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

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AGH-UST Cracow
on behalf of **FCAL Collaboration**

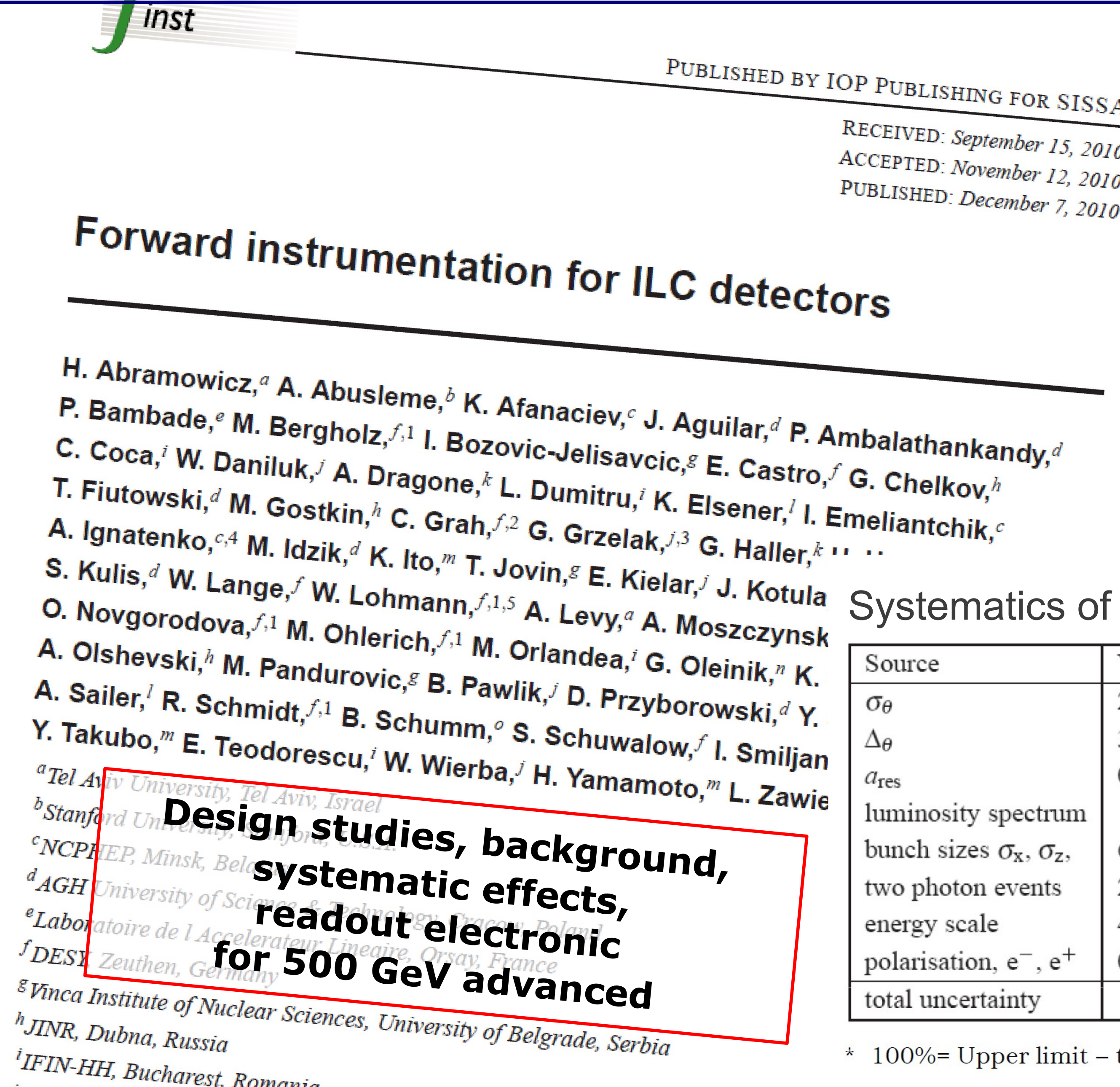
Special Linear Collider Event
Nuclear Science Symposium,
29/10/2012 – 3/11/2012, Anaheim, California

FCAL Collaboration

Institutes involved:

AGH-UST, Cracow, Poland	ANL, Argonne, USA	CERN, Geneva, Switzerland
DESY, Zeuthen, Germany	IFIN-HH, Bucharest, Romania	INP PAN, Cracow, Poland
ISS, Bucharest, Romania	JINR, Dubna, Russia	LAL, Orsay, France
NCPHEP, Minsk, Belarus	SLAC, Menlo Park, USA	Stanford University, Stanford, USA
Tel Aviv University, Tel Aviv, Israel	Tohoku University, Sendai, Japan	UC California, Santa Cruz, USA
University of Colorado, Boulder, USA	Vinca,Belgrade, Serbia	

Detector Design Studies @ ILC



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Forward instrumentation for ILC detectors

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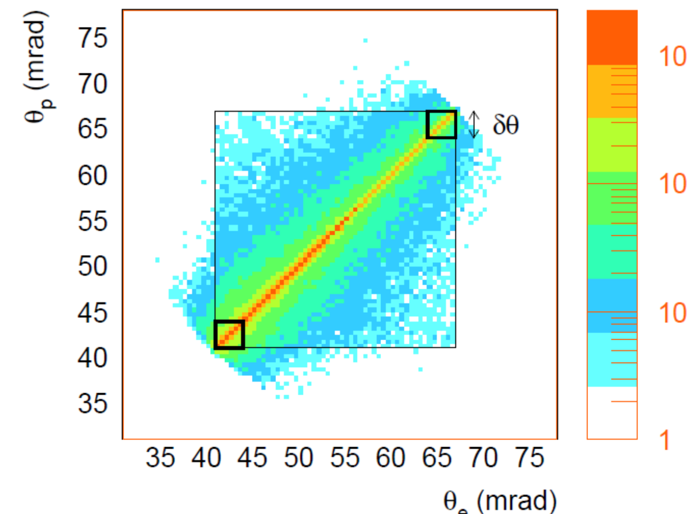
Design studies, background, systematic effects, readout electronic for 500 GeV advanced

Distributions of the polar angles of the outgoing Bhabha e+'s and e-'s (BHSE) @1TeV



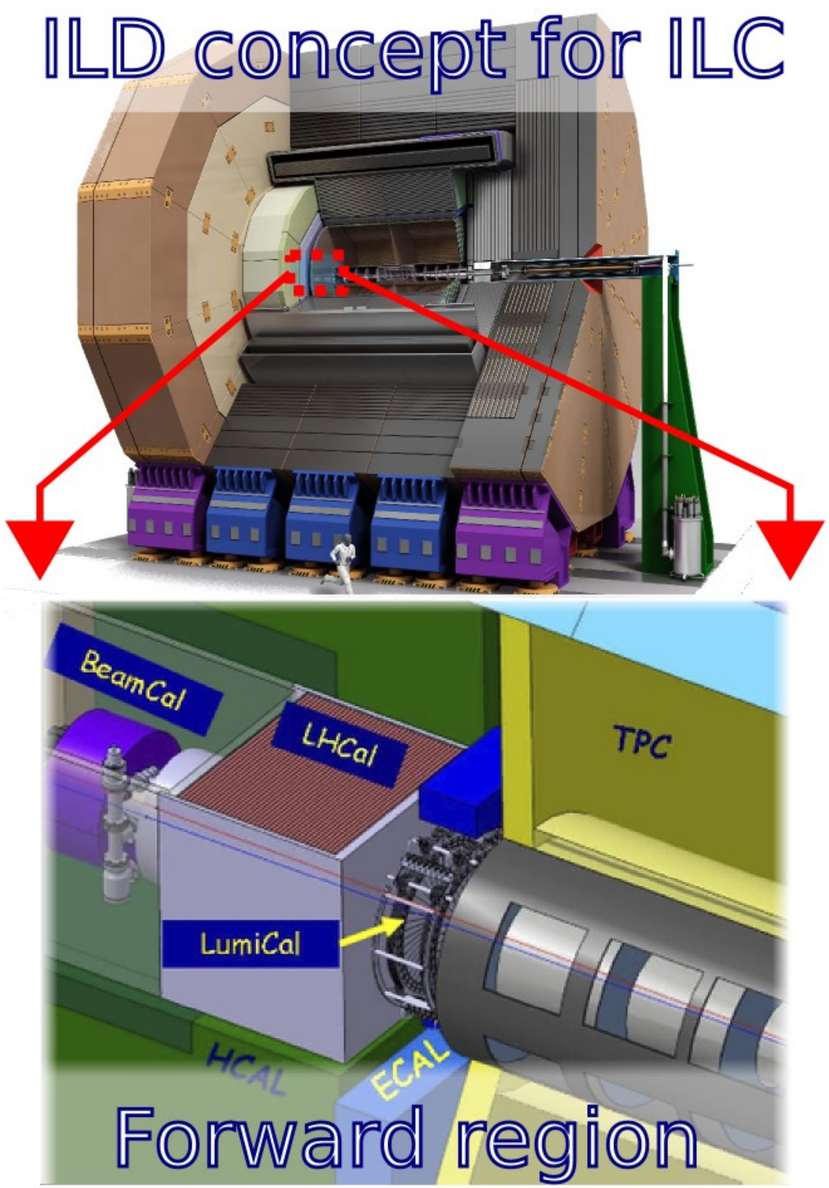
Systematics of luminosity measurement at 500GeV

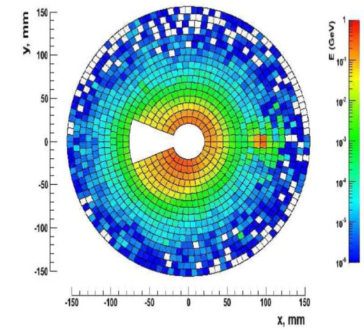
Source	Value	Uncertainty	Luminosity Uncertainty
σ_θ	2.2×10^{-2} [mrad]	100%	1.6×10^{-4}
Δ_θ	3.2×10^{-3} [mrad]	100%	1.6×10^{-4}
a_{res}	0.21	15%	10^{-4}
luminosity spectrum			10^{-3}
bunch sizes σ_x, σ_z,	655 nm, 300 μm	5%	1.5×10^{-3}
two photon events	2.3×10^{-3}	40%	0.9×10^{-3}
energy scale	400 MeV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

Challenges of Forward Region

for ILC and CLIC





BeamCal

low polar angle
electron tagging

BeamCal & Pair Monitor

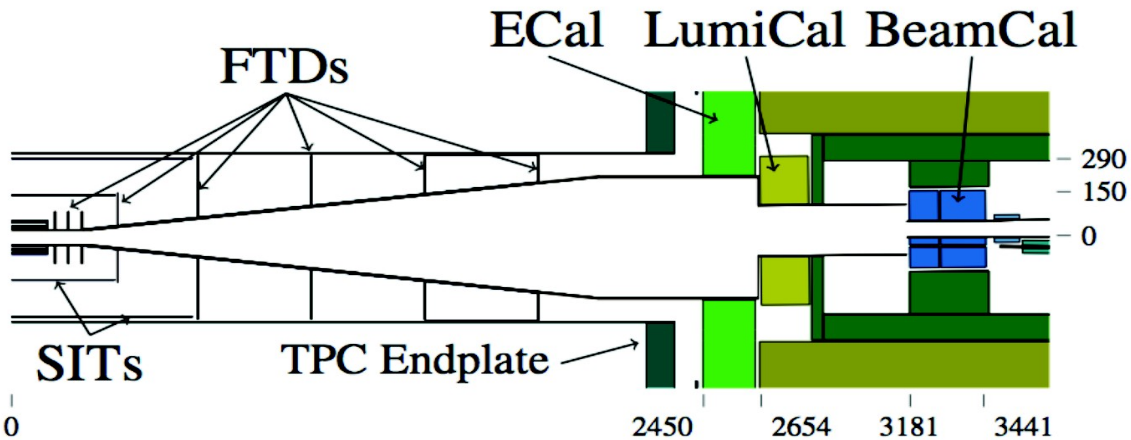
beam tuning and beam diagnostics (% precision)
fast feedback using special option of the ASICs

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)

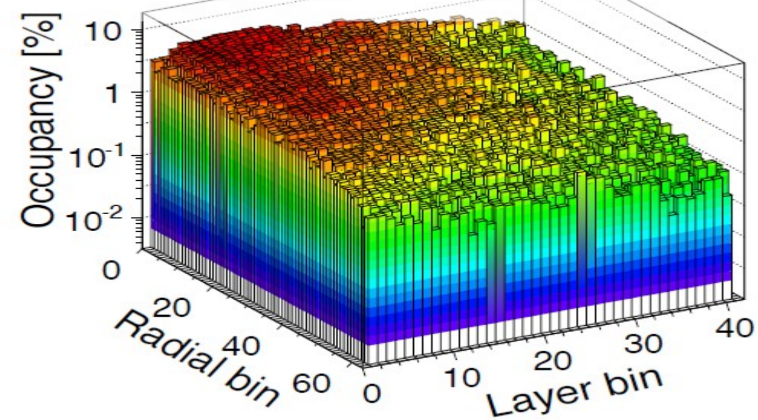
Detector Design Studies for CLIC

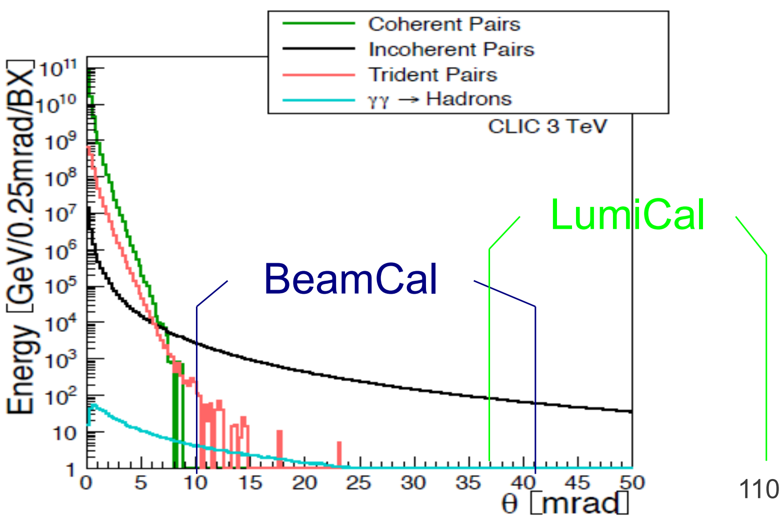


Forward region at CLIC

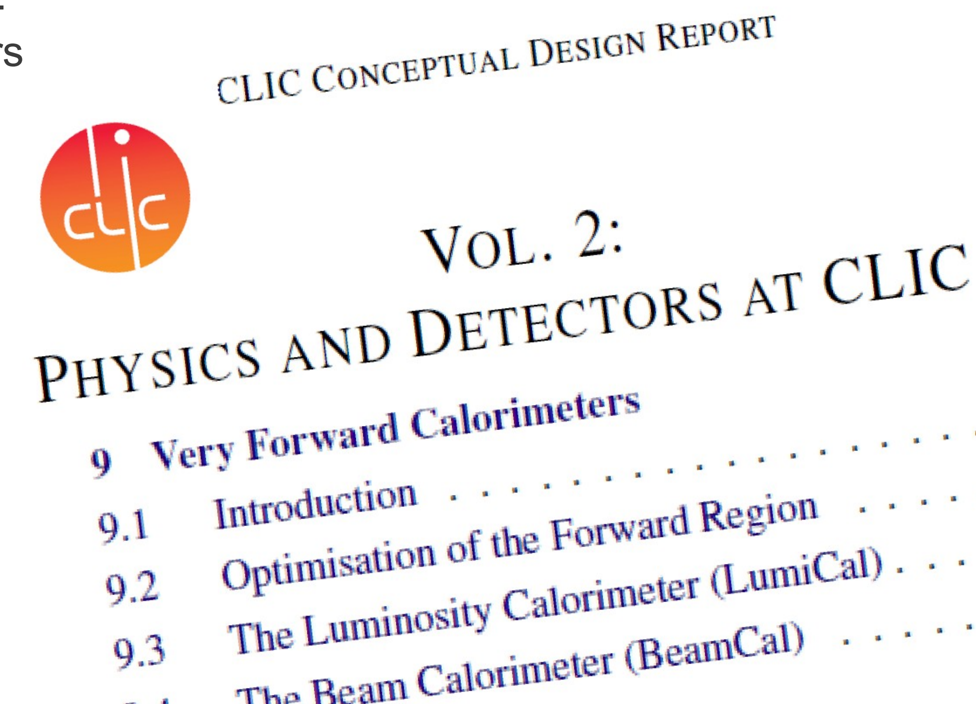
Dimensions and positions of Forward Calorimeters optimized to **minimize** background in LumiCal and number of back-scattered particles from forward region in tracking detectors

Occupancy of LumiCal pads from ϒϒ-> hadrons





Angular distribution of beam induced background


CLIC CONCEPTUAL DESIGN REPORT

VOL. 2:

PHYSICS AND DETECTORS AT CLIC

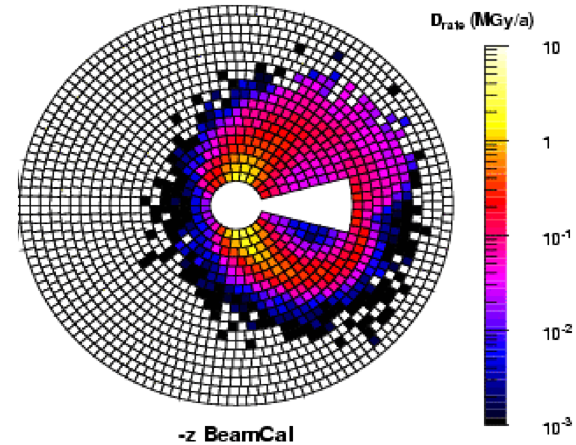
BeamCal sensors

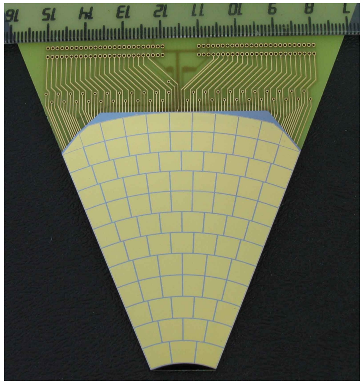
Very high radiation load
(a dose of several MGy per year)

Potential sensor materials:

- GaAs (by JINR Dubna)
  - Operational up to 0.5 Mgy (CCE ~ 10%)
  - Available on (small) wafer scale
- Sapphire
  - Charge collection efficiency a few %
  - Extremely high radiation hardness: after 12 MGy dose it has 30% of initial efficiency
  - Drawback: slow signals
- Poly-Crystalline Diamond (by Element Six and IAF)
  - High radiation hardness: tests up to 7 MGy
  - Availability on wafer scale
  - Drawback: high price
- **Tested in ongoing experiments (spin-offs):**
  - **Beam Halo Monitor @ FLASH**
  - **Beam Condition Monitor @ CMS**

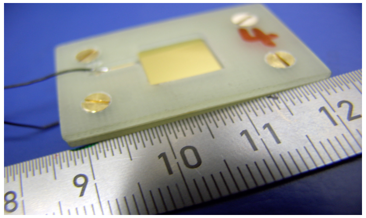
Dose in BeamCal sensor per year





Large area BeamCal pad GaAs sensor prototype

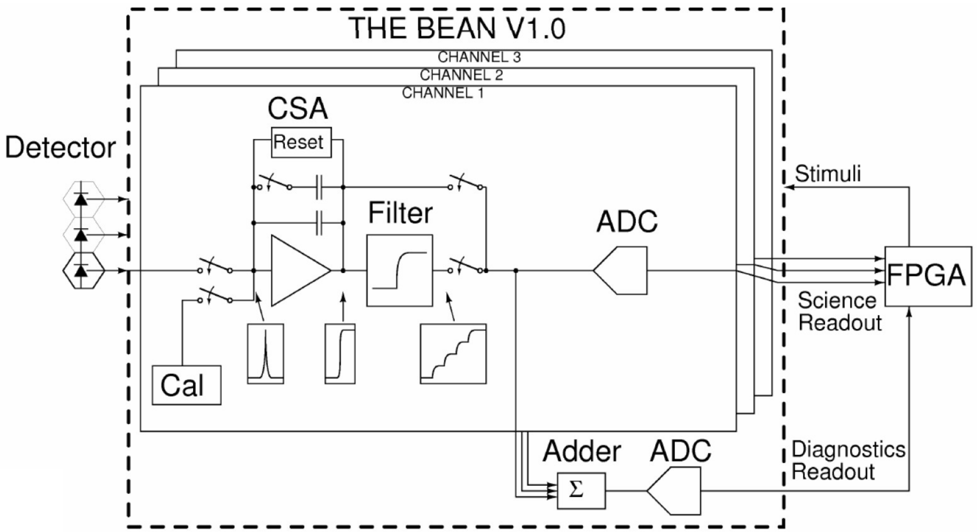
- 500 µm thick detector
- 87 pads (20 - 40mm^2)
- Leakage ~ 7nA/mm^2
- Capacitance ~ 0.3pF/mm^2



pCVD Diamond

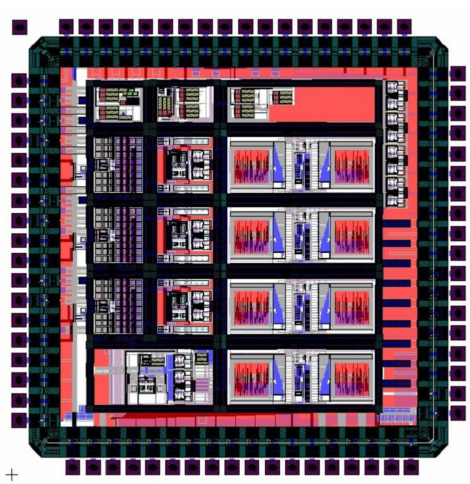
- 1 x 1 cm2
- 200-900 µm thick

BeamCal readout electronic

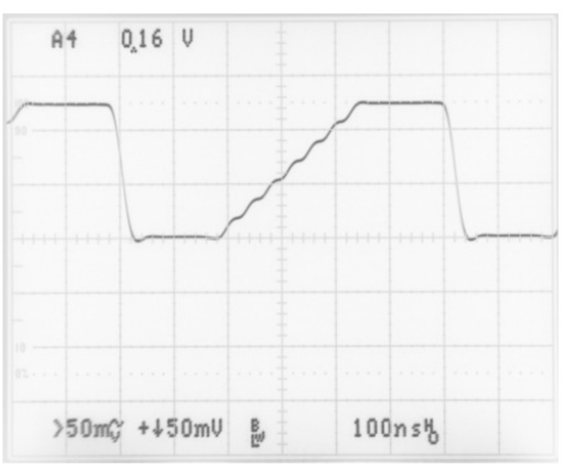


- Prototypes in 180-nm TSMC process
- Charge sensitive preamplifier (CSA)
  - precharge circuit for to maximize output swing
  - Gated reset for quick baseline restoration
- Switched-Capacitor filter
- Analog adder to provide fast feedback
- ADC : 10-bit SAR ADC

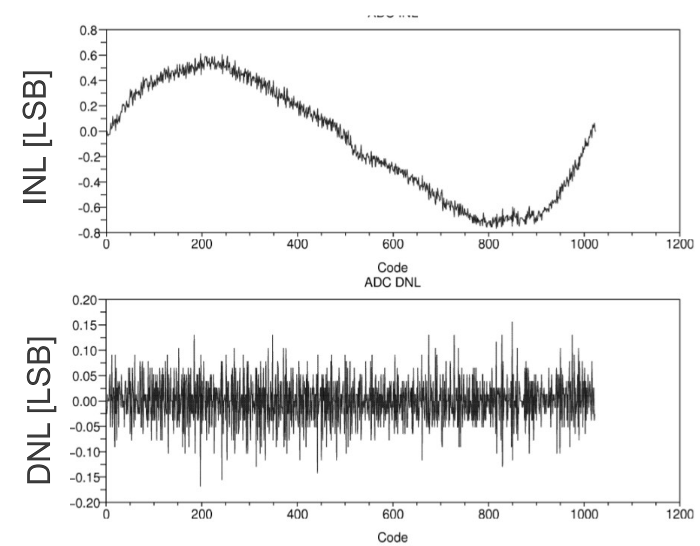
Prototype ASIC Layout



Shaper output



ADC performance



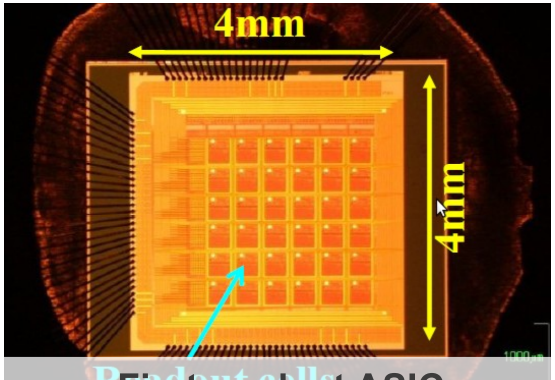
Pair Monitor

Pair Monitor is a silicon pixel detector to measure the beam profile at IP.

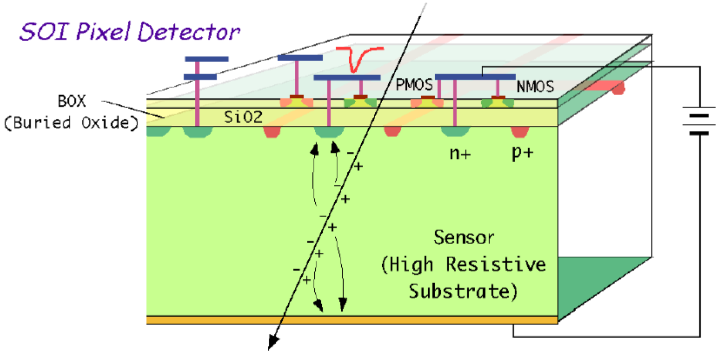
Detector radius 10cm, Pixel size 400x400 μm2, Total number of pixels ~ 200.000

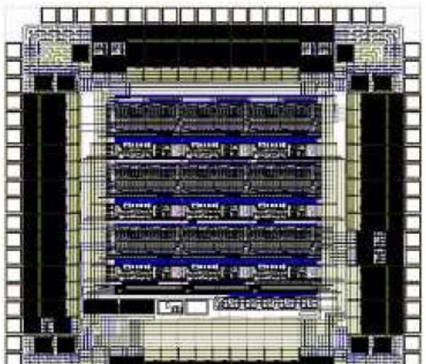
- First readout ASIC
  - CMOS process: **0.25 μm TSMC**
  - Chip size : 4 x 4 mm^2, **6 x 6** pixels (36)
  - Test setup based on KEK-VME 6U module was prepared
  - Sensor needs to be bound bonded

- Silicon On Insulator (SOI) technology – first readout prototype
  - The sensor and readout electronics are integrated in the SOI substrate. (monolithic)
  - **SOI 0.2 μm** CMOS process
  - Chip size : 2.5 x 2.5 mm^2, **3 x 3** pixels (9) (only readout)
  - The noise level is much smaller than typical signal level noise : 260 e^- (+130 e^-/pF) excepted signal : 20000 e^-
  - All the ASIC components work correctly.

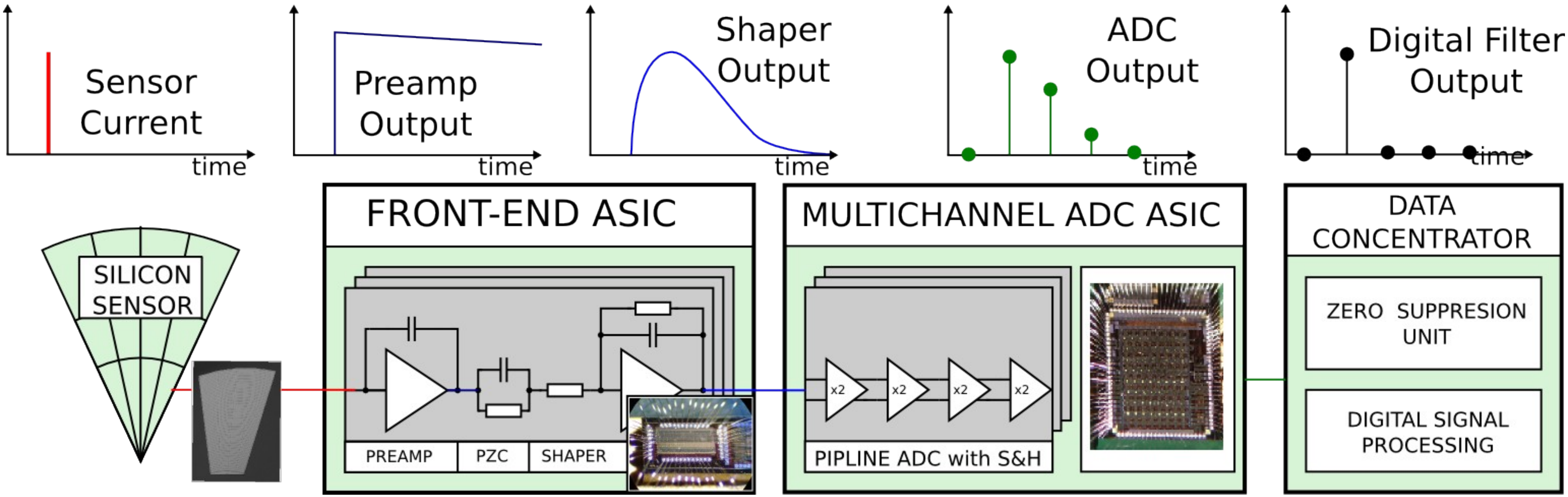


First readout ASIC




SOI prototype layout

LumiCal readout



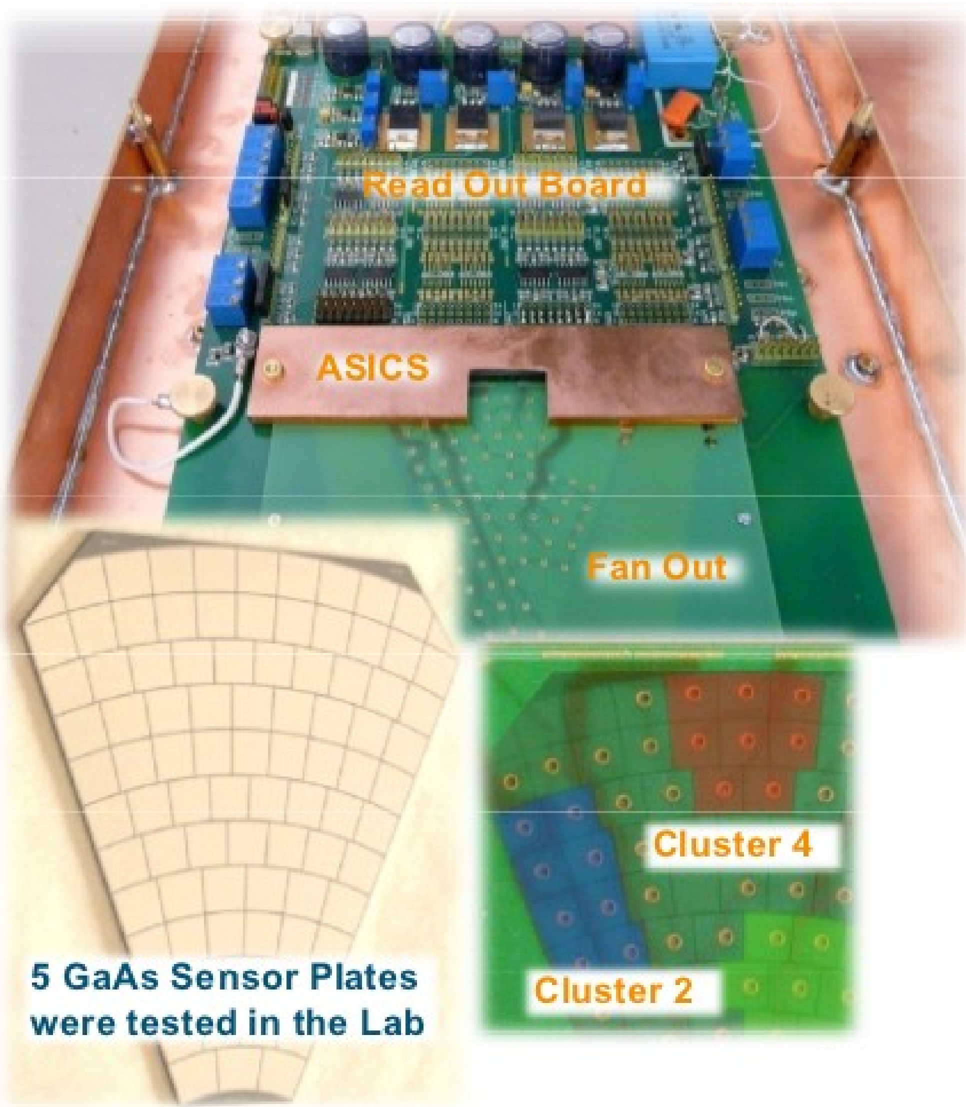
Sensor
- p^+ on n silicon sensor
  300μm thick
- Pad capacitance
  < 25 pF
- Leakage current
  < 5nA @ 500V
- Depletion voltage
  < 50V

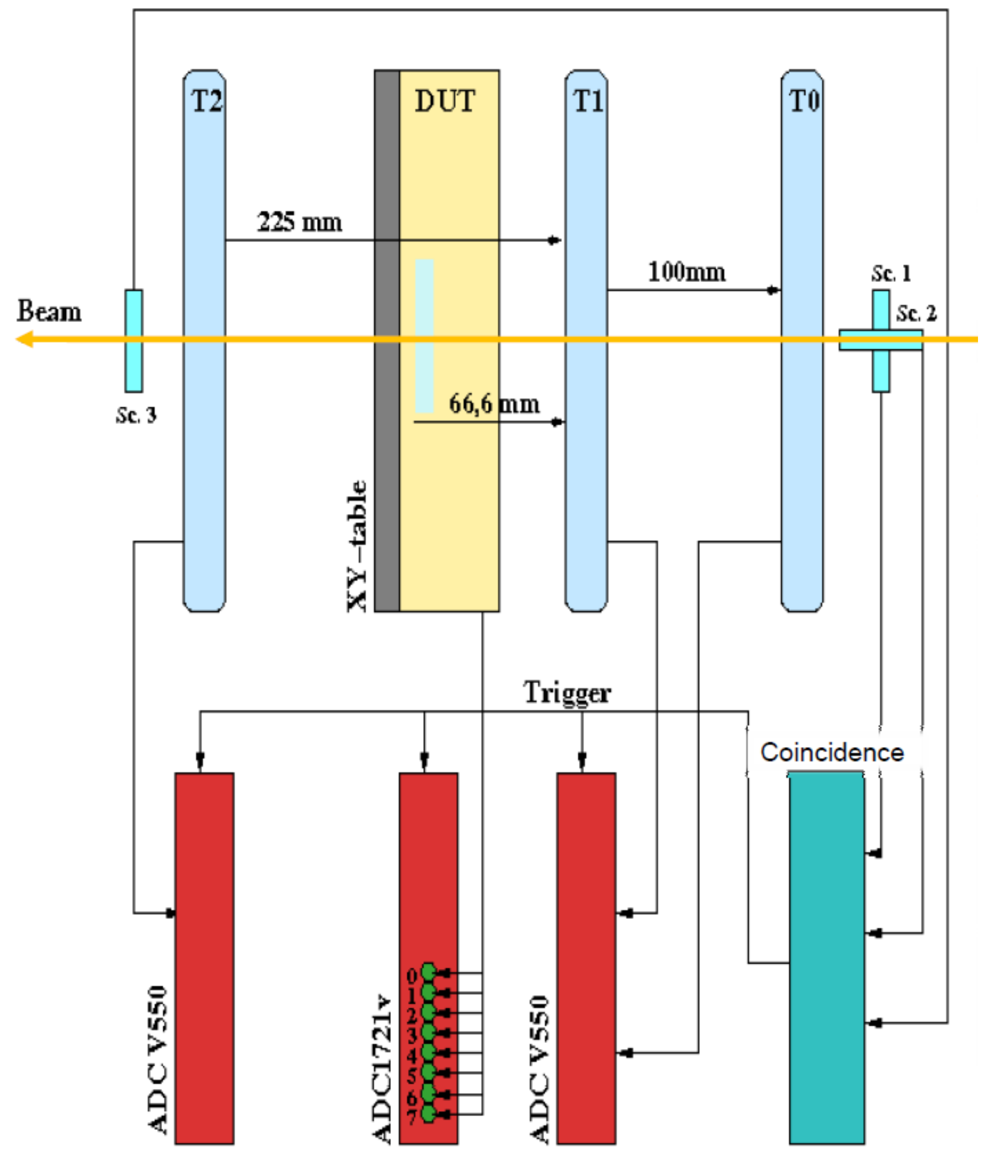
FrontEnd
- 8 channels of preamplifier + PZC + CRRC shaper (Tpeak ≈ 60 ns)
- C_{det} up to 100pF
- variable gain: dynamic range from ~2fC up to 10 pC
- event rate up to 3 MHz
- crosstalk < 1%

ADC Design
- 8 channels of pipeline ADC
- Multimode Digital serializer
- 9.7 ENOB up to 25 Ms/s
- Power consumption:
  ~1.2mW/channel/MHz
- Gain spread < 0.1 %
- Crosstalk < -80dB
- Power pulsing embedded

Used during most recent testbeams

Testbeam Setup 2010

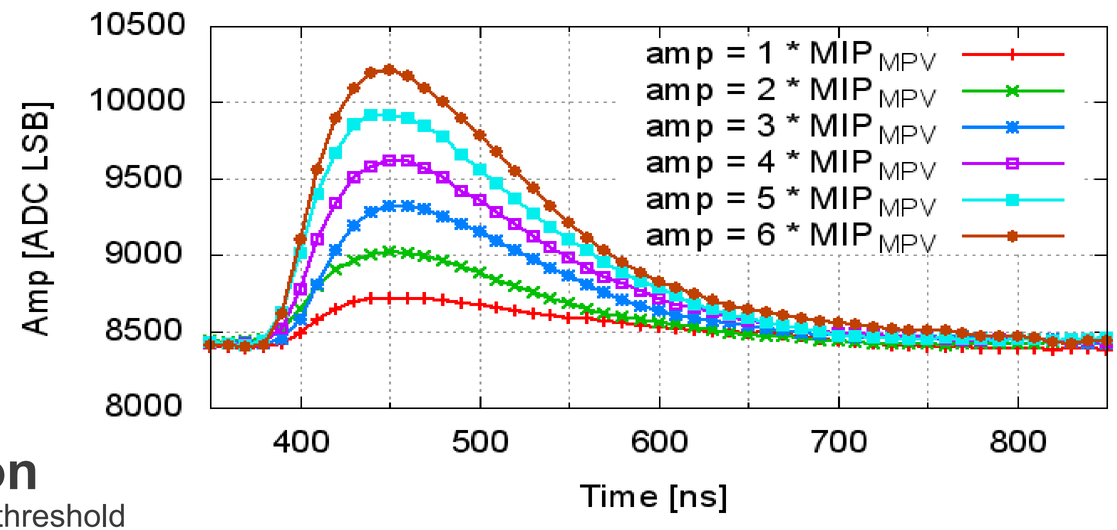




BeamCal / LumiCal sensor + LumiCal front-end + Commercial Sampling ADC

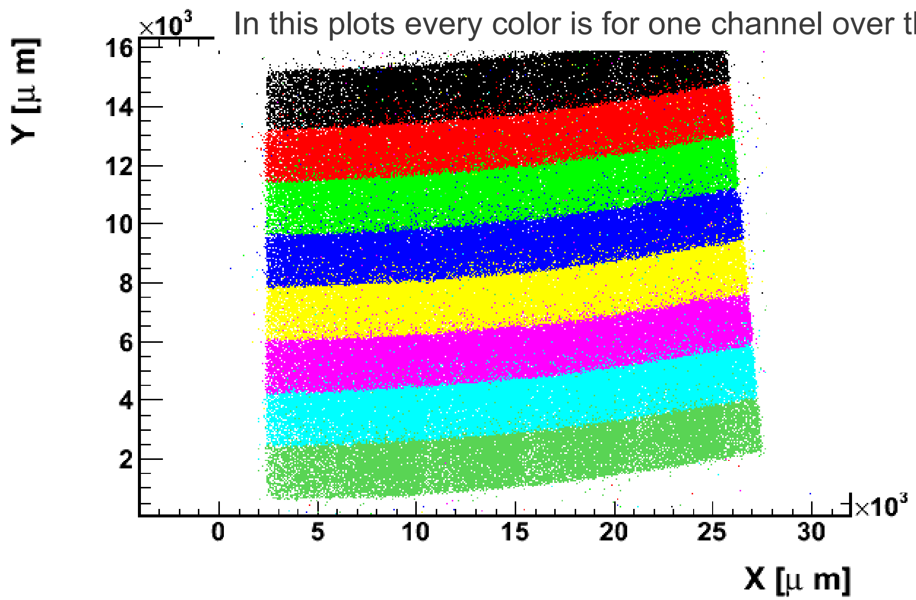
Testbeam Results 2010
(LumiCal Sensor)

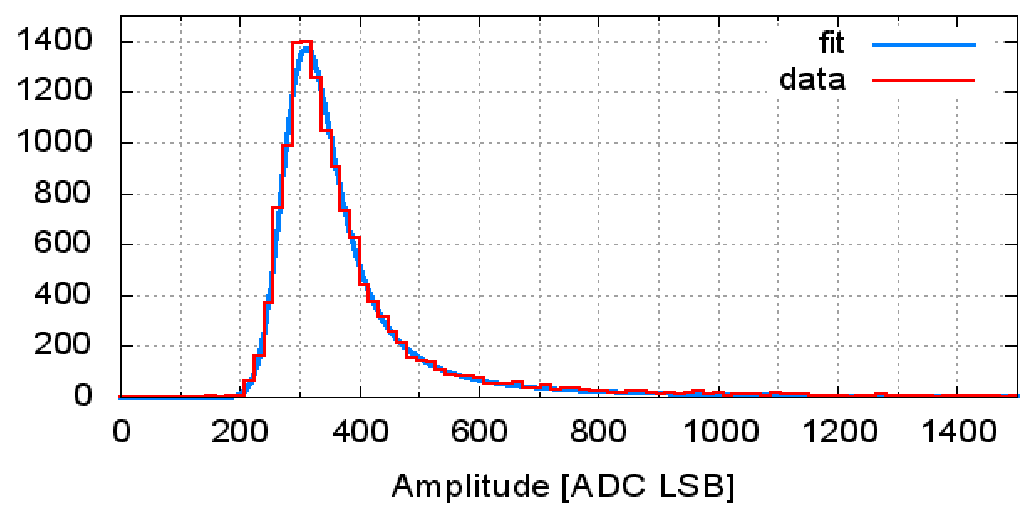
- Front-ends signal shape matches simulations
- Single electron spectrum matches Landau convoluted with Gauss distribution
- Signal to noise ratio (S/R) above 20
- Crosstalk <1%



Position reconstruction

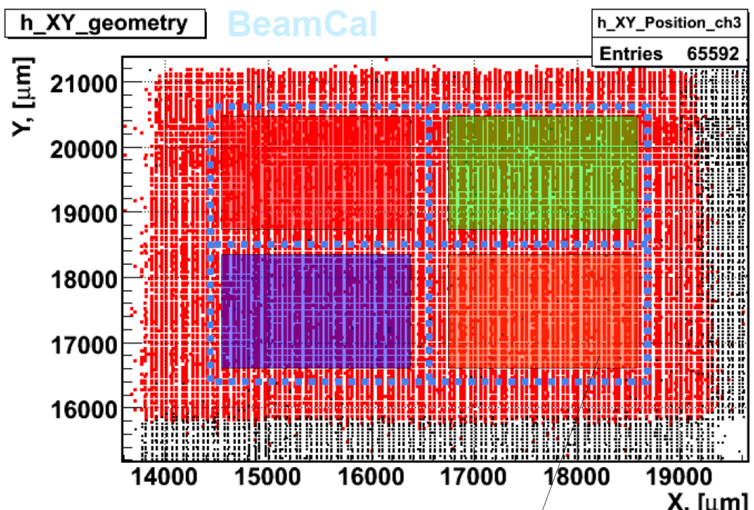
In this plots every color is for one channel over threshold

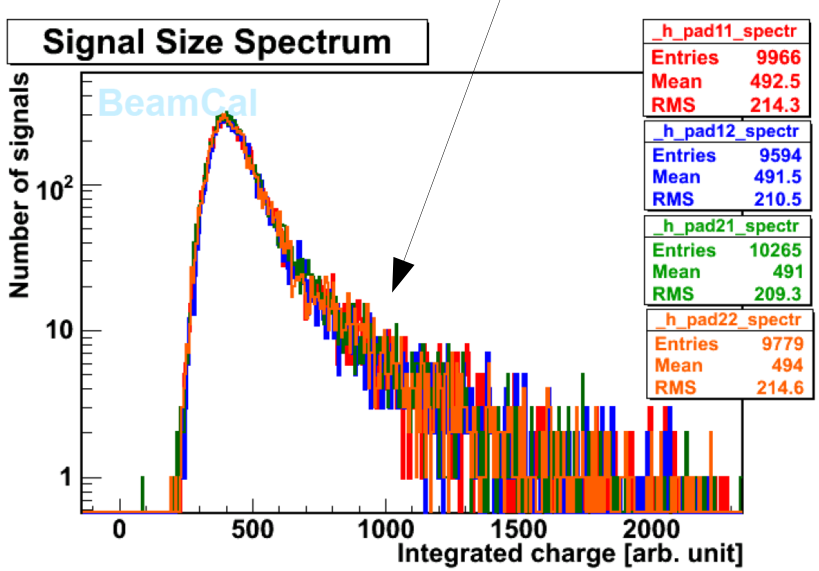




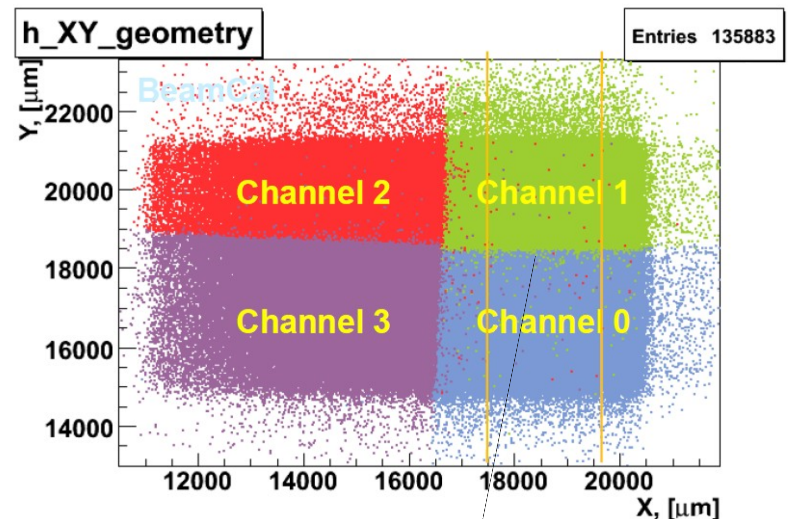
Testbeam Results 2010
(BeamCal Sensor)

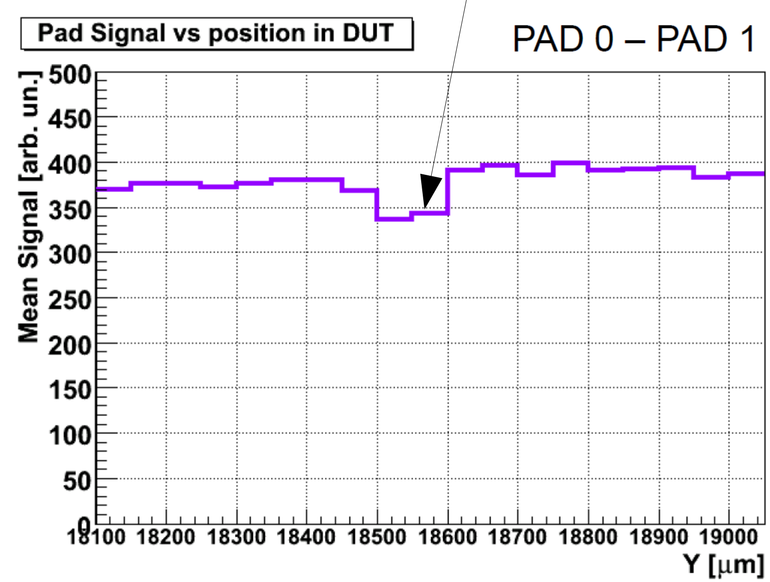
- Signal to noise ratio above 20
- Charge collection homogeneity



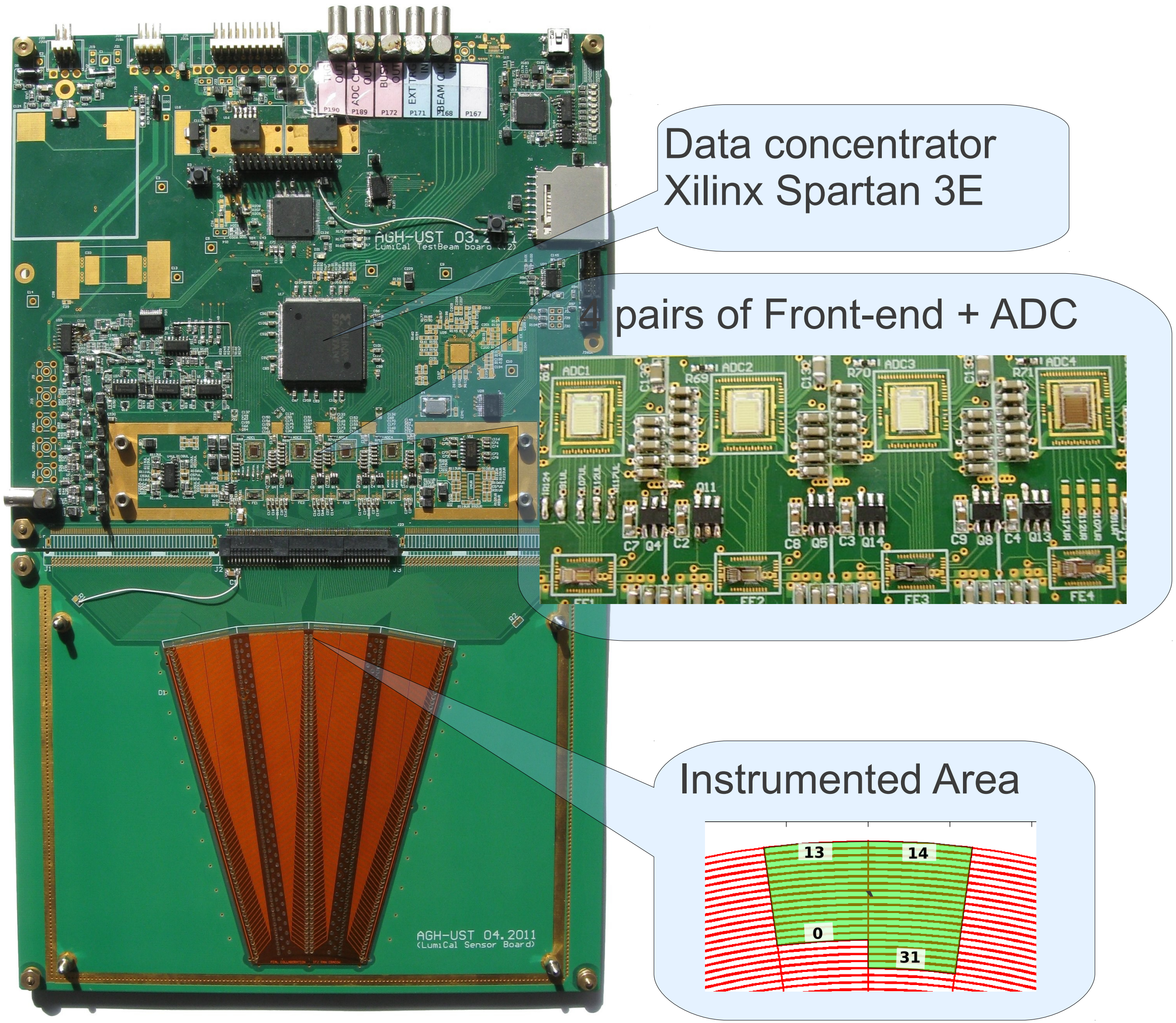


- Charge sharing between pads





Detector Module
towards testbeam 2011

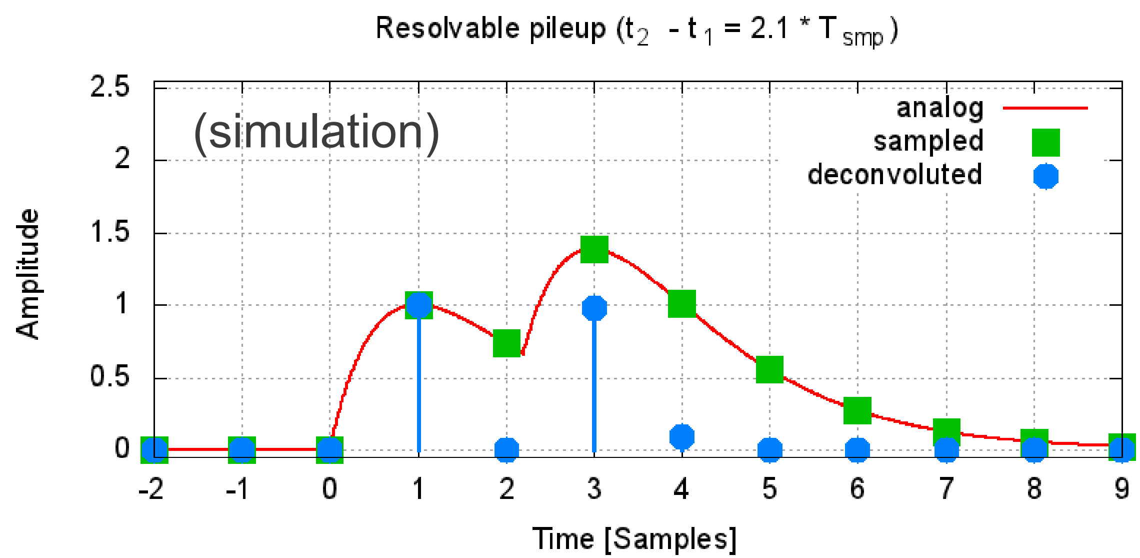


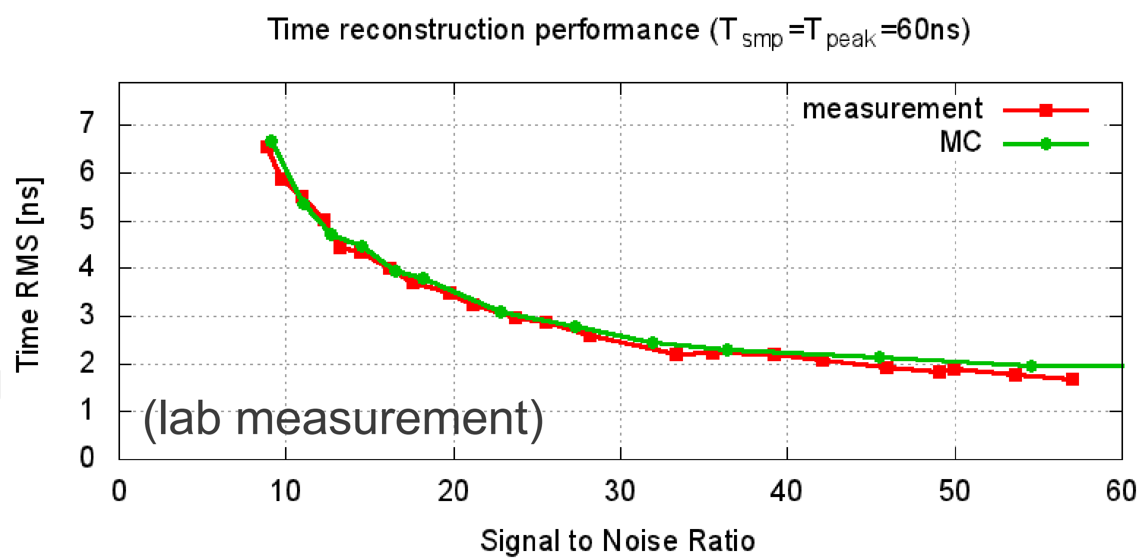
- **32 channels fully equipped channels (Sensor + Front-end +ADC)**
- ADC sampling rate is up to 20 MS/s (6.4 Gbps)
- Data can be transferred using USB
- Signal handshaking with Trigger Logic Unit (TLU)
- ADC Clock source
  - Internal (asynchronous with beam operation) – testbeam & CLIC mode
  - External (beam clock used to synchronize with beam) ILC mode

Deconvolution

as a solution for asynchronous sampling

- Motivation
  - Time tagging for CLIC (CLIC Note)
  - Testbeam data analysis (asynchronous sampling)
- Properties
  - reduces (infinite) number of CR-RC pulse samples to 1 or 2 non zero samples !
  - Great pile-up resolving capabilities (event delayed by 2~3 T_{smp})
  - Time resolution down to 1-2 ns possible for T_{peak} ~ 60 ns
- Deconvolution signal processing technique based on digital samples was developed and heavily tested

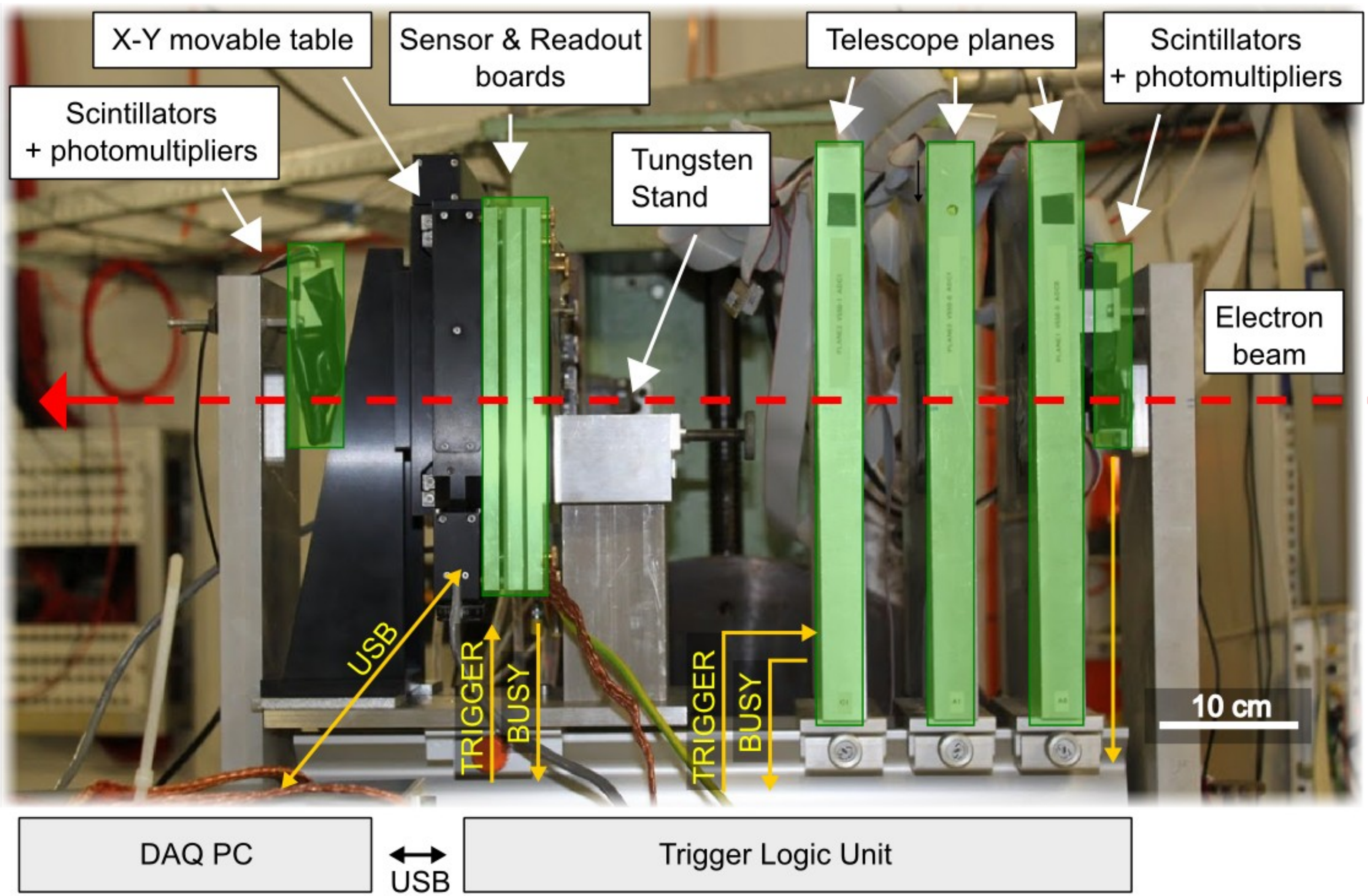


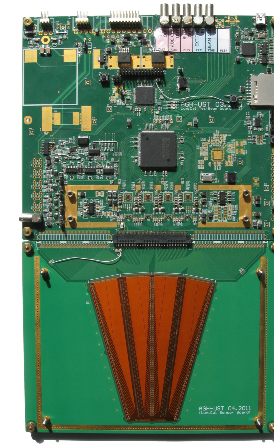


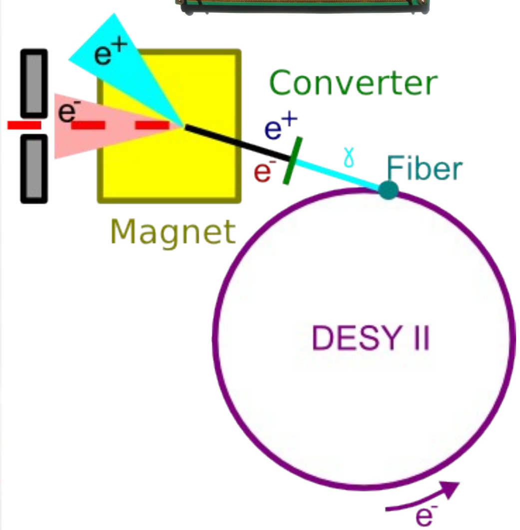
Sz. Kulis, M. Idzik | Workshop on timing detectors, 29 Nov to 01 Dec 2010, Cracow
Triggerless readout with events time and amplitude reconstruction based on deconvolution algorithm.

Collaboration
High precision design

Testbeam Setup 2011



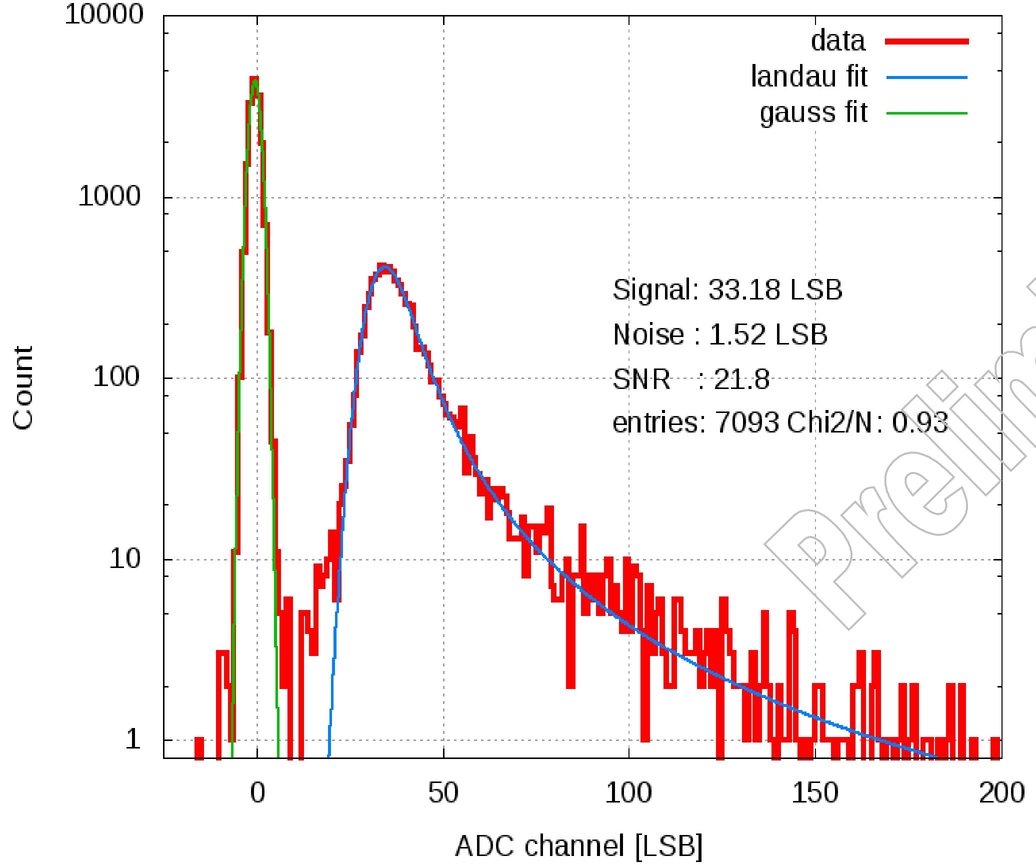




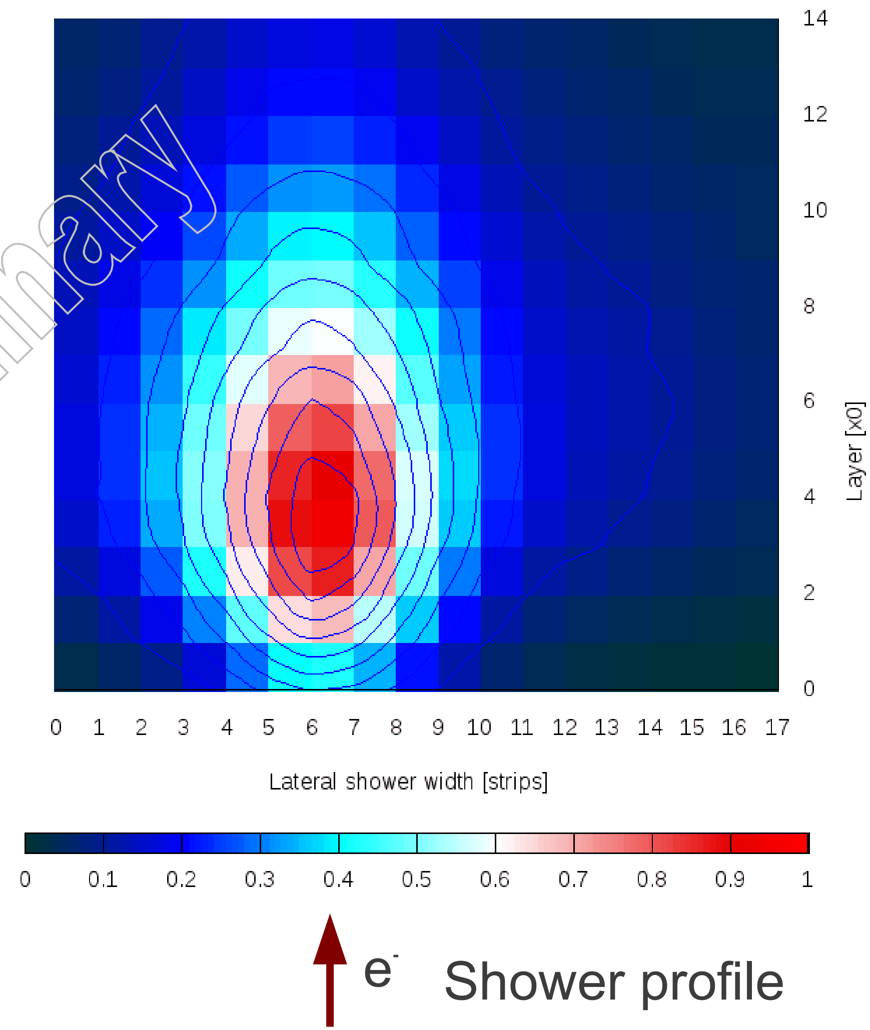
LumiCal sensor + LumiCal front-end + Multichannel ADC + Data concentrator

Testbeam Results 2011

No tungsten absorber



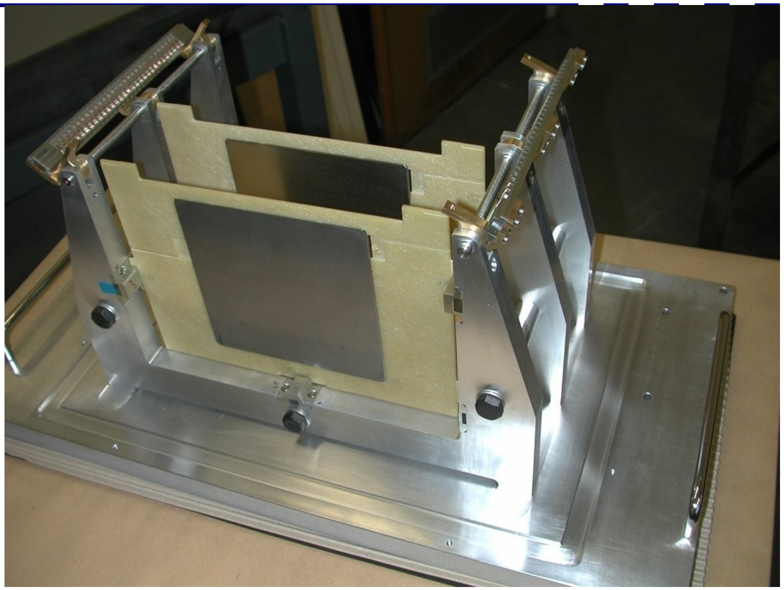
Tungsten absorber in front of sensor



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

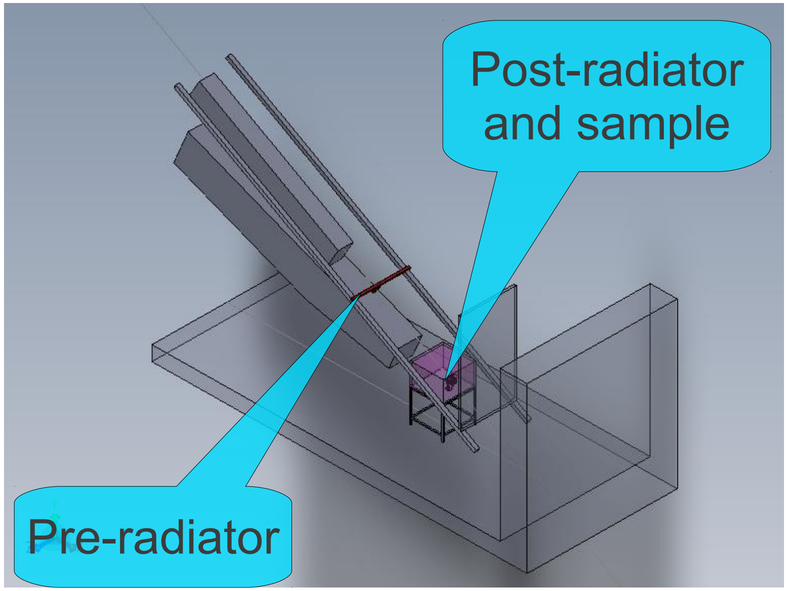
Next testbeam in November

Other ongoing activities



A 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)



Radiation Damage Study Facility

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

Summary & Future plans

Thank you for attention