

# BeAGLE

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MDBPADS LLC

**November 17, 2022**

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# Collaborators and Advisors

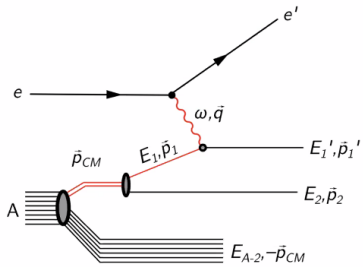
## Benchmark **eA** Generator for **LE**ptoproduction

Also works for photoproduction  $Q^2 < 1 \text{ GeV}^2$

Contributors to BeAGLE code underlined.

- A. Accardi, E. Aschenauer, N. Armesto, MDB, W. Chang, R. Dupré, M. Ehrhart, I. Friscic, F. Hauenstein, O. Hen, D. Higinbotham, C. Hyde, A. Jentsch, J.H. Lee, V. Morozov, P. Nadel-Turonski, D. Nguyen, J. Pybus, C. Robles, A. Schmidt, B. Schmookler, A. Sy, T. Toll, T. Ullrich, Z. Tu, C. Weiss, L. Zheng.
- Advice from: M. Strikman, R. Venugopalan

# BeAGLE Structure



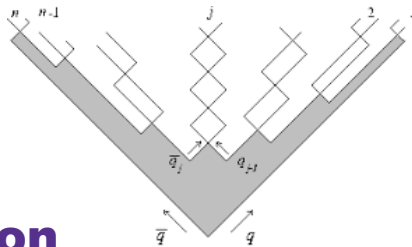
Primary interaction treated by **PYTHIA6** for the hard collision.

# Glauber handled by BeAGLE

**PyQM:** Nuclear Geometry + optional gluon radiation in medium.

Hadronization handled by **PYTHIA6**.

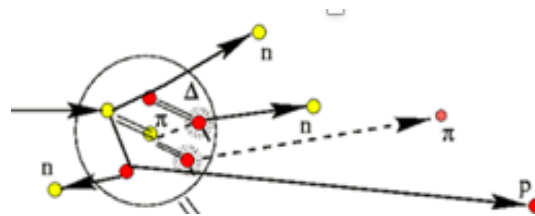
## Primary interaction



## Hadronization

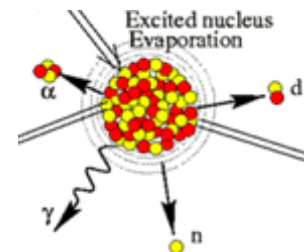
Cascade process  
handled by **DPMJET.**

## Formation time. Stochastic.



## Intra-nuclear cascade

## Nuclear remnant evaporation & breakup



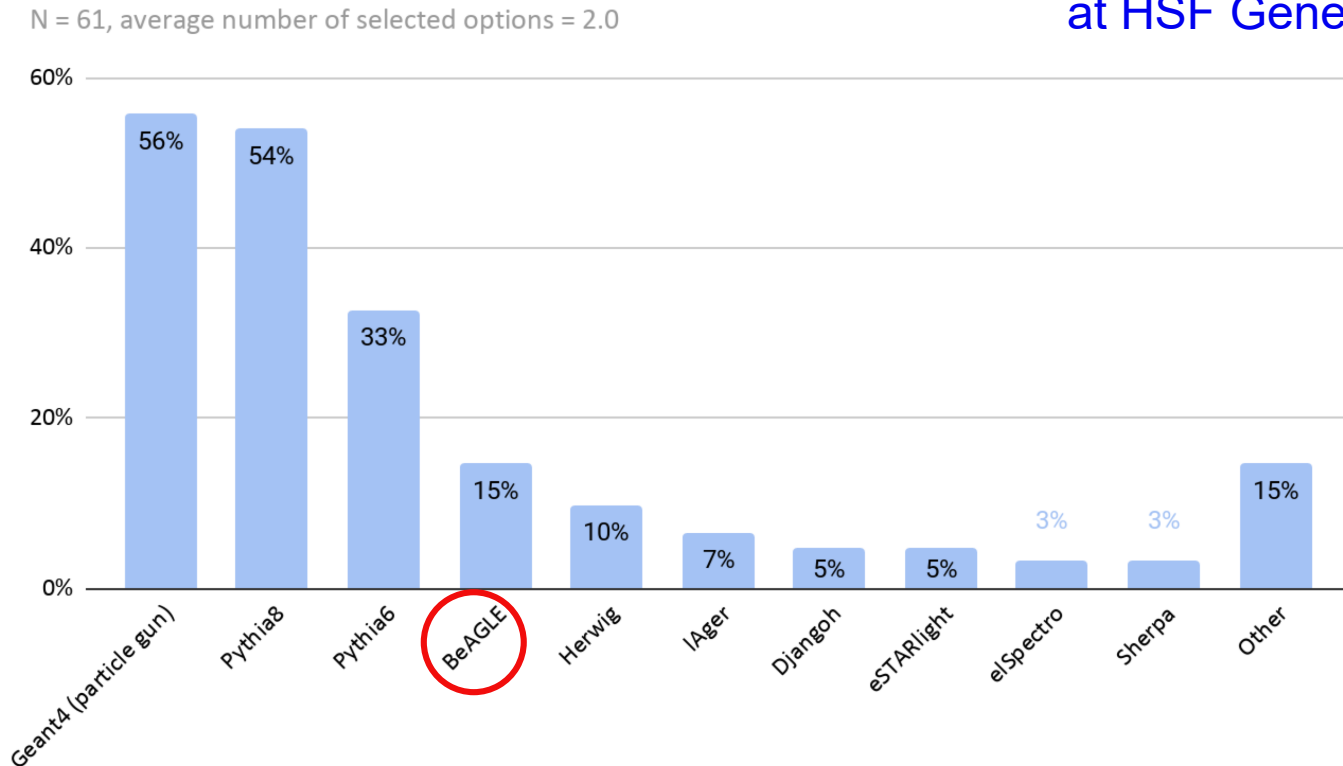
Nuclear remnant  
evaporation and  
break up by **FLUKA**.

# BeAGLE is being used!

## MCEGs used for Yellow Report

See also Daria Sokhan's talk yesterday...

Source [State of Software Survey](#) Talk by Markus Diefenthaler <https://indico.cern.ch/event/1200496/> at HSF Generator WG Meeting



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

HSF Generators Meeting, October 6, 2022.

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Jefferson Lab

# Minutes from ePIC from this week

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Minutes of EPIC Far Forward Meeting 15 Nov 2022

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Present: Alex Jentsch, Michael Murray, Yulia Furletova, Michael Pitt, Lynn Wood, Po-Ju Lin, Sakib Rahman, Peter Steinburg, Wengliang Li, Carlos A, Eden, Zvi Citron, Mark Baker

Agenda & slides at  
<https://indico.bnl.gov/event/17756/>

Michael Pitt presented his study of the B0 EMCAL in the EPIC framework. (See slides) We discussed resolution impacts from conversions of photons upstream of the main detector. Zvi and Michael mentioned the need for physics MC samples to move beyond the particle gun studies. Alex supplied them with the previous study of incoherent vetoing using BeAGLE (<https://arxiv.org/abs/2108.01694>) so they can see what has been done before along these lines. We will look into including some of these events for EPIC simulations.

... (minutes continue)

# Plans for (FY) 2023 (until 8pm yesterday)

- BeAGLE is still being used to tweak the ePIC design and for detector/IR 2 studies.
- Need to fix some BeAGLE "features"
  - "Unusual events" like heavy flavor production are artificially suppressed. (connects to Brian's talk)
  - $A=3$  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. (connects to Daria's talk)

# Plans for (FY) 2023

- BeAGLE is still being used to tweak the ePIC design and for detector/IR 2 studies.
  - Need to fix some BeAGLE "features"
    - "Unusual events" like heavy flavor production are artificially suppressed.
    - $A=3$
    - Four
    - Need
  - BeAGLE has not been validated or fully tuned, leading to uncertainties.
- Look for funding and personpower

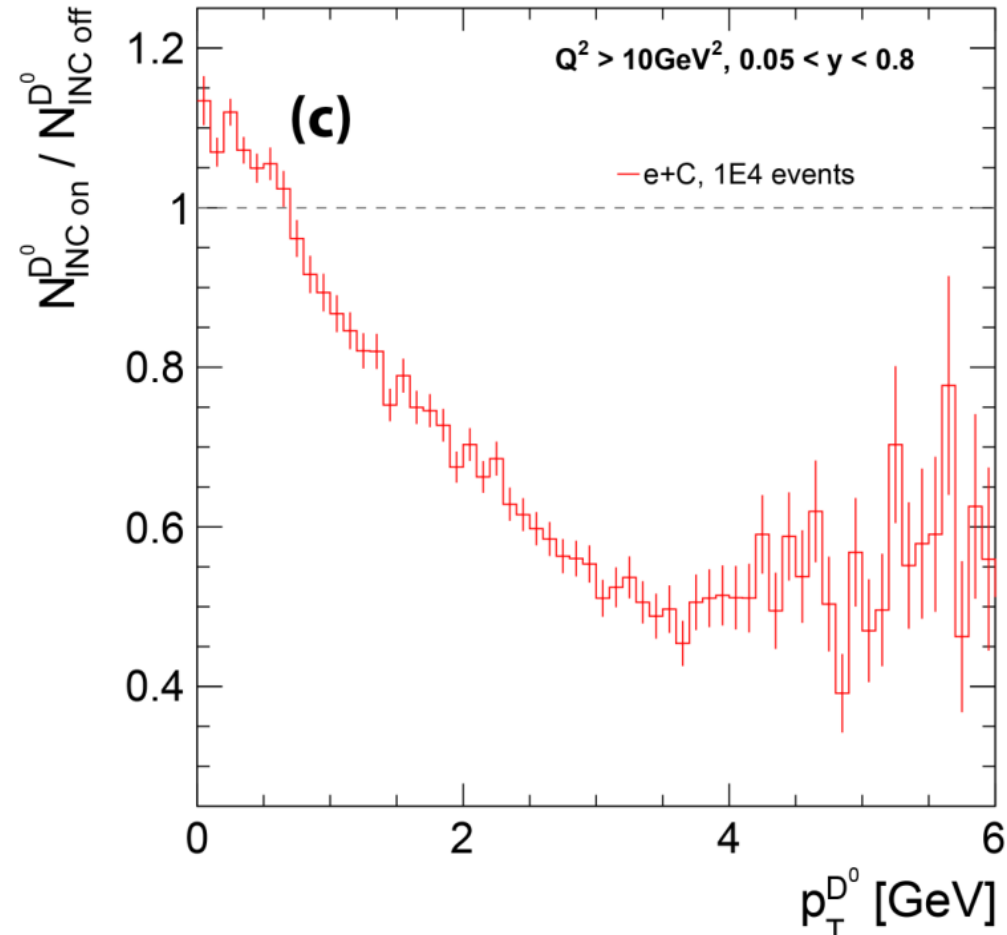
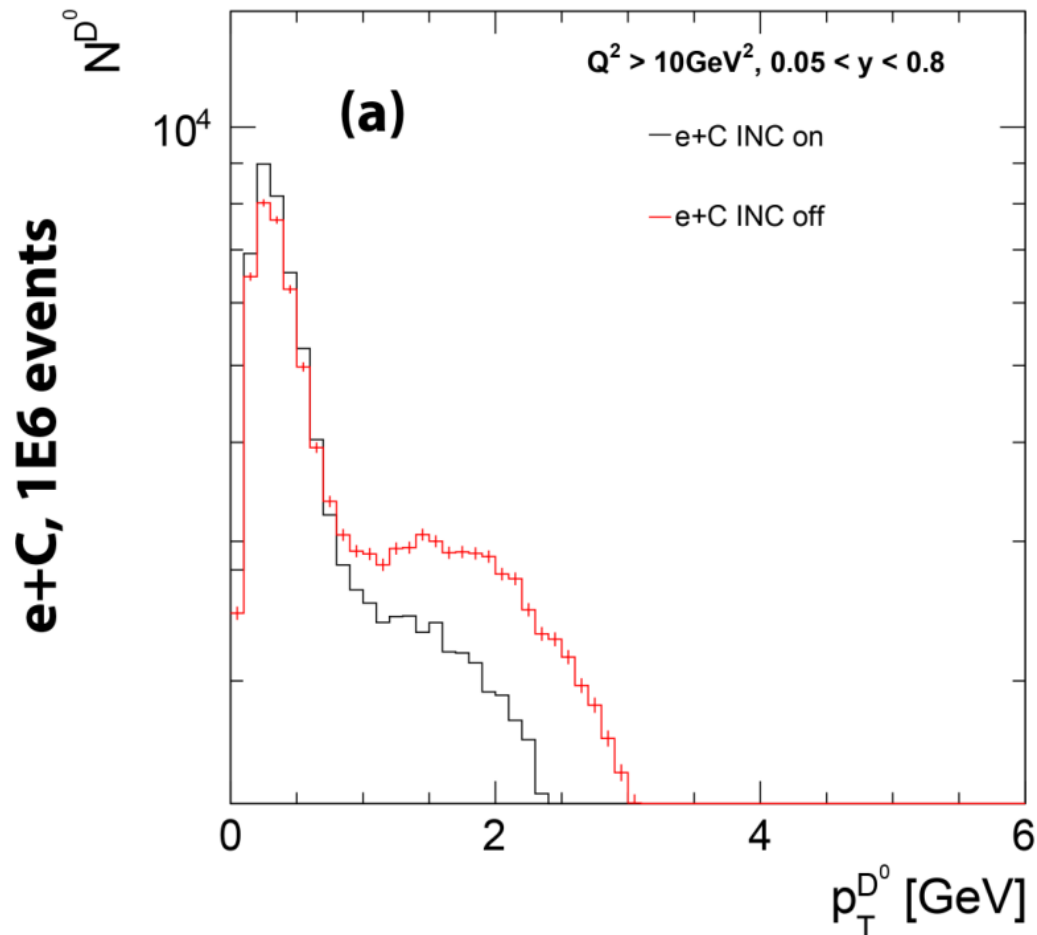
# Bug: BeAGLE (DPMJet) kills charm events

## 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%)





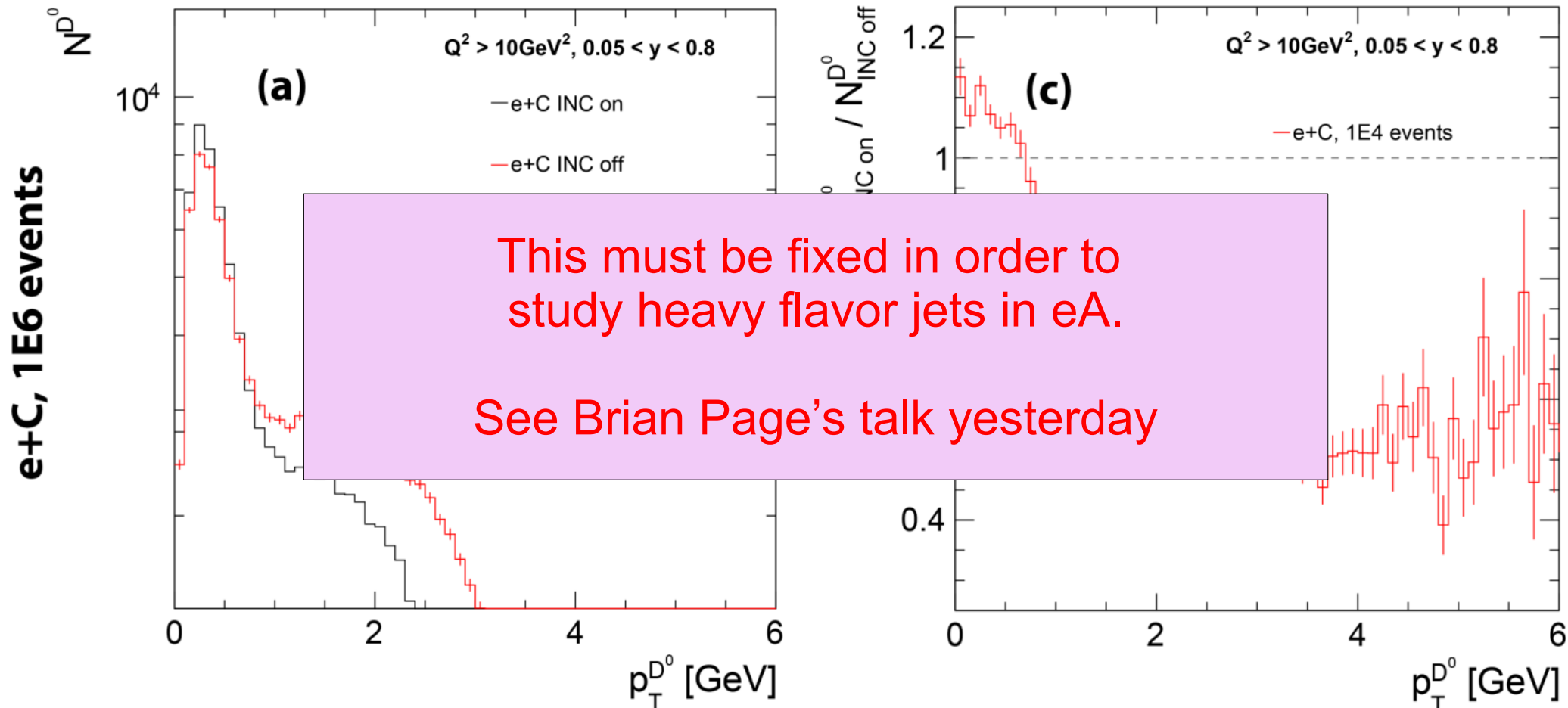
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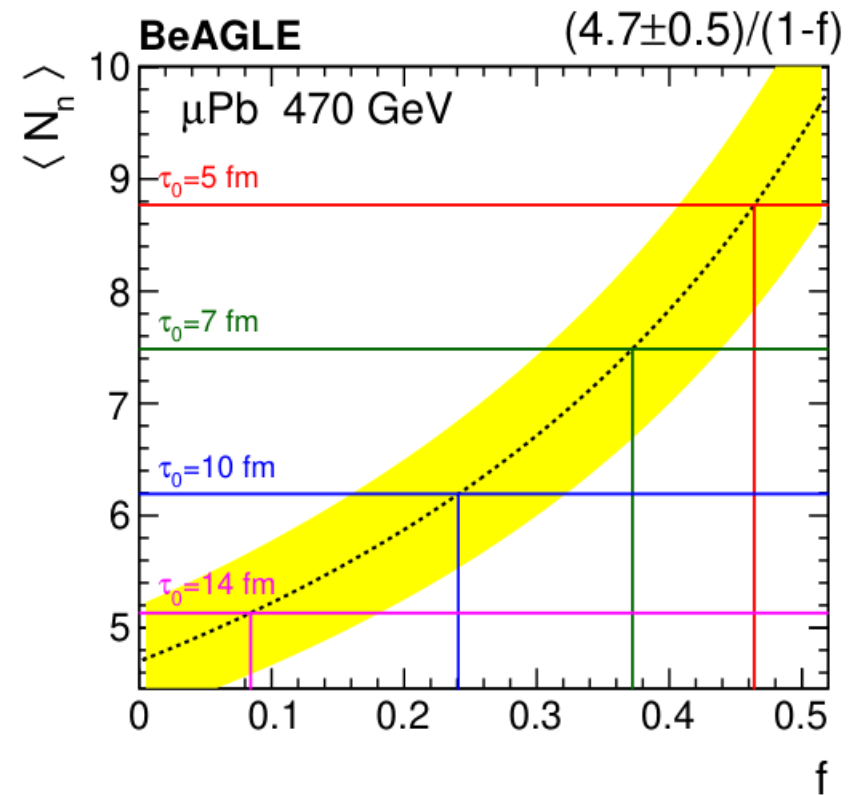
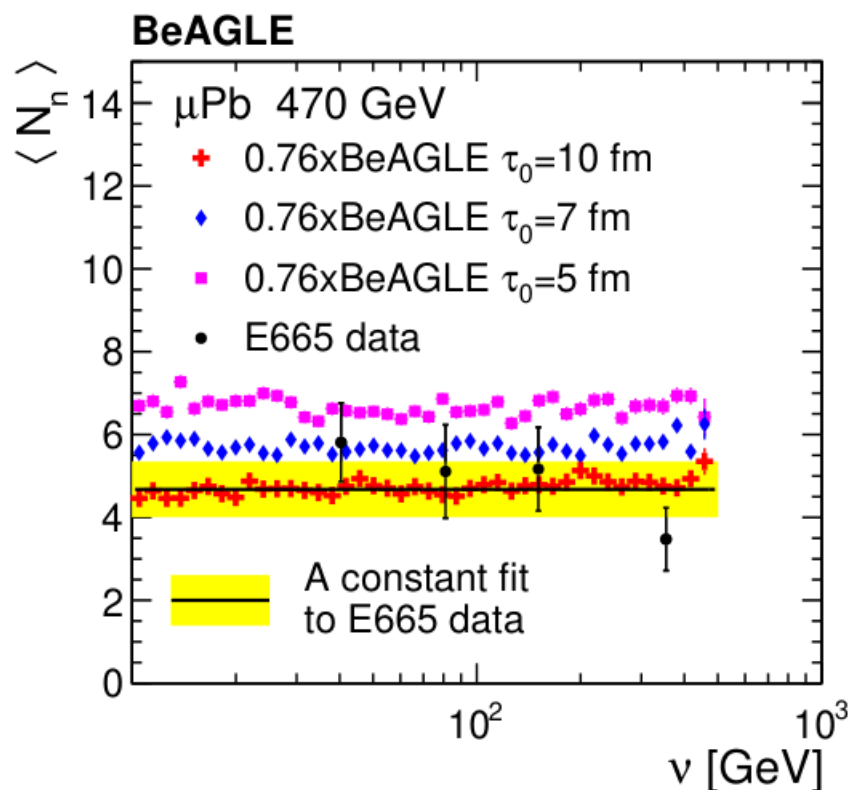


# Tuning BeAGLE parameter $\tau_0$ with neutrons

$\tau_0$  controls the hadron formation time during an IntraNuclear Cascade.

E665 neutrons prefer  $\tau_0=10$  fm/c  
IF we assume  $f=N_{\text{coherent}}/N_{\text{total}} = 0.24$ .

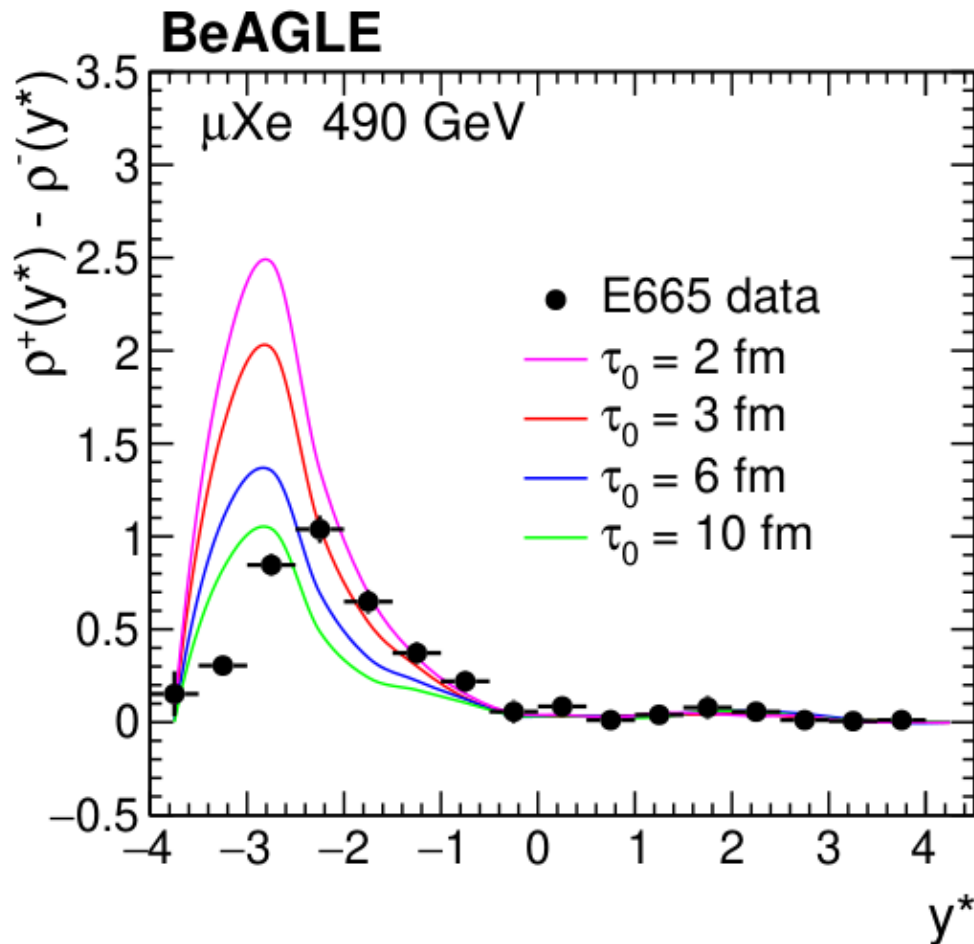
Varying the unknown fraction  $f$ ,  
leads to values between 7-14 fm/c



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.

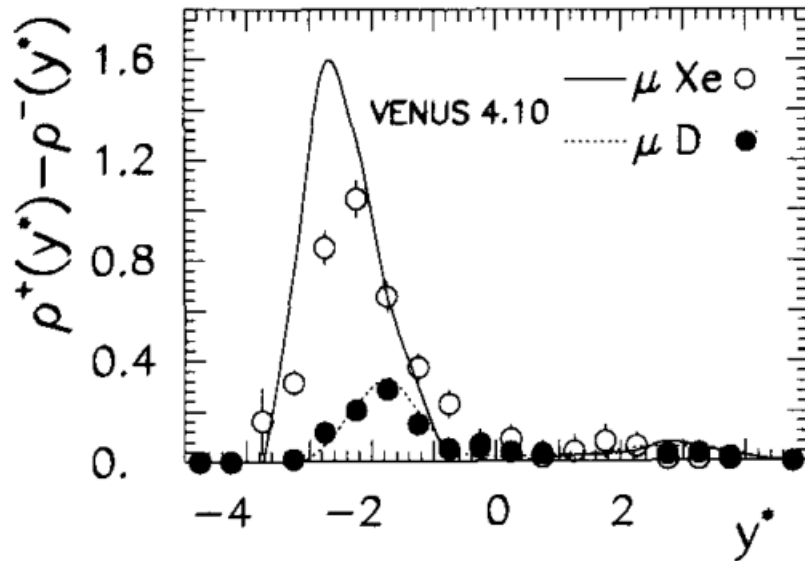
It is unclear whether this is a problem with the model, the data, or our understanding of the trigger and data sample.

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

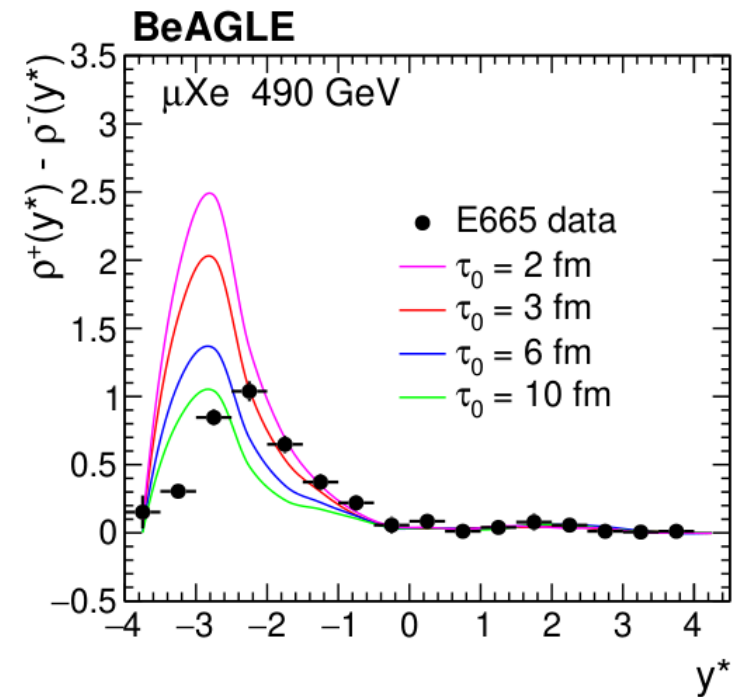
Chang et al., Phys.Rev.D 106 (2022) 1, 012007 • e-Print: 2204.11998 [physics.comp-ph]  
Data from: E665 Collaboration, Z. Phys. C 61(1994), 179-198

# Trying to tune using net charge distributions

**E665 could not describe the data either in 1994**



**Fig. 25.** Normalized cms-rapidity distribution of the hadronic net charge for  $\mu$ D (full circles) and  $\mu$ Xe scattering (open circles). The lines represent the predictions of the VENUS model

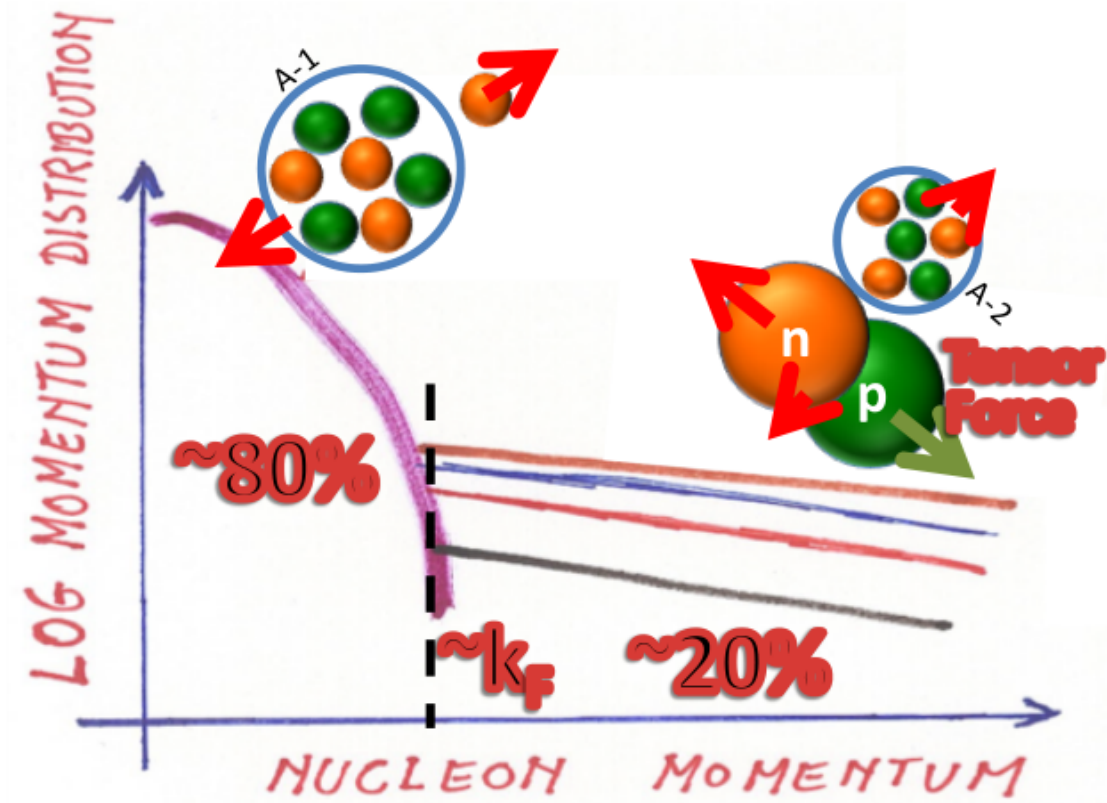
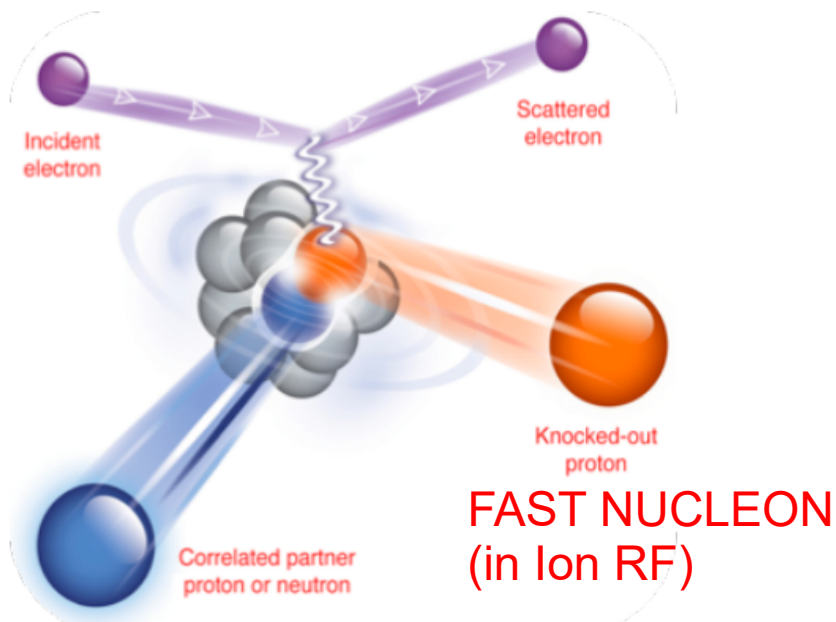


**Note:**  
Filled circles in BeAGLE plot  
Are the open circles from E665

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

# Short-range correlations (quasielastic)

## Probing Correlations Using Hard Knockout Reactions



Correlated SLOW RECOIL NUCLEON  
Probes Intranuclear Cascade (final state interaction)

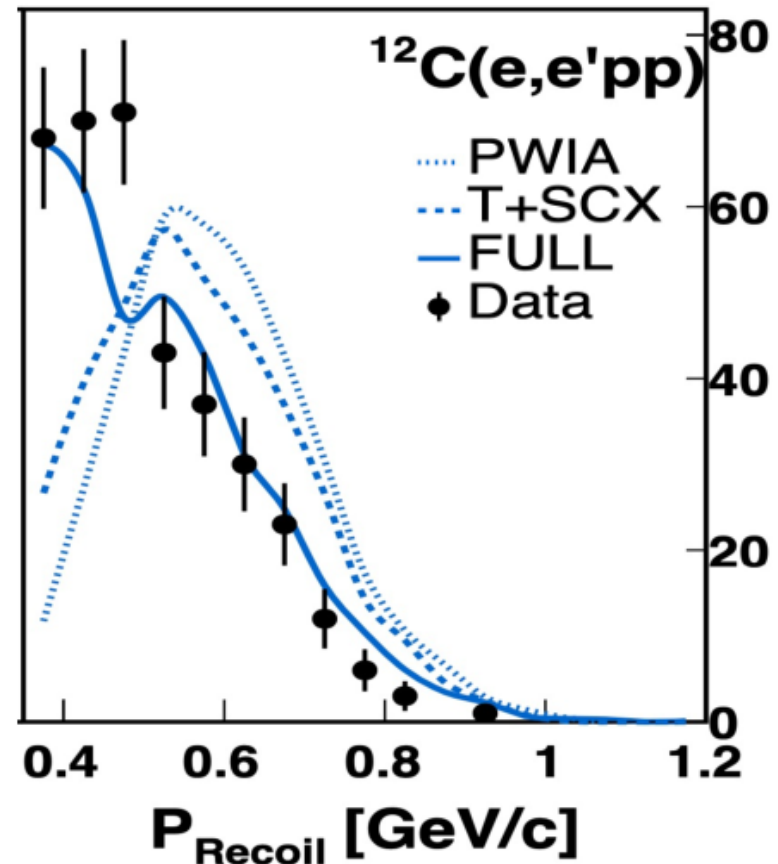
# We could use JLAB data on SRC with FSI

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

Plot from Natalie Wright talk:

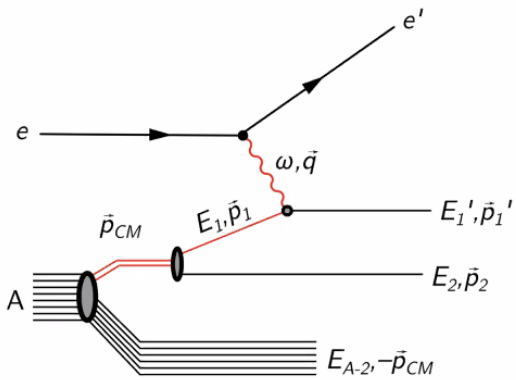
“Transport Estimations of **Final State Interaction** Effects on **Short-range Correlation** Studies”  
@ 3<sup>rd</sup> Workshop on Quantitative Challenges in EMC and SRC Research

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.



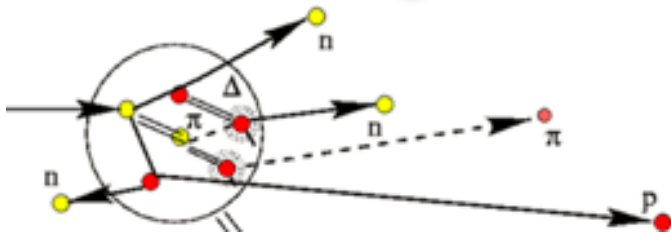
Transport FSI: Excess nucleons at low end of recoil peak.  
Washing out the peak.

# BeAGLE as an afterburner!



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

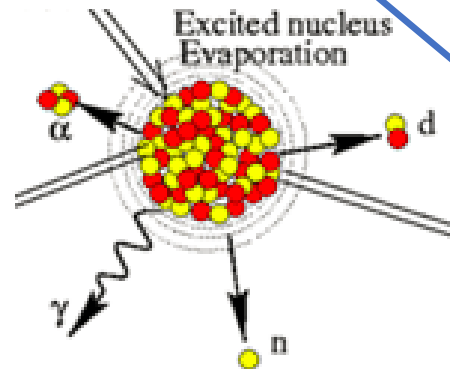
## Primary interaction



## Intra-nuclear cascade

Cascade process  
handled by **DPMJET**.

## Nuclear remnant evaporation & breakup



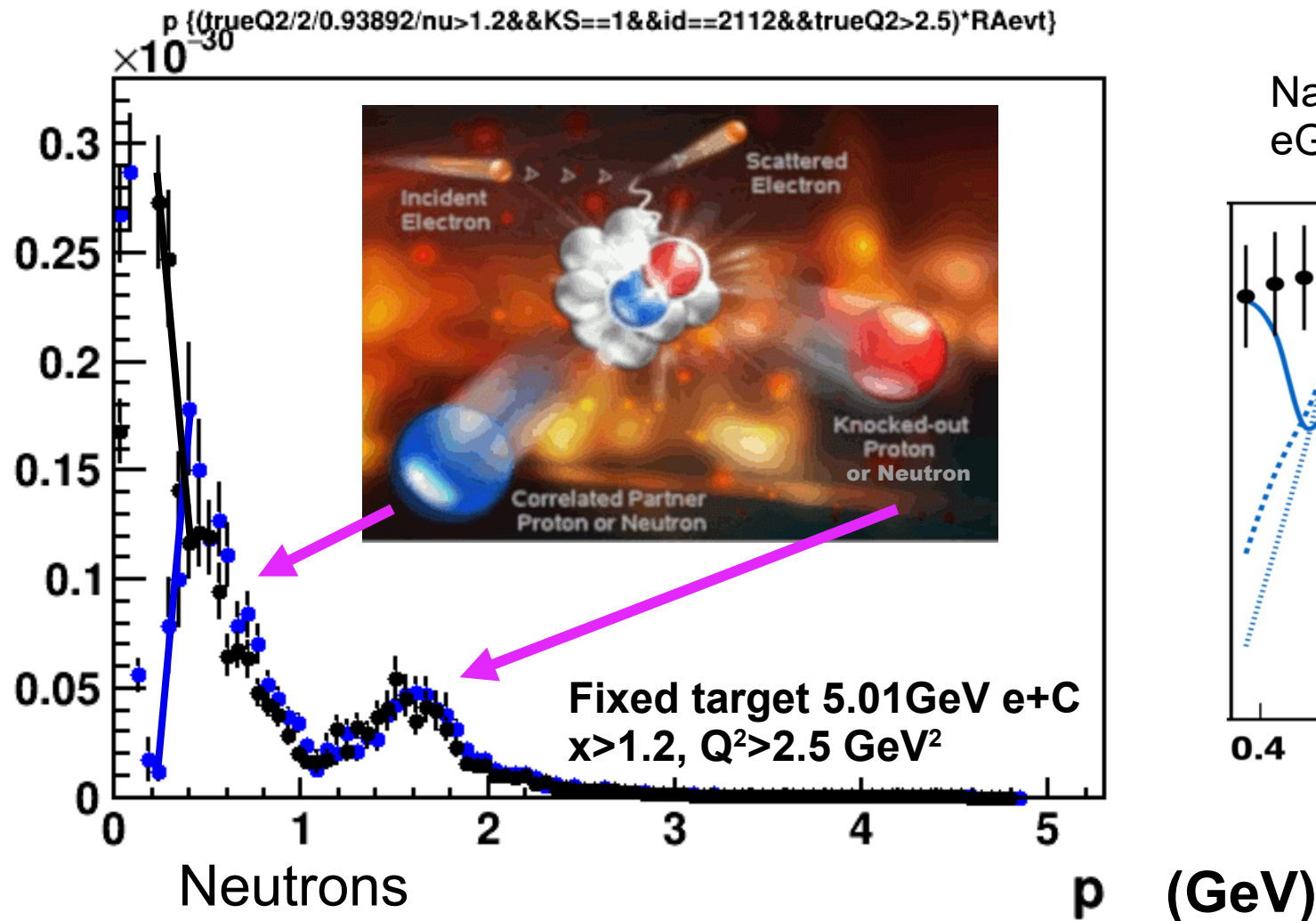
Nuclear remnant  
evaporation and  
break up by **FLUKA**.



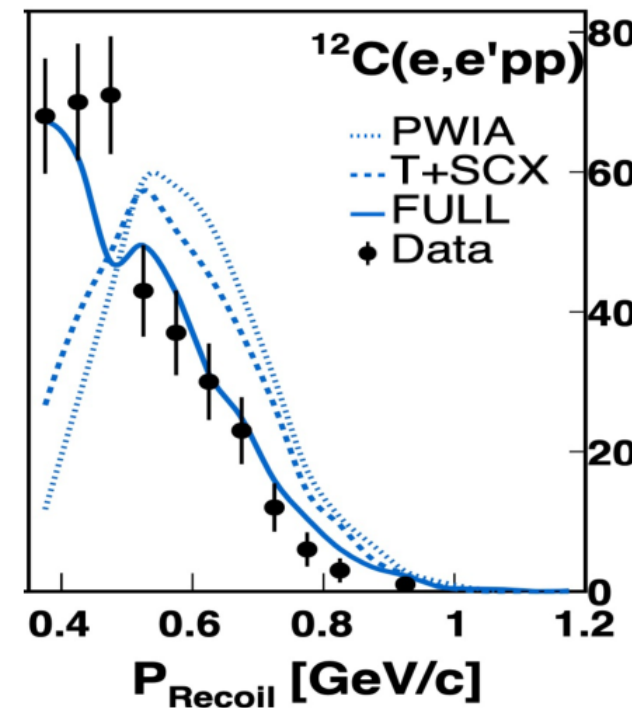
# Recoil nucleon affected by this FSI

Blue is no IntraNuclear Cascade

Black is full BeAGLE



Natalie Wright et al.  
 eGENIE vs. data

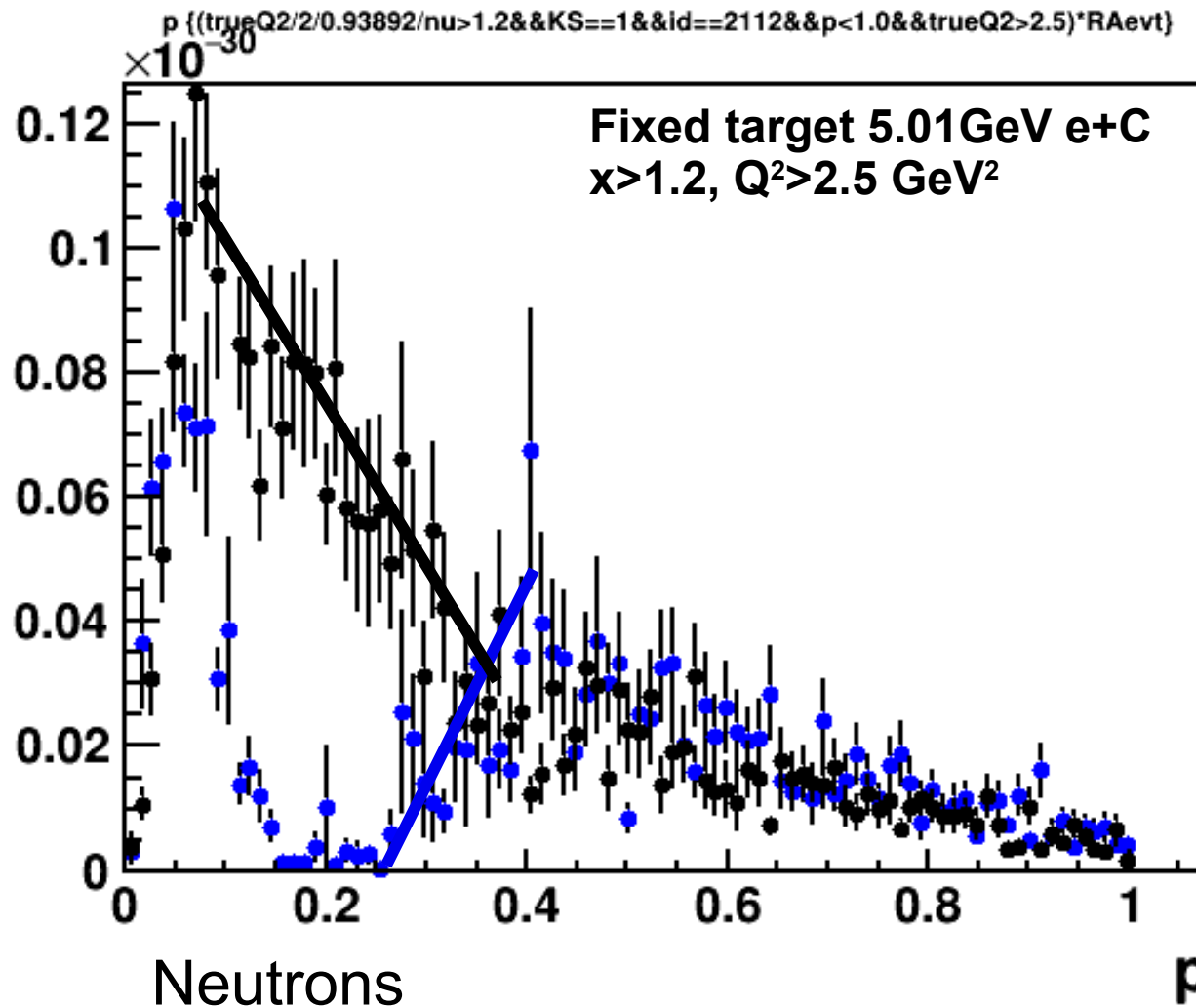




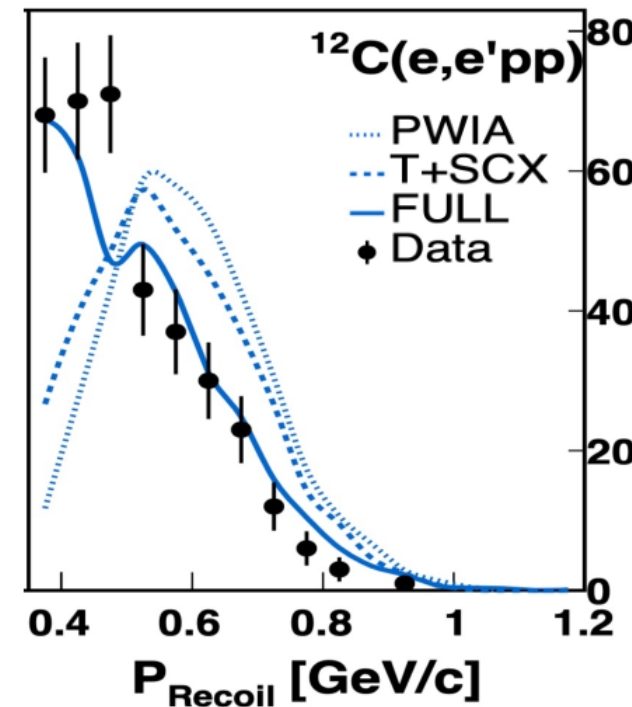
# Low momentum excess washes out peak

Blue is no IntraNuclear Cascade

Black is full BeAGLE



Natalie Wright et al.  
eGENIE vs. data



# What's next for BeAGLE? eA simulation?

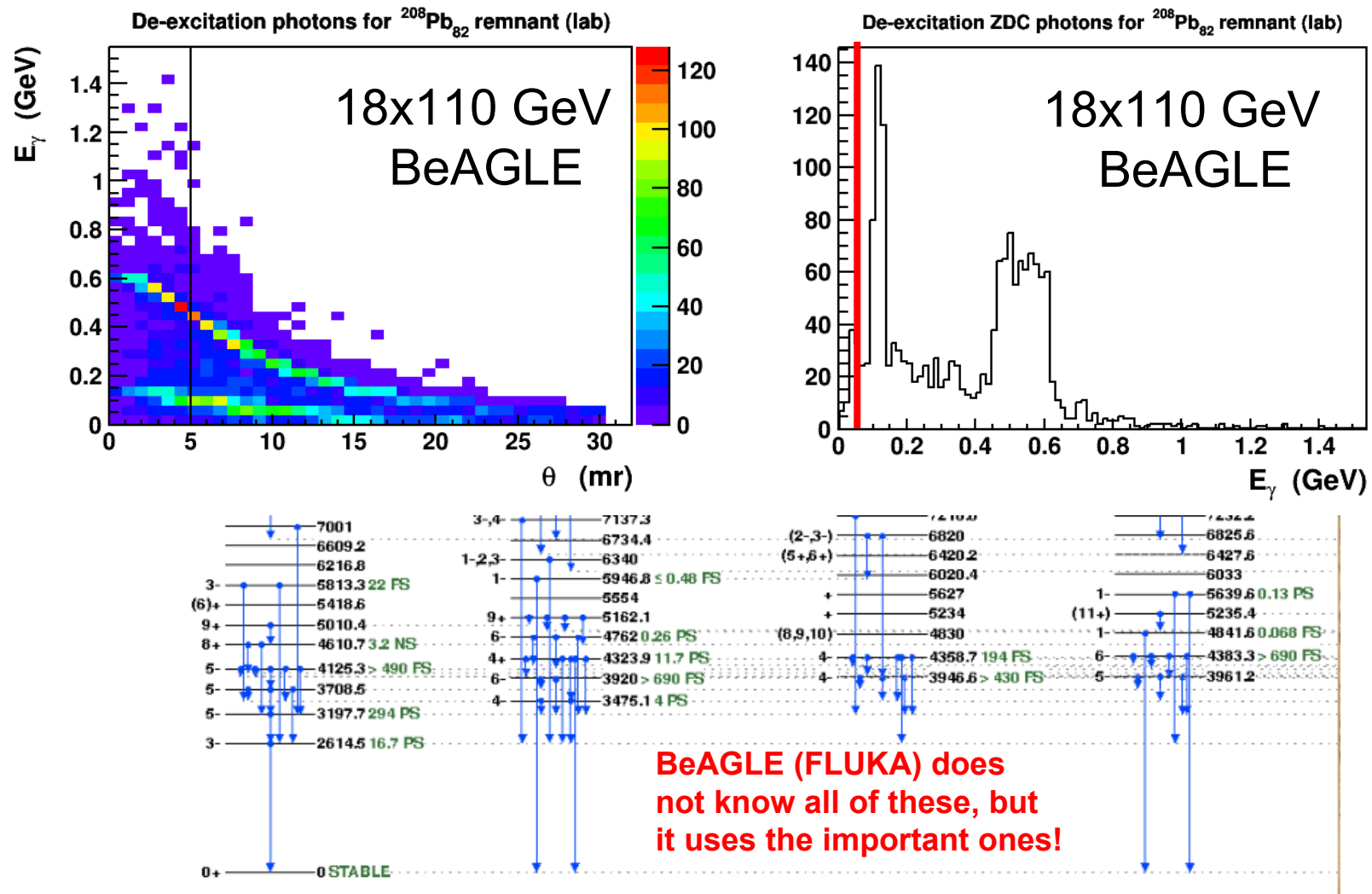
- Still important for EIC detector/IR design
- Urgent needs (unfunded!)
  - Fix known issues (especially heavy flavor).
  - Tune BeAGLE to better trust EIC predictions.
- Strategic question for 2024-2030
  - Rebuild BeAGLE++ with a better structure adding missing physics?
  - Use BeAGLE as a "nuclear response" afterburner to other codes (as we did with GCF)?
  - Add pieces of BeAGLE to other efforts?

# A comment on eA simulations in general

- eA simulations are in a much earlier phase of development than ep, pp, pA, AA etc.
  - We are not comparing QCD orders to 1%...
  - We are trying to understand the relevant degrees of freedom!
    - Quarks, gluons, color dipoles, parton showers, pre-hadrons, hadrons...
  - Heterogenous energy & timescales
    - Few MeV binding energy, photons in nuclear rest frame
    - Few TeV beam electron energy in nuclear rest frame
- This is a feature. Lots of physics to discover!

# Simulation challenge in e+A: nuclear detail

One example: de-excitation photons from  $^{208}\text{Pb}_{82}$  following  $e+\text{Pb} \rightarrow e'+\text{Pb}^*+\text{J}/\psi \rightarrow e'+\text{Pb}+\gamma+\gamma+\gamma+\text{J}/\psi$  in (collider) lab frame



# Some Nuclear Effects

In BeAGLE

Improvable

- Parton distribution functions
- Parton saturation (CGC etc.)
- Short-range correlations
- "Fermi motion"



(GCF)



- Partonic (or "dipole") MS



- Partonic gluon radiation



- Medium-modified hadronization



- Formation times



- Hadronic Cascade



- Nuclear evaporation, breakup



- Photonic de-excitation of  $A^*$



Open source?  
(ABLA, Gemini)  
But no  $\gamma$ 's!

# Conclusions

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- BeAGLE is still being used to tweak the ePIC design and for detector/IR 2 studies.
- Urgent immediate needs:
  - "Unusual events" like heavy flavor production are artificially suppressed.
  - BeAGLE has not been validated or fully tuned, leading to uncertainties.
- We need a coherent strategy to get from here to 2030 for e+A simulations.
  - And a stable source of funding.