AIDA 2020

AGH University of Science and Technology

R&D with Very Forward Calorimeters for Linear Colliders

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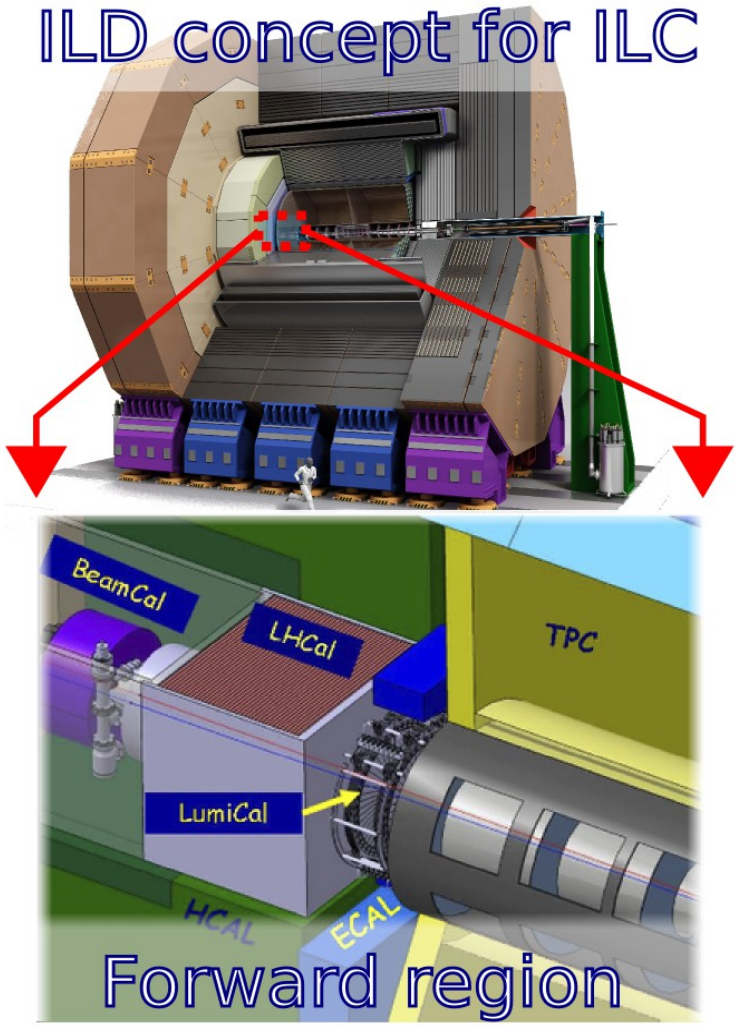
On behalf of
FCAL Collaboration

IEEE NSS , Strasbourg France 29 October – 6 November 2016

Outline

- Introduction to Forward Calorimeters for a Linear Collider
- Test-beam results from a 4-plane LumiCal calorimeter prototype
- R&D for a Very Compact Calorimeter
- Summary

Introduction to Forward Calorimeters
Motivation

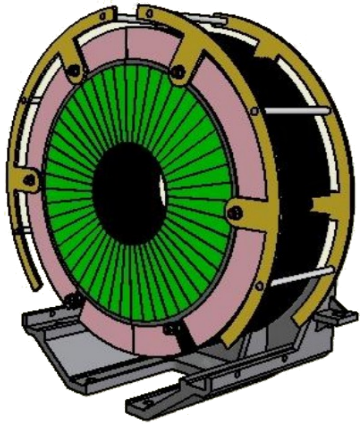


Precise measurement of luminosity (Bhabha events) by LumiCal and fast bunch by bunch estimate by BeamCal with specific requirements and challenges:

- **Compact** (small Moliere radius)
- Fast readout
- High occupancy
- Rad-hard (BeamCal~1MGy/year)
- Mechanical precision (LumiCal)
- Low power dissipation
- Extension of detector coverage

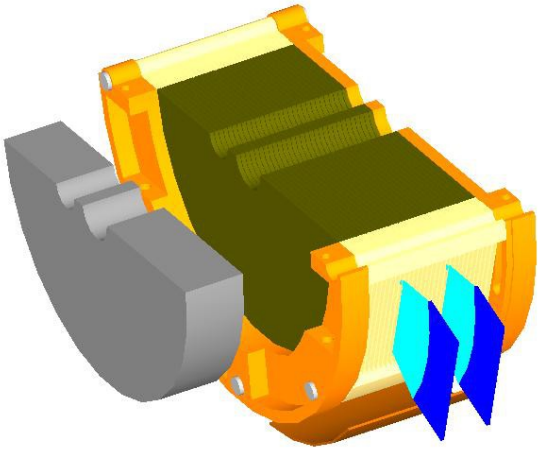
Introduction to Forward Calorimeters
Luminometer and Beam monitor

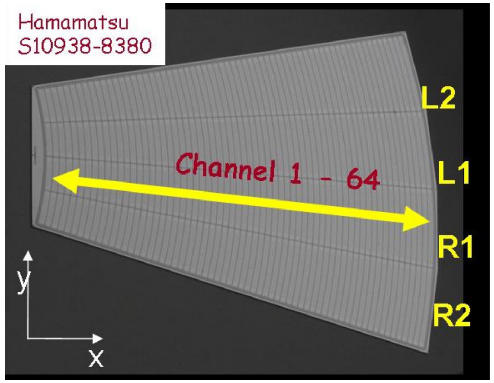
LumiCal



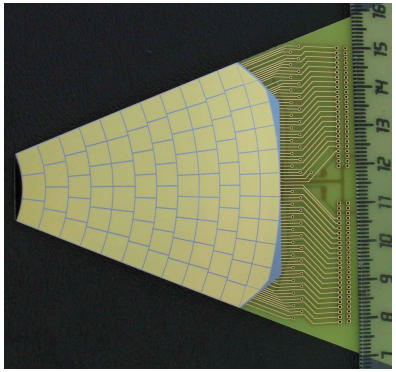
- Sandwich type, very compact (Moliere radius ~1cm), sampling calorimeters
  - LumiCal Si-W,
  - BeamCal GaAs(?)-W
- ILC - 30 layers (~30 X0), CLIC 40 layers
- Low polar angle acceptance
  - LumiCal ~100 mrad
  - BeamCal ~10 mrad

BeamCal





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



- compensated GaAs sensors
- 500 um thick
- uniform segmentation

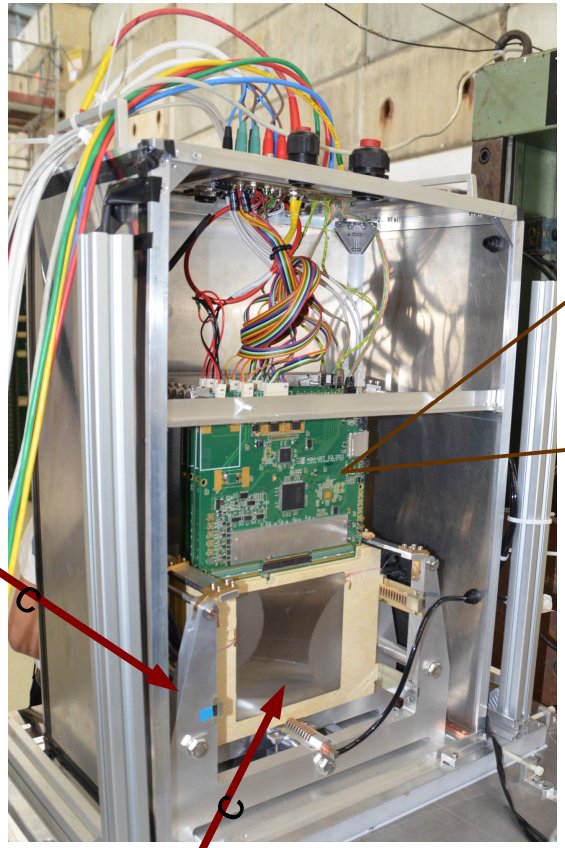
Introduction to Forward Calorimeters
Main FCAL R&Ds

- Prototype of a compact calorimeter comprising:
  - thin (<1mm) sensor modules
  - thin (<3.5mm) readout board with SoC type (System on Chip) ASIC

- Other R&Ds
  - BeamCal - study of other rad-hard materials (e.g. Si) and different detector design (with horizontal sapphire sensors)
  - Studies of tracker in front of LumiCal
  - Studies of LHCal
  - Design of a readout ASIC for BeamCal

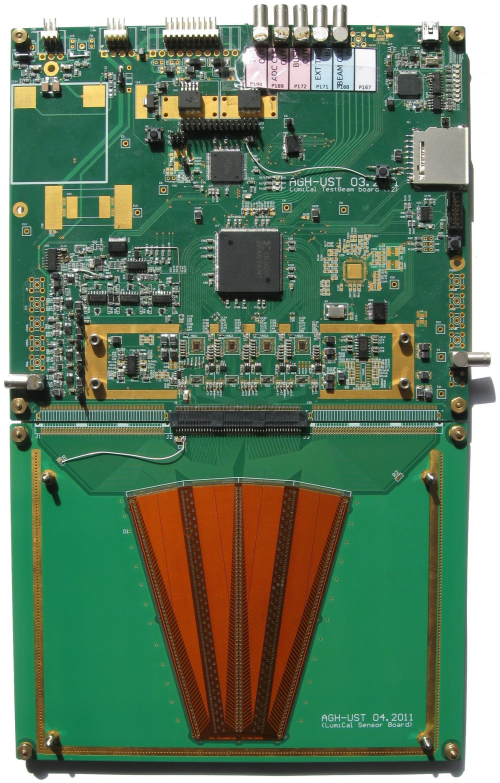
Test-beam with 4-plane LumiCal prototype
LumiCal setup

Precise mechanical frame can hold up to 30 sensor-absorber layers



Prototype tungsten plates 3.5 mm thick (1X0), with flatness on front/back side - 10/50um

Detector planes

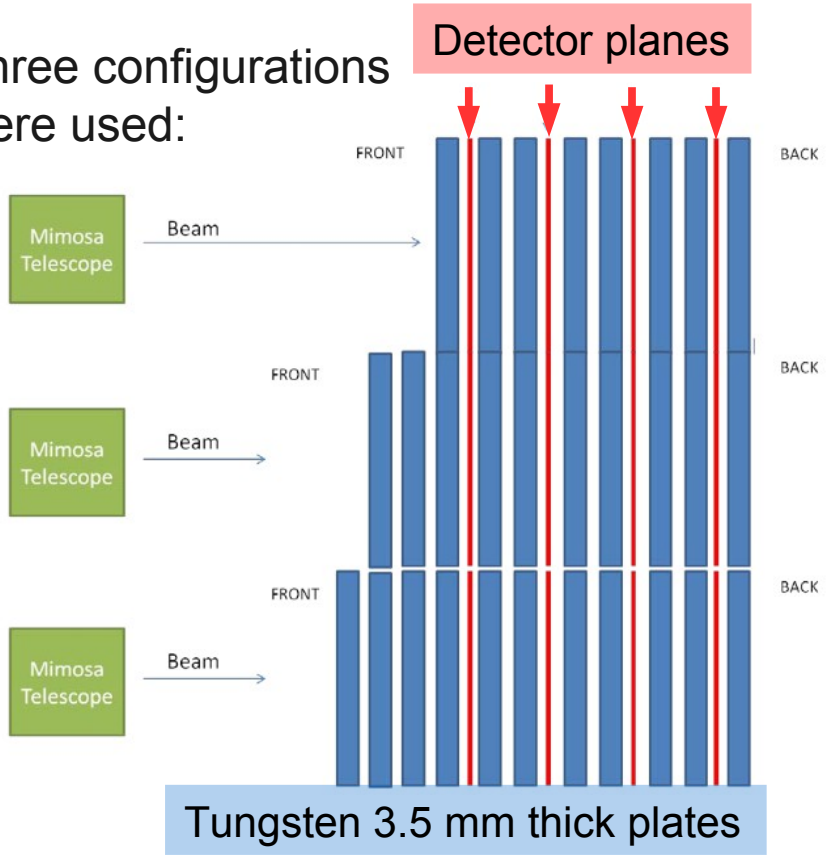


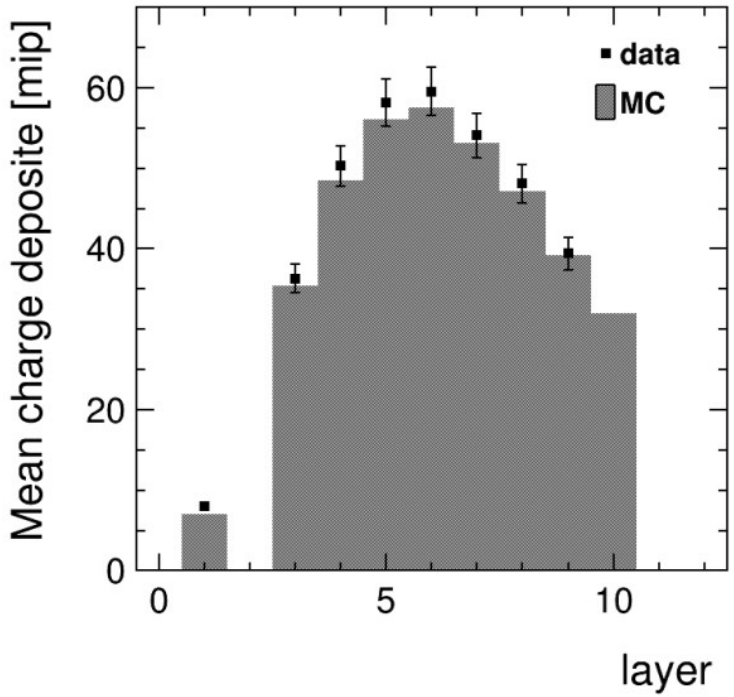
readout board (top) with dedicated ASICs&FPGA, sensor module (bottom)

Test-beam with 4-plane LumiCal prototype
Shower development in 2014 test-beam

Electron, muon and hadron 5 GeV beam from CERN PS was used

Three configurations were used:

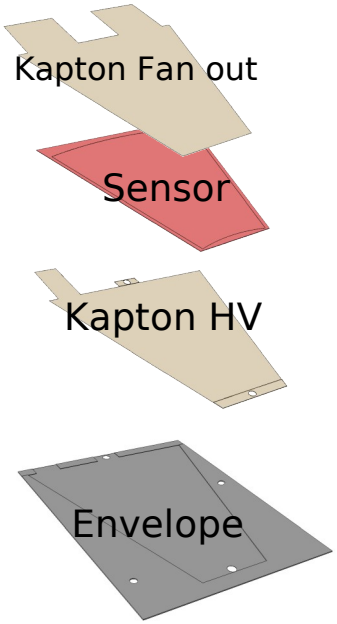


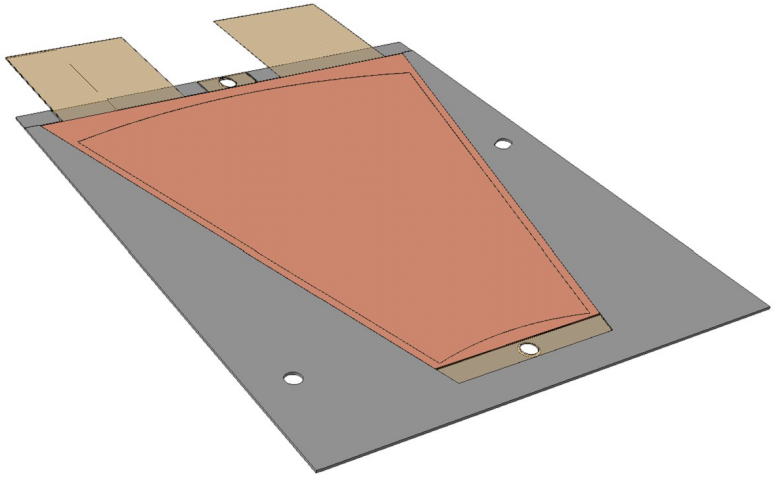


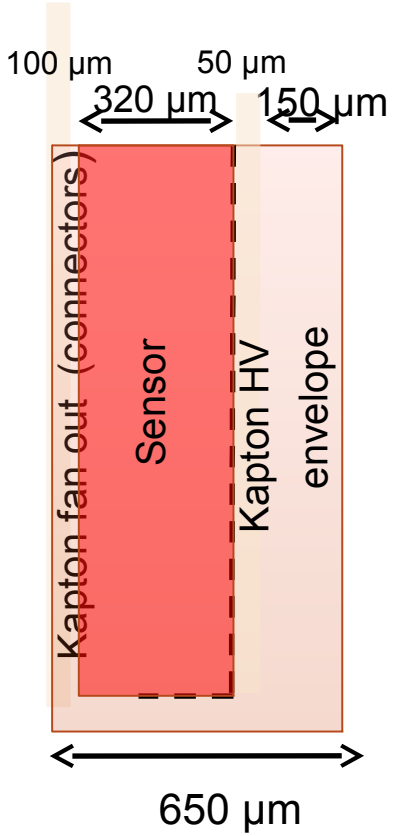
Measured shower development shows good agreement with MC simulations. Analysis of Moliere radius still in progress...

Since the present detector module is rather thick (~1cm) the prototype is not yet **compact**

R&D for Very Compact Calorimeter
Prototype of thin (<1mm) sensor module

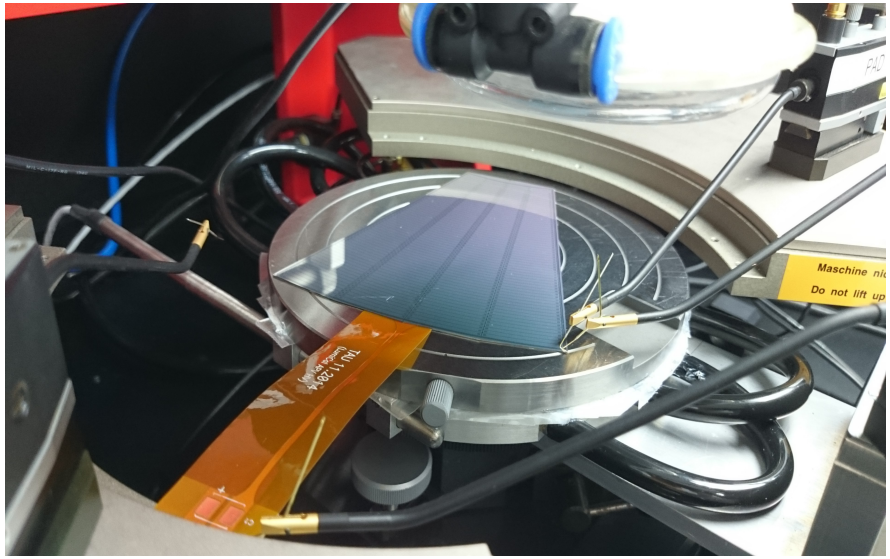


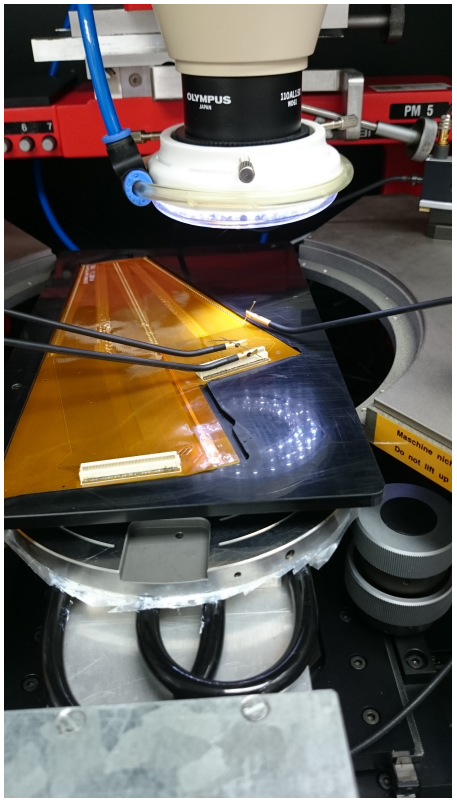


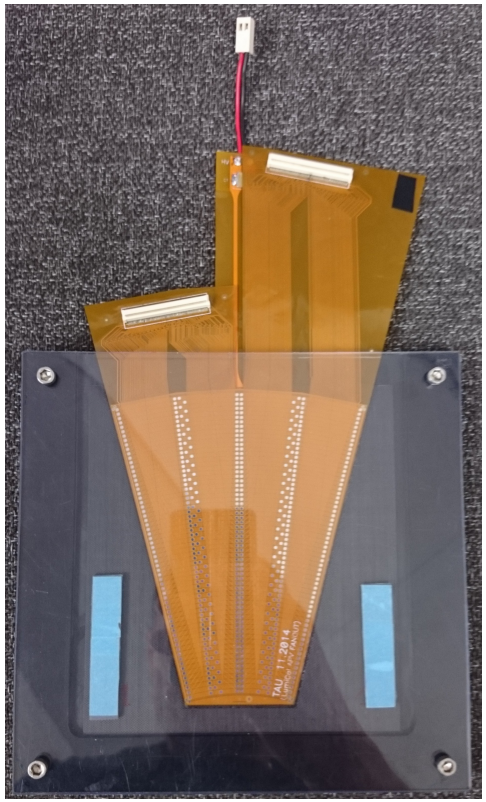


Thin sensor modules comprising envelope, sensor, and kapton fan-outs were designed and fabricated. For the envelope 3D printing and carbon fiber were tried, and carbon fiber was chosen as more rigid

R&D for Very Compact Calorimeter
Thin sensor module fabrication



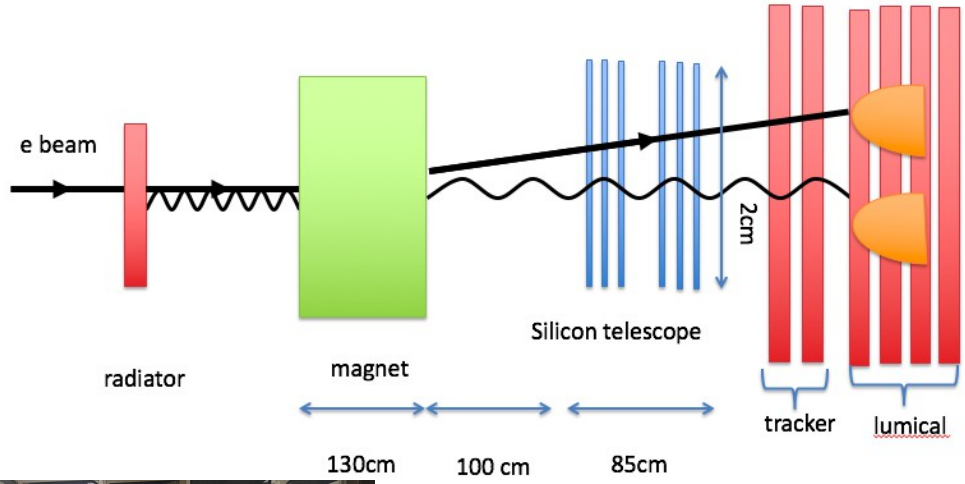


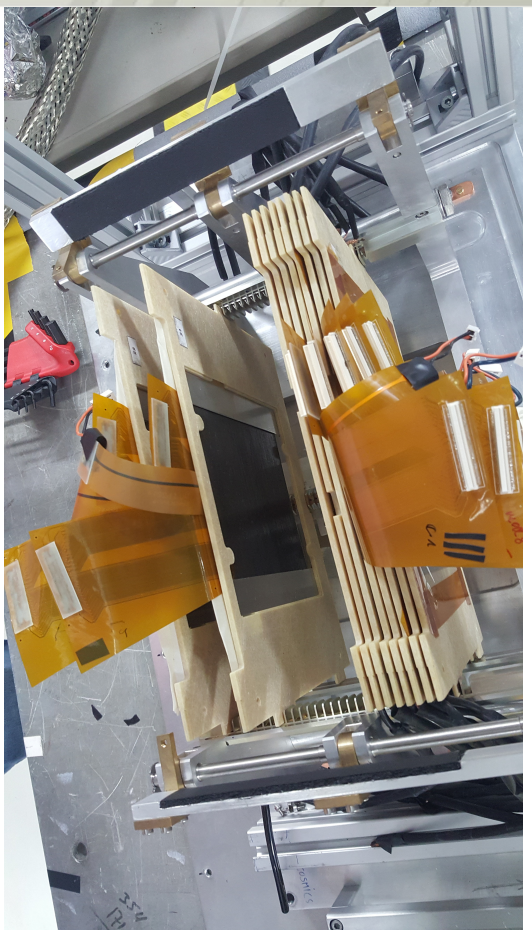


- HV kapton was conductively glued to n-side of the sensor,
- Fan-out with Panasonic connector glued to the p-side, ultrasonic wire bonding used to connect sensor pads to fan-out traces.
- Low-height contacts technologies (TAB bonding, spring contact) under study...

R&D for Very Compact Calorimeter
Test-beam with thin sensor modules

- 2016 test-beam with 1-6 GeV electrons at DESY
- Eight sensor modules (6 in LumiCal and 2 as tracker) used (one with TAB bonding)
- External electronics (ASD-based) used

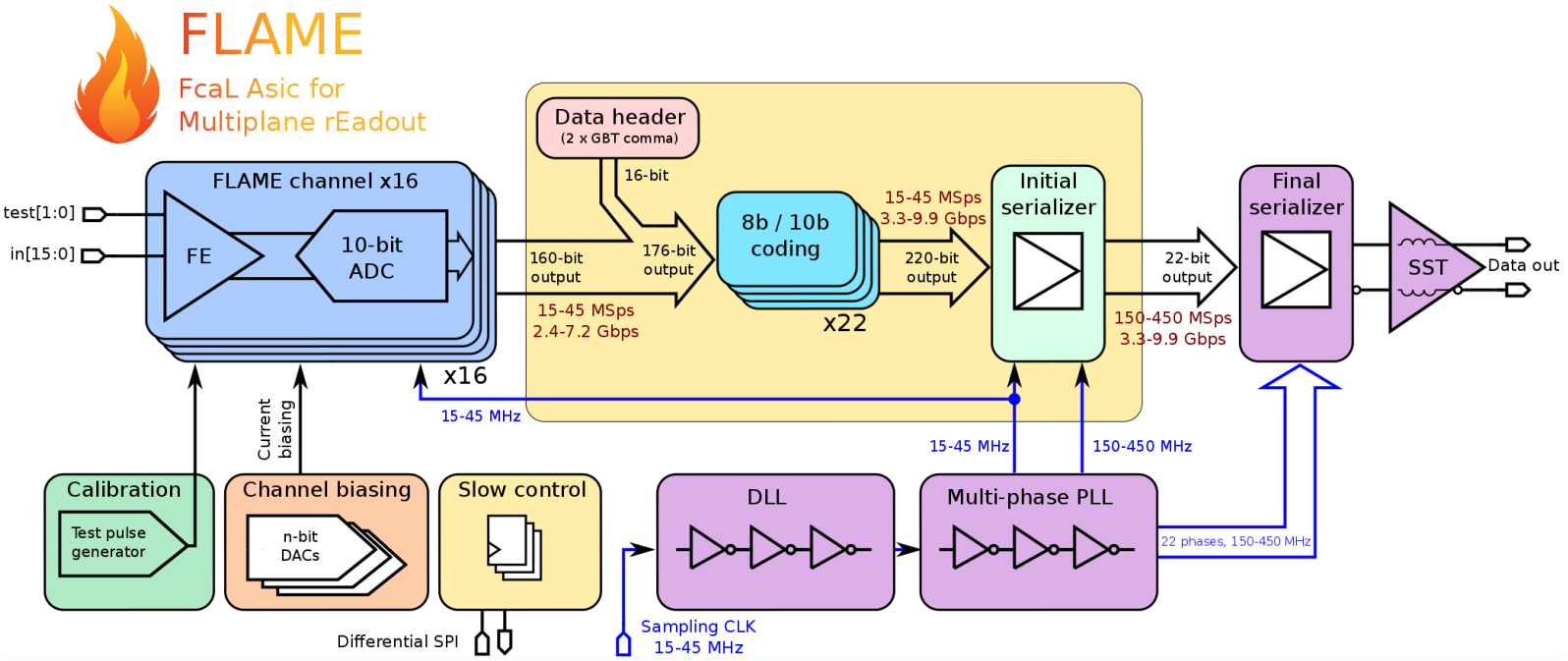




Test-beam has just finished. Data analysis has just started...

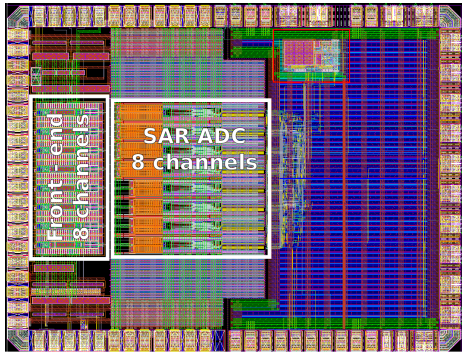
R&D for Very Compact Calorimeter
FLAME new SoC type readout ASIC for LumiCal

- For **very compact** calorimeter an ultra-low power, SoC type readout ASIC needed
- FLAME: project of 16-channel readout ASIC in CMOS 130nm, front-end&ADC in each channel, fast serialization and data transmission, all functionalities in a single ASIC



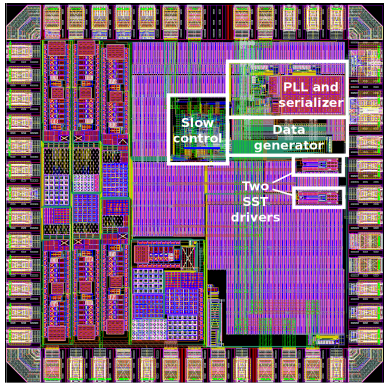
R&D for Very Compact Calorimeter Prototypes of FLAME key blocks

- Prototype 8-channel FE+ADC ASIC:
  - Front-end: variable gain, CR-RC shaper, Tpeak = 50ns, ENC~900el@20pF
  - ADC: 10-bit SAR, fs<=40MSps
  - Power (FE+ADC) <2mW/channel

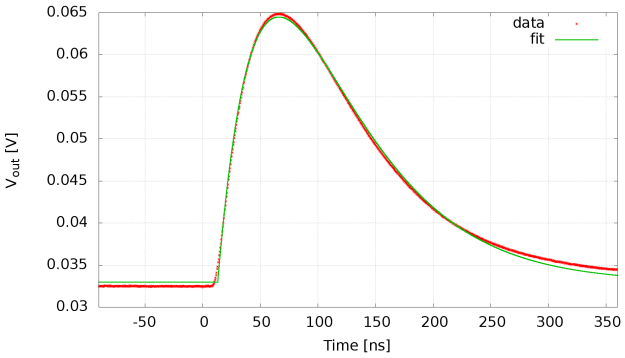


First tests started:
- front-end: OK
- ADC: OK
- front-end&ADC: setup still in preparation...
- serializer: basic functionality OK
- serializer, data transmission: setup still in preparation...

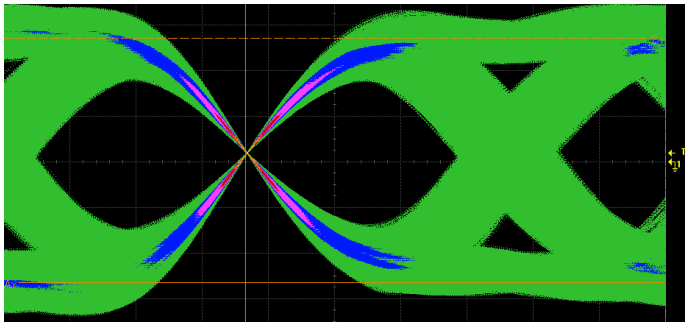
- Prototype serializer ASIC comprising:
  - Fast ultra-low power multi-phase PLL
  - Power <20mW@10Gbps
  - Fast serializer 22b → 1b
  - Fast SST driver



Front-end response for MIP



Eye diagram at 5Gbps



Summary

R&D for very forward calorimetry at future linear collider is carried on within the FCAL collaboration:

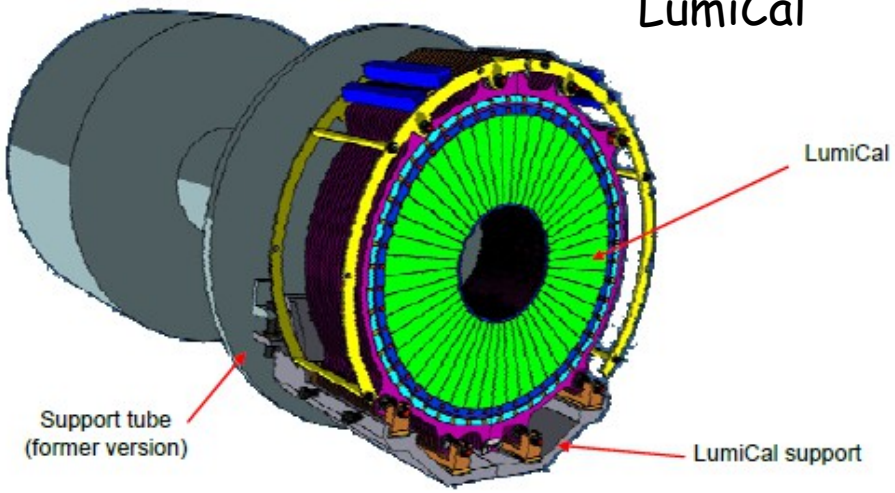
- Development of very compact calorimeter prototype, presently the main FCAL goal, in advanced stage:
  - Prototypes of new thin sensor modules have been already fabricated and used in the test-beam. Data analyses are ongoing...
  - Prototypes of key blocks of FLAME - new fast, ultra-low power SoC type readout ASIC – fabricated and first promising results obtained
- In parallel various R&Ds, like studies of new rad-hard sensors for BeamCal, Tracker in front of LumiCal, design of LHCal, BeamCal readout, are underway.

Thank you for attention

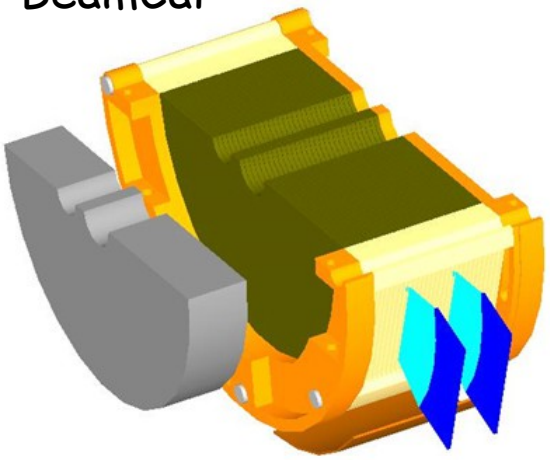
Backup

Forward detectors

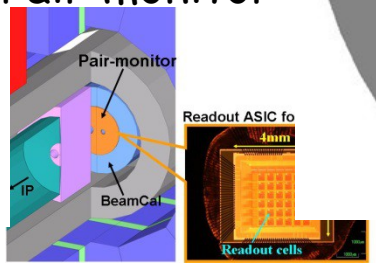
LumiCal

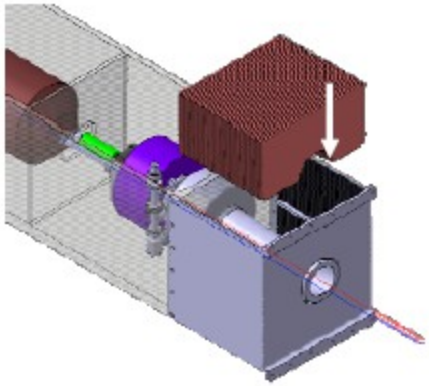


BeamCal

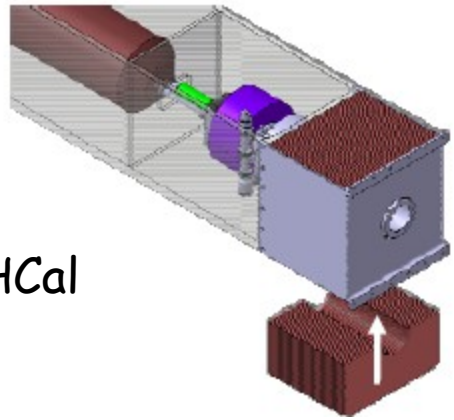


Pair monitor

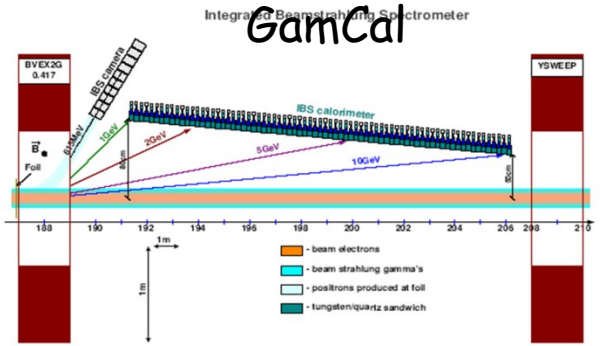




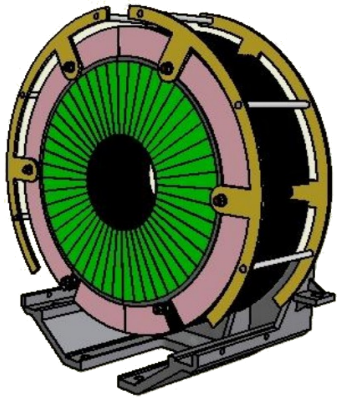
LHCal



GamCal



FCAL overview
Luminosity measurement by LumiCal detector

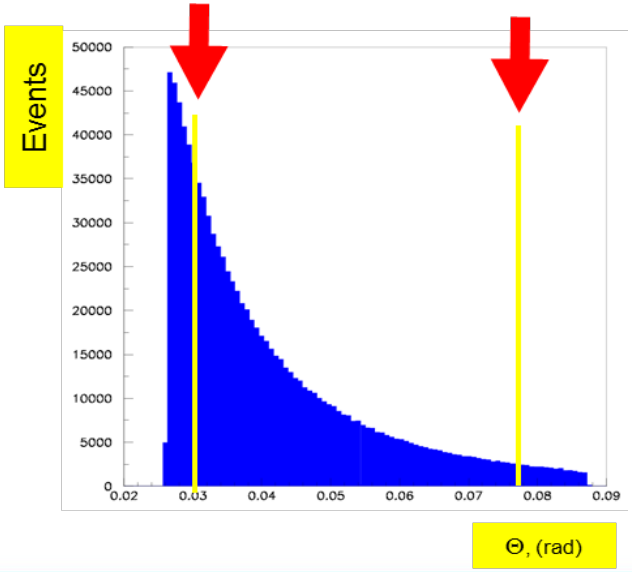


- Precise measurement of luminosity (10^{-3} at ILC, 10^{-2} at CLIC)
- Low angle physics

Gauge process for the luminosity measurement: Bhabha scattering

e+e- ⟶ e+e- (γ)

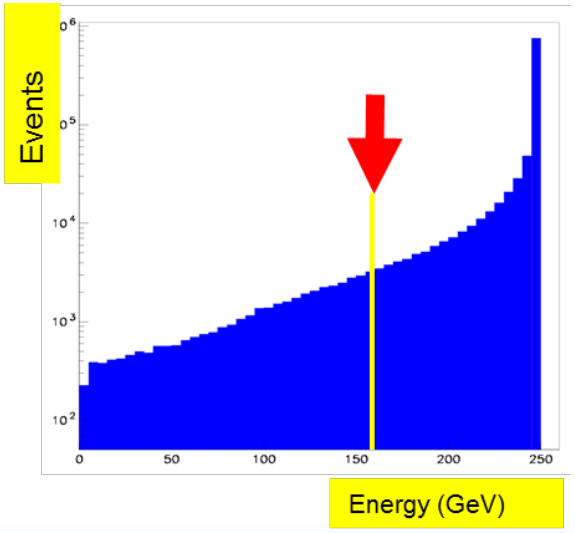
$$\frac{d\sigma_B}{d\theta} = \frac{2\pi\alpha_{em}^2}{s}\frac{\sin\theta}{\sin^4(\theta/2)} \approx \frac{32\pi\alpha_{em}^2}{s}\frac{1}{\theta^3}$$



$L = N / \sigma$

Bhabha events count

From theory

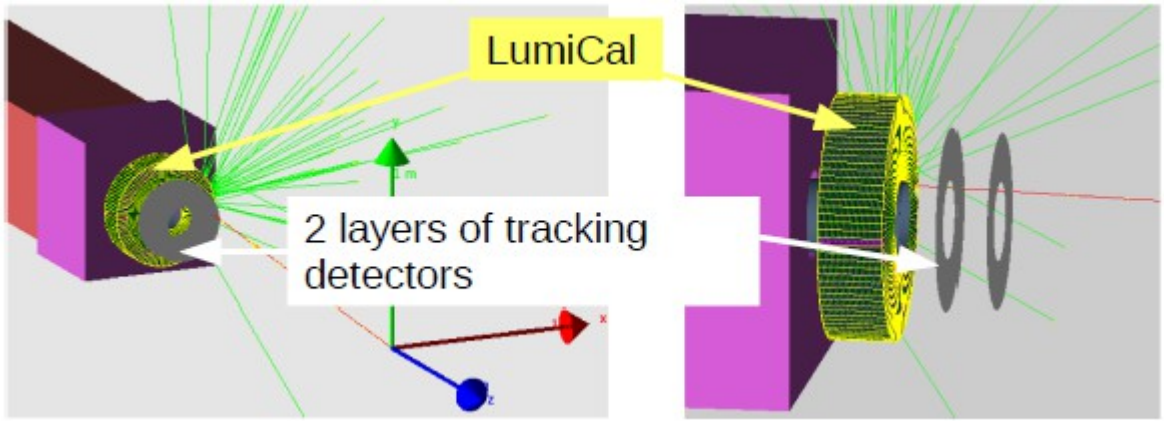


Other FCAL R&Ds
Studies of Tracker in front of LumiCal

Motivation:

• Enable e/γ identification, important for various physics studies, like dark matter searches and photon structure function,

• Improve polar and azimuthal angle measurement accuracy.



In August 2016 test-beam at DESY we would like to study e/γ identification using standard LumiCal sensors as tracking detectors.

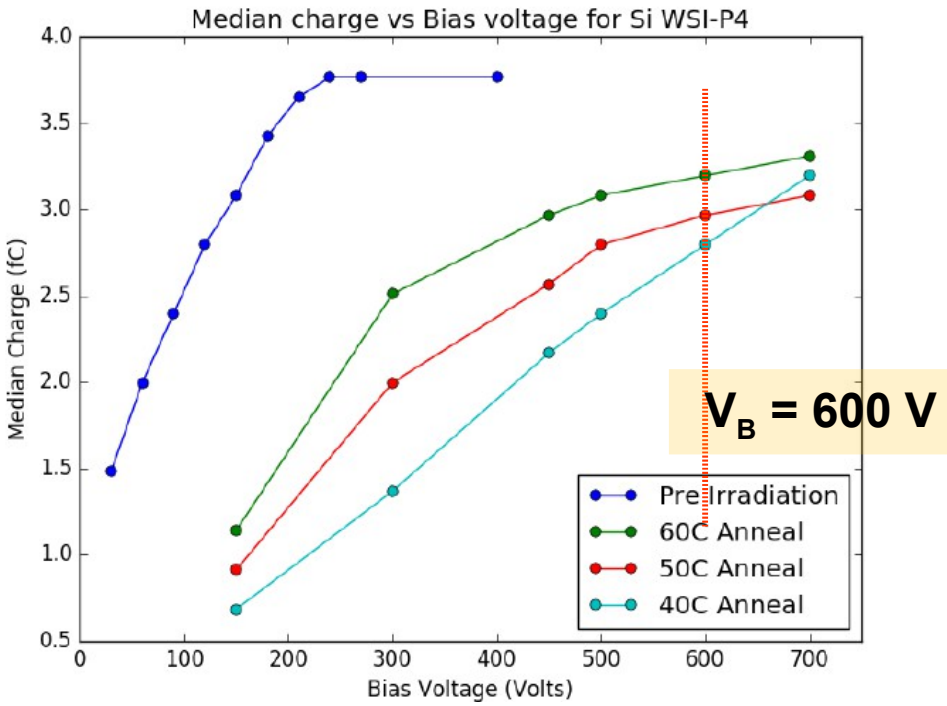
Other FCAL R&Ds
Radiation studies of BeamCal sensors at SLAC

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)

New sensor module
Low-height contact of the sensor

- Approaches :
  - **wirebonding**

    conventional, currently used, minimum height ~100µm
  - **Flat loop wire bonding**

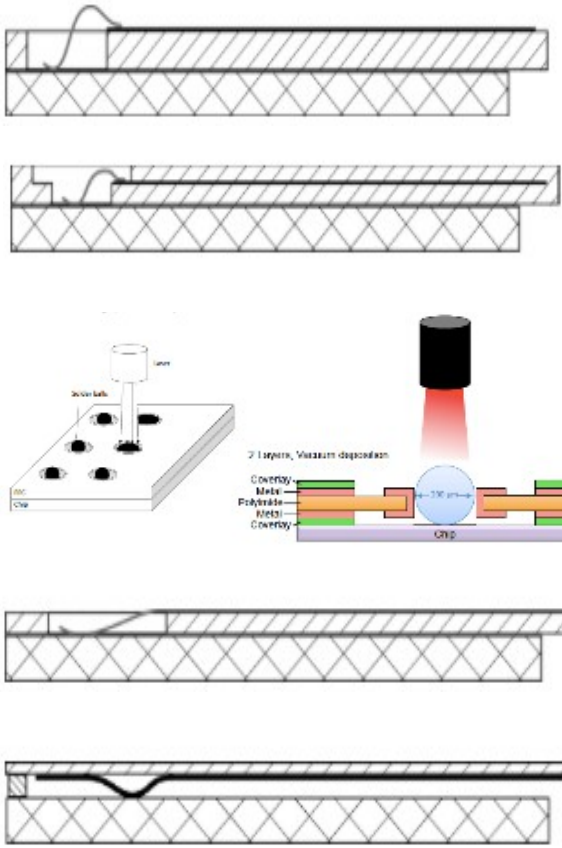
    staggered pcb required
  - **Conductive glue**

    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)



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