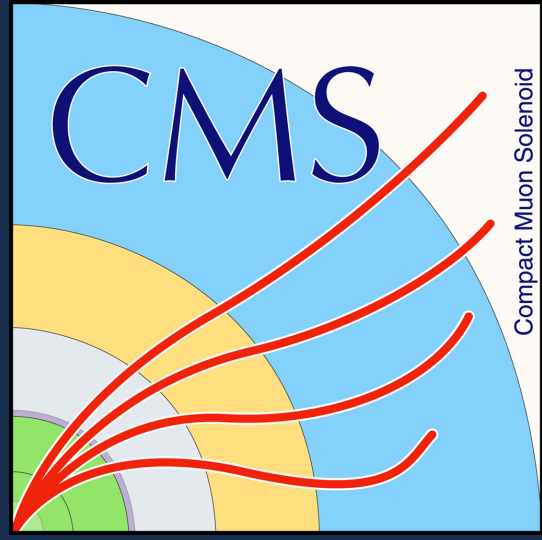


Test and performance of the LiTE-DTU ASIC for the HL-LHC upgrade of the CMS ECAL barrel



Fabio Cossio (INFN Torino) on behalf of the CMS Collaboration

Introduction

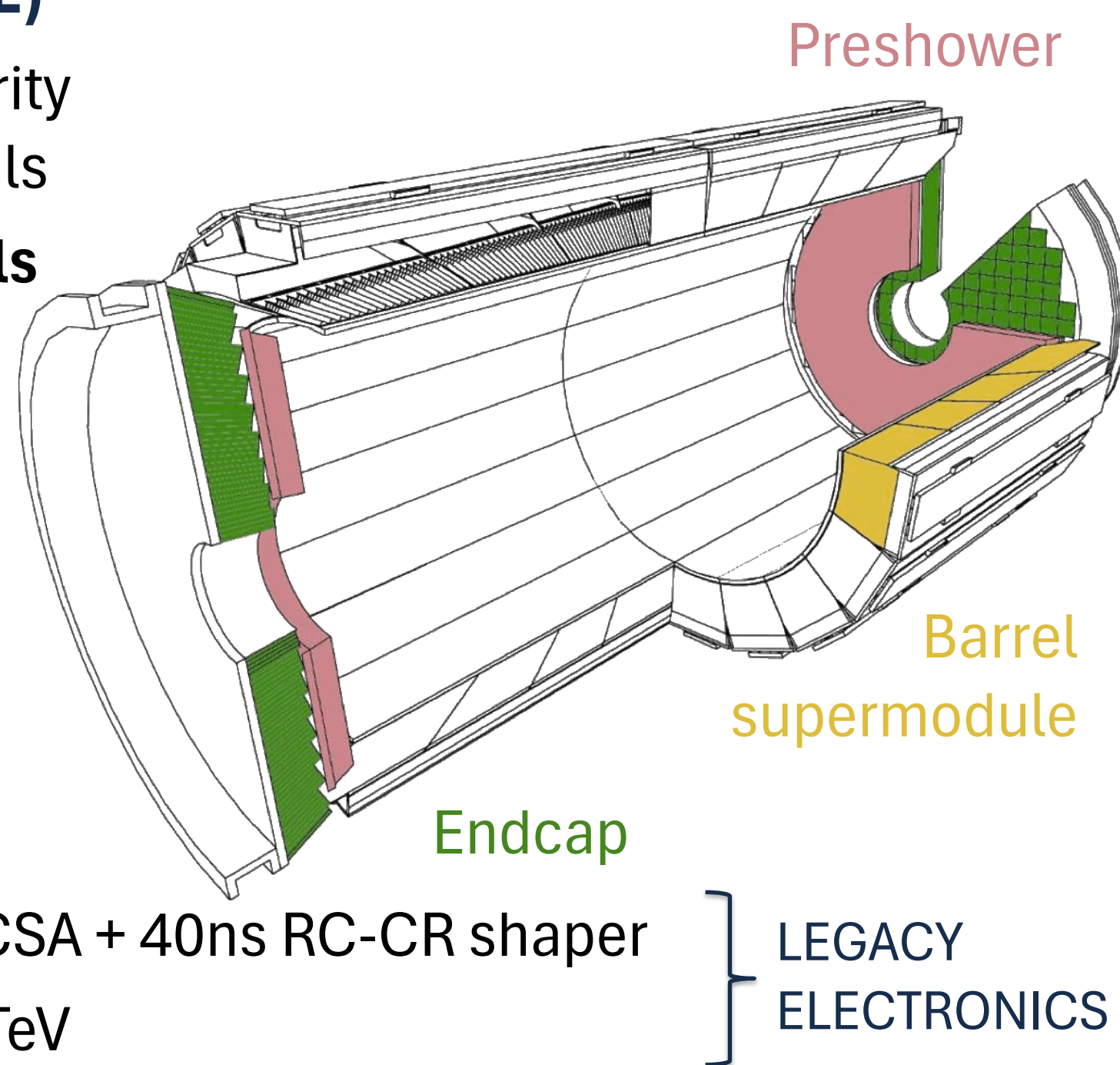
The CMS Electromagnetic CALorimeter (ECAL)

Compact, homogeneous and hermetic high-granularity crystal e.m. calorimeter based on scintillating crystals

- 61.2k (Barrel) + ~14.6k (Endcaps) **PbWO₄ crystals**
- $\tau_{75\%} = 25$ ns, $X_0 = 8.9$ mm, $r_M = 2.19$ cm

ECAL Barrel

- **APD sensors** readout
- 36 supermodules, 1700 crystals each
- 2448 readout units, made of **5x5 crystals**
- 5 VFE cards/unit, 5 channels/VFE
- Multi Gain PreAmplifier (MPGA) x1, x6, x12 gain, CSA + 40ns RC-CR shaper
- 12-bit, 40 MS/s ADC, dynamic range 40MeV – 1.5TeV

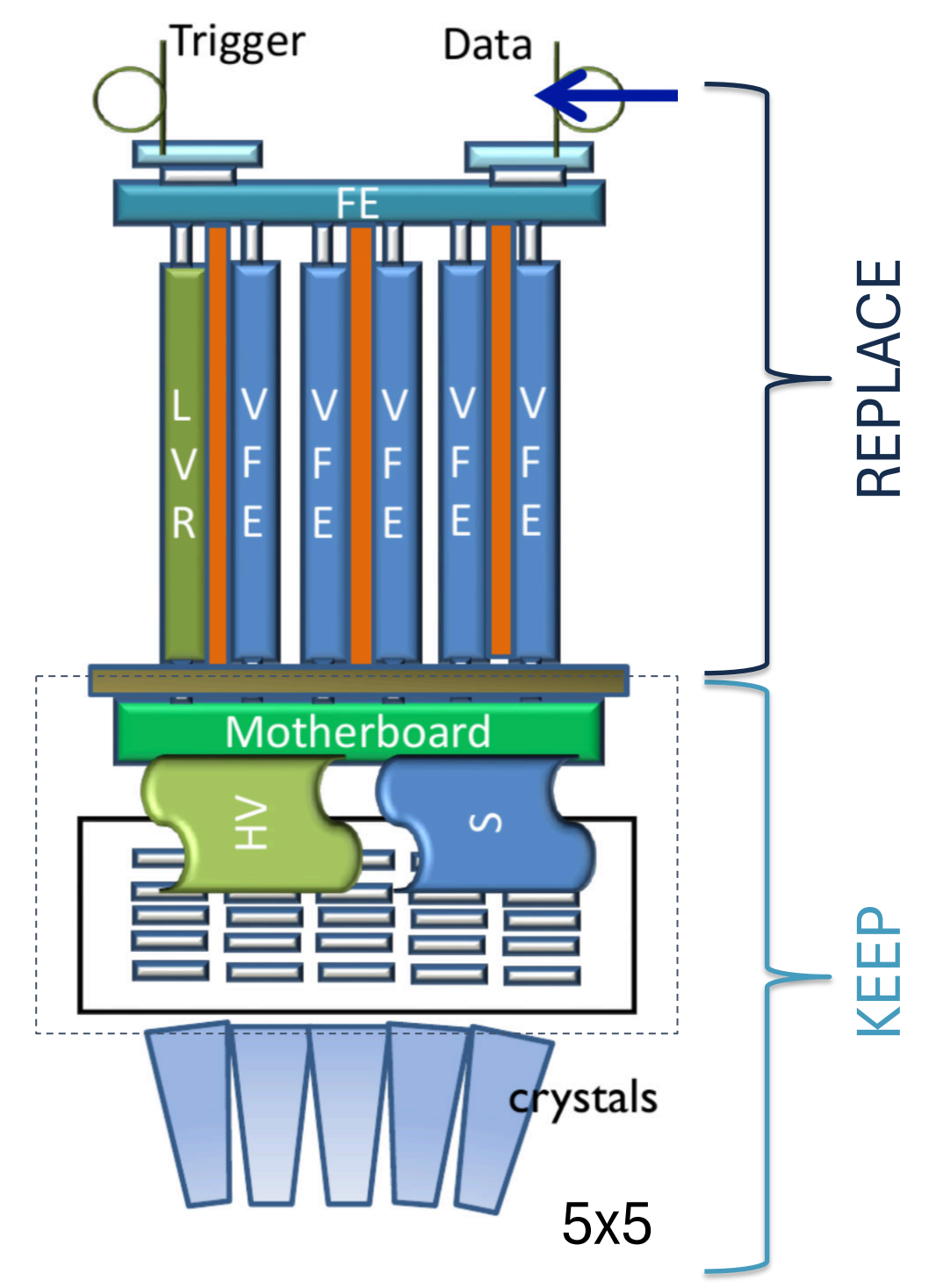


HL-LHC ECAL Upgrade

- Design luminosity: $5-7.5 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$
- High pileup: 140–200 p-p interactions in a single Bunch Crossing
- x10 design integrated luminosity

Radiation-induced detector ageing affects *crystal transparency* and *APD dark current*

- **ECAL Endcap and Preshower:** replace with a completely new detector (HGCAL)
- **ECAL Barrel:** reduce operating temperature from 18°C to 9°C to mitigate APD leakage current and increase light yield (keep crystals and APDs)



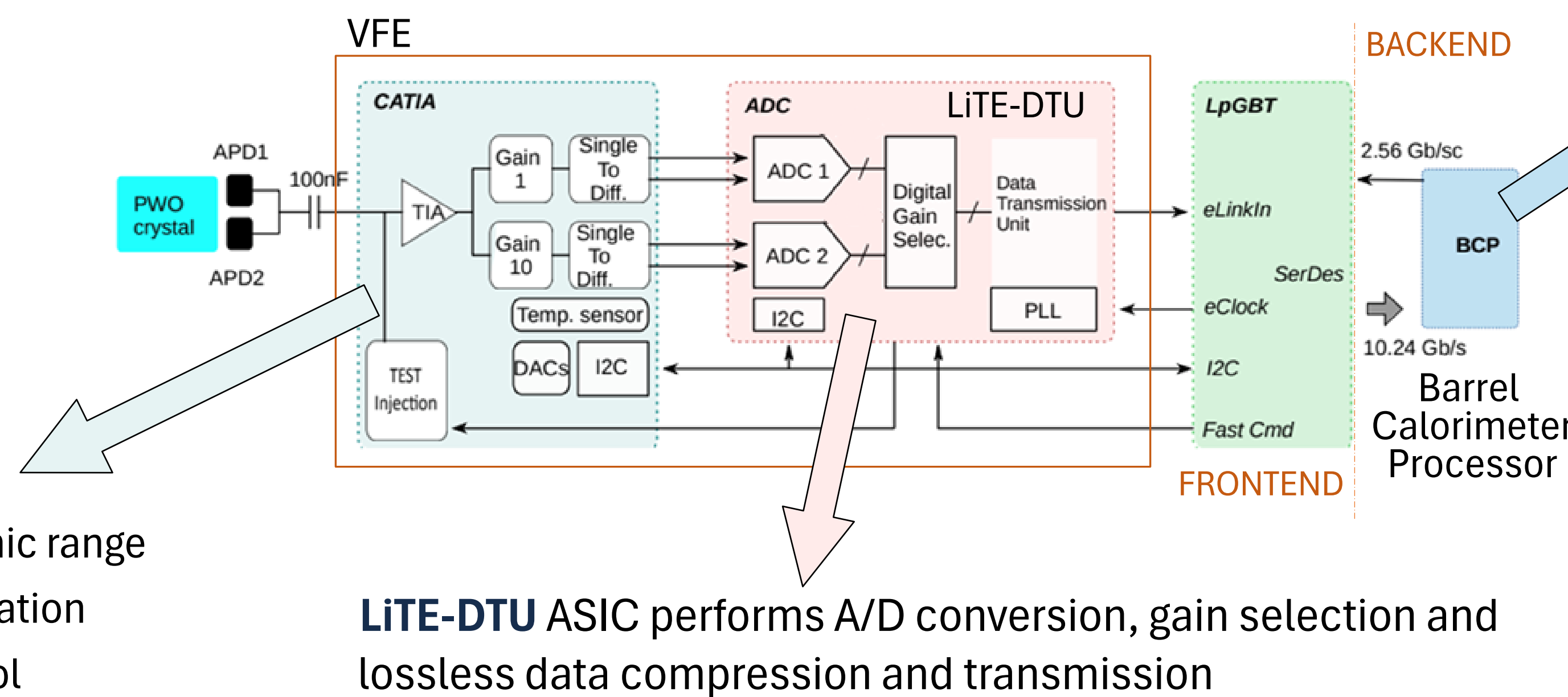
ECAL Barrel Electronics Upgrade

New CMS trigger and DAQ requirements:

- L1 trigger latency: 4.5μs → 12.5μs
- L1 trigger rate: 100kHz → 750kHz
- Trigger granularity: 5x5 crystals → one crystal

APDs signals amplified by CATIA ASIC:

- 130 nm CMOS technology (CEA Saclay)
- RCG input stage → very low Z_{in} , 35 MHz BW
- Dual gain: 10x and 1x → 50 MeV – 2 TeV dynamic range
- Test pulse injection for gain and linearity calibration
- Output differential buffers with pedestal control



Trigger-less front-end: trigger primitives generated in the **BCP**

Faster FE electronics provides:

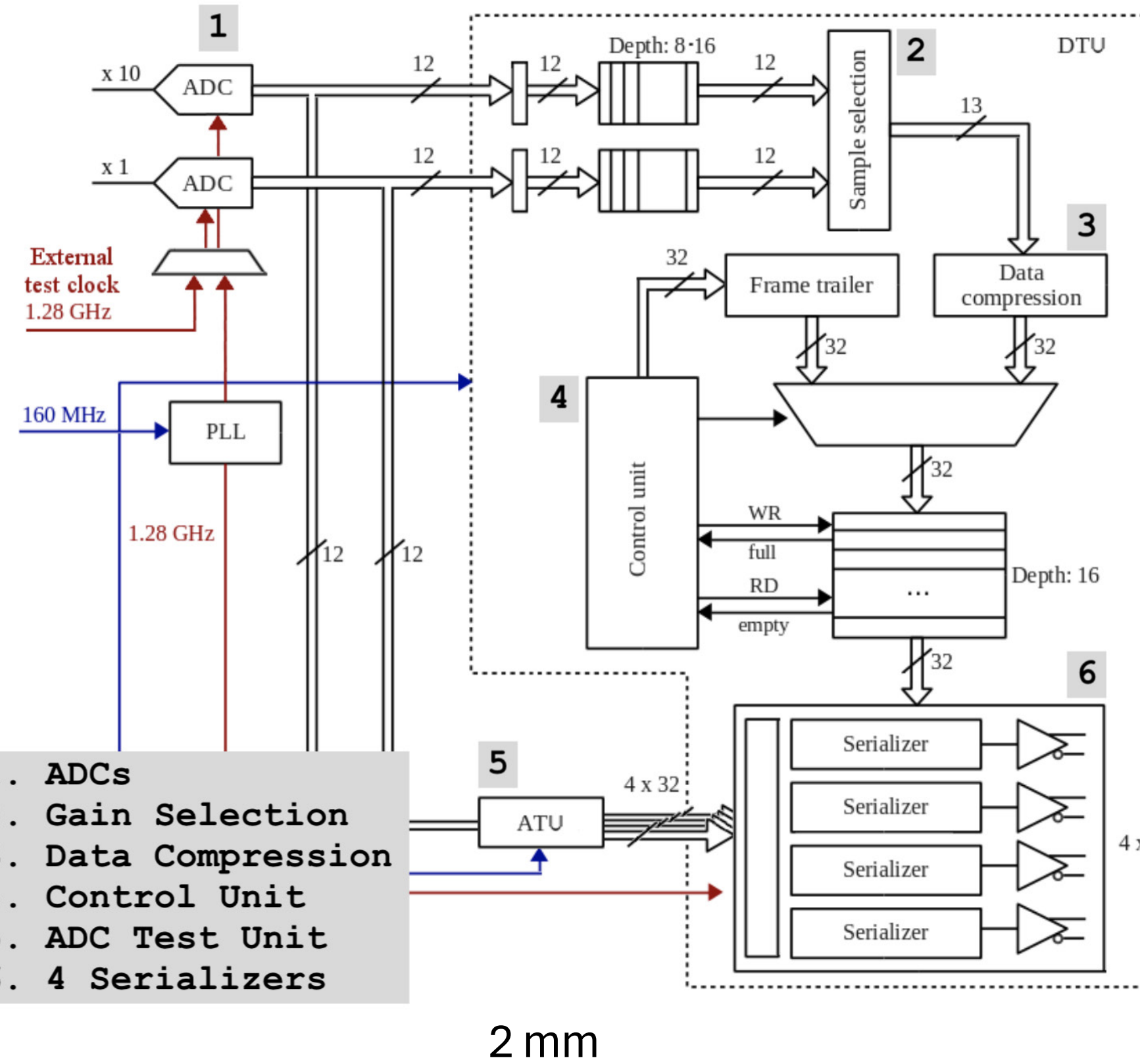
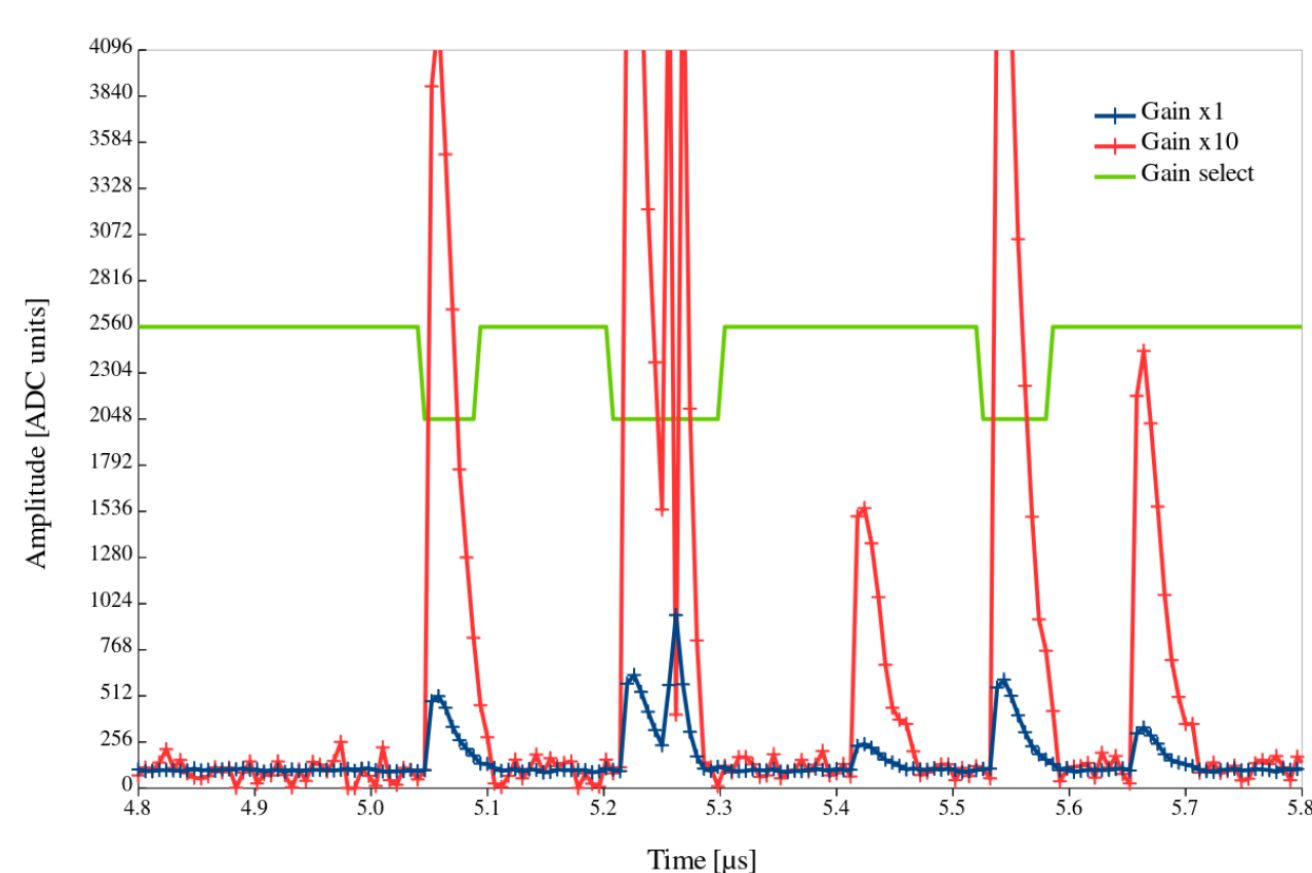
- ☺ Lower APD noise from leakage current
- ☺ Precision time measurement (30 ps resolution for H → γγ photons) for improved primary vertex identification and reduced pile-up
- ☺ Better rejection of “spikes” (signals from direct ionization of APDs) → on the fly pulse shape discrimination

LiTE-DTU: Lisboa and Torino ECAL Data Transmission Unit

2x 12-bit, 160 MS/s ADCs

- IP block from commercial company
- Time-interleaved 80 MHz SAR ADC
- ENOB: 10.2 @ 50 MHz
- P < 20 mW per ADC

Gain Selection



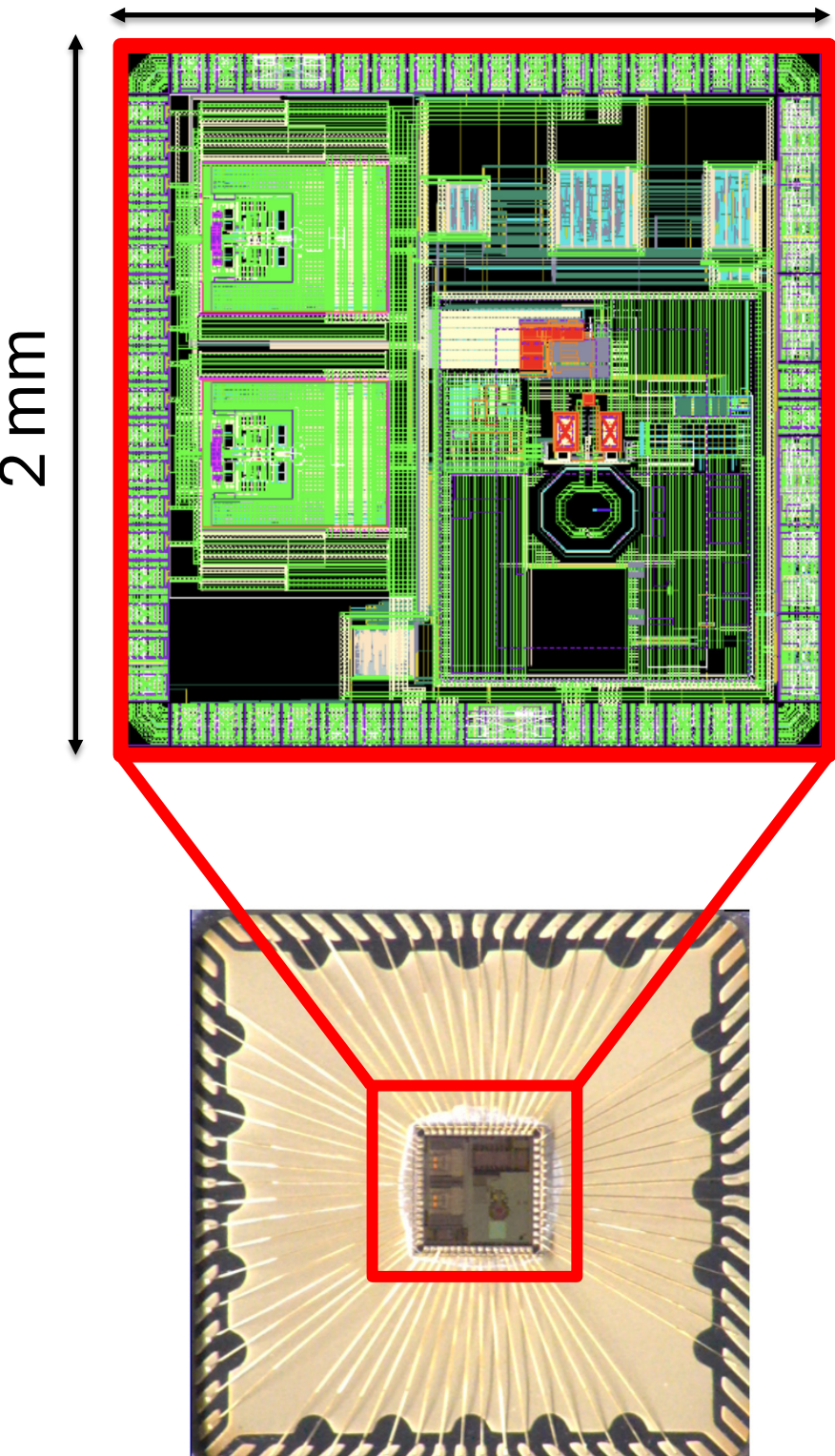
Lossless data compression

- $E < 2.5$ GeV → 6-bit output
- $E > 2.5$ GeV → 13-bit output ($P < 5.8 \cdot 10^{-5}$)
- BW occupation: 2.08 Gb/s → 1.08 Gb/s
- Fit in one lpGBT e-link (1.28 Gb/s)
- Latency < 350 ns

1.28 GHz clock for ADCs and serializers

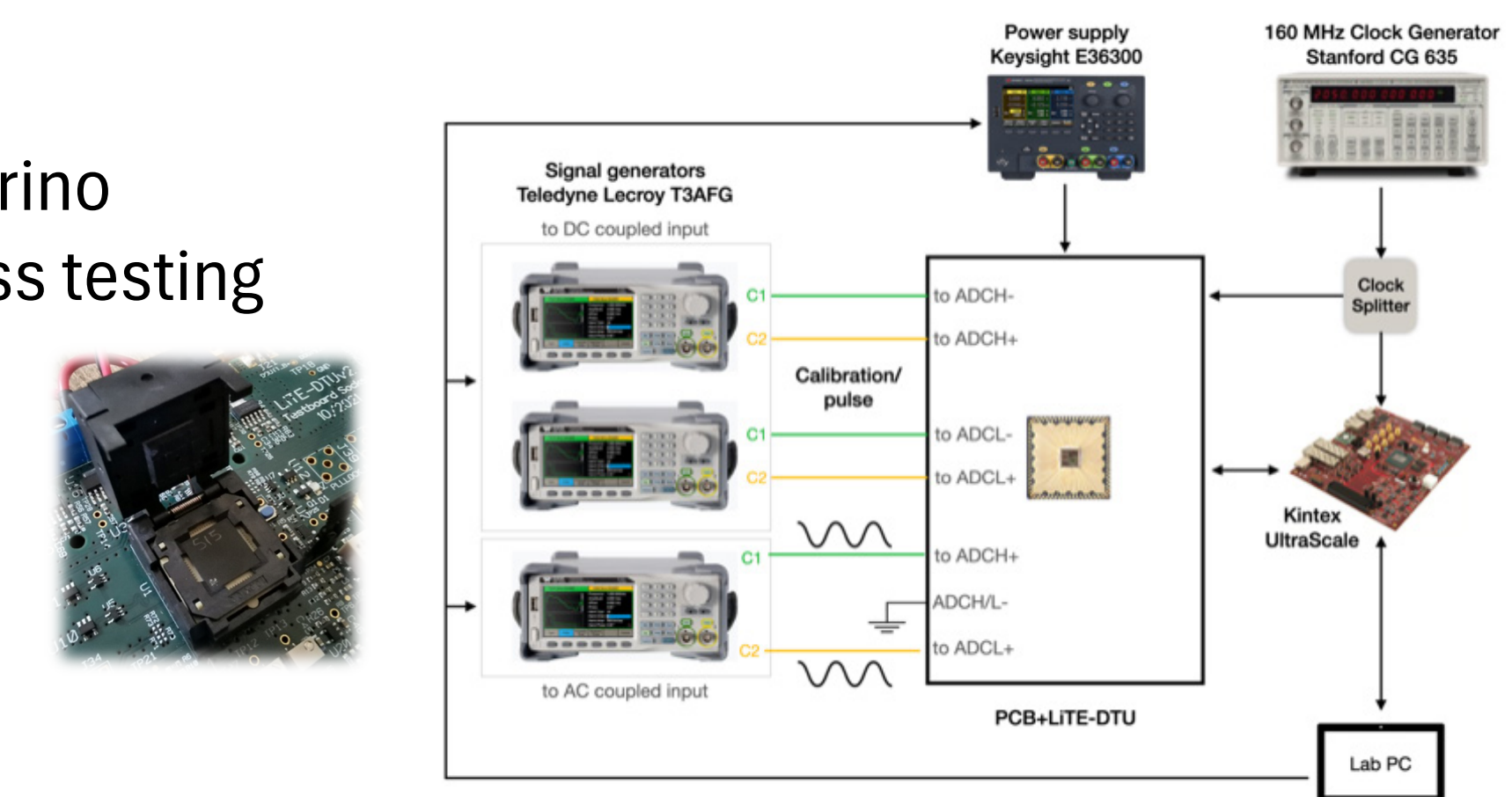
- Generated internally from 160 MHz input clock
- PLL IP block from lpGBT

65 nm CMOS technology, QFN72 package

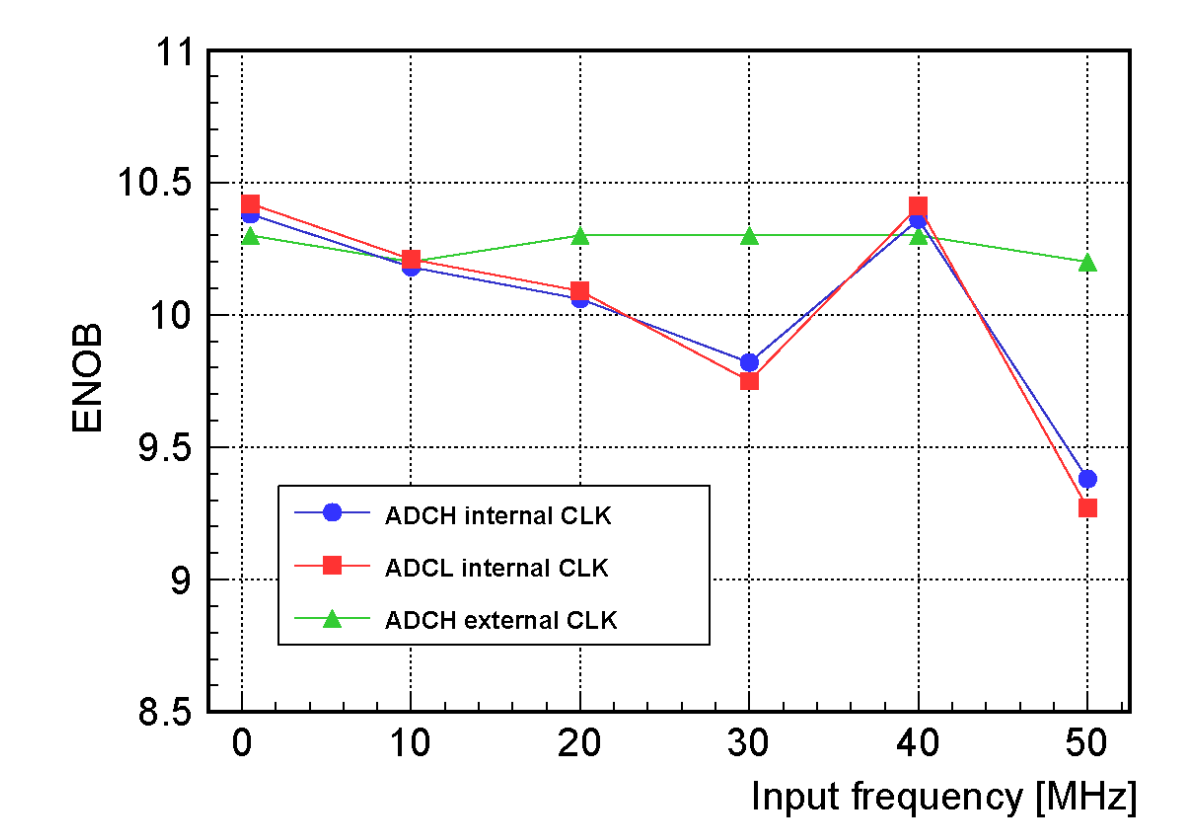
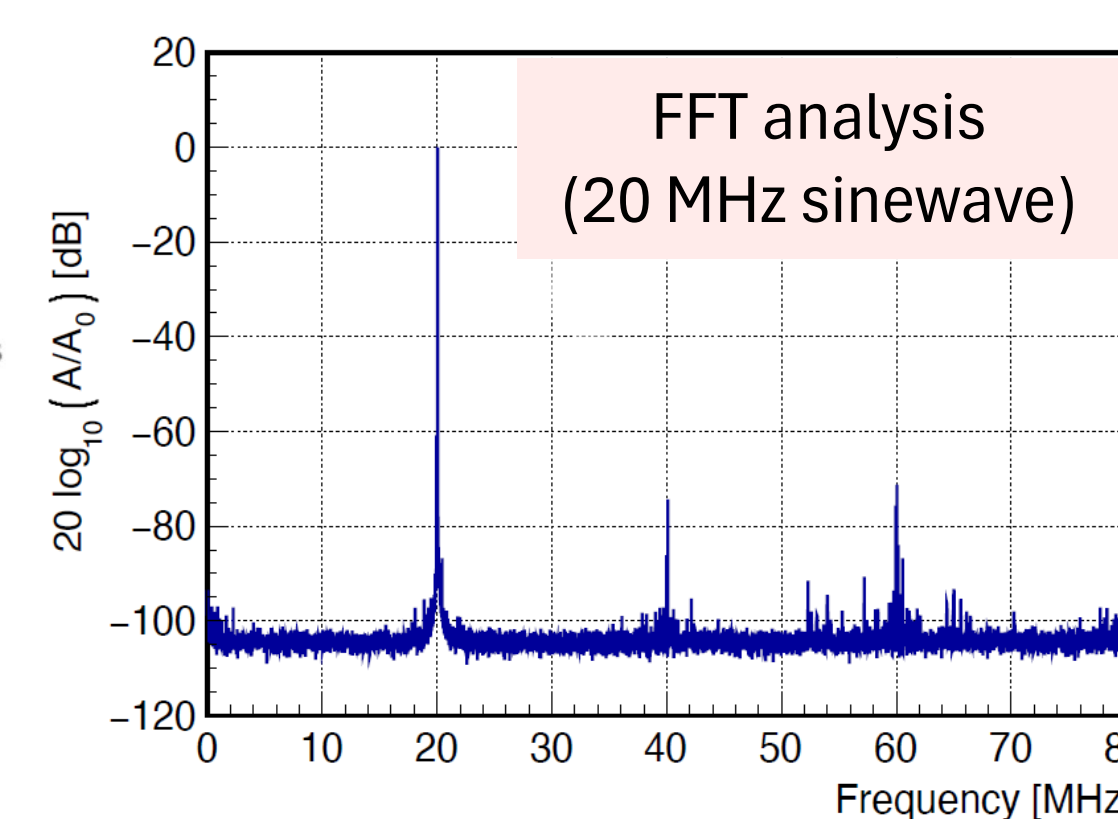


Functional test setup

- Setup developed at INFN Torino towards automation for mass testing
- ZIF socket
- 553 pre-production version chips tested → yield: 97%



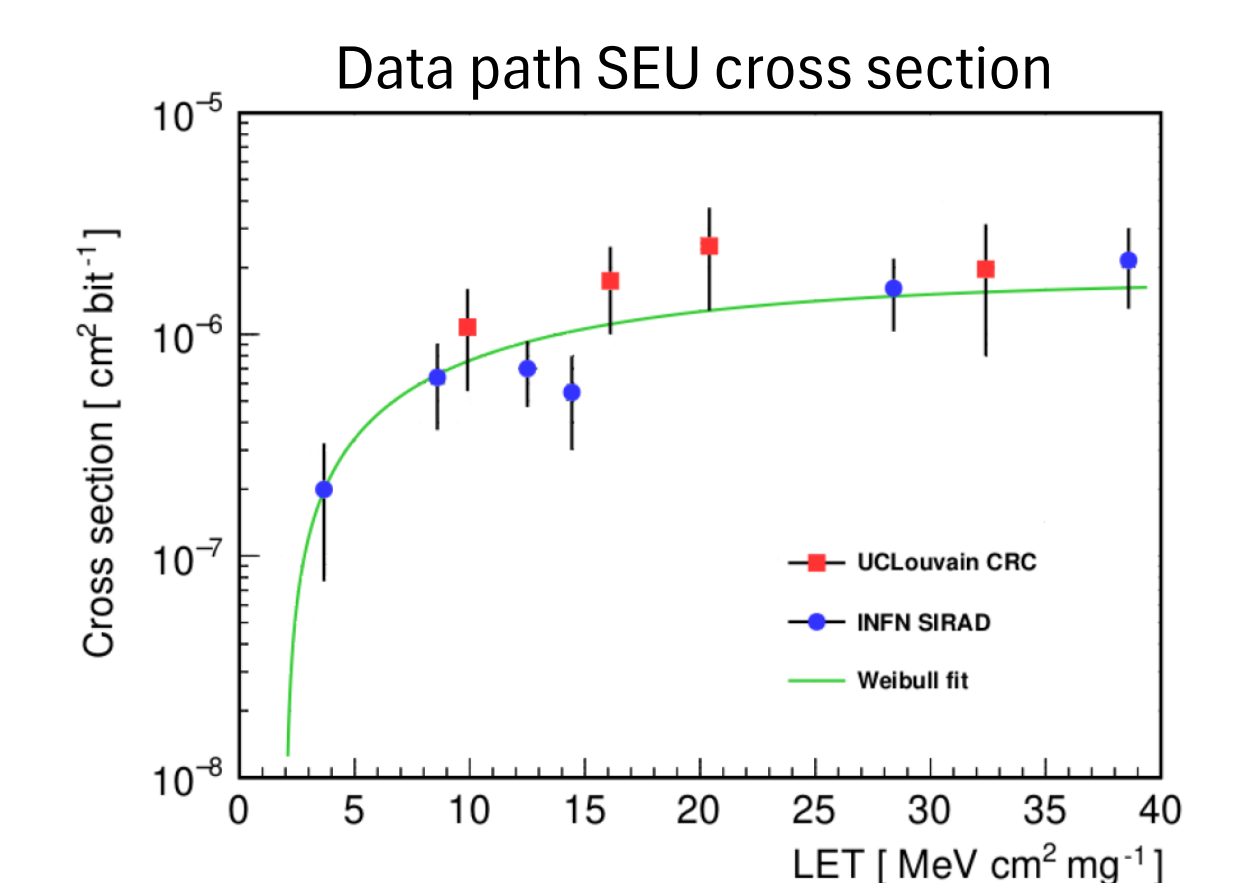
ENOB measurements



Radiation hardness tests

- TID tolerance tested up to 50 kGy at INFN Padova X-ray irradiation facility

SEU	errors/h (single chip)	errors/h (full barrel)
I ² C interface	$9 \cdot 10^{-5}$	5.5
Data path	$10.2 \cdot 10^{-3}$	627



Current status and future perspectives

- Successful beam test campaign at CERN H4 in Jul 2023: supermodule with 200 channels of pre-production FE electronics + first version of the BCP (see *M. Campana's poster*)
- ASIC mass production started in May 2023, first wafers delivered this week
- Full installation during LHC Long Shutdown 3 (2024-2026)

References

- [1] TDR: The Phase-2 Upgrade of the CMS Barrel Calorimeters, CERN, Geneva, Sept 2017, <https://cds.cern.ch/record/2283187>
- [2] G. Mazza et al., “The LiTE-DTU: A Data Conversion and Compression ASIC for the Readout of the CMS Electromagnetic Calorimeter”, in *IEEE Transactions on Nuclear Science*, vol. 70, no. 6, pp. 1215-1222, June 2023, doi: [10.1109/TNS.2023.3274930](https://doi.org/10.1109/TNS.2023.3274930)