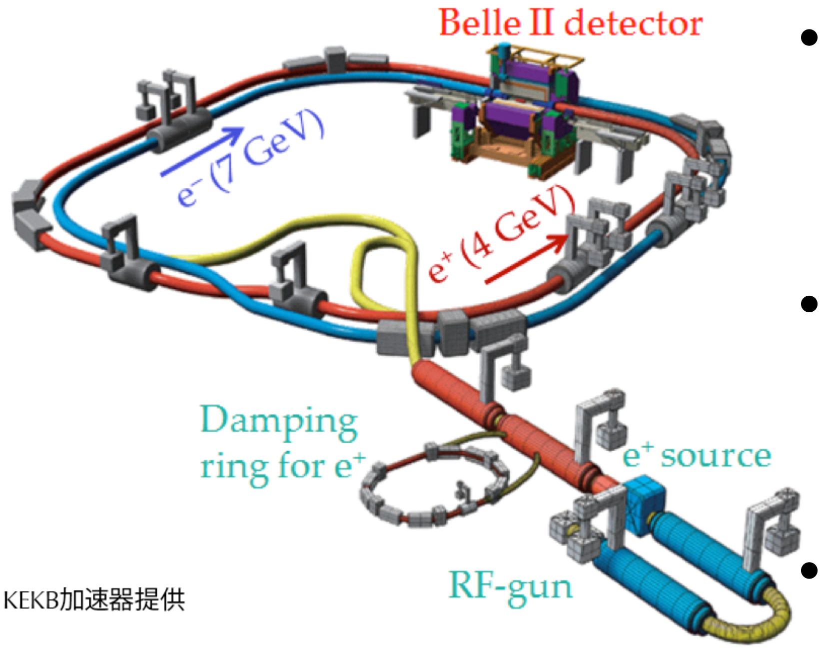
March 28th 2017

Scintillator tiles with SiPM readout for fast timing in SuperKEKB commissioning

Outline

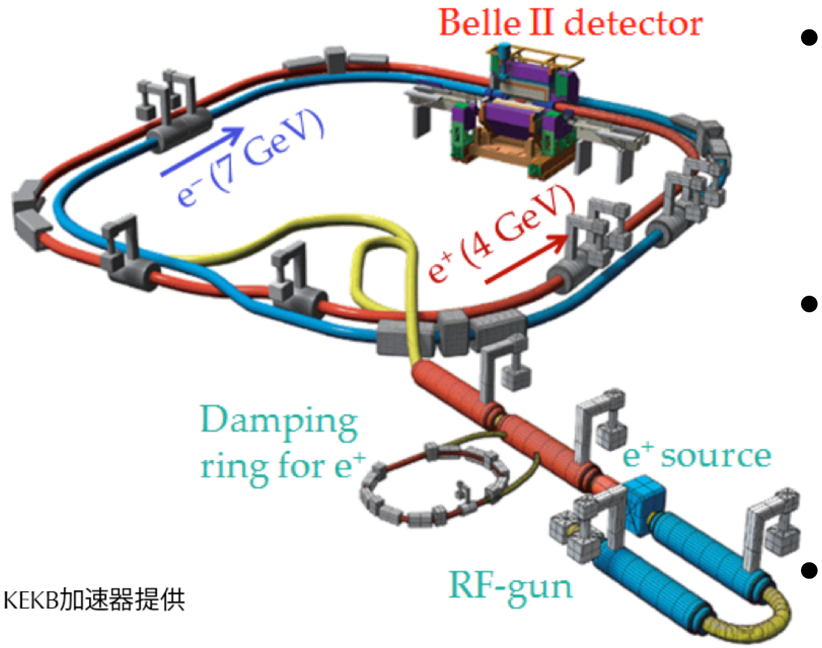
- SuperKEKB
- Beast II - Phase 1
- The CLAWS System
- Results
- Summary & Outlook

SuperKEKB



- extensive upgrade of KEKB & Belle
  - ➡ factor 40 increased luminosity
    - ➡ $8x10^{35}cm^{-2}s^{-1}$
- asymmetric e^+e^- -collider (10.58 GeV Y(4s)):
  - low energy ring for 4 GeV e^+
  - high energy ring for 7 GeV e^-
- B-factory: investigation in CP violation and rare B-, D- & τ- decays

SuperKEKB



KEKB加速器提供

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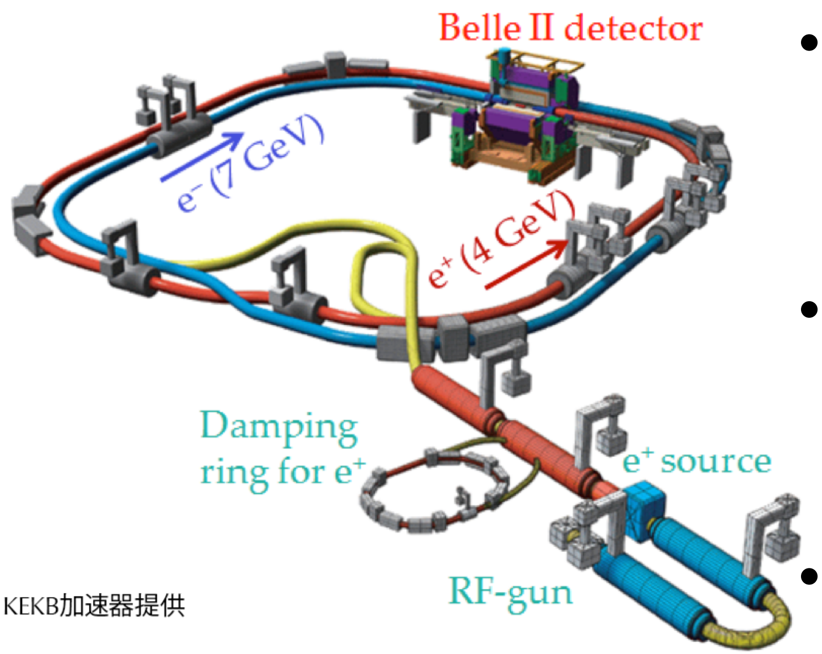
BEAM **E**XORCISM FOR **A** **ST**ABLE BELLE EXPERIMENT **II**

SuperKEKB



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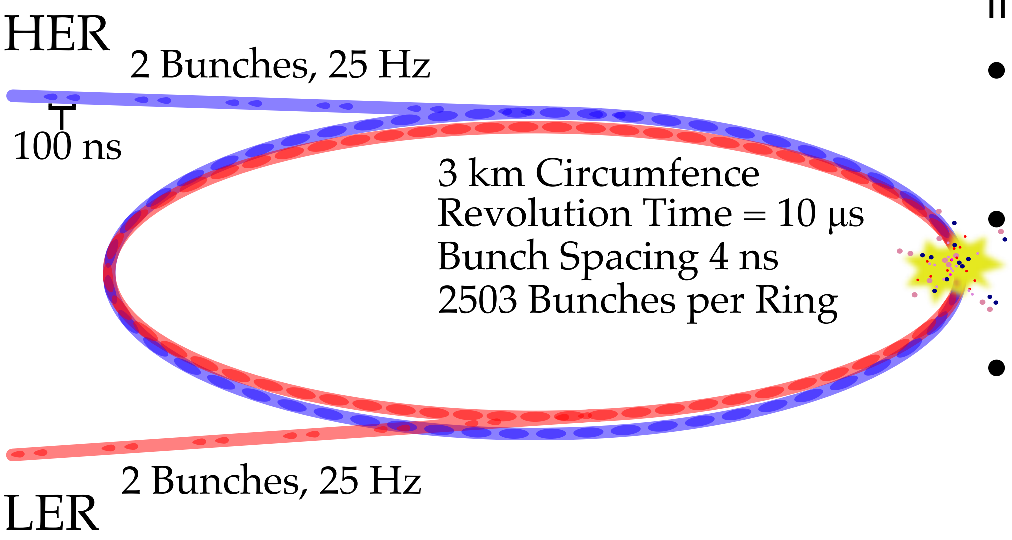
BEAM EXORCISM FOR A STABLE BELLE EXPERIMENT II

Three commissioning phases:

✤ Phase 1 (Feb 2016 - June 2016):

- no Belle II detector
- no beam optics for focussing
- injection in either HER or LER

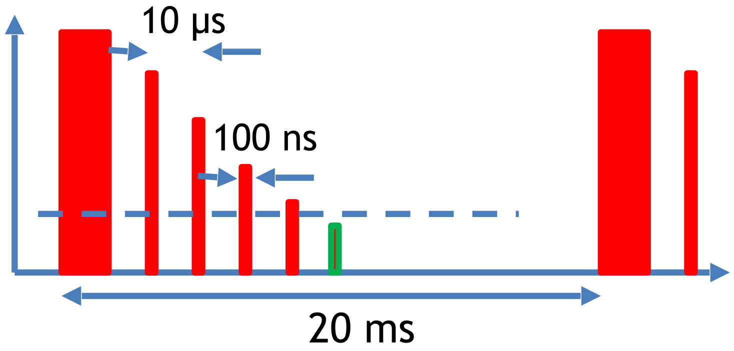
What do we measure?



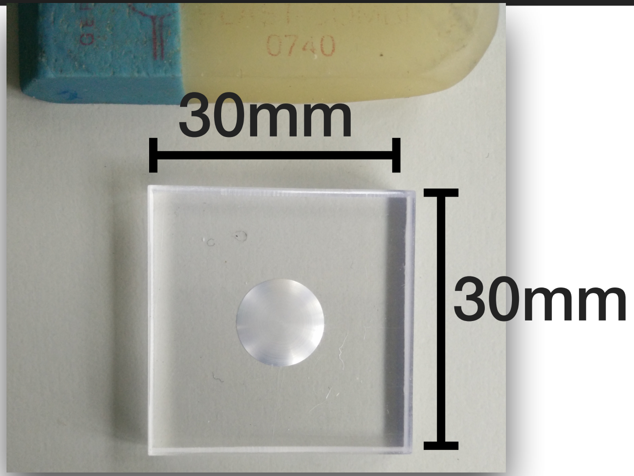
Measurement of particle loss of injection bunches:

- intra-bunch interactions lead to different types of background at the IP
- regular small signal from circulating bunches
- high signal from top-up daughter bunches
  - ➡ high signals decrease turn by turn
- goal: measure decay time of injection noise

Expected signal:



The CLAWS System



- scintillator shape taken from CALICE hadron calorimeter for ILC
- mostly sensitive to charged particles

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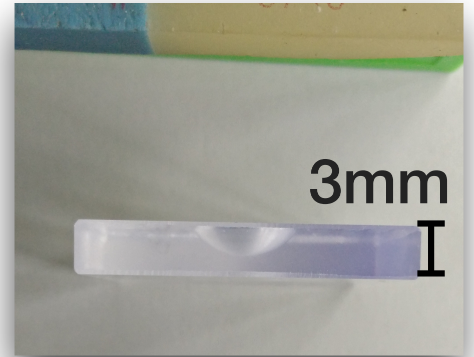

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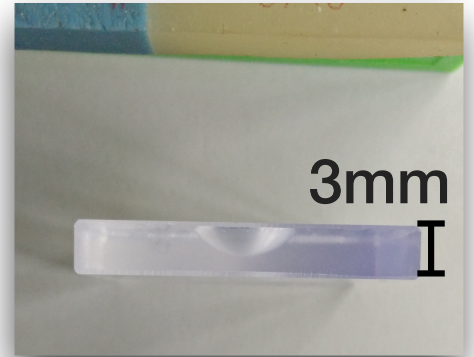

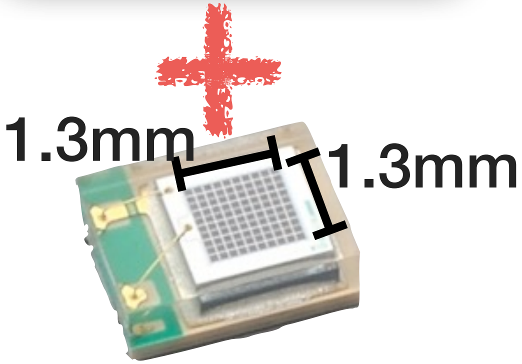

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- Hamamatsu silicon photomultiplier (SiPM) mounted under the dimple of scintillator
- 2668 pixel
- low noise: <1 Hz for 3 p.e.

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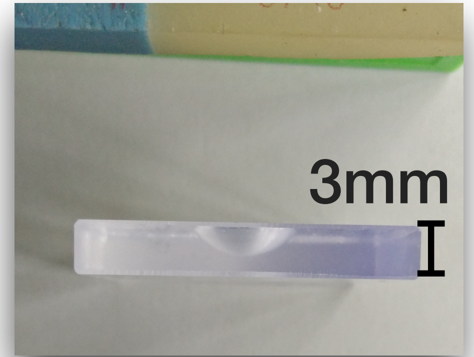

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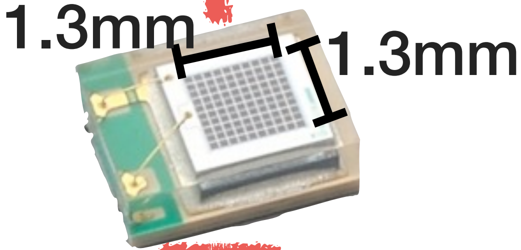

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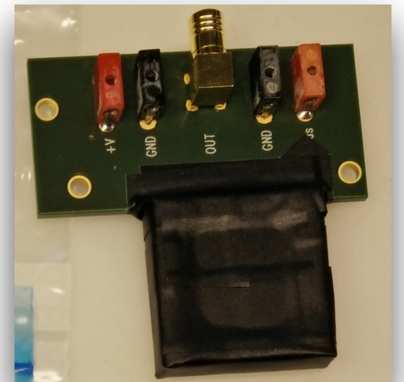

- scintillating tile wrapped in reflecting foil and mounted on a PCB with preamplifier
  ➡ light-tight Claws Sensors
- read-out with sampling rate of 800 ps

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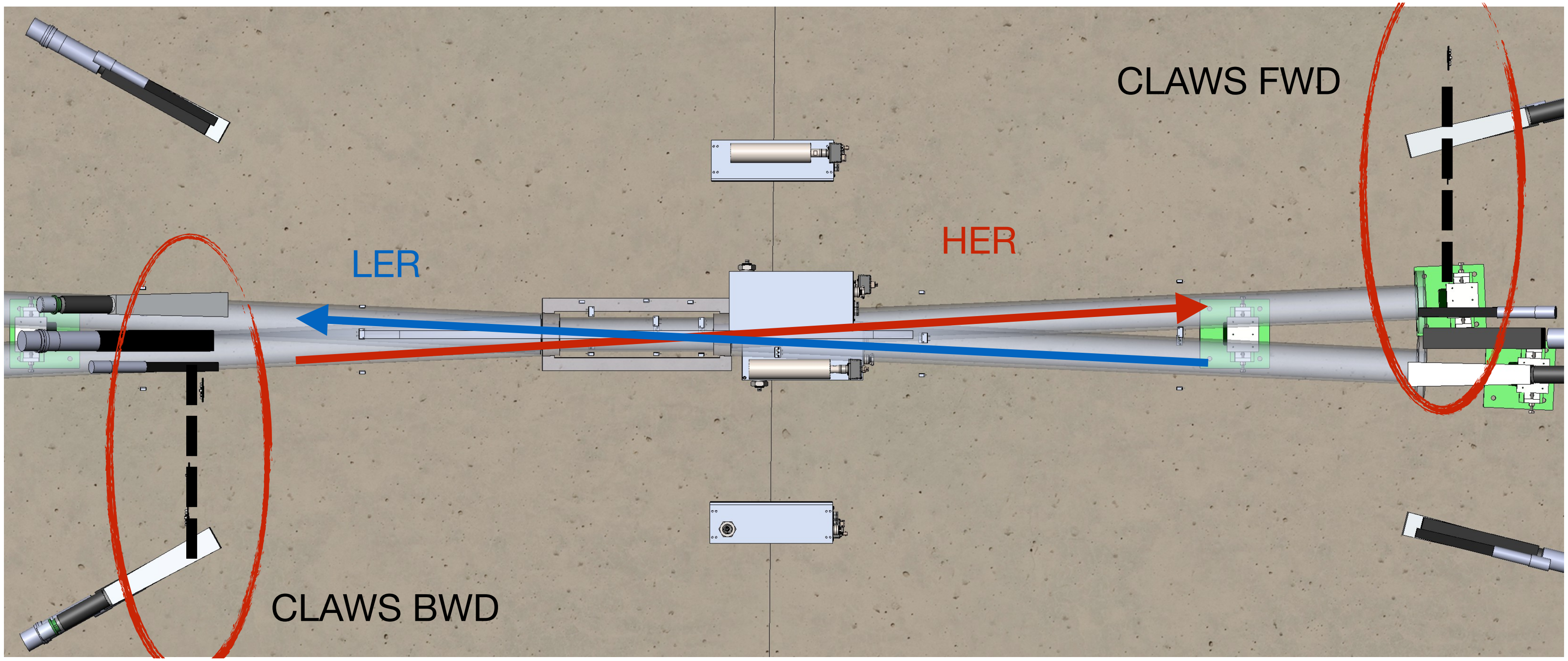
The CLAWS System

SCINTILLATOR **L**IGHT **A**ND **W**AVEFORM **S**ENSORS

- 4 on outer side of ring
- 4 on inner side ring



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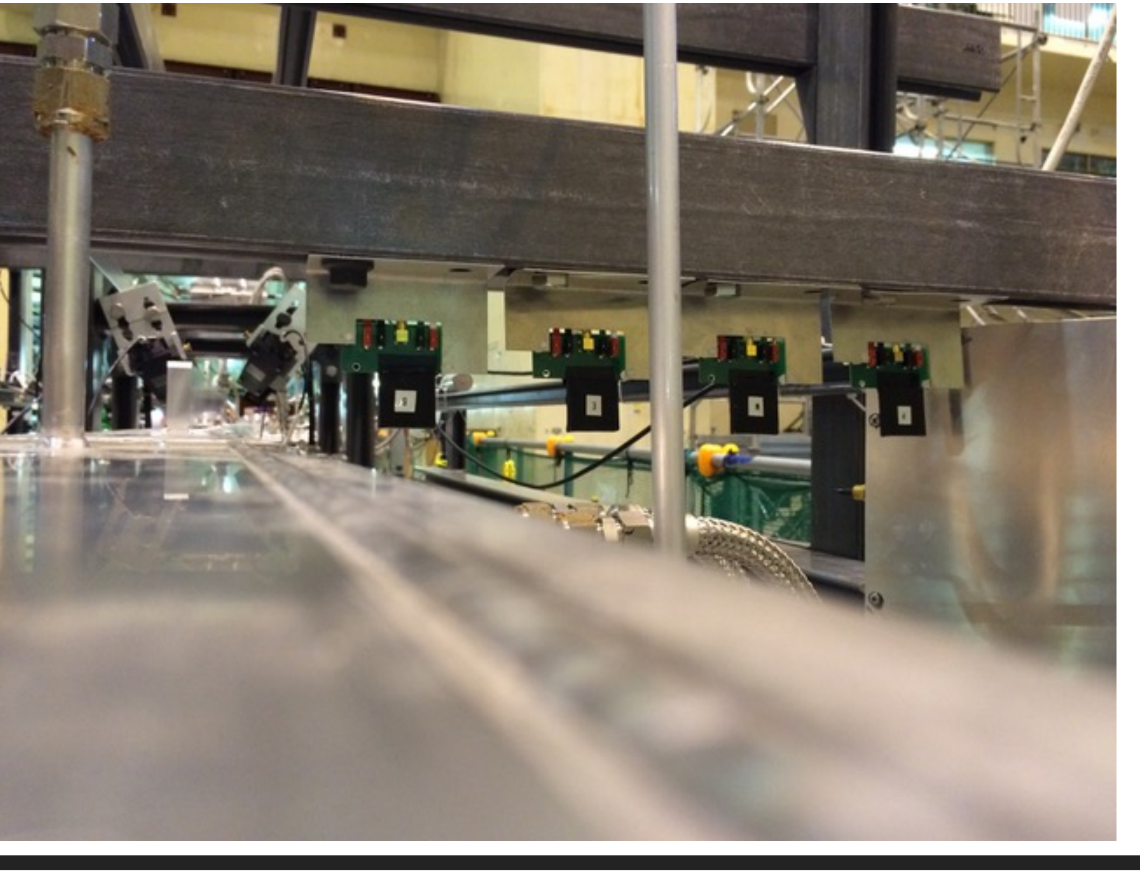
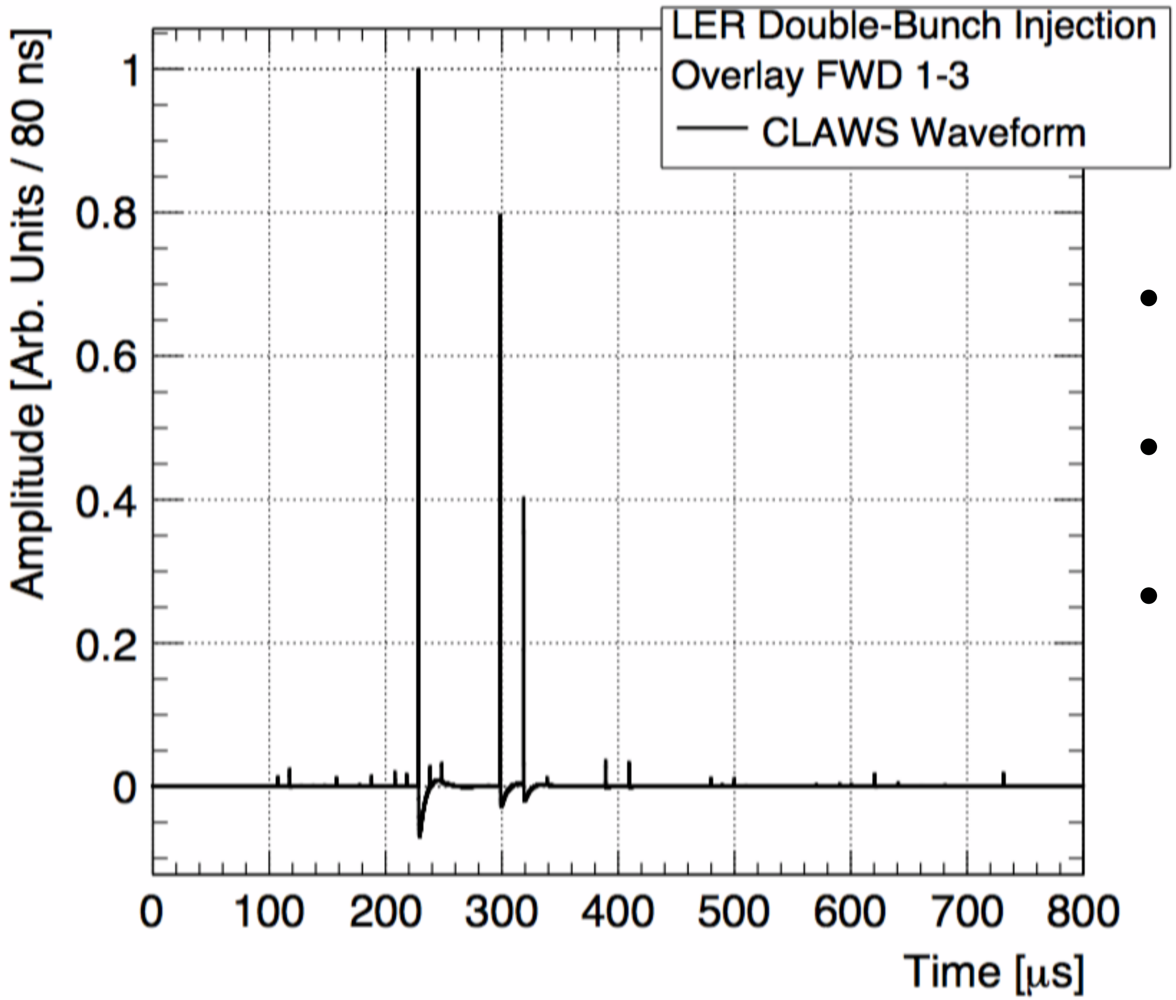


Timing Properties of the Beam

WORK IN PROGRESS

Injection background in LER with double bunch injection



- small signals in the first revolutions ~107 μs after trigger
- very large signals starting ~12 turns after first arrival
- signals substantially reduced after 100 μs of high activity

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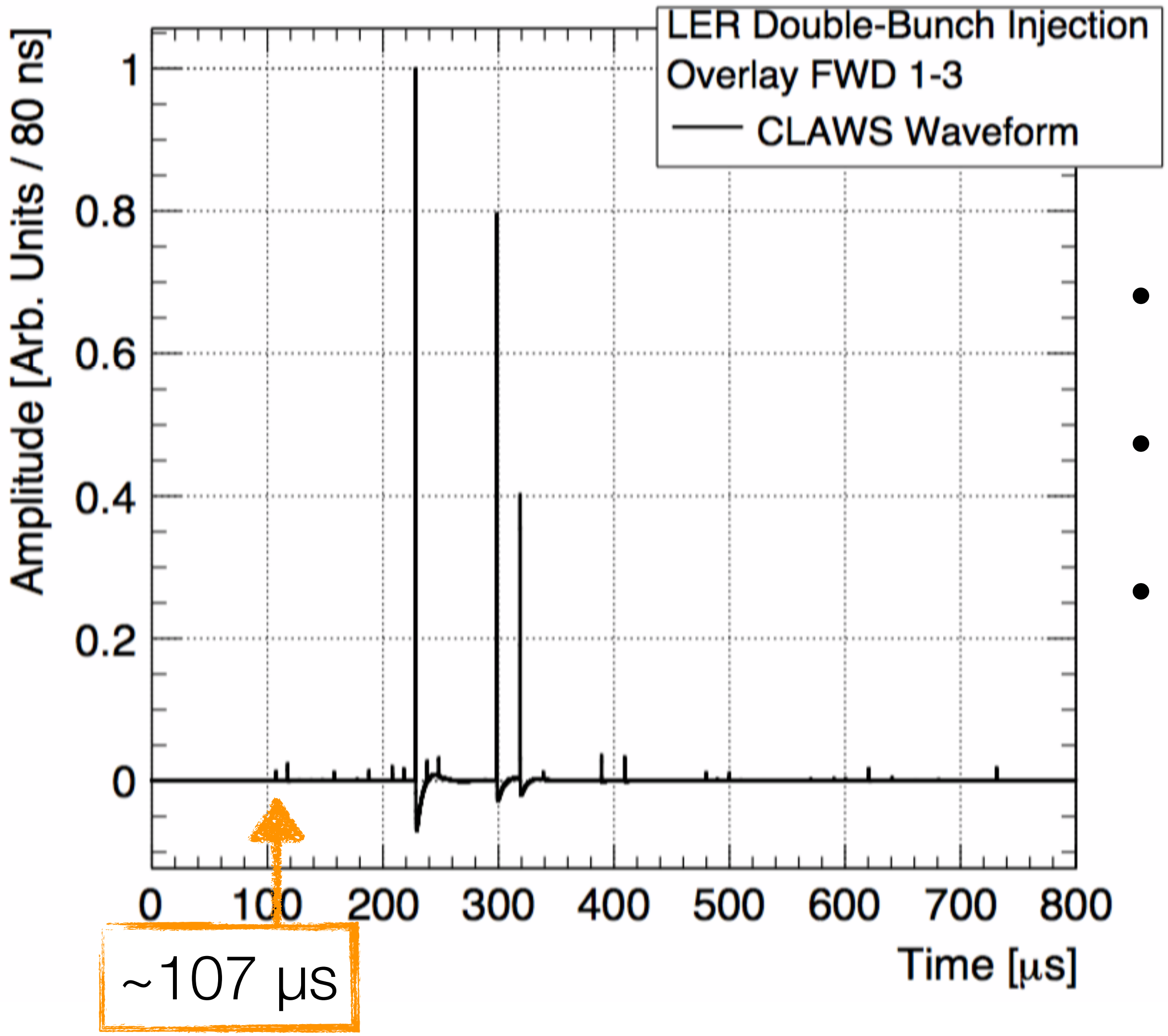

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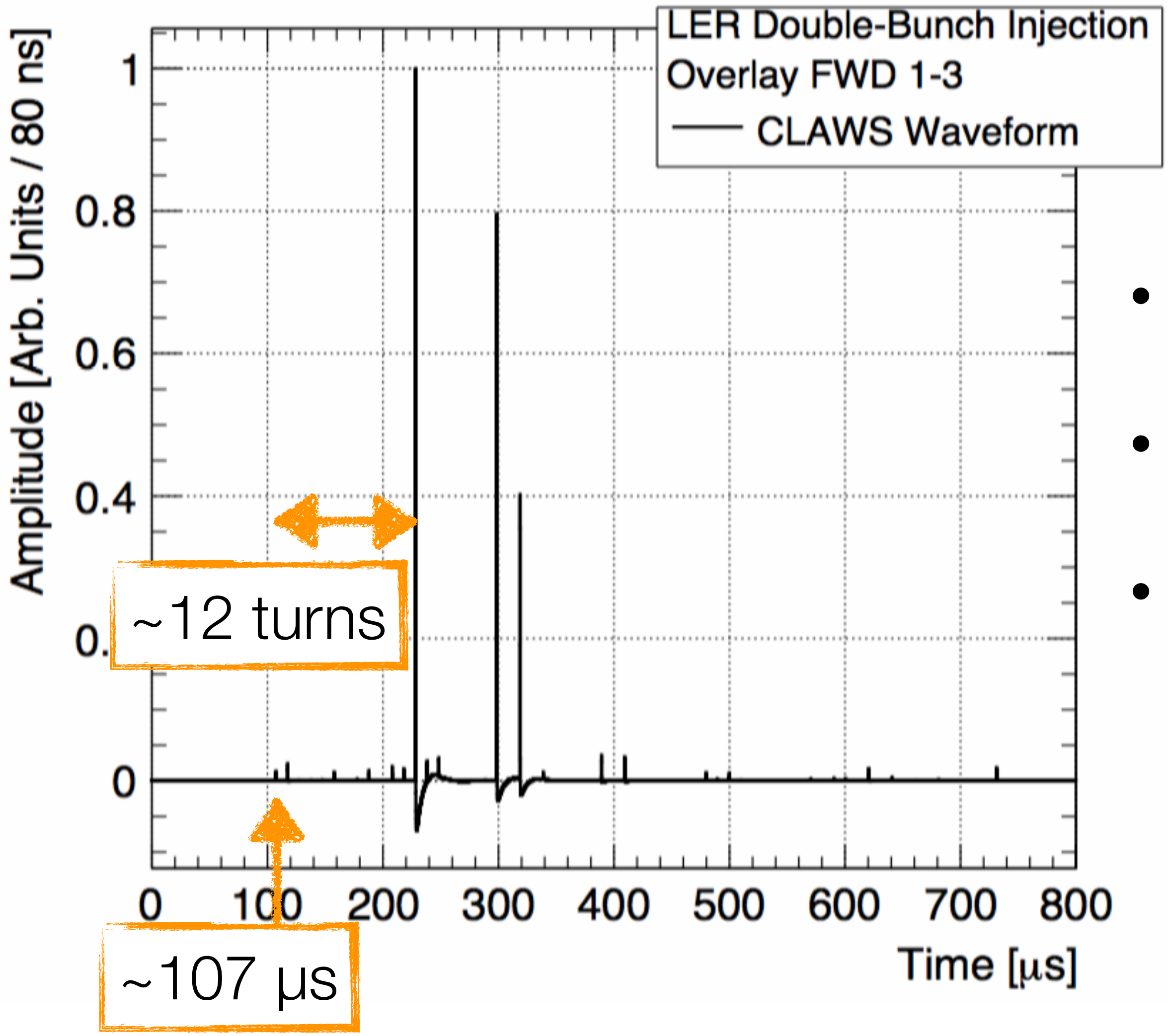

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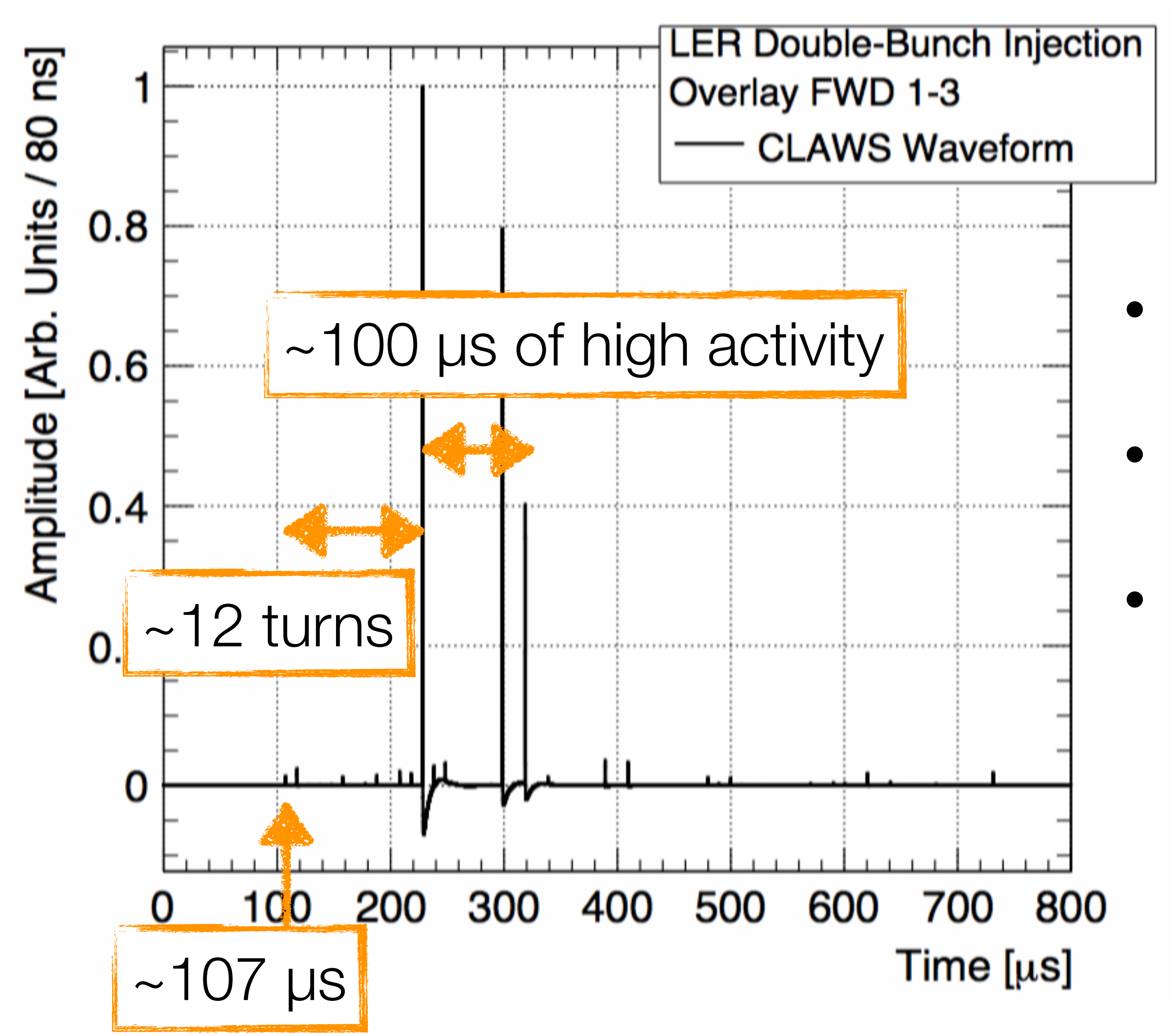

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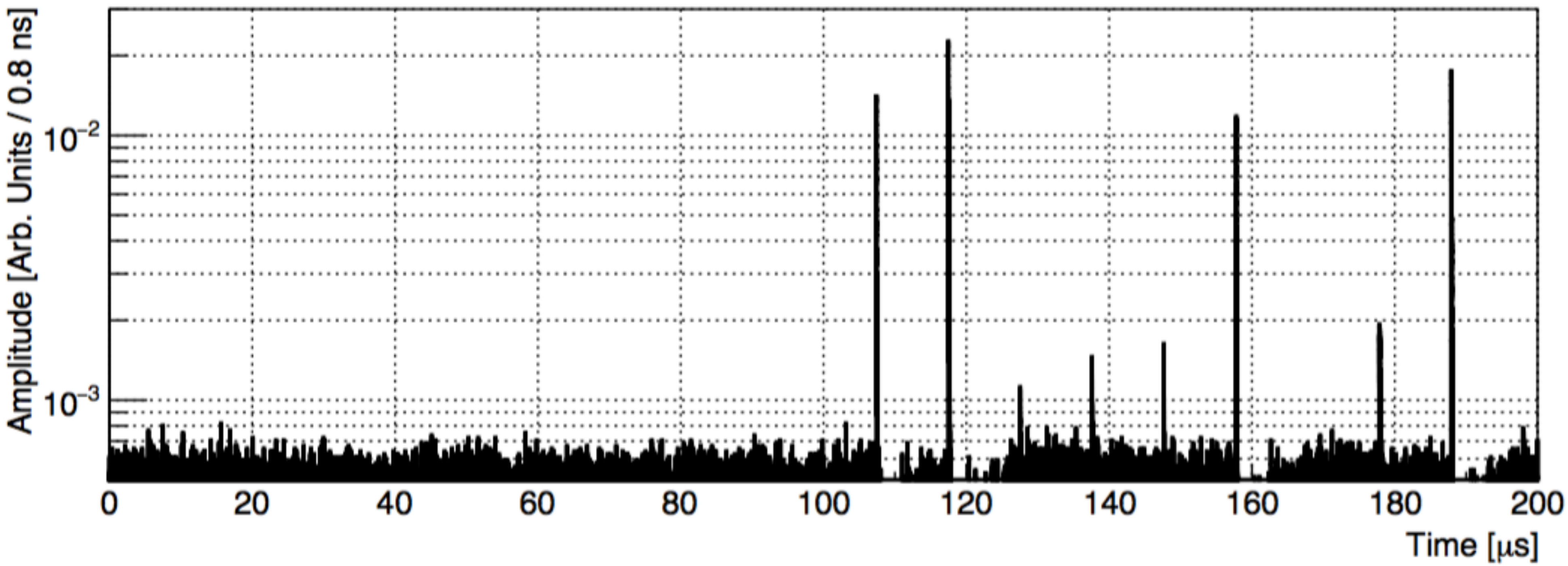
WORK IN PROGRESS

Injection background in LER with double bunch injection

- zoom into the first 200 μs
  - first signal arrives ~107 μs after trigger
  - mostly after every turn a signal
    - ➡ signal at 167 μs is missing
    - ➡ signal at 197 μs is not clearly visible
    - ➡ Betatron oscillation frequency is 44.59/Turn in LER (horiz.)



Arrival of First Particles

WORK IN PROGRESS

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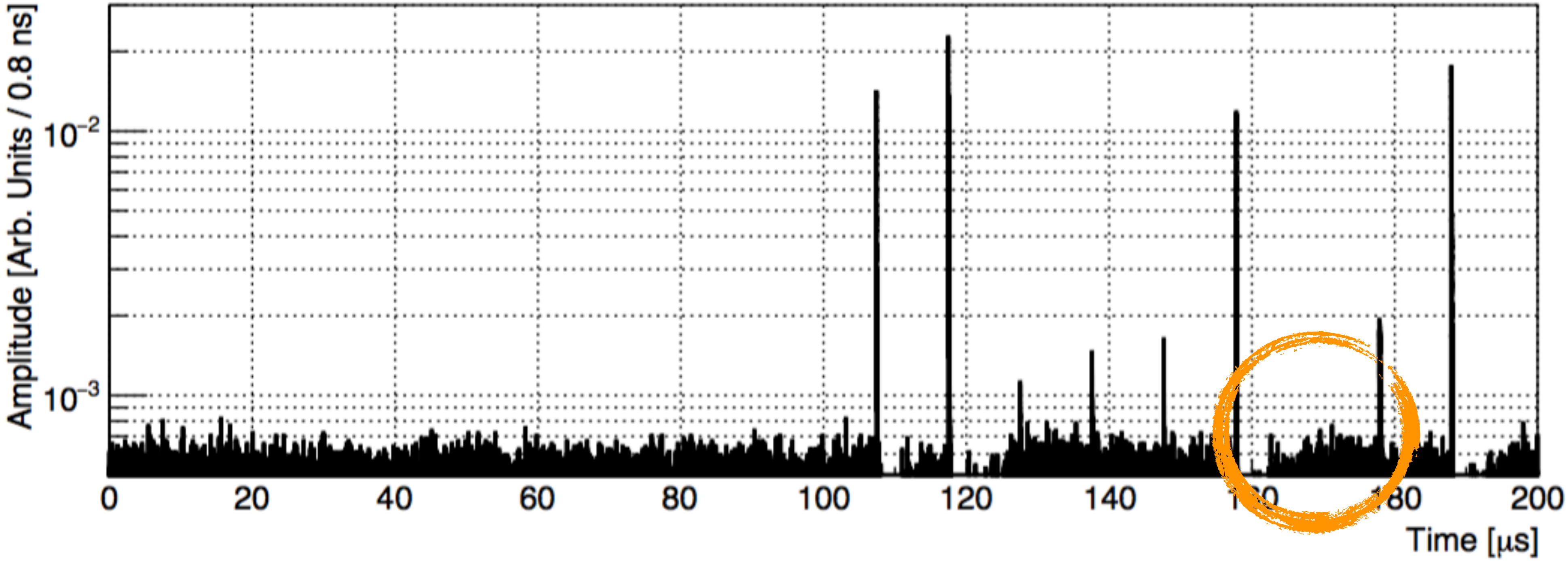

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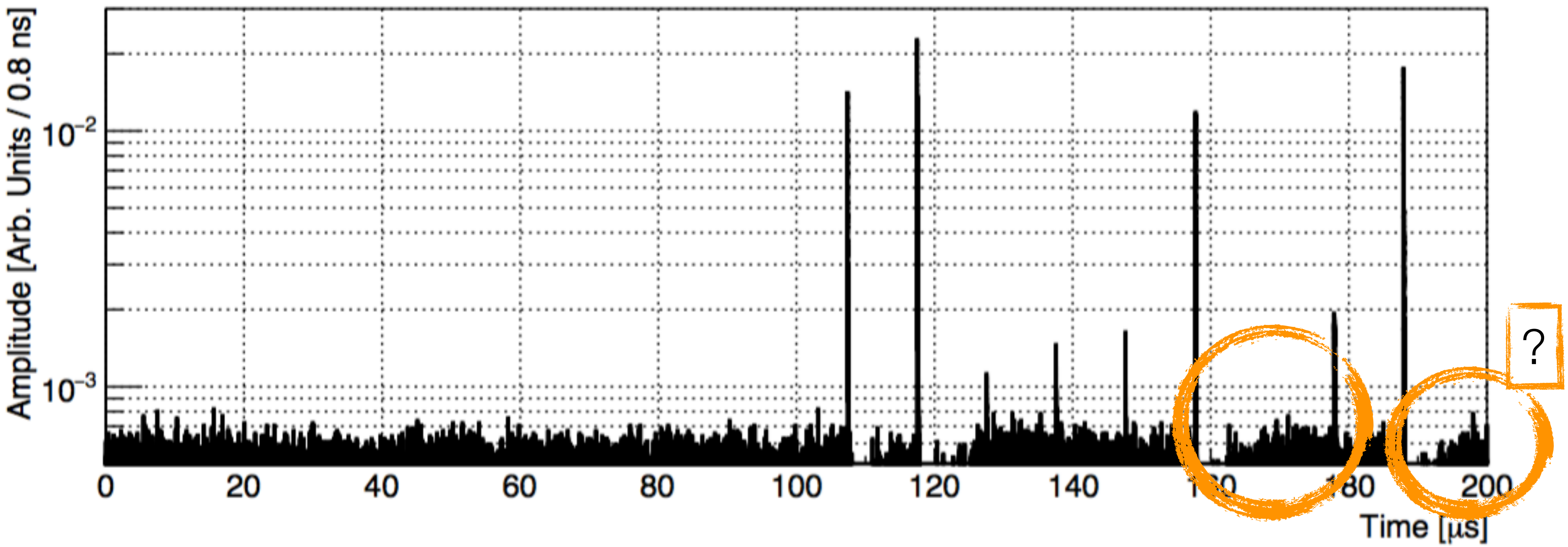
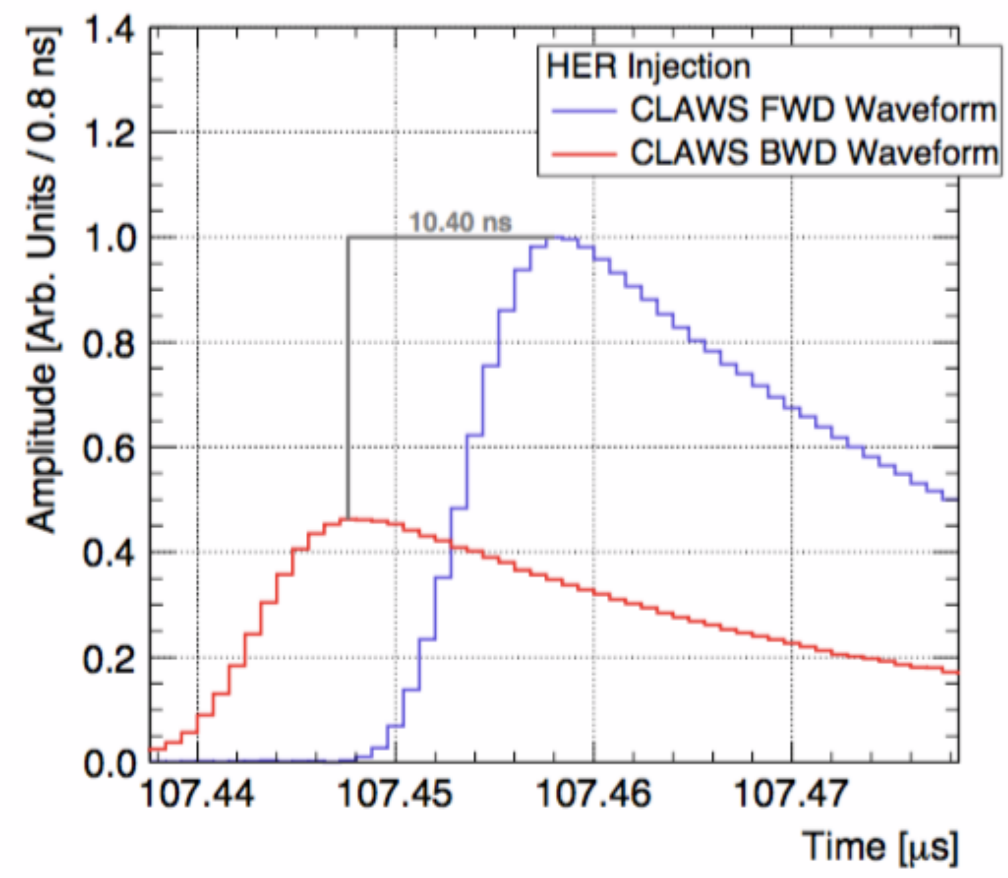
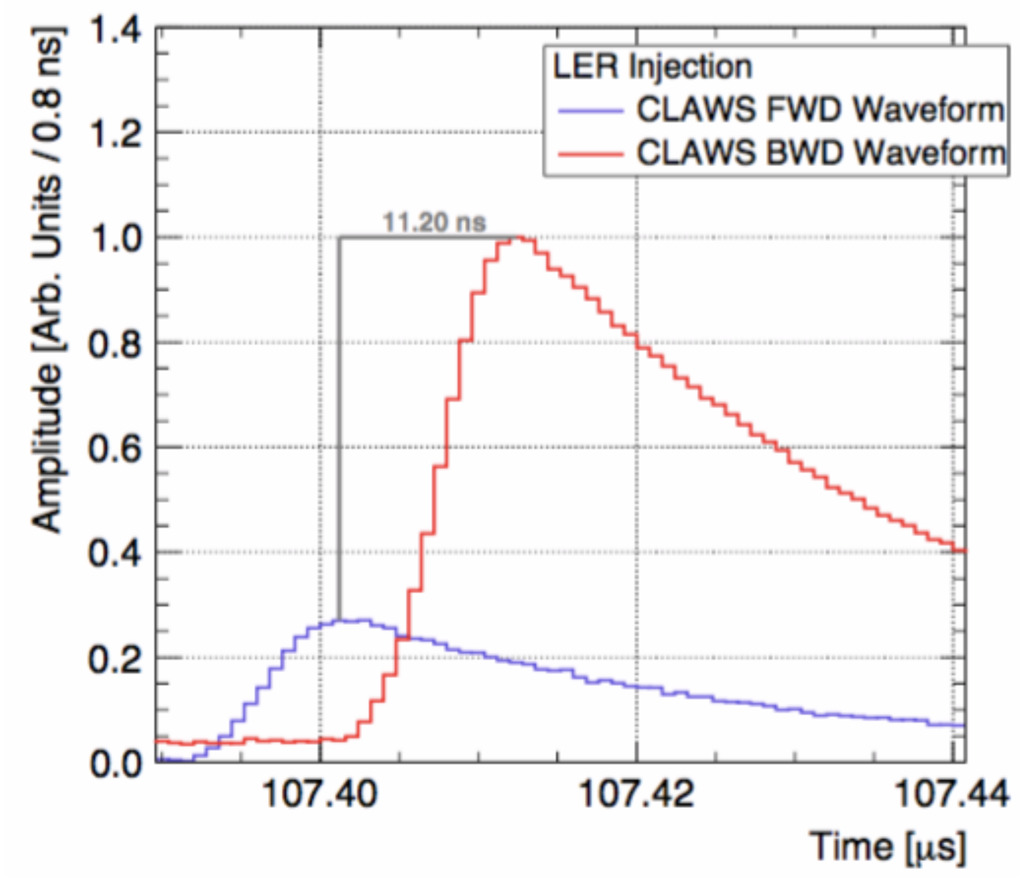


WORK IN PROGRESS

Sanity Check: Speed of light

- forward and backward region are about 3 m apart
  - bunches clearly distinguishable

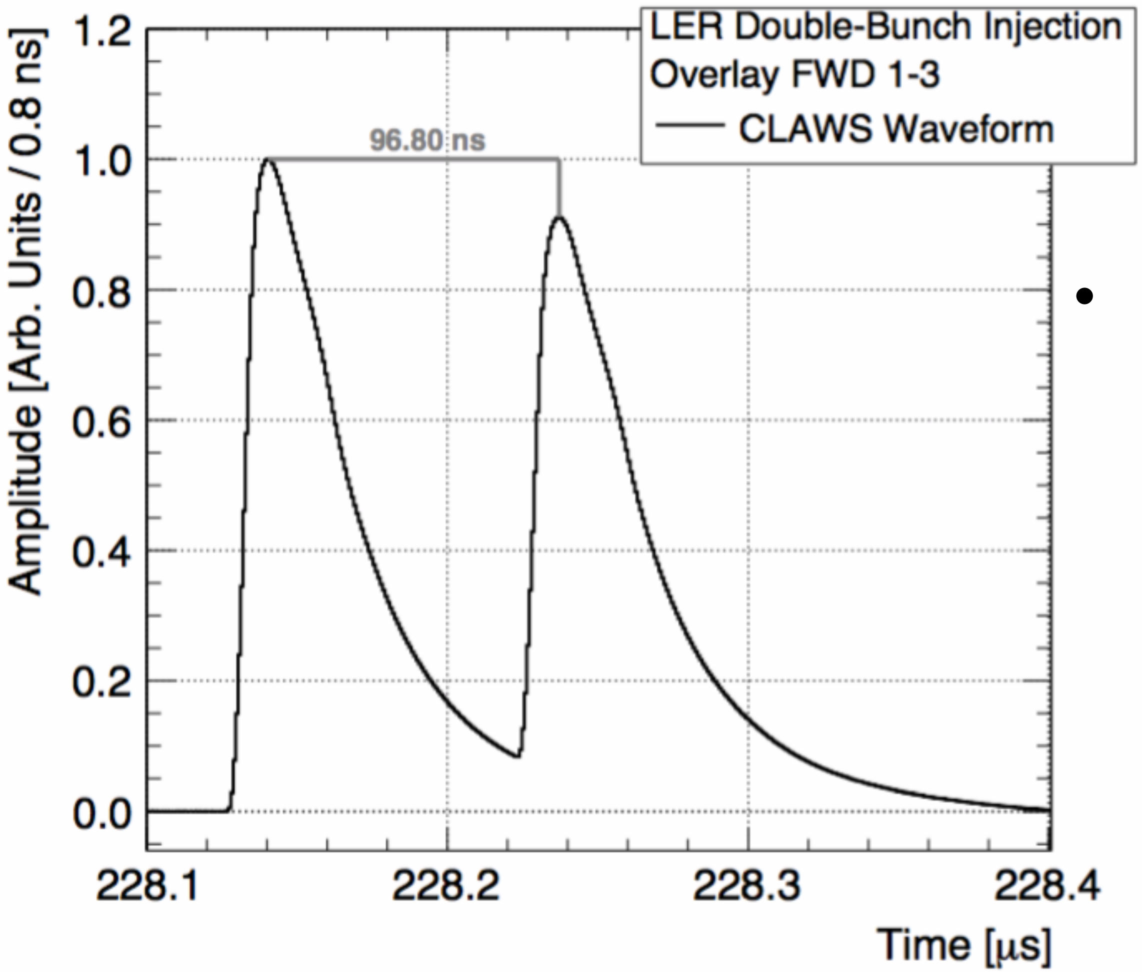




Double Bunch Distance

WORK IN PROGRESS

Injection background in LER with double bunch injection



- design distance of two bunches in a double bunch injection is 96.285 ns
  - ➡ measured distance in agreement with the design value

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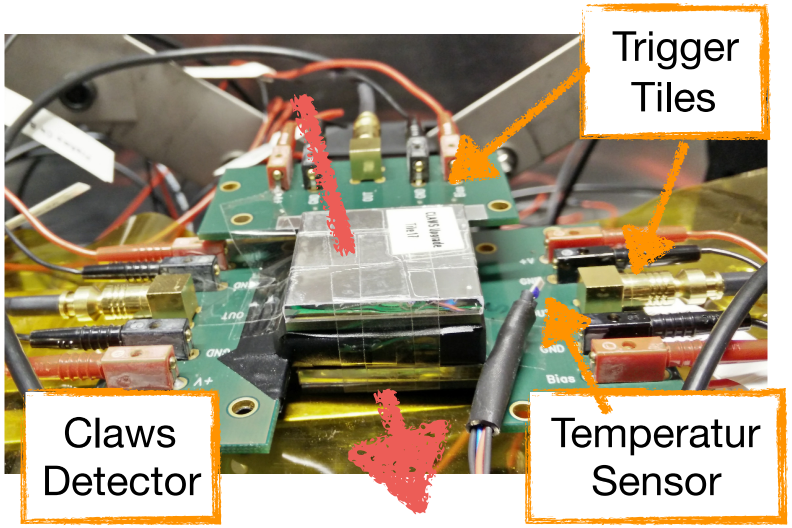
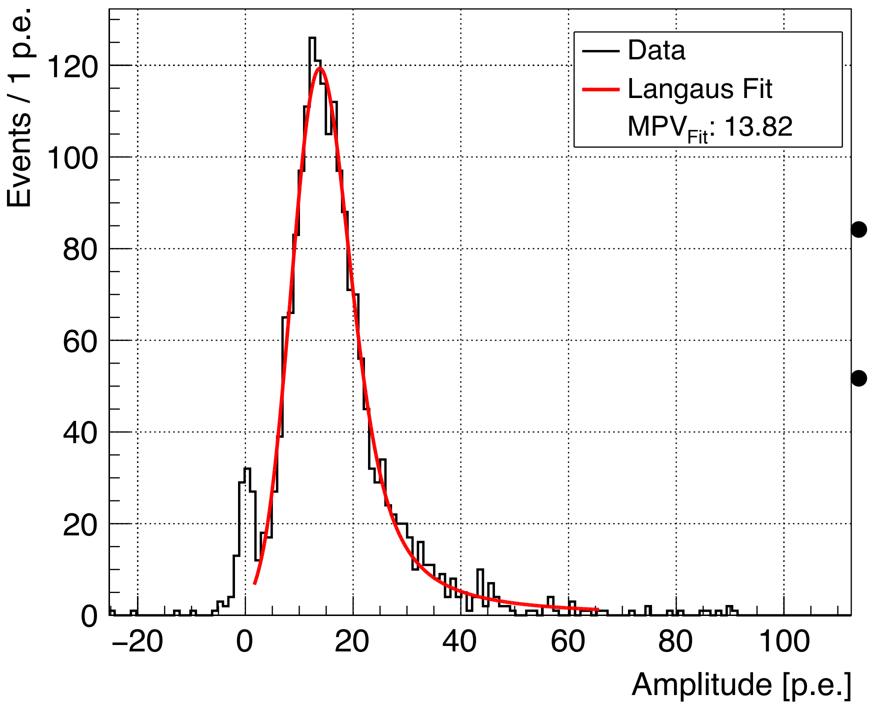
MIP Calibration

WORK IN PROGRESS



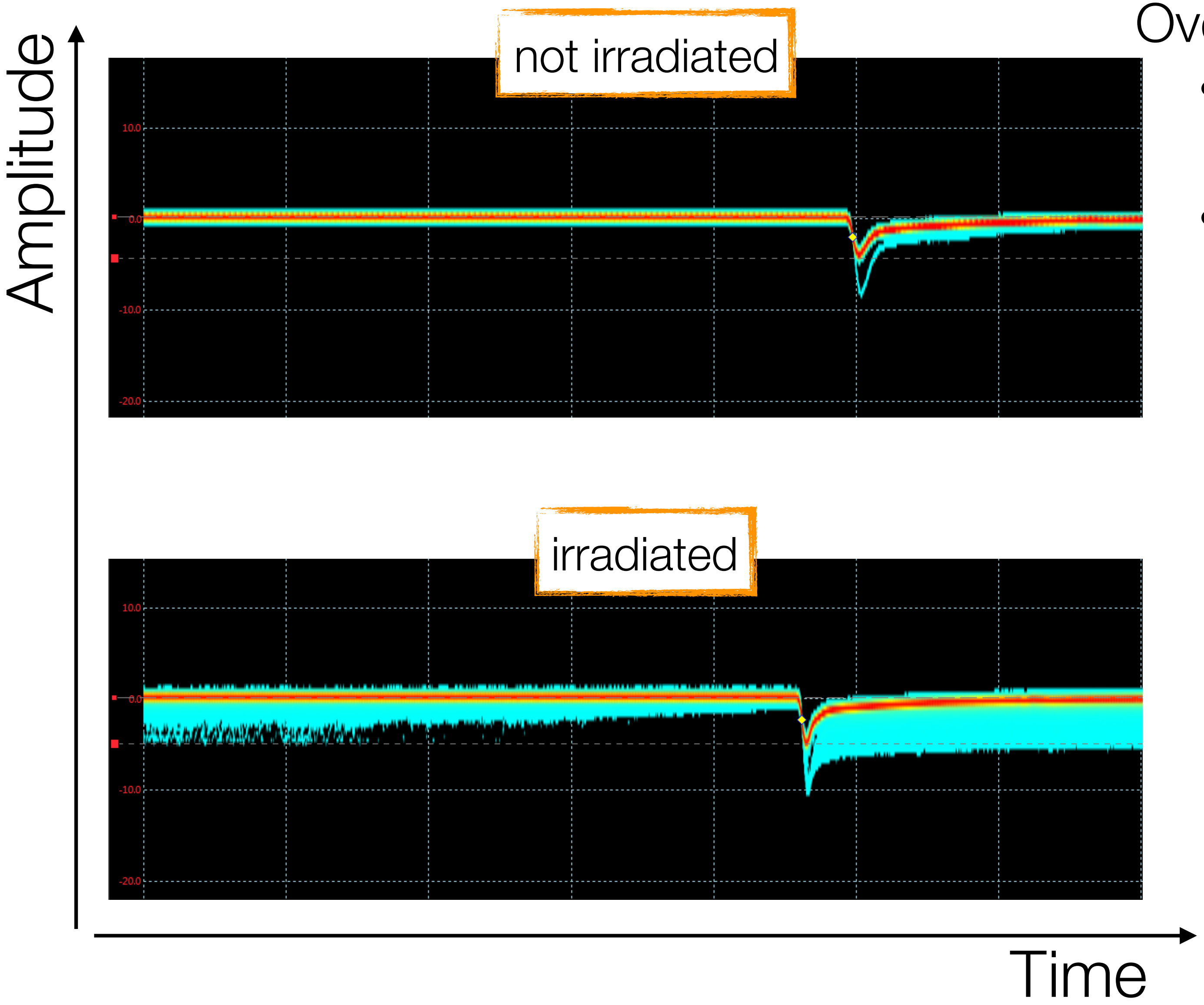


- Minimum Ionizing Particle (MIP) calibration with cosmic muons
- sandwich structure avoids biasing the outcome
  - ➡ trigger on upper and lower sensor
  - ➡ if there is a signal in the upper and lower sensor, the muon must crossed the the sensor in the middle
    - ➡ save the signal

- Langaus is convolution of Landau and Gaussian distribution
- most probable value yields average light yield per MIP

Radiation Effect on CLAWS

WORK IN PROGRESS



Overlay of waveforms unveils

- higher dark rate due to radiation damage
- clearly visible for 1 p.e.

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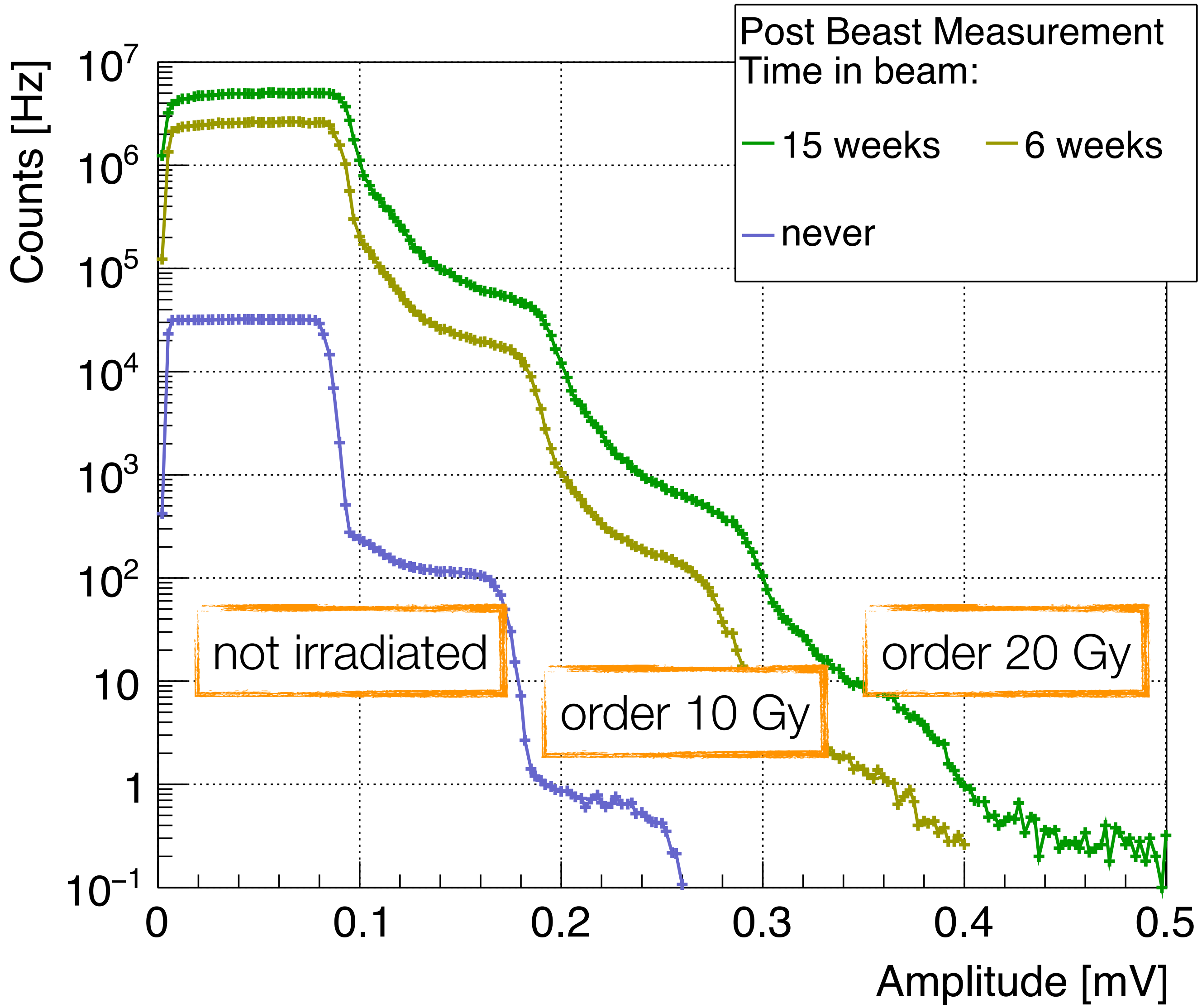
Radiation Effect on CLAWS

WORK IN PROGRESS



SiPM darkrate measurement:

- darkrate raised by factor 100
- photon events smear
- 4 p.e. rate still low
  - ➡ does not change the outcome tremendously

Radiation Effect on CLAWS

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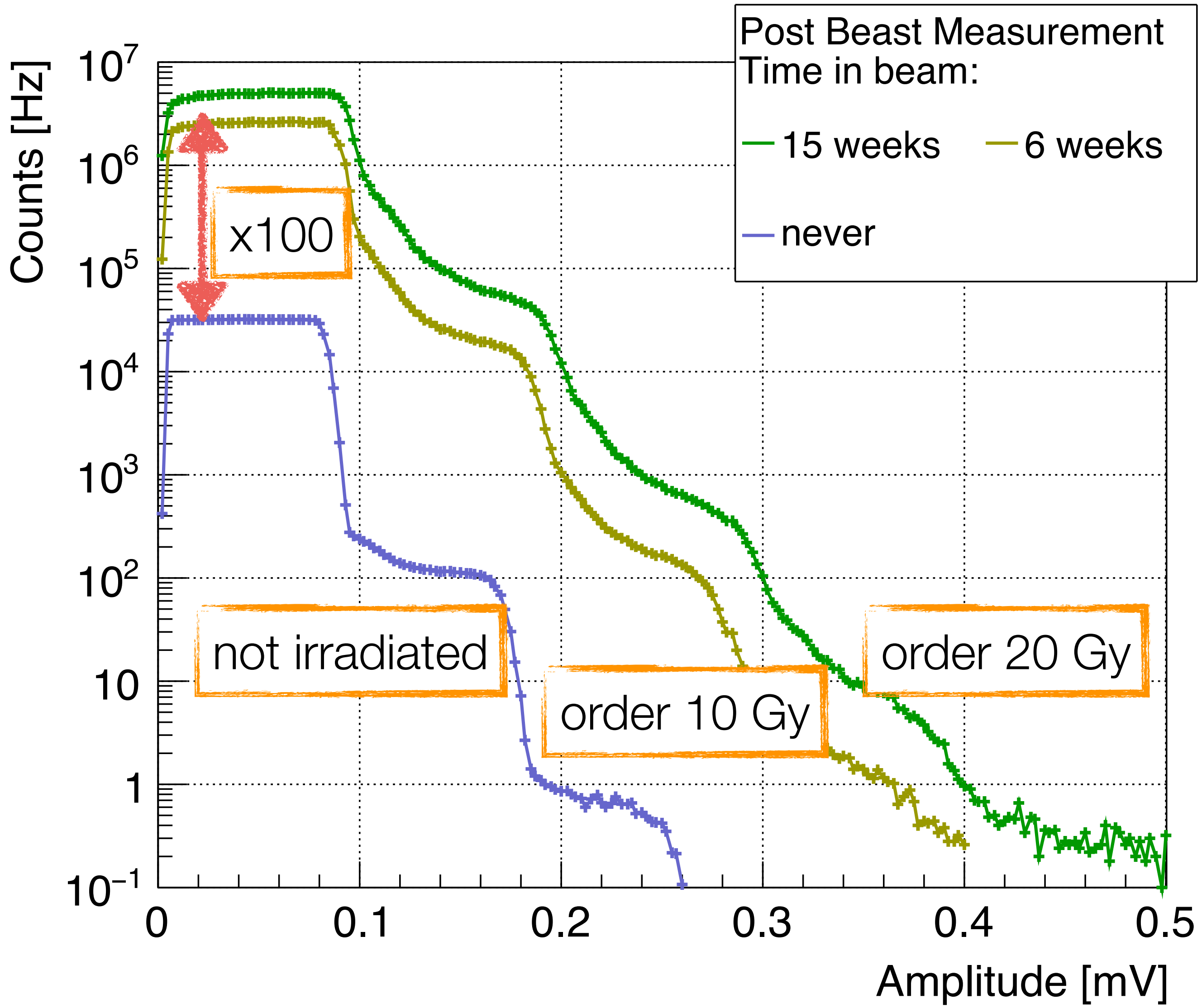

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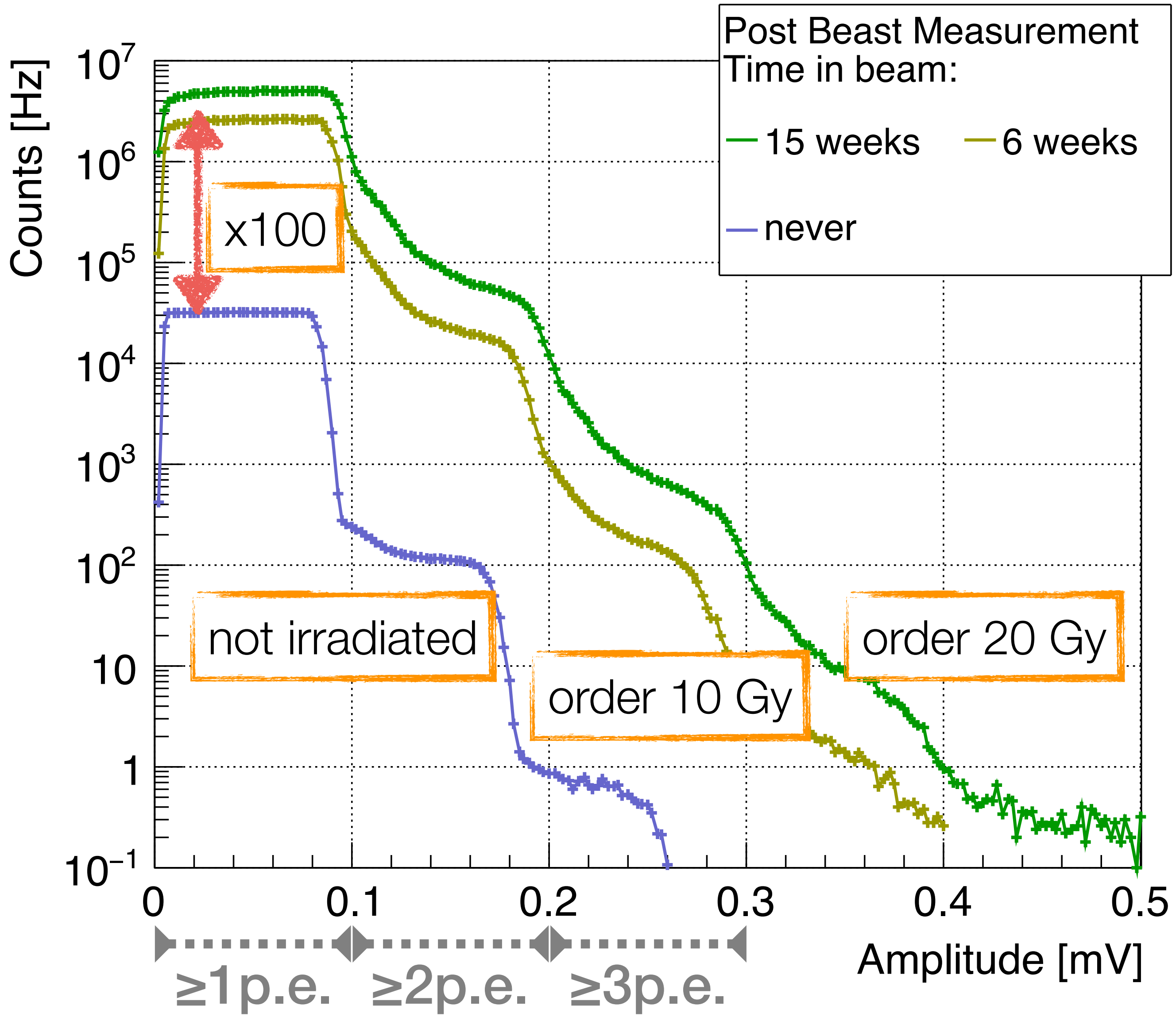

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Summary & Outlook

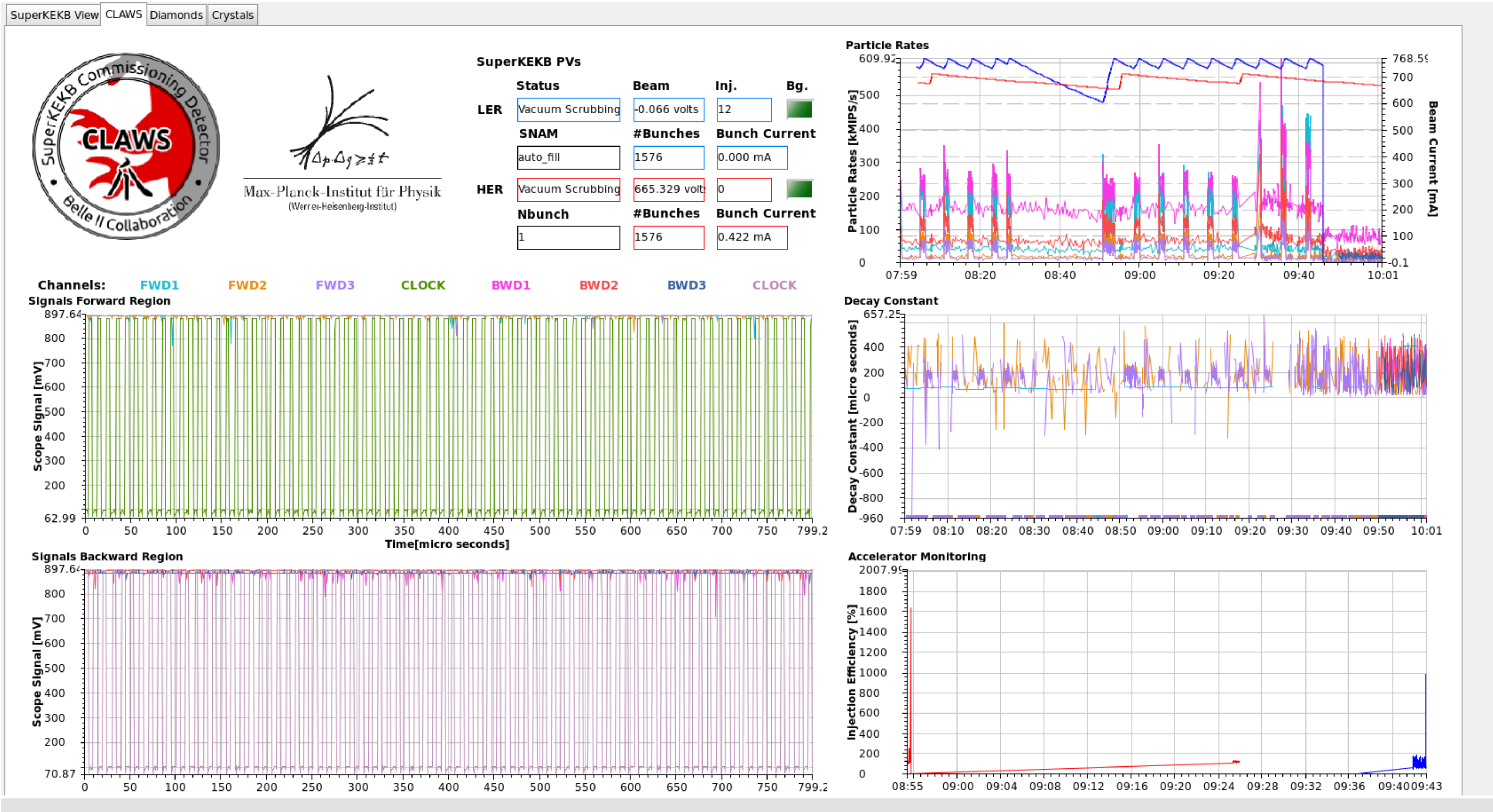
- commissioning of SuperKEKB accelerator started in Feb 2016
- CLAWS - as part of Beast - measured timing properties and particle rates coming from charged particles from injection background

- commissioning of SuperKEKB accelerator will continue mid 2017
- CLAWS in a modified version is part of Beast Phase 2 starting in early 2018
- injection background with final focussing quadrupoles (nano-beam optics) will be measured in detail as preparation for the physics runs in Phase 3

BACKUP

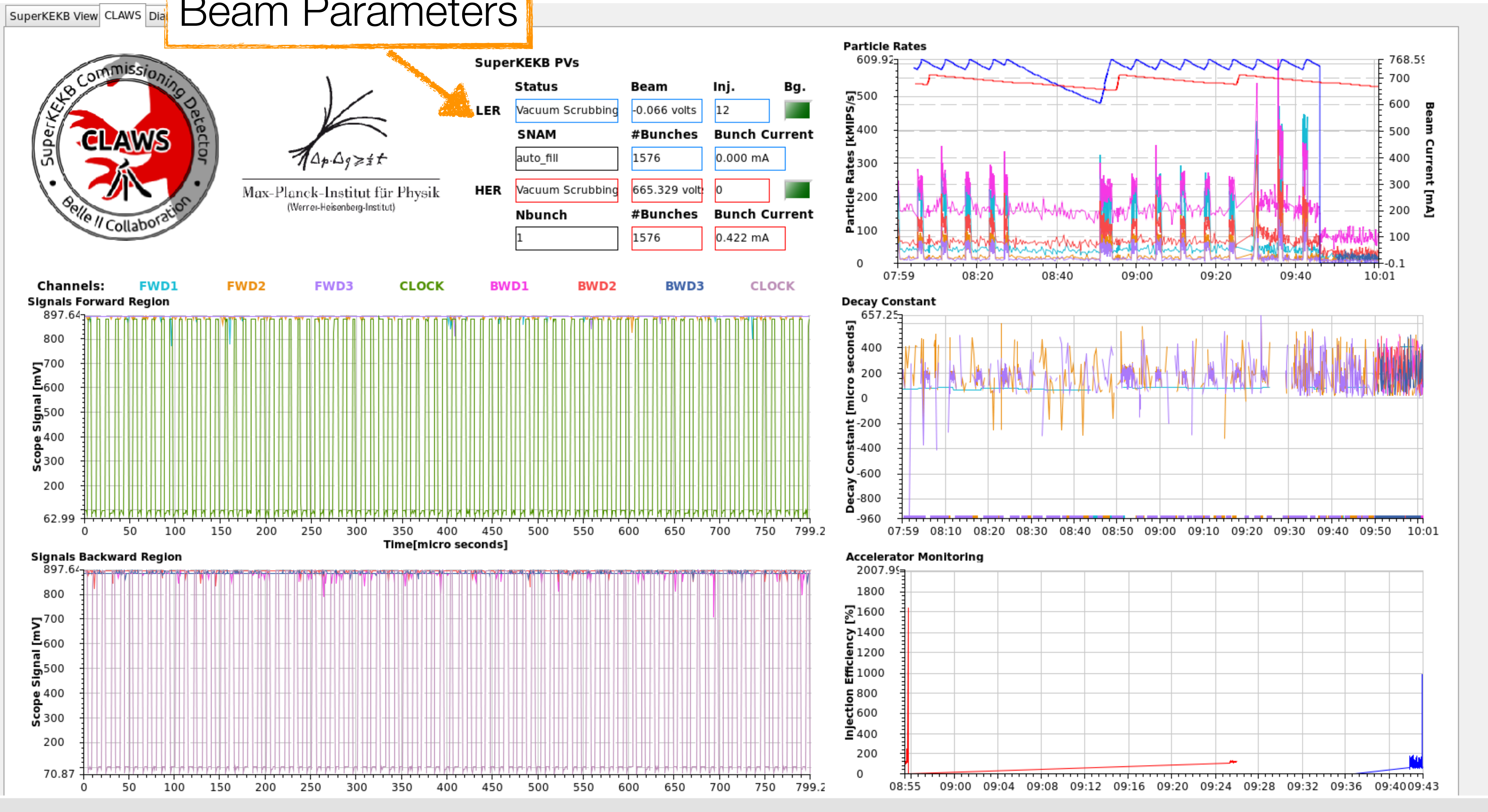
The CLAWS System

The Online Monitor



The Online Monitor

Beam Parameters

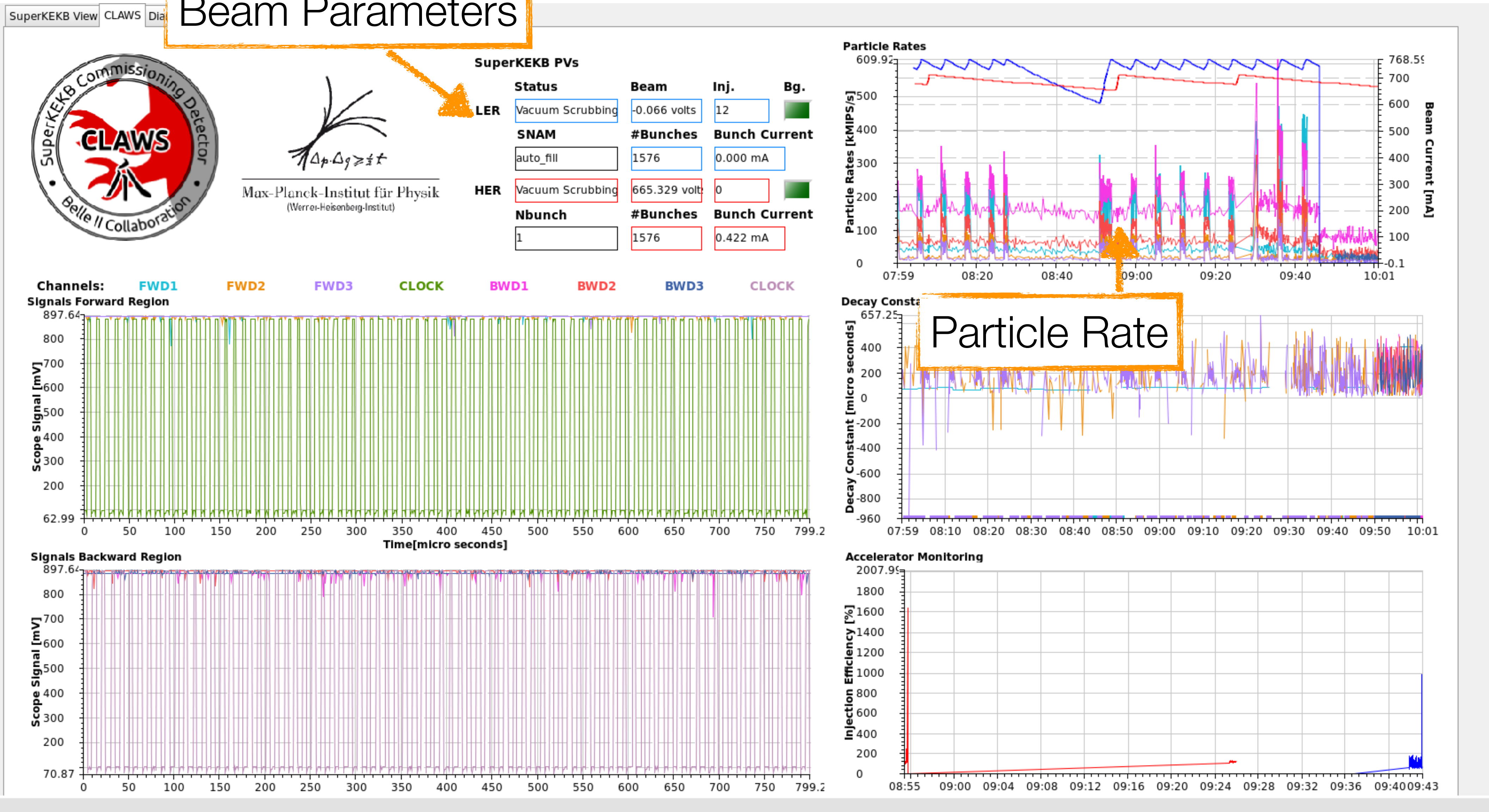


The CLAWS System

The Online Monitor

Beam Parameters

Particle Rate



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The CLAWS System

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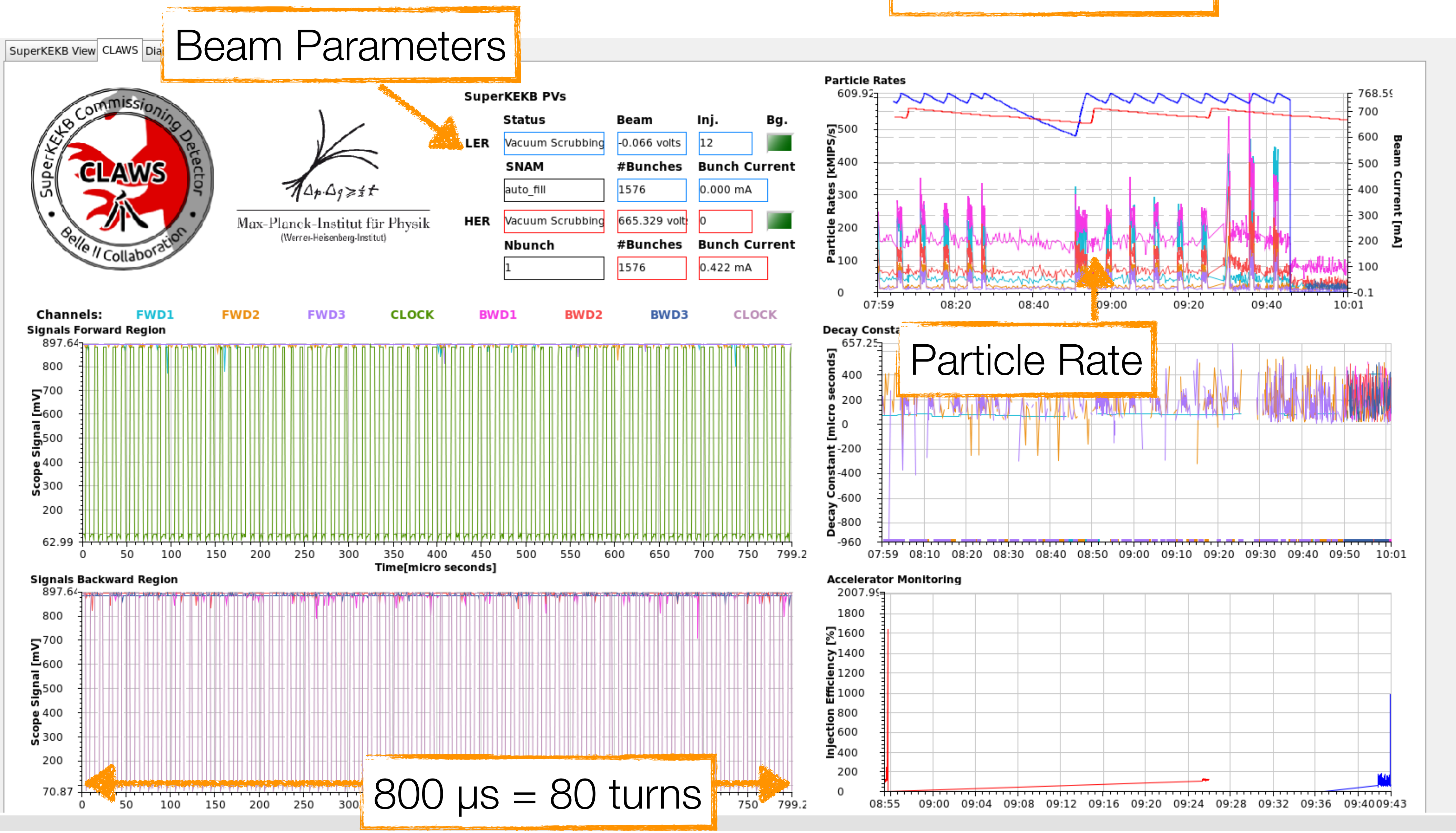

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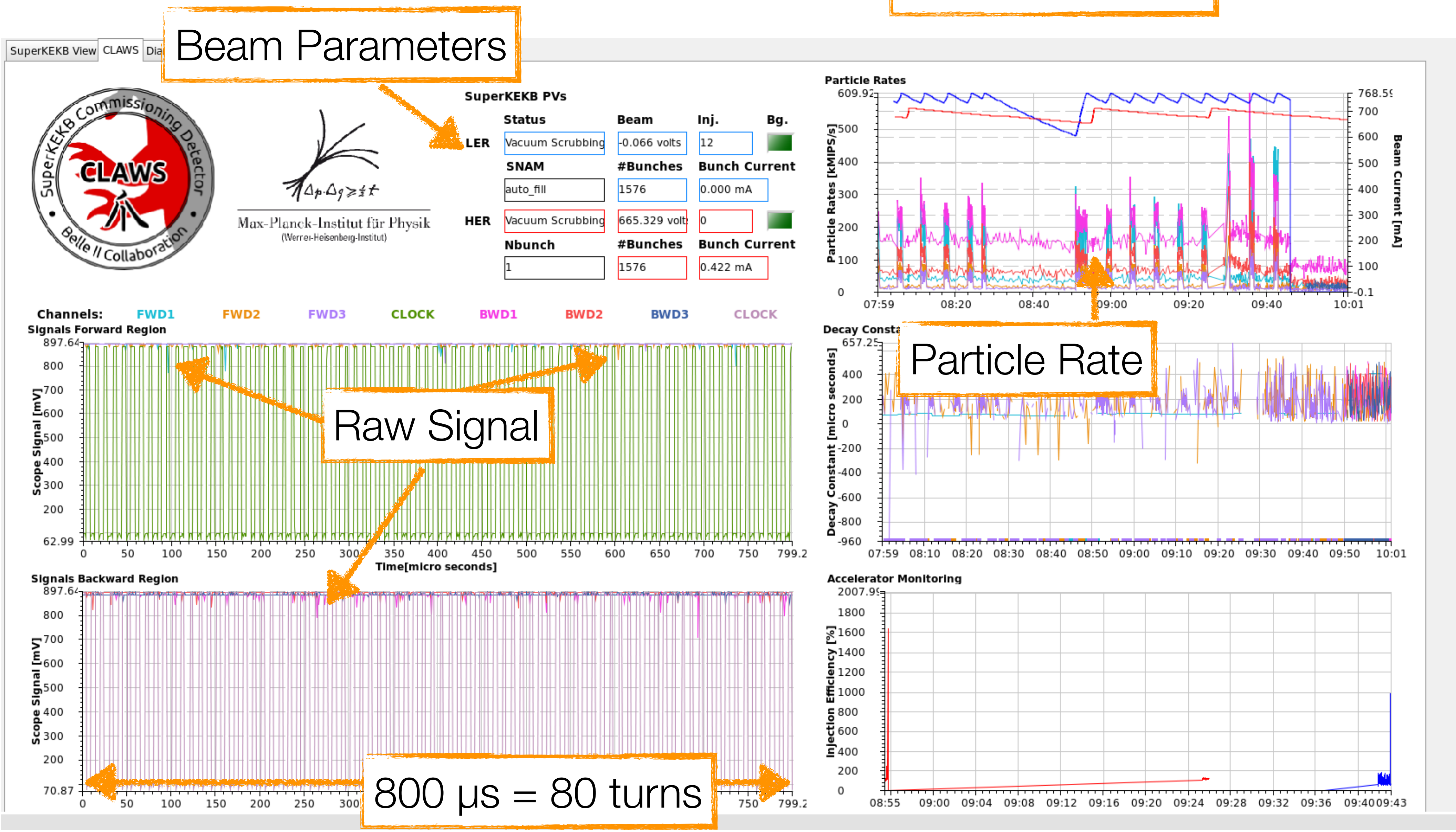
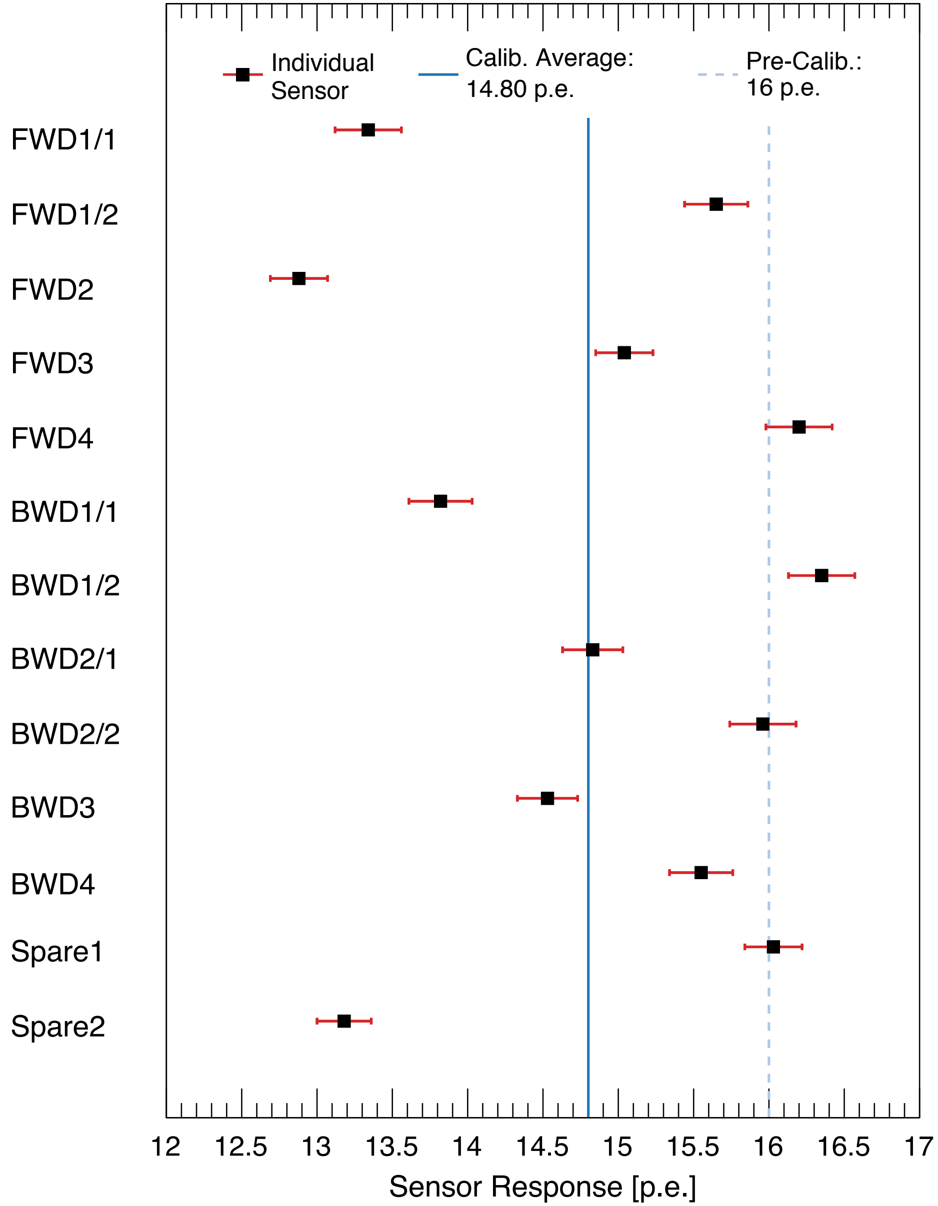
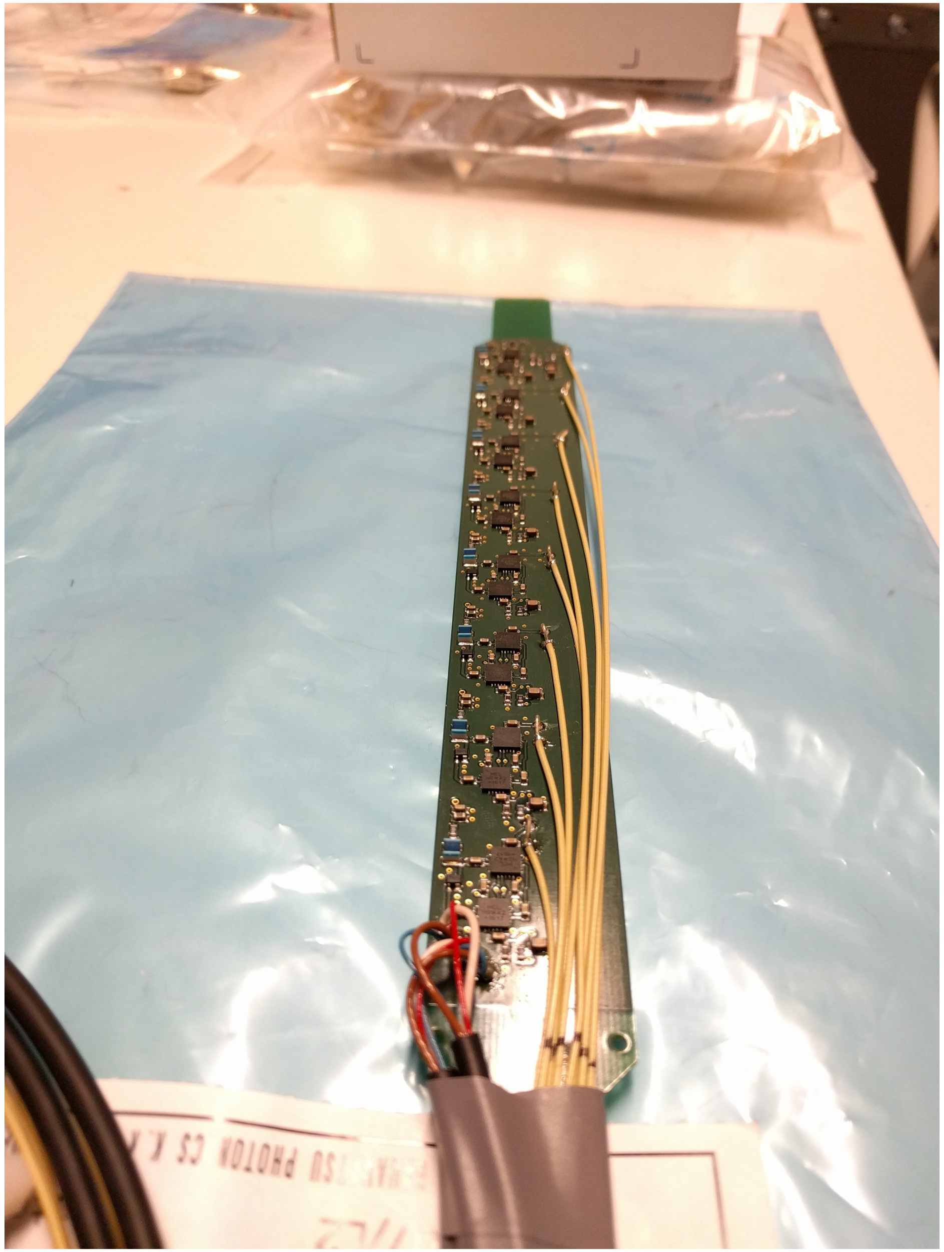


Calibration



Claws Ladder



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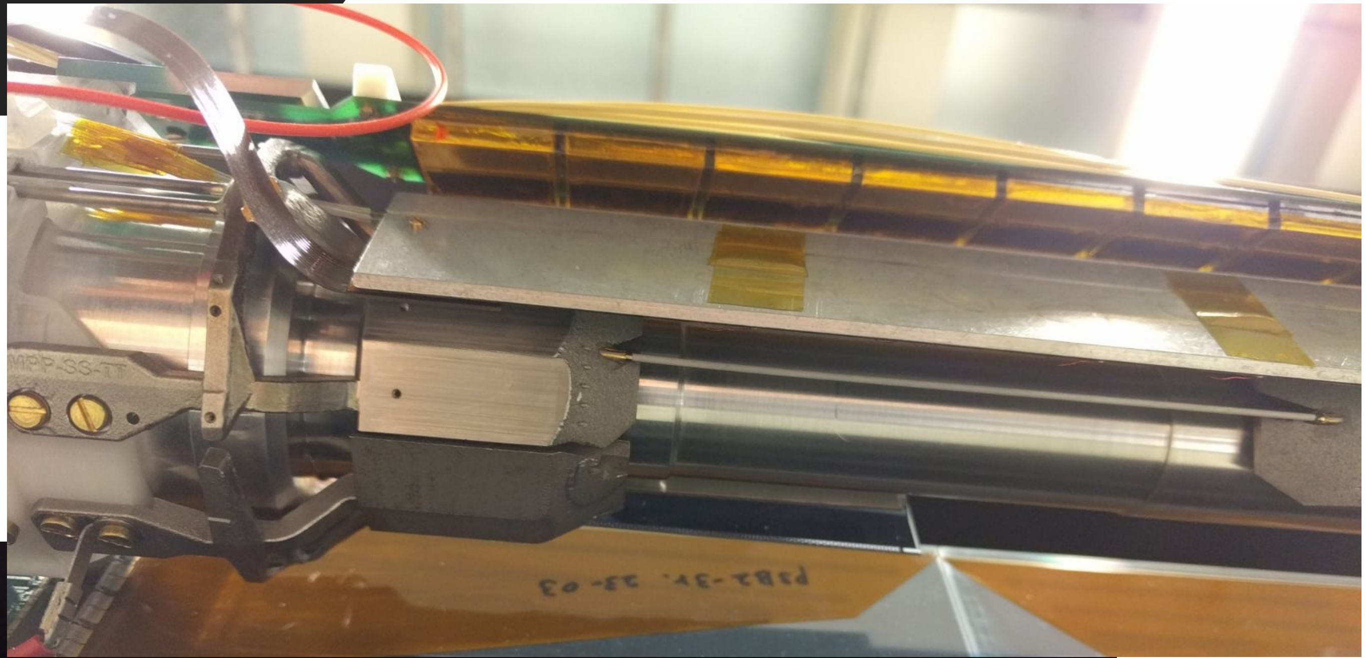
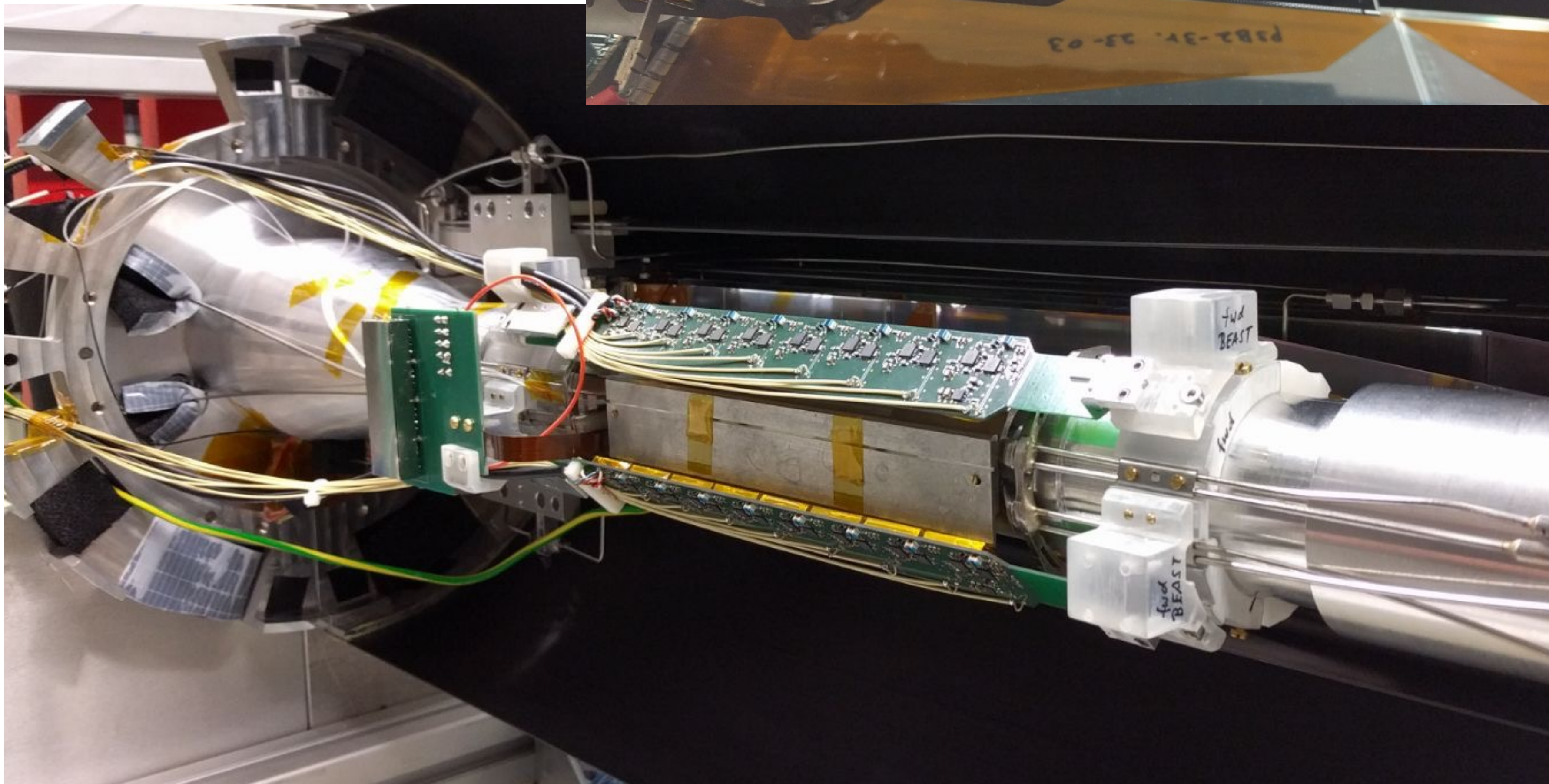
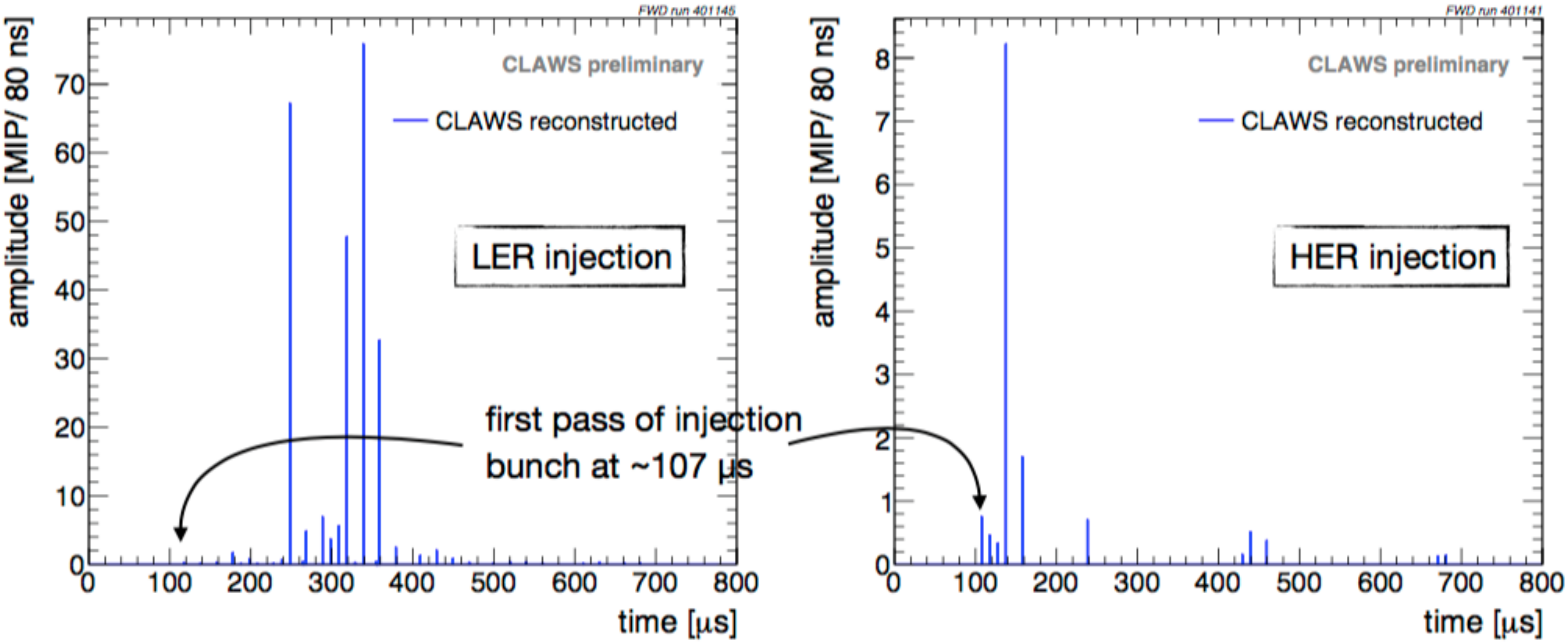




Reference Injection: LER vs HER

TAKEN BY FRANK SIMON

- General observation:
  - ➡ LER injection results in much higher backgrounds than HER injection
  - ➡ very different timing behavior; HER background appears promptly, LER with substantial delay



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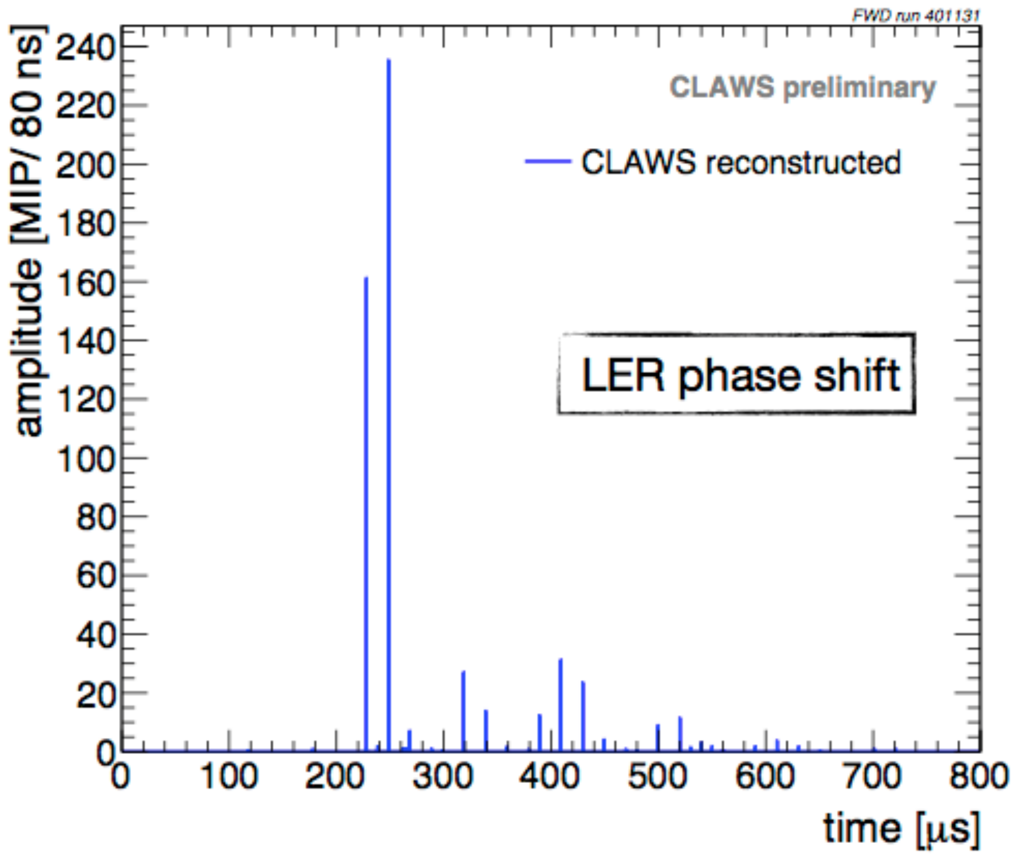
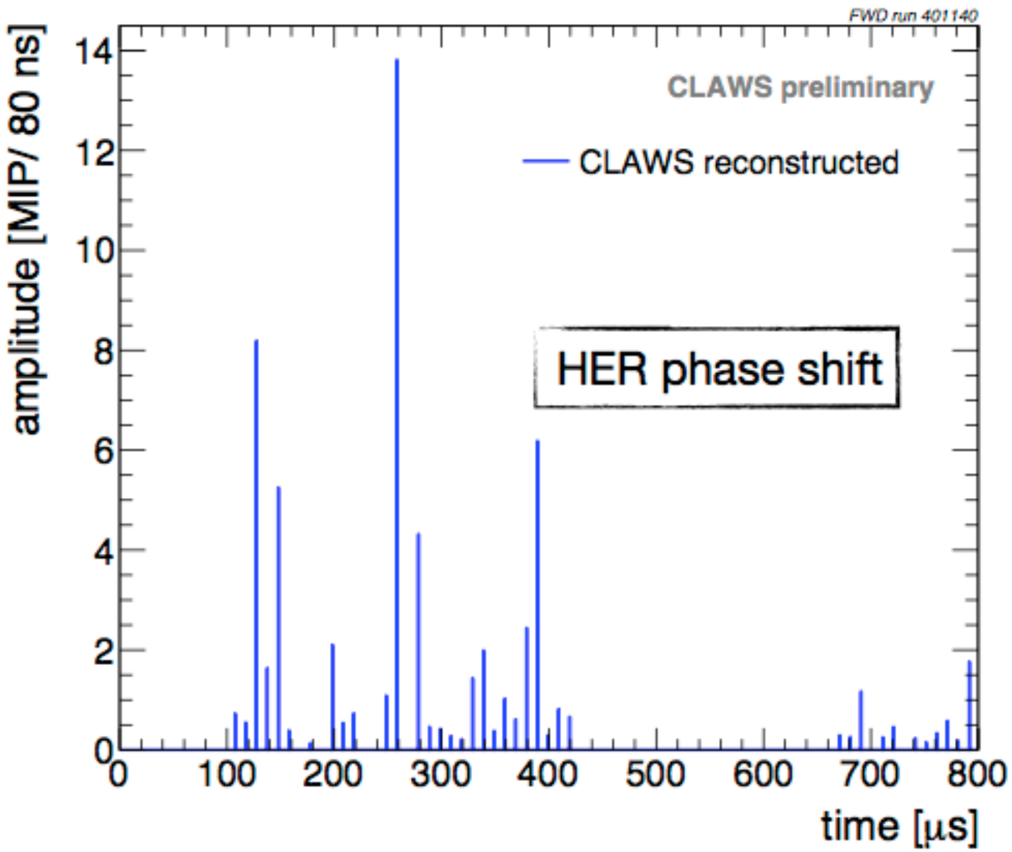
Changing Parameters: Phase Shift

TAKEN BY FRANK SIMON

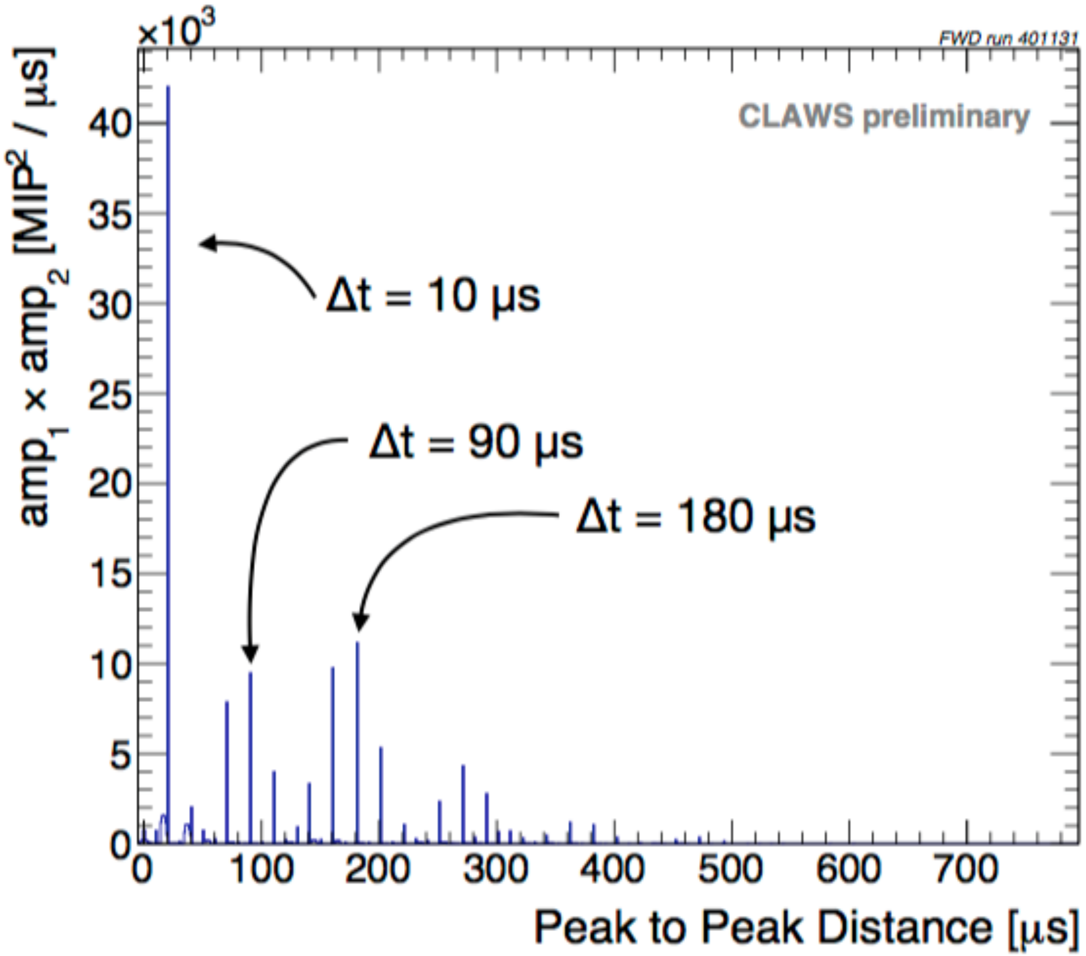
- Substantially increased background
- Some impact on timing properties - phase shift injections used to study timing patterns later





A Closer Look: LER

TAKEN BY FRANK SIMON

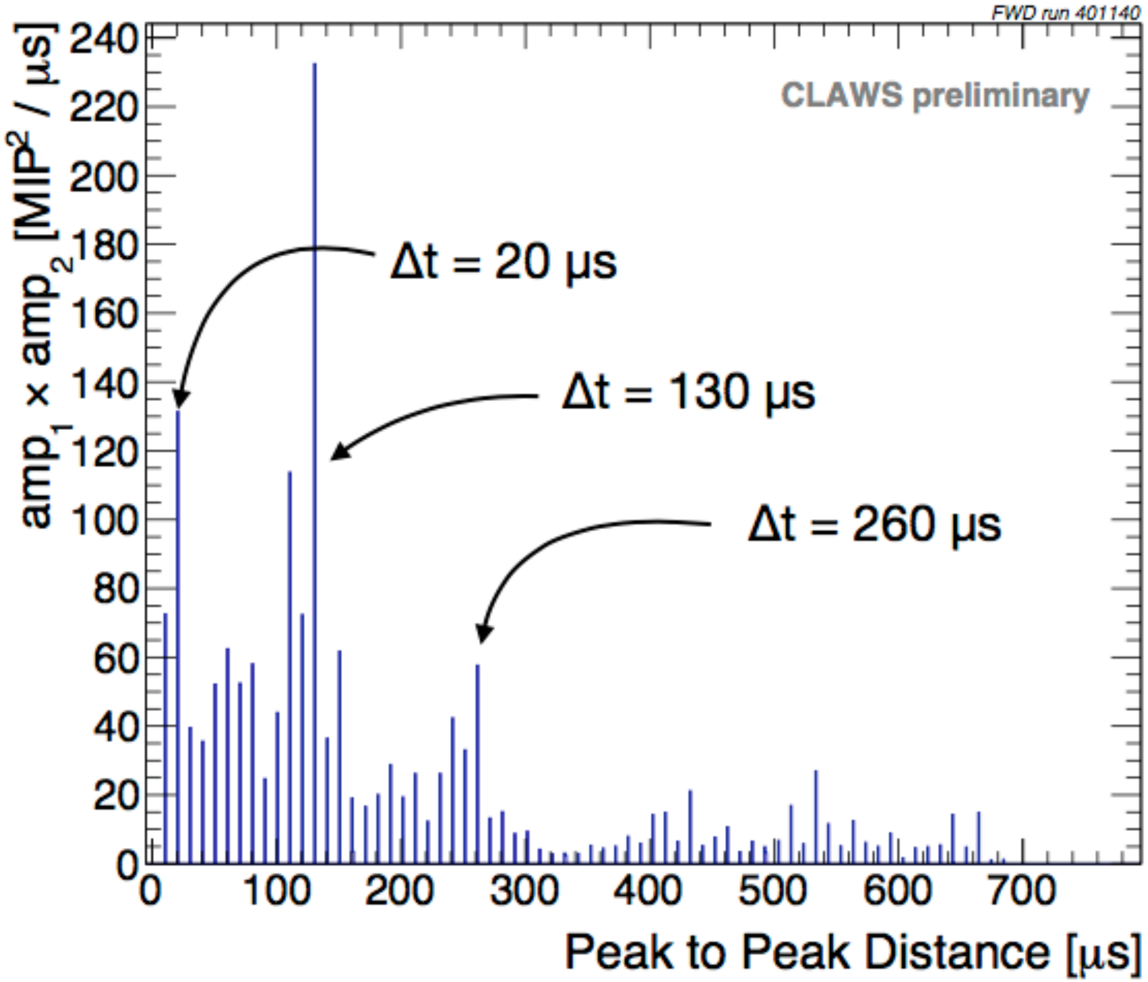


Identify patterns in the time structure of injection signals:

- plot dt for all bin pairs, weighted by the product of amplitudes
- 90 μs super structure
- background seen in consecutive turns

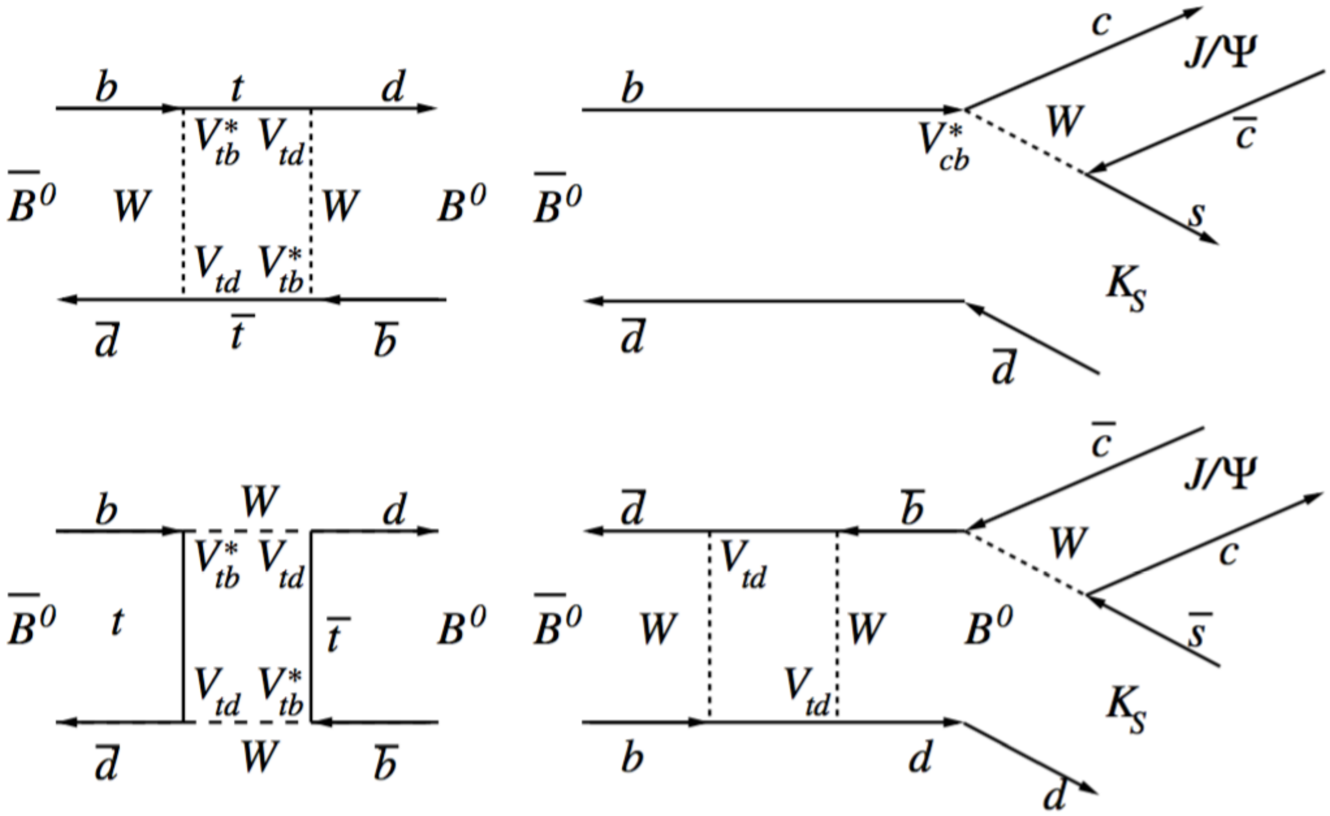
A Closer Look: HER

Taken by Frank Simon



Identify patterns in the time structure of injection signals:

- plot dt for all bin pairs, weighted by the product of amplitudes
- 130 μs super structure
- on-off pattern in background


b
t
d
V_{tb}^* V_{td}
$\overline{B}^0$
W
W
B^0
V_{td} V_{tb}^*
$\overline{d}$
$\overline{t}$
$\overline{b}$
c
J/Ψ
b
W
V_{cb}^*
$\overline{c}$
$\overline{B}^0$
s
K_S
$\overline{d}$
$\overline{d}$
$\overline{c}$
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d
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$\overline{b}$
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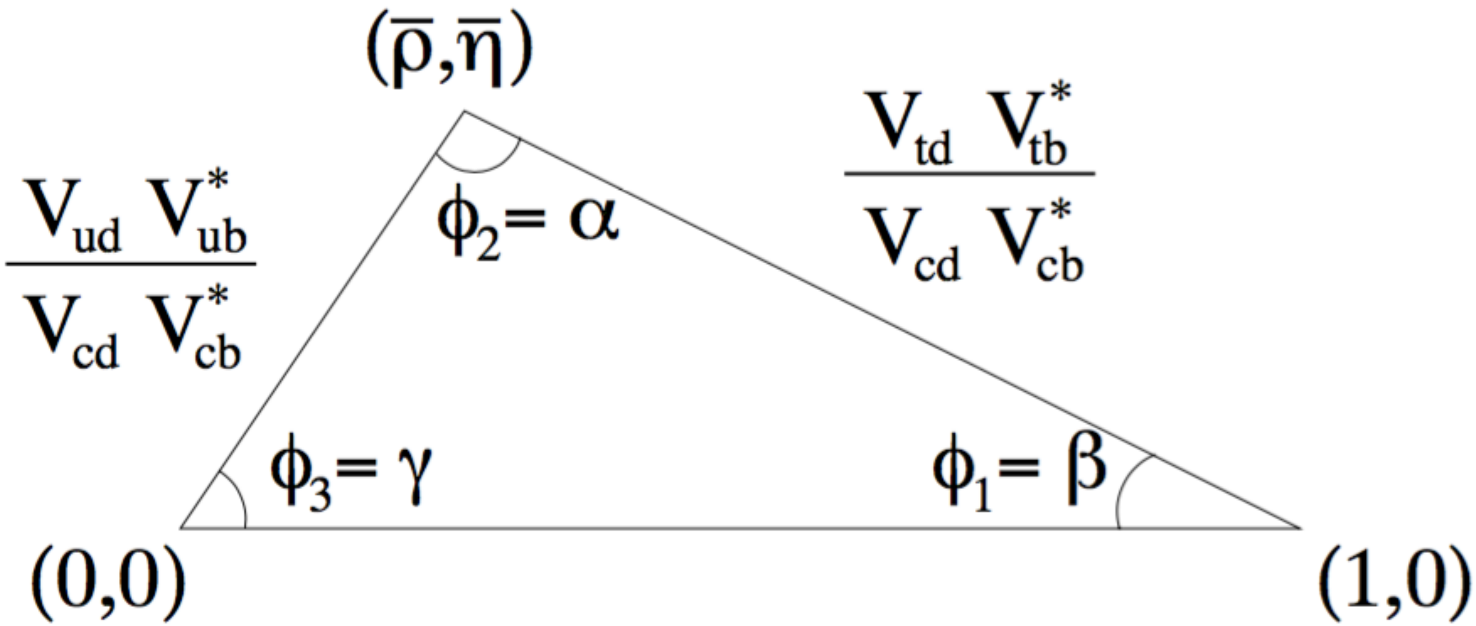
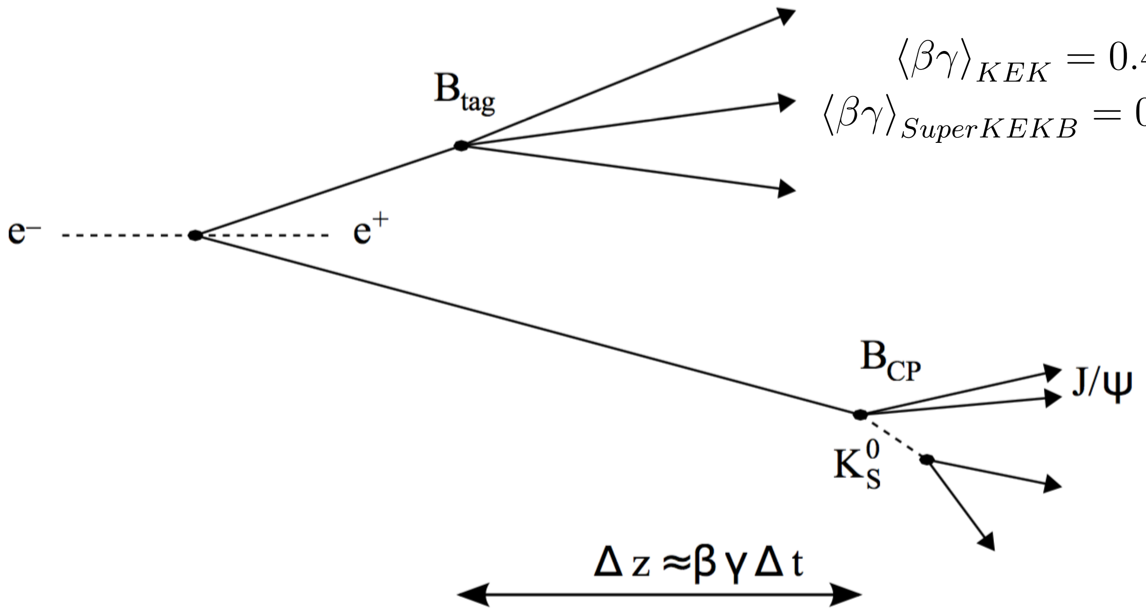
V_{td}
c
$\overline{B}^0$
W
W
B^0
$\overline{s}$
V_{td}
K_S
b
d
d

Theory

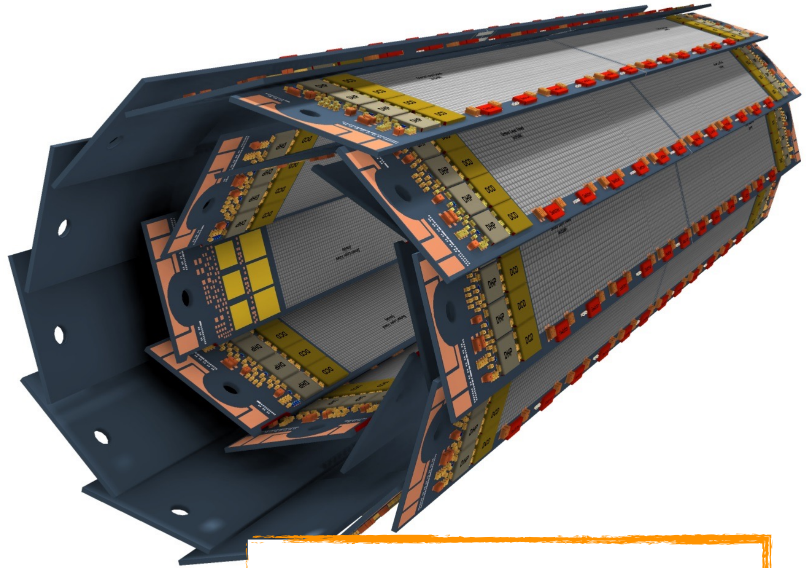


$(\bar{\rho},\bar{\eta})$
$\frac{V_{ud}\,V_{ub}^*}{V_{cd}\,V_{cb}^*}$
$\frac{V_{td}\,V_{tb}^*}{V_{cd}\,V_{cb}^*}$
$\phi_2 = \alpha$
$\phi_3 = \gamma$
$\phi_1 = \beta$
(0,0)
(1,0)

Motivation

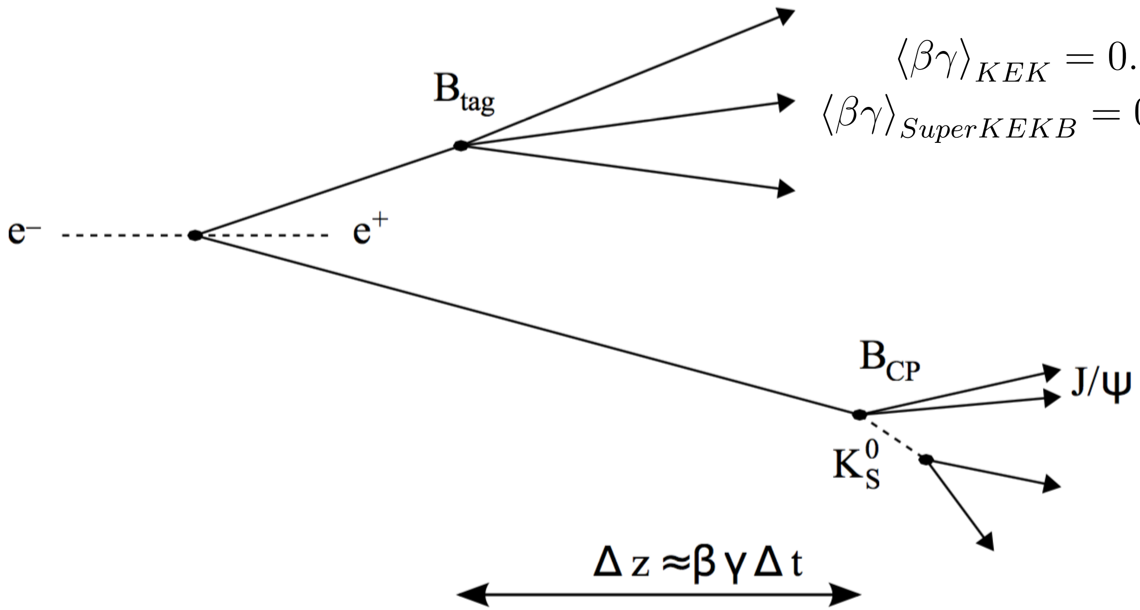


$$\langle\beta\gamma\rangle_{KEK} = 0.425$$
$$\langle\beta\gamma\rangle_{SuperKEKB} = 0.284$$



Belle II Pixel Detector

Motivation



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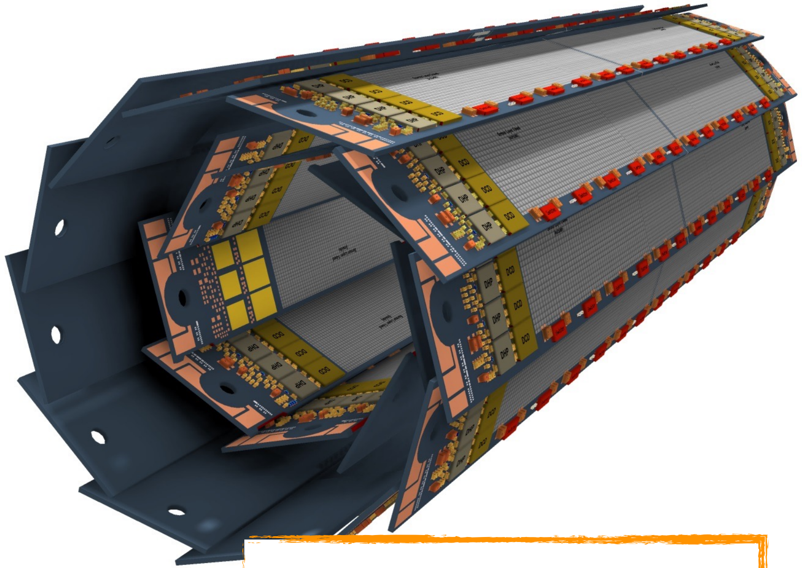
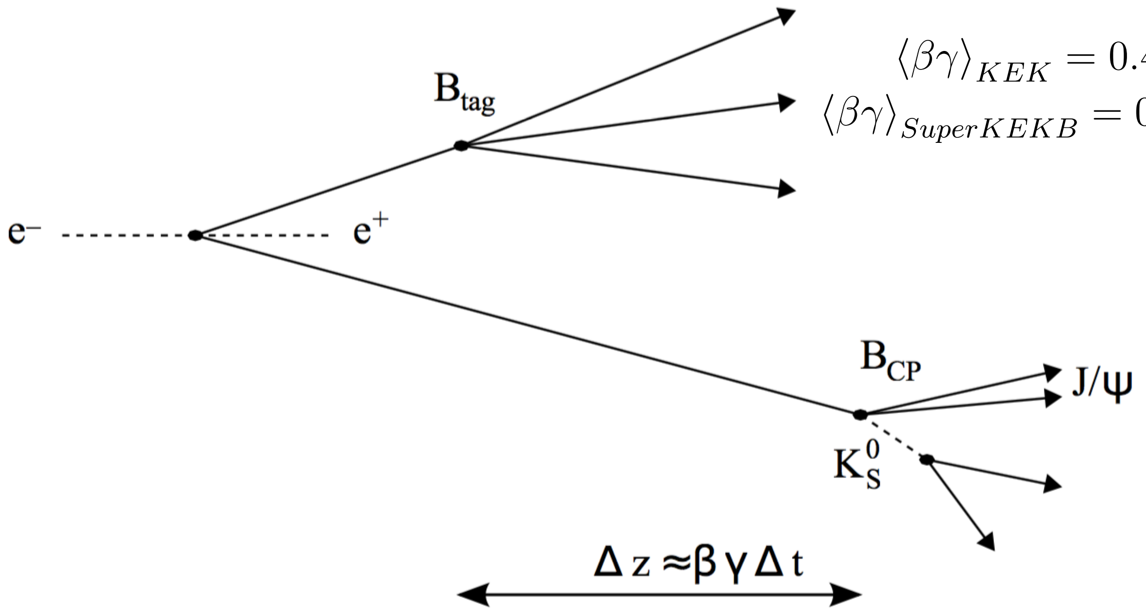


Belle II Pixel Detector

- high luminosity for super high statistics, but:
  - ➡ because of nano-beam scheme low beam life time
    - ➡ solution: continuous top-up injection
      - ➡ injection at full energy
- high noise coming from injection bunches can saturate Belle II PXD
- PXD readout lasts 20 μs (2 turns!)

Motivation



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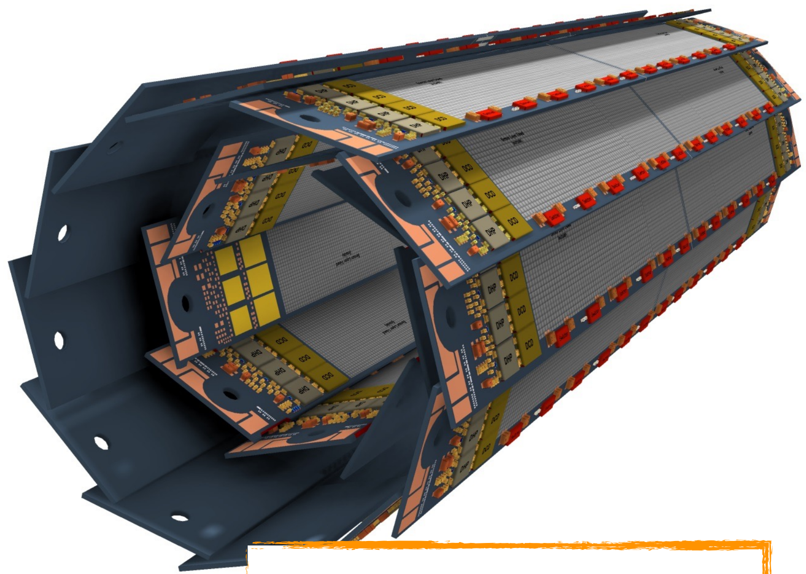

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➡ **detailed knowledge of the time structure of the beam inevitable!**

- PXD can be turned off (gated)

The CLAWS System

- transfer of signal over 45m into daq room

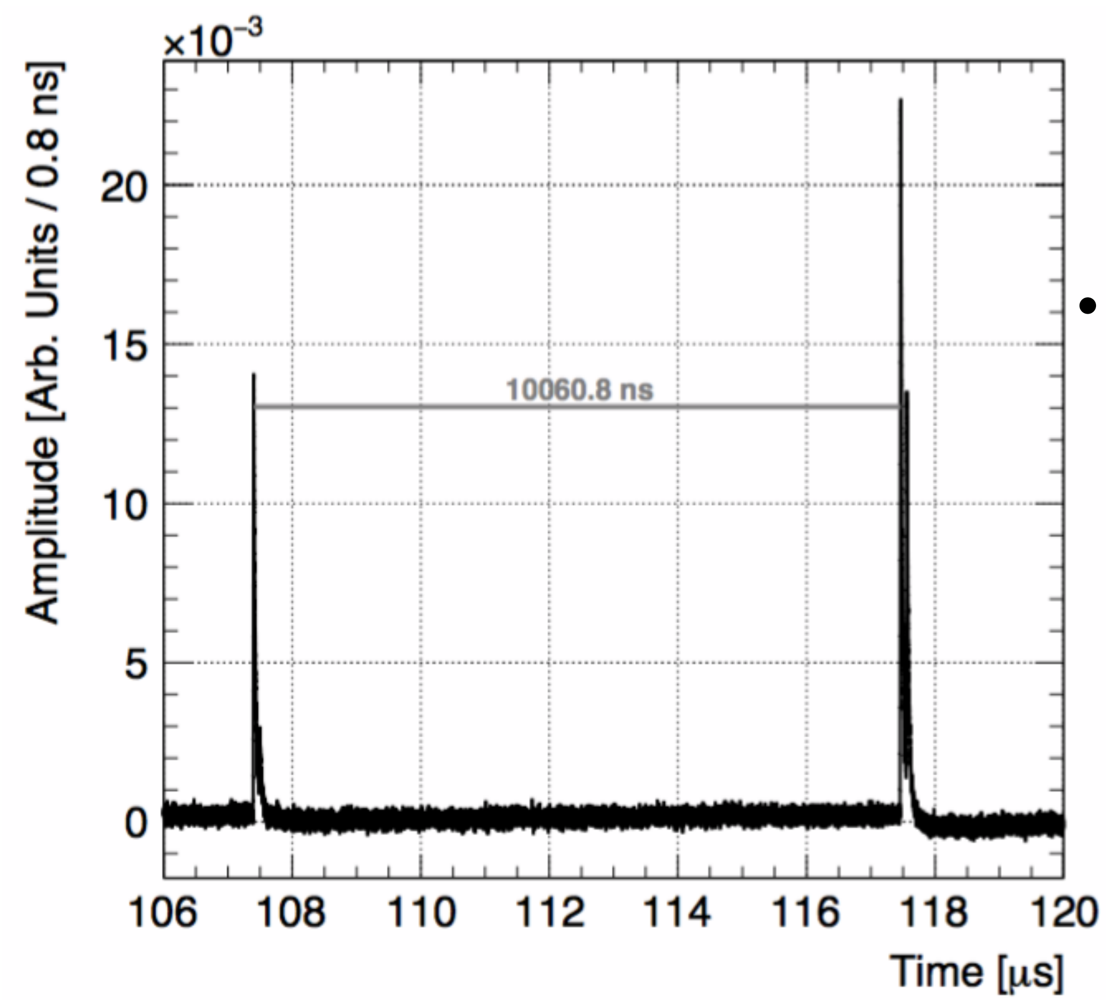
2x Pico 6404D
- 8 bit resolution
- 4 channels + ext. trigger
- sampling rate of 0.8 ns
- can store up to 400 ms/Channel

CLAWS Workstation
- steers and reads out all of the CLAWS hardware

Timing Properties of the Beam

WORK IN PROGRESS

Injection background in LER with double bunch injection



- design revolution time is 10061.4 ns
  ➡ measured peak-to-peak distance in agreement with the design value