Report from the eA Working Group

Vadim Guzey, Dave Morrison,
Thomas Ullrich, Raju Venugopalan

EIC Collaboration Meeting
Lawrence Berkeley National Laboratory
December 11-13, 2008

1. Current Projects and Progress
2. Report from the eA Parallel Meeting
3. Workshops

BROOKHAVEN NATIONAL LABORATORY

Current Projects

- Diffractive Physics in eA
  - Goal: Establish key measurements and methods, define machine & detector requirements
  - Wlodek Guryn, Vadim Guzey, Matt Lamont, Raju Venugopalan, TU
- Parton propagation and fragmentation
  - Goal: Establish key measurements, define detector requirements
  - Alberto Accardi, Raphael Dupre, Kawtar Hafidi
- Jets
  - Goal: Study physics potential of jet measurements, establish machine & detector requirements
  - Gregory Soyez, Raju Venugopalan
- e+A Event Generator
  - Matt Lamont, Cyrille Marquet, Henry Kowalski

Current Projects

That’s the maximum number of projects
we can handle given the current manpower

Progress Reports: EIC Notes

Took up the idea from last EICC Meeting:

3 EIC Notes in preparation (2 ‘almost’ done - drafts available for feedback)

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1. Diffraction in e+A collisions with the EIC

Progress Reports: EIC Notes

Diffraction in e+A collisions with the EIC

The e+A Working Group
(Dated: Draft: December 9, 2008)

Abstract to be added ...

Contents

I. INTRODUCTION

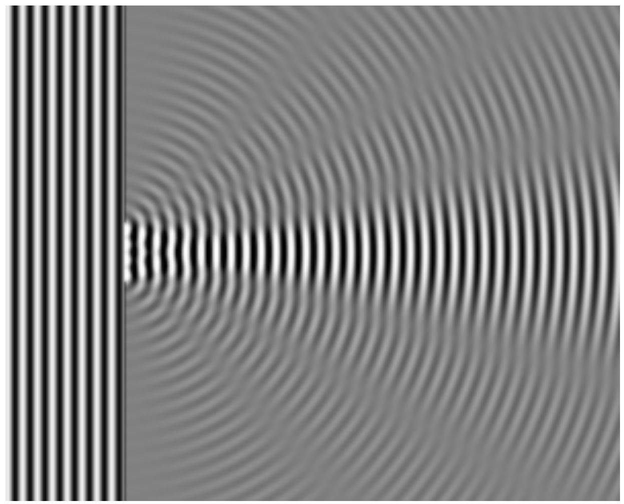

FIG. 1:

Pomeron exchange is that of a colorless combination of two gluons, each of which individually carries color charge. In general, diffractive events probe the complex structure of the QCD vacuum that contains colorless gluon and quark condensates. Because the QCD vacuum is non–perturbative and because much of previously studied strong interaction phenomenology dealt with soft processes, a quantitative understanding of diffraction in QCD remains elusive.

Significant progress can be achieved throught the study of hard diffractive events at collider energies. These allow one to study hadron final states with invariant masses much larger that the fundamental QCD momentum scale of ~ 200 MeV. By the uncertainity principle of quantum

Much of what is reported in note was presented in parallel eA WG session

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1. Diffraction in e+A collisions with the EIC
2. Parton propagation and fragmentation at the EIC

Draft, 10 December 2008

Parton propagation and fragmentation at the EIC

Alberto Accardi[1,2], Raphaël Dupré[3] and Kawtar Hafidi[3,2]

[1] Hampton University, Hampton, VA, 23668, USA
[2] Jefferson Lab, Newport News, VA 23606, USA
[3] Physics Division, Argonne National Laboratory, Argonne, IL, USA

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2. Parton propagation and fragmentation at the EIC
3. Jet Physics at the EIC

Sources (text & figures) stored in repository accessible to group members (subversion/svn)

- ease writing and maintenance process
- easy access of material for presentations

e+A WG Meeting/Parallel Session

1. *J. Qiu* Semi-inclusive processes
2. *C. Marquet* Theory Diffraction
3. *M. Lamont* Diffractive MC studies
4. *W. Guryn* Diffractive Measurements
5. *V. Guzey* DVCS in Nuclei
6. *A. Majumder* E-loss, fragmentation
7. *G. Soyez* Jets
8. Discussion on low-energy staging option

Hard Diffraction in DIS at Small x

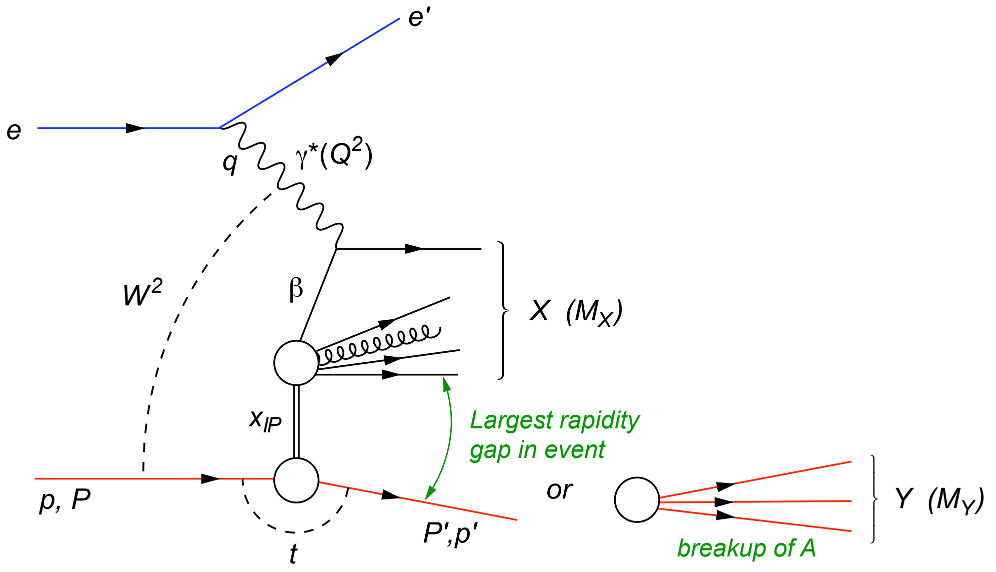
Cyrille Marquet

$$\beta = \frac{Q^2}{2(p-p').(k-k')} = \frac{Q^2}{M_X^2 - t + Q^2}$$

is the momentum fraction of the struck parton w.r.t. the Pomeron

$x_{IP} = x/\beta$

momentum fraction of the exchanged object (Pomeron) w.r.t. the hadron



The measured cross-section:

$$\frac{d^4\sigma^{eh\to eXh}}{dx dQ^2 d\beta dt} = \frac{4\pi\alpha_{em}^2}{\beta^2 Q^4}\left[\left(1-y+\frac{y^2}{2}\right)F_2^{D,4}(x,Q^2,\beta,t) - \frac{y^2}{2}F_L^{D,4}(x,Q^2,\beta,t)\right]$$

The dipole picture:

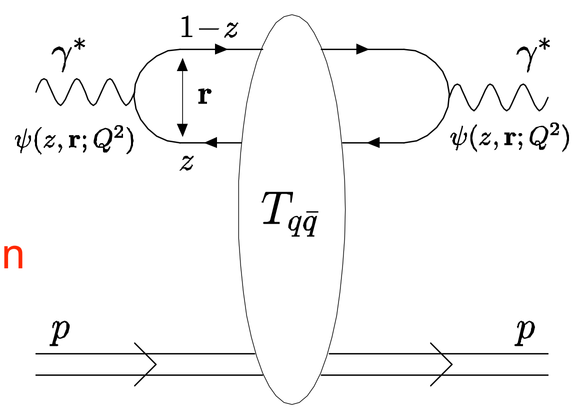
Here inclusive DIS

$$\sigma_{tot}^{\gamma^* p\to X} = 2\int d^2r\, dz \sum_\lambda |\psi_\lambda(r,z,Q^2)|^2 \underbrace{\int d^2b\, T_{q\bar{q}}(r,x,b)}$$

overlap of $\gamma^* \to q\bar{q}$ splitting functions

dipole-hadron cross-section

$T_{q\bar{q}}$ = dipole scattering amplitude



Hard Diffraction and Saturation

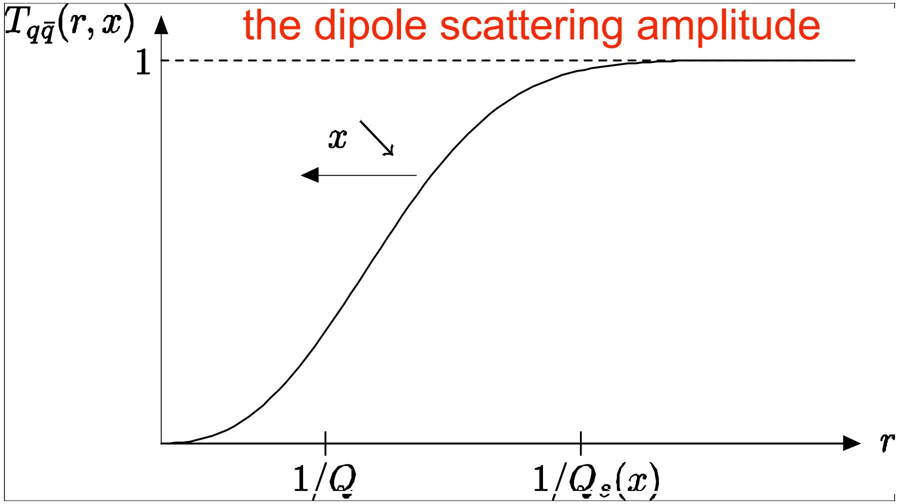
The total cross sections

in DIS

$$\int d^2r\ dz\ \sum_\lambda |\psi_\lambda(r,z,Q^2)|^2 \int d^2b\ T_{q\bar{q}}(r,x,b)$$

in DDIS

$$\int d^2r\ dz\ \sum_\lambda |\psi_\lambda(r,z,Q^2)|^2 \int d^2b\ T^2_{q\bar{q}}(r,b,x)$$



Diffraction directly sensitive to saturation

σ_{DIS} dominated by relatively hard sizes: $1/Q<r<1/Q_S$

σ_{DDIS} dominated by semi-hard sizes: $r \sim 1/Q_S$

Nuclear effects

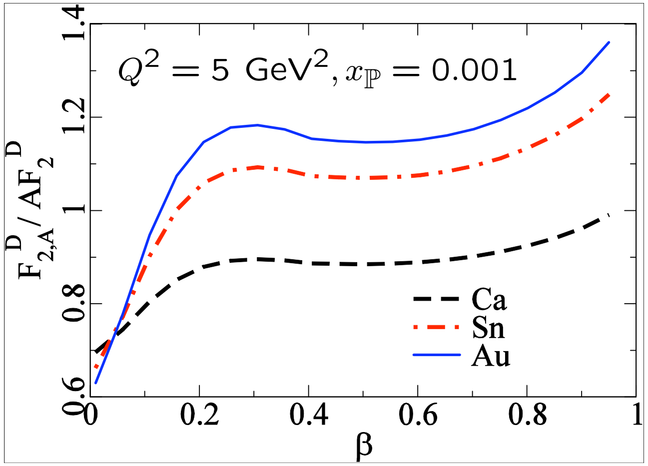
enhancement at large β

the quark-antiquark contribution dominates

the ratio is almost constant and decreases with A

suppression at small β

the quark-antiquark-gluon contribution dominates



Kowalski, Lappi, C.M. and Venugopalan (2008)

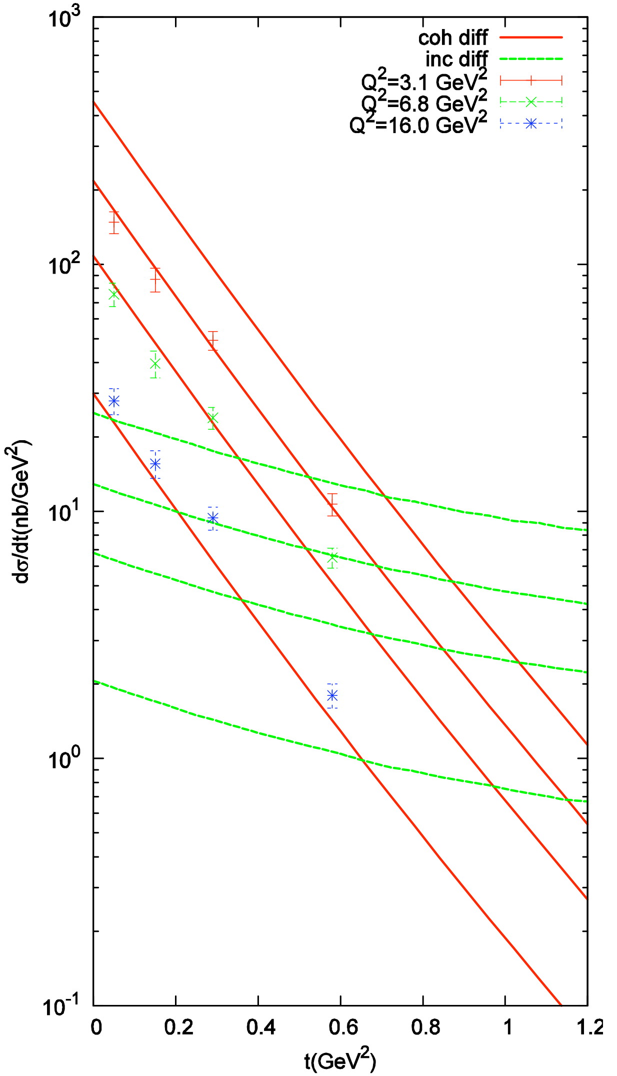
Coherent vs. Incoherent Diffraction

- Diffraction in e+p:
  - coherent ⇔ p intact
  - incoherent ⇔ breakup of p
- Diffraction in e+A:
  - coherent diffraction (nuclei intact)
    → steep exp. fall at small |t|
  - breakup into nucleons (nucleons intact)
    → slower exp. fall at 0.05 < -t < 0.7 GeV^2
  - incoherent diffraction
    → power-law tail at large |t|

e+A → J/ψ+A: Dominguez, C.M. and Wu, in progress

In this study the breakup of the nucleus into pions is allowed

Exclusive Diff.: here e+p

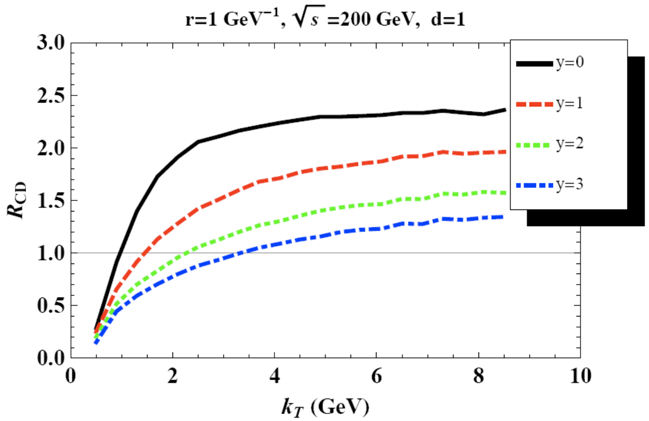


(Semi)-Inclusive Diffraction

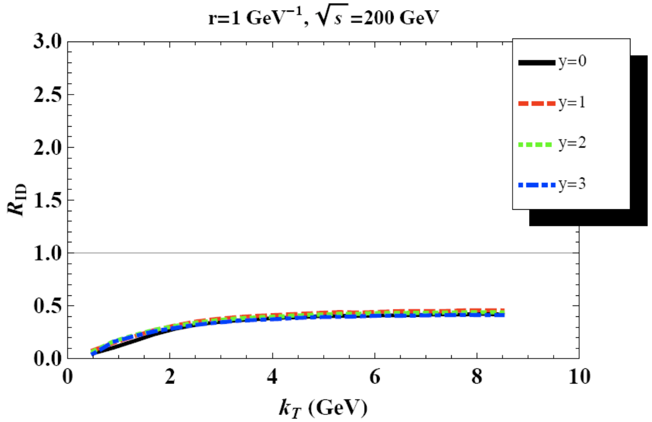
Semi-inclusive e+A → X+h+A (Tuchin, 2008):

- the proportion of incoherent diffraction decreases with A
- Nuclear Modifications (here for pA/pp but same for eA/ep):

antishadowing of coherent diffraction

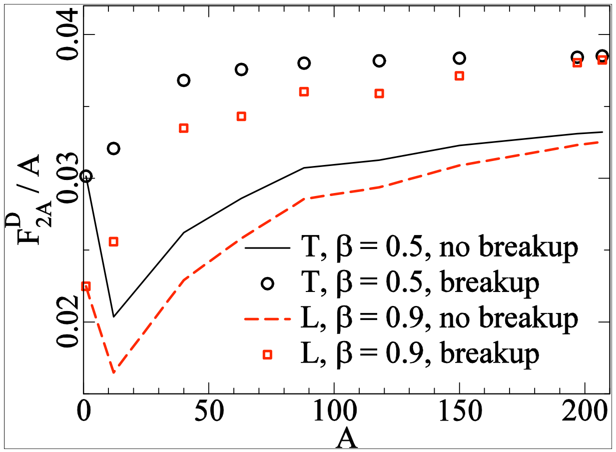


shadowing of incoherent diffraction



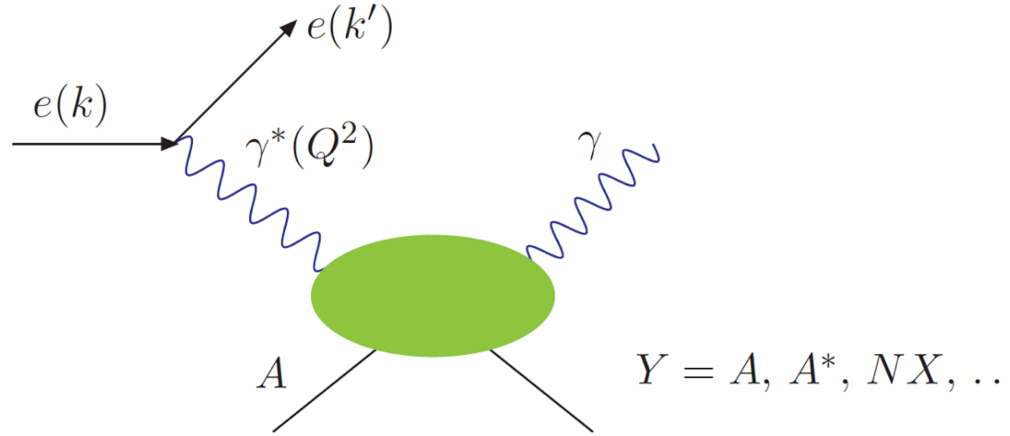
Inclusive e+A (Kowalski, et al., 2008):

- the breakup of the nucleus into nucleons is allowed
- for a gold nucleus, the diffractive structure function is ~20% bigger when allowing breakup into nucleons
- the proportion of incoherent diffraction decreases with A



DVCS with Nuclei at Small-x at the EIC

Vadim Guzey



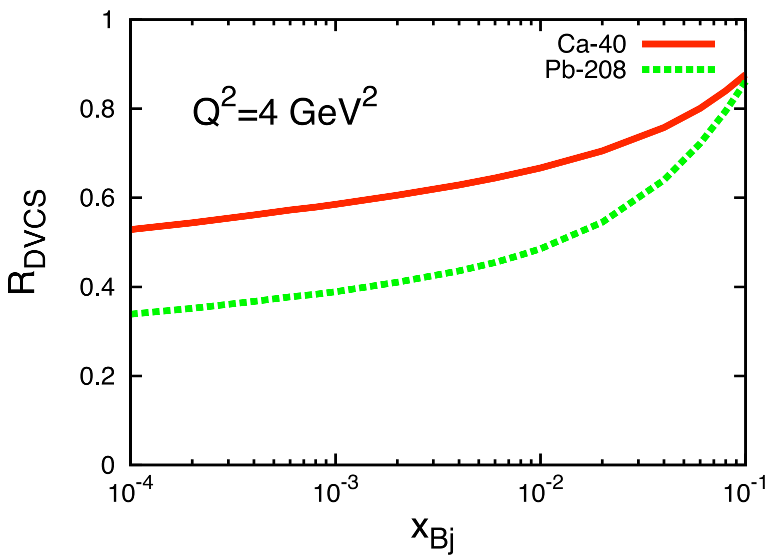
DVCS and with nuclei will address:

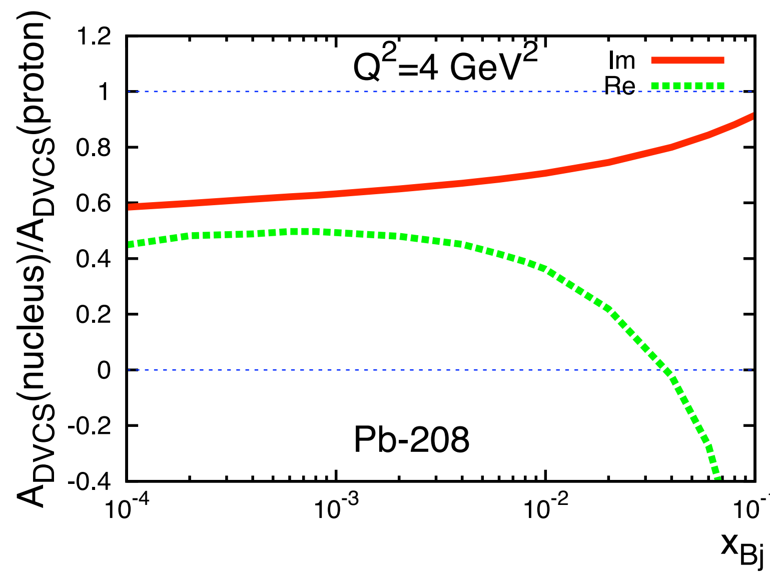
- Interaction of small-size $q\bar{q}$ dipoles with nuclear matter, related to the phenomenon of Color Transparency
- Sea quark and gluon 3D (transverse) imaging through the studies (extraction) of generalized parton distributions (GPDs)
- Approach to the regime of high parton densities (saturation)

Nuclear DVCS is more complex and versatile than DVCS on free proton

LT Approach Predictions for Coherent Nuclear DVCS

Use dual parameterization of nucleon GPDs with nuclear PDFs from LT





Ratio of t-integrated DVCS cross sections, Ratio of nucleus/proton DVCS amplitudes

$$R_{\mathrm{DVCS}} = \frac{\sigma_{\mathrm{DVCS}}}{\sigma_{\mathrm{DVCS}}(\text{no NS})} \propto \frac{\left[\sum_q e_q^2 H_A^q(\xi,\xi,Q^2)\right]^2}{\left[A\sum_q e_q^2 H_N^q(\xi,\xi,Q^2)\right]^2}$$

$$R = \frac{\mathcal{A}^A_{\mathrm{DVCS}}(t_{\min})}{\mathcal{A}^p_{\mathrm{DVCS}}(t_{\min})}$$

EIC will probe nuclear DVCS down to ≈ 5×10^{-4}

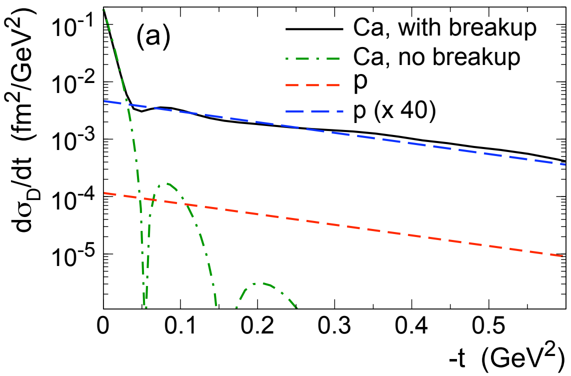
Diffractive Studies with RAPGAP

Matt Lamont

Can we measure diffractive e+A events?

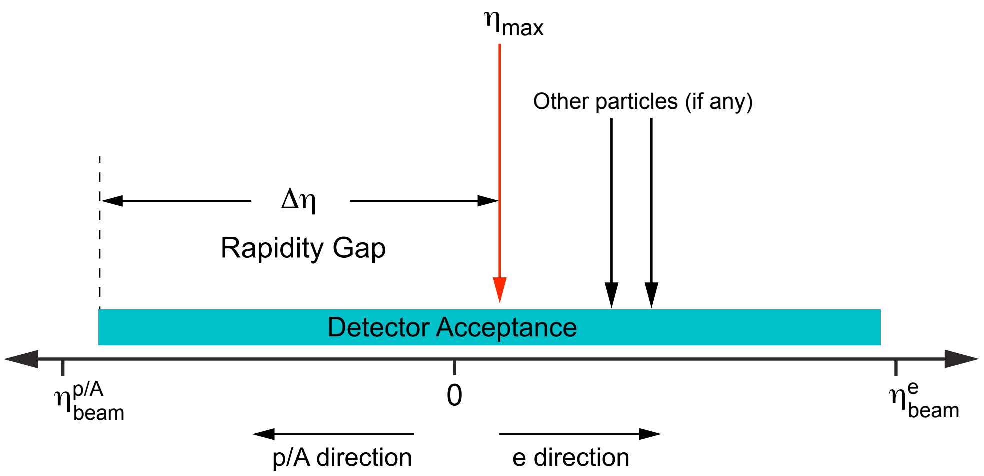
- Measuring the scattered A with Forward Spectrometer
  - coherent ⇒ cannot separate from beam
  - incoherent ⇒ cannot reconstruct all fragments to get **p**'
  - possibly for light ions
- Large Rapidity Gap Method (LRG)
  - identify diffractive events (tag)
  - use Roman Pots and ZDC to distinguish coherent from incoherent diffraction
  - exclusive production allows the reconstruction of *t*

Does LRG work at EIC energies?
What's the tagging efficiency
and the background/contamination
from DIS?

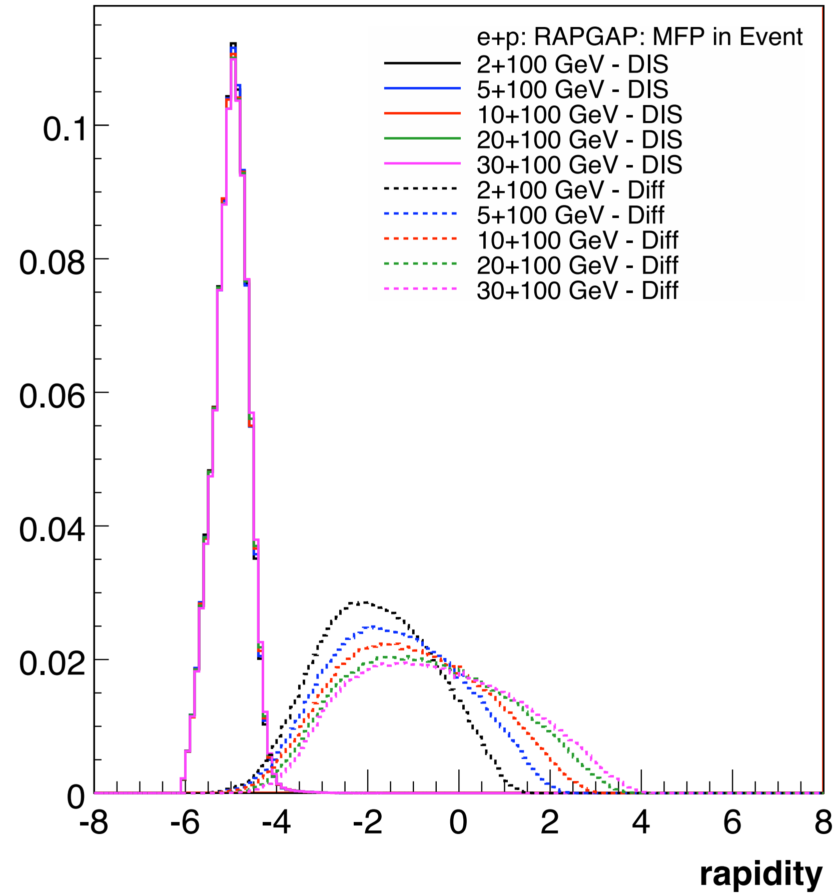


RAPGAP Studies

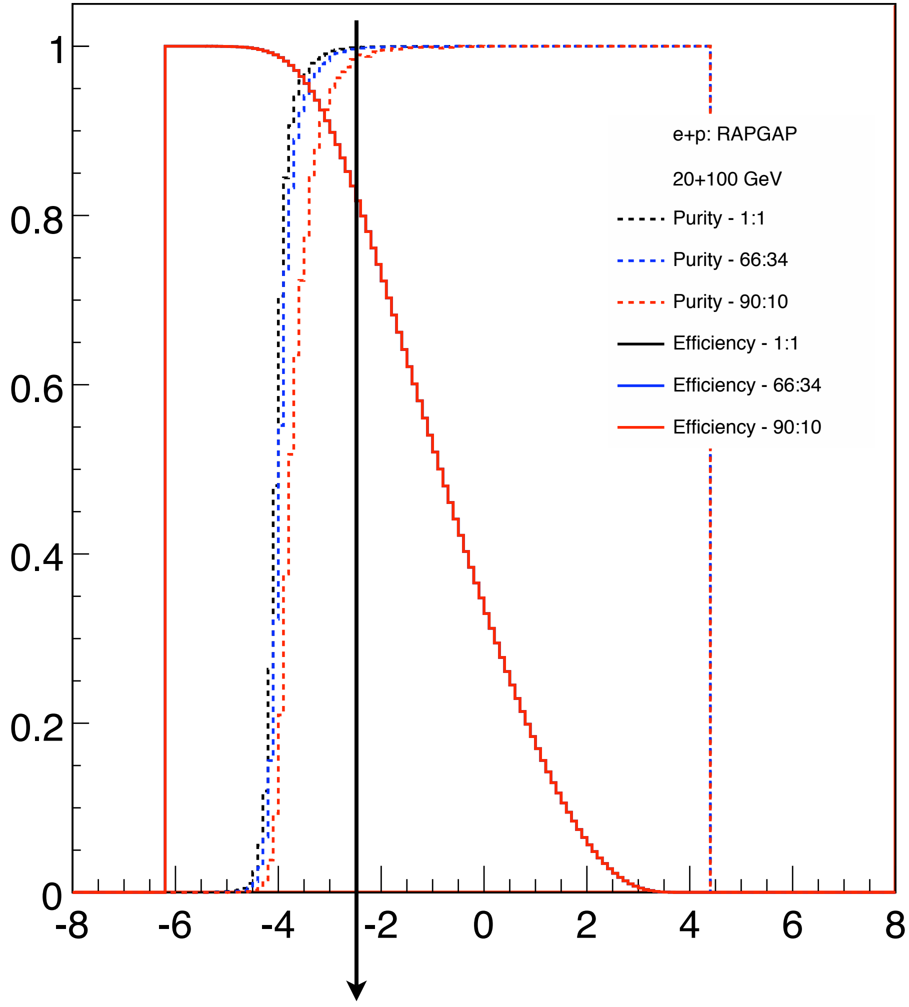
Study Most Forward Going Particle (MFP) using RAPGAP event generator (Kowalski/Jung)



- DIS: MFP distribution doesn't change with energy
- Diff: MFP distributions widen with energy & moves to larger η



Efficiency vs. Purity



Simulations for e+p only!

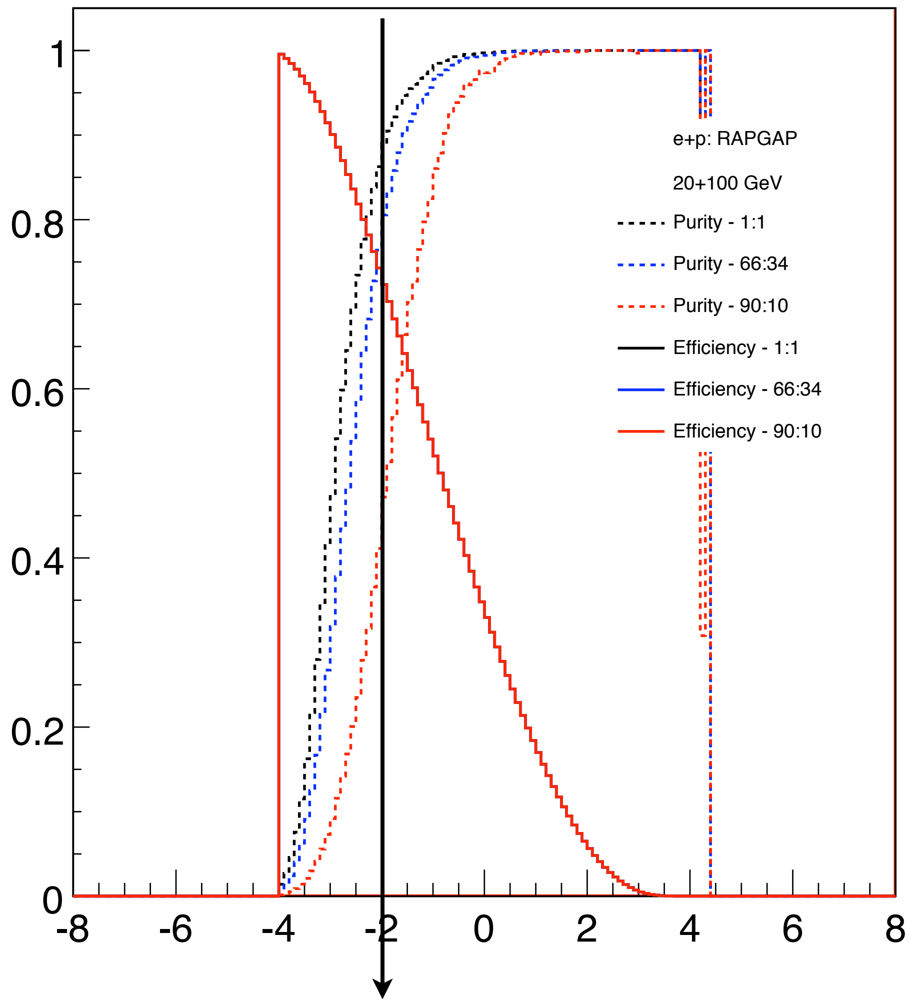
Purity depends on

- $\sigma_{diff}/\sigma_{DIS}$ (weak)

1% contamination, 80% efficiency

Efficiency vs. Purity

$\Delta\eta$ = 1.2 missing



50% contamination, 80% efficiency

Simulations for e+p only!

Purity depends on

- $\sigma_{diff}/\sigma_{DIS}$ (weak)
- detector hermeticity (strong)

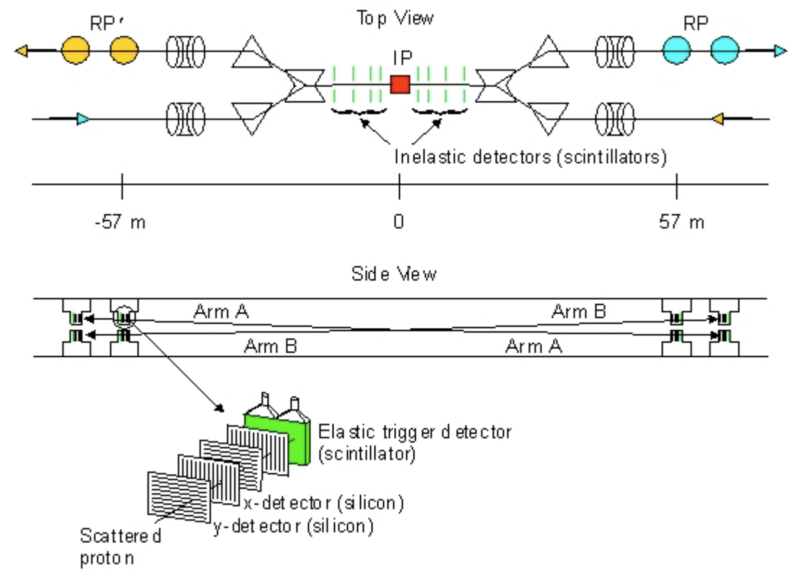
Stringent requirements on detector acceptance
Note: no PID or p measurement necessary

Measuring Diffraction at the EIC

Wlodek Guryn

Forward Spectrometry:

- Protons/Nuclei are scattered at very small scattering angle θ*, hence beam transport magnets determine trajectory scattered protons
- The optimal position for the detectors is where scattered protons are well separated from beam protons
- Need Roman Pot to measure scattered protons close to the beam without breaking accelerator vacuum



The beam angular divergence limits the smallest angle that can be measured:

$$\theta = \sqrt{\frac{\varepsilon}{6\pi\beta^*}}$$

Note: Large β* ⇒ lower L

Semi-Inclusive Processes in e+A Collisions

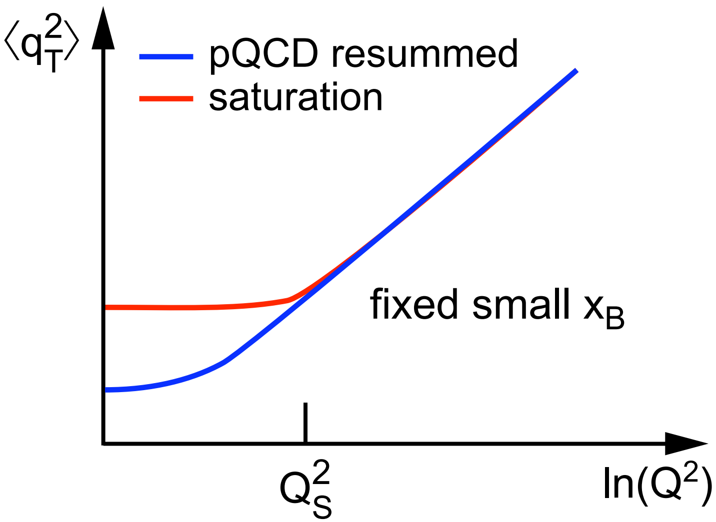
Jiangwei Qiu (see plenary talk)

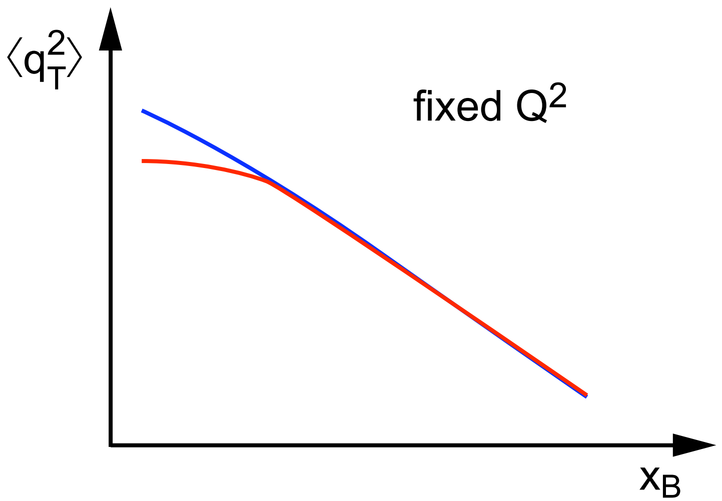
Probe saturation in e+A → e+h+X:

- pQCD resummation technique should be valid for calculating the q_T distribution if x_B is small ($S_{\gamma^*\text{-}A}$ large)

Mean transverse momentum square (Breit frame)

$$\langle q_T^2 \rangle \equiv \int dq_T^2\, q_T^2 \frac{d\sigma_{A\to h}}{dx_B\, dQ^2\, dz\, dq_T^2} \bigg/ \frac{d\sigma_{A\to h}}{dx_B\, dQ^2\, dz}$$





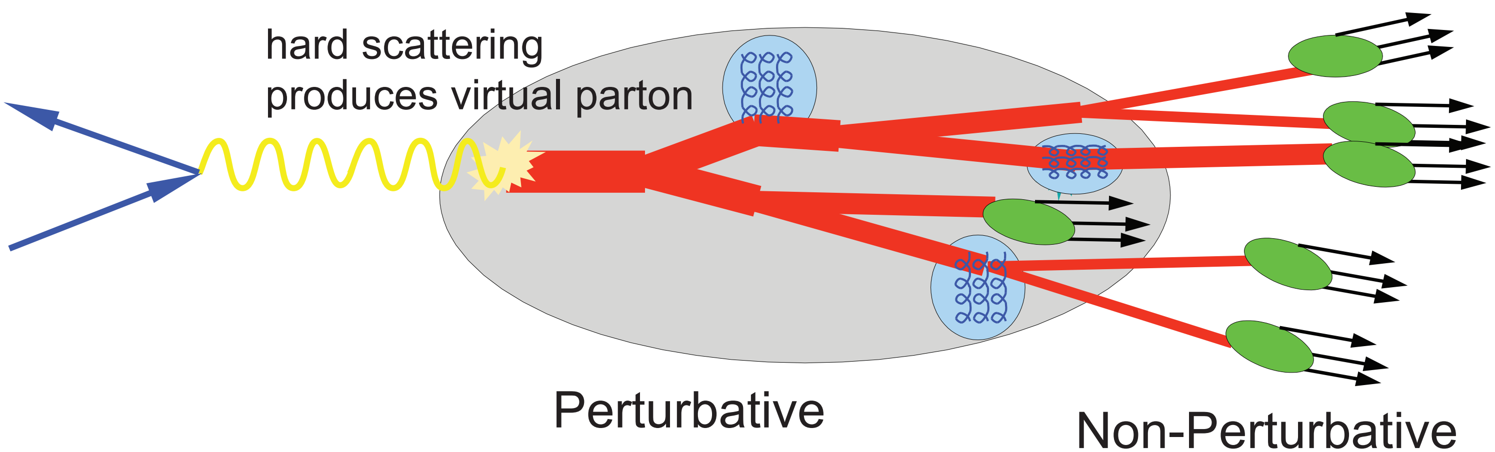
W/o saturation $<q_T^2>$ grows as $\log(1/x_B)$

Energy Loss and Fragmentation of Hard Jets

Abhijit Majumder

- How is jet structure modified by the presence of a dense medium?
- What can be learnt about the structure of the medium from studying jet modification?

Medium modifies the space time evolution of the Jet, and thus its final hadronization

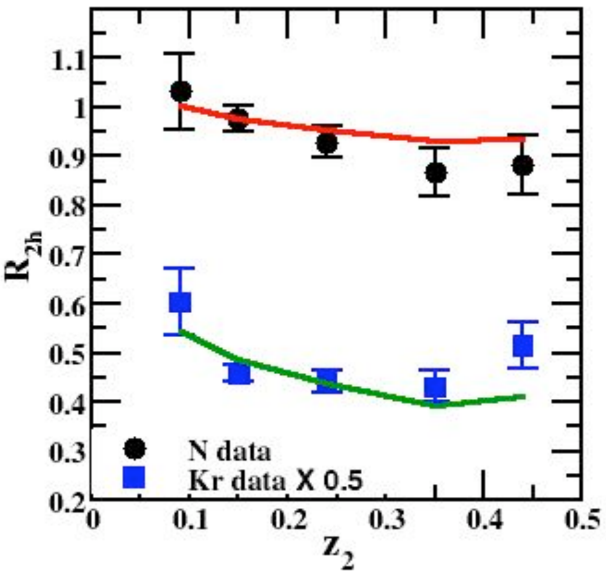


Comparison of Model with Hermes

Dihadron Correlations:

$$R_{2h} = \frac{\dfrac{\#\,\text{of events with at least 2 hadrons with } z_1 > 0.5}{\#\ \text{of events with at least one hadron with } z > 0.5}}{\text{same ratio on Deuterium}}$$

A. Majumder, E. Wang, X. N. Wang, PRL99, 152301 2007



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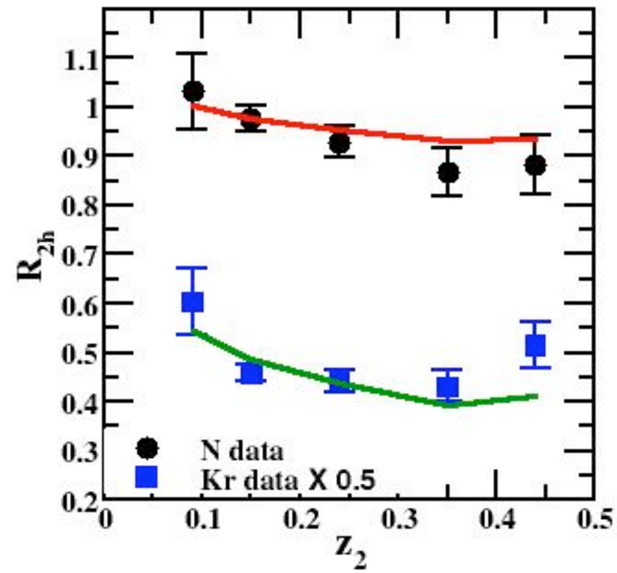

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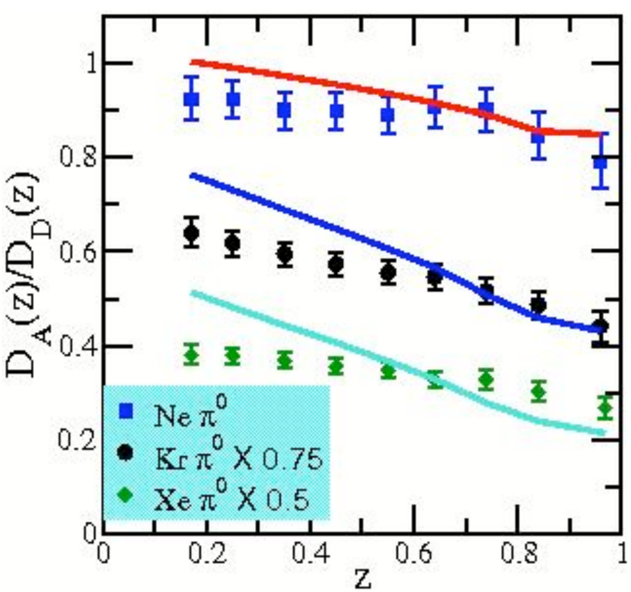
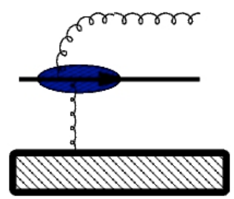
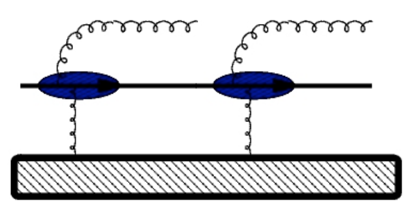
Multiple radiations through evolution:

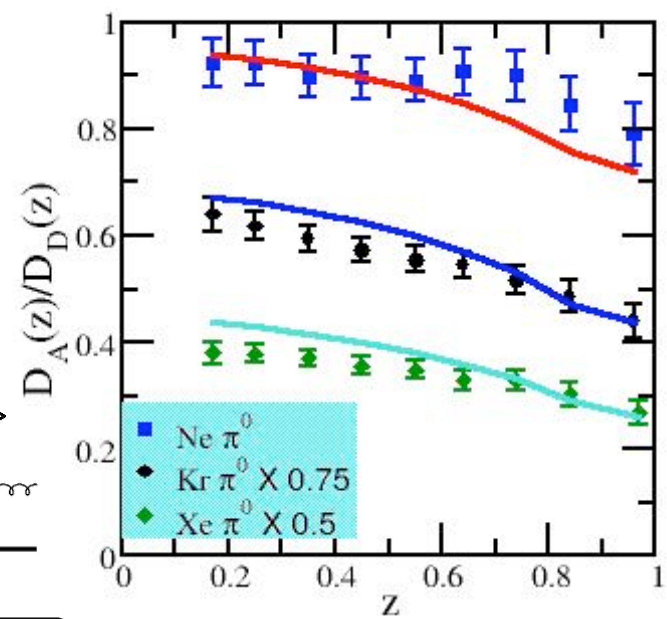




⇐ w/o resummation
1 medium induced emission

w resummation ⇒





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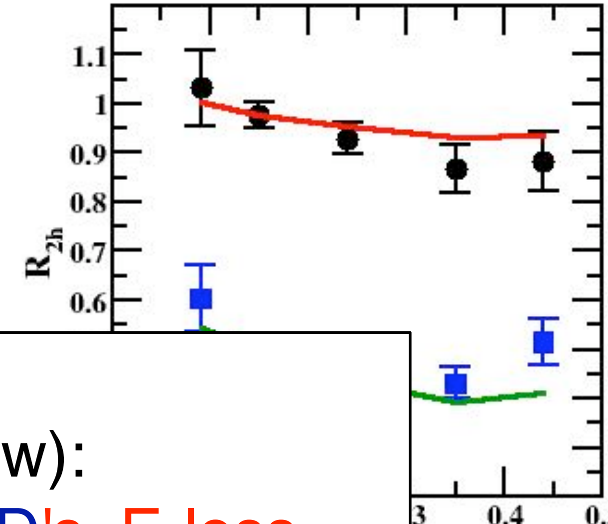
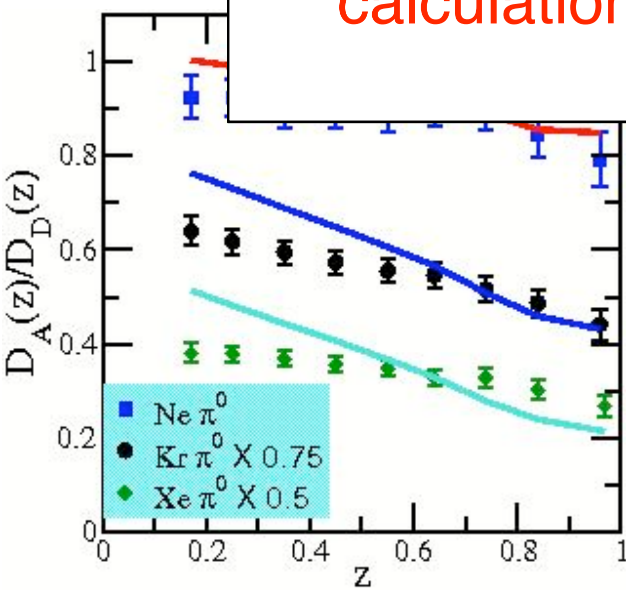


A. Majumde

Multiple

Interesting Statement (in my view):

Without a knowledge of the GPD's, E-loss calculations incomplete!



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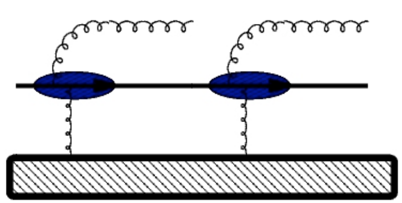
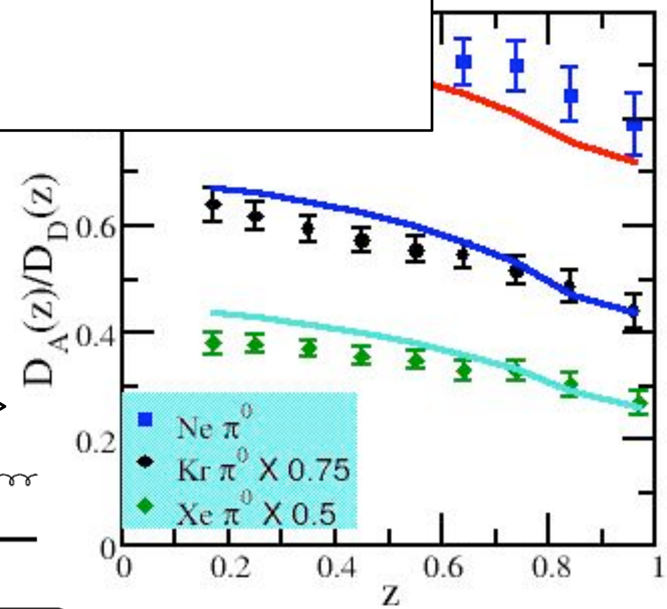




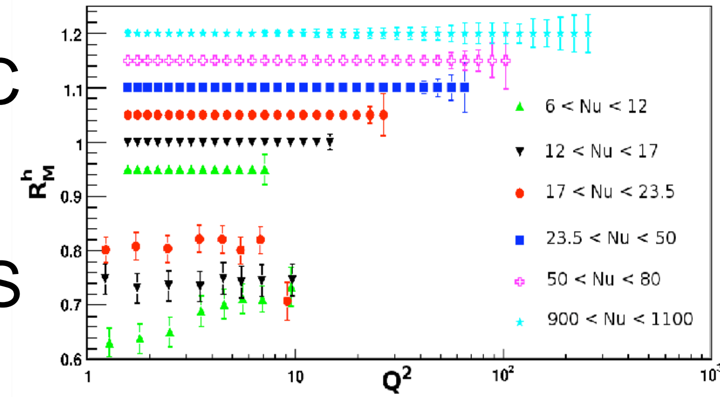
Parton Propagation and Fragmentation

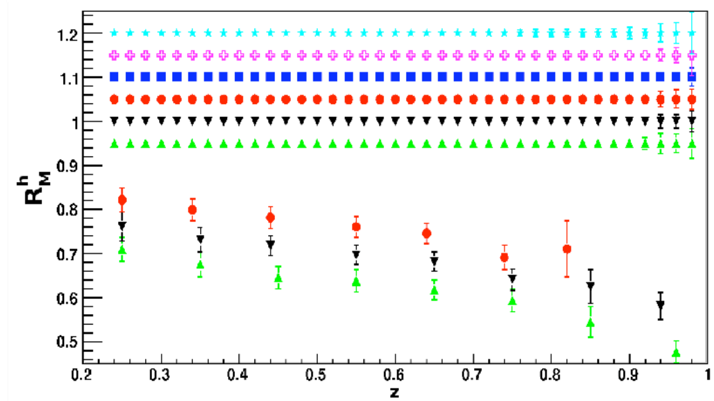
Alberto Accardi (couldn't come)

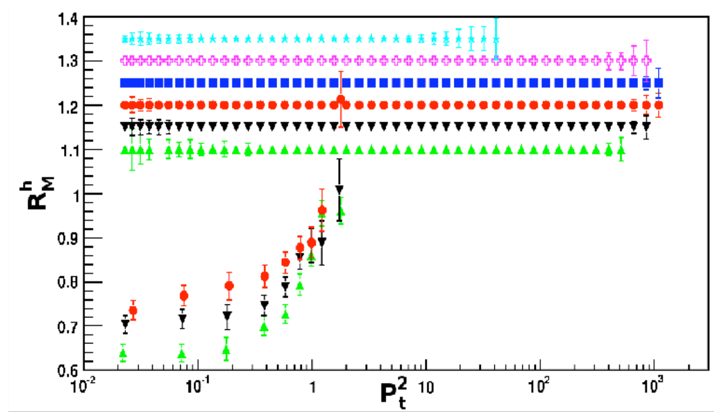
$$R_M^h(z) = \frac{\frac{1}{N_A^{DIS}} \frac{dN_A^h(z)}{dz}}{\frac{1}{N_D^{DIS}} \frac{dN_D^h(z)}{dz}}$$

EIC

HERMES





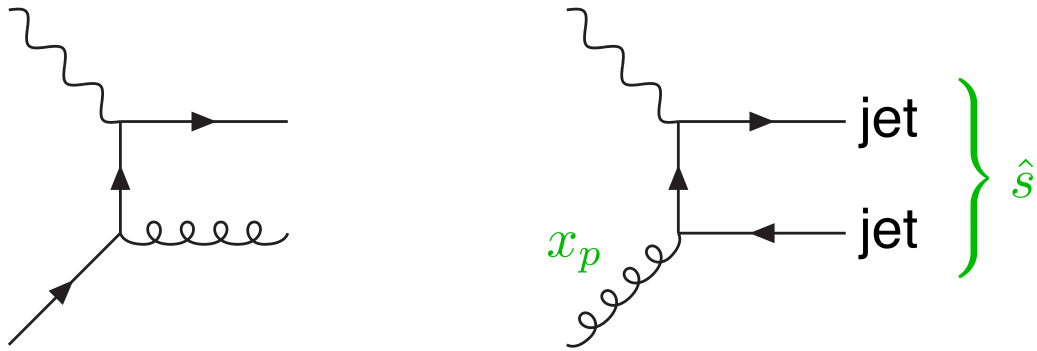


- Simulation with PYTHIA 6.4.19
  - isoscalar nucleus target
  - no nuclear effect yet
  - 10 weeks of beam at eRHIC
    - High statistics:
      - from 2 to 5-dim distributions
- Large reach in Q^2 and p_T
- small ν - hadronization inside A
- large ν - precision tests of QCD
  - parton energy loss
  - DGLAP evolution and showers

Gluon Distribution from Jet Analysis at EIC

Gregory Soyez, Raju Venugopalan

"2+1 jets" becomes more interesting



Main formula:

$$\frac{d^2\sigma^{2+1}}{dx_p dQ^2} = \alpha_s \left[a\, g(x_p, Q^2) + b\, q(x_p, Q^2)\right]$$

Technique:

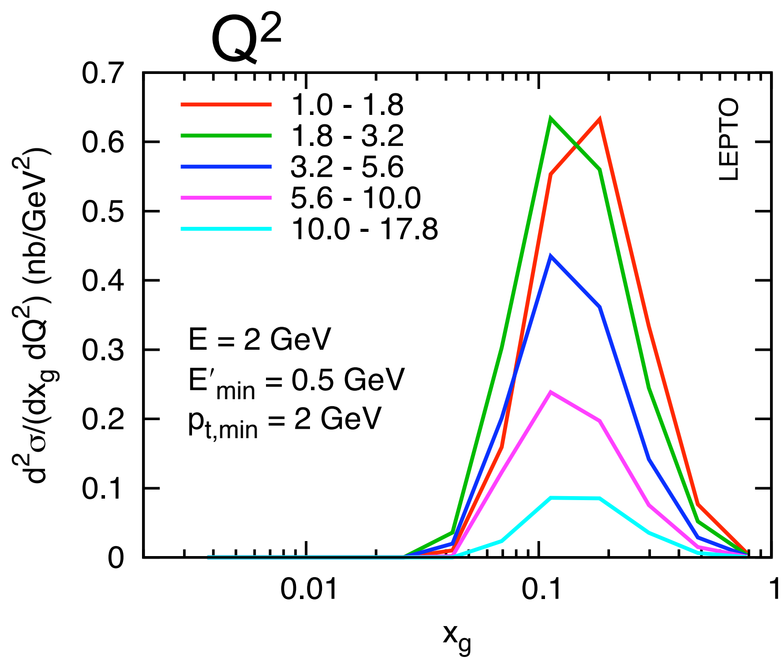
1. a and bq: matrix elements & quark piece from Monte Carlo
2. $x_p = x\left(1 + \frac{\hat{s}}{Q^2}\right)$
3. Extract the gluon distrib: $g_{\text{extr.}} = \frac{1}{a_{\text{MC}}}\left(\sigma_{\text{meas.}} - b_{\text{MC}} q\right)$

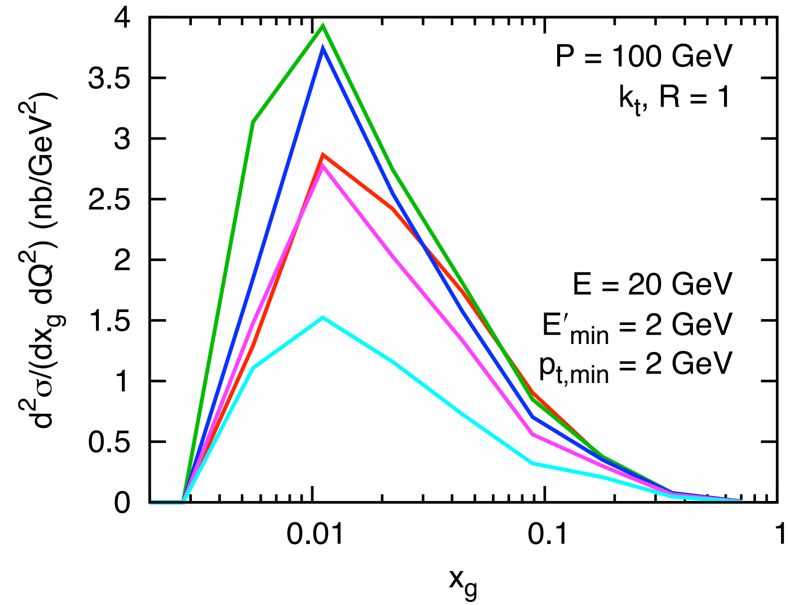
Cross-Sections

Experimental cuts:

- Outgoing electron energy: E'_{min}
- Minimal jet p_T : $p_{T,min}$
- Azimuthal separation between the 2 jets: $\Delta\phi > \pi - \varepsilon$ (in the Breit frame — ensures that the 2 jets come from the hard scattering)
- Clustering: k_T algorithm with R=1

Cross-section for gluon-initiated dijet events (obtained with LEPTO)





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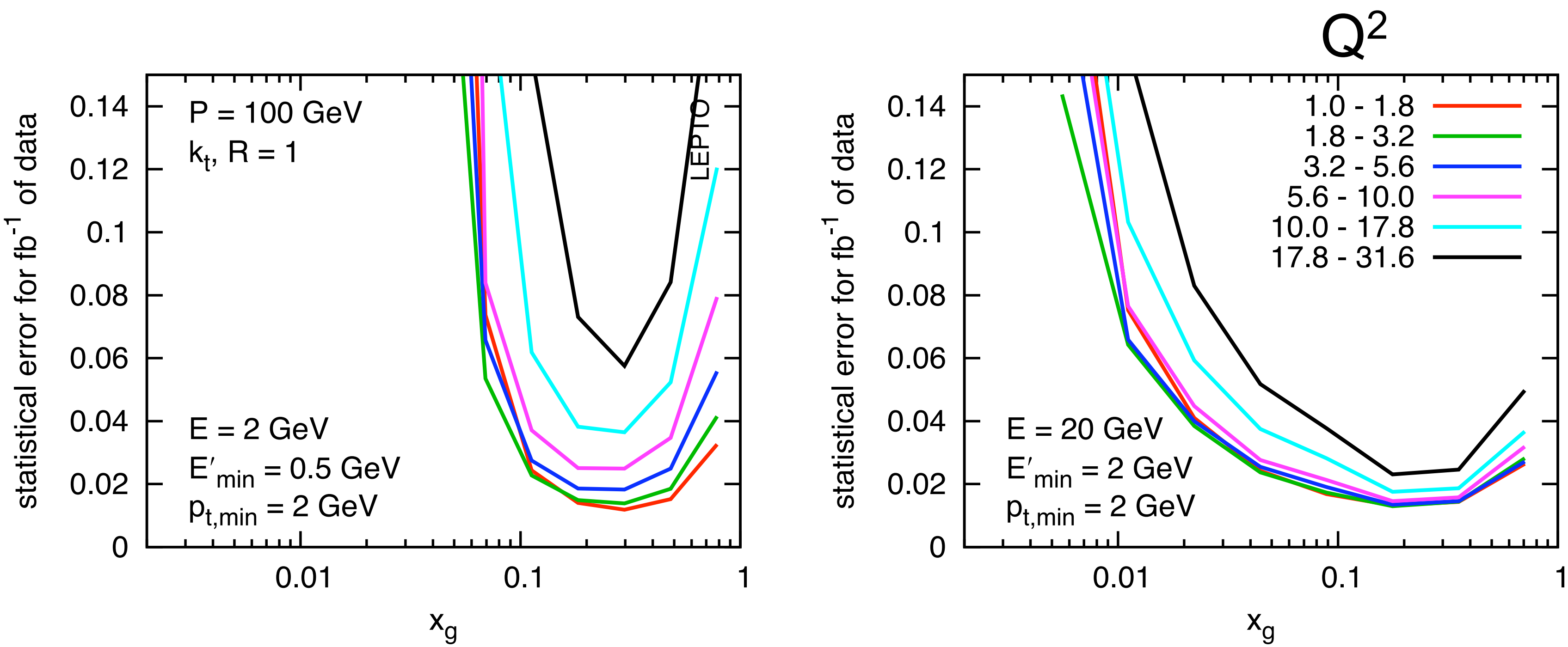
Stat. errors assuming 1 fb^{-1} of data:



Discussion of Physics Case for 2+100 GeV

- Do parts of "full" EIC program upfront:
  - F_L & F^D_L $\Rightarrow$ it's already part of the program need range of $\sqrt{s}$
- Rich E665 program - lots of shortcomings
  - E665 low statistics, large systematics
  - improved data will allow to rule out models (see J. Qiu's talk)
- Moderate to large x Physics
  - EMC-effect, anti-shadowing (relevant for RHIC &LHC)
- Diffraction
- Tomographic structure of nucleus
  - DVCS, diffractive J/psi - *t*-dependence
- Comparison with RHIC
  - medium-to-large *x* at EIC $\Leftrightarrow$ RHIC d+Au forward
  - E-loss in cold matter

eA WG: Meetings & Infrastructure

- Biweekly Phone Meetings (if enough to discuss)
  - Thursday 10:30 am
- EMail list
  - to subscribe http://lists.bnl.gov/mailman/listinfo/eic-bnl-l
- On the web
  - http://www.eic.bnl.gov/

- Repository (subversion)
  - http://rhig.physics.yale.edu/svn/eic
  - Position Paper and Notes
  - for login/passwd ask Matt or TU
- Workshops
  - Workshop on *Physics with EIC low energy option*, Oct 19-23, 2009, INT, Seattle
  - 3 month long INT workshop on *Physics with an EIC*, Fall 2010, INT, Seattle