

## Abstract

At the CERN PS complex, precise fast intensity measurements are very important in order to optimize the transfer efficiencies between the different accelerators. Over the last two years a complete renovation has been ongoing, where the old electronics, based on analogue integrators, have been replaced by a fully digital system enclosed in a single VME based card. This new system called TRIC (Transformer Integration Card) is based on a 12 bit, 212 MS/s ADC and a FPGA for the signal processing. Also located on the same board one finds a 250 V/1.5 W DC-DC converter used to generate precise calibration pulses.

## FBCT Acquisition chain

### Analogue signal conditioning

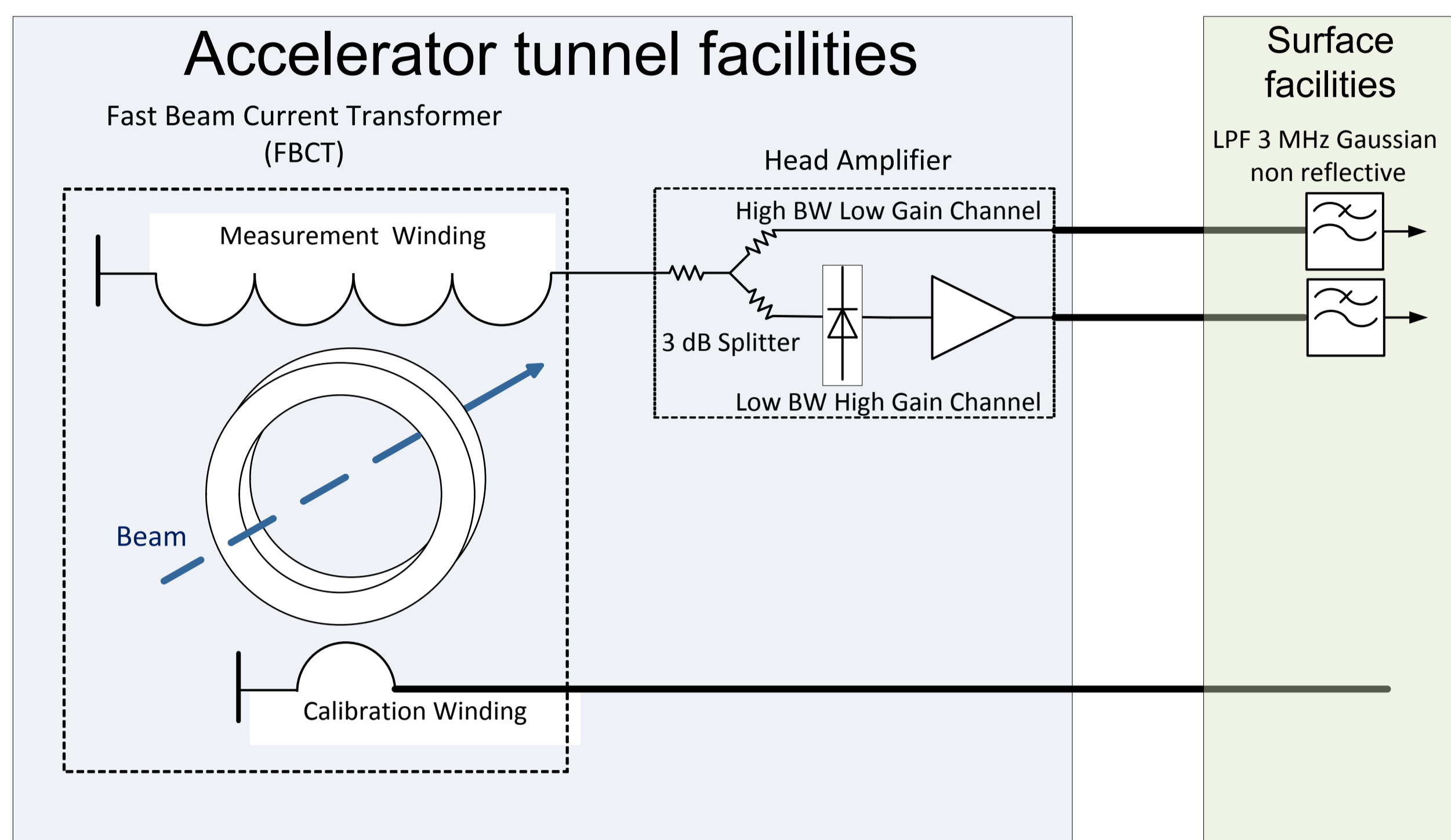


Fig. 1: Analogue path signal conditioning up to TRIC input

### Digital acquisition and control (TRIC)

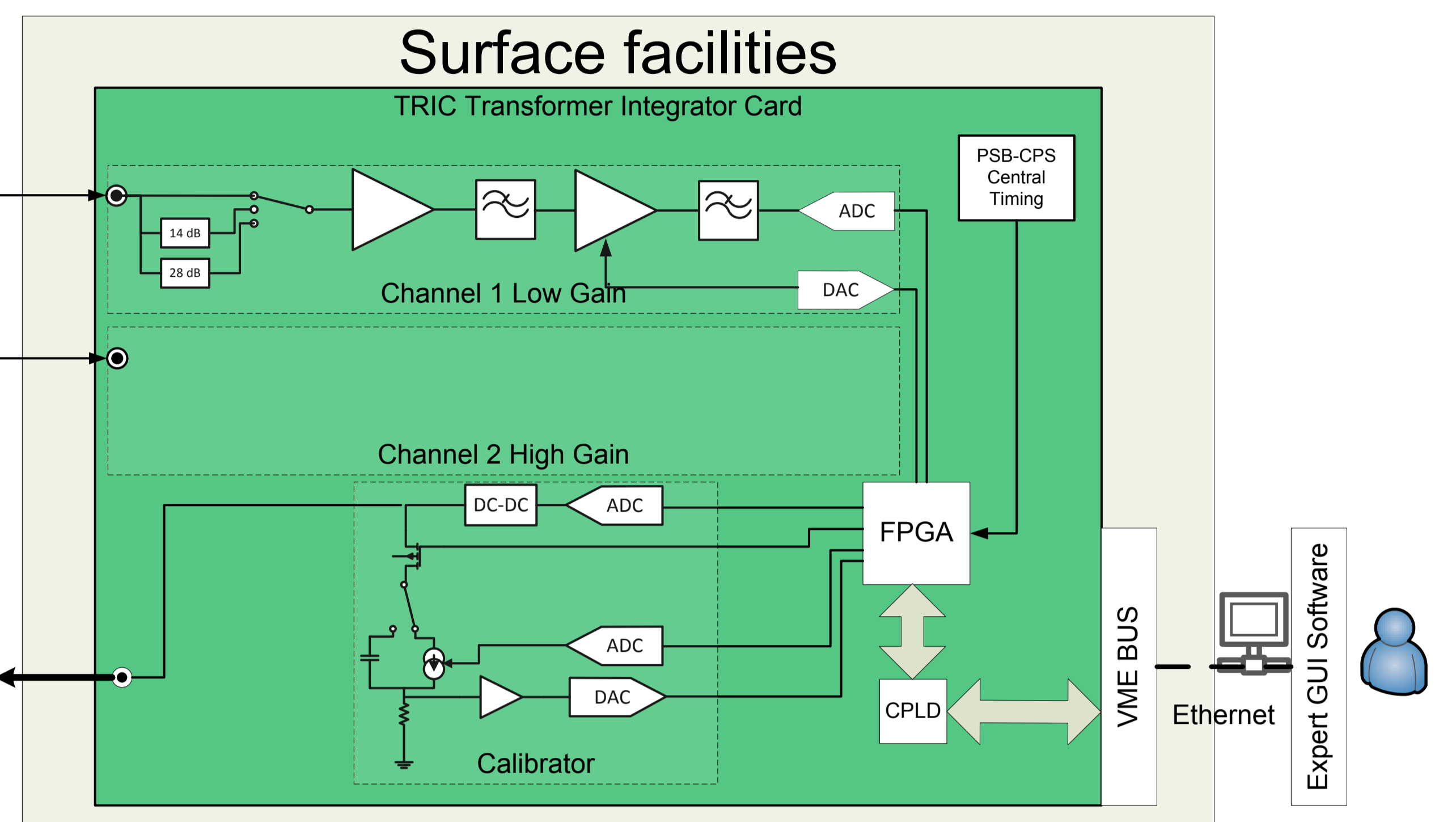


Fig. 2: TRIC includes acquisition, control and calibrator built in the same card

### Analogue chain components FBCT-head amplifier-cabling-LPF

#### FBCT:

- Many different types
- 5 to 40 measurement winding turns
- 1 to 10 calibration winding turns
- $V_{out}$  for 1:40 FBCT from 28.5 mV (LHC PROBE) to 12.52 V (TOF), as beams defined in LIU (LHC Injectors Upgrade)
- Bandwidth from 3 MHz (filter) to 800 MHz (without filter)

#### Head amplifier:

- 2 ways 3 dB resistive splitter at the input
- Low gain high bandwidth output
- High gain input equipped with voltage protection
- High gain output (29 dB) low bandwidth (180 Hz -30 MHz)

#### Cabling:

- Different types of coaxial cables with attenuation @ 50MHz ranging from 4.92 to 0.807 dB/100 m
- Cables length ranges from 30-300 meters

#### Low pass Gaussian filter:

- Reduce integration errors expanding signal shape in time domain
- Non reflective:
  - S11, 22 dB @ 5.1 MHz
  - S11, 20 dB @ 197 MHz

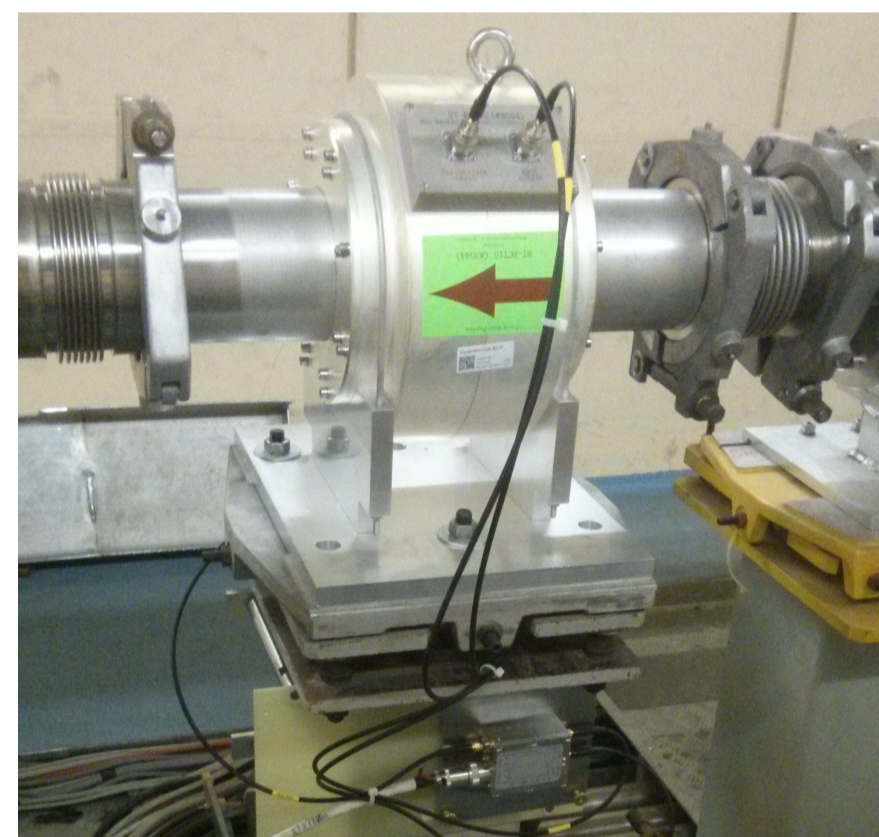


Fig. 3: FBCT in Booster extraction

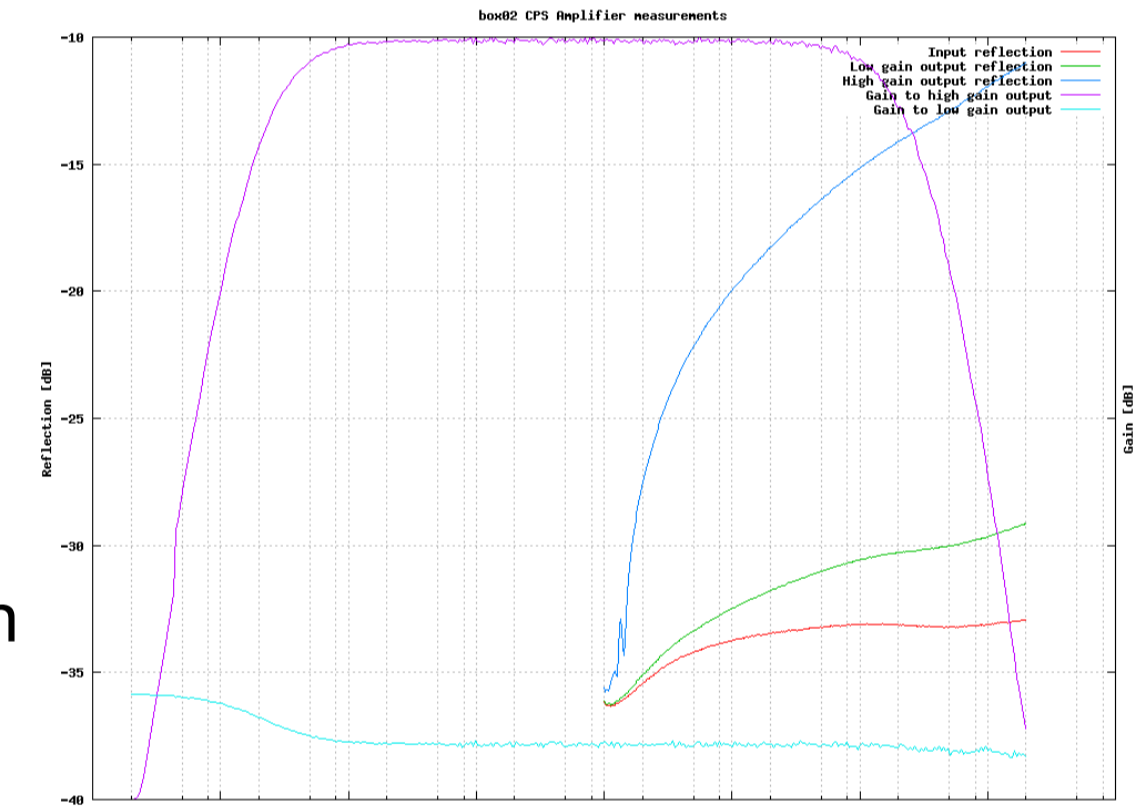


Fig. 4: Head amplifier S21 parameters

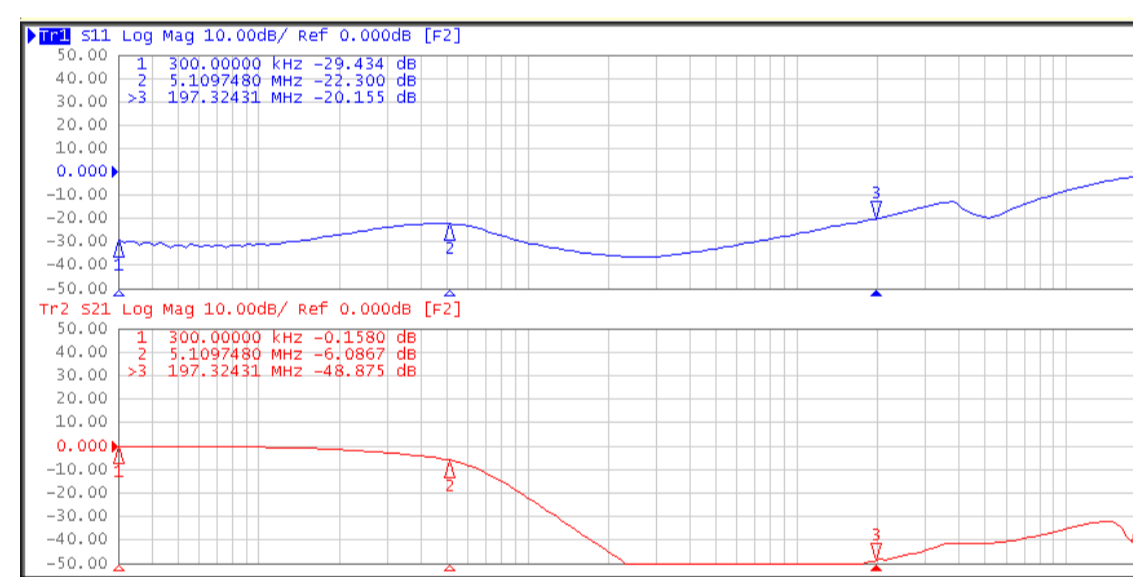


Fig. 5: Gaussian filter 3 MHz S parameters

### Digital acquisition, control and signal processing

#### TRIC features:

- VME64X 6U form-factor card
- FPGA Altera Cyclone EP2C20 Series based
- Two channels 30 MHz analogue BW, 12 bits 212 MS/s ADC
- Selectable input attenuation
- Internal calibrator ammeter and voltmeter
- 3 calibration types
  - Calibration by voltage using a capacitor discharge of 10 nF, 250 V, 1 %
  - Calibration by current up to 100 mA
  - Fixed calibration factor
- Remote programmability
- Remote settings and monitoring

#### TRIC firmware:

Measurement integration gate either delimited by time or by external triggers, integration types:

- Single beam gate measurement integrator (ruled by time)
- Multiple beam gate measurements integrator per ring multigate integrator (ruled by time)
- LINAC integrator (ruled by triggers)

#### Data processing:

- Beam and calibration integration with offset compensation
- Internal analyzer (scope)
- Slope correction either dynamic or fixed
- Mathematical normalizer

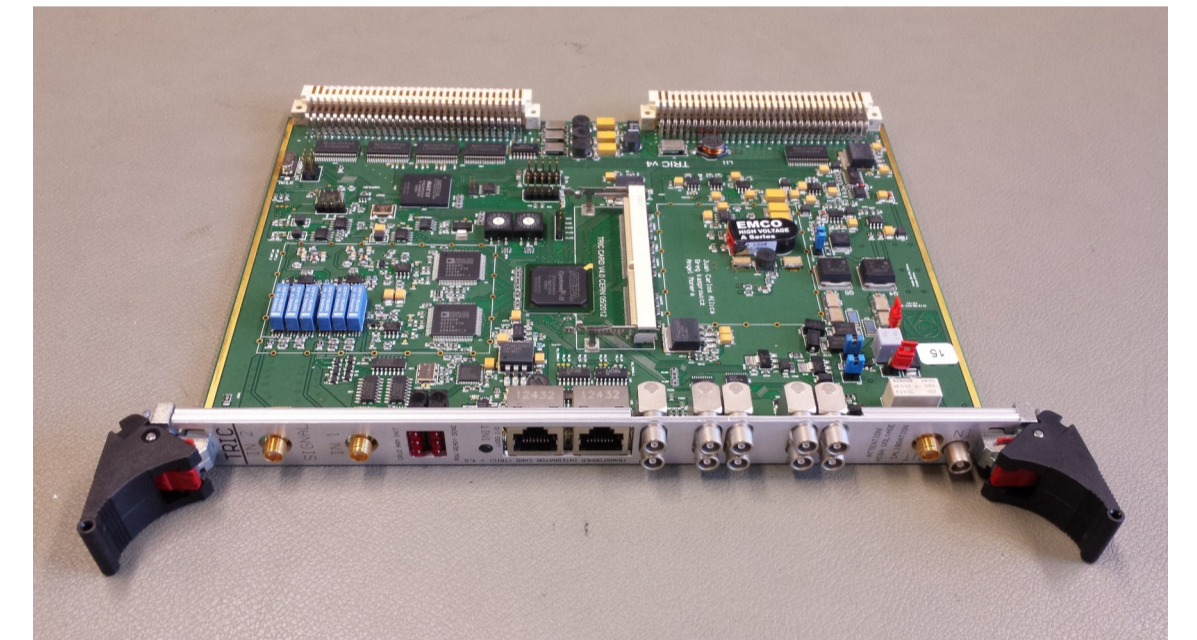


Fig. 6: TRIC ready for installation

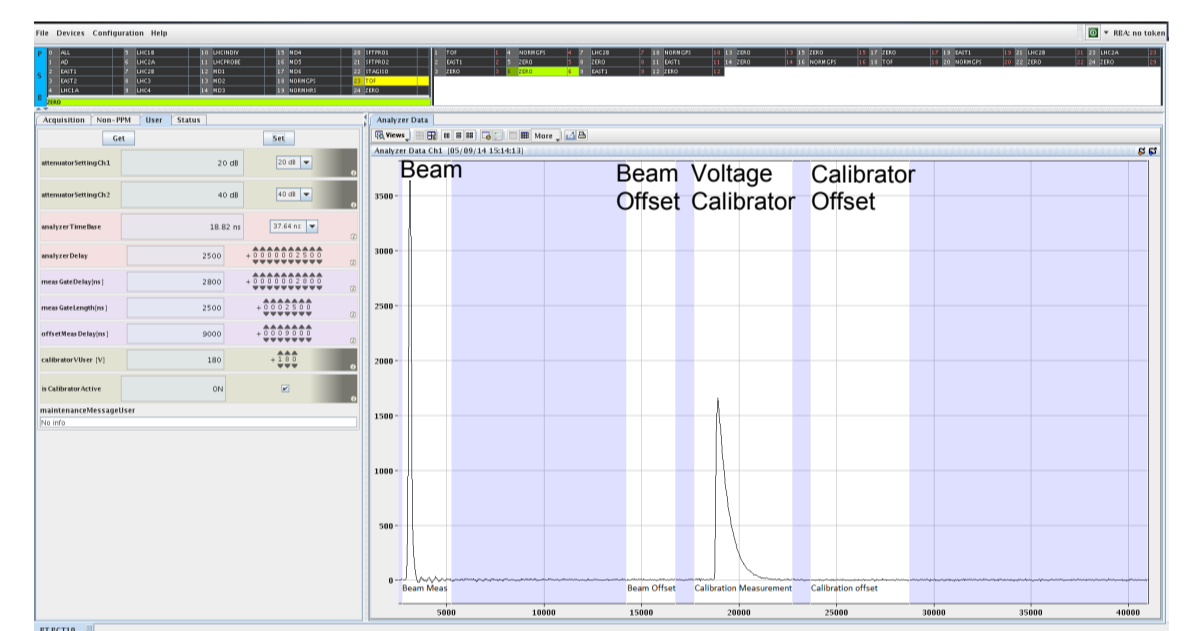


Fig. 7: TRIC expert GUI bins vs. time

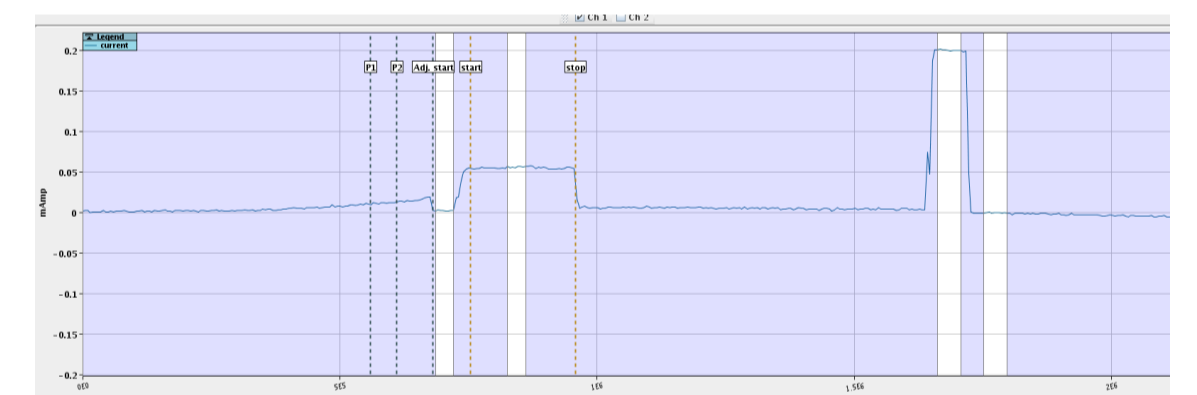


Fig. 8: Slope compensation and LINAC integrator

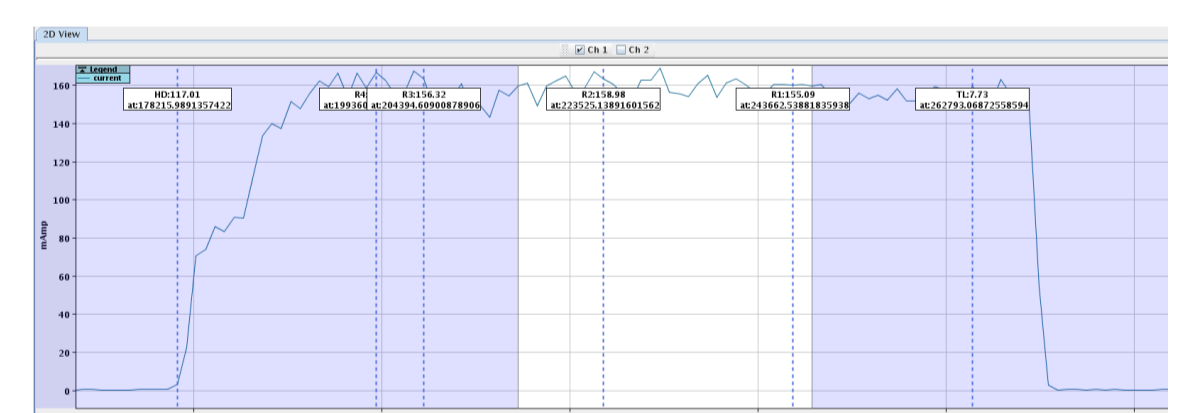


Fig. 9: Multigate integrator, per ring

## Measurements

### TRIC accuracy

The TRIC on-board calibrator simulates the beam injecting a well-defined signal, either a fixed current or voltage (capacitor discharge) into a calibration winding. High accuracies on the calibrators are necessary to obtain a total system accuracy below 1 %. Measurements show accuracies of  $\sigma < 0.1\%$  for current and  $\sigma < 0.3\%$  for voltage.

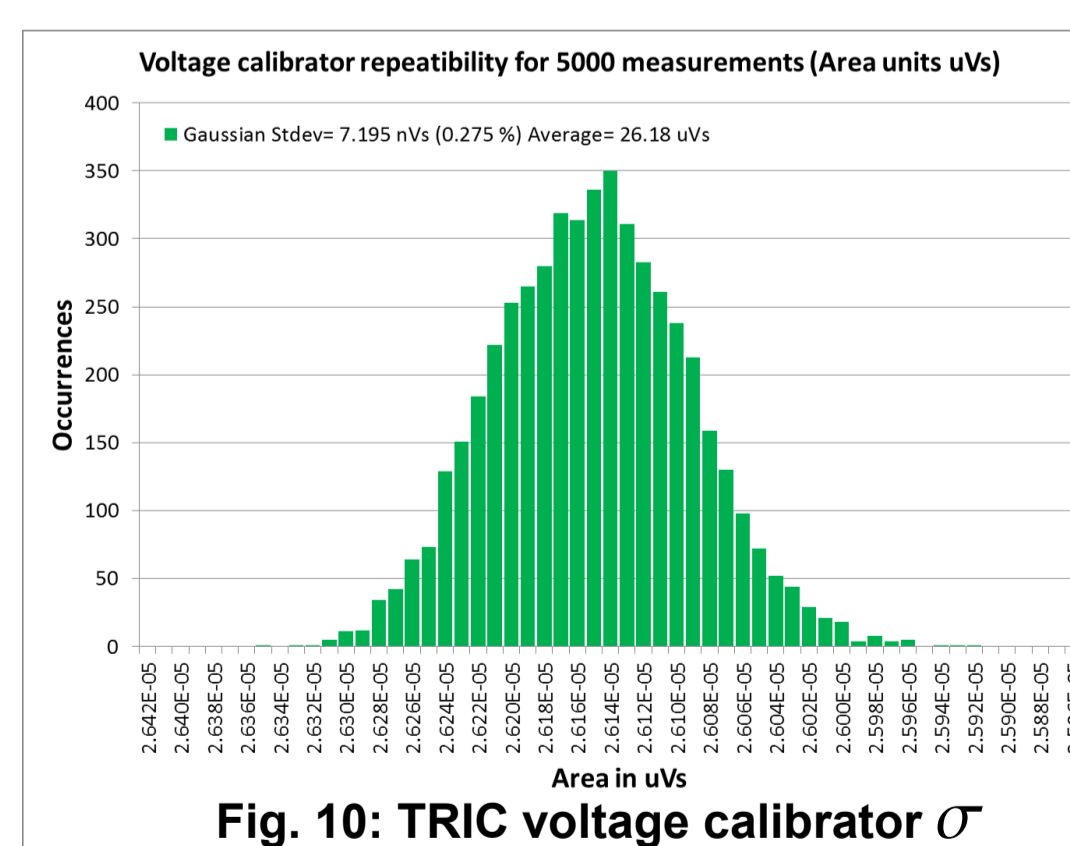


Fig. 10: TRIC voltage calibrator  $\sigma$

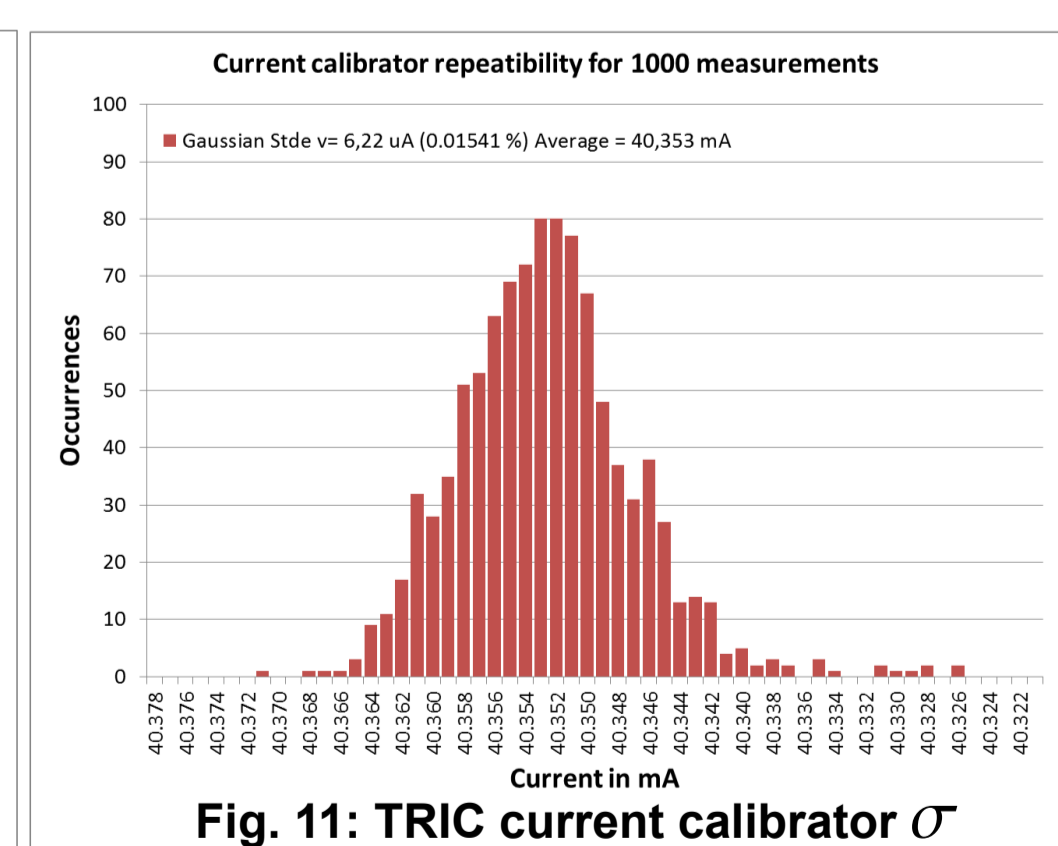


Fig. 11: TRIC current calibrator  $\sigma$

TRIC cards are cross-calibrated to reduce relative measurement error and to optimize the transfer efficiencies between accelerators, the cross-calibration uses a TRIC<sub>ref</sub> voltage calibrator simulating beam as reference. The DUT cards will measure using its voltage calibrator this TRIC<sub>ref</sub> for later averaging all the DUT measurement of this TRIC<sub>ref</sub> in order to reduce its uncertainty. This averaged measurement of TRIC<sub>ref</sub> will be used to normalize all DUT.

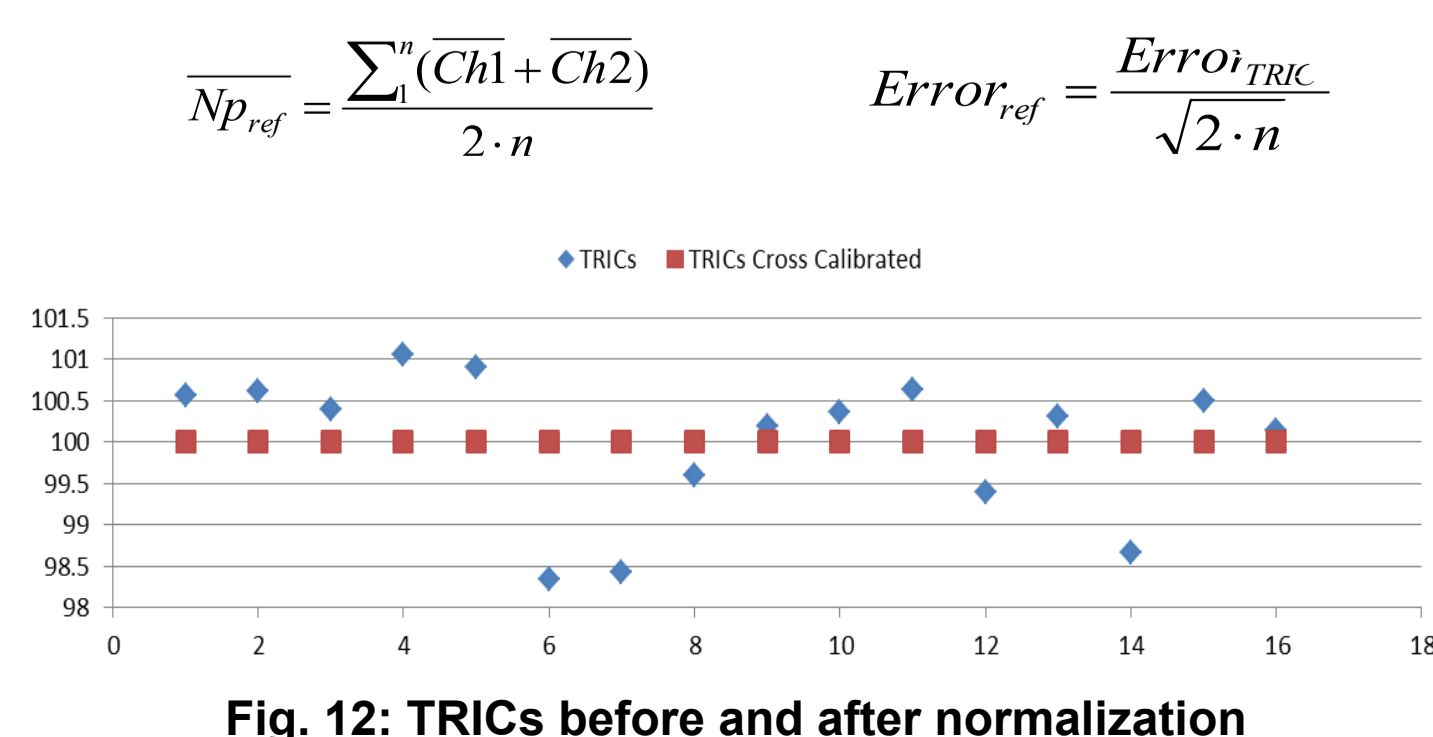


Fig. 12: TRICs before and after normalization

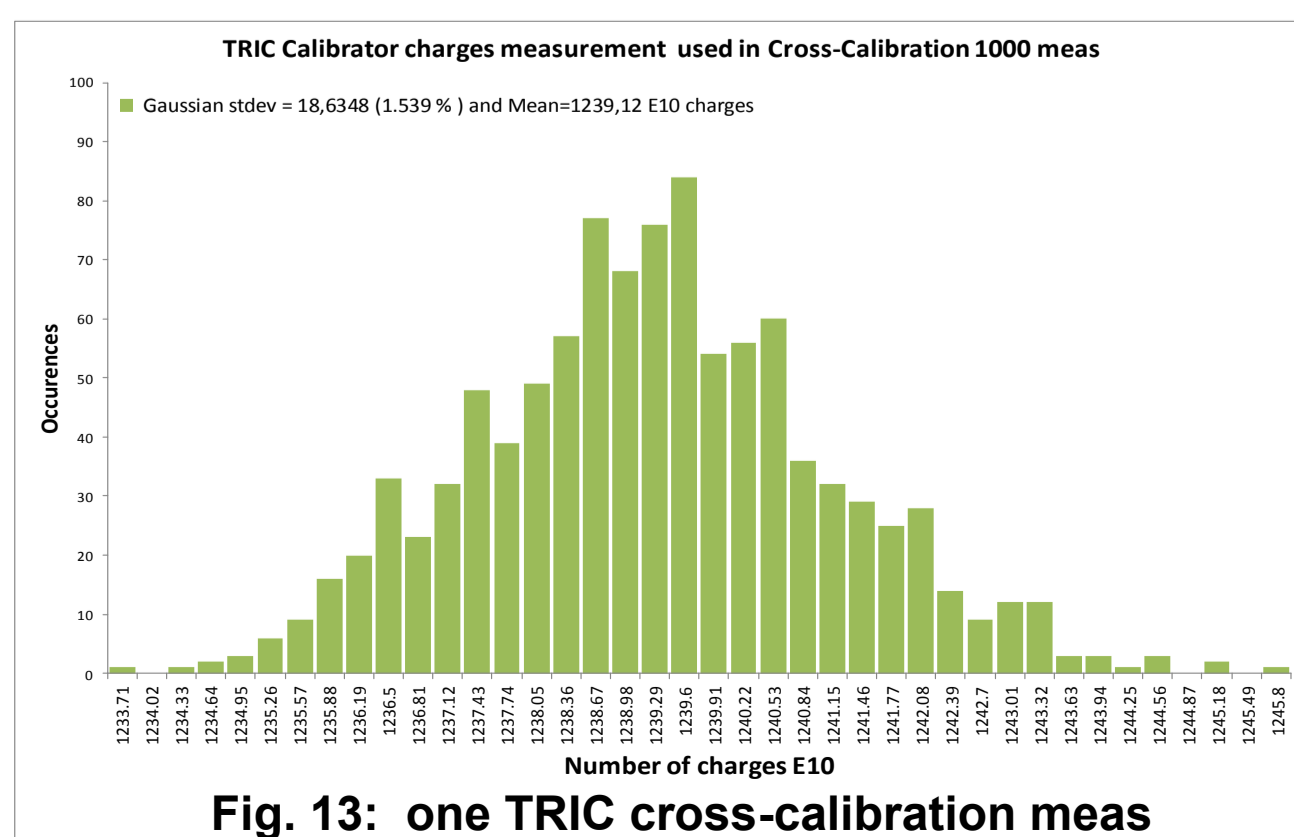


Fig. 13: one TRIC cross-calibration meas

### New cross-calibration

Cross-calibration using a TRIC<sub>ref</sub> has several inconveniences; high TRIC<sub>ref</sub> dependence and the need to recalibrate all the cards when a new set of cards is manufactured. In order to avoid these problems and to obtain better relative error measurements, a new method has been incorporated to the new TRIC version. This new cross-calibration procedure uses the current calibrator to measure a very high stable DC power source (stability  $\sigma < 0.0031\%$  and 1  $\mu$ V resolution) as reference and an internal digitally controlled switch.

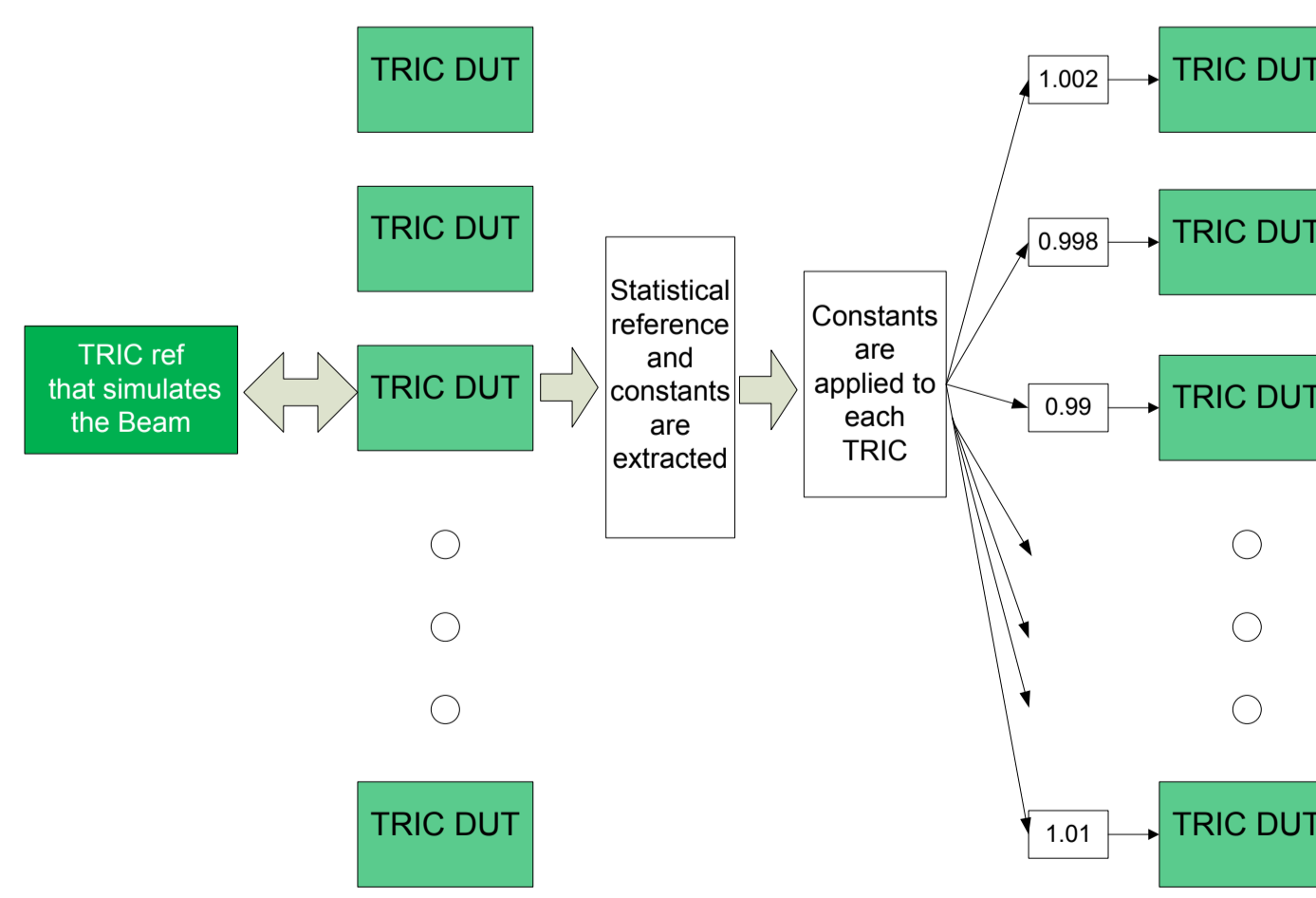


Fig. 14: Current cross-calibration procedure

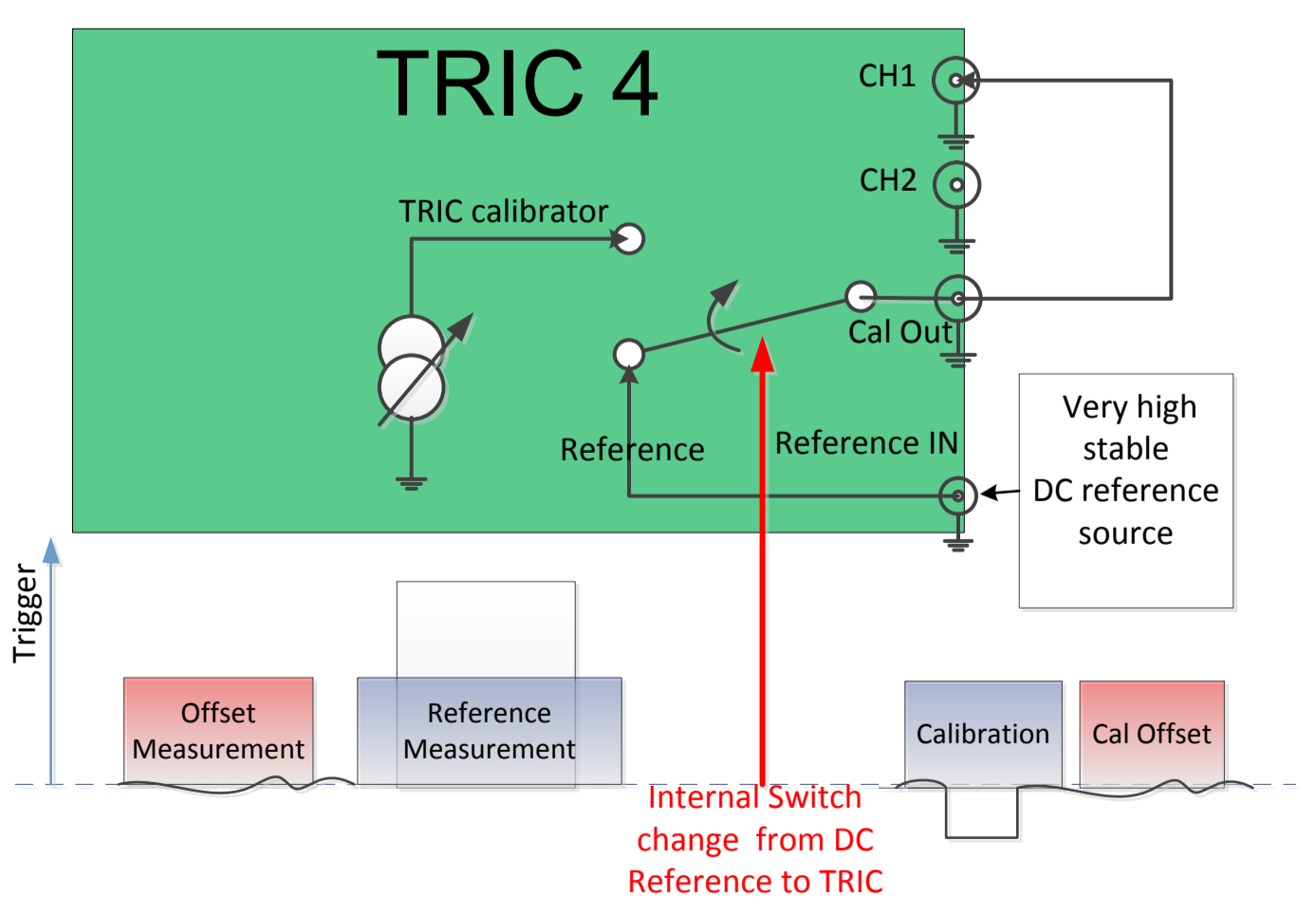


Fig. 15: TRIC new cross-calibration procedure

## Conclusions

The TRIC has become the new standard for beam intensity measurement in the CPS complex with 59 units currently installed LINAC2 (9), LINAC3 (4), LINAC4 (5), AD (5), LEIR (8), PSB injection (11), PSB ejection (3), TOF (1), TT2 (8), ISOLDE (4), PS (1) and 9 more foreseen in LINAC4, the TRIC has completely replaced the old analogue system with very successful results. It has upgraded intensity measurements making configuration and maintenance much easier and introducing a standard acquisition in order to obtain better results in transfer efficiencies between different accelerators.