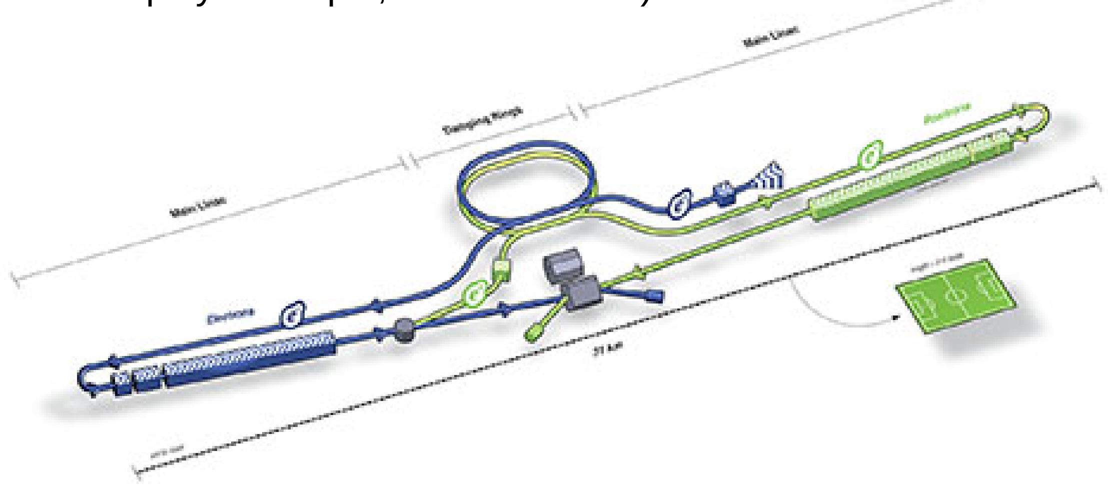
ILD SiW ECAL project

French-Ukranian Workshop, LAL, Oct 2014
Vladislav BALAGURA (LLR – Ecole polytechnique, CNRS / IN2P3)

International Linear Collider



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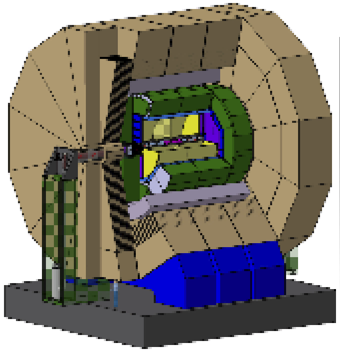

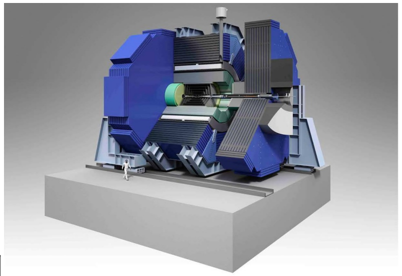

International Linear Collider

two detectors proposed:

- ILD (International Large Detector) and
- SiD (Silicon Detector)

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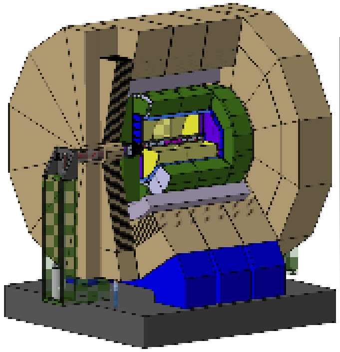

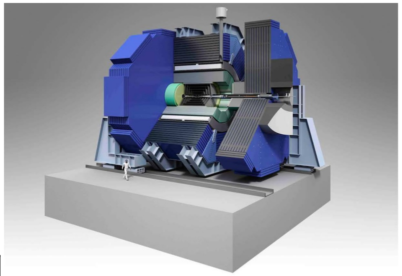

International Linear Collider
two detectors proposed:
- ILD (International Large Detector) and
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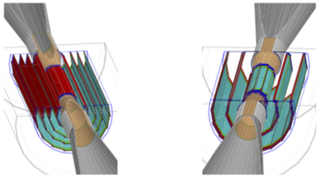
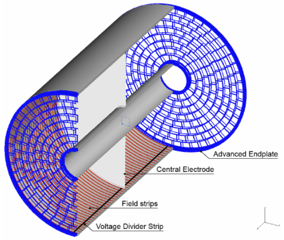
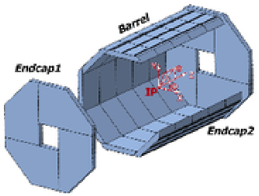
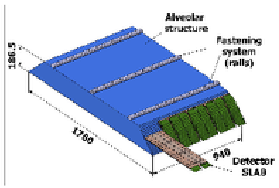
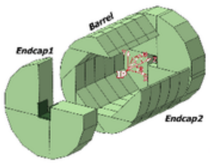
8 French labs participate in ILD:
- vertex detector,
- TPC,
- Silicon-W ECAL and
- Semi-Digital HCAL
(plus accelerator R&D)

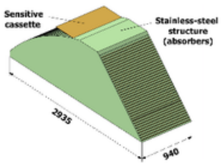












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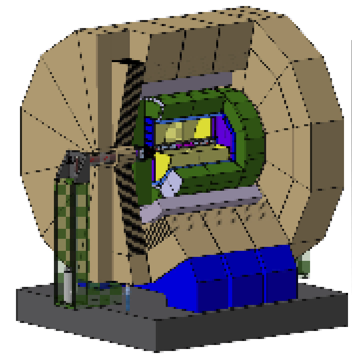
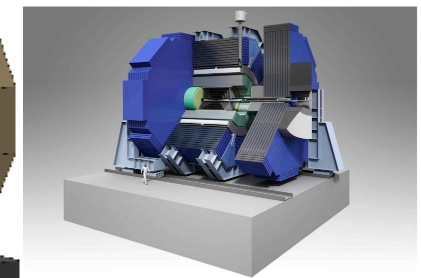

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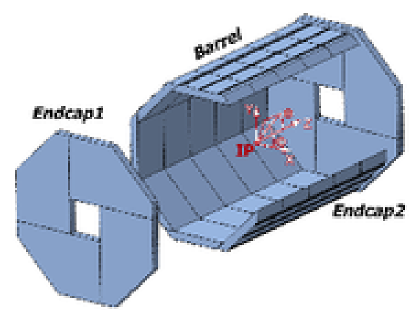
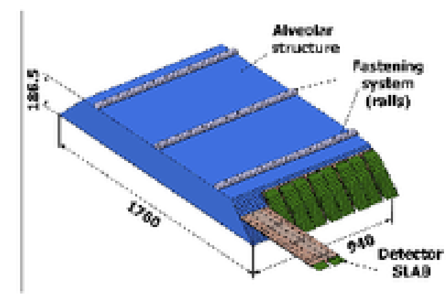
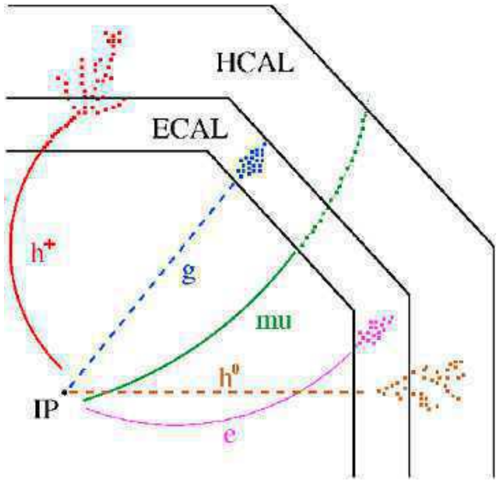




SiW ILD ECAL:
- Omega group, LLR, LAL, LPNHE and LPSC in France
- Tokyo and Kyushu Universities in Japan

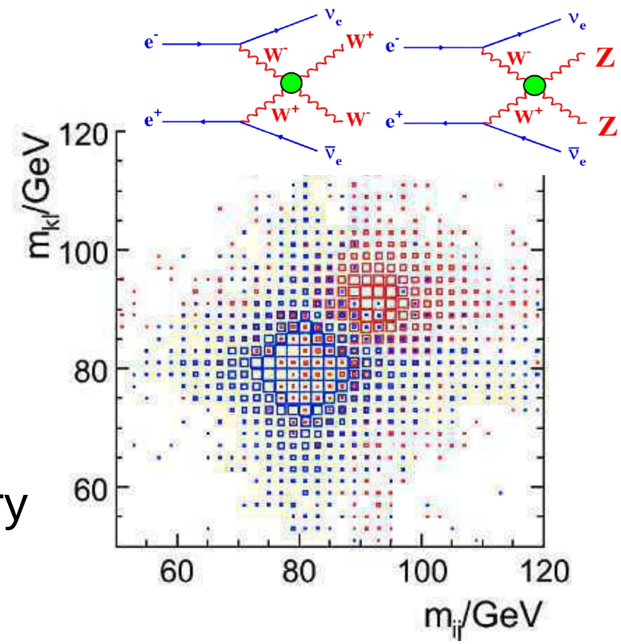
Particle Flow Algorithm (PFA) in calorimetry



Particle Flow Algorithm:

Jet = 65% charged + 25% γ + 10% h0
Tracker ECAL HCAL

$\sigma E/E$ (jet) = 3...4%
about twice better than traditional calorimetry



WW/ZZ separation

– High granularity "imaging" calorimetry is needed to match CAL clusters to tracks. Especially important in ECAL (resolve narrow e-m showers and distinguish them from hadron interactions)
Best granularity with silicon detector (eg. 5x5 mm2 pixels, 100 M channels). Also: perfect linearity, easy calibration, time stability, robustness, thus low systematics.

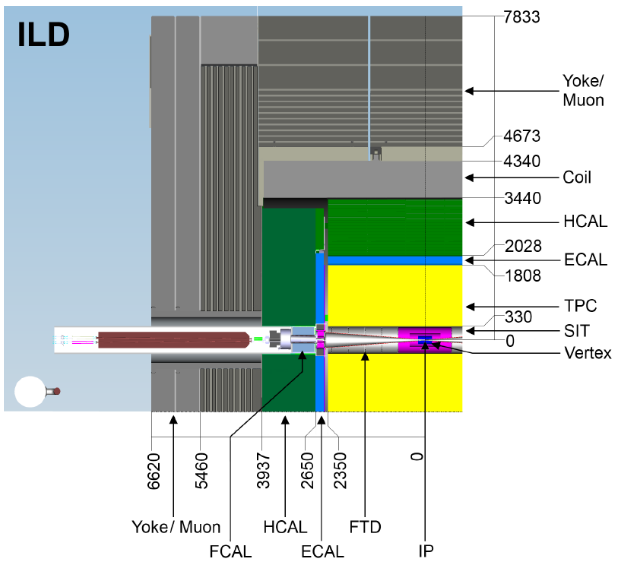
– To avoid overlaps of electromagnetic showers with themselves or with hadronic showers: small Moliere radius and large interaction / radiation length ratio, select tungsten (W) as absorber (140 t)

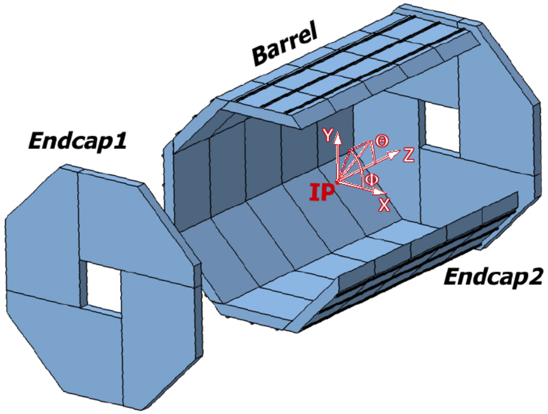
Moderate energy resolution $\sigma E/E = 0.17/\sqrt{E} \oplus 0.01$ is sufficient for jets, since HCAL uncertainty dominates.

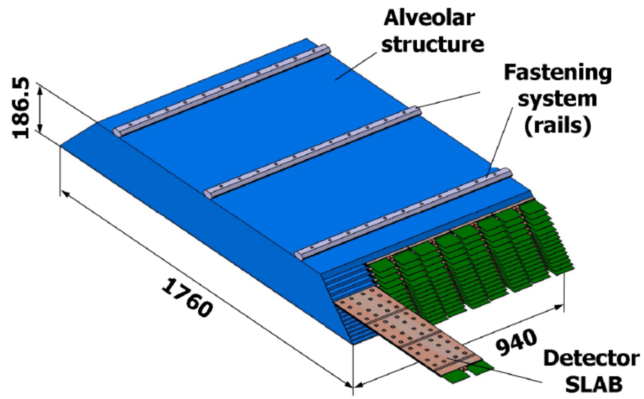
Silicon-tungsten calorimetry

SiW ECAL in ILD:

- TDR: 2600 m2 of Si, 140 t W, ≈20 cm thickness
- modular design (eg. barrel = 8x5 modules, each with 5x15 slabs), no projective cracks
- power pulsing (ON during ILC bunch trains, 1%)



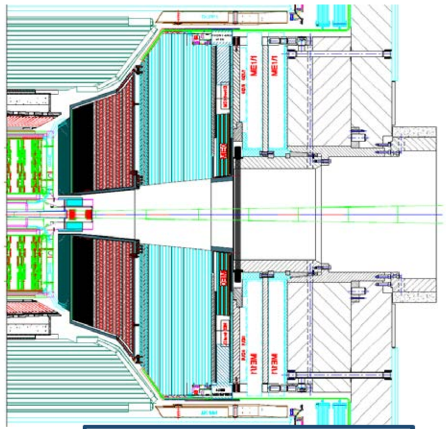


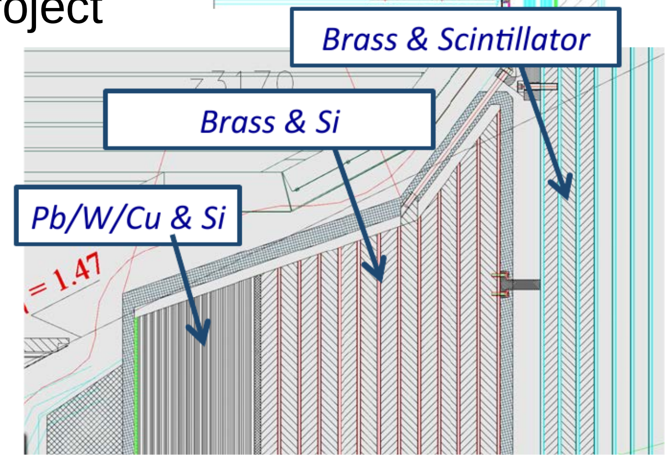


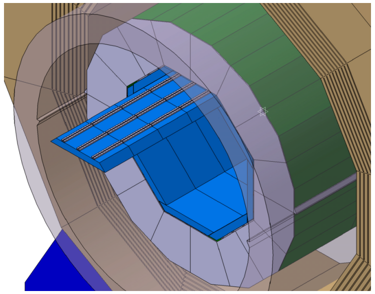
Recent interest to Si-W(Pb) technology for CMS endcap Phase 2 upgrade (HGCAL) and for circular collider projects (TLEP, CEPC).

Technology choice between HGCAL and shashlyk in CMS in spring 2015. Operation starts around 2025.

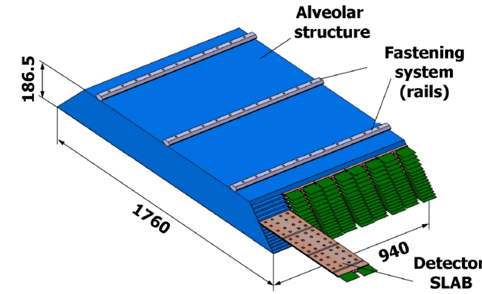
CMS HGCAL endcap upgrade project



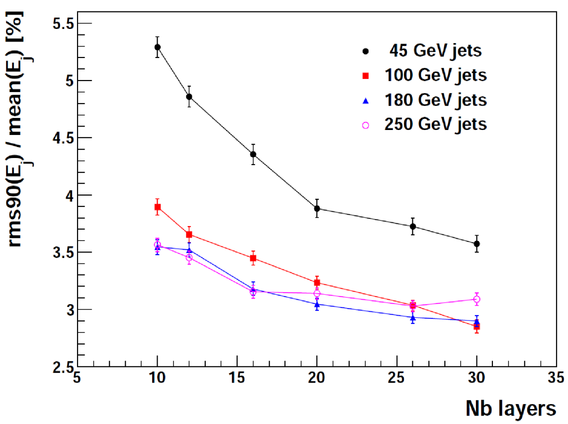




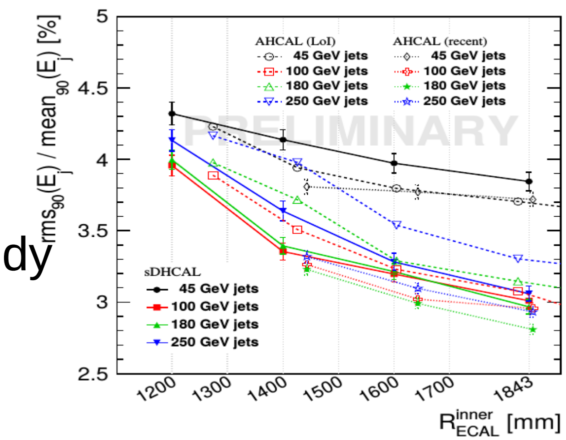
On-going cost / performance optimization of ILD ECAL



– Jet energy resolution dependence on
N ECAL layers, dimensions



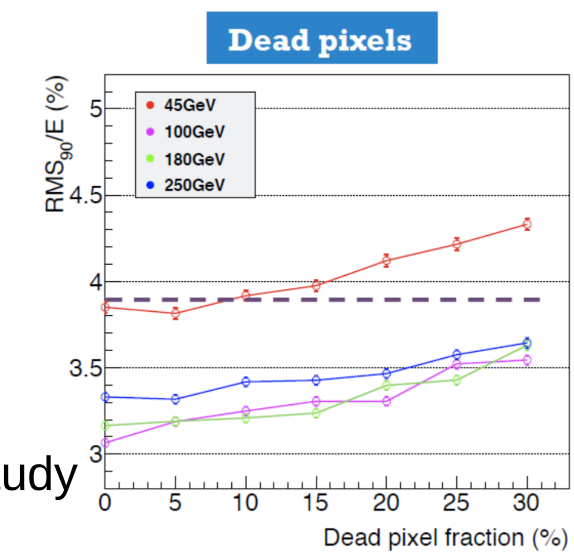
LLR study



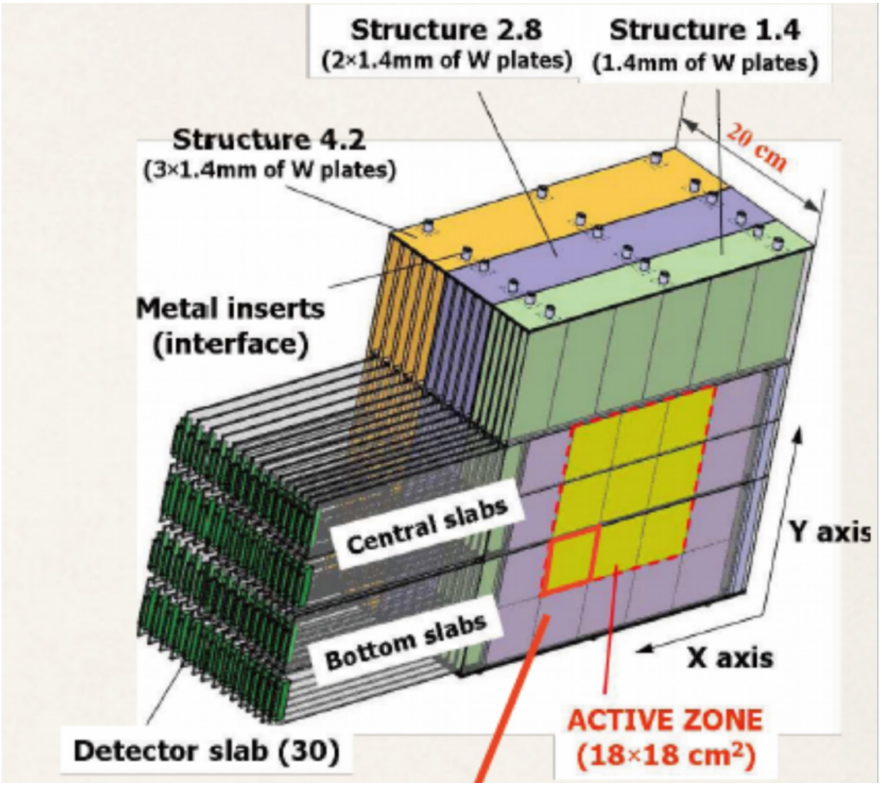
eg. R=1843 -> 1500, N layers = 29 -> 25 reduces the ECAL cost by about 40%

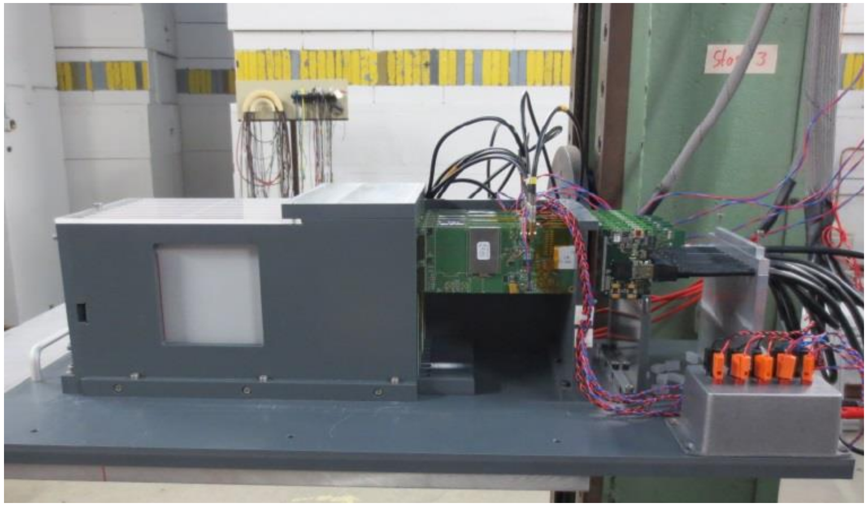
– 10% of bad pixels is affordable (not tracker device), lower price

Tokyo study



Physical prototype: 2005-2011 Technological prototype: present





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%.

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.

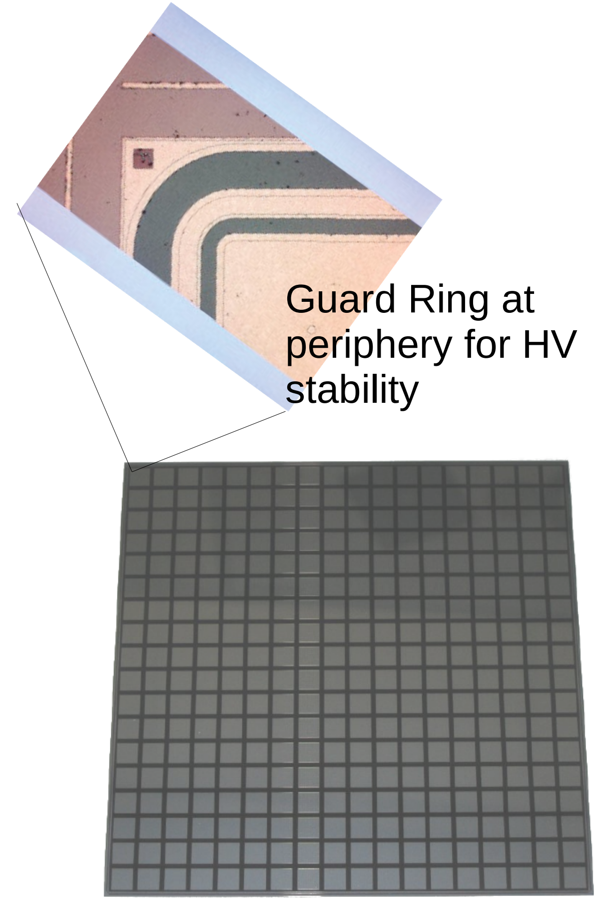
This price is the same as in DBD (3 ILCU/cm2)
Silicon contributes ≈45% to SiW ECAL price

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.

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. R&D is on-going to reduce capacitive x-talk between GR and boundary pixels. HPK produced sensors with different GR designs with 0,1,2,4 segments.



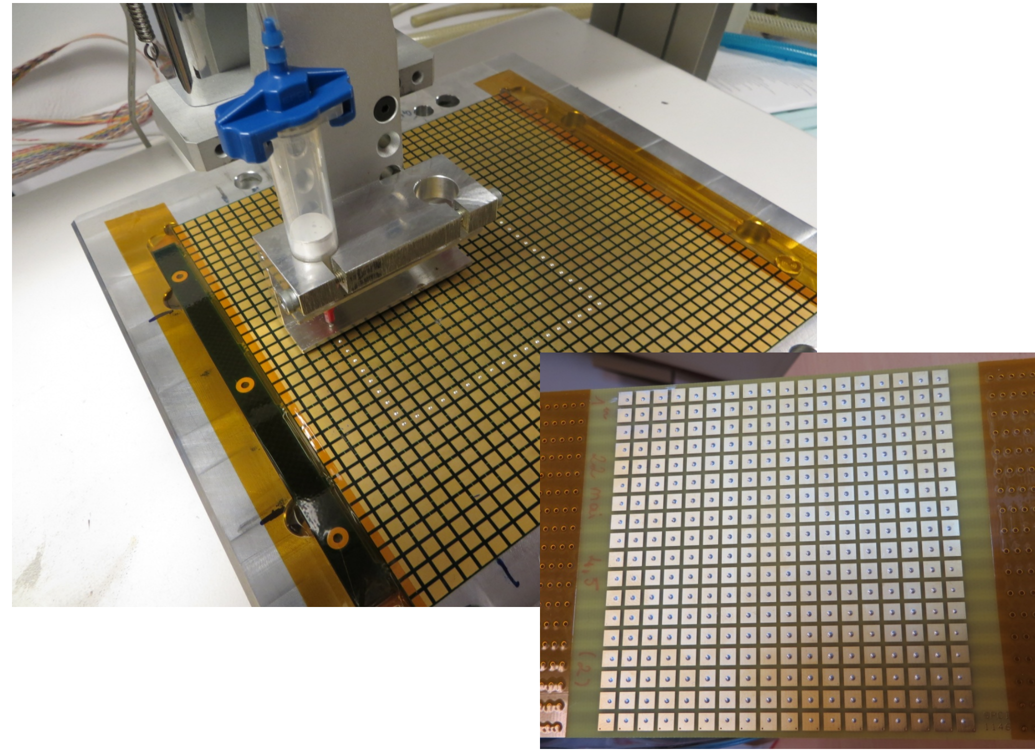
16x16 pixels

Gluing silicon sensors to FEV PCB at LPNHE

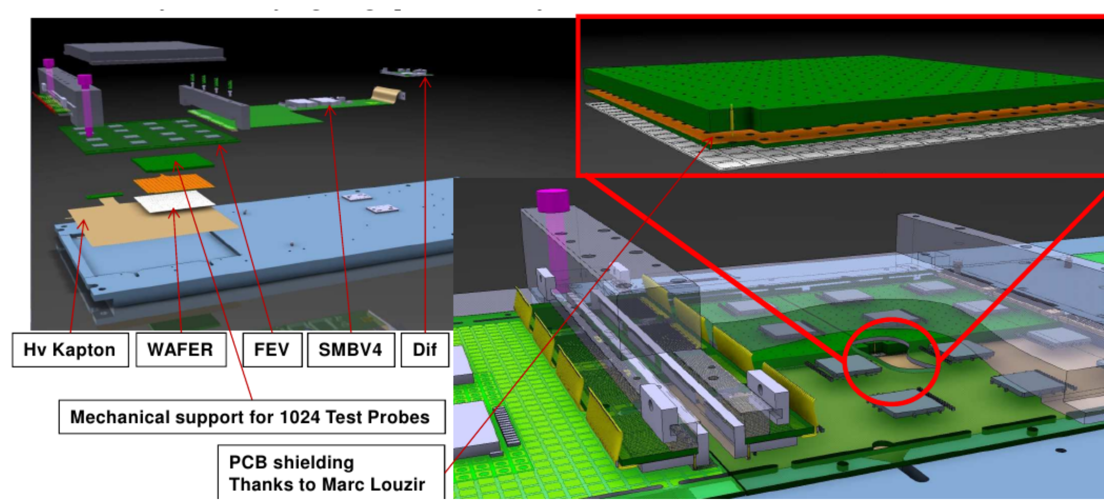
Gluing robot was successfully used to glue 9 sensors to 9 PCBs of technological prototype.

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)



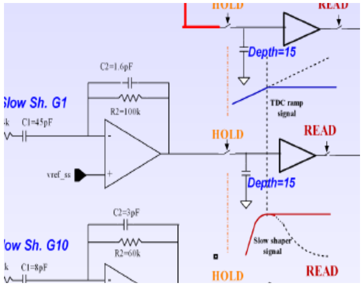
DAQ electronics

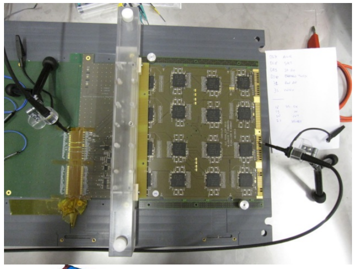
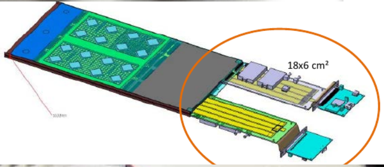
1. FE chip SKIROC2 developed by Omega (Ecole polytechnique)
   1-1500 MIPs, S/N=10–20 (@ MIP).
   Power pulsing successfully tested in 2013
   New BGA packaging, 1.1 mm thick + 1.6mm PCB
   New chip production with bug fixes in fall 2014

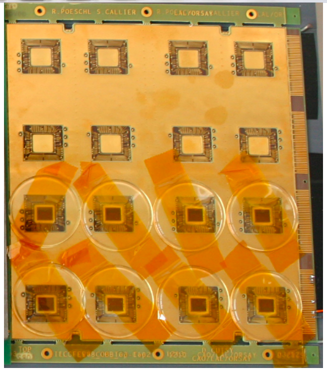
2.
   a) PCB with sensors and FE chips (FEV9,10,11)
   New design, QFP->BGA chip packaging, x4 channels (as in ILD), many improvements this year, goal: industrial mass production. FEV9-11 are produced. Readout of all channels in FEV9 is tested.
   b) clock + voltage distribution (SMB4), serves 1 -> 8 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



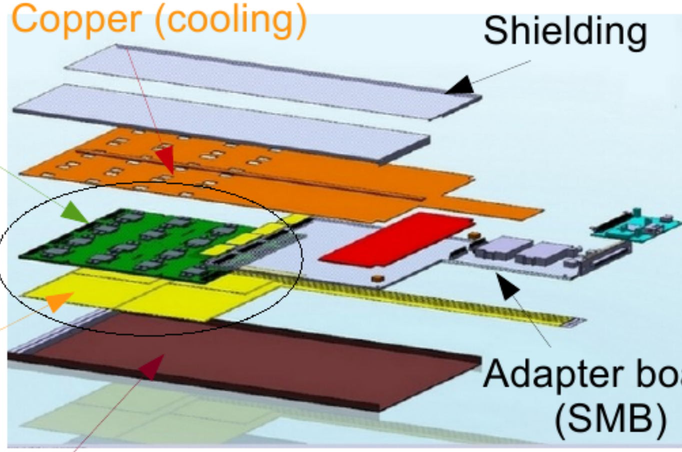



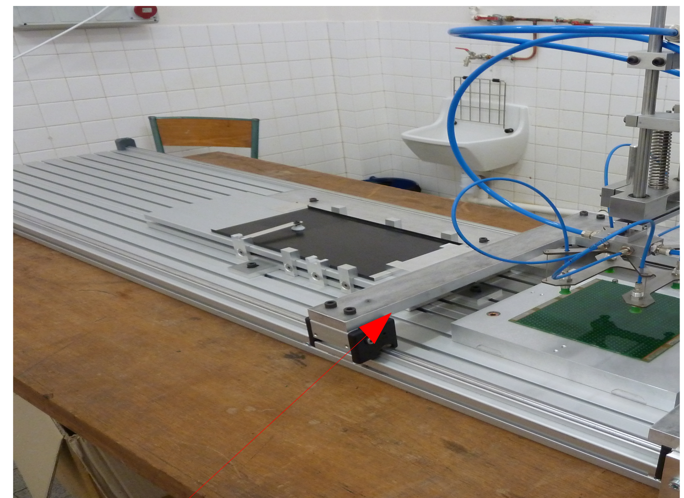
Putting all together: slab assembly

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.

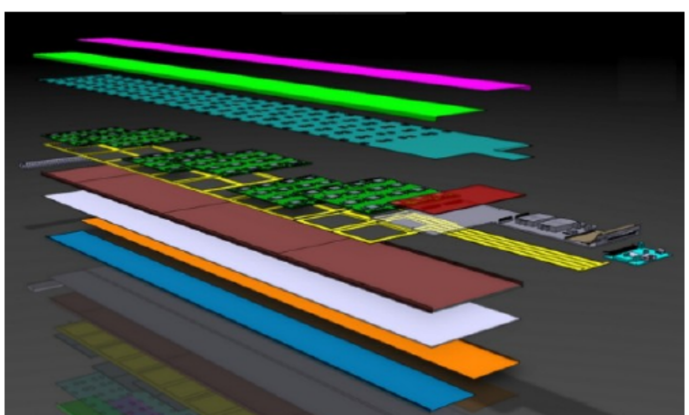
Several assembly benches are built or will be improved



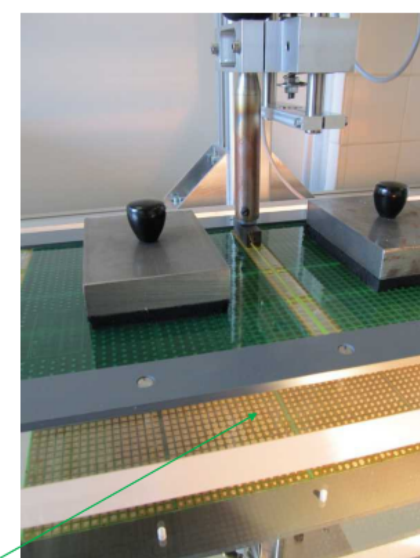
U layout of a short slab



Flexible suspension for exact PCB positioning



U layout of a long slab



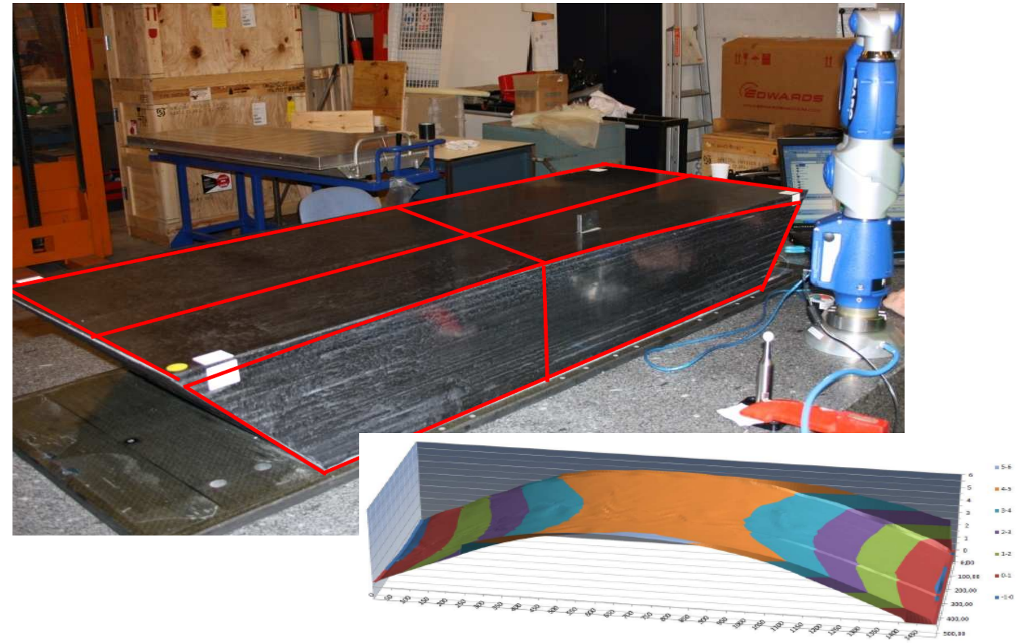
Pressure test

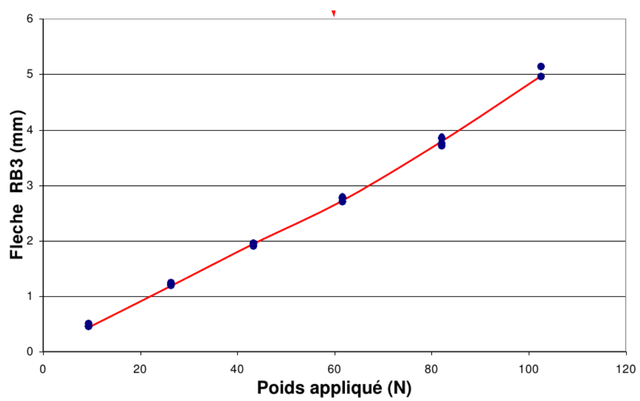
Mirrored PCB image

Mechanical modules with alveoli (common to Si and Sc)

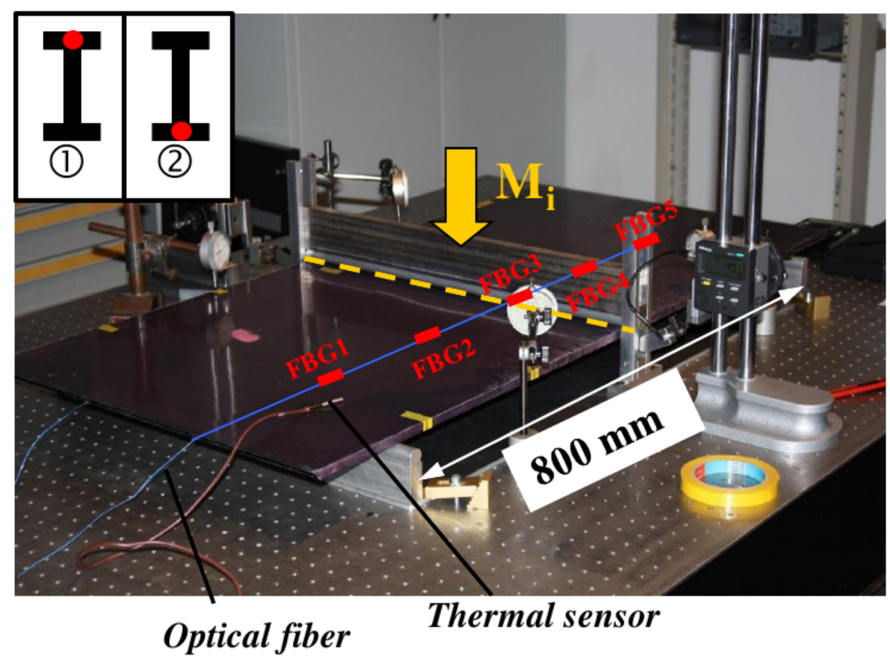
Big prototype with 15 alveoli has been built:
3/5 of one ILD barrel module, ~600 kg.
Separately built layers of carbon fiber + W "cooked" together.
Simulated mechanically & thermally.

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.

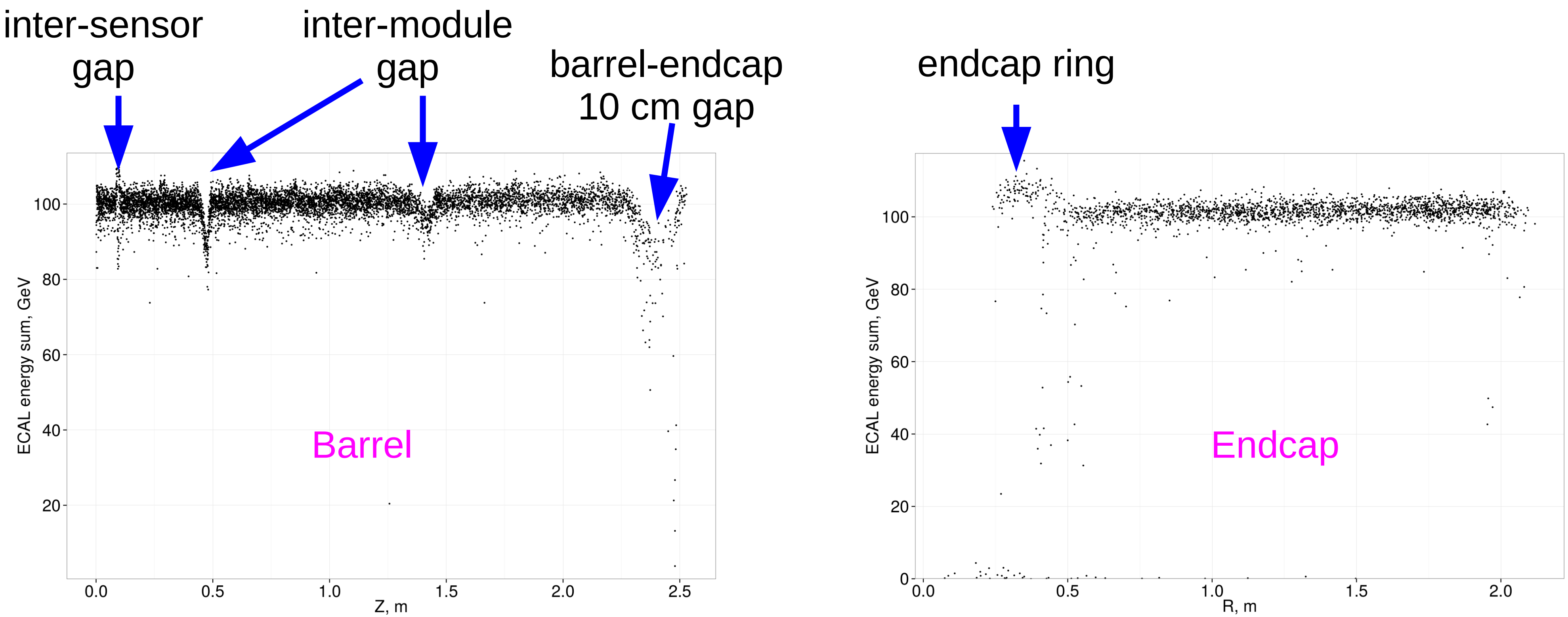
Plan: produce H-shaped slab with W

Participation of Ukrainian students

Iaroslava Bezshyiko – internship student from Kiev, 3 months in LLR in 2013,
Kostiantyn Shpak – PhD student in LLR (Ecole polytechnique + Kharkiv Uni), started in beginning of 2014

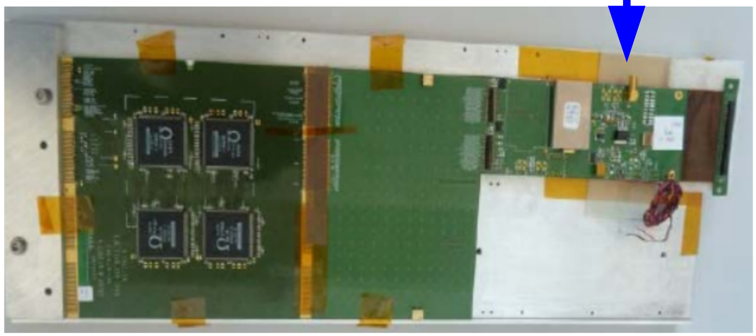
Iaroslava Bezshyiko (Kiev), analysis of ECAL photon energy resolution

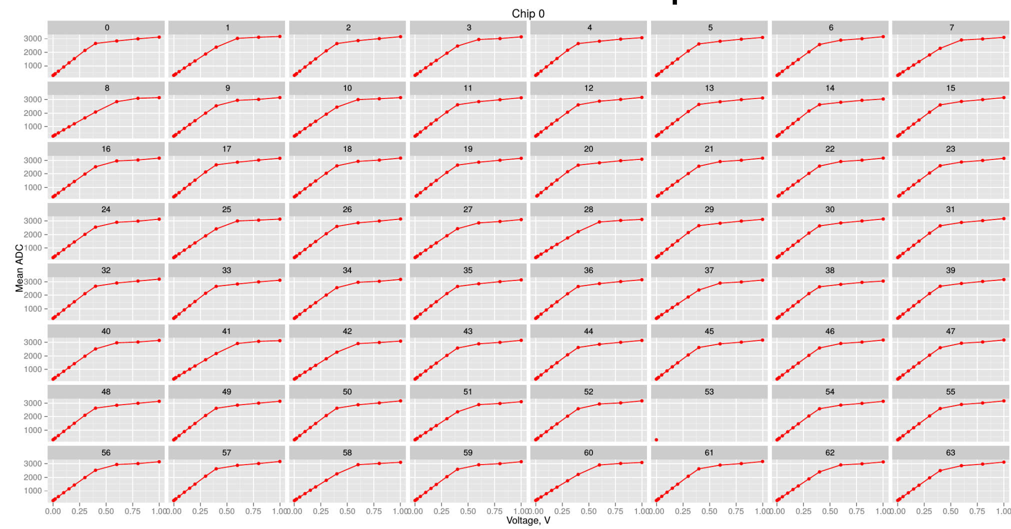
Energy sum of all hits (below) or PFA Pandora program results, 1-100 GeV photons



Kostiantyn Shpak (Kharkiv-Ecole polytechnique), analysis of Si technological prototype

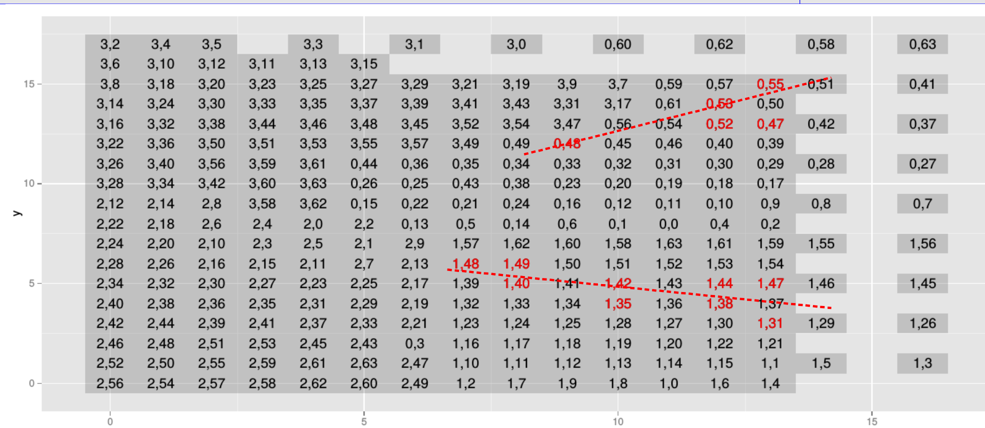
Charge injection into front-end chips, 3 slabs X 256 channels X 11 amplitudes



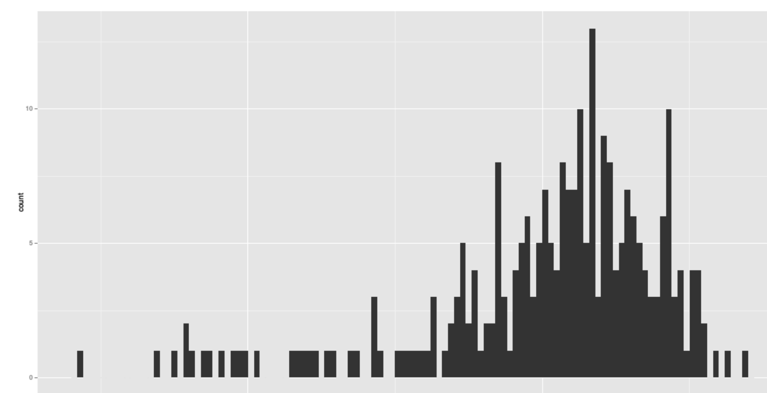


One chip example

RMS of linear slopes within chips 2,3	2...4%
RMS at saturation within chip	1...2%
Bad channels	5%



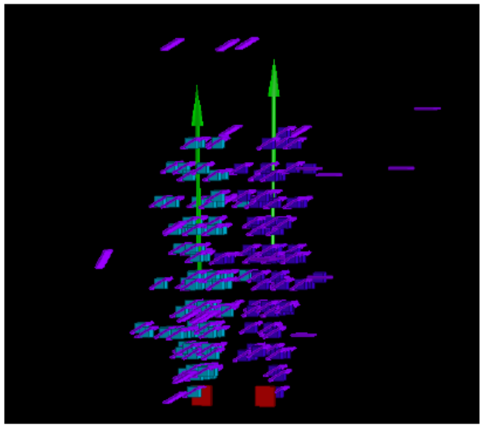
(chip, channel): X-Y position on PCB, red is bad



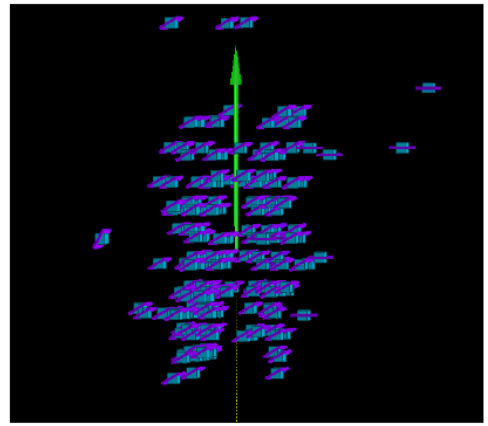
Linear slopes, tails due to chips 0,1 with bad areas

K. Shpak (Ecole polytechnique-Kharkiv), physical prototype capability to separate showers

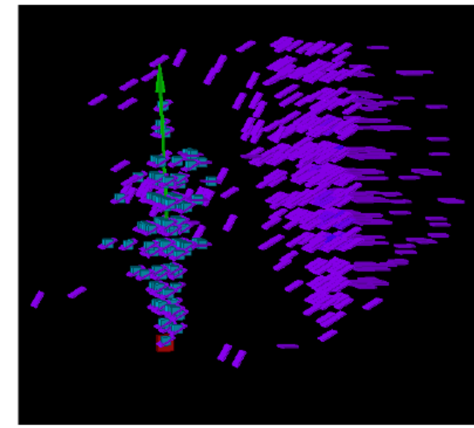
FNAL'2011 data, overlay two single-positron events or positron – hadron and study separation power of several programs: Garlic, Pandora, Arbor. Crucial for PFA.



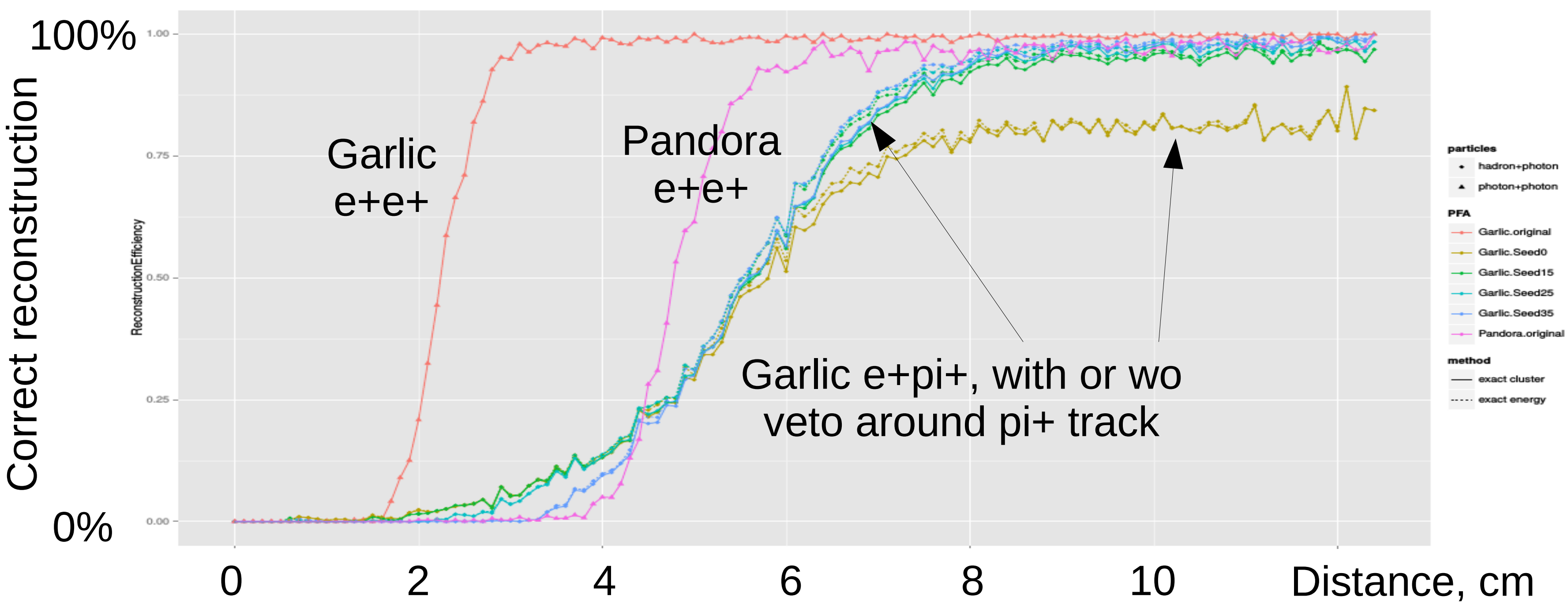
Two e+ reconstructed showers in GARLIC



Merged e+e+ shower in Pandora



EM (left) and hadron (right) showers in GARLIC



Conclusions

Status: Silicon-Tungsten ECAL for ILD is well advanced.

Advantages: the best granularity (5x5 mm2) for PFA,
perfect linearity, easy calibration, time stability, robustness, so low systematics.

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

3. Recent significant reduction of Si sensor price: 2.5 EUR / cm2 offer from Hamamatsu.

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 spring 2015.

Backup slides

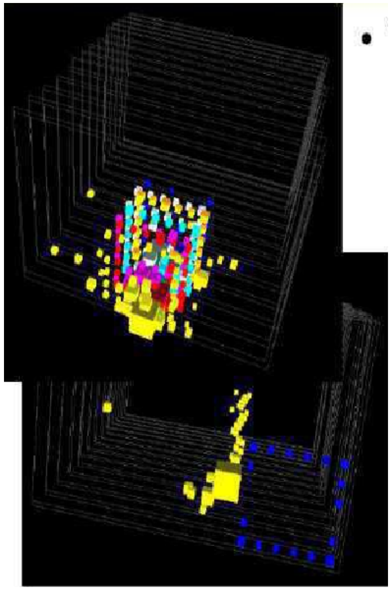
DAQ software

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.

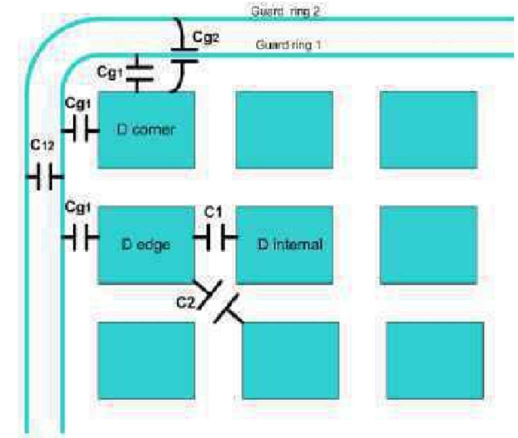
2. Kyushu team develops
– combined DAQ for Si and Sc ECAL based on EUDAQ
– online monitor

“Square” events



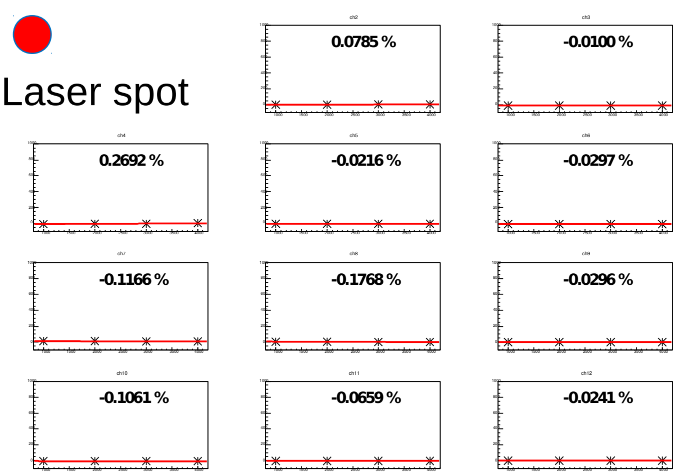
Physical prototype TB “square” event display

… explained by capacitive coupling of boundary pixels to guard ring



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

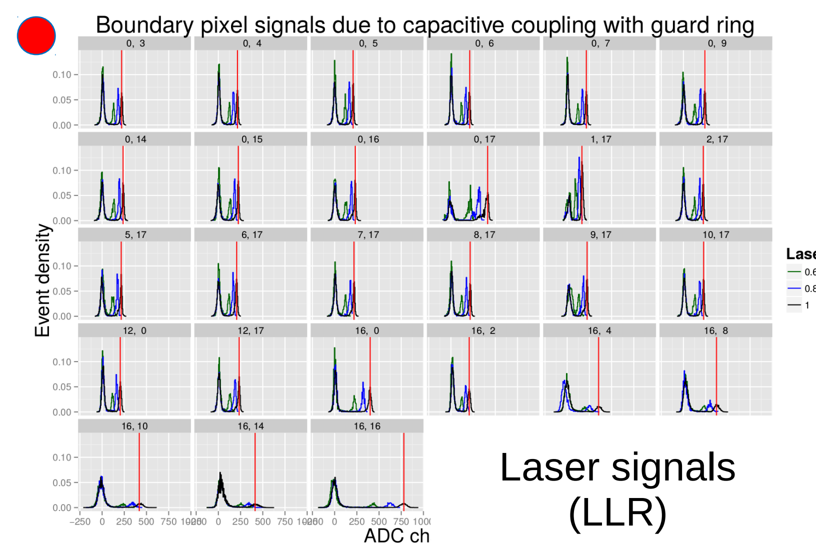
Preliminary results of recent studies using high signals at GR induced by infrared laser light:
GR segmentation or no GR design significantly reduces xtalk, it remains at the level O(1e-3).



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



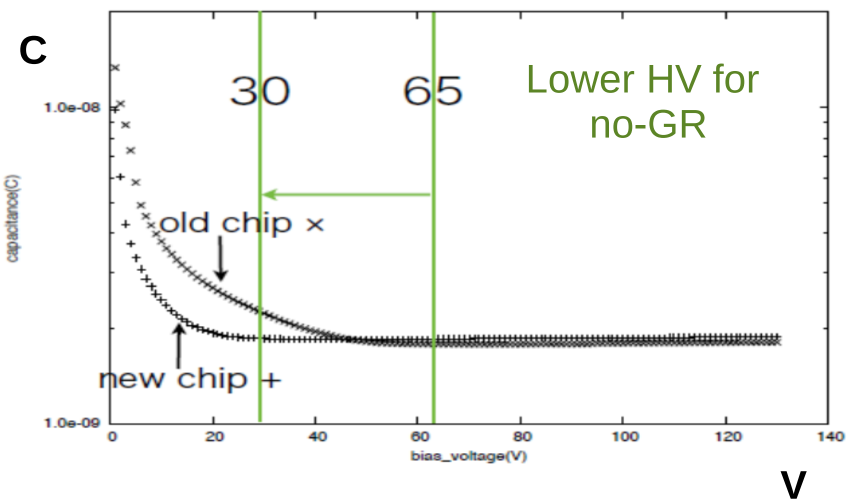
Laser signals (LLR)

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

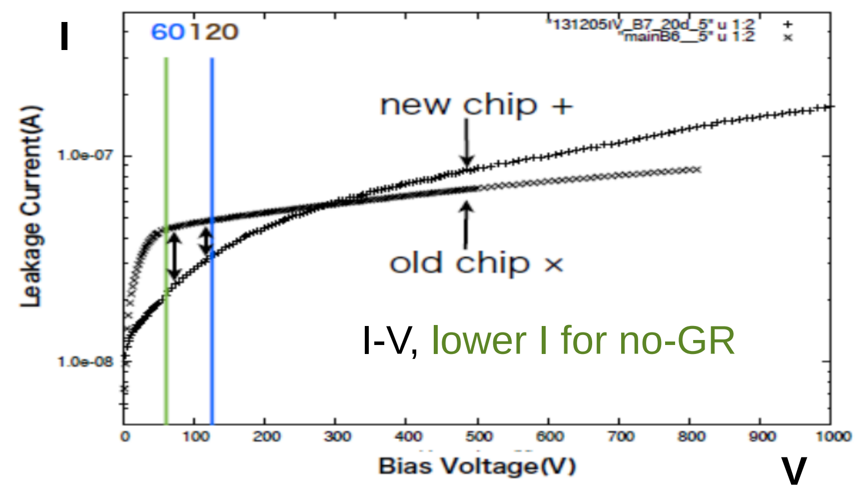
Silicon sensor tests

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



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



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