

# Calorimetry/muon session

# 3 sessions on calorimetry : 10 talks announced, 8.3 presentations

- ▶ New ideas / future
- ▶ Test beam results
- ▶ Simulations

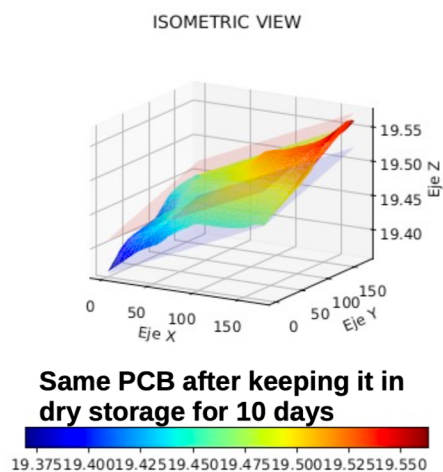
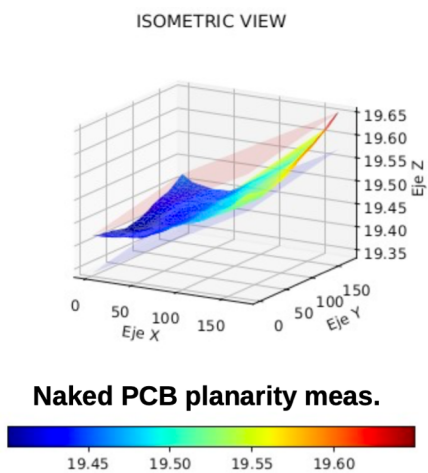
no talk on muon detector ...

# News ideas/future (09/07 morning)

Challenges on sensor-electronics hybridization for compact silicon tungsten electromagnetic calorimeter, Adrian Irls

Studies of sensor-pcb for SiW Ecal (CALICE) and for LUXE Ecal

## SiW ECAL: PCB planarity



Measurements by C. Orero, IFIC

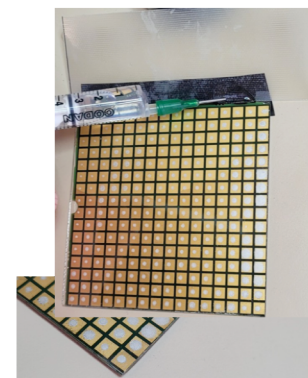
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## SiW ECAL: double adhesive solution for hybridization

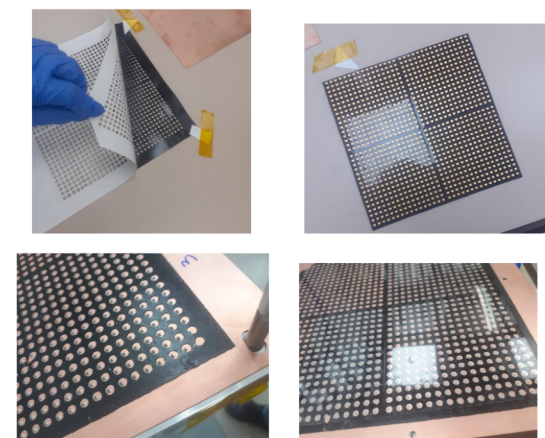
- ▷ Keeping control on the deformation of PCB
  - Wip: study of the stress forces involved (IJCLab)
- ▷ Two solutions being explored, both still with epoxy-silver glue dots for the electrical conductivity
  - Undeform glue (EPO-TEK 301-2FL) → involves second curing.
  - Double tape (3M 5907-F) used as stencil/mask for adherence



C. Blanch, A.I IFIC



A. Thiebaut, IJCLab



C. Blanch, A.I IFIC

### SiW ECAL: the basics

- ▷ Very dense PCBs
- ▷ 4 silicon sensors
  - PiN Diodes of 90x90mm<sup>2</sup>
  - 55x55mm<sup>2</sup> cells
- ▷ No space for wirebonding
- ▷ Glue with conductive epoxy+silver mixes
  - Low temperature curing (40-80 degrees)
- ▷ **Delamination observed** in several modules → partial (or almost total) **wafer-pcb separation** with time

256 P-I-N diode  
0.25 cm<sup>2</sup> each  
9 x 9 cm<sup>2</sup> total area

EUDET layout  
Prototype from Hamamatsu

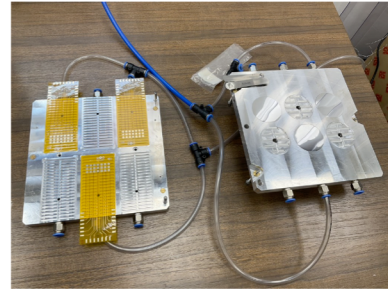
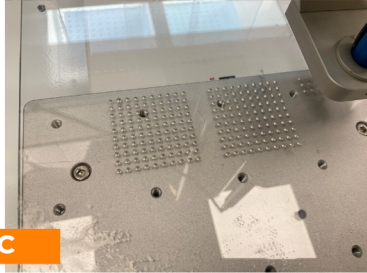
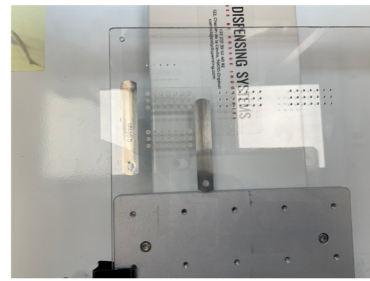
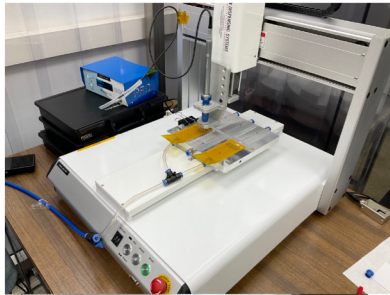
CALICE  
Irls A., 13<sup>e</sup> April 2007

IFIC  
INSTITUT DE FÍSICA  
CORPUSCULAR

Irls A., 9<sup>th</sup> July 2024

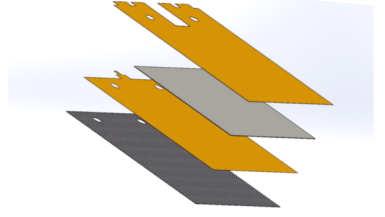
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# Ultra Compact Calo Hybridization



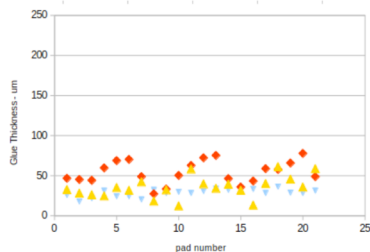
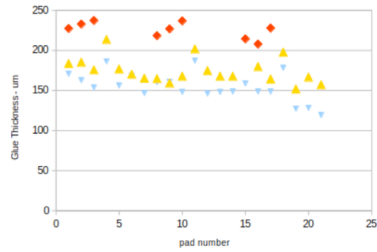
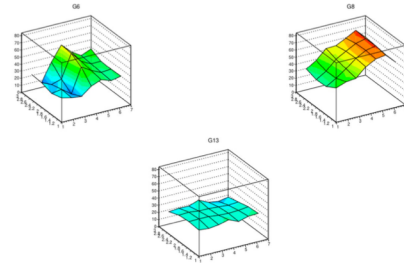
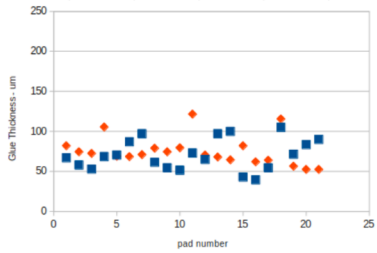
# Ultra Compact Calo Hybridization

- ▷ Large sensors (9x9cm<sup>2</sup>) and **flexible PCBs (compact calo)**
- ▷ **Material budget, thickness:**
  - Total below 1mm
  - 200um CF + 320um sensor
  - ~500um for fanout + HV kapton + 3 layers of glue/Adhesive
- ▷ The main challenge is to obtain a very thin layer of glue, with high repeatability



# Glue thickness study

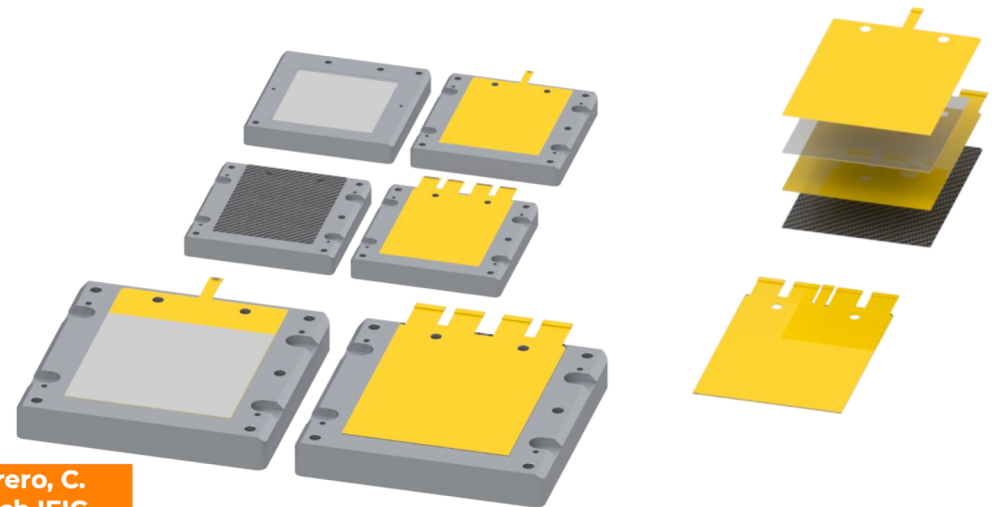
Change of dosification needle



Release of vacuum before curing

# Tooling for precise hybridization

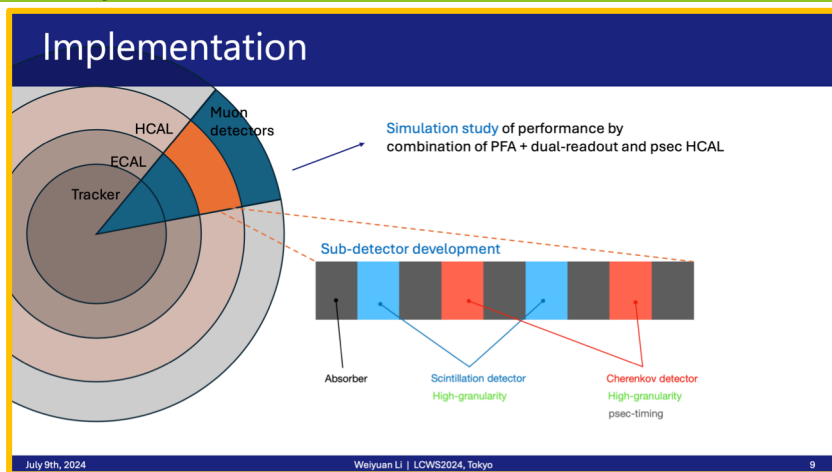
▷ **Work in progress** – design and optimization of the gluing process



C. Orero, C. Blanch IFIC

# News ideas/future (09/07 morning)

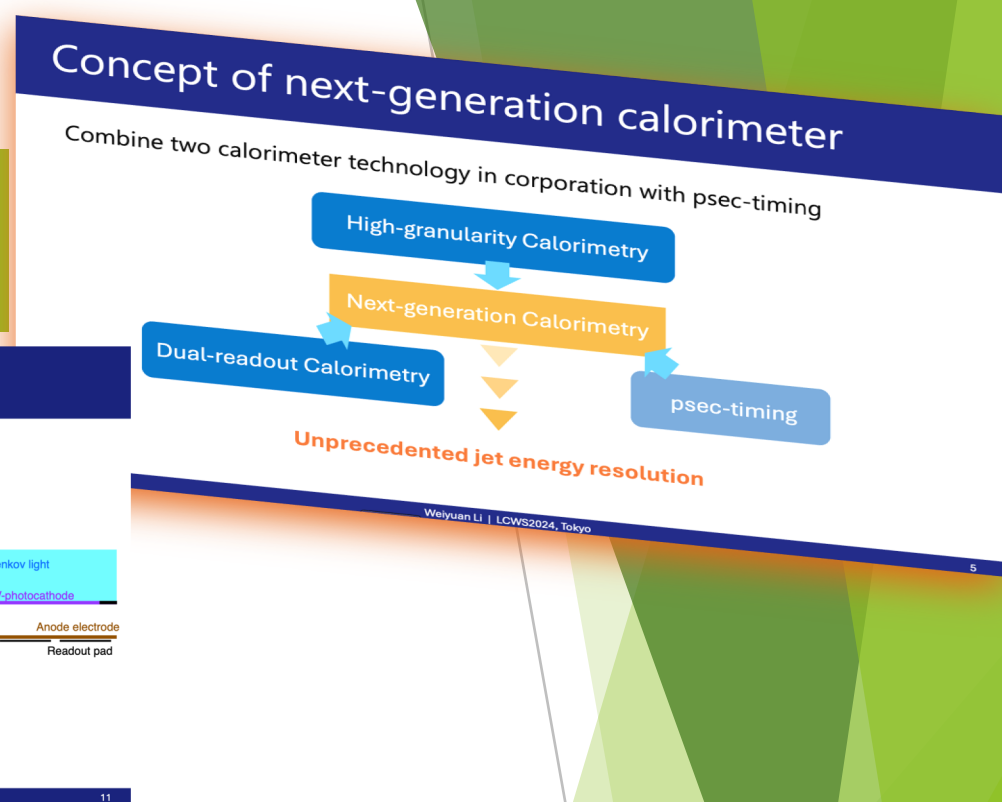
Development of next-generation calorimeter combining high-granularity and dual-readout calorimeter with psec-timing, Weiyuan Li



## Cherenkov detector

- Requires granular readout and psec-timing
- Cherenkov radiator coupled to Gaseous photomultiplier
- Electron amplification by resistive plate chamber (RPC)
  - Fast timing
  - Simple structure → Large area by low cost
  - Readout segmentation
- Diamond-Like Carbon as resistive electrode (DLC-RPC)
  - High-rate-capability > 1 MHz/cm<sup>2</sup>
  - DLC sputtered on polyimide = "film" electrode

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## Cherenkov detector

- Successfully observed Cherenkov light signal!
- Discrete peaks of #p.e. in height(charge) spectrum = photon counting capability
- Low #p.e.
  - Ion-backflow (IBF)? → robust photocathode required
  - Failure in the handling of photocathode?

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## Cherenkov detector

Time resolution depends on #p.e.

- $126/\sqrt{\#p.e.}$  or  $114/\sqrt{\#p.e.} \oplus 31.1$  ps
- 40-50 ps for 10 p.e., 30-40 ps for 20 p.e.
- RPC signal contamination (~ 50%), Photon-feedback (PFB) → Possible reason of discrepancy to estimated value

Improvement planned

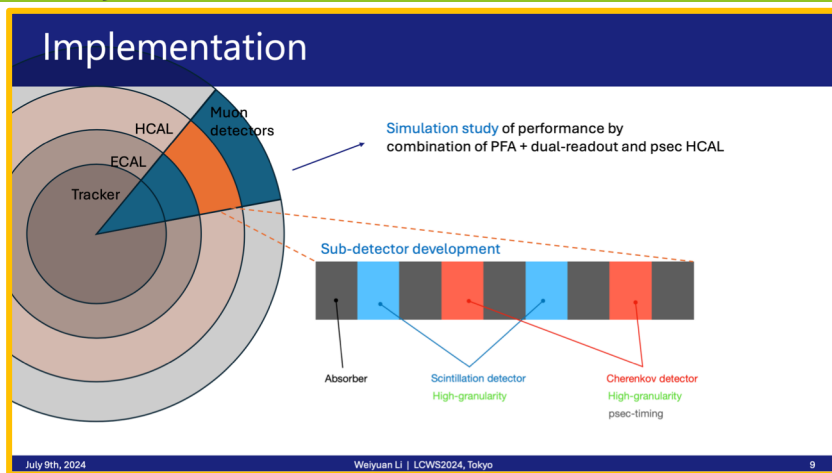
- Reduce gap thickness → mitigate RPC contamination
- Switch to robust photocathode → mitigate PFB

The construction technique been established → Moving on to the upgrade of the detector

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# News ideas/future (09/07 morning)

Development of next-generation calorimeter combining high-granularity and dual-readout calorimeter with psec-timing, Weiyuan Li



## Scintillation detector

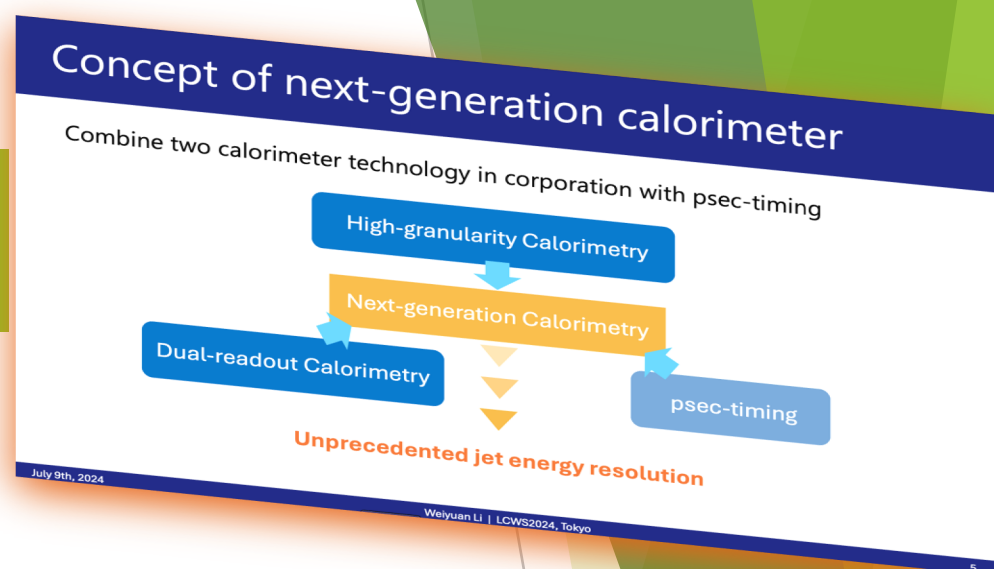
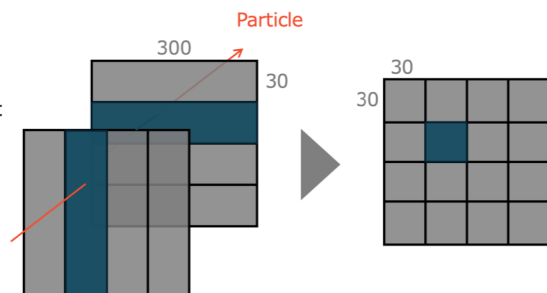
### ➤ Granular readout but moderate number of channels

Place strip scintillator in orthogonal way and realize virtual cell

- Concept already proven in 45 x 5 mm<sup>2</sup> strip for ECAL (Virtual segmentation of 5 x 5 mm<sup>2</sup>)

- Test if it works for large size: 300 x 30 mm<sup>2</sup>

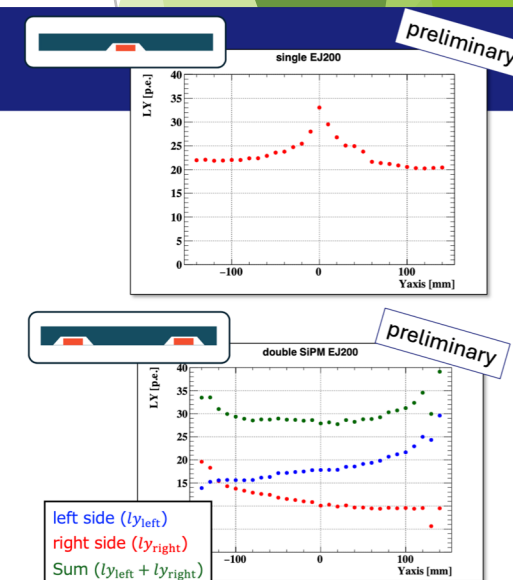
→ See if light yield and its uniformity is sufficient



## Scintillation detector

### Result

- Sufficient light yield + good uniformity for both configuration
    - Non-uniformity around SiPM can be mitigated by dimple design
  - Study for performance evaluation of position reconstruction using charge and time difference in a single strip bar ongoing
- \*Asymmetry in Y axis to be investigated



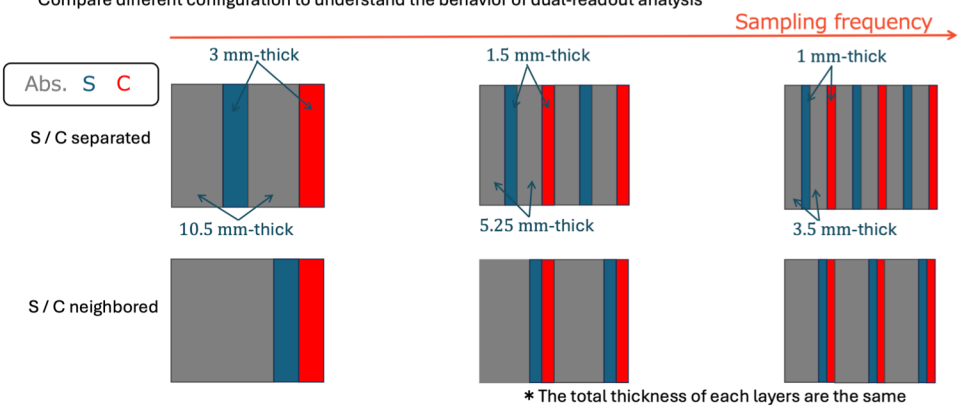
# News ideas/future (09/07 morning)

Development of next-generation calorimeter combining high-granularity and dual-readout calorimeter with psec-timing, Weiyuan Li

simulation

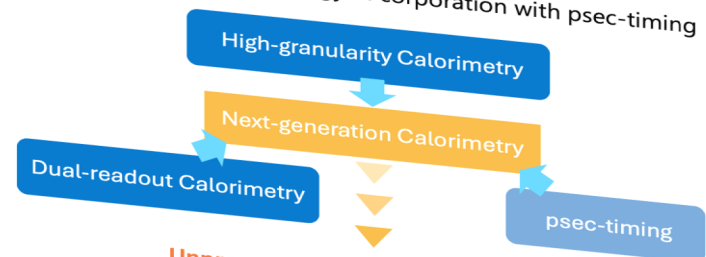
Setup

Compare different configuration to understand the behavior of dual-readout analysis

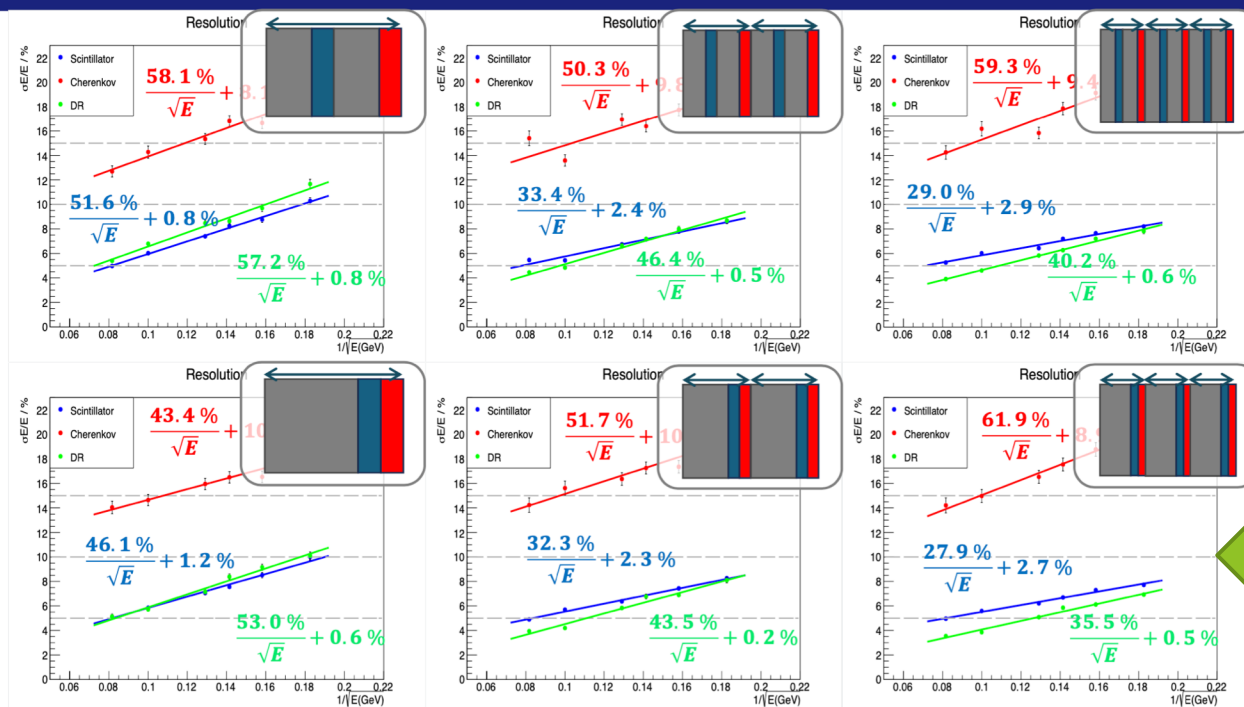


## Concept of next-generation calorimeter

Combine two calorimeter technology in corporation with psec-timing



## Dual-readout analysis



# Test beam results (10/07 morning)

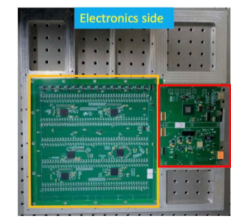
## Status of high granular scintillator calorimeter for future electron positron colliders, Tatsuki Murata

### Sc-ECAL

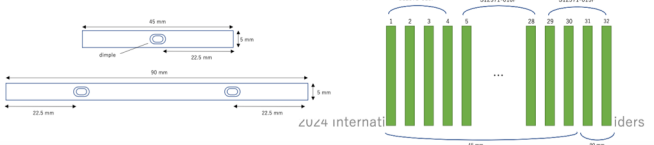
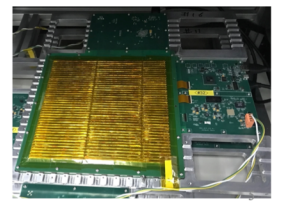
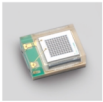
- Scintillator-based Electromagnetic Calorimeter (Sc-ECAL)
  - ECAL concept based on strip-shaped plastic scintillator readout by SiPM
  - Center dimpled readout based on  $5 \times 45 \times 2 \text{ mm}^3$  scintillator strip
- Virtual segmentation of  $5 \times 5 \text{ mm}^2$  cell can be achieved by x-y configuration of strips with strip splitting algorithm (SSA)
- Ghost hit problem
  - False signal from simultaneous hits
  - Expected to be eliminated by double SiPM readout
- Double SiPM readout
  - readout by two SiPMs at strip ends
  - 90mm (dimples at both ends)

### Sc-ECAL large technological prototype

- All channels on each EBU can be individually readout by 6 SPIROC2E chips developed by OMEGA lab and CALICE collab.
  - High and low gain mode for wide dynamic range
  - 16 temperature sensors are implemented
- Two types of MPPC are used for SiPM on detection layer (manufactured by Hamamatsu K. K.)
  - S12571-010P, & -015P
- Last 2 layers have double SiPM readout part
  - Using 90 mm length strip instead of standard 45 mm strip

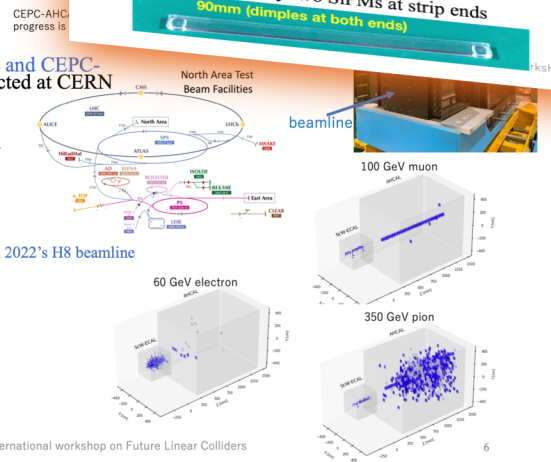


	Pixel size	# of pixel	gain
S12571-010P	10 um	10,000	$1.35 \times 10^5$
S12571-015P	15 um	4,489	$2.3 \times 10^5$



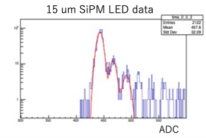
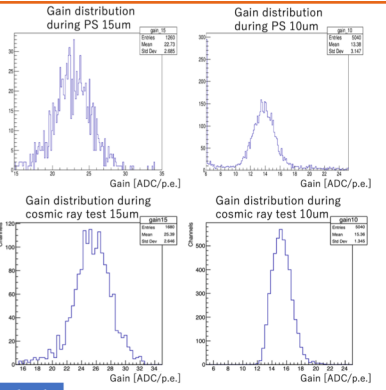
### Test beam experiment

- Test beam experiment for Sc-ECAL and CEPC-AHCAL combined system is conducted at CERN SPS&PS
  - SPS : site 887, H8 beamline
    - October 19<sup>th</sup> to November 2<sup>nd</sup>, 2022
    - High energy beam (10-160 GeV)
    - $\mu^+$ ,  $\pi^+$ ,  $e^+$
  - SPS : Site 887, H2 beamline
    - April 26<sup>th</sup> to May 10<sup>th</sup>, 2023
    - High energy beam (10-350 GeV)
    - Higher energy and purity beam than 2022's H8 beamline
    - $\mu^-$ ,  $\pi^-$ ,  $e^-$ ,  $p^-$
  - PS : Site 157, T9 beamline
    - May 17<sup>th</sup> to 31<sup>st</sup>, 2023
    - Low energy beam (1-15 GeV)
    - $\mu^-$ ,  $\pi^-$ ,  $e^-$
- Collaborators
  - UTokyo, Shinshu university, USTC, IHEP, SJTU



### LED calibration

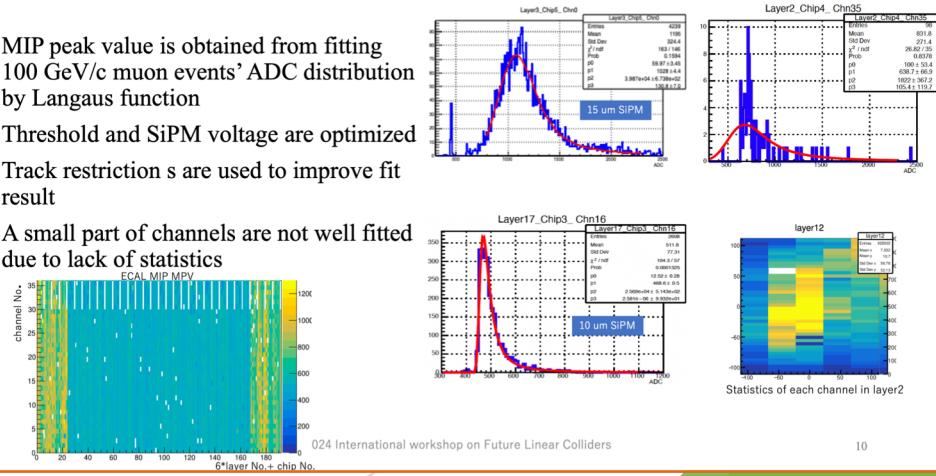
- LED data are taken during the 2023 beam test
  - SPS : 3 times (at the beginning and the middle of the beam test)
  - PS : every day
- LED data are fitted with multi-gaussians to calculate gain for each channel
- Increased the bias voltage of all channels at the beam test to compensate temperature difference from the CR test
  - The gains still decreased compared to the cosmic ray test



	ECAL	Cosmic Ray test	Beam test
temperature		~20 C	25~29 C
Bias voltage		-	+0.5 V

### MIP calibration

- MIP peak value is obtained from fitting 100 GeV/c muon events' ADC distribution by Langaus function
- Threshold and SiPM voltage are optimized
- Track restriction s are used to improve fit result
- A small part of channels are not well fitted due to lack of statistics



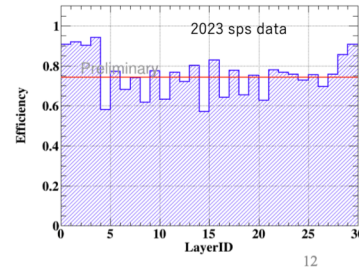
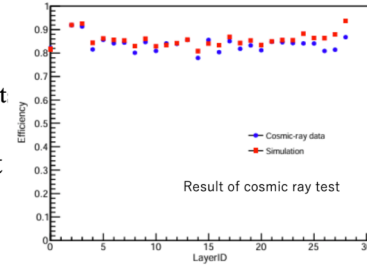
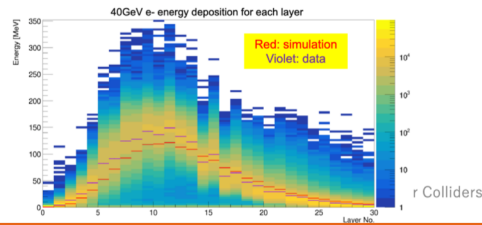


# Test beam results (10/07 morning)

## Status of high granular scintillator calorimeter for future electron positron colliders, Tatsuki Murata

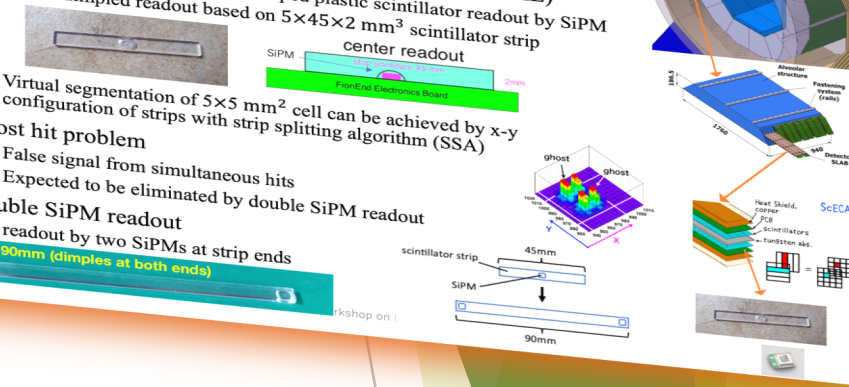
### Detection efficiency of strips

- Definition of efficiency :
  - (# of hits which hit exist on the track fitting) / (estimated # of hit from track fitting)
- Detection efficiency of layers is calculated using track fit
  - A layer's hit strips are excluded from the track fitting
  - Efficiency of a layer is the ratio of events that have corresponding hits in the layer to all events
- Detection efficiency is fluctuating among layers
  - Same behavior with the energy distribution



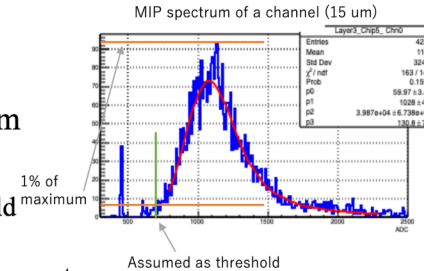
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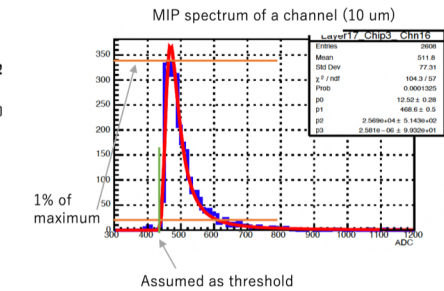
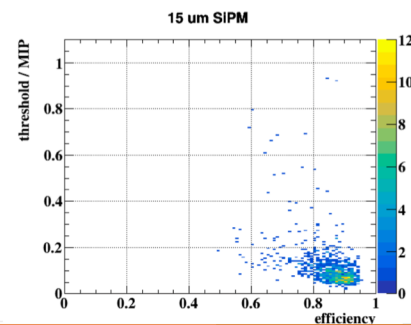
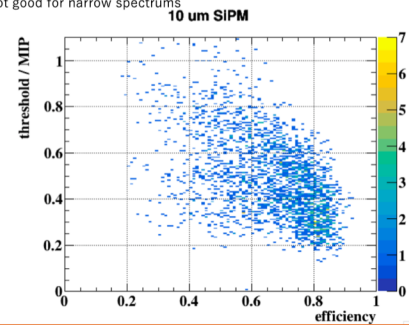


### Correlation of threshold and detection efficiency

- Threshold are too high to cut lower edge of MIP spectrum
- Estimated threshold with constant fraction
  - ADC value with 1% of maximum height is assumed as threshold
    - This method might not be true for 15 um SiPMs
    - Might be a good indicator for 10 um SiPMs with rising edge in the spectrum
- Lower threshold channels have higher efficiency



This MIP is from the fit  
Not good for narrow spectrums



# Test beam results (10/07 morning)

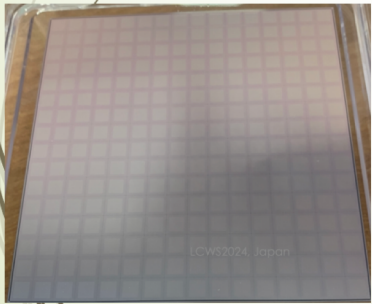
Test-beam measurements of instrumented sensor planes for a highly compact and granular electromagnetic calorimeter, YB

## 2022 test beam @ DESY : detectors

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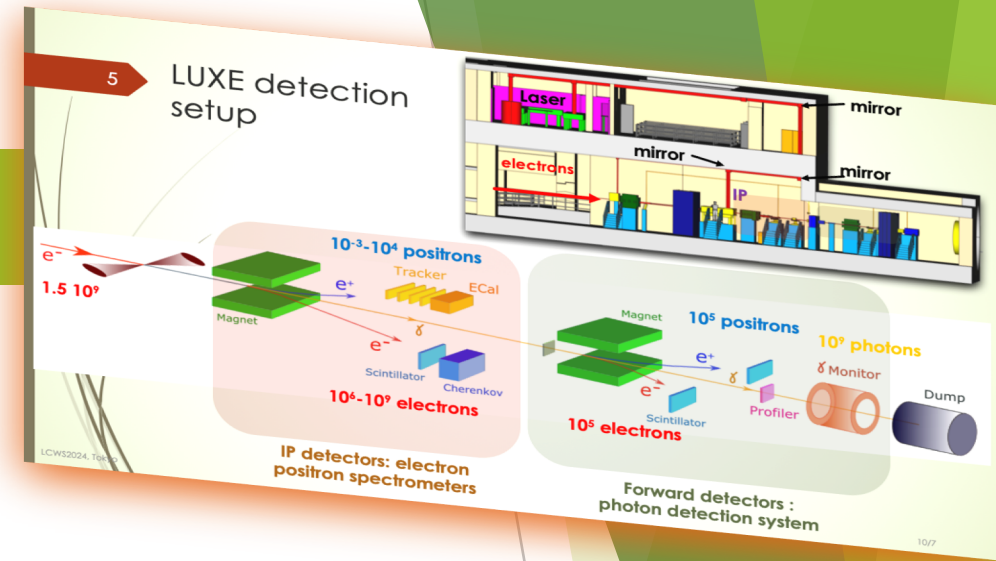
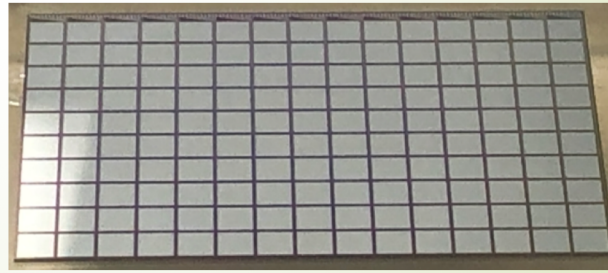
### Silicon (CALICE)

- Array of 5.5x5.5 mm<sup>2</sup>
- Thickness 500μm
- 10μm between pads
- p+ on n substrate
- Produced by Hamamatsu



### Gallium Arsenide

- Array of 4.7x4.7 mm<sup>2</sup>
- Thickness 500μm
- 300μm between pads
- Produced by Tomsk State University

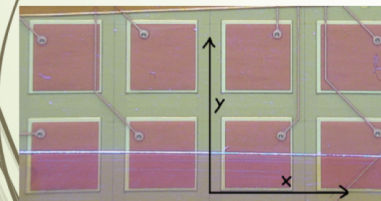
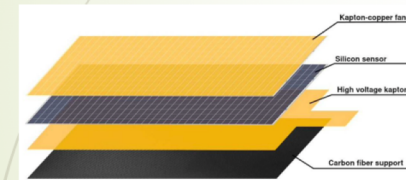


## 2022 test beam @ DESY : connection

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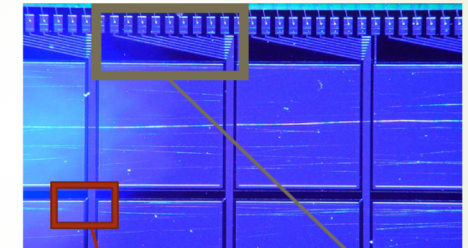
### Silicon (CALICE)

- Kapton fan out with copper traces (to the connector) glued (conductive glue) to the sensor



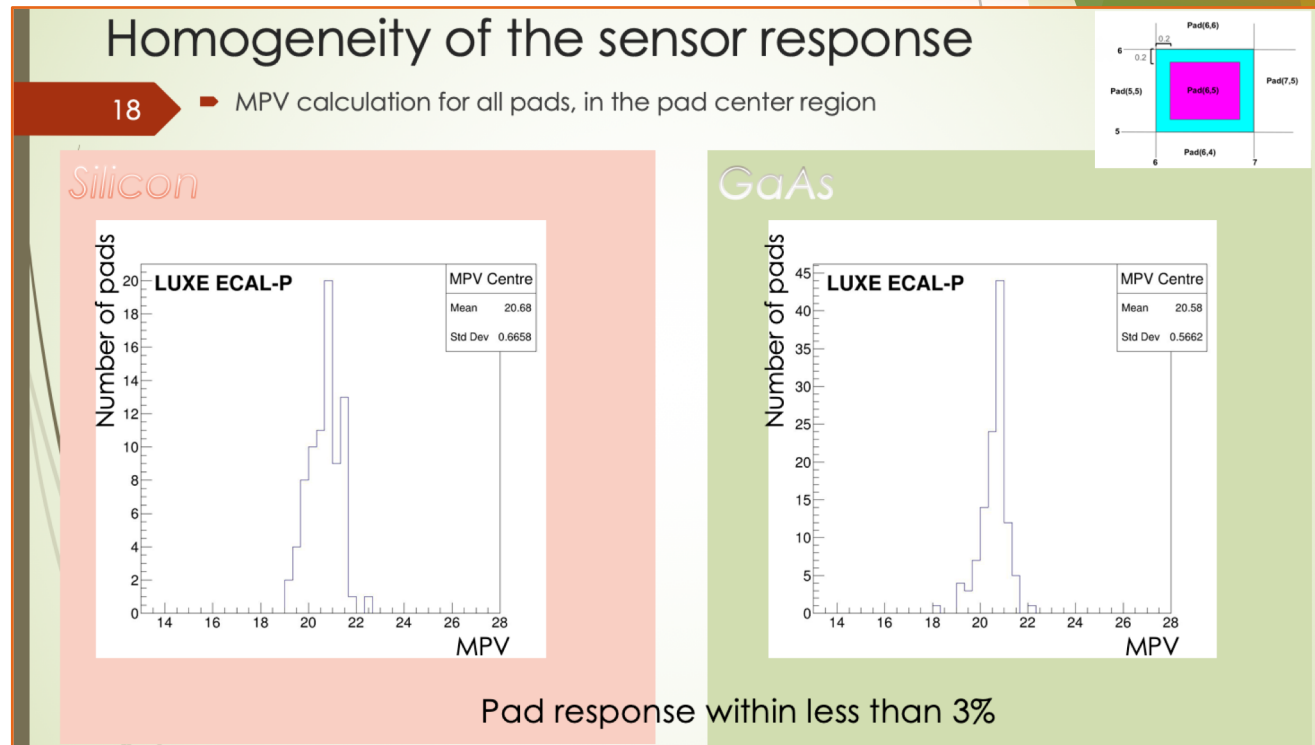
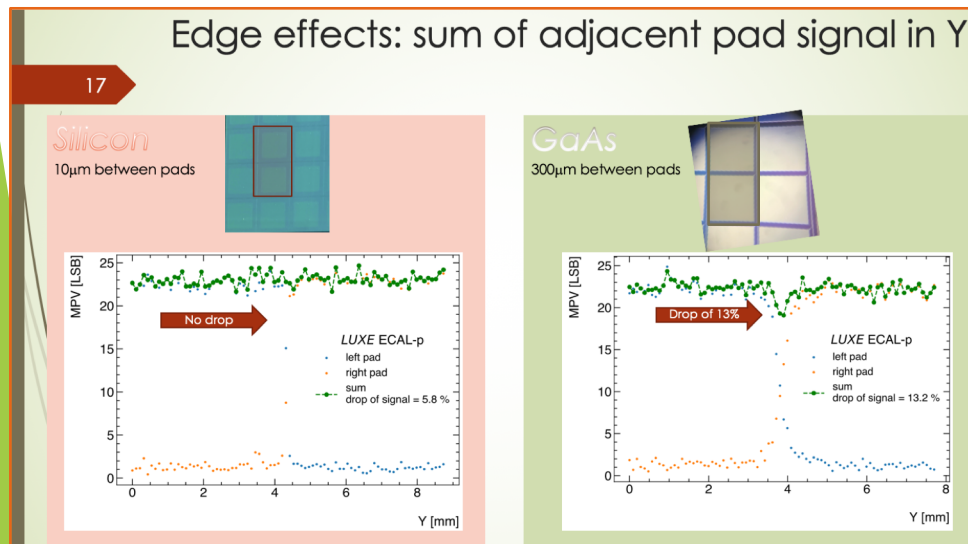
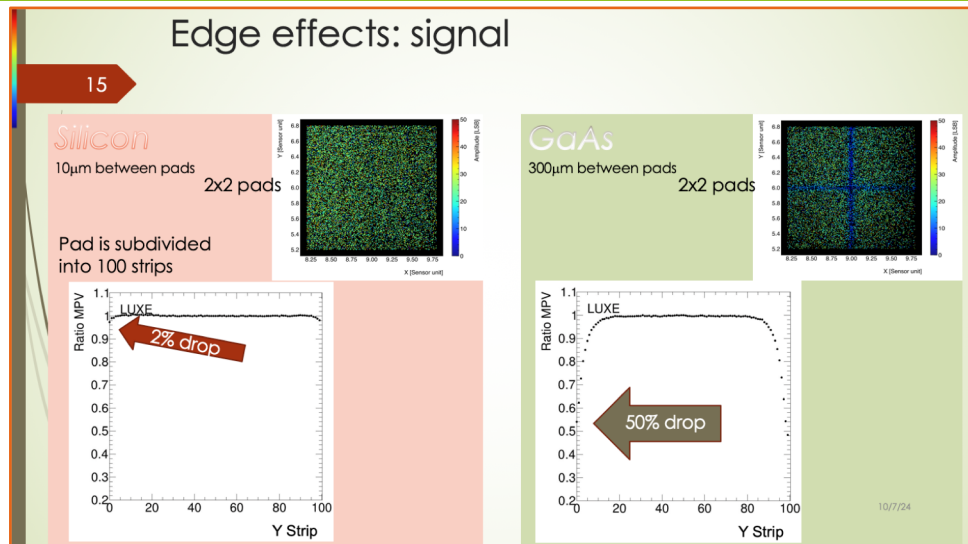
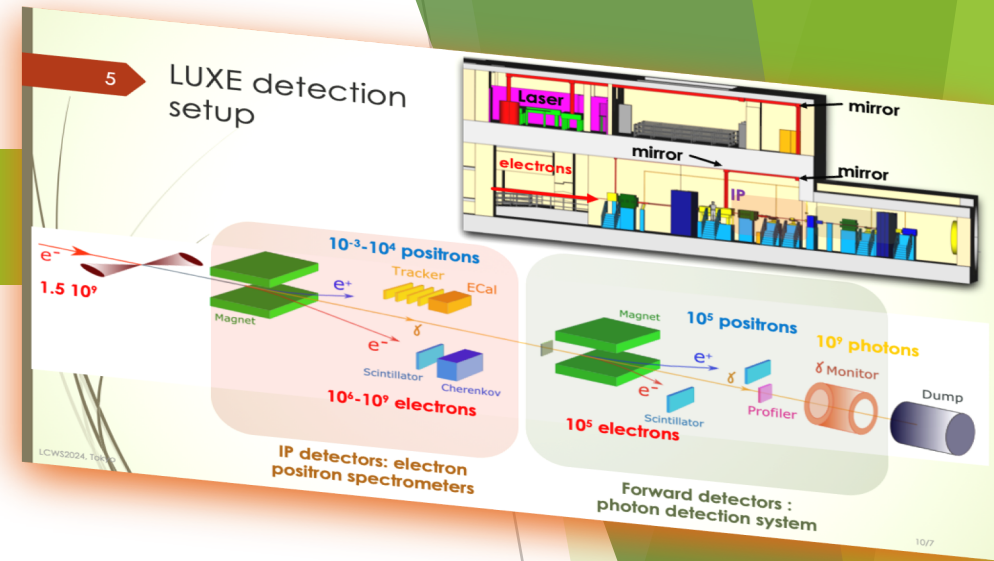
### Gallium Arsenide

- Aluminum traces in between the pads



# Test beam results (10/07 morning)

Test-beam measurements of instrumented sensor planes for a highly compact and granular electromagnetic calorimeter, YB

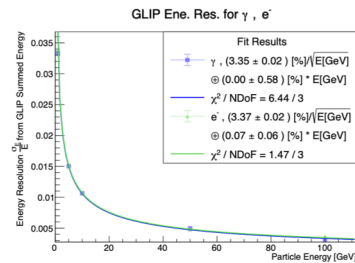


# Test beam results (10/07 morning)

## Photon and Electron Reconstruction in an Ultra-High Granularity Forward Calorimeter , Brendon Madison

### High Granularity Proposal: GLIP

- Granular Long Instrument for Precision (GLIP)
- Multiple designs, original here
- 40  $X_0$  , 1/6  $X_0$  layers, 1mm Si, SiW sandwich in xy detector
- Reco. using various algorithms
- Ene. res. of  $\approx \frac{3.36\%}{\sqrt{E}} + 0.02\%$
- $\theta$  resolution at least  $\approx 0.2$  mrad
- Moliere radius of 9.4 mm
- Length of 110 cm



### Broad Outline

- **What are we doing today?**
- Presenting work on precision forward calorimeter at  $e^+e^-$  Higgs Factories
- **Why?**
- Physics goals require precision on luminosity, **want to measure DiGammas too**
- **How?**
- Use new detector, GLIP, and some new methods

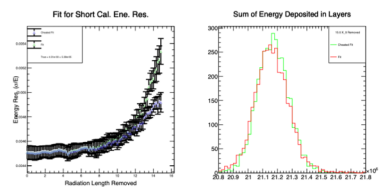
Brendon Madison

July 9, 2024

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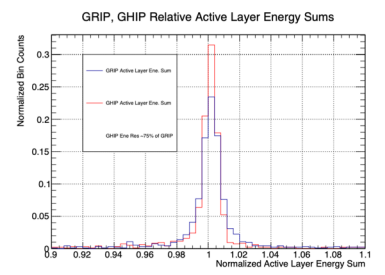
### GRIP the Fit Results

- Decrease in energy resolution but can truncate at least 15  $X_0$  down to 25  $X_0$
- Energy resolution worsened by 18%
- 0.45% to 0.53%
- Reduces GLIP length to 69 cm!
- So GRIP would be much shorter!
- "cheated" result indicates that the model can be much better too



### GHIP , A heavier LumiCal

- Can reduce length by using more than  $\frac{1}{6} X_0$  but will lose energy resolution
- Alternative – Use 1mm CdTe pads to supplement ene. res. of SiW
- Go to  $\frac{1}{3} X_0$
- Si will still be small for space/angle res.
- Reduces GLIP length to 49 cm!
- Energy resolution improves , 75% of GRIP



Brendon Madison

July 9, 2024

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Brendon Madison

July 9, 2024

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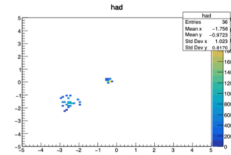
# Test beam results (10/07 morning)

## Photon and Electron Reconstruction in an Ultra-High Granularity Forward Calorimeter , Brendon Madison

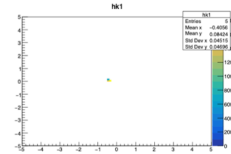
### How to measure angles?

- ILD LumiCal uses layer clustering (here kMeans) and Log-Weighting (LW)
- This will be the “standard”
- Will also propose alternative – MSR
- Minimal Stochastic Reconstruction (MSR) uses local event variance to find least varying measurement

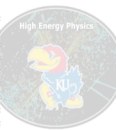
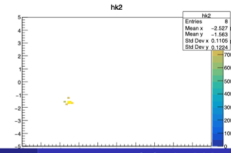
Toy MC of Hits



kMeans + LW Cluster 1



kMeans + LW Cluster 2

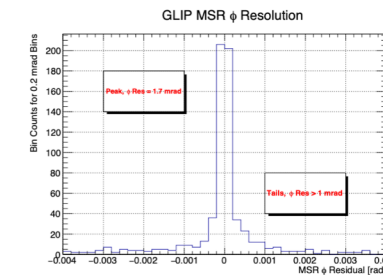
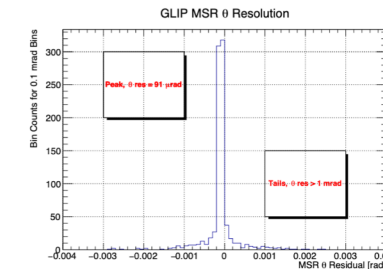


### Broad Outline

- **What are we doing today?**
- Presenting work on precision forward calorimeter at  $e^+e^-$  Higgs Factories
- **Why?**
- Physics goals require precision on luminosity, **want to measure DiGammas too**
- **How?**
- Use new detector, GLIP, and some new methods

### Result, Future of MSR Method

- MSR at least x2 better than clustered LW in  $\theta$  resolution
- MSR at least 10x better in  $\phi$  resolution
- Future: Check complementarity to standard method , looks like some events MSR measures poorly
- If good, could use in boosted decision tree with standard to achieve greater resolution?



# Simulation (10/07 afternoon)

## Longitudinal structure optimization for the high density electromagnetic calorimeter, Aleksander Filip Zarnecki

### Configuration scan

#### Approach

Analytical procedure has been developed, allowing for very fast calibration optimization and energy/position measurement precision estimate for arbitrary configuration of active layers.

Layers can be easily "deactivated" in MC by forcing their calibration factors to zero.

Analytical procedure can be easily repeated for multiple configurations...

With  $N = 20$  gaps in ECALp, the total number of possible layer configurations is

$$N_{\text{comb}} = 2^{20} - 1 = 1'048'575$$

(1 to 20 layers instrumented) which can be checked in  $\mathcal{O}(1h)$  (energy scan 2.5 – 15 GeV).

We can then look for the optimal configuration for given number of instrumented layers...

Energy or position resolution shown relative to that of fully instrumented calorimeter



### Configuration scan

#### Optimization

Position vs energy resolution optimization results for  $N=15$  layer configurations 2.5–15 GeV

Indicated configurations:



### Motivation

#### ECALp longitudinal structure optimization

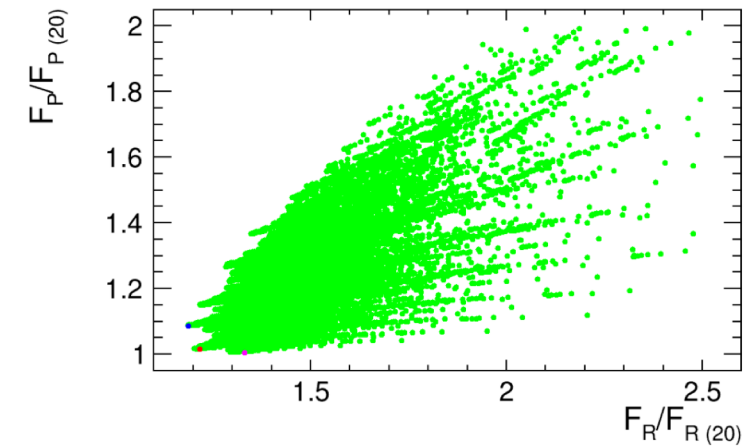
Best solution is always to instrument all calorimeter gaps.

However, only 15 layers likely to be instrumented in LUXE phase I.

- how much will performance of the calorimeter be affected?
- how to choose empty layers to minimize the effect?

⇒ need for a dedicated study

A.F. Zarnecki (University of Warsaw) Optimization for high density calorimeter LCWS2024 July 10, 2024 5 / 22



# Simulation (10/07 afternoon)

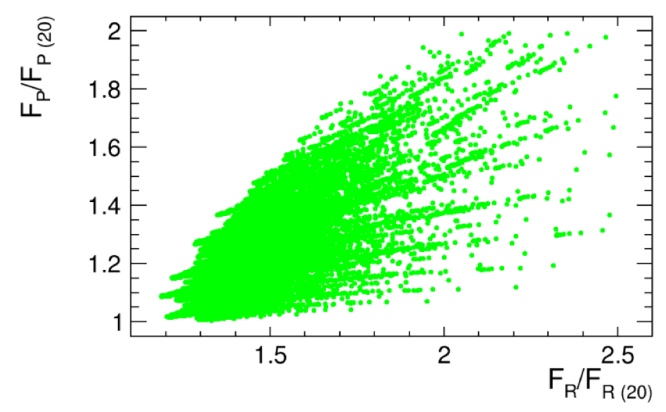
## Longitudinal structure optimization for the high density electromagnetic calorimeter, Aleksander Filip Zarnecki

### Multi-objective optimization



#### Problem

As shown with the configuration scan, optimization result depends on the optimization goal.



How to define the goal, if we need to optimize both energy and position measurement

Pareto front

### Motivation

#### ECALp longitudinal structure optimization

Best solution is always to instrument all calorimeter gaps.

However, only 15 layers likely to be instrumented in LUXE phase I.

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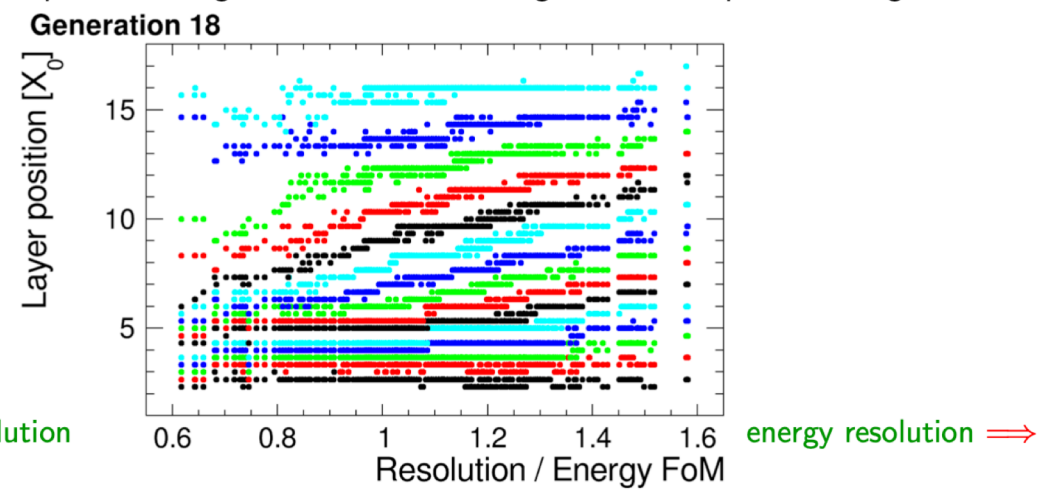
A.F.Zarnecki (University of Warsaw) Optimization for high density calorimeter LCWS2024 July 10, 2024 5 / 22

### Multi-objective optimization



#### Result

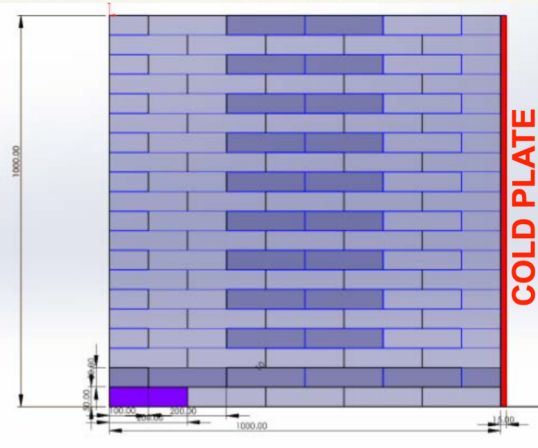
We can see how the preferred longitudinal structure changes with the optimization goal



# Simulation (10/07 afternoon)

## The SiD Digital ECal Based on Monolithic Active Pixel Sensors, Jim Brau

**SiD** Thermal Model for Heat Removal from SiD ECal



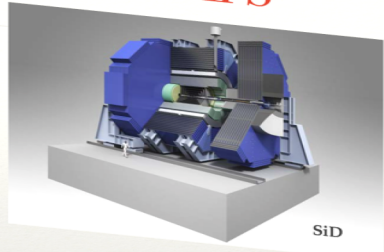
1000.00  
1000.00  
COLD PLATE

- MAPS generates  $1 \mu\text{W}/\text{pixel CW}$ .
  - $\sim \text{kW}/\text{m}^2$  (each sensor is  $100 \text{ cm}^2$ )
- Power pulsing critical for heat management
  - ILC duty cycle  $\sim 0.5\%$  ( $< 10 \text{ W}/\text{m}^2$ )
  - CLIC/C<sup>3</sup>  $< 0.01\%$  ( $< 1 \text{ W}/\text{m}^2$ )
- What is **temperature rise** ( $\Delta T$ ) on end opposite the cold plate?

1 layer of  $5 \times 20 \text{ cm}^2$  MAPS sensors

SiD Digital ECal J. Brau - 10 July 2024 8

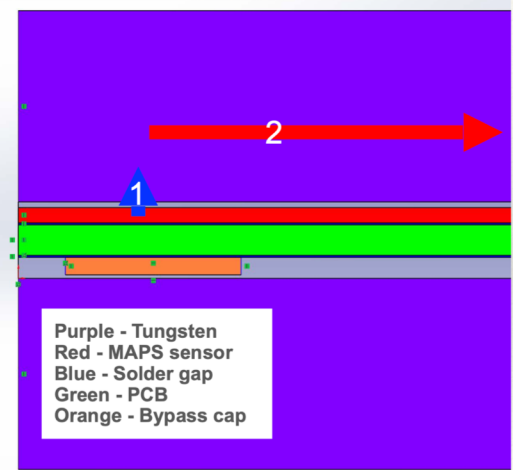
**SiD** SiD Digital ECal Based on MAPS



- SiD upgrade now under development with  $25 \times 100 \mu\text{m}^2$  (or  $25 \times 50/25 \mu\text{m}^2$ ) digital pixels in electromagnetic calorimeter and tracker.
  - Replacing the ILC TDR ECal design using  $13 \text{ mm}^2$  analog pixel sensors.
- Heat management is critical to success.
- How well can we measure energy and shower structure with this digital system:
  - Compared to SiD baseline with analog measurements?
  - Can the detailed structural measurements be used to improve measurement?
  - Would a neural net optimization offer an improvement?
- What are the limits of transverse separation and measurement?

SiD Digital ECal J. Brau - 10 July 2024 2

**SiD** Heat conduction from ECal sensor to cold plate



1 2

- First heat flows through  $300 \mu\text{m N}_2$  to tungsten
  - $\Delta T \ll 1 \text{ K}$
- Then heat flows thru tungsten to cold plate
  - Tungsten absorber lengths  $0.5\text{-}1.0 \text{ m}$
  - Temperature rise is length dependent
- Duty cycle -  $.0007\%$  (C3/CLIC) -  $\Delta T \sim 0.5 - 2 \text{ K}$
- Duty cycle -  $.005\%$  (ILC) -  $\Delta T \sim 4 - 16 \text{ K}$ 
  - Without power pulsing temperature blows up and needs active cooling

Purple - Tungsten  
Red - MAPS sensor  
Blue - Solder gap  
Green - PCB  
Orange - Bypass cap

SiD Digital ECal J. Brau - 10 July 2024 9

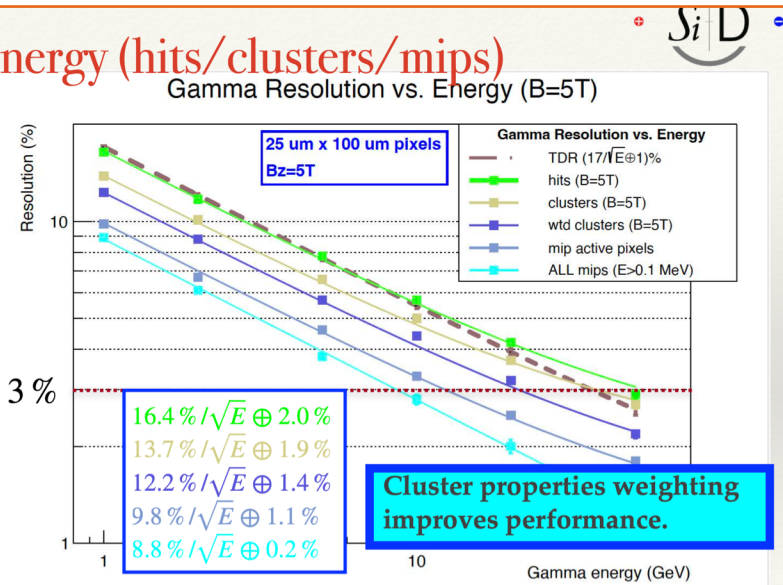
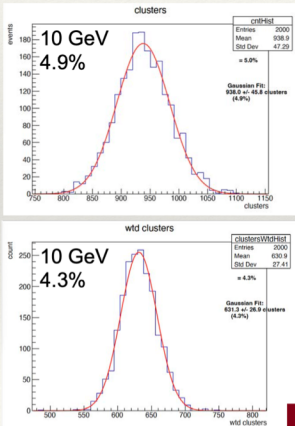


# Simulation (10/07 afternoon)

## The SiD Digital ECal Based on Monolithic Active Pixel Sensors, Jim Brau

### Resolution vs. Energy (hits/clusters/mips)

Resolution vs. Energy (hits/clusters/mips) & weighted clusters.

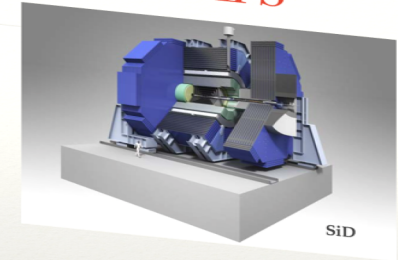


Can a Neural Net Improve Performance?



## SiD Digital ECal Based on MAPS

- SiD upgrade now under development with 25 x 100  $\mu\text{m}^2$  (or 25 x 50/25  $\mu\text{m}^2$ ) digital pixels in electromagnetic calorimeter and tracker.
- Replacing the ILC TDR ECal design using 13 mm<sup>2</sup> analog pixel sensors.
- Heat management is critical to success.



- How well can we measure energy and shower structure with this digital system?
- Compared to SiD baseline with analog measurements?
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- Would a neural net optimization offer an improvement?
- What are the limits of transverse separation and measurement?

SiD Digital ECal

J. Brau - 10 July 2024



## Results: Energy Resolution

Energy	1	2	5	10	20	50
clusters	13.8%	10.1%	6.6%	4.9%	3.7%	2.7%
wtd clusters	12.3%	8.8%	5.7%	4.4%	3.2%	2.2%
3 par TMVA	12.6%	9.5%	6.2%	4.4%	3.4%	2.2%
5 par TMVA	12.8%	9.4%	5.9%	4.3%	3.1%	2.2%

- Weight fits for 2, 10, 50 GeV; extrapolated for 1, 5, 20 GeV.
- NN optimized for each energy
- 3 par = cluster size, layer, radius
- 5 par = cluster size, layer, radius, dY, dZ

Weighted clusters already achieve performance of this neural net.

# Simulation (10/07 afternoon)

## Metrology requirements for the integrated luminosity measurement at ILC, Ivan Smiljanić

### Metrology

Further on beams: axial displacement of the IP ( $\Delta z_{IP}$ )  
 ⇒ beam synchronization

### Beam properties

~ 9 mm (30 ps) at higher energies  
 ~ 4 mm (13 ps) needed at the Z-pole

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Parameters	ILD
Geometrical acceptance (mrad)	31-77
fiducial acceptance (mrad)	41-67
number of layers (W+Si)	30

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### Metrology

Distance between luminometer halves (symmetric) ( $\Delta l$ )

### Detector mechanics and positioning

< 3 mm at higher energies  
 ~ 200  $\mu\text{m}$  at the Z-pole (feasible with FSI)

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## Conclusion on metrology

parameter	Z-pole	250 GeV	500 GeV	1 TeV
$\Delta r_{in}$ ( $\mu\text{m}$ )	20	200	200	200
$\Delta r_{out}$ ( $\mu\text{m}$ )	60	600	600	550
$\sigma_r$ (mm)	0.3	0.5	0.5	0.5
$\Delta l$ (mm)	0.2	2.5	2.5	2.5
$\sigma_{x_{IP}}$ (mm)	0.35	0.65	0.65	0.65
$\sigma_{z_{IP}}$ (mm)	5	10	10	10.5
tilt (mrad)	14	35	35	35
$\Delta x_{IP}$ (mm)	0.3	0.6	0.55	0.6
$\Delta z_{IP}$ (mm)	4	8.5	8.5	9
$\Delta\tau$ (ps)	13	27	27	30
$\sigma_{E_{BS}}$ (MeV)	114	500	1000	2000
$\Delta E$ (MeV)	4.5	125	250	500
$\Delta\mathcal{L}/\mathcal{L}$	$3.3 \cdot 10^{-4}$	$3.3 \cdot 10^{-3}$		

- The major challenges only at the Z-pole
- Inner aperture of the luminometer relaxed with the asymmetric counting
- Position reconstruction in the first plane (300  $\mu\text{m}$ ) slightly below prototyped performance (440  $\mu\text{m}$ ); Can be resolved with a tracker plane in front of the luminometer
- Asymmetric bias in beam energies (~ 5 MeV)
- $\Delta(\sqrt{s})$  for the cross-section calculation (~ 5 MeV, all energies)

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