FCAL COLLABORATION: DEVELOPMENTS AND OUTLOOK

The Asian Linear Collider Workshop

Borysova Maryna

Kiev Institute for Nuclear Research

On behalf of the FCAL collaboration

28 May 2018, Fukuoka, Japan

OUTLINE

- Introduction
- Design and assembly of the thin LumiCal module
- The results of Test beam 2016
- In preparation for Test beam 2019
- Summary & Outlook

- Readout with SRS and APV-25
- 2016 Test-beam setup
- Calibration of the compact LumiCal prototype
- LumiCal energy response
- Position reconstruction
- Electromagnetic shower study in longitudinal direction
- Electromagnetic shower study in transverse plane
- $R_M(E)$ dependence

- New readout ASIC for LumiCal -FLAME
- BeamCal ASIC
- New tungsten plates
- Gallium Arsenide & Si Diode sensors for BeamCal

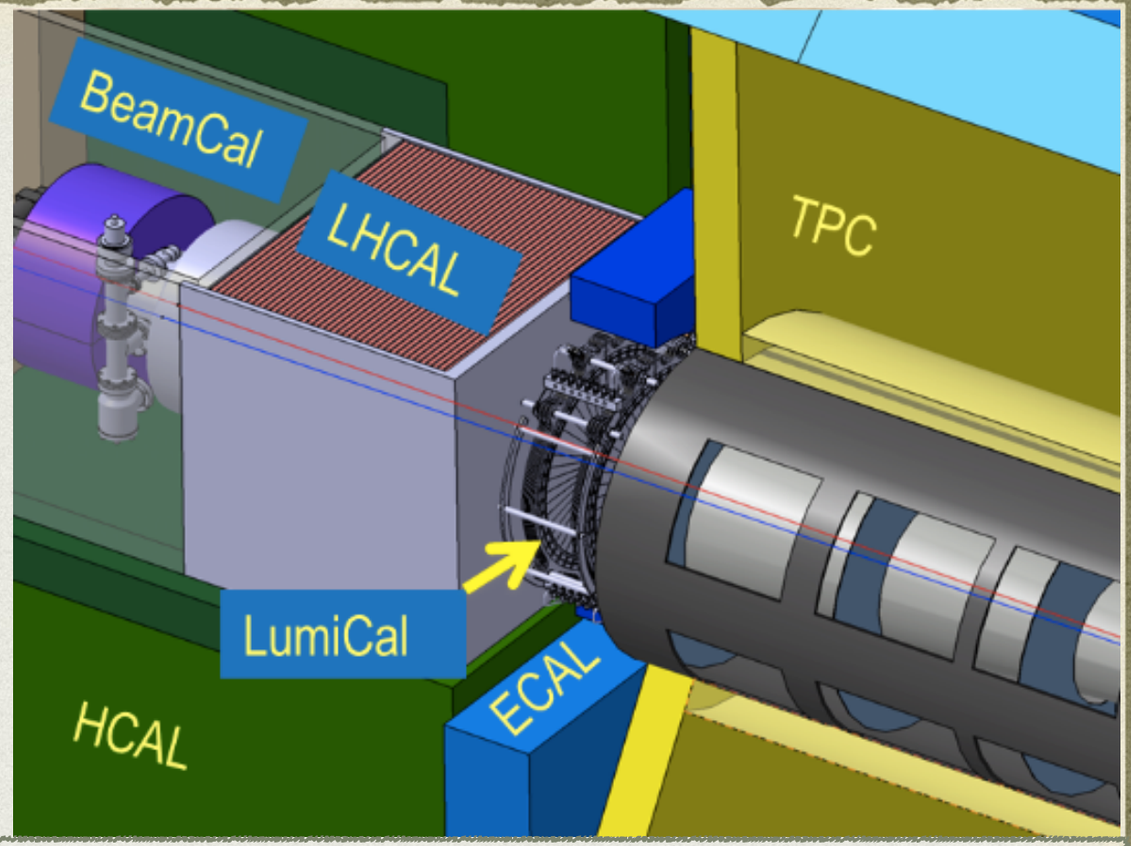
FCAL DETECTORS IN LC EXPERIMENT

LumiCal

- Precise integrated luminosity measurements;
- Extend a calorimetric coverage to small polar angles. Important for physics analysis.

Design

- electromagnetic sampling calorimeter;
- 30 (40 for CLIC) layers of 3.5 mm thick tungsten plates with 1 mm gap for silicon sensors;
- symmetrically on both sides at ~2.5m from the interaction point.



BeamCal

- Complete the coverage of e.m. calorimetry down to very small angles to reject SM backgrounds w/ far-forward activity;
- Instant luminosity measurements;
- Provide information for beam tuning;

- similar construction, with tungsten absorber but radiation hard sensors (GaAs, CVD diamond)

LHCAL

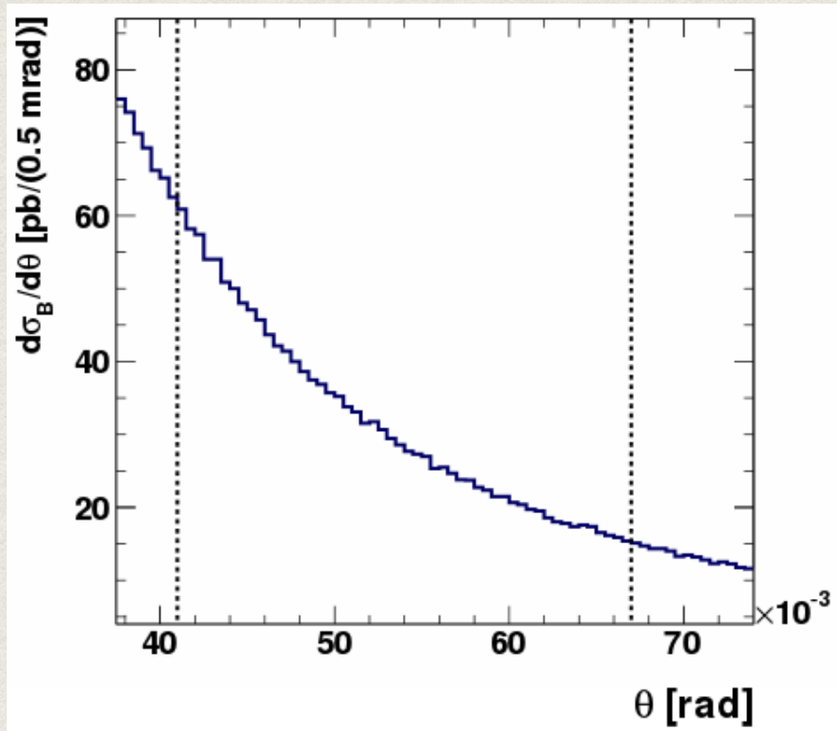
- extends the coverage of HCAL;
  - design is being optimized in simulation studies.

LUMINOSITY MEASUREMENT

- The luminosity can be measured by counting number N_B of Bhabha events in a certain polar angle (θ) range of the scattered electron.

$$L = \frac{N_B}{\sigma_B}$$

σ_B – integral of the differential cross section over the same θ range.



LumiCal fiducial volume: $41 < \theta < 67$ mrad

The cross section of the Bhabha process can be precisely calculated.

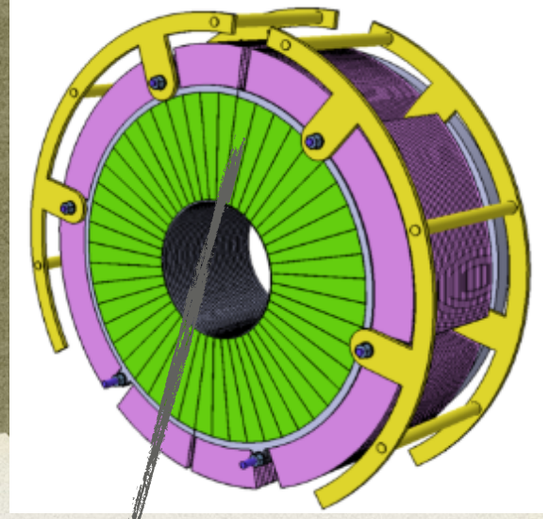
In leading order:

$$\frac{d\sigma_B}{d\theta} = \frac{2\pi\alpha_{em}^2}{s}\frac{\sin\theta}{\sin^4(\theta/2)} \approx \frac{32\pi\alpha_{em}^2}{s}\frac{1}{\theta^3},$$

the approximation holds at small θ.

α is the fine-structure constant, s - center-of-mass energy squared.

LUMICAL SILICON SENSOR



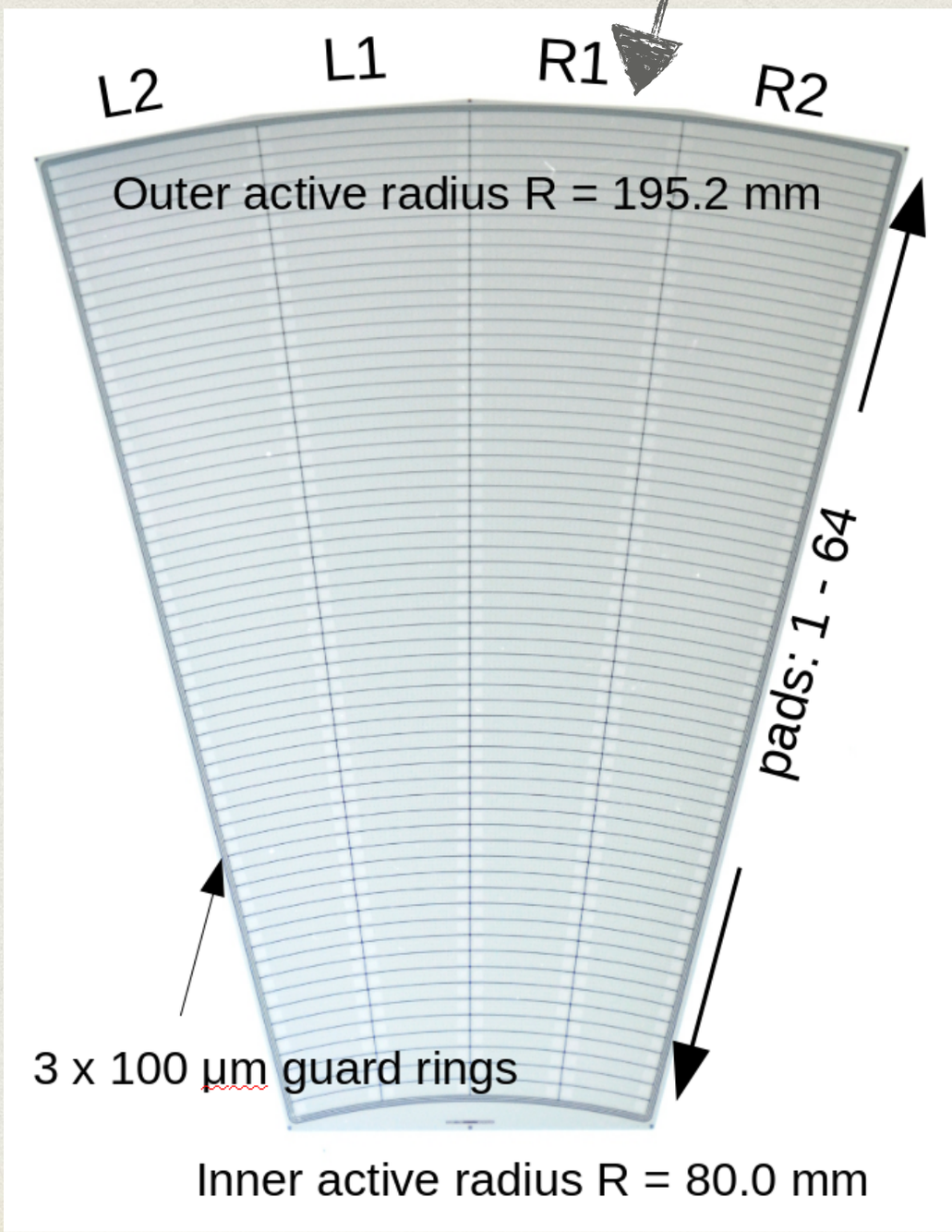
LumiCal is a Si-W electromagnetic sampling calorimeter

- Compact design provides
  - small Moliere radius;
  - bigger fiducial volume;
  - better HE particle detection on top of background.

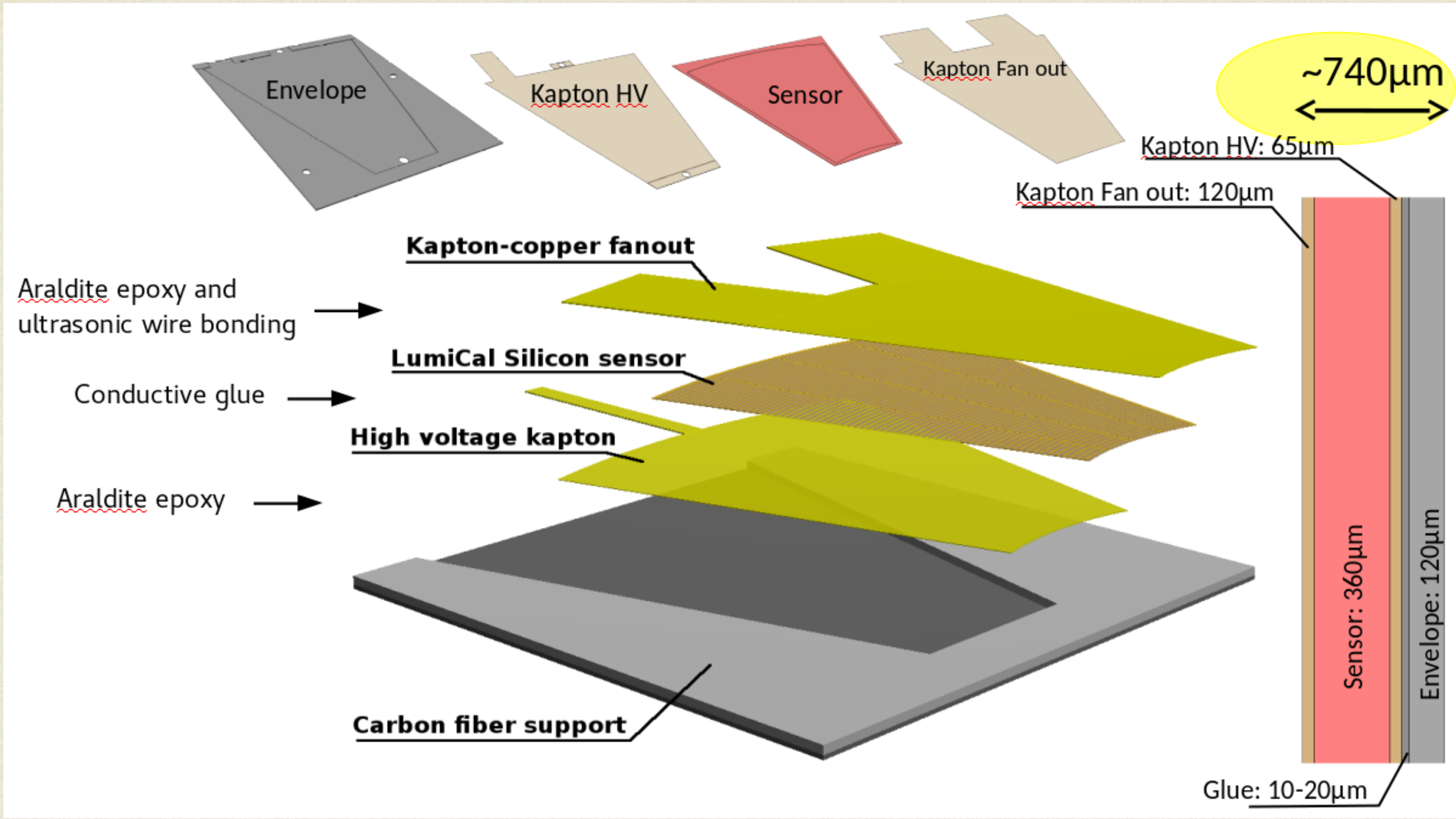
- Challenging requirements on geometrical compactness

Silicon pad sensor prototype is designed for ILD and CLIC; produced by Hamamatsu

- thickness 320 μm
- DC coupled with readout electronics
- p+ implants in n-type bulk
- 64 radial pads, pitch 1.8 mm
- 4 azimuthal sectors in one tile, each 7.5°
- 12 tiles make full azimuthal coverage



LUMICAL MODULE ASSEMBLY



READOUT WITH SRS AND APV-25

Temporary readout solution:

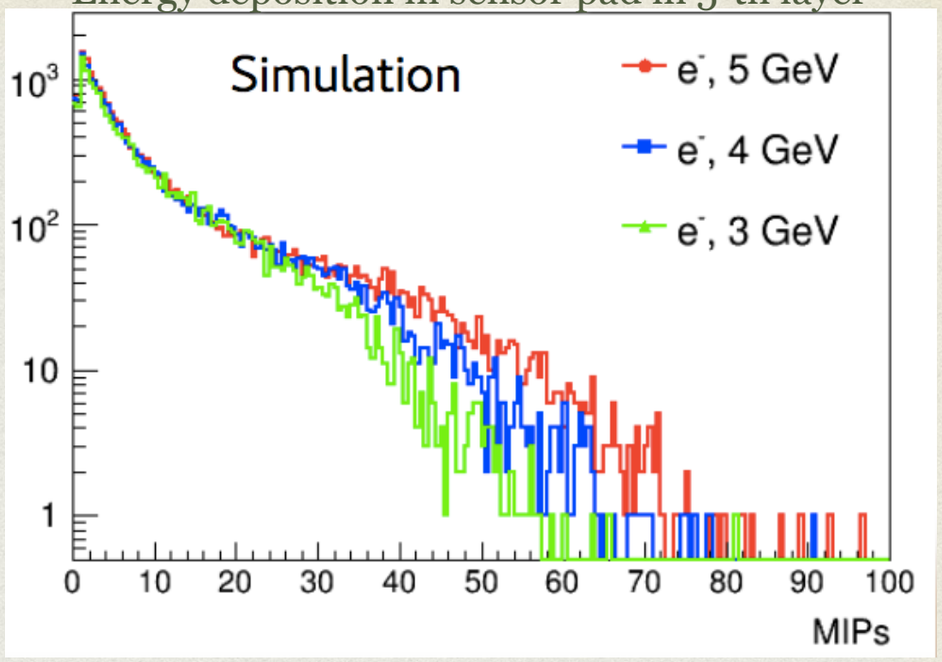
- Front-end chip APV25:
- Designed for CMS silicon microstrip detectors; used for Belle II SVT;
- 128 channels;
- Shaping time: 50 ns;
- Supports both signal polarities;
- Sampling frequency 40 MHz;
- Supported by SRS;
- Available at CERN stock.

The APV-25 range in case of LumiCals sensor: ~ 8 MIPs

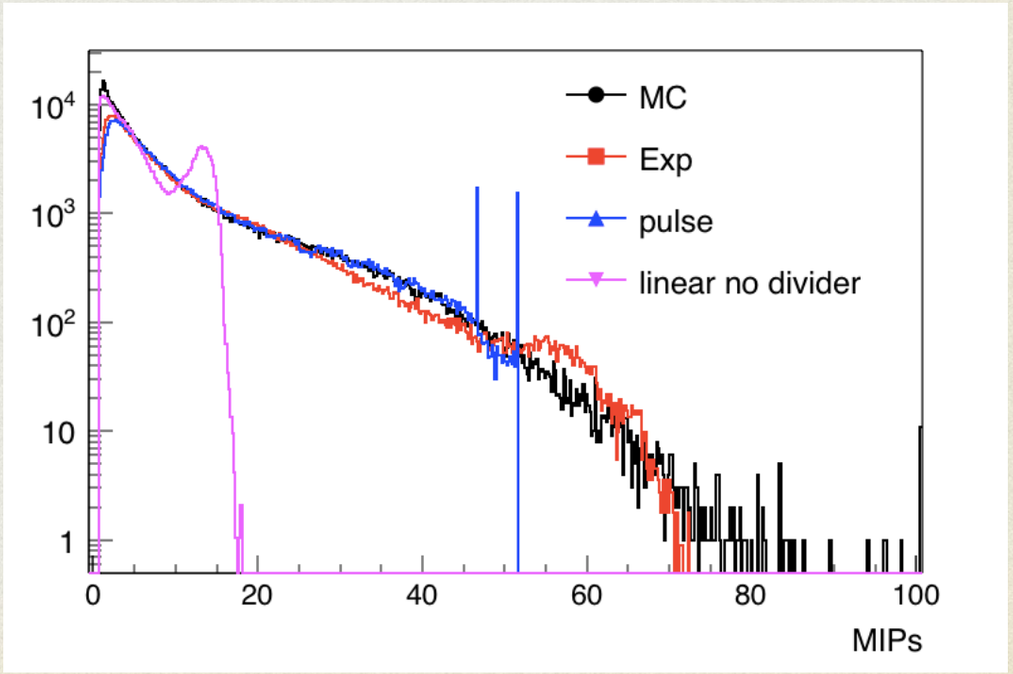
Additional board of "**capacitive charge divider**" was designed and produced to reduce affect of saturation.

- Few per cent are above the saturation level when running w/ charge divider;
- The simulated distribution is well reproduced by the data calibrated based on pulse measurements;
- Small signals are well reproduced by readout w/o charge divider.

Energy deposition in sensor pad in 5-th layer

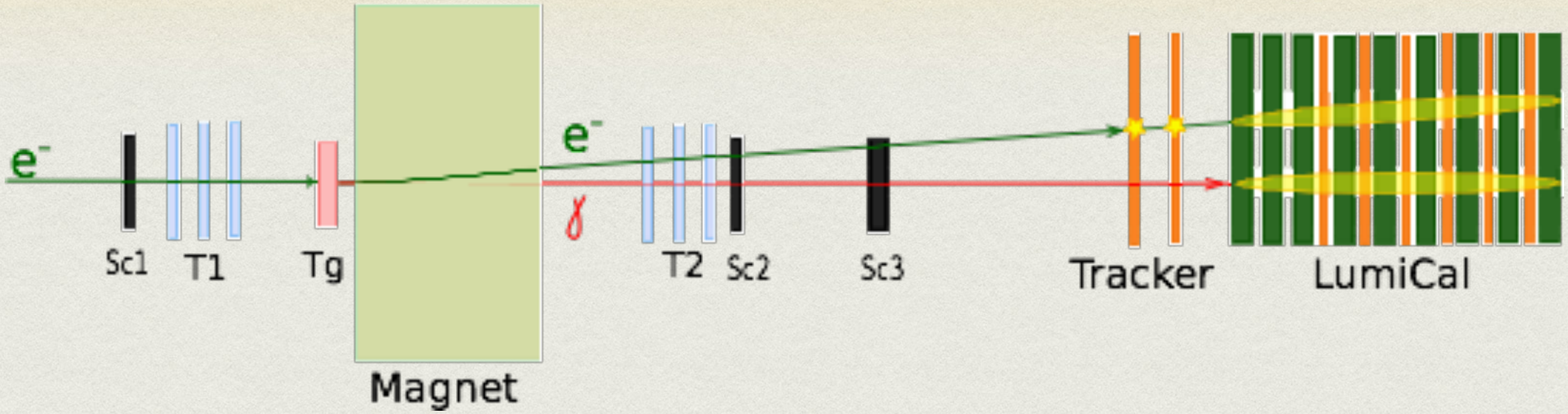


Distribution of the energy deposited in pad of active layer 5 (after ~5X0)



THE RESULTS OF TEST BEAM 2016

2016 TEST BEAM CONFIGURATION



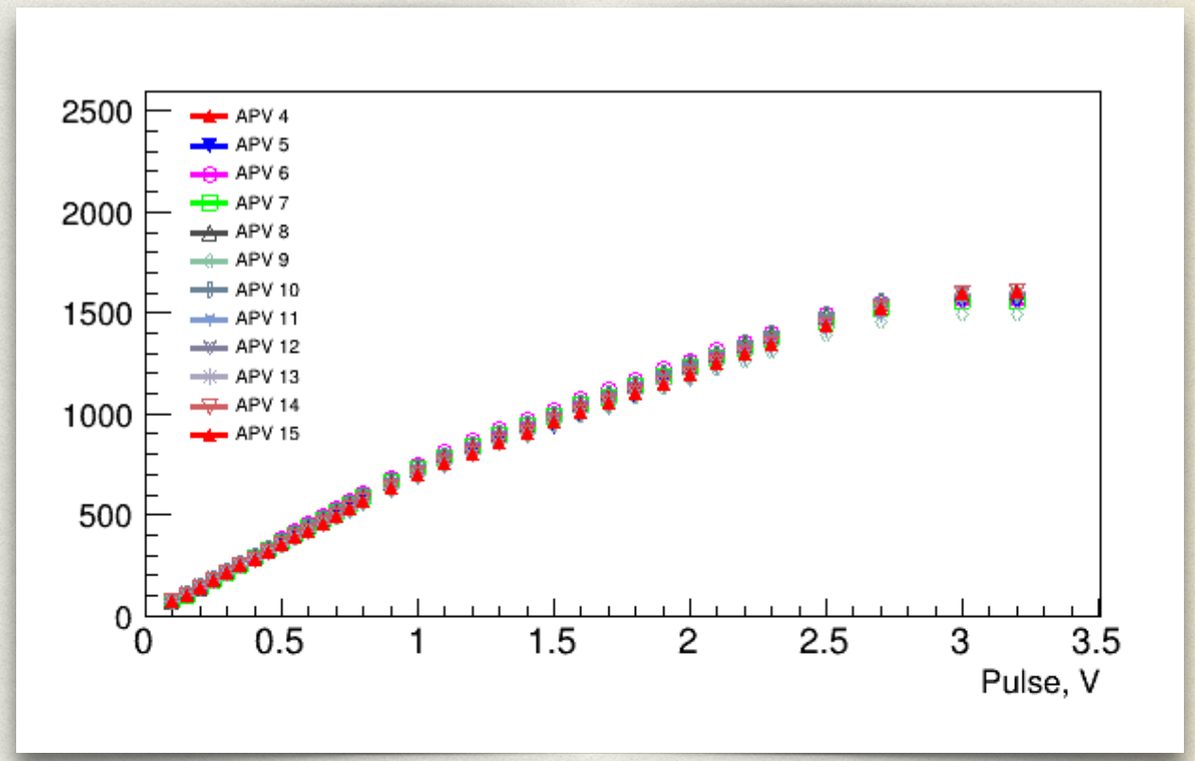
Sc1, Sc2 and Sc3 are scintillator counters; T1, T2 – three pixel detector planes; Tg – the copper target for bremsstrahlung photon production.

- 8 (256 channels) thin LumiCal modules (> 2k channels);
- 2 - used as a tracker / tagger for e/γ separation;
- 6 - in calorimeter (3 - 8 X0) installed in 1 mm gaps between absorbers;
- DAQ : SRS system, designed by RD51 collaboration;
- EUDET / AIDA beam Telescope : 6 planes with MIMOSA chip;

DESY test beam facilities:
- Electron beam 1 – 5 GeV;
- Dipole magnet 1 – 13 kGs;

APV25 CALIBRATION WITH EXTERNAL PULSE

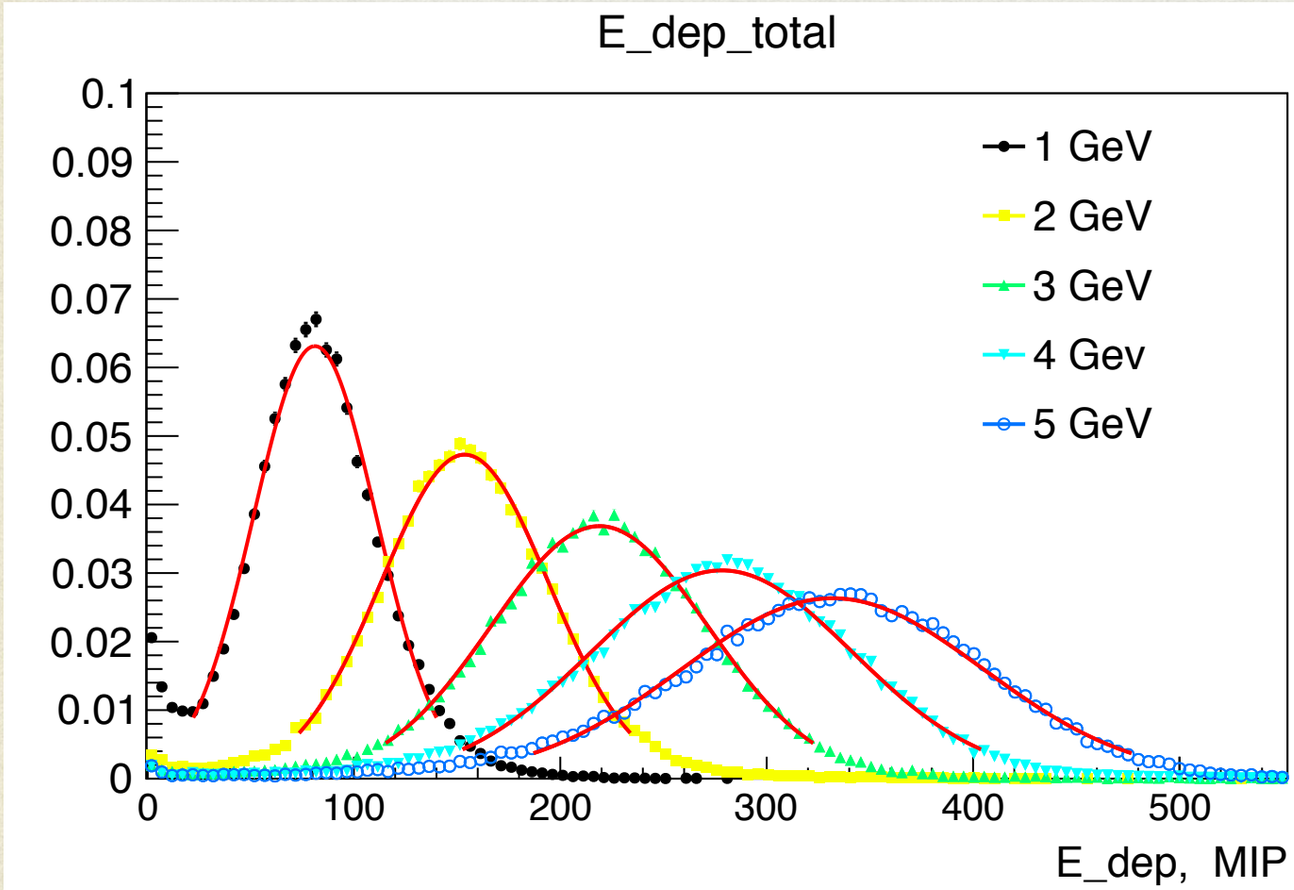
- APV25 is known to be linear up to about 4 MIPs.
- Different functions can be used to approximate non linear response;
- Direct measurements with external pulse performed separately for each APV.

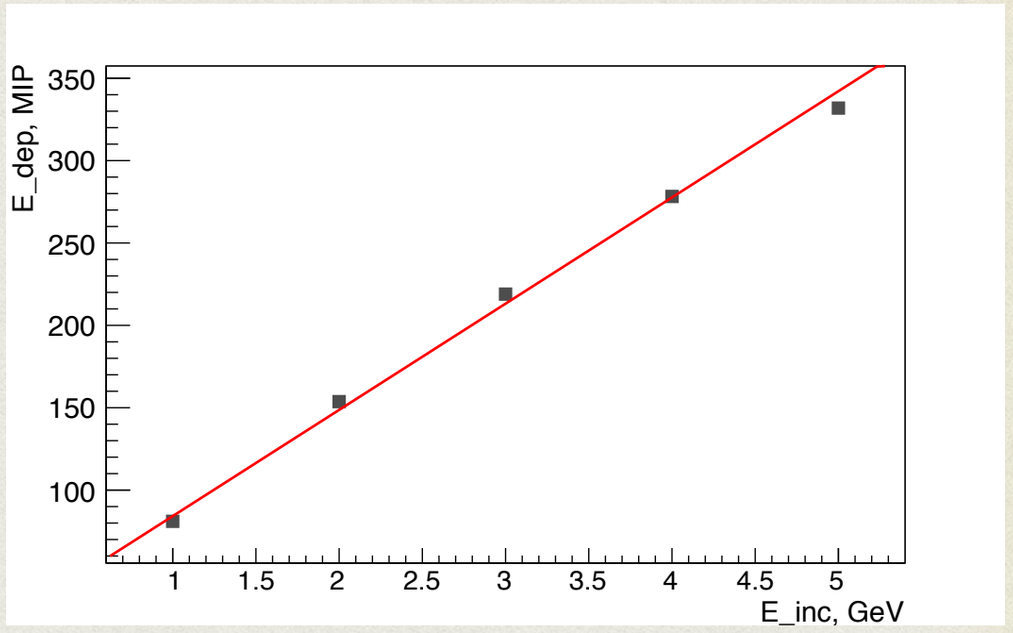


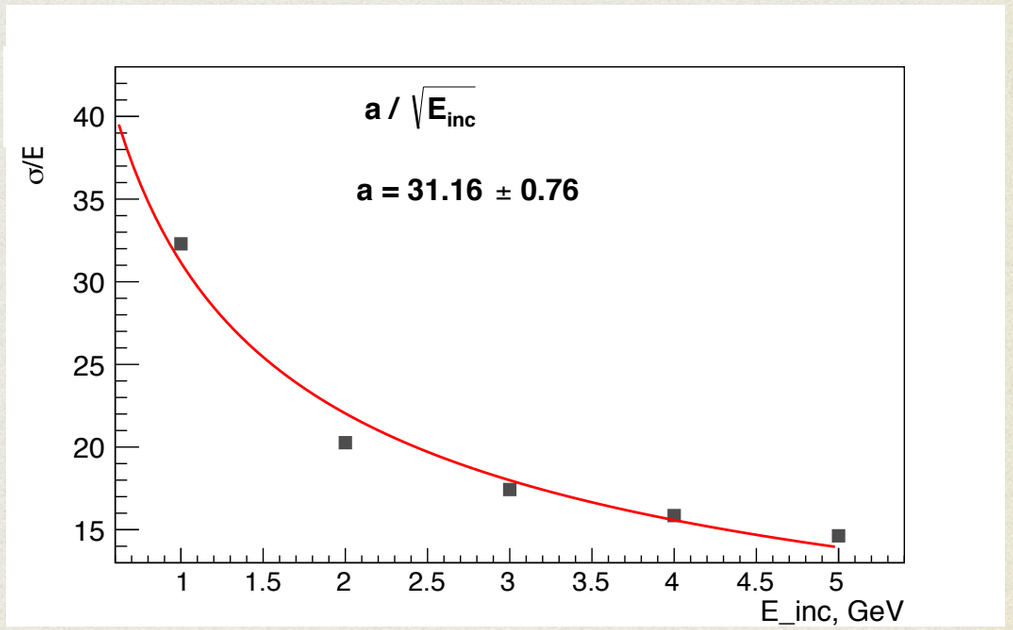
Calibration scale comes from the normalization of Data to MC in 2nd layer of calorimeter ($4X_0$)

LUMICAL ENERGY RESPONSE

LumiCal response to electron beam with E= 1-5 GeV when running with charge divider

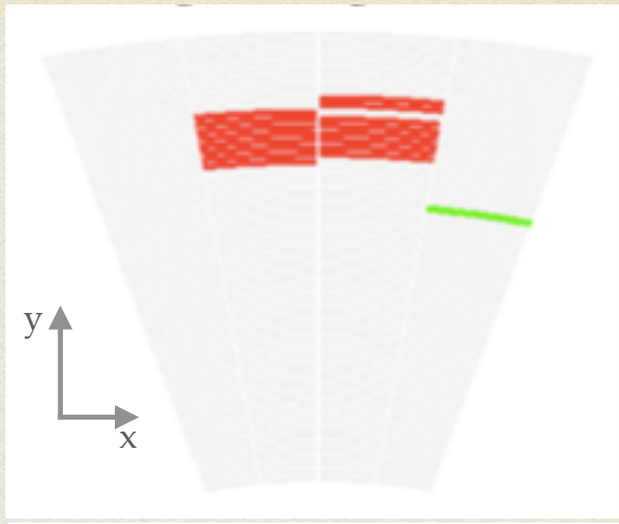


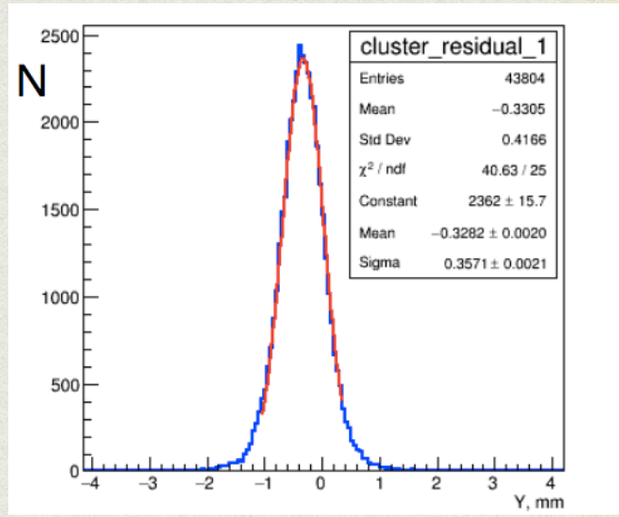




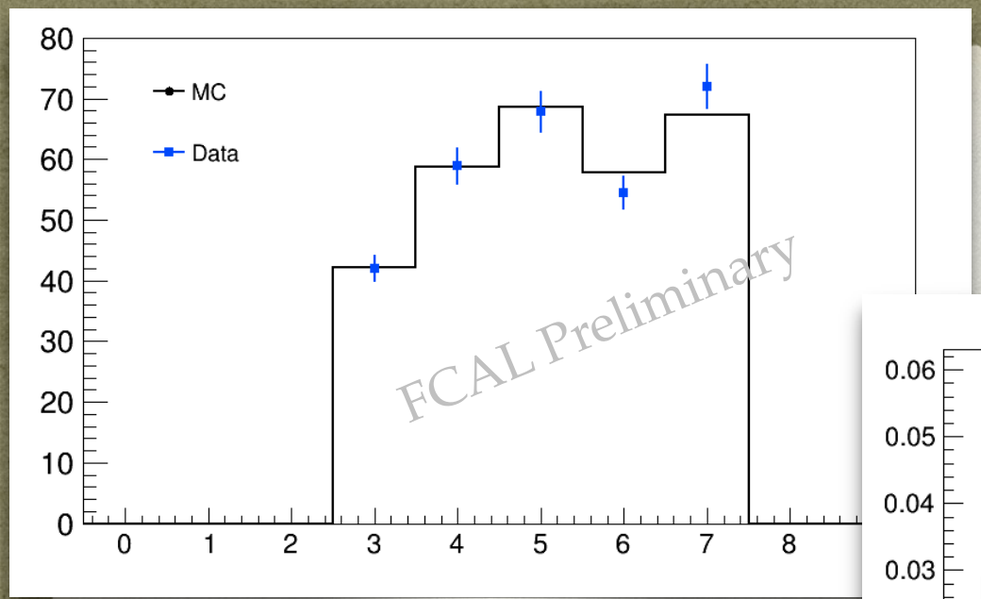
POSITION RECONSTRUCTION

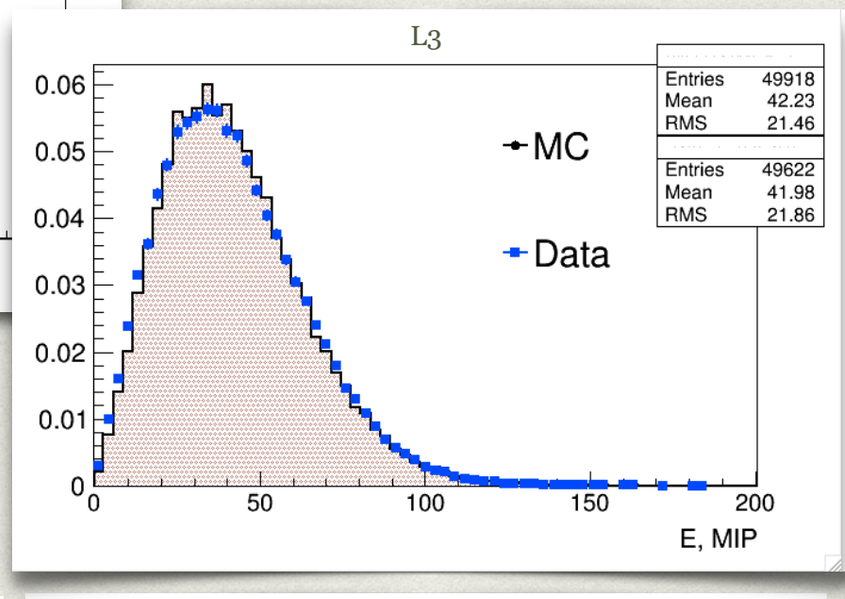
- **Clustering algorithm "linked neighbors"** - all layers together
  - Looks for the closest neighbors (with distance no more then 1 pad in any direction) and then collects them to the cluster
- **Log weighting** for position reconstruction is in *(x,y), w/ const=3.4*
- Particle *y* position within 20% of the central region of the pad **(0.36 *mm*)**
- Selection of cluster position is between **40<pad<50**
- For Longitudinal Shower removed bad pads in L6 Sector 1, Pads 41, 44, 45, 49.

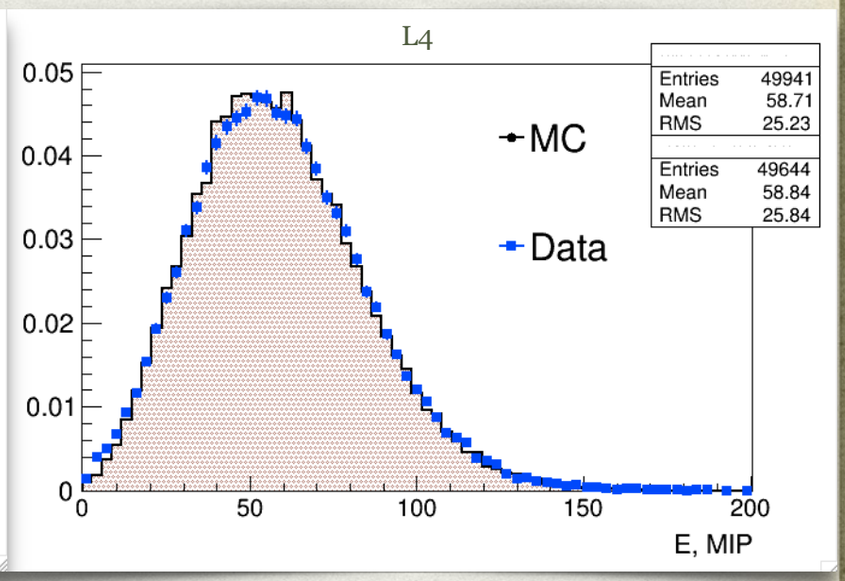


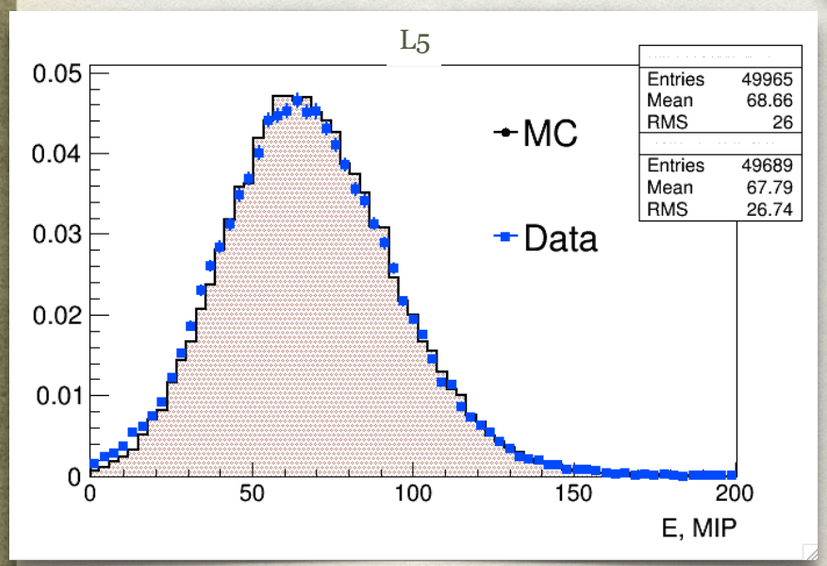


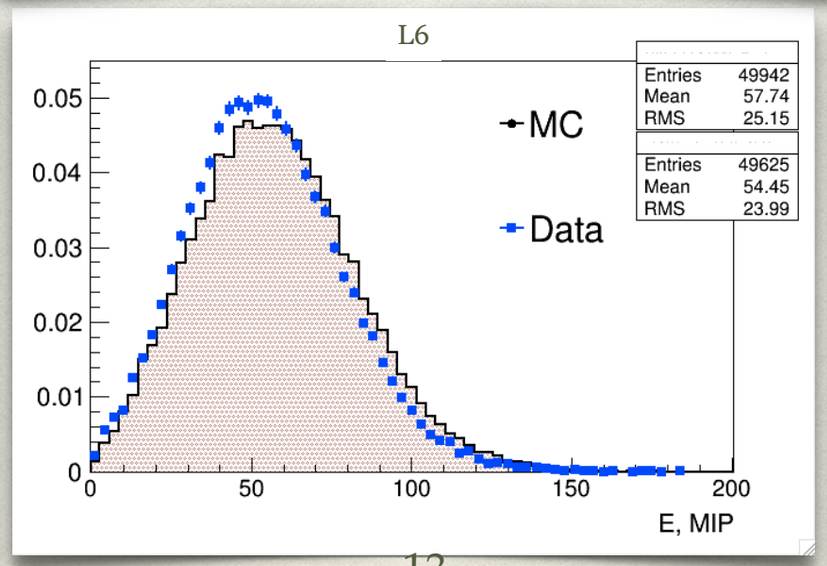
DEPOSITED ENERGY IN EACH LAYER

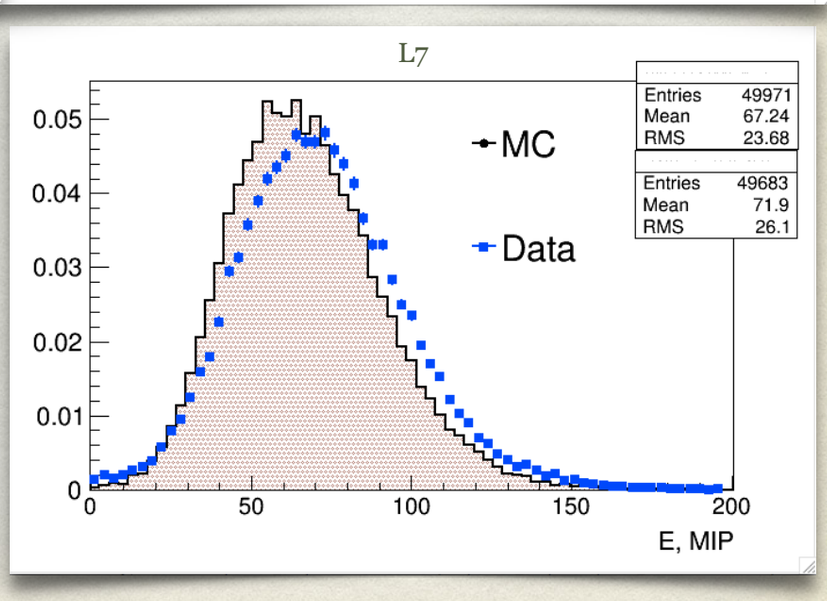












SHOWER STUDY IN TRANSVERSE PLANE

The sensor geometry doesn't allow direct measuring of transverse shower development

Average distribution of deposited energy in transverse plane:

$$F_E(r) = A_C e^{-\left(\frac{r}{R_C}\right)^2} + A_T \frac{2r^\alpha R_T^2}{(r^2 + R_T^2)^2},$$

r – the distance from the shower center;
A_C, A_T, R_C, R_T, α – fit parameters.

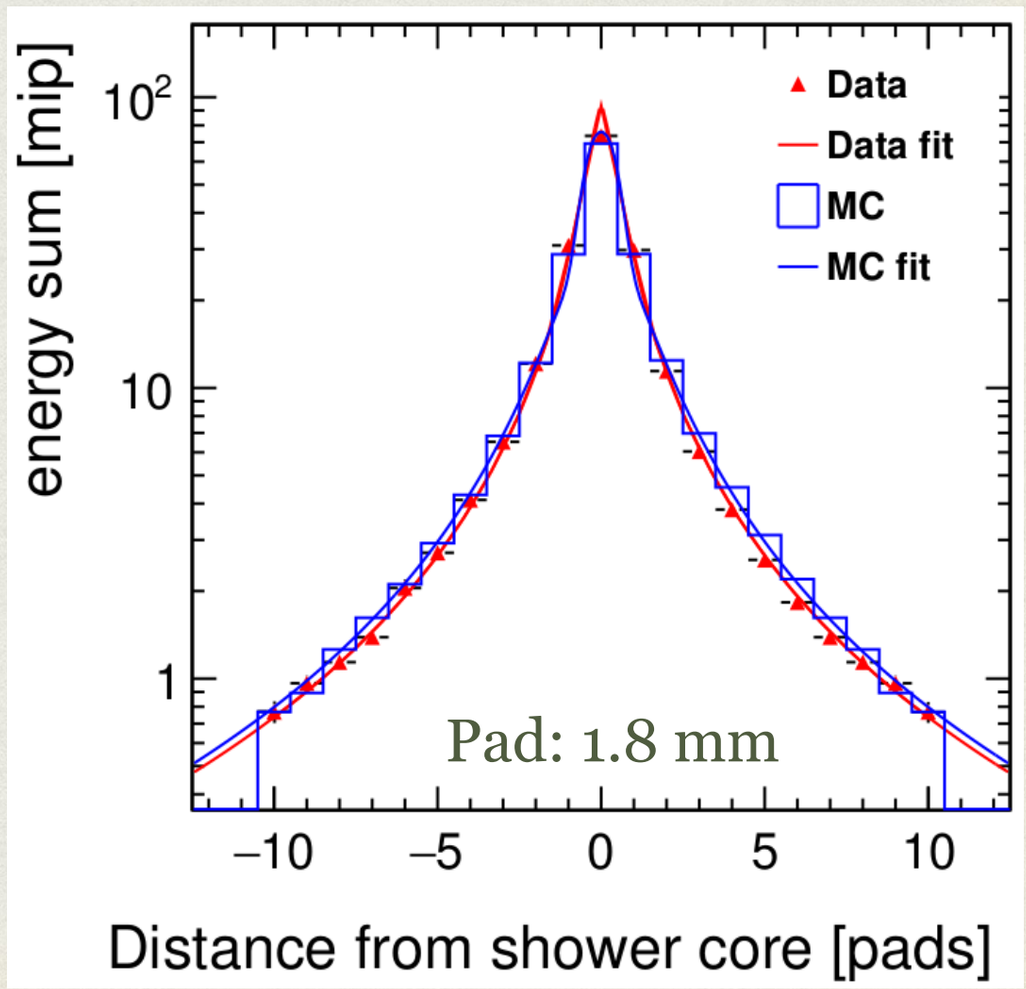
The fitting range corresponds to the area connected to readout.
Fit parameters are found by fitting to MC and data.

Molière radius R_M can be found from the equation:

$$0.9 = \int_0^{2\pi} d\varphi \int_0^{R_M} F_E(r) r dr$$

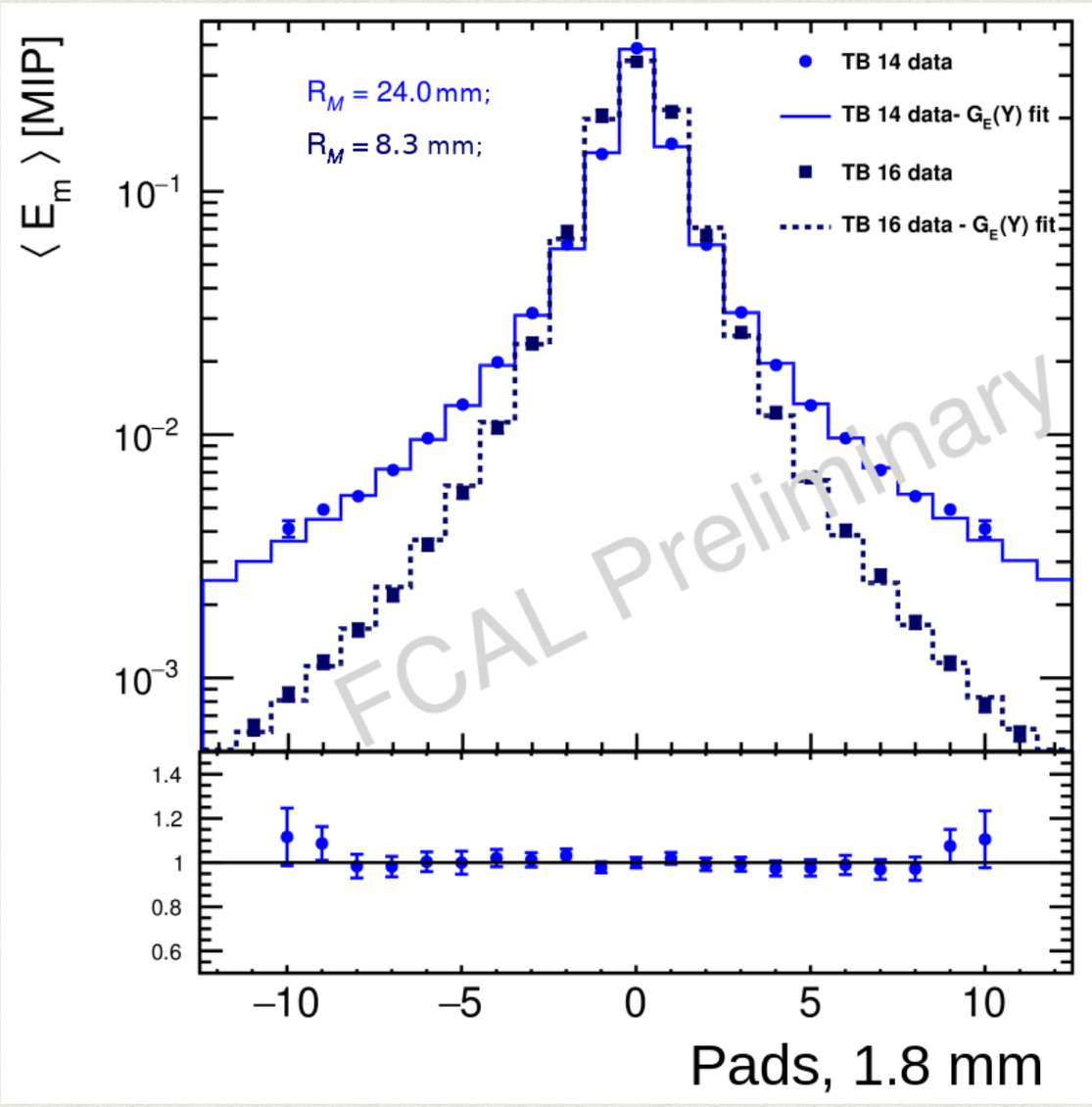
Procedure was developed for 2014 beam test of LumiCal prototype at CERN (PS, 5 GeV e- beam).
Result is

R_M =24.0 ± 0.6(stat.) ± 1.5(syst.) mm
(arXiv:1705.03885)

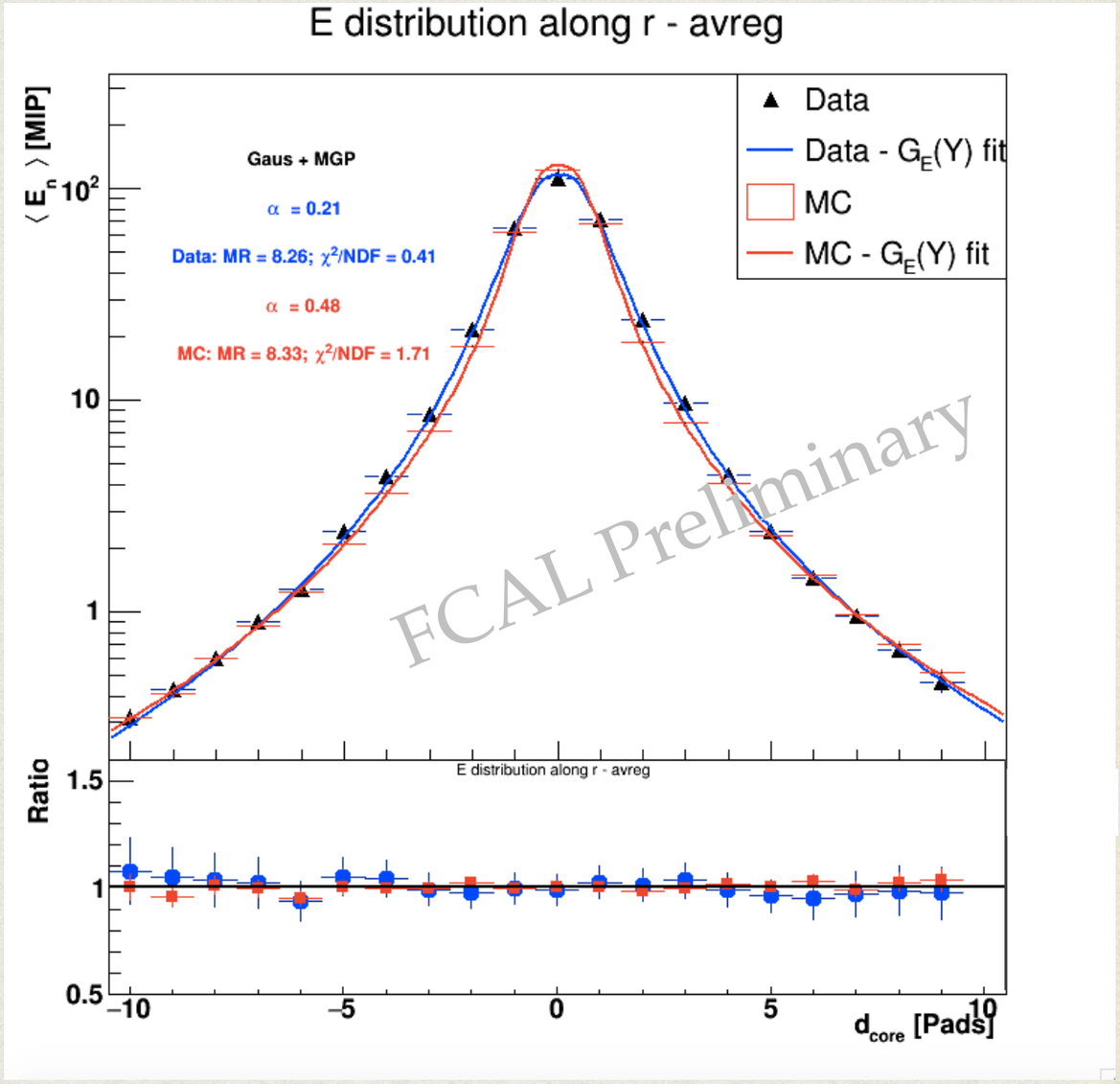


FITTING & MOLIÈRE RADIUS CALCULATION FOR 5GEV DATA

TB2014 vs TB2016

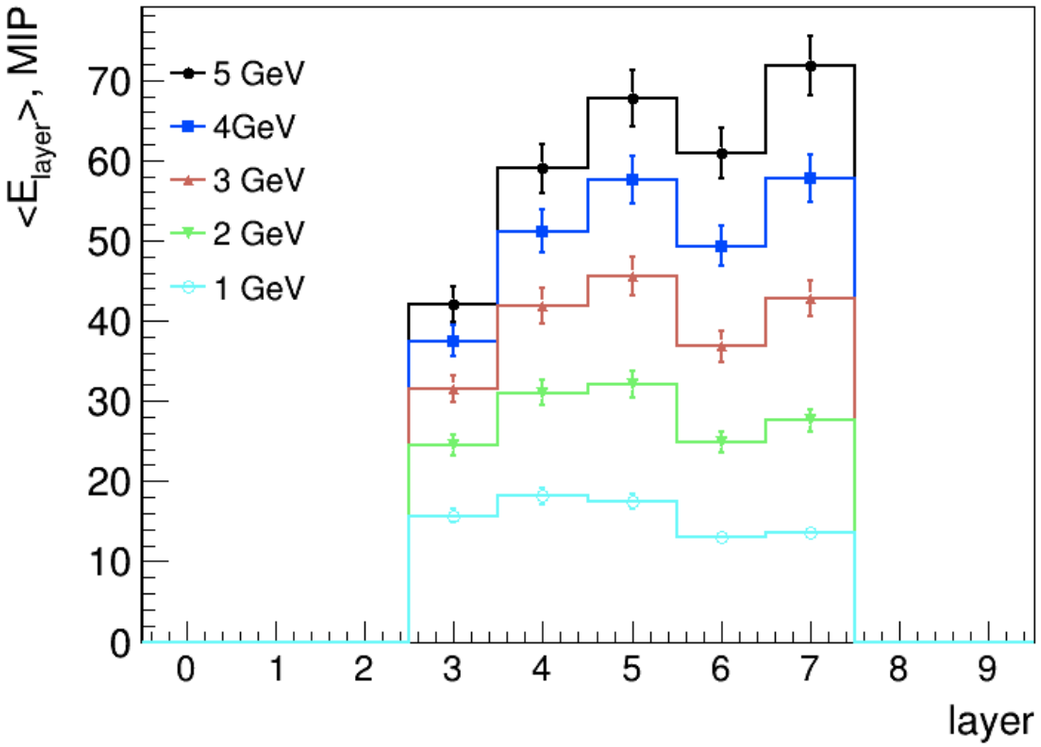


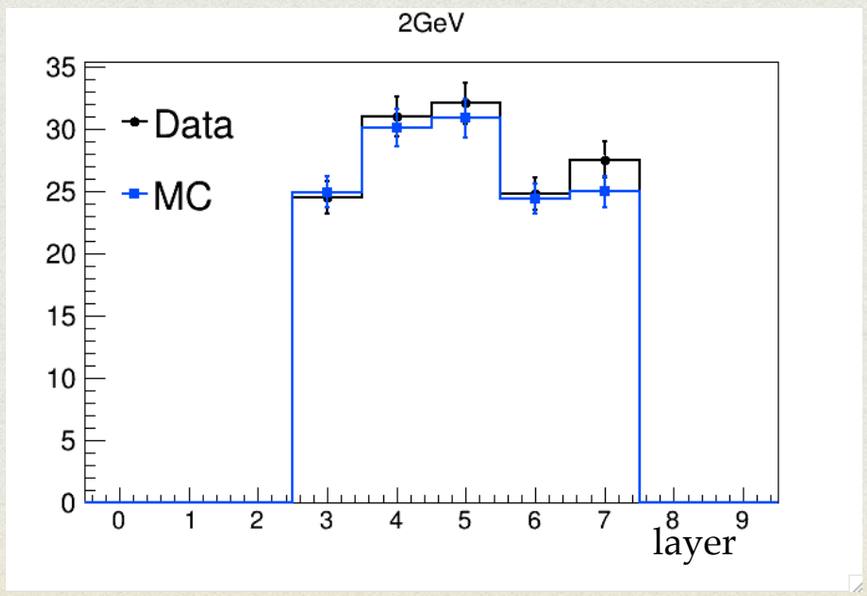
TB2016: DATA vs MC

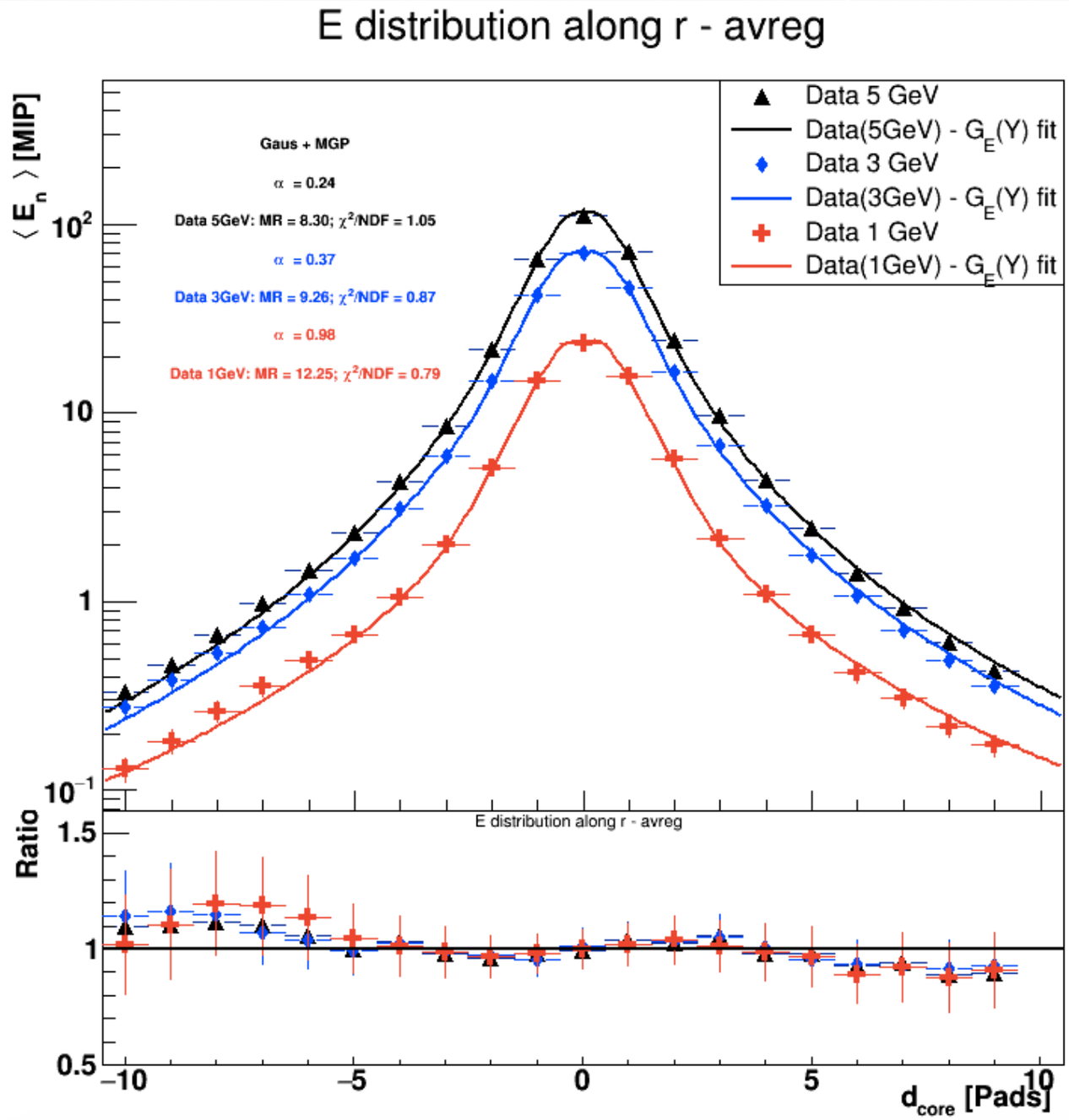


SHOWER DEVELOPMENT FOR DIFFERENT BEAM ENERGIES

LONGITUDINAL & TRANSVERSE PROFILES

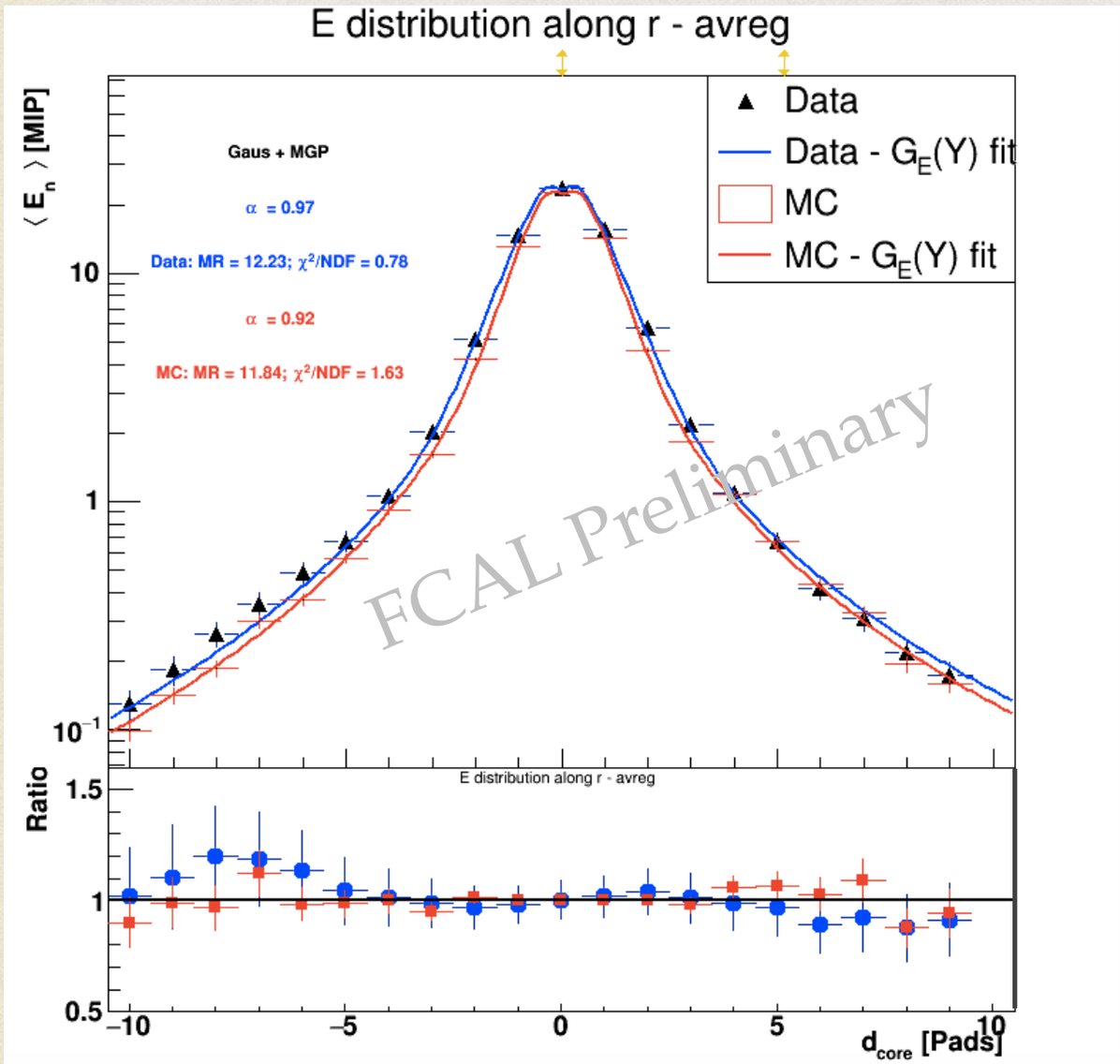




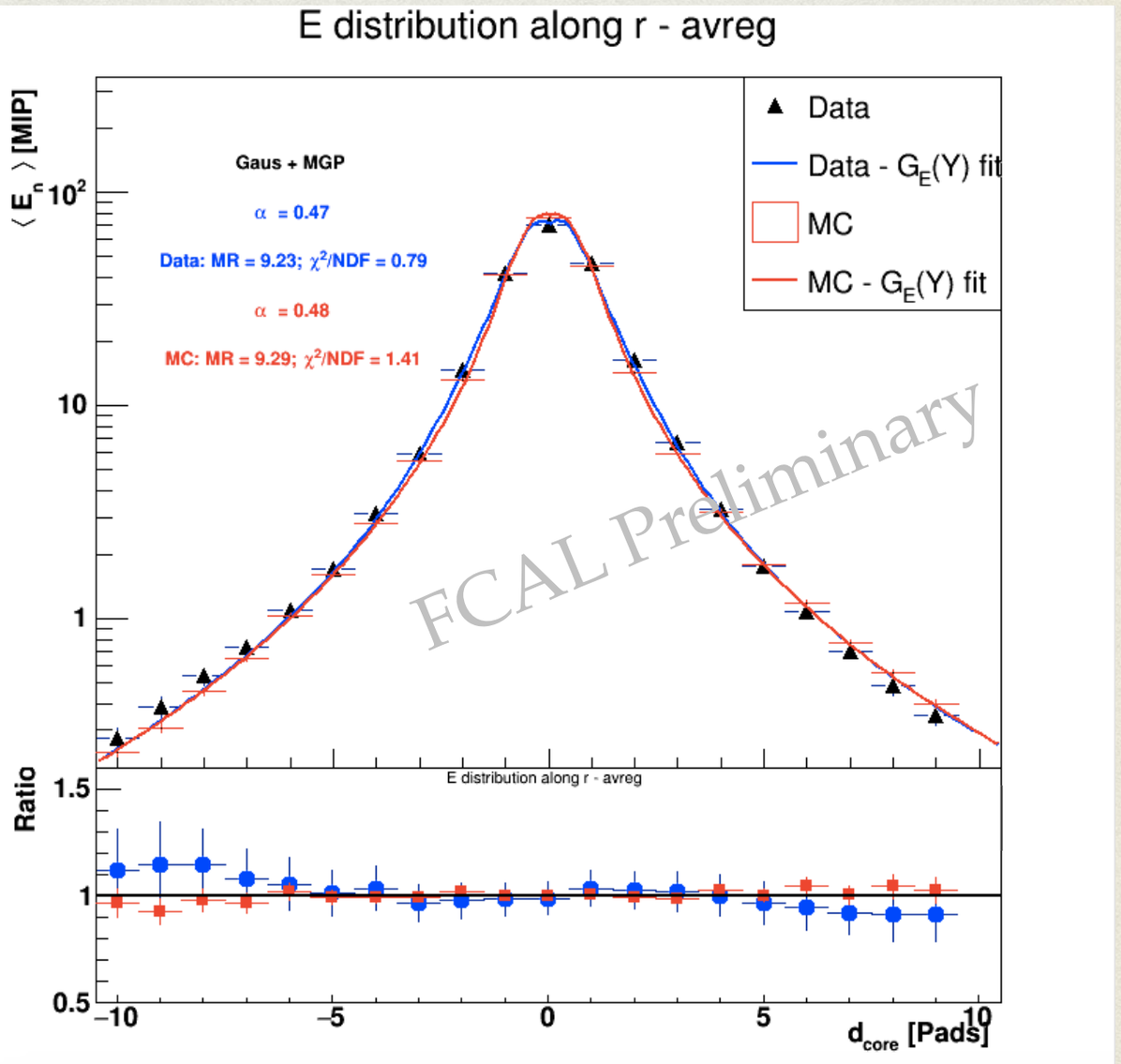


FITTING & $R_{\mathcal{M}}$ CALCULATION FOR 1 &3 GEV ELECTRONS W/ MC COMPARISON

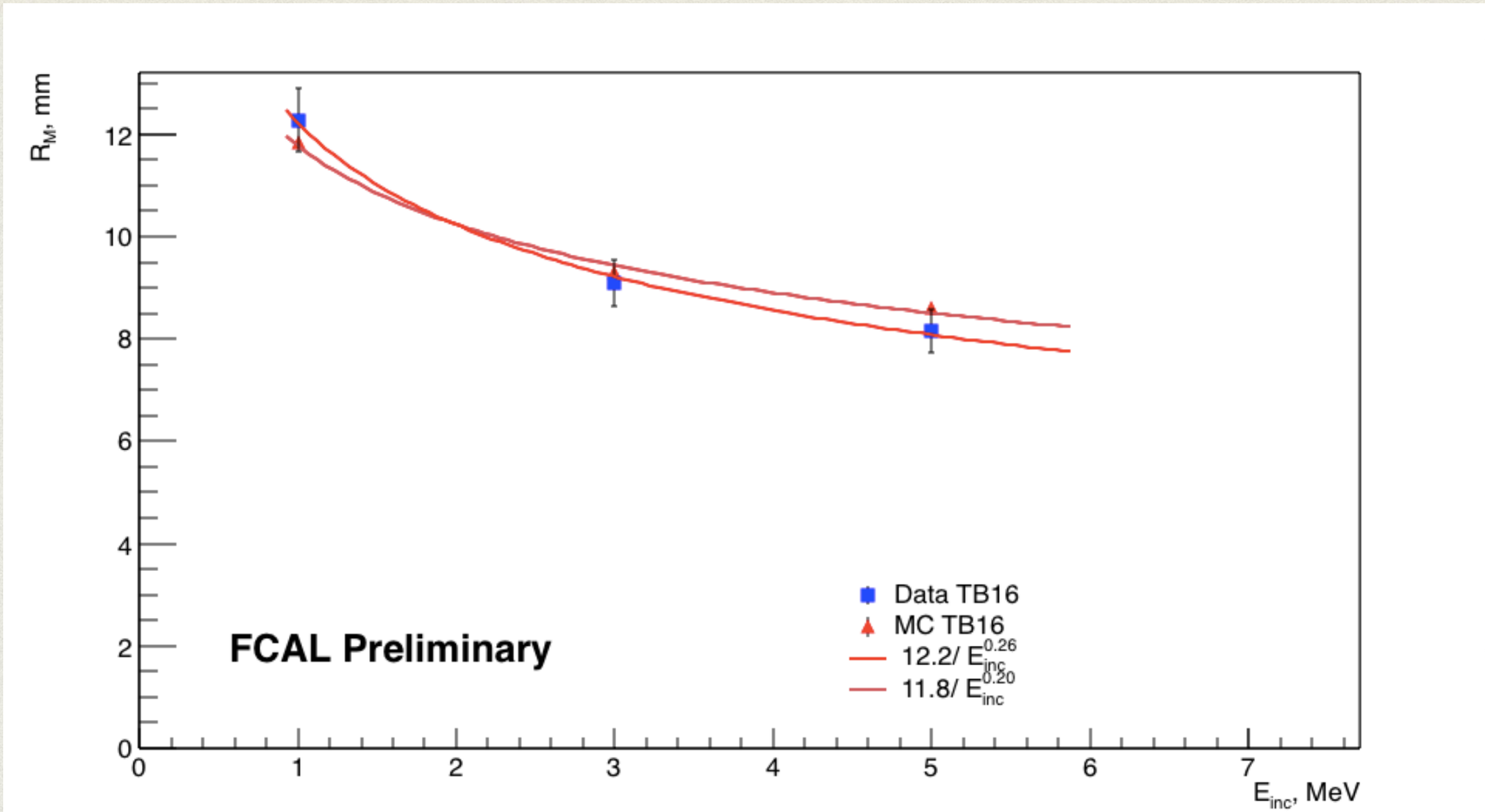
1 GeV



3 GeV



$R_{\mathcal{M}}$ (E) DEPENDENCE



The results of $R_{\mathcal{M}}$(E) dependence show slight dependence on energy which could be attributed to the fact that for higher energies smaller fraction of the shower is deposited in calorimeter with only 6 working layers

IN PREPARATION FOR TEST BEAM 2019

NEW READOUT ASIC FOR LUMICAL -FLAME

FcaL Asic for Multiplane rEadout ASIC architecture (Krakow)

Complete readout ASIC integrating whole functionality (biasing, calibration, etc.)

32 mix-mode channels comprising:

Variable gain front-end

10-bit SAR ADC

Data encapsulation and 8b/10b coding (according to the Xilinx MGT specification)

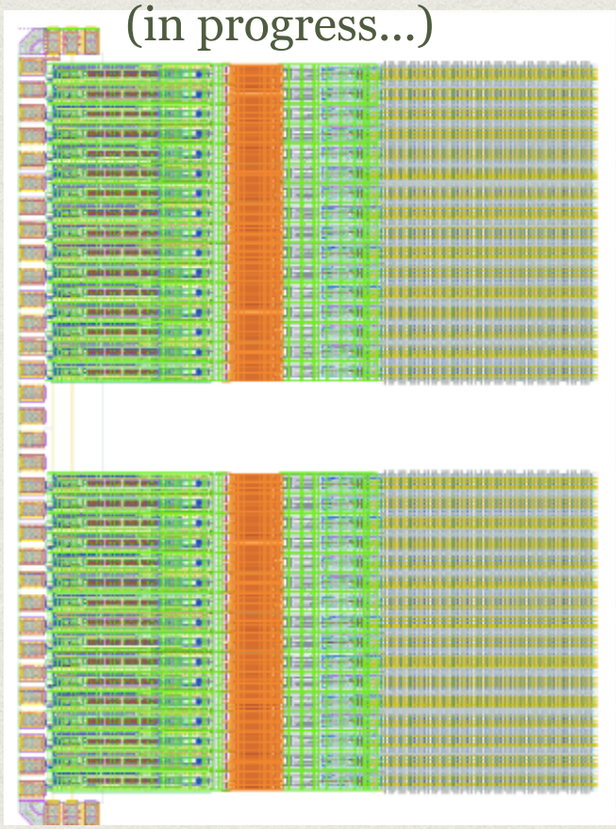
Multi-phase PLL based fast serializer (up to 8 Gbps)

Fast SST driver (up to 8 Gbps)

Mix-mode FLAME part:

~2.5 mm x~3.5 mm

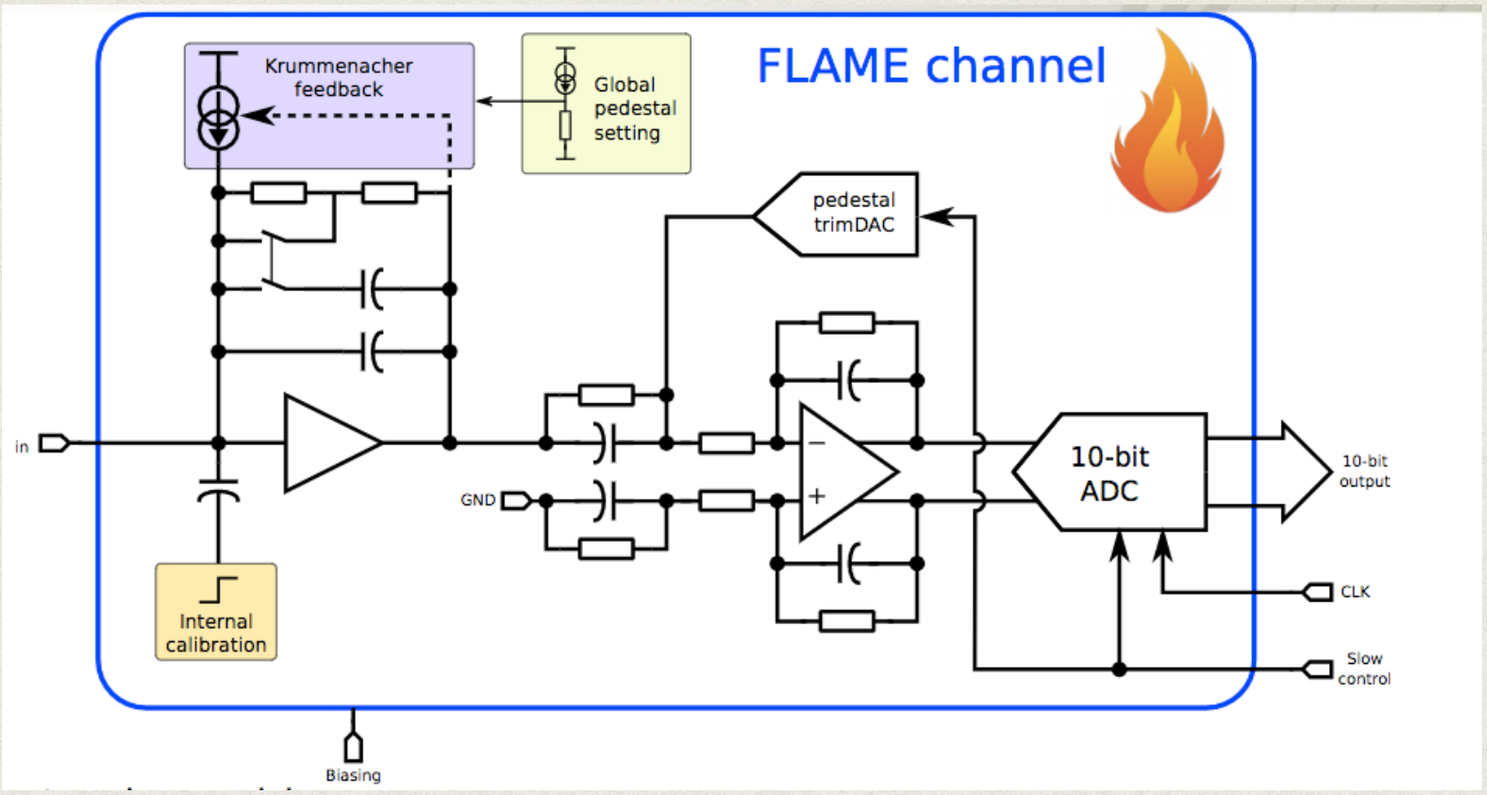
(in progress...)



Single FLAME channel: 2350 μm x 80 μm:

- Development of new readout ASIC for LumiCal – FLAME – is very advanced
- Mixed-mode channel done with very good performance, at least from simulations
- Mixed-mode and digital parts almost ready for final integration

FLAME – FCAL ASIC FOR MULTIPLANE READOUT CHANNEL ARCHITECTURE



Analogue front-end comprising:

- Charge sensitive preamplifier with variable gain:
- High gain – for test beam - up to 200 fC with MIP sensitivity
- Low gain – for shower development (up to 6 pC)
- Differential CR-RC shaper with 50ns peaking time

10-bit multichannel SAR ADC

- Sampling rate up to 50 MSps
- DNL, INL < 0.5 LSB
- ENOB > 9.5
- Ultra low power consumption (below 1 mW per channel at 40 MSps)

CURRENT DEVELOPMENT OF FINAL SERIALIZER

Development of serialization circuit is almost finished

- Post layout simulation shows very good performance
- Serializer works up to 8Gb/s – much higher than needed
- Very low power consumption was obtained: serializer ~4mW + SST driver ~10mW at typical 5.2Gb/s
- Expect to finish the design process within ~next month

BEAMCAL ASIC V3 DESIGN

BeamCal Readout ASIC development at Pontificia Universidad Católica de Chile.

Different sensor materials: GaAs, Si, Diamond, Sapphire;

Different sensor segmentation – input capacitance;

Different MIP response and maximum signal: 0.8 pC – 30 pC.

Specification	Value
Q_{in}	> 2.8 fC
ENC	< 1000 - 1500 e^- rms
Number of channels	8
Maximum input rate	1 / 554ns
Baseline restoration	1%

- Specs are intended for test beam purposes only
- Specs for calibration and data taking will be defined when the sensors are fixed
- This ASIC will be a preliminary proof of concept

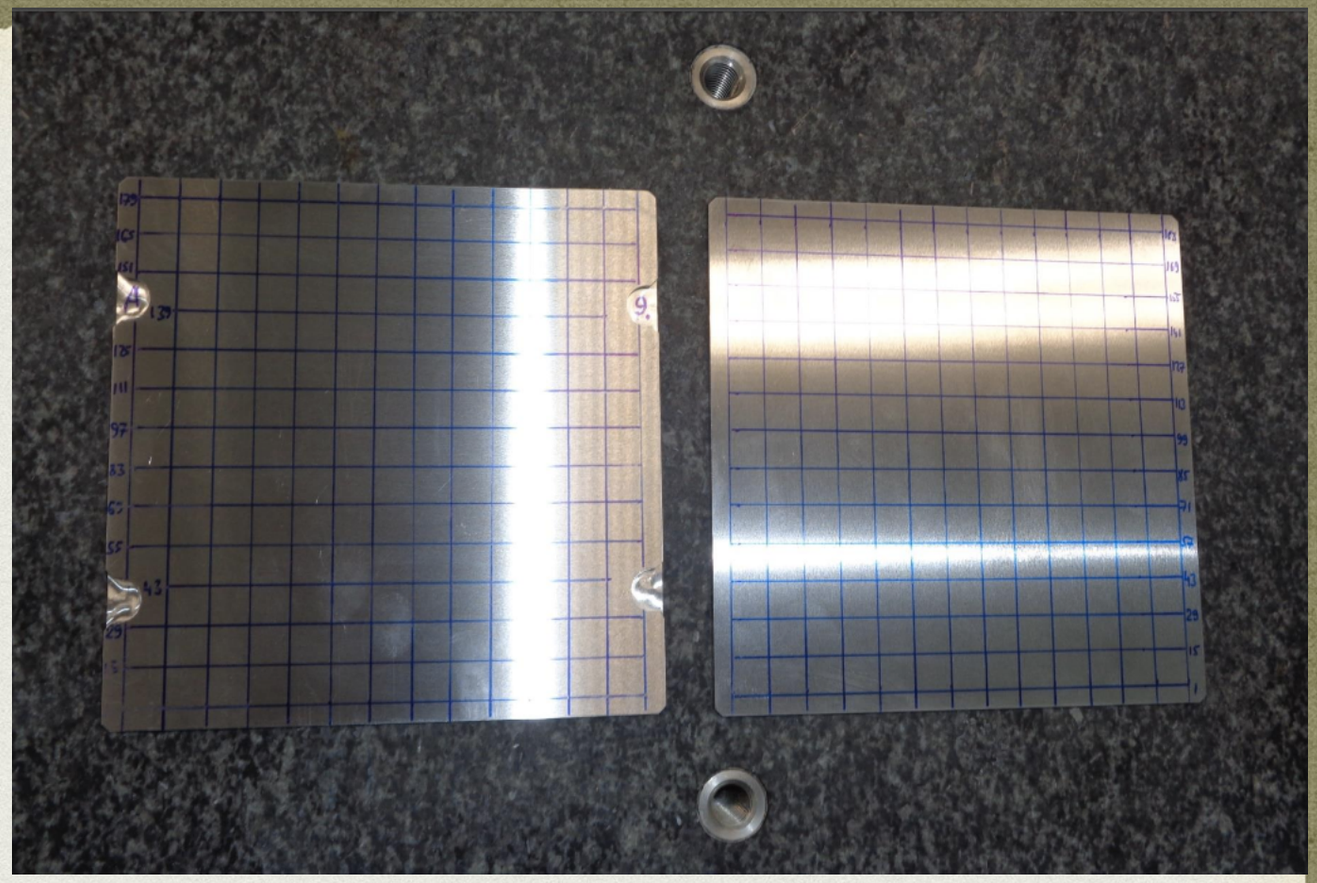
Design and test board: Fall 2018

Get chips by mid Dec

10 NEW TUNGSTEN PLATES

10 new tungsten plates (~50-60 μm) were tested in JINR, Dubna

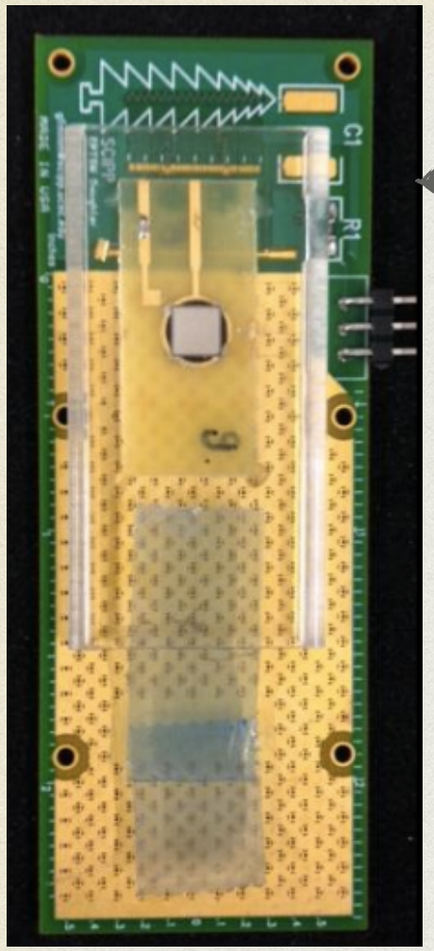
- Thickness Deviation Measurements on both sides were performed.
- Measurements were done with mechanical Zeiss 3D coordinate measurement system, precision 2.5 μm.
- Good flatness ~30 μm observed



Dimensions 140x140x3.5 mm

Density of the tungsten plates correspond to 93% tungsten, 5% nickel & 2% copper.

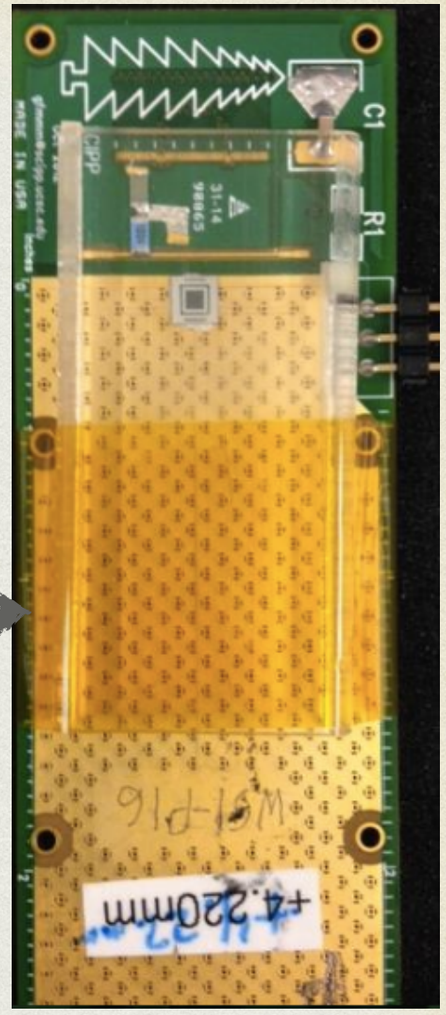
GALLIUM ARSENIDE VS SI DIODE SENSORS FOR BEAMCAL



GaAs Sensor provided by JINR

Sn-doped Liquid
Encapsulated Czochralski fabrication
300 μm thick
0.16 cm² area

Si Sensors produced by the Micron Corporation
PF: ~300 μm thick; area 0.025 cm²
NF: ~400 μm; area 0.09 cm²

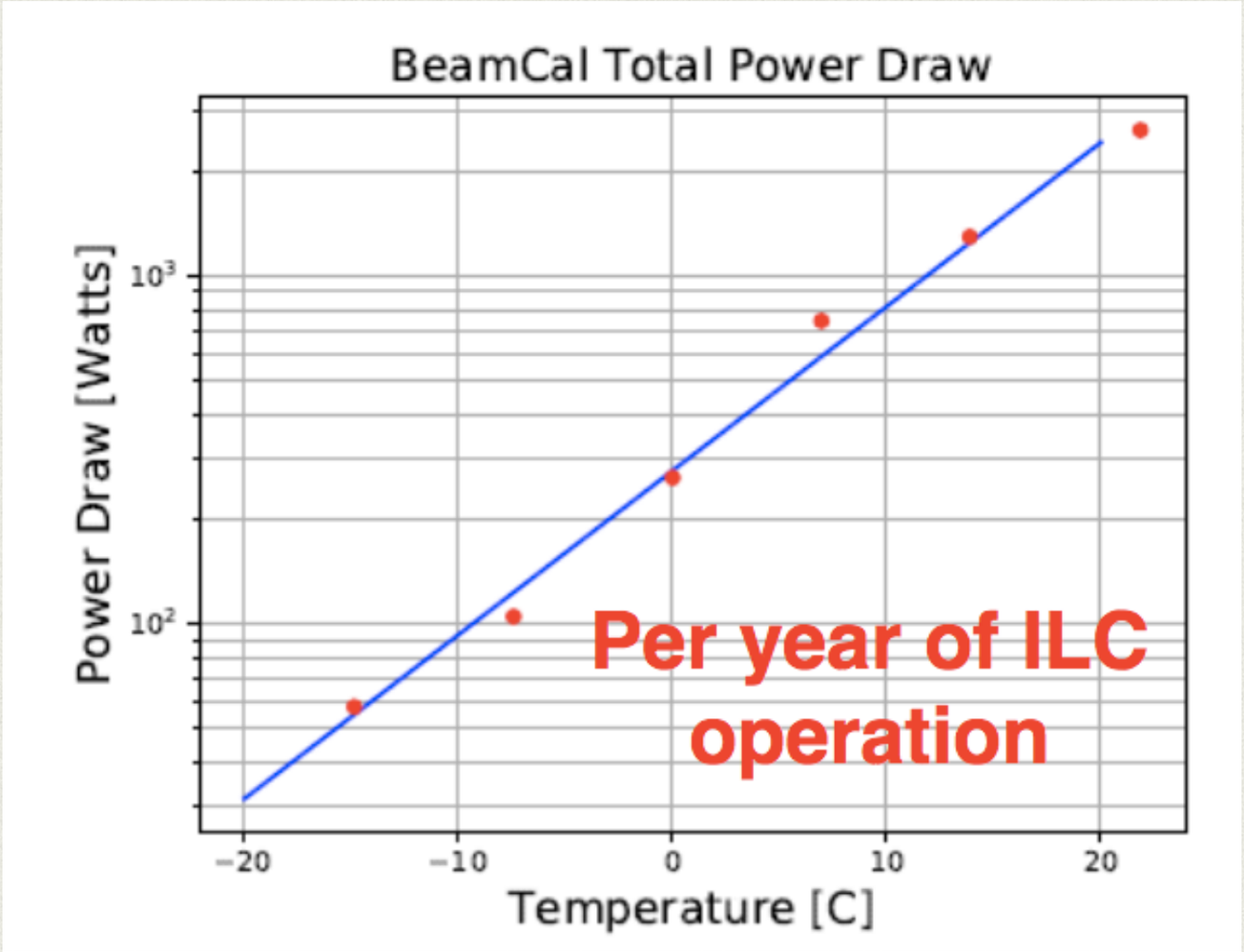


T506 allows rough comparison of Si vs GaAs
Roughly similar performance suggested
charge collection vs. collection time shows no degradation down to ~50 ns

Radiation damage studies performed at UC Santa Cruz Institute for Particle Physics

ALL POWER DRAW VS TEMPERATURE

Fluka simulation sets scale for Si power draw



Can limit accumulation to less than 100W per year by operating below -10°C

•At -30°C (standard for LHC sensor operation), accumulation would be of order 15 W per year

SUMMARY AND OUTLOOK

Results of the TB 16:

- Thin LumiCal module with sub-millimeter thickness was developed and produced. Its geometry meets requirements of LumiCal conceptual design.
- The LumiCal prototype with 8 thin modules and existing mechanical structure was assembled and tested with electron beam. Data analysis is in progress and preliminary results are following:
  - LumiCal prototype demonstrates good linear response to the beam of 1 GeV – 5 GeV.
  - Compact assembly of LumiCal with thin detector module results in significantly narrower transverse shower compared to previous beam tests and much smaller Molière radius.
  - The preliminary results on effective Molière radius calculation give R_M around 8.3 mm for 5 GeV e- and are in good agreement with MC simulations.
  - The results of R_M(E) dependence show slight dependence on energy which could be attributed to the fact that for higher energies smaller fraction of the shower is deposited in calorimeter with only 6 working layers.

In preparation for the TB 19:

- Development of new readout ASIC for LumiCal – FLAME – is in very advanced state;
- BeamCal ASIC - by the end of the year;
- 10 new tungsten plates - w/ good flatness.
- Power draw accumulation as little as 15 W per year for cooled (-30°C) detector

Thank you for attention!

BACK UP

ABSTRACT

We present recent developments by the FCAL Collaboration geared towards the design of compact and precise calorimetry for the forward region of the ILC. A prototype calorimeter has been built with special focus on fully-instrumented ultra-thin sensor planes to ensure a very small Moliere radius. Results of performance studies in a 5 GeV electron beam will be presented. We also present results on radiation damage studies and the design of dedicated readout electronics.
Plans for future work will be mentioned.