Performence of the Time Resolved Spectrometer for the 5 MeV Photo-injector PHIN

D. Egger, Ö. Mete EPFL, Lausanne, Switzerland & CERN, Geneva, Switzerland M. Csatari, A. Dabrowski, S. Döbert, T. Lefèvre, M. Olvegård and M. Petrarca CERN, Geneva, Switzerland

Abstract

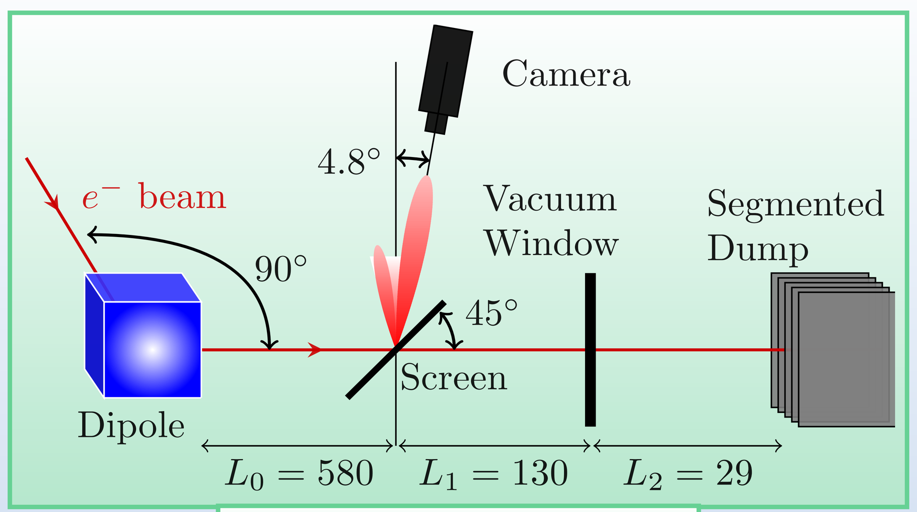
The PHIN photo-injector test facility is being commissioned at CERN in order to fulfil the beam parameter requirements for the 3rd CLIC Test Facility (CTF3), which includes the production of a 3.5 Amp stable beam, bunched at 1.5 GHz with a relative energy spread of less than 1%. A 90° spectrometer is instrumented with an OTR screen coupled to a gated intensified camera, followed by a segmented beam dump for time resolved energy measurements. The following paper describes the transverse and temporal resolution of the instrumentation with an outlook towards single-bunch energy measurements.

PHIN

A joint collaboration between LAL, CCLRC and CERN has been setup to develop and commission PHIN. This photo-injector is to replace the current thermionic gun at the CTF3 to improve the quality of the CLIC drive beam. It produces a 1.2 μs train of 2.33 nC bunches spaced at 1.5 GHz. The beam is accelerated by a 2.5 cell gun to reach a nominal energy of 5.5 MeV. Due to the fully loaded acceleration scheme, heavy beam loading is expected.

PHIN Spectrometer

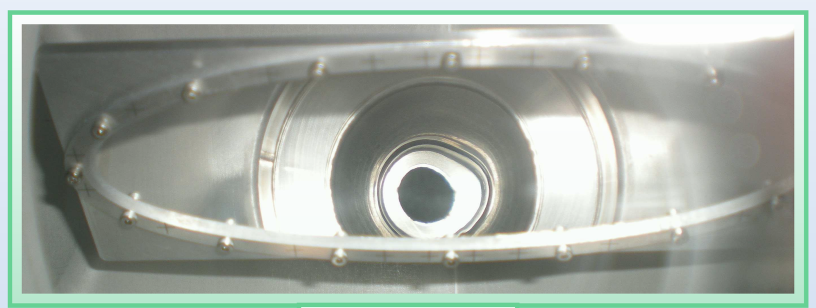
The spectrometer line at PHIN is composed of a 90° bending dipole, an OTR screen for precise transverse measurements and a segmented dump for single shot time resolved measurements. The light emitted by the beam passing through the aluminum screen is imaged by an intensified camera. The dipole gives the electron beam a dispersion of 820.2 mm at the OTR screen and 1067 mm at the segmented dump.



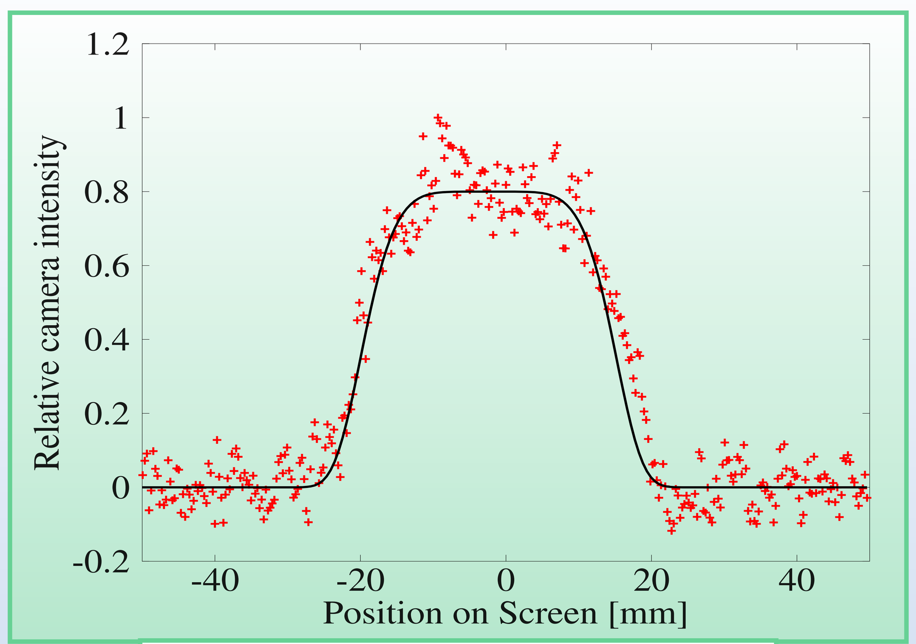
Layout PHIN's Spectrometer

OTR Temporal Resolution

With the 5 ns minimum camera gate, the transverse profile of a 0.1 nC per bunch beam was resolved. Single bunch energy spread measurements can thus be achieved with a faster camera under nominal conditions.



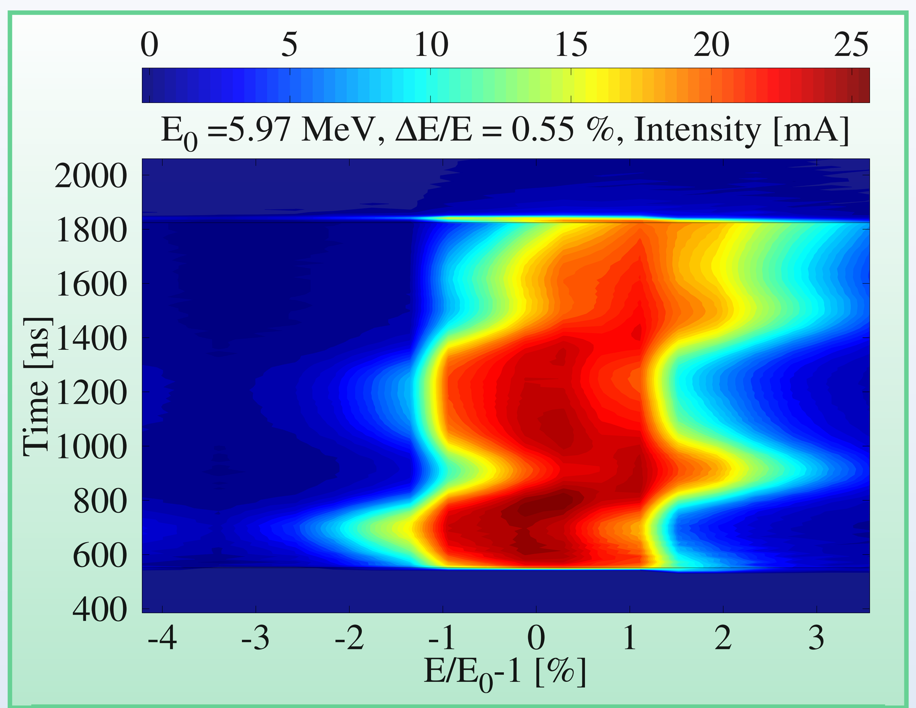
OTR Screen



Profile Measurements with a 5 ns Gate

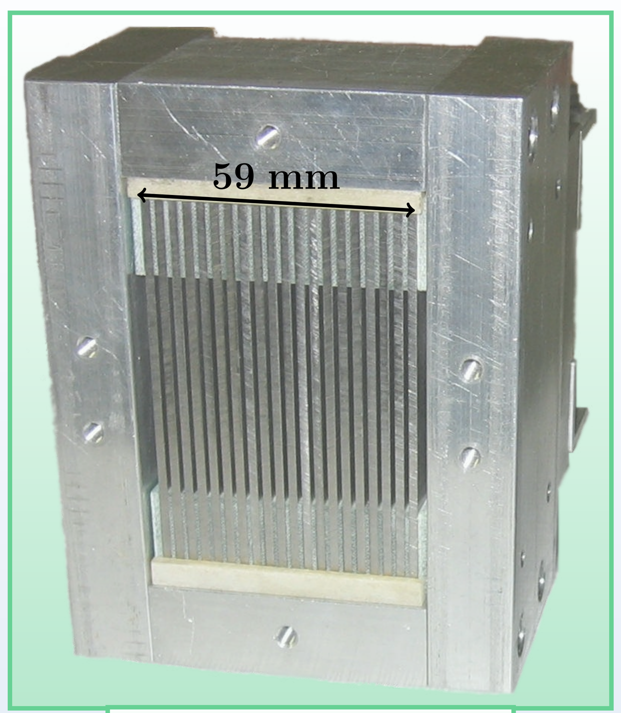
PHIN Segmented Dump

20 parallel stainless steel plates act as Faraday Cups. The beam induced current gives the time resolved horizontal profile encoding the energy spread.

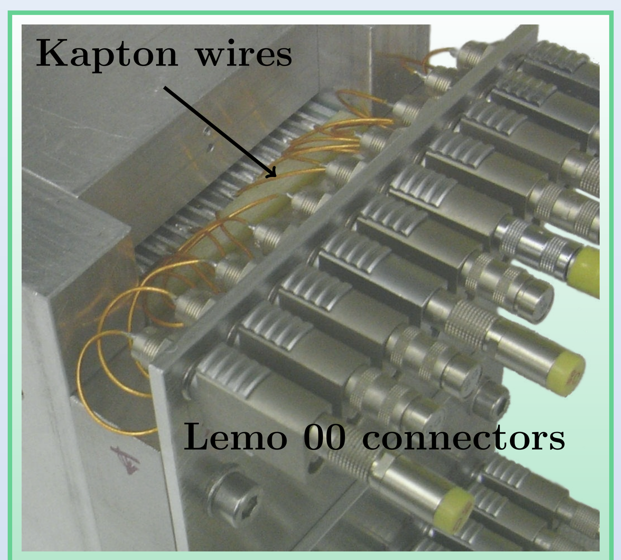


Typical Time Resolved Energy Spread Measurement

Segmented Dump Parameters					
Segment width	2	mm	Kapton wire length	10	cm
Segment spacing	1	mm	BNC cable length	55	m
Resolution	0.25	%	Lemo 00 cable length	2	m
Absolute Error	0.06	%	ADC Sampling	96	MHz



PHIN Segmented Dump



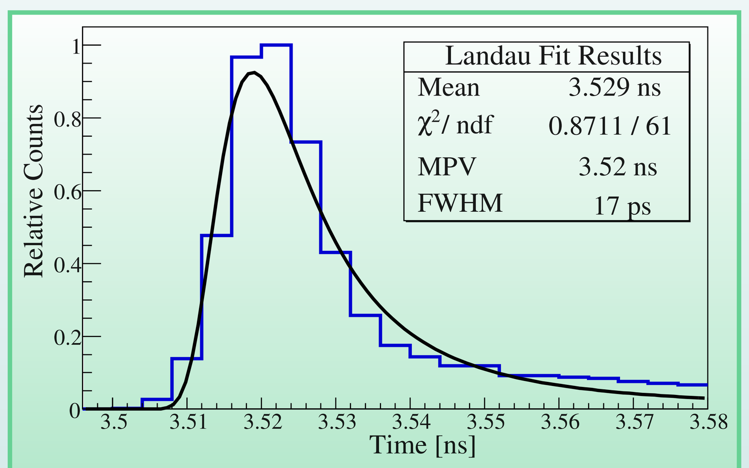
Kapton Wire Connection

Segmented Dump Temporal Resolution

The various contributions to the segmented dump's temporal resolution were explored using dedicated measurements. With a higher quality cable and a fast oscilloscope, the temporal resolution of the system has been measured to be **520 ps**. The limitation is still due to long cables and impedance mismatches in the dump.

Intrinsic Temporal Resolution

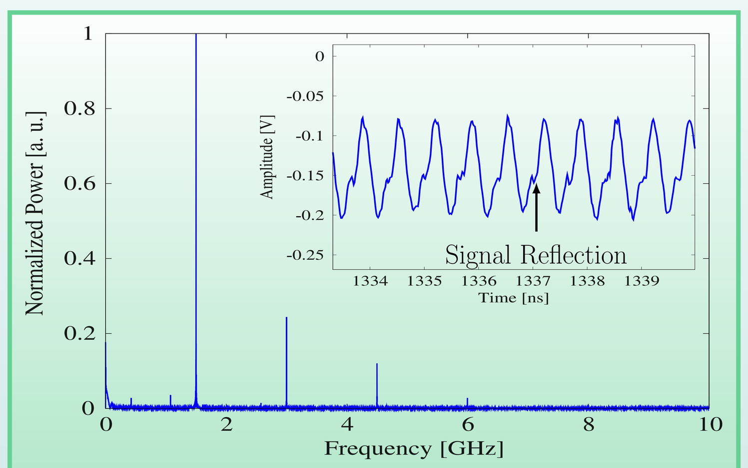
is the time required to stop the electrons in the segments. This was simulated in Geant4; a 5.5 MeV dirac pulse of electrons is broadened by 17 ps.



Simulation

Digitizer Temporal Resolution

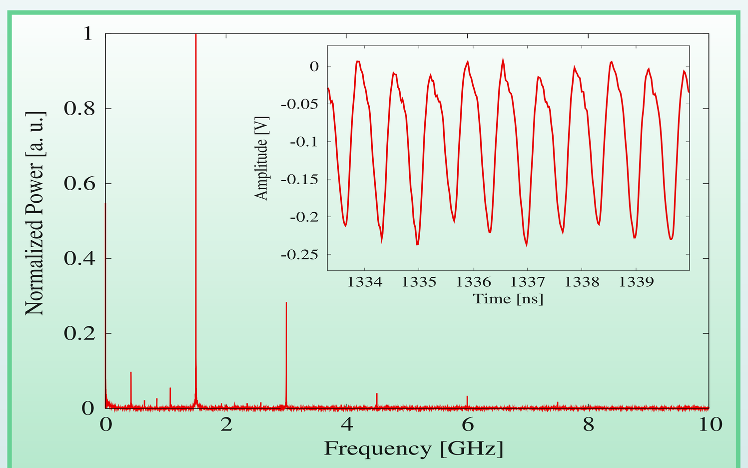
Connecting one channel of the dump to a 18 GHz oscilloscope with an an adequate cable showed that the 1.5 GHz bunch structure can be resolved.



Single Channel Measurement

Impedance Mismatch

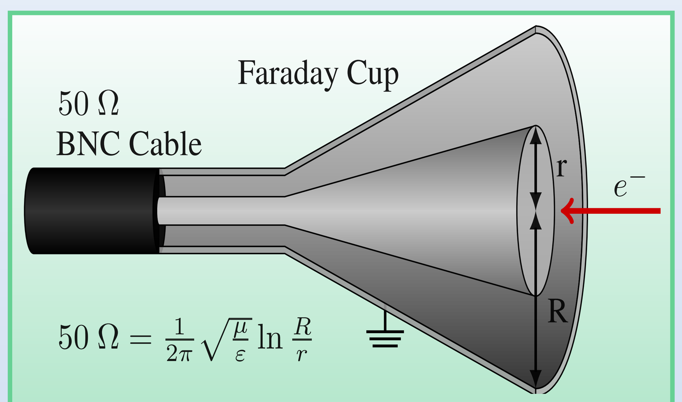
The segmented dump's impedance is much higher then 50 Ω, creating signal reflections. These vanish when using an impedance matched Faraday Cup.



Single Channel Measurement

Cable Attenuation

The attenuation of the cables limit the maximum frequency. At 100 MHz, the BNC cable attenuates the signal by 8 dB. Thus, in normal operation, the ADCs limit the temporal resolution and frequency components above 12 MHz present distortion.



Impedance Matched Faraday Cup

Error Calculation

At 5.5 MeV, multiple scattering of the beam in the OTR screen and vacuum window increases the beam divergence by σ'_s and σ'_{vac}. The energy spread is:

$$\sigma_{E,d} = \sqrt{\left(\sigma_d - L_1 \tan\left(\sigma'_s\right) - L_2 \tan\left(\sigma'_{vac}\right)\right)^2 - \sigma_b^2}$$

Giving the relative energy spread through:

$$\frac{\Delta E}{E} \cong \frac{2}{\pi}\frac{\sigma_{E,d}}{L_0 + L_1 + L_2} \pm \frac{2}{\pi}\frac{\Delta\sigma_{E,d}}{L_0 + L_1 + L_2}$$

The error on $\sigma_{E,d}$ is:

$$\Delta\sigma_{E,d} = \sqrt{\sum_{ij}\left(\partial_{x_i}\sigma_{E,d}\right)^T M_{ij}\partial_{x_j}\sigma_{E,d}}$$

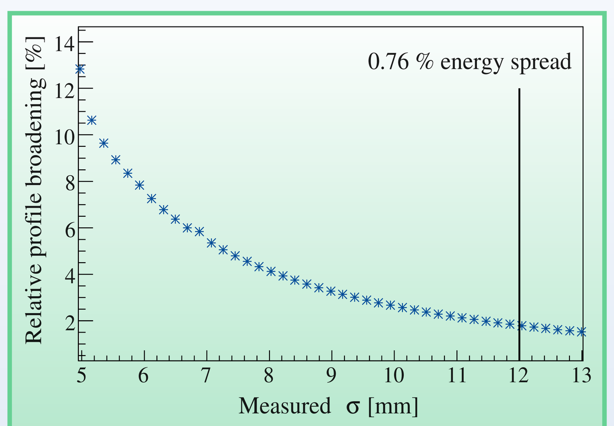
$$\boldsymbol{x} = \left(\sigma_d, \sigma'_s, \sigma'_{vac}, \sigma_b, L_1, L_2\right)$$

$$M_{ij} = \Delta x_i \Delta x_j$$

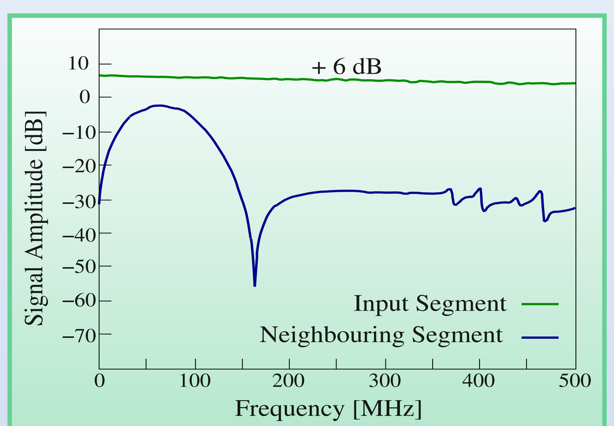
For a typical beam with $\sigma_d = 12 \pm 1$ mm it is found that the absolute error on $\Delta E/E$, measured by the segmented dump, is $\pm$**0.06%**. Making this detector accurate to within 7.4%. The largest contribution comes from the error on the measured profile at the segmented dump, i.e. σ_d.

Electrical Cross Talk

The crosstalk between two neighbouring segments is 10 dB. A nearest neighbour model showed that for a 0.76% relative energy spread beam, the measured profile is only broadened by 1.8%.



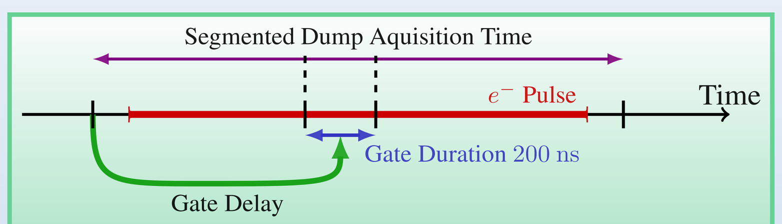
Cross Talk Calculation



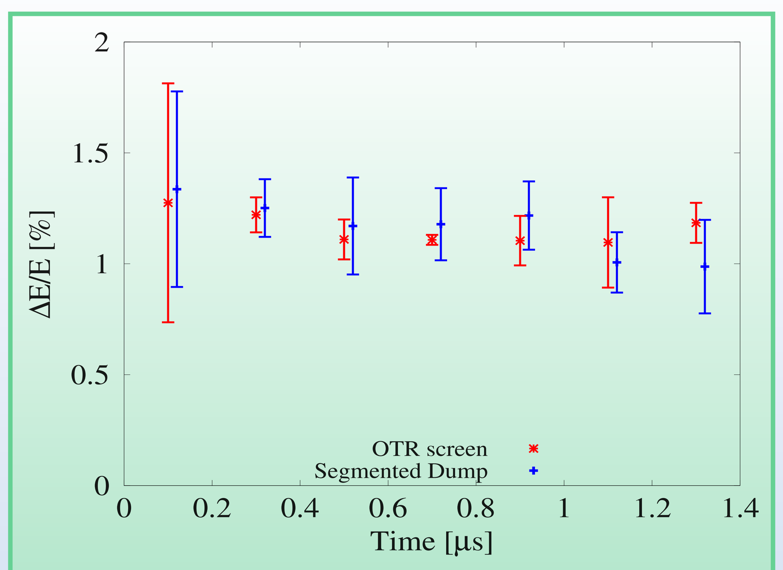
Cross Talk Calculation

OTR and Segmented Dump Agreement

The segmented dump and OTR screen energy spread measurements were compared over 200 ns intervals along the pulse train. Each interval was measured several times. The two detectors measure the same relative energy spread up to $7.8 \pm 4.6\%$



OTR and Segmented Dump Measurements



OTR and Segmented Dump Measurements

Conclusion

The tests presented here show that the instrumentation is well adapted for PHIN's needs: the energy spread as measure with the segmented dump and the OTR screen has been shown to agree within $7.8 \pm 4.6\%$ over 200 ns time intervals. Extrapolating from the OTR measurements, single bunch measurement should be possible. The time response of segmented dump detectors can be improved by carefully designing the cabling and connections. SMA type connectors could directly be soldered to the segments to minimize the number of connectors and to allow a higher bandwidth.