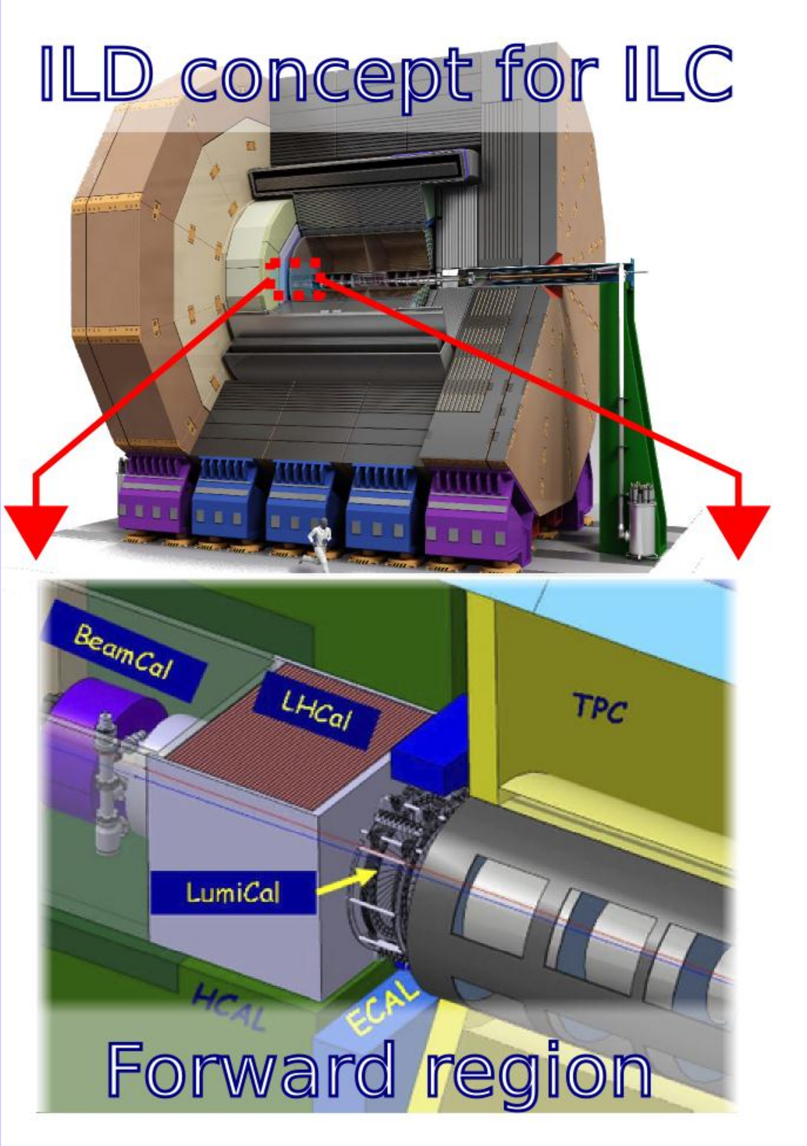
# Forward Instrumentation of ILC and CLIC detectors

Wolfgang Lohmann,

BTU and DESY

On behalf of the FCAL collaboration

Labs involved: Argonne, Vinca Inst, Belgrade, Bukharest IFIN-HH & ISS,
CERN, Univ. of Colorado, Cracow AGH-UST & IFJ-PAN,
JINR Dubna, NCPHEP Minsk, Santa Cruz,
Stanford University, SLAC ,
Tuhoku Univ., Tel Aviv Univ., DESY (Z.),
Pontificia Universidad Católica, Chile




## LumiCal:

- precise luminosity measurement, $10^{-3}$ at ILC , $10^{-2}$ at 3 TeV

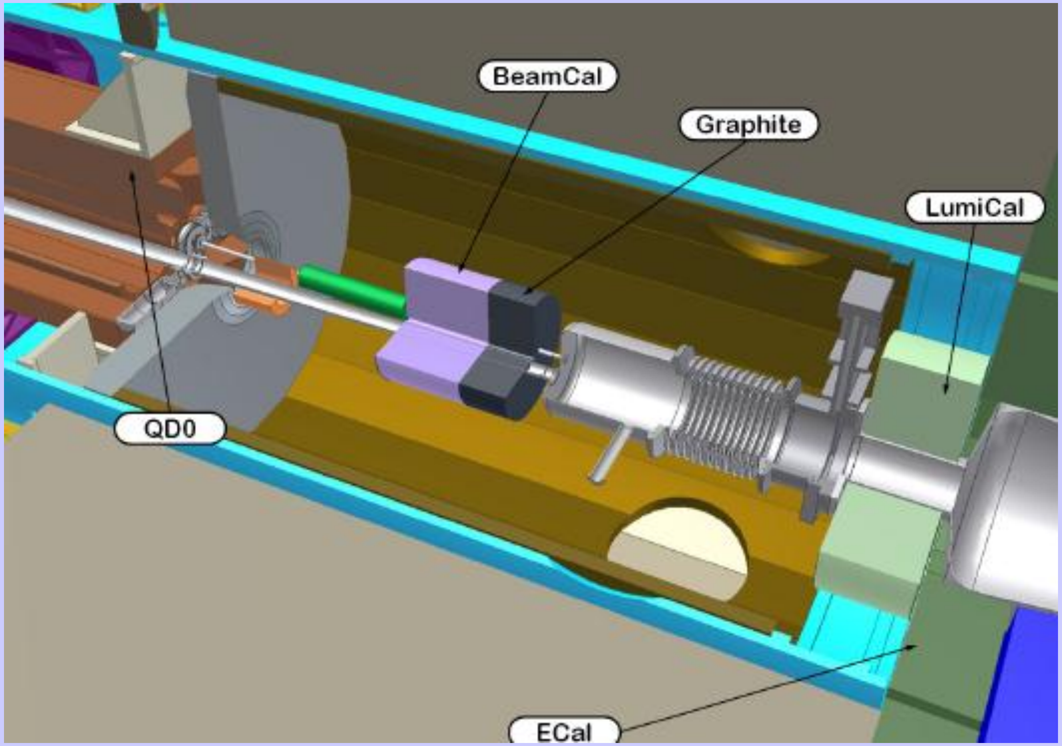
## BeamCal (and Pair Monitor):

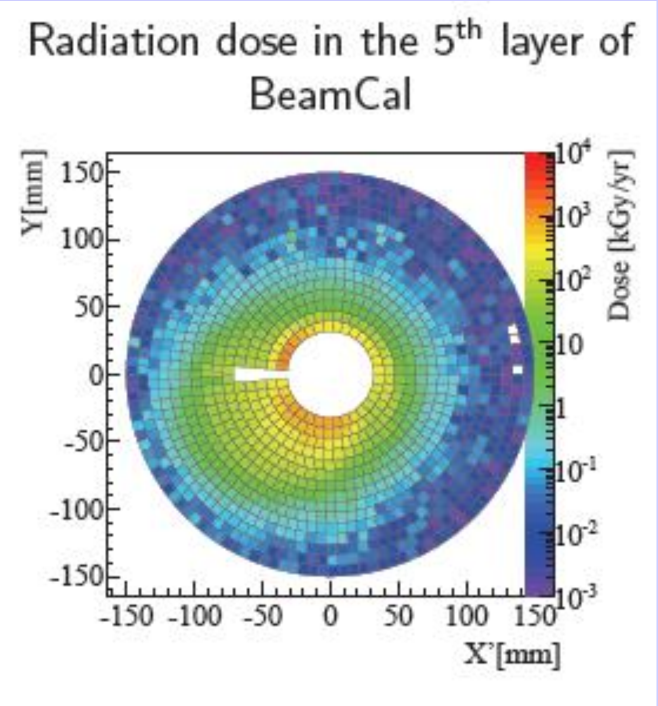
- hermeticity (electron detection at low polar angles),
- assisting beam tuning (fast feedback from BeamCal and pair monitor data to machine)

## Challenges:

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

# Design of the forward region of a CLIC detector



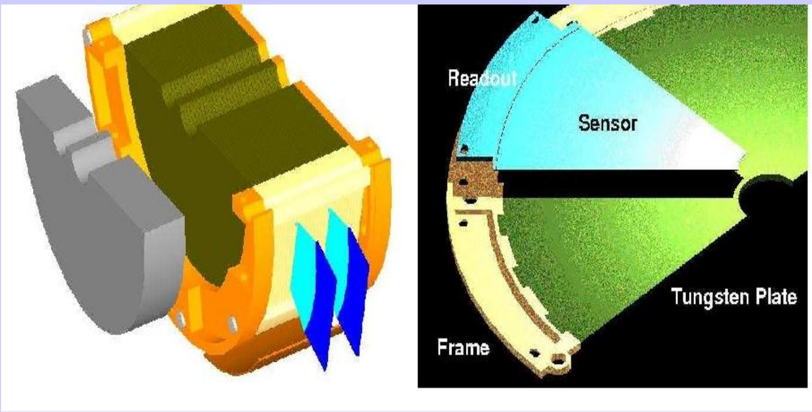

Crossing angle 20 mrad

- BeamCal angular coverage 10 – 40 mrad
- LumiCal coverage 38 - 110 mrad
- 40 $X_0$ depth
- Optimised to minimise backscattered particles

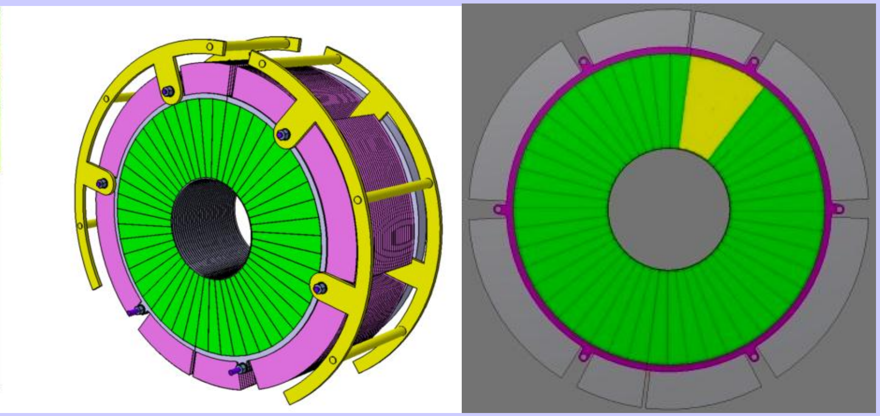
# Calorimeter, general structure

## Technology choice: Finely segmented compact calorimeters

BeamCal




LumiCal



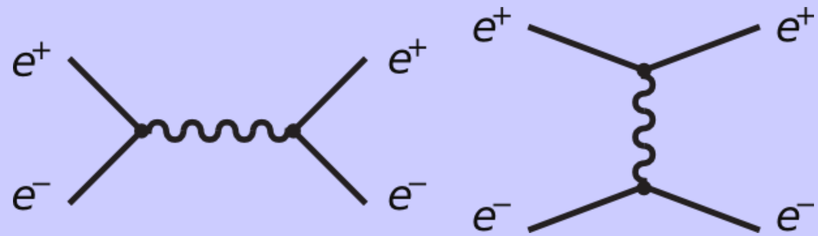
- Tungsten thickness 1 $X_0$, 30 layers
- BeamCal sensors GaAs, 500 $\mu$m thick
- LumiCal sensors silicon, 320 $\mu$m thick
- FE ASICs positioned at the outer radius
- BeamCal angular coverage 5.8 – 43.5 mrad
- LumiCal coverage 31 – 78 mrad

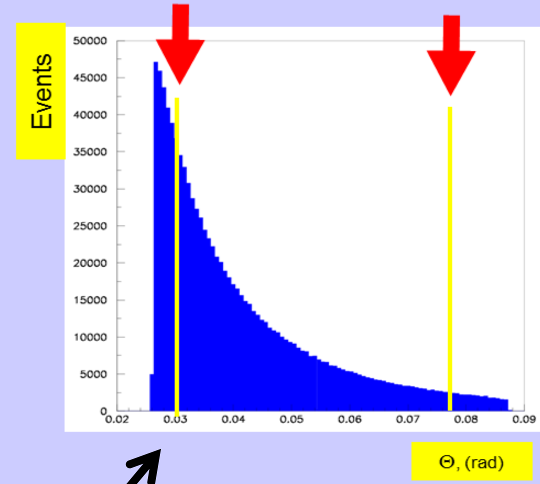
# Detector Design Studies, 500 GeV

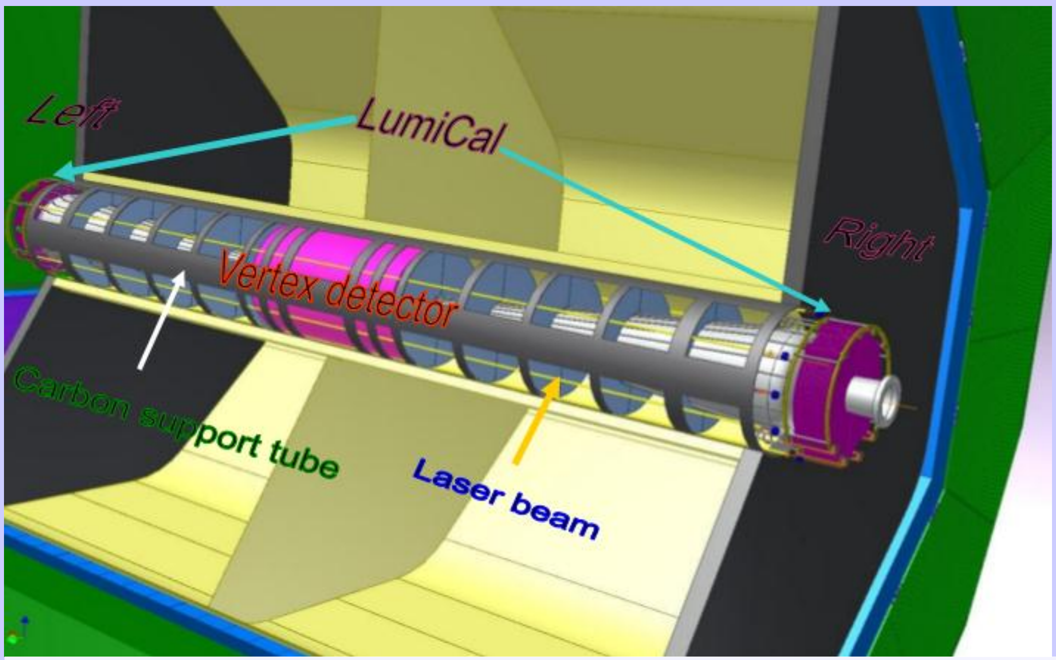
## Luminosity:

$\mathcal{L} = N / \sigma$

## Bhabha scattering:



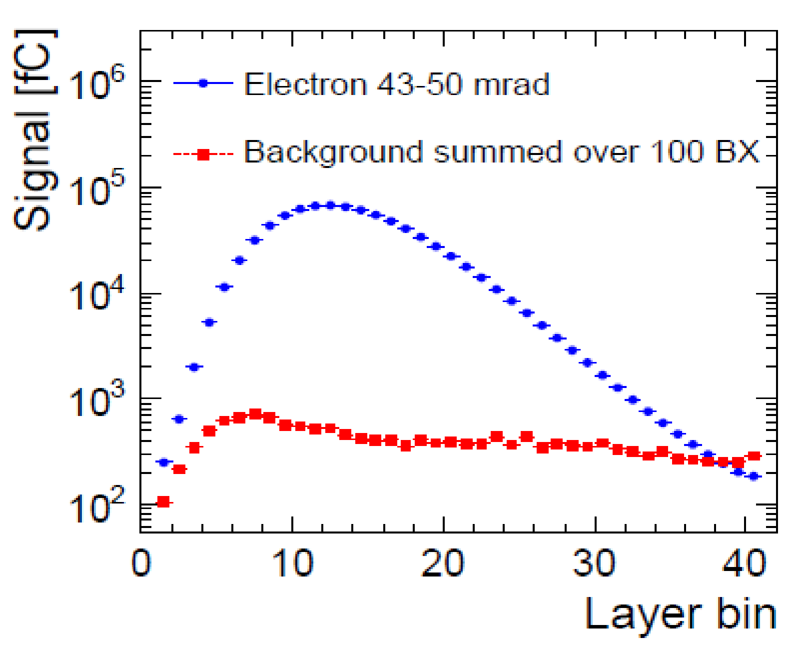

Laser alignment system (LAS) ,
**Integrated in the QD0 alignment**

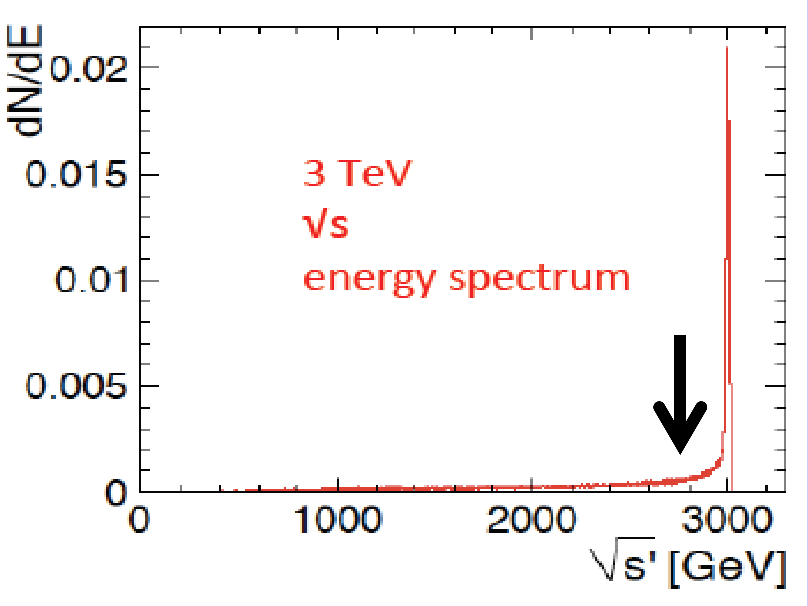
**$\Delta R < 40\ \mu m$**

**$\Delta z < 500\ \mu m$**

CLIC challenges:

- Beam induced background in LumiCal (occupancy)
- Read-out speed (.5 ns between BX)
- Luminosity spectrum

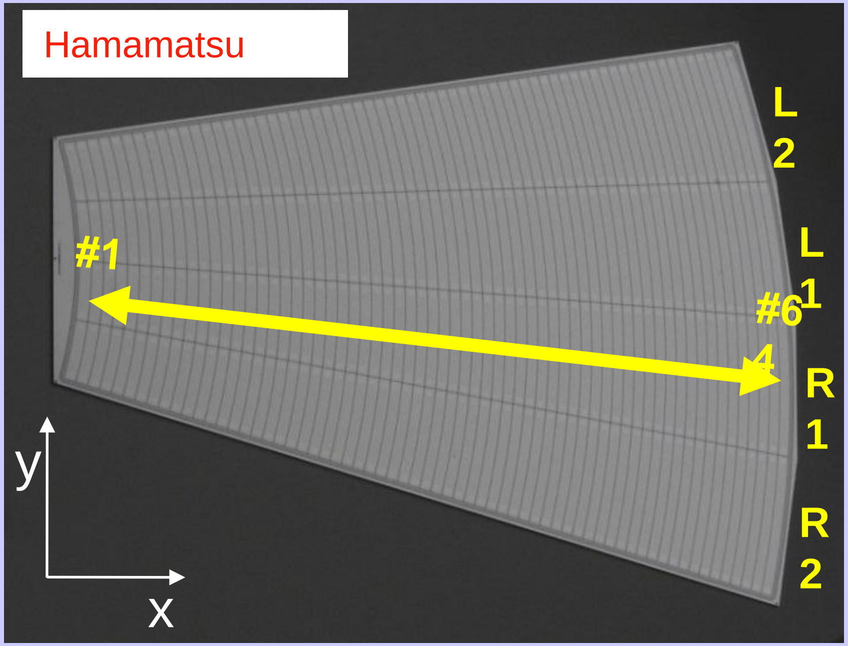



The precise knowledge of the spectrum shape is essential for the precision of the luminosity measurement !!
(how to determine -see talk by Andre Sailer)

# Sensor prototypes

## LumiCal

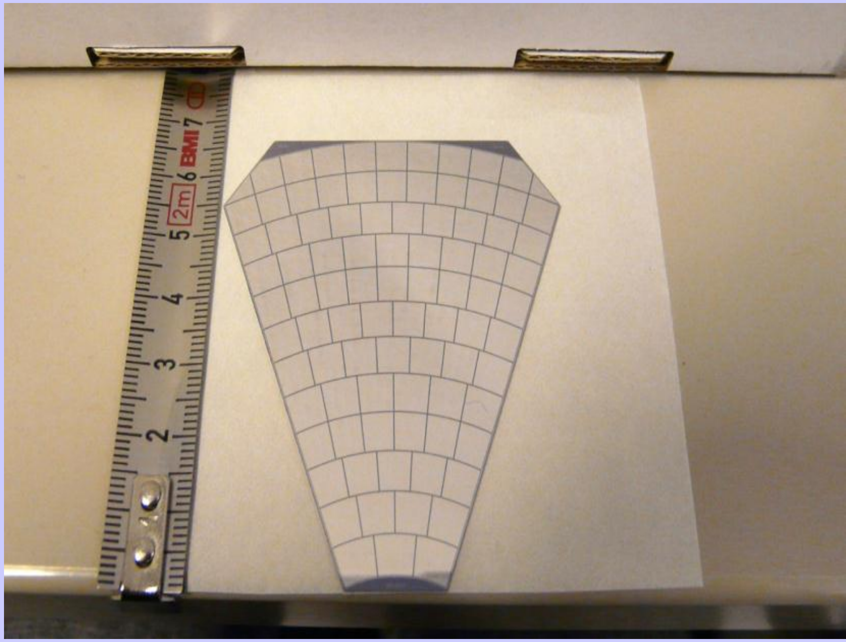



p in n, strip pitch 2.2 mm

40 pieces, joint effort

IFJ PAN Cracow, DESY, TAU

## BeamCal

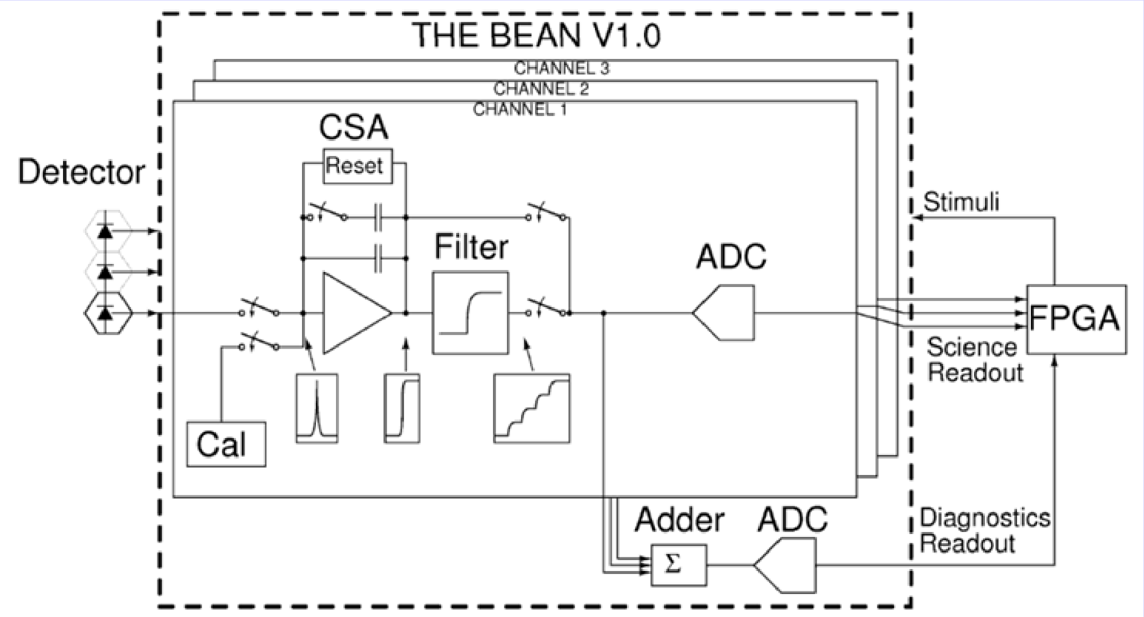


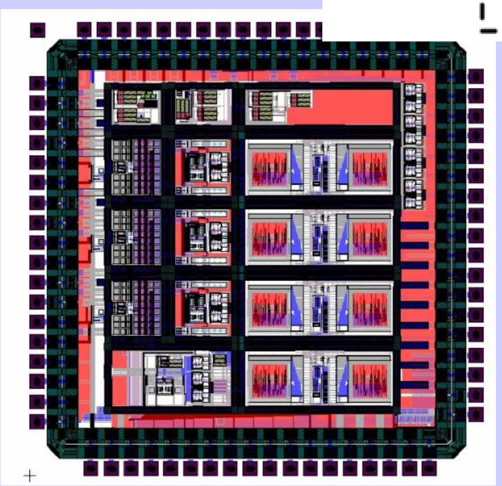
Compensated GaAs

~ 10 pieces,

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

# SLAC/ Universidad Católica, Chile (BeamCal)

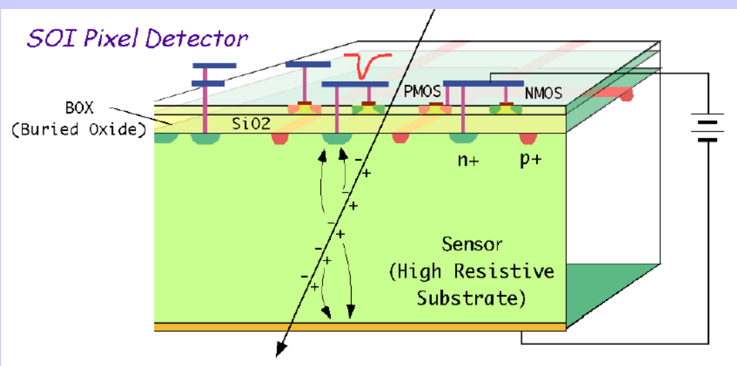


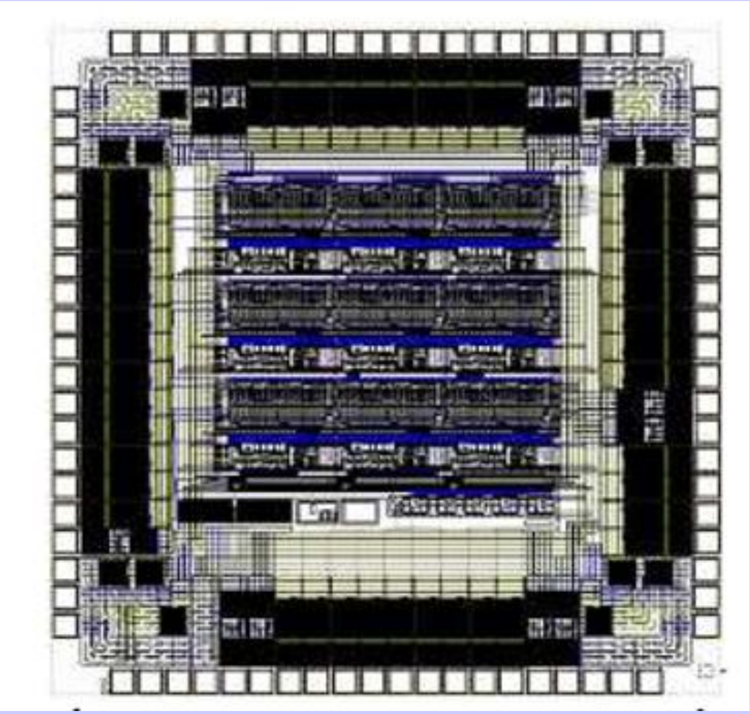



- Prototypes in 180-nm TSMC process
- Charge sensitive preamplifier
- Analog adder to provide fast feedback
- ADC : 10-bit SAR ADC
- Preparation for beam-test foreseen

# Pair Monitor readout (Tohuku Univ.)

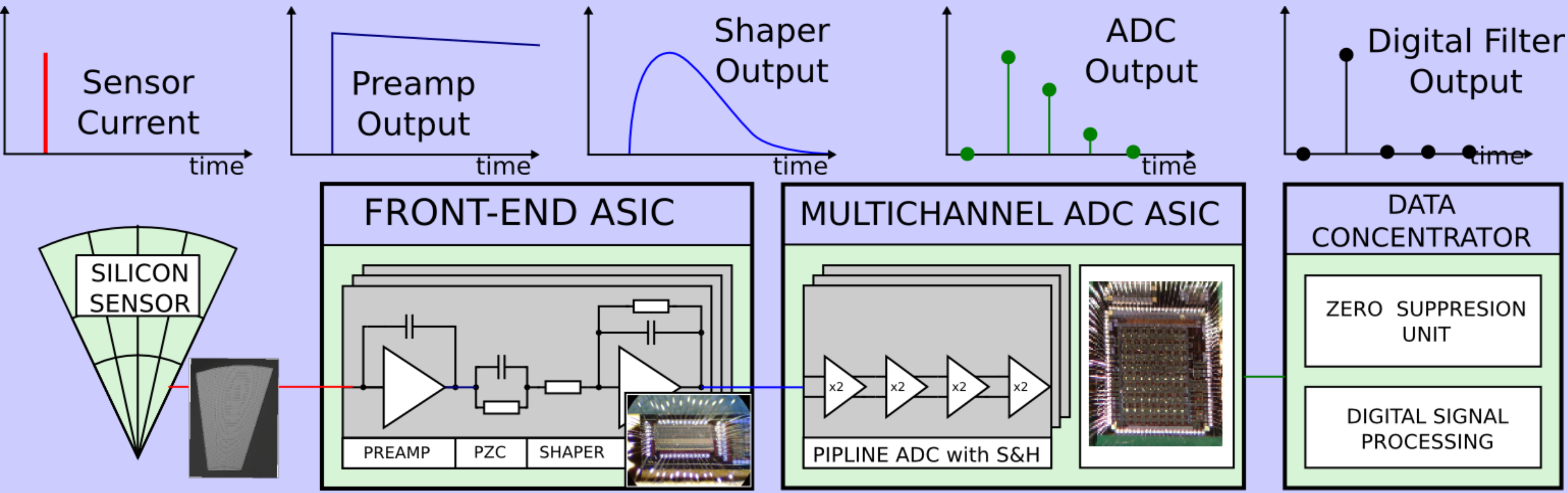
- Silicon On Insulator (SOI) technology – sensor and readout electronics are integrated in the SOI substrate. (monolithic)
- SOI 0.2 µm CMOS process, readout prototype successfully tested noise : 260 $e^-$ (+130 $e^-$/pF) expected signal : 20000 e



# ASICs

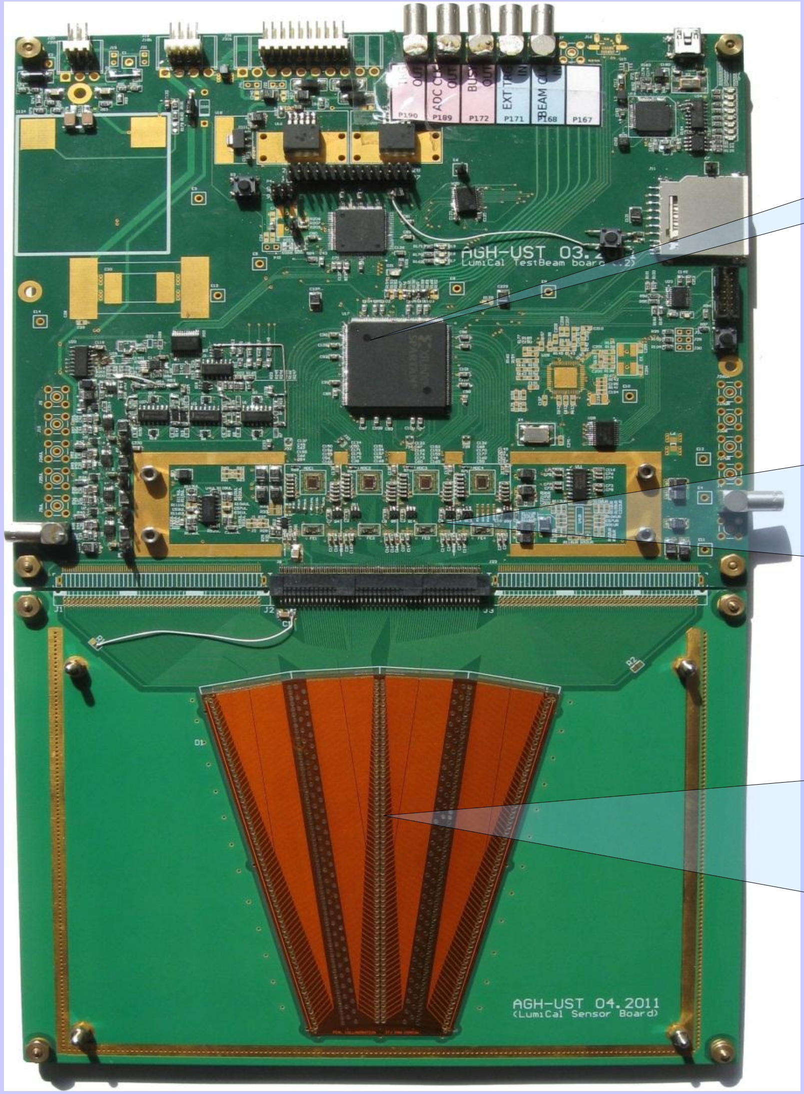
## AGH-UST 0.35 µm CMOS




8 channel Front-End ASIC
- Tpeak ≈ 60 ns
- $C_{det}$ up to 100pF
- switched gain: ~2fC <Qin<10 pC
- RC and FET feedback

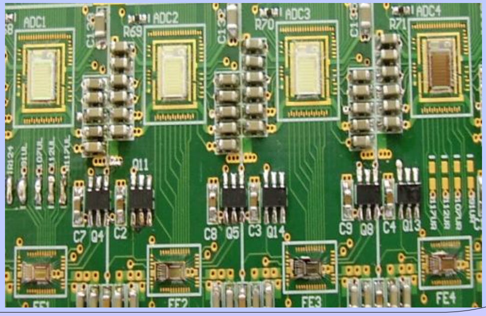
8 channel 10-bit ADC ASIC
- 1.5 bit pipeline architecture
- 25 Ms/s (9.7 ENOB)
- Power: ~1.2mW/chan/MHz
- Power pulsing embedded

# Module Design

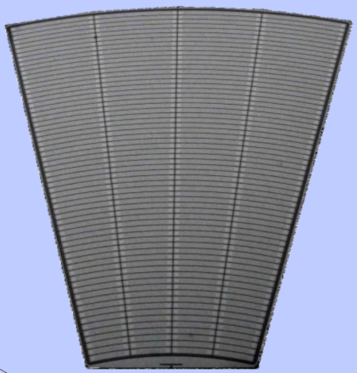


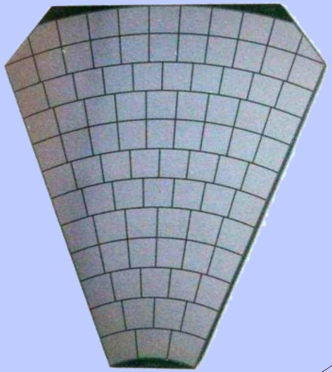

Data concentrator
Xilinx Spartan 3E

4 pairs of Front-end + ADC

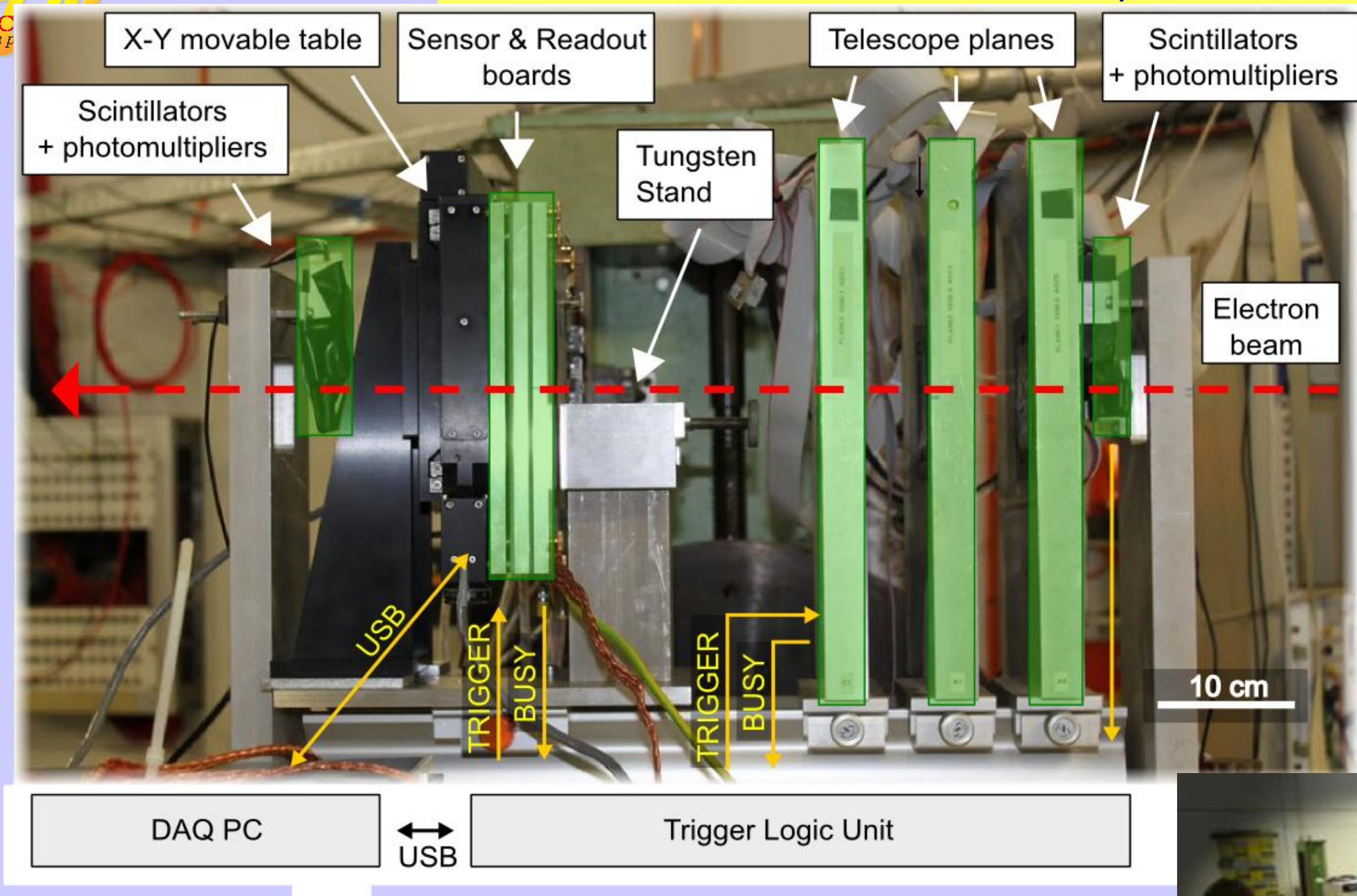


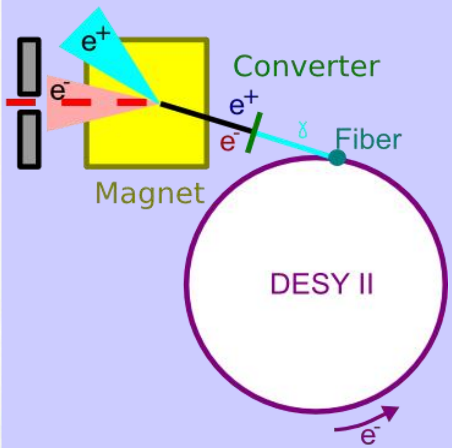
LumiCal / BeamCal sensors



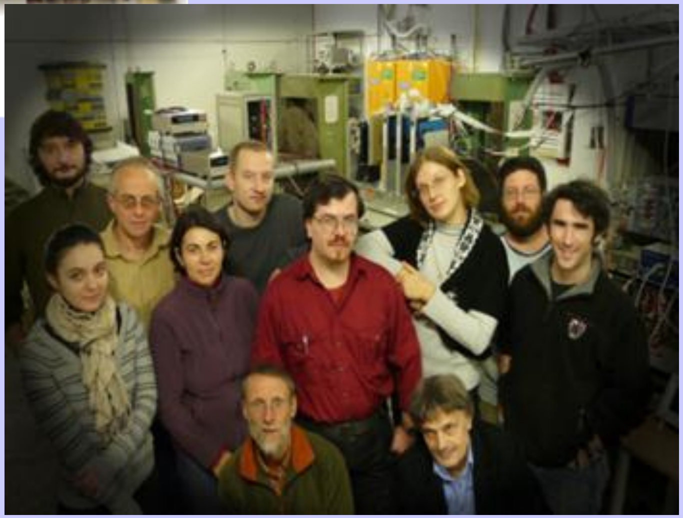


# Test-beam Setup




- $50 \times 10^6$ events recorded
- different areas of the sensor
- different FE settings
- data with FE and external ADC

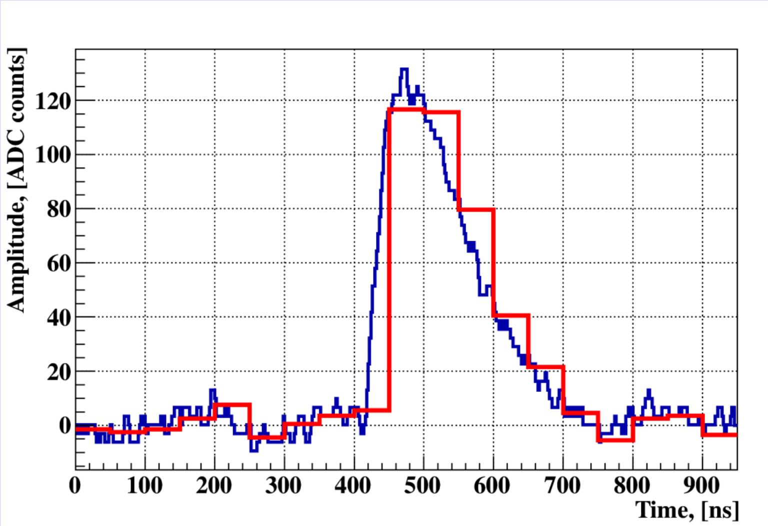


# Readout

**32 channels fully equipped**
**(Sensor + Lumical Front-end + LumiCal ADC)**

- 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
  - ADC sampling rate is up to 20 Ms/s (6.4 Gbps)

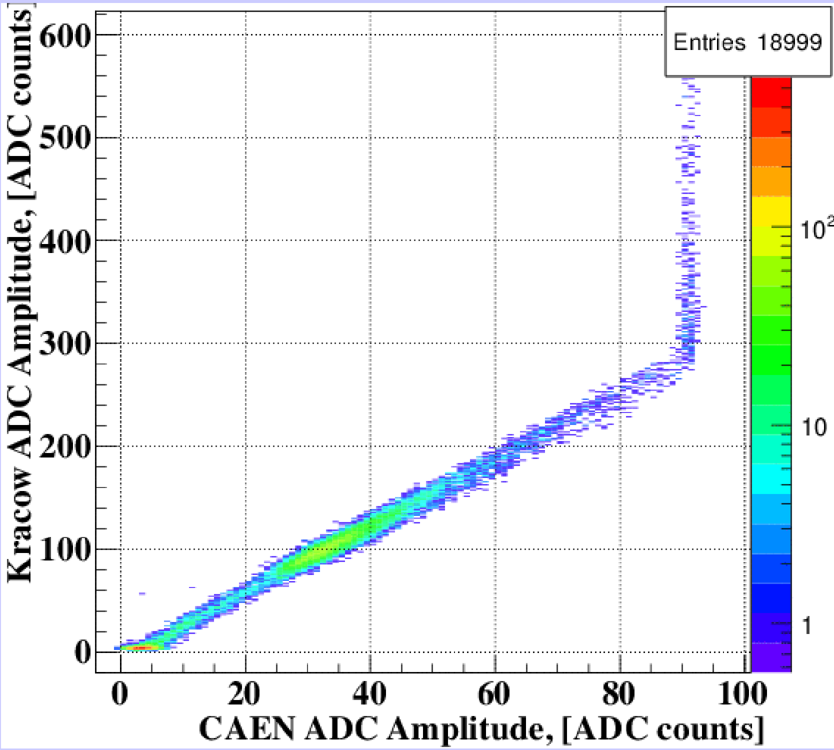
# Test-beam Results



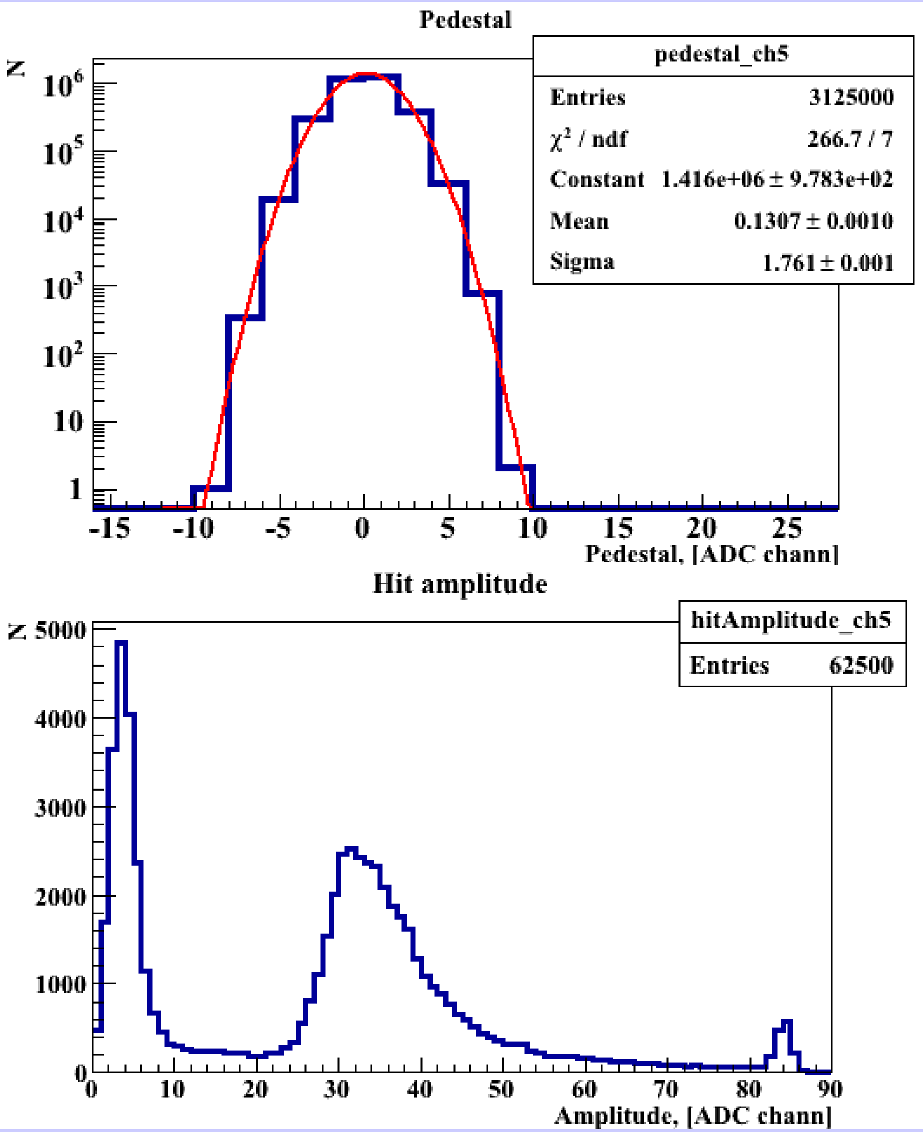

Example signal:

Signal digitized with ADC ASIC (red) and external ADC (blue )

Comparison of the amplitude measured with the ADC ASIC and a CAEN 500 Ms/s flash ADC

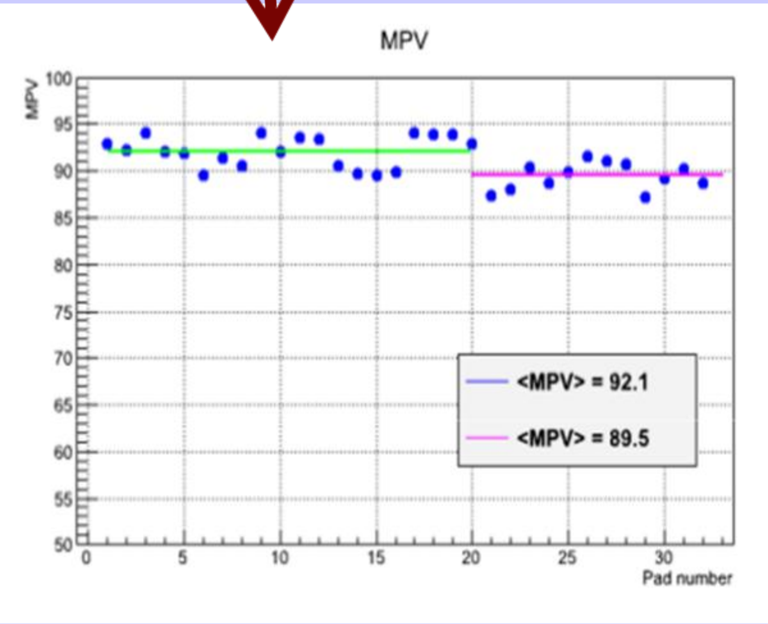


# Test-beam Results

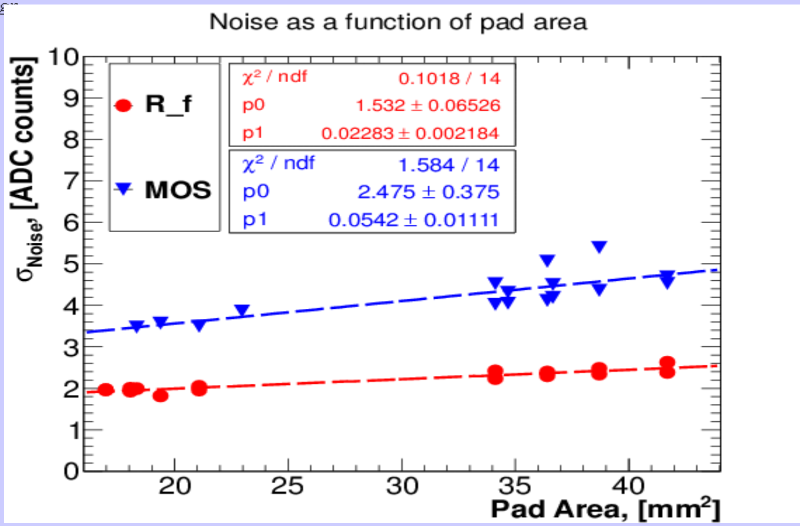



S/N ~ 22 (RC feedback & FET feedback)

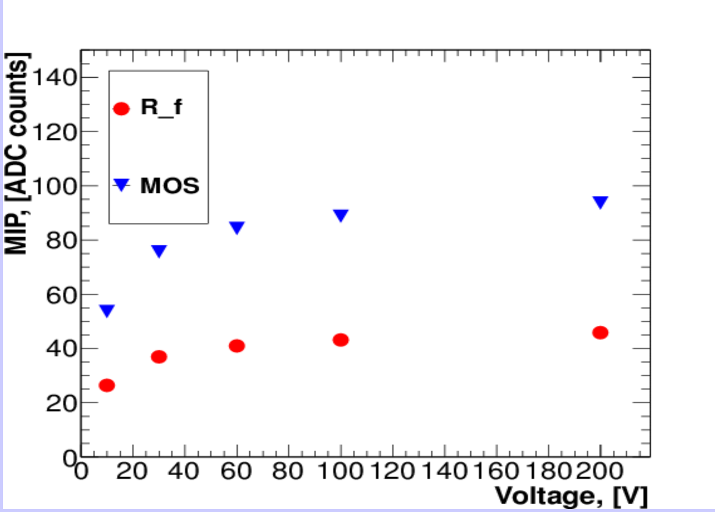
Gain vs. channel



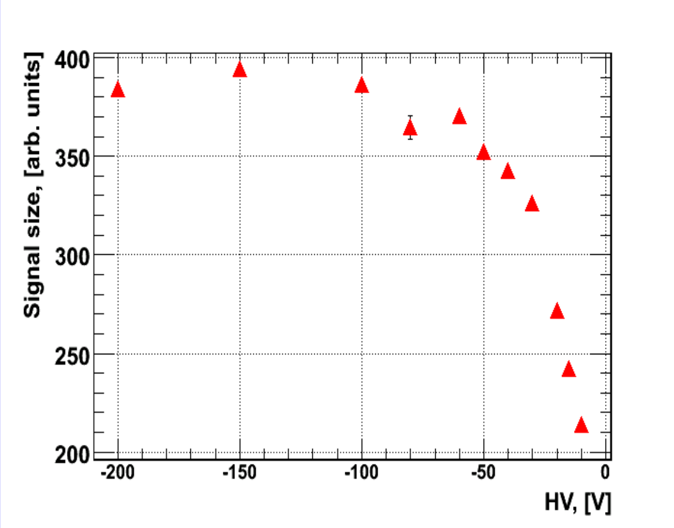
# More Results




$\sigma_{PED}$ as a function of the pad area

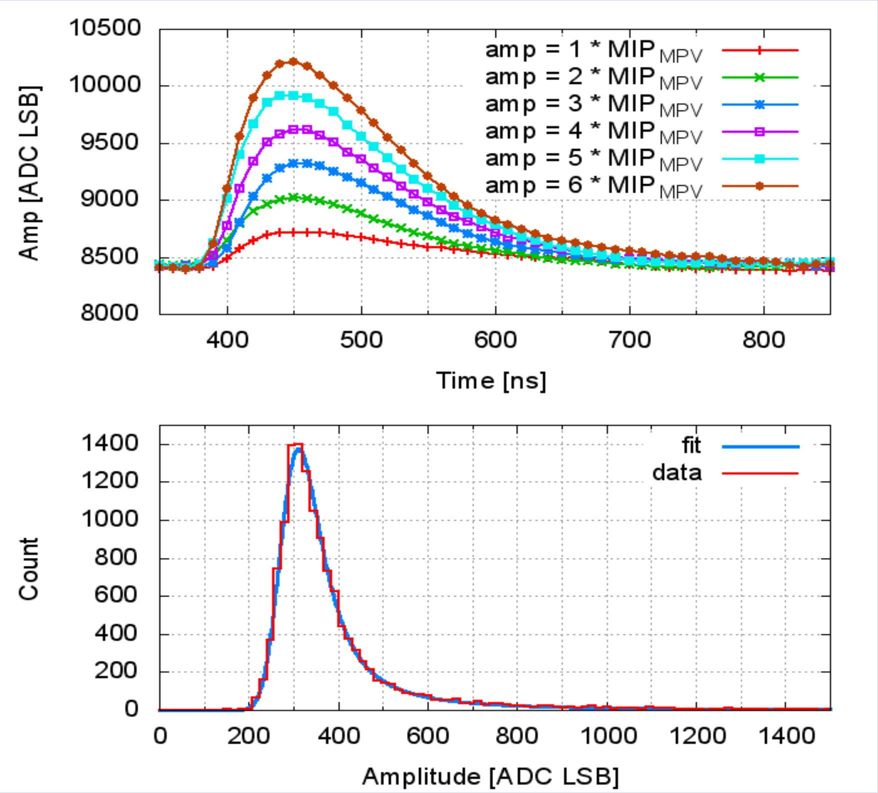



Signal as a function of the voltage, test beam ( GaAs)

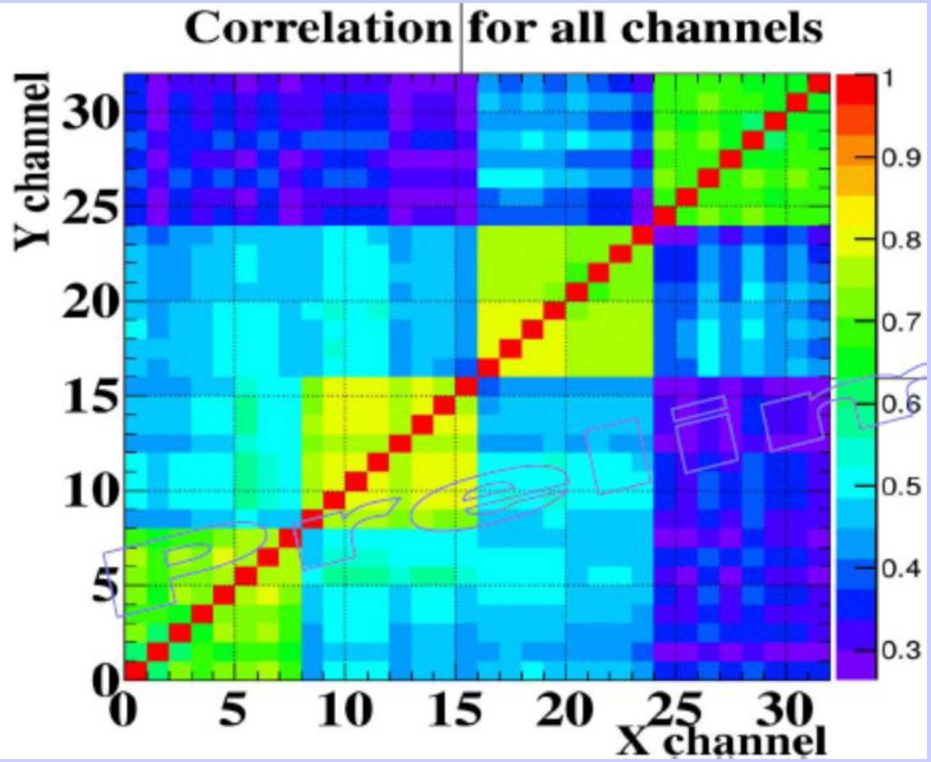



Signal as a function of the voltage, lab measurement

# More Results



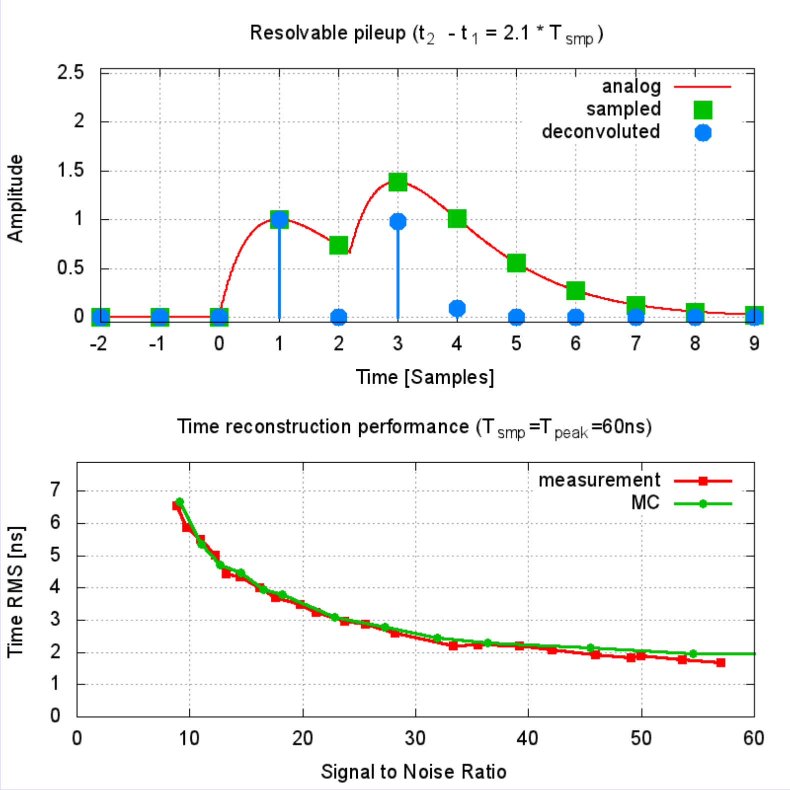

Multiparticle crossing

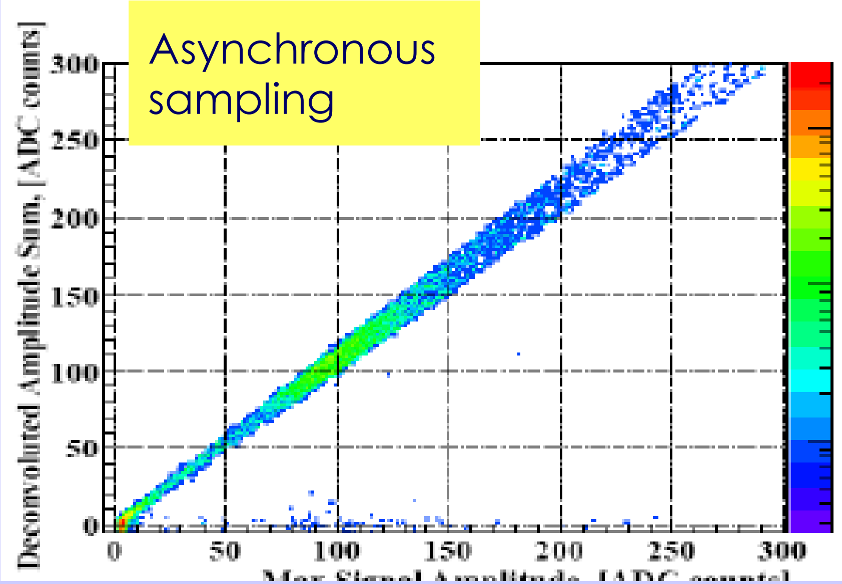


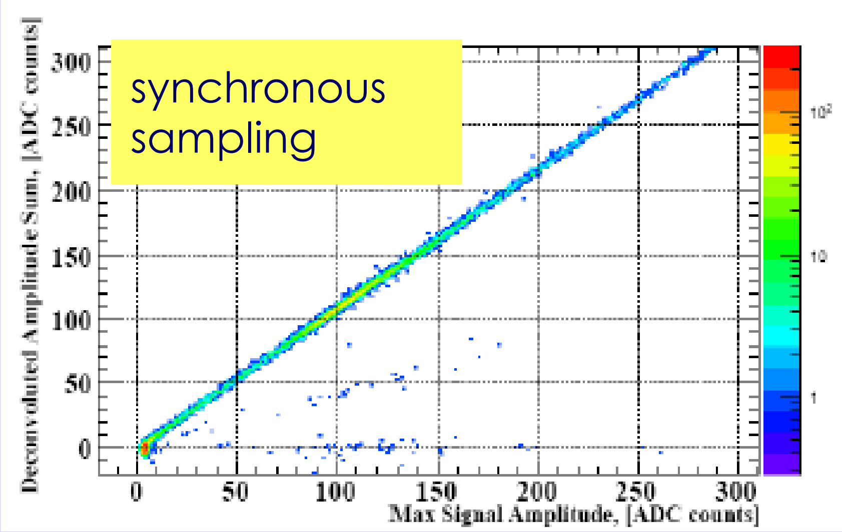

Common mode noise

# Application of signal de-convolution

- Reduction of a long CR-RC pulse to 1 or 2 non-zero samples
- Pile-up resolving

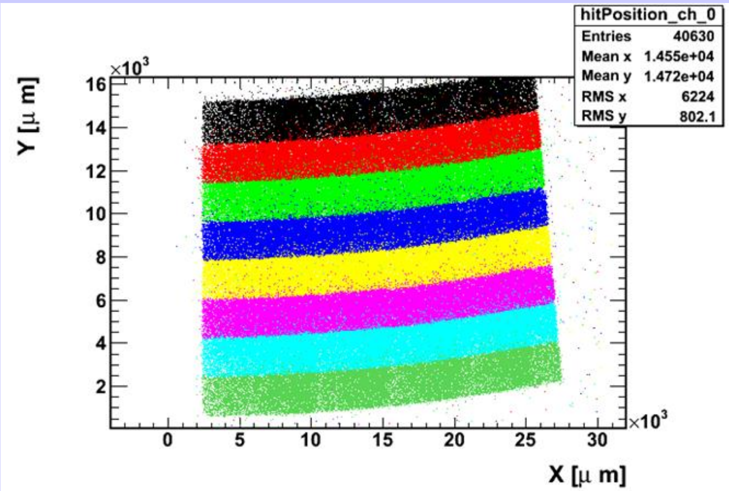


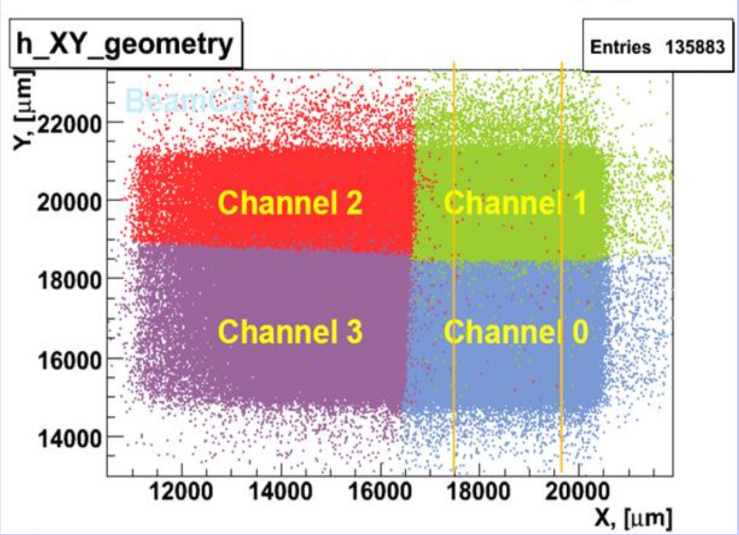



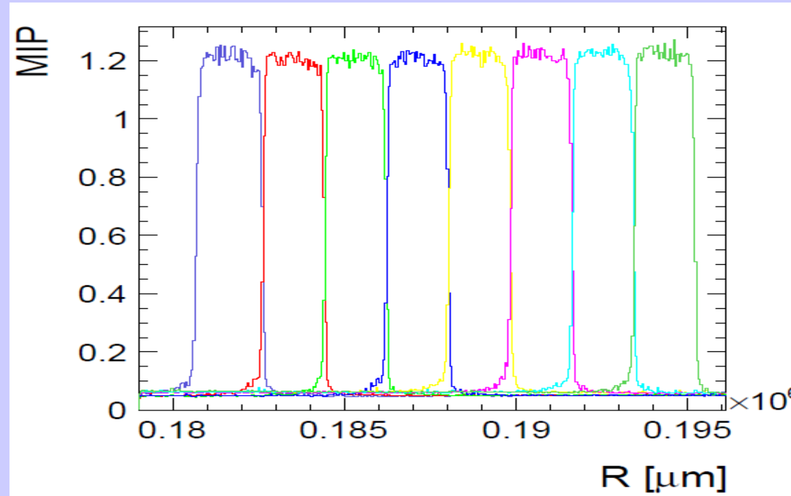
# More Results

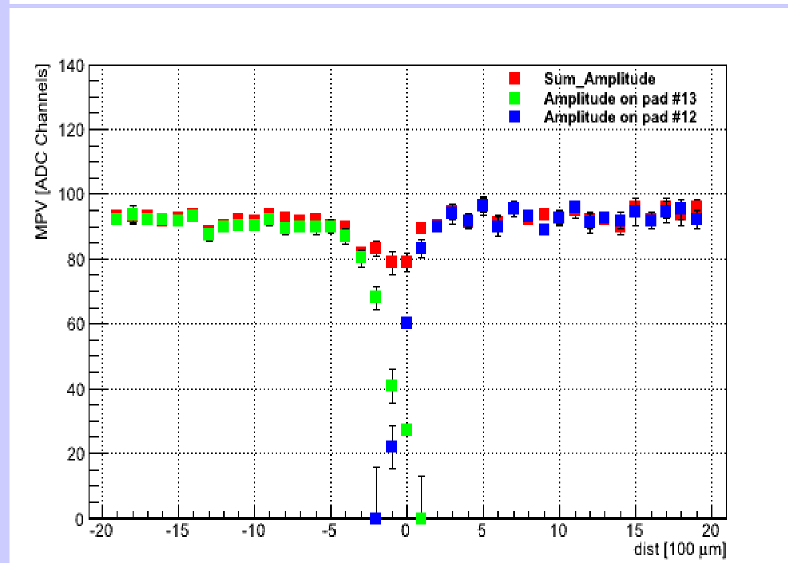
## Track reconstruction using the telescope



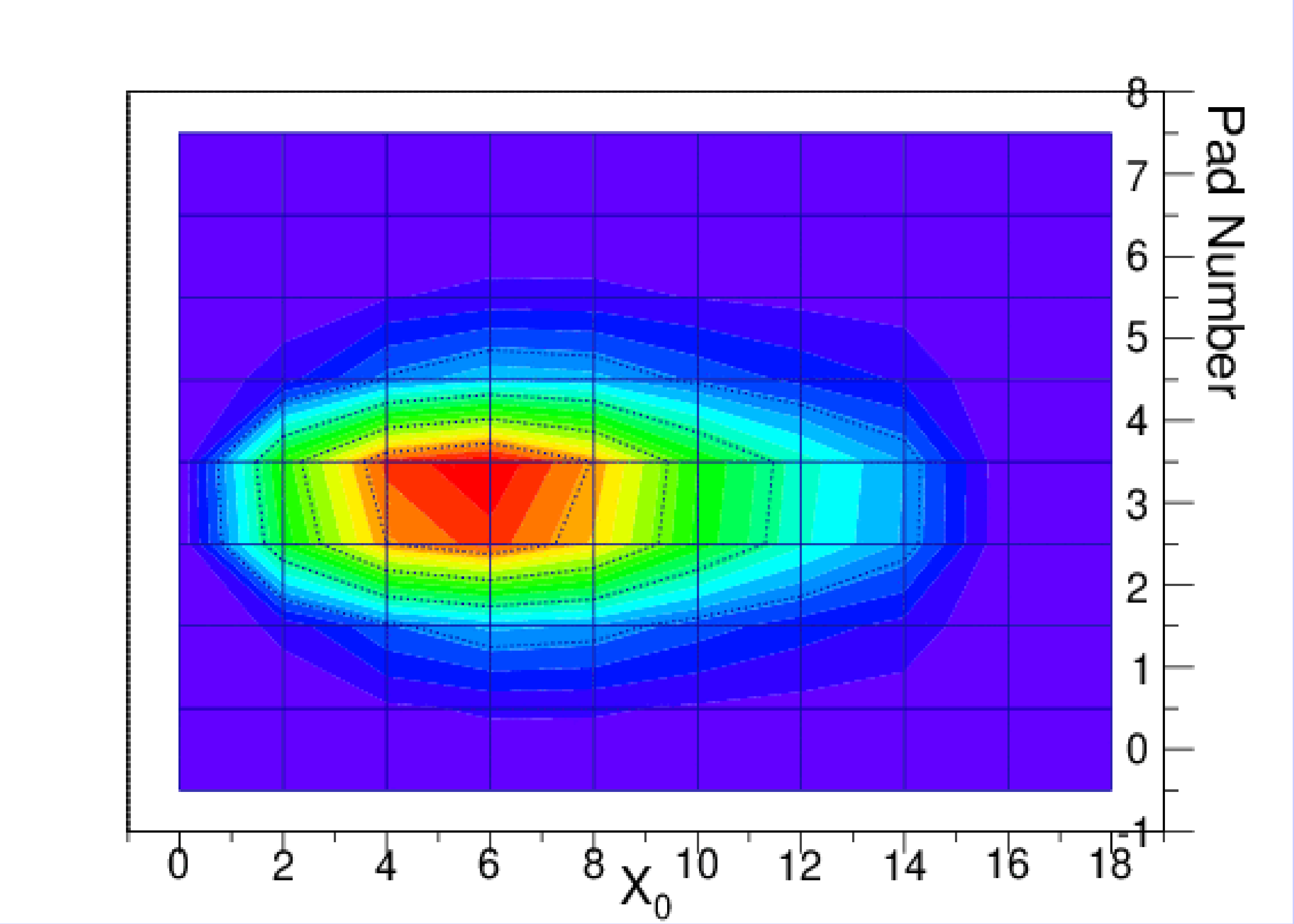




## Signal amplitude on neighbour and between pads

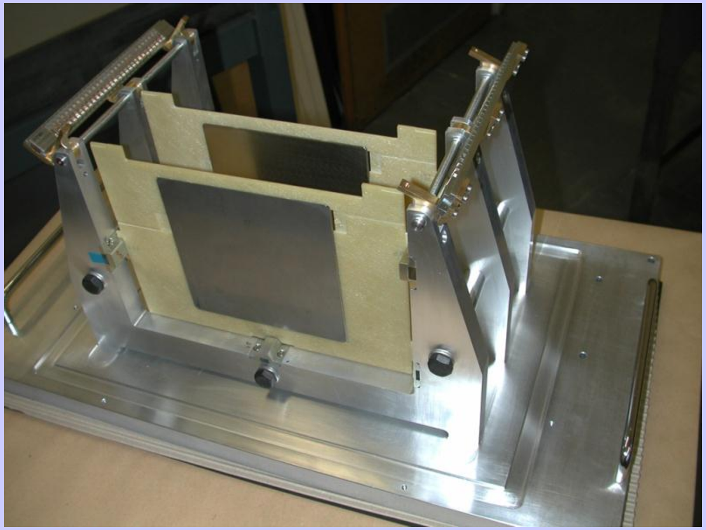


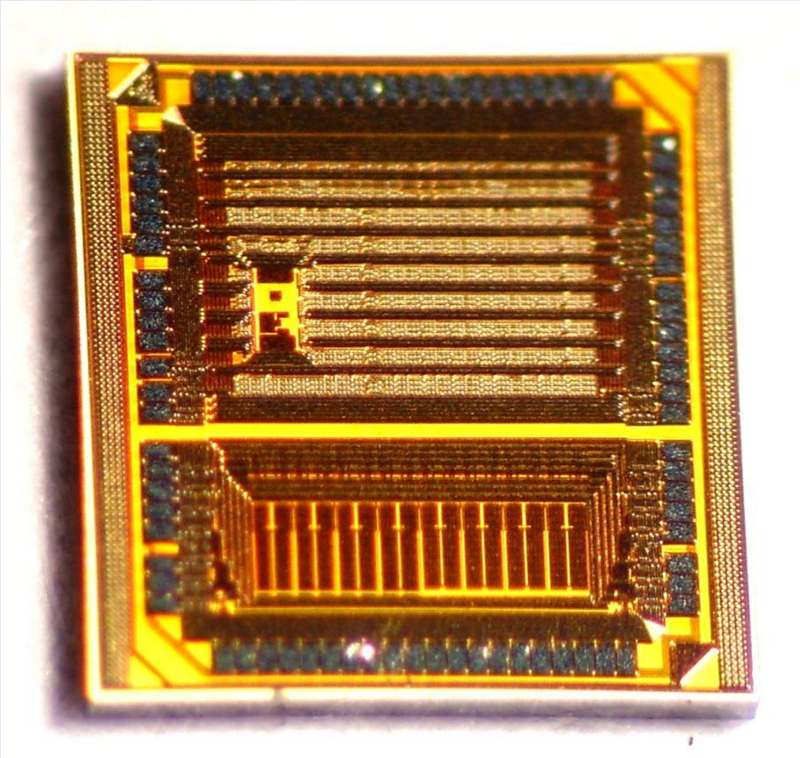
Reconstruction of the 2 D shower shape



# Under development – calorimeter prototype



- 30 sensor layers and tungsten planes
- Precise positioning (50 μm)of sensor and absorber planes, very small clearance (compact calorimeter)



ADC ASIC prototype (130 nm IBM)

- 8 channels 10 bit SAR ADC
- Fully differential
- Sampling frequency 40 MHz

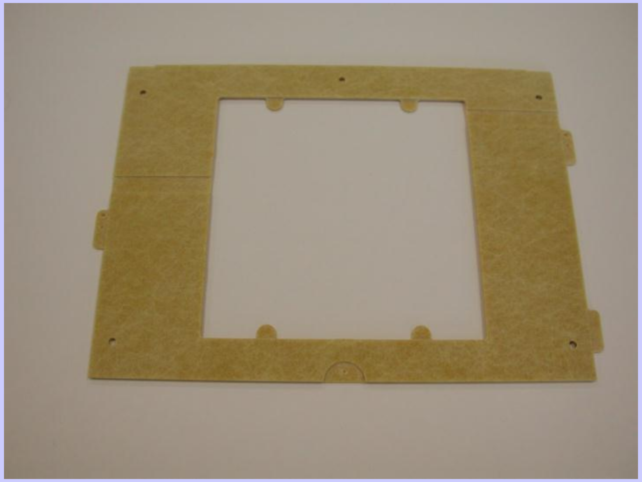
& DAQ matching AIDA standard

# Summary

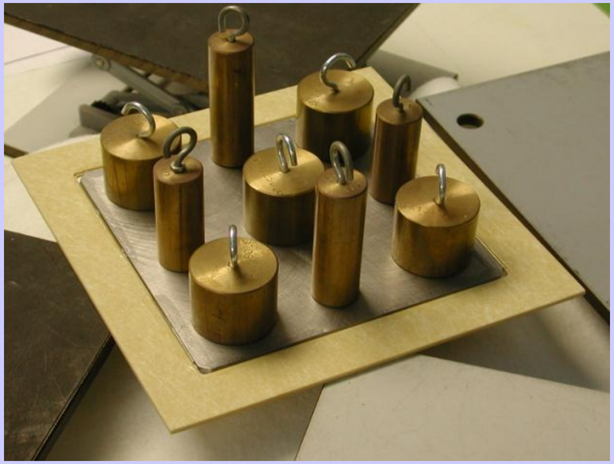
- After detailed design studies, sensors, FE and ADC ASICs are designed, tested and produced
- FE and ADC ASICs are attached to sensor prototypes (both BeamCal and LumiCal sensors) to form a fully operational sensor plane (32 channels connected)
- Performance studies are done in a test-beam
  - Stable operation with S/N ~ 20 (MIPs)
  - Small (~10%) loss of signal in the gaps
  - First estimate of a shower profile
- Ongoing work towards a prototype calorimeter with improved FE and ADC ASICs

# Backup

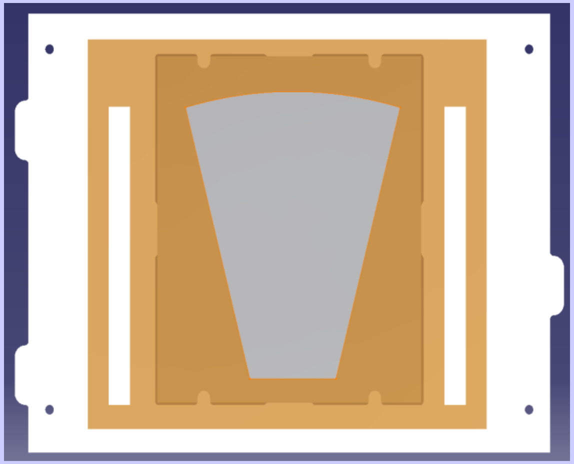
# Mechanical Frame



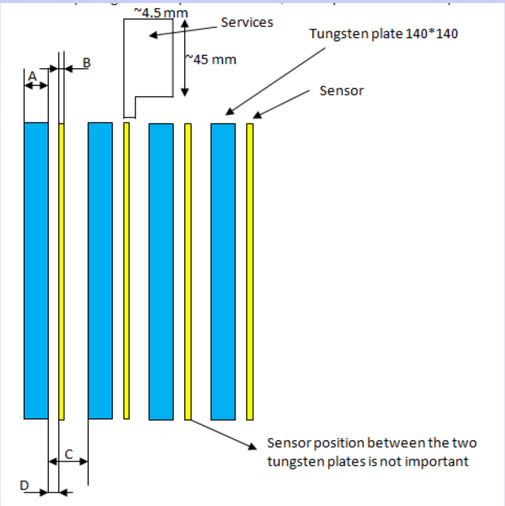
First machined permaglass frame

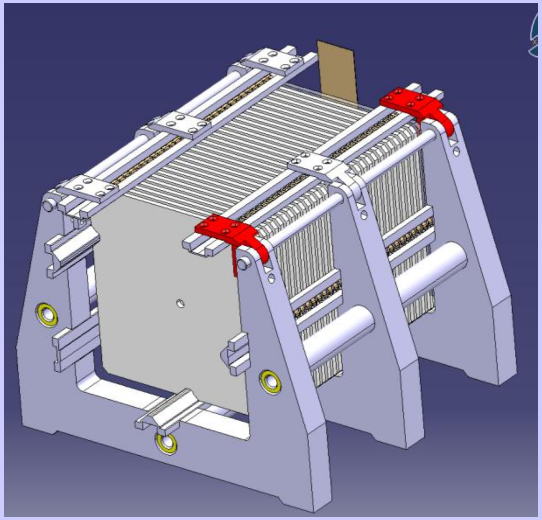


tungsten absorber plate inserted



Sensor plane

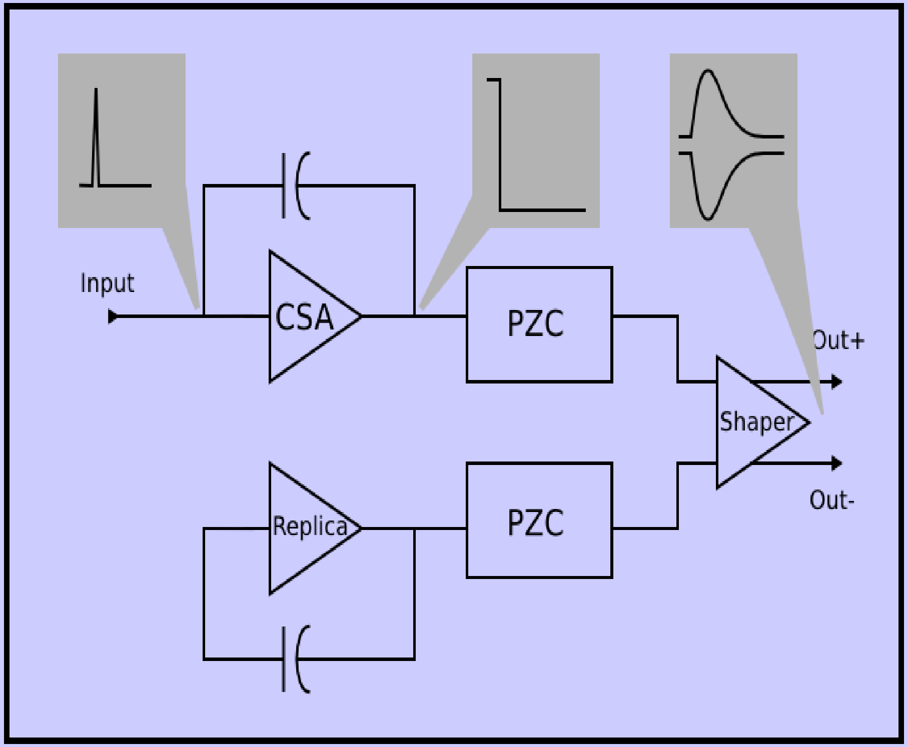


# New ASIC prototypes

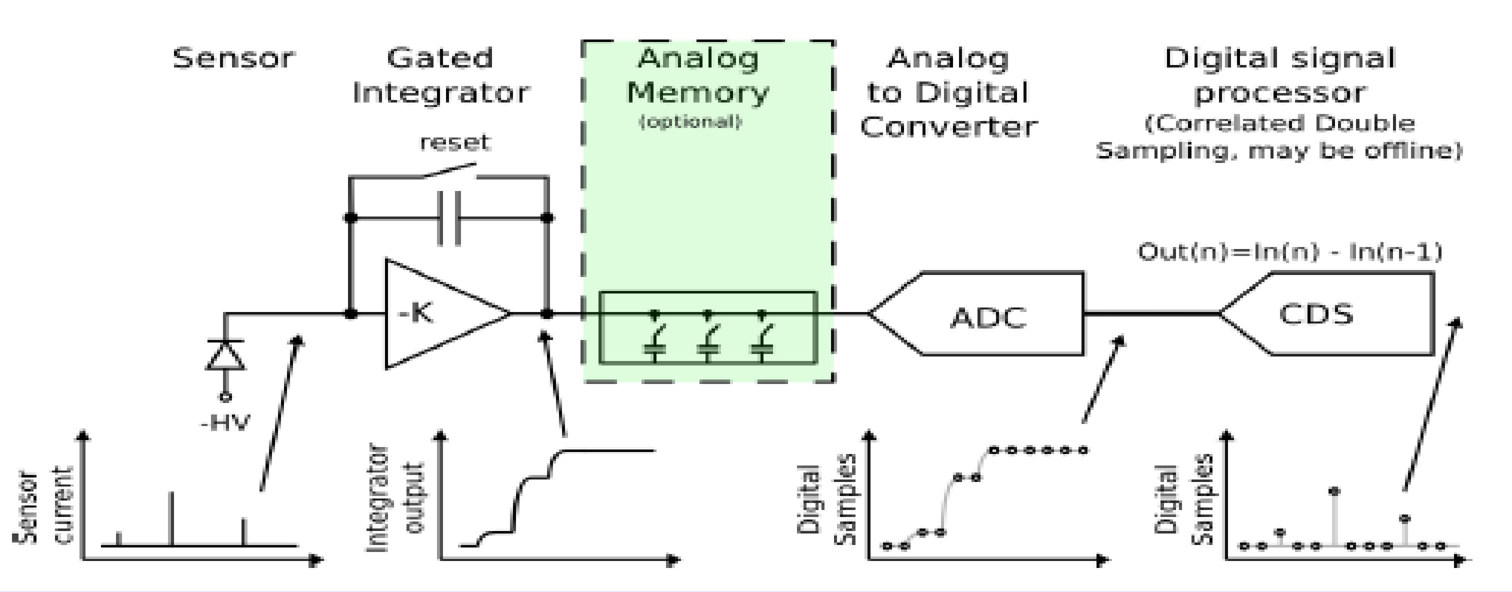
Future ASICs will be designed and produced in 130 nm IBM technology (AGH-UST Cracow)
faster, lower power consumption, radiation hard

- 10 bit SAR ADC (submitted
- in February 2012)
  - 1-2 mW at 40 Ms/s
  - 150 μm pitch
- new FE ASIC, improved ADC (submission 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



# CLIC Electronics (proposal)

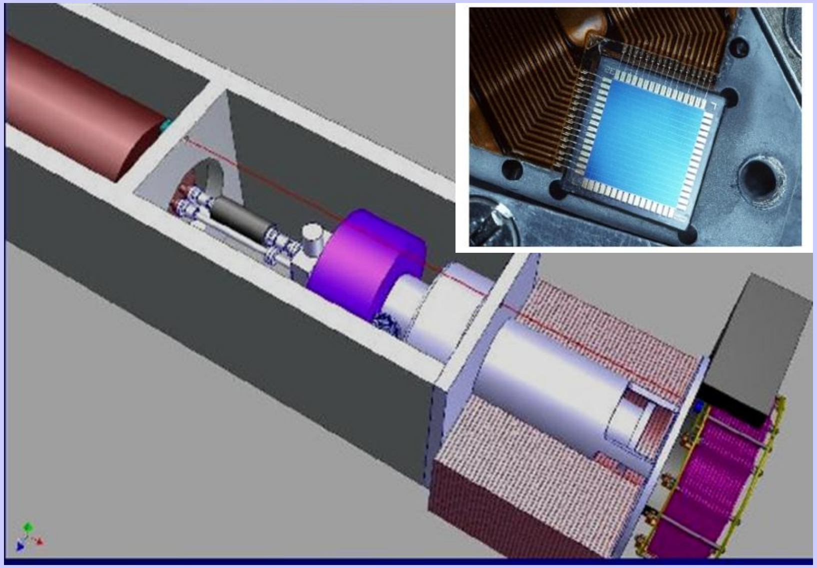
Triggerless time and amplitude reconstruction using asynchronous deconvolution or a gated integrator




With a peaking time of 60 ns and S/N = 20 a time resolution Of < 2ns was obtained (simulation and test with dedicated hardware.

More detailed physics background simulations needed!

# 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

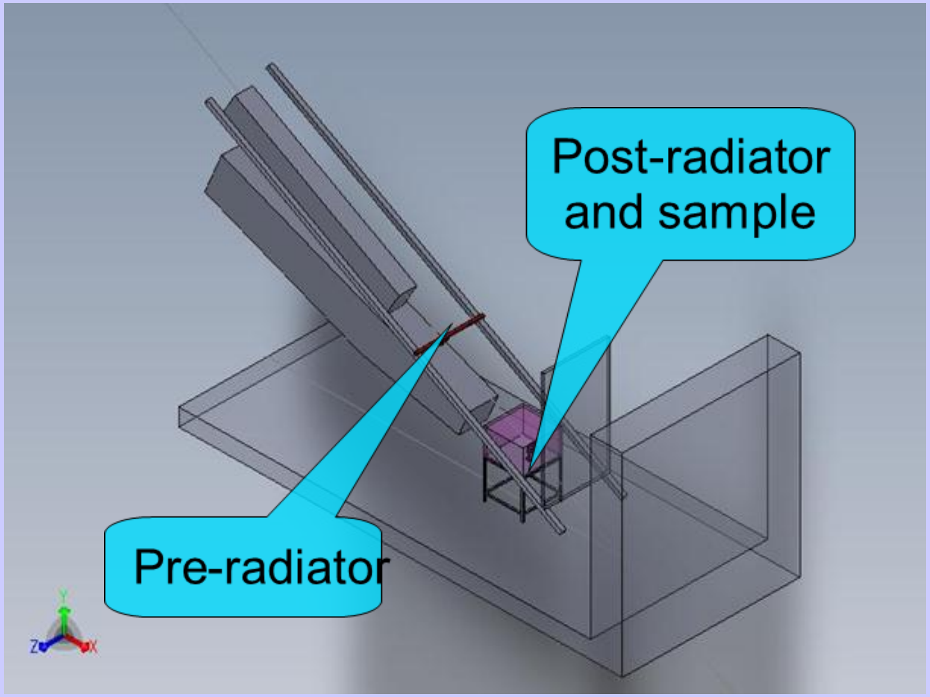
## DAQ (INP and TAU)

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

# Irradiation Studies (Plan)

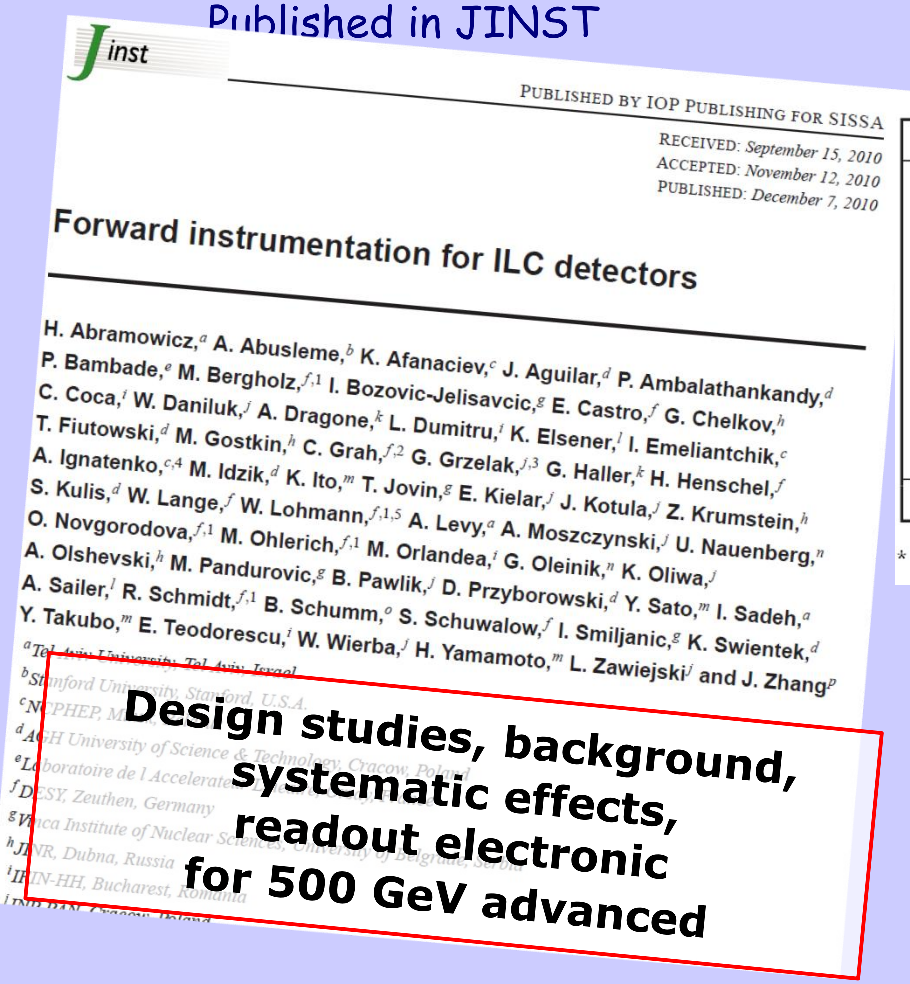
## Radiation Damage Study Facility (Santa Cruz)

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



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

Published in JINST



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## Forward instrumentation for ILC detectors

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[f] DESY, Zeuthen, Germany
[g] Vinca Institute of Nuclear Sciences, University of Belgrade, Serbia
[h] JINR, Dubna, Russia
[i] IFIN-HH, Bucharest, Romania
[j] INP PAN, Cracow, Poland

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

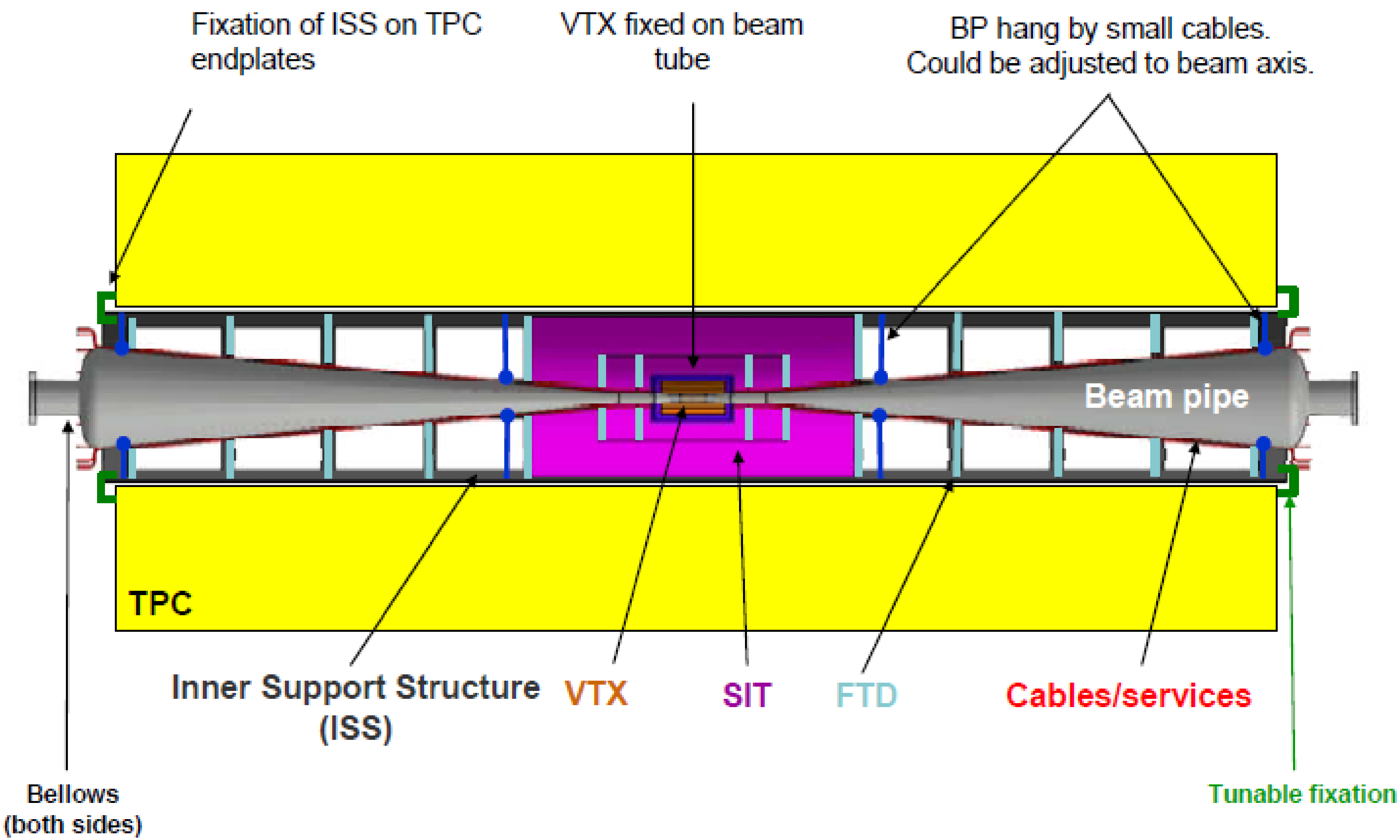
## Systematics of luminosity measurement at 500GeV

| 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 | | | $2.3\times10^{-3}$ |

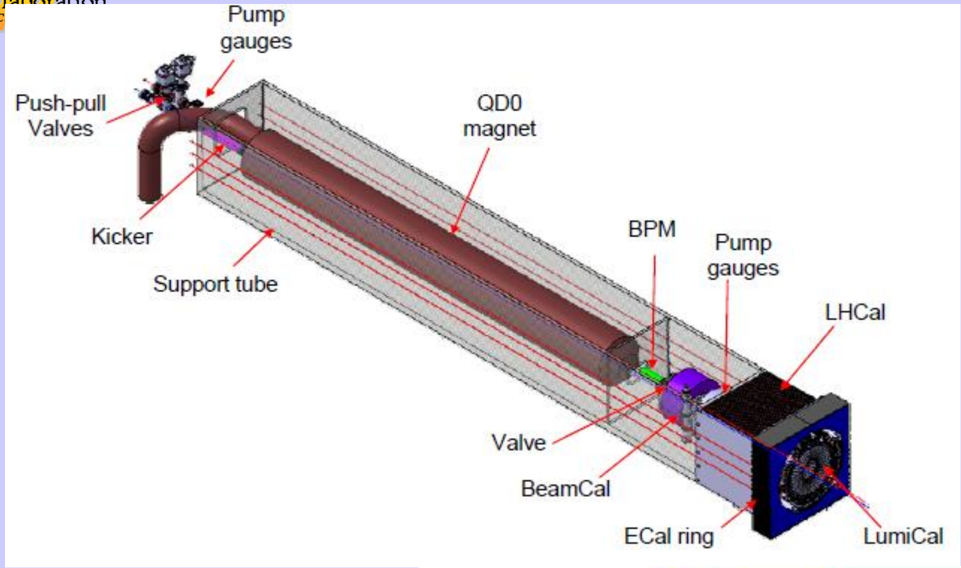
* 100%= Upper limit – the size of effect is taken as uncertainty

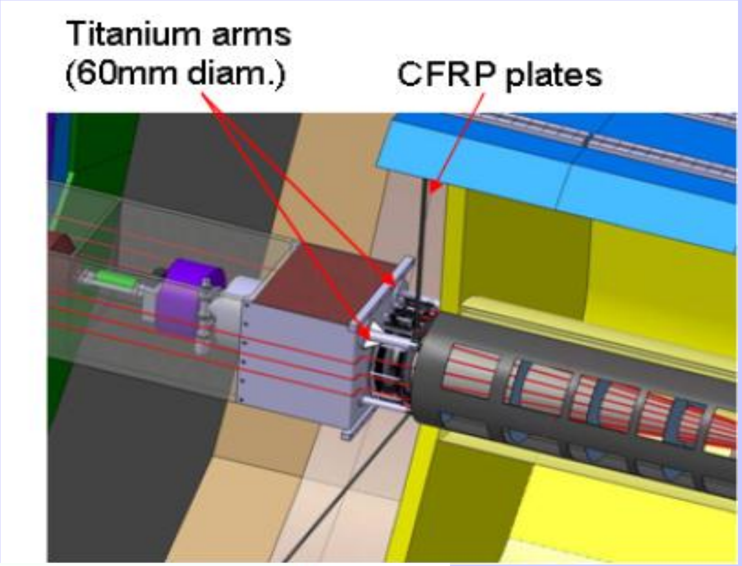
- Cylindrical sensor-tungsten sandwich calorimeter
- Small Moliere radius
- Finely segments
- FE ASICs positioned at the outer radius

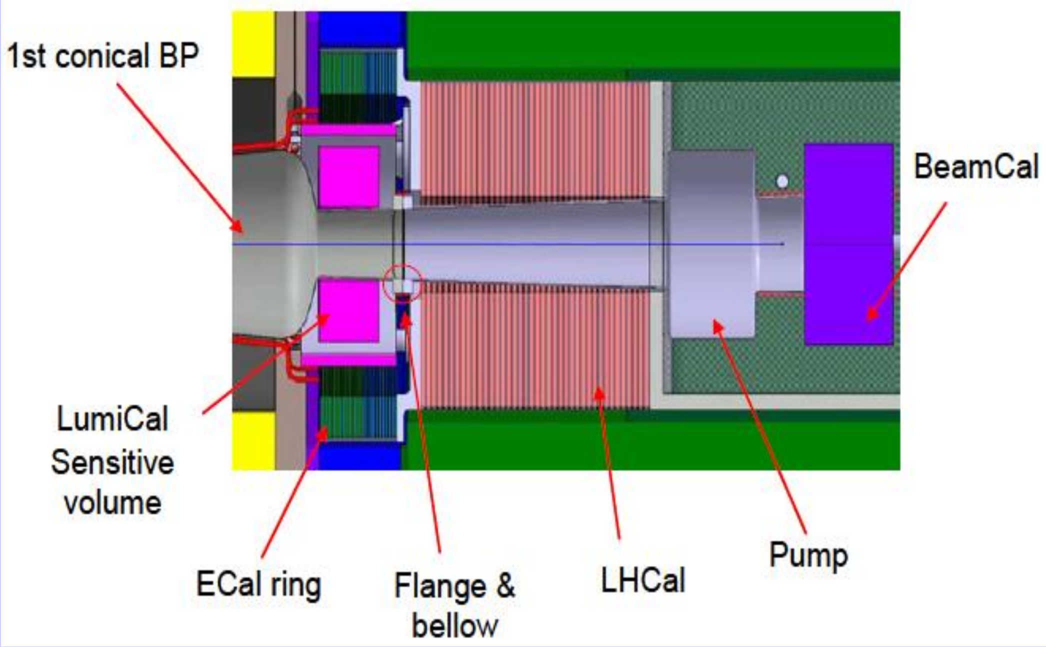
# Forward Region Design, ILD



# Forward Region Design, ILD



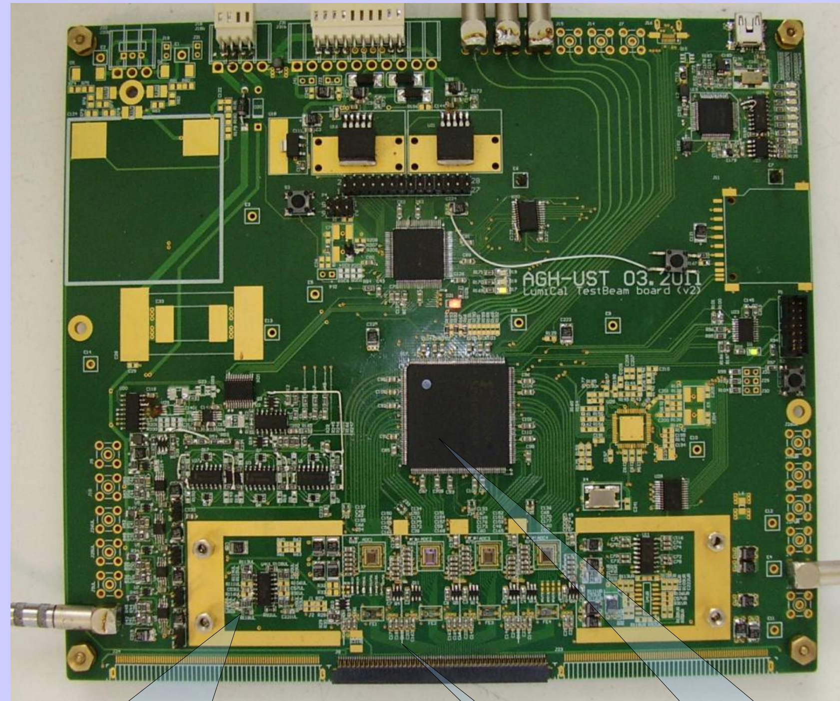



# ASICs

## 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