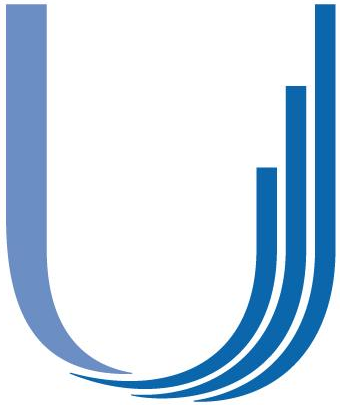


LHC Injectors Upgrade

LHC Injectors Upgrade

SPS Orbit Upgrade

J.L. GONZALEZ

CERN

Outline

- SPS Multi Orbit POsition System (MOPOS)
  - SPS Beams & Beam Position Monitors (BPM)
  - Specifications for Trajectory and Closed Orbit Measurements
- System Architecture
- First Measurements with Beam
- Development Status
- Budget
- Summary and Conclusions

Specifications: SPS Beams

Beam Type	Bunch spacing [ns]	Bunch number	Bunch charge [10^{10}]	Bunch length [4σ, ns]
FT / CNGS	5	400-4000	0.1-2	1-4
LHC25NS	24.96	$N_{bat} \times 72$	1-50	1-4
LHC50NS	49.92	$N_{bat} \times 36$	1-50	1-4
LHC75NS	74.88	$N_{bat} \times 24$	1-50	1-4
LHC single bunch	524.4-2022.6	1-16	0.2-50	1-4
LHC ion / Pb82+	100	$N_{bat} \times 4$	0.01-2	1-4

N_{bat}: number of batches (1..4 for proton beams and up to 13 for ion beams)

Bandwidth: 40 MHz & 200 MHz

Charge Dynamic Range: >70 dB

SPS Beam Position Monitors

Monitor Type	Physical Beam Aperture (mm)	Quantity	Mechanical Section	Comments
BPH	44V x 154H	103	rectangular	Electrostatic shoe-box
BPV	83 x 83	94	square	Electrostatic shoe-box
BPA	269	4	circular	Resonant cavity [LSS2]
BPD	269	2	circular	BPA emulation [LSS1]
BPCN	76	7	circular	Stripline directional couplers **[2 plane BPMs]**
BPCE	206	6	circular	

Total = 216 BPMs: 6 x 36 slots

BPA/BPD: will be replaced with BPCE (mainly used for extraction)

- Current MOPOS channels (shoe-box single-plane BPMs): 240 [6 x 40 slots]
- **No request yet** for 2-plane BPMs [≥ 432 channels]

Specifications: Acquisition Modes

- Trajectory acquisitions (multiple gated batches)
  - Automatic: **50 first turns** (every batch, with one measurement per batch)
  - On request: **10k turns** (for a selected batch)
- Closed Orbit acquisitions (single gated batch)
  - Averaged over 40 turns [40×23 µs = 920 µs]: **up to 100 s** acquisitions @1 kHz → **100k** data points per channel
  - Required: all the data or a subset (every 10 ms for example)
- Intensity information
  - Used to detect beam presence

Specifications: Resolution & Accuracy

- Resolution over ±15 mm BPM-Aperture

	Large intensity beams ($\geq 2\ 10^{10}$ p/bunch)	Low intensity beams (ex. LHC pilot: $2\ 10^{9}$ p/bunch)
ORBIT (AVG 42 turns ~ 1 ms)	100 µm	400 µm
TRAJECTORY (turn-by-turn)	400 µm	1000 µm

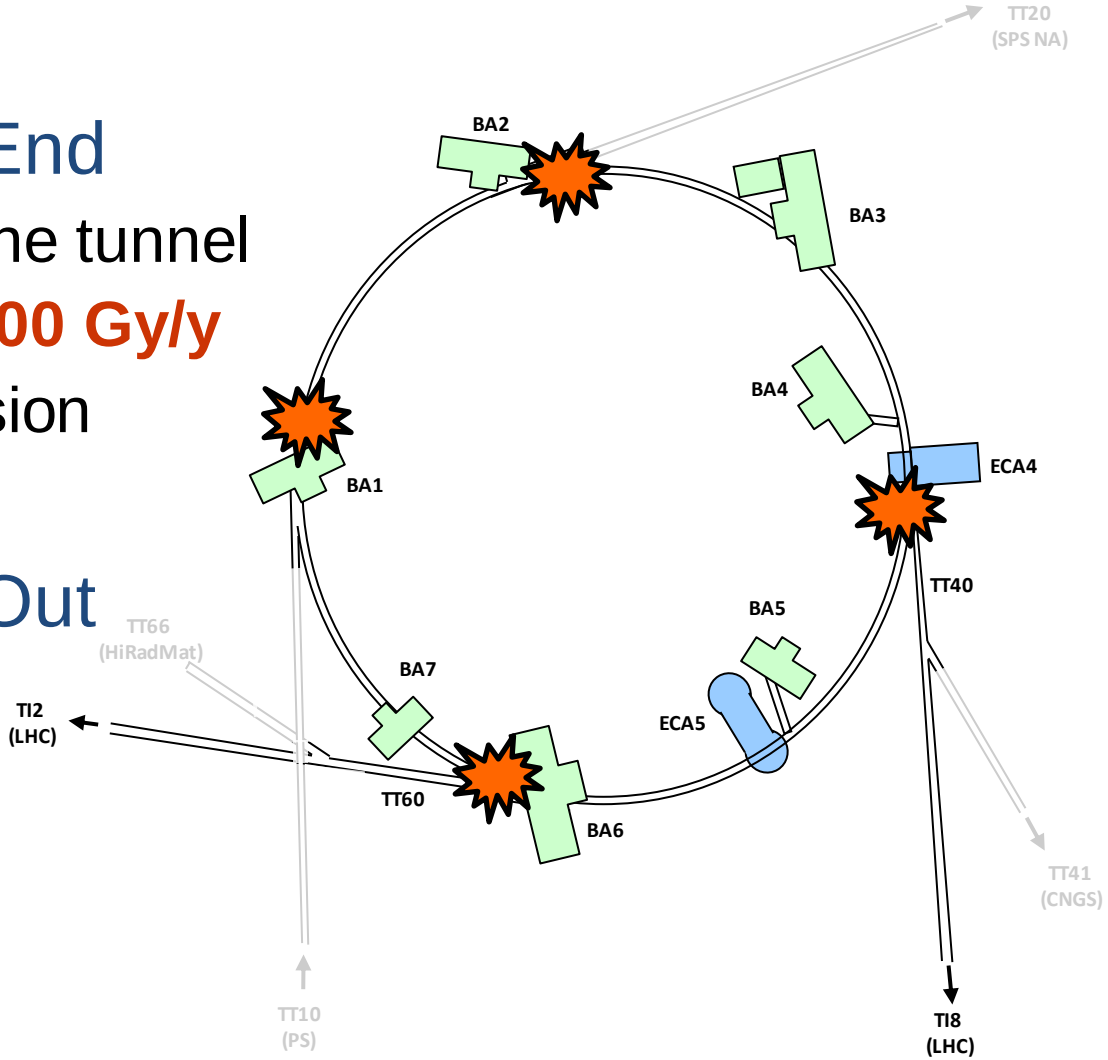
- Required Accuracy: < 0.5 mm RMS

Including mechanical alignment, electrical offsets…

Difficult to guarantee with such old BPMs

System Architecture

- MOPOS Front-End
  - 216 modules in the tunnel
  - Exposed **up to 100 Gy/y**
  - Optical transmission
- MOPOS Read-Out
  - In BA1 ... BA6
  - 6 VME-Crates
  - 9 VFC*/Crate



* VME FMC Carrier

Front-End: Measurement Principle

- Logarithmic derivation of normalized position

$$x = \frac{A-B}{A+B} \quad \Leftrightarrow \quad \frac{A}{B} = \frac{1+x}{1-x}$$

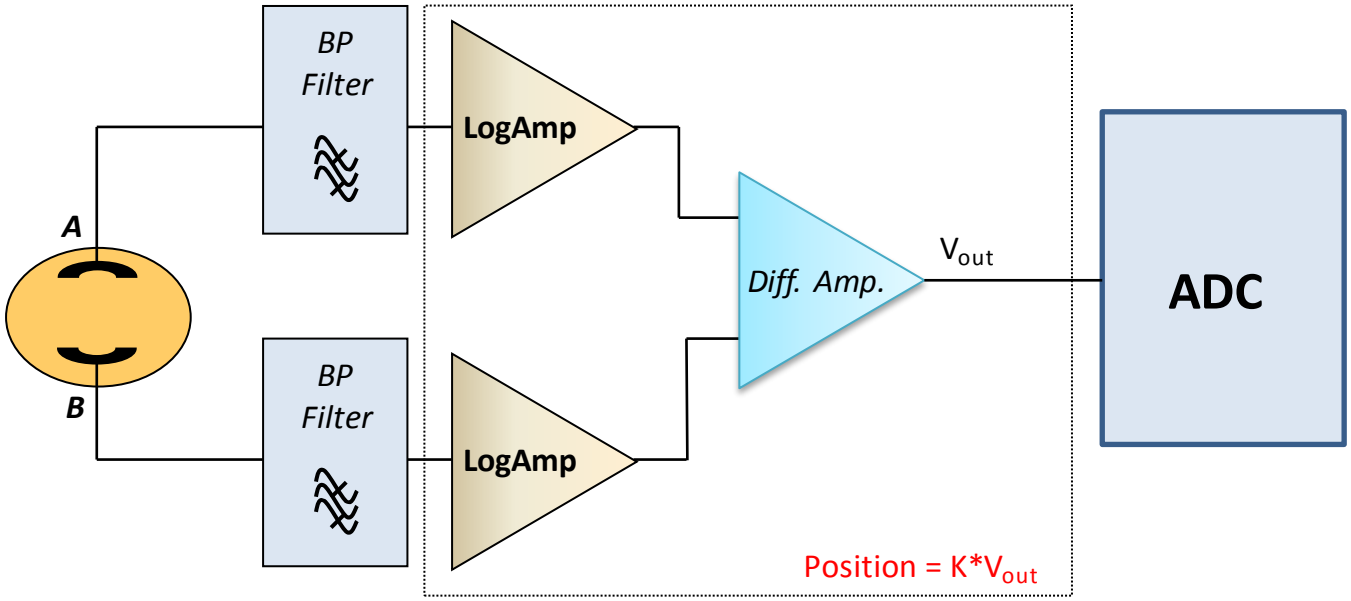
$$\ln \frac{1+x}{1-x} = 2\left(x + \frac{x^3}{3} + \frac{x^5}{5} + \ldots \right)$$

$$\log_a X = \frac{\ln X}{\ln a} \quad \Rightarrow \quad \log\left(\frac{A}{B}\right) \cong \frac{2x}{\ln 10}$$

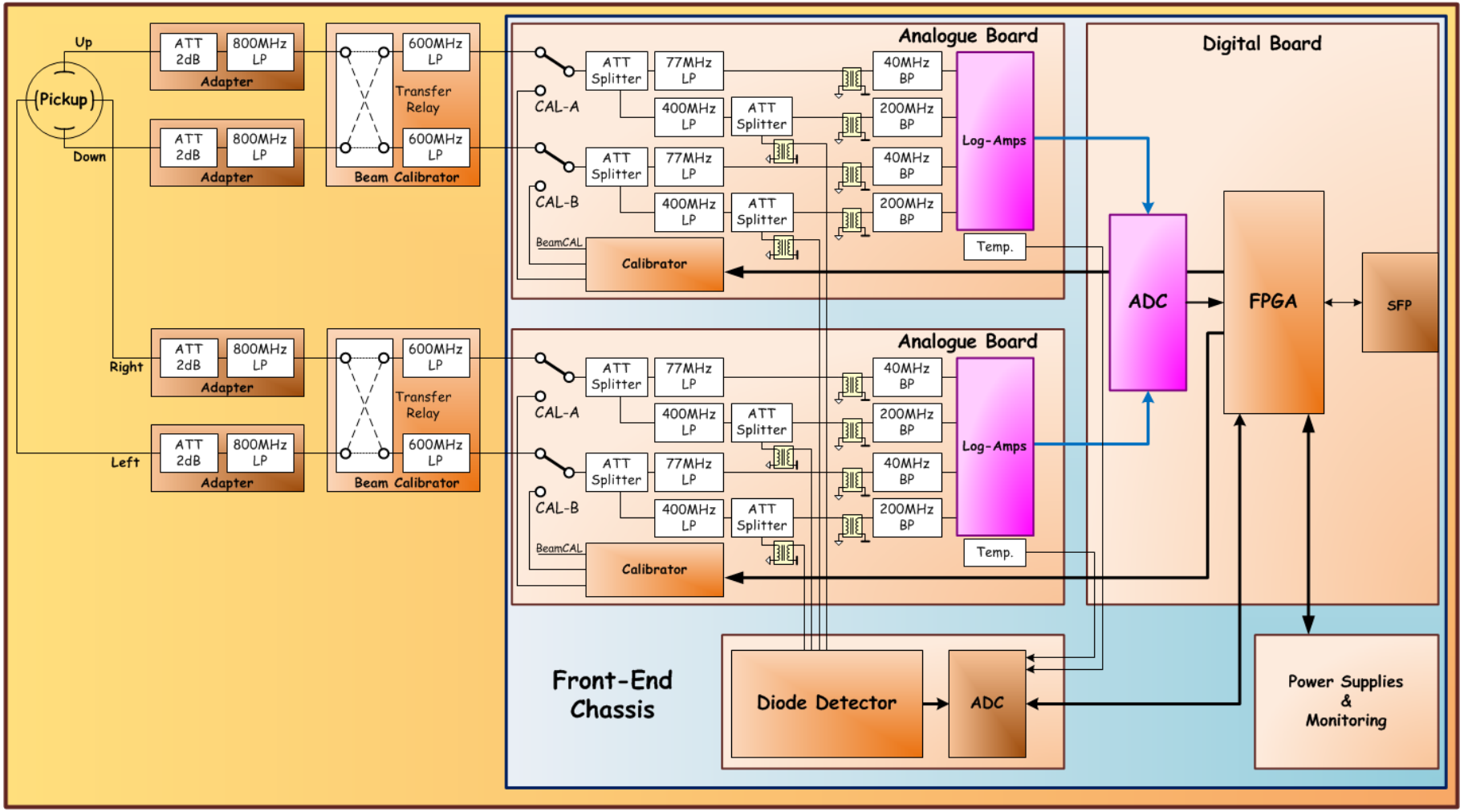
$$x = K\left(\log A - \log B\right)$$

$$K = \frac{\ln 10}{2}$$

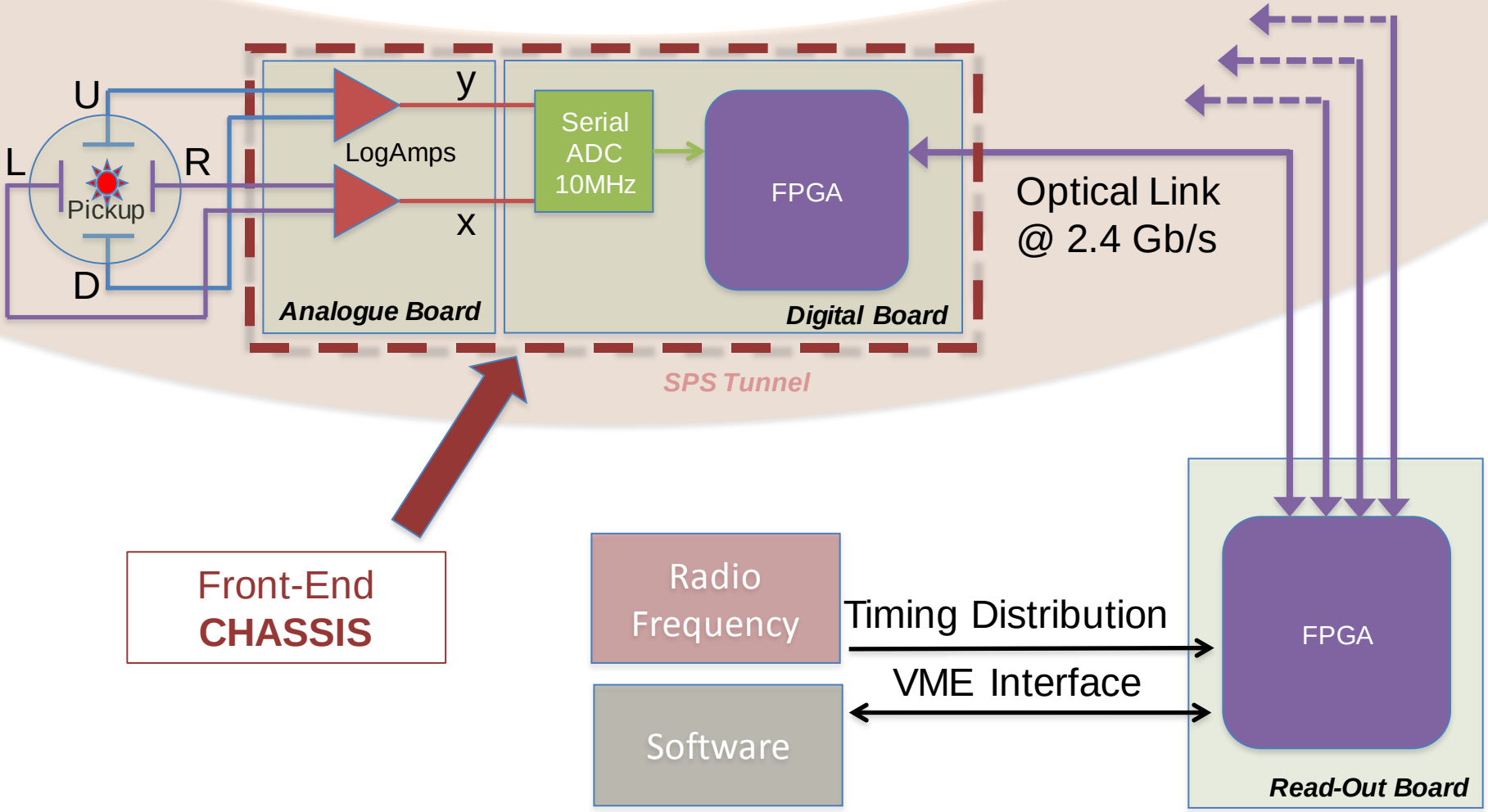
Front-End: Measurement Principle



Front-End: Block Diagram



MOPOS: Simplified Block Diagram



Read-Out Board

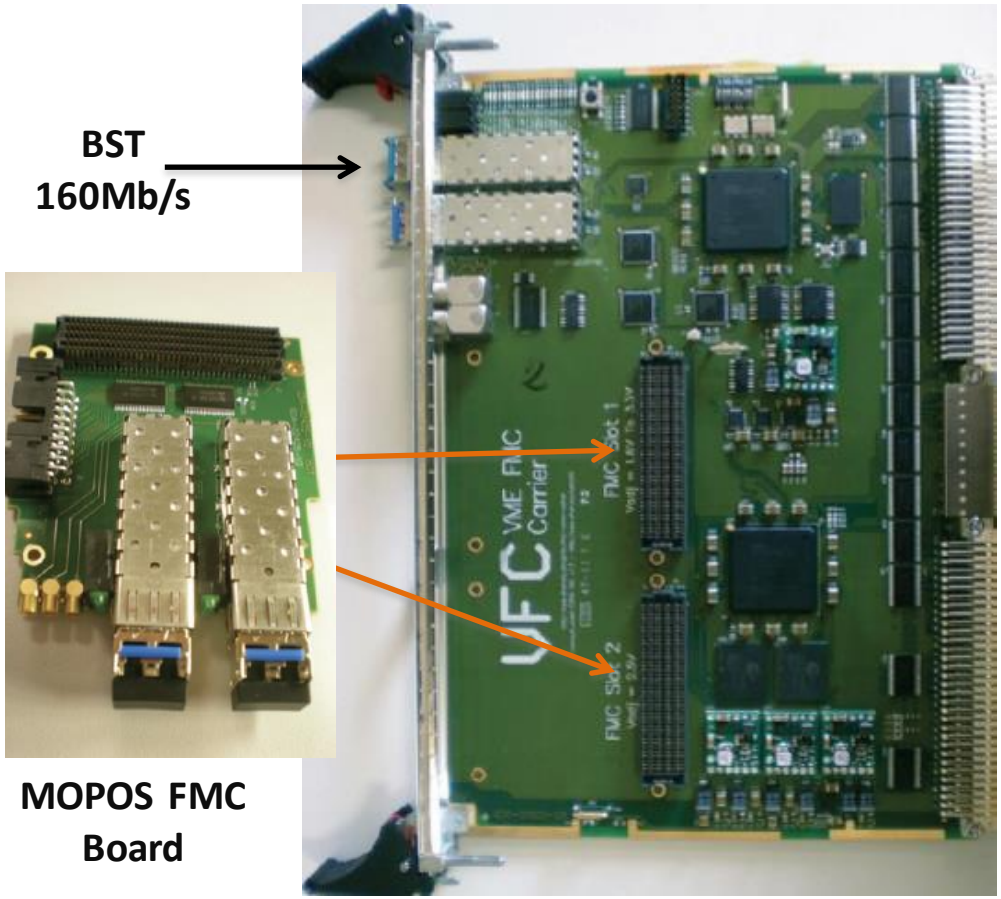
- VME FMC Carrier (VFC)

  General Purpose BI Board

  2 FPGAs : Xilinx Spartan-6 150T

- FMC Board

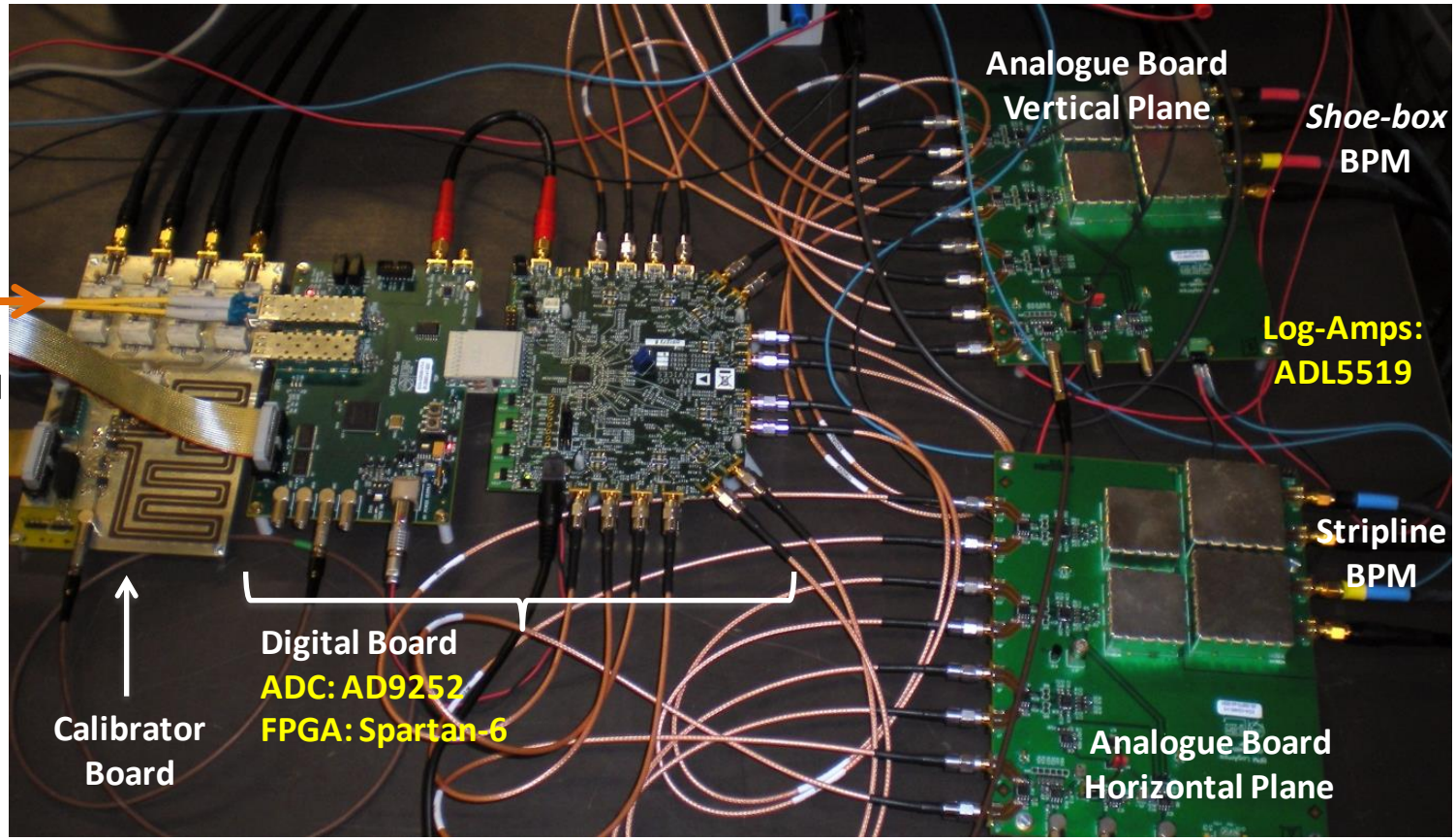
  2 SFP Cages for Commercial Optical Transceivers



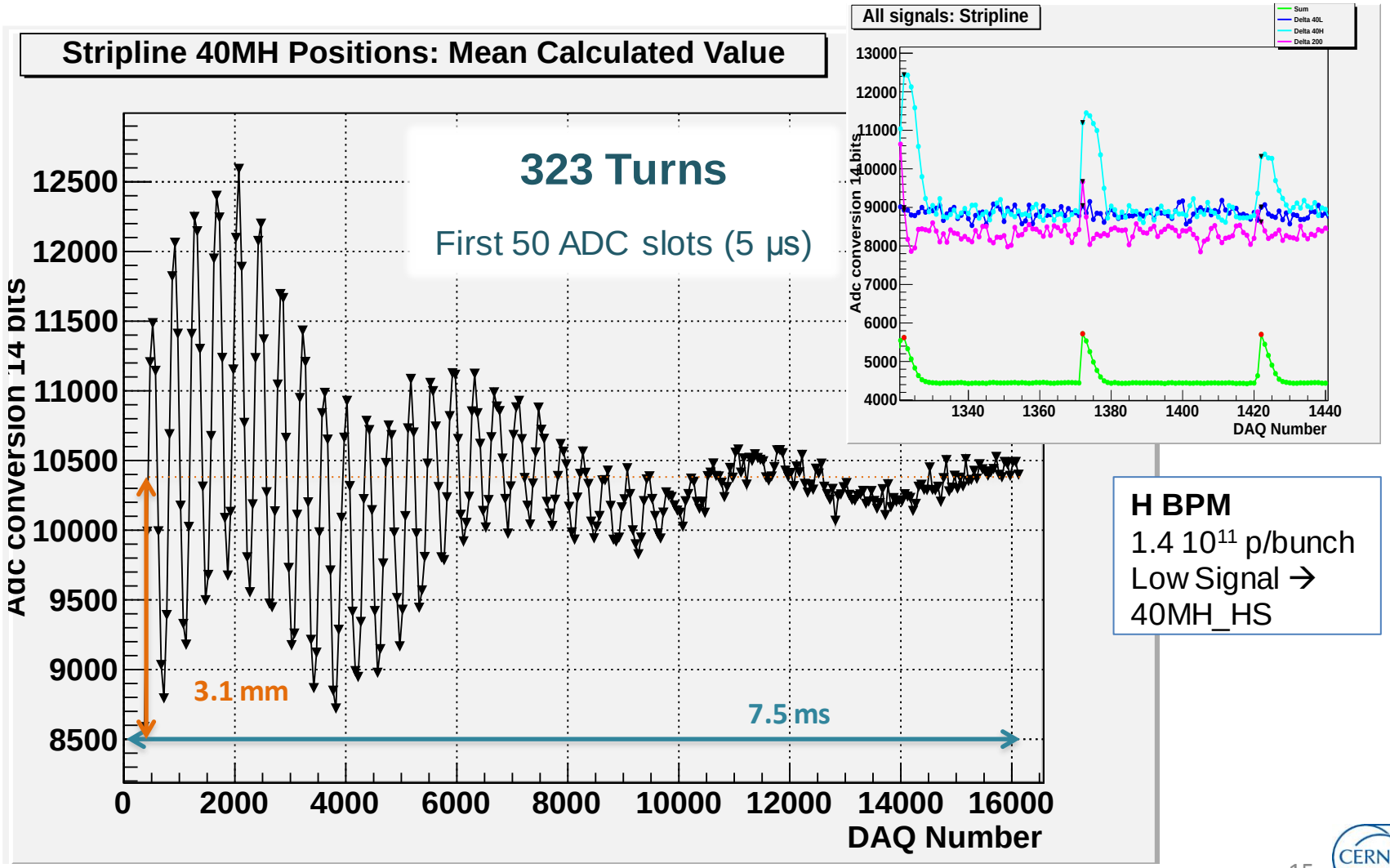
MOPOS FMC Board

Front-End Prototype

- SPS Tests with beam: Jan./Feb. 2013



First Beam Measurements: Single Bunch Proton Injection (LHCFAST2)



H BPM
1.4 10^{11} p/bunch
Low Signal → 40MH_HS

First Beam Measurements:
Ion Injection, 2 bunches/batch @ 200ns

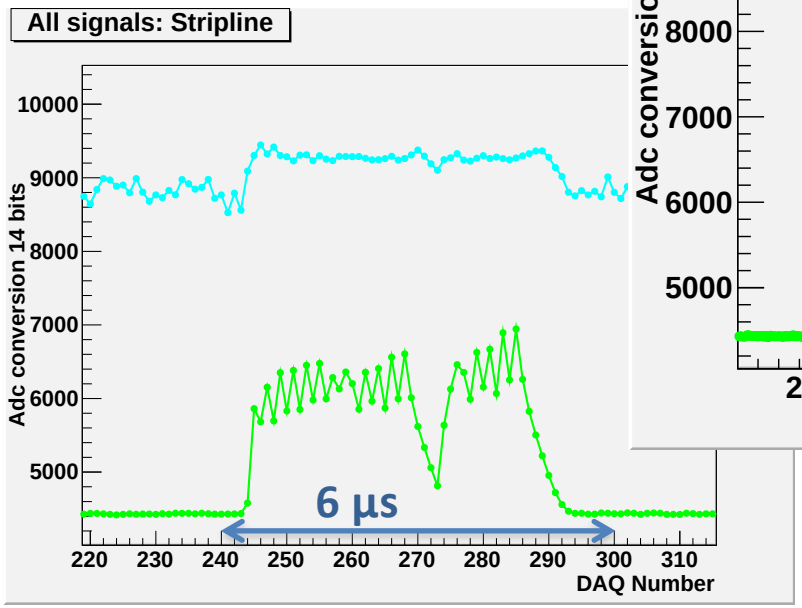
H BPM

Pb^{82+}

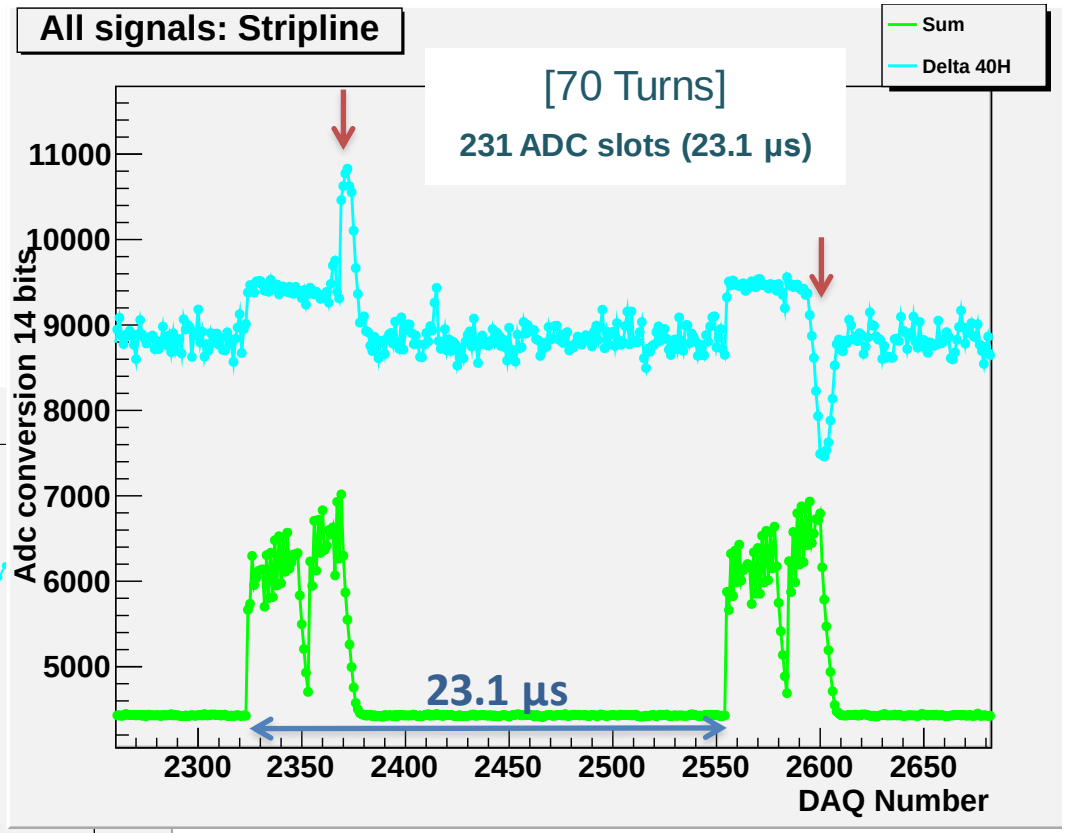
10^{10} charges/bunch

Low Signal

→ 40MH_HS



Batches 1 to 10



Injection of Batch 11

Sensitivity & Resolution

		Sensitivity [µm/ADC-bin]							Noise (Worst Case)	
	Bump [mm]	- 5	- 2.5	- 1	+ 1	+ 2.5	+ 5	AVG	Trajectory (turn-by-turn)	Orbit (1 ms)
Single Bunch	40MH_HS H	1.8	1.7	1.8	2.0	1.7	1.8	1.8		
	40MH_HS V	2.3	2.5	2.6	2.6	2.4	2.4	2.5		
									150 ADC-bin	34 ADC-bin
Multi-Bunch	40MH_LS H	1.9	1.9	1.5	1.7	2.1	1.8	1.8	**375 µm**	**80 µm**
	40MH_LS V	2.3	2.4	2.6	2.6	2.2	2.3	2.4	Required Resolution: **400 µm**	Required Resolution: **100 µm**
	200MH H	1.8	1.7	1.4	1.6	1.9	1.7	1.7		
	200MH V	2.2	2.3	2.6	2.4	2.1	2.1	2.2		

H-Measurements: Stripline BPM
V-Measurements: Shoe-Box BPM

Development Status

- Front-End
  - Final version of analogue board: under test
  - Digital board: still under development
  - ➢ Radiation Resistant Components to be selected and tested (ADC, FPGA)
- Read-Out Board
  - Currently using VFC_V2
  - VFC_HPC is under development
- Production for the Test of a Sextant
  - Front-End Chassis: about 40 modules
  - VFC_V2: about 20 modules

Installation Status

- Mini-Racks in the Tunnel
  - 6U-Model: about 200 units installed
  - 16U-Model: 12 units installed
- Radiation Resistant Optical Fibres
  - Total Quantity: ordered
  - Patch Cords: partially ordered
- Cable Installation
  - Completion during LS1
- Fibre Installation
  - BA6, TS6+ & TS6-: completed
  - BA1 & TS1+: completed
  - BA4, BA5, TS5+ & TS5-: installation on-going
  - BA2, BA3, TS1-, TS2+/-, TS3+/-, TS4+/-: after LS1

Installation and Commissioning Plan

- Installation in parallel with current MOPOS system in Sextant 6 foreseen in 2014 to allow:
  - Radiation resistance testing of the Front-End
  - Software development
- Fibre installation will be completed during long technical stops or in LS2
- Full system installation: as soon as the final version of the Front-End and the VFC are produced and fibres installed.

Project Schedule

	2014	2015	2016	2017	2018
Test Hardware Production & Installation					
Hardware/Software Tests (BA6)					
VFC Development & Production					
Radiation Tests (ADC, FPGA…)					
Rad-Hard Digital Board Development					
Front-End Series Production					
New MOPOS System Installation *					

* Depending on the progress of the fibre installation, the front-end chassis can be placed in surface buildings

Budget Status

Code 64724	2010… 2012	2013
Development & Mini-Racks	300 k	
Rad-Hard Fibre		650 k
Fibre Installation		630 k
Cable Installation		60 k

Budgetary Requirements: 2014…

Description	Code 64724
Front-End Chassis Production (300)	450 k
VFC-HPC Development & Production (75)	200 k
Rad-Hard Components (500)	200 k
Commercial SFPs (300)	60 k
FSU (2014…2016)	240 k
Other (cables, fibre patches…)	100 k
Total:	1250 k

- Electronics cost in line with 1.5M estimate
- Fibre installation, still requires additional 1500 k

Cost Breakdown

Code 64724	MOPOS Electronics	MOPOS Optical Fibres	
2014	350	550	350
2015	300	200	
2016	300	200	
2017	300	200	
2018		400	600
2019		-	600
	1250	**1550**	**1550**

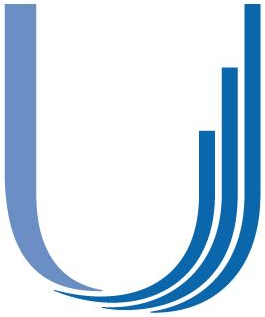
Summary and Conclusions

- The **MOPOS upgrade** is required to **replace** the obsolete electronics and **improve** the **measurements**
- The **first prototype tested** in the CERN-SPS with proton and lead-ion beams has shown that it is able to:
  - **resolve** a **multi-batch** structure
  - **reconstruct** the **injection oscillations**
- The system **resolution** was estimated to:
  - 375 μm in trajectory mode
  - 80 μm in orbit mode

  ➢ These values **agree** with the **specifications**

Summary and Conclusions

- The system is now being optimized to **improve** the **sensitivity** for **low charge** beams
- **Several** commercial components have been already **tested under radiation**. Further tests are planned in 2014 to validate the ADC and the FPGA for the Front-End Digital Board
- The **current MOPOS** electronics and the **upgrade system** will run **in parallel** for one SPS sextant in **2014**

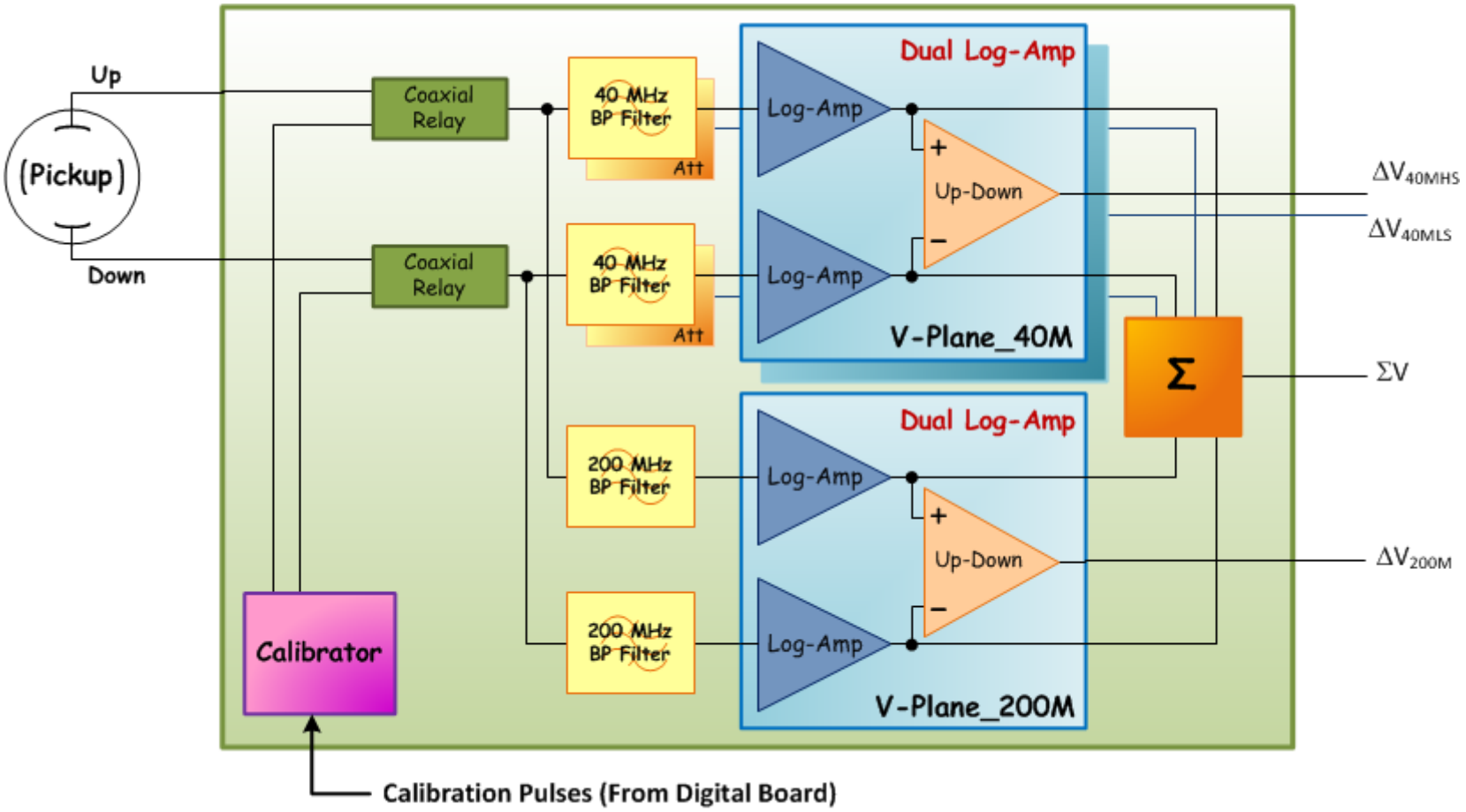


LHC Injectors Upgrade

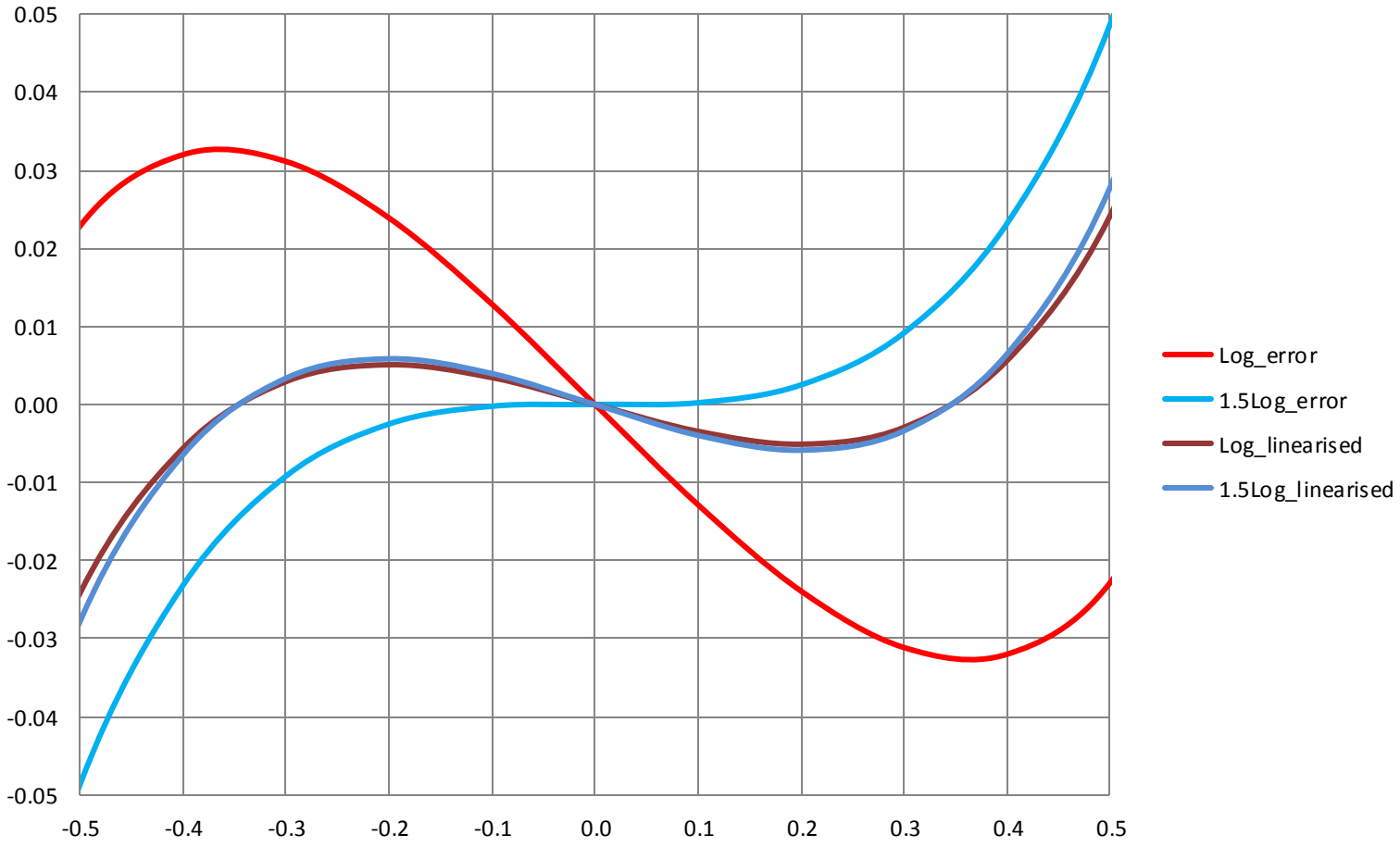
THANK YOU FOR YOUR ATTENTION!

Spare Slides

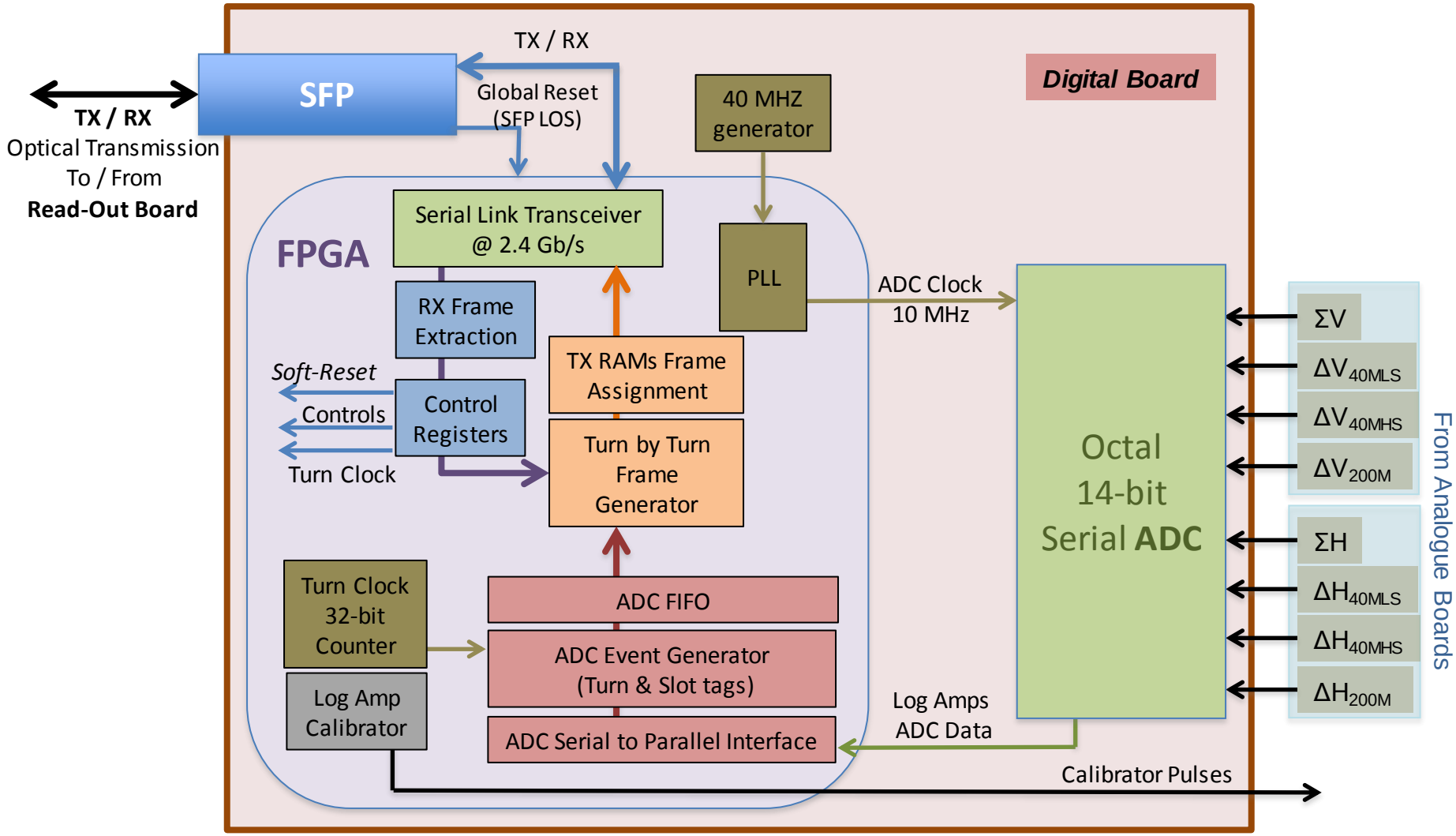
Front-End: Analogue Board



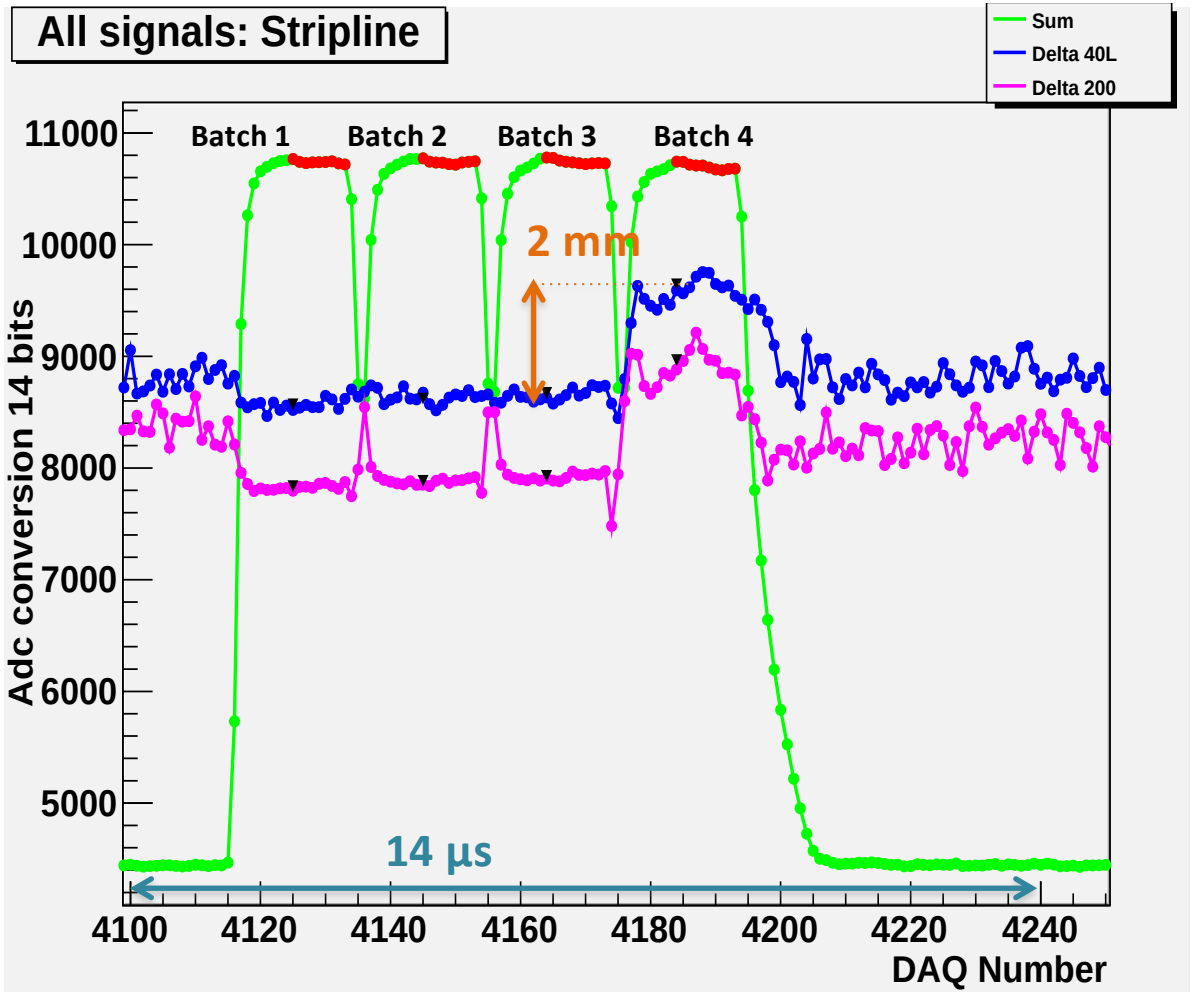
Front-End: Log Conformance Error



Front-End: Digital Board



First Beam Measurements: Proton Injection
4 batches – 36 bunches @ 50ns



H BPM

1.35 10^{11} p/bunch

High Signal

→ 40MH LS

→ 200MH

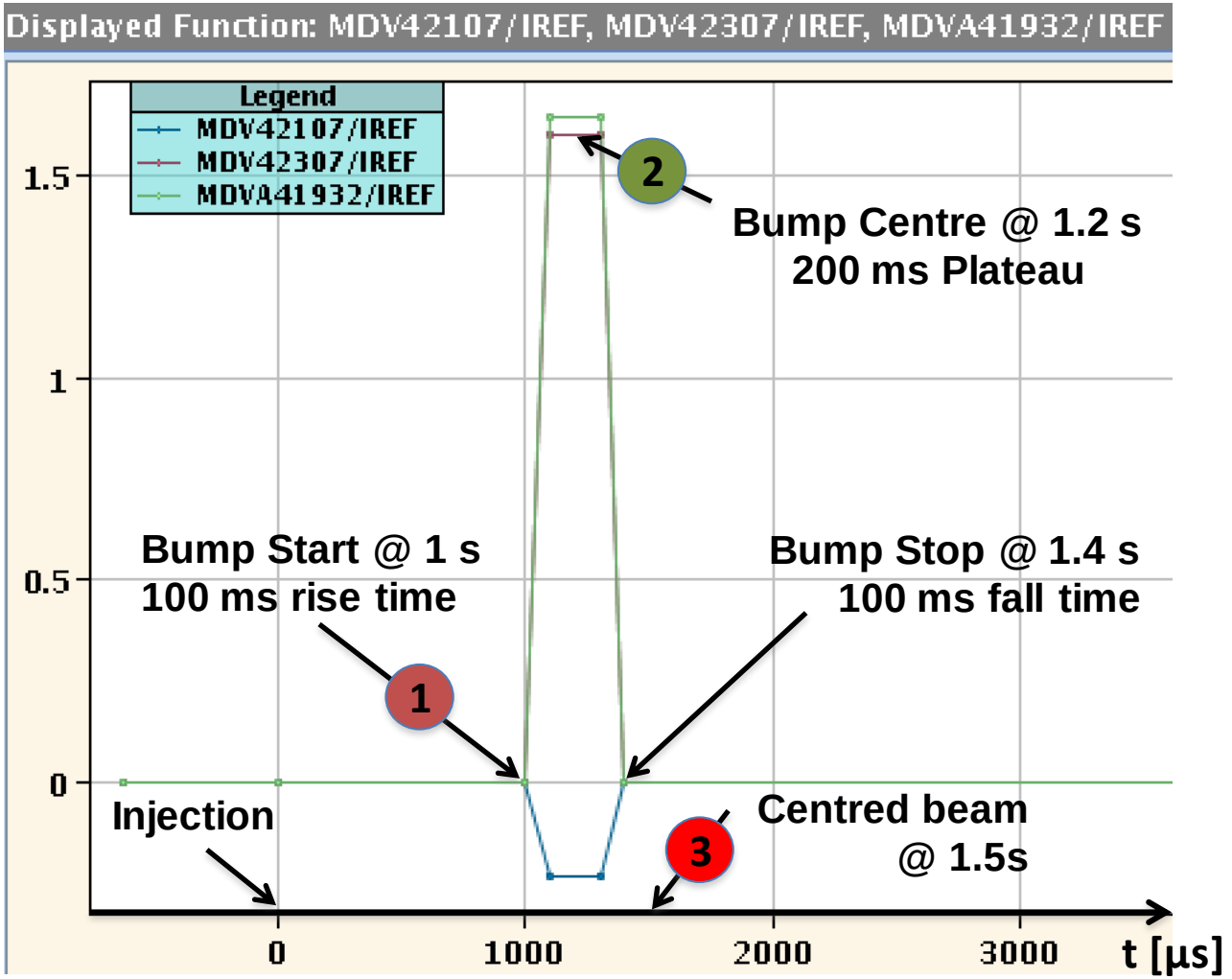
Injection of Batch 4

First Beam Measurements: Local Bumps

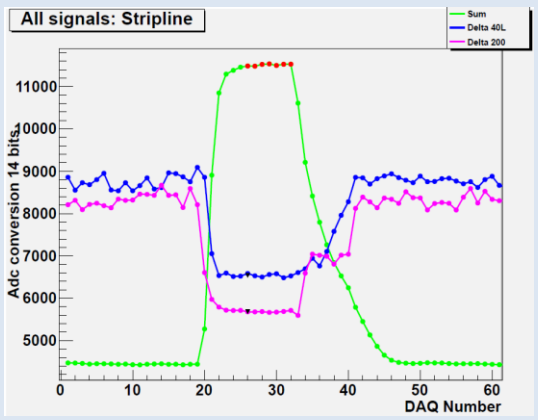
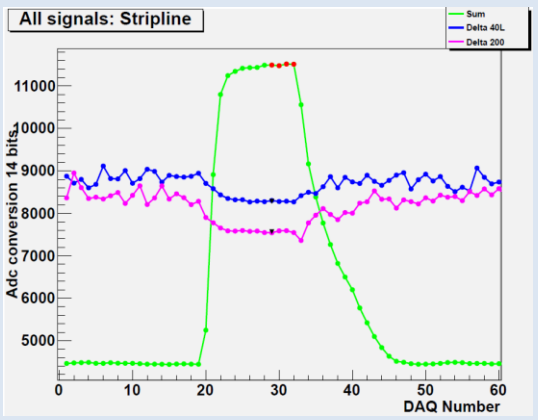
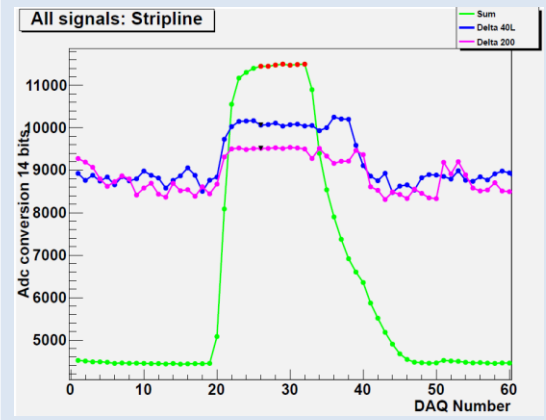
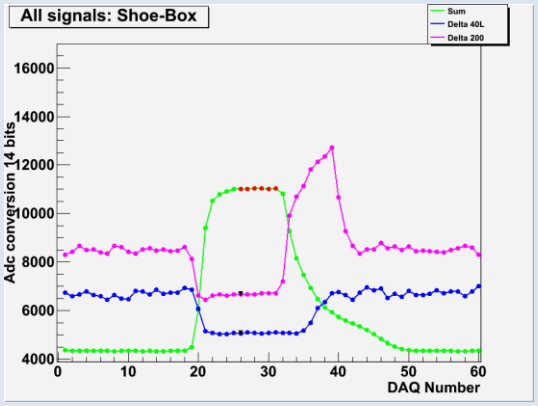
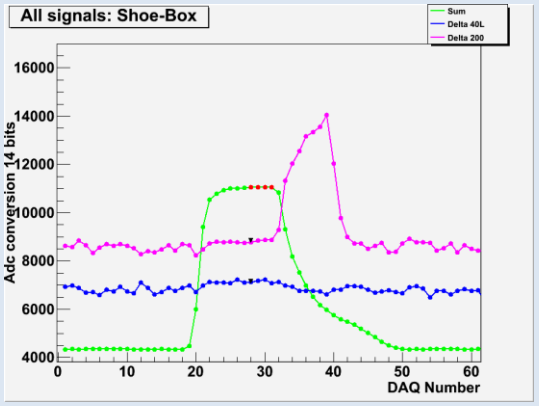
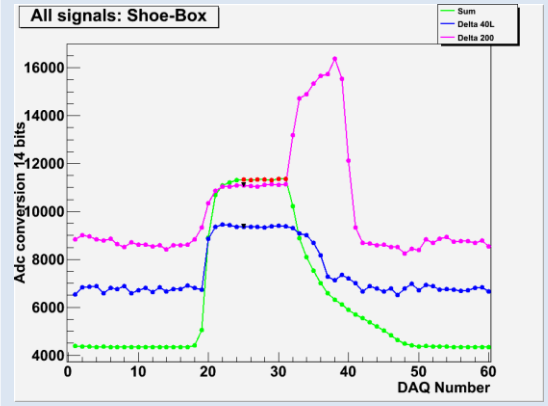
Measurement of beam position

- For **each BPM**
  - ✓ Horizontal
  - ✓ Vertical

  → **6** local **bumps**:
  - ✓ ± 1.0 mm
  - ✓ ± 2.5 mm
  - ✓ ± 5.0 mm
- **For each bump**
  1. **Before**
  2. **Bump Centre**
  3. **After**



Local Bump Measurements

- 5 mm	0 mm	+ 5 mm
		
		

MOPOS Acquisition: Test-Modes

Mode	Type	# SPS turns	# ADC Slots	Mean Values	Timing
FIFO	Debug	Up to 3 (~ 70 µs)	All frames	-	Async
Capture	Operational / Debug	220 (~ 5 ms) 64000 (~ 1.5 s)	All slots 8	-	Sync
Injection Trajectory	Operational	Up to 54 (~ 1.2 ms)	Up to 235	13 batches (width selectable)	Sync
Orbit Diagnostic	Debug	Up to 255 (~ 5.8 ms)	All slots *	One for each slot	Sync
Global Orbit	Operational	Up to 255 (~ 5.8 ms) Default 40 (~ 1ms)	Up to 235	One for each turn (selected slots)	Sync
Continuous Filter	Operational	Permanence	All slots *	One value for each BPM plane	Async

* This parameter is fixed and cannot be changed via software