Digital Signal Processing Techniques to Monitor Bunch-by-bunch Beam Positions in the LHC for Machine Protection Purposes

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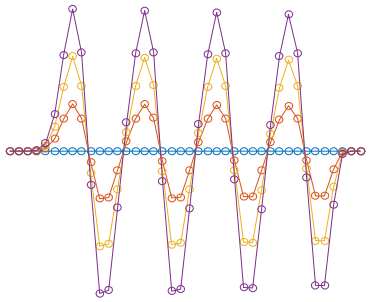
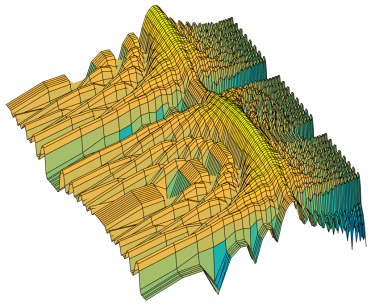


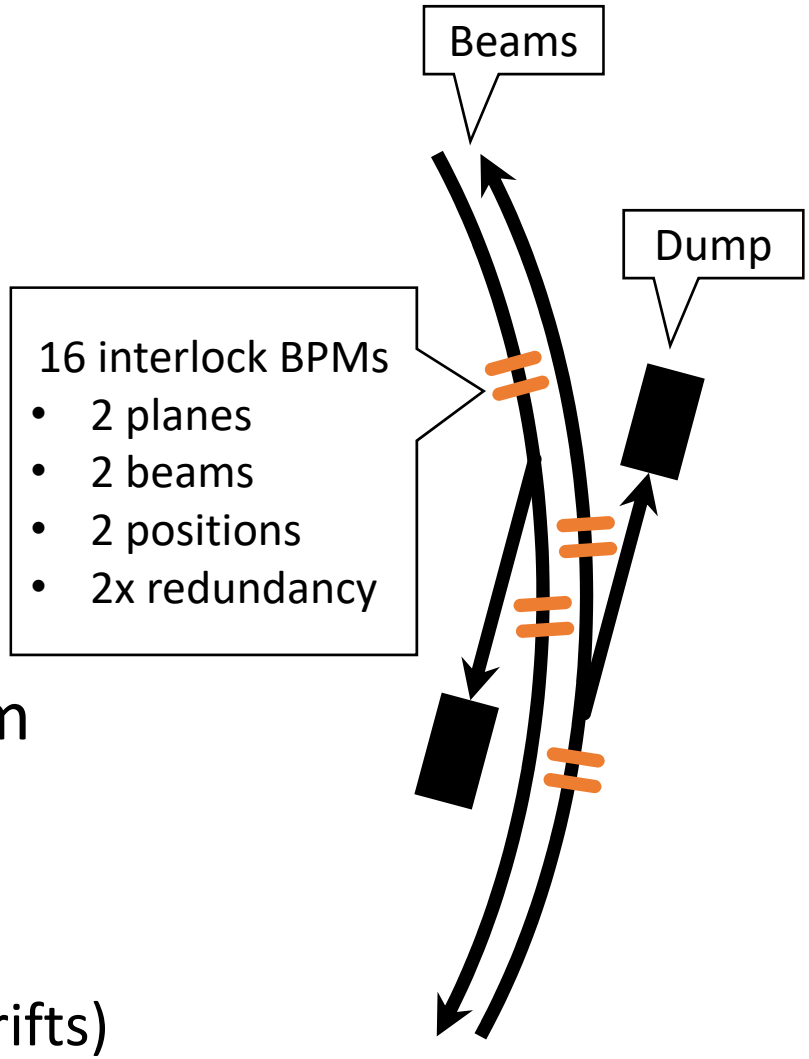


Outline

- Introduction
- Chosen Approach
- Performance Estimation
- Prototype Performance

Introduction

- LHC interlock BPM system
  - Protects beam dump, by checking beam position
  - Real time, bunch-by-bunch, failsafe system
- Limitations of present system
  - Bunch spacing > 25 ns (5 ns doublets !)
  - Variable position offset (due to aging, temperature drifts)



System Requirements

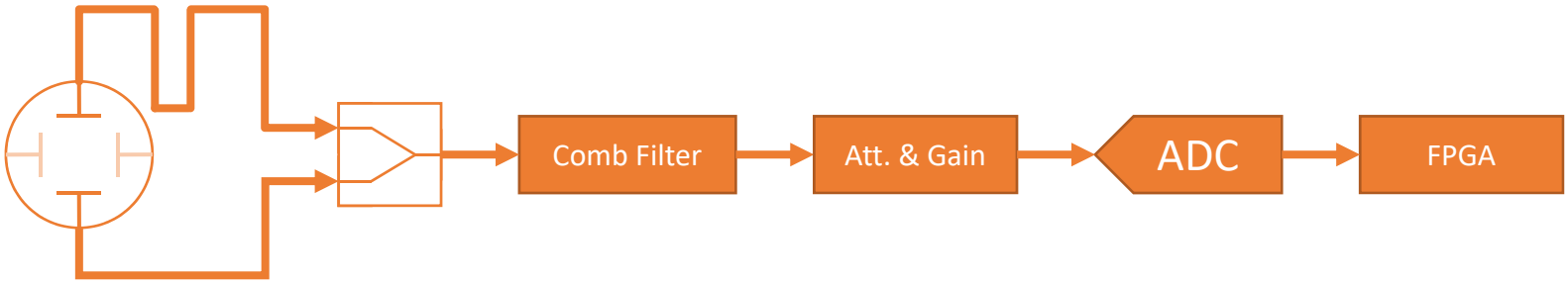
Single bunch:
- Protons
  1.5×10^{9} – 3×10^{11} cpb
- Ions
  1×10^{9} – 5×10^{10} cpb

- Bunch-by bunch measurement
- Cover whole intensity range
  - One fill without gain switching: 1×10^{10} – 2×10^{11} cpb
- Position
  - Beam-dump threshold: ~ 3 mm
  - To be covered at least 2x more: ± 7.5 mm
- Resolution in given range: < 100 µm

Chosen Approach

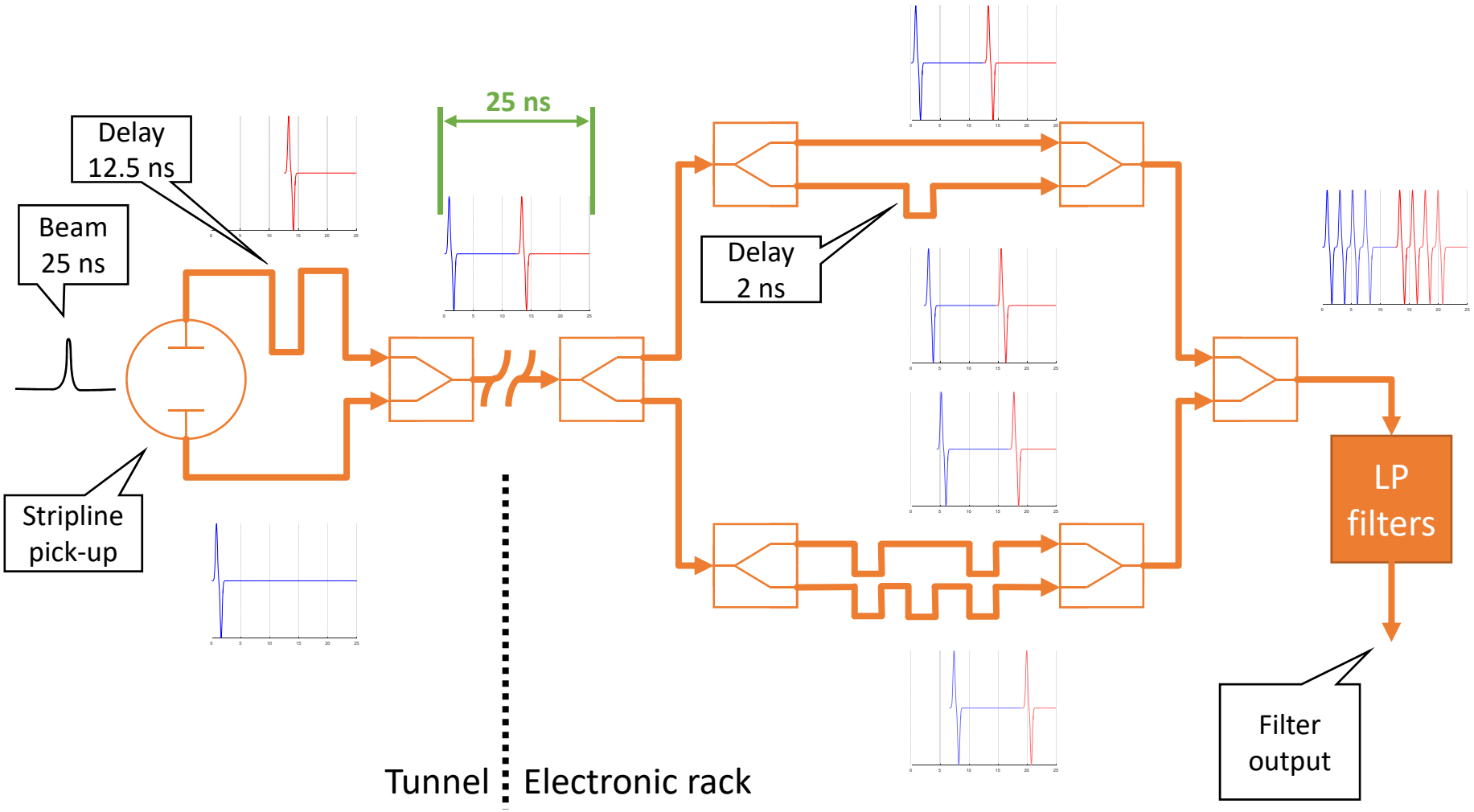
Chosen Approach – Overview

- One chain for both electrodes in one plane
  - Minimize drifts and aging problems

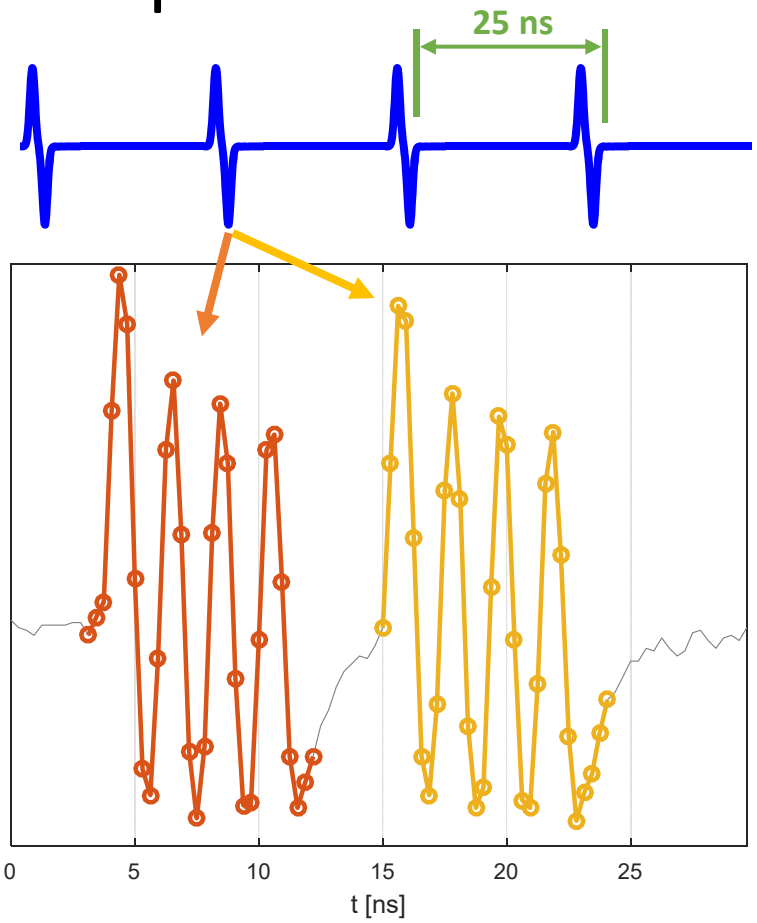


- Direct digitization by fast ADC
  - Prototype with Texas Instruments ADC12J4000
    12 bits, 3.2 GSa/s, ~ 8.7 ENOB

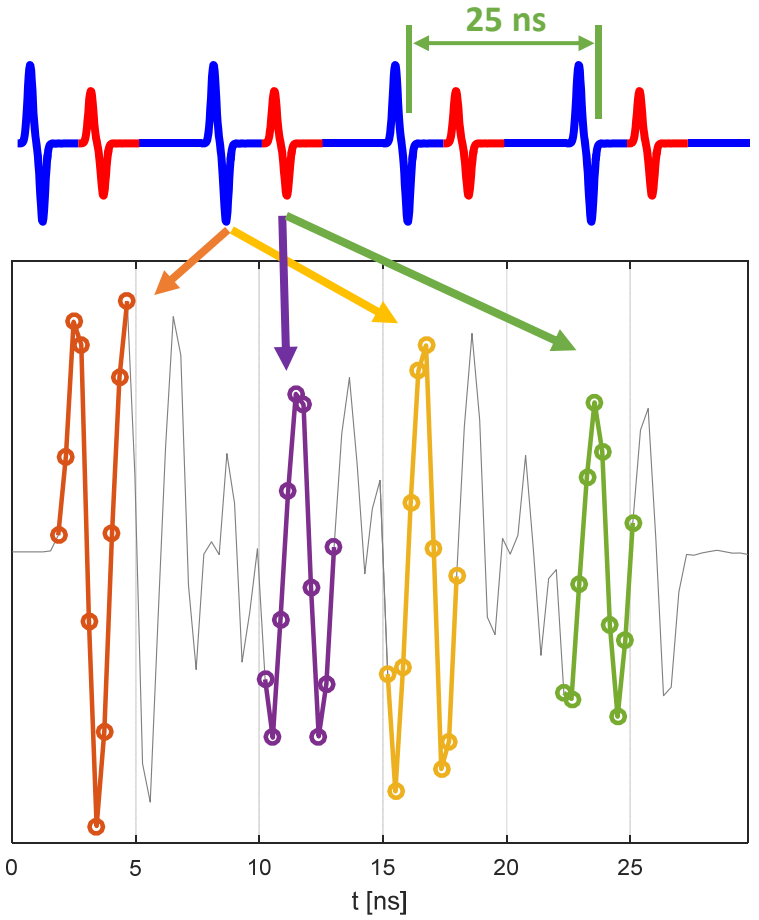
Band-pass Comb Filter



Expected ADC data



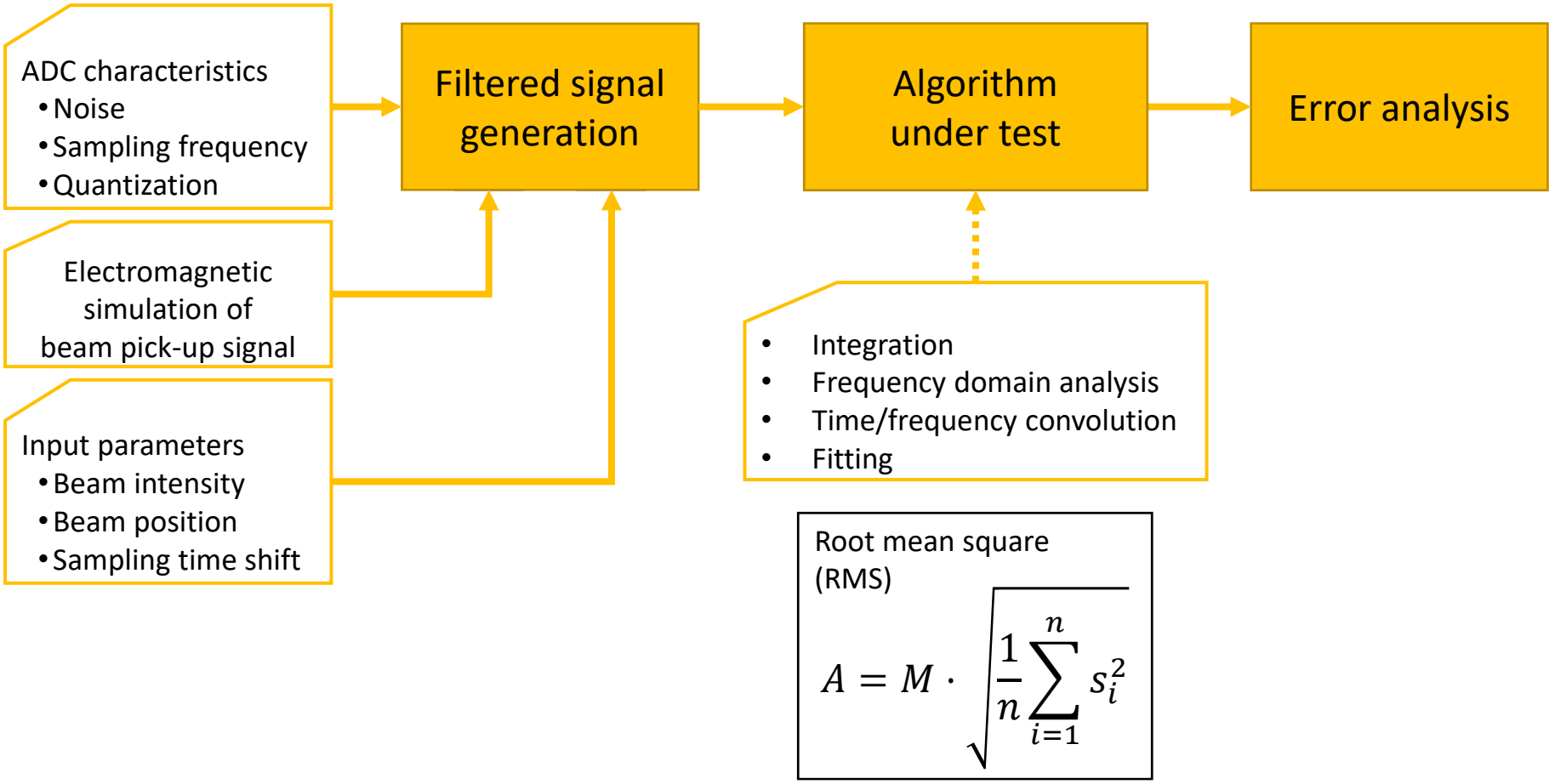
Single bunch (measured)



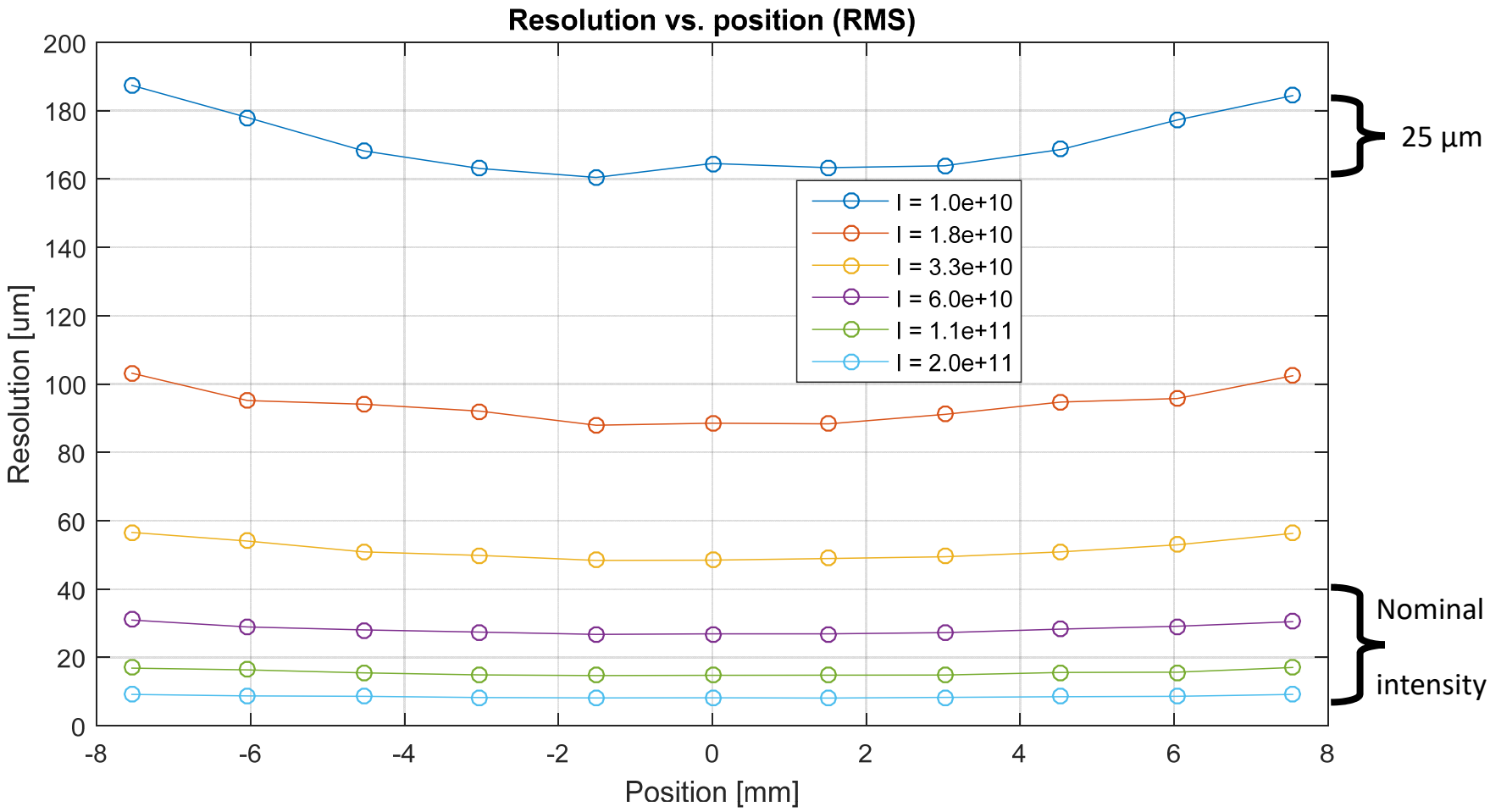
Doublet bunch (simulated)

Performance Estimation

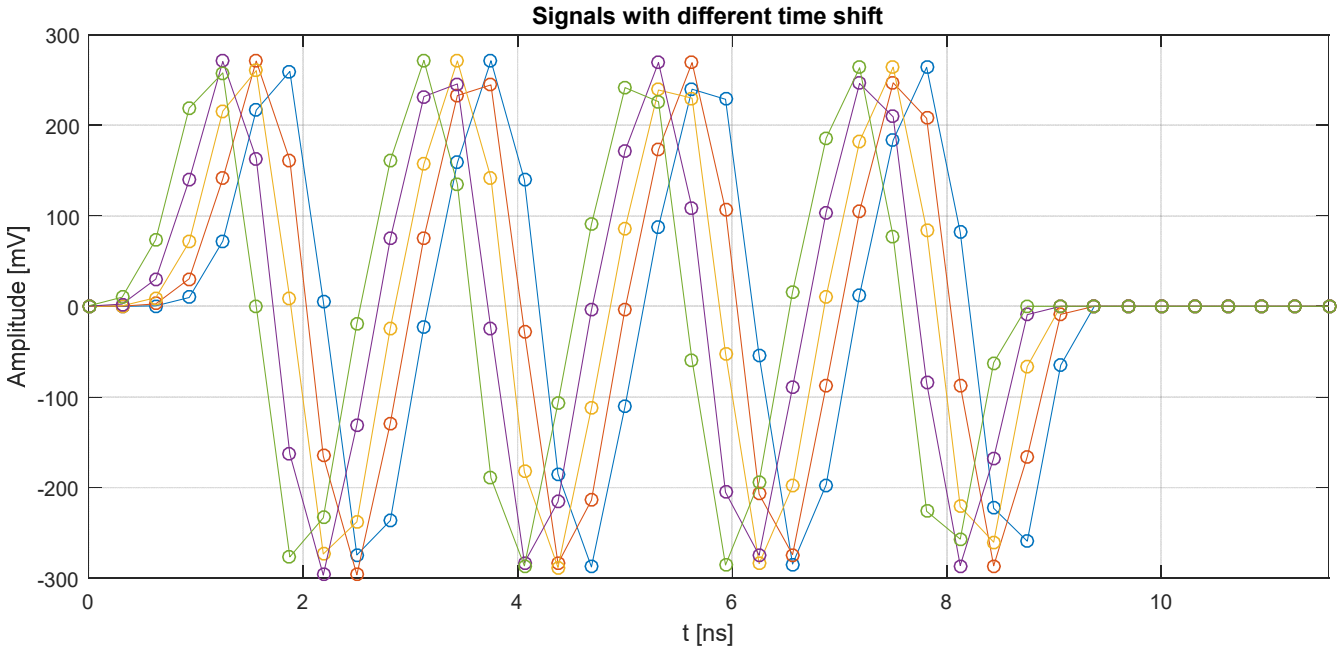
Simulation Framework (MATLAB)



Simulation Results



Simulation Results (Time Shift)

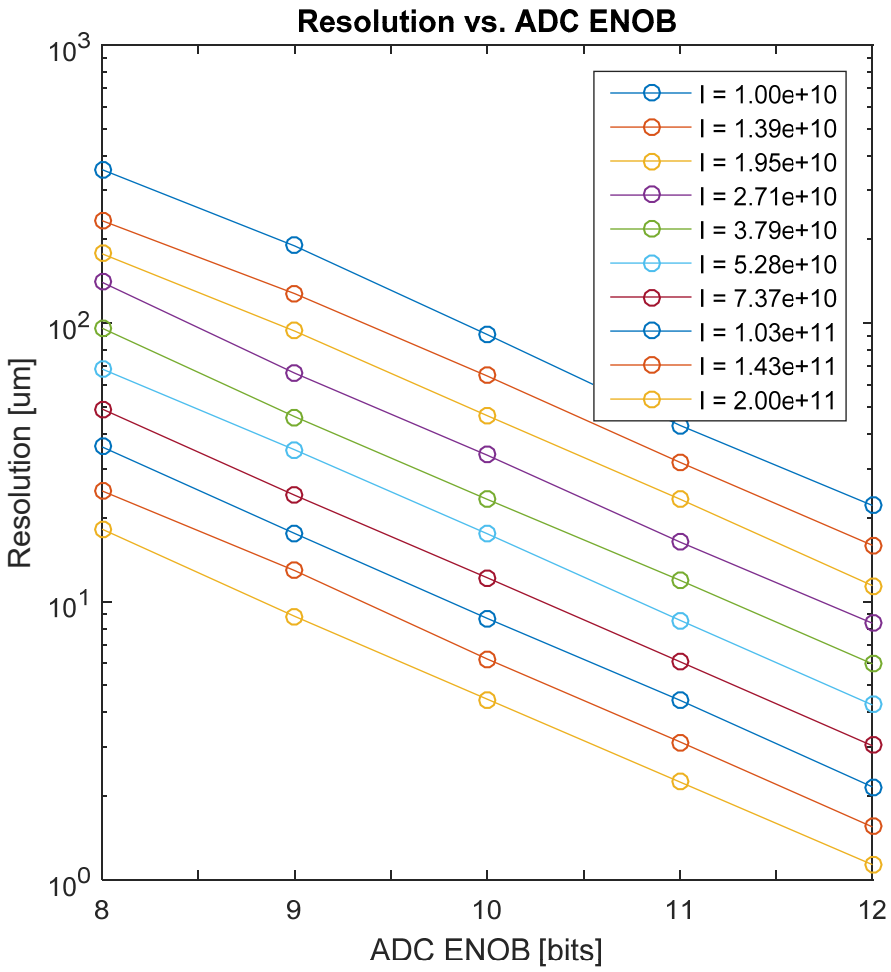


- No sensitivity to time shift observed
- Beam asynchronous sampling possible

Simulation Results (Noise)

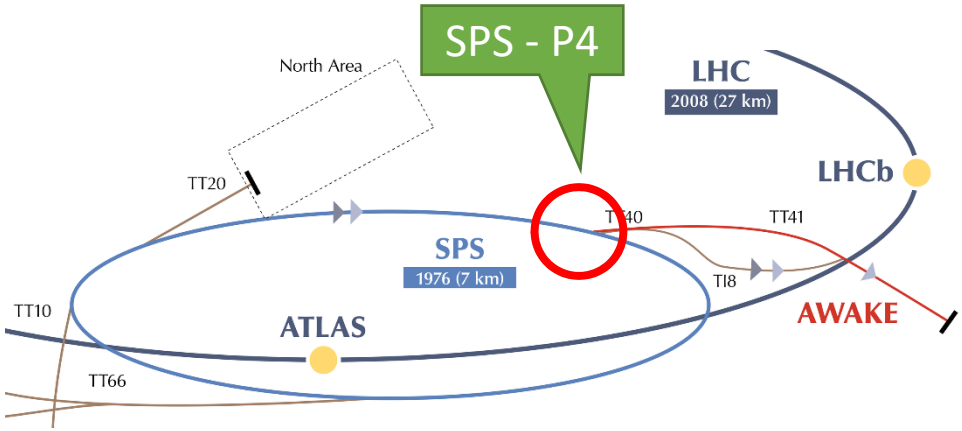
Assuming the ADC to be the dominant noise source:

- Each added ENOB improves resolution by a factor of 2
- Same effect by increasing f_S 4 times



Prototype Performance

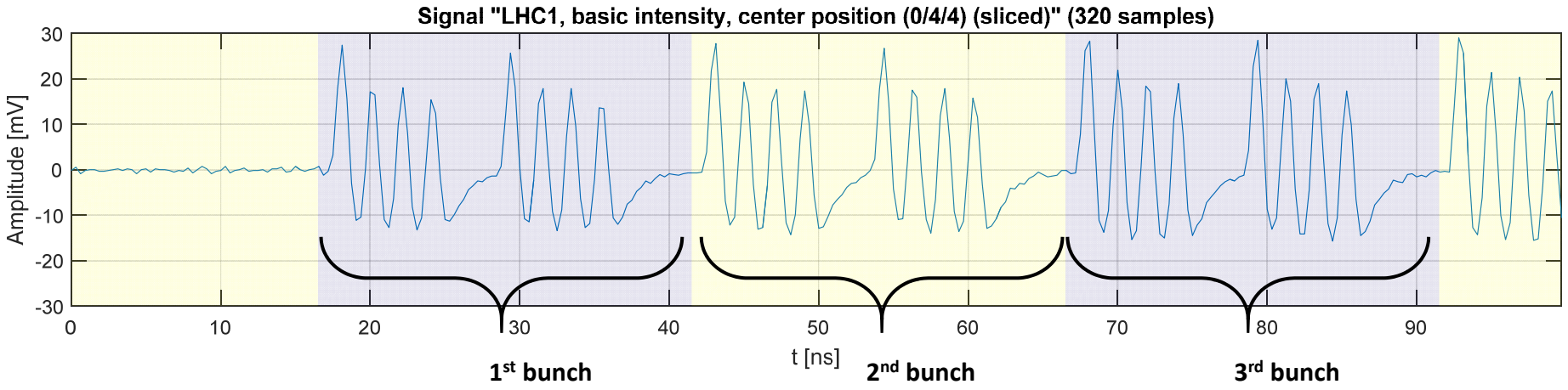
Test Setup



- Conditions
  - SPS point 4
  - Acquisition at flat-top
  - Two measurement campaigns
    - M1: One electrode split – emulated beam position
    - M2: Both electrodes – real beam position scan
- Hardware & Software
  - SPS button pick-up, vertical plane
  - Prototype of comb filter
  - Commercial ADC mezzanine (Vadatech FMC225)
  - CERN BE-BI VME carrier (VFC-HD)
  - Python script for read-out, MATLAB for analysis

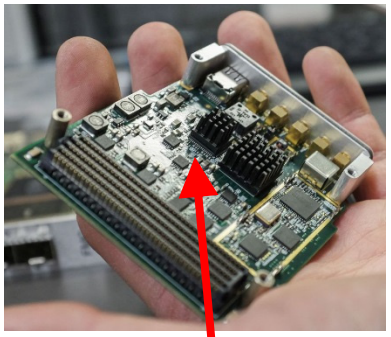
Measurement Details

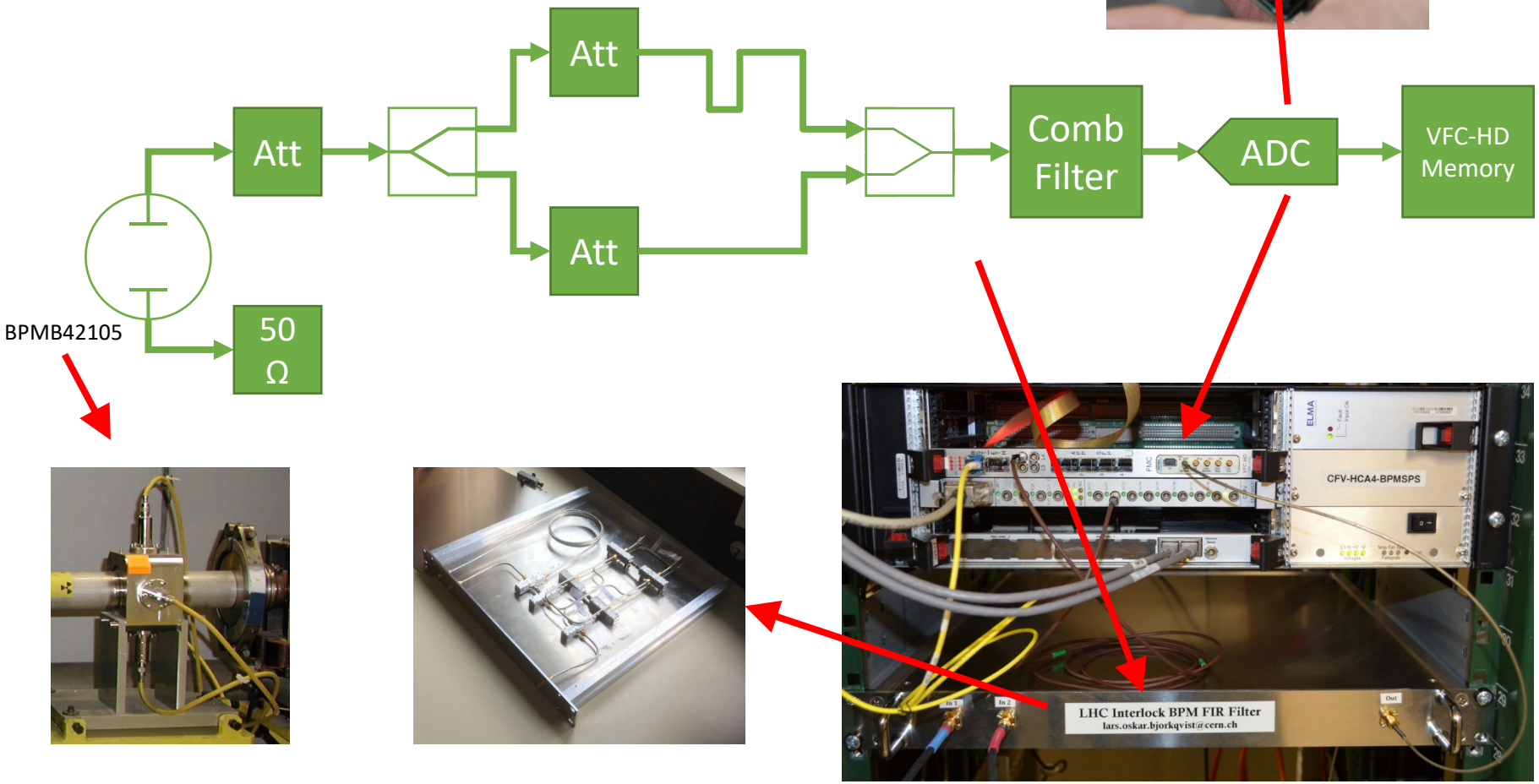
- Typical one-turn acquisition (first 100 ns):



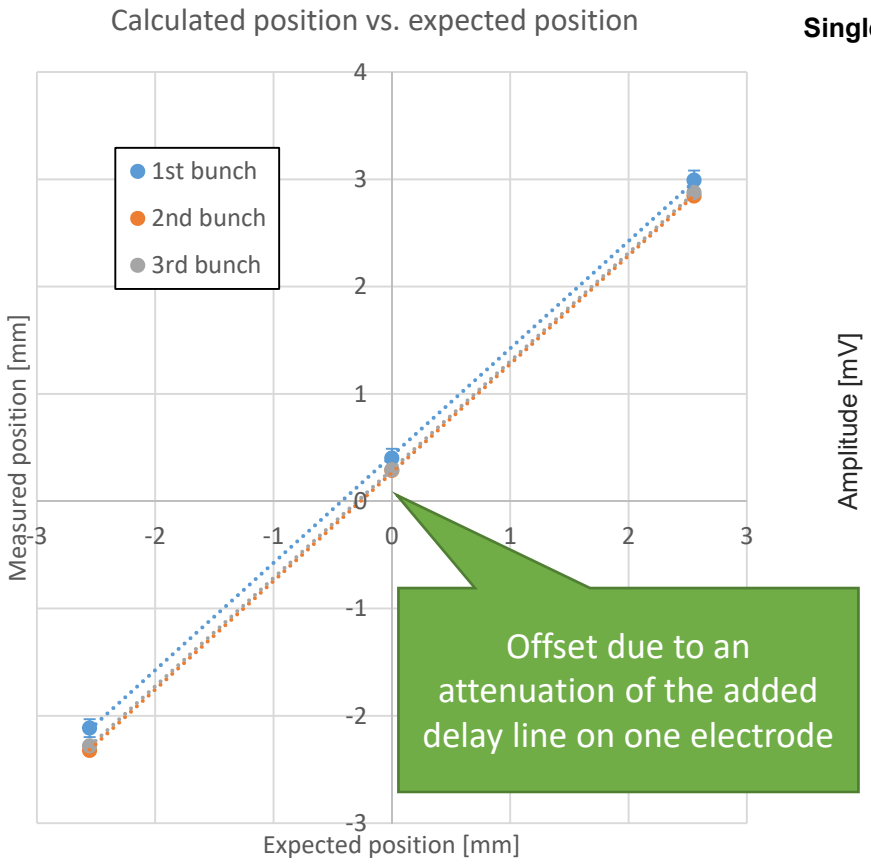
- Position calculated by RMS algorithm
- Position mean and std. dev. calculated in [mm] from > 2000 turns.

M1: Test Setup

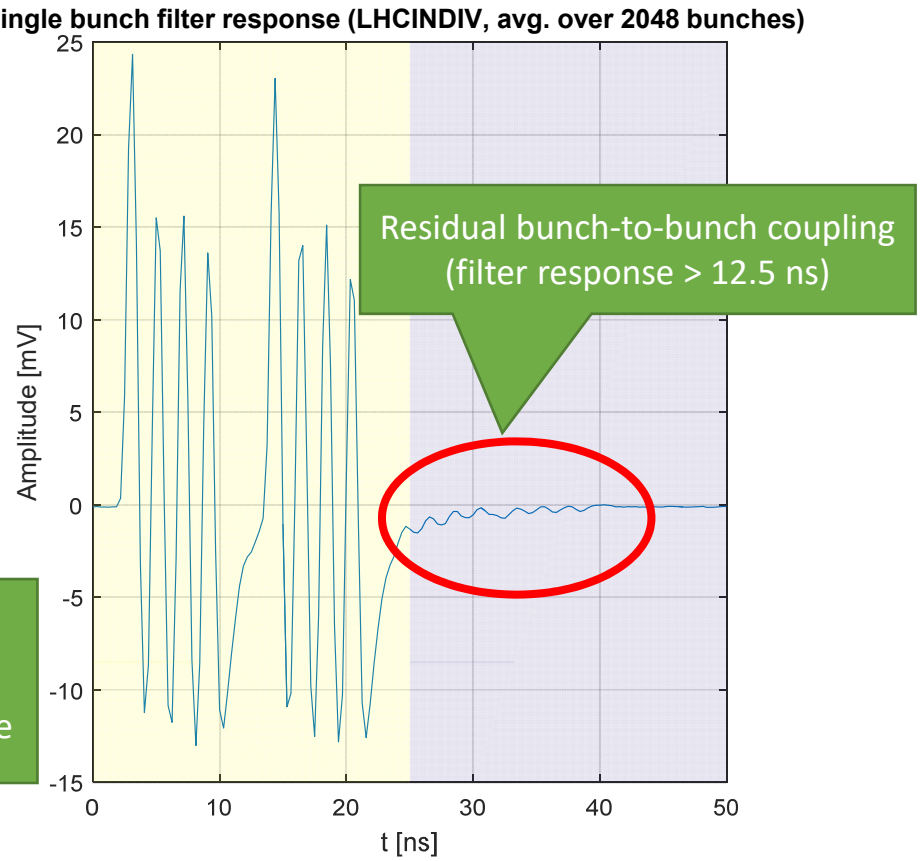




M1: Results

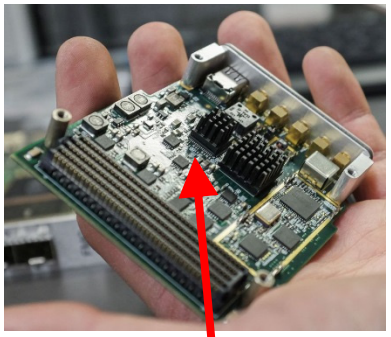


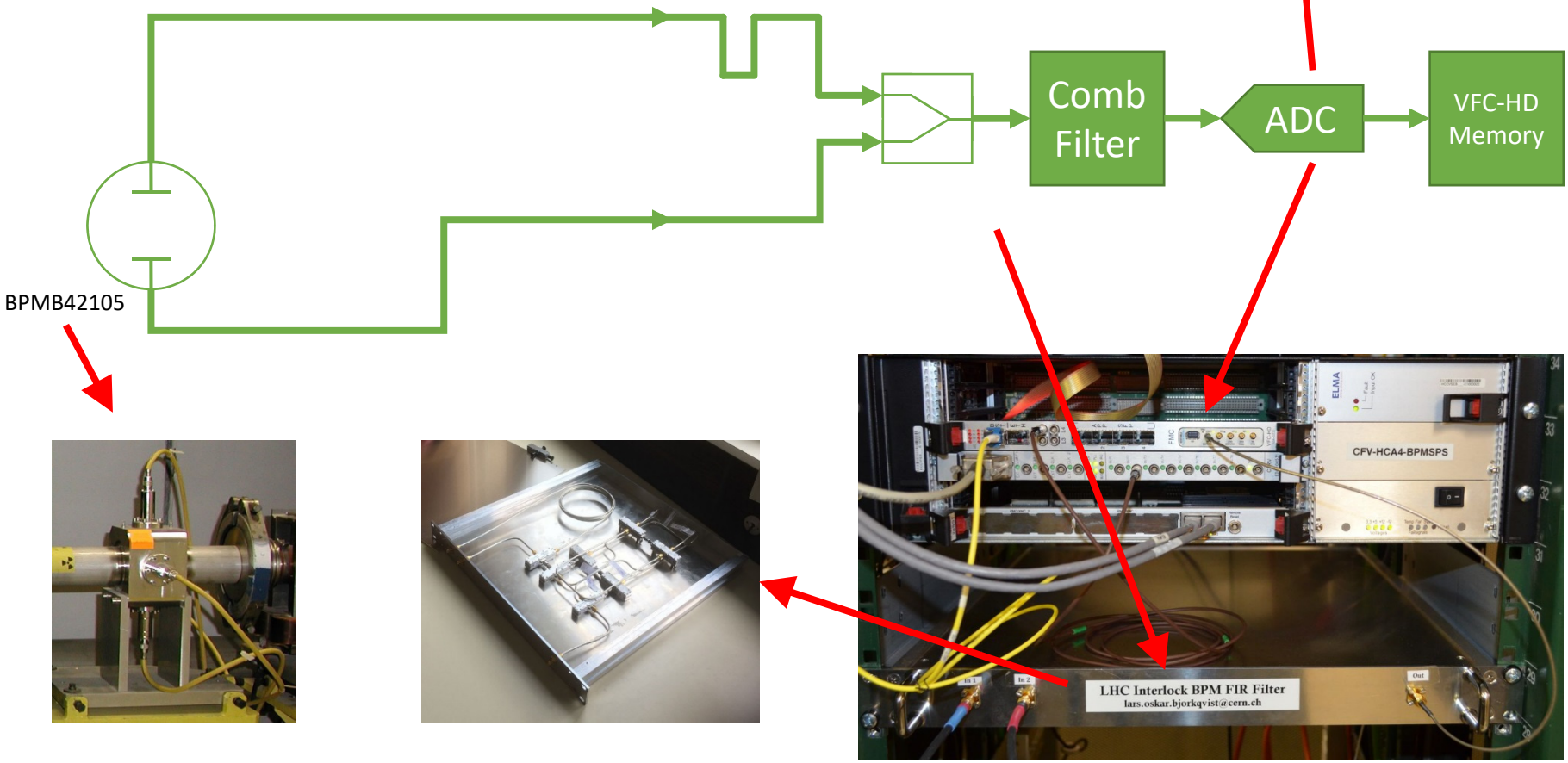
Offset due to an attenuation of the added delay line on one electrode



Residual bunch-to-bunch coupling (filter response > 12.5 ns)

M2: Test Setup





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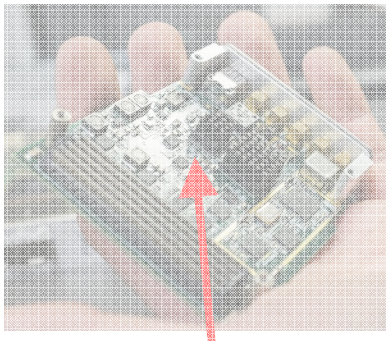

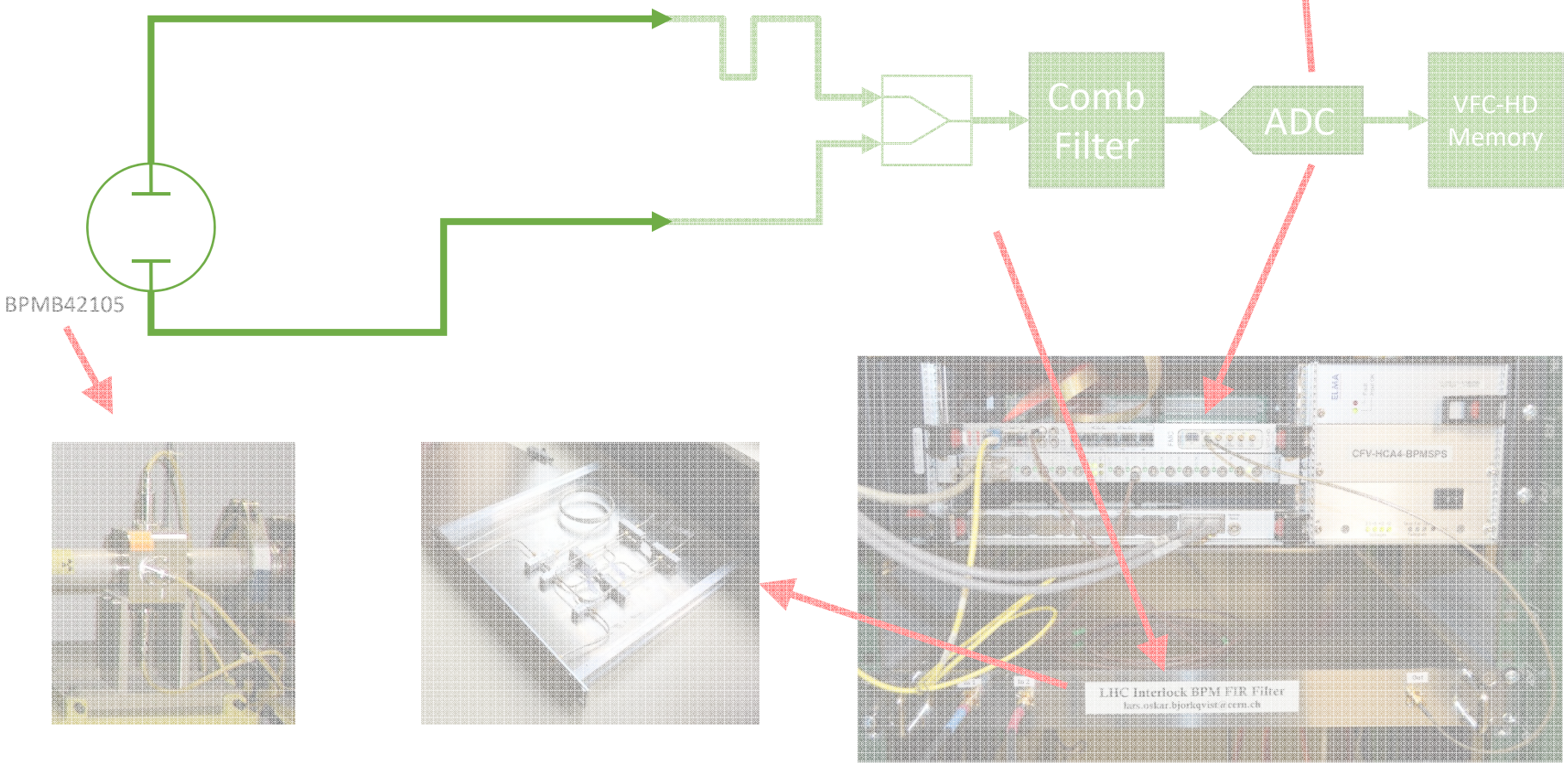

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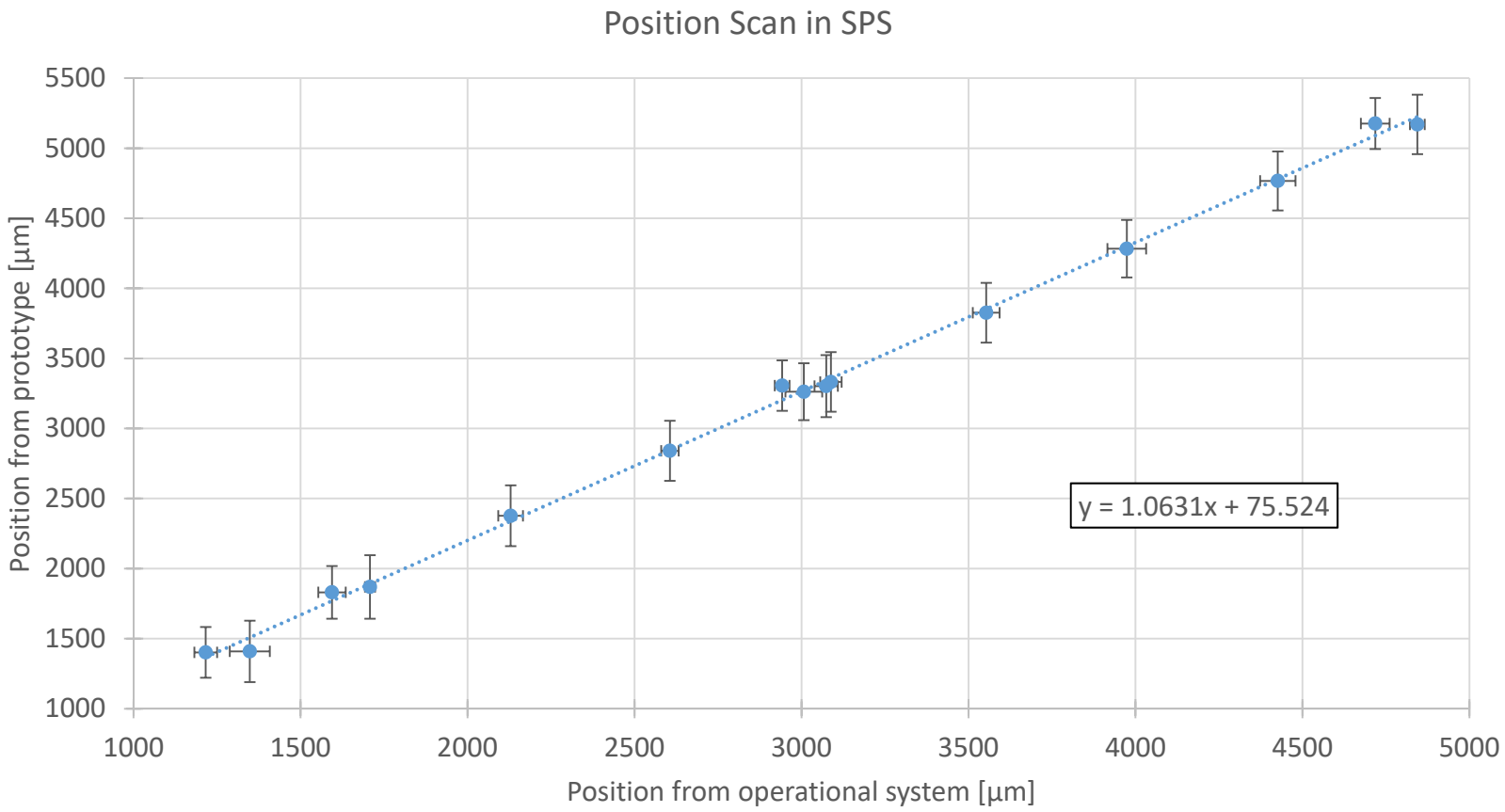
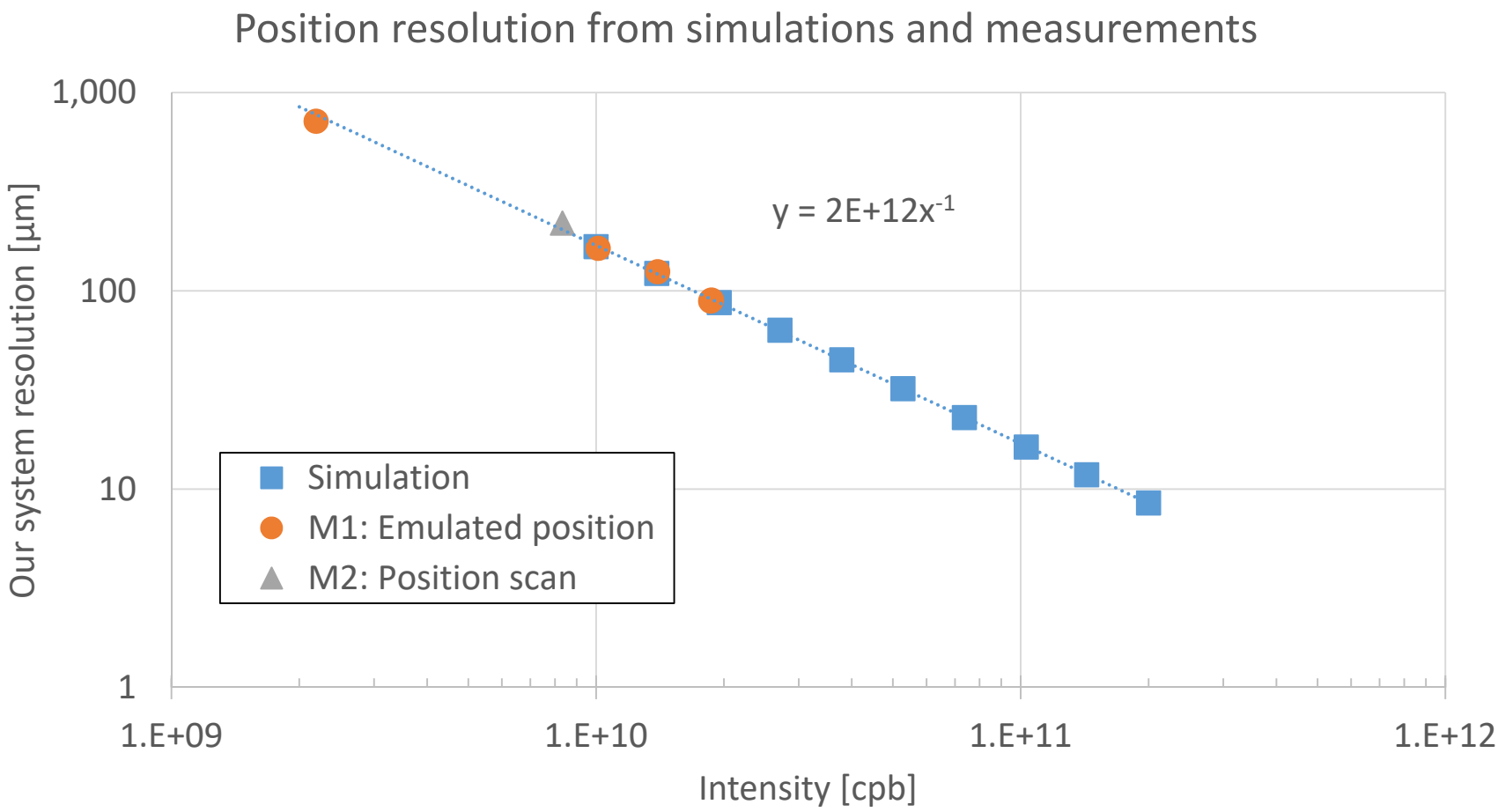

Position Scan in SPS
Position from prototype [µm]
Position from operational system [µm]
y = 1.0631x + 75.524
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
1000
1500
2000
2500
3000
3500
4000
4500
5000

Crosscheck With Simulation



Summary of a new LHC interlock BPM system

- Single-channel scheme with direct digitization
- Bunch-by-bunch measurements
- Single-bunch, single-pass resolution
  - With 25 ns spaced bunches: 9 – 167 µm
  - With 5 ns spaced doublets: (to be measured)
    - Lower resolution expected, but still compatible with the interlock system requirements