# DPMJetHybrid 2.0

# A Tool to Refine Detector Requirements for eA in the Saturation Regime

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09-July-2015

***-co-PIs**

# The proposal in a nutshell

- Forward detector/IR design is happening NOW
  - MEIC aims for hermeticity on principle.
  - eRHIC relies on simulated measurements.
- DIS Models for eA have a serious deficiency.
  - Missing multinucleon recoil from $k_T$ (aka $Q_s$)
  - We don't really know how complete the forward coverage needs to be.
- Upgrade DPMJetHybrid to include known effects
- Simulate a couple of key measurements.
- Complete project in FY2016: $64,000

# ... Looking for El Dorado: The Lost **Golden** Measurement


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E.C.Aschenauer

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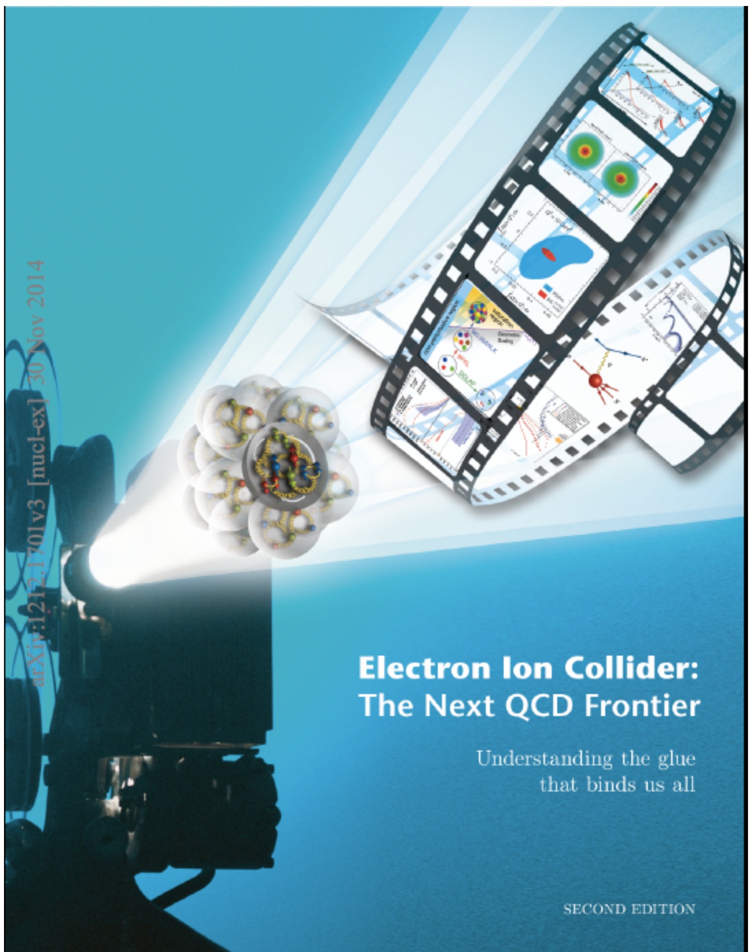
09 July 2015

# Saturation: A key physics goal

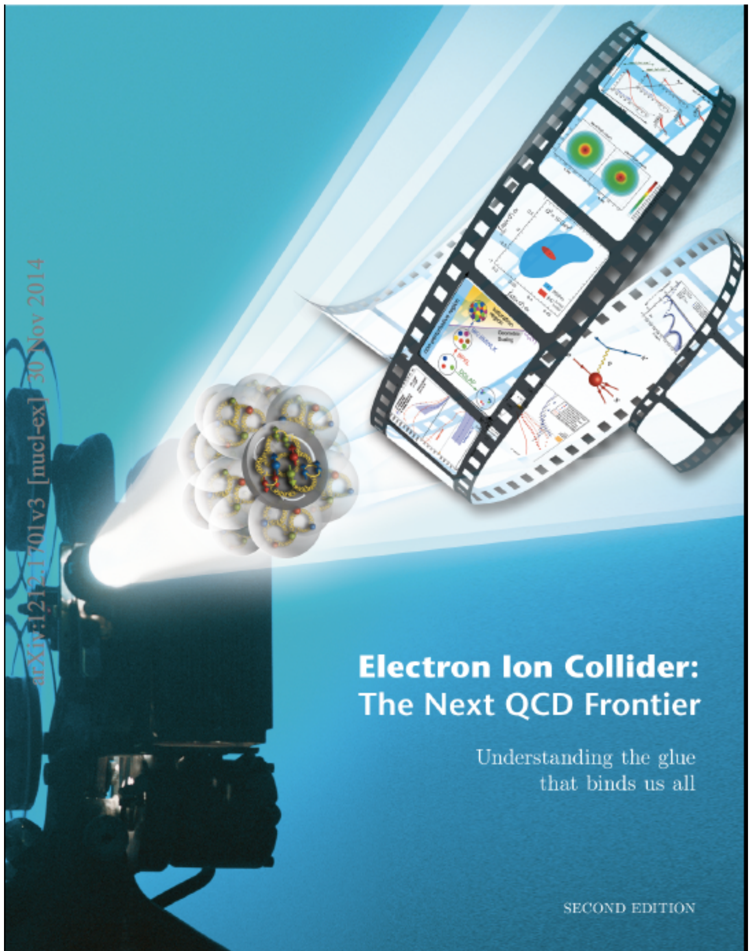



<u>Executive Summary (page ix)</u>

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.

Saturation is one of the key physics connections between ep, eA, AA, pp, pA @ JLAB, RHIC & LHC

# Saturation at EIC is multi-nucleonic




Executive Summary (page ix)

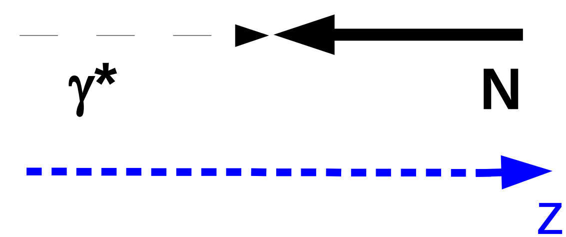
To date this saturated gluon density regime has not been clearly observed, but an EIC could enable detailed study of this remarkable aspect of matter.

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

# Direct measurement of intrinsic $k_T$


**Consider the hadronic center of mass (HCMS) frame**

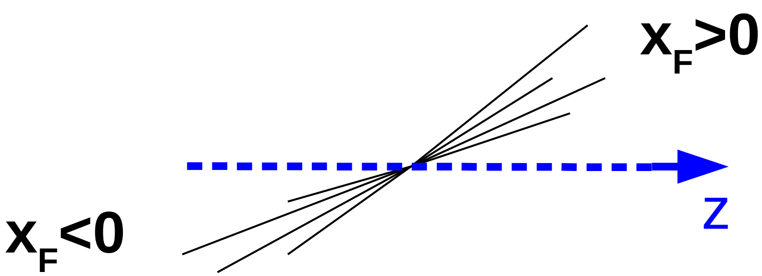
$\gamma^*$N frame (for ep or eA)



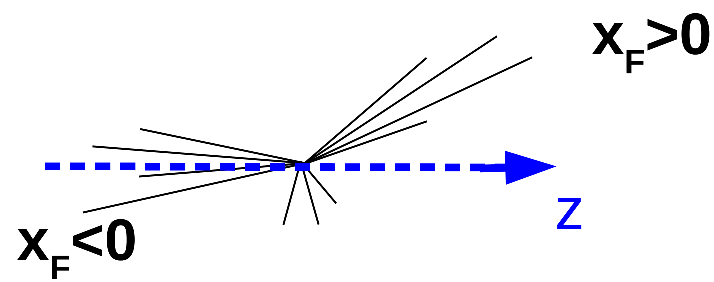

$x_F=2p_z/W$

**Intrinsic $k_T$ at high $|x_F|$.**

**QCD radiation primarily shows up at $x_F \geq 0$**




**HCMS frame**

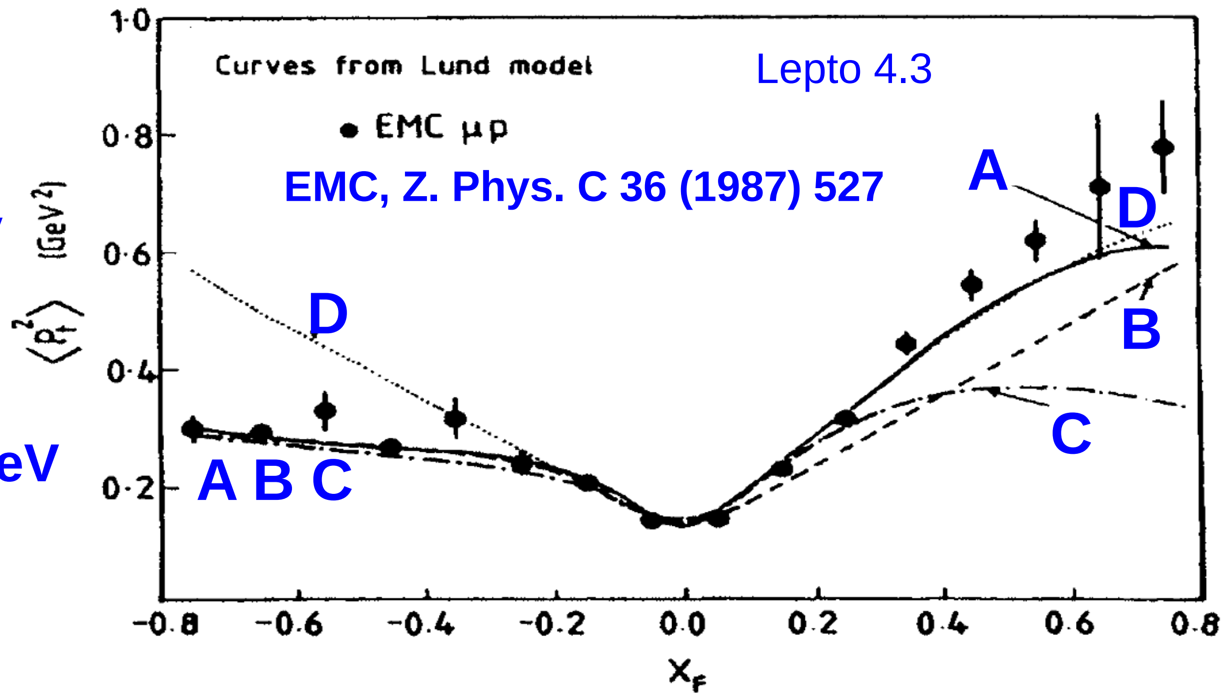


# Direct measurement of intrinsic $k_T$

**$k_T$ (rms)**

**D: 0.88 GeV**

**A-C: 0.44 GeV**




**A: Full QCD (0.44)**
**D: Hard Only(0.88)**

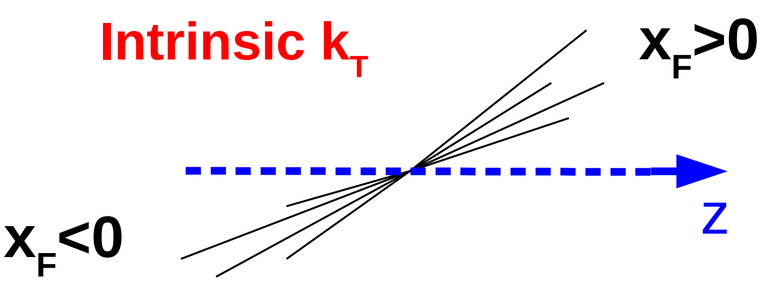
**B: Soft Only (0.44)**

**C: Hard Only(0.44)**

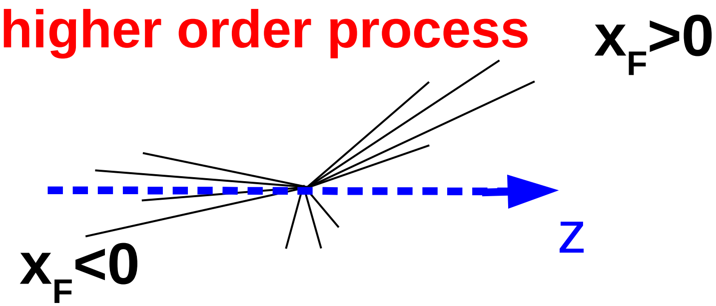
Z

**QCD: Soft: Parton Shower**
**Hard: higher order process**

**Intrinsic $k_T$**




**HCMS frame**



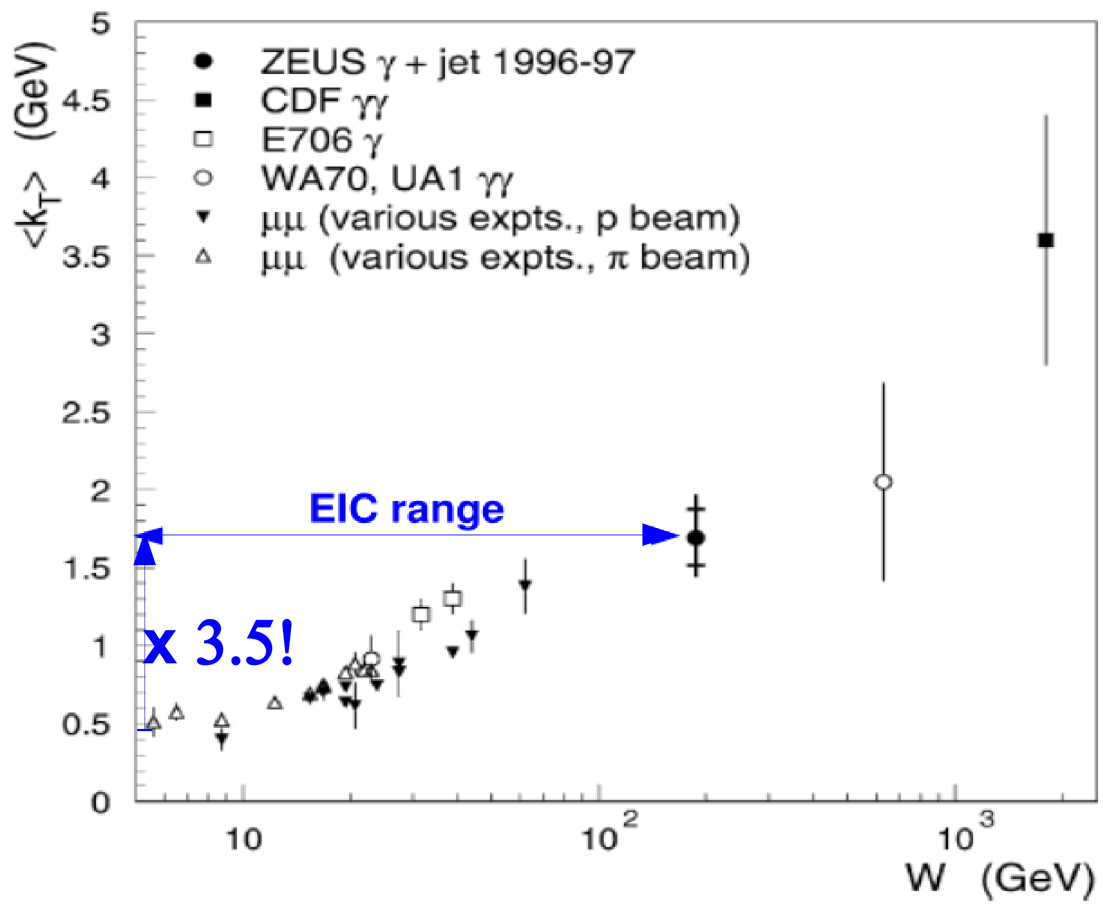
# The switch to "effective" $k_T$

E665, H1 & ZEUS did not use the **golden method,** so it was lost!

"Effective" $k_T$ measured w/o target jet recoil varies a LOT!

In order to relate $k_T$ to fundamentals like $Q_s$, we must actually measure $k_T$

*ZEUS Collaboration / Physics Letters B 511 (2001) 19–32*

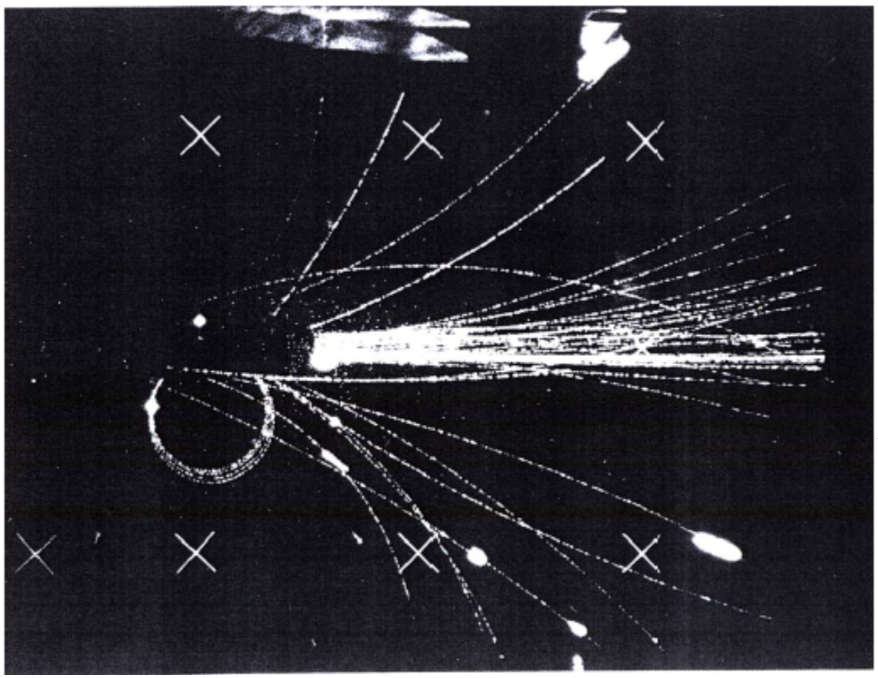


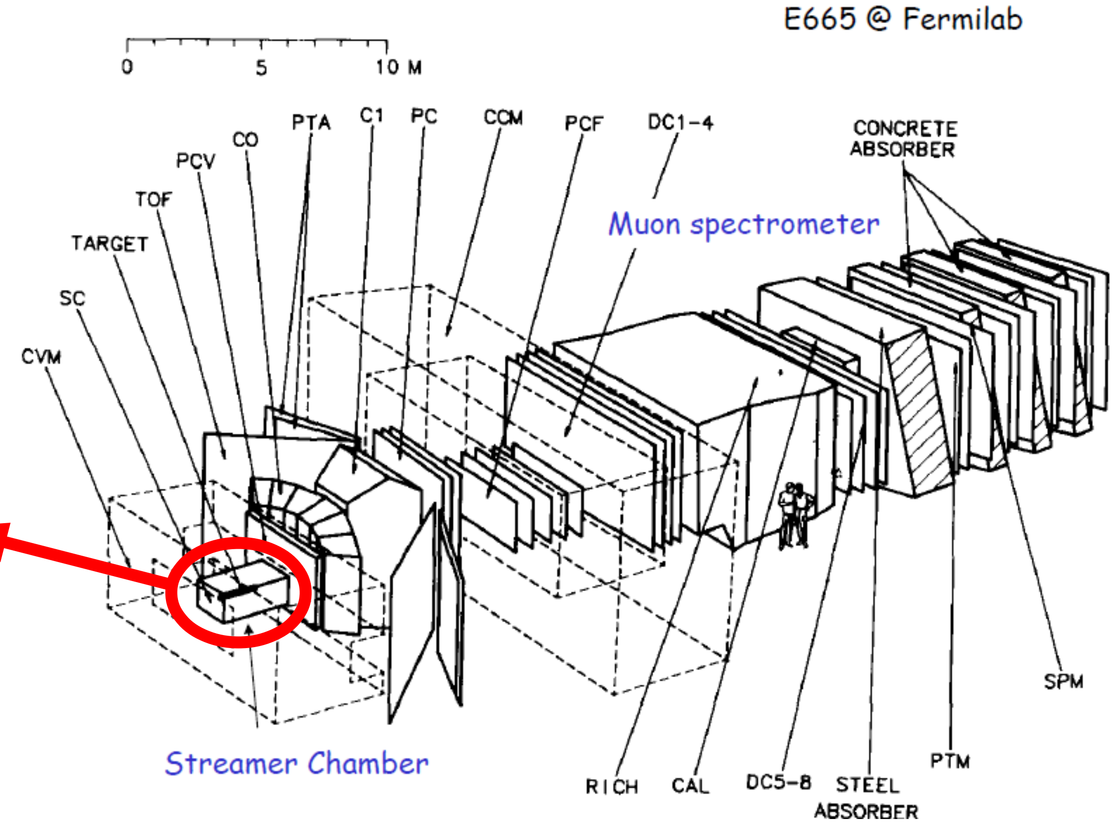

Pythia 6.4 manual hep-ph/0603175

"Any shortfall in [parton] shower activity … has to be compensated by the Primordial $k_T$ source, which thereby largely loses its original meaning."

# FNAL E665: Why not measure it?

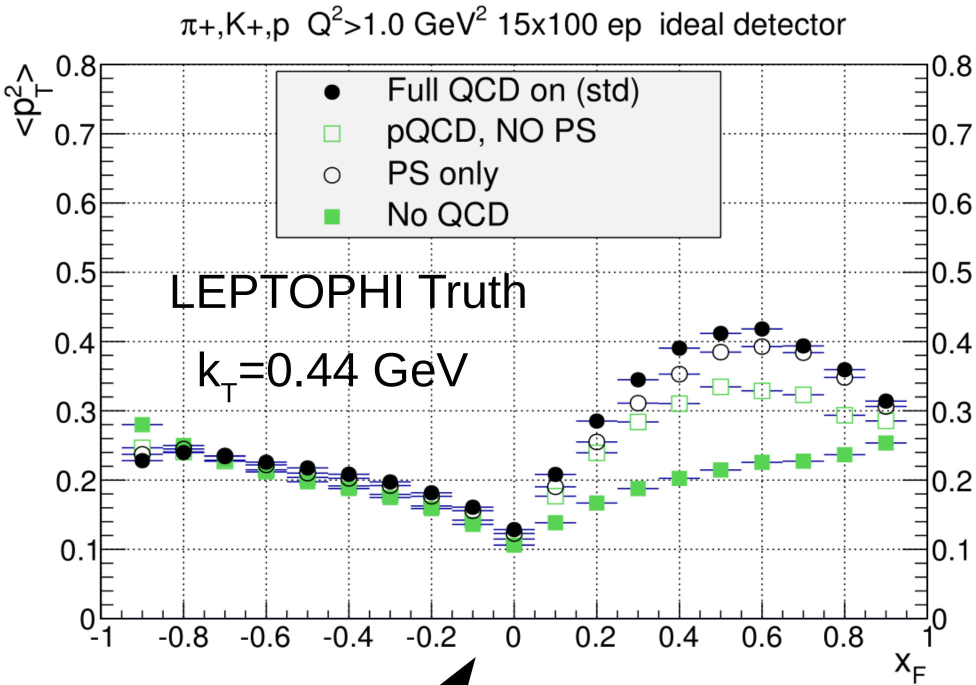
Streamer chamber in FT ideal for this.

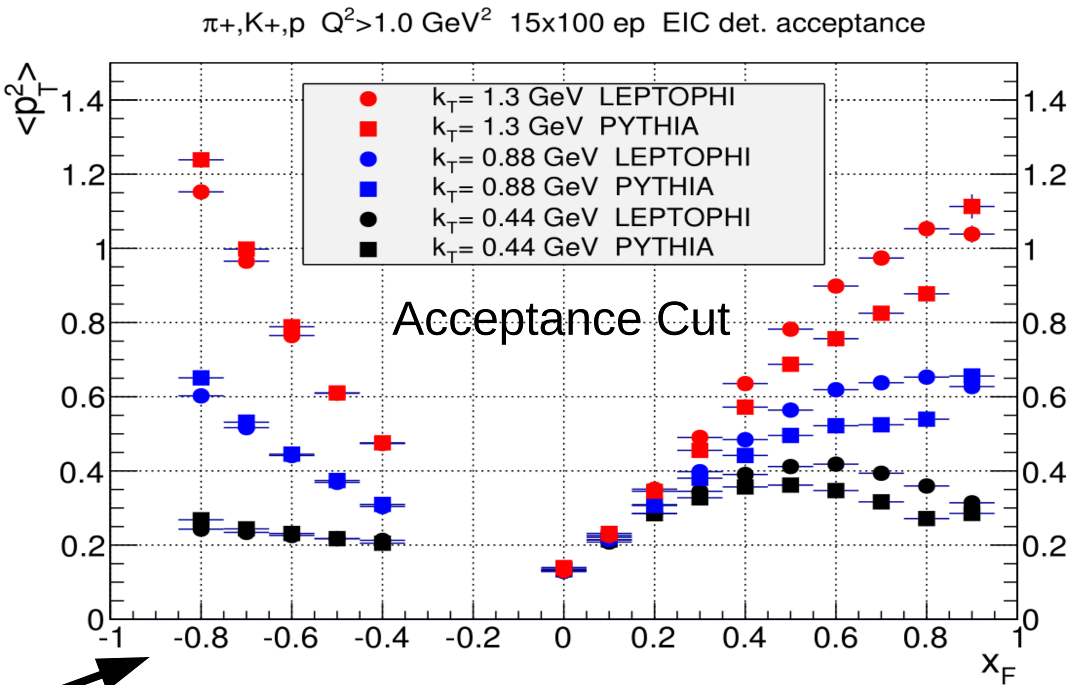


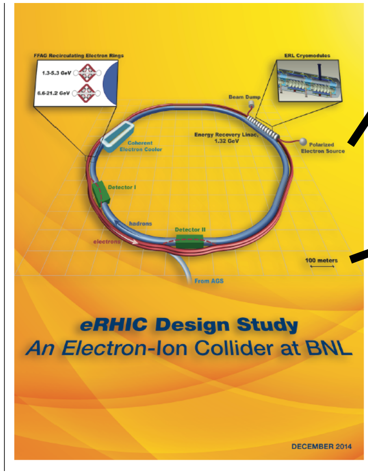



- WHY WOULD WE?
  - Looking for pQCD or deep diffraction.
  - Nobody expected $k_T$ to vary with s or W.
  - Streamer Chamber analysis took time.
- How about HERA?
  - Similar physics (lack of) interest.
  - Measurement harder at a collider.
  - They should have tried after "$k_T$(W)"

# For ep, we can measure $k_T$ at EIC



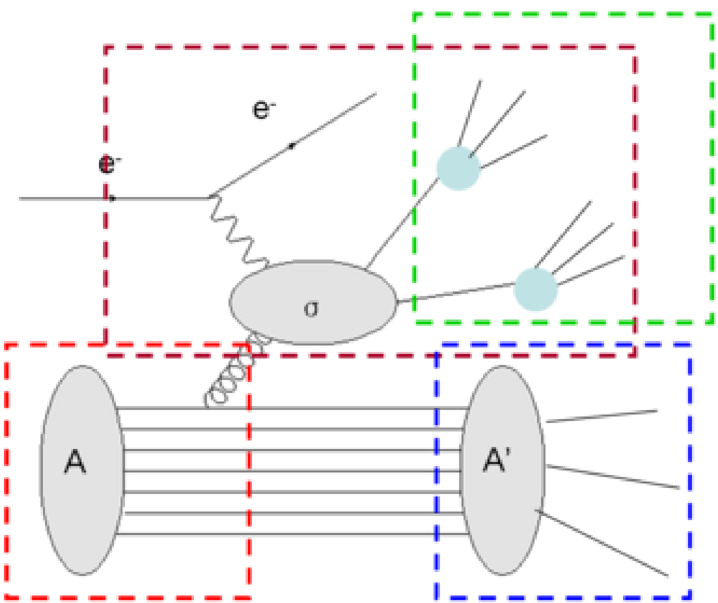

LEPTOPHI based on LEPTO 6.5.1
PYTHIA is PYTHIA 6.4

Detector Requirements:
Detection to η of 5
+ Roman Pots for forward protons

Note: For LHeC this may be enough by itself!

# What about eA? DPMJet-Hybrid (1.0)

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 be picked as a target nucleon in the collision."

**If valid, looking for $Q_s$ in eAu would be easy. Just measure $k_T$ recoil in ep & eAu.**

# eA: Basic Quantum Mechanics

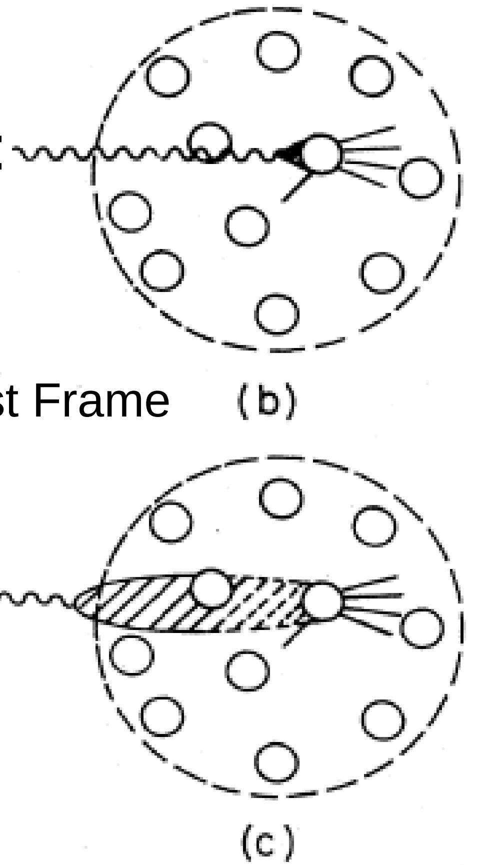
$\hbar=c=1$ $r=0.88$ fm $1/(2Mr) = 0.12$ $\Delta p_z \Delta z = 1/2$

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

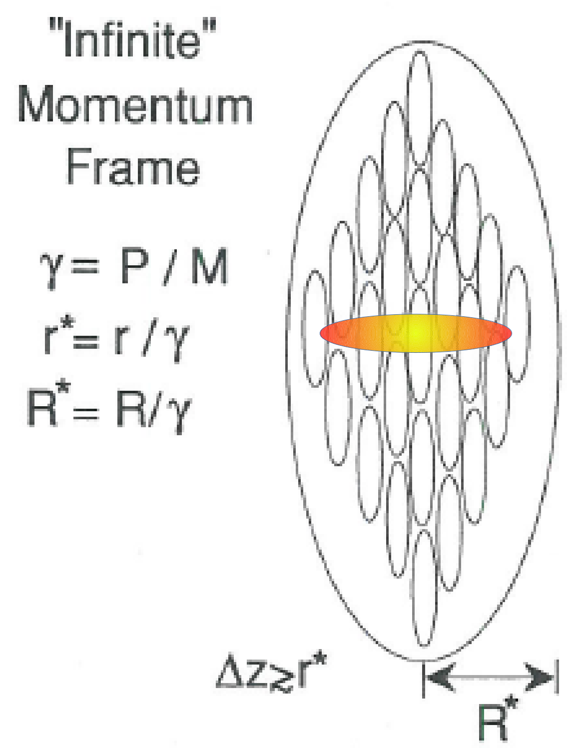
High $x_{Bj}$:

Nucleus Rest Frame

Low $x_{Bj}$:




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




$p_z^{quark} = Mx\gamma$

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

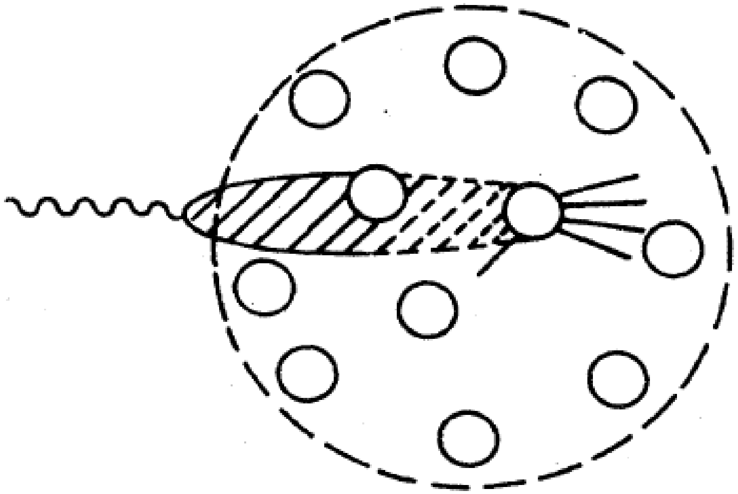
$\Delta z/r^* = 1/(2Mxr)$
$= 0.12/x_{Bj}$

**For $x_{Bj} \ll 0.12$, parton wavefunctions and/or interaction cannot be localized.**

# Impact on eA Forward Physics I

Most of the complications in saturation theory are in predicting the dependence on x, $Q^2$. With Glauber, we can make simple map:

$F_2^A/F_2^N(x,Q^2)$ ⟷ $\sigma_{dipole}$ ⟷ $P(N_{coll},b)$



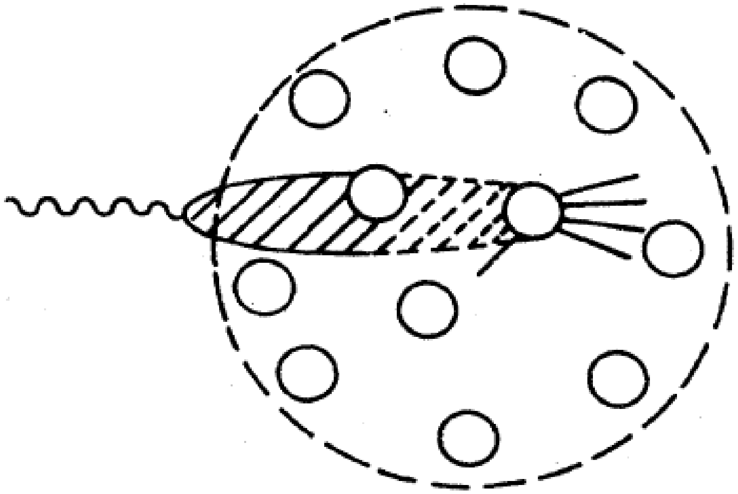
Direct measurement of $k_T$ recoil is more challenging as it is shared between nucleons and/or nucleon remnants.

**It may not be enough to sample forward nucleons,**

**We PROBABLY need to measure most or all of them.**

**And maybe correlate them with current monojets**

# Impact on eA Forward Physics II



(c)

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

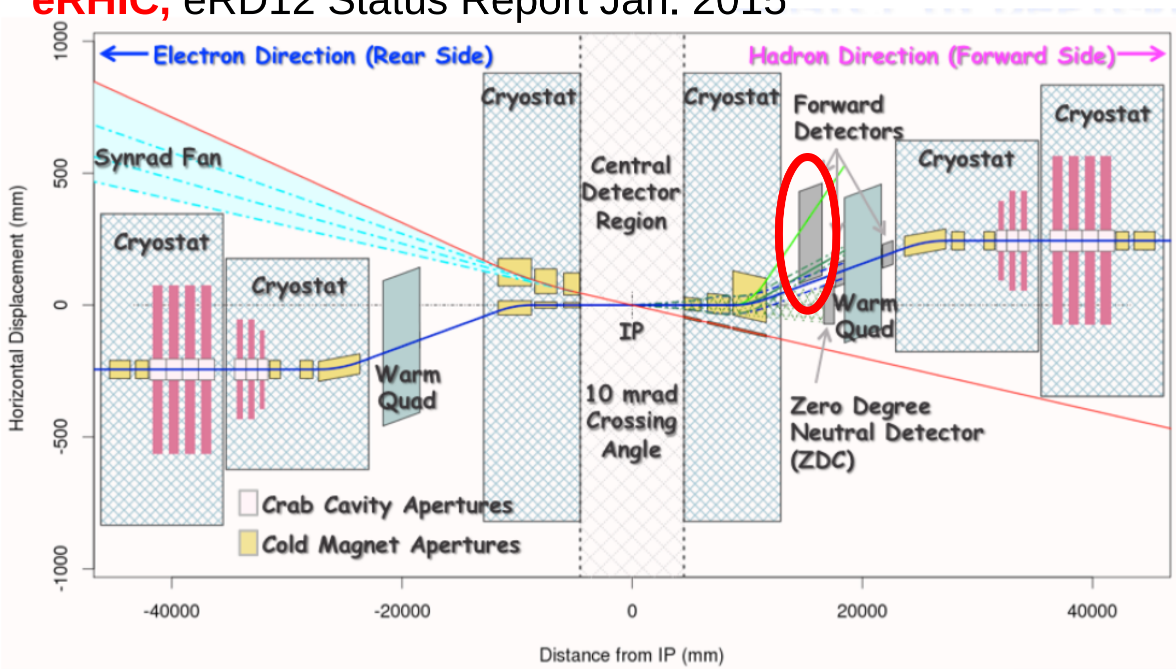
**In the case of saturating eA, it may not be enough to just measure (very forward) evaporation neutrons.**

**We PROBABLY can learn more by including the more modestly forward protons and/or neutrons.**

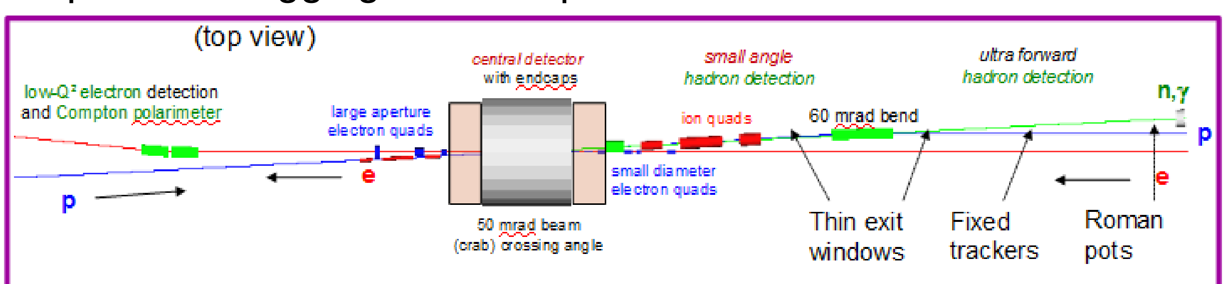
**Let's model this and find out!!**

# Detectors & IRs being optimized NOW w/ incomplete eA info.!

**eRHIC,** eRD12 Status Report Jan. 2015




**MEIC,** Morotov et al. High Energy Nuclear Physics with Spectator Tagging Workshop, March 2014




**eRHIC** – Studies of eAu centrality tagging using the single-struck-nucleon DPMJet model.
**Conclusion so far: forward protons not needed!**

**MEIC** – Goal: near hermetic acceptance for all nuclear fragments in heavy eA. Physics advantage? **To Be Determined.**

**Both** designs can tag forward p or n in polarized e $^3$He.

**Do we need good forward proton acceptance in eA?**

**May be important, but... WE DON'T KNOW!!!**

# Manpower & Timetable

| Person | Institution | Effort (FTE-year) | Cost to Proposal | Remarks |
|---|---|---|---|---|
| E. Aschenauer | BNL | 0.05 | \$0 | cost covered by BNL |
| M.D. Baker | MDBPADS[20] | 0.24 | \$64,000 | |
| J.H. Lee | BNL | 0.10 | \$0 | cost covered by BNL |
| TOTAL: | | 0.39 | \$64,000 | |

Table 1: Personnel Budget Breakdown - fully loaded costs

**Cost of substantial technical contribution from Aschenauer, Lee covered by BNL:**
Expertise on Pythia, DpmjetHybrid, Forward Detectors, Detector/IR interface, eA centrality.

MDB expertise: Intrinsic $k_T$ & QCD in MCs, Nuclear Shadowing, Glauber model,
Implementing new physics in MCs, Forward detectors at RHIC

11 month timetable: Nov. 2, 2015-Sept.30,2016

**Feb. 26, 2016** Simplified implementation in model: no color connections with extra nucleons, no flavor-dependent $k_T$ **(4 months)**

**Apr. 29, 2016** Model testing and physics results with simplified model. Code release. **(2 months)**

**June 29, 2016** Full model implementation **(2 months)**

**Sept. 30, 2016** Final physics results. Code release. Project complete. **(3 months)**

**(11 months)**

# Summary

- Observing saturation is a key physics goal!
- Our eA DIS models don't handle it!
- Need to fix this NOW
  - IR design is ongoing at eRHIC & MEIC.
  - Team with the exact MC expertise is in place.
- Extremely cost-effective.
  - Short-term project.
  - High Impact.
  - Automatically upgrades with new $F_2^A$ info.

# Backup Slides

# The Pythia 6 Manual describes the problem nicely

"It is customary to assign a primordial transverse momentum to … take into account the motion of the quarks inside the original hadron..".

"A number of order … 300 MeV could therefore be expected. However in hadronic collisions much higher numbers than that are often required to describe the data … 1GeV [or] 2 GeV."

"Any shortfall in [parton] shower activity … has to be compensated by the Primordial $k_T$ source, which thereby largely loses its original meaning."

Pythia 6.4 manual hep-ph/0603175

In order to relate $k_T$ to fundamentals like $Q_s$:
We must actually measure $k_T$!

# Words of Wisdom

With apologies to my many very smart theorist friends!

"The deficiency in the present coverage is serious especially if one is to study at all nuclear fragmentation."

Bj, Snowmass, 1996 – discussing plans for forward detection
for eA at HERA - arXiv:hep-ph/9610516

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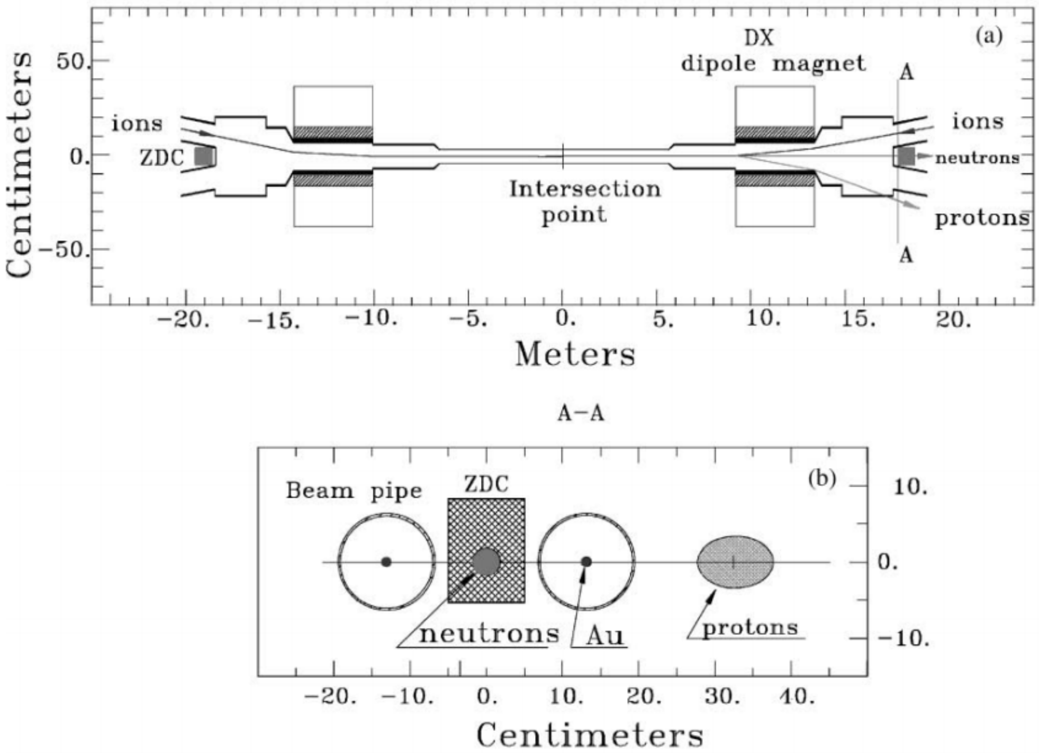
"What matters most for progress is:
a steady advance in technology.
Next is steady progress in experimental techniques
...
Theory is at the bottom of the list."

J.D. Bjorken, from: "Data Matters"
News from ICTP 112 (2005)

# Forward protons: Lessons from RHIC

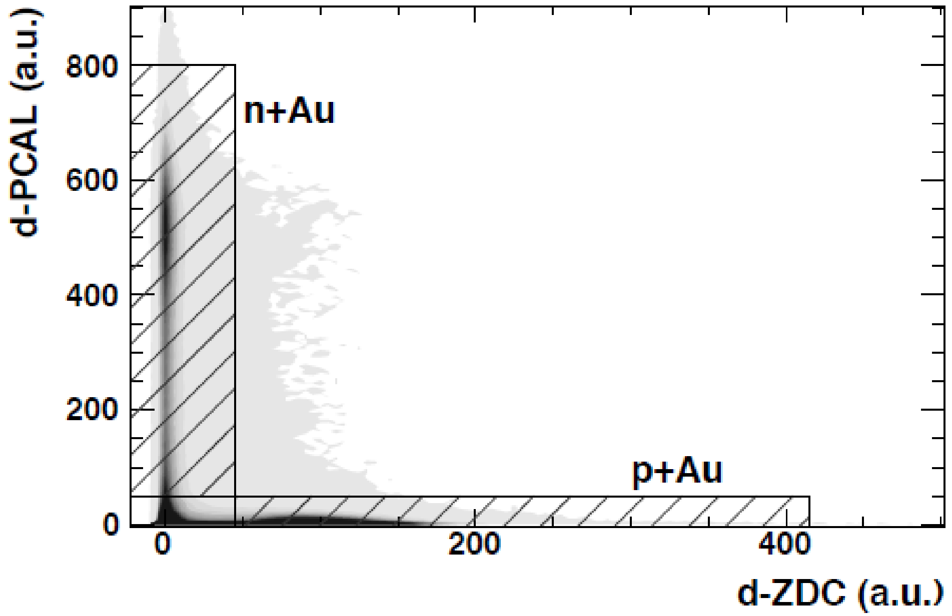
B.Back et al. (PHOBOS) arXiv:1505.06766

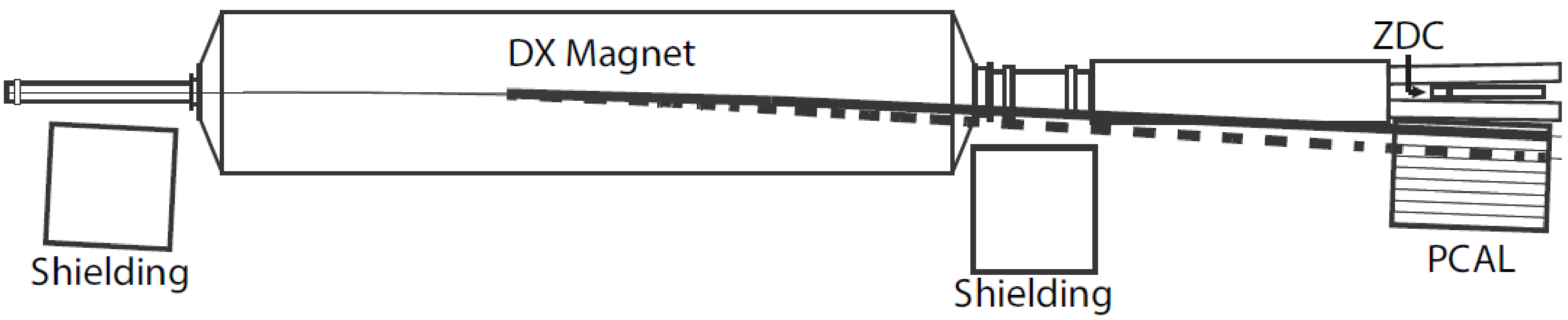



Unlike in ep, spectator protons will be much less rigid than the Au beam

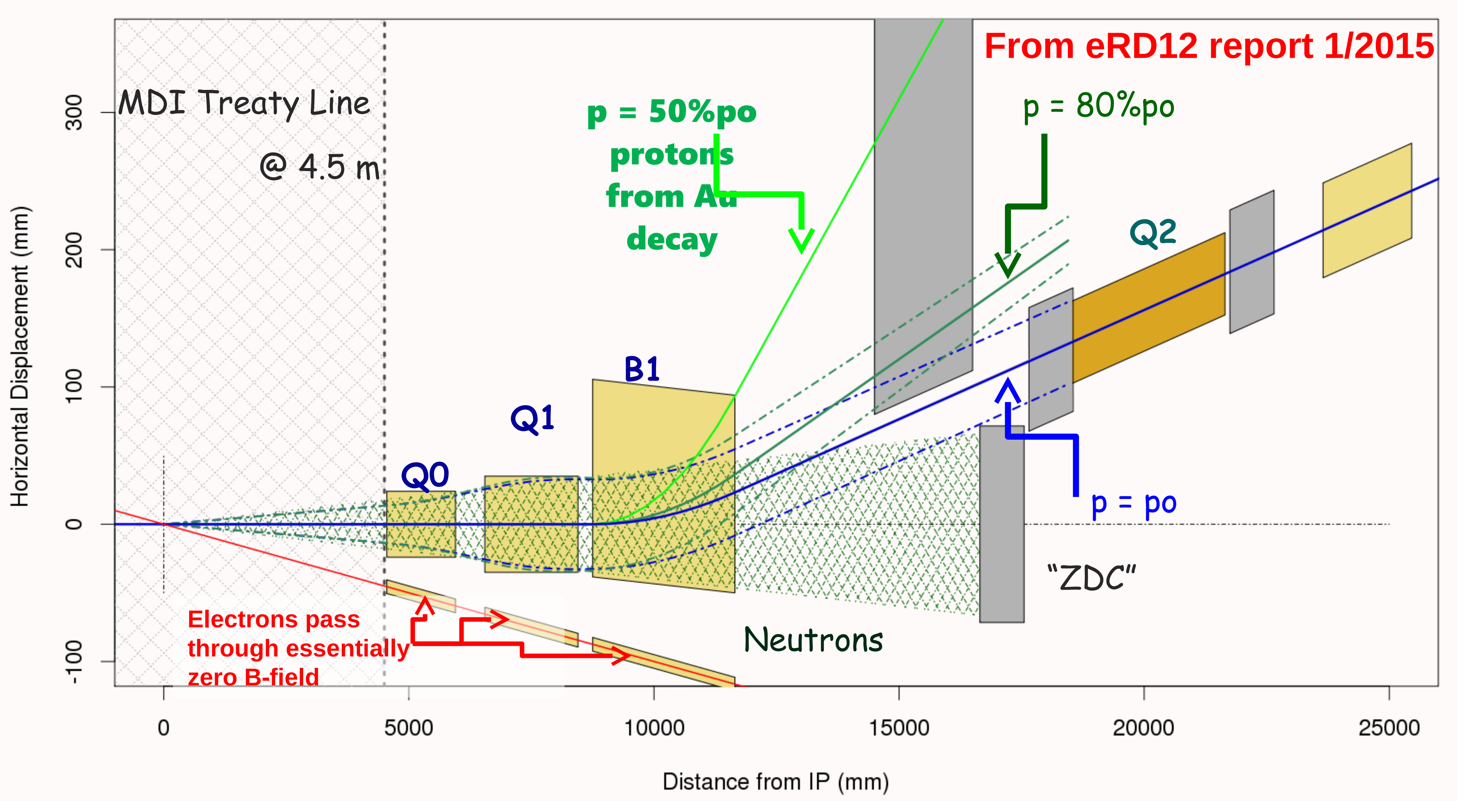
# Forward protons: Lessons from RHIC

B.Back et al. (PHOBOS) arXiv:1505.06766



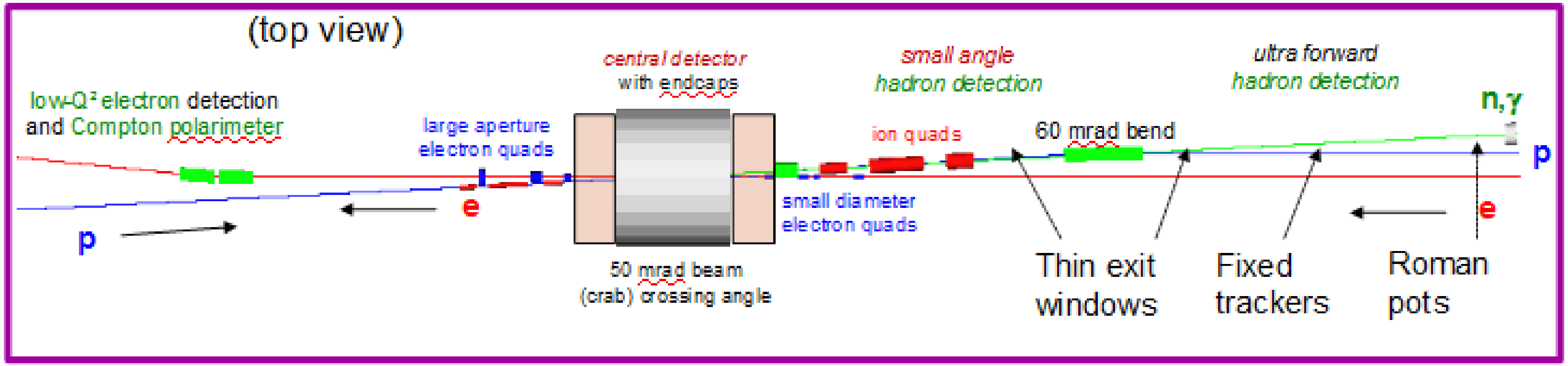



# eRHIC Forward design



# MEIC Forward Design

**MEIC forward detector / IR design** from Morotov et al.
High Energy Nuclear Physics
With Spectator Tagging Workshop
March 2014



# Intranuclear cascade in data

M.R. Adams et al. (E665) Z.Phys.**C65** (1995) 225

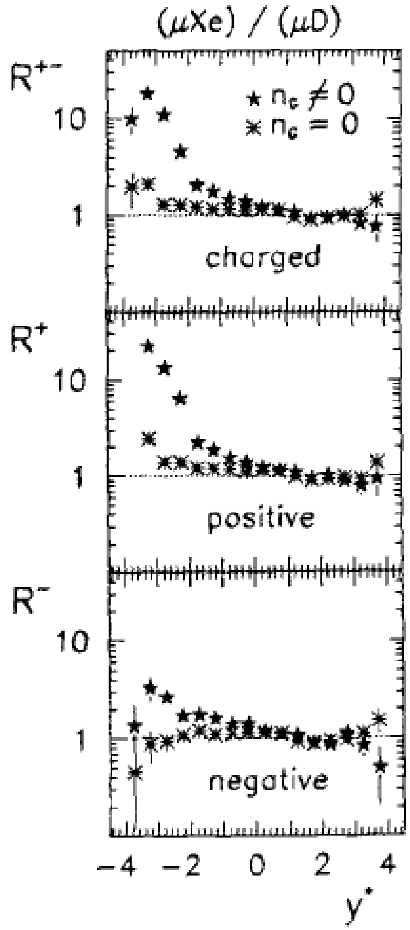



**Fig. 4.** Multiplicity ratio $R = \langle n \rangle_{\mu Xe} / \langle n \rangle_{\mu D}$ as a function of $y^*$, for all charged and for positive and negative hadrons, for $\mu$Xe events with ($n_g \neq 0$) and without ($n_g = 0$) grey tracks

# eA Centrality from Dpmjet

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