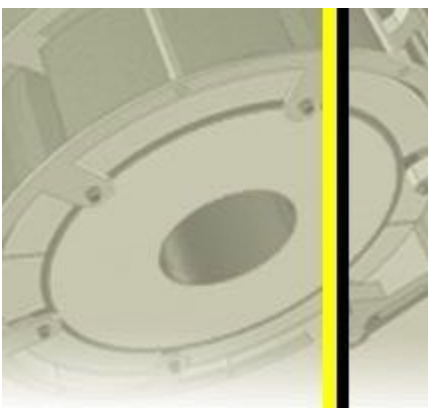
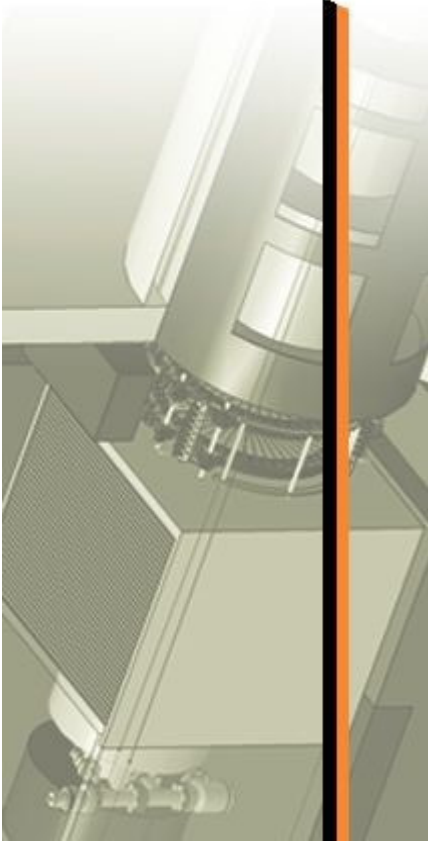




Design and R&D of very forward calorimeters for detectors at future e^+e^- collider

Ivanka Božović-Jelisavčić

[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

inst

Argonne
IFIN Bucharest
CERN
Krakow AGH-UST
Cracow INP
DESY
JINR Dubna

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Forward instrumentation for ILC detectors

H. Abramowicz,¹ A. Abushe,² K. Adamczyk,³ J. Aguilar,⁴ P. Akerstedt,⁵ S. Andersson,⁶ J. Backlund,⁷ M. Beggiani,⁸ K. Belyaev,⁹ I. Bortone,¹⁰ J. Brice,¹¹ C. Bunker,¹² C. Bunker,¹³ C. Bunker,¹⁴ C. Bunker,¹⁵ C. Bunker,¹⁶ C. Bunker,¹⁷ C. Bunker,¹⁸ C. Bunker,¹⁹ C. Bunker,²⁰ C. Bunker,²¹ C. Bunker,²² C. Bunker,²³ C. Bunker,²⁴ C. Bunker,²⁵ C. Bunker,²⁶ C. Bunker,²⁷ C. Bunker,²⁸ C. Bunker,²⁹ C. Bunker,³⁰ C. Bunker,³¹ C. Bunker,³² C. Bunker,³³ C. Bunker,³⁴ C. Bunker,³⁵ C. Bunker,³⁶ C. Bunker,³⁷ C. Bunker,³⁸ C. Bunker,³⁹ C. Bunker,⁴⁰ C. Bunker,⁴¹ C. Bunker,⁴² C. Bunker,⁴³ C. Bunker,⁴⁴ C. Bunker,⁴⁵ C. Bunker,⁴⁶ C. Bunker,⁴⁷ C. Bunker,⁴⁸ C. Bunker,⁴⁹ C. Bunker,⁵⁰ C. Bunker,⁵¹ C. Bunker,⁵² C. Bunker,⁵³ C. Bunker,⁵⁴ C. Bunker,⁵⁵ C. Bunker,⁵⁶ C. Bunker,⁵⁷ C. Bunker,⁵⁸ C. Bunker,⁵⁹ C. Bunker,⁶⁰ C. Bunker,⁶¹ C. Bunker,⁶² C. Bunker,⁶³ C. Bunker,⁶⁴ C. Bunker,⁶⁵ C. Bunker,⁶⁶ C. Bunker,⁶⁷ C. Bunker,⁶⁸ C. Bunker,⁶⁹ C. Bunker,⁷⁰ C. Bunker,⁷¹ C. Bunker,⁷² C. Bunker,⁷³ C. Bunker,⁷⁴ C. Bunker,⁷⁵ C. Bunker,⁷⁶ C. Bunker,⁷⁷ C. Bunker,⁷⁸ C. Bunker,⁷⁹ C. Bunker,⁸⁰ C. Bunker,⁸¹ C. Bunker,⁸² C. Bunker,⁸³ C. Bunker,⁸⁴ C. Bunker,⁸⁵ C. Bunker,⁸⁶ C. Bunker,⁸⁷ C. Bunker,⁸⁸ C. Bunker,⁸⁹ C. Bunker,⁹⁰ C. Bunker,⁹¹ C. Bunker,⁹² C. Bunker,⁹³ C. Bunker,⁹⁴ C. Bunker,⁹⁵ C. Bunker,⁹⁶ C. Bunker,⁹⁷ C. Bunker,⁹⁸ C. Bunker,⁹⁹ C. Bunker,¹⁰⁰ C. Bunker,¹⁰¹ C. Bunker,¹⁰² C. Bunker,¹⁰³ C. Bunker,¹⁰⁴ C. Bunker,¹⁰⁵ C. Bunker,¹⁰⁶ C. Bunker,¹⁰⁷ C. Bunker,¹⁰⁸ C. Bunker,¹⁰⁹ C. Bunker,¹¹⁰ C. Bunker,¹¹¹ C. Bunker,¹¹² C. Bunker,¹¹³ C. Bunker,¹¹⁴ C. Bunker,¹¹⁵ C. Bunker,¹¹⁶ C. Bunker,¹¹⁷ C. Bunker,¹¹⁸ C. Bunker,¹¹⁹ C. Bunker,¹²⁰ C. Bunker,¹²¹ C. Bunker,¹²² C. Bunker,¹²³ C. Bunker,¹²⁴ C. Bunker,¹²⁵ C. Bunker,¹²⁶ C. Bunker,¹²⁷ C. Bunker,¹²⁸ C. Bunker,¹²⁹ C. Bunker,¹³⁰ C. Bunker,¹³¹ C. Bunker,¹³² C. Bunker,¹³³ C. Bunker,¹³⁴ C. Bunker,¹³⁵ C. Bunker,¹³⁶ C. Bunker,¹³⁷ C. Bunker,¹³⁸ C. Bunker,¹³⁹ C. Bunker,¹⁴⁰ C. Bunker,¹⁴¹ C. Bunker,¹⁴² C. Bunker,¹⁴³ C. Bunker,¹⁴⁴ C. Bunker,¹⁴⁵ C. Bunker,¹⁴⁶ C. Bunker,¹⁴⁷ C. Bunker,¹⁴⁸ C. Bunker,¹⁴⁹ C. Bunker,¹⁵⁰ C. Bunker,¹⁵¹ C. Bunker,¹⁵² C. Bunker,¹⁵³ C. Bunker,¹⁵⁴ C. Bunker,¹⁵⁵ C. Bunker,¹⁵⁶ C. Bunker,¹⁵⁷ C. Bunker,¹⁵⁸ C. Bunker,¹⁵⁹ C. Bunker,¹⁶⁰ C. Bunker,¹⁶¹ C. Bunker,¹⁶² C. Bunker,¹⁶³ C. Bunker,¹⁶⁴ C. Bunker,¹⁶⁵ C. Bunker,¹⁶⁶ C. Bunker,¹⁶⁷ C. Bunker,¹⁶⁸ C. Bunker,¹⁶⁹ C. Bunker,¹⁷⁰ C. Bunker,¹⁷¹ C. Bunker,¹⁷² C. Bunker,¹⁷³ C. Bunker,¹⁷⁴ C. Bunker,¹⁷⁵ C. Bunker,¹⁷⁶ C. Bunker,¹⁷⁷ C. Bunker,¹⁷⁸ C. Bunker,¹⁷⁹ C. Bunker,¹⁸⁰ C. Bunker,¹⁸¹ C. Bunker,¹⁸² C. Bunker,¹⁸³ C. Bunker,¹⁸⁴ C. Bunker,¹⁸⁵ C. Bunker,¹⁸⁶ C. Bunker,¹⁸⁷ C. Bunker,¹⁸⁸ C. Bunker,¹⁸⁹ C. Bunker,¹⁹⁰ C. Bunker,¹⁹¹ C. Bunker,¹⁹² C. Bunker,¹⁹³ C. Bunker,¹⁹⁴ C. Bunker,¹⁹⁵ C. Bunker,¹⁹⁶ C. Bunker,¹⁹⁷ C. Bunker,¹⁹⁸ C. Bunker,¹⁹⁹ C. Bunker,²⁰⁰ C. Bunker,²⁰¹ C. Bunker,²⁰² C. Bunker,²⁰³ C. Bunker,²⁰⁴ C. Bunker,²⁰⁵ C. Bunker,²⁰⁶ C. Bunker,²⁰⁷ C. Bunker,²⁰⁸ C. Bunker,²⁰⁹ C. Bunker,²¹⁰ C. Bunker,²¹¹ C. Bunker,²¹² C. Bunker,²¹³ C. Bunker,²¹⁴ C. Bunker,²¹⁵ C. Bunker,²¹⁶ C. Bunker,²¹⁷ C. Bunker,²¹⁸ C. Bunker,²¹⁹ C. Bunker,²²⁰ C. Bunker,²²¹ C. Bunker,²²² C. Bunker,²²³ C. Bunker,²²⁴ C. Bunker,²²⁵ C. Bunker,²²⁶ C. Bunker,²²⁷ C. Bunker,²²⁸ C. Bunker,²²⁹ C. Bunker,²³⁰ C. Bunker,²³¹ C. Bunker,²³² C. Bunker,²³³ C. Bunker,²³⁴ C. Bunker,²³⁵ C. Bunker,²³⁶ C. Bunker,²³⁷ C. Bunker,²³⁸ C. Bunker,²³⁹ C. Bunker,²⁴⁰ C. Bunker,²⁴¹ C. Bunker,²⁴² C. Bunker,²⁴³ C. Bunker,²⁴⁴ C. Bunker,²⁴⁵ C. Bunker,²⁴⁶ C. Bunker,²⁴⁷ C. Bunker,²⁴⁸ C. Bunker,²⁴⁹ C. Bunker,²⁵⁰ C. Bunker,²⁵¹ C. Bunker,²⁵² C. Bunker,²⁵³ C. Bunker,²⁵⁴ C. Bunker,²⁵⁵ C. Bunker,²⁵⁶ C. Bunker,²⁵⁷ C. Bunker,²⁵⁸ C. Bunker,²⁵⁹ C. Bunker,²⁶⁰ C. Bunker,²⁶¹ C. Bunker,²⁶² C. Bunker,²⁶³ C. Bunker,²⁶⁴ C. Bunker,²⁶⁵ C. Bunker,²⁶⁶ C. Bunker,²⁶⁷ C. Bunker,²⁶⁸ C. Bunker,²⁶⁹ C. Bunker,²⁷⁰ C. Bunker,²⁷¹ C. Bunker,²⁷² C. Bunker,²⁷³ C. Bunker,²⁷⁴ C. Bunker,²⁷⁵ C. Bunker,²⁷⁶ C. Bunker,²⁷⁷ C. Bunker,²⁷⁸ C. Bunker,²⁷⁹ C. Bunker,²⁸⁰ C. Bunker,²⁸¹ C. Bunker,²⁸² C. Bunker,²⁸³ C. Bunker,²⁸⁴ C. Bunker,²⁸⁵ C. Bunker,²⁸⁶ C. Bunker,²⁸⁷ C. Bunker,²⁸⁸ C. Bunker,²⁸⁹ C. Bunker,²⁹⁰ C. Bunker,²⁹¹ C. Bunker,²⁹² C. Bunker,²⁹³ C. Bunker,²⁹⁴ C. Bunker,²⁹⁵ C. Bunker,²⁹⁶ C. Bunker,²⁹⁷ C. Bunker,²⁹⁸ C. Bunker,²⁹⁹ C. Bunker,³⁰⁰ C. Bunker,³⁰¹ C. Bunker,³⁰² C. Bunker,³⁰³ C. Bunker,³⁰⁴ C. Bunker,³⁰⁵ C. Bunker,³⁰⁶ C. Bunker,^{307</}

- 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

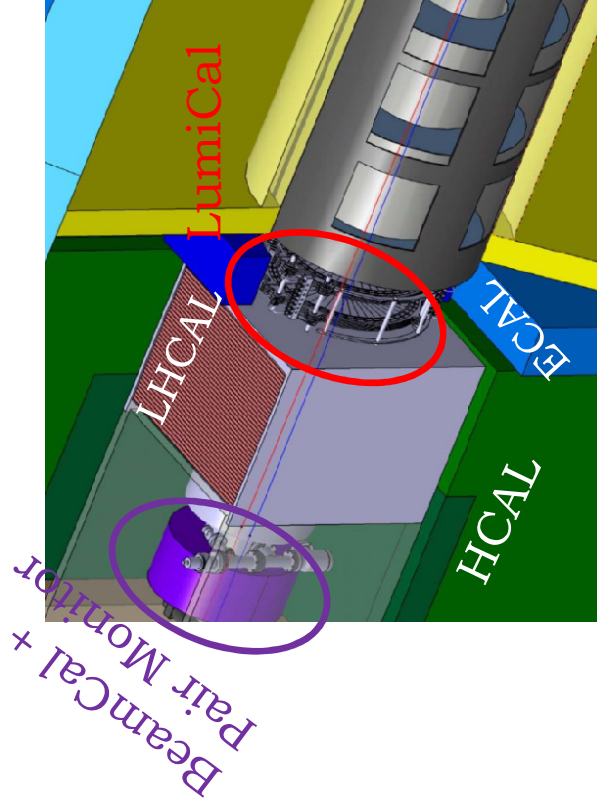
Ongoing simulations to optimize

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

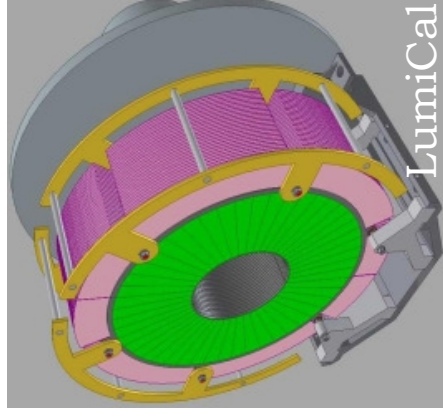
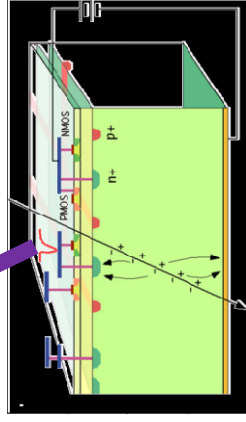
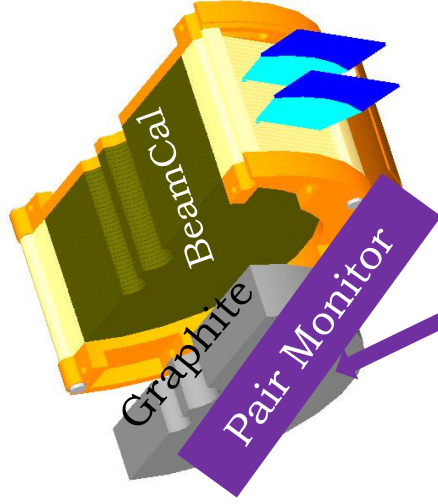
Challenges:

- **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

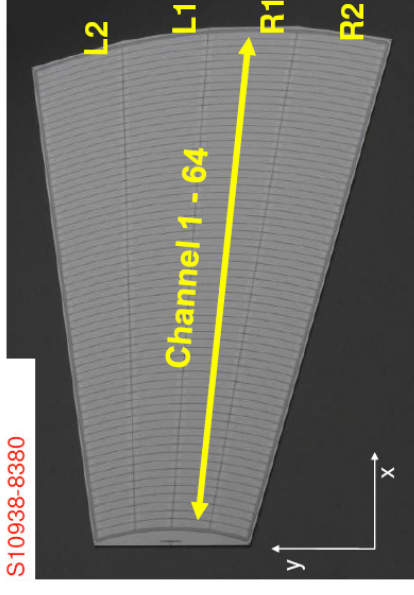
Detectors in the forward region

Technologies:

- **LumiCal** sampling SiW
- **BeamCal** W absorber +poly(mono)crystalline CVD diamond/GaAs/rad-hard Si
- **Pair Monitor** $2 \cdot 10^5$ Si pixel (0.4. 0.4)mm

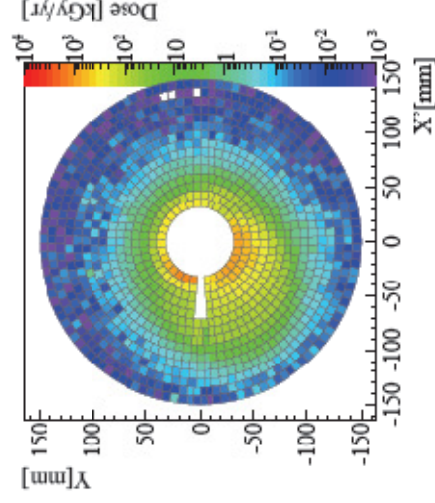


Hamamatsu
S10938-8380

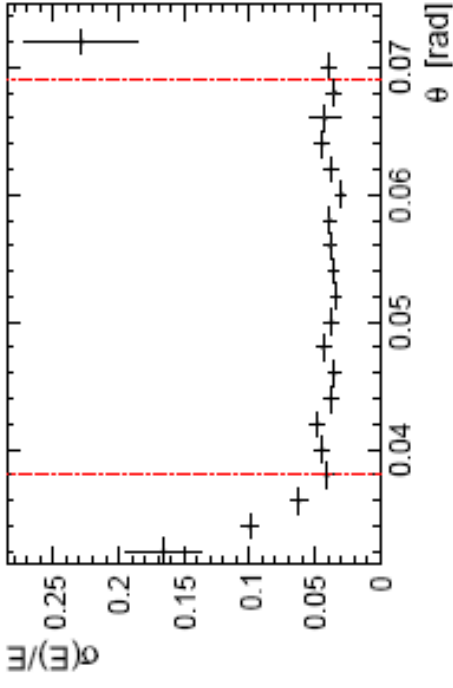
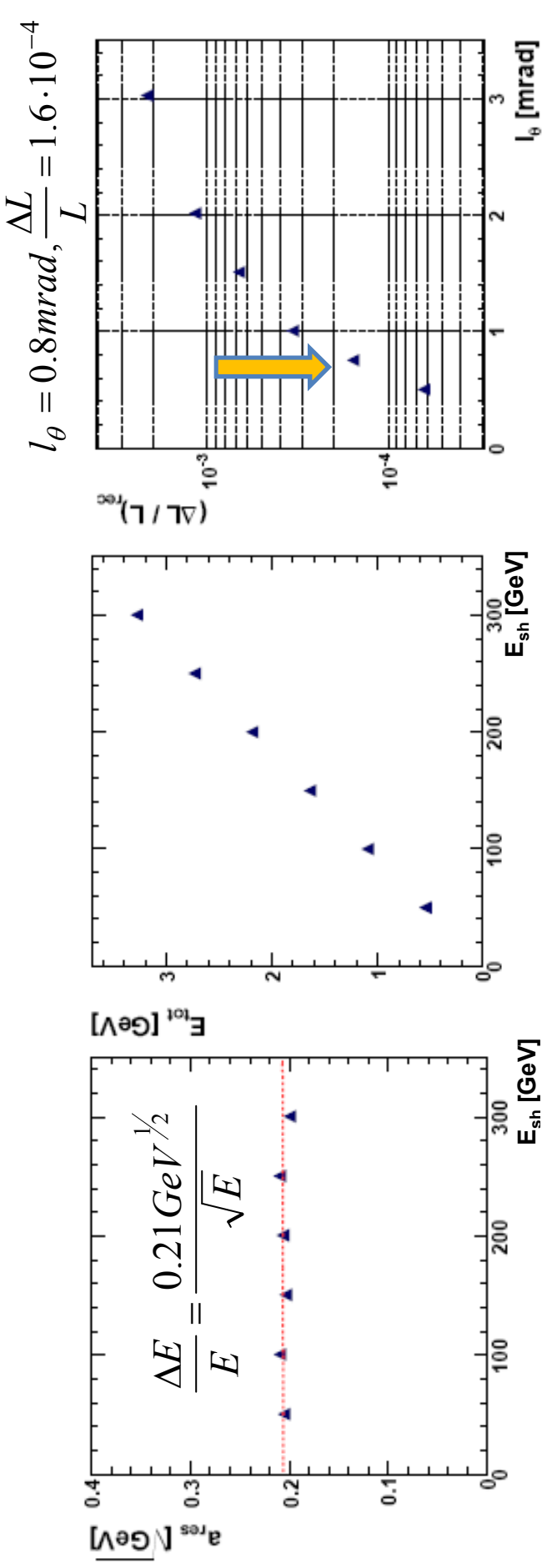


- small Moliere radius $O(1\text{cm})$ – good E resolution
- segmentation (azimuthal/radial): 48/64
 - energy resolution: $0.21 [\text{GeV}^{1/2}]$
 - resolution in polar angle: $(2.18 \pm 0.02) \cdot 10^{-2} \text{ mrad}$
- Radiation hard sensors
- Beam parameters measurement
- (σ_x permille level, $\sigma_y, \sigma_z \sim \text{few percent}$)

Radiation dose in the 5th layer of BeamCal

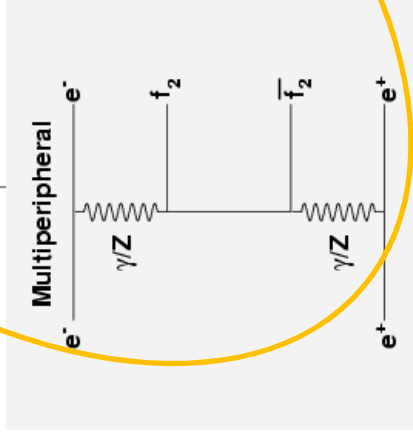
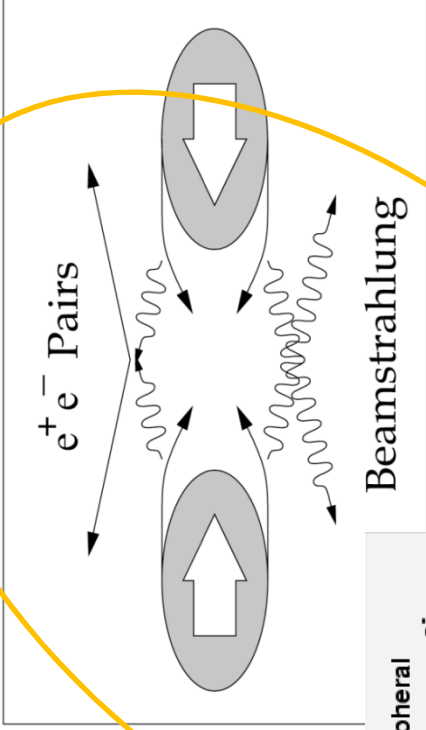
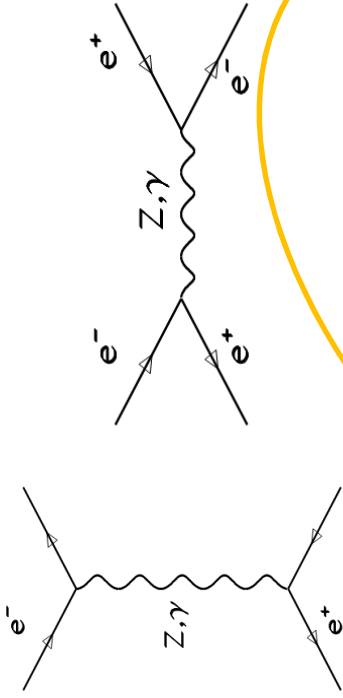


LumiCal performance: simulation



- 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



$$L_{\text{int}} = \frac{N_{th}}{\sigma_B} \quad \xrightarrow{\text{red arrow}} \quad L_{\text{int}} = \frac{N_{\text{exp}} - \frac{\sum_i N_i^{cor}}{\alpha_i}}{\epsilon \cdot \sigma_B}$$

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

- 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 500GeV

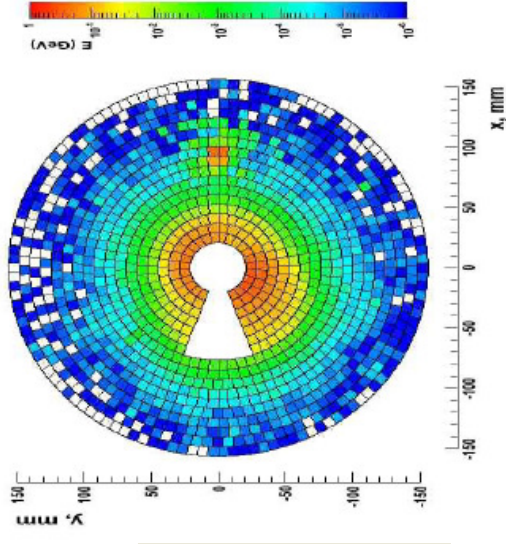
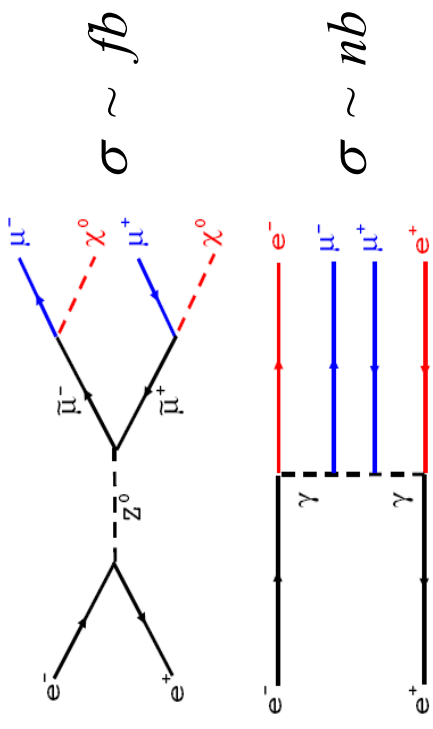
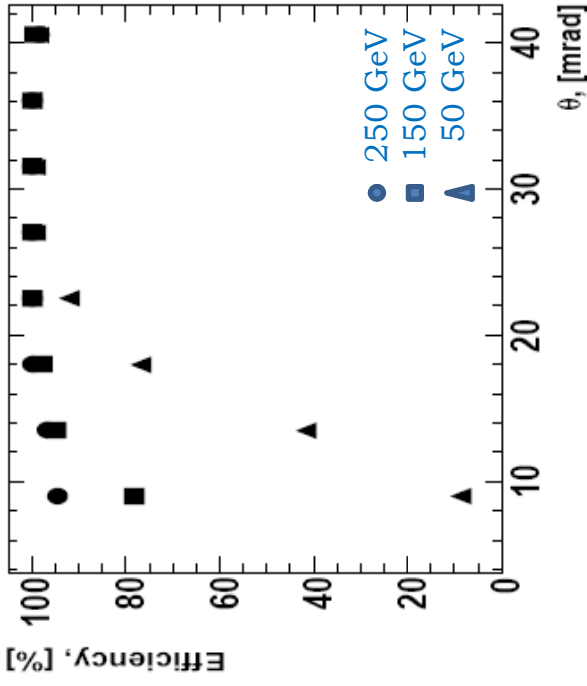
Source	Value	Uncertainty	Luminosity Uncertainty
σ_{θ}	2.2×10^{-2} [mrad]	100%	1.6×10^{-4}
$\Delta\theta$	3.2×10^{-3} [mrad]	100%	1.6×10^{-4}
a_{res}	0.21	15%	10^{-4}
luminosity spectrum			10^{-3}
bunch sizes σ_x, σ_z ,	655 nm, 300 μm	5%	1.5×10^{-3}
two photon events	2.3×10^{-3}	40%	0.9×10^{-3}
energy 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

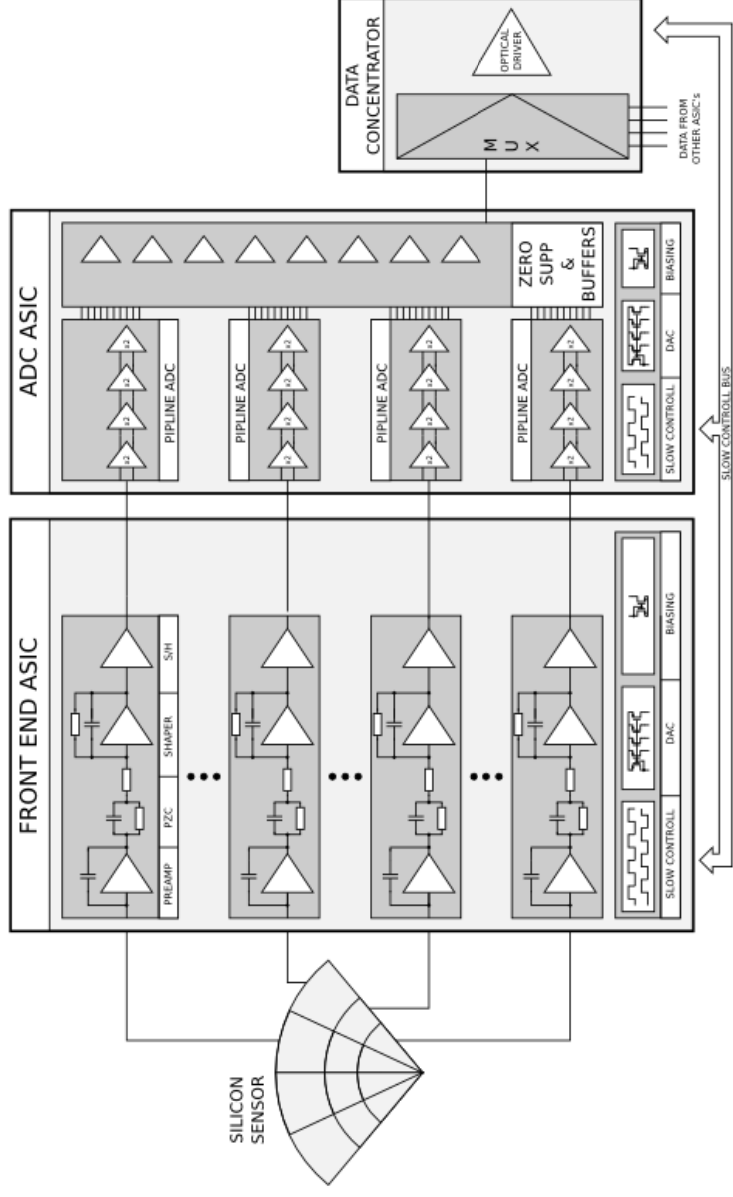
-Most of the systematic effects can be taken as corrections once their experimental uncertainties are known ($\Delta\theta$, miscounts due to physics background, BHSE).

Electron identification in the forward region



- 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

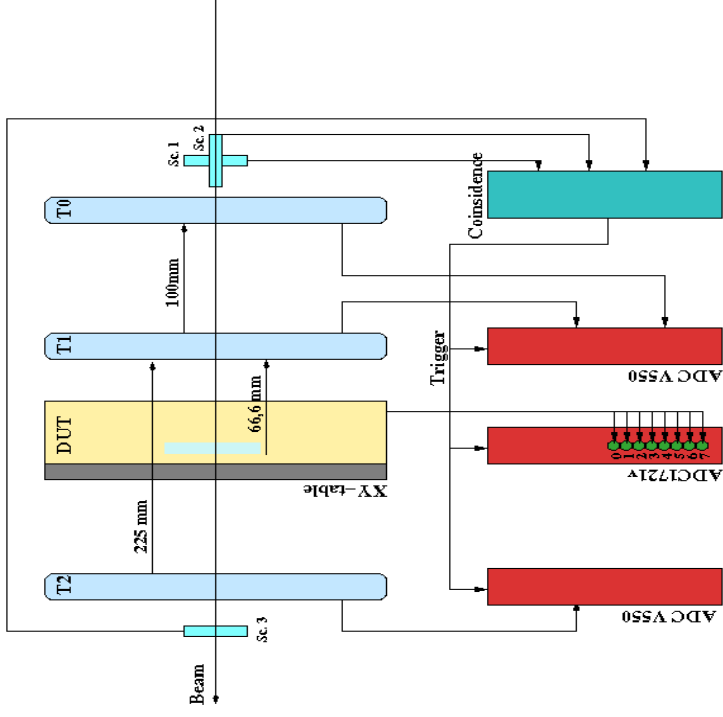


LumiCal readout architecture:

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

First prototypes of all blocks already done: Silicon sensor from Hamamatsu, 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 (Krakow) and tested/ Cracow, DESY

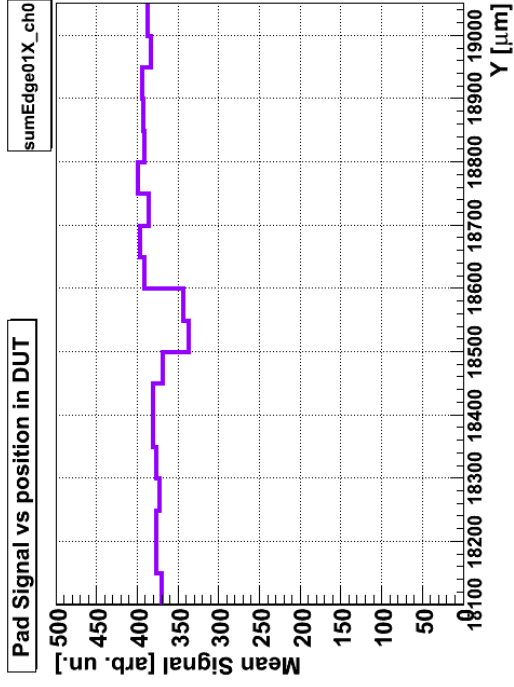
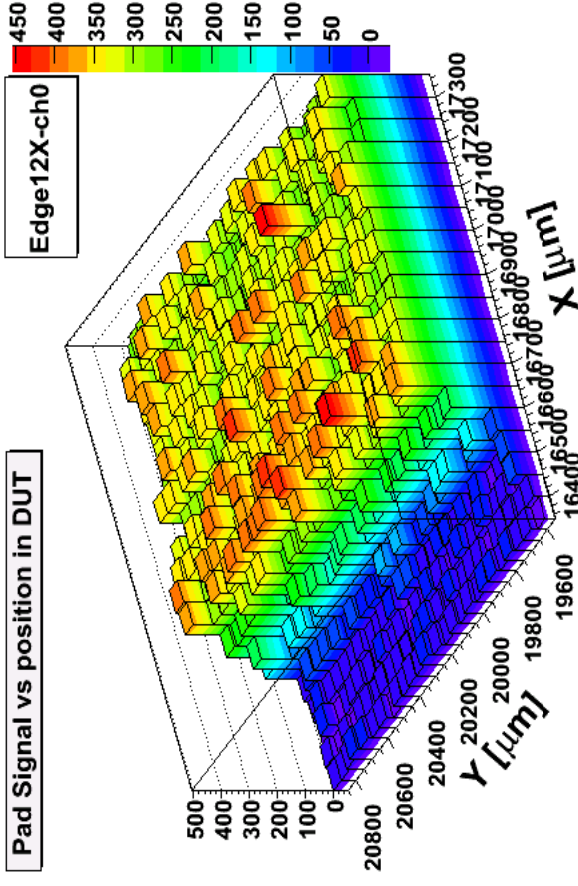
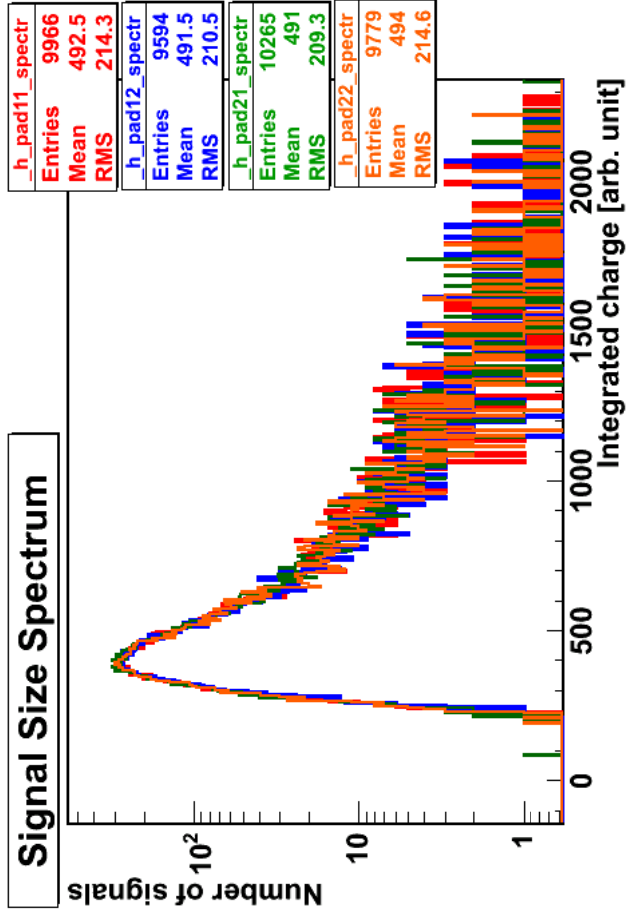
BeamCal

- Sensor prototyped for different technologies (GaAs, rad-hard Si)/ JINR, SLAC

- Frontend ASICs designed and prototyped/Cracow

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

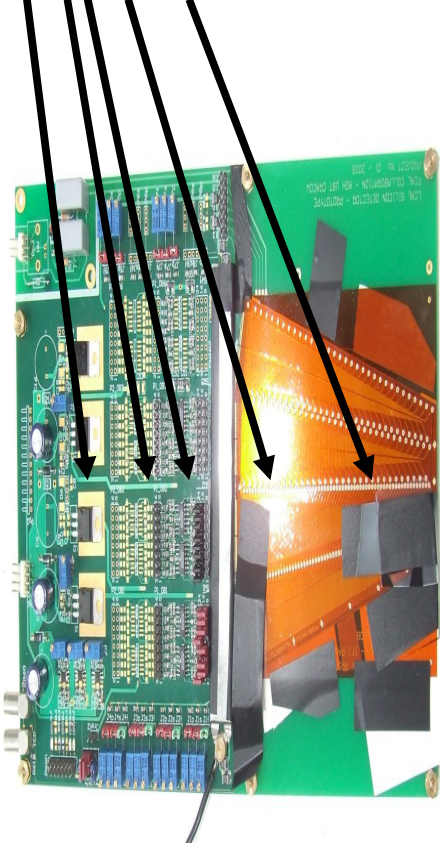
BeamCal performance: test-beam



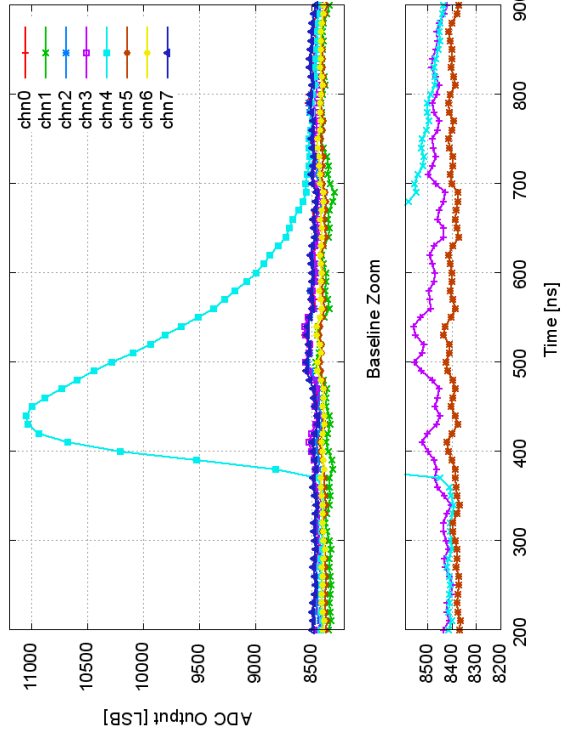
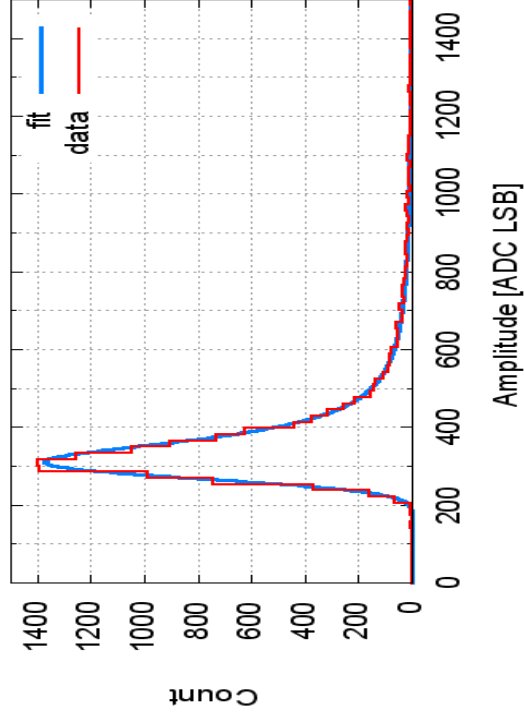
- GaAs plate with Al metallization: 500 μm thick
- 45 deg tiles, segmented into 12 rings, 5x5mm² pads
- **S/N ratio and CCE are good: CCE ~33% at 60V, S/N ~19 for all channels.**
- 4 independent pad areas show identical charge collection.
- Homogeneous response of the pad signal.
- Edges loose of about 10% of the signal.

LumiCal performance: test-beam

Readout chain

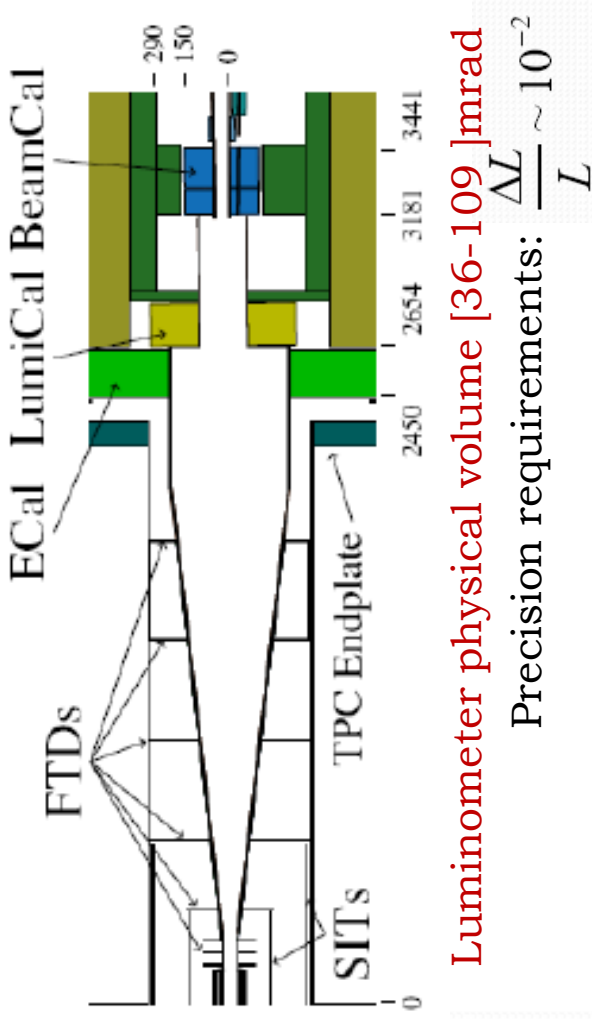
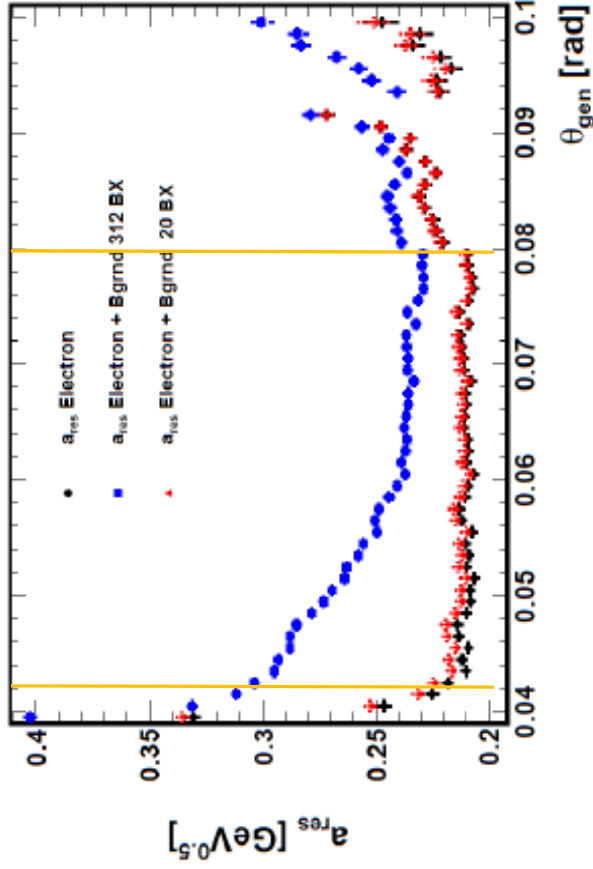


Biasing and power blocks
Output buffers
FE ASICs bonded onto PCB
Sensor and fanout glued
16 sensor pads bonded (300µm Si, 1.8mm pitch, 10.5mm - 25.5mm wide)



Signal to noise ratio ~ 19
Cross-talk $\leq 1\%$

CLIC within FCAL



- 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)

- Luminometer fiducial volume [43-80] mrad
- (Incoherent) pair background deteriorates E resolution for 1% (20 BX), 10-30% for 1 train (312 BX)

Summary

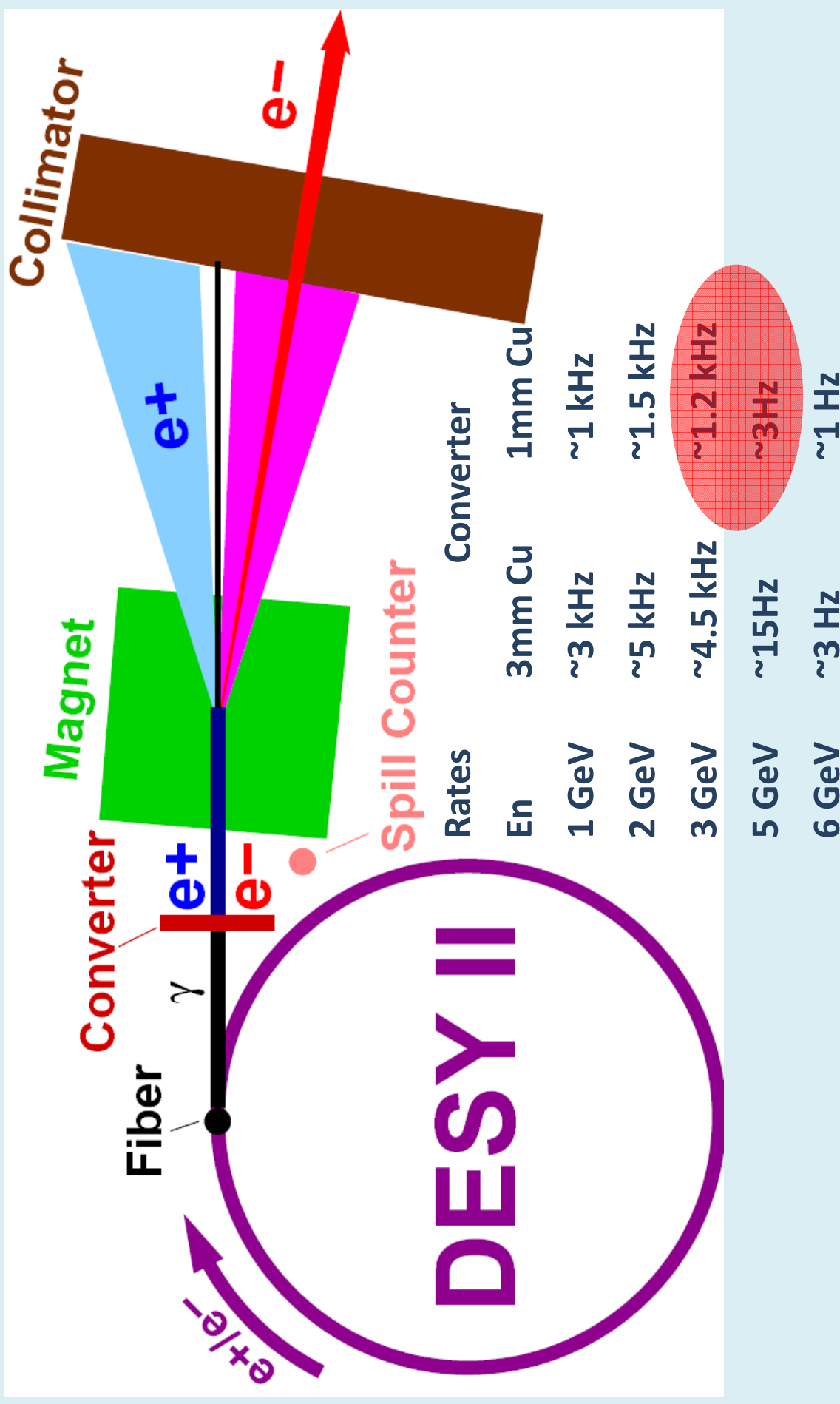
- Design of the calorimeters in the very forward region at future linear collider (ILC) is developed and **optimized with Monte Carlo simulations**. FCAL design study is extended to CLIC.
- Sensors and read-out electronics have been **designed** and **prototyped**.
- Assembled prototypes (sensor-fan-out- 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

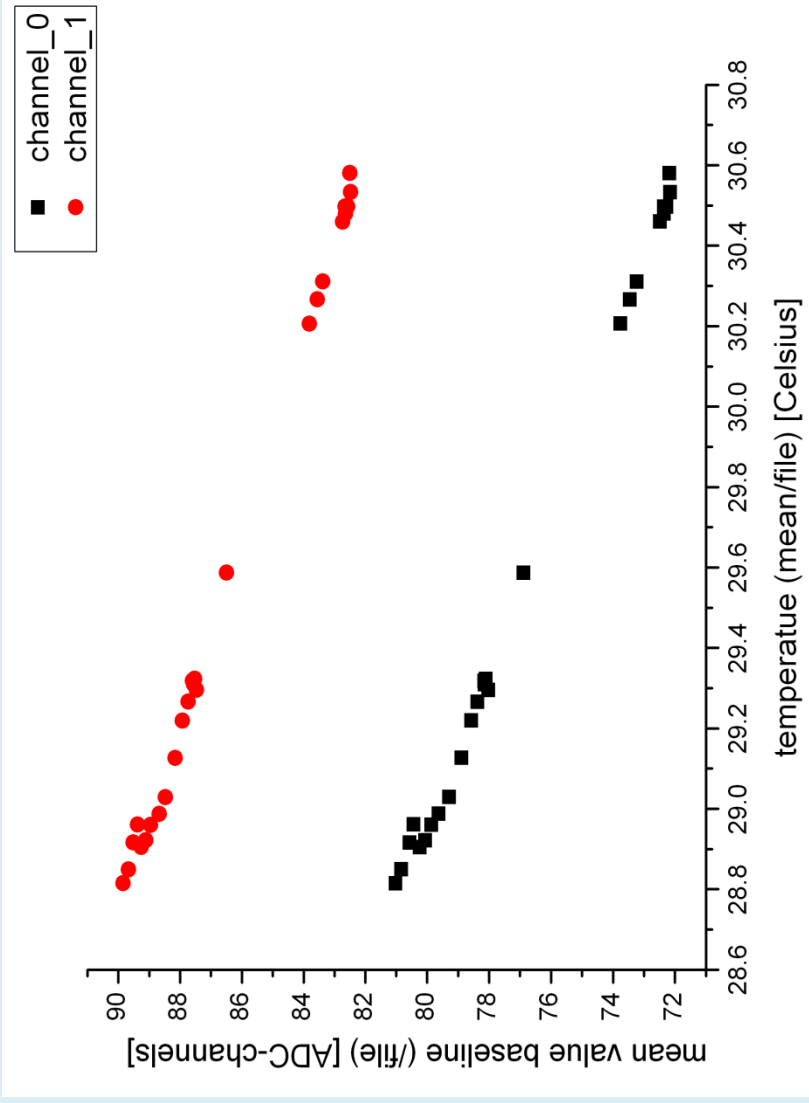
- Ongoing preparation of ILC EDR 2012 and CLIC CDR until the end of 2011
- FCAL at AIDA (FP7-INFRASTRUCTURES-2010-1):
 - Design and construction of the mechanical structure to accommodate the prototype calorimeter (design 2012, manufacturing 2013, ready 2014)
 - Multichannel (64) readout ASICs: design 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

TestBeam DESY II



BeamCal test-beam: temperature dependence

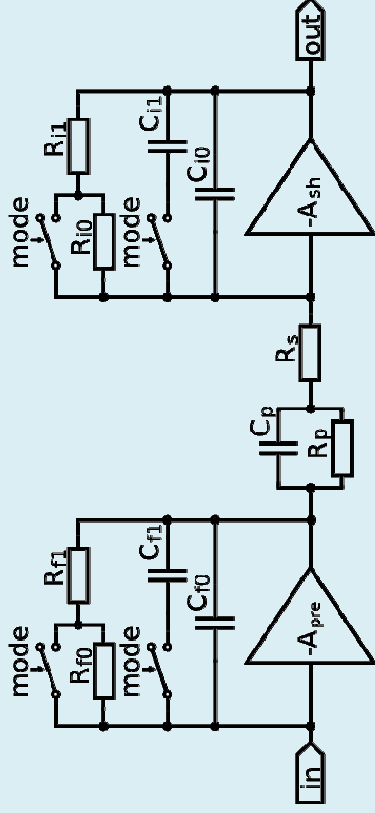


- Operation at room temperature

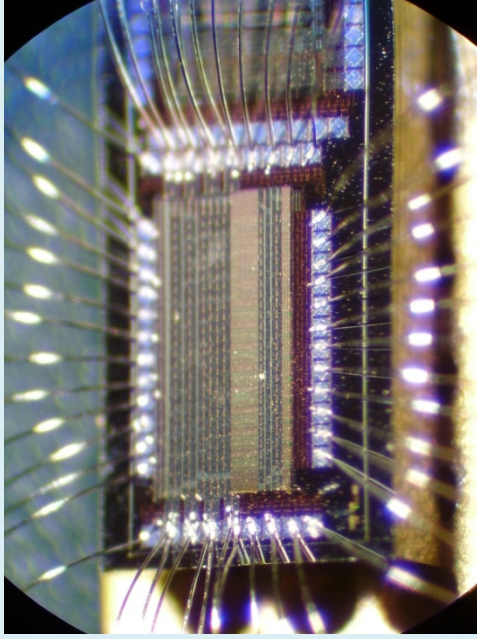
-Low leakage current $\sim 200\text{nA}$

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

LumiCal Front-End electronics

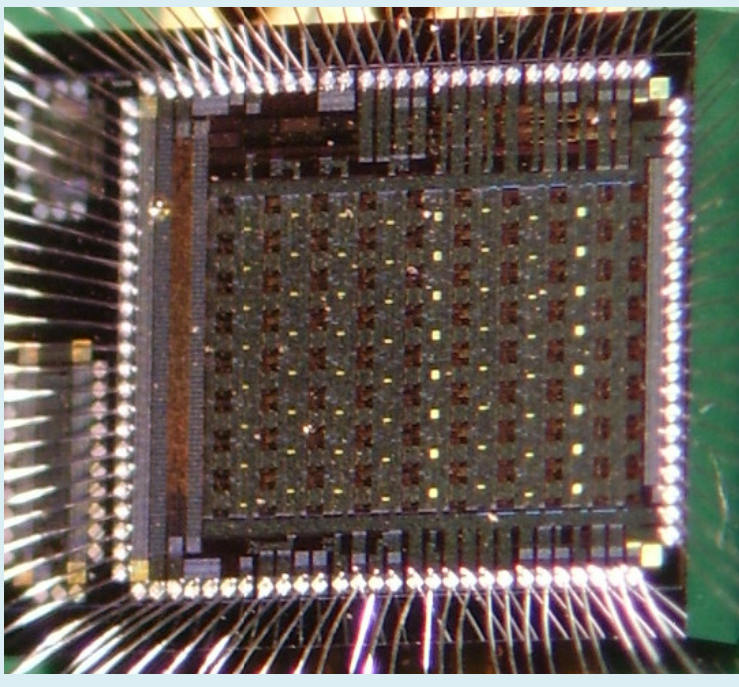


- Existing prototypes:**
- 8 channels in AMS 0.35um
 - $C_{det} \approx 0 \div 100\text{pF}$ (in new specs: $C_{det} < 30\text{pF}$)
 - 1st order shaper ($T_{peak} \approx 60\text{ ns}$)
 - Variable gain:
- calibration mode - MIP sensitivity ($\sim 4\text{fC}$)
 - physics mode - input charge up to 10pC
 - **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 f_{sm} ~ 3 MSps)
 - Parallel mode (~250MHz): one data link per channel (max f_{sm} ~ 25 MSps)
 - Test mode: single channel output (max f_{sm} ~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)

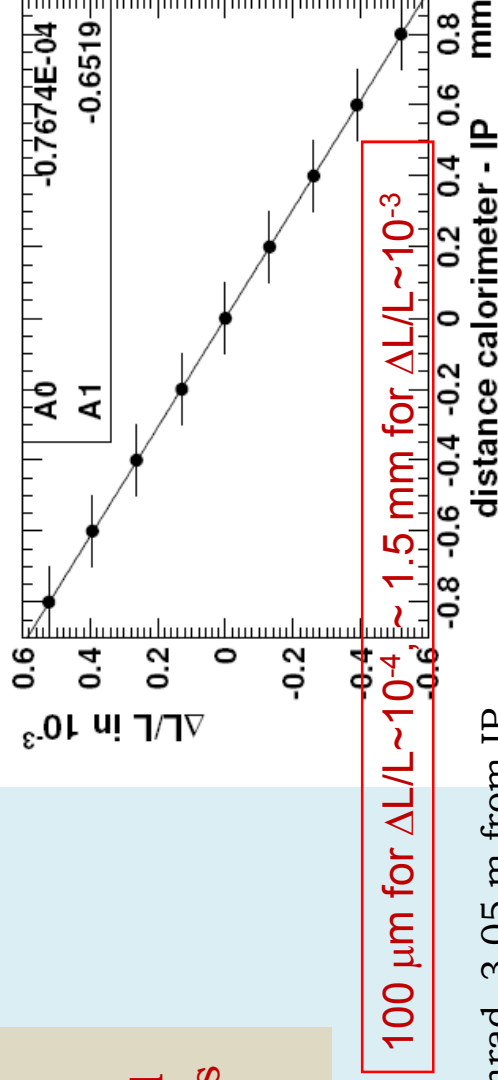
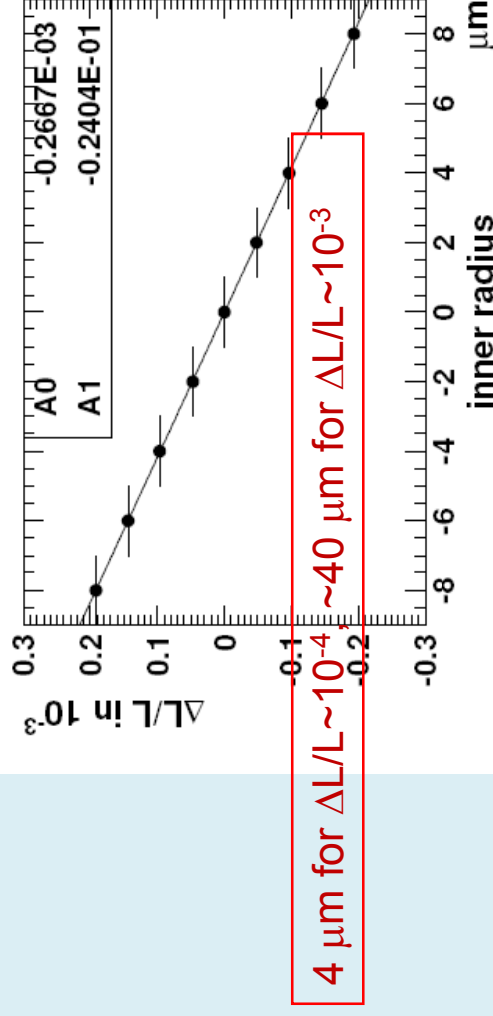


2.6mm x 3.2mm

LumiCal mechanical issues

IN SITU

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



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