Development of AHCAL Scintillator Tile Batch Testing System

Yanyun Duan (SJTU)
For the CEPC calorimeter working group

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CEPC Physical Goal

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- Precise measurement of the Higgs particle's properties
- Explores new physics outside the standard model
- Precise measurement of the electric weak interaction parameters related to Z and W bosons.

Requirements of CEPC AHCAL: high granularity

- Jet energy range: 100GeV
- Energy resolution: σ_E/E good than $60\%/\sqrt{E}$
- Jet energy resolution (ECAL, HCAL and tracker combined): $\sigma_E/E \approx 3\% - 4\%$

Operation mode	$\sqrt{s}$ (GeV)	L per IP ($10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	Years	Total $\int L$ (ab^{-1}, 2 IPs)	Event yields
H	240	3	7	5.6	1×10^6
Z	91.2	32 (*)	2	16	7×10^{11}
W^+W^-	158–172	10	1	2.6	2×10^7 (†)

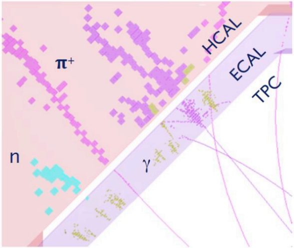
Particle Flow Algorithm

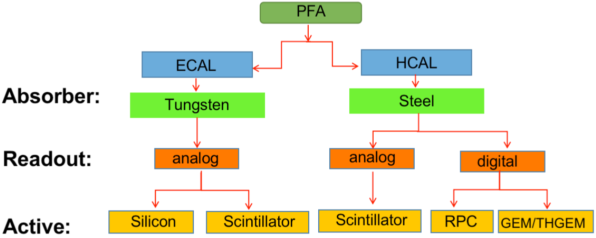
- Traditional calorimetric ($60\%/\sqrt{E(GeV)}$):
  - Measure all components of jet energy in ECAL/HCAL.
  - Approximately 70% of energy measured in HCAL.
- Particle Flow Algorithm:
  - Charged particle momentum measured in tracker.
  - Photon energy measured in ECAL.
  - Only neutral hadron energy (10% of jet energy) measured in HCAL: much improved resolution

Particles in jets	Fraction of energy	Measured with	Resolution [σ^2]
Charged	65 %	Tracker	Negligible
Photons	25 %	ECAL with $15\%/\sqrt{E}$	$0.07^2 E_{jet}$
Neutral Hadrons	10 %	ECAL + HCAL with $50\%/\sqrt{E}$	$0.16^2 E_{jet}$
Confusion	Required for $30\%/\sqrt{E}$		$\leq 0.24^2 E_{jet}$

(Charged + Photons + Neutral Hadrons: $18\%/\sqrt{E}$)

Imaging calorimeter





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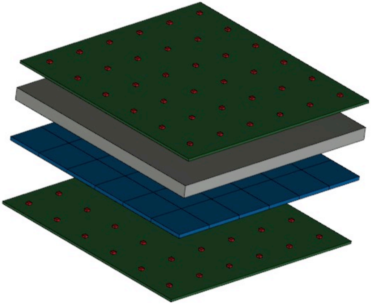
CEPC AHCAL

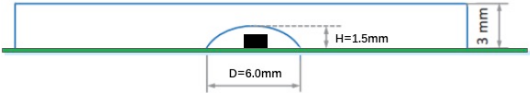
The AHCAL task in the MOST2 CEPC R&D project

- To validate the CEPC AHCAL option by designing, building and testing a full AHCAL prototype.

CEPC AHCAL: SiPM-on-Tile configuration

- Prototype: 72cm×72cm×100cm with 40 layers
- Detector cell size: 40mm×40mm×3mm
- PCB: 2mm, with SiPMs, temperature sensors and SPIROC2E
- Absorber: steel (20mm Fe)
- Active: scintillator made of polystyrene and wrapped in enhanced specular reflector (ESR) films.





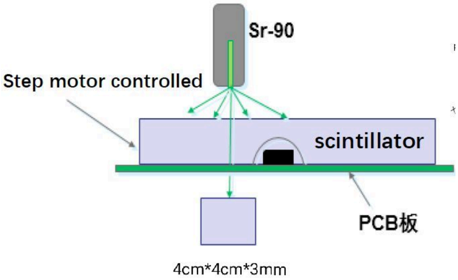
Test Principle

Testing Principle:

- Radiation source: ^{90}Sr, ^{90}Sr producing beta rays (electron beams).
- Scintillator: produce photons by deposited energy
- SiPM: turn the photons to photoelectrons and multiply them
- SPIROC2E (36 channel): collected and amplified the photoelectrons

Test time estimation:

- ^{90}Sr source activity: several mCi.
- Electronics' dead time: about 1 ms.
- Readout system receives about 1,000 events/s.
- Each scintillator stay 5 minutes. 144 scintillators can be tested in 12 hours.
- When finished, stop automatically.



Specific Task and Test Plan

Batch test system:

- 144 scintillators, 12 hours.
- 3 Batch test system in total.
- Estimated test time of scintillator tiles batch testing: 44 days.

USTC, IHEP and SJTU specific tasks:
Plan A:

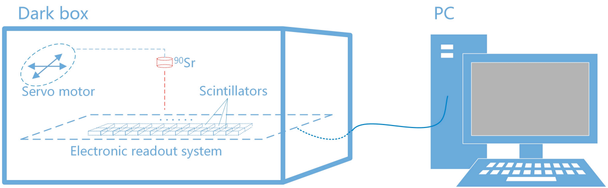
- USTC: 20% batch testing and assembly work
- IHEP: 40% batch test and assembly work
- SJTU: Batch test equipment, 40% batch testing and assembly work

Plan B:

- ^{90}Sr activity in SJTU is 3-8 $\times$ 10^3bq, around 0.2μCi, may be slow for batch testing.
- Batch testing in USTC or IHEP with higher rate ^{90}Sr source, with SJTU manpower support.
- Plan A should be mostly ok, as long as the electronics dead time has limitation which already prevent high rate.

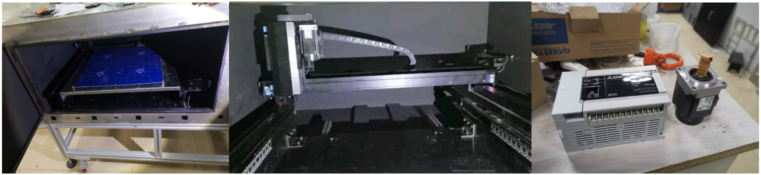
CEPC AHCAL Batch Test System

- PC: control servo motor and electron readout system.
- Touch screen: control servo motor
- Dark box: shield environmental light
- Inside the dark box
  - PCB with SiPMs: 4 SPIROC2E+ 144 SiPM (S13360-1325PEs)
  - temperature sensors
  - electronic readout system
  - aluminum frame: fix the scintillators to their expected positions
  - two sliding rails: PCB movable
  - servo motor: carry the ^{90}Sr radioactive source



CEPC AHCAL Batch Test System

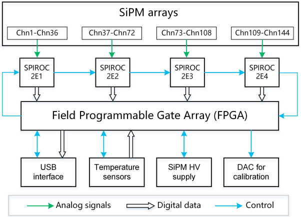
- 3 batch test system in total, USTC one has been finished, and the other 2 in process.

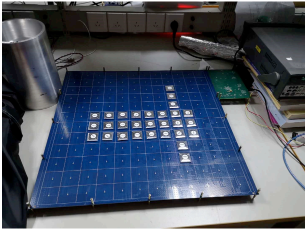


Electronic Readout System

Electronic readout system:

- SPIROC2Es: in PCB
  - collect, sample and digitize the analog signals
  - send the digital charge and time signals to PC
  - dynamic range is 1-2000 photoelectrons
- FPGA: in DIF
  - all digital logic functions
  - receive the digital temperature signals and then send it to PC





SiPM Test

Data and analysis from USTC (Hao Liu, Zhongtao Shen, Yunlong Zhang, Yukun Shi, etc).
The result shown in this slide is from the same scintillator tile, data taking outside the dark box.

SiPM: S13360-1325PEs

- operating voltages: 56.51V-57.3V
- work under common high voltage source C11204-02.
- SiPMs cathode: high voltage source (57.8V)
- SiPMs anode: internal DAC (output voltage: 5V) of SPIROC2E

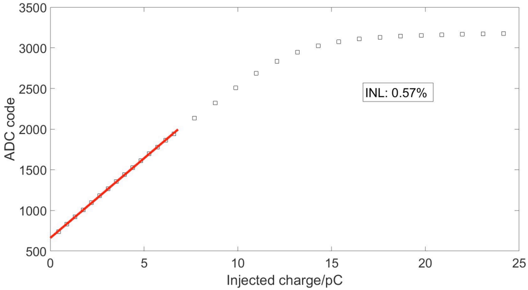
SiPM gain:

- Strongly relies on temperature.
- Breakdown Voltage of APDs increases with the rise of temperature.
- Reverse Voltage (operating voltage) of SiPM should be several volts higher than the breakdown voltage of APDs.
- 16 temperature sensors, temperature monitoring. Environment temperature increases 1 °C, reverse voltage increase 54 millivolts

Electronic Calibration

Data and analysis from USTC (Hao Liu, Zhongtao Shen, Yunlong Zhang, Yukun Shi, etc).

- Output ADC code linear with the injected charge up to about 12 pC (10^{-12} Coulomb).
- The integral nonlinearity is 0.57% and the slope is 195.93.
- Injected charge increases 1 pC, the output ADC code will increase 195.93.

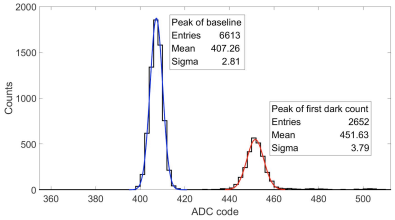


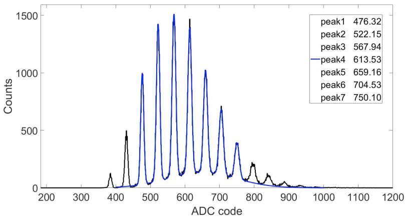
⇒All channels are working properly with great linearity.

Single Photon Calibration

Data and analysis from USTC (Hao Liu, Zhongtao Shen, Yunlong Zhang, Yukun Shi, etc).

- Single photon calibration, the dark count of the SiPM.
- The dark count: current pulse produced by the carriers
- Left plot: Single photon calibration results of a single channel
- Right plot: LED calibration results
- Observable dark peaks.



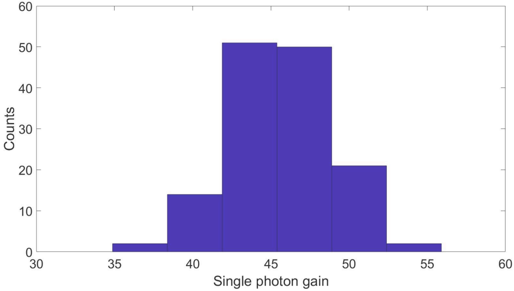


⇒ The baseline of each channel is obtained.

Single Photon Calibration

Data and analysis from USTC (Hao Liu, Zhongtao Shen, Yunlong Zhang, Yukun Shi, etc).

- Distribution of single photon gains of all channels (144).

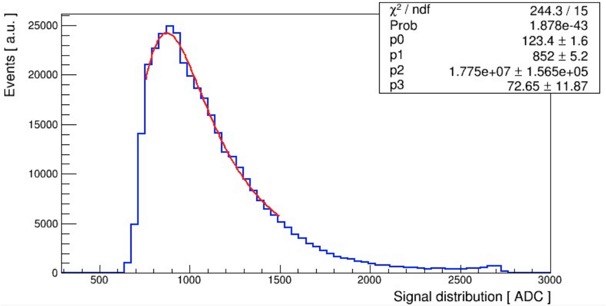


⇒ A clearly visible single photon spectrum is obtained and the single photon gain is calculated out.

Light Yield Measurements

Data and analysis from USTC (Hao Liu, Zhongtao Shen, Yunlong Zhang, Yukun Shi, etc).

- Landau + Gaussian fitted
- Minimum Ionizing Particle (MIP) with baseline deducted: 852 ADC code.
- Sigma of Landau distribution: 123.4 ADC code.

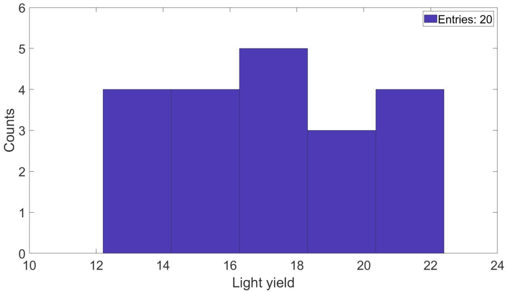


Light Yield Measurements

Data and analysis from USTC (Hao Liu, Zhongtao Shen, Yunlong Zhang, Yukun Shi, etc).

$$LY = \frac{ADC_{MIP} - ADC_{baseline}}{Gain_{SinglePhoton}}(perMIP) \quad (1)$$

- ADC_{MIP} - $ADC_{baseline}$=852 ADC, $Gain_{SinglePhoton}$ = 44.37 ADC, LY = 19.20 photons per MIP.
- Light yield of all scintillators calculated out.
- Distribution of light yields of 20 tested scintillators.



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Sum Up

CEPC AHCAL: SiPM-on-Tile configuration

- Prototype: 72cm$\times$72cm$\times$100cm, 40 layers
- Detector cell size: 40mm$\times$40mm$\times$3mm
- Scintillators: made of polystyrene and wrapped with ESR

Batch test system: SPIROC2E-based scintillator test system

- servo motor carry the radioactive source ^{90}Sr, range of motion covers all scintillators.
- electronic readout system and temperature monitors connected to PC.
- PCB: SPIROC2E+SIPM;
- DIF: all digital logic functions, FPGA.

Calibration and light yield measurements:

- Channels works properly with great linearity.
- Baseline of each channel is obtained.
- Clearly single photon spectrum obtained
- The single photon gain calculated out.
- Light yield is calculated out.

Thank You!.