BeAGLE

A Tool to Refine Detector Requirements for eA

EIC Generic R&D proposal #4:

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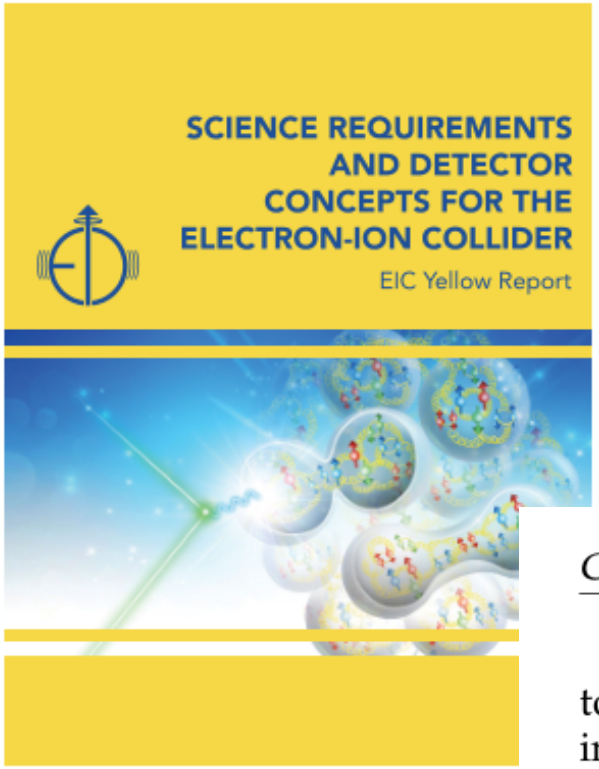
Executive Summary – p.1

- Supporting BeAGLE in FY2023 is essential to reduce risk for the project detector, its upgrades, and the 2nd detector.
  - We must understand the eA collisions as well as possible or we risk having a nonoptimal design that does not fully address important physics goals.
  - BeAGLE, as the only general purpose eA Monte Carlo, will be critical for the design of the 2nd IR & detector as well as upgrades to the 1st detector.
  - BeAGLE will continue to be used to refine the 1st detector design details.

Executive Summary – p.2

- BeAGLE is not ready to use "out of the box"
  - "Unusual events" like heavy flavor production are artificially suppressed.
  - A=3 does not work correctly at all.
  - Four-momentum is not conserved in all events.
  - Needs code cleanup and better documentation.
- BeAGLE has not been validated or fully tuned, leading to uncertainties.
- A one year project will put BeAGLE in a much better state and reduce the risks.

EIC Yellow Report



http://www.eicug.org/web/sites/default/files/Yellow_Report_v1.1.pdf

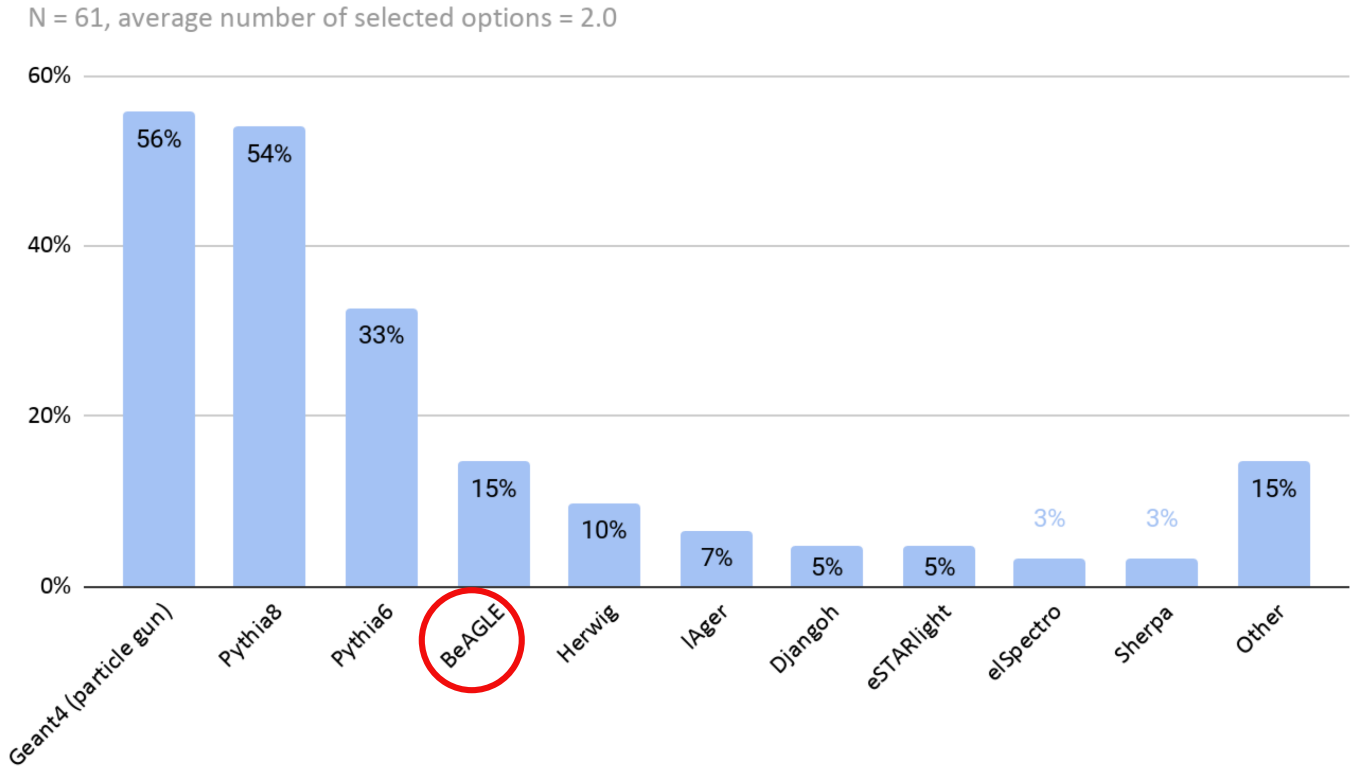
tors, with Fresnel lens focalization in the former and with gas and aerogel radiators in the latter. New coating materials like nano-diamonds to replace Cesium-Iodide (CsI) for RICH photo sensors are also under investigation. Time-of-Flight detectors, as well as Roman Pots for forward proton detection, require highly segmented AC-coupled Low-Gas Avalanche Detector (AC-LGAD) sensors whose development has just started to get support from the program. Besides hardware R&D the program has supported various vital projects such as machine background studies and simulation software developments to enable more accurate definition of the physics' requirements. Sartre and Beagle are two examples of Monte-Carlo event generators whose development was substantially boosted by the program. Both were extensively used in the context of this report.

[generic EIC-related R&D]

From HEP Software Foundation meeting

MCEGs used for Yellow Report

Source State of Software Survey Talk by Markus Diefenthaler https://indico.cern.ch/event/1200496/

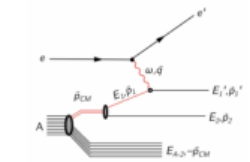


Other (N = 9): personal computer codes (N = 2), ACT, CLASDIS, ComptonRad, GRAPE-DILEPTON, MADX, MILOU, OPERA, RAYTRACE, Sartre, Topeg, ZGOUBI

From HEP Software Foundation meeting

Benchmark eA Generator for LEptoproduction — Mark Baker et al.

Talk by Markus Diefenthaler https://indico.cern.ch/event/1200496/



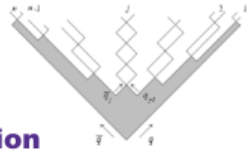
Primary interaction

Primary interaction treated by **PYTHIA6** for the hard collision.

Glauber handled by BeAGLE

PyQM: Nuclear Geometry + optional gluon radiation in medium.

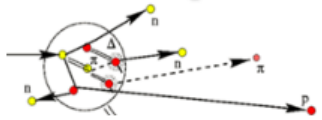
Hadronization handled by **PYTHIA6.**



Hadronization

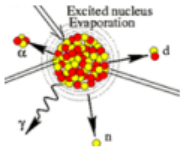
Cascade process handled by **DPMJET.**

Formation time. Stochastic.



Intra-nuclear cascade

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



Nuclear remnant evaporation & breakup

Some Nuclear Effects

	In BeAGLE
Parton distribution functions	✓
Parton saturation (CGC etc.)	
Short-range correlations	✓ (GCF)
"Fermi motion"	✓
Partonic (or "dipole") MS	✓
Partonic gluon radiation	✓
Medium-modified hadronization	
Formation times	✓
Hadronic Cascade	✓
Nuclear evaporation, breakup	✓
Photonic de-excitation of A*	✓

HSF Generators Meeting, October 6, 2022. 25 Jefferson Lab

NOTE: eA generators are very rudimentary compared to ee, ep, pp, pA, AA…
More support is needed in the outyears – but beyond the scope of this proposal.

A risk or concern involving BeAGLE

- BeAGLE is heavily used as the best general purpose eA MC option available.
  - Used to design the forward detectors and IR6.
  - Being used by ePIC & 2nd detector advocates now.
- More work is needed.
  - There are known bugs.
  - The nuclear response has not really been validated and only loosely tuned.
    - FNAL E665 μA data from 1987-88 (papers from 1994-1995) is limited and not corrected for important detector & trigger effects.

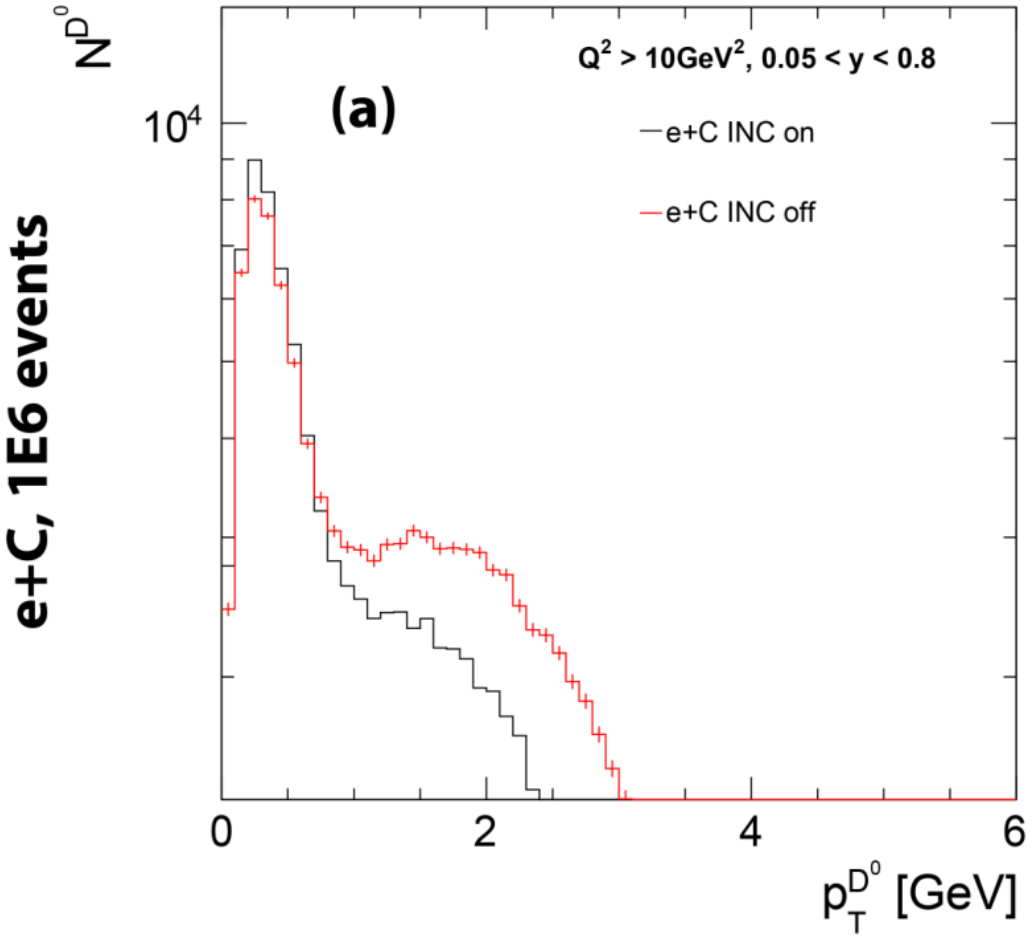
Bug example: BeAGLE kills charm events

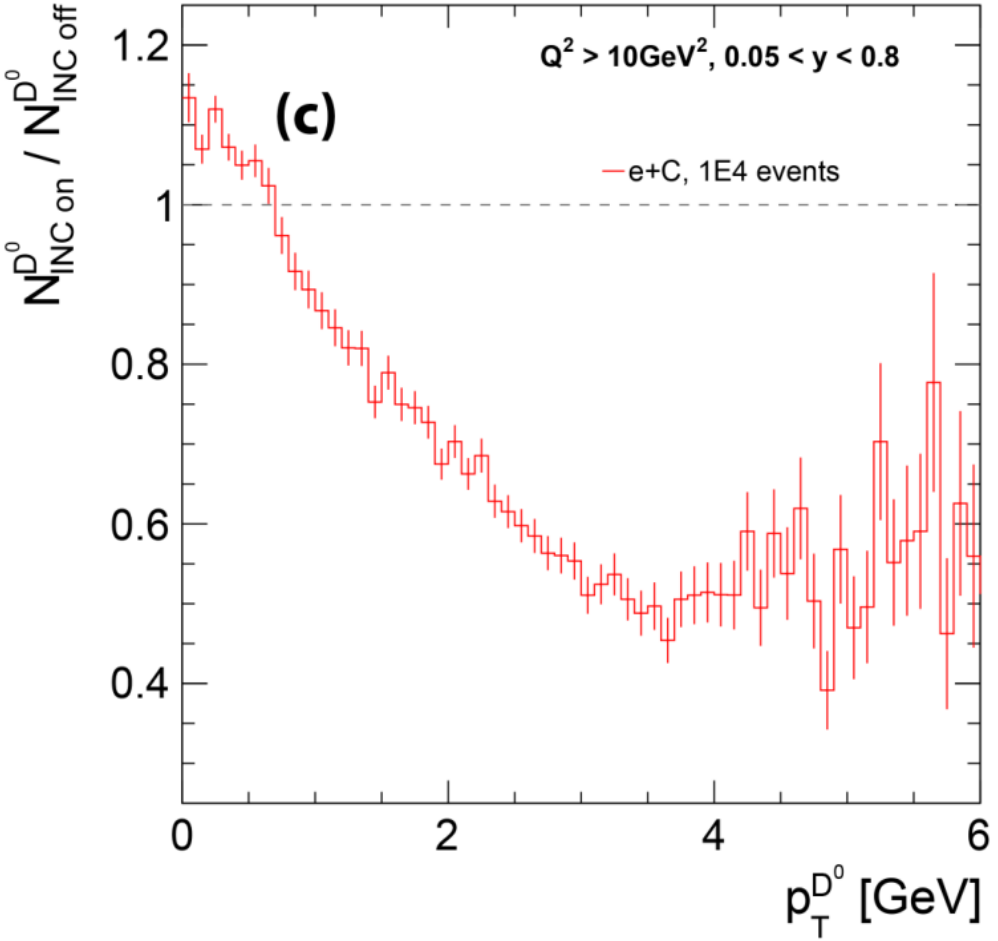
Features of Charm Hadron Production in BeAGLE

Kyle Devereaux, Wenqing Fan, Barak Schmookler

September 2, 2022

N^{D^0} existing before/after each routine call			
Routine	e+Au INC off	e+Au INC on	e+C INC on
after DT_KKEVNT	1252	1389	1613
before DT_FICONF	1252	1389	1613
after DT_FICONF	1252 (100%)	1050 (76%)	923 (57%)



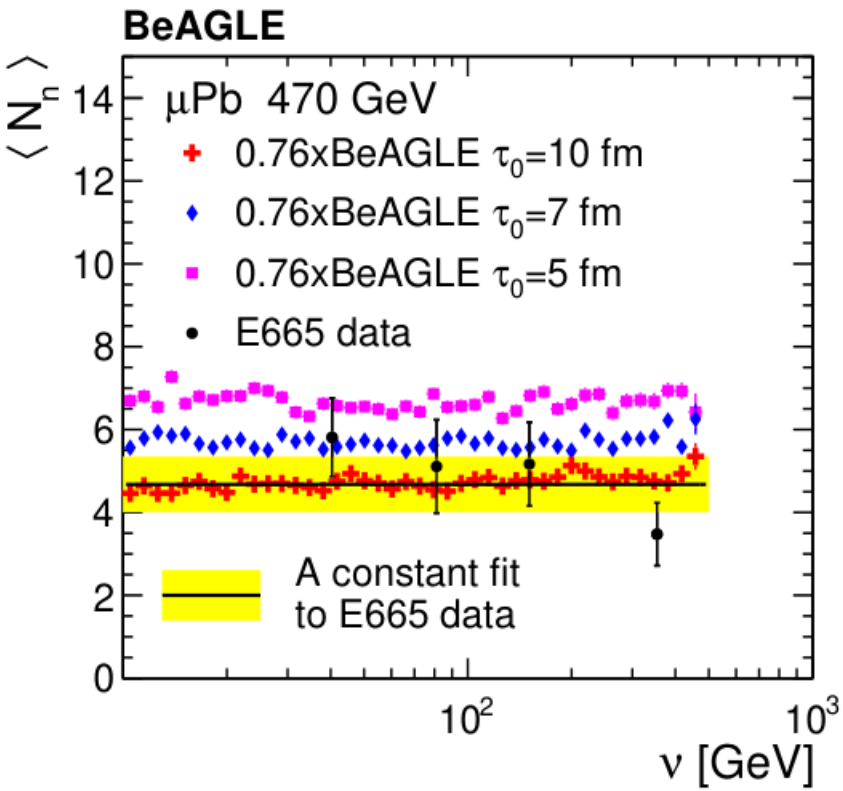


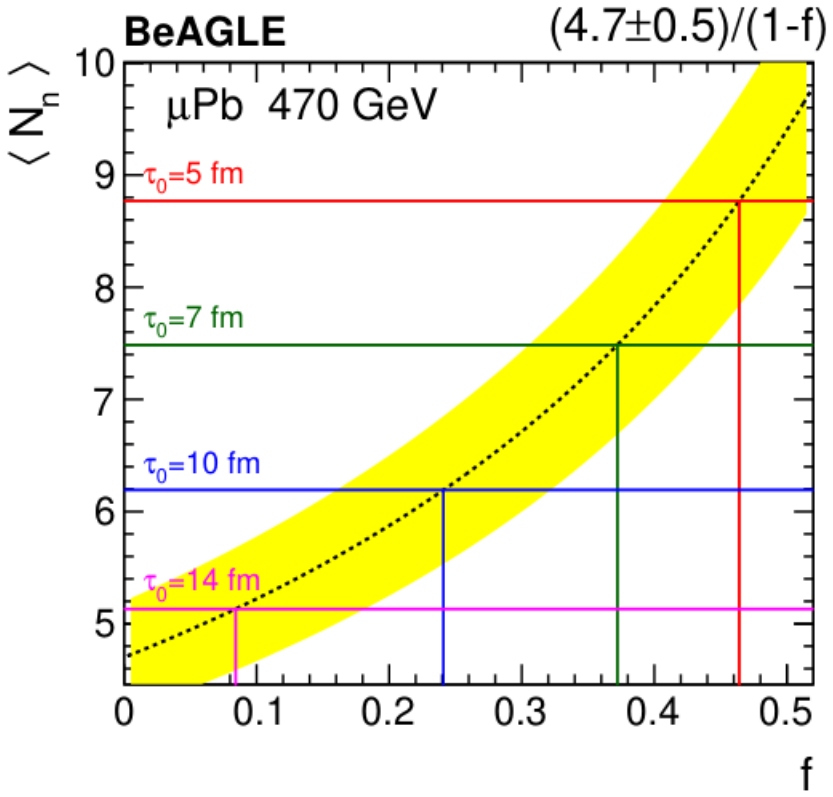
Tuning BeAGLE parameter τ_0 with neutrons

τ_0 controls the hadron formation time during an IntraNuclear Cascade.

E665 neutrons prefer τ_0=10 fm/c
IF we assume f=$N_{coherent}/N_{total}$ = 0.24.

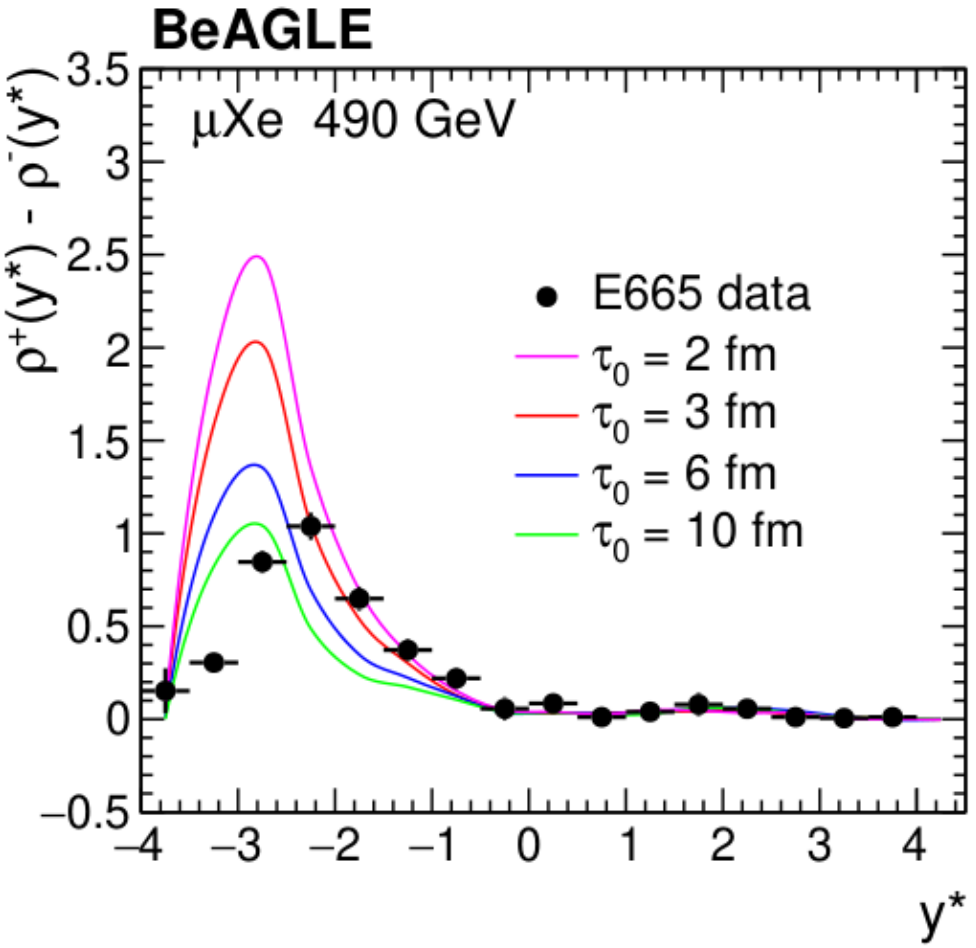
Varying the unknown fraction f,
leads to values between 7-14 fm/c





Chang et *al.*, Phys.Rev.D 106 (2022) 1, 012007 • e-Print: 2204.11998 [physics.comp-ph]
Data from: M. R. Adams et al. (E665), Phys. Rev. Lett. 74, 5198 (1995), [Erratum: Phys.Rev.Lett. 80, 2020–2021 (1998)].

Trying to tune using net charge distributions



E665 target jet data from 1987-88 is difficult to describe with BeAGLE.

It is unclear whether this is a problem with the model, the data, or our understanding of the trigger and data sample.

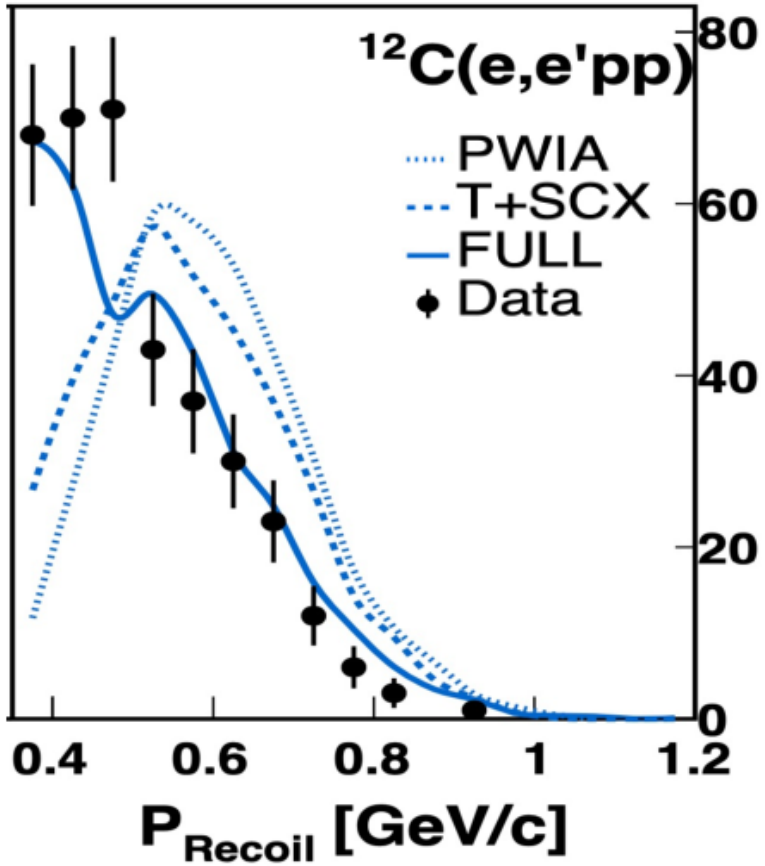
We need to tune with more recent data that we understand better.

Chang et *al*., Phys.Rev.D 106 (2022) 1, 012007 • e-Print: 2204.11998 [physics.comp-ph]
Data from: E665 Collaboration, Z. Phys. C 61(1994), 179-198

We could use JLAB data on SRC with FSI

https://indico.jlab.org/event/428/timetable/#20210325.detailed

Plot from Natalie Wright talk:
"Transport Estimations of Final State Interaction Effects on Short–range Correlation Studies"
@ 3rd Workshop on Quantitative Challenges in EMC and SRC Research

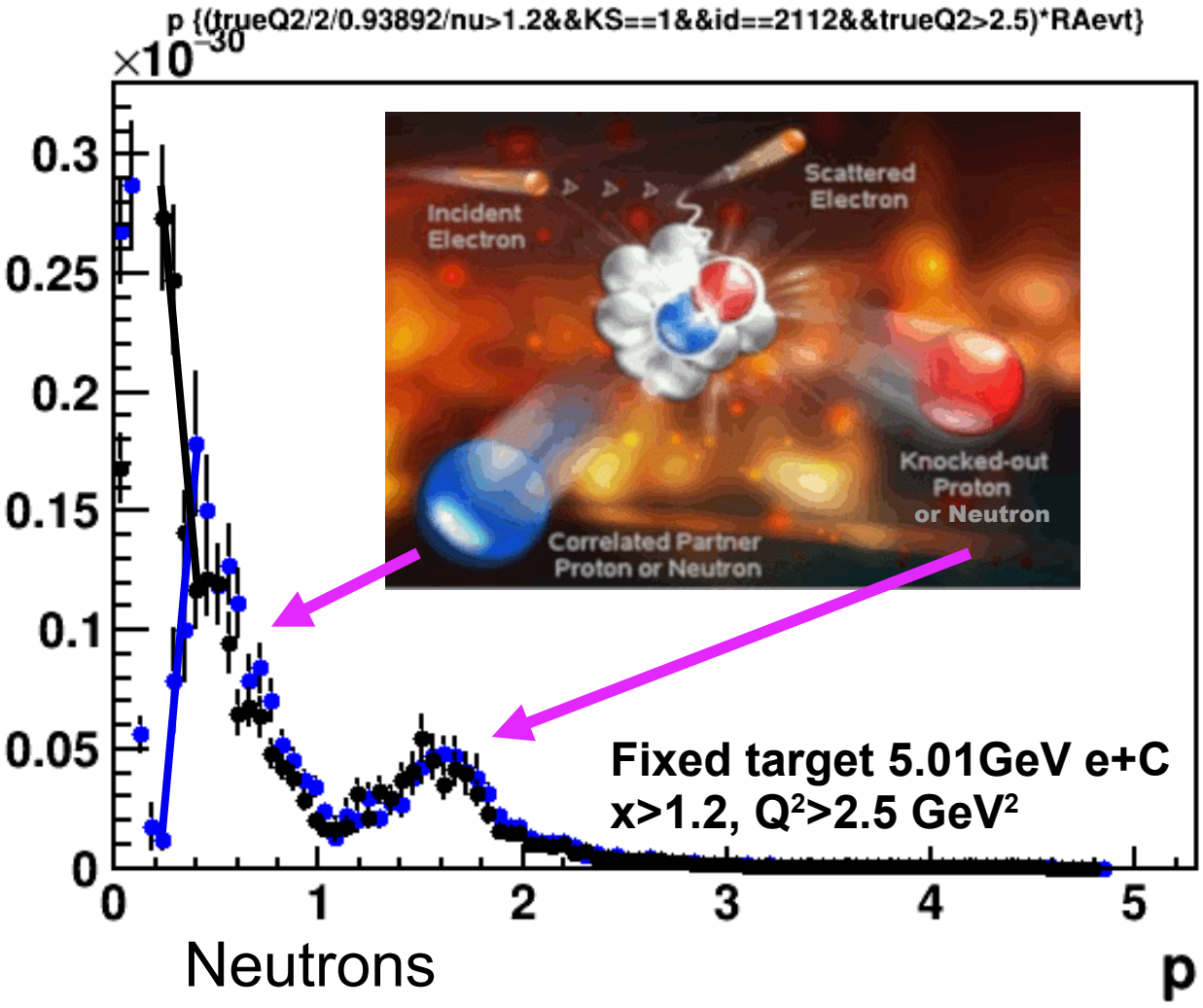


eGENIE (used for light ions and low energies) allows a single hadron-hadron scatter instead of a full cascade, but is otherwise similar to BeAGLE in terms of FSI.

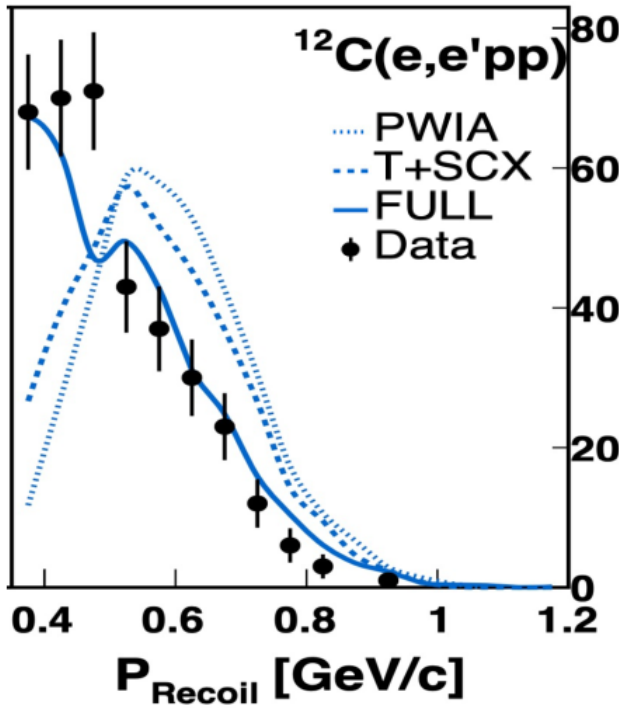
Transport FSI: Excess nucleons at low end of recoil peak.
Washing out the peak.

Recoil nucleon affected by this FSI

Blue is no IntraNuclear Cascade
Black is full BeAGLE



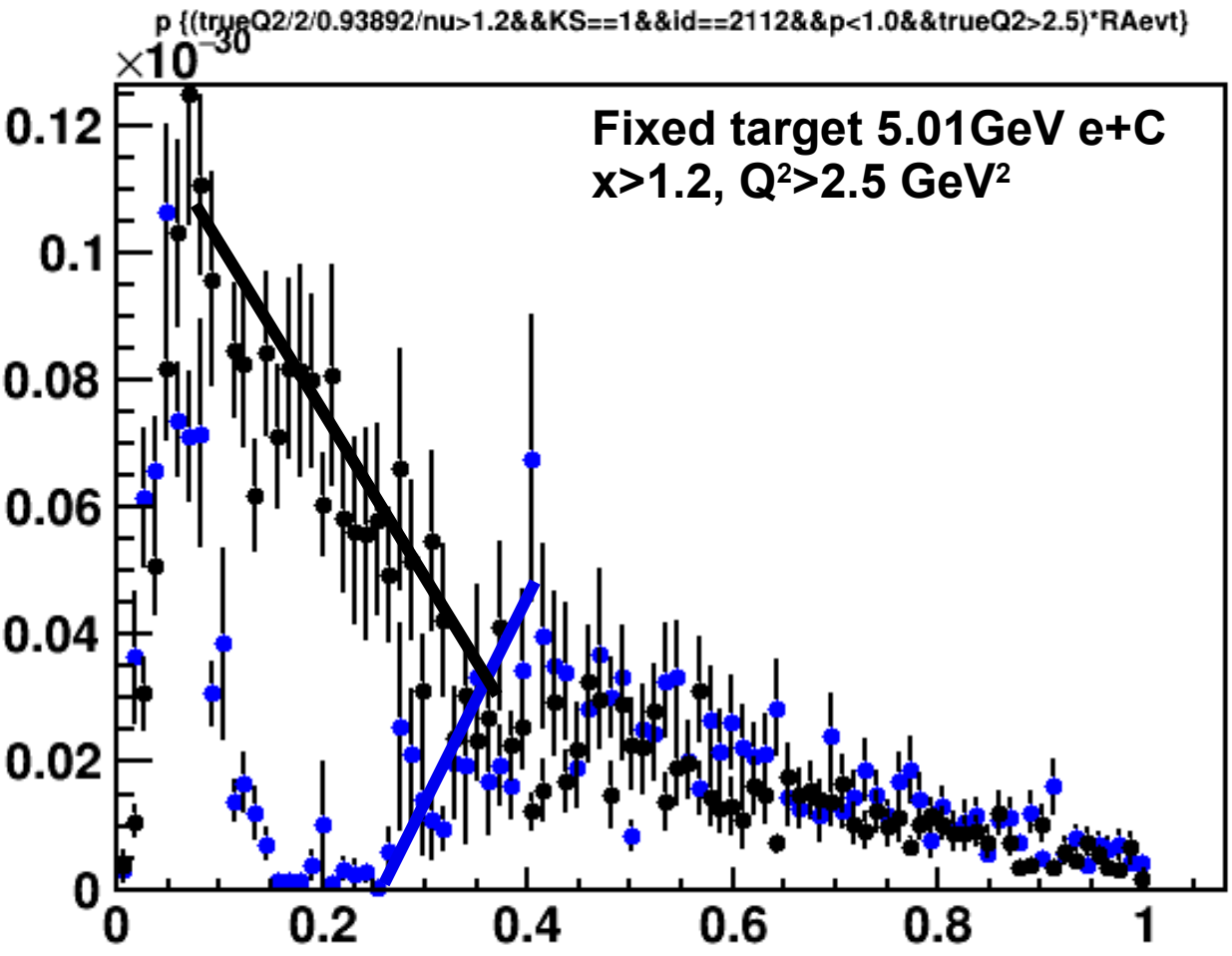
Natalie Wright et al.
eGENIE vs. data



Low momentum excess washes out peak

Blue is no IntraNuclear Cascade

Black is full BeAGLE



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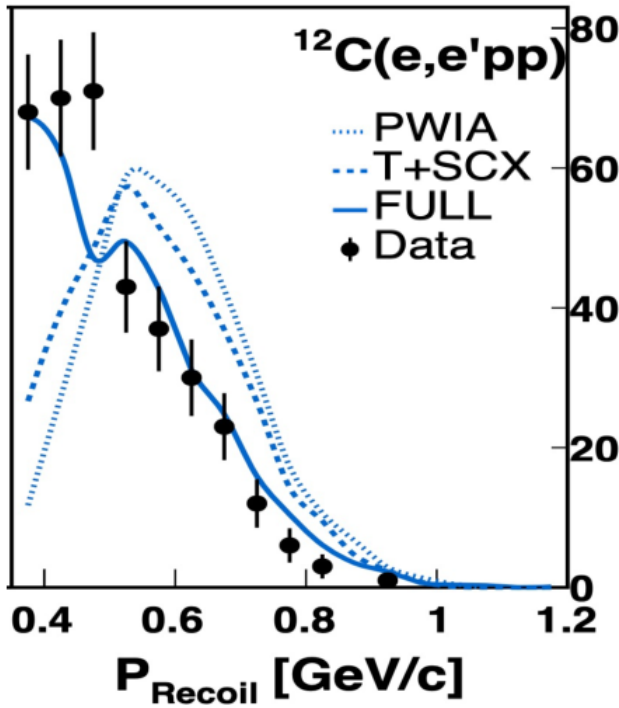

Proposed Work: 1-year project (FY2023)

- Fix handling of A=3 nuclei.
- Fix "rejected events" and nonphysical suppression of interesting rare events.
- Comparison to JLAB SRC FSI data: validation and tuning of BeAGLE.
- Fix 4-momentum non-conservation errors.
- Cleanup code (remove unused code etc.)
- Improve documentation

Proposed Funding

Item	100%	80%	60%
MDBPADS LLC cost	\$70.4k	\$68.3k	\$63.2k
MIT student support	\$30.0k	\$15.0k	\$0k
Travel	\$5k	\$1k	\$0k
Total	\$105.4k	\$84.3k	\$63.2k

Table 1: Budget for Year 1. All items include institutional overheads.

Mark Baker (MDBPADS) is an expert on BeAGLE.

Natalie Wright (MIT student) is an expert on use of eGENIE and comparison to JLAB SRC data.

Jackson Pybus (MIT student) is an expert on GCF (SRC simulation) and A=3 simulation.

Impact of Reduced Funding

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Table 1: Budget for Year 1. All items include institutional overheads.

100%: the goals and deliverables are achievable.

80%: Can fix known problems and compare with data.
Tuning, cleanup & documentation if time permits.

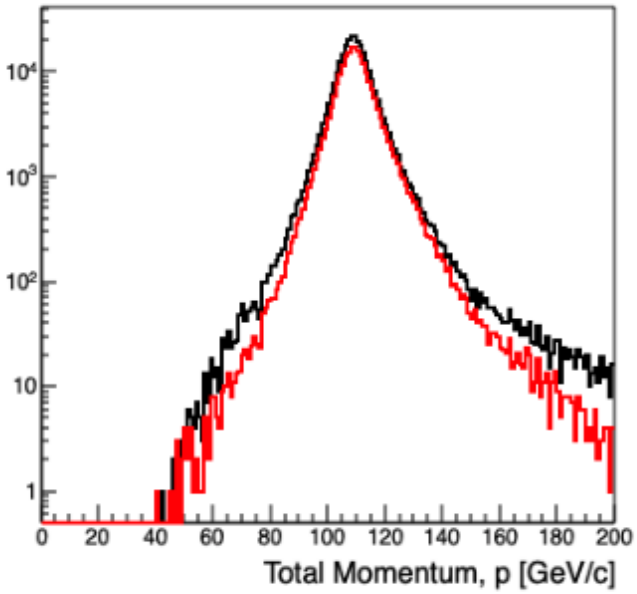
60%: Can fix known problems.
Comparison with data & tuning at risk.
Code cleanup and documentation will be dropped.

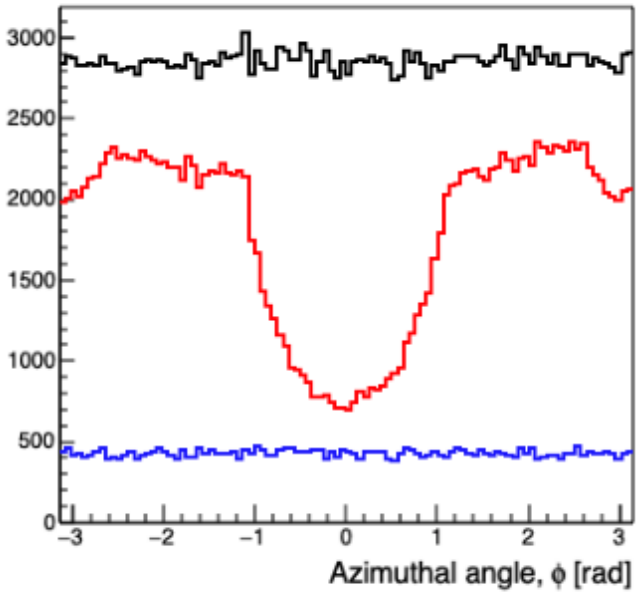
Conclusions

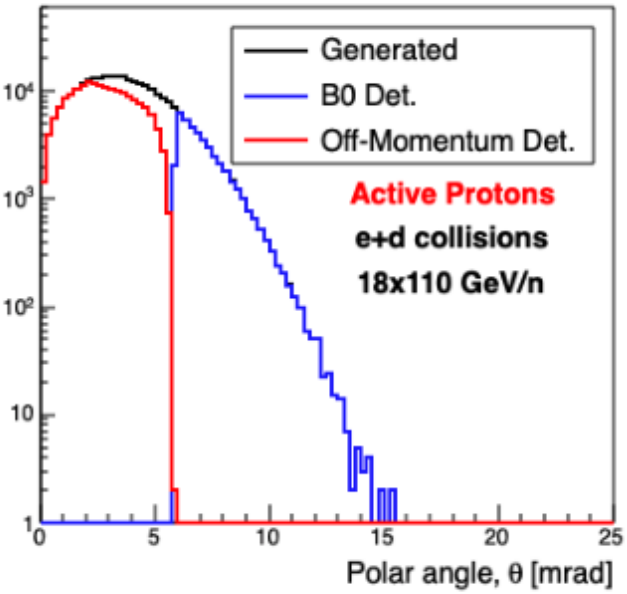
- BeAGLE has been and continues to be heavily used for IR & detector design.
- More work is needed!
  - There are known bugs.
  - The nuclear response has not really been validated and only loosely tuned.
- We outlined a one year project to put BeAGLE into a more reliable and well understood state.
- Full funding is recommended to reduce risks to the eA physics goals for both detectors.

Extra slides

Example: diffractive e+D→e'+p+n+J/ψ





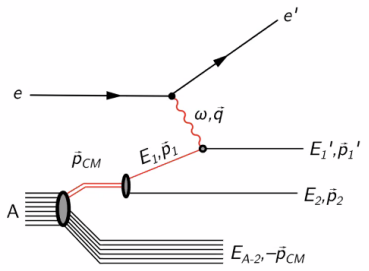


Yellow Report Figure 11.103
BeAGLE + GEANT

http://www.eicug.org/web/sites/default/files/Yellow_Report_v1.1.pdf

BeAGLE Structure using GCF

Use: GCF (generalized contact formalism) for primary interaction.
F. Hauenstein et al., PRC 105(2022) 3 034001



Primary interaction

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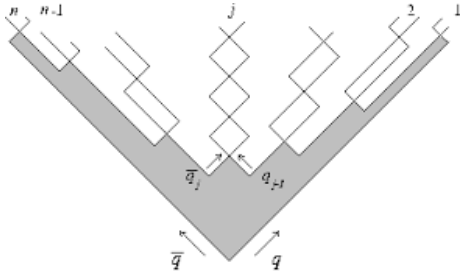

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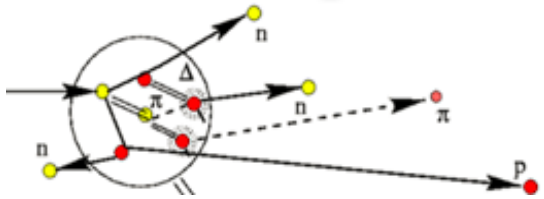
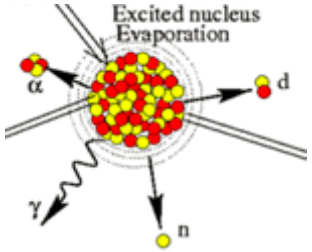
Formation time. Stochastic.

Hadronization



Intra-nuclear cascade

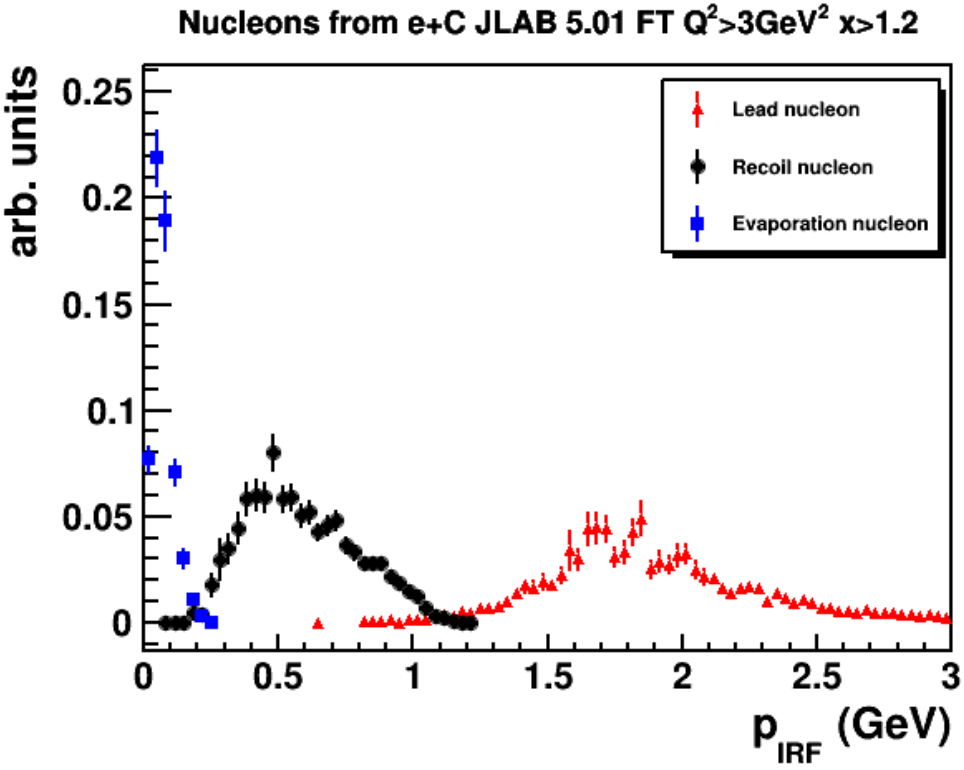
Nuclear remnant evaporation and break up by **FLUKA.**



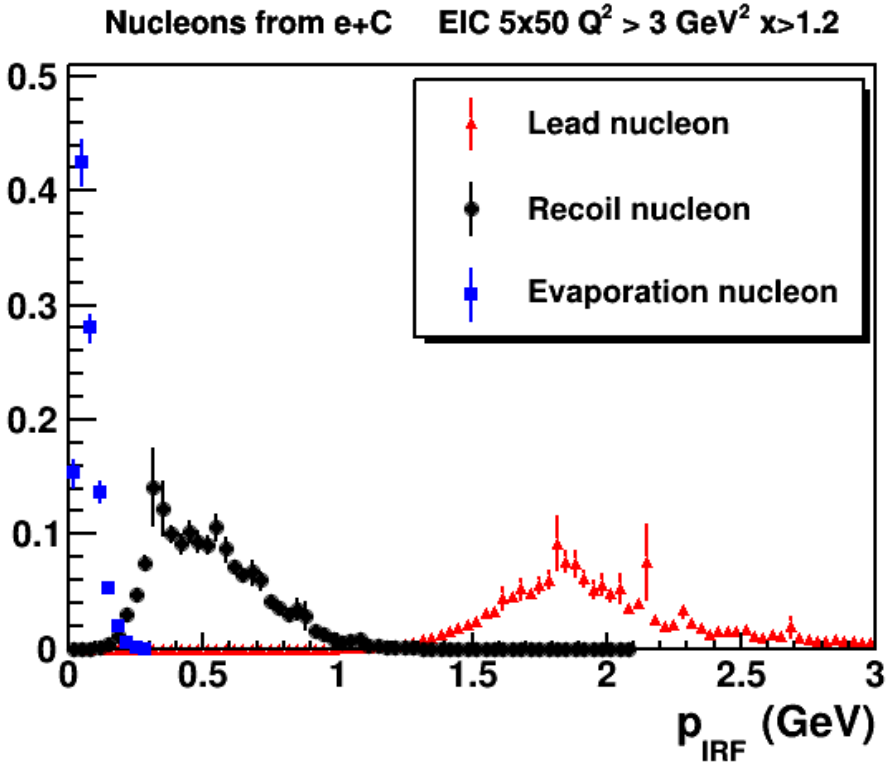
Nuclear remnant evaporation & breakup

JLAB & EIC look similar in the Target/Ion RF

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



GCF(Generalized Contact Formalism) + BeAGLE
w IntraNuclear Cascade turned off.