Calibration and Alignment for ILD Calorimeter System

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LCWS2016, Dec.5-9, 2016, Morioka

Questions on ILD Sub-detector Calibration and Alignment

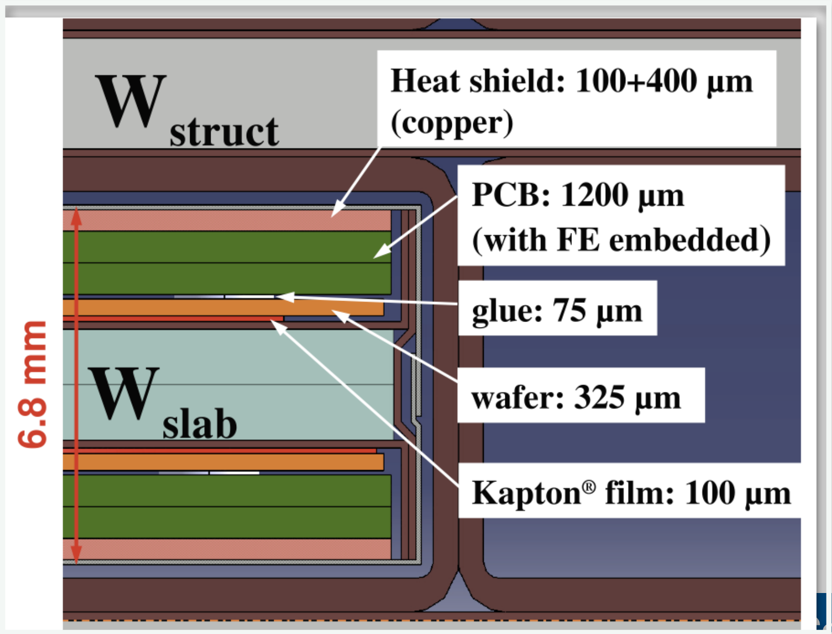
- **Questions from ILD ET**
  1. Outline the strategy for alignment and calibration of your subdetector.
  2. What calibration and alignment parameters need to be measured with particles (either from collisions or cosmics) for your subdetector?
  3. What precision is needed on the calibration and alignment parameters for your subdetector? What is the basis for this assessment?
  4. How many usable particles per sub-detector element are needed to establish the calibration and alignment constants at the above level of precision?
  5. What particles and kinematic criteria are needed?
  6. What is the smallest solid-angle subtended by an individual sub-detector element?
  7. Does your subdetector plan to use power-pulsing?
  8. Are cosmics useful for the alignment/calibration of your sub-detector?
  9. Are beam halo muons useful for the alignment/calibration of your sub- detector?
  10. If power-pulsing is used, what is the effective live-time percentage?
  11. Is data with the magnetic field needed for your sub-detector?
  12. On which time-scales do you anticipate that the alignment and/or calibration of your sub-detector will be stable? In particular would it be reasonable to assume that data collected over multiple running periods in multiple years can be used collectively to refine the overall calibration or alignment?
  13. Do you foresee particular challenges in the alignment and calibration of your subdetector?
- **This is to summarise (current) answers from calorimeter groups (ScECAL, SiECAL, AHCAL and SDHCAL)**

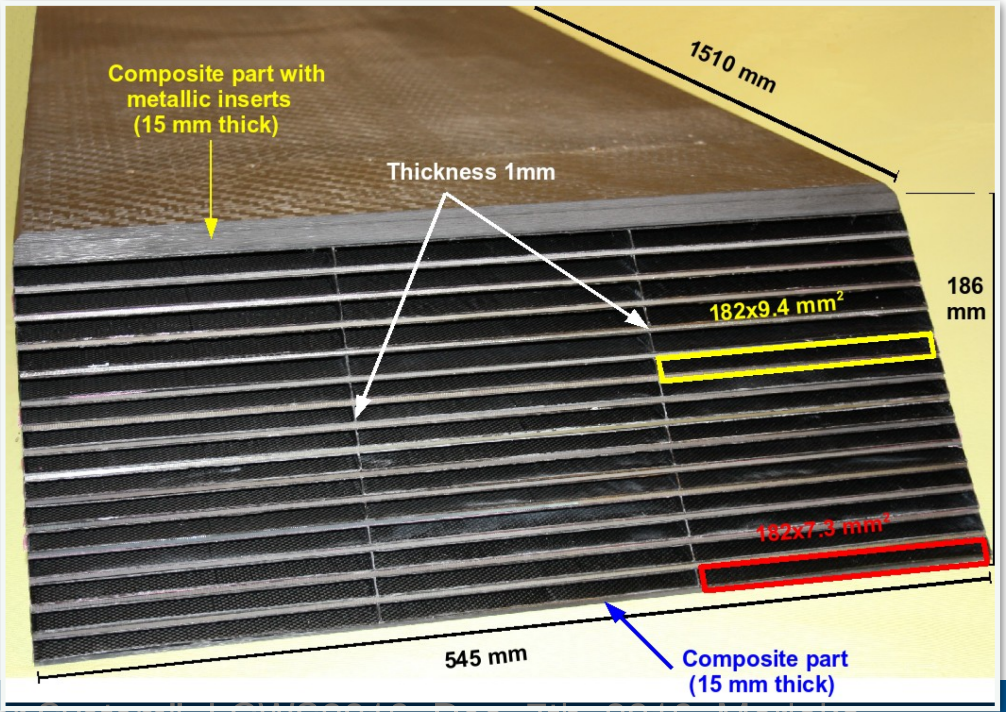
Calibration and Alignment for Calorimeter

- **Different calorimeter technology requires different strategy for calibration and alignment.**
- **Possible tools**
  - **Z-pole:** Great advantage in statistics
  - **Cosmic ray:** Useful at surface and with increasing duty-cycle of power-pulsing (by~10%?)
  - **Muon beam halo:** In-time with beam (no influence of power-pulsing)
  - **Tracks in high energy collision data**
  - **Built-in calibration system** (LED, charge injection,…)
- **Monitoring**
  - Stability of calibration constants
  - Temperature
  - Influence of radiation damage
  - Noise
- **N.B. Strategies for calibration and alignment are not completely determined and some of questions are still to be answered.**

Silicon ECAL

- **Technology**
  - Active material: **Silicon PIN diode sensor (pad size of 5×5mm²)**
  - Absorber material: **Tungsten**
- **Silicon PIN diode is "an example of stability".**
  - One of the major argument for the use of this active material for calorimeter (in addition to high S/N at MIP level)
- **Excellent stability comes from**
  - The depleted zone will not change in time. In addition, running in over depleted regime avoids gain variation with temperature or pressure or water air content
  - The tungsten thickness will not change with time
  - The gain of the VFE entry preamplifier can be easily under control by charge injection





Strategy

SiECAL

- **Calibration**
  - Calibrated at construction.
  - No need for re-calibration
  - Just cross-check afterwards with *E/p* for electron (or $e^+e^- \rightarrow \mu^+\mu^- \gamma$)
- **Monitoring**
  - Check of variation of gain of VFE pre-amplifier by charge injection
- **Alignment**
  - Aligned in assembly in cassette and mechanical structure
  - Precise alignment with EM shower in collision data
- **No need of Z-pole data**

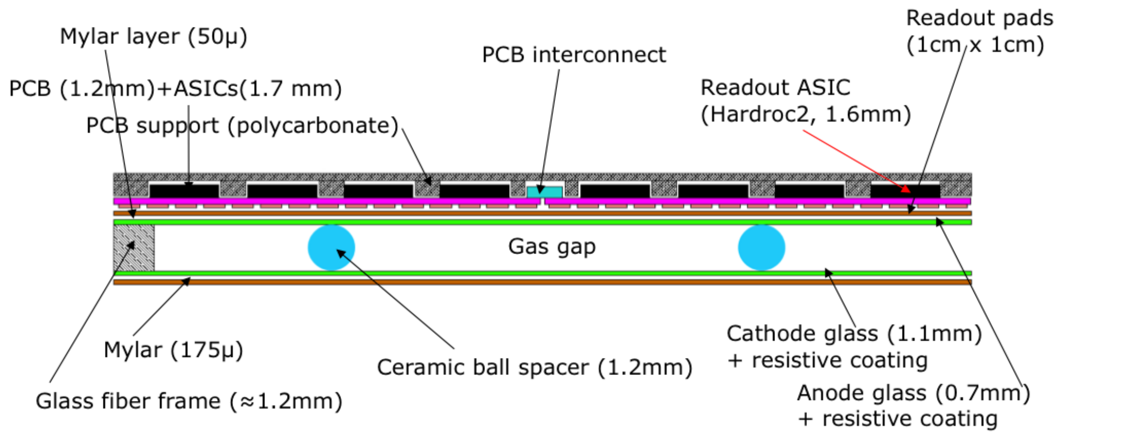
Required Precision and Statistics

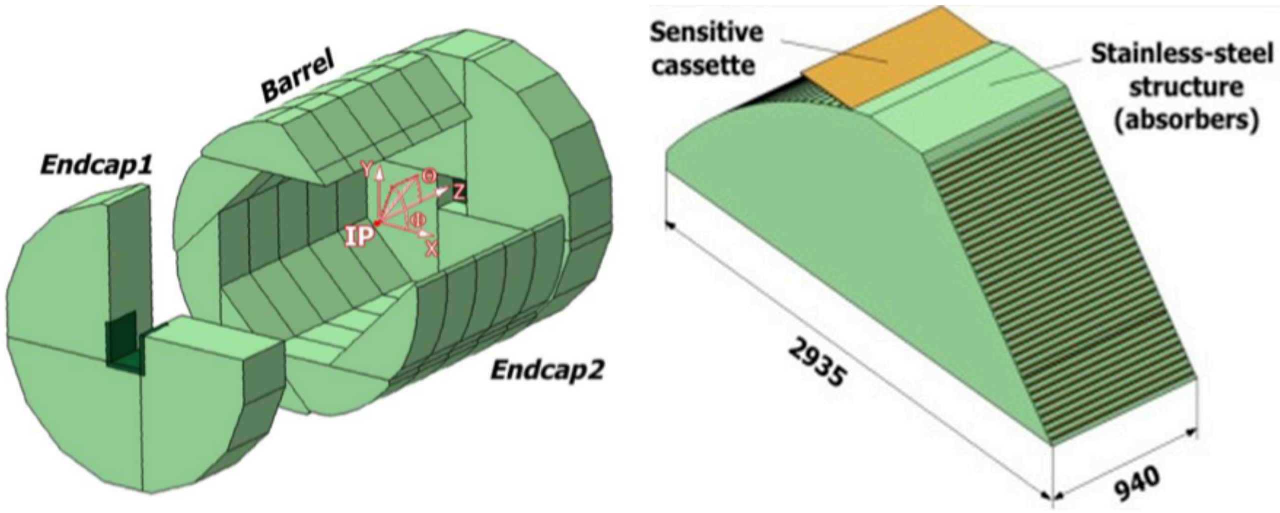
SiECAL

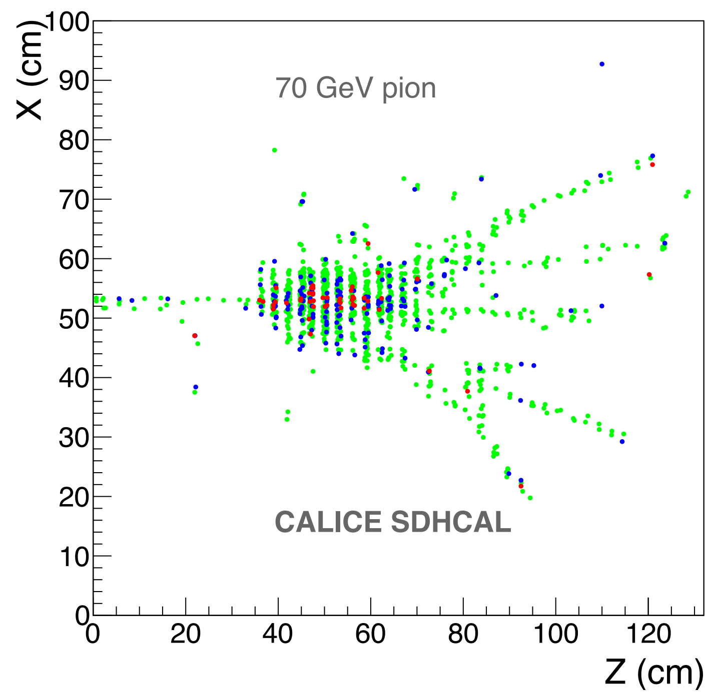
- **Calibration precision at per-mil level or better foreseen**
  - $1\%/\sqrt{N_{cell}}$ with N_{cell}~50 per GeV for EM shower and N_{cell}~30 (=N_{layer}) for MIP
    - Could be even better than per-mil for electron >10GeV
  - With a reasonable hypothesis without correlation btw channels
- **The stability has been demonstrated to be better or at the level of 1% to 2% /cell for 10 years.**
- **Precise alignment at few tens of microns level with EM shower**

SDHCAL

- **Technology**
  - Active material: **GRPC ($1\times1 cm^2$ pad readout)**
  - Absorber material: **Steel**
  - Semi-digital readout (three thresholds)
- **GRPC = very stable and homogeneous detector**
  - Stable if (T, p) HV correction applied
  - Calibration is rather simple
  - Large number of readout is challenging
- **Energy reconstruction**
  - $E_{rec} = \beta(N_{tot})\, N_1 + \beta(N_{tot})\, N_2 + \gamma(N_{tot})\, N_3$
    - N_1, N_2 and N_3 : exclusive number of hits associated to first, second and third threshold.
    - α, β, γ are quadratic functions of the total number of hits (N_{tot})



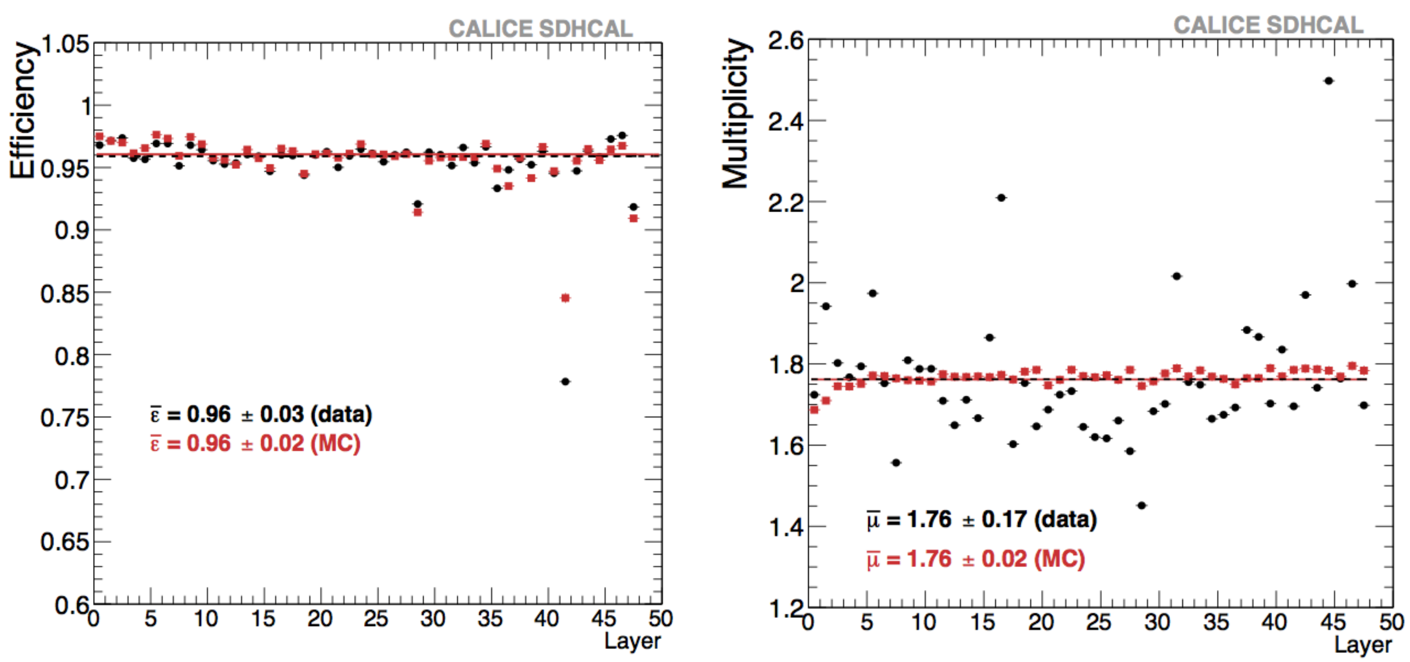




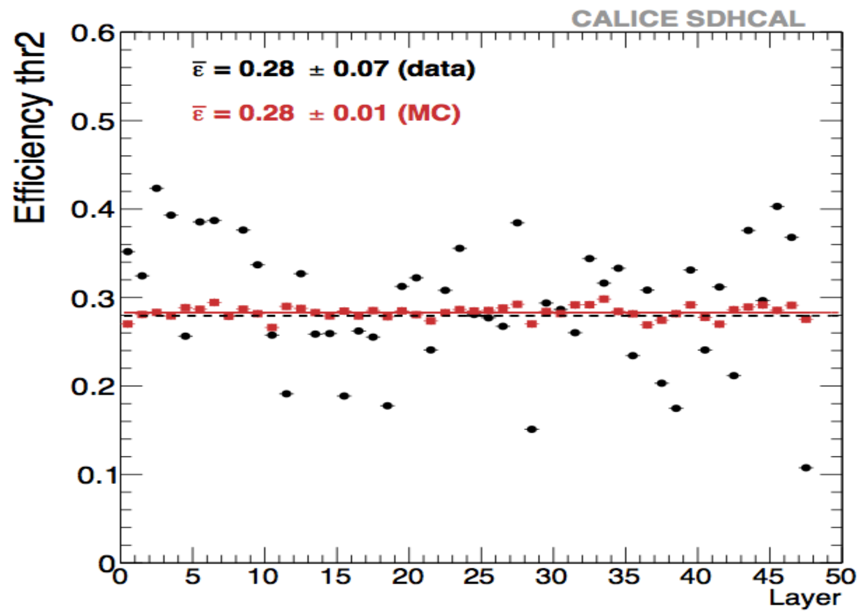
Strategy

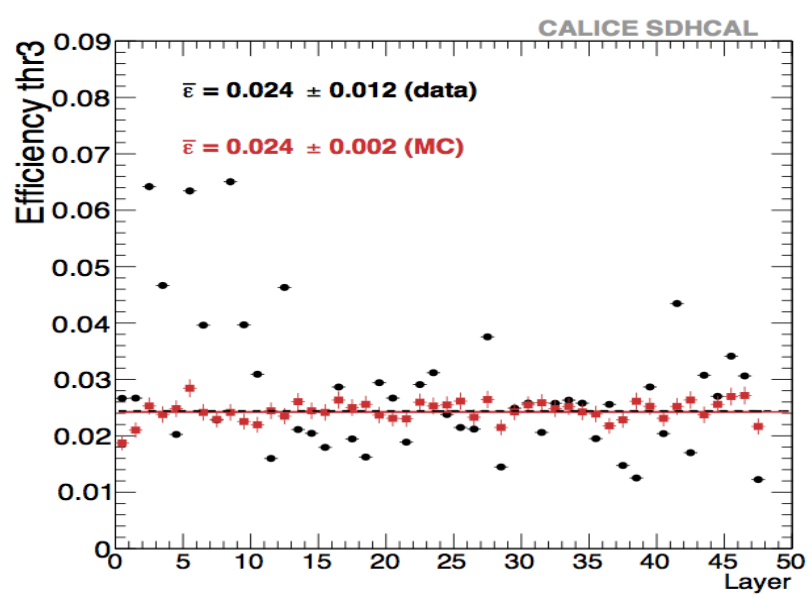
SDHCAL

- **To monitor stability of energy measurement over time:**
  - Need to control the stability of MIP efficiency and pad multiplicity
  - The percentage of N_1, N_2 , N_3 for MIP should be the same over all the modules and constant over time. They will be monitored using MIP/track-segment and used to correct for the energy reconstruction



Beam muon efficiency and multiplicity





Strategy

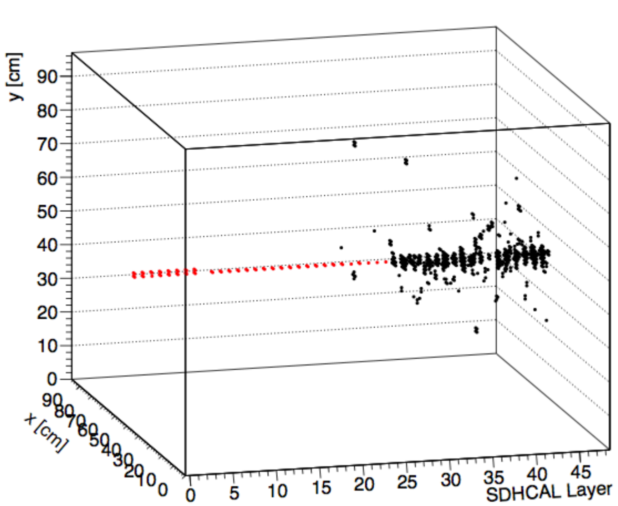
SDHCAL

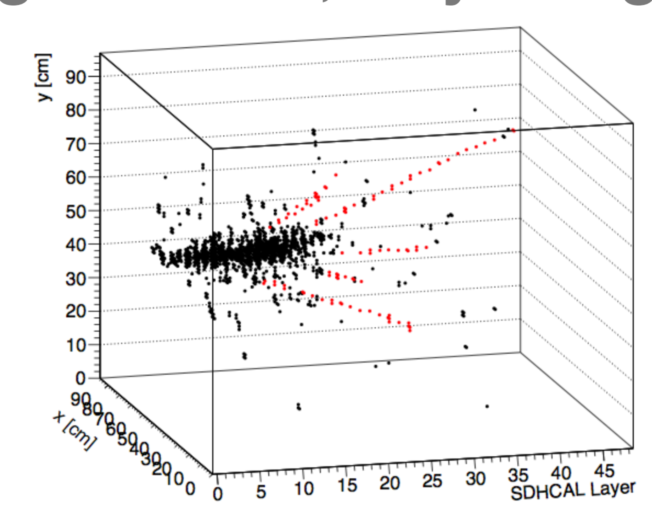
- **Alignment**
  - Determined by mechanical structure
  - Expected precision < few mm
  - Cosmics and beam halo muons will be used to check relative alignment btw different detectors
- **Electronics calibration**
  - Calibration before installation
    - Noise curve, gain correction and DAC/charge conversion for each ch
  - Control after installation
    - Strategy is under study.
- **Detector calibration**
  - Calibration before installation
    - Homogeneity of each detector will be tested using cosmic bench
    - 200 days if a unique bench is used
  - Control after installation
    - Only global detector efficiency will be monitored

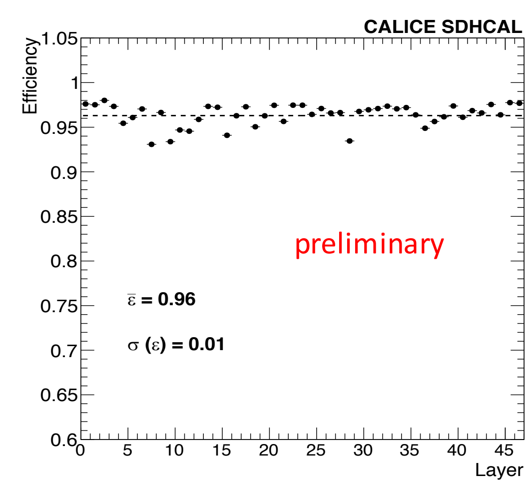
Calibration Sources

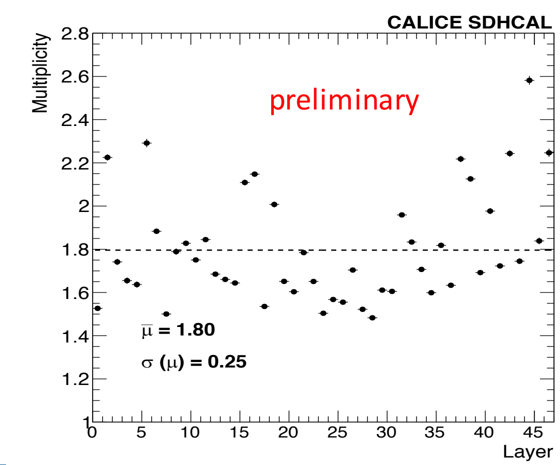
SDHCAL

- **Cosmics**
  - A few hours for lower part horizon GRPCs with a reduced live-time due to power-pulsing
  - Further limited after installation underground
- **Halo muons**
  - Essentially useful in the end-cap regions even with halo shielding
  - Only few seconds to check global efficiency at end-cap
- **Track segments within hadronic showers everywhere:**
  - Hough Transform method is used to extract track segments
  - Similar efficiency and pad multiplicity results are obtained with the track segments as for beam muon
  - ~2000 MIP hits/s for Z-pole run with 10^{33} cm^{-2}s^{-1}
  - In presence of magnetic field, only straight line tracks will be used





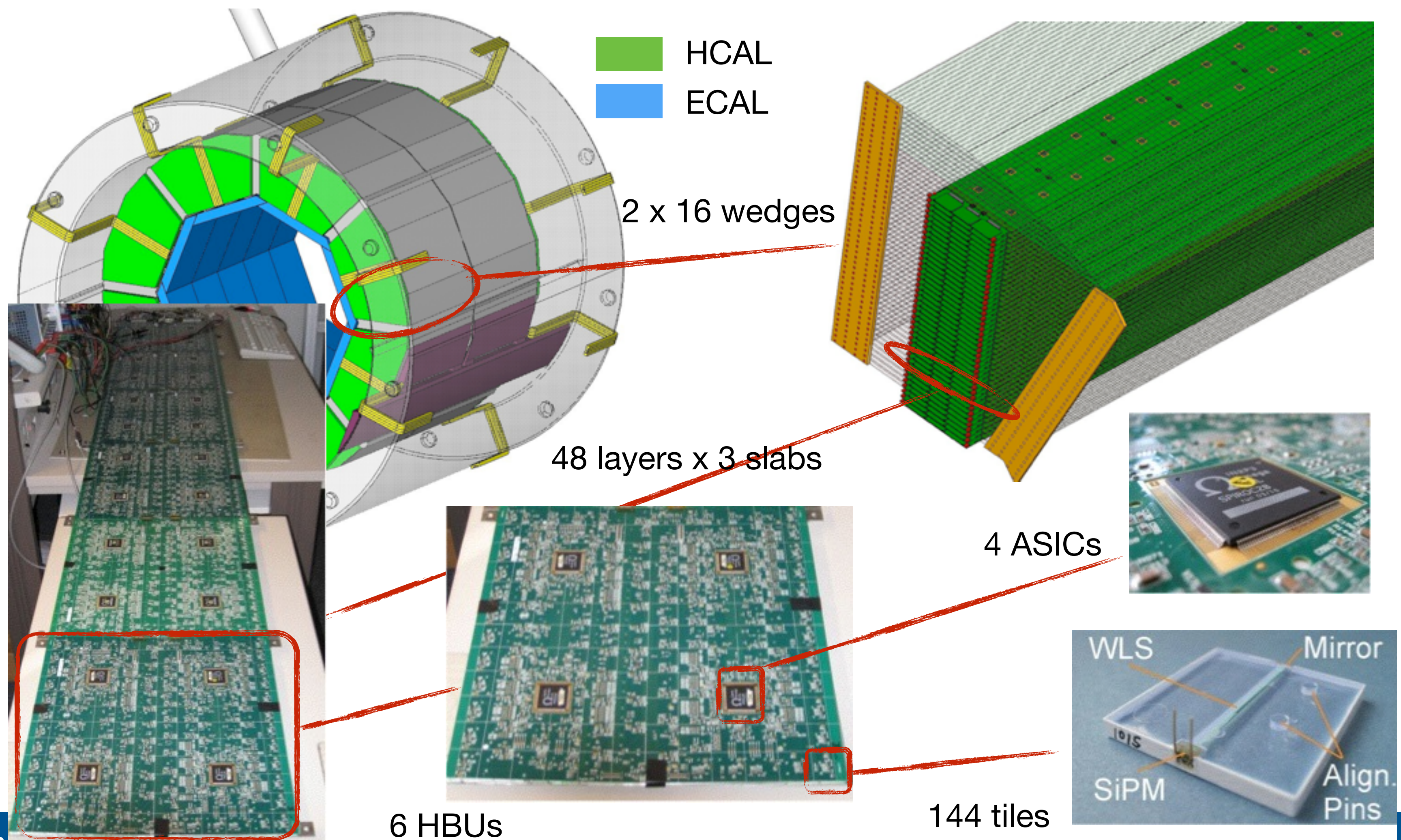




Scintillator HCAL (=AHCAL)

AHCAL

- **Technology**
  - Active material: **Scintillator tile ($30 \times 30 mm^2$) with SiPM readout**
  - Absorber material: **Steel**
- **SiPM charge signal depends on gain and efficiency, which both only depend on the over-voltage (V_{bias} - V_{BD})**
  - break-down voltage depends in uniform way on temperature and can thus be actively adjusted, keeping SiPM response stable
- **For the radiation levels of the ILC, no variations of the scintillator light yield are expected**



Strategy

AHCAL

- **Calibration**
  - Equalisation of cell responses (often called “MIP calibration”):
    - MIPs: cosmic or muon beams (many layers simultaneously)
    - SiPM corrections: test bench parameters and LED system
  - Electromagnetic and hadronic scales, weight factors:
    - beam test of sample structures
    - should include boundary regions (tests with two adjacent modules) for validation of dead material corrections
- **Alignment**
  - stable within required precision
  - layer-wise (transverse) parameters sufficient
  - few tracks
- **Monitoring**
  - LED system to check SiPM stability
  - track segments add redundancy and cross-check

Required Precision

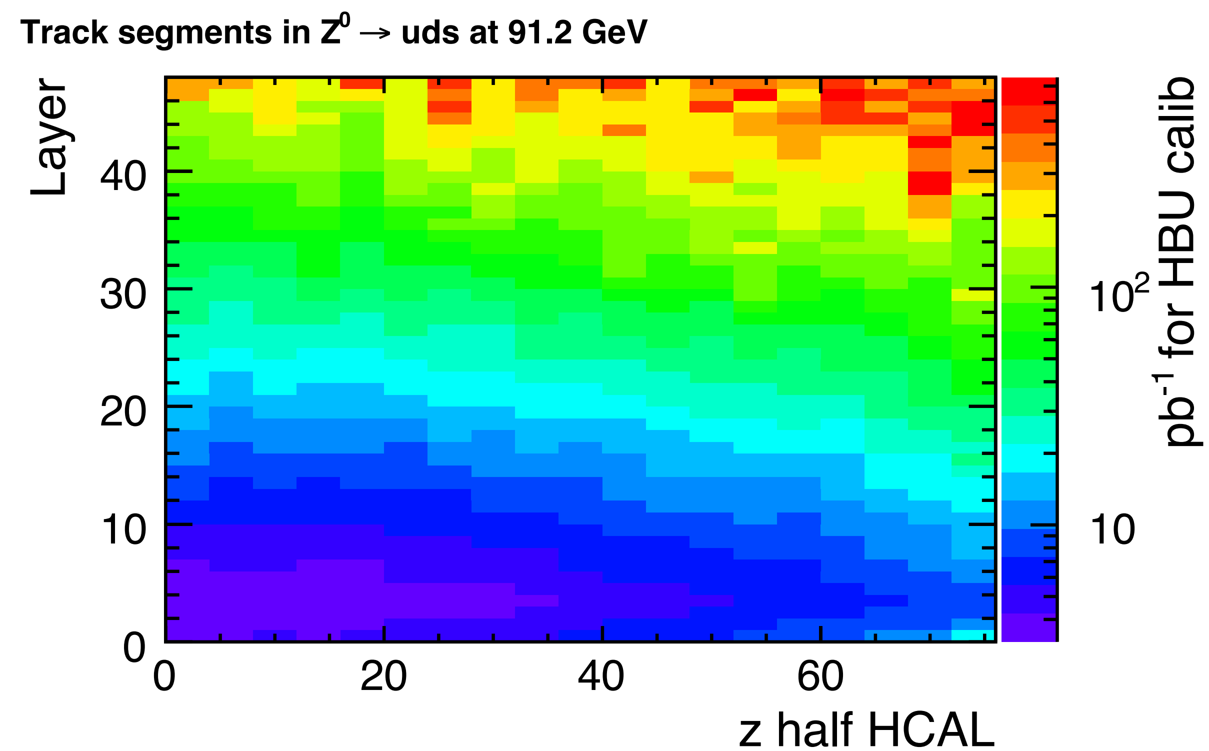
AHCAL

- **Studied in response to IDAG questions to LOI and documented in addendum and CAN-018 (2009)**
  - Simulations of single hadrons and jets with different mis-calibration scenarios
- **Maximum allowed cell-to-cell uncorrelated mis-calibrations of cells**
  - 50% (limited by track finding for calibration check)
- **Maximum allowed layer-to-layer uncorrelated mis-calibrations of layers**
  - no noticeable effect for up to 15%
- **Global drifts of the response scale**
  - 5% RMS fluctuation increases resolution by 1.02 for jets at 100 GeV, by 1.06 at 500 GeV
  - fast variation: never observed, obtain small constant term in TB
  - slow variation: temperature compensation and LED cross-check
  - easy to detect with small statistics
- **Global scale precision at jet level, beyond HCAL alone**
  - to be monitored by di-jet mass

Required Statistics

AHCAL

- **MIP calibration: 1000 entries for 3-4% precision**
- **Test beam: typically 2 tracks per shower, 20 cells hit**

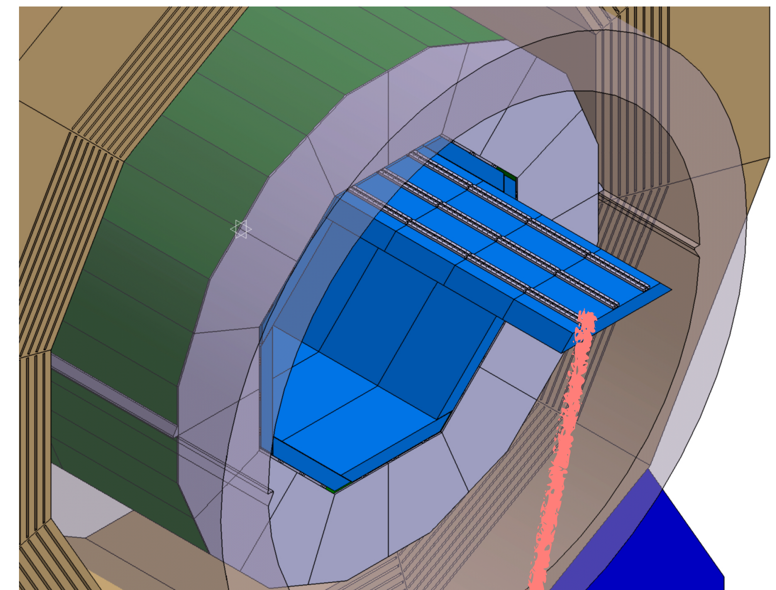


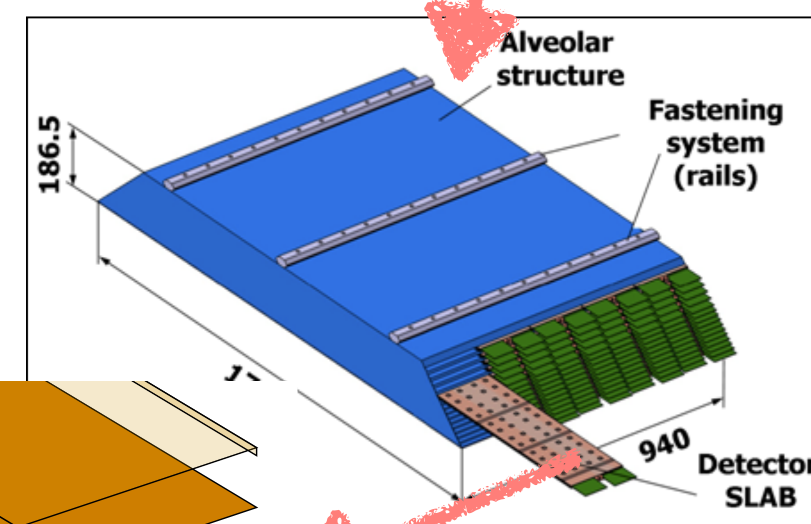
- **Z pole:**
  - 1 pb^{-1} 1000 tracks per layer in each module (3000 cells) up to layer 20
  - 20 pb^{-1} for layer 48, 10 pb^{-1} if $Z \rightarrow \mu\mu$ added, less if layers combined
- **500 GeV:**
  - 2 fb^{-1} 1000 tracks per layer in each module (3000 cells) up to layer 20
  - 20 fb^{-1} for layer 48, less if outer layers combined

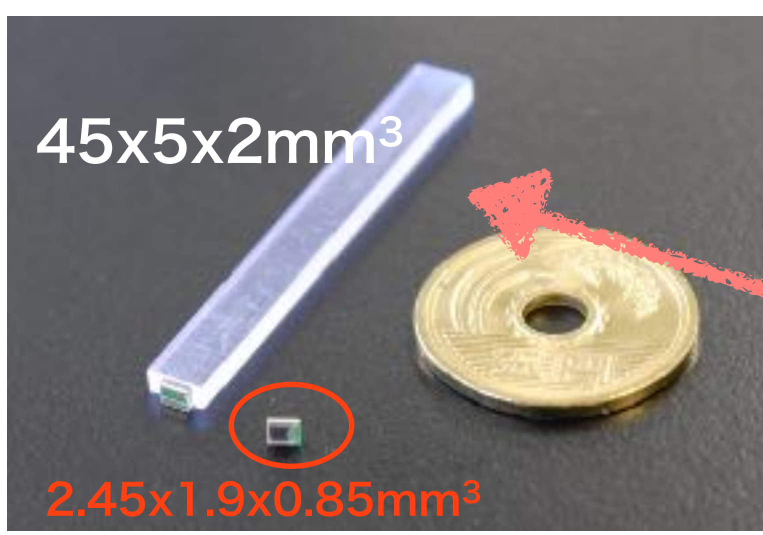
Scintillator ECAL

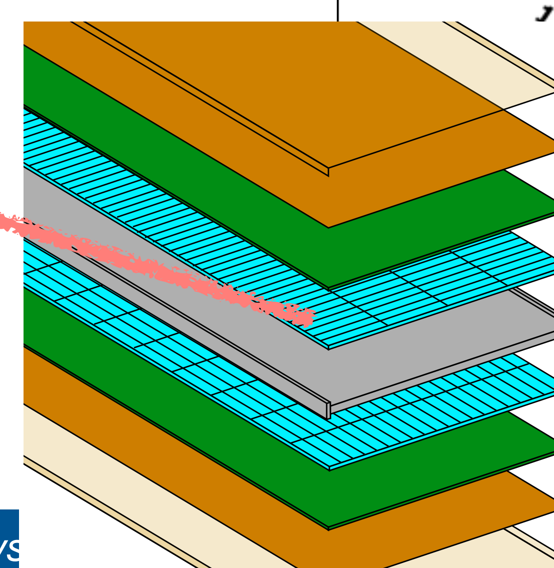
SCECAL

- **Technology**
  - Active material: **Scintillator strip with SiPM readout (virtual segmentation of 5×5mm^2)**
  - Absorber material: **Tungsten**
- **Integrated readout electronics**
  - EBU: same technology as HBU of AHCAL
- **Mechanical structure**
  - Same mechanical module as SiECAL can be used









Strategy

SCECAL

- **Similar calibration/alignment strategy to AHCAL anticipated since it's based on same technology.**
  - A little higher requirement for precision because of higher resolution expected
- **Calibration**
  - MIP response
    - Any MIP (cosmic, beam halo muon, muon/charged pion in collision data,…)
  - SiPM gain
    - Built-in LED system
  - Electromagnetic and hadronic scales
    - Test beam data
- **Alignment**
  - Aligned in assembly in cassette and mechanical structure (strip-wise, layer-wise)
  - Module-wise alignment can also be done by laser
  - Alignment can be checked with tracks in collision data
- **Monitoring**
  - SiPM gain with LED system
  - Temperature with several temp. sensors on each EBU

Required Precision and Statistics

ScECAL

- **Calibration**
  - Random strip-by-strip fluctuation on MIP/gain constants is acceptable up to 20-30% in terms of single particle resolution
  - Statistics: 50MIPs per strip necessary to achieve this level of precision
  - Effect on JER under study
- **Alignment**
  - A few hundred micron precision can be achieved.

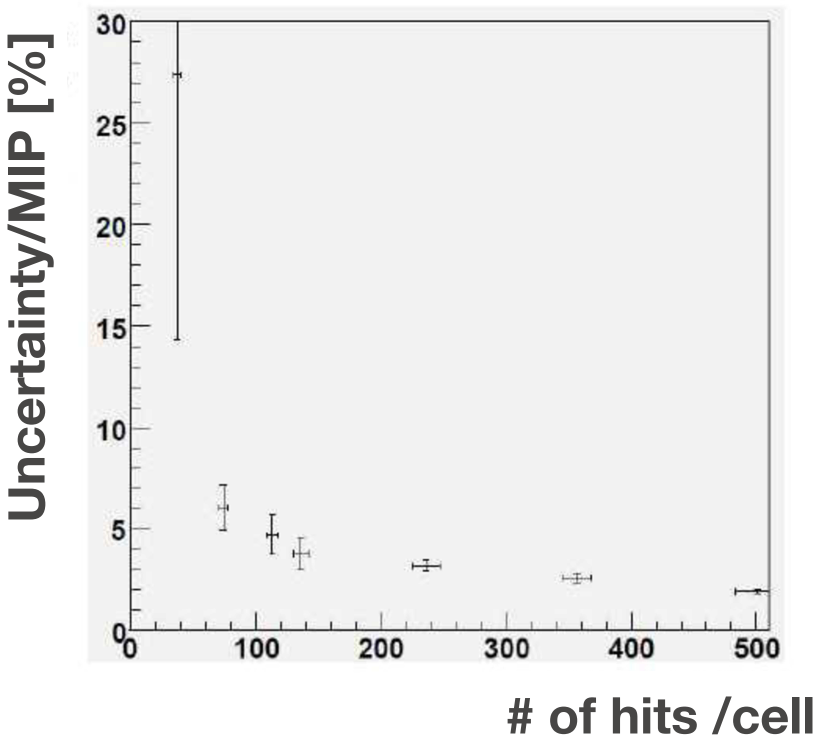


Table 2: Number of days to get 50 hits on a cell.

$\sqrt{s}$ (GeV)	luminosity ($\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	required days
91 GeV	4×10^{33}	1
200 GeV	2×10^{34}	200
500 GeV	2×10^{34}	1200

Summary

- **Different calorimeter technology requires different strategy for calibration and alignment.**
- **Calibration**
  - Response to single particles will be measured in beam test
  - Cell-to-cell equalisation will be done with MIPs at construction time
  - MIP constants can be monitored using track-segments in hadron showers in collision data
  - Silicon is intrinsically stable, while the others can be kept stable using active adjustment of operation parameters
  - Jet energy scale calibration depends on whole ILD detector and needs further study
- **Alignment**
  - Reasonably good alignment is already achieved when assembled in well-defined mechanical structure
  - It will be checked or further improved with tracks
- **Need further studies to have more complete strategies.**