CEPC Calorimetry DAQ: considerations and estimates after CDR

Yong Liu (Institute of High Energy Physics, CAS),
on behalf of the CEPC Calorimetry Working Group

International Workshop on High Energy Circular Electron-Positron Collider
Oct. 26-28, 2020

Considerations and estimates for ECAL DAQ

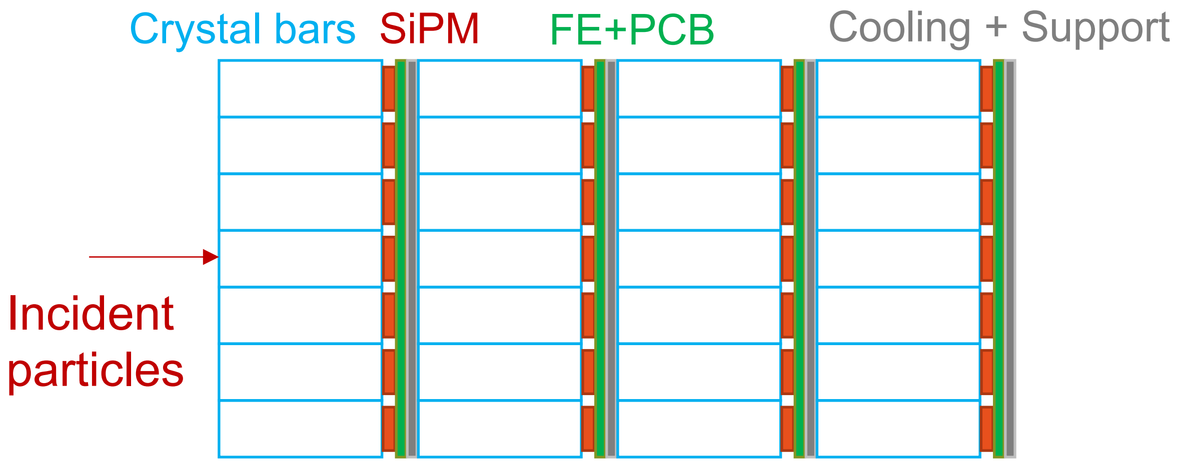
CEPC CDR: DAQ for ECAL

- Maximum event rate: 100 kHz
  - Peak event rate: ~32kHz at Z-pole
  - Safety margin: a factor of ~3
  - 10 μs time window for readout
- ECAL: 2 options in CDR
  - Si-W ECAL: $10\times10\ \mathrm{mm}^2$ silicon pads
  - Sc-W ECAL: $45\times5\ \mathrm{mm}^2$ scintillator strips
  - Longitudinal depth: 24X0

ECAL options	#Channels [Million]	Occupancy [%]	#bit per channel	#readout channels/evt	Data Volume per event	Data rate at 100kHz
SiW ECAL Barrel	17	0.17	32	28.8 k	117 kByte	11.7 GBytes/s
SiW ECAL Endcap	7.3	0.31	32	22.4 k	90 kByte	9.0 Gbytes/s
ScW ECAL Barrel	7.7	0.17	32	13.1 k	53 kByte	5.3 GBytes/s
ScW ECAL Endcap	3.3	0.31	32	10.2 k	41 kByte	4.1 Gbytes/s

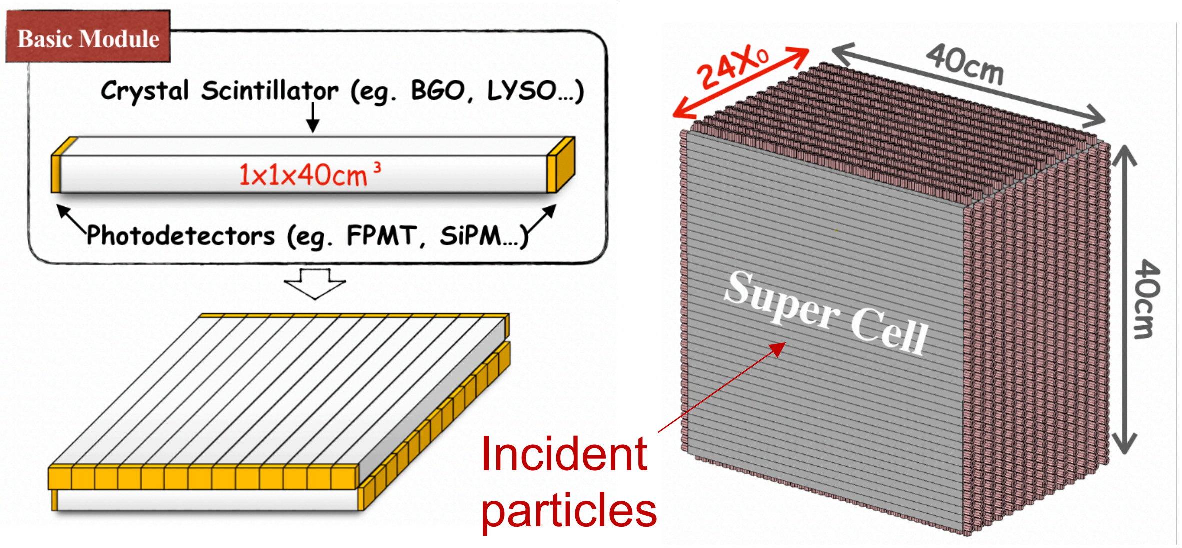
Crystal ECAL: a new concept

Design 1



- Longitudinal segmentation
- Fine transverse segmentation
  - 1×1cm or 2×2cm cells
- Single-ended readout with SiPM
- Potentials with PFA

Design 2 (current focus)



- Long bars: 1×40cm, double-sided readout
  - Super cell: 40×40cm cube
- Crossed arrangement in adjacent layers
- Significant reduction of #channels
- Timing at two sides: positioning along bar

DAQ for crystal ECAL: considerations (1)

- Based on the CDR values: scaling exercise
- 2 Major scaling factors
  - #channels: generally crystal ECAL will have much less channel count (higher occupancy)
  - #bit per channel: higher precision to cover a large dynamic range
- Considerations
  - Design 2: detector layout with long crystal bars
    - e.g. 24 longitudinal layers, $40 \times 1 \times 1\ \mathrm{cm}^3$ long bars
      - 2 readout channels for a $40 \times 1 \times 1\ \mathrm{cm}^3$ crystal bar
    - A factor of 20 less in terms of #channels -> (Roughly) a factor of 20 increase of occupancy
    - Need to cover (on the order of) 10 GeV energy deposition in a single crystal
    - Trigger threshold: 0.15 MeV (1.5% of MIP) -> Energy Dynamic range: 60000 -> 16 bit ADC
    - Rough estimate on timing resolution: ~100ps; bunch spacing: 680ns at Higgs -> 12 bit TDC
    - Reserve 4-bit for channel/module ID and redundancy

DAQ for crystal ECAL: considerations (2)

- Based on the CDR values: scaling exercise
- 2 Major scaling factors
  - #channels: generally crystal ECAL will have much less channel count (higher occupancy)
  - #bit per channel: higher precision to cover a large dynamic range
- Considerations
  - Design 1: detector layout with short crystal bars
    - e.g. 10 longitudinal layers, $2{\times}2\ \mathrm{cm}^2$ transverse size (Note: the granularity not finalised)
      - 1 readout channel for a $2{\times}2{\times}2\mathrm{cm}^3$ crystal cube
    - A factor of 8 less in terms of #channels -> (Roughly) a factor of 8 increase of occupancy
    - Need to cover (on the order of) 20 GeV energy deposition in a single crystal (from simulation)
    - Trigger threshold: 0.3 MeV (1.5% of MIP) -> Energy Dynamic range: 60000 -> 16 bit ADC
    - Rough estimate on timing resolution: ~100ps; bunch spacing: 680ns at Higgs -> 12 bit TDC
    - Reserve 4-bit for channel/module ID and redundancy

DAQ for crystal ECAL: considerations

ECAL options	#Channels [Million]	Occupancy [%]	#bit per channel	#readout channels/evt	Data Volume per event	Data rate at 100kHz
Crystal ECAL with long bars (Barrel)	0.85	3.4	32	28.9 k	116 kByte	11.6 GBytes/s
Crystal ECAL with long bars (Endcap)	0.36	6.2	32	22.4 k	90 kByte	9.0 Gbytes/s
Crystal ECAL with short bars (Barrel)	2.13	1.36	32	28.9 k	116 kByte	11.6 GBytes/s
Crystal ECAL with short bars (Barrel)	0.913	2.48	32	22.4 k	90 kByte	9.0 Gbytes/s

- #channels is reduced in crystal ECAL, but occupancy gets increased.
- If the occupancy scales up linearly with reducing #channels (to be verified), the data rate remains unchanged
- Another open issue: how much data volume required for high-bandwidth waveform sampling for better timing resolution

Considerations and estimates for HCAL DAQ

CEPC CDR: DAQ for HCAL

- Maximum event rate: 100 kHz
  - Peak event rate: ~32kHz at Z-pole
  - Safety margin: a factor of ~3
  - 10 μs time window for readout
- HCAL: 2 options in CDR
  - Scintillator HCAL: $30\times30\ \mathrm{mm}^2$ scintillator tiles
  - SDHCAL: $10\times10\ \mathrm{mm}^2$ RPC pads
  - Longitudinal depth: 40 layers (~4.7λ)

ECAL options	#Channels [Million]	Occupancy [%]	#bit per channel	#readout channels/evt	Data Volume per event	Data rate at 100kHz
Scintillator HCAL Barrel	3.6	0.02	32	0.72 k	2.9 kByte	0.3 GBytes/s
Scintillator HCAL Endcap	3.1	0.12	32	3.72 k	15 kByte	1.5 Gbytes/s
RPC HCAL Barrel	32	0.004	8	1.28 k	1.28 kByte	0.13 GBytes/s
RPC HCAL Endcap	32	0.01	8	3.2 k	3.2 kByte	0.32 Gbytes/s

HCAL updates after CEPC CDR

- Based on the CDR values: scaling exercises
- One major scaling factor for scintillator-HCAL (AHCAL)
  - #channels: generally scintillator HCAL will have less channel count
    - Scintillator tiles: $30 \times 30\ \mathrm{mm}^2$ -> $40 \times 40\ \mathrm{mm}^2$ (a factor of ~1.8)
    - #channels is reduced in HCAL, but occupancy would get increased.
    - If the occupancy scales up linearly with reducing #channels (to be verified), the data rate remains unchanged
- DAQ for SDHCAL remains the same as CDR
- Other considerations on the SDHCAL
  - Currently R&D efforts ongoing on high-precision timing capability for SDHCAL
    - Timing resolution on the order of 10 ps would require higher **#bit/channel**
    - Remains to be estimated, based on the detailed technical design

CEPC CDR: estimates of DAQ for HCAL

- Maximum event rate: 100 kHz
  - Peak event rate: ~32kHz at Z-pole
  - Safety margin: a factor of ~3
  - 10 μs time window for readout
- HCAL: 2 options in CDR
  - Scintillator HCAL: $40 \times 40\ \mathrm{mm}^2$ scintillator tiles
  - SDHCAL: $10 \times 10\ \mathrm{mm}^2$ RPC pads
  - Longitudinal depth: 40 layers ($\sim 4.7\lambda$)

HCAL options	#Channels [Million]	Occupancy [%]	#bit per channel	#readout channels/evt	Data Volume per event	Data rate at 100kHz
Scintillator HCAL Barrel	2.0	0.036	32	0.72 k	2.9 kByte	0.3 GBytes/s
Scintillator HCAL Endcap	1.7	0.216	32	3.72 k	15 kByte	1.5 Gbytes/s
RPC HCAL Barrel	32	0.004	8	1.28 k	1.28 kByte	0.13 GBytes/s
RPC HCAL Endcap	32	0.01	8	3.2 k	3.2 kByte	0.32 Gbytes/s

Summary

- New developments in calorimetry after CDR
  - Crystal calorimeter: evolving design, currently focused on performance studies
  - Granularity optimized for Scintillator-Steel Hadron Calorimeter
  - High-precision timing proposed for further calorimetry R&D

- Further studies necessary for DAQ requirements, considering
  - Updates from Z-pole running
  - Occupancy (vs. granularity) estimates
  - Electronics requirements for crystal readout
  - Data volume required by high-precision timing information
  - …