A Longitudinal Density Monitor for the LHC

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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]

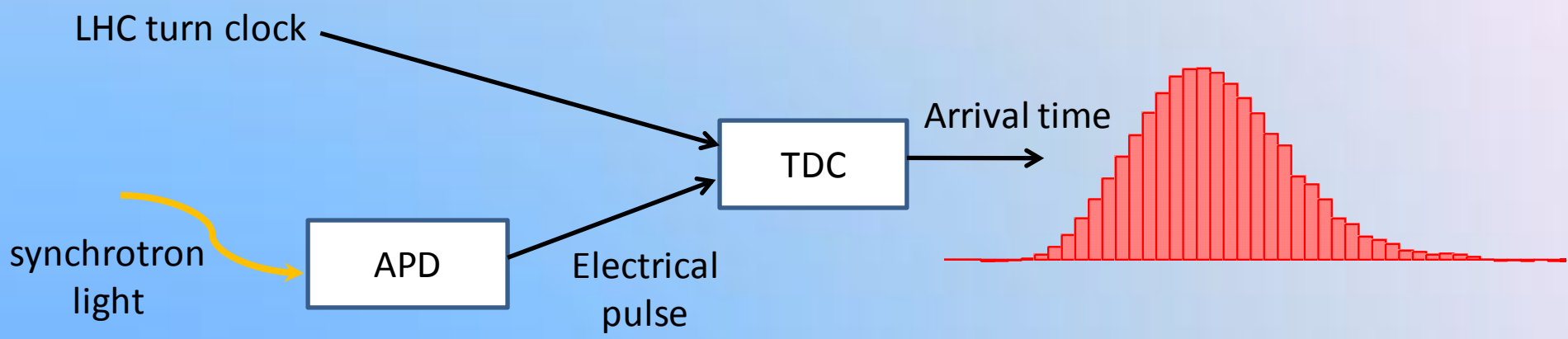
9 out of 10 buckets ***should*** be empty…

…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

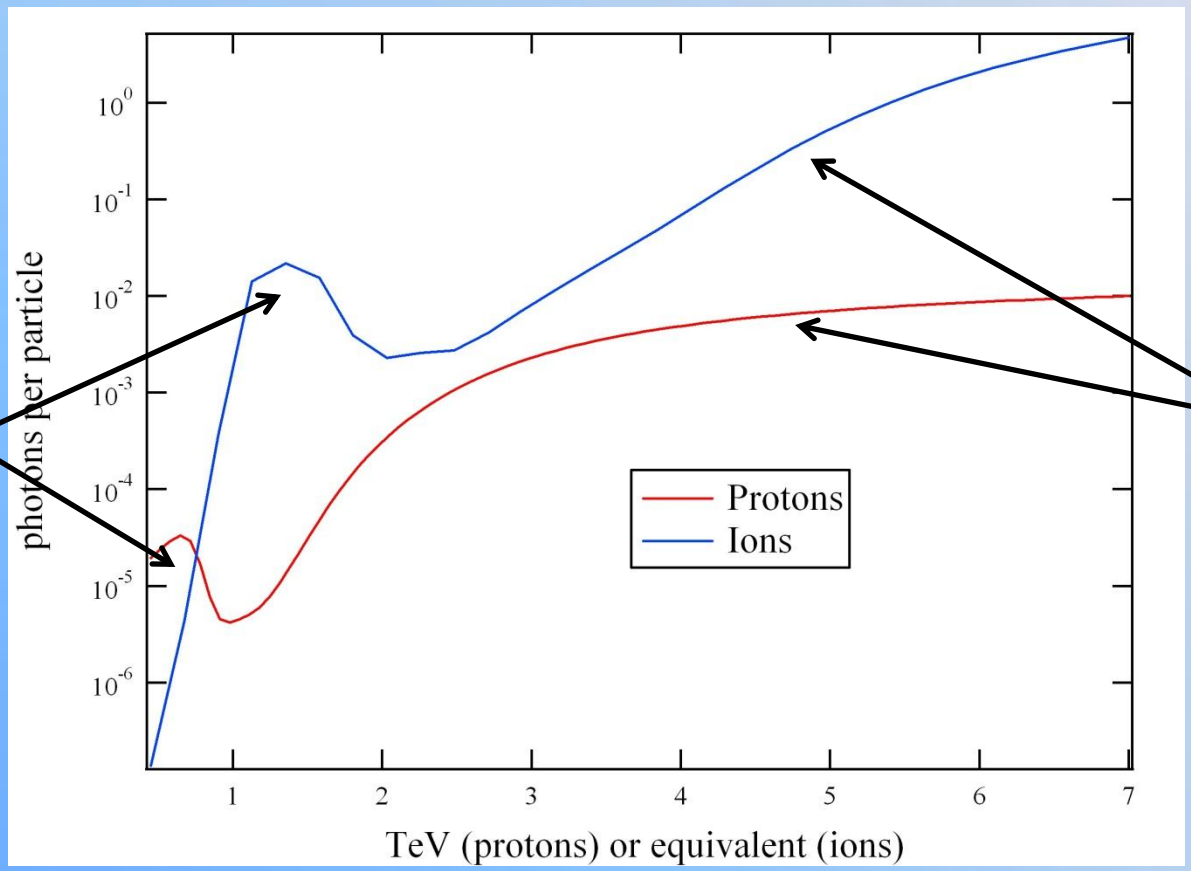


Single photon counting is used to achieve a high dynamic range:

> 10^5 with 15 minutes integration

Synchrotron light from protons…

… and even lead ions!

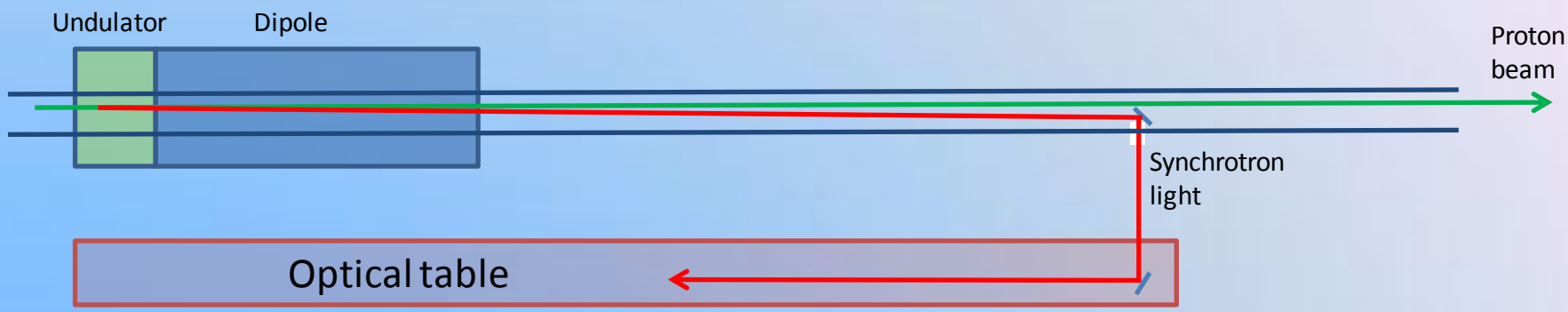


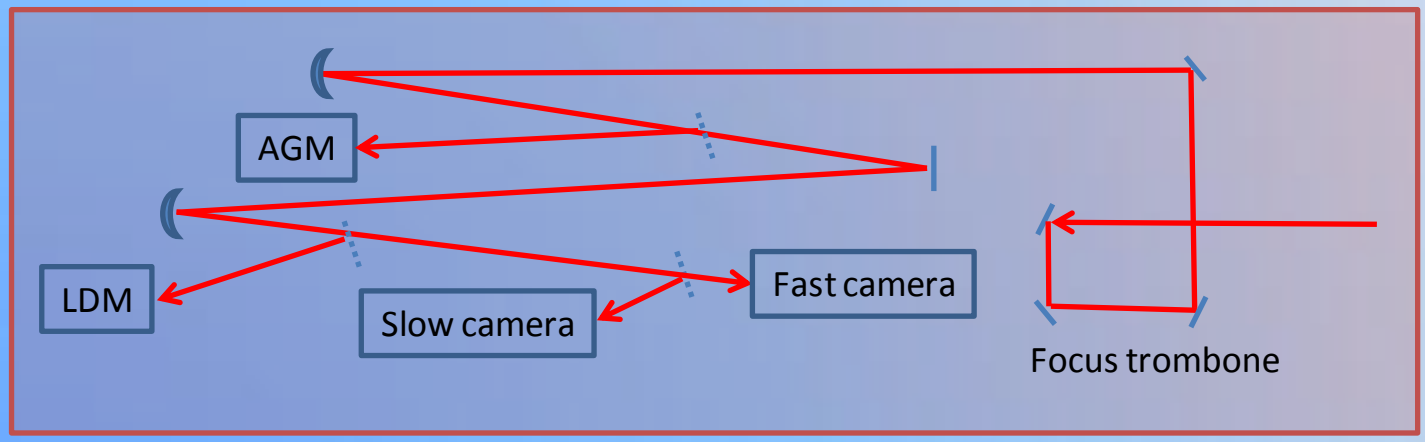
Undulator

Dipole

Dedicated undulator for diagnostics gives visible light at injection

Optical layout

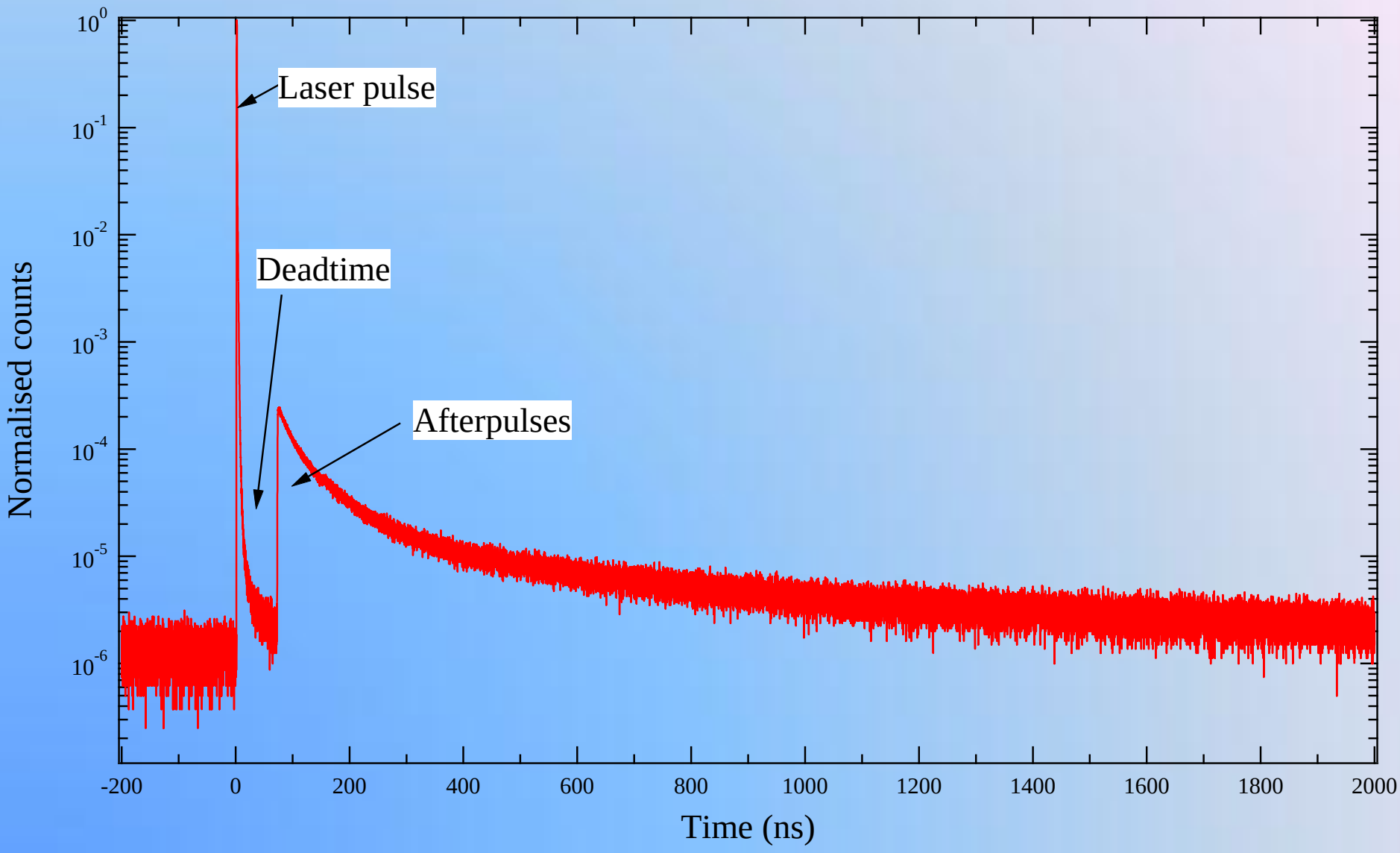




TOP VIEW

LDM receives 7% of collected light

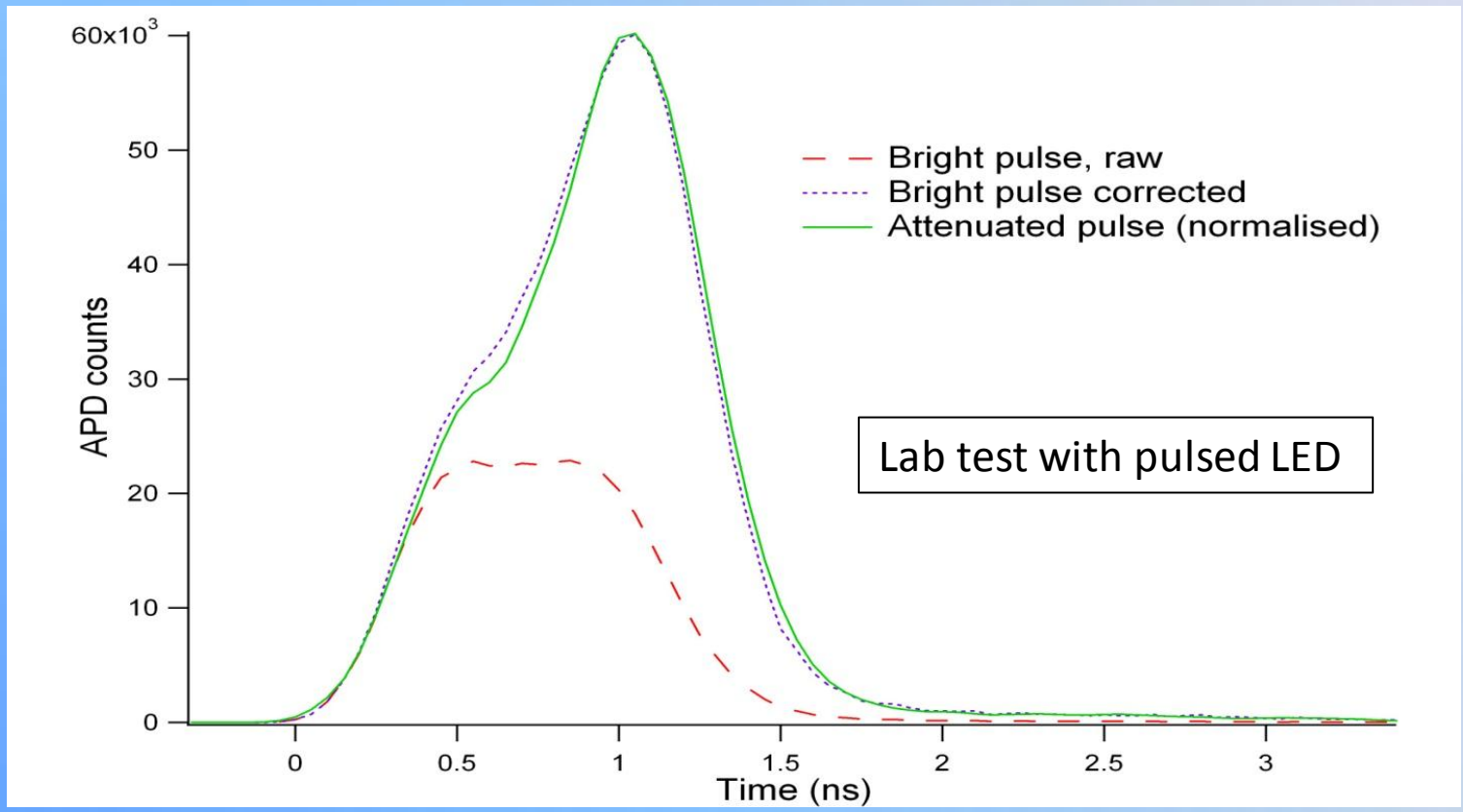
Instrument response



Deadtime Correction

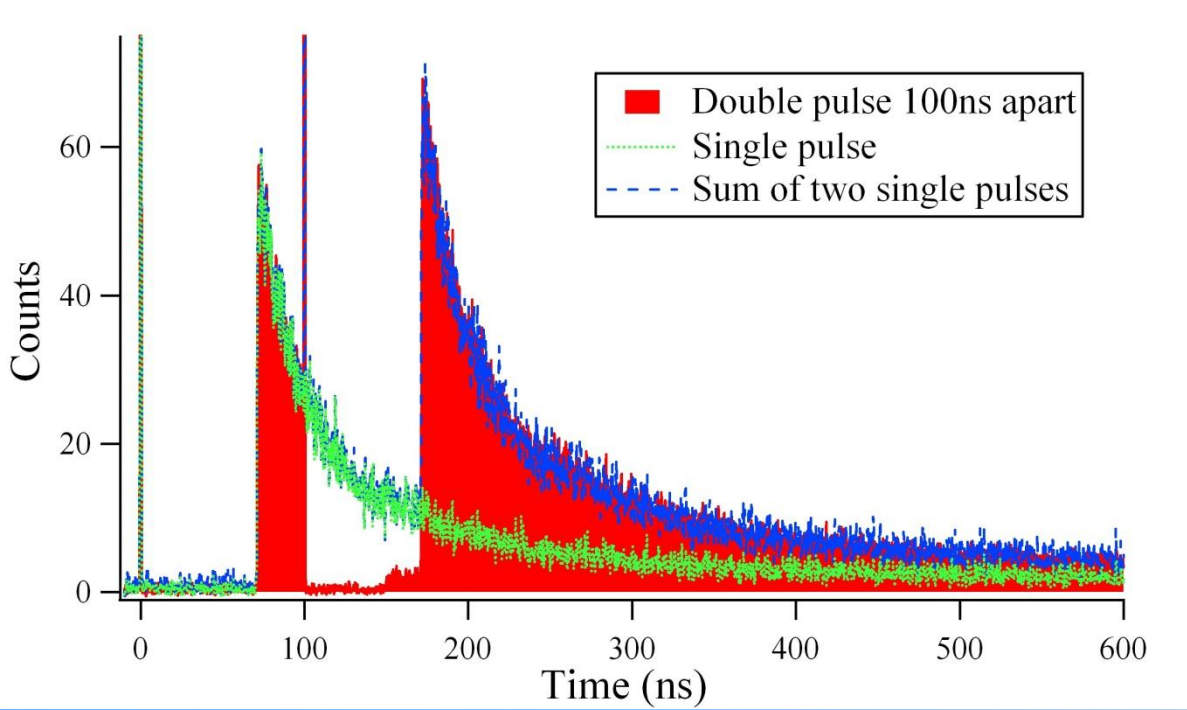
Deadtime correction is essential

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

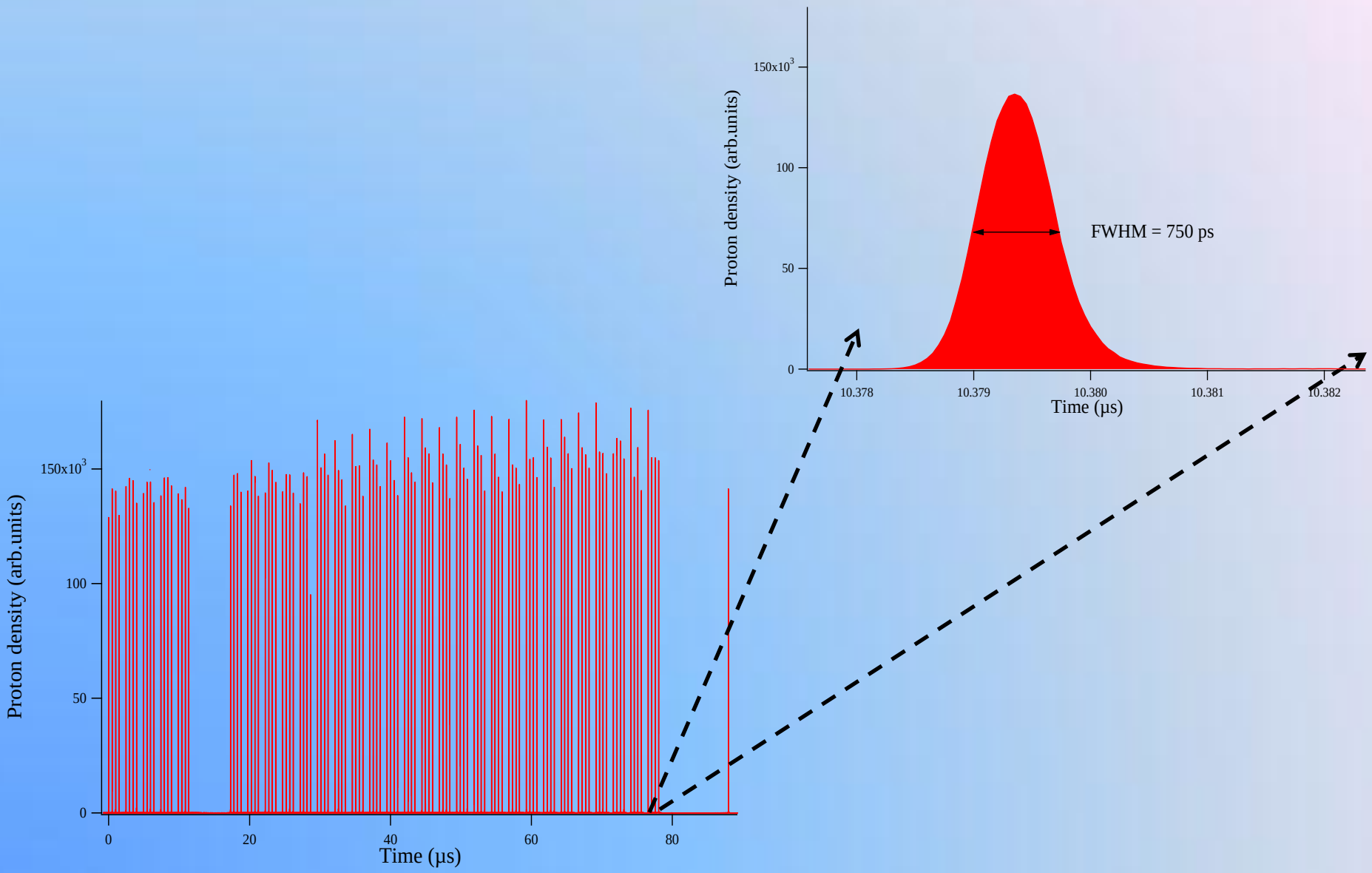


Afterpulse Correction

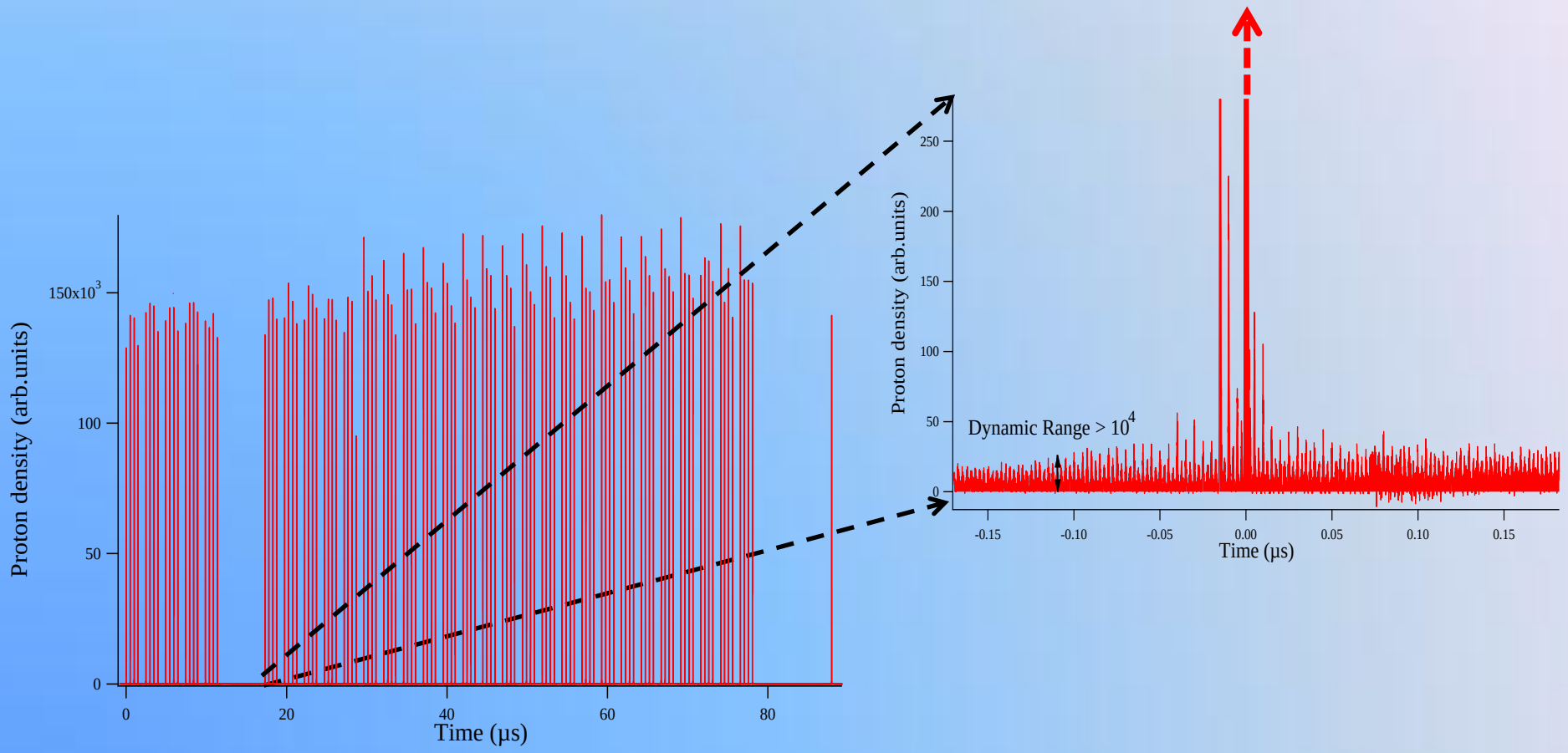
- Afterpulses occur due to charge carriers trapped in the silicon
- Start at end of deadtime but continue for many µs
- Fit by sum of multiple exponentials
- Afterpulses are additive

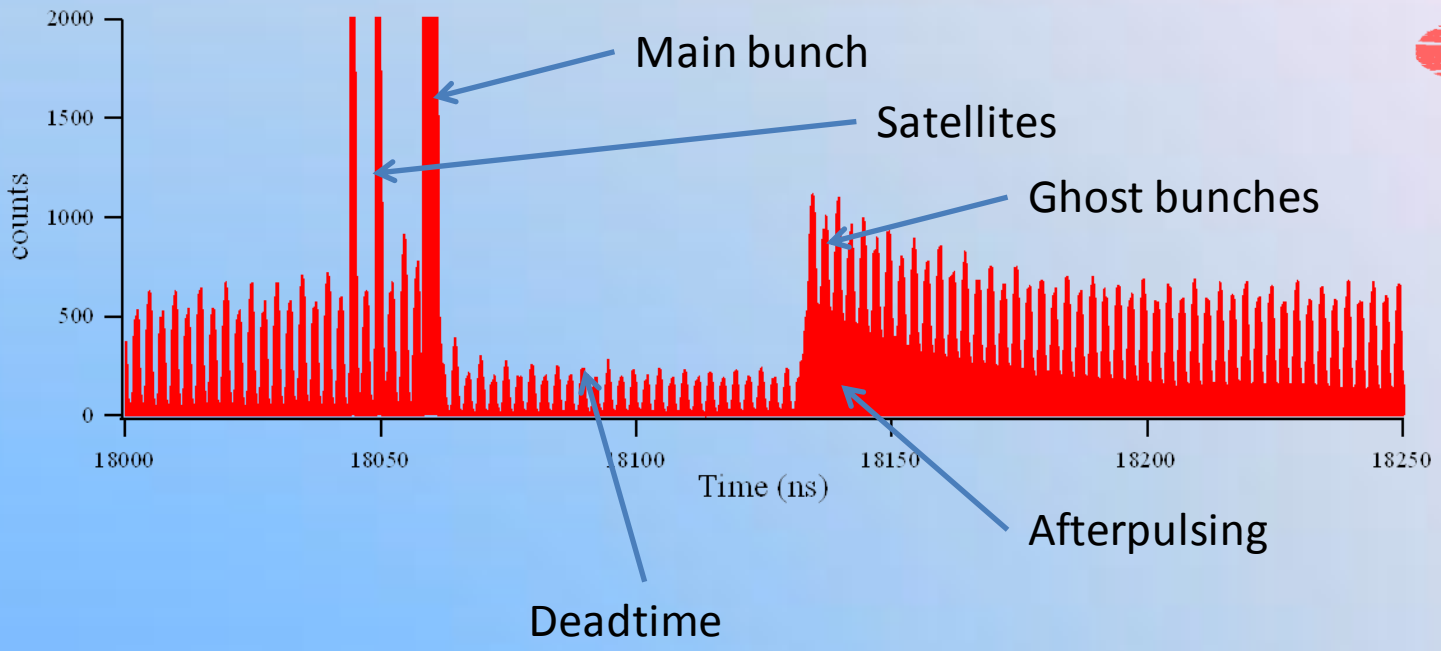


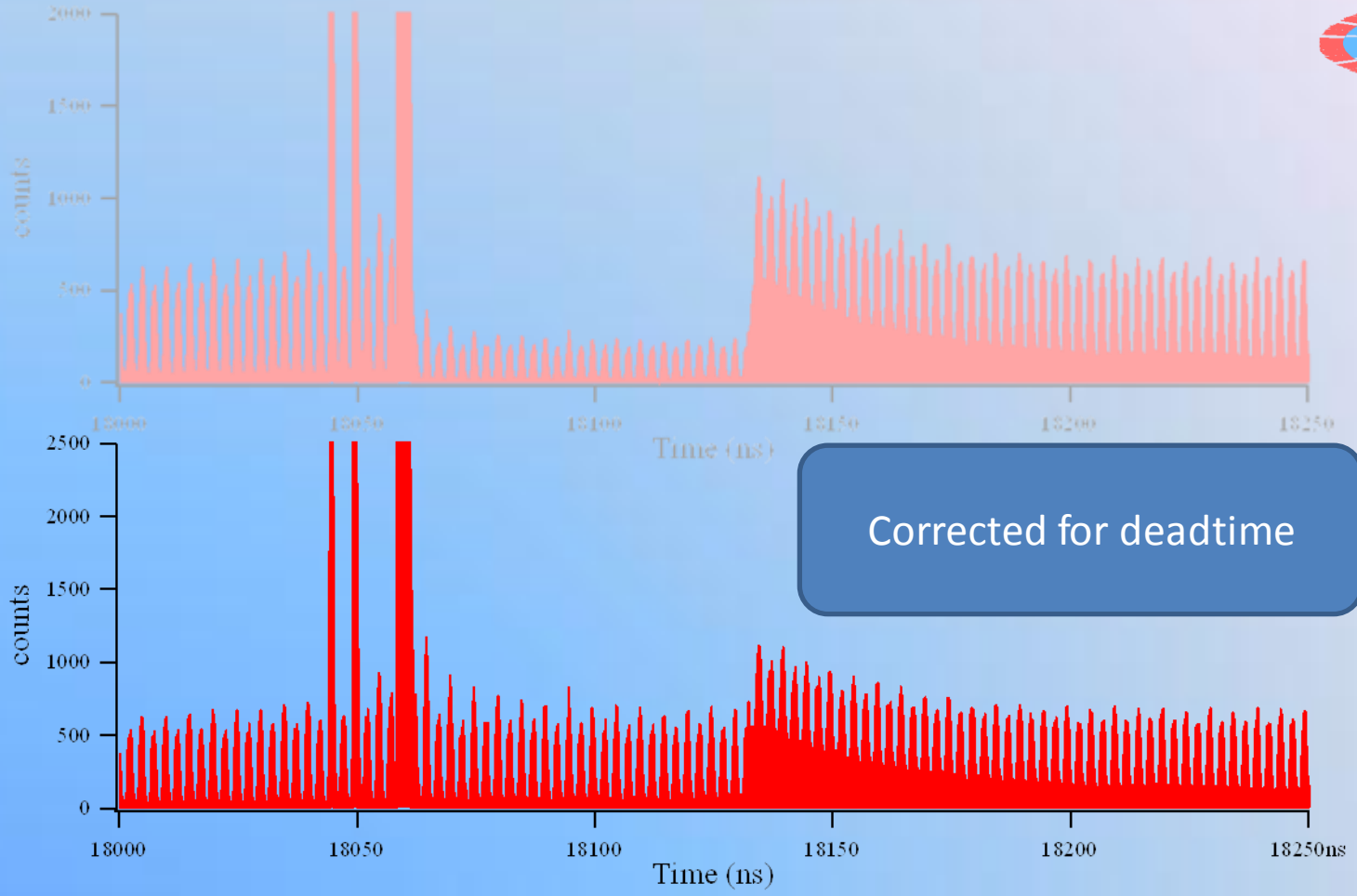
Results


150x10^3
100
50
0
Proton density (arb.units)
0
20
40
60
80
Time (μs)
FWHM = 750 ps
10.378
10.379
10.380
10.381
10.382
Time (μs)

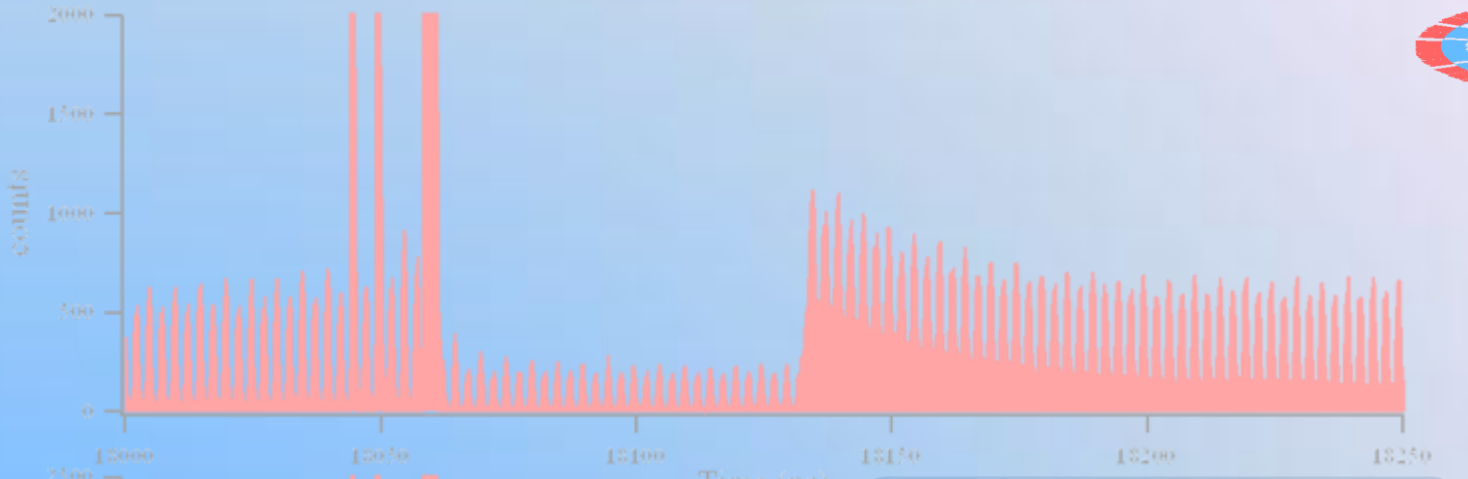
Results

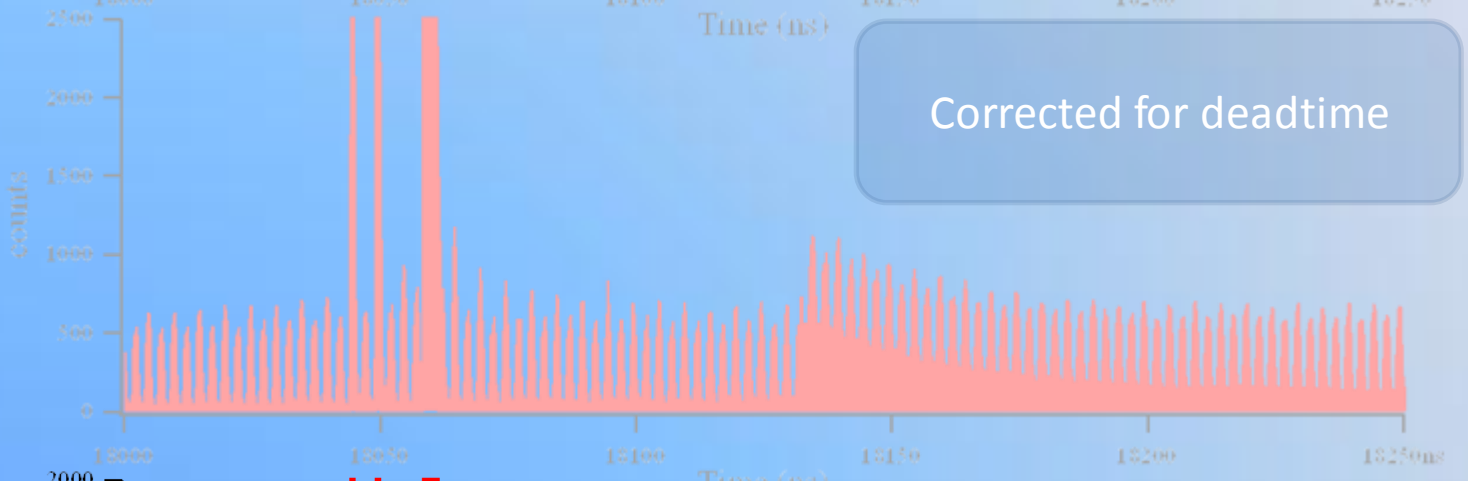

Proton density (arb.units)
150x10^3
100
50
0
0
20
40
60
80
Time (µs)
Proton density (arb.units)
250
200
150
100
50
0
Dynamic Range > 10^4
-0.15
-0.10
-0.05
0.00
0.05
0.10
0.15
Time (µs)


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

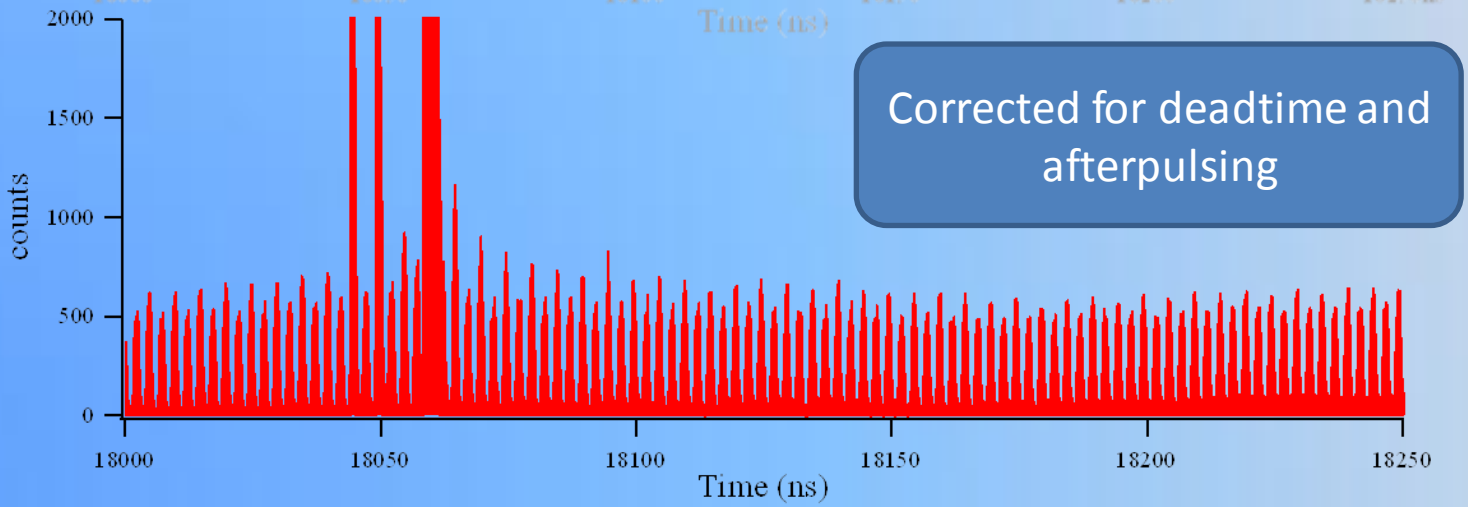


Corrected for deadtime



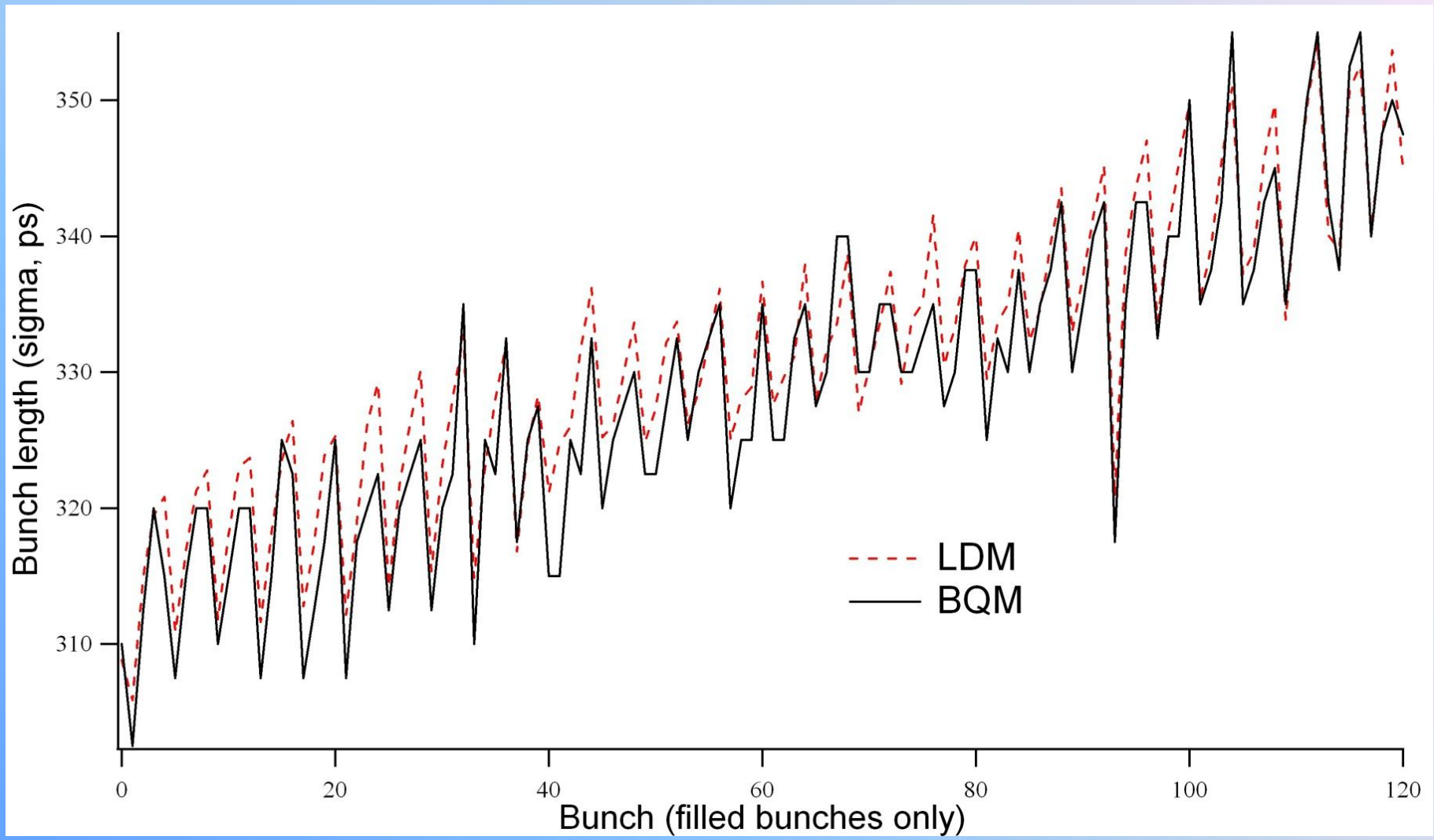


Corrected for deadtime

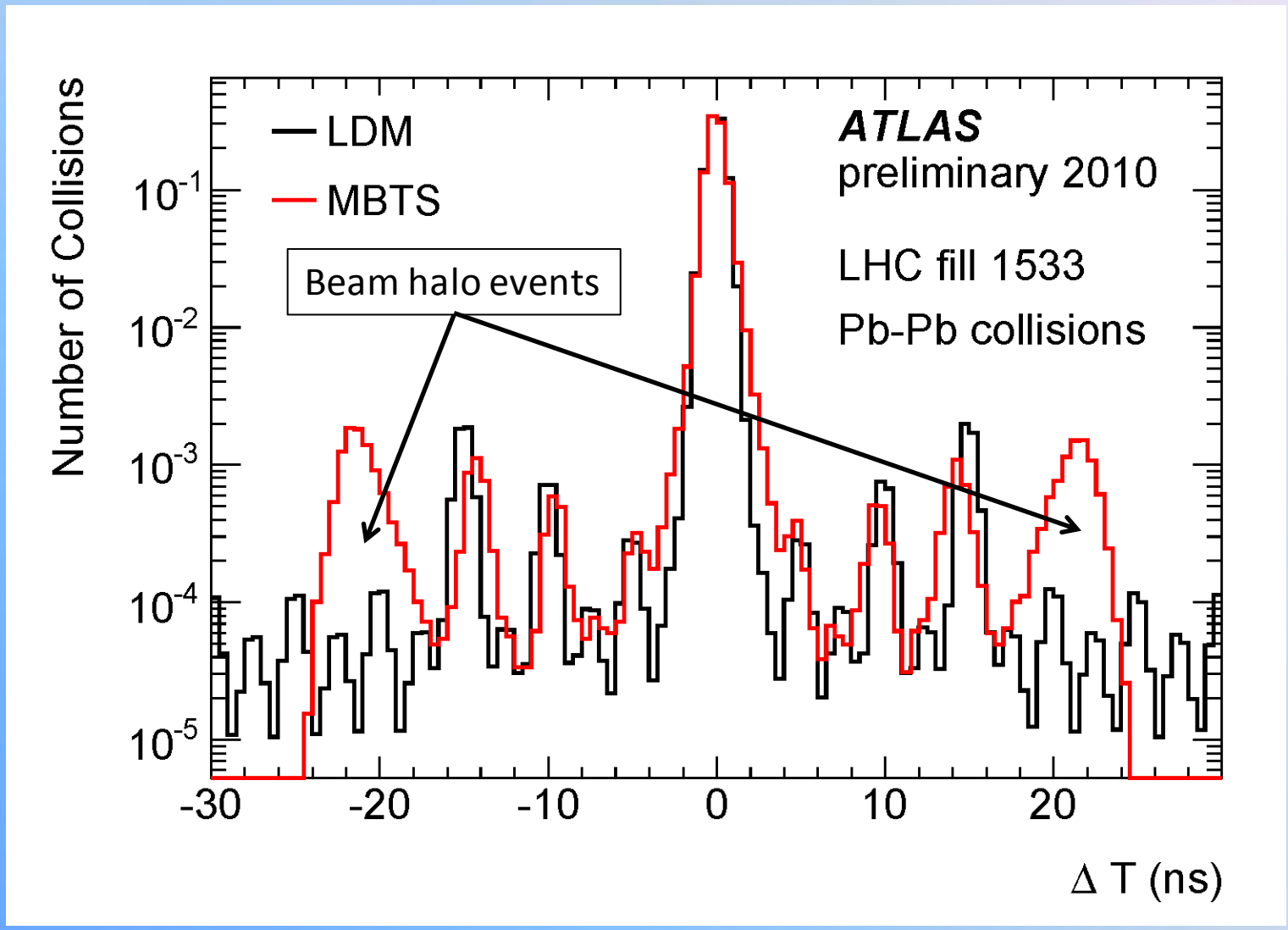


Corrected for deadtime and afterpulsing

Bunch lengths

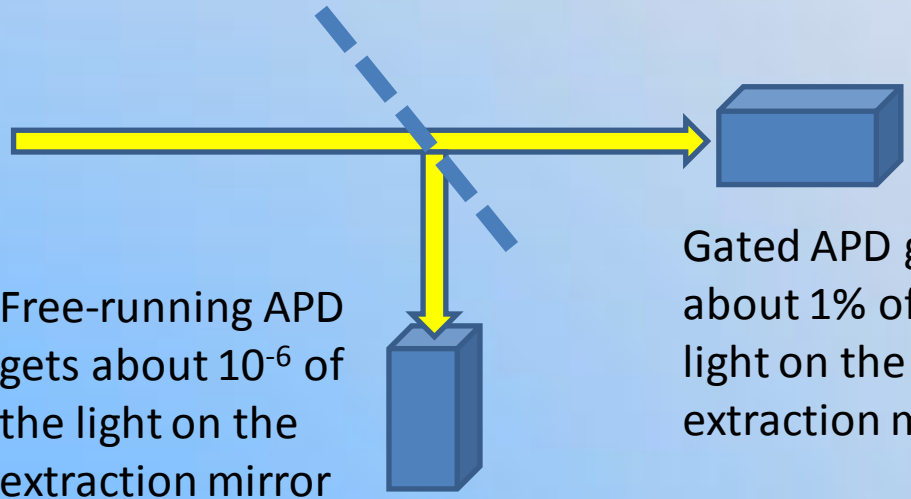


Satellite Fraction



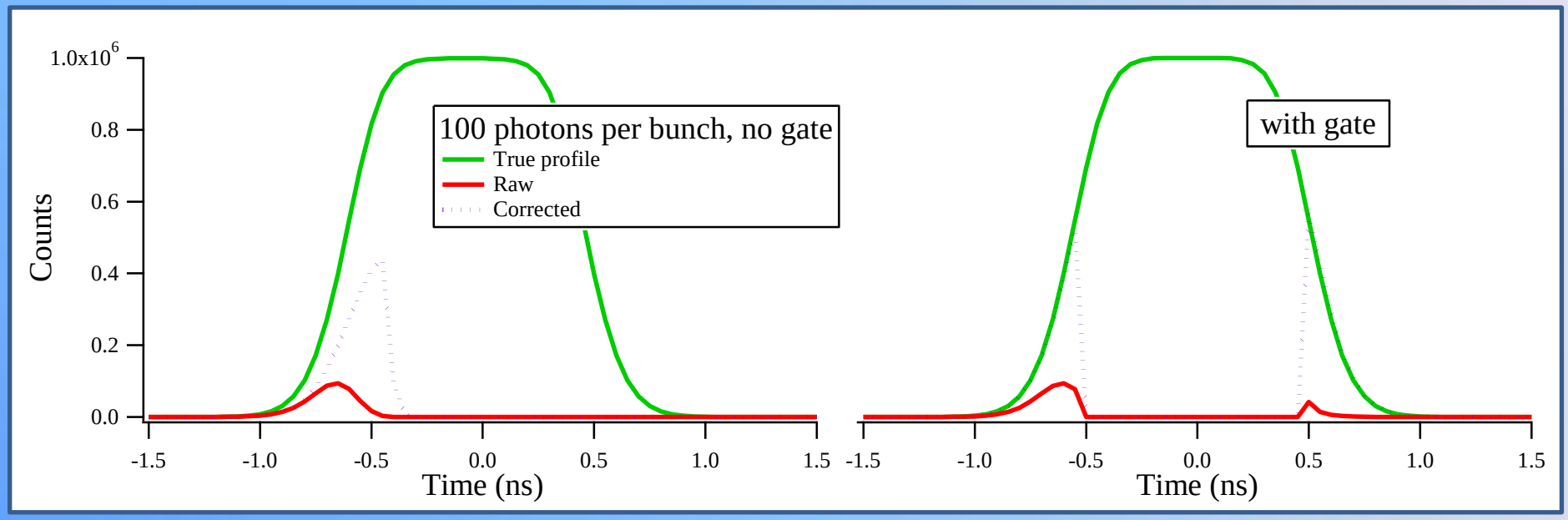
With thanks to Beate Heinemann for MBTS the plot

High-DR scheme

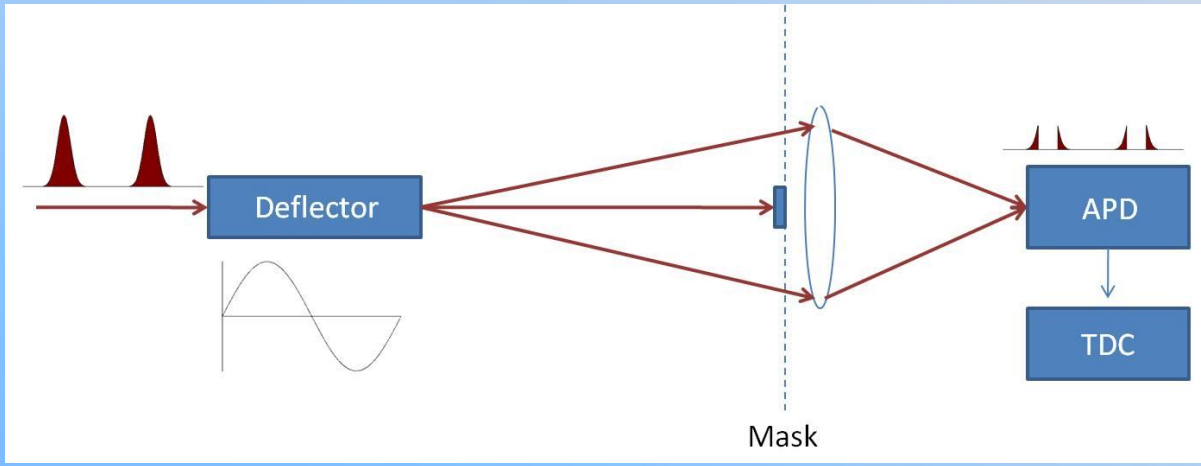


Free-running APD gets about 10^{-6} of the light on the extraction mirror

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

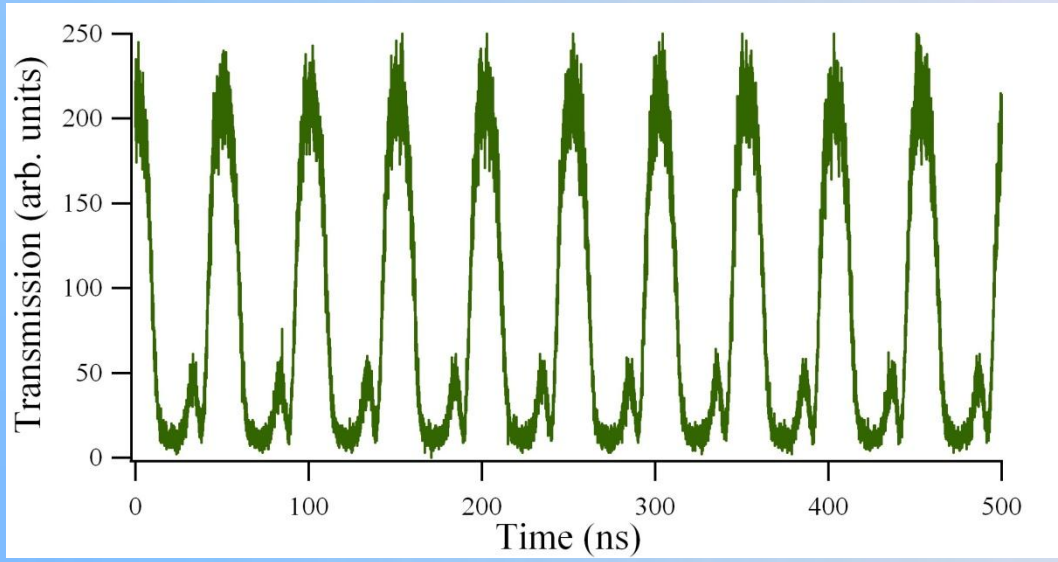


Optical gating

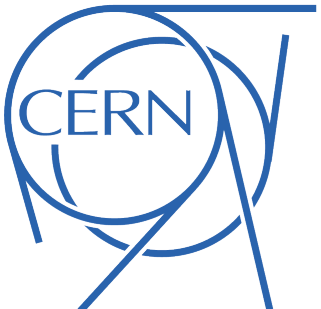


Electro-optic deflector maps longitudinal profile onto transverse plane

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

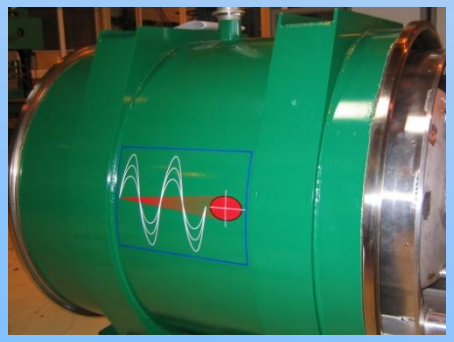


Thanks for your attention



Spare slides

Schematic



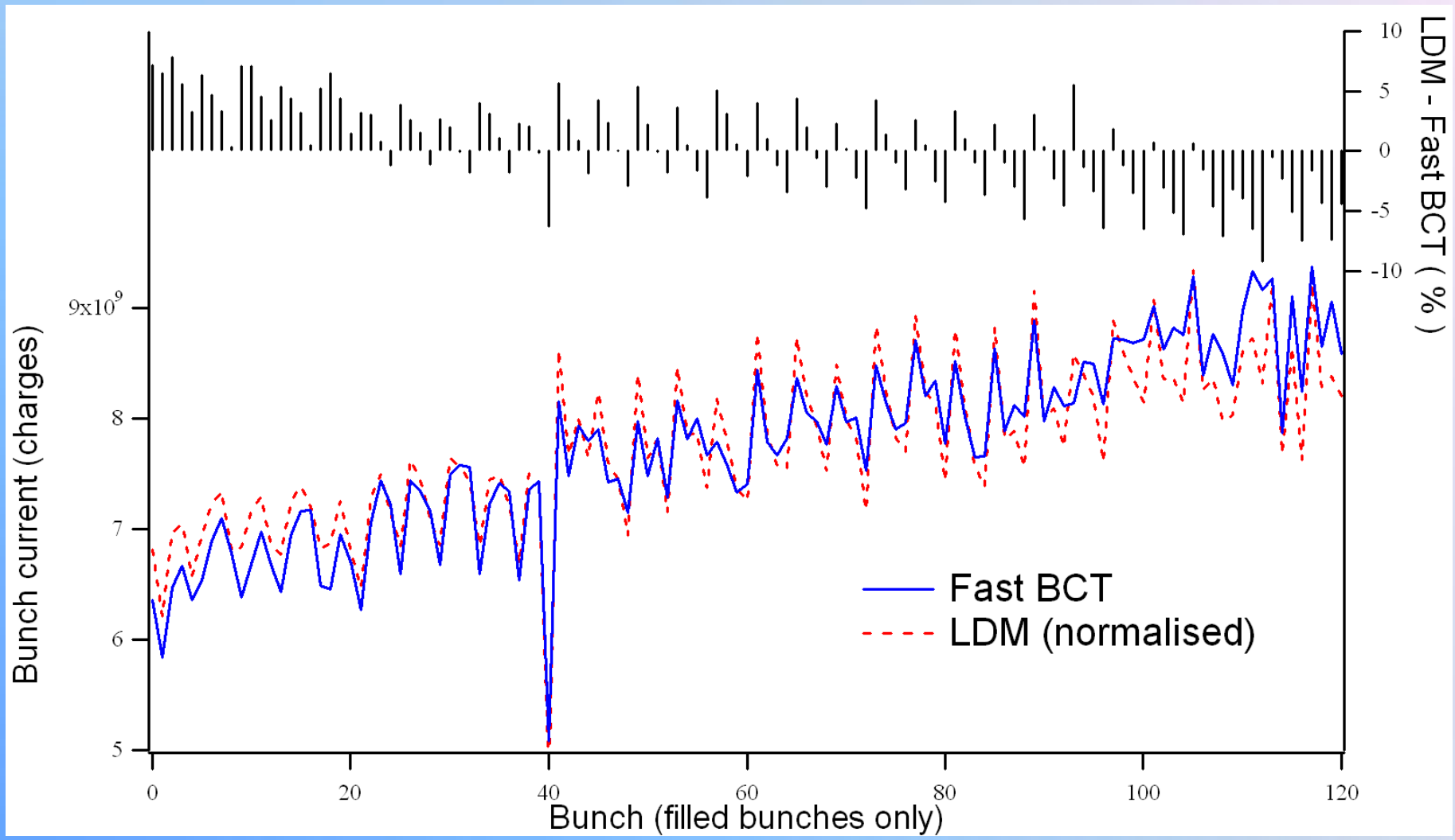
Synchrotron light from undulator and dipole

Geiger-mode Avalanche photodiode converts photon to electrical pulse

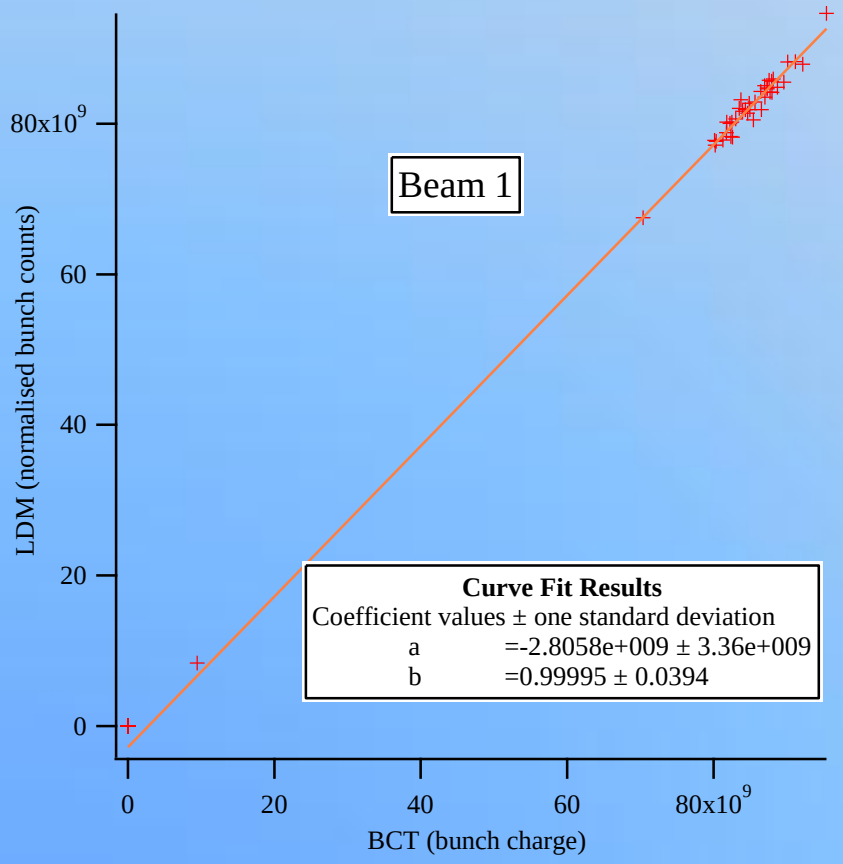
Time to Digital converter records pulse arrival time

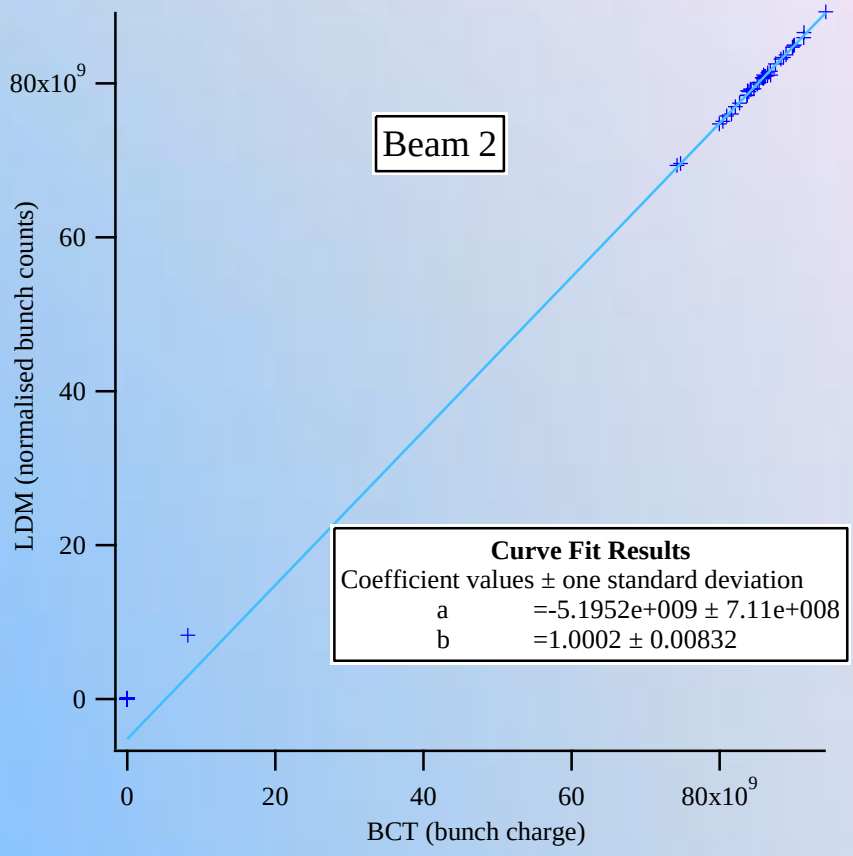
cPCI computer makes histogram and corrects for APD dead-time and afterpulsing

Bunch currents



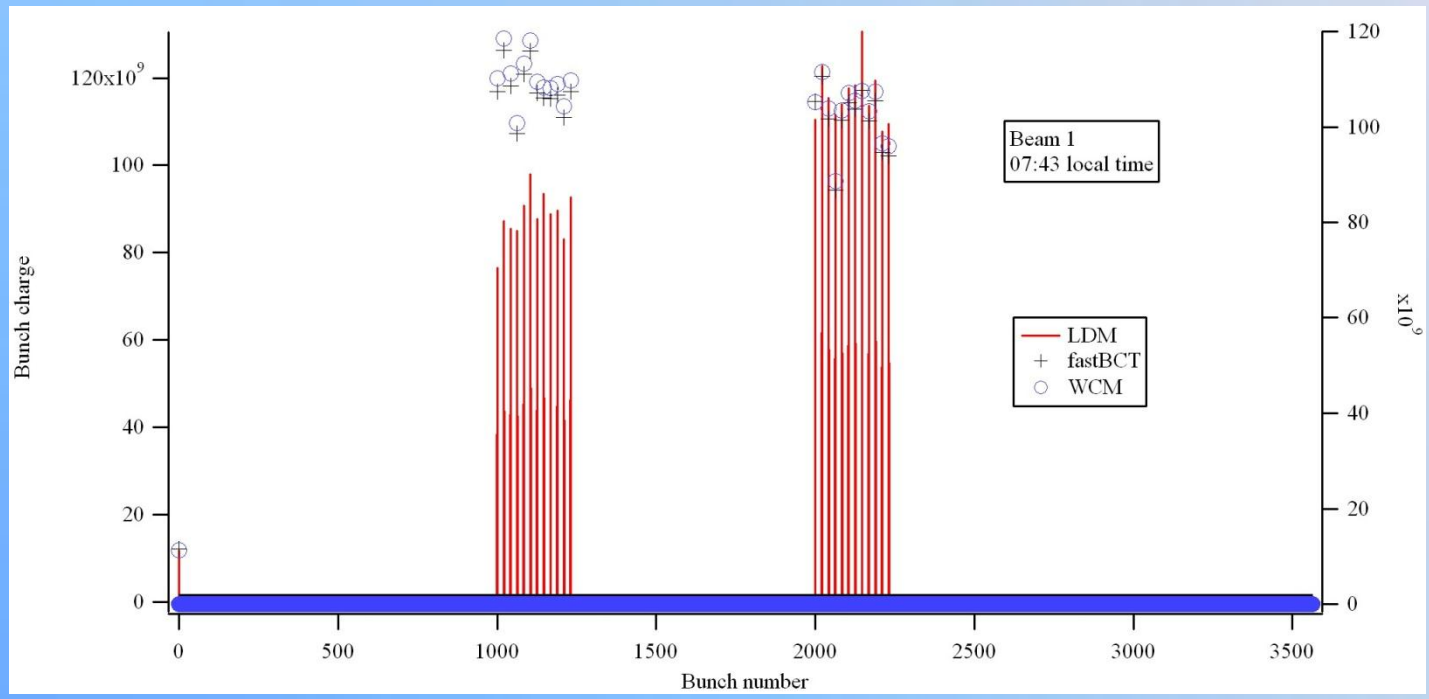
Linearity / offset wrt BCT





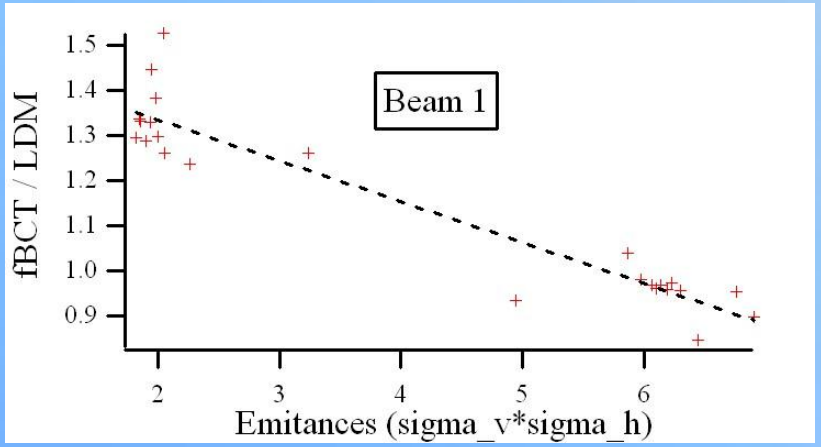
- Fit for nominal bunches only
- Statistical errors only

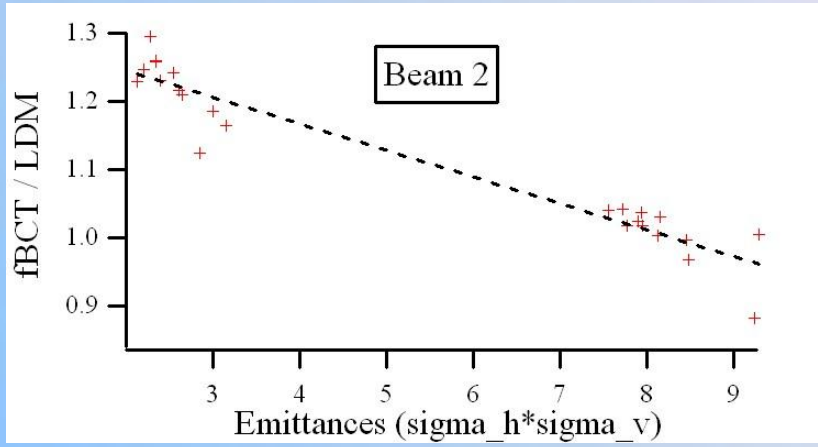
Emittance dependence



- 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