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Accelerator Operation

Joint QUASAR and THz Group Workshop 2010

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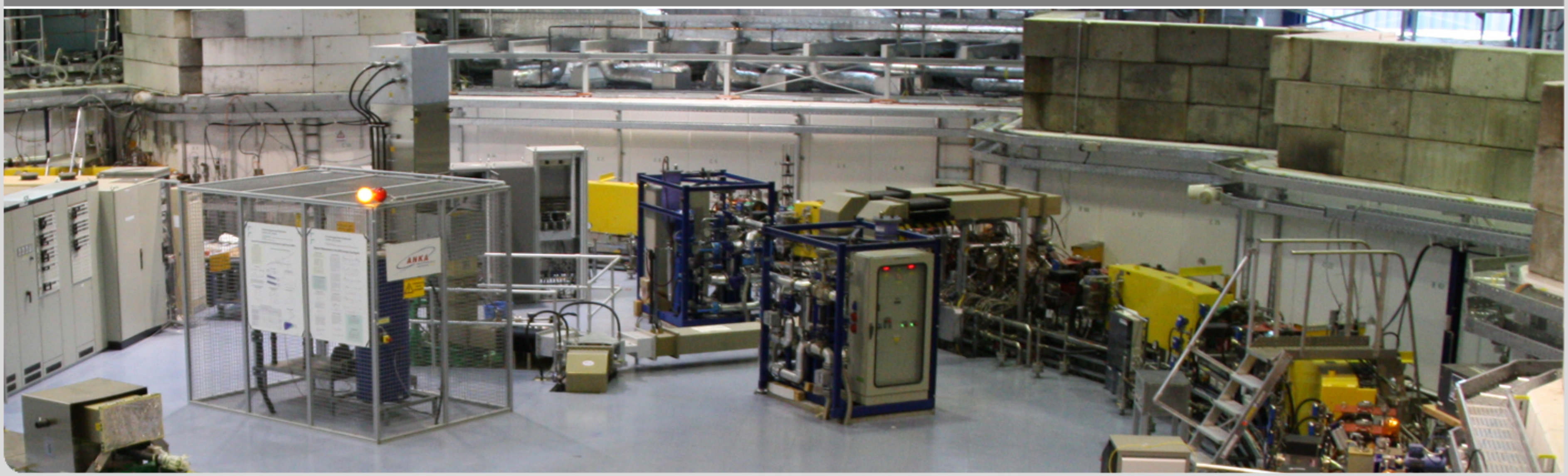


Outline

- Challenges in Accelerator Operation
- Timing System for Accelerator Synchronization (André)
- Single Photon Counting for Filling Pattern Measurements (Benjamin)
- Bunch-By-Bunch Fast Feedback System for Damping Instabilities (Sebastian)
- Conclusion

CHALLENGES IN ACCELERATOR OPERATION

Challenges in Accelerator Operation

- Beam Quality
  - Stability
  - High Current
  - High Life Time
  - Beam Size
- Injection
  - Optimizing Injection
  - Tailored Filling Patterns

Beam Quality

- Oscillations of the beam caused by instabilities can affect
  - Lifetime
  - Synchrotron adiation users
- Understand Type and Origin of Instabilities
  - Analyze Beam Signals (Beam Position Monitors, Strip Line, etc.)
  - Analyze Synchrotron Radiation (Avalanche Photo Diode, Hot Electron Bolometer, etc.)
- Damp Beam Oscillations
  - Bunch-by-Bunch Fast Feedback Systems
  - Fast Orbit Correction
- Optimize Optics (e.g. Working Point and Chromaticity)
  - Modeling and Control System Tools

Injection

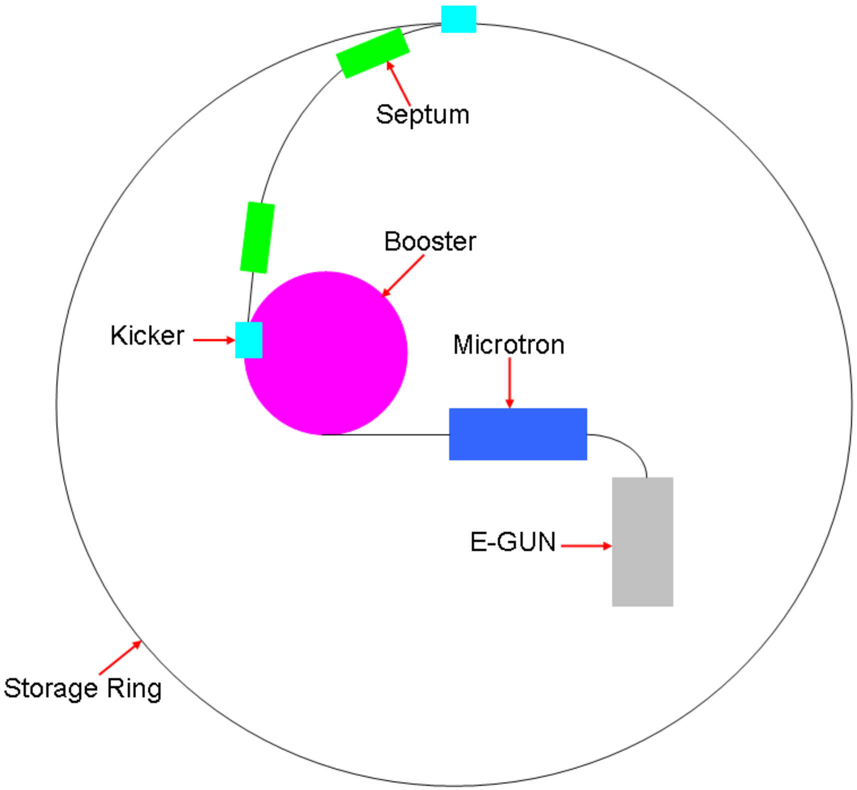
- Accurate timing is crucial for injection
- Timing System synchronizes
  - Electron Gun
  - Booster Synchrotron
  - Storage Ring
  - Kickers
- Timing System has to provide pico-second scale synchronization
- Tailored filling patterns are useful for machine physics and for users
- Single Photon Counting can be used to verify filling patterns

TIMING SYSTEM

Timing System

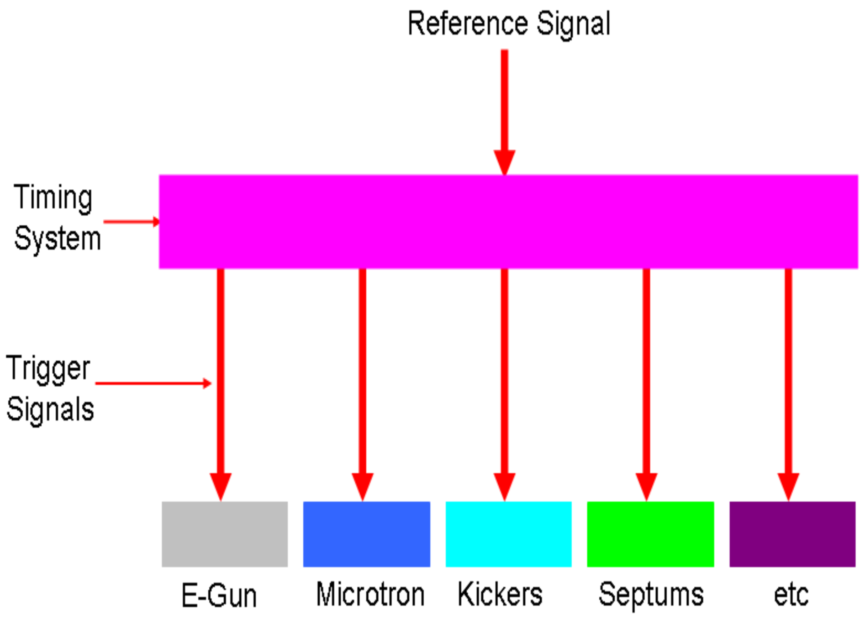
- Introduction
- What is a Timing System
- Timing System at ANKA
- Summary

Introduction



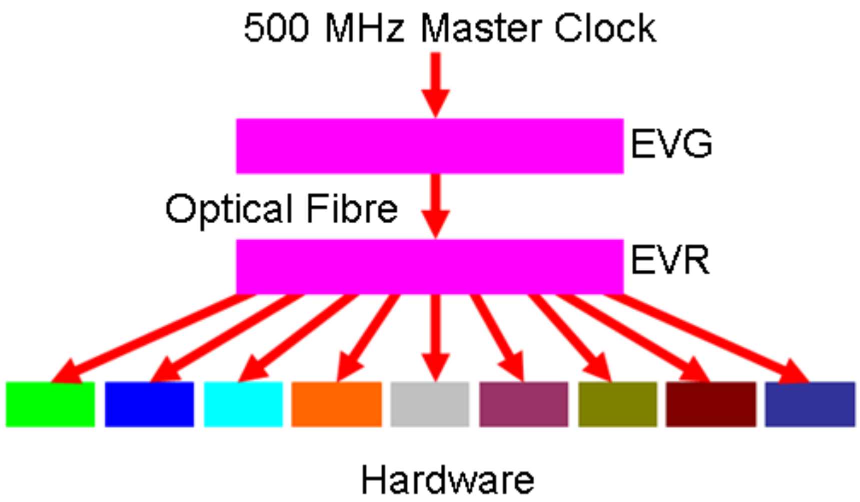
- Electrons are generated from an E-Gun and pre-accelerated e.g. in a microtron and a booster
- For the extraction, from the booster and injection into the storage ring, kicker- and septum magnets are needed
- For a successful injection, the E-Gun, the pre-accelerators and all magnets have to be triggered at the correct time

Timing System



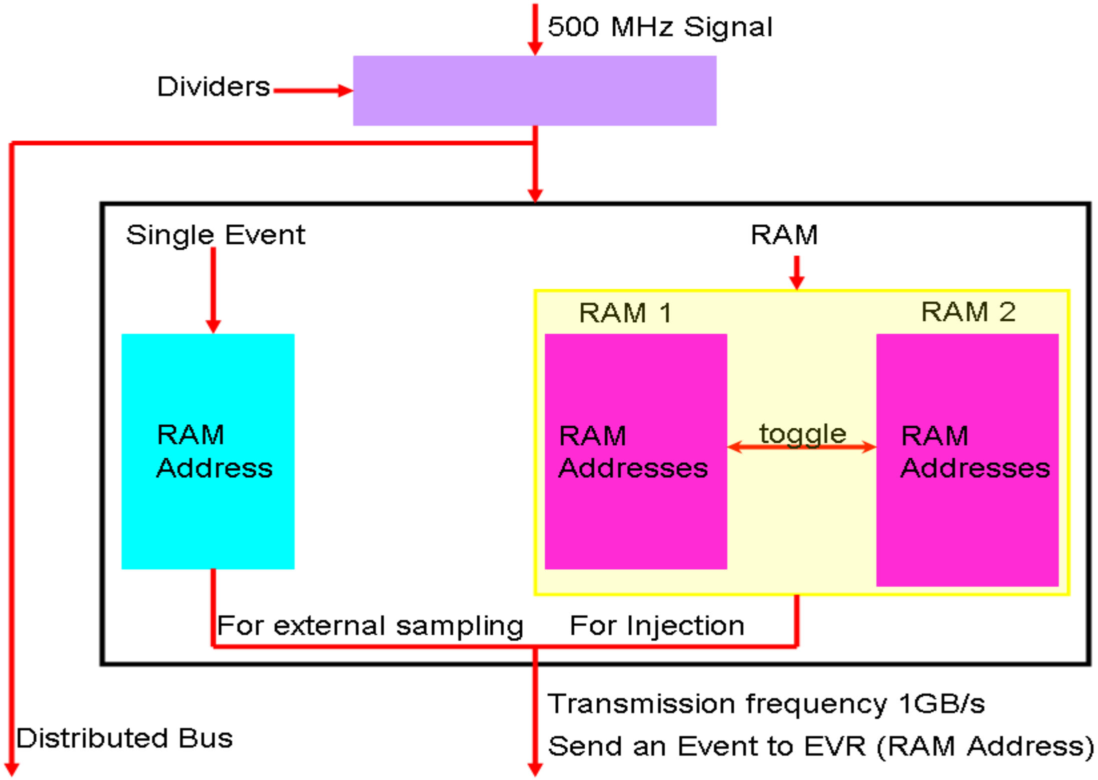
- The distribution of the trigger signals are controlled by a timing system
- The trigger signals are related to a reference signal

Timing System at ANKA



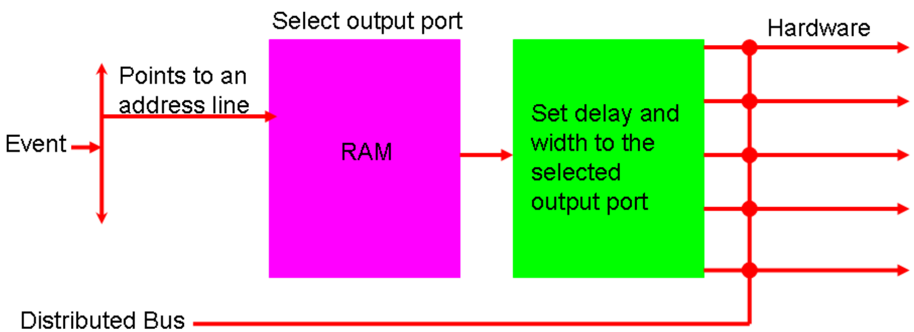
- Consists of an Event Generator (EVG) and an Event Receiver (EVR)
- An 8 bit distributed bus is implemented which allows the simultaneous distribution of real time clock signals
- Events in form of RAM addresses and the state of the distribution bus are transmitted via optical fibre to the EVR
- The 500 MHz RF clock is used as reference signal

Event Generator



- All events must be synchronised to the coincidence signal from booster and storage ring
- The reference signal is divide to get the correct transmission frequency
- For injection, the time steps are taken from the corresponding EVG RAM.
- The distributed bus is directly transmitted to the EVR

Event Receiver

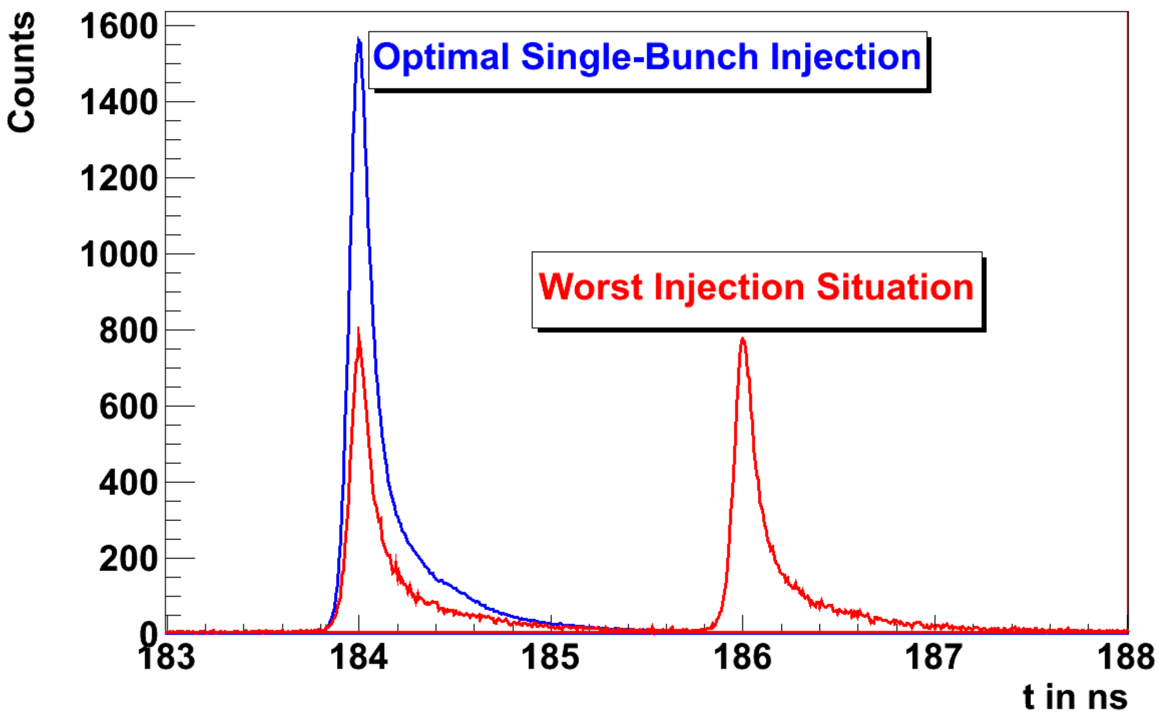


- The received event points to the RAM memory configured for the next output port to be activated
- Width and offset values are set for the selected output port
- Transmitting of the trigger signal to the hardware
- Direct application of the distributed bus to the hardware

Output Ports

- Timing System has TTL, CML and LVPECL outputs
- TTL outputs allows a timing resolution of 8 ns over 100 hours
- LVPECL outputs allows a fine timing resolution of 10 ps over 10 ns, together with a course resolution of 8 ns over 100 hours
- TTL output are used for triggering the microtron, septum's and kickers, because a resolution of 8 ns is acceptable
- LVPECL output ports are used for the gun delay and for the distribution of the 2.7 MHz trigger signal

Calibration E-Gun Trigger



- To set the gun delay, a scanning process was done to find the worst injection situation
- The worst is found when two neighbouring buckets are quite equally filled
- To get the correct trigger position the trigger need only be shifted by 1 ns

Summary

- A timing system is needed for an injection
- The ANKA timing system consists of a EVG and an EVR
- The EVR generates events in form of RAM addresses
- Events were applied to the EVG, which distribute trigger signals at the correct time step and with the correct width to the hardware

SINGLE PHOTON COUNTING

Single Photon Counting for Filling Pattern Measurements

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- Filling Pattern Measurements
  - Why?
  - How?
- Single Photon Counting
  - Principle
  - Single Photon Avalanche Diode
- Results

Filling Pattern Measurements

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Why?

- Quality check of timing system
- Control of special pattern for time-resolved experiments
- Analysis of multibunch effects

Filling Pattern Measurements

How?

- Detector output linear to number of electrons
  - (Angular) electrode
  - Photomultiplier Tube (PMT)
  - Avalanche Photodiode (APD)
- Signal amplified and read out / digitized
- Problems
  - SNR can be bad
  - Limited bandwidth deforms signal
  - Cable effects (reflections / noise-pick-up)

Photon Counting

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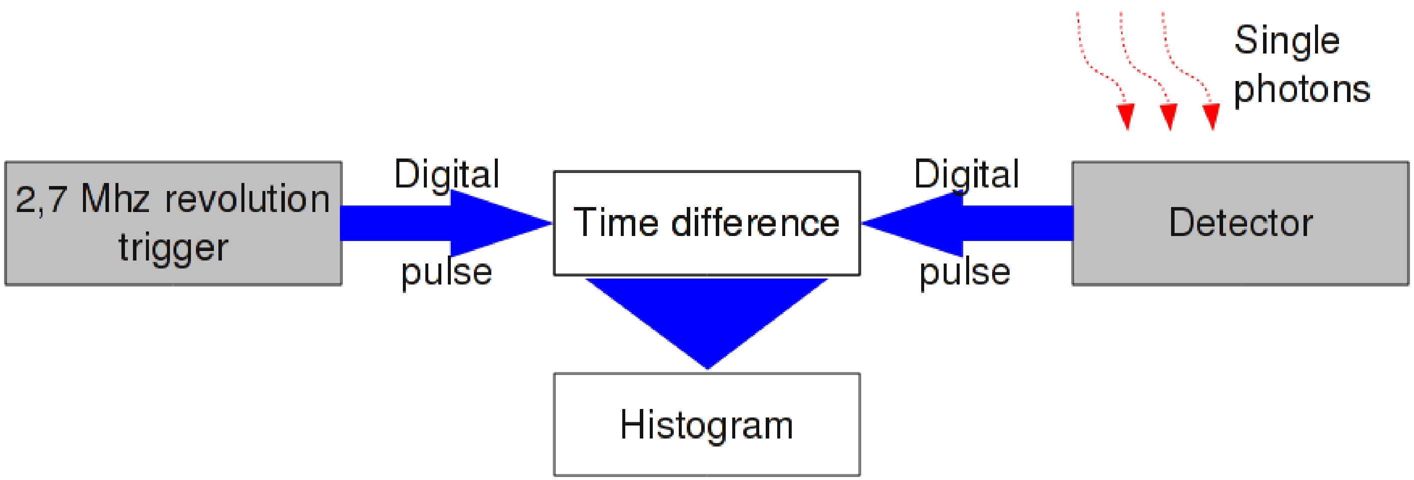
Principle

- Photon flux lowered to single photons
  - Incoherent radiation $\Rightarrow I(t) \propto N_e$
- Detector sensitive to single photons
  - Delivers digital pulse
- Signal reconstruction by determing pulse density



Photon counting

Disadvantages

- Special equipment needed
- Longer acquistion times

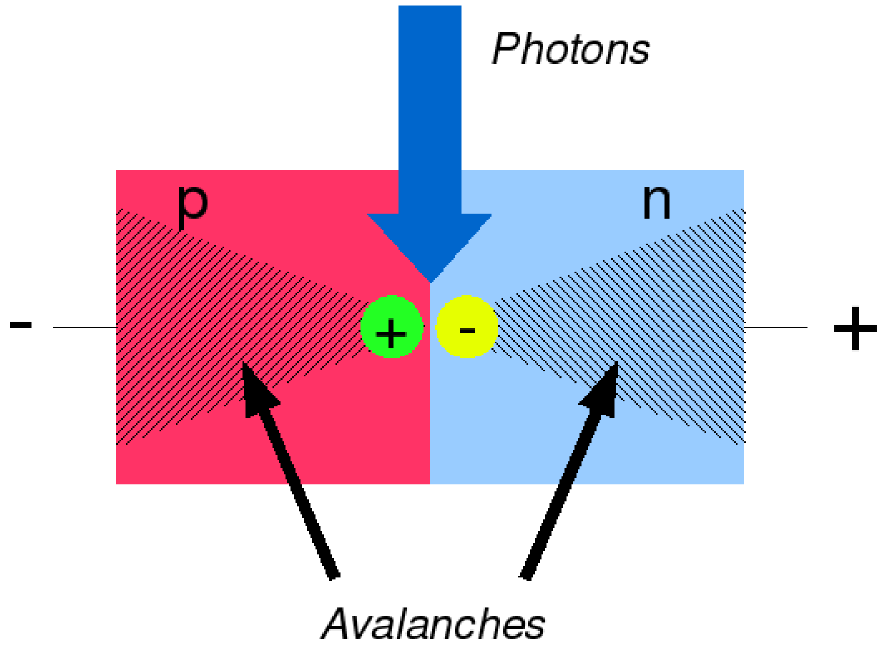
Advantages

- Digital pulses $\Rightarrow$ good SNR
- No bandwidth problems

$\Rightarrow$ Single Photon Counting well suited for Filling Pattern Measurements

Detectors

- Photomultiplier Tube (PMT)
- Single Photon Avalanche Diode (SPAD)
  - Reverse biased pn-junction
  - High voltage ⇒ Single photon triggers avalanche (Geiger mode)



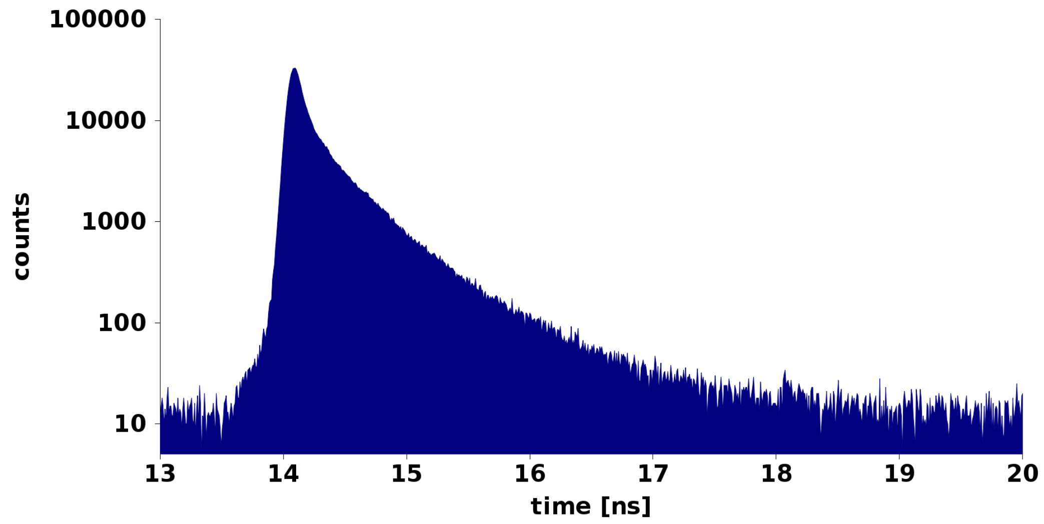
Single Photon Avalanche Diode (SPAD)

Advantages

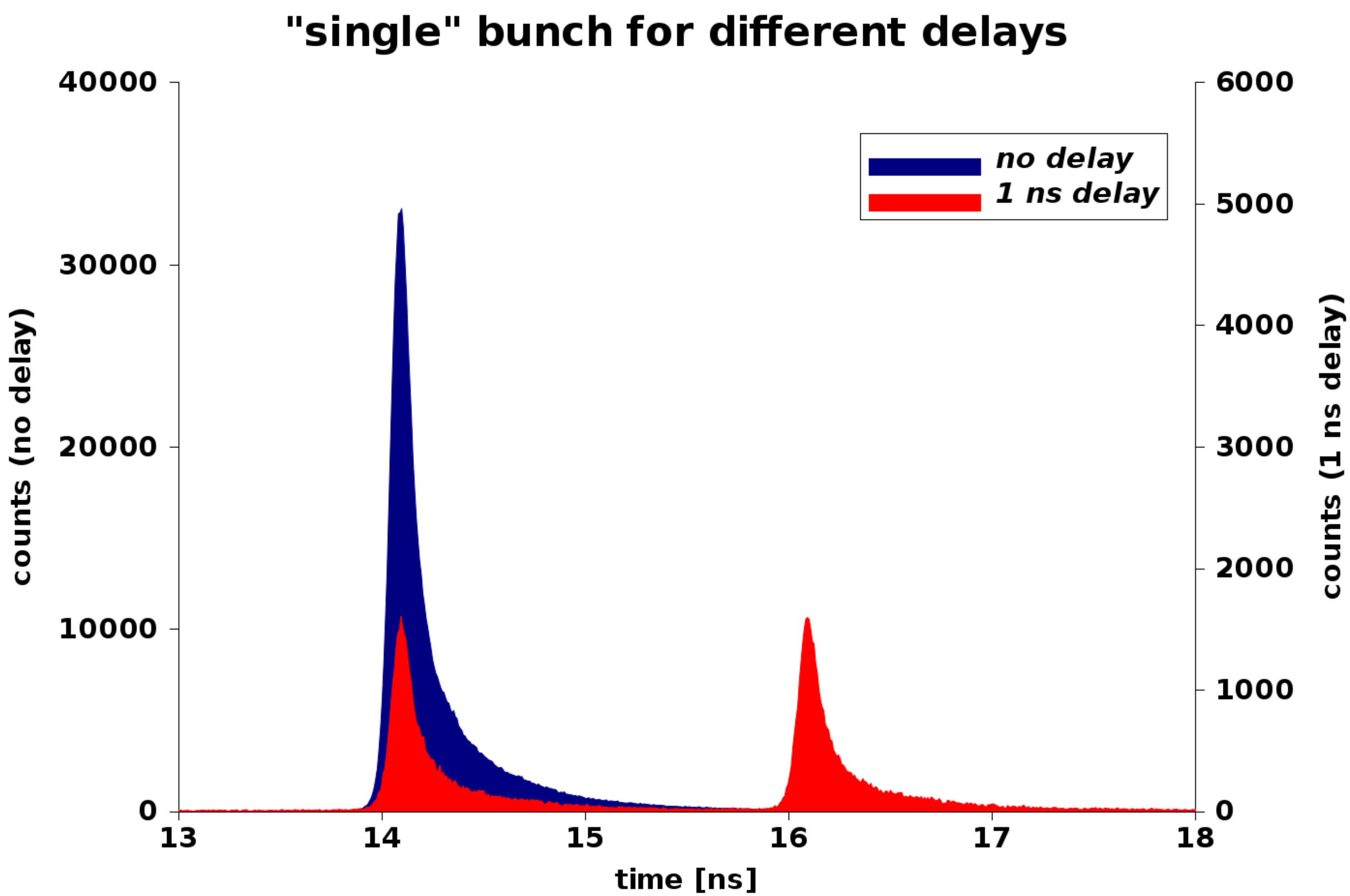
- Insensitive to high exposure
- Insensitive to magnetic fields

Disadvantage

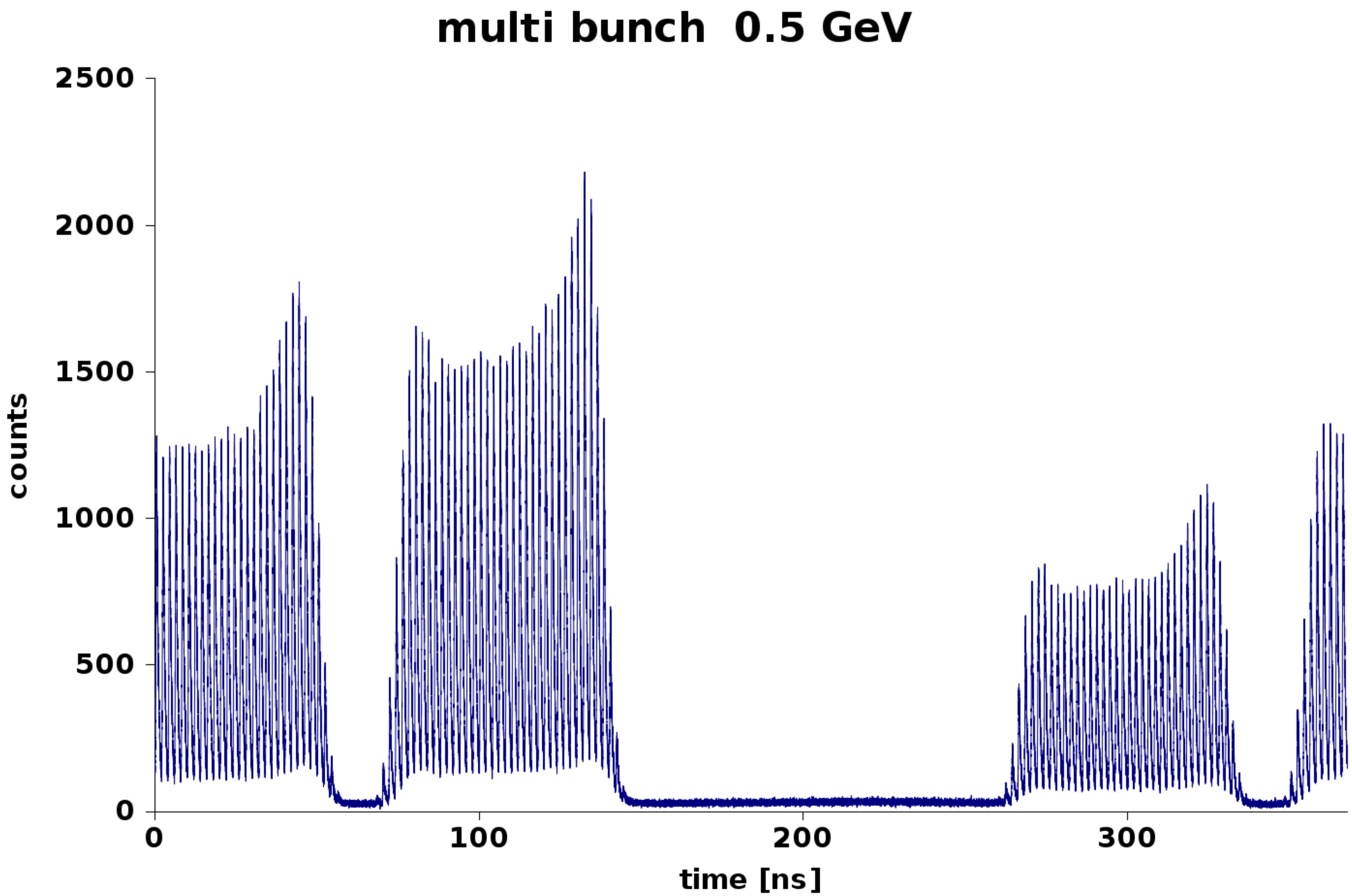
- "Tail" of instrument response function $\Rightarrow$ bad for bunch purity measurements



Results

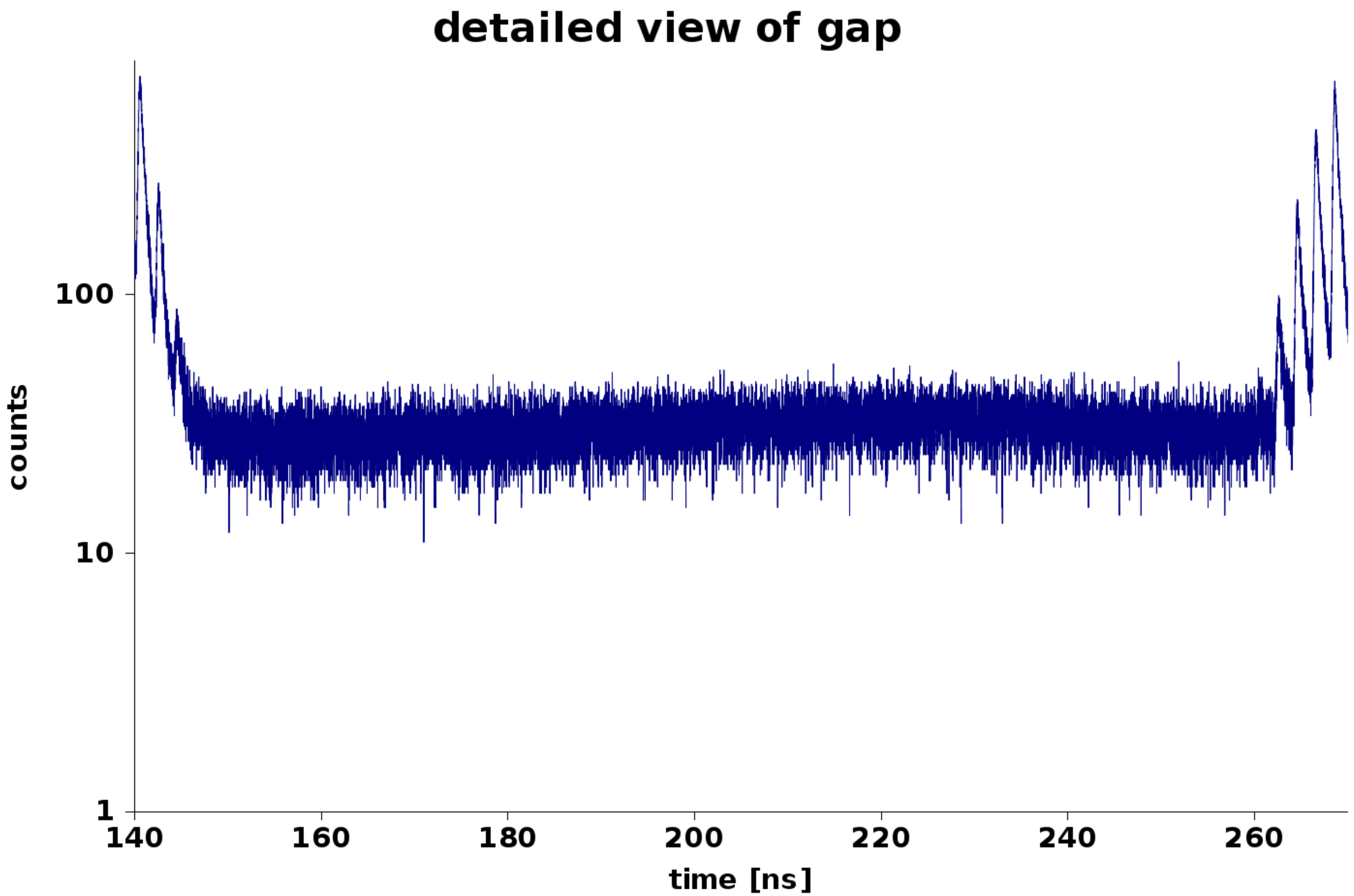

"single" bunch for different delays
no delay
1 ns delay
counts (no delay)
counts (1 ns delay)
time [ns]
40000
30000
20000
10000
0
6000
5000
4000
3000
2000
1000
0
13
14
15
16
17
18

Results



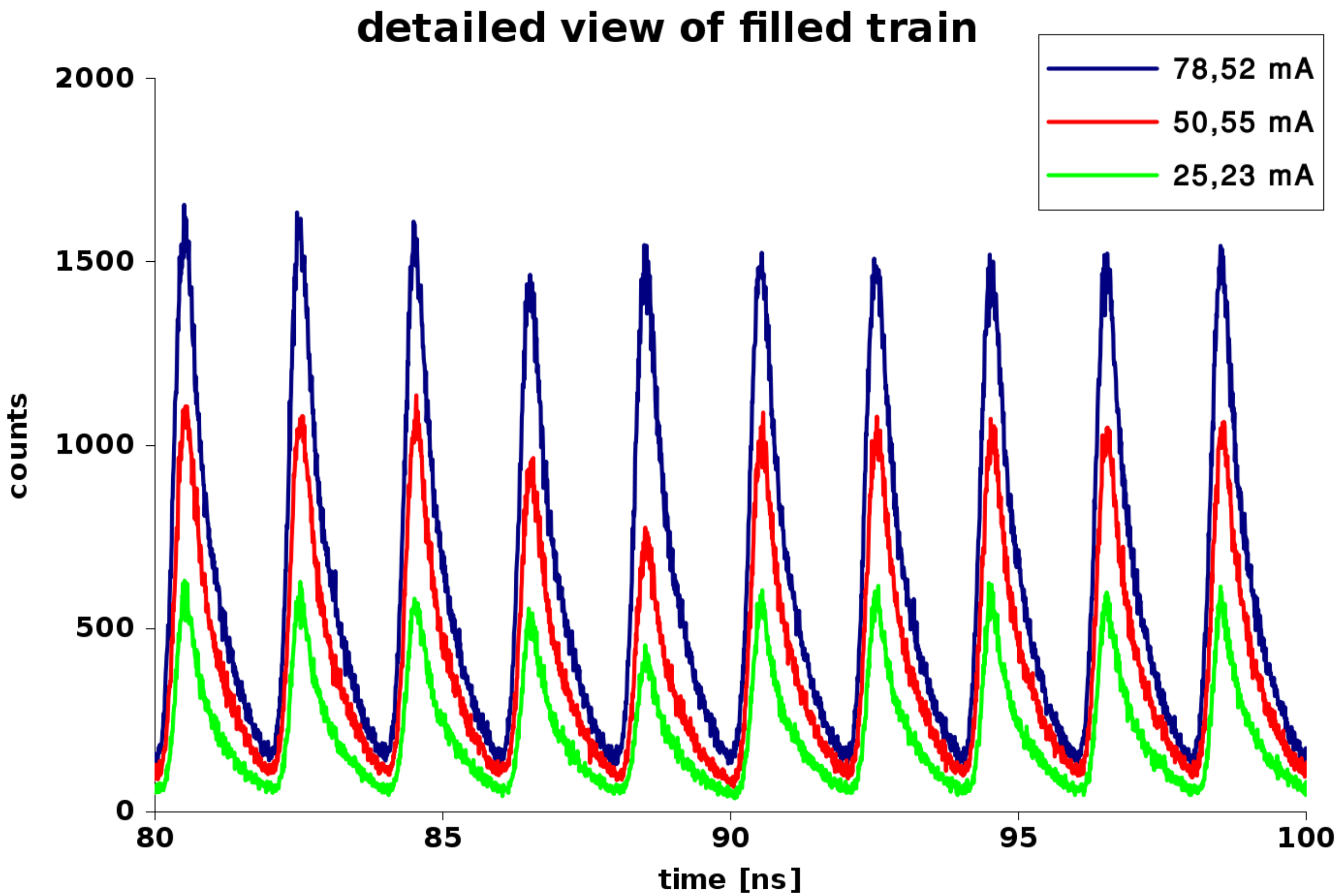
multi bunch 0.5 GeV
counts
2500
2000
1500
1000
500
0
0
100
200
300
time [ns]

Results



detailed view of gap
counts
100
10
1
140
160
180
200
220
240
260
time [ns]

Results



detailed view of filled train
78,52 mA
50,55 mA
25,23 mA
counts
2000
1500
1000
500
0
80
85
90
95
100
time [ns]

Outlook

- Acquisition of own equipment
- Fixed installation of detector
- Integration in control system

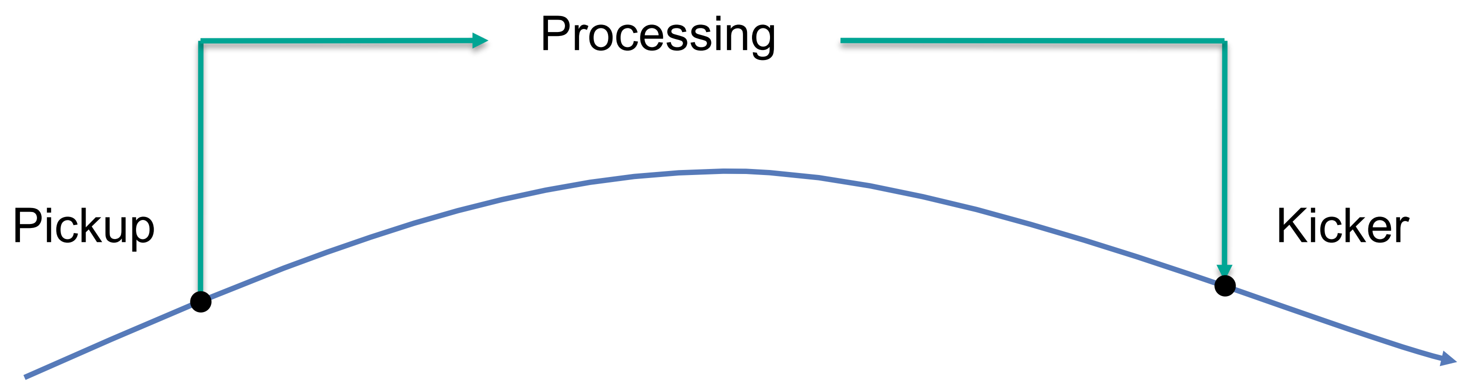
BUNCH BY BUNCH FAST FEEDBACK SYSTEMS

Bunch-by-Bunch Fast Feedback Systems

- What is it?
- How does it work?
- Why do we want it?
- Examples
- What are the next steps?

What is a Bunch by Bunch Fast Feedback System?

- Fast data acquisition (one sample per RF bucket)
- Real-Time processing using a Field-Programmable Gate Array (FPGA)
- Feedback of filtered signal



- At ANKA: Instrumentation Technologies Libera Bunch-by-Bunch

Why do we want it?

Main Use

- Damping of bunch instabilities
- Improve beam stability
- Improve life time
- Increase current that can be stored

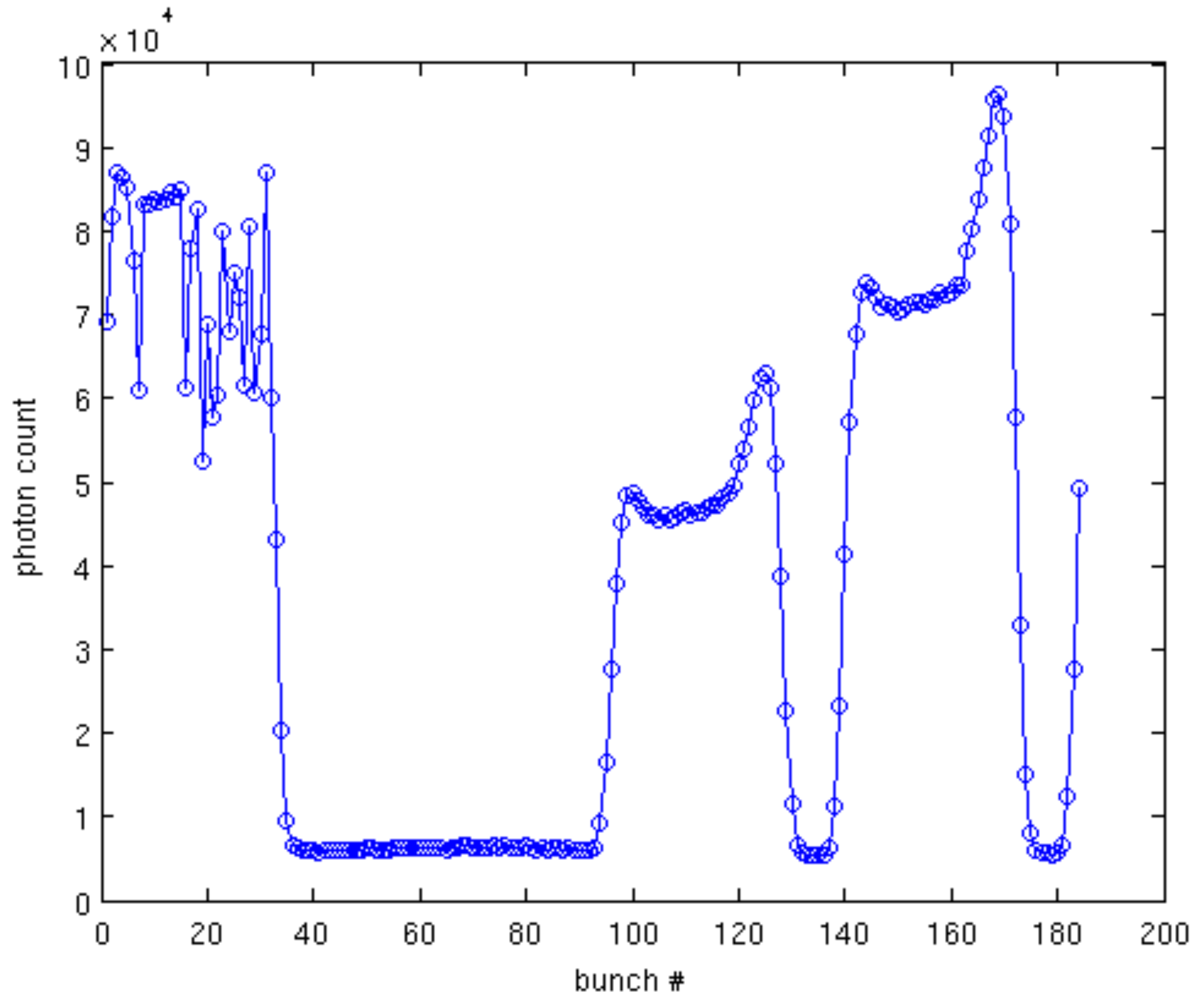
Extra Use

- Beam diagnostics
- Frequency domain measurements
- Analyze instabilities
- Grow Damp Measurements

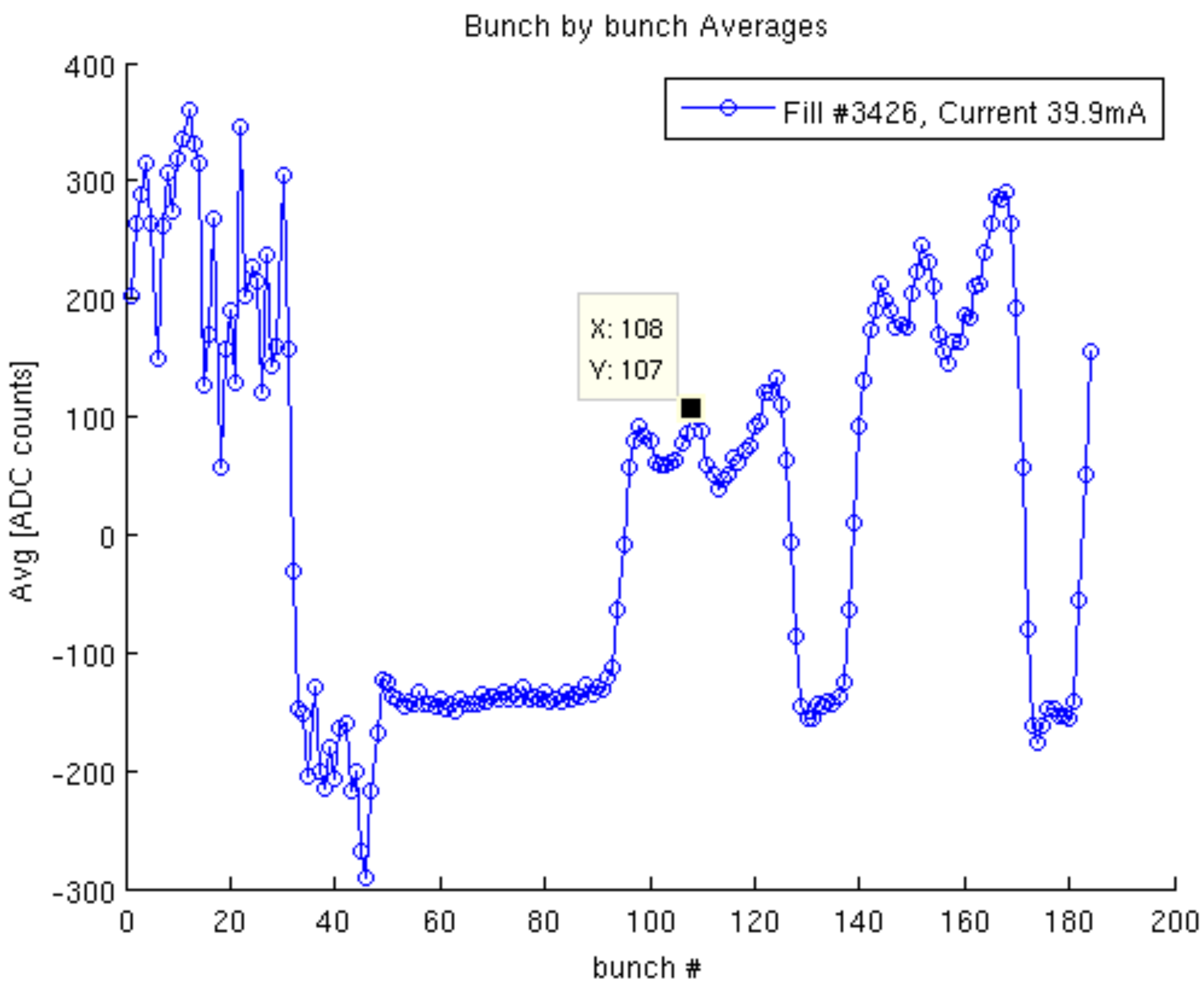
Benefits of Bunch by Bunch Feedback

- Damp instabilities thus gaining lower emittance and better life time
- Example for ANKA:
  - Theoretical bunch length increases with energy
  - But instabilities at injection energy (0.5 GeV) increase the bunch length
  - Low-Alpha Mode works at 1.3 GeV (beam is more stable)
  - Fast Feedback could help to damp instabilities at 0.5 GeV, thus allowing for even shorter bunch length

Fill Pattern Measured with Avalanche Photo-Diode



Looking at oscillations of a bunch



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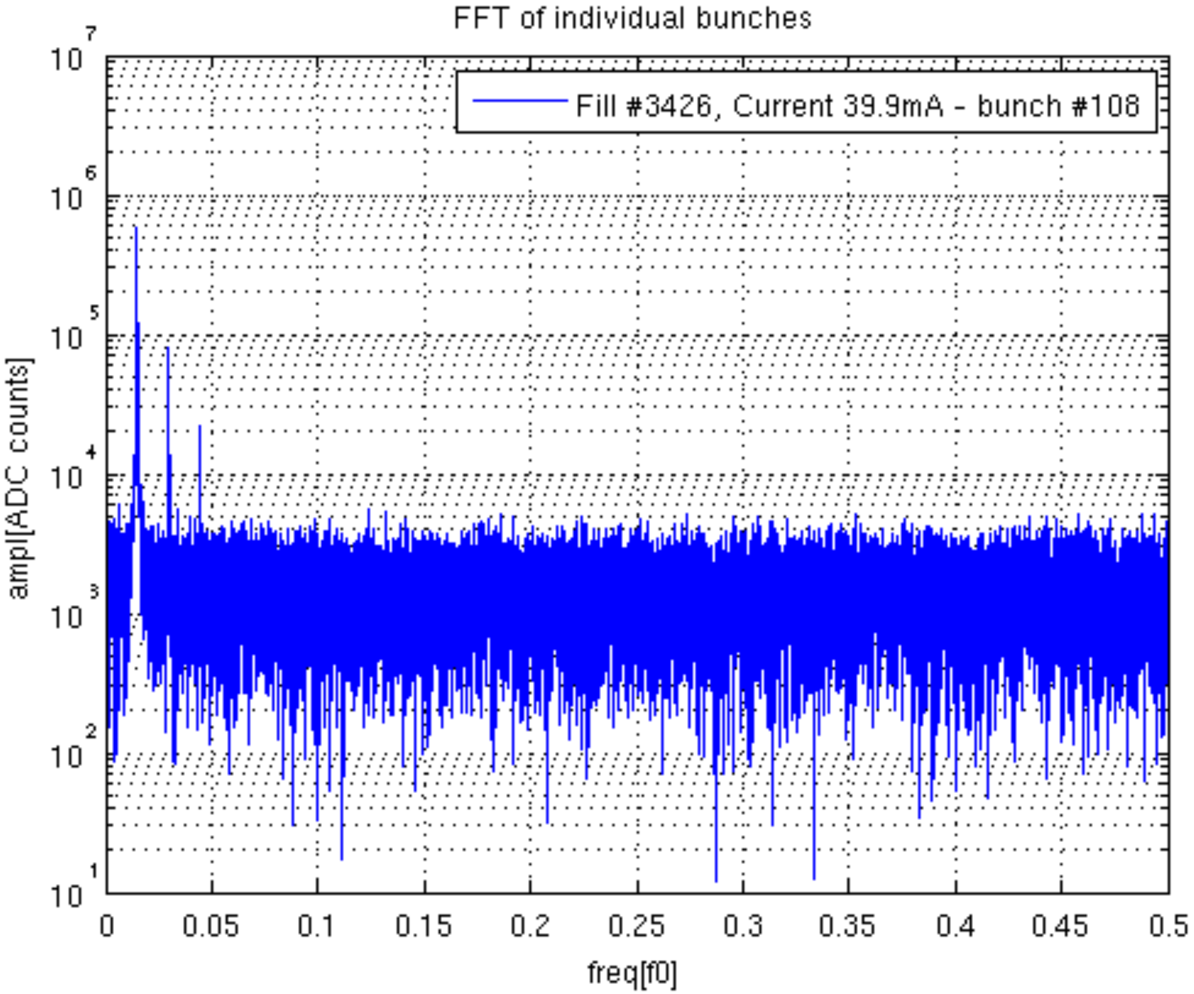
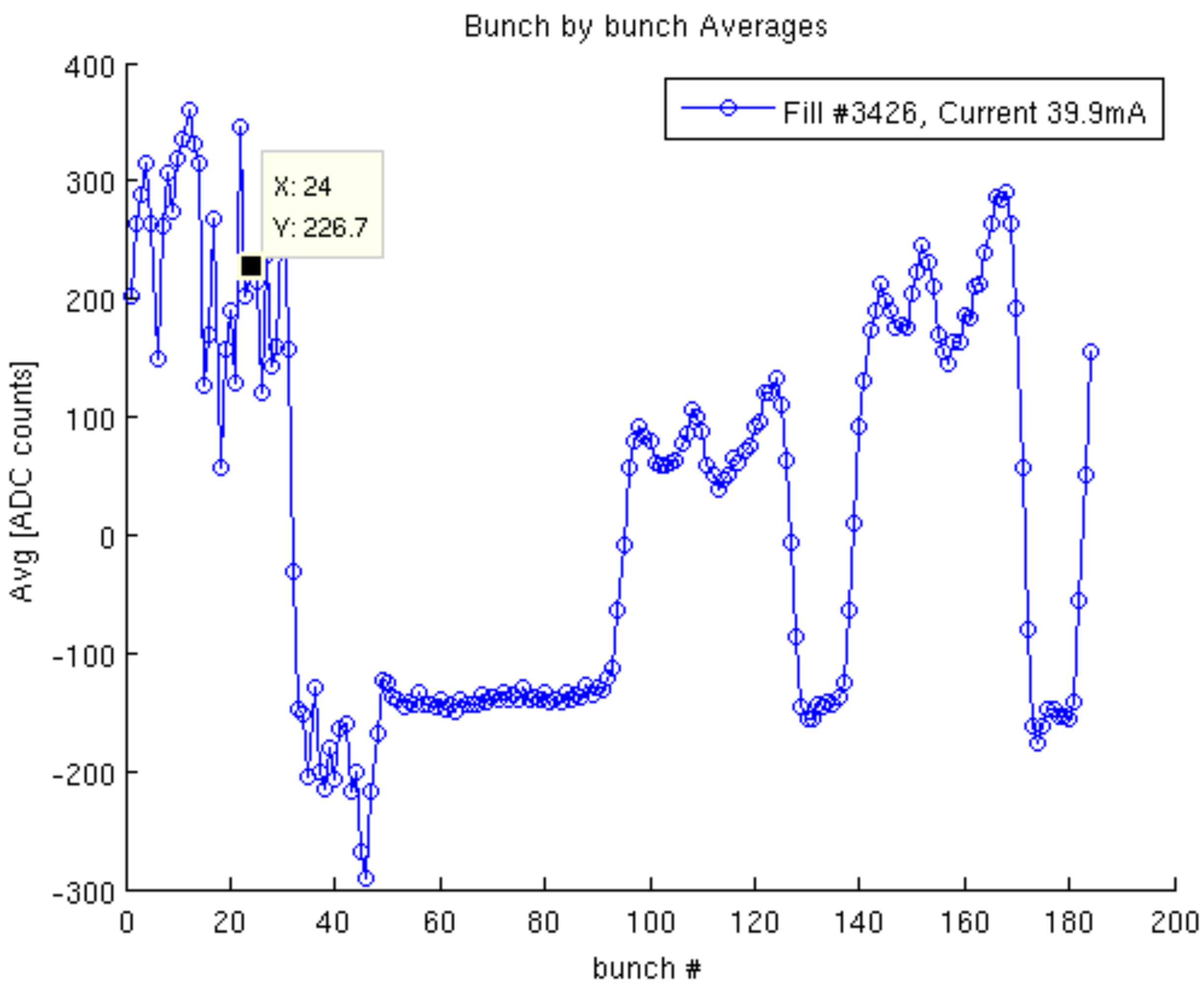
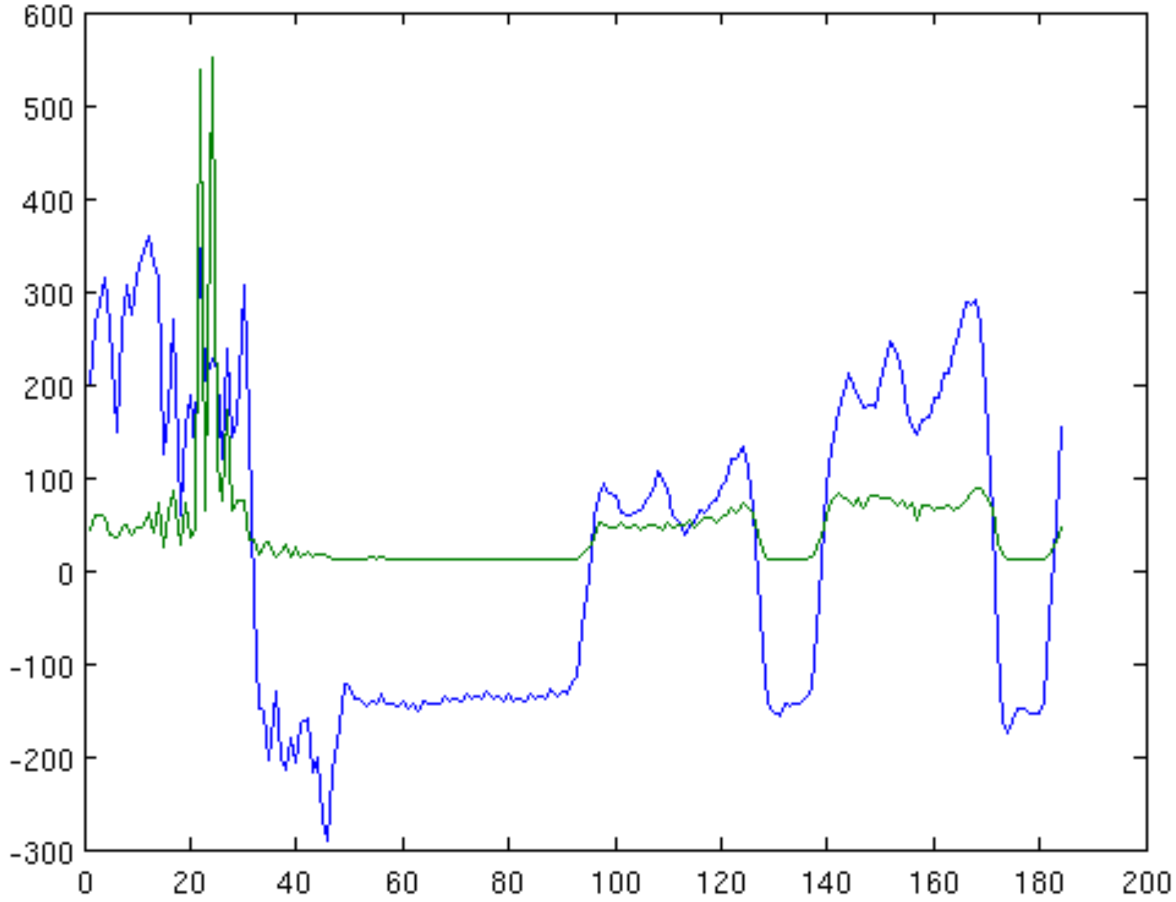


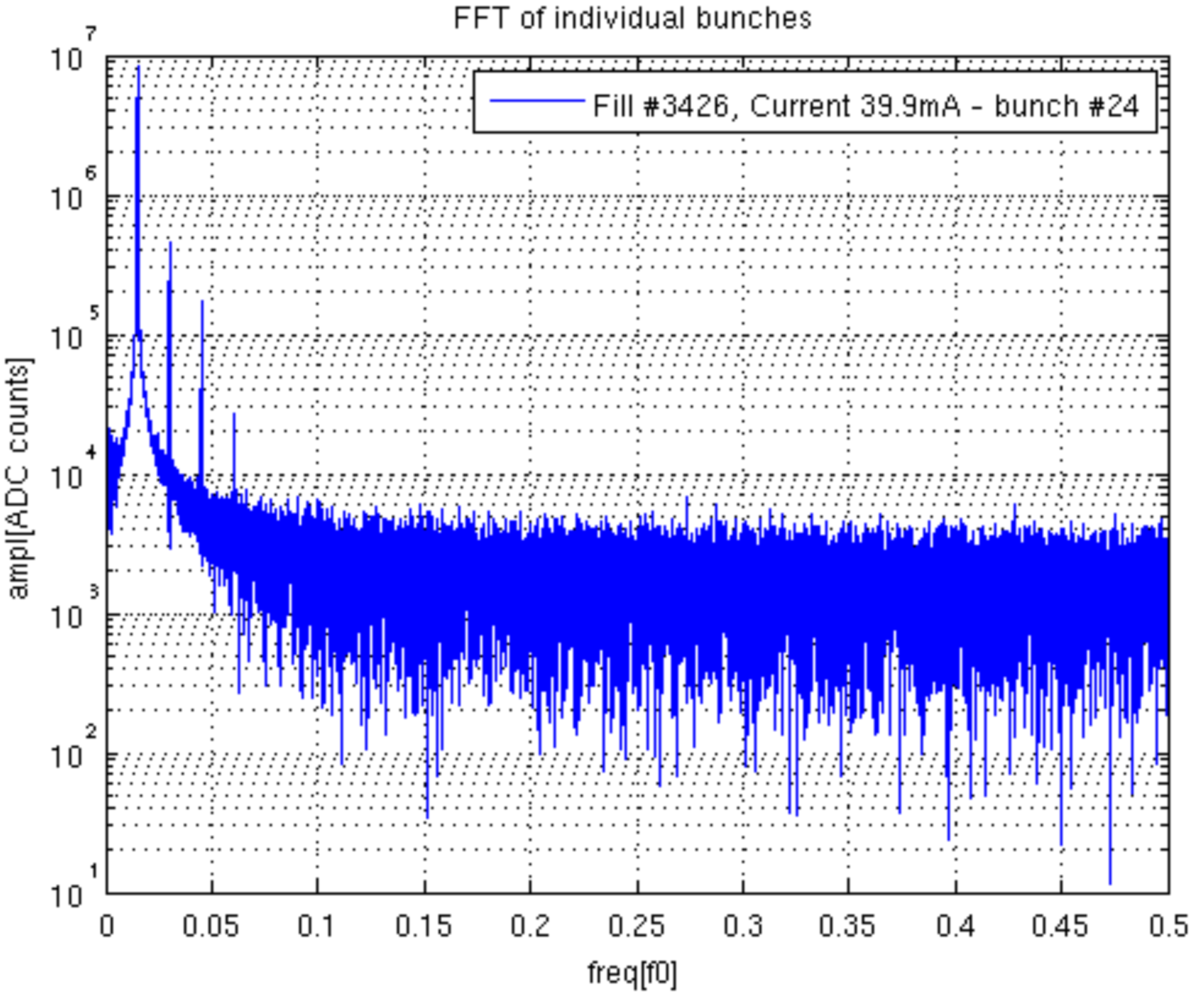
Looking at instabilities



Looking at Instabilities



Looking at Instabilities



Problem: Inter-Bucket Coupling of Signals

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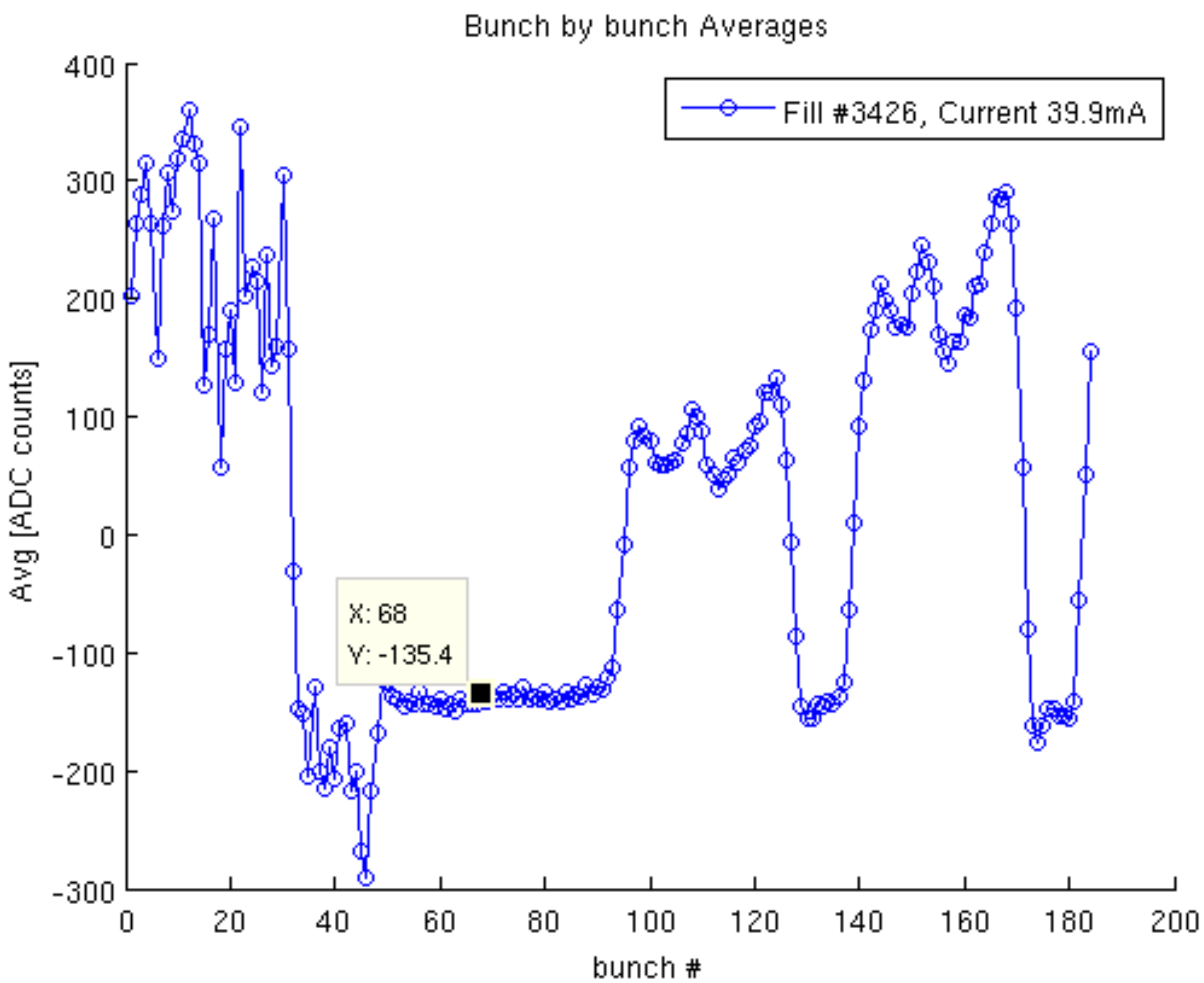

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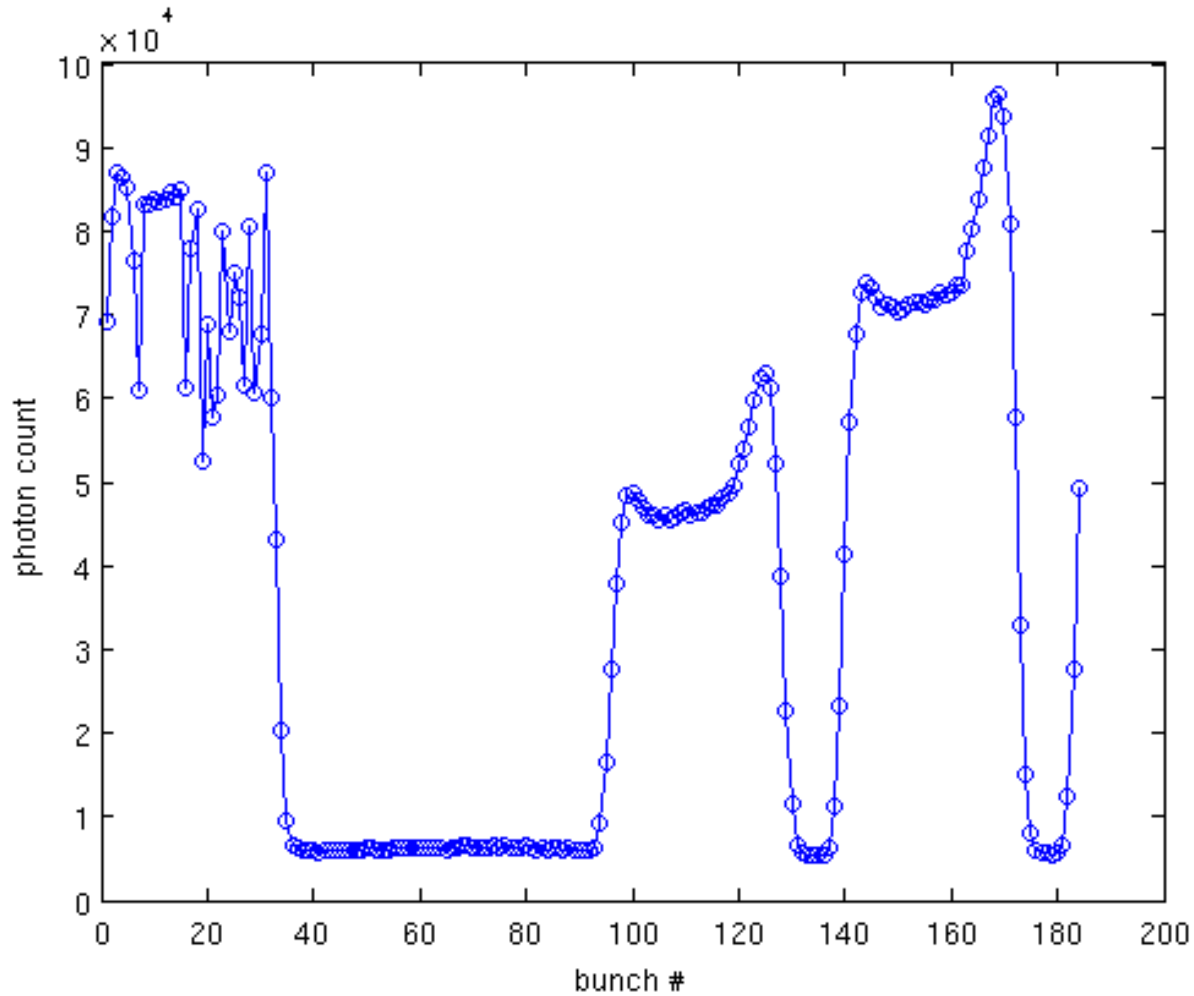

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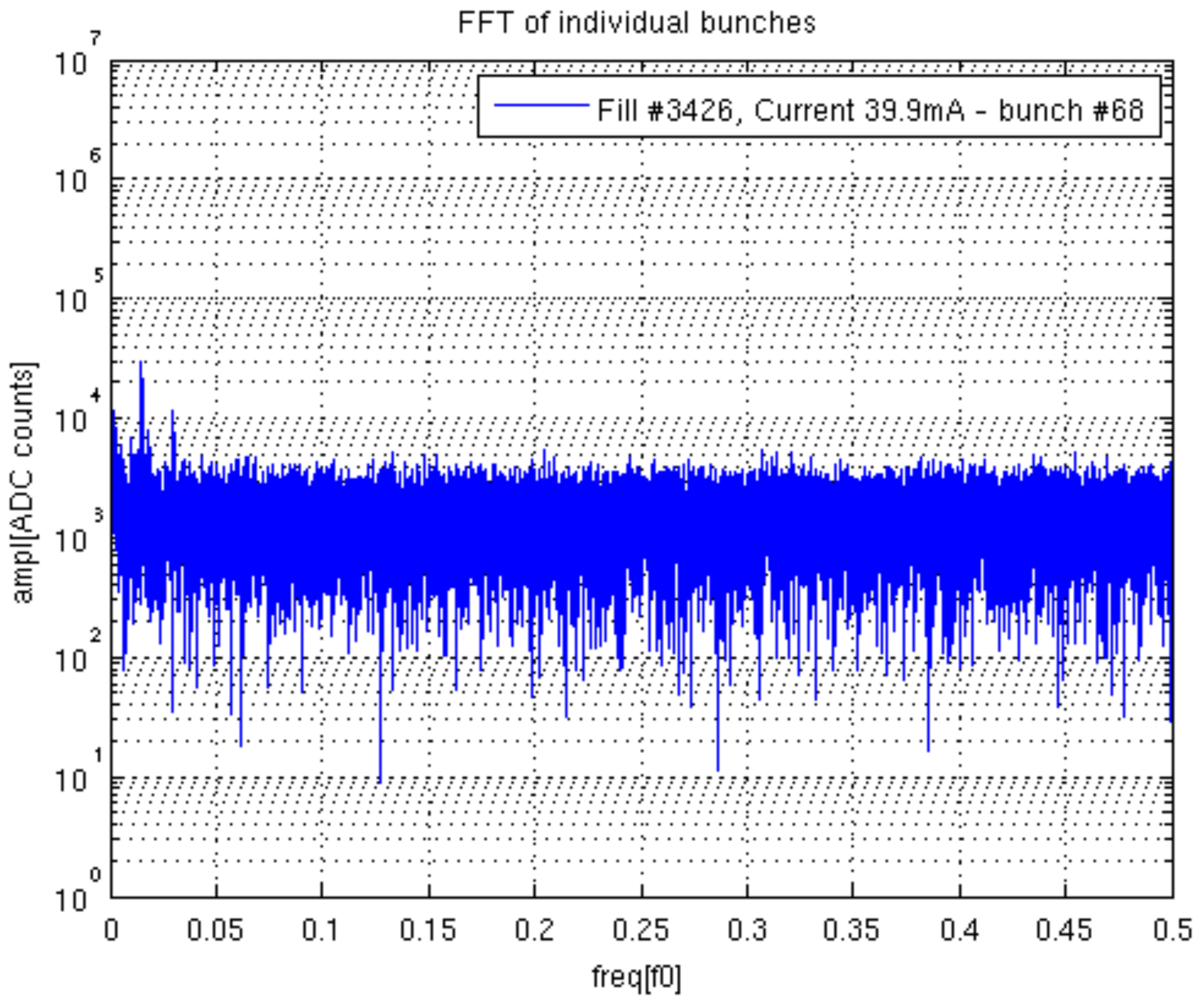

Next Steps

- Understand RF frontend of Fast Feedback System
- Find source of instabilities
- Make feedback work
  - In Energy ramp
  - In all three dimensions
- Create a new Low-Alpha Mode at injection energy

(Okay, that's really the final step)

Conclusion

- Sophisticated Timing System is important for injection and thus for overall accelerator operation
- Diagnostics like Single Photon Counting are needed for verification and optimization as well as for understanding the origin of problems
- Bunch-by-Bunch Fast Feedback System can help with diagnosing and damping of beam instabilities

Accelerator operation is a continuous process requiring a good toolset for diagnostics and control

Contacting us

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