A Longitudinal Density Monitor for the LHC

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CERN BI day
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Aim

Longitudinally profile the entire LHC beam with 50ps time resolution and high dynamic range.

Contents

- Motivation
- Description of the system
- Signal Correction methods
- Results & comparison with existing instruments
- Scheme for even higher dynamic range

What is it for?

	Protons	Lead Ions
Maximum beam energy (2010-11)	3.5 TeV	3.5 x 82 TeV / ion
Revolution period	89 μs	
RF period	2.5 ns	
Minimum bunch spacing	25 ns	100 ns
Maximum number of bunches	2808	592
Bunch population (ultimate)	1.7×10^{11}	8.2×10^{9} charges [10^{8} ions]

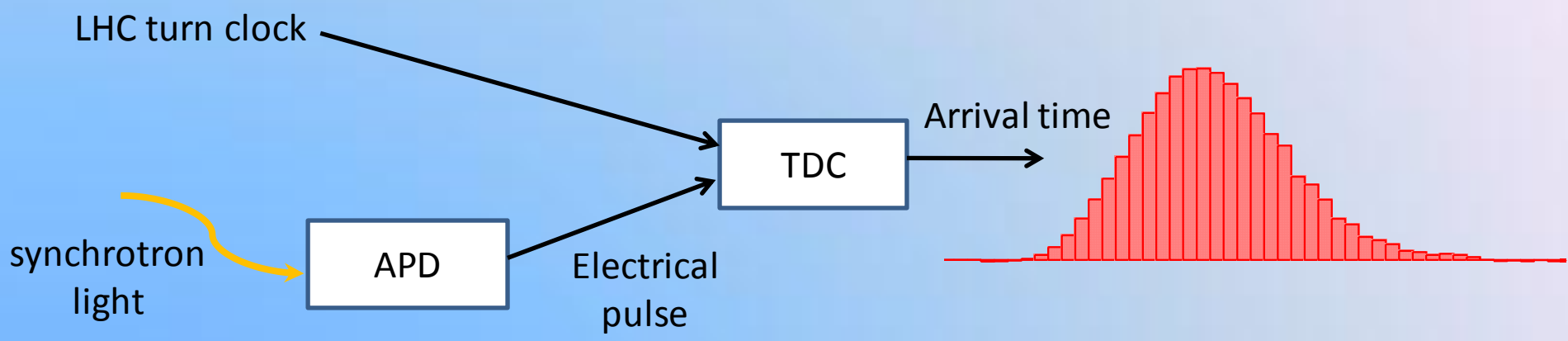
9 out of 10 buckets ***should*** be empty…

…but they're not.

Satellite bunches are important…

- Current & luminosity normalisation
- Machine protection (e.g. satellites in kicker window)
- Experiment background
- Satellite - main collisions used in the low-luminosity IPs

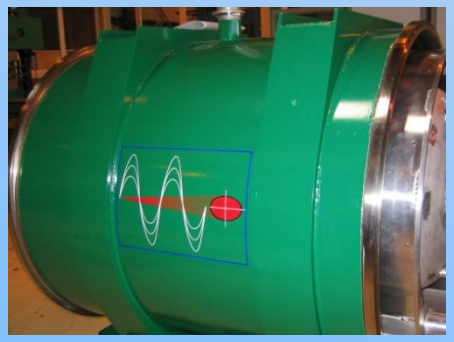
Single photon Counting



Single photon counting is used to achieve a high dynamic range:

> 10^5 with 15 minutes integration

Schematic



Synchrotron light from undulator and dipole

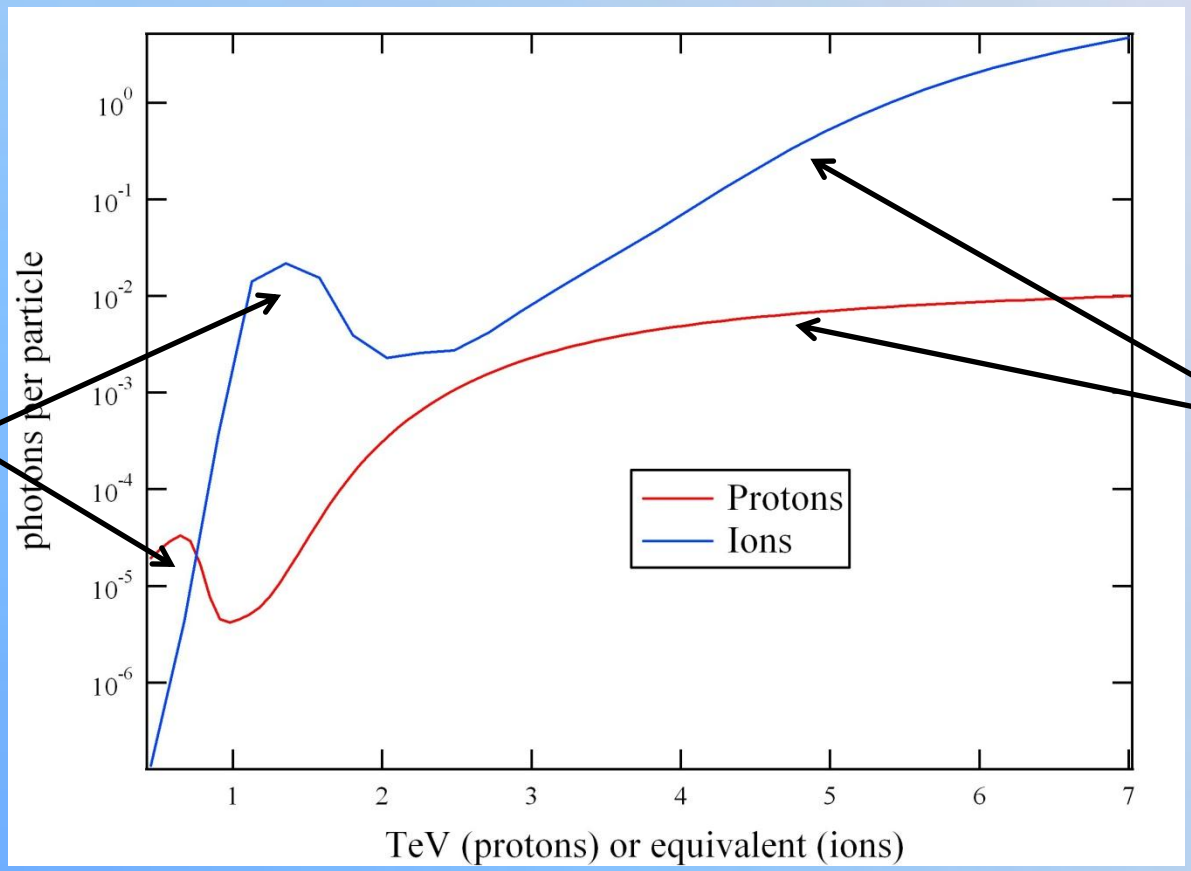
Geiger-mode Avalanche photodiode converts photon to electrical pulse

Time to Digital converter records pulse arrival time

cPCI computer makes histogram and corrects for APD dead-time and afterpulsing

Synchrotron light from protons…

… and even lead ions!

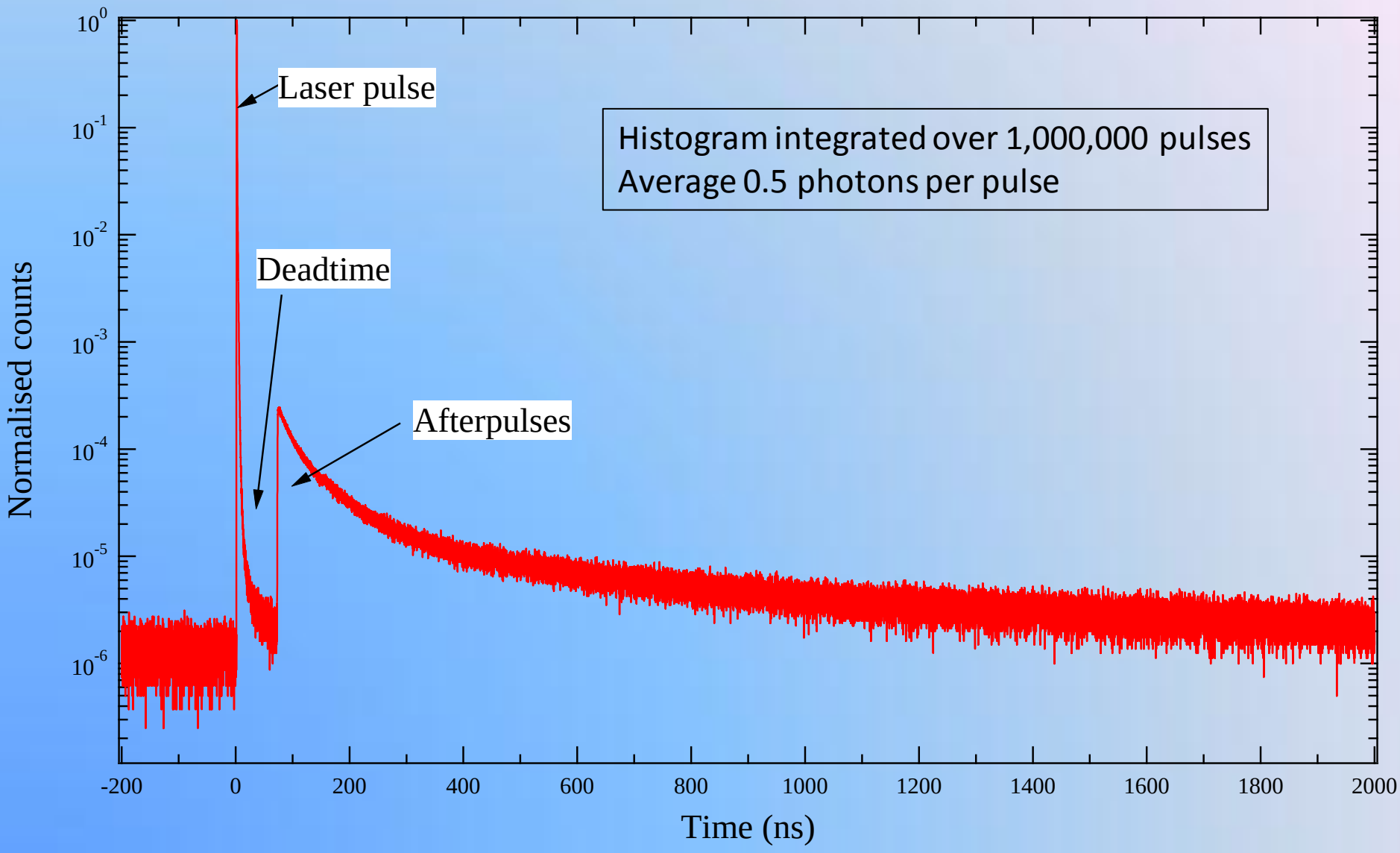


Undulator

Dipole

Dedicated undulator for diagnostics gives visible light at injection

Instrument response

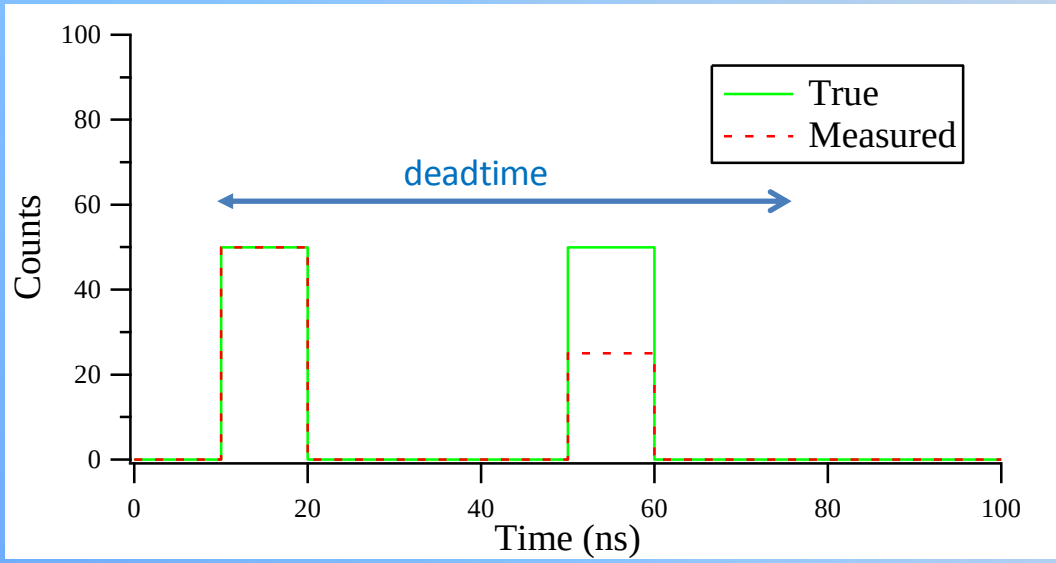


Deadtime Correction

Deadtime correction is essential

- to restore the true bunch shape
- to measure satellites following the main bunch

Integrating over 100 turns…



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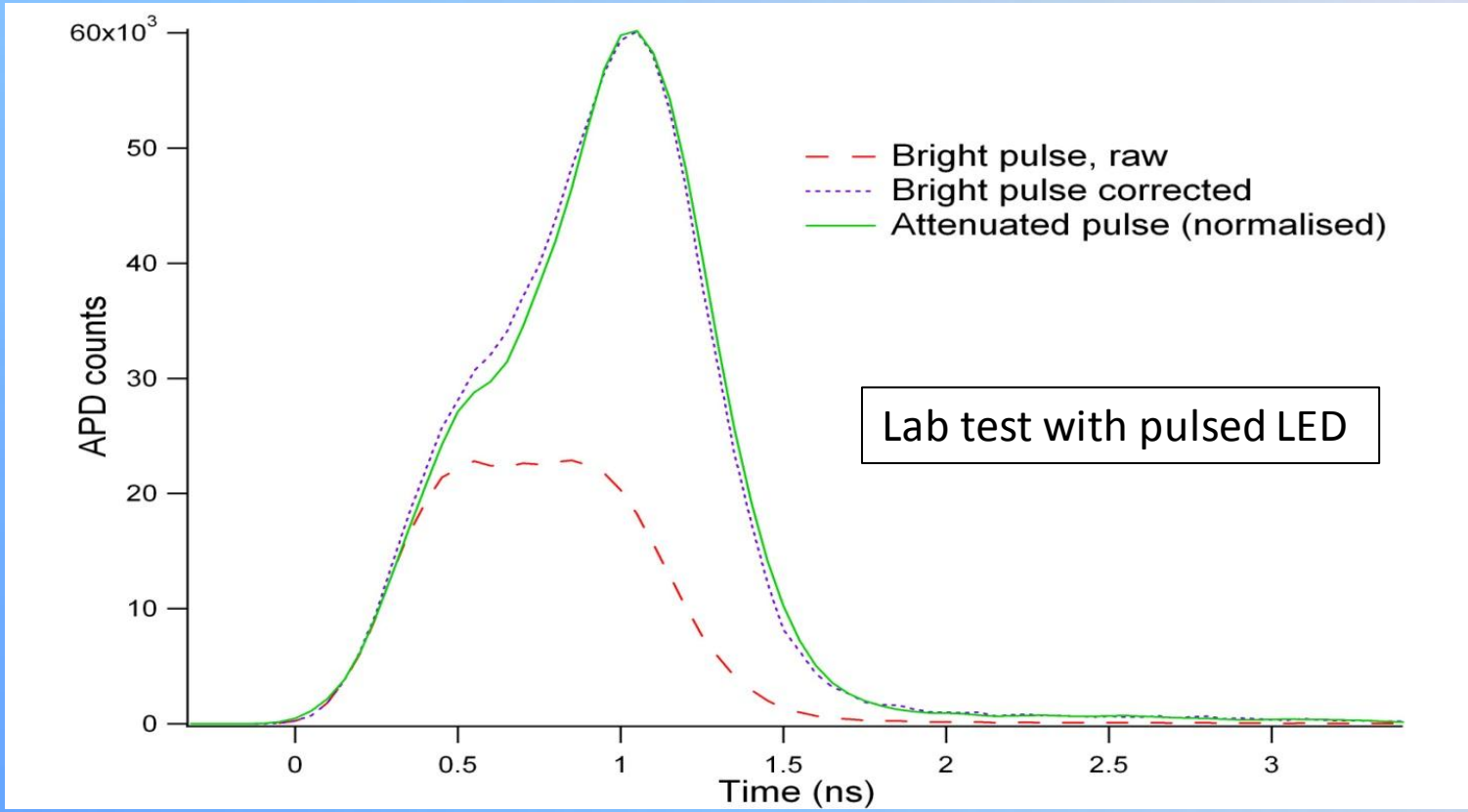
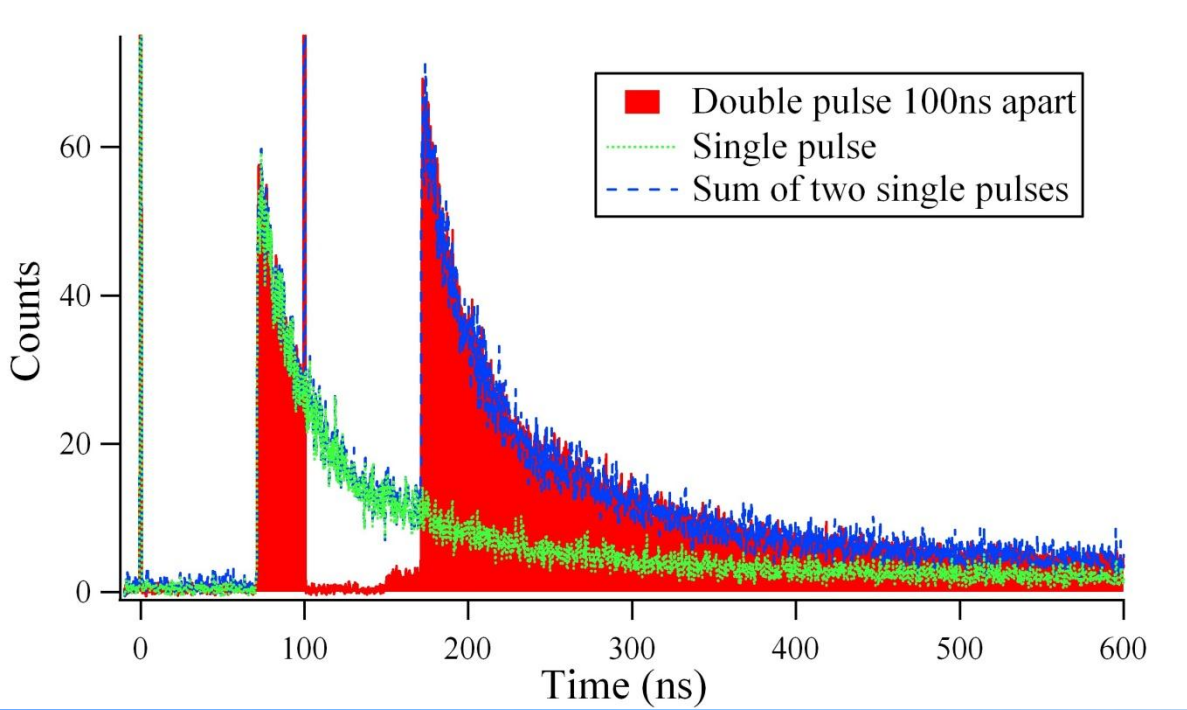
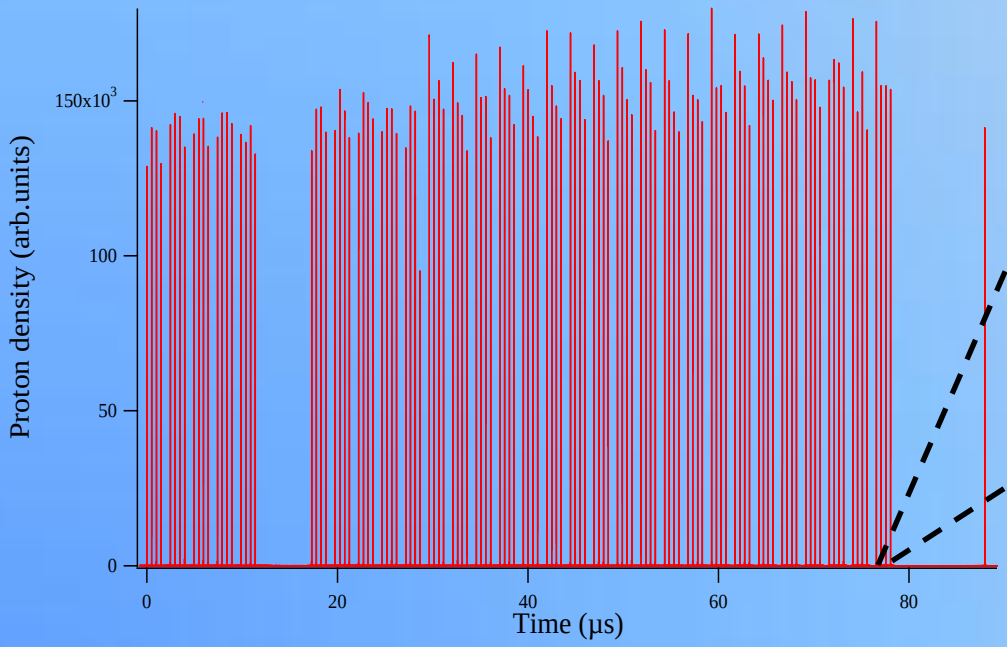


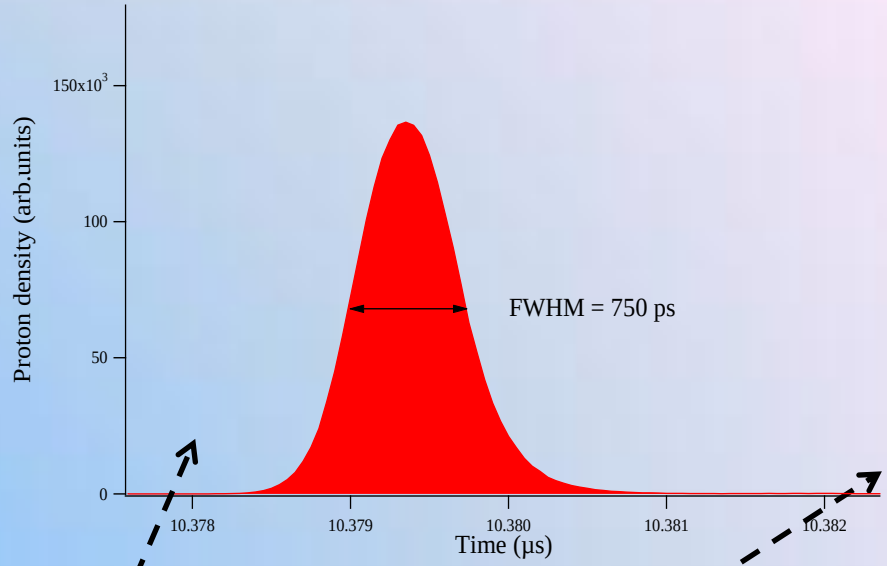
Afterpulse Correction

- Afterpulses occur due to charge carriers trapped in the silicon
- Start at end of deadtime but continue for many µs
- Fit by sum of multiple exponentials
- Afterpulses are additive

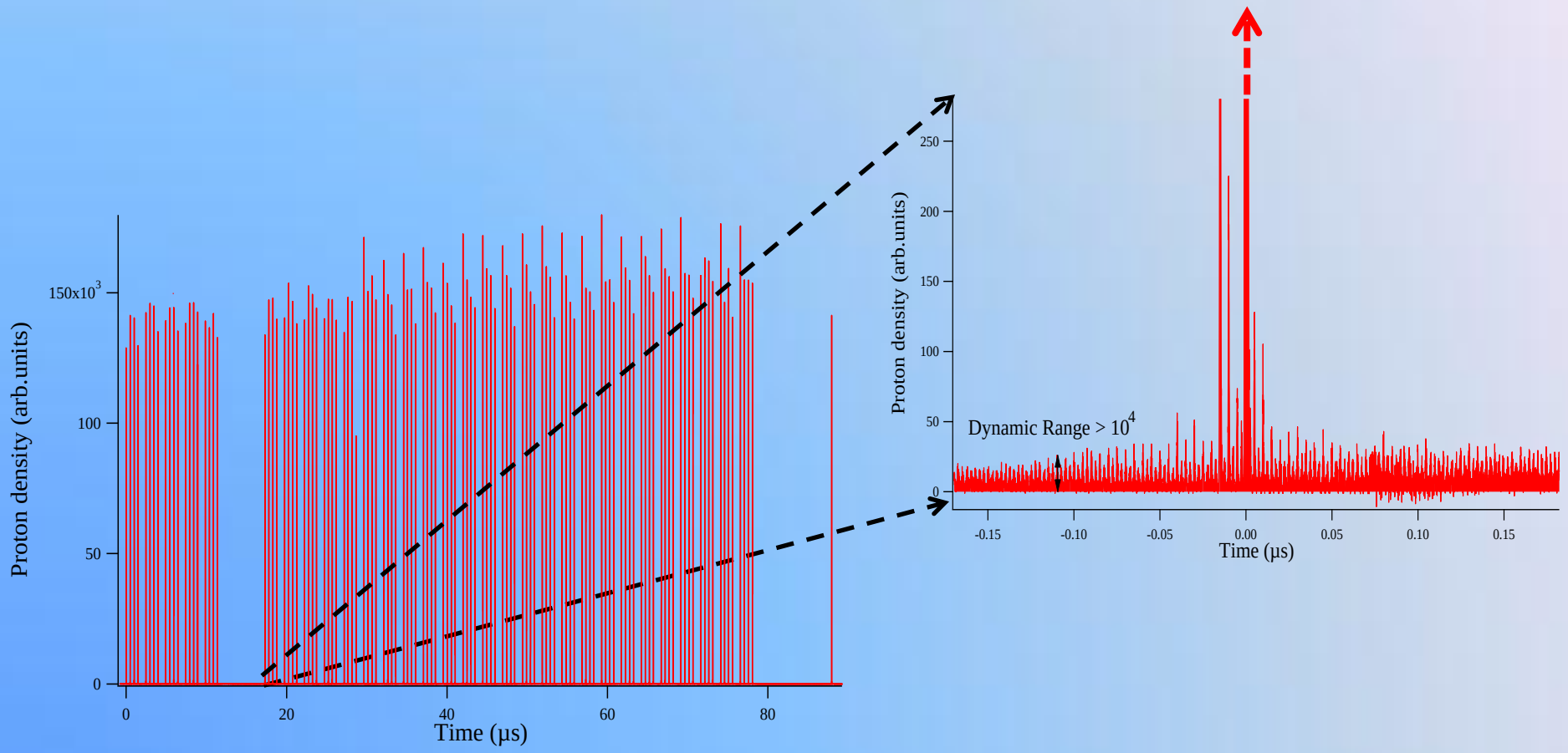


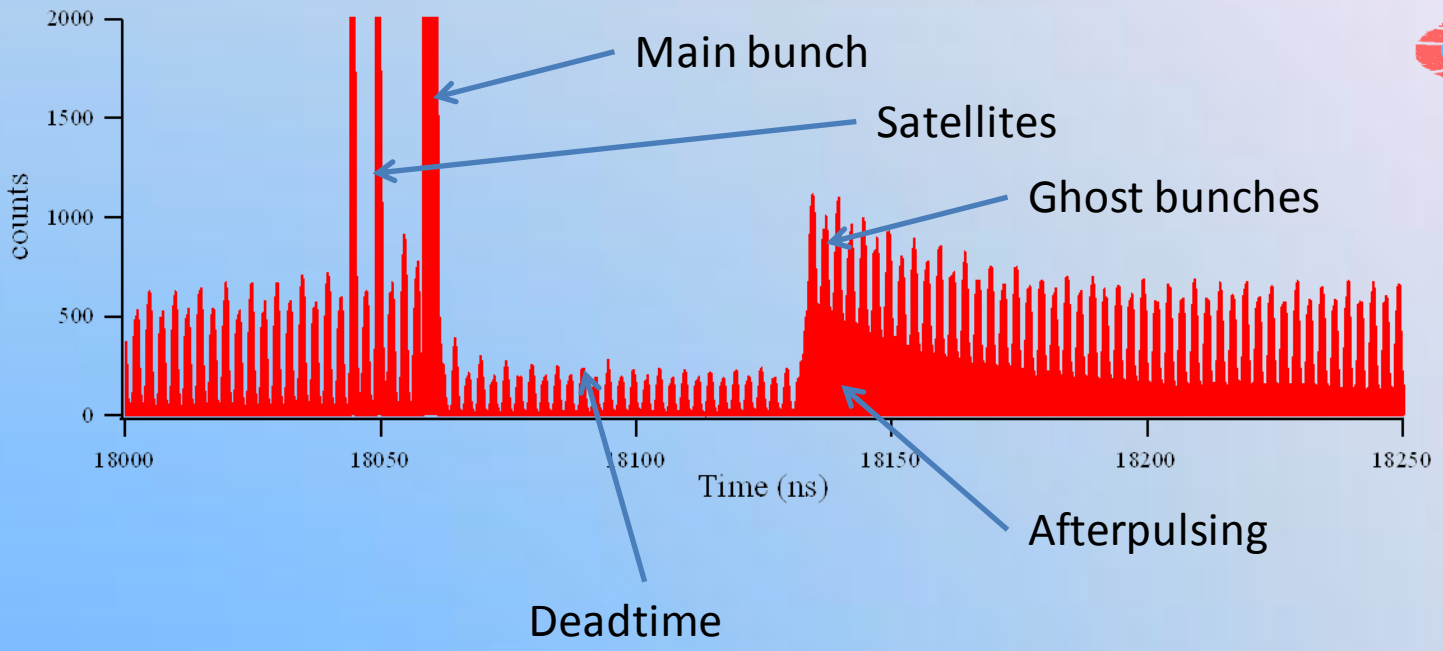
Results

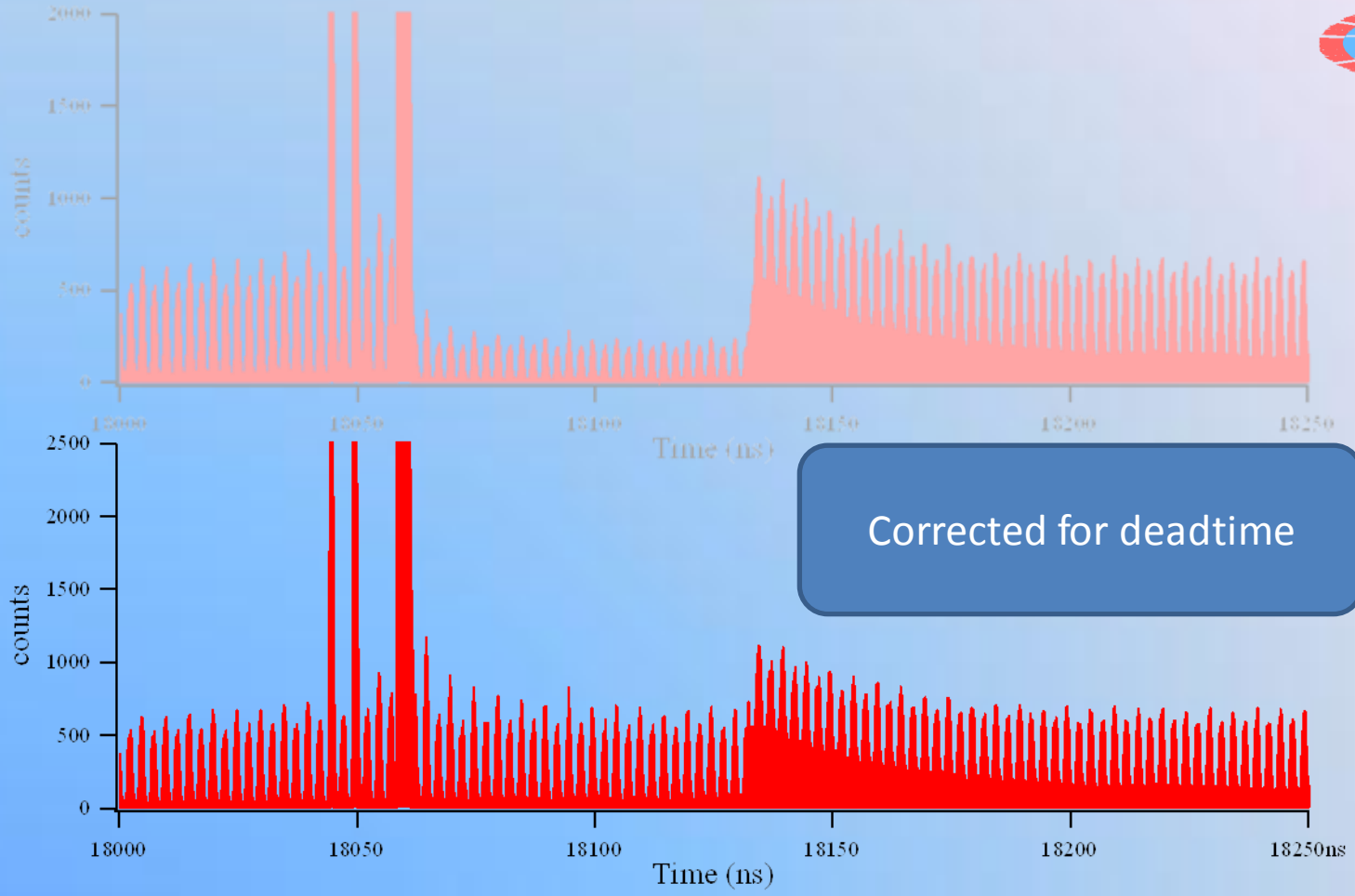

150x10^3
100
50
0
Proton density (arb.units)
0
20
40
60
80
Time (μs)


150x10^3
100
50
0
Proton density (arb.units)
FWHM = 750 ps
10.378
10.379
10.380
10.381
10.382
Time (μs)

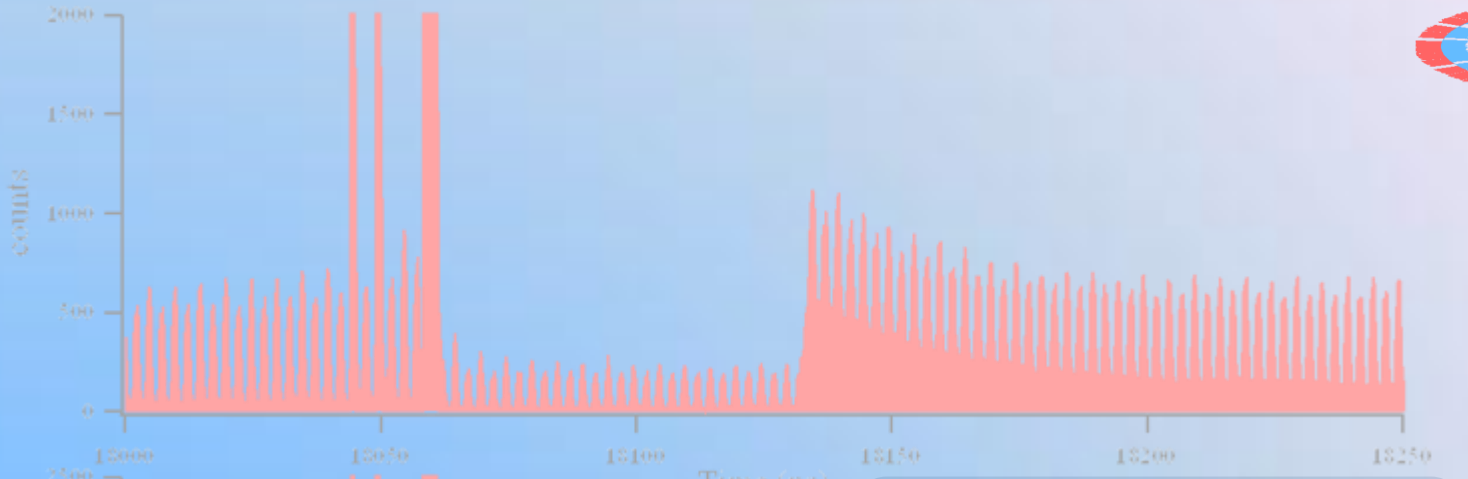
Results

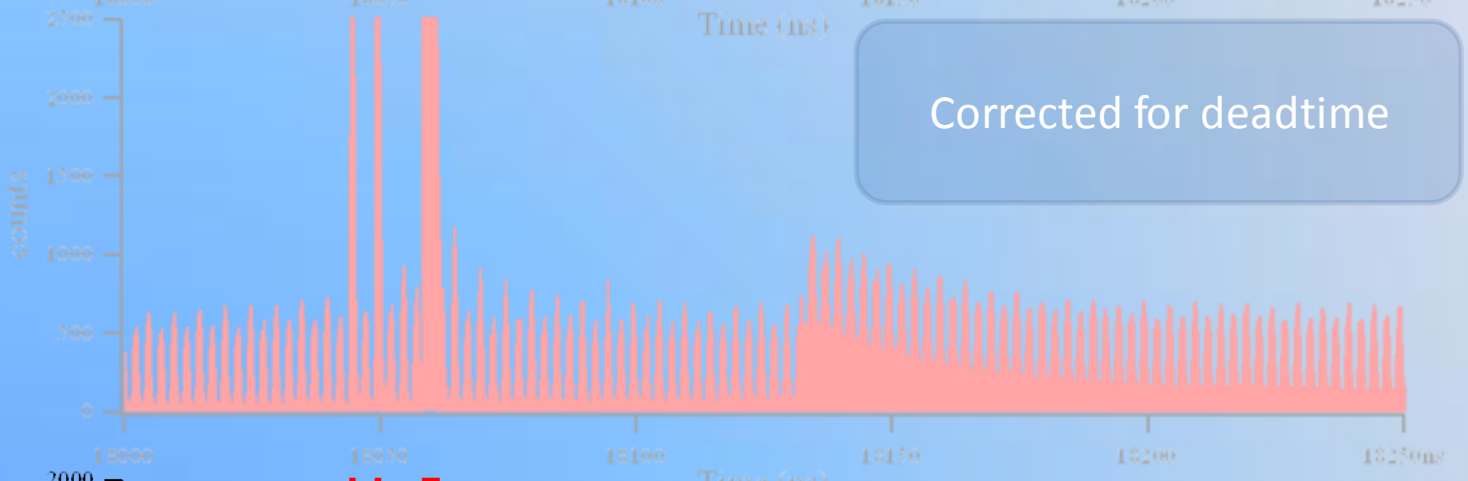

Proton density (arb.units)
150x10^3
100
50
0
0
20
40
60
80
Time (µs)
Proton density (arb.units)
250
200
150
100
50
0
Dynamic Range > 10^4
-0.15
-0.10
-0.05
0.00
0.05
0.10
0.15
Time (µs)


Main bunch
Satellites
Ghost bunches
Afterpulsing
Deadtime
counts
Time (ns)
2000
1500
1000
500
0
18000
18050
18100
18150
18200
18250

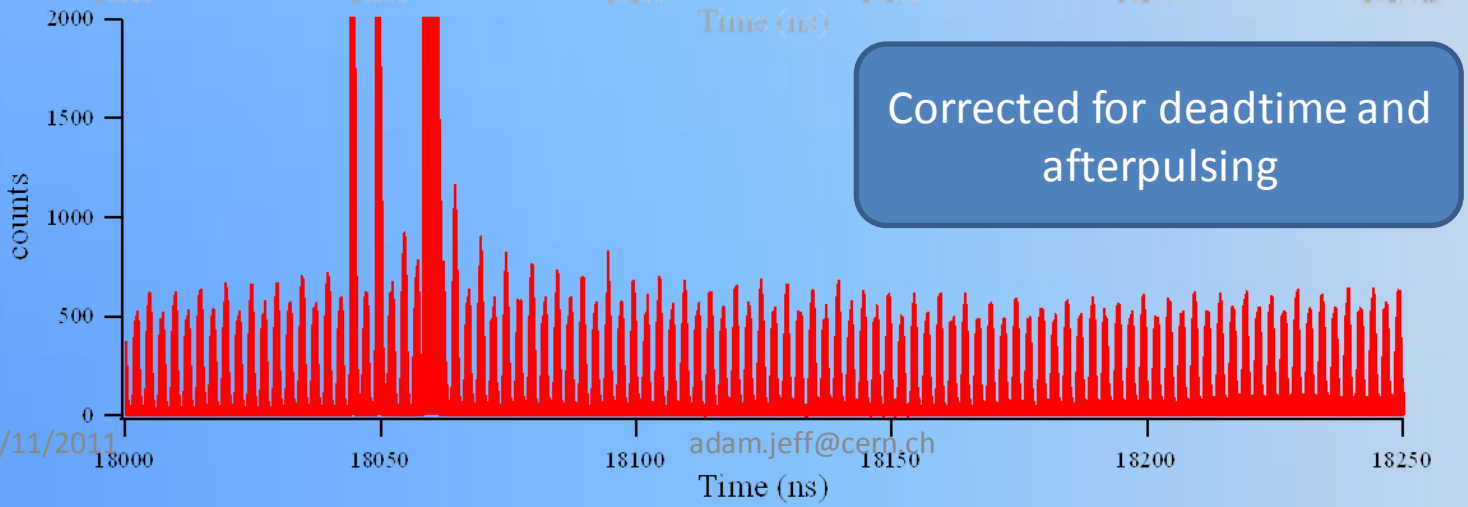


Corrected for deadtime



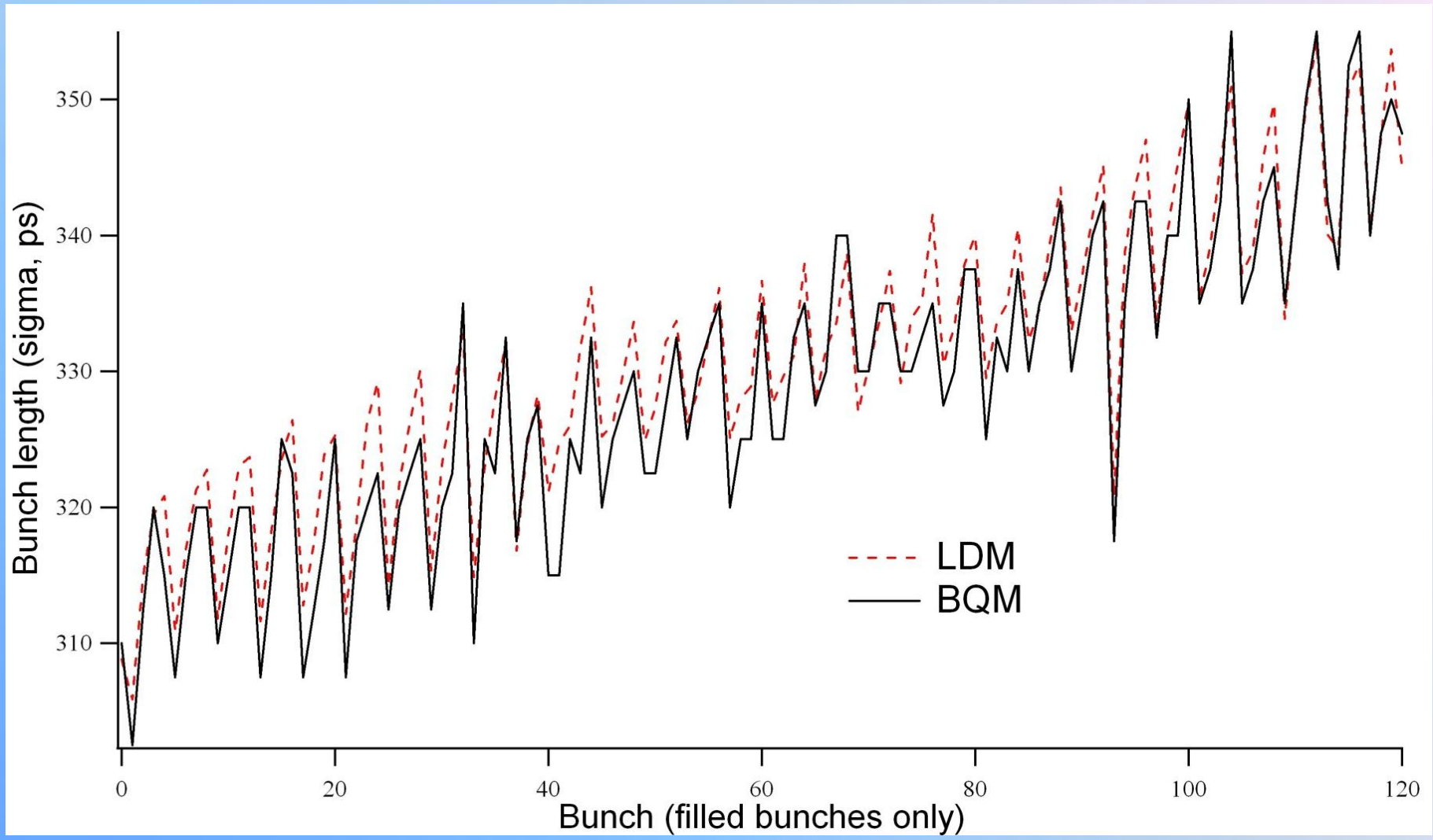


Corrected for deadtime



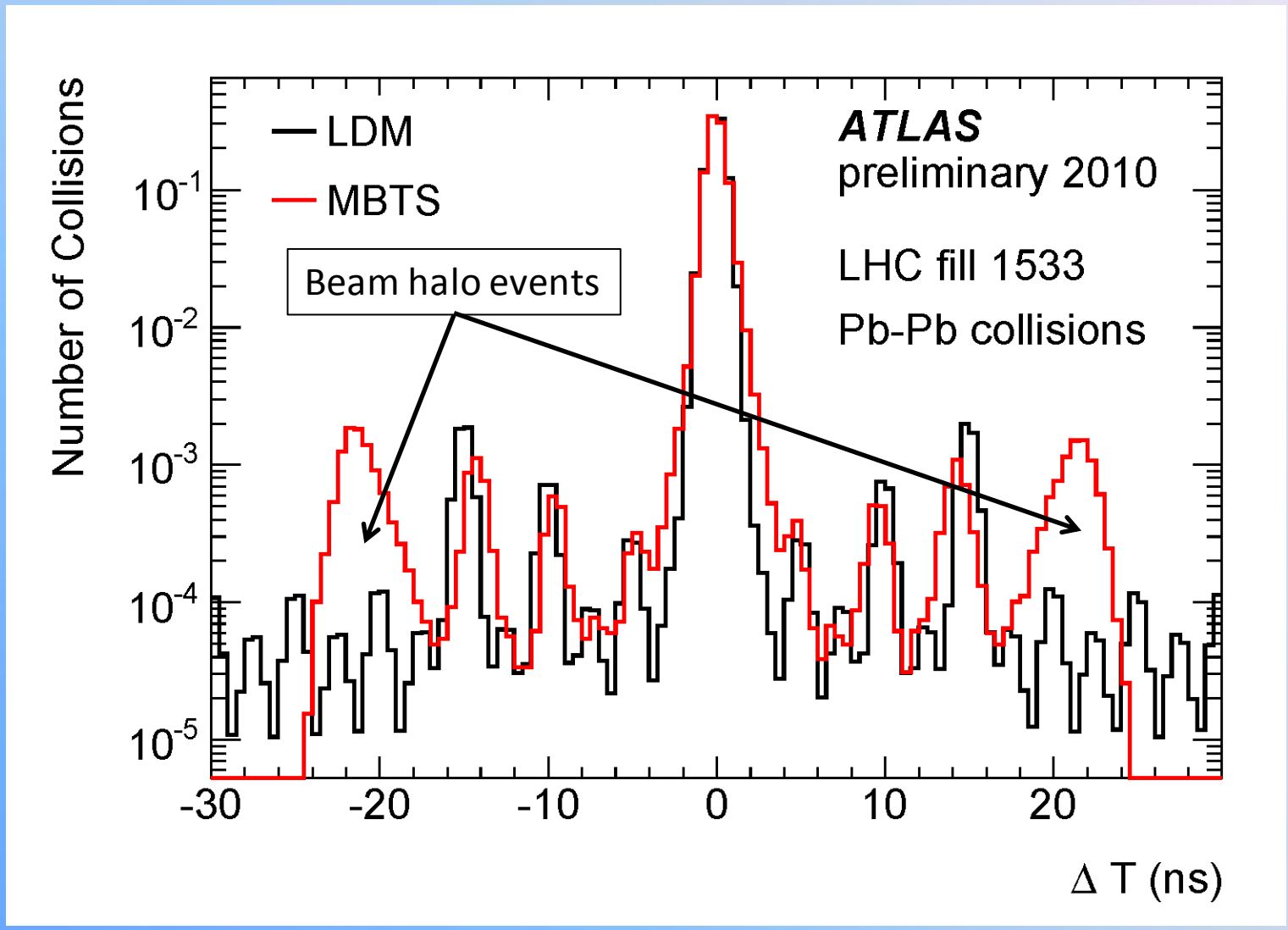
Corrected for deadtime and afterpulsing

Bunch lengths



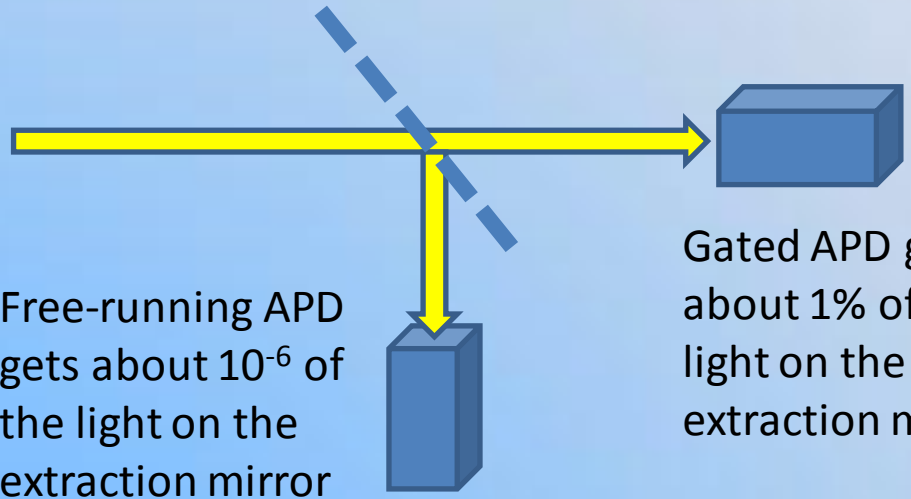
LDM bunch length: Gaussian fit $\oplus$ 90ps LDM time resolution

Satellite Fraction



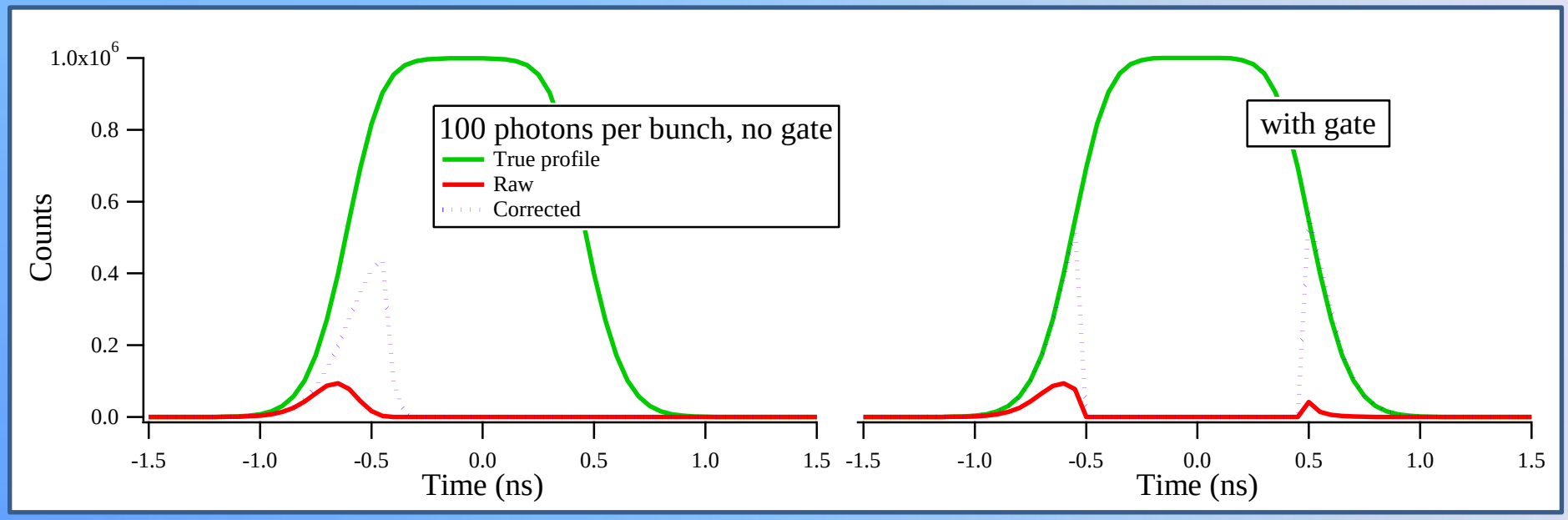
With thanks to Beate Heinemann for the MBTS plot

High-DR scheme

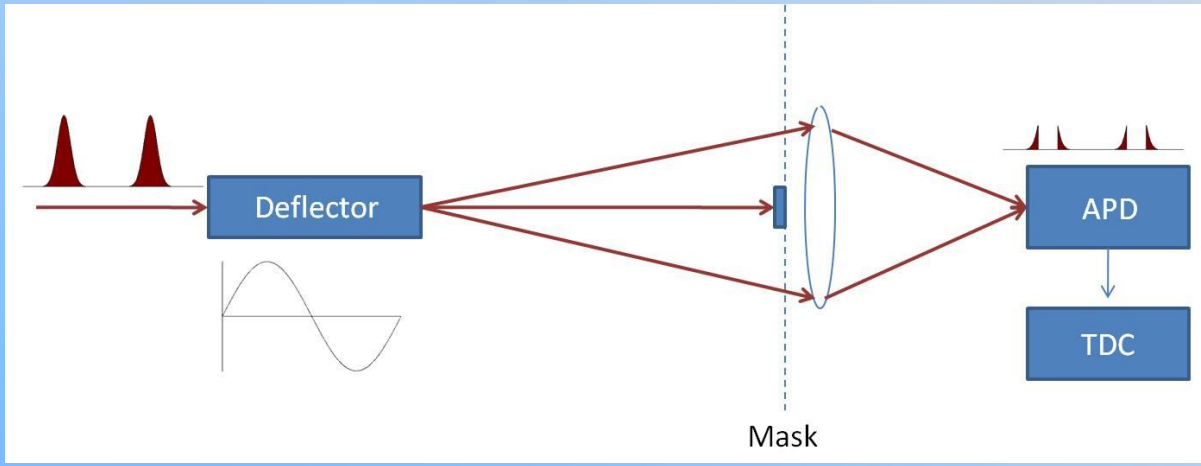


Free-running APD gets about 10^{-6} of the light on the extraction mirror

Gated APD gets about 1% of the light on the extraction mirror

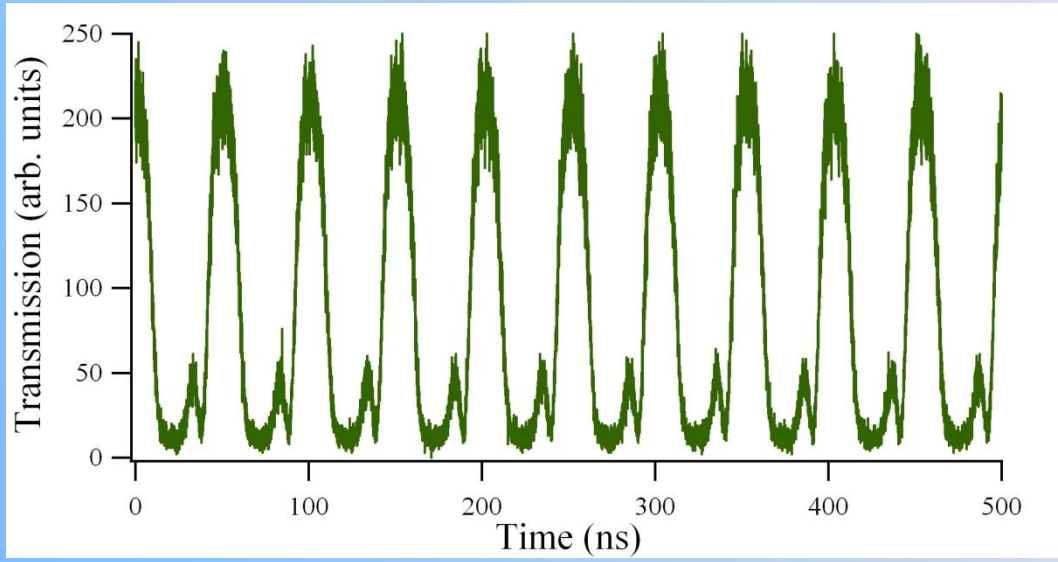


Optical gating

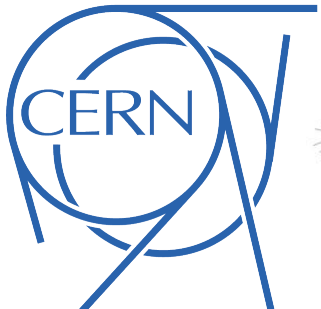


Electro-optic deflector maps longitudinal profile onto transverse plane

First lab test:
Extinction ratio 20:1
Limited by diffraction & driver



Thanks for your attention



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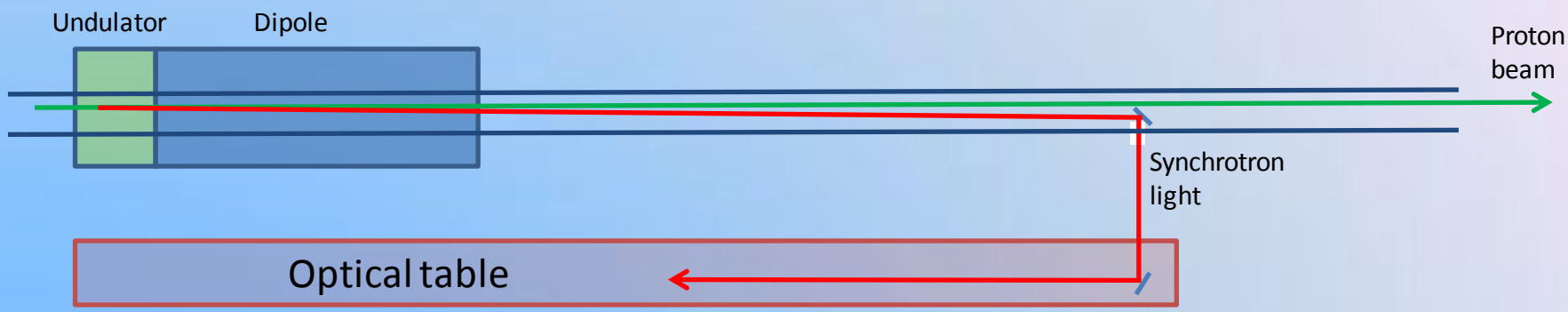
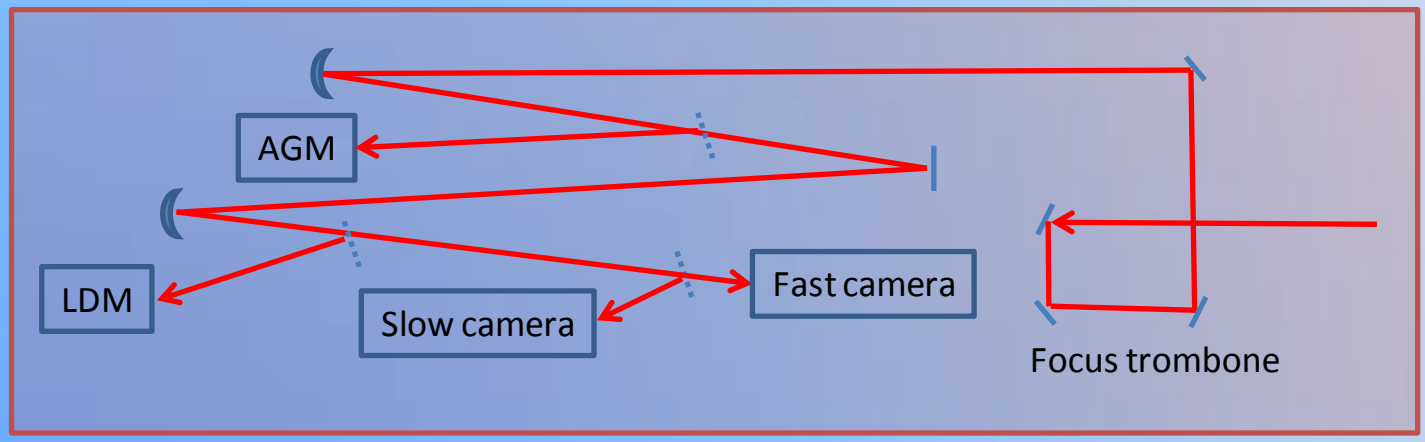
Spare slides

Optical layout

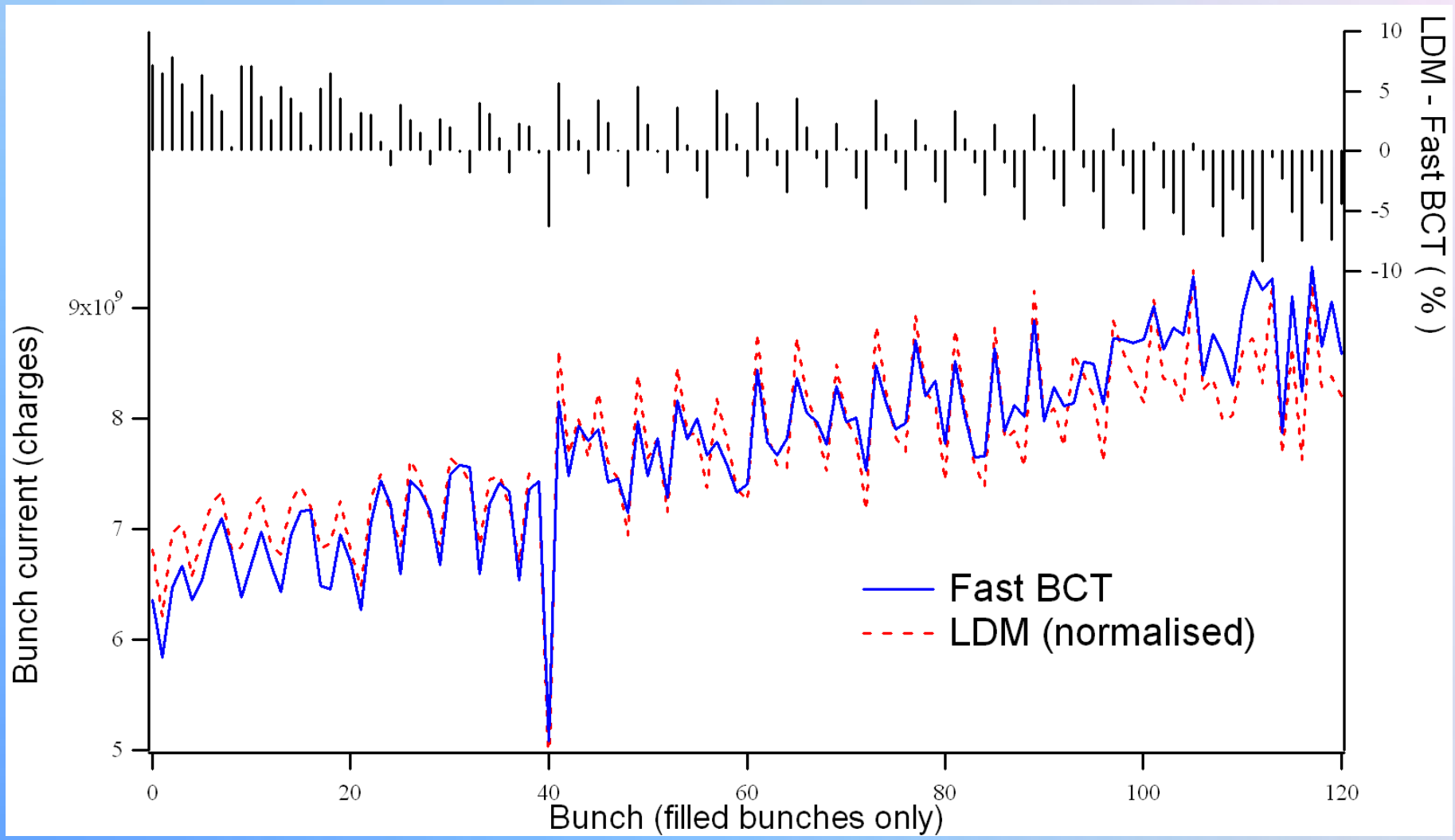




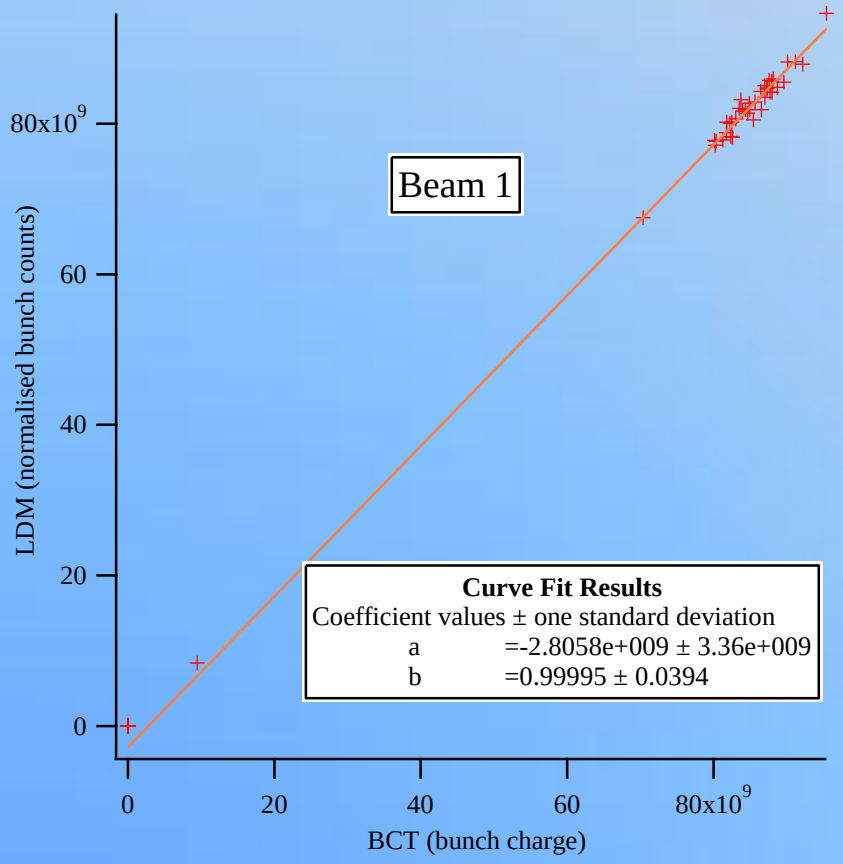
TOP VIEW

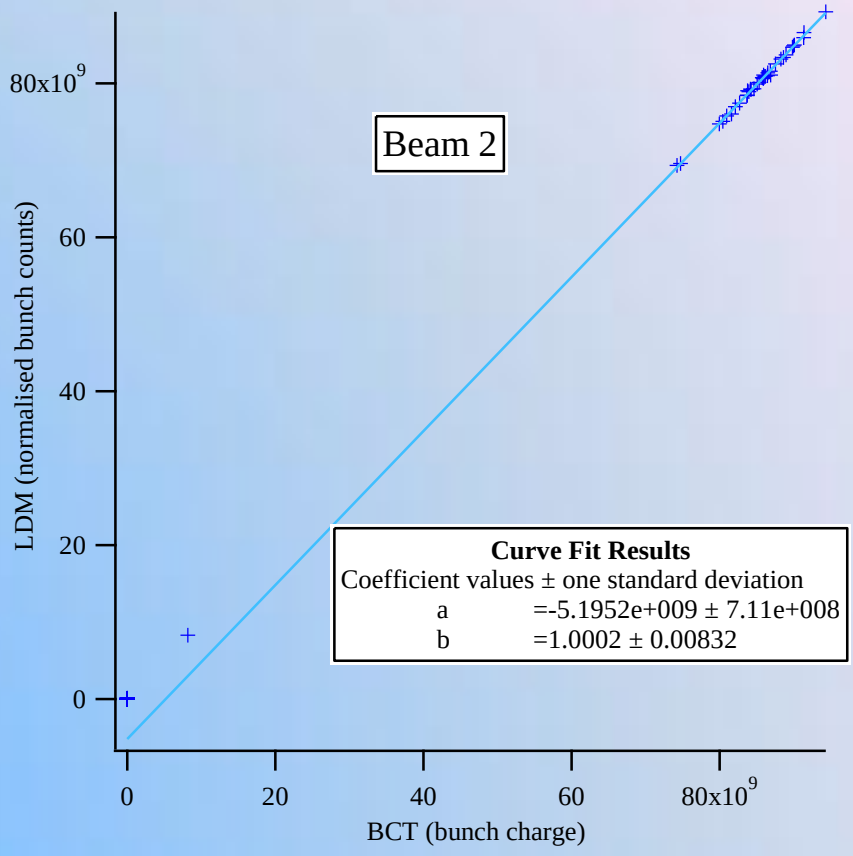
LDM receives 7% of collected light

Bunch currents



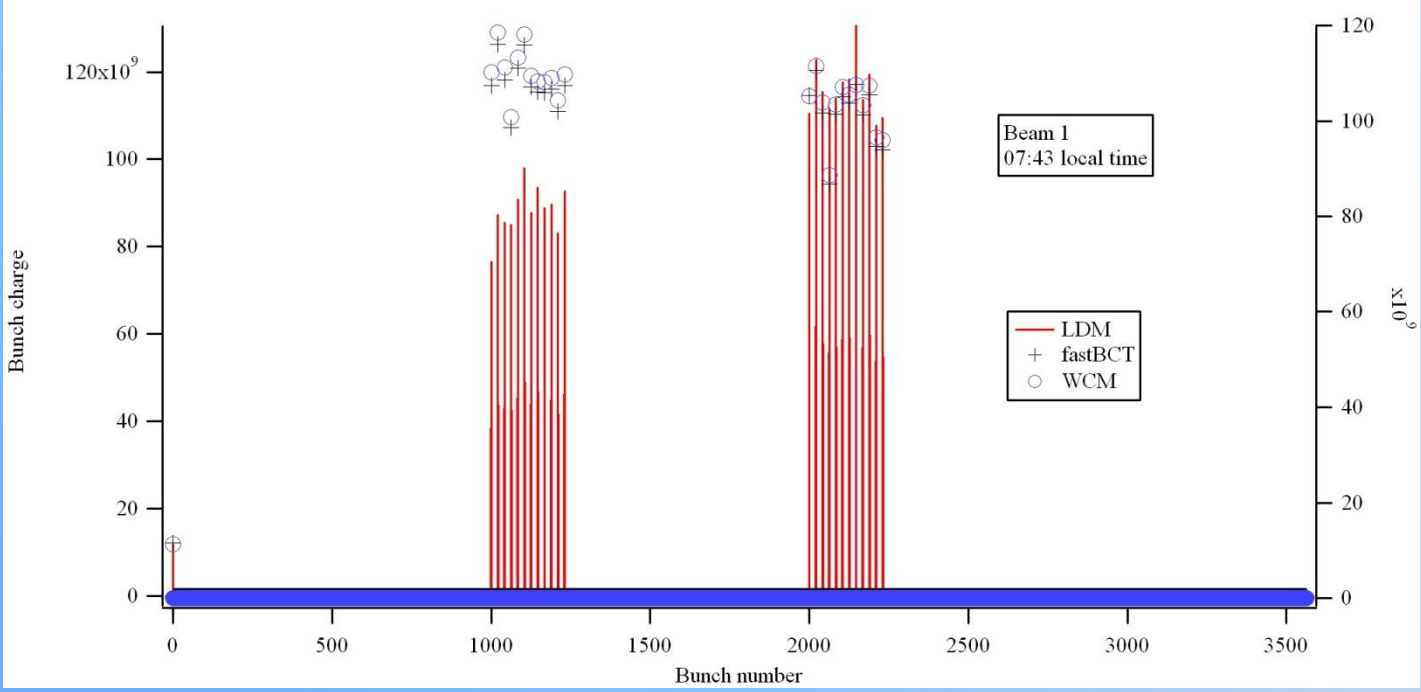
Linearity / offset wrt BCT





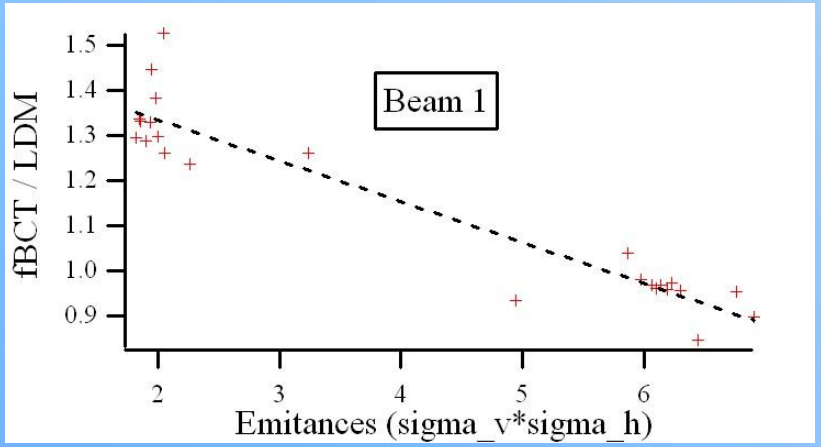
- Fit for nominal bunches only
- Statistical errors only

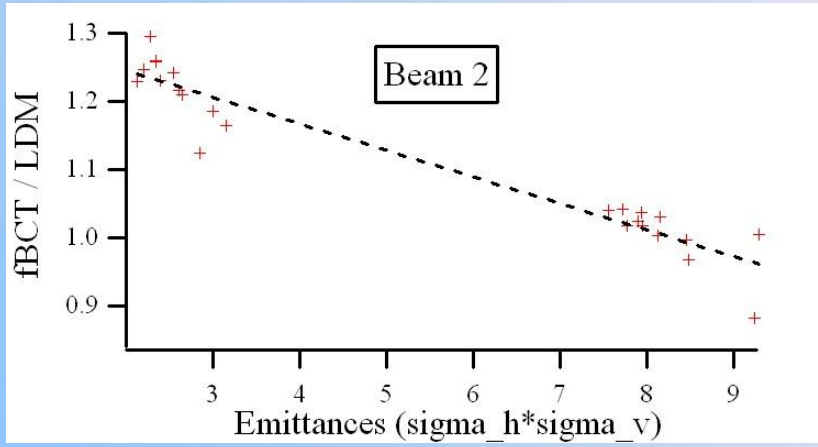
Emittance dependence



- MD with one group of low-emittance bunches and one group with large emittance

Emittance dependence





- Active area of APD is only 50 microns
- Samples only part of the beam spot
- Slope depends on steering of the LDM
- Can be corrected with an optical diffuser