BSRL - The LHC longitudinal density monitor

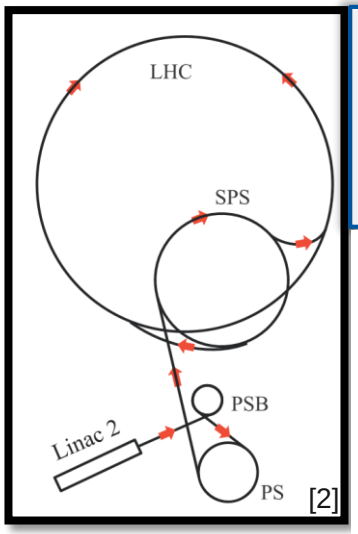
M. Palm (BE-BI-PM)

- Overview
- Highlights from Run 2
- Outlook

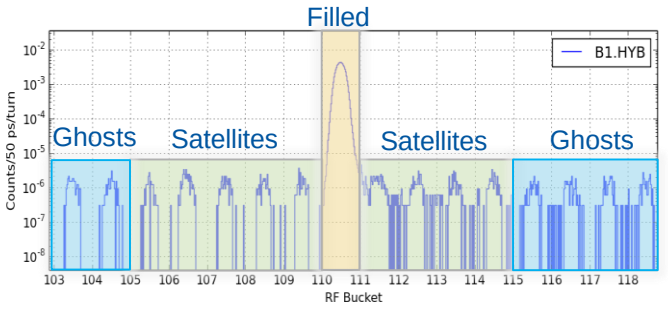
- **Overview**
- Highlights from Run 2
- Outlook

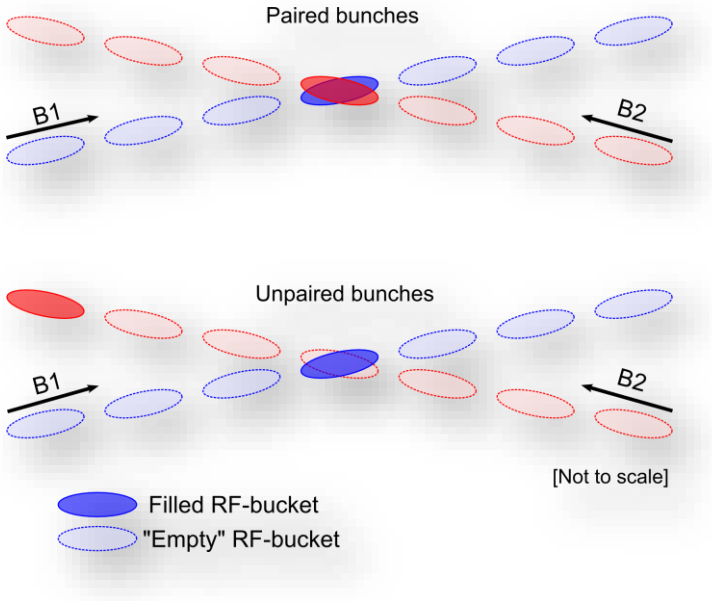
Purpose

- **DCCT**: Total number of particles in the ring
- **FBCT**: Number of particles per nominal bunch
- **BSRL**: Measure the longitudinal distribution of particles in the LHC with a sufficiently high dynamic range to quantify the relative population in nominally empty buckets.
  - Luminosity calibration
  - Injection quality
  - Origin of background signal at IPs [1]
  - **Requirements**: A dynamic range of 5 orders of magnitude, and a time resolution of 100 ps

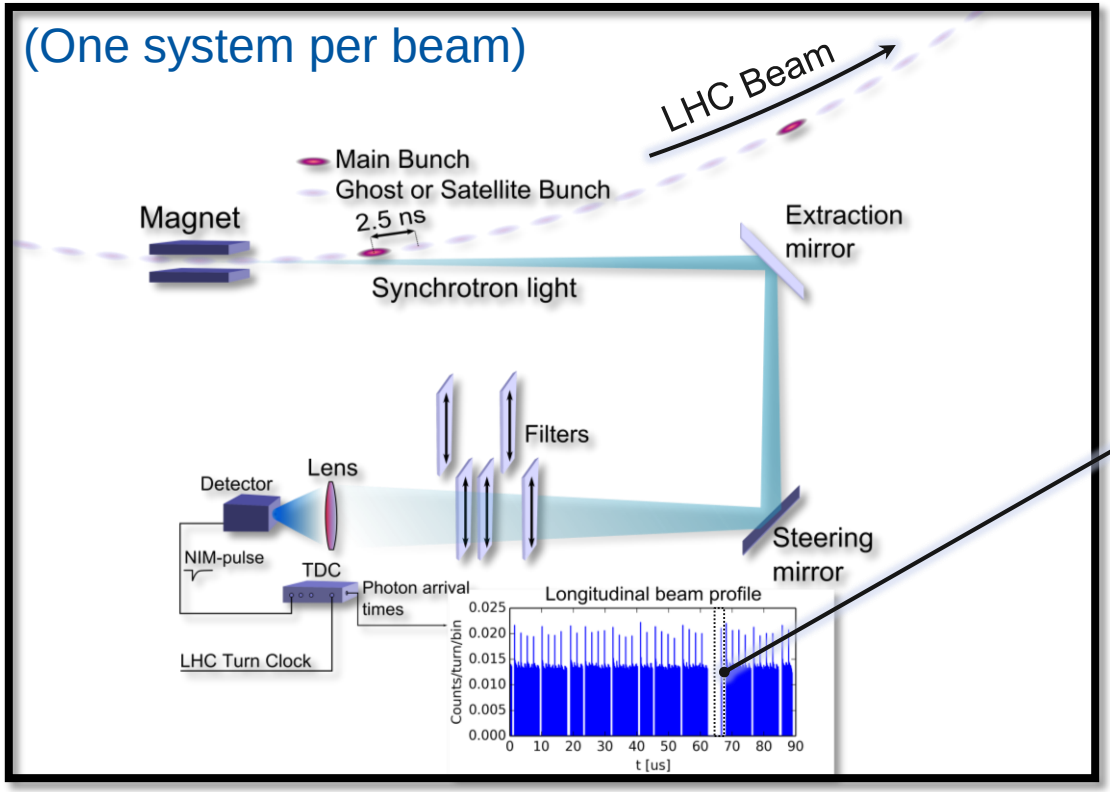


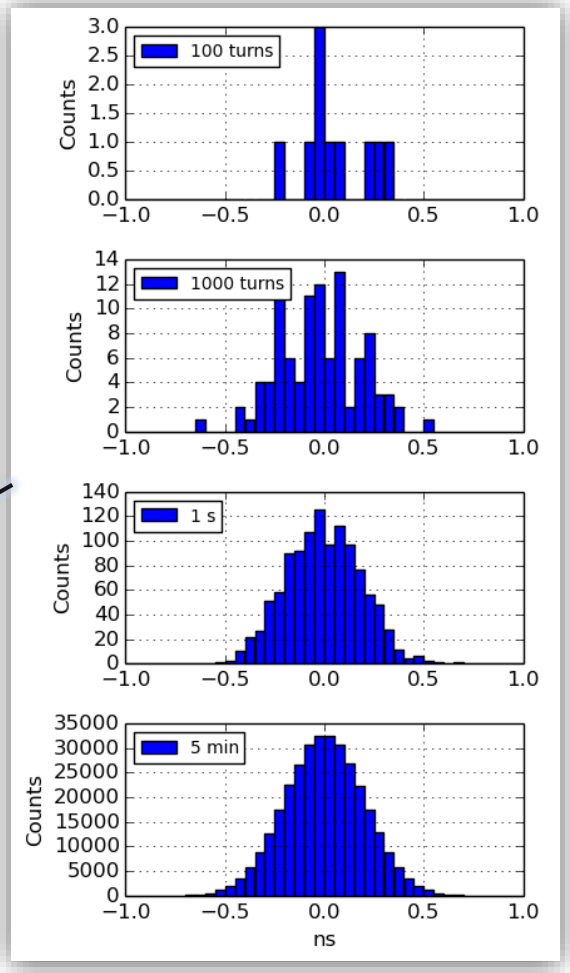
Along the LHC injector chain, a small fraction of the beam may be trapped in RF-buckets that should be empty. These low-intensity bunches are called “Satellite” and “Ghost” bunches.





Principle



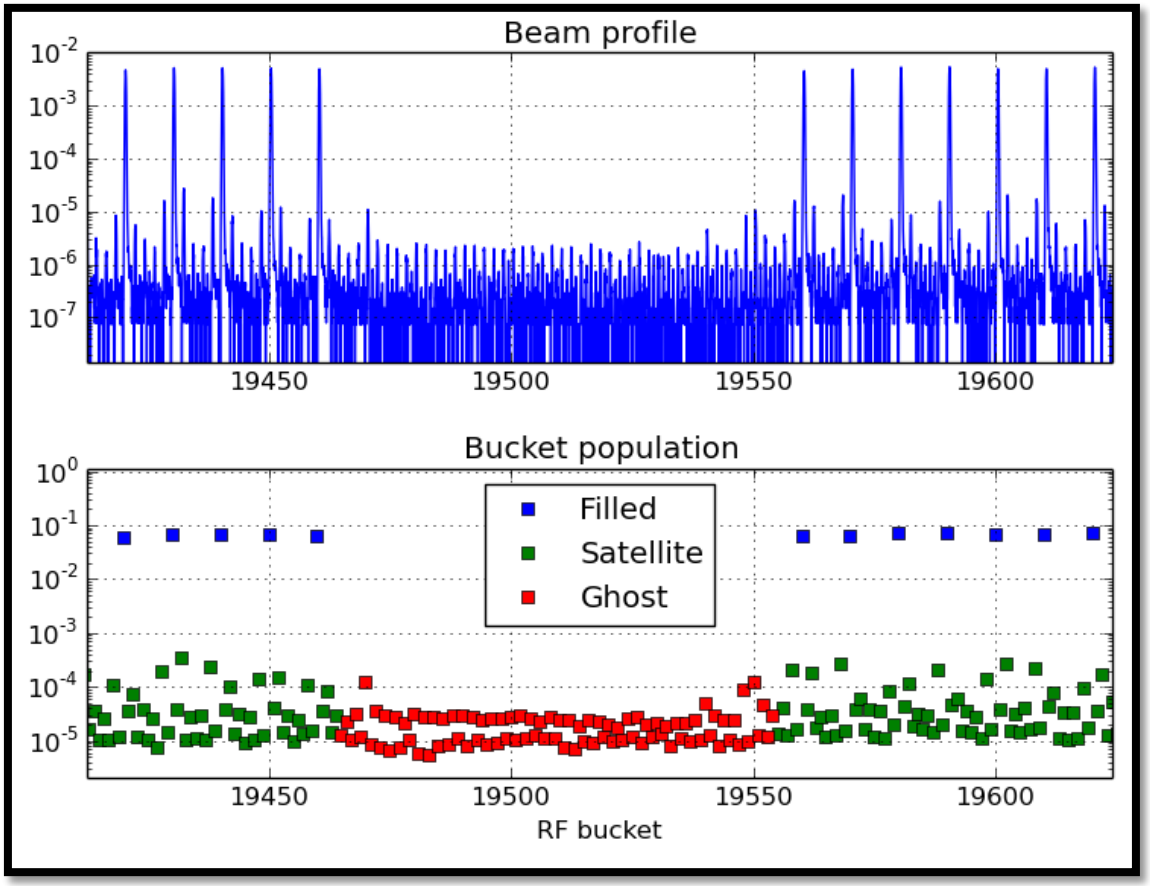


- Time-correlated single photon counting

- Resolution: 50 ps
- 1,780,000 bins per histogram
- 5 min integration time

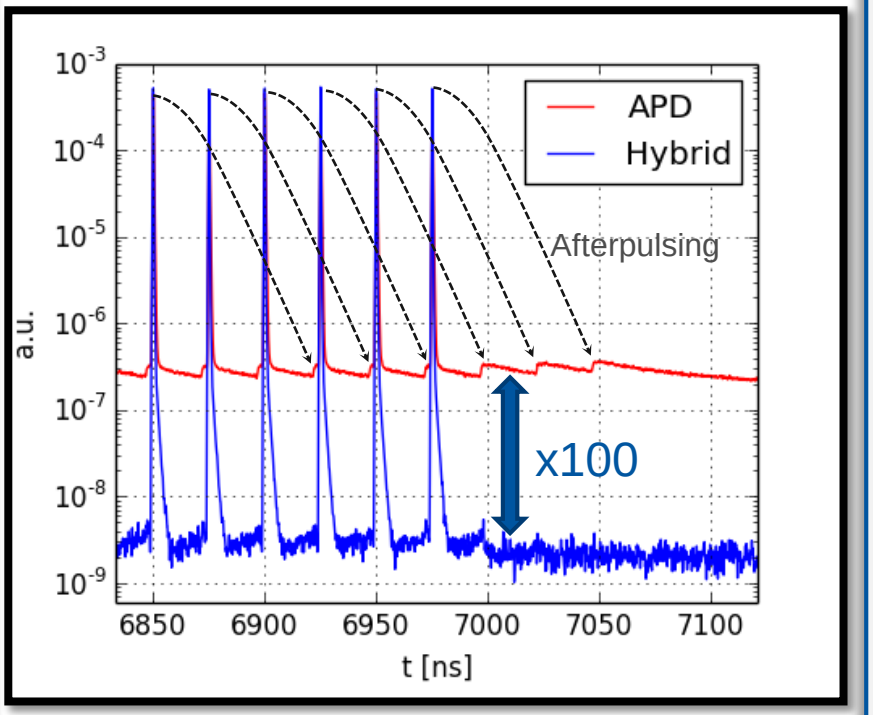
Analysis

- Signal correction: pile-up and deadtime (TDC)
- Bucket-wise integration (population per bucket)
- => Fraction of beam in satellite & ghost buckets (Q_{sat}, Q_{ghost})
- …



Detectors

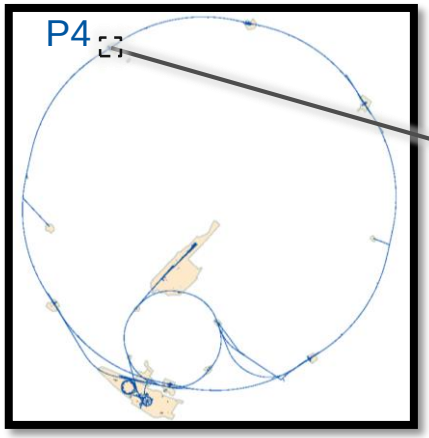
- **APD**
  - Single-photon avalanche diode
  - Robust
  - 70 ns deadtime
  - 50 μm sensor
  - Afterpulses
  - Used 2010-2015

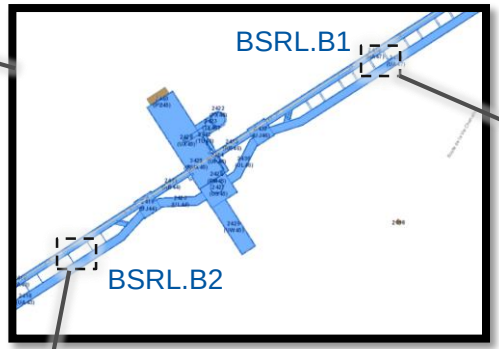


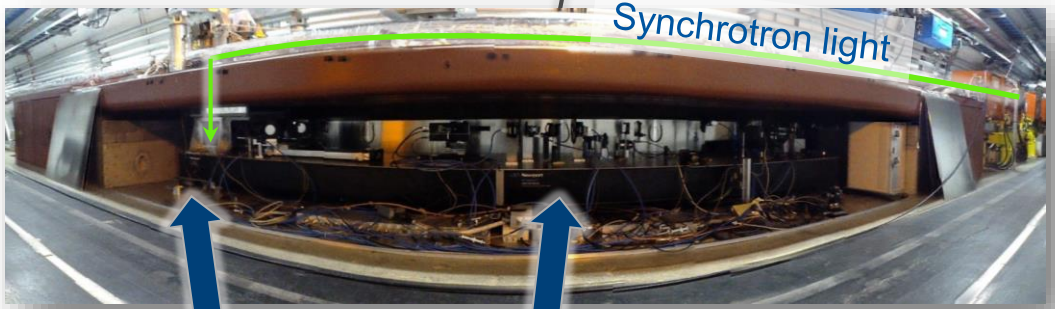
- Detector responses to laser pulse train (25 ns separation)

- **Hybrid**
  - Electron bombardment + avalanche
  - Damaged by too intense light
  - No deadtime
  - 6 mm sensor
  - No afterpulses (almost)
  - Dark count rate <50cps
  - Used since 2015

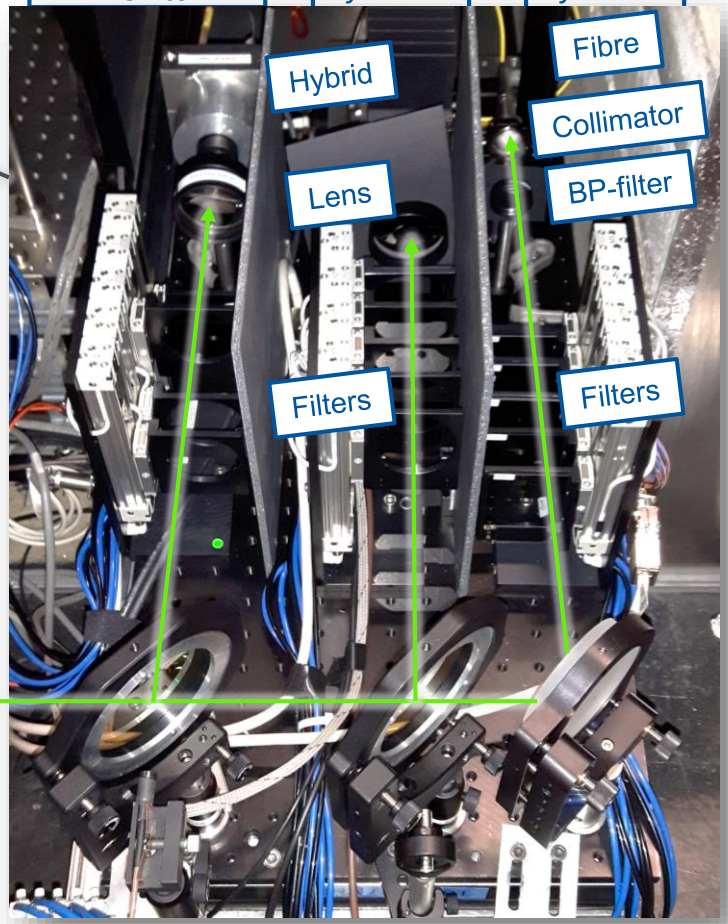
Installation







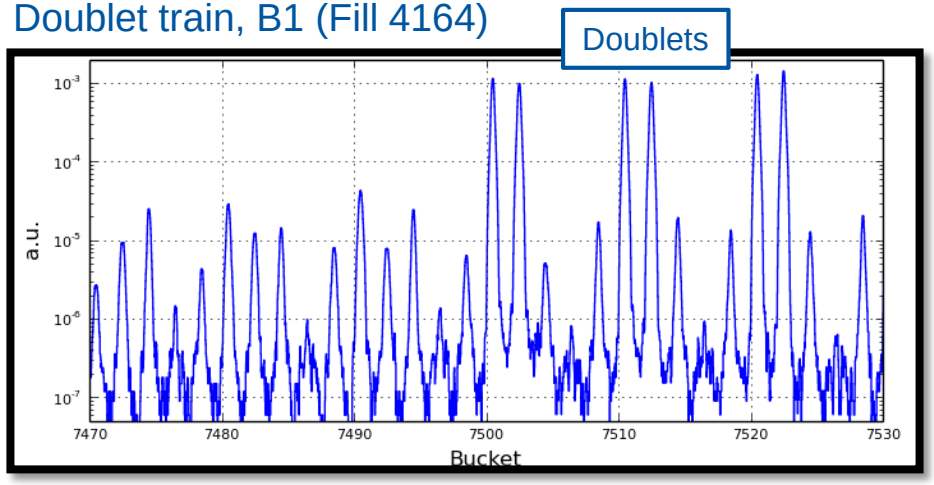
[Courtesy G. Trad]



- Overview
- **Highlights from Run 2**
- Outlook

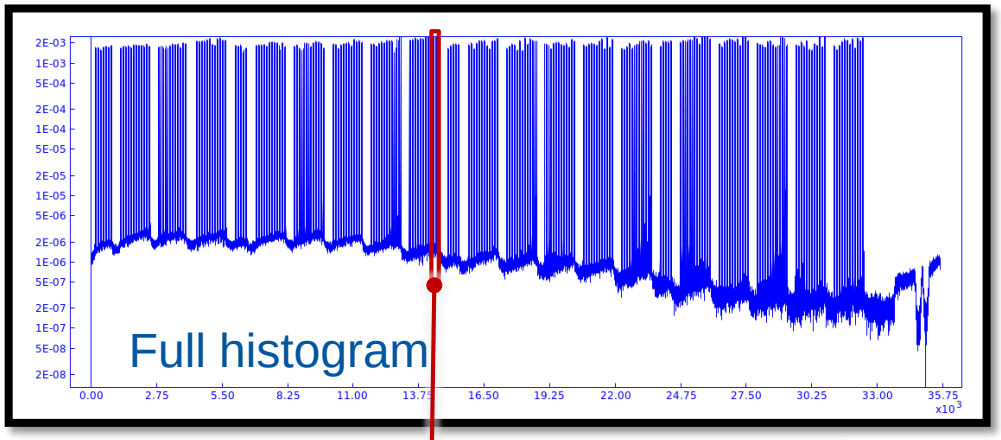
Performance

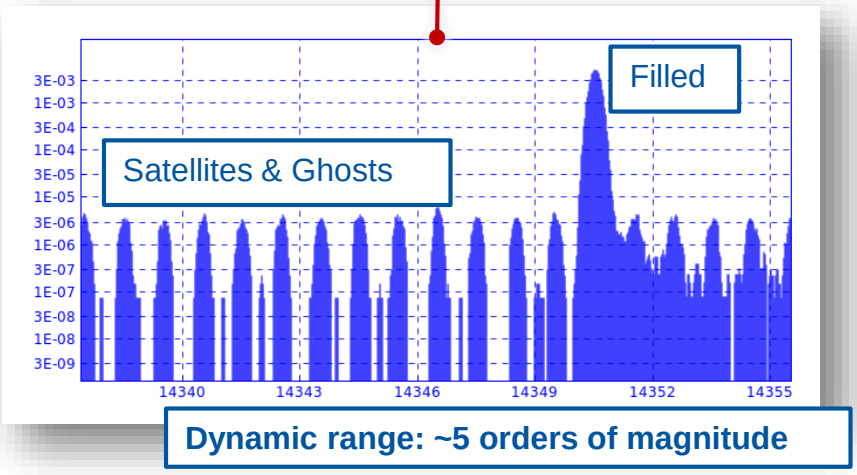
Doublet train, B1 (Fill 4164)



Performance

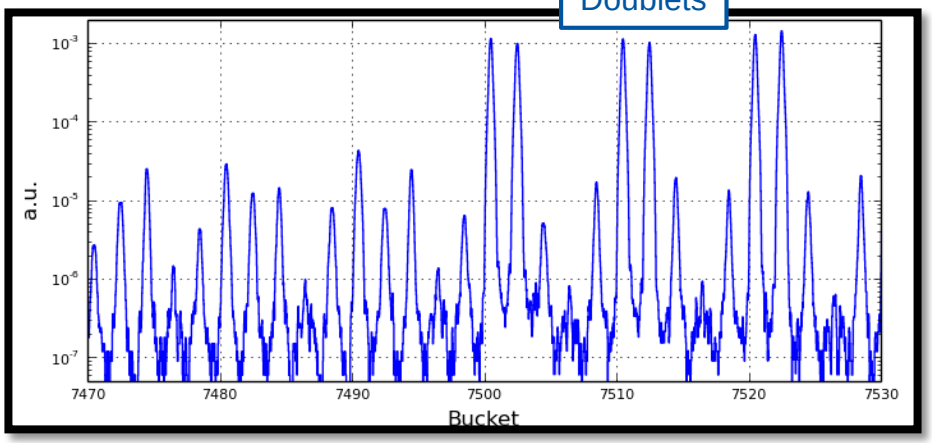
Ions: B1 Hybrid @ 2015-12-06 09:58 [UTC]





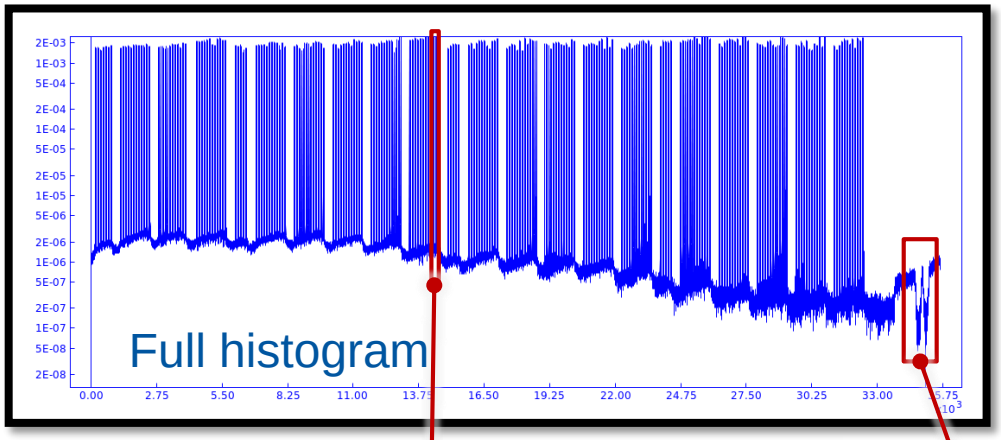
Dynamic range: ~5 orders of magnitude

Doublet train, B1 (Fill 4164)

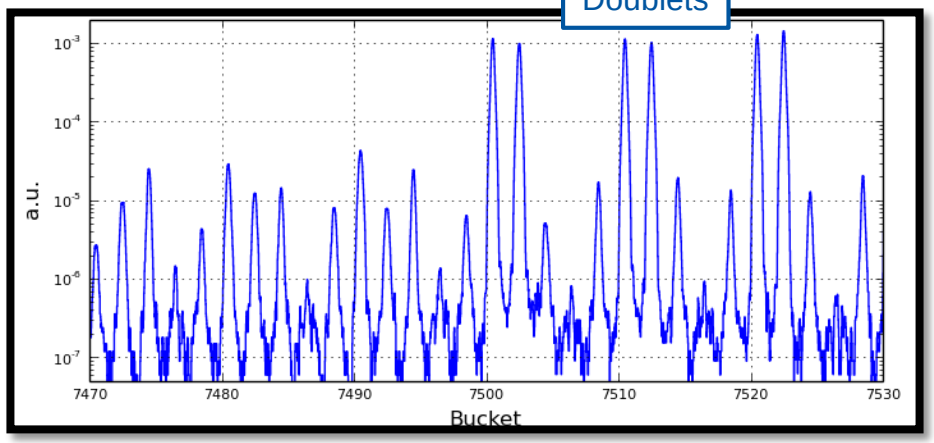


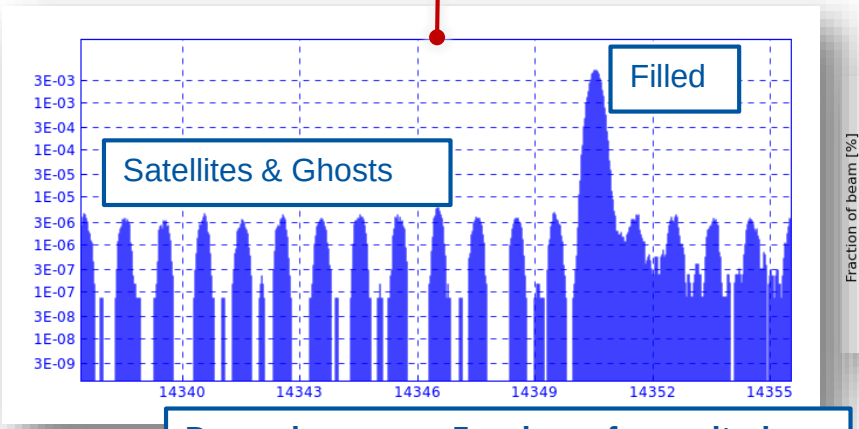
Performance

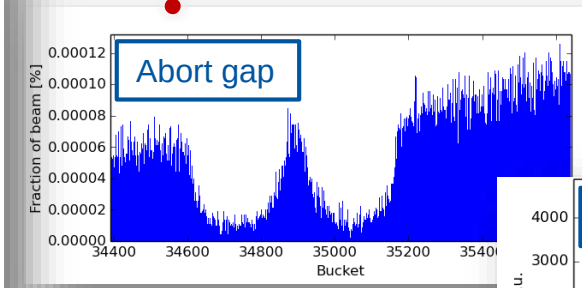
Ions: B1 Hybrid @ 2015-12-06 09:58 [UTC]

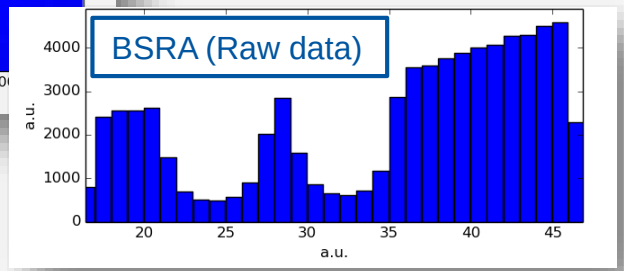


Doublet train, B1 (Fill 4164)







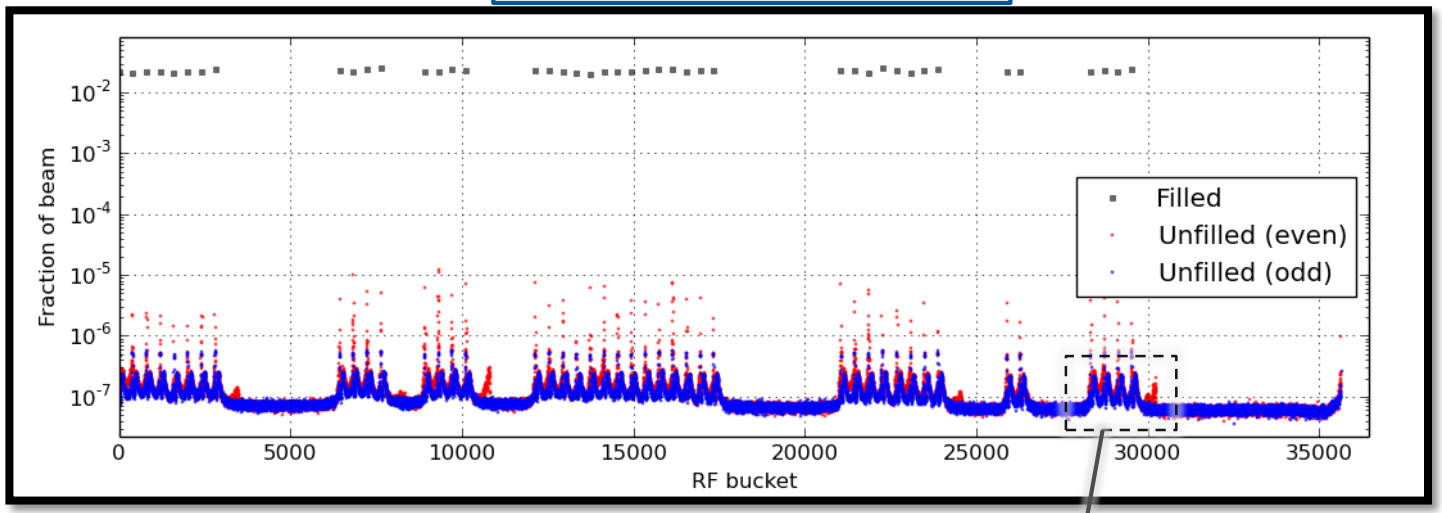


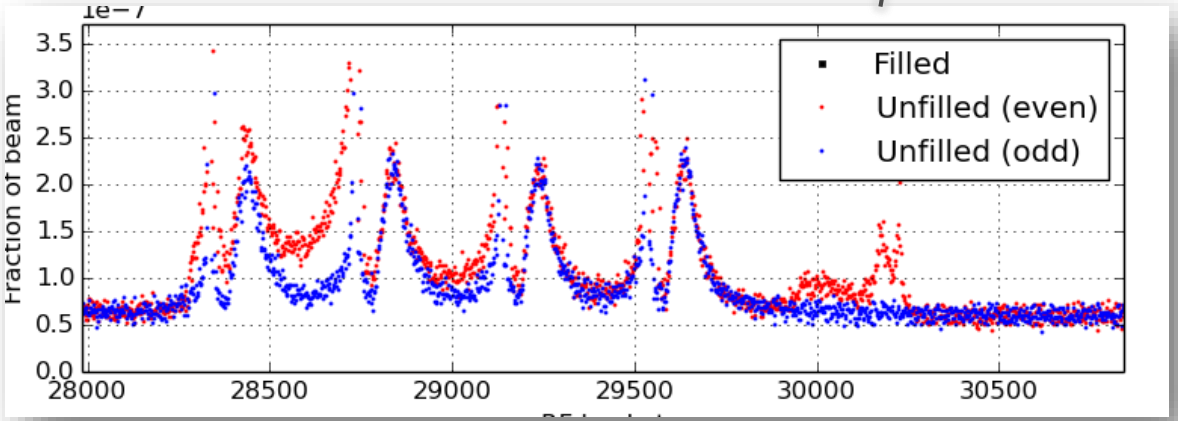
Dynamic range: ~5 orders of magnitude

Precision

- Relative bucket population
- Sum of all histograms from STABLE beam mode
- Small injection artefacts ($< 10^{-5}$ of nominal bunches) made visible by longer integration time

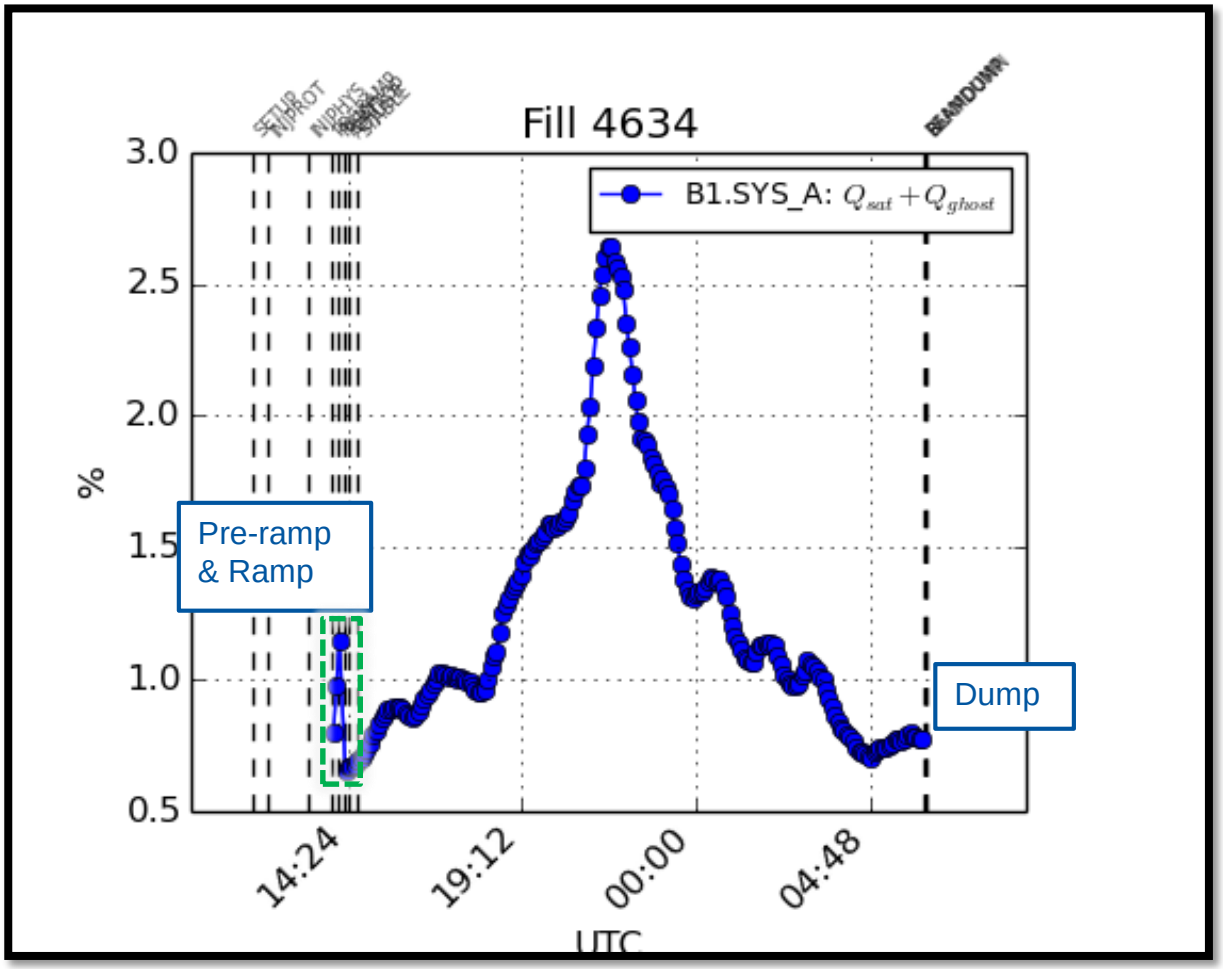
Fill 4634, B2, STABLE





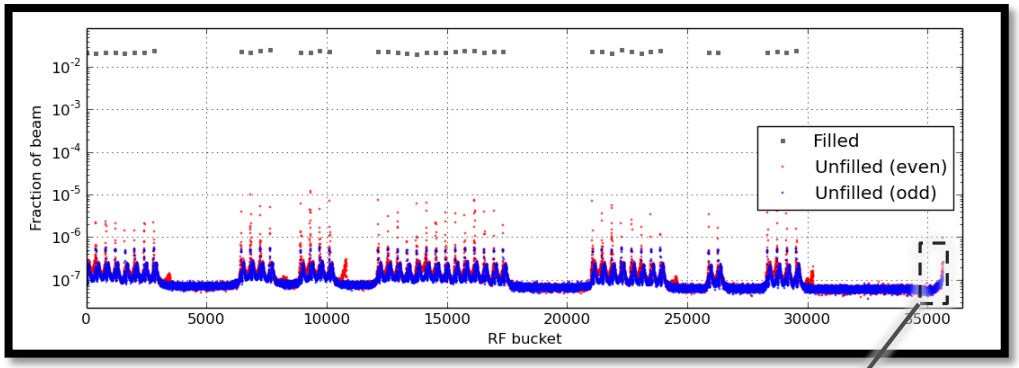
Ghost & Satellite fraction

- Example, B1: Fill 4634 (Protons, 2.51 TeV, 44 bunches)
- Fraction of beam in nominally empty buckets varies strongly during fill.
  - Decreases during ramp
  - Peaks at 2.7%
  - Unbunched
- Consistent with BSRA?

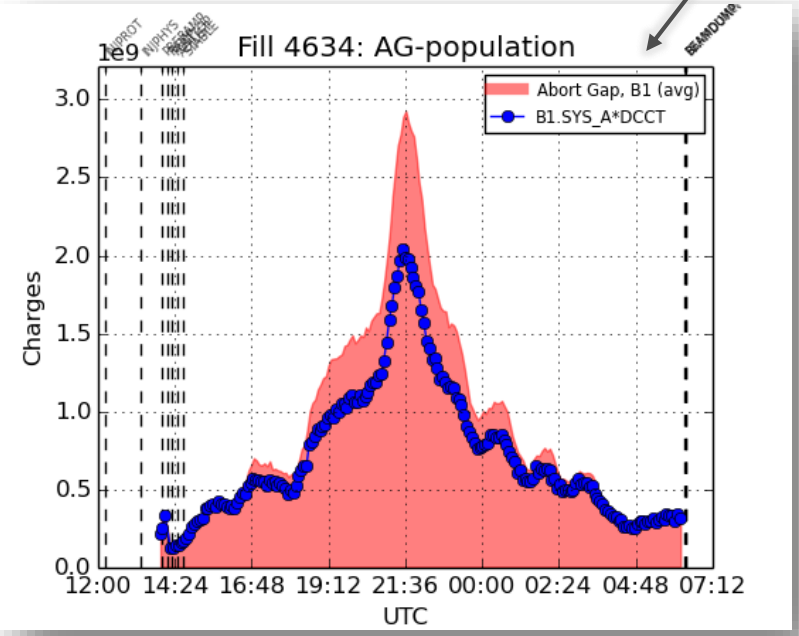


Ghost & Satellite fraction

- Example, B1: Fill 4634 (Protons, 2.51 TeV, 44 bunches)
- Fraction of beam in nominally empty buckets varies strongly during fill.
  - Decreases during ramp
  - Peaks at 2.7%
  - Unbunched
- Consistent with BSRA?
  - Yes!

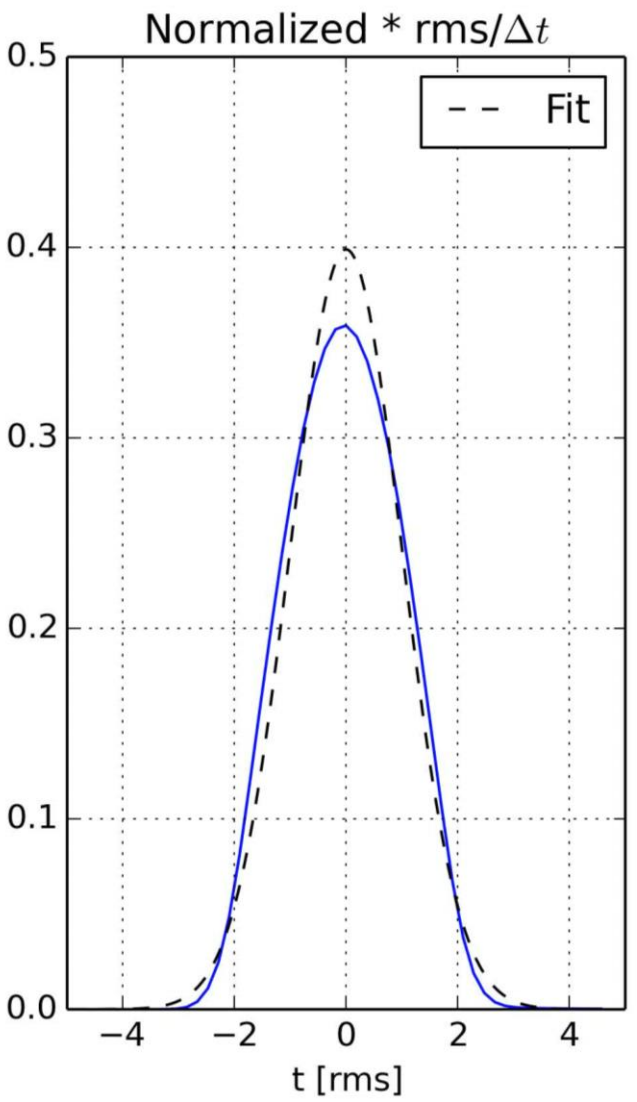


$DCCT \times \sum Abort\ Gap =$
Abort gap population (BSRL)



Extras

- Different measures of bunch length
  - FWHM, RMS, σ_{fit}
- Bunch shape
- Synchronous phase shift (time averaged)
- …

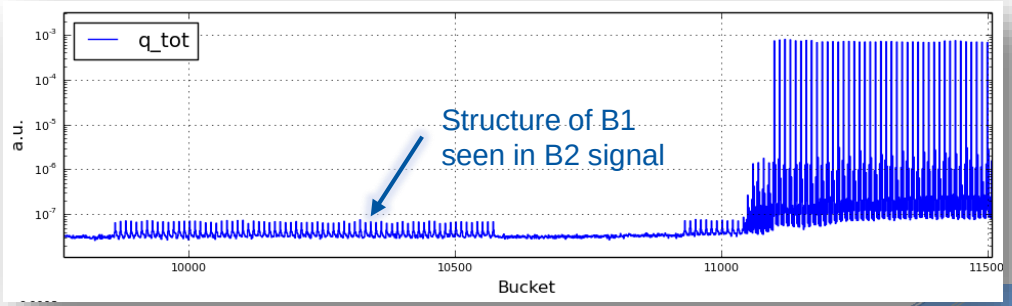


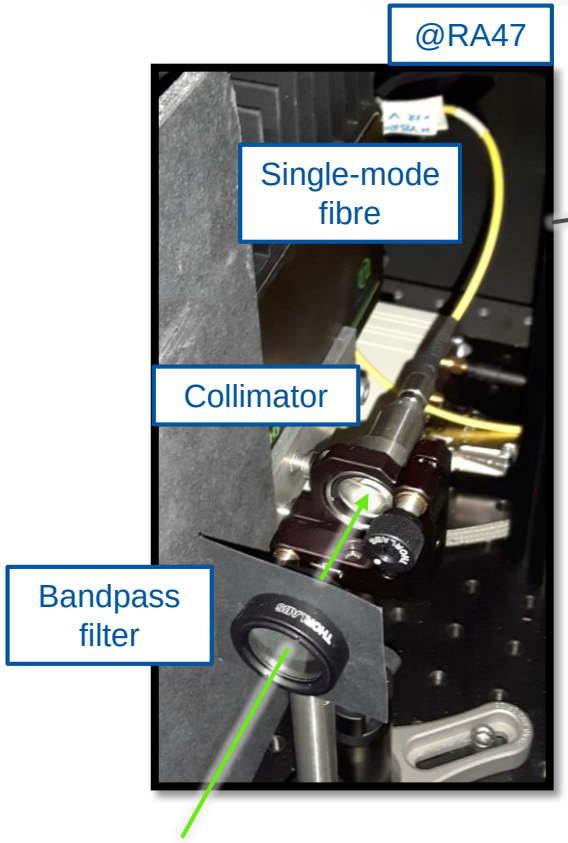
[Animation]

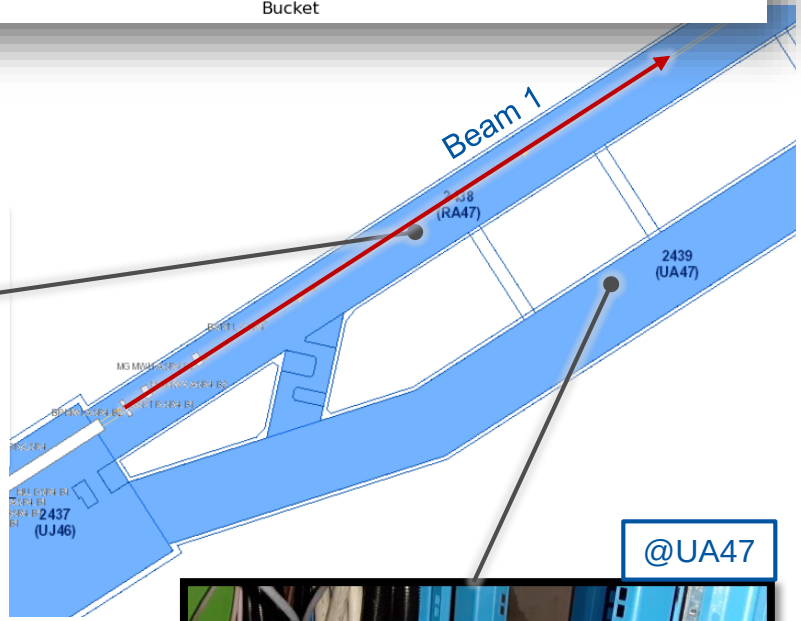
- Overview
- Highlights from Run 2
- **Outlook**

Outlook

- Beam losses from opposite beam interfering with SR-signal
- Off-line correction possible. Long-term damage?
- Third hybrid installed in UA47 for feasibility test







Thanks to:

Stefano

Enrico

Federico

Aurelie

Georges

Thank you for your attention!

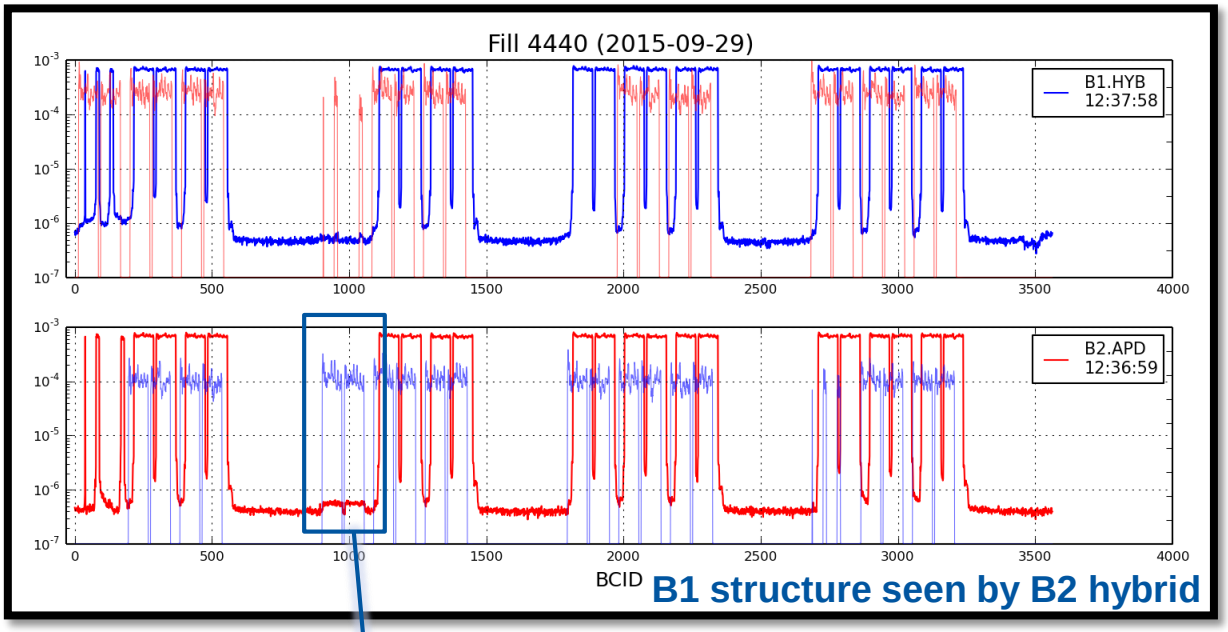
[1] Preprint: *Beam-induced and cosmic ray backgrounds observed in the ATLAS detector during the 2012 proton-proton running period* (DAPR-2014-01), The ATLAS collaboration

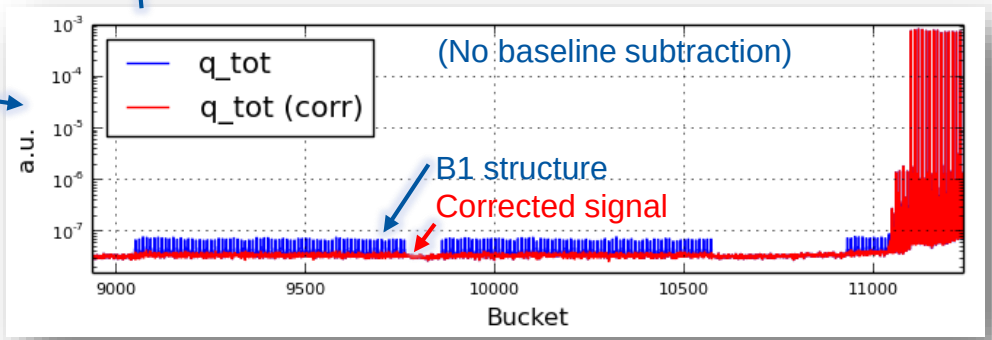
[2] *First results of the LHC longitudinal density monitor*, A. Jeff et.al, Nuclear Instrumentation and Methods in Physics Research A 659 (2011) 549-556

Backups

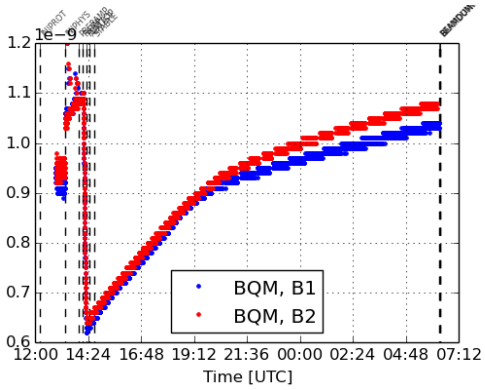
Beam loss interference

- Profile of opposite beam is detected
  - Most likely beam losses(?)
  - Bunched signal from wrong beam corrupts measurement
  - …can be corrected
  - Long term damage?

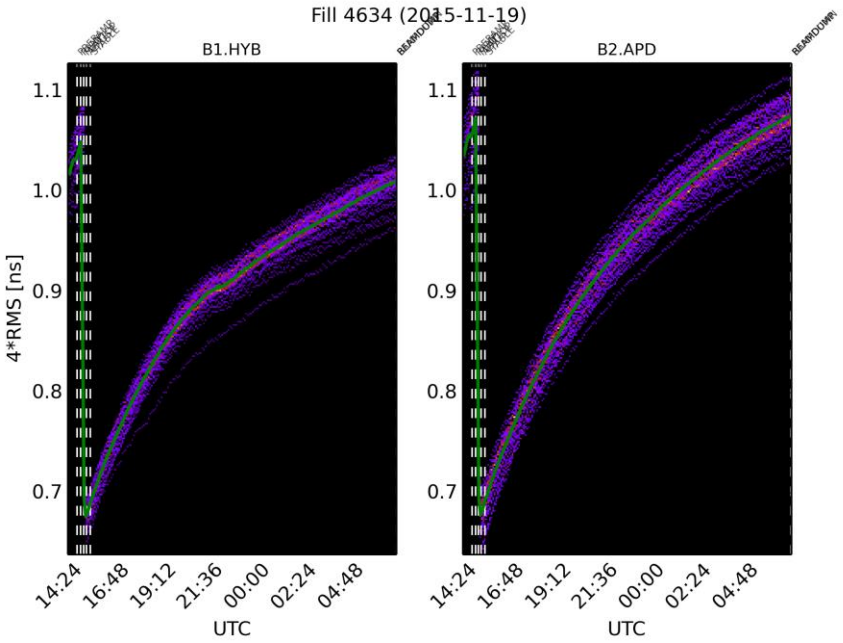




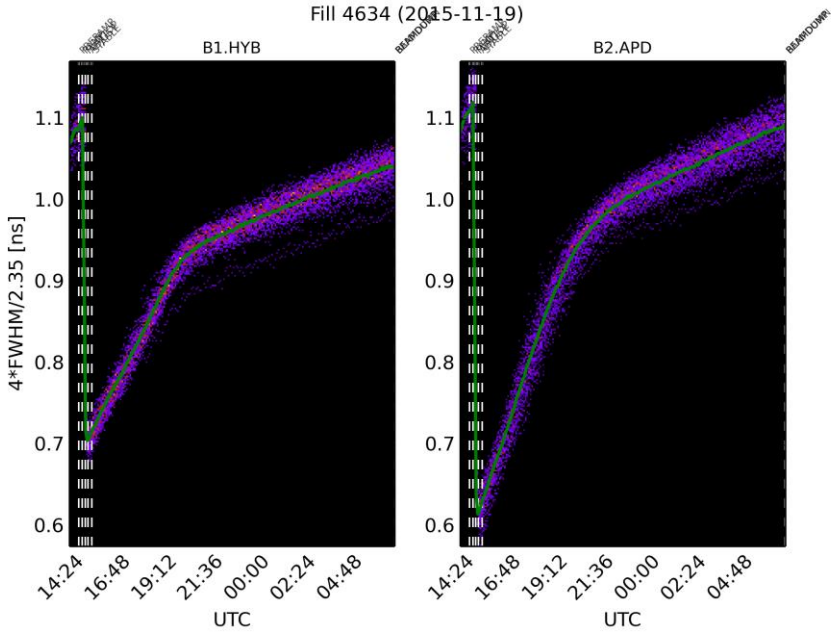
Bunch length



Distribution of all bunch lengths during fill 4634

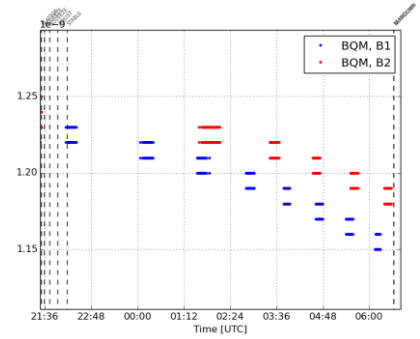


$$4 \times RMS = 4\sqrt{\int (t - \langle t \rangle)^2 \rho(t) dt}$$

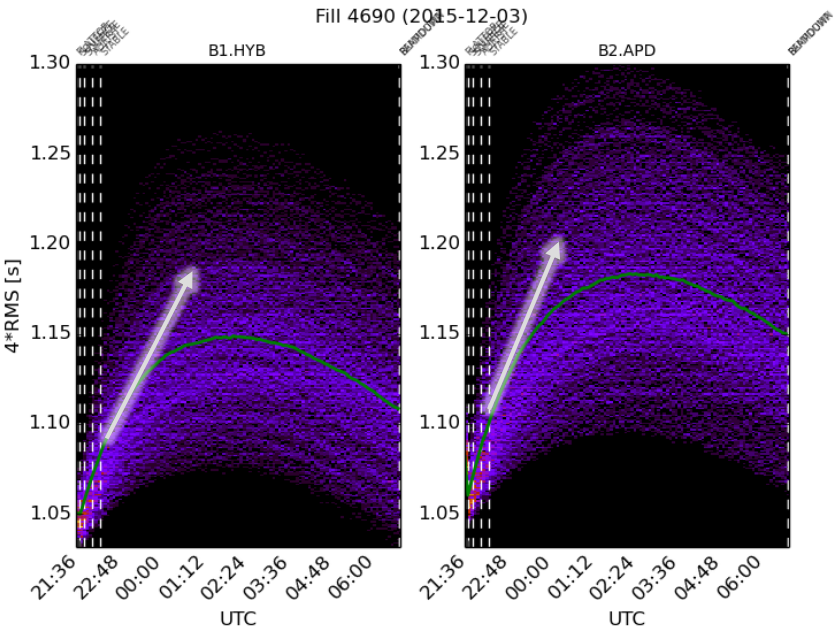


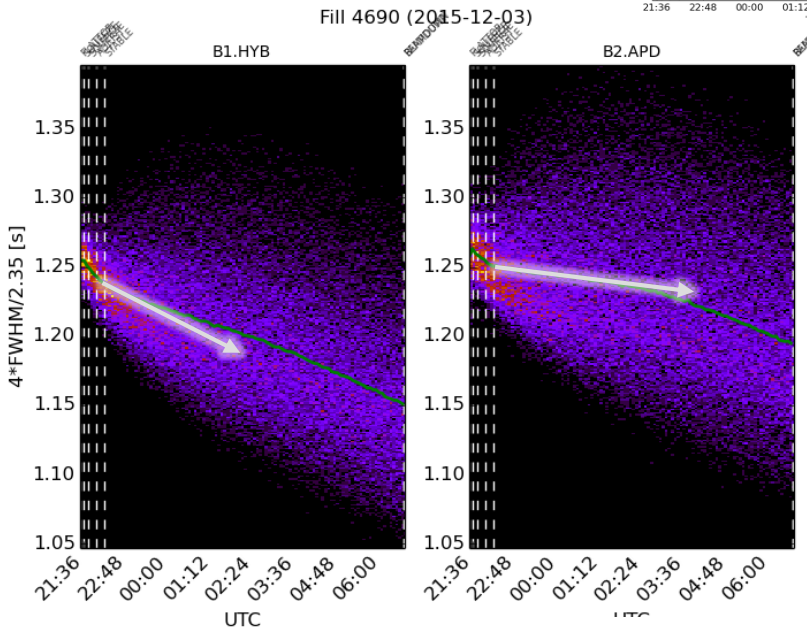
$$4 \times FWHM/2.35$$

Bunch length (2)

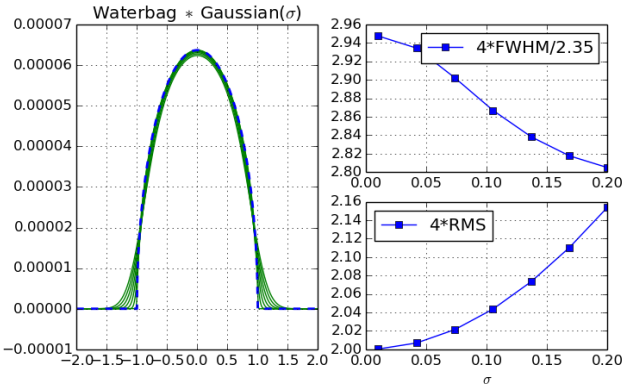


Distribution of bunch lengths during fill 4690

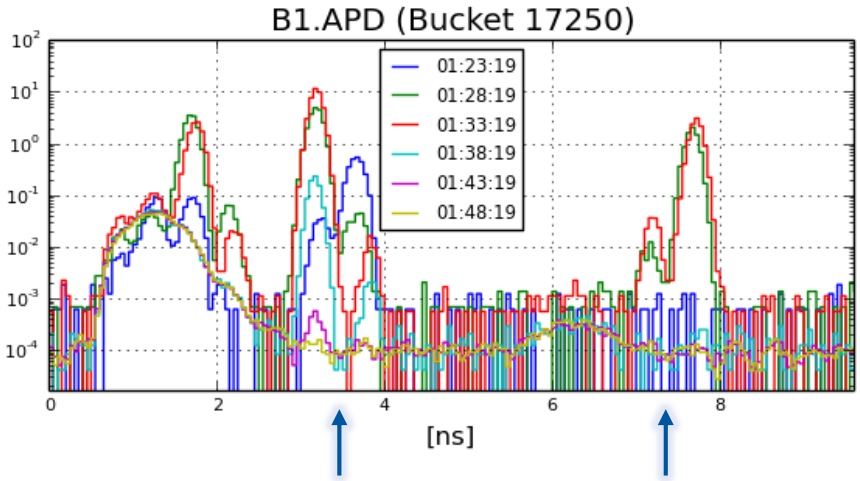




- Initially: RMS increasing, FWHM decreasing
- Consistent with a flatter bunch shape (e.g. square or waterbag) being exposed to Gaussian diffusion (convolution w. Gaussian) and bunch compression



APD: Performance

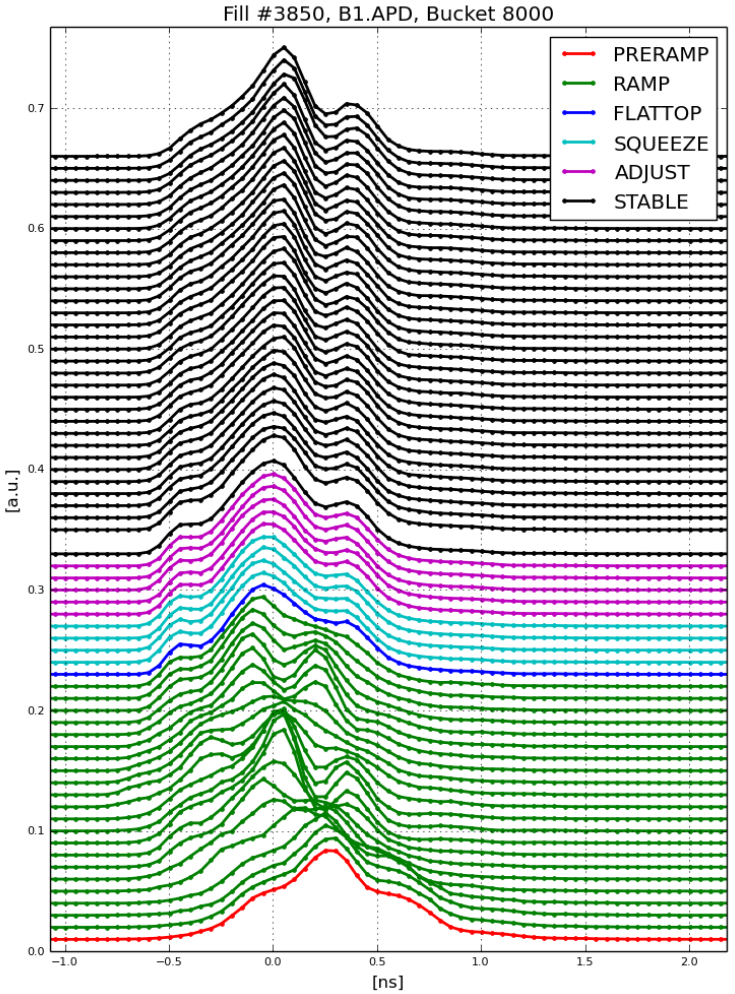


“Phantom” bunches

“Phantom” bunch signal typically decreases during the fill

Mechanism not fully understood…

- Possible cause: bias voltage ripple (>GHz) leading to sensitivity fluctuations and avalanche onset.



Distorted bunch profile