The CDF
Time of Flight Detector

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October 21, 2003 IEEE NSS/MIC PORTLAND, Oregon
Outline

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• TOF resolution
• Physics with TOF
  – B physics
  – Minimum bias QCD
  – Exotic physics
• Conclusions
TOF in CDF

Cylinder of 216 scintillator bars at radial distance from beam pipe 1.4 m
- Bicron BC-408
- Att. length 2.5 m
- Fast rise time 0.9 ns
- 4 x 4 x 280 cm

PMT at each end
- Hamamatsu R7761
- Fine mesh, 19 stage
- Gain reduction 500 @ B=1.4 T
- Small TTS: 250-400ps

TOF Milestones
- Test run (5% “full scale”) in 1995
- Approved in January 1999
- Fully installed in August 2000
- Electronics in August 2001
- Stable data taking from October 2001
TOF technique

Objective: flight time of the particle from collision to TOF detector

\[ t_s = \frac{d}{s} \]

\[ t_w = \frac{\alpha}{\sqrt{\text{adc}}} \]

\[ TDC = C_s - (t_0 + \text{tof} + t_s + t_c + t_w) \]

\[ d = L/2 \pm z \] (\( L = 280 \text{ cm} \))
Calibrations

- ADC calibration
  - Pedestals measurement and linearity check
- Time-to-Amplitude Converter (TAC) calibration
  - Digital delay generator to study non-linear response

- Time walk effect
  - Due to dependence of discriminator time on pulse height (~2 ns)
- Speed of signal propagation in bars
  - Times depend on z position of hit along the bar (~20 ns)
- Channel-to-Channel time offset
  - Includes cable lengths and clock signals (~1 ns)
- Residual correction in z position along the bar
  - Residual dependence of time with the position (~200 ps)
Calibrations (II)

Time walk correction

Due to leading edge pick-off method

Larger pulses fire the discriminator at earlier time than smaller pulses

Effect studied with tracks passing through two adjacent bars of scintillator

\[ F(Q) = \frac{-\alpha}{\sqrt{Q}} \]

Time difference vs. z

The effective speed of light comes from the fitted slope

Time walk dependence is absorbed in the fit

\[ t_E - t_w = t_E^0 - t_w^0 - [F_E(Q) - F_W(Q)] + 2z/s \]
t_0\text{ calculation}

The CDF TOF detector has unique conditions
Long bunches $\sigma_z \sim 30 \text{ cm} \Rightarrow \Delta t_0 = \sigma_z/c \sim 1 \text{ ns} \gg \sigma_{\text{tof}}$

Need to calculate $t_0$ event by event to achieve the design resolution

Perform likelihood fit track by track
$\geq 3$ good tracks/event but the track of interest

For each track hitting TOF
$t_0^{\pi,k,p} = \text{TDC} - t_c - t_w(Q) - t_s(z) - \text{TOF} \pi,k,p$
Choose $\pi,k,p$ with probabilities $f_{\pi,k,p}$ ($\Sigma f_i = 1$)

$$\sigma(t_0) \sim \frac{100 \text{ ps}}{\sqrt{N_{\text{tracks}}}}$$

Three $p\bar{p}$ interactions in one bunch crossing at the same $z$
Times of individual collisions measured with TOF detector
**TOF triggers**

**Low amplitude threshold**  
Minimum Ionizing Particle (MIP)  

COT multiplicity > 22  
14 MIPs hits in TOF (MIP > 400 ADC)

**QCD physics**  
Studies of Minimum Bias (high multiplicity) events  
Try to explain non perturbative soft interactions

**High amplitude threshold**  
Highly Ionizing Particle (HIP)  

Trigger rate is kept below ½ Hz  
Data shows a linear response from zero to four MIPs

**Exotic physics**  
Dirac Magnetic Monopole Search  
Deposit large amount of energy along the way
TOF resolution
(pure pion sample)

- Data (~65 pb⁻¹): two displaced tracks, $P_t > 2$ GeV/c
- Decay of interest: $D^* \rightarrow D^0 \pi^\pm \rightarrow [K\pi]\pi^\pm$

$\Delta t \equiv \text{ToF}_{\text{measured}} - \text{ToF}_{\text{expected}}$

$\Delta t$ sideband subtracted, $p < 1.3$ GeV/c

Narrow gaussian $\Rightarrow 129 \pm 2$ ps
Broad gaussian $\Rightarrow 378 \pm 9$ ps

less events $\sim 12\%$

Narrow gaussian $\Rightarrow 118 \pm 2$ ps
Broad gaussian $\Rightarrow 340 \pm 22$ ps

$\sim 33\%$

t₀ correlation between two pions
Get $t_0$ from fast $\pi$ ($|\Delta t| < 0.1$ ns), used to the second $\pi$
Sample, high $P_t$ electrons

Decay of interest

$Z^0 \rightarrow e^+e^-$

TOF resolution

$(175 \pm 8)/\sqrt{2} = 124 \pm 6$ ps

Also done with other high $P_t$ samples:
- Dijet with resolution of $123 \pm 11$ ps
- Multijets with resolution of $139 \pm 4$ ps
Physics with TOF (I)

B physics TOF designed mainly for flavor tagging
Flavor oscillation and CP asymmetry → determine the B flavor via kaon ID

Opposite side tagging:
exploits B weak decays $b \rightarrow c \rightarrow s$
($b \rightarrow K^-X$ but $b \rightarrow K^+X$)

Same side tagging:
exploits correlation between $b$ flavor and particles produced in hadronization
$\pi \leftrightarrow B^0$, $\pi^- \leftrightarrow B^0_s$, $K^+ \leftrightarrow B^0_s$
Physics with TOF (II)

B physics $\Lambda_b \rightarrow \Lambda_c l \nu \rightarrow [pK\pi]l\nu$

TOF (and dEdx) used to identify the proton to reduce greatly backgrounds

Particle ID with pseudo likelihood ratio (signal efficiency = 64 %)

$\Lambda_b$ lifetime can be measured using an unbinned likelihood fit to the proper decay lengths of the $\mu + \Lambda_c$
Physics with TOF (III)

Exotic physics
Massive long-lived charged particles (CHAMPS)
High $P_t$ muon events
Large energy loss
Isolated candidate tracks
Search for slow particles

Cosmic rays rejection
High Pt muon pairs

High $P_t$ physics
Significant background to Electroweak & Exotic physics
Conclusions

- TOF fully operational and reliably working since October 2001
- Resolution sensitive to $t_0$ calculation, depends on the analysis
- Trigger hardware (MIP and HIP) installed and working
- Being used for several physics analysis
- Flavor Tagging results soon
Backup slides
TOF group at CDF

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Mechanics and phototubes

- Custom-made Hamamatsu R7766
  - 19 dynode (high gain)
  - Fine mesh (increased tolerance @ 1.4 T)
  - Small size 1.5 x 2.5 inches
  - Operated with a positive HV up to 2500 V
  - Gain reduction factor at B = 1.4 T \( \sim 500 \)

- Scintillators assembled in 72 triplets
- PMT in Alu holders
- Tight radial clearance (few mm)
TOF signal path

Electronics contribution to overall resolution < 25 ps

19-stage Hamamatsu R7761
Gain ~ 30000 @ B = 1.4 T

HV base: differential signal from anode and last dynode

Pulse split for time and charge measurement

Bilinear gain a wide dynamic range ~2 for largest pulses ~15 for smallest pulses

TAC: linear charging of timing capacitors

Time digitized by 12-bit ADC

Charge digitized by 10-bit ADC

Gate of adjustable width for charge measurement
Mass separation
Monopoles
CHAMPS

Escapes detector, evades bounds from existing searches

Muon Detector

Penetrating (will look like muon)

Time-of-Flight (TOF) detector

Tracking Chamber

Slow moving, high transverse momentum ($P_T$)

Isolated

Large Time-of-Flight (TOF)

Large ionization (dE/dx) energy loss