Centrality Tagging in eA at EIC

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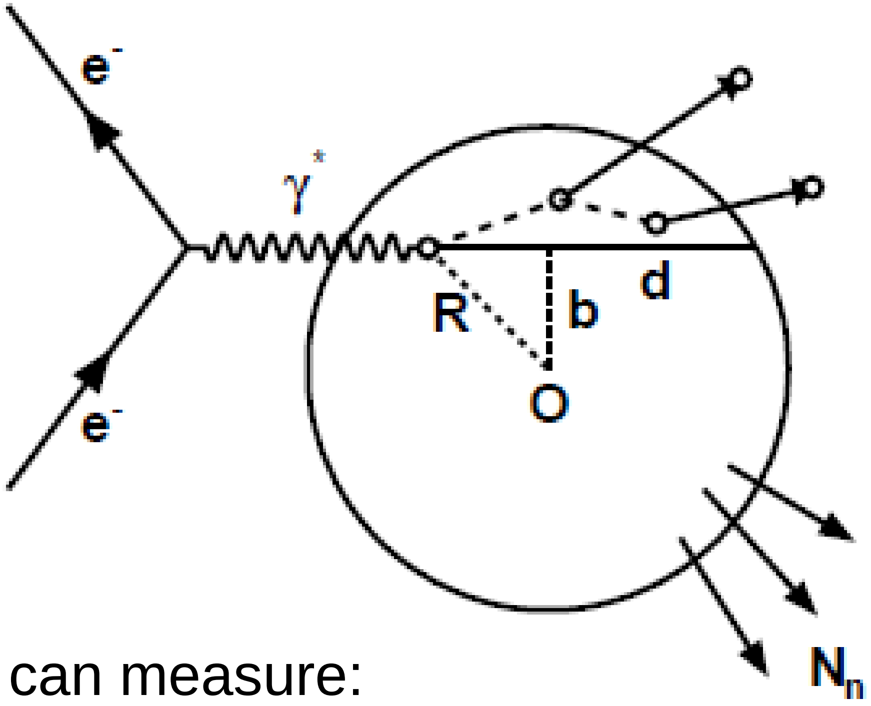
Next Generation Nuclear Physics with JLab12 and EIC

Centrality tagging in eA



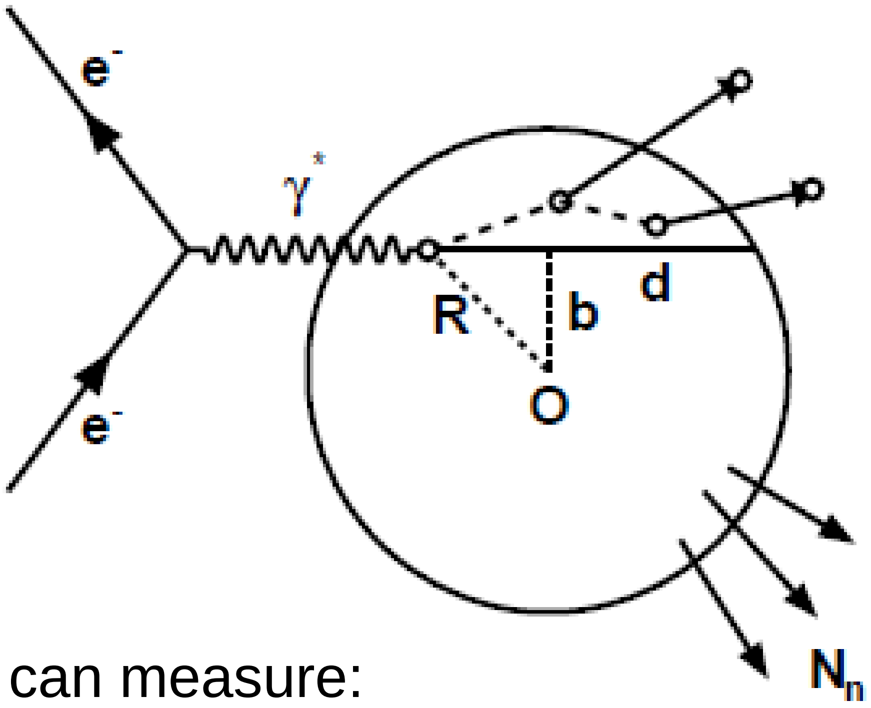
b = impact parameter

d = distance traveled
in nucleus after
first interaction

We can measure:

- Primaries from the target remnant jet(s)
- Particles from the intranuclear cascade (grey)
- Evaporation neutrons/fragments/protons (black)

Centrality tagging in eA



b = impact parameter

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in nucleus after
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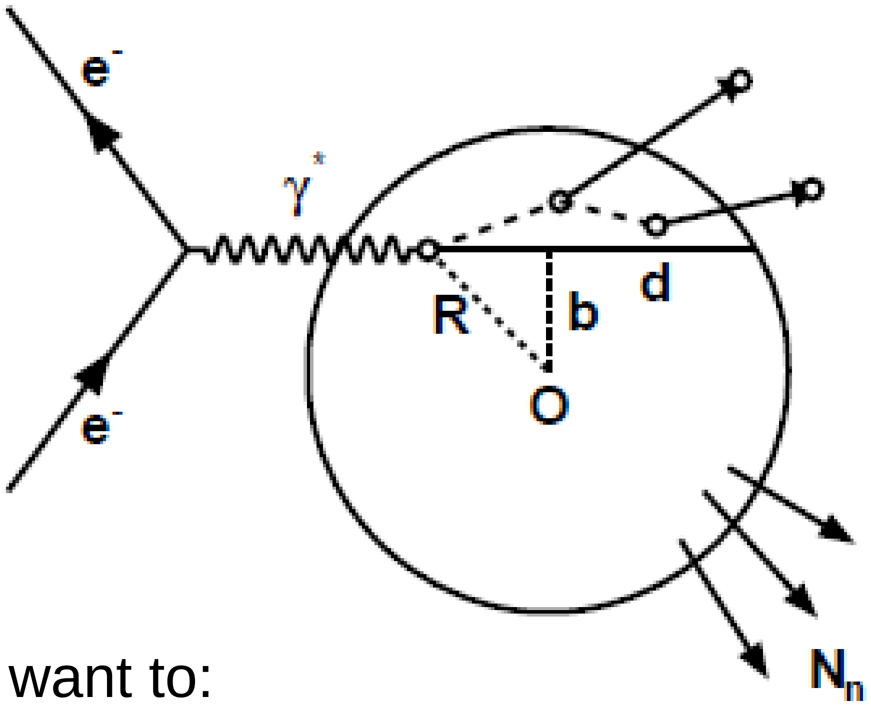
We are measuring d!

We can measure:		Sensitive to:
Primaries from the target remnant jet(s)		??
Particles from the intranuclear cascade	(grey)	**d**
Evaporation neutrons/fragments/protons	(black)	**d**

Centrality tagging physics



b = impact parameter

d = distance traveled
in nucleus after
first interaction

We mostly care about d!

We want to:

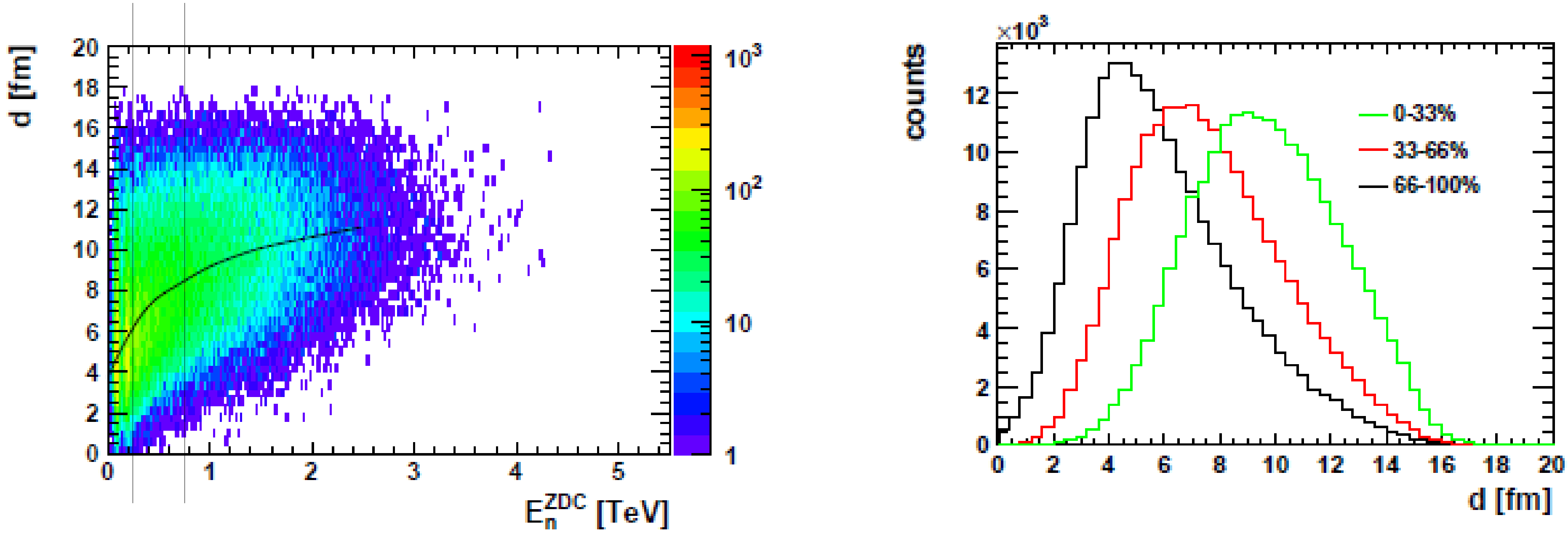
Sensitive to:

- Study medium modification of jets/hadronization **d**
- Sample “clean” events from the back of the nucleus **d**
- Sample events with enhanced parton saturation (for x<0.01): **d (!?)**

Large activity means large d

Zheng, Aschenauer, Lee, Eur.Phys.J.**A50** (2014) 189

1st look simulation based on DPMJet. 100 GeV beam energy.
ZDC covers θ<4mr and in this simulation, mostly sees evaporation neutrons.

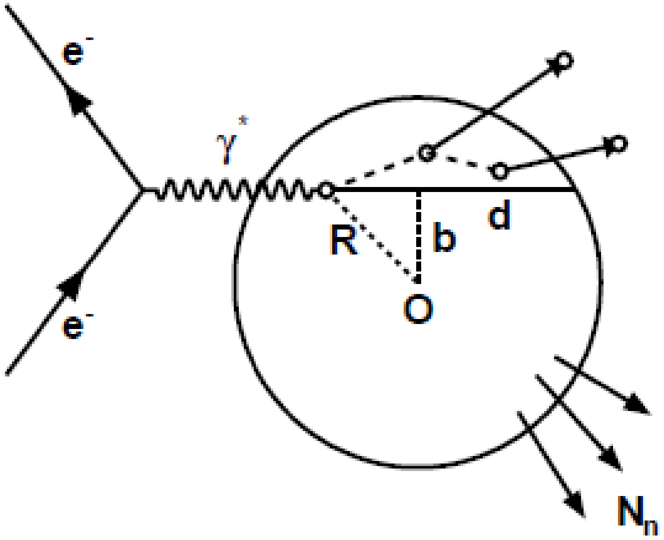


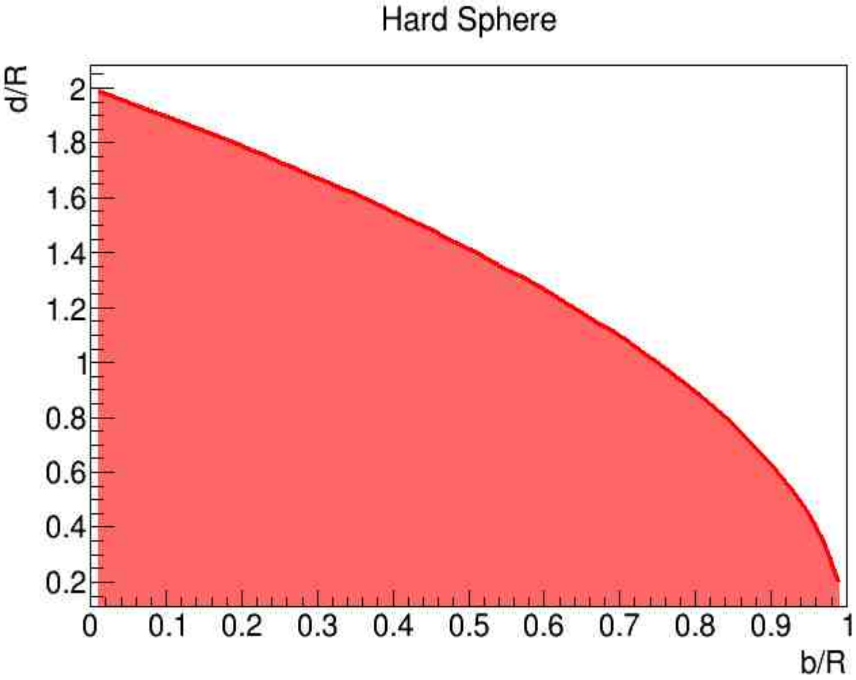
e+Au 10x100 GeV

d and b are correlated

Consider the case x>0.1:

No nuclear shadowing (& no parton saturation)





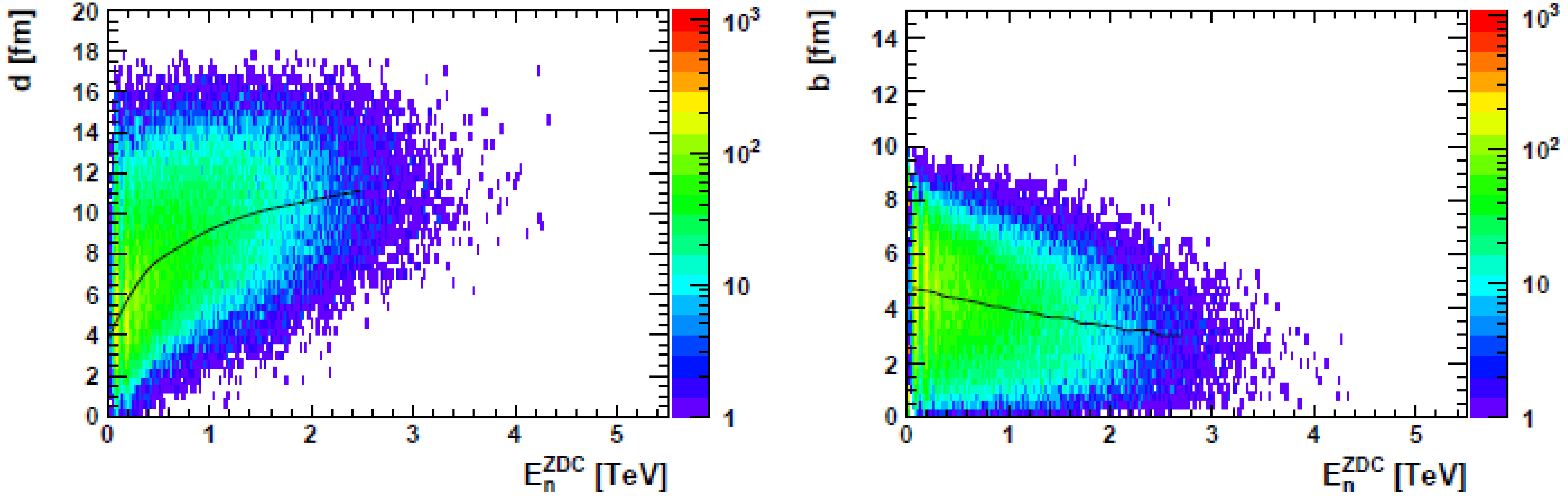
Measurement of b is less direct:

High values of d exclude peripheral (large b) events.

Small d is a mix of peripheral and central.

Measuring d is easier than b

Zheng, Aschenauer, Lee, Eur.Phys.J.**A50** (2014) 189 e+Au 10x100 GeV



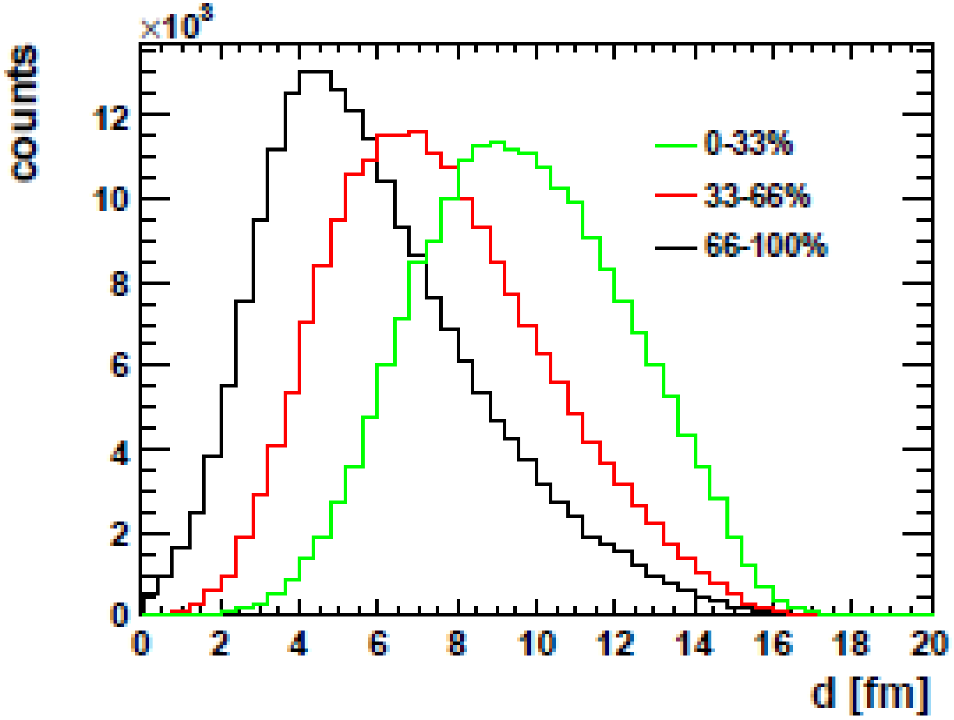
Good news 1: We have some handle on both d and b at the EIC!
Fly in the ointment: Some important physics needs to be added to the MC.
Good news 2: The changes may improve the resolution!

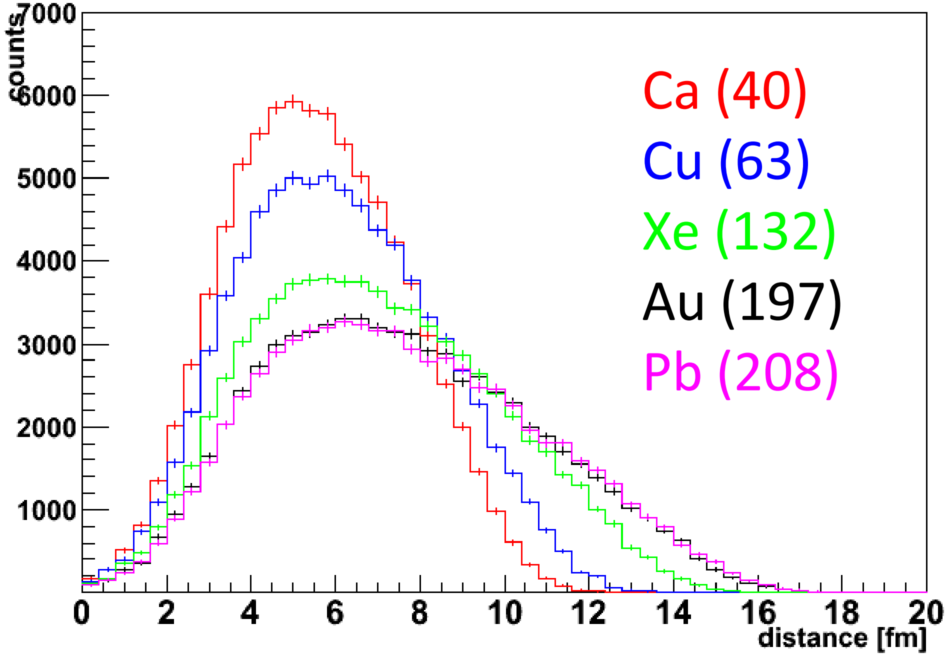
Centrality Tagging is better than A!

Zheng, Aschenauer, Lee,
Eur.Phys.J.**A50** (2014) 189

e+Au 10 + 100 GeV centrality bins
Based on E(ZDC)

From Zheng & Lee talk:
https://wiki.bnl.gov/eic/index.php/2014-4-17





Event generation process

From Zheng & Lee talk:
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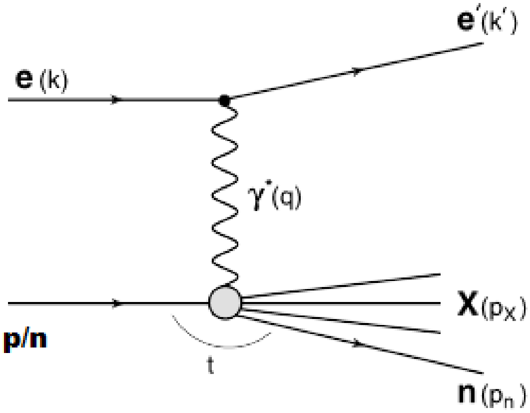
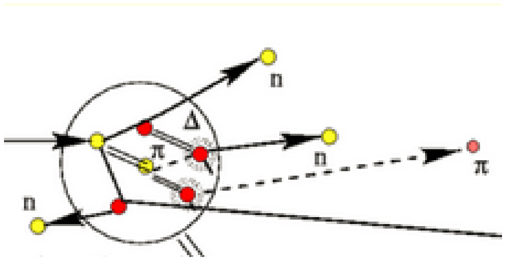
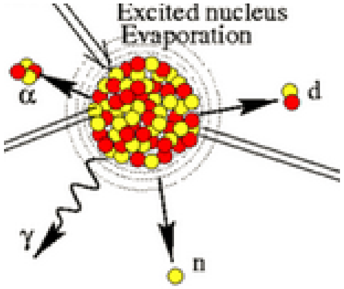






Primary interaction + Intranuclear cascade + Nuclear remnant evaporation

Pick 1 nucleon (typically) from initial geometry:

e+p/n -> X+n

All ep/en underlying processes are possible.

DPMJet III + Pythia 6

Secondary interactions with the rest of the nucleon before flying outside

h + N -> h$^{(*)}$ + N$^{(*)}$
h = pi/K/p/n, N=p/n

Formation Zone + HADRIN

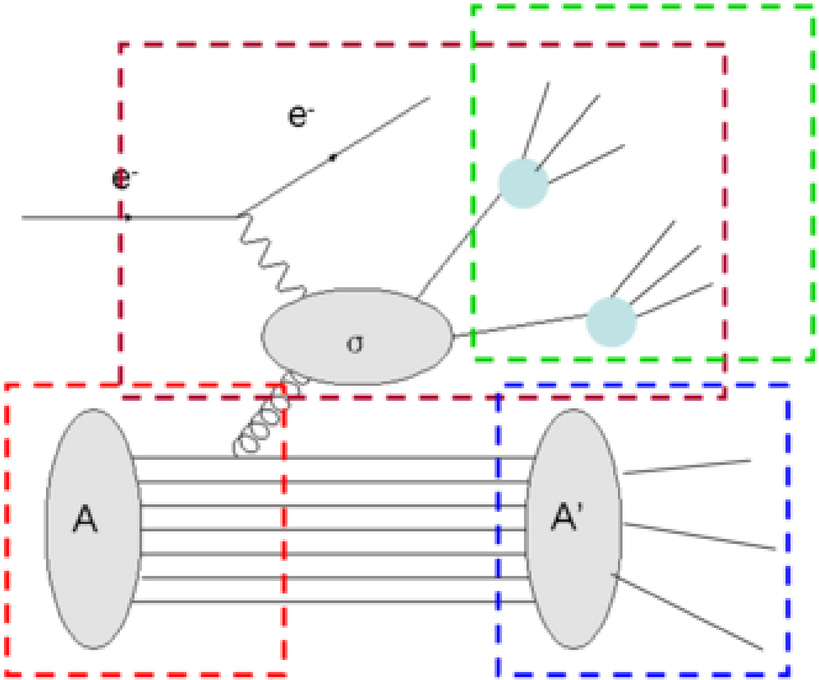
Need only mass, charge, excitation energy, no memory for prior history

$$P_j(E)dE = \frac{(2S_j+1)m_j}{\pi^2\hbar^3}\sigma_{\text{inv}}\frac{\rho_f(U_f)}{\rho_i(U_i)}EdE$$

FLUKA

DPMJet-Hybrid (1.0)

Zheng, Aschenauer, Lee   From: https://wiki.bnl.gov/eic/index.php/DpmjetHybrid



A hybrid model consisting of DPMJet and PYTHIA with nPDF EPS09.

Nuclear geometry by DPMJet and nPDF provided by EPS09.

Parton level interaction and jet fragmentation completed in PYTHIA.

Nuclear evaporation (gamma dexcitation/nuclear fission/fermi break up) treated by DPMJet

Energy loss effect from routine by Salgado&Wiedemann to simulate the nuclear fragmentation effect in cold nuclear matter

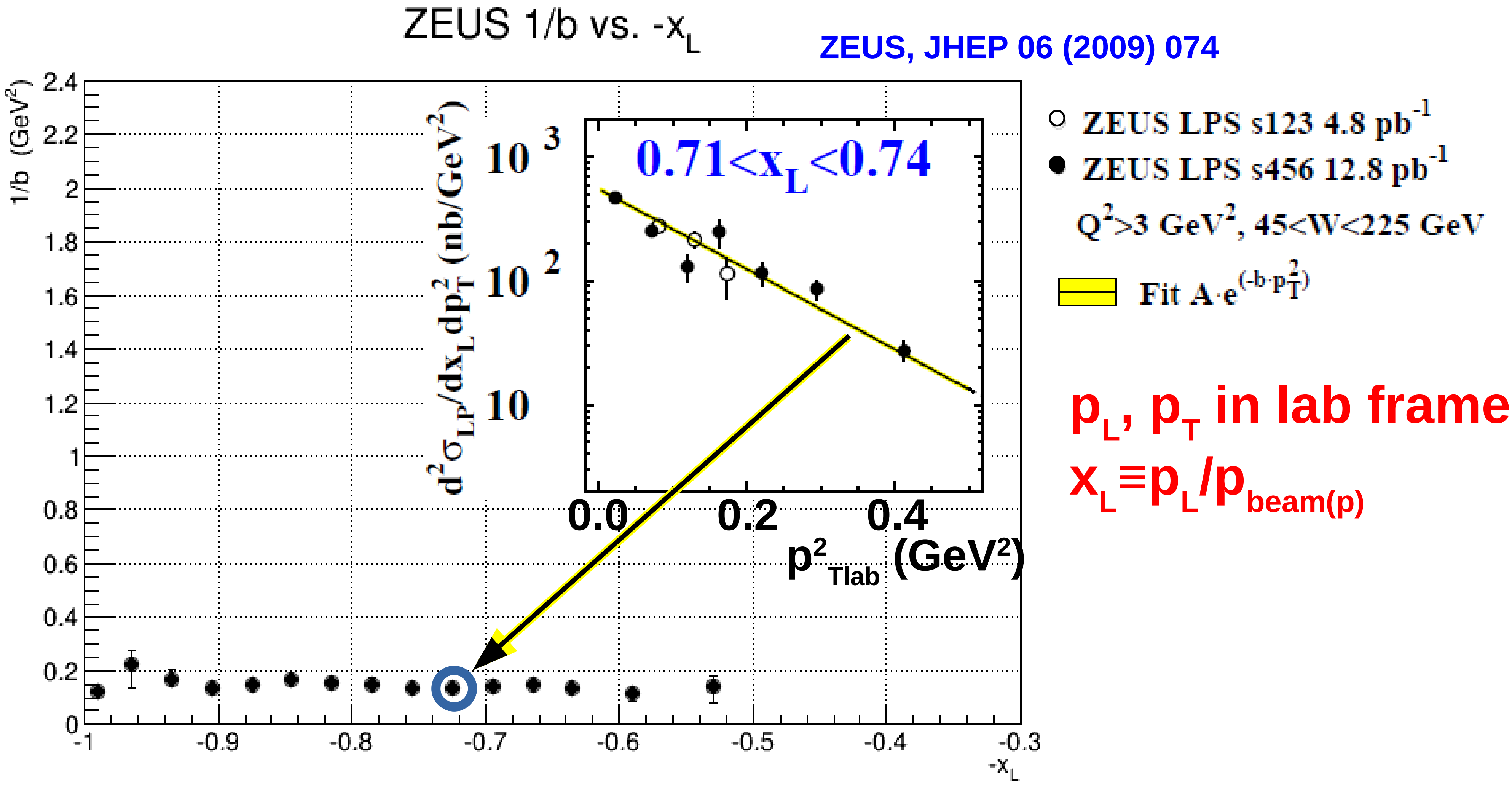
“One thing to be mentioned for the case to run PYTHIA in DPMJET is that only **one nucleon in the nucleus** will (typically) be picked as a target nucleon in the collision.” EM-like cross-section used to decide whether a second collision occurs.

DPMJetHybrid 2.0 Plan

Baker, Aschenauer, Lee, Zheng

- EIC R&D project (eRD17), FY2016-17
  - Tool for Forward Detector Optimization
  - Urgency: IRs are being designed NOW
- Two major technical changes
  - Better tune of target-remnant jet in Pythia
  - Multi-nucleon interaction for x<0.1
- Centrality tagging is one of the main tests for the upgraded program

Tune to 1/b vs. x_L from ZEUS fits

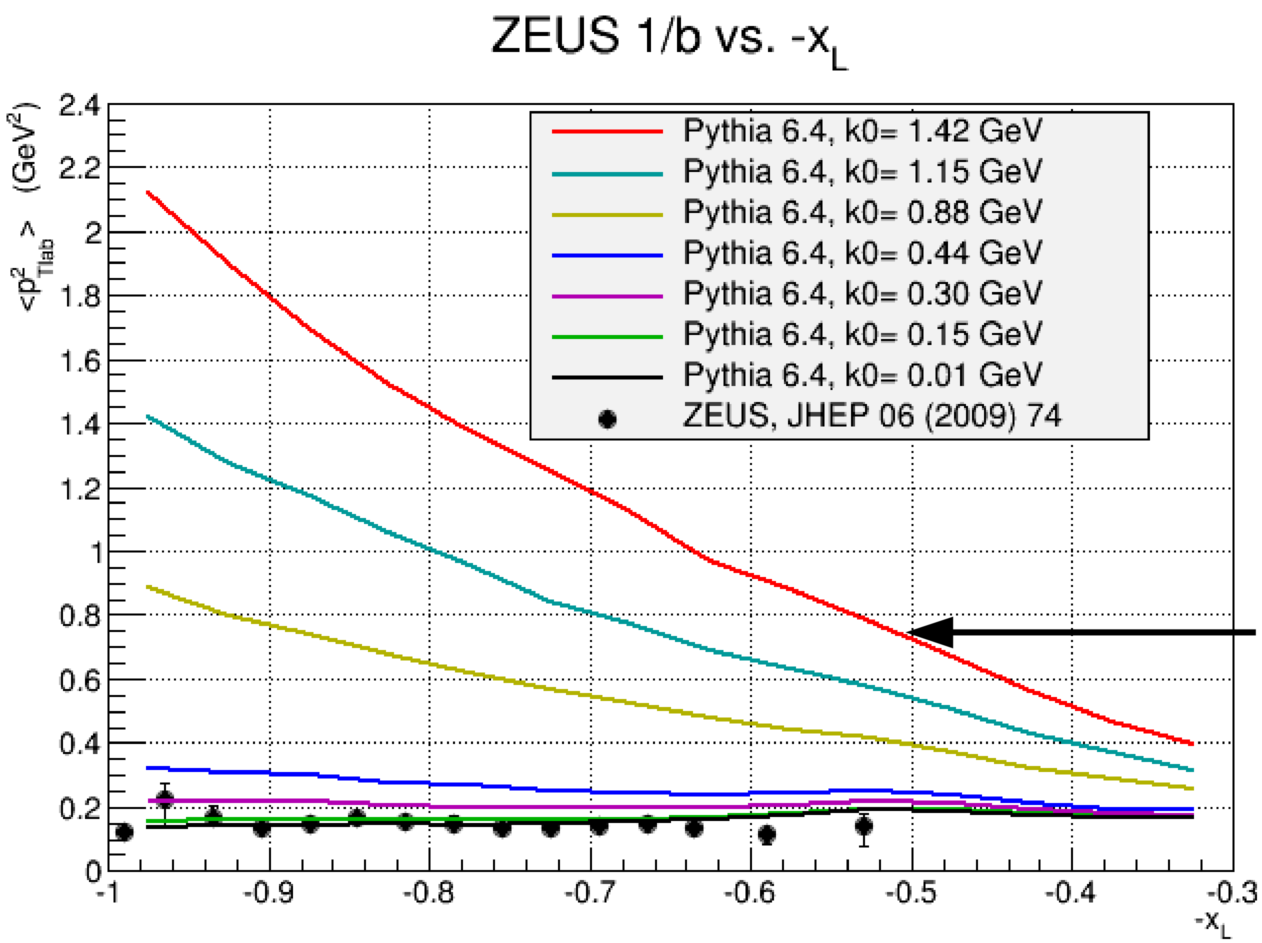


ZEUS, JHEP 06 (2009) 074

p_L, p_T in lab frame

$x_L \equiv p_L / p_{beam(p)}$

Default Pythia tune way off in p_T



Pythia 6.4.28
EIC/BNL version

$k_0 = k_T^{rms}$ = PARP(91)

Default = 2.0 !

$k_0 \neq$ 1.42 GeV

$k_0 \approx$ 0.15 GeV OR
$k_0 \approx$ 0.01 GeV

PROOF POSITIVE: The beam remnant jet is not contaminated by “QCD” effects

For more details see:
https://conferences.lbl.gov/event/56/session/8/contribution/40/material/slides/0.pdf

Pythia longitudinal tuning

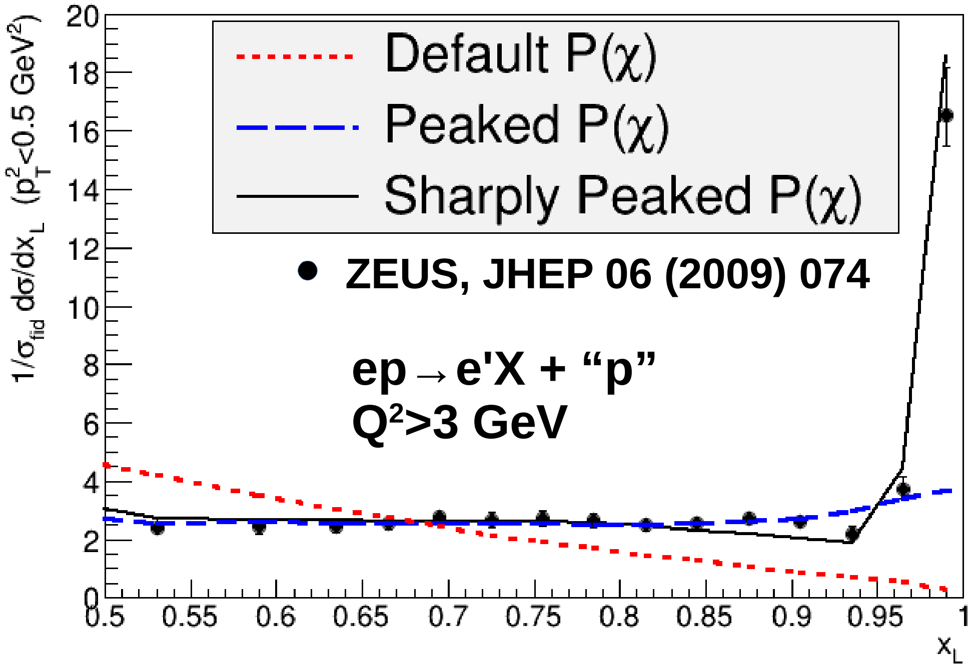
Non-trivial beam remnant clusters fragment into diquark+meson or baryon+quark. The p_+ fraction carried by baryon/diquark is called χ.

We tuned $P(\chi)$ to better match ZEUS data. More forward particles.

	MSTP(94)	PARP(97)	$P(\chi)$
Default	3	-	Frag. function
Peaked	2	9	$10(1-\chi)^9$
Sharply	2	75	$76(1-\chi)^{75}$

We also lowered k_T to better match ZEUS data. More forward particles.

$\sigma_{fid} = \sigma$ for h+ $0.5<x_L<0.89$, $p_T^2<0.5$ GeV^2

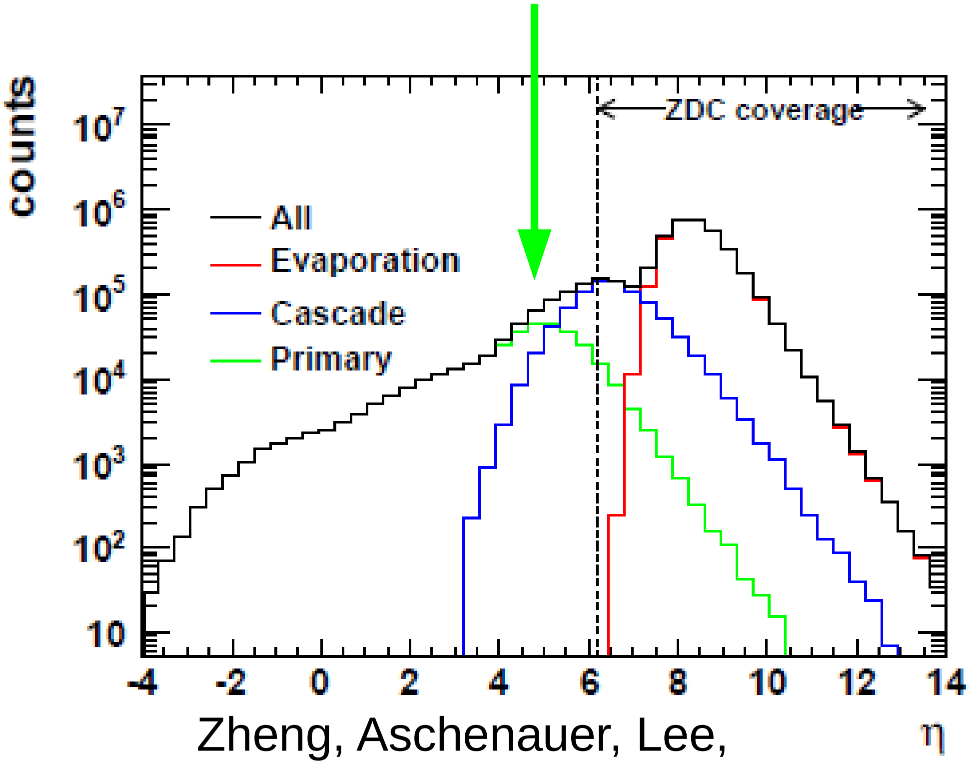


NOTE: p_T distribution is NOT strongly affected by $P(\chi)$.

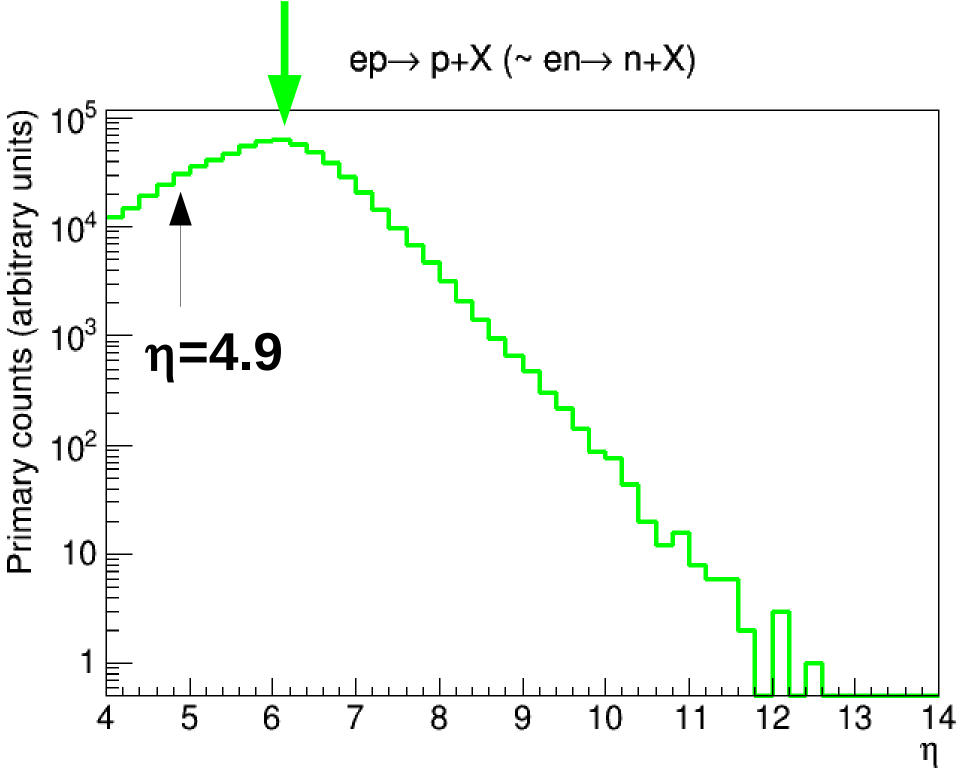
Effect of Pythia tuning

DPMJet eA primary neutrons peak at η=4.9

Tuned Pythia ep → p (en → n) Primaries peak at η=6.1

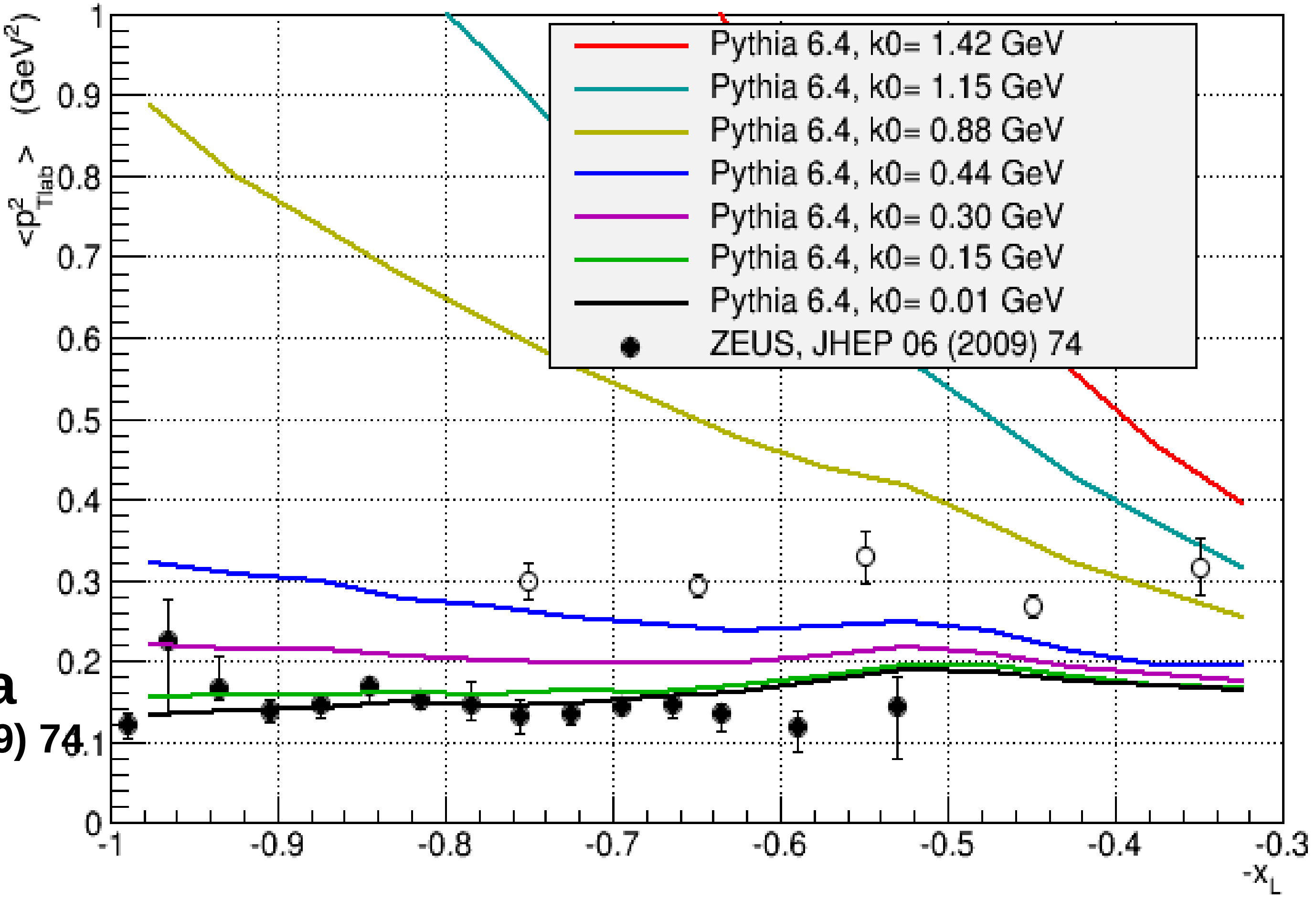


Zheng, Aschenauer, Lee, Eur.Phys.J.**A50** (2014) 189



Primaries, and therefore also cascade particles, will shift forward.

More to do. Tune to EMC too! Hadron $\langle p_T^2 \rangle$: ZEUS = ½ EMC

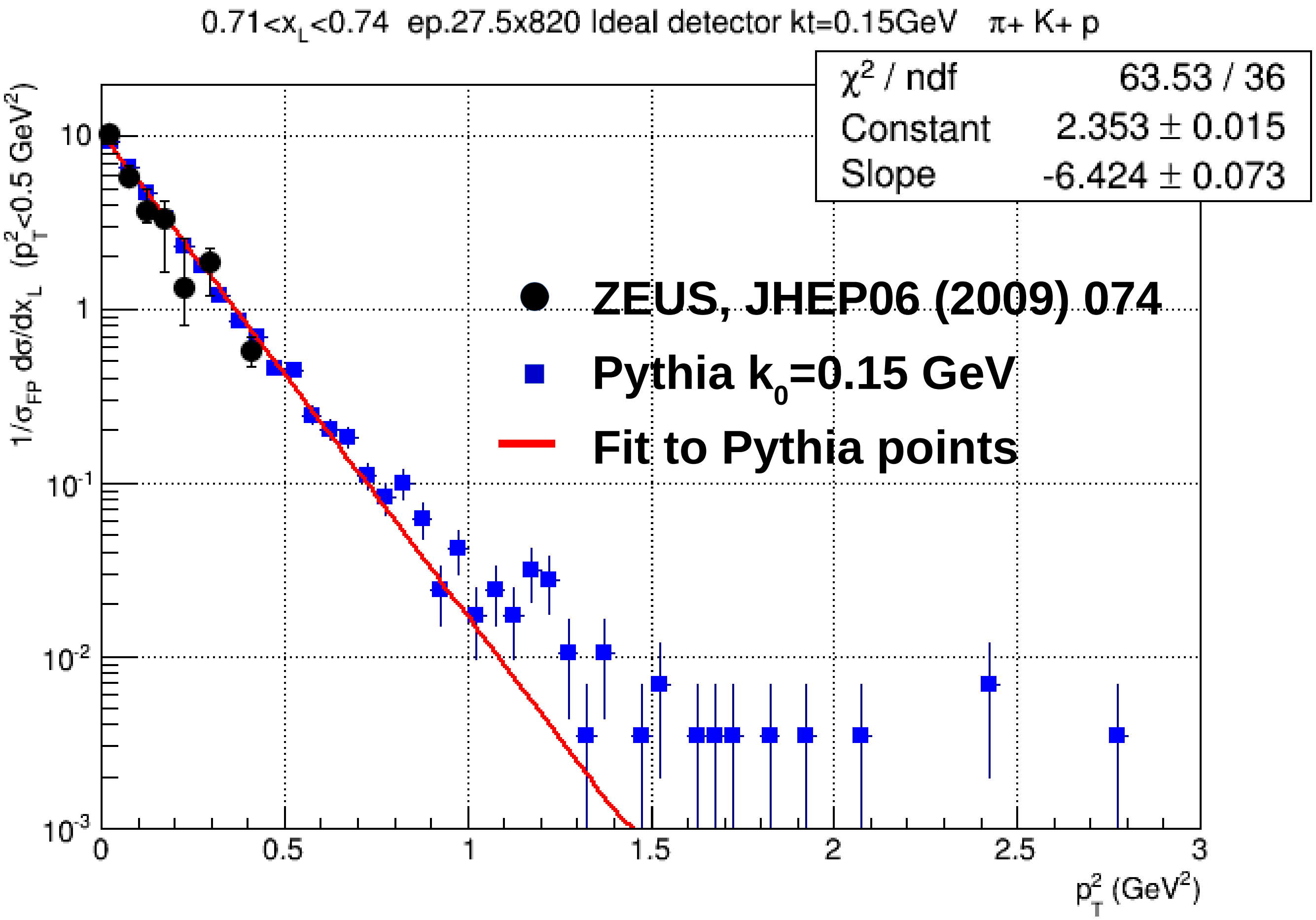


ZEUS data
JHEP 06 (2009) 74

← **EMC**
adapted from
ZPC 36 (1987) 527

(p_T^{2*} vs x_F)

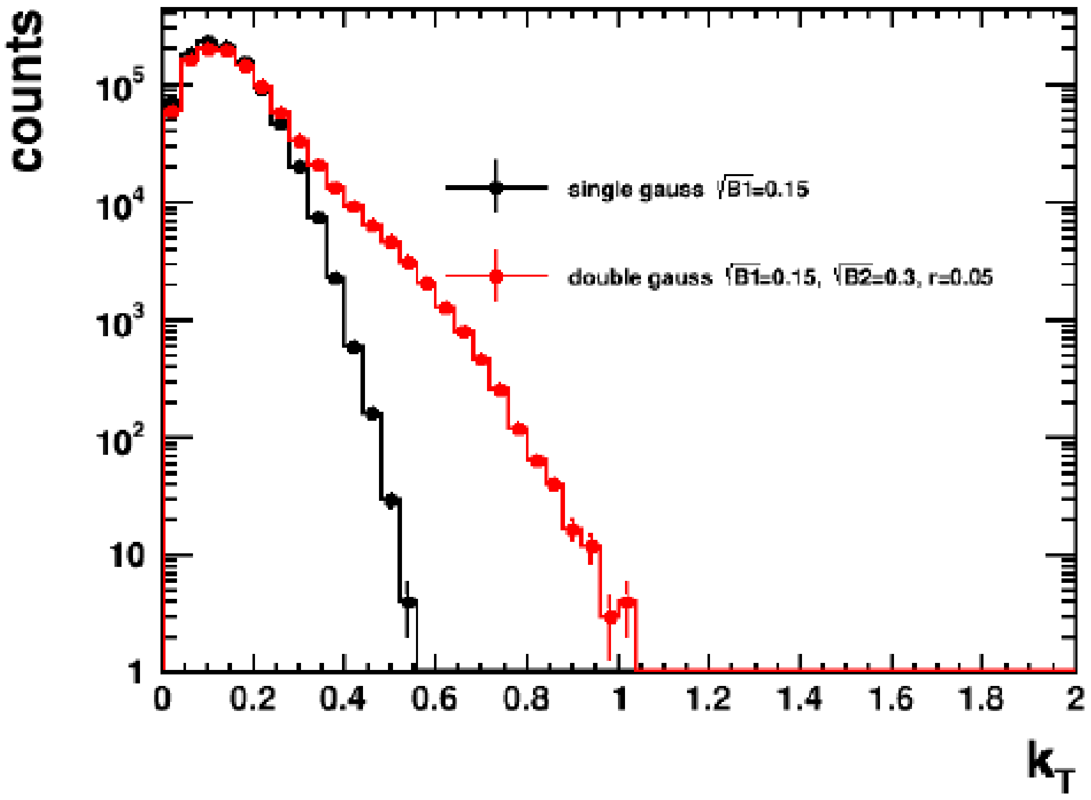
ZEUS's acceptance is limited



EMC used a streamer chamber and a fixed target – nearly complete acceptance.

Non-gaussian tails
For p_T^2>0.5 GeV^2
could explain
k_T(ZEUS)<k_T(EMC)

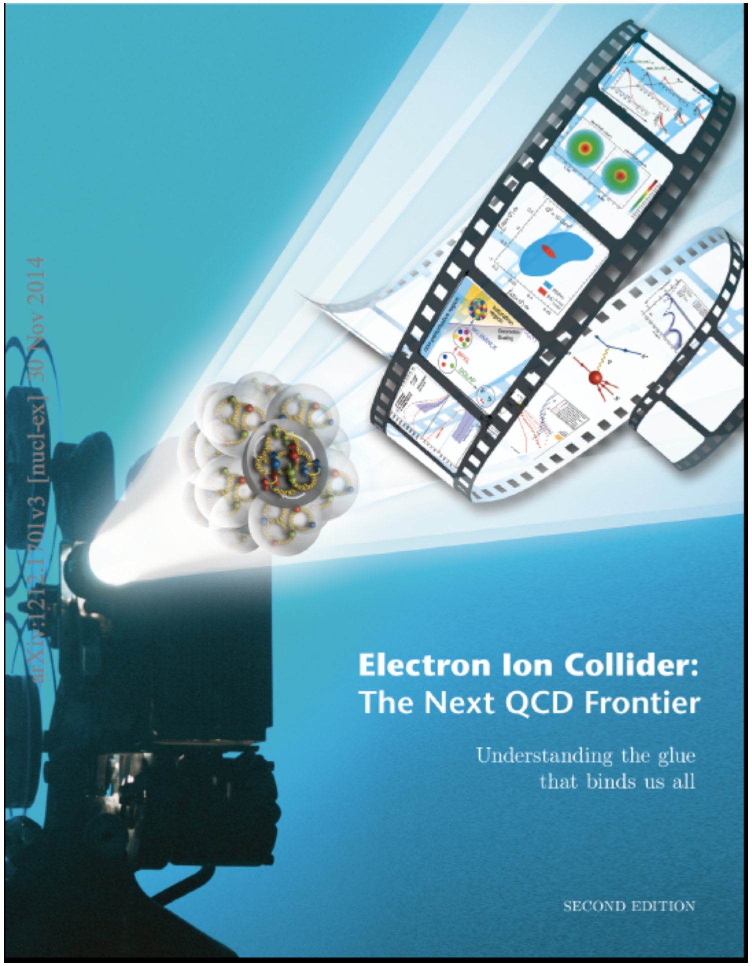
Implement double gaussian k_T



$$d^2Ndk_T^2 = \exp(k_T^2/B1) + r*\exp(k_T^2/B2)$$

Note: May implement more sophisticated functions in the future, inspired by theory or by fits. Send us your favorite!

Saturation at EIC is multi-nucleonic

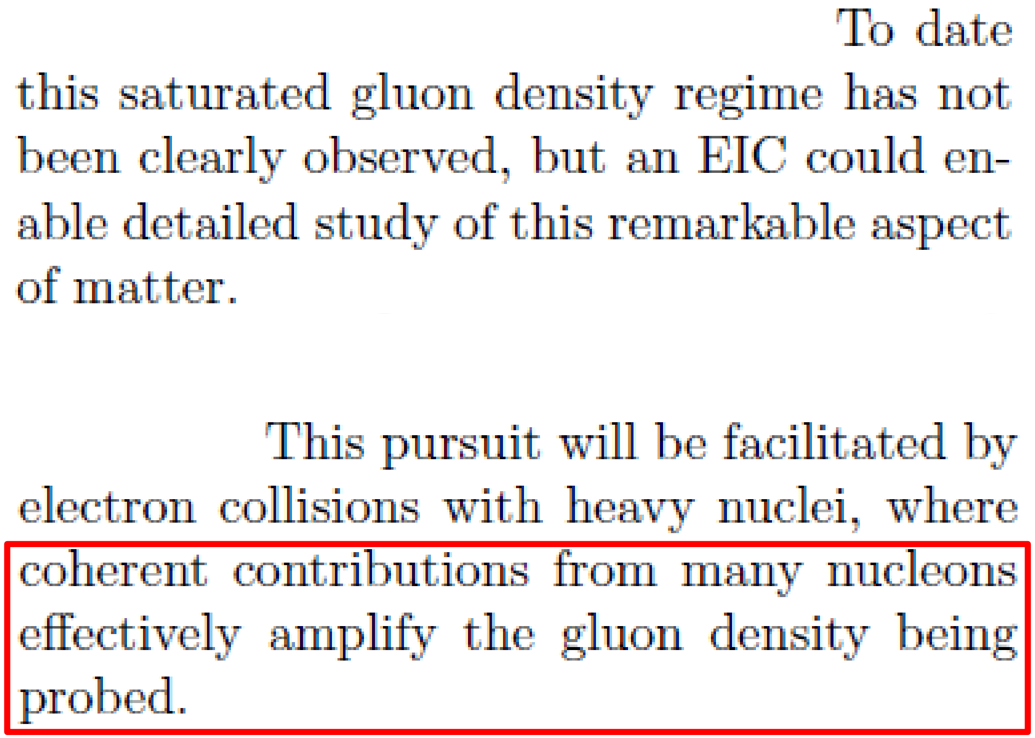


Electron Ion Collider:
The Next QCD Frontier

Understanding the glue
that binds us all

SECOND EDITION

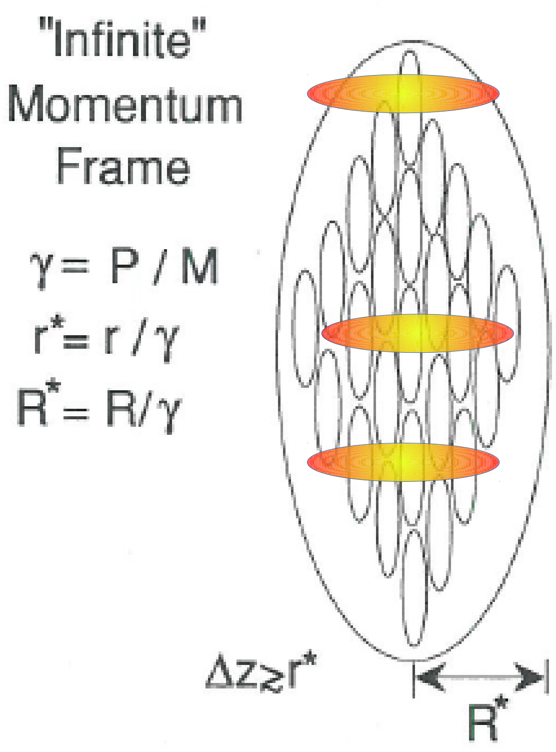
Executive Summary (page ix)



To date this saturated gluon density regime has not been clearly observed, but an EIC could enable detailed study of this remarkable aspect of matter.

This pursuit will be facilitated by electron collisions with heavy nuclei, where coherent contributions from many nucleons effectively amplify the gluon density being probed.

Nuclear shadowing in eA in the parton model



$\hbar = c = 1$ $\Delta p_z \Delta z \geq 1/2$

$r = 0.88$ fm $1/(2Mr) = 0.12$

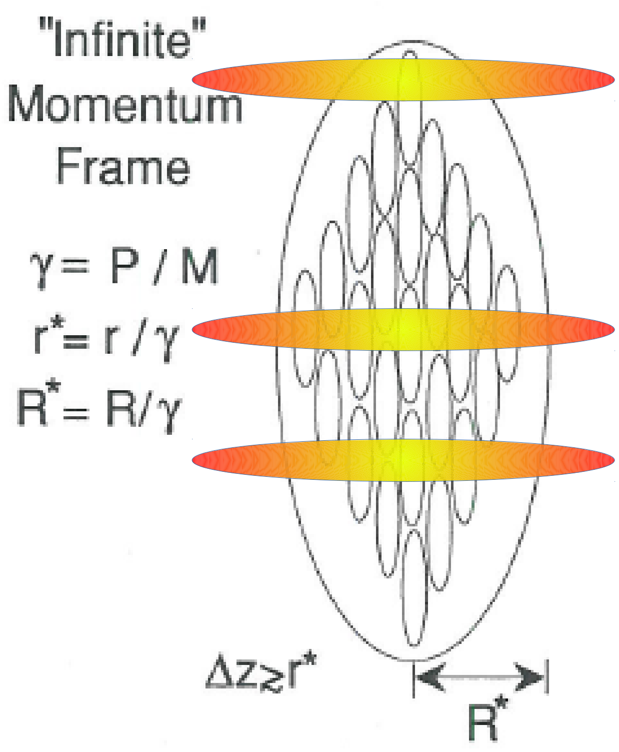
$p_z^{quark} = Mx\gamma$ $\Delta z = 1/(2Mx\gamma)$

$\Delta z / r^* = 1/(2Mxr) = 0.12/x_{Bj}$

For x<0.1, partons extend outside the nucleon, increasing the effective parton density seen by a probe at small b.

Parton saturation stronger in eA than in ep, SO $\sigma^{(A)}/\sigma^{(N)} < A$
Nuclear shadowing and parton saturation are intimately related.

Nuclear shadowing in eA in the parton model



$\hbar = c = 1$ $\qquad \Delta p_z \Delta z \geq 1/2$

$R_{Pb} = 6.6$ fm $\qquad 1/(2MR) = 0.016$

$p_z^{quark} = Mx\gamma \qquad \Delta z = 1/(2Mx\gamma)$

$\Delta z/2R^* = 1/(4MxR) = 0.008/x_{Bj}$

For x<0.01, all partons extend throughout the nucleus longitudinally.

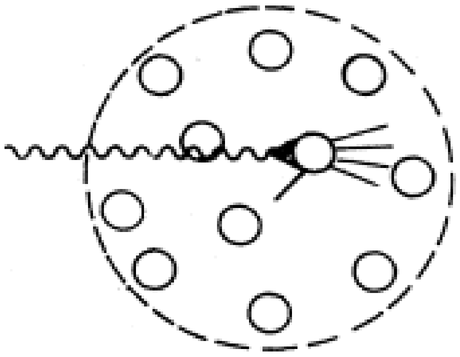
The parton density is increased by a factor $d_{max}(b)/\lambda$ where λ is the average distance between nucleons in the rest frame.

For x<0.01: $Q_s^2(b) \sim G^{(N)}(x,Q^2)*d_{max}(b)/\lambda$

DIS in the target rest frame:
The Dipole Model

Bauer, Spital, Yennie, Pipkin
Rev. Mod. Phys. 50 (1978) 261

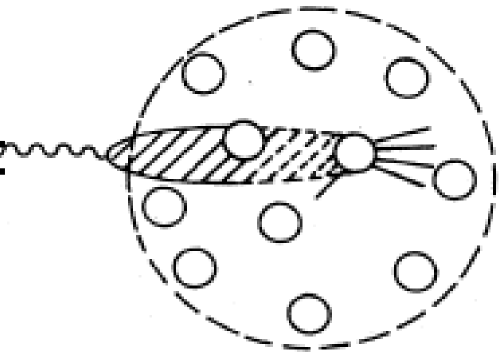
High x_{Bj}:



Nucleus Rest Frame

(b)

Low x_{Bj}:



(c)

$\lambda_h/r \approx 1/(2Mxr) = 0.12/x_{Bj}$

The virtual photon fluctuates into a hadronic state which lasts for a time given by quantum mechanics, leading to a correlation length: λ_h

Low x corresponds to a long λ_h and so for x<0.01, the first struck nucleon is usually on the FRONT FACE of the nucleus, leading to $\sigma(eA) \sim A^{2/3}\sigma(ep)$. The nucleons on the interior are said to be ***shadowed*** and we also have:

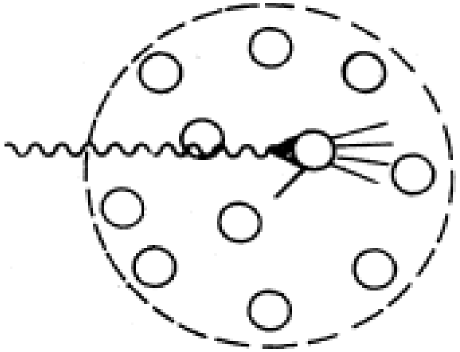
$$\mathbf{d(b) \approx d_{max}(b)}$$

$\lambda_h/2R \approx 1/(4MxR) = 0.008/x_{Bj}$

Same conclusion in either frame

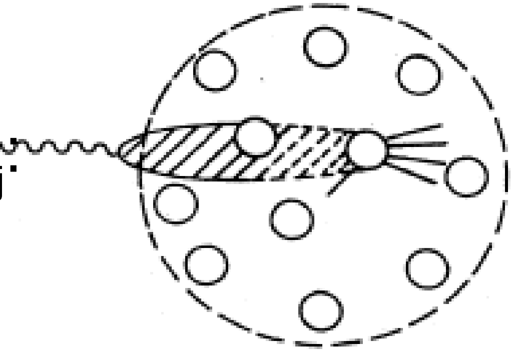
Bauer, Spital, Yennie, Pipkin
Rev. Mod. Phys. 50 (1978) 261

High x_{Bj}:



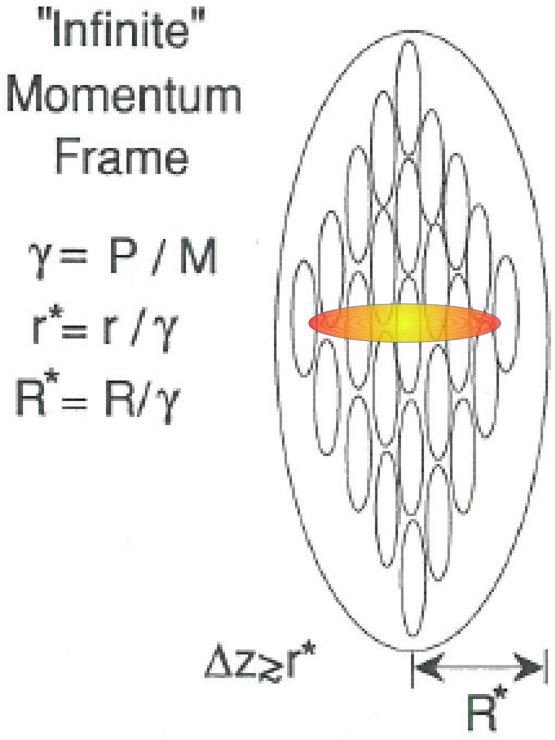
Nucleus Rest Frame (b)

Low x_{Bj}:



(c)

$\boxed{\lambda_h/r \approx 1/(2Mxr) = 0.12/x_{Bj}}$



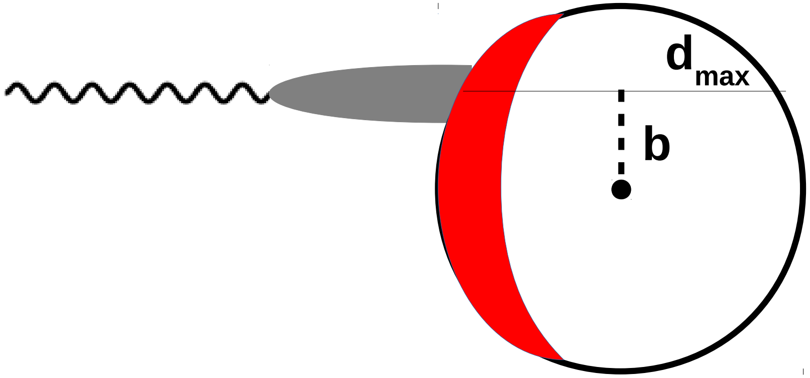
$p_z^{quark} = Mx\gamma$

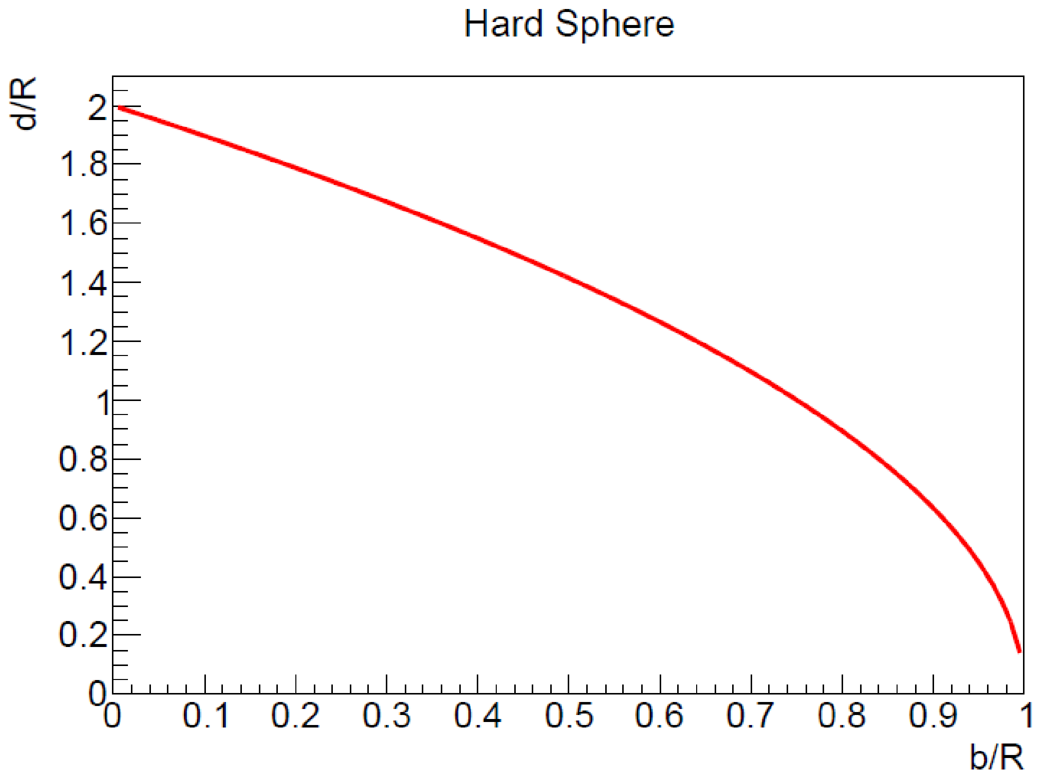
$\Delta z = 1/(2Mx\gamma)$

$$\boxed{\begin{aligned}\Delta z/r^* &= 1/(2Mxr)\\ &= 0.12/x_{Bj}\end{aligned}}$$

For x_{Bj}<<0.12, parton wavefunctions and/or interaction cannot be localized to one nucleon.

Putting it all together





For $x<0.01$: $Q_s^2(b) \sim G^{(N)}(x,Q^2)*d_{max}(b)/\lambda$

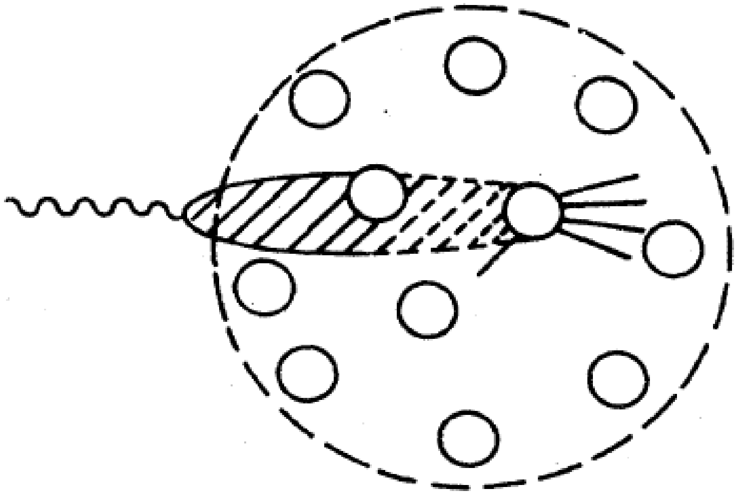
& $d(b) \approx d_{max}(b)$

SO: $Q_s^2 \sim d * (G^{(N)}(x,Q^2)/\lambda)$

Implementation plan (x<0.1)

- Very simplified, minimal assumptions:
  - Correlation length $\lambda_h \sim 1/2Mx_{Bj}$
  - Invert: $\sigma_{dipole}(x,Q^2)$ + Glauber → $\sigma^{(A)}/\sigma^{(N)}(x,Q^2)$
    $\sigma^{(A)}/\sigma^{(N)}(x,Q^2)$ + Glauber→$\sigma_{dipole}(x,Q^2)$
- Event by event, use σ_{dipole} and allow multiple nucleons to participate.
- Each one contributes a 2-vector k_T to the final struck parton and recoils.
- Can easily input improved $q(x,Q^2)$ & $G(x,Q^2)$!

Impact on eA Centrality Tagging



(c)

Centrality measure for eA in order to look for enhanced saturation at b~0 should be EASIER due to stronger d-b correlation, extra recoiling nucleons and significant enhancement of intra-nuclear cascade.

In the case of saturating eA, it may not be optimal to just measure (very forward) evaporation neutrons.

We PROBABLY can learn more by including charged evaporation fragments and also the slightly less forward “grey track” protons, neutrons & fragments.

Let's model this and find out!!

Possible upgrades (FY2017++)

- Different intrinsic k_T distributions for gluons and different flavors of quarks.
- Distinguish between gluon and quark saturation.
- Allow the σ_{dipole} to fluctuate after each nucleon interaction.
- EMC effect dynamics?
- Antishadowing (vs. b)
- Incorporate better heavy quark simulation!?
  - See talk by Charles Hyde
- <<Insert your favorite physics...>>

Summary

- Centrality tagging in eA looks promising!
  - We measure “d” and that's what we want
- DPMJet-Hybrid is being upgraded
  - Improve Pythia tune for forward particles
  - Add multinucleon interaction / shadowing / parton saturation
    - Use a simplified model to get the bulk of the physics
- Stay tuned...