The ultimate resolution drift chamber

A "traditional" drift chamber, read by recording the drifting of each ionization cluster

(for the future Super B and ILC)

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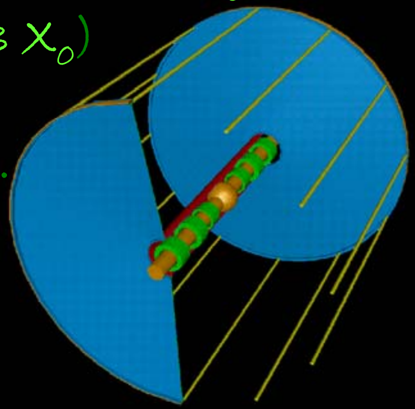
“traditional” …

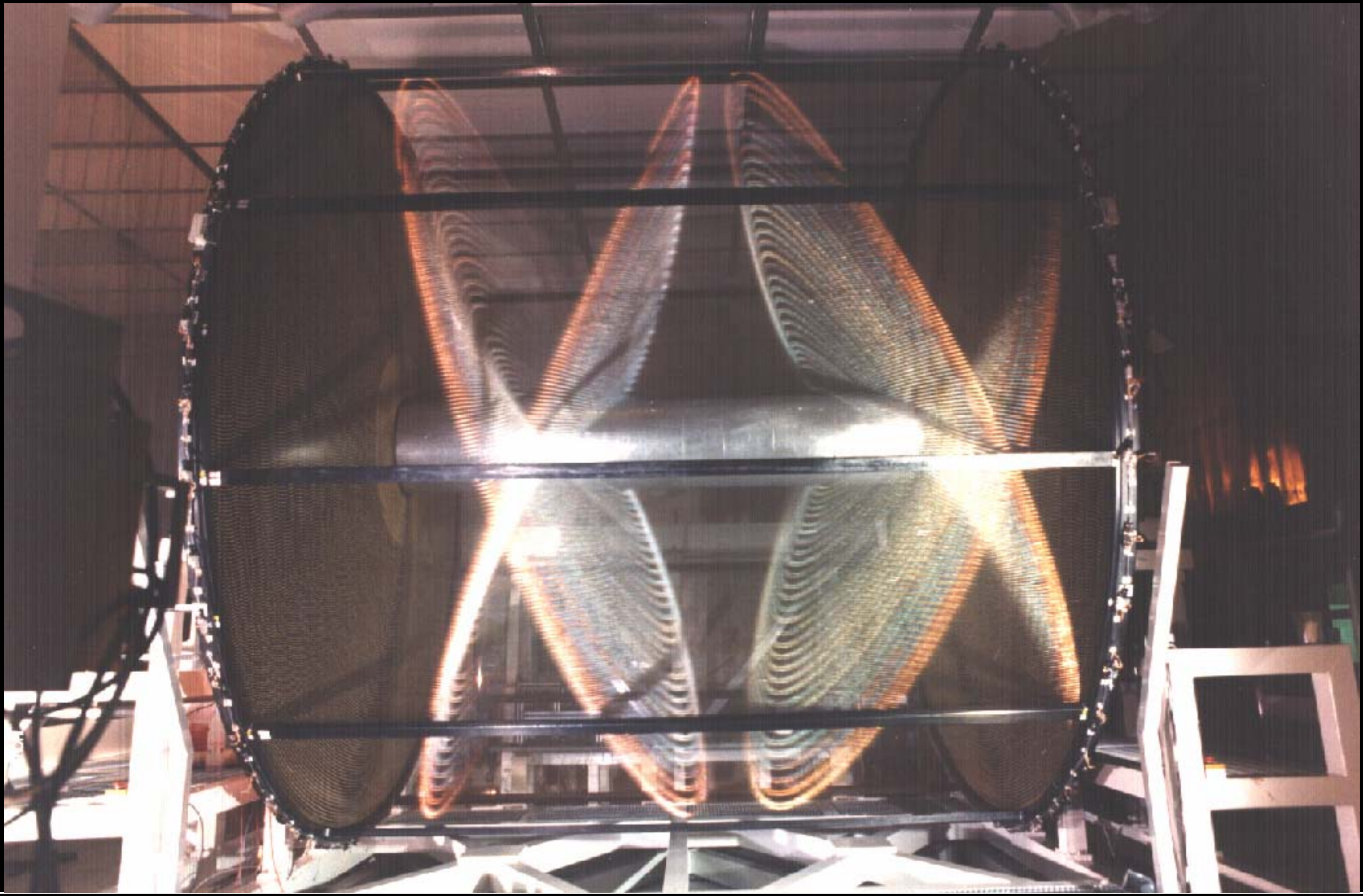
- transparent (KLOE numbers):
  - spherical end-plates 8 mm C-fiber + 30 µm Cu foil (0.032 X_0)
  - inner wall 0.7 mm C-fiber + 30 µm Al foil (0.003 X_0)
  - outer wall C-fiber–hex cell sandwich (0.020 X_0)
  - gas (0.0015 X_0) + wire (0.0006 X_0) contr. to m. s.
- Al field wires (80 µm)
- He based gas (90% He + 10% iC_4H_{10})
- uniform cells with alternating stereo layers



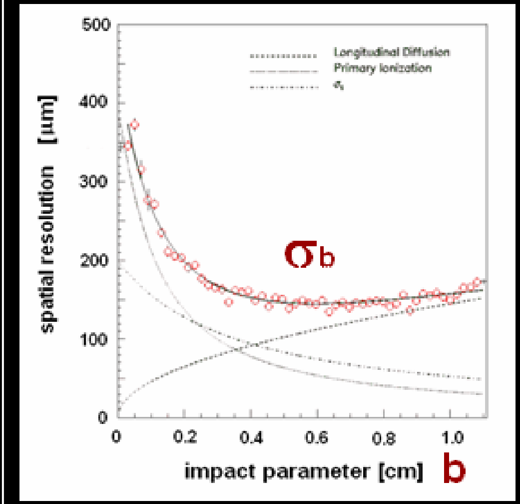
… but read-out by recording the drifting of each ionization cluster

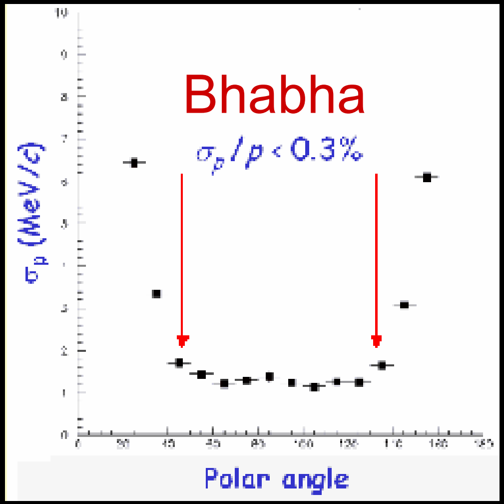
KLOE drift chamber

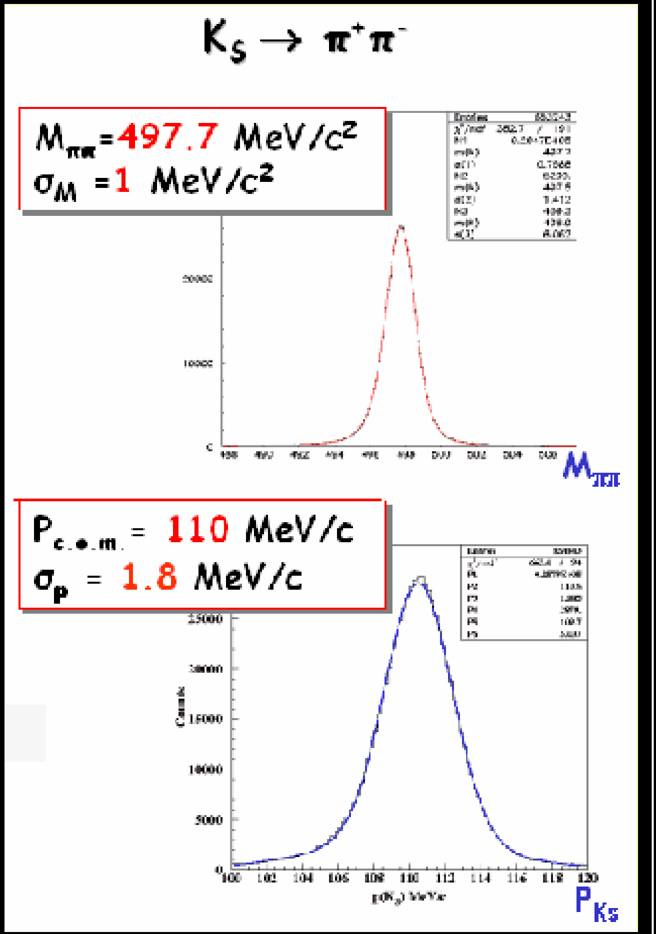
12582 sense wires
38622 field wires
936 guard wires



KLOE drift chamber performances







From fit:

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

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

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

$\sigma_t = 4.8 \pm 0.2\ ns$

Expected:

$\sigma_p/p = (1.0\times10^{-3})\times p \oplus (2.0\times10^{-3})$

$\sigma_p = 1.0$ MeV/c

@ $\theta = 90^o$

Momentum resolution

$$\left.\frac{\Delta p_\perp}{p_\perp}\right|_{\text{meas. error}} = \frac{\sqrt{720} \times \sigma_{xy}}{.3B \times \ell^2 \sqrt{n}}\, p_\perp$$

$\sqrt{720} \rightarrow 320$ if beam constr.

($p_\perp$ in *GeV/c*)

$$\left.\frac{\Delta p_\perp}{p_\perp}\right|_{\text{mult. scatt. contribution}} = \frac{5.4 \times 10^{-2}}{B \times \ell} \sqrt{\ell / X_0}$$

Start designing a generic drift chamber for a new generation flavor factory. Assume:

- 3.0 m diameter x 3.0 m. length;
- n=60 measuring points along a radius;
- spatial resolution in the transverse plane =150μm;
- B=1 Tesla

}

- 12000 hex. cells (~2.5 cm)
- 12000 20μm W sense w.
- 25000 80mm Al field w.

$$\left.\frac{\Delta p_\perp}{p_\perp}\right|_{\text{meas. error}} = 7.7 \times 10^{-4}\, p_\perp$$

($p_\perp$ in *GeV/c*)

= @ ⇓

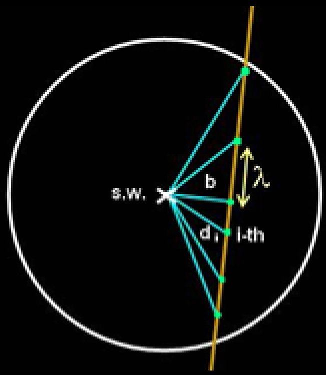
$$\left.\frac{\Delta p_\perp}{p_\perp}\right|_{\text{mult. scatt. contribution}} = (1.2 + 0.7) \times 10^{-3}$$

He mix — wires

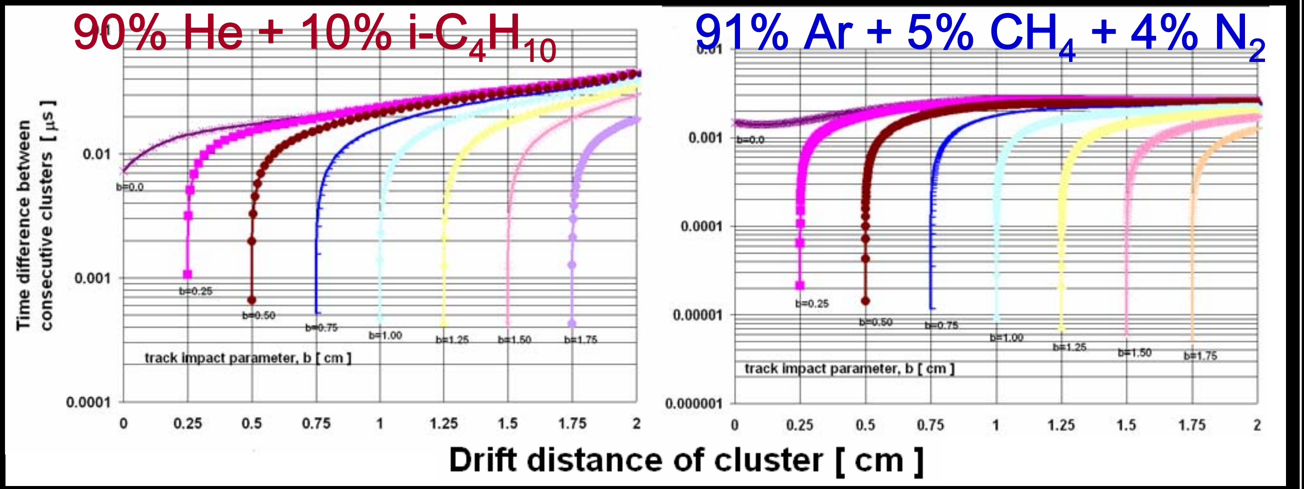
$p_\perp$ = 2.5 GeV/c

Cluster Counting (1)

cylindrical tube
r = 2 cm
gain = few × 10^5



Time separation (MC) between closest ionization clusters along a track as a function of their distance from the sense wire for different track impact parameters



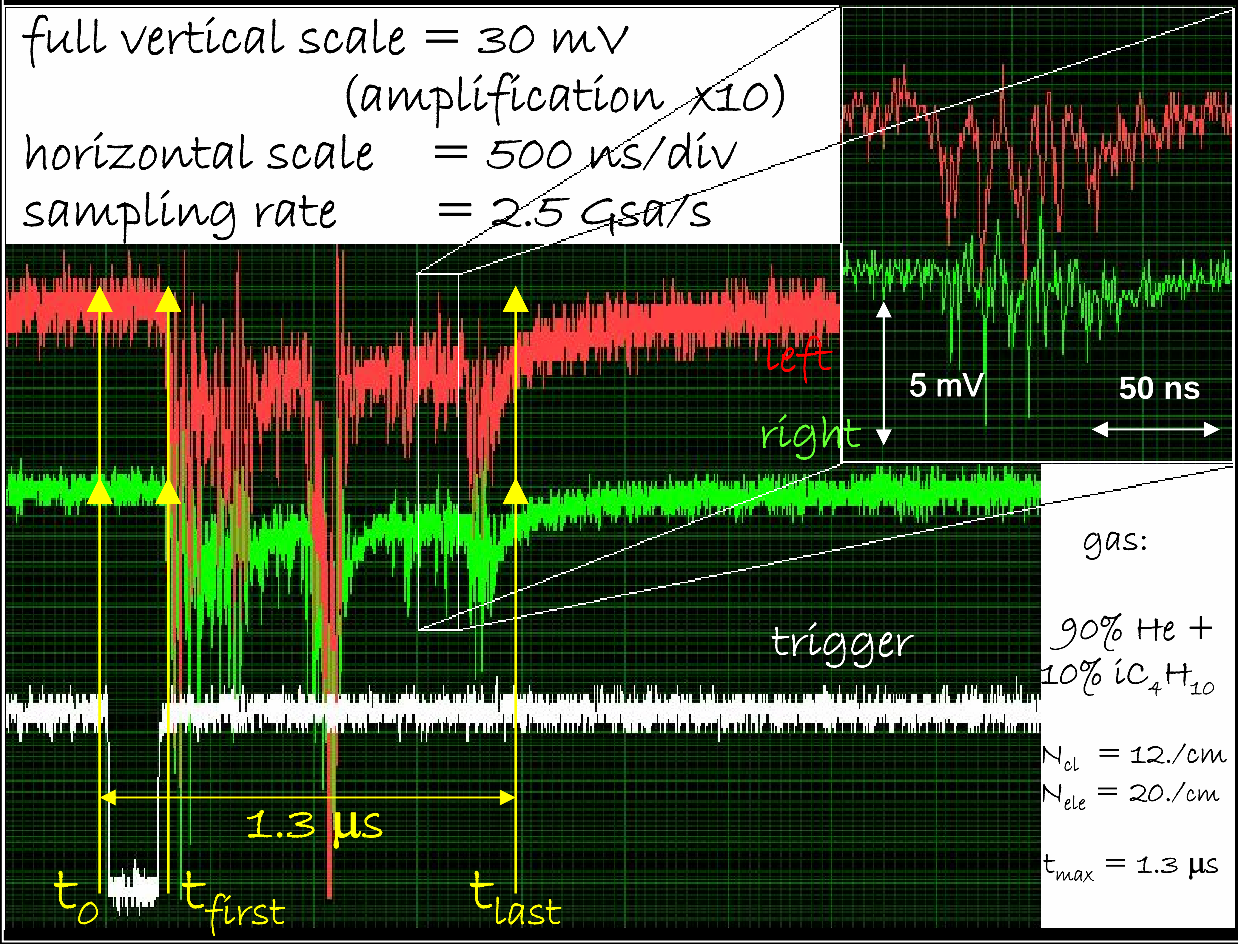
In He , provided that:

rise (and fall) time of single electron signals < 1ns
sampling frequency of electron signals > 2 Gsa/s

<u>single electron counting is possible.</u>

CAVEAT: Multiple electron clusters (30% in this He mixture) complicates the picture

Cluster Counting (2)



Cosmic ray triggered by scintillatore telescope and read out by a digital sampling scope: 8 bit, 4 GHz, 2.5 Gsa/s
Amplifier bandwith: 1.8 GHz, gain ×10

$$t_0 = t_{last} - t_{max}$$

$$b_f = \int_{t_0}^{t_{first}} v(t)\, dt$$

$$(c/2)^2 = r^2 - b_f^2$$

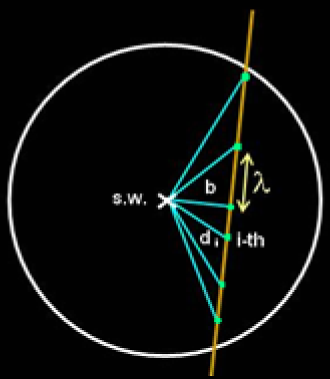
$$N_{cl} = c/\lambda_{\beta\gamma} \times 1./\sin\theta$$

$$N_{ele} = N_{cl} \times 1.6$$

$$\{t_i\}_{i=1,Nele} \quad \{P(cl)_i\}_{i=1,Nele}$$

Cluster Counting Performances (1)

Spatial resolution



$$d_i = \int_{t_0}^{t_i} v(t)\,dt$$

$$b_i = \sqrt{[d_i^2 - (i \cdot \lambda/2)^2]}$$

In principle,
given the time ordered sequence
of the drifting clusters,
$\{t_i\}_{i=1,Nele}$ and $\{P(cl)_i\}_{i=1,Nele}$
each cluster contributes to the
impact parameter with an
independent estimate and

$$\sigma_b = \sigma_{bi} / \sqrt{N_{cl}}$$

(saturated by other conributions, like position of the sense wire, time to distance conversion,…)

In reality, multiple electron clusters and single electron diffusion tend to confuse the picture.

For
$N_{cl} = 12\ cm^{-1}$ and
60 stereo layers
($\pm \sim 100$ mrad),
is reasonable
to assume:

$\sigma_{xy} \approx 50\ \mu m$

$\sigma_z \approx 500\ \mu m$

Cluster Counting Performances (2)

Transverse momentum resolution

1° case:

- $l = 1.5$ m
- $\sigma_b = 50$ μm
- $B = 1$ T
- $n = 60$ layers

$$\left.\frac{\Delta p_\perp}{p_\perp}\right|_{meas.} = 2.6 \times 10^{-4}\, p_\perp \quad (p_\perp \text{ in } GeV/c)$$

$$\left.\frac{\Delta p_\perp}{p_\perp}\right|_{\text{mult. scatt. contribution}} = 1.9 \times 10^{-3}$$

= @ $p_\perp$ = 7.3 GeV/c

2° case:

- $l = 1.5$ m
- $\sigma_b = 50$ μm
- $B = 5$ T
- $n = 100$ layers

$$\left.\frac{\Delta p_\perp}{p_\perp}\right|_{meas.} = 4.0 \times 10^{-5}\, p_\perp \quad (p_\perp \text{ in } GeV/c)$$

$$\left.\frac{\Delta p_\perp}{p_\perp}\right|_{\text{mult. scatt. contribution}} = 2.4 \times 10^{-3}$$

= @ $p_\perp$ = 60 GeV/c

Cluster Counting Performances (3)

Estimate of dip angle

$$N_{cl} = c/\,\lambda_{\beta\gamma} \times 1./\sin\theta$$

For an average c and a minimum ionizing track, $N_{cl} = 40$

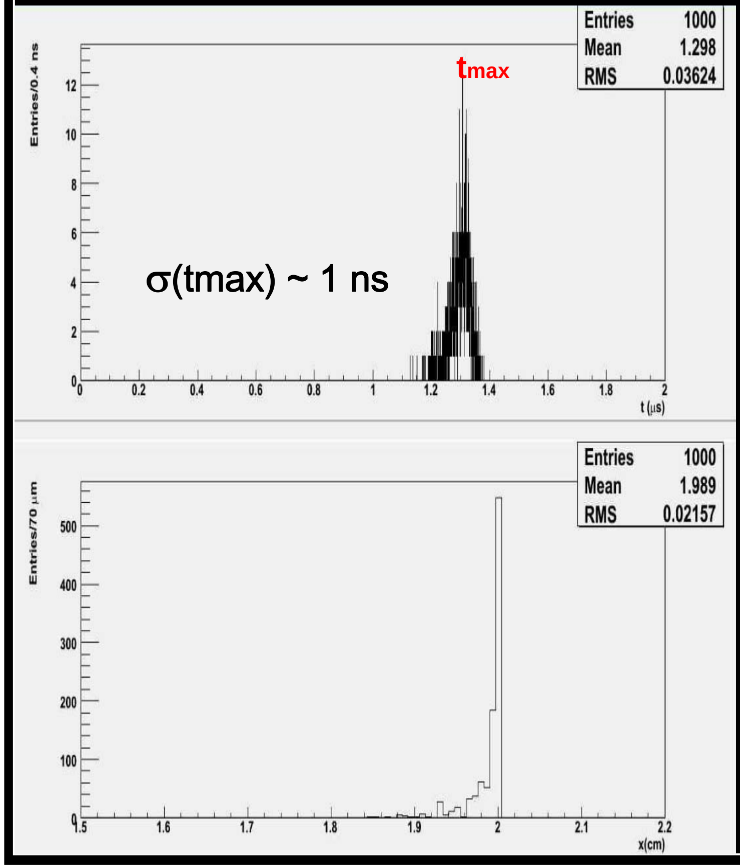
$$\sigma_\theta \approx 150\text{–}200 \text{ mrad}$$

Extremely powerful in track finding to extrapolate z from a stereo layer to the next with an uncentanty of a few mm.

(Equivlent to charge division applied cluster by cluster)

Cluster Counting Performances (4)

triggerability



Drift time of last arriving electron corrected for t.o.f. and for transit time on the wire.
Assumed 10 tracks with 100 hits each.

From t_{max} one gets t_0 event by event, avoiding long and complicated calibration procedures.

Moreover, $\sigma(t) \sim 1$ ns idenifies the trigger of the event

Cluster Counting Performances (5)

Particle identification

Assuming

$$\sigma(dE/dx)/(dE/dx)_{min} = \sigma(N_{cl})/N_{cl,min}$$

A 2.0 m minimum ionizing track segment produces, in average, $N_{cl} = 2400$

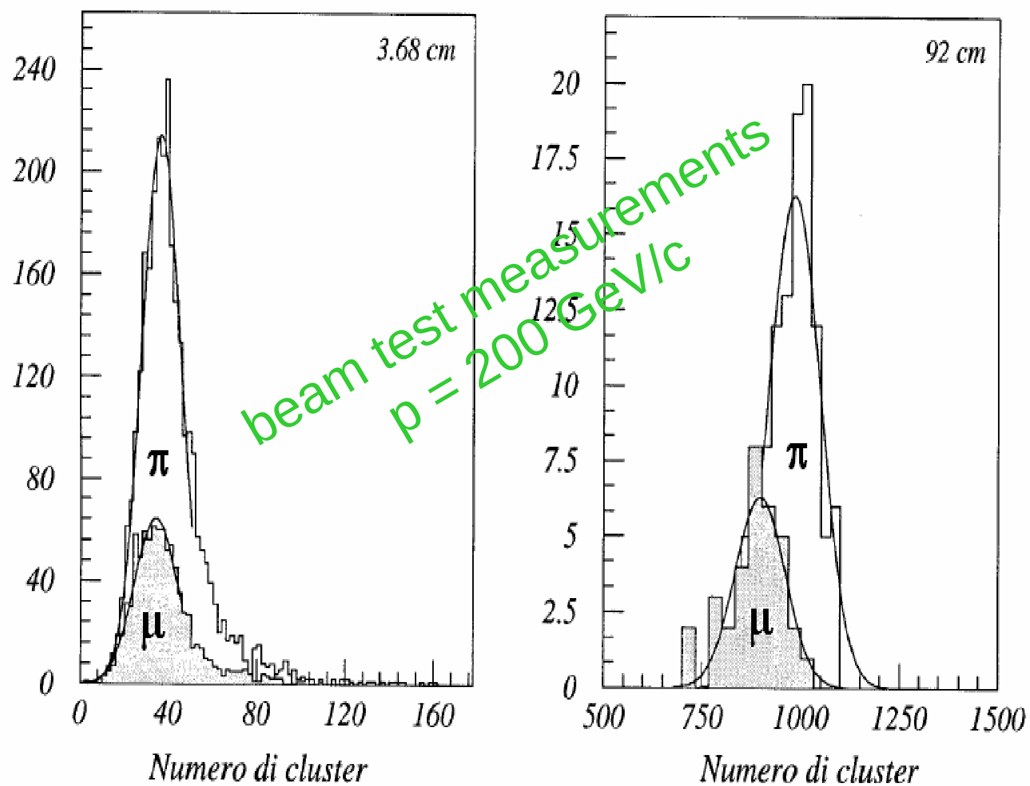
$$\sigma(dE/dx) = 2\%\ (dE/dx)_{min}$$ expected

Example from test beam data: **π/μ** sepration @ 200 MeV/c

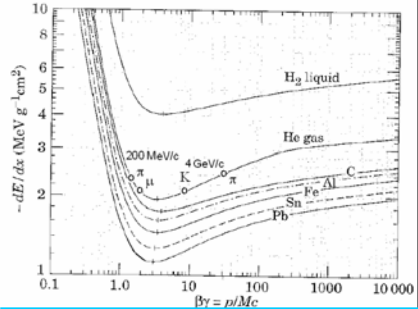
G.Cataldi, F.Grancagnolo and S.Spagnolo, INFN-AE-96-07, Mar. 1996, 23p.
G.Cataldi, F.Grancagnolo and S.Spagnolo, NIM A386 (1997) 458-469

Cluster Counting Performances (5')

gas mixture = 95%He+5%iC_4H_{10} N_{cl} = 10/cm



	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
π	92.0 cm	978.20	60.53	982.50	65.08
μ	3.7 cm	38.45	16.39	34.07	9.69
μ	92.0 cm	882.30	70.82	896.20	63.39



at 200MeV/c

experiment:

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

theory:

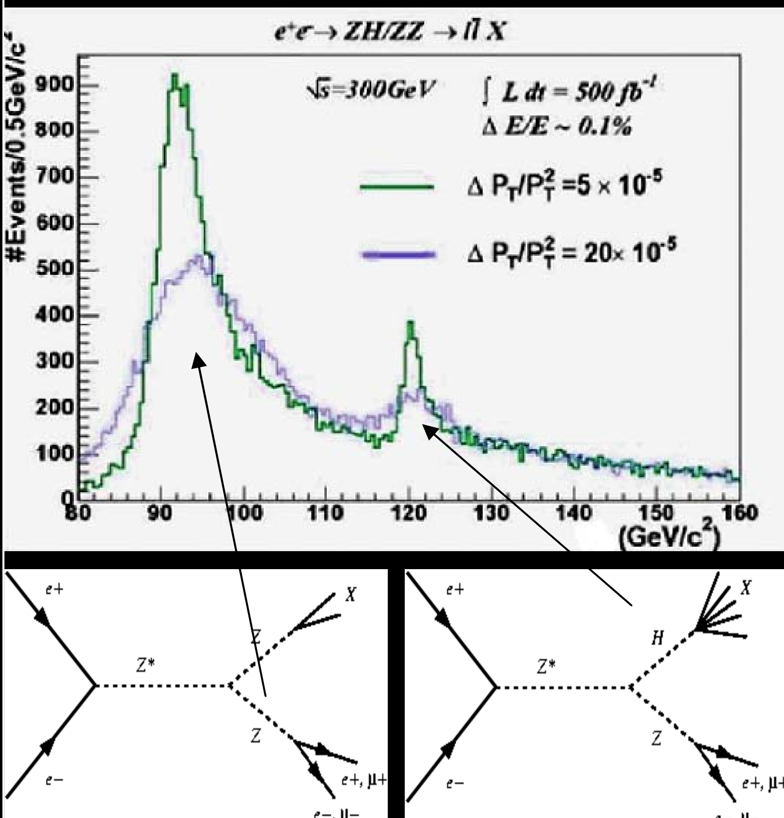
$\pi/\mu = 2.5\ \sigma$

trunc. mean:

$\pi/\mu = 0.5\ \sigma$

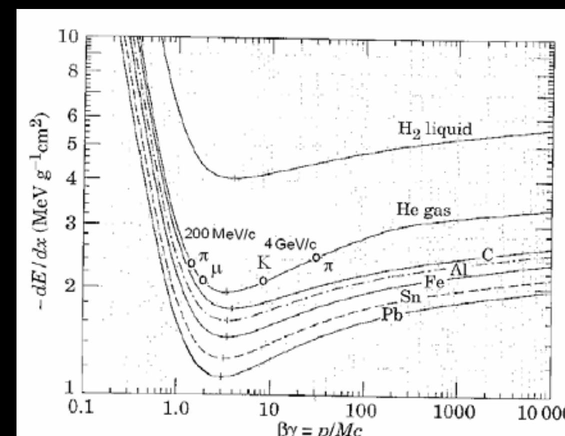
Examples

Tracking at ILC



Particle ID at SuperB

π/K @ 4 GeV/c



88%He+12%iC_4H_{10}, Ncl = 20/cm

π/K (4 GeV/c) = 6.0 σ

present BaBar (RICH) π/K = 2.7 σ

SuperB (RICH+TOF) π/K = 4.0 σ

Conclusions 1

In principle, we should be capable of building a very light, transparent, He based gas, all stereo layers, drift chamber having the following properties:

- 40,000 wires, 12,000 cells (2.5 cm)
  [100,000 wires, 30,000 cells (1.5 cm)]
- total transparency to the calorimeter: ~ 3% X_0
- spatial resolutions: σ_{xy} ~ 50 μm , σ_z ~ 500 μm
- transv. mom. resolution dominated by m. s. up to
  7.3 (60.) GeV/c
- trigger capability
- differential energy loss as good as ~ 2%

Conclusions 2

- The concept of cluster counting is being applied to a traditional drift chamber.
- A detailed MC is under study to simulate all relevant processes and to compare results with test data
- A VLSI chip (amplifier, digitizer, storage, I/O) is being developed for the r-o by INFN.
- Conting algorithms are being optimized to extract the most complete information from data.
- Physics simulation and analysis programs within a modular ROOT framework to optimize the working parameters of the chamber are at an advances state.