Time-of-Flight Software Status

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Outline:
• Motivation
• Time-of-Flight subsystem
• Status
• Validation results
• Timing resolution
• Summary
TOF Reconstruction

- Goal for FTOF: combined timing resolution in the range 35-80 ps. → Main focus here.
- $\pi - K$ separation rises to $p=3.4$ GeV from 3.0 GeV.
- $\pi - p$ separation rises to $p=6.6$ GeV from 6.0 GeV.
- $K - p$ separation rises to $p=5.8$ GeV from 5.2 GeV.

- Outputs
  - Times ($T_L, T_R$ from TDCs)
  - Positions ($x_{\text{cluster}} = v_{\text{eff}} (T_L - T_R)/2$, $y_{\text{cluster}}$ depends on cluster size)
  - Hit times ($T_{\text{hit}}$ from $(T_L + T_R)/2$)
  - Deposited energy ($E_{\text{dep}}$ from ADCs)

Diagram:

Looking out from the target

$x$

$y$
TOF Reconstruction

- **Forward Time-of-Flight (FTOF)**
  - 6 sectors, double-sided PMT readout.
  - **Paddles:**
    - Panel 1a - 23, 15-cm wide, 70-130 ps timing requirement.
    - Panel 1b - 62, 6-cm wide, 40-100 ps timing requirement.
    - Panel 2 – 5, 15-cm wide, 140-165 ps timing requirement.

- **Central Time-of-Flight (CTOF)**
  - 48 paddles, double-sided PMT readout.
  - form hermetic barrel around target.
  - 60-ps timing resolution requirement.
FTOF Software Status

- First version of standalone TOF reconstruction code (CLAS-NOTE 2014-003) ported to coatjava.
- Results of DC reconstruction used to extrapolate track to FTOF panels.
- Geometry obtained from Java package for FTOF reconstruction and gemc.
- Updated to latest versions of Common Tools.
- Part of upcoming Common Tools 2.5 release.
- Validation studies ongoing (results below).
FTOF Software Validation Studies

• Run Conditions:

<table>
<thead>
<tr>
<th>Software 1</th>
<th>Software 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>JLab v1.2</td>
<td>gemc v2.2</td>
</tr>
<tr>
<td>coatjava 2.0</td>
<td>Single paddle hits.</td>
</tr>
</tbody>
</table>
| Event generators – uniform distributions | $ep \rightarrow e'p$
| | $ep \rightarrow e'\pi^+\pi^-$ |
| Magnetic fields off | |

• Studies
  
  o Particles: $e', p, \pi^+, \pi^-$
  
  o Quantities:
    \[
    \Delta X = X_{gemc} - X_{recon} \\
    \Delta Y = Y_{gemc} - Y_{recon} \\
    \Delta T = T_{gemc} - T_{recon} \\
    Y_{recon} \text{ versus } X_{recon} \\
    E_{dep}, \ ADCL, \ ADCR \\
    TDCR, \ TDCL
    \]

Looking out from the target

x

y
Position Studies - 1

\[ \Delta X = X_{gemc} - X_{recon} \pm 3 \text{ mm} \]

Magnetic fields set to zero.

Panel widths:
1A – 15 cm
1B – 6 cm
2 – 22 cm

Histograms show difference between simulation and reconstruction parameters.

Geometry used in coatjava 2.0 from same database used by gemc.
Position Studies - 2

Magnetic fields set to zero.

Panel widths:
1A – 15 cm
1B – 6 cm
2 – 22 cm

Widths reflect geometry of each paddle.

Spike in panel 2 and a wee bit in panel 1b likely due to hit in neighboring counter. Under investigation.

\[ \Delta Y = Y_{gemc} - Y_{recon} \ (\pm 20 \text{ cm}) \]
Deposited Energy and ADCs

- **\( E_{\text{dep}} \)**
- **\( e^- \)**
- **\( p \)**
- **\( \pi^+ \)**
- **\( \pi^- \)**

Magnetic fields set to zero.

Panel thickness:
- 1A – 5 cm
- 1B – 6 cm
- 2 – 5 cm

Position of \( E_{\text{dep}} \) peak consistent with past measured response and thickness of the paddle.

\[ E_{\text{dep}} (0 - 10 \text{ MeV}) \]

\[ E_{\text{dep}} (0 - 20 \text{ MeV}) \]
Timing

\[ \Delta T = T_{gemc} - T_{recon} \ (\pm 20 \text{ ps}) \]

Timing resolutions

Panel 1a: 70-130 ps
Panel 1b: 40-100 ps
Panel 2: 140-165 ps.

TDC digitization in gemc needs to be made more realistic – DONE!

Required timing resolution is in the range 35-80 ps for combined panels 1a and 1b.
1. Start with ‘gold’ events first: single hits in panels 1a and 1b, all signals present.

2. Cluster coordinates:

\[ x_{\text{cluster}} = \frac{v_{\text{eff}}}{2} (TDCL - TDCR) \]
\[ y_{\text{cluster}} = \text{middle of counter} \]

3. Cluster matching within a panel

\[ x_{\text{cluster}}^{1a} - x_{\text{track}}^{1a} < \text{parm}_{1a}^{x} \quad \text{Panel 1a} \]
\[ y_{\text{cluster}}^{1a} - y_{\text{track}}^{1a} < \text{parm}_{1a}^{y} \]
\[ x_{\text{cluster}}^{1b} - x_{\text{track}}^{1b} < \text{parm}_{1b}^{x} \quad \text{Panel 1b} \]
\[ y_{\text{cluster}}^{1b} - y_{\text{track}}^{1b} < \text{parm}_{1b}^{y} \]


\[ (x_{\text{cluster}}^{1a} - x_{\text{corr}}) - x_{\text{cluster}}^{1b} < \text{parm}_{1ab}^{x} \]
\[ (y_{\text{cluster}}^{1a} - y_{\text{corr}}) - y_{\text{cluster}}^{1b} < \text{parm}_{1a}^{y} \]

where \( x_{\text{corr}} / y_{\text{corr}} \) is an extrapolation back to the panel 1b hit location and the \( \text{parm}_{i}^{j} \) are to be determined.
5. Compute correct hit time using

\[
    t_{corr} = \frac{\frac{t_{1b}^{cluster}}{1/\sigma_{1b}^2} + \frac{t_{1a}^{cluster} - \Delta r/\beta}{1/\sigma_{1a}^2}}{\frac{1}{\sigma_{1b}^2} + \frac{1}{\sigma_{1a}^2}}
\]

where the \(\sigma_{1a}\) and \(\sigma_{1b}\) are the counter time resolutions. The times \(t_{1a}^{cluster}\) and \(t_{1b}^{cluster}\) are the hit times relative to the RF. The term \(\Delta r/\beta\) accounts for the path length difference between the panel 1b cluster hit coordinate and the panel 1a one (depends on tracking).

6. Study time resolutions by comparing the widths of the distributions:

\[
\sigma[(t_{1b} - t_{RF}) - t_{1b}^{hit}, p], \sigma[(t_{1a} - t_{RF}) - t_{1a}^{hit}, p], \sigma[(t_{corr} - t_{RF}) - t_{1b}^{hit}, p]
\]

which are also functions of momentum.
7. Use ‘silver’ events: multiple paddle hits in panels 1a and 1b, all signals present.

\[ x_{\text{cluster}} = \frac{\sum_{i=1}^{\text{nhits}} x_{\text{hit}}^{i}}{\sum_{i=1}^{\text{nhits}} E_i^2} \]

\[ y_{\text{cluster}} = \frac{\sum_{i=1}^{\text{nhits}} y_{\text{hit}}^{i}}{\sum_{i=1}^{\text{nhits}} E_i^2} \]

\[ E_i \equiv \text{deposited energy} \]

\[ \text{nhits} \equiv \text{cluster size} \]

8. Cluster matching – same as above for gold events.

9. Hit time for cluster

\[ t_{1b}^{\text{cluster}} = \frac{\sum_{i=1}^{\text{nhits}} t_{1b}^{i}}{\sum_{i=1}^{\text{nhits}} 1/\sigma_{1b}^2} \]

\[ t_{1a}^{\text{cluster}} = \frac{\sum_{i=1}^{\text{nhits}} t_{1a}^{i}}{\sum_{i=1}^{\text{nhits}} 1/\sigma_{1a}^2} \]

10. Corrected hit time – same as above for gold events.

11. Time resolutions – same as above for gold events.

Summary

1. Standalone TOF reconstruction software updated and in coatjava 2.5.
2. Matching between DC track and FTOF hits done.
3. FTOF and gemc getting calibration constants from the same source.
4. Validation studies ongoing.
5. Timing resolution studies starting.