Ivan Vitev

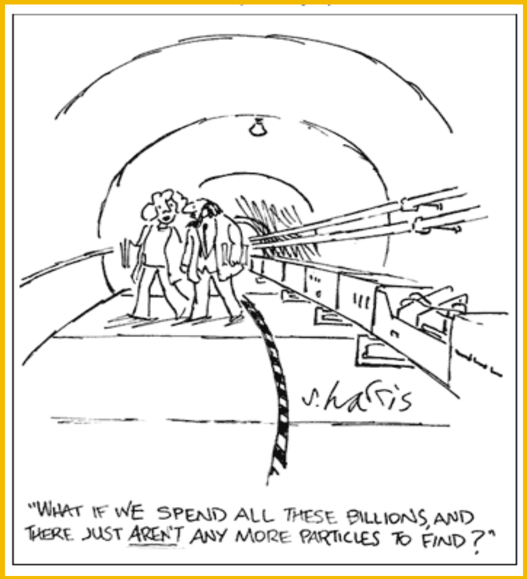
Jets and nuclear modifications at EIC

Next generation nuclear physics with JLab12 and EIC
Miami, FL, February 10 – 13, 2016

Outline of the Talk

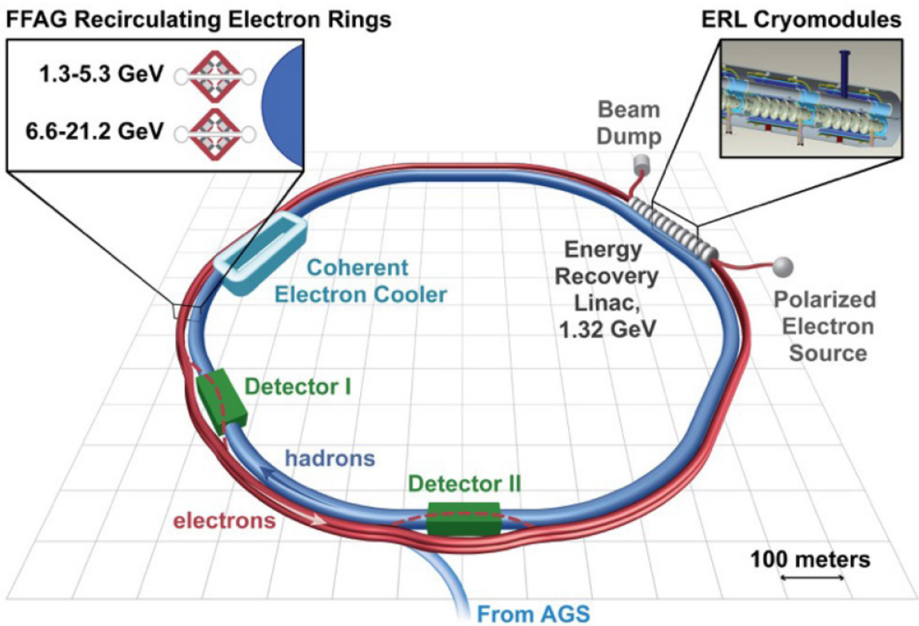
- EIC, design and kinematics suitable for jet physics. Qualitative expectation, comparison between heavy ion collisions and SIDIS/ jet production in DIS. SCET and formal developments
- Hadron production and attenuation in semi-inclusive DIS. Energy loss and hadron absorption. QCD evolution techniques to in-medium modification of fragmentation functions
- Reconstructed jets at the EIC, jet cross sections. Jet substructure observables in DIS, jet shapes and jet fragmentation functions
- Event shapes at the EIC. Thrust and N-jettiness, extraction of the strong coupling constant. Polarized reactions at EIC
- Summary of EIC physics that can be addressed with jets

I. Background and comparison



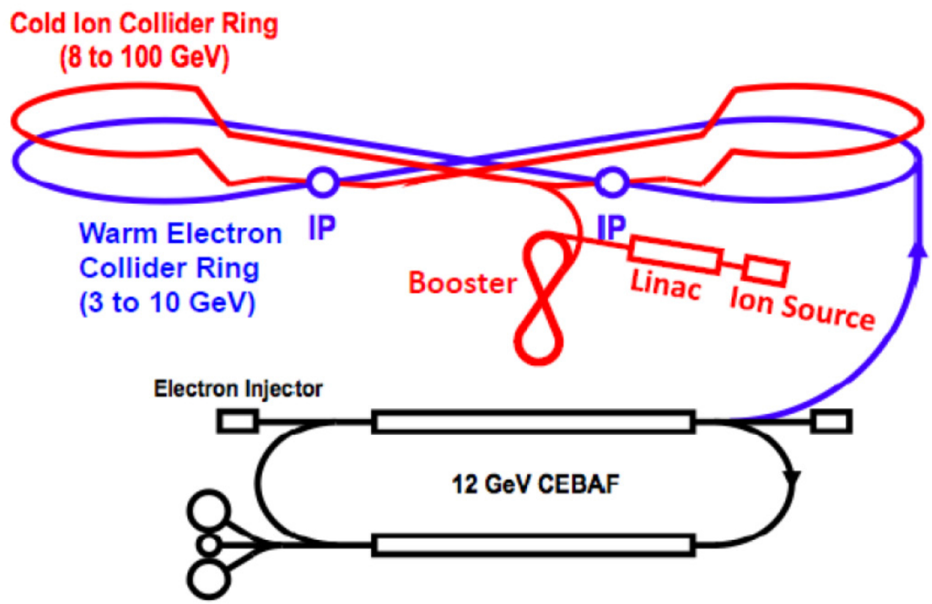
EIC design and capabilities

BNL design



- 5-10 GeV electron ring (upgradable to 20-30 GeV)
- 50-250 GeV proton/ion

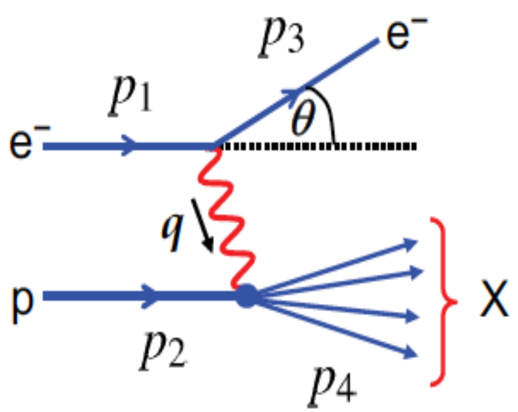
JLab design



- 3-10 GeV electron ring
  10-100 GeV proton/ion

NSAC long range plan (2015)

The accessible jet energy



$$Q^2 \equiv -q^2 = -(k - k')^2$$

$$y \equiv \frac{P \cdot q}{P \cdot k}$$

$$x \equiv \frac{Q^2}{2P \cdot q}$$

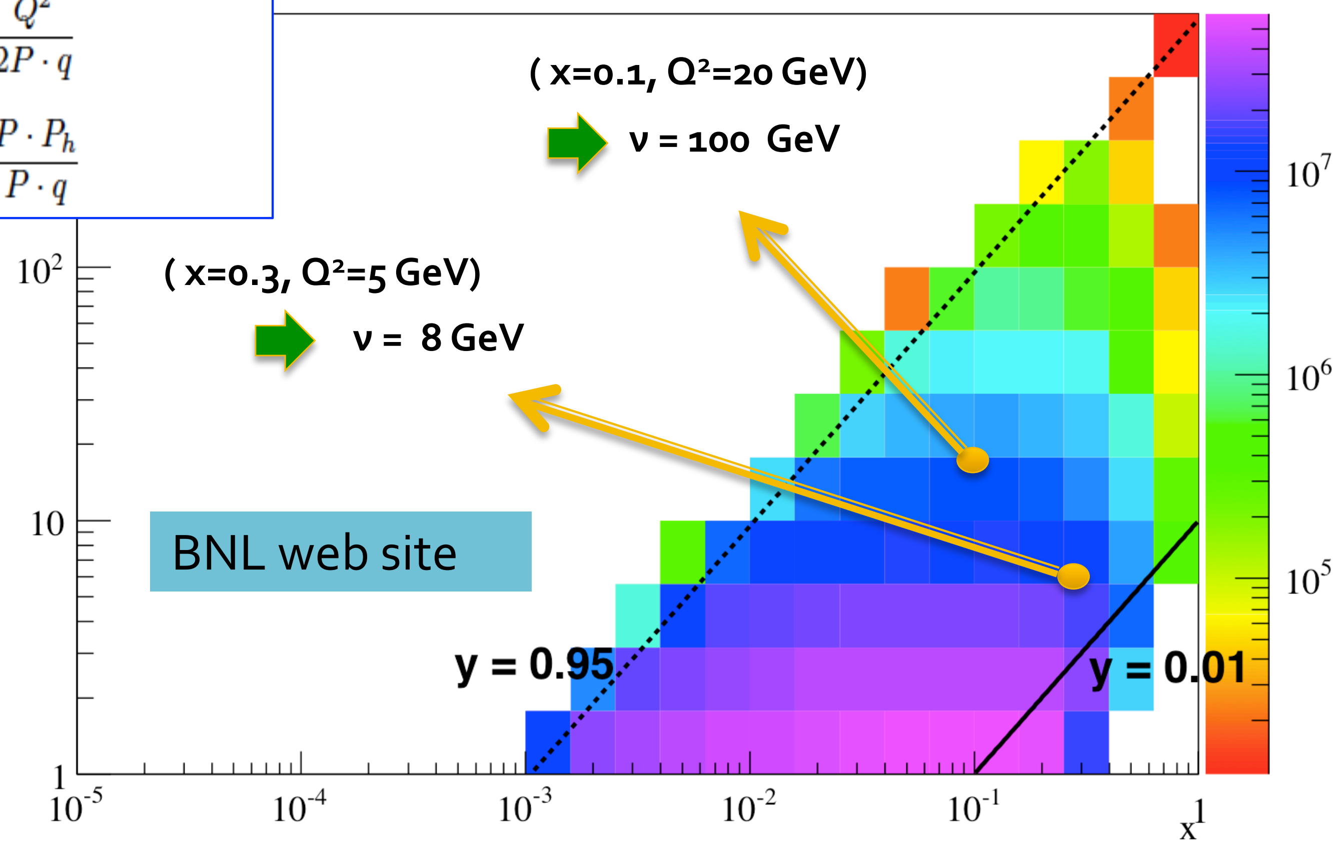
$$z \equiv \frac{P \cdot P_h}{P \cdot q}$$

$$x = \frac{Q^2}{2M\nu}$$

- The important quantity is the energy of the struck quark (patron) in the rest frame of the nucleus, ν

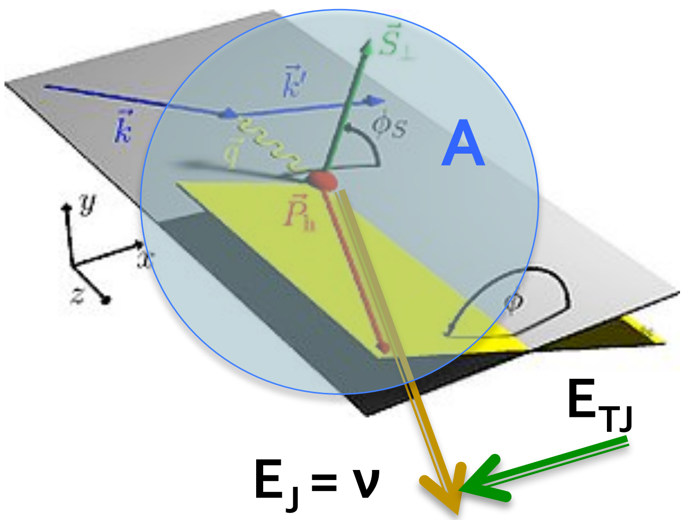
- Let's take an example that covers both designs

Energies 5 x 50 GeV

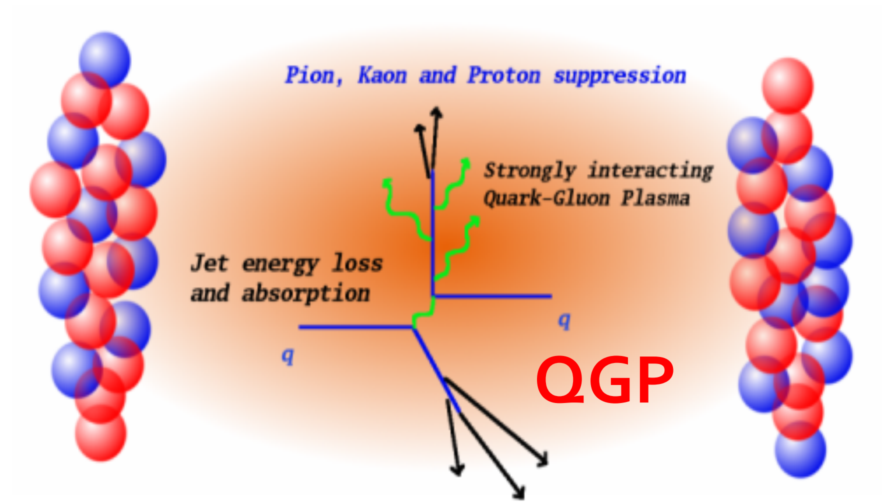


Comparison to RHIC and LHC jet energies

- Medium-induced parton shower modification is evaluated in the rest frame of the medium



ν in the range
(5 GeV – 200 GeV)

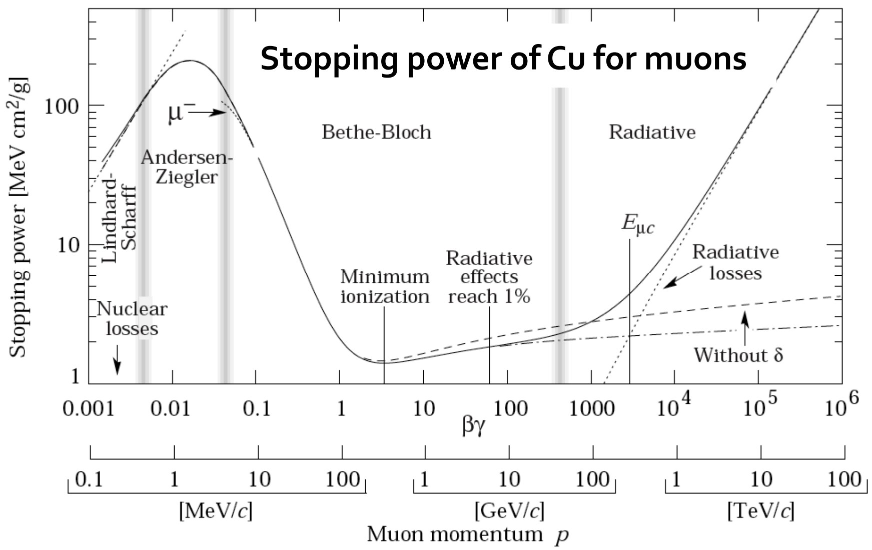


p_T / E_T in the range
(5 GeV – 200 GeV)

- EIC will cover jet energy ranges where the bulk of the jet quenching phenomena are at RHIC and LHC. Note that we are interested in ν

Parton energy loss at the EIC

- The stopping power of matter is fundamental probe of the matter properties, in QED known to 1-2%



B. Zakharov, (1996)

R. Baier et al., (1997)

M. Gyulassy et al., (2000)

X. Guo et al., (2001)

P. Arnold et al., (2003)

The nature of the QCD theory gives rise to novel phenomena, such as the non-Abelian LPM effect

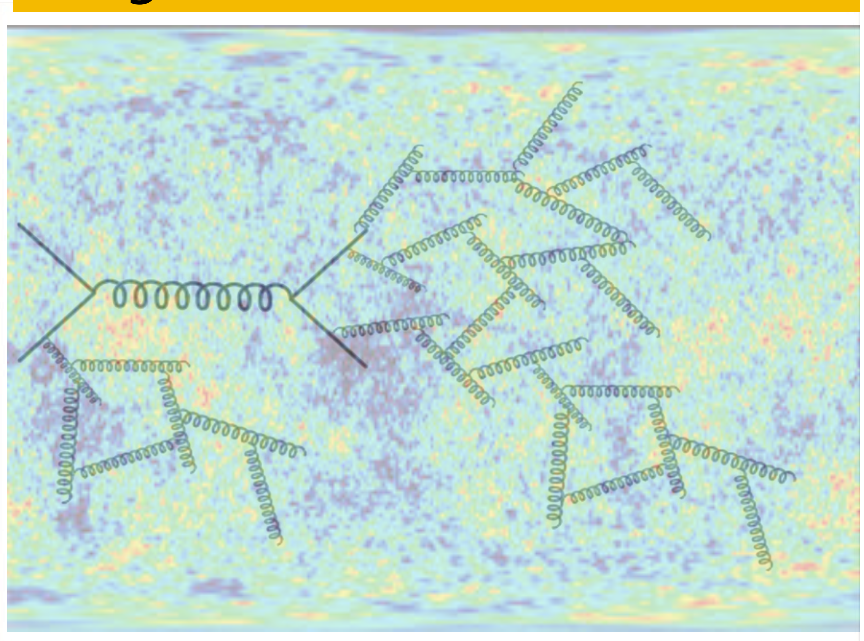
Parametric high energy behavior

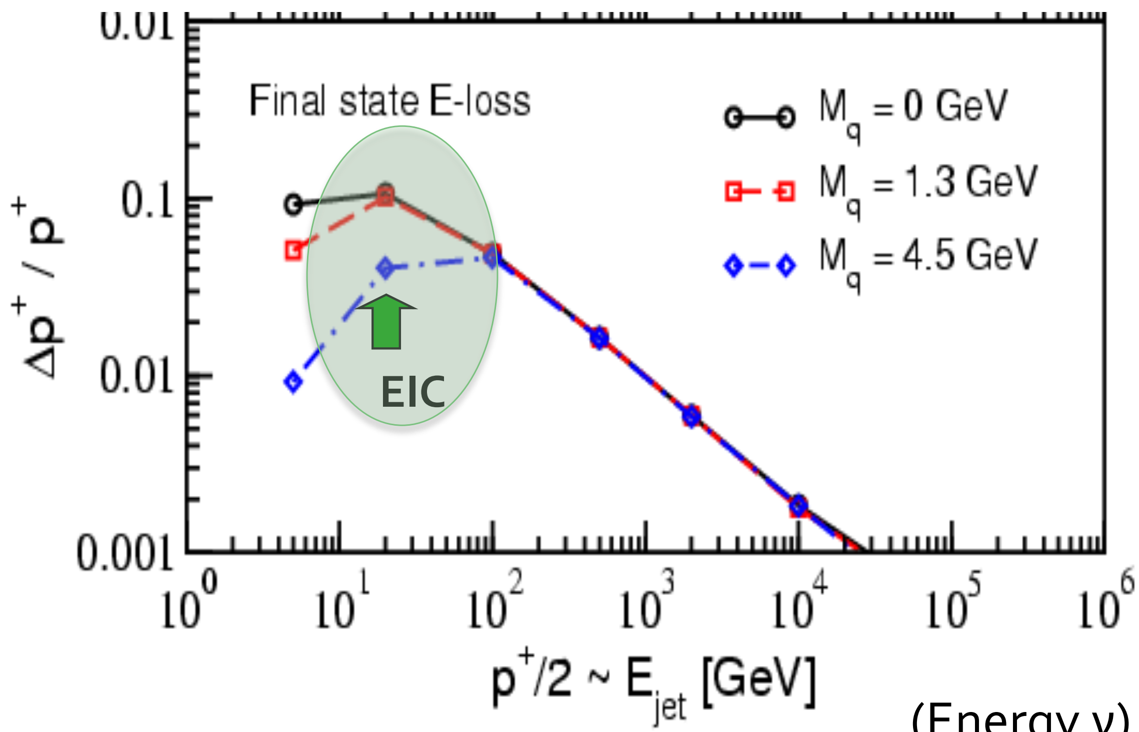
$$k^+ \frac{dN_g}{dk^+ d^2 k_\perp} \sim \left[\sum_{m=1}^{n} \left(\cos\left(\sum_{k=2}^{m} \omega_{(k\ldots n)} \Delta z_k \right) - \cos\left(\sum_{k=1}^{m} \omega_{(k\ldots n)} \Delta z_k \right) \right) \right] \Rightarrow \frac{\Delta E}{E} \propto \frac{\mu^2 L^2}{\lambda_g} \frac{\ln E / Q_0}{E}$$

- For processes that involve hard scattering there is cancellation of the medium-induced bremsstrahlung at very high energies

The strength of the jet modification at EIC

- A scenario where the parton shower forms in the strong background gluon field of the nucleus





(Energy ν)

IV., 2007

- We expect parton energy loss, or more generally, the redistribution of the energy between vacuum and medium induced showers, to be factor of 2 (RHIC)-3 (LHC) smaller than in the QGP but not orders of magnitude smaller. From this point of view, lower energy is good

New development: common approach to jet-medium interactions

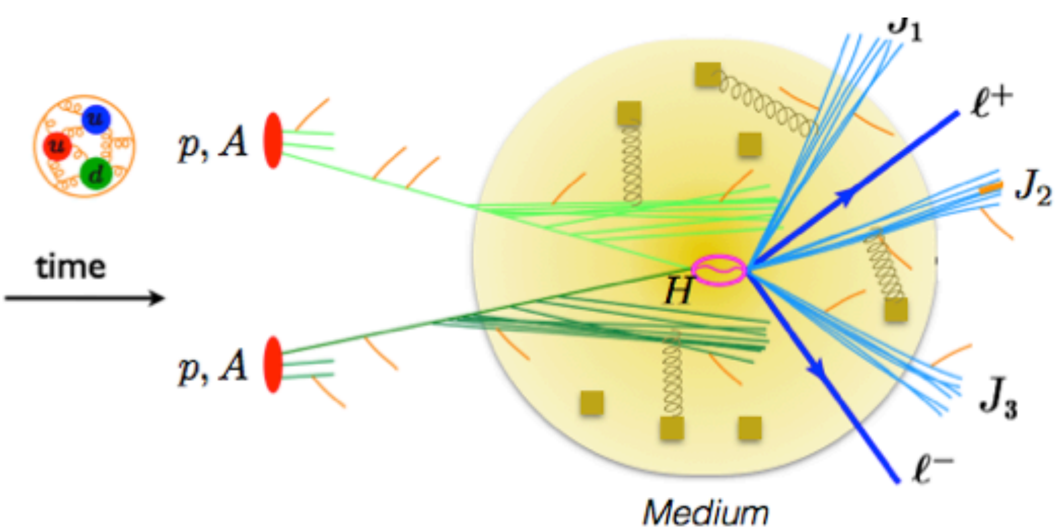
- Jet physics presents a multi-scale problem, EFT treatment

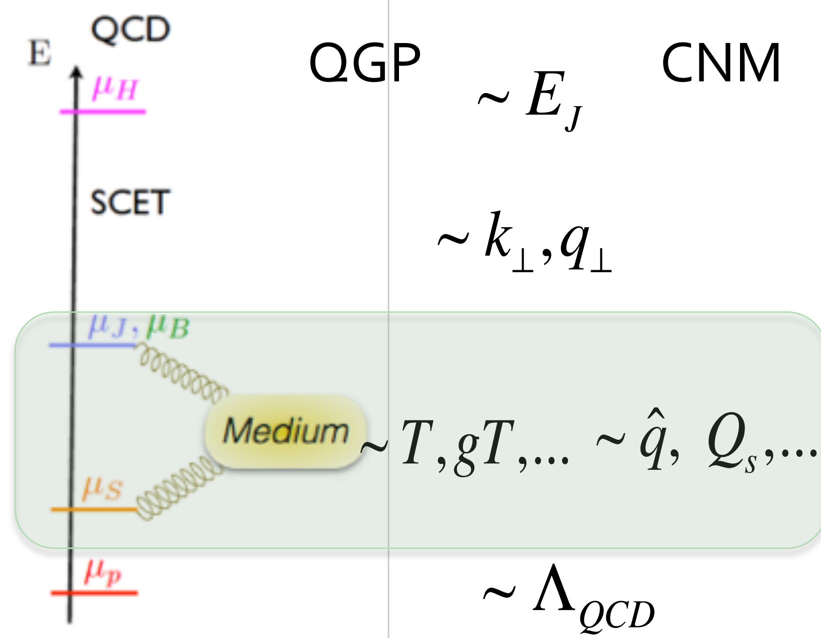
SCET (Soft Collinear Effective Theory)

C. Bauer et al. (2001)

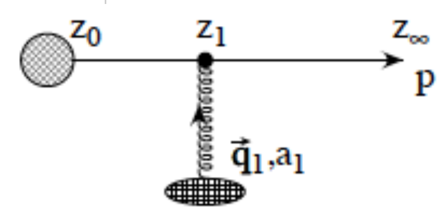
D. Pirol et al. (2004)

modes	$p^\mu = (+, -, \perp)$	p^2	fields
collinear	$Q(\lambda^2, 1, \lambda)$	$Q^2\lambda^2$	$\xi_n,\ A_n^\mu$
soft	$Q(\lambda, \lambda, \lambda)$	$Q^2\lambda^2$	$q_s,\ A_s^\mu$





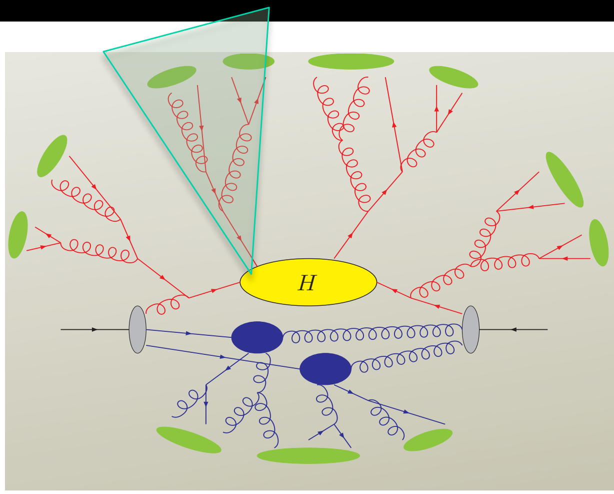
Glauber gluons to mediate physical interactions with the QCD medium



A. Idilbi et al. (2008)

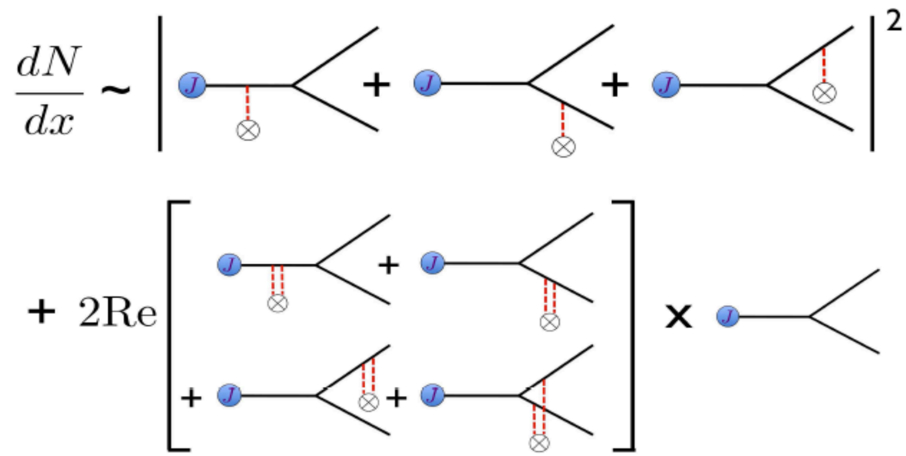
Ovanesyan et al. (2011)

Effective Field Theory Advances



G. Ovanesyan et al. (2012)

In-medium splitting functions beyond the soft gluon approximation



As in vacuum, a total of 4 splitting functions

$$
\begin{aligned}
\left(\frac{dN}{dx\, d^2\boldsymbol{k}_\perp}\right)_{q\to qg} = {} & \frac{\alpha_s}{2\pi^2} C_F \frac{1+(1-x)^2}{x} \int \frac{d\Delta z}{\lambda_g(z)} \int d^2\mathbf{q}_\perp \frac{1}{\sigma_{el}} \frac{d\sigma_{el}^{\rm medium}}{d^2\mathbf{q}_\perp} \Bigg[-\left(\frac{A_\perp}{A_\perp^2}\right)^2 + \frac{B_\perp}{B_\perp^2}\cdot\left(\frac{B_\perp}{B_\perp^2} - \frac{C_\perp}{C_\perp^2}\right) \\
& \times \left(1-\cos[(\Omega_1-\Omega_2)\Delta z]\right) + \frac{C_\perp}{C_\perp^2}\cdot\left(2\frac{C_\perp}{C_\perp^2} - \frac{A_\perp}{A_\perp^2} - \frac{B_\perp}{B_\perp^2}\right)\left(1-\cos[(\Omega_1-\Omega_3)\Delta z]\right) \\
& + \frac{B_\perp}{B_\perp^2}\cdot\frac{C_\perp}{C_\perp^2}\left(1-\cos[(\Omega_2-\Omega_3)\Delta z]\right) + \frac{A_\perp}{A_\perp^2}\cdot\left(\frac{A_\perp}{A_\perp^2}-\frac{D_\perp}{D_\perp^2}\right)\cos[\Omega_4\Delta z] \\
& + \frac{A_\perp}{A_\perp^2}\cdot\frac{D_\perp}{D_\perp^2}\cos[\Omega_5\Delta z] + \frac{1}{N_c^2}\frac{B_\perp}{B_\perp^2}\cdot\left(\frac{A_\perp}{A_\perp^2}-\frac{B_\perp}{B_\perp^2}\right)\left(1-\cos[(\Omega_1-\Omega_2)\Delta z]\right)\Bigg].
\end{aligned}
$$

A,B … transverse propagators,
Ωs … interference phases

Applications and the soft gluon limit

Properties

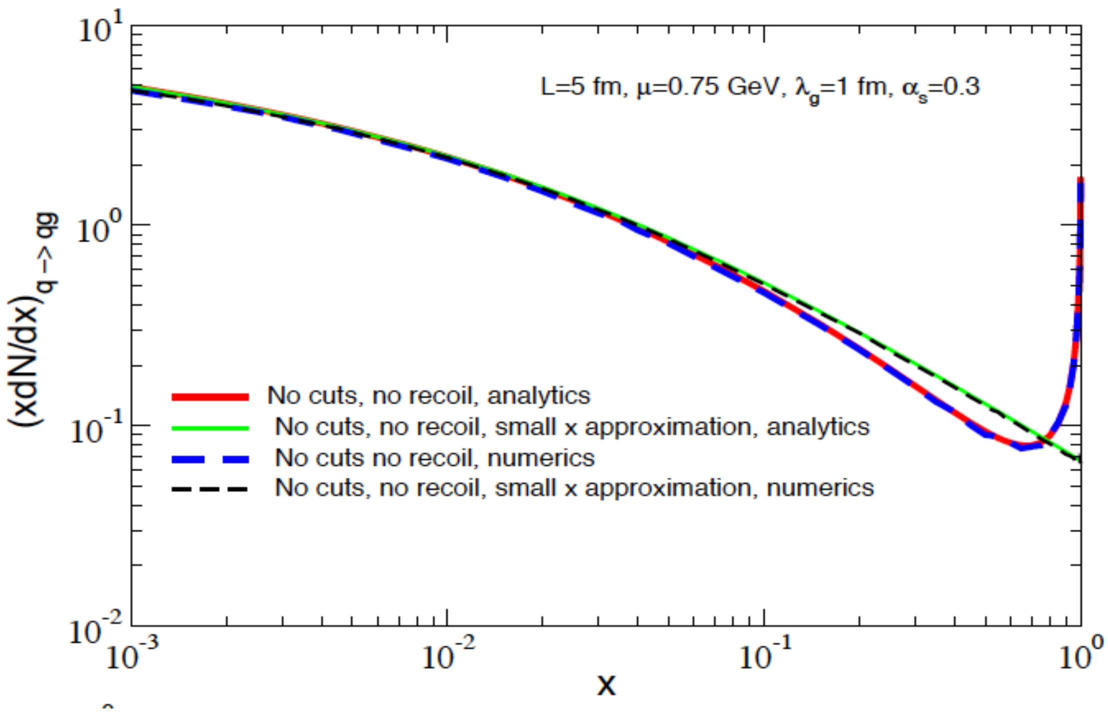
- Implemented in DGLAP evolution equations

$$\frac{dN(tot.)}{dxd^2k_\perp} = \frac{dN(vac.)}{dxd^2k_\perp} + \frac{dN(med.)}{dxd^2k_\perp}$$

- Proven gauge invariance and factorization from H
- Being implemented in jet substructure

M. Gyulassy et al. (2012)

- Soft gluon emission – the only well defined energy loss limit

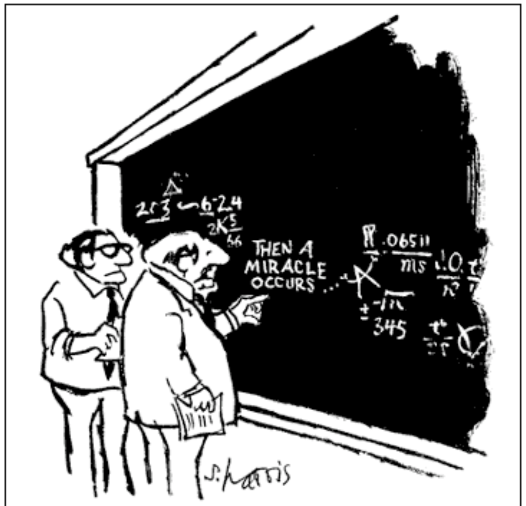


$$x\left(\frac{dN}{dx}\right)_{\left\{\begin{array}{l} q\to qg \\ g\to gg \end{array}\right\}} = \frac{\alpha_s}{\pi^2}\left\{\begin{array}{l} C_F[1+\mathcal{O}(x)] \\ C_A[1+\mathcal{O}(x)] \end{array}\right\}\int\frac{d\Delta z}{\lambda_g(z)}\int d^2\mathbf{k}_\perp d^2\mathbf{q}_\perp \frac{1}{\sigma_{el}}\frac{d\sigma_{el}^{\text{medium}}}{d^2\mathbf{q}_\perp}$$

$$\times\frac{2\boldsymbol{k}_\perp\cdot\boldsymbol{q}_\perp}{\boldsymbol{k}_\perp^2(\boldsymbol{k}_\perp-\boldsymbol{q}_\perp)^2}\left[1-\cos\frac{(\boldsymbol{k}_\perp-\boldsymbol{q}_\perp)^2}{xp_0^+}\Delta z\right].$$

- Only 2 medium-induced splittings survive
- There is no flavor (q, g) mixing
- Results can be interpreted as energy loss

II. Semi-inclusive DIS, e-loss and hadronization



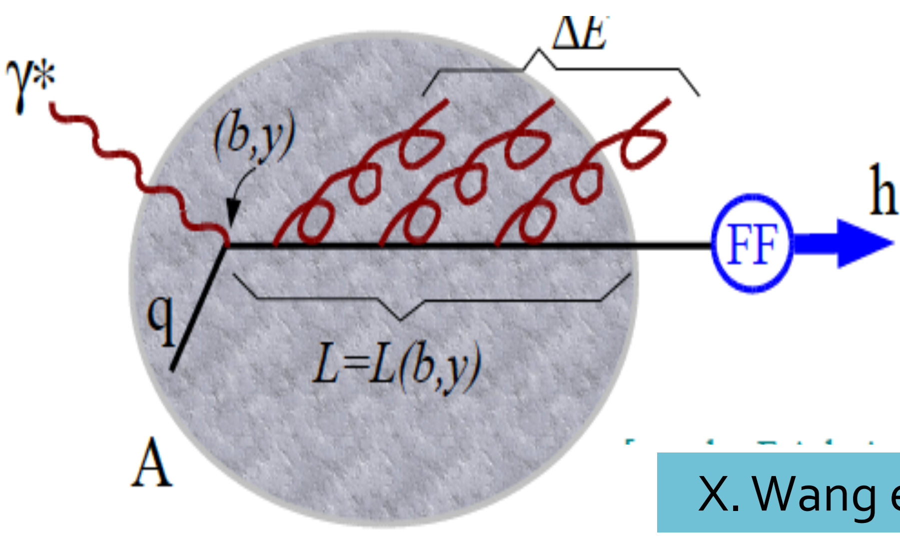
"I think you should be more explicit here in step two."

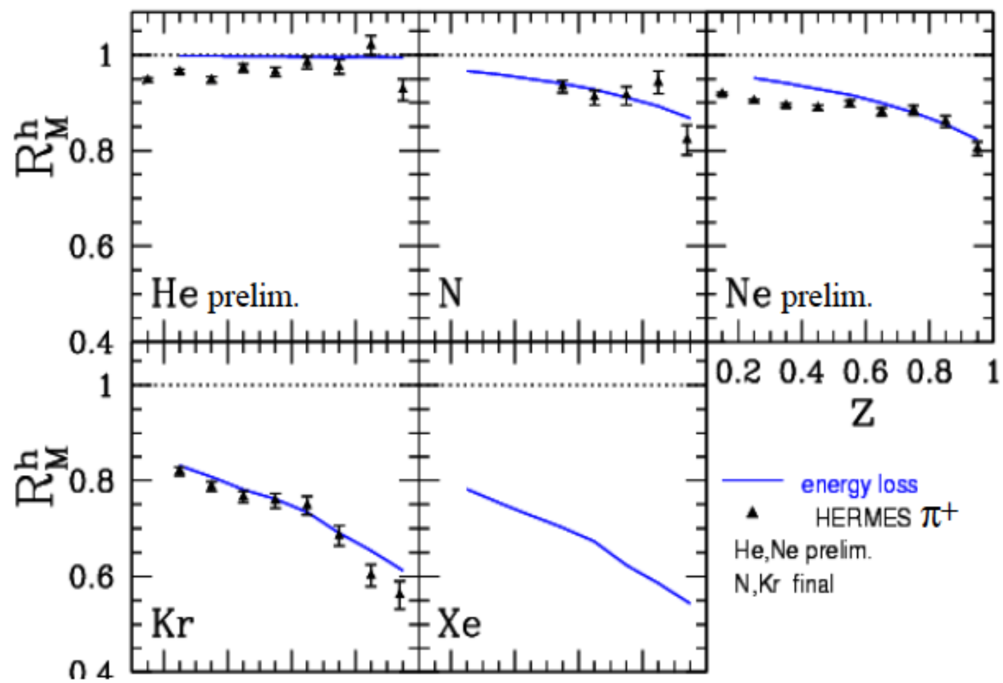
Semi-inclusive hadron suppression

- Energy loss-based approach compared to Hermes data

$$R_A^h(z,\nu) = \left(\frac{N^h(z,\nu)}{N^e(\nu)}\Big|_A\right) \Big/ \left(\frac{N^h(z,\nu)}{N^e(\nu)}\Big|_D\right)$$

$$= \left(\frac{\Sigma e_q^2 q(x)\widetilde{D}_q^h(z)}{\Sigma e_q^2 q(x)}\Big|_A\right) \Big/ \left(\frac{\Sigma e_q^2 q(x) D_q^h(z)}{\Sigma e_q^2 q(x)}\Big|_D\right)$$





X. Wang et al. (2002)

F. Arleo et al. (2003)

- A wide range of $\hat{q}$ obtained from < 0.1 GeV²/fm to 0.7 GeV²/fm

Hybrid approach to hadron attenuation at the EIC

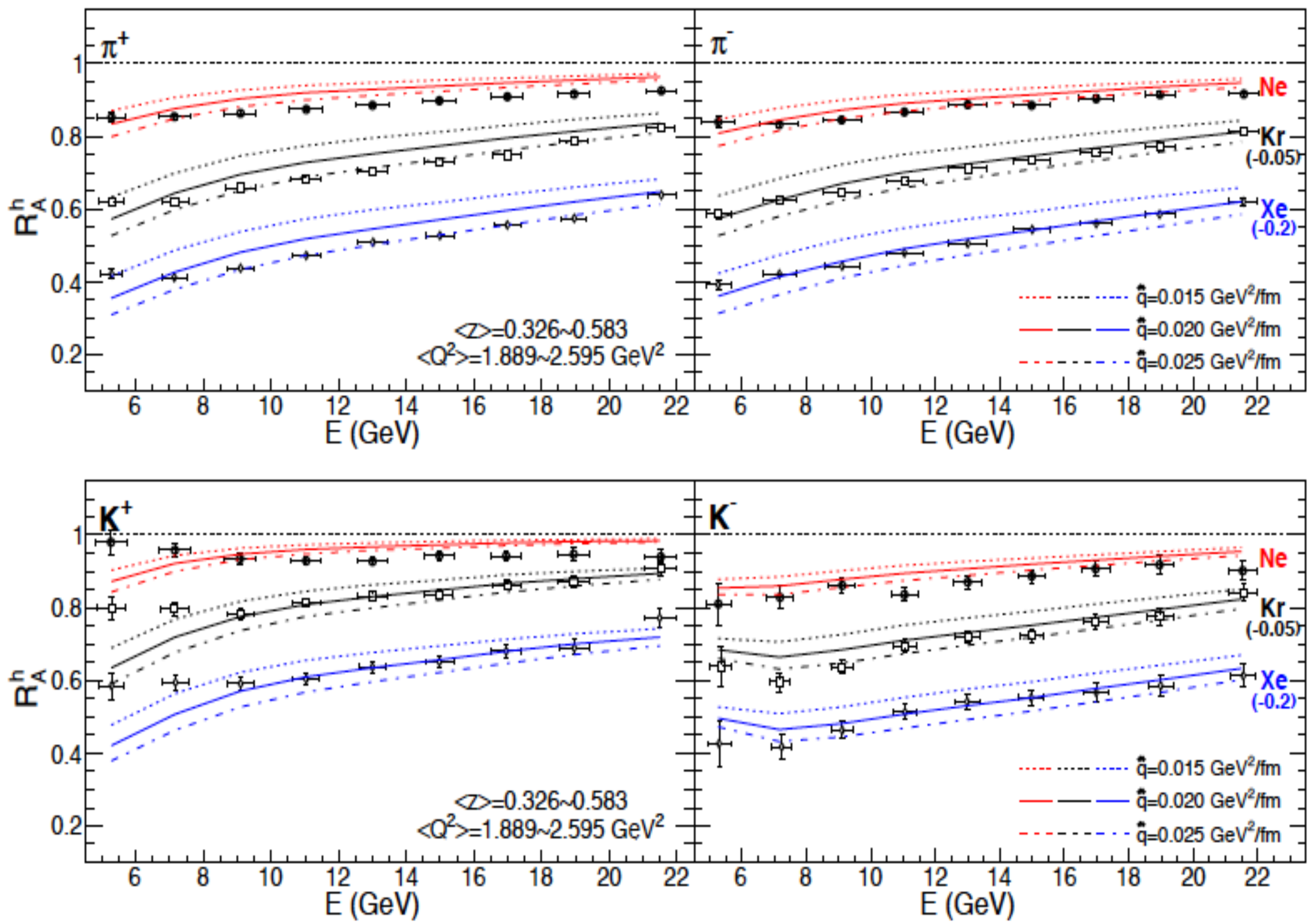
N. Chang et al. (2014)

Using E-loss initial conditions

Energy loss initial conditions followed by DGLAP evolution. Up to a small scale Qo

$$D_{h/c}(z) \Rightarrow$$

$$\int_0^{1-z} d\epsilon \, P(\epsilon) \, \frac{1}{1-\epsilon} D_{h/c}\left(\frac{z}{1-\epsilon}\right)$$



- A quite small $\hat{q} = 0.02 \; GeV^2 / fm$. Again factor of 10 discrepancy in the transport properties of cold nuclear matter

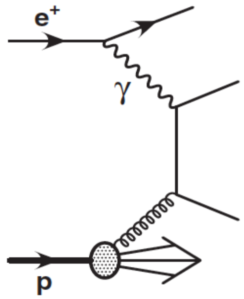
Dijet momentum imbalance and transverse momentum broadening

- One way to further constrain is the transverse momentum broadening or two particle momentum imbalance

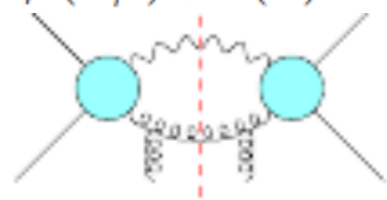
EIC reaction

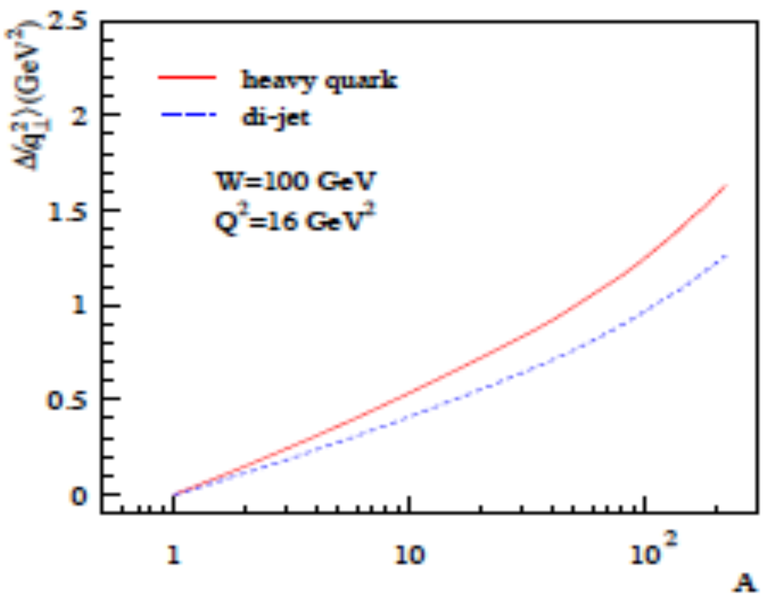
Dijet imbalance

Dihadron imbalance



$$\gamma^*(P_{\gamma^*}) + A(P) \to J_1(p_1) + J_2(p_2) + X$$





H. Xing et al . (2012)

- Can directly constrain the transport properties of large nuclei

A. Schafer et al . (2012)

- Transverse momentum broadening, Cronin effect and scale dependence of the broadening. At present some discrepancy in SIDIS and DY broadening. EIC et higher Q^2 and energy will provide definitive answers

Full QCD evolution approach

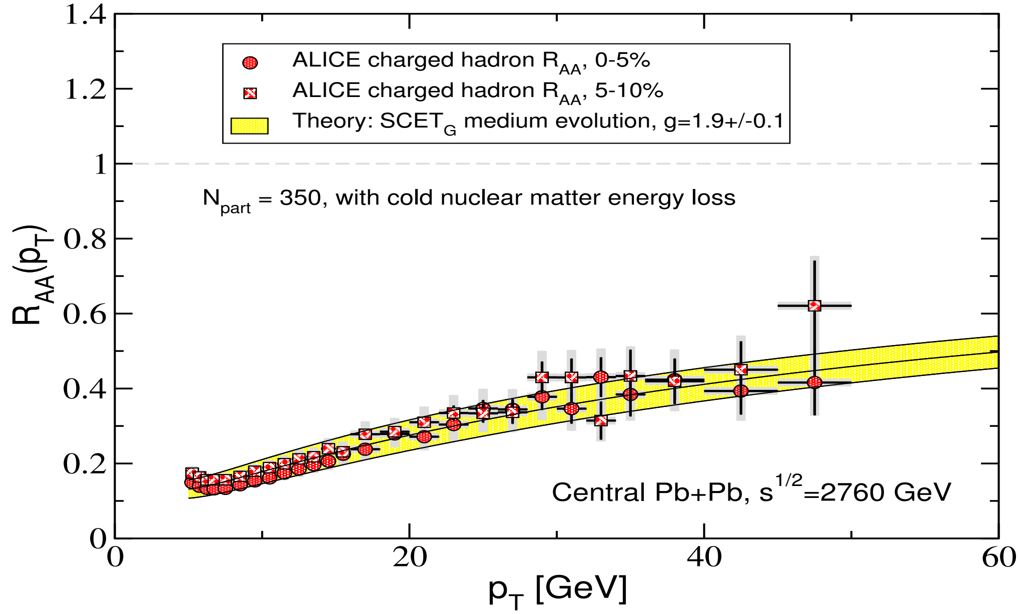
- Based on DGLAP evolution with with SCET_G medium-induced splitting kernels (LHC example)

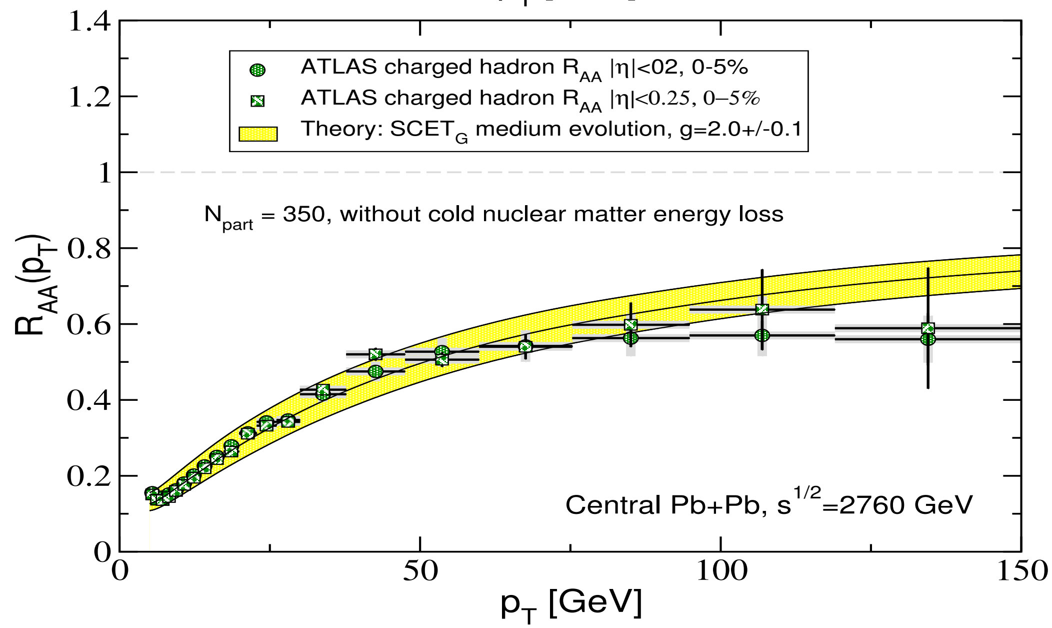
Z. Kang et al. (2014)

$$\frac{dD_{h/q}(z,Q)}{d\ln Q} = \frac{\alpha_s(Q)}{\pi}\int_z^1 \frac{dz'}{z'}\left[P^{\rm med}_{q\to qg}(z',Q;\beta)D_{h/q}\left(\frac{z}{z'},Q\right) + P^{\rm med}_{q\to gq}(z',Q;\beta)D_{h/g}\left(\frac{z}{z'},Q\right)\right],$$

$$\frac{dD_{h/g}(z,Q)}{d\ln Q} = \frac{\alpha_s(Q)}{\pi}\int_z^1 \frac{dz'}{z'}\left[P^{\rm med}_{g\to gg}(z',Q;\beta)D_{h/g}\left(\frac{z}{z'},Q\right) + P^{\rm med}_{g\to q\bar{q}}(z',Q;\beta)\sum_q D_{h/q}\left(\frac{z}{z'},Q\right)\right].$$

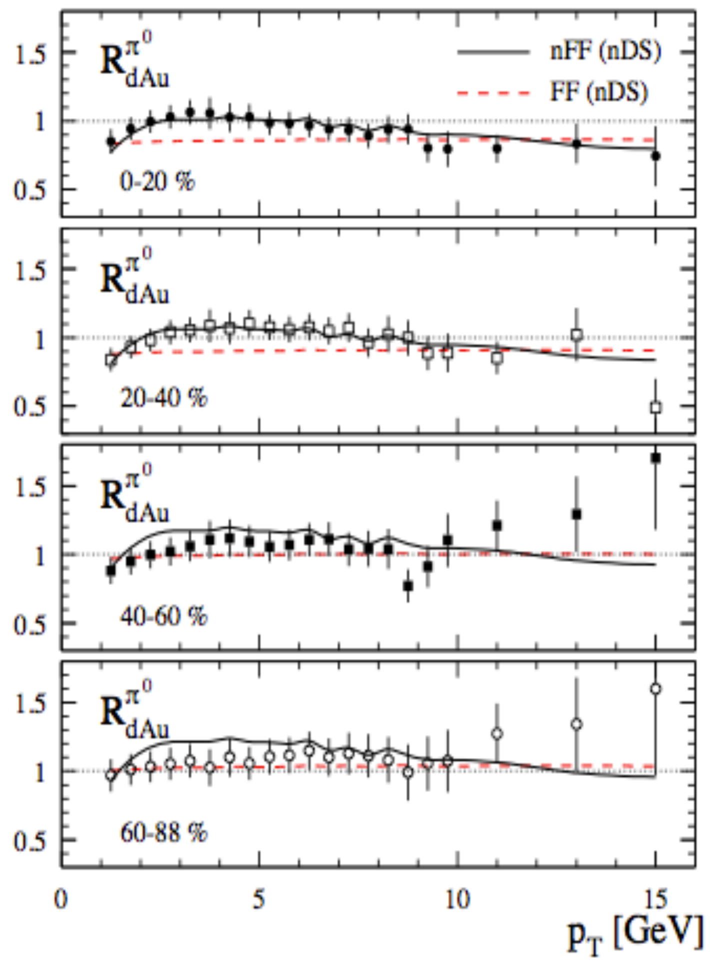
- With larger Q^2 and jet energy ν, this will be implemented for the EIC. But is important to be able to look at lower ν for largest effects

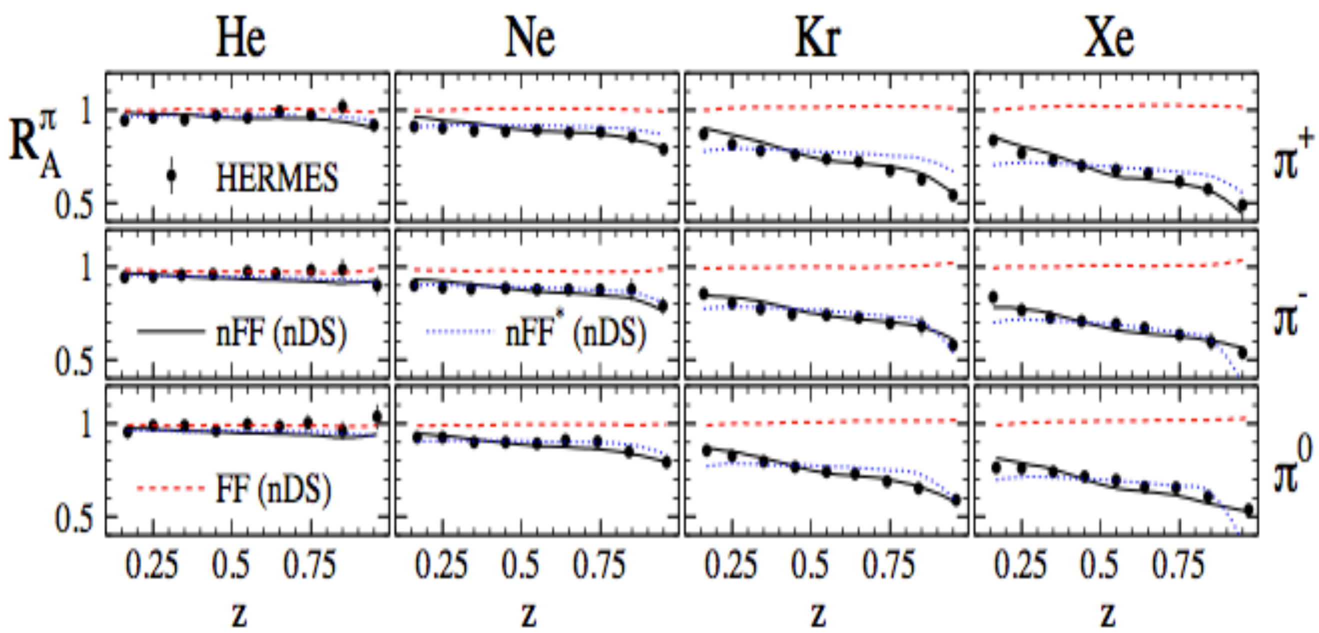




Modified fragmentation functions via global analysys

- Really depends what you analyze and where you put the effects nDS



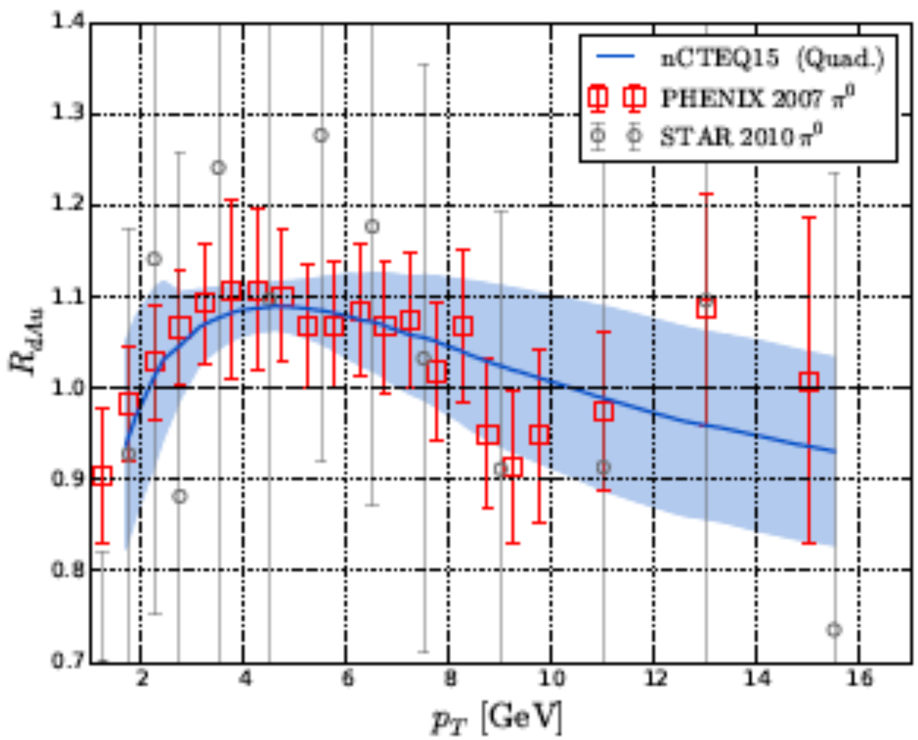


R. Sassot et al. (2010)

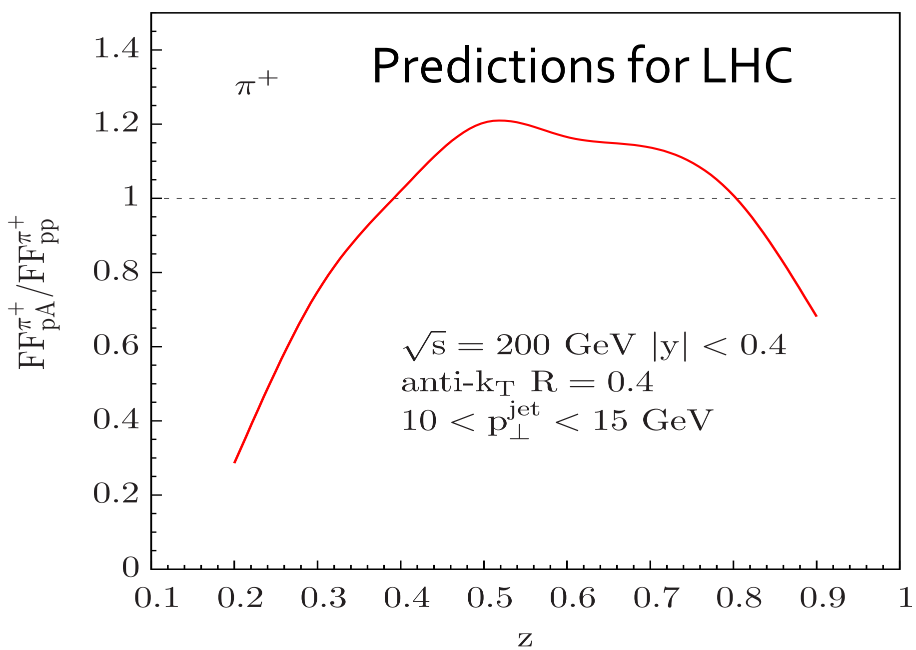
- Electron Ion Collider will at least eliminate the IS interactions, much cleaner

General word of caution about including data into analysis

- For example the the RHIC pion data is included in some global analyses.
- Cronin effect sits at pT = 2 - 5 - 7 GeV at all energies

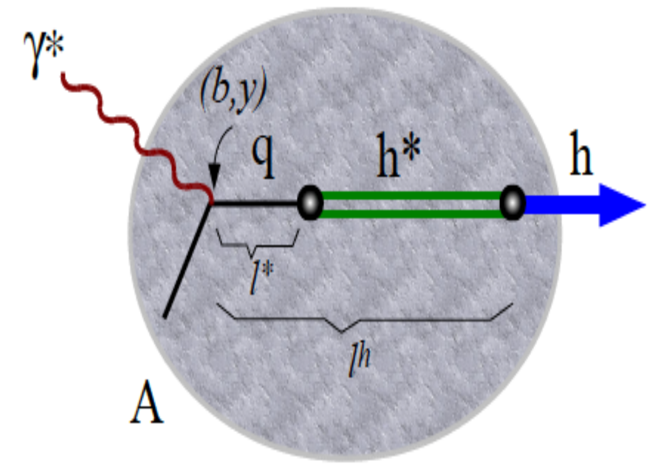


K. Kovarik et al. (2015)



- Electron Ion Collider will at least eliminate the IS interactions, much cleaner. Has to be tested at low and high energies

Hadron formation and absorption

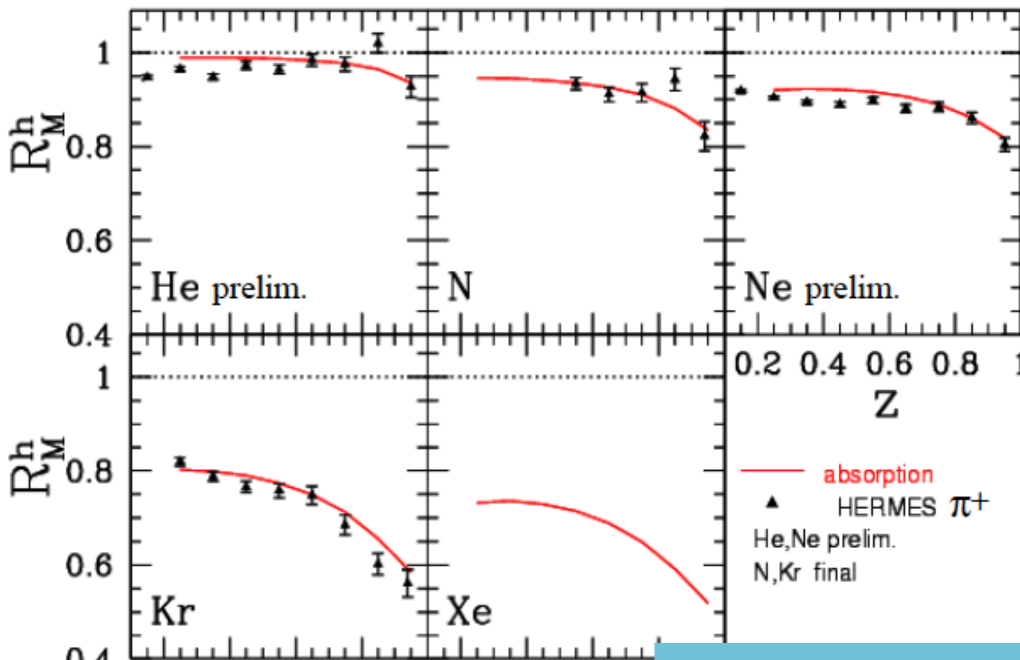


- Includes hadron but also pre-hadron formation and absorption

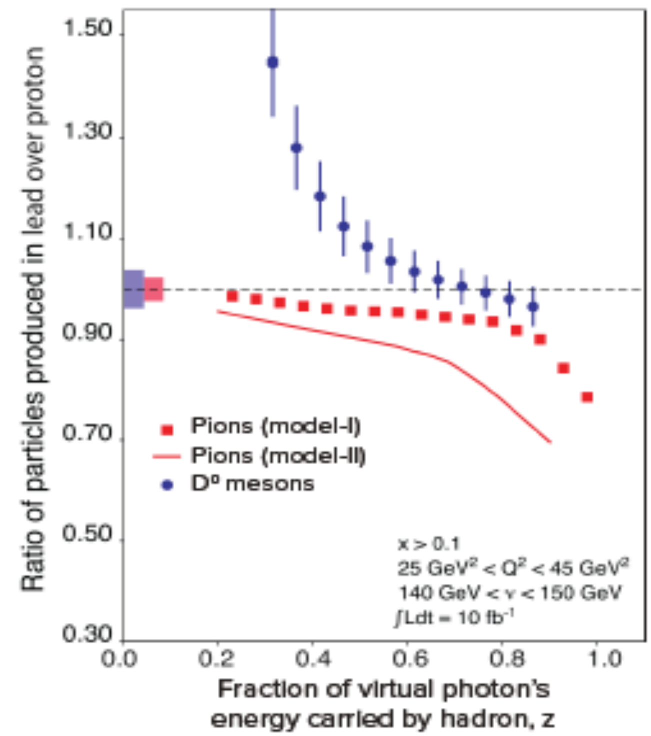
A. Accardi et al., 2003

B. Kopeliovich et al., 2003

$$\Delta y^{+} = \frac{1}{\Delta p^{-}} = \frac{(0.2\ GeV.fm)\ 2z(1-z)p^{+}}{k_{\perp}^{2} + (1-z)m_{h}^{2} - z(1-z)M_{q}^{2}}$$



A. Accardi et al., 2005



III. Jet production at the EIC and jet substructure

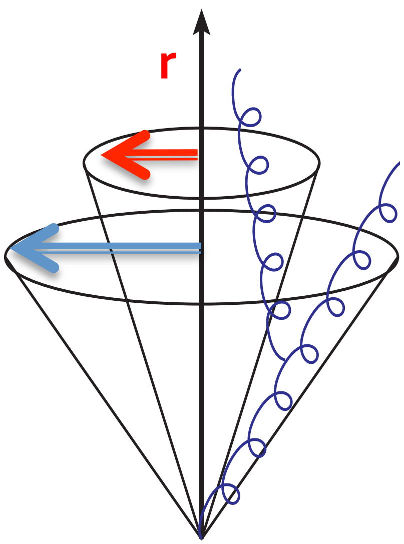
"I'm firmly convinced that behind every great man is a great computer."

Jet substructure observables

- The jet shape

S. Ellis et al. (1993)

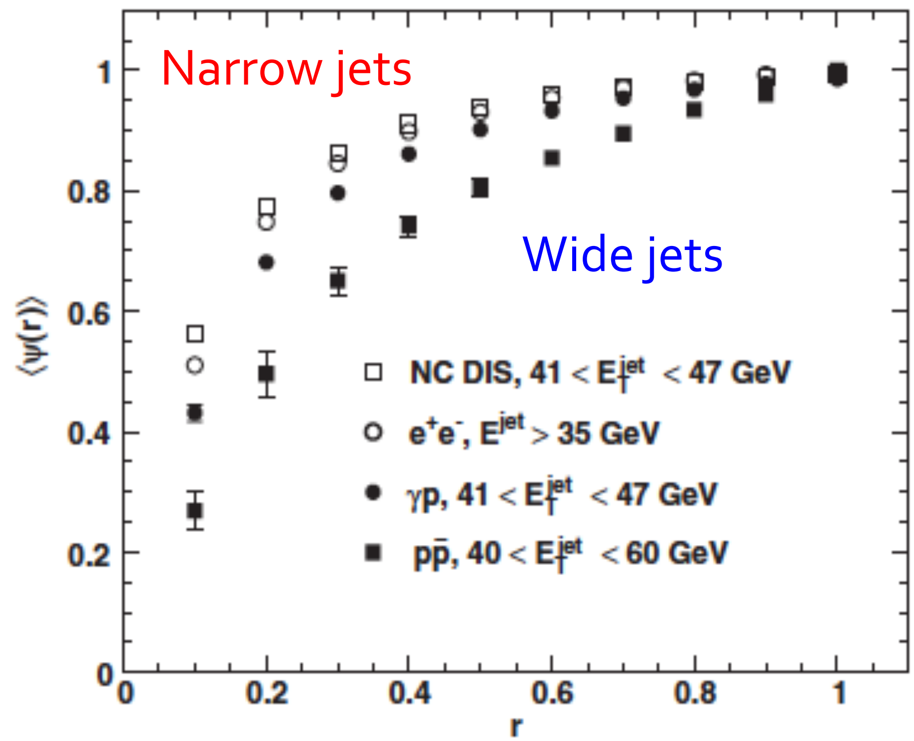
S. Ellis et al. (1993)



$$\Psi_{\rm int}(r;R) = \frac{\sum_i (E_T)_i \Theta(r-(R_{\rm jet})_i)}{\sum_i (E_T)_i \Theta(R-(R_{\rm jet})_i)}$$

$$\psi(r;R) = \frac{d\Psi_{\rm int}(r;R)}{dr} .$$

The transverse energy density inside a jet



Akers et al. (1994)

Breitweig et al. (1999)

Abe et al. (1993)

- A lot of advances in understanding jet substructure come from SCET, motivated by boosted heavy particle decay

Factorization in SCET

- Convolution of had, beam, jet and soft functions

C. Bauer et al. PRD (2001)

D. Pirol et al. PRD (2004)

$$\sigma = \mathrm{Tr}(HS) \otimes \prod_{i=1}^{n_B} B_i \otimes \prod_{j=1}^{N} J_j$$

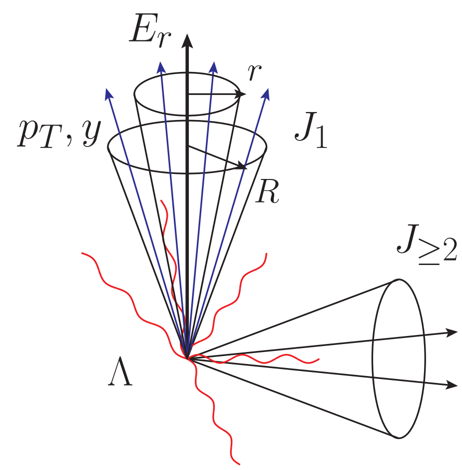
- Under very specific restrictions can be written as a product

$$\frac{1}{\sigma_0}\frac{d\sigma}{dE_r dp_{T_i} dy_i} = H(p_{T_i}, y_i, \mu) J_{\omega_1}(E_r, \mu) J_{\omega_2}(\mu) \dots J_{\omega_N}(\mu) S_{n_1 n_2 \dots n_N}(\Lambda, \mu) + \mathcal{O}\left(\frac{\Lambda}{Q}\right) + \mathcal{O}(R) \,.$$

Measured jet energy function

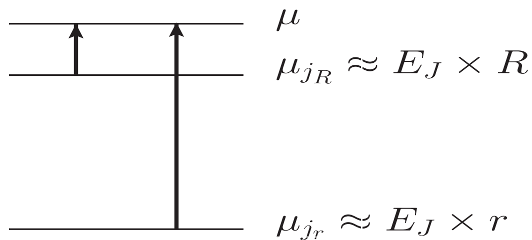
$$\Psi_J(r) = \frac{E_r}{E_R} = \frac{E_r^c + E_r^s}{E_R^c + E_R^s} = \frac{E_r^c}{E_R^c} + \mathcal{O}(\lambda)$$

$$J_\omega(E_r, \mu) = \sum_{X_c} \langle 0|\bar{\chi}_\omega(0)|X_c\rangle\langle X_c|\chi_\omega(0)|0\rangle \delta(E_r - \hat{E}^{<r}(X_c))$$



NLL calculation of jet shapes

- We use SCET resummation techniques and $\mathrm{SCET}_{G.}$ (RG evolution)



We start form the natural scales that eliminate all large logarithms in the fixed order calculation and evolve to a common scale [resumming ln(r/R)]

$$\frac{dJ_\omega^{qE_r}(\mu)}{d\ln\mu} = \left[-C_F\Gamma_{\mathrm{cusp}}(\alpha_s)\ln\frac{\omega^2\tan^2\frac{R}{2}}{\mu^2} - 2\gamma^q(\alpha_s)\right] J_\omega^{qE_r}(\mu)$$

$$\frac{dJ_\omega^{gE_r}(\mu)}{d\ln\mu} = \left[-C_A\Gamma_{\mathrm{cusp}}(\alpha_s)\ln\frac{\omega^2\tan^2\frac{R}{2}}{\mu^2} - 2\gamma^g(\alpha_s)\right] J_\omega^{gE_r}(\mu)$$

$$\Gamma_{\mathrm{cusp}}(\alpha_s) = \left(\frac{\alpha_s}{4\pi}\right)\Gamma_0 + \left(\frac{\alpha_s}{4\pi}\right)^2\Gamma_1 + \cdots ,$$

$$\gamma(\alpha_s) = \left(\frac{\alpha_s}{4\pi}\right)\gamma_0 + \left(\frac{\alpha_s}{4\pi}\right)^2\gamma_1 + \cdots .$$

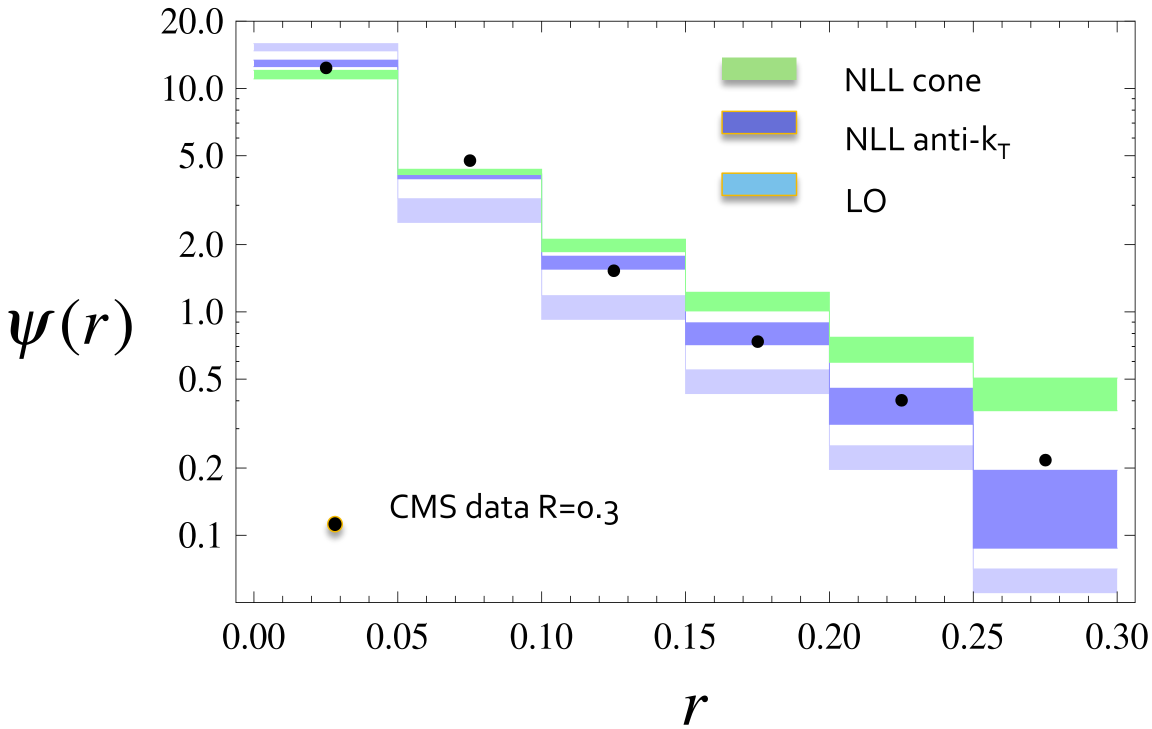
Order	Γ_{cusp}	γ	β
NLL	2-loop	1-loop	2-loop

- To resum the jet shape to NLL accuracy

NLL	1-loop	2-loop
β	$\beta_0 = \frac{11}{3}C_A - \frac{4}{3}T_F n_f$	$\beta_1 = \frac{34}{3}C_A^2 - \frac{20}{3}C_A T_F n_f - 4C_F T_F n_f$
Γ_{cusp}	$\Gamma_0 = 4$	$\Gamma_1 = 4\left[\left(\frac{67}{9} - \frac{\pi^2}{3}\right)C_A - \frac{20}{9}T_F n_f\right]$
γ	$\gamma_0^q = -3C_F,\ \gamma_0^g = -\beta_0$	

NLL calculation of jet shapes

- Recent renewed interest in this area was sparked in traditional QCD resummation



$$\Psi_\omega(r) = \frac{\langle E_r \rangle_\omega}{\langle E_R \rangle_\omega} = \frac{J_\omega^{E_r}(\mu)/J_\omega(\mu)}{J_\omega^{E_R}(\mu)/J_\omega(\mu)} = \frac{J_\omega^{E_r}(\mu)}{J_\omega^{E_R}(\mu)}$$

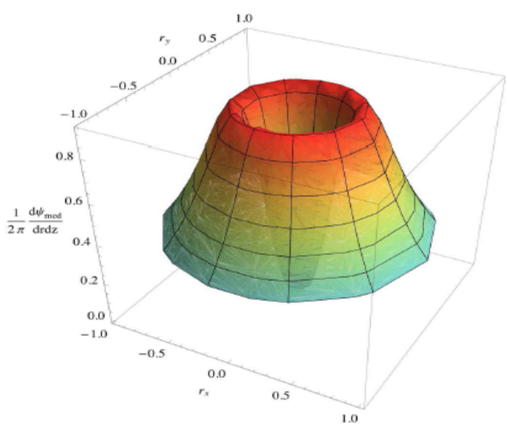
H-n. Li et al. (2011)

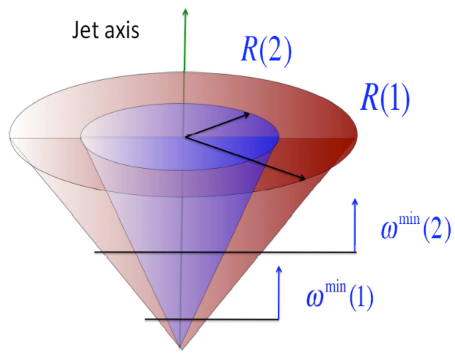
- The algorithm dependence of the jet shapes (anti)k_T vs cone is included
- Significant improvement over fixed order calculation
- Examples for Tevatron, LHC

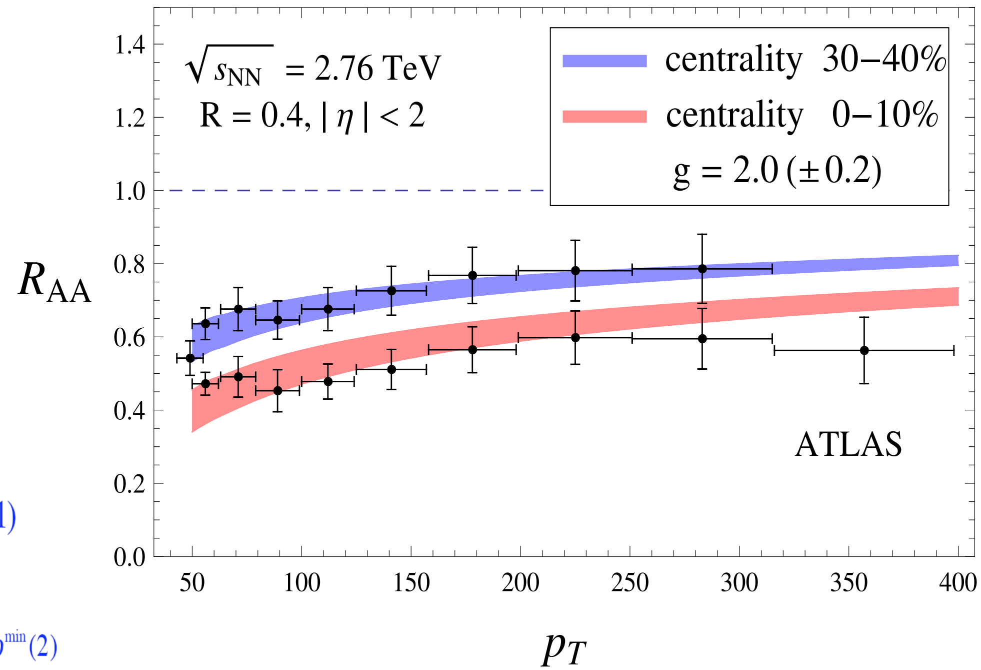
Y.-T. Chien et al. (2014)

Jet cross section attenuation at the LHC and EIC, e+A

- The key physics that jets in QCD matter probe is the modification of the partion shower (broader and softer)





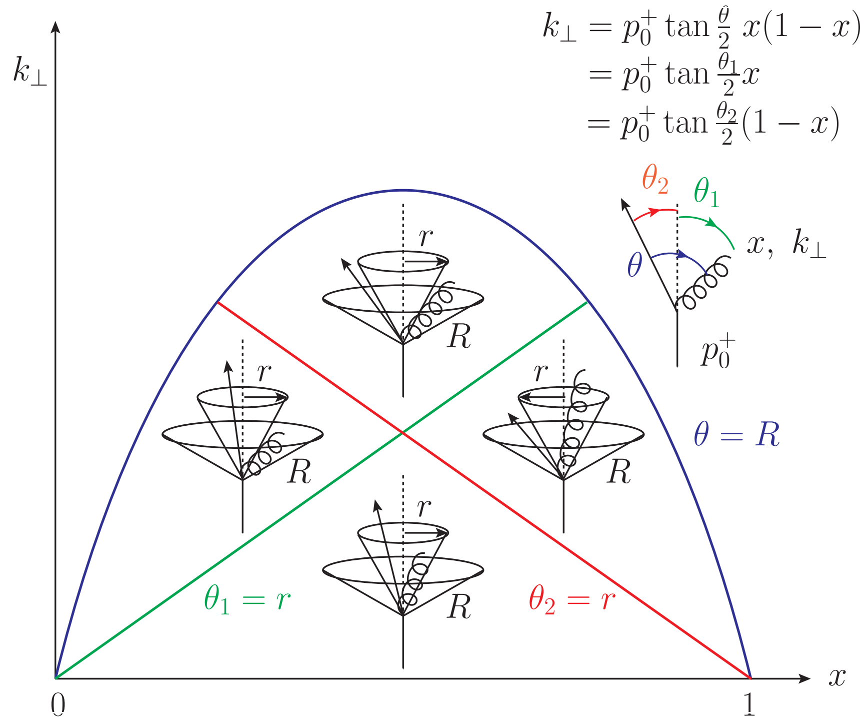


Y.-T. Chien et al. (2015)

- The in-medium parton splitting allow to generalize the concept of jet energy loss beyond the soft gluon approximation

$$\epsilon_q = \frac{2}{\omega}\Big[\int_0^{\frac{1}{2}} dx k^0 + \int_{\frac{1}{2}}^1 dx(p^0 - k^0)\Big] \int_{\omega x(1-x)\tan\frac{R}{2}}^{\omega x(1-x)\tan\frac{R_0}{2}} dk_\perp \frac{1}{2}\Big[\mathcal{P}^{med}_{q\to qg}(x,k_\perp) + \mathcal{P}^{med}_{q\to gq}(x,k_\perp)\Big]$$

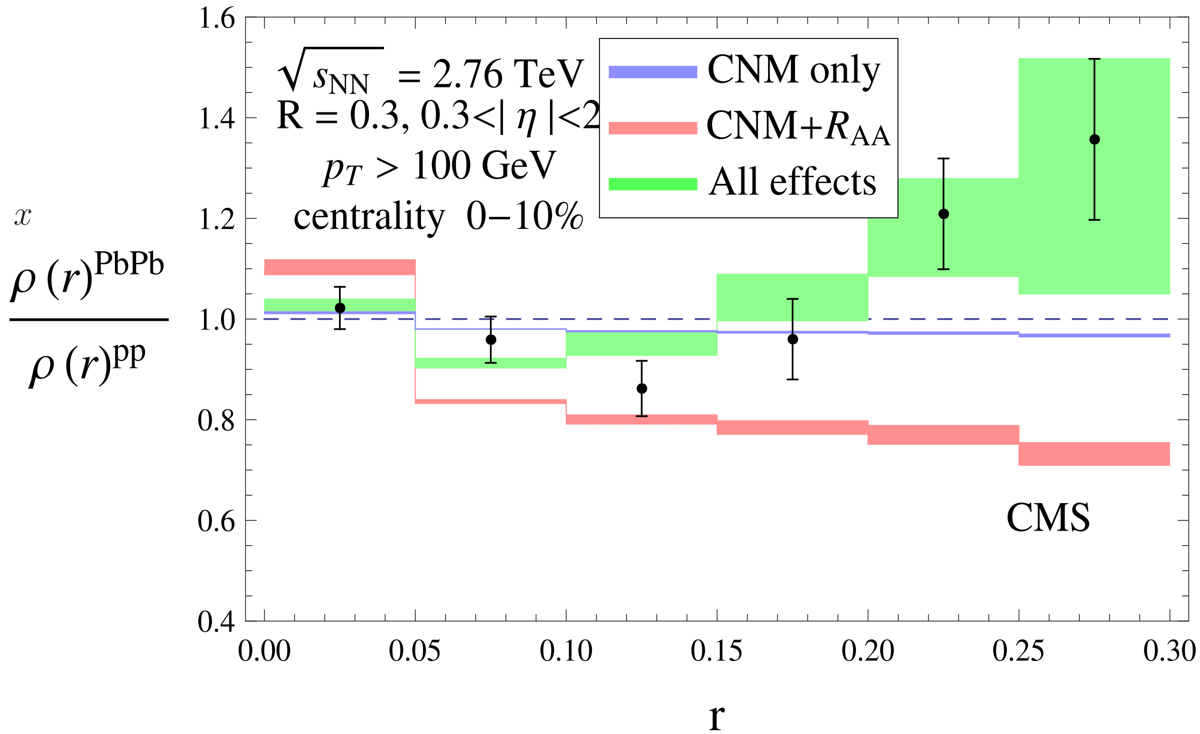
Medium-modified jet shapes



- One can evaluate the jet energy functions from the splitting functions

$$J^i_{\omega,E_r}(\mu) = \sum_{j,k} \int_{PS} dx dk_\perp \mathcal{P}_{i\to jk}(x,k_\perp) E_r(x,k_\perp)$$

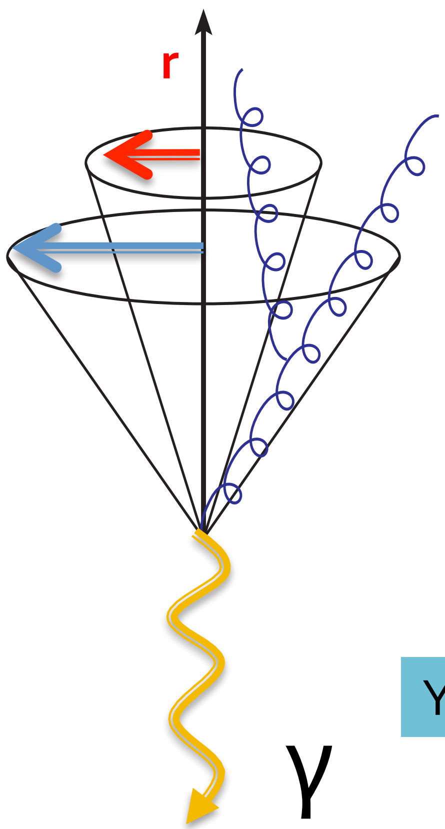
$$J_{\omega,E_r}(\mu) = J^{vac}_{\omega,E_r}(\mu) + J^{med}_{\omega,E_r}(\mu).$$



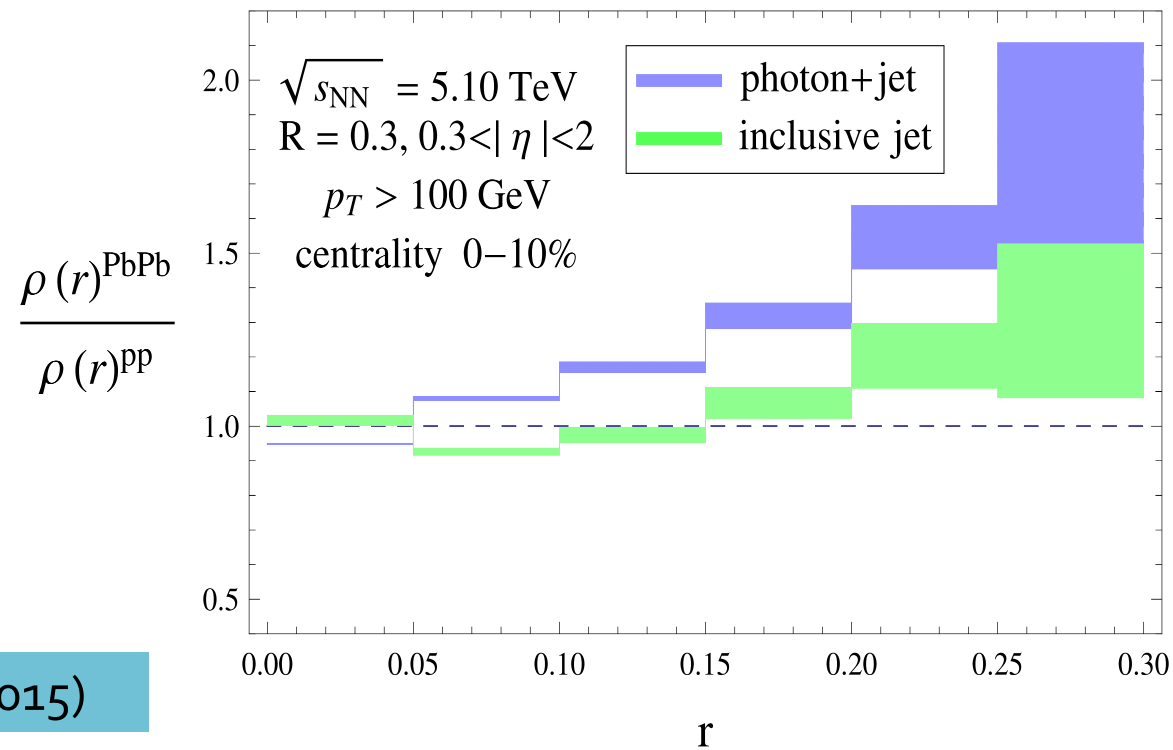
- First quantitative pQCD/SCET description of jet shapes in QCD matter

What can we expect at the EIC?

- At EIC, in the kinematic region of interest there is a dominance of quark initiated jets. Excellent for jet substructure studies



We can mimic this in hadronic collisions by photon tagging



Y.-T. Chien et al. (2015)

- Larger broadening of narrower quark jets

Jet fragmentation functions

- Jet fragmentation functions probe the longitudinal jet substructure

M. Procura et al. (2010)

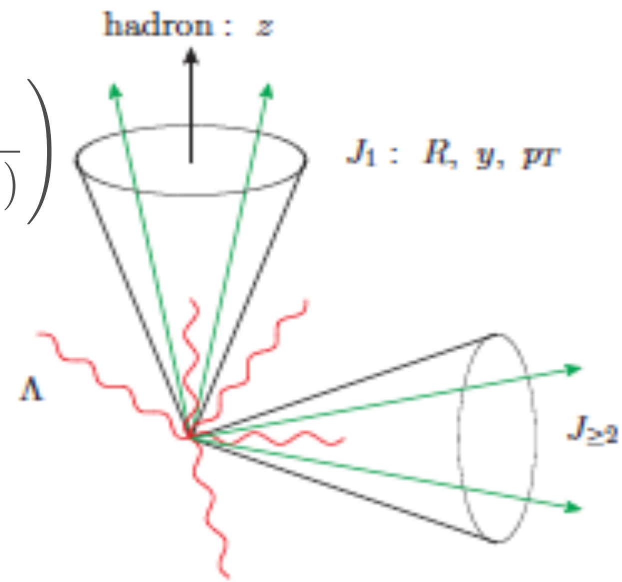
$$\frac{d\sigma^h}{dy_i dp_{T_i} dz} = H(y_i, p_{T_i}, \mu)\, \mathcal{G}^h_{\omega_1}(z, \mu) J_{\omega_2}(\mu) \cdots J_{\omega_N}(\mu) S_{n_1 n_2 \cdots n_N}(\Lambda, \mu) + \mathcal{O}\left(\frac{\Lambda}{Q}\right) + \mathcal{O}(R)$$

$$\frac{d\sigma}{dy_i dp_{T_i}} = H(y_i, p_{T_i}, \mu) J_{\omega_1}(\mu) \cdots J_{\omega_N}(\mu) S_{n_1 n_2 \cdots n_N}(\Lambda, \mu) + \mathcal{O}\left(\frac{\Lambda}{Q}\right) + \mathcal{O}(R)$$

Definition

$$\mathcal{G}^h_i(\omega, R, z, \mu) = \sum_j \int_z^1 \frac{dx}{x} \mathcal{J}_{ij}(\omega, R, x, \mu)\, D^h_j\left(\frac{z}{x}, \mu\right) + \mathcal{O}\left(\frac{\Lambda^2_{\mathrm{QCD}}}{\omega^2 \tan^2(R/2)}\right)$$

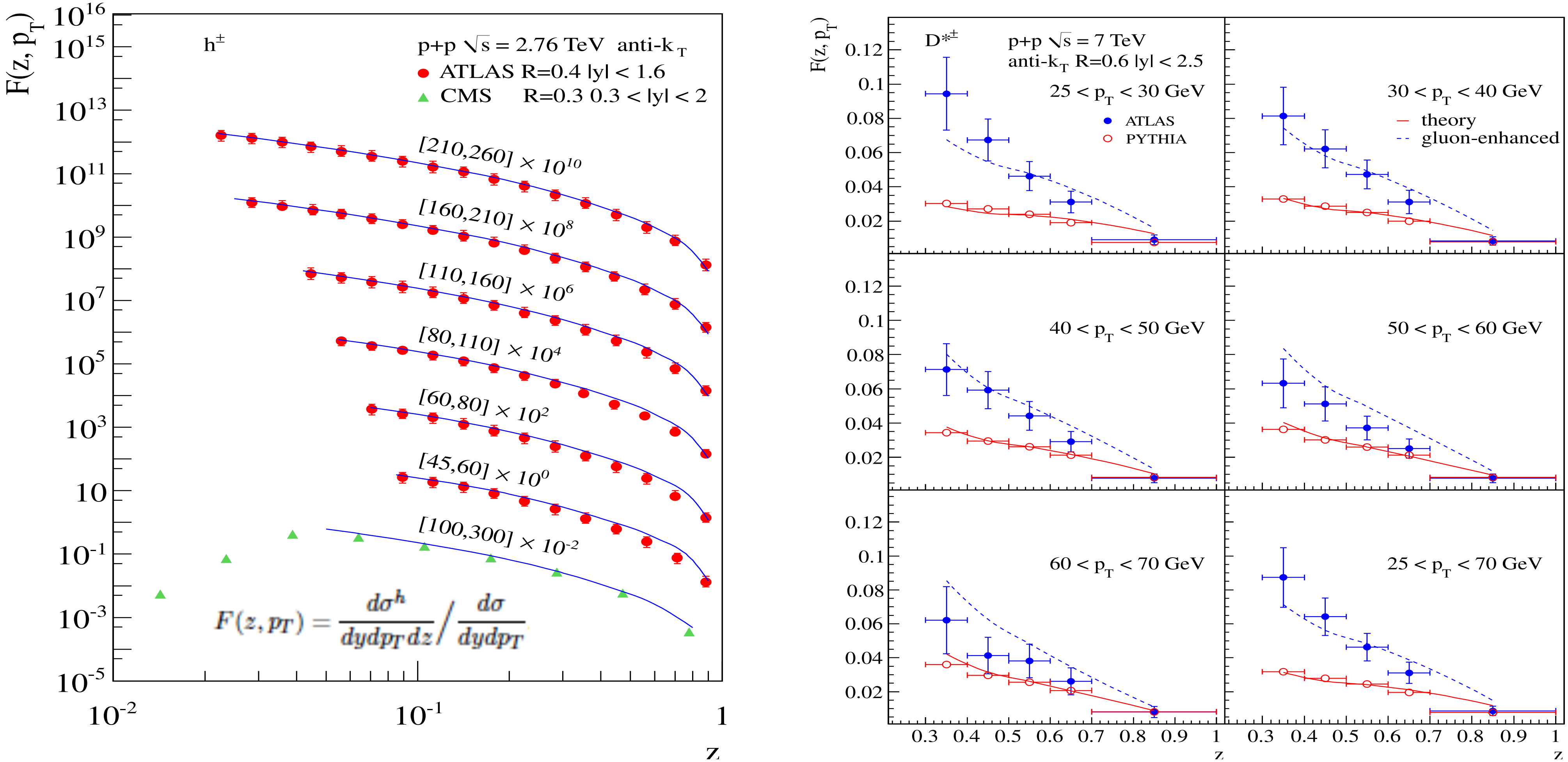
$$F_{\omega_1}(z, p_{T_i}) = \frac{d\sigma^h}{dy_i dp_{T_i} dz} \Big/ \frac{d\sigma}{dy_i dp_{T_i}} = \frac{\mathcal{G}^h_{\omega_1}(z, \mu)}{J_{\omega_1}(\mu)}$$



- A ratio of a fragmenting jet function and unmeasured jet function, resummed to NLL accuracy

Y. T. Chien et al. (2015)

Results for jet fragmentation functions at LHC and EIC

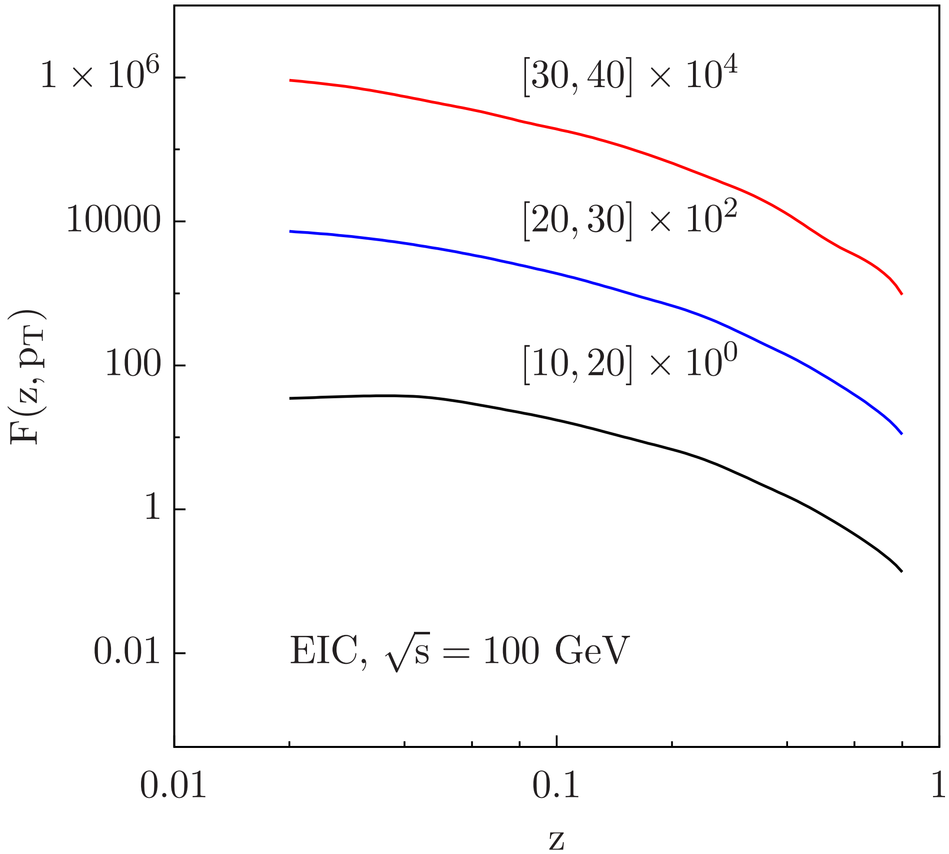


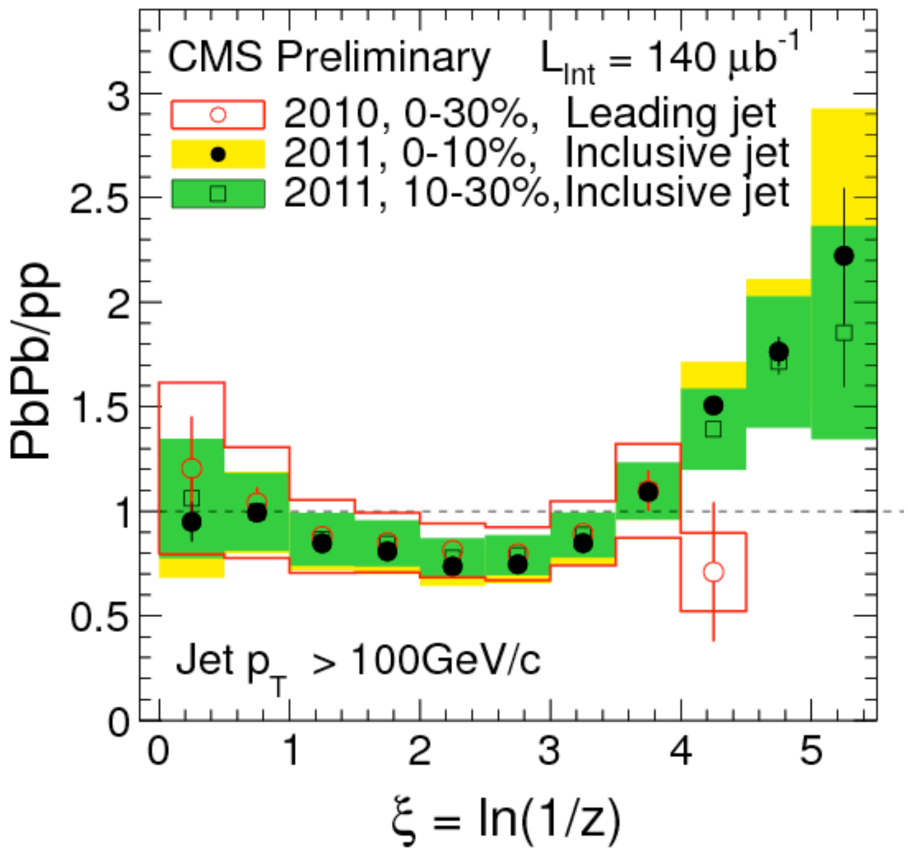
- Very good comparison to data for z not too small and light hadrons. Both MC and pQCD /SCET fail for heavy flavor

T. Kauffman et al. (2015)

Y.-T. Chien et al. (2015)

Jet fragmentation functions at EIC and expected modification

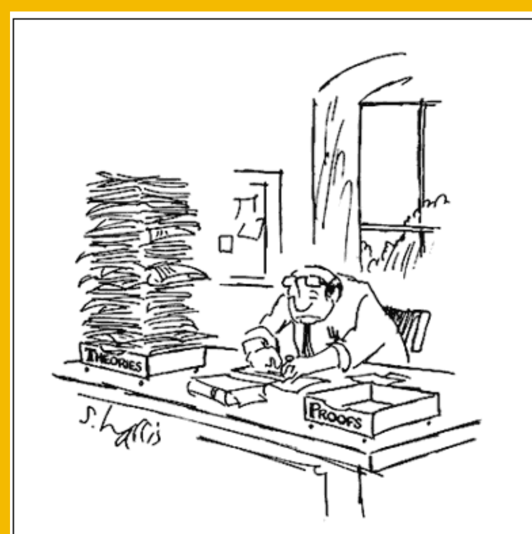




- The behavior of the jet fragmentation functions is similar to the one at pp colliders

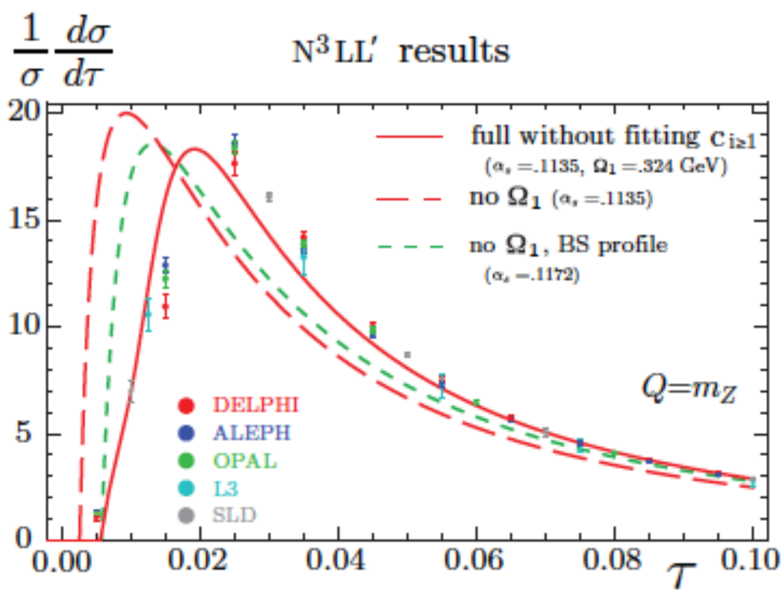
- Expected modification is softening of the fragmentation functions, but also depletion due to suppression of gluon jets

IV. Event shapes at the EIC and α_s



Global event shape observables

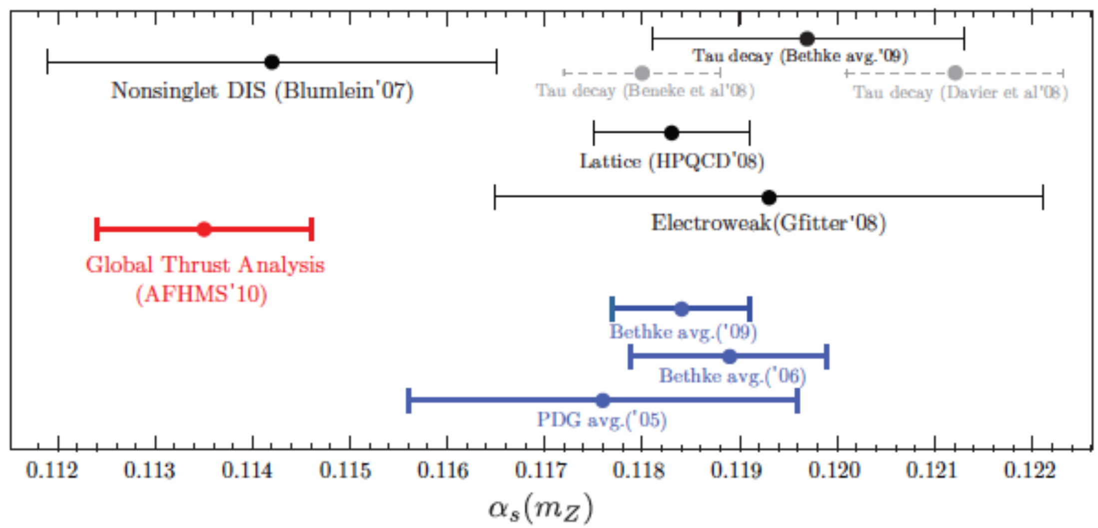
- Thrust, jet broadening, angularities, N-jettiness



R. Abatte et al. (2010)

$$T = \max_{\hat{t}} \frac{\sum_i |\hat{t}\cdot\vec{p}_i|}{\sum_i |\vec{p}_i|}\,,$$

τ=1-T



Extraction of α_s

- Although the treatment of thrust is the most complete, there is discrepancy with the PDG average. Large (but universal) non-perturbative effects Ω

N-jettiness, α_s extraction

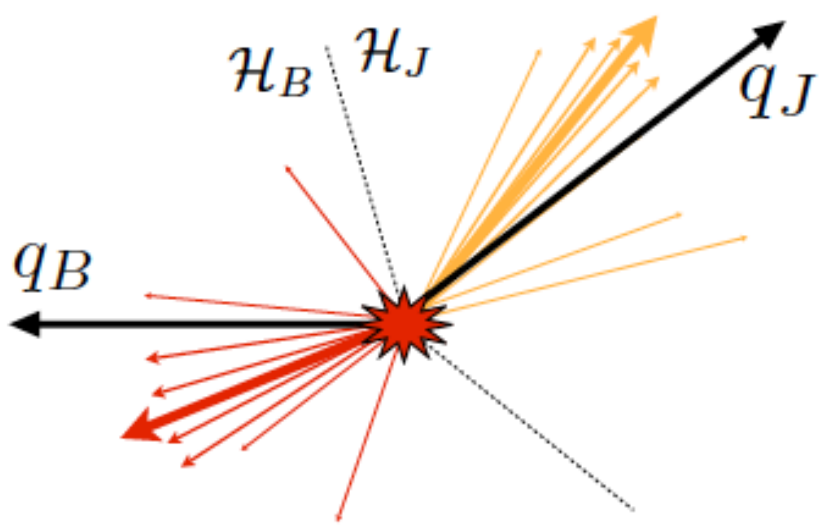
- Generalization of thrust with N+1 collinear directions

$$\tau_N = \frac{2}{Q^2} \sum_i \min\{q_B \cdot p_i, q_1 \cdot p_i, \ldots, q_N \cdot p_i\}$$

I. Stewart et al. (2010)

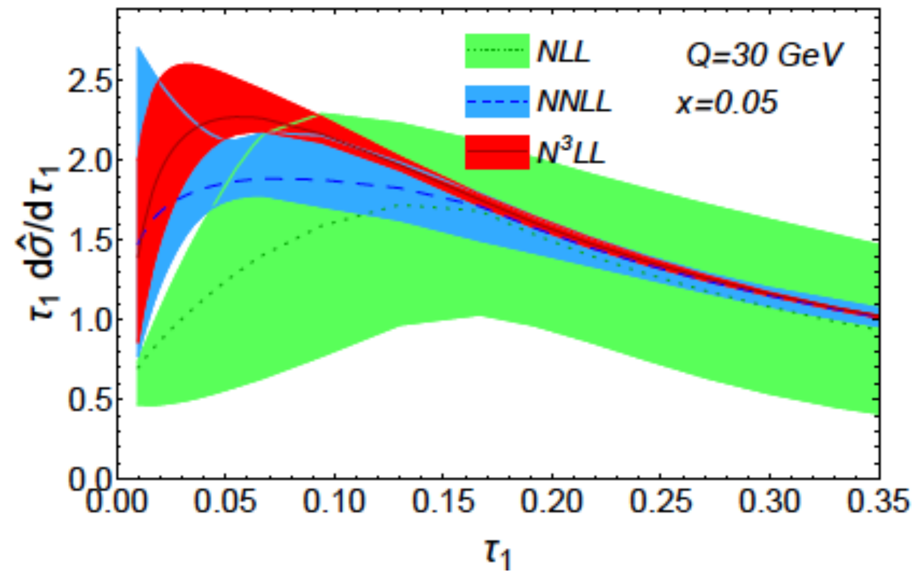
Z. Kang et al. (2012)

D. Kang et al. (2013)



C. Lee et al. in preparation

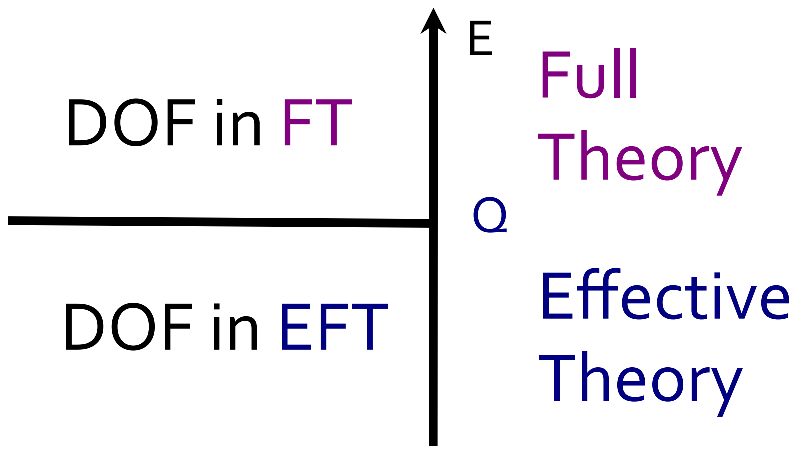
- 1-jettines considered to avoid certain complications (NGL)



Conclusions

- EIC opens unique possibilities to study jet/hadron production in cold dense QCD matter and provides ideal kinematics
- Jet and hadron production at the EIC will pinpoint the transport properties of large nuclei, the stopping power nuclear matter, and can test the strong gluon field paradigm
- Hadron production and attenuation in semi-inclusive DIS will shed light on the process of hadronization and the nature of color neutralization and confinement
- Jet substructue observables can provide a detailed picture of in-medium parton shower (longitudinal and transverse structure) in the background of strong color fields
- Event shape observables can be used for precise extraction of the strong coupling constant

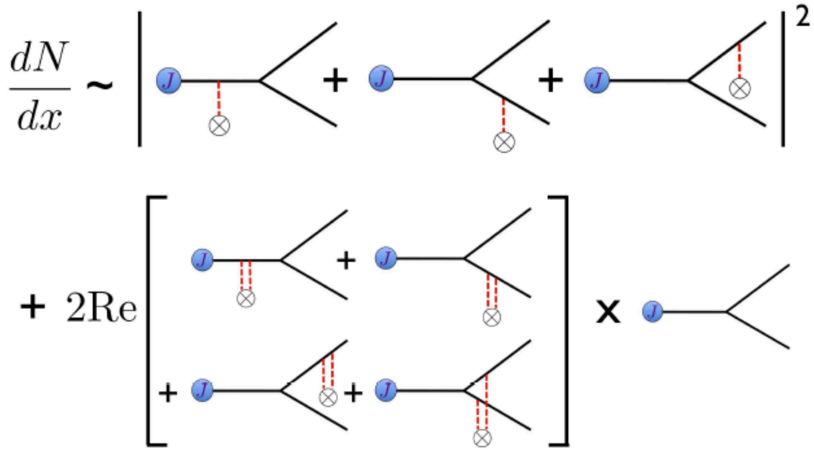
Examples of effective field theories [EFTs]



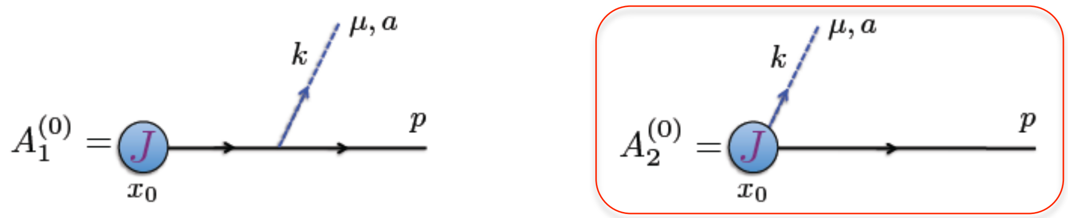
- Simple but powerful idea to concentrate on the significant degrees of freedom [DOF]. Manifest power counting

	Q	power counting	DOF in FT	DOF in EFT
Chiral Perturbation Theory (ChPT)	Λ_{QCD}	p/Λ_{QCD}	q, g	K,π
Heavy Quark Effective Theory (HQET)	m_b	Λ_{QCD}/m_b	ψ,A	h_v, A_s
Soft Collinear Effective Theory (SCET)	Q	$p_\perp/Q$	ψ,A	ξ_n, A_n, A_s

III. Main results: in-medium splitting / parton energy loss



Gluon splitting functions factorize form the hard scattering cross section only for spin averaged processes

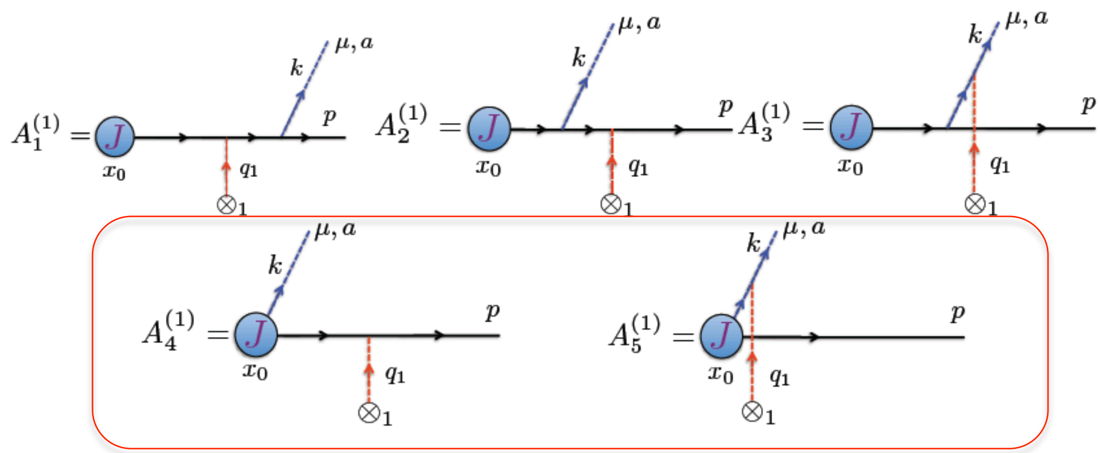


$$\Gamma_W^{\alpha,a}(k) = gT_r^a \frac{\bar{n}^\alpha}{k^+ + i\epsilon}$$

Altarelli-Parisi splitting

G. Altarelli et al. (1978)

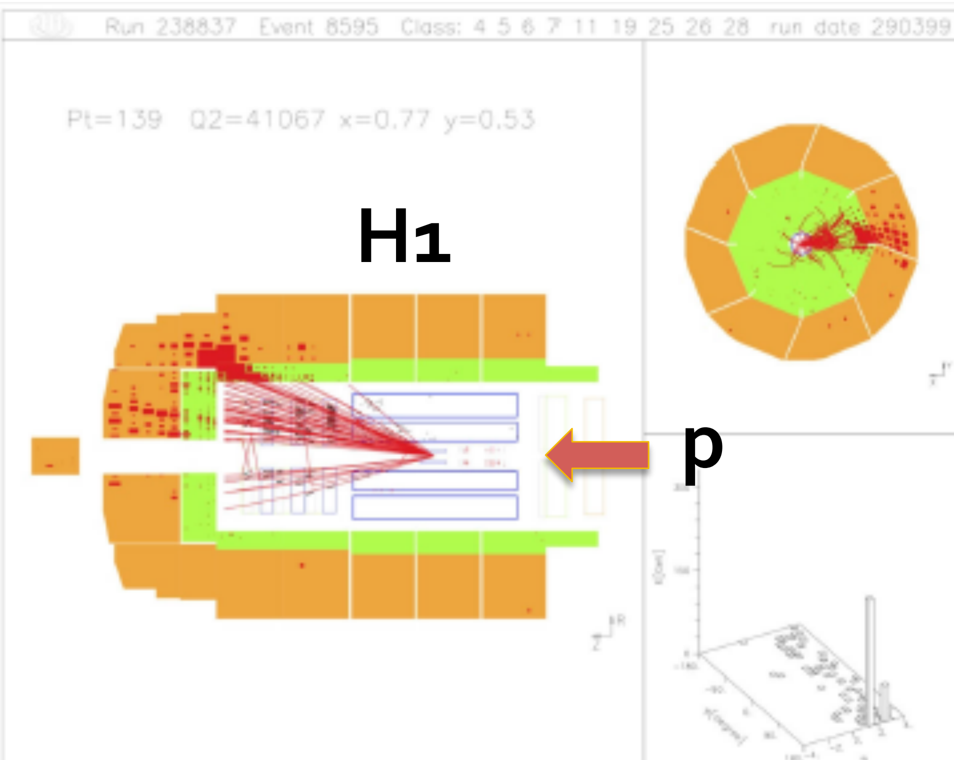
- Note that a collinear Wilson line appears in the R_ξ gauge



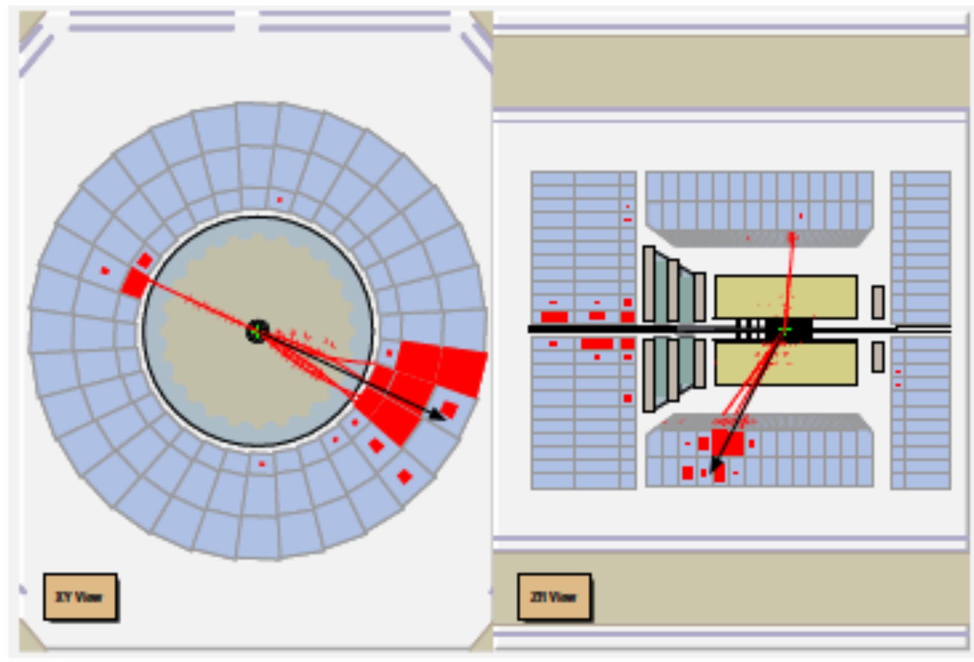
Single Born diagrams

Jet and inclusive hadron measurements

- For the purpose of this talk I will assume jet and hadron measurement capabilities, E_T/p_T, rapidity, momentum fraction z, in addition to DIS invariants



- Tracking, calorimetry, lepton and heavy flavor identification



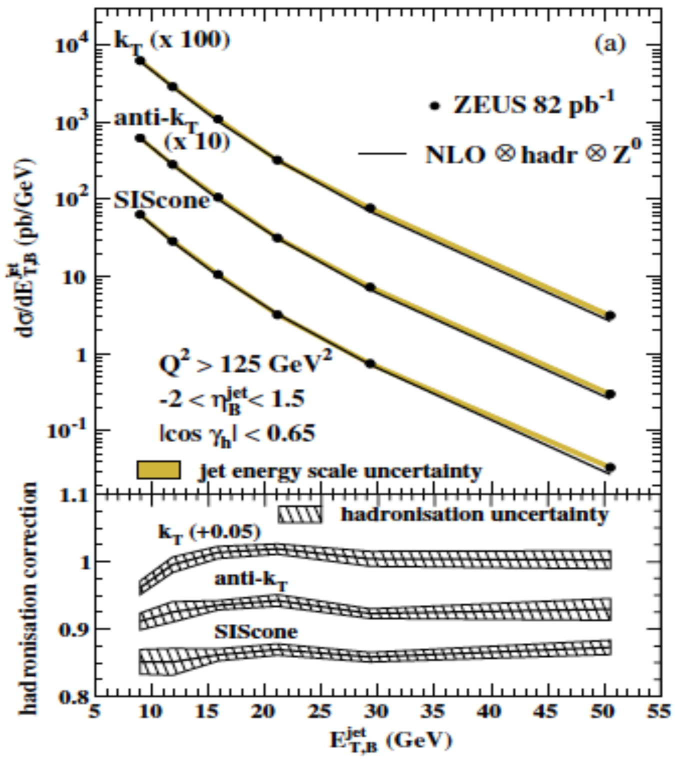
ZEUS

P. Neuman et al. (2014)

See talk E. Aschenauer

Jet production at the EIC, e+p

- For e+p results for 2 and 3 jets are known to NLO



Inclusive jet production

Abramovitz et al, 2010

Direct production

Mirkes et al. (1996)

Catani et al. (1997)

Nagy et al. (2001)

Photo production

Gordon et al. (1992)

Harris et al. (1997)

- Provides excellent test for QCD formalisms. Compare and connect the collinear and k_T factorization formalisms

Generally smaller hadronization corrections