Parton propagation and fragmentation – summary & outlook –

Alberto Accardi

Hampton U. & Jlab

Nuclear QCD @ EIC

Argonne, 7-9 April, 2010

Jefferson Lab

The 'ppf' working group

- Wiki:

  `https://eic.jlab.org/wiki/index.php/EA_Parton_propagation_and_fragmentation`

- Weekly phone meetings

- Please join us!

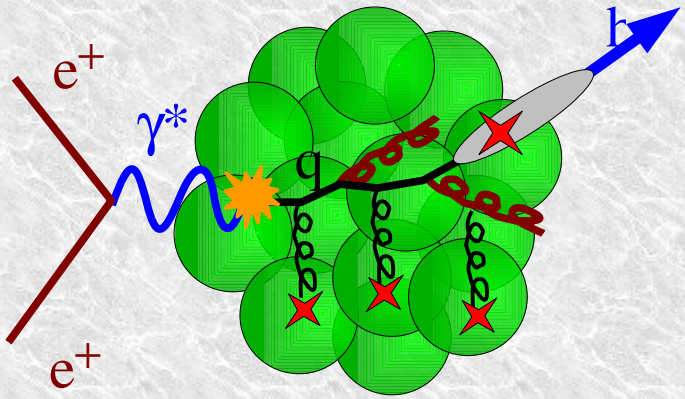
Review papers

- Accardi, Arleo, Brooks, d'Enterria, Muccifora,
  Riv.Nuovo Cim.032:439-553,2010 [arXiv:0907.3534]

- Majumder, van Leuween, arXiv:1002.2206

Physics motivations

- **Nuclei as space-time analyzers**
- **Non perturbative aspects of hadronization**
  - Color confinement dynamics: how do partons dress up?
  - What do gluons look like? [Majumder]
  - Test of fragmentation mechanisms [Bentz]
- **Parton propagation in perturbative QCD**
  - testing pQCD
  - DGLAP parton showers, jets
- **Connection to other fields**
  - Properties of QGP, ν-oscillations
  - TMDs in nucleons [Avakian]
  - gluon GPDs [Majumder]
- **Experimental data!!** [Di Nezza, Mineeva]



Physics motivations

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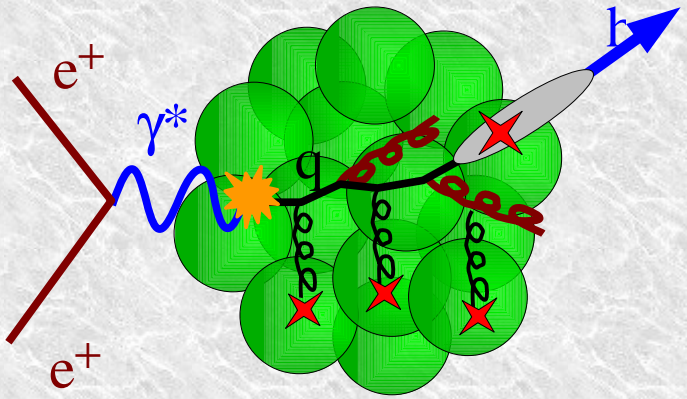
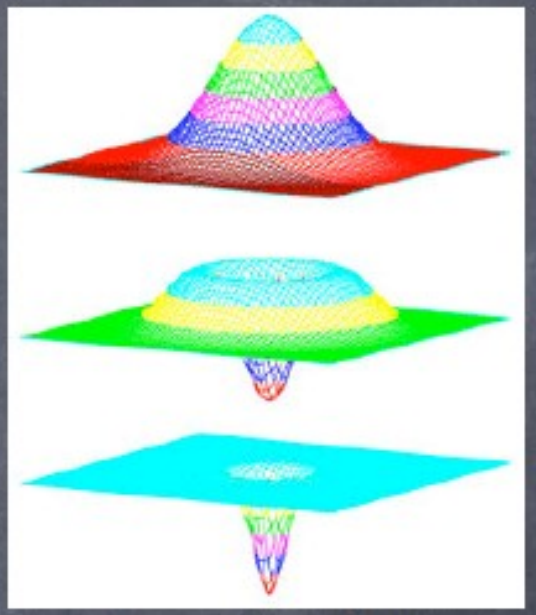


- **Experimental data!!** [Di Nezza, Mineeva]

How long for final data ??

THE QUESTION:

Electron scattering gives the charge density or quark density inside a nucleon



J. Arrington, G. Miller

What does the gluon density look like ?

How confined are low-x gluons (fluctuations)?

Are there other long range correlations in nuclei ?

How does this change with resolution ?

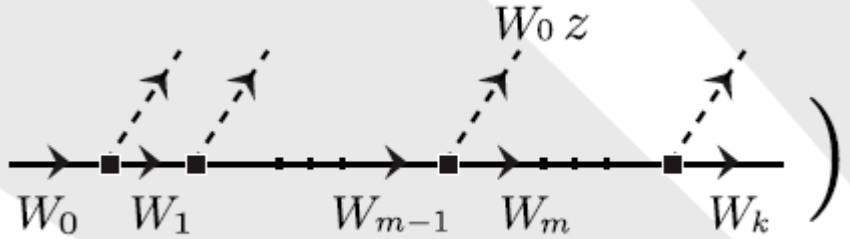
Need a colored probe !

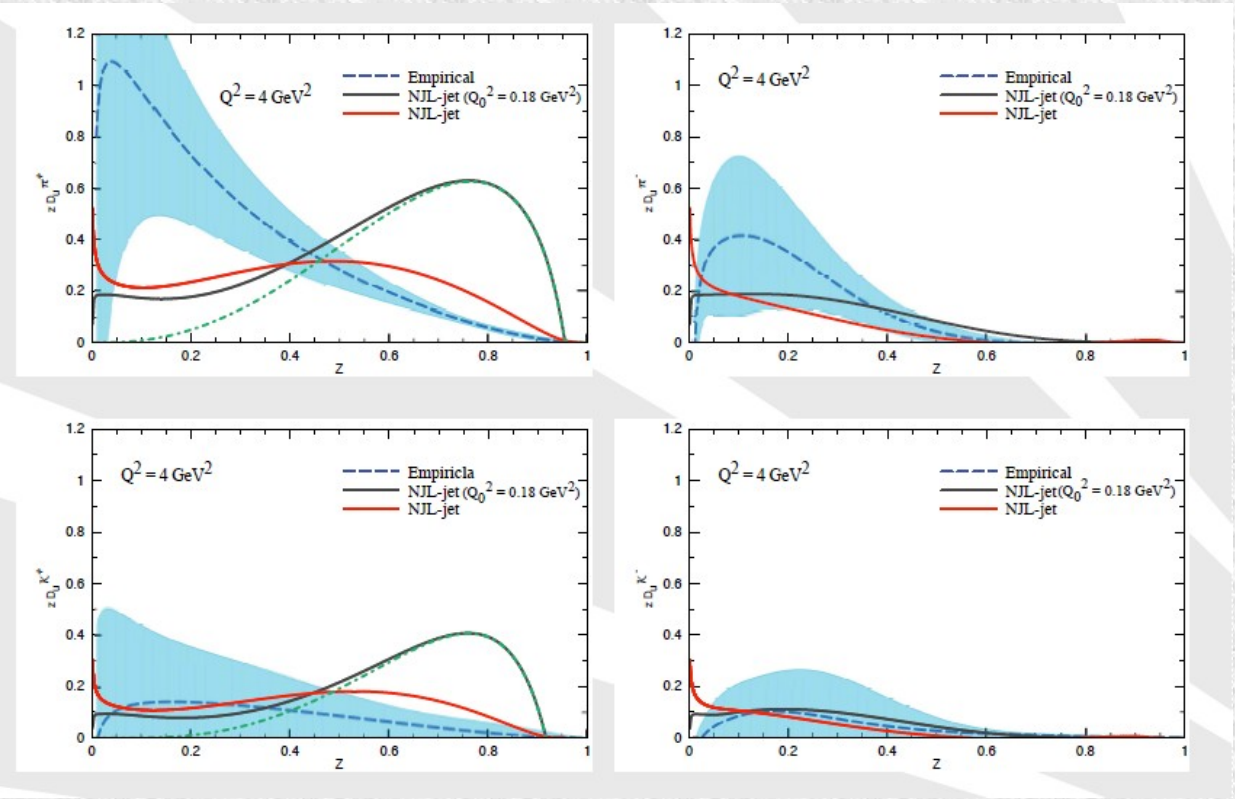
A.Majumder

Fragmentation in the NJL model

[Bentz]

$$D_q^{\pi}(z) = \sum_{k=1}^{N} P(k) \Big(\sum_{m=1}^{k} \cdots \Big)$$





- **How to test in nDIS ?**
- **medium modifications of the NJL vertex ?**
- **Formation length ?**

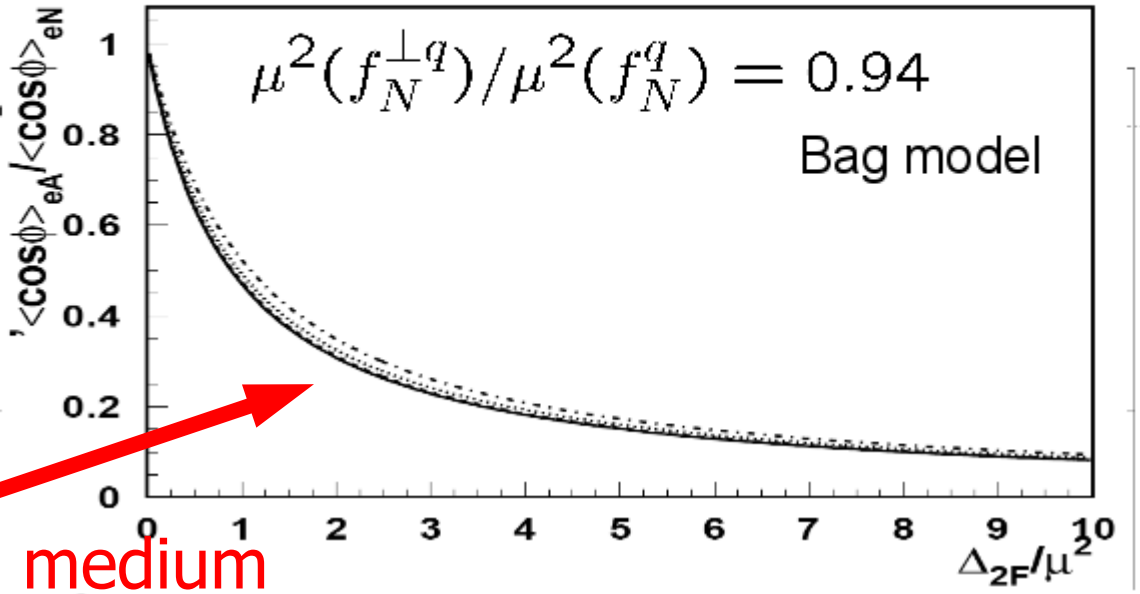
Modification of Cahn effect

$$< cos\phi >_{eN} \propto \frac{|\vec{k}_T| x f_N^{\perp q}(x, k_T)}{f_N^q(x, k_T)}$$

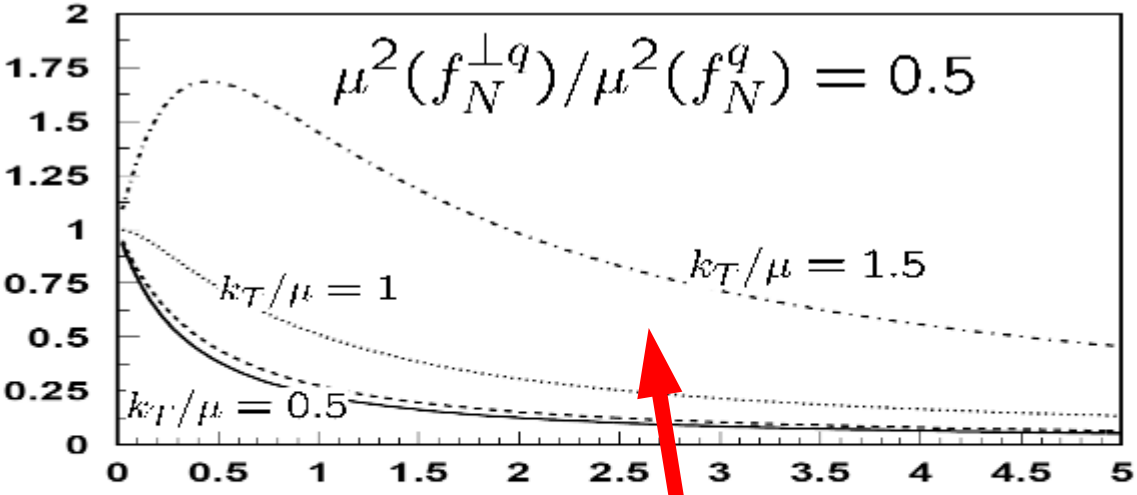
$$f_N^q(x, k_T) = \frac{1}{\pi \mu_2^2} f_N^q(x) e^{-k_T^2/\mu_2^2}$$

$$\frac{< \cos\phi >_{eA}}{< \cos\phi >_{eN}} = \frac{\mu_2^2}{\mu_2^2 + \Delta_{2F}}$$

~ qhat



Info on nuke medium



Gao, Liang & Wang
arXiv:1001.3146

- Nuclear modification of Cahn may provide info on k_T broadening and proton TMDs

Modification of Cahn effect

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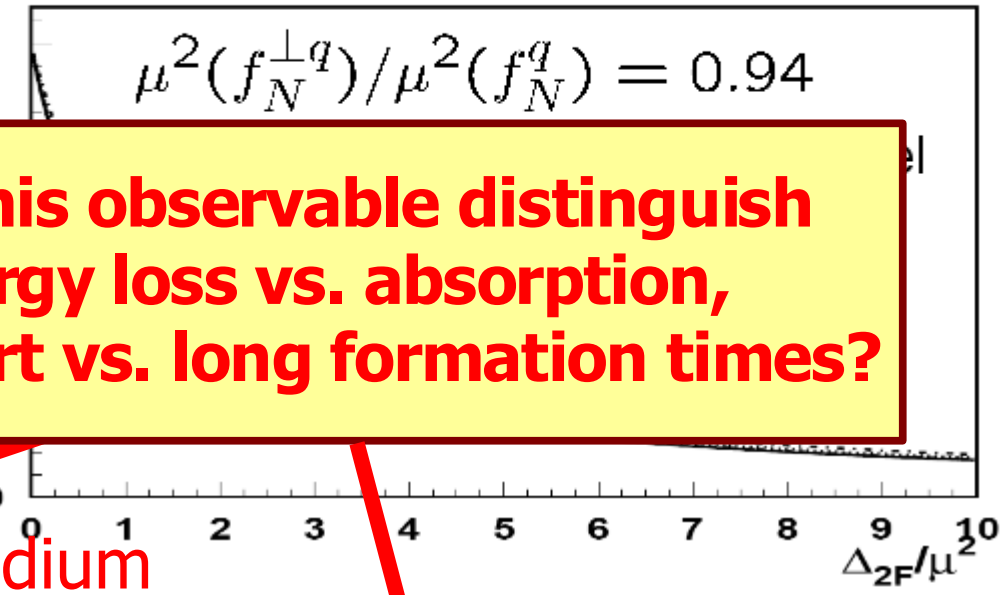

Can this observable distinguish energy loss vs. absorption, i.e., short vs. long formation times?

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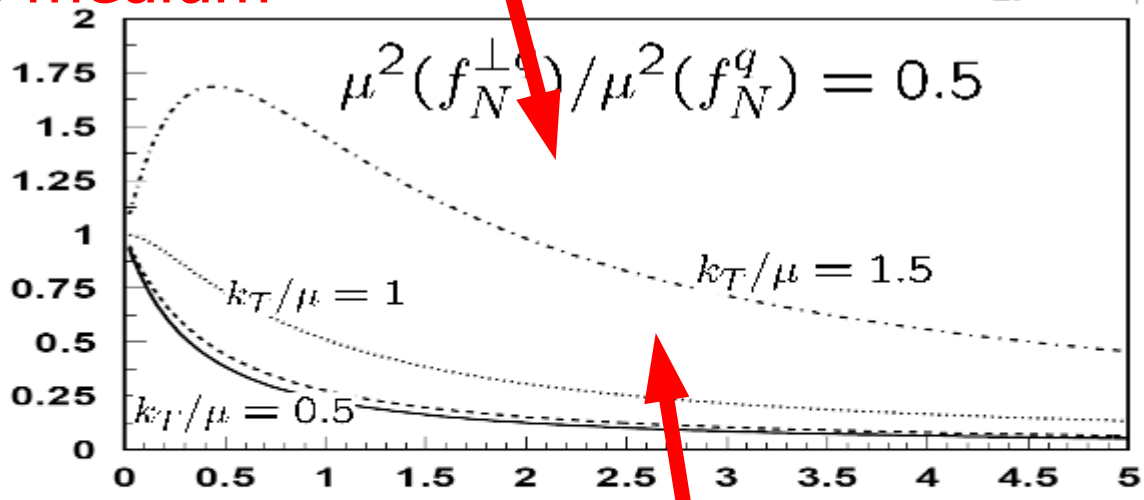

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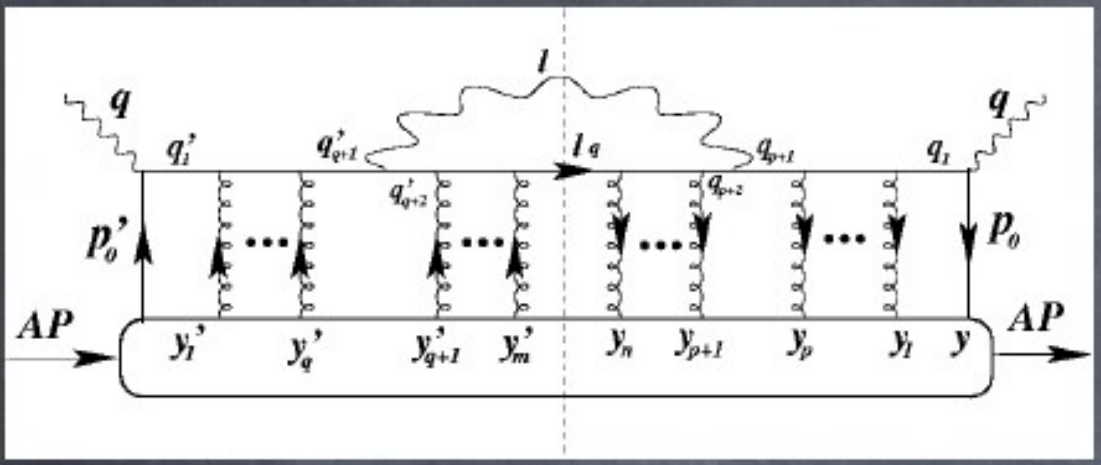
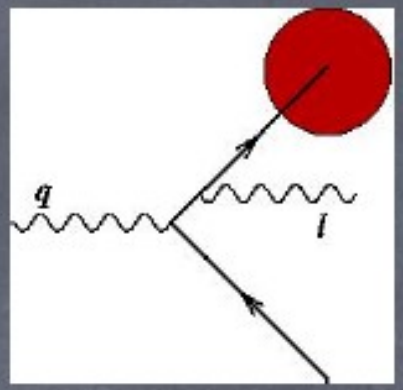
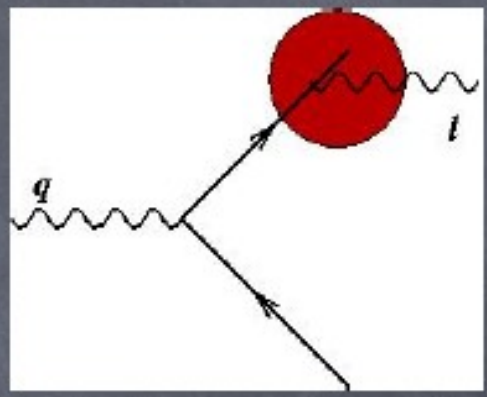
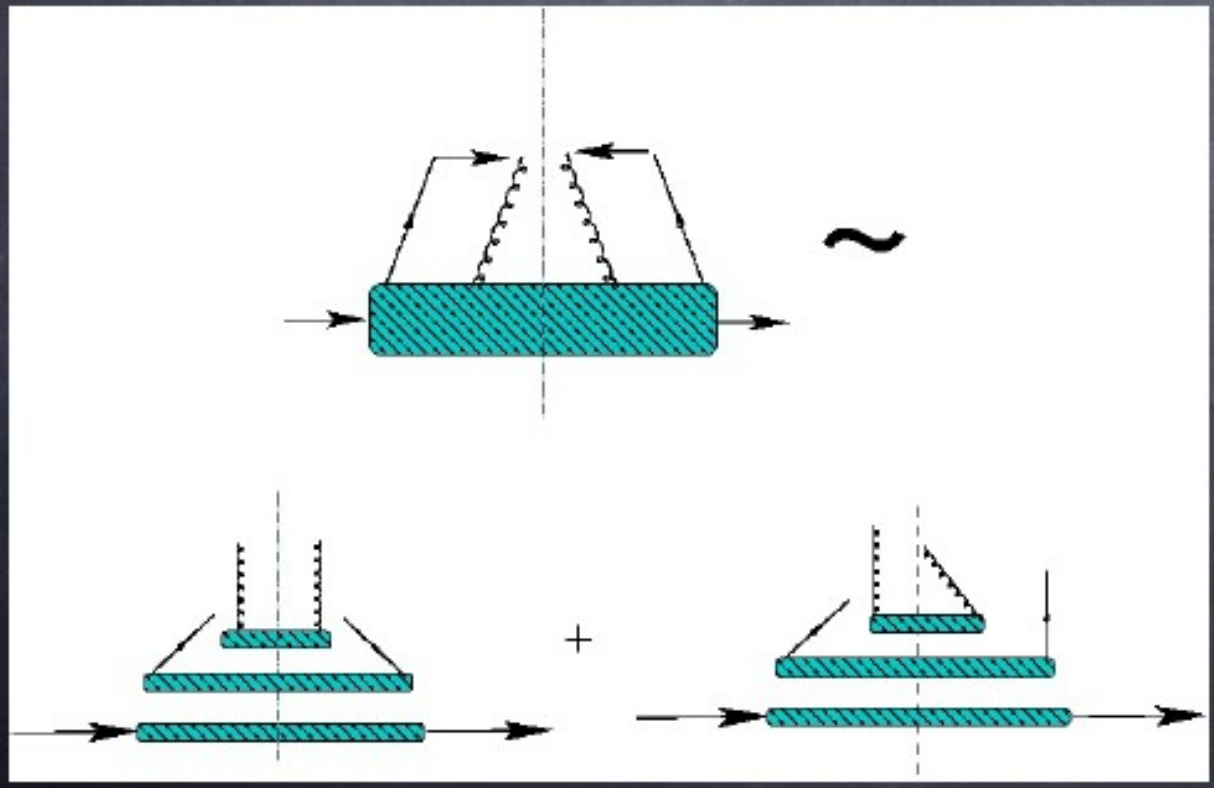
Relaxing the assumptions on the gluon correlation

consider photon Brem.









This is basically a gluon GPD

It does not yet involve color correlations over several nucleons

only momentum correlations

A.Majumder

Observables – priority list

For longer list: `https://eic.jlab.org/wiki/index.php/EA_propagation:_observables`

- **Light quarks**
  - π^0, η (energy loss vs prehadron absorption)
  - Attenuation at smallish ν
    - Benchmark on HERMES / JLAB data
    - check, improve EMC data
  - p_T-broadening:
    - vs. Q^2 – to understand HERMES data growing values
    - vs. z - for precision tests of theory models
    - as a measure of the saturation scale Q_s

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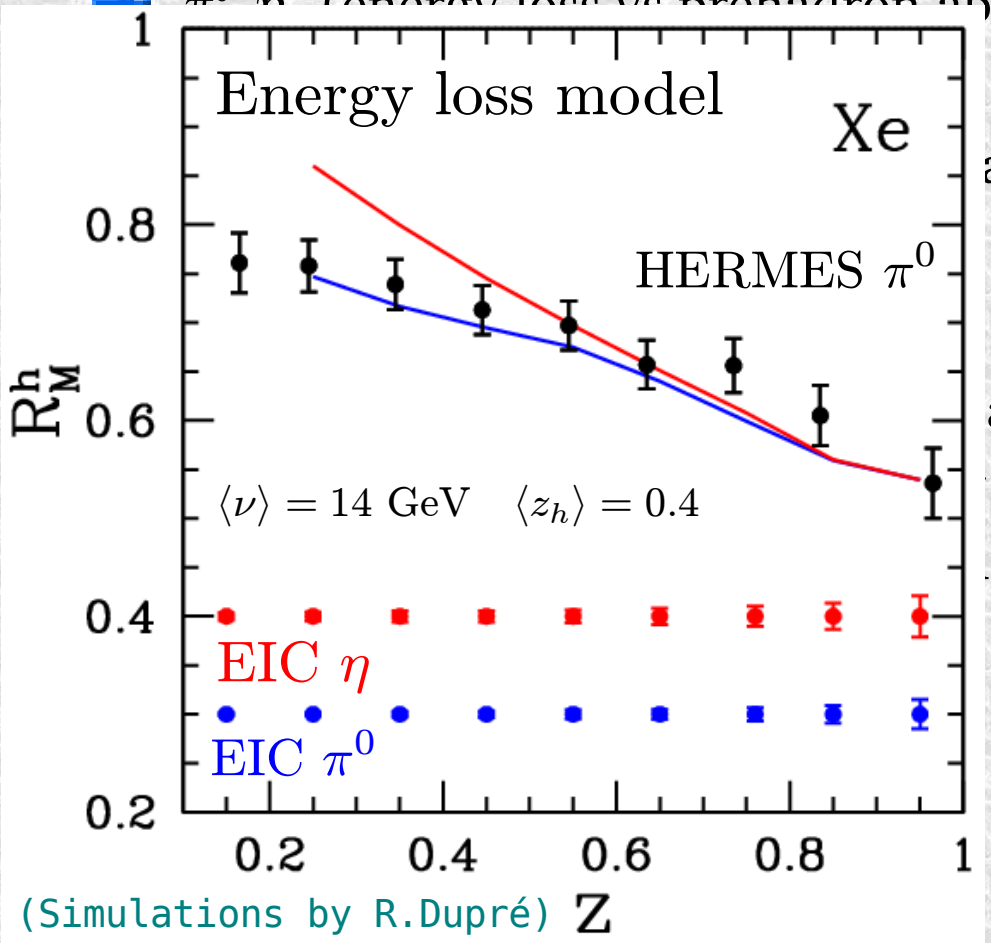
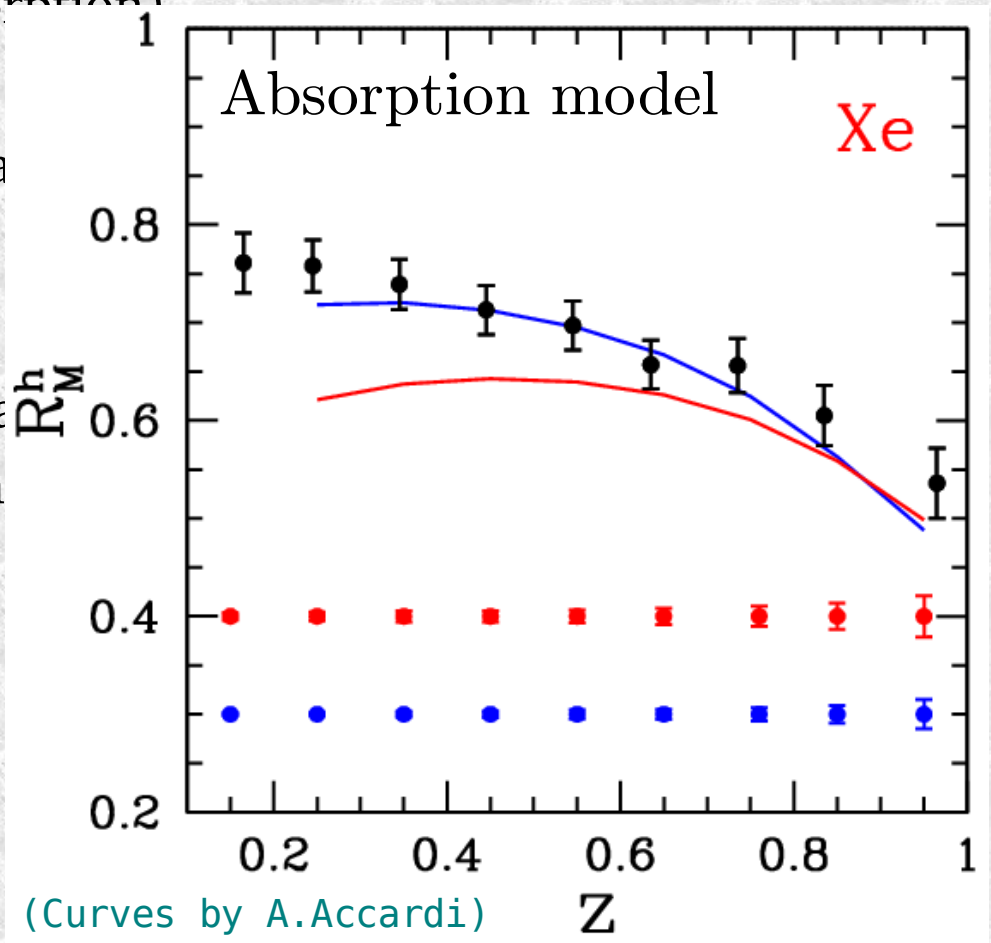


(Simulations by R.Dupré)



(Curves by A.Accardi)

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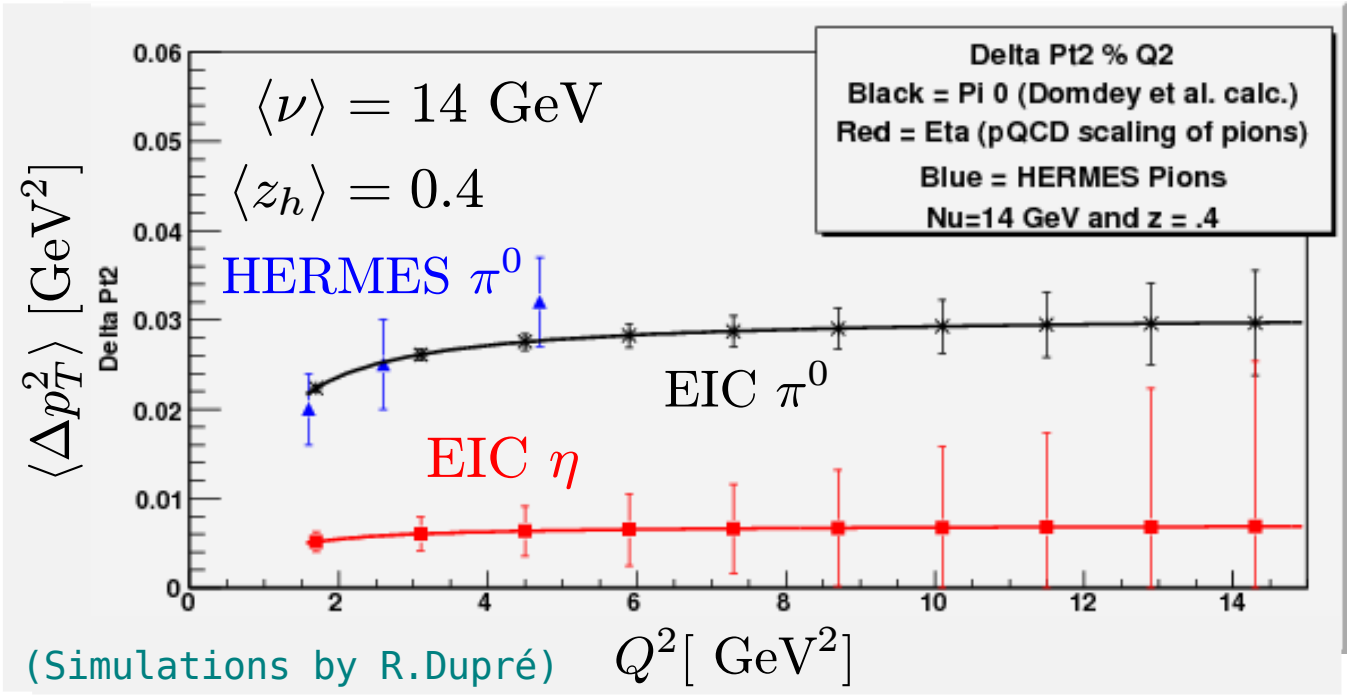

(Simulations by R.Dupré)

$$\Delta\langle p_T^2\rangle = \langle p_T^2\rangle_A - \langle p_T^2\rangle_D$$

medium-modified DGLAP (Domdey et al.)

pQCD scaling of pions

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- **Heavy Quarks**
  - heavy vs. light mesons in general
  - B vs D mesons (heavy flavor puzzle)
  - Attenuation, p_T-broadening

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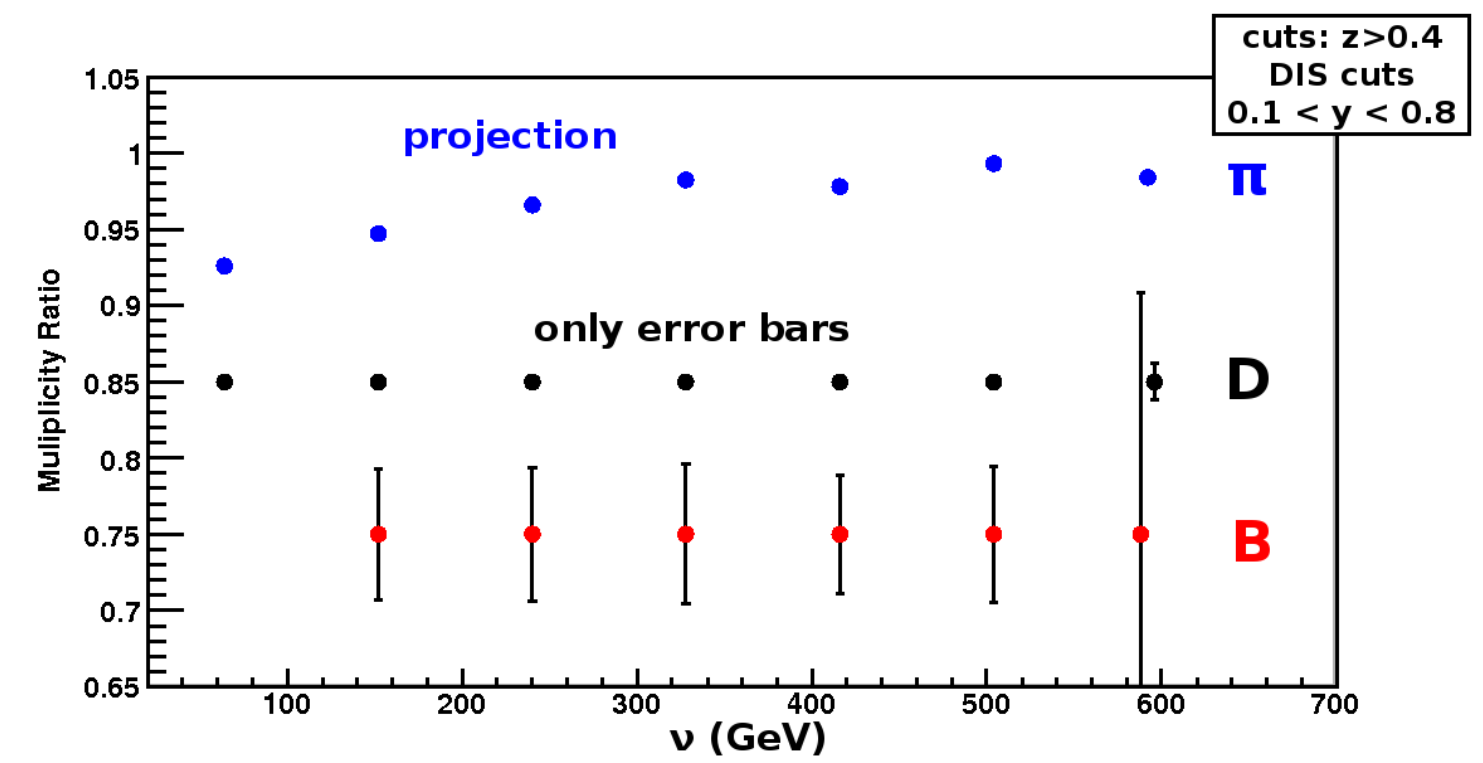

11+30 GeV/A Fe
$L = 0.4\ 10^{33}\ cm^{-2}\ s^{-1}$
1 month 100% running

[Dupré]

Observables – priority list

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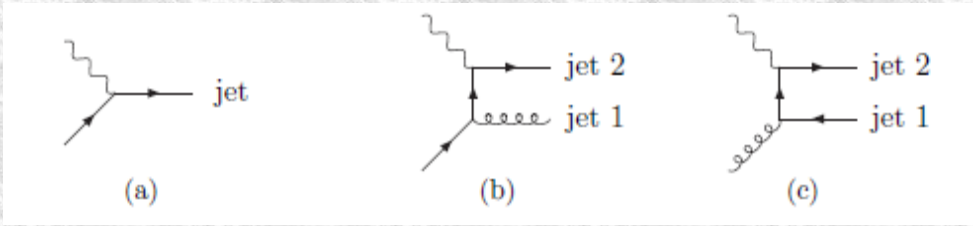
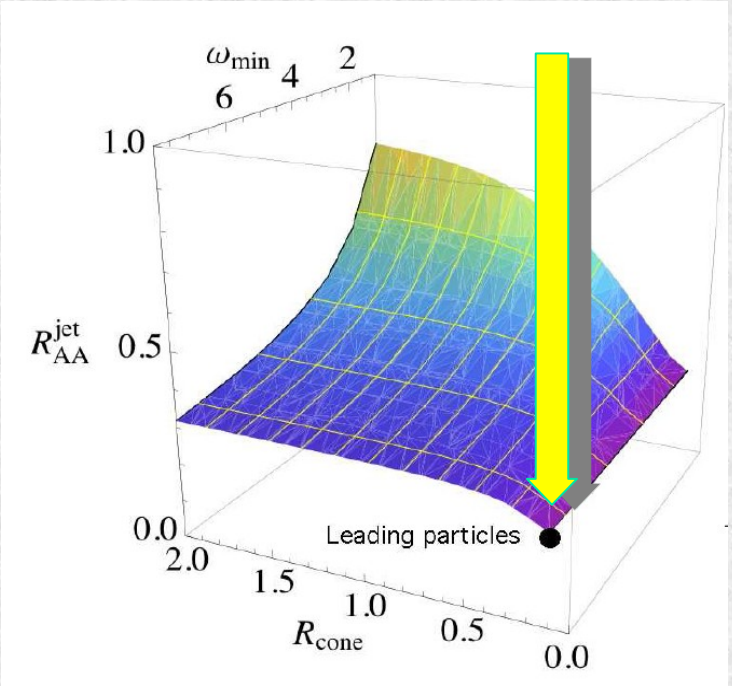
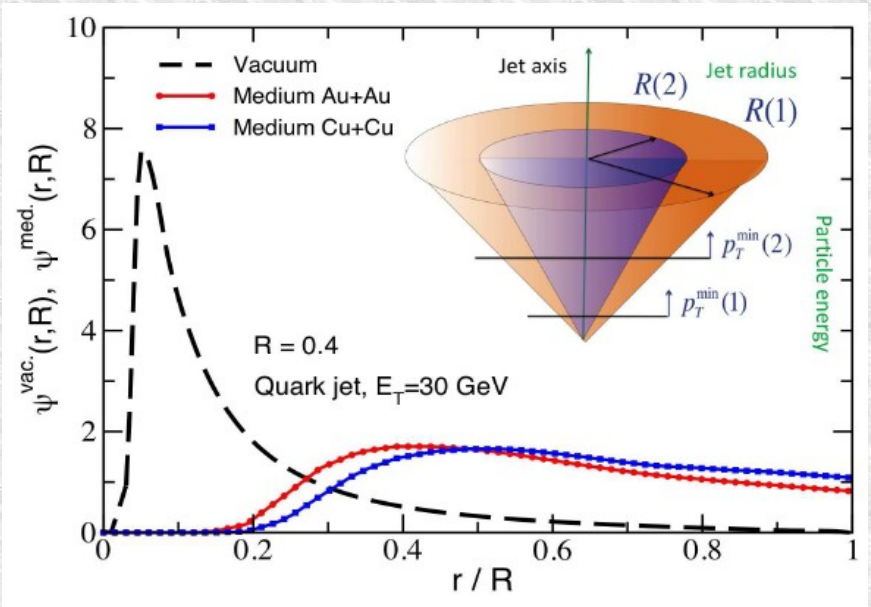
- **Light quarks**
- **Heavy Quarks**
- **Jets (1+1)**
  - rates vs. cone radius – gluon radiation will broaden jets
  - ... vs. p_T^{min}, E^{min} : more handles on energy loss [Vitev]
  - jet p_T-broadening – direct parton p_T-broadening







Observables – to be investigated

For longer list: `https://eic.jlab.org/wiki/index.php/EA_propagation:_observables`

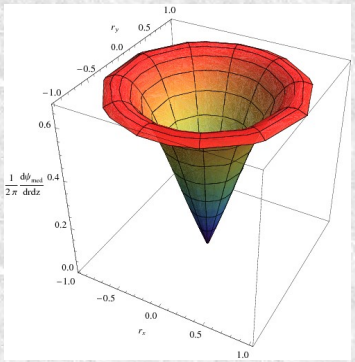
- **Photons**
  - induced γ absent in pure absorption mechanisms !!
  - calculable angular pattern relative to hadron
  - different from fragmentation γ
  - access to nuclear gluon GPDs

Majumder, Vitev(?)

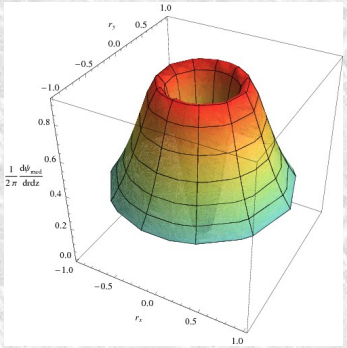
Timescales ??

Intensity scale

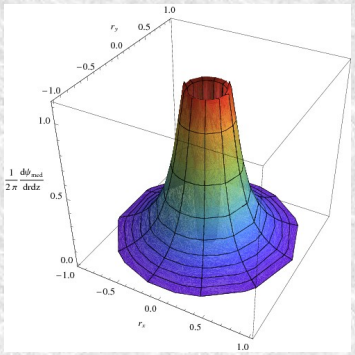
$\omega = 1$ GeV



$\omega = 3$ GeV



$\omega = 10$ GeV



IV, PLB (2005)

N.B. The calculation is for coherent FS gluon emission. Expect similar pattern for γ

Observables – to be investigated

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- **Photons**
  - induced γ absent in pure absorption mechanisms !!
  - calculable angular pattern relative to hadron — Majumder, Vitev(?)
  - different from fragmentation γ — Timescales ??
  - access to nuclear gluon GPDs

- **Neutrons in target fragmentation** — Strikman, Ciofi(?), J.C.Peng(?)
  - impact parameter measurement
  - correlation to leading hadrons — Timescales ??

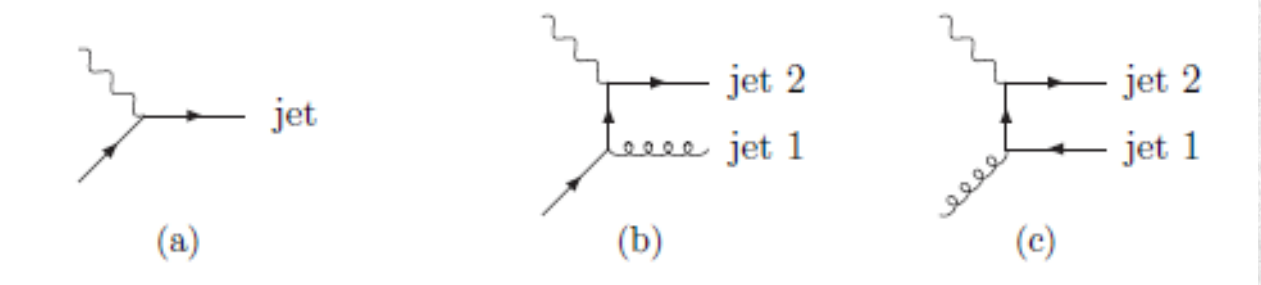
- **Nuclear modifications of spin asymmetries** — Avakian & TMD friends (?)
  - medium properties / time scales
  - properties of nucleon TMDs — Timescales ??

Observables – to be investigated

For longer list: `https://eic.jlab.org/wiki/index.php/EA_propagation:_observables`

- **2+1 jets: access to nuclear gluons**

Ploszkon (?)
BNL summer students (?)



known from inclusive DIS

$$\frac{\mathrm{d}^2\sigma_{2+1}}{\mathrm{d}x_p\,\mathrm{d}Q^2} = A_q(x_p,Q^2)\,q(x_p,Q^2) + A_g(x_p,Q^2)\,g(x_p,Q^2),$$

calculable in pQCD

Observables – to be investigated

For

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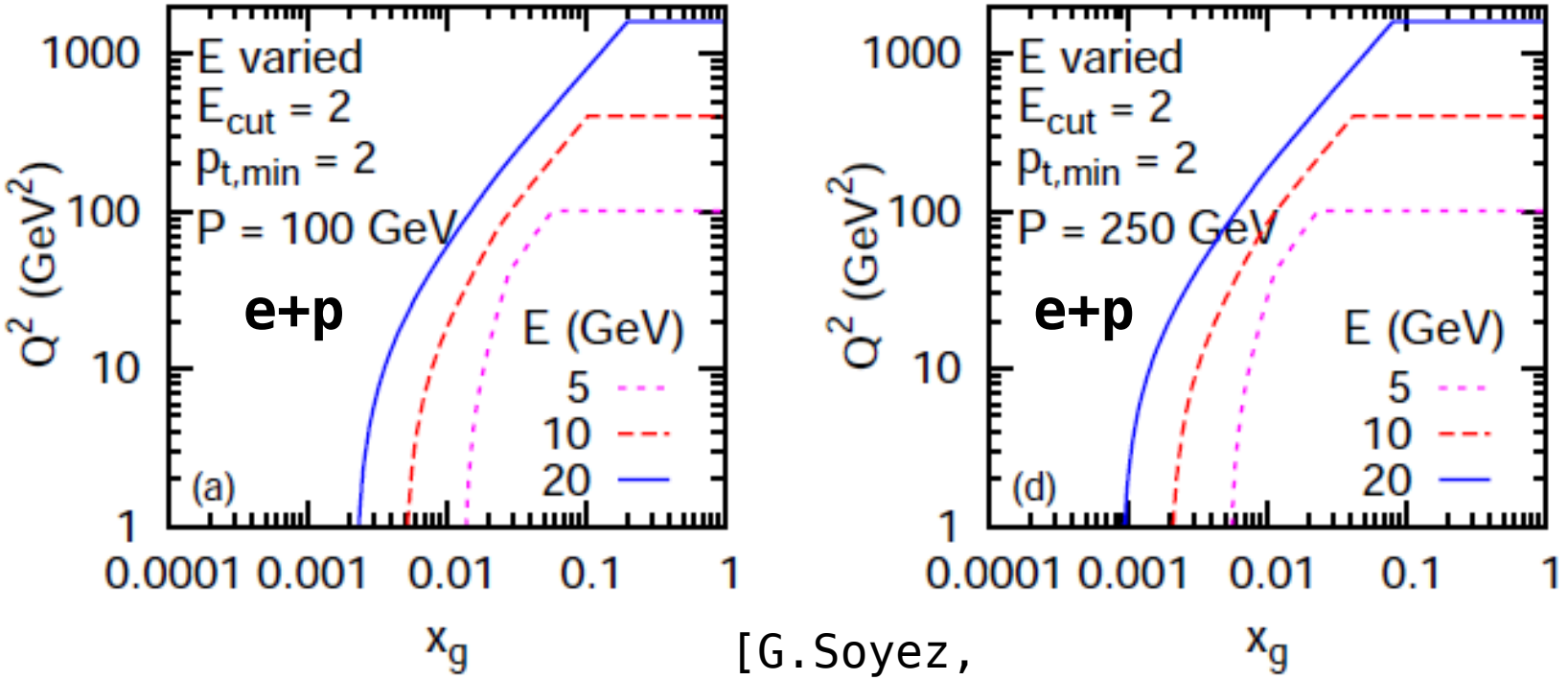

[G.Soyez, unpublished (ask M.Lamont)]

A final note concerns the medium effects in e+A collisions. Since the outgoing jets have to travel in the medium, the coefficients A_a and A_g will be affected by in-medium propagation. We shall assume here that the measurements of 1+1-jet cross-sections allow to control how jets propagate in the medium and hence to know the corrections to A_q and A_g. This is not completely trivial as 1+1-jet events will be highly dominated by quark-initiated jets, while in the 2+1-jet case, we can have both quarks and gluons. As a consequence, the medium effects on A_q and A_g will probably introduce an additional systematic error coming from the uncertainty on the gluon-jet propagation[3].

Agenda

- **Estimate statistical errors**
- **Angles, momentum plots**
  - help for detector design

Now: no detectors, just cut out the beam
fold in branching ratios only, if needed

Future: geometric acceptance, fast MC
real particle reconstruction

- **Simulations with physics effects:**
  - En.loss vs. absorption – potential for separation
  - pure en.loss regime at large nu:
    - signatures,
    - tests of en. loss
    - differences between models
  - ...

Monte Carlo priorities

- **Finish PyQM implementation** Dupré
  - enables to study Lund fragmentation vs. FF
- **Cold nuclear geometry in Q-Pythia** **Volunteers needed!!**
  - jets
  - modifed DGLAP
- **Q-Pythia development**
  - HT energy loss Majumder – at least 6 months
  - integration with PQM, PyQM
    - * Lund fragmentation vs. FF
    - * **SW vs GLV**

Daniel + Loizides

Monte Carlo questions

- **Is p_T-broadening corectly implemented in our MCs ??**
  - PyQM: known issues, need help for solutions [Dupré]
  - Q-Pythia ??
  - GiBUU: no direct pT-broadening, “nuclear filtering” effect [Gallmeister]

- **Do we need en.loss & absorption in the same MC?**

  - as separate options, sharing the rest of the simulation
  - merging them together ?? If so, how ??

  - Embed GiBUU absorption routines in Q-Pythia ?
  - Embed (some) energy loss option in GiBUU ?

Towards the white papers

- **"ppf" WG note**
  - general intro, EIC carachteristics / pecularities [done]
  - list of hadrons, production rates, channels [done*]
  - quick list of open questions, interesting observables [from this w.shop]

- **June7-9:** Jlab users group meeting
  - Use "ppf" note as draft
  - add list of observables under study, or planned

- **Summer:** Jlab white paper
  - add results for observables, plots, simulations, new ideas
    [results can be preliminary]
  - serious effort, will need real commitment from everybody
    [read: you need to contribute some writing – group effort]

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All speakers, WG members & friends!

Send me in writing your ideas:

– a brief summary of your talk (speakers)
– your ideas for observables
– anything to be included in these documents

DEADLINE: MAY 20th

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- **End of Sep:** INT program on nuclear matter – **November:** EIC workshop @ INT
  - present nice nearly-final results

- **Winter:** INT white paper on "The science cas for an EIC"
  - Detailed presentation of propagation and hadronization program @ EIC

INT program "gluons and quarks at high-E"

week	dates	topics
1	13–17 Sept	**Workshop** on "Perturbative and Non-Perturbative Aspects of QCD at Collider Energies"
2	20–24 Sept	open conceptual issues: factorization and universality, spin and flavor structure, distributions and correlations
3–5	27 Sept –15 Oct	small x, saturation, diffraction, nuclear effects; connections to p+A and A+A physics; fragmentation/hadronization in vacuum and in medium
6–7	18–29 Oct	parton densities (unpolarized and polarized), fragmentation functions, electroweak physics
8–9	1–12 Nov	longitudinal and transverse nucleon structure; spin and orbital effects (GPDs, TMDs, and all that)
10	15–19 Nov	**Workshop** on "The Science Case for an EIC"

http://www.int.washington.edu/PROGRAMS/10-3/

The EIC parton energy loss and hadronization program

	EIC	fixed target
★ Precision tests of pQCD energy loss, DGLAP showers	√	
★ Jet event shape modifications, time evolution	√	
★ Space-time picture of parton fragmentation (perturbative regime)	√	≈
★ Hadronization from current to target region	√	≈

Not energy nor luminosity hungry (except B mesons, rare had's, 5D ?)

but **needs good PID, vertex detector**