CEPC ECAL

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CEPC CDR International Review
Physics & Detector

IHEP, Beijing
September 14, 2018

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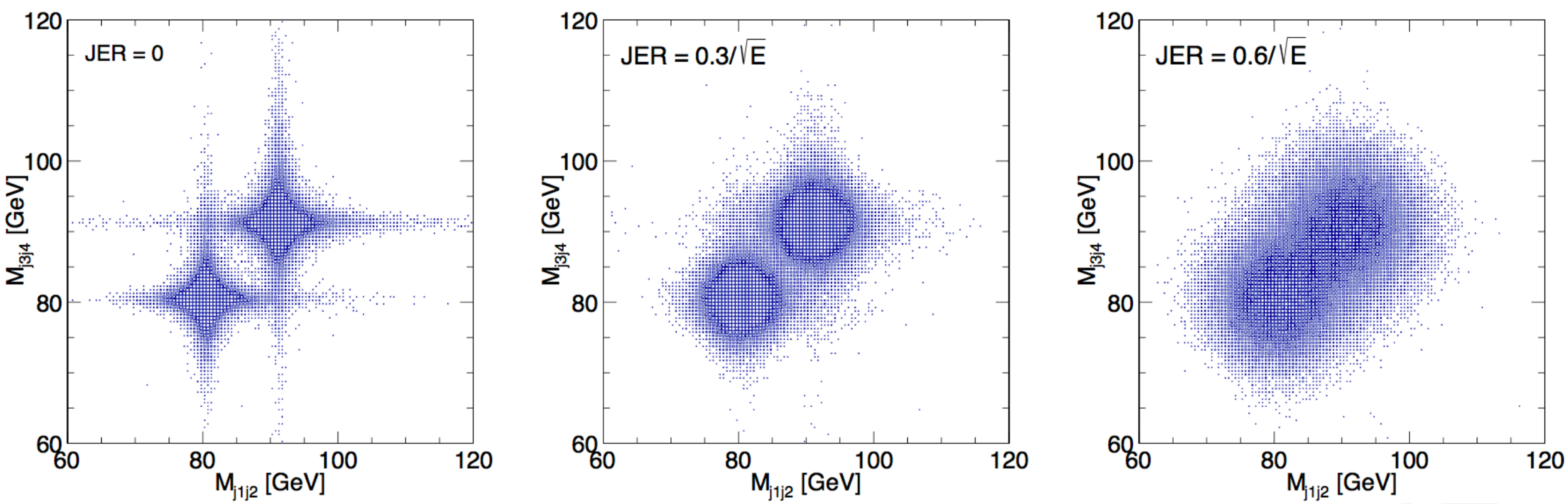
Jet measurement at CEPC

- Separation of W/Z bosons in their hadronic decays translates into a jet energy resolution requirement of ~ 30% /√E (E<100GeV).

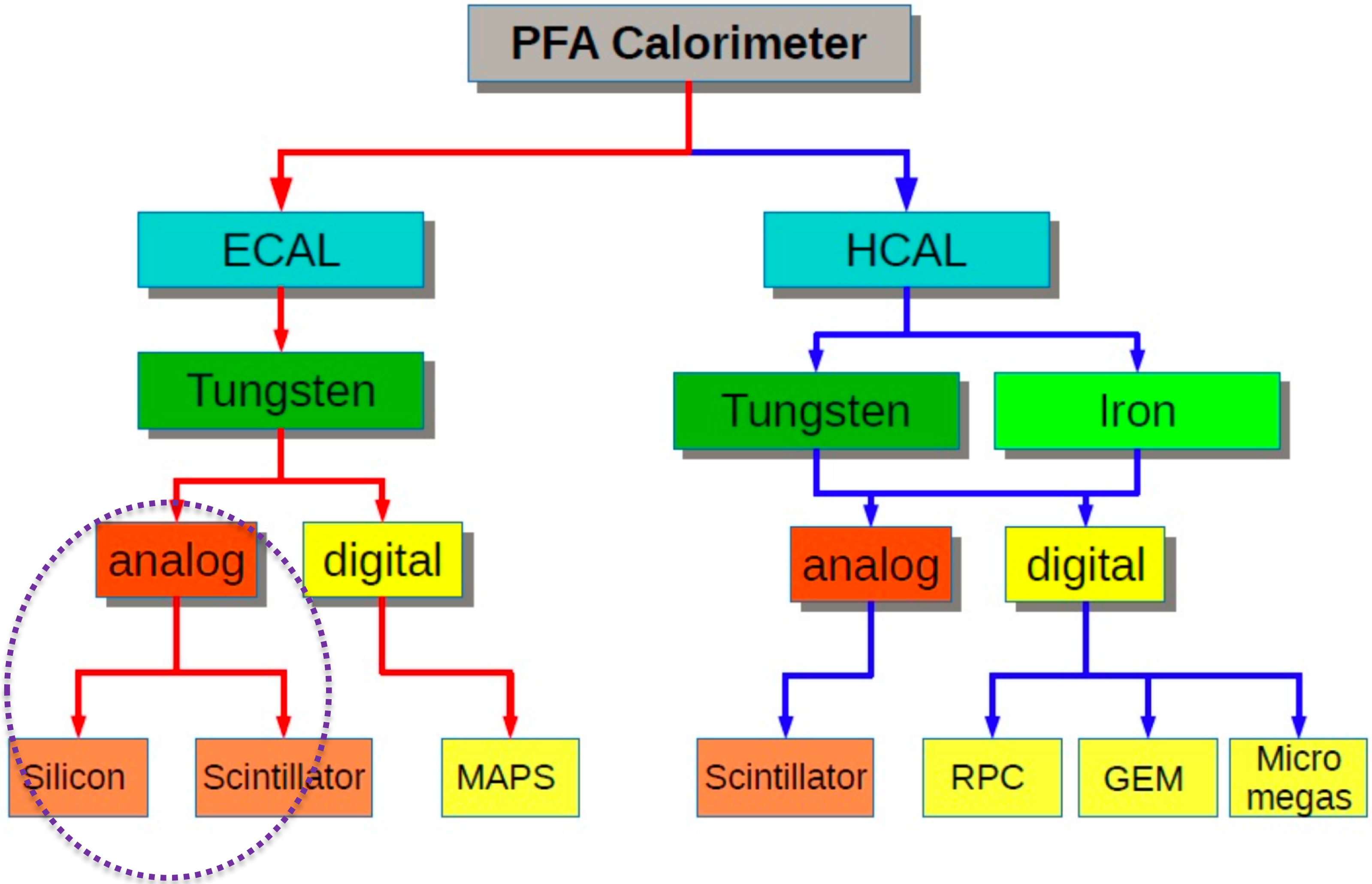


WW→4j and ZZ→4j

Particle Flow Algorithm

- Particle Flow Algorithm (PFA) is a very promising approach to achieving the unprecedented jet energy resolution of 3%-4%.
  - All particles are individually reconstructed.
  - Energy/momentum of each particle in a jet is determined by making use of the optimal sub-detector.
- A highly segmented and full-contained calorimeter system is required, and combined with a transparent and high-resolution tracking system.

PFA calorimeters



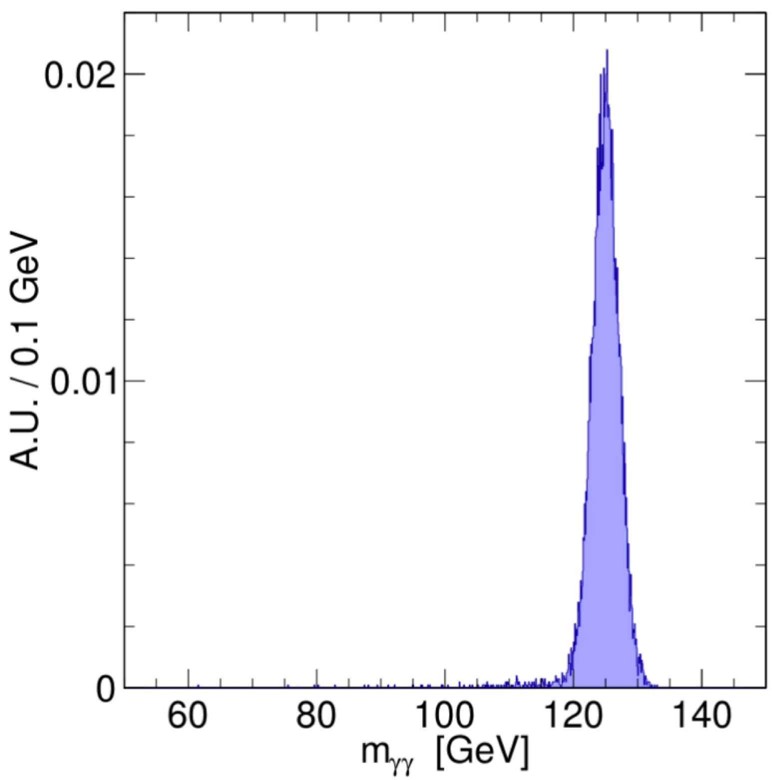
- Analog ECAL options are considered for CEPC.

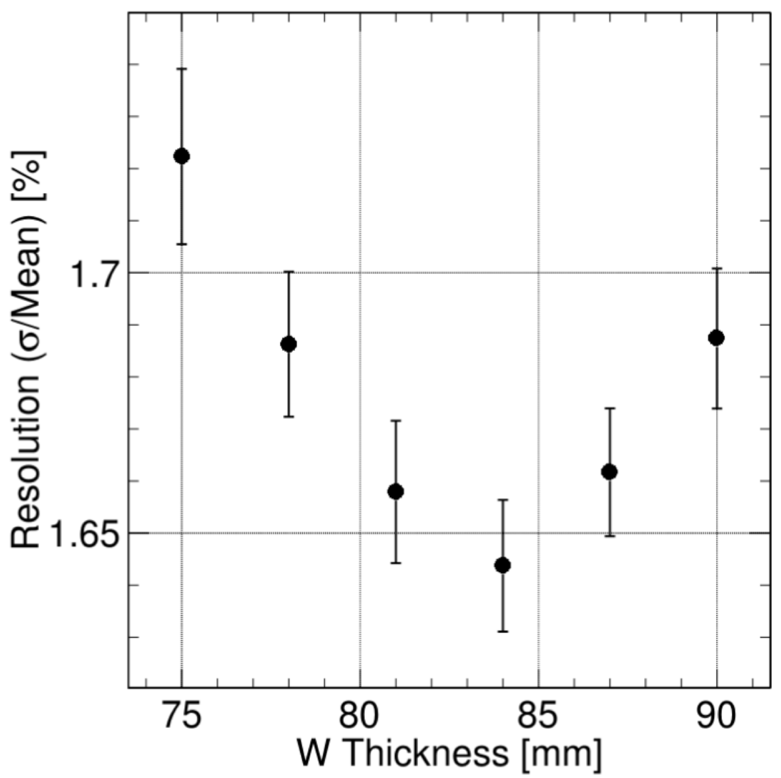
ECAL Design Considerations

- A sampling calorimeter consisting of sensitive layers of either silicon pads or scintillator tiles interleaved with tungsten absorber layers.
  - Tungsten (W): short radiation length, small Moliere radius, large ratio of interaction length over radiation length.
  - Two detector options from the two sensitive materials:
    - Si-W, Sci-W
- Highly segmented both transversely and longitudinally for excellent particle shower separation.
- Si-W is taken as the ECAL baseline option.

Design Optimisation (I)

- Total absorber thickness → 84 mm

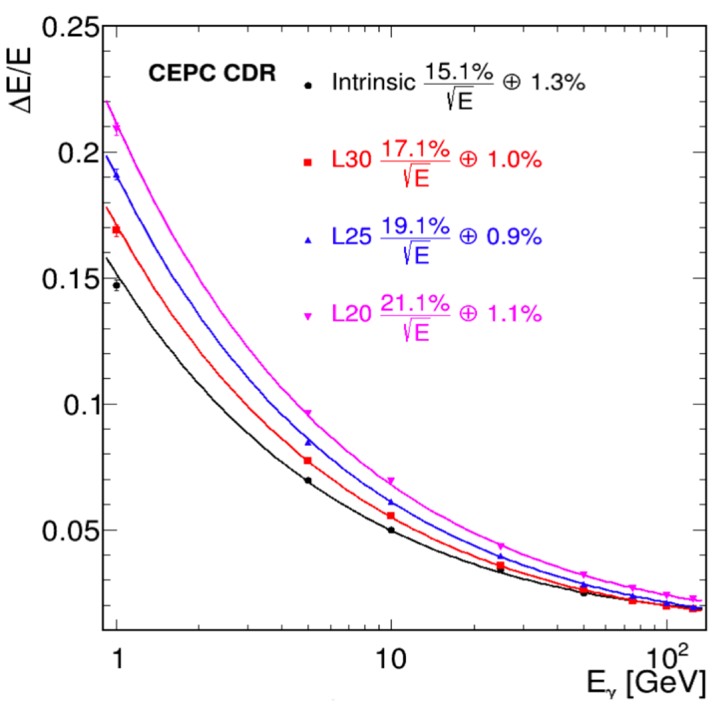


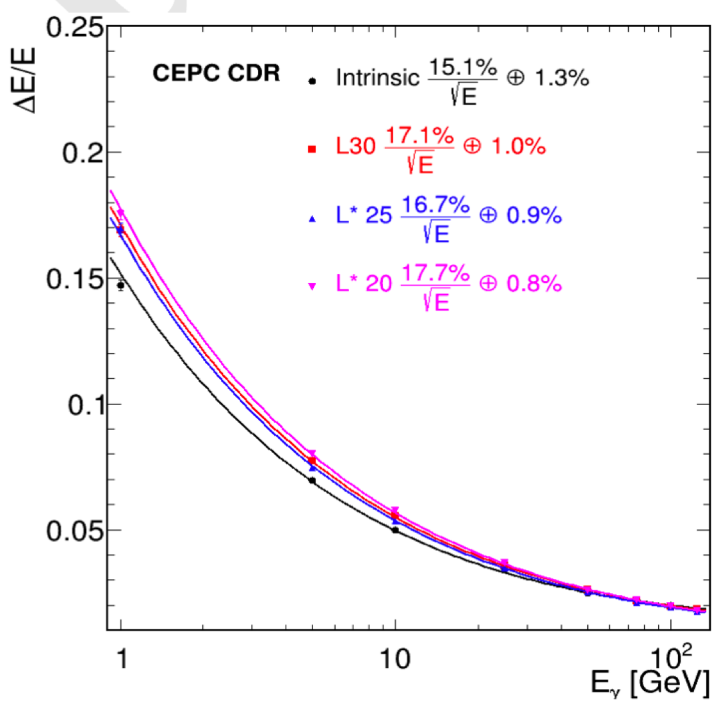


Benchmarked with H→$\gamma\gamma$: Higgs mass vs. thickness

Design Optimisation (II)

- Number of sampling layers → 30





Single photon energy resolution vs. Number of layers and Silicon thickness
Constant absorber layer thickness vs. Varying thickness

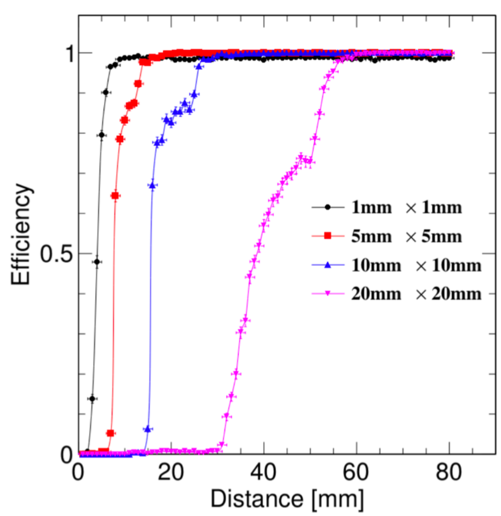
Baseline: 30 layers of 0.5mm silicon, 2.1mm W for first 20 layers and 4.2mm for the last 10 layers.

Design Optimisation (III)

- Cell size → 10×10 mm^2

Silicon sensor size (mm)	Higgs boson mass resolution (with statistic error)
5	3.74 ± 0.02 %
10	3.75 ± 0.02 %
20	3.93 ± 0.02 %

Higgs mass in $H \rightarrow gg$ vs. cell size



Di-photon reco. efficiency

Cell size (mm)	Percentage of inseparable photons
1	0.07%
5	0.30%
10	1.70%
20	19.6%

Percentage of inseparable photons from τ decays in $Z \rightarrow \tau\tau$ events

ECAL Baseline Design Profile

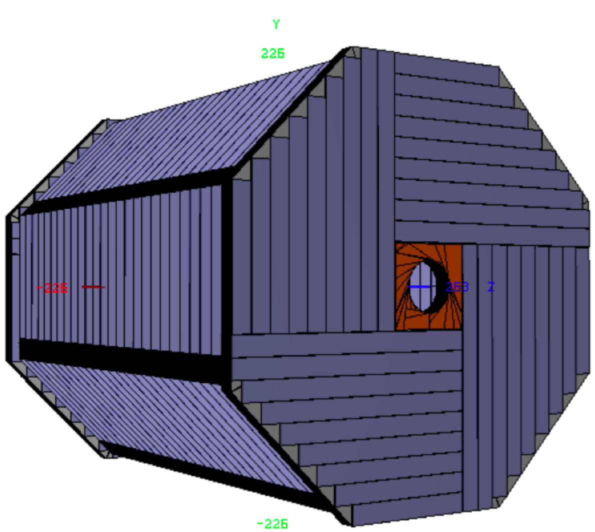
- A Si-W sandwich calorimeter
- Absorber
  - 30 layers of W plates: 20 layers of 2.1mm plates followed by 10 layers of 4.2mm plates.
  - 84 mm thick in total (24 X_0)
- Active medium
  - 30 layers of Si plates, 0.5 mm thick each, divided into square cells of 10*10 mm^2 each.

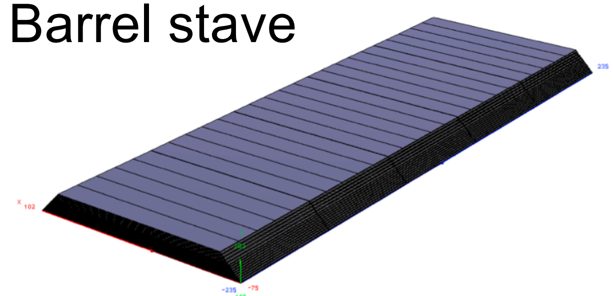
Sensor

- Silicon PIN diodes with high resistivity
  - Stable operation
  - Uniform response
  - Flexible geometry
  - High signal to noise ratio
  - Costly

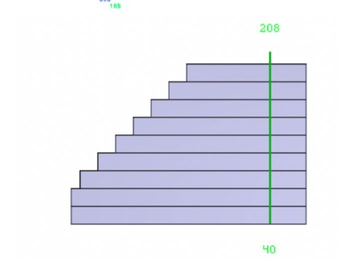
Layout and Structure

- One cylindrical barrel + two disk-like endcaps
- 2.028 m in radius, and 5.270 m long.
- 8 barrel sections: 1 section → 8 staves, 1 stave → 5 modules, 1 module → 5 columns
- Each endcap → 4 quadrants, 1 quadrant → 9 columns
- Column: slabs integrated into supporting structures
- Best possible hermeticity and minimum crack regions

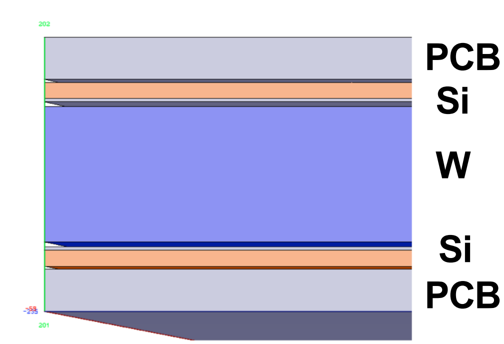




Barrel stave



Endcap quadrant



Slab

Electronics Parameters

- Numbers of channels
  - 17.3 M for barrel, 7.43 M for endcaps
- Dynamic range
  - 9.6 fC (MIP) - 96pC (EM shower) → 10000
- Timing
  - ~1ns for 5MIPs with SKIROC. Can be enhanced with dedicated electronics.
- Power consumption
  - 5 mW/ch from SKIROC in continuous mode, desirable to be further reduced.
- Occupancy
  - Very low, room for ultra-low power electronics design

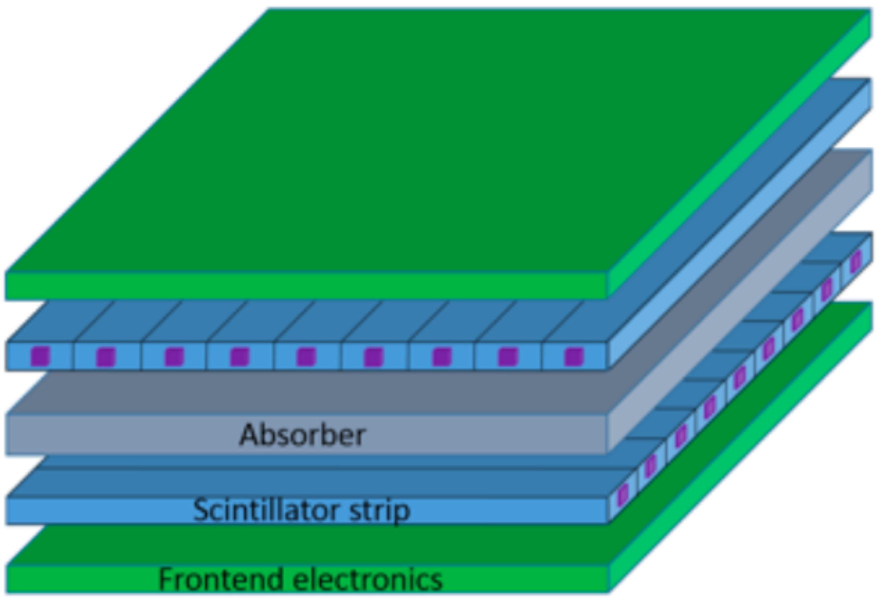
Power consumption and cooling

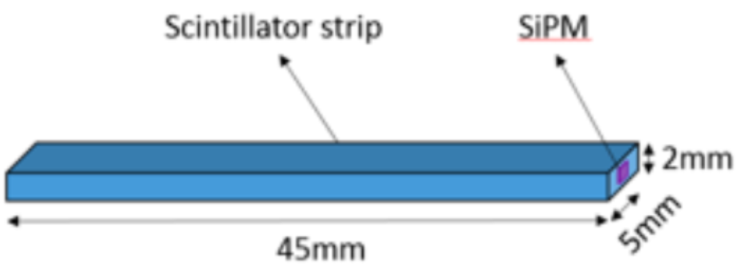
- Total power consumption
  - 124 kW (SKIROC) + 22 kW (DIF) ~ 146 kW
- Active cooling is the baseline cooling scheme, and a two-phase, low mass CO2 cooling system is a promising technology option.
- Passive cooling is also considered, but requires a reduced density of channels.
  - May work for ECAL with a cell-size of 20mm*20mm

An alternative ECAL: Sci-W

- Advent of compact photo sensors made this option possible. Big advantage in cost due to use of scintillator.
- Layout and structure quite similar to Si-W
- The primary difference is in the thickness of active layers
  - 2 mm thick scintillator
- Scintillator read out with SiPM
- Explore strip configuration to get a higher effective granularity
  - Have adjacent scintillator strip layers placed perpendicular to each other

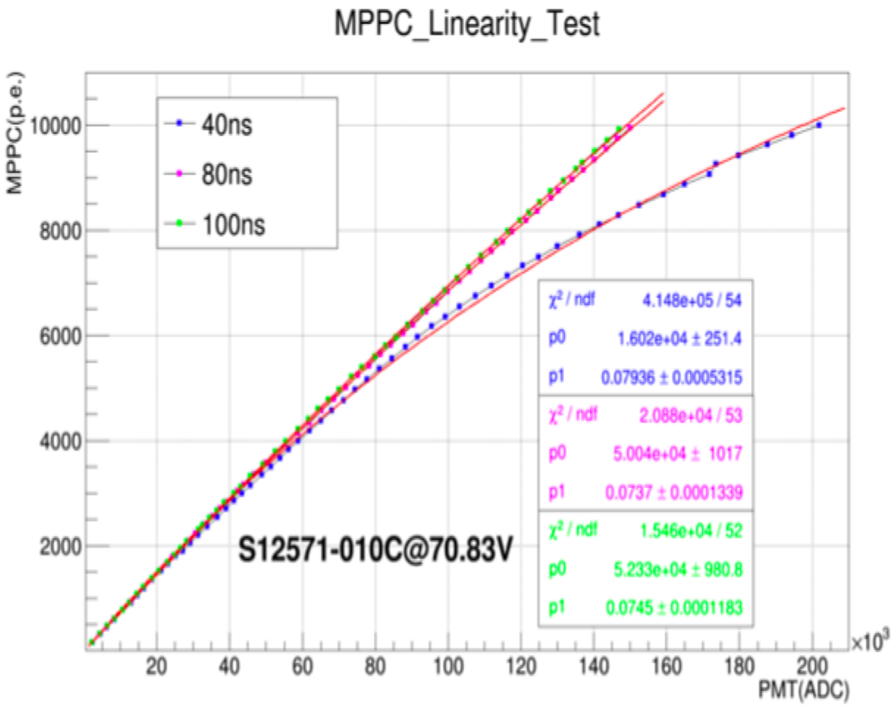
Layout of a Sci-W module

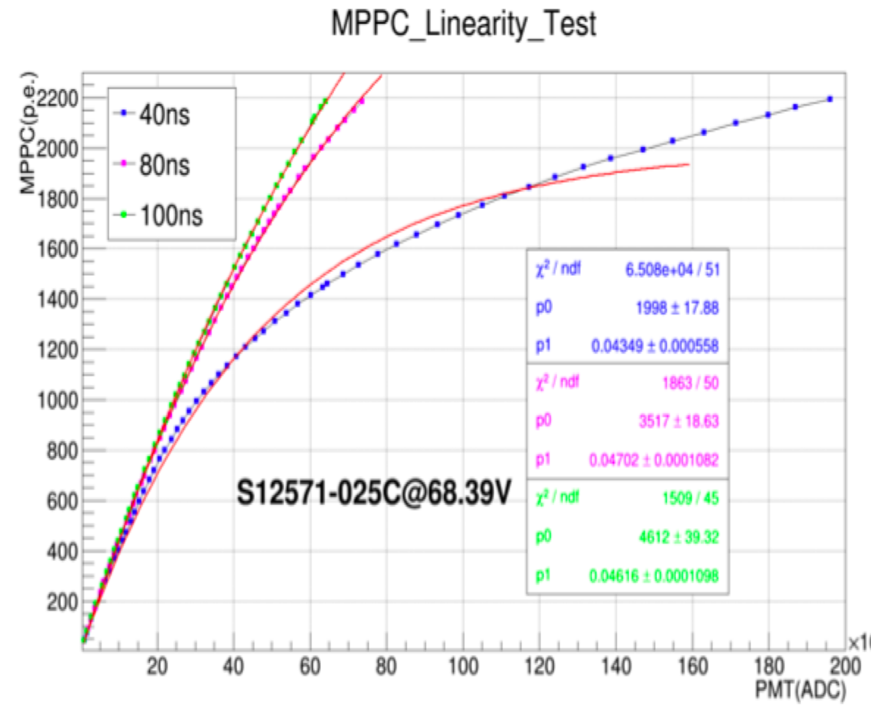




- More studies required to demonstrate the effectiveness of the strip configuration

SiPM dynamic range

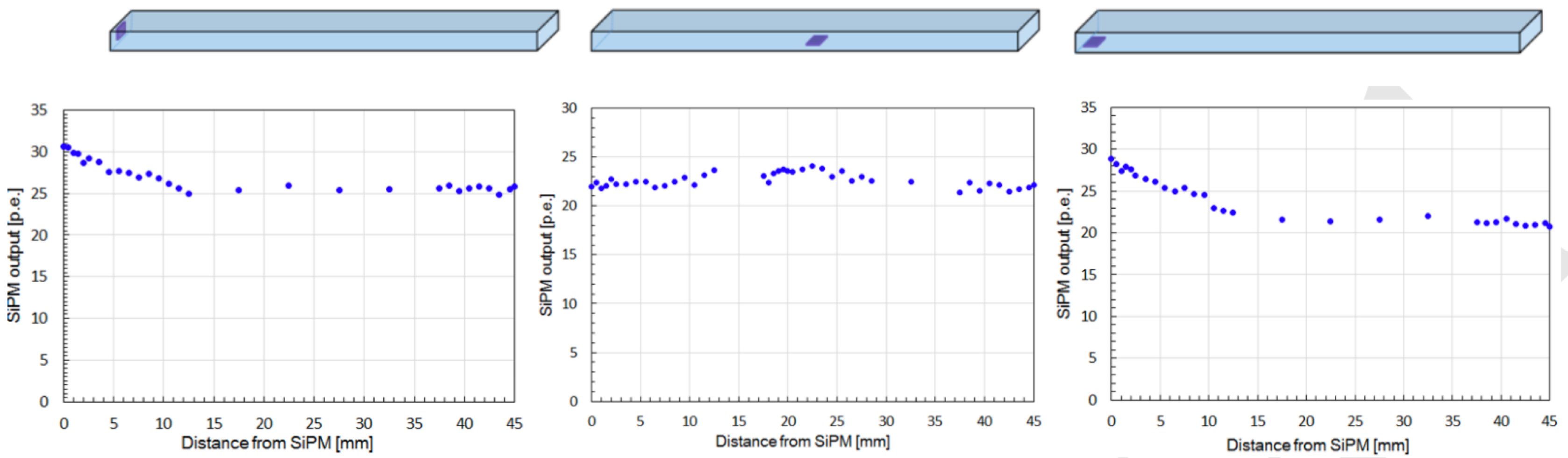


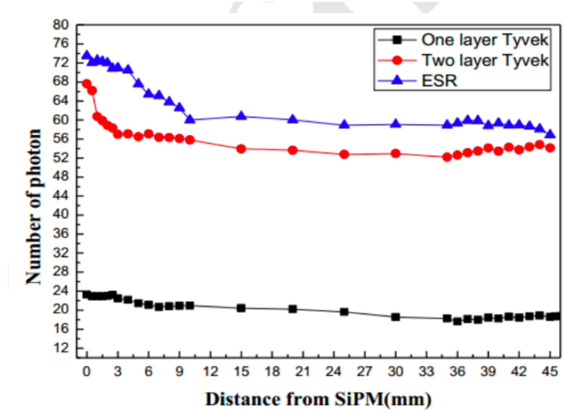


- A dynamic range of up to ~800 MIPs is required for $H \to \gamma\gamma$ measurement. This corresponds to ~10000 PEs assuming 15 PEs for a MIP.
- High-pixel SiPM (small pitch, e.g. 10 μm, or large-area) is needed.

Scintillator Sensitive Unit

- Bottom-center: the best coupling of SiPM to scintillator strip.
  - Good uniformity
  - Possible to employ large-area SiPMs

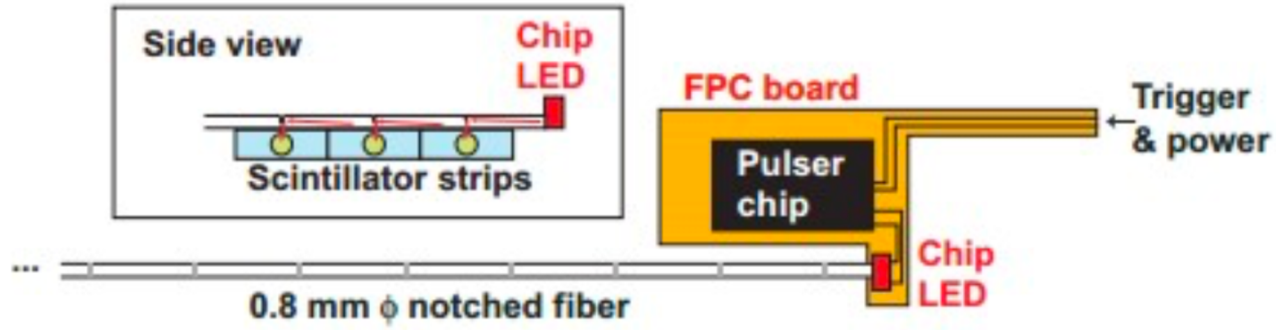




ESR is a good reflector film

SiPM Readout and Calibration

- SPIROC chip can be a starting point for SiPM readout of CEPC ECAL.
  - Large dynamic range and good charge resolution
  - Sub-ns timing resolution
  - Modifications needed to accommodate the CEPC continuous mode
- A SiPM monitoring and calibration system consisting of pulse generators, chip LEDs, and notched fibers is considered.



Summary

- Baseline PFA ECAL for CEPC
  - Si-W, 30 sampling layers
  - Absorber layers
    - 84 mm thick W (24 X_0), 20 layers of 2.1mm W plates + 10 layers of 4.2mm W plates
  - Active layers
    - 0.5 mm thick Si plates divided into square 10*10 mm^2 cells
- Alternative option
  - Sci-W
  - 2mm thick scintilator read out with SiPM