Time Stamping

CDC/TPC Comparison Studies

Keisuke Fujii, KEK
Why Time Stamping?
JLC/NLC Bunch Structure and Min-Jet BG
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1.4ns x 192 bunches

1.4ns

@100/120Hz
JLC/NLC Bunch Structure and Min-Jet BG

1.4\text{ns} \times 192 \text{bunches}

@100/120Hz
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2-Photon Mini-Jet Production

\[ \langle E \rangle \approx 2.5 \text{ GeV} \]

\[ \langle n_{\text{ch}} \rangle \approx 5 \]

in chamber acceptance
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$\ll L_{\text{max drift}} / \nu_{\text{drift}}$

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All the tracks will be recorded as from a single event

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Confusion in topology recognition

\[ L_{\text{max}} \neq \frac{\nu_{\text{drift}}}{v_{\text{drift}}} @100/120Hz \]
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Degradation of M-jet resolution

........
How to Time-Stamp a Track?
In the Case of JLC-CDC
In the Case of JLC-CDC

Staggered Cells
In the Case of JLC-CDC

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Wrong TO breaks a track!
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\[ \Delta x = 2 \, v_{\text{drift}} \times \Delta T_0 \]
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$$\Delta x = 2 \, v_{\text{drift}} \times \Delta T_0$$

Naively we expect
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Staggered Cells

Wrong TO breaks a track!

\[ \Delta x = 2 v_{\text{drift}} \times \Delta T_0 \]

Naively we expect

\[ \sigma \Delta T_0 \approx \frac{\sigma_{xy}}{v_{\text{drift}} \sqrt{n}} \]
In the Case of JLC-CDC

Staggered Cells

Wrong T0 breaks a track!

\[ \Delta x = 2 \ v_{\text{drift}} \times \Delta T_0 \]

Naively we expect

\[ \sigma_{\Delta T_0} \approx \frac{\sigma_{xy}}{v_{\text{drift}} \sqrt{n}} \]

- \( \sigma_{xy} = 85 \ \mu m \)
- \( v_{\text{drift}} = 0.7 \ \text{cm/\mu s} \)
- \( n = 50 \)

\[ \sigma_{\Delta T_0} \approx 1.7 \ \text{ns} \]
In the Case of TPC
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External Z Detector (T0 Device)
In the Case of TPC

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Wrong T0 makes a Z-shift!
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Wrong T0 makes a Z-shift!

\[ \Delta z = v_{\text{drift}} \times \Delta T_0 \]

Naively we expect
In the Case of TPC

Wrong $T_0$ makes a $Z$-shift!

\[ \Delta z = v_{\text{drift}} \times \Delta T_0 \]

Naively we expect

\[
\sigma_{\Delta T_0} \approx \frac{2\sigma_z}{v_{\text{drift}} \sqrt{n}} \left[ 1 + 3 \left( \frac{d}{L} \right) + 3 \left( \frac{d}{L} \right)^2 \right]^{-\frac{1}{2}}
\]
In the Case of TPC

Wrong T0 makes a Z-shift!

\[ \Delta z = \nu_{\text{drift}} \times \Delta T_0 \]

Naively we expect

\[
\sigma_{\Delta T_0} \simeq \frac{2\sigma_z}{\nu_{\text{drift}} \sqrt{n}} \left[ 1 + 3 \left( \frac{d}{L} \right) + 3 \left( \frac{d}{L} \right)^2 \right]^{-\frac{1}{2}}
\]

\[
\simeq \frac{2\sigma_z}{\nu_{\text{drift}} \sqrt{n}} \quad \text{if} \quad \left( \frac{d}{L} \right) \ll 1
\]
In the Case of TPC

External Z Detector (T0 Device)

Wrong T0 makes a Z-shift!

\[ \Delta z = v_{\text{drift}} \times \Delta T_0 \]

Naively we expect

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\[ \approx \frac{2\sigma_z}{v_{\text{drift}} \sqrt{n}} \quad \text{if} \quad \left( \frac{d}{L} \right) \ll 1 \]

Assuming that Z resolution of the external detector is negligible
In the Case of TPC

Wrong T0 makes a Z-shift!

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Assuming that Z resolution of the external detector is negligible

\[
\sigma_z = 500 \ \mu m \\
v_{\text{drift}} = 5 \ \text{cm/\mu s} \\
n = 120
\]
In the Case of TPC

Wrong T0 makes a Z-shift!

Naively we expect

\[ \Delta z = v_{\text{drift}} \times \Delta T_0 \]

External Z Detector (T0 Device)

Assuming that Z resolution of the external detector is negligible

\[ \sigma_{\Delta T_0} \approx \frac{2\sigma_z}{v_{\text{drift}} \sqrt{n}} \left[ 1 + 3 \left( \frac{d}{L} \right) + 3 \left( \frac{d}{L} \right)^2 \right]^{-\frac{1}{2}} \]

\[ \approx \frac{2\sigma_z}{v_{\text{drift}} \sqrt{n}} \quad \text{if} \quad \left( \frac{d}{L} \right) \ll 1 \]

\[ \sigma_{\Delta T_0} \approx 2.0 \text{ ns} \]

\[ \sigma_z = 500 \mu m \]

\[ v_{\text{drift}} = 5 \text{ cm/\mu s} \]

\[ n = 120 \]
More Realistic Estimation

Helix Fit CDC Hits with T0 as an Additional Fit Parameter
CDC Case
CDC Case

Chi2 Distribution (axial only)
CDC Case

Chi2 Distribution (axial only)

\[ \chi^2 \text{ distribution for } \]
\[ \text{ndf} = 50 \times 2 - 6 = 94 \]
\[ \text{mean} = \text{ndf} = 94 \]
\[ \text{RMS} = \sqrt{2 \times \text{ndf}} = 13.7 \]

Helix Fit with \( T_0 = 21\text{ns} \)

<table>
<thead>
<tr>
<th>hChi2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries</td>
</tr>
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CDC Case

Chi2 Distribution (axial only)

Helix Fit with $T_0=21\text{ns}$

$\chi^2$ distribution for

- $\text{ndf} = 50 \times 2 - 6 = 94$
- mean = ndf = 94
- $\text{RMS} = \sqrt{2 \times \text{ndf}} = 13.7$

Fit seems OK!
T0 from Helix Fit (axial only, 100GeV)
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Default 3T Configuration with $\sigma_{xy} = 85\mu m \times 50$ pts

$\sigma_{T_0} = 1.75$ ns
To from Helix Fit (axial only, 100GeV)

We can determine T0 with ~1.8ns accuracy as expected!
What happens if we add stereo layers?

At certain Z positions, we lose L/R staggering of the neighboring layers!

Stereo layers allow additional freedom to eliminate track discontinuity by adjusting dip angle!

----> Degradation of time stamping capability?
Chi2 Distribution (axial+stereo, 100GeV)
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Helix Fit with $T_0 = 21$ns

$\chi^2$ distribution for

- $\text{ndf} = 50 \times 2 - 6 = 94$
- mean = ndf = 94
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Chi2 Distribution (axial+stereo, 100GeV)

Fit seems OK!
T0 from Helix Fit (axial+stereo, 100GeV)
T0 from Helix Fit (axial+stereo, 100GeV)
T0 from Helix Fit (axial+stereo, 100GeV)

We can still determine T0 with ~2.2ns accuracy!
What about Low Pt Tracks?
Multiple Scattering Effects (axial+stereo, 1GeV)
**Multiple Scattering Effects (axial+stereo, 1GeV)**

\[ \kappa \equiv \frac{1}{P_T} \]

\[ \sigma_\kappa = (2.01 \pm 0.02) \times 10^{-4} \]

\[ \sigma_{T_0} = 1.87 \text{ns} \]
Multiple Scattering Effects (axial+stereo, 1GeV)

$\kappa \equiv 1/P_T$

$\sigma_\kappa = (2.01 \pm 0.02) \times 10^{-4}$

$\sigma_T = 1.87\text{ns}$

$\sigma_\kappa = (8.57 \pm 0.6) \times 10^{-4}$

$\sigma_T = 1.94\text{ns}$
Multiple Scattering Effects (axial+stereo, 1GeV)

\[ \kappa \equiv \frac{1}{P_T} \]

\( \sigma_{\kappa} = (2.01 \pm 0.02) \times 10^{-4} \)

Only Small Effect on T0

\( \sigma_{T_0} = 1.87 \text{ns} \)

\( \sigma_{\kappa} = (8.57 \pm 0.6) \times 10^{-4} \)

\( \sigma_{T_0} = 1.94 \text{ns} \)
In the Case of TPC

Assuming a generic TPC with

\[ R_{\text{out}} - R_{\text{in}} = 120 \text{ cm} \]
\[ \sigma_{xy} = 150 \mu m \]
\[ \sigma_z = 500 \mu m \]
\[ B = 4T \]
\[ n = 120 \]
\[ v_{\text{drift}} = 5 \text{ cm/\mu s} \]

and a T0 device with

\[ \sigma_z^{T0} = 10 \mu m \]

Helix Fit TPC hits Including the External Z Hit with T0 as an Additional Fit Parameter
TO from Helix Fit (d=5cm, 100GeV)
**TO from Helix Fit (d=5cm, 100GeV)**

TPC with $\sigma_z = 500 \mu m \times 120$ pts

$\sigma_{T_0} = 2.00$ ns

0ns, 7ns, 14ns, 21ns
**T0 from Helix Fit (d=5cm, 100GeV)**

We can determine T0 with ~2.0ns accuracy as expected!
What about Low Pt Tracks?
Multiple Scattering Effects (d=5cm, 0.6\%X0, 2GeV)
Multiple Scattering Effects (d=5cm, 0.6%X0, 2GeV)

TPC with $\sigma_z = 500\mu\text{m} \times 120$ pts

$P_T = 2\text{GeV}$
M.S. OFF

Input $T_0 = 14\text{ns}$

$\sigma_T = 2.0\text{ns}$
Multiple Scattering Effects (d=5cm, 0.6%X0, 2GeV)
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MS Effect more significant than for CDC
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This is probably due to the fact that there is only a single break point to decide T0.
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MS Effect more significant than for CDC

This is probably due to the fact that there is only a single break point to decide $T_0$.

The material thickness between TPC and TO detector does not matter as long as it stays just in front of the TO detector.
Multiple Scattering Effects (d=5cm, 0.6%X0, 2GeV)

MS Effect more significant than for CDC

This is probably due to the fact that there is only a single break point to decide T0.

The material thickness between TPC and T0 detector does not matter as long as it stays just in front of the T0 detector.

0.6%X0 to 3.0%X0 --> 2% shift in T0 resolution
Summary & Conclusions
We have just started CDC/TPC comparison studies for time stamping capability.
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CDC alone can determine T0 on a track by track basis with a time resolution of ~2ns.
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CDC alone can determine TO on a track by track basis with a time resolution of ~2ns.

The TO resolution is rather insensitive to multiple scattering.
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CDC alone can determine T0 on a track by track basis with a time resolution of ~2ns.

The T0 resolution is rather insensitive to multiple scattering.

TPC can determine T0 together with a T0 device with a similar precision.
We have just started CDC/TPC comparison studies for time stamping capability.

CDC alone can determine TO on a track by track basis with a time resolution of ~2ns.

The TO resolution is rather insensitive to multiple scattering.

TPC can determine TO together with a TO device with a similar precision.

Multiple scattering effect is, however, more significant.
Further Studies
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Refinement of the mini-Jet BG estimate.
Further Studies

- Refinement of the mini-Jet BG estimate.
- Effect of curling up tracks.
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- Effect of curling up tracks.
  - Effect is probably more serious for TPC than for CDC.
- Linking to VTXD to eliminate primary tracks originating from a displaced vertex in Z.
- Repeat everything for multi-jet events.