Worldwide Study of
the Physics and Detectors
for Future Linear
$e^+ e^-$ Colliders

BILCW07

# TPC R&D for an ILC Detector

## Beijing Tracking Review

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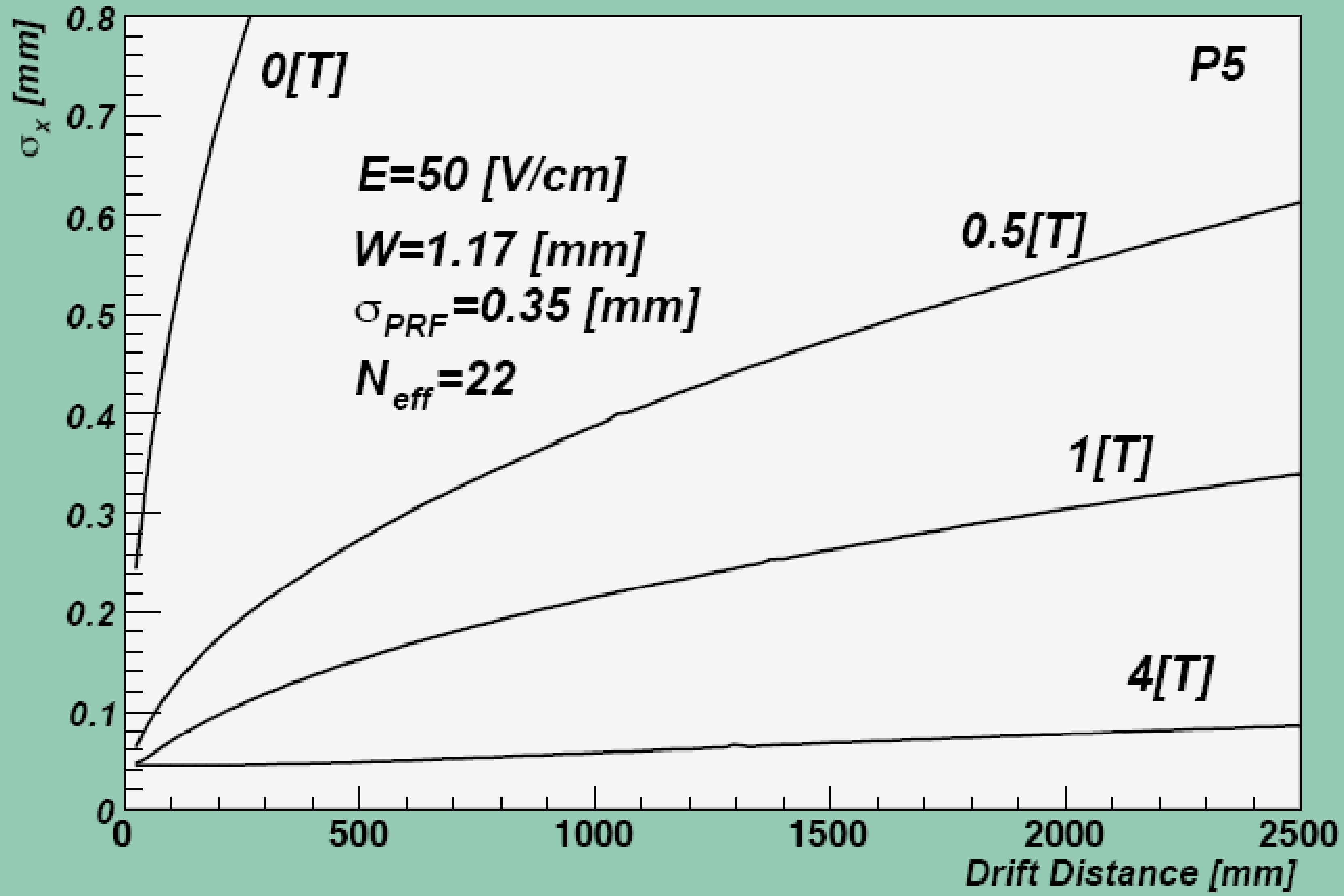
# LC-TPC Motivation/Goals

…to be tested@the R&D where possible…

- continuous 3-D tracking, easy pattern recognition throughout large volume, well suited for large magnetic field
- ~99% tracking efficiency in presence of backgrounds
- time stamping to 2 ns together with inner silicon
- minimum of $X_0$ inside Ecal (<3% barrel, <30% endcaps)
- $\sigma_{pt}$ ~ 100µm (rφ) and ~ 500µm (rz) @ 4T
- 2-track resolution <2mm (rφ) and <5-10mm (rz)
- dE/dx resolution <5% -> e/pi separation, for example
- easily maintainable if designed properly, in case of beam accidents, for example
- design for full precision/efficiency at 20 x estimated backgrounds

Keisuke Fujii



# Use of particle identification by measurement of the specific energy loss $dE/dx$ in physics analysis at OPAL

M. Hauschild
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## 1 b-Tagging via Semi-Leptonic Decays

### 1.1 $\Gamma_{b\bar{b}}$

Paper: PR076, CERN-PPE/93-46 (9-March-1993)
submitted to Phys. Lett. B
Title: Measurement of $\Gamma(Z^0 \to b\bar{b})/\Gamma(Z^0 \to \text{hadrons})$ using Leptons
dE/dx: Rejection of hadronic background for Muons:
dE/dx-norm for Muons $\geq -2.0\sigma$ for $N_{dE/dx} \geq 20$
Electron identification:
dE/dx-norm for Electrons $\geq -2.0\sigma$ for $N_{dE/dx} > 40$

Paper: PR056, CERN-PPE/92-38 (6-March-1992)
Zeitschrift für Physik C55 (1992) 191-207
Title: A Measurement of Electron Production in Hadronic $Z^0$ Decays and a Determination of $\Gamma(Z^0 \to b\bar{b})$
dE/dx: Electron identification:
dE/dx-norm for electrons $\geq -2.0\sigma$ for $N_{dE/dx} > 40$

### 1.2 b-Lifetime

Paper: PR048, CERN-PPE/91-201 (15-November-1991)
Phys. Lett. B274 (1992) 513-525
Title: Measurement of the Average B hadron Lifetime in $Z^0$ Decays
dE/dx: Electron identification:
dE/dx-norm for electrons $\geq -2.0\sigma$ for $N_{dE/dx} > 40$

### 1.3 $B^0$-$\bar{B}^0$ Mixing

Paper: PR049, CERN-PPE/91-212 (2-December-1991)
Phys. Lett. B276 (1992) 379-392
Title: Measurement of $B^0$-$\bar{B}^0$ Mixing in Hadronic $Z^0$ Decays
dE/dx: Rejection of hadronic background for muons:
Muon probability $> 1$ % IF $N_{dE/dx} \geq 60$
Electron identification:
dE/dx-norm for electrons $\geq -2.0\sigma$ for $N_{dE/dx} > 40$

## 2 $\tau$ Branching Ratios

### 2.1 Topological Branching Ratios

Paper: PR058, CERN-PPE/92-66 (29-April-1992)
Phys. Lett. B288 (1992) 373-385
Title: Measurement of the $\tau$ Topological Branching Ratios at LEP
dE/dx: Electron identification:
dE/dx-norm(pion) $>$ -2.5 $\sigma$ for $N_{dE/dx} > 20$
Rejection of photon conversions:
Pairs of oppositely charged tracks with both dE/dx-norm(electron) $>$ -2.0 $\sigma$

### 2.2 Exclusive Branching Ratios

Paper: PR041, CERN-PPE/91-103 (25-June-1991)
Phys. Lett. B266 (1991) 201-217
Title: Measurement of Branching Ratios and $\tau$ Polarization from $\tau \to e\nu\bar{\nu}$, $\tau \to \mu\nu\bar{\nu}$ and $\tau \to \pi(K)\nu$ Decays at LEP
dE/dx: Cross-check of electron selection efficiency in $\tau \to e\nu$ using dE/dx-distribution of low-momentum electron tracks ($x_e = 0.05 - 0.10$).

## 3 Exclusive b- and c-Decays

### 3.1 $B_s^0$

Paper: PR064, CERN-PPE/92-144 (3-September-1992)
Phys. Lett. B295 (1992) 357-370
Title: Evidence for the Existence of the Strange b-flavoured Meson $B_s^0$ in $Z^0$ Decays
dE/dx: Kaon selection and Pion rejection in $D_s$ decays:
dE/dx within $\pm 2\sigma$ of expected Kaon dE/dx AND below $-1\sigma$ of expected Pion dE/dx
Electron identification:
dE/dx-norm for electrons $\geq -2.0\sigma$ for $N_{dE/dx} > 40$
Rejection of hadronic background for muons:
Muon probability $> 1$ % IF $N_{dE/dx} \geq 60$

### 3.2 b-Baryons, $\Lambda_b$

Paper: PR055, CERN-PPE/92-34 (28-February-1992)
Phys. Lett. B281 (1992) 394-404
Title: Evidence for b-flavored Baryon Production in $Z^0$ Decays at LEP
dE/dx: Proton selection in $\Lambda$-Decays $\Lambda \to p\pi$:
dE/dx of larger momentum track compatible with proton
Rejection of hadronic background for muons:
Muon probability $> 1$ % IF $N_{dE/dx} \geq 60$
Electron identification:
dE/dx-norm for electrons $\geq -2.0\sigma$ for $N_{dE/dx} > 40$

### 3.3 $J/\psi \to l^+l^-$

Paper: PR039, CERN-PPE/91-92 (12-June-1991)
Phys. Lett. B266 (1991) 485-496
Title: Observation of $J/\psi$ Production in Multihadronic $Z^0$ Decays
dE/dx: Rejection of hadronic background in $J/\psi \to \mu^+\mu^-$:
Muon probability $> 1$ % IF $N_{dE/dx} \geq 60$
Electron identification in $J/\psi \to e^+e^-$:

## 4 c-tagging via $D^{*\pm}$

### 4.1 c Fragmentation Function

Paper: PR034, CERN-PPE/91-63 (8-April-1991)
Phys. Lett. B262 (1991) 341-350
Title: A Study of $D^{*\pm}$ – Production in $Z^0$ Decays
dE/dx: Kaon selection in $D^{*\pm} \to K\pi\pi$:
Kaon probability $> 10$ % for $x_D^* < 0.5$

## 5 QCD

### 5.1 Baryon Correlations

Paper: PR072, CERN-PPE/93-26 (8-February-1993)
Submitted to Phys. Lett. B
Title: Evidence for Chain-Like Production of Strange Baryon Pairs in Jets
dE/dx: Proton selection: ???

**10 examples, year 1992**

**Aleph ~ similar list… also: π/e separation for Ecal jet i.d. was extremely important**

**This dE/dx tool used effectively for S/N ehancement in >hundred papers for all of Lep1/Lep2 running for Opal and Aleph…**

# Therefore, BOUNDARY CONDITION: when you think of a solution for the ions:

- Don't touch the point resolution
- Don't touch the dE/dx resolution

# Step through the design issues described in the written report

# Ion build-up

Three sources of space charge are (a) ion build-up at the readout plane, (b) ion build-up in the drift volume and (c) ion backdrift, when ions created in the gas amplification drift back into the TPC volume.

(a) Ion Build-up at the readout plane.

At the surface of the gas-amplification plane during the bunch train of about 3000 bunch crossings spanning 1 ms, there will be few-mm thick layer of positive ions built up due to the incoming charge, subsequent gas amplification and ion backflow. An important property of MPGDs is that they suppress naturally the backflow of ions produced in the amplification stage. Steps to minimize this backflow are described in Sec. 5.6, where a suppression to 0.25% is shown to be achievable. Thus this layer of ions will reach a density of $\mathcal{O}(100)$ fC/cm$^3$, fC/cm$^3$, depending on gas gain and the background conditions during operation. Its effect will be simulated, but intuitively it should affect coordinate measurement only by a small amount since the drifting electrons incoming to the anode experience this environment during only the last few mm of drift. The TPC must plan to run with the lowest possible gas gain, meaning $\sim$ 1–2 $\times$ $10^3$, in order to minimize this effect.

(b) Ion build-up in the drift volume.

In the drift volume, an irreducible positive-ion density due to the primary ionization will be collected during about 1s (the time it takes for an ion to drift the full length of the TPC). The positive-ion density will be higher near the cathode and will be a few fC/cm$^3$ at the estimated occupancy of $\sim$ 0.5%. The effect of the charge density will be established by our R&D program, but the experience of the STAR TPC[20] indicates that 200 fC/cm$^3$ is tolerable (Sec. 3.7(b)) and a few fC/cm$^3$ is well below this limit.

(c) Ion backdrift and gating.

# Ion backdrift, gating

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(c) Ion backdrift and gating.

The operational conditions at the linear collider – long bunch trains, high physics rate – require an open-gate operation without the possibility of intra-train gating between bunch-crossings should the delivered luminosity be optimally utilized. As already mentioned, MPGDs lend themselves naturally to the intra-train un-gated operation at the ILC since they can operate with a significant suppression of the back-drifting ions. In order to minimize the impact of ion drifting back into the drift volume, a required backdrift suppression of about 1/gasgain has been used as a rule-of-thumb, since then the total charge introduced into the drift volume is about the same as the charge produced in the primary ionization.

Not only have these levels of backdrift suppression not been achieved during our R&D (Sec. 5.6), but also this rule-of-thumb is misleading. Lower backdrift levels will be needed since these ions would drift as few-mm thick sheets through the sensitive region during subsequent bunch trains. The charge density in the sheets would be much higher than a few fC/cm$^3$ (Sec. 3.6(b)) since the volume in the sheets is $\sim$ 100 times smaller than that of the drift volume. How these sheets would affect the track reconstruction will be simulated to understand their influence, but since this backdrift into the drift volume can in principle be completely eliminated by a gating plane, a gate should be foreseen, to guarantee a stable and robust chamber operation. The added amount of material for a gating plane will be small (e.g., it was $< 0.5\%X_0$ average thickness for the Aleph TPC). The gate will be closed between bunch trains and remain open throughout one full train. This will eliminate the need to

# Field non-uniformity

(a) Magnetic field.

Non-uniformity of the magnetic field of the solenoid will be by design within the tolerance of $\int_{\ell_{\mathrm{drift}}} \frac{B_r}{B_z} dz < 2\mathrm{mm}$ as used for previous TPCs. This homogeneity is achieved by corrector windings at the ends of the solenoid. At the ILC, larger gradients will arise from the fields of the DID (Detector Integrated Dipole) or anti-DID, which are options for handling the beams inside the detector at the IRs with 14 mrad crossing-angle (as has been decided for the ILC). This issue was studied intensively at the 2005 Snowmass workshop[22][23], where it was concluded that the TPC performance will not be degraded if the B-field is mapped to $10^{-4}$ relative accuracy and the calibration procedures outlined in the next point (Sec. 3.8) are followed. These procedures will lead to an overall accuracy of $2 \times 10^{-5}$ which has been shown to be sufficient[23] and was already achieved by the Aleph TPC[22]. Based on past experience, the field-mapping gear and methods should be able to accomplish the goal of $10^{-4}$ for the B-field. The B-field should also be monitored during running since the DID or other corrector windings may differ from the configurations mapped; for this purpose the option of a matrix of Hallplates and NMR probes mounted on the outer surface of the fieldcage is being studied.

# Field non-uniformity

(b) Electric field.

Non-unformity of the electric field can arise from the fieldcage (Sec. 3.4) and from the processes explained in Sec. 3.6: ion build-up at the gas-amplification plane and due to primary ionization in the drift volume. The other source in Sec. 3.6, ion-sheets drifting back through the chamber can be eliminated via a gating plane, as explained there.

–For the first, the field cage design, the non-uniformities can be minimized using the experience gained in past TPCs.

–The effect due to the second, ion build-up at the readout plane can be minimized by running at the lowest possible gain.

–The effect due to the third, the primary ions, is due to backgrounds and is irreducible as already mentioned. The maximum allowable electrostatic charge density remains to be specified, but studies by the STAR experiment[20] for their high-luminosity running in future, and taking into account that the LCTPC will use a gas with high $\omega\tau$ (Sec. 3.5), indicate that about 0.2 pC/cm$^3$ at the center of the TPC will give a ~10 mm displacement, which is of the same order as due to that of the anti-DID and is correctable. At the nominal occupancy due to backgrounds of $\sim$ 0.5%, the space charge is estimated to be of order 1 fC/cm$^3$. This will be revisited by simulation within the R&D program (Sec. 6).

# Calibration

The tools for solving this issue are Z-peak running, the laser system, the B-field map, a matrix of Hallplates/NMR probes outside the TPC and Si-layers inside the inner fieldcage and outside the outer fieldcage. In general[24] about 10/pb of data at the Z peak will be sufficient during commissioning for the alignment of the different subdetectors, and typically 1/pb during the year may be needed depending on the backgound and operation of the ILC machine (e.g., beam loss). A laser calibration system will is foreseen (see e.g., [21][20][14]) which can be used to understand both magnetic and electrostatic effects, while a matrix of Hallplates/NMR probes may supplement the B-field map. The $z$ coordinates determined by the Si-layers inside the inner fieldcage of the TPC were used in Aleph[25] for drift velocity and alignment measurements, were found to be extremely effective and will thus be included in the LCTPC planning. The overall tolerance is that (Sec. 3.7) systematics have to be corrected to about $2 \times 10^{-5}$ throughout the chamber volume[22][23], and this level was already achieved by the Aleph TPC[22][25].