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A global extraction of the jet transport coefficient in cold nuclear matter

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arXiv: 1907.11808

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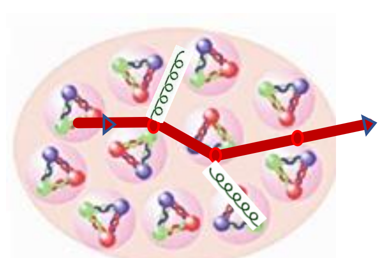
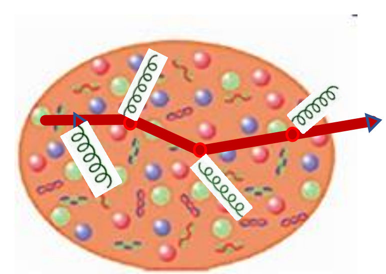


Cold nuclear matter

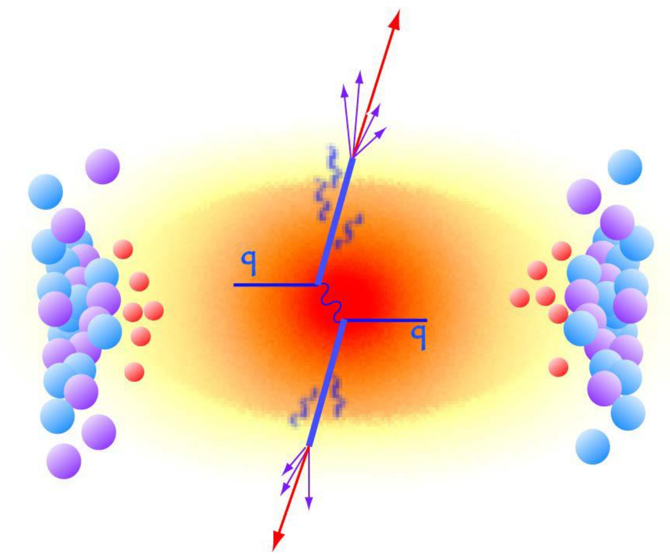


Quark gluon plasma

Questions

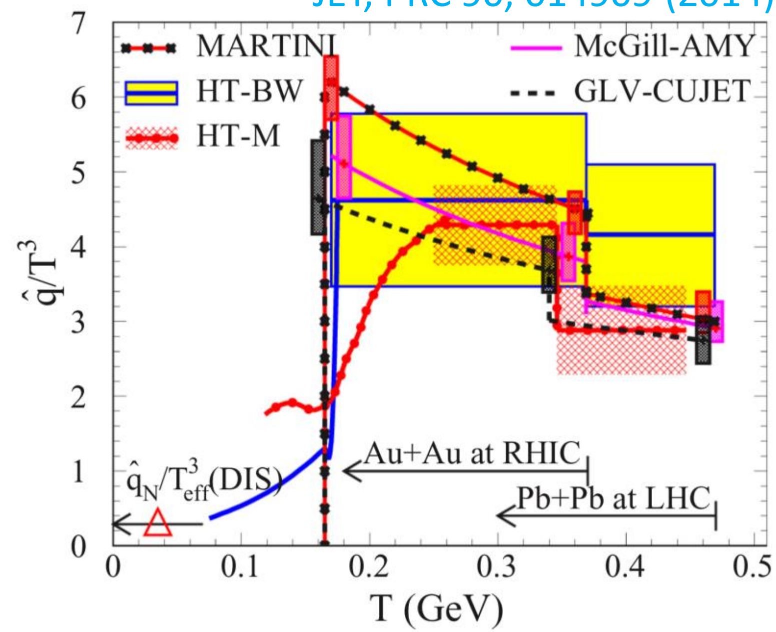
- Why study $\hat{q}$ for cold nuclear matter?
- Universality of medium property in various processes?
- Description of global data within one framework (high-twist)?
- $\hat{q}$: constant or kinematic/scale dependent?
- Extension to Jet quenching in quark-gluon plasma?

$\hat{q}$ for cold nuclear matter



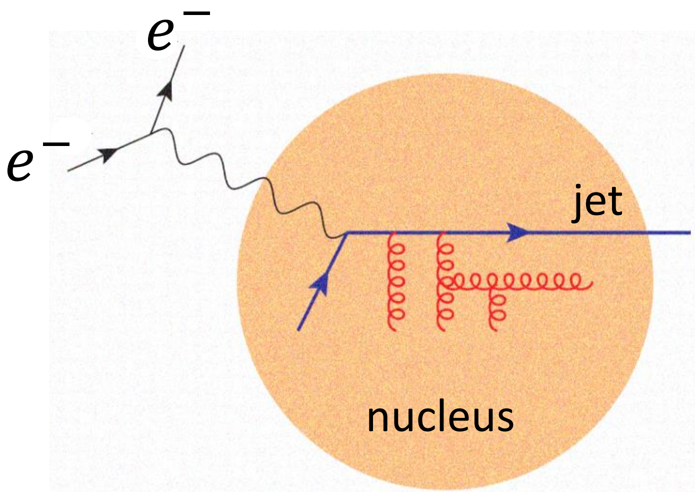
Jet quenching

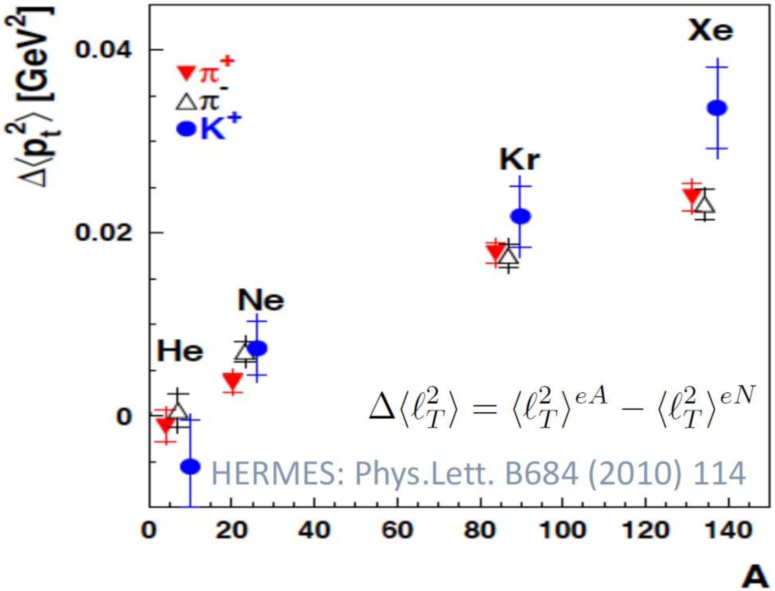
JET, PRC 90, 014909 (2014)



- $\hat{q}$ is an important **non-perturbative** input in jet-quenching models.
- Transverse momentum broadening per unit length for propagating parton.
- Characterize **interaction strength** between hard probe and nuclear medium.
- **Medium property** is encode in $\hat{q}$.

$\hat{q}$ for cold nuclear matter



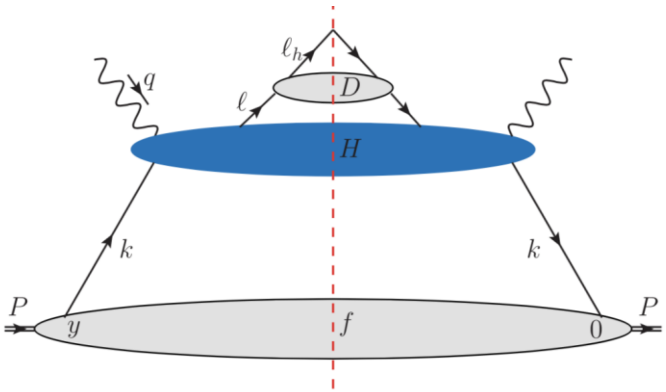


- eA and pA collisions provide a **clean environment** for both experimental and theoretical study.
- Significant **transverse momentum broadening** in SIDIS, DY and heavy-quarkonium production has been observed.
- Theoretical framework of **high-twist expansion** is well developed.
- A comprehensive study of in $\hat{q}$ cold nuclear matter is needed!

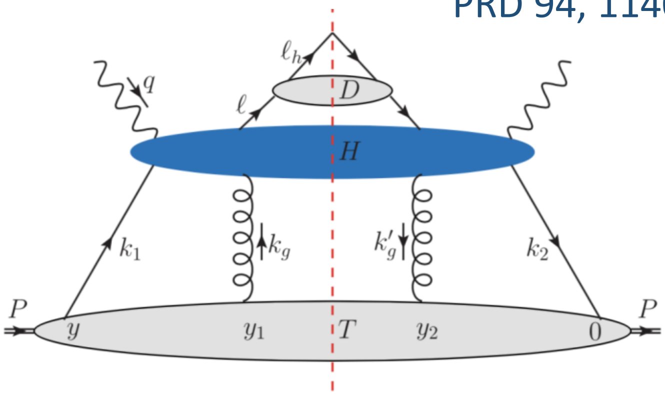
Multiple parton scattering in HT framework

Transverse momentum broadening
in semi-inclusive deep inelastic scattering (SIDIS)

Kang, Wang, Wang, Xing,
PRL 112, 102001 (2014)
PRD 94, 114024 (2016)



Single scattering



Double scattering

Twsit-4 quark-gluon correlation function:

$$T_{qg}(x) = \int \frac{dy^-}{2\pi} e^{ixp^+y^-} \int \frac{dy_1^- dy_2^-}{4\pi} \theta(-y_2^-)\theta(y^- - y_1^-)\langle p_A | F_\alpha^+(y_2^-)\bar{\Psi}_q(0)\gamma^+\Psi_q(y^-)F^{\alpha+}(y_1^-)|p_A\rangle$$

Transverse momentum broadening:

$$\Delta\langle p_T^2\rangle = \frac{4\pi^2\alpha_s z_h^2}{N_c}\frac{\sum_q e_q^2 T_{qg}(x,\mu^2)D_{h/q}(z_h,\mu^2)}{\sum_q e_q^2 f_{q/A}(x,\mu^2)D_{h/q}(z_h,\mu^2)}$$

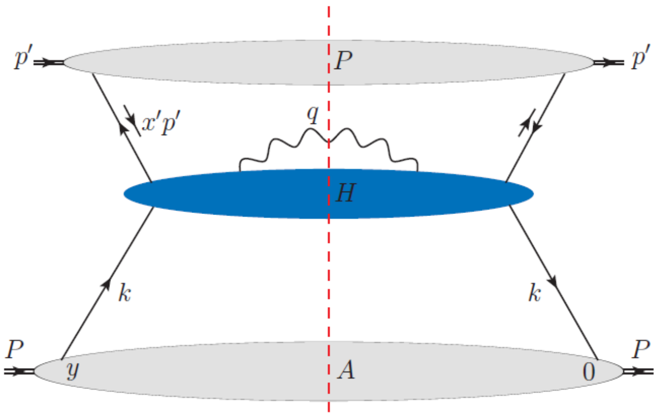
Expressed with $\hat{q}$:

$$T_{qg}(x,\mu^2) \approx \frac{9R_A}{8\pi^2\alpha_s} f_{q/A}(x,\mu^2)\,\hat{q}(x,\mu^2)$$

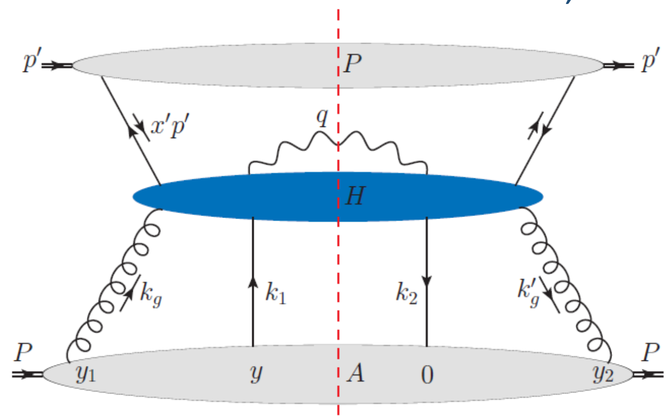
Multiple parton scattering in HT framework

Transverse momentum broadening
in Drell-Yan (DY) dilepton production in pA

Kang, Qiu,
PRD 77, 114027 (2008)
Kang, Qiu, Wang, Xing,
PRD 94, 074038 (2016)



Single scattering



Double scattering

Transverse momentum broadening:

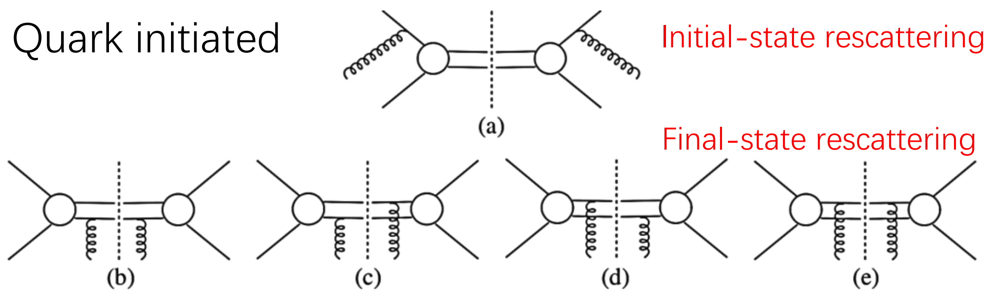
$$\Delta\langle p_T^2\rangle = \frac{4\pi^2\alpha_s}{N_c}\frac{\sum_q e_q^2\int\frac{dx'}{x'}f_{\bar{q}/p}(x',\mu^2)T_{qg}(x,\mu^2)}{\sum_q e_q^2\int\frac{dx'}{x'}f_{\bar{q}/p}(x',\mu^2)f_{q/A}(x,\mu^2)} \approx \frac{3R_A}{2}\frac{\sum_q e_q^2\int\frac{dx'}{x'}f_{\bar{q}/p}(x',\mu^2)f_{q/A}(x,\mu^2)\,\hat{q}(x,\mu^2)}{\sum_q e_q^2\int\frac{dx'}{x'}f_{\bar{q}/p}(x',\mu^2)f_{q/A}(x,\mu^2)}$$

Multiple parton scattering in HT framework

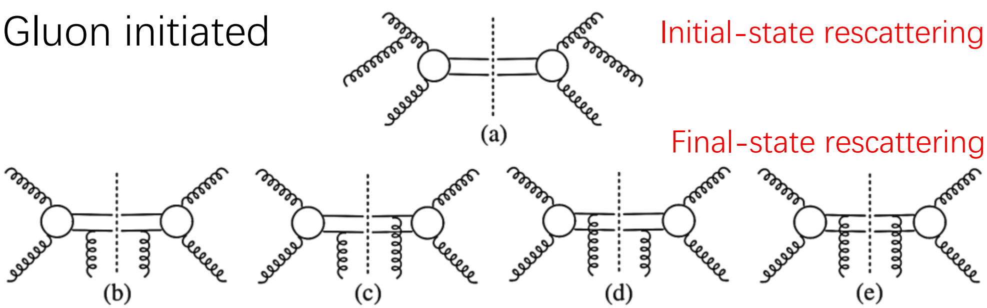
Transverse momentum broadening of
heavy quarkonium(J/ψ, Υ) production in pA

Kang, Qiu,
PRD 77, 114027 (2008)
PLB 721, 277 (2013)

Quark initiated



Gluon initiated



Transverse momentum broadening:

Color Evaporation model:

$$\Delta\langle p_T^2\rangle^{CEM} = \frac{3R_A\,\hat{q}_0}{2}\frac{(1+C_A/C_F)\sigma_{q\bar{q}} + 2C_A/C_F\sigma_{gg}}{\sigma_{q\bar{q}}+\sigma_{gg}}$$

NRQCD effective theory:

$$\Delta\langle p_T^2\rangle^{NRQCD} = \frac{3R_A\,\hat{q}_0}{2}\frac{(1+C_A/C_F)\sigma_{q\bar{q}}^{(0)} + 2C_A/C_F\sigma_{gg}^{(0)} + \sigma_{q\bar{q}}^{(1)}/C_F}{\sigma_{q\bar{q}}^{(0)}+\sigma_{gg}^{(0)}}$$

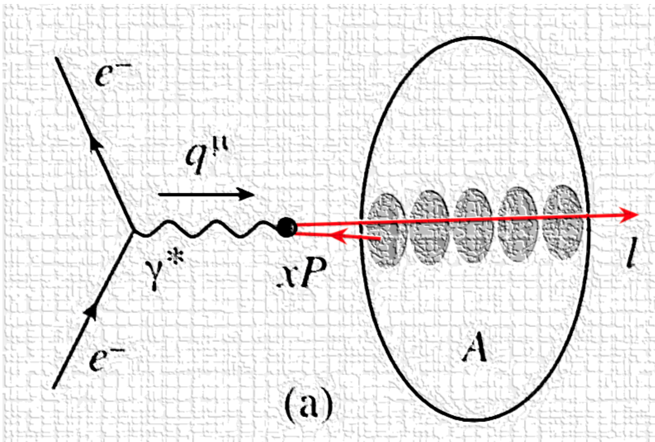
Twsit-4 gluon-gluon correlation function:

$$T_{gg}(x) = \int \frac{dy^-}{2\pi}e^{ixp^+y^-}\int\frac{dy_1^- dy_2^-}{2\pi}\theta(-y_2^-)\theta(y^- - y_1^-)\frac{1}{xp^+}\langle p_A|F_\alpha^+(y_2^-)F^{\sigma+}(0)F_\sigma^+(y^-)F^{\alpha+}(y_1^-)|p_A\rangle$$

Multiple parton scattering in HT framework

Dynamical shadowing in DIS nuclear structure function

Qiu, Vitev, PRL 93, 262301 (2004)



$$F_T^A(x,Q^2) \approx \sum_{n=0}^{N} \frac{A}{n!}\left[\frac{\xi^2(A^{1/3}-1)}{Q^2}\right]^n x^n \frac{d^n F_T^{(\mathrm{LT})}(x,Q^2)}{d^n x}$$

$$\approx A F_T^{(\mathrm{LT})}\left(x + \frac{x\xi^2(A^{1/3}-1)}{Q^2}, Q^2\right),$$

$$F_L^A(x,Q^2) \approx A F_L^{(\mathrm{LT})}(x,Q^2) + \sum_{n=0}^{N} \frac{A}{n!}\left(\frac{4\xi^2}{Q^2}\right)$$

$$\times \left[\frac{\xi^2(A^{1/3}-1)}{Q^2}\right]^n x^n \frac{d^n F_T^{(\mathrm{LT})}(x,Q^2)}{d^n x}$$

$$\approx A F_L^{(\mathrm{LT})}(x,Q^2) + \frac{4\xi^2}{Q^2} F_T^A(x,Q^2),$$

Nuclear modification ratio:

$$R_{AD}(x,Q^2) = \frac{F_2^A(x,Q^2)}{F_2^D(x,Q^2)}$$

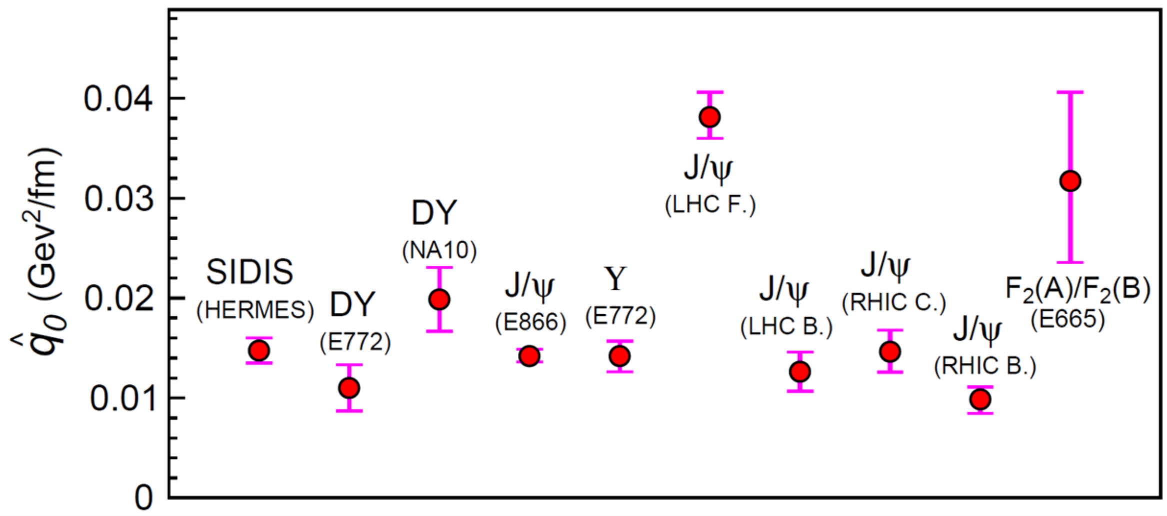
$$F_T^{(\mathrm{LT})}(x,Q^2) = \frac{1}{2}\sum_f Q_f^2 \phi_f(x,Q^2) + \mathcal{O}(\alpha_s)$$

$$F_L^{(\mathrm{LT})}(x,Q^2) = \mathcal{O}(\alpha_s),$$

$$F_2(x,Q^2) = 2x[F_L(x,Q^2) + F_T(x,Q^2)]$$

Universality of medium property

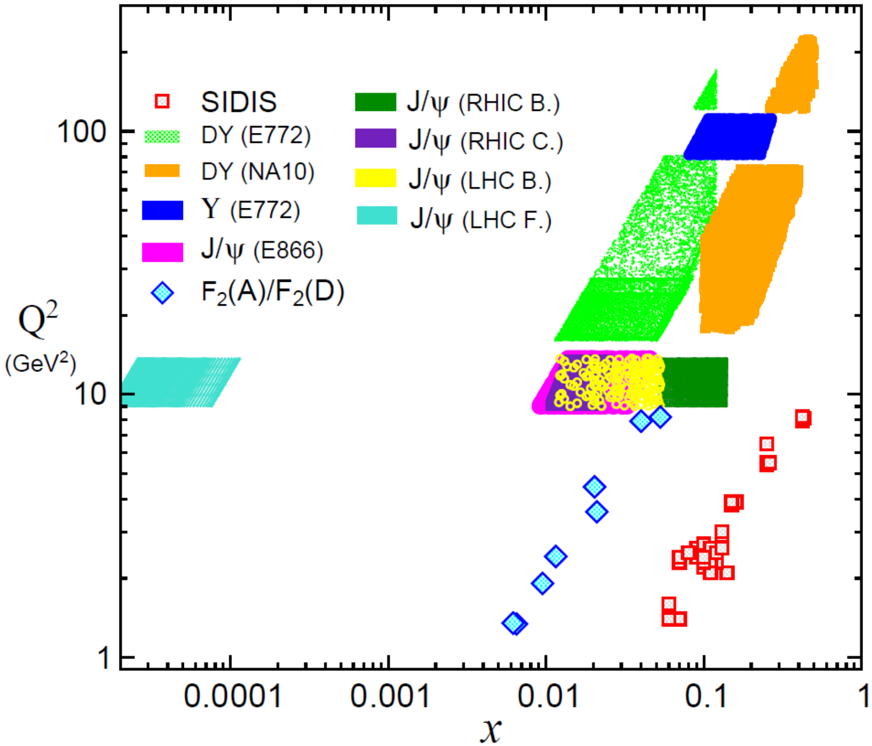
A test with a constant transport coefficient: $\hat{q} = \hat{q}_0$



- A **constant** $\hat{q}$ as an input **fails** to describe different processes (or same process but in different kinematic regions).
- The fitted $\hat{q}$ values for individual observable can even **differ by a factor of 2 -- 4**.
- Strongly indicates a non-trivial **kinematics and probing scale** (x and Q^2) dependence of $\hat{q}$.

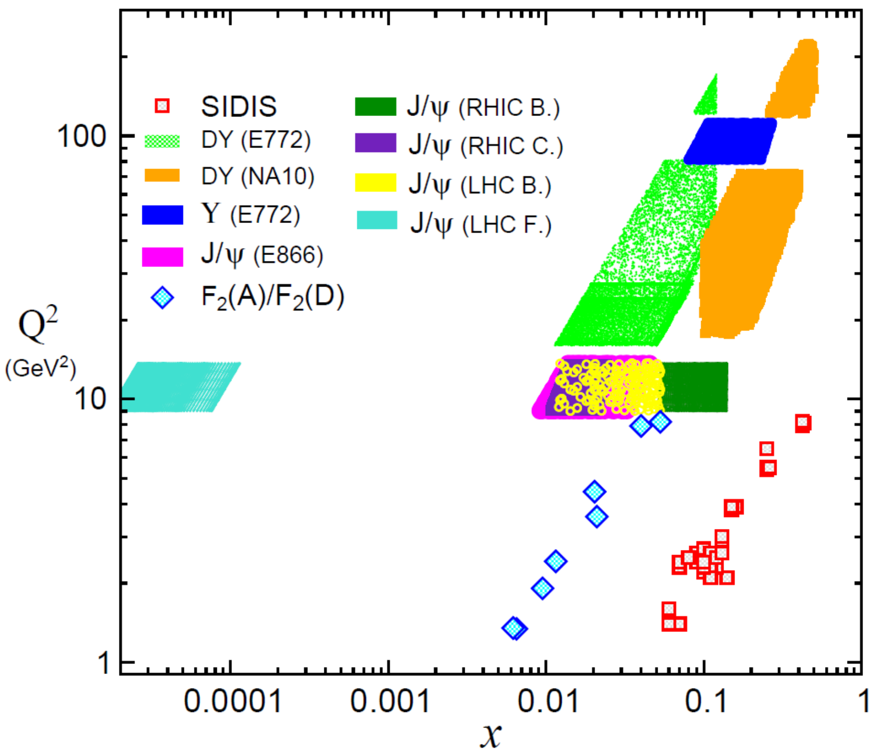
Universality of medium property

A kinematics and probing scale
(x and Q^2) dependent $\hat{q}$



Universality of medium property

A kinematics and probing scale (x and Q^2) dependent $\hat{q}$



Parametrization of $\hat{q}(x, Q^2)$:

$$\hat{q}(x, Q^2) = \hat{q}_0 \alpha_s(Q^2) x^\alpha (1-x)^\beta [\ln(Q^2/Q_0^2)]^\gamma$$

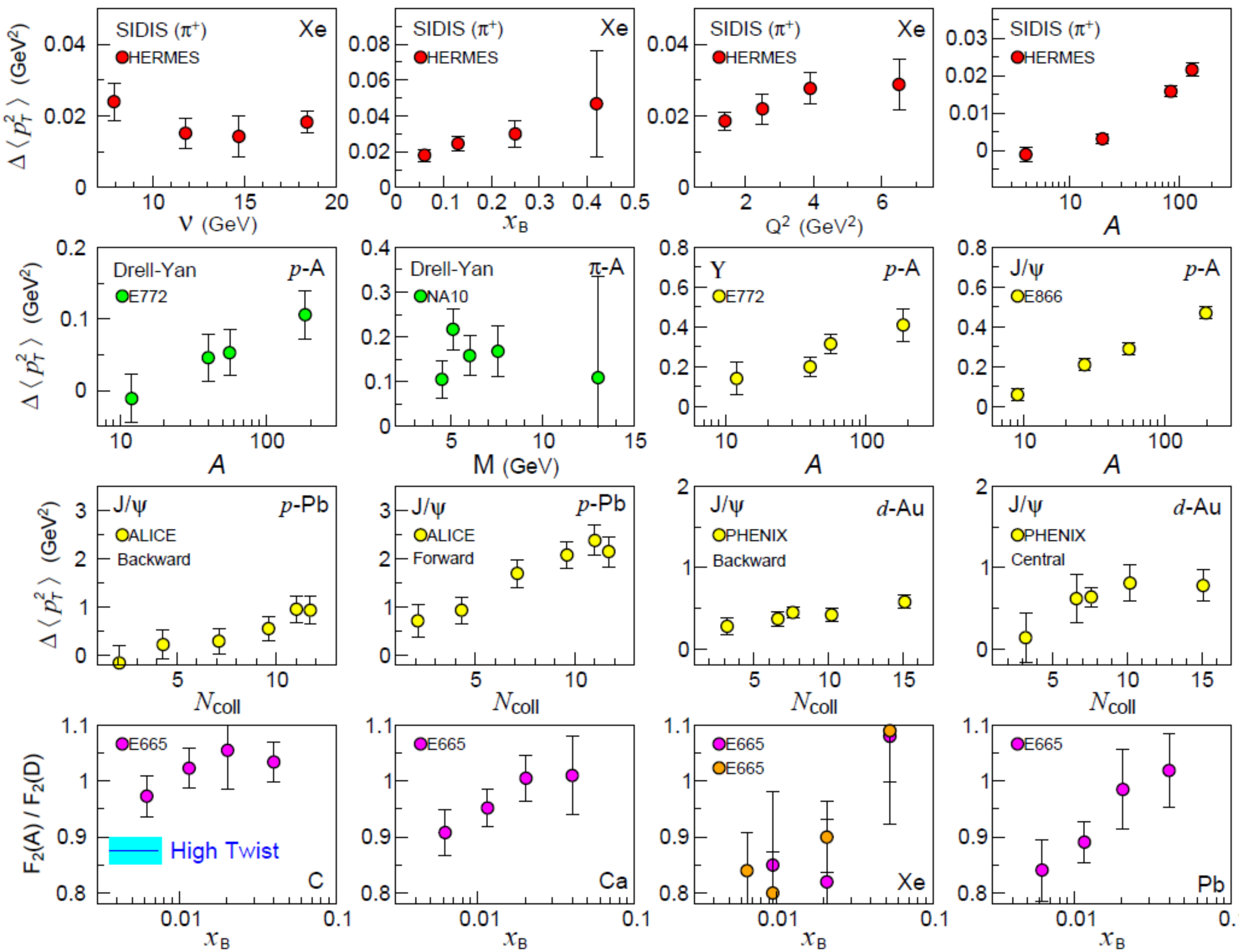
4 parameters to be fitted to data:

$$\hat{q}_0,\ \alpha,\ \beta,\ \gamma$$

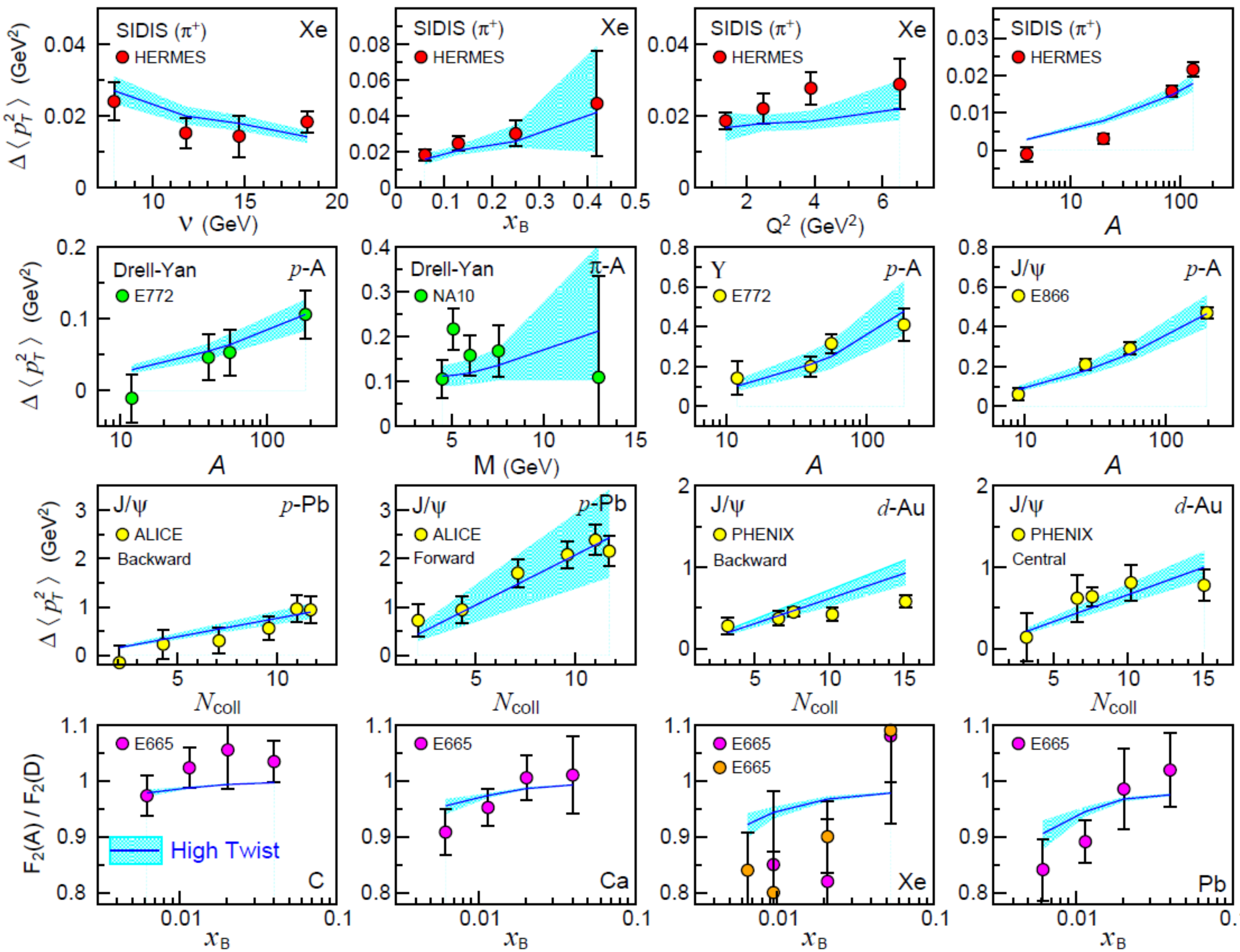
experiment	data type	data points	χ^2
HERMES [21]	SIDIS	156	189.7
FNAL-E772 [24]	DY	4	1.6
SPS-NA10 [29]	DY	5	6.5
FNAL-E772 [22, 26]	Υ	4	2.7
FNAL-E866 [23, 25]	J/ψ	4	2.4
RHIC [27]	J/ψ	10	31.0
LHC [28]	J/ψ	12	4.8
FNAL-E665 [34, 35]	DIS	20	21.5
TOTAL:		215	260.2

χ^2/NDP=1.21

Universality of medium property



Universality of medium property



Increases with x at large x

$\sim A^{1/3}$

$\propto N_{coll}$

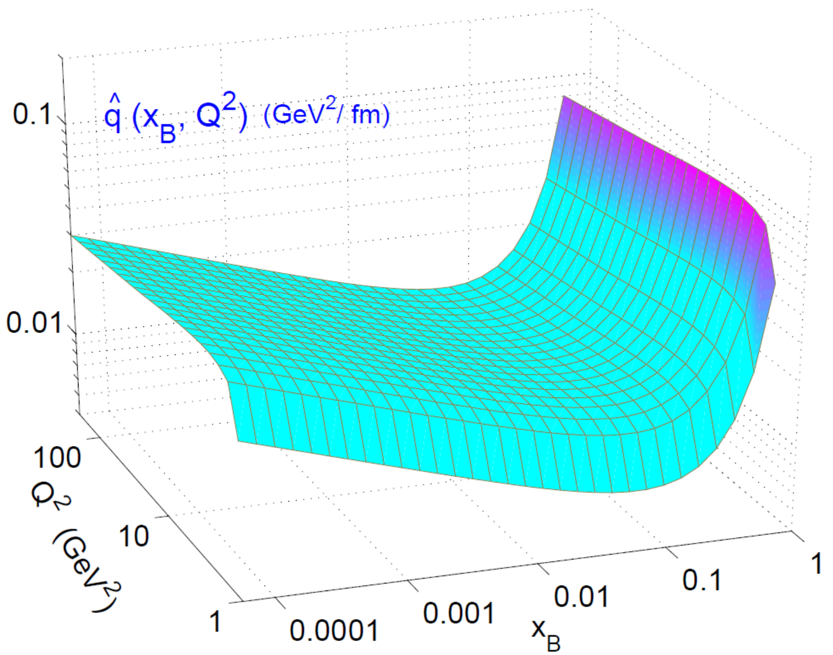
decreases with x at small x

Stronger shadowing for heavier nucleus

Further study and extension to Jet quenching in QGP

$$\hat{q}(x, Q^2) = \hat{q}_0 \alpha_s(Q^2) x^{\alpha} (1-x)^{\beta} [\ln(Q^2/Q_0^2)]^{\gamma}$$

$\hat{q}_0 = 0.022 \ \ \alpha = -0.174, \ \beta = -2.79, \ \gamma = 0.254$



- More data in wider kinematic range.
- NLO improvement.

Further study and extension to Jet quenching in QGP

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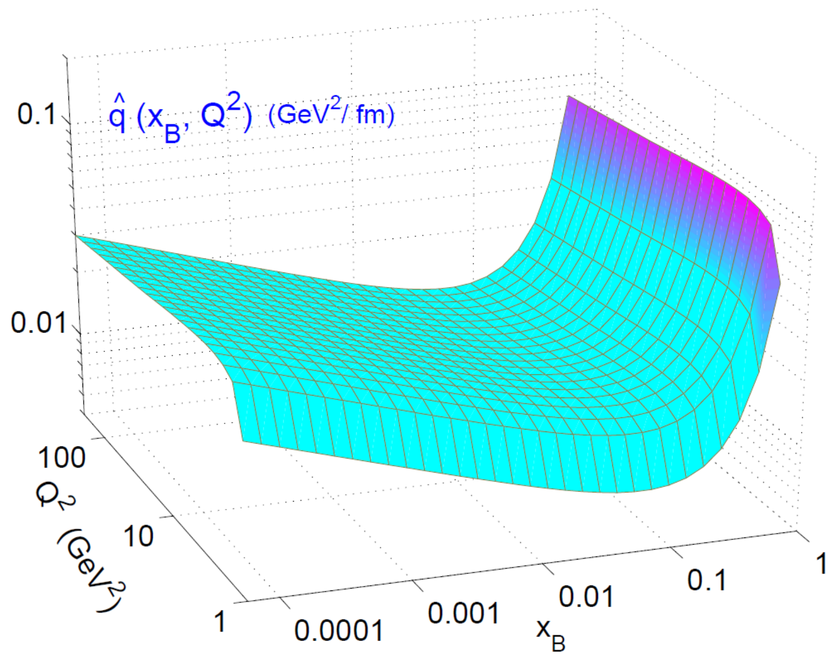

- More data in wider kinematic range.
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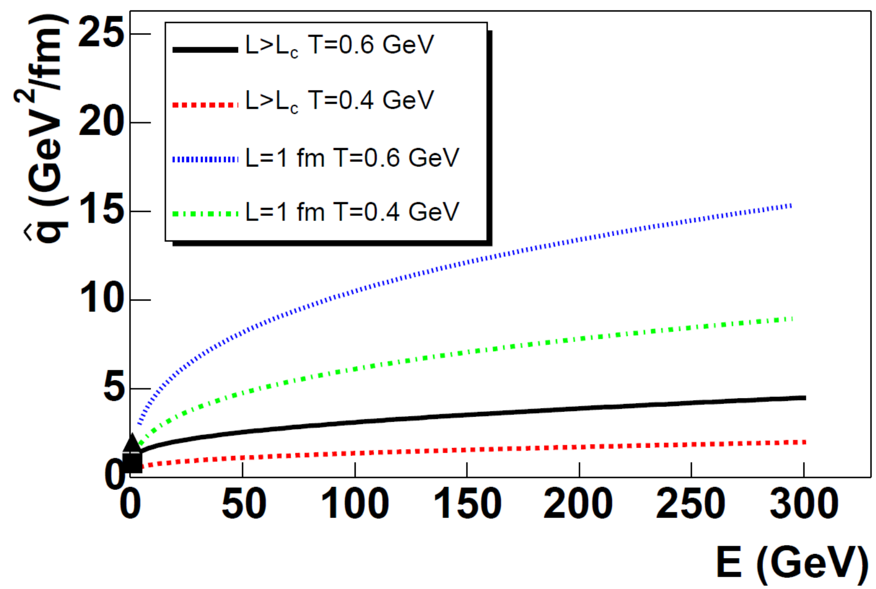
$\hat{q}$ in quark-gluon plasma

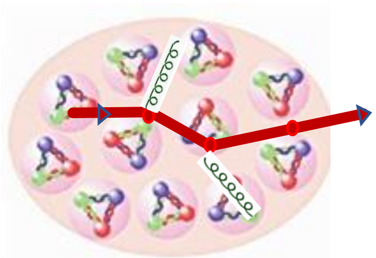
Jet energy dependence



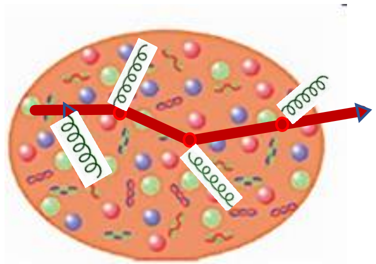
J. Casalderrey-Solana, X.-N. Wang
PRC,77, 024902 (2008)

Summary

- First global analysis of $\hat{q}$ for cold nuclear matter.
- A unified description of data within framework of generalized factorization in pQCD (high-twist).
- First quantitative evidence of the universality and kinematics and probing scale dependence of nuclear medium property.
- Can be extended to precisely understand jet quenching in heavy ion collisions.



Cold nuclear matter



Quark gluon plasma

Summary

Thanks for your attention!

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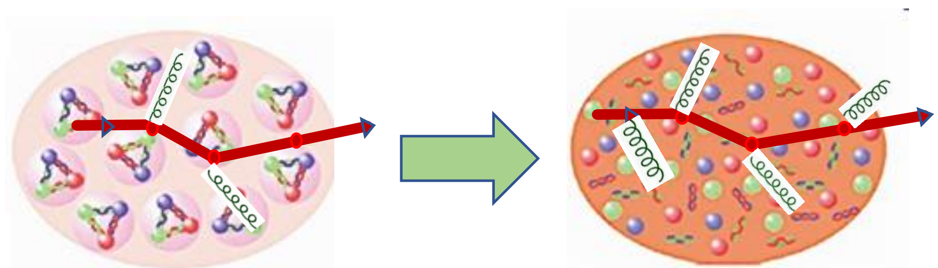

Cold nuclear matter　　　Quark gluon plasma

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