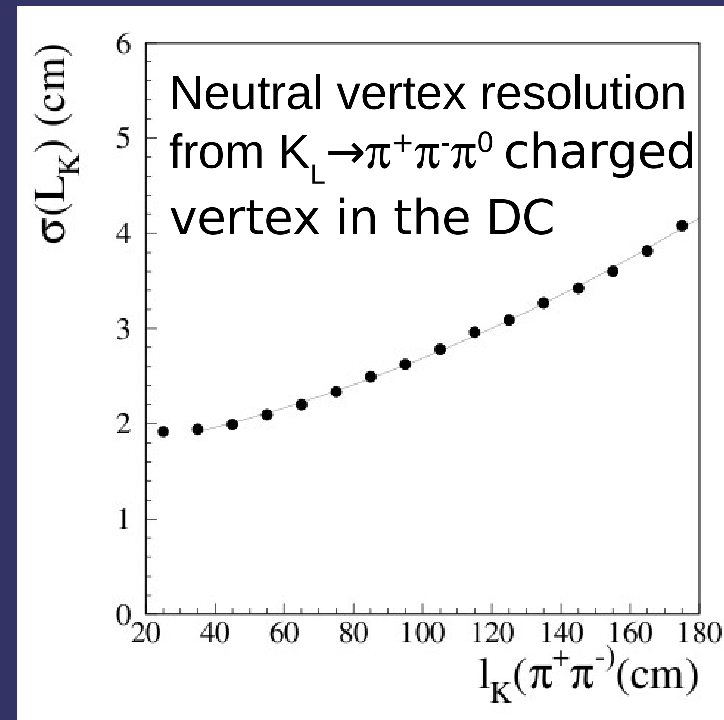


M_{trk} from track momentum and 3 body kinematic in hypothesis of 0 missing mass.

Neutral vertex in $K_L \rightarrow 3\pi^0$

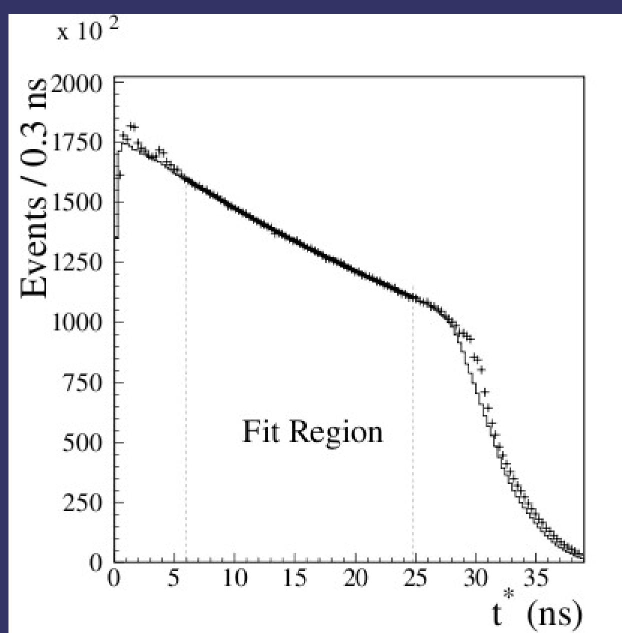


From I.P photon ToF



Proper time
$t^* = l_K/\beta\gamma$

From K_S momentum



$\tau = 50.92 \pm 0.17_{stat.} \pm 0.25_{syst.}$ ns

Calorimeter related systematics

50 ps Vertex correction
35 ps Absolute time scale

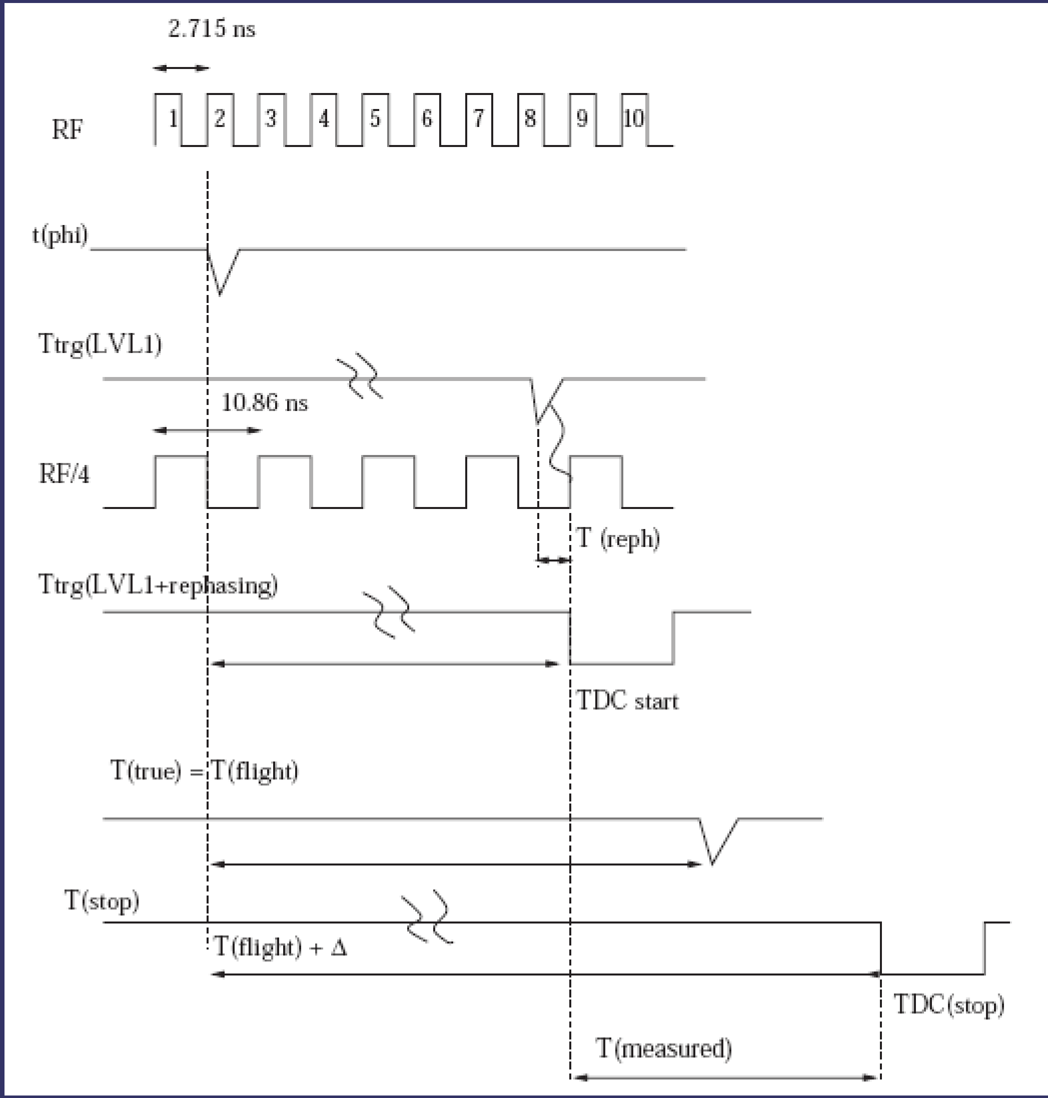
Conclusions and outlook

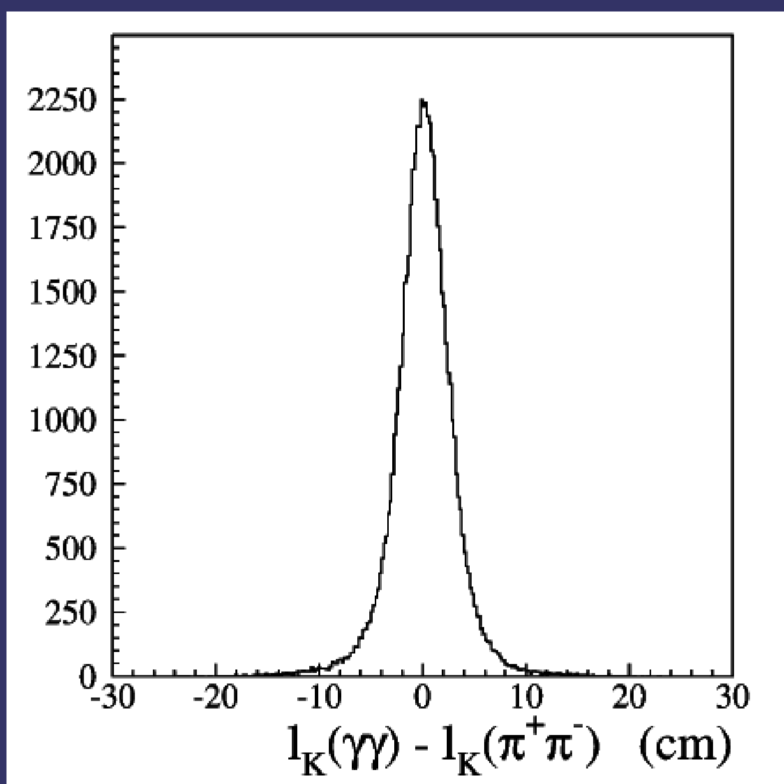
- Good performance of the detector above all for ToF measurement and e/(μ,π) discrimination;
- Improvements under studies for detector upgrade (KLOE-2) :
  - High quantum efficiency (possible implementation)
  - Higher granularity using Multi-anode (proof of concept).

спасибо

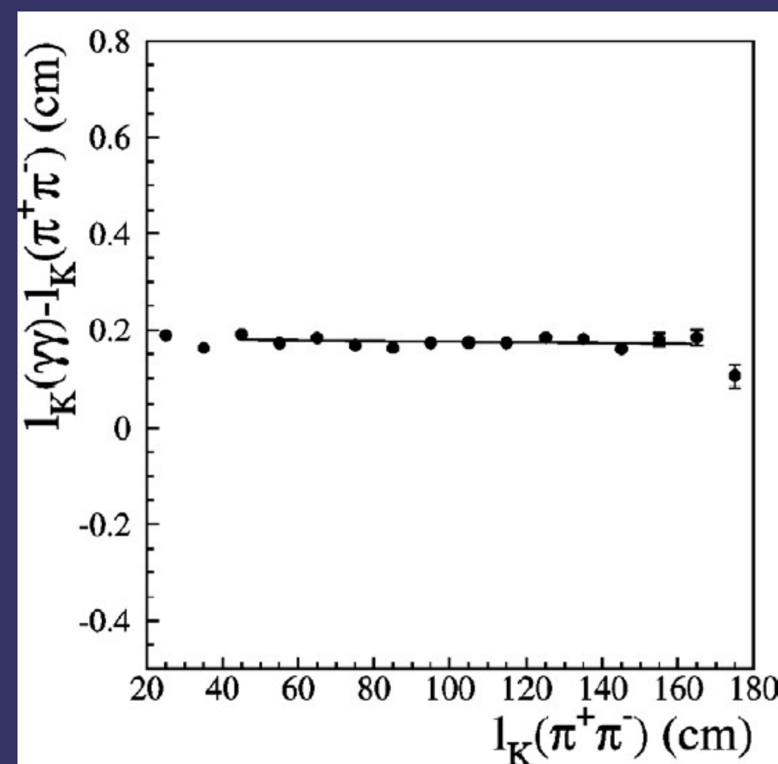
Backup Slides

Б. ДИ МИККО

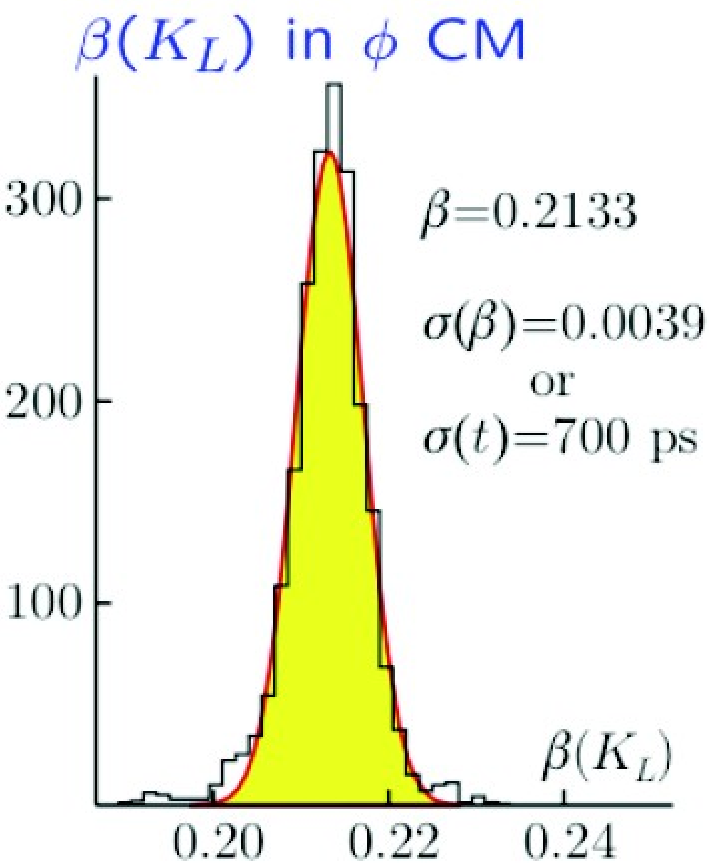

2.715 ns
RF
1
2
3
4
5
6
7
8
9
10
t(phi)
Ttrg(LVL1)
10.86 ns
RF/4
T (reph)
Ttrg(LVL1+rephasing)
TDC start
T(true) = T(flight)
T(stop)
T(flight) + Δ
TDC(stop)
T(measured)



2250
2000
1750
1500
1250
1000
750
500
250
0
-30
-20
-10
0
10
20
30
$l_K(\gamma\gamma) - l_K(\pi^+\pi^-)$ (cm)

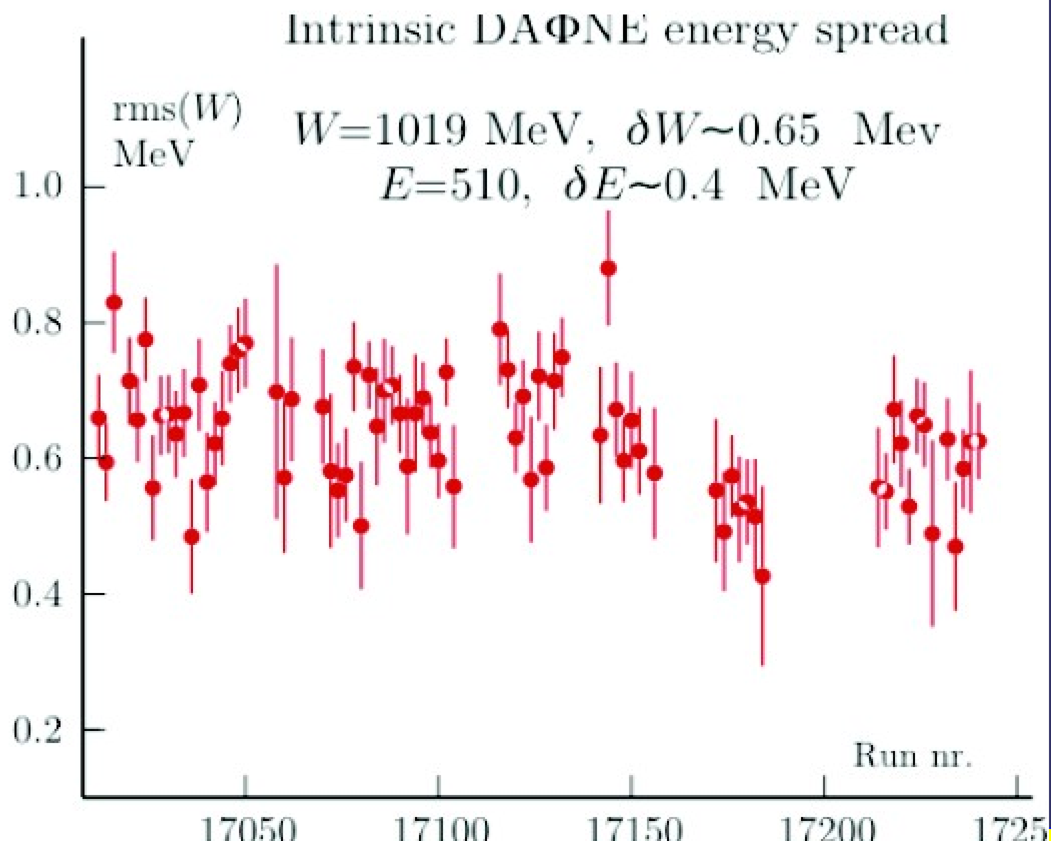


0.8
0.6
0.4
0.2
0
-0.2
-0.4
$l_K(\gamma\gamma)-l_K(\pi^+\pi^-)$ (cm)
20
40
60
80
100
120
140
160
180
$l_K(\pi^+\pi^-)$ (cm)



Reconstruction of β^* depends on the φ boost. Its width measures the machine energy spread

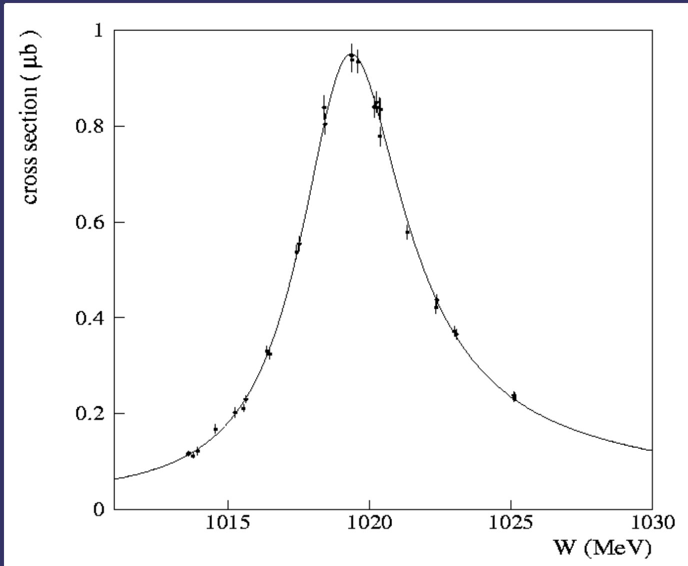
$\delta E_\phi \sim 1$ MeV $\Rightarrow \delta\beta^* \sim 0.004$



$\sqrt{s}$ absolute calibration

The $\sqrt{s}$ is measured run by run using $e^+e^- \to e^+e^-$ @ $\tau_\gamma > 50^\circ$ (~ 40,000 each 2h of data taking)

The absolute scale is determined fitting the $e^+e^- \to K_S K_L$ cross section



The fit takes into account the ISR effect and the phase space factor of the KK couple.
The fitting function is the same used by CMD-2 at VEPP-2M.

We obtain: $m_\phi = 1019.329 \pm 0.011$ MeV

To compare with:

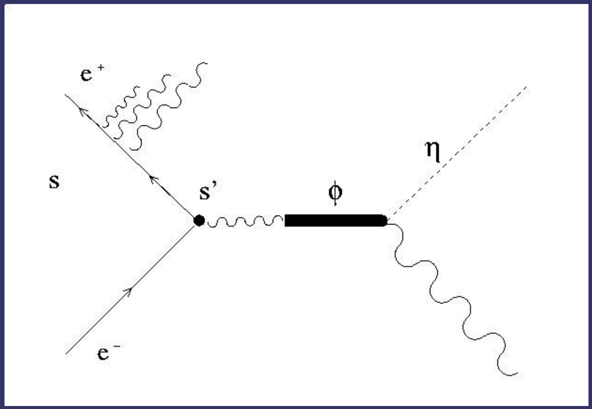
m_ϕ (CMD-2) = 1019.483±0.011±0.025 MeV

Phys. Lett. B508, 217

VEPP-2M very good knowledge of beam energies through resonant depolarization technique.

The ratio m_ϕ (CMD-2)/m_ϕ (KLOE) is used to set the absolute $\sqrt{s}$ scale.

ISR correction



The energy available for the ϕ decay is lower than the e^+e^- beam energy.

It produces an important correction Δ to the measured η mass.

The correction has been evaluated on MC and checked with DATA as a function of $\sqrt{s}$