The Timepix telescope for charged particle tracking

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(On behalf of the LHCb Collaboration)

Why bother...?

- Telescope built primarily to qualify the TimePix chip as a viable option for the Velo Upgrade (see talk of P.Rodriguez)
- Collaboration between Medipix group and LHCb
- Extended under AIDA project to provide flexible, high precision, fast telescope to support generic detector R&D (specifically including LHC-style readout)
 - Telescope based in CERN SPS North Area (H8)

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 - **ToA** (Time of Arrival): pixel starts counting with first hit, counts until shutter closes
 - **ToT** (Time over Threshold): linear pixel discharge, time over threshold $\propto$ charge

Telescope setup

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- Readout system developed at Nikhef - RELAXD
- Whole telescope built for flexibility - remote movement of telescope (x-y for whole setup, x-y- θ for DUT) + DUT, mounting inside/upstream/downstream

- Data taking is shutter based
 - Bursts of triggers then $\sim 10\text{ms}$ readout dead time
- Each telescope frame contains many tracks - time matched offline to DUT data
- Max frame rate of $\sim 60\text{Hz}$, with 10-200 tracks/frame gives up to **12kHz** track rate
- No hardware integration of the DUT. Data taking separate, only interaction between systems is trigger to and busy from DUT. Hardware timestamp required in DAQ

External users

Medipix3 - PXI readout system

ATLAS Planar Pixel Silicon

CLiC

LHCb Scintillating Fibres

- Tracks are reconstructed using a straightforward extrapolation along z (beam) axis
 - Extrapolate in z, look for clusters, fit prototrack, extrapolate, search...
- Low chip noise vital for clean reconstruction

z-axis extrapolation and KDTree search

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Reconstruction of a single frame: 25 - 100 tracks cm^{-2}

Single plane resolution versus angle

- Single chip extensively tested before building the telescope proper
 - K.Akiba et al, Nucl. Instr. A 661 (2011) 31-49
- For 300 μm sensor at moderate bias, best resolution of $\sim 4\mu\text{m}$ achieved
- From MC including scattering and single plane resolution, get $< 2\mu\text{m}$ pointing resolution

MC Determination of pointing resolution

Single plane performance plots

Reconstruction efficiency

- Detection efficiency of chips $> 99\%$ (as expected)
- Adding more tracks in the same area means distance between tracks scales as $1/(\text{occupancy}^2)$
- Inefficiencies in track reconstruction come (mainly) from
 - Tracks being close to each other
 - Multiple scattering

Tracks reconstructed v. tracks expected

CPU for reconstruction / event v. occupancy

Performance - results with dut

Detection efficiency in 3D sensors

Column structure

Resolution v. angle for $2 \times 10^{15} \text{ 1 MeV n}_{\text{eq cm}^{-2}}$

Charge sharing studies - location of n-pixel clusters across the unit cell

- New chip from Medipix3 collaboration, submission ~end of 2012
 - Testbed for several experiments interested in custom TimePix chips (LHCb, CLIC..)
- Frame based concept discarded in favour of high-rate data-driven readout
 - Environments such as LHCb VELO upgrade require all data to be sent off-detector, for each 25ns bunch crossing => no time for triggers
 - **Data driven readout**
- Will give huge advantages in terms of rate and event reconstruction
 - Fast oscillator for timing measurements better than global clock frequency (1.6ns resolution)
 - Simultaneous charge and time measurement
 - 20 Mhits cm⁻²

- TimePix telescope has been developed as a high-speed, high-precision tracking telescope
- Pointing resolutions of less than **2 μm** have been demonstrated, with **ns** time resolution, at average track rates between **3kHz** and **12kHz**
- External device integration has been carried out under the philosophy of minimal hardware integration and time-matching of data offline - results with external devices have been shown (and presented elsewhere in this conference)
- An upgrade to TimePix3 chips is expected once available in 2012
 - Time tagging and data driven readout will lead to cleaner event reconstruction
 - Data rates far higher than present will be achievable
- Eventually leading on to a fully pixel-VELO prototype...?

BACKUP

Telescope setup

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External DUT integration

- Ethos behind integration of devices has been driven by experience and cynicism
 - There is always something new to test, that only arrived yesterday, and is read out with an entirely different set of hardware + software...
- Integration required to take data has been kept to a minimum
 - For event-triggered devices only a **trigger** and **busy** signal are used
 - A time stamp is required on the external device data, to match the data offline
 - Timestamp should be implemented in hardware - $O(100\text{ns})$ sufficient
- Offline, each shutter looks like a barcode
 - Look at trigger spacings in DUT and TDC
 - Set strict requirements on matched fractions to avoid mis-matching ($\sim 95\%$)

Time difference between TDC and DUT timestamps

Shutter (telescope continuously sensitive)

- Analysis software based loosely on Gaudi framework
 - All algorithms consist of 3 parts:
 - **Initialisation** - histograms are initiated, variables set up, etc.
 - **Execution** - this is the code which is run on each frame
 - **Finalisation** - any actions which are required after running over all events
- Events (shutters) are analysed sequentially, with each event passing through the analysis stages requested
- Information passed between algorithms using global “clipboard”

Track time-stamping

- Timing plane records time between particle arrival and shutter close
 - Granularity of global clock - tuneable from 100MHz to 2.5MHz (~300kHz if externally supplied)
- For practical data taking, this means tuning of parameters to beam conditions
 - Granularity of ToA clock should be much less than time between triggers
 - Max shutter length should then be $11800 \times \text{clock period}$
 - Number of triggers per frame should be between 10 and 200
- Tracks are reconstructed **spatially**, with last plane containing timing information instead of charge
 - Track gains a timestamp with respect to the shutter close
- TDC records not only the trigger times, but shutter open and close
 - TDC information used to extract “real” track time with resolution $\sim 1\text{ns}$

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- Frame based concept discarded in favour of high-rate data-driven readout
 - Environments such as LHCb VELO upgrade require all data to be sent off-detector, for each 25ns bunch crossing => no time for triggers
- Several improvements in front end electronics
 - Simultaneous timing and charge measurement
 - Low expected timewalk ($< 25\text{ns}$)
 - Fast oscillator for timing measurements better than global clock frequency

- Data scheme of TimePix3 telescope very different from current setup
 - Data driven readout
 - Up to ~ 40 MHz hit pixel rate (> 10 MHz raw beam)
 - TimePix3 timing resolution (1.6 ns) $\approx$ scintillator resolution
- Telescope would read out **every** particle, with dut recording hits at maximum sustainable rate (current beam intensities at CERN SPS < 1 MHz average rate)
- Frame based readout (and associated pattern recognition) replaced with “clean” reconstruction environment
 - Easy to distinguish noise clusters when tracking through several planes
 - Low/zero combinatorics $\Rightarrow$ fast processing time