Reviewing high bandwidth BPM technologies

Genoa, October 2024

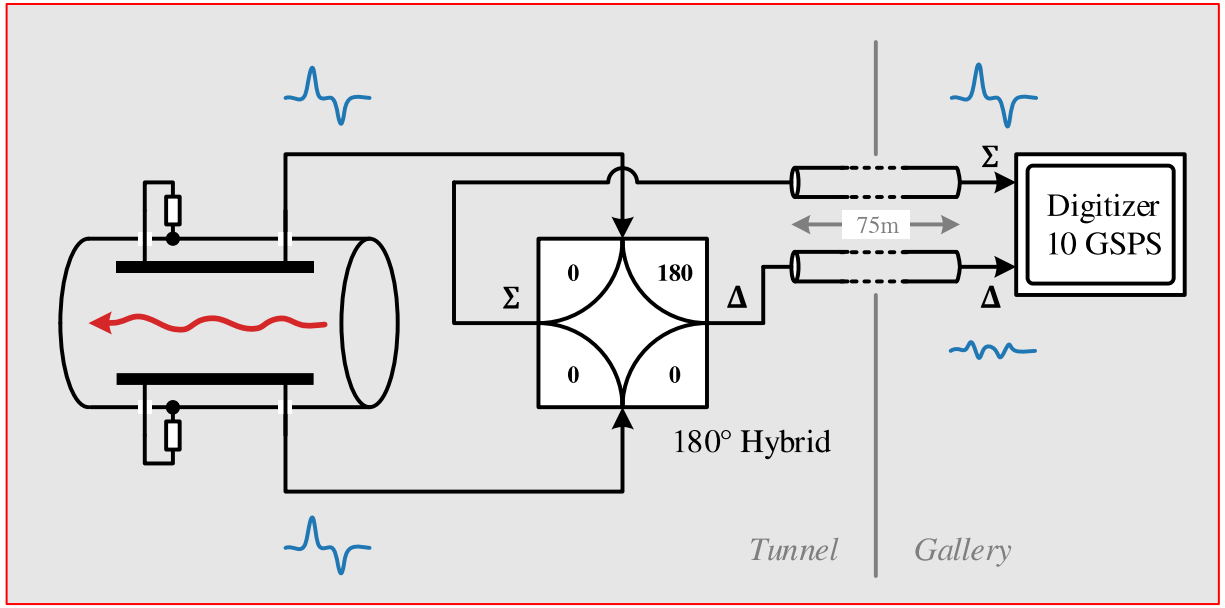
Thibaut Lefevre on behalf of WP13

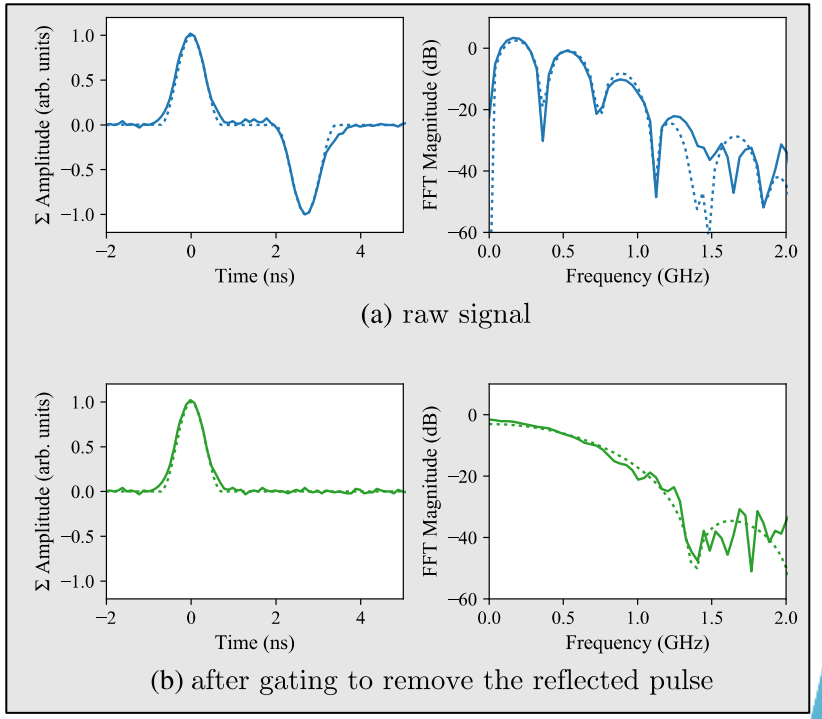
Task 13.5 - High Bandwidth BPM (BPW)

- Measuring intra-bunch motion with high bandwidth and high sampling rate (beam crabbing and instability monitoring)
  - With the goal to provide a better instrument than the classical Head-Tail monitor

Current Head-tail monitoring in LHC

- Stripline BPM, hybrid Δ/Σ, long cables and fast sampling oscilloscope





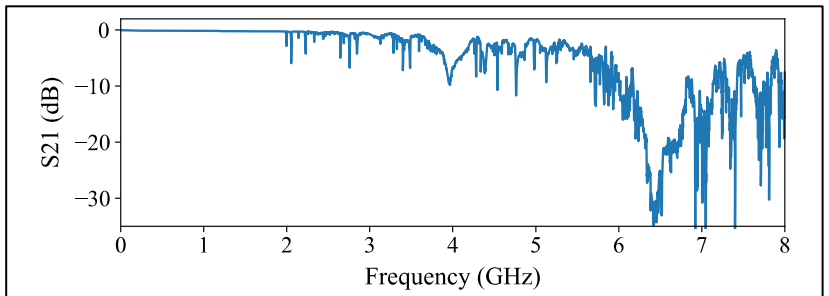
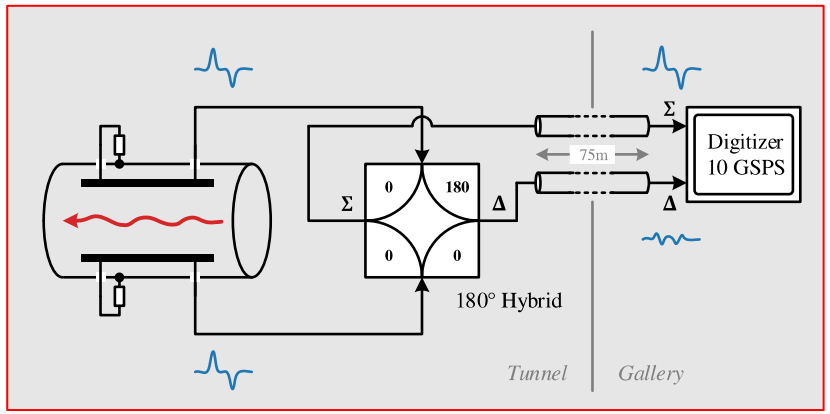


FIG. 4. S-Parameter transmission measurement from the upstream to downstream port of a 40 cm stripline BPM.

Current Head-tail monitoring in LHC

- Stripline BPM, hybrid Δ/Σ, long cables and fast sampling oscilloscope

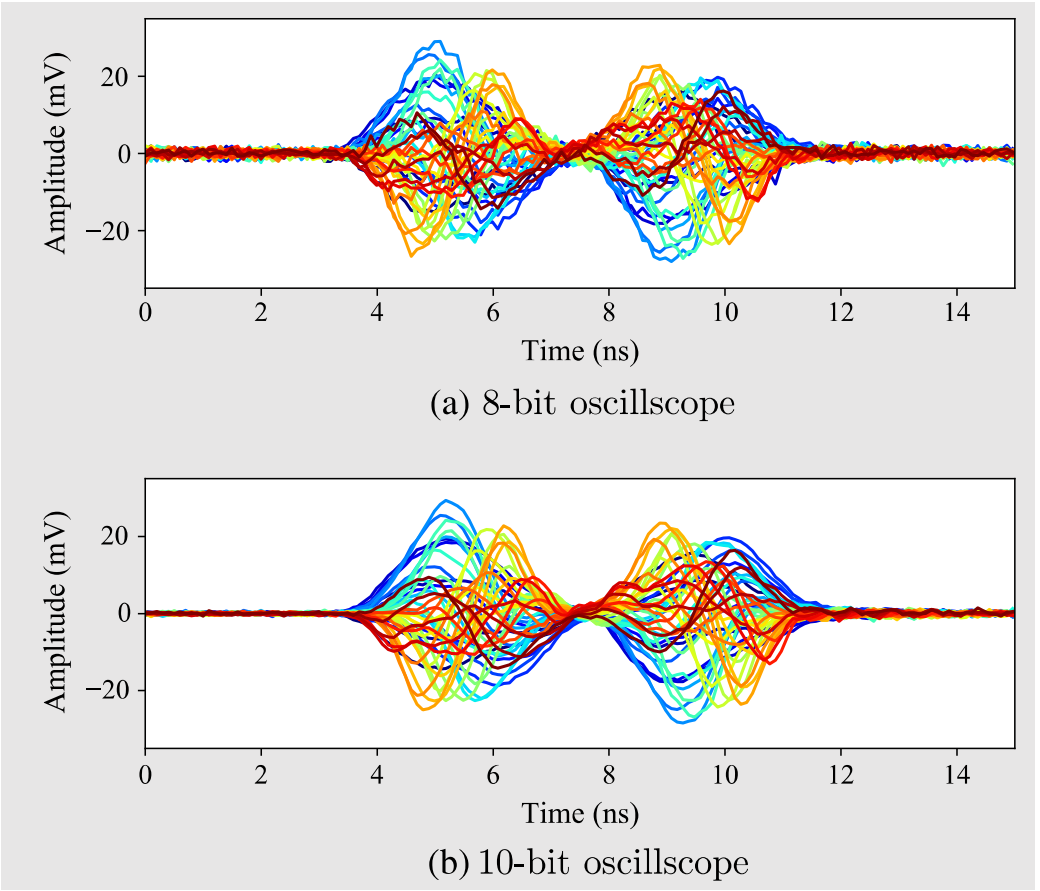


PHYSICAL REVIEW ACCELERATORS AND BEAMS **22,** 112803 (2019)

Automatic detection of transverse beam instabilities in the Large Hadron Collider

T. E. Levens, * K. Łasocha,† T. Lefevre, M. Gąsior, R. Jones, T. Włostowski, J. P. Ellis,‡ and R. J. Steinhagen§
CERN, CH-1211 Geneva 23, Switzerland

Improved DAQ using better performing oscilloscope

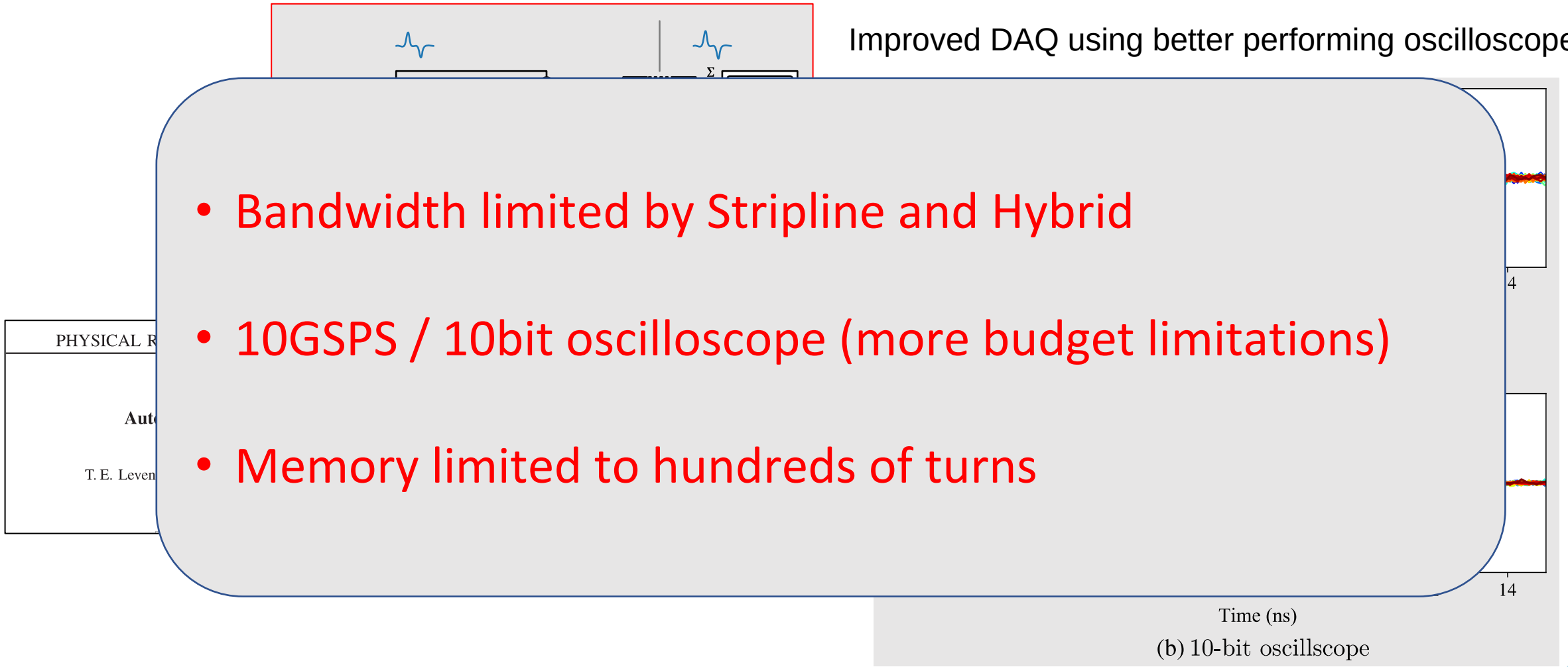


Current Head-tail monitoring in LHC

- Stripline BPM, hybrid Δ/Σ, long cables and fast sampling oscilloscope

Improved DAQ using better performing oscilloscope

- Bandwidth limited by Stripline and Hybrid
- 10GSPS / 10bit oscilloscope (more budget limitations)
- Memory limited to hundreds of turns



HL acceptance criteria for High bandwidth PU's

- Approved in 2021 https://edms.cern.ch/document/2369610/1.2
  - High dynamic range
  - Two levels of performance criteria

Parameter Description	Value	Unit
Pilot Bunch Intensity	5×10^{9}	Charges
Nominal Bunch Intensity	2.2×10^{11}	Charges

Key performance criteria

Criterion	Value	Units
Single bunch, single pass resolution at bunch centre for pilot bunch intensity	100	um
Single bunch, single pass resolution at bunch centre for nominal bunch intensity	10	um
Precision[1] of the measurement for nominal bunch intensity	10	um
Long term stability[2] of the offset for nominal bunch intensity	50	um
High frequency cut-off (-3dB)	5	GHz
Low frequency cut-off (-3dB)	≤ 1	MHz
In-band (between -1dB low and high cut-off roll-off) response variation	≤ 1	dB
Time resolution for single bunch, single pass measurement	50	ps
Acquisition length for a single bunch measurement on successive turns	> 1000	turn
Minimum time between two successive measurements	25	ns

Target performance criteria

Criterion	Value	Units
Single bunch, single pass resolution at bunch centre for pilot bunch intensity	50	um
Single bunch, single pass resolution at bunch centre for nominal bunch intensity	5	um
Precision[1] of the measurement for nominal bunch intensity	5	um
Long term stability[2] of the offset for nominal bunch intensity	20	um
High frequency cut-off (-3dB)	10	GHz
Low frequency cut-off (-3dB)	≤ 500	kHz
In-band (between -1dB low and high cut-off roll-off) response variation	≤ 1	dB
Time resolution for single bunch, single pass measurement	25	ps
Acquisition length for a single bunch measurement on successive turns	10000	turn
Minimum time between two successive measurements	25	ns

Acceptance criteria for High bandwidth PU's

- Approved in 2021 https://edms.cern.ch/document/2369610/1.2
  - High dynamic range
  - Two le

Parameter Description	Value	Unit
Pilot Bunch Intensity	5×10^{9}	Charges
Nominal Bunch Intensity	2.2×10^{11}	Charges

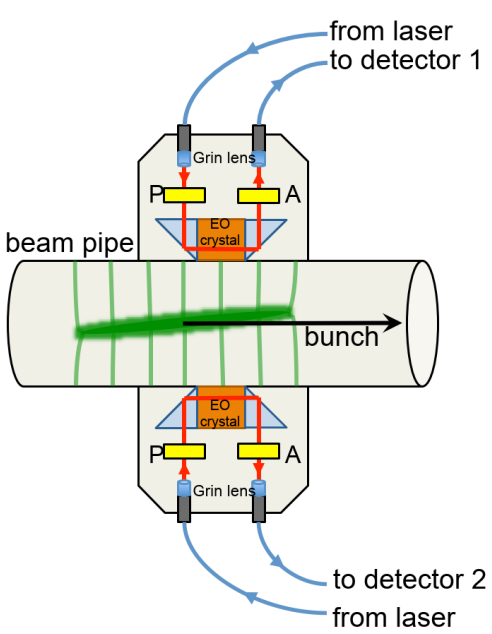
- Analogue Bandwidth 10GHz
- Time resolution 25ps
- Position sensitivity 10um
- Measuring all bunches (40MHz)
- Towards larger number of turns acquired

Key p ce criteria

Single bunch, single pass resoluti			pilot bunch intensity	50	um
Single bunch, single pass resoluti intensity			nominal bunch	5	um
Precision[1] of the measurement f			sity	5	um
Long term stability[2] of the offset			nsity	20	um
High frequency cut-off (-3dB)				10	GHz
Low frequency cut-off (-3dB)				≤ 500	kHz
In-band (between -1dB low and			ponse variation	≤ 1	dB
Time resolution for single bunch,			ent	25	ps
Acquisition length for a single bunch			on successive turns	10000	turn
Minimum time between two successive measurements	25	ns	Minimum time between two successive measurements	25	ns

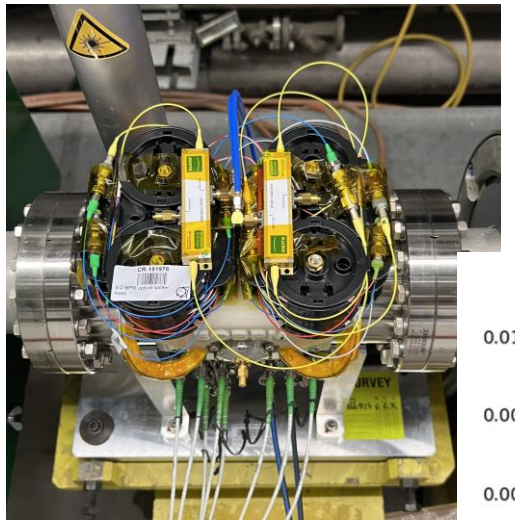
High Bandwidth BPM development plans

- Developing full E-O Pick-Ups (started in 2016)
  - *Encoding the time varying beam signals onto a laser using birefrigent crystal (Lithium Niobate)*
  - *Replacing cables by optical fibers*
  - *Relying on fast detectors and fast oscilloscope*

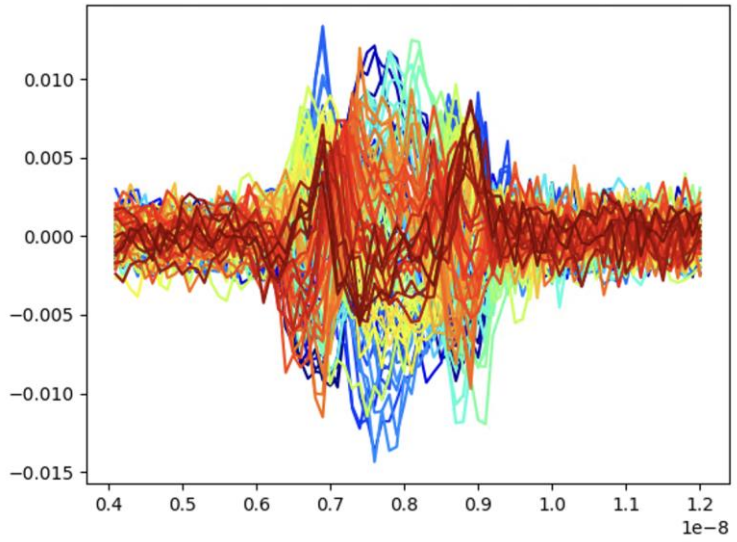


DC Laser

Fast photo-detectors → Oscilloscope

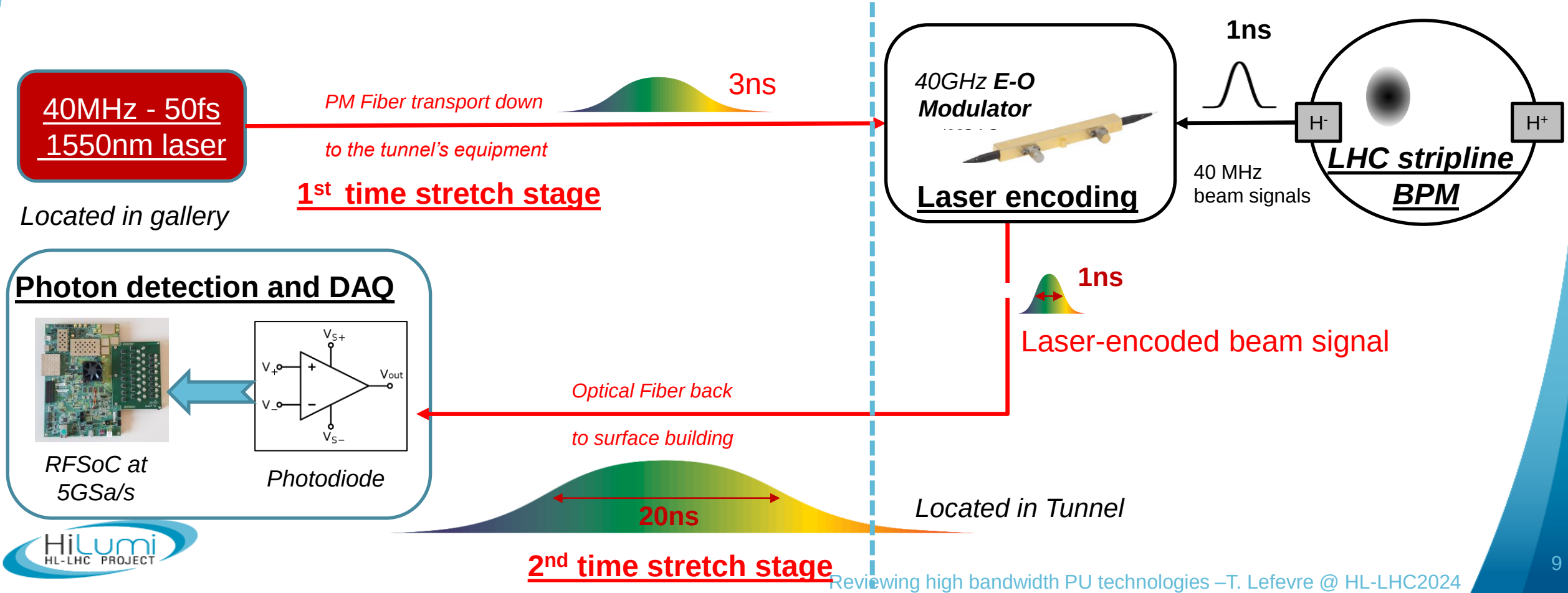


Talk by Max



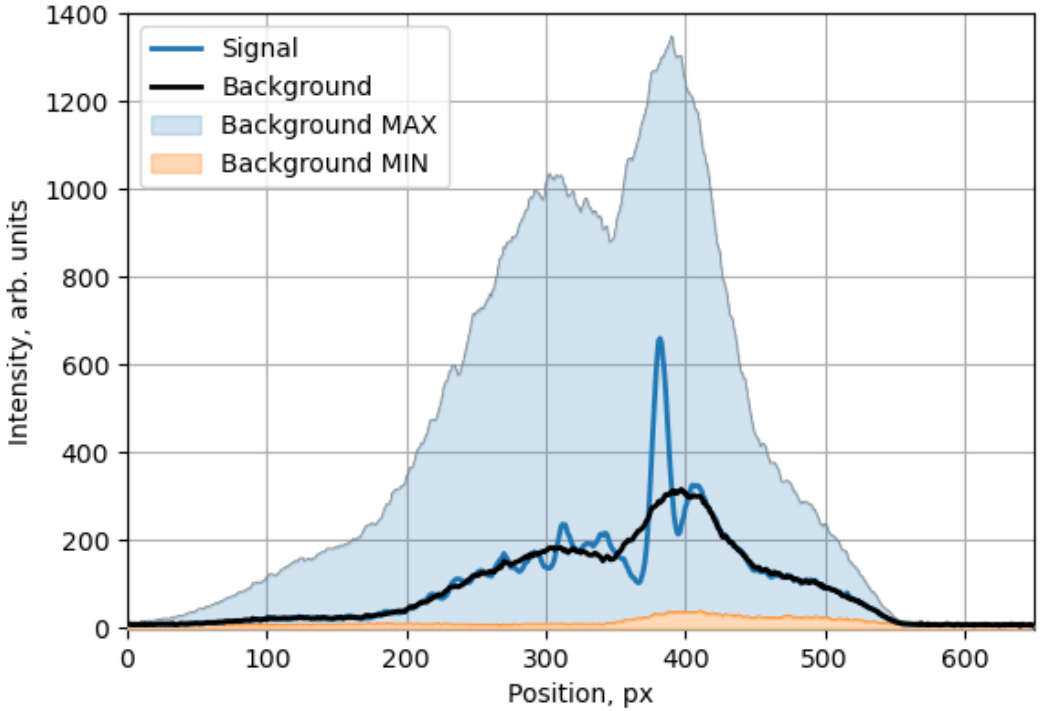
High Bandwidth BPM development plans

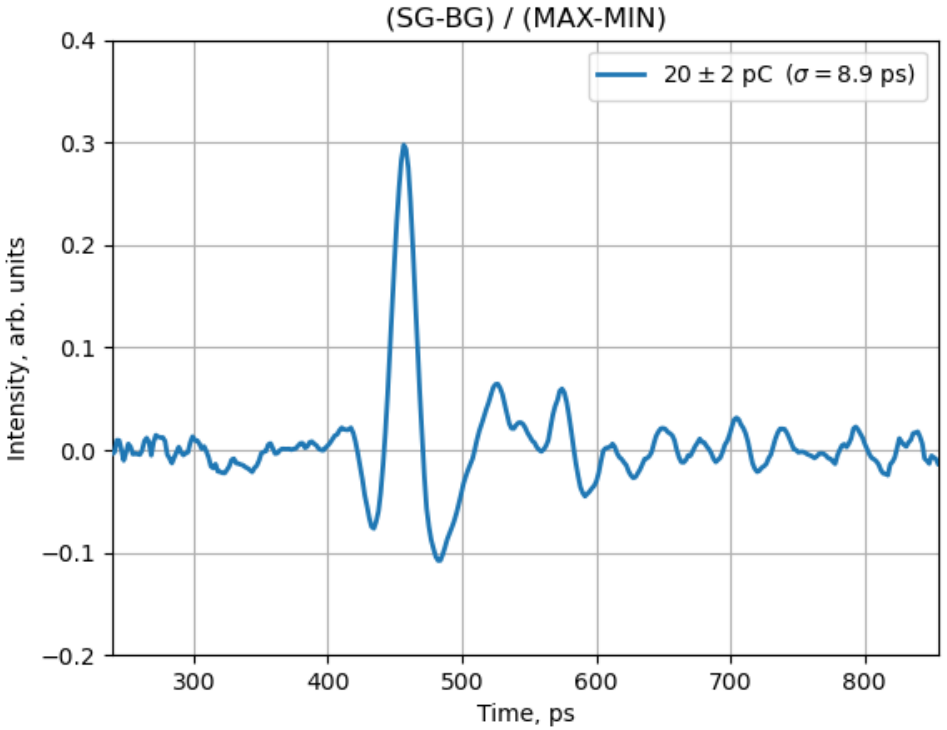
- Developing Electro-optical Time stretch techniques
  - *Keeping EM BPM (i.e. stripline), possibly better performing one (higher bandwidth)*
  - *Using electro-optical modulator to encode electrical beam signals on laser beam – optical fiber transmission*
  - *Using chirped laser pulses to use time stretch techniques to improve the DAQ system (better and cheaper)*



High Bandwidth BPM development plans

- Developing Electro-optical Time stretch techniques
  - *Proof of concept test performed at CLEAR in 2024 using Time stretch at 780nm wavelength*





See: A. Schlögelhofer, invited talks @ IBIC 2024 Beijing

- *Validation test to be performed in 2025 on LHC stripline pick-up using Time Stretch at 1550nm (to assess the performance of longer stretching)*

Reviewing the High bandwidth PU technology

Hilumi LHC high bandwidth BPM review – December 2024

The main goal of the review is to assess the **performances and limitations of the different technologies** that can be considered for high bandwidth intra-bunch position monitoring in the LHC, especially for time domain crab cavity diagnostics. The panel will review the **monitor's architecture and implementation**, including both the pick-up's design as well as its control and read-out system. The panel will be asked to assess the **performance of the proposed solutions with respect to the monitor acceptance criteria** (https://edms.cern.ch/document/2369610/1.2). They shall also highlight the **main risks for a successful deployment of the system in the LHC during the Long Shutdown 3 (LS3)**, including both budget and schedule considerations.

Reviewing the High bandwidth PU technology

Hilumi LHC high bandwidth BPM review – December 2024

Charge Questions:

1- *Does the proposed monitor's architecture satisfy the functional specifications ?*

2- Is the strategy proposed to solve the technical issues or unknowns well defined and in line with an implementation during LS3 ?

3- Are the pros and cons of the different technical solutions all well addressed ?

4- Are there changes to be considered to the functional specifications that would increase the chance of success ?

Proposed talks :

- *Overview of Head-tail monitoring in LHC*
- *Overview of the HL high bandwidth functional specifications and constrains for installation*
- *EO PU development status and plans*
- *EM Stripline development status and plans*
- *Time stretch EO modulators acquisition system development and plans*
- *WP13.6 BPW – High frequency BPM project budget and schedule*

Summary

- WP13 worked on an exciting R&D program towards the development of improved high bandwidth BPM
- As we are entering the final phase of the project, a technology choice must be made
- Review in December 2024 will allow to identify the best system design and prepare for its implementation during LS3.