State-of-the-art in Forward Calorimetry
and other Miscellaneous Detector Applications

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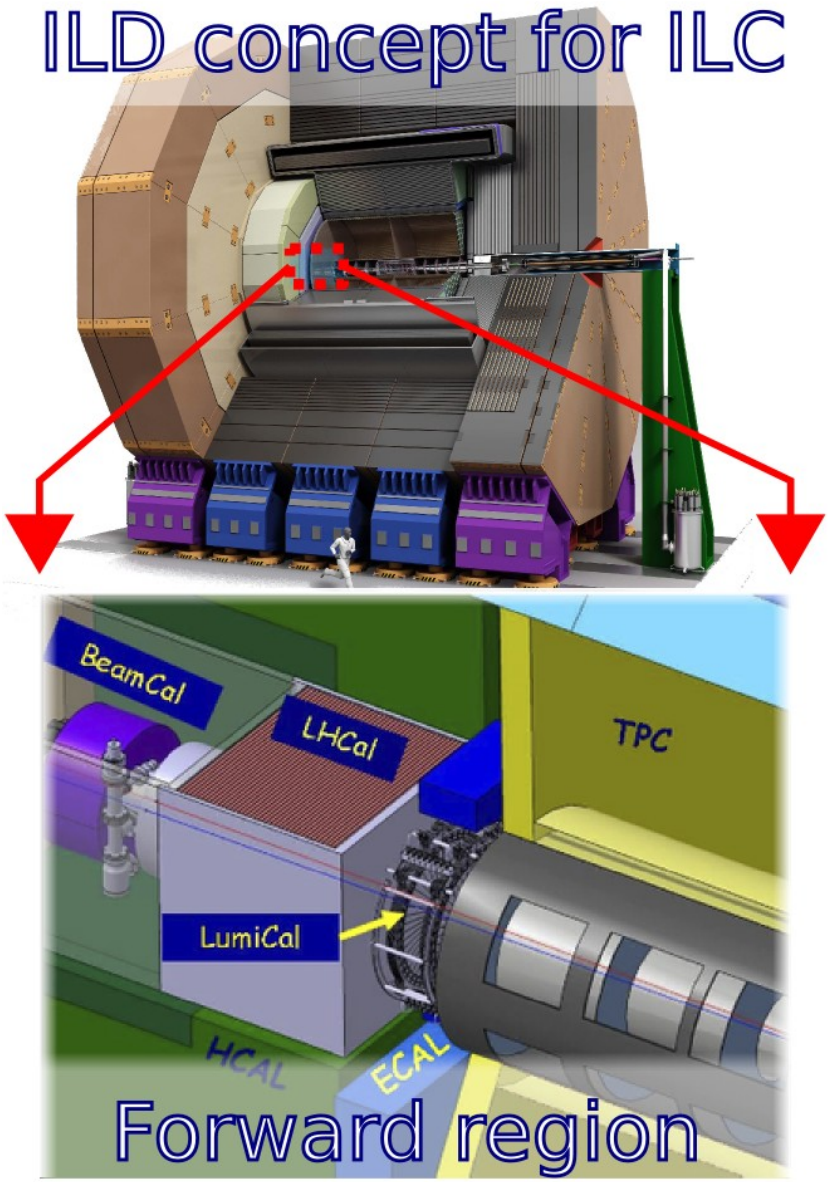
on behalf of **FCAL Collaboration**

Special Linear Collider Event
Nuclear Science Symposium,
29/10/2012 – 3/11/2012, Anaheim, California

Challenges of Forward Region

for ILC and CLIC



BeamCal (and Pair Monitor)

- low polar angle electron tagging
- beam tuning and beam diagnostics
- fast feedback using special features of the ASICs

LumiCal

precise luminosity measurement
(10^{-3} at 500 GeV @ ILC, 10^{-2} at 3 TeV @ CLIC)
derived from the expected statistics of the high cross section physics channels

Challenges:

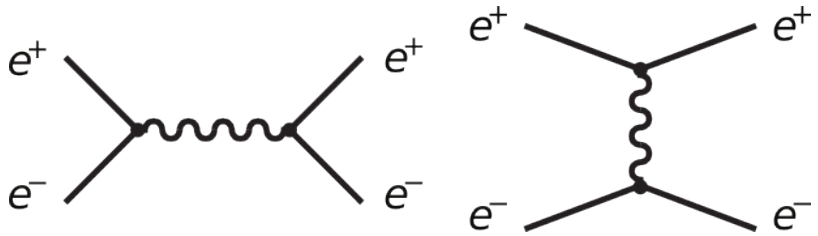
- high precision (LumiCal),
- radiation hardness (BeamCal),
- very fast read-out (both)

Precise Luminosity Measurement

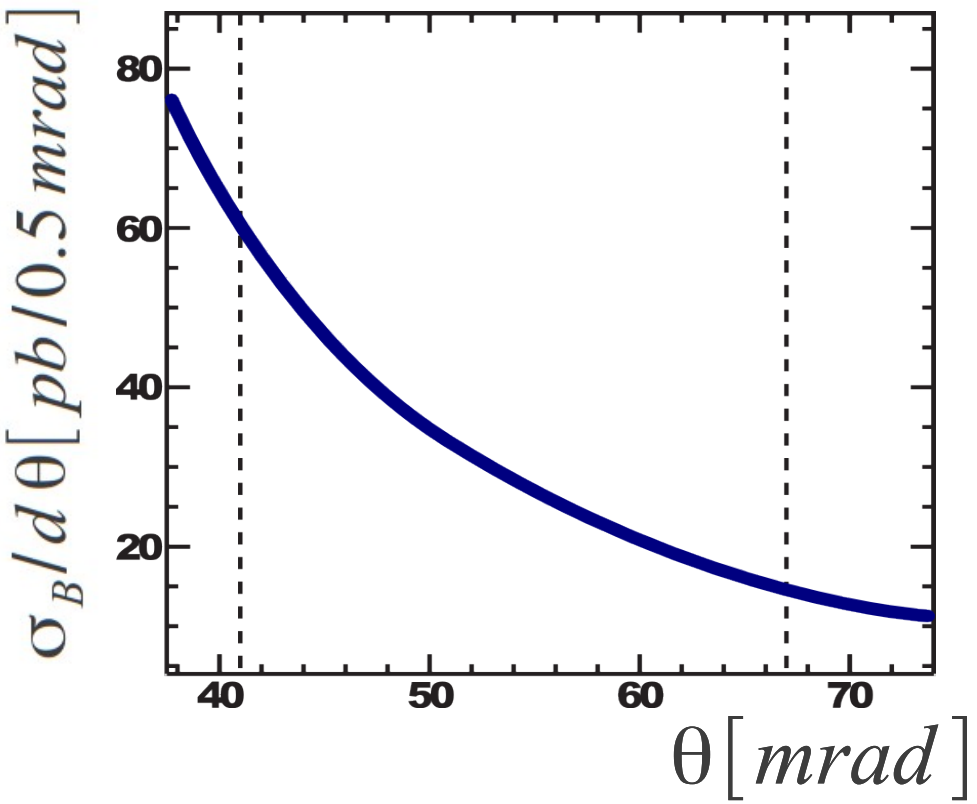
Luminosity:

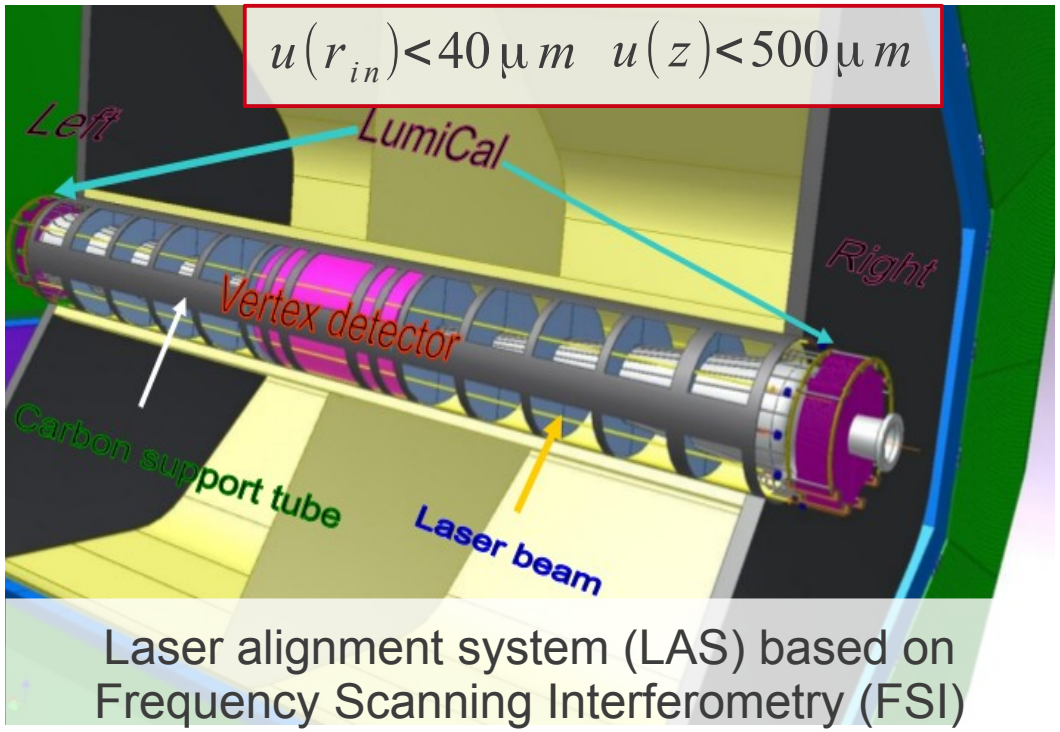
$$L = \frac{N_B}{\sigma_B}$$

Bhabha scattering:



$$\sigma_B \approx \frac{32\pi\alpha_{em}^2}{s}\frac{1}{\theta^3}$$

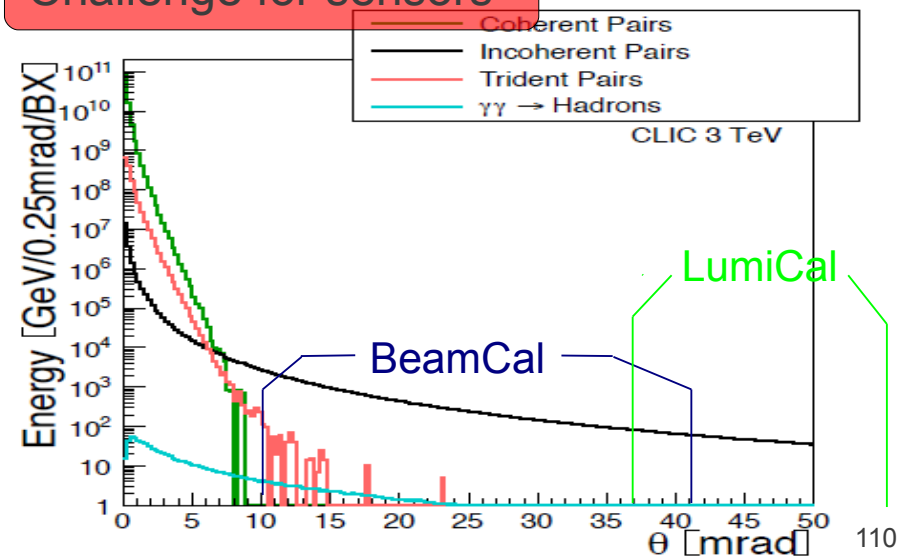




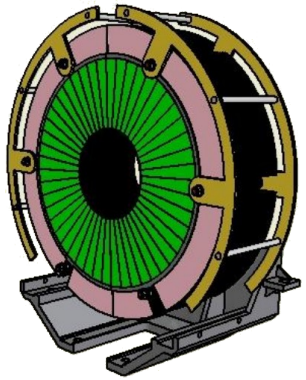
Laser alignment system (LAS) based on Frequency Scanning Interferometry (FSI)

Detector Design Optimization

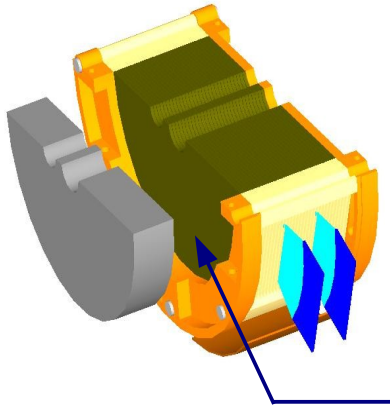
Challenge for sensors



LumiCal

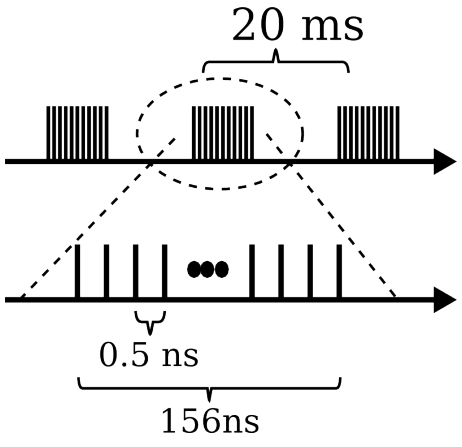


BeamCal

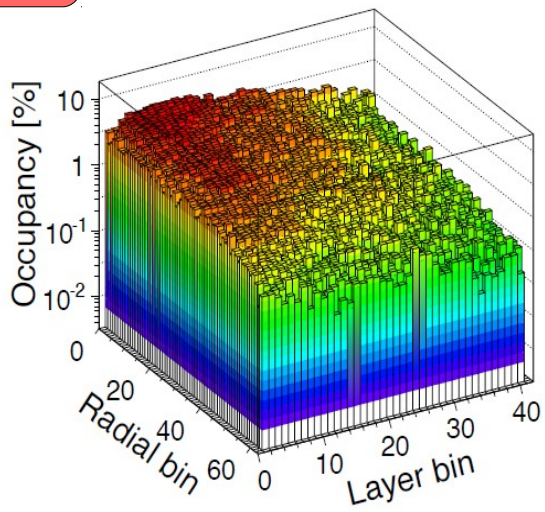


Sensor-tungsten sandwich EM calorimeters
30 / 40 (ILC/CLIC) tungsten disks of 3.5 mm thickness

Challenge for readout



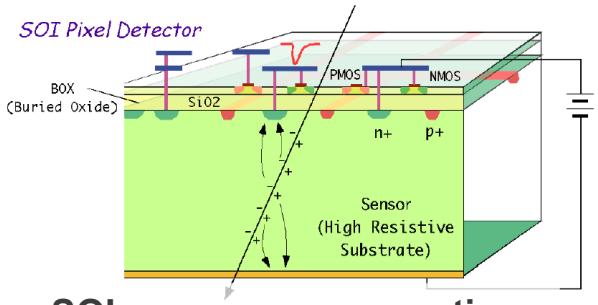
CLIC Beam



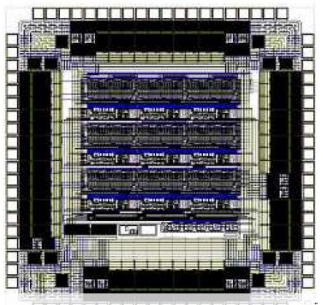
Occupancy of LumiCal pads

Pair Monitor

- detector radius 10cm
- pixel size 400x400 μm2
- total no. of pixels ~ 200k



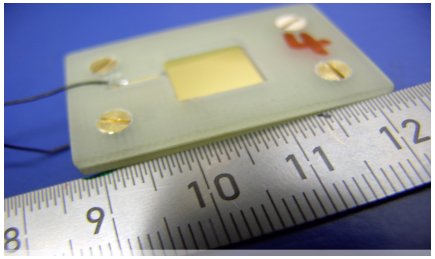
SOI process cross section



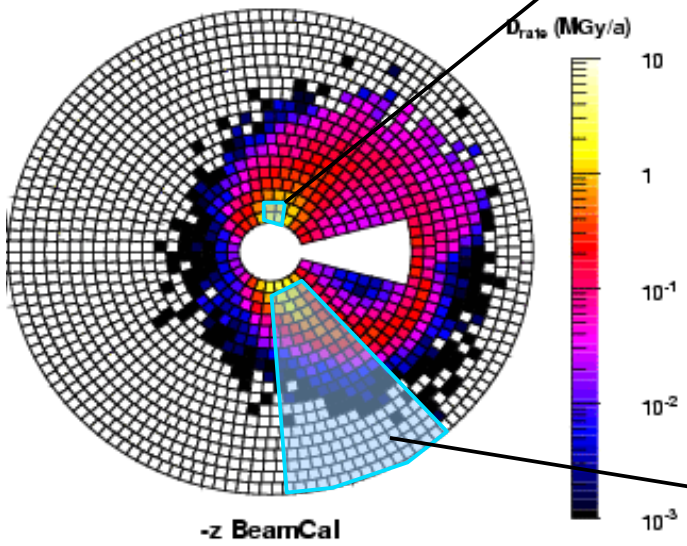
ASIC layout

BeamCal – Radiation Hard Sensors

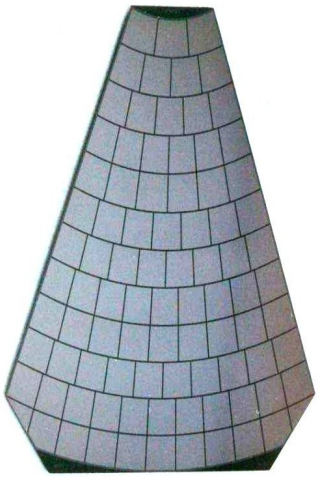
Very high radiation load
(up to 1MGy per year)



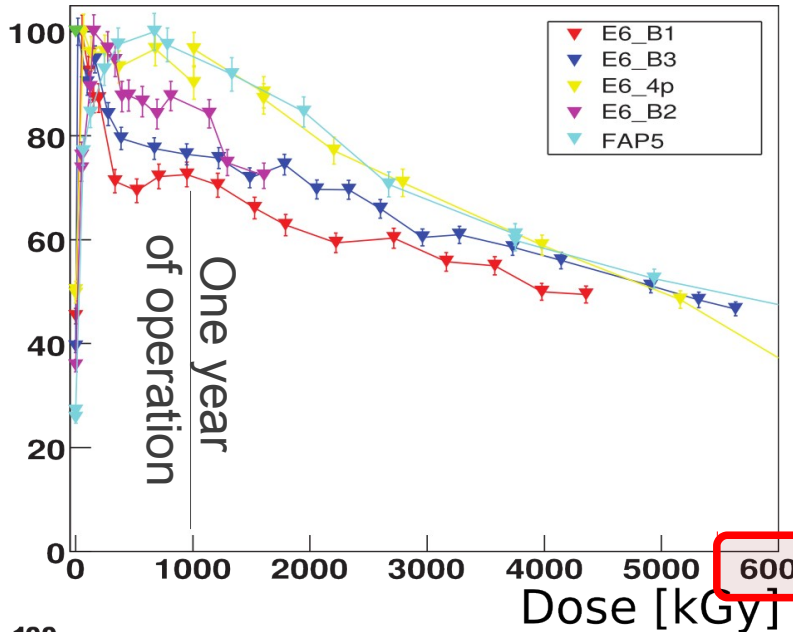
pCVD Diamond *
- 1 x 1 cm2
- 200-900 μm thick
- Leakage <1pA/cm^2

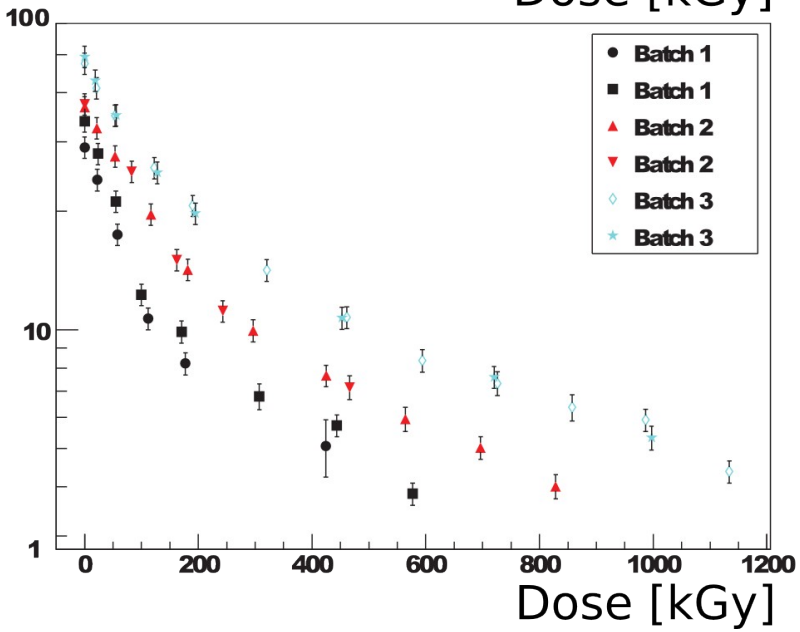


Dose in BeamCal sensor per year



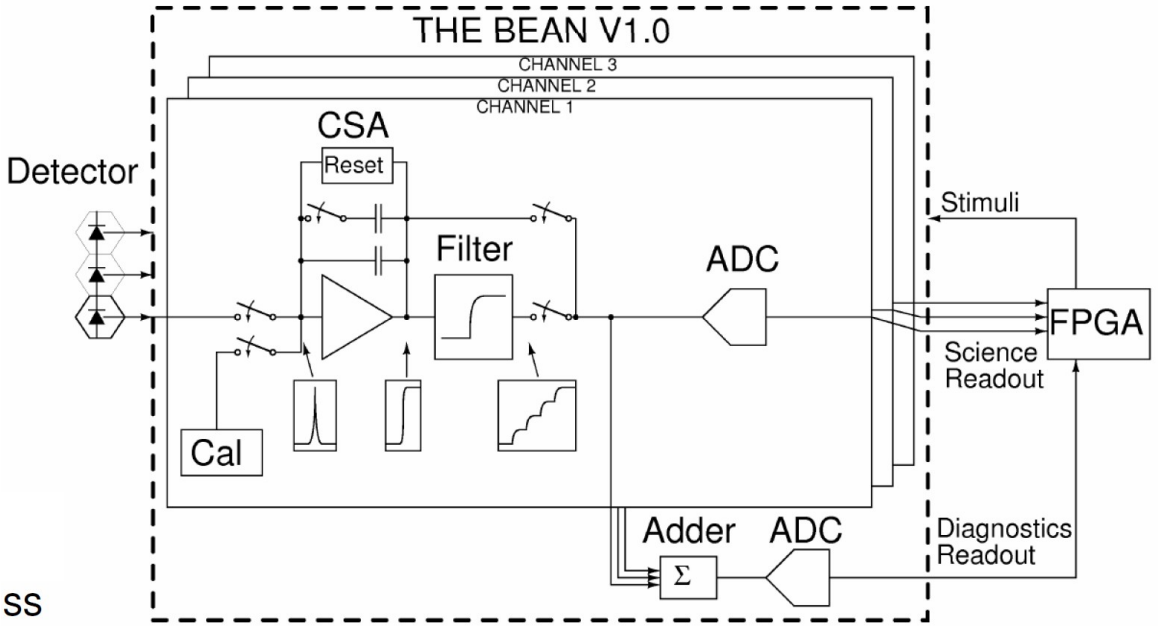
GaAs sensor prototype
- 500 μm thick sensor
- 87 pads (20 - 40mm^2)
- Leakage ~ 7nA/mm^2
- Capacitance ~ 0.3pF/mm^2





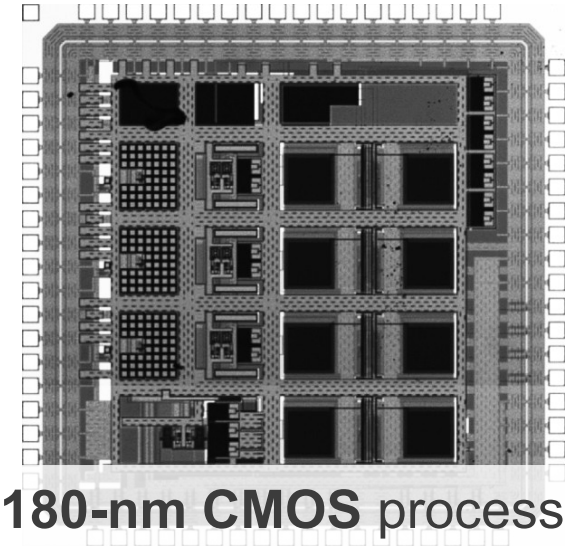
*)**Tested in ongoing experiments:**
- Beam Halo Monitor @ FLASH
- Beam Condition Monitor @ CMS

BeamCal Readout Electronics



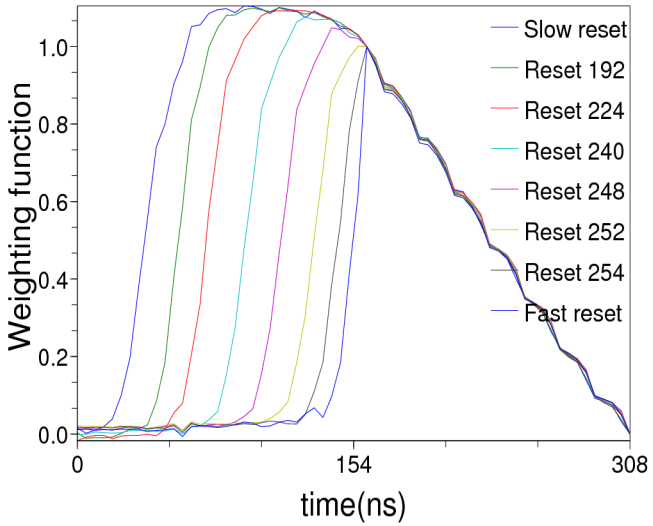
- Charge sensitive preamplifier (CSA) Gated reset for quick baseline restoration
- Switched-Capacitor filter
- ADC : 10-bit SAR ADC
- Analog adder to provide fast feedback

Prototype ASIC Micrograph

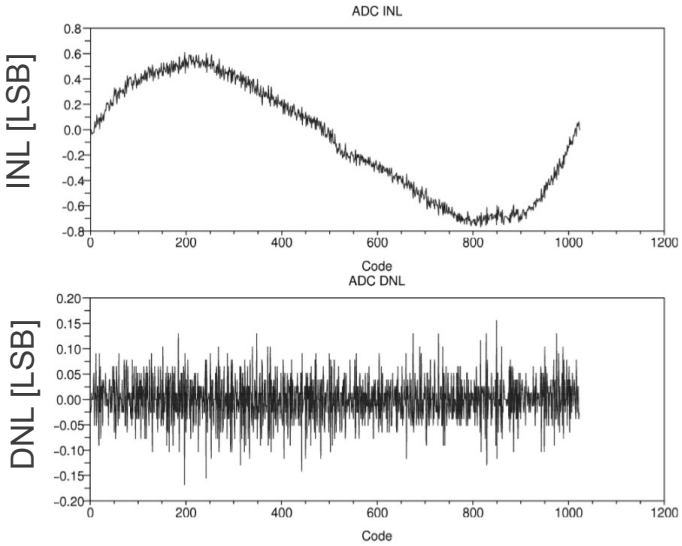


180-nm CMOS process

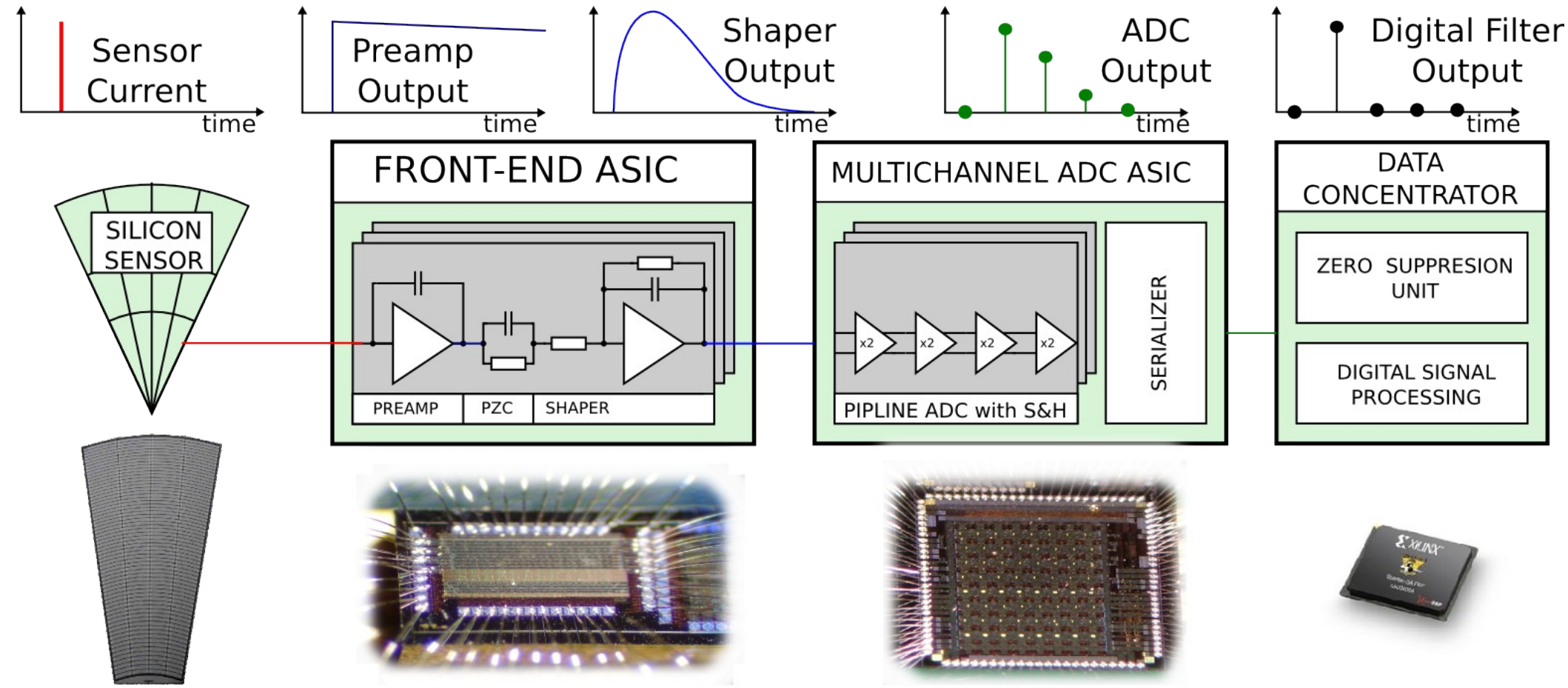
Shaper output



ADC Nonlinearities



LumiCal Readout

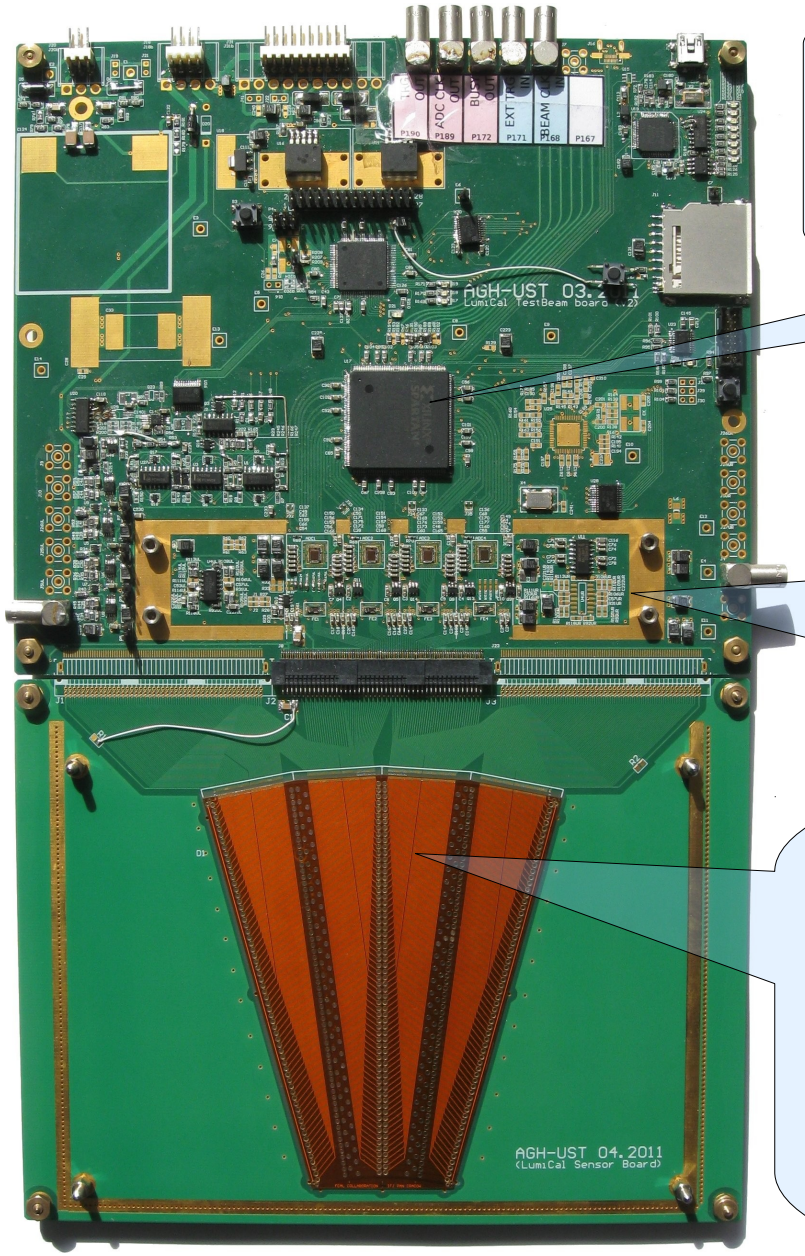


Sensor
- p^+ on n 300μm Si
- C_{det} < 25 pF
- I_{leak} < 5nA @ 500V
- V_{dep} < 50V

8 channel Front-End ASIC
- Preamp. + PZC + CR-RC
- $T_{peak} \approx 60$ ns
- C_{det} up to 100pF
- Switched gain: ~2fC <Qin<10 pC
- Event rate up to 3 MHz

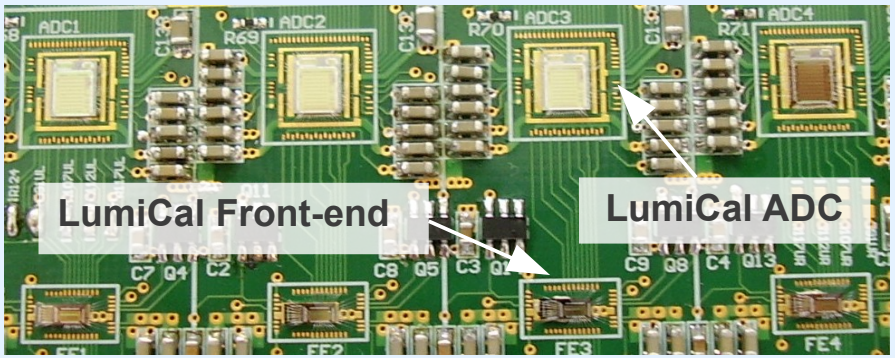
8 channel 10-bit ADC ASIC
- 1.5 bit pipeline architecture
- Digital serializer
- F_{max} 25 Ms/s (9.7 ENOB)
- Power: ~1.2mW/chan/MHz
- Power pulsing embedded

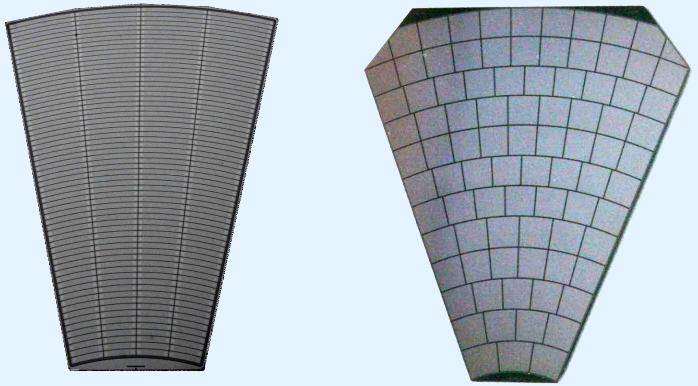
Detector Module



- FPGA based **data concentrator**
- **6.4 Gbps continues data stream**
- Compatible with **EUDET Infrastructure**
  (Trigger Logic Unit + Telescopes)

32 fully equipped readout channels





LumiCal / BeamCal sensors

Signal Processing - Deconvolution

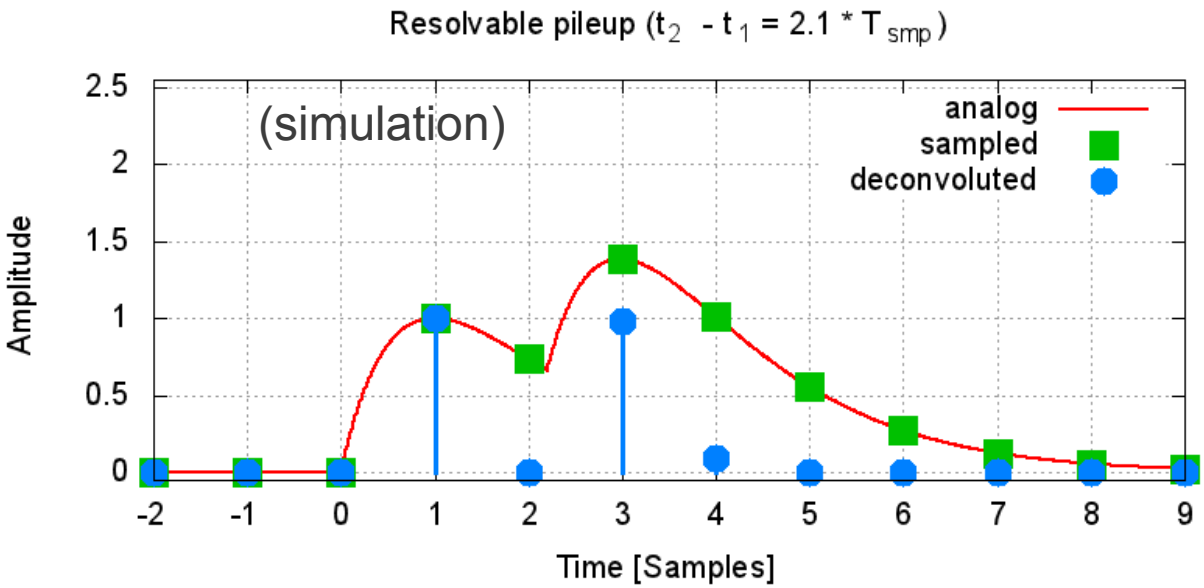
- Lightweight implementation
  (Finite Impulse Response Filter)

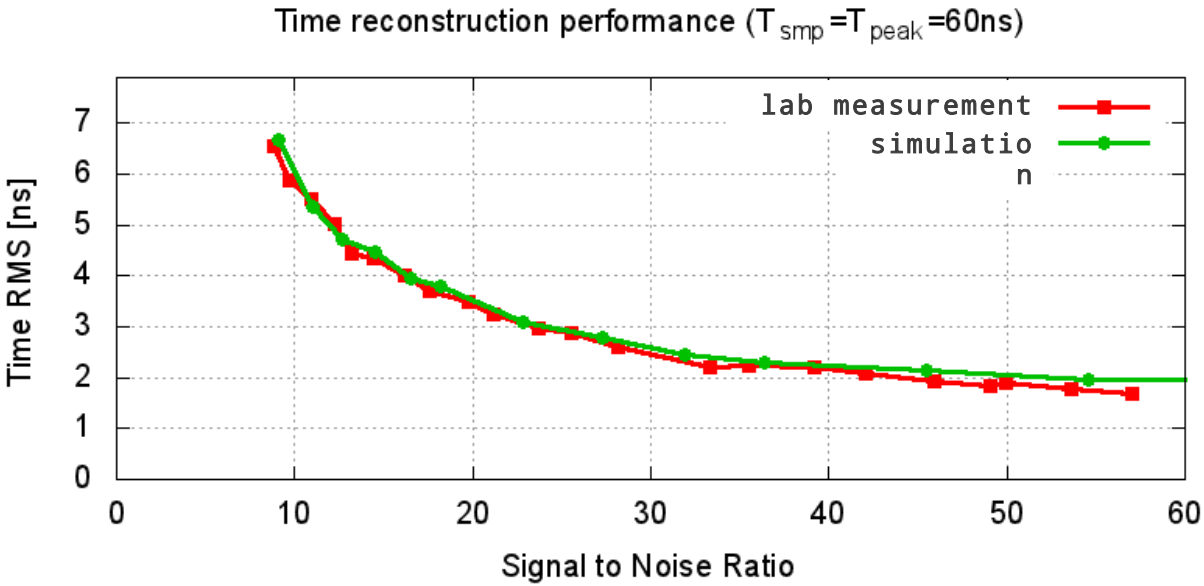
$$s_k = w_0 v_k + w_1 v_{k-1} + w_2 v_{k-2}$$

- Motivations / Applications
  - Precise time measurement
    (time tagging for CLIC,
    already used for FCAL testbeams)
- Properties / Advantages
  - Reduces long CR-RC pulse to 1 or 2 non-zero samples after deconvolution

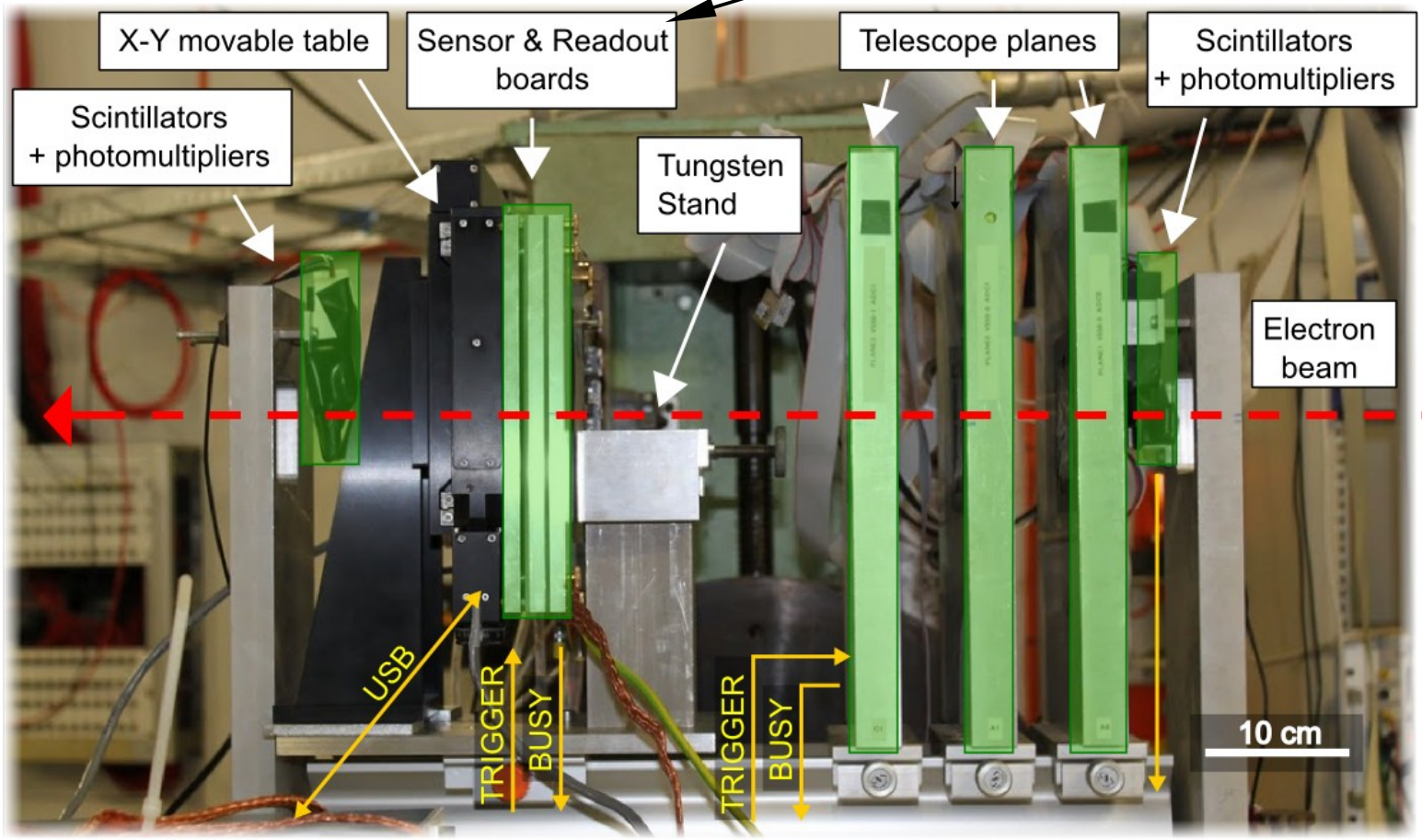
    ↓

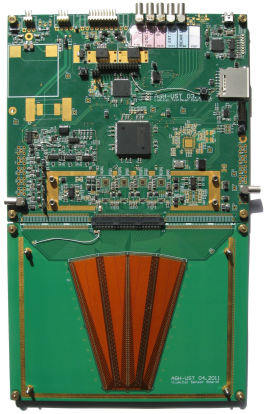
    Great pile-up resolving capabilities
  - Time resolution down to 1-2 ns possible for T_{peak} ~ 60 ns
  - Amplitude resolution only slight degradation

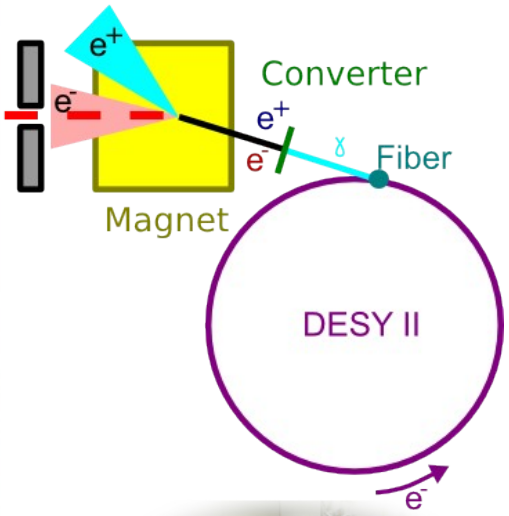


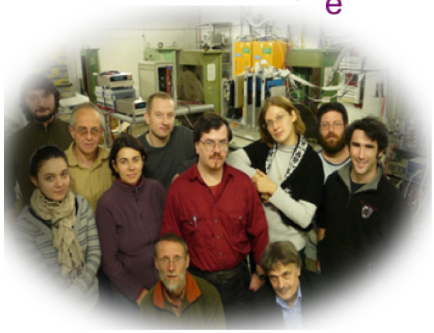


Testbeam Setup





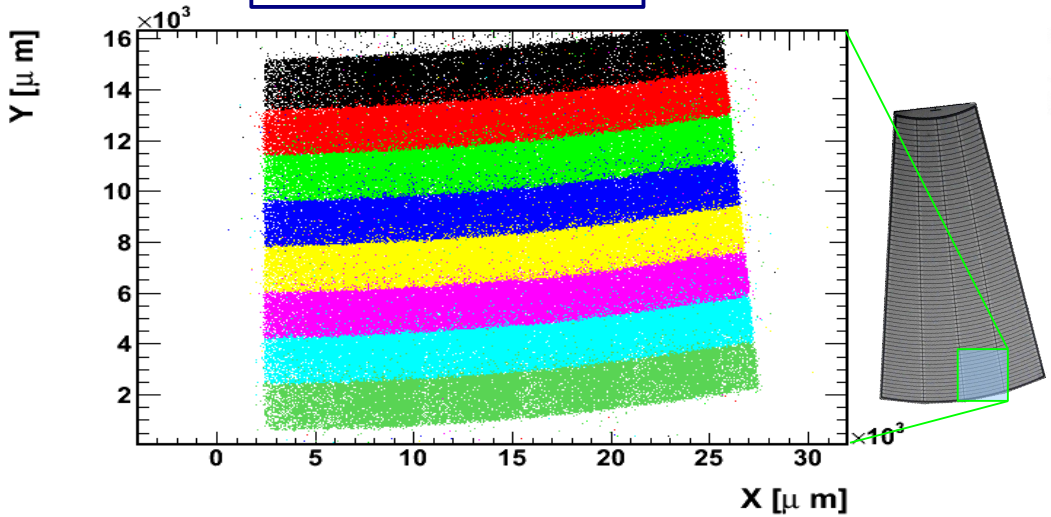


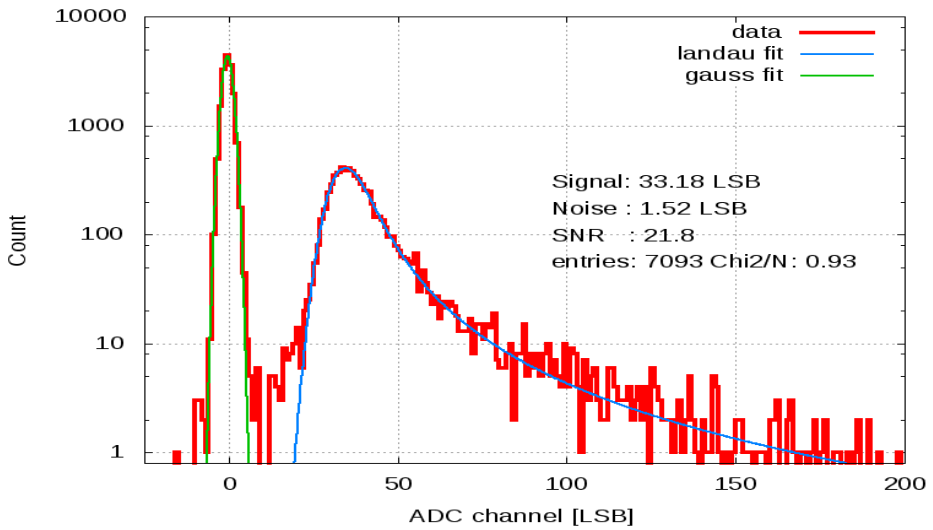


Several successful testbeam campaigns with complete detector module

Testbeam Results

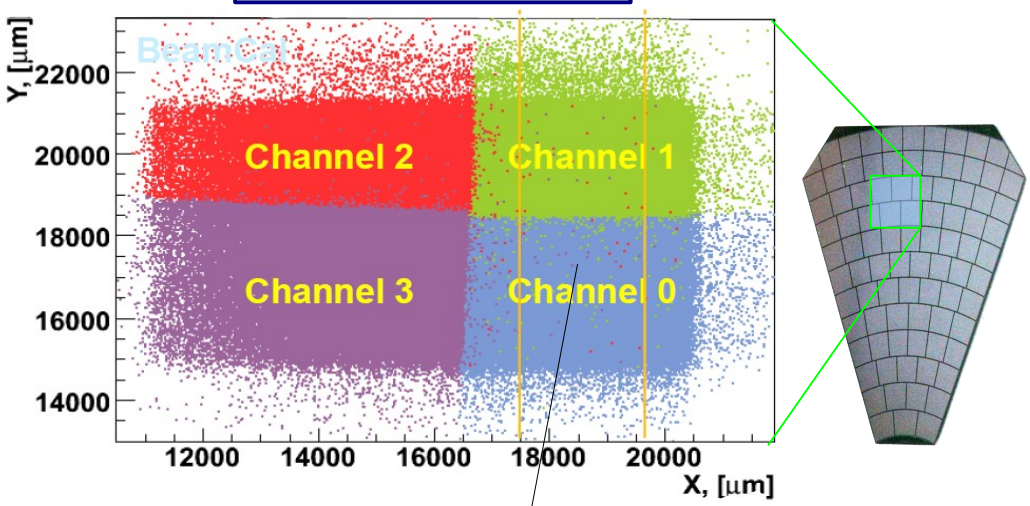
LumiCal sensor

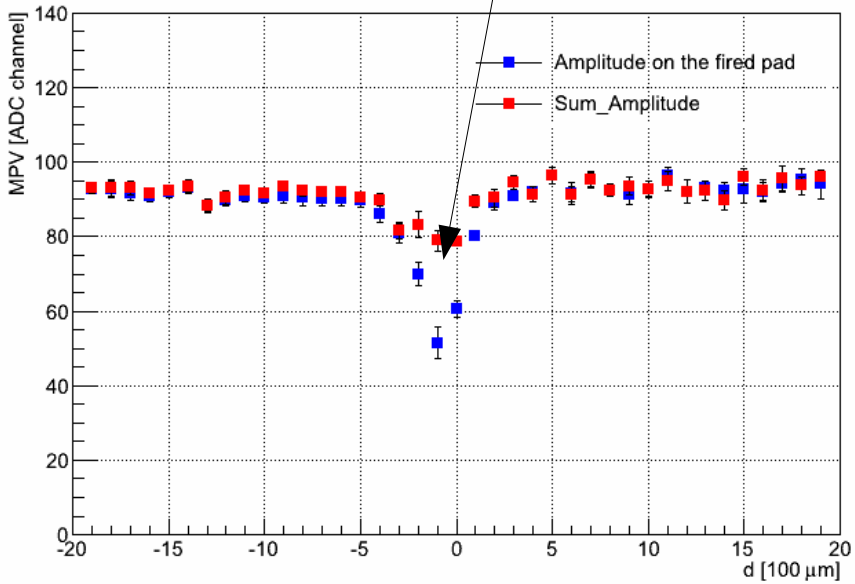




- Events processed using deconvolution algorithm
- Data well described by fitted Landau-Gauss distribution
- S/R is above 20 for each channel

BeamCal sensor

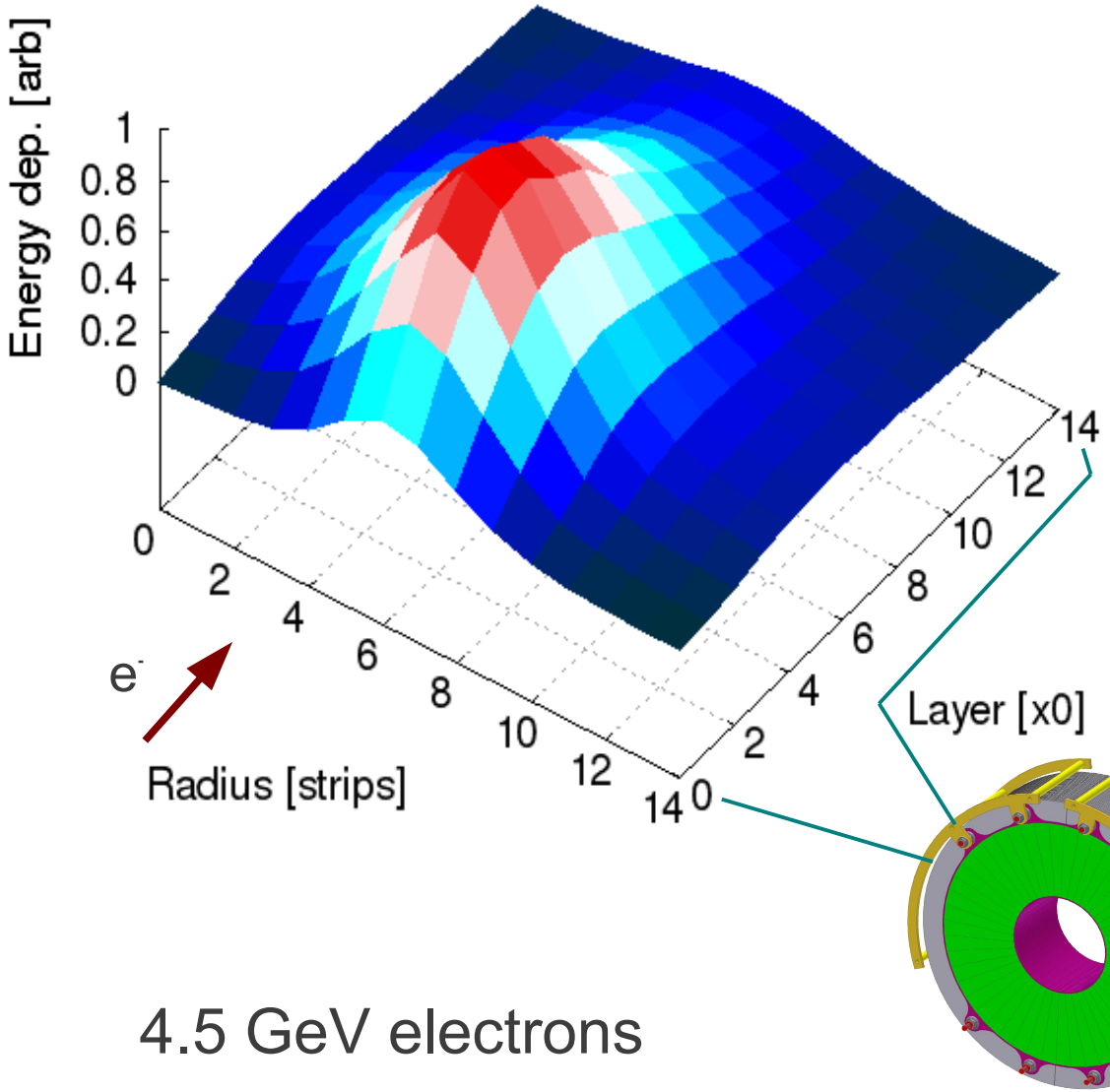




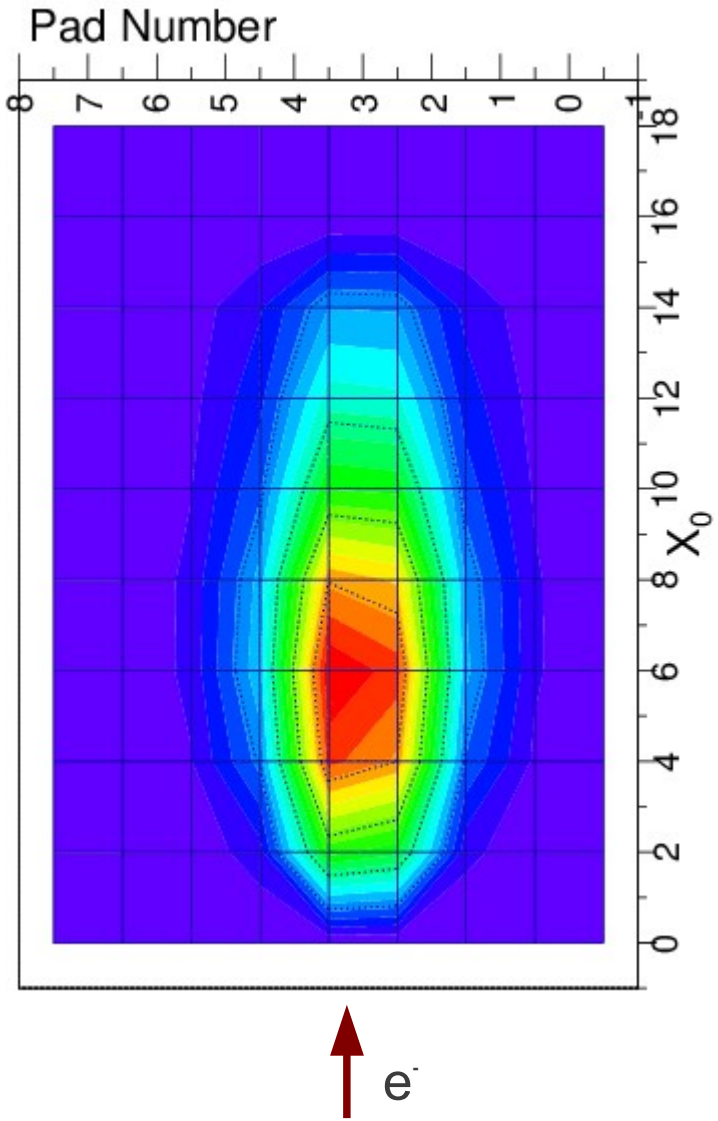
- Sensor responses are in good agreement with expectations

Reconstruction of Shower Shape

LumiCal sensor

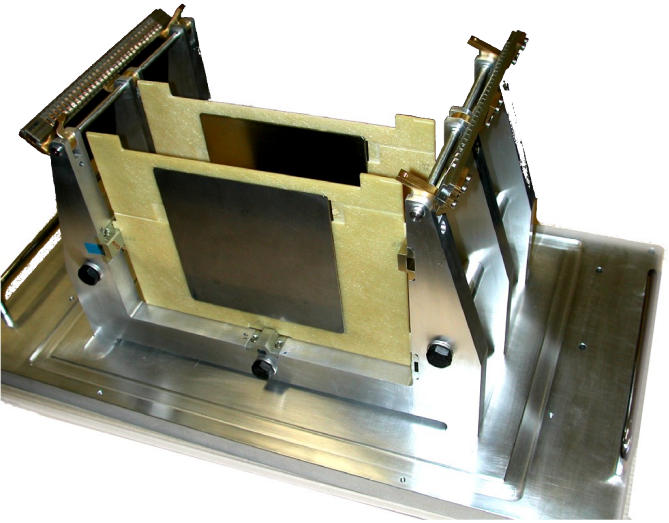


BeamCal sensor



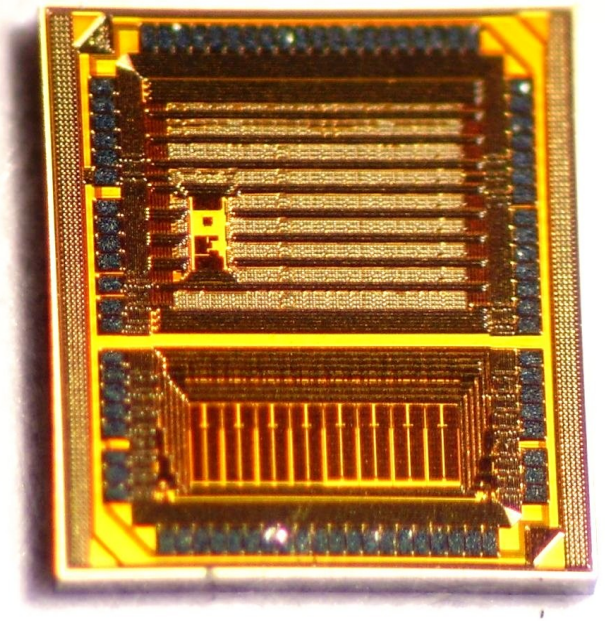
4.5 GeV electrons

Ongoing activities



Flexible mechanical infrastructure

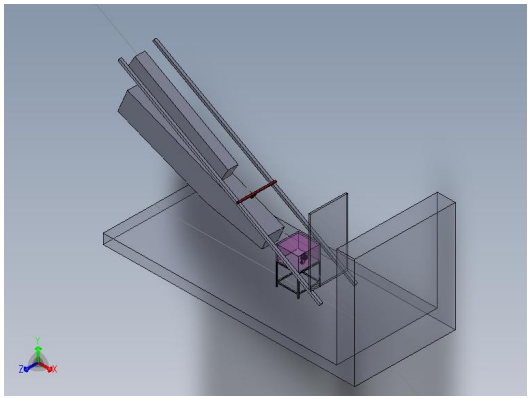
is being produced to allow testing individual sensors or complete segments of LumiCal or BeamCal Calorimeters. (up to **30 tungsten plates** with variable distance between plates)



New developments in IBM CMOS 130nm

The design of LumiCal readout with the same architecture (FE+ADC+ Serializer) has been started in IBM 130nm

First prototypes of: 10-bit SAR ADC, PLL, SLVS I/O,Serializer



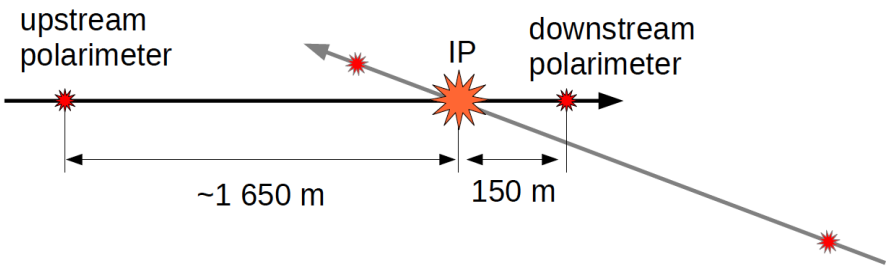
Radiation Damage Study Facility

will allow performing radiation hardness studies under more realistic conditions, e.g. considering also the hadronic component in electromagnetic showers

Polarimetry at Linear Colliders

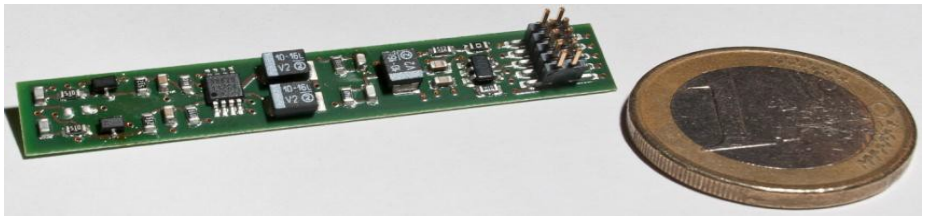
Challenge

determine average beam polarisation at IP to $\delta P/P \approx 0.1\%$



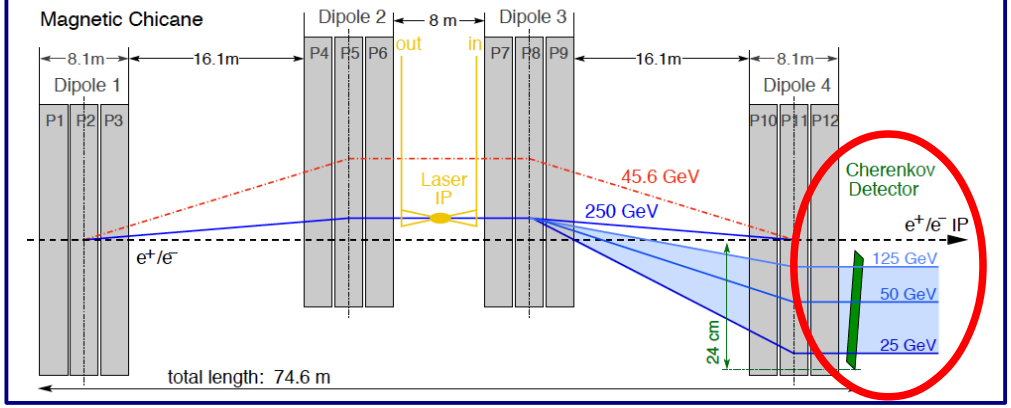
R&D on Gas Cherenkov detector

- PMT calibration: in-situ control of non-linearity ≤ 0.5%
- Driver for stable LED pulses:



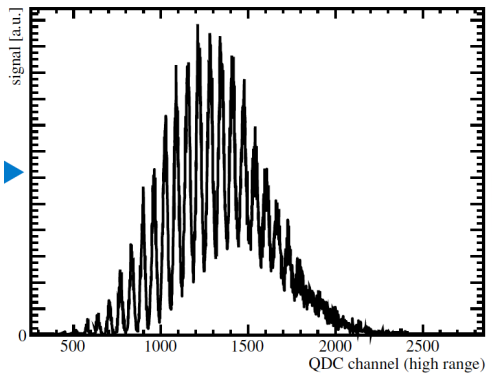
Laser Compton polarimeters

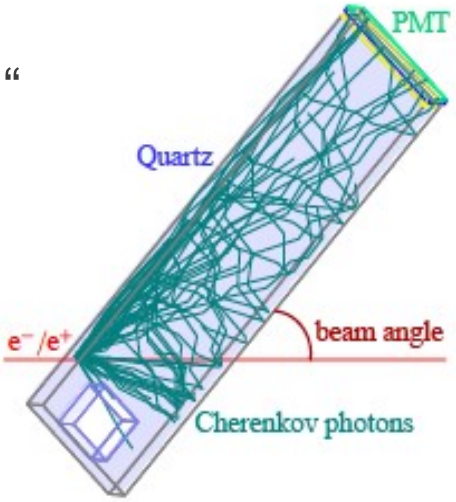
provide real time measurement to $\delta P/P \approx 0.25\%$ (syst.)



Alternative Cherenkov medium: Quartz

- high light yield
- „self-calibrating“





Summary

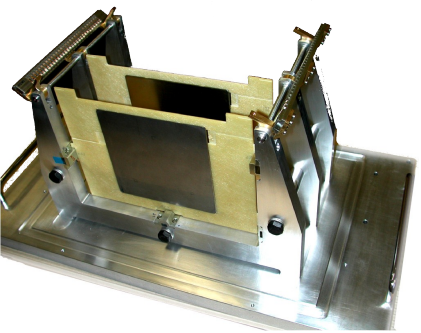
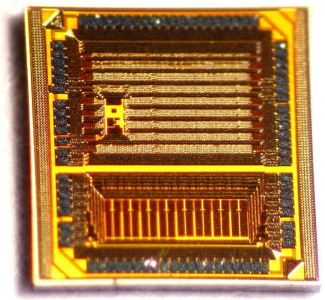
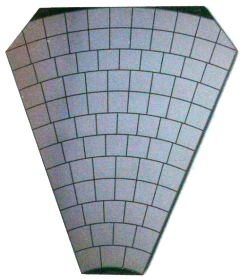
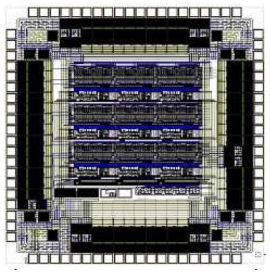
Challenges for the Very Forward Region:

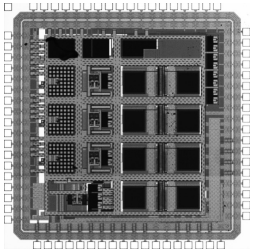
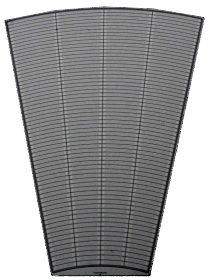
high precision → precise mechanics, laser alignment system

high radiation load → radiation-hard sensors

high occupancy → fast, low-power dedicated ASIC-based read-out

Thank you for attention !

FCAL Collaboration

Institutes involved:

AGH-UST, Cracow, Poland
DESY, Zeuthen, Germany
ISS, Bucharest, Romania
NCPHEP, Minsk, Belarus
Tel Aviv University, Tel Aviv, Israel
University of Colorado, Boulder, USA

ANL, Argonne, USA
IFIN-HH, Bucharest, Romania
JINR, Dubna, Russia
SLAC, Menlo Park, USA
Tohoku University, Sendai, Japan
Vinca,Belgrade, Serbia

CERN, Geneva, Switzerland
INP PAN, Cracow, Poland
LAL, Orsay, France
Stanford University, Stanford, USA
UC California, Santa Cruz, USA
Pontificia Universidad Católica, Chile