Detector R&D

G. Eigen, Bergen

rECFA meeting, Oslo, October 2, 2015

Outline

- 3D Si pixel detectors for ATLAS phase II upgrade
- Master student project 3DCT of Si Pixels
- The 3DMiMic project
- Forward calorimeter R&D for ALICE phase II upgrade
- Calorimeter R&D for ILC experiment
  - Gain stability of SiPMs
  - Measurement of SiPM properties
- Beam radiation monitor

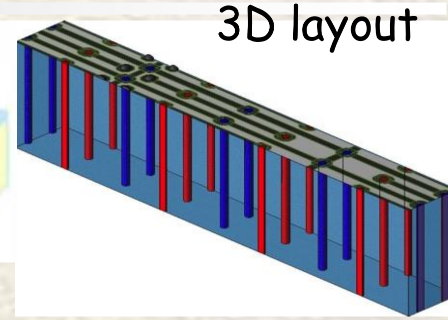
3D Si pixel Detectors for ATLAS Phase II Upgrade

(A. Heggelund, O. Røhne, H. Sandaker, N. Pacifico, B. Stugu, Z. Yang)

'3D' Pixel Sensor Design by SINTEF for ATLAS Phase II Upgrade

- Motivation: ATLAS-ITk (IBL) funds HEPP Project (see Farid's talk)
- Intial work in close collaboration with inventors at SLAC (S. Parker), who also helped in parts of the processing steps
- Several communities have designs with SINTEF & collaborate about wafer processing costs
- Thinning and active edge capabilities offered by 'full 3D' technology
- 3D sensors are radiation hard:
  CMS type sensor, M.Bubna et al JINST 9 (2014) C0719
- Testbeam for ATLAS '3D' collaboration
  (with participation from Oslo+Bergen)

3D layout



Pictures: A Kok, IEEE presentations 2011,2012

IV curves

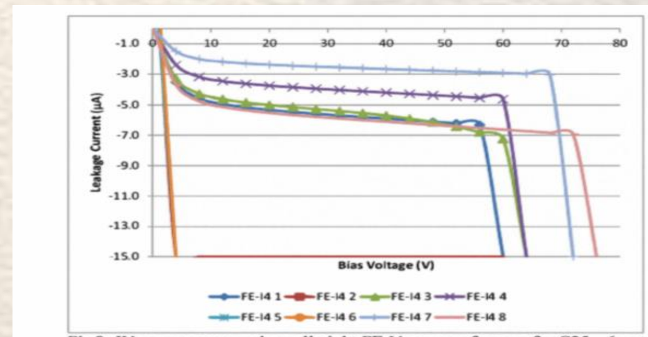
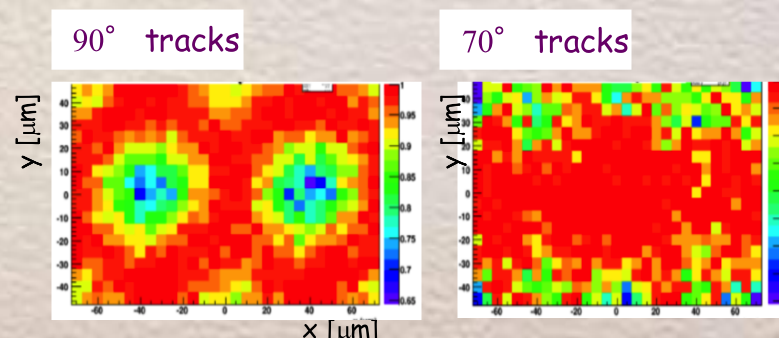


Fig.8: IV curves measured on all eight FE-I4 sensors from wafer C25. 6 out of 8 sensors have good diode characteristics with a total leakage current between 2 and 7 µA and a breakdown voltage of above 50V.

Occupancy after irradiation of 10^{14} p/cm^2

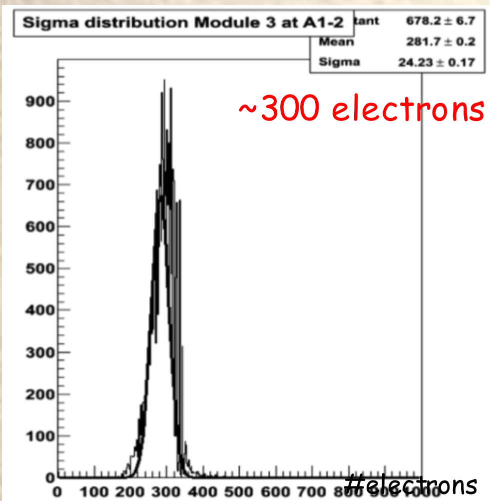


ε_{cell}=94.2% ε_{cell}=96.5%

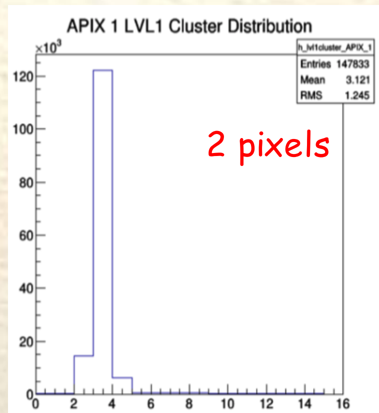
First Test Beam Results

- 3D sensor: $50 \times 250\ \mu m^2$, $230\ \mu m$ thick
- Bump bonded to FEI4 chip

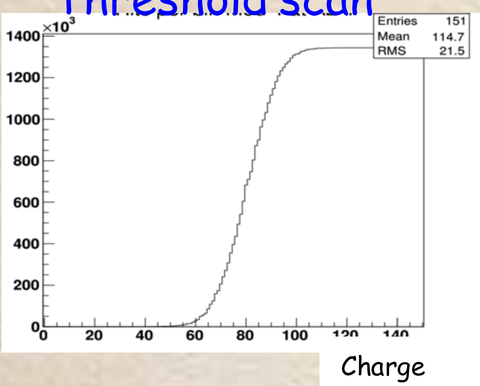
Noise



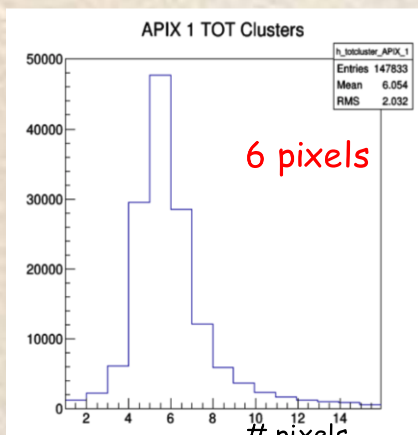
Cluster distribution

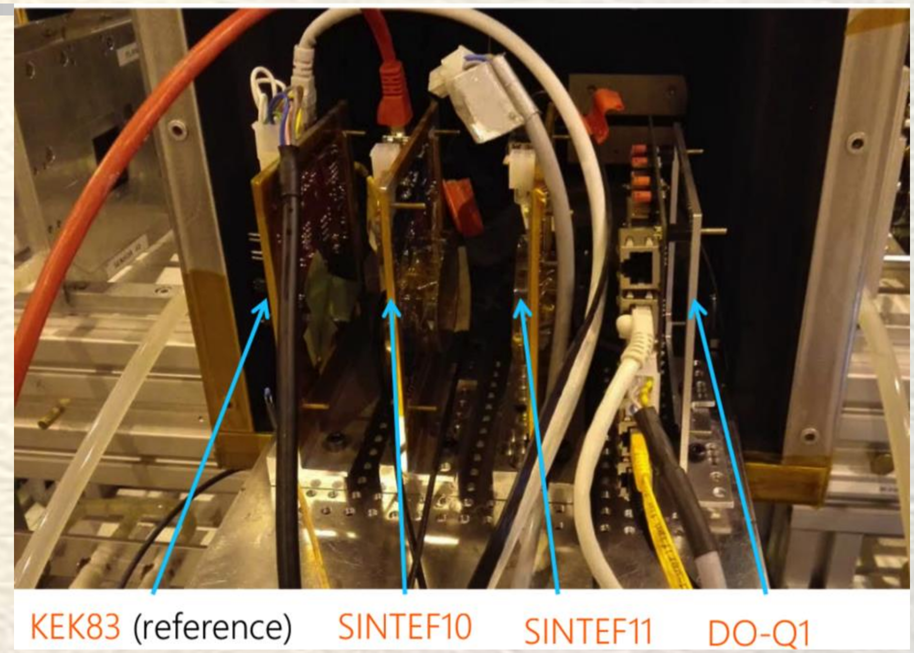


Threshold scan

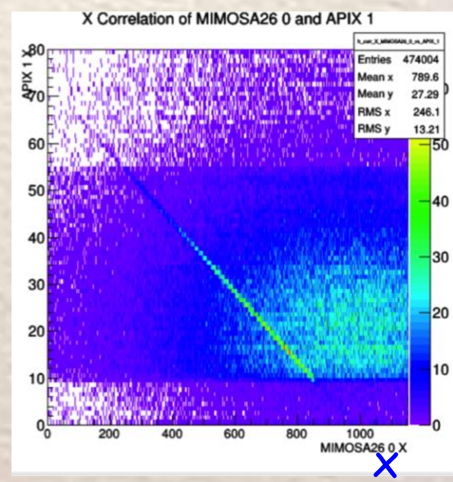


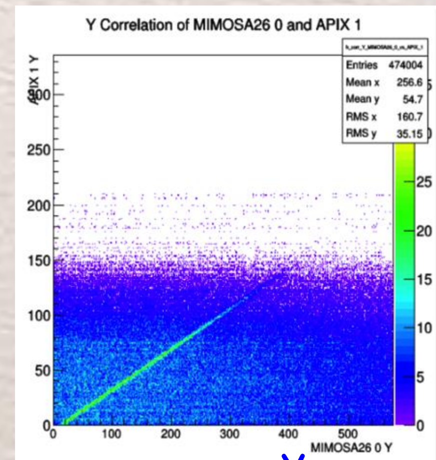
ToT clusters





Hit correlations for 3D vs EUDET





- Test beam of FEI4 modules at SPS with pions (18-22 September 2015)
- Hits are correlated with hits in Eudet telescope as expected

Further Work with SINTEF '3D' Sensors

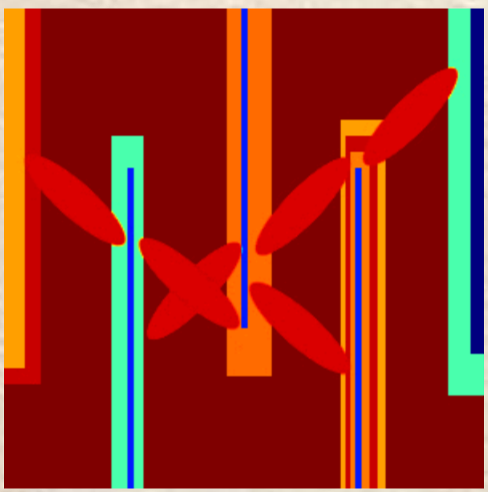
- Goal is to have something viable in 2016 for the ATLAS ITk pixels
  - Evaluate the run-3 devices with ATLAS FEI-4 chip
  - Next design round (run-4, funded by HEPP) is just about to being launched
    - Thinner sensors (50 μm and 100 μm)
    - Smaller electrode diameters
    - Reduced pixel pitches, compatible with new 'RD53' prototype readout chip, are included.

Master Project
3DCT of Si Pixels

M. Yassin, A. Read, O. Røhne (Oslo)

3D Charge Collection Efficiency

- Exploring the possibilities of 3D Charge Collection Efficiency (3DCCE) with reduced number of projections
- To get a precise 3DCCE with traditional methods about 180-360 projections are needed. Each projection is a test-beam exposure at a different angle
- If we use Fourier Slice Method followed by a Compressed Sensing recovery technique called “Recursive Spatially Adaptive Filtering”, we can make a reliable 3DCCE with around 20 projections



Original detector image –
the diagonal ellipses simulate irregular low efficiency,
the vertical patterns are most difficult to reconstruct
at low number of projections

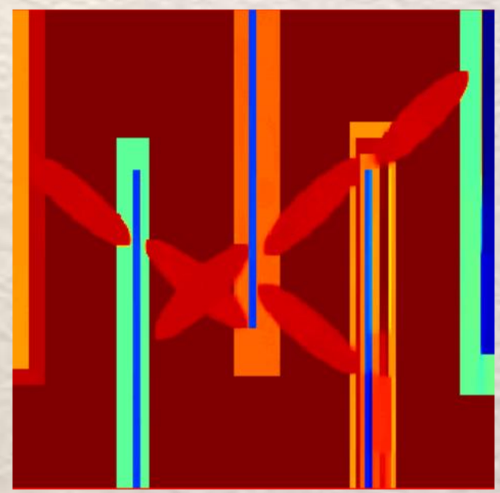


Image estimate after
20 projections and
1095 iterations

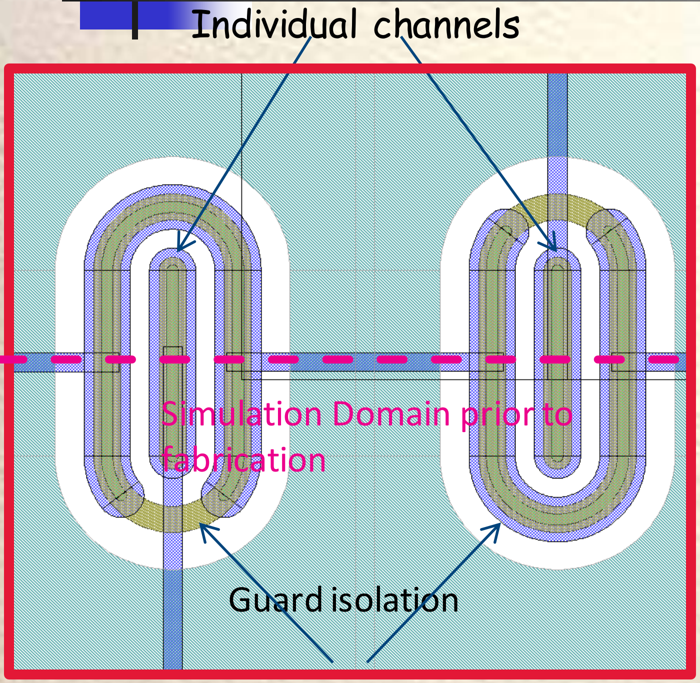
The 3DMiMic Project

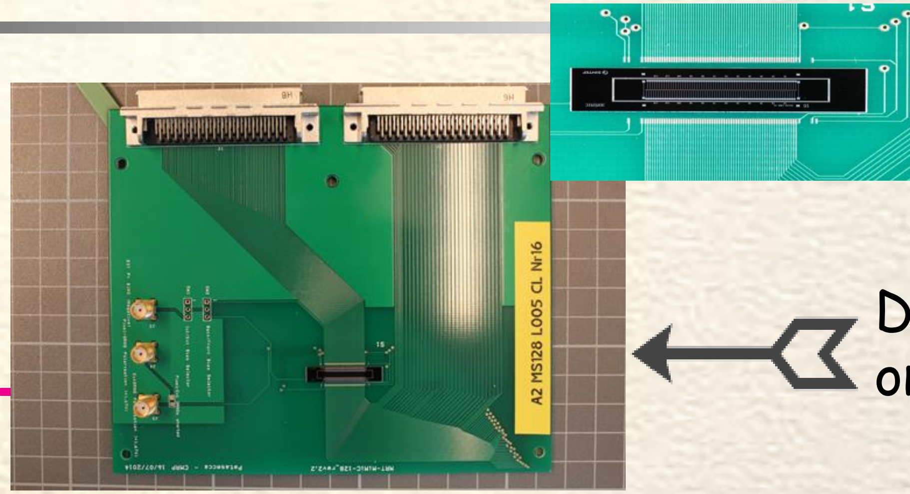
NFR funded (Nanotechnlology): Project owner: SINTEF (A. Kok)
Partners: UiO (M. Povoli), UiB (N. Pacifico, H. Sandaker B. Stugu)
Further collaborators: ESRF (Grenoble) ,Wollongong (Australia), UiB-H.I. group
Community/network: EU-COST action TD1205

The 3DMiMic Project

- Medical physics purposes
  - Produce beam monitors as part of developing methods for MRT, (Microbeam Radiation Therapy), using synchrotron radiation
  - Thin (10 μm thickness) segmented strip sensors for monitoring of arrays of intense parallel X-ray microbeams (typically 50 μm wide, 400 μm apart)
  - Designed using SINTEF 'Rad hard' technology
  - Use the 3D prosessing technology at SINTEF to develop microdosimeters with granularity at the level of human cells (Processing soon to be completed)
  - Design is compatible with readout with the CERN-Medipix/TimePix chip.

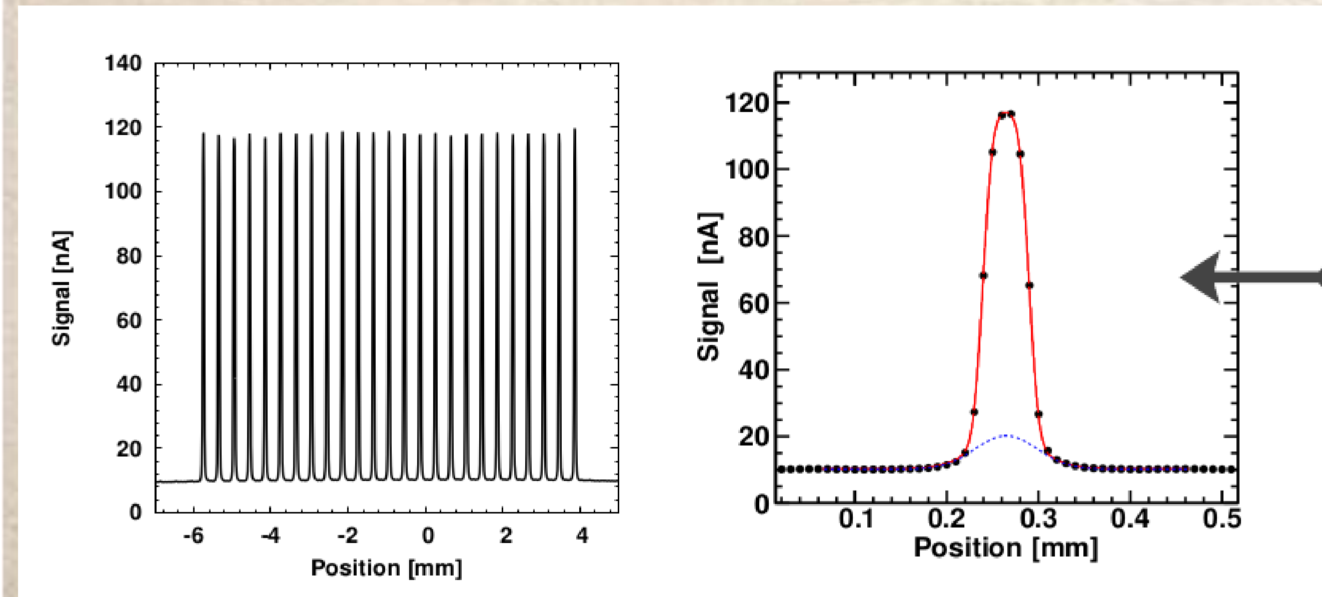
3DMiMic Beam Monitor Design and Results





Device mounted on readout board

Detail of strip and guard ring design



Test results from MRT beams at ESRF (recent JINST submission)

Scan in steps of 10 μm with single channel readout

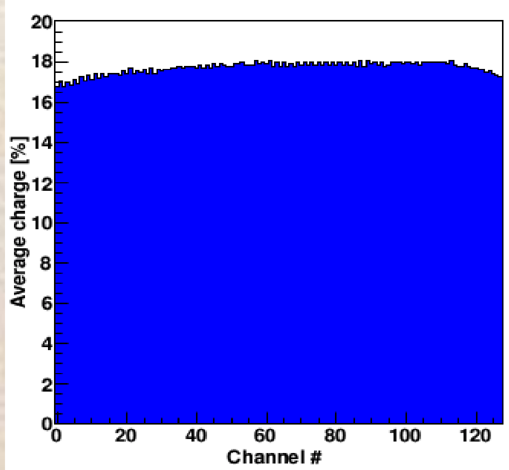
Excellent results are also obtained with system of parallel RO of all channels

Fit to box with smearings compatible with expected 8 μm resolution (+ tails)

3DMiMic Results with Parallel Readout System

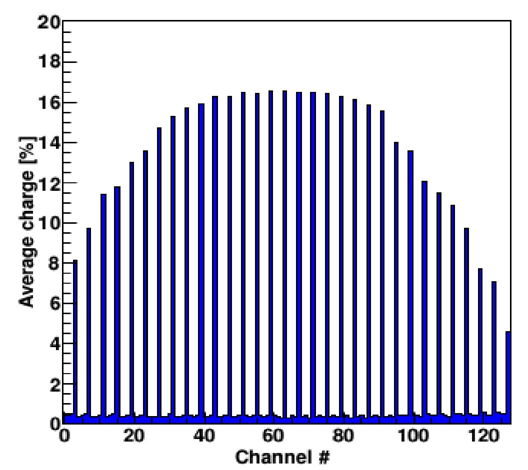
- System, developed at CMRP, Wollongong uses simultaneous readout of 128 channels to monitor the intensity of 25 parallel microbeams, and most importantly, also the intensity in the valleys between the peaks
- Require high dynamic range
- Transverse flow of e & h prevents use of conventional microstrips
- Solution:
  - point-like measurements, with guard-ring insulation between read-out elements
  - Ultra thin sensors
- Drawback:
  - Insensitive regions in the sensor
  - Need for good alignment with beams, and/or good understanding of effects on alignment mismatch

No collimator



No slits, illuminate entire sensor

MRT collimator



50 μm slits 400 μm apart

Forward Calorimeter R&D for ALICE Phase II Upgrade

D. Adnevik, K. Austreim, D. Fehlker, H. Pettersen, D. Röhrich, K. Ullaland, S. Yang

ALICE Forward Calorimeter

- FoCal (under discussion)
  - electromagnetic calorimeter for ©and □^{0} measurements
    + hadronic calorimeter for isolation and jet measurements
  - $\eta \approx 5$
  - main challenge: separation of ©/□^{0} at high energy
  - need small Molière radius, high-granularity read-out
    ➔SiW calorimeter with low- and high-granularity layers

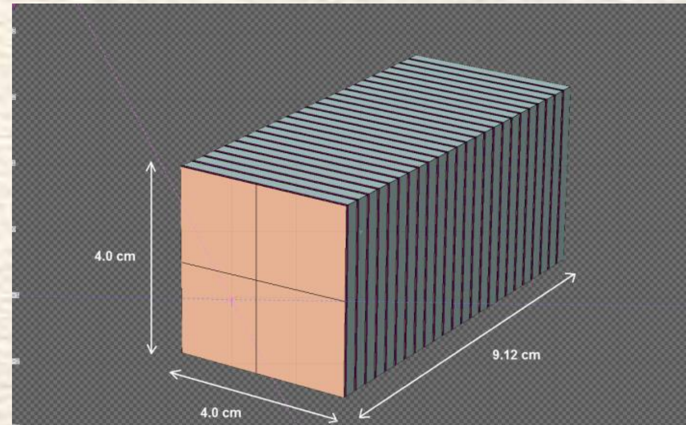
- FoCal prototype
  - high-granularity digital tracking calorimeter

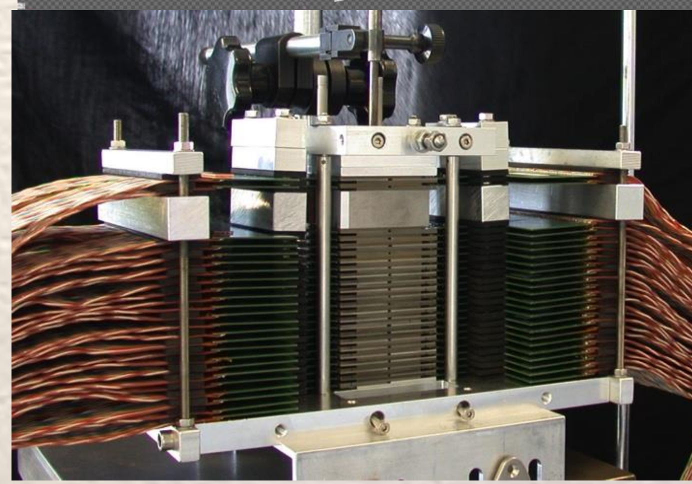
    Institute of Physics and Technology, University of Bergen, Bergen, Norway
    Institute for Subatomic Physics, Utrecht University and Nikhef, Utrecht, the Netherlands

Digital Tracking Calorimeter Prototype (I)

- Silicon-tungsten sampling calorimeter
  - optimized for electromagnetic showers
  - compact design 4x4x11.6 cm^3
  - 24 layers
  - absorbers: 3.5 mm of W ($\approx 1\ X_0$)
    Molière radius: 11 mm
  - active layers: MAPS – MIMOSA 23*
    4 chips per layer -> 96 chips in total

- Readout: 39 Mpixels
  - raw data rate: 61 Gb/s
  - FPGA based readout and DAQ
    - Spartan 6 FPGAs interfacing the MIMOSA chips
    - Virtex 6 based DAQ

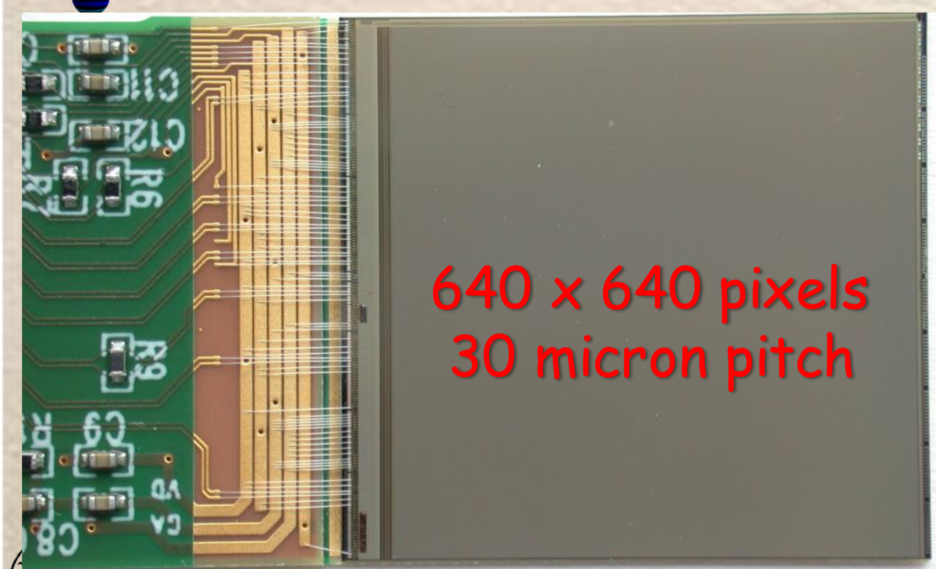


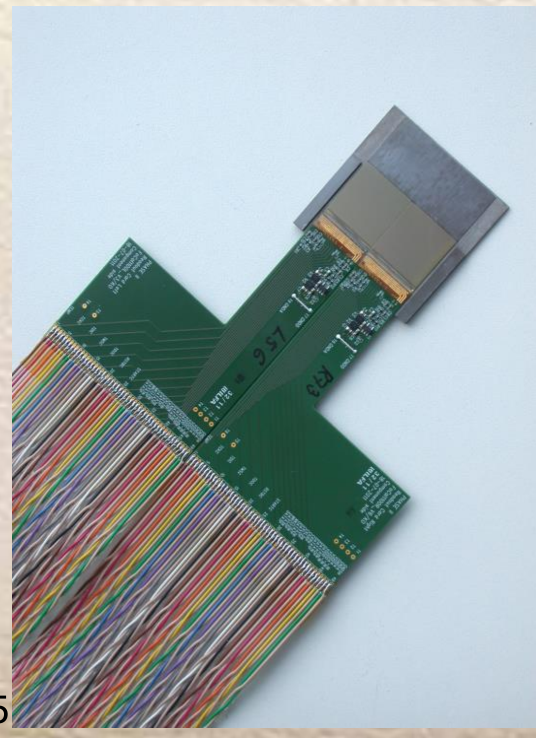


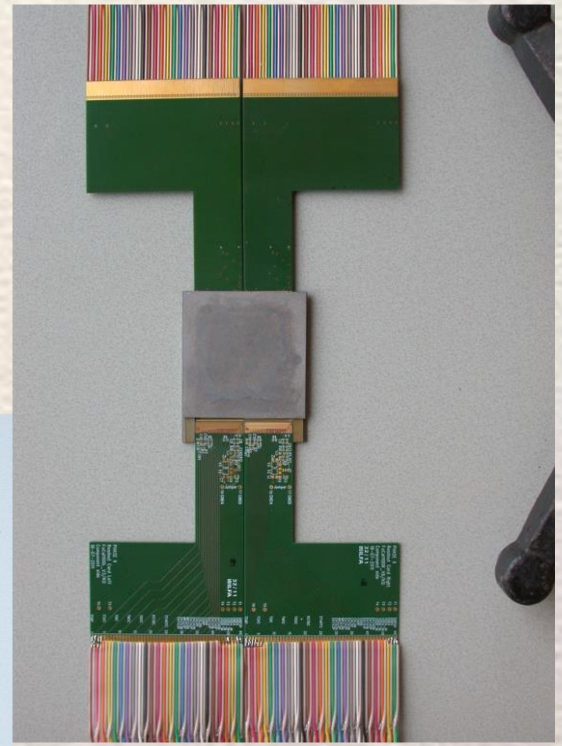
* IPHC Strasbourg

Digital Tracking Calorimeter Prototype (I)

- MIMOSA 23
  - on-chip digitization
    - chip-level threshold setting
    - 1 bit per pixel
  - sequential row readout (“rolling shutter”) -> pixel integration time: 642 μs
  - continuous readout
  - no zero-suppression







Integration of four sensors per layer

Test Beam Results

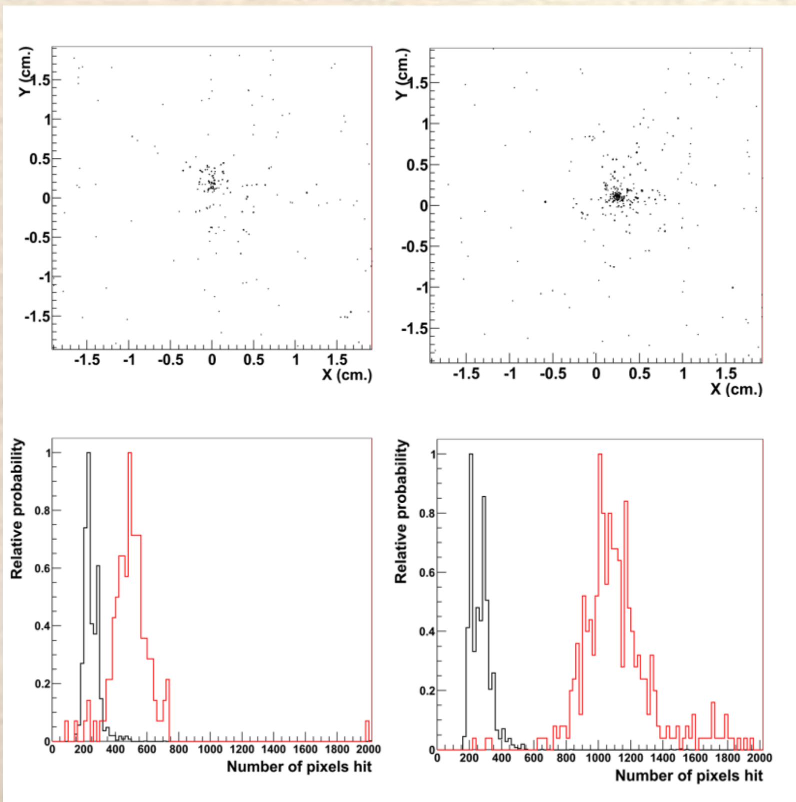
- Digital calorimeter
  - particle counting method -
    number of hits should be proportional to the particle energy

electrons

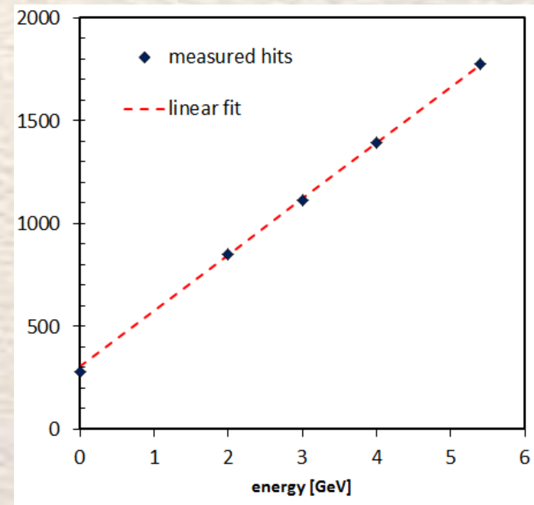
2 GeV   5 GeV

shower pattern

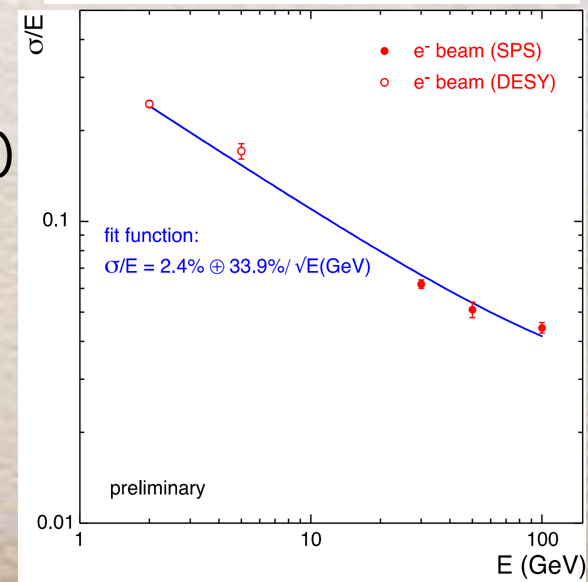
hit distribution



linearity



energy resolution (preliminary)



E. Rocca, ICHEP 2014

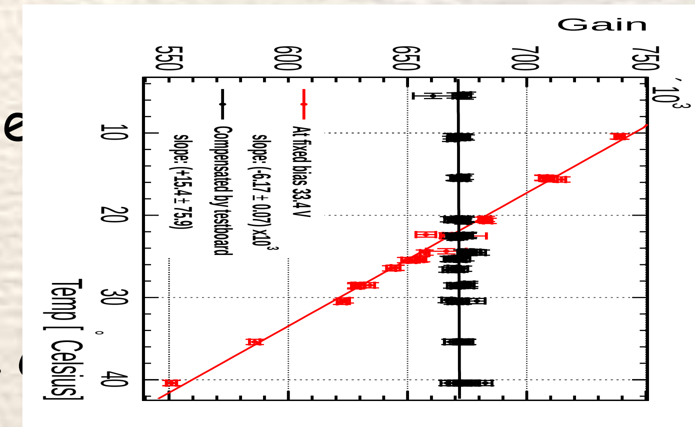
Gain Stability of SiPMs

member of AIDA and AIDA II projects

G. Eigen, A. Traet, E. van der Kraaij, J. Zalieckas
in collaboration with ASCR Prague

Principle of Gain Stabilization

- The gain of SiPMs increases with V_{bias} and decreases with Temperature
- For stable operation, gains (G) need to be kept constant, especially in large detectors such as an ILC hadron calorimeter with 10^6 channels
- The technique consists of adjusting V_{bias} when T changes ➔ requires knowledge of dV/dT that can be determined from measurements of dG/dV dG/dT

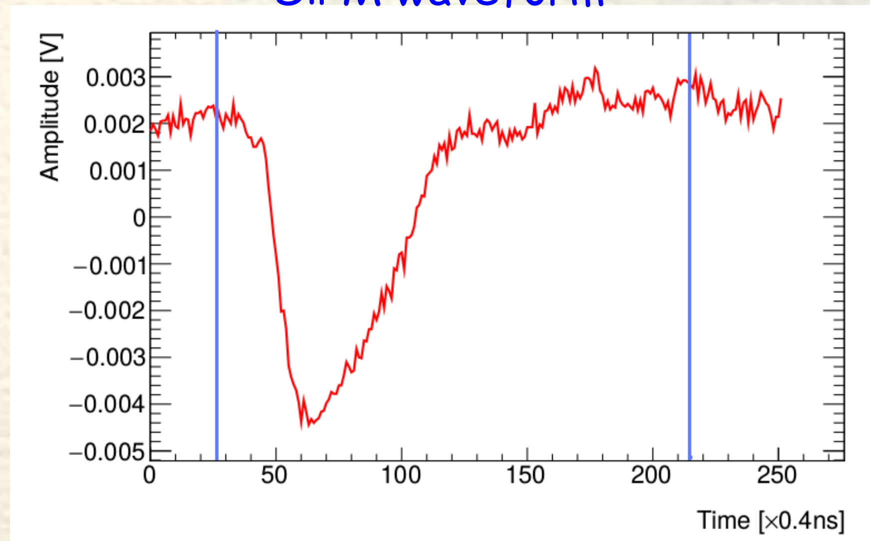


- Measure dG/dV and dG/dT for 17 SiPMs from 3 manufacturers in 3 test periods in a climate
  ➔improved readout in last test (August 2015)
- Built V_{bias} regulator test board to show proof of principle single SiPMs
- Test gain stability with 7 SiPMs
- Goal is to show gain stabilization in a system test with 10-20 SiPMs
- This work is performed in the AIDA2020 framework
  ➔connected to the analog hadron calorimeter R&D for ILC/CLIC
  ➔useful for other applications (e.g. PET scanners)

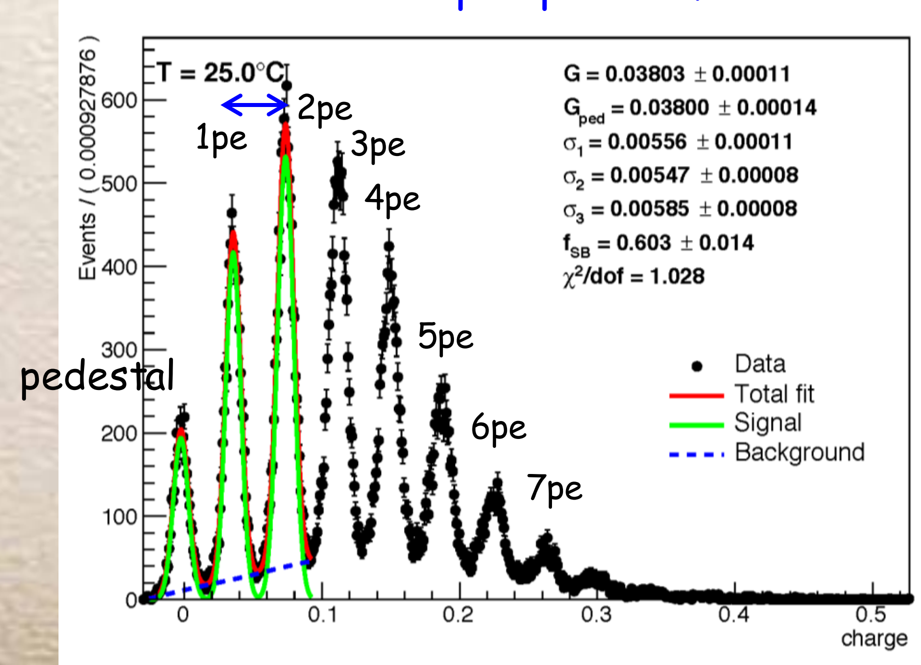
Gain Determination

- Measure waveform of SiPM with 12 bit digital oscilloscope
- Subtract DC offset and integrate all 50k waveforms over fixed time window (74 ns) to determine charge ➔ spectrum of pe
- Determine pe peak position by fitting Gaussian functions to peaks of pedestal, 1pe and 2pe spectra
- Parameterize small background by sensitive nonlinear iterative peak-clipping algorithm
- Gain is determined from the distance between 1pe and 2pe peaks

SiPM waveform

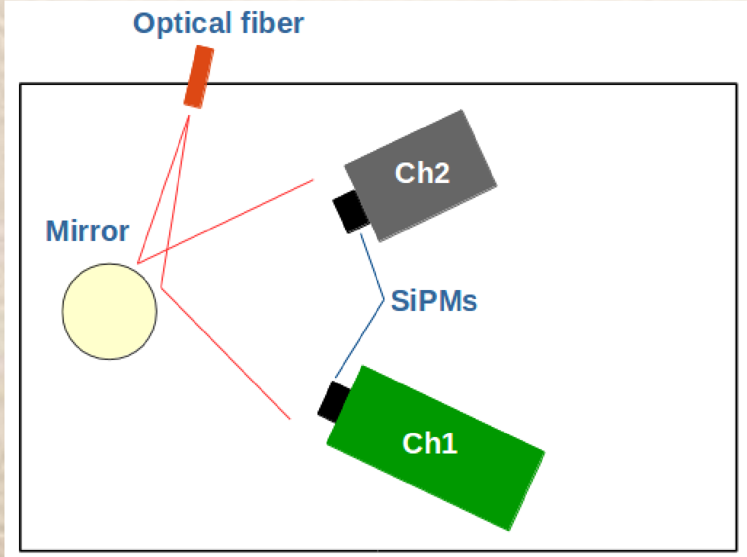


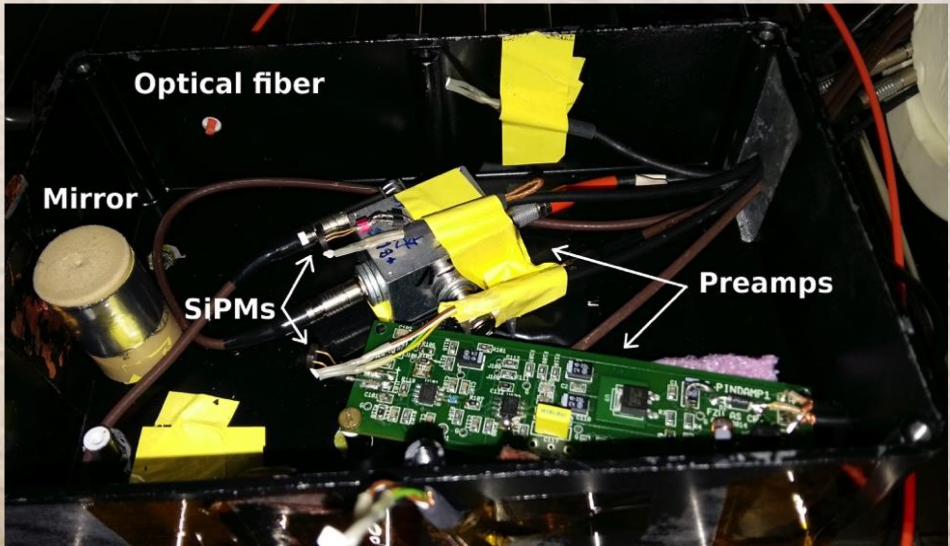
SiPM pe spectrum



Gain Stabilation Test Setup

- Work in a climate chamber at CERN
- Readout 2 channels/preamps simultaneously with digital oscilloscope (12 bit ADC, 2.5 GS/s)
- Low voltage, bias voltage and scope controlled by LabView program
- Shine light from blue LED via optical fiber and mirror onto SiPMs
- Measure temperature with 4 Pt1000 sensors

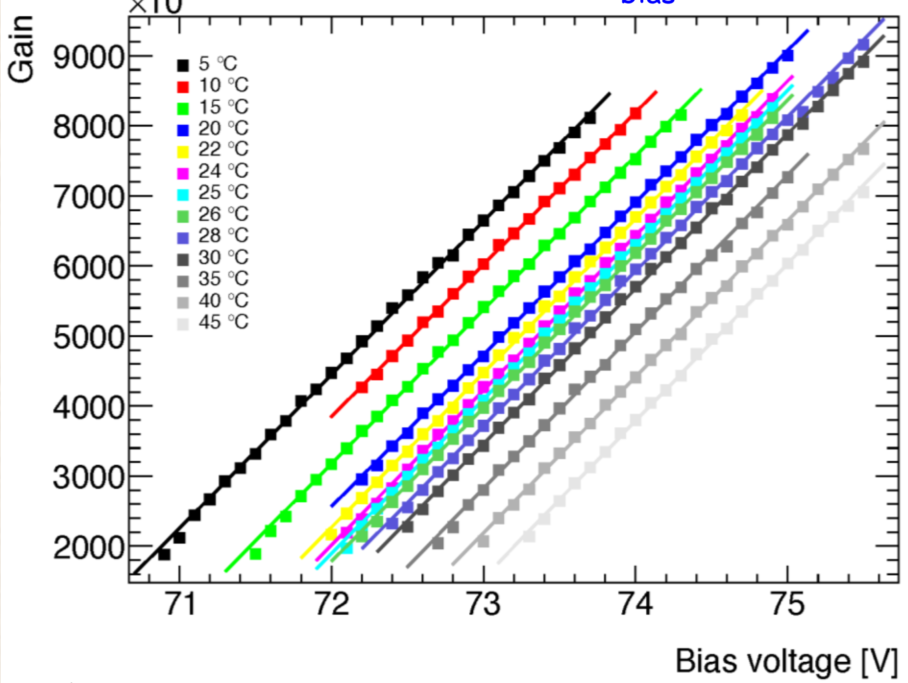




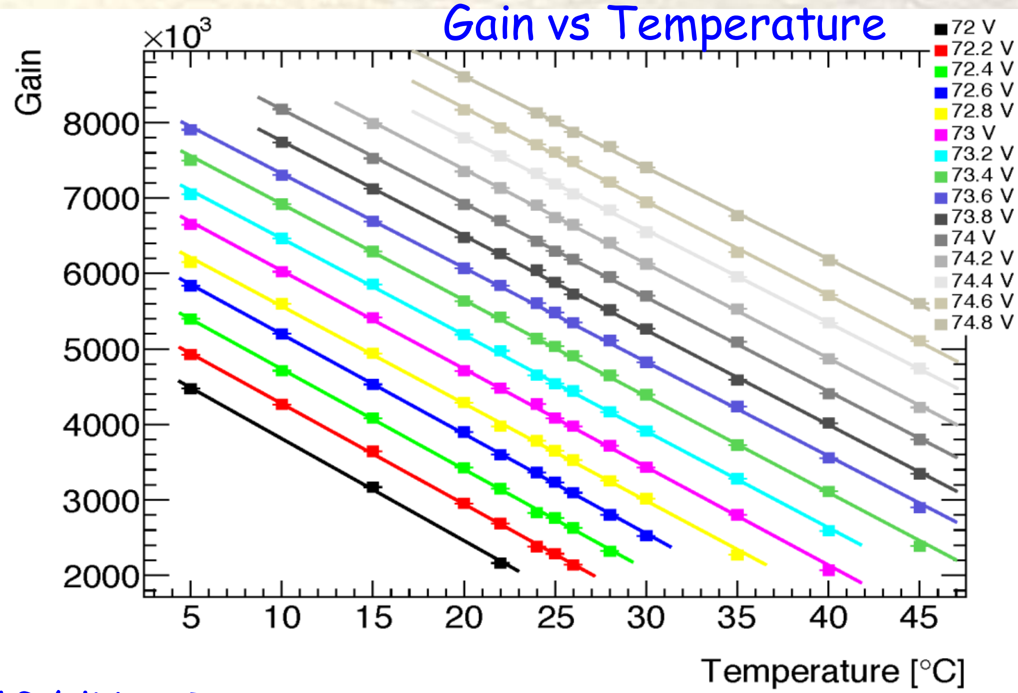
dG/dV and dG/dT Measurements

- Take samples of 50k at different T and V values

Gain vs V_{bias}



Gain vs Temperature



- Measure

$\langle dG/dV \rangle = (22.02 \pm 0.04) \times 10^5/V$

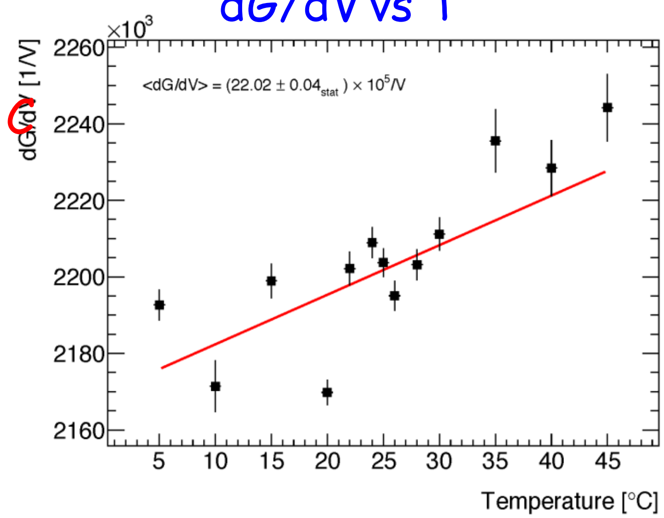
$\langle dG/dT \rangle = -(128.04 \pm 0.01) \times 10^3/°C$

- Extract

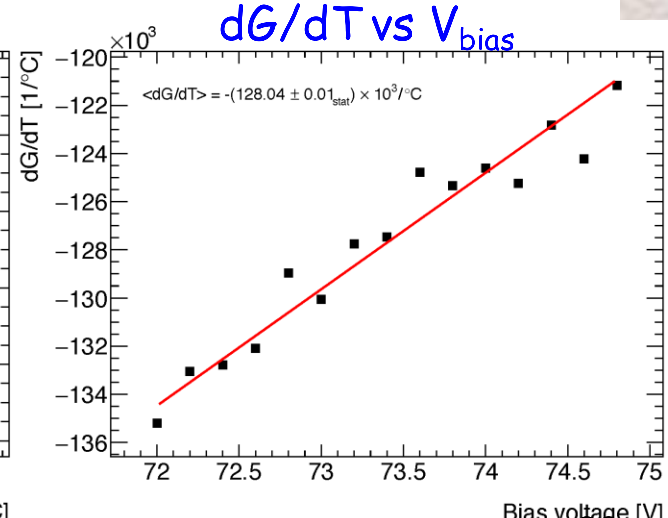
$dT/dV = -(dG/dV)/(dG/dT)$

$= (58.15 \pm 0.1) mV/°C$

dG/dV vs T



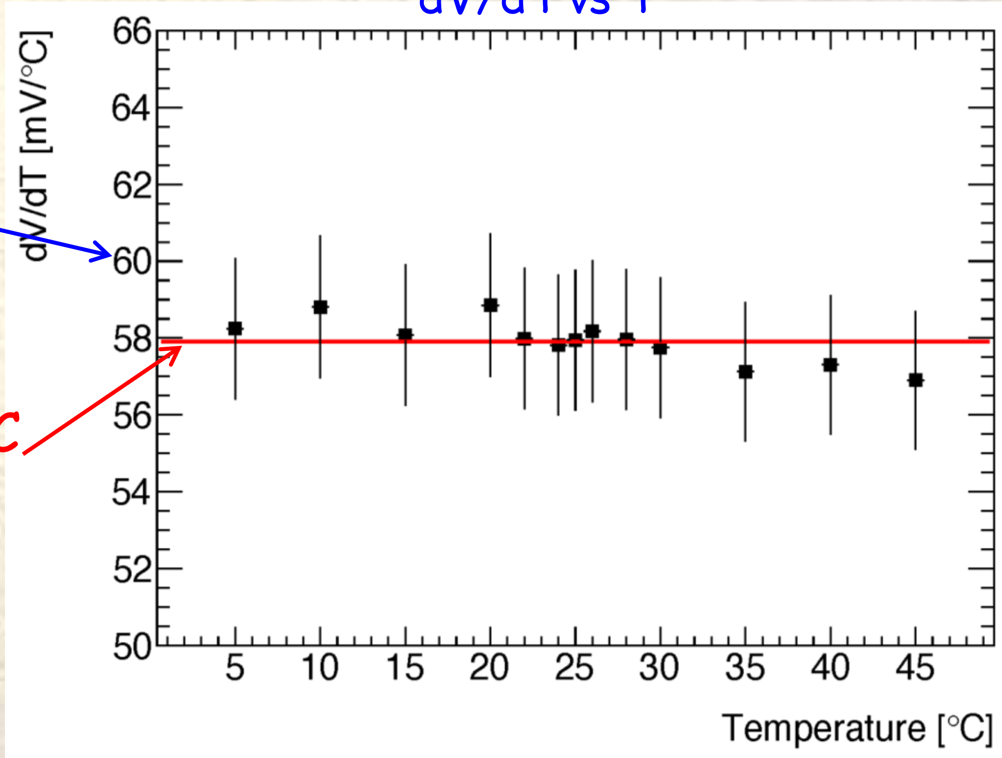
dG/dT vs V_{bias}



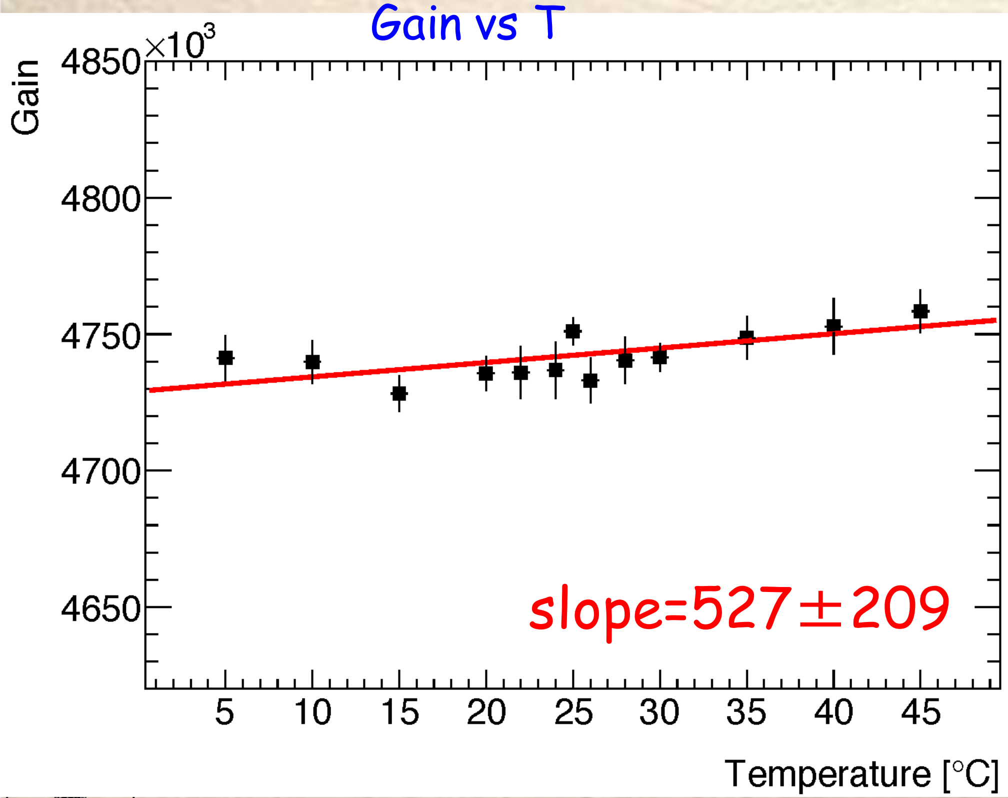
Test of Gain Stabilization

- Determine dV/dT distribution by dividing all dG/dT measurements by dG/dV at each T
- Average dV/dT distribution at each T value and compute error
  ➔ estimate of systematic error
  $dV/dT=(58.15\pm0.10_{stat}\pm0.51_{sys})$ mV/° C

dV/dT vs T



Gain vs T



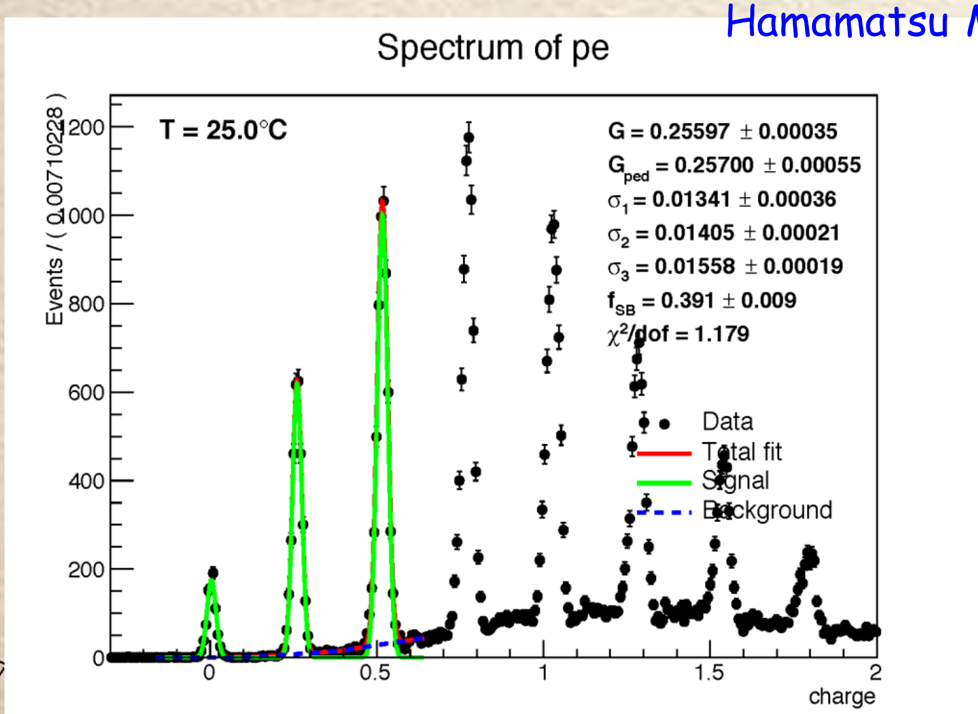
- Adjust V_{bias} with regulator board using compensation of 58 mV/° C
- Test gain stability in 5-45° C T range
- At each T take 10 samples with 50k waveforms
- Gain is uniform in 5-45° C T range non-uniformity is < ±0.1%

Measurement of SiPM Properties

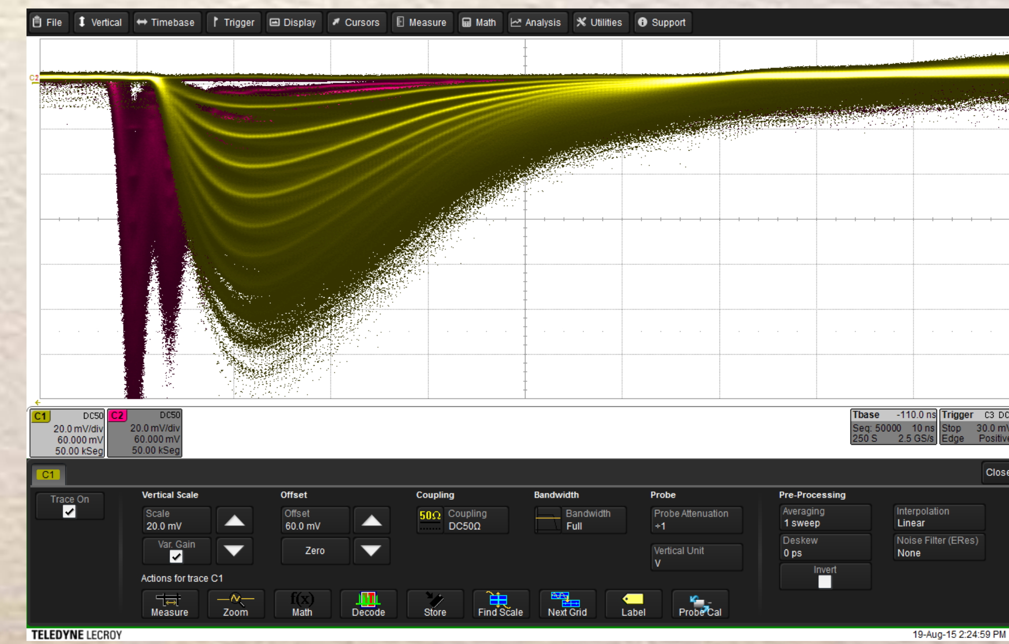
G. Eigen, A. Traet, E. van der Kraaij, J. Zalieckas,

Study of SiPM properties & Optical Readout

- SiPMs are pixelated APDs operated in the Geiger mode
  - Number of pixels determine dynamic range for analog signals
    ➔detectors are non linear
- Gain, nonlinearity, noise, cross talk, after pulsing
- Have 18 different SiPMs in hand from 3 manufacturers
  - Size: 1 × 1 mm² and 3 × 3 mm²
  - Pixel sizes: 15 μm, 20 μm, 25 μm, 40 μm, 50 μm
  - new detectors with trenches (reduces cross talk) ➔very clean



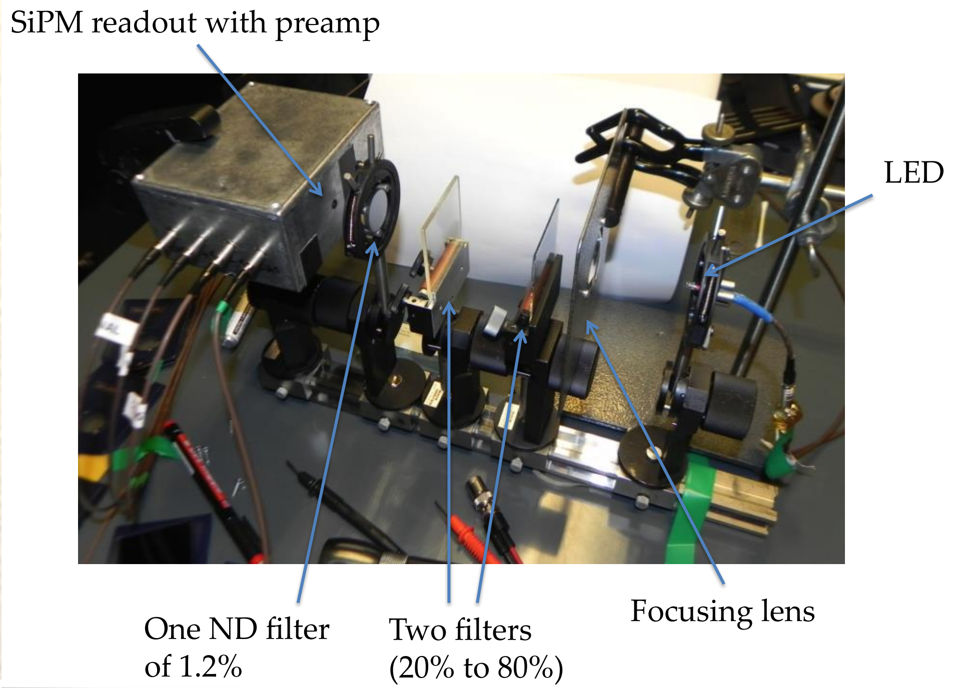
Hamamatsu MPPC with trenches

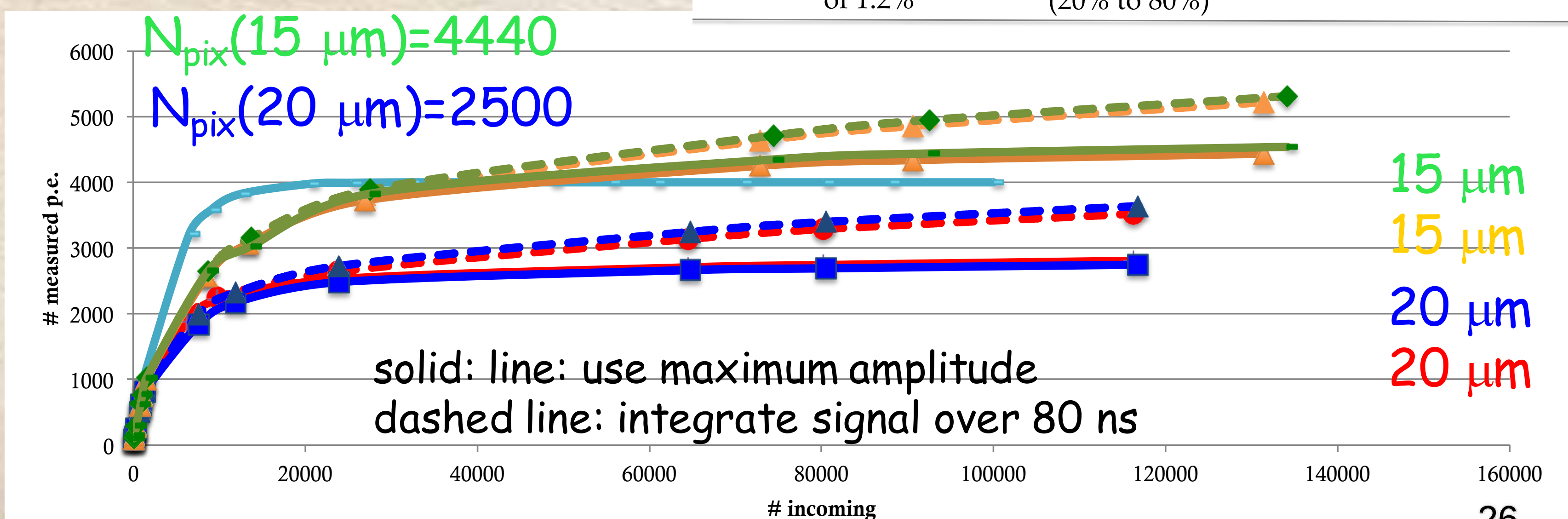


Measurement of Nonlinearity

- With LED and filters we tried to measure the dynamic range at CERN
- Minimum pulse length of 10 ns is too long to see saturation (due to after-pulsing)
- Thus, will redo study with blue laser (50 ps pulse)
- Expected saturation

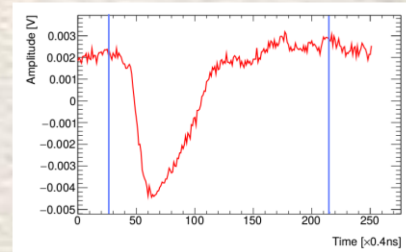
$$N_{obs} = N_{pix}\left(1 - e^{-\frac{N_\gamma}{N_{pix}}\varepsilon(1+\kappa)}\right)$$



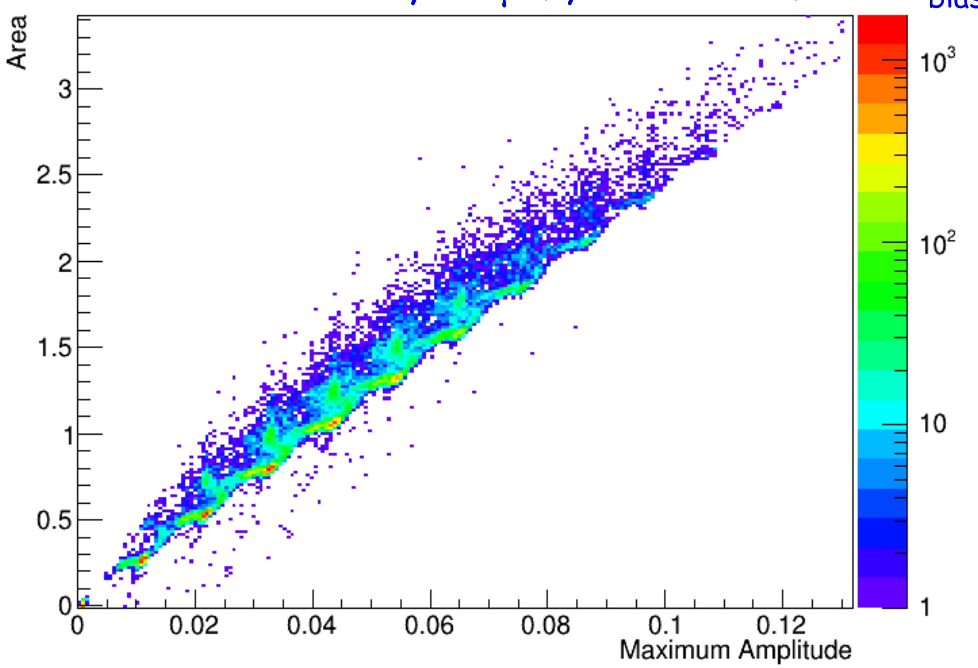


Waveform Analysis

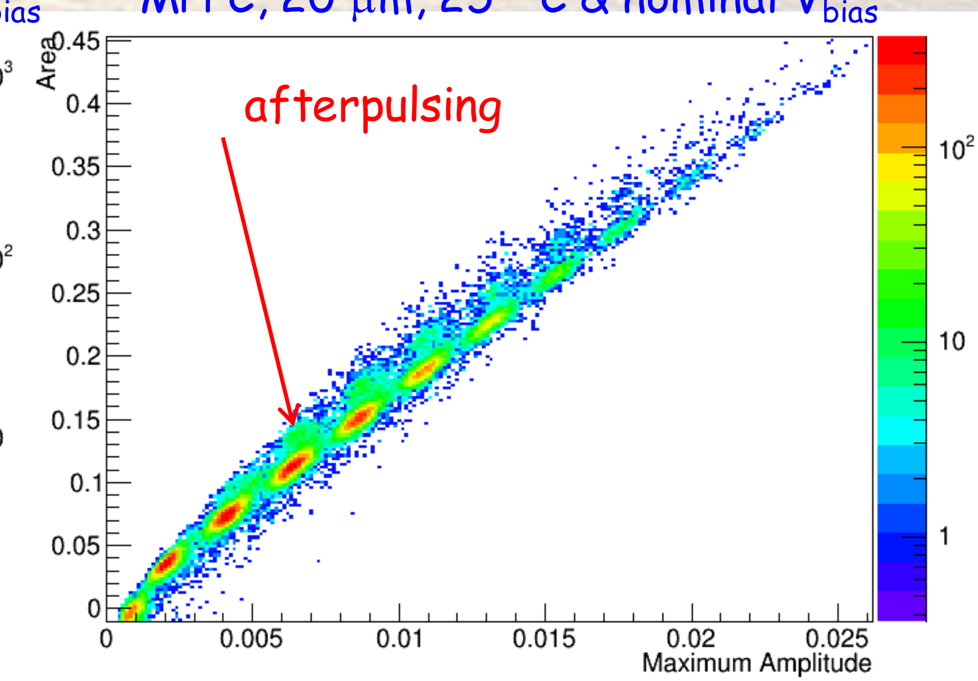
- Compare photoelectron spectra obtained from integrated charge to photoelectron spectra obtained from peak position of waveform
- Since after-pulsing is typically delayed, it will affect the decay time and thus the integrated signal but not the minimum amplitude
  ➔ from comparison may learn something about afterpulsing
- MPPC with trenches show less afterpulsing than that without trenches



MPPC with trenches, 40 μm, 25° C nominal V_{bias}



MPPC, 20 μm, 25° C & nominal V_{bias}

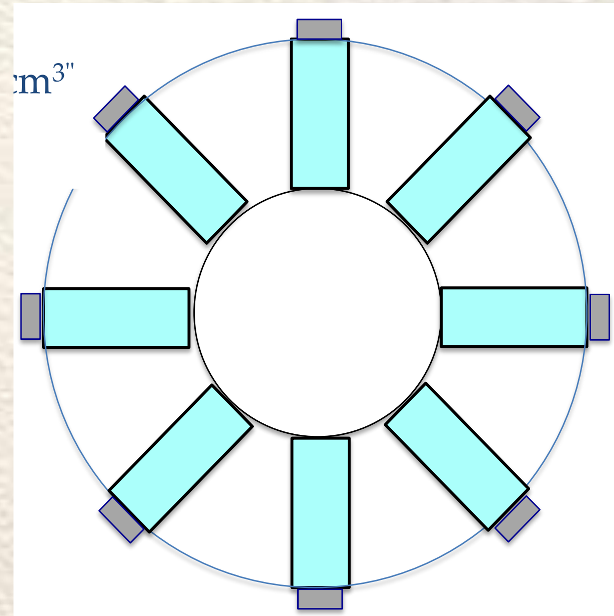


Beam Radiation Monitor

G. Eigen, A. Marinov

Beam Radiation Monitor

- Task is to build a beam radiation monitor for KLOE at the DaΦne experiment in Frascati
- Detector consists of an array of 8 LYSO crystals arranged in a ring around the beam pipe to record beam radiation photons in 100 keV energy range
- Each crystal (dimension: 0.5 x 0.5 x 4 cm^3) is wrapped in ESR film and is read out with a KETEK SiPM (3 x 3 mm^2) with 12100 20 x 20 μm^2 pixels
- All 8 crystal are completed 6 were tested with ^{133}Ba, ^{57}Co, ^{22}Na, ^{137}Cs & ^{60}Co sources
- Preamp is not optimally matched to SiPM
  ➔signal is rather long (integration time > 200 ns)
  ➔work on faster preamp
-

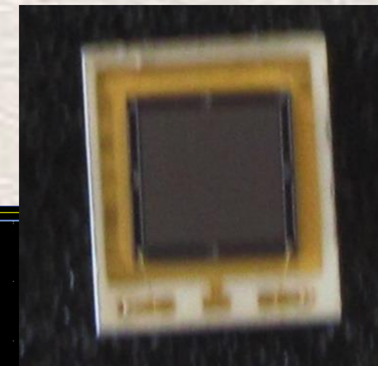


Setup of LYSO Crystal Measurements

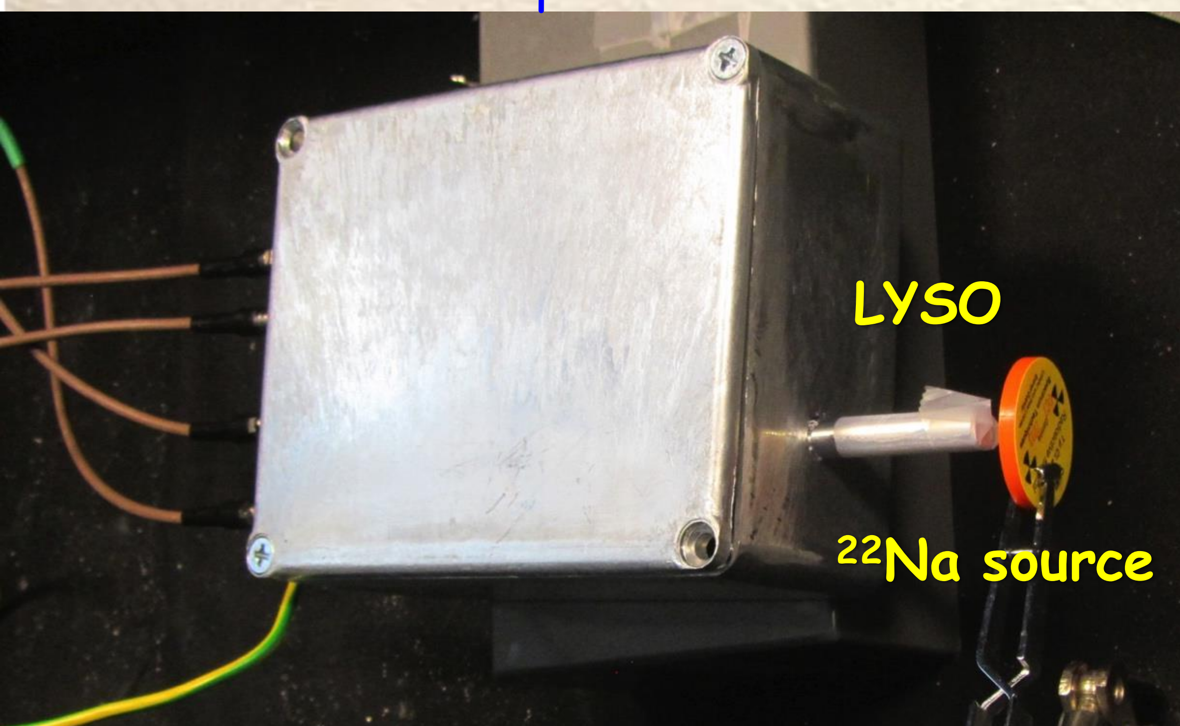
- Shield SiPM & preamp in metal box
- Wrap LYSO crystals in 2 layers of Tyvec & 1 layer of silvered mylar, place silvered mylar at front face & around the SiPM
- Record spectra from various sources in a black box

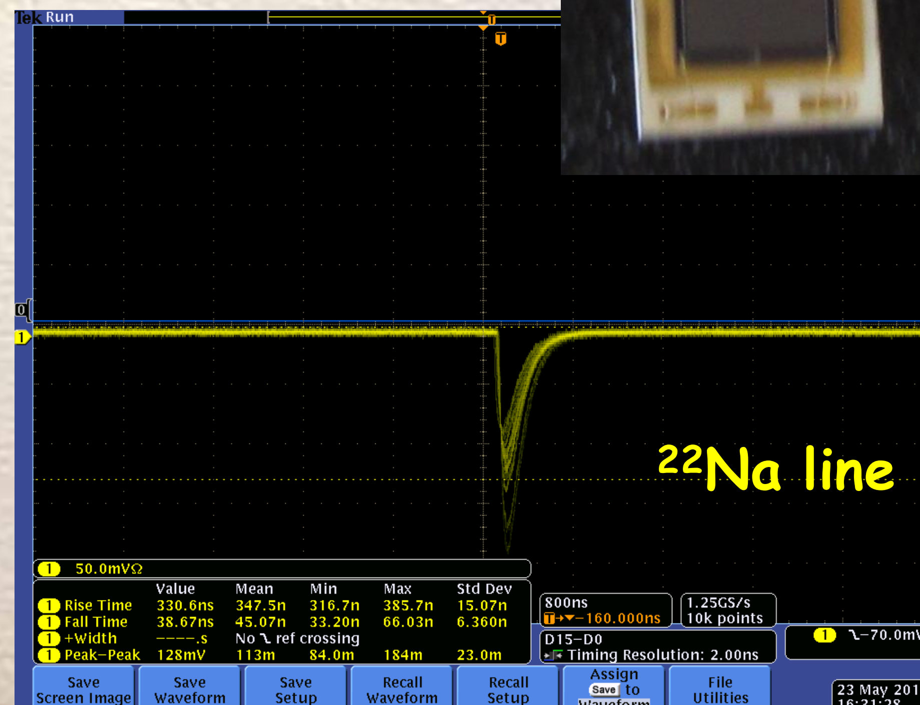
LYSO crystal

KETEK SiPM



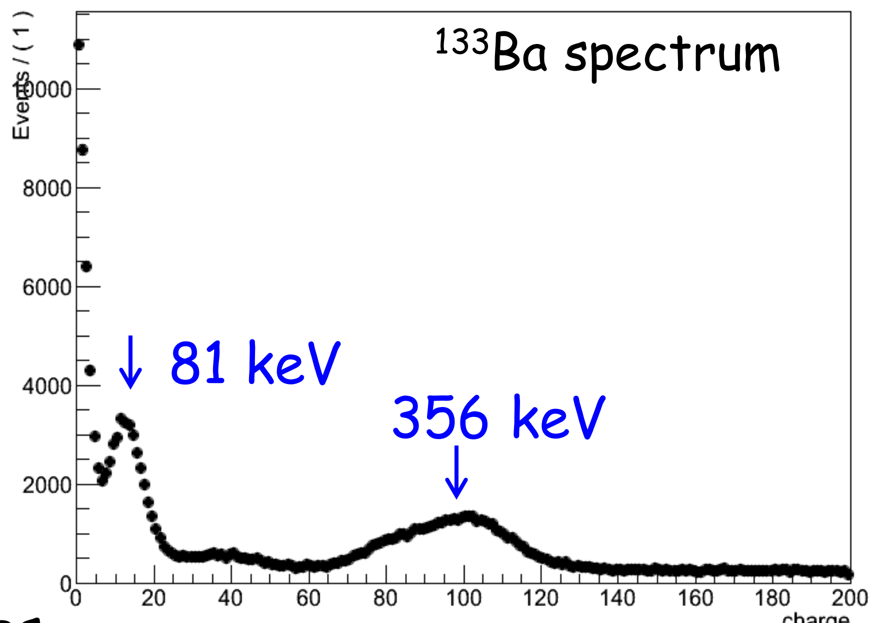
Setup inside black box

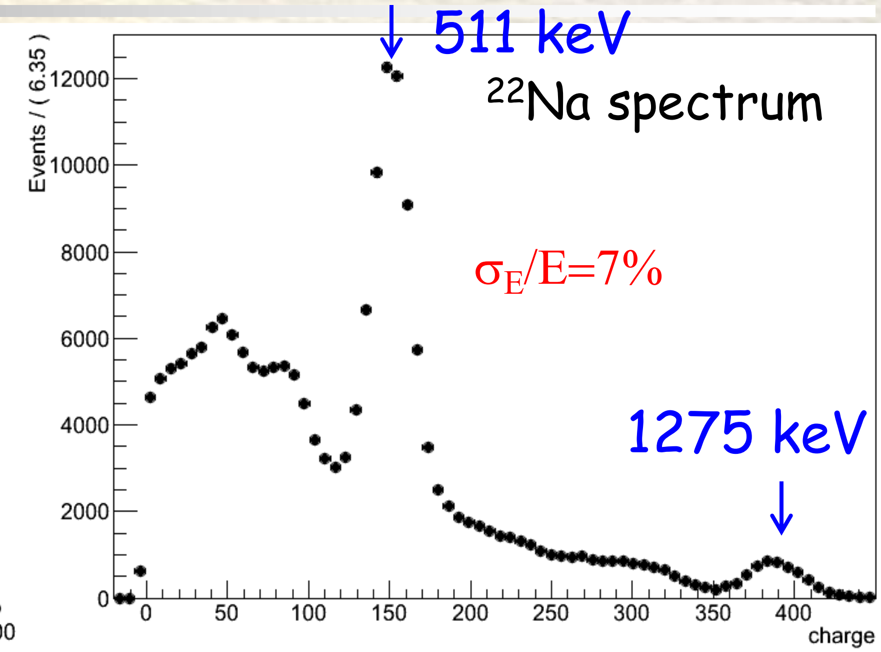




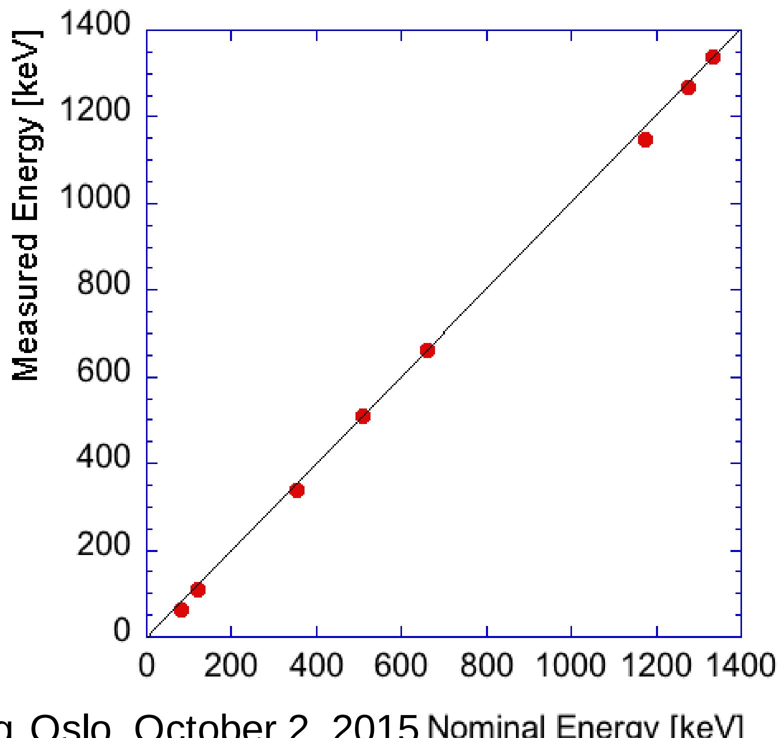
Results of LYSO Crystal Measurements

- Measure photon energy spectra from ^{22}Na, ^{57}Co, ^{60}Co, ^{133}Ba & ^{137}Cs sources

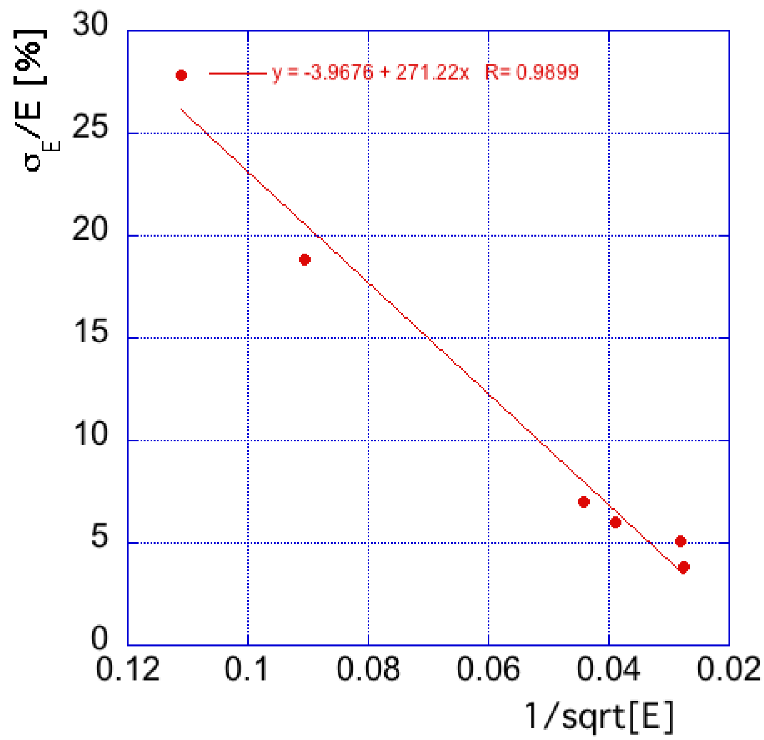




- Energy scale is linear at least up to 1.33 MeV



- Energy resolution is consistent with $1/\sqrt{E}$ dependence



Concluding Remarks

- We conduct a rich detector R&D program on
  - 3D Si detectors for ATLAS phase II upgrade
  - 3D charge collection efficiency

    ➔ Use ATLAS funds
  - 3D MiMic application ➔ NFR funded
  - forward calorimeter for ALICE phase II upgrade ➔ Use ALICE funds
  - gain stabilization of SiPMs
  - studies of SiPM properties
  - beam radiation monitor

    ➔ No university and NFR funding only AIDA/AIDA 2020 support and existing manpower

- 4 years ago, NFR cut grant for future accelerators/experiments by 30%

➔ Since then R&D for ILC/CLIC has diminished ➔ caused problems with AIDA tasks

➔ déjà vu, need postdoc to fulfill AIDA 2020 tasks, funding is not clear