Recent results on SiW ECAL

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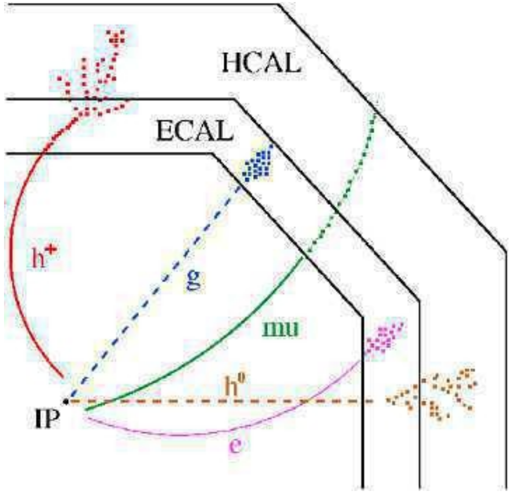
on behalf of SiW ECAL collaboration
ILD meeting 2014, Oshu

People

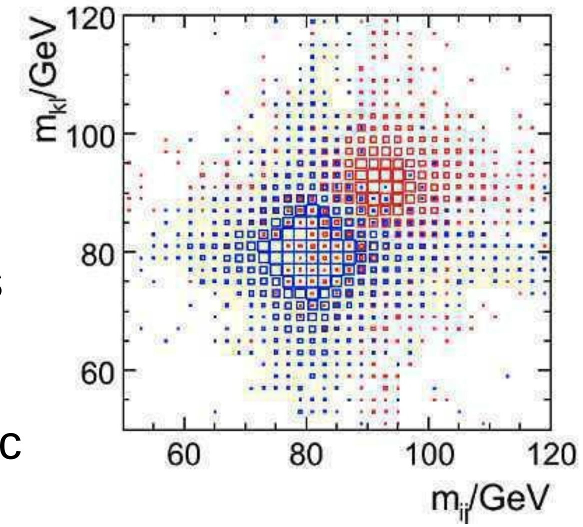
Japan: ICEPP (Tokyo Uni), RCAPP (Kyushu Uni),
France: Omega group, LAL, LPNHE, LPSC, LLR



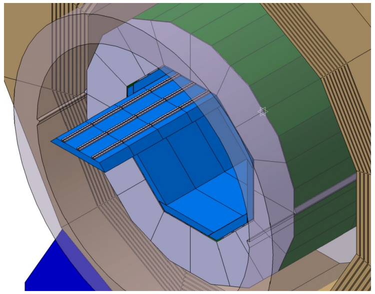
Particle Flow Algorithm:
Jet = 65% charged + 25% γ + 10% h0
Tracker ECAL HCAL

σE/E (jet) = 3...4%

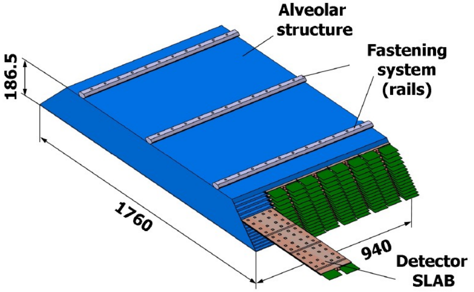
– High granularity imaging calorimetry is needed to assign CAL clusters to tracks.
– To avoid overlaps of electromagnetic showers with themselves or with hadronic showers: small Moliere radius and large interaction / radiation length ratio, select tungsten (W) as absorber (140 t)



Distinguish WW/ZZ in
e+e- → WW$\nu\underline{\nu}$ → WW/ZZ $\nu\underline{\nu}$



Two main options for active detector:
– Scintillator (next talk by T.Takeshita)
– Silicon (subject of this talk)



Si advantages:
– best granularity (eg. 5x5 mm2, then 100 M channels in TDR with 29 layers, ie. without first preshower ECAL layer which was never used in reconstruction)
– simple calibration (mainly, electronics gain, silicon signal depends on the thickness which is rock stable)
– linearity (determined by electronics)
– time stability
– robustness
– low systematics

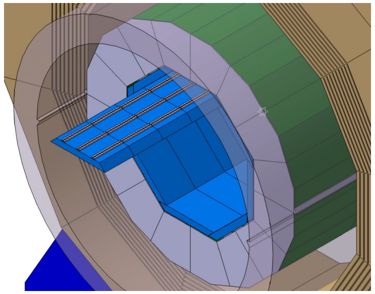
– Disadvantage: high cost (2600 m2 of Si in TDR)

Comparison with HCAL:
– stat. error: $\sigma E/\sqrt{E}$ = 17% or 60% for ECAL, HCAL, so
constraints on systematic errors are much more stringent for ECAL
(eg. linearity incl. saturation, uniformity, calibration accuracy and time stability)

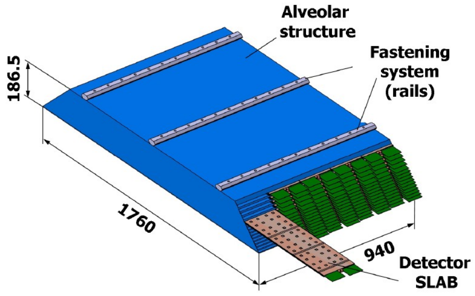
– contribution of stat. error to jet energy resolution (neglecting fluctuations of charged/e.m./neutral hadron fractions = 0.65/0.25/0.10):

$\sigma E = 0.17 \sqrt{(E*0.25)} \oplus 0.60 \sqrt{(E*0.10)} = (0.085 \oplus 0.19)\sqrt{E} = 0.21\sqrt{E}$,
so, HCAL term dominates, moderate ECAL statistical resolution of 17%/$\sqrt{E}$ is sufficient

	Scintillator	Silicon	Comment
MIP response	7 photons	37 K pairs	Poisson fluctuation for Sc
amplification	SiPM: (2 – 3)e5	1	
Total MIP signal	(1.5 – 2)e6	40 – 60 times lower signal. Compensated by electronics gain	Electronics with lower noises is required for Si. Harder than in tracking detectors because of larger pads and associated input capacitances.
Uniformity	Optimization on-going	Close to 1	
Intrinsic linearity	SiPM saturation, asymptotic value != N pix, sometimes no asymptotic, not understood	Linear	Sc calibration in full dynamic range is required, probably per channel
Calibration	As a function of HV, temperature	Once, “forever”	Per SiPM, to be included to the cost
Stability	Monitoring of HV, T, continuous on-line calibration	Perfect	
Intrinsic xtalk	O(1%), HV dependent, MIP absolute calibration is required	Absent, except at guard ring	Continuous on-line LED calibration is not absolute
FE chip xtalk	Present	Present	Unavoidable with low power electronics, to be simulated
Automation	One strip at a time	256 pixels per sensor at a time	
Cost	1 ILCU/SiPM = 0.44 ILCU/cm2 for 0.5x4.5 strips	3 ILCU / cm2, real offer	Cost of SiPM characterization, strip wrapping, assembly is not included



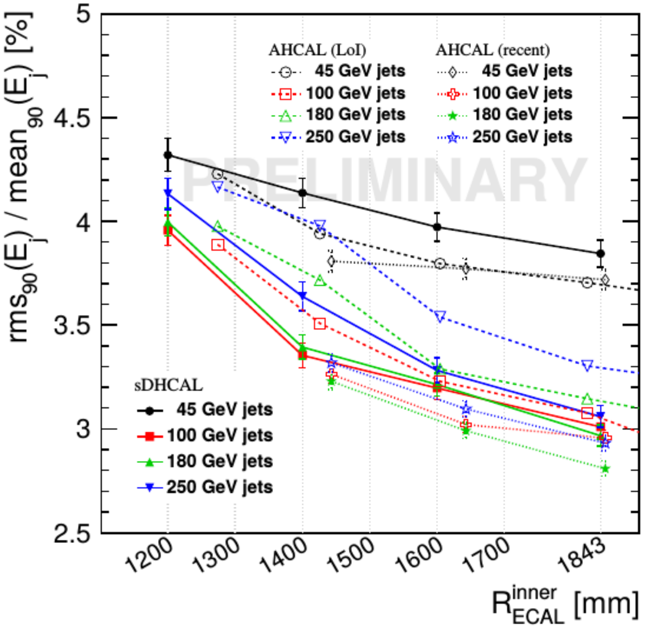
Cost / performance optimization



– N ECAL layers and dimensions

eg. R=1843 -> 1500, N layers = 29 -> 25 reduces the ECAL cost by about 40%

(see V.Boudry's and M.Thomson's talks)

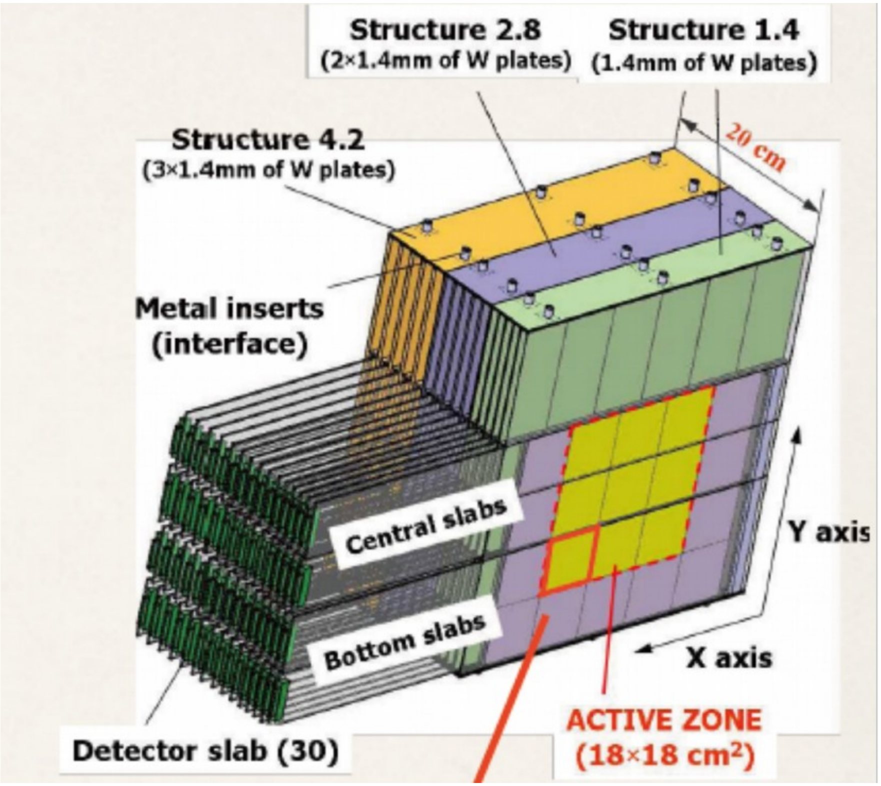


– 10% of bad pixels is affordable (not tracker device), lower price

Recent interest to Si-W(Pb) technology

... for CMS endcap Phase 2 upgrade (HGCAL) and for circular collider projects (TLEP, CEPC)

Physical prototype: 2005-2011

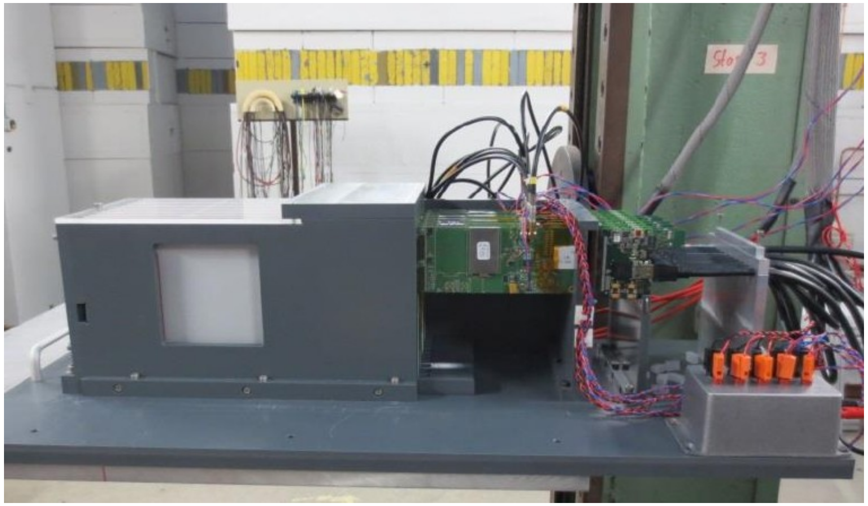


Conceptual proof of PFA,
verification of MC

10x10 mm2, 30 layers
Electronics outside

$\sigma E/E = 16.6\%/\sqrt{E} \oplus 1.1\%$,
linearity within 1%.

Technological prototype: present



Embedded electronics

Assess feasibility, choose and finalize design, prepare mass production

SKIROC 2 chip: autotrigger, power pulsed (gives higher noises at acceptable level) channel-wise zero suppression is planned for SKIROC 3.

Charge injection + cosmic + laser tests,
4 TB @DESY 1-5 GeV e- in 2012-2013.

Silicon sensors

Hamamatsu (HPK) offer in 2013: 31000 Yen per 98x98 mm2 sensor or 2.54 EUR/cm2, full ILD ECAL production.

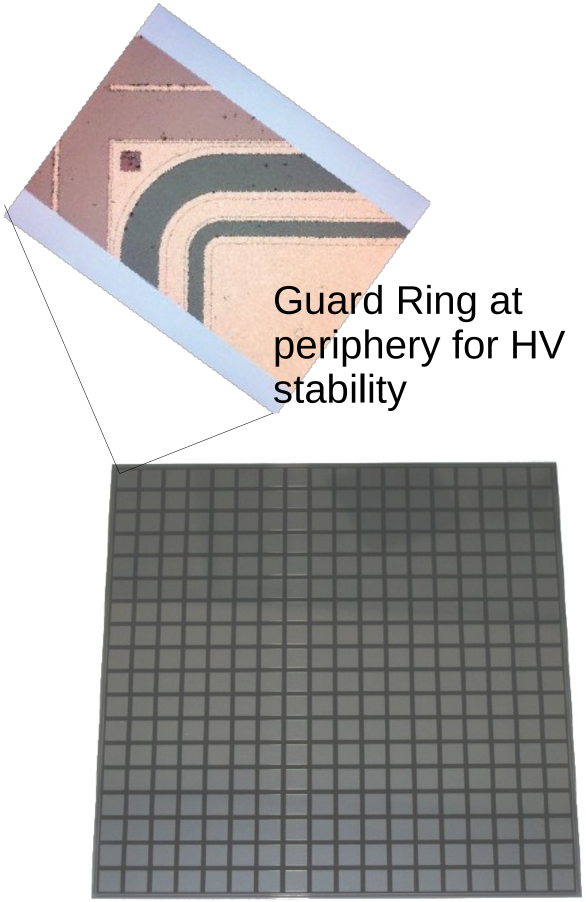
This price is the same as in DBD (3 ILCU/cm2)
Silicon contributes 45% to SiW ECAL price

Sensor is made from 6' raw wafers, for sensor thicknesses 300 – 500 um the price is the same (but 500 um gives 8% better resolution), for 650 um it is 10-15% higher

Lfoundry in Europe: 8' wafers, 700 um, first test production is planned to evaluate quality. New geometrical model with 8' is proposed in V.Boudry's talk.

Constraint on ECAL dimensions, optimally:
N * sensor length + all inter-wafer gaps

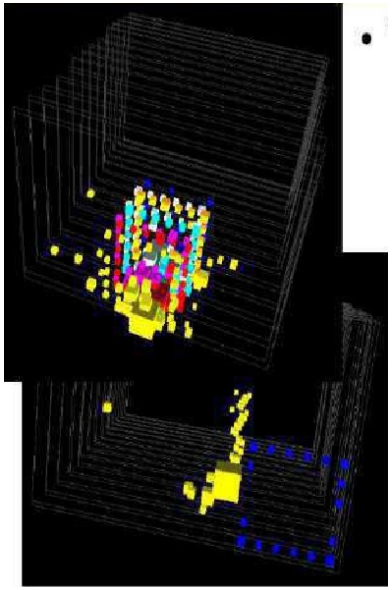
Guard Ring(s) (GR) at periphery ensures HV stability and low dark currents. HPK produced sensors with different GR designs with 0,1,2,4 segments.



Guard Ring at periphery for HV stability

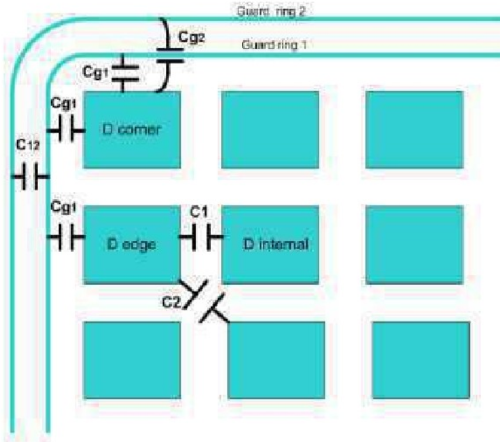
16x16 pixels

“Square” events



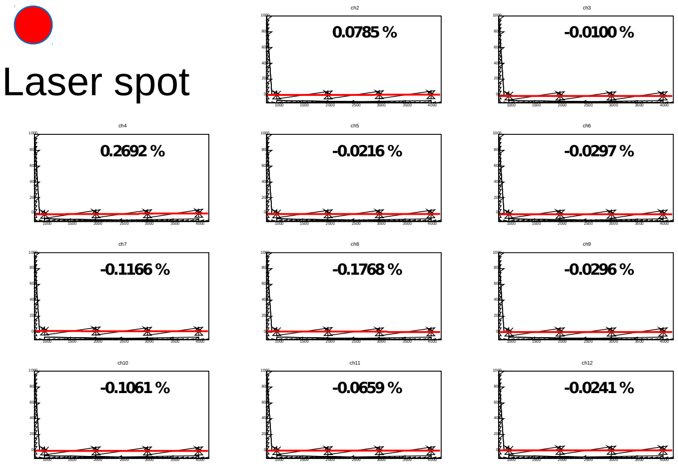
Physical prototype TB “square” event display

… explained by capacitive coupling of boundary pixels to guard ring



Capacitive coupling is minimized either by segmenting GR or avoiding it.

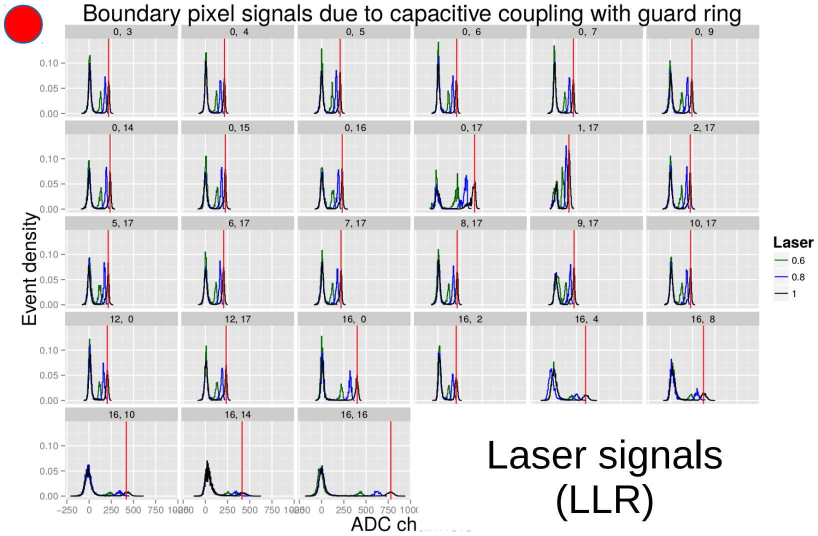
Preliminary results of recent studies using high signals at GR induced by infrared laser light:
GR segmentation or no GR design significantly reduces xtalk, it remains at the level O(1e-3).



no GR, small 4x4 pixels sensor, xtalk <= 0.1% except one pixel

HPK also produced sensors with meshed electrodes which allow laser light injection inside pixels.

Plan: test more sensors with various designs, possibly using upgraded DAQ electronics



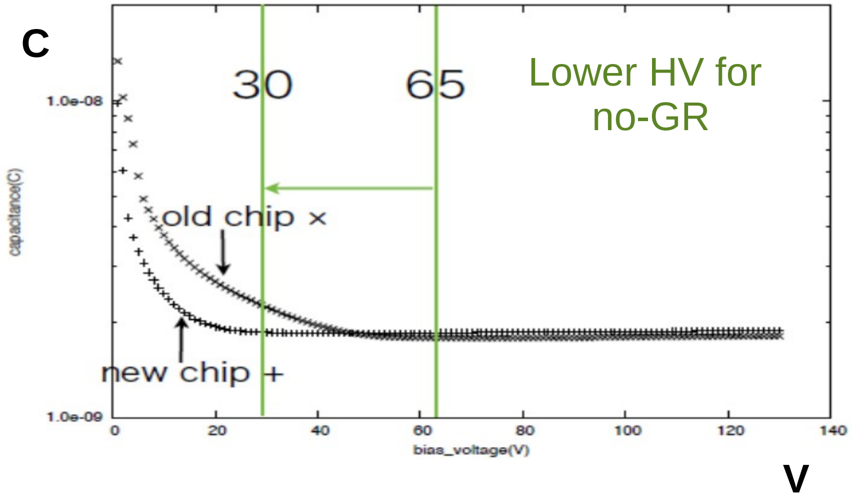
Laser signals (LLR)

2 segments GR, xtalk = 0.4-0.5% per outer pixel side.

Silicon sensor tests

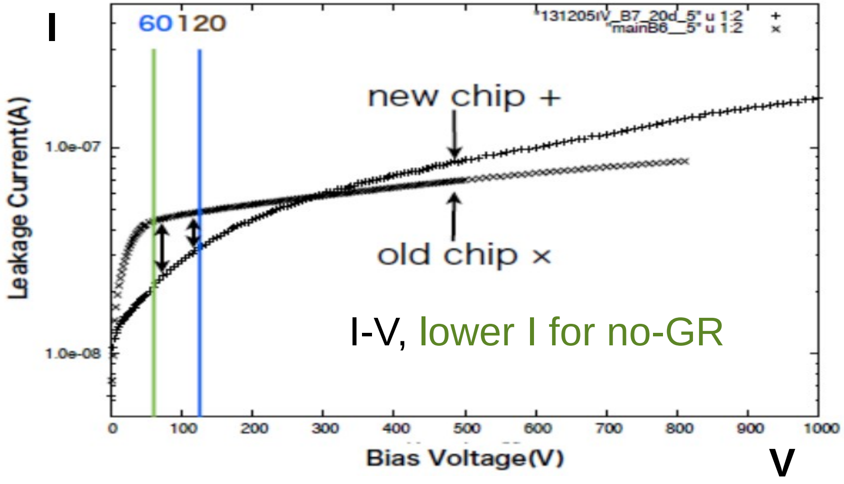
I-V and C-V tests (current and capacitance vs HV) of different Hamamatsu designs with 0,1,2,4 GR.

Recently: no-GR design is very promising
Plan: test more sensors



Lower HV for no-GR

The leakage current at 120 V is 31nA (old : 48nA), at 60 V is 21nA.

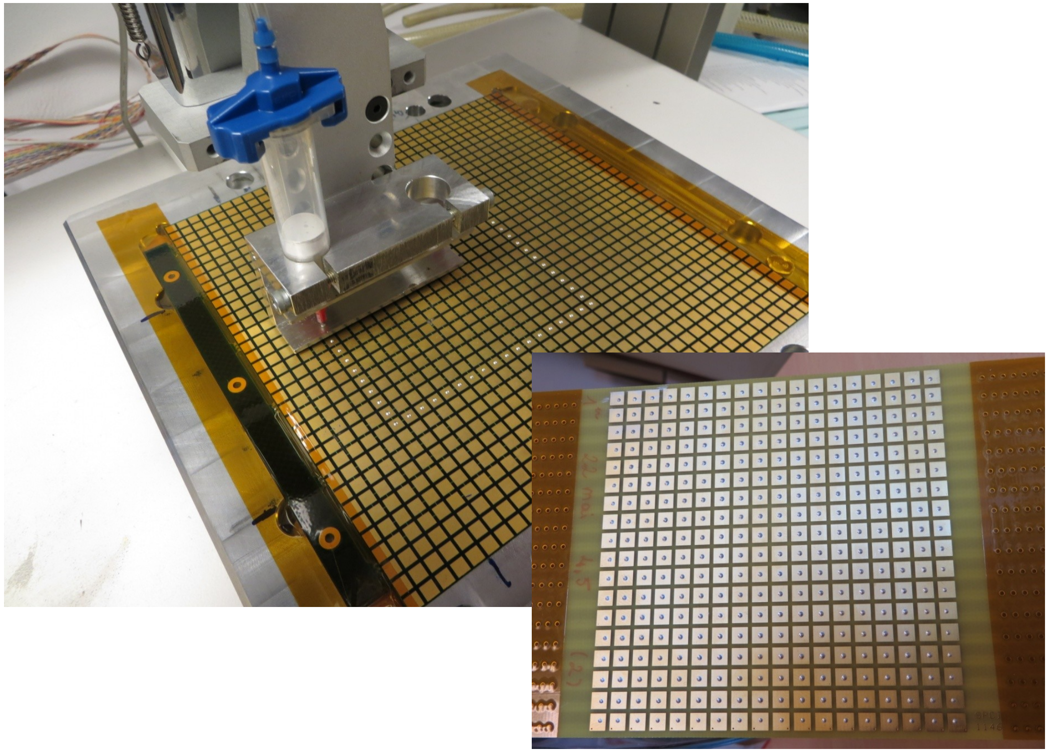


I-V, lower I for no-GR

Irradiation tests at nuclear reactor are planned for sensors and super-capacitors (used for power-pulsing LV electronics)

Gluing silicon sensors to FEV PCB

Gluing robot was successfully used to glue 9 sensors to 9 PCBs of technological prototype.



Next steps:

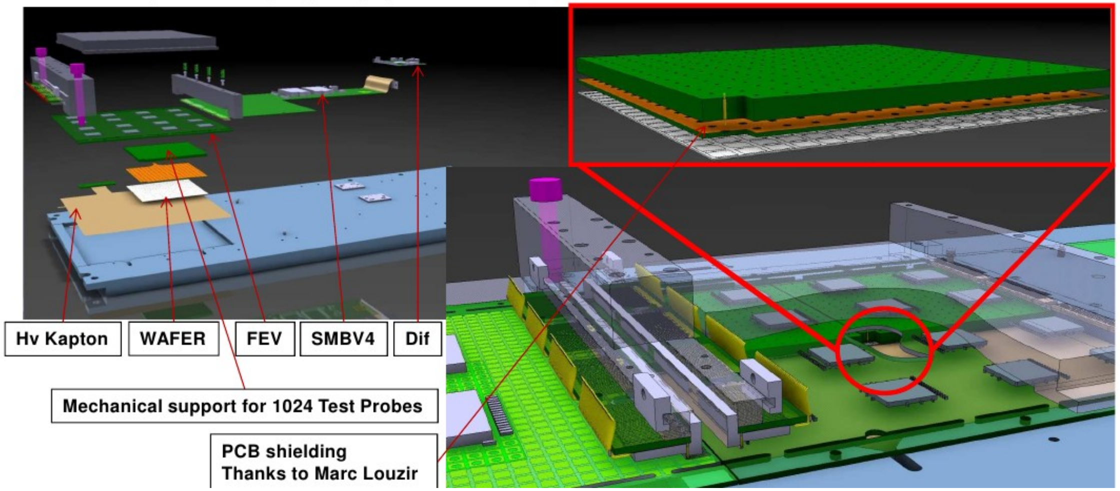
– combine gluing and positioning robots,

– glue 4 sensors to one PCB (already tested with 4 glass plates instead of sensors)

– move to clean room

– formalize all procedures (transportation, verification tests) for mass production

To test sensors before gluing: new setup with 1024 spring contacts (without neither glue nor soldering)



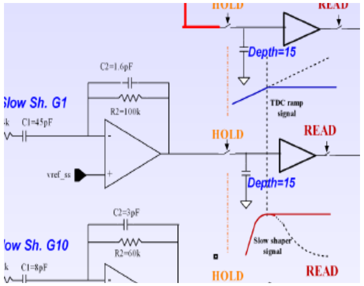
PCB shielding
Thanks to Marc Louzir

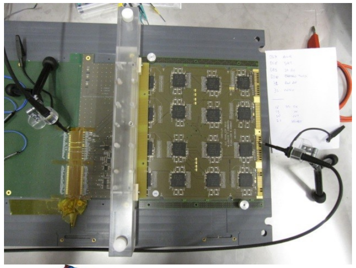
DAQ electronics

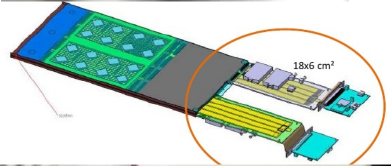
1. FE chip SKIROC2 developed by Omega (Ecole polytechnique)
   1-1500 MIPs, S/N=10–20 (@ MIP).
   Power pulsing successfully tested in 2013
   New BGA packaging, 1.1 mm thick + 1.6mm PCB
   New chip production with bug fixes in fall 2014
2.
   a) PCB with sensors and FE chips (FEV9,10,11)
   New design, QFP->BGA chip packaging, x4 channels (as in ILD),
   many improvements this year, goal: industrial mass production.
   FEV9-11 are produced. Readout of all channels in FEV9 is tested.
   b) clock + voltage distribution (SMB4), serves 1 -> 8 FEVs
   Designed, produced, not yet tested
   c) Detector Interface (DIF) board, improved firmware
   d) Gigabit Data Concentrator Card (GDCC) sending data to PC
   Working version in spring'13, continuously improved.
   No packet losses any more.

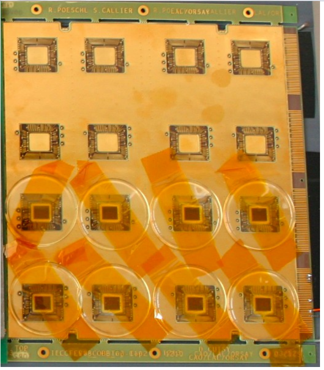
3. Chip-on-board PCB (FEV8) version (very thin: 1.2–1.5 mm incl. chip), Korean SKKU/EOS company. Flatness is not yet sufficient for gluing Si. May be improved: new production in Jul'14

4. Omega SKIROC test board (Kyushu) with analog+digi outputs
   Summer 2014: QFP->BGA packaging, possibility to connect
   DIF or old FPGA





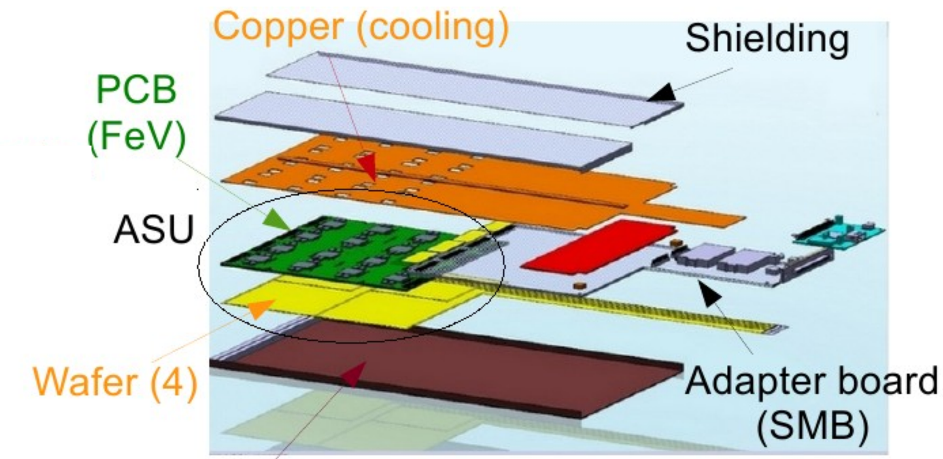




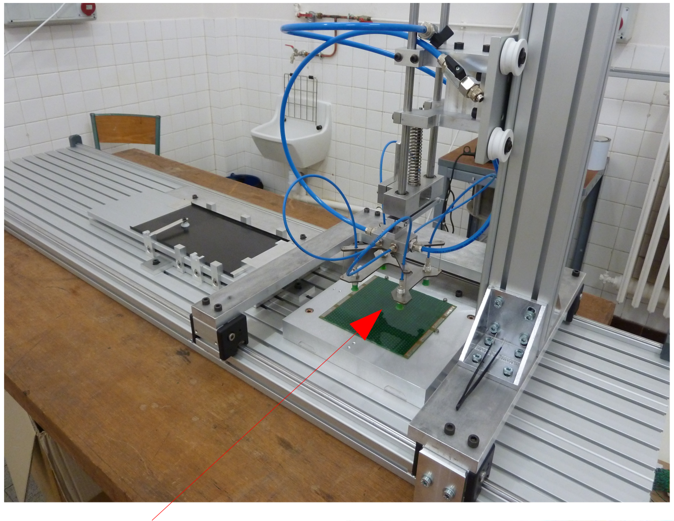
Putting all together: slab assembly

ILD goal: mount several interconnected square FE PCBs (up to 8 in barrel), each with 4 sensors, along long slab. First short slab(s) with 1 PCB: in the end of this year.

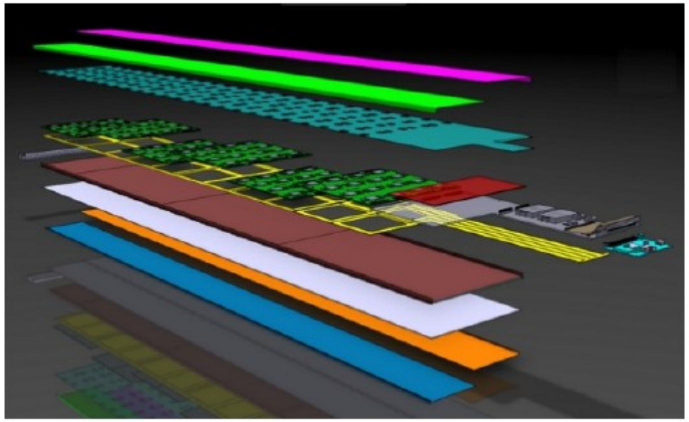
Several assembly benches are built or will be improved



U layout of a short slab

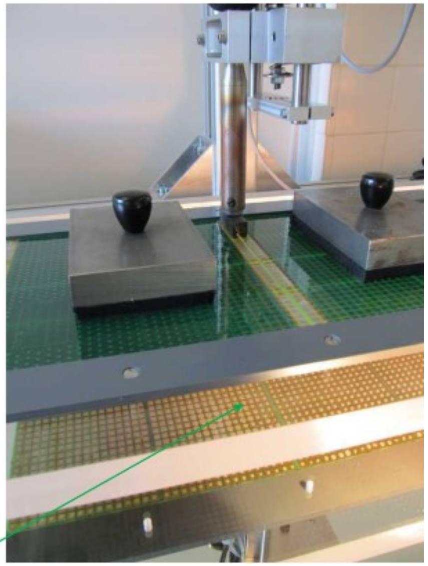


Flexible suspension for exact PCB positioning



U layout of a long slab

Pressure test

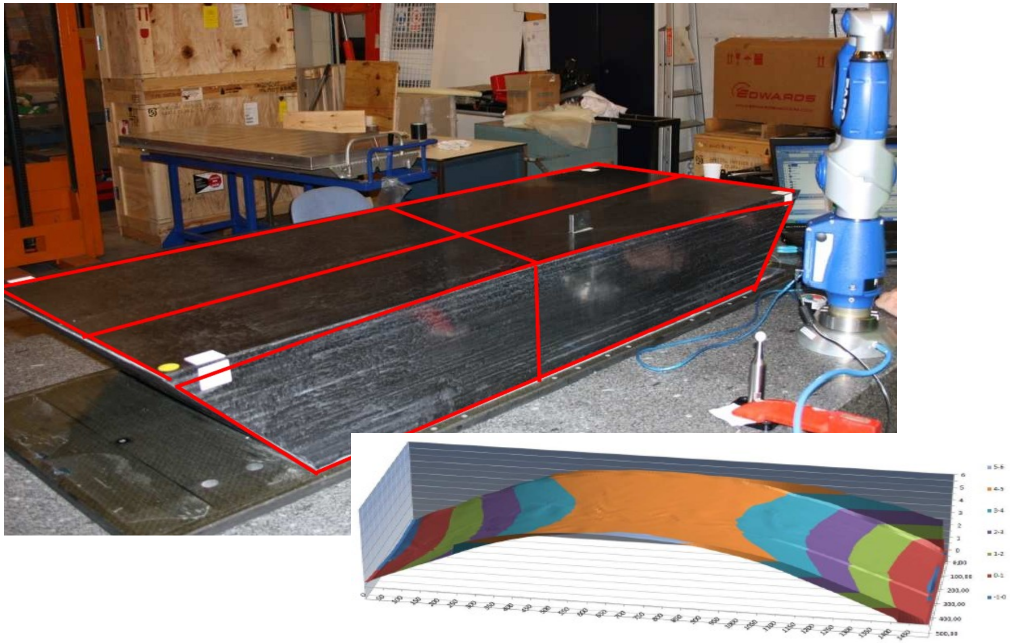


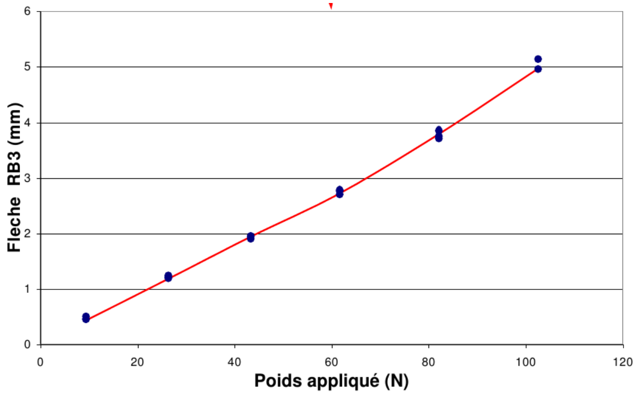
Mirrored PCB image

Mechanical modules with alveoli (common to Si and Sc)

Big prototype with 15 alveoli has been built:
3/5 of one ILD barrel module, ~600 kg.
Separately built layers of carbon fiber + W "cooked" together.
Simulated mechanically & thermally.

Another prototype with molded Bragg grating fibers, 2013. Detailed verification of simulated elongations under loads (by monitoring frequency shift of light reflected by fiber).

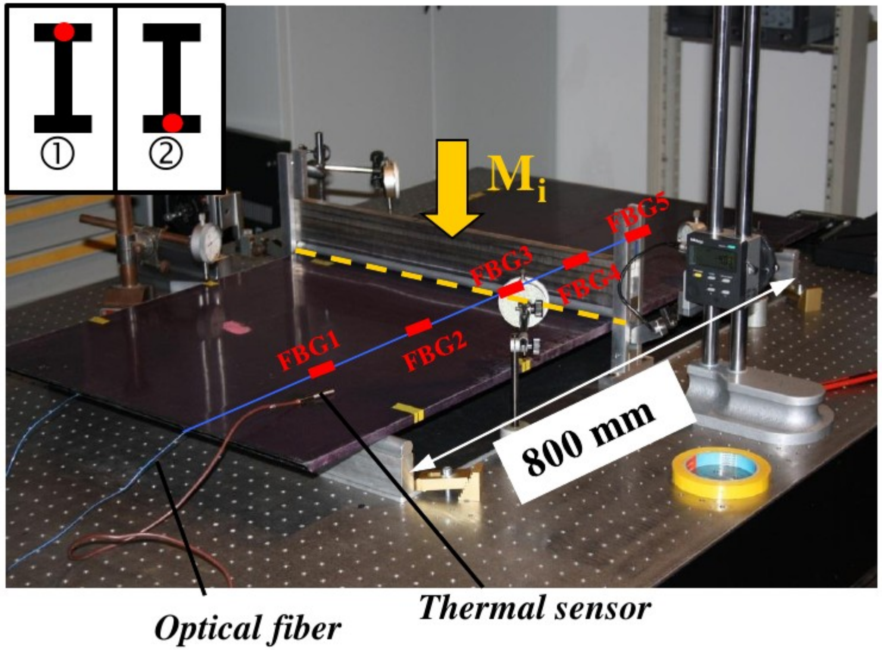




Vérification des paramètres du modèle en comparant la flèche FBG3 mesurée et simulée

Similar studies for endcap and fastening rails.
According to thermal simulations, only passive cooling is required inside alveoli.

Plan: produce H-shaped slab with W



DAQ software

1. Version 2 of PYRAME, generic DAQ framework, is released this month
– multiple acquisition PCs
– hierarchical configuration, dumped at each run (XML)
– C++ or python
– many improvements

Previous version with specialized SiW ECAL drivers has been used to take all technological prototype data since Jan'2013.

2. Kyushu team develops
– combined DAQ for Si and Sc ECAL based on EUDAQ
– online monitor

Conclusions

Hamamatsu (HPK) offered Si at the same price as in DBD (45% of ECAL cost)

Status: **well advanced, R&D may be required for low noise, low power readout electronics**

Plans:

1. Finalize optimization (geometry, Si sensor, GR, electronics, mechanics, cooling)
2.
   a) Test new electronics (FEV11 / SMB4 / GDCC) and software
   b) Produce short and long slabs
   c) Extend technological processes towards mass production

Recent interest to Si ECAL technology from future circular colliders TLEP/CEPC and CMS endcap calorimetry Phase 2 upgrade project, HGCAL. Decision on HGCAL or shashlyk by end 2014.