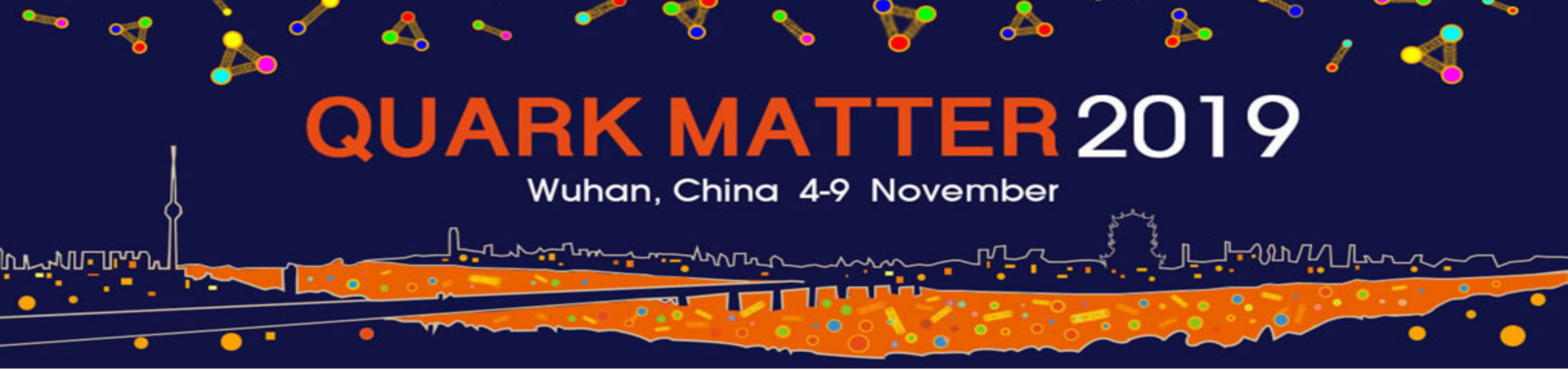


Extracting jet transport coefficient of cold nuclear matter

Hongxi Xing

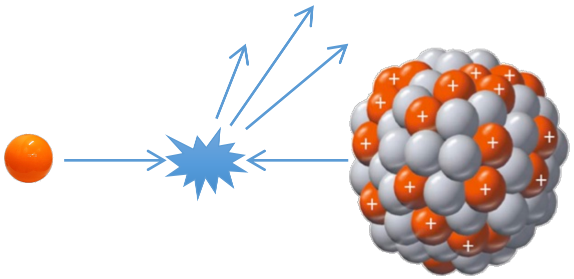
Many thanks to my collaborators: Z. Kang, J. Qiu, P. Ru, E. Wang, X. Wang and B. Zhang
arXiv: 1907.11808

Institute of Quantum Matter
South China Normal University

Why are we interested in cold nuclear matter?

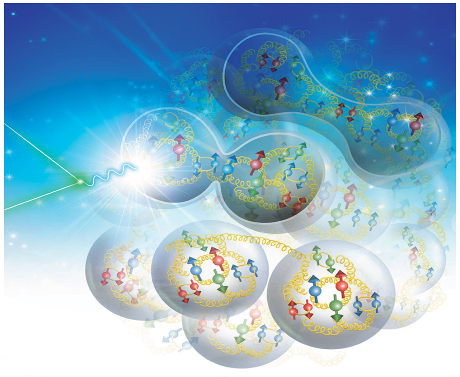
❑ Collision systems

Proton-nucleus collision



RHIC, LHC

Electron-ion collision



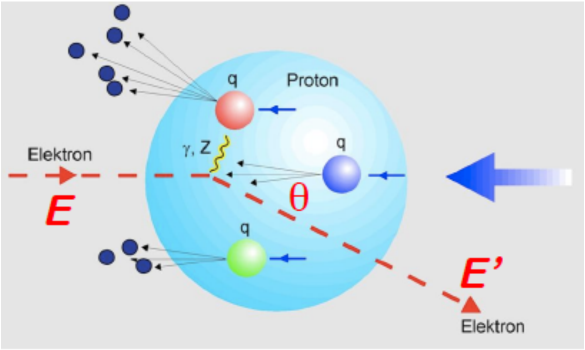
EIC, EicC

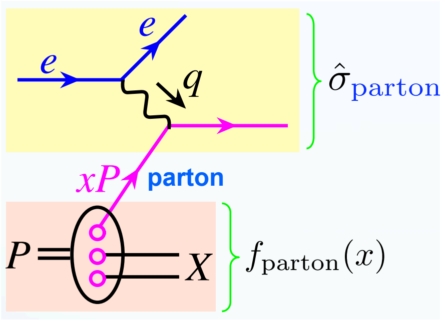
❑ Multi-purposes

- Mapping out the fundamental structure of nuclear matter
- Test of QCD factorization: high-twist, small-x saturation
- Baseline for nucleus-nucleus collision program

QCD factorization theorem

❑ QCD factorization in deep inelastic scattering





- Question: cross section involving identified hadron(s) is **not** infrared safe
  Hadronic scale ~ 1/fm is non-perturbative, the cross section is **not** perturbative calculable.

- Solution from theory advances: QCD factorization theorem

Cross Section $=$ **Infrared-Safe** $\otimes$ **Nonperturbative-distribution**

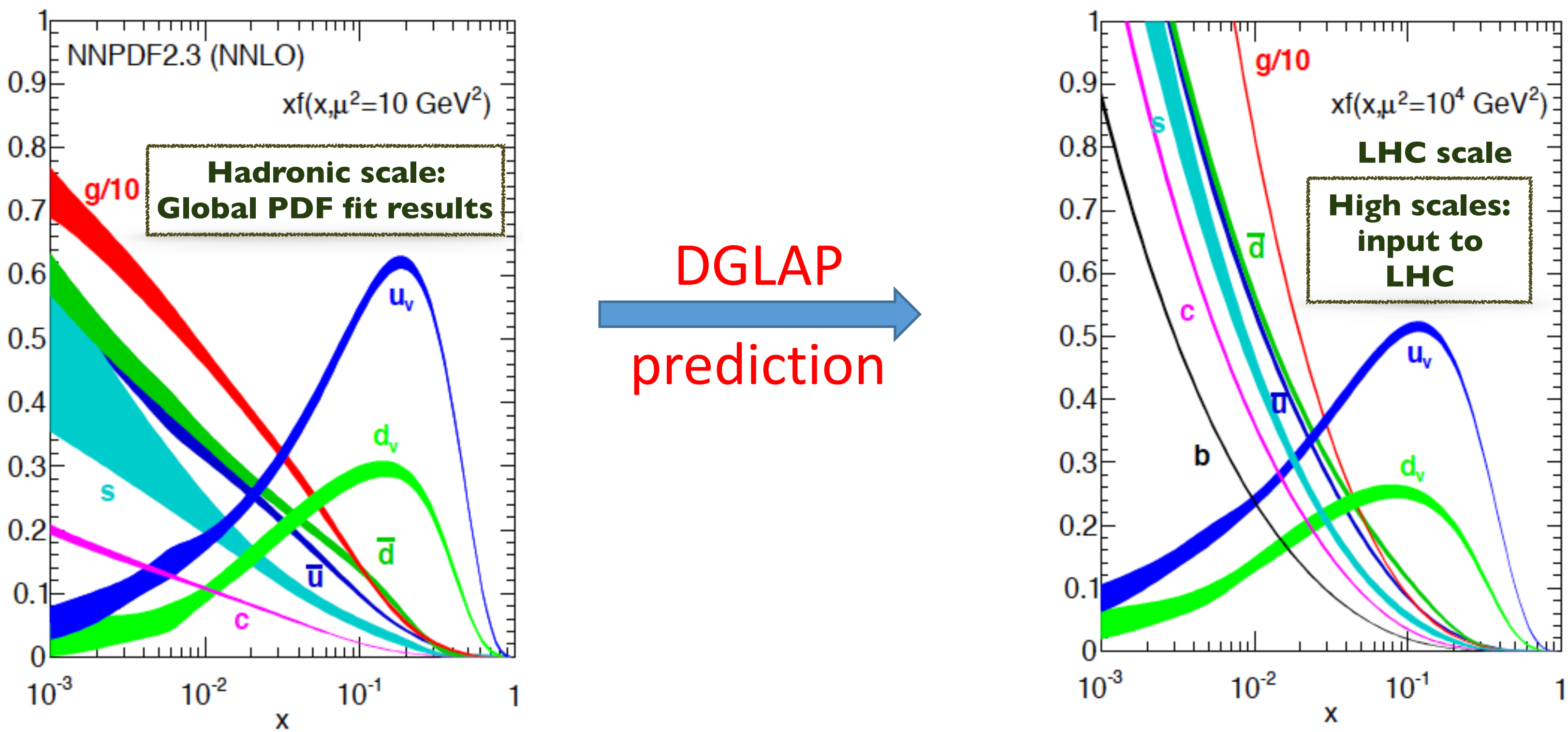
↑ **Measured** ↑ **Hard-probe** ↑ **Universal-hadron structure**

The predictive power of pQCD

- Predict the proton inner structure with higher resolution scale

$$\sigma_{\text{proton}}(Q) = f_{\text{parton}}(x) \otimes \hat{\sigma}_{\text{parton}}(Q)$$

Universal (measured) **calculable**

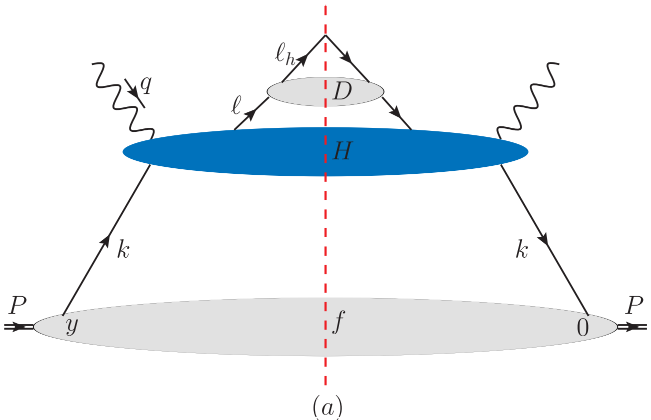


Proton structure is encoded in the Parton Distribution Functions (PDFs)
PDFs: probability density for finding a parton in a proton with momentum fraction x.

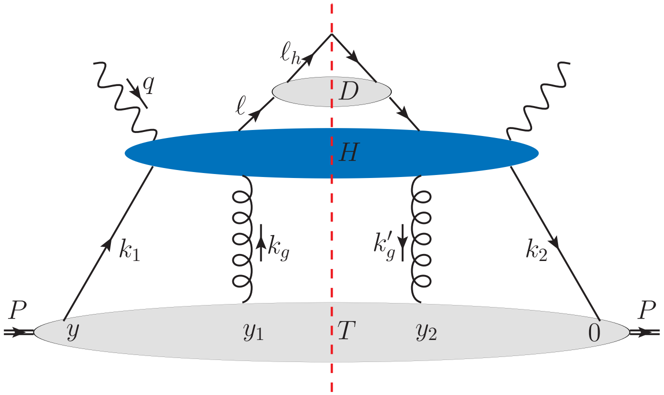
QCD factorization for double scattering

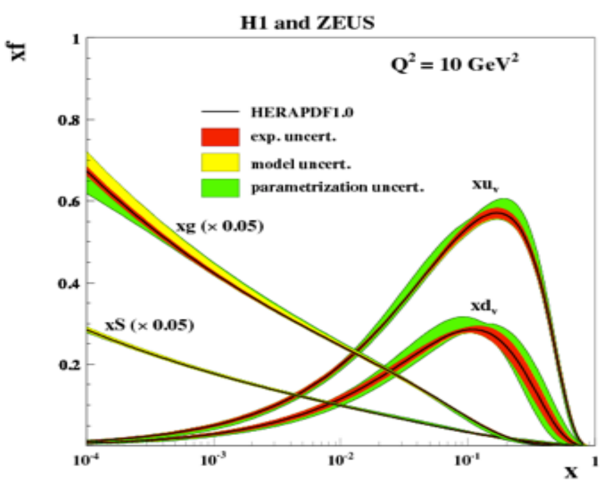
- SIDIS as an example to show QCD factorization for final state double scattering

Single scattering



Double scattering

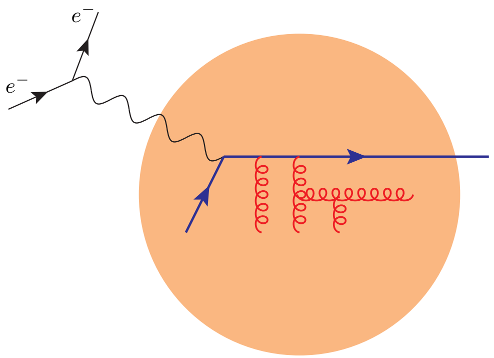


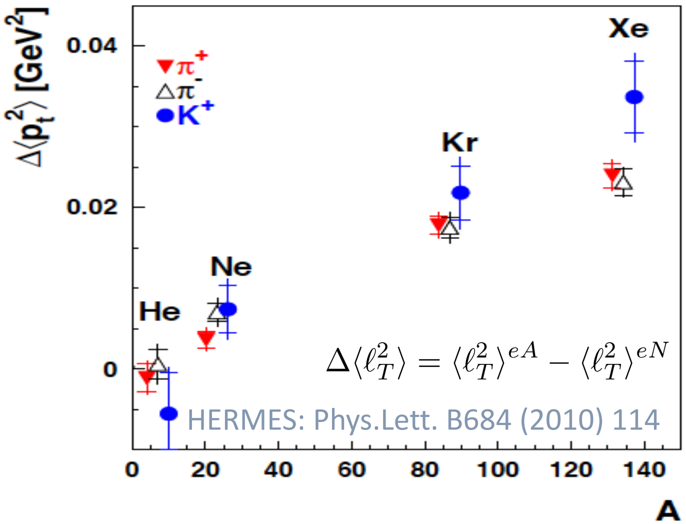


A good observable to probe nuclear medium

- Transverse momentum broadening

Guo, 1998; Guo, Qiu 2000





- Sensitive to nuclear quark-gluon quantum correlation (jet transport coefficient)

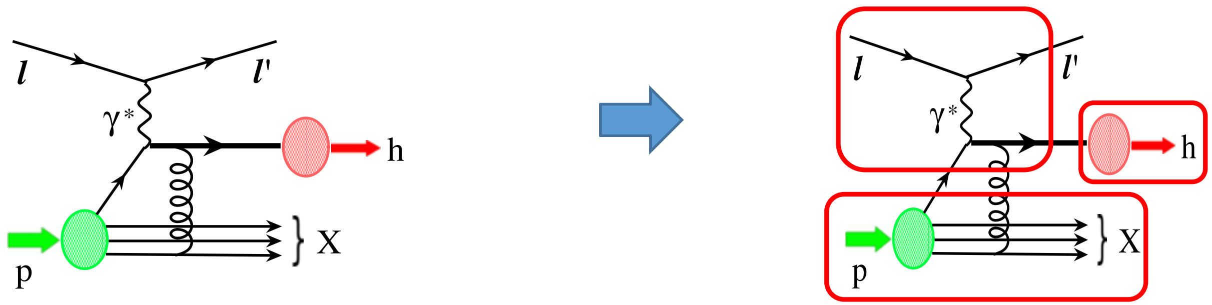
$$\Delta\langle \ell_{hT}^2\rangle = \langle \ell_{hT}^2\rangle_{eA} - \langle \ell_{hT}^2\rangle_{ep} = \left(\frac{4\pi^2\alpha_s}{N_c} z_h^2\right) \frac{\sum_q e_q^2 \boxed{T_{qg}(x_B,0,0)} D_{h/q}(z_h)}{\sum_q e_q^2 f_{q/A}(x_B) D_{h/q}(z_h)}$$

- A direct probe of the nuclear quark-gluon quantum correlation
- Characterize the fundamental nuclear QCD structure
- Phenomenological applications to investigate properties of quark-gluon plasma

PRL **112,** 102001 (2014) PHYSICAL REVIEW LETTERS week ending 14 MARCH 2014

Next-to-Leading Order QCD Factorization for Semi-Inclusive Deep Inelastic Scattering at Twist 4

Zhong-Bo Kang,[1] Enke Wang,[2] Xin-Nian Wang,[2,3] and Hongxi Xing[1,2,4]



✓ **Verification of QCD factorization theorem for double scattering at NLO**

$$\frac{d\langle \ell_{hT}^2 \sigma\rangle}{dz_h} \propto D_{q/h}(z,\mu^2)\otimes H^{LO}(x,z)\otimes T_{qg}(x,0,0,\mu^2) + \frac{\alpha_s}{2\pi} D_{q/h}(z,\mu^2)\otimes H^{NLO}(x,z,\mu^2)\otimes T_{qg(gg)}(x,0,0,\mu^2)$$

Multiple scattering (hard probe) and medium properties can be factorized!!!

❑ Resolution scale dependence of nuclear q-g correlation function

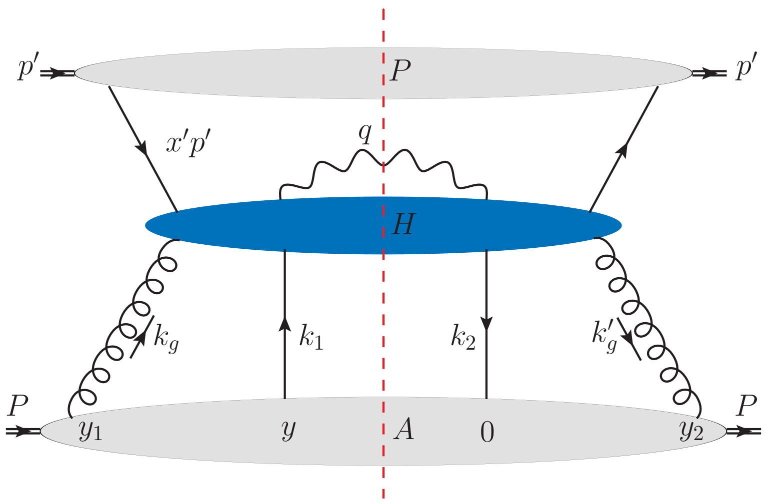
$$\mu_f^2 \frac{\partial}{\partial \mu_f^2} T_{qg}(x_B,0,0,\mu_f^2) = \frac{\alpha_s}{2\pi}\int_{x_B}^{1}\frac{dx}{x}\left[\mathcal{P}_{qg\to qg}\otimes T_{qg} + P_{qg}(\hat{x})T_{gg}(x,0,0,\mu_f^2)\right]$$

First time we derived how medium properties evolve with probing scale.

Universality of nuclear medium property

- NLO transverse momentum broadening for Drell-Yan dilepton production in pA collisions

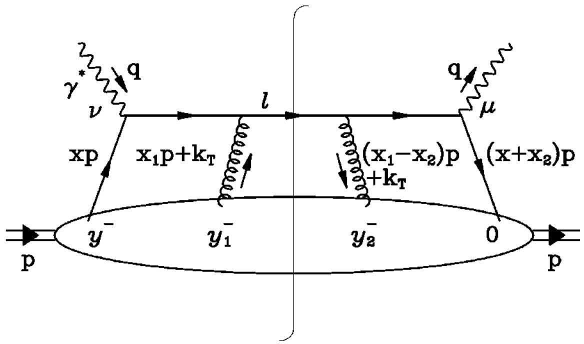
Kang, Qiu, Wang, **HX**, PRD (2016)



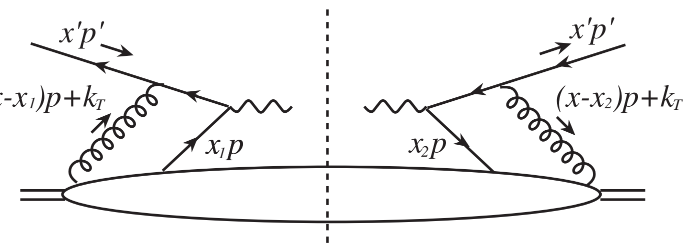
- Factorization of initial state double scattering (DY twist-4)
- Process dependence of partonic multiple scattering
- Universality of twist-4 quark-gluon correlation function (universality of medium property)

Transverse momentum broadening in CNM

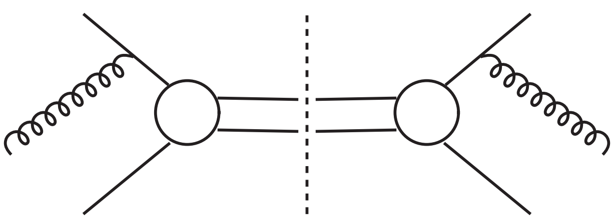
❑ Transverse momentum broadening in eA and pA collisions



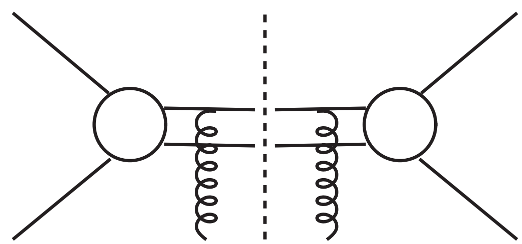
SIDIS



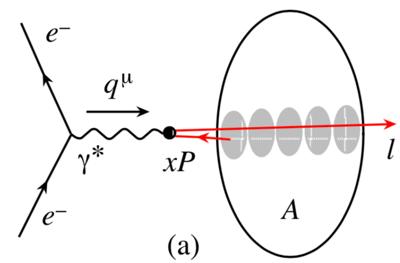
Drell-Yan



Heavy quarkonium
Initial state multiple scattering



Heavy quarkonium
Final state multiple scattering



Dynamic shadowing
in DIS

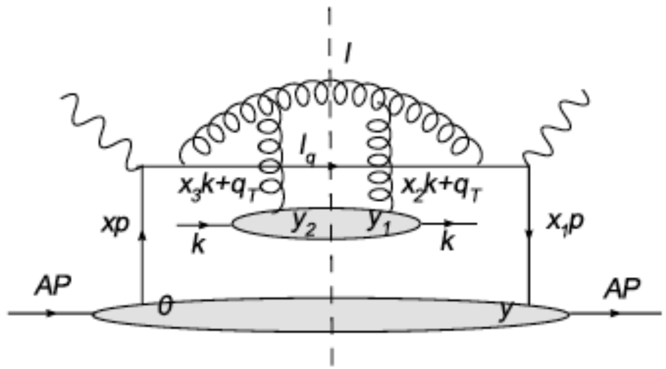
Kang, Qiu, PRD, 2008, 2012

Qiu, Vitev, PRL, 2006

❑ Parametrization of jet transport coefficient

$$\Delta\langle p_T^2\rangle = \langle p_T^2\rangle_{eA} - \langle p_T^2\rangle_{ep} \sim T_{qg/gg}(x,0,0)$$

- Considering a large and loosely bound nucleus



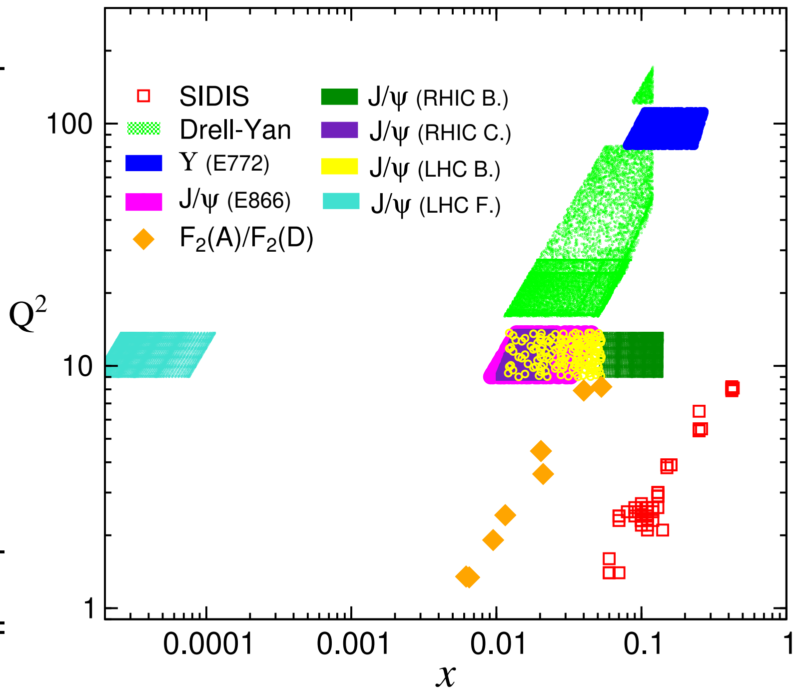
$$T_{qg}(x,0,0,\mu^2) \approx \frac{9R_A}{8\pi^2\alpha_s} f_{q/A}(x,\mu^2)\hat{q}(x,\mu)$$

Medium property is encoded in jet transport coefficient qhat.

Global analysis of the world data

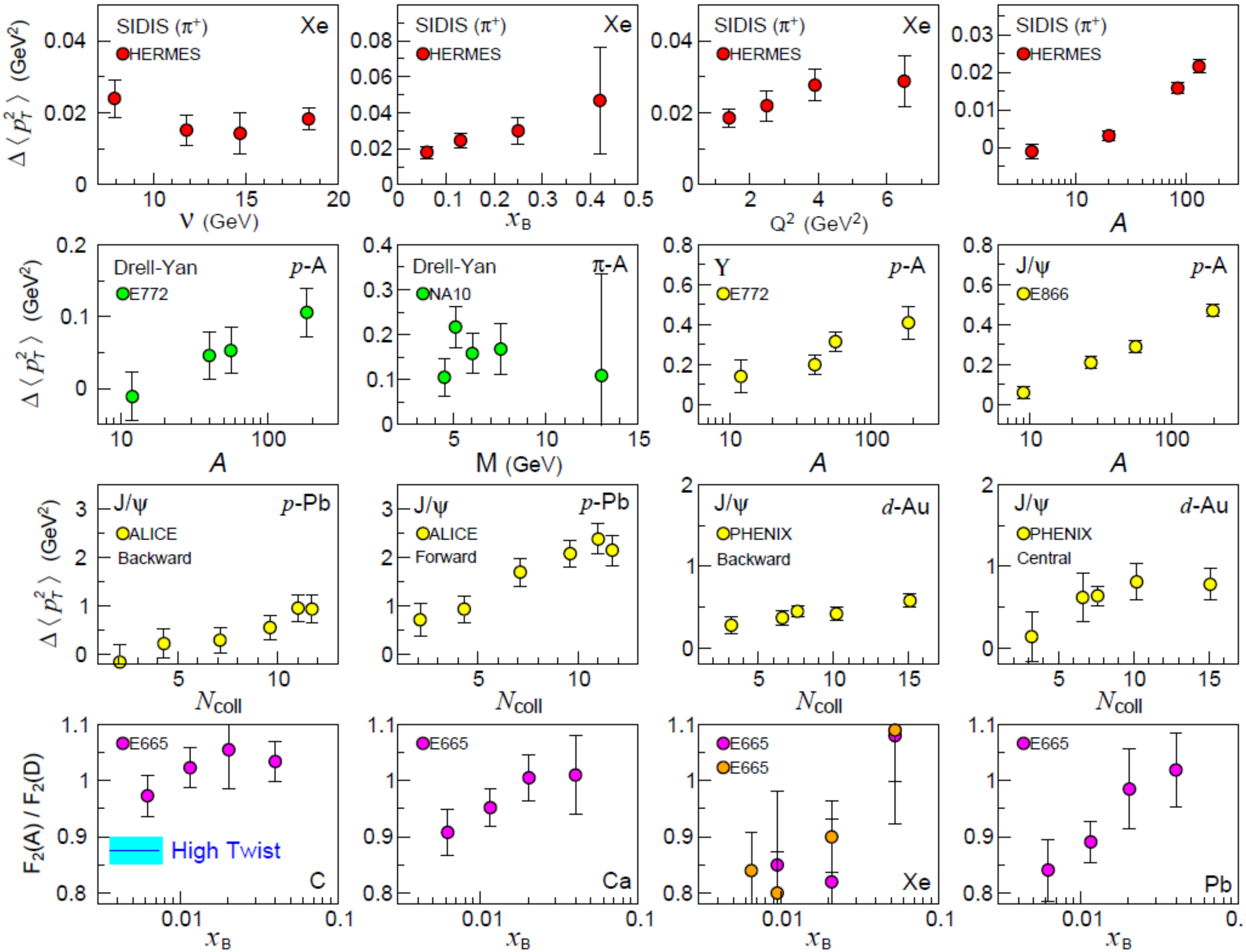
❑ Data included in our global fit

experiment	data type	data points
HERMES [21]	SIDIS	156
FNAL-E772 [24]	DY	4
SPS-NA10 [29]	DY	5
FNAL-E772 [22, 26]	Υ	4
FNAL-E866 [23, 25]	J/ψ	4
RHIC [27]	J/ψ	10
LHC [28]	J/ψ	12
FNAL-E665 [34, 35]	DIS	20
TOTAL:		215



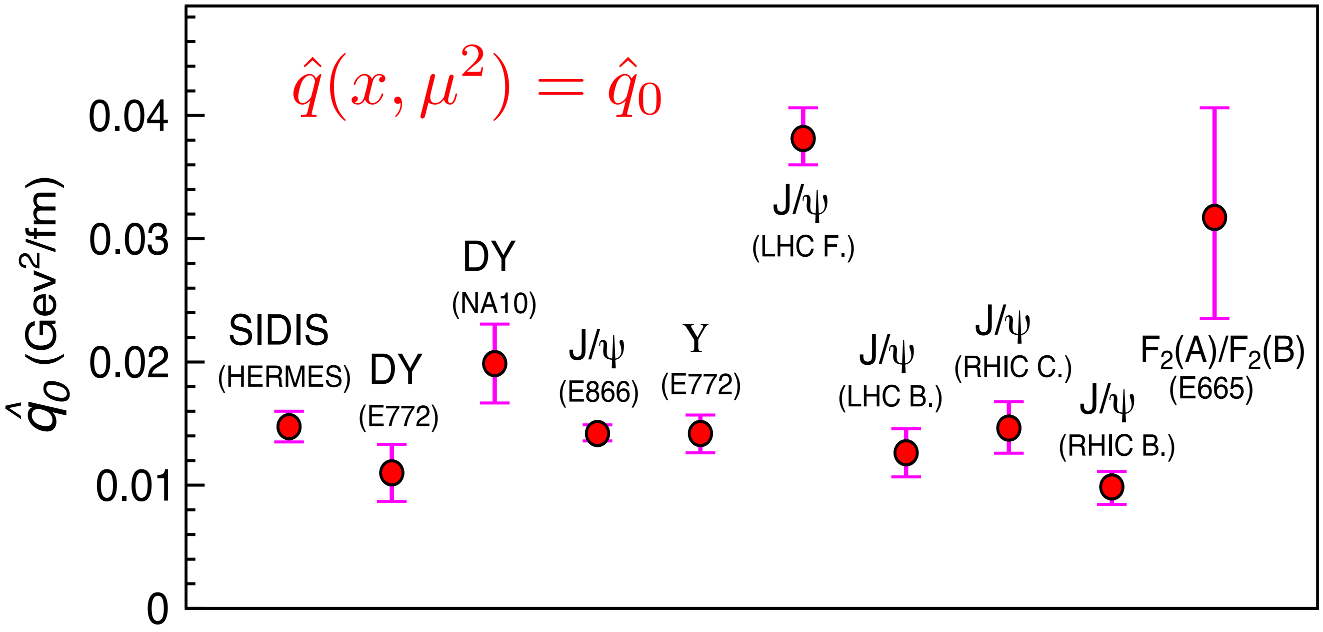
- 215 data points from four processes, the collision energy ranging from 7.5 GeV to 5.02 TeV
- Current data sets are mainly located in the intermediate x and Q^2 region.

❑ Data included in our global fit



Global analysis of the world data

- Constant qhat -> Non-universality of medium property?



- The global fit with constant qhat fails to converge.
- The fitted qhat values for individual observable are not consistent, can differ by a factor of 2-4. This indicates the medium property is not universal, which is wrong!

Need non-trivial kinematic and scale dependent qhat.

Global analysis of the world data

❑ Kinematic and scale dependence of qhat

$$\hat{q}(x,\mu^2) = \hat{q}_0\,\alpha_s(\mu^2)\,x^\alpha(1-x)^\beta\,\ln^\gamma(\mu^2/\mu_0^2)$$

normalization

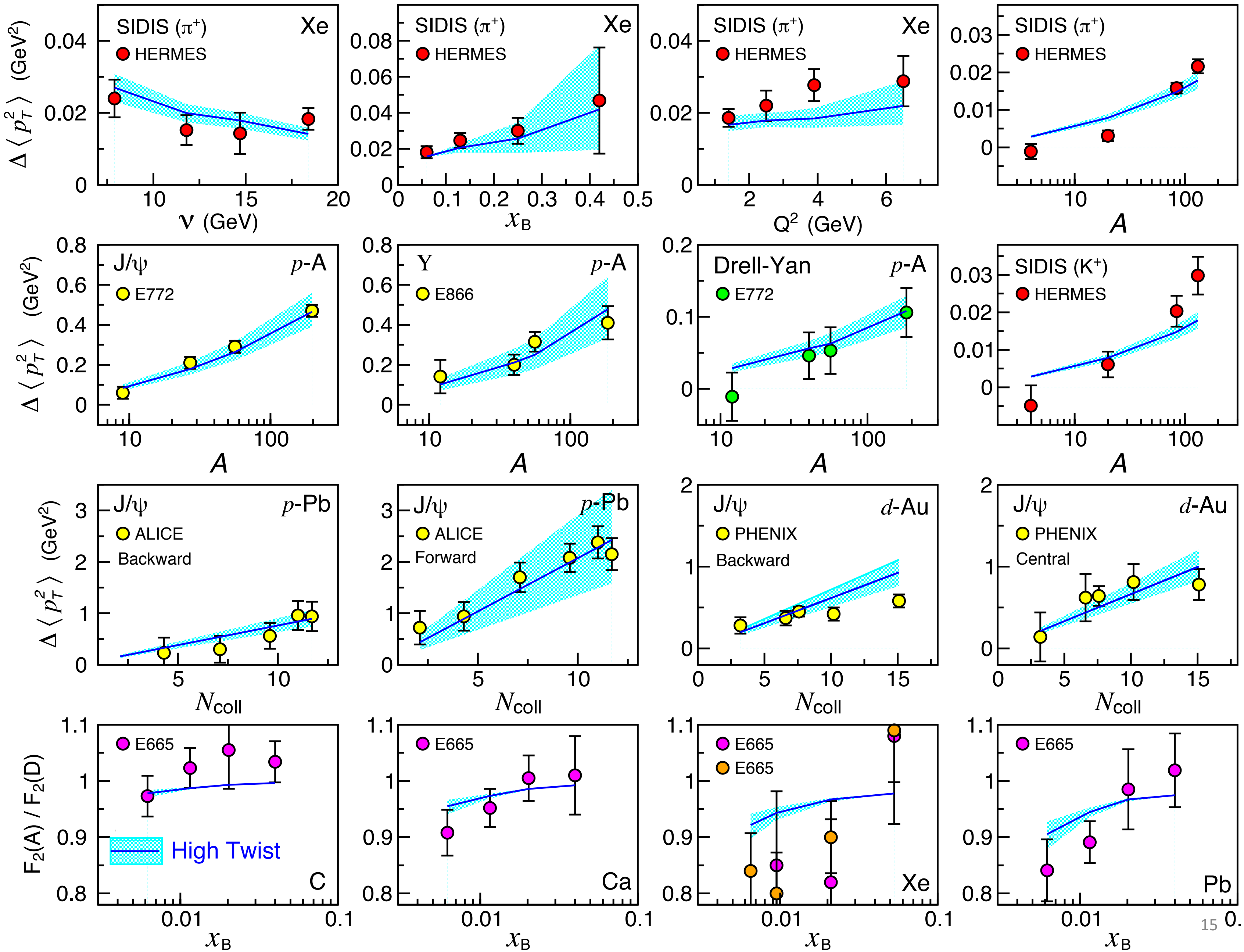
Small-x saturation

Large-x power correction

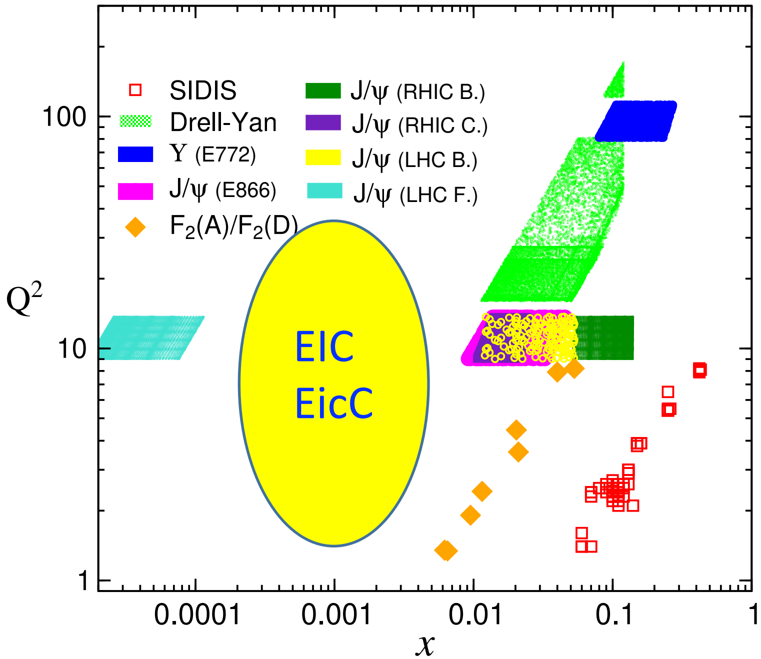
Scale dependence

Four free parameters to be fitted to data.

❑ Global analysis of world data



❑ Kinematic coverage and fitted qhat

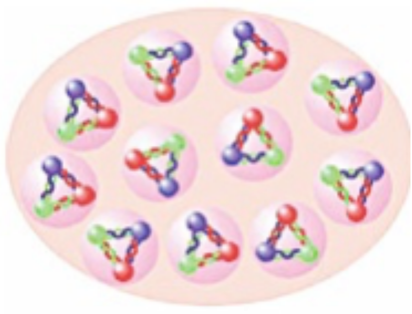


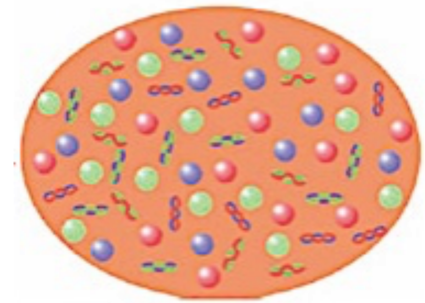
experiment	data type	data points	χ^2
HERMES [21]	SIDIS	156	189.7
FNAL-E772 [24]	DY	4	1.6
SPS-NA10 [29]	DY	5	6.5
FNAL-E772 [22, 26]	Υ	4	2.7
FNAL-E866 [23, 25]	J/ψ	4	2.4
RHIC [27]	J/ψ	10	31.0
LHC [28]	J/ψ	12	4.8
FNAL-E665 [34, 35]	DIS	20	21.5
TOTAL:		215	260.2

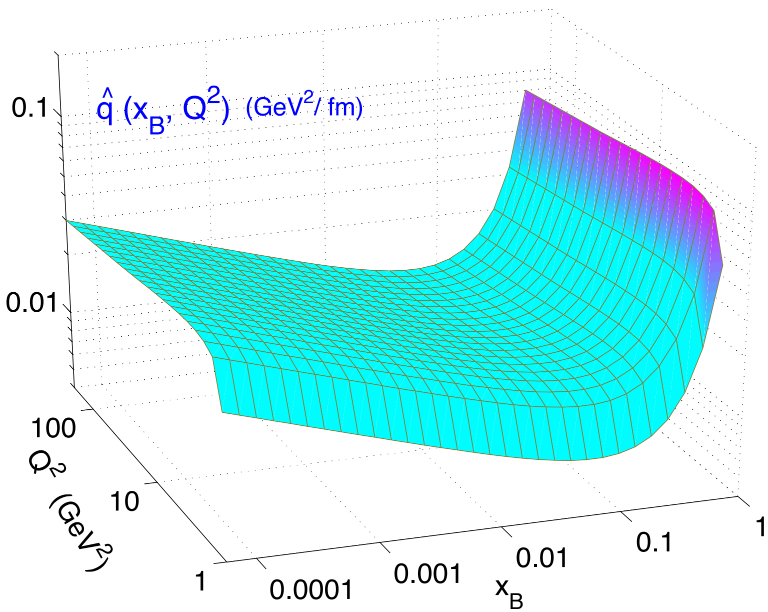
$$\hat{q}_0 = 0.02GeV^2/fm,\ \alpha = -0.17,\ \beta = -2.79,\ \gamma = 0.25$$

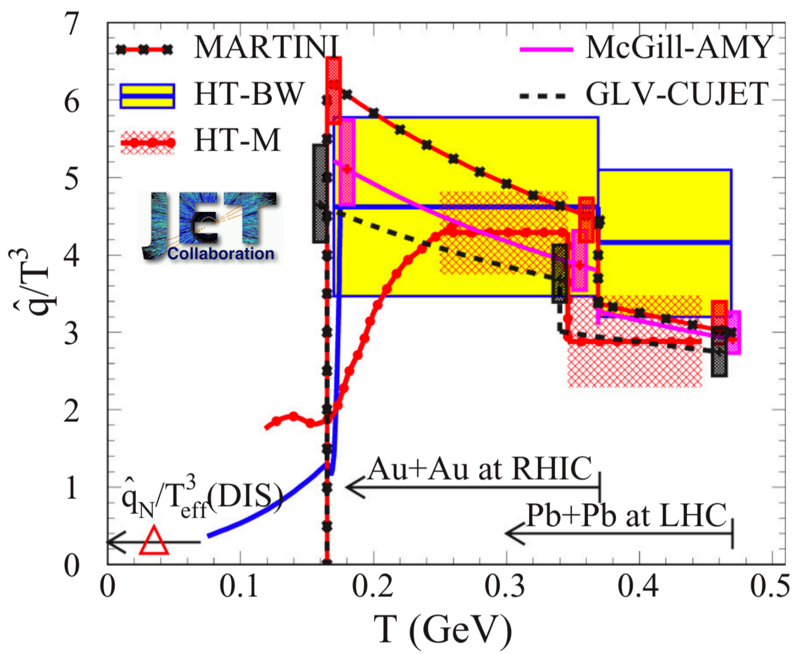
Extension to QGP

- Jet transport in hot dense medium









Summary

- Jet transport coefficient represents the fundamental property of nuclear medium, characterizes the interaction strength between hard probe and medium.
- We show explicitly the validation of QCD factorization for double scattering in eA and pA collisions at NLO.
- First time determination of the parametrization form of jet transport coefficient through a global analysis of world data on transverse momentum broadening in eA and pA collisions.

Summary

- Jet transport coefficient represents the fundamental property of nuclear medium, characterizes the interaction strength between hard probe and medium.

- We show explicitly the validation of QCD factorization for double scattering in eA and pA collisions at NLO.

- First time determination of the parametrization form of jet transport coefficient through a global analysis of world data on transverse momentum broadening in eA and pA collisions.

Thanks for your attention!