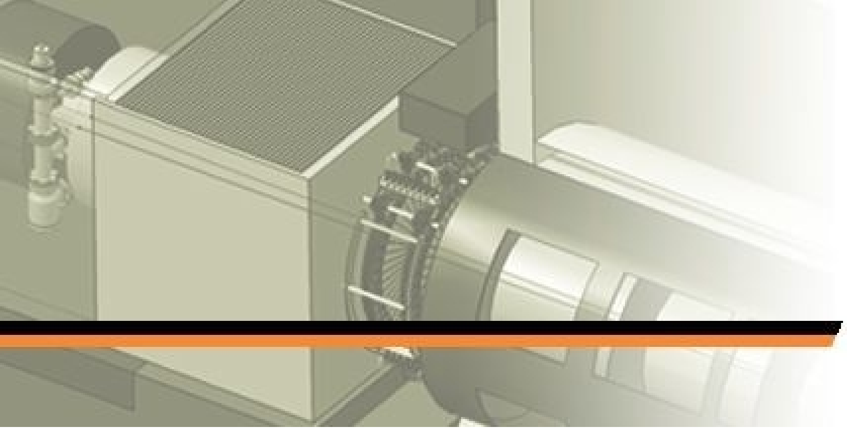

Design and R&D of very forward calorimeters for detectors at future e^+e^- collider

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[on behalf of the FCAL Collaboration]

Vinča Institute of Nuclear Sciences Belgrade, Serbia

Outline

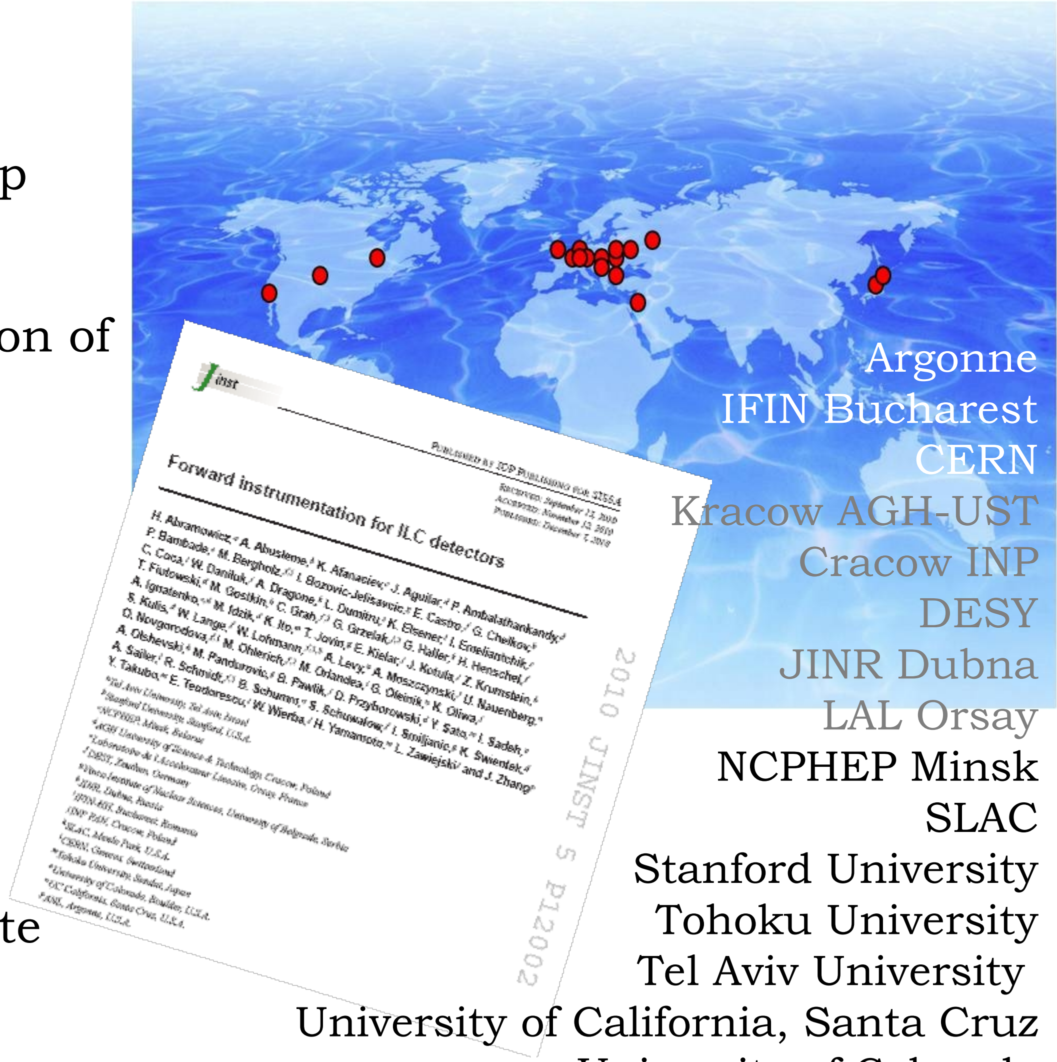
- R&D of FCAL
- Design, status and challenges of the forward region
- Detectors in the forward region
- LumiCal and BeamCal performance: simulation
- Luminosity measurement
- Electron identification in the forward region
- Read-out electronics for the forward calorimeters
- LumiCal and BeamCal performance: test-beam
- CLIC within FCAL
- Summary and future plans

R&D of FCAL

- FCAL dedicated effort to develop novel detector technologies to instrument the very forward region of future linear collider

- ILC, CLIC are in our focus

- Estimates of performance benchmarks are based on the Standard Model – concepts should be flexible to accommodate LHC discoveries

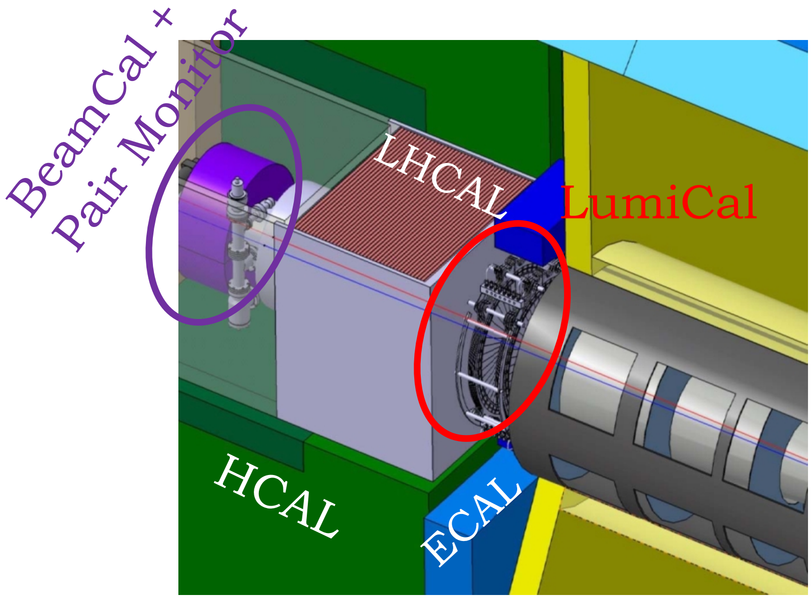


Argonne
IFIN Bucharest
CERN
Kracow AGH-UST
Cracow INP
DESY
JINR Dubna
LAL Orsay
NCPHEP Minsk
SLAC
Stanford University
Tohoku University
Tel Aviv University
University of California, Santa Cruz
University of Colorado
Vinca Institute Belgrade

Design, status and challenges

Ongoing simulations to optimize detector design for :

- precise luminosity measurement,
- hermeticity (missing energy, multi-jet final states),
- electron detection at low polar angles (SUSY)
- assisting beam tuning (fast feedback of BeamCal data to machine)
- shielding to the inner detectors.



Very forward region of the ILD detector
LumiCal [31,77]mrad
BeamCal [5.8,43.5]mrad

Challenges:
- Luminosity precision at permille level, mechanical precision of the LumiCal
- BeamCal: e identification over the huge beamstrahlung background, extreme radiation hardness (10^4/BX low energetic e^+e^- pairs ~10 TeV/BX or several MGy/year)

+ Read-out: high input rate (3.25 MHz), high occupancy

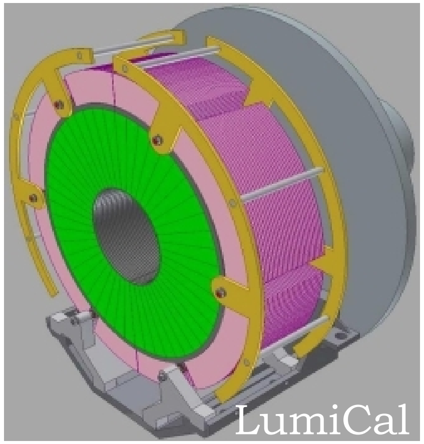
Detectors in the forward region

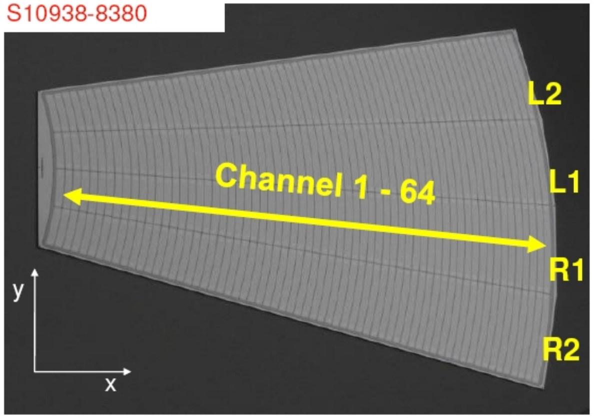
Technologies:

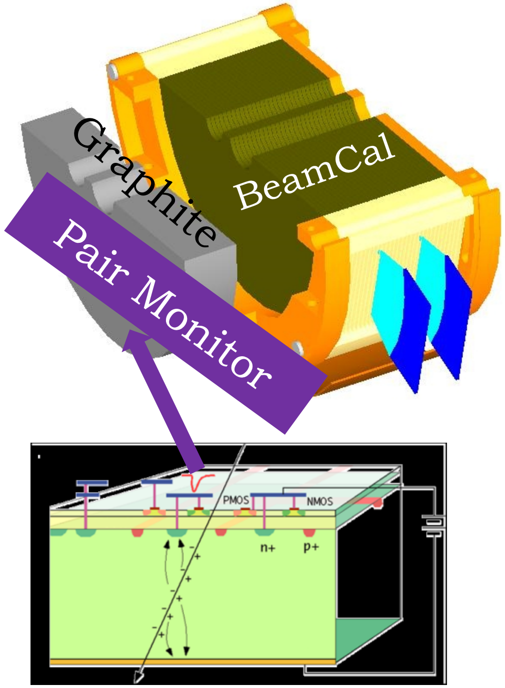
- LumiCal sampling SiW

- BeamCal W absorber +poly(mono)crystaline CVD diamond/GaAs/rad-hard Si

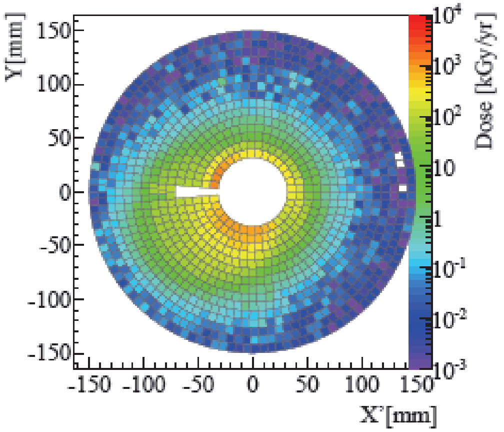
- Pair Monitor $2 \cdot 10^5$ Si pixel (SoI) (0.4, 0.4)mm







Radiation dose in the 5th layer of BeamCal



-small Moliere radius O(1cm) – good E resolution

- segmentation (azimuthal/radial): 48/64

- energy resolution: 0.21 $[GeV^{1/2}]$

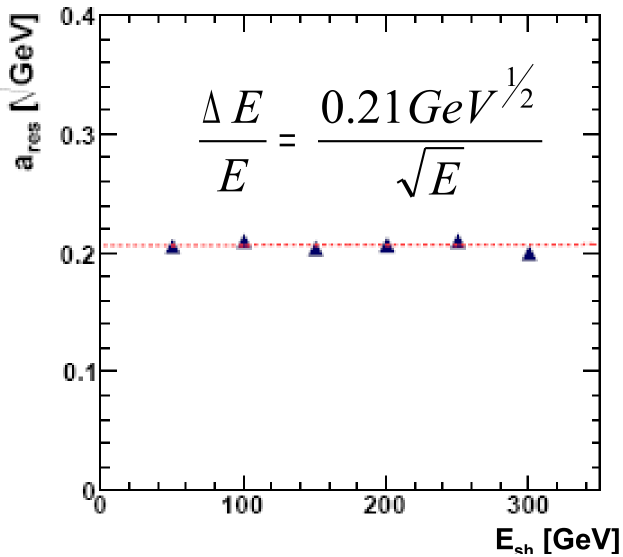
-resolution in polar angle: $(2.18 \pm 0.02) \cdot 10^{-2}$ mrad

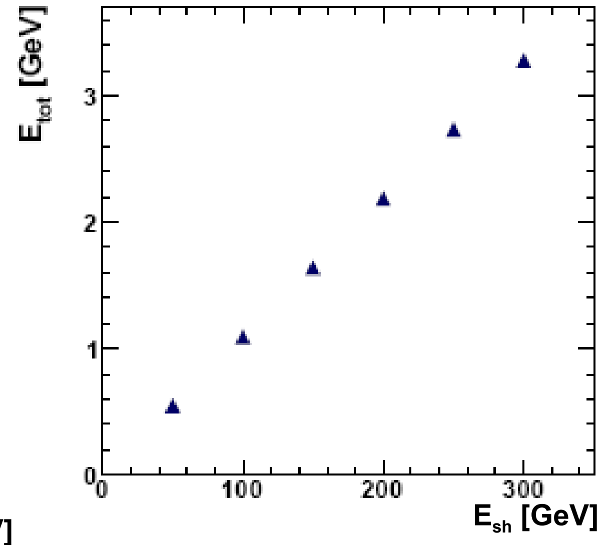
- Radiation hard sensors

-Beam parameters measurement

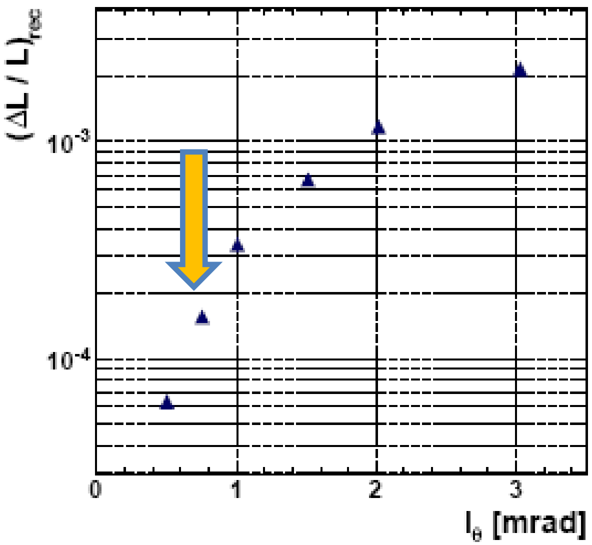
- (σ_x permille level, σ_y, σ_z ~ few percent)

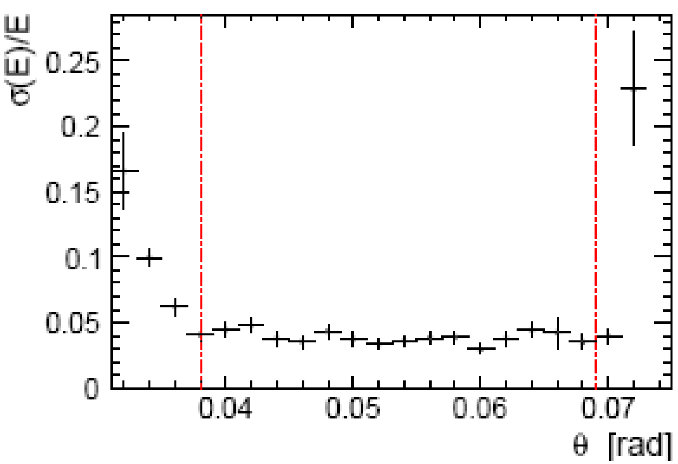
LumiCal performance: simulation





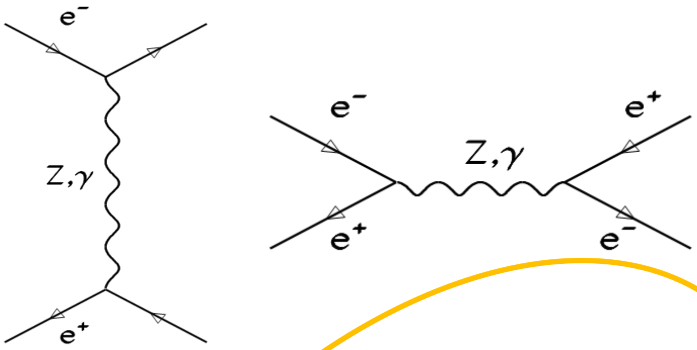
$$l_\theta = 0.8 mrad, \frac{\Delta L}{L} = 1.6 \cdot 10^{-4}$$

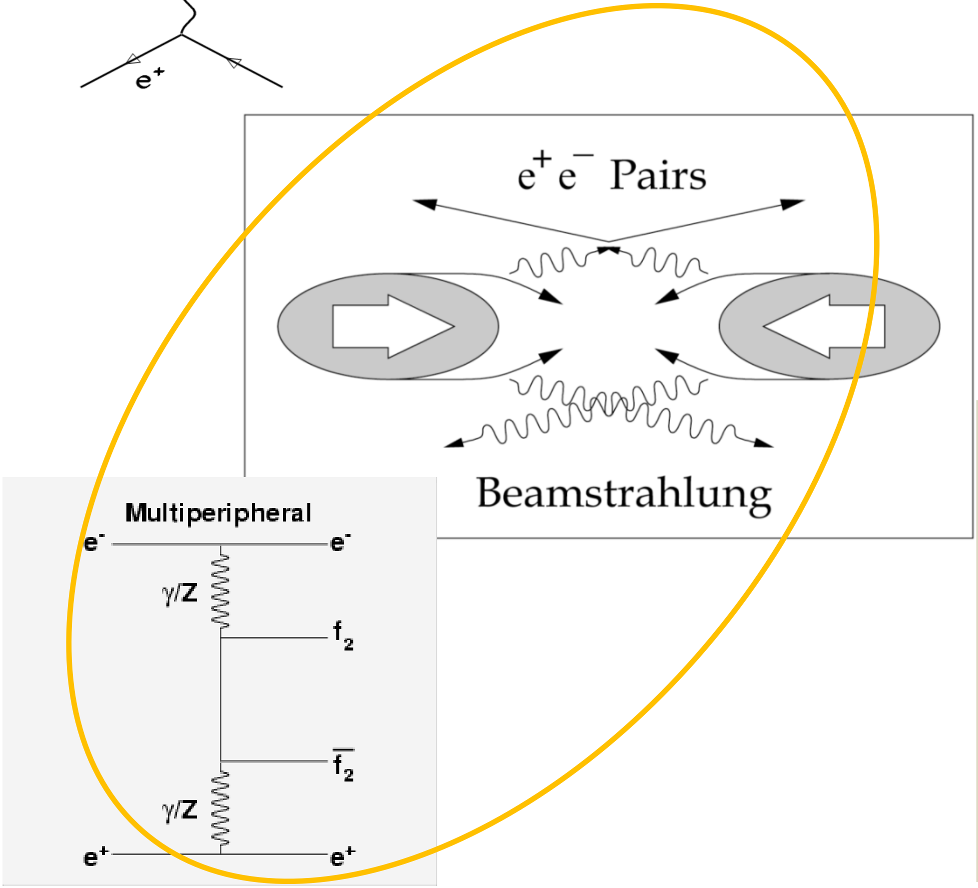




-Stable sampling term vs. shower energy
- Linearity of the integrated deposited energy vs. shower energy
- Cell size sufficiently small to provide excellent θ reconstruction
- Stable E resolution within [38, 69] mrad

Luminosity measurement





$$L_{\mathrm{int}} = \frac{N_{th}}{\sigma_B} \Rightarrow L_{\mathrm{int}} = \frac{N_{\exp} - \sum_i N_i^{cor}}{\varepsilon \cdot \sigma_B}$$

α_i

$$\left(\frac{\Delta L}{L}\right)_i = \frac{\Delta \alpha_i}{\alpha_i}$$

- Bhabha scattering is pure (99%) QED process.
- Counting experiment.
- However, corrections (and their uncertainties are present).
- Dominant systematics comes from 2-photon process and beam-beam interaction effects

Systematic uncertainties of luminosity measurement at 500 GeV

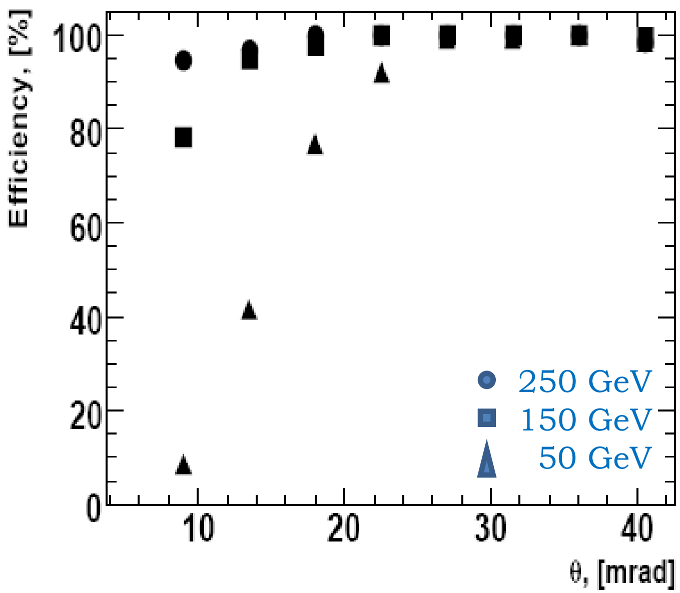
Source	Value	Uncertainty	Luminosity Uncertainty
σ_θ	2.2×10^{-2} [mrad]	100%	1.6×10^{-4}
Δ_θ	3.2×10^{-3} [mrad]	100%	1.6×10^{-4}
a_{res}	0.21	15%	10^{-4}
luminosity spectrum			10^{-3}
bunch sizes σ_x, σ_z,	655 nm, 300 μm	5%	1.5×10^{-3}
two photon events	2.3×10^{-3}	40%	0.9×10^{-3}
energy scale	400 MeV	100%	10^{-3}
polarisation, e^-, e^+	0.8, 0.6	0.0025	1.9×10^{-4}
total uncertainty			2.3×10^{-3}

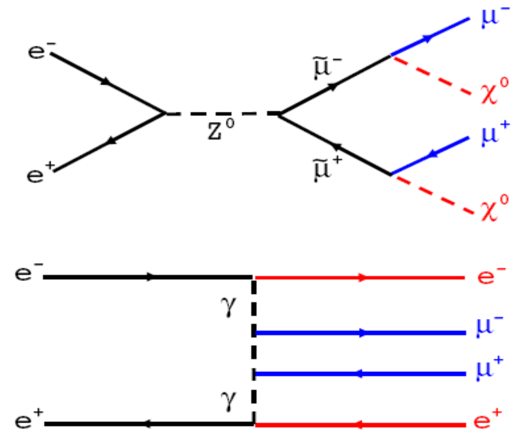
* 100% = Upper limit – the size of effect is taken as uncertainty

-It is proven (in simulation) that luminosity can be measured at 500 GeV center-of-mass energy at a permille level

-Most of the systematic effects can be taken as corrections once their experimental uncertainties are known (Δθ, miscounts due to physics background, BHSE).

Electron identification in the forward region

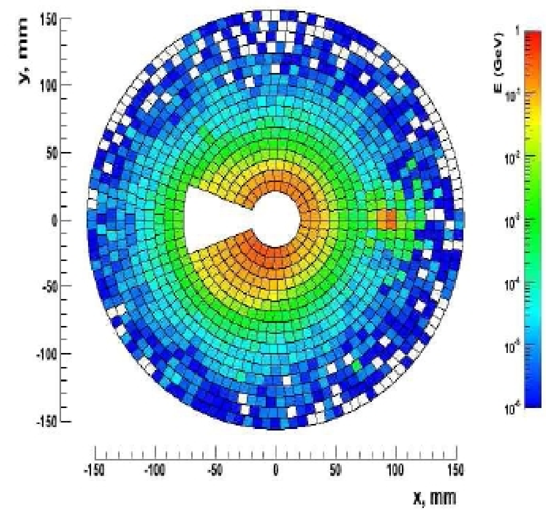




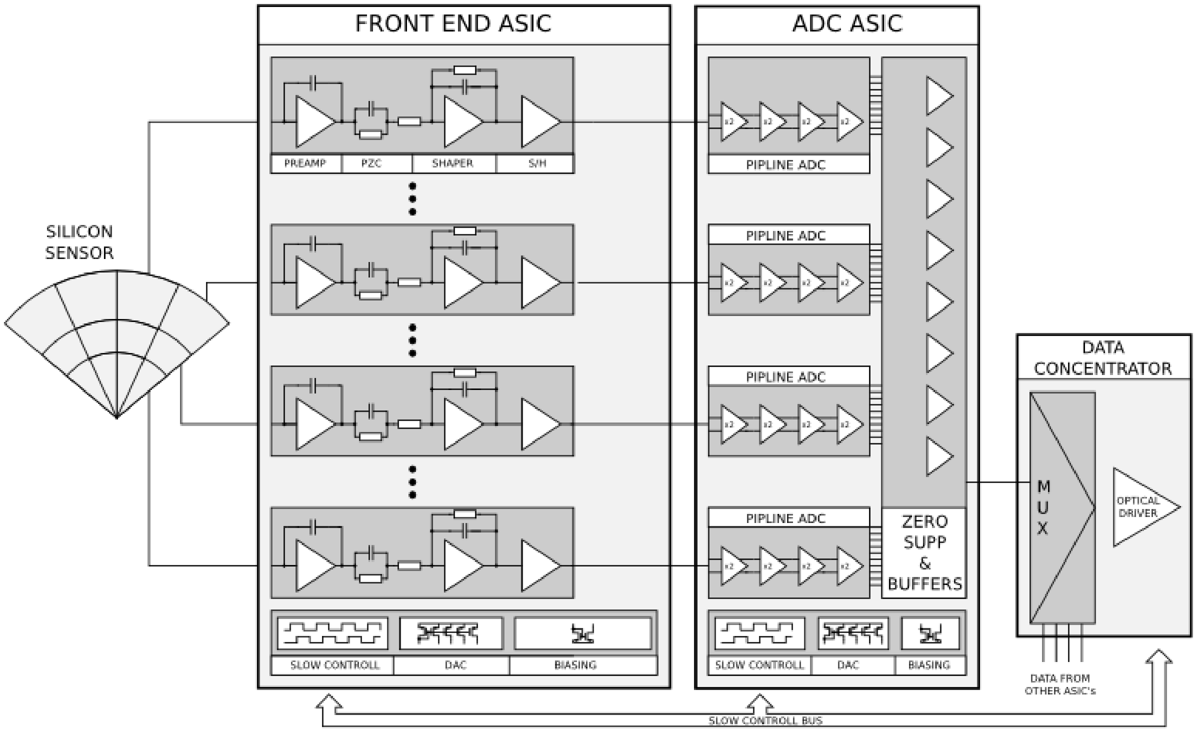
$\sigma \sim fb$

$\sigma \sim nb$

- Subtraction of pair deposits + shower finding algorithm = high electron detection efficiency
- Important for SM background reduction in E-missing searches



Read-out electronics for the forward calorimeters

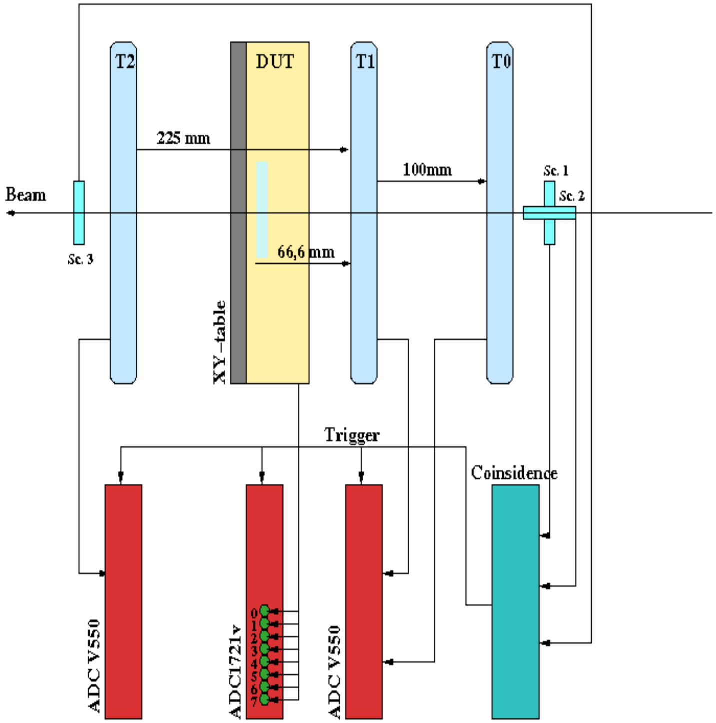


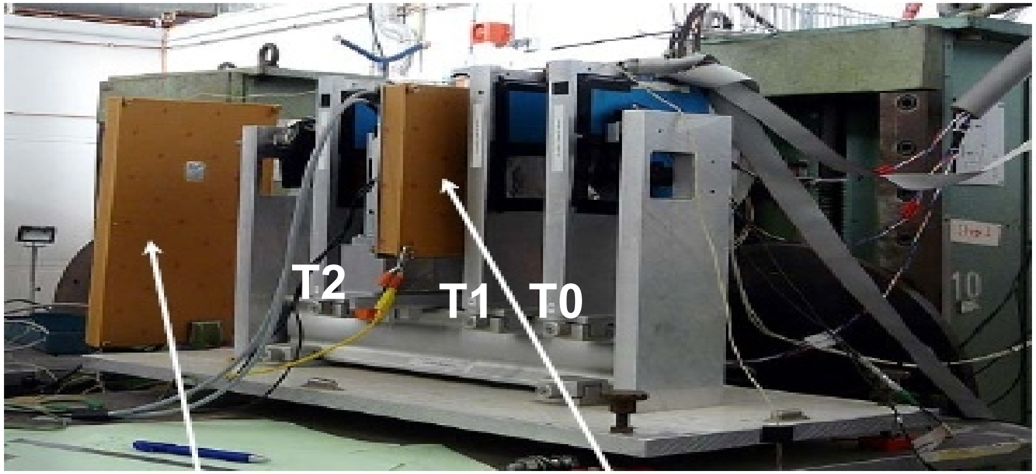
LumiCal readout architecture:

- 2barrels * 30planes * 48sectors * 64pads
- ~200 000 channels

First prototypes of all blocks already done: Silicon sensor from Hammamatsu, 8 channels front-end ASIC, 8 channels 10 bit pipeline ADC, Data concentrator implemented in Xilinx FPGA

Test Beam DESYII





Stand-by box Device under test

LumiCal

-Sensors prototyped and cross-calibrated in different labs/Cracow, DESY, Tel Aviv

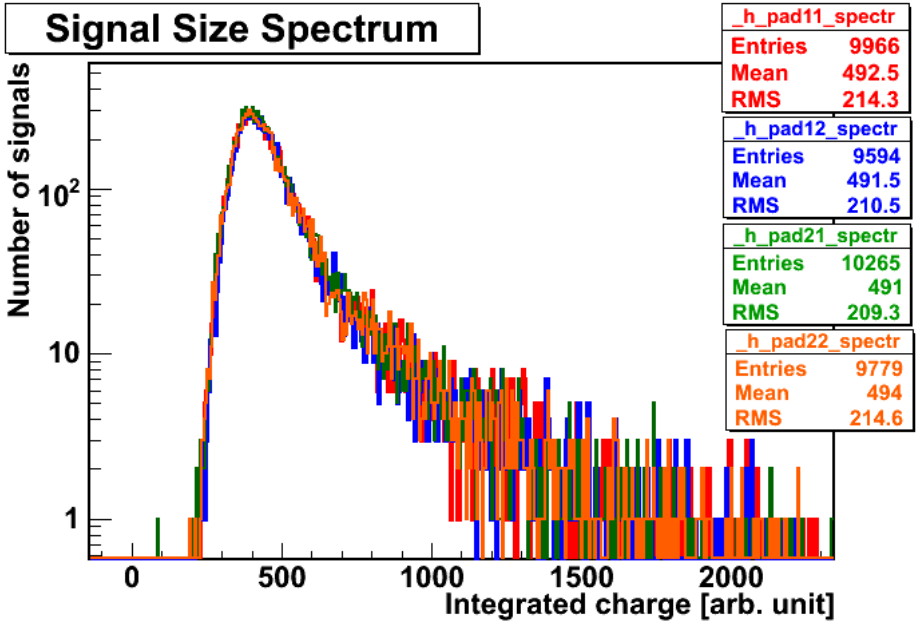
- FE and ADC ASICs developed (Cracow) and tested/ Cracow, DESY

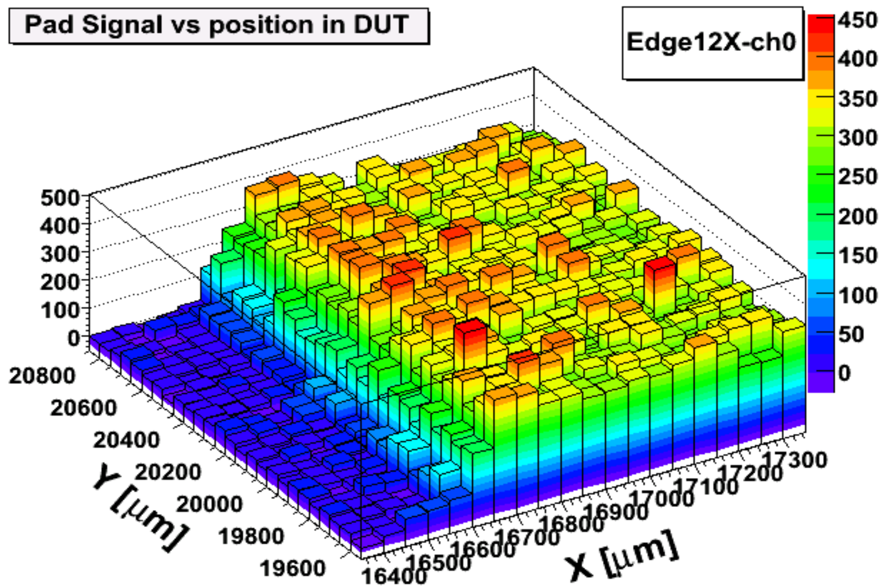
BeamCal

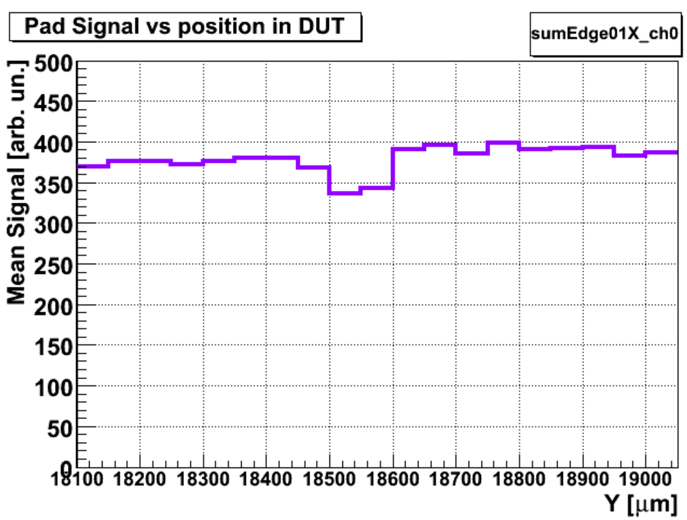
- Sensor prototyped for different technologies (GaAs, rad-hard Si)/JINR, SLAC
- Frontend ASICs designed and prototyped/Cracow, SLAC

The full chain sensor-fan-out- FE ASICs tested at Beam 22 at DESY II, 4.5 GeV electrons

BeamCal performance: test-beam







- GaAs plate with Al metallization: 500 µm thick 45 deg tiles, segmented into 12 rings, 5x5mm² pads

- S/N ratio and CCE are good: CCE ~33% at 60V, S/N ~19 for all channels.

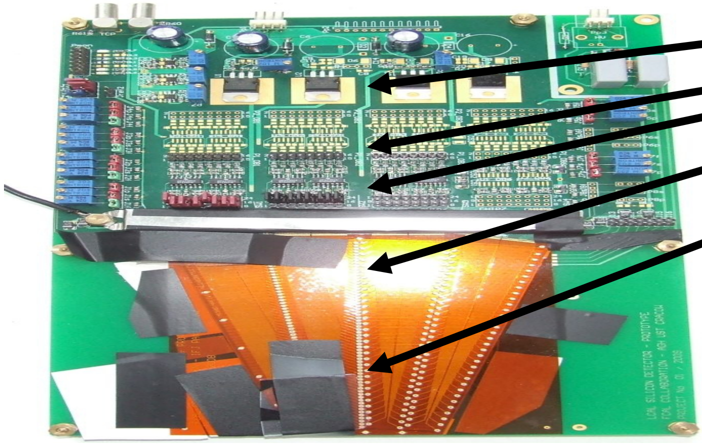
-4 independent pad areas show identical charge collection.

- Homogeneous response of the pad signal.

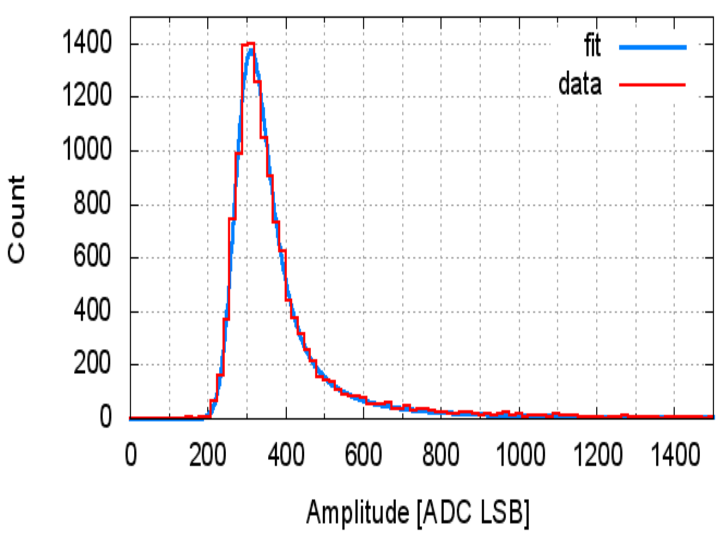
- Edges loose of about 10% of the signal.

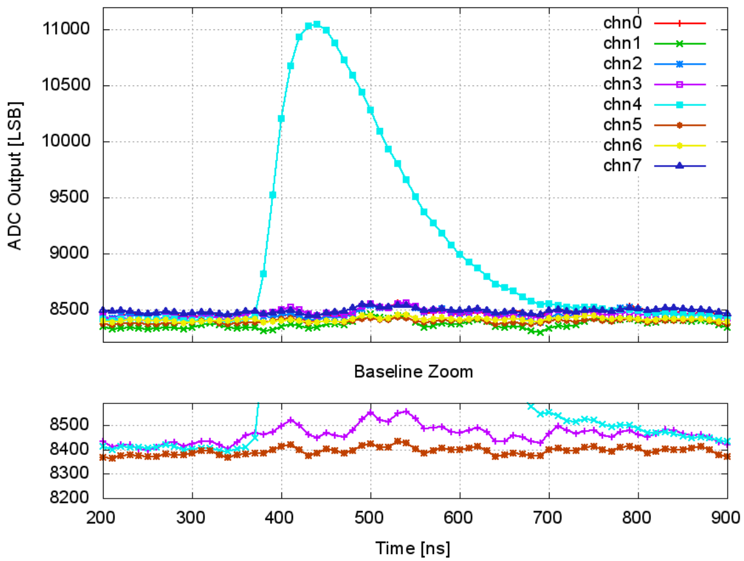
LumiCal performance: test-beam

Readout chain



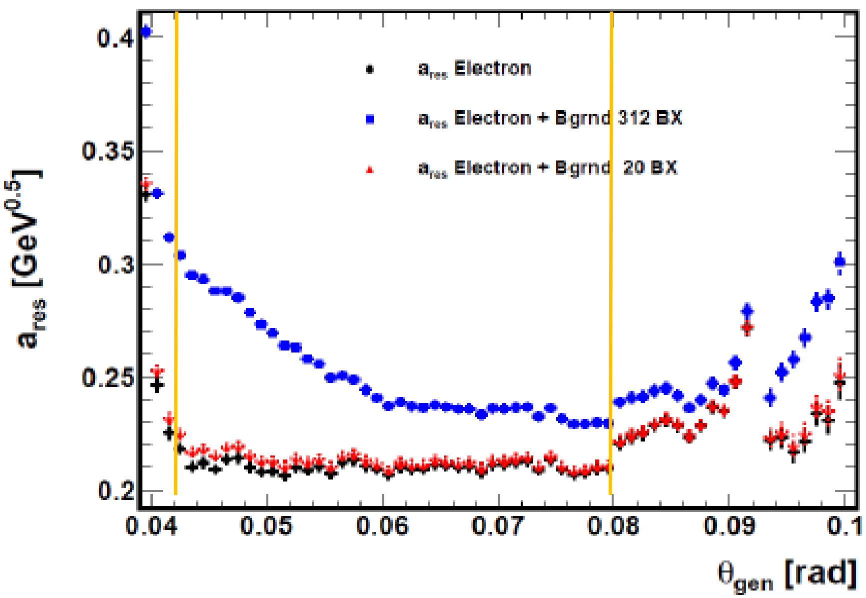
- Biasing and power blocks
- Output buffers
- FE ASICs bonded onto PCB
- Sensor and fanout glued
- 16 sensor pads bonded (300μm Si, 1.8mm pitch, 10.5mm - 25.5mm wide)

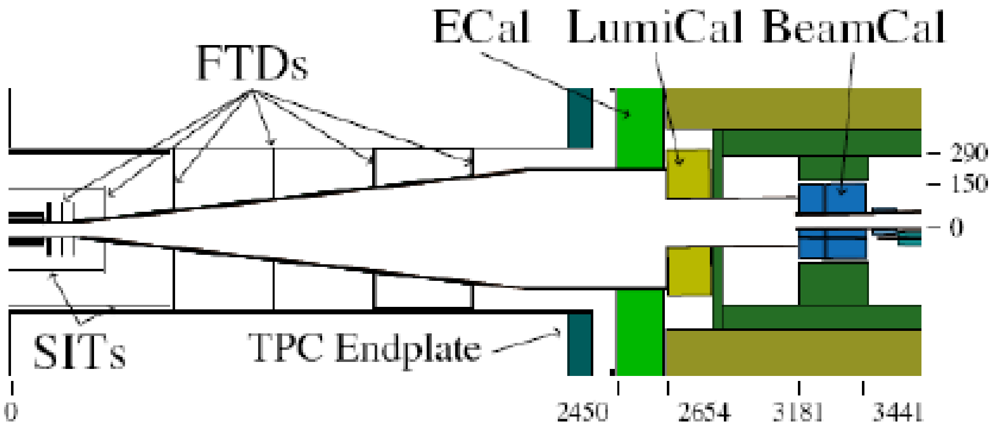




Signal to noise ratio ~19
Cross-talk ≤ 1%

CLIC within FCAL





Luminometer physical volume [36-109]mrad

Precision requirements: $\frac{\Delta L}{L} \sim 10^{-2}$

-Luminometer fiducial volume [43-80]mrad

- (Incoherent) pair background deteriorates E resolution for 1% (20 BX), 10-30% for 1 train (312 BX)

Ongoing studies:

- Background from coherent and incoherent pairs (CERN)
- Background impact on energy resolution (Tel Aviv)
- Physics background (4-f) (Vinca Belgrade)

+ Design and construction of the mechanical structure for FCAL (CERN)

Summary

- Design of the calorimeters in the very forward region at future linear collider (ILC) is developed and optimized with Monte Carlo simulations. FCAL design study is extended to CLIC.

- Sensors and read-out electronics have been designed and prototyped.
- Assembled prototypes (sensor-fan-out- FE ASICs) have been satisfactorily tested for both calorimeters: luminometer and the beam calorimeter.

- It has been shown that luminometer can be designed in such a way to meet requirement on luminosity precision at permille level (precision EW, extended gauge theories, anomalous TGCs…).

- It has been demonstrated that high energy electrons can be efficiently detected down to very low polar angles of a few mrad.

Future plans

- Ongoing preparation of ILC EDR 2012 and CLIC CDR until the end of 2011

-FCAL at AIDA (FP7-INFRASTRUCTURES-2010-1):

    -Design and construction of the mechanical structure to accommodate the prototype calorimeter (design 2012, manufacturing 2013, ready 2014)
    - Multichannel (64) readout ASICs: design start 2011, 1st prototype production, 2012, 2nd 2013
    - Complete prototype of sensor plane 2012
    - DAQ: 1st DIF prototype 2011, prototype of complete DAQ 2012, ready 2013
    - Design fixed - beginning 2013
    - Production 2014

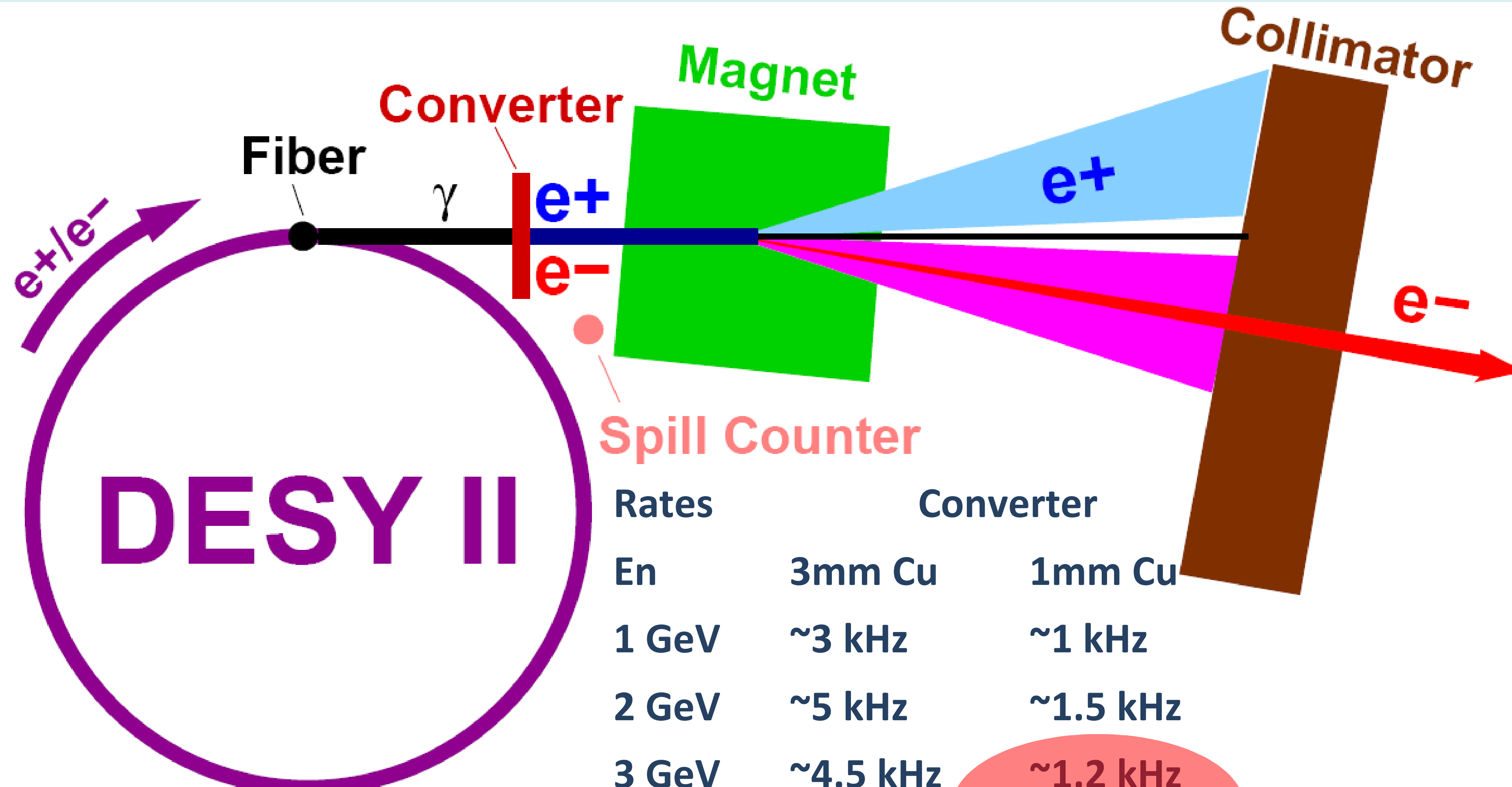
BACKUP

LumiCal and BeamCal parameters

LumiCal	Unit	
Absorber layer	mm	3.5
Air gap	mm	0.1
Sensor thickness + pad metalization $1 X_0$	mm	0.320 + 0.020
Fanout thickness	mm	0.4
Total plane thickness	mm	4.355
Total X_0	int	30
x/y/z position	mm	+15.9/0/2500
R_{inner}^* (sensitive area)	mm	80
R_{outer} (sensitive area)	mm	195.2
θ_{inner}	mrad	31
θ_{outer}	mrad	78
Tilt	mrad	7
Space for electronics (outside the plane)	mm	4.5
Mass of the LCAL (1 arm)	kg	211.319

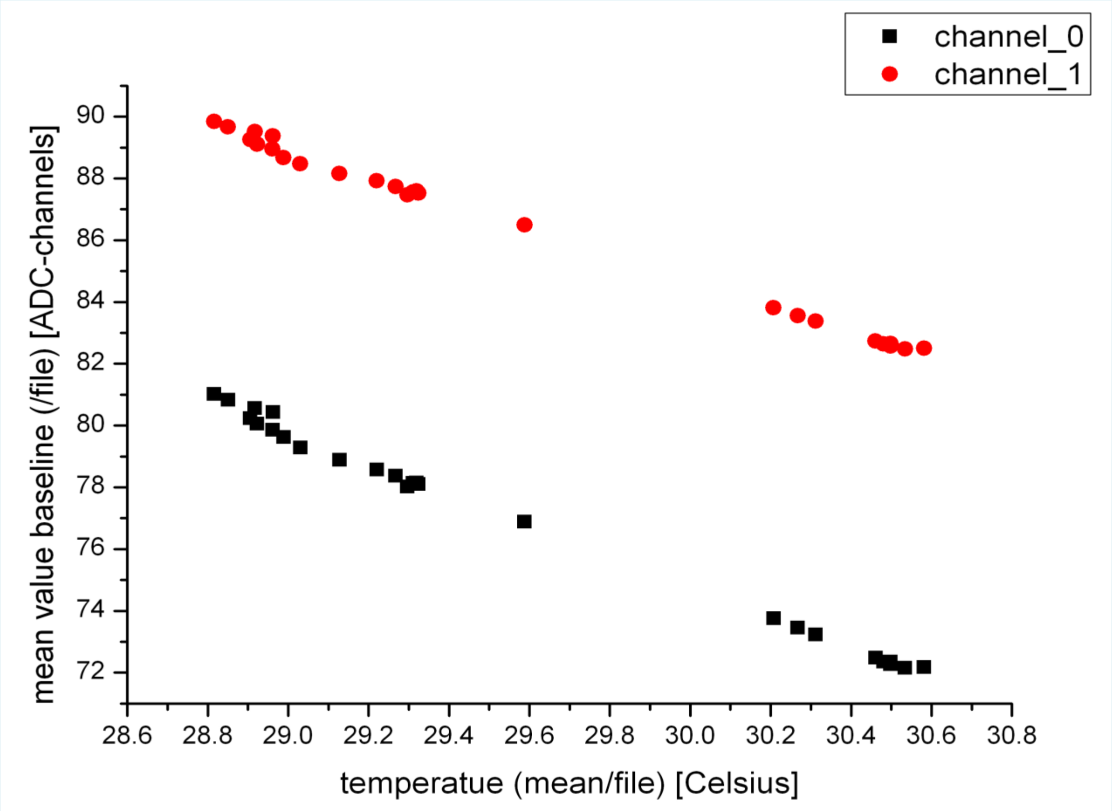
BeamCal	Unit	14 mrad
Graphite shield thickness	mm	100
Absorber layer	mm	3.5
Sensor layer $1 X_0$	mm	0.3
Readout plane /air gap	mm	0.2
total X_0	int	30
x/y/z position	mm	+24.2/0/±3450
R_{inner} (sensitive area)	mm	20
R_{outer}^* (sensitive area)	mm	150
$R_{beam\_in}^{**}$	mm	15
θ_{inner}	mrad	5.8
θ_{outer}	mrad	43.5
Tilt	mrad	7
~ Weight of absorber and sensor (sensitive area)	kg	144.4

TestBeam DESY II



Rates	Converter	
En	3mm Cu	1mm Cu
1 GeV	~3 kHz	~1 kHz
2 GeV	~5 kHz	~1.5 kHz
3 GeV	~4.5 kHz	~1.2 kHz
5 GeV	~15Hz	~3Hz
6 GeV	~3 Hz	~1 Hz

BeamCal test-beam: temperature dependence

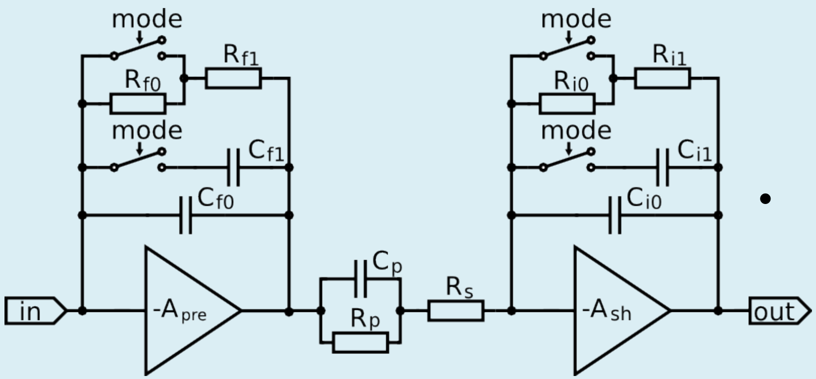


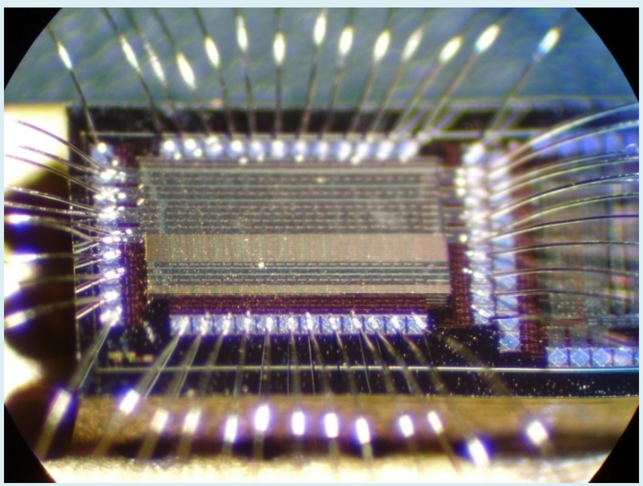
- Operation at room temperature

-Low leakage current ~200nA

-Leakage current can be significantly reduced by cooling up to 0 deg

LumiCal Front-End electronics





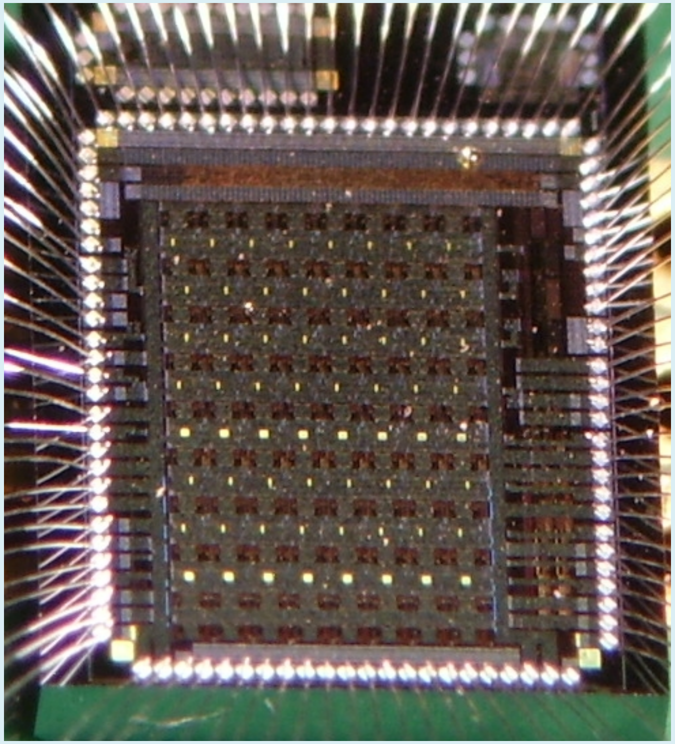
Existing prototypes:

- 8 channels in AMS 0.35um
- Cdet ≈ 0 ÷ 100pF (in new specs: Cdet<30pF)
- 1st order shaper (Tpeak ≈ 60 ns)
- Variable gain:
  - calibration mode - MIP sensitivity (~4fC)
  - physics mode - input charge up to 10pC
- Prototypes fabricated and tested
  - power consumption 8.9 mW/channel
  - event rate up to 3 MHz
  - Crosstalk < 1%

Multichannel ADC

- 8 channels of 10 bit pipeline ADC
- AMS 0.35um technology
- Layout with 200um ADC pitch
- Digital multiplexer/serializer:
  - Serial mode (~250MHz): one data link per all channels (max fsmp ~ 3 MSps)
  - Parallel mode (~250MHz): one data link per channel (max fsmp ~ 25 MSps)
  - Test mode: single channel output (max fsmp ~50 MSps)
- High speed LVDS drivers (<=1GHz)
- Power switching on/off
- Low power DAC voltage/current biasing
- Precise BandGap reference source
- Temperature sensor
- The only external analog signal - reference voltage (differential)

- SINAD ~60dB, ENOB 9.7 bit
- INL<0.7LSB, DNL<0.65 LSB

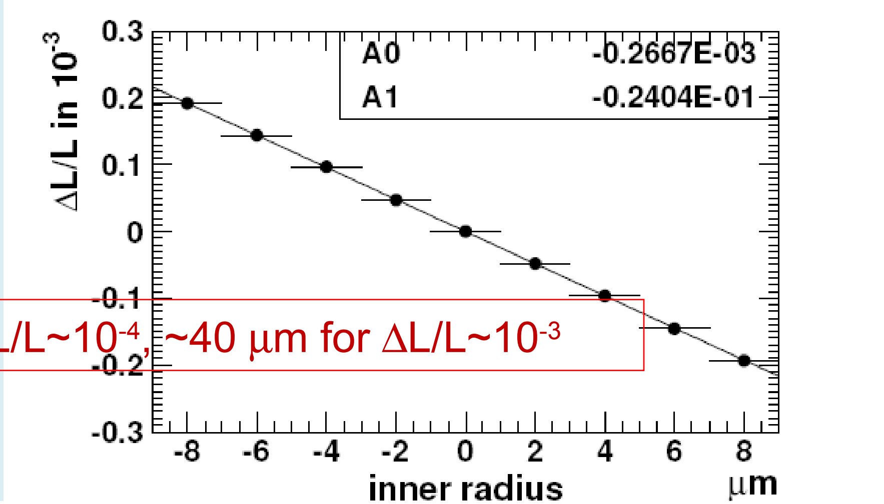


2.6mm x 3.2mm

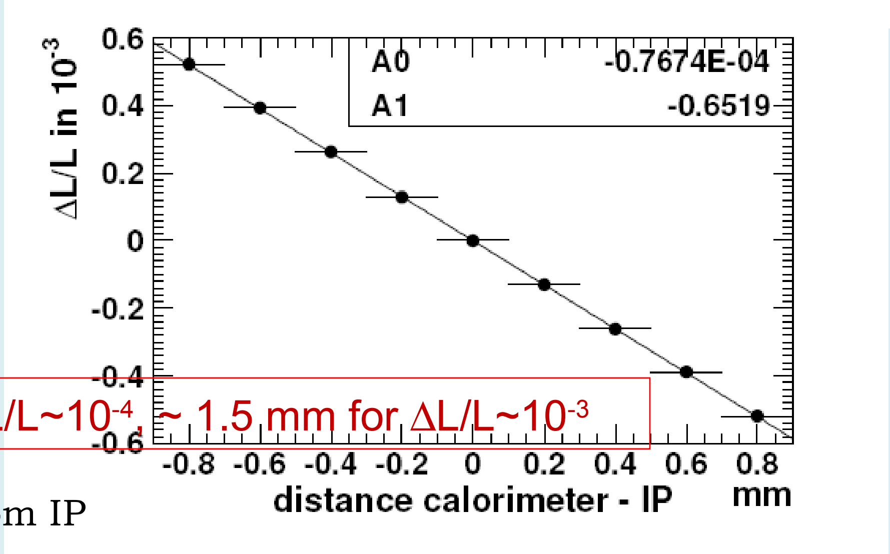
LumiCal mechanical issues

IN SITU

- **LPS prototype** monitors LumiCal as a whole object
- Obtained accuracy 0.5μm in the X-Y plane and 1.5μm in z direction – two orders of magnitude better than required
- Method for measuring displacement of individual sensor layers/inner radius under study



4 μm for $\Delta L/L \sim 10^{-4}$, ~40 μm for $\Delta L/L \sim 10^{-3}$



100 μm for $\Delta L/L \sim 10^{-4}$, ~ 1.5 mm for $\Delta L/L \sim 10^{-3}$

All by A.Stahl, old geometry [26,82] mrad, 3,05 m from IP