Facets of Strong-Interaction Physics

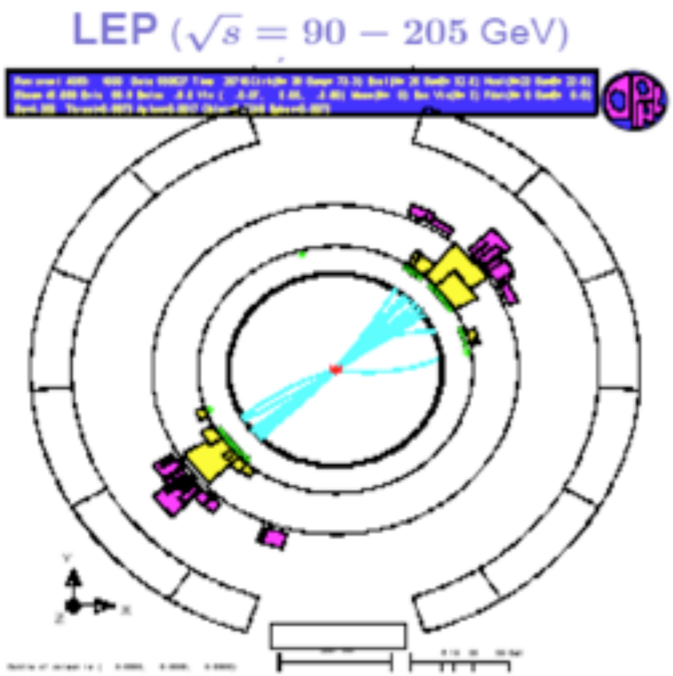
January 15-21 2012

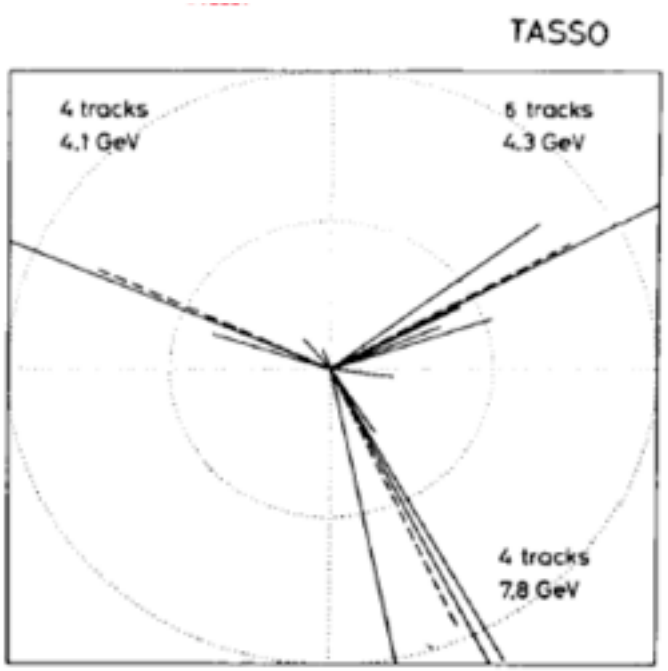
Jet Propagation in Medium

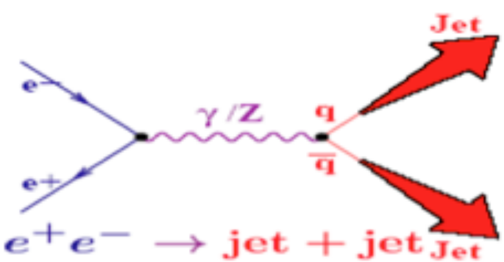
Xin-Nian Wang

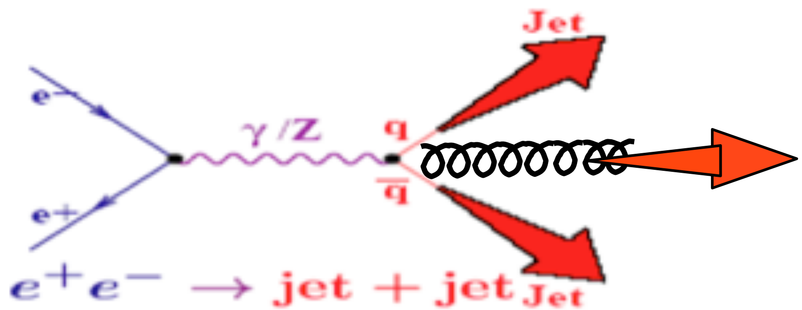
CCNU & LBNL

Jets in high-energy reactions

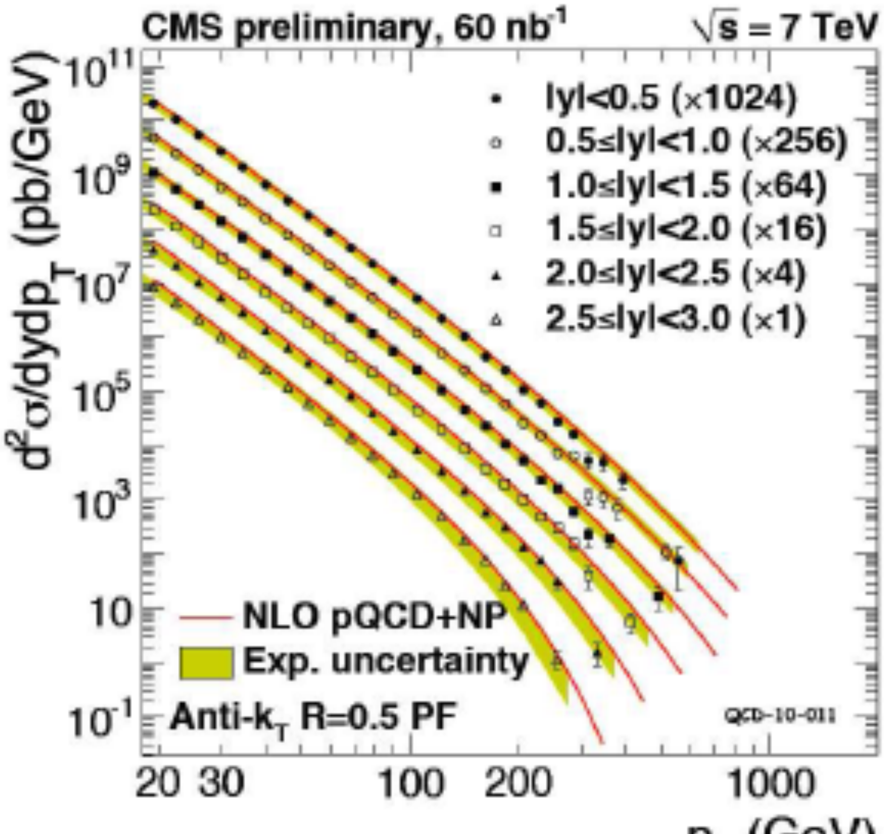




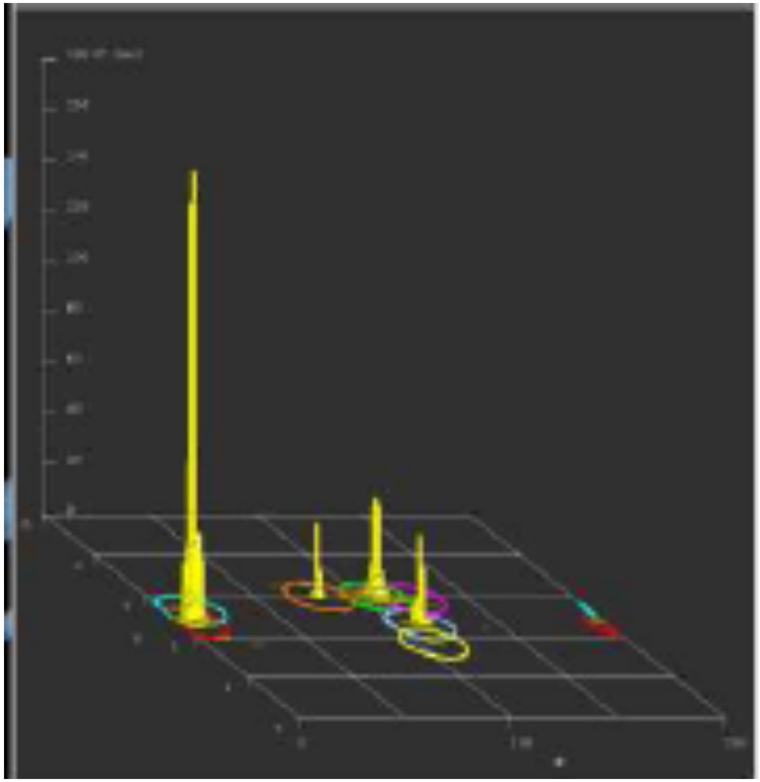




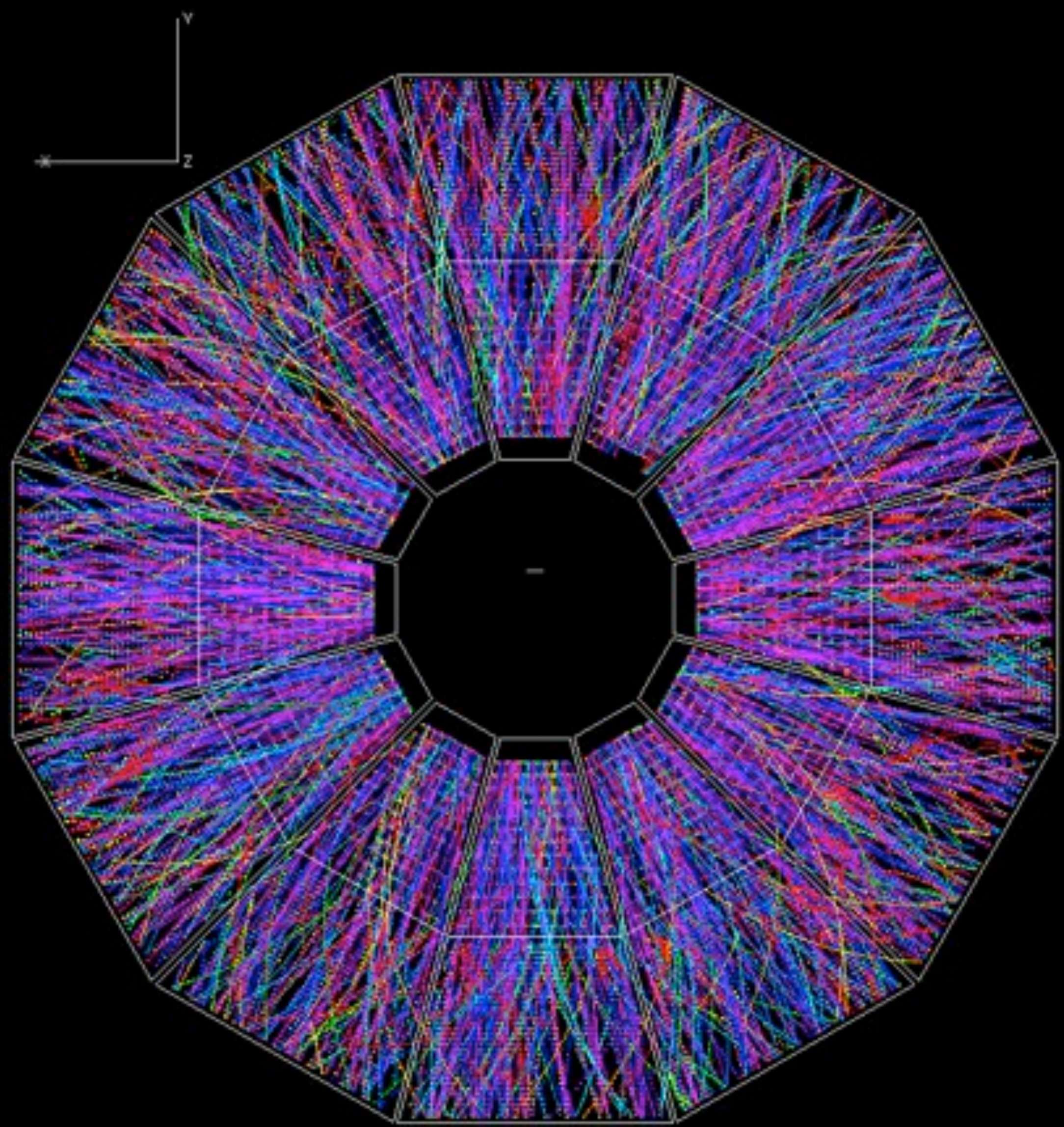
Jets in pp collisions at LHC



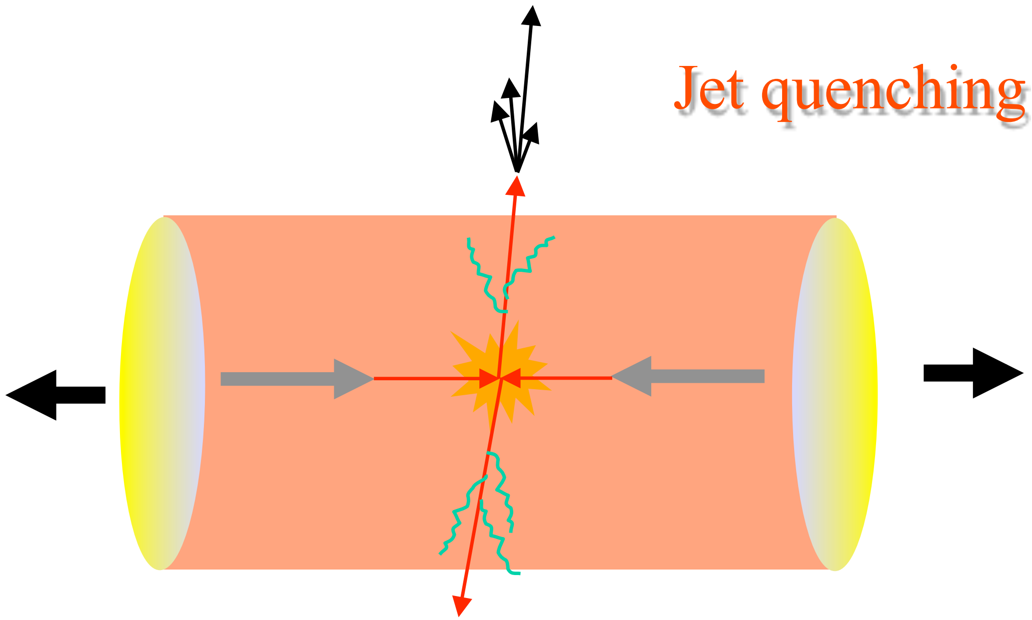
$x_T = p_T/\sqrt{s} = 0.005$



Jets in Heavy-ion Collisions



Hard Probes of Dense Matter



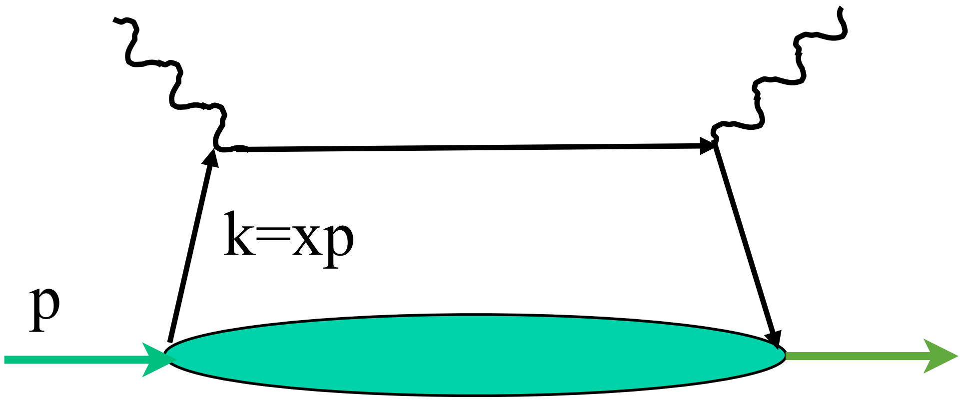
$\Delta D(z, k_\perp)$

k_T broadening

$$\frac{dE}{dx}$$

$$\hat{q}$$

Deeply Inelastic Scattering

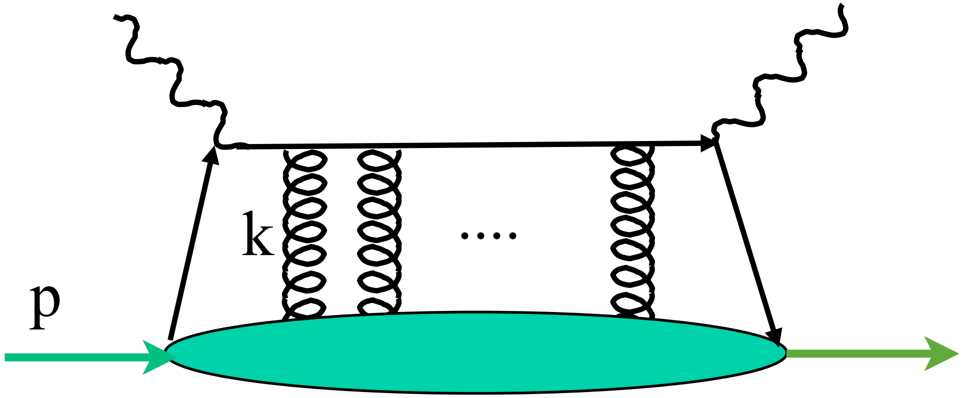


Quark distribution in collinear factorized pQCD parton model:

$$f_A^q(x) = \int \frac{dy^-}{4\pi} e^{ixp^+y^-} \langle A|\bar{\psi}(0)\gamma^+\psi(y^-)|A\rangle$$

quarks carrying momentum fraction x of the nucleon (nucleus)

Gauge Invariance and Multiple Interaction

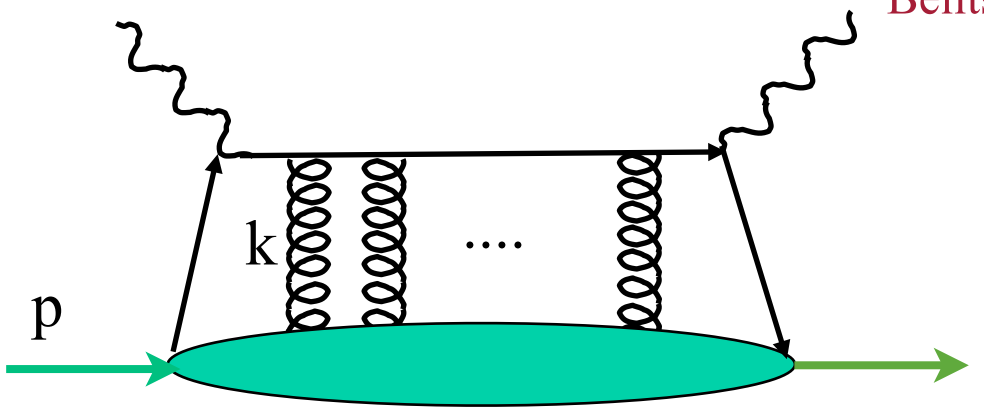


$$f_A^q(x) = \int \frac{dy^-}{4\pi} e^{ixp^+y^-} \langle A|\bar{\psi}(0)\gamma^+ \mathcal{L}_{\parallel}(0, y^-; \vec{0}_\perp)\psi(y^-)|A\rangle$$

$$\mathcal{L}_{\parallel}(0, y^-; \vec{0}_\perp) = \mathcal{P}\exp\left[ig\int_0^{y^-} d\xi^- A_+(\xi^-, \vec{0}_\perp)\right]$$

TMD parton distribution in DIS

Belitsky, Ji and Yuan (2002)

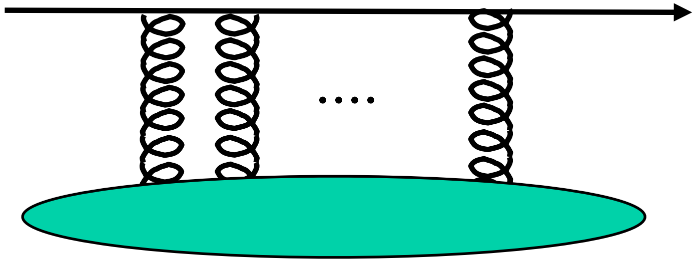


$$f_A^q(x,\vec{k}_\perp) = \int \frac{dy^-}{4\pi}\frac{d^2y_\perp}{(2\pi)^2} e^{ixp^+y^- - i\vec{k}_\perp\cdot\vec{y}_\perp}\langle A|\bar{\psi}(0)\gamma^+\mathcal{L}(0,y)\psi(y)|A\rangle$$

$$\mathcal{L}(0,y) = \mathcal{L}_\parallel^\dagger(\infty,0;\vec{0}_\perp)\,\mathcal{L}_\perp^\dagger(\infty;\vec{y}_\perp,\vec{0}_\perp)\,\mathcal{L}_\parallel(\infty,y^-;\vec{y}_\perp)$$

$$\mathcal{L}_\parallel(0,y^-;\vec{0}_\perp) = \mathcal{P}\exp\left[ig\int_0^{y^-} d\xi^- A_+(\xi^-,\vec{0}_\perp)\right] \quad \mathcal{L}_\perp(\infty;\vec{y}_\perp,\vec{0}) = \mathcal{P}\exp\left[-ig\int_{\vec{0}_\perp}^{\vec{y}_\perp} d\vec{\xi}_\perp\cdot\vec{A}_\perp(\infty,\vec{\xi}_\perp)\right]$$

Jet Transport in Medium



Classical Lorentz force: $\frac{d\vec{p}_\perp}{d\tau} = g\vec{F}_{\perp\mu} v^\mu$

$$\vec{W}_\perp(y^-, \vec{y}_\perp) \equiv i\vec{D}_\perp(y) + g\int_{-\infty}^{y^-} d\xi^- \vec{F}_{+\perp}(\xi^-, y_\perp)$$

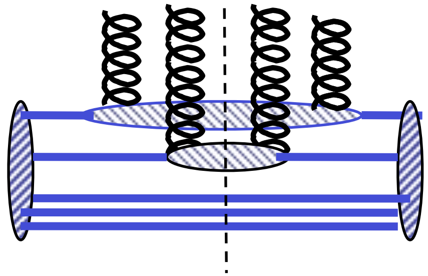
Jet Transport Operator

$$f_A^q(x, \vec{k}_\perp) = \int \frac{dy^-}{4\pi} e^{ixp^+y^-} \langle A|\bar{\psi}(0)\gamma^+ \exp[\vec{W}_\perp(y^-)\cdot\nabla_{k_\perp}]\psi(y^-)|A\rangle \delta^{(2)}(\vec{k}_\perp)$$

Liang, XNW & Zhou （2008）

Momentum Broadening

$$\left\langle\left\langle W_\perp^{2n}\right\rangle\right\rangle_A \sim \left[\int dy \frac{\rho_A(y)}{2p^+}\langle N|F_{+\perp}F_{+\perp}|N\rangle\right]^n \sim \left[\int dy \rho_A(y) x G_N(x)\right]^n$$



2-gluon correlation approximation

$$f_A^q(x,\vec{k}_\perp) \approx \frac{A}{\pi\Delta}\int d^2q_\perp \exp\left[-\frac{(\vec{k}_\perp-\vec{q}_\perp)^2}{\Delta}\right] f_N^q(x,\vec{q}_\perp)$$

Momentum Broadening

$$f_A^q(x, \vec{k}_\perp) \approx \frac{A}{\pi\Delta} \int d^2q_\perp \exp\left[-\frac{(\vec{k}_\perp - \vec{q}_\perp)^2}{\Delta}\right] f_N^q(x, \vec{q}_\perp)$$

$$\Delta = \langle \Delta k_\perp^2 \rangle = \int d\xi_N^- \hat{q}(\xi_N)$$

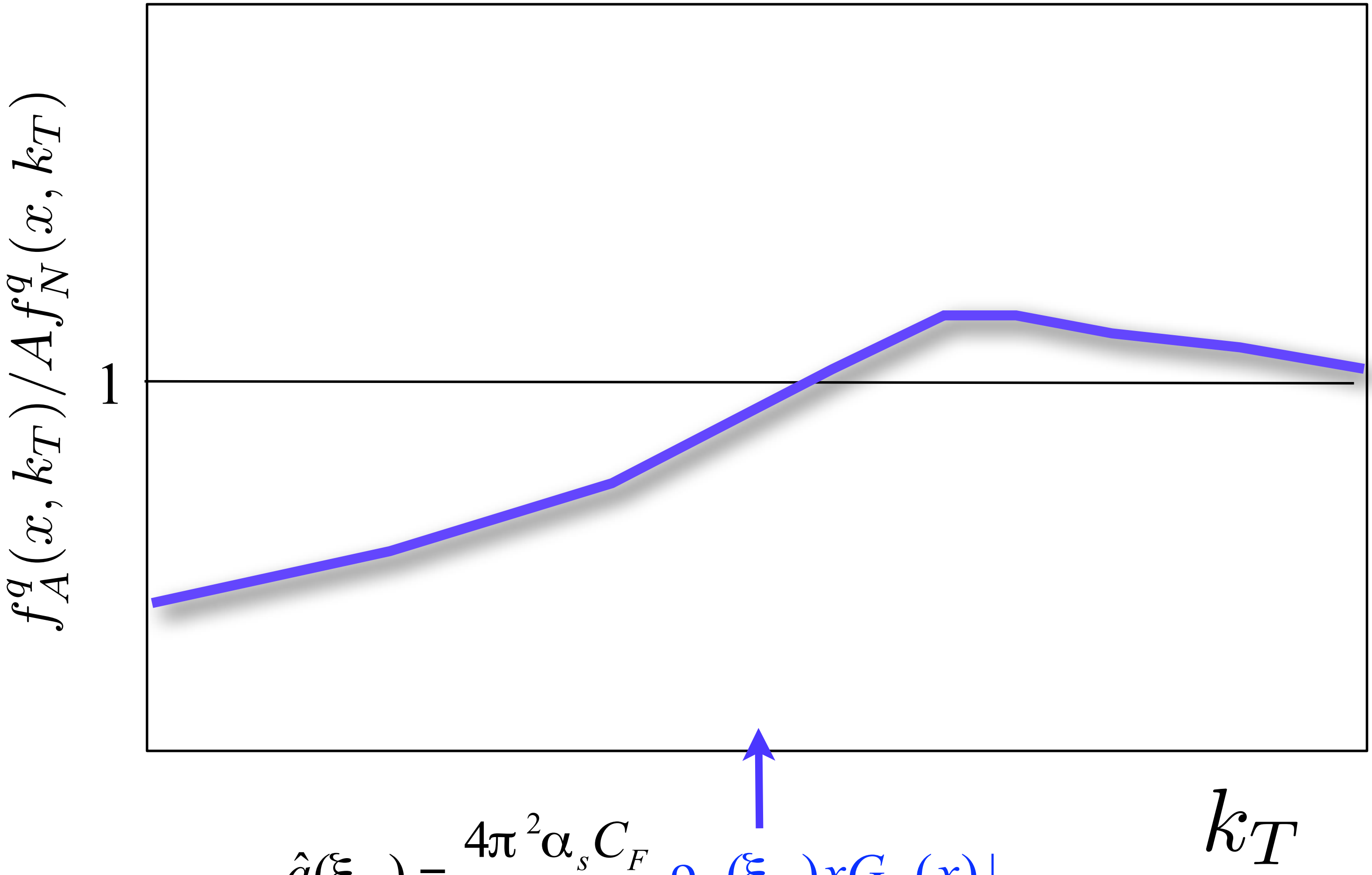
Liang, XNW & Zhou'08
Majumder & Muller'07
Kovner & Wiedemann'01
BDMPS'96

$$\hat{q}(\xi_N) \equiv \frac{4\pi^2\alpha_s C_F}{N_c^2 - 1} \rho_A(\xi_N) x G_N(x)|_{x\approx 0}$$

Jet transport parameter

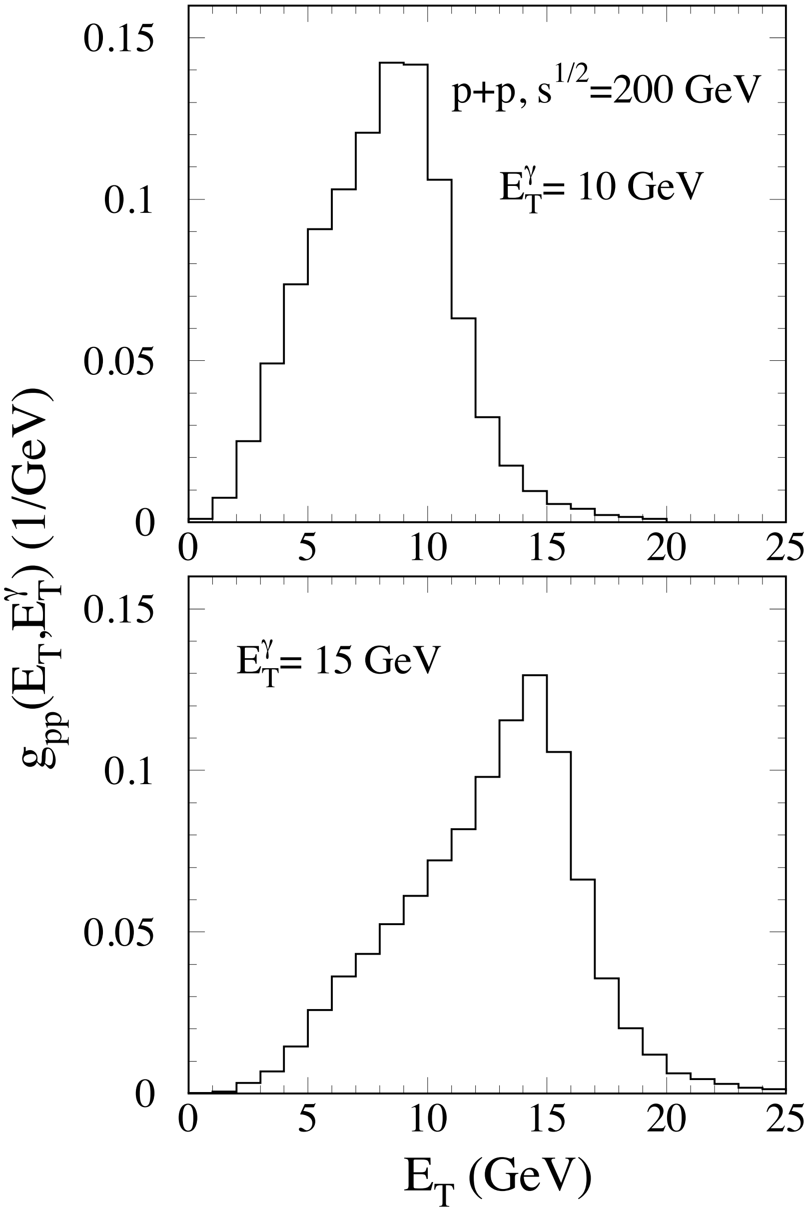
P_T Broadening

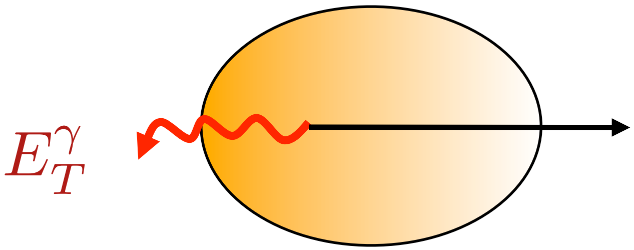
$$f_N^q(x, k_T) \sim 1/(k_T^2 + p_0^2)^\alpha$$



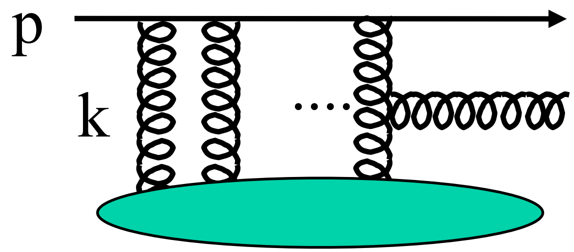
$$\hat{q}(\xi_N) \equiv \frac{4\pi^2 \alpha_s C_F}{N_c^2 - 1} \rho_A(\xi_N) x G_N(x)|_{x \approx 0}$$

Jet Acoplanarity





Parton Energy Loss



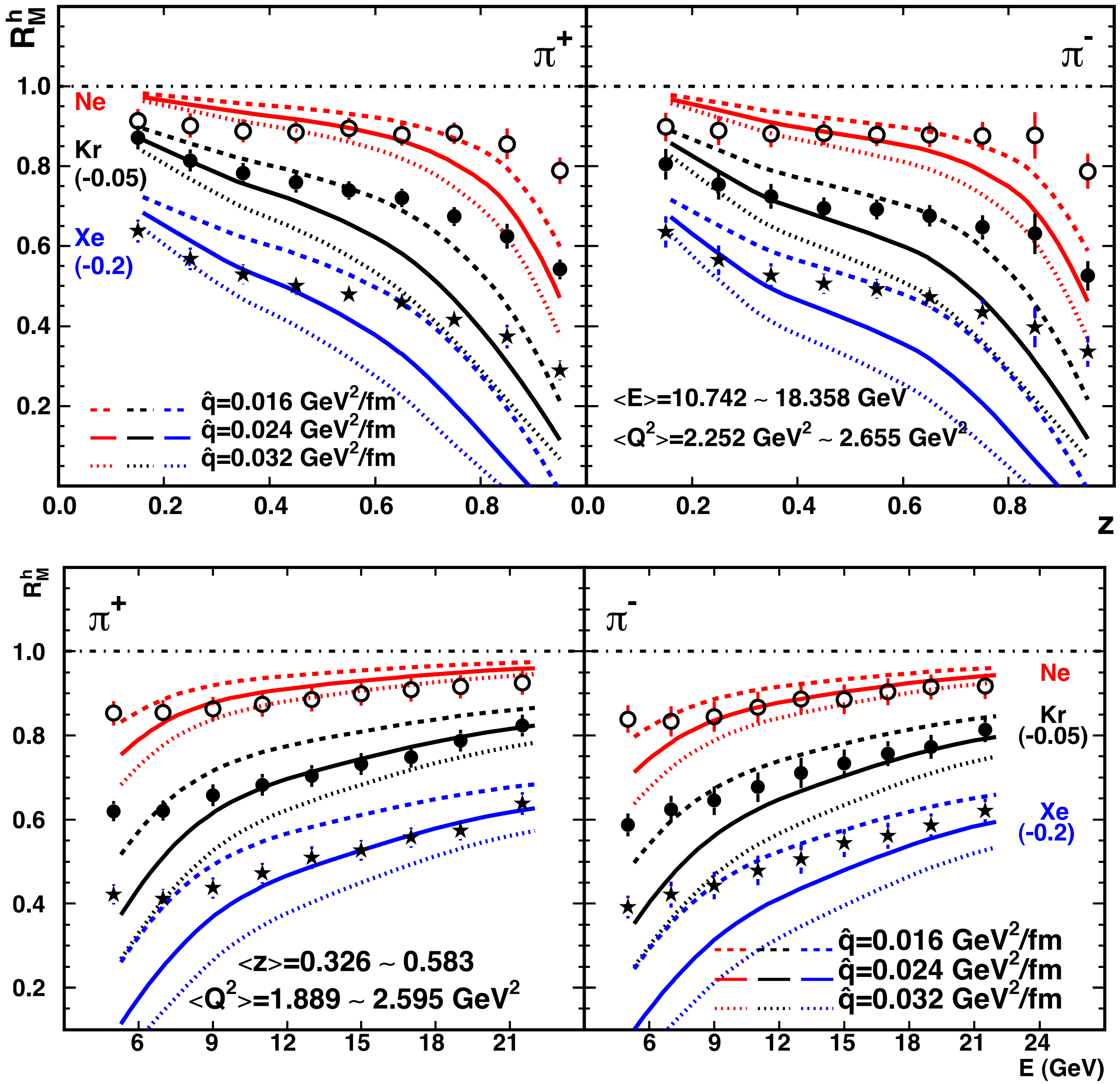
Splitting functions in medium

$$\Delta\gamma(z,\ell_\perp^2) = C_A \frac{1+z^2}{(1-z)_+}\frac{2}{\ell_\perp^4}\int d\xi^- \hat{q}(\xi)[1-\cos(x_L p^+ \xi^-)]$$

Parton Energy Loss

$$\frac{\Delta E}{E} = C_A \frac{\alpha_s}{2\pi}\int \frac{dl_T^2}{l_T^4}\int dz[1+(1-z)^2]\int d\xi^- \hat{q}(\xi) 4\sin^2(x_L p^+ \xi^-/2)$$

DIS of large nuclei

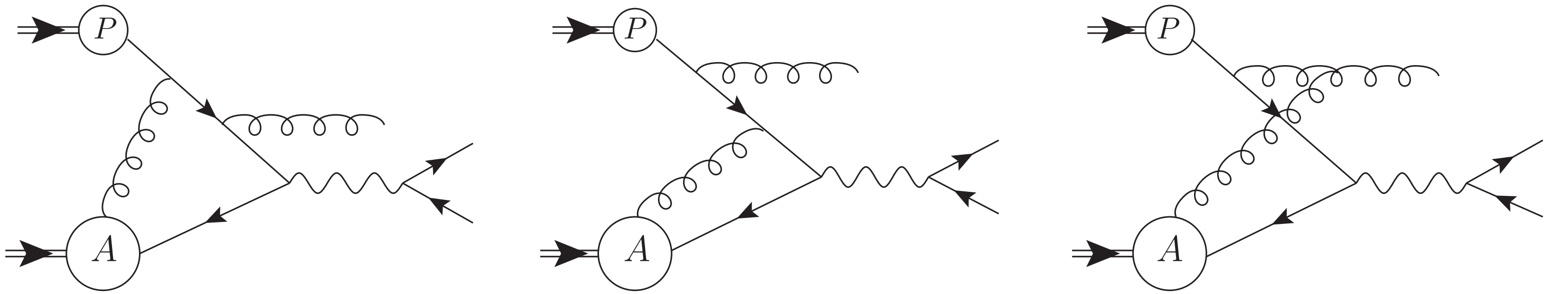


$$R = \frac{N_h^{eA}}{N_h^{eD}}$$

Deng & XNW (**2010**)

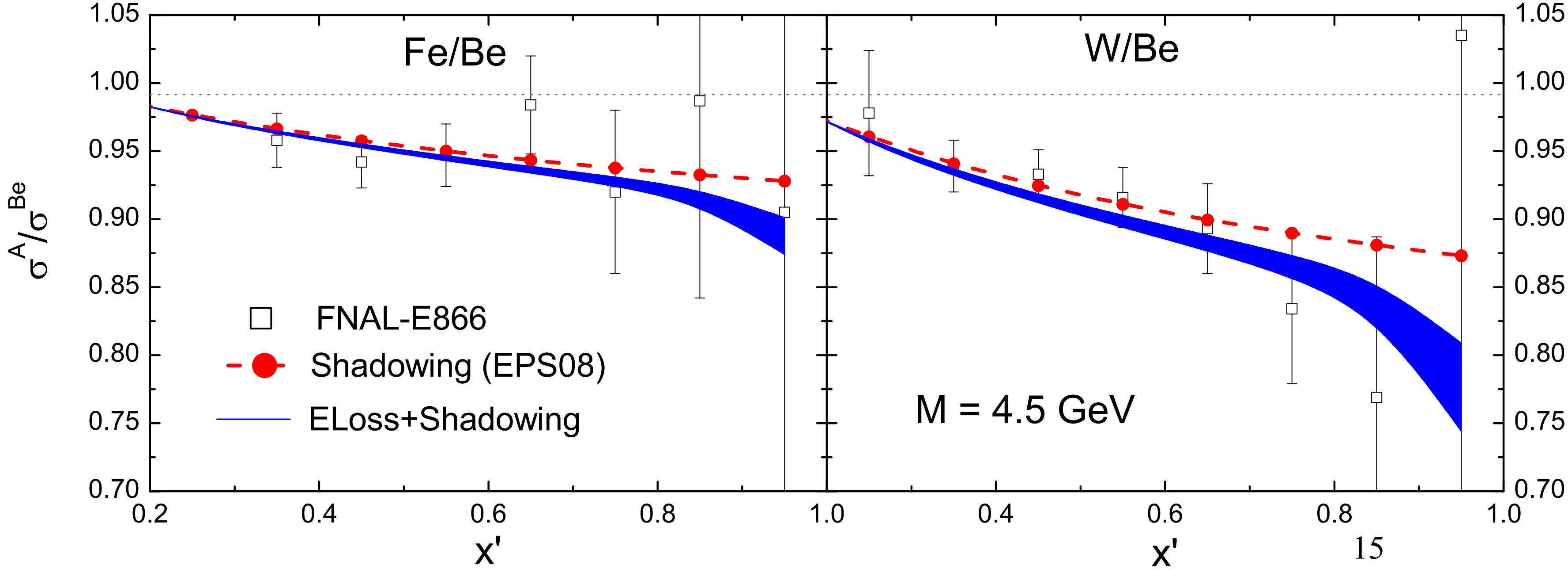
$$\hat{q}_N \approx 0.02\ \mathrm{GeV}^2/\mathrm{fm}$$

Drell-Yan in pA Collisions

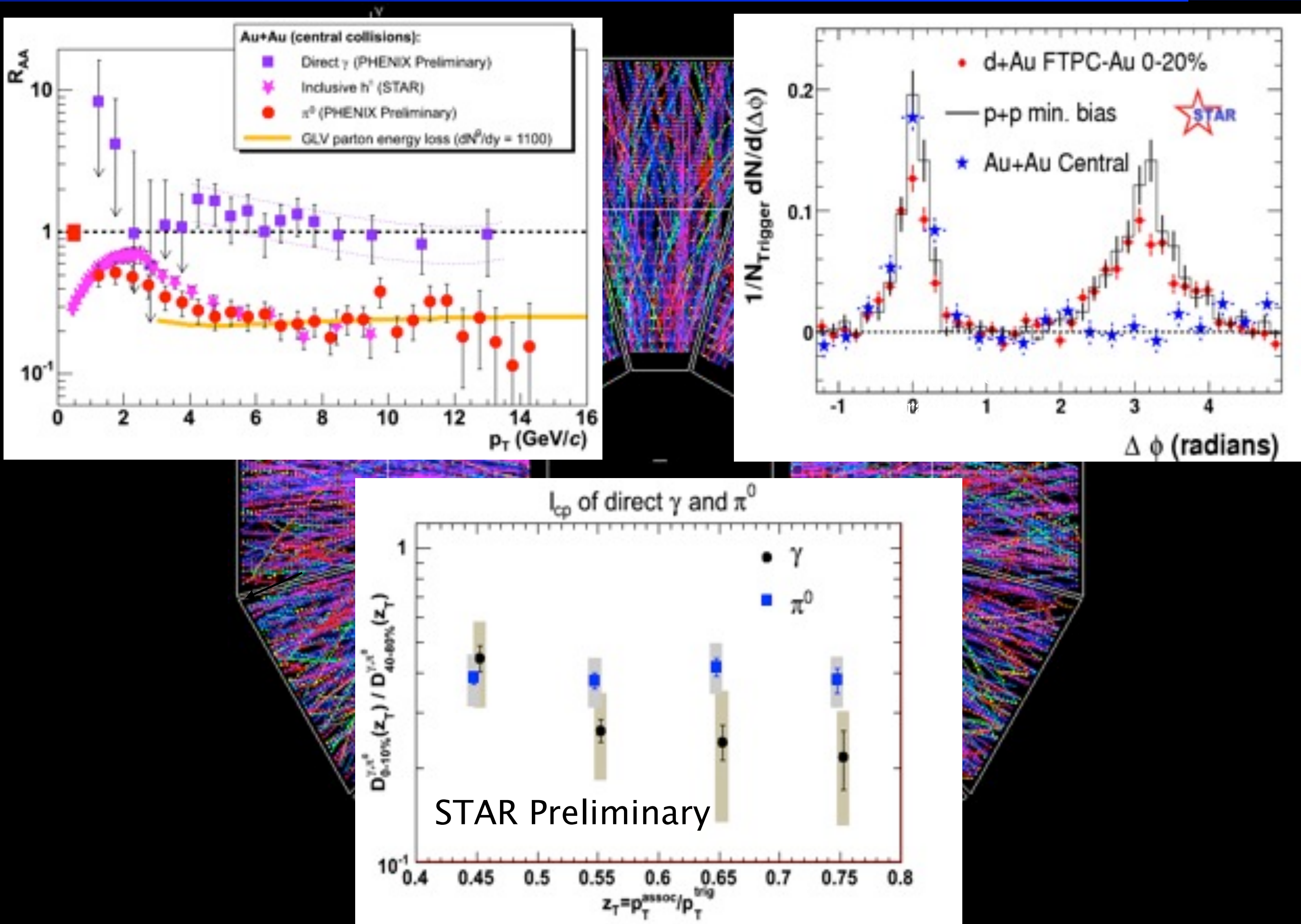


Xing & XNW **arXiv:1110.1903**

$\hat{q}_N \approx 0.02\ \text{GeV}^2/\text{fm}$

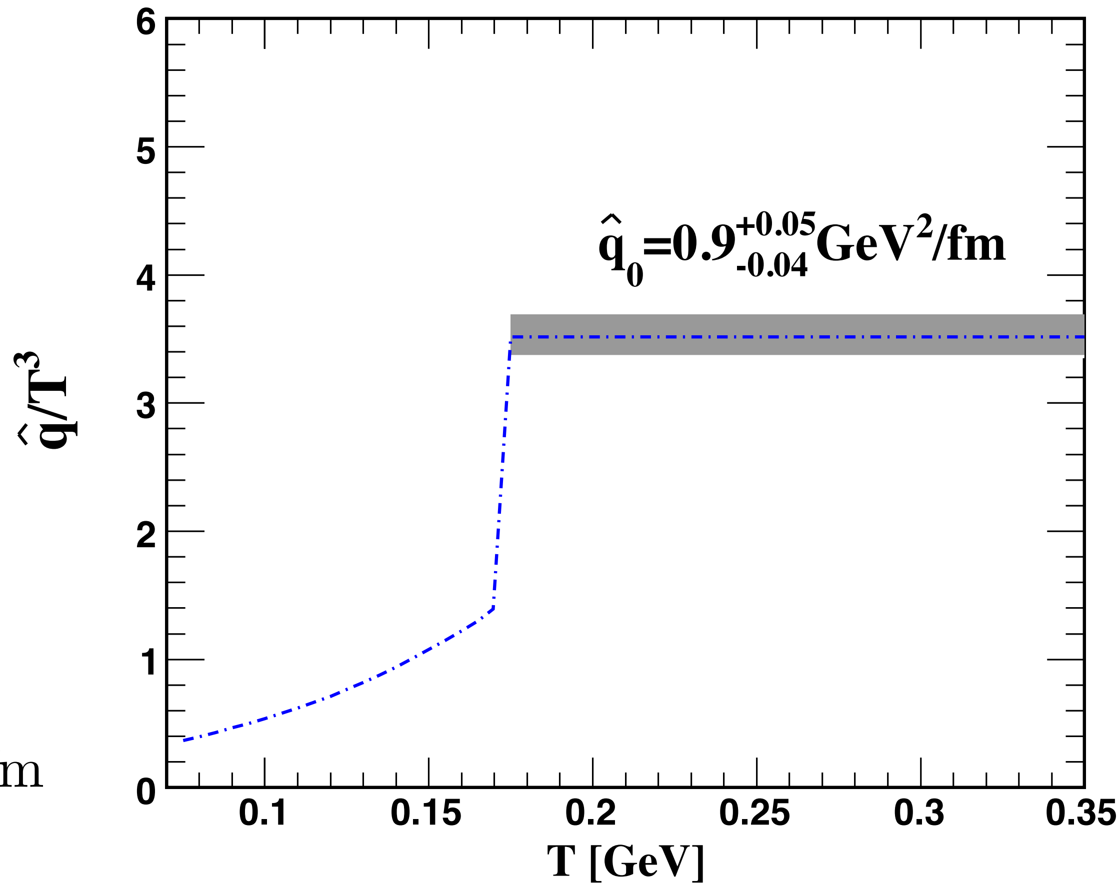


Jet Quenching phenomena at RHIC



Jet quenching in QGP & hadronic phase

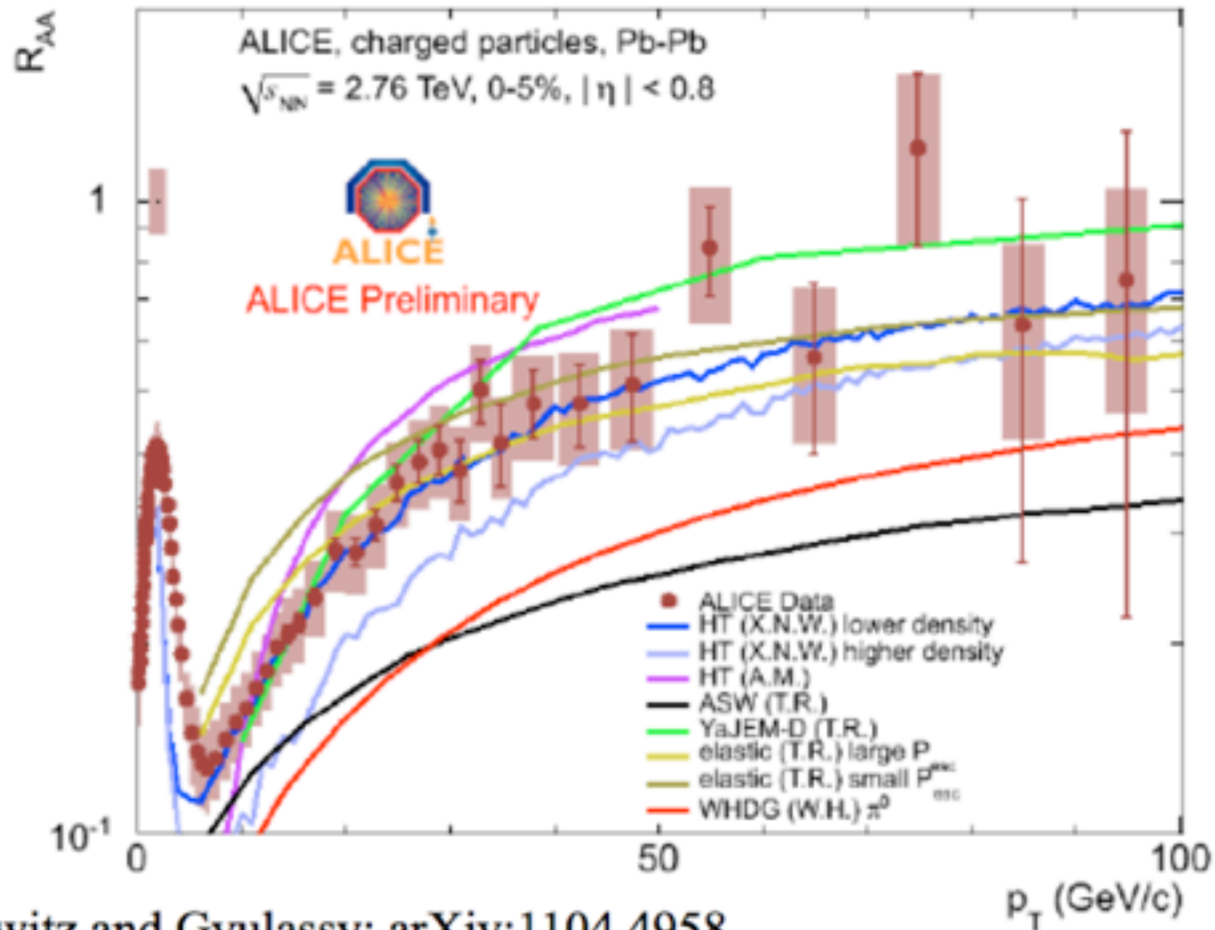
Chen, Greiner, Wang, XNW, Xu （2010）



$$\hat{q}_N = 0.02 \ \ \mathrm{GeV}^2/\mathrm{fm}$$

30% quenching from hadronic phase

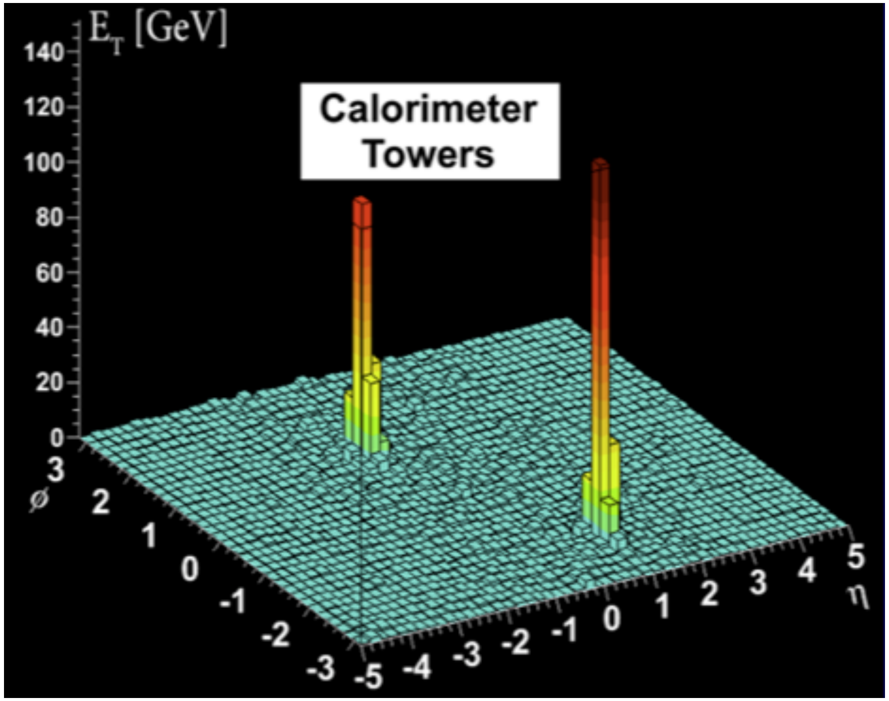
Survival under the LHC sea

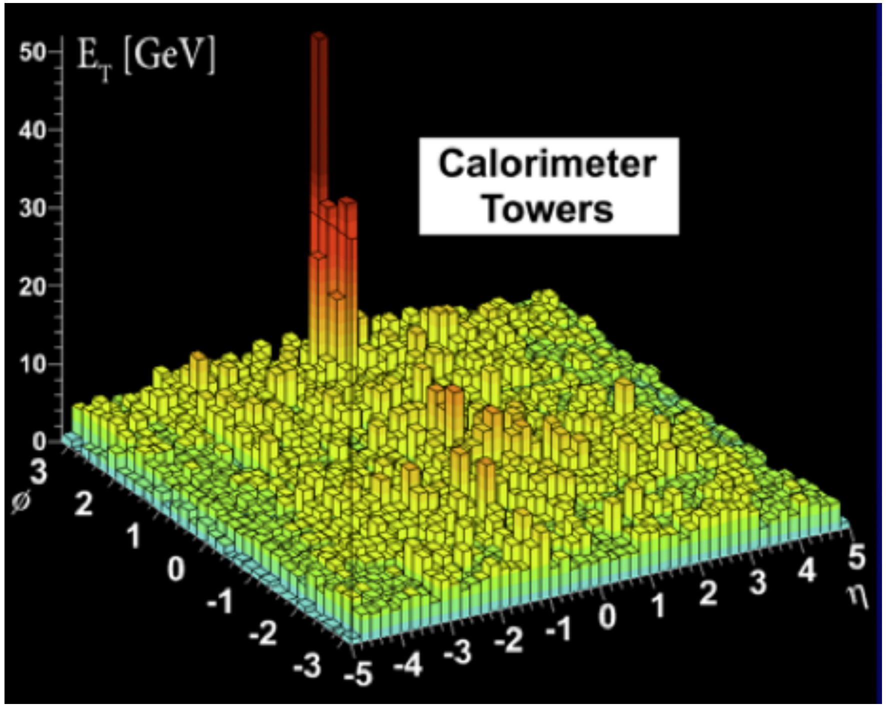


$$\hat{q} \propto \frac{1}{\tau_0 \pi R_A^2} \frac{dN_{ch}}{d\eta}$$

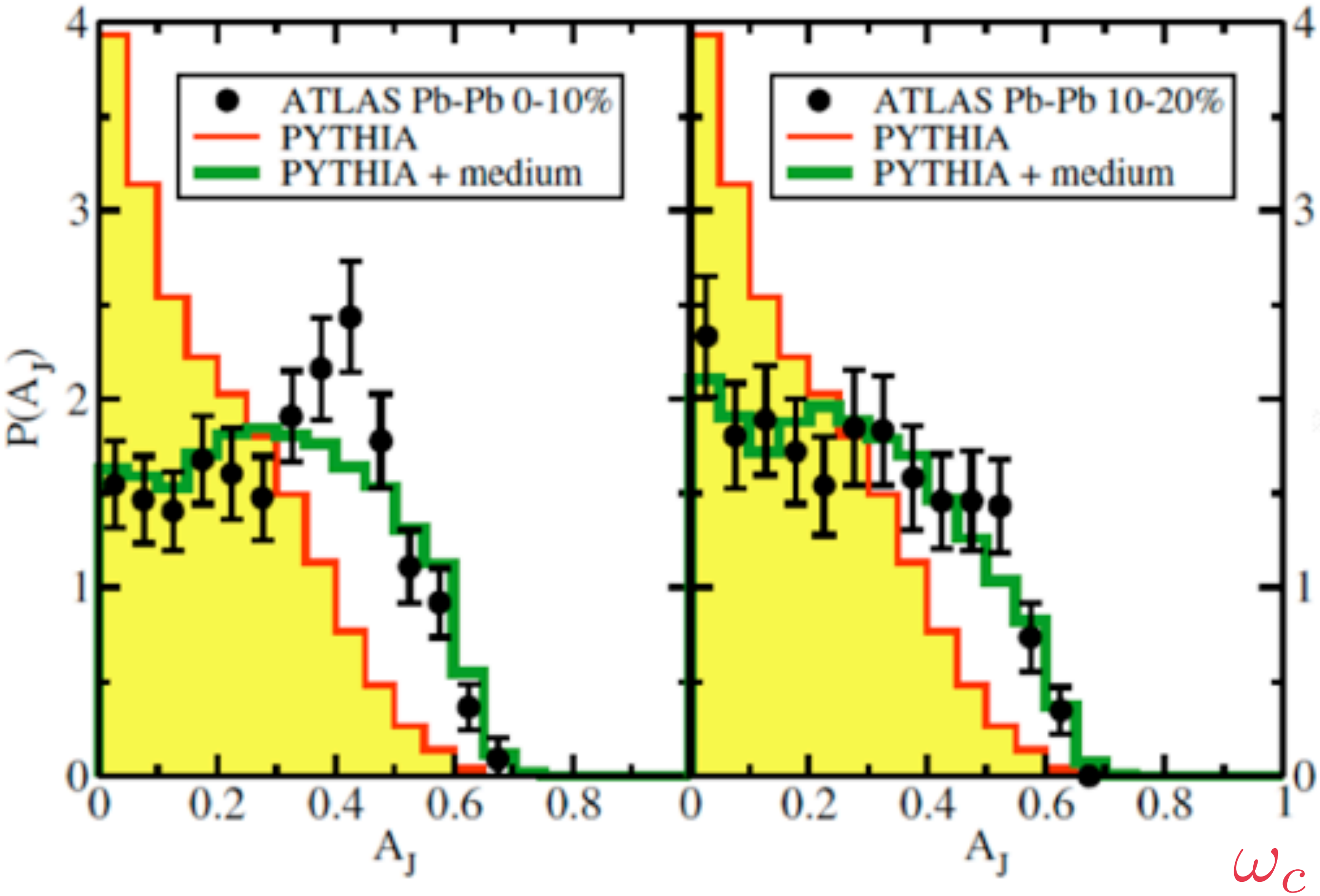
Horowitz and Gyulassy: arXiv:1104.4958
Majumder and Shen: arXiv:1103.0809
Chen et. al. arXiv:1102.5614

Jet Quenching at LHC





Di-Jet Asymmetry



$$A_J = \frac{E_{T\,1} - E_{T\,2}}{E_{T\,1} + E_{T\,2}}$$

$$\omega > \omega_c$$

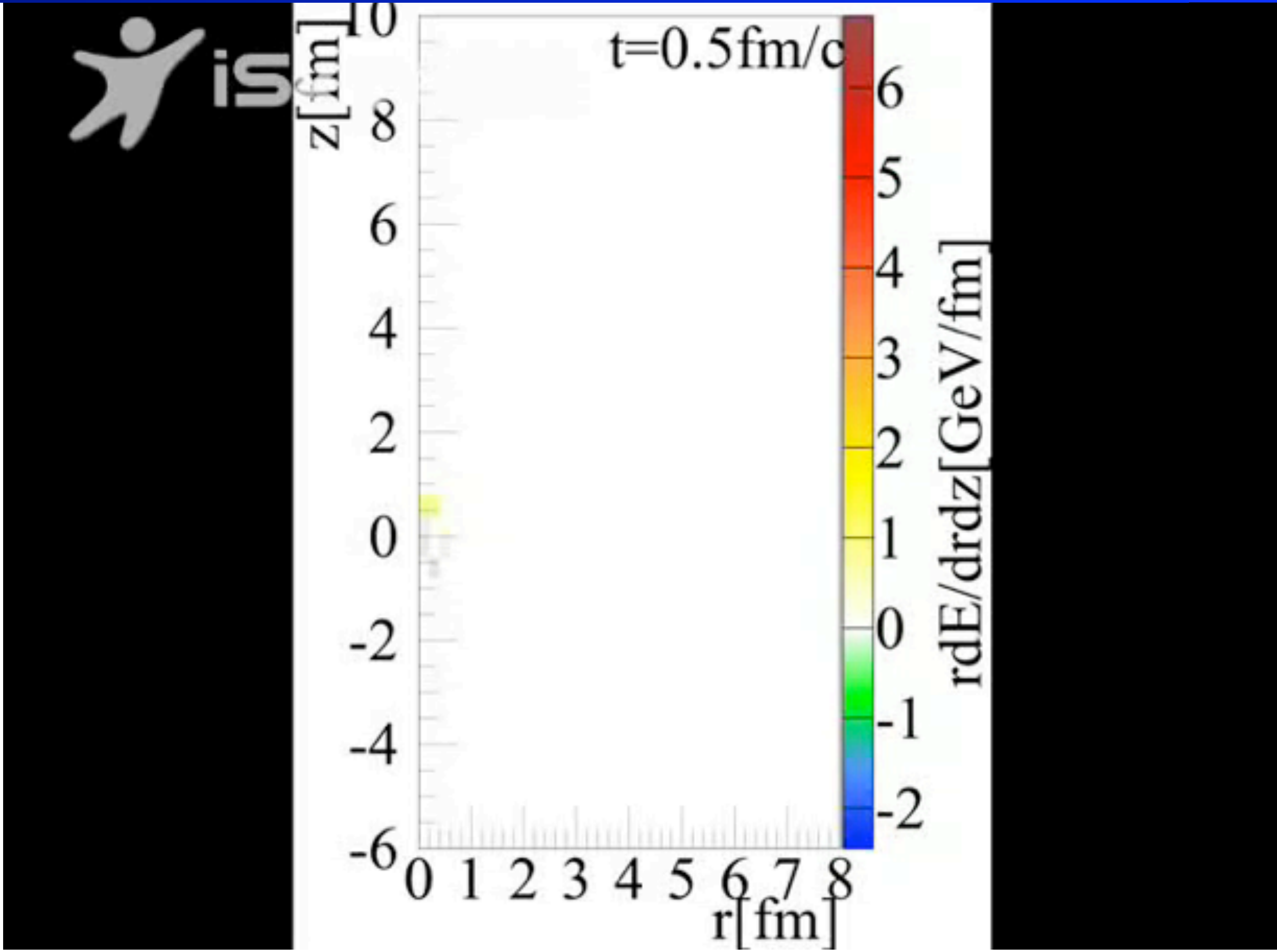
$$\omega_c = 1 - 2\ \mathrm{GeV}$$

Qin and Muller Phys.Rev.Lett.106:162302,2011

B. Schenke, C. Gale, S. Jeon, Phys.Rev.C80:054913 (2009)

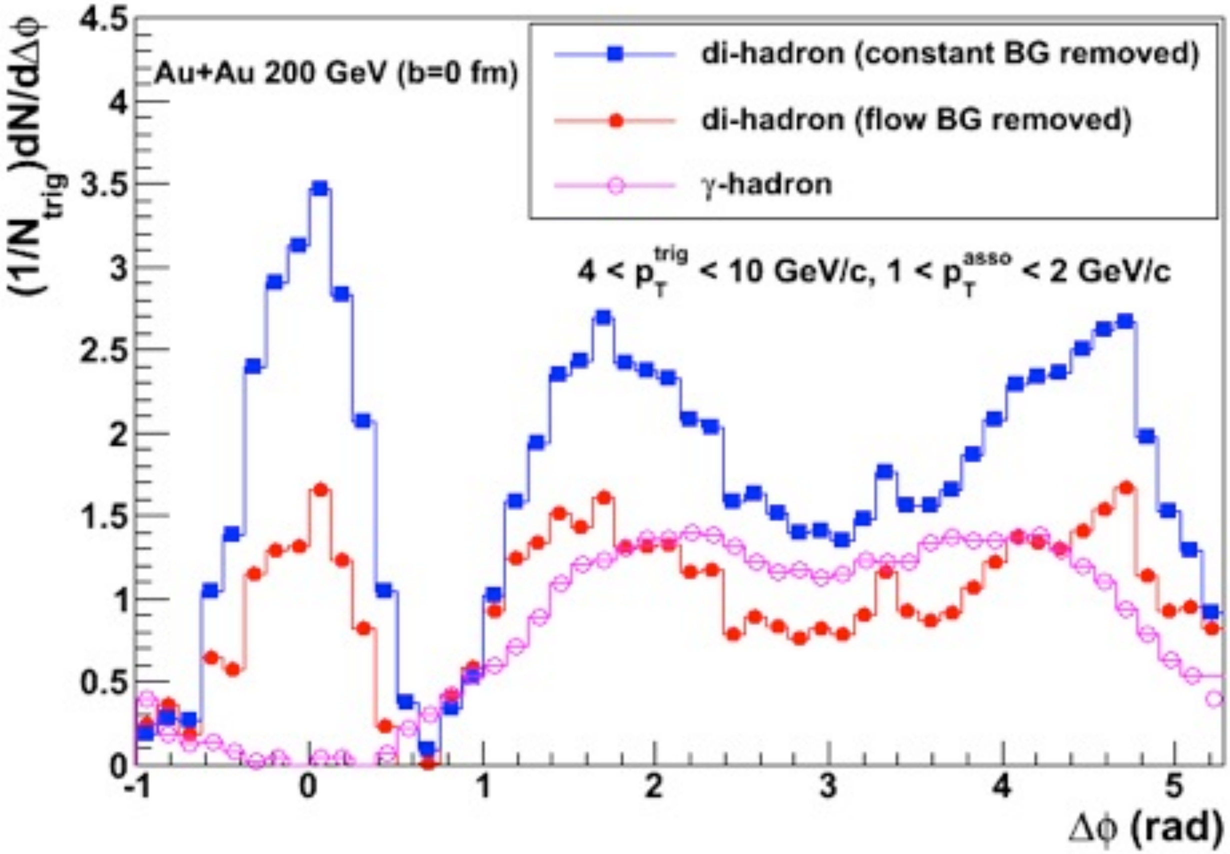
Y. He, Vite, B.W. Zhang, arXiv:1105.2566

Mach-cone-like excitation



gamma-hadron correlation

Guo-liang Ma & XNW (2011)

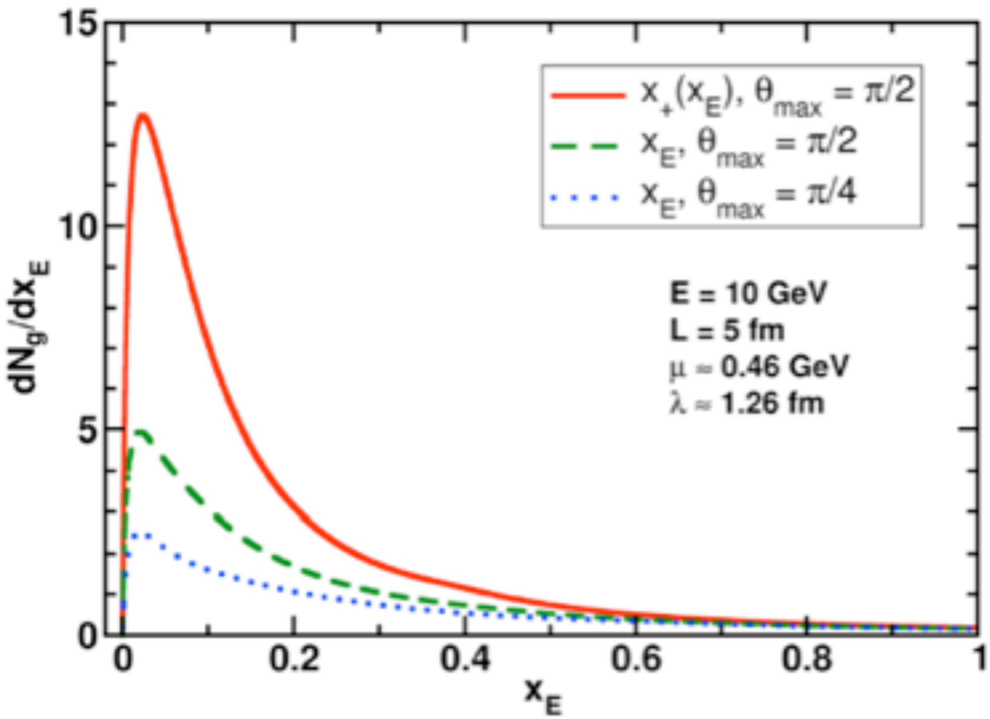


Summary

- Jet propagation in medium leads to pt broadening and parton energy loss
- Jet transport in medium can be studied through pt broadening and jet quenching
- Jet quenching in heavy-ion collisions shows large jet transport parameter
- Jet quenching also leads to medium excitation that can be measured via correlation

Theoretical uncertainties

Systematic comparisons of different approaches: N. Armesto et al. arXiv:1106.1106

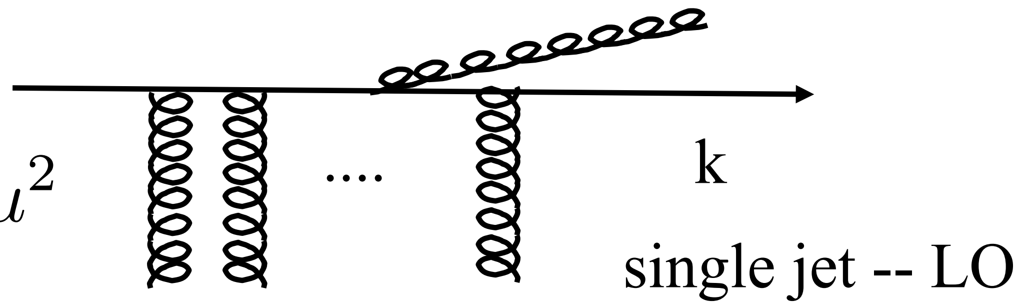


Single gluon emission

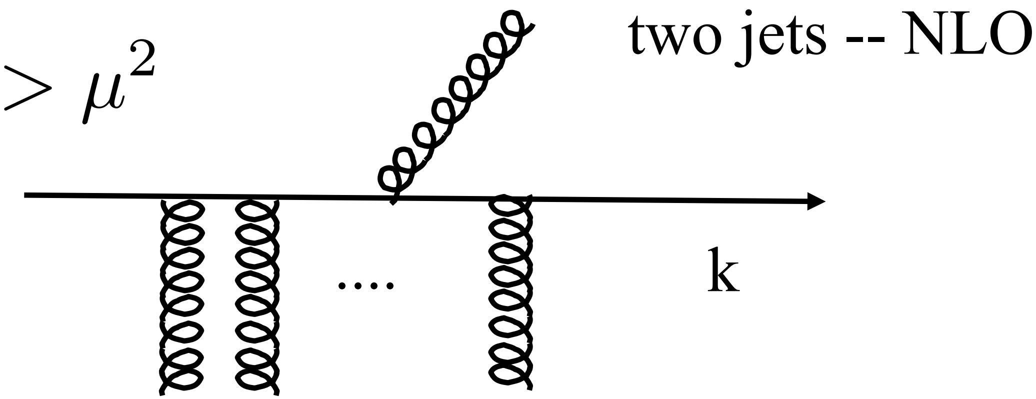
Sensitivity to maximum angle cut-off for gluon emission

Collinear approximation & NLO pQCD

collinear $k_\perp^2 < \mu^2$



large angle $k_\perp^2 > \mu^2$



Future Perspectives

JET Collaboration