eHIJING: an event generator for jet tomography at the EIC

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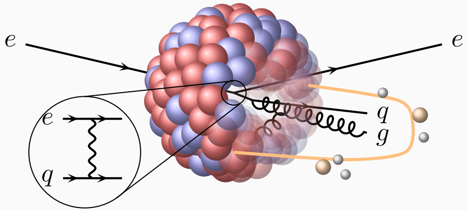
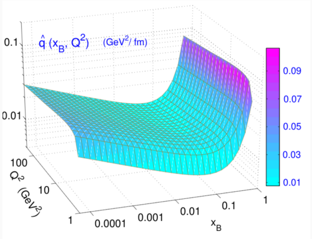
Jet tomography of the cold nuclear matter

e-*A*: EM probe of hadron/nuclei, also a strong probe through final-state interactions.





$$\hat{q} = \frac{d\langle(\delta p_T)^2\rangle}{dL}$$

[P Ru et al PRD 103, 031901]

- A clean environment to study energy loss & momentum broadening of fast partons.
- Sensitive to color opacity of cold nuclear matter ($\hat{q}(x, Q^2)$) $\leftrightarrow$ gluon d.o.f. of nuclei.

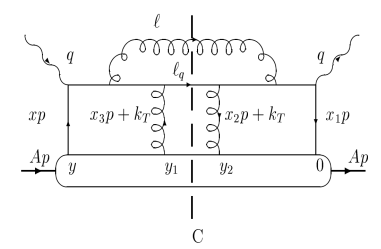
Event generator: complimentary to first-principle method. Direct study of the multi-particle final state.

Electron-Heavy-Ion Jet Interaction Generator (eHIJING)

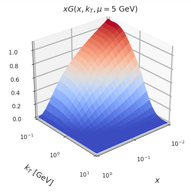
HIJING (Heavy-Ion Jet Interaction Generator) [X-N Wang, M. Gyulassy Phys.Rev. D 44 3501 (1991)].

*e*HIJING (electron-Ion)

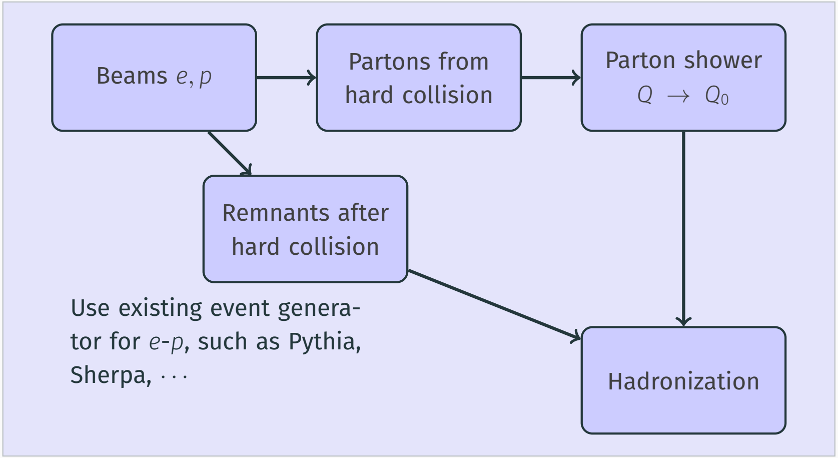
- Hard process.
- Multiple q-A, g-A interaction.
    - Focus on multiple collisions on different nucleons (enhanced by $A^{1/3}$).
- Medium-modified parton shower.
- A model for hadronization.



Multiple collisions involves the TMD gluon distribution $\Phi_g(x, \mathbf{k}_\perp)$



Overview of the eHIJING design, phase I



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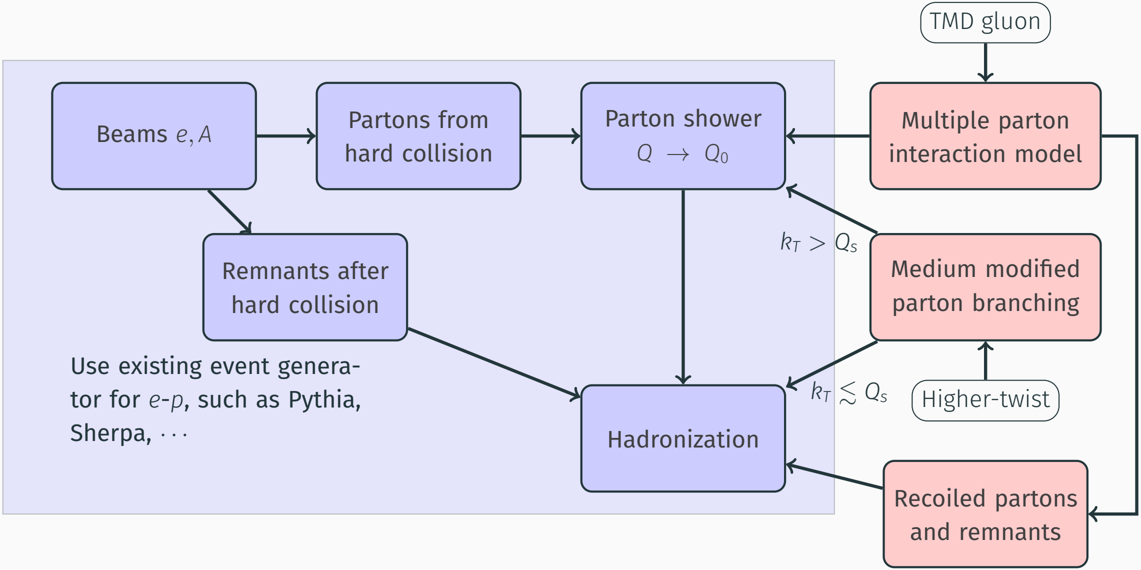
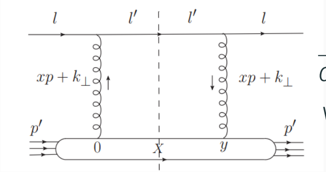


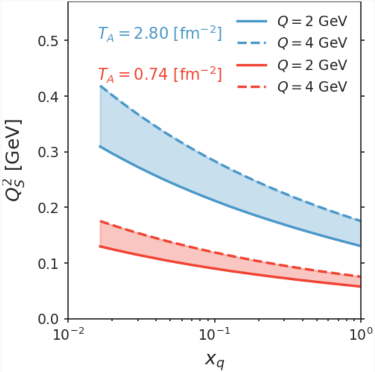
Multiple collision between hard parton and gluon with momentum $xp + \mathbf{k}_\perp$



$$\frac{d\sigma}{d\mathbf{k}_\perp^2} = \frac{4\pi^2 C_R}{(2\pi)^2 d_A} \frac{\alpha_s \phi_g(x, \mathbf{k}_\perp)}{\mathbf{k}_\perp^2}$$ [Y-Y Zhang, G-Y Qin, X-N Wang PRD 100, 074031]

We use a simple form of ϕ_g [D Kharzeev, E Levin PLB 523 79-87]

$$\alpha_s \Phi_G(x, k_\perp^2, Q_s^2) = N(1-x)^n x^\lambda / \max\{k_\perp^2, Q_s^2\}$$

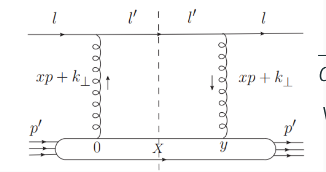


- Φ_G saturates when $k_\perp < Q_s$. Q_s is determined self-consistently [Y-Y Zhang and X-N Wang, 2104.04520]

$$Q_s^2(x, Q^2; T_A) = \frac{4\pi^2 C_A}{d_A} T_A \int_\mu^{\frac{Q^2}{x}} \frac{d^2 k_\perp}{(2\pi)^2} \alpha_s \phi_g\left(x\frac{k_\perp^2}{Q^2}, k_\perp^2; Q_s^2\right)$$

A TMD & saturation-based multiple collision model

Multiple collision between hard parton and gluon with momentum $xp + \mathbf{k}_\perp$



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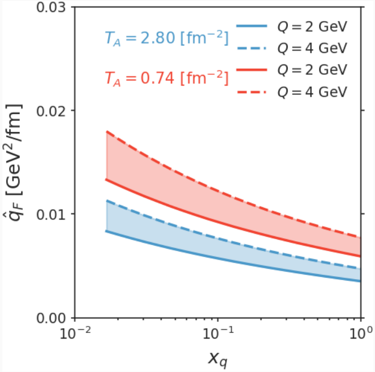
- Such procedure also fix the jet transport parameter

$$\hat{q}_R = \frac{d\langle \Delta p_{\perp,R}^2 \rangle}{dL} = \frac{C_R}{C_A} \frac{Q_s^2}{L}$$



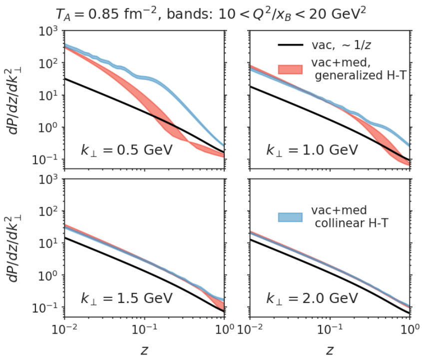
Collisional induced bremmsstrahlung in p_T-ordered parton shower ($l_\perp > Q_s$)

Vacuum emission + 1st-order medium correction.

$$\frac{dP}{dz d\mathbf{l}_\perp^2} = \frac{\alpha_s(\mathbf{l}_\perp^2)}{2\pi}\frac{P_0(z)}{\mathbf{l}_\perp^2}[1+\Delta_1]$$

1. Higher-twist expansion ($l_\perp \gg k_\perp, z \ll 1$, $x_g \ll 1$) [X-N Wang and X Guo]

$$\Delta_1^{\rm Col} = \int_0^L dt \frac{2\hat{q}_A}{\mathbf{l}_\perp^2}\left[1-\cos(t/\tau_f)\right], \qquad \underbrace{\tau_f = \frac{2zE}{l_\perp^2}}_{\text{“Formation time”}}$$



2. Generalized higher-twist: $z \ll 1$, $x_g \ll 1$, no hierarchy for $l_\perp, k_\perp$ [Y-Y Zhang and X-N Wang]

$$\Delta_1^{\rm Gen} = \int_0^L dt \int \frac{d^2\mathbf{k}_\perp}{\mathbf{k}_\perp^2}\alpha_s \frac{C_A\rho(t)\phi_g(x_g,\mathbf{k}_\perp^2)}{2d_A}\frac{2\mathbf{k}_\perp\cdot\mathbf{l}_\perp}{(\mathbf{l}_\perp-\mathbf{k}_\perp)^2}\left[1-\cos(t/\tau_f)\right], \quad \tau_f = \frac{2zE}{(\mathbf{l}_\perp-\mathbf{k}_\perp)^2}$$

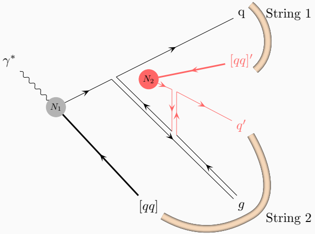
Both methods enhance small-τ_f gluons ($\Delta_1 \sim Q_s^2/l_\perp^2 \propto A^{1/3}/l_\perp^2$) in parton shower and cause energy loss to leading parton.

Medium-modified fragmentation ($l_\perp < Q_s$)

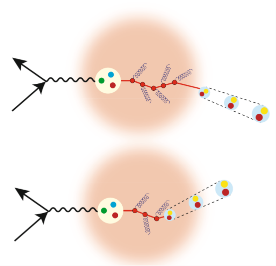
- We consider p_T-ordered shower break down when $l_\perp < Q_s$. Instead, one samples pure medium-induced radiations [N-B Chang, W-T Deng, and X-N Wang PRC 89, 034911 (2014)]. Further, we sample multiple radiations ordered in formation-time

$$\frac{dP}{dz d\mathrm{l}_\perp^2} = \frac{\alpha_s(\mathrm{l}_\perp^2)}{2\pi}\frac{P(z)}{\mathrm{l}_\perp^2}\Delta_1, \quad \tau_{f,1} < \tau_{f,2} < \cdots < E/\Lambda^2$$

- Include nucleon remnants from multiple collisions in string fragmentation.
- Future: hadronic interactions for small-τ_f hadrons.

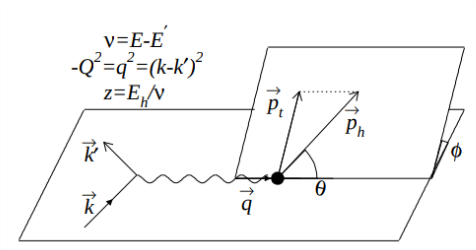


Model remnants by quark + diquark.



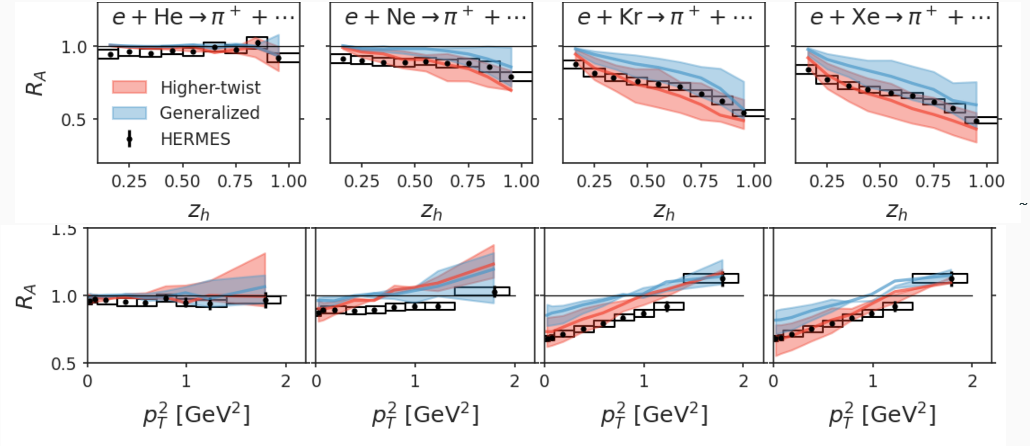
[Fig. from EPJ A52, 268 (2016)]

Application to the SIDIS at HERMES experiment



- Projectile: 27.6 GeV $e^{\pm}$
  Fixed targets: d, ^{4}He, ^{20}Ne, ^{84}Kr, ^{139}Xe.
- Typical $Q^2 \sim 2$ GeV^2 and $x = O(0.1 \sim 1)$.
  $l_T^2 < z(1-z)Q^2 \sim Q_s^2 \to$ help to tune the modified hadronization model.

z_h and p_T-dependent nuclear modification factor



[HERMES, Nuclear Physics B 780, 24 (2007)]

- Nuclear modification $R_A = \left(N_h(\nu, Q^2; z_h, p_t)/N_\gamma\right)_{eA} / \left(N_h(\nu, Q^2; z_h, p_t)/N_\gamma\right)_{ed}$.
- HT (red) & generalized HT (blue). Bands: $\langle \hat{q}_q \rangle_{\mathrm{eff}}$ varies from 0.01 to 0.04 GeV^2/fm.
- Consistent with the A-dependence of data from $A = 4$ to $A = 139$.

Summary and prospects

eHIJING

- Multiple parton-nucleus scattering from TMD gluon distribution.
- Medium-modified parton shower from higher-twist calculation.
- A model for medium-modified fragmentation process.
- Application to HERMES data $R_A(\nu, Q^2, z, p_t)$, and test the A-dependence of medium-modified hadronization.

Prospects

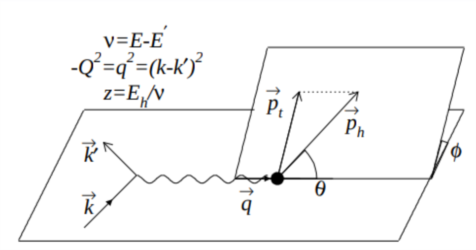
- Higher-twist beyond soft & static limit + k_T-dependent quark PDF [Y-Y Zhang and X-N Wang]
- Hadronic dynamics of the remnant.
- Use e-p event generator beyond LO (Sherpa).

Questions?

Backup slides: HERMES experiments on SIDIS

Projectile: 27.6 GeV $e^{\pm}$

Fixed targets: d, ^{4}He, ^{20}Ne, ^{84}Kr, ^{139}Xe.

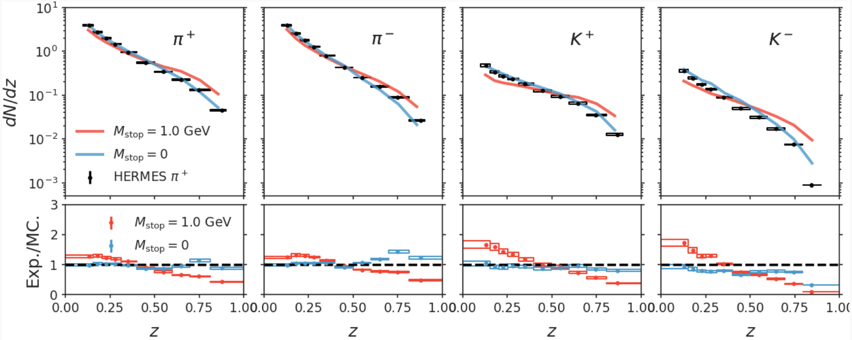


$z > 0.2$, $Q > 1$ GeV, $W > 2$ GeV, $\nu > 6$ GeV, $y < 0.85$

- $Q^2 = -q^2 = -(k - k')^2$: virtuality of the exchange photon (γ).
- $\nu = E - E'$: γ energy.
- $z = E_h/\nu$: energy fraction of hadron relative to γ.
- p_T: transverse momentum of hadron relative to γ.
- $W = \sqrt{(p_\gamma + p_N)^2}$: γ-N center-of-mass energy.
- $y = \nu/E$: inelasticity.

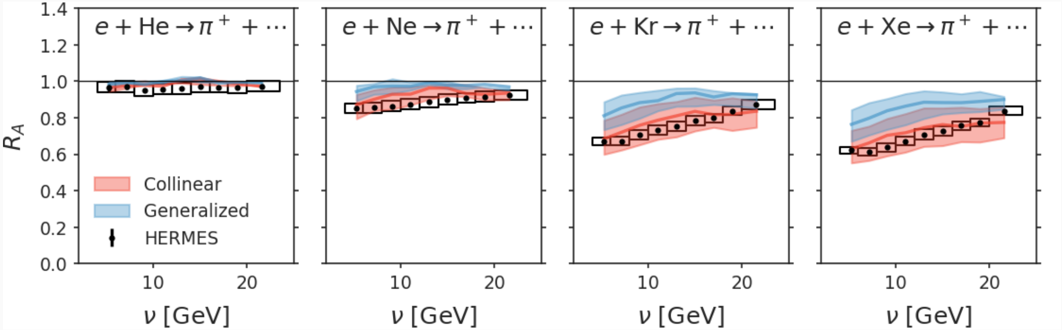
- Typical $Q^2 \sim 2$ GeV^2 and $x = O(0.1 \sim 1)$.
- $l_\perp^2 < z(1-z)Q^2 \sim Q_s^2 \rightarrow$ the HERMES data help to tune the modified hadronization model.

Backup slides: π and K from SIDIS in e-d



- Change of default Pythia8 fragmentation parameters $M_{\rm stop}$ (cut-off invariant mass of string breaking) to better fit pion and kaon measurement in the e-d collisions.

ν-dependent modification



Q^2-dependent modification