# US-Japan Program
# ILC Detector R&Ds

Presented by
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US-Japan 40th Anniversary Symposium
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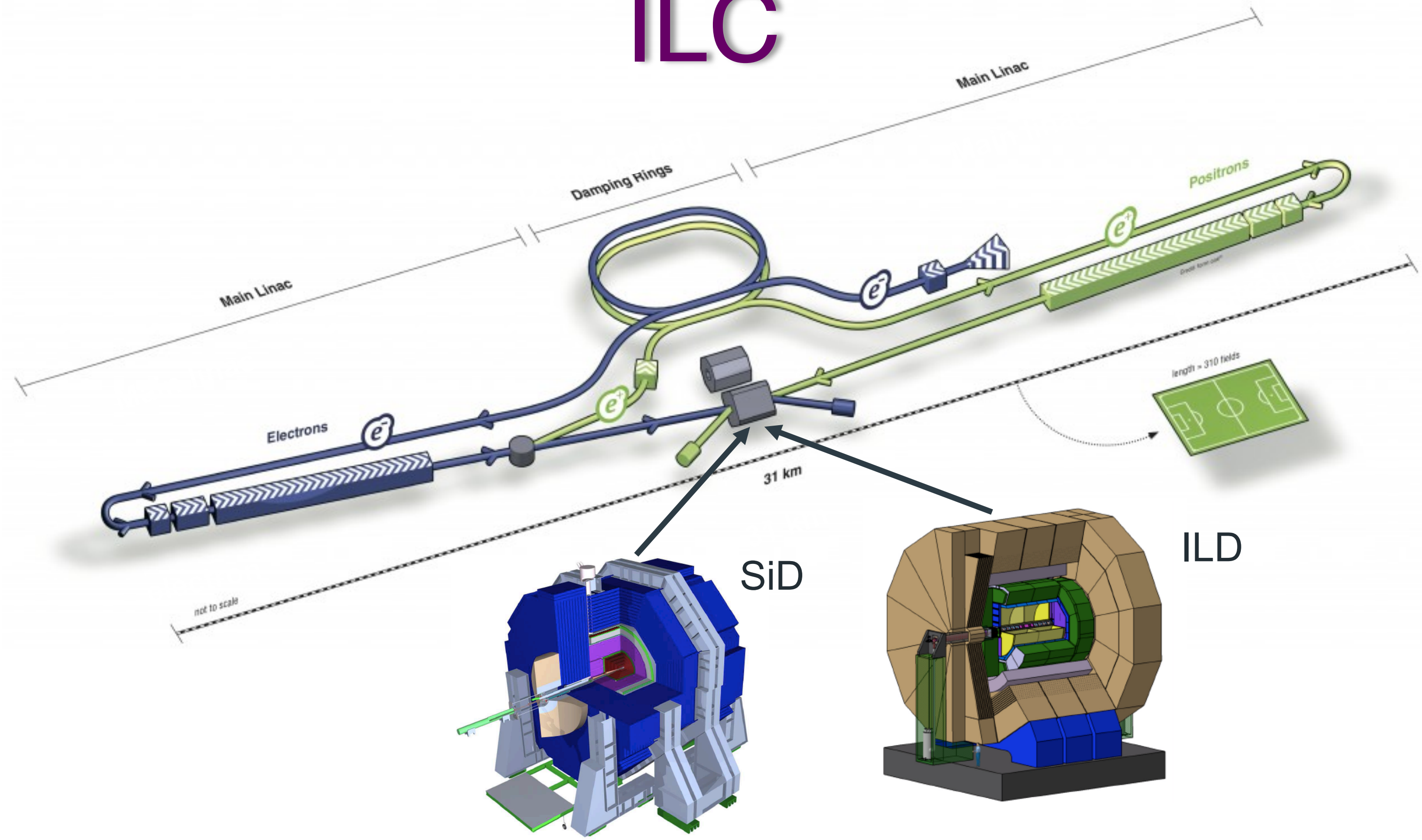
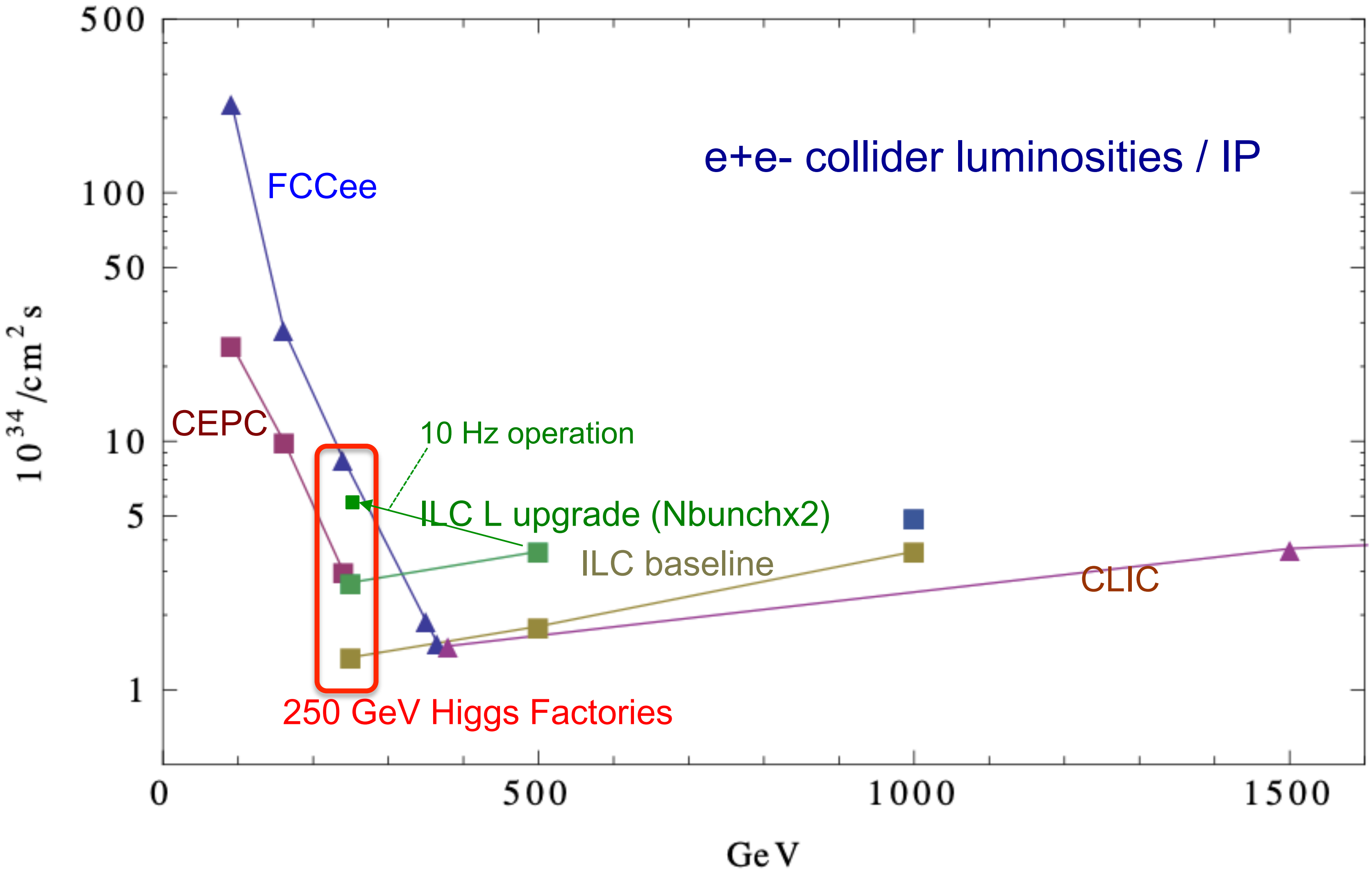
# ILC




## ILC 1$^{st}$ stage:

- Ecm = 250 GeV, L = 1.35 x $10^{34}$ /cm$^2$s
- Polarization (e+/e-) = ±0.3/±0.8
- 1312 bunches/train, 5 Hz (trains/sec)
- Wall plug power = 129 MW

# Luminosity vs Energy



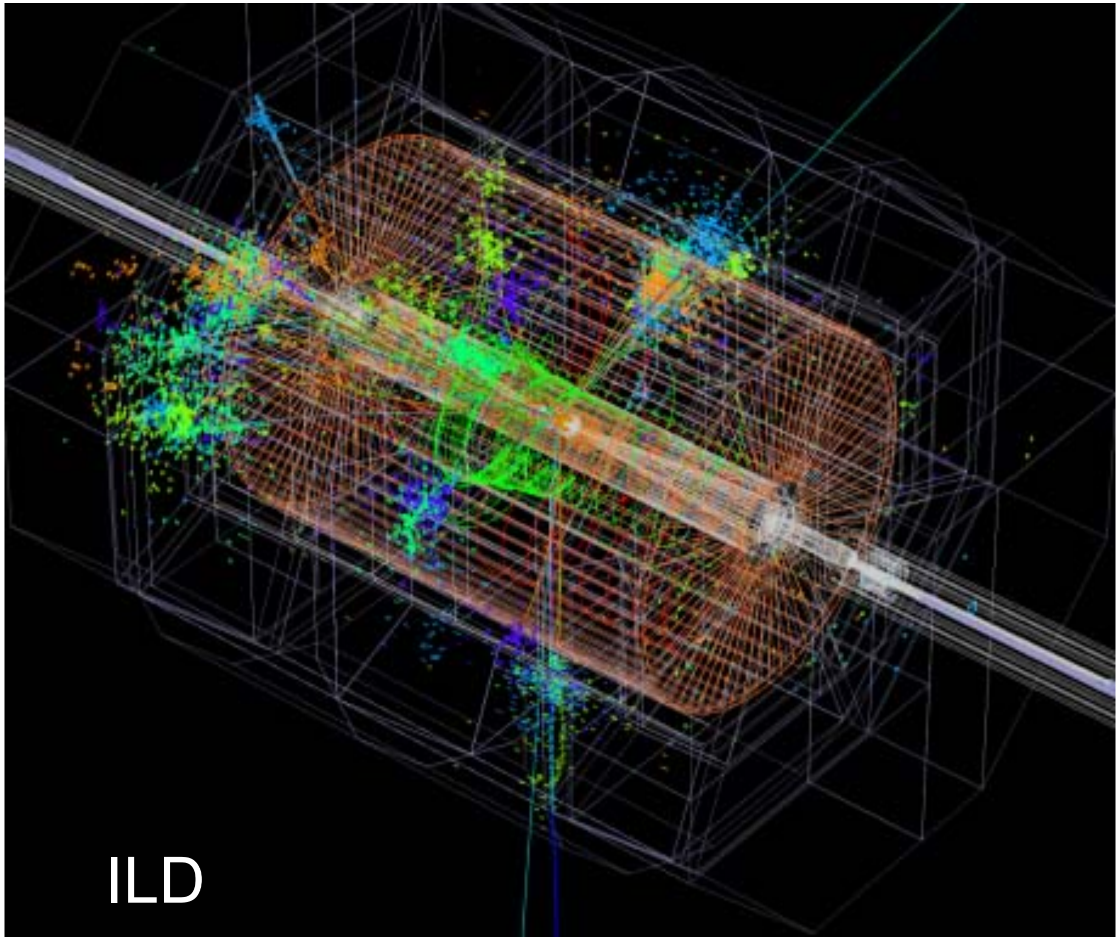

- Cost increase for ILC Nbunchx2 upgrade ~ 6%
- FCCee/CEPC points are for 1 IP (CDRs have 2 IPs each)
- ILC Higgs Factory numbers do not include effective x 2~3 by polarization

# ILC Detectors

## PFA
(particle flow algorithm)

Jet Energy Measurement:

- Charged particles
  - Use trackers
- Neutral particles
  - Use calorimeters
- Remove double-counting of charged showers




| #ch | ECAL | HCAL |
|---|---|---|
| ILC (ILD) | 100M | 10M |
| LHC | 76K(CMS) | 10K(ATLAS) |

Jet energy resolution ~ ½ of LHC

X$10^3$ for ILC
Need new technologies !

US-Japan program is part of such effort

# US-Japan Program in ILC Detector R&Ds

Productive US-Japan collaborations became possible thanks to this US-Japan program.

It fostered not just US-Japan collaborations but also collaborations between ILD (Europe-Asia based) and SiD (North Americas based).

- ‘Research and development for ILC detectors based on an advanced silicon technology’: 2013 ~ 2016

  PIs: Marcel Demarteau (ANL), Martin Breidenbach (SLAC), Hiroaki Aihara (U Tokyo)

  - 3D silicon sensor (‘VIP’ chip) for tracking
  - EMCal Sensor & Readout (KPiX chip) (tracking also)

- ‘Further development of ILC detector optimization and physics studies’: 2013 ~ 2016

  PIs: Akiya Miyamoto (KEK), Jan Strube (PNNL)

  - Computing infrastructures, GRID computing
  - Physics studies for the ILC

- Sensor Development for Future e+e- Colliders: 2017 ~

  PIs: Martin Breidenbach (SLAC), Hitoshi Yamamoto (Tohoku U.)

  - Sensors for ECAL and HCAL
    - KPiX chip, VIP chip
    - Position Sensitive Detector (PSD), Low-Gain Avalanche Diode(LGAD)
    - Silicon Strip sensors, Scintilator strips/pads,
    - Mass production technologies
  - Physics case for the ILC (detector optimization)

# Sensor Development for Future e+e- Colliders

## ECAL (EMCaL) and HCAL

2017~ : Currently active ILC detector R&D program

### Japan

Hitoshi Yamamoto* (Tohoku University)
Tomoyuki Sanuki (Tohoku University)
Akimasa Ishikawa (Tohoku University)
Hiroaki Aihara (University of Tokyo)
Sachio Komamiya (University of Tokyo)
Satoru Yamashita (Uiversity of Tokyo)
Wataru Ootani (University of Tokyo)
Yoshiyuki Onuki (University of Tokyo)
Tohru Takeshita (Shinshu University)
Kiyotomo Kawagoe (Kyushu University)
Tamaki Yoshioka (Kyushu University)
Taikan Suehara (Kyushu University)
Daniel Jeans (KEK)
Keisuke Fujii (KEK)
Akiya Miyamaoto (KEK)

### US

Martin Breidenbach* (SLAC)
Angelo Dragone (SLAC)
Andrew White (U.T.A.)
James Brau (U. Oregon)
Raymond Frey (U. Oregon)
David Strom (U. Oregon)
Marcel Demarteau (Argonne)
Gerald Blazey (NIU)
Alexander Dyshkant (NIU)
Vishnu Zutshi (NIU)

∗ representative

# GRID/Software Activities

Japan

Develop and operate GRID-based MC production system

LCFIPlus flavor tagging software (vertex finding package)

Tape storage at KEKCC.

Study ILC physics case, including the application of EFT formalism.

US

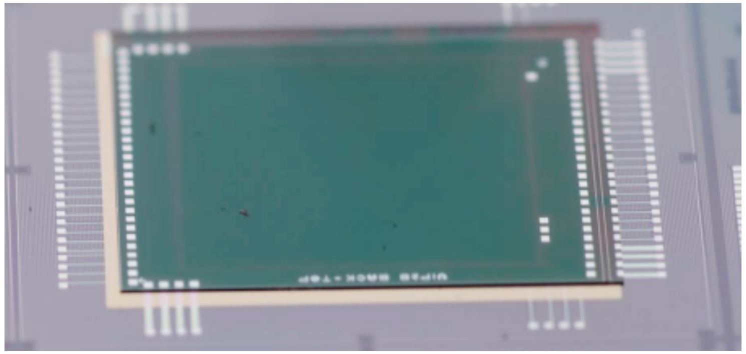
Maintain and operate Disk Storage at PNNL

Develop the EFT formalism and study ILC physics case

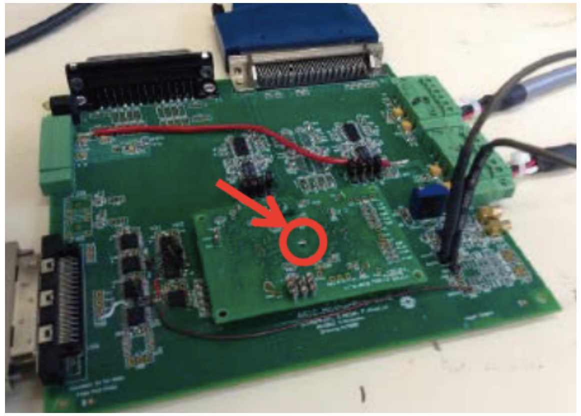
- SiD detector model and two ILD detector models, Large and Small, were implemented and data reconstruction tools were developed.
  - Validated by a series of test MC productions.
- In 2018, a large scale MC production was done and detector optimization studies are now being performed.
- The framework based on the EFT was developed. It was a critical element in establishing the scientific case of the ILC250.

# VIP Chip

VIP chip bonded to sensor



VIP chip test



VIP (Vertical Integrated Pixel) chip fabricated at Fermilab

- For ILC or Belle II upgrade
- 180 nm feature size
- 2-tier (analog and digital)
- 192x192 pixels, 1 pixel: (24 $\mu$m)$^2$

VIP chip characterized

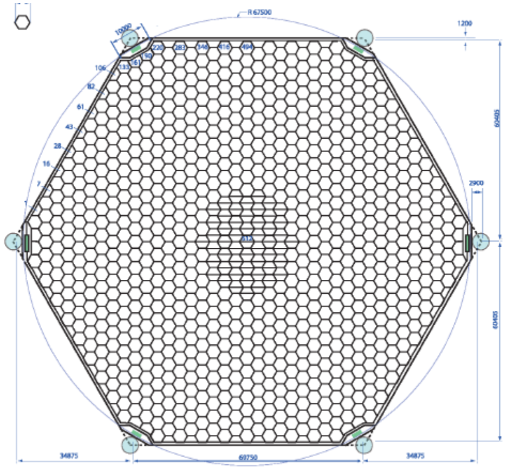
* All 192x192 channels were read out

* Noise 8e + 05/fF

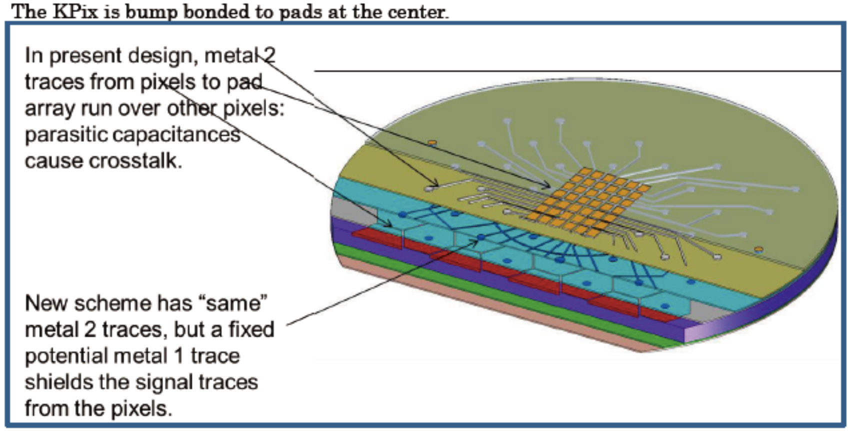
* Poor charge injection response in a limited area of the chip
  Due to bad digital-analog contact → redesign for specific application

# EMCal sensor and KPiX chip

SiD EMCal sensor



Sensor Metal Layer design




Sensor 1024 channel/sensor 13mm$^2$ ~(3.6mm)$^2$ (6in wafer)

KPiX: readout chip 1024 channel

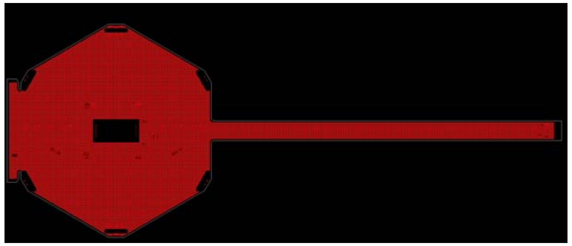
Bump bonded and tested in beam

- Bonding was difficult – UBM by Hamamatsu for new one: fabricated and bonded
- Reset noise - corrected
- Cross talk - New design for traces (solution: fixed potential for metal 1)

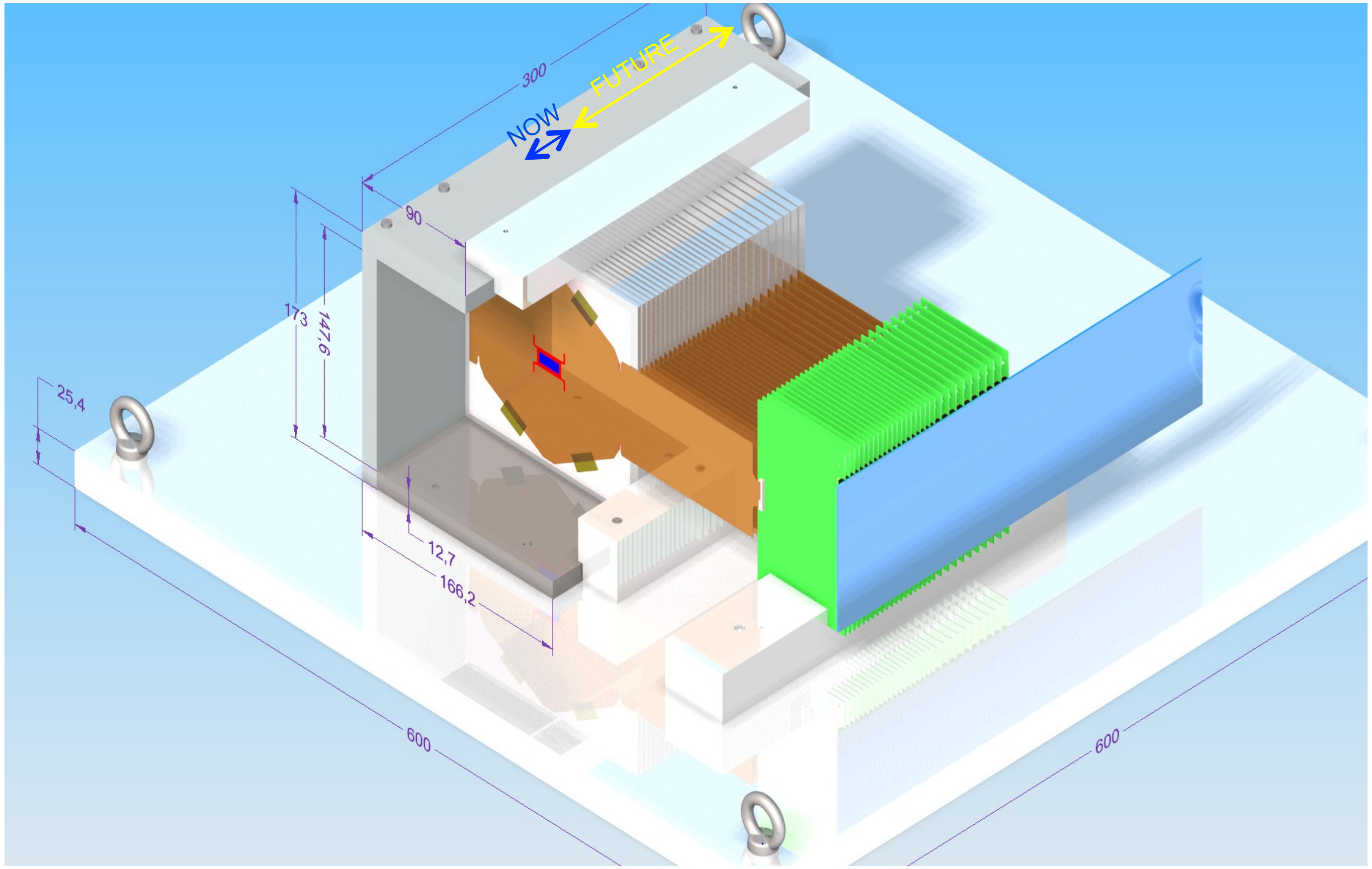
  Fabricated – now being tested

Monolithic pixel sensor based on KPiX ('KPiXM') being designed

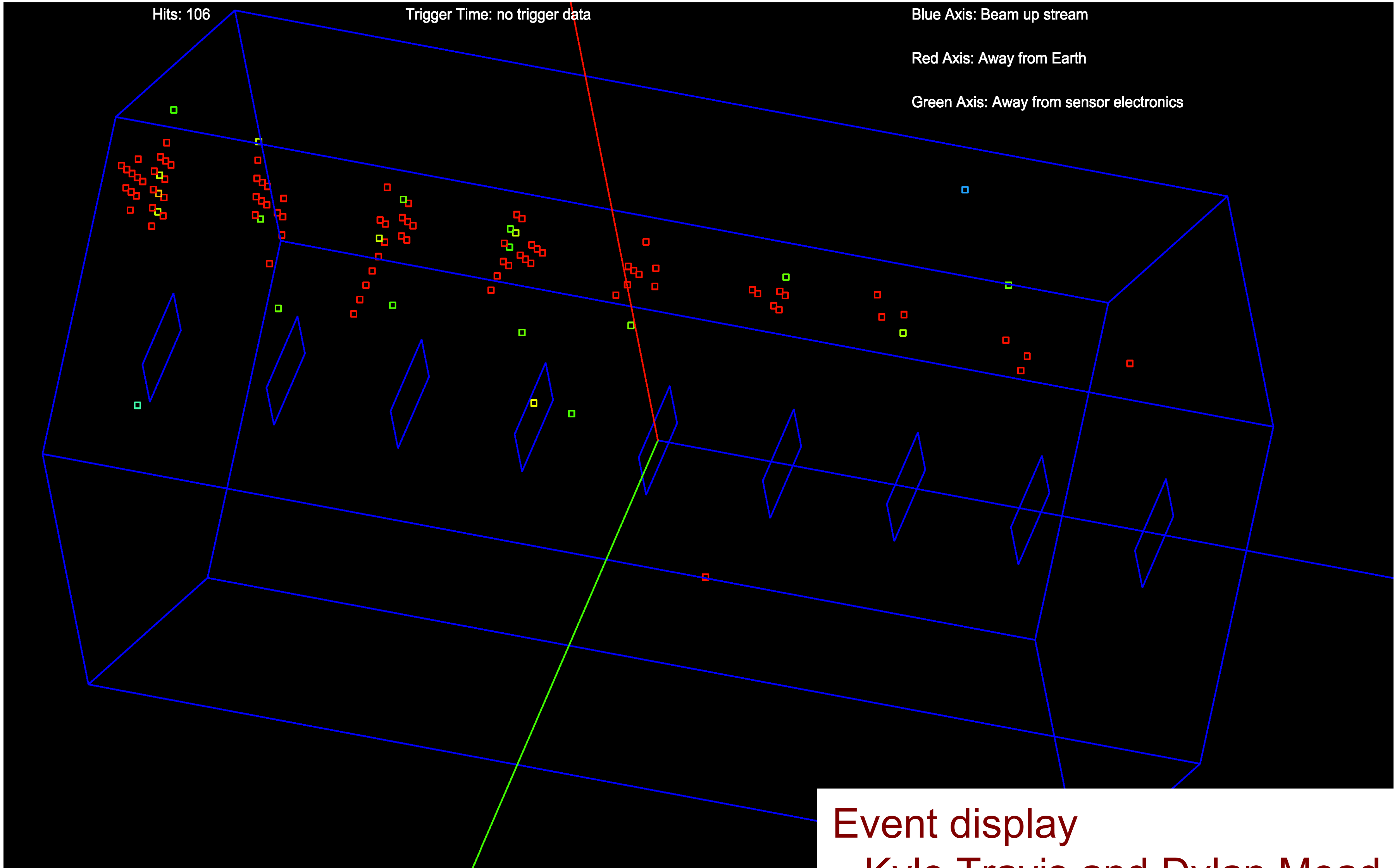
# Test beam module: 9 Si + 8 W layers (~ 6 $X_0$)



Kapton cable
Designed to simplify the readout

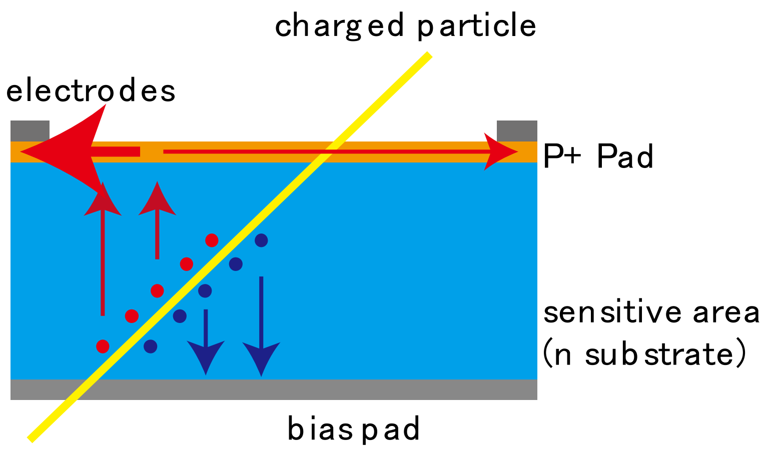


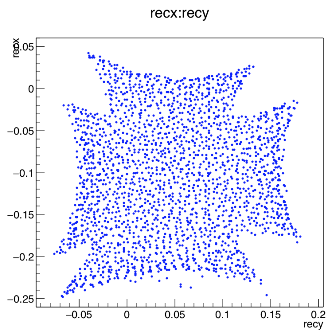
# Beam test: Single-electron showers



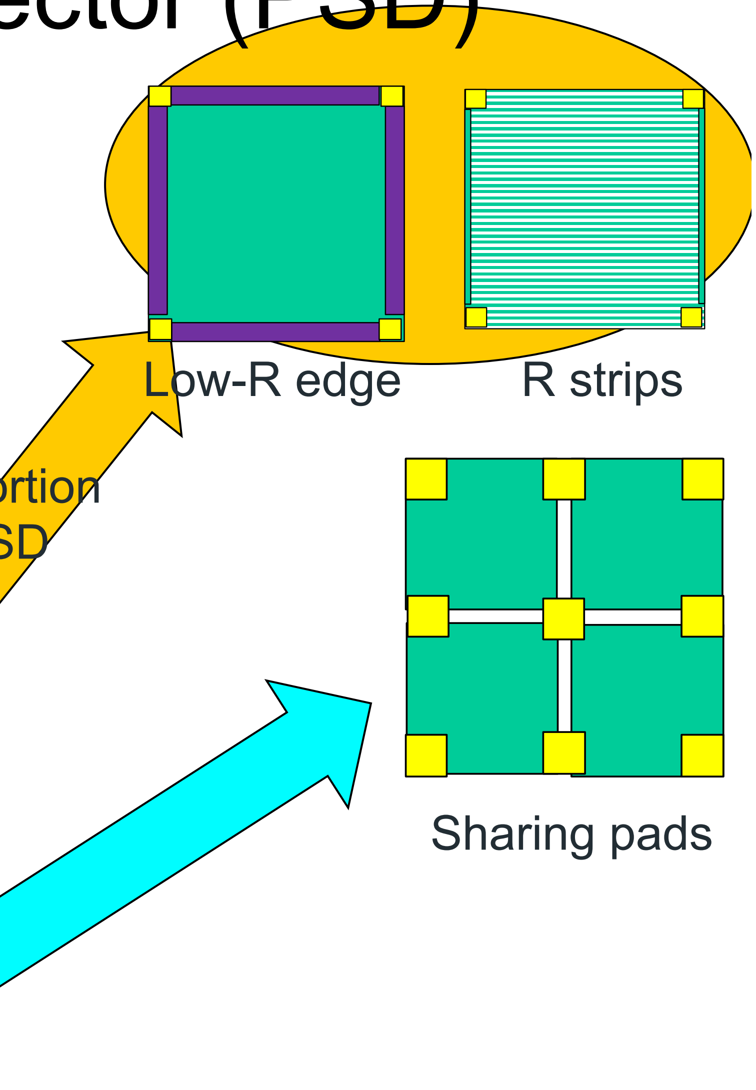

Event display
– Kyle Travis and Dylan Mead

# Position Sensitive Detector (PSD)




Position distortion with old PSD



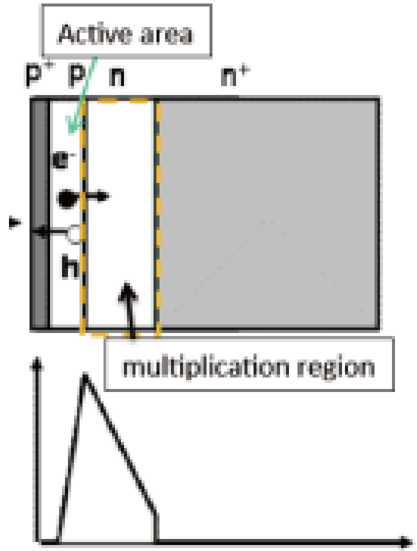

- Charge sharing
  → S/N ratio is important
- Position distortion
  →Various ideas to reduce the distortion
- Increase of readout channels
  → sharing pads to keep number of readout channels small

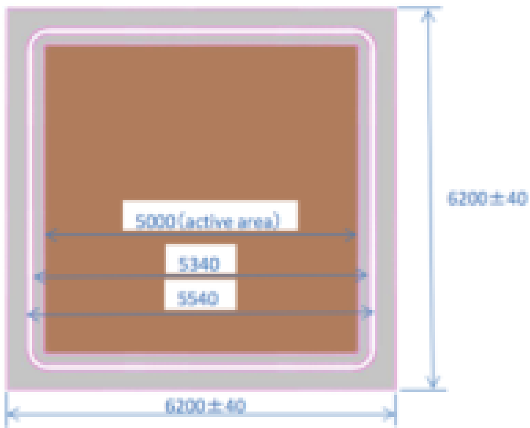
# Low Gain Avalanche Diode (LGAD)

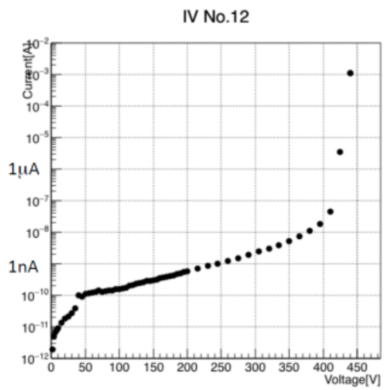
Multiplication (Gain: a few – a few tens)

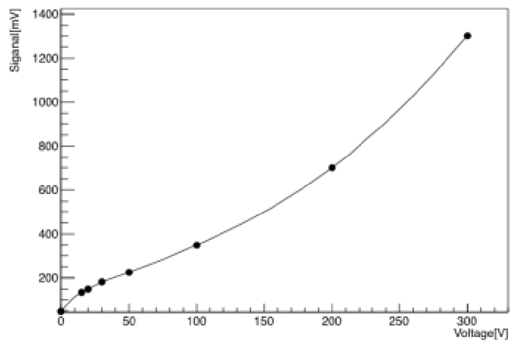
- Better S/N for PSD
- Time resolution: goal is ~20 ps (ToF particle ID in ILC)

Test APD ('Inverted LGAD') first

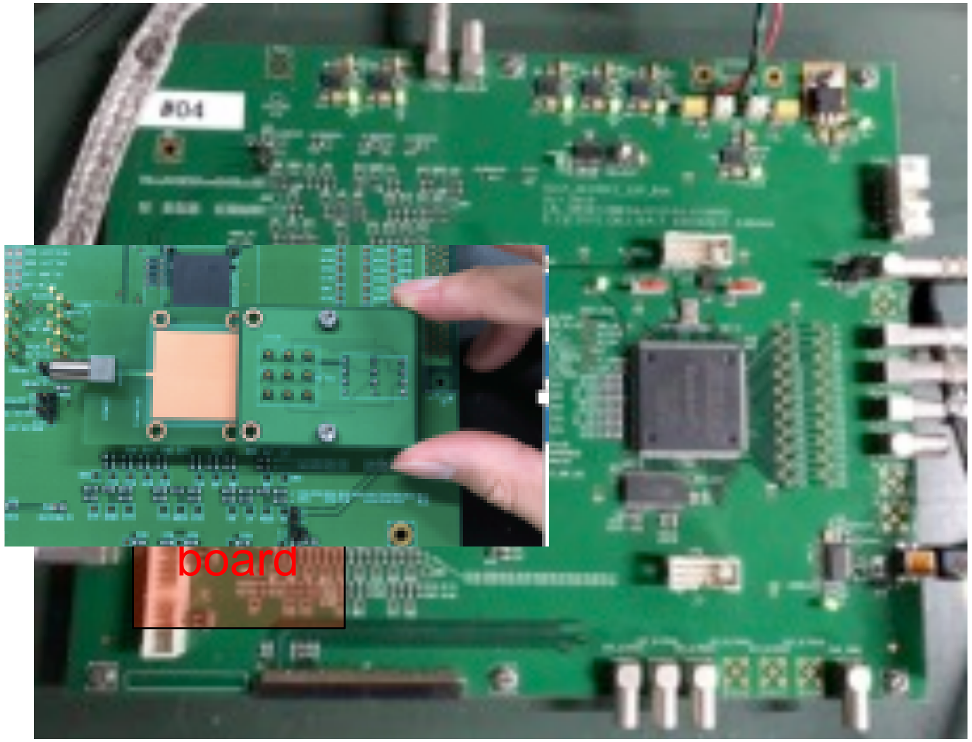


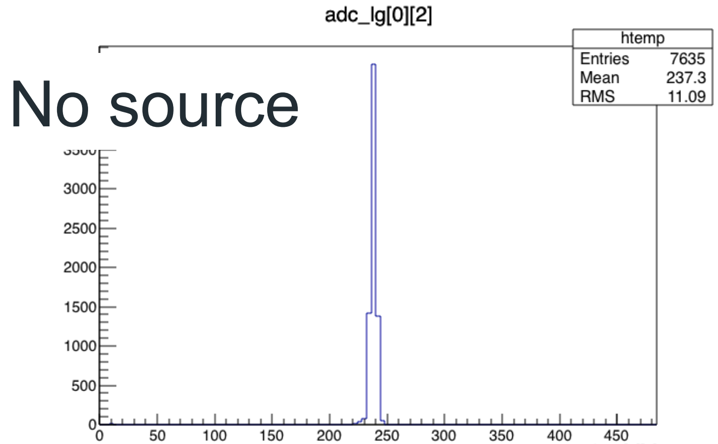



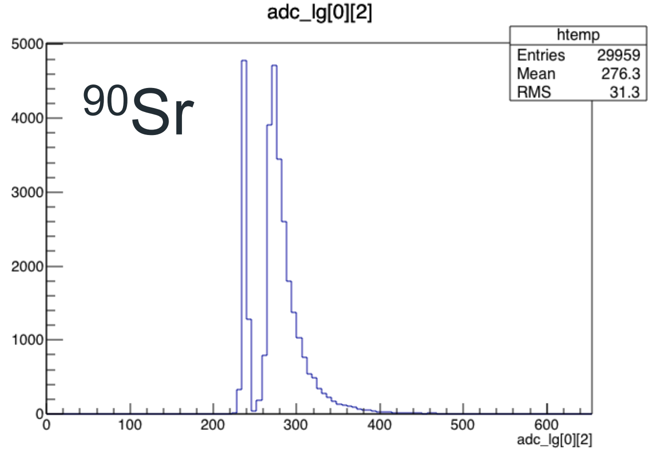
# APD Measurement with test board




SKIROC2A testboard with sensor board

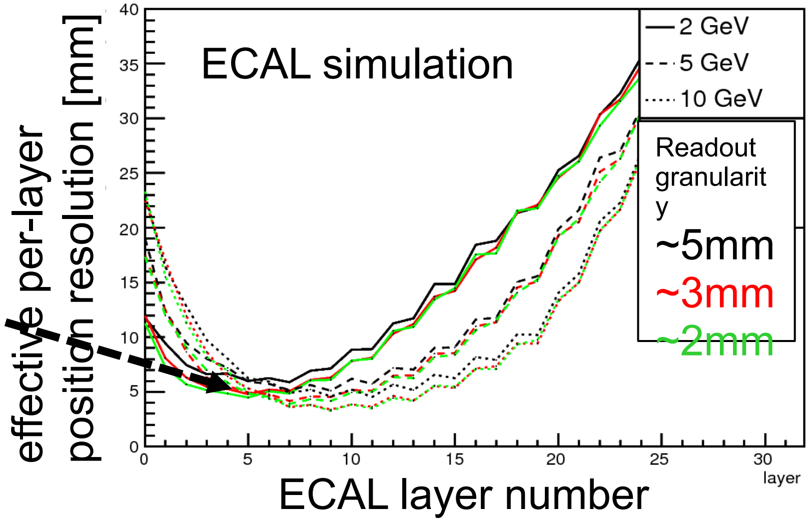
SKIROC2A: ILD ECAL ASIC
used in the tech. prototype




APD tested with beta and gamma sources
as well as laser
LGAD design being discussed with Hamamatsu

# Strip-readout ECAL




## Simulation study (2017)

Changing granularity from 5 → 3 mm gives ~20% improvement near shower maximum

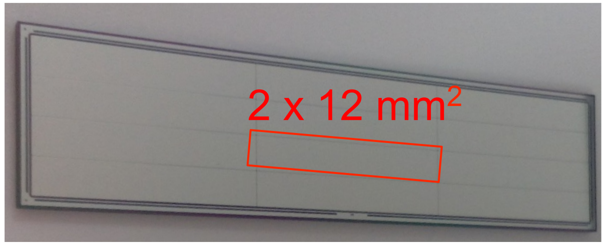
## Technical solution:

Strip-based readout of silicon sensors

## "Strip splitting algorithm":

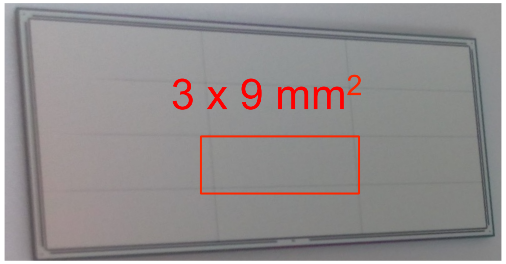
Orthogonal layer resolves position along strip length

- Verified for HCAL by simulation




Keep similar per-cell area as square cell design

→ possible performance improvement for fixed cost




Prototype sensors produced (Hamamatsu P.K.)

(2x12) mm$^2$ and (3x9) mm$^2$ segmentation

# Overview of HCAL Activities

**Common R&Ds**

Scintillator material

Mass production/test (incl. Mega-tile, injection molding)

Integrated Readout Layer (IRL)

Combined test beam experiments (CALICE framework)

**U.S. responsibilities (non exclusive)**

Overall design for SiD AHCAL

Design support

**Japan responsibilities (non-exclusive)**

Scintillator strips

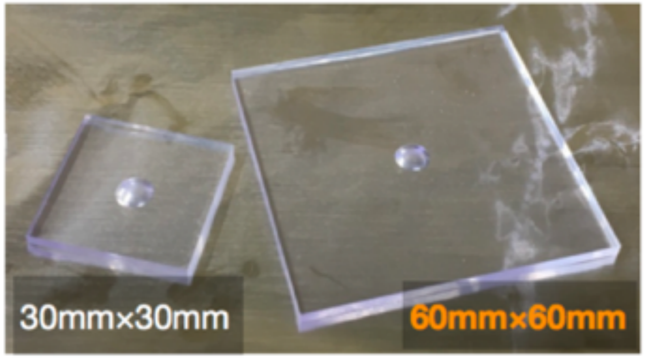
SiPM corner readout

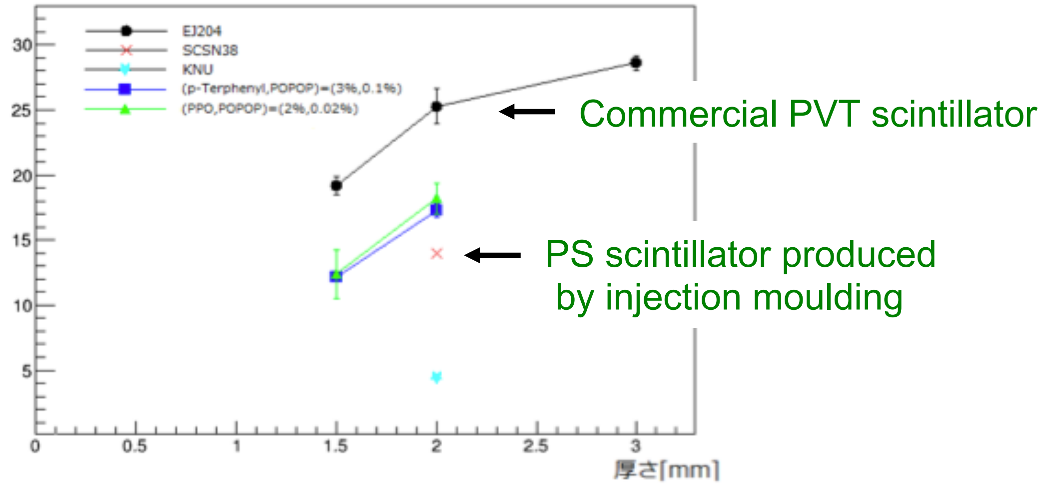
Mixed granularity study (layer-dependent granularity)

# Scintillator Material Study

Improve light yield for polystyrene-based scintillator produced by injection molding, which is suitable for large scale production

Production parameters are still being optimised, but reasonably good light yield (~70% of commercial PVT scintillator) is already achieved.



# Mega-tile Active Layer

Make grooves on a big scintillator sheet to form pads.

Sawing: faster and cheaper than machining.
Light yield tested: 10~15% lower than milled.


Mega-tile

6-teeth saw (6 inch dia)

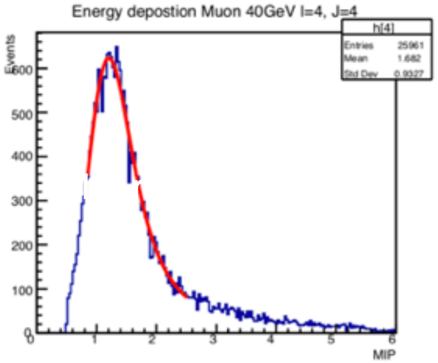
# Granularity Study and Combined Test Beam with CALICE AHCAL

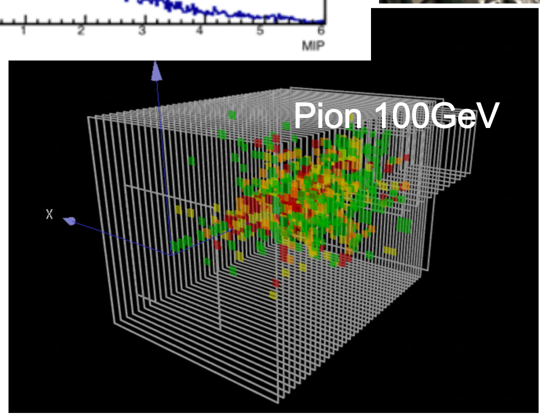
Demonstrated excellent performance of larger scintillator tile ($60 \times 60 mm^2$)

Developed active layer with larger tile for granularity study

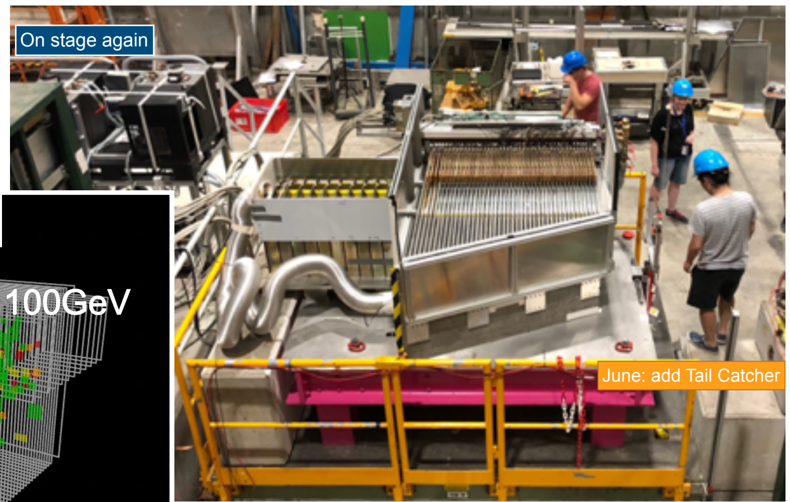
Integrated into CALICE AHCAL prototype and tested in test beam experiments at CERN SPS

It worked quite well and the data analysis is in progress




Pion 100 GeV

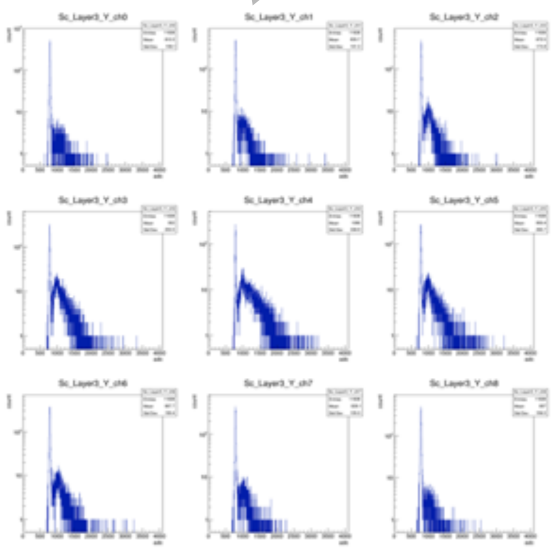


# Strip HCAL

**Scintillator strip option for HCAL under study**

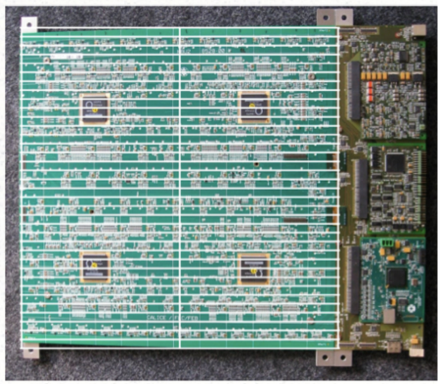
- Scintillator strip (1cm×18cm) with WLSF
    - Effective granularity: 1cm×1cm
- Integrated readout electronics

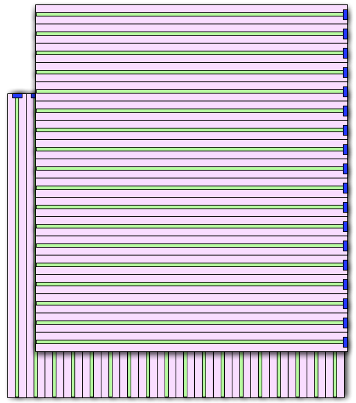
**Beam tests at Tohoku U.**

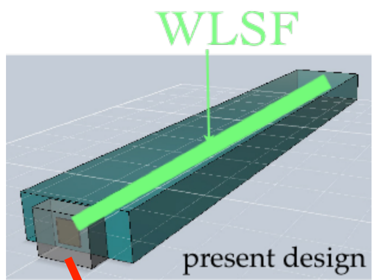


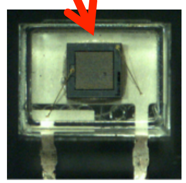
Tohoku ELPH beam test

18cm*1cm scintillator strip





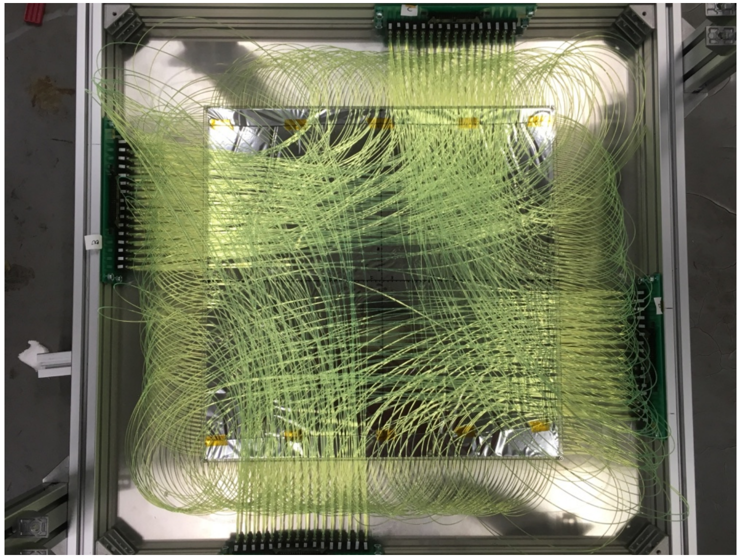


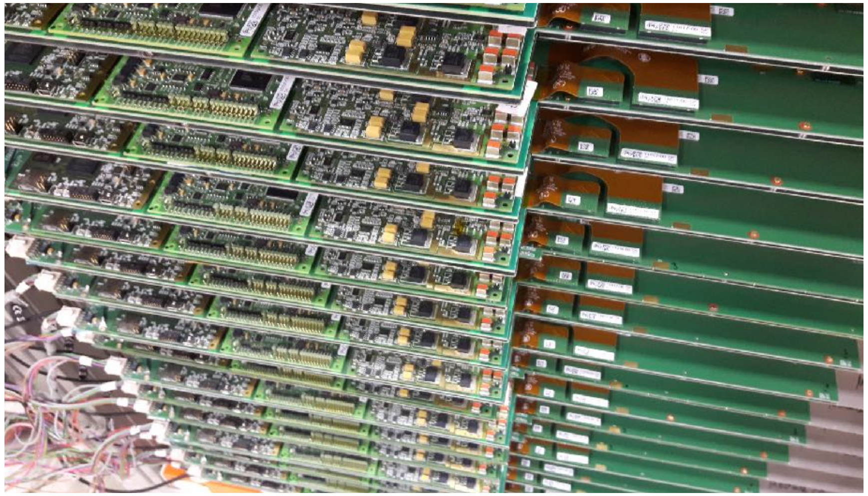



1mmx1mm MPPC

# Development of Cosmic-ray Hodoscope

- Cosmic-ray hodoscope with high position resolution developed for commissioning of active layers
- Cosmic ray test up to 18 layers at a time





# Summary

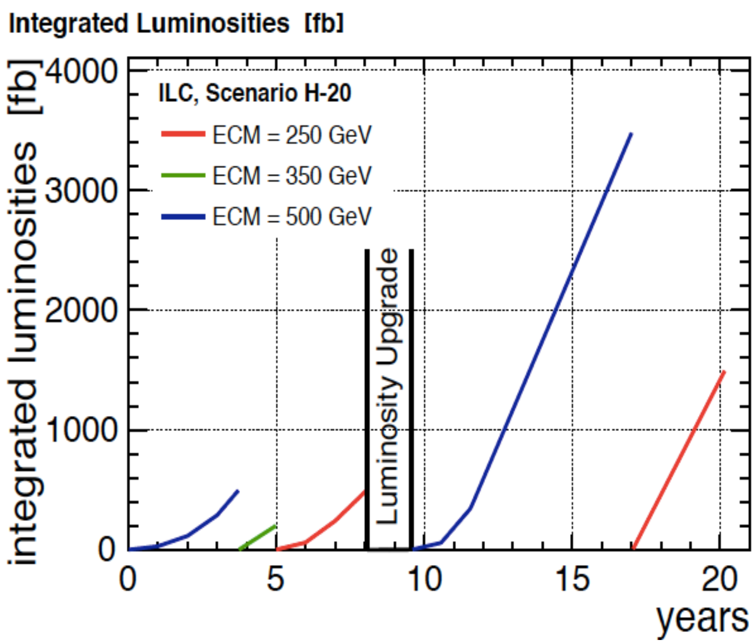
The US-Japan programs on ILC-related detector R&Ds have been extremely useful in fostering productive joint efforts between US and Japan.

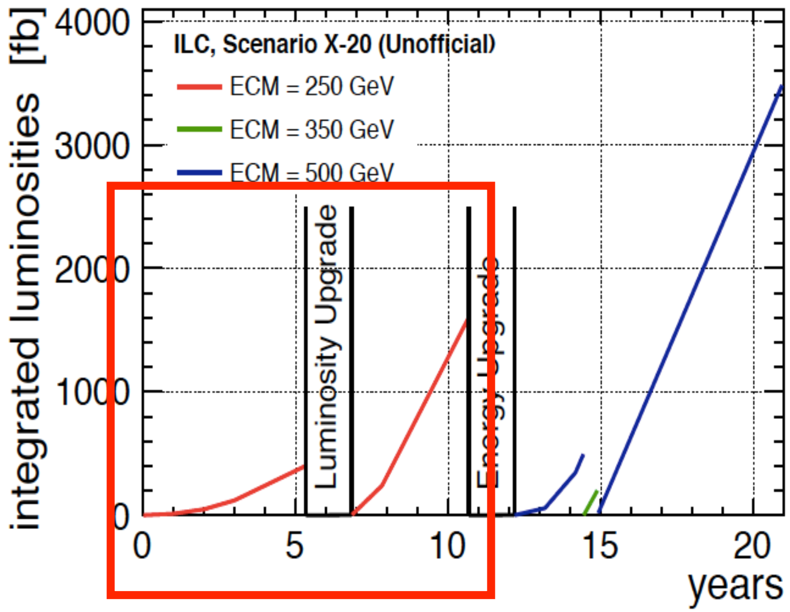
These efforts have also been a critical element for the global collaboration on ILC detector (ILD and SiD).

We would like to thank the support for the ILC-related detector efforts that US-Japan program has provided.

# Backups

# Staging：ILC250 Higgs Factory




ILC250 Higgs Factory

Build the ILC250 Higgs factory as the first stage ‘program’

～40% cost reduction wrt ILC500

# Machine Parameters

ILC250 Higgs Factory

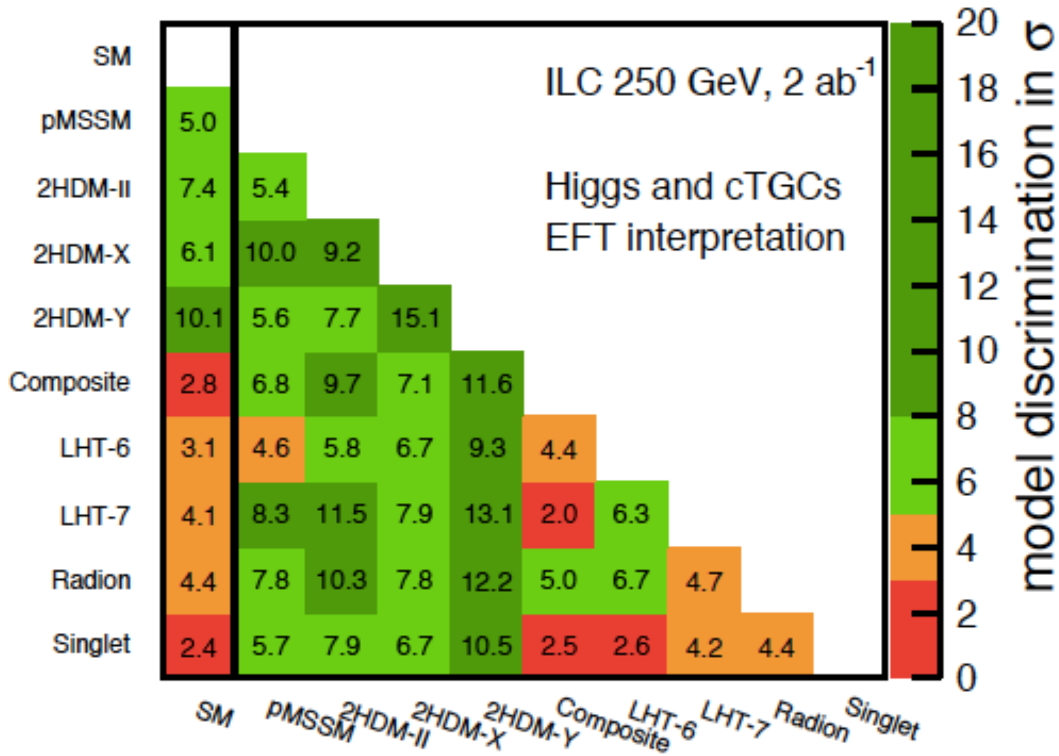
| Quantity | Symbol | Unit | Initial | $\mathcal{L}$ Upgrade | TDR | Upgrades | |
|---|---|---|---|---|---|---|---|
| Centre of mass energy | $\sqrt{s}$ | GeV | 250 | 250 | 250 | 500 | 1000 |
| Luminosity | $\mathcal{L}$ | $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ | 1.35 | 2.7 | 0.82 | 1.8/3.6 | 4.9 |
| Polarisation for $e^-(e^+)$ | $P_-(P_+)$ | | 80 %(30 %) | 80 %(30 %) | 80 %(30 %) | 80 %(30 %) | 80 %(20 %) |
| Repetition frequency | $f_{\mathrm{rep}}$ | Hz | 5 | 5 | 5 | 5 | 4 |
| Bunches per pulse | $n_{\mathrm{bunch}}$ | 1 | 1312 | 2625 | 1312 | 1312/2625 | 2450 |
| Bunch population | $N_{\mathrm{e}}$ | $10^{10}$ | 2 | 2 | 2 | 2 | 1.74 |
| Linac bunch interval | $\Delta t_{\mathrm{b}}$ | ns | 554 | 366 | 554 | 554/366 | 366 |
| Beam current in pulse | $I_{\mathrm{pulse}}$ | mA | 5.8 | 5.8 | 8.8 | 5.8 | 7.6 |
| Beam pulse duration | $t_{\mathrm{pulse}}$ | $\mu$s | 727 | 961 | 727 | 727/961 | 897 |
| Average beam power | $P_{\mathrm{ave}}$ | MW | 5.3 | 10.5 | 10.5 | 10.5/21 | 27.2 |
| Norm. hor. emitt. at IP | $\gamma\epsilon_{\mathrm{x}}$ | $\mu$m | 5 | 5 | 10 | 10 | 10 |
| Norm. vert. emitt. at IP | $\gamma\epsilon_{\mathrm{y}}$ | nm | 35 | 35 | 35 | 35 | 30 |
| RMS hor. beam size at IP | $\sigma^*_{\mathrm{x}}$ | nm | 516 | 516 | 729 | 474 | 335 |
| RMS vert. beam size at IP | $\sigma^*_{\mathrm{y}}$ | nm | 7.7 | 7.7 | 7.7 | 5.9 | 2.7 |
| Luminosity in top 1 % | $\mathcal{L}_{0.01}/\mathcal{L}$ | | 73 % | 73 % | 87.1 % | 58.3 % | 44.5 % |
| Energy loss from beamstrahlung | $\delta_{\mathrm{BS}}$ | | 2.6 % | 2.6 % | 0.97 % | 4.5 % | 10.5 % |
| Site AC power | $P_{\mathrm{site}}$ | MW | 129 | | 122 | 163 | 300 |
| Site length | $L_{\mathrm{site}}$ | km | 20.5 | 20.5 | 31 | 31 | 40 |

TABLE I: Summary table of the ILC accelerator parameters in the initial 250 GeV staged configuration (with TDR parameters at 250 GeV given for comparison) and possible upgrades. A 500 GeV machine could also be operated at 250 GeV with 10 Hz repetition rate, bringing the maximum luminosity to $5.4 \cdot 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ [10].

Cost of $\mathcal{L}$ upgrade ($2.7\times10^{34}$): ~6% of initial cons

10 Hz repetition rate upgrade is not considered as Il

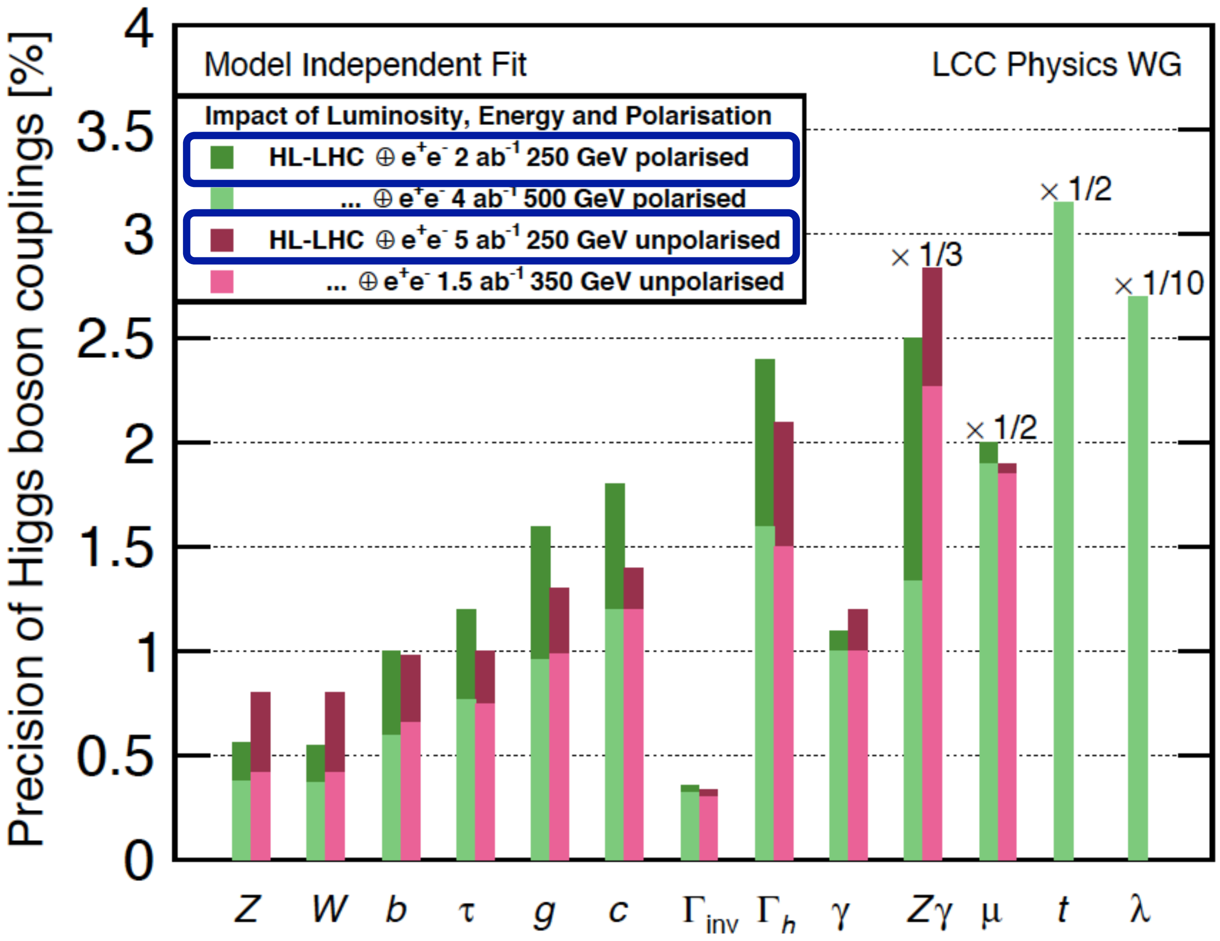
# Model Discrimination




Separation among models in #sigma
(for 9 models unlikely to be rejected by HL-LHC)

ILC250 can identify the correct model more or less by pinpoint
The precision of ILC250 is necessary!

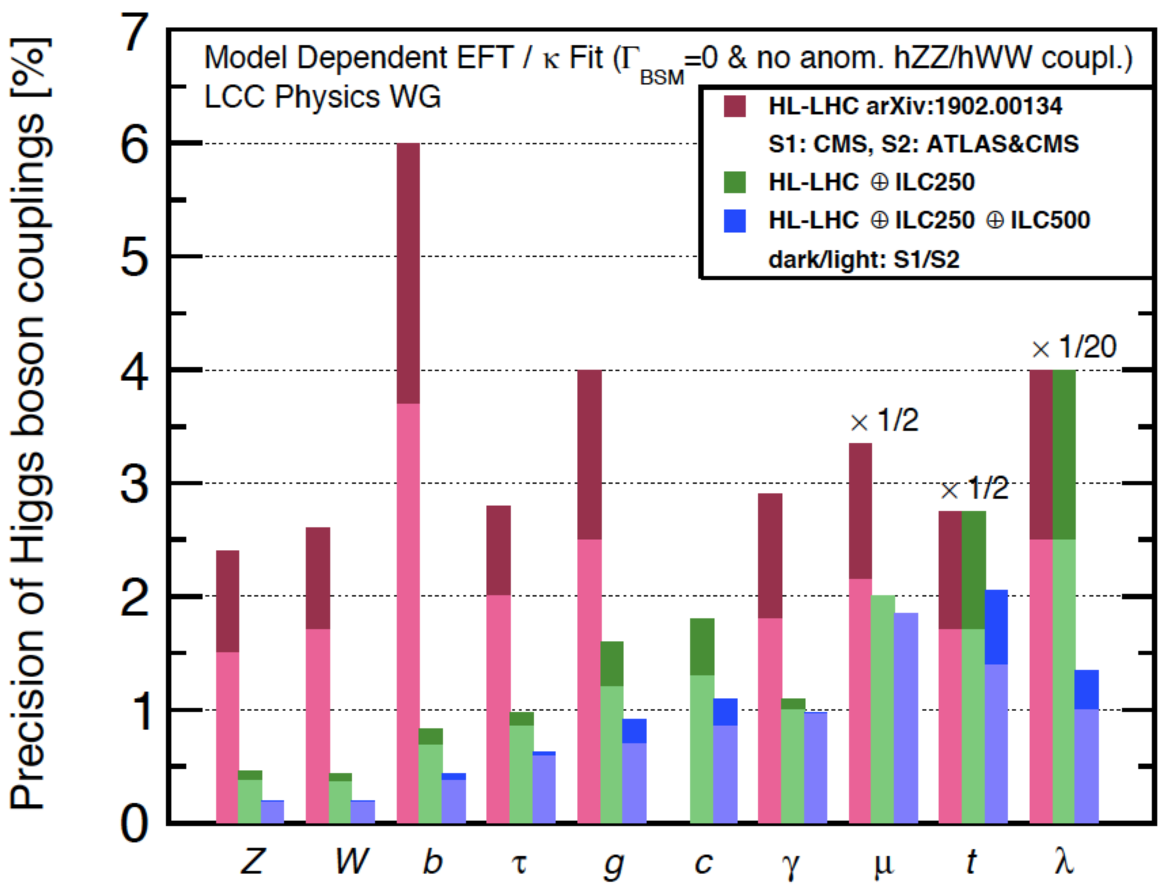
# Power of Polarization




Polarization:
(e- e+) = (±0.8 ±
(−+, +−, ++, −−) :
(45%, 45%, 5

- 2 ab-1 (polarized) is roughly equivalent to 5 ab-1 (unpolarized)
- Effective luminosity ∽ x 2.5 by polarization

# Comparison with HL-LHC




Dark: S1 = current understanding of systematics

Light: S2 = with improvements in systematics

# $e^+e^-$ Higgs Factory Power Comparisons

Updated 13/04/2019