GCF & the BeAGLE Simulation Code

Mark D. Baker

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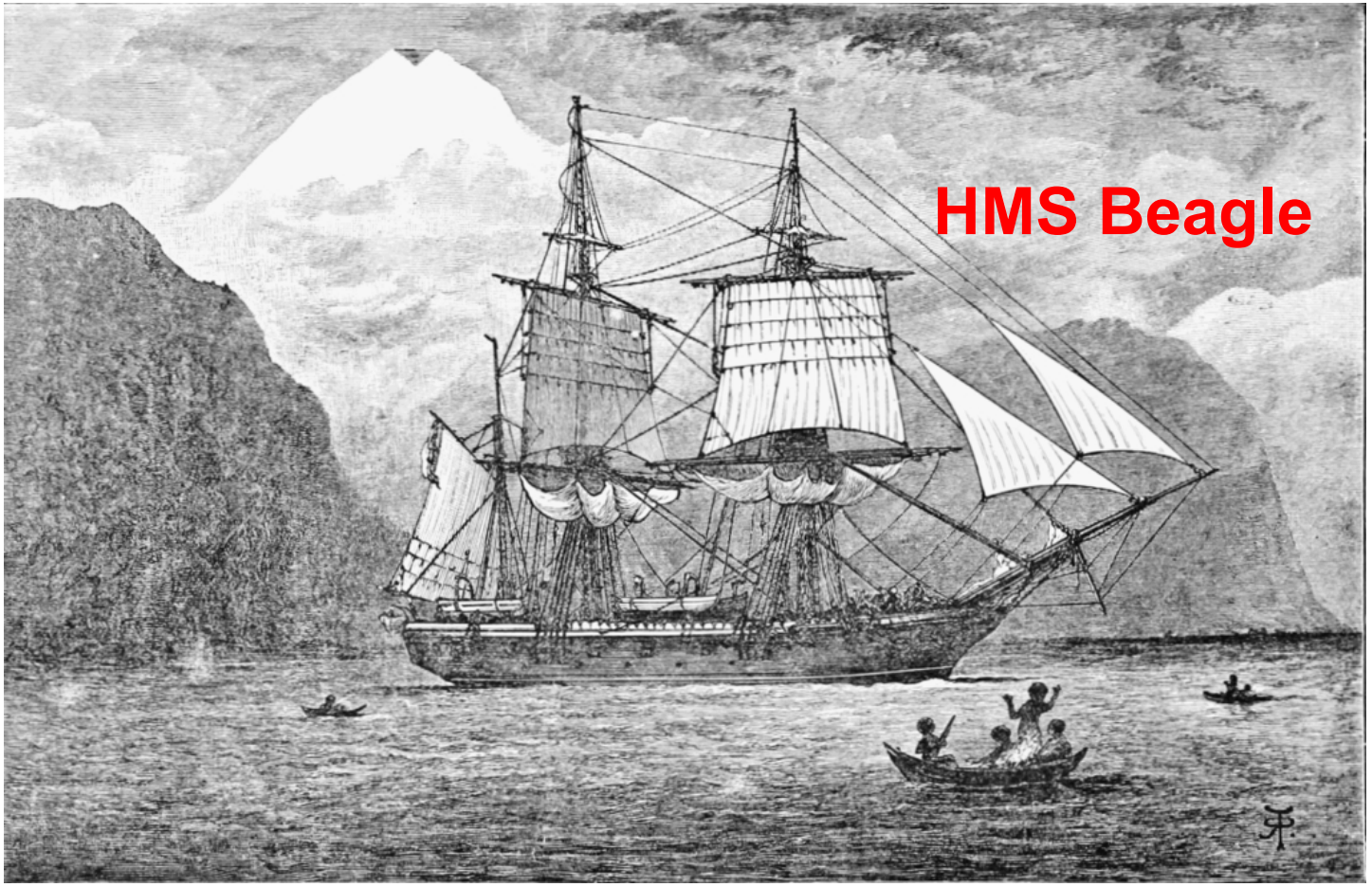


March 25, 2021

SRC Collaborators

- I. Friscic, D. Higinbotham, F. Hauenstein, O. Hen, C. Hyde, A. Jentsch, D. Nguyen, J. Pybus, A. Schmidt, B. Schmookler, Z. Tu…
- Theory: M. Strickman, R. Venugopalan, C. Weiss

You know GCF! What is BeAGLE?

BeAGLE – Benchmark eA Generator for LEptoproduction

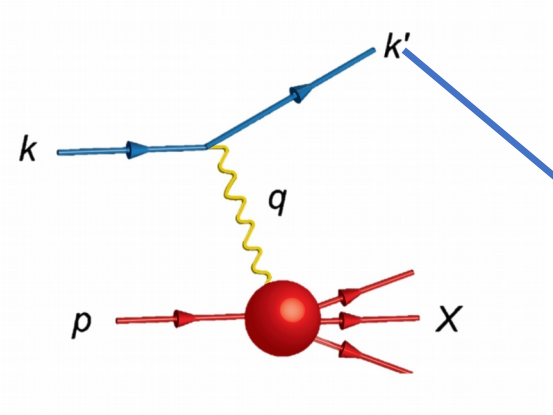
- E.Aschenauer, MDB, W. Chang, A. Jentsch, J.H.Lee, Z. Tu, L.Zheng

Contact: mdbaker @mdbpads.com,@jlab.org, @bnl.gov

- Merger of
  - Pythia6: **hard interaction**
  - MC "Glauber" w/ multinucleon shadowing
  - DPMJET3-F (DPMJET3+Fluka): **nuclear response**
    - Intranuclear Cascade + Excited nucleus decay
- Tuned to HERMES & ZEUS & FNAL E665
- Heavily used for EIC IR/Forward Detector Design and studies. See EIC Yellow Report!

What is BeAGLE?

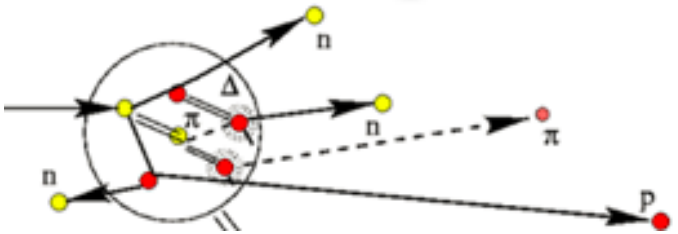
BeAGLE (**B**enchmark **eA** **G**enerator for **LE**ptoproduction)



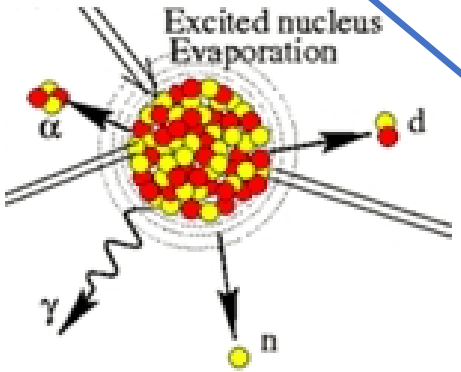
Primary interaction

Primary interaction
treated by **PYTHIA**
hard collision.

Cascade process
handled by **DPMJET.**



Intra-nuclear cascade

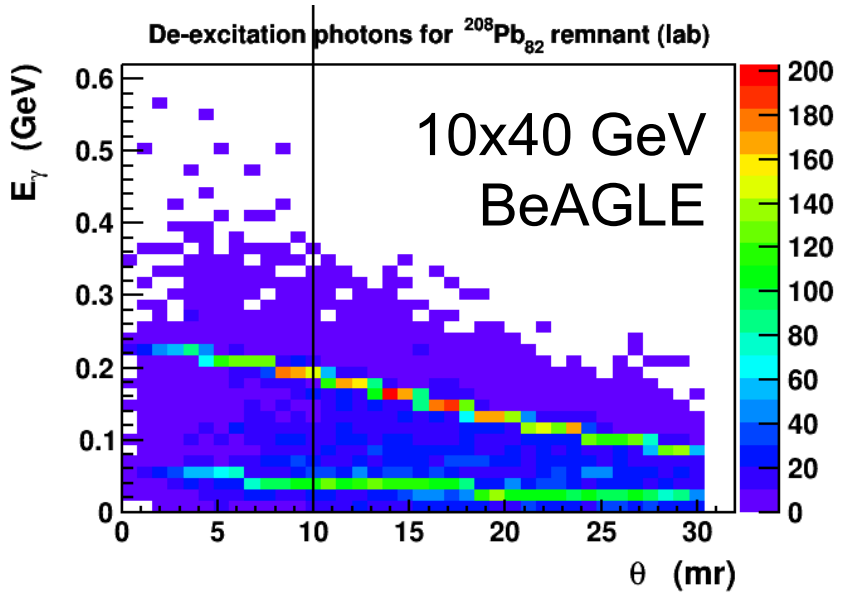


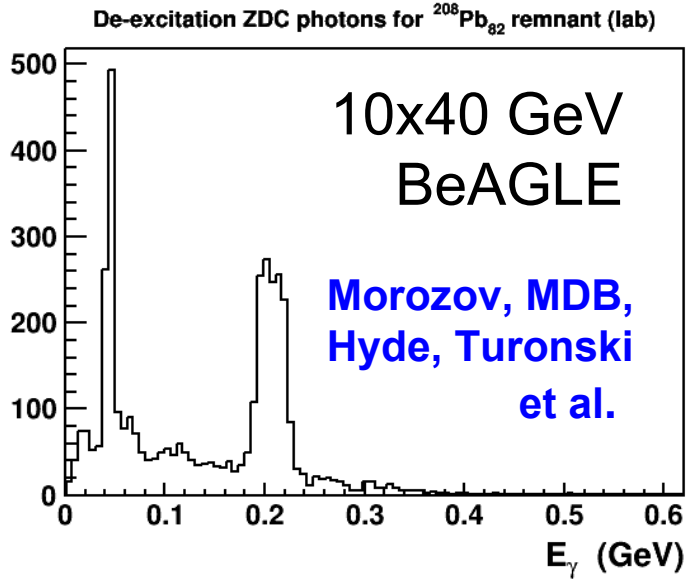
Nuclear remnant
evaporation and
break up by **FLUKA.**

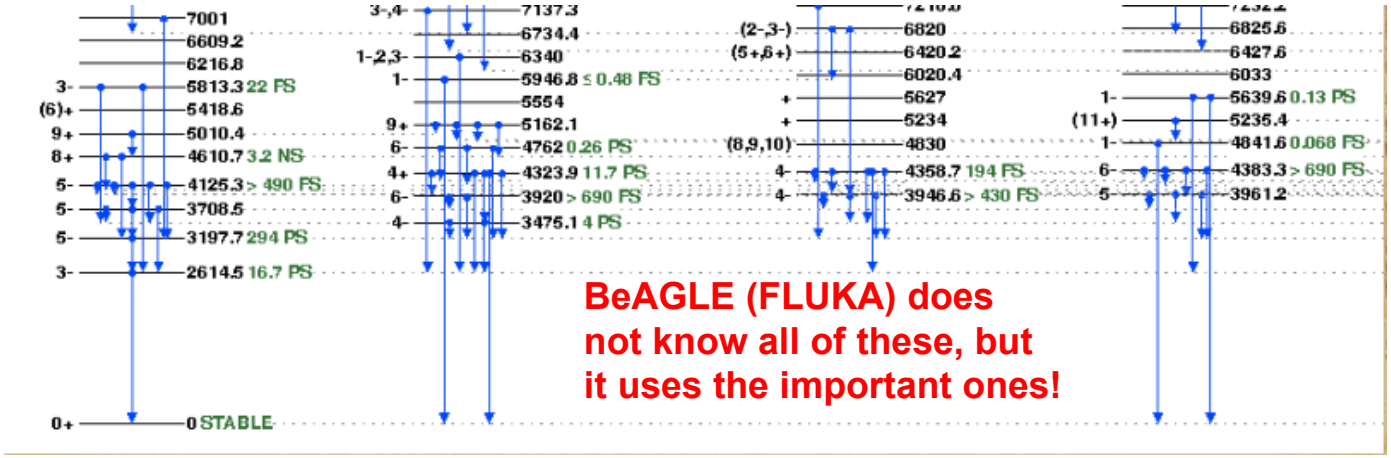
Nuclear remnant evaporation & breakup

Simulation challenge in e+A: nuclear detail

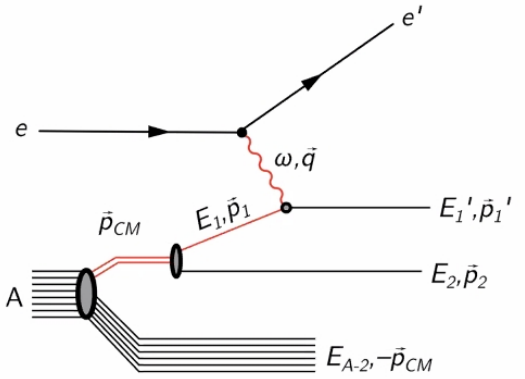
One example: de-excitation photons from $^{208}Pb_{82}$ following e+Pb →e'+Pb*+J/ψ →e'+Pb+γ+γ+γ+J/ψ in (collider) lab frame







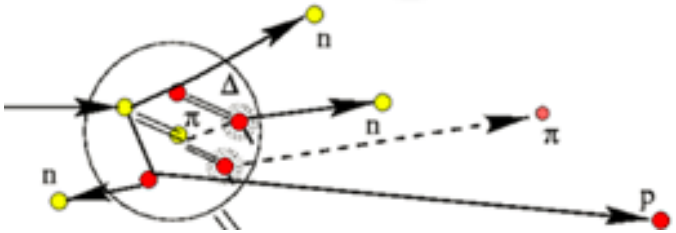
How about GCF (QE) + BeAGLE!



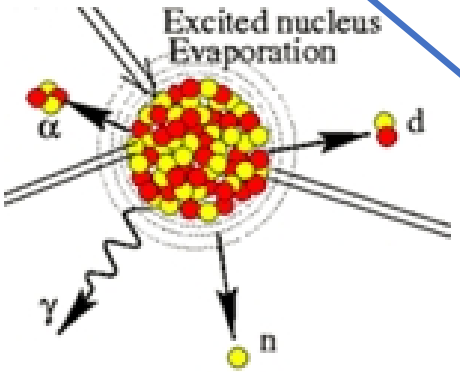
Primary interaction input from **GCF!** for the hard collision.

Primary interaction

Cascade process handled by **DPMJET.**



Intra-nuclear cascade



Nuclear remnant evaporation and break up by **FLUKA.**

Nuclear remnant evaporation & breakup

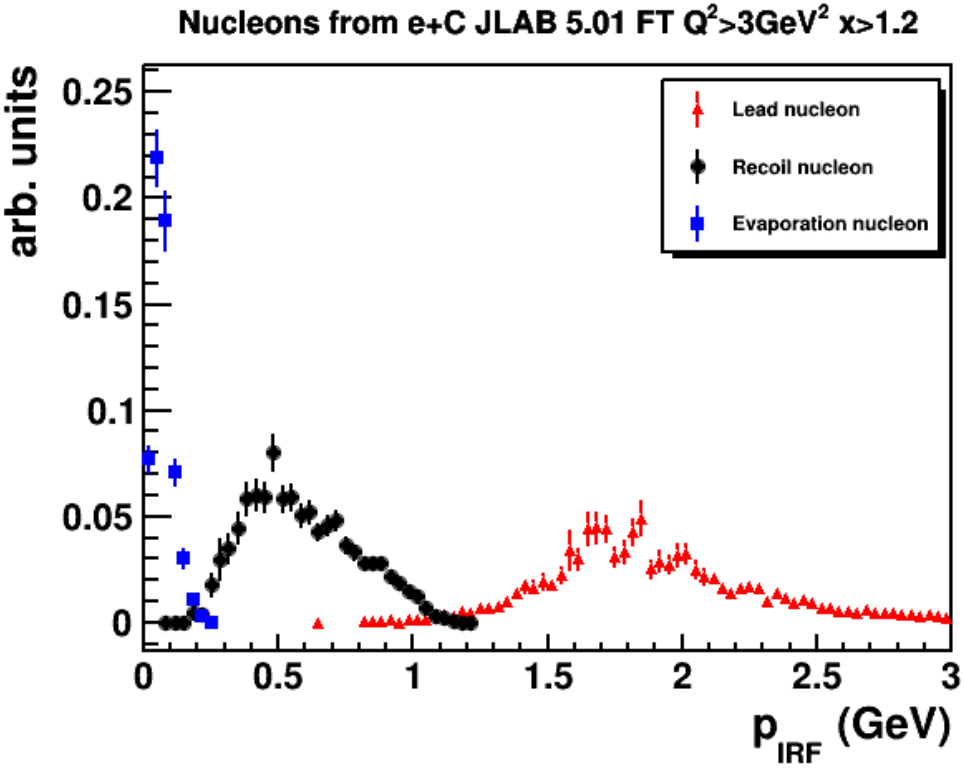
GCF (QE event generator) + BeAGLE!

Three levels of nuclear response available.

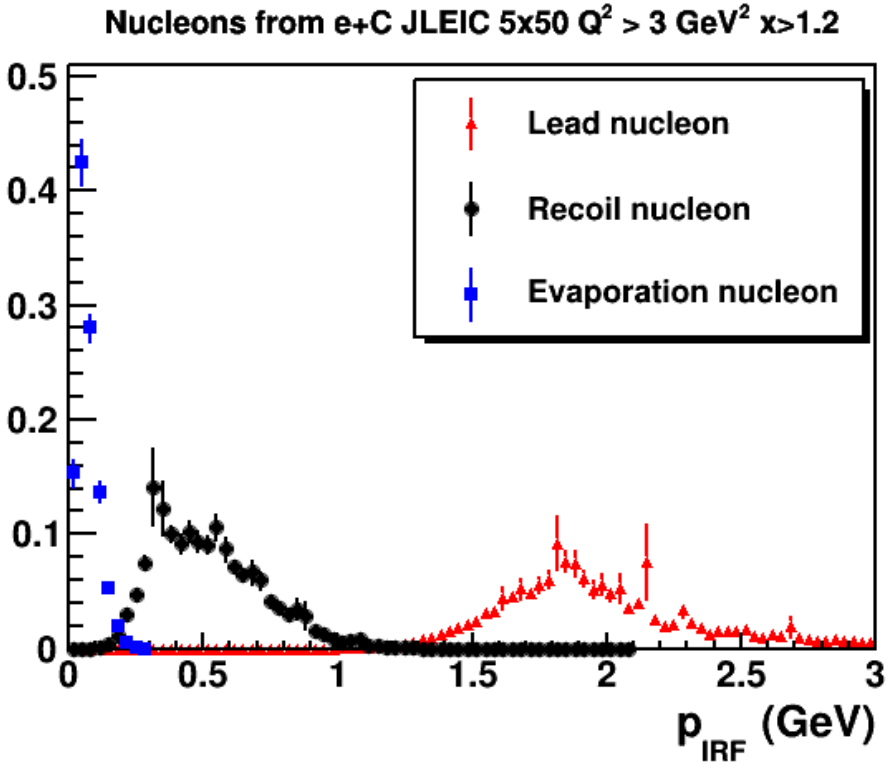
1) No response, just pass N+N+(A-2)* through.
   - Useful for handing GCF to EIC codes
2) Pass N+N. Fluka decays (A-2)*.
   - See Florian's talk for quantitative studies.
3) Full DPMJET3-F nuclear response.
   - Really new!
   - Urgent for EIC detectors (ECCE) & 2nd IR.
   - Would like to validate using CLAS/CLAS12.

GCF+BeAGLE(Fluka only)

JLAB 5.01 GeV FT e+C
Q^2>3 GeV^2, x>1.2



EIC 5x50 e+C
Q^2>3 GeV^2, x>1.2



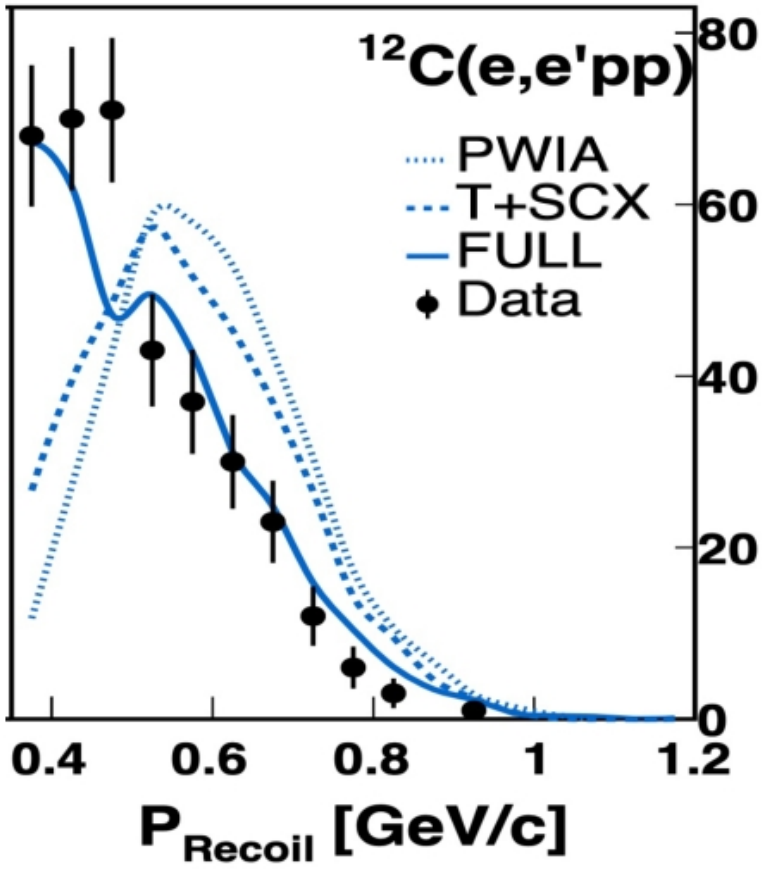
Lead and recoil nucleons are distinct.
Evaporation nucleons should not confuse us.

GCF-QE + BeAGLE

- Intranuclear cascade (in DPMJET) can:
  - 1) Scatter our original pair nucleons
  - 2) Knock out additional nucleons
  - 3) Make it harder to define the "recoil" nucleon
    - e.g. recoil neutron strikes an additional spectator neutron and they scatter in a 2→2 process. Do we consider one of the outgoing neutrons a scattered version of the recoil nucleon? Which one?
  - 4) Create pions or other secondary particles...

Expectation from data & Natalie Wright et al.

Plot taken from Or Hen's slides



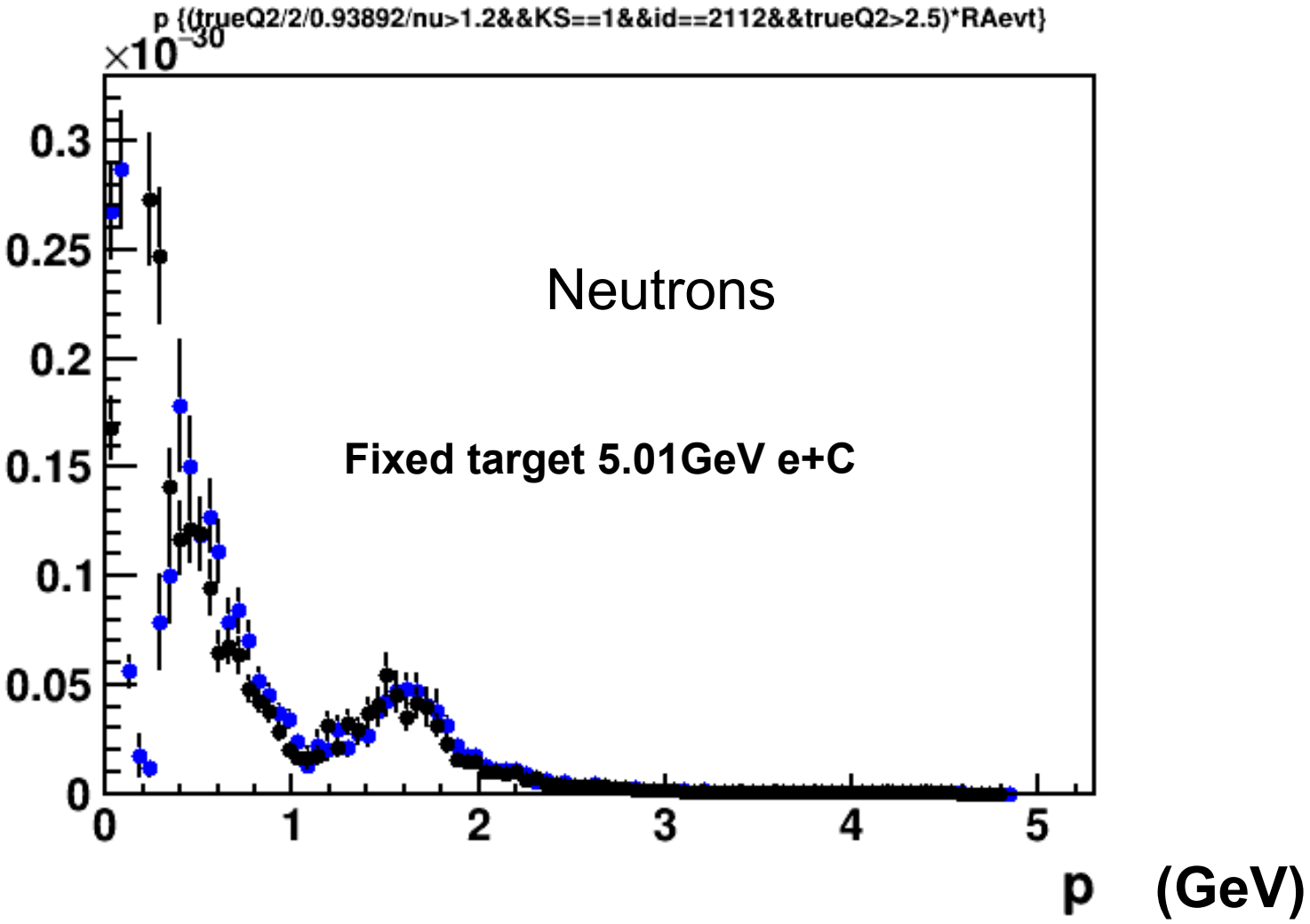
Transport FSI: Excess nucleons at low end of recoil peak.

Washing out the peak.

Lead nucleon largely unaffected by this FSI

Blue is no INC x>1.2, Q^2>2.5 GeV^2

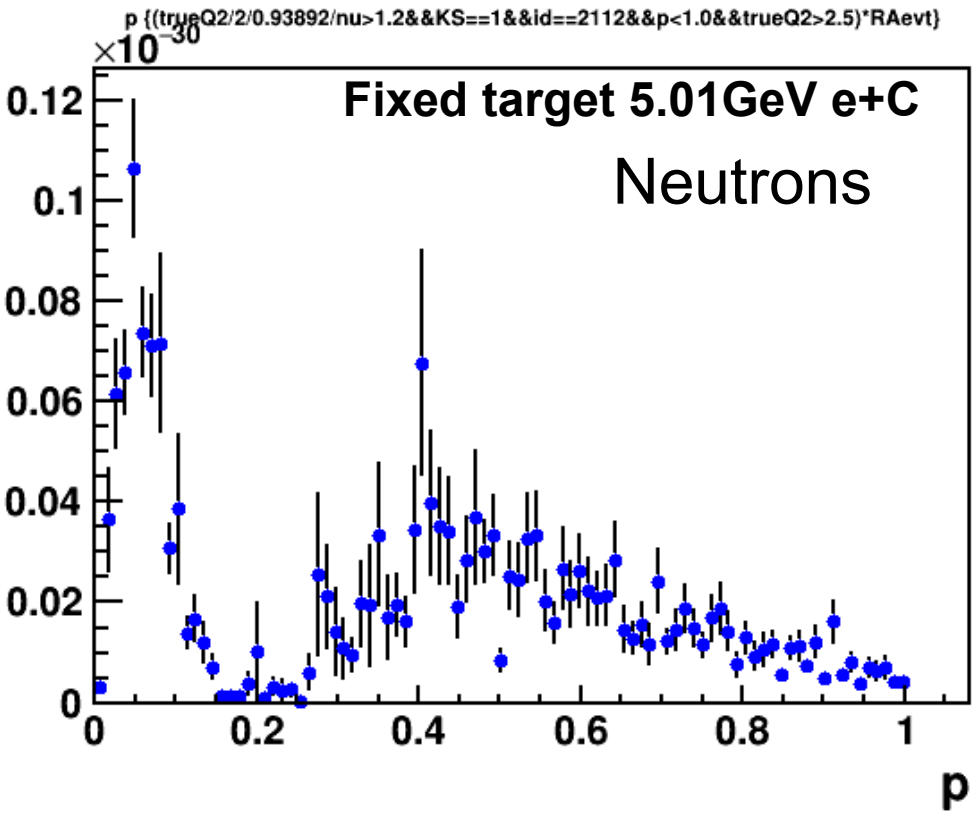
Black is full BeAGLE x>1.2, Q^2>2.5 GeV^2

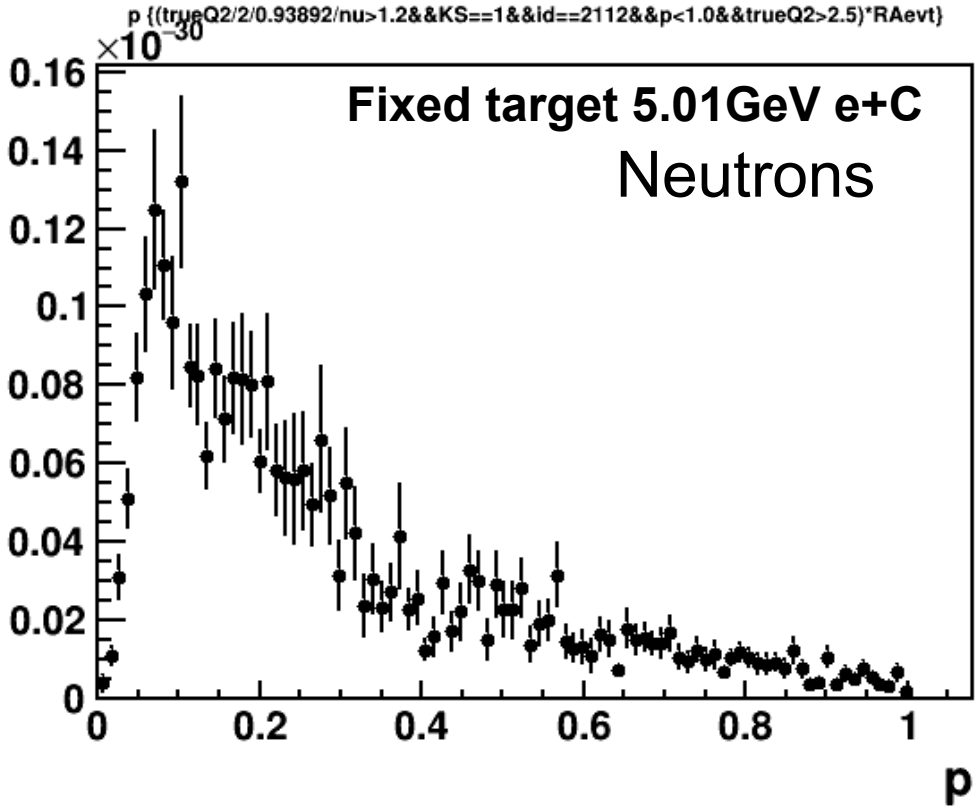


Low momentum excess washes out peak

Blue is no INC — x>1.2, Q^2>2.5 GeV^2

Black is full BeAGLE — x>1.2, Q^2>2.5 GeV^2





Correlation plots (e.g. ϕ-ϕ_{lead}) may be less confusing

Low momentum excess washes out peak

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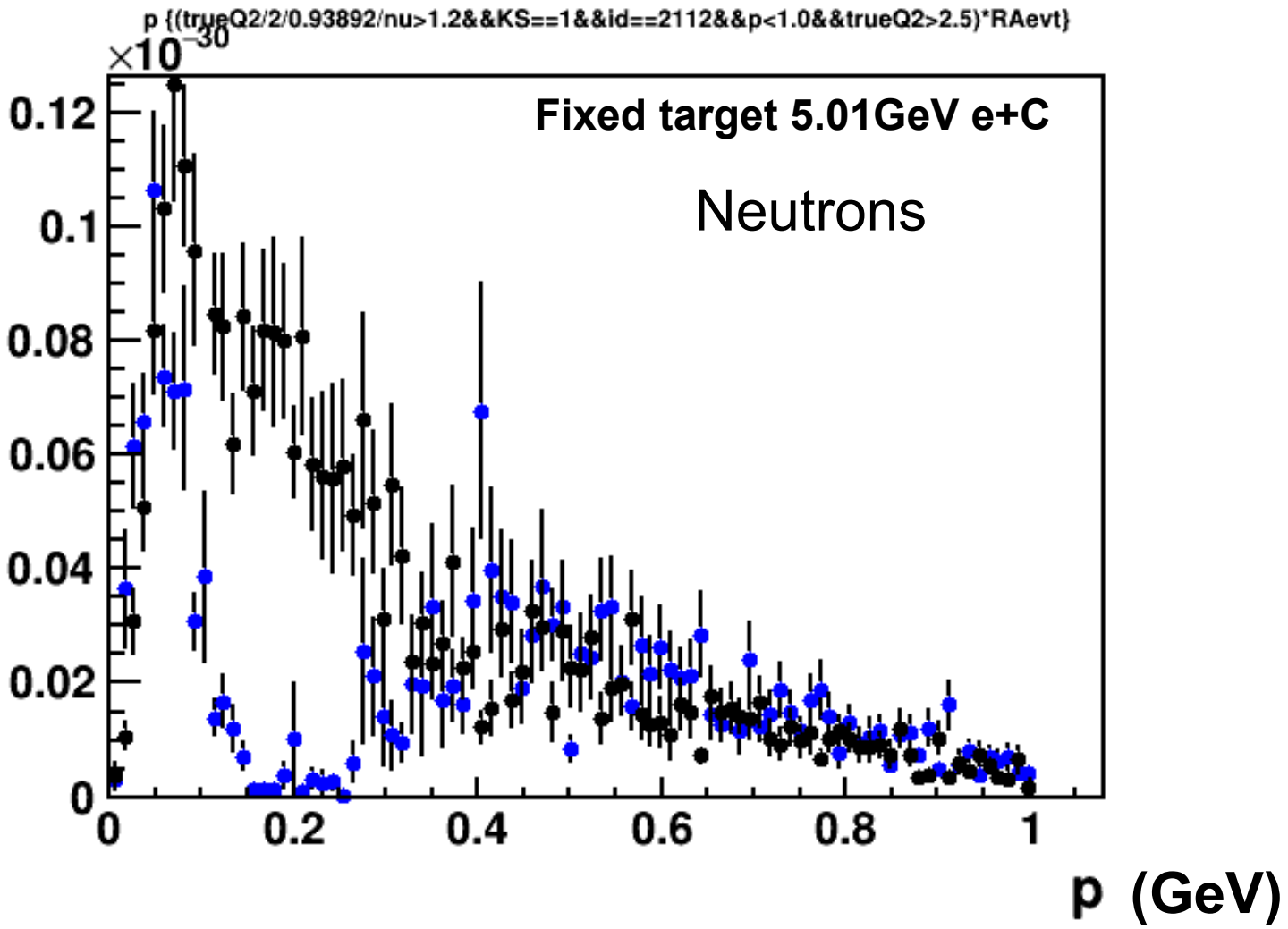
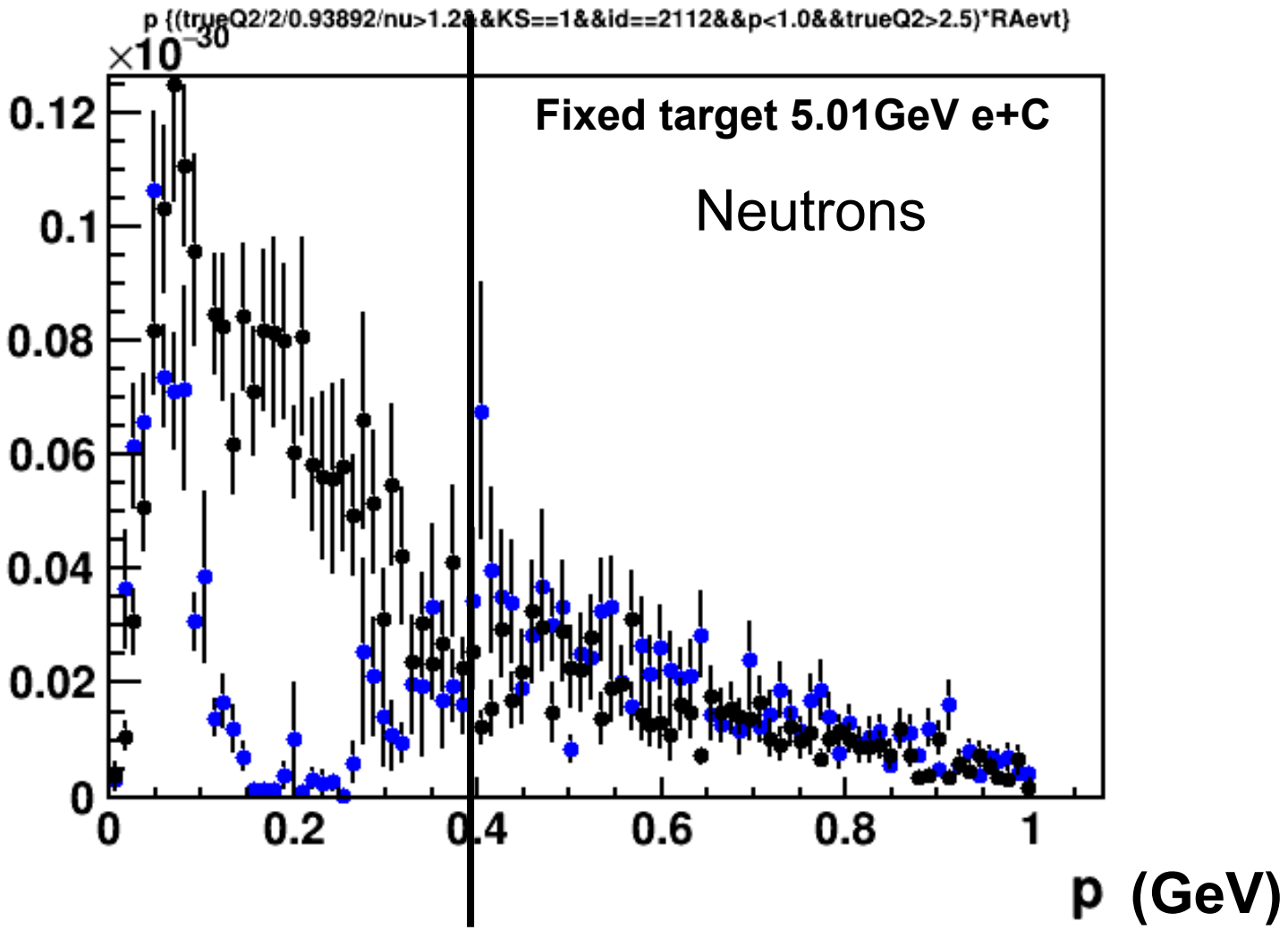
Black is full BeAGLE x>1.2, Q^2>2.5 GeV^2



Looks OK for p>400 MeV/c

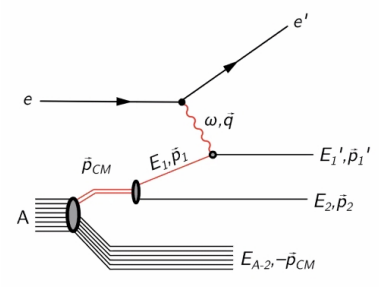
Blue is no INC x>1.2, Q^2>2.5 GeV^2

Black is full BeAGLE x>1.2, Q^2>2.5 GeV^2



How about GCF (DIS) + BeAGLE!

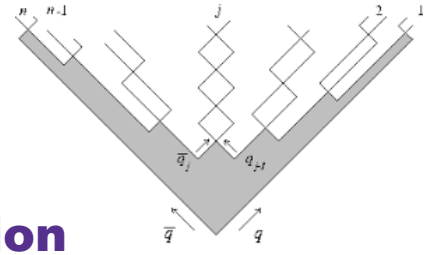
Coming soon!



Primary interaction input from **GCF!** for the hard collision.

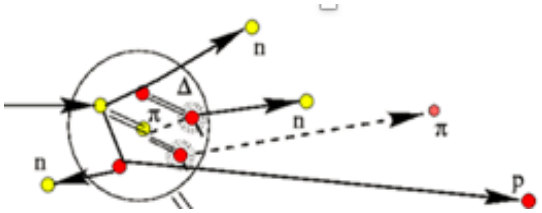
Primary interaction

Hadronization handled by **PYTHIA.**



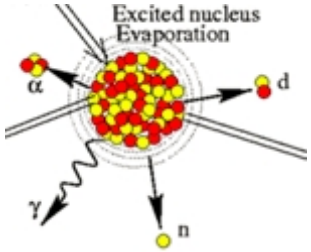
Hadronization

Cascade process handled by **DPMJET.**



Intra-nuclear cascade

Nuclear remnant evaporation and break up by **FLUKA.**



Nuclear remnant evaporation & breakup

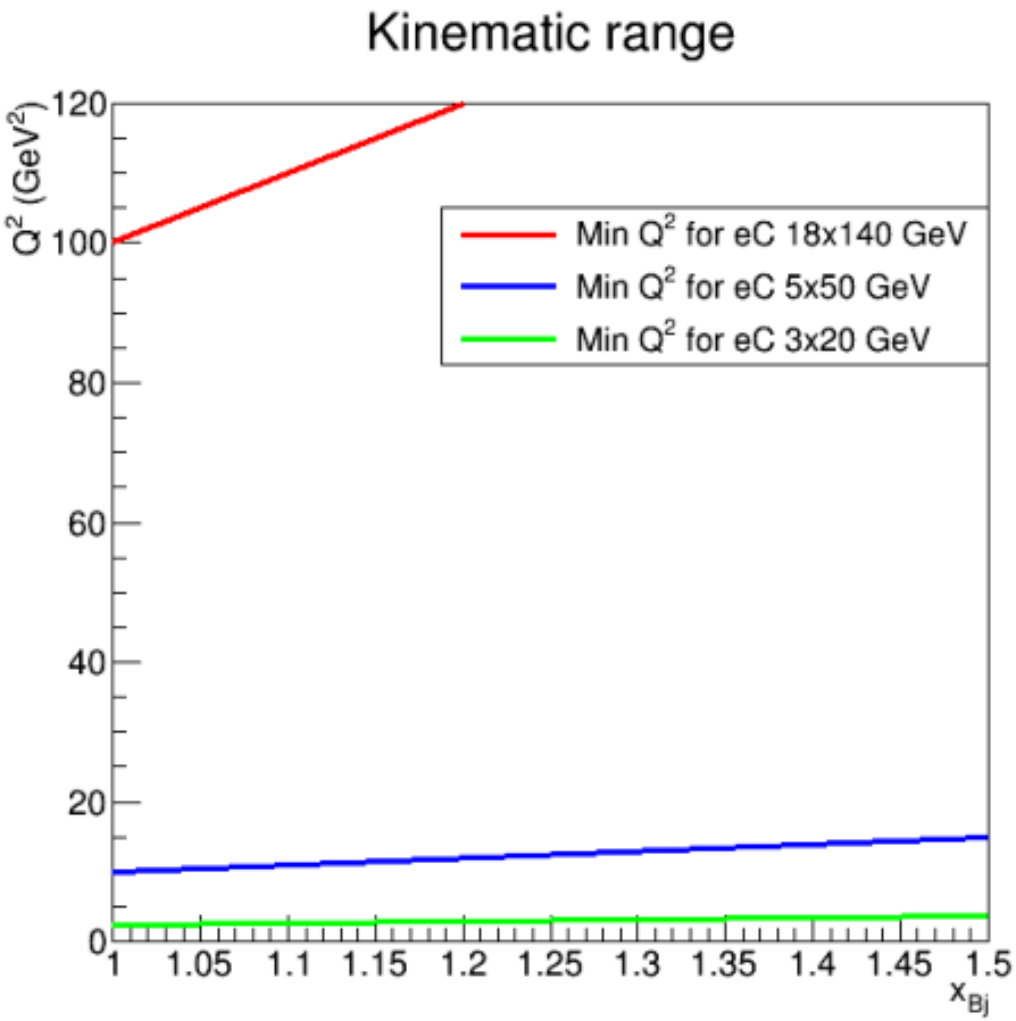
Lepton limitations at the EIC

- Problem
  - Note $x = Q^2/y(s-M^2) = Q^2/4E_eE_py$, so high x is low y.
  - $\sigma_x/x \sim \sigma_y/y \sim (1/y)\,\sigma(E_e')/E_e'$ gets ugly fast @ low y!
- Approach:
  - For e+p colliders: mix of leptonic and hadronic information at low y especially.
  - E665 e+A mostly restricted to y>0.2.
  - For collider e+A this is a research project!
    - Nuclear debris & mismatch of meaning ($\Delta \sim k_z/M$)

Kinematic reconstruction → lower s

- $Q^2 = 4E_e E_N xy$
  where E_N=ion energy/nucleon
- So $Q^2_{min} = 4E_e E_N x\, y_{min}$

- Optimistically assume y>0.01
- $Q^2 > xE_e E_N/25$



Outlook

- BeAGLE/GCF-QE (Full) – w/ Florian et al.
  - Compare to CLAS/CLAS12 results?
  - Quantitative quasielastic SRC studies for EIC.
- BeAGLE/GCF-DIS
  - Code still needs debugging (Baker).
  - BeAGLE provides three things in this case:
    1) Quarks from GCF hadronized in Pythia6
    2) Struck nucleon remnant handled in Pythia6
    3) Nuclear response as in BeAGLE/GCF-QE
- Measuring x at the EIC will be tricky.