Simulating photonuclear backgrounds in the hadron calorimeter for the Light Dark Matter eXperiment

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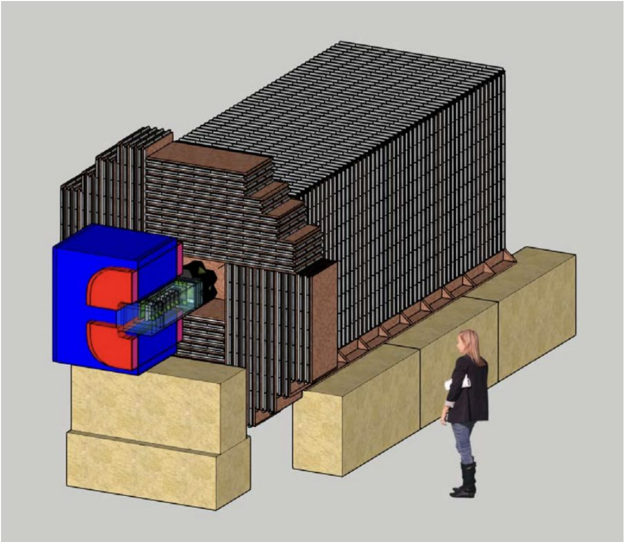
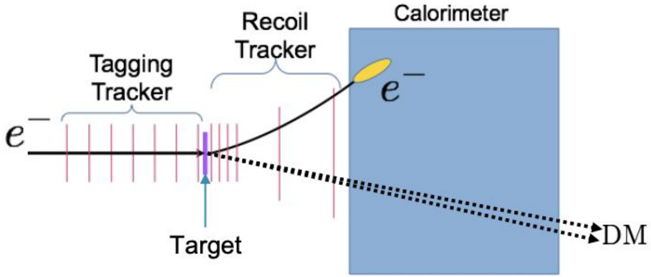
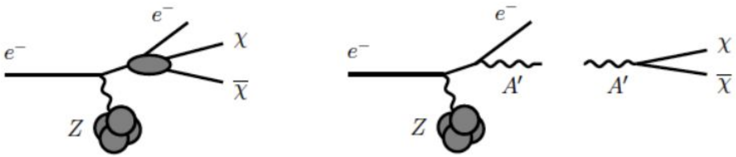
LDMX: a fixed target missing momentum experiment

- Increasing interest in expanding dark matter search to sub-GeV mass range
- DM production identified through missing energy or momentum in the detector
- Refer to Matt's talk for more information

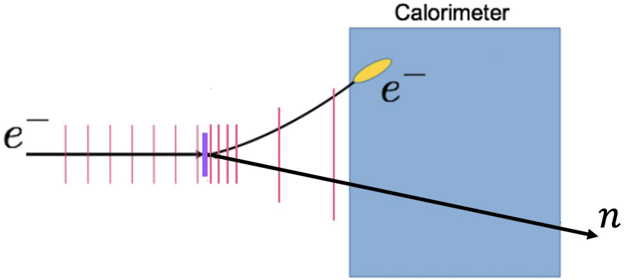


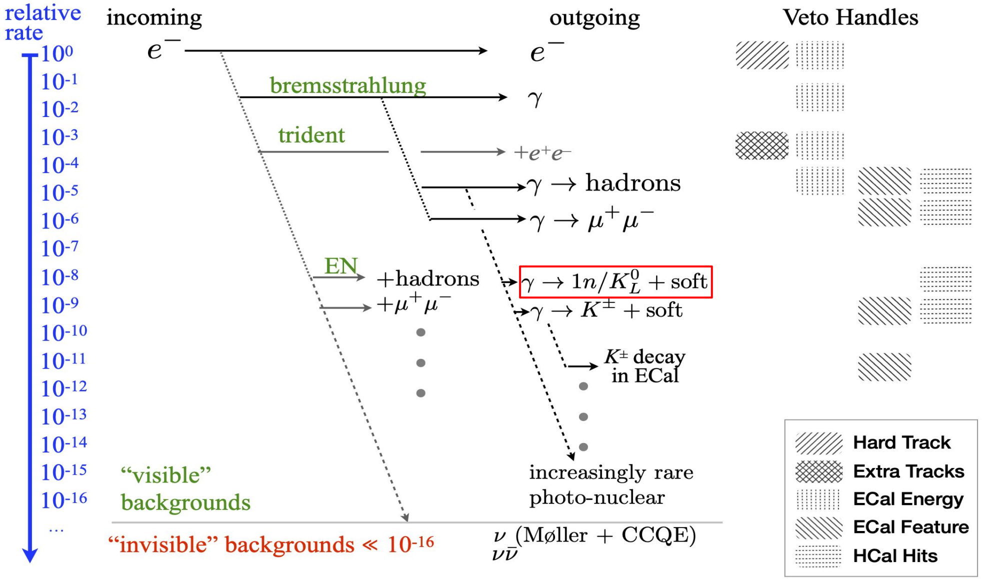




Missing momentum backgrounds

- For a benchmark 10^{14} electrons on target, we would face up to ~10^6 events with a single hard forward neutron or neutral kaon.
  - Require better than a 10^{-6} neutron rejection inefficiency in HCal.

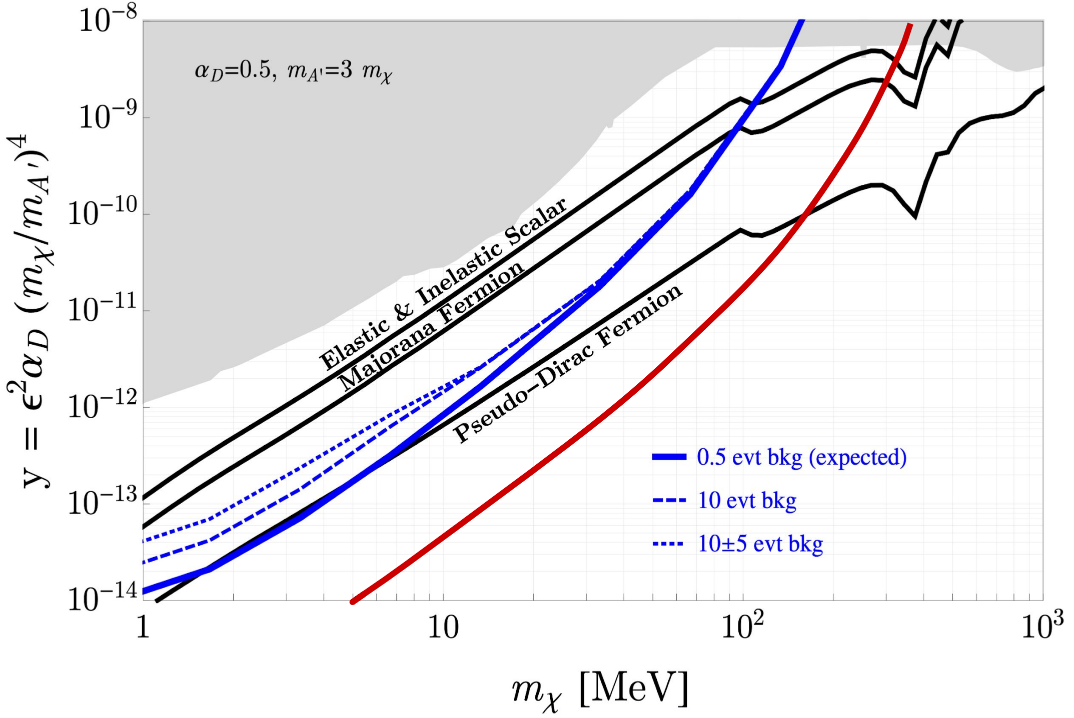




Sensitivity

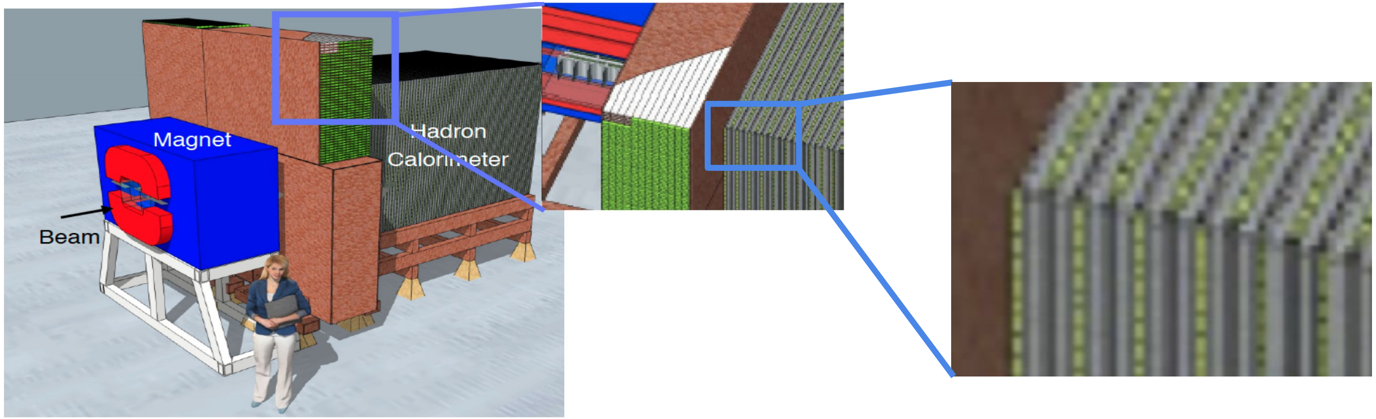
Phase 1: 4 GeV, 10^{14} electrons
Phase 2: 8 GeV, 10^{16} electrons

- All systems handling veto: expect < 1 background event for 4 x 10^{14} EOT with 4 GeV beam energy
- Even with 20x expected background events, LDMX would provide competitive sensitivity
    - We still want to optimize our sensitivity



The Hadron Calorimeter (HCal) for LDMX

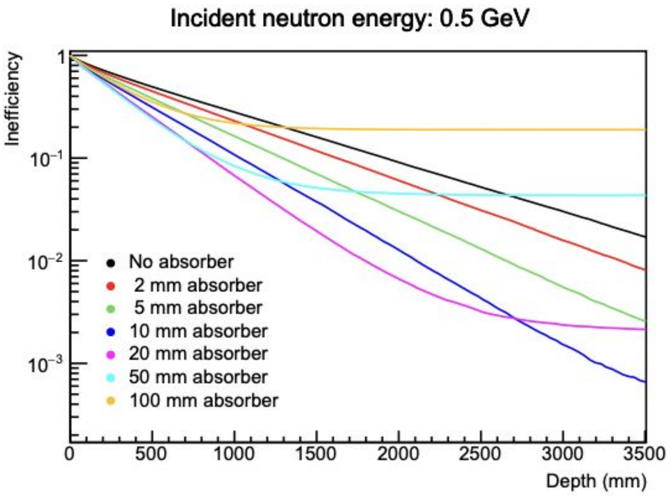
- Segmented steel and plastic scintillators with wavelength shifting fibers read out by SiPM
  - Current design is 100 layers, each contains 25mm steel absorber & 20mm plastic scintillator
  - Highly efficient, vetoes events producing >5 photoelectrons
  - Based on the Mu2e Cosmic Ray Veto Design

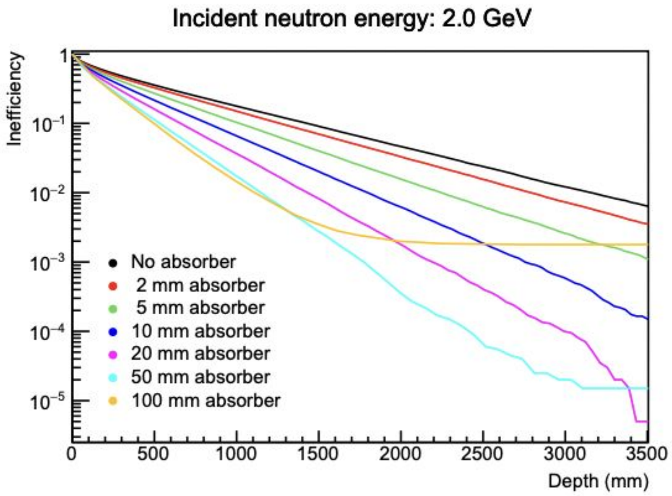


Using simulations for LDMX

Using simulations for LDMX

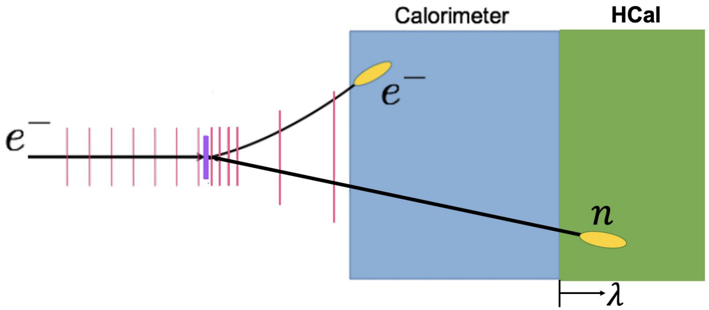
- Simulations have helped inform us on the design of the HCal
  - Absorber thickness of 25mm is motivated by simulation results that provide the least inefficiency for both lower and higher energy neutrons





Simulation procedure

- Preliminary results show different versions of Geant4 produce different inefficiencies
- Fire neutrons or k-longs at front face of the back HCal
  - 100 layers of HCal = 17 strong interaction lengths
- Find the minimum depth (in units of interaction length λ) in HCal from the reconstructed hit that is sufficient to veto the event
- Plot inefficiency as a function of λ
- Compare results with different hadronic models and different versions of Geant4

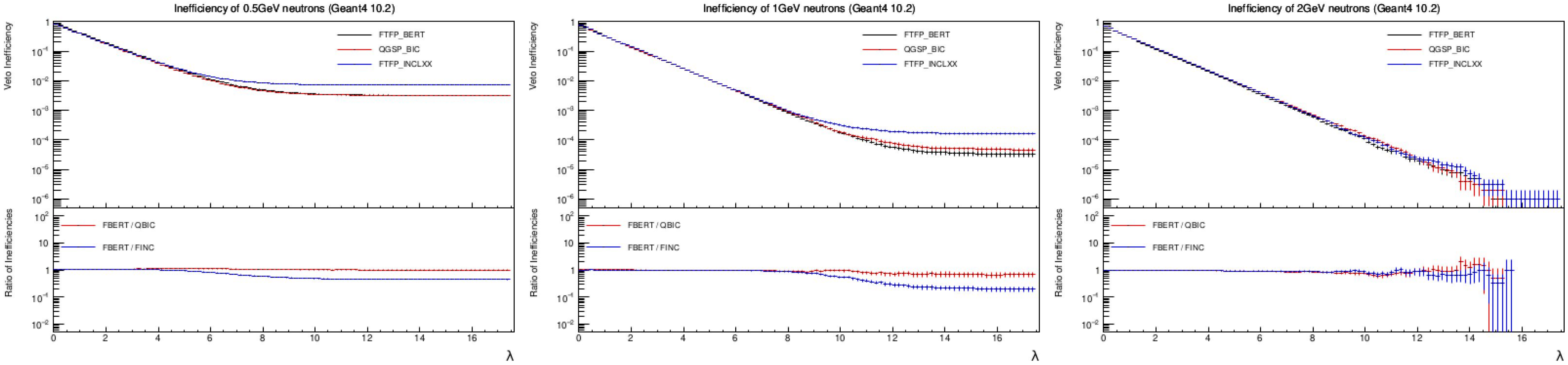


Hadronic models in Geant4

- FTFP_BERT (FRITIOF string model, Bertini cascade model)
  - FTFP: 4 GeV - 100 TeV (10.2), 3 GeV - 100 TeV (10.5, 10.7)
  - BERT: 0 eV - 5 GeV (10.2), 0 eV - 12 GeV (10.5), 0 eV - 6 GeV (10.7)
- QGSP_BIC (Quark Gluon string model, Binary cascade model)
  - QGSP: 12 GeV - 100 TeV
  - BIC: 0 eV - 9.9 GeV (10.2, 10.5), 0 eV - 6 GeV (10.7)
  - FTFP: 9.5 GeV - 25 GeV (10.2, 10.5), 03 GeV - 25 GeV (10.7)
- FTFP_INCLXX (Liege intra-nuclear cascade model)
  - FTFP: 15 GeV - 100 TeV
  - INCL++: 1 MeV - 20 GeV
  - PRECO: 0 eV - 2 MeV
- These lists are a “best guess” of the physics needed for a given case, but it is up to the user to validate the physics for a particular application

Discrepancies using different hadronic models

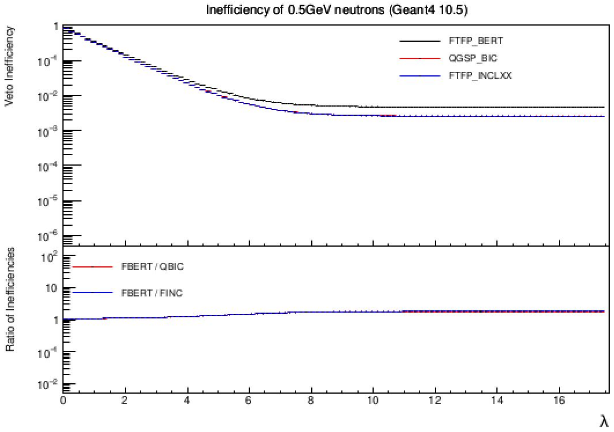
Geant4 10.2 neutron simulations

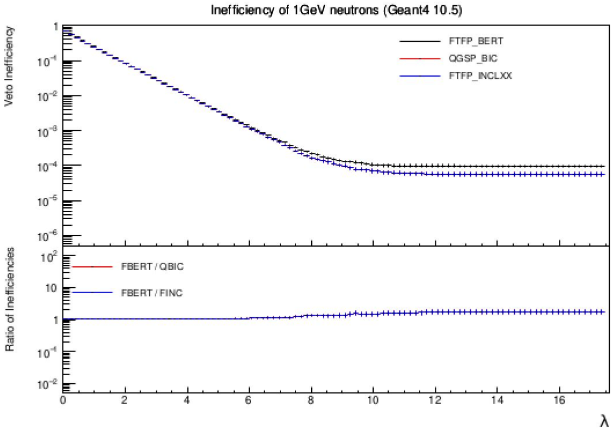


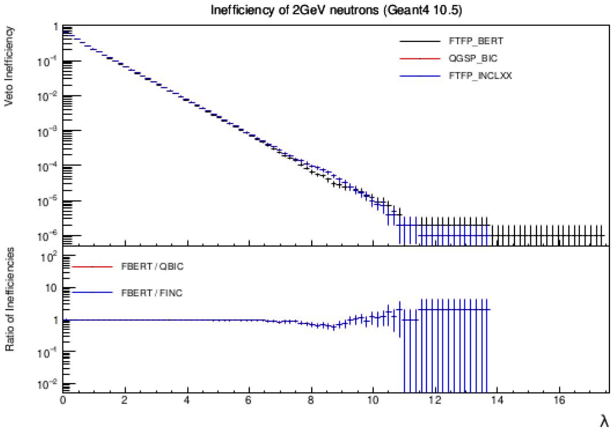
<u>Big takeaways</u>: No noticeable asymptote difference for 2 GeV neutrons, FTFP_INCLXX is more inefficient in Geant4 10.2 and 10.7, but less inefficient in 10.5.

Discrepancies using different hadronic models

Geant4 10.5 neutron simulations







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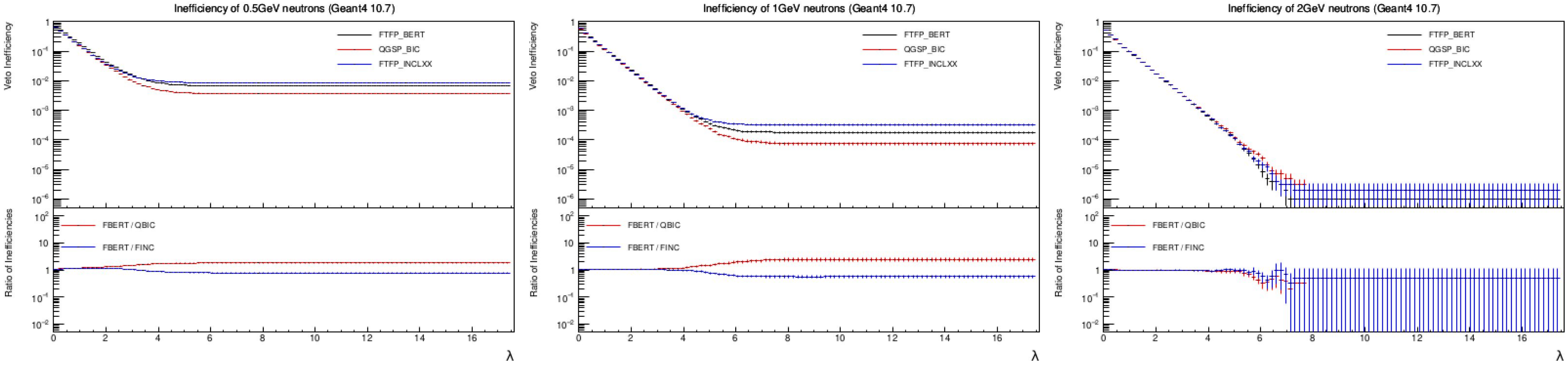
Discrepancies using different hadronic models

Geant4 10.7 neutron simulations



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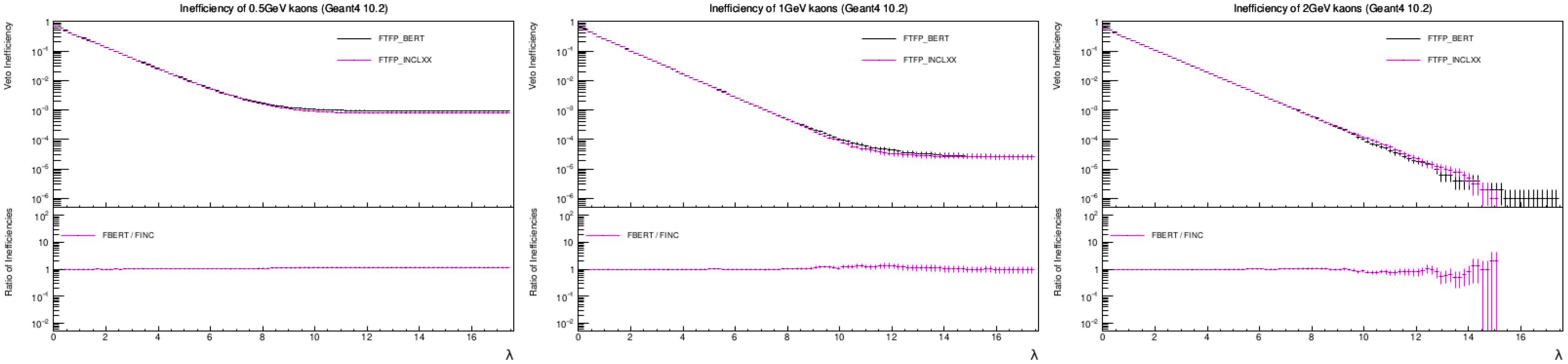
Discrepancies using different hadronic models

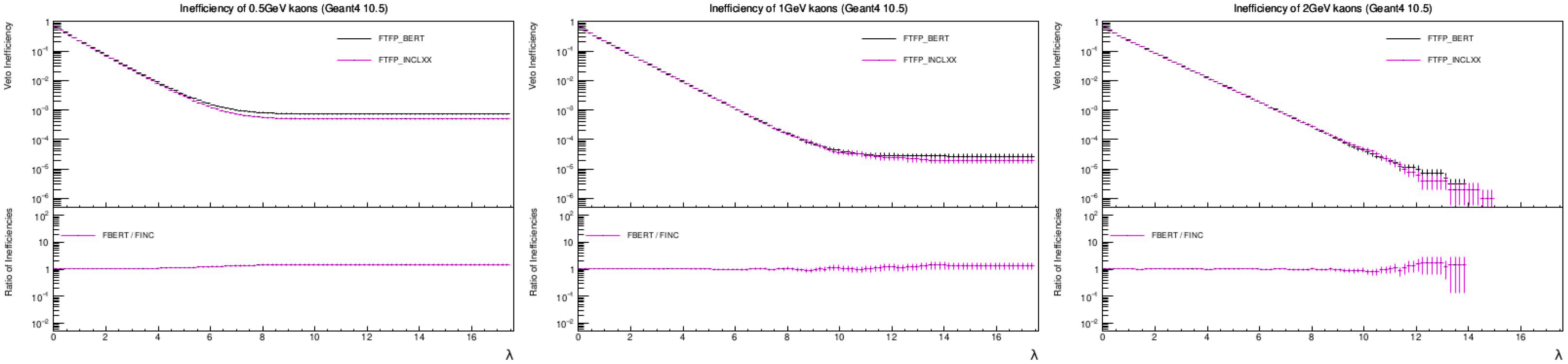
Geant4 10.2 kaon simulations



<u>Big takeaways</u>: No notable difference outside of 10.7

Discrepancies using different hadronic models

Geant4 10.5 kaon simulations



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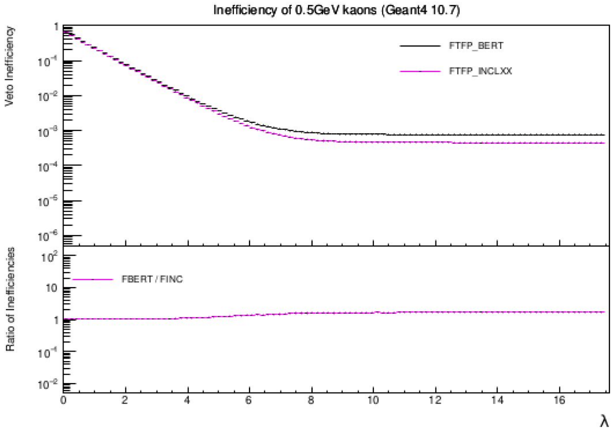
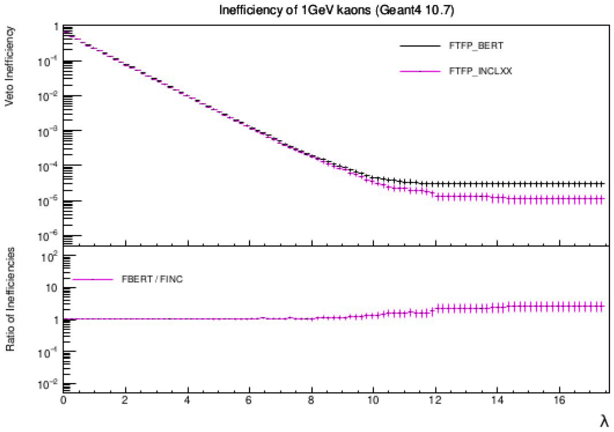
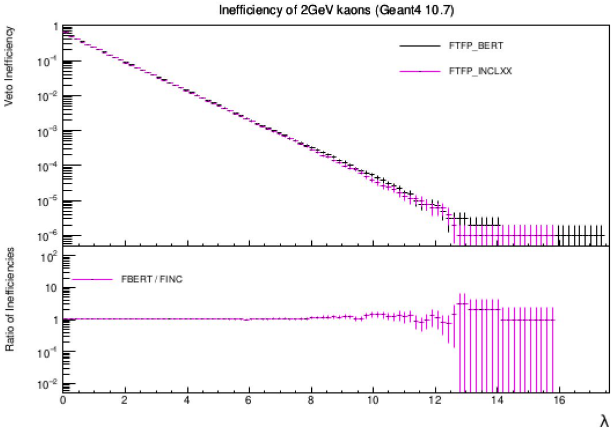
Discrepancies using different Geant4 versions

Geant4 10.7 kaon simulations







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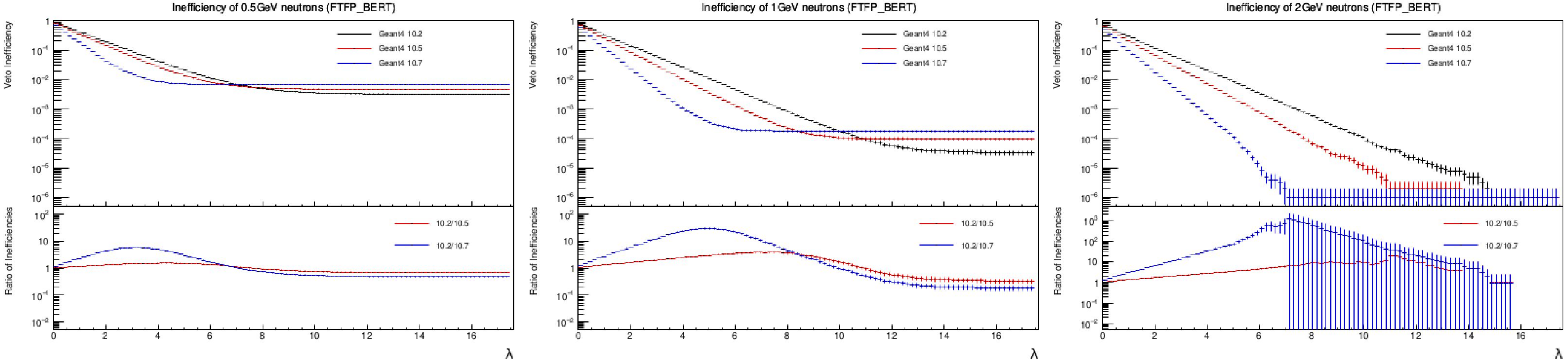
Discrepancies using different Geant4 versions

- By default, LDMX simulations are run with Geant4 10.2. But other versions of Geant4 can be used.
  - Testing results with 10.2, 10.5, and 10.7
- We plan to shift to 10.7 if we can validate the results of simulations.
- Big takeaway: 10.7 shows a much steeper slope, so we can reach target inefficiency with less material than expected

Discrepancies using different Geant4 versions

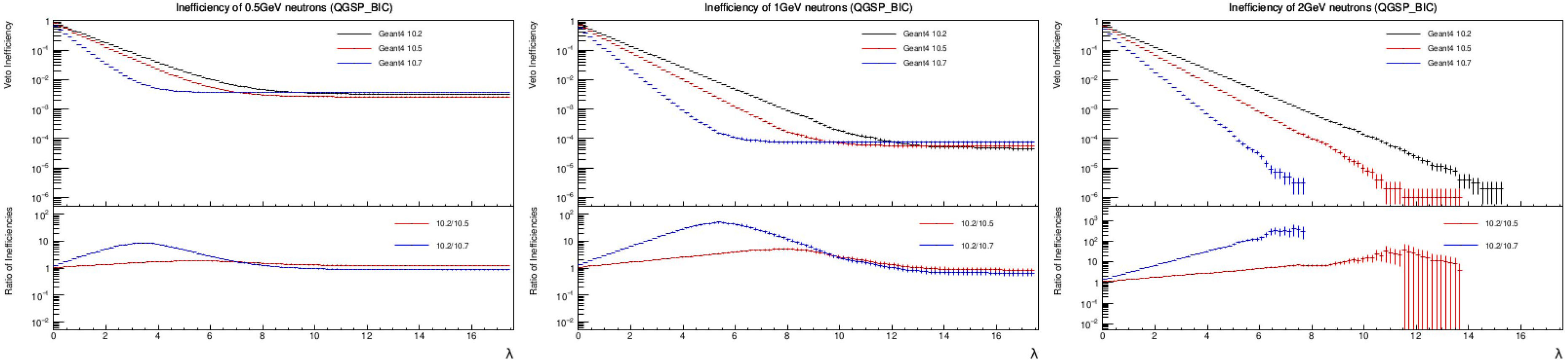
FTFP_BERT neutron simulations



Big takeaway: newer versions of Geant4 shows a much steeper slope, so we can reach target inefficiency with less material than expected.

Discrepancies using different Geant4 versions

QGSP_BIC neutron simulations



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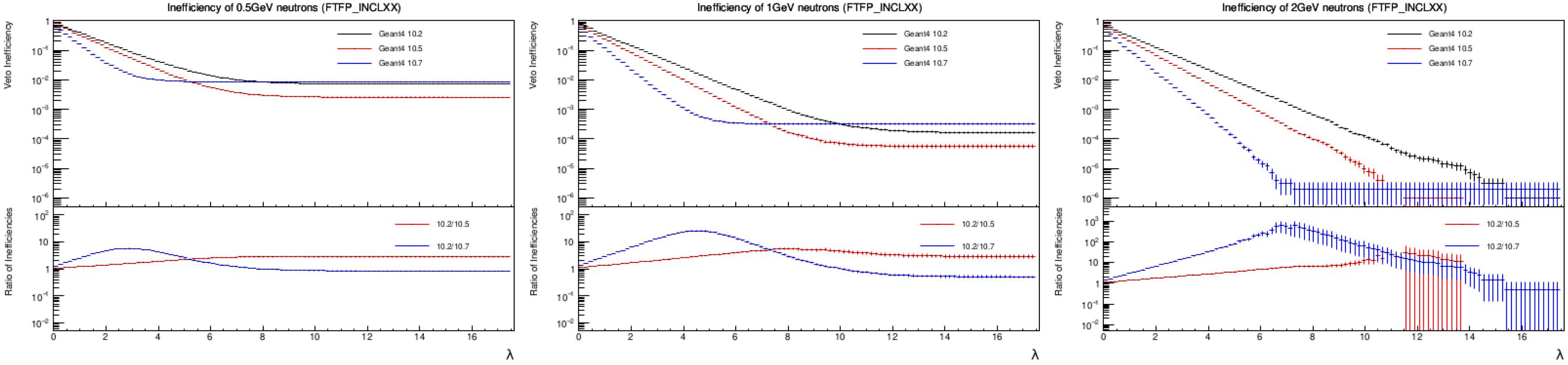
Discrepancies using different Geant4 versions

FTFP_INCLXX neutron simulations



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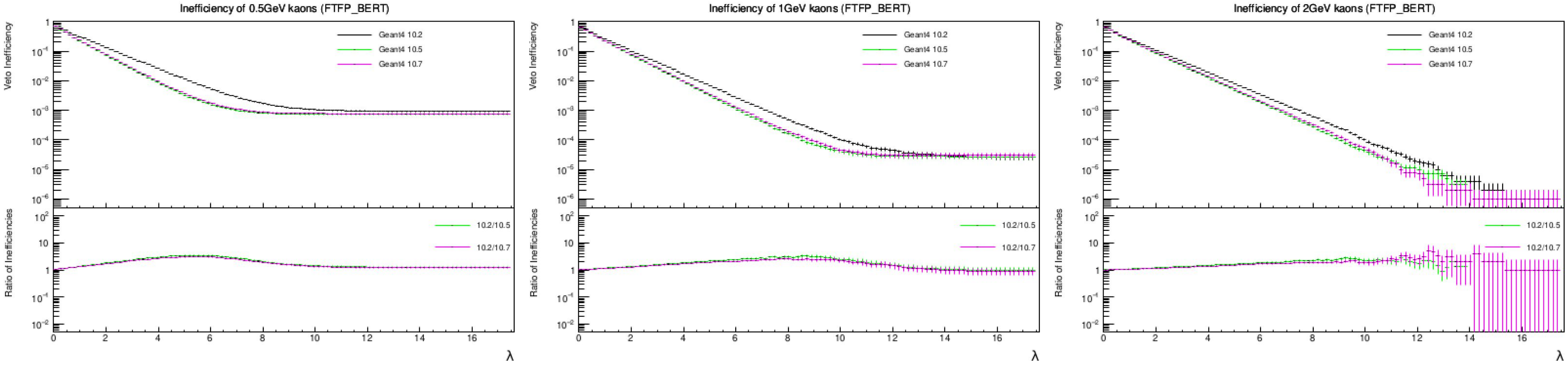
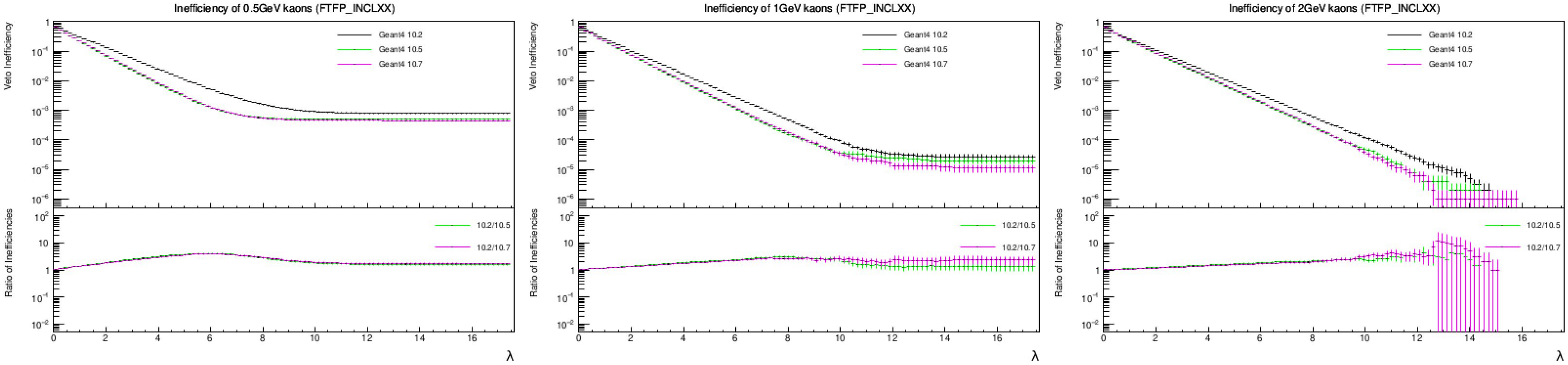


Big takeaway: Steeper slopes in new versions of Geant4, but no change from 10.5 to 10.7.

Discrepancies using different Geant4 versions

FTFP_INCLXX kaon simulations



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Possible explanation for discrepancy

- Discrepancy from physics lists could be caused by different final states of hadronic showers
- From Geant4 10.5 release notes:
  - Updated inelastic cross section for neutrons
  - Hadronic string models give higher energy response compared to previous versions
    - Believed to be an underestimate of Birks quenching factor, a phenomenological function of light yield as a function of energy loss
- From Geant4 10.7 release notes:
  - Higher energy response and more compact hadronic showers
    - Only expected in 5 - 20 GeV range
  - More accurate inelastic cross sections for neutrons

Conclusion and next steps

- LDMX is a high sensitivity probe of sub-GeV thermal relic dark matter with sufficient background vetoing
- Understanding the physicality of these simulation results will aid in the optimal design of the HCal
- Next steps:
  - Perform a more in-depth study of the energy deposition between different versions of Geant4
  - Why does inefficiency slope change from 10.5 to 10.7 for neutrons but not kaons?
  - Validate against neutron/kaon data in our energy range (100 MeV - 3 GeV)
    - Note: Not much data to compare
- For more on kaon simulations in LDMX, stick around for Chloe's talk

Using a higher photoelectron veto threshold (backup)