eA collisions within GiBUU

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Model
Pythia, GiBUU, prehadronic FSI

Results
EMC@100-280
Hermes@27
CLAS@5
EIC
Observables, Experiments

\[ R^h(z_h, \ldots) = \frac{N_h(z_h, \ldots)}{N_e(\ldots)} \bigg|_A \]

\[ \Delta p_T^2 = \langle p_T^2 \rangle_A - \langle p_T^2 \rangle_D \]

- hadronic: \( z_h = \frac{E_h}{\nu}, \ p_T, \ldots \)
- photonic: \( \nu, Q^2, W, x_B, \ldots \)

Experiments

\[ E_{\text{lepton}} = \]

- EMC \( 100 \ldots 280 \text{ GeV} \)
- Hermes \( 27 \text{ GeV} \)
  \( 12 \text{ GeV} \)
- CLAS \( 12 \text{ GeV} \) (upgrade)
  \( 5 \text{ GeV} \)
- EIC \( \text{ e.g. } 3+30 \text{ GeV} \)

...multiple combinations of targets
Model

\( \gamma^* N \rightarrow X \) using PYTHIA

*additional:*
- binding energies
- Fermi motion
- Pauli blocking
- coherence length effects

*extended for exclusive channels*

propagation of final state \( X \) within GiBUU transport model

http://gibuue.physik.uni-giessen.de

- elastic/inelastic scatterings (coupled channels)
- experimental acceptance
Model: Hadronization in String Model (Pythia/Jetset)

3 times/points per particle:
- "Production 1“ String-Breaking
- "Production 2“ String-Breaking
- "Formation“ Line Meeting

leading vs. non-leading

XS evolution scenarios:

CT
Results: EMC & Hermes

- Constant cross section
  
  \[ t = t_P \cdots t_F : \]
  
  \[ \sigma^* = 0.5 \sigma_H \]

- Quadratic increase
  
  \[ \sigma^* = \left( \frac{t - t_P}{t_F - t_P} \right)^2 \sigma_H \]
Results: EMC & Hermes

\[
\frac{\sigma^*}{\sigma_H} = \frac{r_{\text{lead}}}{Q^2} + \left( 1 - \frac{r_{\text{lead}}}{Q^2} \right) \left( \frac{t - t_P}{t_F - t_P} \right)
\]

EMC@100...280 GeV
and
Hermes@27 GeV
described simultaneously

pedestal value?
…small effect!
here: averaged times
in code: individual times
Averaged Times

\[ \tau_F \sim m_H \]
Hermes@27: A. Airapetian et al., NPB780(2007)1

**Pions**

- $^{2}d_{1}$
- $^{4}He_{2}$
- $^{20}Ne_{10}$
- $^{84}Kr_{36}$
- $^{131}Xe_{54}$

no diffractive
CLAS@5, $\pi^+$ : selected $(\nu, Q^2)$ bins

Data:
- CLAS preliminary
- no error bars shown

Calculations:
- not tuned !!!
- no Fermi Motion  
  (W<2 GeV possible)
- no potentials

As good as at higher energies!
EIC@3+30: hadrons

Strong dependence on $Q^2$
EIC@3+30: $\pi^0$ vs. $\eta$

Figure 4. Multiplicity ratio for HERMES neutral pions from a Xenon target together with calculations in an energy loss model\textsuperscript{29} calculation from 2007 and in an absorption model\textsuperscript{30} for neutral pions and the eta meson. These calculations suggest that the comparison of $\eta$ and $\pi^0$ will distinguish between these two reaction mechanisms.
Slow Neutrons & interaction point

Pauli Blocking

Evaporation, Binding etc.: GiBUU afterburner (Gaitanos)
Hermes@27: $p_T$ Broadening

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

Default: normal attenuation

In-Medium modifications:

$$\langle k_T^2 \rangle_{Xe} = (0.44 \text{ GeV})^2 \quad \rightarrow \quad (0.50 \text{ GeV})^2$$

$$\langle \sigma_p \rangle_{Xe} = 0.36 \text{ GeV} \quad \rightarrow \quad 0.40 \text{ GeV}$$

data: Y.van Haarlem et al., arXiv:0704.3712 [hep-ex]
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Conclusions

**GiBUU:**
- coupled channel transport code (semi classical)
- from some MeV to tens of GeV (Pythia v6.4 for high energy)
- multi purpose: $p, \pi, \gamma^*, \nu$ – induced reactions
  Heavy Ion Collisions

**pre-hadron cross section:** linear in time
  (EMC,Hermes,CLAS)

**Transverse momentum broadening**
- attenuation leads to broadening
- medium modification of fragmentation parameters ???

**EIC:** important for testing FSI at beginning of hadronization

**Cold Nuclear Matter as baseline for Heavy Ion Collisions**
understand hadronic FSI

- proton, pion beam
- beam energies: 3 – 30 GeV/c
- critical test for hadronic fsi

aim: adjust flux for …
- MiniBooNE
- SciBooNE
- K2K
elementary: $pp \rightarrow \pi^{\pm} X$

Pythia v6.4 describes elementary data very well

\[ \pi^\pm \text{Pb} \rightarrow \pi^\pm X \text{ (forward, 12 GeV/c)} \]

data: M.G. Catanesi et al. (HARP), arXiv:0902.2105 [hep-ex]

- forward production described very well
- pion beam slightly better described than proton beam
\[ pA \rightarrow \pi^+ X \text{ (backward, 3 GeV/c)} \]
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**HARP:** Critical test for hadronic FSI

**Cold Nuclear Matter as baseline for Heavy Ion Collisions**