Performance of a highly compact electromagnetic calorimeter for future electron-positron colliders

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on behalf of the FCAL collaboration

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3. FLAME ASIC
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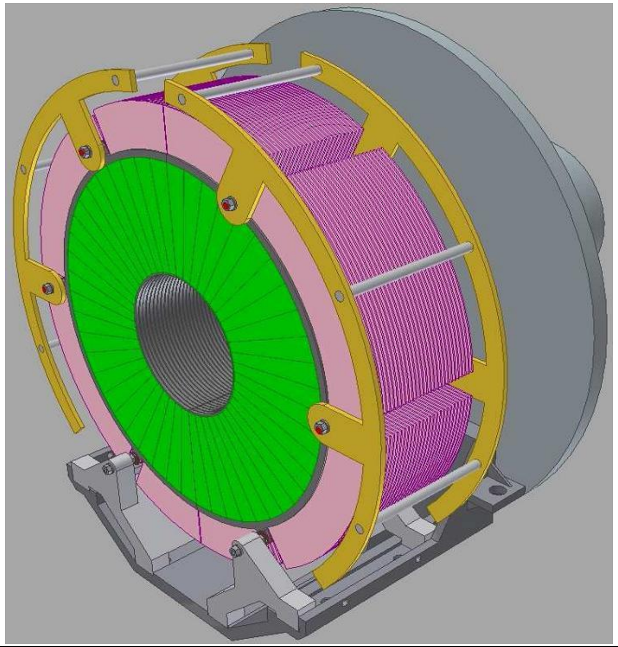
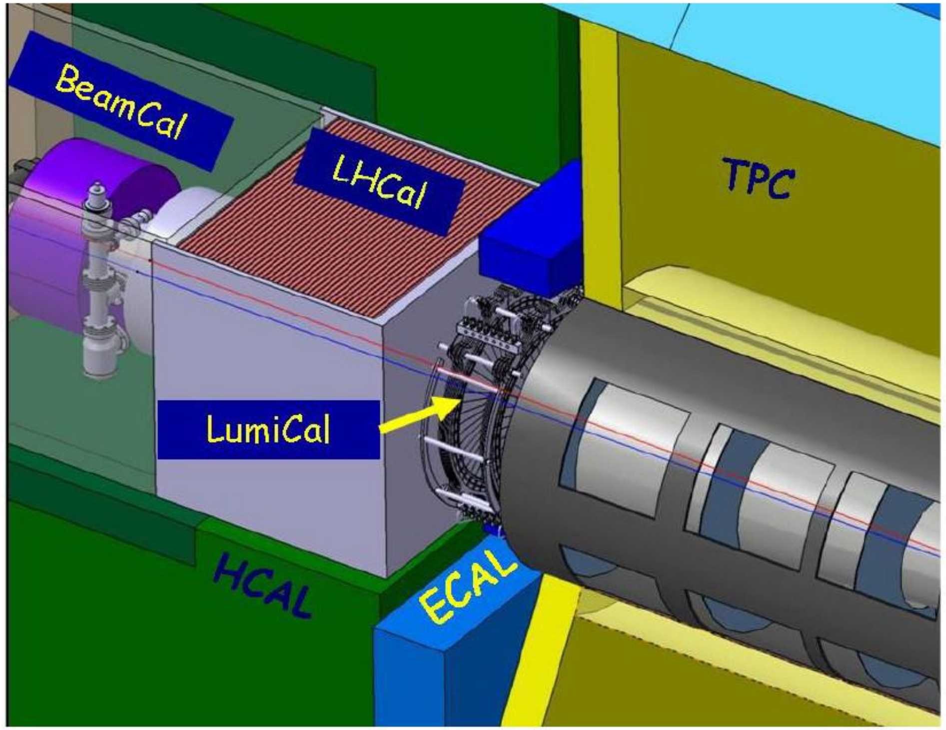
6. SUMMARY

FCAL OVERVIEW

FCAL luminosity system = BeamCal + LumiCal
(fast) (precise)

- Precise cross-section measurement requires a precise luminosity measurement.
- Luminosity at an e+e- collider can be measured by counting number of Bhabha events N_B, in a certain polar angle range (ϑ_{min}, ϑ_{max}) of the elastically scattered electron.
- Bhabha scattering is a well-known and theoretically-controlled process.



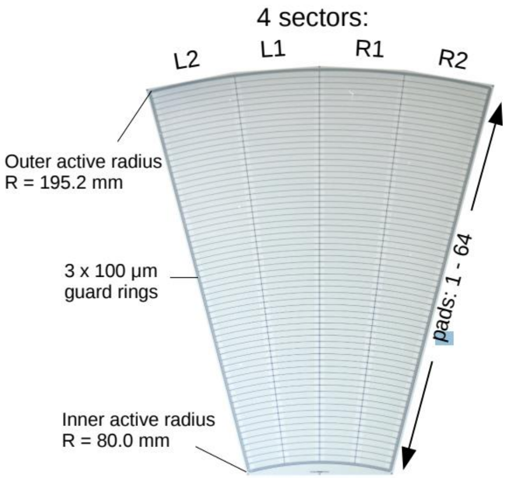


LumiCal:
- Si-W sandwich calorimeter
- Highly compact
- Measuring the rate of Bhabha events at low angles. Achieving the desired precision of 10^{-4} is a challenge.
- Improving the hermeticity of the ILC detector by providing electron and photon identification down to polar angles of a few mrad

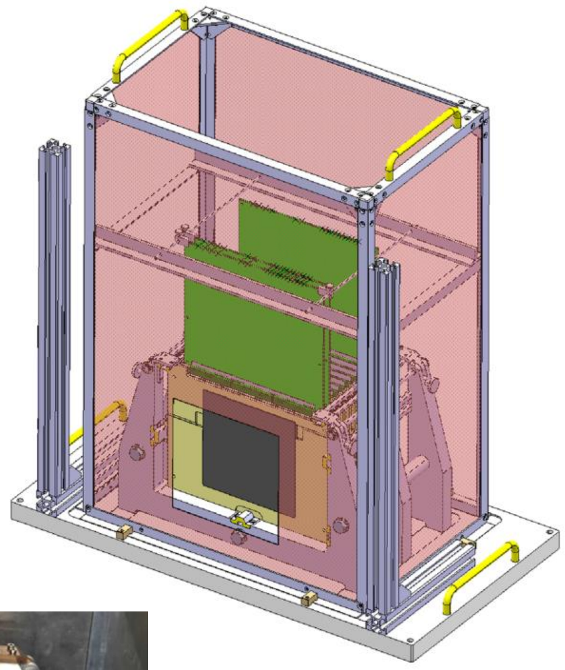
LUMICAL SENSOR & ABSORBER

Silicon pad sensor prototype was designed for ILC:

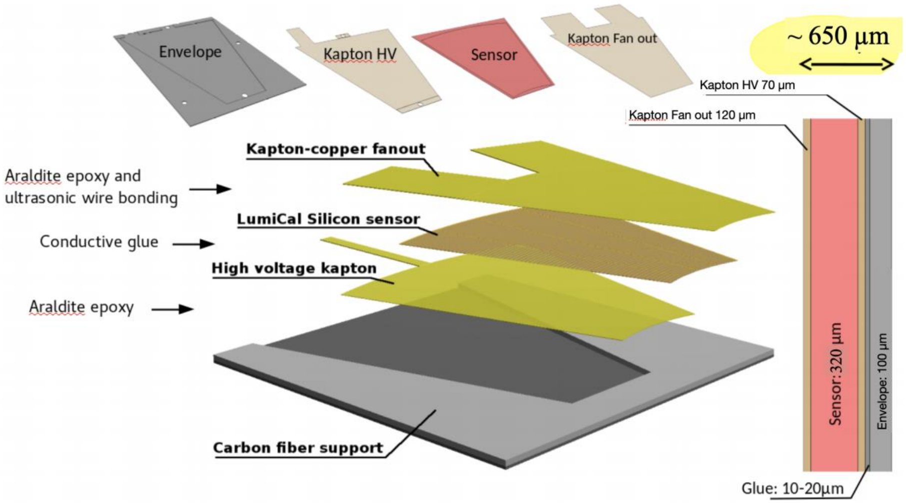
- ring segment of 30 degrees, 4 sectors of 7.5 each
- 64 radial pads, pitch 1.8 mm
- 11 cm long with an inner radius of 80 mm
- thickness 320 μm
- p+ implants in n-type bulk
- Produced by Hamamatsu
- Total thickness of a complete sensor module < 700um



Mechanical frame for the positioning of sensor modules and absorber plates

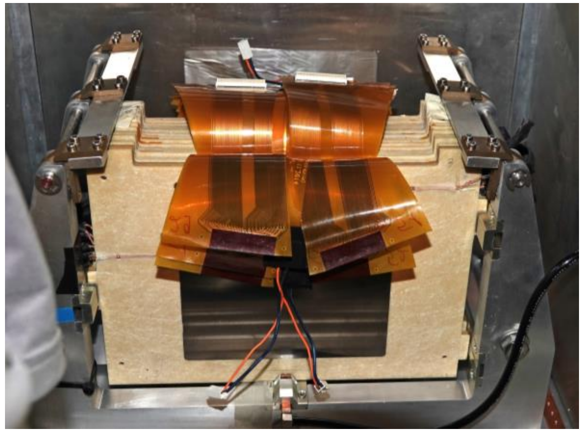


Sensor module structure

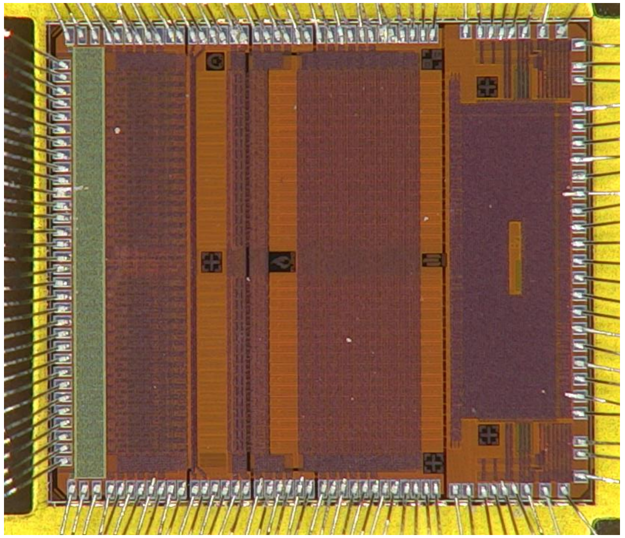


Absorber plates:

- W plates - alloy
  93 % tungsten,
  5 % nickel,
  2 % copper.
- 1 X0 – 3.5 mm thick
- Flatness of W plates is better than 30 um



LUMICAL READOUT – FLAME ASIC

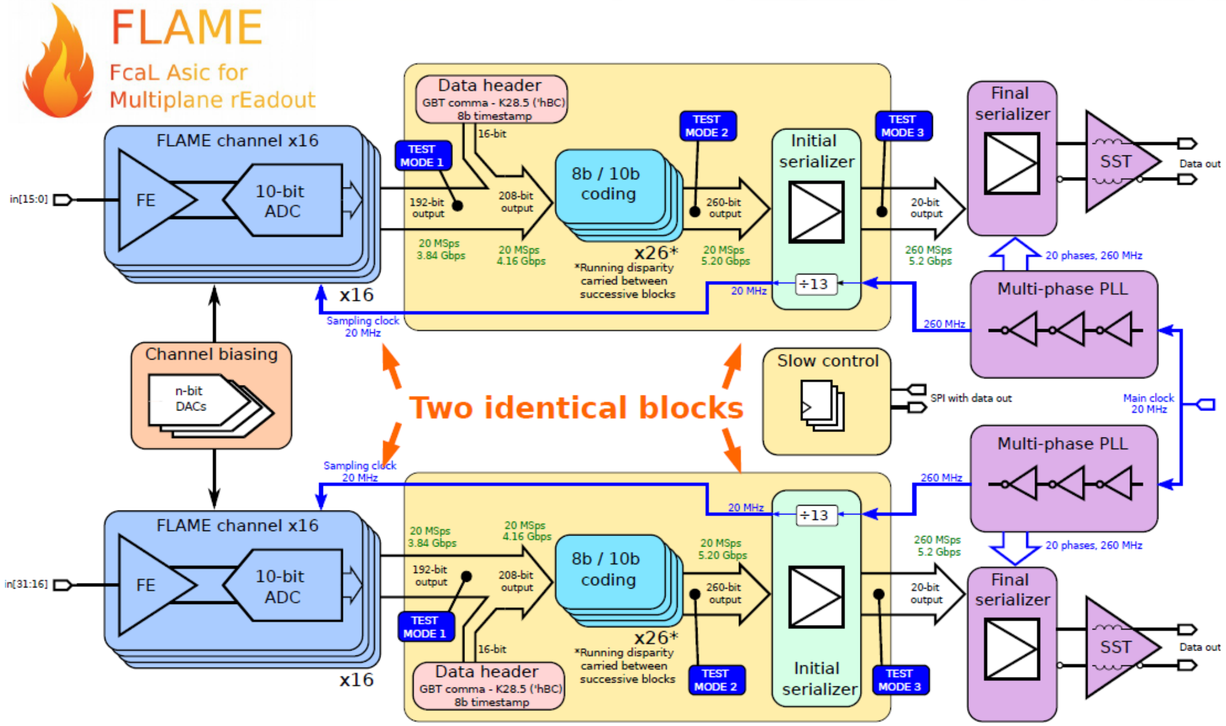


FLAME:

- ➢ 32-channels per ASIC
- ➢ designed in CMOS 130 nm
- ➢ each channel contains FE+ADC
- ➢ followed by high speed data link

Data send directly to Zynq UltraScale FPGA for online processing:

- pedestal, CM subtraction
- pulse detection
- deconvolution
- ToA and amplitude reconstruction



Analog front-end:

- ➢ Charge sensitive preamplifier with variable gain: from MIP sensitivity, up to 6pC
- ➢ Differential CR-RC shaper – **for simple amplitude and time deconvolution**
- ➢ Power consumption ~1mW

10-bit SAR ADC:

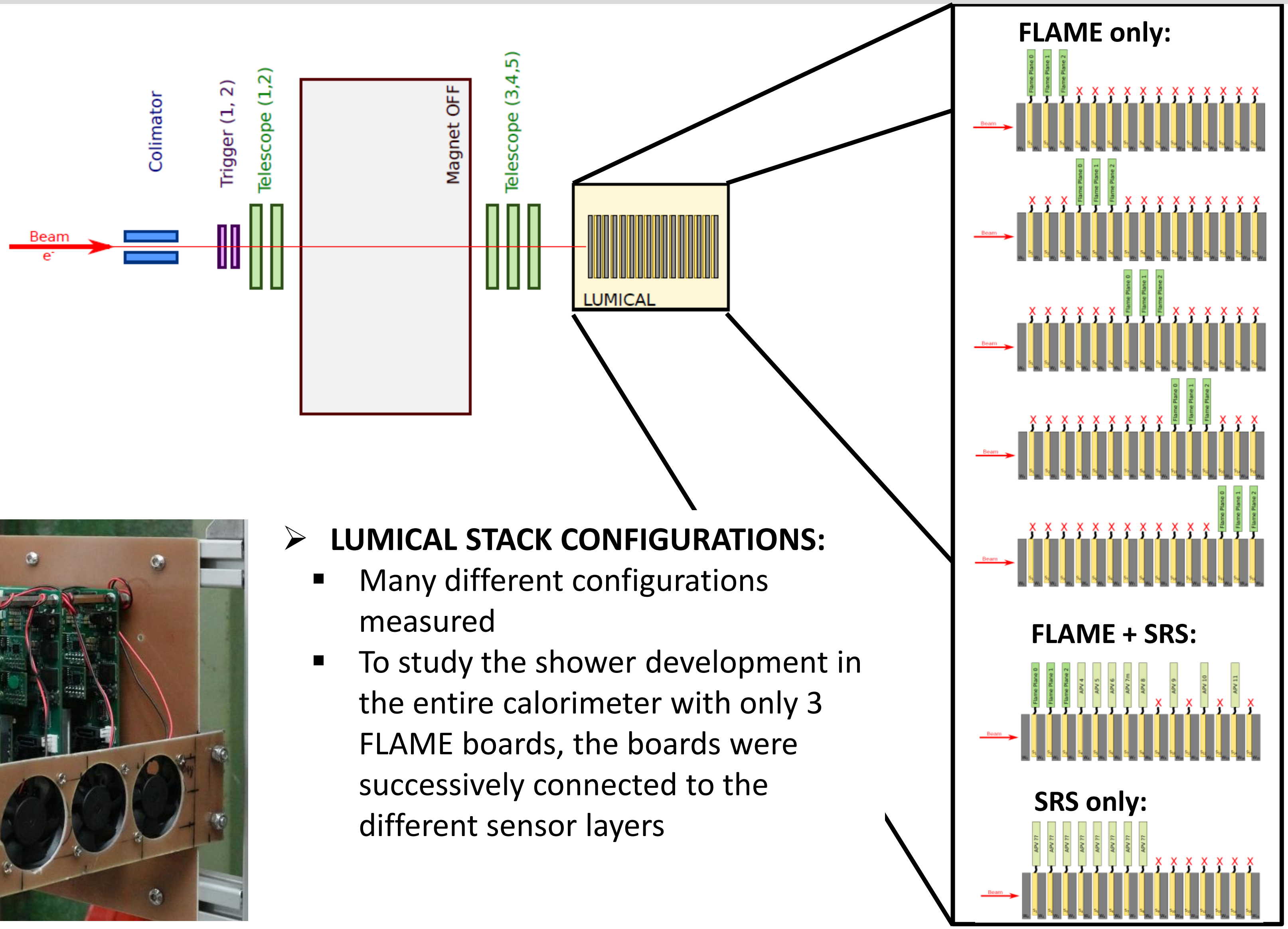
- ➢ Sampling rate 20 MS/s (Max 50 MS/s)
- ➢ ENOB > 9.5
- ➢ DNL, INL < 0.5 LSB
- ➢ Ultra low power consumption (<0.5mW/channel@20MSps)

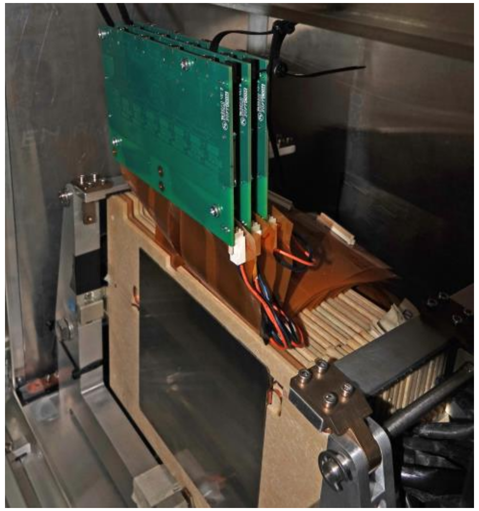
Serializer & driver:

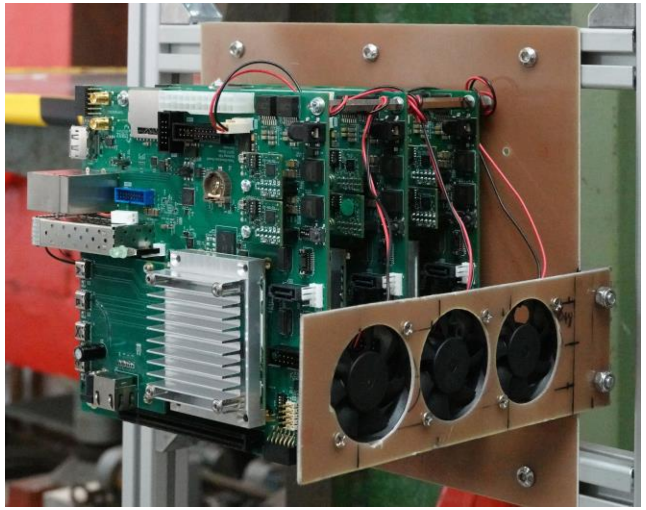
- ➢ PLL generates 260MHz clocks from 20MHz reference (x13)
- ➢ 5.2 Gb/s output data rate

2020 Testbeam: Setup

- 1 - 5,6 GeV electrons @ DESY
- 5 ALPIDE planes for tracking
- LumiCal setup built of 16 Tungsten plates and silicon sensors
- Available readout boards:
  - 3 FLAME readout boards
  - 8 SRS readout boards
- **First tests on beam with FAME readout**
- Data acquired for:
  - various beam energies (1-5.6 GeV)
  - various impact positions
  - various incident angles
  - various stack configurations







- **LUMICAL STACK CONFIGURATIONS:**
  - Many different configurations measured
  - To study the shower development in the entire calorimeter with only 3 FLAME boards, the boards were successively connected to the different sensor layers

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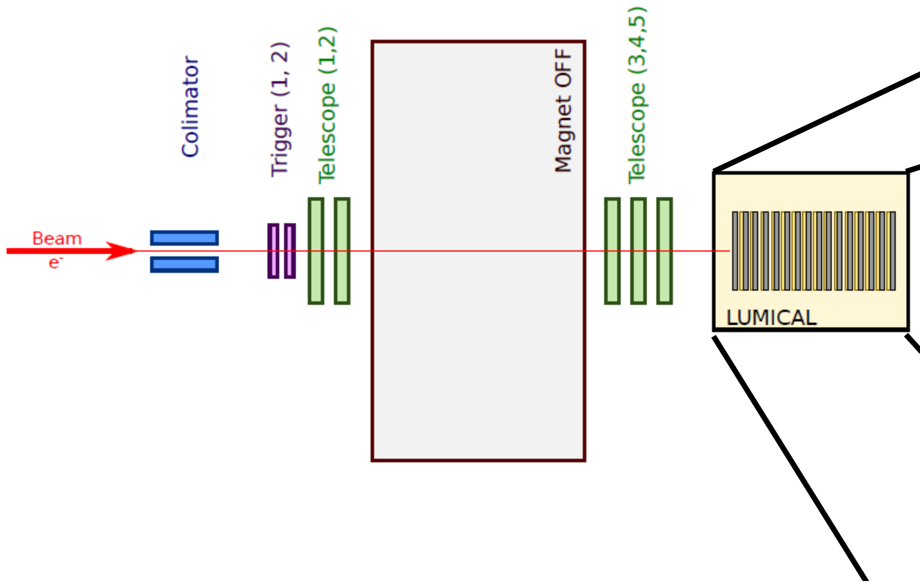
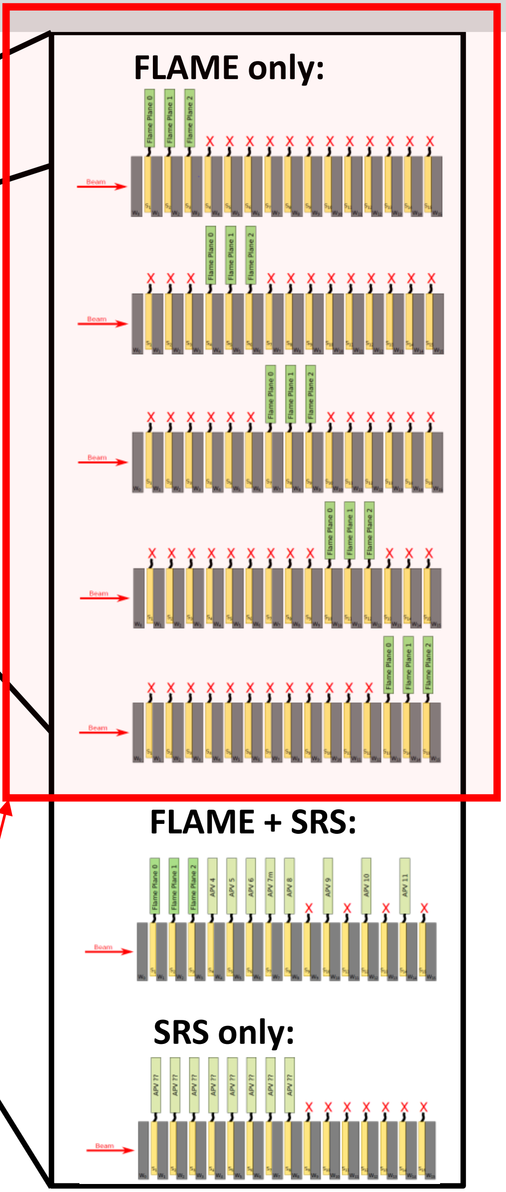
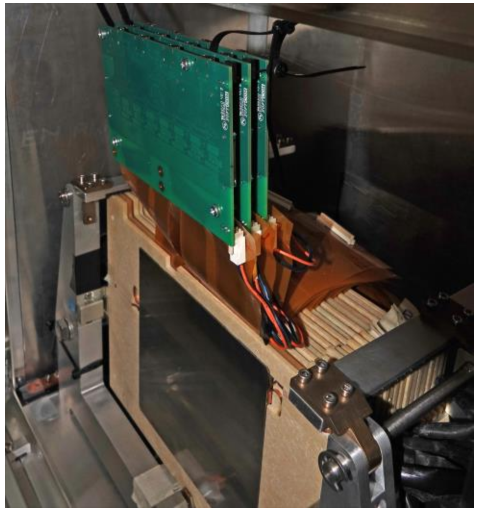
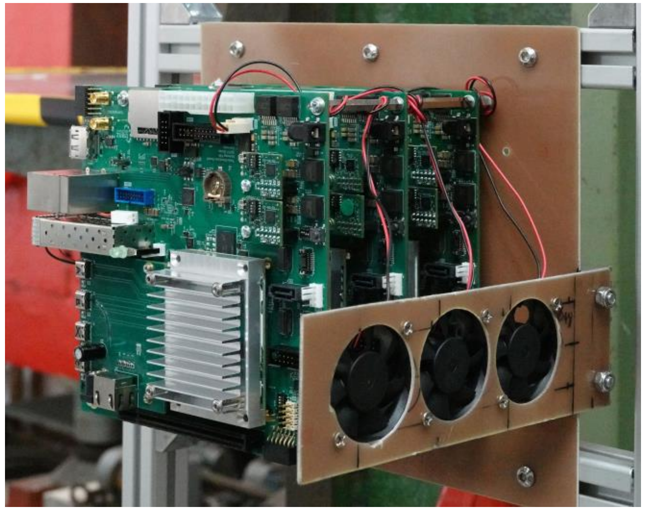




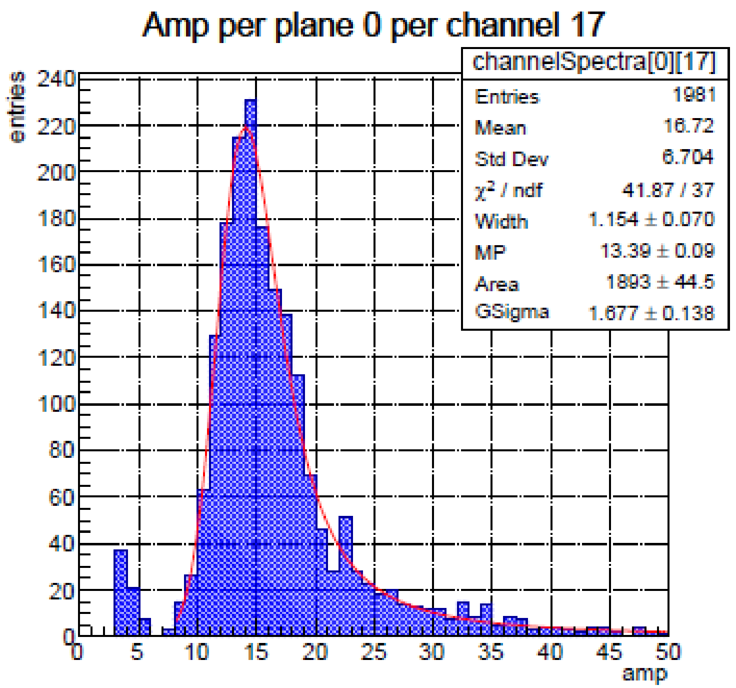


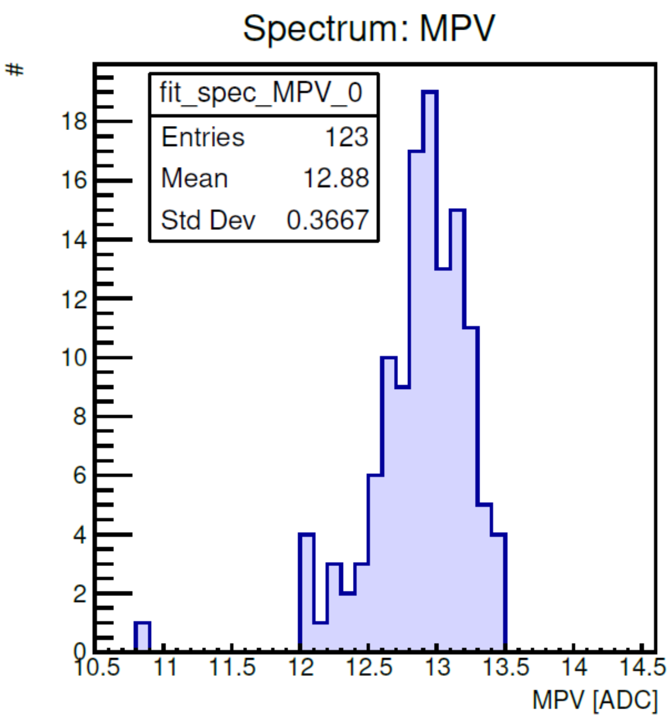


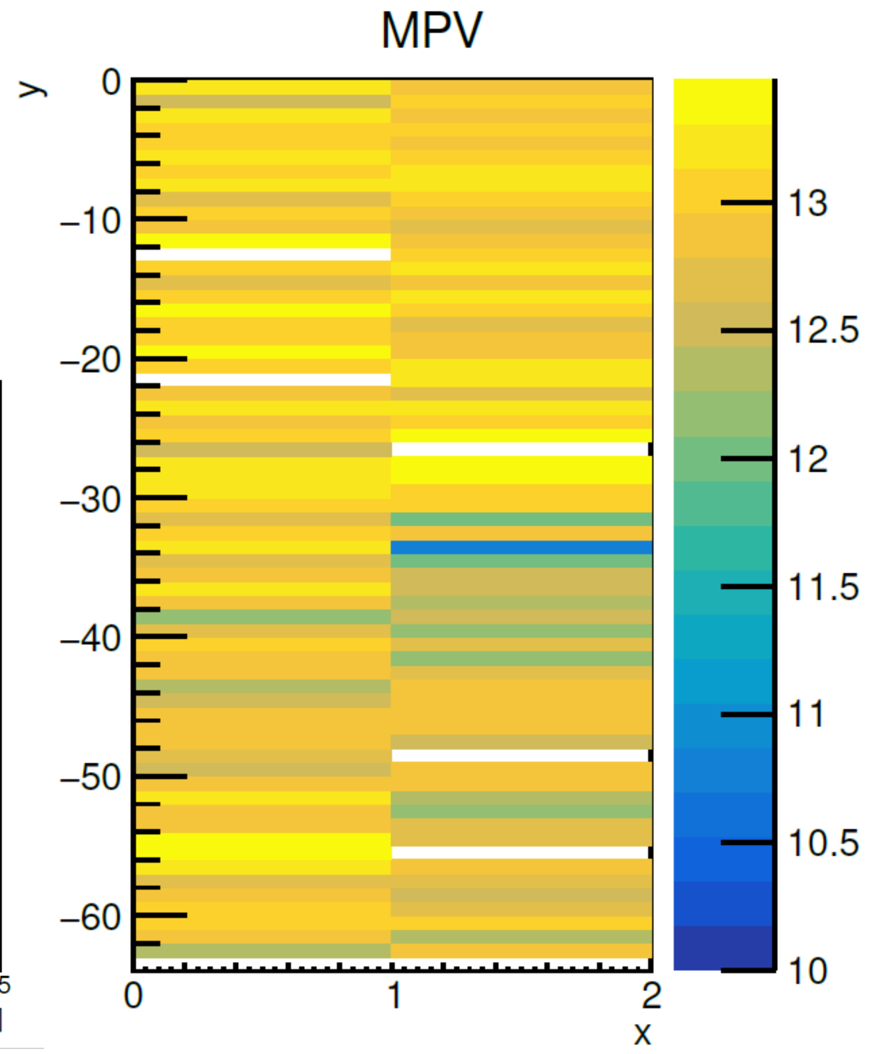
- **LUMICAL STACK CONFIGURATIONS:**
  - Many different configurations measured
  - To study the shower development in the entire calorimeter with only 3 FLAME boards, the boards were successively connected to the different sensor layers
  - This presentation: focused on results for FLAME standalone configurations

2020 TESTBEAM: RESULTS – CALIBRATION

- Channel by channel gain calibration can be done by looking on the response of sensor directly exposed on MIPs
- For each pad the (Landau ∗ Gauss) function was fitted to energy spectrum
- MVP = 12.88 +/- 0.37 [ADC]
- The analysis showed very small deviations from channel to channel. (<5% - small enough to neglect in the first analysis)



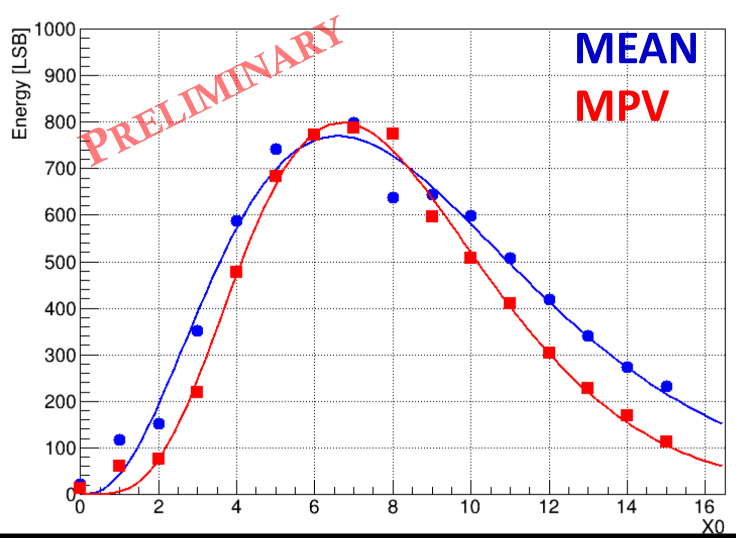


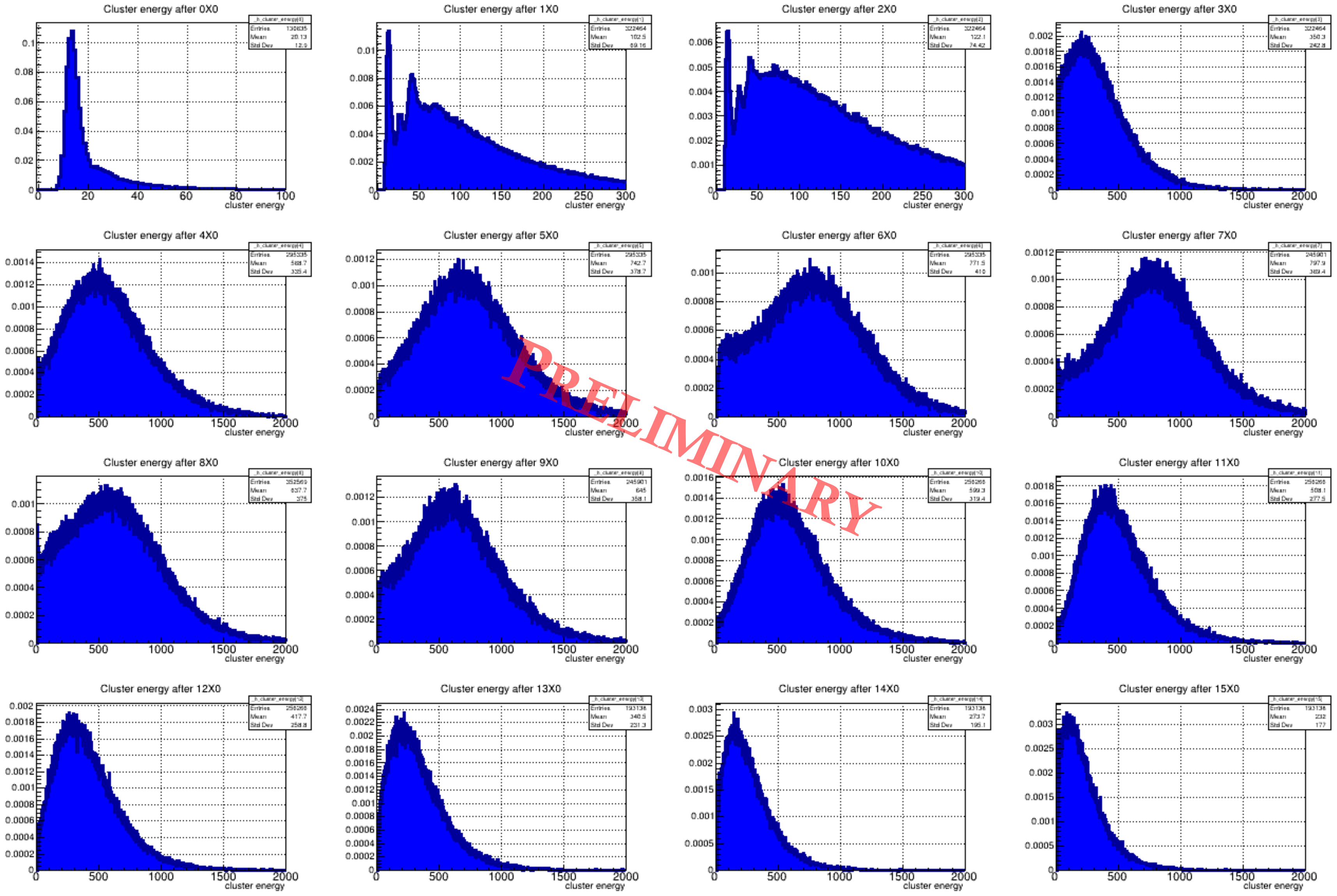


2020 Testbeam: Results – Cluster energy

- Relatively high noise observed in the TB environment, but still much below the MIP signal (some cuts may be still tuned a bit)
- Clustering by integrating all pads exciding the threshold
- The maximum energy deposition for **5 GeV electrons** at around **$7X_0$** → as expected
- Longitudinal shower profile well fitting to:

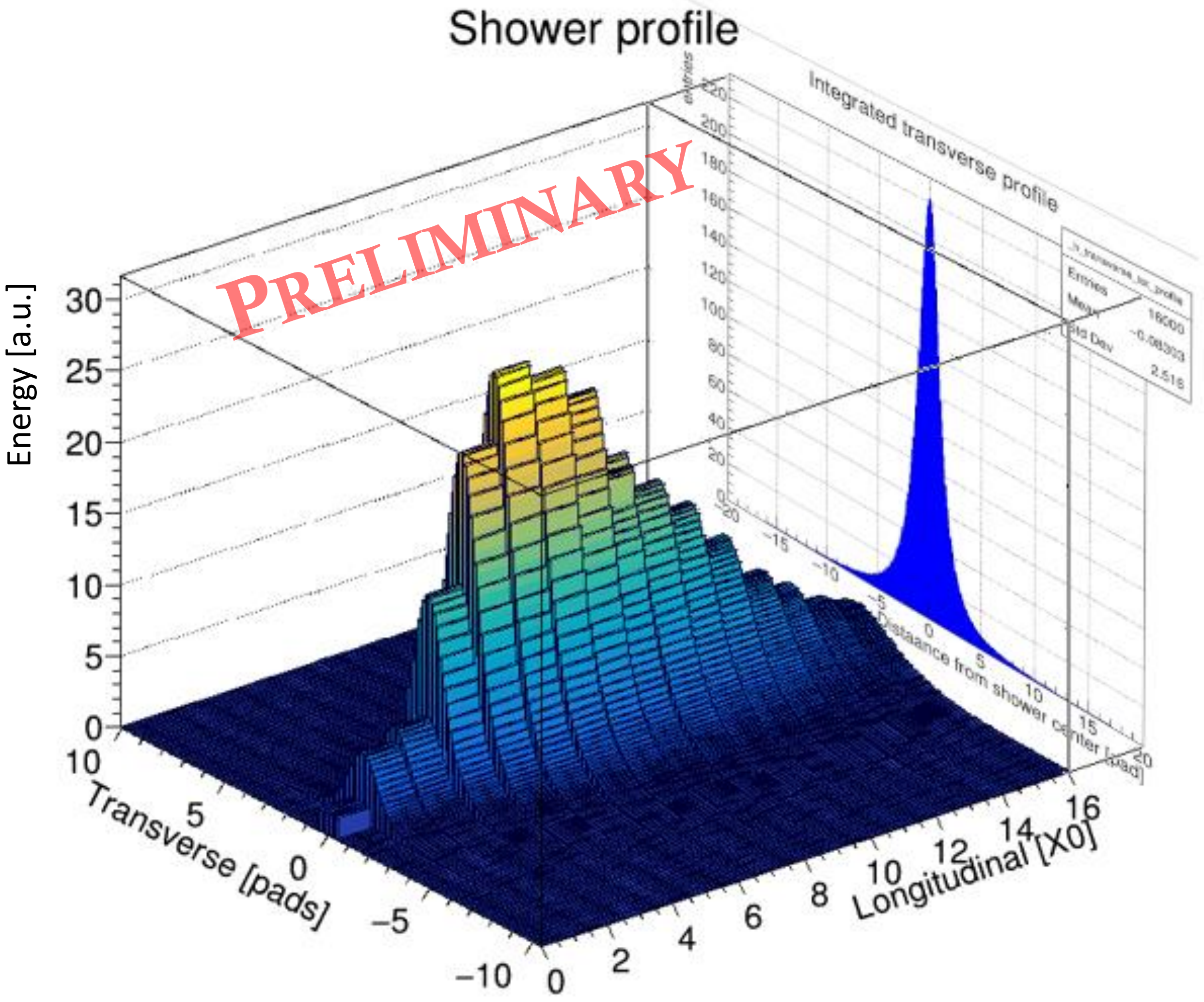
$$\frac{dE}{dt} = E_0 t^{\alpha} \exp(-\beta t)$$





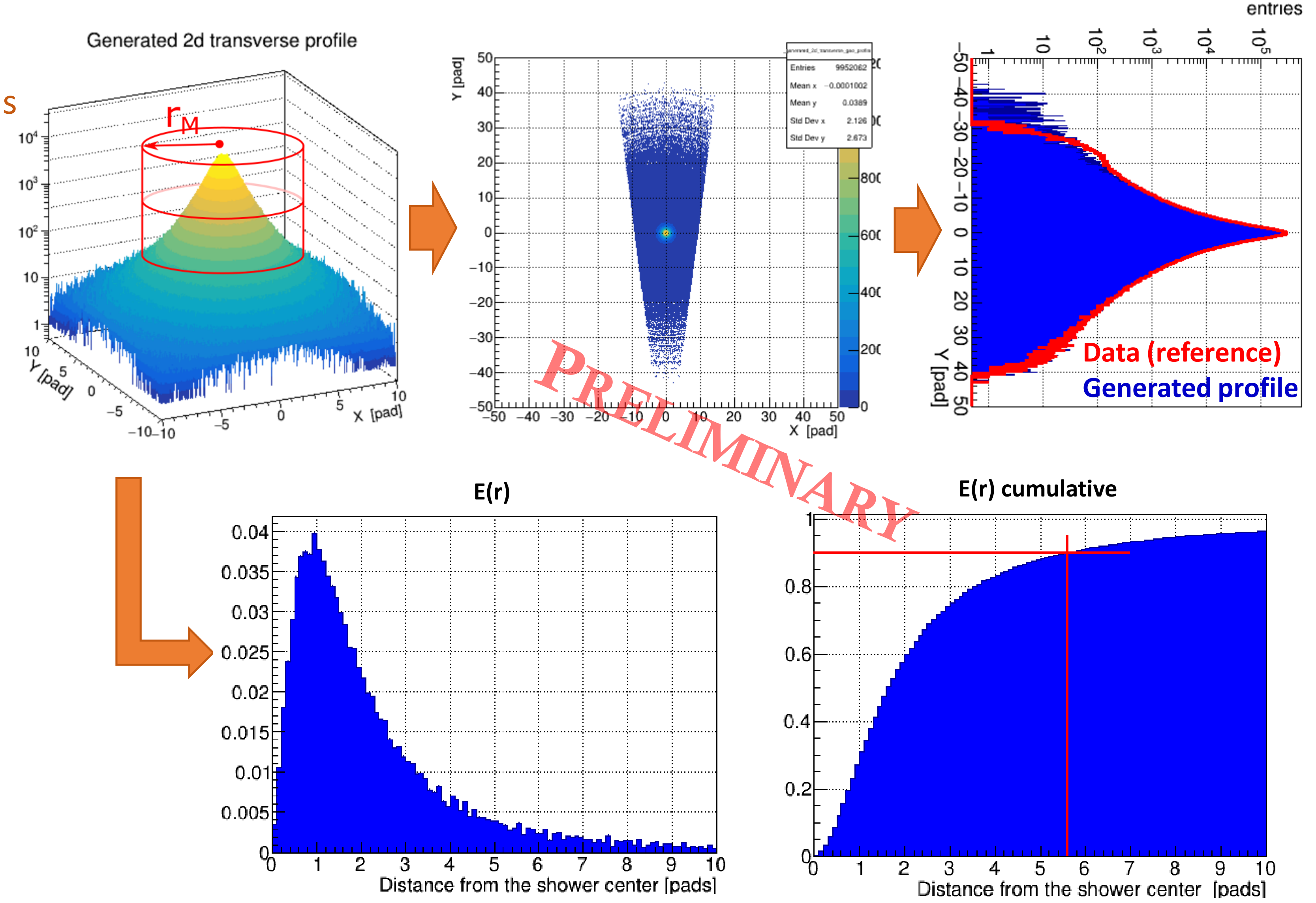
2020 Testbeam: Results – Shower Profile

- By merging data from different setup configuration, the average shower profile development over the whole stack can be obtained
- For 5 GeV electrons the majority of the deposition (>90%) caught within 15 detector layers (15 X_0)
- Based on the transverse energy profile integrated over the whole stack one can measure the effective Moliere radius for given detector configuration
- Comparison with a MC simulation in progress



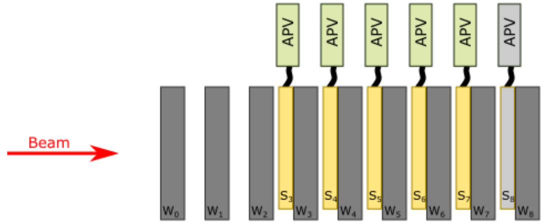
2020 Testbeam: Results – Moliere radius

- **Moliere Radius** - radius of a cylinder containing on average 90% of the shower's energy deposition
- Pad size in φ too large to directly measure 2D transverse profile
- Numerical searching for a 2D profile based on the measured radial transverse profile
- Having a 2D transverse profile one can get the function of the energy deposited at certain distance from the center of the shower: E(r)
- And obtain the Moliere radius as a value for which its cumulative = 0.9
- **For LUMICAL the effective Moliere radius has been estimated to be 5.6 pads → 10.1 mm**



CROSSCHECK WITH THE PREVIOUSLY REPORTED RESULTS

2016 Test Beam:



- Compact calorimeter geometry has been already measured during the 2016 beam test
- APV-based readout (FLAME readout not yet available)
- Much smaller stack – 5 active planes in the highest depositions region (3-7 X_0)
- Results published in: **„Performance and Molière radius measurements using a compact prototype of LumiCal in an electron test beam"**
  Eur. Phys. J. C **79,** 579 (2019).
  https://doi.org/10.1140/epjc/s10052-019-7077-9
- Effective Moliere radius (@5GeV):
  Data: 8.1 ± 0.1 (stat) ± 0.3 (syst) mm
  MC : 8.4 mm

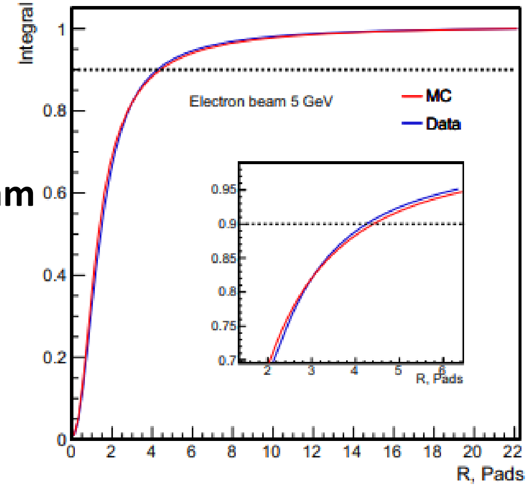
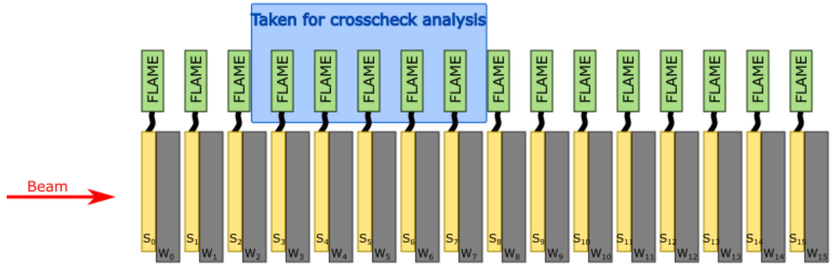
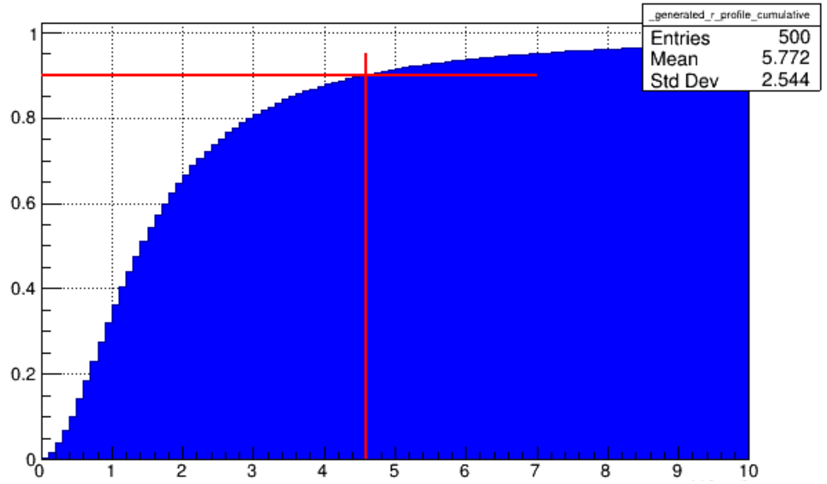


Fig. 22 The ratio of the integrals in Eq. (10) using $F_E(r)$ obtained from the fit, as a function of the radius R in units of the pad dimension (1.8 mm), for data (blue) and MC (red), for a 5 GeV electron beam. The insert shows an expanded view of the region $2 < R < 6$ pads

2020 Test Beam:



- Similar results expected from current data limited to the same active region
- The resulting effective Molier radius for this „limited setup" is 4.6 pads → **8.3 mm**



SUMMARY

- Prototype of **Compact LumiCal has been developed**
  3.5mm W absorber + 1mm sensor plane
- Dedicated **FLAME readout ASIC** together with FPGA back-end were developed and for the first time **tested on beam**
- Intense **2 week test beam** was performed in 2020
- First analysis of shower development gives very promising results
- **Effective Moliere radius** of the 15X_0 deep stack estimated to be **10.1mm**

OUTLOOK:

- **Monte Carlo** simulation in progress in order **to validate obtained results**
- Large part of collected **data still needs to be processed:**
  - other energies
  - tilt angles
  - different setups (APV readout / APV+FLAME)
- **Preparation for next testbeam**