Forward Calorimeters for ILC and CLIC detectors

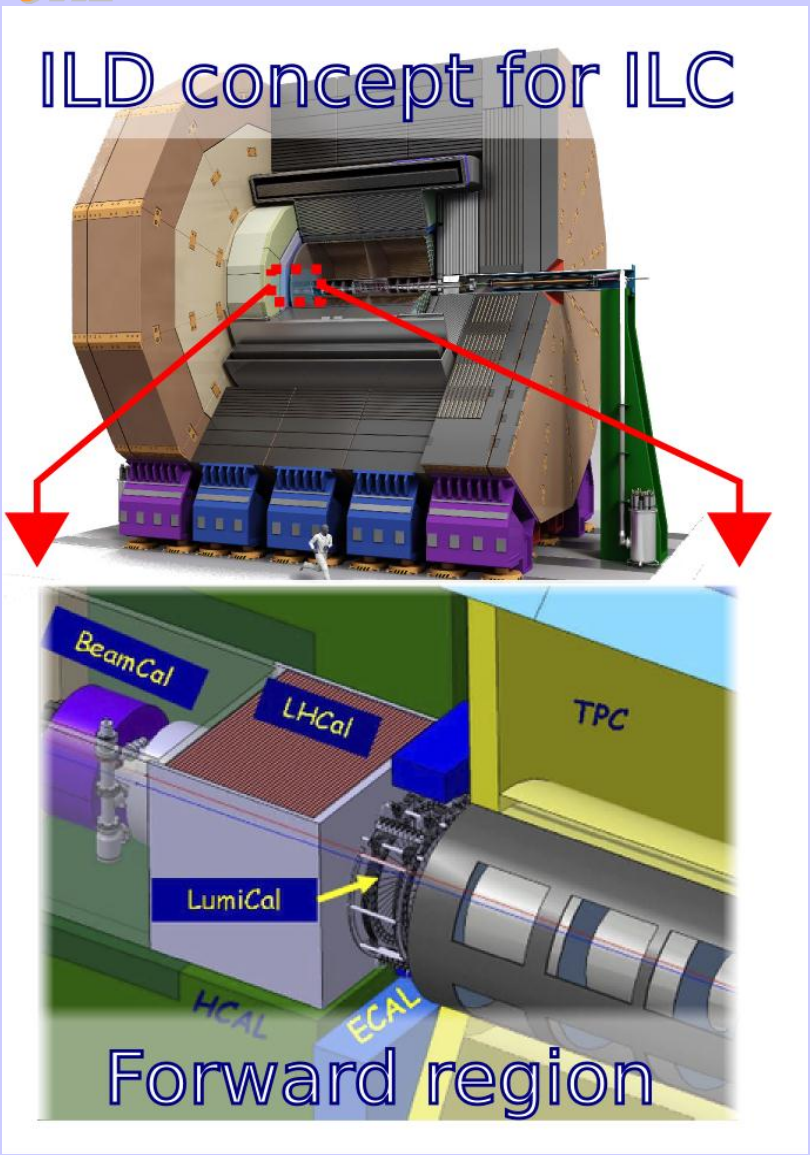
Wolfgang Lohmann,

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

Very Forward Instrumentation- Example ILD



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)

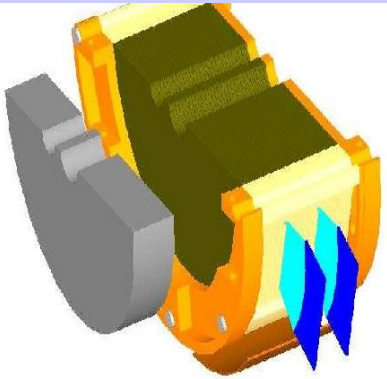
Challenges:

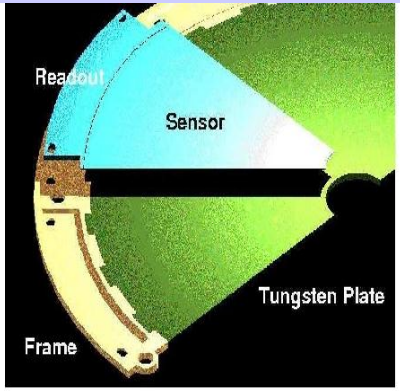
- radiation hardness (BeamCal),
- high precision (LumiCal) and
- fast readout (both)

Calorimeter, general structure

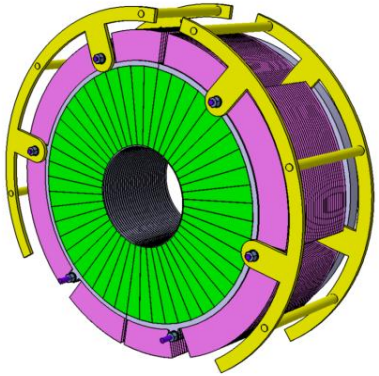
Technology choice: Finely segmented compact calorimeters

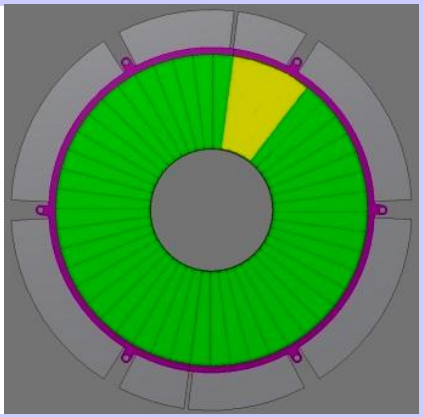
BeamCal





LumiCal





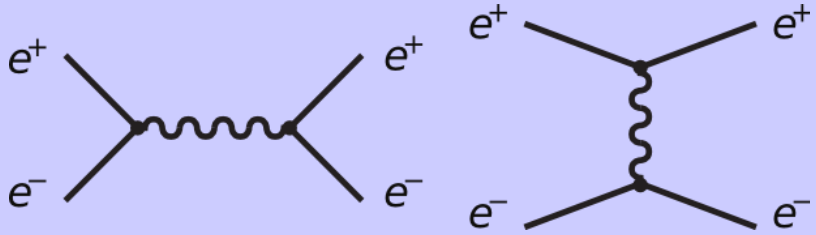
- Tungsten thickness 1 X_0, 30 layers
- BeamCal sensors GaAs, 500 μm thick
- LumiCal sensors silicon, 320 μm thick
- FE ASICs positioned at the outer radius
- BeamCal angular coverage 5.8 – 43.5 mrad
- LumiCal coverage 31 – 78 mrad

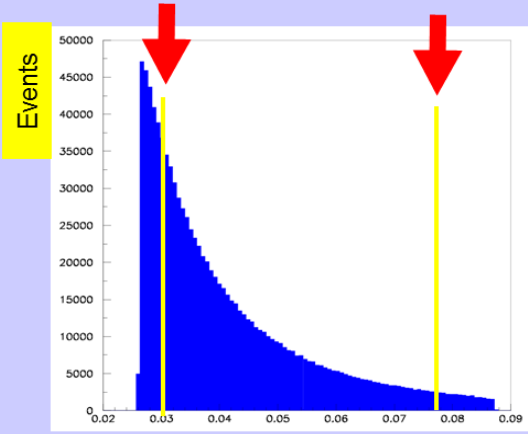
Detector Design Studies, 500 GeV

Luminosity:

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

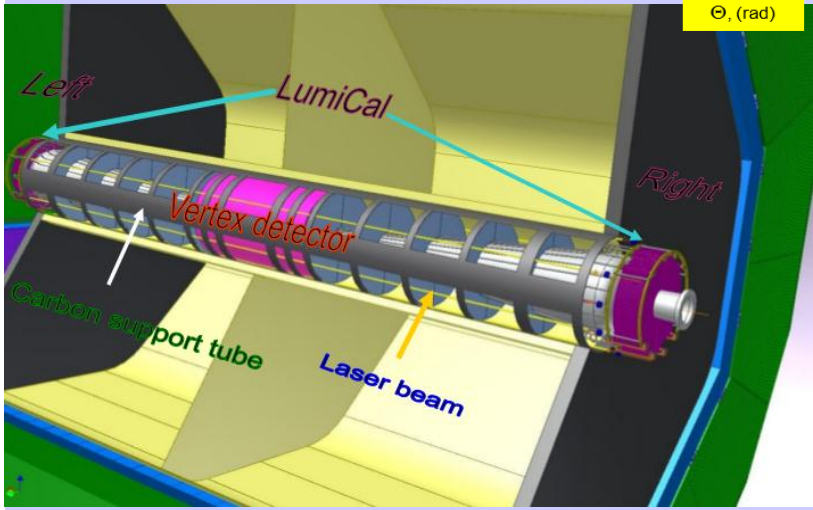
Bhabha scattering:





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}

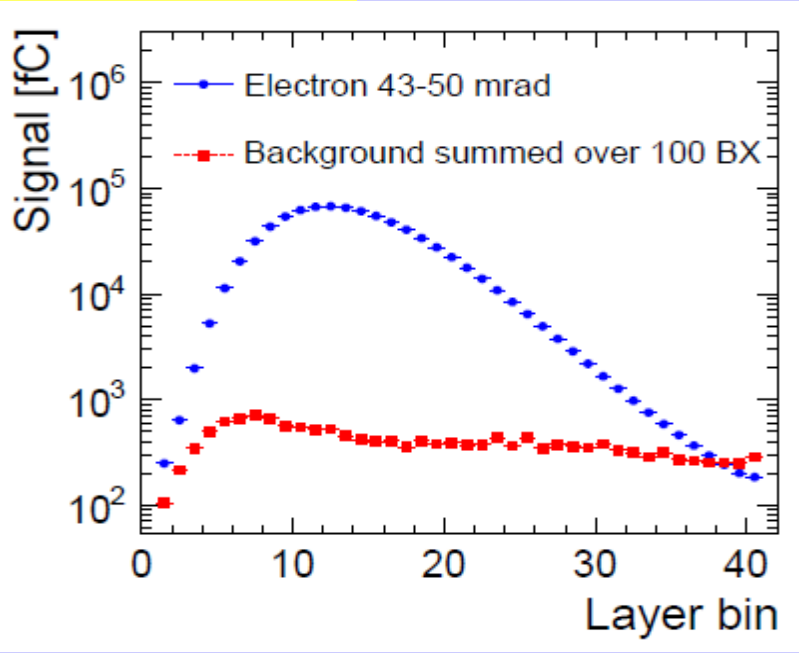
* 100%= Upper limit – the size of effect is taken as uncertainty

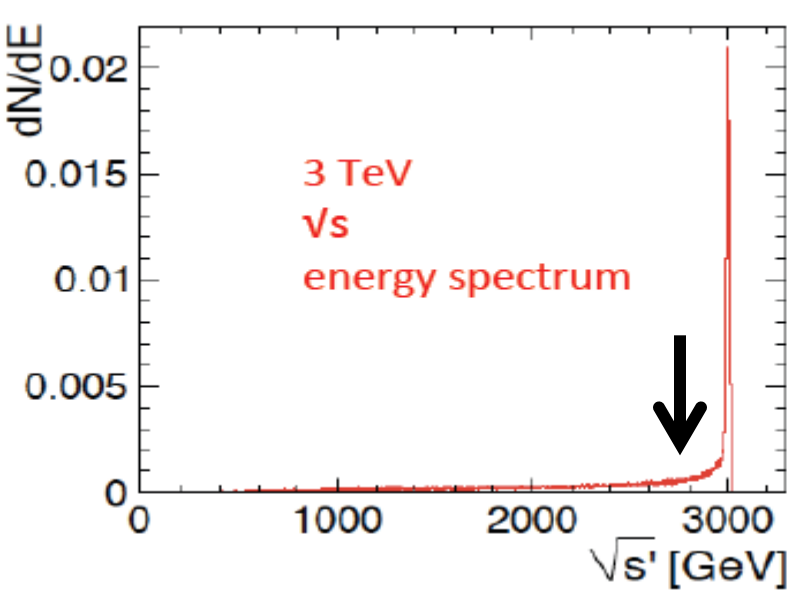


Laser alignment system (LAS) integrated in the QD0 alignment

CLIC challenges:

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

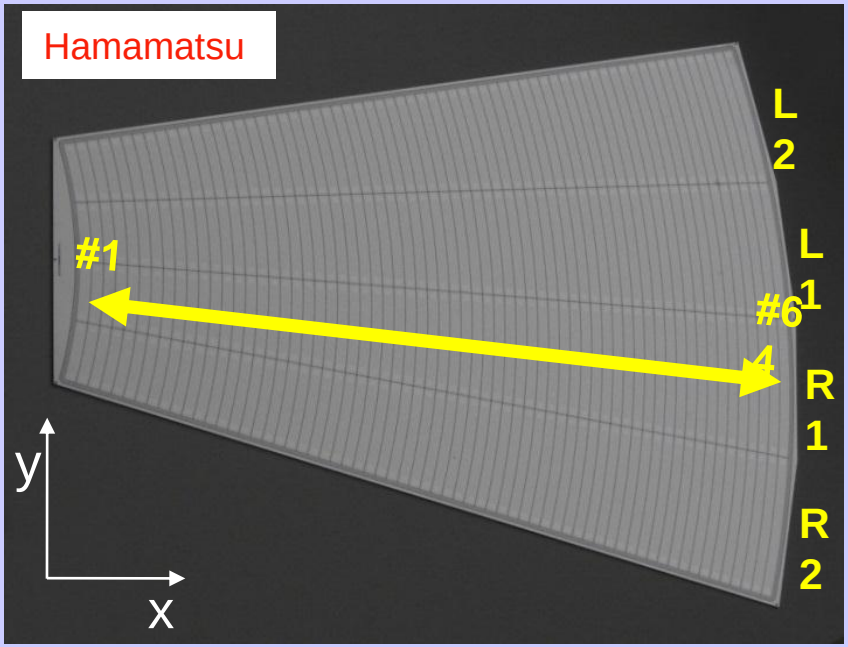




The precise knowledge of the spectrum shape is essential for the precision of the luminosity measurement !!
(how to determine -see talk by Andre Sailer)

Sensor prototypes

LumiCal

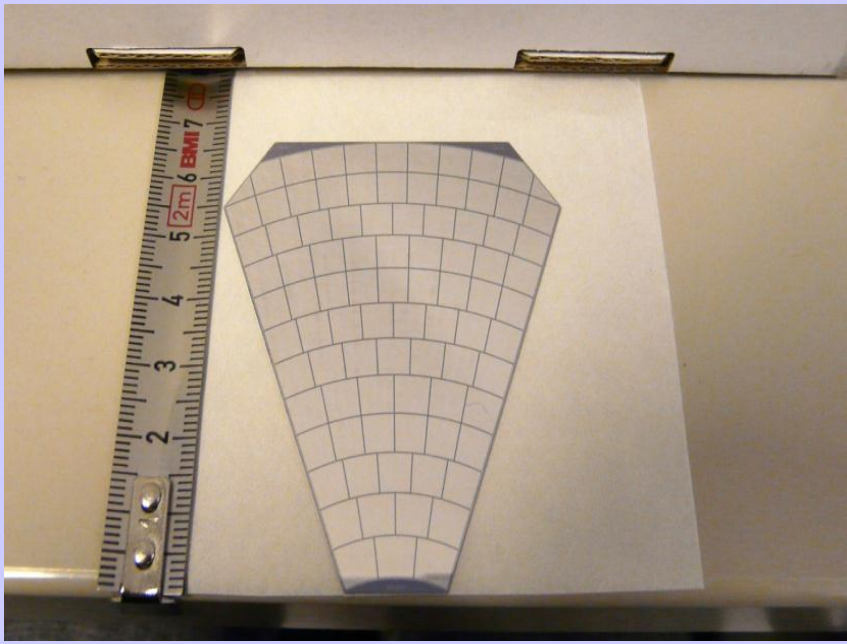


p in n, strip pitch 2.2 mm

40 pieces, joint effort

IFJ PAN Cracow, DESY, TAU

BeamCal

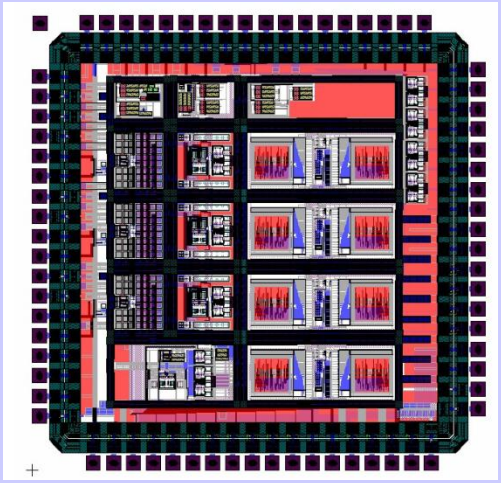


Compensated GaAs

~ 10 pieces,

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

ASICs

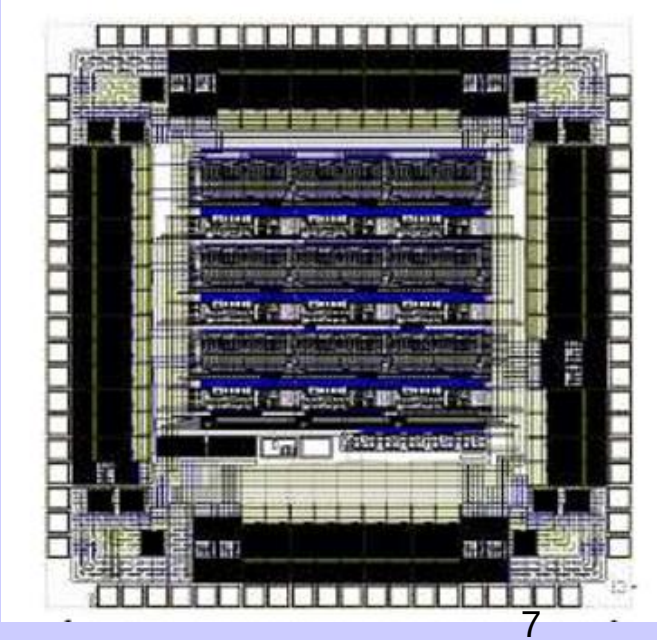


SLAC/ Universidad Católica, Chile (BeamCal)

- 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

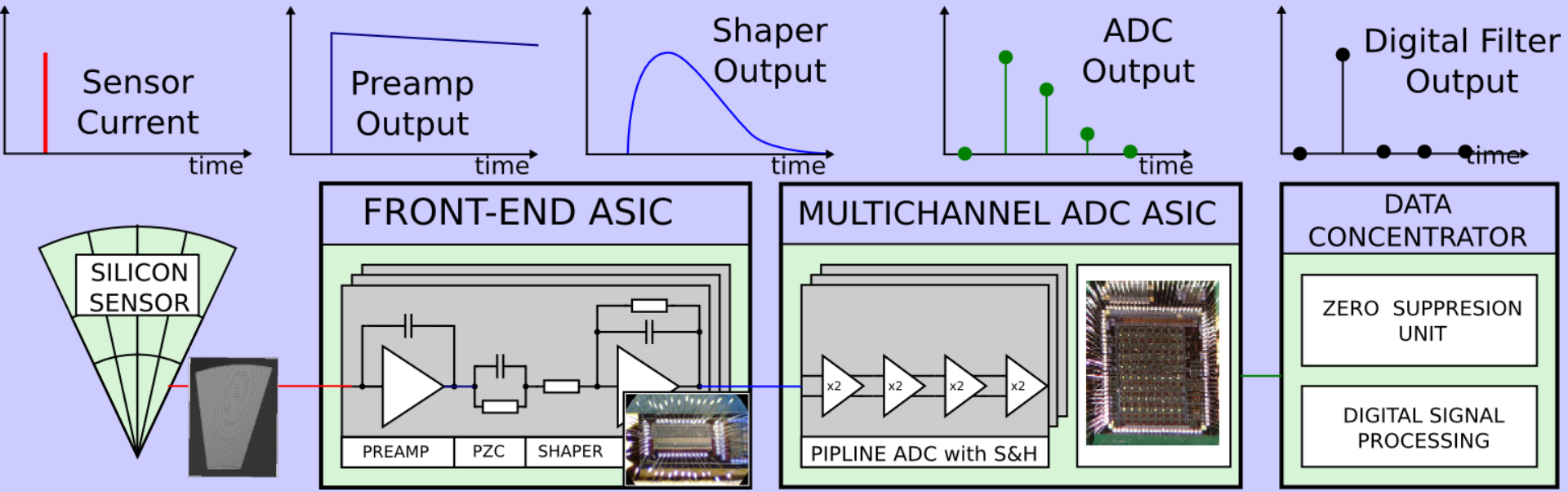
Pair Monitor readout (Tohuku Univ.)

- Silicon On Insulator (SOI) technology – 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 0.35 µm CMOS



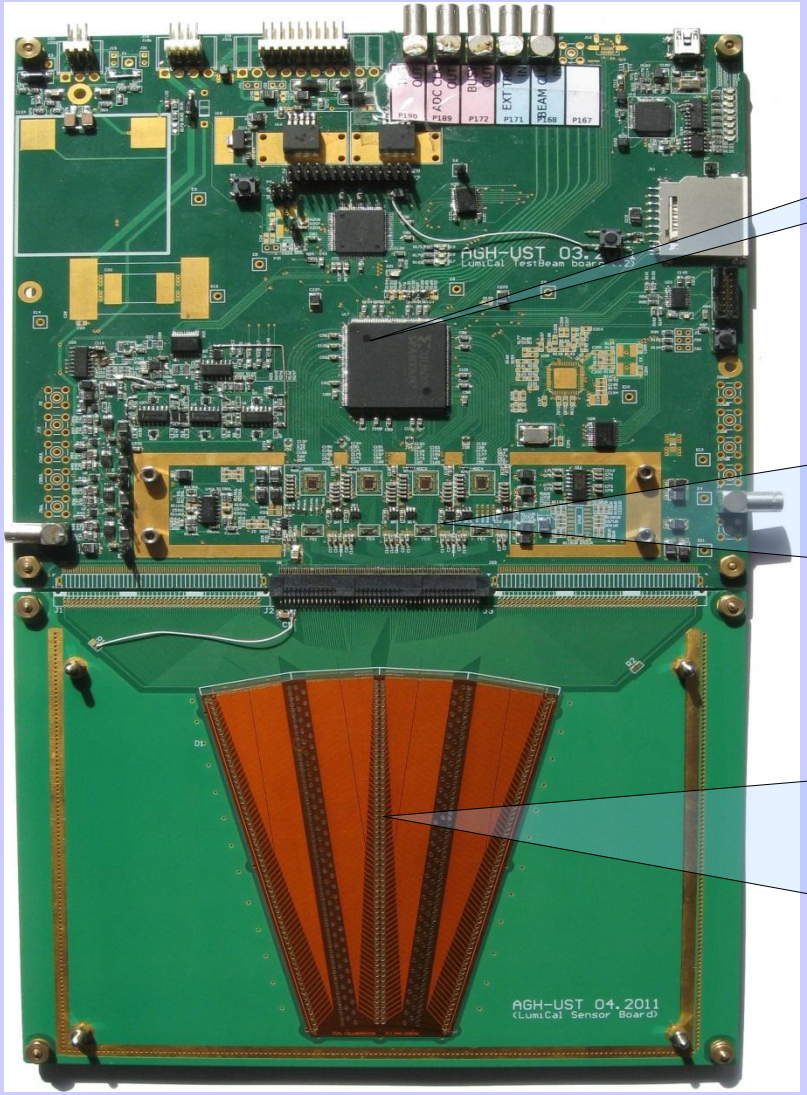
8 channel Front-End ASIC

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

8 channel 10-bit ADC ASIC

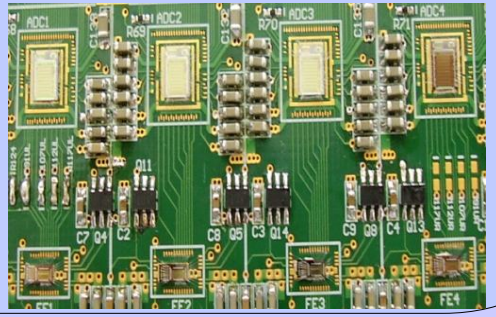
- 1.5 bit pipeline architecture
- 25 Ms/s (9.7 ENOB)
- Power: ~1.2mW/chan/MHz
- Power pulsing embedded

Module Design

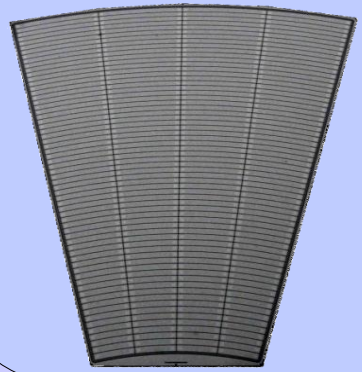


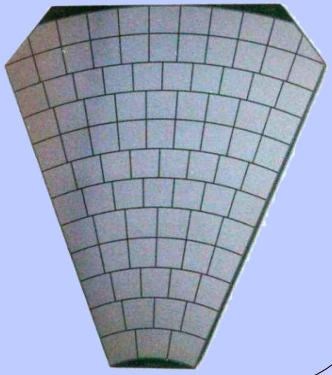
Data concentrator
Xilinx Spartan 3E

4 pairs of Front-end + ADC

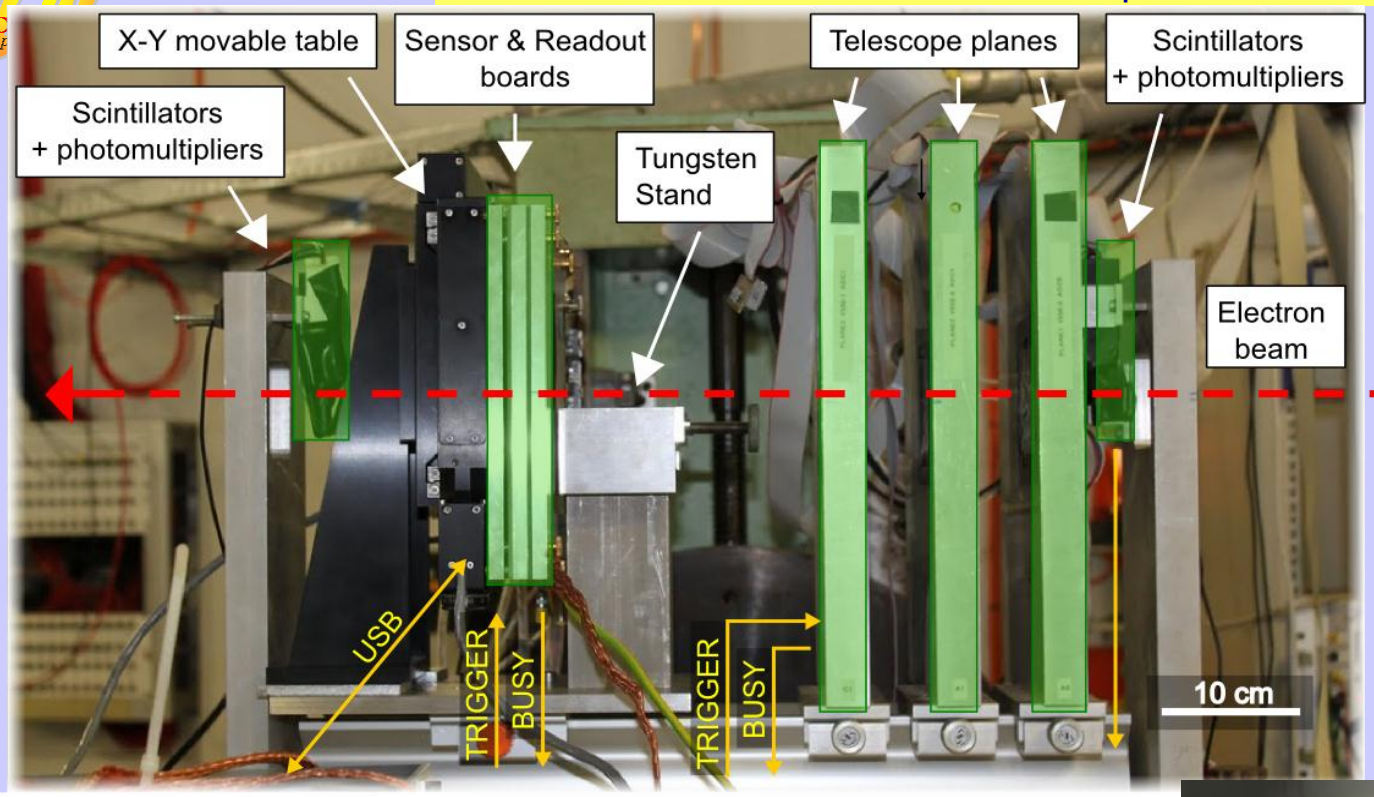


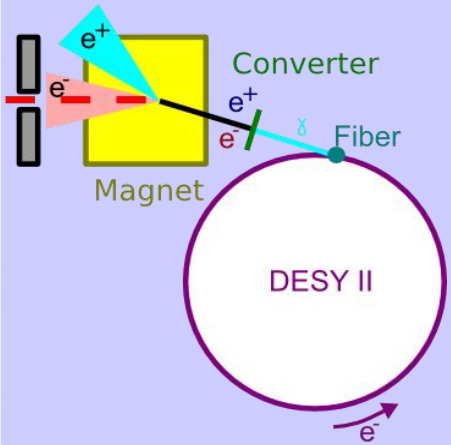
LumiCal / BeamCal sensors

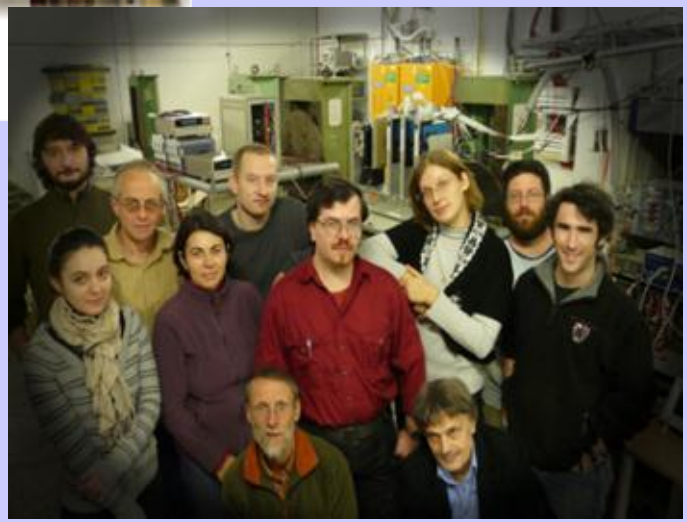




Test-beam Setup





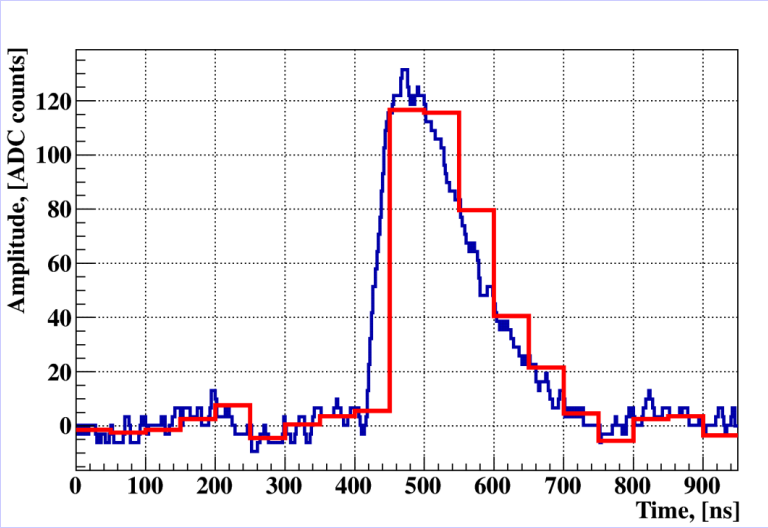


- 50×10^6 events recorded
- different areas of the sensor
- different FE settings
- data with FE and external ADC

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

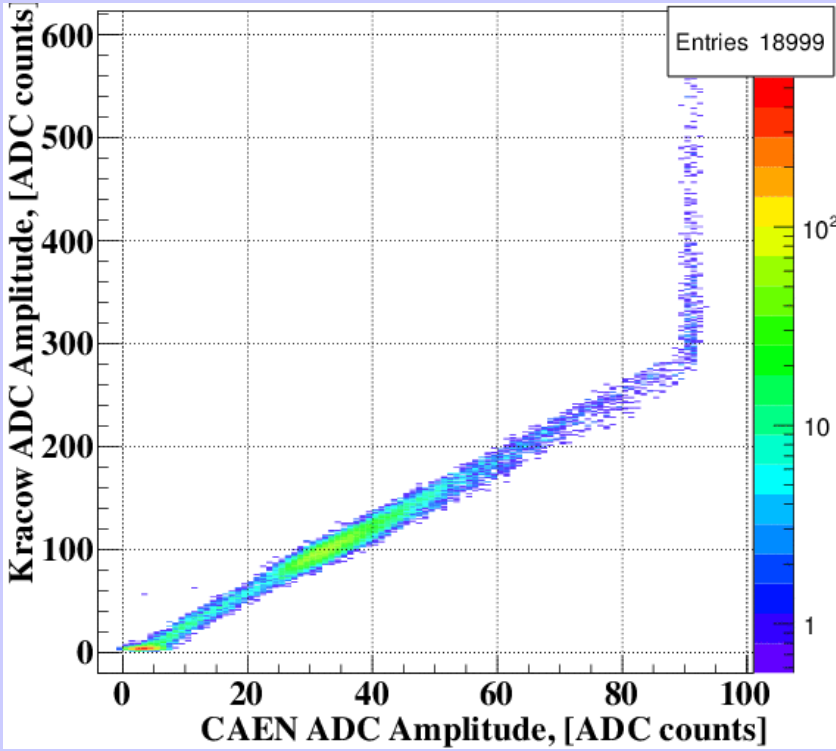
- Signal handshaking with Trigger Logic Unit (TLU)
- ADC Clock source
  - Internal (asynchronous with beam operation) – testbeam & CLIC mode
  - External (beam clock used to synchronize with beam) ILC mode
  - ADC sampling rate is up to 20 Ms/s (6.4 Gbps)

Test-beam Results

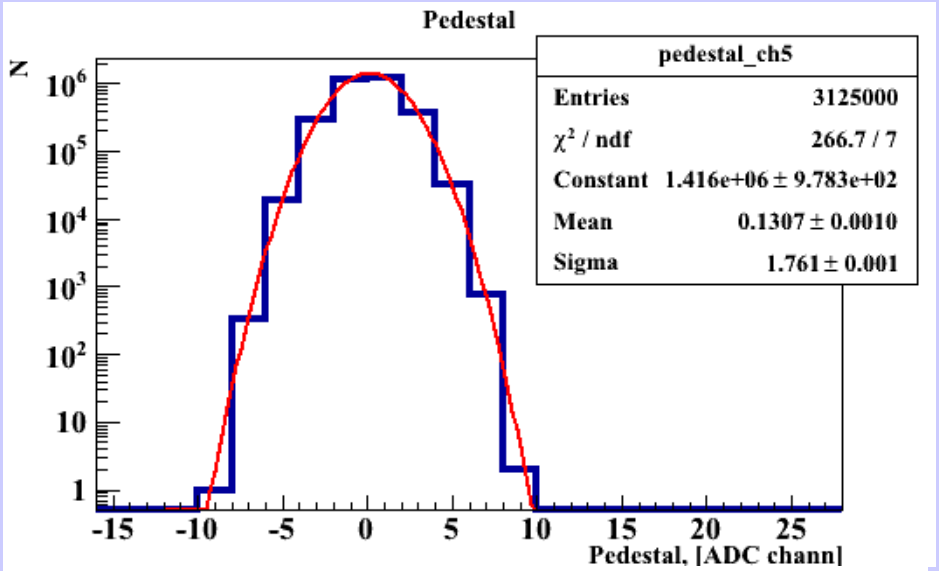


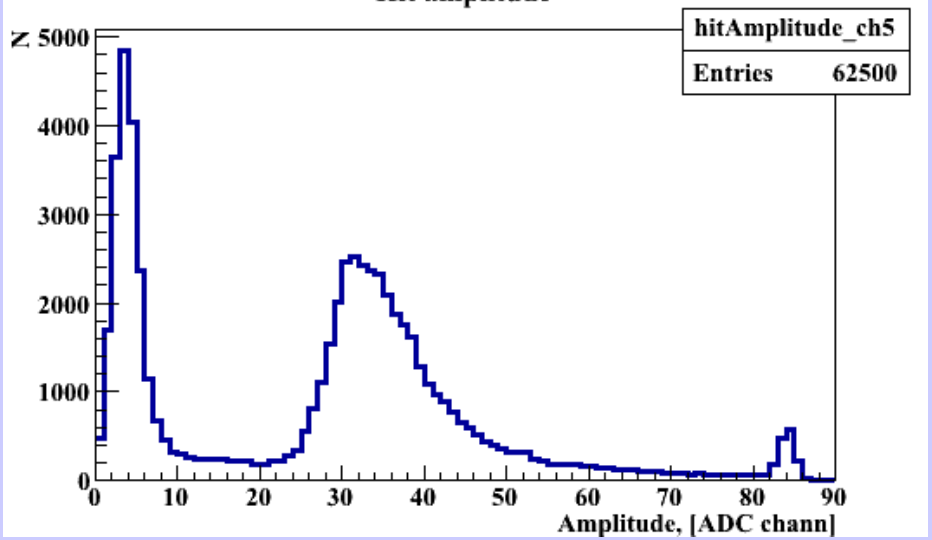
Example signal:
Signal digitized with ADC ASIC (red) and external ADC (blue)

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



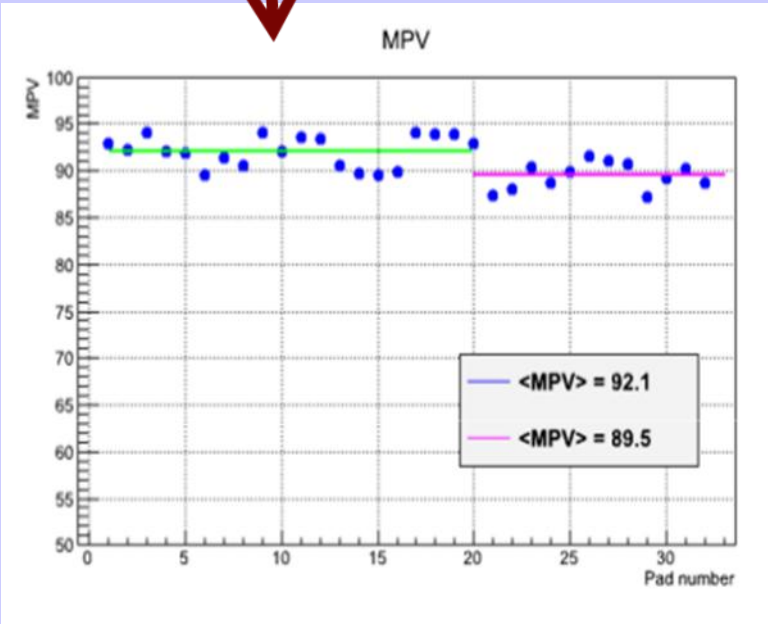
Test-beam Results



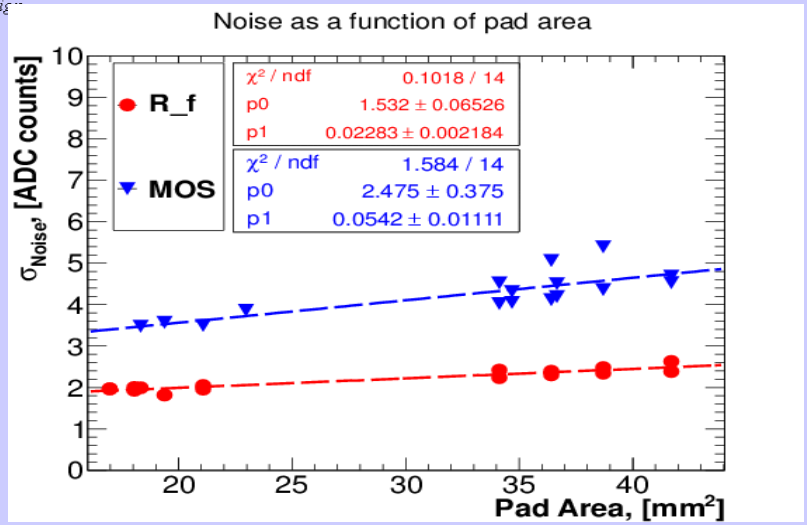


S/N ~ 22 (RC feedback & FET feedback)

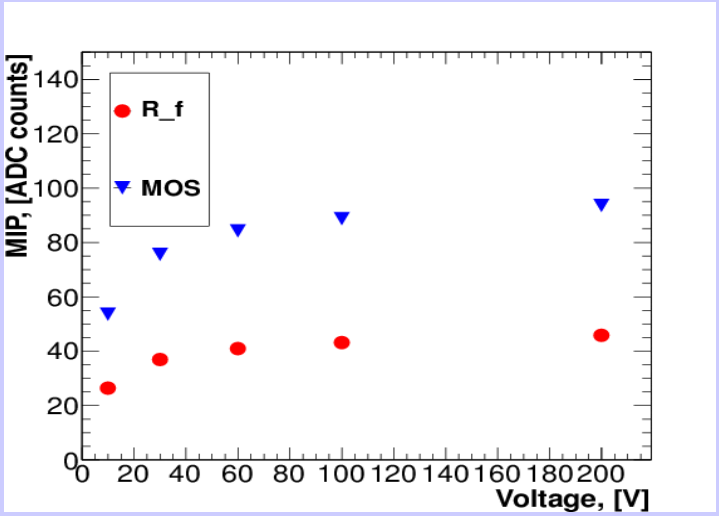
Gain vs. channel



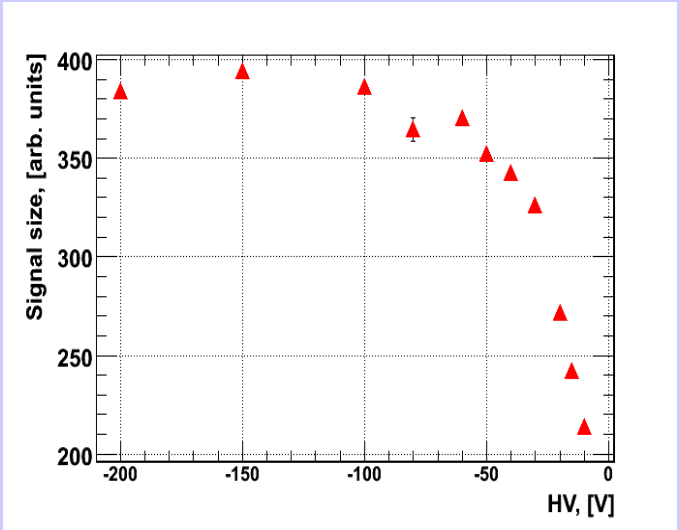
More Results



σ_{PED} as a function of the pad area

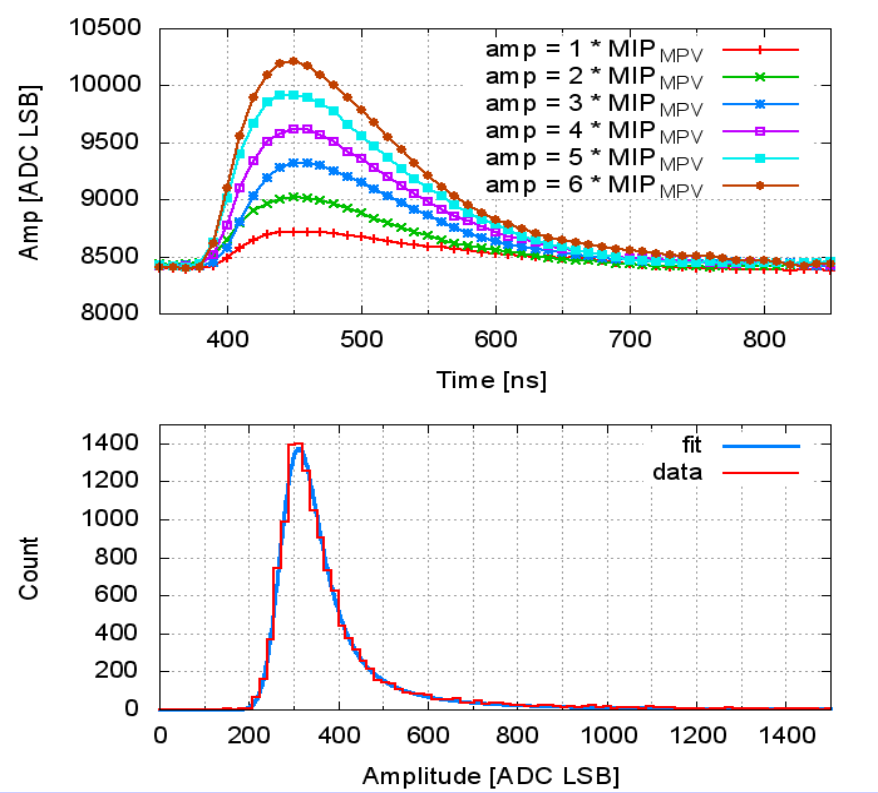


Signal as a function of the voltage, test beam (GaAs)

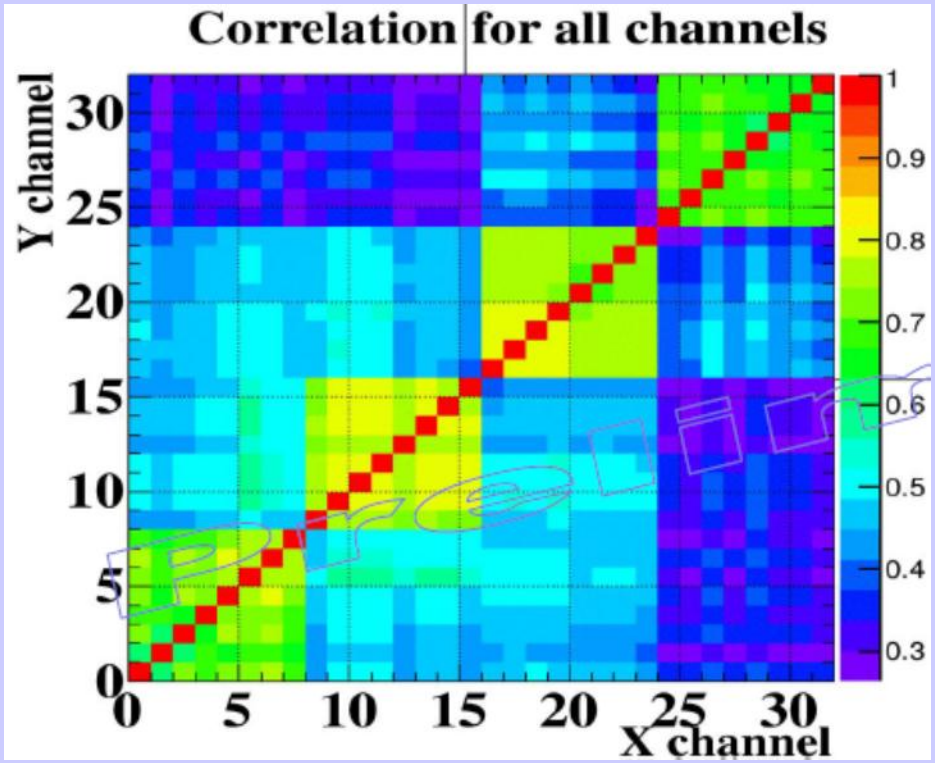


Signal as a function of the voltage, lab measurement

More Results



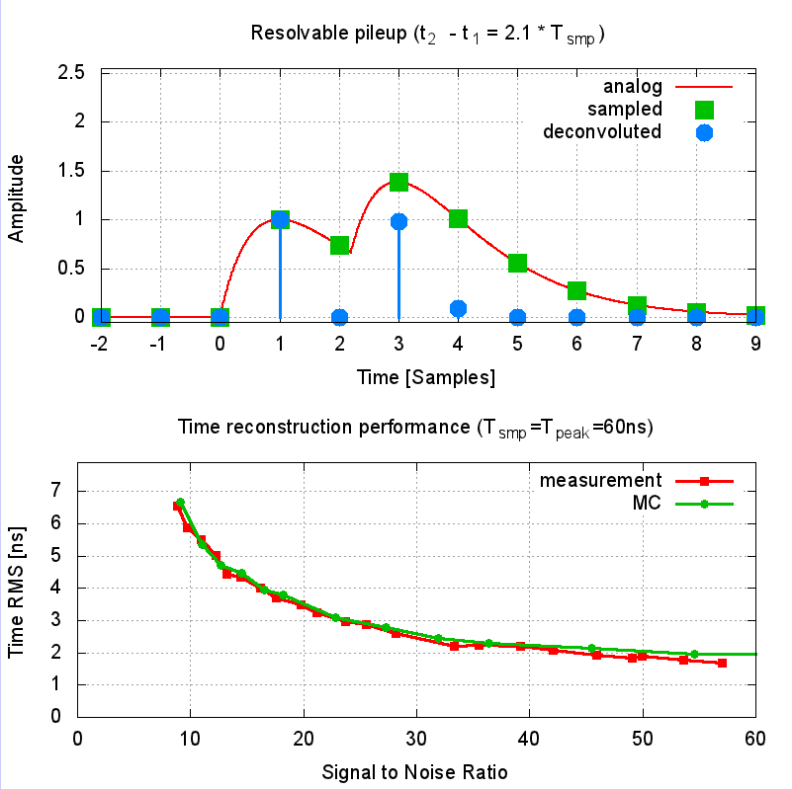
Multiparticle crossing

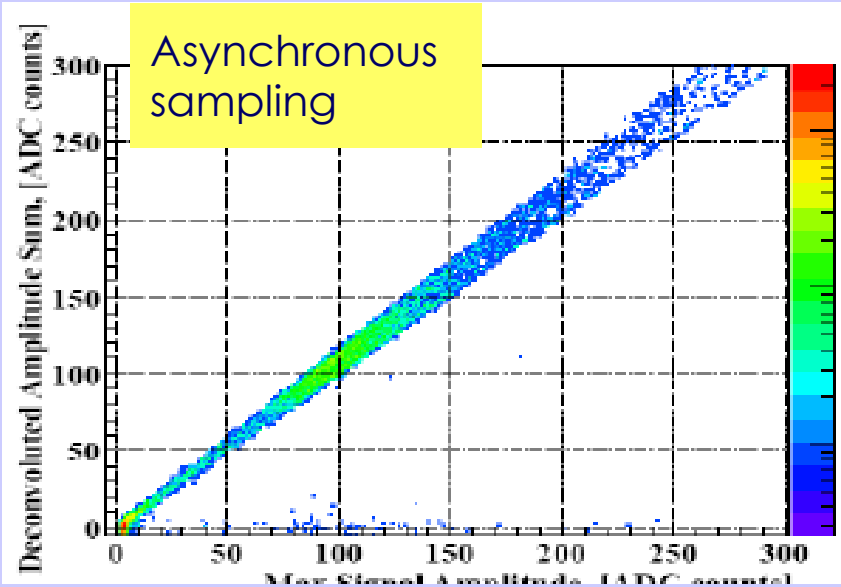


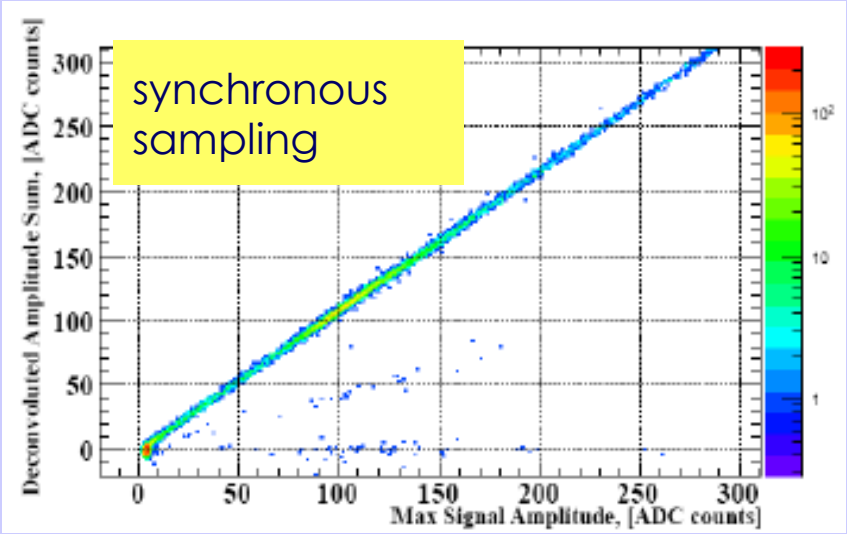
Common mode noise

Application of signal de-convolution

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

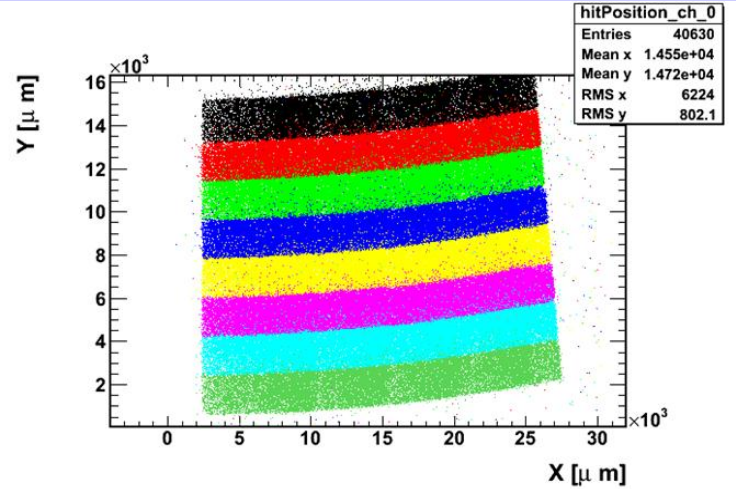


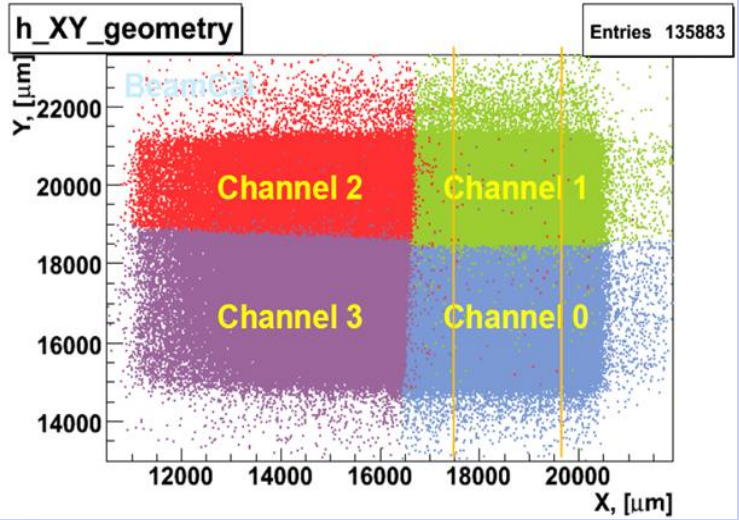




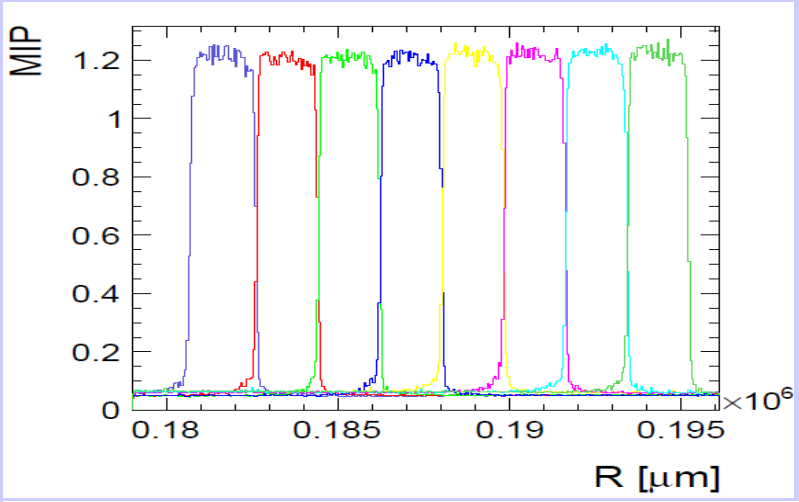
More Results

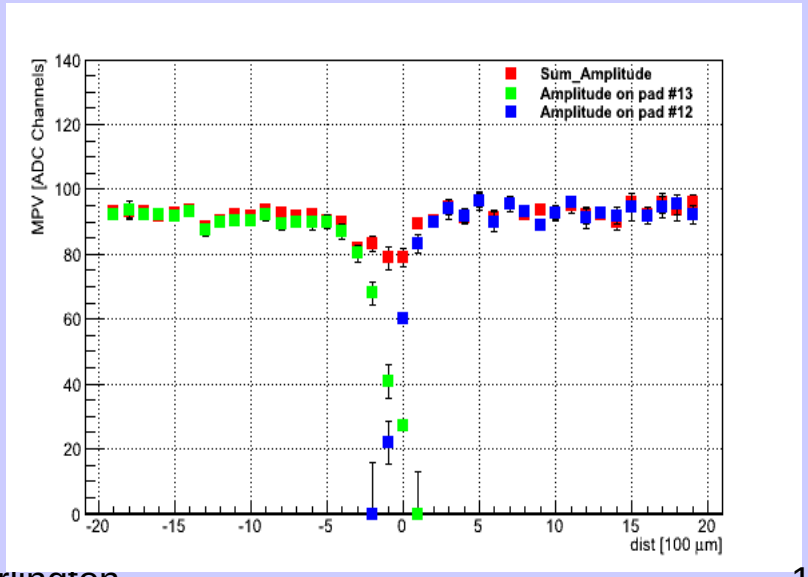
Track reconstruction using the telescope



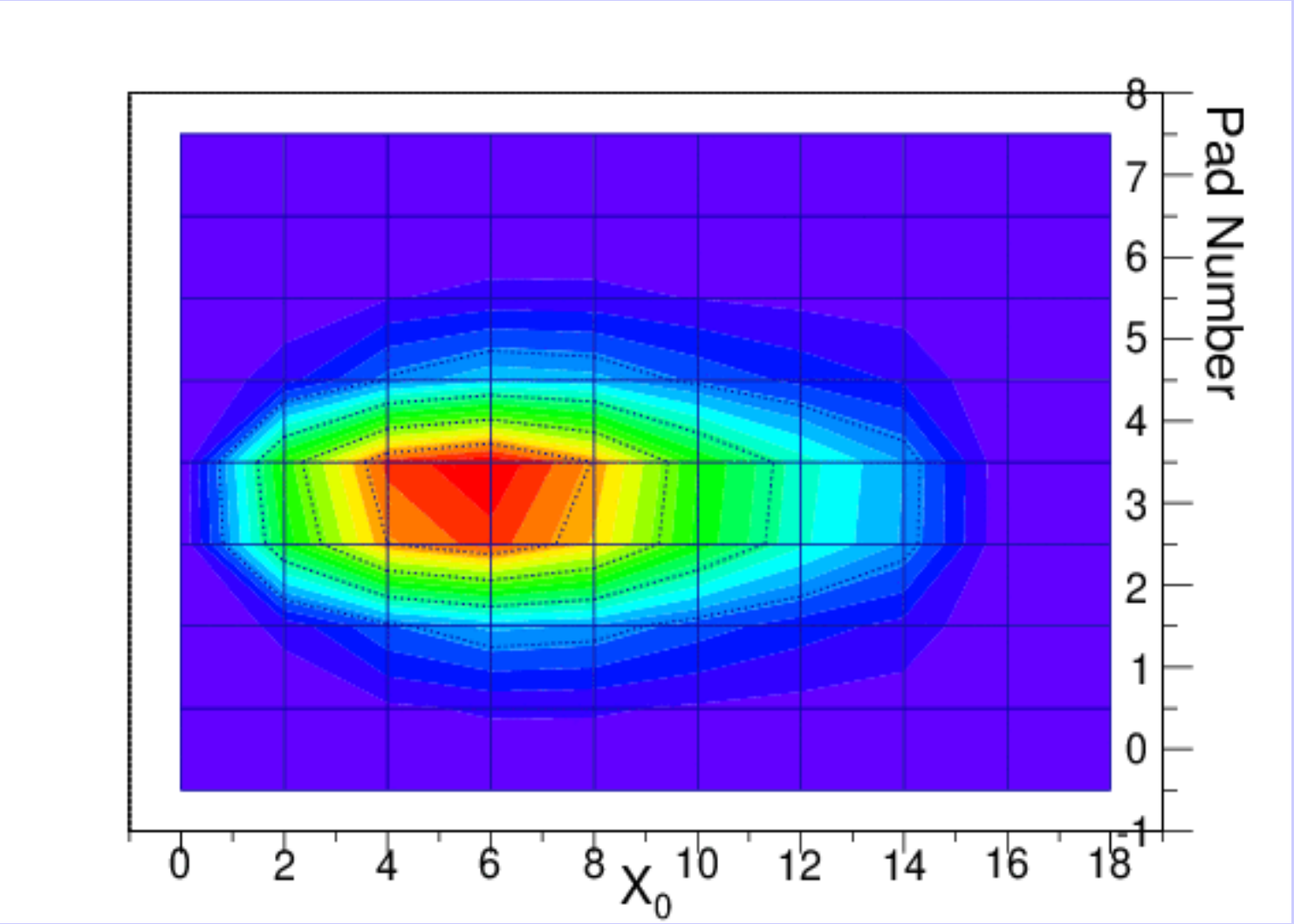


Signal amplitude on neighbour and between pads

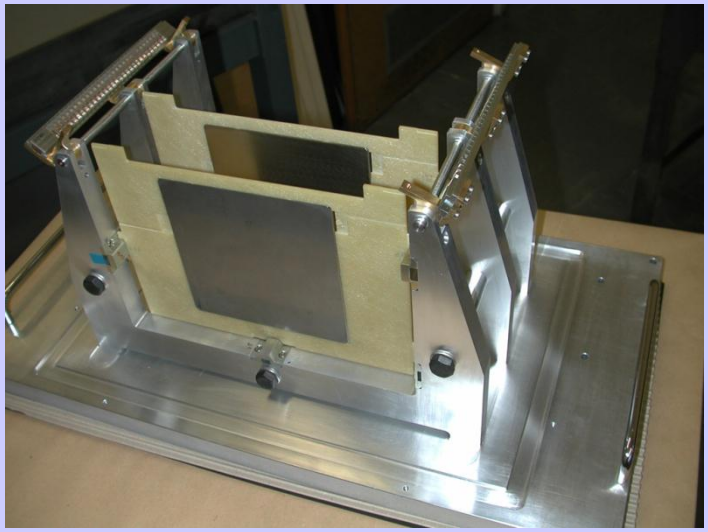




Reconstruction of the 2 D shower shape



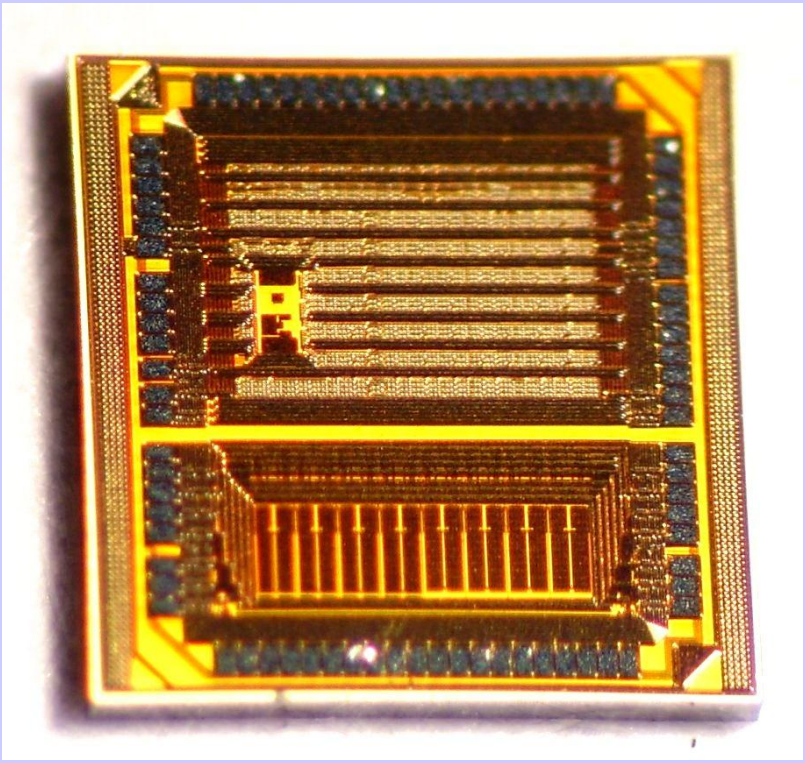
Under development – calorimeter prototype



- 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



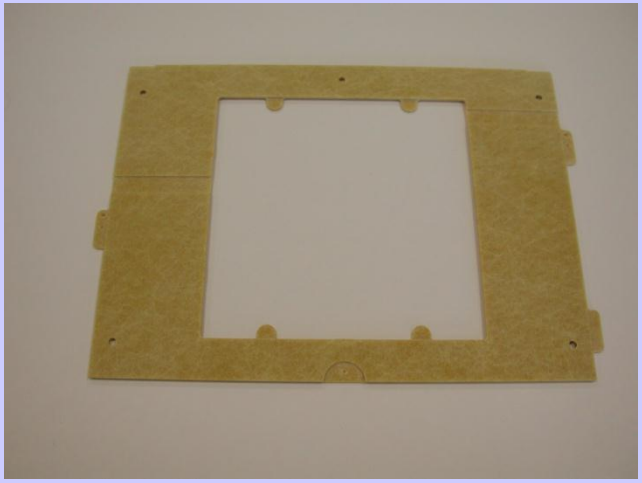
& DAQ matching AIDA standard

Summary

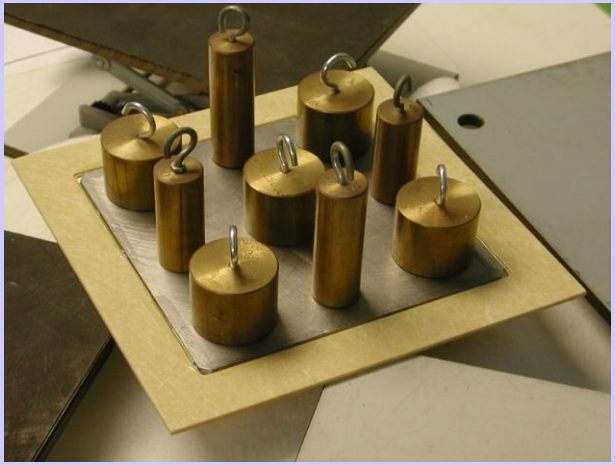
- After detailed design studies, sensors, FE and ADC ASICs are designed, tested and produced
- FE and ADC ASICs are attached to sensor prototypes (both BeamCal and LumiCal sensors) to form a fully operational sensor plane (32 channels connected)
- Performance studies are done in a test-beam
  - Stable 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

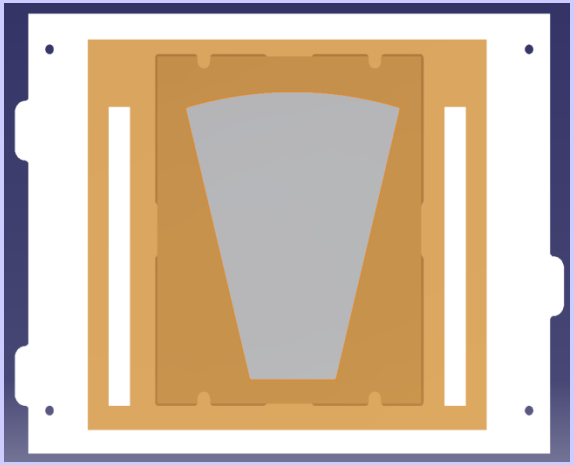
Mechanical Frame



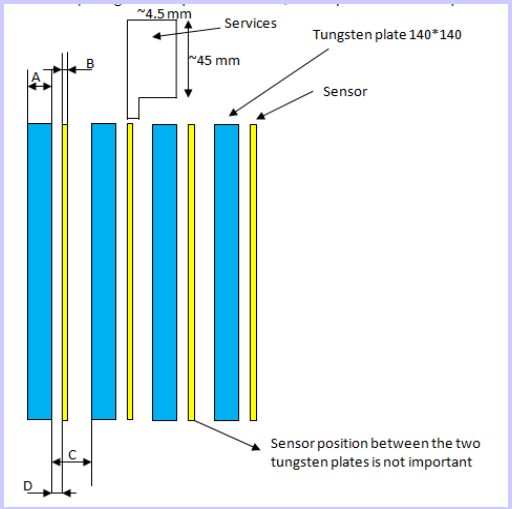
First machined permaglass frame

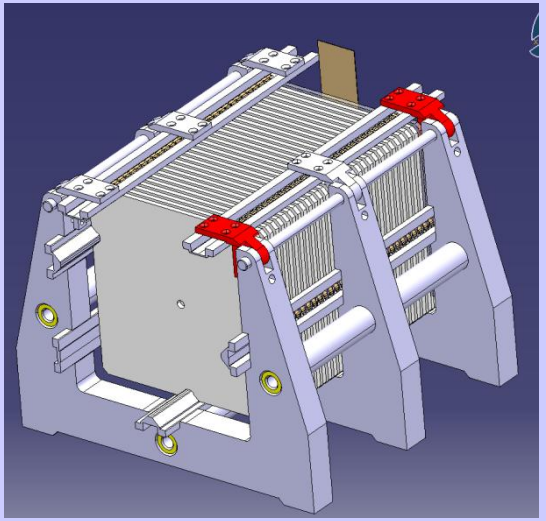


tungsten absorber plate inserted



Sensor plane

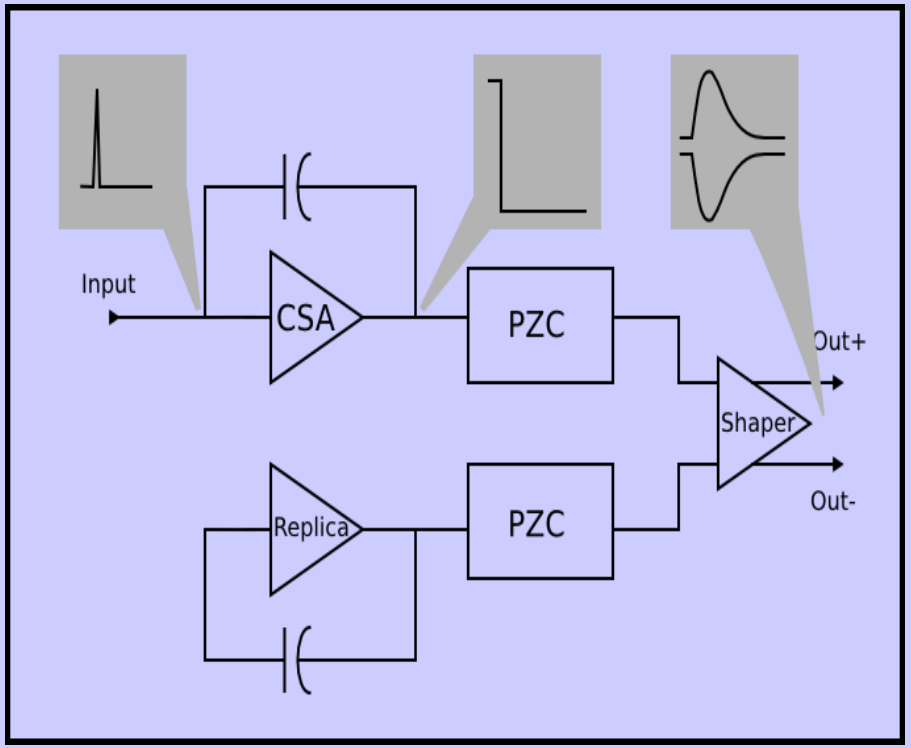




New ASIC prototypes

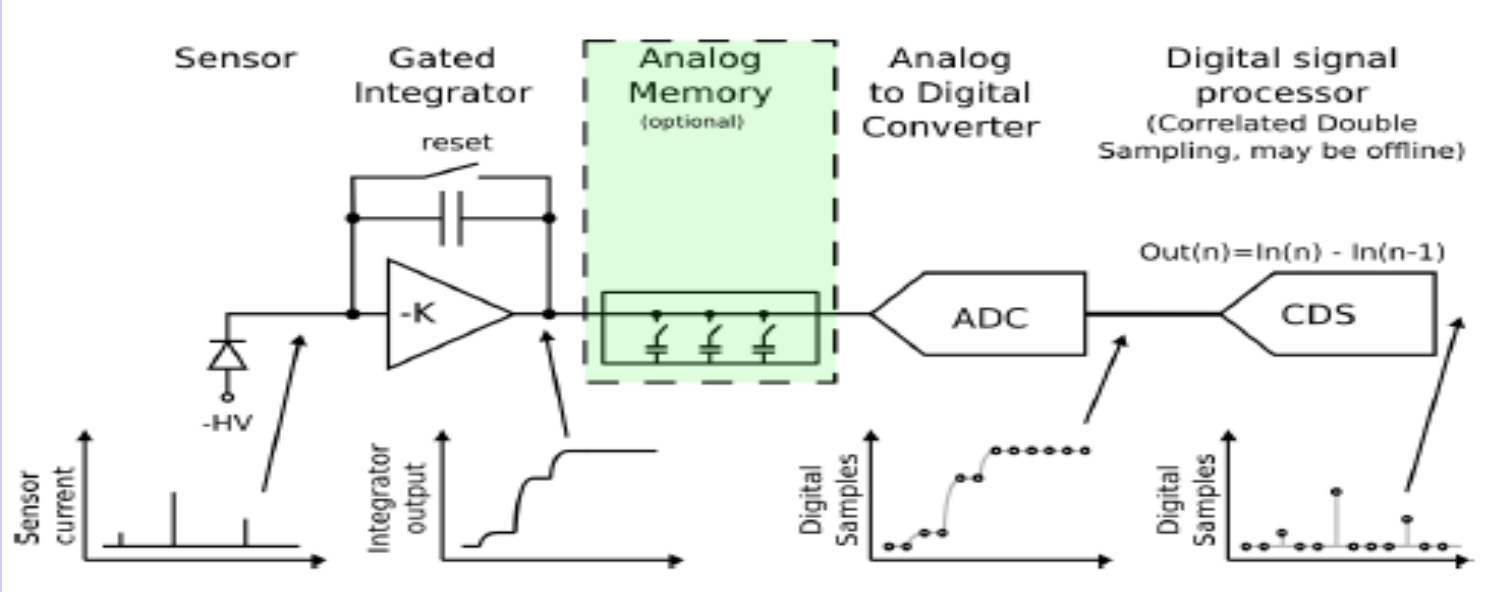
Future ASICs will be designed and produced in 130 nm IBM technology (AGH-UST Cracow)
faster, lower power consumption, radiation hard

- 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



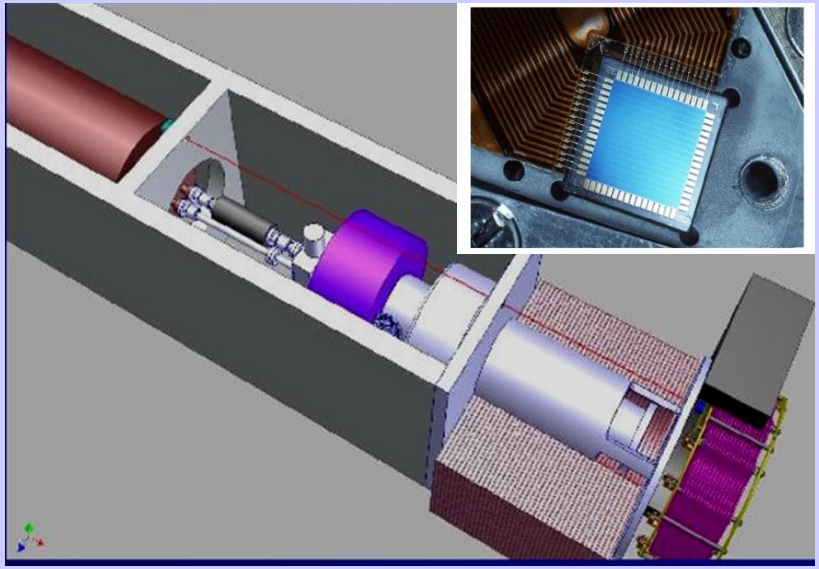
CLIC Electronics (proposal)

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!



Alignment Concept (INPAS Cracow)

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

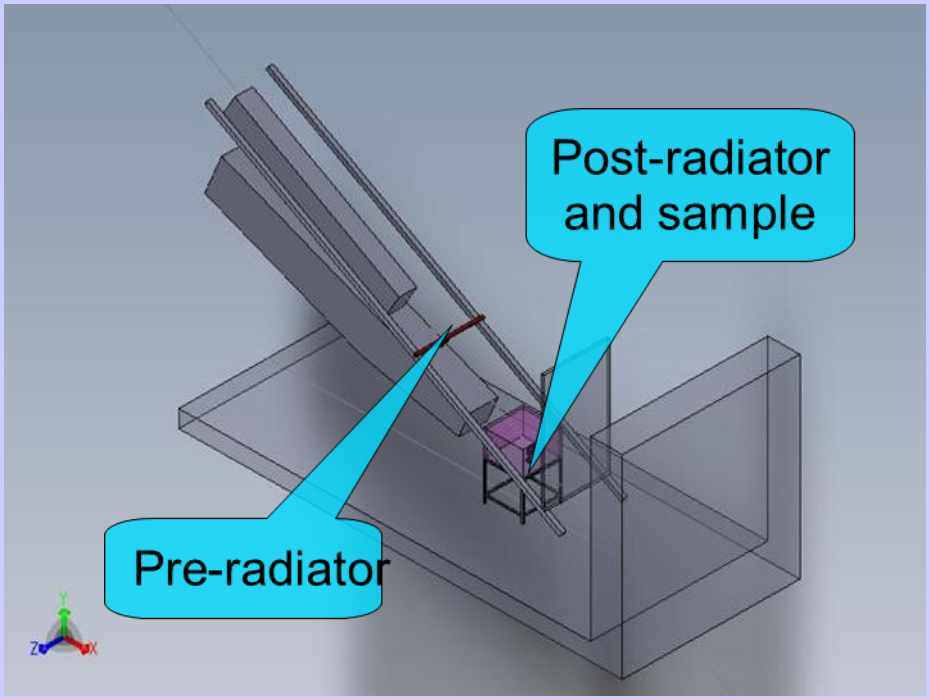
DAQ (INP and TAU)

- 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)

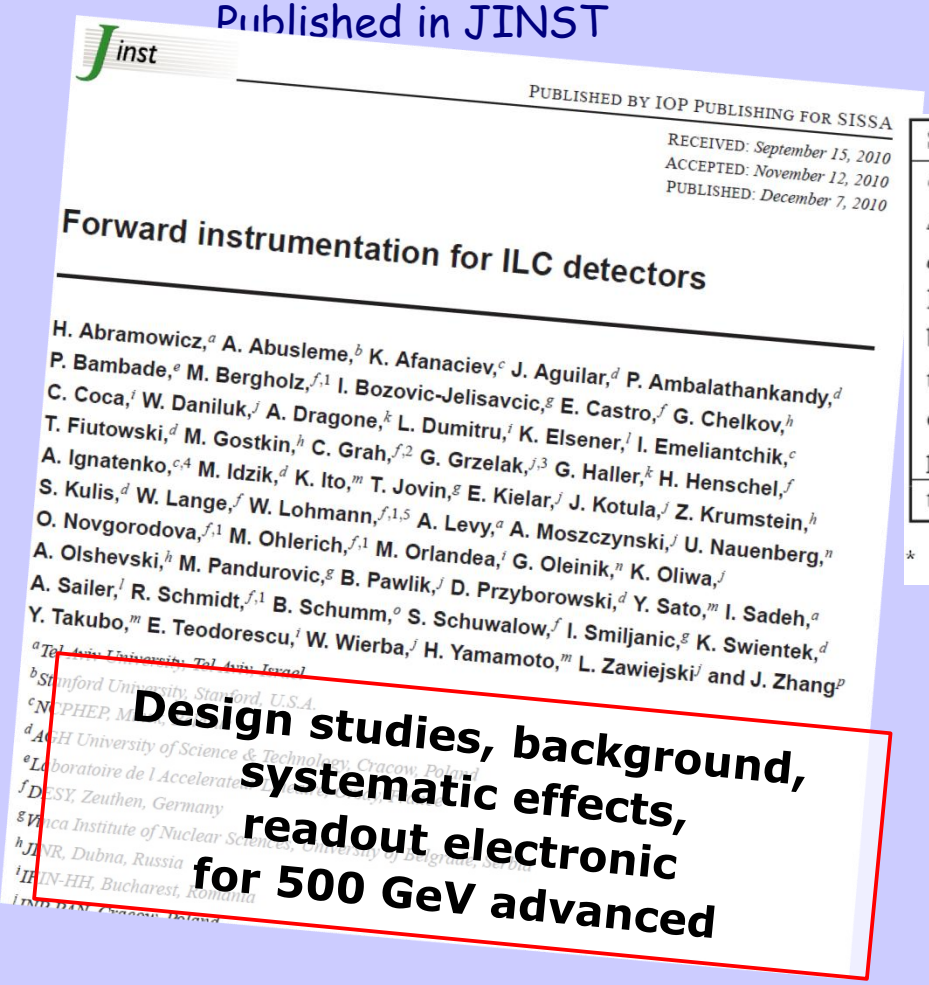
Radiation Damage Study Facility (Santa Cruz)

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

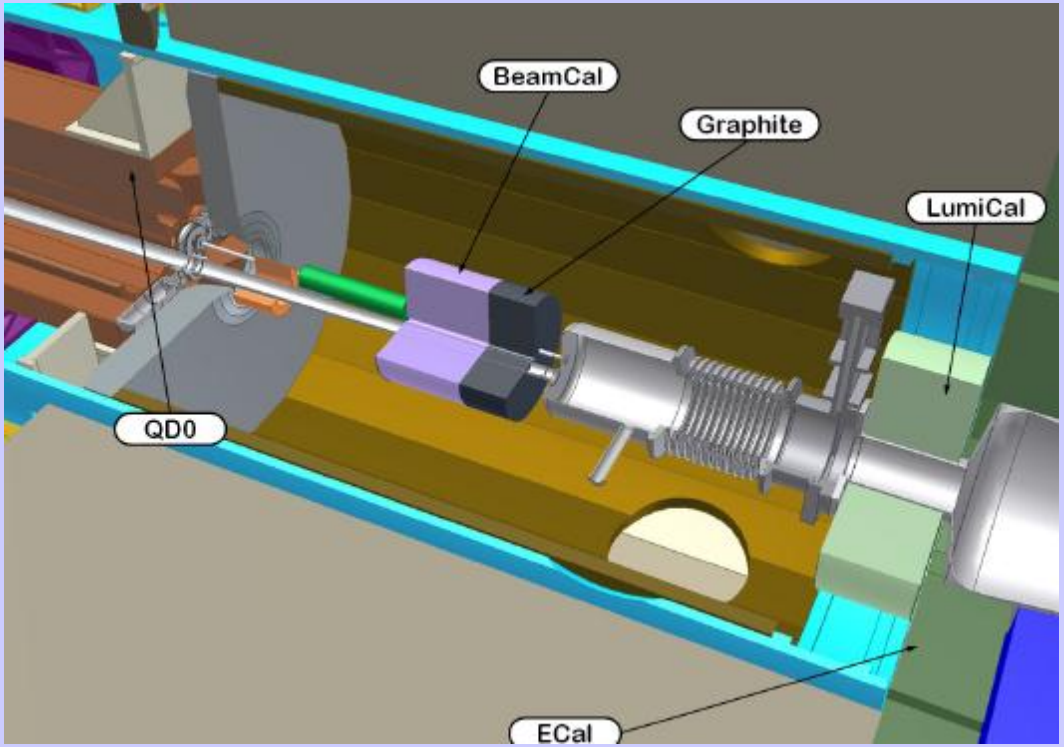
Systematics of luminosity measurement at 500GeV

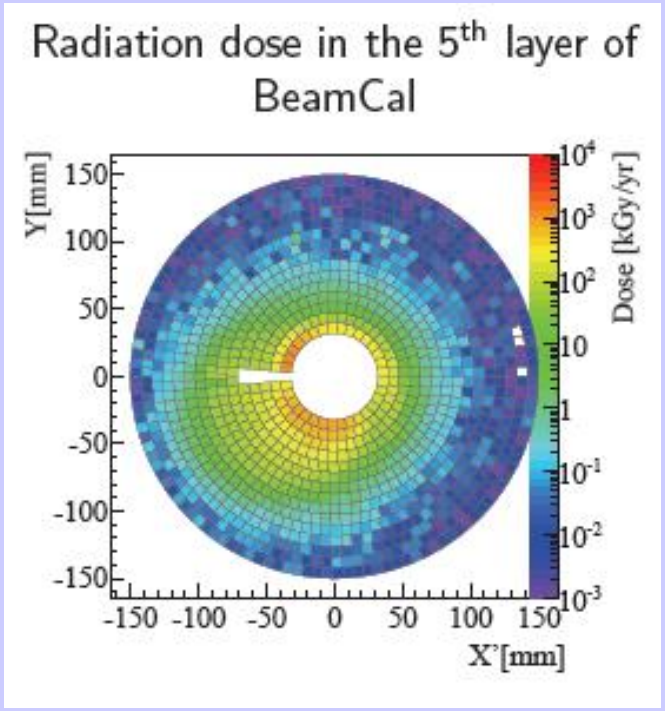
Source	Value	Uncertainty	Luminosity Uncertainty
σ_θ	2.2×10^{-2} [mrad]	100%	1.6×10^{-4}
Δ_θ	3.2×10^{-3} [mrad]	100%	1.6×10^{-4}
a_{res}	0.21	15%	10^{-4}
luminosity spectrum			10^{-3}
bunch sizes σ_x, σ_z,	655 nm, 300 μm	5%	1.5×10^{-3}
two photon events	2.3×10^{-3}	40%	0.9×10^{-3}
energy scale	400 MeV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

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

Design of the forward region of a CLIC detector

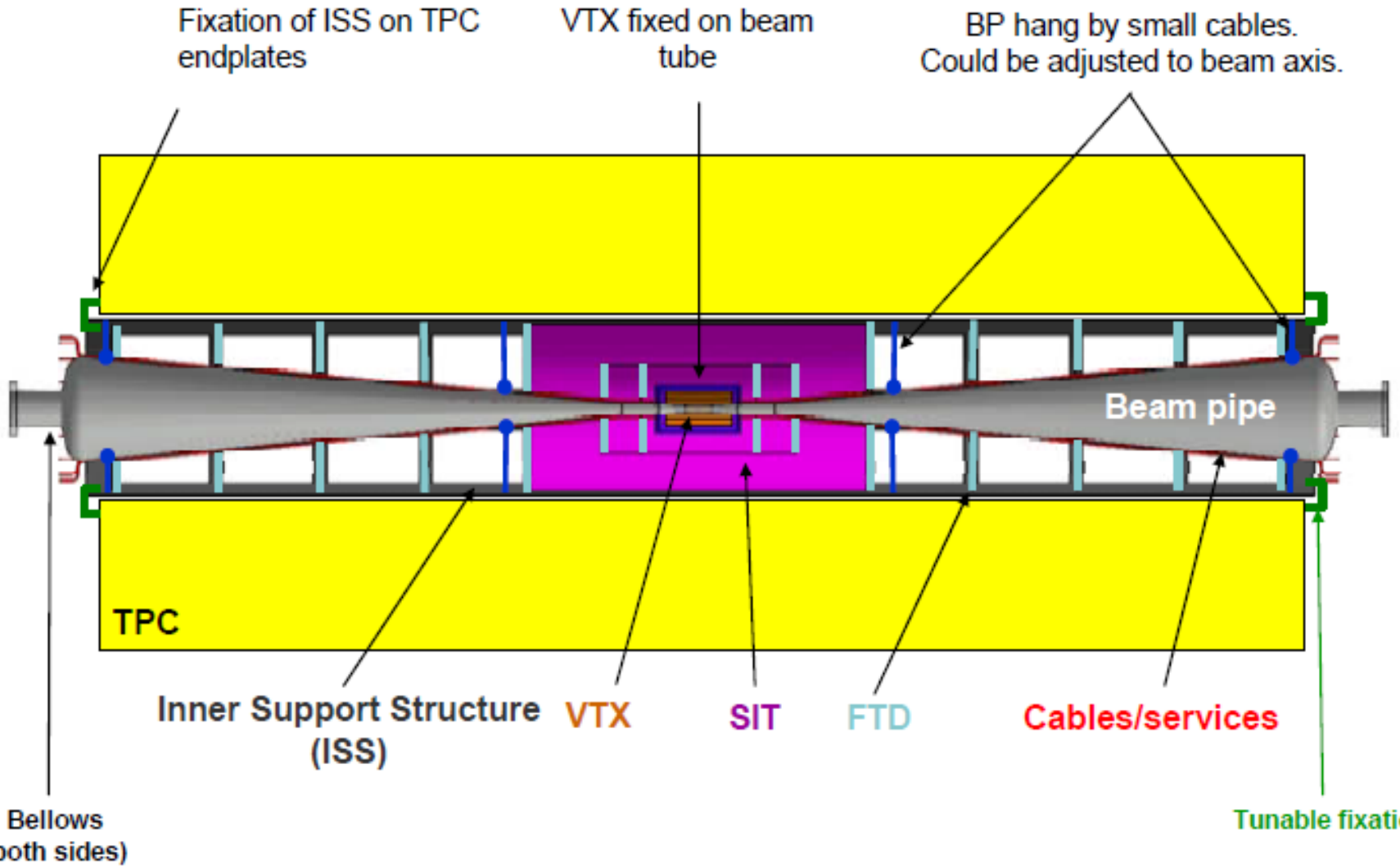




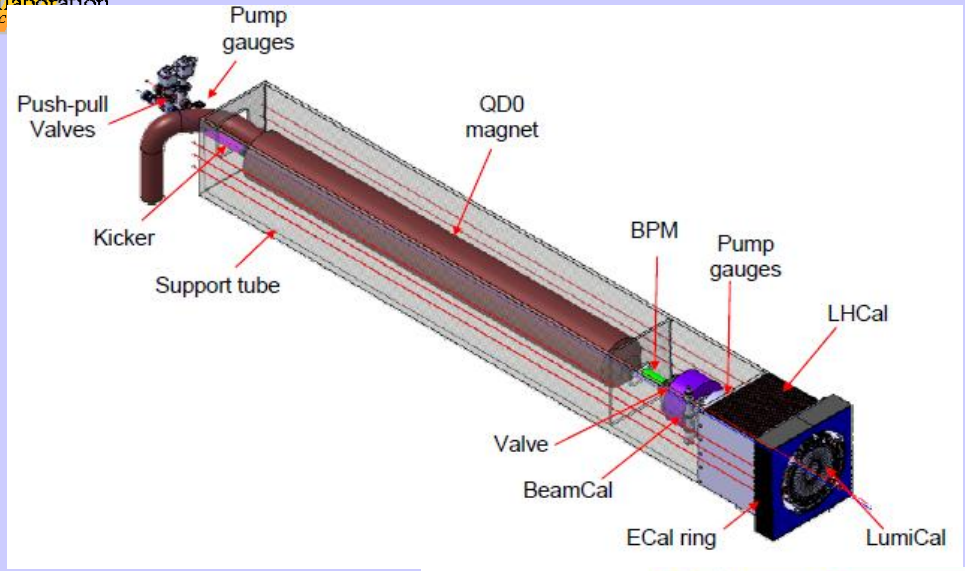
Crossing angle 20 mrad

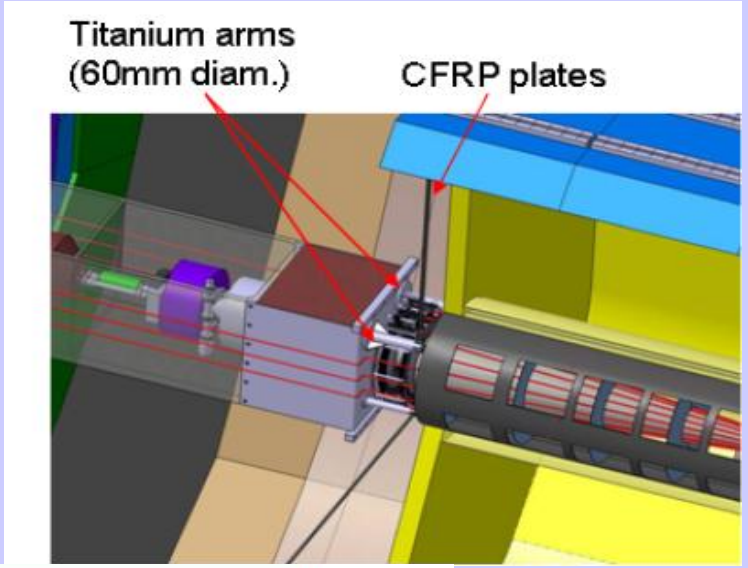
- BeamCal angular coverage 10 – 40 mrad
- LumiCal coverage 38 - 110 mrad
- 40 X_0 depth
- Optimised to minimise backscattered particles

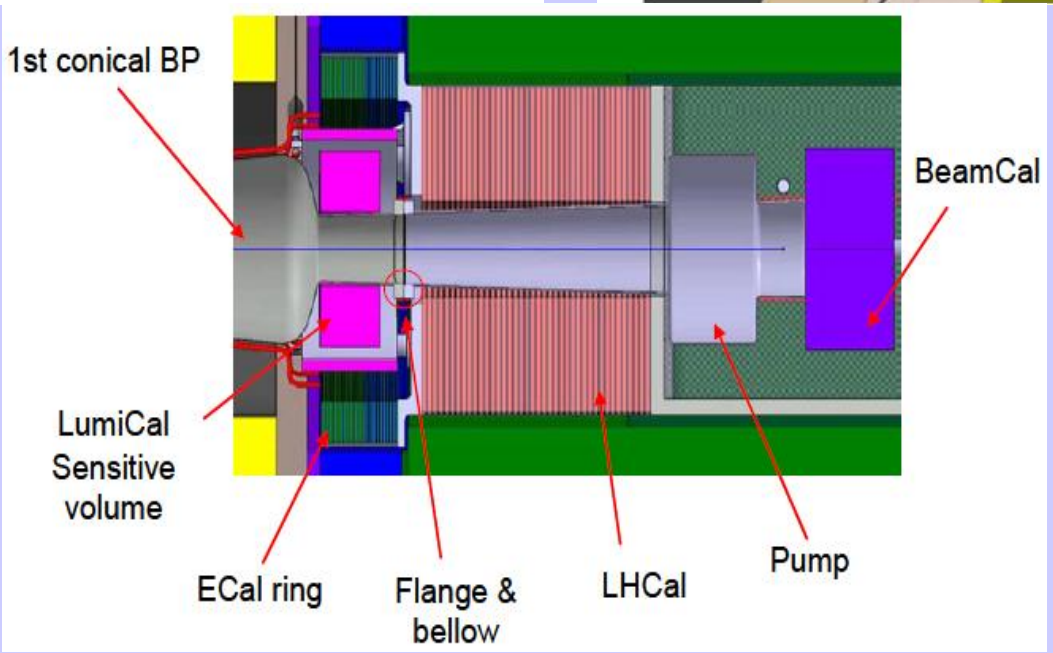
Vorward Region Design, ILD



Vorward Region Design, ILD

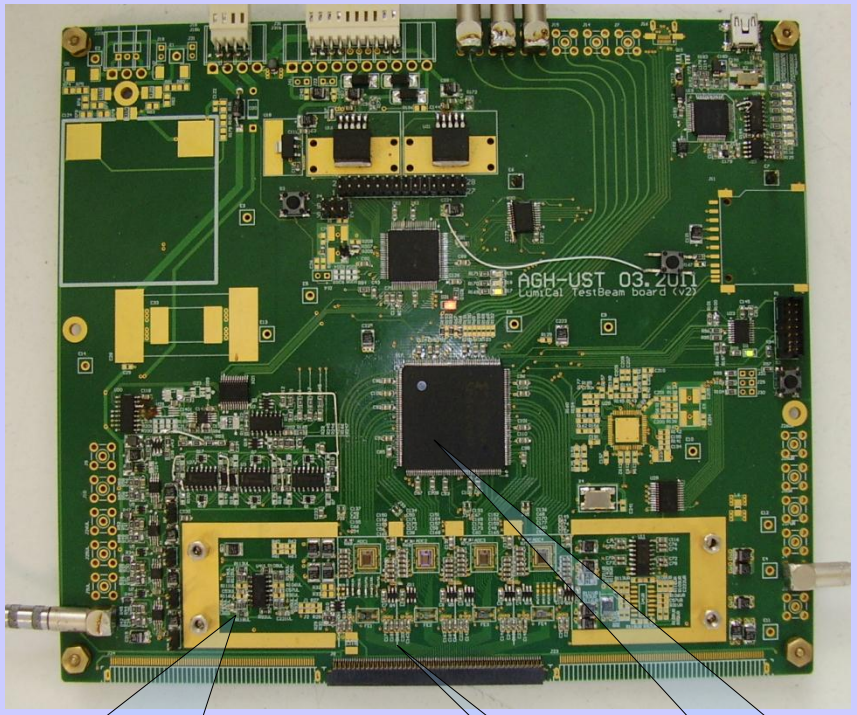




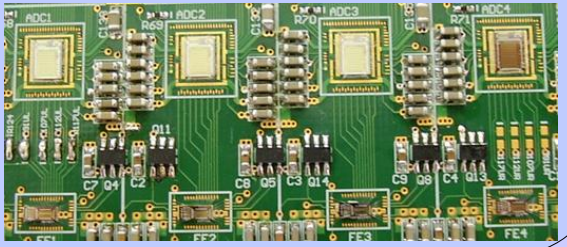


AGH-UST Cracow Readout board, 32 channels

- 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