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AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY

AIDA 2020

FCAL Collaboration High precision design

Compact forward calorimetry at future linear collider

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On behalf of

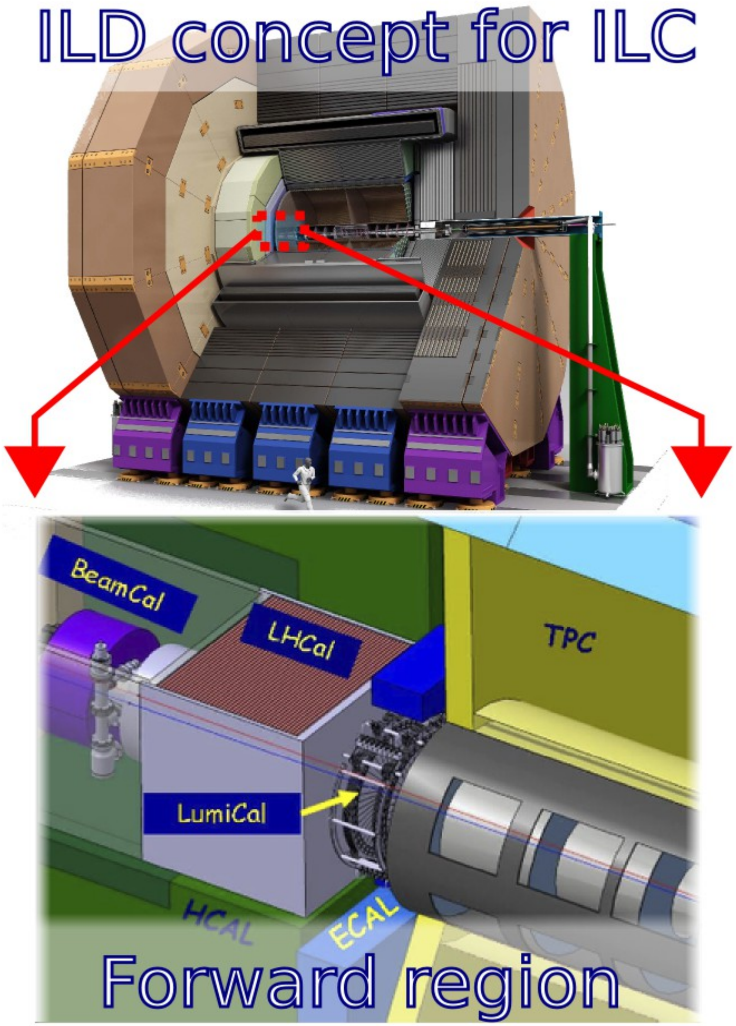
FCAL Collaboration

Energy and time measurement with High Granularity Silicon Devices , DESY 13-14 June 2016

Outline

- Motivation&Status
- Prototype of Very Compact Calorimeter – next FCAL Goal
- Other FCAL R&D
- Summary

Motivation for this work

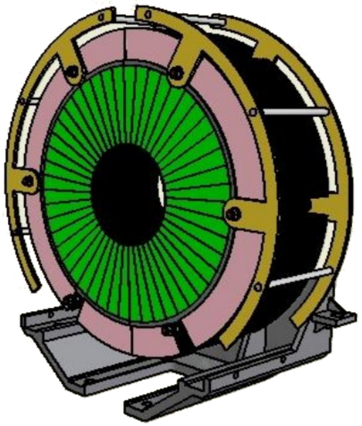


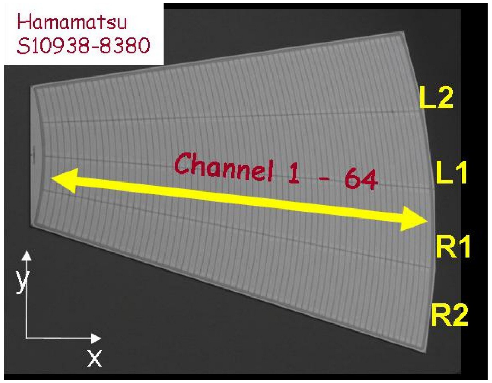
Development of the very forward region calorimeters for the precise measurement of luminosity (LumiCal) and a fast beam monitoring (BeamCal) in future Linear Collider, with specific requirements/challenges:

- Compact (small Moliere radius)
- Fast readout
- High occupancy
- Rad-hard (BeamCal~1MGy/year)
- Mechanical precision (LumiCal)
- Coverage extension

Motivation
Forward detectors to build: LumiCal, BeamCal

LumiCal

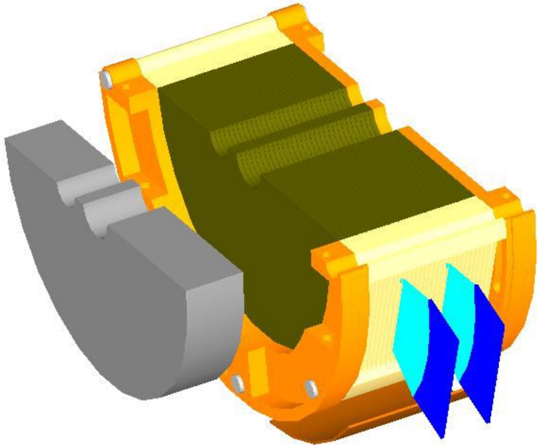


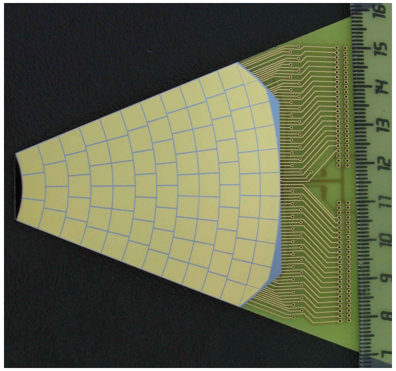


- standard *p* in *n* Si sensors
- 300 um thick, pad pitch 1.8 mm
- Azimuthal/radial segmentation 48 sectors / 64 pads

- Sandwich type sampling calorimeters
  - LumiCal Si-W,
  - BeamCal GaAs(?)-W
- 30 layers at ILC, 40 layers at CLIC. One W layer – 1 X0
- Very compact calorimeters (Moliere radius ~1cm)
- Low polar angle acceptance
  - LumiCal ~100 mrad
  - BeamCal ~10 mrad

BeamCal





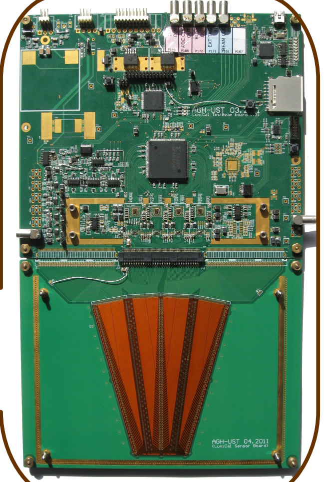
- compensated GaAs sensors
- 500 um thick
- uniform segmentation

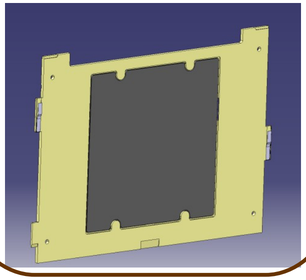
Forward detectors Status&Goal
Prototype of Compact calorimeter

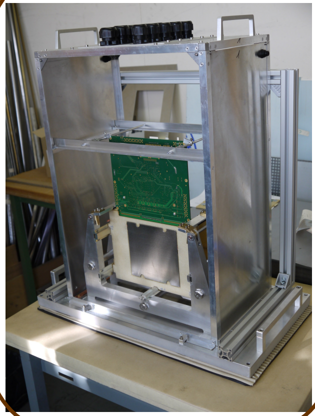
Present Status

Existing LumiCal/BeamCal prototype comprises:

- Detector modules:
  - Sensor modules for BeamCal/LumiCal
  - Readout ASICs
  - Back-end electronics
- Precise absorber layers
- Precise mechanical frame



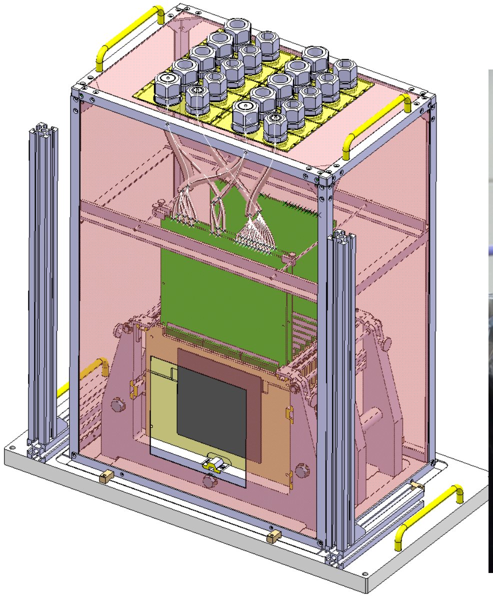


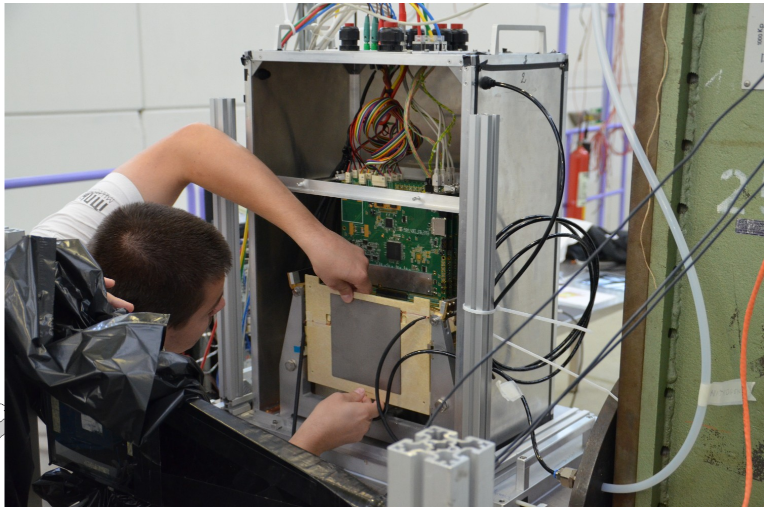


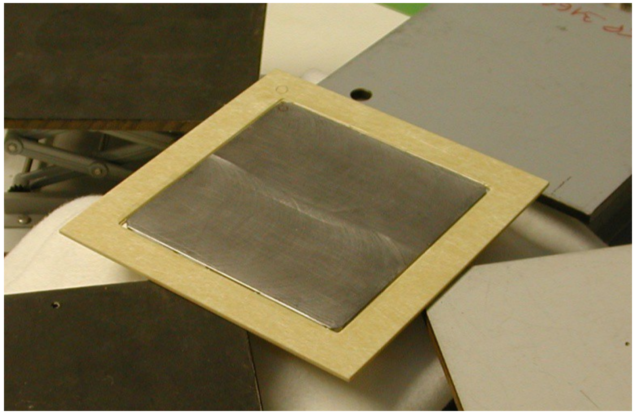
The goal is to make it very compact

- To verify MC simulations
- To proof the used technologies

Next FCAL goal
Precise mechanical frame and absorber plates







Precise mechanical frame

- can hold up to 30 sensor-absorber layers
- Various configurations of detector modules and absorber plates are possible

Prototype tungsten plates

- 3.5 mm thick (1X0)
- Required flatness on front/back side - 10/50um
- 11 prototype plates from two companies. Four of them fulfill flatness specifications

Existing mechanical frame and tungsten plates were already used in testbeams and match the requests for compact prototype

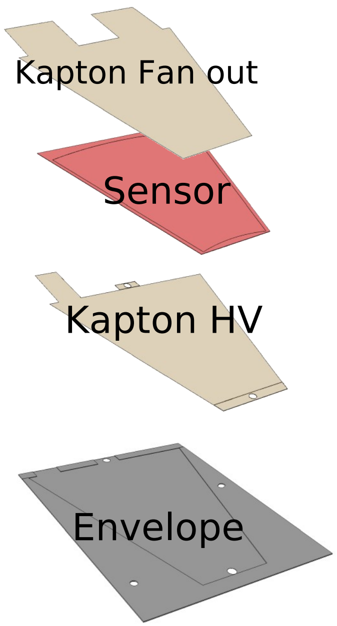
Next FCAL goal
New detector module

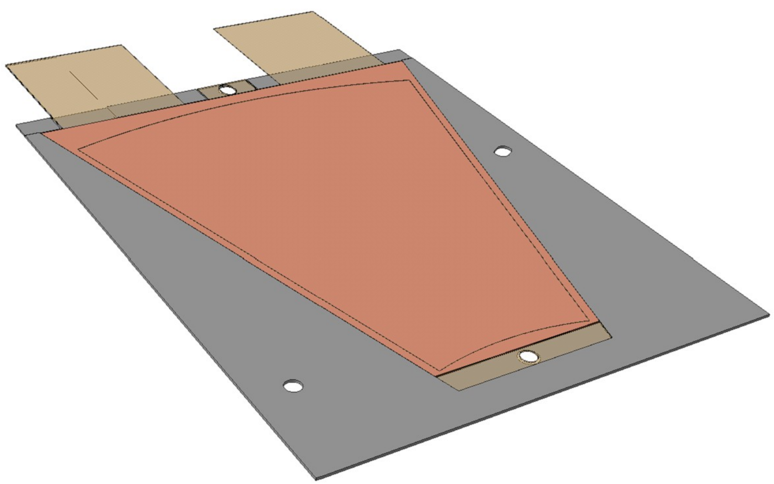
For very compact calorimeter (Moliere radius ~1cm) the existing detector module (sensor+readout) is much too thick (>1cm) and needs to be miniaturisied:

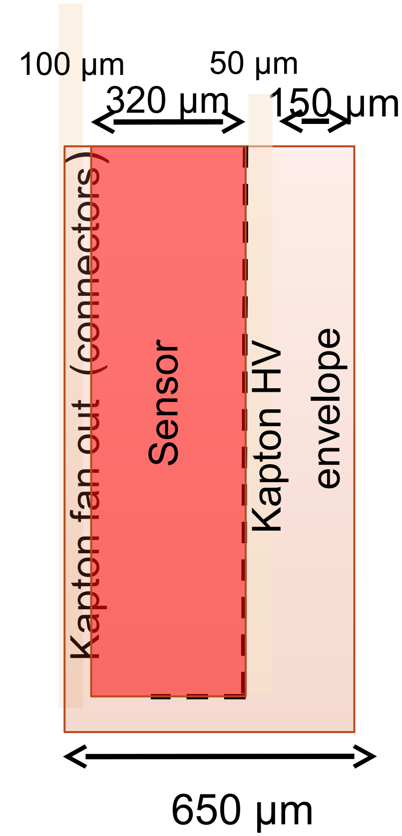
- A very thin (<1 mm) **new sensor module is needed**
  - using existing silicon sensors
- A thin (<4.5 mm) **new readout board** with SystemOnChip (SoC) type ultra-low power readout ASICs
  - **New readout ASICs needed**
  - **New FPGA based readout needed**

New sensor module
The goal: thickness < 1 mm

Project of new sensor module





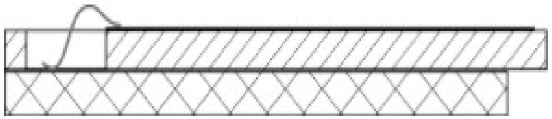


For the envelope 3D printing and and carbon fiber prototypes were done.
Carbon fiber prototypes were chosen as more rigid.

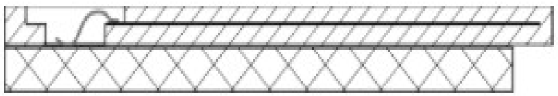
New sensor module
Low-height contact of the sensor

- Approaches :
  - **wirebonding**

    conventional, currently used, minimum height ~100µm

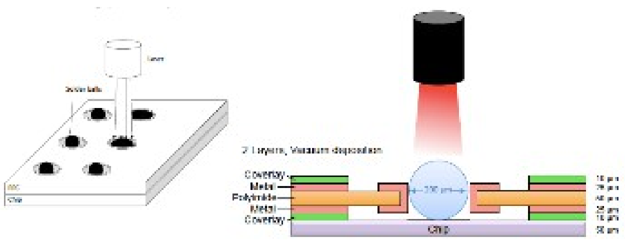
    
  - **Flat loop wire bonding**

    staggered pcb required

    
  - **Conductive glue**

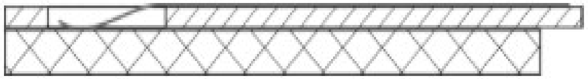
    tested at DESY, Krakow,TAU : not satisfying …
  - **Laser bonding**

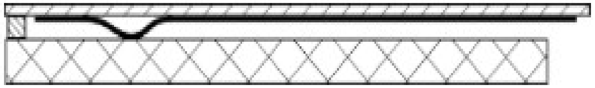
    tested by TAU : not possible because aluminum pads

    
  - **tape automated bonding (TAB)**

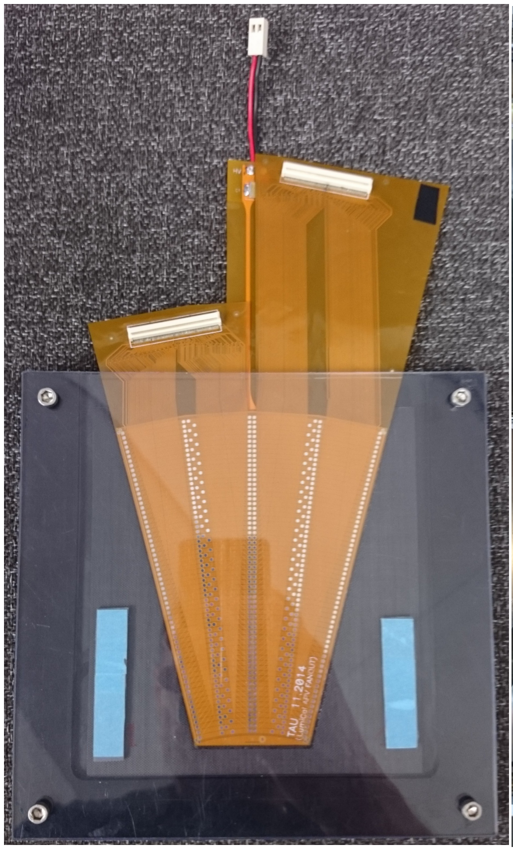
    first enquiries by TAU

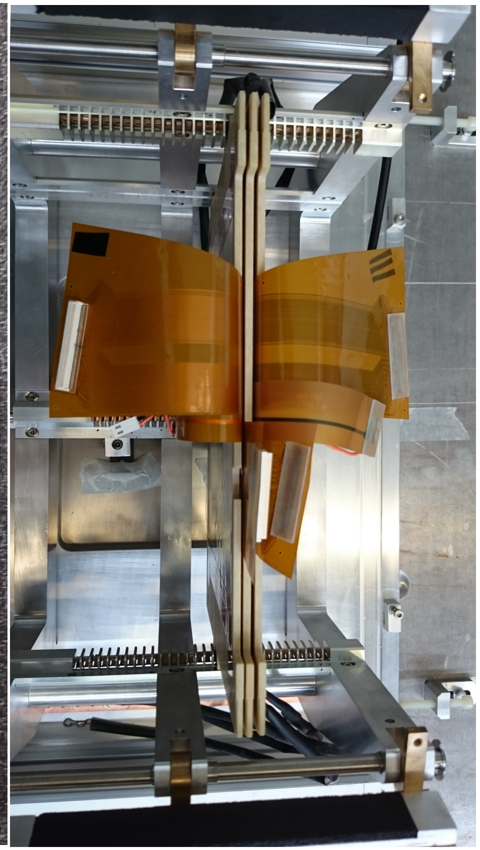
    bonding wedge & dedicated fanout sample received

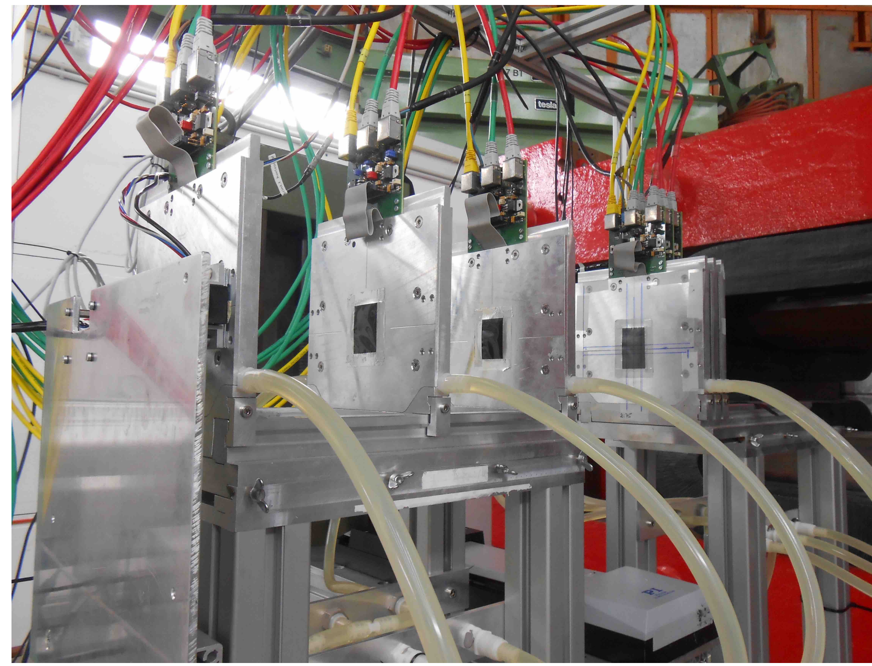
    
  - **Spring loaded contact**
    - technology tests by DESY (Zeuthen)



New sensor module
Fabrication and first test-beam





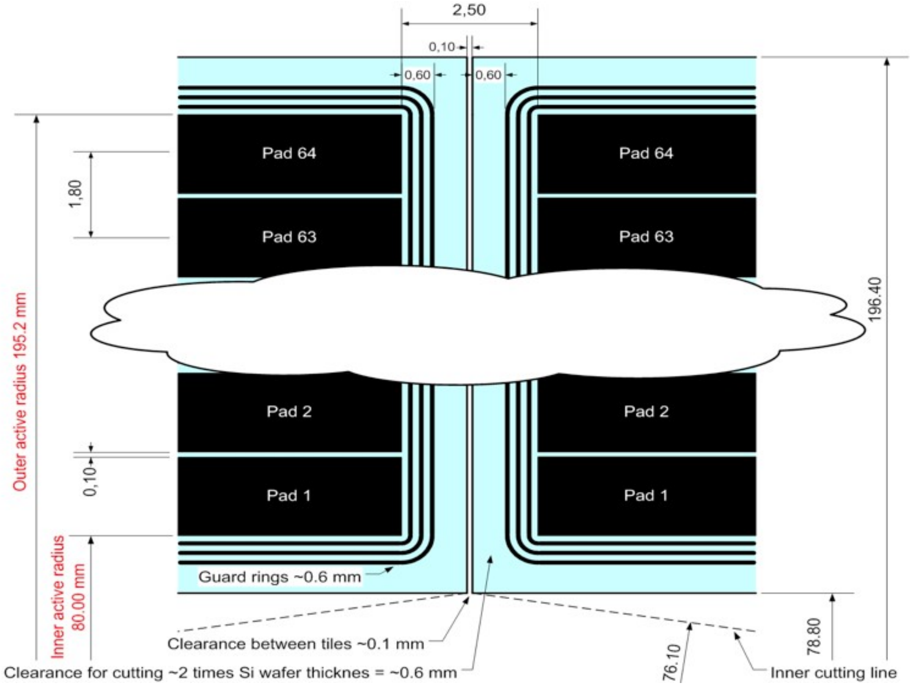


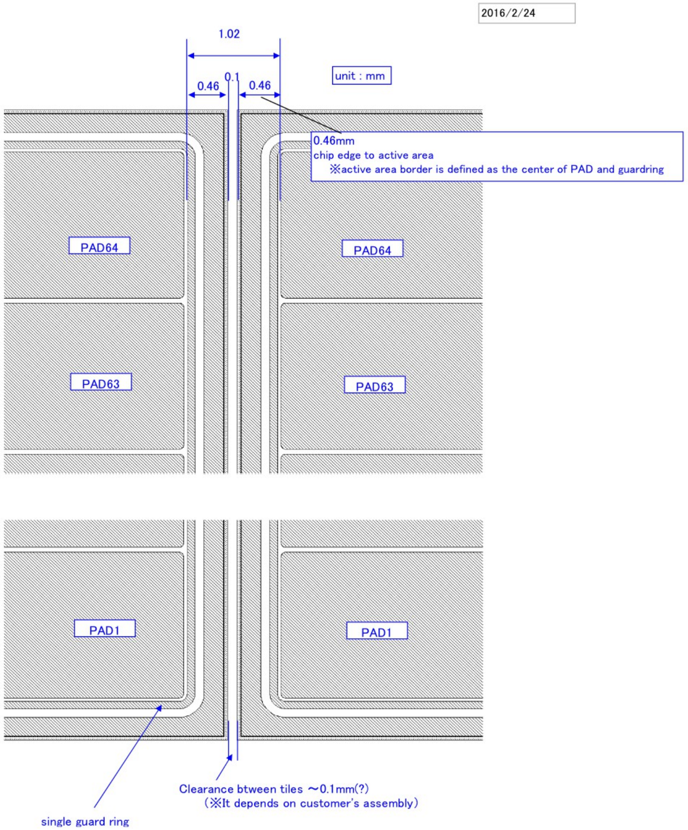
Thin prototypes of sensor modules comprising the envelope, fanouts and sensor have been developed and put on beam at the end of 2015. Data analyses in progress...

New LumiCal sensor R&D
"Edgeless" Si sensors

New study ongoing with Hamamatsu to limit dead area at the edges between tiles (each tile has 4 sectors)

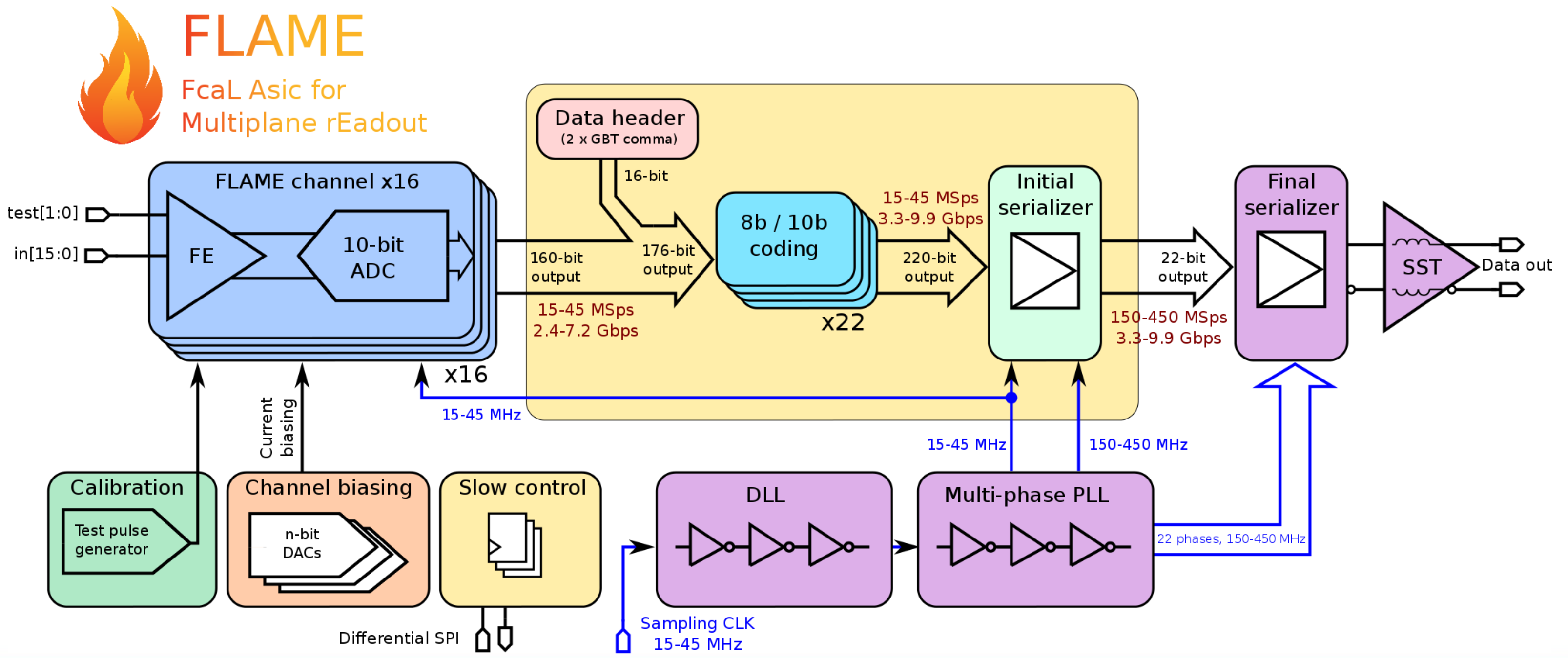
2.5 mm → 1 mm



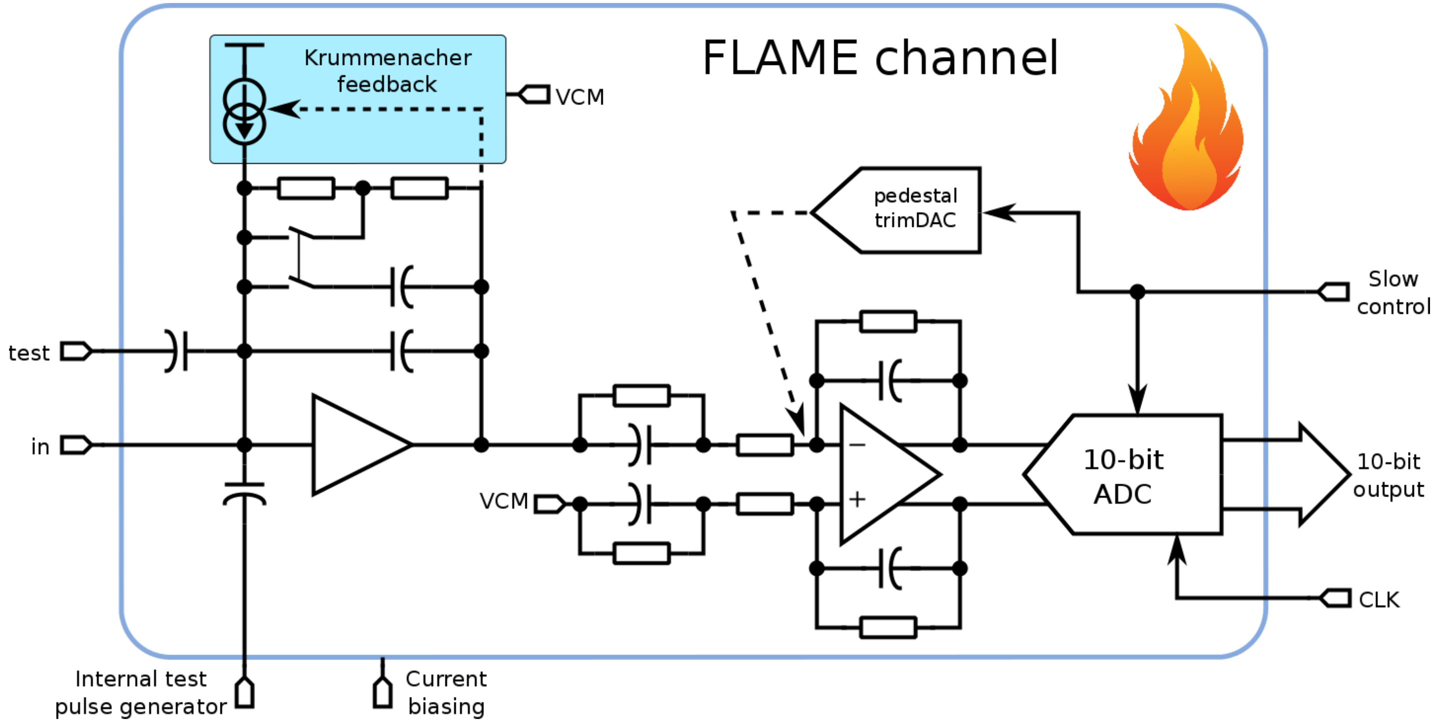


New readout ASIC
FLAME – FcaL Asic for Multiplane rEadout

- For **very compact** calorimeter we need an ultra-low power, SoC type (all functionalities on chip) readout ASIC
- FLAME: 16-channel ultra-low power readout ASIC in CMOS 130 nm, FE&ADC in ech channel, fast serialization and data transmission, all functionalities in single ASIC



New readout ASIC
Channel architecture

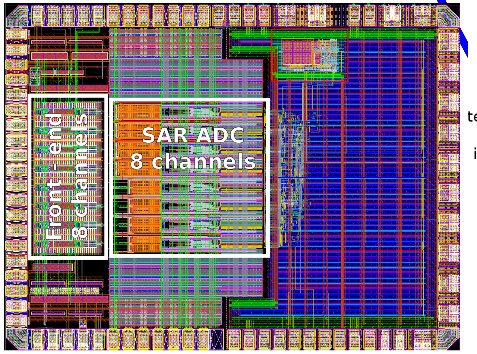


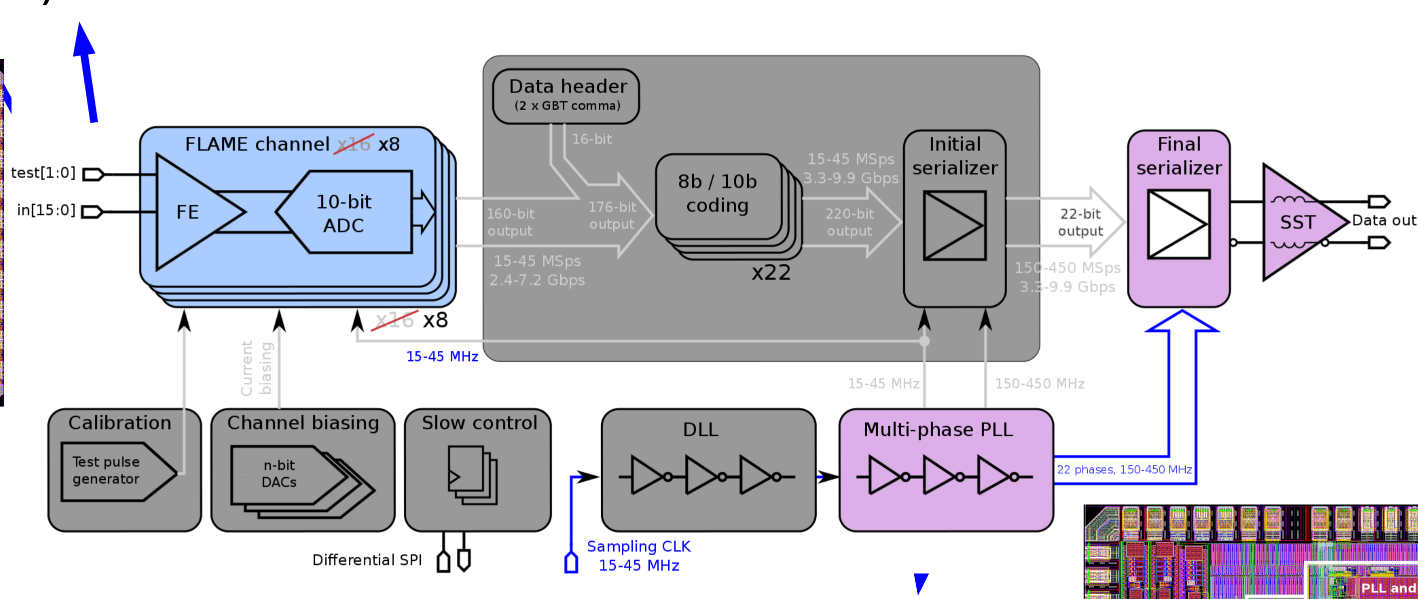
- Analogue front-end comprises:
  - Charge sensitive preamplifier with variable gain
    - High gain – MIP sensitivity for calibration
    - Low gain – for shower development (up to 6 pC)
  - Differential CR-RC shaper with 50ns peaking time
  - Cdet 5-50 pF
  - Power ~1.2mW

- 10-bit ADC
  - Sampling rate up to 40 MSps
  - DNL, INL < 0.75 LSB
  - ENOB > 9
  - **Ultra-low power <1mW@40Msps**

New readout ASIC FLAME current status

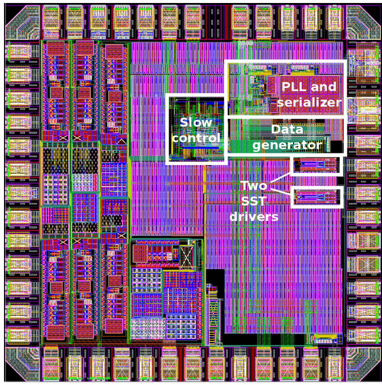
- Prototype ASIC comprising 8 almost fully functional FLAME channels:
  - Front-end with variable gain, differential CR-RC shaper, Tpeak = 50ns, ENC~900el@20pF
  - 10-bit multichannel SAR ADC
  - **Power (FE+ADC) <2mW/channel**





Prototypes arrived to Cracow in March 2016. Test setups under preparation...

- Prototype serializer ASIC comprising:
  - Fast ultra-low power multi-phase PLL
  - **Power <20mW@10Gbps**
  - Fast serializer 22b → 1b
  - Fast SST driver



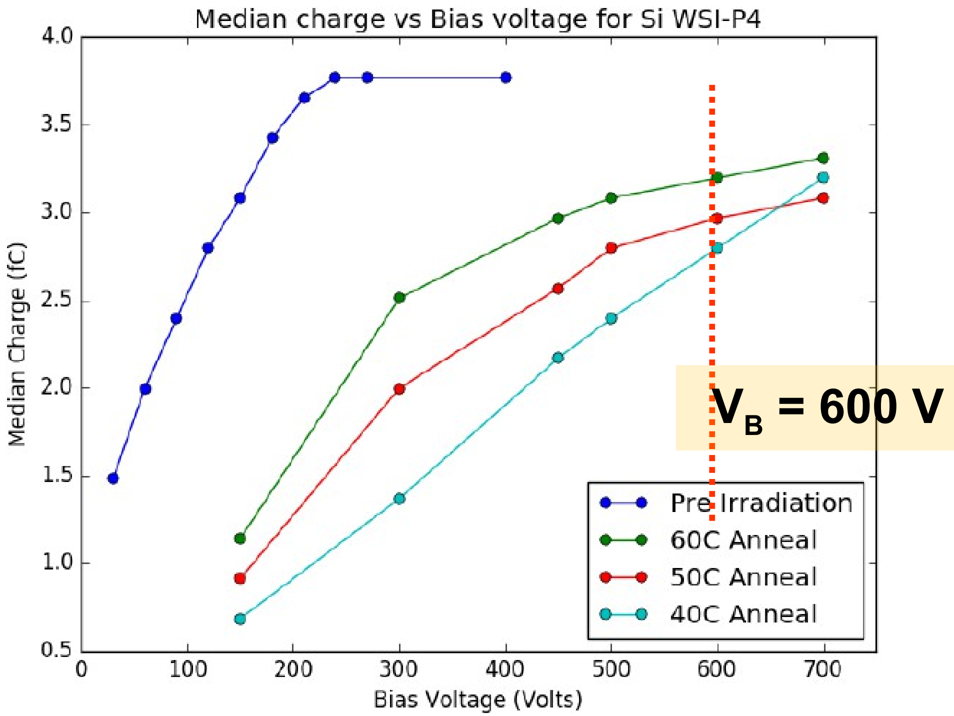
Other FCAL R&Ds
Radiation studies of BeamCal sensors at SLAC

Studies done in realistic radiation field, as expected for ILC/CLIC

Sensor Type	Notable Exposures (Mrad)
GaAs	20
SiC	80
Si PF	270, 570
Si NF	300
Si PC	300
Si NC	290

Promising results with Si
(although cooling would probably be required...)

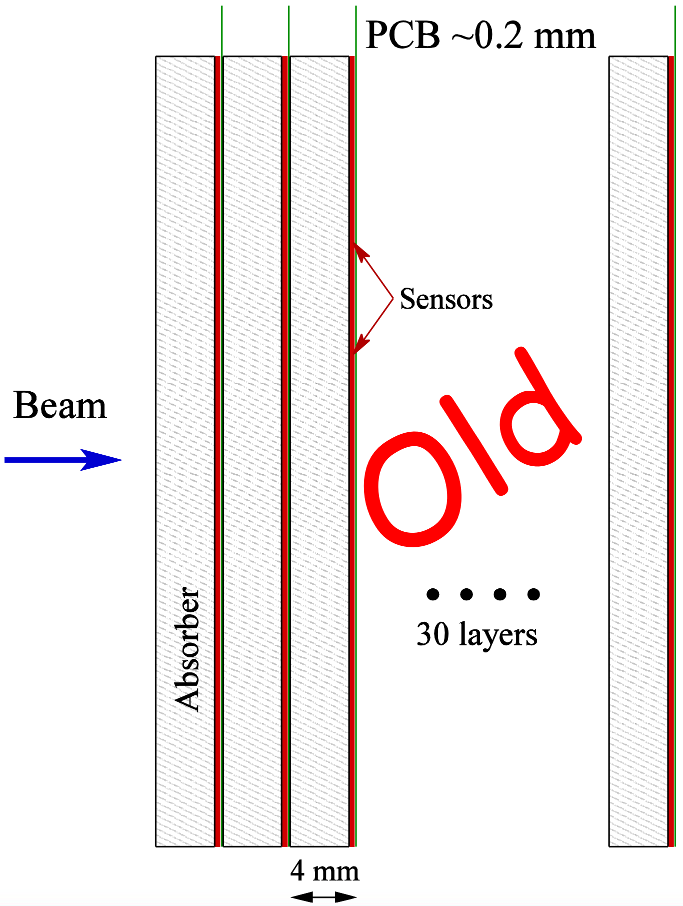
P-type Float Zone Si
Charge Collection after 2.7MGy=270Mrad

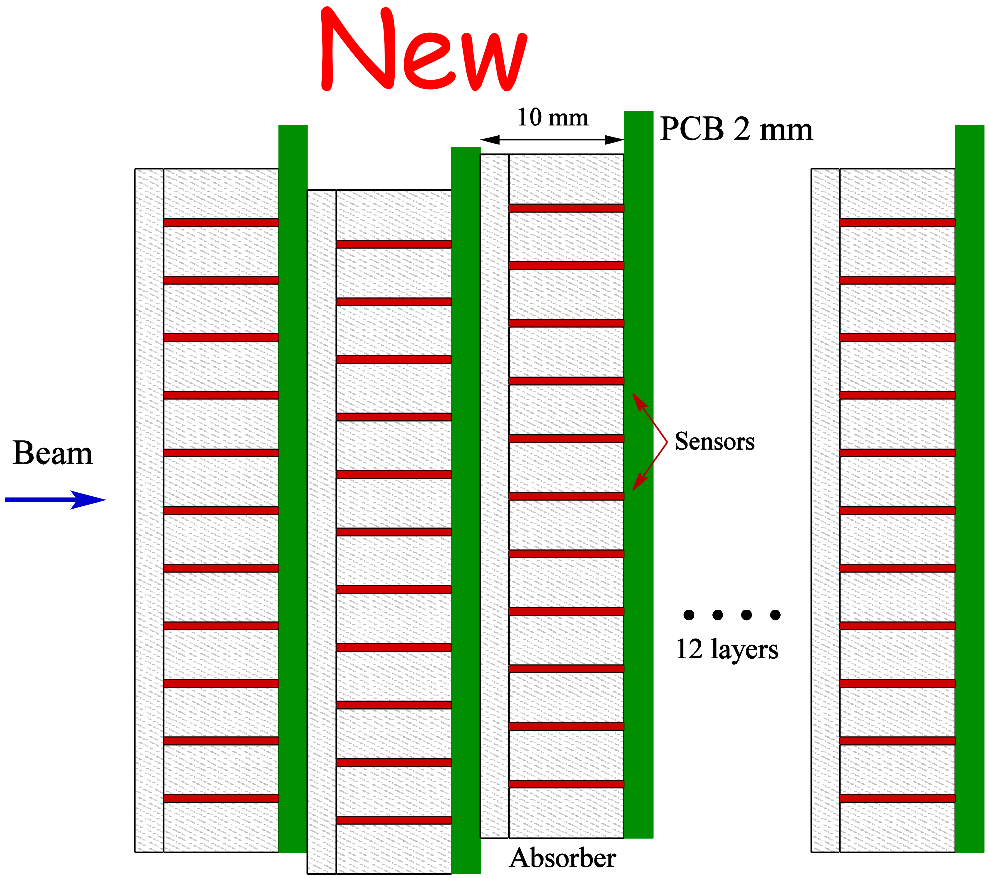


@600 V, ~20% charge collection loss (60C annealing)

Other FCAL R&Ds
New BeamCal design with sapphire sensors

Motivation: extreme radiation hardness of sapphire,
reduced dynamic range of the front-end electronics





Summary

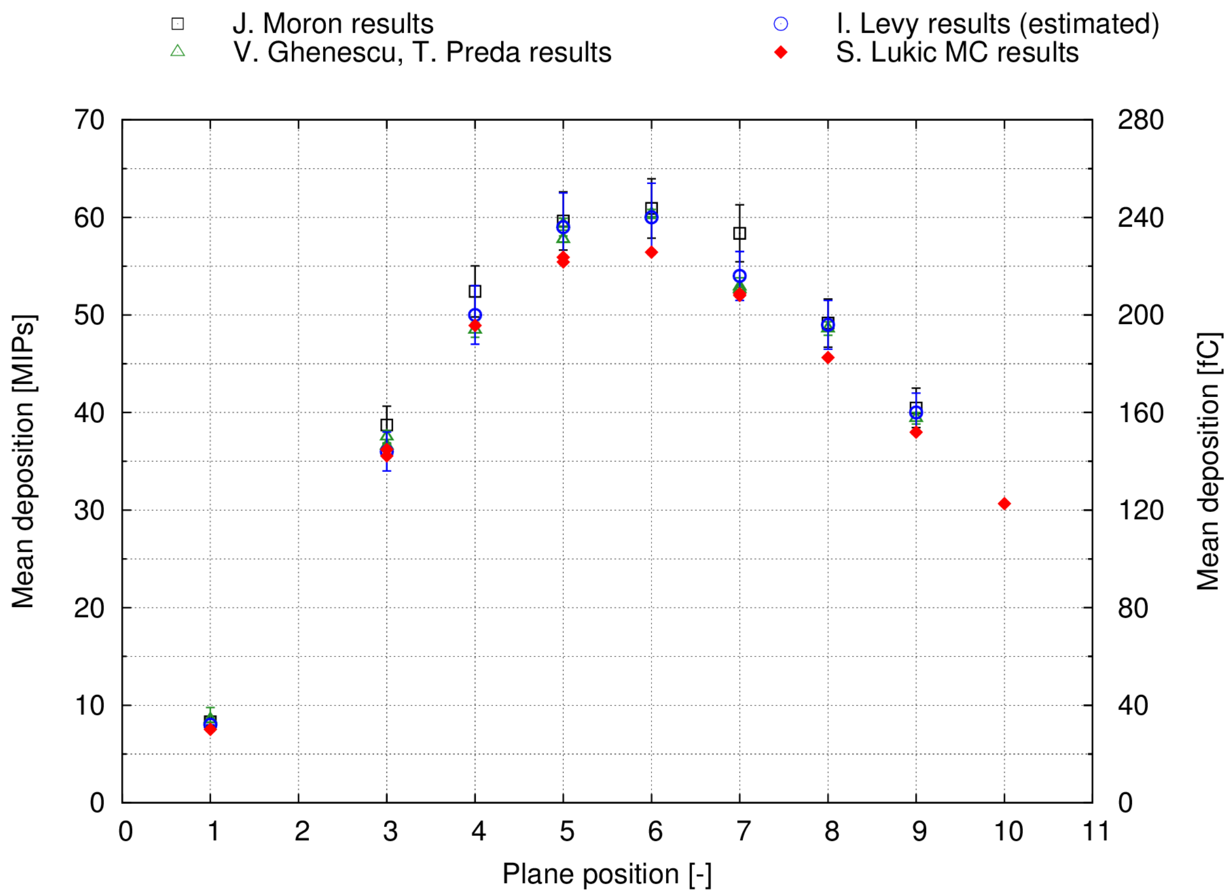
• Dedicated R&D is ongoing for forward calorimetery at future linear collider. Prototype of very compact calorimeter – FCAL next goal – is in advanced stage:

- Precise mechanical frame and tungsten plates have been developed
- Prototypes of **new** thin sensor modules are just being completed
- Prototypes of **new** fast, ultra-low power SoC type readout ASIC will be tested soon,
- In parallel various R&Ds, like studies of **new** rad-hard sensors for BeamCal, are underway.

Thank you for attention

Backup

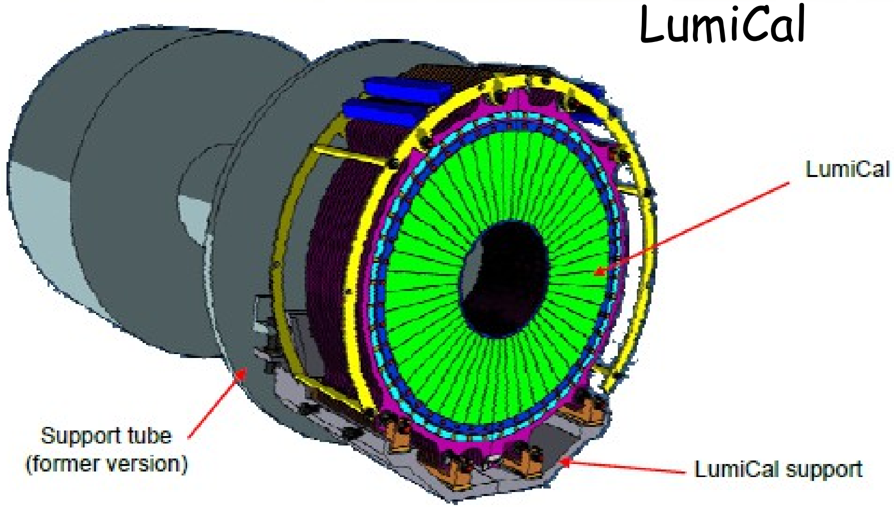
Shower development from 2014 test-beam



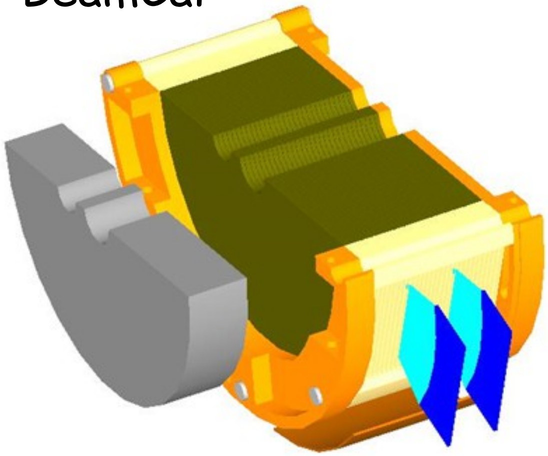
Measured shower development for 5 GeV electrons shows good agreement with MC simulations

Forward detectors

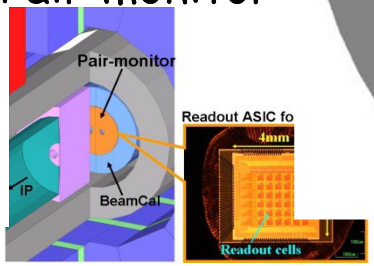
LumiCal

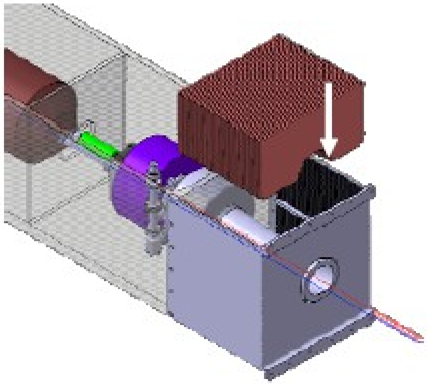


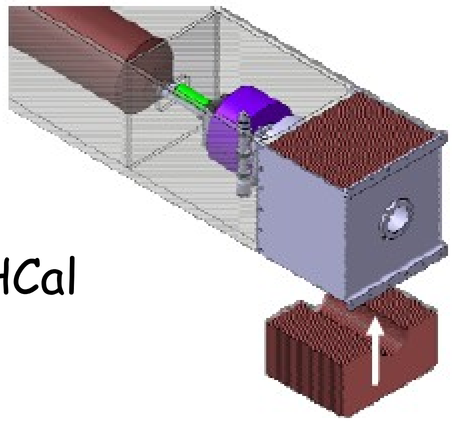
BeamCal



Pair monitor

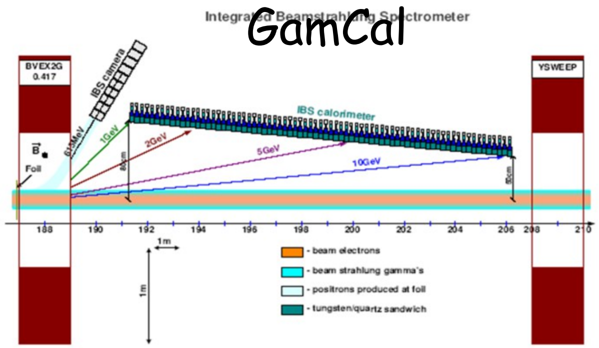




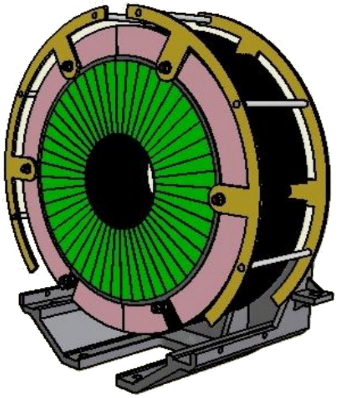


LHCal

GamCal



FCAL overview
Luminosity measurement by LumiCal detector

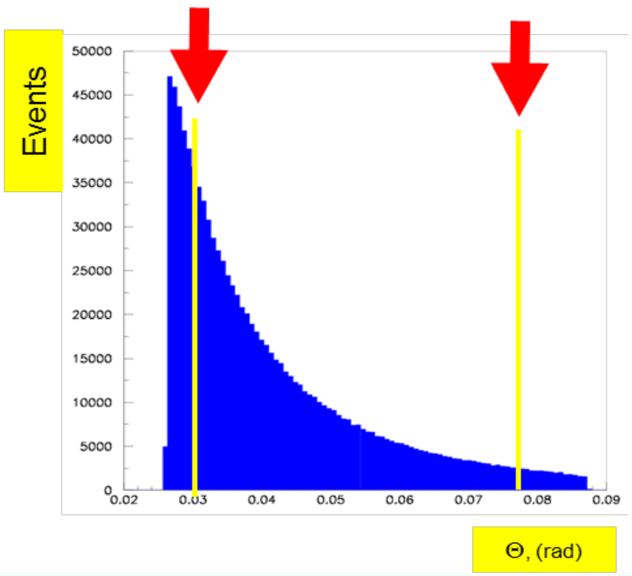


- Precise measurement of luminosity (10^{-3} at ILC, 10^{-2} at CLIC)
- Low angle physics

Gauge process for the luminosity measurement: Bhabha scattering

e+e- ⟶ e+e- (γ)

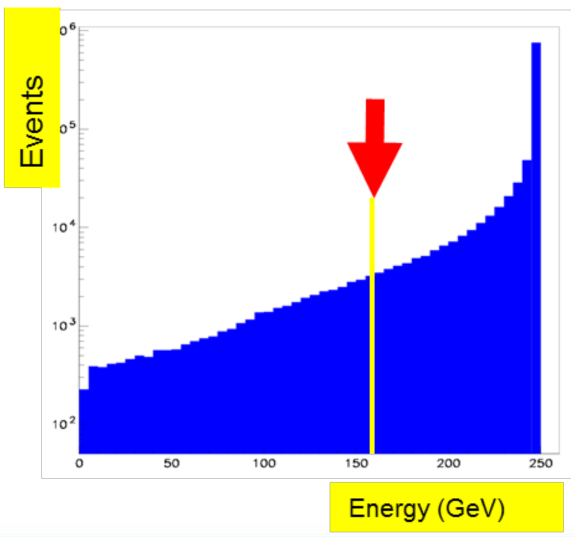
$$\frac{d\sigma_B}{d\theta} = \frac{2\pi\alpha_{em}^2}{s}\frac{\sin\theta}{\sin^4(\theta/2)} \approx \frac{32\pi\alpha_{em}^2}{s}\frac{1}{\theta^3}$$



$L = N / \sigma$

Bhabha events count

From theory



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BeamCal sensor material propoertioiies

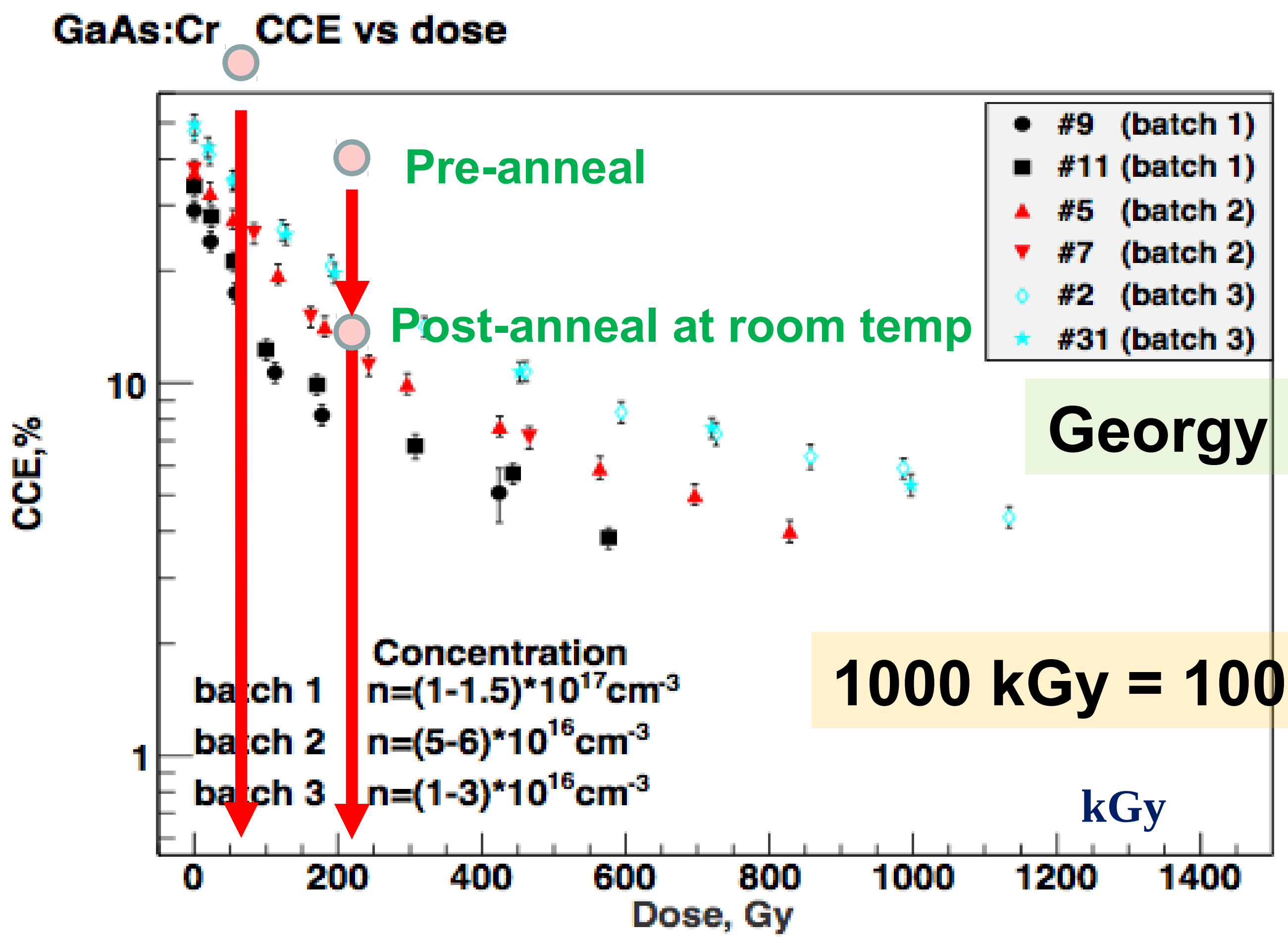
	Sapphire	Diamond	GaAs	Si
Density, g/cm3	3.98	3.52	5.32	2.33
Dielectric constant	9.3 – 11.5	5.7	10.9	11.7
Breakdown field, V/cm	~106 *	107	4.105	3.105
Resistivity, Ω·cm	>1014	>1011	107	105
Band gap, eV	9.9	5.45	1.42	1.12
El. mobility, cm2/(V·s)	>600 **	1800	~8500	1360
Hole mobility, cm2/(V·s)	-	1200	-	460
MIP eh pairs created, eh/μm	22	36	150	73

+First irradiation tests of SiC

* Typical operation field ~1-2·104 V cm-1

** at 20ºC, ~30000 at 40ºK

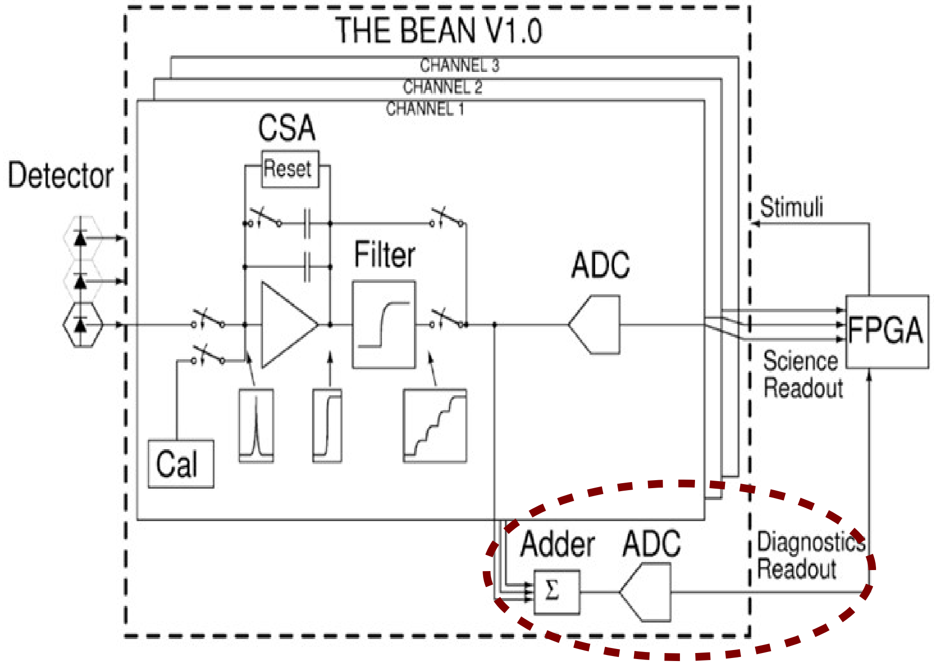
GaAs radiation studies

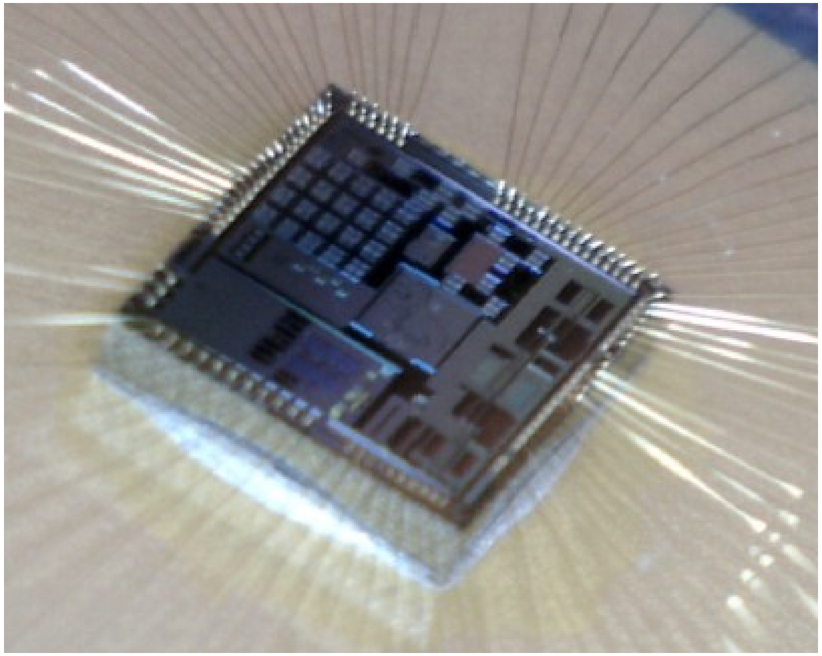


Georgy Shelkov, JINR

1000 kGy = 100 Mrad

Ongoing FCAL R&D on ASICs
Readout ASICs for BeamCal in CMOS 180 nm





- Novel front-end architecture based on switched-capacitor filter
- Front-end and 10-bit ADC in each channel (as in LumiCal readout)
- Adder circuit for fast beam diagnostics
- First single channel prototypes fabricated and tested
- Development of next ASIC version in progress at PUC Chile

A. Abusleme, A. Dragone, G. Haller, B. Wooley "BeamCal Instrumentation IC: Design, Implementation and Test Results", IEEE Transactions on Nuclear Science, 59(3) 2012