The ILD/CALICE Silicon-Tungsten Electromagnetic Calorimeter: status and potential

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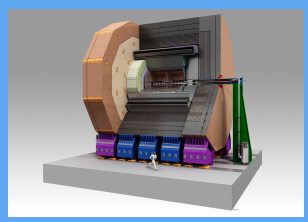
SiW-ECAL

- highly granular ECAL for Particle Flow Algorithms (PFA)
- 20–30 silicon Si active readout layers, 5x5mm^2 cells
- tungsten W absorber, roughly 23X_0, 0.8λ
- for ILD (ILC), CEPC, FCC, same technology in CMS HGCAL, ATLAS HGTD for High Luminosity LHC

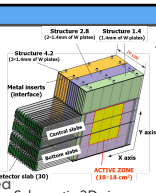
International Large Detector (ILD) for e^+/e^- International Linear Collider (ILC)

- tracker & calorimeters optimised for PFA
- 3–4% jet energy resolution for 40 GeV<E_{jet}<250 GeV
- other detector concept, Silicon Detector (SiD), also has SiW ECAL

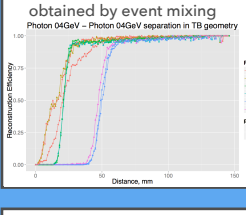


Physics prototype

- confirmation of PFA physics principles
- 30 Si layers: 18x18cm^2 active area, 6x6cm^2 sensors, 1x1cm^2 cell size
- VFE electronics not embedded into active layer
- <~1% ECAL nonlinearity and 1.1% syst. error for 6…45 GeV e^-
- verification of PFA: separation of 2 showers obtained by event mixing



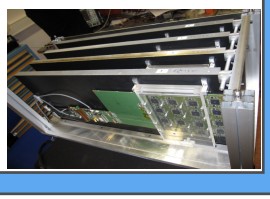
Schematic 3D view on ECAL physics prototype



Probability to reconstruct 4+4 GeV EM showers with correct energies and positions by 3 PFA programs as a function of shower distance. Good agreement between data and MC.

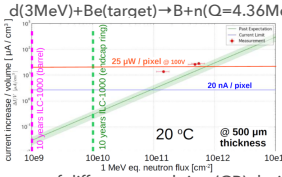
Technological prototype

- R&D and tests of technological options suitable for future mass production
- 5x5mm^2 cells, embedded VFE electronics,
- dedicated ASIC chip SKIROC2 with 64 channels, 1fQ–10pQ dynamic range
- duty cycle of ILC bunch trains: 1ms/200ms=0.5%, VFE electronics is switched ON ~1ms before bunches for stabilisation and OFF in ILC idle time to reduce power dissipation = power pulsing



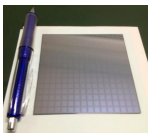
Silicon Sensor Studies

- neutron irradiation of small sensors at Kobe tandem accelerator: E_n<7.8MeV, d(3MeV)+Be(target)→B+n(Q=4.36MeV)

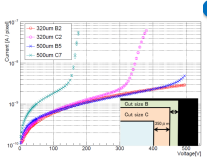


Increase on dark current is acceptable for 1 TeV ILC 10 year operation

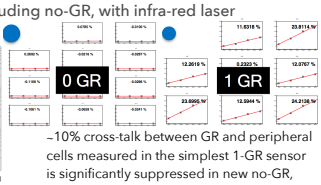
- tests of different guard-ring (GR) designs, including no-GR, with infra-red laser



Sensor with 5.5x5.5mm^2 cells



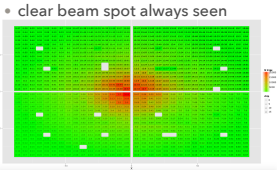
Leakage current no-GR



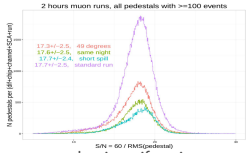
~10% cross-talk between GR and peripheral cells measured in the simplest 1-GR sensor is significantly suppressed in new no-GR, (2,4)-GR designs.

SiW-ECAL beam tests (Nov'15, CERN)

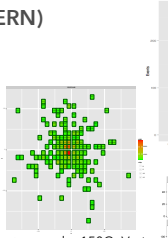
- stable operation of the first prototype with 3 layers, each with 1024 channels (Active Sensor Units, ASU), during 2 weeks of tests
- 15…150 GeV e^+, π^+, μ^+ beams
- clear beam spot always seen



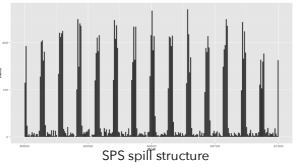
- 2.2% channels masked
- good signal over noise ratio S/N=17…18



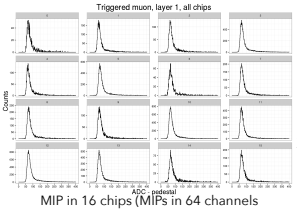
- very good gain uniformity across all channels (≈5%): Si thickness=const, variation dominated by VFE electronics
- average μ^+ efficiency: 98–99%



Event example: 150GeV e^+ after 8.4X_0 of W.

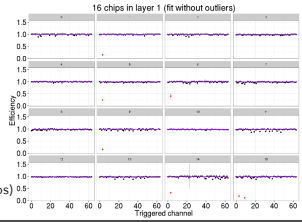


SPS spill structure



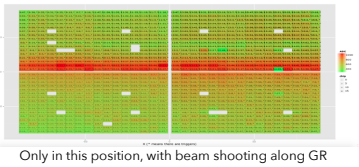
MIP in 16 chips (MIPs in 64 channels within one chip are also the same)

μ^+ beam: normal and 49° incidence, standard and short period of data taking, ~60 hours of operation, each histogram entry corresponds to one pedestal spectrum

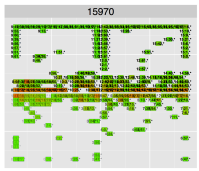


Efficiency in one layer (64 channels x 16 chips)

- improved GR design, very low rate (<0.04%) of induced "square events", when many peripheral cells are fired due to capacitive coupling to GR



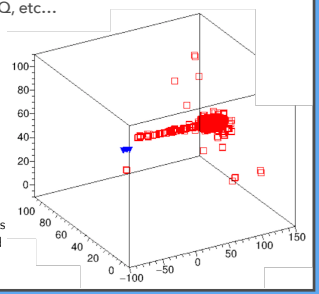
Only in this position, with beam shooting along GR side, we got significant amount of "square" events.



"Square" event example

SiW-ECAL+SDHCAL combined beam tests (Jun'16, CERN)

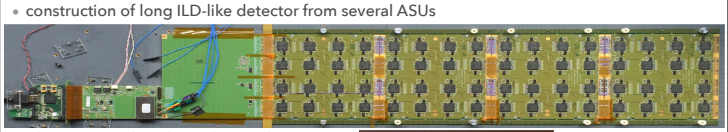
- debugging of synchronisation, common running, DAQ, etc…
- suffered from high noises in ECAL, to be improved



π^+ event: SiW ECAL hits in blue, SDHCAL in red

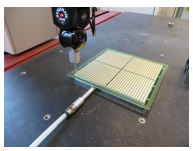
Ongoing SiW ECAL activities

- new version of VFE chip SKIROC2B is produced, to be tested
- construction of long ILD-like detector from several ASUs

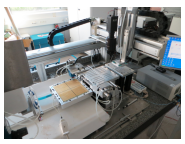


- Chip On Board (without chip packaging) alternative more compact design, but difficult technologically

- preparation for industrialisation: well defined procedures, metrology checks, robotic gluing of Si to PCB, etc…



Si metrology tests before gluing

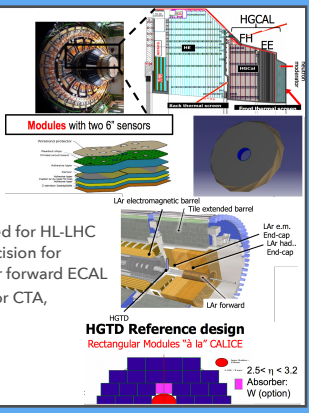


Robot for gluing Si wafers to PCB

- thermal studies for ILD SiW ECAL

ILD/CALICE SiW ECAL inspired other groups

- HGCAL, full upgrade of CMS calorimeter endcups, approved for HL-LHC
  - 312 cassettes, 44k wafers, 100k FE ASICs, 6M channels
  - high radiation (max 10^{16}n/cm^2), thinner 100-300μm Si wafers to limit radiational damage
  - -30°C operational temperature
  - continuous current operational mode 100kW
  - difficult reconstruction because of high pile-up
- ATLAS HGTD, dedicated "timing" detector device, proposed for HL-LHC
  - 4 layers of high granularity Si with 20-30ps timing precision for 2.5<η<4.3, currently covered by inner wheel of the LAr forward ECAL
- FE and DAQ for T2K-Wagasci, PM calibration test bench for CTA, JUNO part of the DAQ of the TT



References

1. Development of a Highly Granular Silicon-Tungsten ECAL for the ILD, Nucl.Part.Phys.Proc. 273-275 (2016)
2. SKIROC2, front end chip designed to readout the Electromagnetic CALorimeter at the ILC. Journal of Instrumentation, 6(12):C12040, 2011
3. Design and electronics commissioning of the physics prototype of a Si-W electromagnetic calorimeter for the International Linear Collider. JINST 3 (2008) P08001