Development of the CEPC Scintillator-Steel HCAL Prototype

Jiechen Jiang On behalf of the CEPC Calorimeter working Group

2020 international workshop on the high energy CEPC October 27th, 2020



Outline

Background introduction

• Simulation of AHCAL prototype

- Absorber thickness
- Number of layers
- Detector cell size

• Optimization of detector cells

- Improvement of injection molding scintillator
- Selection of SiPMs, HPK & NDL

• Assembly and batch testing of tiles

- Tiles wrapping
- Gluing trial of tiles
- Batch tiles testing platform
- Summary



Background Introduction

• e^+e^- Higgs(Z) factory

- 100km , $E_{cm} \approx 240 {\rm GeV}$, 2IP,
- luminosity $\geq 2x10^{34}cm^{-2}s^{-1}$
- 1M Higgs in 10 years,
- At the z-pole 10¹⁰ Z bosons/year
- CEPC physical goals

FAS

院高能物理研究所

nstitute of High Energy Physics Chinese Academy of Sciences

- The precision measurement of the Higgs boson properties, precision 1% or better
- The precision measurement of the electric weak interaction parameters related to W/Z boson

TAS

- Upgradable to pp collision with $E_{cm} \approx 50-100$ TeV
 - A discovery machine for BSM new physics

CEPC booster ring (100km)



CEPC collider ring (100km)





J.C. Jiang 27/10/2020

CEPC Linac injector (1.2km, 10GeV)

Background Introduction





學院高能物理研究所

nstitute of High Energy Physics Chinese Academy of Sciences

Structure of AHCAL Prototype

- Task BMR < 4% and $60\%/\sqrt{E} \oplus 3\%$
 - Validate the CEPC AHCAL option by designing, building and testing a full AHCAL prototype.
- Prototype
 - Transverse dimension: 72cm×72cm
 - Number of layers: 40
- Single layer
 - Stainless steel as absorber: 20 mm
 - Scintillator as sensitive medium: 3 mm_n
 - SPIROC2E electronics: 2 mm
- Detector cell
 - Cell size: 40mm × 40mm
 - Sensor: SiPMs from HPK & NDL





Single layer and detector part





titute of High Energy Physics J.C. Jiang 27/10/2020 Chinese Academy of Sciences

International Workshop on the High Energy CEPC

Full Simulation of AHCAL



 Considering the light output of detector cells, the dimension of 40 mm × 40 mm × 3 mm was chosen.

J.C. Jiang 27/10/2020



院高能物理研究所

institute of High Energy Physics Chinese Academy of Sciences

Simulation of AHCAL Prototype



Energy resolution requirement: $60\%/\sqrt{E} \oplus 3\%$

The dimension is 72 cm \times 72 cm with 40 layers for AHCAL prototype.



Chinese Academy of Sciences

能物理研究所 J.C. Jiang 27/10/2020 nstitute of High Energy Physics

Simulation of AHCAL Prototype



nstitute of High Energy Physics

Chinese Academy of Sciences

學院為能物理研究所 J.C. Jiang 27/10/2020 40

primary E(GeV)

60

20

80

- Structure of scintillator tiles
 - 30 mm \times 30 mm \times 3 mm and 40 mm \times 40 mm \times 3 mm



- The cell size is from $3 \text{ cm} \times 3 \text{ cm}$ to 4 cm to 4 cm
 - The cell size of 4 cm can satisfy the jet requirements
 - The transverse area is near 2 times than cell size of 3 cm with the same cost
- ESR is chosen as the reflector and the design can be compatible with wrapping machine





中國科學院為能物理研究所 Institute of High Energy Physics Chinese Academy of Sciences

- Uniformity testing within a tile
 - Tile of 40 mm \times 40 mm \times 3 mm with a NDL SiPM 1010
- Light output is within $\pm 10\%$ for 95% of the testing points
 - The structure of the tiles is feasible
 - The light output need to be improved
- The craft of scintillator tiles and options of SiPMs can improve the light output





Trail of injection molding scintillator

- Improvement of recipe and craft
- Material of PVT and PS
- Light output measurements
 - NDL SiPMs typed 22-1313-15S
 - Read out by 1 or 2 SiPMs of one unit
- The light output is near 20 p.e. read out by 1 SiPM
- The light output can be around 40 p.e. read out by 2 SiPMs
- PS tiles by injection molding technique can satisfy the requirement.
- Considering the aging and radiation damage for long time running, read out by 2 SiPMs is suitable

Chinese Academy of Sciences

$40 \text{ mm} \times 40 \text{ mm} \times 3 \text{ mm}$ 22-7





Light output read out by 1 SiPMs

Num	1	2	3	4	5
PS	18.32	18.14	16.74	17.58	17.63

Light output read out by 2 SiPMs

Num	1	2	3	4	5	
PS	42.2	43.89	40.01	44.56	39.15	



• HPK-SiPM

- Low dark rate and crosstalk
- High breakdown and price

- NDL-SiPM:
 - High PDE, dark rate and crosstalk
 - Low breakdown and price
- Light output measured with the same tiles of 40 mm × 40 mm × 3 mm and different SiPMs
- Light output read by HPK SiPMs of 1.3 mm \times 1.3 mm is a little low





• NDL-SiPM 22-1313-15S

Breakdown[V]	19
PDE@400nm [%]	45
Transverse dimension [mm^2]	4.45×3.65
Thickness [mm]	0.95
Number of Pixel	7400×4

22-1313-15S -----> 12-1313-15S





- 2 SiPMs of a unit is enough
 - Type 12-1313-15S is simply cut from 22-1313-15S
- 2 photoelectrons can be observed
- **45**^o position of the SiPMs

學院高能物理研究所

institute of High Energy Physics Chinese Academy of Sciences

• Light output can be more uniform







14

- NDL-SiPM 22-1313-15S
- Stability testing
 - Dark noise with dedicated preamplifier
 - Gain and crosstalk versus time (hour)
 - LED with SPIROC2E electronics
 - Sigma and SNR versus time (day)
- SNR is the ratio of pe/sigma

1600

1400

1200

1000

800 600 400

200

0 350

400

450

500

- pe is average value of the ADC between peaks
- sigma is the mean value of the sigma for all peaks





3.5

Automatic wrapping machine

- 7M detector cells for CEPC-AHCAL
- Reflector packaging can't be done by manual
- Progress
 - Investigate different companies related to the preliminary design
 - A novel way by using a robotic arm
- Function
- It can be used for detector cell size of $2 \text{ cm} \times 2 \text{ cm}$,

 $3 \text{ cm} \times 3 \text{ cm}$ and $4 \text{ cm} \times 4 \text{ cm}$;





中國科學院為能物別加完所 Institute of High Energy Physics Chinese Academy of Sciences

J.C. Jiang 27/10/2020

YAMAHA机器

- Automatic wrapping machine •
 - Wrapping cycle is around 45s
- Alternative wrapping mode for • different cell size of tiles
 - Change the main parts of the machine
 - Reposition the robot arm
- **Current status**
 - All parts can be applied for • AHCAL tiles of $3 \times 3 \ cm^2$ and 4 $\times 4 \ cm^2$
 - The machine can run well

资高能物好 研究 所

nstitute of High Energy Physics Chinese Academy of Sciences



92120

SLLLO

02130

17141



J.C. Jiang 27/10/2020

12120

01140

92120

09120

88120

2\$110

Gluing of scintillator tiles

- Assemble tiles on PCB quickly and effectively
- procedure
 - Prepare a brush and container used to fill glue (Araldite 2011)
 - Put the dedicated stencil on the testing board and disperse the glue on the surface of it
 - Remove the stencil and the glue in the hole will remain on the board
 - Paste the wrapped tiles one by one and put a plate on them
 - Wash the stencil and brush by alcohol





Options of AHCAL prototype electronics

- ASIC design: SPIROC2E or KLauS
- HBU design: 18×18 readout channel per layer
- Besides the function of signal readout, electronics calibration, light calibration and temperature monitor is also implemented on HBU.
- Plan to finish at the end of this year
- DAQ system development: FELIX card+DAQ board+DIF (Data Interface) boards+ HBU





nstitute of High Energy Physics J.C. Jiang 27/10/2020 Chinese Academy of Sciences

• The progress of scintillator testing platform (STP)

- Quickly check the performance of detector cells
- Uniformity of different scintillator tiles
- Calibration and monitor by LED
- The platform is in a dark box

nstitute of High Energy Physics Chinese Academy of Sciences

- ⁹⁰Sr, step motor and detector systems
- 4 SPIROC2E+ 144 SiPMs (S13360-1325PEs)+FPGA in DIF
- 3 batch test systems in total, one of them has been finished, and the other 2 are in process





Summary and Plan

- The design of AHCAL prototype can satisfy the requirements, the energy resolution is $48\%/\sqrt{E} \oplus 3\%$ and linearity is $\pm 1.5\%$ from simulation
- The light output of injection molding tiles can be near 40 p.e. read out by the NDL SiPMs 12-1313-15S and the tiles of 13.5k will be produced soon
- The detector cells can be assembled effectively for wrapping and gluing
- Front-end electronics and batch testing systems is under development
- The prototype will be constructed in next year









中國科學院為能物記碼完備 Institute of High Energy Physics Chinese Academy of Sciences J.C. Jiang 27/10/2020

International Workshop on the High Energy CEPC

Requirement of BMR

• BMR < 4% \leftarrow 2 σ separation

The invariant mass distributions of the hadronic decays of the W (red), Z (green) and Higgs (blue) bosons for different BMR values. All distributions are normalized to unit height. The distributions of the W and Z bosons are modeled with Breit-Wigner distributions of widths of 2 and 2.5 GeV, respectively, convoluted with detector resolutions of different BMR values. The distributions of the Higgs bosons are obtained similarly, but from an intrinsic narrow width distribution.





nstitute of High Energy Physics Chinese Academy of Sciences

院為能物財為完施 fHigh Energy Physics J.C. Jiang 27/10/2020

International Workshop on the High Energy CEPC

Simulation of AHCAL

Calibration and reconstruction

- Scintillator thickness optimization
- 40 layers: each layer has 20mm Steel and 2mm PCB
- Scintillator thickness for each layer ranges from 2 to 5mm
- KL reconstructed energy at different scintillator thickness





Simulation of AHCAL

• Linearity of different transverse dimension and layers



Optimization of Tiles

• Uniformity of scintillator tiles

- NDL-22-1313-15S
- Voltage: 23V
- Scintillator: PS tile







個科學院為能物招加完約 Institute of High Energy Physics J.C. Jiang 27/10/2020 Chinese Academy of Sciences

HPK VS NDL

Company	НРК			NDL		
Туре	1251- 025P	13360- 1325PE	14160- 1315PS	1010C	3030C	125
Active area[mm ²]	1	1.69	1.69	1	9	1
Pixel number	1600	2700	4400	10000	90000	6400
Breakdown[V]	65	53	38	27.5	27.5	21.5
Overvoltage[V]	3.4	4	5	6.5	6.5	3
Dark counts[kHz]	82	120	290	550	5150	470
Crosstalk[%]	22.6	1.59	1.17	4.4	8	8.1
Gain[10 ⁵]	2.83	5.11	2.5	1.295	1.3	1.91
Light Output [p.e.]	23	26	28	16	158	18

All parameters are measured in laboratory at room temperature.



Distribution of Final State particles decayed from H →gg



- Momentum of More than 95% particles are below 20GeV.
- More than 99% of energy density is less than 25MIP in all AHCAL hits.



• SPIROC Range: 300pc

- 8,000 p.e. for NDL 22-1313-15S (Gain 2.2 × 10⁵)
- Larger SiPM has less saturation effect and more light yield which needs more electronics range thus has a much better resolution

• Dark Count Over 10p.e. for NDL-15um:<0.043Hz

J.C. Jiang 27/10/2020

• SiPM CrossTalk probability:11.5%



International Workshop on the High Energy CEPC

28



nstitute of High Energy Physics Chinese Academy of Sciences

Testing parameters

- Voltage: 23V
- Scintillator: Thermal polymerization
- SiPMs: NDL 22-1313-15S

Performance

- Gain:2.44imes 10⁵
- DCR:330,574 Hz
- CT: 8.5%
- Dark current:1.48 uA





MIP Spectrum





國科學院為能物現研究所 Institute of High Energy Physics

Chinese Academy of Sciences