# eRD17: BeAGLE

## A Tool to Refine Detector Requirements for eA

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China University of Geosciences
(Wuhan)

24-Jan.-2019

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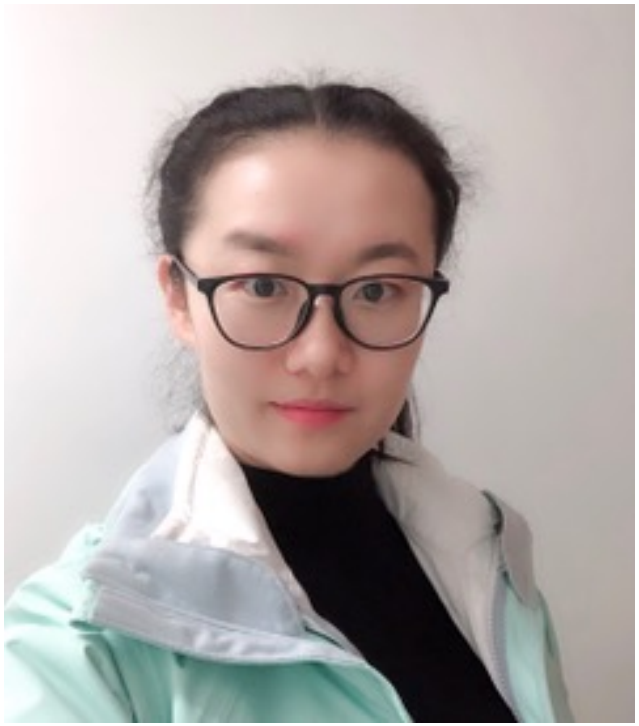
# New collaborators



Zhoudunming (Kong) Tu
- Goldhaber Fellow @ BNL
- Funding in Place (BNL/CFNS)
- Modified BeAGLE already (!)

Wan Chang
- Student at CCNU (a la Liang)
- Elke is her co-advisor
- Resident at BNL
- Worked with BeAGLE already
- Funding needed to engage in more extensive BeAGLE work.

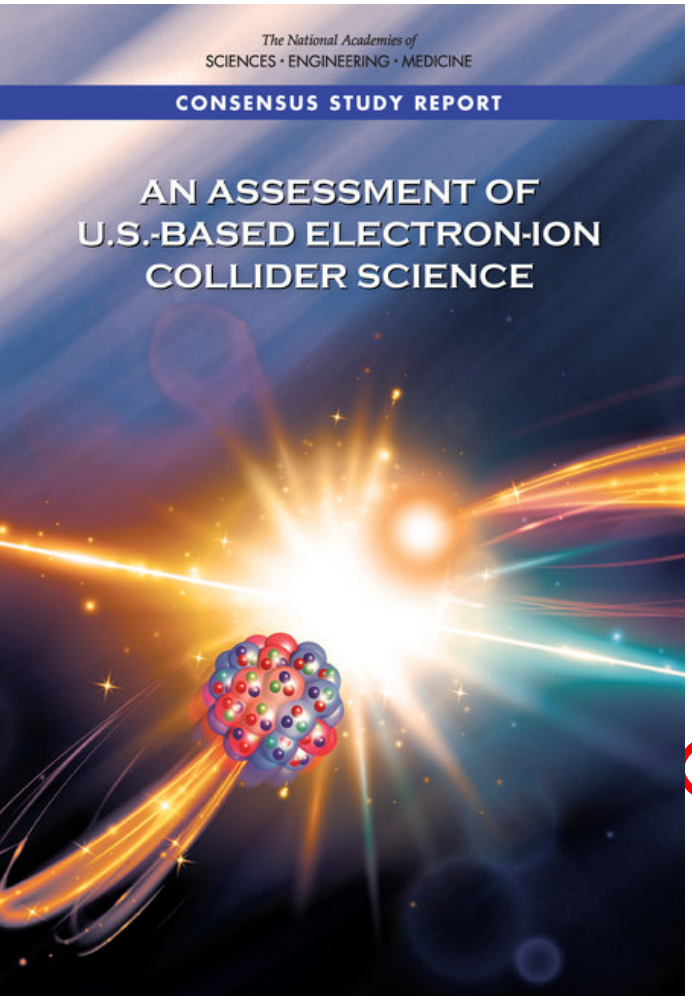
# External Support

- Salaries from home institutions:
  E. Aschenauer, W. Chang, J.H. Lee, Z. Tu, L. Zheng
- Approved JLAB LDRD: Short-range correlations in medium-to-heavy nuclei at JLEIC
  MDB, F. Hauenstein(postdoc), D. Higinbotham (PI),
  O. Hen, C. Hyde, V. Morozov , P. Nadel-Turonski, LZ
  - Also collaborating with BNL/SBU SRC effort:
    A. Deshpande, B. Shmookler (postdoc),
    Z. Tu (fellow), T. Ullrich

Note: D. Higinbotham & O.Hen are active established scientists in the DIS field now joining the EIC planning/design effort.

# NAS Report – R&D requirements chapter

Chapter 4: Accelerator Science, Technology, and Detectors Needed for a U.S.-Based Electron-Ion Collider

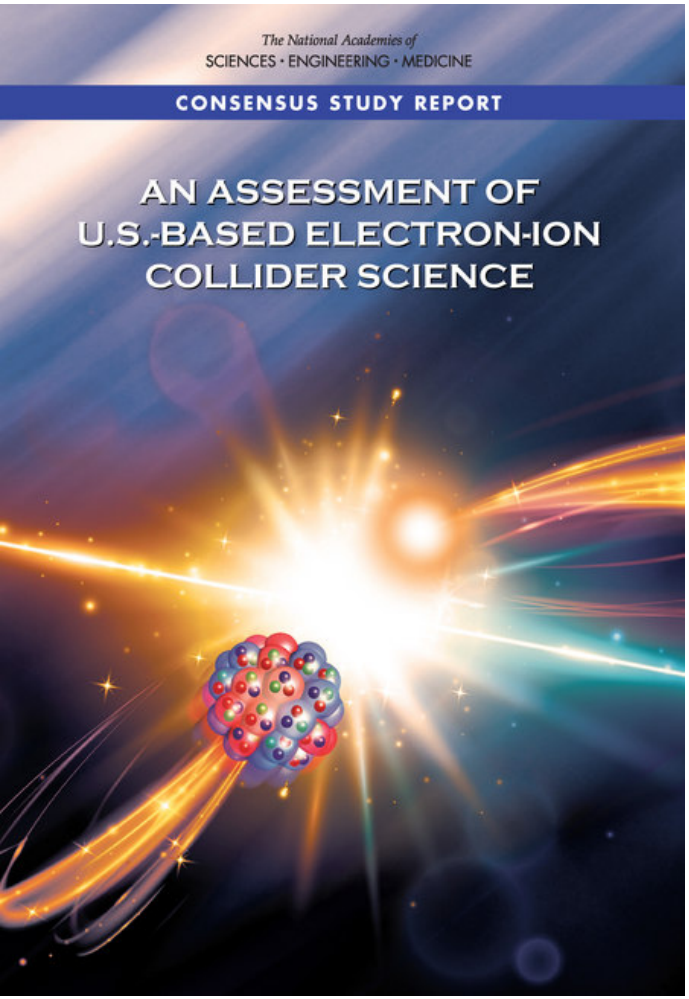



An EIC must enable the following:

- Extensive center-of-mass energy range, from ~20-~100 GeV, upgradable to ~140 GeV, to map the transition in nuclear properties from a dilute gas of quarks and gluons to saturated gluonic matter.
- Ion beams from deuterons to the heaviest stable nuclei.
- Luminosity on the order of 100 to 1,000 times higher than the earlierelectron-proton collider Hadron-Electron Ring Accelerator (HERA) at Deutsches Elektronen-Synchrotron (DESY), to allow unprecedented three-dimensional (3D) imaging of the gluon and sea quark distributions in nucleons and nuclei.
- Spin-polarized (~70 percent at a minimum) electron and proton/light-ion beams to explore the correlations of gluon and sea quark distributions with the overall nucleon spin. Polarized colliding beams have been achieved before only at HERA (with electrons and positrons only) and Relativistic Heavy Ion Collider (RHIC; with protons only).
- One or more interaction regions, which integrate the detectors into the collider and preserve the extensive kinematic coverage for measurements.

# NAS – Diffraction is still a key physics driver

Chapter 2: The Scientific Case for an Electron-Ion Collider






"The expected differential cross section for coherent and incoherent diffractive production of J/ψ particles on nuclei."

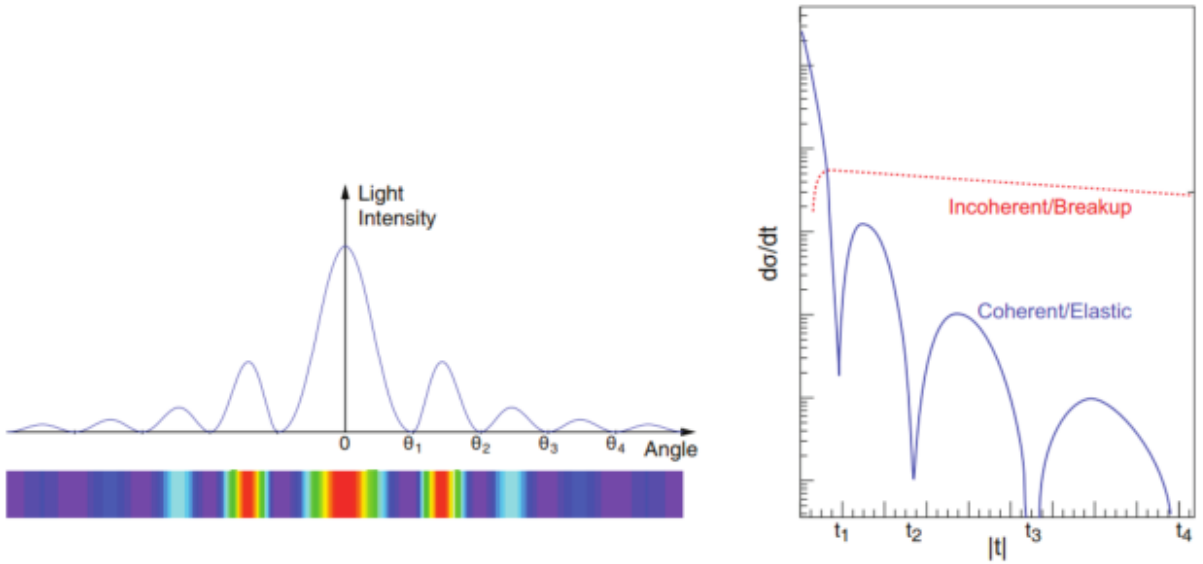
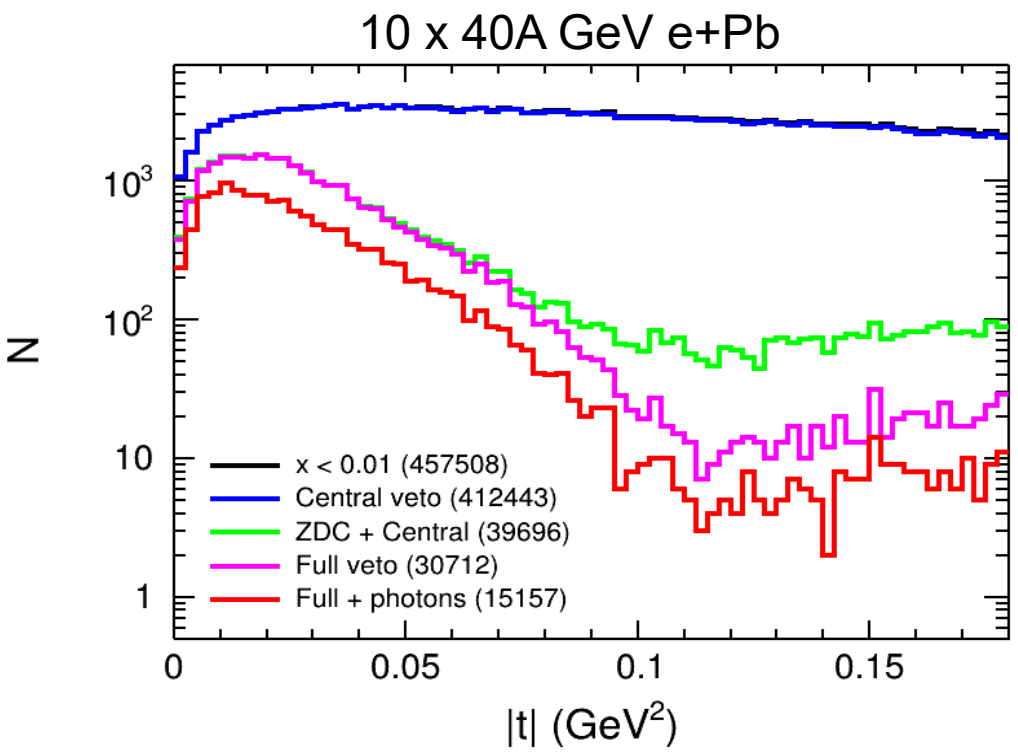


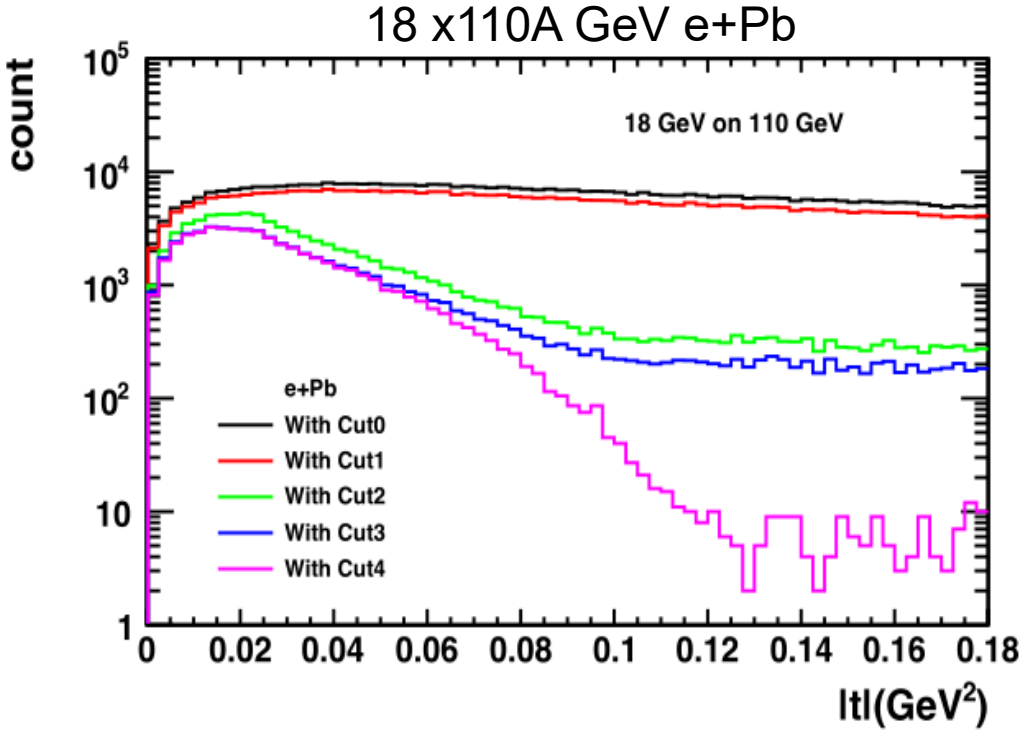

**FIGURE 2.9** *Left:* Diffraction pattern in optics, showing the light intensity landing on a screen behind a circular obstacle. *Right:* The expected differential cross section for coherent and incoherent diffractive production of J/ψ particles on nuclei. The variable *t* is related to the momentum carried by the scattered proton, which provides a measure of the scattering angle. The incoherent/breakup curve is explained in the text. SOURCE: *Reaching for the Horizon,* 2015 DOE/NSF Long Range Plan for U.S. Nuclear Science.

# BeAGLE+GEANT Veto Studies ongoing

e+Pb→e'+J/ψ+X incoherent diffraction – background to coherent e+Pb→e'+Pb+J/ψ

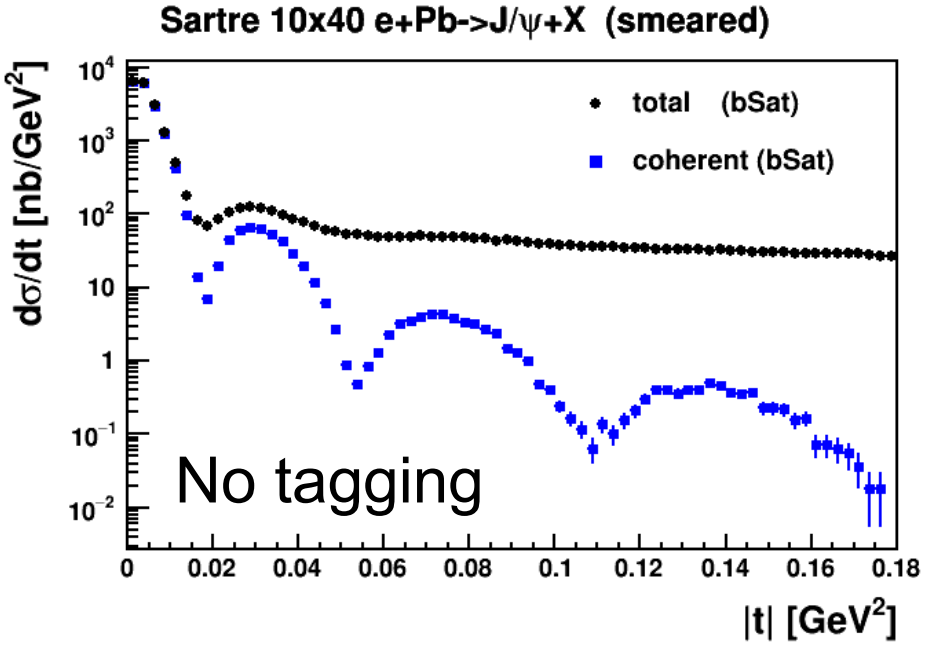


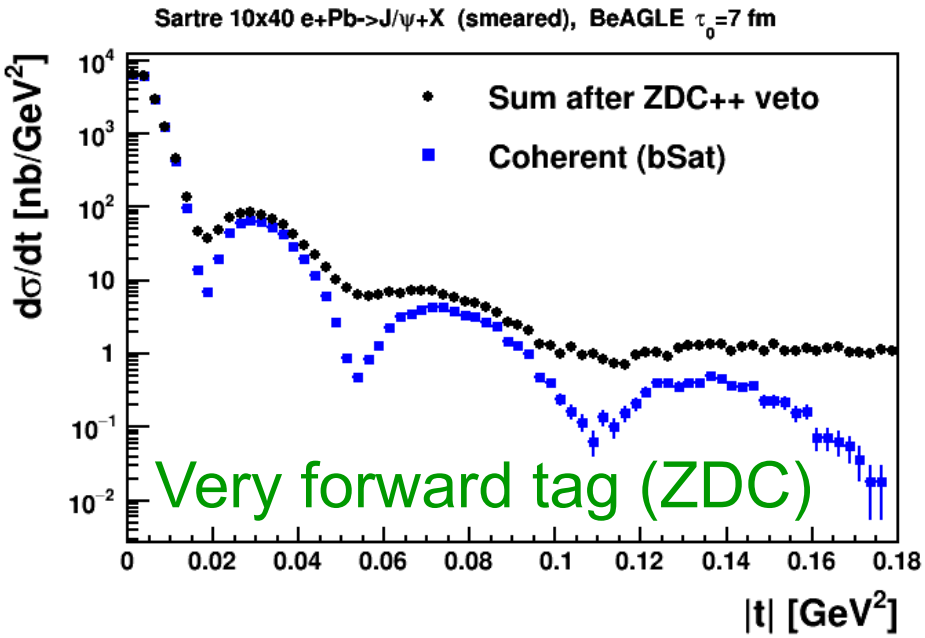

Plot by Morozov+Sy (JLAB) et al.

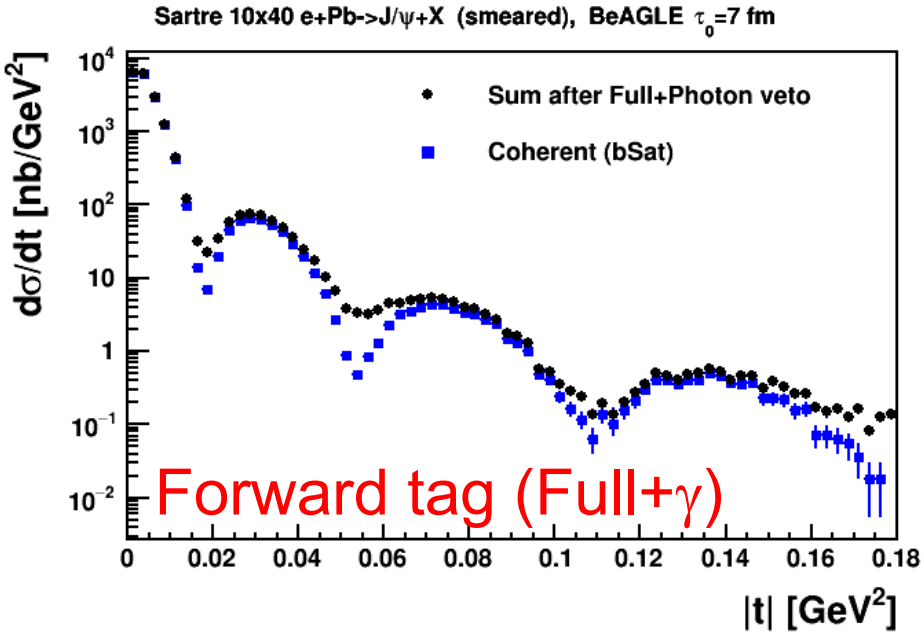



Plot by W. Chang(BNL/CCNU) w/ Z.Tu (BNL)

# JLEIC veto tagging results (e+Pb)



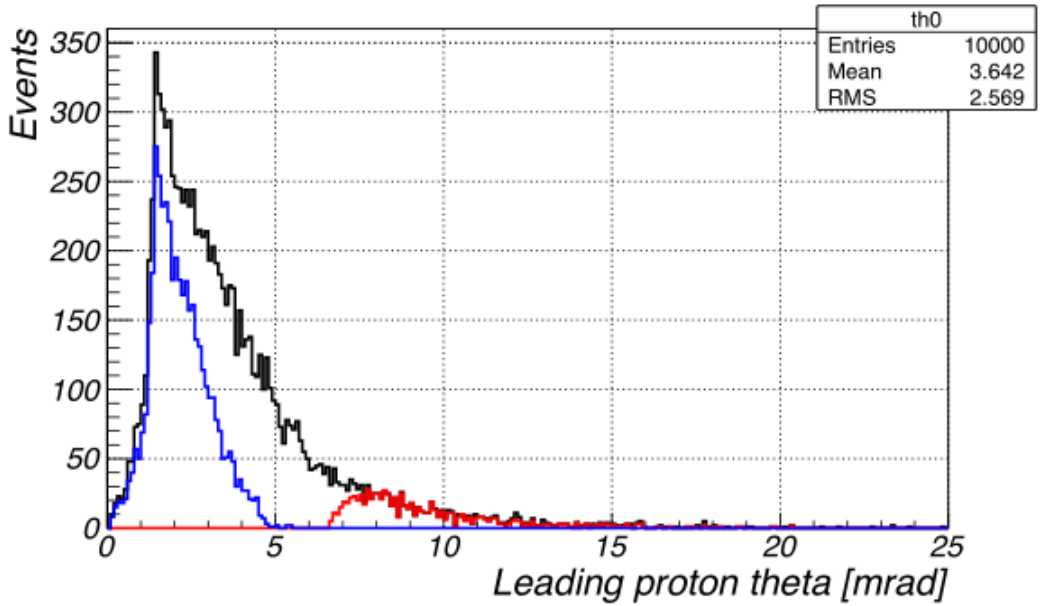

- Veto tagging helps.
- Very forward tag alone is questionable (need 3 dips).

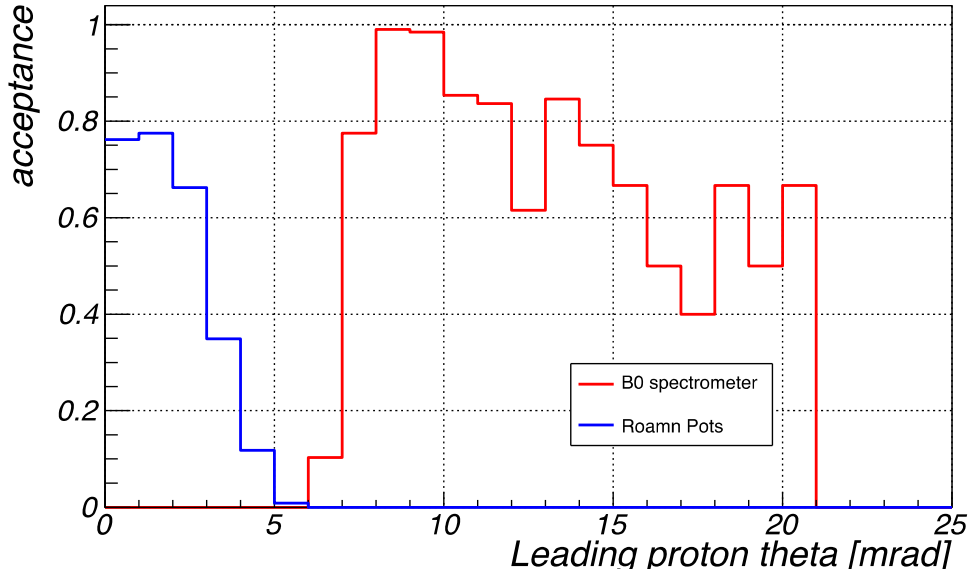
- Forward tag better. Not ideal.
- Still studying impact on G(b) reconstruction.

# eRHIC Forward Detector Acceptance Studies

W. Chang w/ Z. Tu plots

First look: Forward protons in e+Pb J/ψ incoh. diffractive events at eRHIC




MC truth

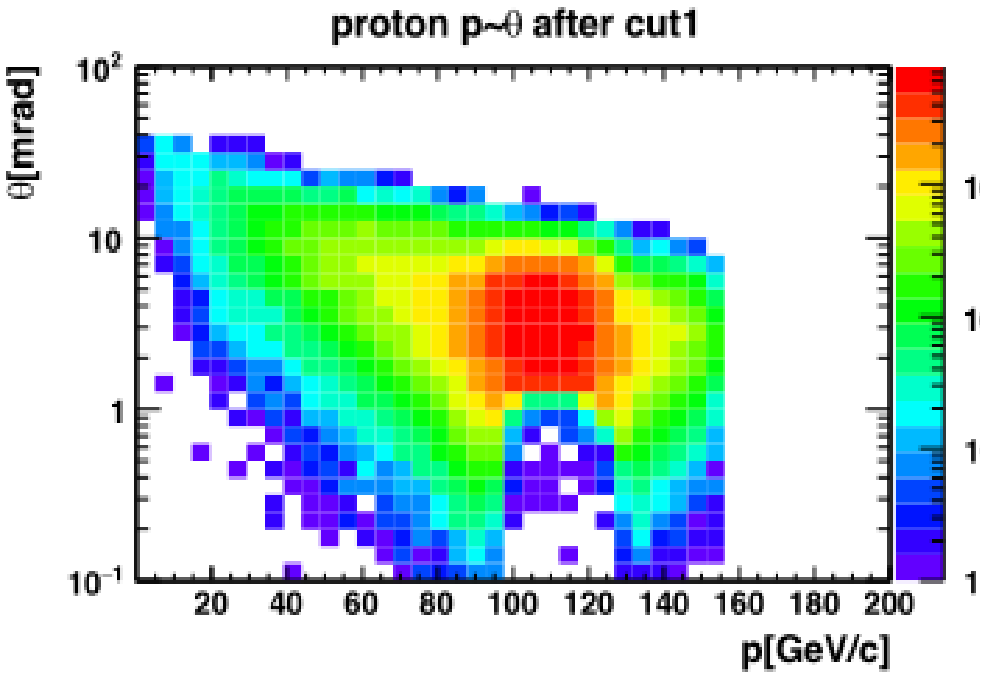
Roman pots acceptance

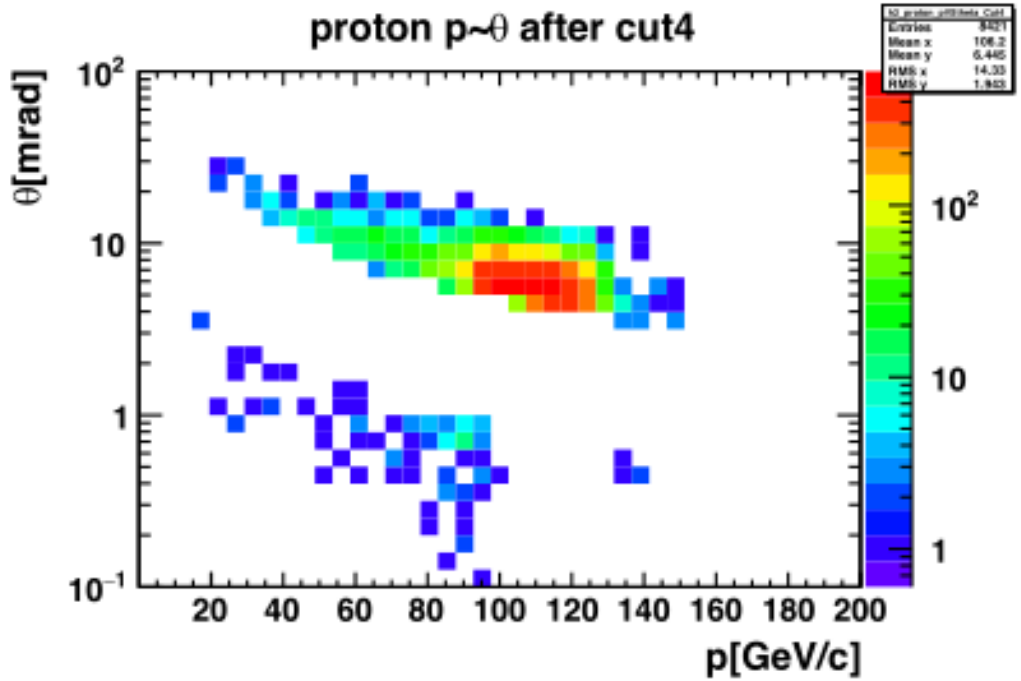
B0 spectrometer acceptance

# eRHIC Forward Detector Acceptance Studies

W. Chang + Z. Tu plots

First look: Forward protons in e+Pb J/ψ incoh. diffractive events at eRHIC



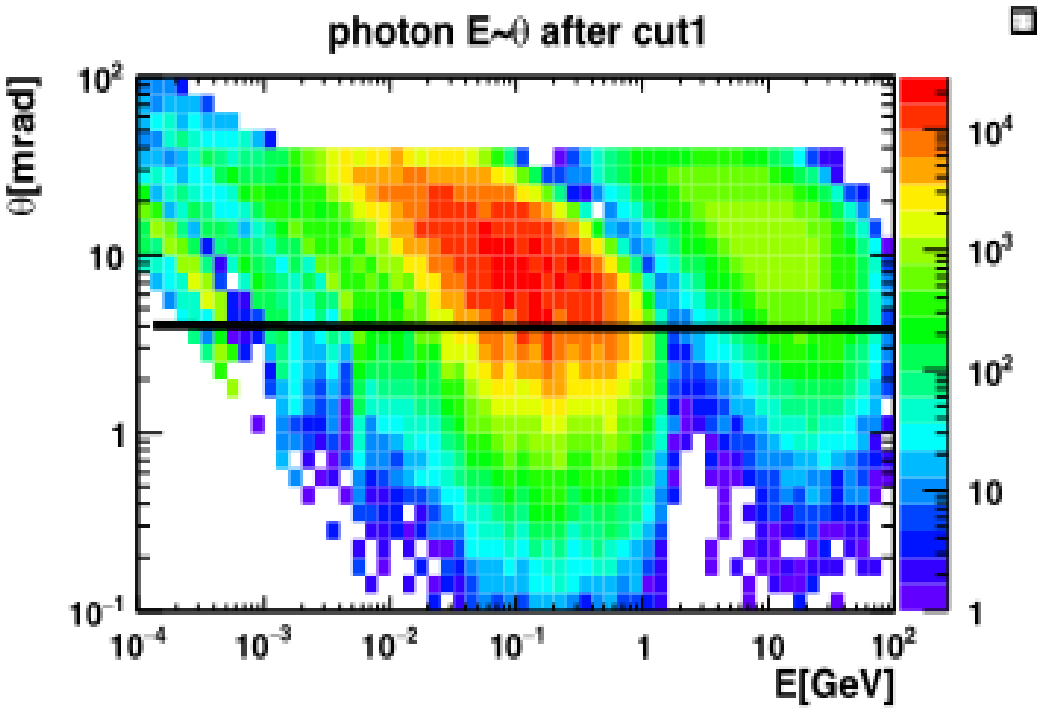

Cut 1 = Clean in central detector (e' & J/ψ only)

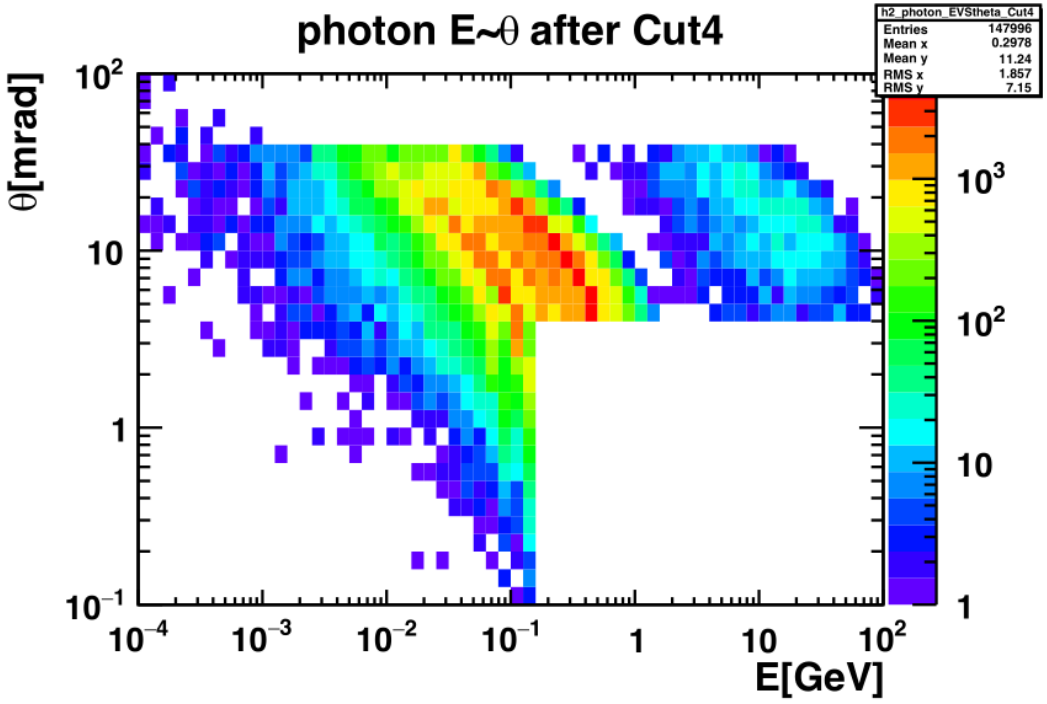
Cut 4 = Clean central detector & No n or γ(>150 MeV) in 4mr ZDC, & No detectable forward proton.

# eRHIC Forward Detector Acceptance Studies

W. Chang + Z. Tu plots

First look: Forward photons in e+Pb J/ψ incoh. diffractive events at eRHIC

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Cut 4 = Clean central detector & No n or γ(>150 MeV) in 4mr ZDC, & No detectable forward proton.

# User Demand for e+D (& SRCs)

Recall from July 2018 meeting:
In July 2018 several groups asked about running e+D in BeAGLE for:

- Spectator proton tagging to simulate e+n collisions in DIS and/or diffractive physics (with or without spin polarization).
- Full reconstruction of e+D → e'+p+n+J/ψ for low |t| and high relative transverse momentum of the p and n in order to study p+n interaction.
- Full reconstruction of e+D→ e'+p+n+J/ψ as a reference sample for short-range correlations (SRCs) in heavier nuclei, which may be driven by quasi-deuterons in the nucleus.

BNL Goldhaber Fellow Zhoudunming (Kong) Tu volunteered to collaborate on BeAGLE development to enable e+D.
Theoretical motivation and guidance from Christian Weiss (JLAB), Raju Venugopalan (BNL), Thomas Ullrich (BNL) & Matt Sievert (LANL)

# Conceptual problem for e+D w/ large k

Main problem – Everything lives on mass shell.
No remnant to absorb energy-momentum imbalance.

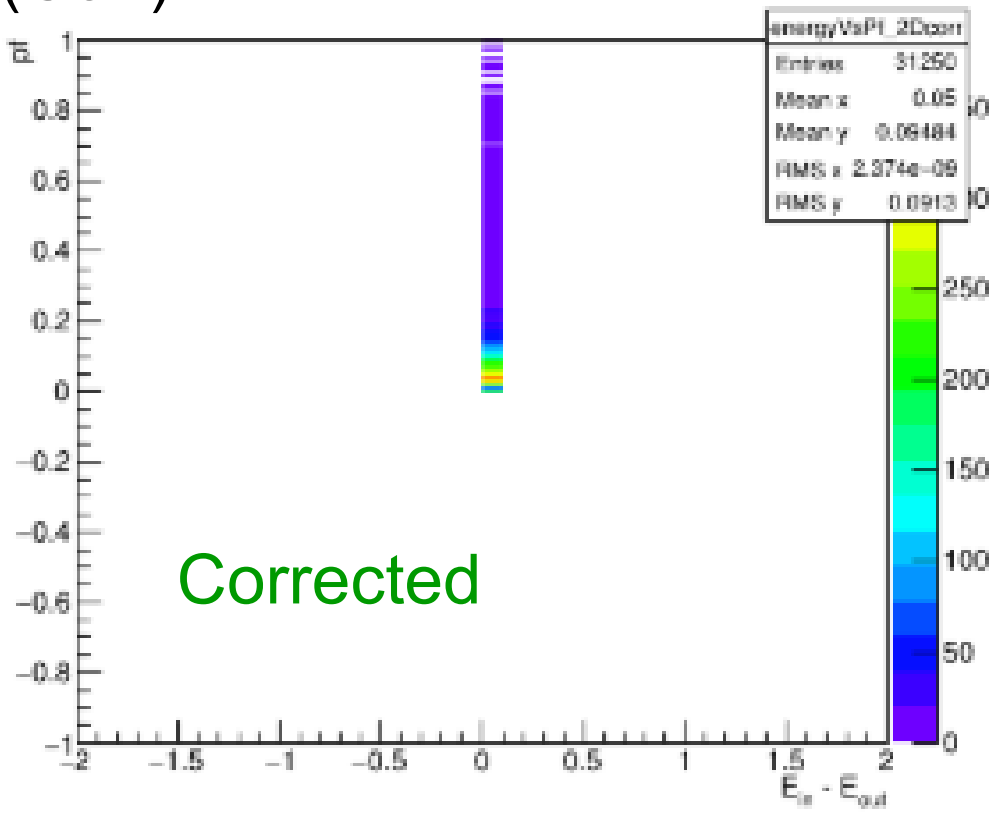

$W^{\mu} = \{\nu + M_d;\ 0,\ 0,\ \mathrm{sqrt}(\nu^2 + Q^2)\}$

$W^{\mu} = \{\nu + E_n + E_p;\ 0,\ 0,\ \mathrm{sqrt}(\nu^2 + Q^2)\}$

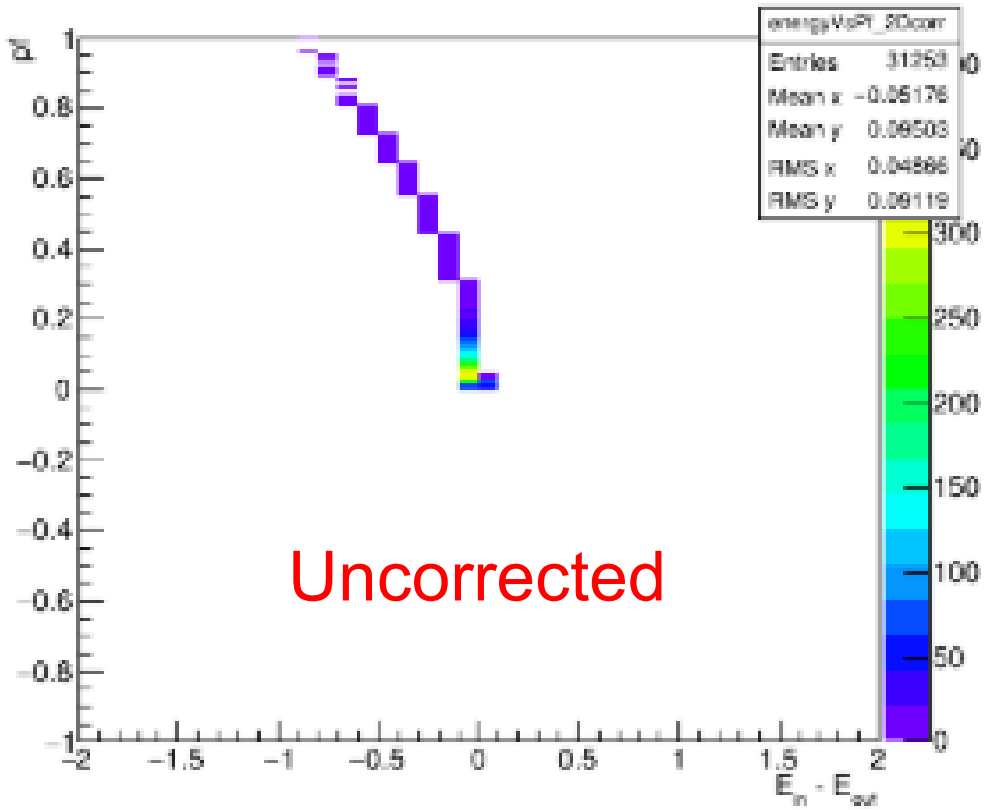
Energy not conserved in the ion rest frame (E & $p_z$ fail in other frames)
Note: DPMJET3-F has the same problem. Minimized due to minimal $p_F$.
Must adjust 4-momenta of final state.

# Correction works (MDB + Kong)

k (GeV)

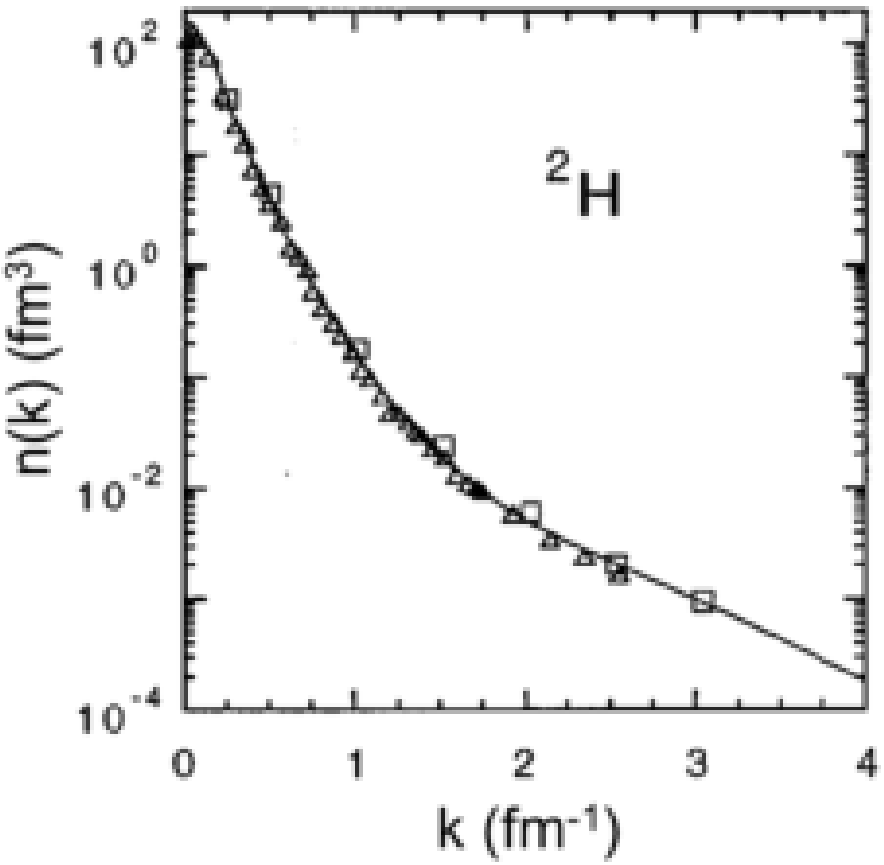



$\sum E_{correct} - \sum E_{simulated}$ (GeV)
In full HCMS




$\sum E_{correct} - \sum E_{simulated}$ (GeV)
In full HCMS

# High k tails of nucleons in the deuteron



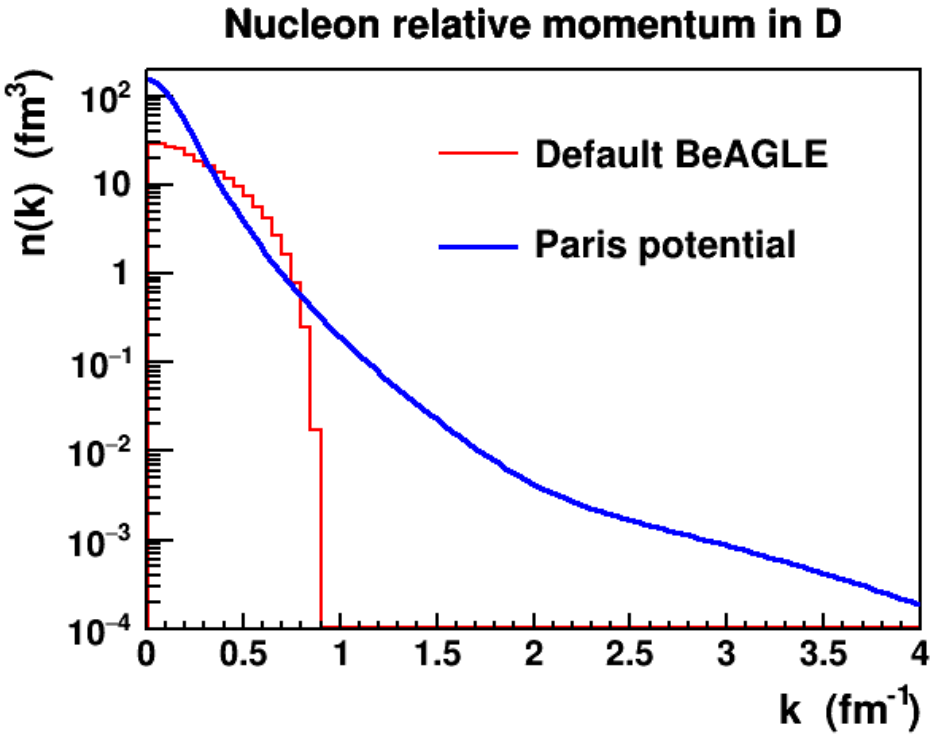

Hen et al., RMP 89 (2017)045002 Fig. 4
adapted from Fig. 1 of
Ciofi degli Atti, Simula, PRC 53 (1996) 1689

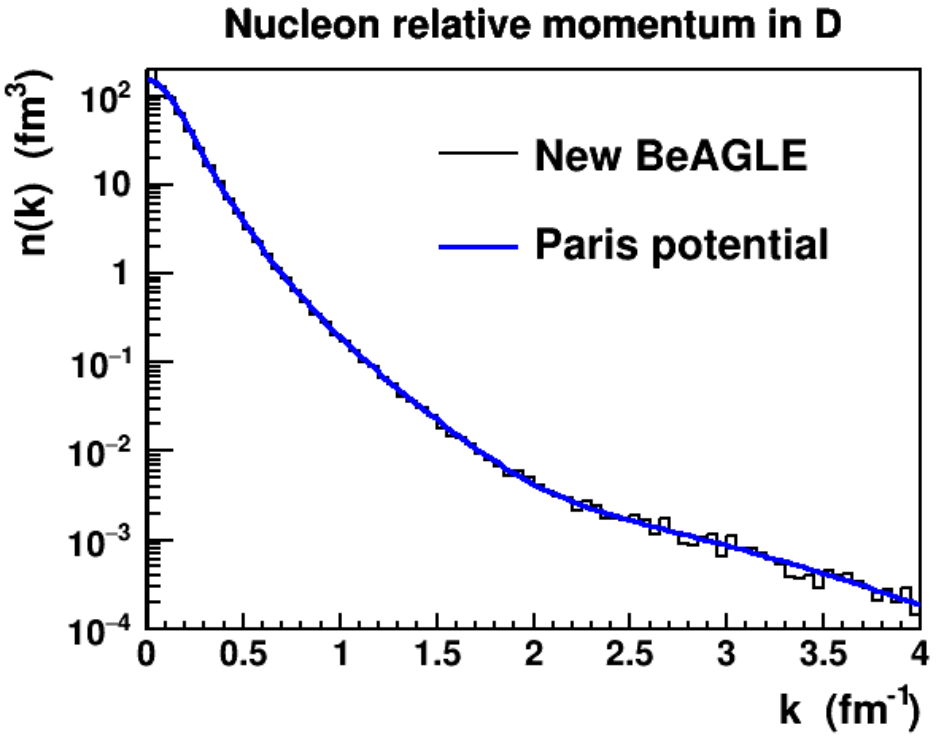
Variable k = nucleon momentum wrt deuteron cm: generalized "Fermi momentum".

$n(k) = k^{-2}\, dN/dk = \int d\Omega (d^3N/dk^3)$
$fm^{-1} \sim 197$ MeV

The curve is theory. Squares & triangles are data from:
C. Ciofi degli Atti et al., PRC 43 (1991) 1153;
M. Berheim et al.: NPA 365 (1981) 349;
S. Turck-Chieze et al.: PLB 142 (1984) 145.

# Kong (+MDB) implemented the D-tails

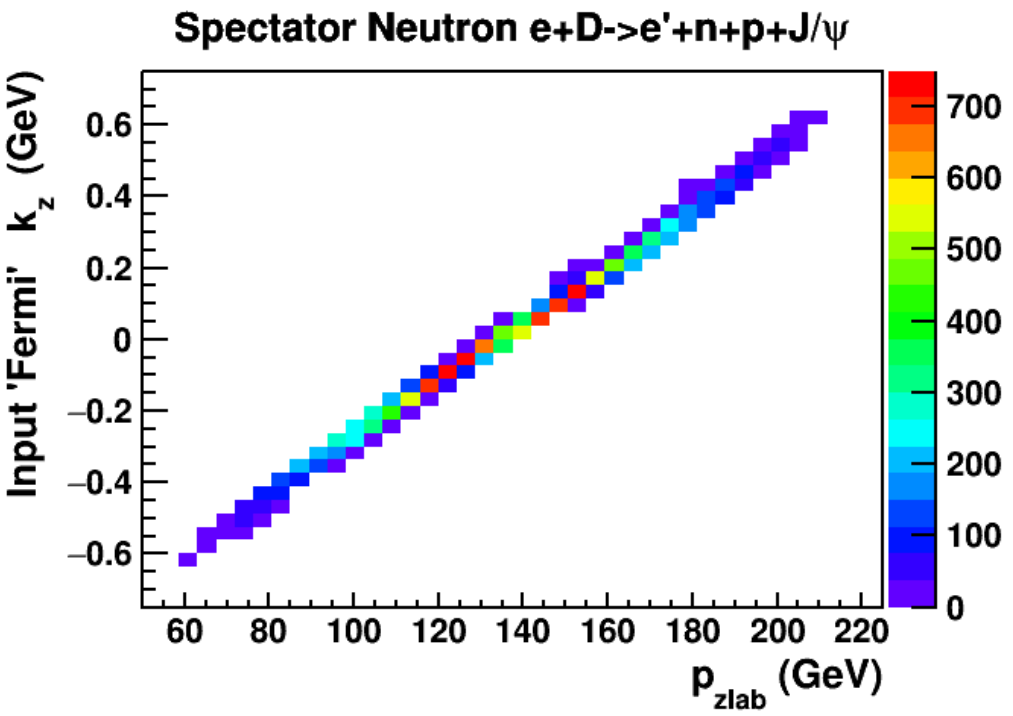


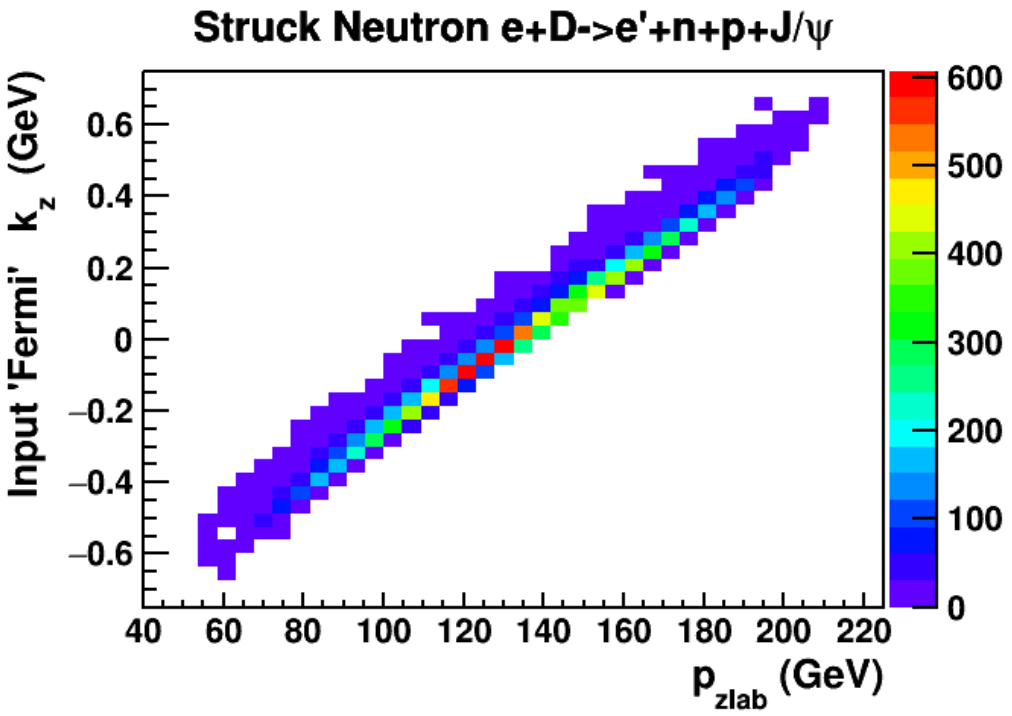




$n(k) = k^{-2} * dN/dk = \int d\Omega(d^3N/dk^3)$ from PRC 53 (1996) 1689
k is nucleon momentum wrt deuteron cm

Default BeAGLE distribution from DPMJet (little Fermi drop)

# 18x135 e+D momentum tail effect



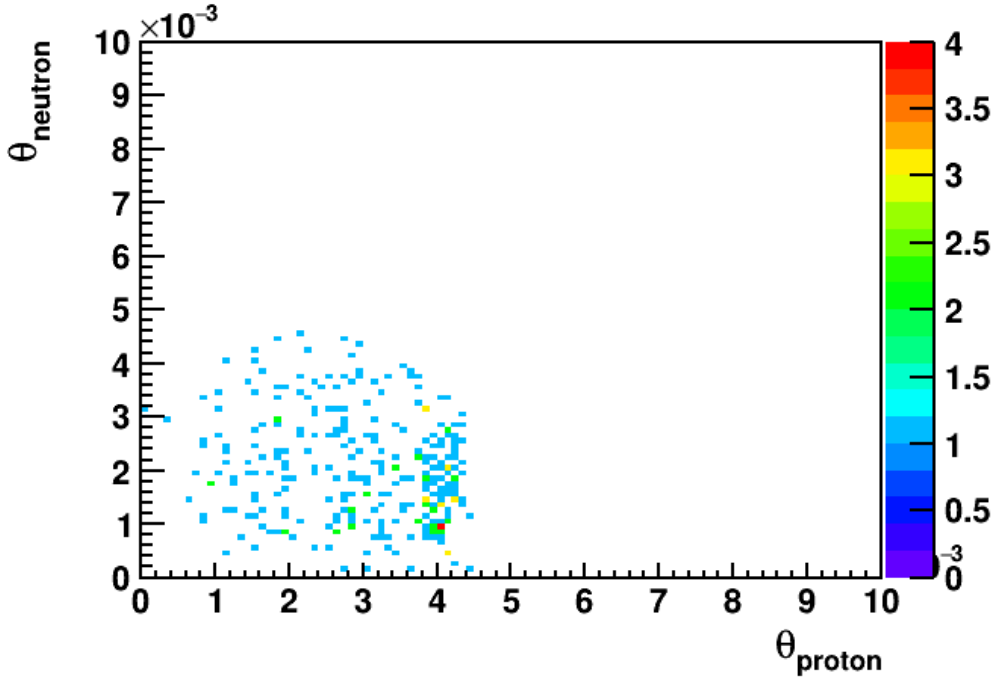

Any p-kick (IS or FS) along the “z” direction in the ion rest frame is magnified!
High $p_z$ tails will be easy to pick out and measure.

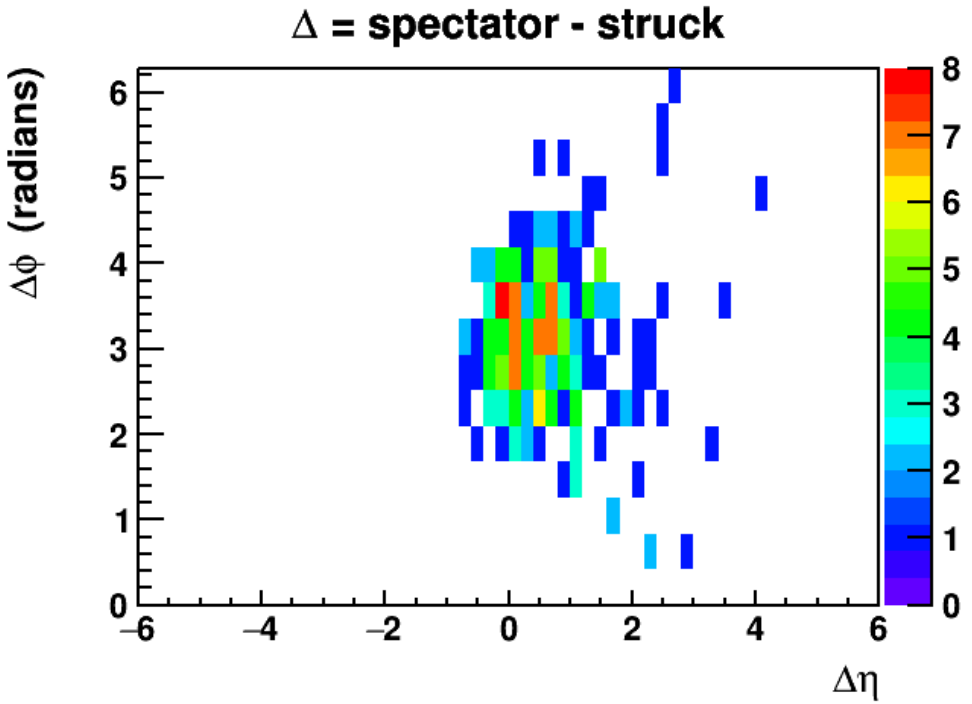
Note: k is the relative momentum of n wrt D (arbitrary distribution)
$k_z$ wrt z along $\gamma$*D axis in IonRF. $p_{zlab}$ has z along eD axis in lab.

# Correlations

18x135 GeV e+D→e'+n+p+J/ψ

For struck neutron, spectator proton – lab variables
|t|<0.1 GeV$^2$, 550 < k < 600 MeV




Keeping |t|<0.1 GeV$^2$ contains forward nucleons in θ<5 mr!

Nucleons are back to back.

# Further user interactions @ Workshops

Talks: M.D. Baker et al.

- "SRCs @ EIC: Challenges in forward detection and simulation", CFNS Workshop on Short-range Nuclear Correlations at BNL, Sept. 5-7, 2018
- "MC Event Generator BeAGLE for Forward Physics at the EIC", CFNS workshop on Forward Physics and Instrumentation From Colliders to Cosmic Rays at Stony Brook University, October 17-19, 2018.
  - Made contact with some of the authors and current maintainers of DPMJet as well as members of the Fluka collaboration.
- Unable unable to accept an invitation to talk at the Seattle INT Workshop "Probing Nucleons and Nuclei in High Energy Collisions" during the "eA Collisions" weeks Oct. 29-Nov.9, 2018 in Seattle, Washington.
  - Apparantly a lot of discussion on e+D & SRCs

# Technical Progress

| Feature added or error corrected | 07/2018 | 12/2018 | Planned |
|---|---|---|---|
| 1-8. Early BeAGLE features (see previous reports). | YES | YES | YES |
| 9. Shadowing coherence length | NO | NO | YES |
| 10. Partial shadowing effect | YES | YES | YES |
| 11a. Effective $\sigma_{dipole}$ for J/ψ averaged over x & $Q^2$ | YES | YES | YES |
| 11b. Effective $\sigma_{dipole}$ for ϕ averaged over x & $Q^2$ | YES | YES | YES |
| 11c. Eff. $\sigma_{dipole}(x,Q^2)$ for V=ψ,ϕ,ρ,ω from Sartre (ePb) | NO | NO | YES |
| 11d. Use correct $R_{shf}^{(A=208)}(x,Q^2)$ for V from Sartre | NO | NO | YES |
| 11e. Improved $\sigma_{dipole}$ for V, if necessary | NO | NO | YES |
| 12. Tune to E665 μA Streamer Chamber data | NO | NO | YES |
| 13. FS $p_T$ for hard process correct | YES | YES | YES |
| 14. Kinematic matching between DPMJet&Pythia | YES | YES | YES |
| 15. Protect against very high E* values. | YES | YES | YES |
| 16. Enable nPDF with any value of A,Z (EPS09) | YES | YES | YES |
| 17. Extend R→ $\sigma_{dipole}$ map to more values of A | YES | YES | YES |
| 18. Tune the t distribution for multiple scattering. | NO | NO | YES |
| 19a. Release α version BeAGLE/RAPGAP | YES | YES | YES |
| 19b. Release β version BeAGLE/RAPGAP | NO | YES | YES |
| 19c. Release tested version BeAGLE/RAPGAP | NO | NO | YES |
| 19d. Extend RAPGAP to include e+n (w/ H. Jung) | NO | NO | YES |
| 20. Allow diffraction w/ individual V=ψ,ϕ,ρ,ω | YES | YES | YES |
| 21. Cleanup and document BeAGLE work so far. | NO | YES | YES |
| 22. Update Fermi momentum distributions for e+D. | NO | YES | YES |
| 23. Put e+D on mass-shell (light-cone prescription) | NO | Ad-hoc | YES |
| XX. Implement UltraPeripheral Photon Flux | NO | NO | NO |
| XX. Tune BeAGLE to UPC data (RHIC &/or LHC) | NO | NO | NO |

Table 2. Technical accomplishments and plans through FY2019.


| | | | |
|---|---|---|---|
| 19a. Release α version BeAGLE/RAPGAP | YES | YES | YES |
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- Successful at releasing BeAGLE and configuring it for a broader developer & user base.
- Significant progress on e+D.
- Delay in RAPGAP implementation.
  - No showstoppers seen.
- Difficulty of tuning to data is unknown.

# Response to Committee Recommendations

*Recommendations:*

The committee recommends this proposal be funded.

Since BeAGLE is essential to establishing the EIC detector requirements, by the next meeting in January 2019 the committee would like to see a plan for accelerating the work, ensuring BeAGLE expertise is held more widely, and addressing continuity.

- Good progress on these issues. BeAGLE is:
  - Documented: https://wiki.bnl.gov/eic/index.php/BeAGLE
  - Widely accessible & version controlled
    - All versions merged & installed at BNL & JLAB
    - Available on git (repository / version control system)
  - Attracting a growing base of developers (& users)
    - Now: MDB + Mathieu Ehrhart + Zhoudunming Tu +LZ
    - Soon: Florian Hauenstein, Barak Shmookler + ...

# Big Picture / External Funding / Continuity

| | Fiscal Year | BNL eRD17 | JLAB LDRD |
|---|---|---|---|
| Original Proposal: DIS at low x | FY2016 | DIS Shadowing year 1 | |
| | FY2017 | DIS Shadowing year 2 | Geometry Tagging year 1 |
| Committee/Users push: Diffraction & Validation | FY2018 | Add RAPGAP & Tune year 1 | Geometry Tagging year 2 |
| | FY2019 | Add RAPGAP & Tune year 2 | Short-Range Correlations year 1 |
| | FY2020 | ? | Short-Range Correlations year 2 * |

<u>FY2019 Midcourse corrections:</u>

Add e+D. - Driven by strong user demand
UPC – Looking for new expert collaborators – Trying to keep the project achievable
Strengthen User/Developer base – Suggested by committee & driven by users.

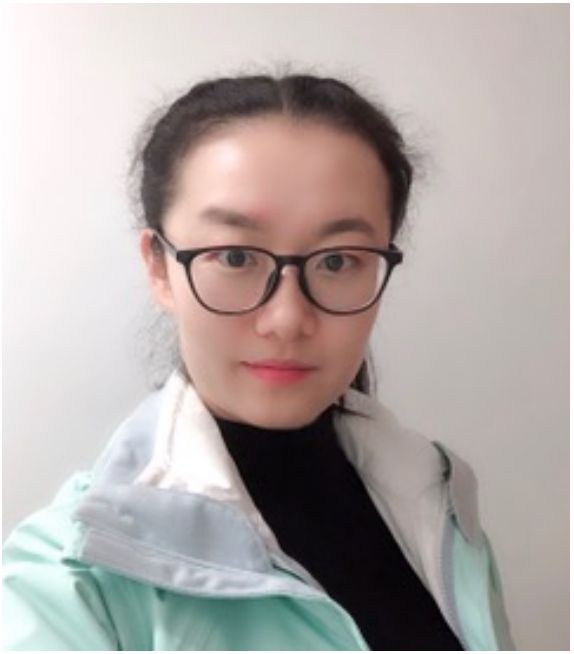
<u>Continuity: contract vs. institutional employee model for key personnel (Baker):</u>

MDBPADS was established in 2011 and has operated continuously since then.
Approved projects through 2020 (funding for 2020 not guaranteed)
History of contracts directly w/ BNL & JLAB as well as BNL/eRD17
Senior lab employees have little time to devote to model-building (esp. in the US)
Note: A multi-year contract *would* be preferable to year-by-year

# Accelerating the Work

Wan Chang, supervised by Elke, working on a day-to-day basis with Kong Tu w/ support from Baker is now a proven formula, based on the acceptance studies.

Plan: Use this approach for BeAGLE tuning.



FY2019 Supplemental Proposal

Wan Chang – travel support (per diem + housing only)

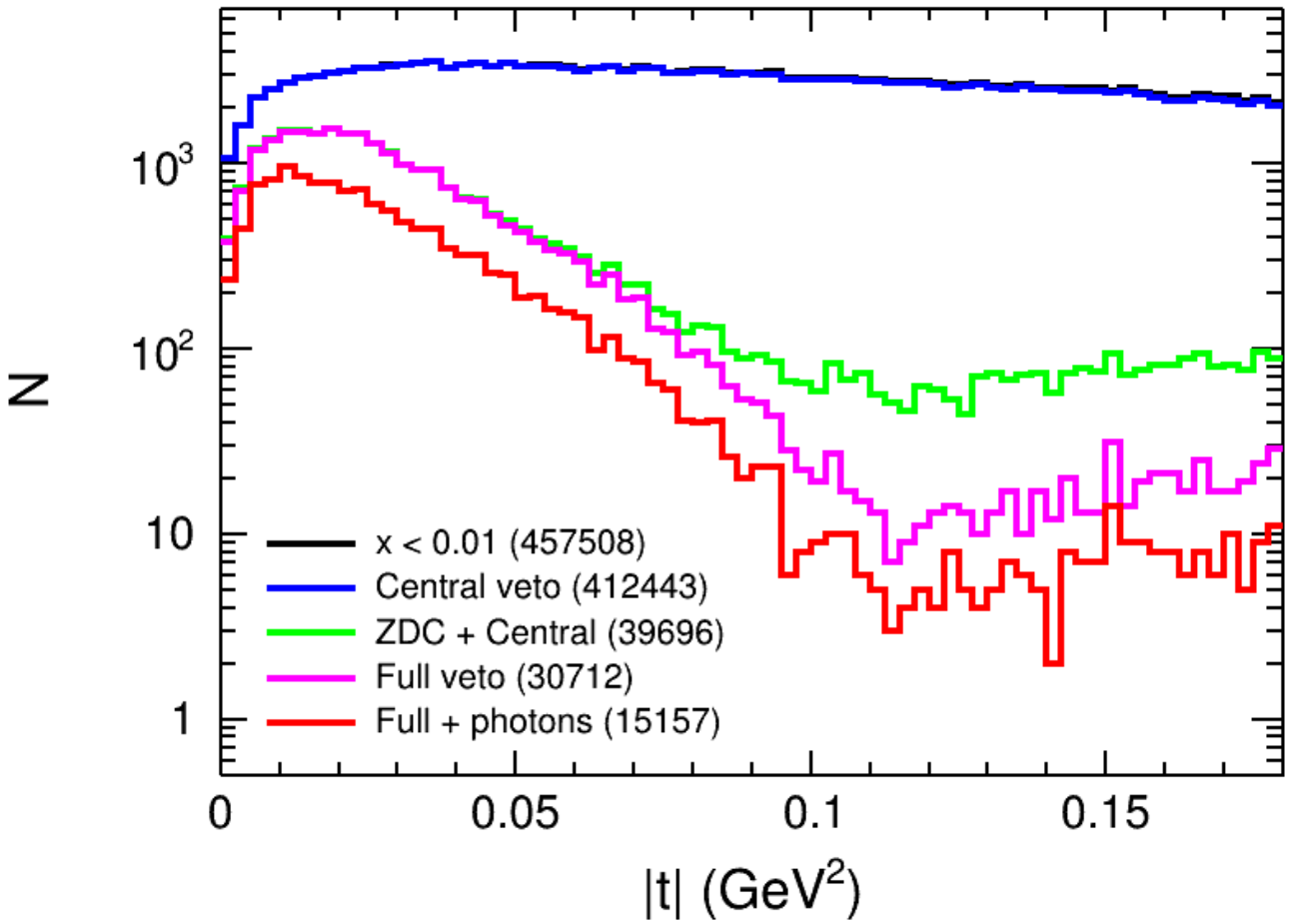
| Effort Level | Additional Funding | Comments |
|---|---|---|
| 3 FTE months = 0.25 FTE years | $14,400 | Minimum practical |
| 5 FTE months = 0.42 FTE years | $24,000 | PROPOSED |
| 7 FTE months = 0.58 FTE years | $33,600 | Maximum practical |

# Conclusions

- BeAGLE is used at both labs to understand detector acceptances and requirements.
- BeAGLE expertise is growing rapidly.
  - Accessible and version-controlled.
  - Collaborative rather than support-based approach.
- BeAGLE validation w/ RAPGAP & E665 data is progressing, but somewhat delayed.
  - As suggested by the committee in the July homework discussions, we propose a $24k supplement to accelerate the effort.

# Extras

# JLEIC Event Veto: BeAGLE + GEMC




VETO USING:

Non-forward particles
$\theta$>100 mr ($E_\gamma$>500 MeV)

w/ very forward particles
($E_\gamma$>40 MeV)

(w/ very forward neutrals
or forward charged)

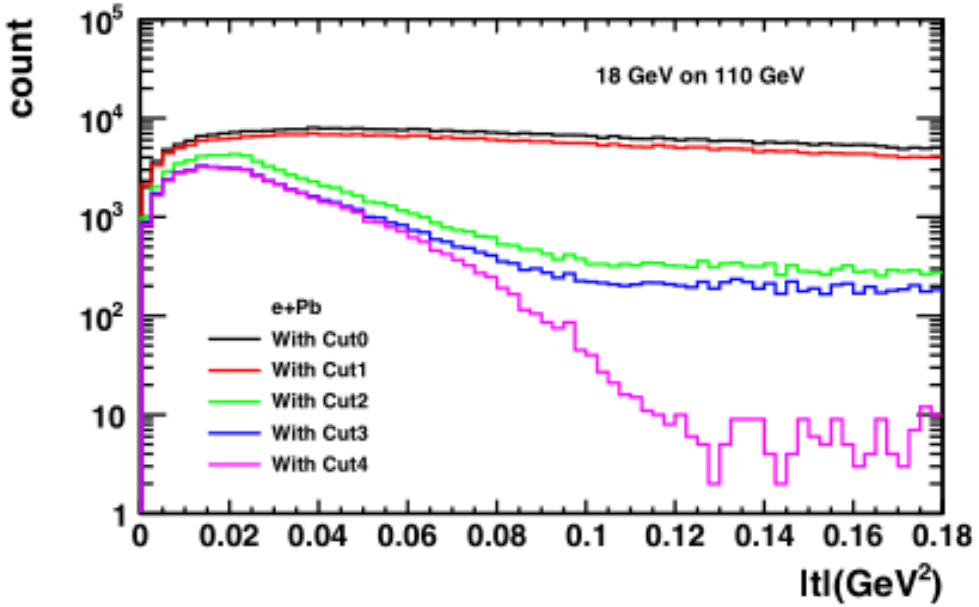
w/ forward particles
($E_\gamma$>40 MeV)

BeAGLE models incoherent e+A diffraction as Glauber $\Sigma$ e+N

Full + photons means we veto on all forward particles which make it through the first spectrometer dipole.

# Event distribution

eRHIC veto cuts




| Event Count | |
|---|---|
| Cut0 | 1000000 |
| Cut1 | 766250 |
| Cut2 | 122059 |
| Cut3 | 85872 |
| Cut4 | 68461 |

**Cut0:** no cut

**Cut1:**

- no activity in the main detector other than the $J/\Psi$ and scattered electron

**Cut2:**

- Cut1
- no neutron in ZDC($\theta$ < 4mrad)

**Cut3:**

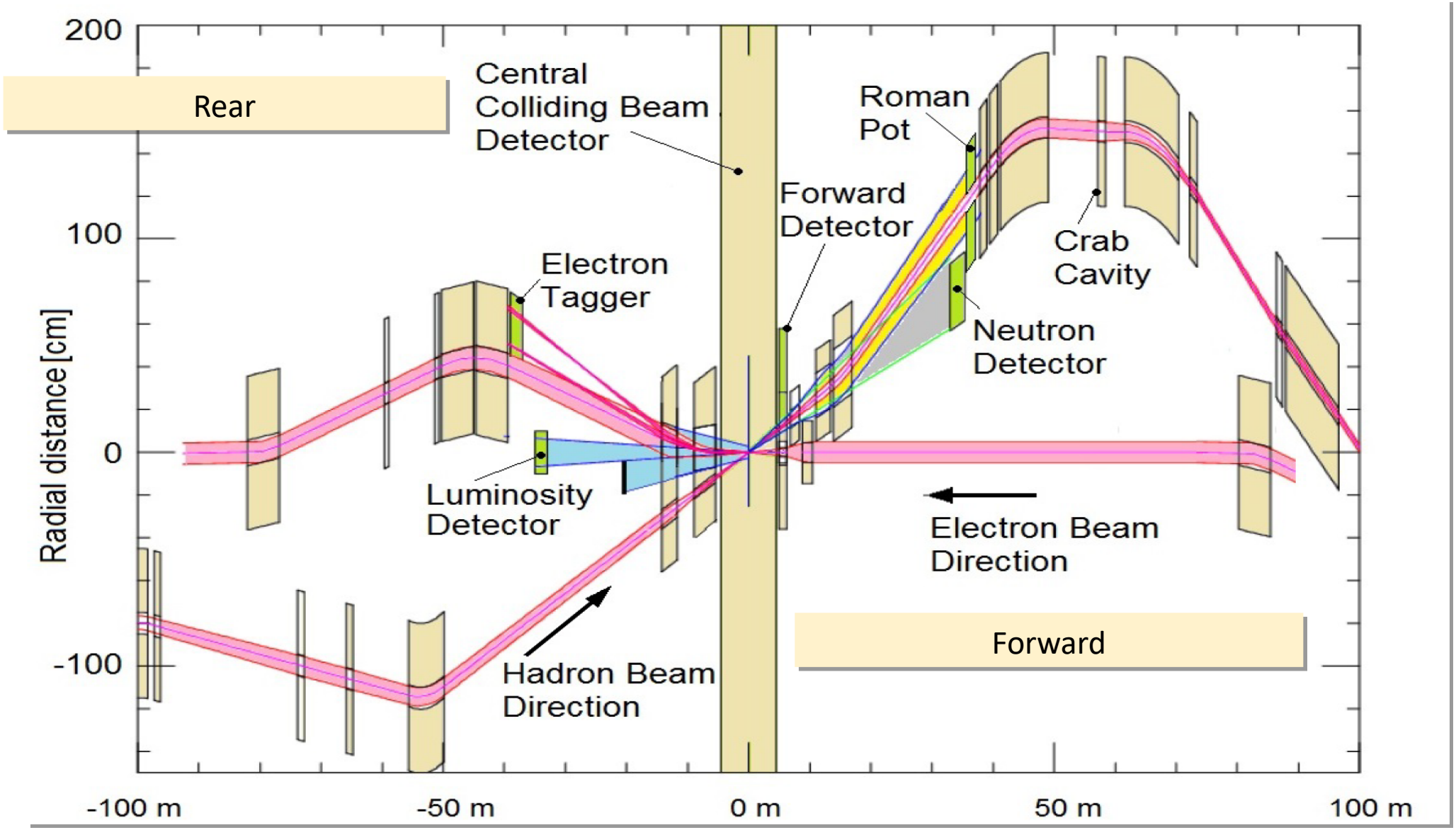
- Cut2
- no photon E>150MeV in ZDC

**Cut4:**

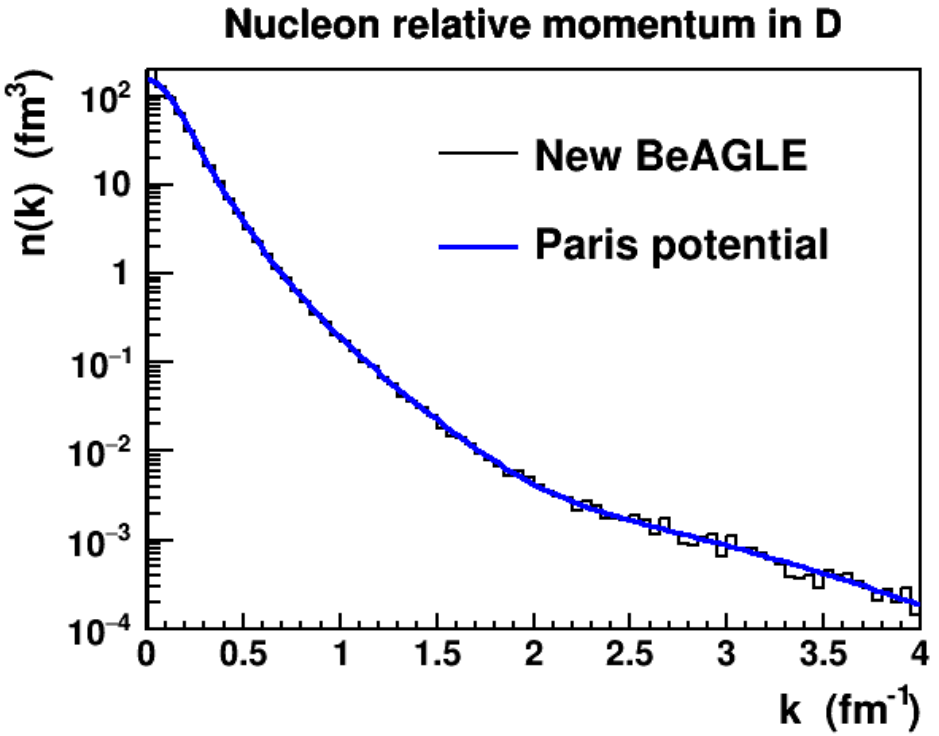
- Cut3
- no proton in $\frac{0.2}{R} < p_T < \frac{1.3}{R}$ (Pb: A→208, Z→82, R = A/Z )

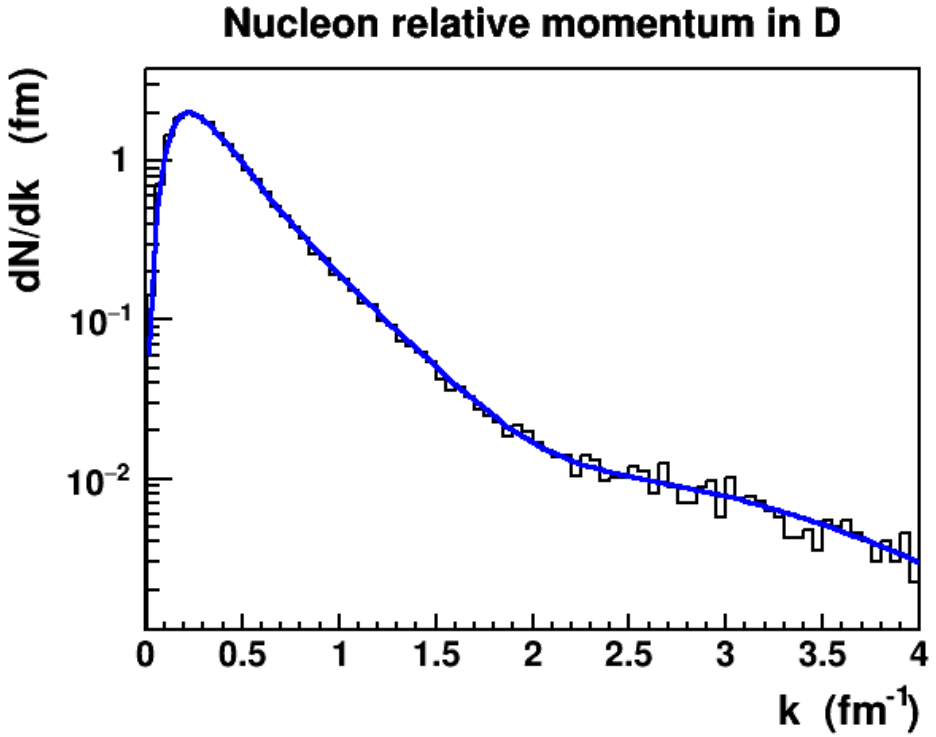
# eRHIC detector

https://www.bnl.gov/cad/eRhic/Documents/eRHIC_Design_Update_Nov2018.pptx



# 3d versus 1d distributions



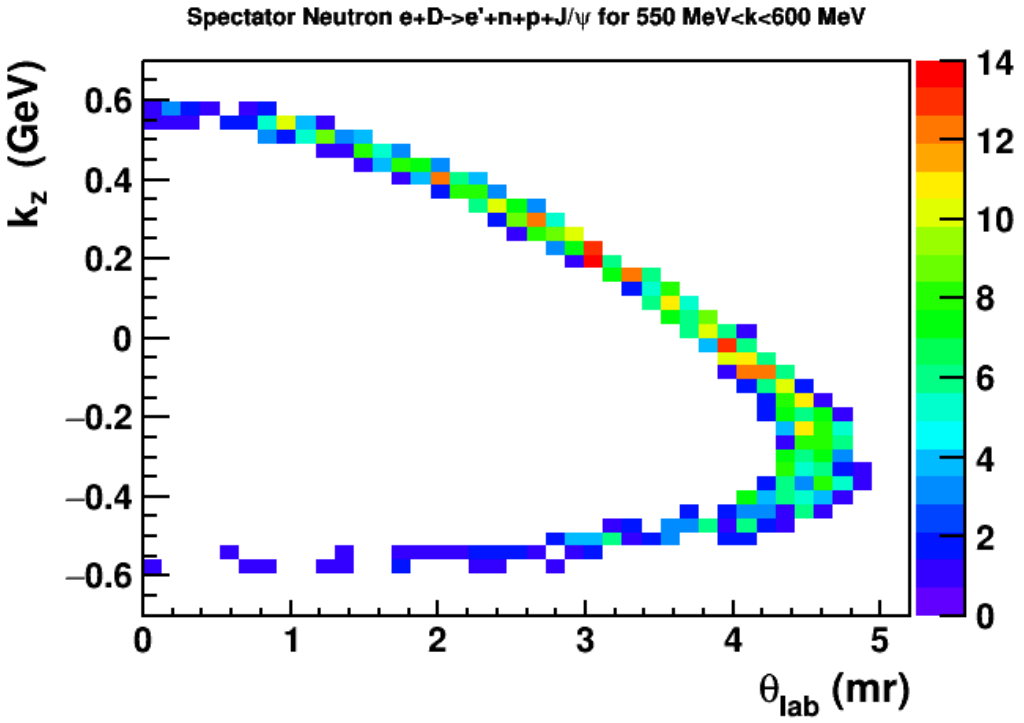

$n(k) = k^{-2} * dN/dk$

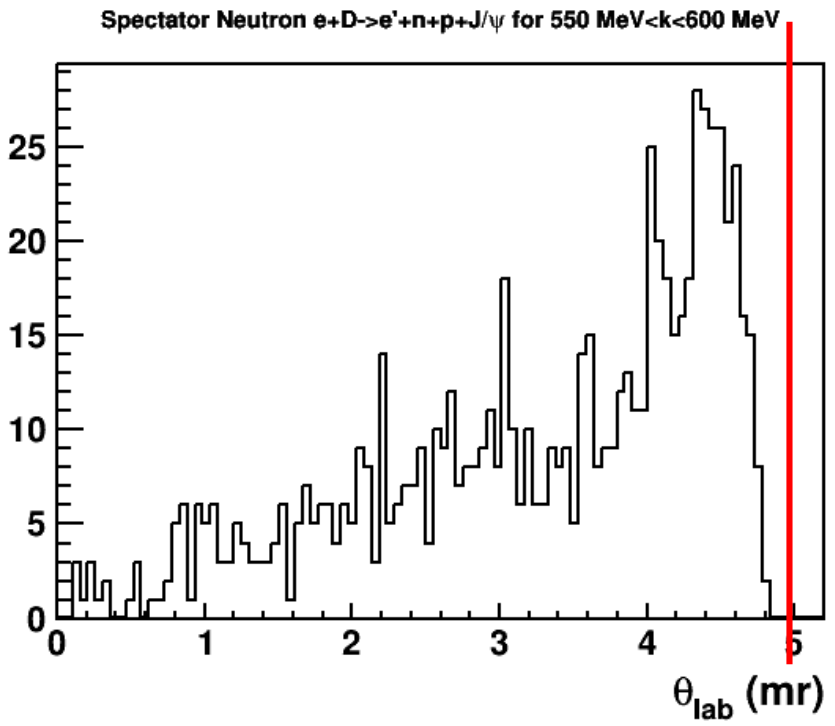
$= \int d\Omega (d^3N/dk^3)$

$dN/dk = k^2\, n(k)$

# Spectator neutrons (or p's) for k~575 MeV

18x135 GeV e+D→e'+n+p+J/ψ




Spectators are very forward, even for 550<k<600 MeV
Neutrons basically contained in ZDC.
Protons need study, but the prognosis is good.

# FY2019 Budget Proposal

| Person | Institution | Effort (FTE-year) | Cost to Proposal | Remarks |
|---|---|---|---|---|
| E. Aschenauer | BNL | 0.05 | \$0 | cost covered by BNL |
| M.D. Baker | MDBPADS[18] | 0.25 | \$62,400 | |
| J.H. Lee | BNL | 0.05 | \$0 | cost covered by BNL |
| L. Zheng | CUGW | 0.10 | \$0 | cost covered by CUGW |
| TOTAL: | | 0.45 | \$62,400 | |

Table 2: Personnel Budget Breakdown for FY2019

| Item | Cost |
|---|---|
| Personnel: | \$62,400 |
| Zheng Travel | \$4,500 |
| Other Travel | \$1,500 |
| TOTAL: | \$68,400 |

= FY2018 + inflation
NEW ITEM
NEW ITEM

Table 3: Total Budget Breakdown for FY2019