Characterization and first field results of TIGER ASIC for the readout of GEM detectors

RD51 Collaboration Meeting and the "MPGD Stability" Workshop

Munich 18-22 June 2018

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CGEM-IT Group

Outline

- Introduction
- TIGER ASIC architecture
- TIGER ASIC performance
- Results from tests with GEM detectors
- Summary and outlook

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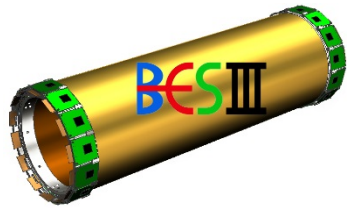
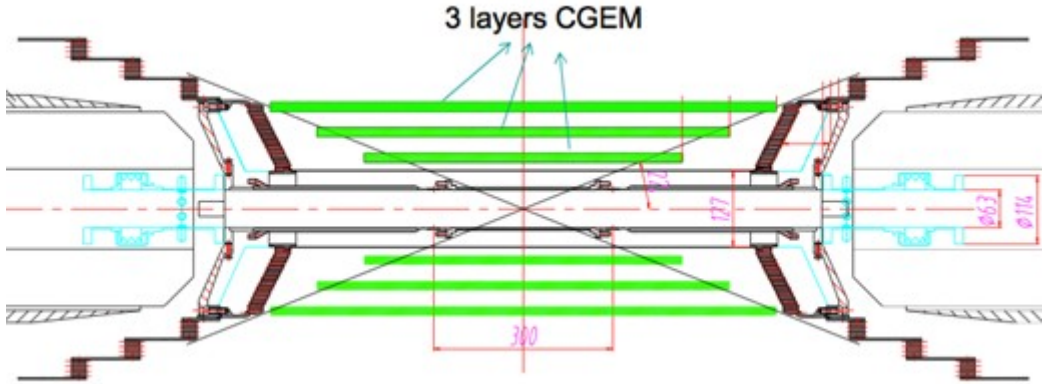
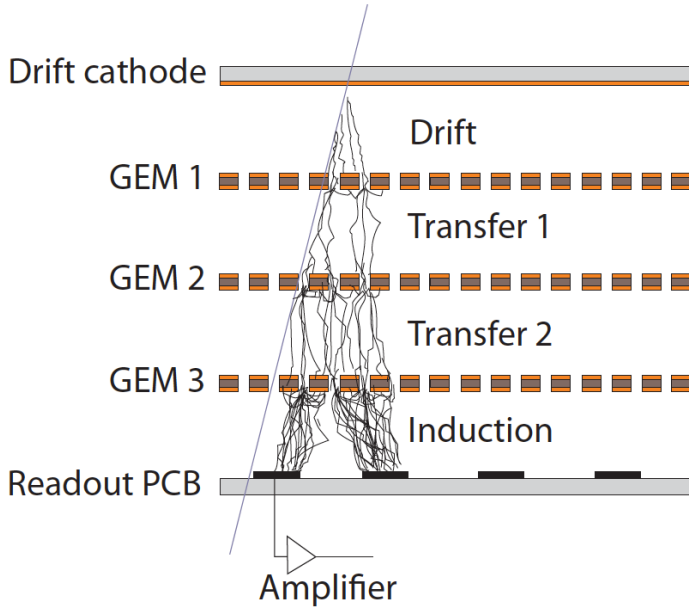
CGEM Inner Tracker for BESIII



- BESIII Experiment 2018-2019 upgrade
- New Inner Tracker: 3 layers of **Cylindrical Gas Electron Multiplier** (CGEM-IT) detector
- Each layer: triple GEM with charge collected at the anode by 2D segmented readout strips

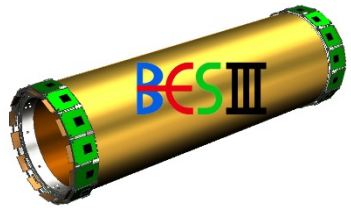


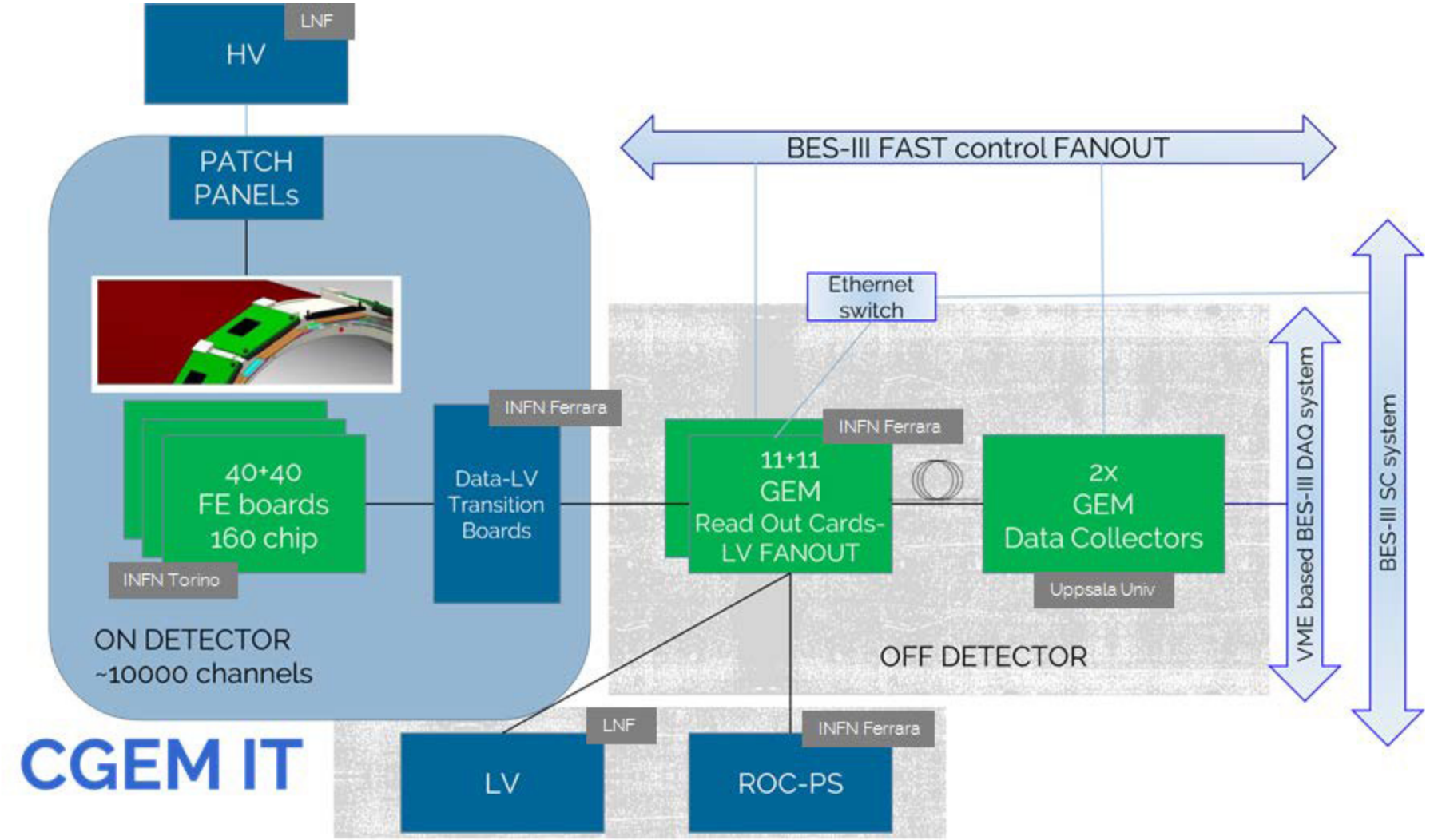
- **TIGER** (**T**urin **I**ntegrated **G**em **E**lectronics for **R**eadout) dedicated 64-channel readout ASIC
- Must provide **charge** and **time measurement** for the analogue readout of the CGEM
- This enables **charge centroid** and **micro-TPC** algorithms to improve resolution and reduce the number of channels



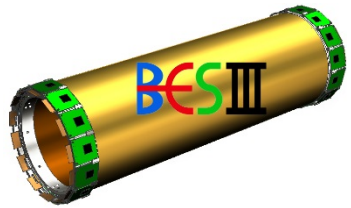
Readout	Analogue
Spatial resolution	130 µm
Pitch strip	650 µm
# channels	~ 10 000
Sensor capacitance	100 pF
Channel rate	60 kHz
Collected charge	3 – 50 fC

Overview of CGEM readout electronics

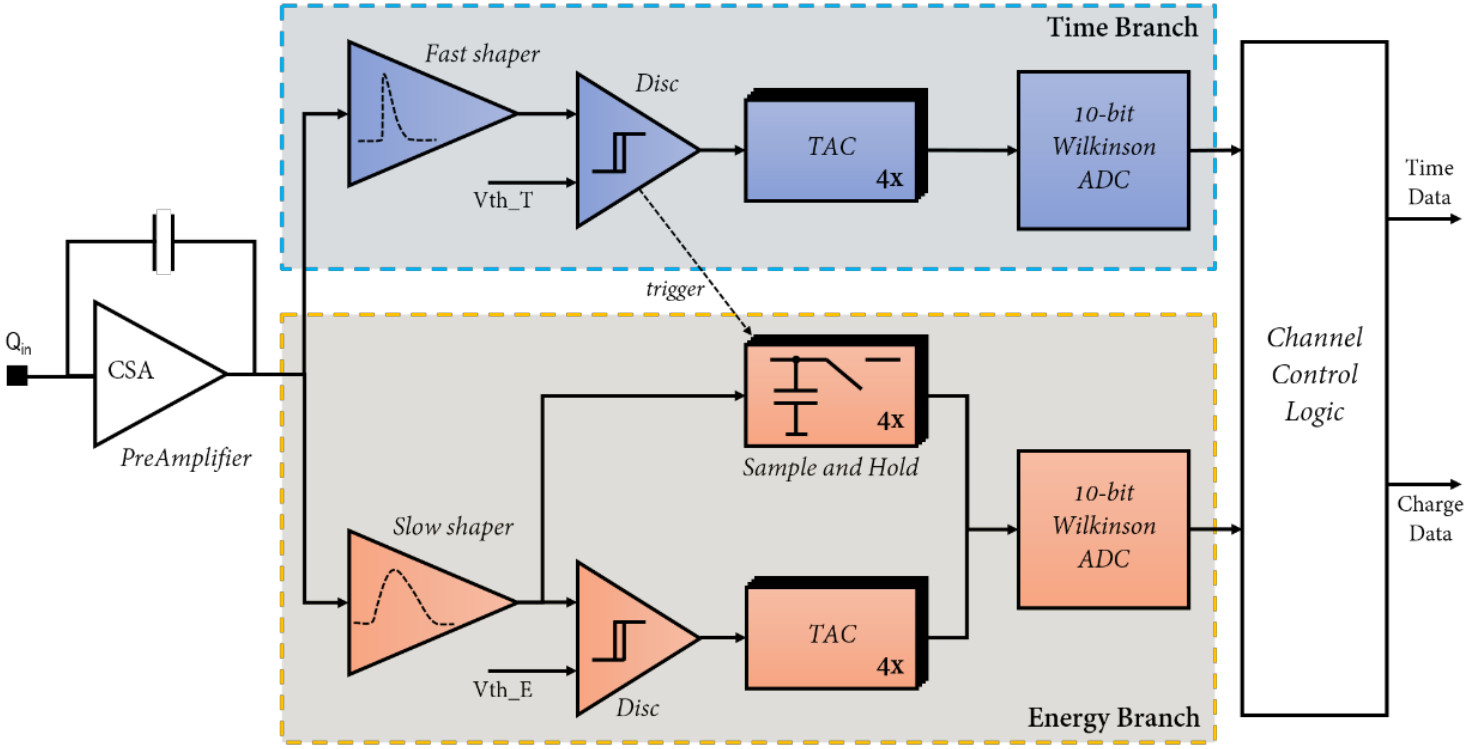




TIGER channel architecture

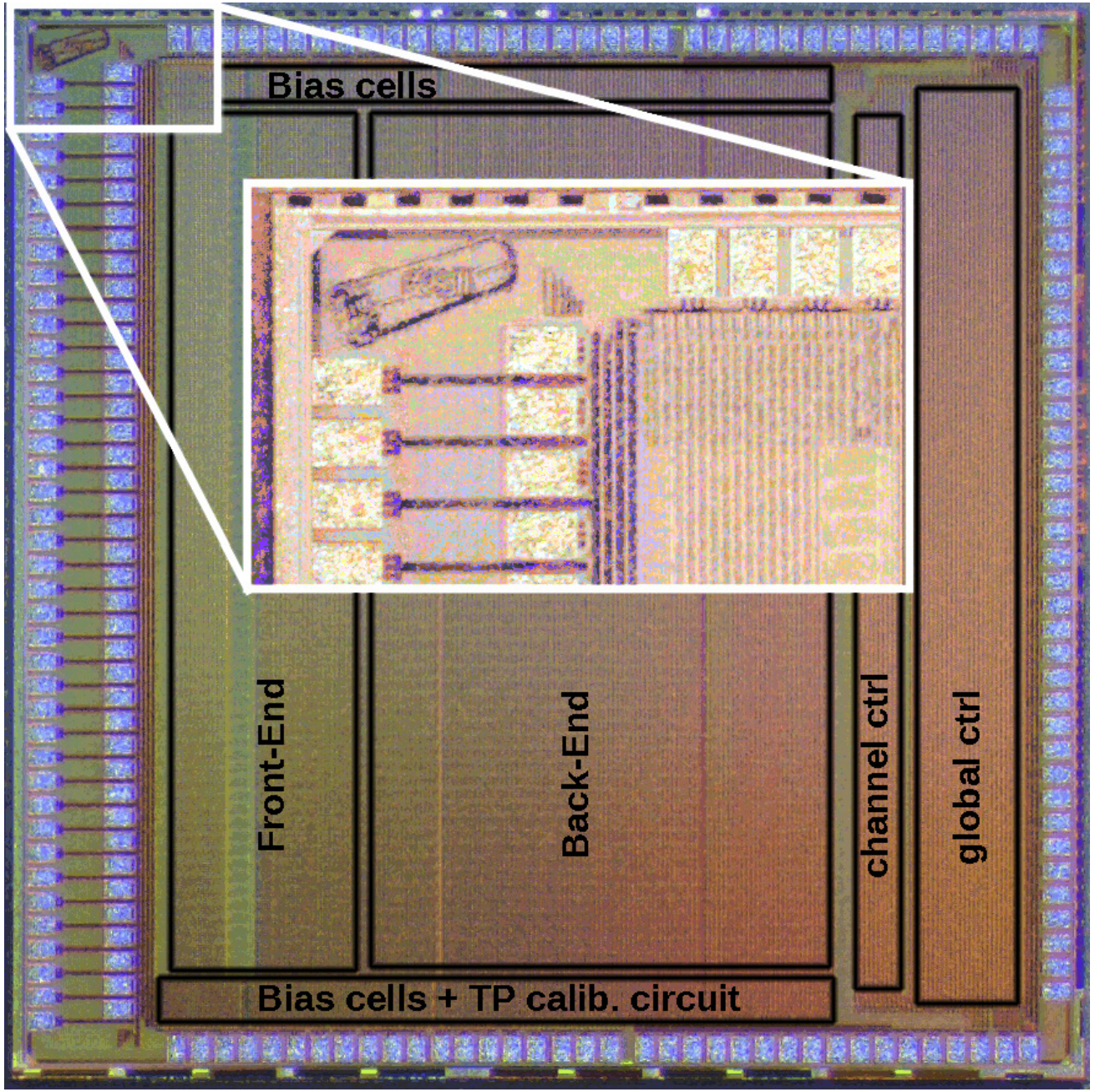


- Analogue Front-End:
  - Charge Sensitive Amplifier
  - **Dual-branch** shaper
  - Gain ≈ 11 mV/fC
  - Input dynamic range = 3 – 50 fC
  - ENC < 2000 electrons (C_{in} = 100 pF)
- **Timestamp** on rising edge of fast branch
  - Time resolution < 5 ns
- **Charge** measurement:
  - **ToT**: timestamp on rising/falling edge (sub-50 ps binning quad-buffered TDCs based on analogue interpolation)
  - **S/H**: slow shaper output sampled and digitized with a 10-bit Wilkinson ADC
- Power consumption ≈ 12 mW/ch



TIGER: Turin Integrated Gem Electronics for Readout

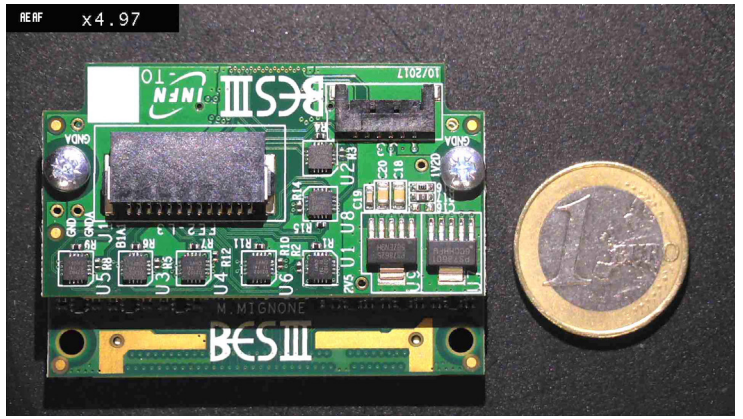
- 5 x 5 mm2 110nm CMOS technology
- 64 channels: preAmp, shapers, TDC/ADC, local controller
- Digital backend inherited from TOFPET2 ASIC (SEU protected)
- On-chip bias and power management
- On-chip calibration circuitry
- Fully digital output
- 4 TX SDR/DDR LVDS links, 8B/10B encoding
- Nominal 160 MHz system clock
- 10 MHz SPI configuration link
- Sustained event rate > 100 kHz/ch



TIGER characterization

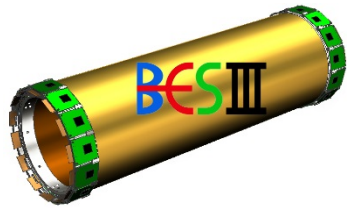
- Tapeout of first silicon: MPW May 2016
- Tests of prototype from Nov 2016 to Apr 2017
- Engineering run with different design flavours and minor design revisions (Aug 2017)
- Test and characterization of final version from Jan 2018

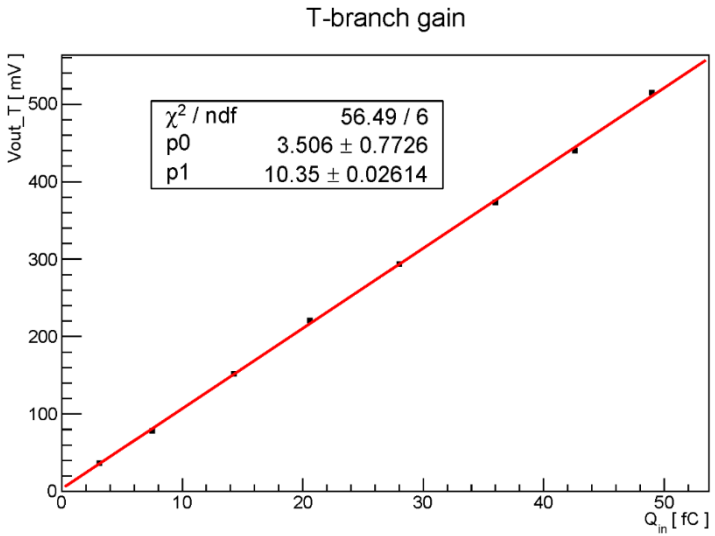
2 TIGER ASICs wire-bonded on the Front-End Board (FEB)

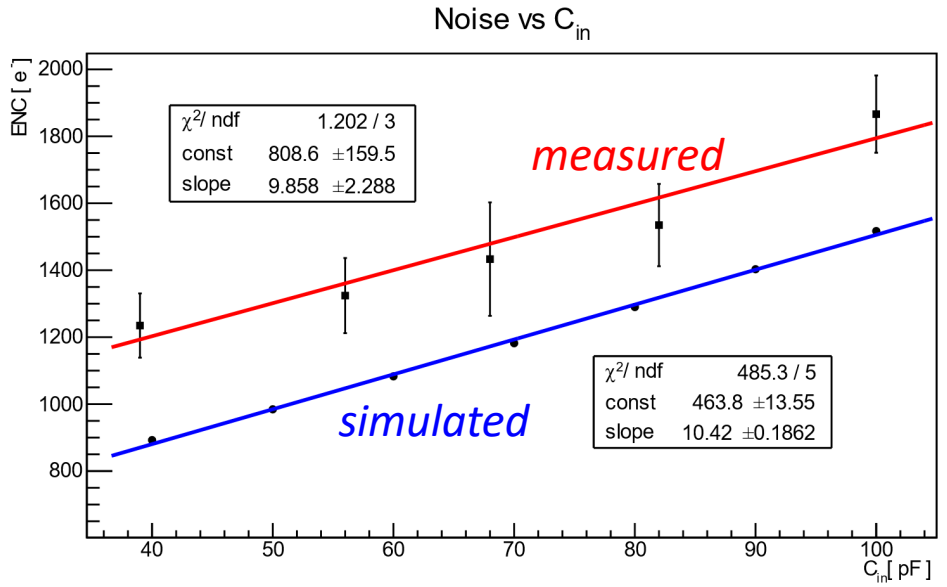


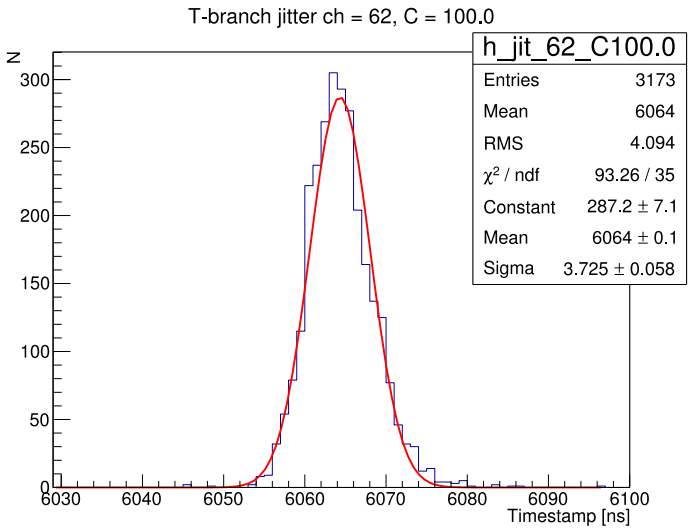
Layer-3 Front-End Board (FEB)

Gain and Noise performance









GAIN

1. External charge injection (1 channel)
   - **Gain ≈ 10.35 mV/fc**
     (expected 11 mV/fC from simulation)
2. Injection of Q_{in} = 8 fC with internal TP (all channels)
   - **Average gain ≈ 10.75 mV/fC** with 3.5% RMS dispersion

NOISE

- E-branch RMS noise for C_{in} = 100 pF
  - **ENC ≈ 1800 e^-** (measured) vs 1500 e^- (simulated)
  - Large contribution from resistor in ESD protection circuit of the Test Board
  - Removed in the final **Front-End Board**

JITTER

- Q_{in} = 3 fC, C_{in} = 100 pF
  - T-branch RMS **jitter ≈ 3.7 ns**

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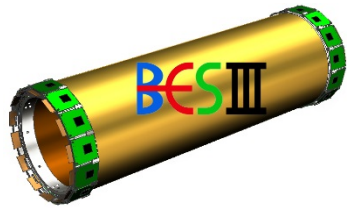
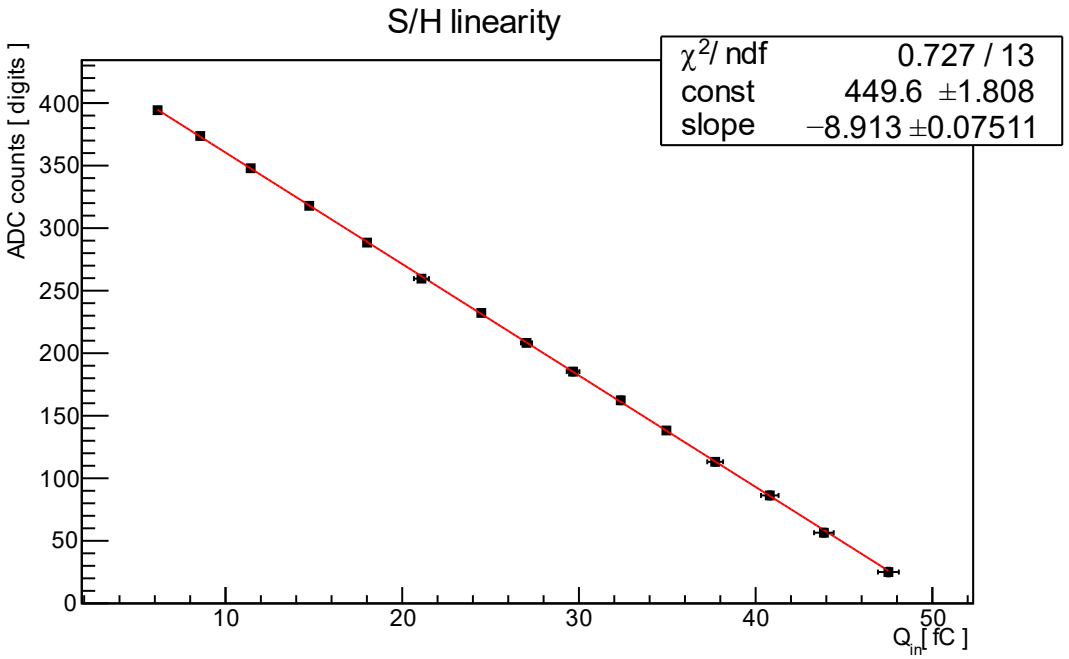
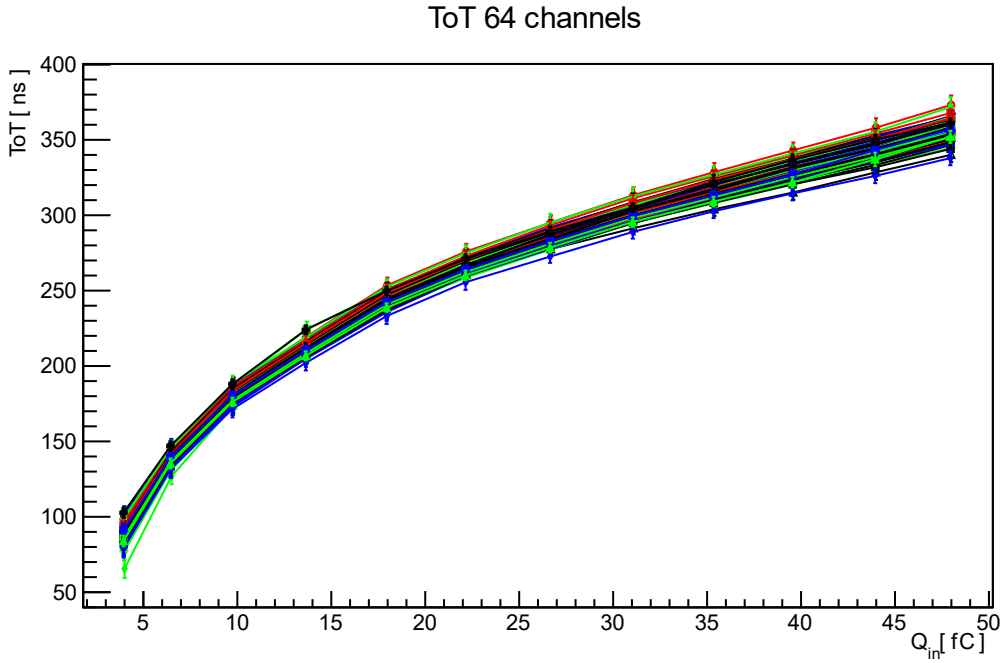
Charge measurement







Sample-and-Hold

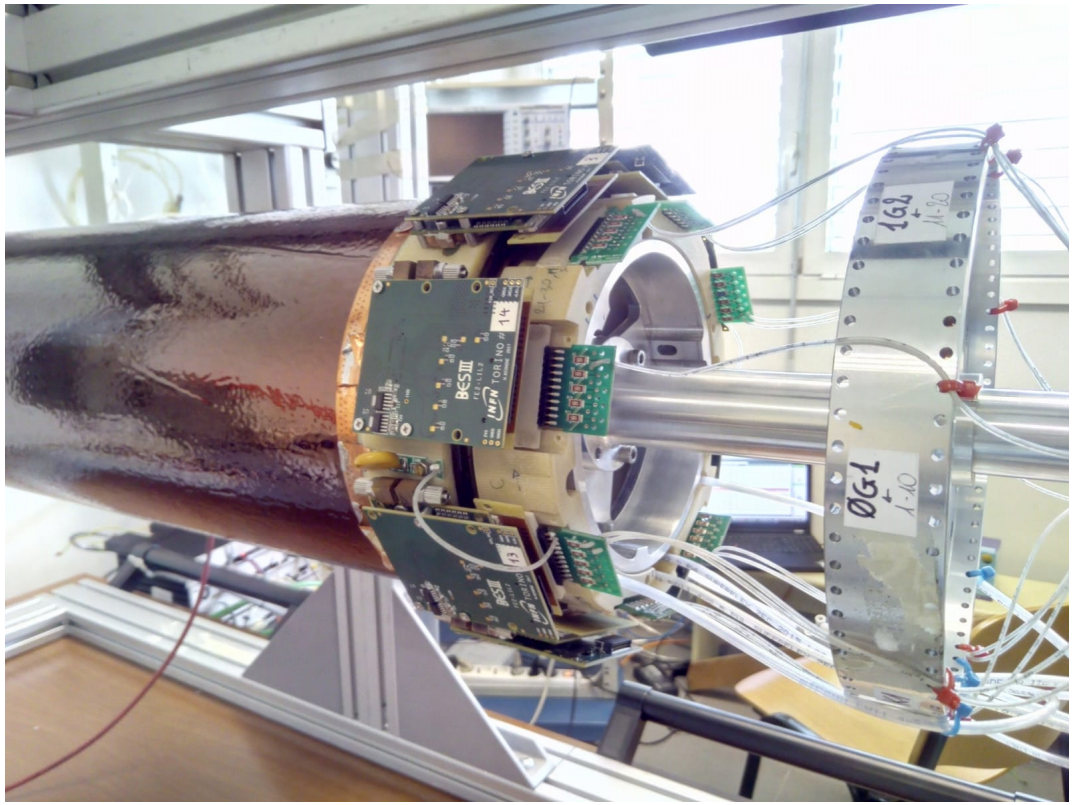
- Linear up to ~ 50 fC
- Saturation for Q_{in} > 50 fC

Time-over-Threshold

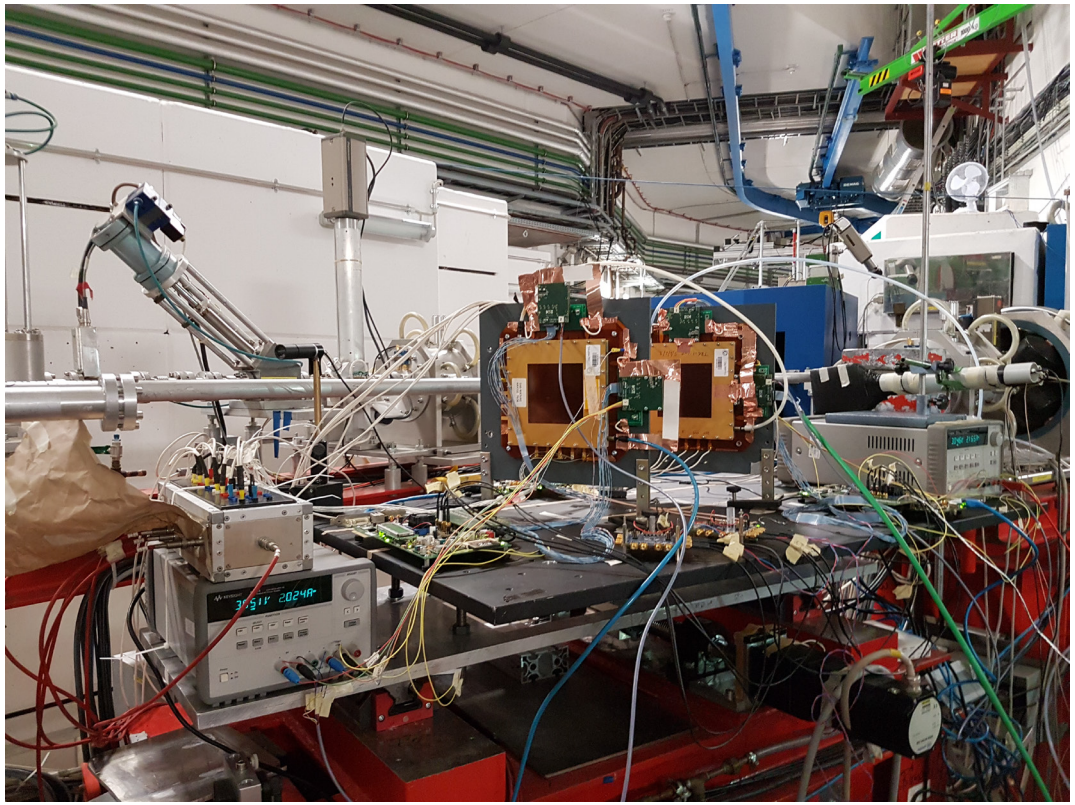
- ToT curve due to the intrinsic non-linear pulse duration of CR-RC^n shapers

Calibration curves to compensate channel-by-channel offsets

Results from test with GEM detectors



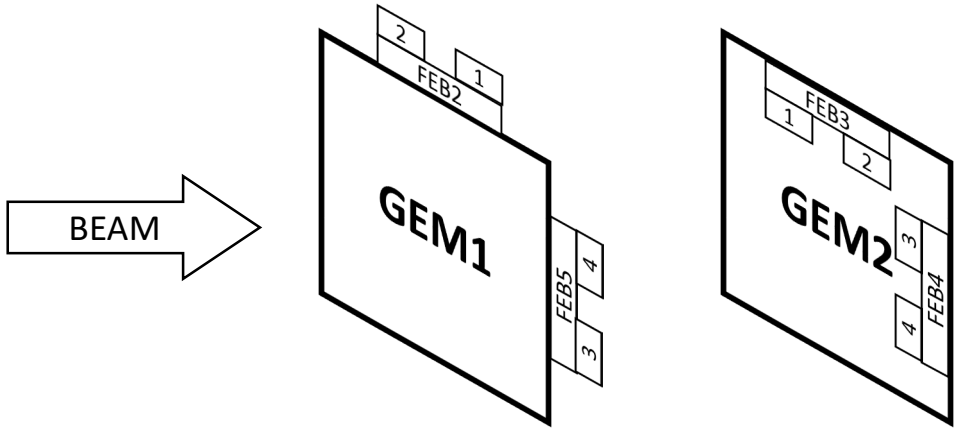
CGEM Layer-1 fully instrumented

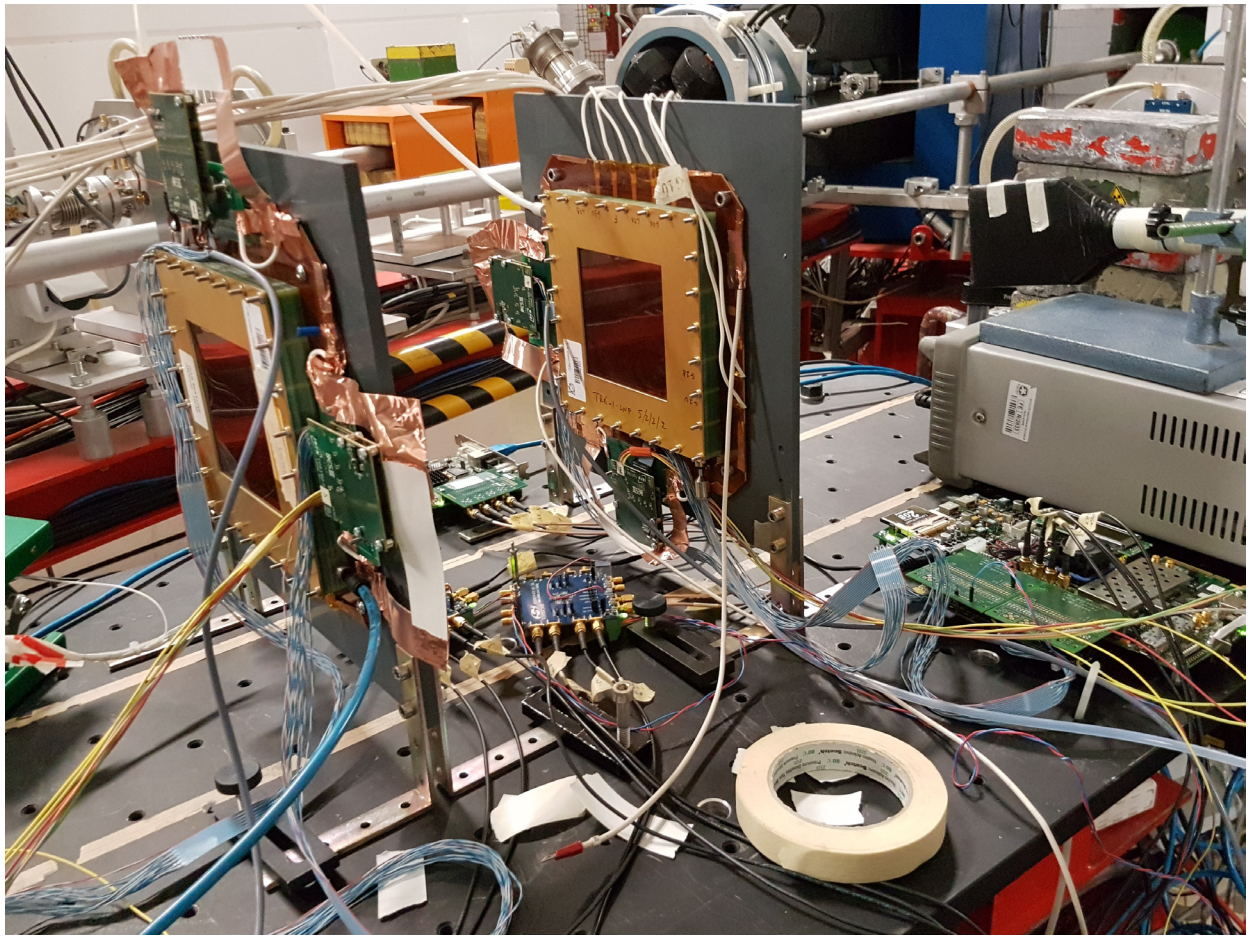


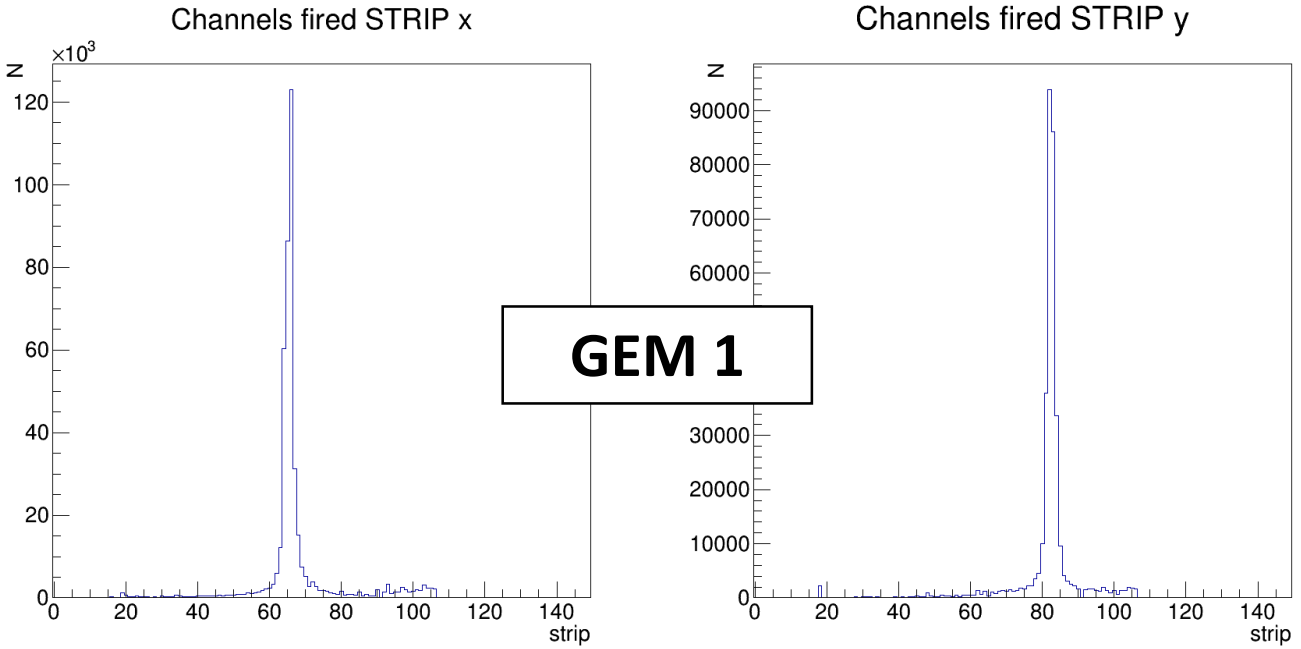
Test beam at Mainz with planar GEMs

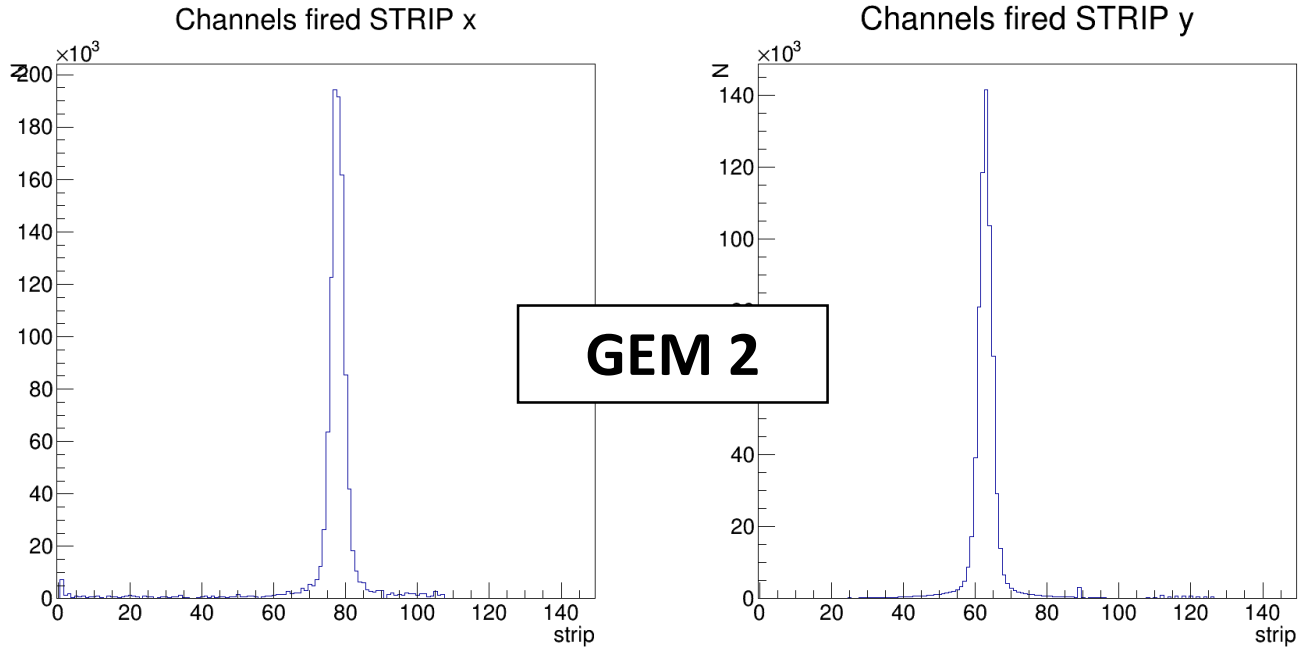
Mainz Test Beam

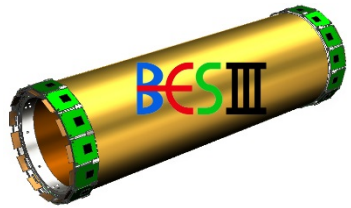
- MAMI (MAinz MIcrotron), Nov 13-16
- Test detector (planar GEMs) + electronics (TIGERv0) to fully validate the system
  - 2 planar GEMs
  - 4 FEBs = 8 TIGER (2 FEBs for each GEM)



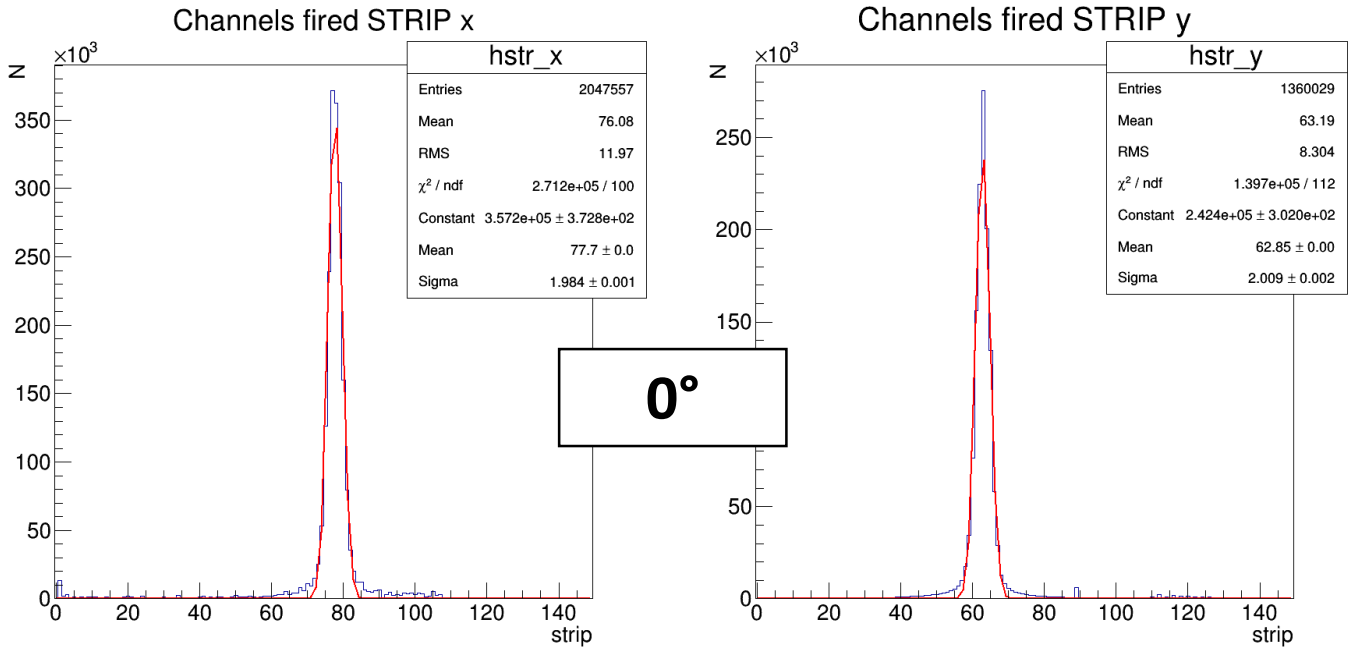


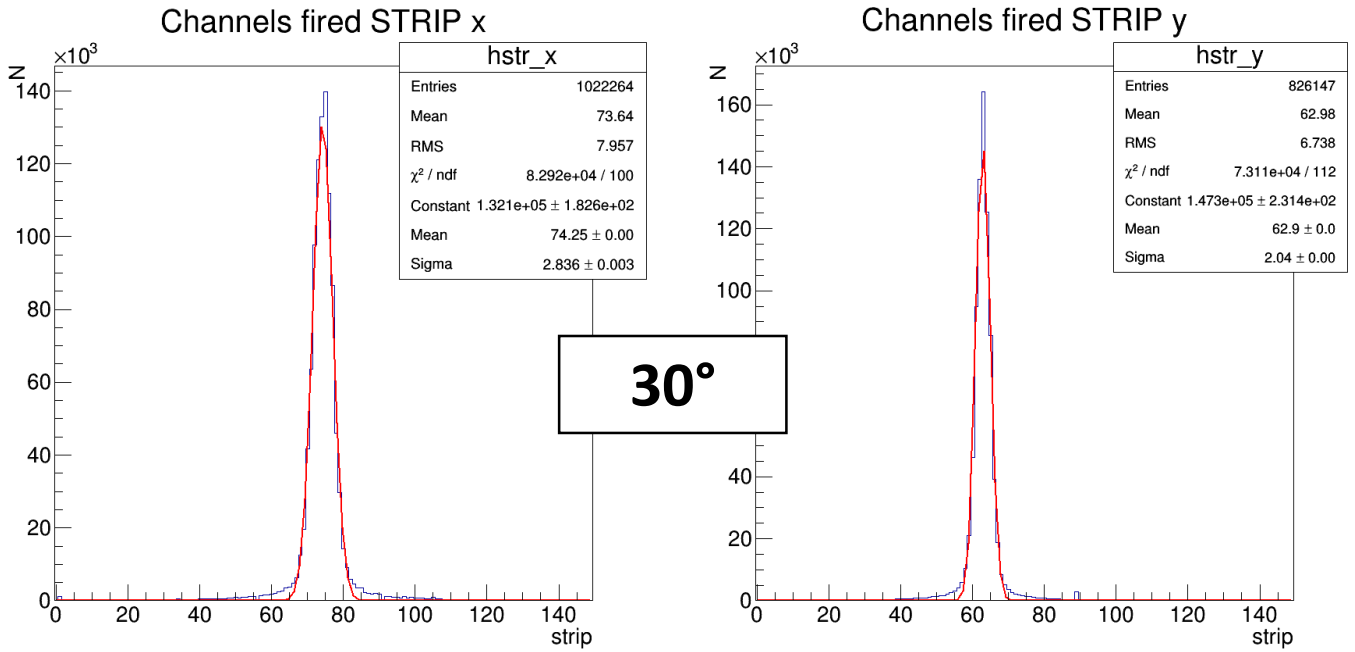






Beam profile





Beam profile

GEMs rotated 30° along the X-axis to replicate the conditions in BESIII Experiment

- enlarged X-strip profile
- same Y-strip profile

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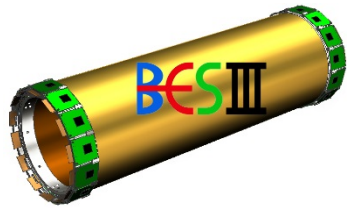
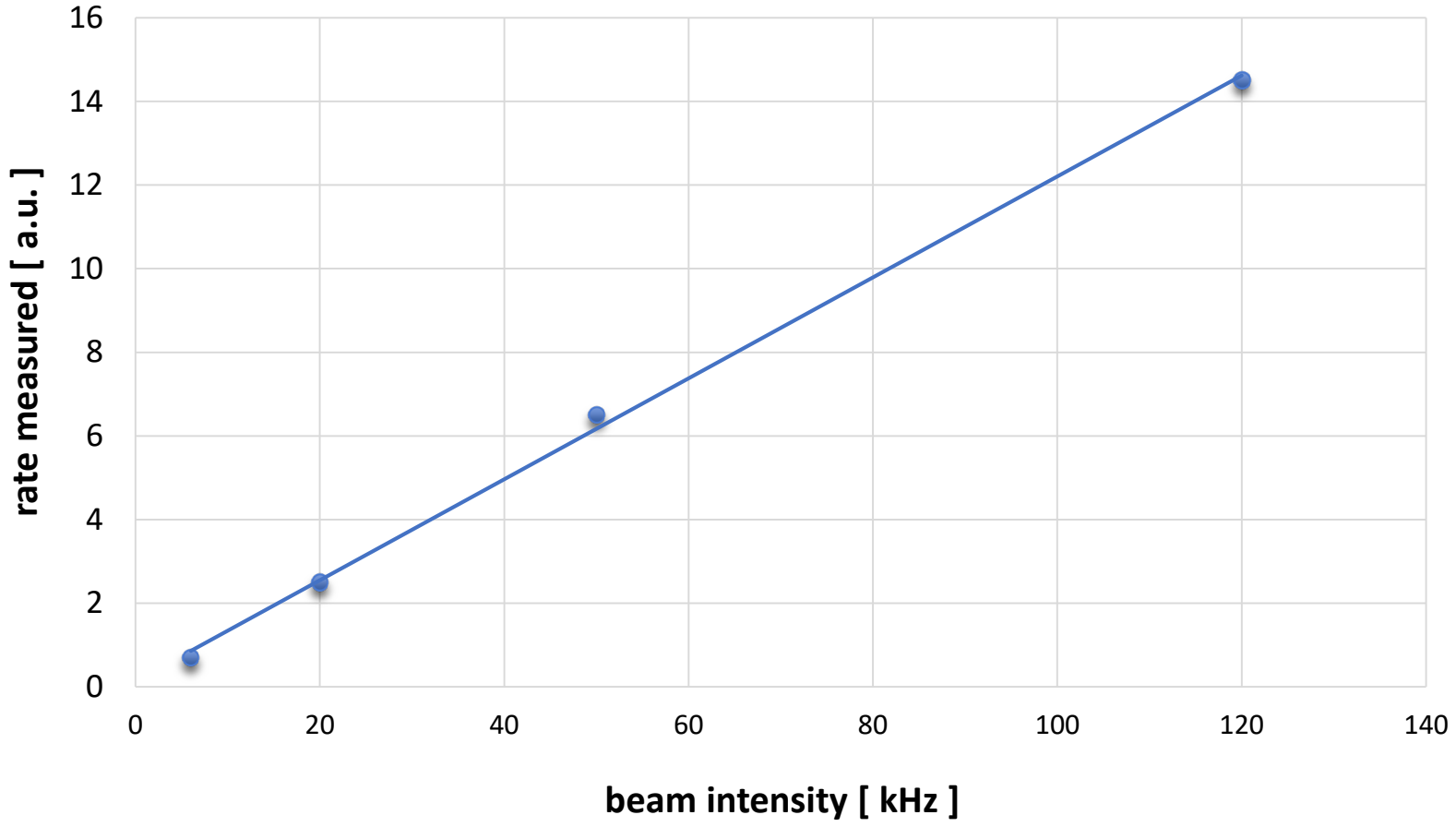
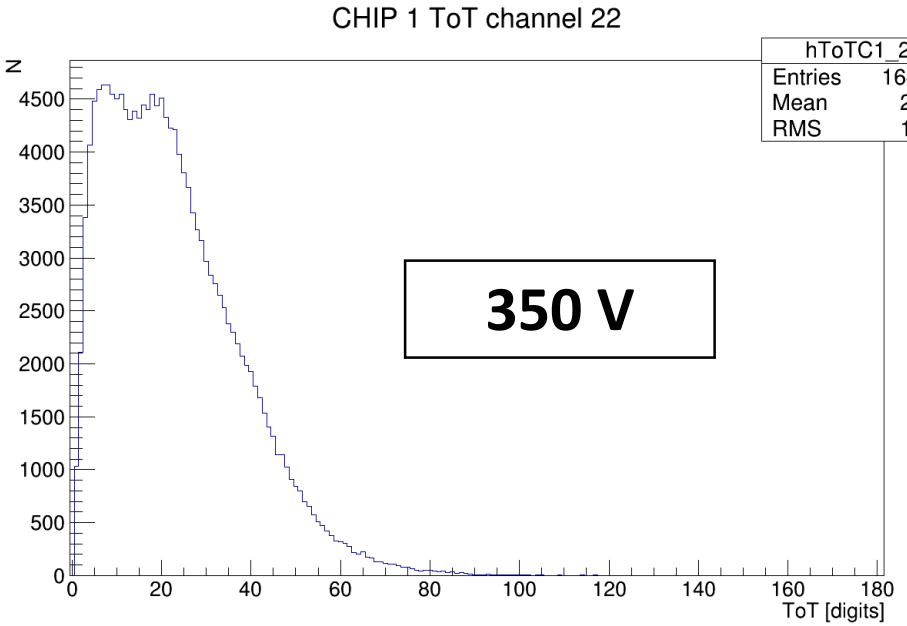
Rate capability



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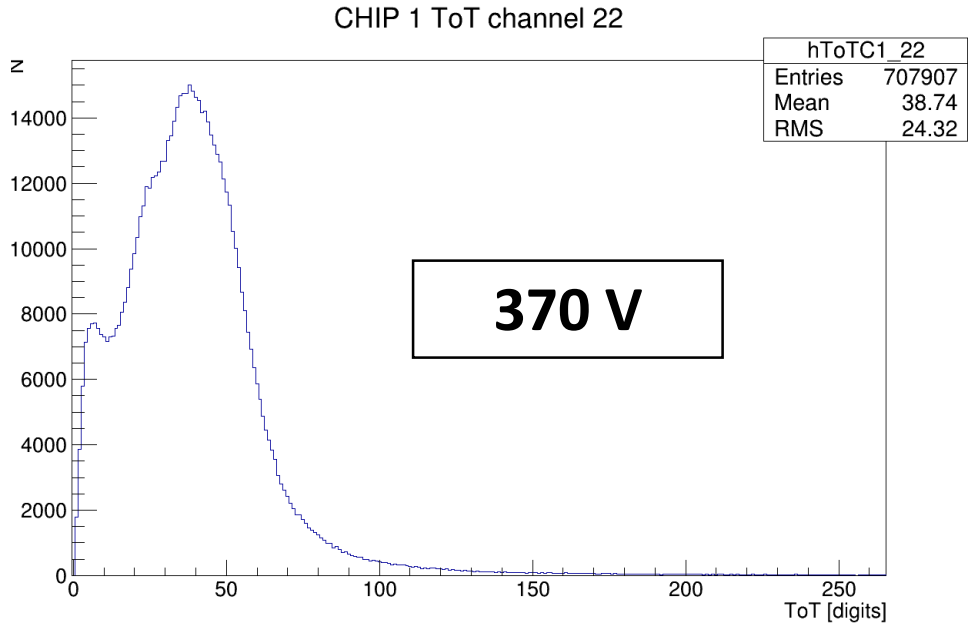
hToTC1_22
Entries 164168
Mean 22.92
RMS 14.95
N
ToT [digits]
350 V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Mean 38.74
RMS 24.32
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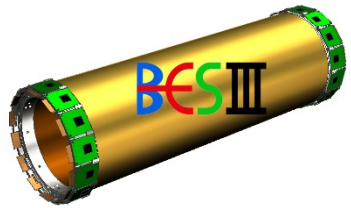
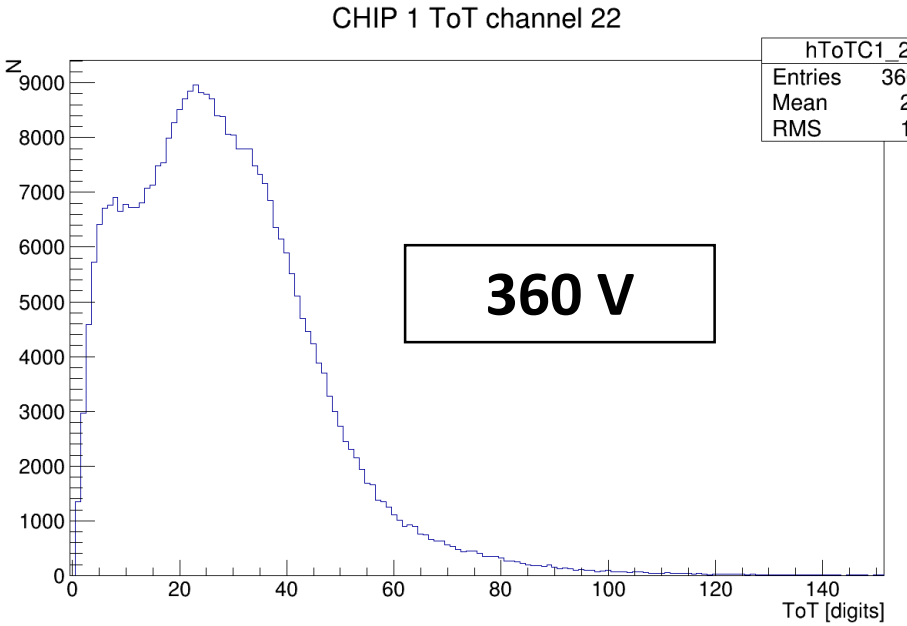
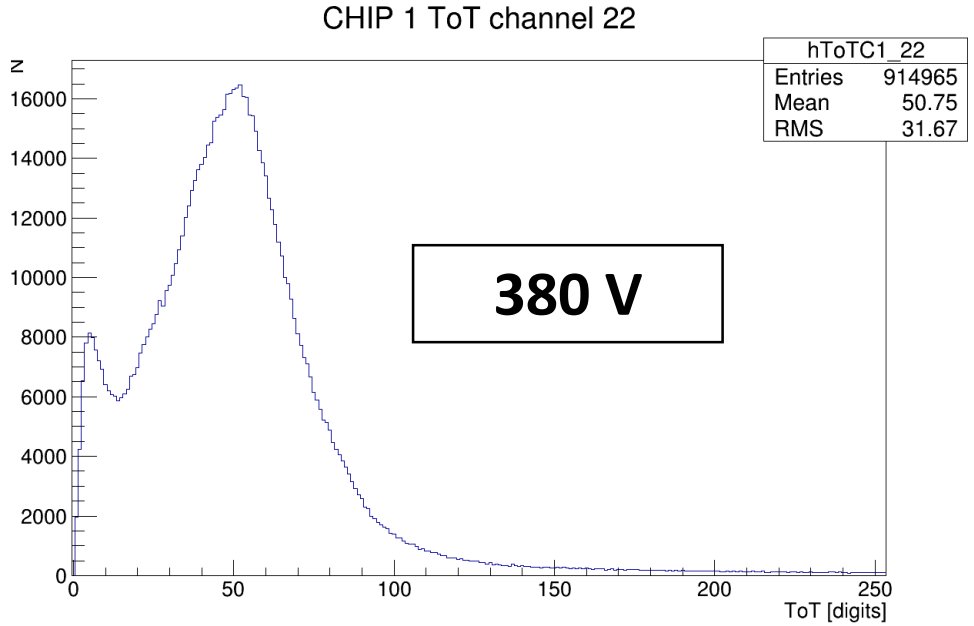
ToT [digits]
370 V


BESIII

HV scan


CHIP 1 ToT channel 22
hToTC1_22
Entries 360203
Mean 28.35
RMS 17.49
N
ToT [digits]
360 V


CHIP 1 ToT channel 22
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Entries 914965
Mean 50.75
RMS 31.67
N
ToT [digits]
380 V

Summary and Outlook

- ASIC fully functional and validated
  - Time-based readout working properly
  - Charge measurement: good linearity with S/H
  - Successful validation of a fully-equipped double planar GEM setup with 8 TIGER chips (~512 channels)
- FEB production for all layers completed
  - Layer-1 FEBs test and calibration completed, installed on detector
  - Layer-2/3 FEBs characterization ongoing (installation expected by mid July)
- Tests with cylindrical GEMs ongoing
  - signals from cosmic rays and ^{90}Sr
- In situ (BESIII @ IHEP) commissioning of fully instrumented BESIIICGEM-IT (Autumn 2018)

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Istituto Nazionale di Fisica Nucleare
SEZIONE DI TORINO

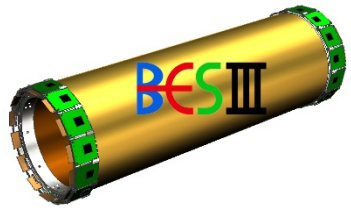
Torino TIGER WG

M. Alexeev, A. Bortone, J. Chai, W. Cheng, F. Cossio, M. D. Da Rocha Rolo, G. Giraudo, M. Greco, M. Maggiora, S. Marcello, M. Mignone, A. Rivetti, R. Wheadon

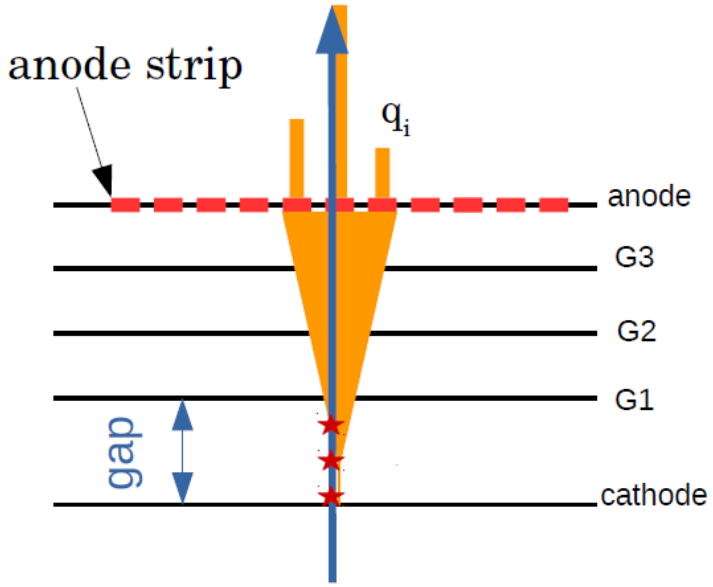
The BESIIICGEM project has been funded by European Commission within the call H2020-MSCA-RISE-2014

Backup Slides

Why an analogue readout?

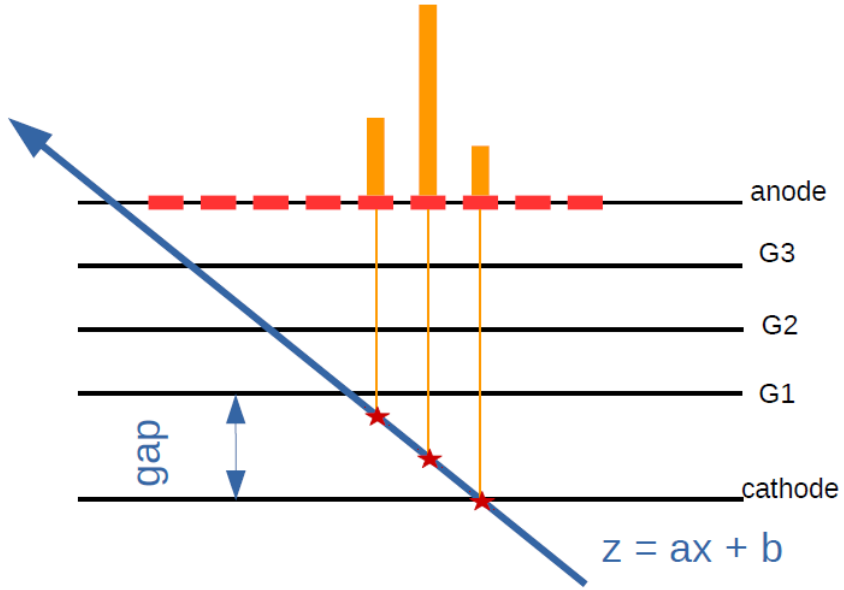


Charge Centroid algorithm



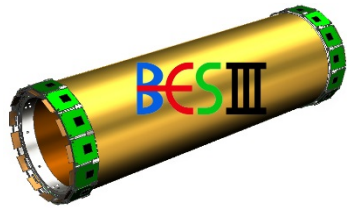
- Weighted average position from fired strips
- Improve spatial resolution vs digital readout (constrained to the strip pitch)

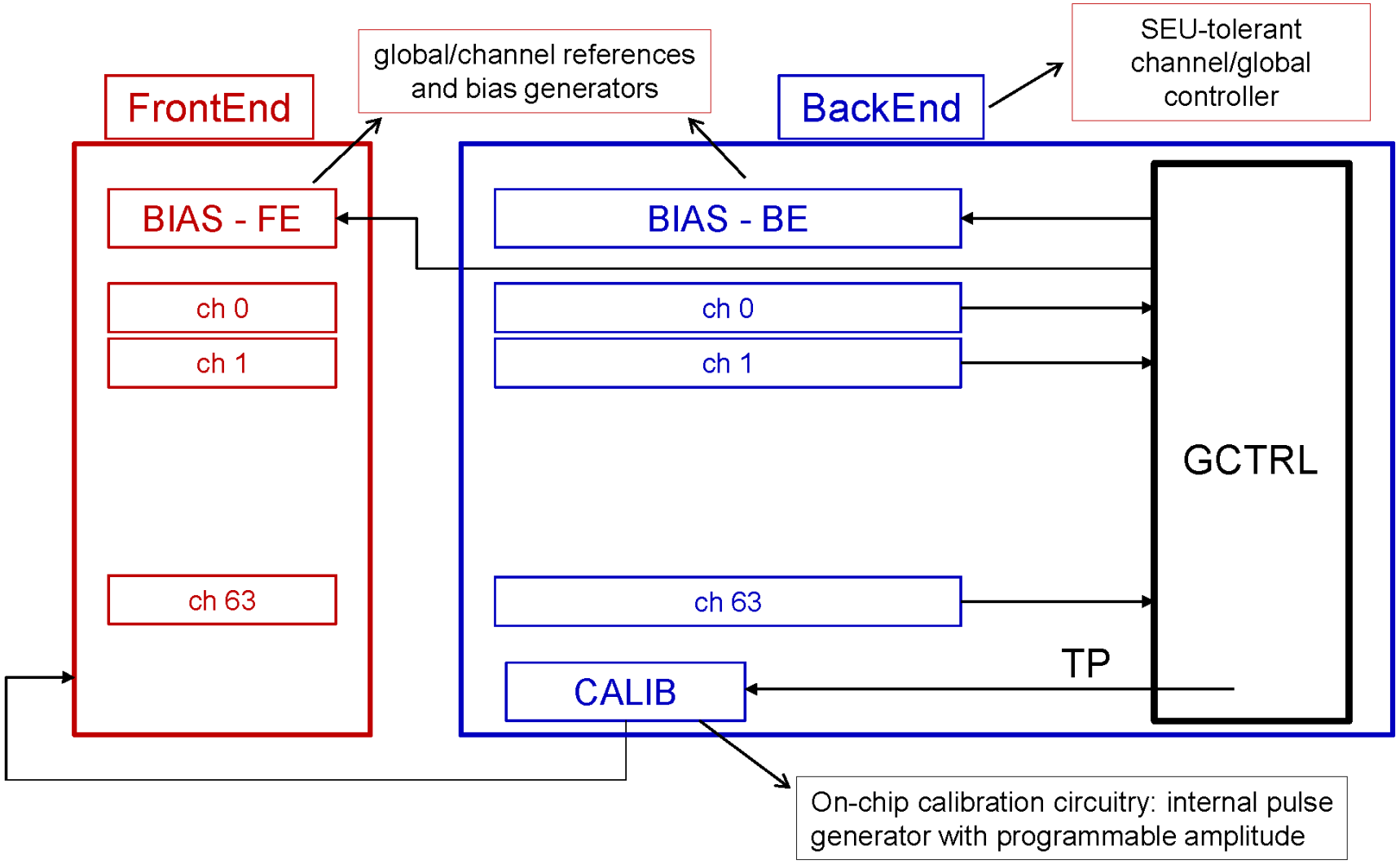
μ-TPC mode



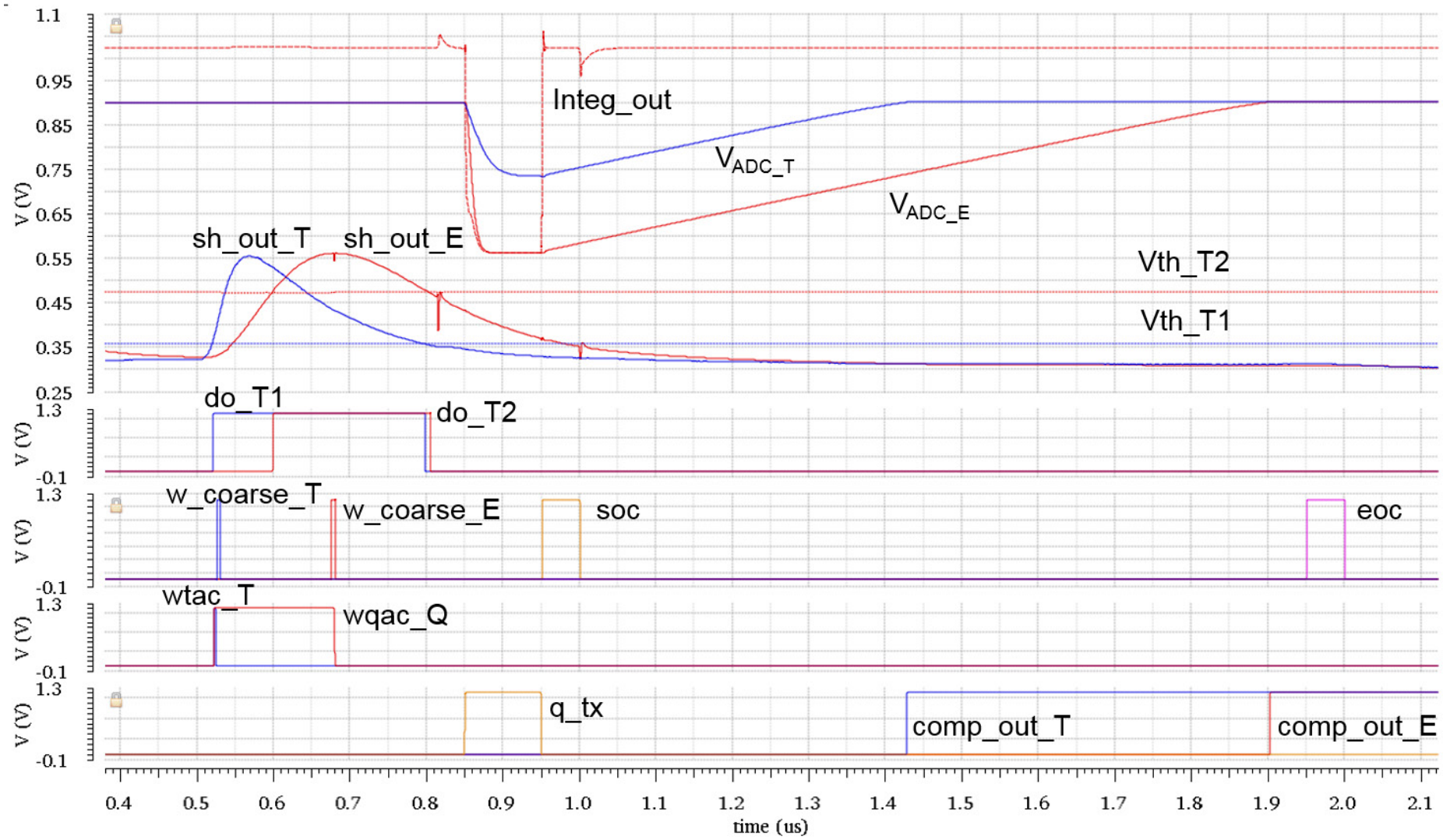
- Known the drift velocity, use time information to assign to each fired strip a 2D point
- Reconstruct the particle track from these coordinates
- Improve the spatial resolution in magnetic field, especially for angled tracks

Overview of the chip architecture

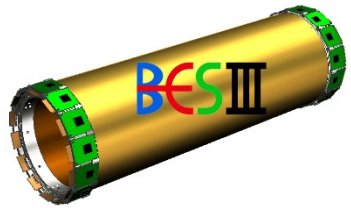




Simulation of one event



TIGER v2



- **TIGER V**ersatile **D**igitizer
  - Alternative design, shared engineering run
  - Versatile front-end, can be used for readout of GEM or other sensors

- RGC (common-gate with gm-boosting) input-stage
  - Current-mode amplification
  - Low configurable input impedance
  - Programmable gain: 3-bit DAC, range 50-300 fC Input