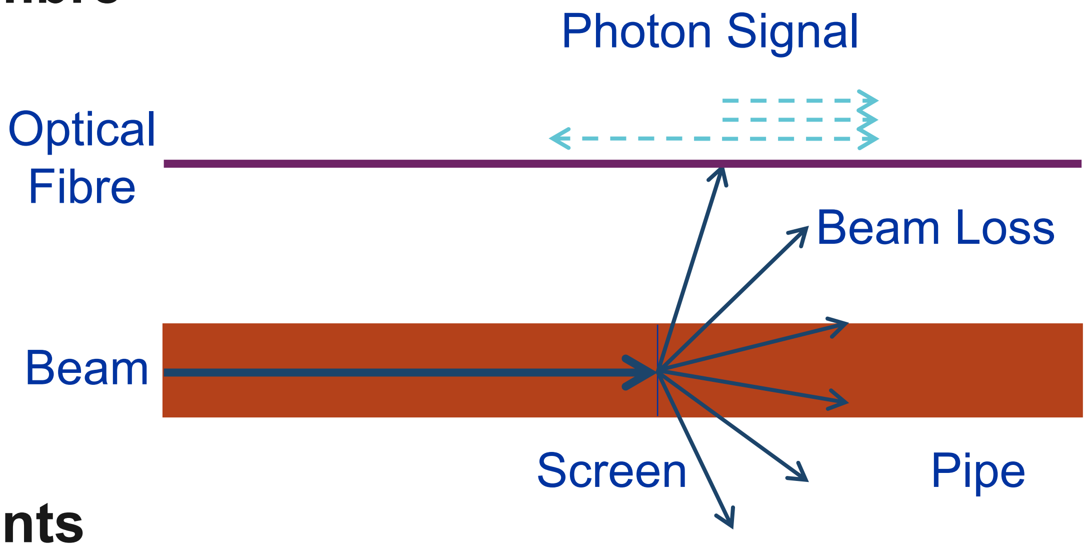
Novel optical beam loss monitor at CLEAR

A systematic investigation of beam losses and position reconstruction techniques

M. King, S. Benitez, A. Christie, E. Effinger, J. Esteban, W. Farabolini, P. Korysko, J. M. Meyer, B. Salvachua, C. Welsch and J. Wolfenden

Optical Beam Loss Monitors

- **Multimode optical fibres parallel to beam line**
- **Beam losses induce photons when traversing fibre**
- **Cherenkov radiation occurs when charged particles traverse an optical medium at velocities larger than the speed of light within the medium**
- **Readout either side with photodetectors**
- **Can cover large distances with only few elements**



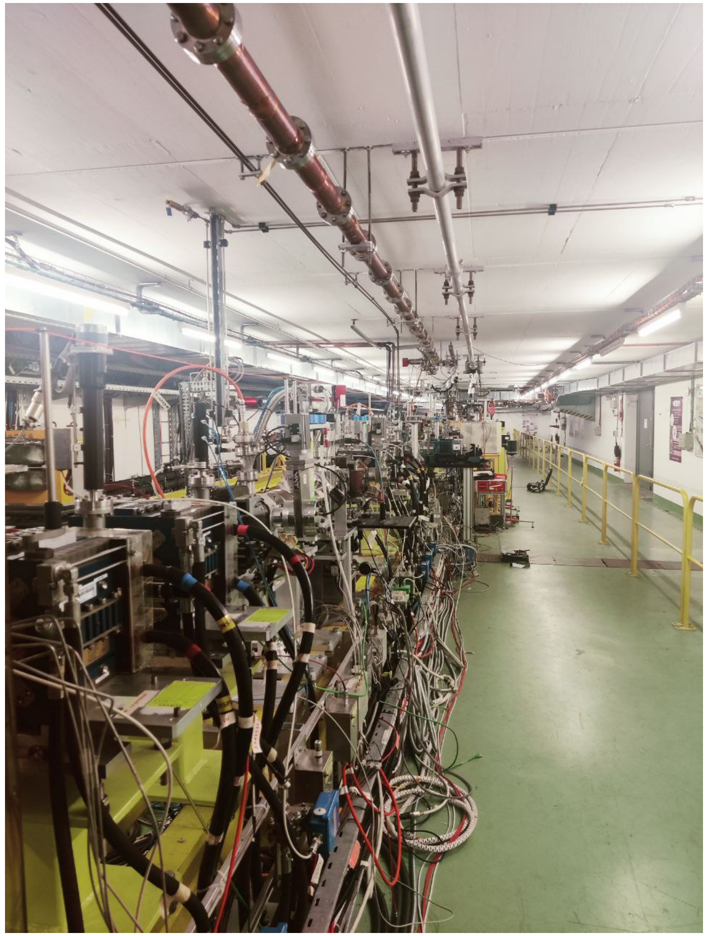
CLEAR

- CERN Linear Electron Accelerator for Research

- 20m long accelerating structure followed by 20m long experimental beam line

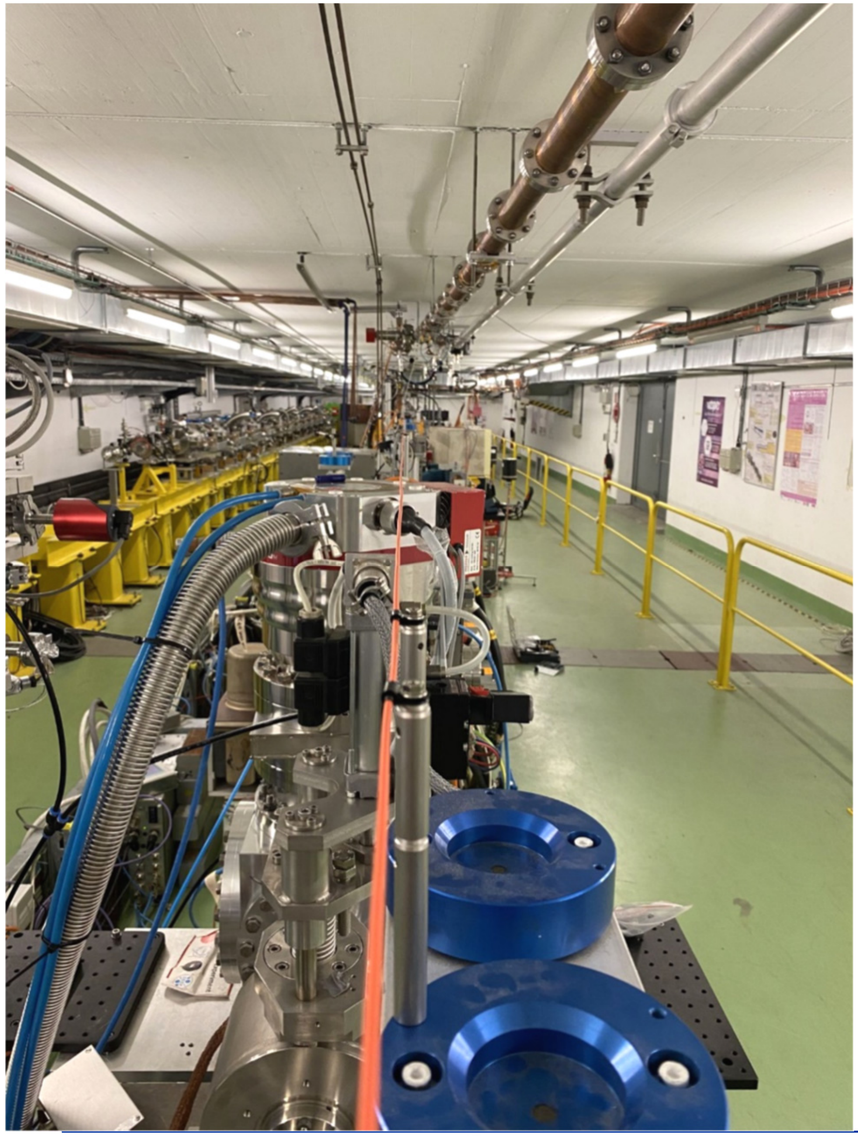
- Wide range of beam parameters to test:
  - Plasma lens and THz acceleration
  - Medical applications of electron beams
  - Beam instrumentation

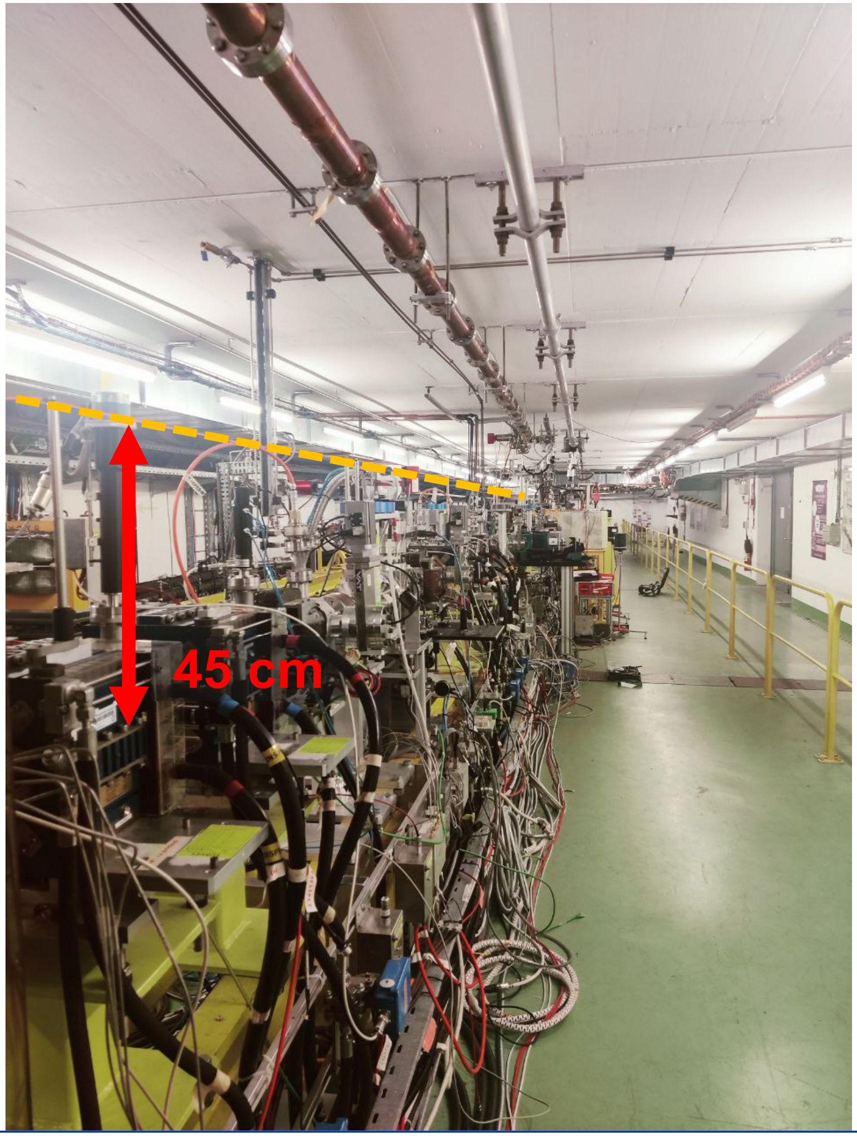
- Desire for oBLM installation expressed after successful test campaign with prototype[1] by Sara Benitez to visualise beam losses

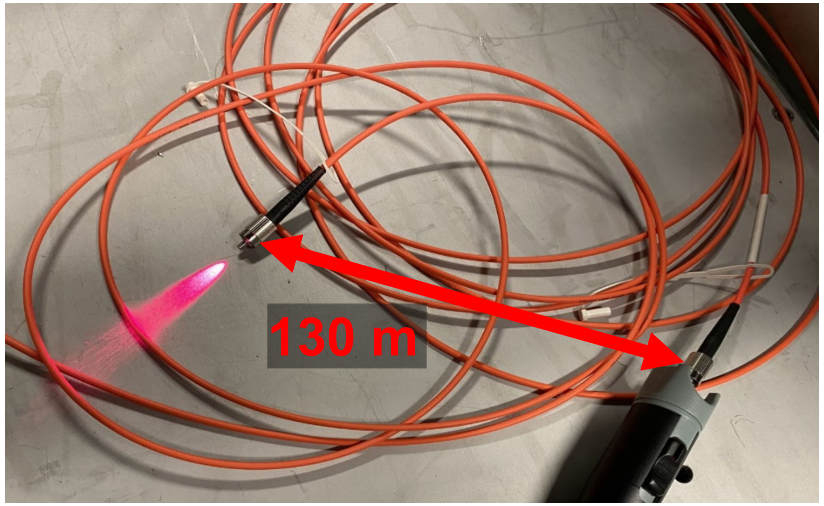


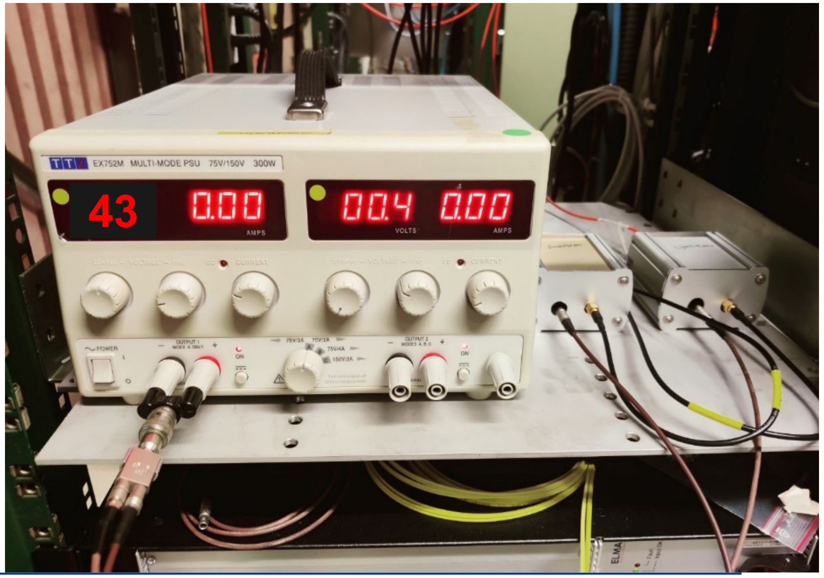
[1] Sara Benitez et al. "Beam loss detection based on generation of cherenkov light in optical fibers in the cern linear electron accelerator for research", Phys. Rev.Accel. Beams, vol. 27, p. 052 901, 5 2024.

CLEAR - Installation



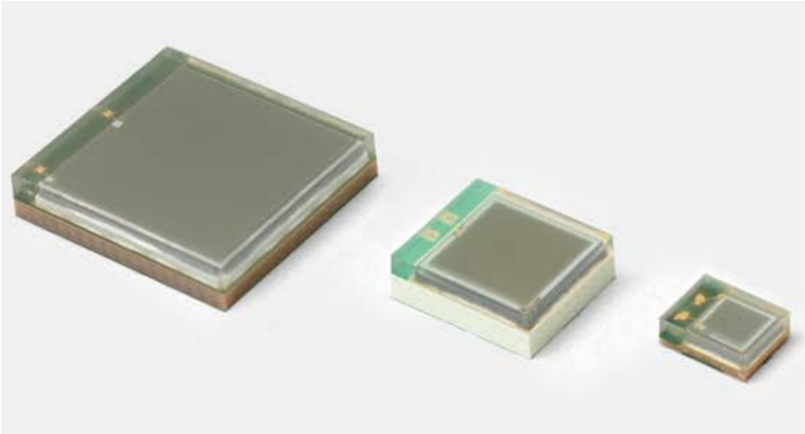






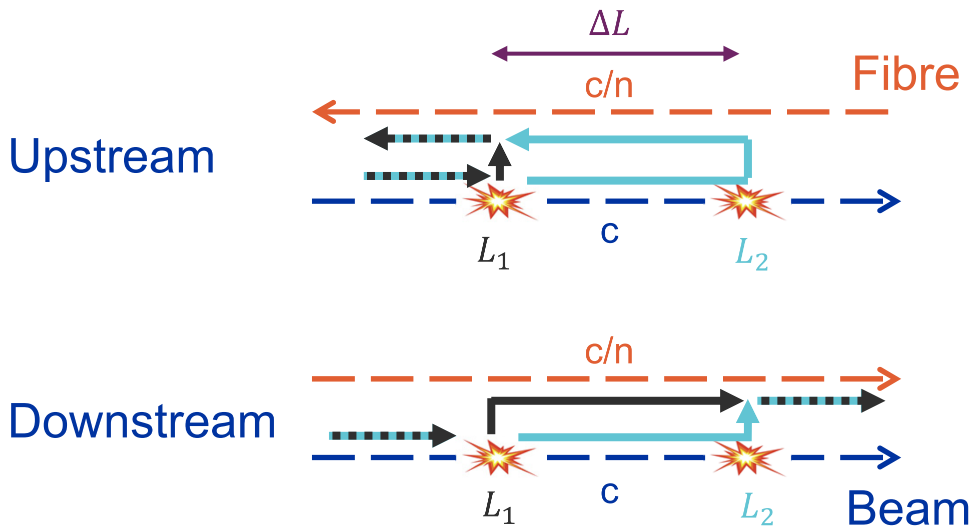
CLEAR – Installation

- **Hamamatsu S14160-3010PS SiPMs**
  - Cheap
  - Low operating voltage
  - Good Photon Detection Efficiency over large wavelength range
- **Thorlabs 130 m, 200 µm, 0.22 NA Fibre, FG200LEA**
  - Low attenuation
  - Sufficient signal capture
- **Readout with CLEAR Oasis System (Oscilloscope)**



Position Reconstruction

- **Create losses with screens or magnets**
  - Screens are more suitable for a precise calibration
- **Readout induced signals at both ends**
  - Upstream has better time to position conversion but lower signals due to loss shower directionality
- **Convert measured signal into timestamp**
  - Peak position, constant threshold, constant fraction discrimination or signal gradient

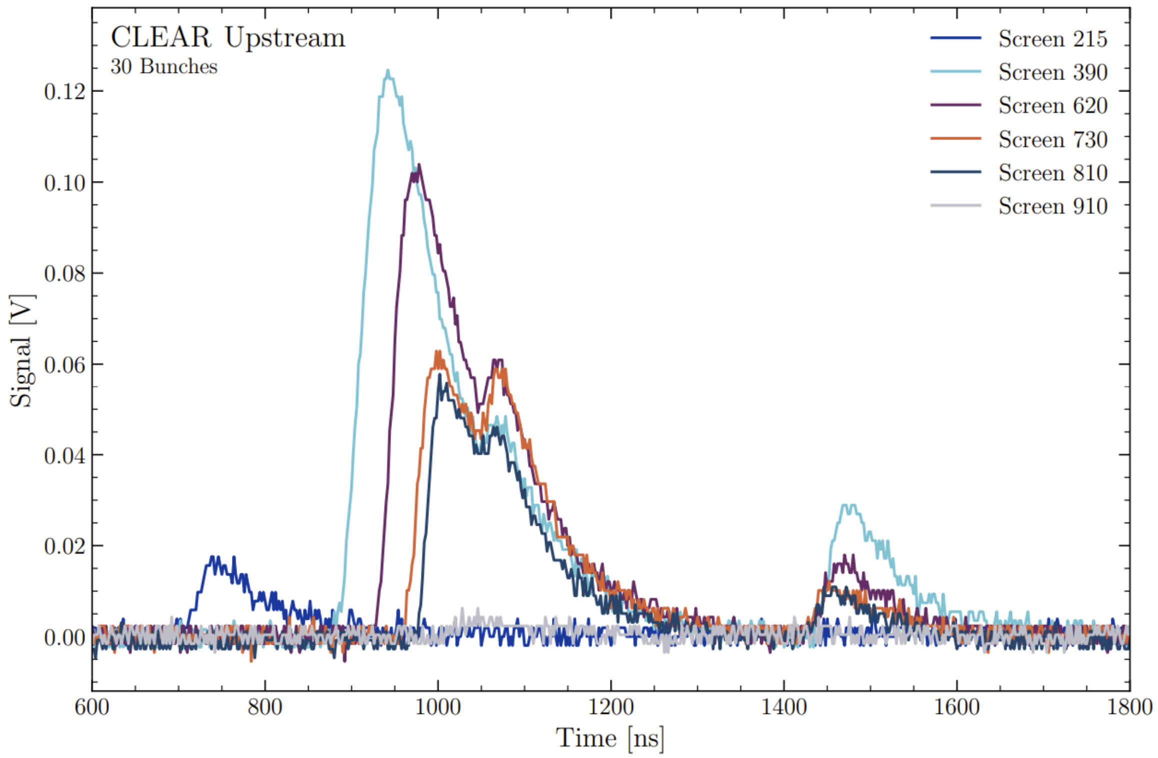


$$\Delta t = \Delta L * (1 \pm n)/c$$
$$\Delta t_{Upstream} = 2.5\ \Delta L/c$$
$$\Delta t_{Downstream} = -0.5\ \Delta L/c$$

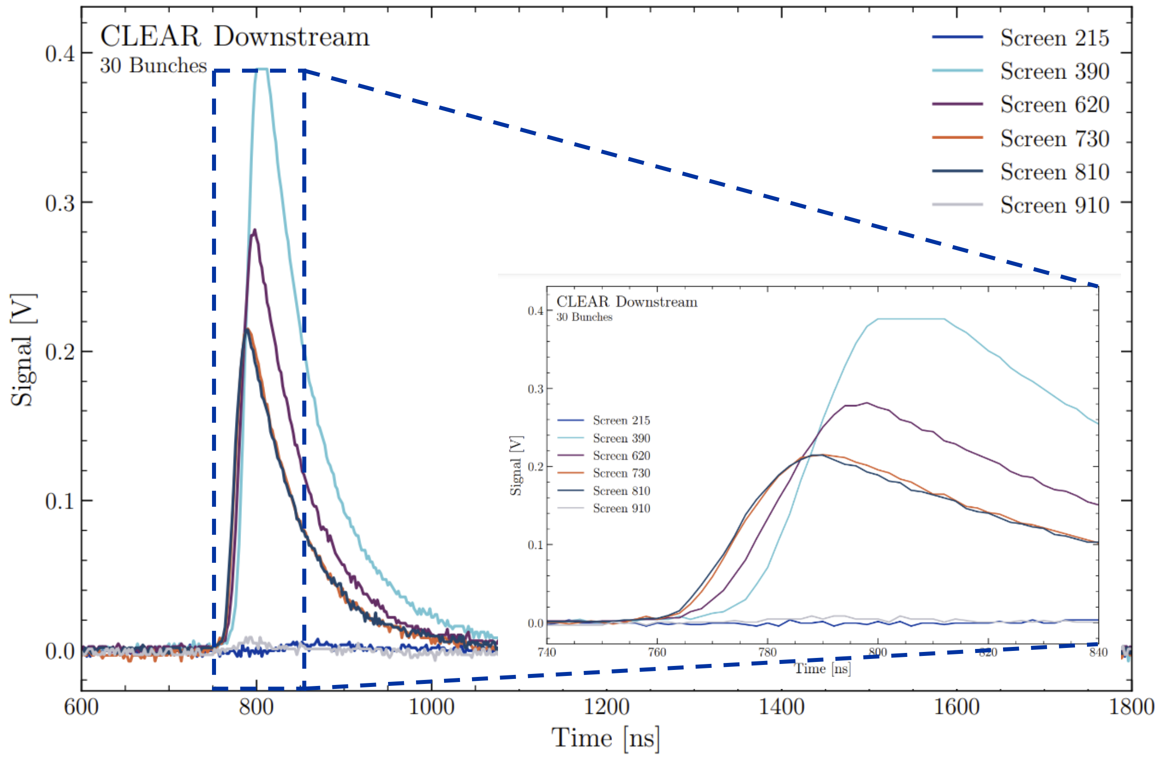
Upstream vs Downstream

- **Single waveforms measured for losses created by inserting different screens**

Upstream

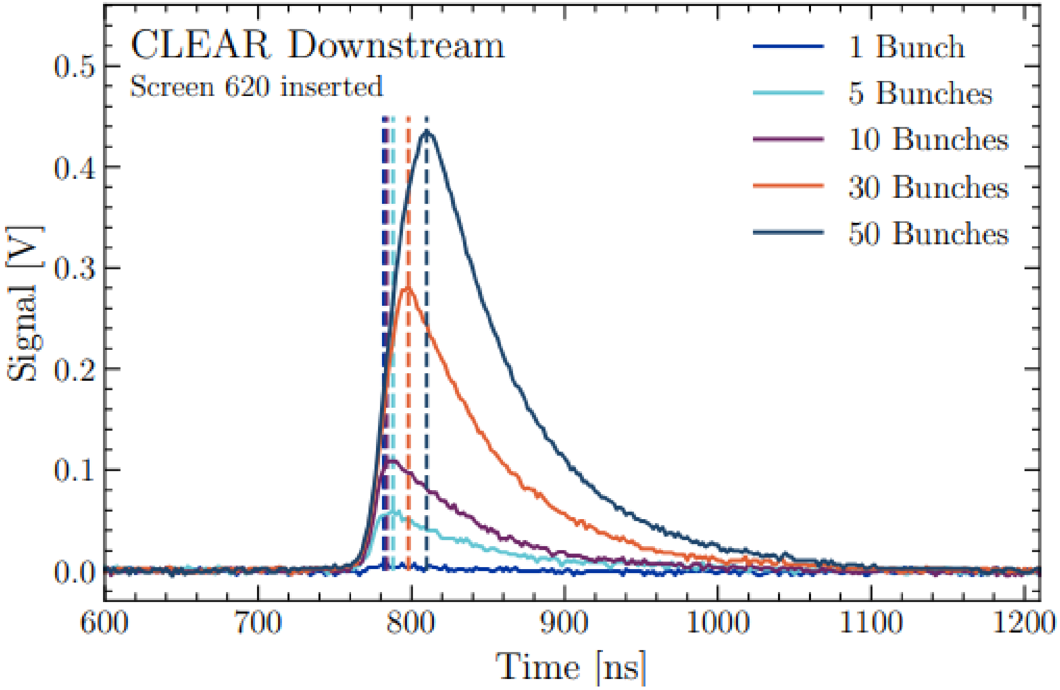


Downstream



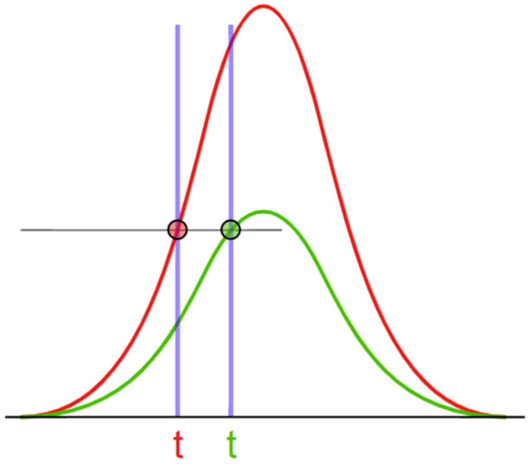
Peak Position

- **Use the maximum of the waveform as timestamp**
- **Maximum position shifts with bunch number due to bunch spacing**
  - ➢ Compensate train length by subtracting half of the train length from timestamp
  - ➢ This effectively shifts trigger from start of train to the middle of train

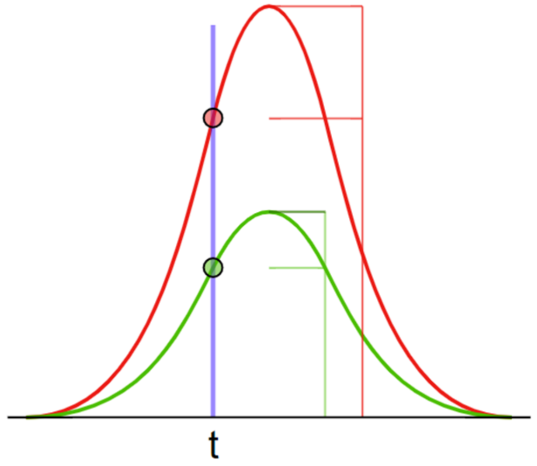


Constant Fraction Discrimination

- Constant fraction of maximum signal is used as threshold for the corresponding waveform
- Especially useful when comparing significantly varying signal heights
- In this case, fraction of 40% was chosen

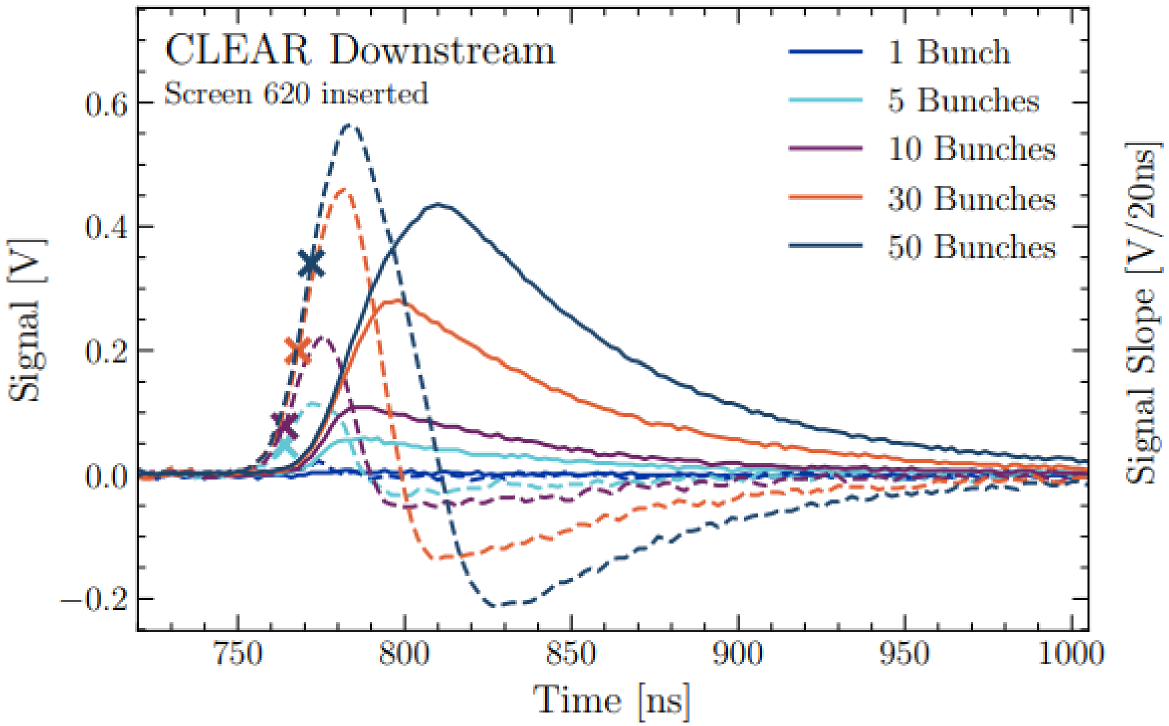


https://en.wikipedia.org/wiki/Constant_fraction_discriminator



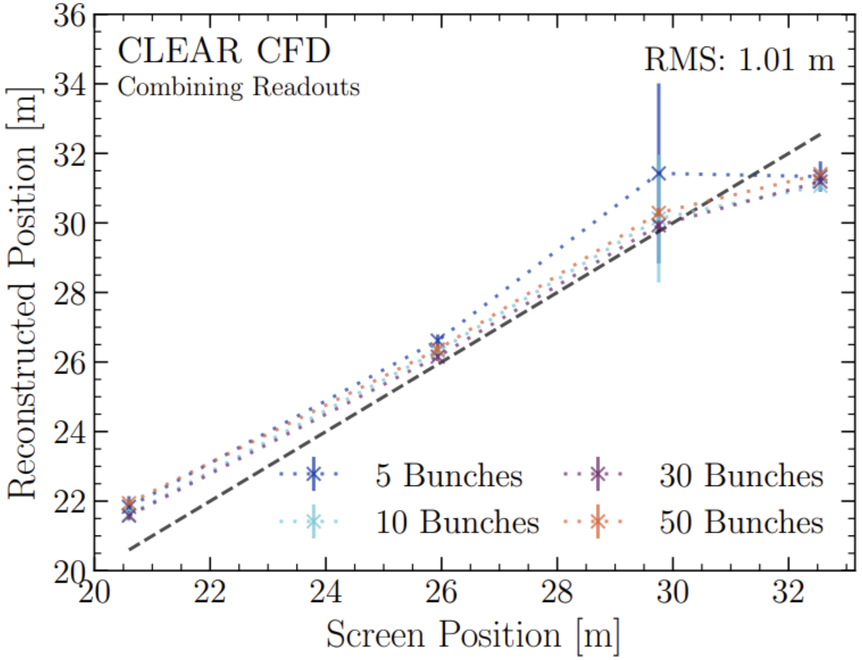
Signal Gradient

- **First order derivative is calculated**
- **Threshold on the derivative is set to max signal/30ns**
- **Local maxima easily identifiable**



Position Reconstruction – Analysis

- **20 measurements taken for each combination of:**
  - Bunch number (5, 10, 30, 50)
  - Screen (390, 620, 730, 810)
- **Waveforms analysed for all combinations of:**
  - Upstream, Downstream, Combined
  - Peak position, constant threshold, constant fraction discrimination and gradient
- **Dashed line of form $y = x$ with reconstructed position y and screen position x**
- **Calculated root mean square (RMS) deviation from line**



Position Reconstruction – Discussion

IBIC2024 Sept. 9-13, 2024 · Beijing, China

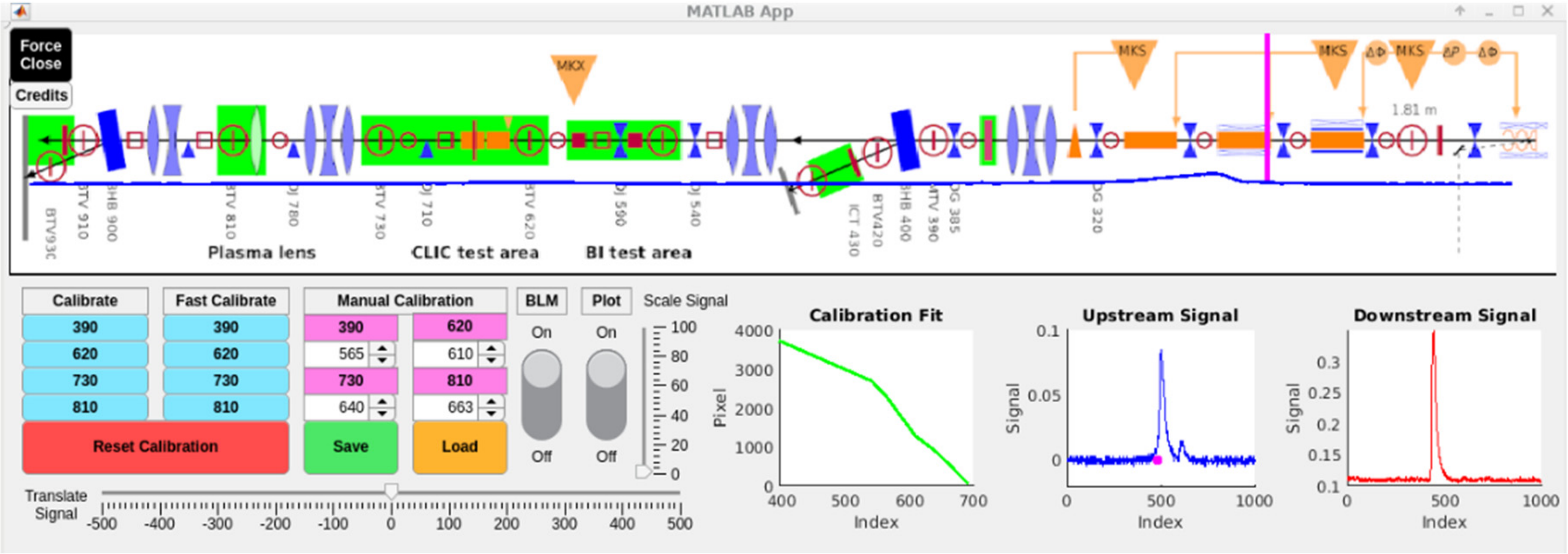
- Constant fraction discriminator > constant threshold > peak position
- Combining readout seems better than upstream
- Downstream is worse by factor ~ 2
- Gradient is best when neglecting 5 bunch measurements

➢ **Accuracy of 1 m** achievable with this setup

RMS [m]	Up.	Down.	Comb.
Peak	1.60	3.00	1.59
Const.	1.45	2.70	1.33
CFD	1.01	2.42	1.01
Gradient	9.63 (0.73)	1.99 (1.94)	8.12 (0.76)

Values in brackets neglect 5 bunch measurements

GUI for Operators



- Visualises relative beam loss magnitude and position in real time
- Written in MATLAB by Pierre Korysko and Alexander Christie
- Especially useful during setup of beam, e.g. after shutdown or changing parameters

Conclusion and Outlook

- **Successfully installed new oBLM at CLEAR**
- **Loss position accuracy of 1 m achieved in real time along entire beam line**
- **For single loss positions, combining up- and downstream readout and applying a constant fraction discrimination seems to be optimal for position reconstruction**
- **Further investigations will explore full potential and loss position resolution**
- **Installations at further, more demanding, accelerators around CERN in progress**

CERN