BeAGLE: A Tool to Refine Detector Requirements for eA Collisions in the Nuclear Shadowing / Saturation Regime
EIC R&D Project eRD17: Progress Report (January-June 2017) and Proposal

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Abstract

The BeAGLE program for simulating e+A collisions has been upgraded to include multinucleon effects in the low x shadowing/saturation regime, as originally proposed. Since the last meeting, the code has been thoroughly debugged and shaken down, and can now provide a unique capability for physics-driven refinement of detector requirements, particularly in the forward region. Remaining tasks for 2017 include some lower priority upgrades and improvements.

Since the last meeting, we also took a first look at a key EIC physics measurement using BeAGLE: Veto-tagging of incoherent eA diffractive events. Coherent diffraction, where the nucleus stays intact, with a cross-section proportional to the *square* of the gluon distribution, plays a key role in EIC e+A physics and the study of parton saturation. It is a demanding measurement since the incoherent cross-section is expected to be 100–430 times as large as the coherent cross-section in the third "dip" of the coherent cross-section, exactly where you most need precision. The EIC white paper indicated that tagging would not be that difficult, and that, for instance, evaporation neutrons would be plentiful in the events we want to veto. We discovered, however, that as many as 12% of the incoherent events emit *no* evaporation neutrons, leaving a S/N ratio in the range 1/36–1/12 rather than the desired 1:1 or 3:1. Clearly a more careful study will be needed to establish the detector reqirements for this critical EIC measurement. It should also be noted that incoherent diffractive events

are themselves sensitive to saturation and are therefore interesting in their own right as well.

We therefore propose, in FY2018-2019, to extend BeAGLE to better describe diffractive physics in e+A collisions and also in ultra-peripheral A+A collisions. The first step will be to make the effective dipole cross-section process dependent, which will, among other things, change the relative A-dependence of diffraction and DIS compared to the current approach. The next step will be to include the program RAPGAP as an option in BeAGLE as an alternative to Pythia. With this program in place, we should be able to better understand the E665 trigger and tune more accurately to all relevant E665 data. Finally, we plan to apply BeAGLE to ultra-peripheral AA collisions in order to study the physics and tune even more thoroughly using a broader set of existing data. Finally, this will allow us to best understand the detector requirements for the critical and demanding physics measurement: the transverse spatial gluon distribution along with saturation effects.

1 Introduction

Our project involved upgrading the e+A DIS event generator DPMJetHybrid [1], now renamed to BeAGLE [2] (**B**enchmark **eA** **G**enerator for **LE**ptoproduction), to include some key nuclear shadowing / parton saturation effects that were missing in the suite of eA event generators available for physics simulations. These event generators, partly supported by previous EIC R&D funding, have been essential in establishing detector requirements for various physics measurements [3, 4]. However, the particle production model in the forward region for eA (along the ion direction) needed, and still needs, improvement in order to clarify those requirements for measurements at either eRHIC or JLEIC.

The original project, proposed in FY2016, involved adding a flexible model for intrinsic k_T and multi-nucleon k_T-recoil sharing for eA collisions. This model will automatically factor in improved information as we include updated nuclear PDFs from RHIC or the LHC. In order to test and shakedown the model, it was used to study the impact of forward detectors on geometry tagging using forward particles. The results from this study are encouraging: forward neutron detection alone should allow excellent geometry tagging, leading to data samples with significantly enhanced nuclear thickness ($T(b)$) over the minimum-bias samples. BeAGLE can now be used to study quantitatively any possible advantage gained by more complete forward detection.

In terms of our future plans, the Electron-Ion Collider Detector Advisory Committee report from January 2017 [5] was eerily prescient and an excerpt will serve to summarize our proposal: “The outline for future work and manpower on it seem realistic, but as the proponents state there can always be unforeseen difficulties. In particular, line 11 of the Table hides potential challenges since it involves the role of diffractive processes as A increases. This will need better data- the data from the EIC itself to sort out, hence elements of this work will be an ongoing project for a considerable time.” In fact, we have discovered, as mentioned in the abstract and detailed below, that a better simulation of diffraction in e+A collisions is *essential* to EIC physics and to determining the detector requirements. In particular, vetoing diffractive e+A events where the nucleus does not stay intact is challenging and we need a more accurate simulation than that provided by Pythia [6], combining the improved description of $\gamma^* N$ diffraction from RAPGAP [7] with the IntraNuclearCascade, nuclear evaporation and breakup built into BeAGLE.

The organization of the remainder of the document is as follows. Section 2 summarizes the progress of the project from January-June 2017. Section 3 outlines the planned minor upgrades to BeAGLE which remain. Section 4 contains the proposal for the new extension of eRD17: upgrading BeAGLE to include a better description of diffraction by adding RAPGAP and confronting BeAGLE with a more complete set of E665 forward data as well as ultraperipheral A+A data. This would lead to a version of BeAGLE which will be optimal for understanding the tradeoffs between the completeness and quality of forward detection on the one hand and our ability to measure transverse spatial nuclear gluon distributions and saturation on the other. Section 5 discusses external funding as well as other projects and proposals involving BeAGLE and their synergy with eRD17. Finally, Section 6 contains a summary of the progress report and proposal.

2 BeAGLE Status: Achievements through June 2017

Table 1 is an update of the popular table from the January 2017 eRD17 Status Report [5]. The structure has been modified slightly. Lines 14 and 15 were dropped since they were not considered part of eRD17 (Line 14 referred to PyQM testing which is part of the JLAB LDRD and Line 15 referred to a possible future project: implementing event-by-event initial state Fermi momentum in the eN subcollision). Lines 5 and 6 have been split into 5/6a: implemented and 5/6b: debugged. Also the first two columns (DPMJet alone and Pythia alone) have been dropped.

The main accomplishment during the reporting period is that the program has been debugged and is ready for use. Baker and Zheng audited the program thoroughly to ensure that Pythia and DPMJet were completely consistent. The following errors were found and corrected:

- Accounting error fixed which had been effectively adding $(N_{part} - 1)M_N$ to the nuclear excitation energy. This was the main cause of the "nucleus exploding" for multinucleon collisions.
- Several places in DPMJET where the nucleon mass was hard-coded to M_p were changed to the correct value (M_p or M_n depending on context). This small error was being magnified by a rather extreme example of small differences of large numbers, leading to a miscalculation of the excitation energy.
- An index inconsistency between Pythia and DPMJet was fixed. Its effect was minor, causing one of the nucleons in the nucleus to not fully participate in the IntraNuclear Cascade.

Feature added or error corrected	DPMJet-Hybrid	BeAGLE Jan. 2017	BeAGLE June 2017	BeAGLE (planned)
1. Hard processes correct.	YES	YES	YES	YES
2. Tuned to ZEUS ep→p+X data	YES	YES	YES	YES
3. IntraNuclear Cascade	YES	YES	YES	YES
4. Nuclear evaporation/breakup	YES	YES	YES	YES
5a. Multinucleon shadowing	NO	YES	YES	YES
5b. Debug multinucleon shadow.	NO	NO	YES	YES
6a. Correct nucleon remnant (n/p)	NO	YES	YES	YES
6b. Debug M_n vs. M_p	NO	NO	YES	YES
7. Correct eA target rest frame	NO	YES	YES	YES
8. Tuned to E665 μPb→n+X data	YES	YES/NO	YES	YES
9. Shadowing coherence length	NO	NO	NO	YES
10. Partial shadowing effect	NO	NO	NO	YES
11. Process-specific A dependence	NO	NO	Postponed	N/A
12. Tuned to more E665 μA data	NO	NO	Attempted	N/A
13. FS p_F for hard process correct	NO	NO	NO	YES

Table 1: Progress on eRD17 as a function of time.

- The π^0 particles were changed to correctly decay only AFTER participating in the IntraNuclear Cascade. We are used to decaying these particles "promptly" as the $c\tau \sim 25$nm is very short on the distance scales of particle detectors, but in fact quite long on the distance scale of the nucleus.

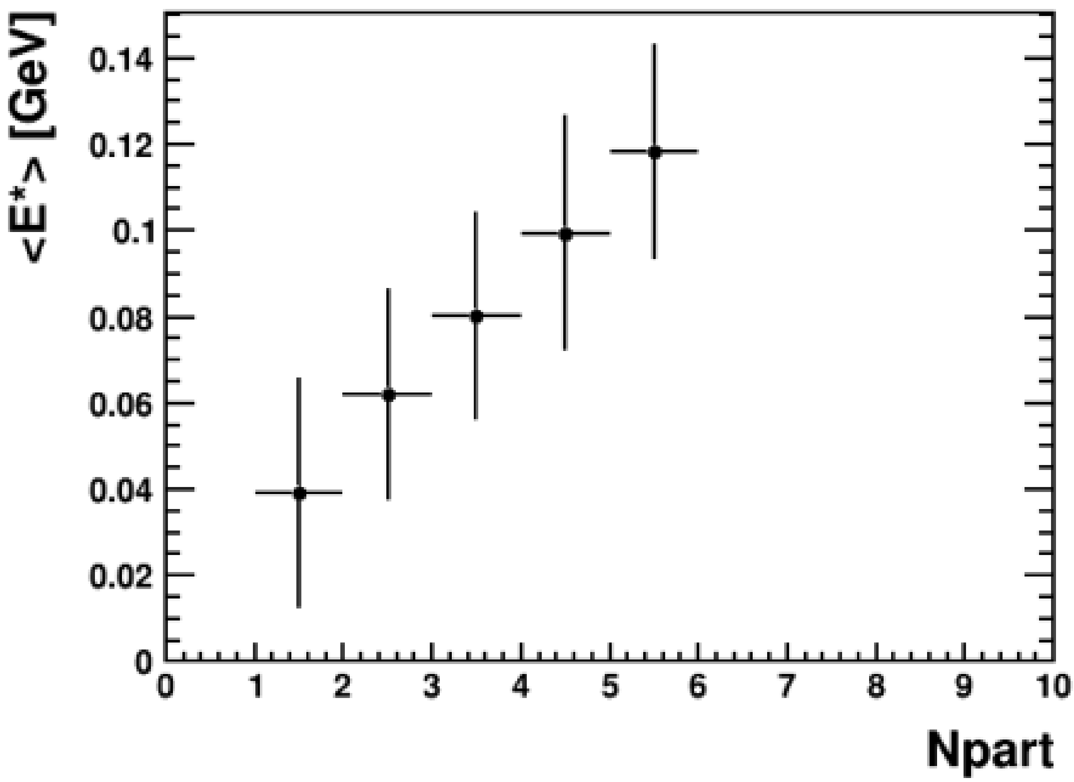


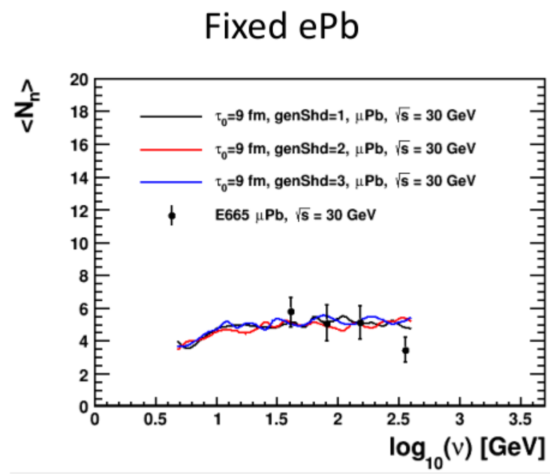
Figure 1: Nuclear excitation energy vs. number of nucleon participants in BeAGLE with multinucleon shadowing turned on (genShd=3). The error bars represent the rms spread of the E^* for each given N_{part} bin.

Figure 1 shows that the excitation energy now grows linearly with the number of partipating nucleons in a natural way, rather than jumping dramatically between $N_{part} = 1$ and $N_{part} = 2$.

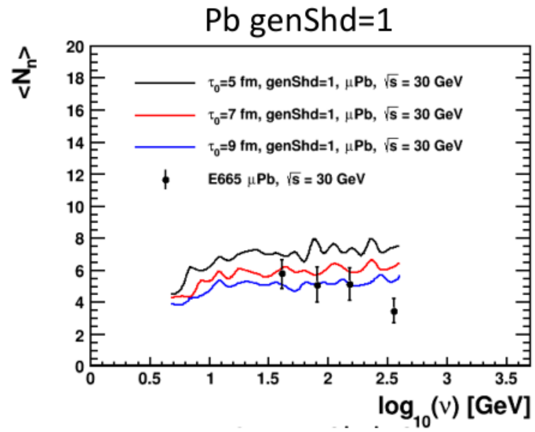
Following these changes, we found that at E665 energies, the average number of evaporation neutrons is basically the same for all three values of the genShd parameter:

genShd=1 No multinucleon shadowing. $N_{coll} = 1$.

genShd=2 Multinucleon shadowing (Glauber) with the hard Pythia collision chosen at random from participating nucleons.

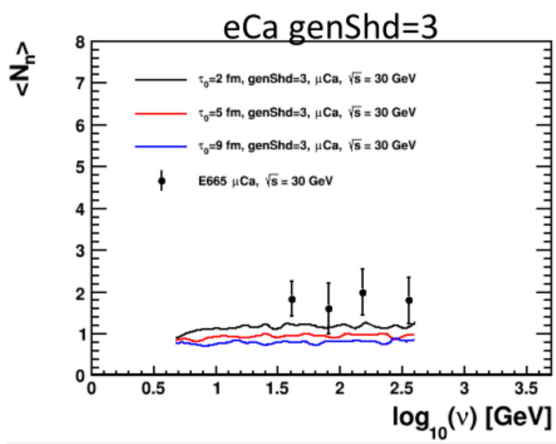


(a) Varying values of genShd setting

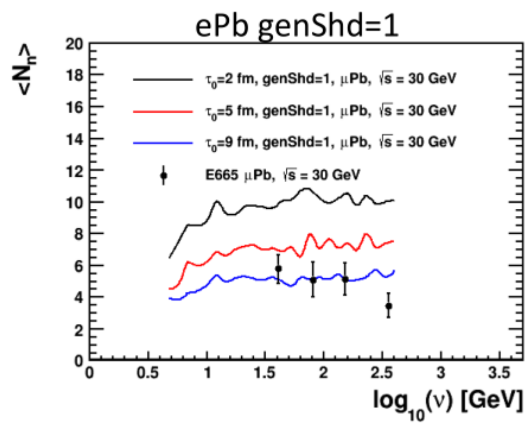


(b) Varying values of τ_0

Figure 2: Comparison of E665 (fixed target) soft neutron data adapted from Ref. [8] and different BeAGLE settings: a) Formation time parameter $\tau_0 = 9$ fm, various choices of the genShd setting; b) genShd=1, various choices for τ_0.



(a) Varying values of τ_0 for Ca



(b) Varying values of τ_0 for Pb

Figure 3: Comparison of E665 (fixed target) soft neutron data adapted from Ref. [8] and different BeAGLE formation time parameter (τ_0) settings for: a) E665 $\mu + Ca$ data; b) E665 $\mu + Pb$ data.

genShd=3 Multinucleon shadowing (Glauber) with the first struck nucleon undergoing the hard Pythia collision.

Figure 2 shows that the formation time parameter for the INC $\tau_0 = 9$ fm fits the E665 μ+Pb neutron data for all three settings of genShd. We also attempted to fit the E665 μ+Ca neutron data (line 12 in the table), but as seen in Figure 3, the Ca data prefer a much smaller value of $\tau_0 < 2$ fm, which would imply a stronger IntraNuclear Cascade, inconsistent with the Pb data. This parameter was not expected to be A-dependent. Rather than trying to use a compromise value like 5 fm, we will stick with the more conservative value of $\tau_0 = 9$ fm for collisions involving Pb and Au and will revisit this issue in the future when we have a better understanding of the mix of deep inelastic scattering and diffraction in the E665 data. The higher value of τ_0 is more conservative in the sense that it decreases the impact of multinucleon scattering at EIC energies. It should also be noted that $\tau_0 = 9$ fm was used for the original DPMJet-based EIC studies because it fit the E665 Pb data as well [9].

Line 11 in the table, the idea of modifying the relative A-dependence of various subprocesses (such as diffraction vs. DIS), has been postponed and included in the overall upgrade of diffraction handling in BeAGLE.

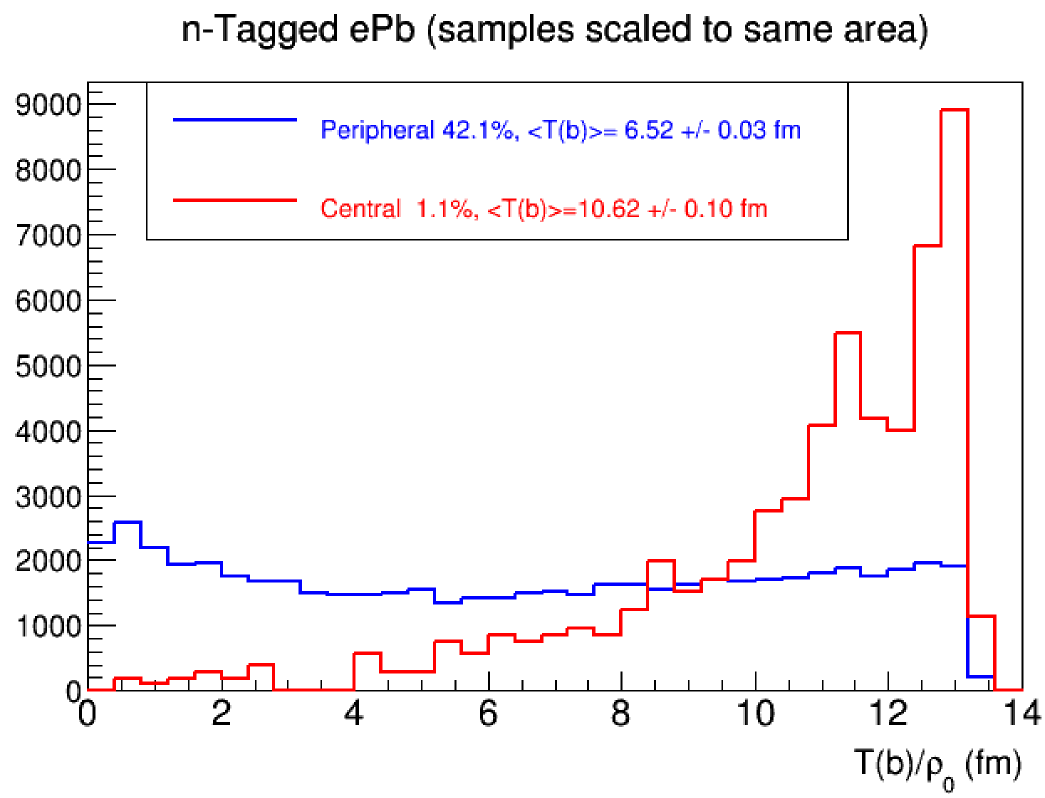


Figure 4: Distribution of the normalized nuclear thickness function $T(b)/\rho_0$ for the 42.1% most peripheral and 1.1% most central geometry tagged data sets based on cuts on the number of evaporated neutrons, N_n^{Evap}. The distributions are scaled to have the same area. Taken from Ref. [10].

A typical physics result, using BeAGLE, is shown in Figure 4 where the nuclear thickness function distribution is shown for two samples. The normalization parameter ρ_0, refers to the nuclear density of the the Lead nucleus at the origin. The central data have a large thickness and should have enhanced saturation compared to the peripheral data.

In summary, substantial progress has been made in this reporting period. The e+A model code BeAGLE can now be used to simulate e+A collisions and relate the detector requirements to physics observables. The remaining tasks to be completed will be detailed below in Section 3.

2.1 Manpower

Include a list of the existing manpower and what approximate fraction each has spent on the project.

The only funded manpower consists of Baker, who has officially spent 0.12 FTE-year so far during FY2017, with 0.14 FTE-year total planned.

Zheng contributed a significant amount of effort, about 0.1 FTE-year already in upgrading BeAGLE, running simulations, and making plots.

Aschenauer and Lee have participated in meetings and contributed a significant amount of advice. Aschenauer also modified the standard Pythia installation at BNL to be usable directly by BeAGLE.

3 Immediate Plans

The main activity planned for the remainder of FY2017 is to make a few more minor improvements to BeAGLE, as listed in Table 1. These items are reasonably well understood and not expected to cause particular difficulties.

Item 9, "shadowing coherence length", refers to the effective distance over which the quantum fluctuation of the γ^* to a $q\bar{q}$ dipole (or more complicated state) survives in the nuclear rest frame. At low values of x, such as $x < 0.01$, we can treat this is infinite: the dipole will sample the entire nucleus. At higher values such as $x > 0.1$, the dipole is very short and we can treat it as zero: the dipole will interact directly with only one nucleon in the nucleus. These two extremes are already implemented. At intermediate values $0.01 < x < 0.1$, the dipole should have a length which is comparable to the nuclear radius R rather than much smaller or much larger. This will require a modification to our Glauber simulation of the multinucleon interaction probability.

Item 10, "partial shadowing effect", refers to an intermediate choice of how nuclear parton distribution functions are used. Currently, we have two choices. The parameter setting genShd=1 treats the difference between the nuclear and nucleonic PDFs as purely a modification to the parton distributions of the nucleons inside the nucleus. The virtual photon will interact with one and only one nucleon. The second choice, covered by both genShd=2 or 3, treats the nucleons inside the nucleus as unchanged and attributes the entire difference (at low x) to shadowing of the virtual photon interaction due to its hadron-like dipole fluctuation interacting with more than one nucleon. Implementing the multi-nucleon shadowing was the main point of the eRD17 project so far. It is possible, however, to allow intermediate interpretations with some fraction of the nuclear modification being due to a genuine modifcation of the parton distributions and some fraction being due to shadowing. In fact, this is relatively easy to implement once the two extremes are in place.

Item 13, "FS p_F for hard processes correct" refers to fixing a problem in the original DP-MJetHybrid/BeAGLE implementation. Due to the way Pythia is initialized in BeAGLE, all of the hard $e+p$ and $e+n$ collisions are treated with the proton and neutron at rest in the nuclear rest frame, ignoring the fact that they should have some Fermi momentum. We essentially take a slightly moving nucleon in the initial Glauber configuration of the ion A and replace it with the contents of the Pythia final state, thereby throwing away it's initial state momentum. Our plan is to just boost the Pythia products to approximately reinstate the correct energy and momentum that would otherwise be lost. This will be done before the IntraNuclear Cascade step.

4 Proposal for FY2018-FY2019

The proposed main goal for FY2018 is to upgrade BeAGLE to include a better description of diffraction. This will provide a unique tool to best understand incoherent exclusive vector meson production through diffraction in e+A collisons. This physics is a key EIC measurement in its own right and is also the main background to another key EIC measurement: *coherent* exclusive vector meson production through diffraction in e+A collisions. Coherent production itself would not be directly included in BeAGLE, but it would be straightforward to mix background events from BeAGLE with coherent events from Sar*t*re and then present those events to GEMC (JLAB) or eicroot/eic-smear (BNL) in order to understand the effect of the detector design on the measurement.

The proposed main goal for FY2019 is to make a concerted effort to tune BeAGLE, as well as possible, to all relevant data, both from E665 and from ultraperipheral heavy ion data. This will further improve our description of *both* diffraction and DIS. In turn, this will reduce the uncertainty in our physics simulations and in the detector requirements.

4.1 EIC Physics Motivation for the Project

The EIC White Paper [3] states the importance of diffraction as well as the experimental challenges quite clearly: "What makes the diffractive processes so interesting is that they are most sensitive to the underlying gluon distribution, and that they are the *only* known class of events that allows us to gain insight into the spatial distribution of gluons in nuclei. However, while the physics goals are golden, the technical challenges are formidable but not insurmountable, and require careful planning of the detector and interaction region." [Emphasis in the original].

Exclusive coherent vector meson production $e + A \to e' + V + A$ where the nucleus remains intact is expected to be one of the most important measurements at the EIC [3]. The measured quantity $d\sigma/dt$ can be directly related, through a Fourier-like transform, to the transverse spatial distribution of gluons in the nucleus $F(b)$. For Bjorken-x values $x < 0.01$ and at modest values of Q^2 (say $Q^2 > 1\text{GeV}^2$), the effective renormalization scale,

μ^2 at which we are sampling the gluon distribution $G(x, \mu^2)$ is $\mu^2 \sim \max(Q^2, M_V^2)$. The J/ψ particle, with $M^2 = 9.6$ GeV^2 should effectively sample the baseline, unsaturated, gluon distribution, while the ϕ particle with $M^2 = 1.0$ GeV^2 should be directly sensitive to gluon saturation as a function of Q^2.

Exclusive *incoherent* vector meson production in nuclei $e + A \to e' + V + X$ occurs when the nucleus breaks up due to its interaction with the vector meson. This physics is quite interesting in its own right and so it will be important to identify these events. The really challenging issue, though, is that for high values of $|t|$, the incoherent production swamps the coherent production and we need to be able to veto the incoherent case in order to measure the coherent production.

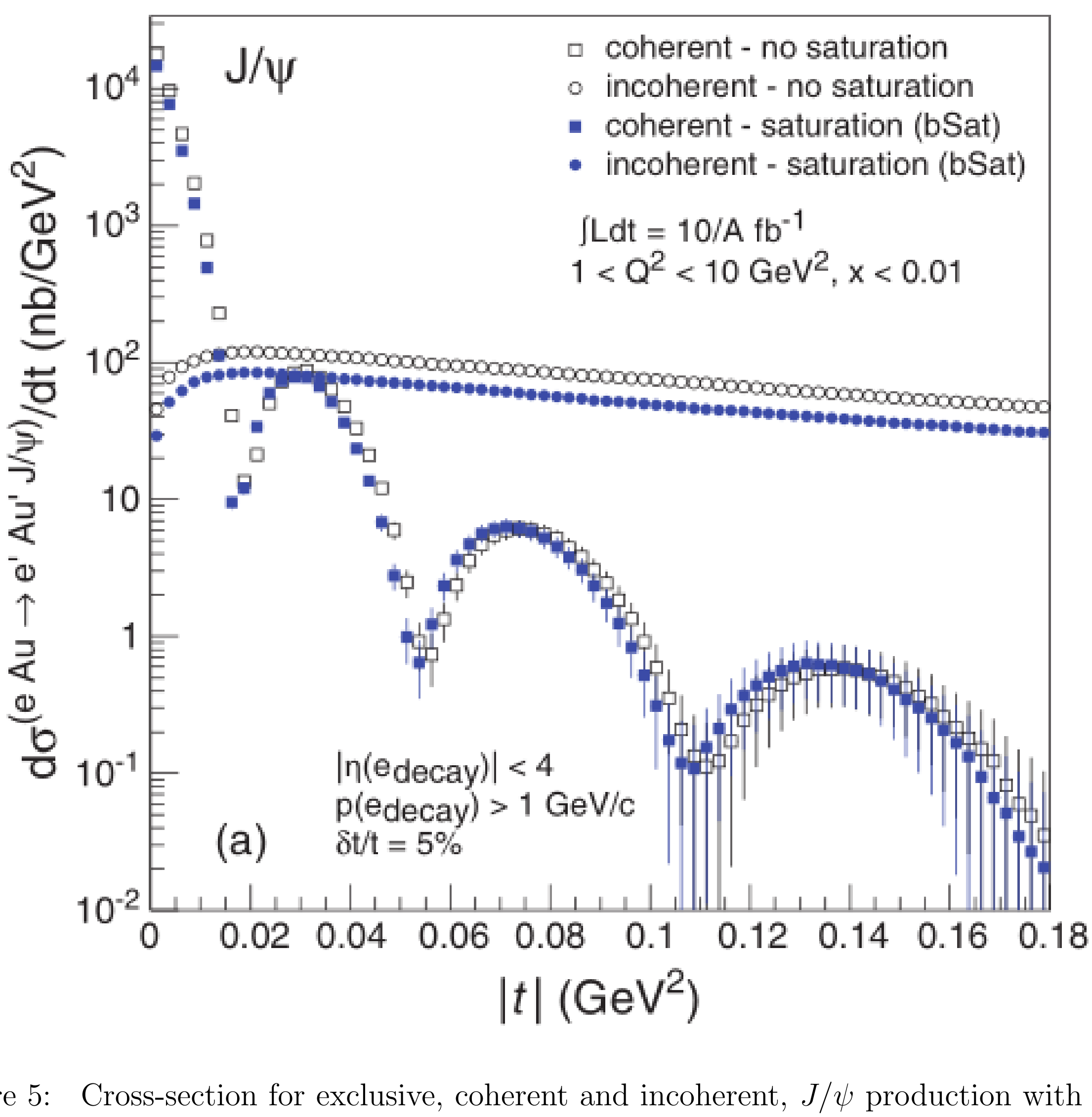


Figure 5: Cross-section for exclusive, coherent and incoherent, J/ψ production with and without saturation from Sar*t*re [12, 3].

Studies using Sar*t*re [11, 12] indicate that in order to measure the gluon spatial distribution precisely with coherent production, you need to include the third dip in the spectrum, going out to $|t| \sim 0.15\ \mathrm{GeV}^2$ in the case of ϕ-nonsat, although you get a reasonable measurement with just the first two dips. If you omit the second dip, you make errors comparable to the expected size of the saturation effect. This allows us to set the scale for the required background rejection. Figure 5 shows the expected results for the J/ψ in the presence of saturation and in a model without saturation. Saturation actually makes our job easier by suppressing the background, but only slightly in the case of the J/ψ. The minimum requirement for any reasonable measurement would be that we need to be able to achieve a 1:1 S/N ratio for the second dip of the J/ψ which requires a one-hundred fold reduction in background or a 99% veto-tagging efficiency. A much better goal would be to achieve a 3:1 S/N ratio for the third dip which requires a 1300-fold reduction in background or a 99.92% veto efficiency. So our target should be 99–99.92%.

The white paper was written before BeAGLE was available and its predecessor, DPMJetHybrid, was itself rather new. Therefore the quick studies of the detector capabilities used some crude estimates of how the nucleus would respond to an exclusive incoherent diffractive event. In particular, the nuclear excitation energy was assumed to be, on average, more than 10x larger than BeAGLE indicates it should be. Based on those crude assumptions, the white paper concluded that: "the nuclear breakup in incoherent diffraction can be detected with close to 100% efficiency by measuring the emitted neutrons in a zero degree calorimeter placed after the first dipole magnet that bends the hadron beam."

The current incarnation of BeAGLE has two features in the description of diffraction which need improvement. It uses Pythia rather than RAPGAP to estimate the behavior of diffractive events, and it also assumes that diffractive and DIS events have effectively the same dipole cross-section. Nevertheless, because it includes a good simulation of the multinucleon interaction, intranuclear cascade and nuclear evaporation and breakup, it is currently our best tool to estimate our vetoing efficiency. Figure 6 shows the fraction of events versus the number of evaporation neutrons for events where a vector meson was produced and remained intact while the nucleus did not. It should be noted that the average number of evaporation neutrons grows slightly with increasing $|t|$, so we restricted the results to $|t|$ values at and beyond the third dip. The surprising result is that there are *zero* evaporation neutrons in more than 12% of the events! The current BeAGLE estimate veto-tagging efficiency based on evaporation neutrons alone is about 88%, far short of the target 99–99.92%. The S/N at the second dip would be about 1:12 and at the third dip 1:36.

Of course, we can use other detectors to increase our ability to tag these events, but the main point is that the challenge is even greater than assumed in the white paper, and this study needs to be done. As described in Section 5, there is an effort underway to use BeAGLE, as-is, to study the veto-tagging efficiency of the JLEIC full-acceptance detector. This effort is valuable, as BeAGLE is currently our best tool. In parallel to this effort, though, we need to improve BeAGLE's description of diffractive events for several reasons:

1. The incoherent diffractive events described by BeAGLE are one of the most sensitive

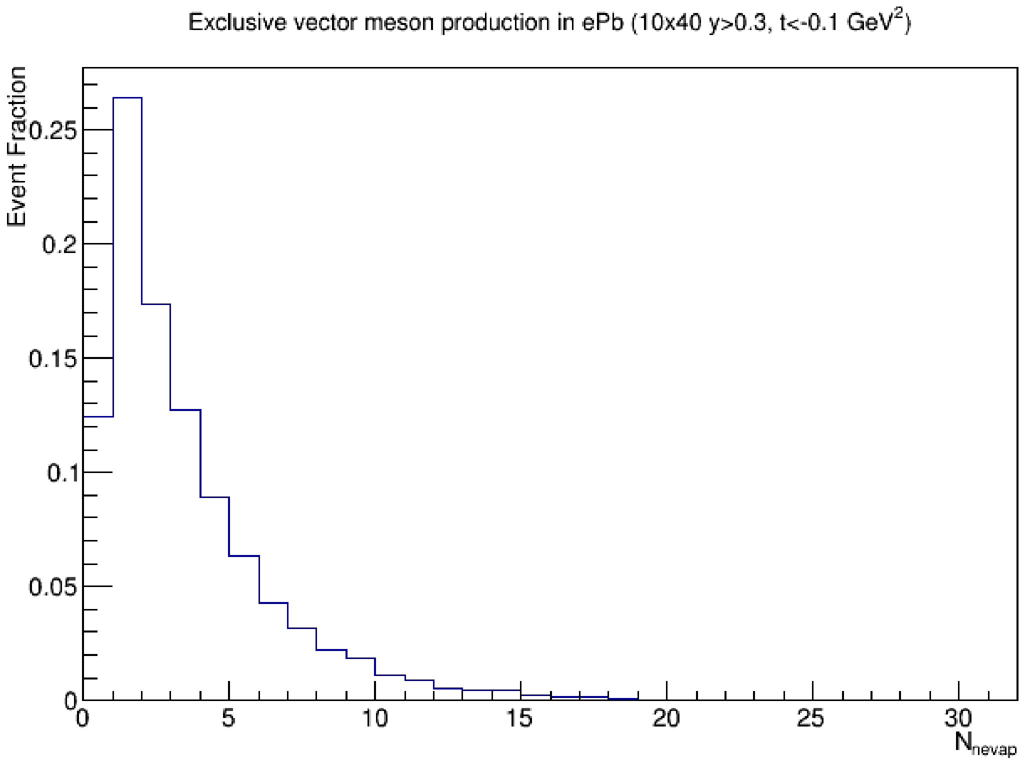


Figure 6: Event fraction vs. the number of evaporation neutrons for exclusive vector meson production in BeAGLE. Note: as is standard for root histograms with integers, the bin from 0–1 refers to 0, 1–2 refers to 1, etc..

probes of saturation [3], and we need to make sure that we can identify them and measure their properties, ideally including geometry tagging (impact parameter).

2. In order to demonstrate our ability to achieve background rejection factors of 100–1300, we need an accurate description of the physics, and presumably a very good detector. This may be one of the key design drivers for forward detection and the IRs.

3. Until EIC comes online, the old E665 data and the current ultraperipheral diffractive heavy ion collisions provide our best chance to tune our models and understand what we can expect.

4. The ultraperipheral data is interesting in its own right and should be understood.

For eRD17, due to the importance of diffractive physics, including both incoherent and coherent, we propose to improve BeAGLE's description of diffraction in several ways. First, we will implement a process-dependent effective "dipole" cross-section in BeAGLE. This will modify the relative A-dependence between diffraction and DIS (and possibly higher order hard processes), thereby fulfilling the original Table 1 item 11. It will also allow the nucleus to respond differently to diffractive and DIS events. Second, we will implement RAPGAP as an alternative model to PYTHIA, controllable by a switch within BeAGLE. RAPGAP uses PYTHIA for fragmentation, but has a more sophisticated and up-to-date description of ep diffraction physics. Finally, we will engage in a more comprehensive effort to confront BeAGLE with all relevant data. The E665 forward neutron data for e+Pb and e+Ca [8] and especially the E665 Streamer Chamber data [13] contain a complicated event mix including coherent diffractive, incoherent diffractive and DIS data. An optimal simulation of this data should mix our best understanding of each of these event types and then attempt to apply the event selection criteria used by E665. This is somewhat complicated, and most comparisons to E665 neutron data, including ours so far, have assumed that the Pythia mix approximates the data. In addition, BeAGLE can be confronted with ultraperipheral data from heavy ion collisions at RHIC and the LHC.

The phenomena of diffraction, nuclear shadowing and parton saturation are increasingly topical and important in the study and interpretation of AA, pA and potential eA data at RHIC and LHC energies. In fact they provide a lot of connections between these data sets [14]. While we now have a significantly improved Monte Carlo Model in BeAGLE, especially for describing DIS in e+A, it is clear that the diffractive physics is still not optimally modeled and further improvements are needed. Since diffractive physics is likely to be one of the physics-based design drivers for the ongoing optimization of forward detectors and their integration with the IR and the EIC machine elements for both eRHIC and JLEIC, it is important to have a complete suite of accurate eA event generators as soon as possible.

4.2 Personnel, Timetable and Budget

The overall timetable of this project covers 24 months from Oct. 2, 2017–Sept. 30, 2019, with the current proposal covering FY2018. Key milestones for FY2018 are listed below.

Jan. 15, 2018 Process-dependent dipole cross-section implemented in BeAGLE

Mar. 30, 2018 BeAGLE with RAPGAP code alpha release.

June 29, 2018 BeAGLE with RAPGAP code beta release.

Sept. 28, 2018 BeAGLE with RAPGAP released. First quick look at results.

The exact order and timing of tasks for FY2019 have not been decided yet, but the current idea of the overall task list is found below.

- Mix Sar*t*re and BeAGLE events and simulate rough E665 trigger and event selection for E665 Streamer Chamber data [13] which is a mix of diffractive and DIS events.

- Tune BeAGLE to match E665 Streamer Chamber data as well as possible.

Person	Institution	Effort (FTE-year)	Cost to Proposal	Remarks
E. Aschenauer	BNL	0.05	$0	cost covered by BNL
M.D. Baker	MDBPADS[15]	0.25	$60,000	
J.H. Lee	BNL	0.05	$0	cost covered by BNL
L. Zheng	CCNU	0.10	$0	cost covered by CCNU
TOTAL:		0.45	$60,000	

Table 2: Personnel Budget Breakdown for FY2018

Funding Level	%Funding	% Project	Impact
$60,000	100%	100%	Full results for FY2018
$48,000	80%	75%	First three milestones stretch out over the whole year
$36,000	60%	50%	First two milestones stretch out over the whole year

Table 3: Impact of Reduced Funding in FY2018

- Simulate rough trigger and event selection for the E665 forward neutron paper [8] and re-tune BeAGLE to better match both the Pb and Ca data if possible.
- Compare BeAGLE to ultra-peripheral heavy ion data, either by implementing the UPC γ^* flux directly into Pythia and/or RAPGAP, or if necessary, by reweighting BeAGLE results to match the UPC flux.

For FY2019, we would propose a similar level of funding, adjusted for inflation.

4.3 Impact of Reduced Funding

Table 3 shows the impact of reduced funding. Note that there is some inefficiency incurred in dropping below quarter-time effort.

5 External Funding

5.1 FY2017

During FY2017, Aschenauer, Lee, and Zheng's salaries were provided by their home institutions. The BNL Physics Department provided substantial travel support and hosted Zheng for three months, which was very valuable to the project.

Baker and Zheng participated in a JLAB LDRD "Geometry Tagging for Heavy Ions at JLEIC" (V. Morozov et al.) in FY2017 which so far supported the installation of BeAGLE and Sar*t*re at JLAB, interfacing them to the GEMC simulation at JLAB as well as a first look at geometry tagging at JLEIC energies. Figure 7 shows a GEMC event display of the detector region at JLEIC with tracks from BeAGLE and Sar*t*re events. Figure 4 above

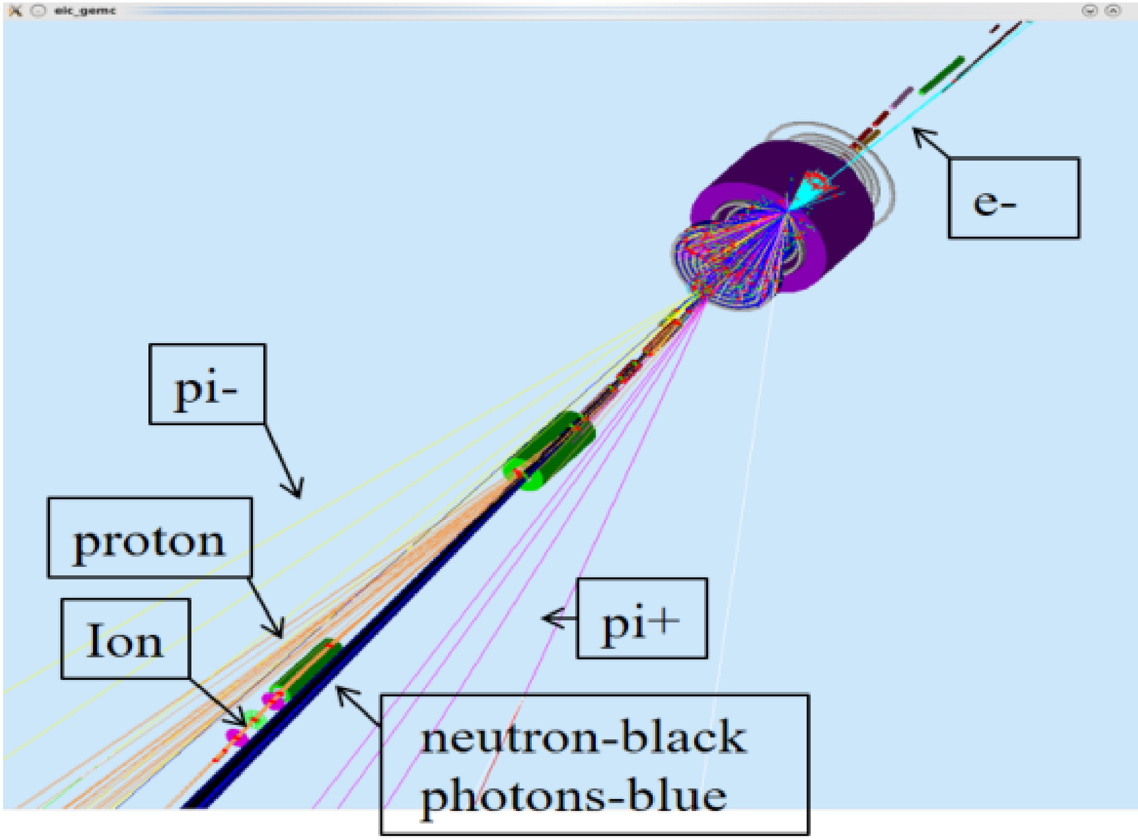


Figure 7: Snapshot of the GEMC event display showing the detector region with tracks from a few BeAGLE and Sartre events. Taken from the JLAB LDRD FY2018 proposal "Geometry Tagging for Heavy Ions at JLEIC" [10].

shows an example of a simulated physics result. Further physics studies at JLEIC energies are expected in FY2017, with some emphasis on hadron attenuation studies.

5.2 FY2018

During FY2018, Aschenauer, Lee and Zheng's salaries are expected to still be provided by their home institutions.

Baker and Zheng and collaborators have proposed an extension to the JLAB LDRD into FY2018. The proposal includes two major components. First, modifying BeAGLE so that it has a 3 dimensional Glauber and can handle nonsymmetric nuclei, such as Uranium. Second, using the *existing* BeAGLE diffractive framework along with Sartre in order to begin to study veto-tagging of incoherent exclusive vector meson production with the JLEIC full-acceptance detector.

The JLAB LDRD work is synergistic with eRD17, but is explicitly designed to not duplicate effort.

6 Summary

The main technical and strategic goals of the original eRD17 proposal have been achieved. The BeAGLE program for simulating e+A collisions has been upgraded to include multi-nucleon effects in the low x shadowing/saturation regime. Since the last meeting, the code has been thoroughly debugged and shaken down, and is now being used at both prospective host laboratories for physics-driven refinement of detector requirements, particularly in the forward region.

Since the last meeting, we also discovered that a key EIC physics measurement, incoherent diffractive exclusive vector meson production in e+A collisions, is likely to be an important driver of forward detector requirements, but is not yet well simulated. This measurement, especially in the case of ϕ production, is sensitive to gluon saturation. The process, especially in the case of the J/ψ, is also a background to coherent production, which would allow the measurement of the transverse spatial gluon distribution along with saturation effects.

We therefore propose, in FY2018-2019, to extend BeAGLE to better describe diffractive physics in e+A collisions and also in ultra-peripheral A+A collisions. This was actually discussed as a possibility at the last EIC R&D Meeting, and the importance has only become clearer as we have looked into it. Given the ongoing detector and machine design optimization, this project is urgent and should not be delayed.

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