# FCAL

# Forward Instrumentation

# Part 1: Hardware, Testbeam

# (+ DBD)

Konrad Elsener, CERN

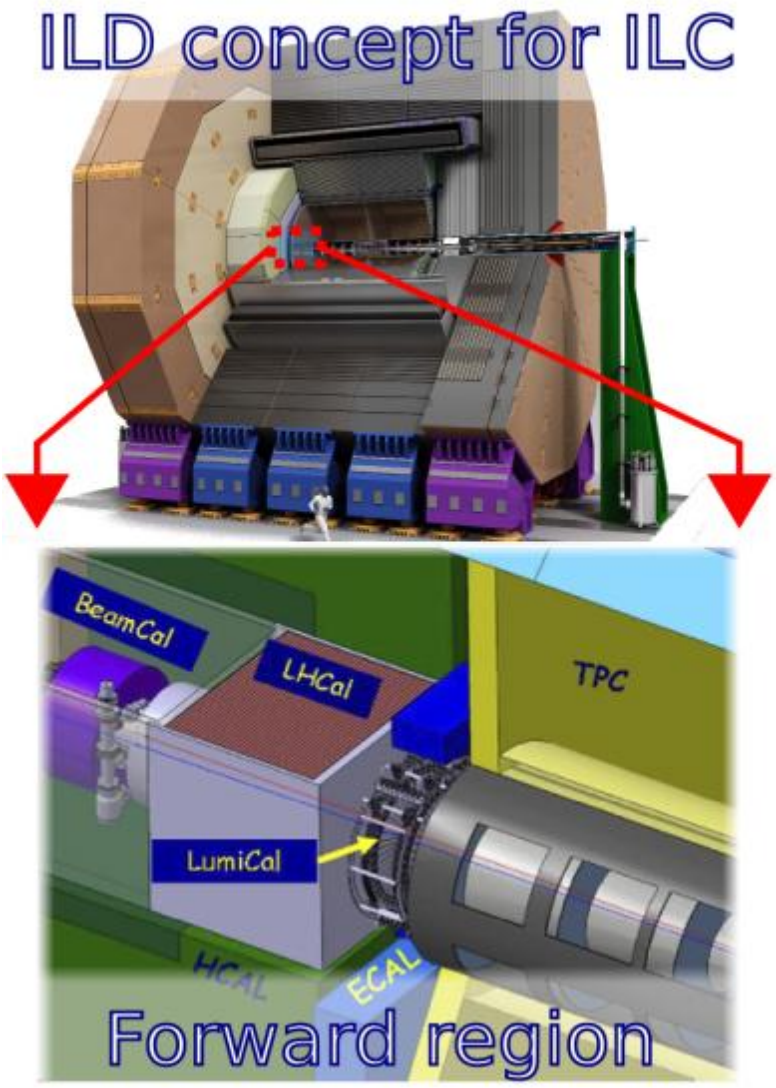
on behalf of the FCAL collaboration

(most slides from Wolfgang Lohmann, BTU and DESY)

# FCAL Collaboration


**Institutes involved:** AGH-UST, Cracow, Poland,ANL, Argonne, USA , CERN, Geneva, Switzerland, DESY, Zeuthen, Germany, IFIN-HH,and ISS Bucharest, Romania, INP PAN, Cracow, Poland, 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 ; **recently welcomed**: Pontificia Universidad Catolica de Chile

# Very Forward Instrumentation - Example ILD




## LumiCal

- precise absolute luminosity measurement, $10^{-3}$ at 0.5 TeV

## BeamCal and Pair Monitor

- hermeticity (electron detection at low polar angles),
- assisting beam tuning (fast feedback of BeamCal and Pair Monitor data to the accelerator)

Challenges:

- radiation hardness (BeamCal),
- high precision (LumiCal) and
- fast readout (both)

# Detector Design Studies for 500 GeV

## Design studies, background, systematic effects for 500 GeV advanced

JINST

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**Forward instrumentation for ILC detectors**

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Published in JINST

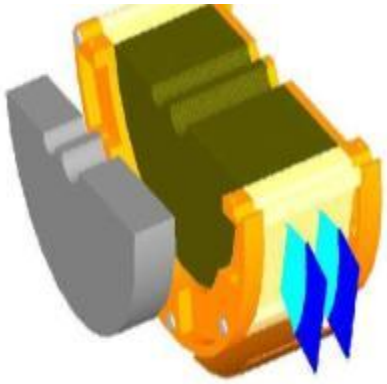
- Cylindrical sensor-tungsten sandwich calorimeter
- Small Moliere radius
- Finely segmented
- Crossing angle 14 mrad

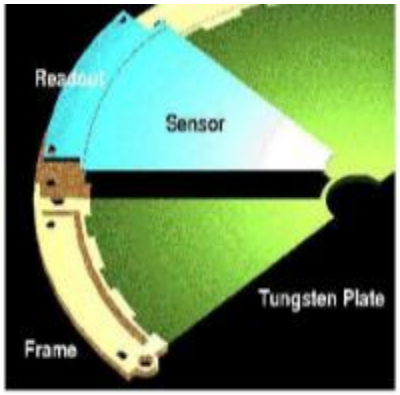
### Systematics of luminosity measurement at 500 GeV

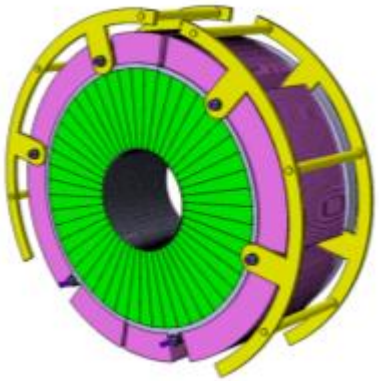
| Source | Value | Uncertainty | Luminosity Uncertainty |
|---|---|---|---|
| $\sigma_\theta$ | $2.2\times10^{-2}$ [mrad] | 100% | $1.6\times10^{-4}$ |
| $\Delta_\theta$ | $3.2\times10^{-3}$ [mrad] | 100% | $1.6\times10^{-4}$ |
| $a_{res}$ | 0.21 | 15% | $10^{-4}$ |
| luminosity spectrum | | | $10^{-3}$ |
| bunch sizes $\sigma_x$, $\sigma_z$, | 655 nm, 300 $\mu$m | 5% | $1.5\times10^{-3}$ |
| two photon events | $2.3\times10^{-3}$ | 40% | $0.9\times10^{-3}$ |
| energy scale | 400 MeV | 100% | $10^{-3}$ |
| polarisation, $e^-$, $e^+$ | 0.8, 0.6 | 0.0025 | $1.9\times10^{-4}$ |
| total uncertainty | | | $2.3\times10^{-3}$ |

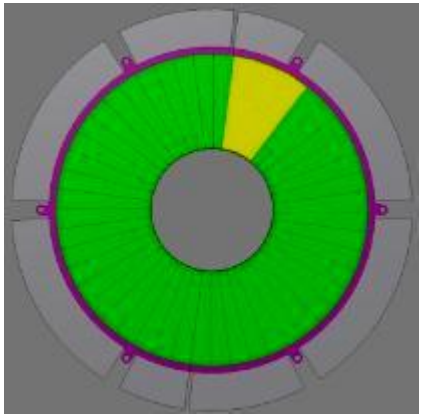
* 100%= Upper limit – the size of effect is taken as uncertainty

# Calorimeter - General Structure



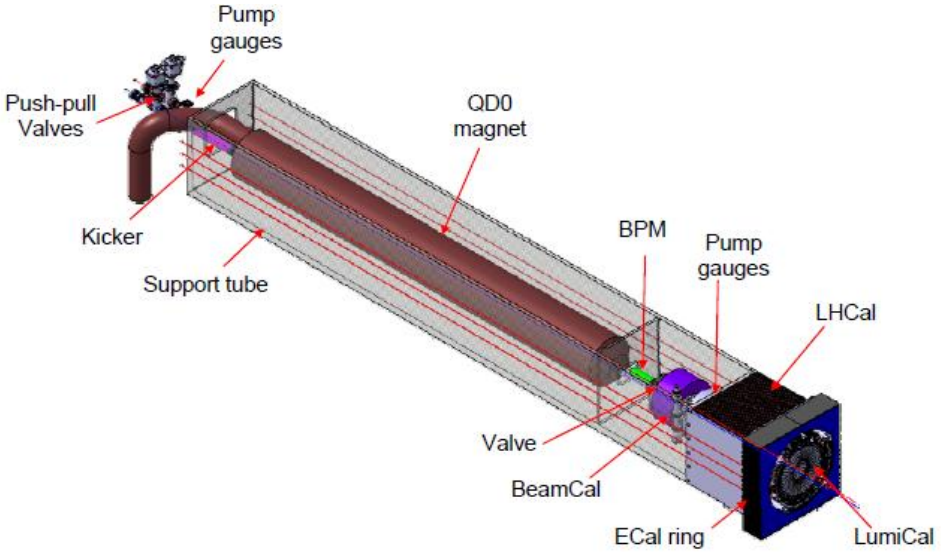


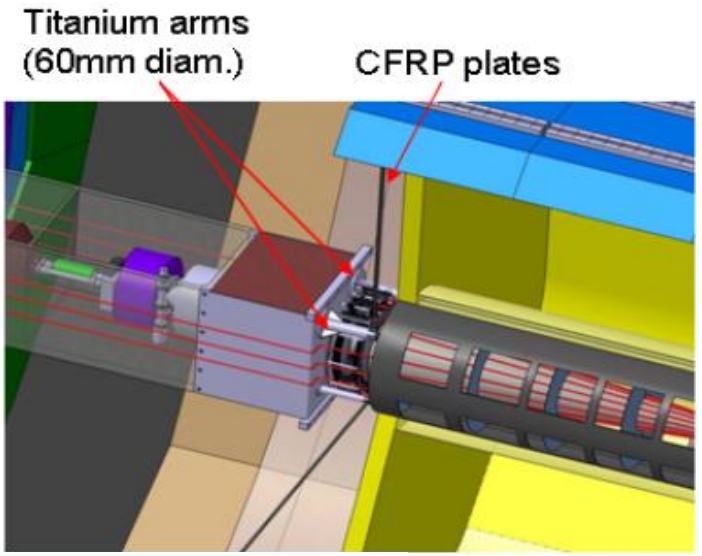



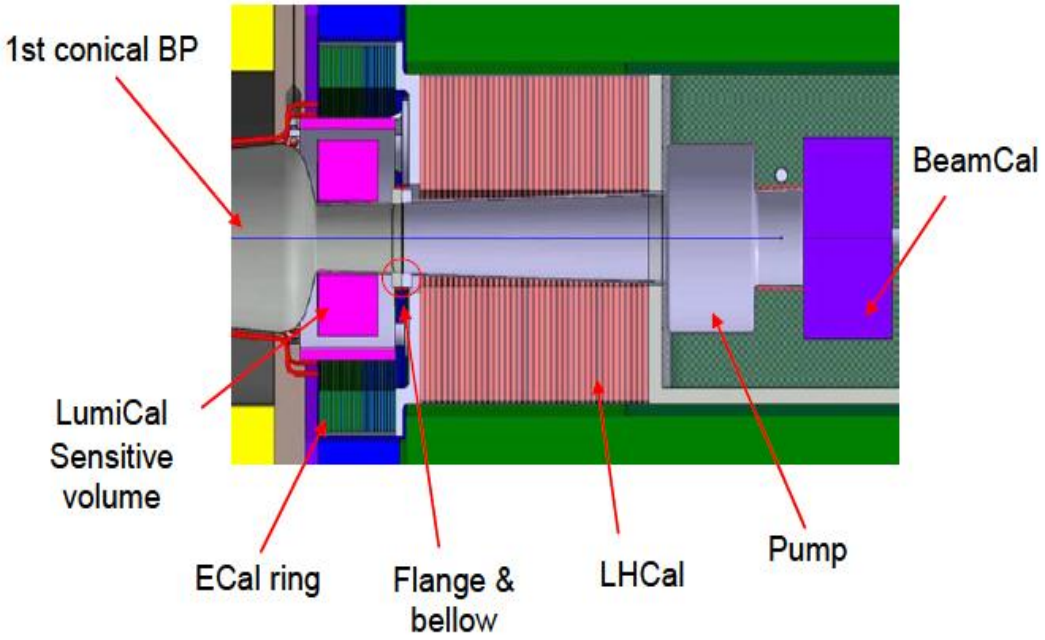


- Tungsten layer thickness 1 $X_0$ , 3.5 mm, 30 layers
- BeamCal sensors GaAs, 500 mm thick
- LumiCal sensors silicon, 320 mm thick
  (gap between W layers: 0.5 mm -> challenge)
- FE ASICs positioned at the outer radius
- BeamCal angular coverage 5.8 – 43.5 mrad
- LumiCal coverage 31 – 78 mrad

# Forward Region Design, ILD



# Sensor Requirements

## LumiCal

- Mechanically precise
- Finely radially segmented

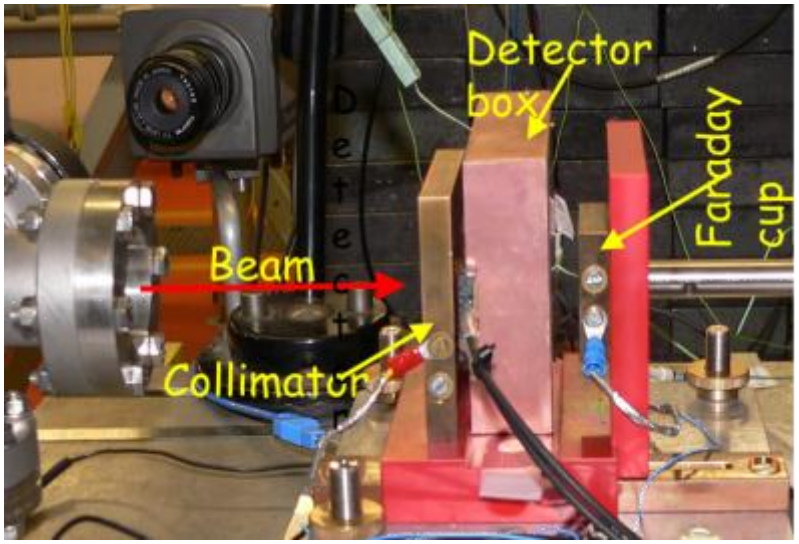
## BeamCal

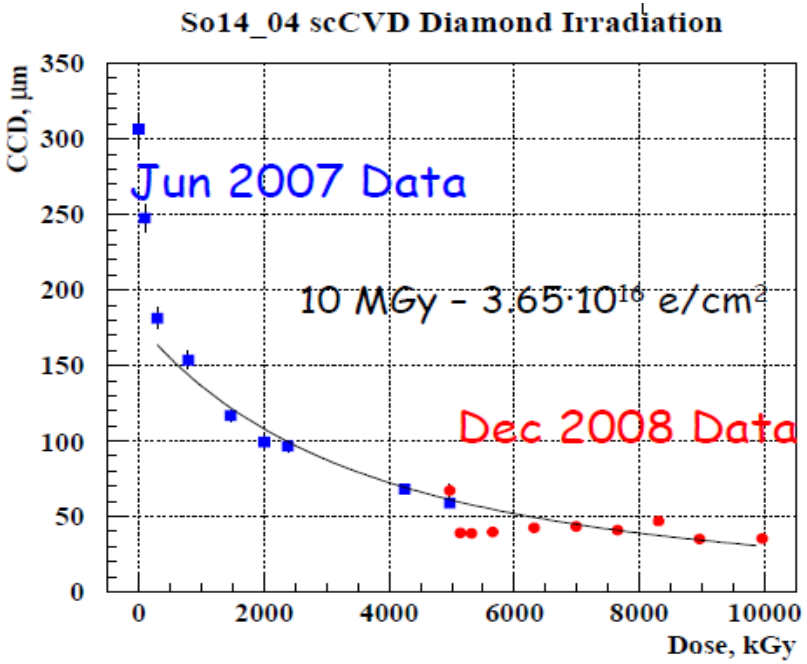
- Radiation hard
- Segmentation < $R_M$

Radiation hardness studies in low energy (10 MeV) electron beams

- pcCVD diamond
- scCVD diamond
- GaAs – baseline option

(availability of larger areas, lower price, radiation tolerance almost 1 MGy)

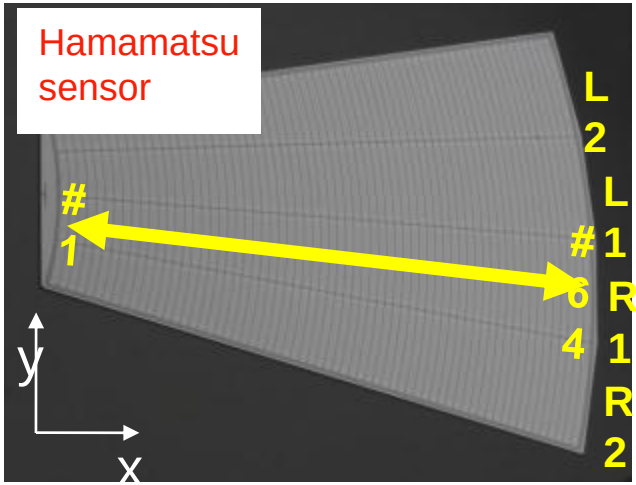



Charge collection distance vs. Dose

# Sensor prototypes

## LumiCal

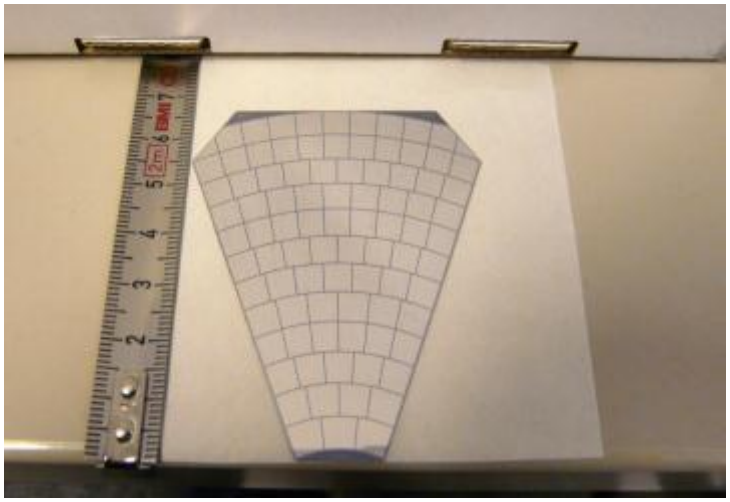



p in n, strip pitch 2.2 mm

40 pieces, joint effort

IFJ PAN Cracow, DESY, TAU

## BeamCal



Compensated GaAs several sectors under test,

Pads of 8x8 $mm^2$ (?)

Institute in Tomsk, DESY-JINR collaboration (BMBF supported)

# ASIC requirements

ILC:

Train frequency 5 Hz

About 3000 bunches per train

300 ns between bunches

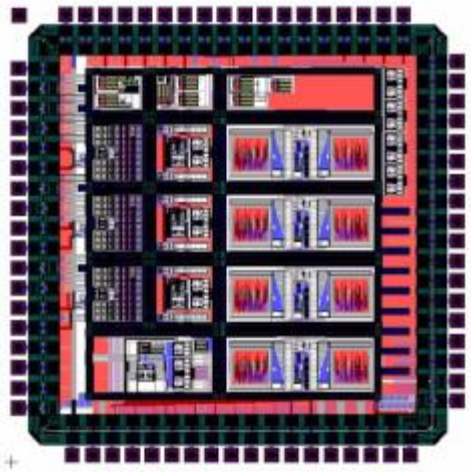
$C_{pad}$ : < 100 pF

$Q_{pad}$: 2 fC – 10 pC

Event rate: 3 MHz

# ASICs

## SLAC-Stanford chip (BeamCal)

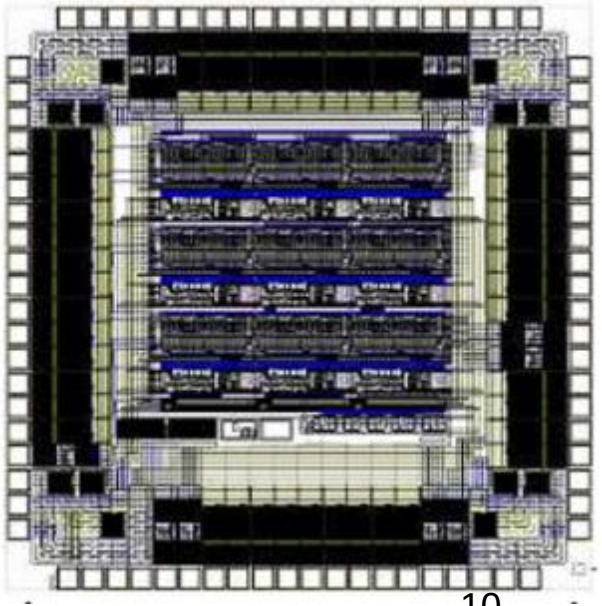


- Prototypes in 180-nm process
- Charge sensitive preamplifier
- Analog adder to provide fast feedback and beam diagnostics
- ADC : 10-bit SAR ADC
- Lab tests done / performance to specs

## **Pair Monitor** readout (Tohoku Univ.)

- Silicon On Insulator (SOI) technology – first the sensor and readout electronics are integrated in the SOI substrate. (monolithic)
- SOI 0.2 μm CMOS process;
noise : 260 $e^-$ (+130 $e^-$/pF)

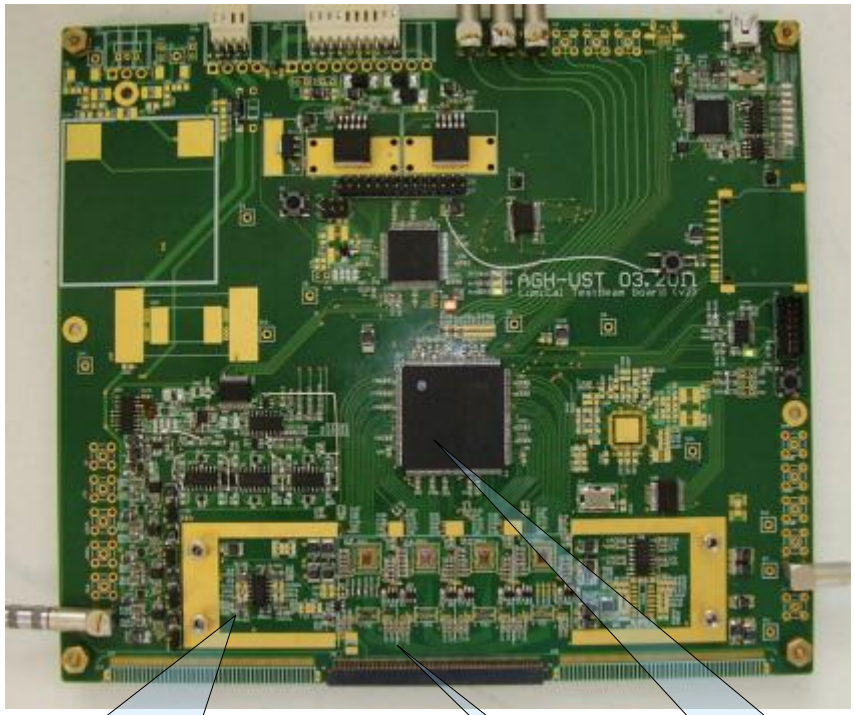
expected signal : 20000 e



# ASICs

## AGH-UST Cracow Readout board, 32 channels

- AMS 350 nm
- 20 Ms/s ADC
- External and self trigger
- Internal or ‘beam’ clock
- Data transfer via USB
- Power pulsing
- Handshaking with Trigger Logic Unit (TLU)
- Used in several beam-test ventures



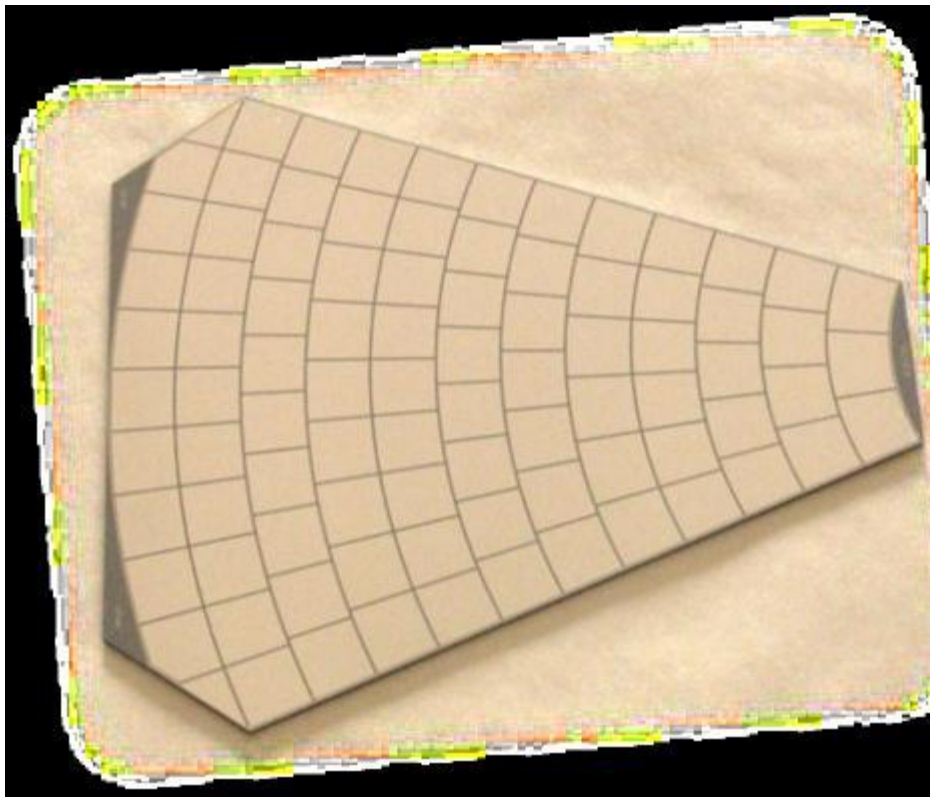

4 pairs of front-end+ADC ASICs

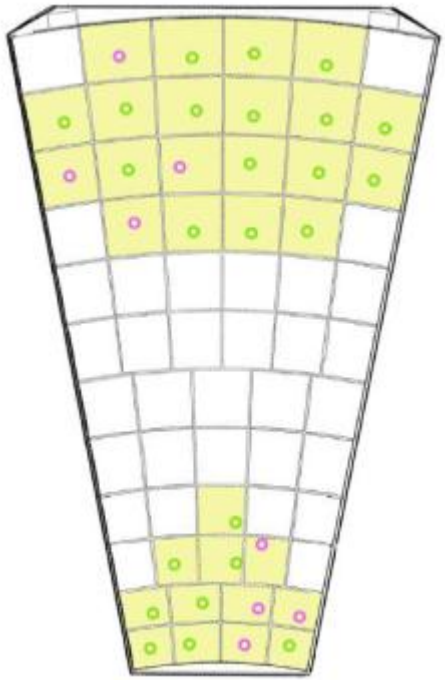
Data concentrator
Xilinx Spartan 3E

sensor
connector

→ Slide shown at LCWS11, Granada ←

# GaAs sensor tests - BeamCal





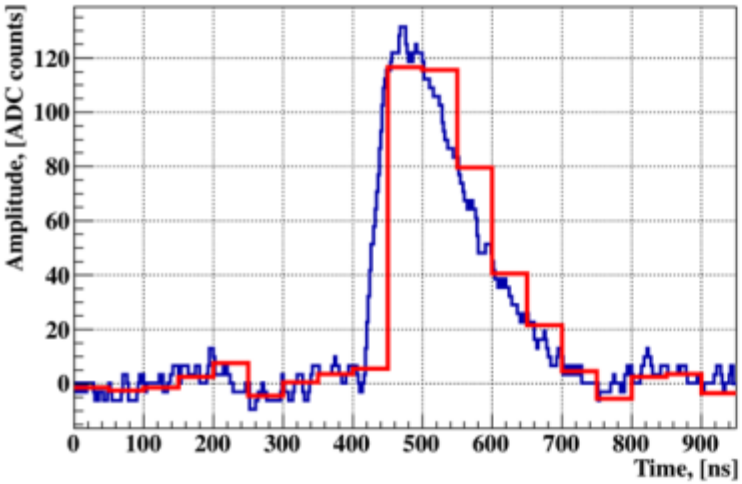
GaAs ensor pads will be read out by the full Cracow electronics chain - as LumiCal (FE ASICS plus ADC ASICS)

**Forthcoming testbeam period**: consolidate results, will provide the FCAL input to the DBD

- Updated analysis of testbeam data (July-Aug. and Nov. 2011)
  - LumiCal and BeamCal

BeamCal prototypes were tested at the
2 -4,5 GeV DESY electron beam in November 2011

**ASIC's ADC + ASIC's FE + fan-out + sensors,**
positively verified on test beam (O. Novgorodova)

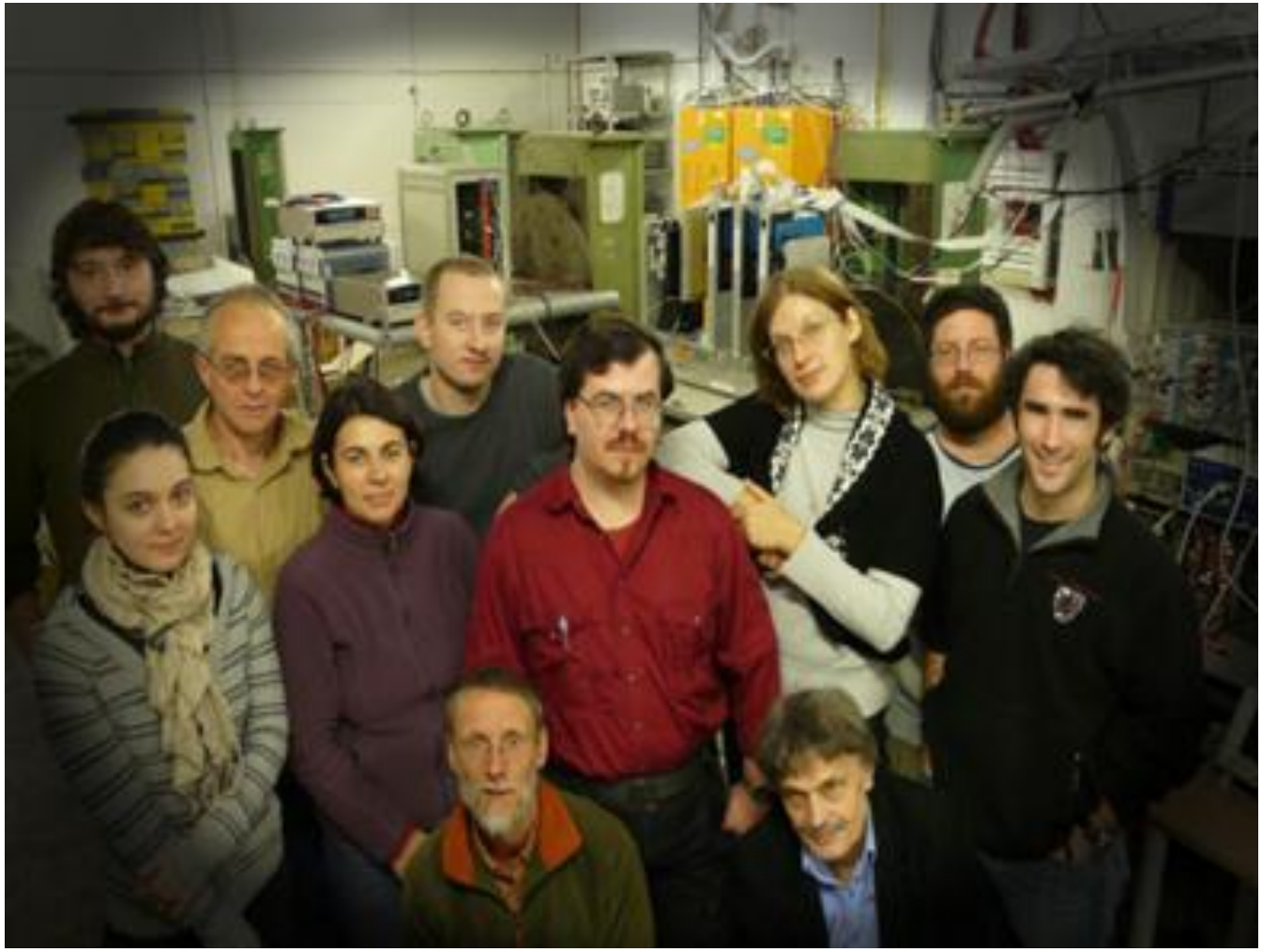



Example signal:
Signal digitized with ADC ASIC (red) and external ADC (blue )

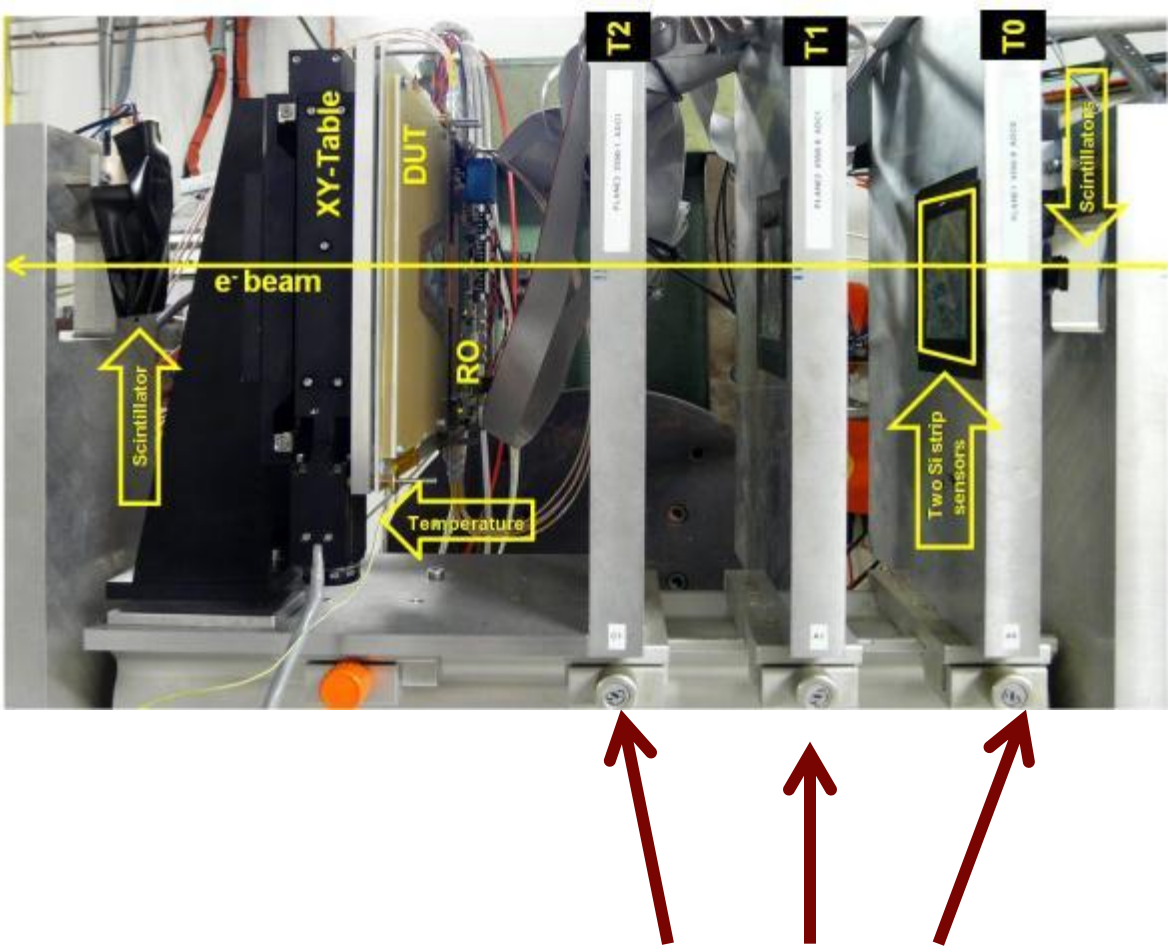
PRELIMINARY !

- Discussion on errors in abs. Luminosity and Luminosity Spectrum
- Discussion on DBD matters

# Beam-Tests at DESY



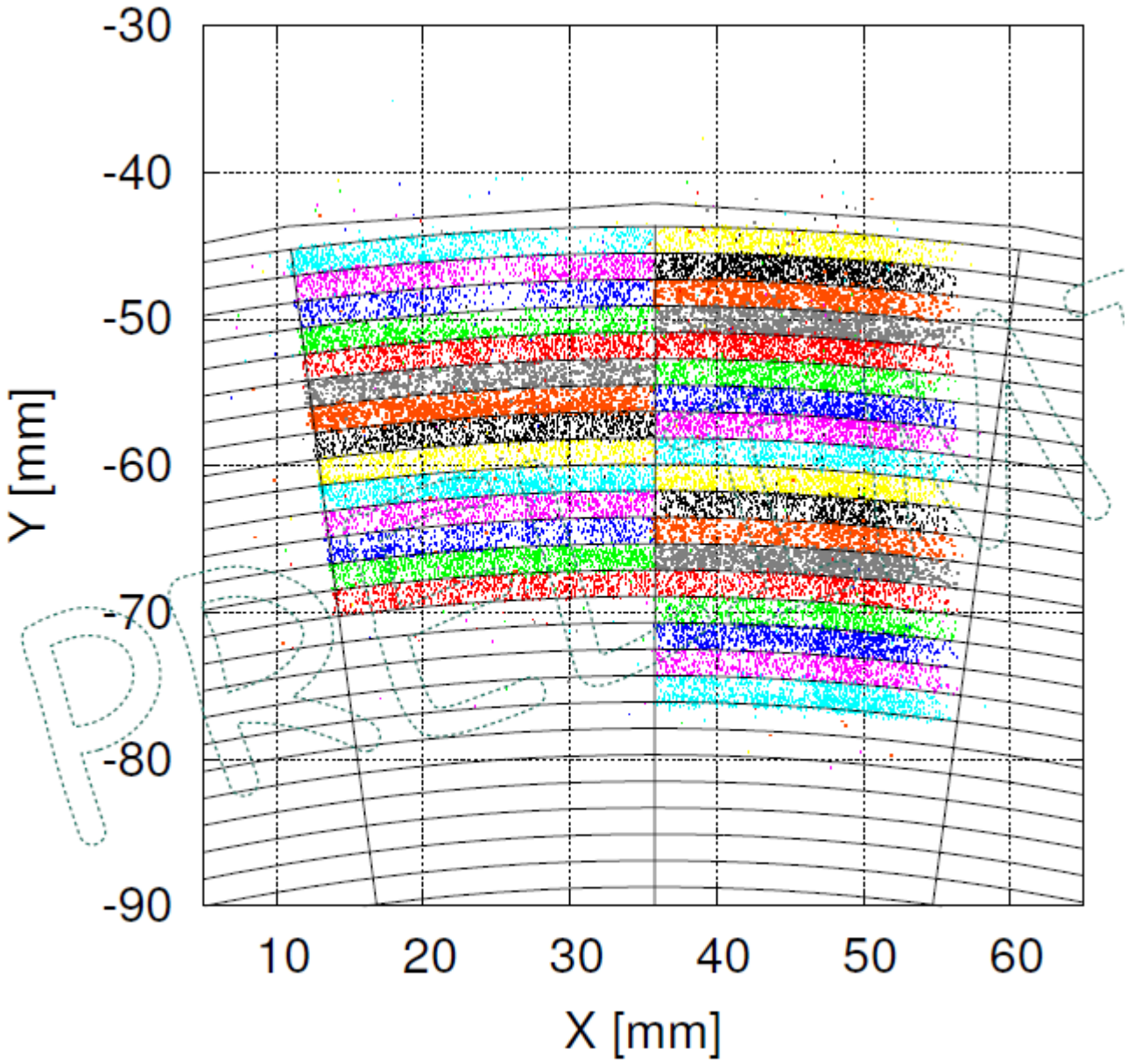
# Beam-Tests at DESY




- $50x10^6$ trigger
- different areas of the sensor
- different FE settings (feedback in the FE ASICs)
- data with FE and external ADC

Silicon strip planes

# Beam-Test – LumiCal sensor with full electronics chain




Sensor's geometry nicely reflected.

Points on the right missing ~~probably~~ because of X-Y table got stuck.

## Preparation of a “prototype” Calorimeter Sector:

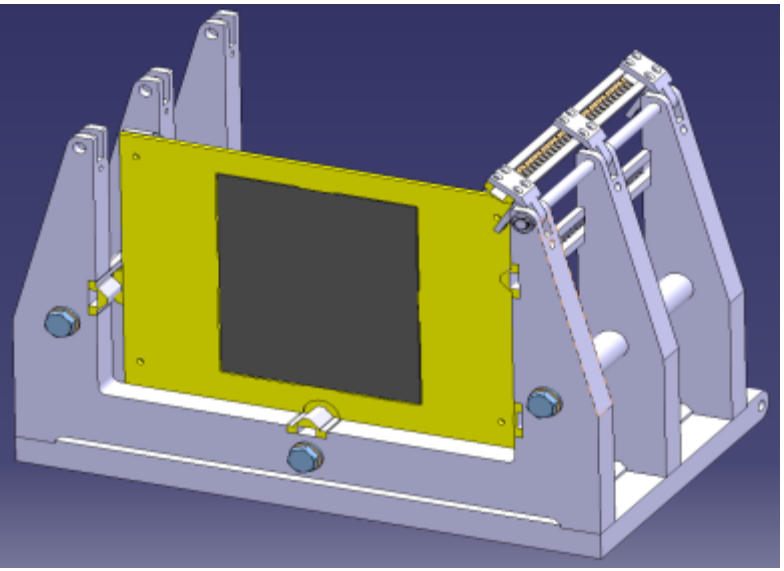
- Flexible, high precision tungsten structure
- FE ASICs in 130 nm technology
- Position control devices
- Fully assembled sensor planes, covering ≥ $30^0$
- Power pulsing

## Infrastructure common with others:

- Data acquisition
- Tracking in front of the calorimeter

Participating Institutes: AGH-UST (Cracow), CERN, DESY (Zeuthen), IFJPAN (Cracow), TAU (Tel Aviv), (IFIN, VINCA associated)

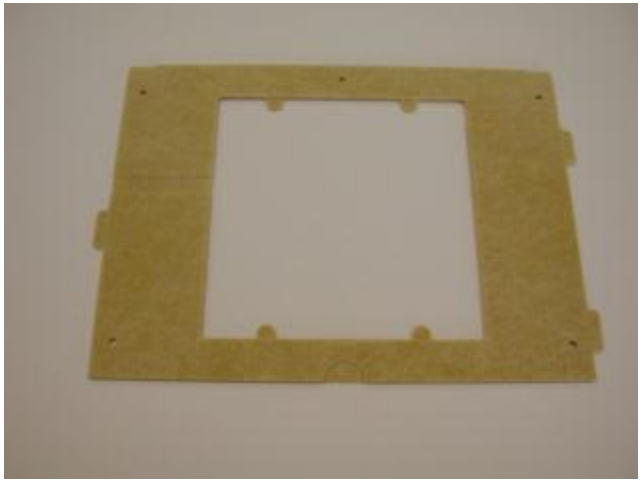
# Mechanical structure



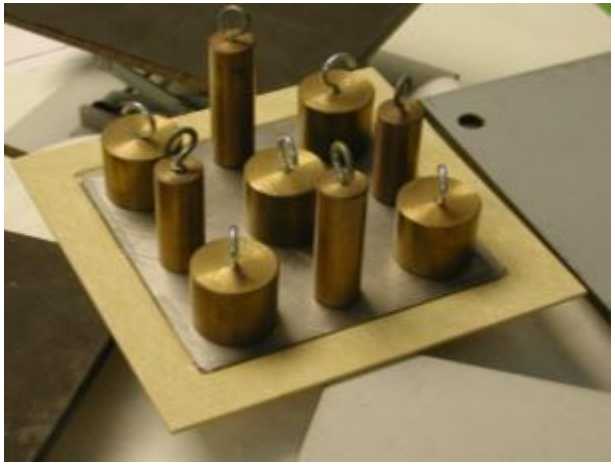
- 30 Tungsten absorber plates, 3.5 mm ($1X_0$)
- sensor gap 2, 1 (and 0.5) mm
- precision 50 µm
- flexible, easy exchange of sensor layers

Designed and manufactured by CERN , Physics department, Detector technology group

# Mechanical structure

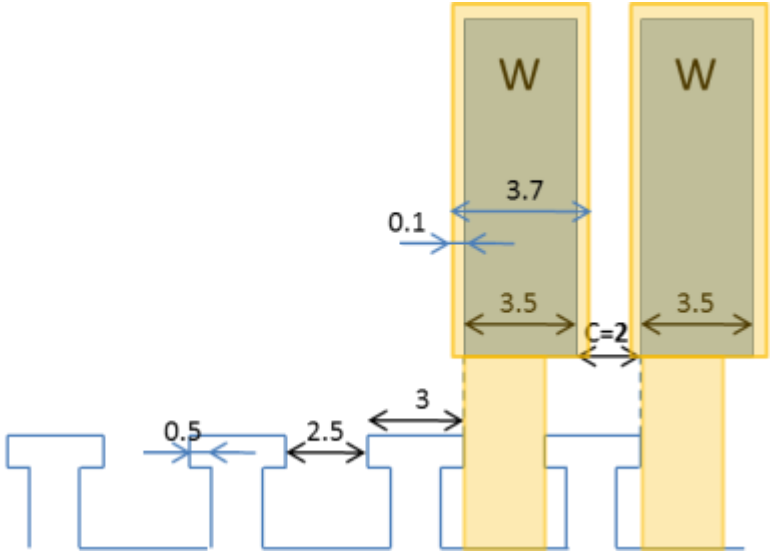


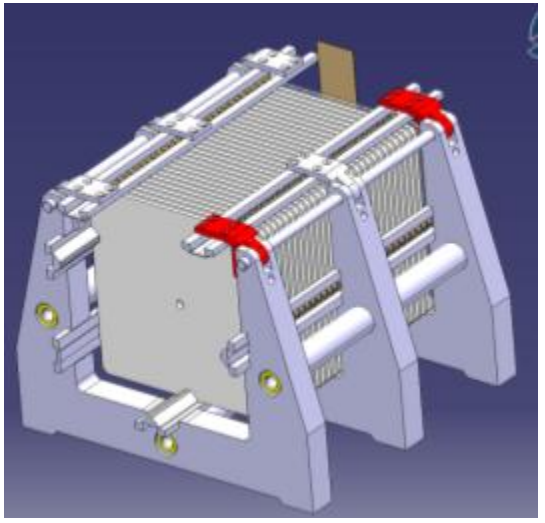
First machined permaglass frame



“bad” tungsten absorber plate inserted, test of glue

Sensor plane

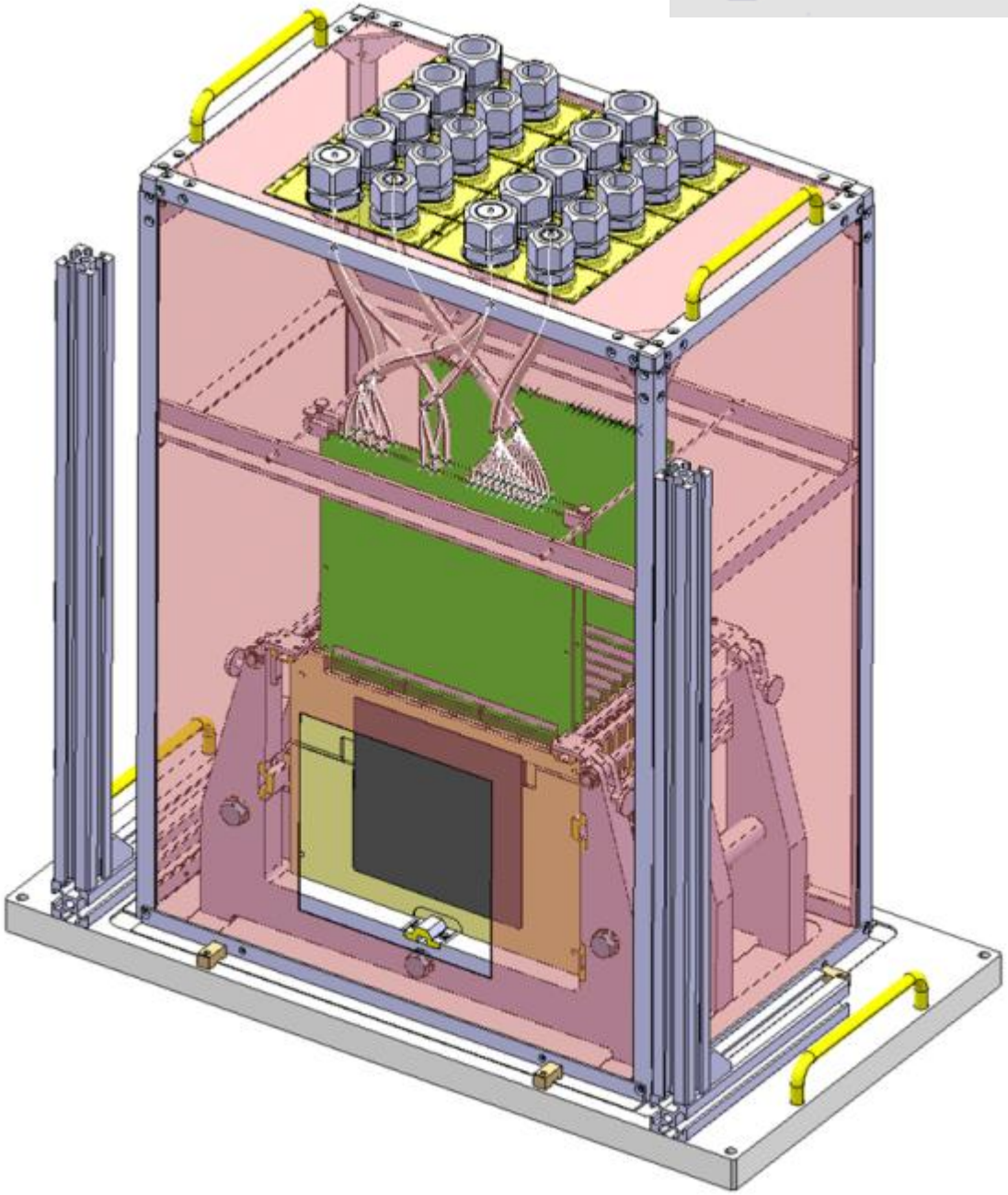


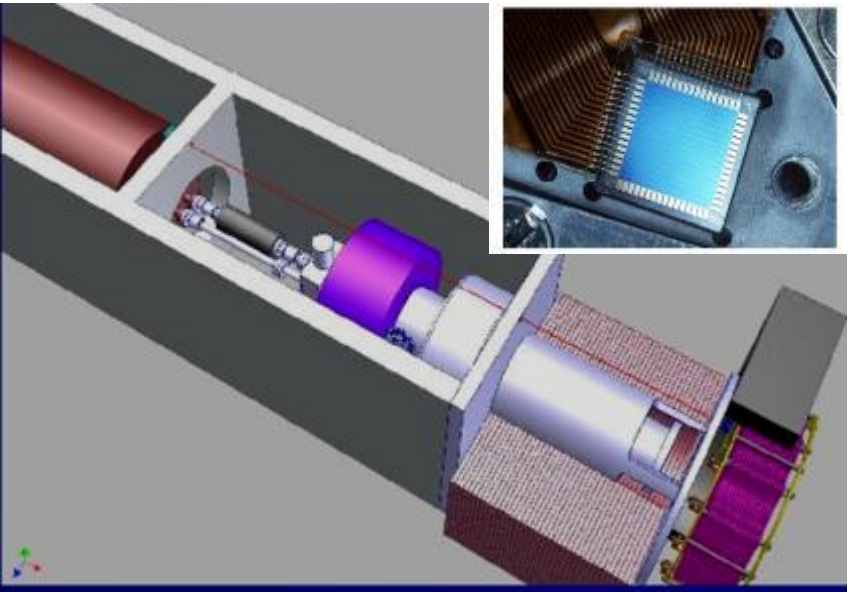
# Mechanical structure

Awaiting from industry
(two companies –
5 plates from each):

Very precisely machined
tungsten plates –
roughness + flatness
to allow for overall
± 50 μm accuracy on
distance between plates



# Laser Alignment and DAQ



## Alignment Concept (INPAS Cracow)

- Reference for position monitoring QD0
- Laser beams and sensors between QD0 and LumiCal
- Laser beams between both LumiCal

## DAQ (INPAS and TAU)

- Follows the ILD standard (Calice, LCTPC)
- 4 Detector Interface units are ordered
- 1 Link Data Aggregator under test
- Concept not yet finished

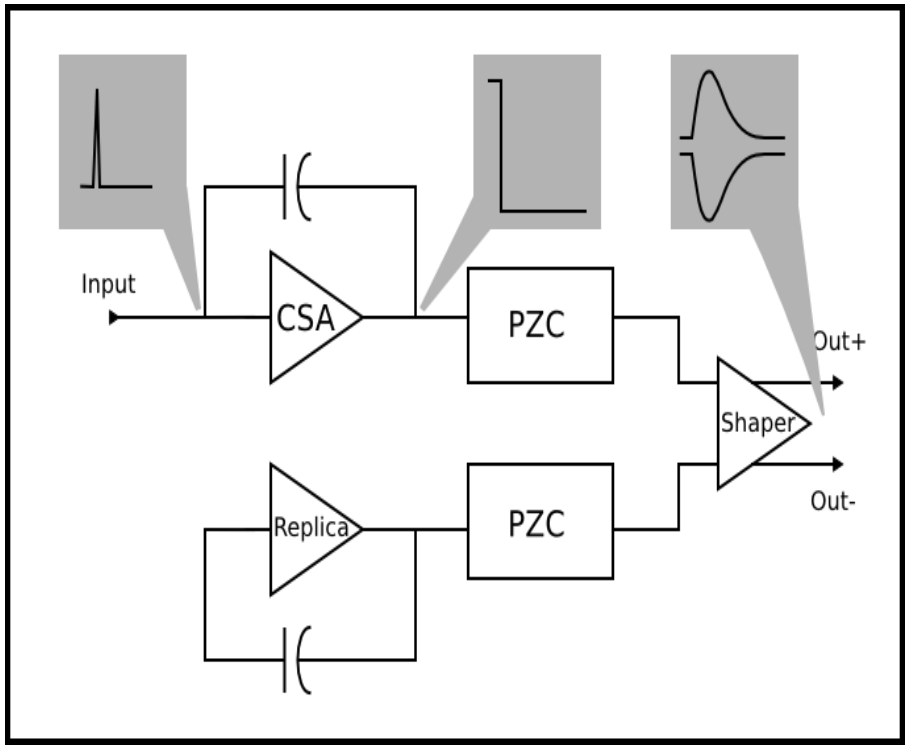
# New ASIC prototypes

Future ASICs will be designed and produced in 130 nm IBM technology (AGH-UST Cracow)
faster, lower power consumption, radiation hard

- 10 bit SAR ADC (submitted
- in February 2012)
  - 1-2 mW at 40 Ms/s
  - 150 μm pitch

- new FE ASIC, improved ADC (submitted in May)
  - Charge sensitive, PZC
  - Gain 0.15mV/fC and 15 mV/fC (switchable)
  - Peaking time 25-100 ns variable
  - 2 mW/channel

- Multichannel version in 2013



# Future Plans – outside/beyond AIDA

-> further work on pair monitor system

-> further work on simulations / systematic errors
on the absolute luminosity

-> further work on luminosity spectrum and its
measurement through a known physics channel

-> continued collaboration ILC – CLIC, also inside FCAL

# FCAL and DBD matters

Proposal made by IDAG at KLIC12 workshop, Korea
(sorry if there is a misunderstanding here…):

a common, separate chapter in the DBD "common part" about
the design and R&D of the instrumentation in the very forward region

(In the chapters of ILD and SiD then only details on the specific
geometry of the forward region will be described.)

The FCAL collaboration considers that this is a reasonable option.

**Independently of this, work is starting to write the material for the DBD (editors will have to re-group / cut text etc.)**

# FCAL and DBD matters

**\subsubsection{FCAL mission}** (Halina and Wolfgang)
2 pages
\begin{itemize}
\item Luminosity measurement –
LumiCal
\item Luminosity monitoring –
BeamCal, Pair Monitor
\item Detector Hermeticity –
BeamCal, (LumiCal, LHCAL never
yet investigated}
\item Geometrical layout
\end{itemize}

**\subsubsection{LumiCal}**
\begin{itemize}
\item Detector optimization (Halina, Bogdan)
\item Mechanical design (Woitek, Leszek)
\item Alignment (Woitek, Leszek)
\item Test bench of silicon sensors (Woitek)
\item Background and systematics estimates
(Ivanka, Philip)
\item ASICs development (Marek)
\begin{itemize}
\item Front-end electronics
\item ADC design
\item Performance measurements
\end{itemize}
\item Beam tests (Szymon)
\end{itemize}

# FCAL and DBD matters

**\subsubsection{BeamCal}**
\begin{itemize}
\item Detector design (Sergey)
\item Functionality and Performance (Aura, Olga)
\item Studies of radiation hardness (Sergey)
\begin{itemize}
\item CVD diamond sensors
\item GaAs sensors
\end{itemize}
\item ASICs development (Angel)
\begin{itemize}
\item Circuit implementation
\item Bench test results (Olga, Vladimir)
\end{itemize}
\item Beam tests (Olga, Titi)
\end{itemize}

**deadline for draft text (FCAL internal): end of June 2012**

**\subsubsection{Pair monitor}** (Hitoshi)
\begin{itemize}
\item Detector design
\item Readout
\end{itemize}

\subsubsection{Future plans}
\begin{itemize}
\item Prototype design (Marek, Konrad)
\item Beam tests program (Marek)
\item Further design optimization (Bogdan, Aura)
\item Physics benchmarking (Philip)
\end{itemize}

# Summary

- FCAL collaboration is rigorously pursuing R&D for the three monitoring systems:
  LumiCal -- BeamCal -- PairMonitor
- plenty of testbeam data to analyze -> DBD
- busy workplan for the near and mid-term future
- progress with DBD – organised contributions in FCAL