Read-out of the ATLAS BPTX

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About this Presentation

- Thoughts on a possible read-out system for ATLAS BPTX monitors
- First experience with a test-system
- Information could be useful for other experiments
- Any comments and feedback are welcome!

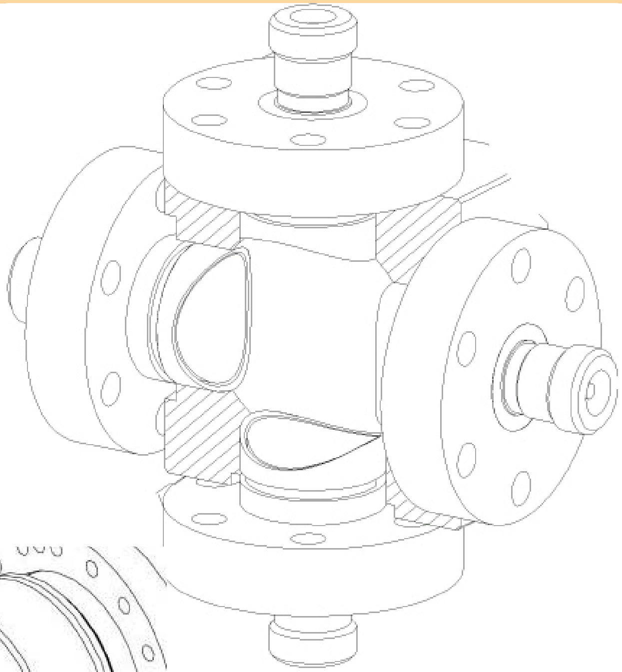
Outline

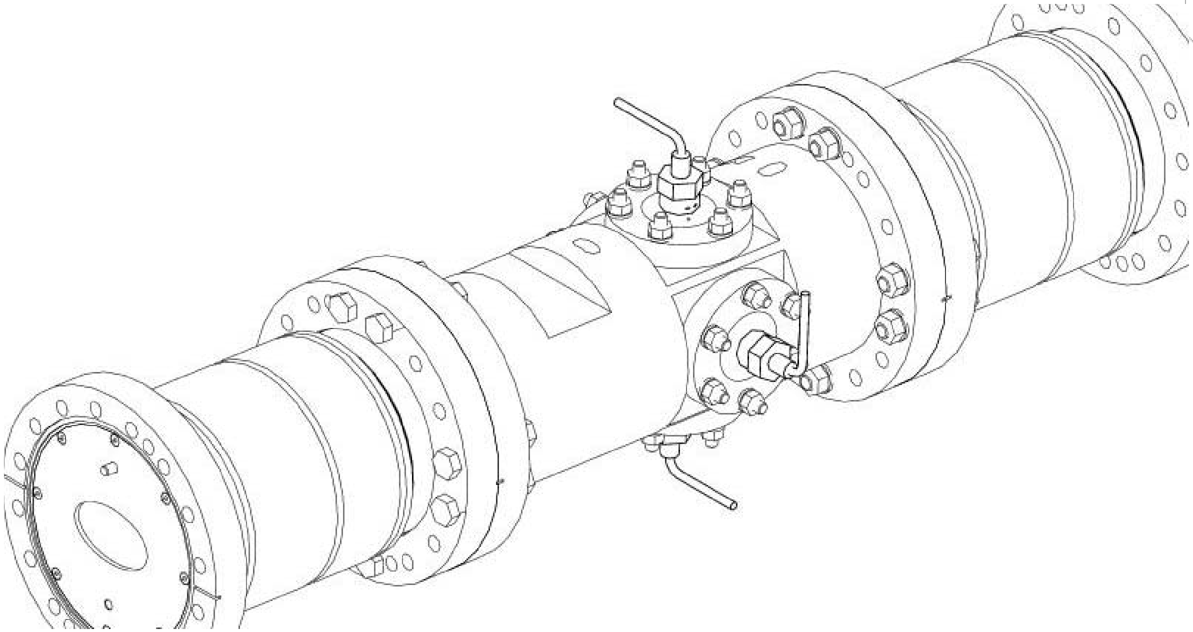
- ATLAS BPTX:
  - Button Electrode
  - Signal Expectation
  - Transmission Line
- Use of BPTX by ATLAS
- ATLAS Requirements
- Proposal: Off-the-shelf Oscilloscope
  - Acquisition Modes/Scope Trigger
- Test with Tektronix TDS3054B:
  - Exercise: Proof of Principle
  - Resolution for Clock Edge Measurement
  - Sensitivity Test for Fit to BPTX signal
- Glimpse at other Equipment
- To-Do-List
- Conclusions

ATLAS BPTX

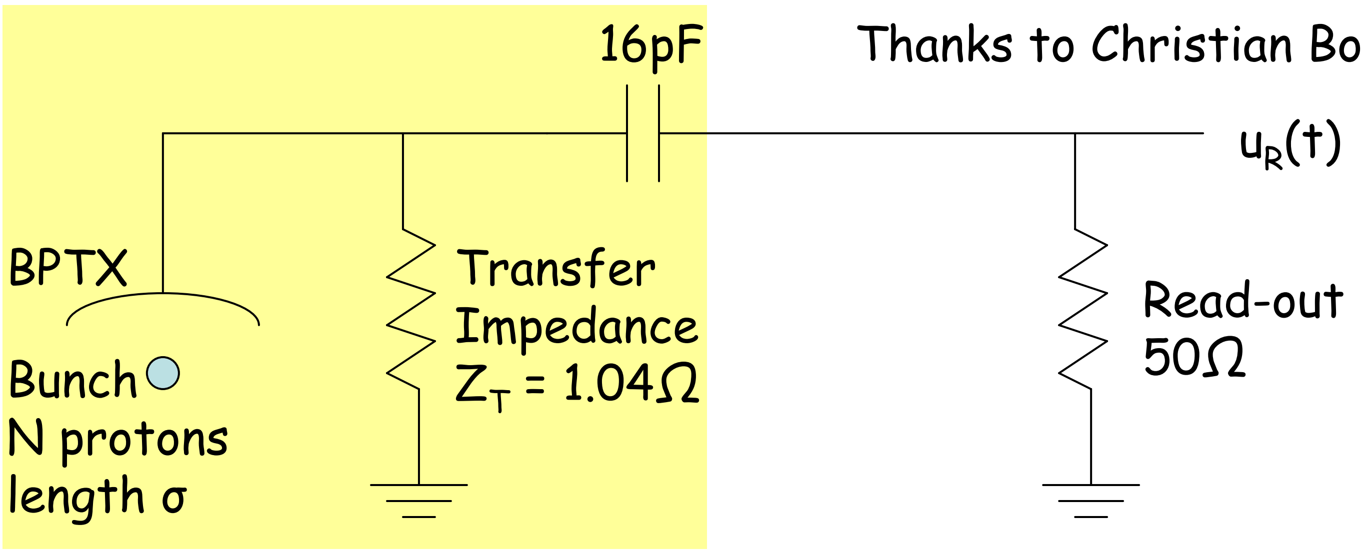
- 2 ATLAS specific Beam Position Monitors for timing purposes (called BPTX), 1 per incoming beam:
  - Names: _BPTX.5L1.B1 and _BPTX.5R1.B2
  - 175m away from IP
- Will be built and installed by AB
- ATLAS is responsible for their read-out
- Technology: Electro-static button pick-up
- 4 buttons per BPTX, signals will be merged via an adapted 50Ω-RF-4-to-1-Combiner:
  - To first order: Sum of all 4 signals is independent of the beam position

BPTX (2)





Signal Expectation



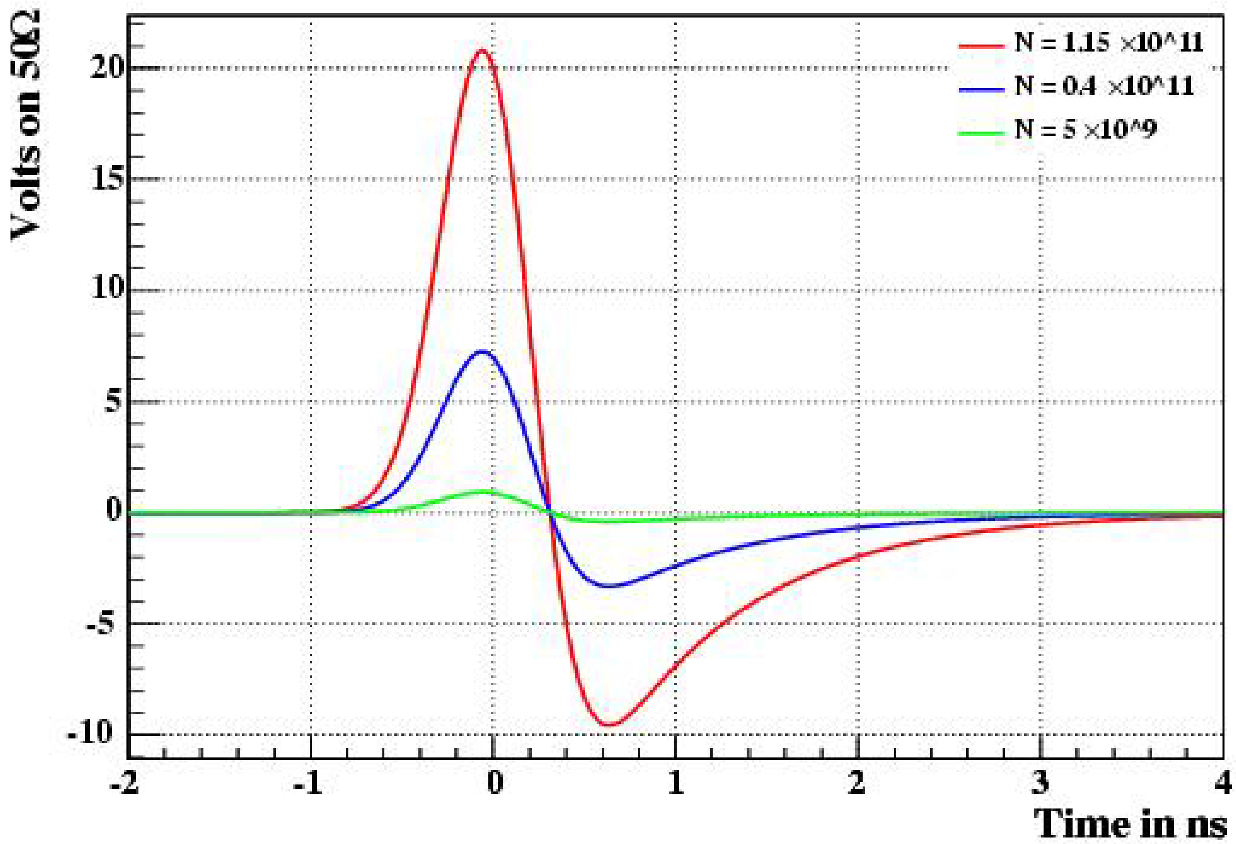
- Longitudinally Gaussian-shaped bunch produces a current of mirror charge on the button surface, which gives a voltage signal on the transfer impedance:

Basic model: "Differentiated Gaussian convolved with an exponential due to the RC"

$$u_R(t) = -\int_{-\infty}^{t} \mathrm{d}t' \frac{Z_T N e}{\sqrt{2\pi}\sigma} \cdot \frac{t'}{\sigma^2} \mathrm{e}^{-\frac{t'^2}{2\sigma^2}} \mathrm{e}^{-\frac{t+t'}{RC}}$$

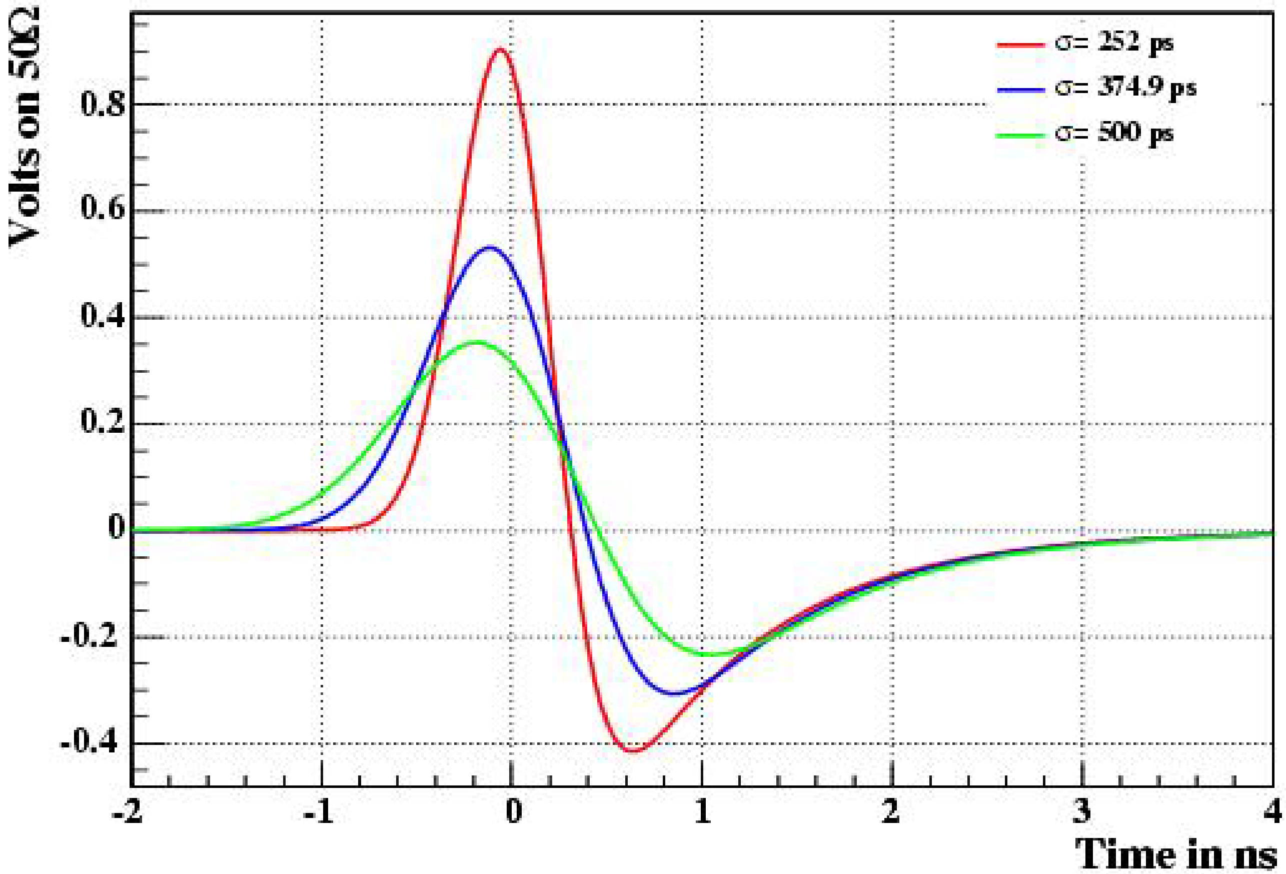
(no transmission line yet)

Signal Expectation vs Intensity



- Bunch passes the BPTX at t=0s
- Bunch length Gaussian σ = 252ps (nominal at 7 TeV)
- Nominal LHC intensity: 1.15 x 10^{11} p/bunch
- Zero-crossing independent of bunch intensity

Signal Expectation vs Bunch Length



- σ = 375ps at injection, σ = 252ps at 7 TeV → 100ps shift
- Conclusion: Zero-crossing position depends on bunch length
- Expected fluctuations in bunch length? If small, the timing info is preserved

Transmission line

- Need to fold in additional effects from the transmission line:
  - Additional inductance and capacitance
  - Frequency dependent attenuation
  - Dispersion
- Possible additional effects:
  - RF 4-1 Combiner
  - RF 1-2 Splitter
  - Beam-Position higher order

Transmission Line: Cable

- Low-loss coaxial cable (with cellular PE and Cu screening tube)
- Length: ~200m, to be cut and installed
- Propagation time will be measured after installation
- 50Ω, 0.19μH/m, 76pF/m, 3.79ns/m

- Attenuation: (back-of-envelope calc.)

  16dB/200m at 500 MHz (bulk of signal)

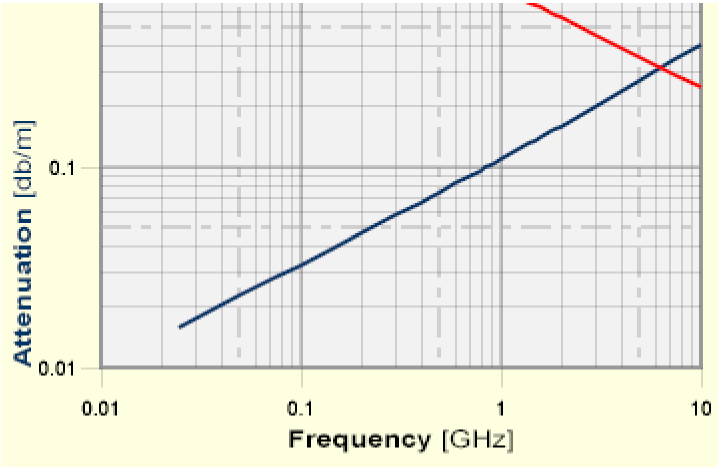
  $V(200m) = V_0 / 10^{16/20} = V_0 / 6$

  i.e. for nominal LHC bunch:

  V=-1.5..3.5V (single button)

  V=-6..14V (sum of 4)

  Need an attenuator to bring it into the dynamic range of standard oscilloscopes?

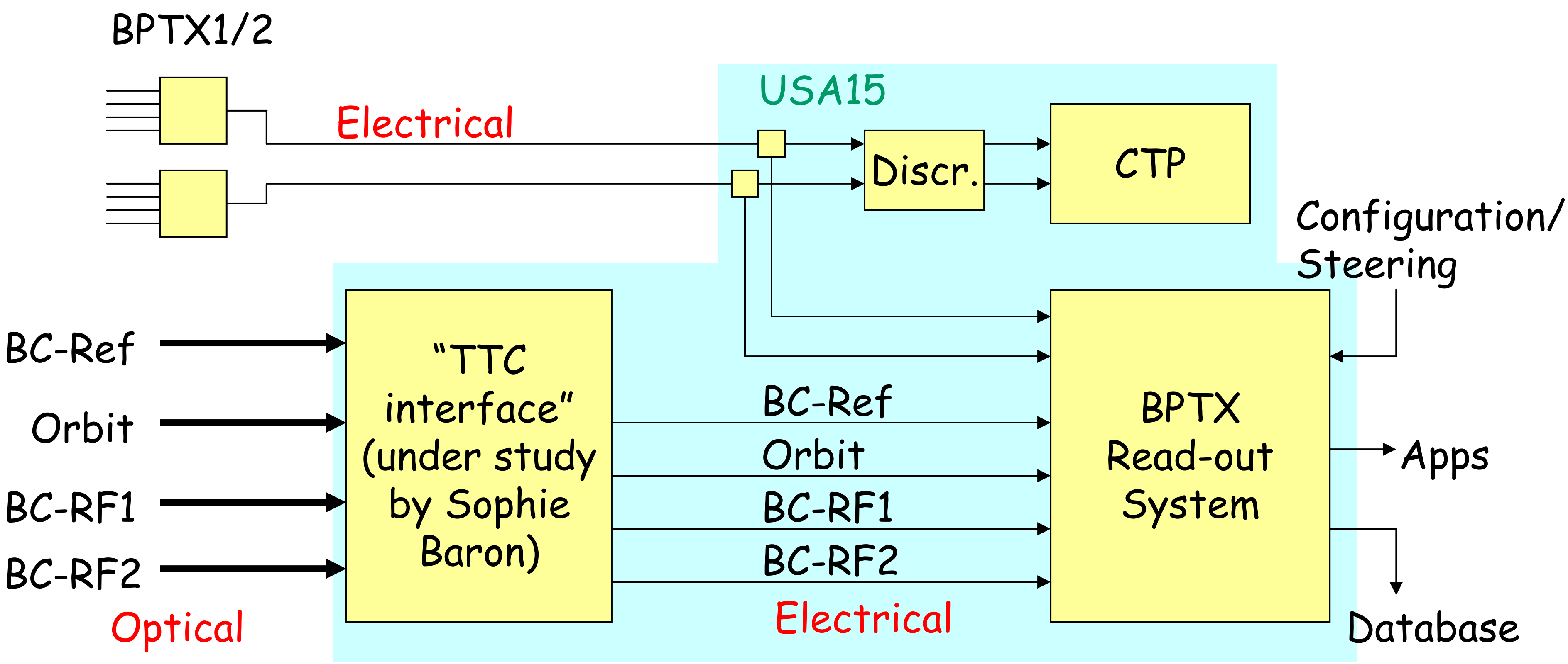


Information in the BPTX Signal

- Clean conditions:
  - Background will hopefully be small and under control (noise, reflections, etc.)
  - Complete signal description will exist, and can be used as a fit function. Fit parameters:
    - t_0 Time of closest approach of bunch to BPTX,
    - N Number of protons in bunch
    - σ Bunch length (Gaussian σ)
- Dirty conditions:
  - Perform some signal discrimination and play some tricks to extract information
  - Large uncertainty from interpretation of the zero-crossing

Use of BPTX by ATLAS

- Assumed situation:



Use of BPTX by ATLAS (2)

- Seeing the incoming bunches:
  - Find the optimal phase between bunches and clock that drives the detector electronics
  - Check the phase of each individual bunch with the phase of the clock
  - Detection of gaps in the bunch train, timing-in of the sub-detectors
- Monitoring of the clock from the machine:
  - Detection of clock drift, due to
    - Problems in the signal chain
    - Temperature drifts in optical fibres

ATLAS Requirements (1)

- Requirements not yet widely discussed in the ATLAS community
- Core requirements:
  - Monitoring at a frequency ~ once per minute
  - Time information for BPTX1, BPTX2, BC-Ref, BC-RF1, BC-RF2, Orbit. Monitor for each bunch the phase between:
    - BC-RF1 and BPTX1
    - BC-RF2 and BPTX2
    - BC-Ref and BPTX1
    - BC-Ref and BPTX2
    - BPTX1 and BPTX2 (gives location of interaction region)
    - Accuracy: ~10..20ps (LAr requested a resolution small compared to their intrinsic resolution of 50..100ps)
  - Bunch intensity to be quantified as best as possible for each single bunch
  - Intensity and time information for satellite bunches shall be quantified for each RF bucket (2.5ns)

ATLAS Requirements (2)

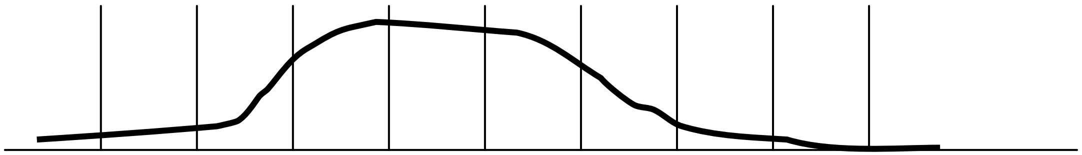
- Others:
  - Each monitoring measurement shall be time-stamped (precision of ~sec required, probably ~ms possible) and stored
  - Each monitoring measurement shall be made available for monitoring applications, phase adjustments, pre-scaler configuration
  - Discrimination of the BPTX signals by preserving the time information of each bunch at the level of a few ns to serve as input to the Level-1 Central Trigger Processor (filled-bunch-trigger)
  - Configuration of the read-out system: flexible, remotely, automatic.

Proposal: Off-the-shelf Oscilloscope

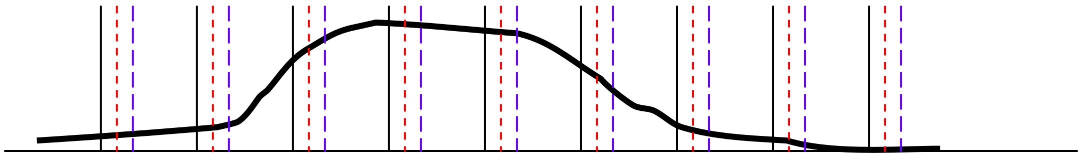
- Cheap (several 10 kCHF), no hardware and low-level software development
- Guaranteed support
- Signal is fully visible, no signal discrimination before read-out: necessary for debugging
- Usually maximum of 4 Channels: 2 scopes required for 6 signals. For instance:
  - Scope 1: Orbit, BC-Ref, BC-RF1, BPTX1
  - Scope 2: Orbit, BC-Ref, BC-RF2, BPTX2

Acquisition Mode/Scope Trigger

- Acquisition modes:
  - Real-time sampling (single shot, averaging mode)



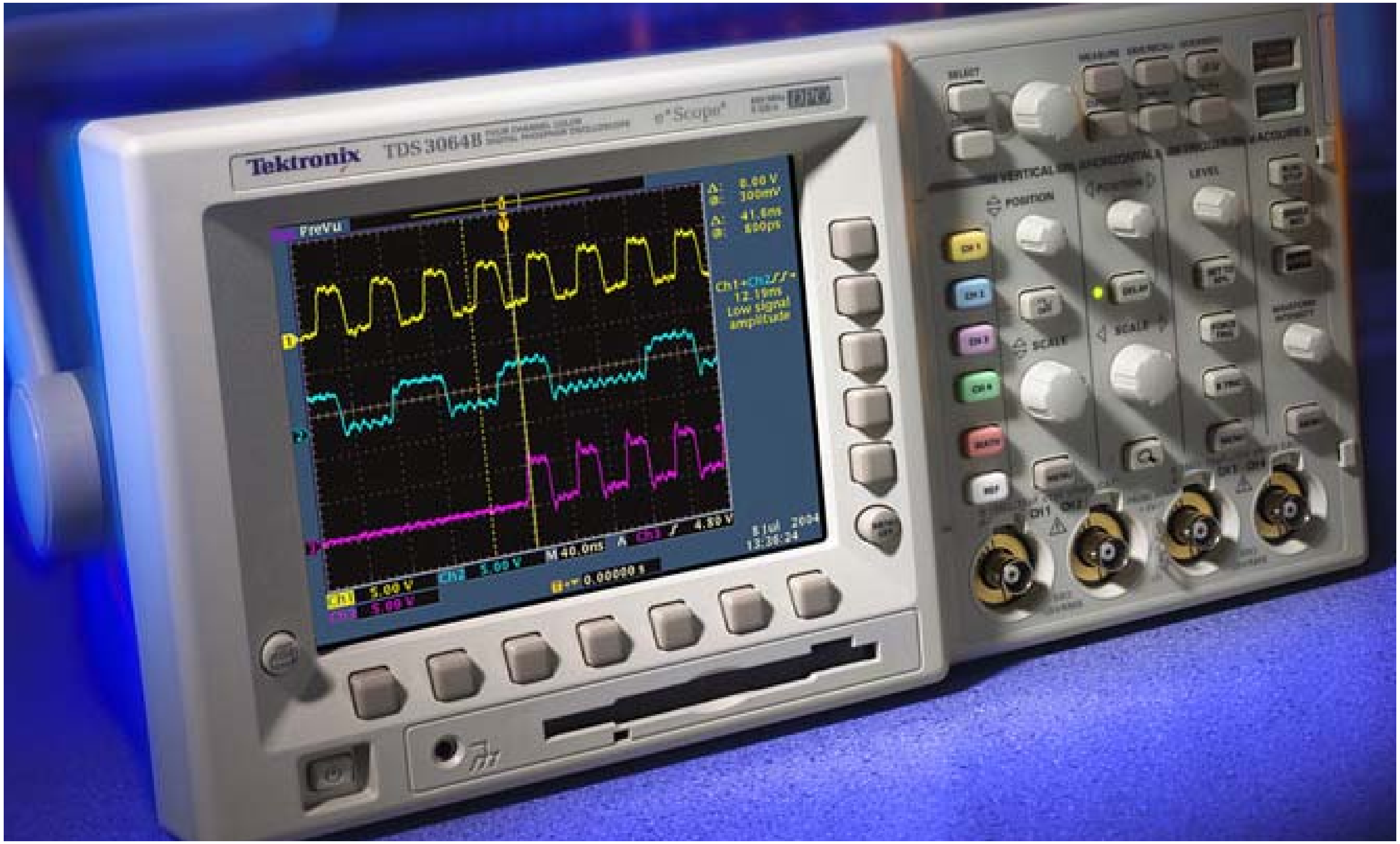
  - Equivalent-time sampling (only for repetitive signals)



- Different trigger possibilities:
  - For a real-time single shot mode, any trigger can be used: whole bunch train is read out.
  - For averaging or equivalent-time sampling, a trigger signal with small jitter is needed. Possibilities:
    - Orbit signal
    - Combination: First Orbit, then clock edge
    - BPTX signal itself, with trigger hold-off time set to find particular gaps in the bunch train

Tektronix TDS 3054B

The ATLAS Trigger group currently owns a Tektronix TDS3054B.
This scope was used to study issues related to the BPTX read-out.



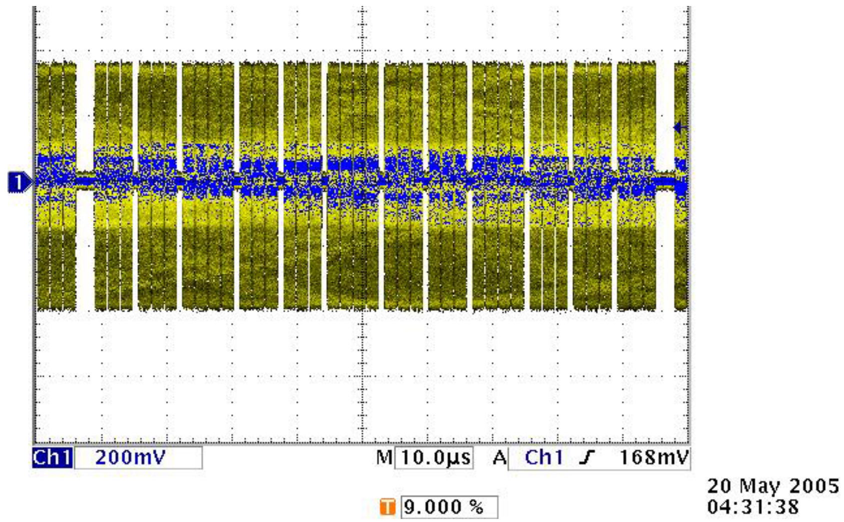
Tektronix TDS 3054B (2)

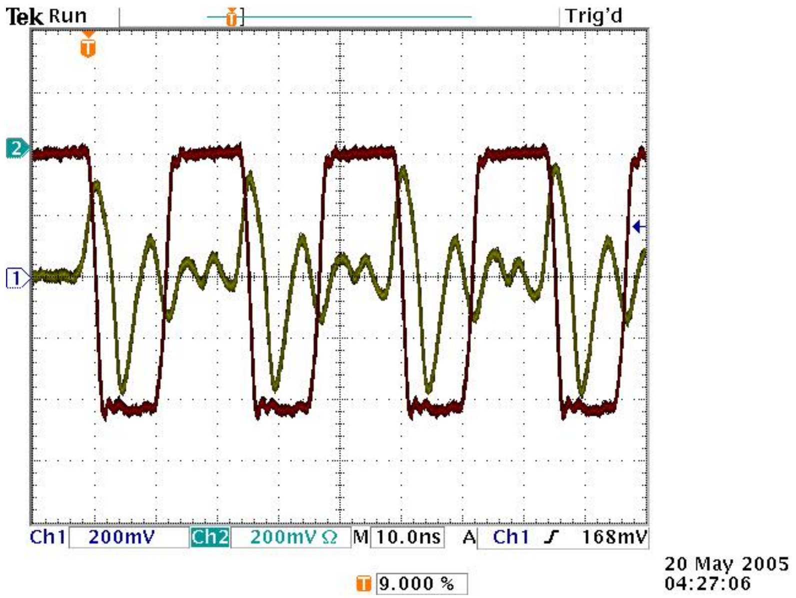
- 5 GS/s real-time sampling rate, i.e. measurements every 200ps
- Memory depth: 10k, i.e. 2μs
- Max voltage on 50Ω:

  $5V_{RMS}$ with peaks < ±30V
- 8-bit vertical resolution, ~0.3%
- 4 channels
- Built-in ethernet port: configuration and read-out possible using HTTP1.1
- 15 kCHF

Exercise: Proof of Principle with TDS 3054B

- BPXT Test signal: Shaped output from a pattern generator (Local Trigger Processor)
- Clock from a TTCvx: 40MHz (100ppm, i.e. 2.5ps)
- Trigger on long-gap with hold-off time to 88.924µs-x (with x < 2.75µs)

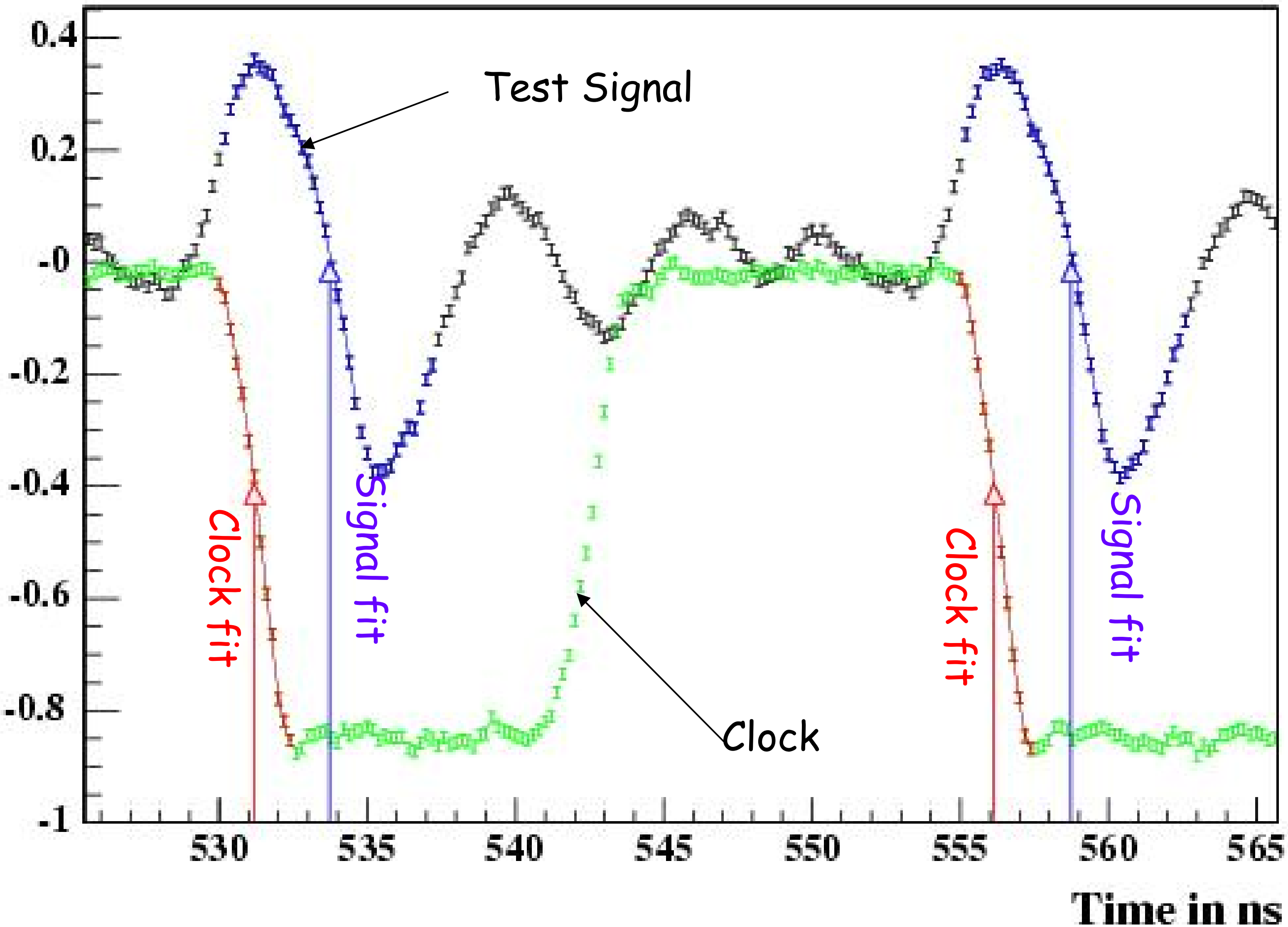




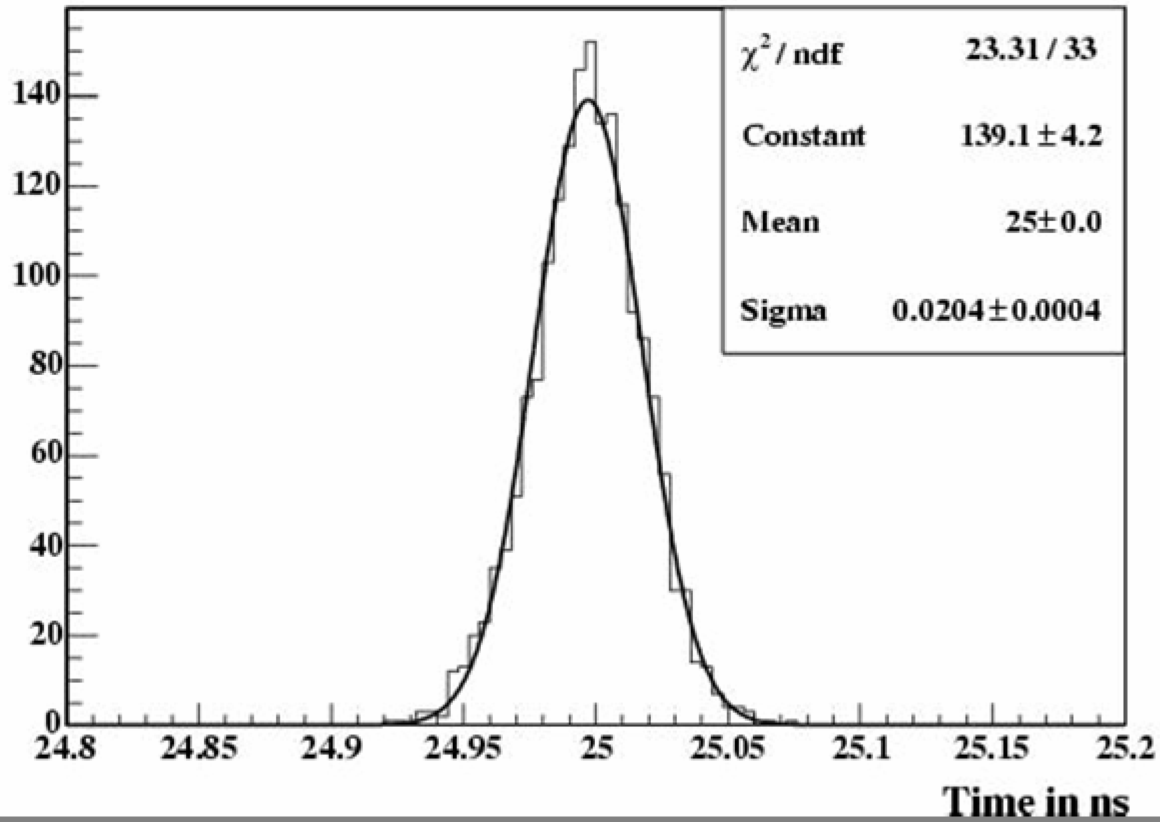
Exercise: Proof of Principle with TDS 3054B (2)

- TDS3054B waveform covers 2μs:
  10k measurements, 1 every 200ps
- Read-out of the waveform via Ethernet using HTTP1.1
- LHC bunch train is 89μs long
  → Read out 45 chunks of 2μs, use the trigger delay function of the scope. Takes 2.5 minutes on lxplus (Not sure yet why it takes so long)
- Data analysis in software (ROOT-based):
  - find zero-crossing of BPTX signal or edge of clock, and perform a fit to the data points (e.g. polynomials)

Exercise: Proof of Principle with TDS 3054B (3)



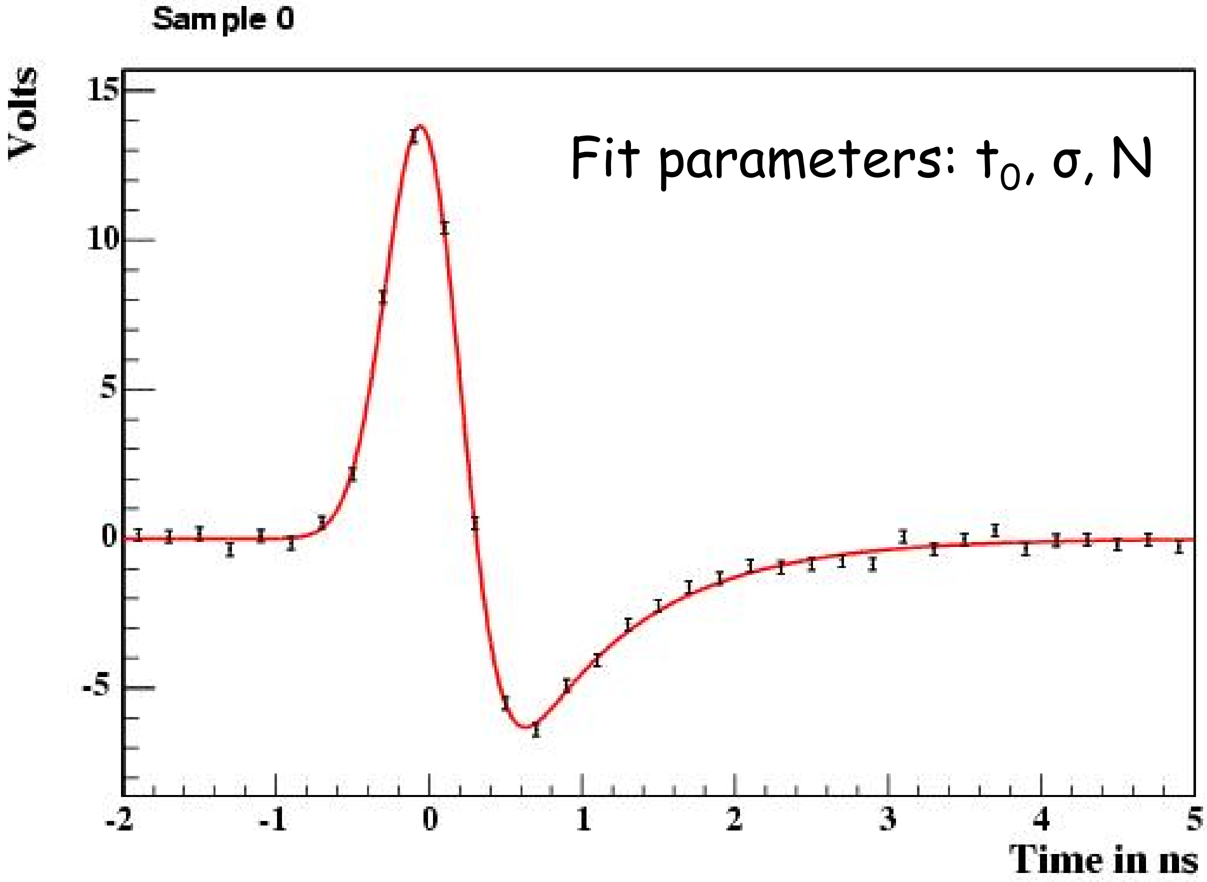
Resolution for Clock Edge Measurement



- Difference of two consecutive clock signals
- Resolution of phase measurement: 20ps
- Resolution of single time measurement: 20ps/√2 = 14ps

Sensitivity of BPTX Signal Fit

- Toy-Simulation, 1000 samples with nominal LHC bunch parameters, TDS3054B resolutions (vertical resolution: 0.2V)



Sensitivity of BPTX Signal Fit (2)

- No background taken into account
- Result:

  $t_0 = 0 \pm 2.6ps$

  $\sigma = 252ps \pm 3.0ps$

  $N = (1.150 \pm 0.015) \times 10^{11}$

  t_0 uncorrelated to σ, N

  Correlation between σ and N: 0.68
- Effect of vertical scope resolution:

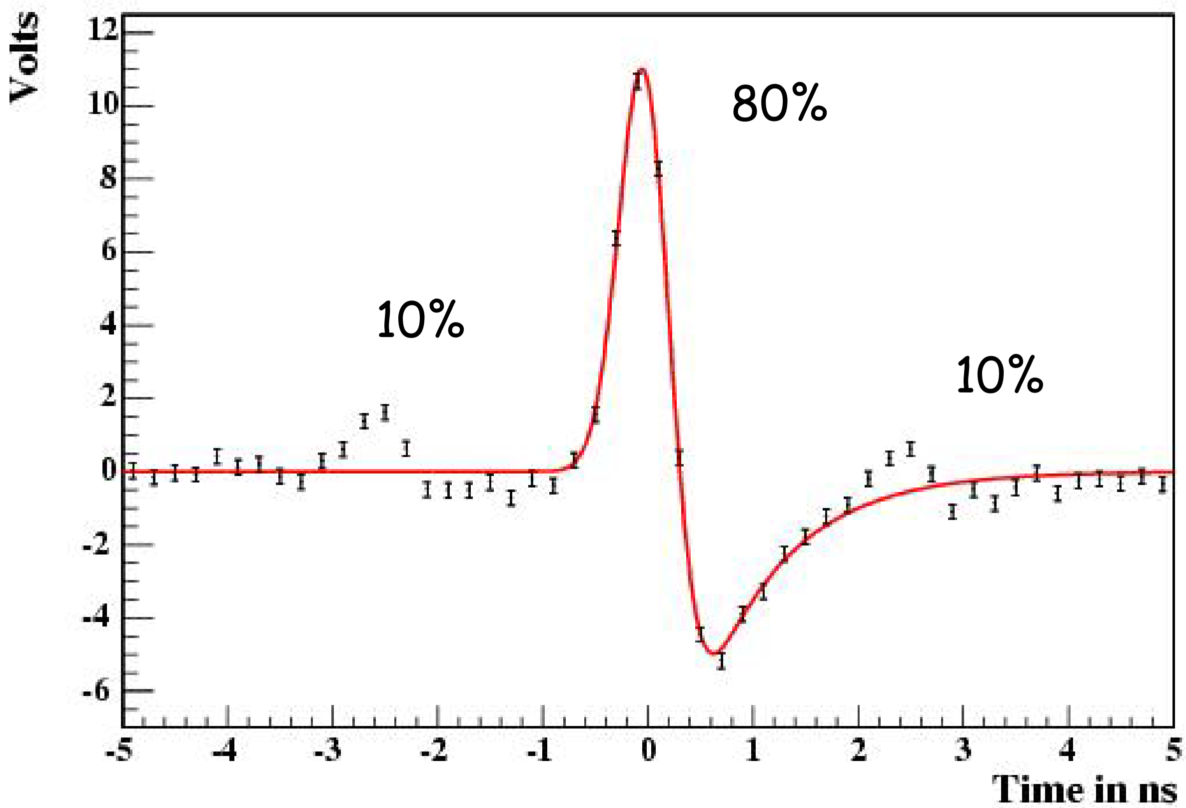
  0.2V $\delta t_0 = 2.6ps$

  0.4V $\delta t_0 = 5.0ps$

  1V $\delta t_0 = 12.9ps$

Effects of Satellite Bunches

- Jörg's presentation from July 2003:
  "Satellite bunches: possibly ~% level"
- Exaggerated example: 10%-80%-10%



Effects of Satellite Bunches (2)

- What's the effect of partially filled satellite bunches on the timing resolution?
- Could satellite bunches be included in the fit?
  - Stable fit?
- To be studied!

Glimpse at other Equipment

- <u>Tektronix scopes:</u>
  - TDS5000B, 4 channels, 5GS/s (real-time), 250GS/s (equiv-time), 4 channels, 1.6ms memory, ~20 kCHF
  - TDS7000B series: 4 channels, 5GS/s (real-time), 1 TS/s (equiv-time), 800 μs memory, ~60 kCHF
  - TDS6000 series: 4 channels, 20GS/s (real-time), 2TS/s (equivalent time), 1.6 ms memory, ~80 kCHF

- <u>Agilent scopes:</u>
  - 54832B Infiniium: 4 channels, 4 GS/s, >8ms memory, ~30kCHF
  - 54852A: 4 channels, 10 GS/s, 100 μs memory, ~40kCHF
- CAEN VME 16 Channel Multihit TDC
  - V1290N: 52μs memory, 21-bit time resolution (→ 25ps), 5ns double hit resolution, NIM input, 5.5 kCHF
- Acqiris PCI Waveform Digitizer DC211A:
  - 4 Channel, 8-bit vertical, 1GS/s, up to 8ms memory

To-Do List

- BPTX read-out system must be fully operational for the first LHC beam (2007)
- Testing of possible read-out equipment & final purchase.
  - Also need splitters and discriminator (constant fraction) for CTP input
- Measurement of cable properties
- Once cables are installed: Measurement of the propagation time in the cable, effects of the RF-Combiners, Splitters, ...
- Software development for: configuration, read-out, interface to databases, communication with other applications, etc.
- Understand the signal and backgrounds, test fit procedure:
  - Possibly get real beam data before first LHC beam, maybe from SPS or LHC sector test?

Conclusions

- The read-out requirements for the ATLAS BPTX can be fulfilled with 2 modern off-the-shelf sampling oscilloscopes with:
  - 4 channels each
  - Sampling rate ≥ 5 GS/sec
  - Memory deep enough to accommodate 89µs
  - Communication via ethernet

- Write-up: will soon be made available
  https://edms.cern.ch/document/588275/1