PID Issues for Linear Collider Detectors

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- Physics Needs
- Cerenkov Devices
- dEdx

Physics Needs
(Possible Use of PID)

- B-physics
- b,c tagging
- Detection of long-lived heavy charged particles (e.g. $\tilde{\tau}$ in GMSB)
- Input for Kalman tracker

B-Physics

Main sources of b at LC:

$$e^+e^- \to Z\gamma,\ t\bar{t},\ Ze^+e^-,\ b\bar{b}$$

$\sigma_{b\bar{b}} \sim$ 5 pb total ($\sqrt{s} \sim$ 500 GeV)

50 fb^{-1} $\quad\to\quad$ 2.5×10^5 $b\bar{b}$ pairs

e^+e^- B-factory: $\sim 10^8$ $b\bar{b}$ pairs/yr

$\to$ needs 10^3 times more stat.

But, if 50 fb^{-1} on Z^0 $\to$ 3×10^8 $b\bar{b}$'s

LC not competitive in B-physics unless $>$ 50 fb^{-1} on the Z^0 peak

b, c tagging

For example:

$$e^+e^- \to Z^0 H^0, \quad H^0 \to b\bar{b}, c\bar{c}$$

Methods:

1. **Vertexing**

   b-tag: $\epsilon = 55\%$, purity $= 98\%$
   c-tag: $\epsilon = 45\%$, purity $= 75\%$

2. **Exclusive charm reconstructions**

   $$c \to D^{*+},\ D^{*+} \to D^0\pi^+,\ D^0 \to K^-\pi^+$$

   Overall $Br \sim 0.01$, $\epsilon_{\mathrm{det}} \sim 0.4$.
   Other channels $\to$ $\epsilon_{\mathrm{c-tag}} \sim 0.02$.
   Purity $\sim 90\%$ for the cleanest.

   Not competitive w.r.t. vertexing.
   But provides independent check.
   (b-counting, c-counting)

Cerenkov Devices

- **Forward type**

  HERA-B Gas RICH, L =3 m
  π/K upto 90 GeV

  LHC-B Aerogel, π/K 1.4-12 GeV
  Gas RICH, π/K 8-140 GeV

  Long path length, $B = 0$
  $\rightarrow$ not applicable for LCD.

- **Barrel type**

  DELPHI Gas+liquid RICH, **60 cm thick**
  π/K 0.7-40 GeV

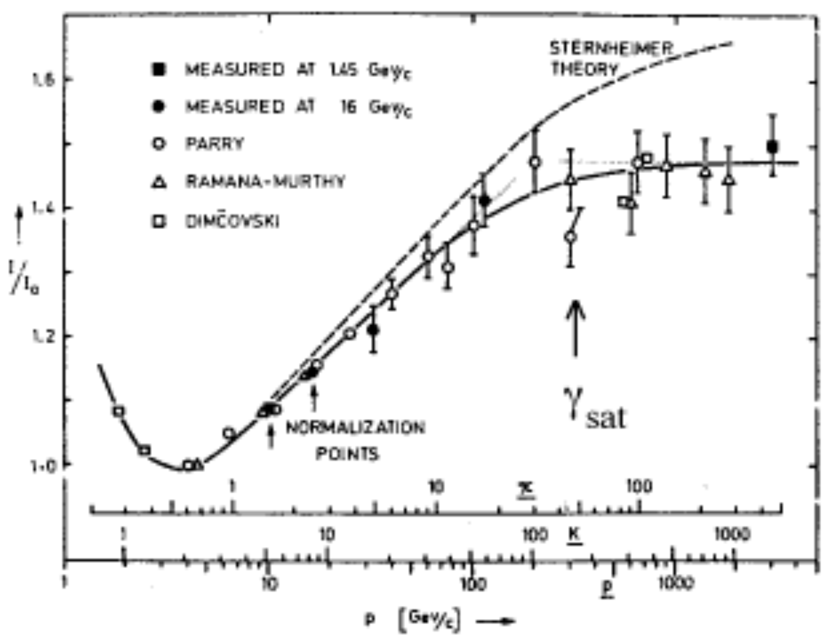
  CLEO-3, BaBar, Belle, Alice
  10-30 cm thick, $X_0 = 10 - 15\%$
  π/K upto 3-4 GeV **- realistic for LCD**

dEdx

$$\boxed{\gamma \text{sat} \sim \frac{I}{\hbar\omega_p}}$$

$$I \sim 12Z(\text{eV}) \quad \text{(ionization energy)}$$

$$\hbar\omega_p \sim 20\sqrt{\rho(g/\text{cm}^3)}\ (\text{eV})\ \text{(plasma freq)}$$



Saturation Point for Gasses (1 atm)

gas	I (eV)	$\hbar\omega_p$ (eV)	γ_{sat}	$p_{\text{sat}}^{\pi/K}$ (GeV/c)
He	41.8	0.27	154	21/76
Ar	188	0.82	230	32/115
Xe	482	1.41	341	48/170
CH_4	41.7	0.61	68.4	10/34
C_2H_6	45.4	0.82	55.3	8/28
C_3H_8	47.1	0.96	49.1	7/24
C_4H_{10}	48.3	1.14	42.4	6/21

Saturation point is higher for heavier atoms.
Hydro-carbons: $\gamma_{\text{sat}} \sim 50$.

$dEdx(\pi) \sim dEdx(K)$ at $p_{\text{sat}}(K) \sim 3.6 p_{\text{sat}}(\pi)$.

$\rightarrow \pi/K$ separation starts to degrade at $p_{\text{sat}}(\pi)$
and completely useless at $p_{\text{sat}}(K)$.

Bethe-Bloch Formula (Max-T improved)
(PDG 1998)

$$\frac{dE}{dx} \propto \frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_e\beta^2\gamma^2 T_0}{I^2} - \frac{\beta^2}{2}\left(1+\frac{T_0}{T_{\mathrm{max}}}\right) - \frac{\delta}{2}\right]$$

$$T_0 = \min(T_{\mathrm{cut}}, T_{\mathrm{max}})$$

T_{max}: maximum kinetic energy of recoil electron.

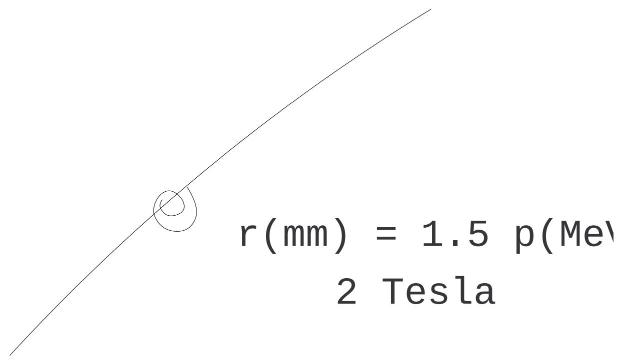
$$T_{\mathrm{max}} = \frac{2P^2 m_e}{M^2 + m_e^2 + 2Em_e}$$

M, E, P: mass, energy, momentum of projectile.

$T_{\mathrm{max}} \sim E$ for $\gamma \gg M/m_e$.
$\rightarrow$ separate track

T_{cut} : effective cutoff on recoil energy

Effective Cutoff T_{cut}



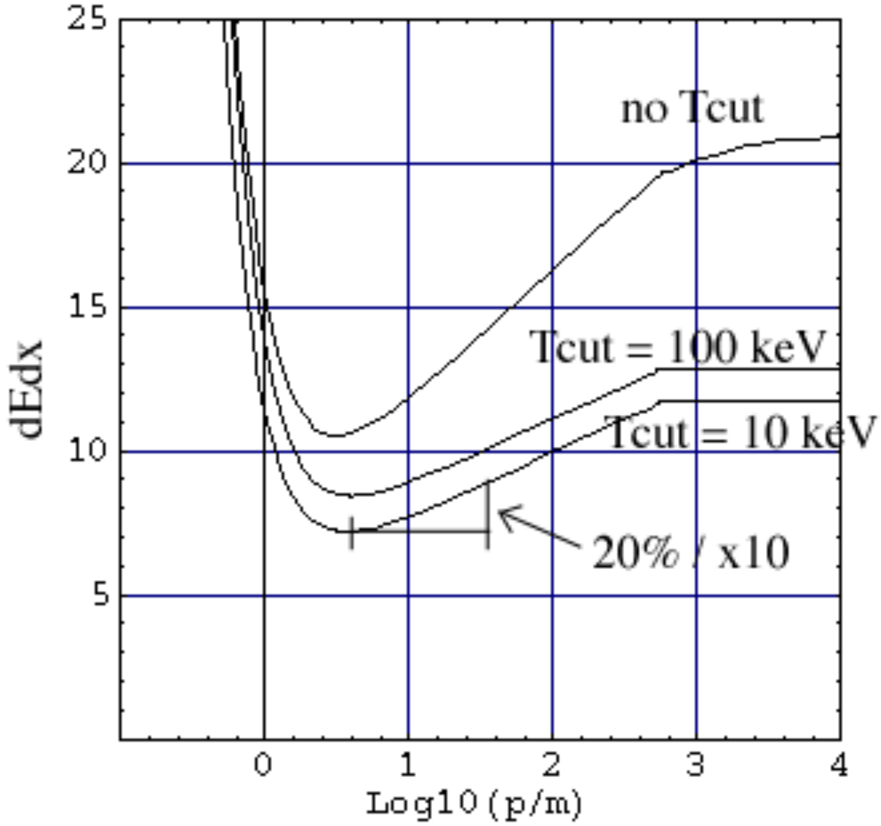
- If the **radius of curler** is larger than order 1 mm, the hit may be rejected. $\rightarrow T_{\text{cut}} \sim$ a few 100 keV.

- **Average energy deposit**:
  $\sim$ 3 keV/cm for Ar, C_2H_4 ...
  $\sim$ 0.35 KeV/cm for He.

  $\rightarrow T_{\text{cut}}$ of a few 100 keV is a cut on the energy deposit on a single drift chamber cell (i.e. the measured pulse height).

Effect of T_{cut}

Ar at STP

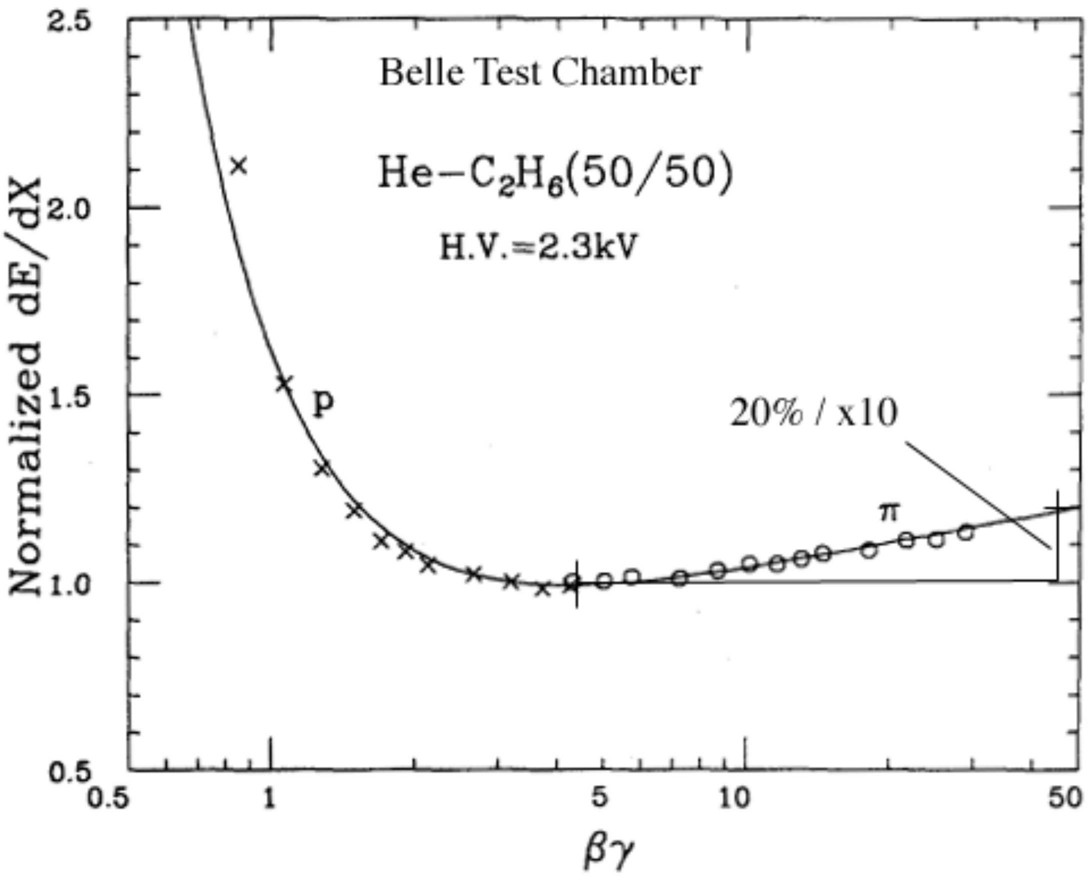


- The kink at $\log_{10} p \sim 2.7$ is due to the density effect:

$$\frac{\delta}{2} \sim -\ln \gamma_{\text{sat}} + \ln \beta\gamma - \frac{1}{2}$$

- The logarithmic rise reduced by about factor of 2 by T_{cut}, but no difference between $T_{\text{cut}} = 100$ keV and 10 keV.

Comparison with data



Discard top 20% of pulse heights.
($T_{\text{cut}} \sim 10$ keV)

dEdx resolution

Empirical formula for gas-sampling device (Walenta)

$$\boxed{\frac{\sigma}{\mu}(dEdx) = 0.41 n^{-0.43} (xP)^{-0.32}}$$

n	# sample
x	sample thickness (cm)
P	pressure (atm)

Fairly independent of the type of gas.

The Allison-Cobb obtains $n^{-0.46}$ dependence.

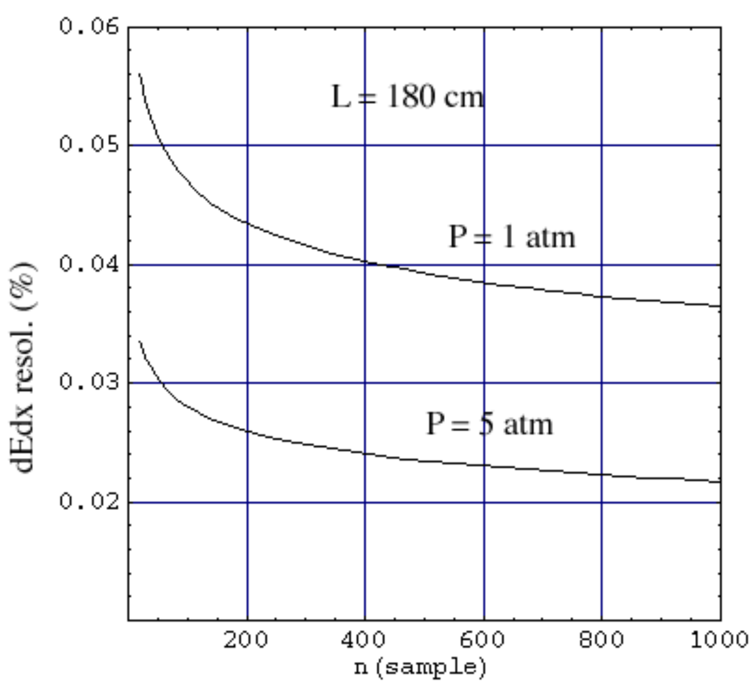
If each layer (xP) is independent, and simply increase the number of samples, one expects

$$\frac{\sigma}{\mu} \propto n^{-0.5}$$

Expected and measured dEdx resolutions

det.	n	x(cm)	P	exp.	meas.
Belle	52	1.5	1 atm	6.6%	5.1% (μ)
CLEO2	51	1.4	1 atm	6.4%	5.7% (μ)
Aleph	344	0.36	1 atm	4.6%	4.5% (e)
TPC/PEP	180	0.5	8.5 atm	2.8%	2.5%
OPAL	159	0.5	4 atm	3.0%	3.1% (μ)
MKII/SLC	72	0.833	1 atm	6.9%	7.0% (e)

Optimization: for a fixed total length, increase n:
(use the scaling law)



One cannot indefinitely increase n.

- # of primary iinization n_p

$$n_p \sim 1.5\, Z/\text{cm} \quad (Z : \text{per molecule})$$

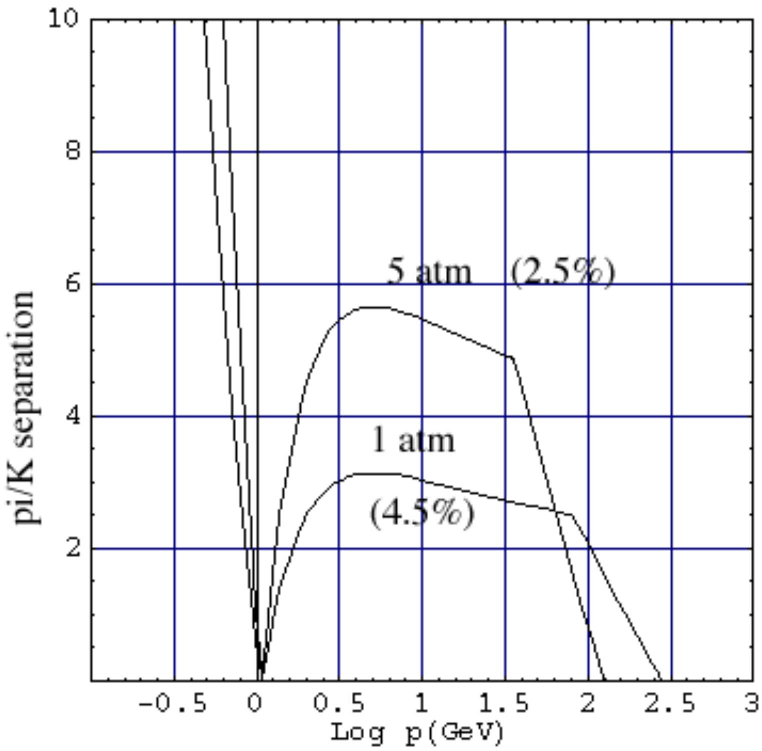
n_p = 2/cm (He), 15/cm (CH_4), 27/cm (Ar)
No gain after $n_p \sim 1$ (i.e. $x \sim$ mm)

- electronical noise

Assume 4.5% for 1 atm chamber
2.5% for 5 atm chamber .

Note: the higher the pressure, the larger the $\hbar\omega_p$
$\rightarrow$ quicker the saturation.

π/K Separation



1 atm: $> 2\sigma$ for $p < 0.8$, $1.75 < p < 100$ GeV/c

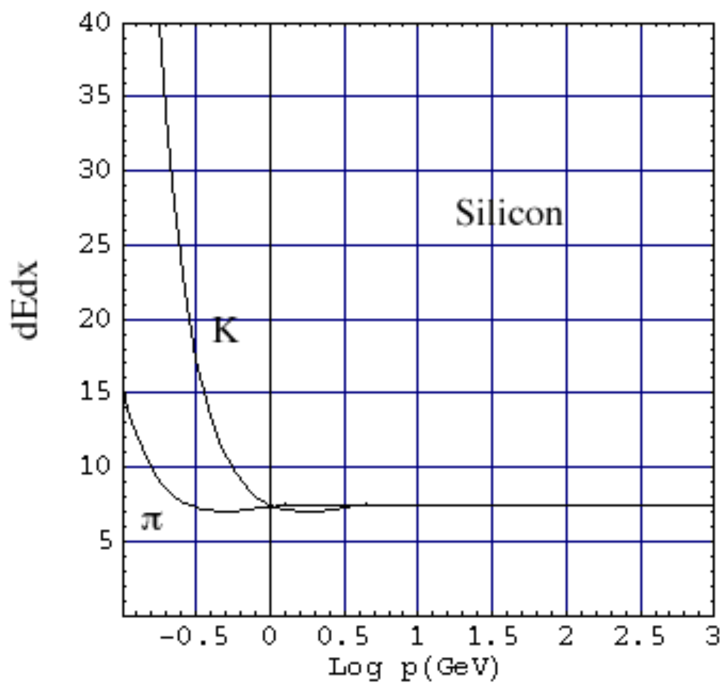
5 atm: $> 2\sigma$ for $p < 0.9$, $1.25 < p < 65$ GeV/c
$> 4\sigma$ for $1.75 < p < 50$ GeV/c

dEdx in Silicon

$$\rho(\text{Si}) = 2.33\ \text{g/cm}^3 \gg \rho(\text{gas})$$
$$\hbar\omega_p(\text{Si}) \sim 35\hbar\omega_p(\text{gas})$$

$$\gamma_{\text{sat}}(\text{Si}) = \frac{I}{\hbar\omega_p} \sim 5.4\ (\text{ref: } \gamma_{\text{min}} \sim 4)$$

$\rightarrow$ Essentially no logarithmic rise



dE in 5 lyrs of 0.3mm-thick Si = 0.6 MeV
($\sim$ 1.5 m of gas) : a Si layer is **'thick'**.

dEdx Resolution in Silicon

At the mercy of landau tail.

- **Babar study (Schumm)**

5 lyrs Si strip, 0.3mm each
Simulation based on the Vavilov model.

Discard top n pulse heights.

n	0	1	2	3	4
$\sigma/\mu(\%)$	13.9	11.3	10.4	11.7	13.7

(π at 450 MeV/c)

- **ALICE study (Batyunya)**

2 lyrs Si strip + 2 lyrs Silicon drift
Simulation based on GEANT.

Discard top 2 pulse-heights.

p_K(GeV/c)	0.44	0.5	0.78	0.88	0.98
$\sigma/\mu(\%)$	8.6	9.1	10.4	10.6	10.6

(Kaon)

π/K **Separation by Silicon**

4∼5 layers of Silicon layers 0.3mm each
$\rightarrow \sim$ 11% resolution near MIP.

Assume $n^{-0.43}$ and $x^{-0.32}$ dependence

$$\frac{\sigma}{\mu}(dEdx) \sim 0.14\, n^{-0.43} x(\text{mm})^{-0.32}$$

Model detector (small): $n = 6$, $x = 0.3$mm.
dEdx resolution $\sim$ 9.7%.

$> 2\sigma$ π/K separation for $p < 0.65$ GeV/c.

- Adequate for slow and stable $\tilde{\tau}$ search.
- But no good for high-P D reconstruction etc.

Dynamic range required to go down to
100 MeV/c: $\sim 20\times$MIP.

dEdx Summary

Gas:

- The scaling law $n^{-0.43}x^{-0.32}$ works reasonably.
- For Ar $L = 180$ cm,
  1 atm: 4.5%, $\pi/K > 2\sigma$ up to 100 GeV
  5 atm: 2.5%, $\pi/K > 4\sigma$ up to 50 GeV.
- The 'blind spot' near 1 GeV/c is 0.95 GeV/c wide for 1 atm, 0.35 GeV/c for 5 atm.
- Number of sampling: larger the better up to around 1000.
- In general, the heavier atom the better
  Ar over He or hydro-carbons.
- Pressurization improves resolution, but brings down the saturation momentum.

Silicon:

- No relativistic rise for Si:
  effective only for $p < 0.65$ GeV/c.
  The resolution of 10% is readily achievable and adequate for heavy charged particle searches.
- Dynamic range up to 20 MIP is needed.