Forward Region Calorimetry

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

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FCAL Collaboration

Institutes involved:

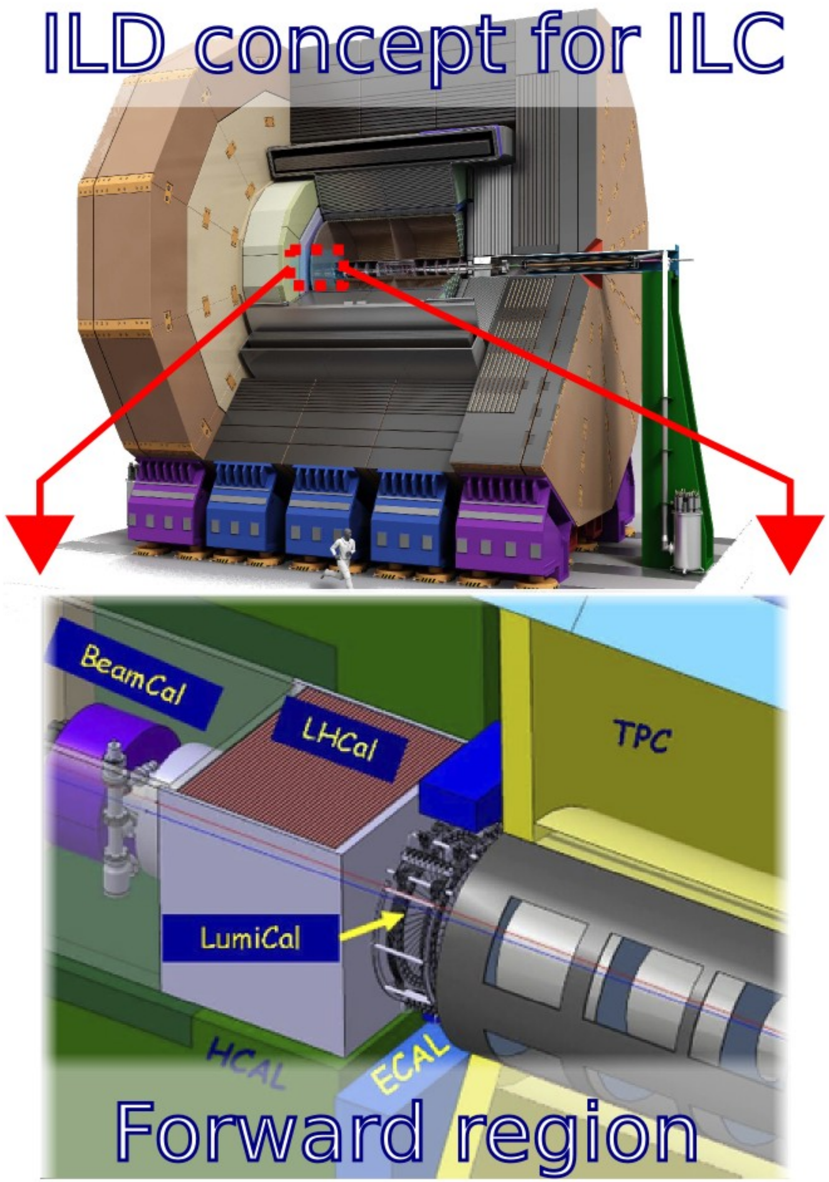
AGH-UST, Cracow, Poland
DESY, Zeuthen, Germany
ISS, Bucharest, Romania
NCPHEP, Minsk, Belarus
Tel Aviv University, Tel Aviv, Israel
University of Colorado, Boulder, USA

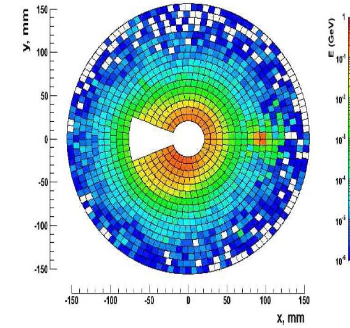
ANL, Argonne, USA
IFIN-HH, Bucharest, Romania
JINR, Dubna, Russia
SLAC, Menlo Park, USA
Tohoku University, Sendai, Japan
Vinca,Belgrade, Serbia

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

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 ILC

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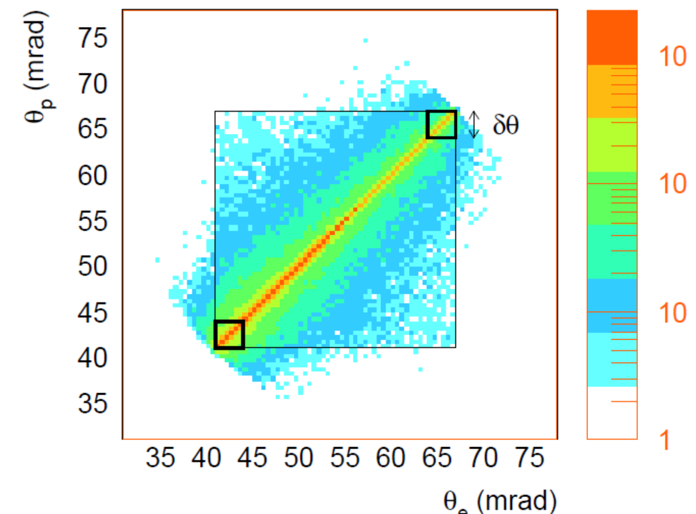
Forward instrumentation for ILC detectors

H. Abramowicz,[a] A. Abusleme,[b] K. Afanaciev,[c] J. Aguilar,[d] P. Ambalathankandy,[d] P. Bambade,[e] M. Bergholz,[f,1] I. Bozovic-Jelisavcic,[g] E. Castro,[f] G. Chelkov,[h] C. Coca,[i] W. Daniluk,[j] A. Dragone,[k] L. Dumitru,[i] K. Elsener,[l] I. Emeliantchik,[c] T. Fiutowski,[d] M. Gostkin,[h] C. Grah,[f,2] G. Grzelak,[j,3] G. Haller,[k] ... A. Ignatenko,[c,4] M. Idzik,[d] K. Ito,[m] T. Jovin,[g] E. Kielar,[j] J. Kotula S. Kulis,[d] W. Lange,[f] W. Lohmann,[f,1,5] A. Levy,[a] A. Moszczynsk O. Novgorodova,[f,1] M. Ohlerich,[f,1] M. Orlandea,[i] G. Oleinik,[n] K. A. Olshevski,[h] M. Pandurovic,[g] B. Pawlik,[j] D. Przyborowski,[d] Y. A. Sailer,[l] R. Schmidt,[f,1] B. Schumm,[o] S. Schuwalow,[f] I. Smiljan Y. Takubo,[m] E. Teodorescu,[i] W. Wierba,[j] H. Yamamoto,[m] L. Zawie

[a]*Tel Aviv University, Tel Aviv, Israel*
[b]*Stanford University, Stanford, U.S.A.*
[c]*NCPHEP, Minsk, Bel*
[d]*AGH University of Science & Technology, Cracow, Poland*
[e]*Laboratoire de l'Accelerateur Lineaire, Orsay, France*
[f]*DESY Zeuthen, Germany*
[g]*Vinca Institute of Nuclear Sciences, University of Belgrade, Serbia*
[h]*JINR, Dubna, Russia*
[i]*IFIN-HH, Bucharest, Romania*

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

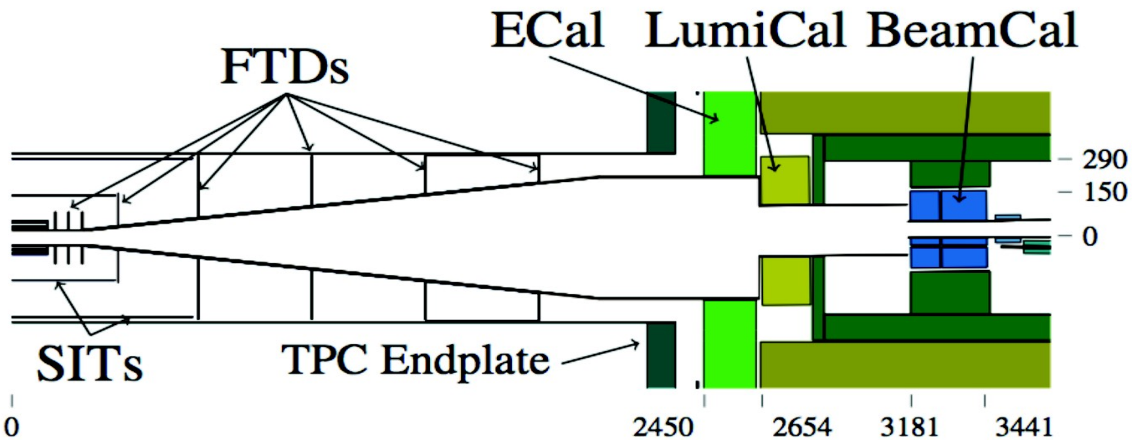


Systematics of luminosity measurement at 500GeV

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

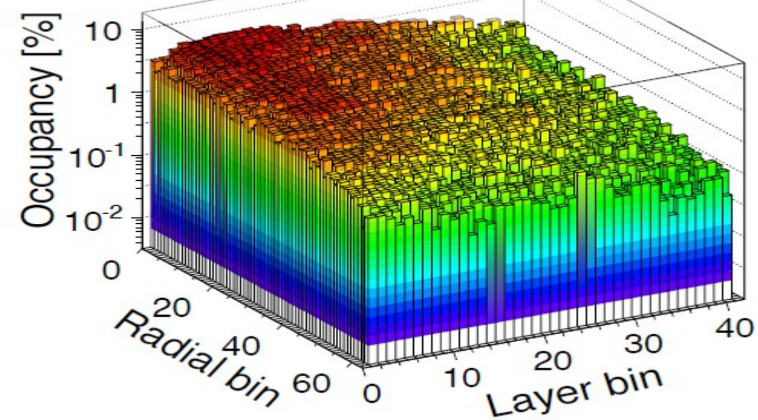
Detector Design Studies for CLIC

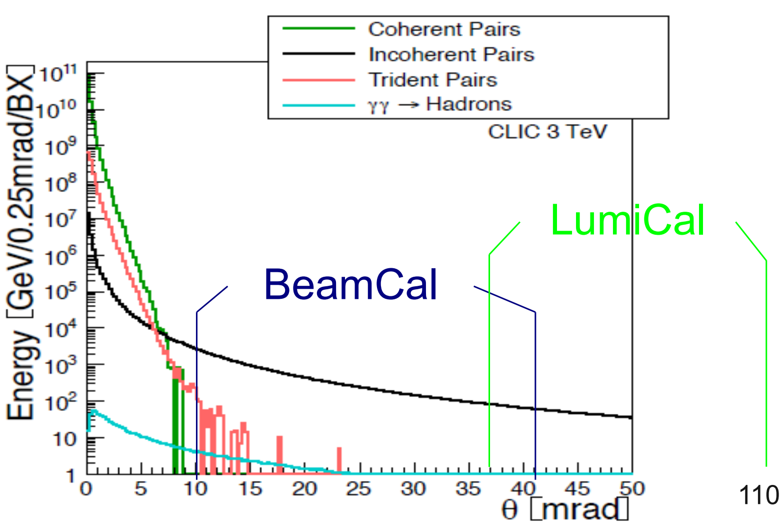


Forward region at CLIC

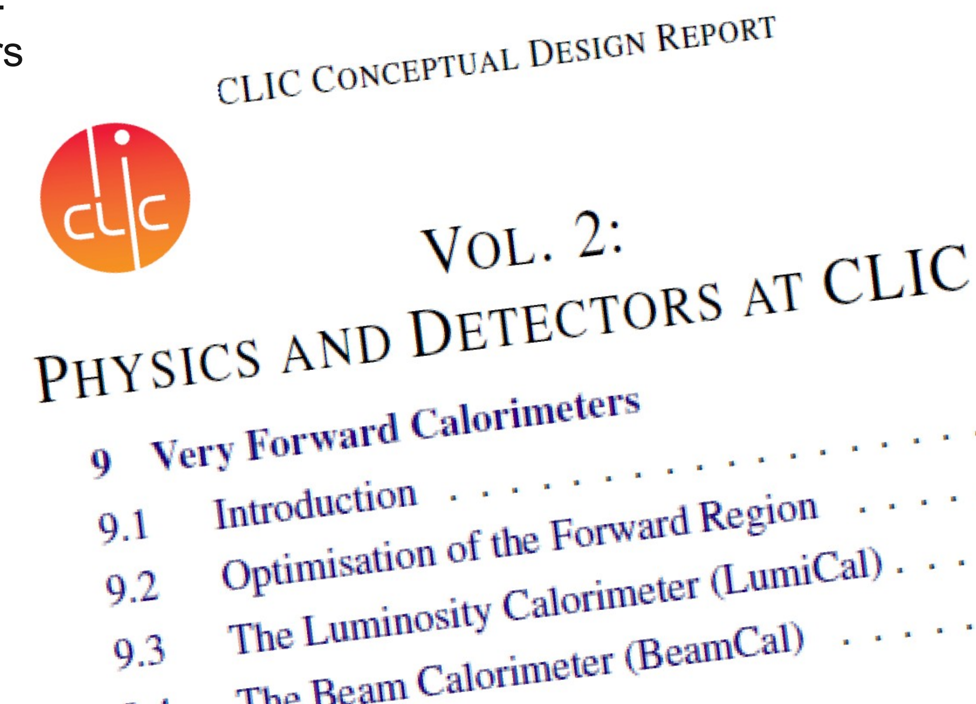
Dimensions and positions of Forward Calorimeters optimized to **minimize** background in LumiCal and number of back-scattered particles from forward region in tracking detectors

Occupancy of LumiCal pads from ϒϒ-> hadrons





Angular distribution of beam induced background


CLIC CONCEPTUAL DESIGN REPORT

VOL. 2:

PHYSICS AND DETECTORS AT CLIC

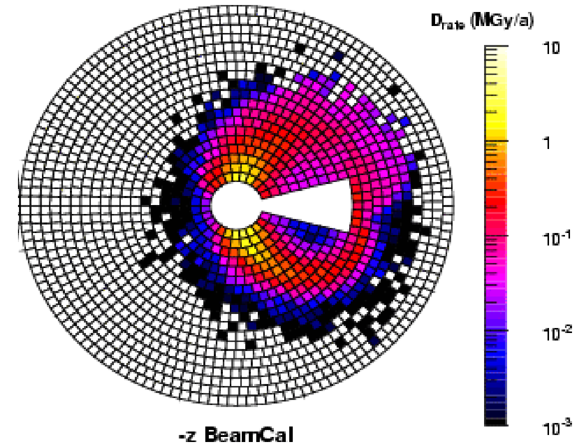
BeamCal sensors

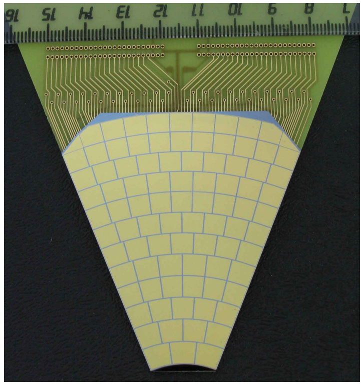
Very high radiation load
(a dose of several MGy per year)

Potential sensor materials:

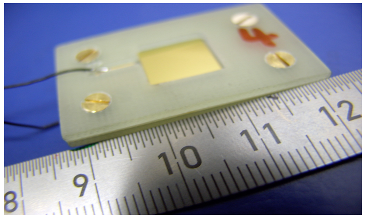
- GaAs (by JINR Dubna)
  - Operational up to 0.5 Mgy (CCE ~ 10%)
  - Available on (small) wafer scale
- Sapphire
  - Charge collection efficiency a few %
  - Extremely high radiation hardness: after 12 MGy dose it has 30% of initial efficiency
  - Drawback: slow signals
- Poly-Crystalline Diamond (by 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



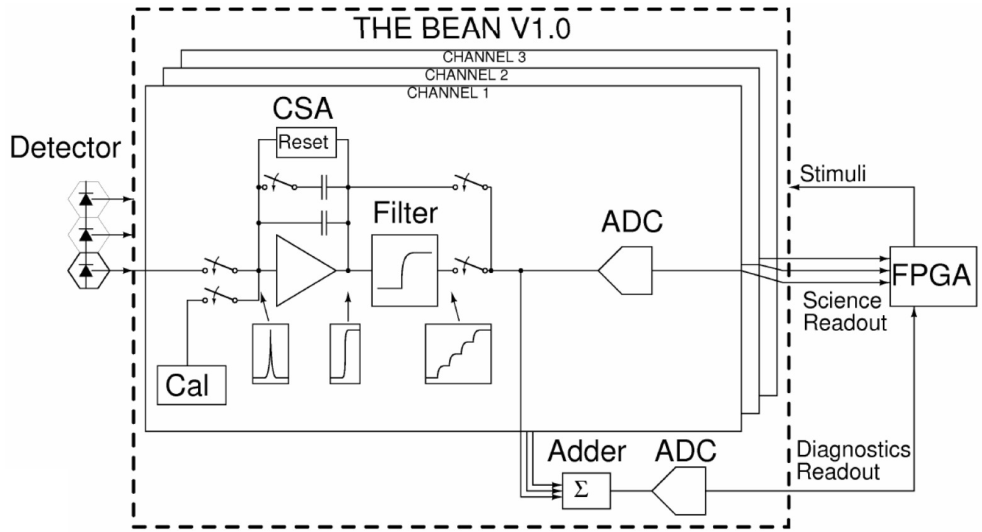


Large area BeamCal pad GaAs sensor prototype
- 500 μm thick detector
- 87 pads (20 - 40mm^2)
- Leakage ~ 7nA/mm^2
- Capacitance ~ 0.3pF/mm^2



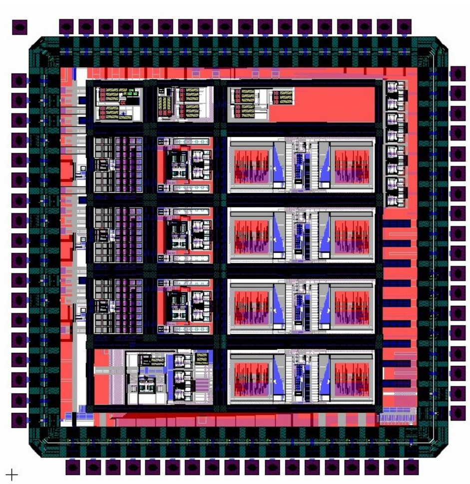
pCVD Diamond
- 1 x 1 cm2
- 200-900 μm thick

BeamCal readout electronic

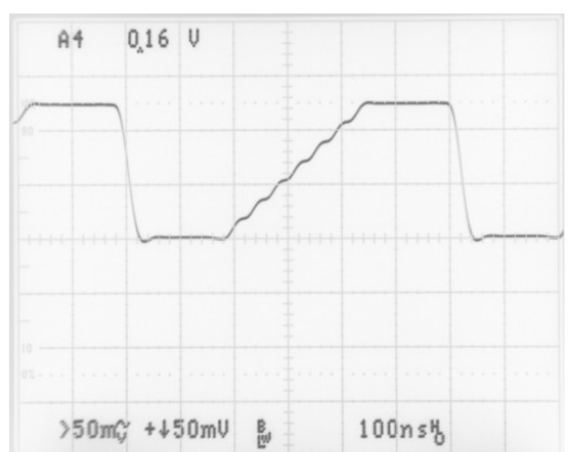


- Prototypes in 180-nm TSMC process
- Charge sensitive preamplifier (CSA)
  - precharge circuit for to maximize output swing
  - Gated reset for quick baseline restoration
- Switched-Capacitor filter
- Analog adder to provide fast feedback
- ADC : 10-bit SAR ADC

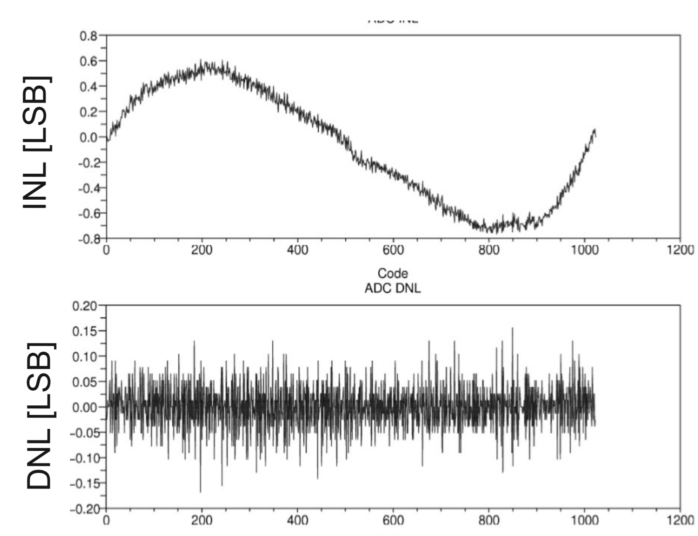
Prototype ASIC Layout



Shaper output



ADC performance



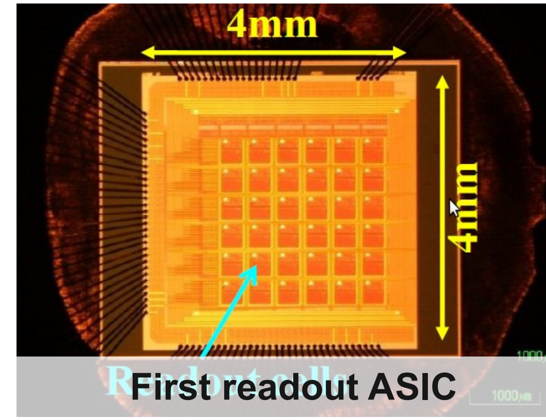
Pair Monitor

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

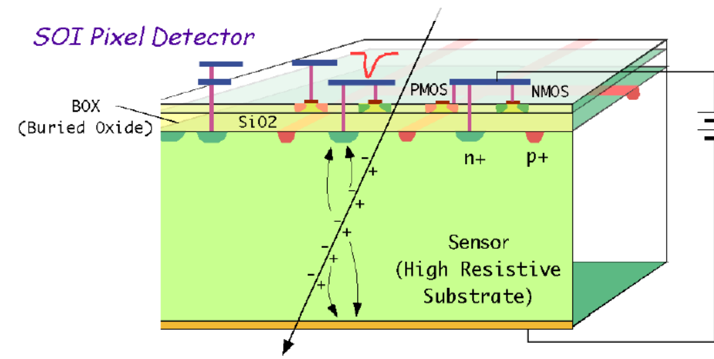
Detector radius 10cm, Pixel size 400x400 µm2, Total number of pixels ~ 200.000

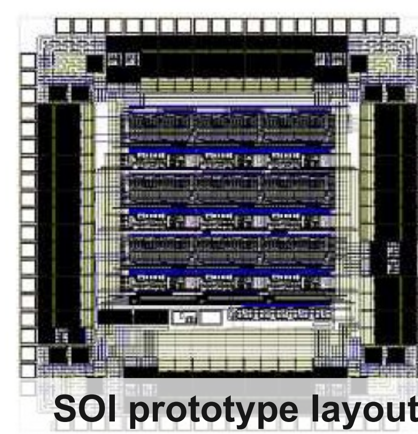
- First readout ASIC
    - CMOS process: **0.25 µm TSMC**
    - Chip size : 4 x 4 mm^2, **6 x 6** pixels (36)
    - Test setup based on KEK-VME 6U module was prepared
    - Sensor needs to be bound bonded

- 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.

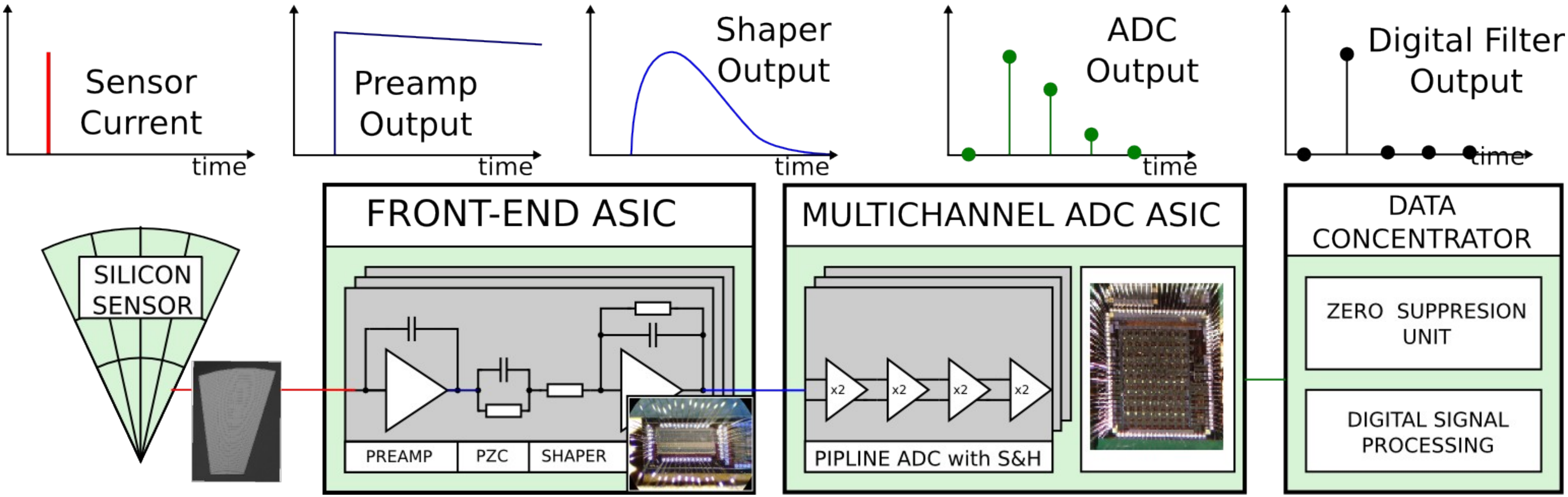


First readout ASIC




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

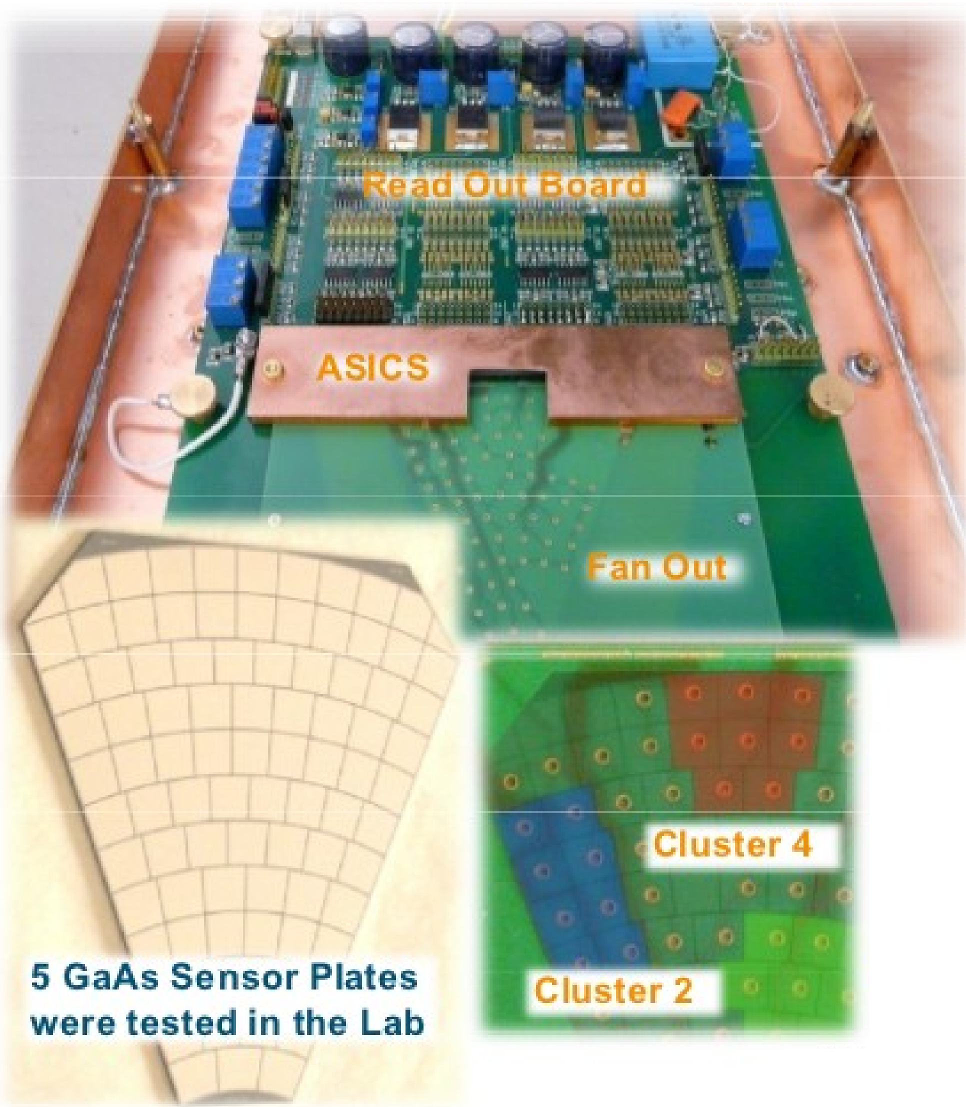
- 8 channels of preamplifier + PZC + CRRC shaper (Tpeak ≈ 60 ns)
- C_{det} up to 100pF
- variable gain: dynamic range from ~2fC up to 10 pC
- event rate up to 3 MHz
- crosstalk < 1%

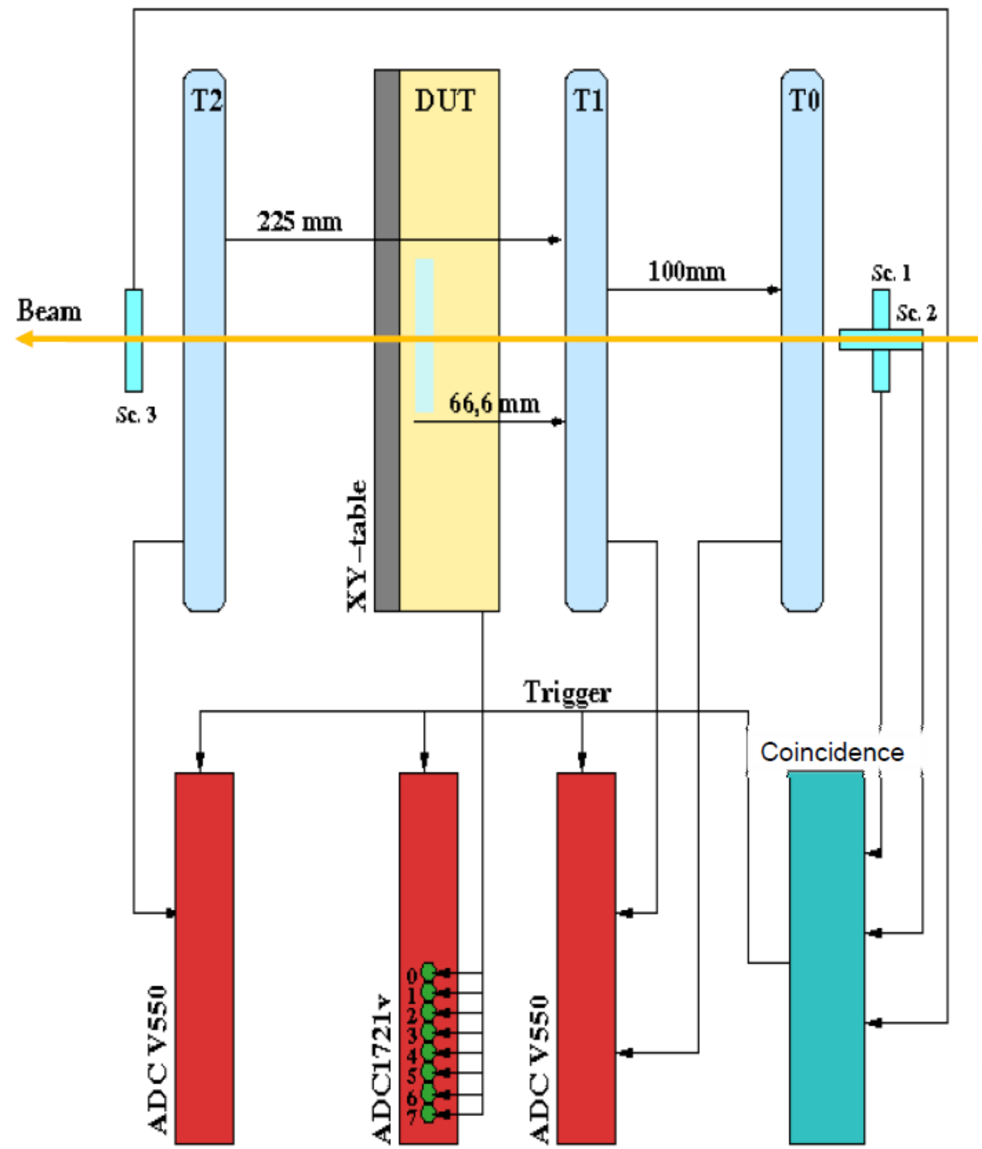
ADC Design

- 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

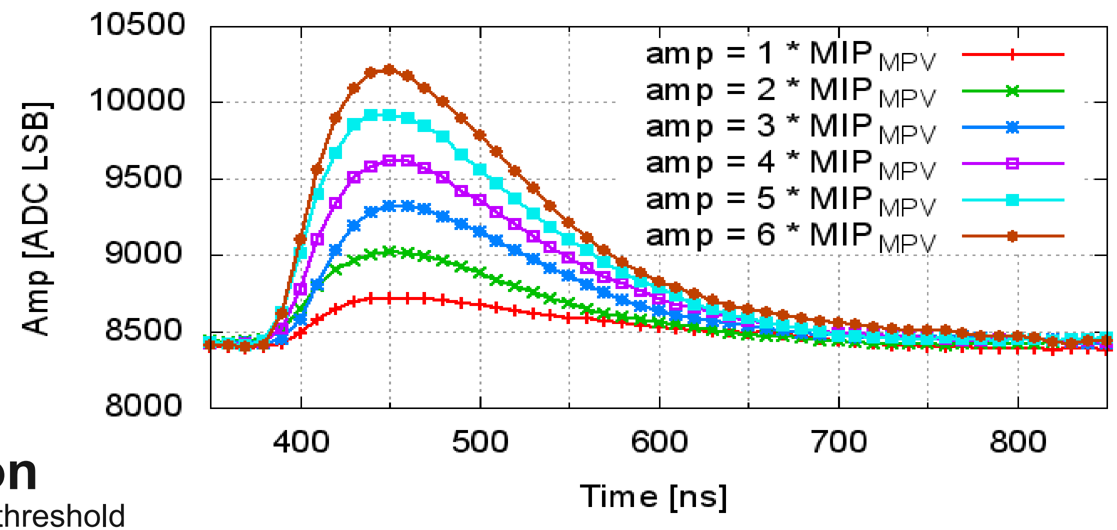




BeamCal / LumiCal sensor + LumiCal front-end + Commercial Sampling ADC

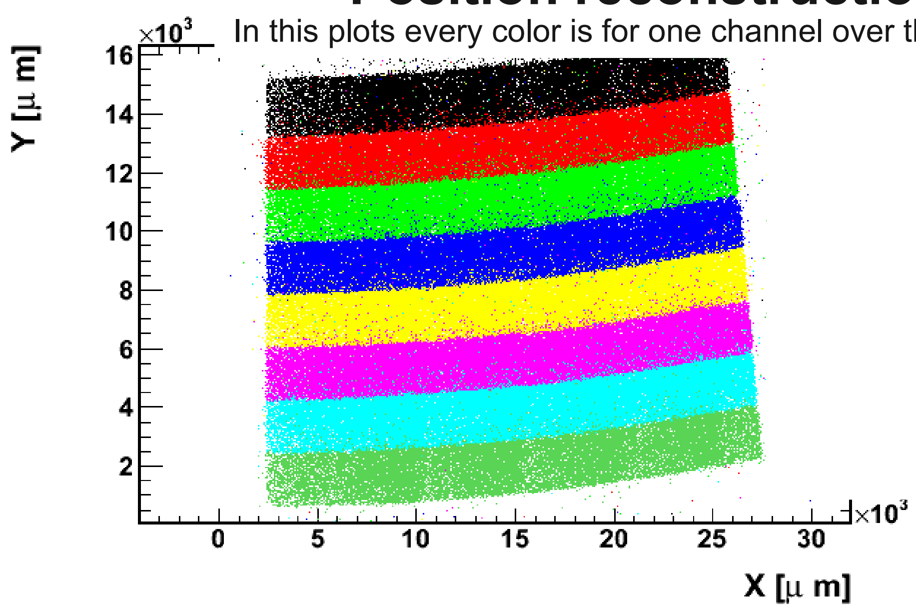
Testbeam Results 2010
(LumiCal Sensor)

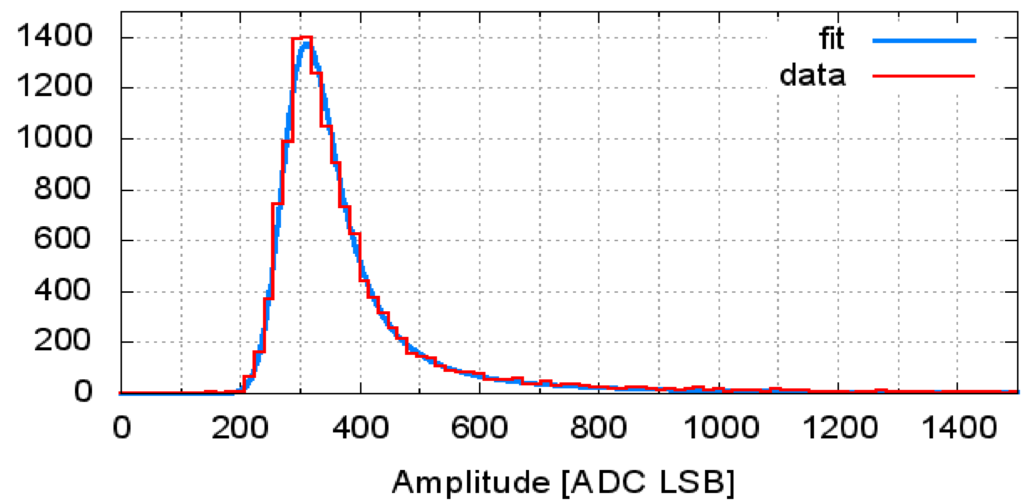
- Front-ends signal shape matches simulations
- Single electron spectrum matches Landau convoluted with Gauss distribution
- Signal to noise ratio (S/R) above 20
- Crosstalk <1%



Position reconstruction

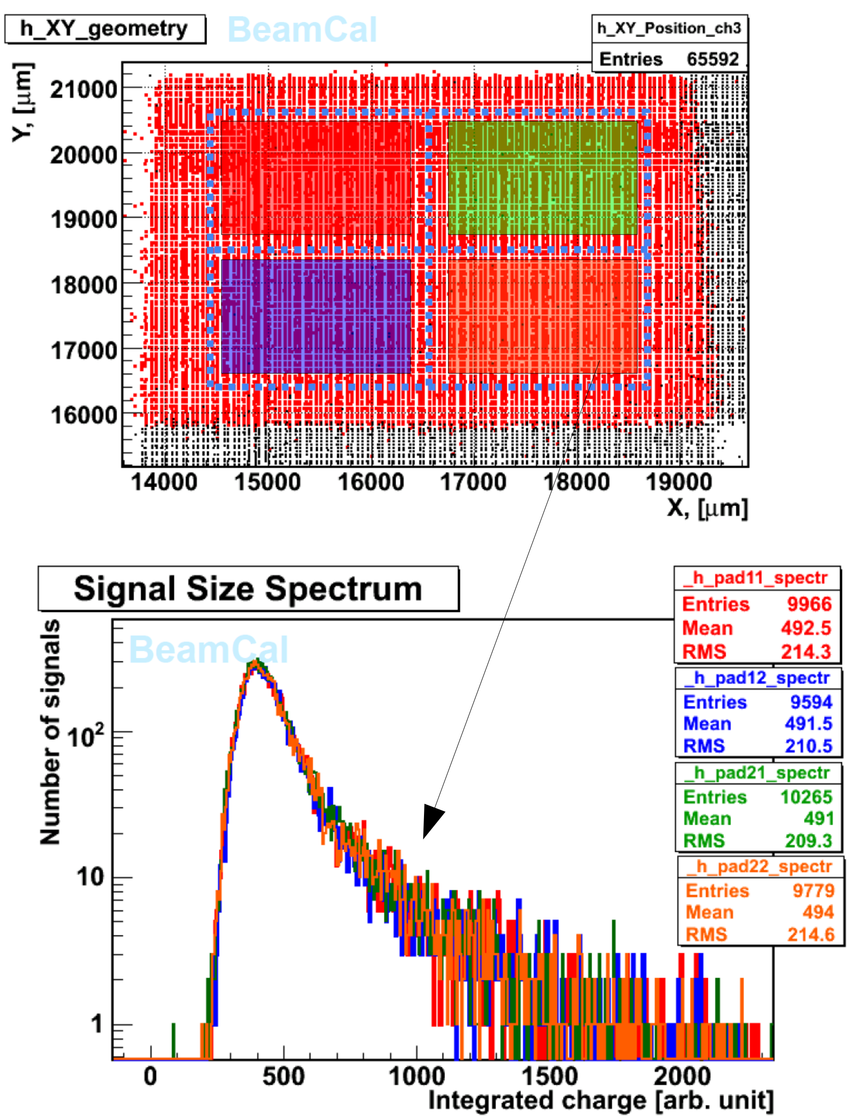
In this plots every color is for one channel over threshold



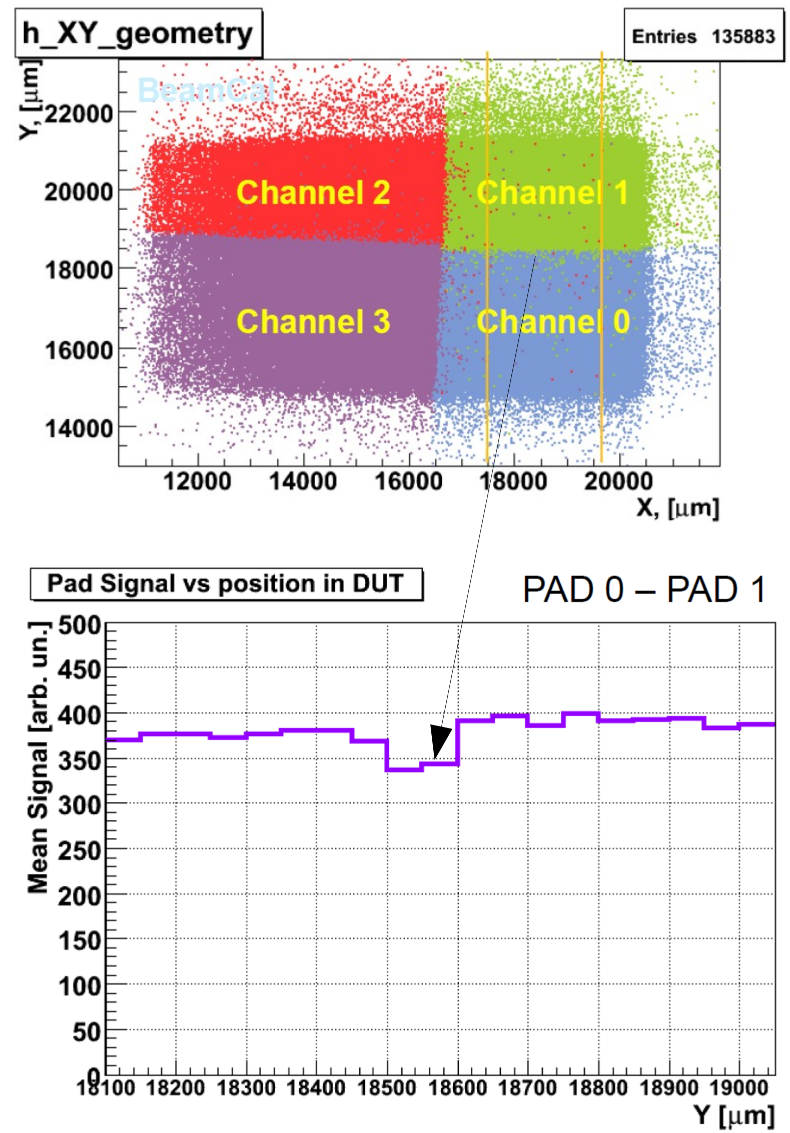


Testbeam Results 2010
(BeamCal Sensor)

- Signal to noise ratio above 20
- Charge collection homogeneity

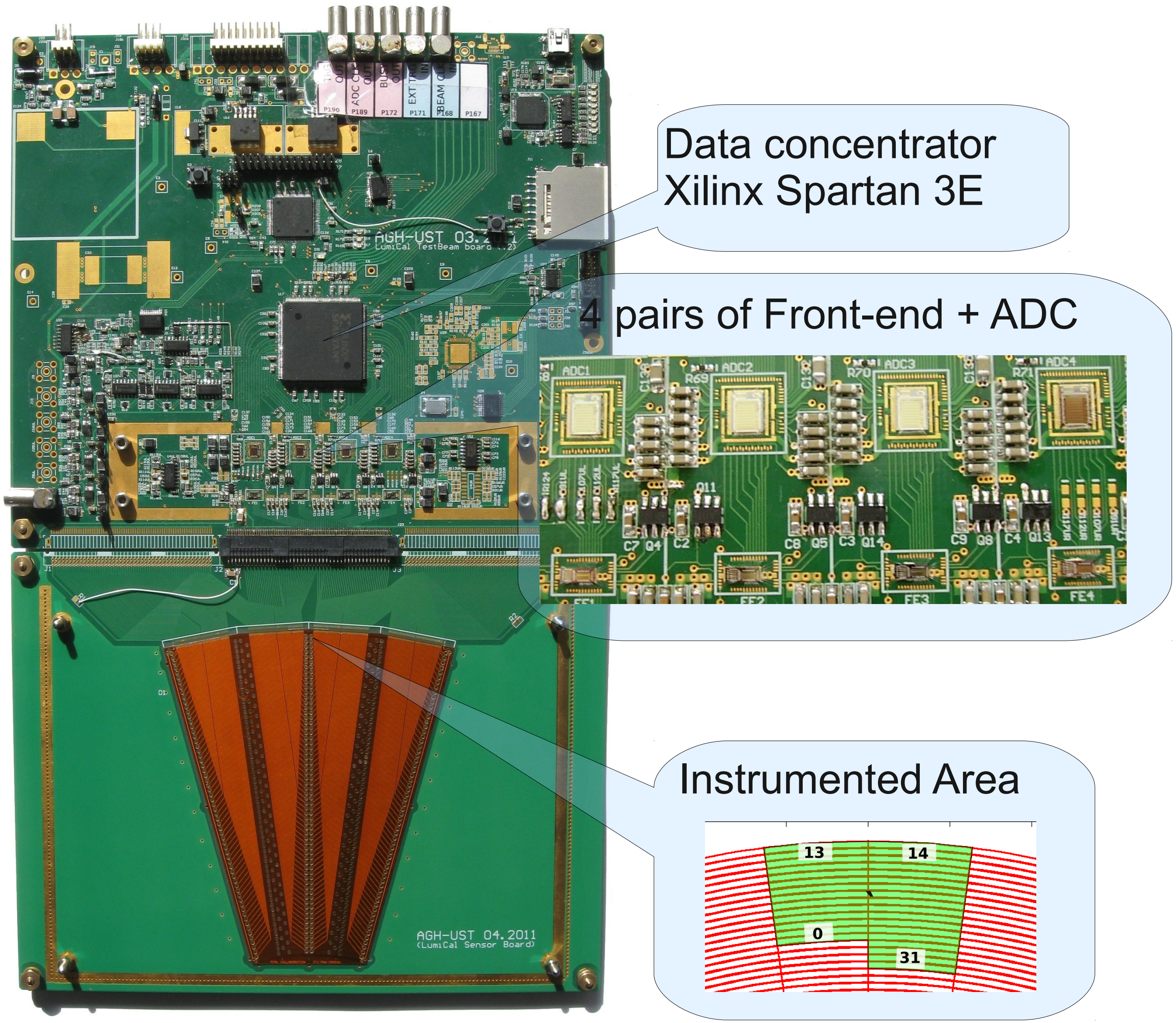


- Charge sharing between pads



Detector Module

towards testbeam 2011

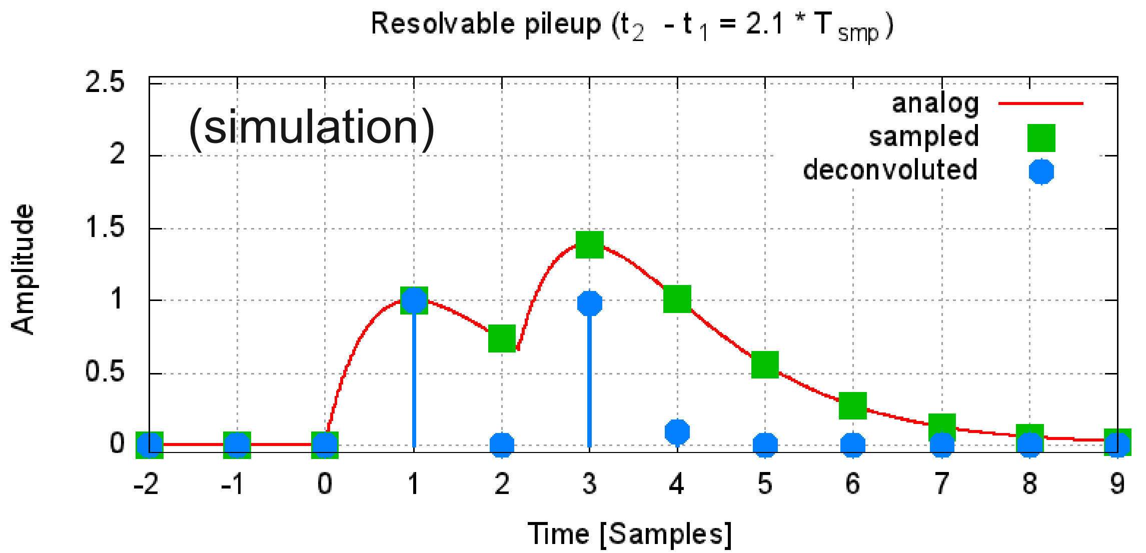


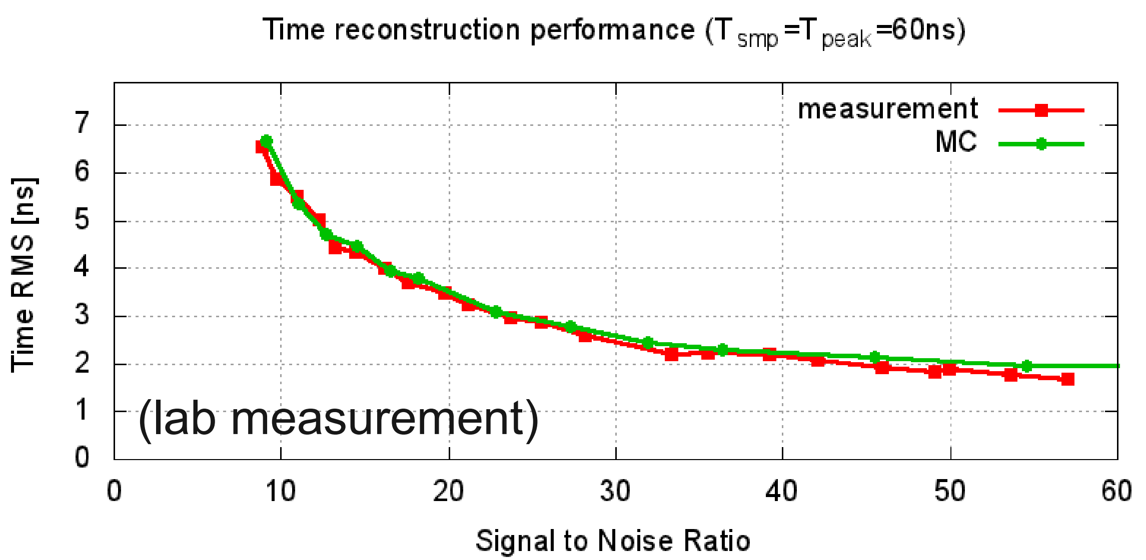
- **32 channels fully equipped channels (Sensor + Front-end +ADC)**
- ADC sampling rate is up to 20 MS/s (6.4 Gbps)
- Data can be transferred using USB
- Signal handshaking with Trigger Logic Unit (TLU)
- ADC Clock source
  - Internal (**asynchronous with beam operation**) – testbeam & CLIC mode
  -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

Deconvolution

as a solution for asynchronous sampling

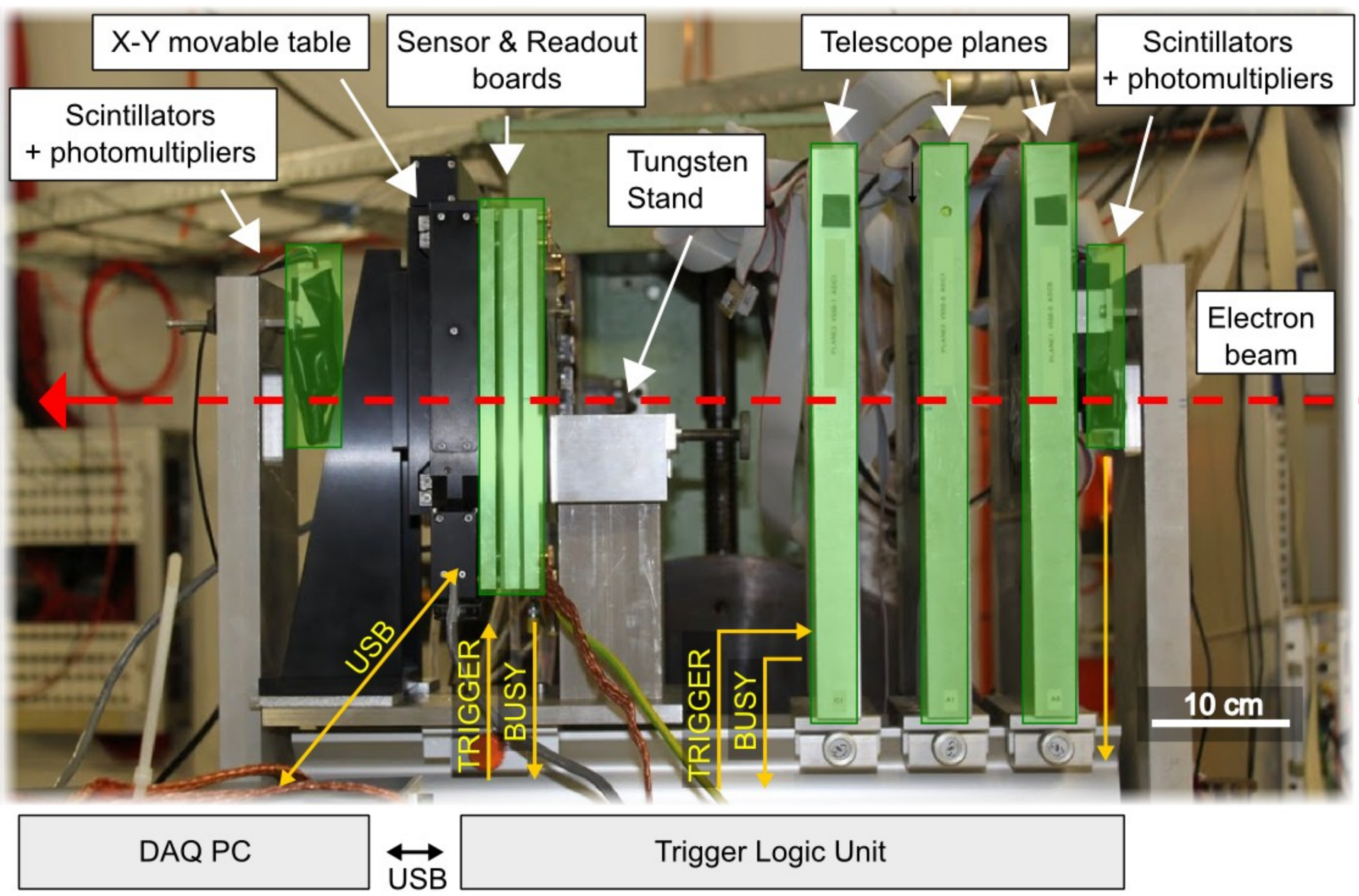
- Motivation
  - Time tagging for CLIC (CLIC Note)
  - Testbeam data analysis (asynchronous sampling)
- Properties
  - reduces (infinite) number of CR-RC pulse samples to 1 or 2 non zero samples !
  - Great pile-up resolving capabilities (event delayed by 2~3 T_{smp})
  - Time resolution down to 1-2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

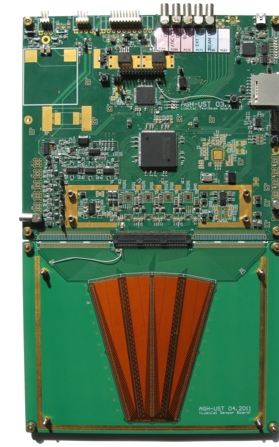


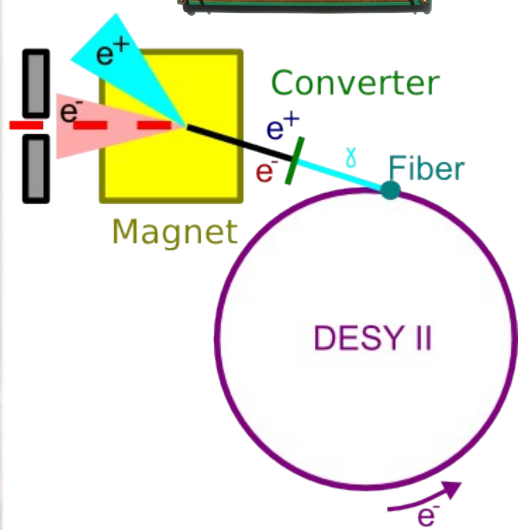


Sz. Kulis, M. Idzik | Workshop on timing detectors, 29 Nov to 01 Dec 2010, Cracow
Triggerless readout with events time and amplitude reconstruction based on deconvolution algorithm.

Testbeam Setup 2011



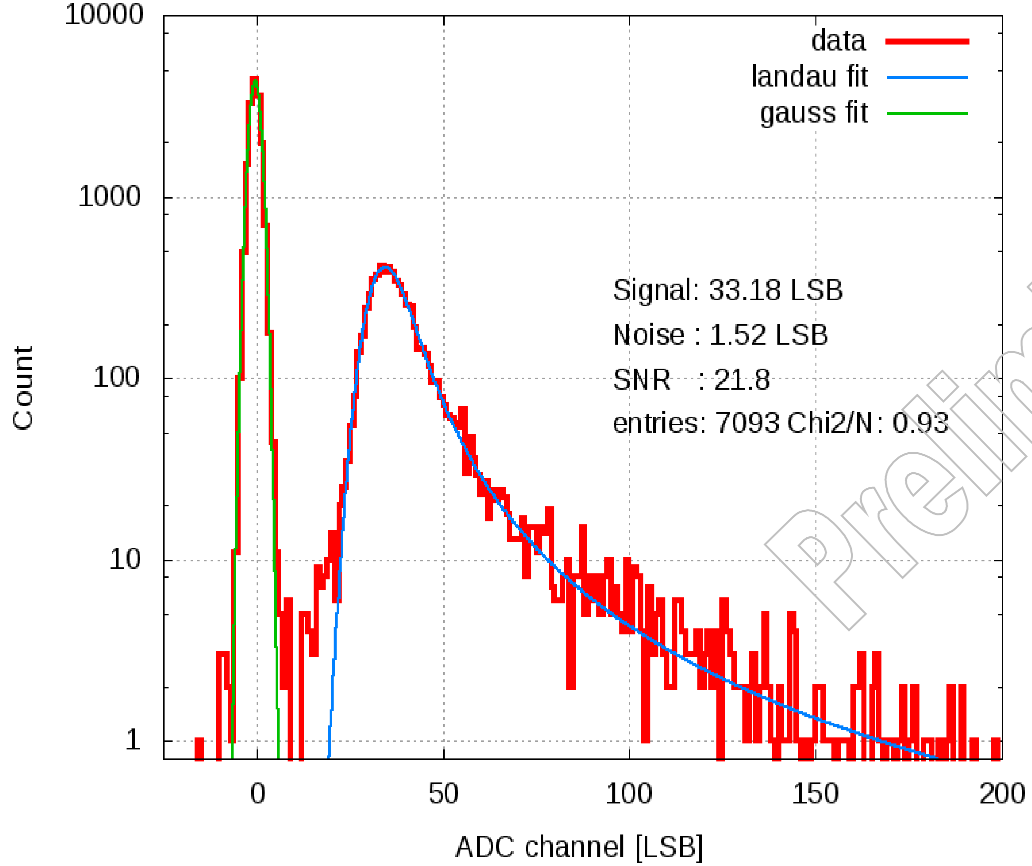




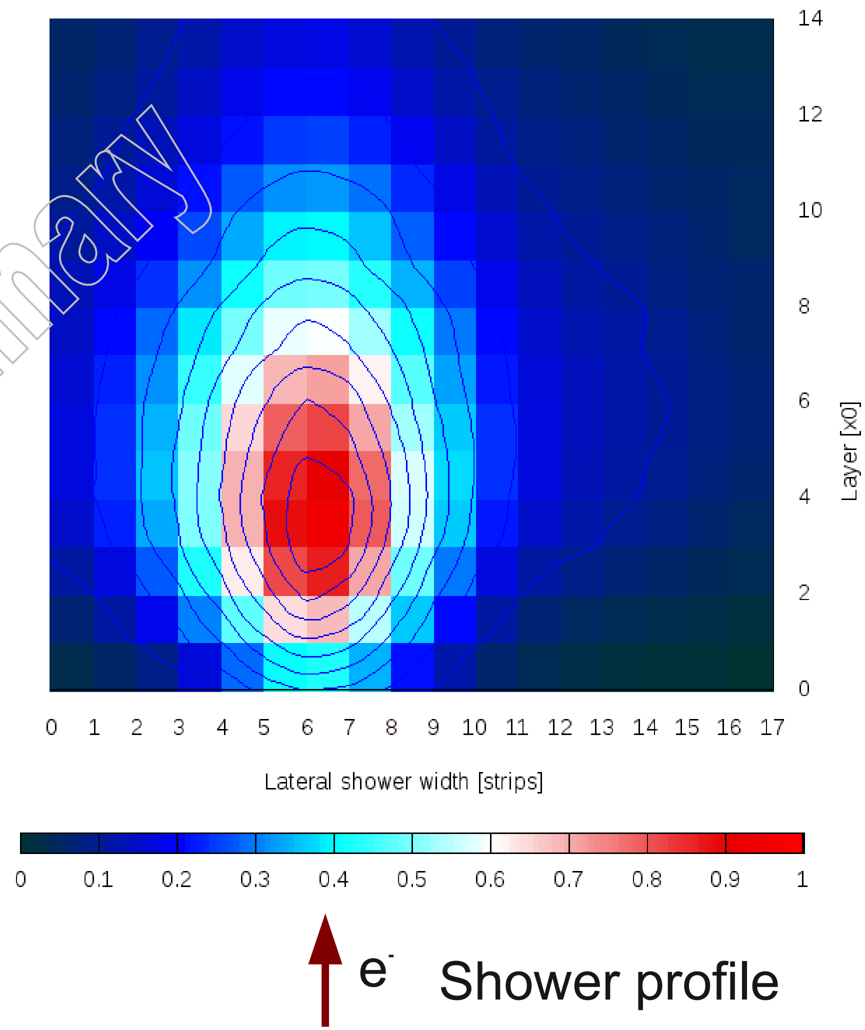
LumiCal sensor + LumiCal front-end + Multichannel ADC + Data concentrator

Testbeam Results 2011

No tungsten absorber



Tungsten absorber in front of sensor



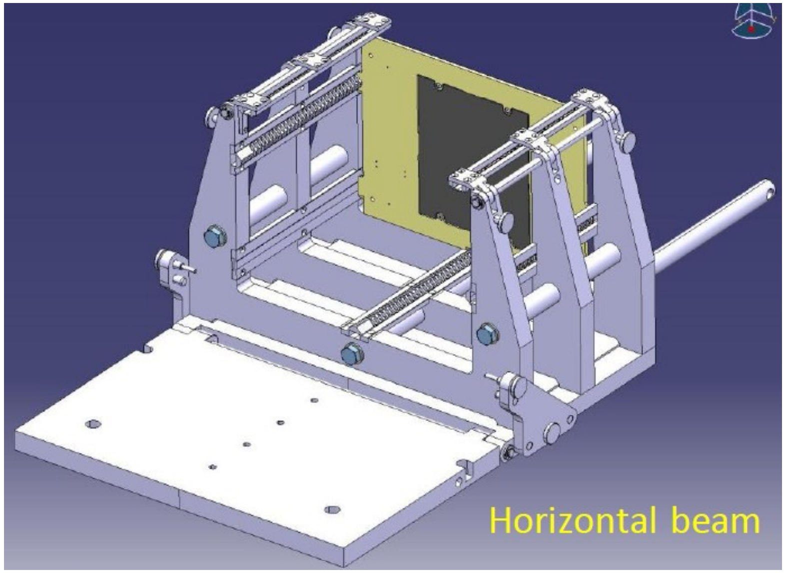
- Events processed using deconvolution algorithm
- Data well described by fitted Landau-Gauss distribution
- S/R is above 20 for each channel

Next testbeam in November

Other ongoing activities

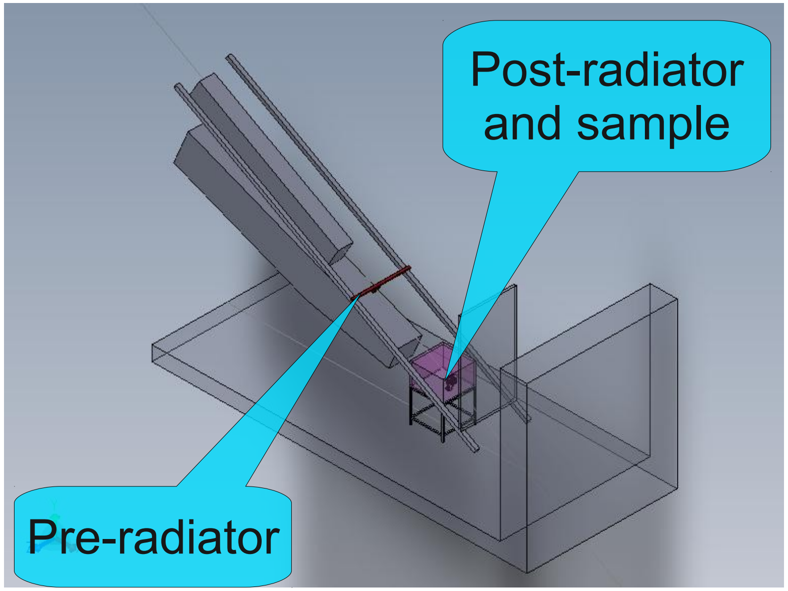
A flexible mechanical infrastructure will be built to allow testing individual sensors or complete segments of LumiCal or BeamCal Calorimeters.

(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



Future plans

AIDA project schedule :

- Flexible mechanical infrastructure:
  design 2012, manufacturing 2013, ready 2014
- Multichannel readout ASICs (for LumiCal):
  design start 2011, 1st prototype production 2012, 2nd 2013, final 2014
- Complete prototype of sensor plane 2013-2014
- Detector position monitoring using laser beams
- DAQ:
  1st DIF prototype 2011, prototype of complete DAQ 2012, ready 2013
- Design fixed beginning 2013
- Production 2014

ILC detector DBD 2012:

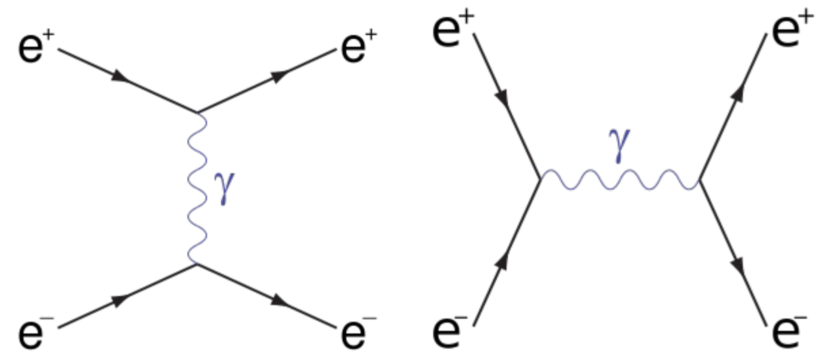
- completing the performance measurements with fully assembled sensor plane prototypes
- refining design considerations (MC studies)

Thank you for attention

BACKUP SLIDES

LumiCal
Precise Measurement of Luminosity

- **Bhabha scattering** ee → ee is the **gauge process**
- **Counting Bhabha** events in a well known acceptance region
  $L = N/\sigma$
- High statistics at **low angles**
  $N_{Bhabha} \sim 1/\theta^3$
- **Well known** electromagnetic **process**, the current limit on the theoretical cross section error is at ~5 10^{-4}.



- **Corrections** (with uncertainties) are needed **because of background**:
  - 2 photon processes
  - EM deflection and energy loss due to beamstrahlung of Bhabha's electrons

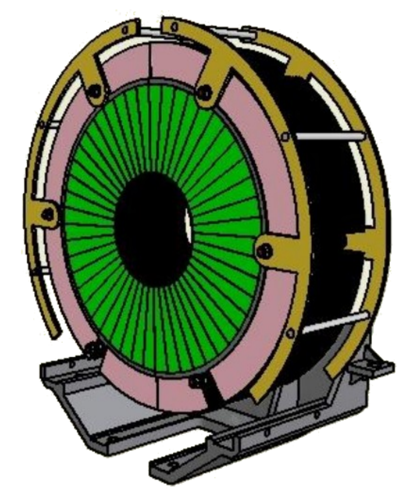
Required precision is:
- $\Delta L/L \sim 10^{-4}$ (GigaZ@ILC)
- $\Delta L/L < 10^{-3}$ (ILC)
- $\Delta L/L < 10^{-2}$ (CLIC)

LumiCal requirements

Option	Req. **ΔL/L**	Znom [mm]	Rmin [mm]	θmin [rad]	Δθmax [rad]	Δzmax [mm]	Δrmax [mm]
ILC GigaZ	≤ 10-4	2500	80	0.032	1.6x10-6	< 0.125	< 4x10-3
ILC 500 GeV	≤10-3	2500	80	0.032	1.6x10-5	< 1.25	< 4x10-2
CLIC 3 TeV	≤ 10-2	2654	100	0.038	1.9x10-4	< 13.3	< 0.5

The contribution of polar angle offset to relative error on luminosity can be estimated using approximate formula

$$\frac{\Delta L}{L} \approx 2 \frac{\Delta \Theta}{\Theta_{min}}$$



Δz_{max} and Δr_{max} is simple trigonometry ...

Systematic uncertainties 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}
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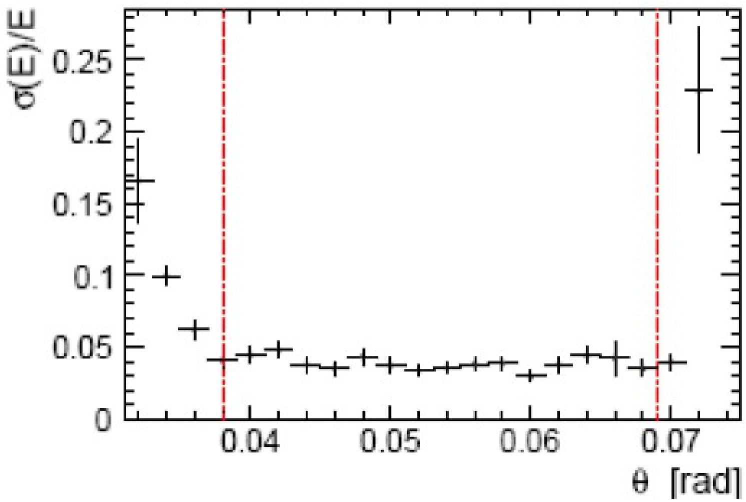
luminosity spectrum			10^{-3}
bunch sizes σ_x, σ_z,	655 nm, 300 μm	5%	1.5×10^{-3}
two photon events	2.3×10^{-3}	40%	0.9×10^{-3}
energy scale	400 MeV	100%	10^{-3}
polarisation, e^-, e^+	0.8, 0.6	0.0025	1.9×10^{-4}
total uncertainty			2.3×10^{-3}

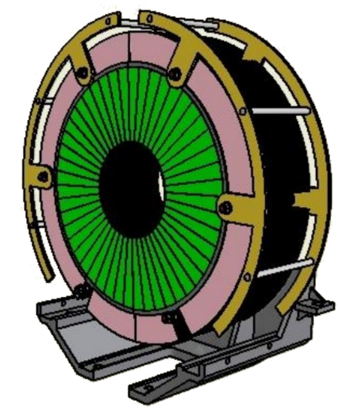
* 100%= Upper limit – the size of effect is taken as uncertainty

- 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 (θ, miscounts due to physics background, BHSE).

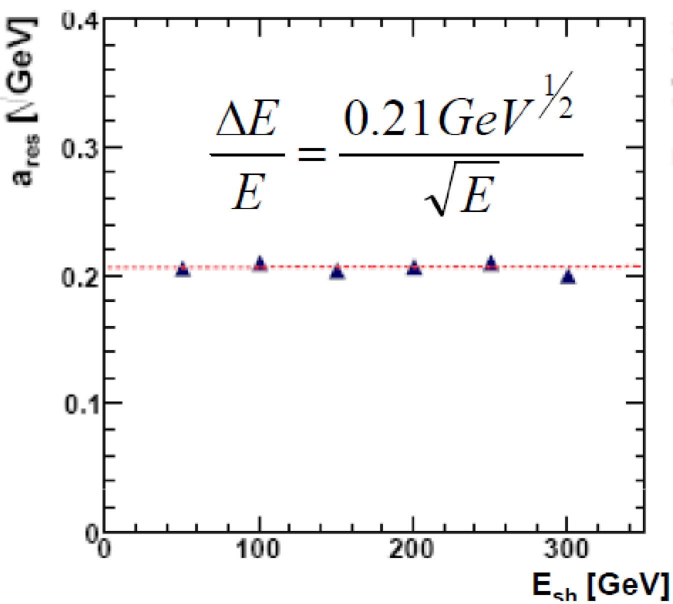
LumiCal performance studies



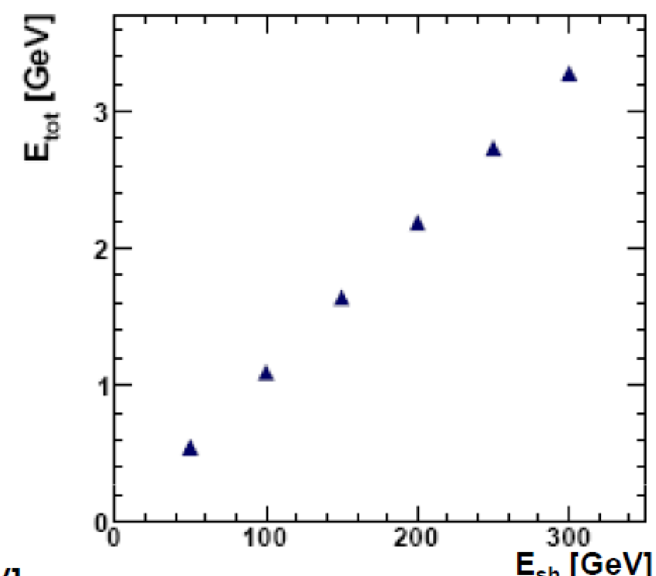
Energy resolution vs polar angle



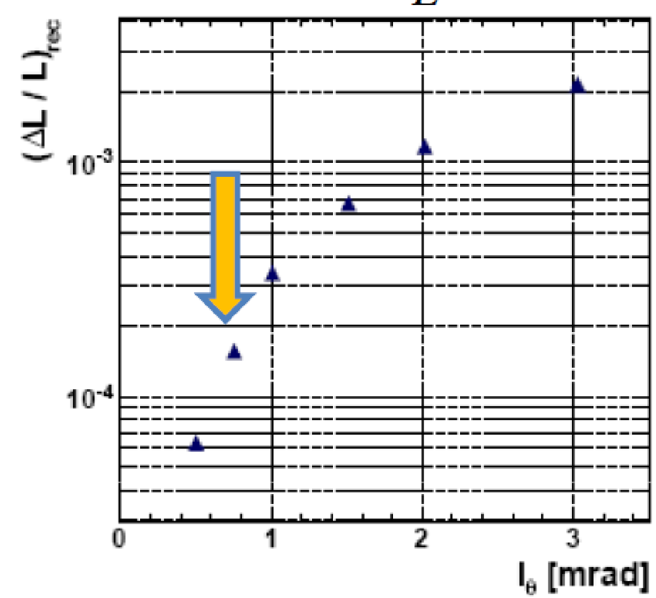
$$l_\theta = 0.8 mrad, \frac{\Delta L}{L} = 1.6 \cdot 10^{-4}$$



Energy resolution



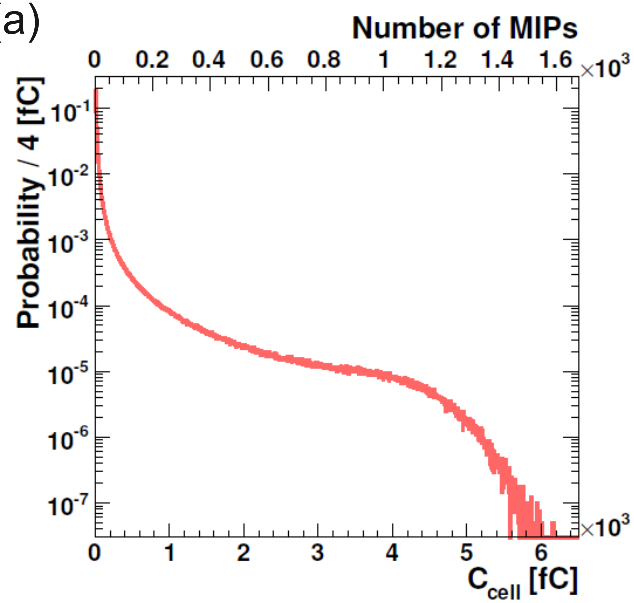
Linearity



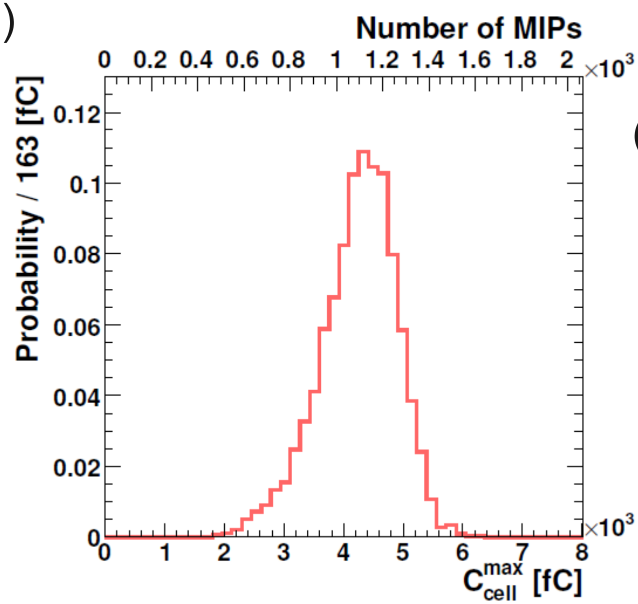
ΔL/L vs pad size

LumiCal readout requirement

(a)



(b)



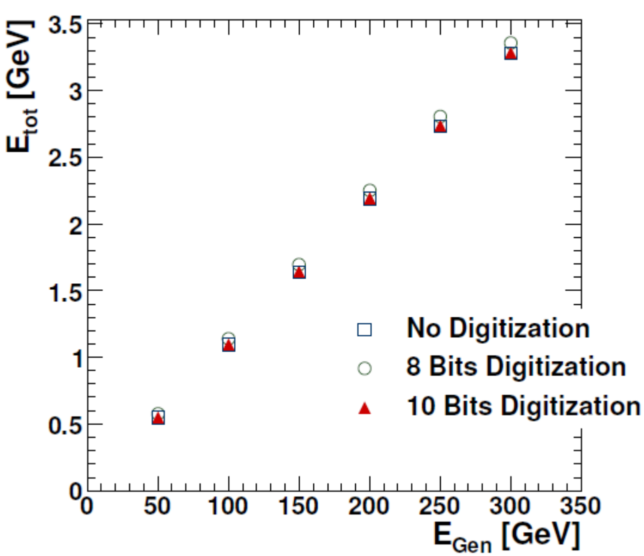
Front-End requirements:

(a) distribution of the charge deposited in a detector cell by 250 GeV electron showers.

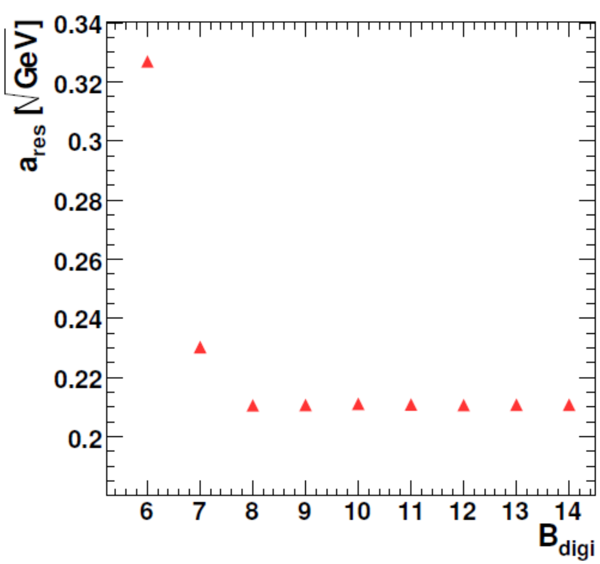
(b) Normalized distribution of the maximal charge collected in a single cell per shower for 250 GeV electron showers.

FE accepts up to ~10 pC

(a)



(b)



ADC Requirements :

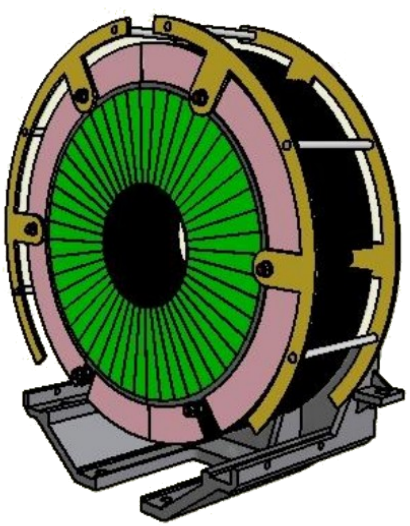
(a) Recorded energy as a function of electron which initiated the shower

(b) The energy resolution vs number of bits (250 GeV electron shower)

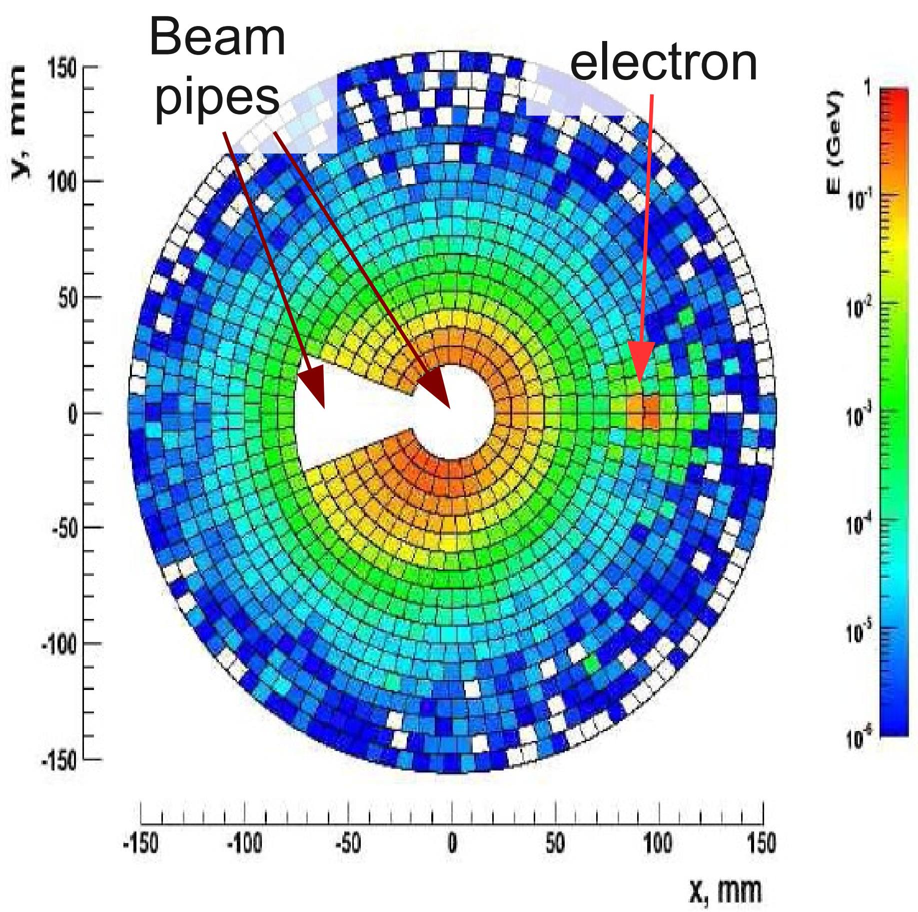
10 bit ADC

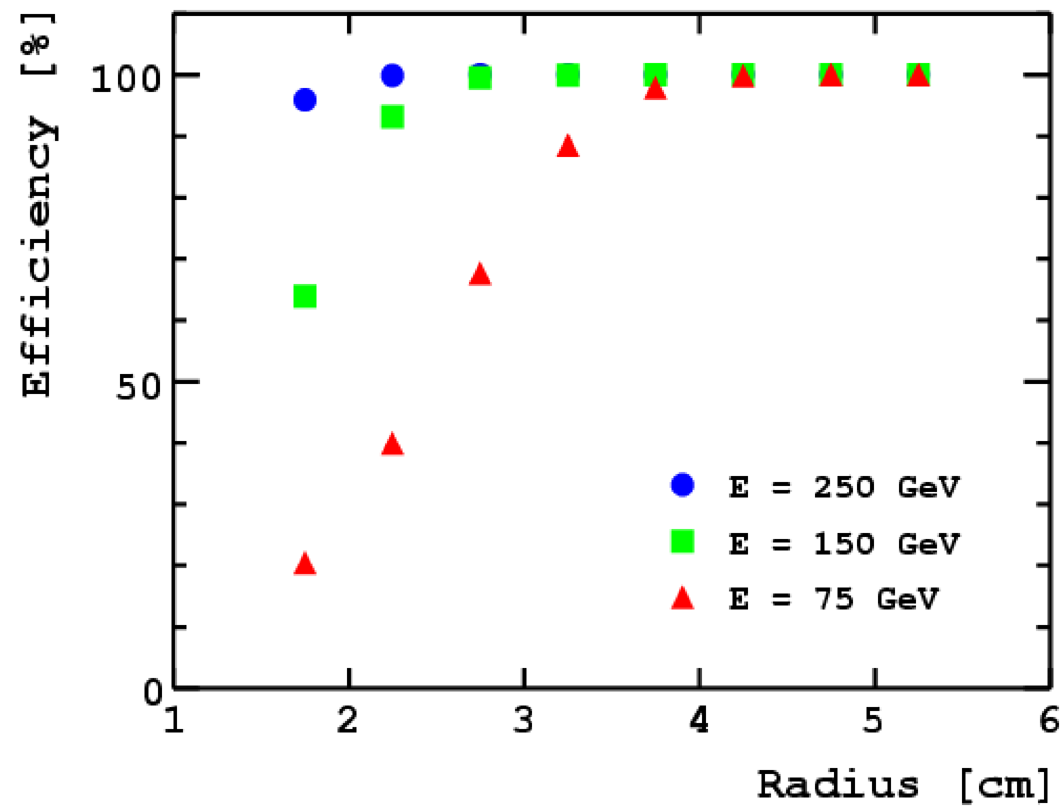
LumiCal baseline design

Parameter	ILC	CLIC
Absorber [mm]	Tungsten 3.5	Tungsten 3.5
Sensor [μm]	Si 300	Si 300
R inner [mm]	80	100
R outter [mm]	195.2	290
Θ inner [mrad]	31	37
Θ outter [mrad]	78	110
Z pos [mm]	2500	2654
Layers	300	40
Mass [kg]	210	660



BeamCal performance studies

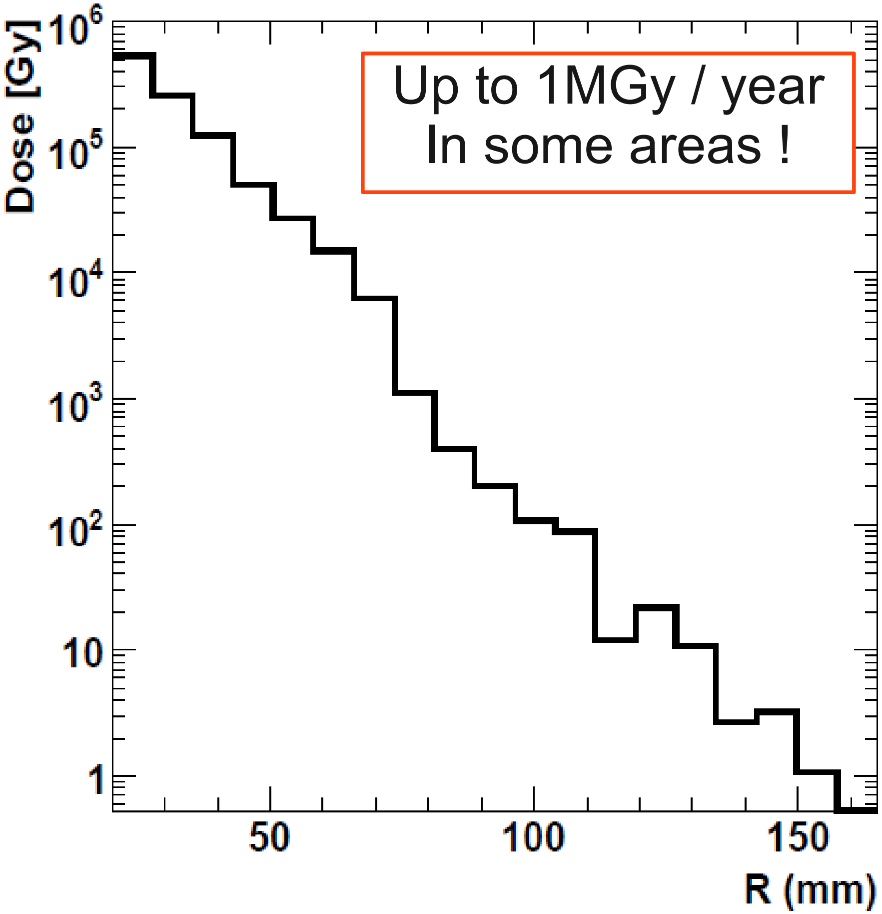


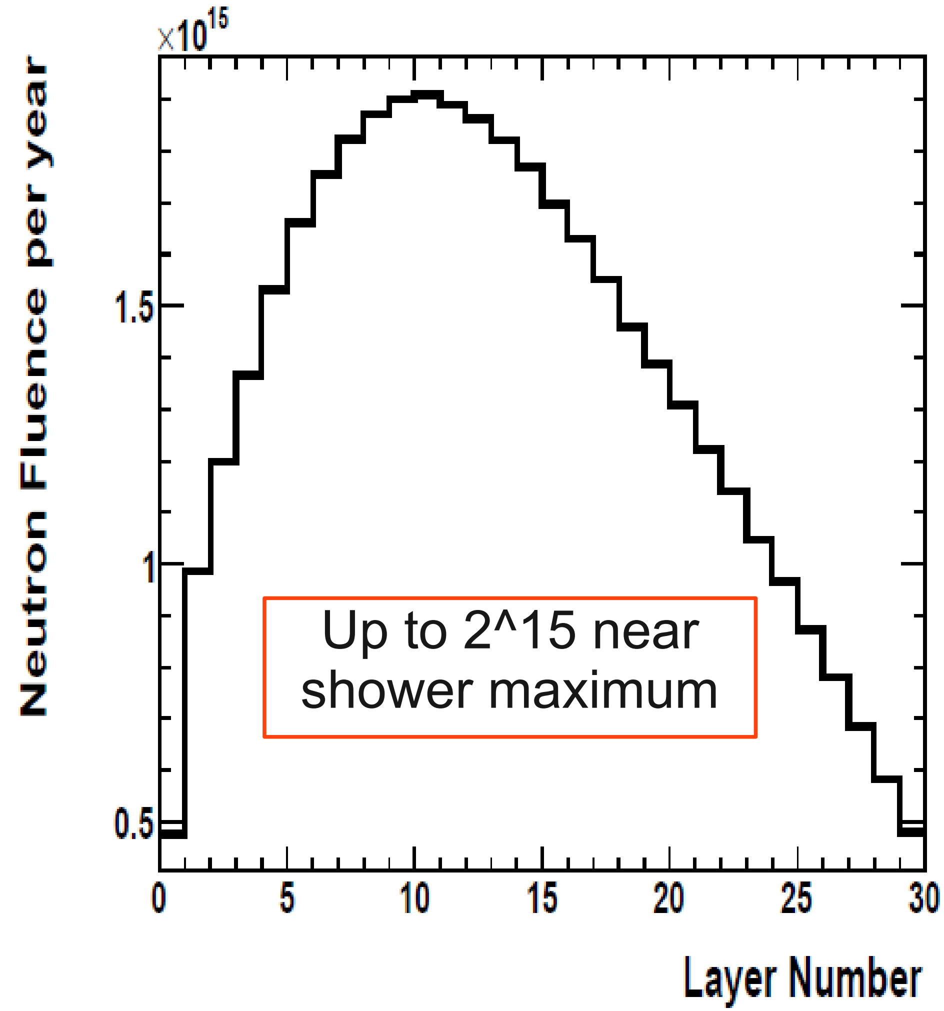


The energy deposited by beamstrahlung pairs after one bunch. Superimposed is the deposition of a single high energy electron.

The efficiency to detect single high energy electrons on top of the beamstrahlung background

BeamCal radiation load





The dose in BeamCal sensors per the radial distance from the bea

The fluence of neutrons per year vs the sensor layer number

Beam-Beam Interactions

ILC/CLIC - Single pass machine

↓ To keep Luminosity

Very small beams
(x) 44 nm, (y) 1 nm, (z) 45µm

↓

High charge density &
strong fields

↓

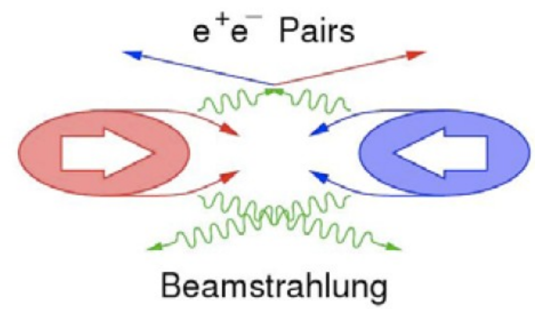
Deflection of Particles
(Pinch effect)

↓

Deflected particles produce
Beamstrahlung
(~ 2.2 photons per beam particle !)

↓

Beamstrahlung photons interact with strong fields and particles, produce large number of background particles



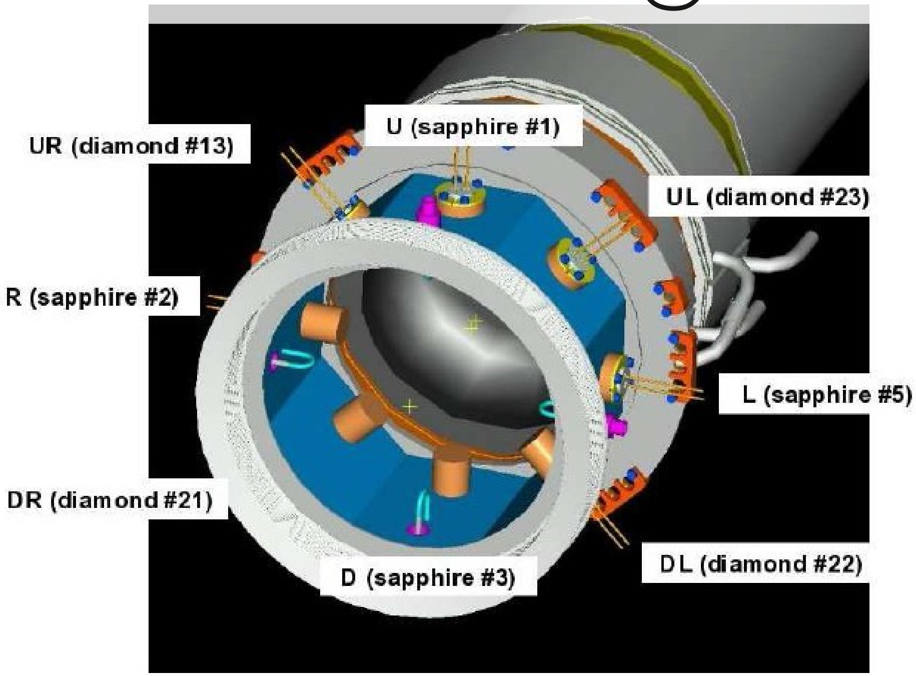
Incoherent Pairs
Beamstrahlung photons interacting with particles from the other bunch

Coherent Pairs
Beamstrahlung photons interacting with coherent field of other bunch

Trident (e → eee) Pairs
Bunch particles interact with coherent field of other bunch

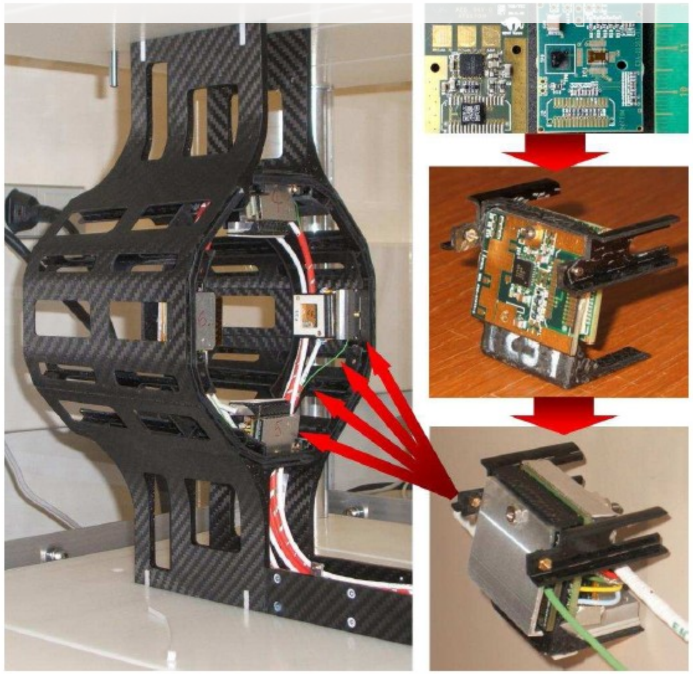
FCAL Spin offs

Beam Halo Monitor @ FLASH



- Several sensors (poly-crystalline CVD diamonds and mono-crystalline sapphires) developed within FCAL were used in Beam Halo Monitor for FLASH
- Used for beam dump diagnostic
  - Beam tuning
  - Alarm signals generation

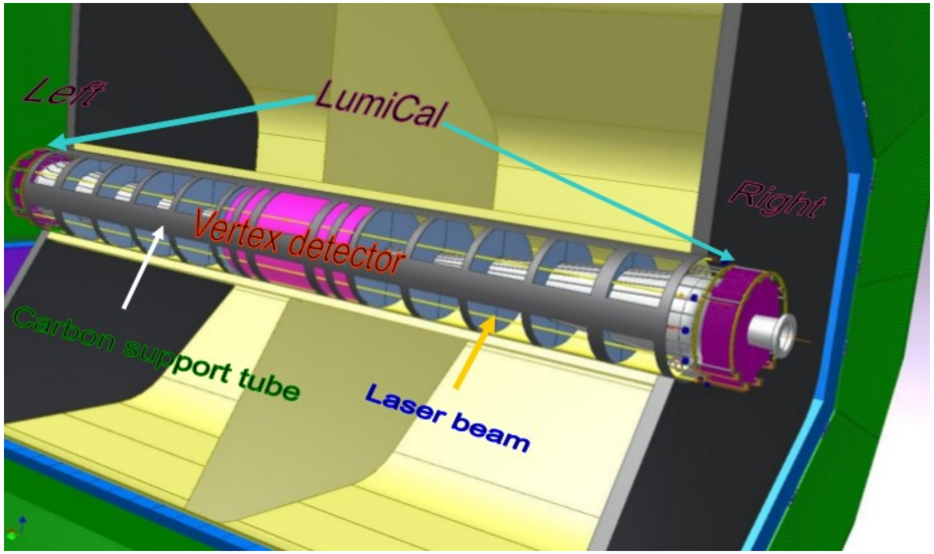
Beam Condition Monitor @ CMS

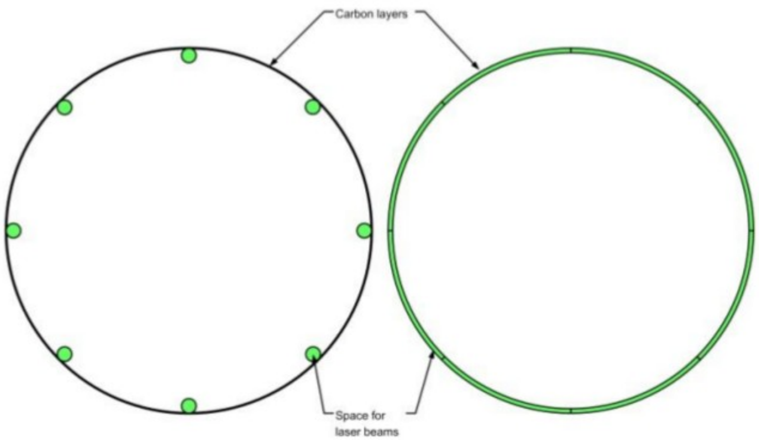


- Utilizes single-crystal Chemical Vapor Deposition diamonds (sCVD) – small and fast
- Sensitive to fast changes of beam conditions
- Unprecedentedly high radiation
- Diagnostics with a time resolution better then the time between BX

Detector alignment studies

- High-accuracy luminosity measurements require very precise measurement of the LumiCal detector position (an accuracy below 100 um in X,Y, Z directions is required)
- The laser alignment system (LAS) based on **Frequency Scanning Interferometry (FSI)** is considered for LumiCal and Vertex
- **Space** for laser beams around vertex
  - Carbon tube with glued carbon pipes (left) less material, less stiffness, limited number of laser beams
  - Double layer carbon tube (right) more material, more stiffness, lot of space for many laser beams
- **Reference points on QD0**





(recently) Published References

Pair Monitor ASICS :

Yutaro Sato et all,
“Readout ASIC of pair-monitor for international linear collider”
Nucl. Instr. and Meth. A 623 (2010) 501–503

LumiCAL front-end ASIC:

M. Idzik, Sz. Kulis, D. Przyborowski
"Development of front-end electronics for the luminoisty detector at ILC"
Nucl. Instr. and Meth. A 608 (2009) pp.169-174

LumiCal ADC ASICs:

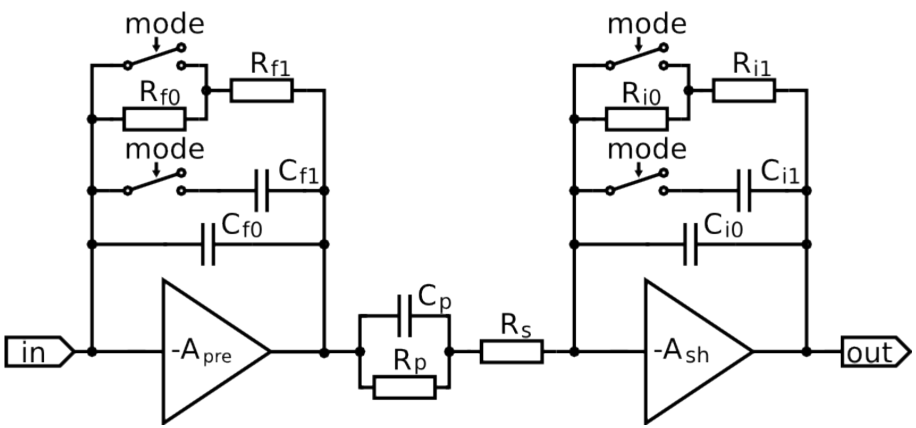
M. Idzik, K. Swientek, T. Fiutowski, S. Kulis, P. Ambalathankandy
“**A power scalable 10-bit pipeline ADC for Luminosity Detector at ILC**”
JINST 6 P01004 2011

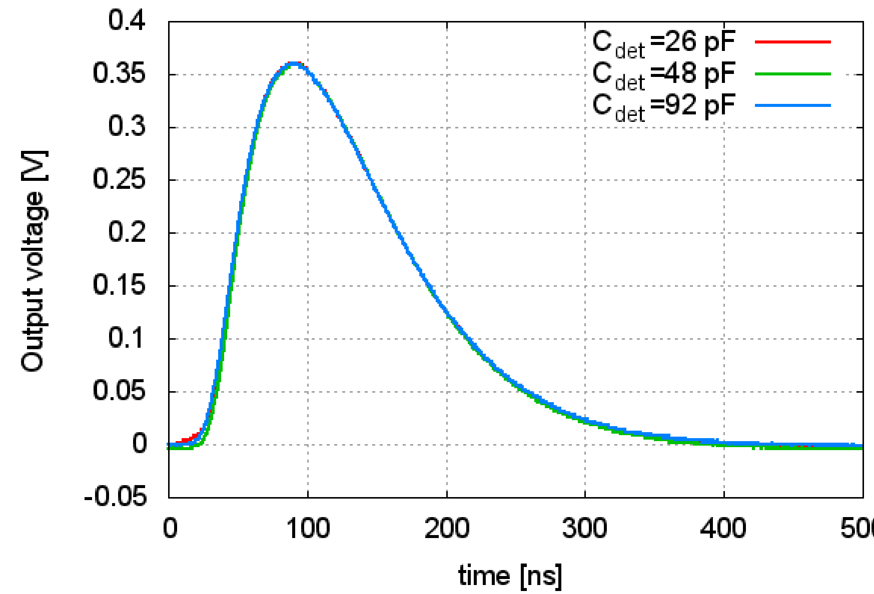
M Idzik, K Swientek, Sz. Kulis
“**Development of pipeline ADC for the Luminosity Detector at ILC**”
JINST 5 P04006 2010 Link

BCM@CMS

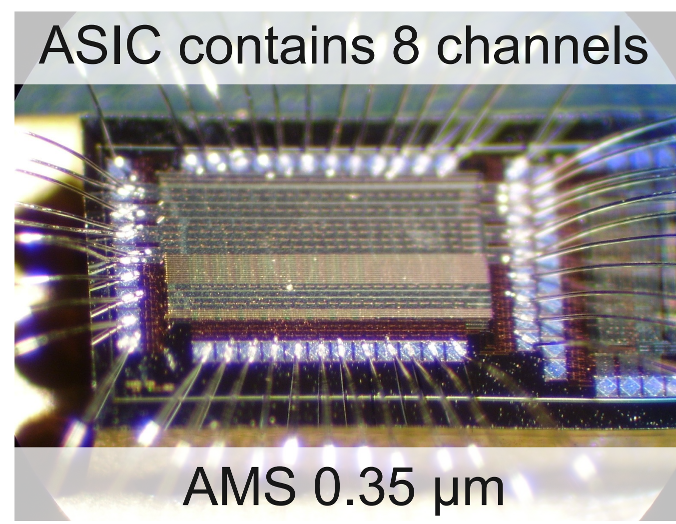
A. Bell et all
“Fast beam conditions monitor BCM1F for the CMS experiment“
Nucl. Instr. and Meth. A 614 (2010) 433–438

LumiCal frond-end electronic





- Cdet ≈ 0 ÷ 100pF
- 1st order CRRC shaper (Tpeak ≈ 60 ns)
- variable gain:
  - calibration mode - MIP sensitivity (~4fC)
  - physics mode - input charge up to 10 pC



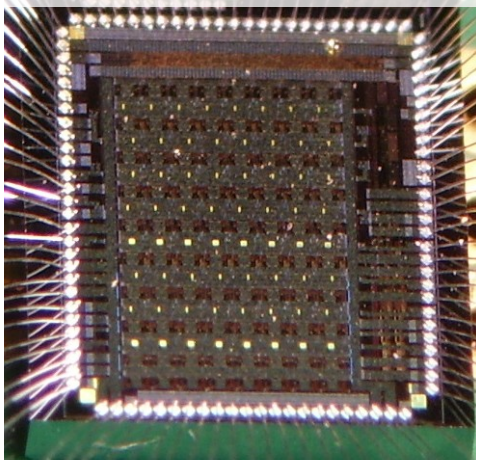
- prototypes fabricated and tested
  - power consumption 8.9 mW/channel
  - event rate up to 3 MHz
  - Crosstalk < 1%

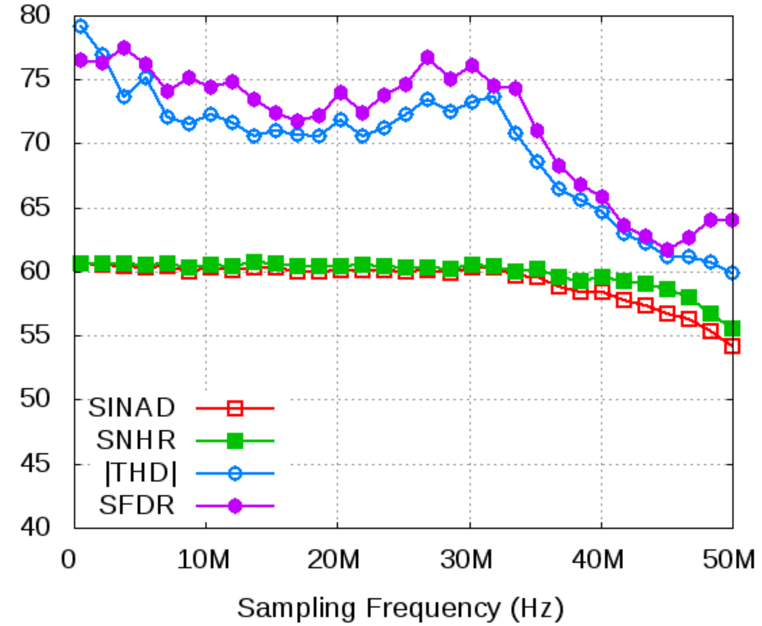
See more : M. Idzik, Sz. Kulis, D. Przyborowski "Development of front-end electronics for the luminoisty detector at ILC" Nucl. Instr. and Meth. A 608 (2009) pp.169-174

LumiCal Multichannel ADC

- Design
  - **8 channels** of pipeline ADC
  - **Multimode Digital multiplexer/serializer**
  - **High speed LVDS** drivers (~1GHz)
  - Low power **DAC control references**
  - Precise **BandGap** reference source
  - **Temperature sensor**
- Performance
  - **9.7 ENOB** up to 25 Ms/s (8 channels)
  - Power scales linearly with sampling rate **~1.2mW/channel/MHz**
  - ADC core works up to **50 Ms/s** (1 channel)
  - Gain spread < 0.1 %
  - **Crosstalk < -80dB**
  - **Power pulsing embedded**

ADC ASIC prototype

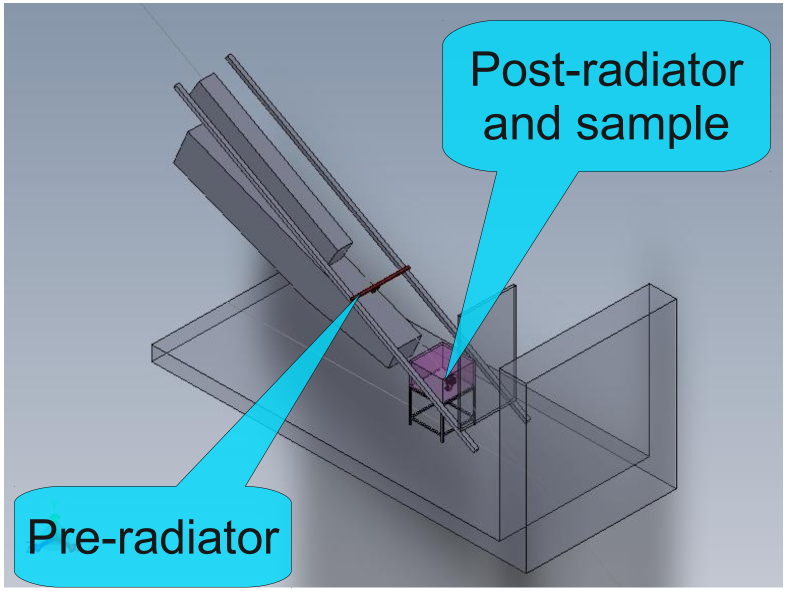


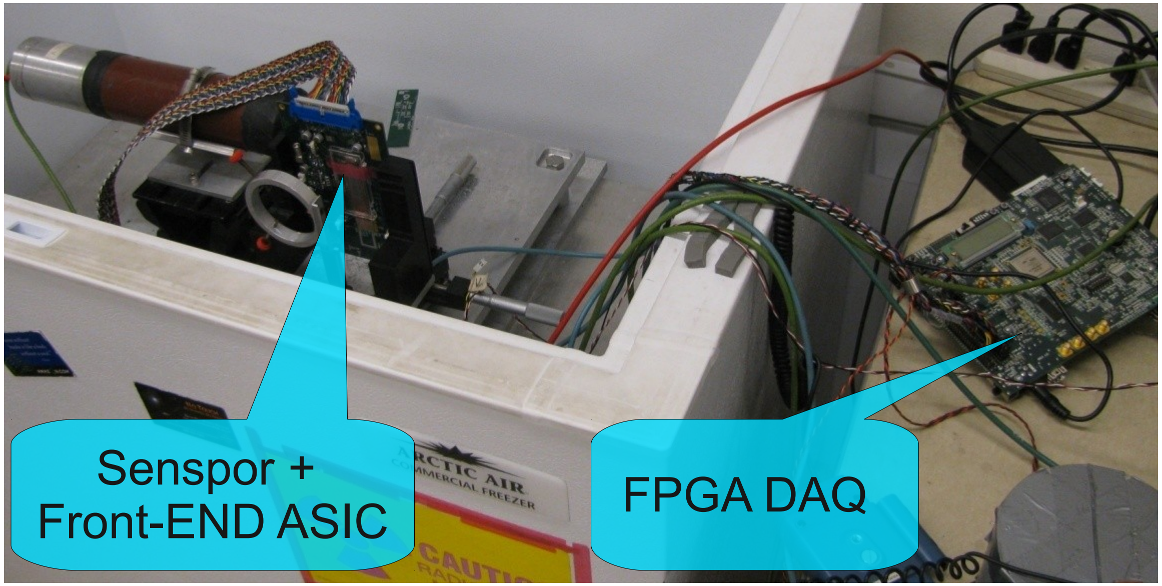


Radiation Damage Study Facility

- **Motivation : perform radiation hardness studies under more realistic conditions, e.g. considering also the hadronic component in electromagnetic showers**

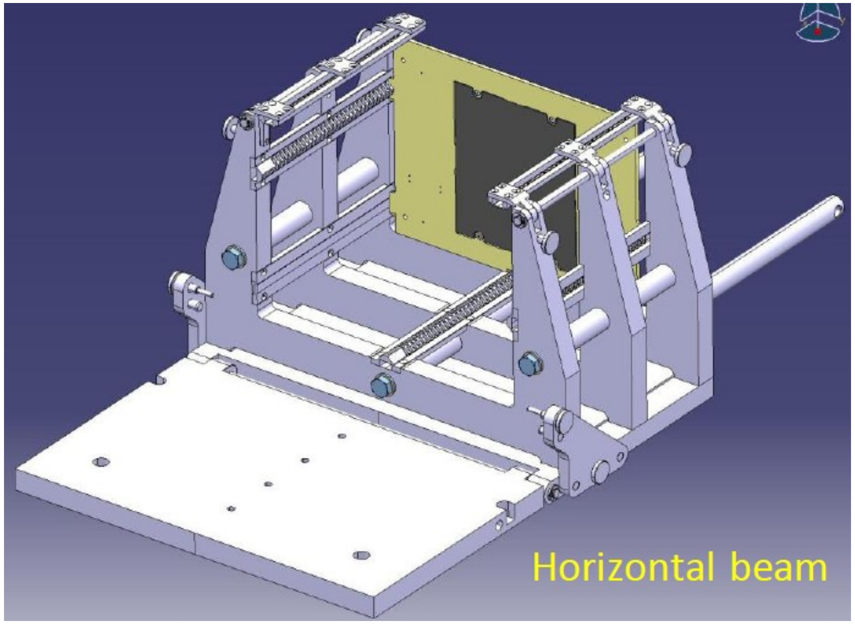
- **Modularity** will allow easy evaluation of different sensor technologies
- **Cooling** module to avoid spurious annealing effects
- Firsts **runs** foreseen at SLAC, several samples should be irradiated up to 100 MRad





Mechanical Infrastructure

A **flexible mechanical infrastructure** will be built to allow testing individual sensors or complete segments of LumiCal or BeamCal Calorimeters.



The mechanical structure:

- up to **30 tungsten plates** of 3.5 mm thickness paired with sensor planes.
- Variable distance between plates (**2, 1 or 0.5 mm**).
- Requirement of **50 micron mechanical accuracy** (roughness, flatness) of each tungsten plate and of the distance between the plates.

Machined tungsten

Tungsten machining tests already started. Differetnt material options are considered for prototype (pure Tungsten / Densimet / Inermet / Sparkal X)

Detector Design Studies for CLIC

CLIC Conceptual Design Report

CLIC CONCEPTUAL DESIGN REPORT

VOL. 2:
PHYSICS AND DETECTORS AT CLIC

CLIC Notes

- Study of readout architectures for triggerless high event rate detectors at CLIC
- The CLIC_ILD_CDR Geometry for the CDR Monte Carlo Mass Production
- Radiation Dose in the QD0 Quadrupole in the CLIC Interaction Region
- Simulation of Beam-Beam Background at CLIC
- A Luminosity Monitor for CLIC