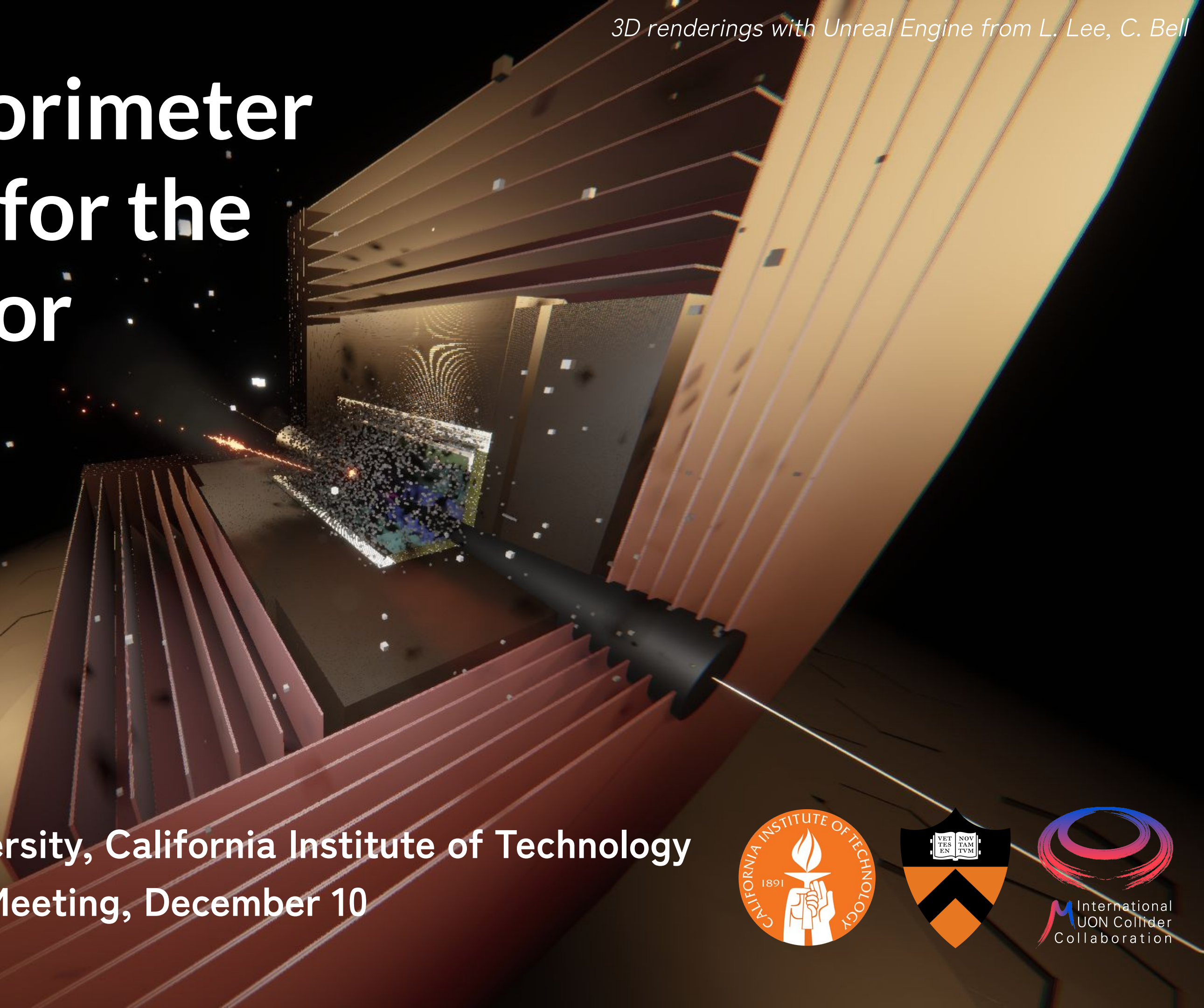
Hadronic Calorimeter Performance for the MAIA Detector



3D renderings with Unreal Engine from L. Lee, C. Bell

Elise Sledge, Princeton University, California Institute of Technology

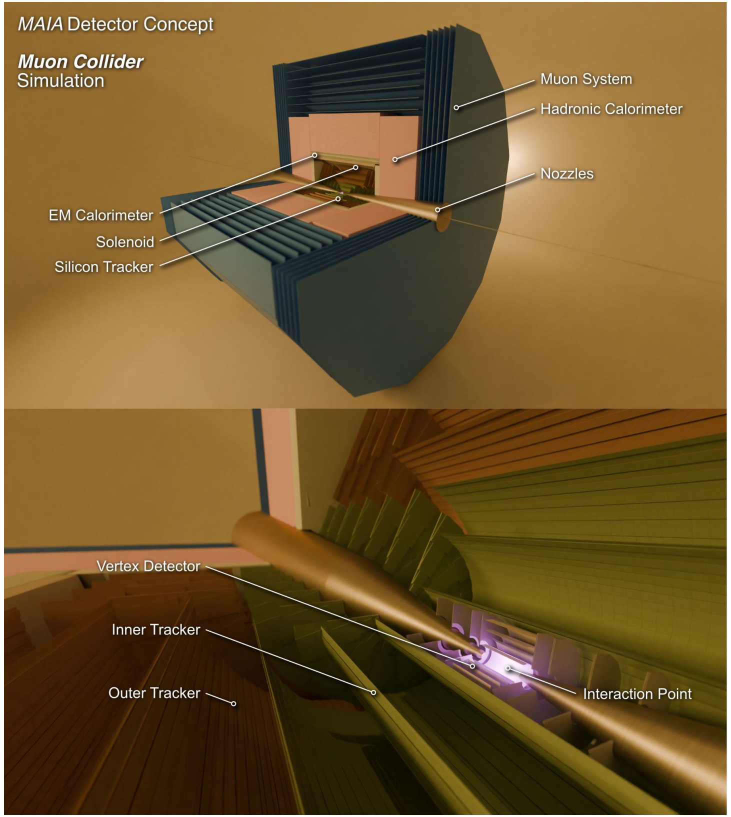
IMCC Physics and Detector Meeting, December 10

International MUON Collider Collaboration

Introduction

On November 12th, Ben Rosser presented *The MAIA Detector for a 10 TeV Muon Collider* outlining recent work on the MAIA (Muon Accelerator Integrated Apparatus) detector for a 10 TeV collider

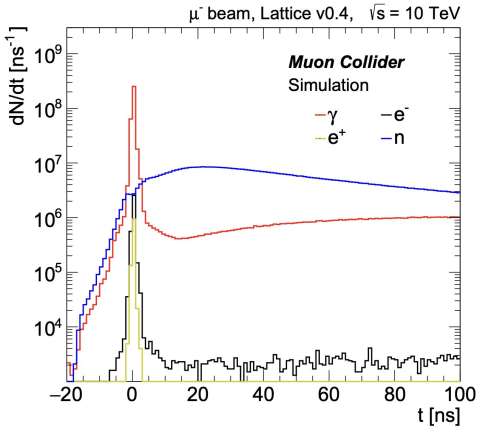
- Some reminders from this presentation:
  - MAIA extends previous detector studies adapted from CLIC at 1.5 and 3 TeV
  - Moving away from CLIC, MAIA moved the solenoid inside of the calorimeters to mitigate BIB effects (ECAL especially)
    - The B-field strength increased from **3.57** to **5** T
- However, the hadronic calorimeter performance for neutrons was not yet ready, so I will present these results today



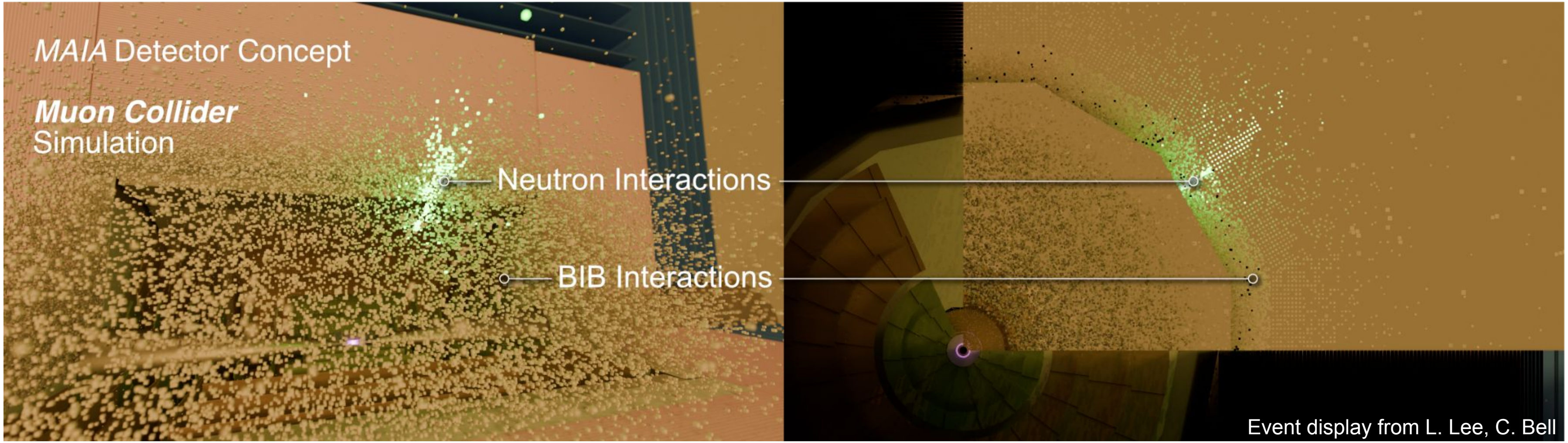
BIB mitigation and the HCAL

- Beam-induced-background (BIB) mitigation
  - Two cone shaped borated polyethylene (BCH2) coated tungsten nozzles
- BIB properties
  - BIB particles are characterized by their large number, low momentum, and their timing offset with respect to bunch crossings
    - Necessitates an HCAL with good timing and energy resolution (5D Calorimetry)
- MAIA's HCAL
  - Similar to the ATLAS TileCal
  - 75 layers compared to CLIC's 50

	Hadron Calorimeter
Cell type	Iron - Scintillator
Cell Size	30.0 mm × 30.0 mm
Sensor Thickness	3.0 mm
Absorber Thickness	20.0 mm
Number of layers	75



Neutrons and beam-induced-background



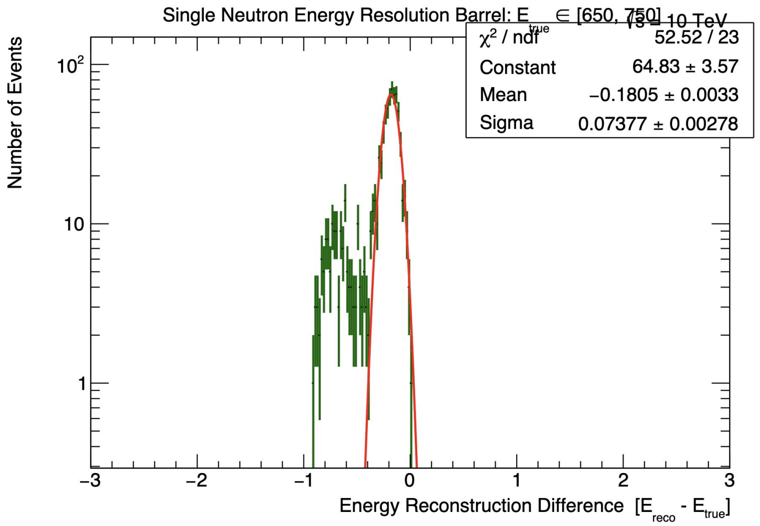
- Green: Detector hits from the shower of a 73 GeV neutron
- Orange: Hits from beam-induced-background (BIB) overlay
  - BIB particles are espcially difficult to separate in the HCAL compared to the ECAL
- Calorimetry goals:
  - 35%/√E energy resolution
  - 100 ps timing resolution

Particle and BIB simulation

- Neutrons were simulated with the with Key4hep in the iLCSoft framework and BIB samples where produced and overlaid with FLUKA
- Neutron generation parameters
  - Generated in 3 Energy batches (0-50 GeV), (50-250 GeV), and (250-1000 GeV) with flat distributions in E
    - As well as flat distributions in $0 < \phi < 2\pi$ and $0 < \theta < \pi$
- Neutron reconstruction was completed using Pandora particle flow creating particle flow objects (PFOs)
  - For samples without the BIB overlay, anti-k_T and cone clustering methods were tested, but Pandora has worked best once the BIB overlay is introduced

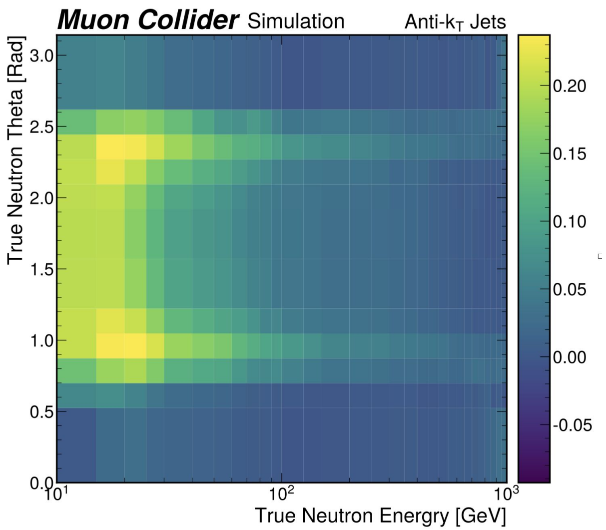
PFO matching and selection

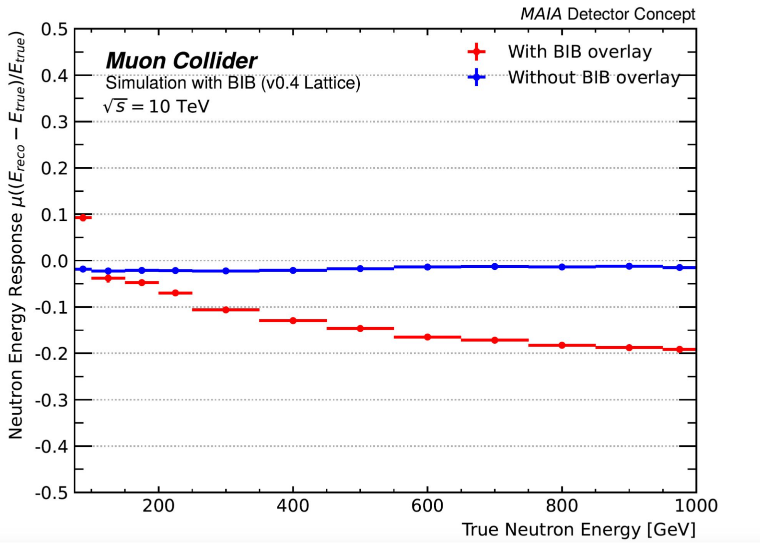
- Candidate neutron PFOs were matched with an incident neutron
  - The single matched PFO neutron has the highest p_T and is closest to the generator neutron in ΔR
    - A maximum $\Delta R < 0.2$ cutoff was applied
  - Require PFO energy > 60 GeV
    - PFOs < 60 GeV cannot be discerned from BIB currently



Neutron energy response

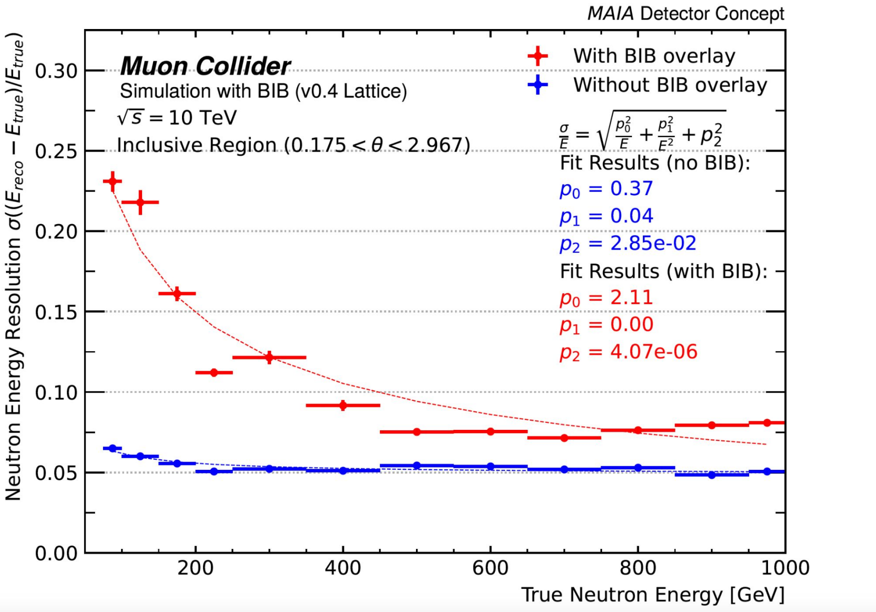
- As Ben mentioned previously, the ECAL is calibrated using **response function** where the response in a theta, energy bin is used to correct the reconstructed energy
  - This was completed without BIB for the HCAL using anti-k_T jets with R = 0.4
  - However, this calibration no longer is accurate for Pandora PFOs
    - For the HCAL, a **response function** is not currently being applied

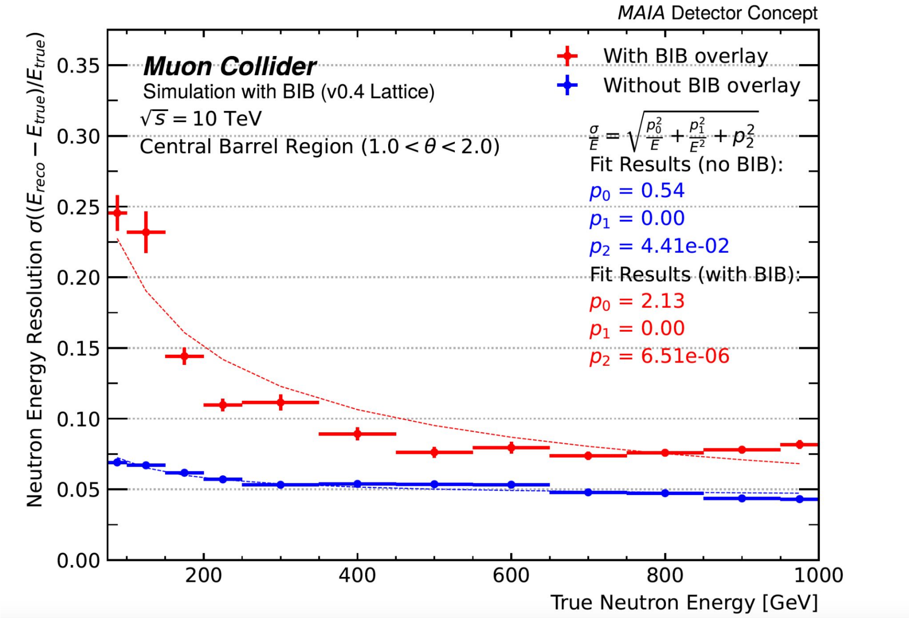




Neutron energy resolution

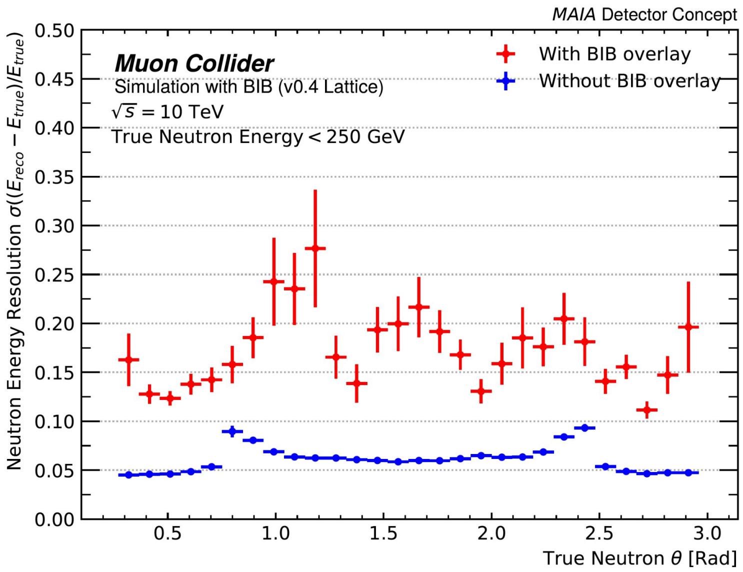
- Neutron energy resolution with and without BIB is within the HCAL performance goals
  - The addition of the BIB overlay moderately degrades energy resolution
    - But, we expect to see improvements with more refined reconstruction methods

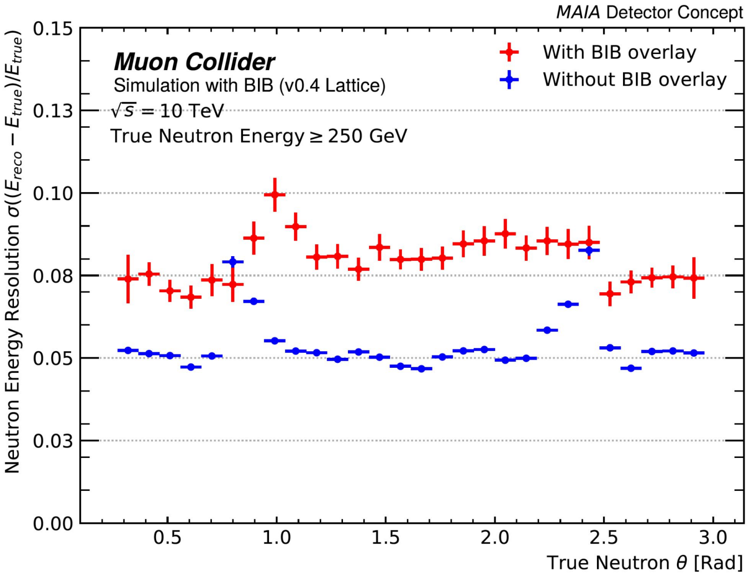




Neutron energy resolution

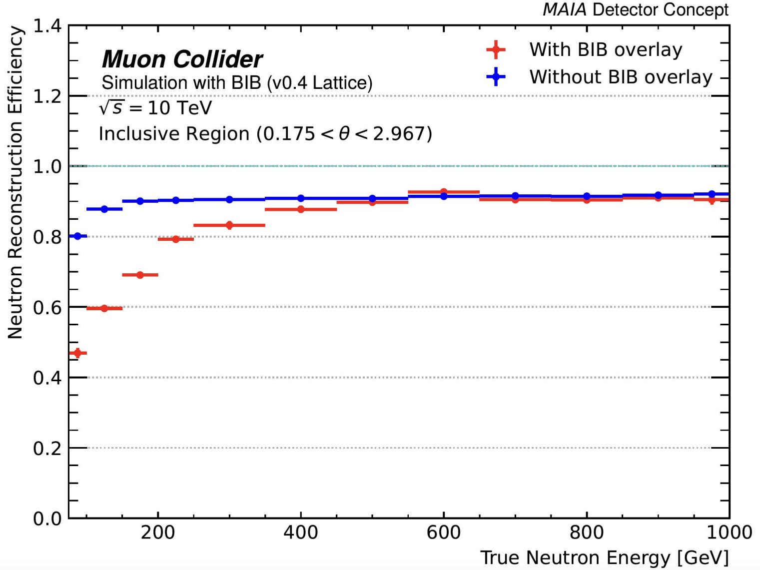
- High energy neutron resolution relatively flat across theta
  - Improvements in BIB statistics needed to characterize the theta distribution profile

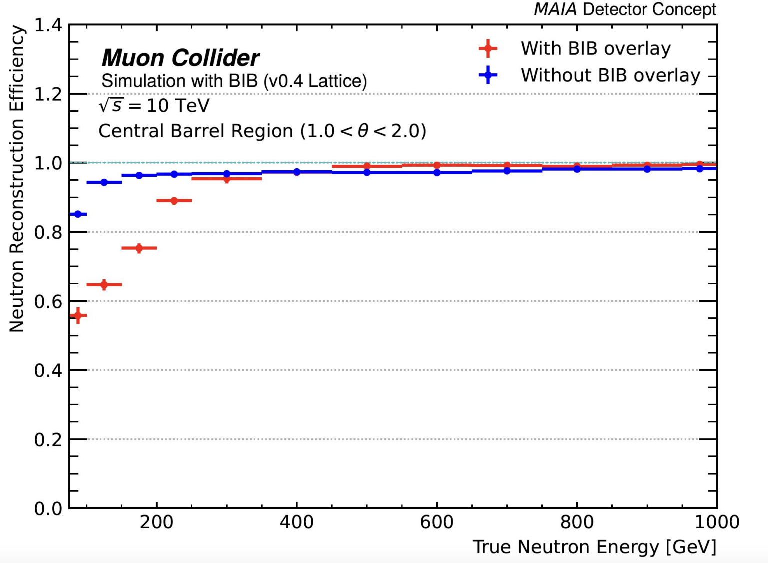




Neutron reconstruction efficiency

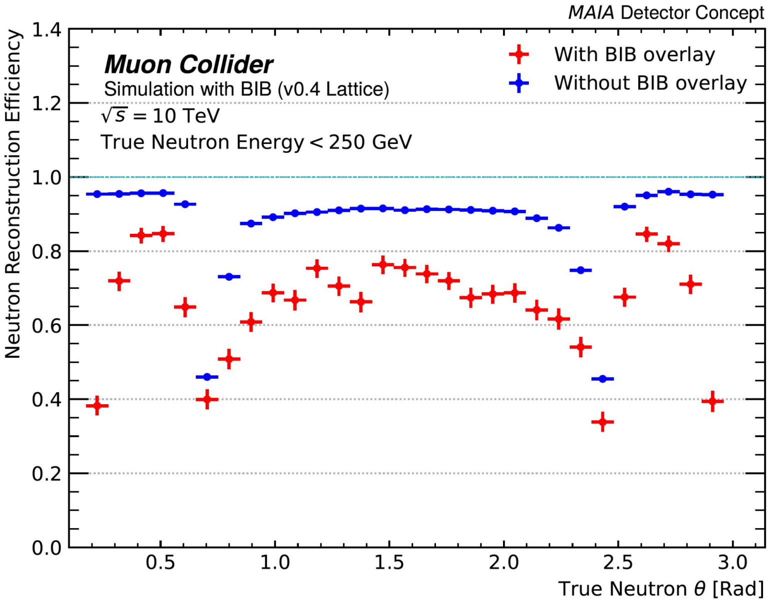
- Low energy (<100 GeV) neutrons with BIB overlay are challenging to reconstruct
- However, high energy efficiencies are good (>90%) especially in the center barrel
  - This is comparable to previous 3 TeV Results

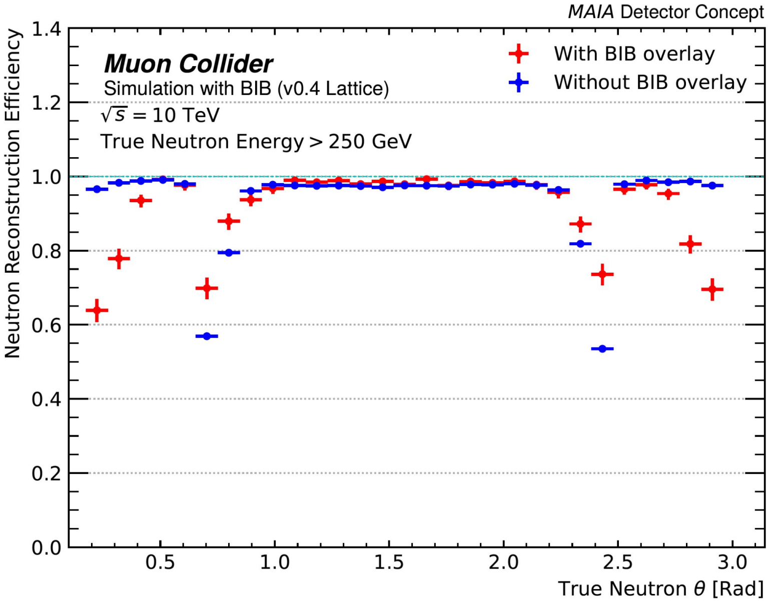




Neutron reconstruction efficiency

- Leading causes of inefficiency are low energy reconstruction, transition region, and endcap near nozzle





Conclusion and future work

Conclusions

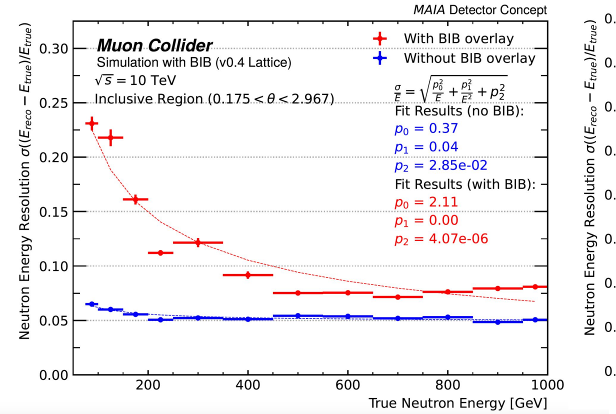
- MAIA's HCAL performs well after the move of the solenoid further into the detector
- The calorimeter meets initial design goals, especially at higher neutron energies
  - Low energy neutrons struggle with PFO reconstruction and are difficult to discern from BIB signals

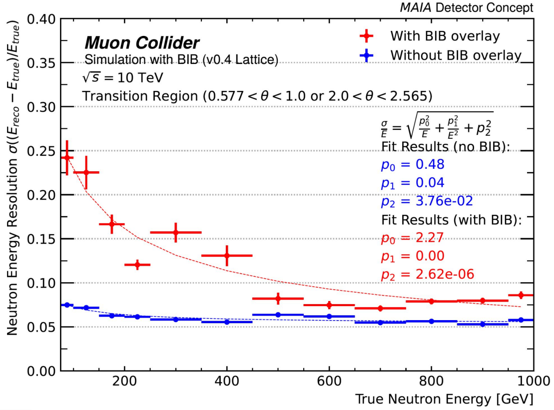
Future work

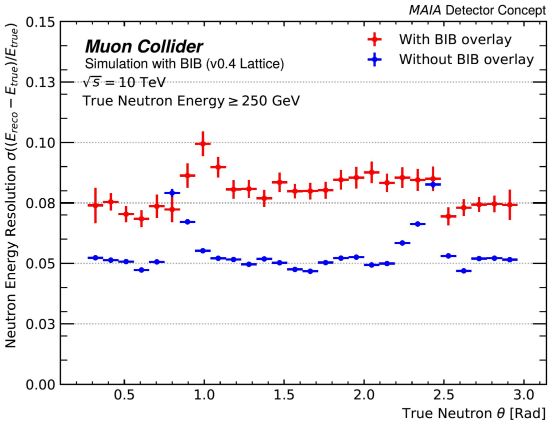
- Ben previously laid out many areas of improvement for MAIA such as muon systems, nozzle geometry, triggering, and more!
- For the HCAL specifically,
  - Increase BIB overlay statistics
  - Adapting Pandora for a muon collider will likely improve neutron energy resolution and reconstruction efficiency
    - Especially for lower energy neutrons. Hopefully PFOs < 60 GeV could be looked at in this case
  - The HCAL could undergo another 2D response calibration using PFOs
    - Also, PFO matching criteria could be improved to capture more of the incident neutron energy
  - Non-physical neutrons being reconstructed by Pandora in the presence of BIB can hopefully be reduced
  - Future BIB mitigation could increase the number of low energy neutrons discernible from BIB signals
  - Performance in the endcap and transition regions also needs to be further investigated

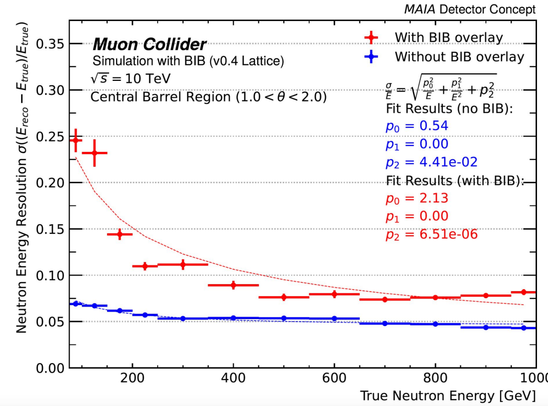
Backup Slides

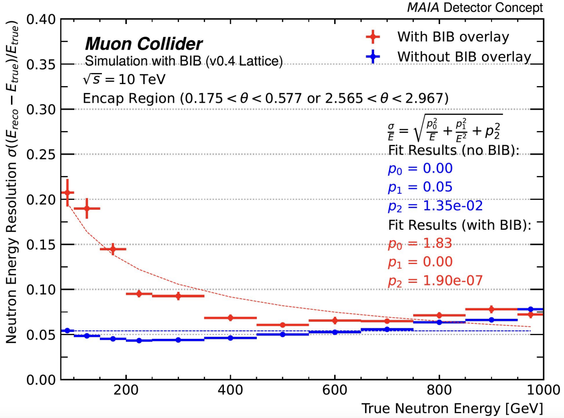
Neutron energy resolution

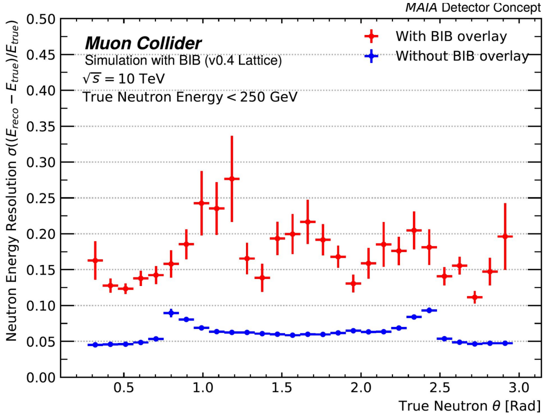




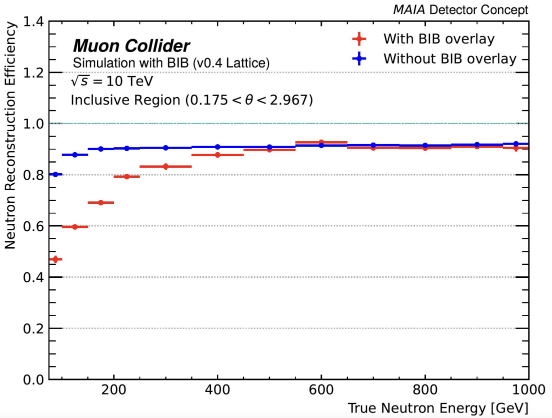


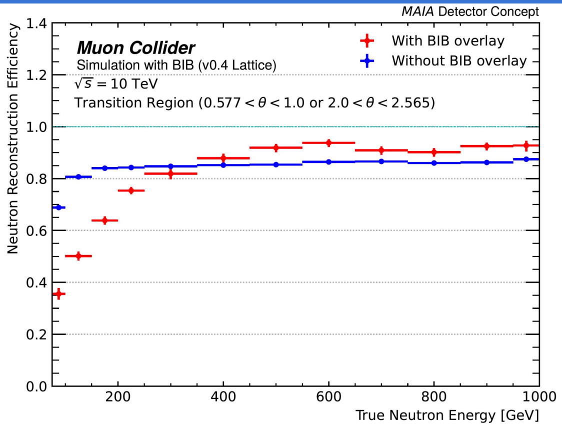


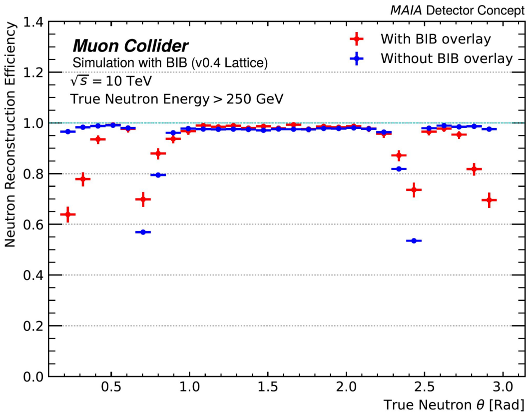


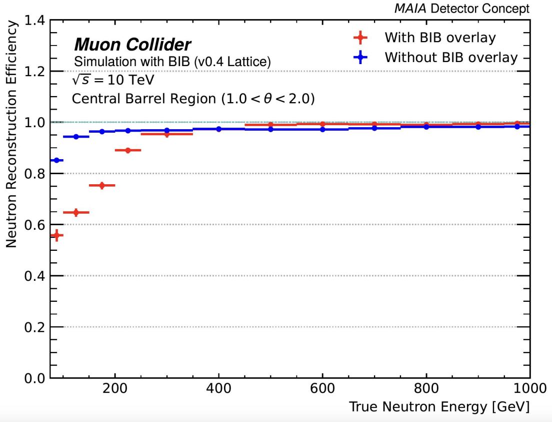


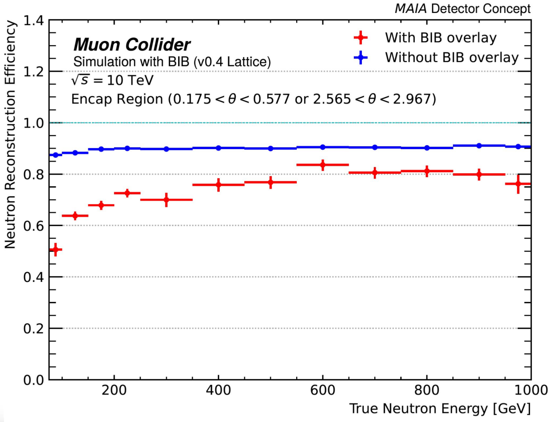
Neutron reconstruction efficiency

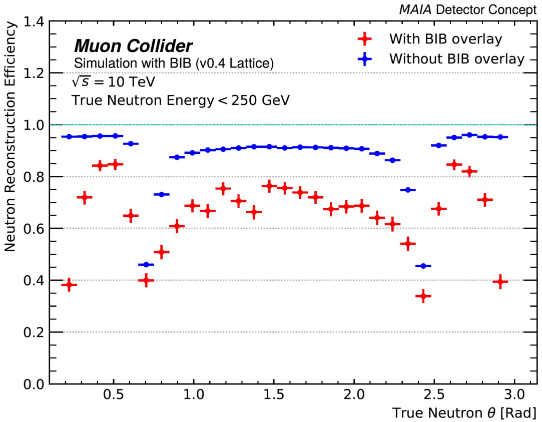




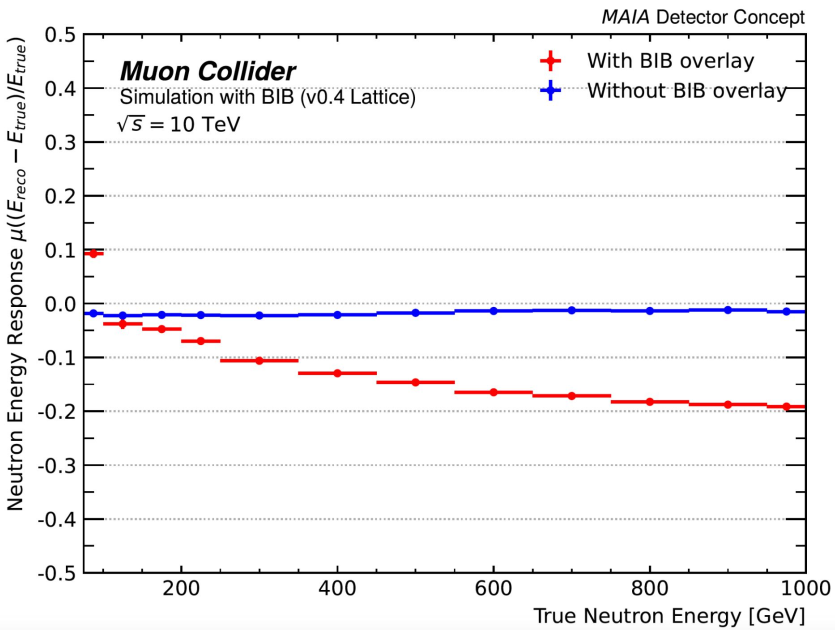


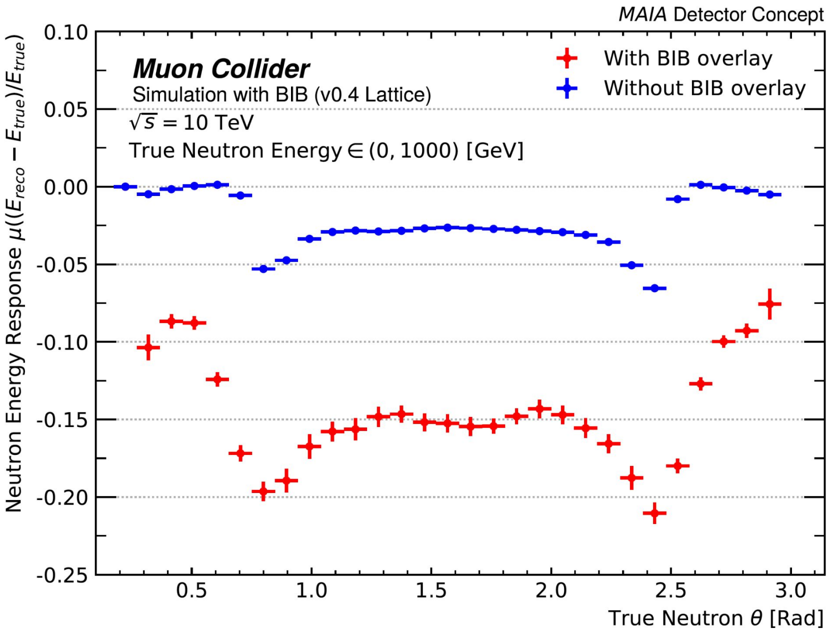






Neutron energy response





ECAL/photon results