BeAGLE @ small x

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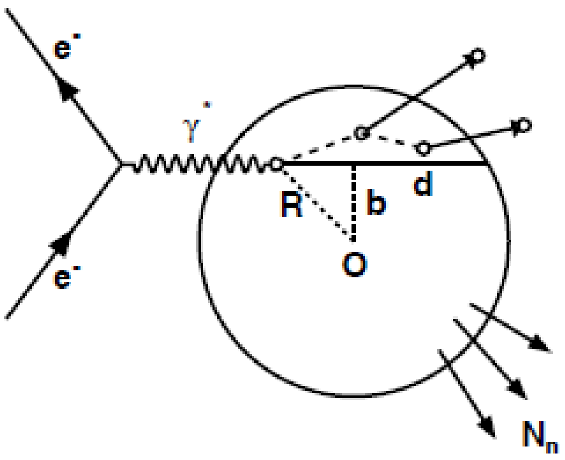
Key features of BeAGLE

Try to model both hard process AND nuclear interaction.



<u>Multistep process.</u>

Hard interaction (DIS or diffractive) involving one or more nucleons (Glauber).

Intra Nuclear Cascade w/ Formation Zone

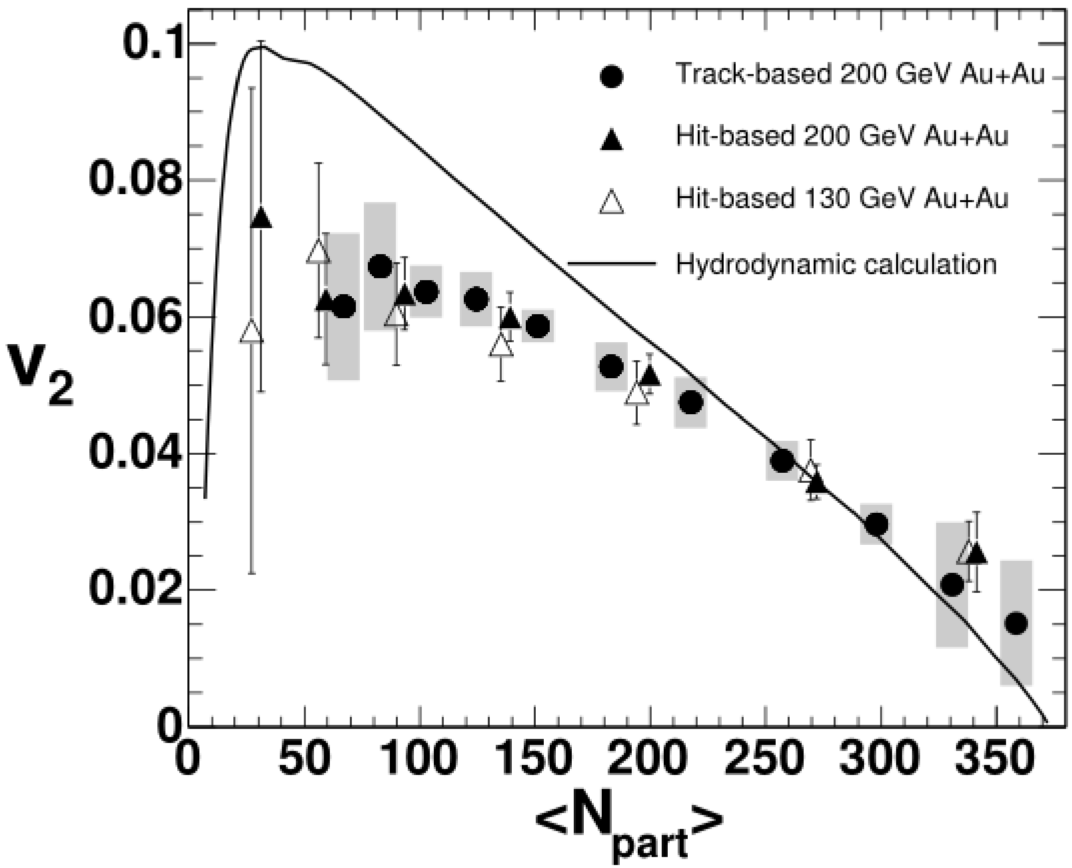
Excited nuclear remnant decays by:
- Fission &/or evaporation of nucleons
- De-excitation by gamma emission.

BeAGLE @ small x: Executive Summary

- Forward (nuclear remnant) tagging is important for small x physics..
  - We can remove the e+"skin" collisions and enhance nuclear effects substantially.
  - We can tag incoherent vs. coherent diffraction
- BeAGLE (or it's nuclear breakup functionality) must be preserved and improved upon.
  - Need from theory: better description of the hard γ^*+multiple nucleon collisions, including nucleonic remnants.

Precise centrality bins were crucial at RHIC

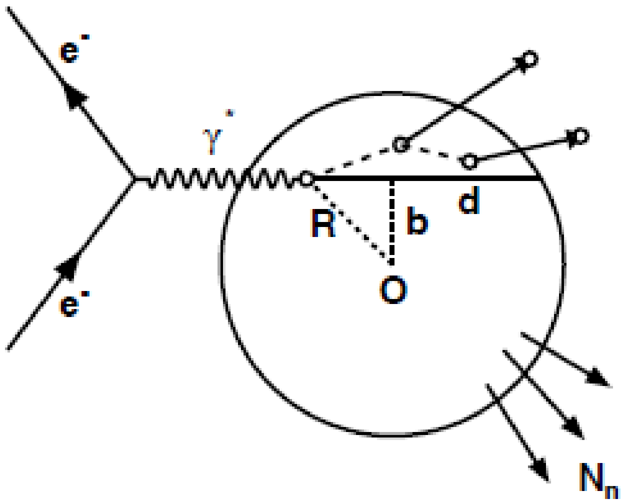
B.B. Back et al., PHOBOS Collaboration, "The Phobos Perspective on Discoveries at RHIC", Nucl. Phys. A757 (2005) 28

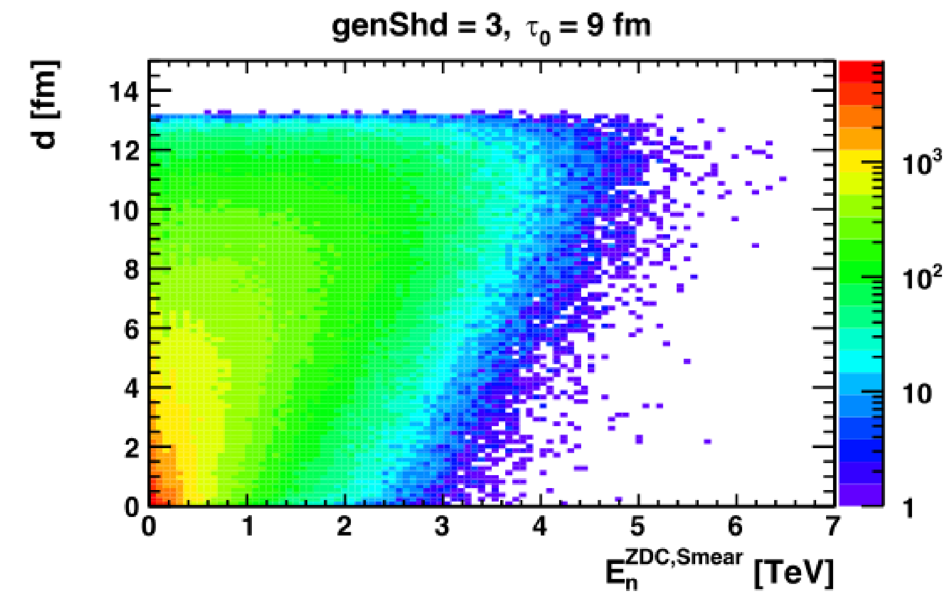


Event characterization was used by all 4 experiments @ RHIC to make the "near-perfect liquid QGP" discovery.

Zero Degrees in e+Pb

BeAGLE Plots from Wan Chang

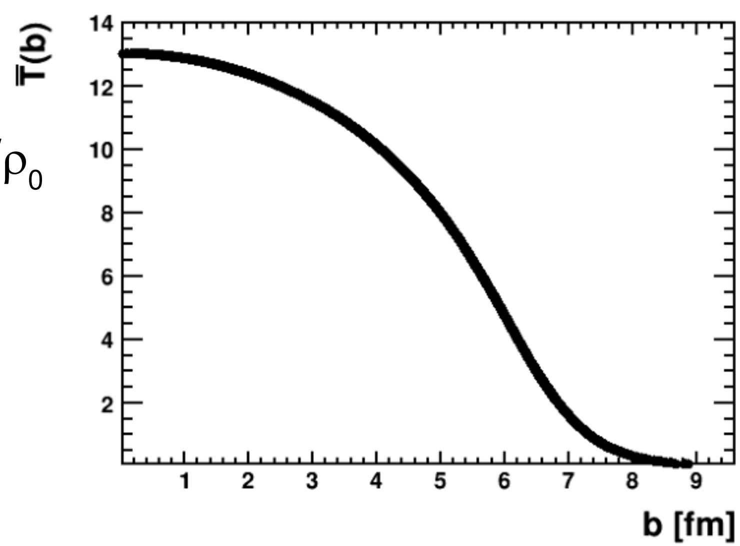


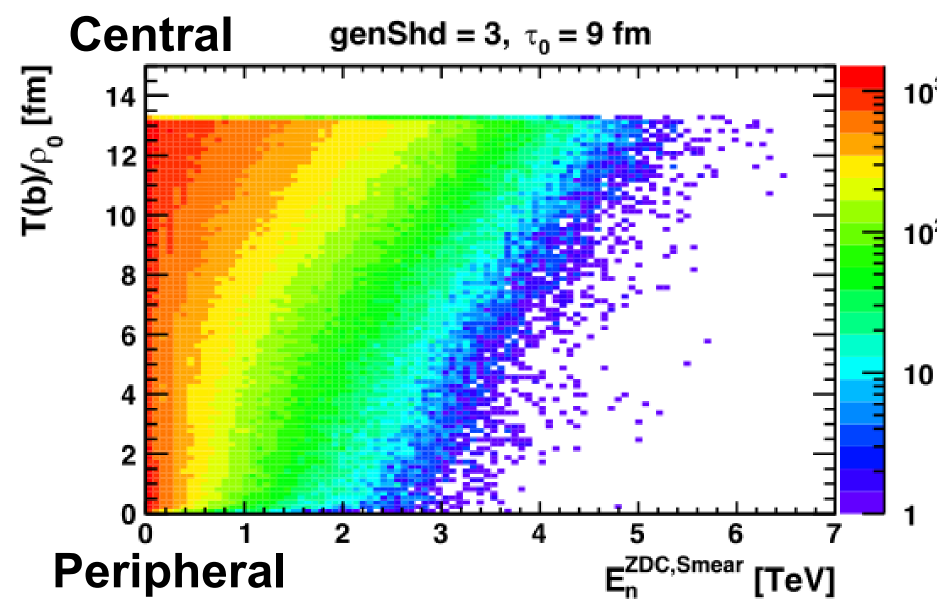


$d \equiv \int dz\, \rho(x,y,z)/\rho_0$ from $Z_{collision} \rightarrow \infty$

$T(b) \equiv \int dz\, \rho$ from $-\infty \rightarrow \infty$

$T(b)/\rho_0$ [fm]

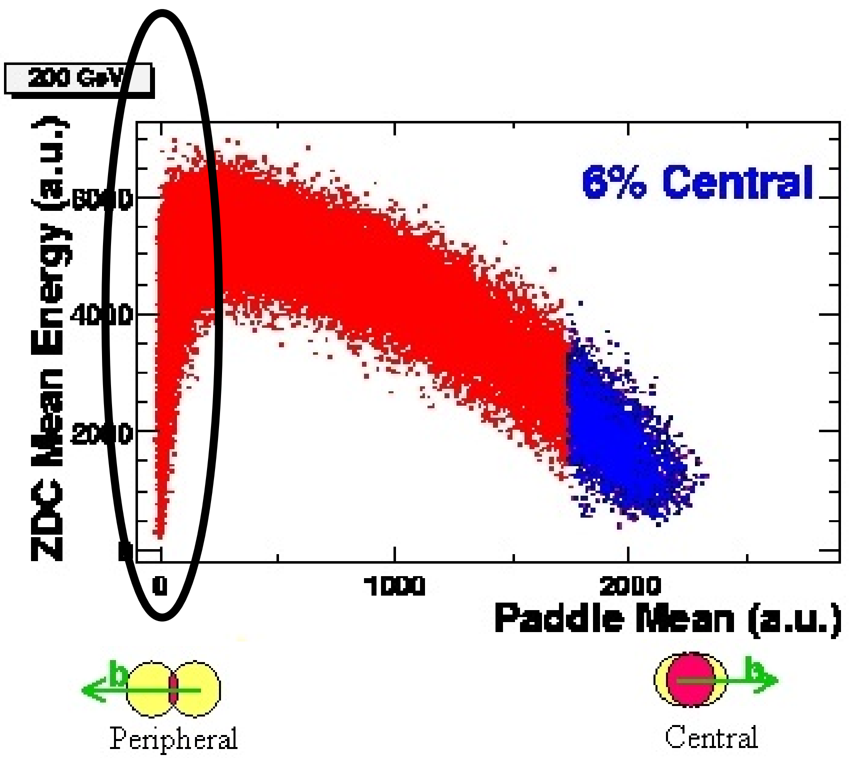


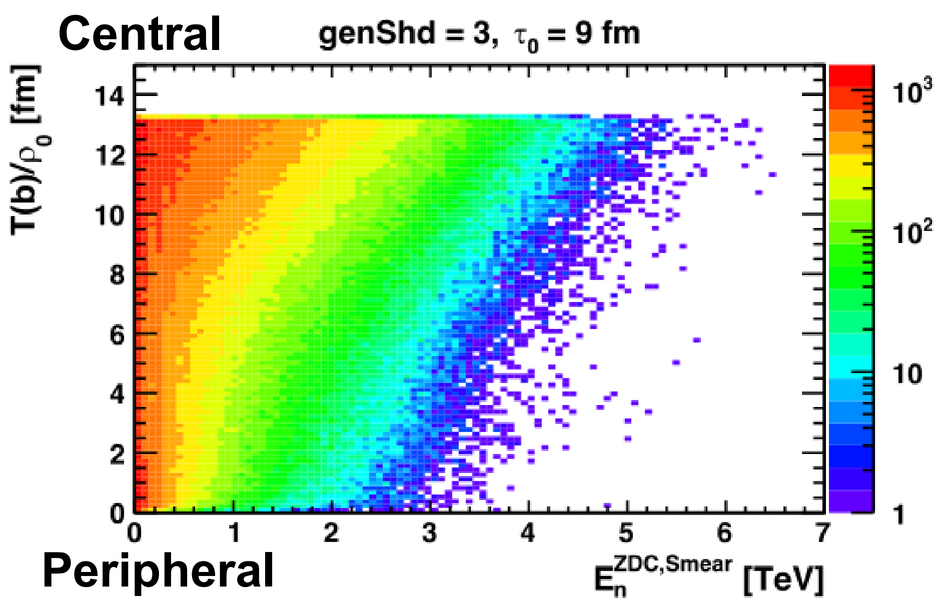


e+A is like very peripheral A+A

A+A
Very peripheral region:
Excitation & breakup like in e+A

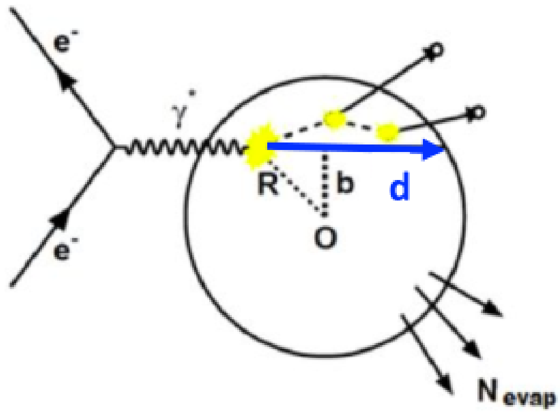
e+A
Evaporation neutrons increase with centrality – high E_{ZDC} @ b=0



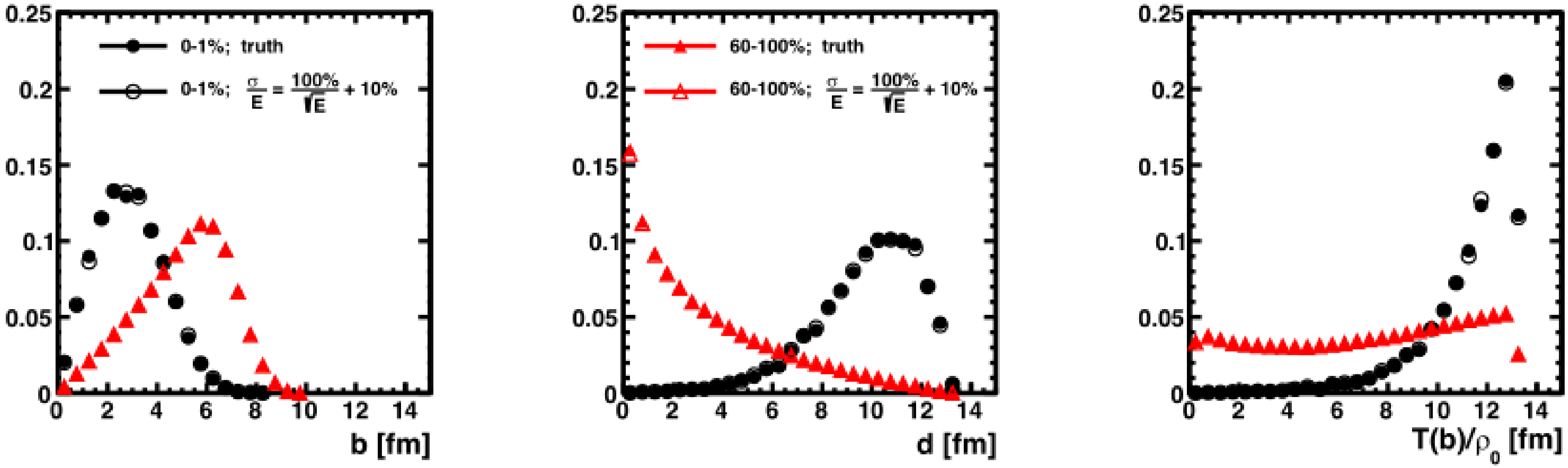


Centrality tagging – remove peripheral e+A

e+Pb collisions at the EIC

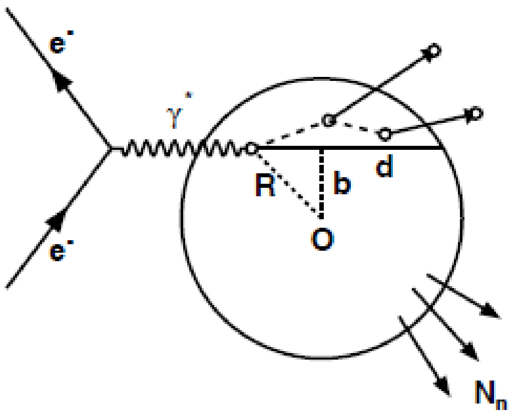


The b, d, $T(b)/\rho_0$ comparison between **central** and peripheral collisions.



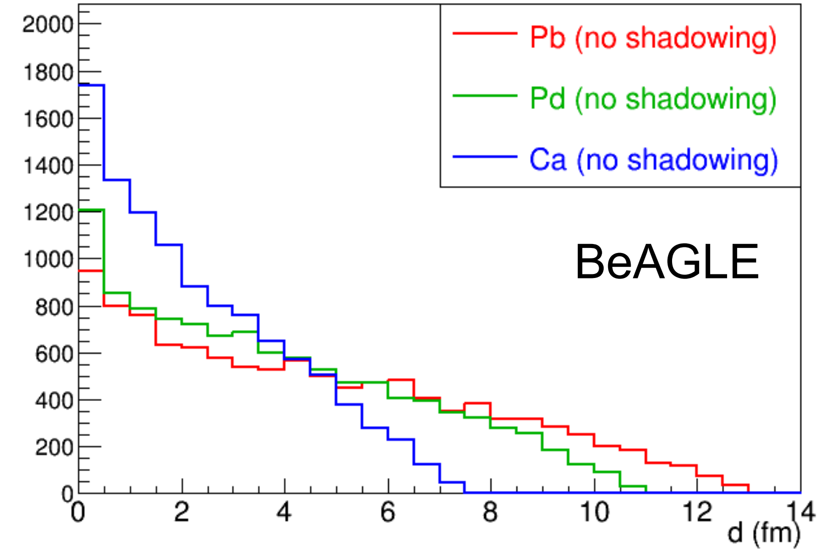
- The true distribution and the smeared one are almost identical.
- A higher resolution calorimeter is not required for this analysis.

Geometry tagging vs. A-scan

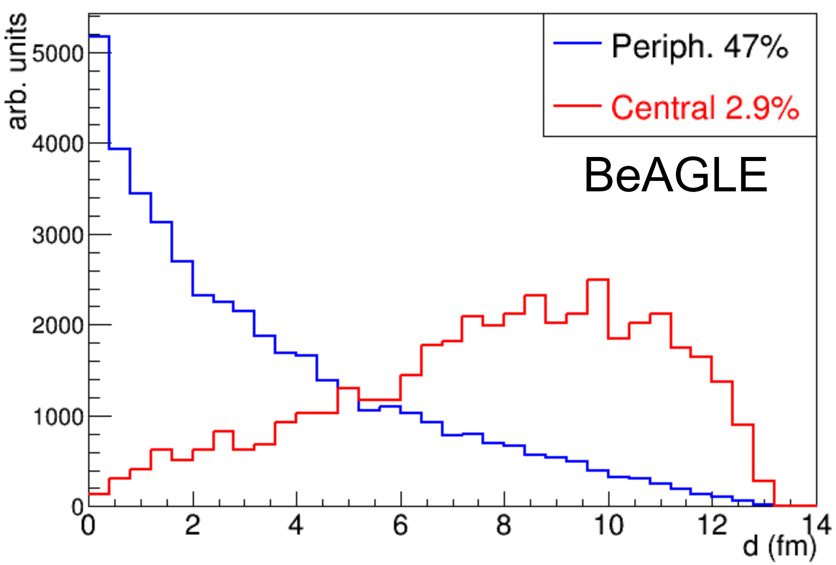


Intra-nuclear cascading increases with d (forward particle production)

Leads to evaporation of nucleons from excited nucleus (very forward)



Tagged ePb (samples scaled to same area)



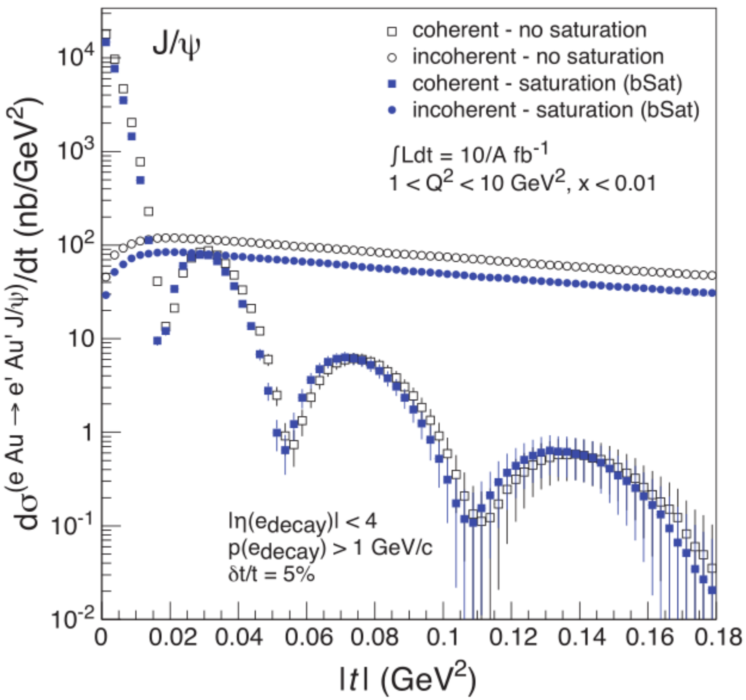
<d> increases w/ A, but all nuclei have a lot of “skin” (low d events).

ZDC tagging allows more distinctive low d and a high d samples

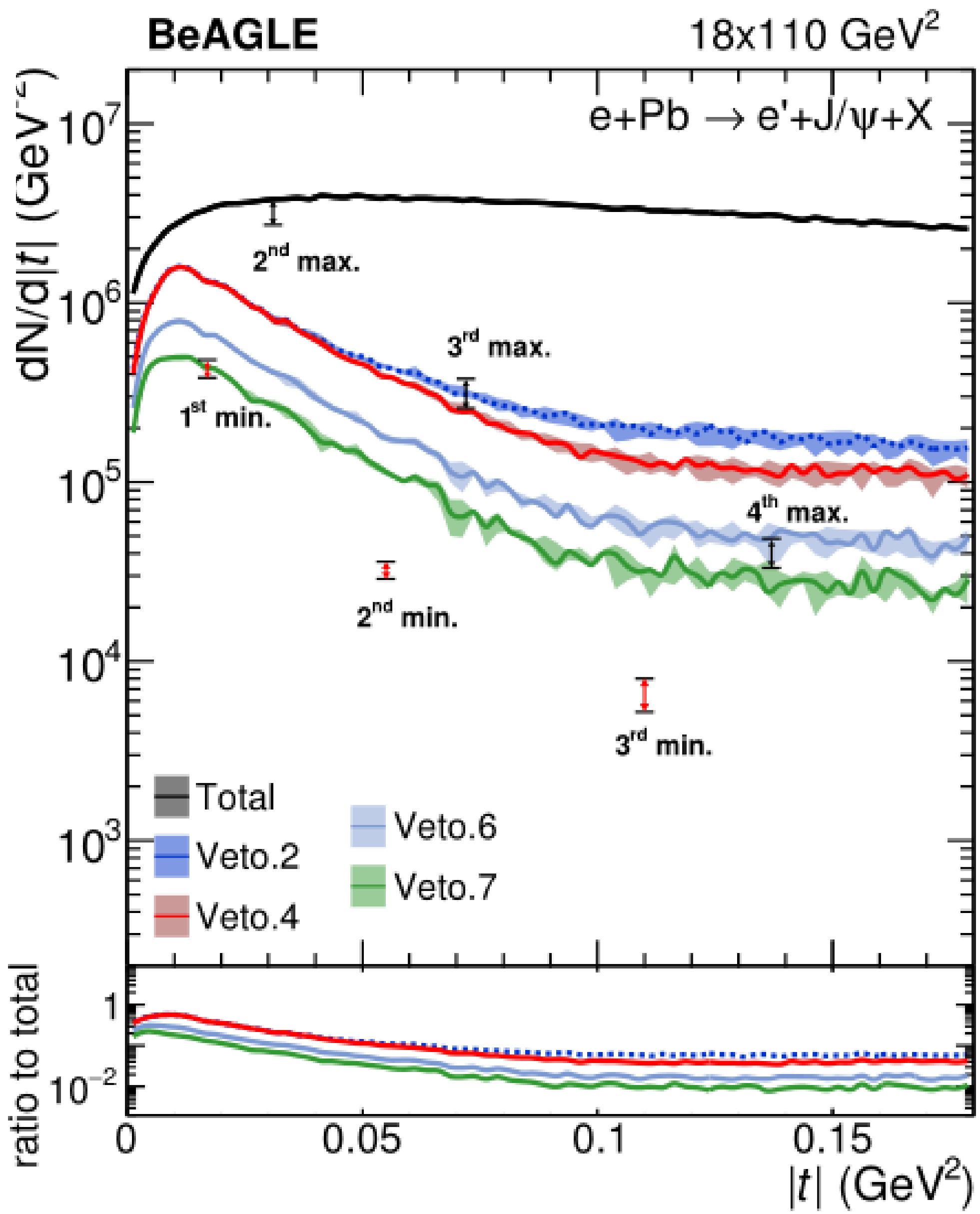
Also high T(b) samples.

Veto tagging of incoherent J/ψ diffraction

Sartre: Toll, Ulrich
PRC **87** (2013) 0249



Chang et al. arXiv:2108.01694v2 [nucl-ex]



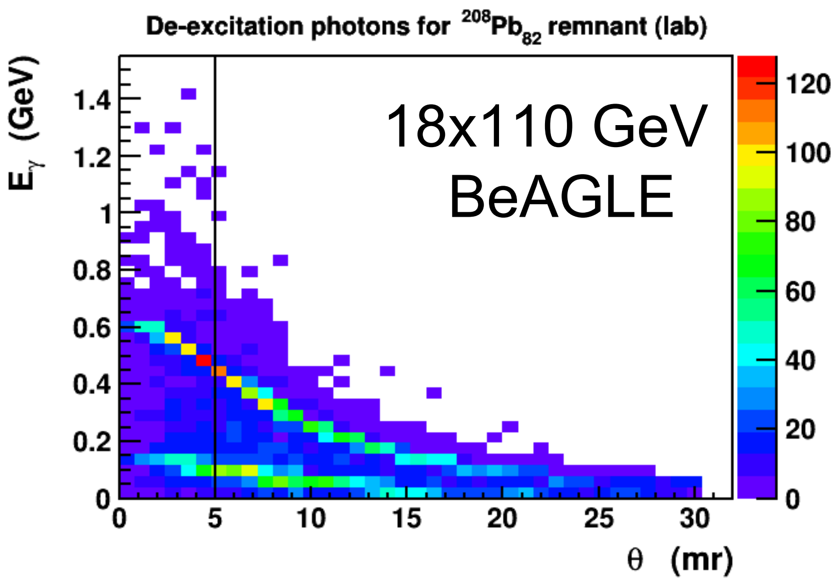
Incoherent,
No sat.
No veto

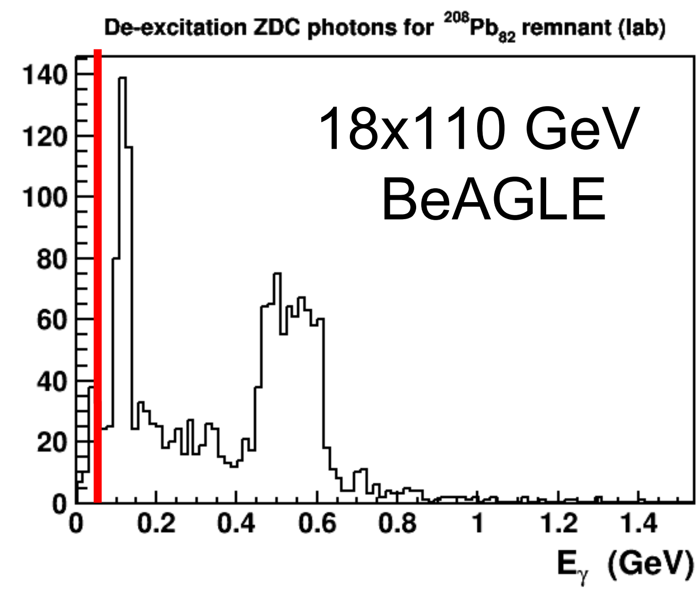
VETO ON:

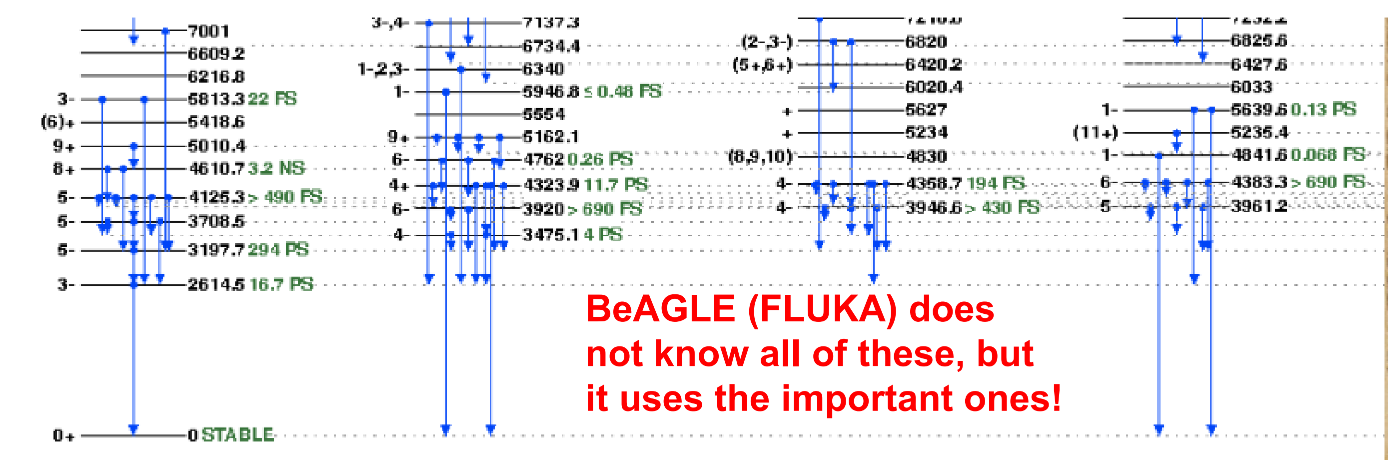
Main + ZDC
& RP + OMD
& B0 incl. γ
& ZDC γ

Simulation challenge in e+A: nuclear detail

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







BeAGLE (FLUKA) does not know all of these, but it uses the important ones!

BeAGLE @ small x: Executive Summary

- Forward (nuclear remnant) tagging is important for small x physics..
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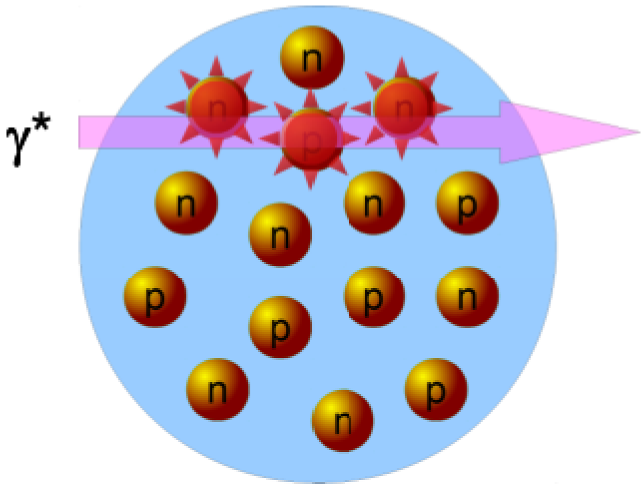
  - Need from theory: better description of the hard γ^*+multiple nucleon collisions, including nucleonic remnants.

What does the low-x hard remnant look like?

In the ion rest frame, the virtual photon fluctuates into a dipole or other semi-hadronic state and interacts with multiple nucleons.



We model this in BeAGLE, but we need more theoretical guidance or tools to improve our description.

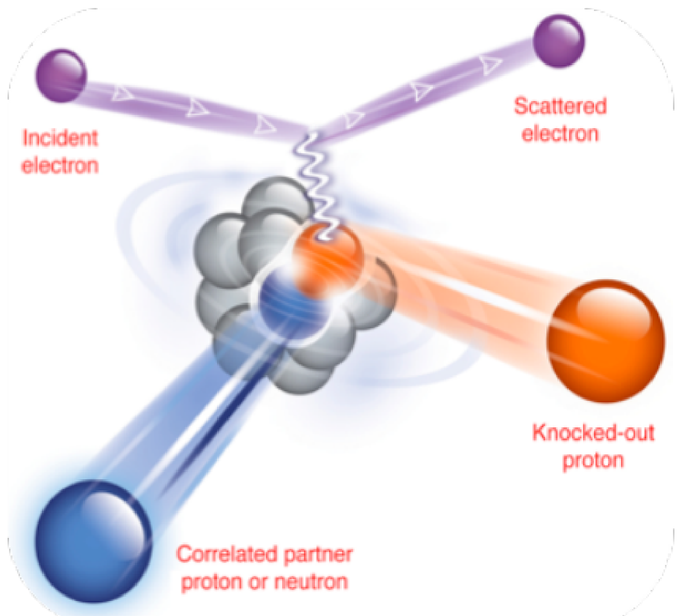
1) Better “dipole cross-sections” and nucleonic remnant to build into BeAGLE.

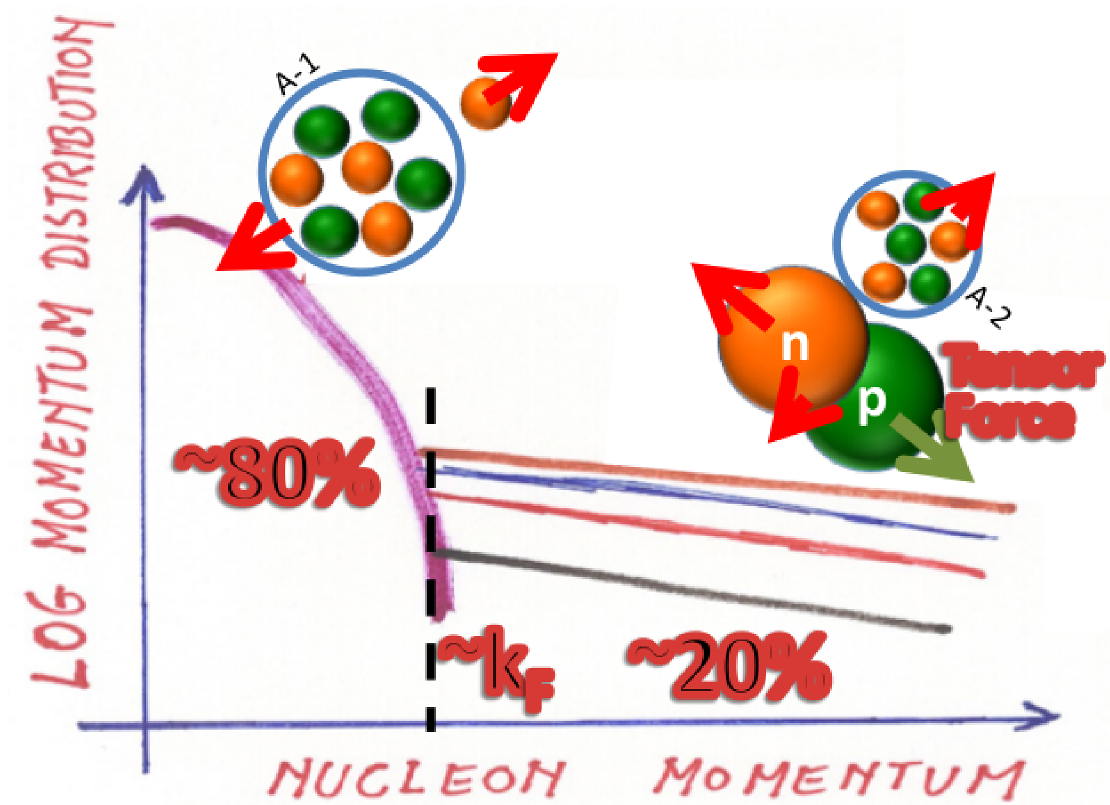
2) Model the hard interaction outside of BeAGLE and use BeAGLE as an afterburner.

High x example: Quasi elastic SRCs

SRC = Short Range Correlations

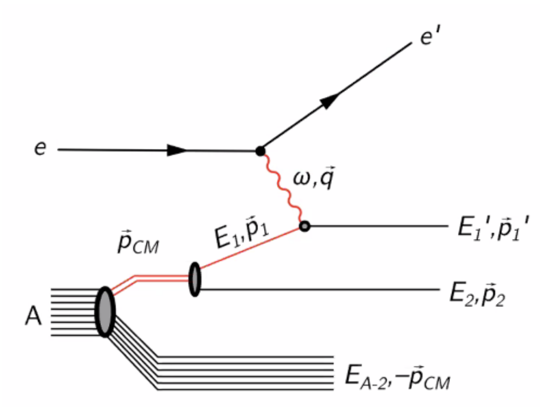
Probing Correlations Using Hard Knockout Reactions





Figures from Or Hen

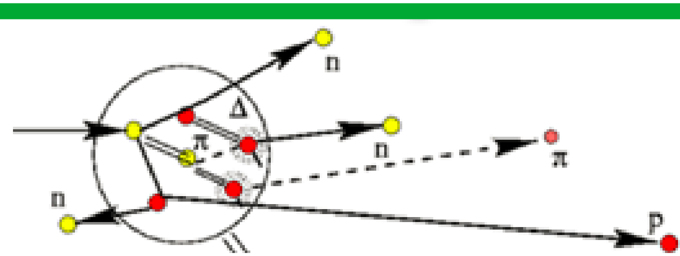
BeAGLE as an afterburner!



Primary interaction

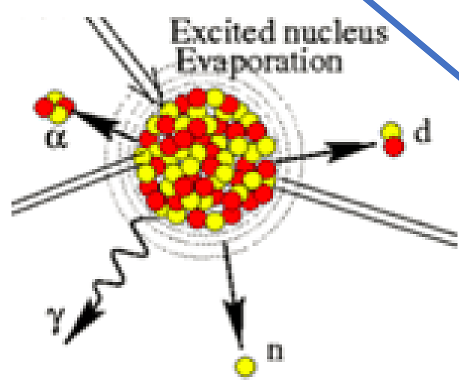
Primary interaction input from **GCF!** for the hard collision.

Cascade process handled by **DPMJET.**



Intra-nuclear cascade

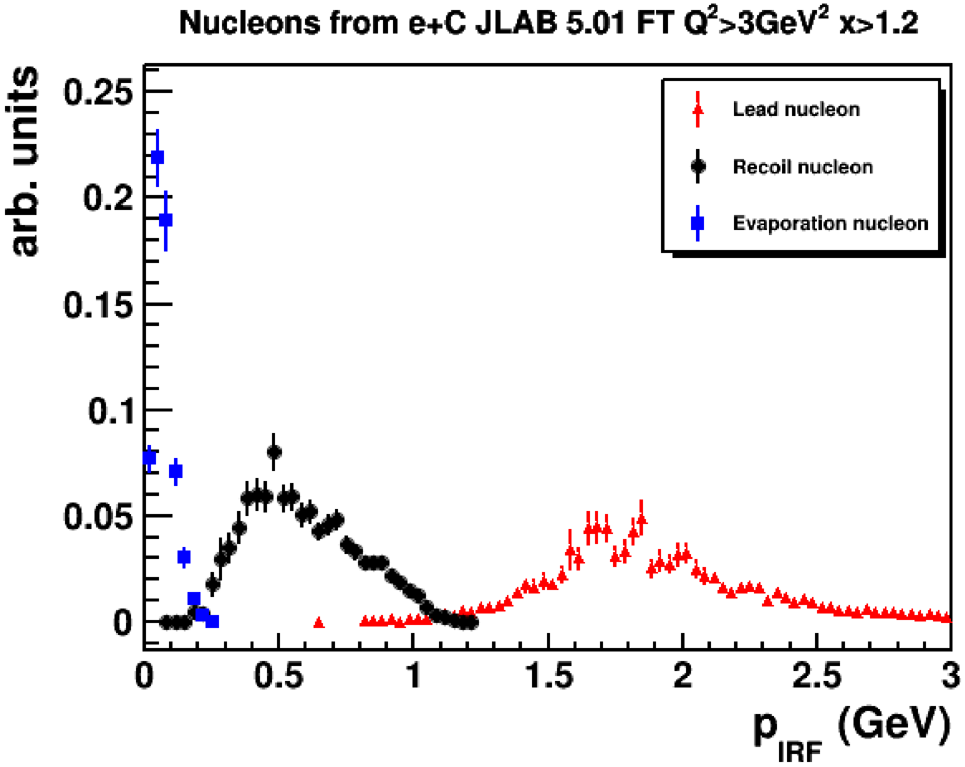
Nuclear remnant evaporation and break up by **FLUKA.**



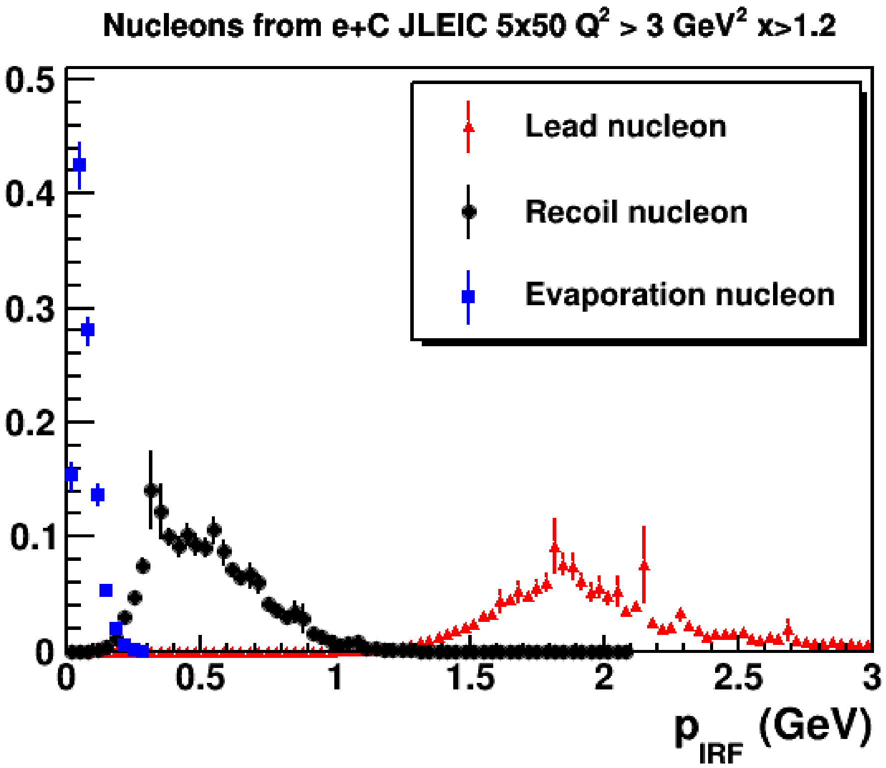
Nuclear remnant evaporation & breakup

GCF+BeAGLE w/o IntraNuclear Cascade

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



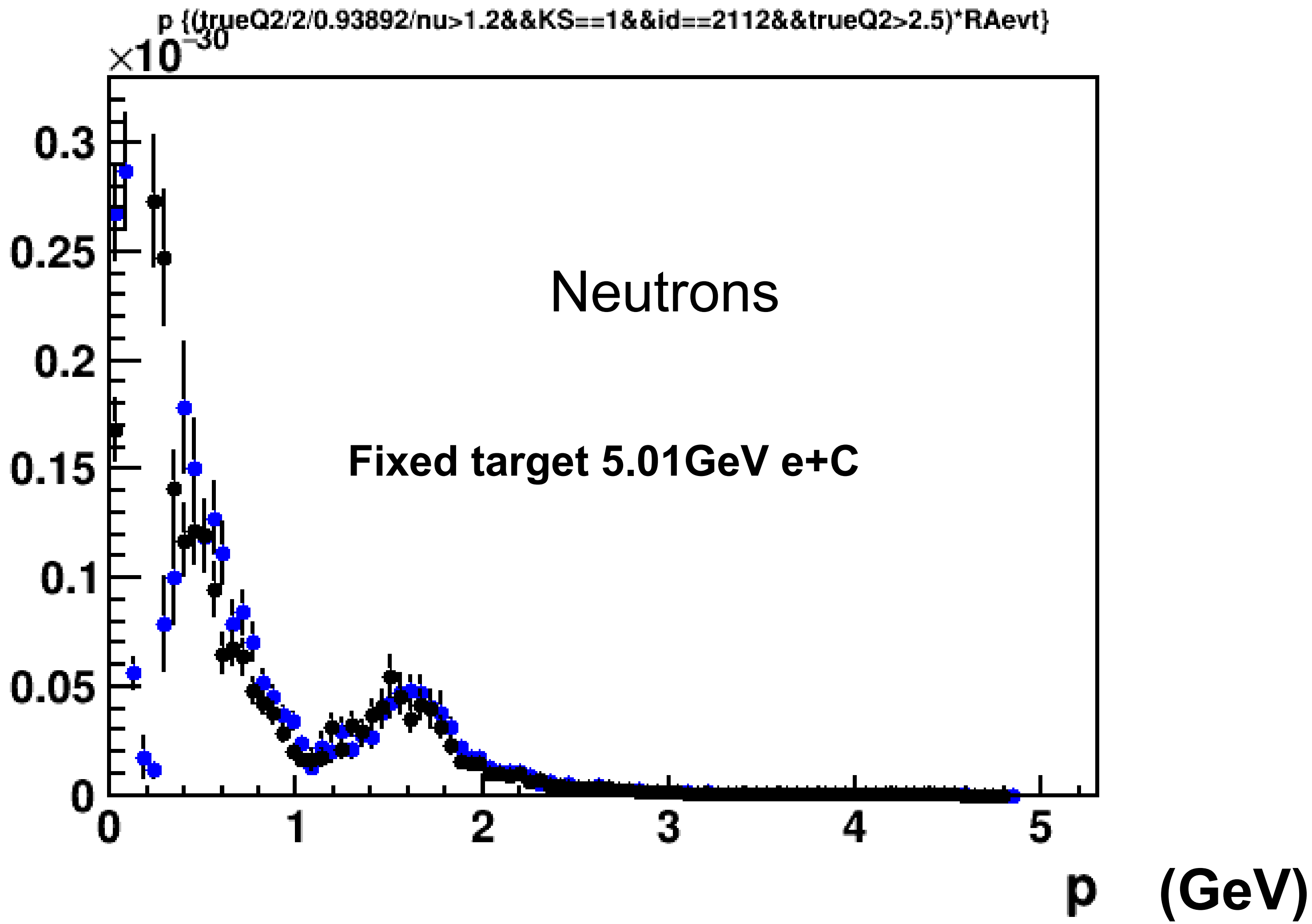
EIC 5x50 e+C
Q^2>3 GeV^2, x>1.2



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

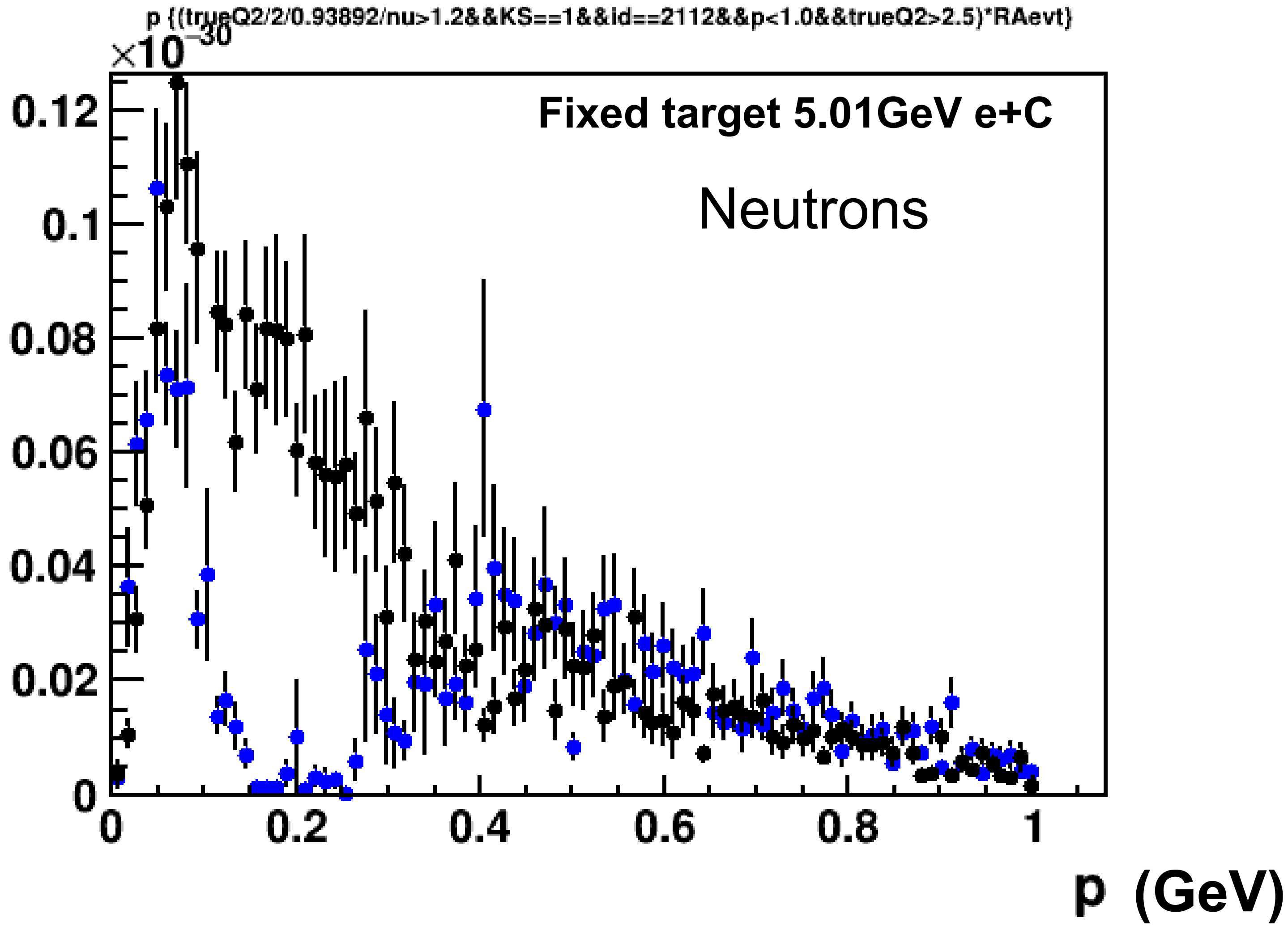
Lead nucleon largely unaffected by this FSI

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



Recoil nucleon peak washed out

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



BeAGLE @ small x: Conclusions

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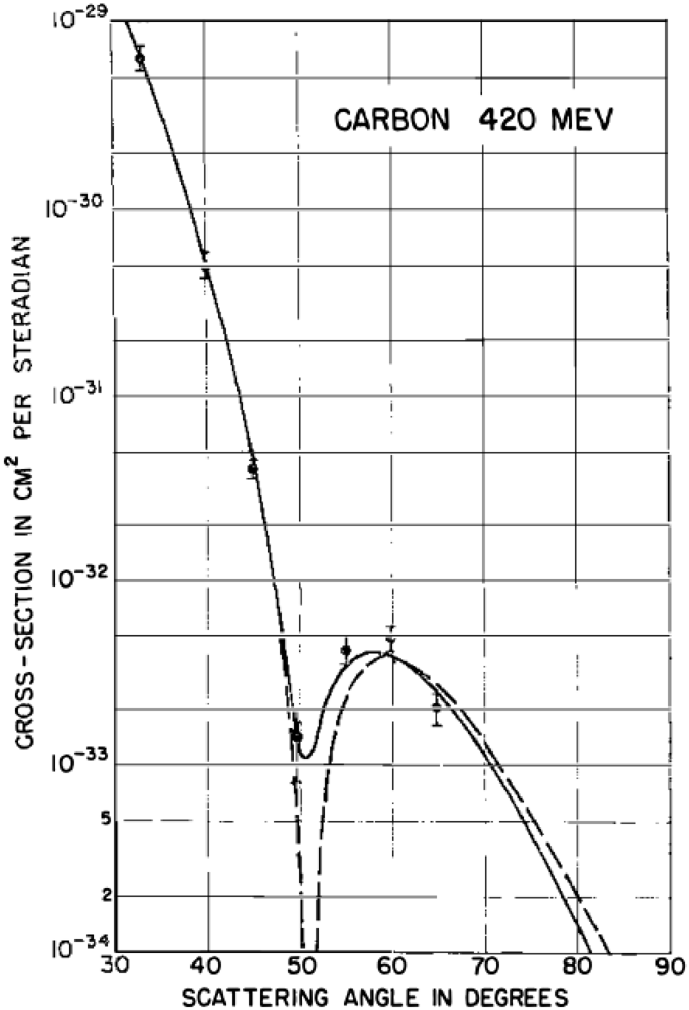
Extras

Theory/Motivation Summary

- Vector meson diffraction should allow us to:
  - Access the spatial distribution of Gluons in the nucleus.
  - See gluon saturation effects
- More theory work is needed
  - The dip (zero) structure is over-simplified at the moment.
  - Relating spatial distribution to dN/dt (or dN/dp_T^2 or …) takes a more detailed calculation.
- We have used the dip-less electron diffraction results to great effect for >50 years, so the VM measurement should be valuable.
- We still need to reject the background using forward veto tagging.

What about the dips?

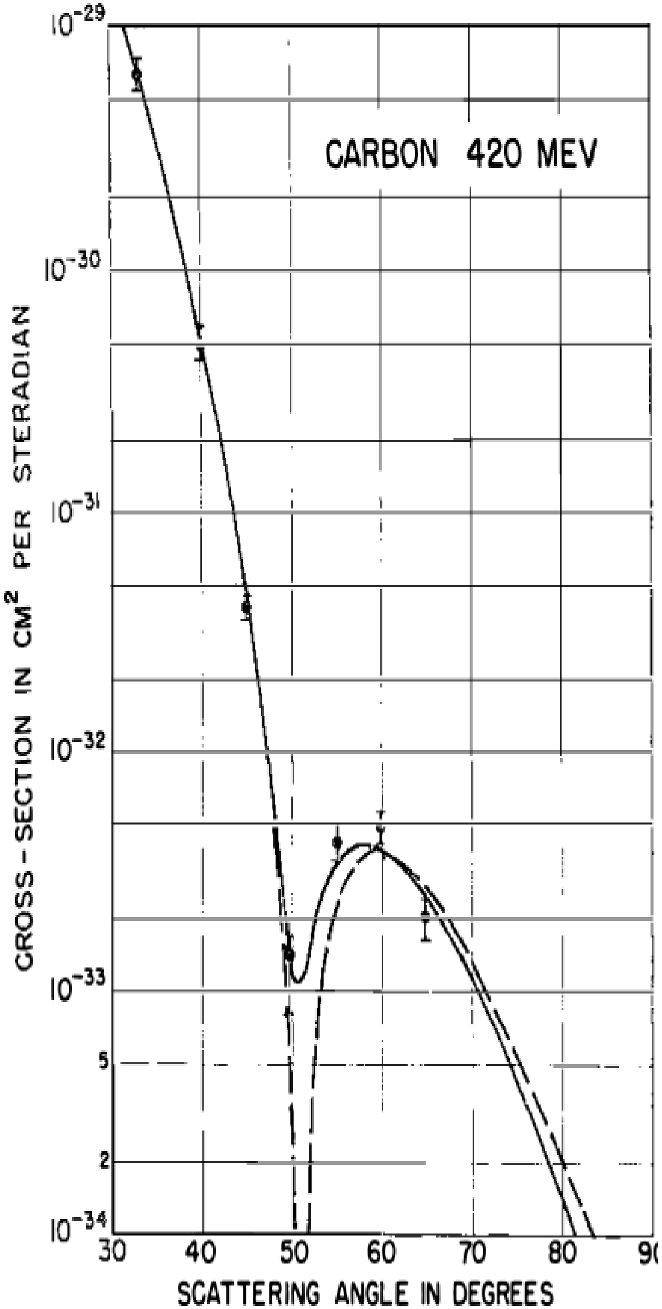


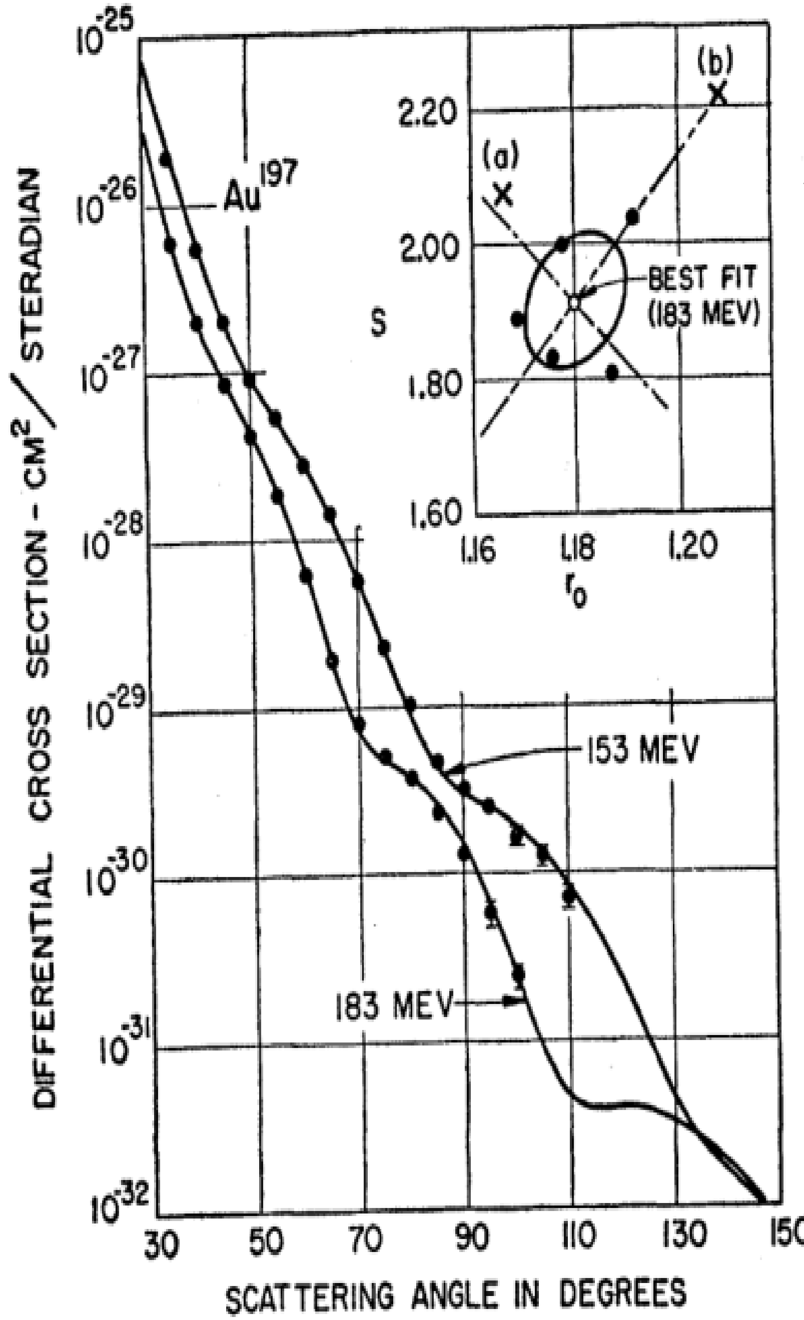
Classic electron scattering review papers by Robert Hofstadter:
Ann.Rev.Nucl.Sci 7 (1957) 231
& Rev. Mod. Phys. 28 (1956) 214

Dashed line: Born approximation & harmonic well charge distribution. Minima go to zero.
Solid line: "Accurate phase-shift calculation".

1) The electron dispersion relation $\omega(k)$ changes in the electric field of the nucleus.
Shifts minimum to left
2) Born approximation breakdown
A) Higher order effects in $Z\alpha$ (for us $A^{1/3}\alpha_s$?)
B) Complex amplitude doesn't go to zero easily
Fills in dips

What about the dips for high A?





Robert Hofstadter:
Ann.Rev.Nucl.Sci 7 (1957) 231
& Rev. Mod. Phys. 28 (1956) 214

"Dip-filling corrections" should go like $Z\alpha$ in QED.

For us $A^{1/3}\alpha_s$?

What about the dips for the strong interaction?

We have J/ψ + A instead of e+A.
We have pomeron or two gluons or a gluon ladder instead of a photon.

Nothing important changes in the argument.
We are still using effectively the Born approximation.

Born approximation breakdown

A) Higher order effects in Zα (for us $A^{1/3}\alpha_s$?)

B) Complex amplitude doesn't go to zero easily

<u>Fills in dips</u>

<u>A detailed calculation is needed to know the magnitude of the "dip-filling" effect.</u>