CLUster COUnting Drift Chamber for ILC (a viable alternative to TPC?)

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(on behalf of the *4th Concept*)

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CLUster COUnting Drift Chamber for ILC

OUTLINE

- The KLOE Drift Chamber and its performance
- CLUster COUnting and expected performance
- Proposal for a Central Tracker at ILC
- Status and Perspectives

The KLOE Drift Chamber

($e^+e^- \rightarrow \Phi \rightarrow KK$ @ DAFNE, Frascati)

Requirements:

- large tracking volume (K_L decay length = 340 m);
- uniformity and isotropy because of K decays;
- transparency to reduce K regeneration, multiple scattering and conversion of low E photons.

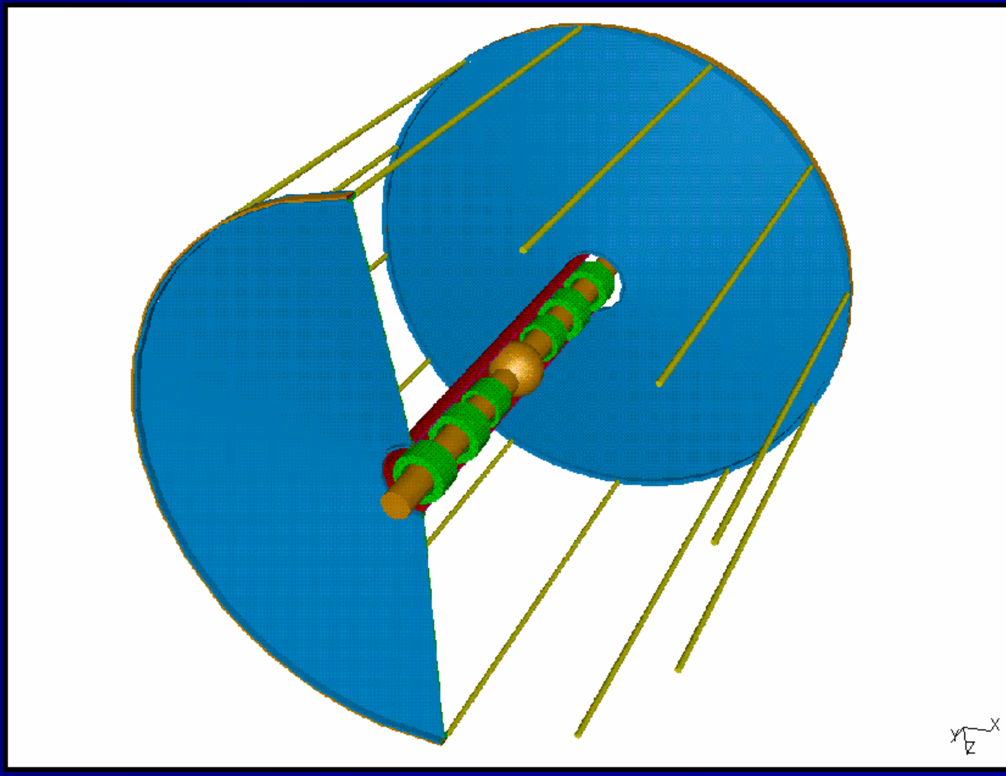
Solutions:

- 4.0 m. diameter x 3.3 m. length, 40.000 field wires + 12.600 sense wires;
- uniform cell structure throughout the active volume with all stereo layers ($\pm 60 \leq \varepsilon \leq \pm 150$ mrad);
- mechanical structure entirely in C-fiber, high X_0 gas (90% He+10% i-C_4H_{10}), 80 μm Al field wires.

The KLOE Drift Chamber

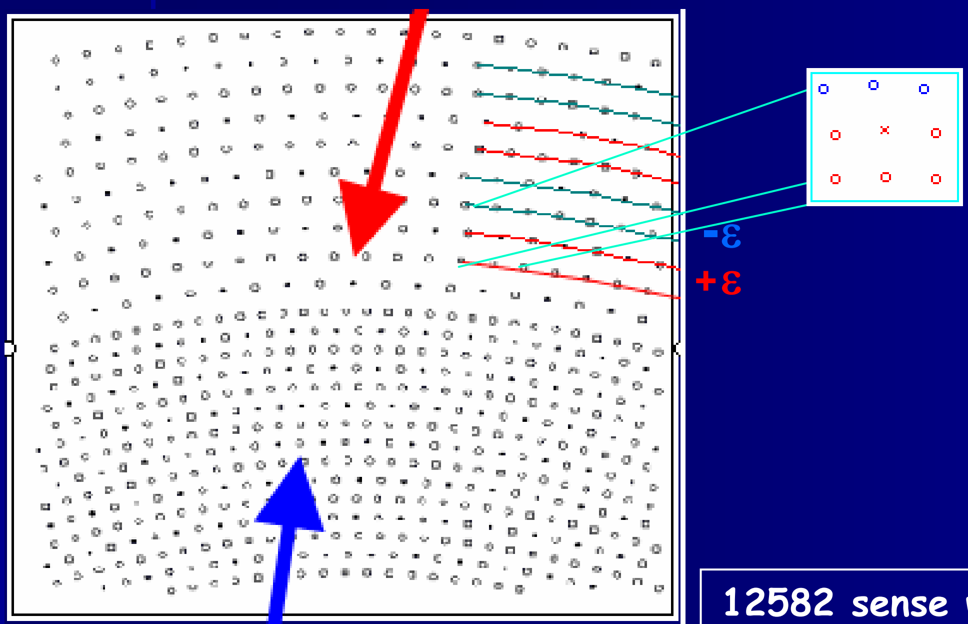
Transparency:

- spherical end-plates:
  8 mm C-f + 30 mm Cu foil
  (0.032 X_0);
- inner wall:
  0.7 mm C-f + 30 mm Al foil
  (0.003 X_0);
- outer wall:
  C-f / hex cell (0.020 X_0);
- gas (0.00125 X_0);
- wires (0.00064 X_0).



The KLOE Drift Chamber

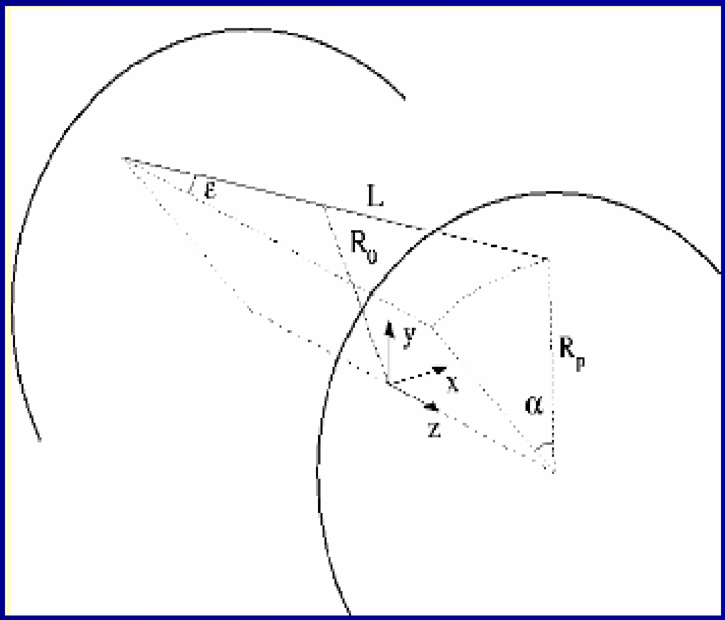
46 outer layers 3 cm x π cm



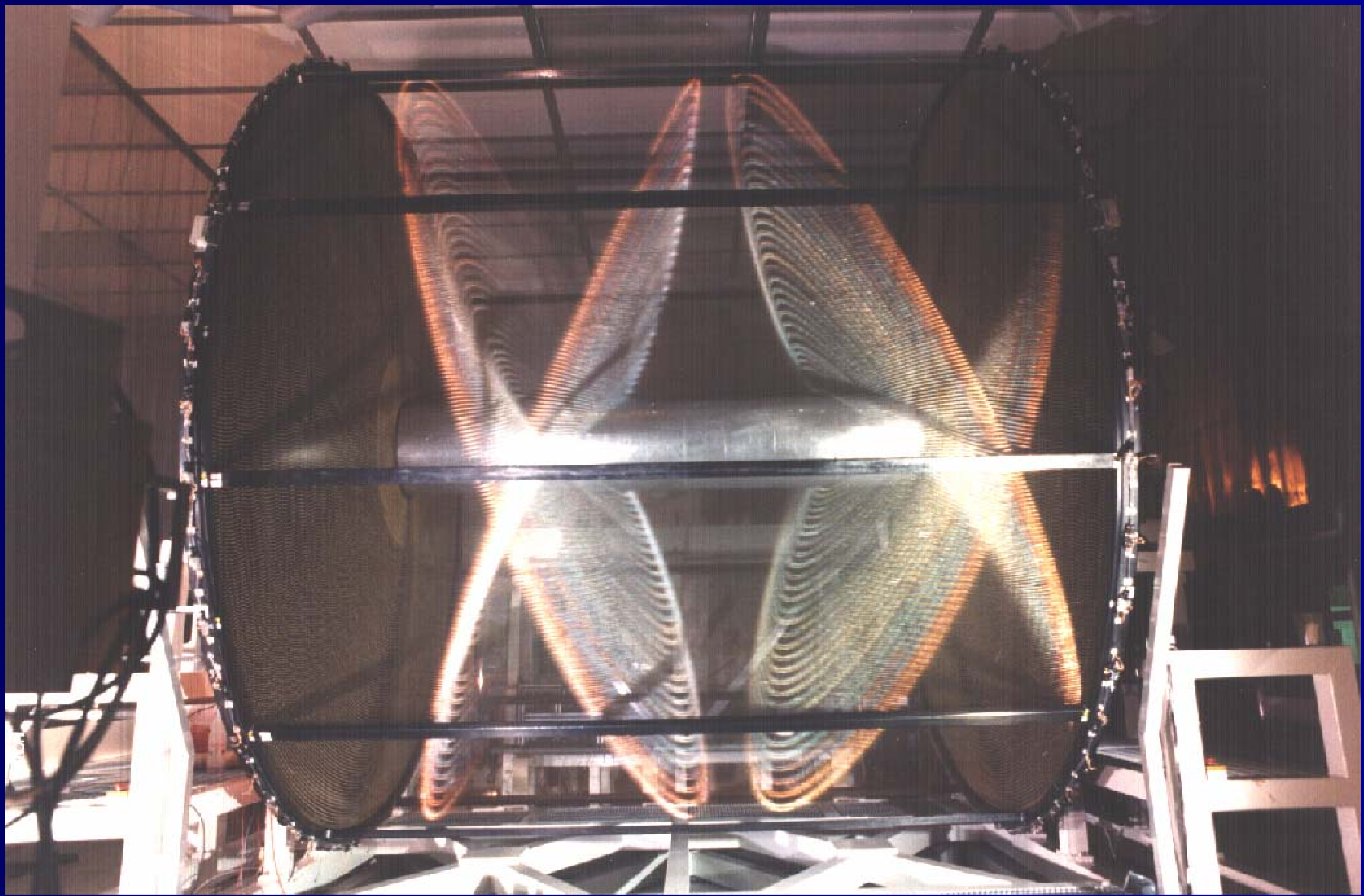
12 inner layers 2 cm x 2/3 π cm

12582 sense wires
38622 field wires
936 guard wires

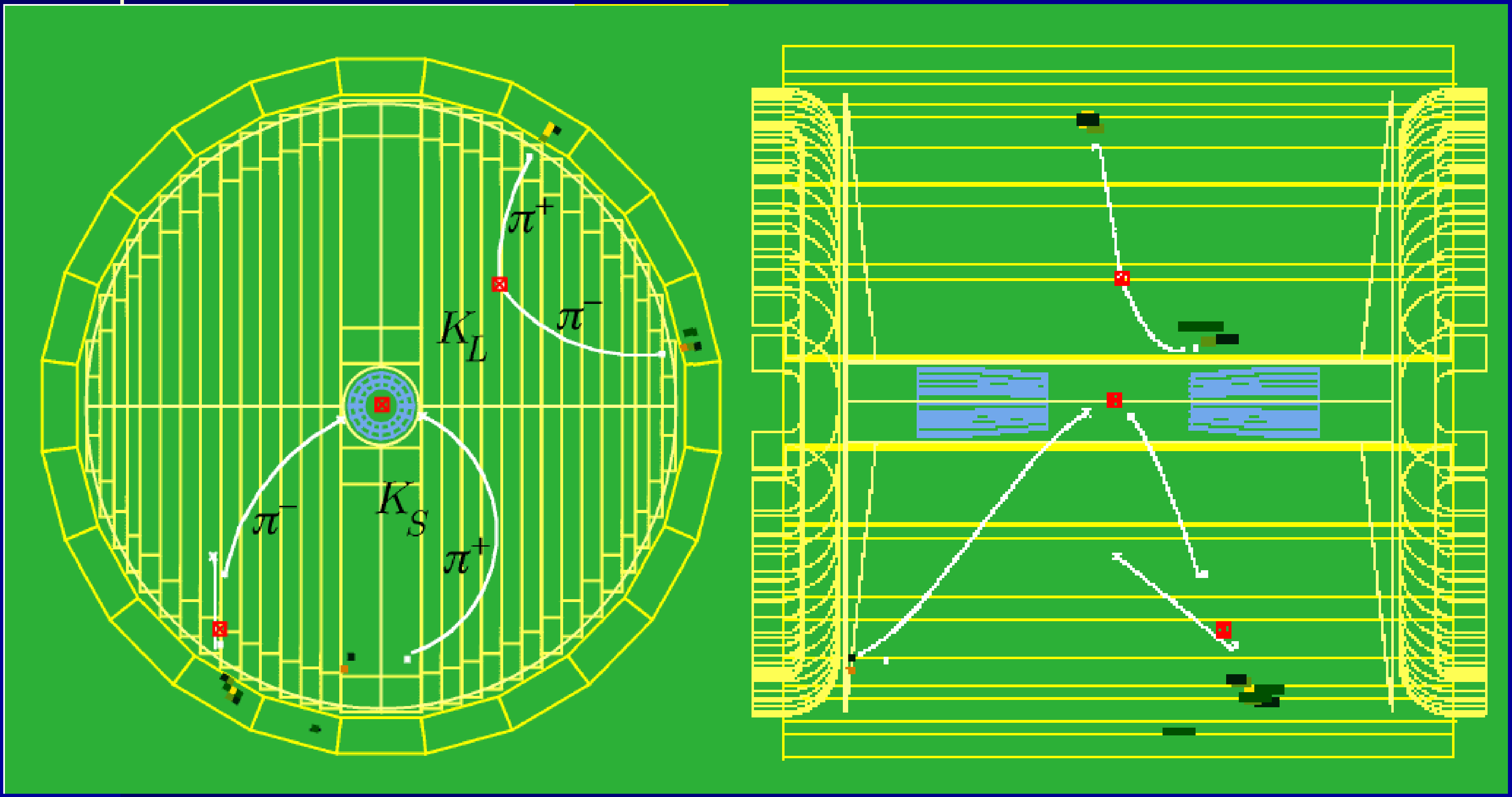
Stereo angles $\varepsilon = \pm 60 \div \pm 150$ mrad
Constant stereo drop $R_P - R_0 = 1.5$ cm



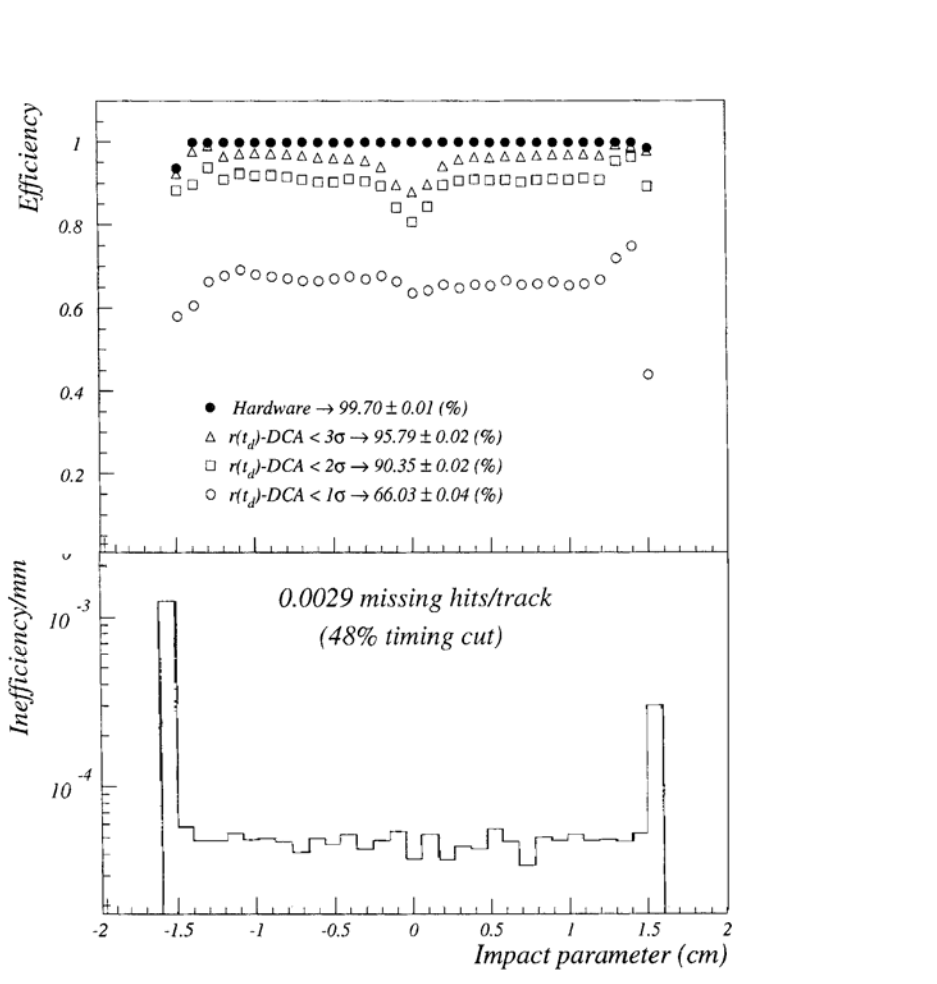
The KLOE Drift Chamber



The KLOE Drift Chamber



The KLOE Drift Chamber



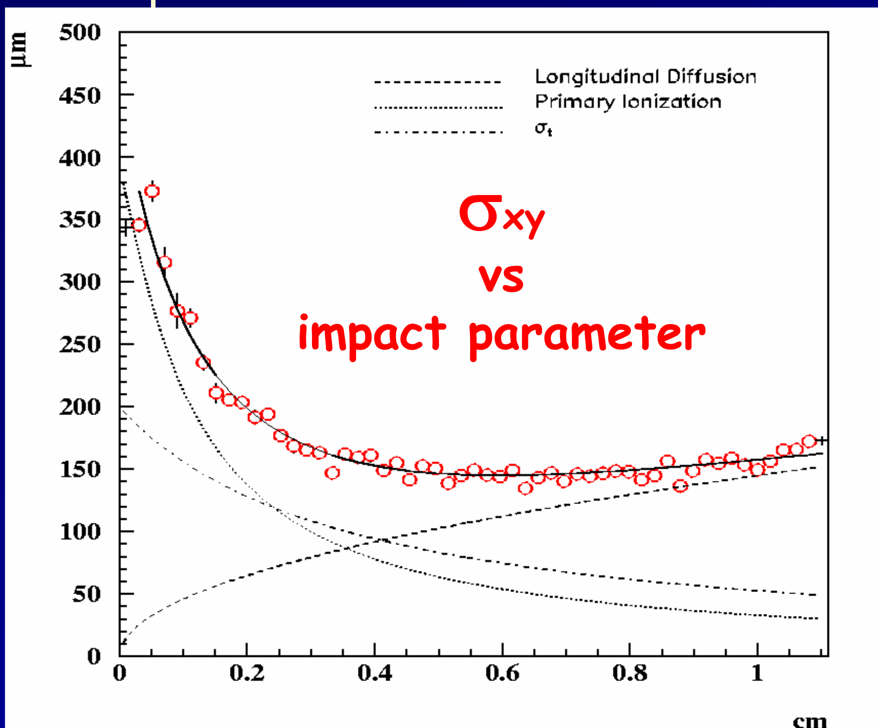
Efficiencies

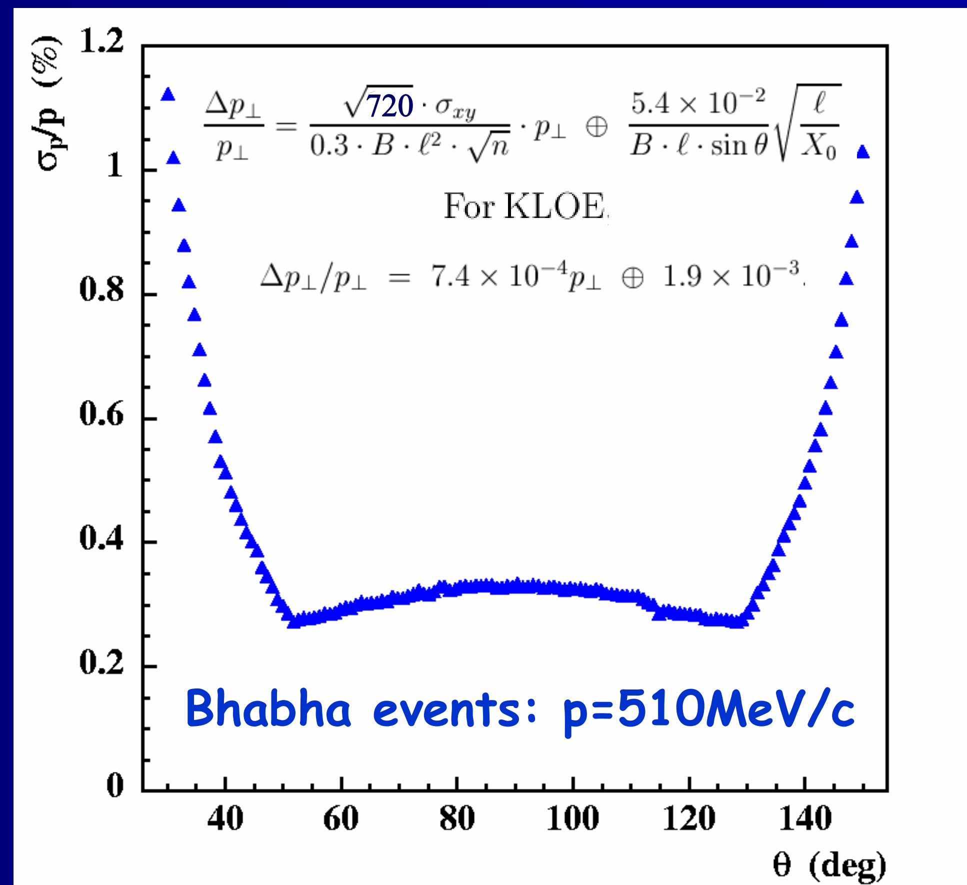
$K \to \pi\pi$	K_S	K_L
track finding	99.9	87.2
track fit	98.7	97.4
vertex fit	98.8	93.8
total efficiency	97.4	79.7

not decaying π, not looping π

The KLOE Drift Chamber

Resolutions





From fit:

$\lambda = 770 \pm 14\ \mu m$

$n_p = 12.9 \pm 0.1\ cm^{-1}$

$\sigma_D = 140\ \mu m\ cm^{-1/2}$

$\sigma_t = 4.8 \pm 0.2$ ns

The KLOE Drift Chamber

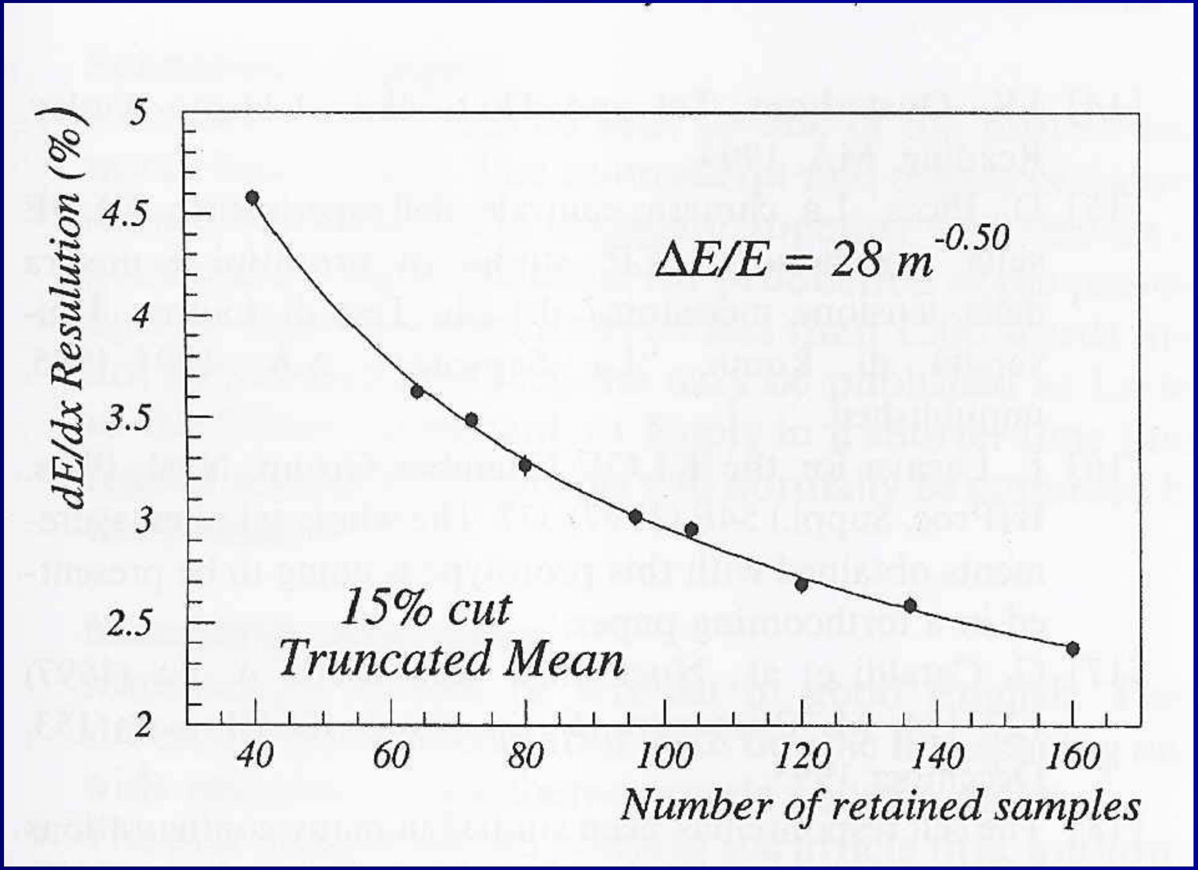
Resolutions

dE/dx

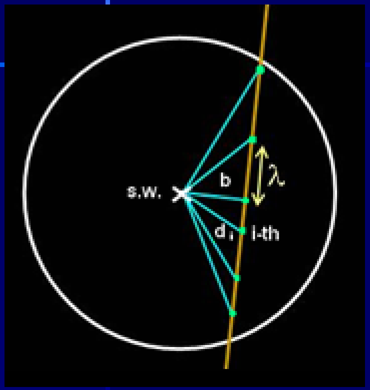
1 sample = 3xπ cm cell
σ(dE/dx)/dE/dx = 28%
(measured)

2 m track = 67 samples
15% cut = 10 samples

σ(dE/dx)/dE/dx ~ 4%
(expected)



CLUster COUnting



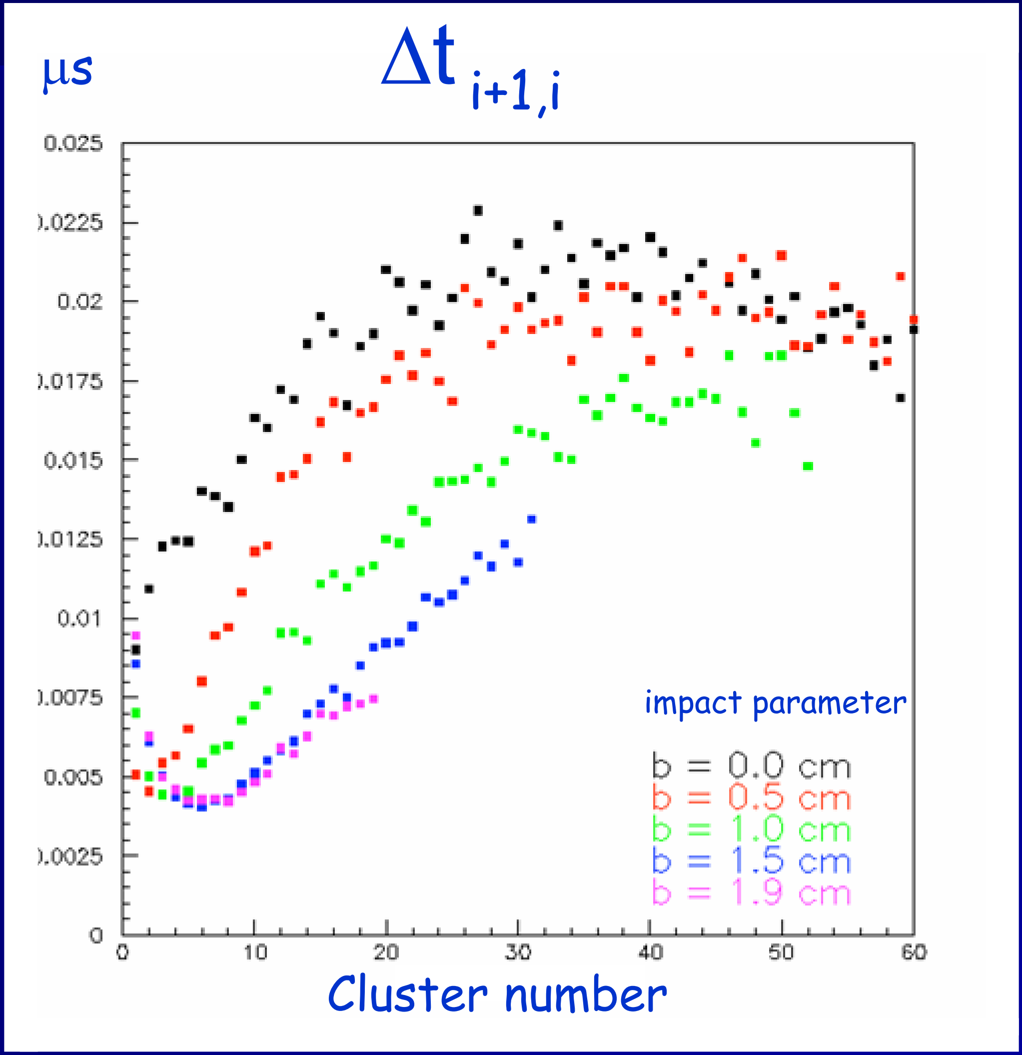
2 cm drift tube

90%He-10%iC_4H_{10}

few x 10^5 gain

$\Delta t_{i+1,i}$: time separation between consecutive ionization clusters, as a function of their ordinal number, for different impact parameters.

(caveat: electrons!)



CLUster COUnting

MC generated events:

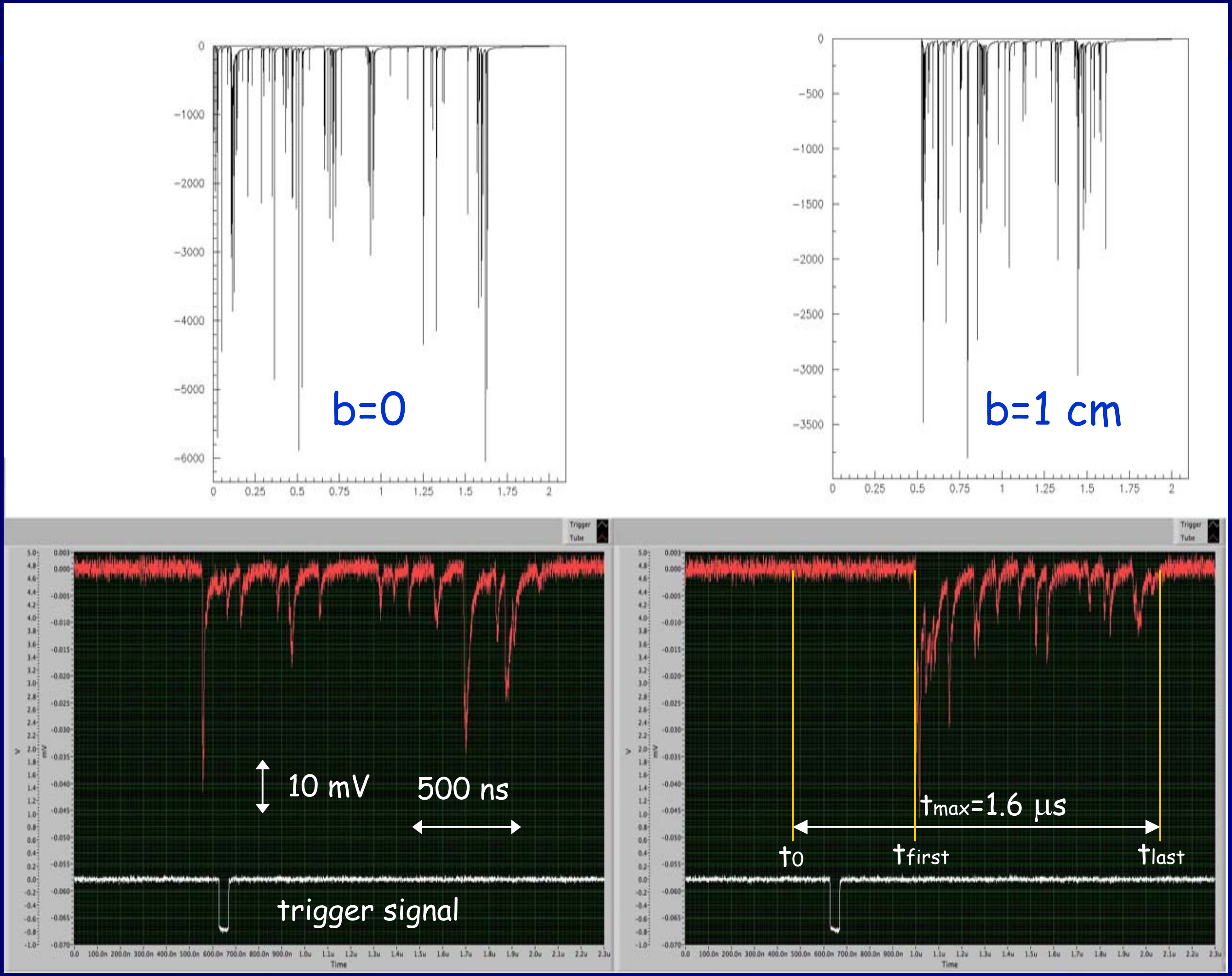
2cm diam. drift tube

gain = few x 10^5

gas: 90%He-10%iC_4H_{10}

no electronics simulated

cosmic rays triggered by scintillator telescope and readout by:
8 bit, 4 GHz, 2.5 Gsa/s digital sampling scope through a 1.8 GHz, x10 preamplifier



CLUster COUnting

For a given set up, and a digitized pulse
(t_{last} is constant with a spread < 20 ns)

$t_0 = t_{last} - t_{max}$	gives the trigger time
$b_f = \int_{t_0}^{t_{first}} v(t)\,dt$	first approx. of impact parameter b
$(c/2)^2 = r^2 - b_f^2$	length of chord
$N_{cl} = c \,/\, (\lambda(\beta\gamma) \times \sin\theta)$	expected number of cluster
$N_{ele} = 1.6 \times N_{cl}$	expected number of electrons (to be compared with counted one)
$\{t_i\}$ and $\{A_i\}$, $i=1,N_{ele}$	ordered sequence of ele. and Ampl.
$P(i,j)$, $i=1,N_{ele}$, $j=1,N_{cl}$	probability i-th ele. $\in$ to j-th cl.

CLU.COU. Performance

Position resolution

Given the ordered sequence of drift times $\{t_i\}$ and a known constant density, λ, along an ionizing track, in principle, each cluster contributes to the measurement of the impact parameter, b, with an independent estimate weighted according to the Poisson nature of the process $\oplus$ the electron diffusion along the drift path.

The resolution on the impact parameter, σ_b, improves with the addition of each cluster beyond the first one.

It, however, saturates at a value of 30-35 μm, convolution of:

- spread in mechanical tolerances (position of sense wire; gravitational sag; electrostatic displacement)
- timing uncertainties (trigger timing; electronics calibration; t_0)
- degree of knowledge of time-to-distance relation
- instability of working parameters (HV, gas temperature and pressure, gas mixture composition)

Reasonable to assume σ_b = 50 μm per sense wire

CLU.COU. Performance

Transverse momentum resolution

Consider a cylindrical drift chamber:

- with ~1.5 m outer radius
- filled with 90% He – 10% iC_4H_{10} gas mixture
- in a solenoidal magnetic field B = 3.5 T
- with 120 stereo layers made of hexagonal drift cells 1.0 cm wide
- with all layers at an average stereo angle $\varepsilon = \pm 150$ mrad
- with position resolution given by clu.cou. of $\sigma_{xy} = 50\ \mu m$

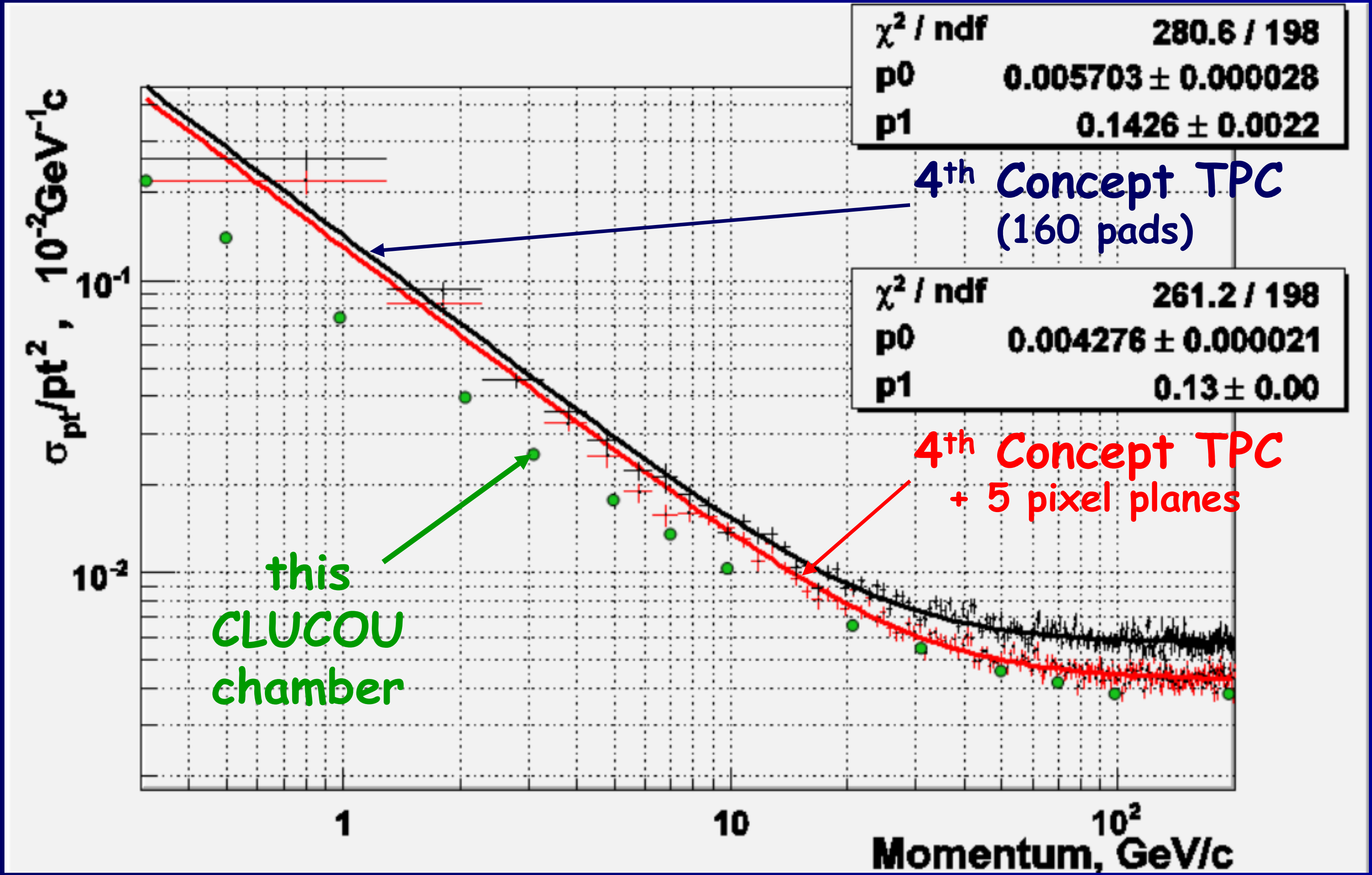
This can be realized with 32000 sense wires and 83000 field wires (~twice KLOE) (see proposed chamber below).

$$\frac{\Delta p_\perp}{p_\perp} = \frac{\sqrt{320}\cdot\sigma_{xy}}{0.3\cdot B\cdot\ell^2\cdot\sqrt{n}}\cdot p_\perp \oplus \frac{5.4\times 10^{-2}}{B\cdot\ell\cdot\sin\theta}\sqrt{\frac{\ell}{X_0}} \Rightarrow \Delta p_\perp/p_\perp = \mathbf{3.5\times 10^{-5}}\ p_\perp \oplus \mathbf{7.0\times 10^{-4}}$$

75% from wires
25% from gas

CLU.COU. Performance

Transverse momentum resolution



CLU.COU. Performance

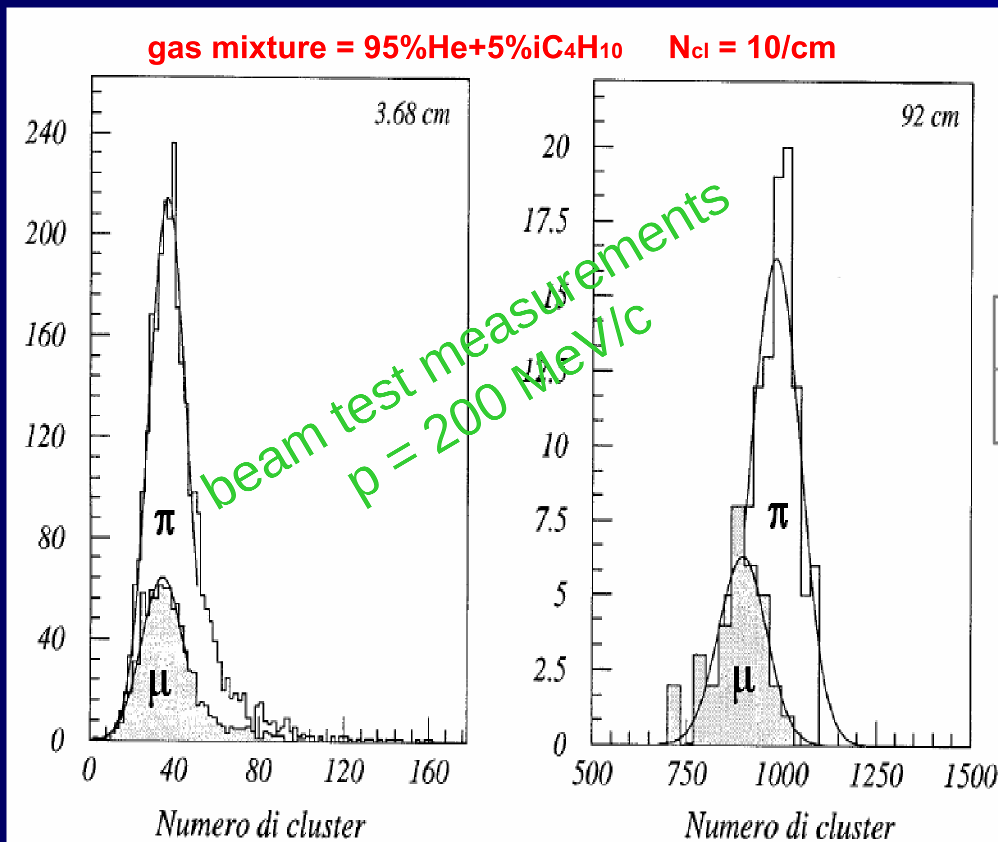
Particle Identification

at 200MeV/c

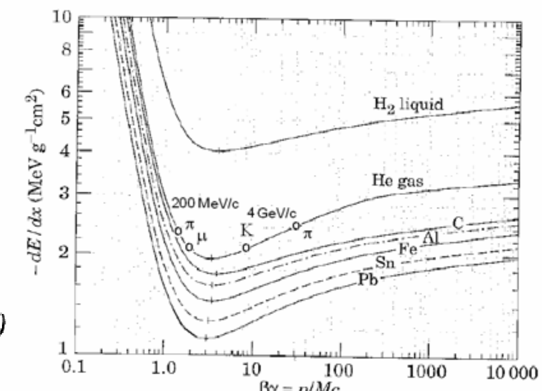
experiment:
$\pi/\mu = 1.3\ \sigma$

theory:
$\pi/\mu = 2.0\ \sigma$

trunc. mean:
$\pi/\mu = 0.5\ \sigma$



	traccia	statistica N_{cl}	statistica r.m.s.	fit N_{cl}	fit σ
π	3.7 cm	41.17	15.91	36.34	8.83
	92.0 cm	978.20	60.53	982.50	65.08
μ	3.7 cm	38.45	16.39	34.07	9.69
	92.0 cm	882.30	70.82	896.20	63.39

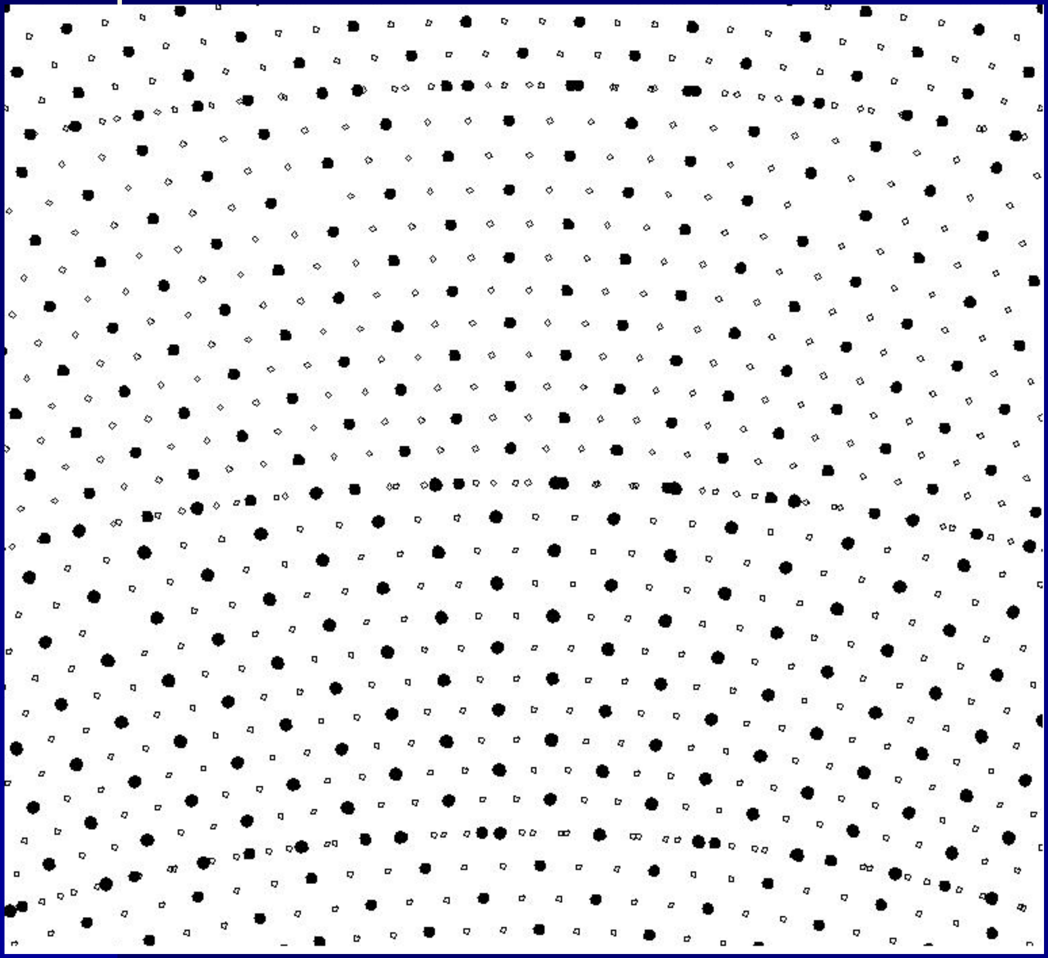


CLU.COU. chamber expected dN_{cl}/dx resolution for a 1.5 m m.i.p. at 13 cluster/cm:

$\sigma(dN_{cl}/dx)/(dN_{cl}/dx) = 2.3\ \%$

CLUCOU Drift Chamber

Layout



Hexagonal cells f.w./s.w.=2:1

height:

1.04 cm at r = 22.5 cm

1.65 cm at r = 145.0 cm

(max. drift time < 300 ns !)

16 superlayers at alternating stereo angles ±50 ÷ ±150 mrad

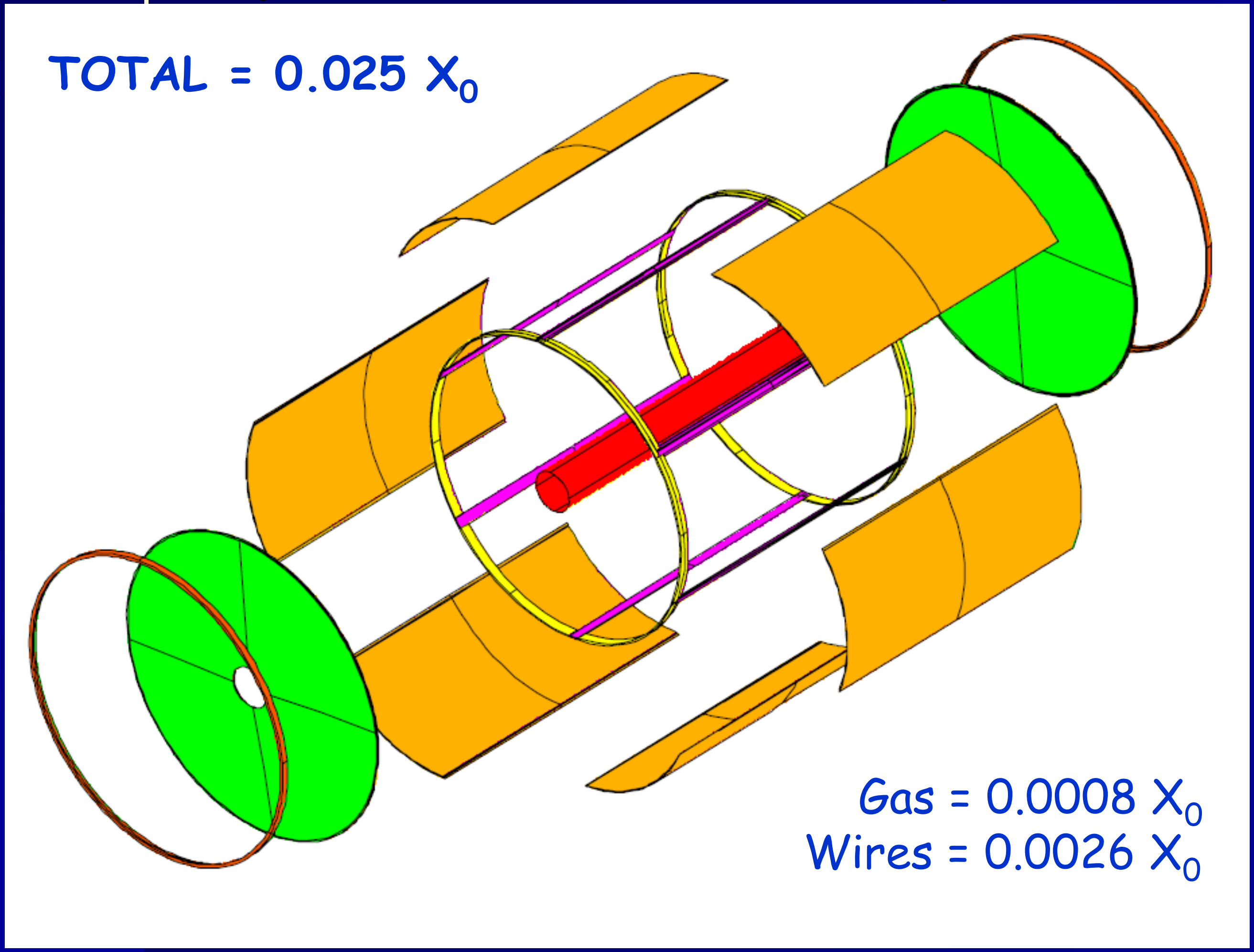
32000 sense w. 25 μm W

83200 field w. 100 μm Al

easy t-to-d r(t) (1 parameter)

CLUCOU Drift Chamber

Layout and assembly technique



Length:
3.4 m at r = 22.5 cm
3.0 m at r = 147.0 cm

Spherical end plates:
C-f. 12 mm + 30 μm Cu
(0.047 X_0)

Inner cylindrical wall:
C-f. 0.2 mm + 30 μm Al
(0.001 X_0)

Outer cylindrical wall:
C-f./hex.cell. sandwich
held by 6 1dir. struts
0.020 X_0)

Retaining ring

Stiffening ring

CONCLUSIONS

A drift chamber à la KLOE with cluster counting (≥ 1GHz, ≥ 2Gsa/s, 8bit)

- uniform sampling throughout the active volume
- 32000 hexagonal drift cells in 16 stereo superlayers (±150 mrad)
- cell width 1.04 ÷ 1.65 cm (max drift time < 300 ns)
- 32000 sense wires (25 μm W), 83200 field wires (100 μm Al)
- high efficiency for kinks and vees
- spatial resolution on impact parameter σ_b = 50 μm (σ_z = 300 μm)
- particle identification $\sigma(dN_{cl}/dx)/(dN_{cl}/dx) = 2.3\%$
- transverse momentum resolution $\Delta p_\perp / p_\perp = 3.5 \cdot 10^{-5} \oplus 7.0 \cdot 10^{-4}$
- gas contribution to m.s. 0.08% X_0, wires contribution 0.26% X_0
- high transparency (barrel 2.5% X_0, end plates 4.8%/cosθ X_0)
- easy to construct and very low cost

is realistic, provided:

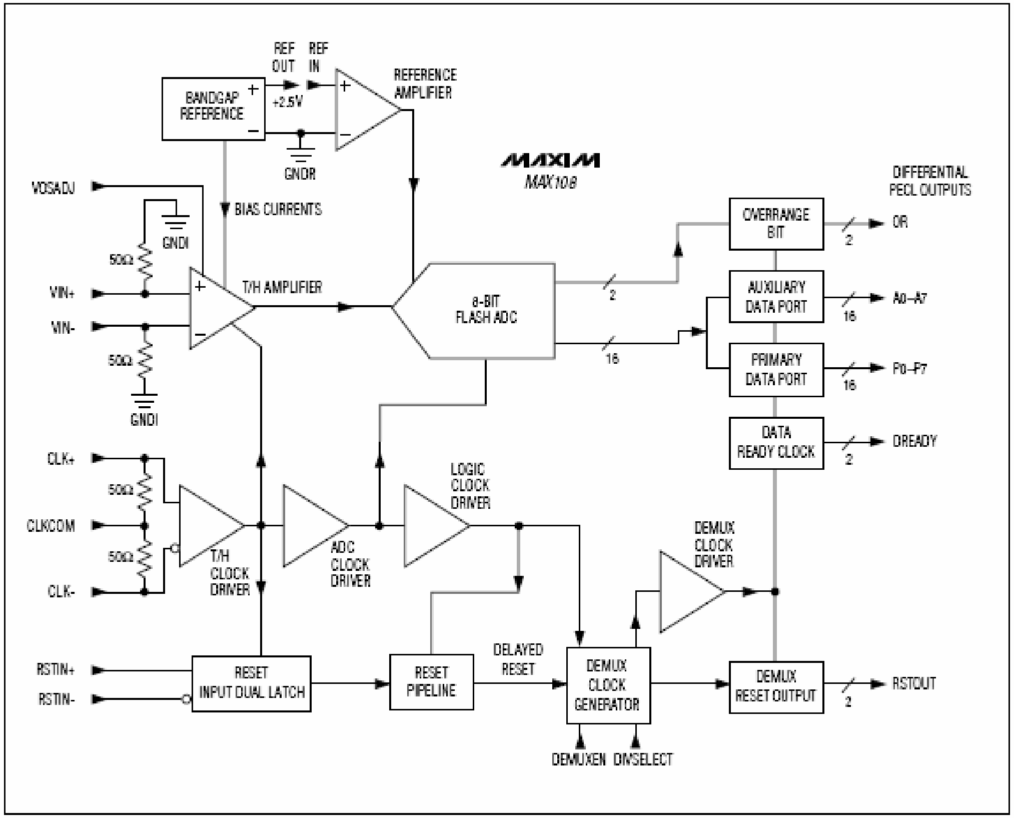
- cluster counting techique is at reach (front end VLSI chip)
- fast and efficient counting of single electrons to form clusters is possible
- 50 μm spatial resolution has been demonstrated

Commercially available chip

±5V, 1.5Gsps, 8-Bit ADC with On-Chip 2.2GHz Track/Hold Amplifier

http://datasheets.maxim-ic.com/en/ds/MAX108.pdf

MAX108



Features

- 1.5Gsps Conversion Rate
- 2.2GHz Full-Power Analog Input Bandwidth
- 7.5 Effective Bits at f_{IN} = 750MHz (Nyquist Frequency)
- ±0.25LSB INL and DNL
- 50Ω Differential Analog Inputs
- ±250mV Input Signal Range
- On-Chip, +2.5V Precision Bandgap Voltage Reference
- Latched, Differential PECL Digital Outputs
- Selectable 8:16 Demultiplexer
- Internal Demux Reset Input with Reset Output
- 192-Contact ESBGA Package
- Pin Compatible with MAX104 (1Gsps) and MAX106 (600Msps)

MAX108

DALLAS SEMICONDUCTOR MAXIM

Status (up to yesterday)…

- rudimentary experimental set up made of
  - scintillator telescope for c.r. trigger
  - cylindrical drift tubes (different radii)
  - NIM preamplifiers
  - DAQ on a fast digital scope (four ch.)

- sophisticated software system
  - GARFIELD and MAGBOLTZ
    (to be checked continuously …)
  - counting algorithms

… and perspectives

- Sept. 2006: CLUCOU proposal approved by INFN
- Jan. 2007: CLUCOU proposal financed by INFN
  > to study and develop front-end VLSI chip
    in CMOS 0.13 μm:
    - preamplifier (high bandwidth: ≥ 1 GHz),
    - shaper,
    - 8 bits f. ADC (≥ 2 Gsa/s),
    - memory buffer
  > to build high precision tracking telescope
  > to check cluster counting tech. at a beam test
- presented funding request at US University-based ILC Detector R&D Program (DOE/NSF - FY2007).

Si-μstrip telescope

- 3+3 Measuring view: XYX + XYX (minimal configuration)
- Tracking plane: run2B 4SVXIV+2Si modules provided by Fermilab (75μm pitch)
- PCI-FPGA based DAQ: PTA card + PMC mezzanine provided by Fermilab
- Linux&Root based software: RX roots software provided by C. Ciobanu and T. R. Junk (University of Illinois)
- *One Si-module readout successfully at Lecce* (last week)