CEPC Crystal Calorimeter
Status and Prospective

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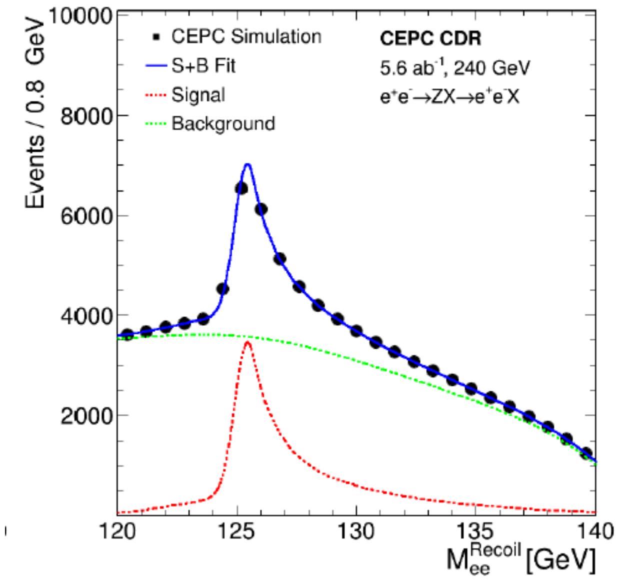
Aug. 16, 2019

CEPC Day at IHEP, Beijing

Overview: motivations

- Why crystal calorimeter?
  - Homogeneous structure
    - (Mostly) all material sensitive to particles
  - Provide optimal energy resolution
  - Fine segmentation
    - Potentials in PFA for precision measurements of jets
  - Energy recovery of electrons: to improve Higgs recoil mass
    - Corrections to the Bremsstrahlung of electrons

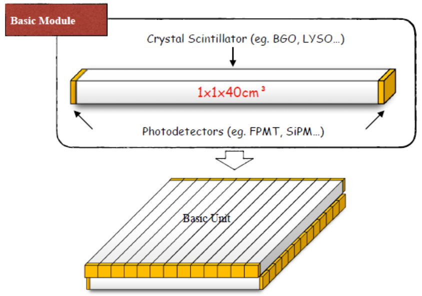


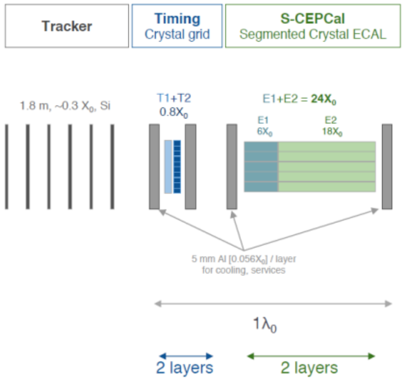
(b)

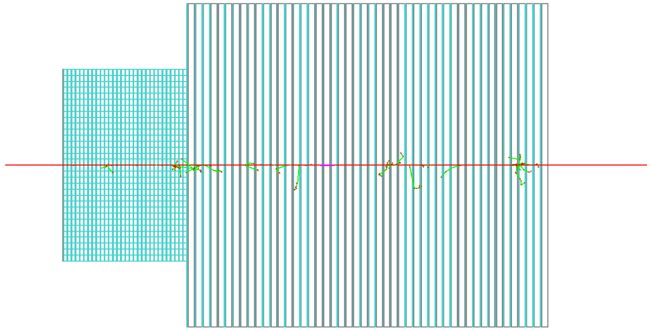
- CEPC crystal ECAL status
  - Proposed first in the CEPC Calorimetry Workshop in March 2019
  - Followed in the CEPC Oxford Workshop in April 2019

Overview: designs of crystal ECAL

- 3 major designs being pursued
  - Long crystal bars with optical readout at both ends (Y. Wang, et al.)
    - Use timing information for hit positions; less #channels
  - Long crystal bars with optical readout at single ends (C. Tully, et al.)
    - Less segmentation in the longitudinal direction; space for cooling
  - Thin crystal tiles with optical readout at single ends (Y. Liu, et al.)
    - Started with ultra-fine segmentation (both longitudinal and transverse)
    - Seeking trade-off between #channels and performance



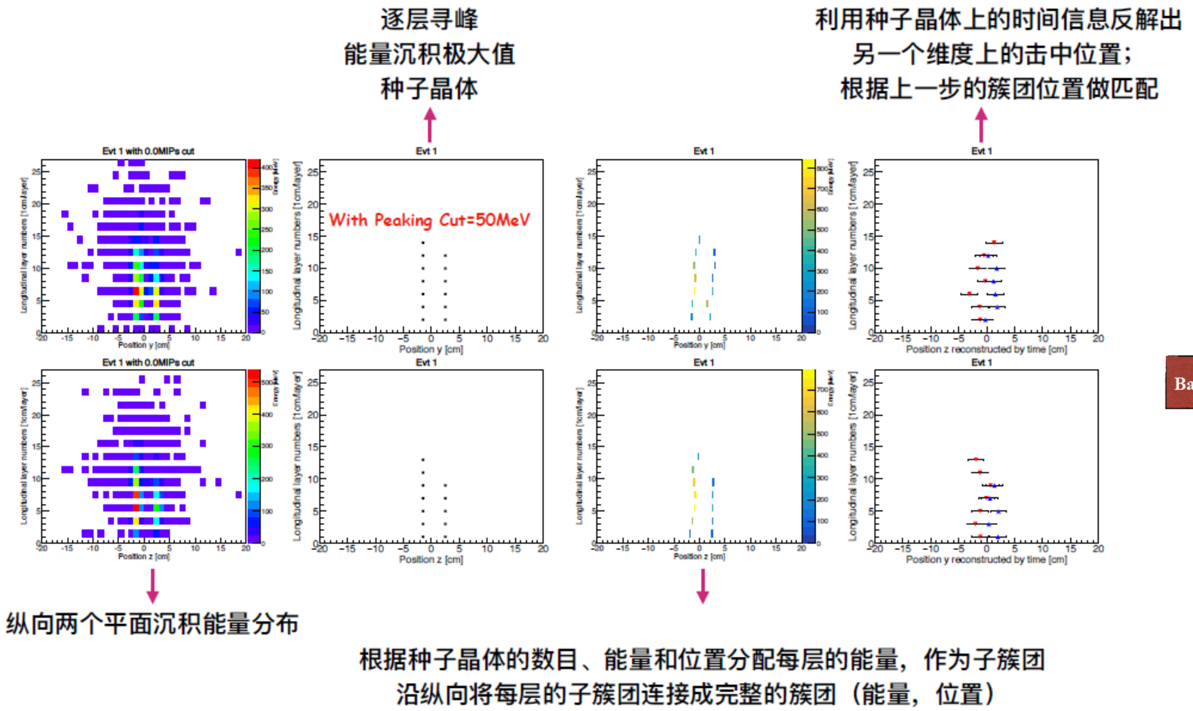




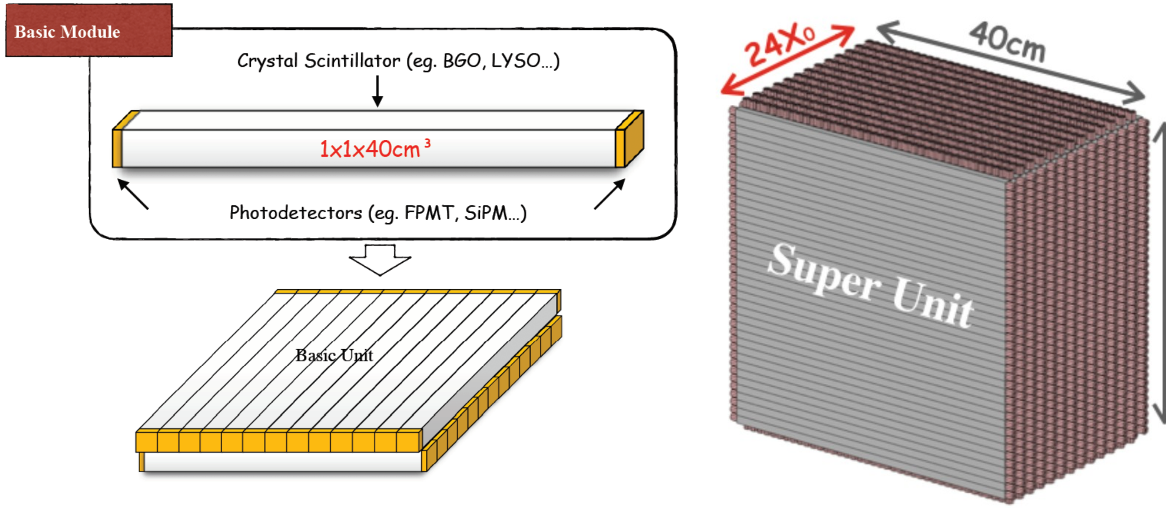
ECAL with crystal bars

Yuexin Wang (IHEP)

Idea on Reconstruction of di-photon event



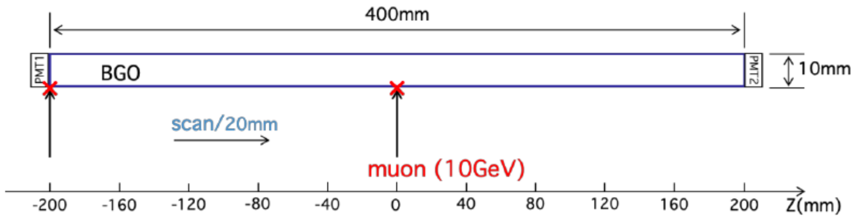
- Find the seed (max. energy in crystal)
- Reconstruct the hit positions based on the timing information
- Connections of sub-clusters into a complete shower



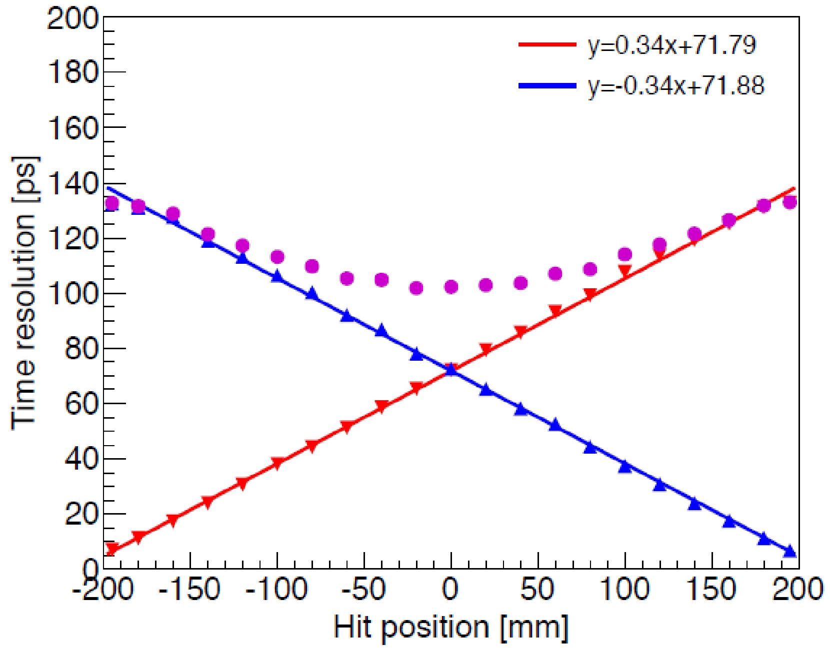
ECAL with crystal bars

Yuexin Wang (IHEP)

- Geant4 full simulation with a single long bar
  - Implemented realistic optical properties: detailed simulation of optical photons
  - Time stamps and #photons at both 2 PMTs for muons
  - Extract timing resolutions at different hitting positions



Parameter	Value
发光光谱峰位能量 Photon Energy	2.59eV (480nm)
发光光谱半峰宽 Photon Energy Width	0.6987eV (420-550nm)
快成分时间常数 FastTime Constant	60ns
慢成分时间常数 SlowTime Constant	300ns
光衰减长度 Absorption Length	7-15m
光产额 Scintillation Yeild	9000-10000/MeV
折射率 Refractive Index	2.15

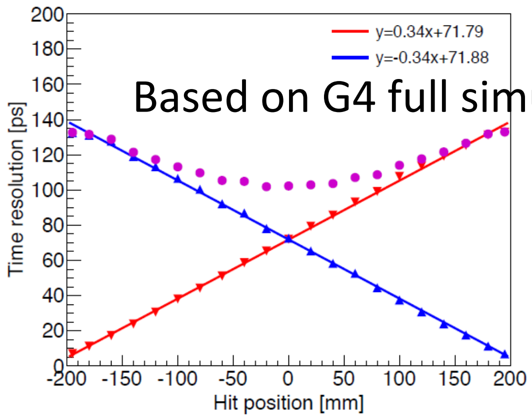


Separation power: di-photons showers

Simplified Digitization

$\sigma_t = \sigma_{intrinsic} \oplus \sigma_{PMT} \oplus \sigma_{electronics} \oplus \sigma_{time\text{-}walk}$

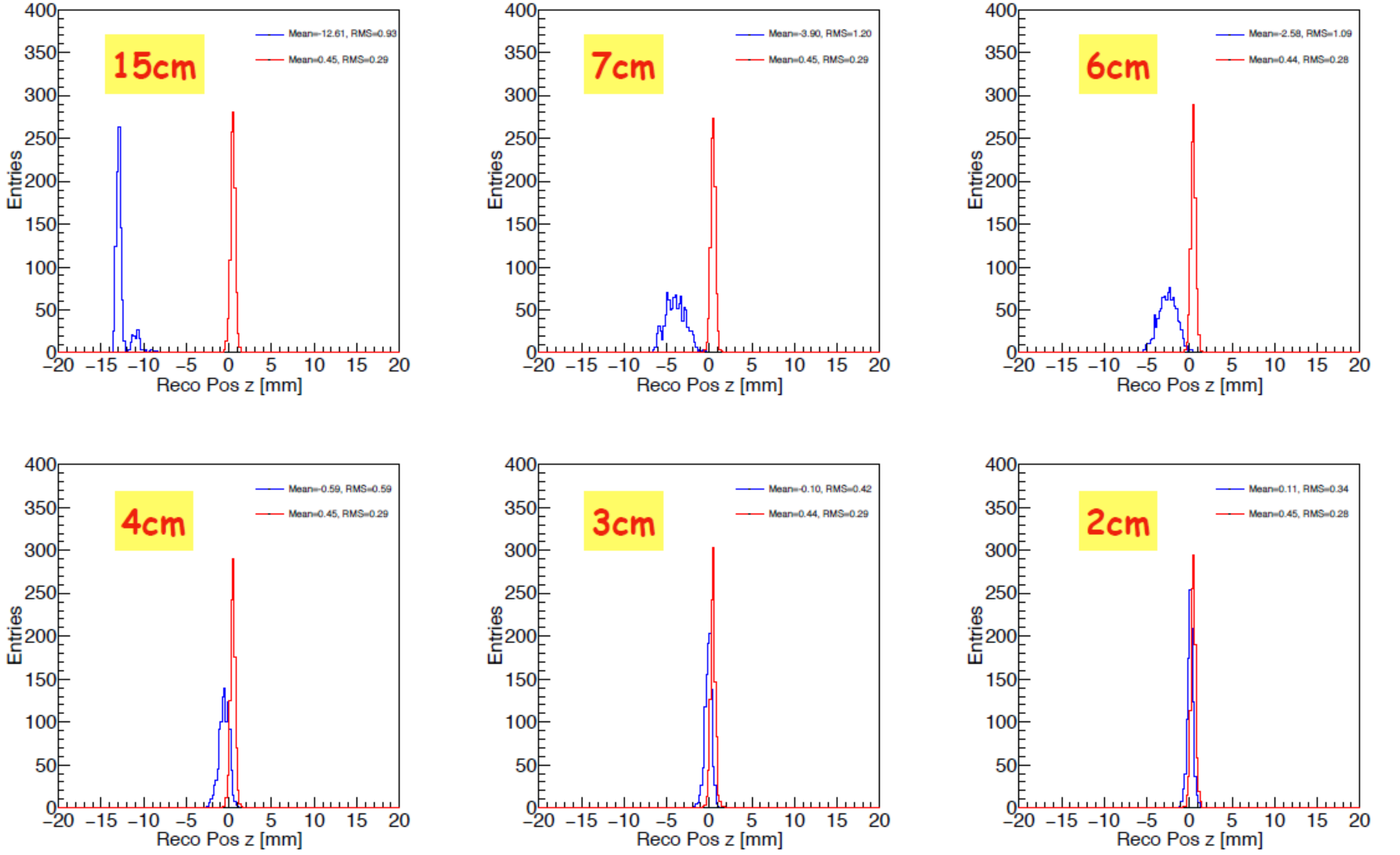
σ_{PMT}: 30ps; $\sigma_{electronics}$: 20ps; $\sigma_{time\text{-}walk}$: 0ps



Based on G4 full simulation

5GeV diphoton

145ps



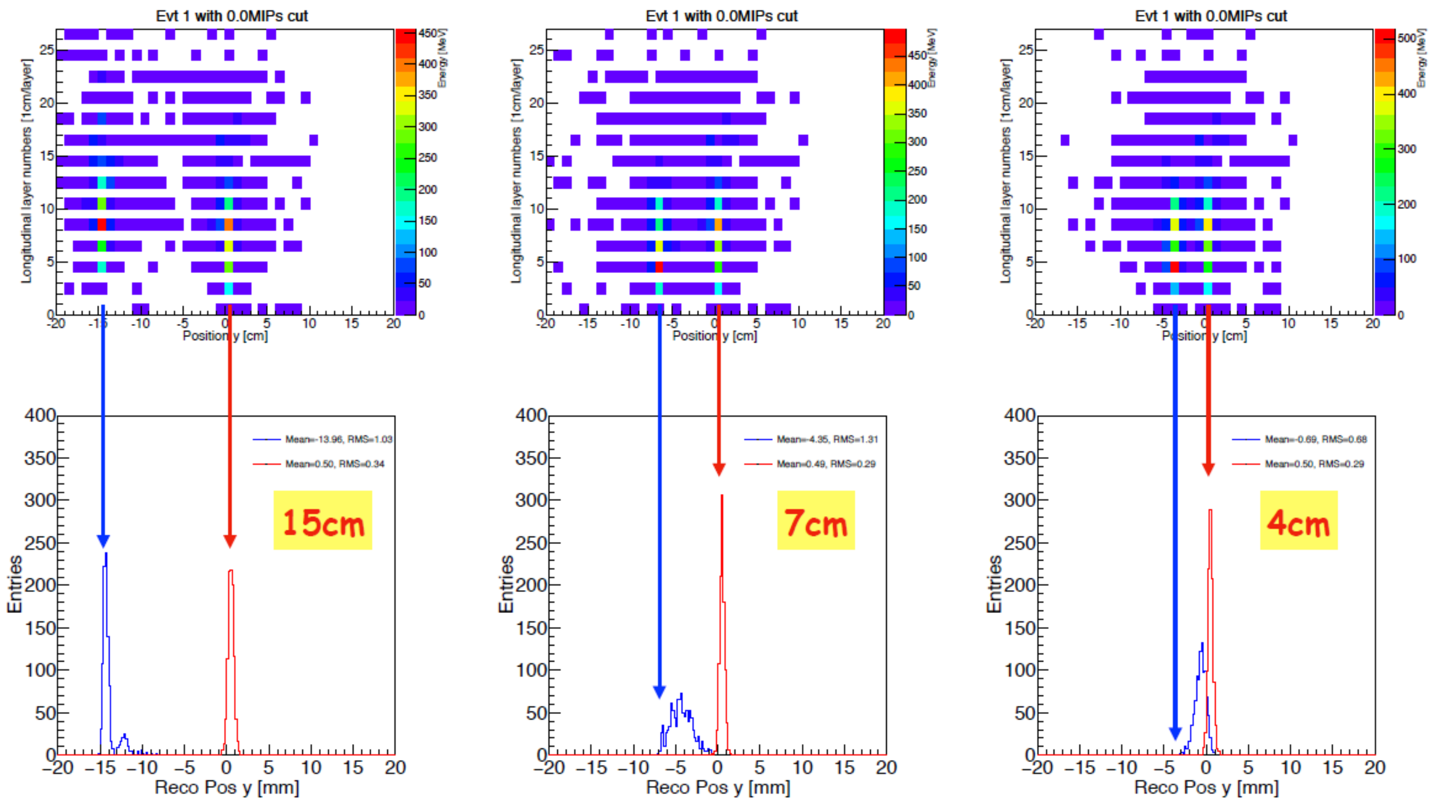
- Can separate 5GeV di-photon showers when distance >= 4cm with ~145 ps resolution

~145 ps as the conservative estimate for the intrinsic timing resolution

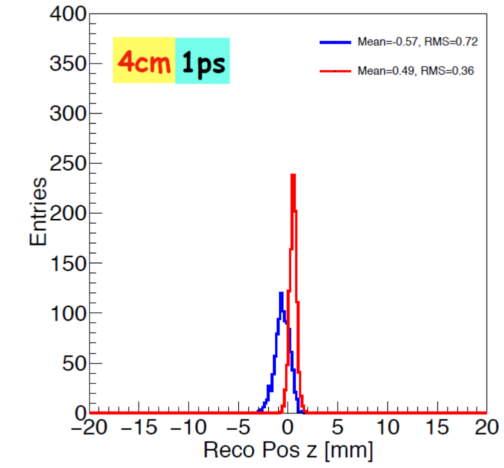
Separation power: di-photons showers

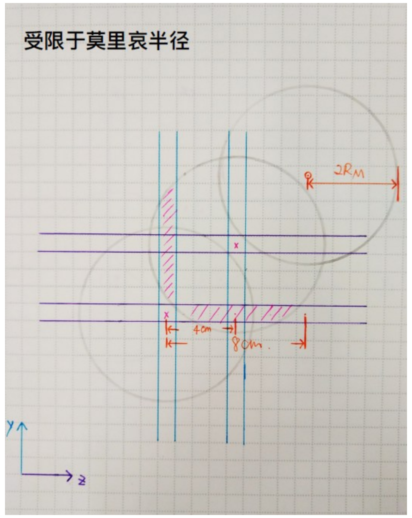
Yuexin Wang (IHEP)

5GeV diphoton



5GeV diphoton



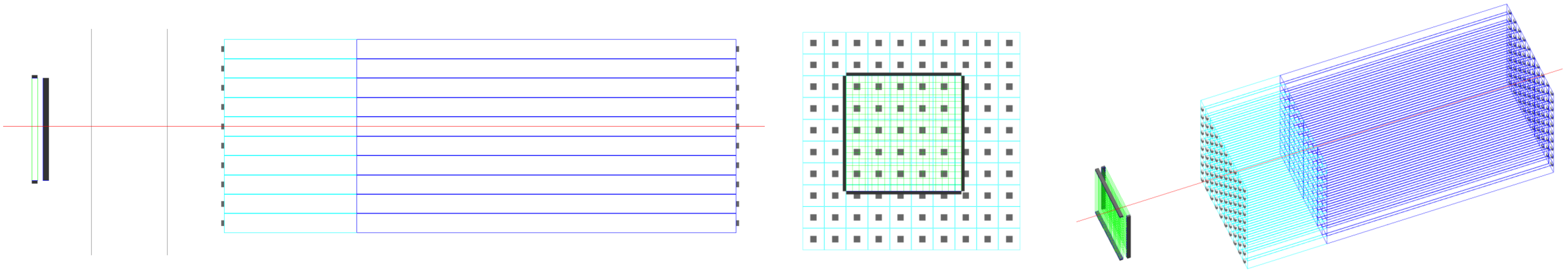


Considerations: majorly limited to Moliere radius

4cm is around $2\rho_M$ of BGO

Crystal ECAL status at US

Christopher Tully (Princeton)



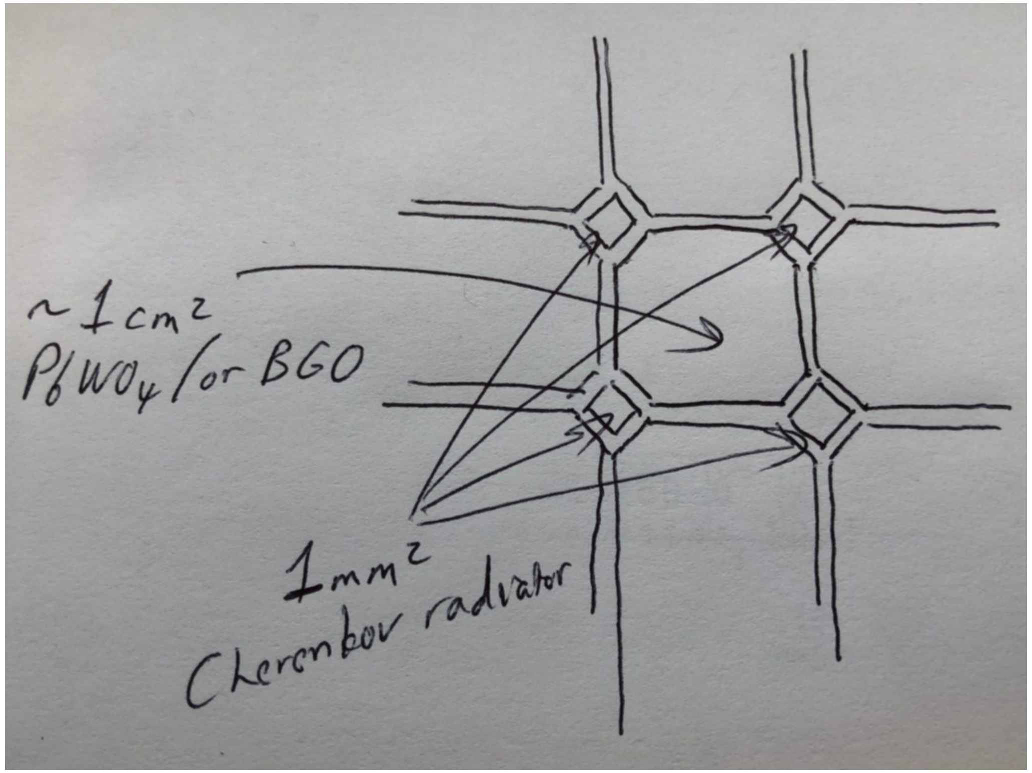
Design and simulation studies at CEPC Oxford Workshop (Apr. 2019)

- Crystal ECAL: new ideas
  - Exploring ways of dual readout in the ECAL (i.e. in the first nuclear interaction length)
    - Proposal sent to DR colleagues
  - Maintain a large fraction of active crystal volume to provide 3%/sqrt(E) for electrons/photons
  - Also provide projective Cherenkov sampling (C)
  - Compare the EM fraction (C) with the total from the crystals (S)

Crystal ECAL status at US

Christopher Tully (Princeton)

- Crystal ECAL: new design for dual readout
  - Crystal (PbWO4or BGO): 1x1cm², chambered, optically isolated
  - 2 pieces of Cherenkov radiator (1mm²): glued on the opposite sides

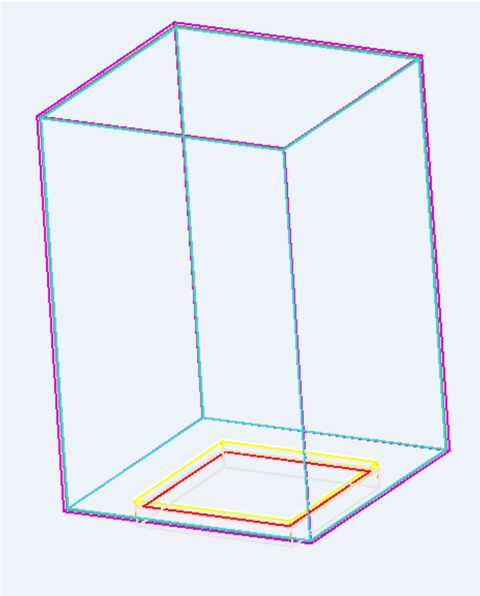


- Plan
  - Introduce a crystal geometry into the PFA simulation software

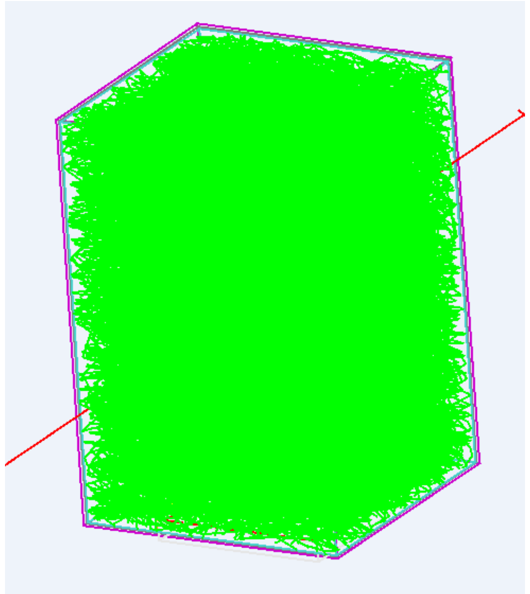
Sketch looking from the interaction point

Full simulation for a crystal bar

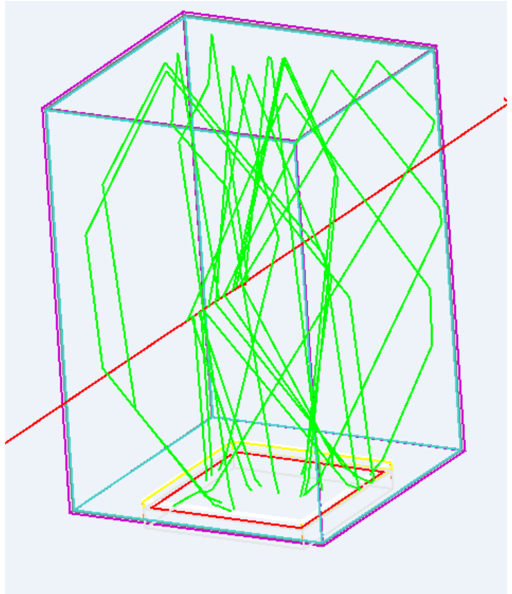
- Established Geant4 full simulation with optical photons
  - A single PbWO crystal bar, directly coupled with a SiPM
  - Able to perform detailed studies: comparison with measurements, <u>fast timing</u>, etc.



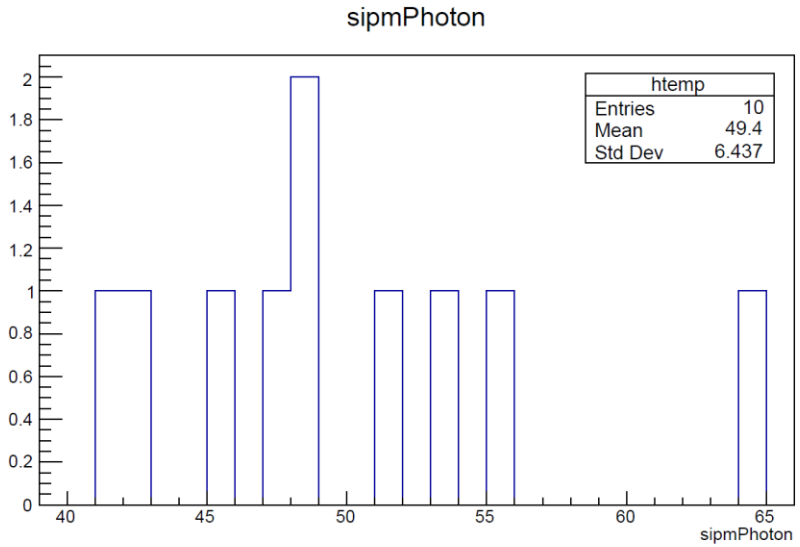
Geometry



All photons produced



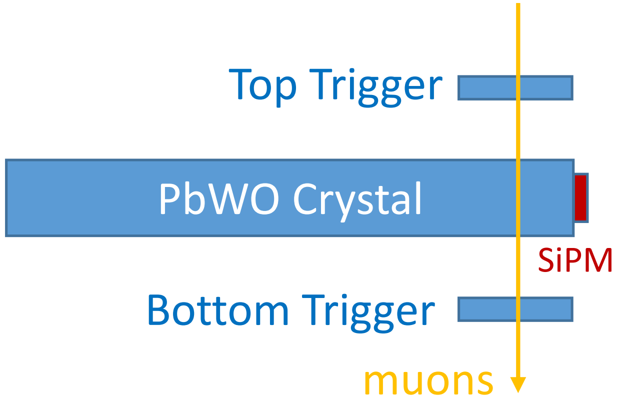
Detected photons

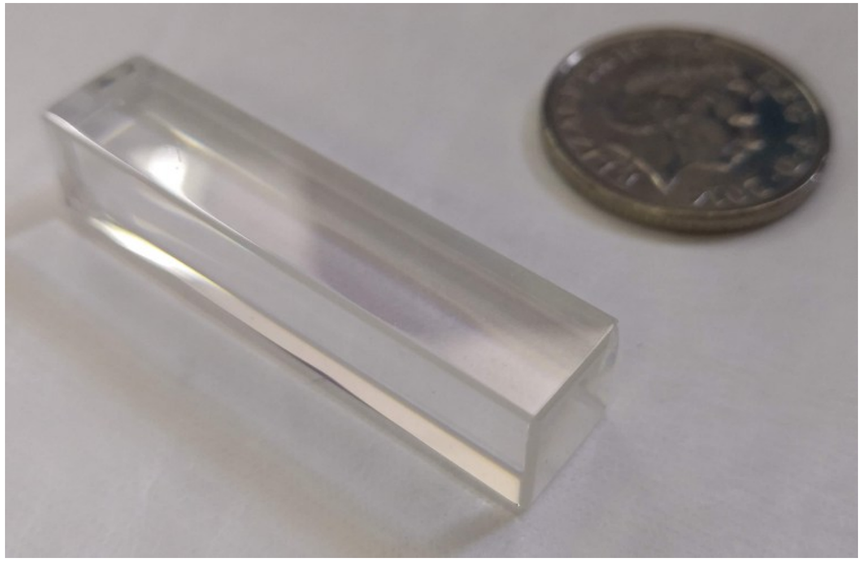


An example: #photons detected at a SiPM ($6x6mm^2$)

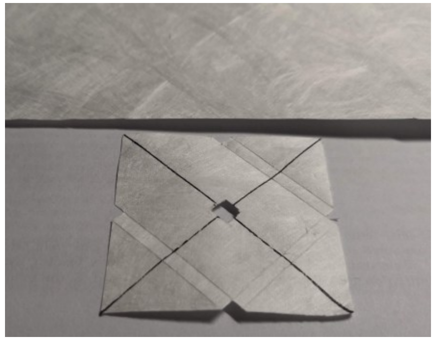
Cosmic ray tests with PbWO crystal

- Tested a PbWO crystal with cosmic muons
  - PbWO crystal from SIC, tested at IHEP
  - Wrapped with Tyvek paper and ESR foil
  - Read out with a 3x3mm² SiPM (from BNU-NDL)

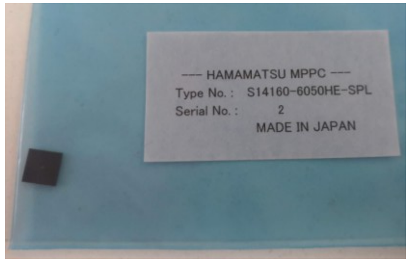




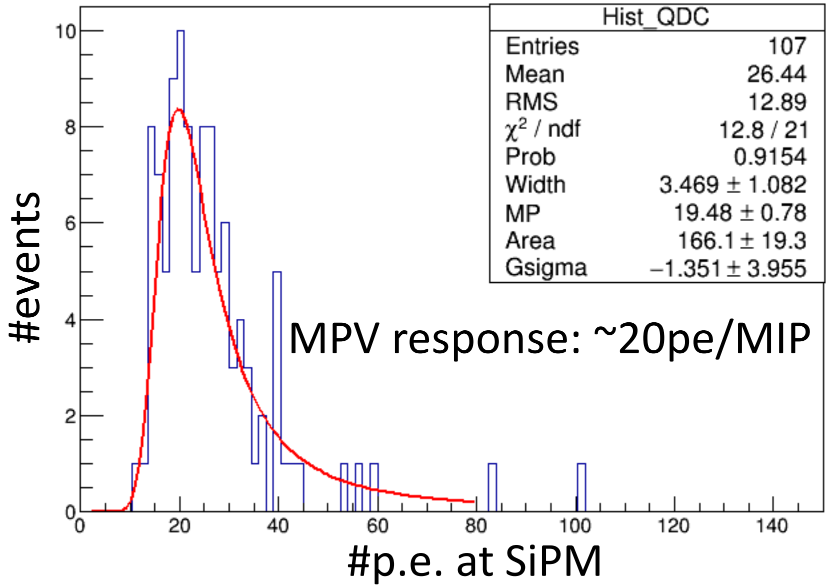
PbWO crystal, 10x10x150 mm³,
by courtesy of Zhigang Wang (IHEP)



Example of pre-cut Tyvek paper



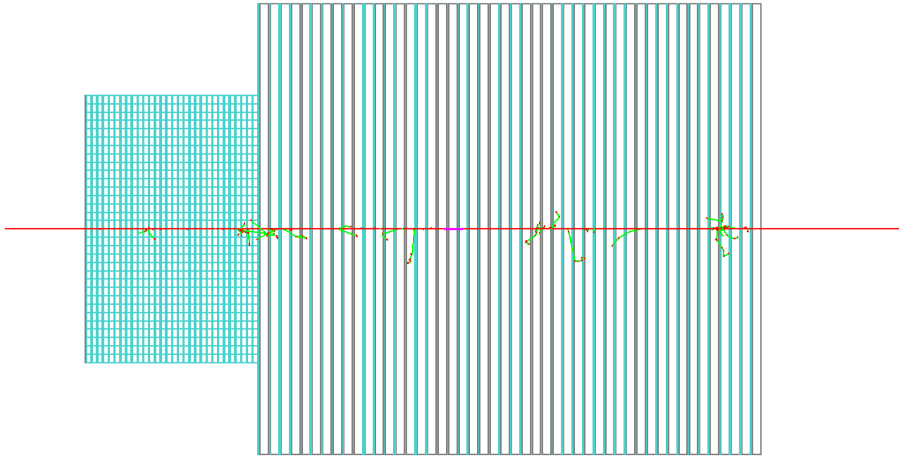
6x6mm² SiPM planned, but TSV-point broken after soldering...



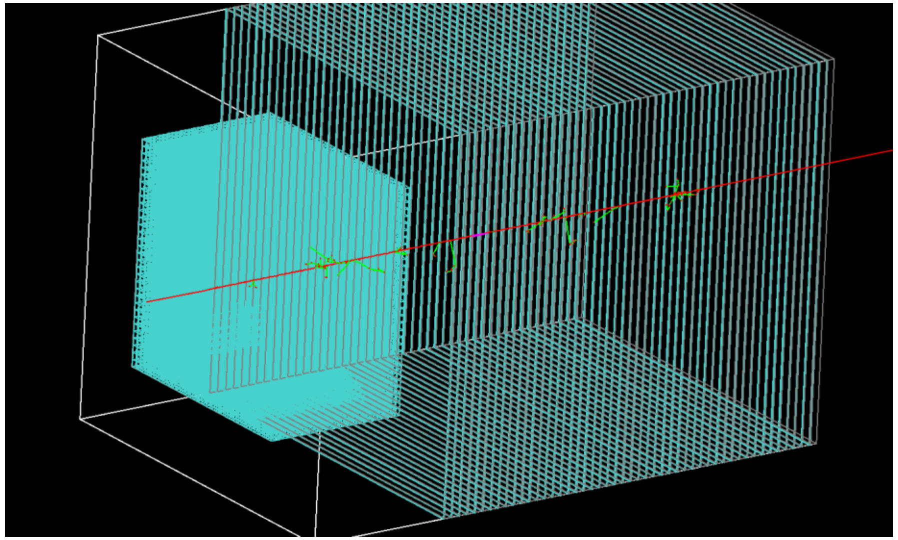
Simulation for ECAL+HCAL

Geant4 version 10.5.0

- Combined setup ECAL+HCAL
  - Established stand-alone Geant4 simulation (no optical photons at this large scale)
  - Crystal ECAL: 30 layers (30X0)
    - BGO/PbWO crystal tiles, 1X0 thick
    - Transverse granularity: 20mm (~Moliere radius)
  - HCAL: scintillator + steel plates
    - 48 layers in total
    - Plastic scintillator: 3mm thick, 30x30mm^2
    - Steel: 20 mm
- Digitization in simulation: crucial
  - For scintillator: crystal (ECAL), plastic (HCAL)
  - Energy depositions (hits) → scintillation photons → SiPM pixels → ADC signals in electronics



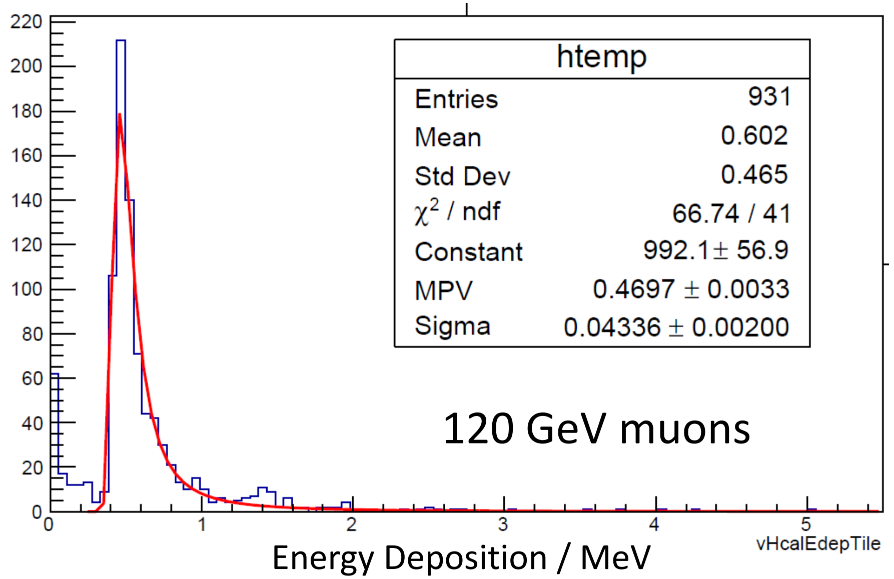
Calibration runs: 120 GeV mu-



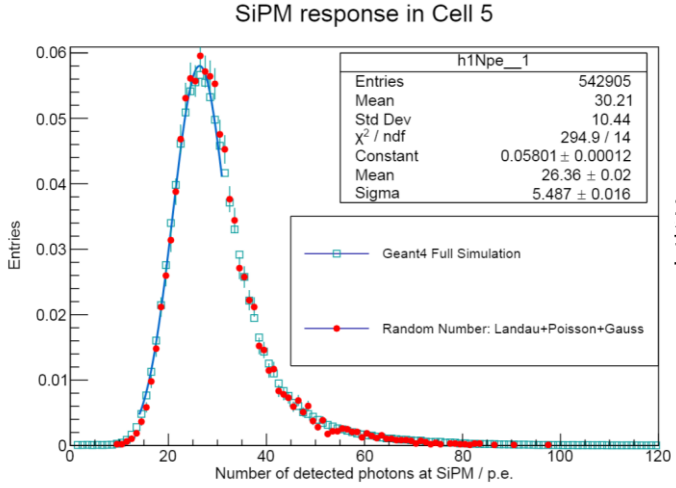
Digitization in a nutshell

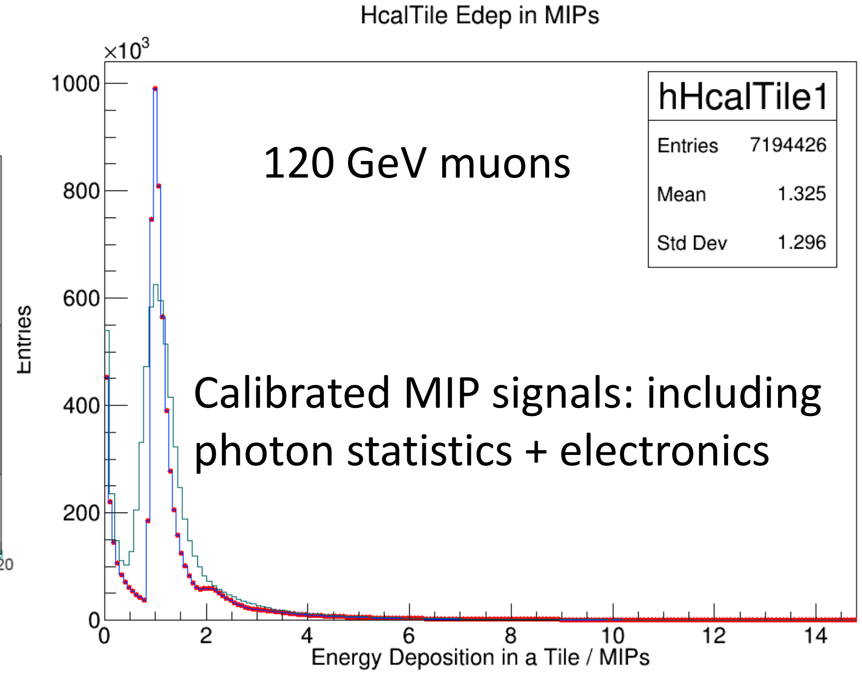
Geant4 version 10.5.0

Energy Deposition in a scintillator



Digitizer can reproduce G4 full simulation with optical photons



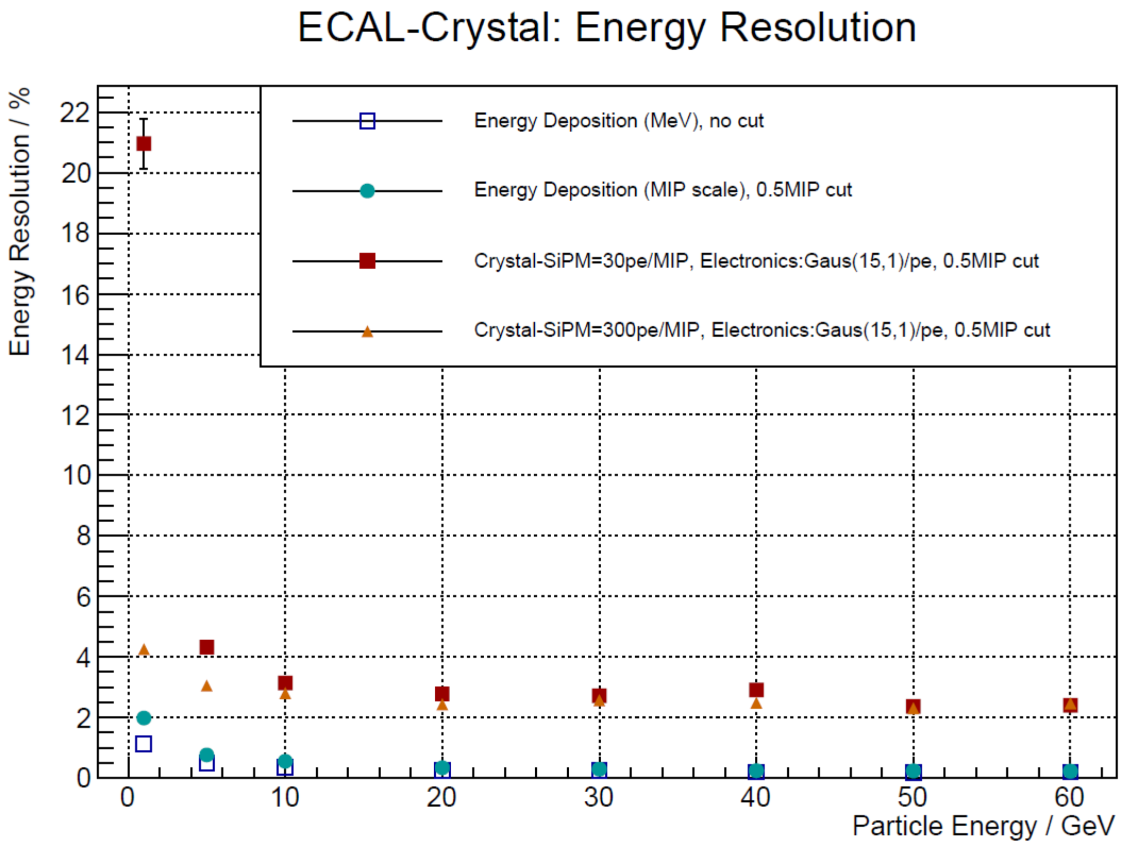


- Geant4 hit (energy deposition) → ADC signal in electronics (charge)
- Extra effects that degrades resolution
  - Photon statistics: #photons/MIP
  - Electronics resolution: #ADCs/photon

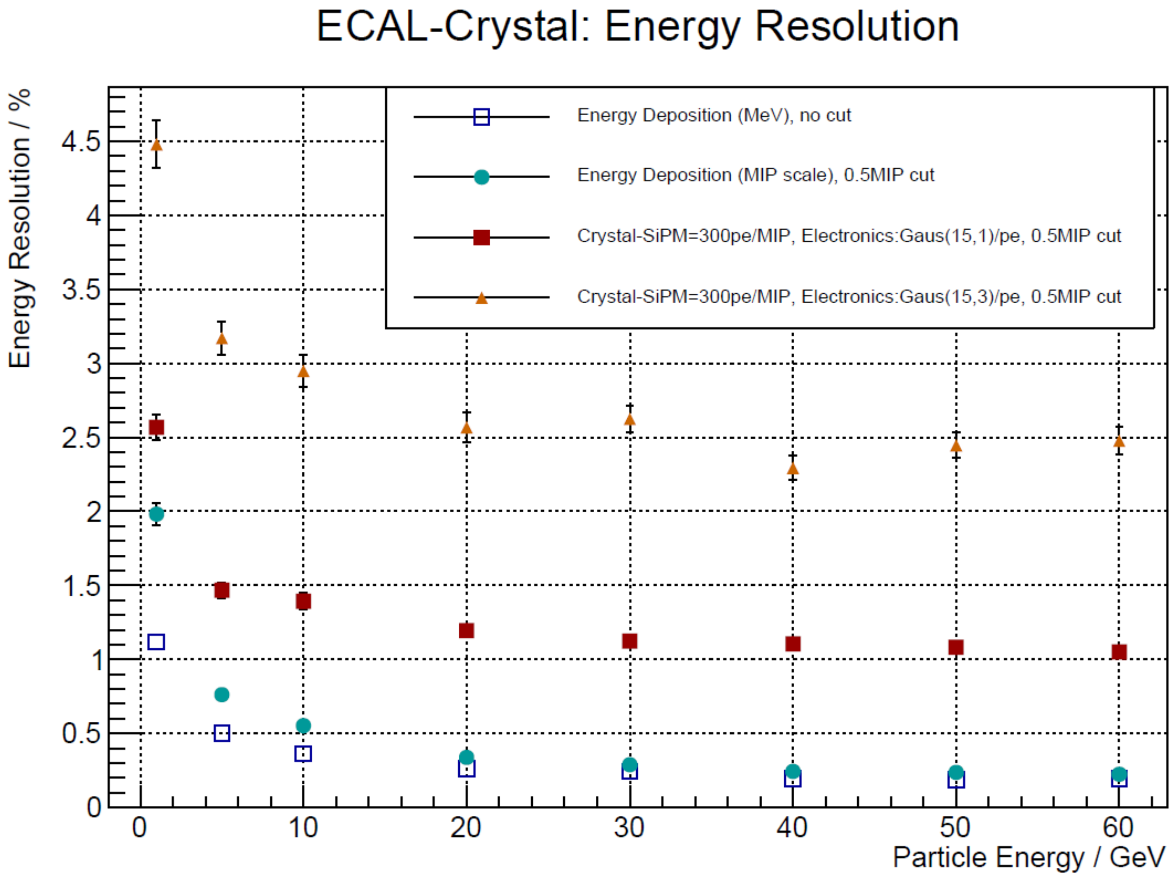
Digitization: impacts to energy resolution

Geant4 version 10.5.0

MC samples: electrons



Impact from photon statistics:
30 p.e./MIP vs 300 p.e./MIP



Impact from electronics resolution for single photons:
Sigma of SiPM gain ~7%/p.e. vs <u>20%/p.e.</u>

Plans

- Study the hadronic shower profiles in crystal ECAL
  - MC samples ready
- Probe the potentials of precision timing for shower separation and PID
- Further crystal studies: measurements and G4 full simulation
  - Performance with the BGO crystals
  - Validate the G4 full simulation
  - Improve the digitizer for crystals