Jet (de)coherence in PbPb collisions at the LHC

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21 May 2014, QM2014, Darmstadt, Germany

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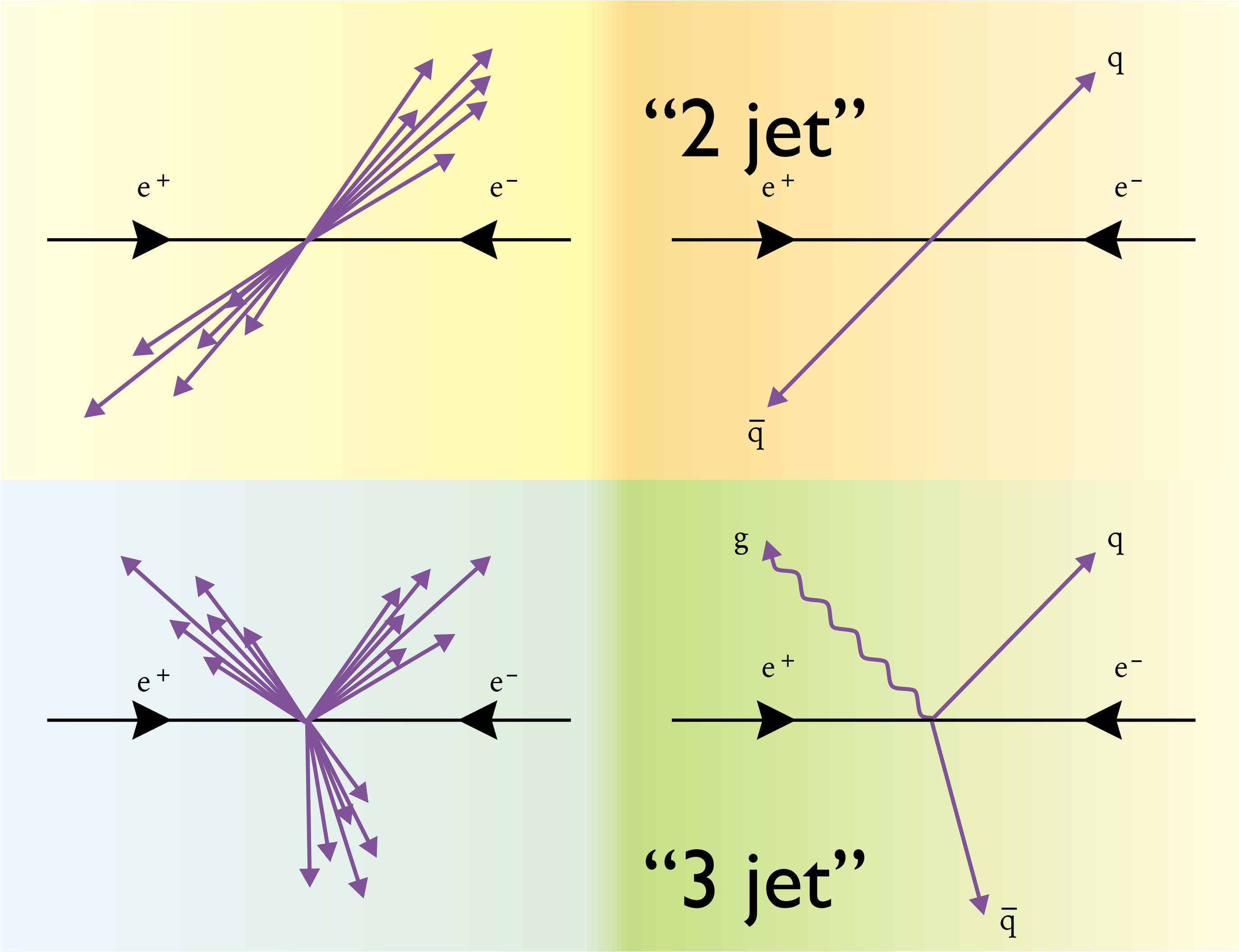
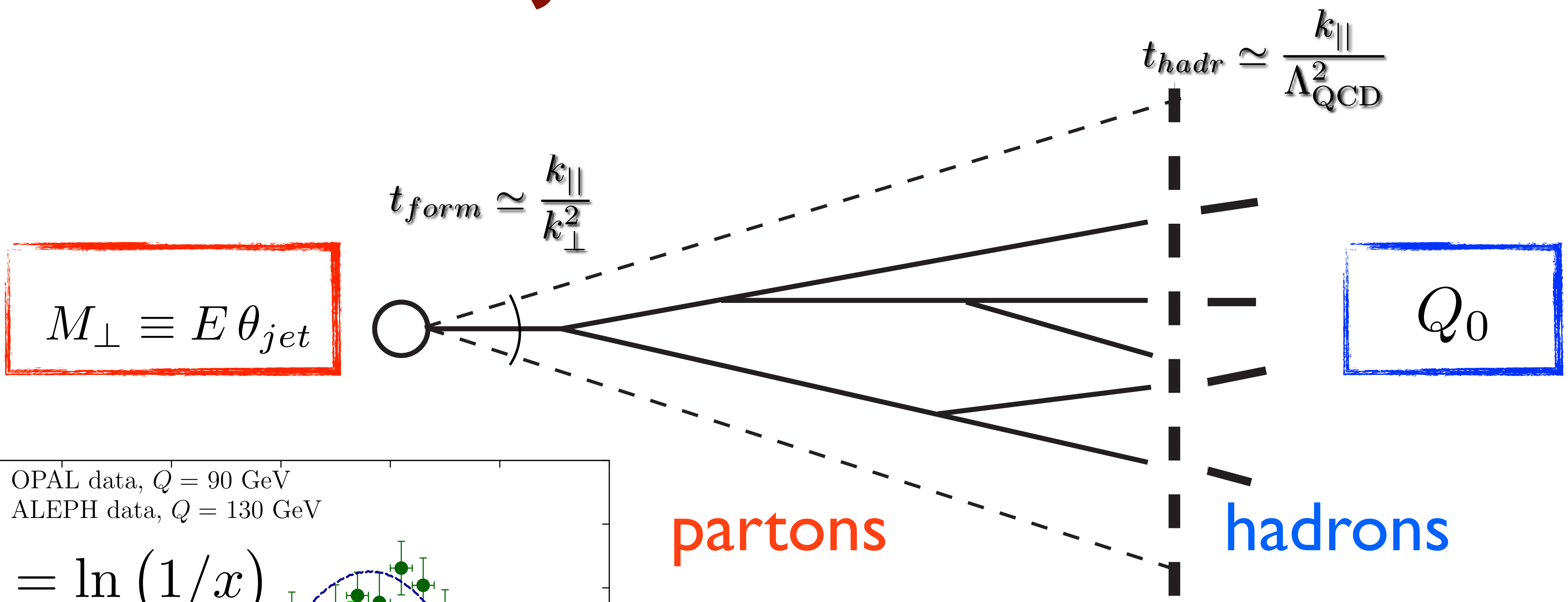
Jets

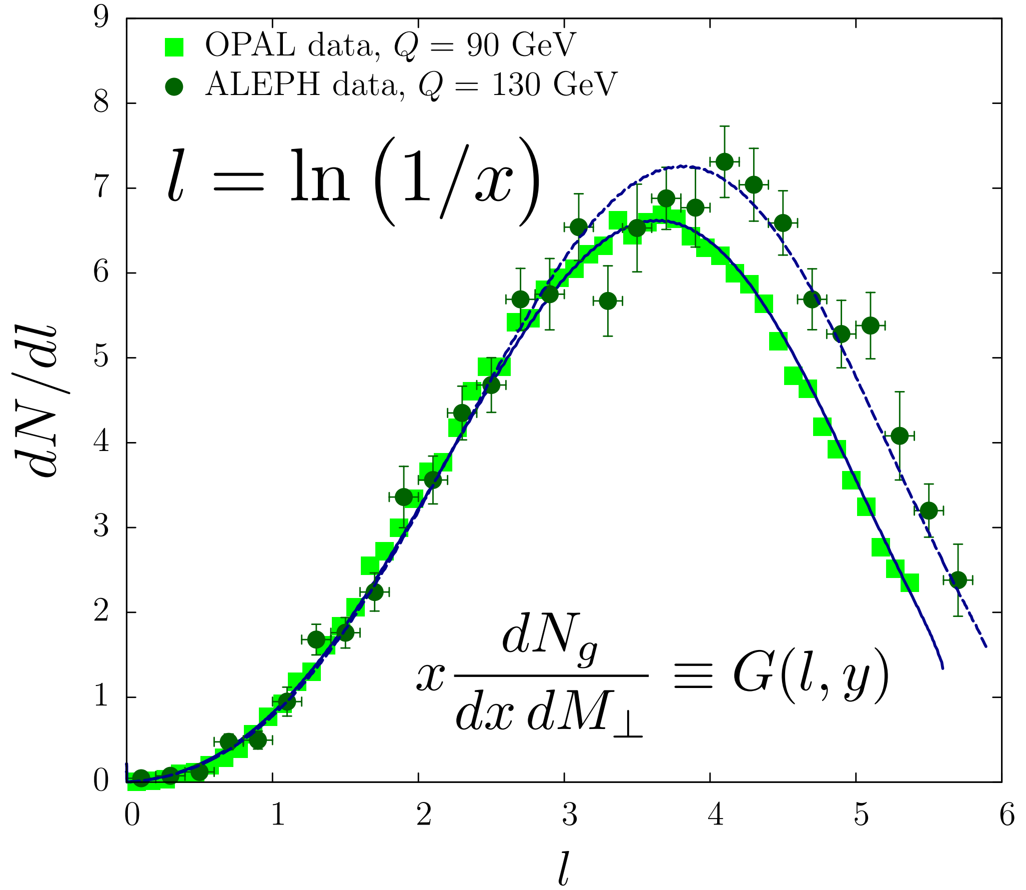


- physically: sprays of particles in the detector — probing partonic degrees of freedom
- well defined objects in perturbation theory*
- ideal hard probes for extracting properties of the medium!

* *free from problems related to hadronic fragmentation functions…*

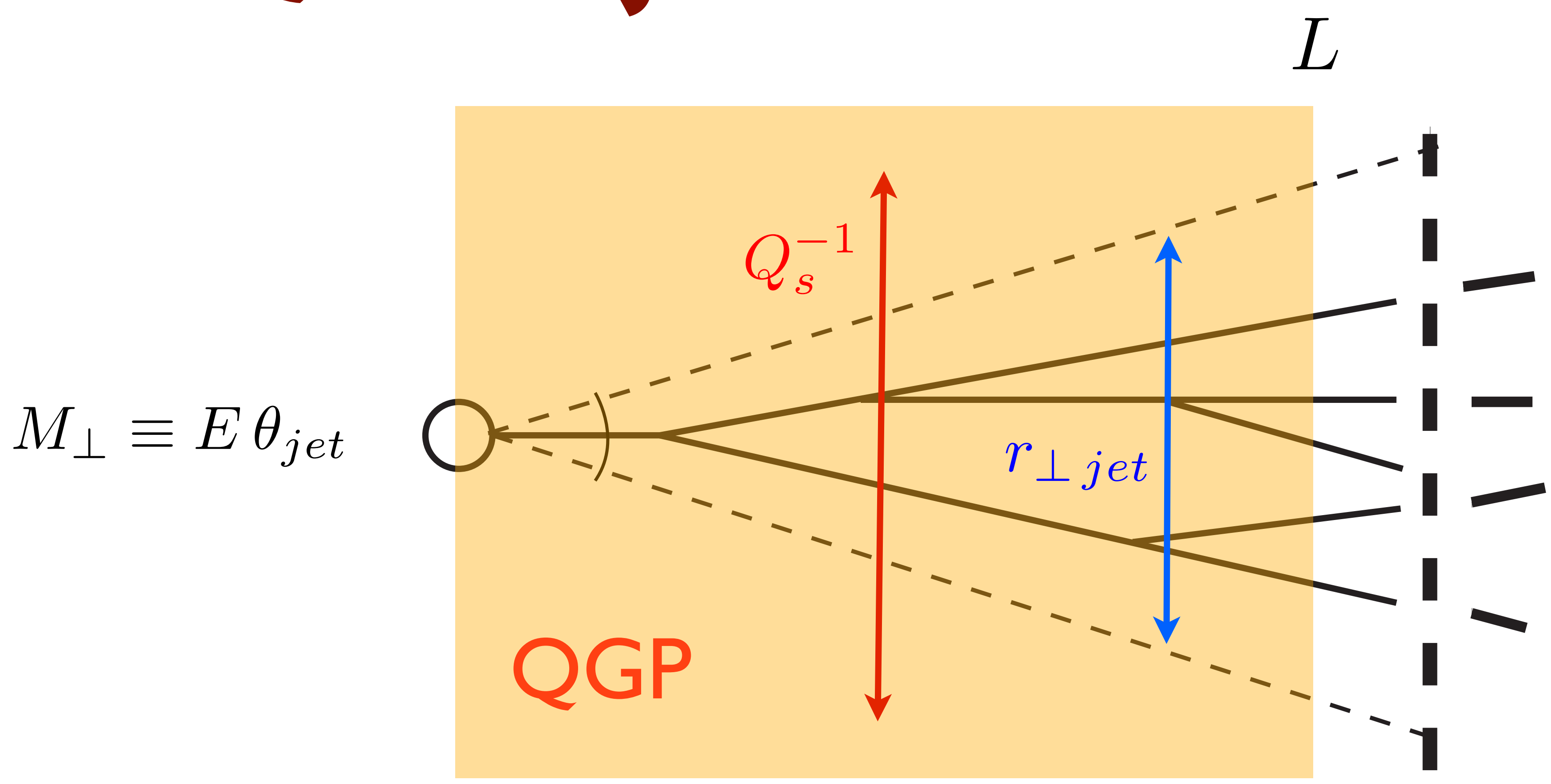
QCD jet in vacuum





- probabilistic picture, factorization
- jet scales — perturbative evolution
- angular ordering — essential for small x
- MLLA + Local-Parton-Hadron-Duality

QCD jet in medium



New scales:

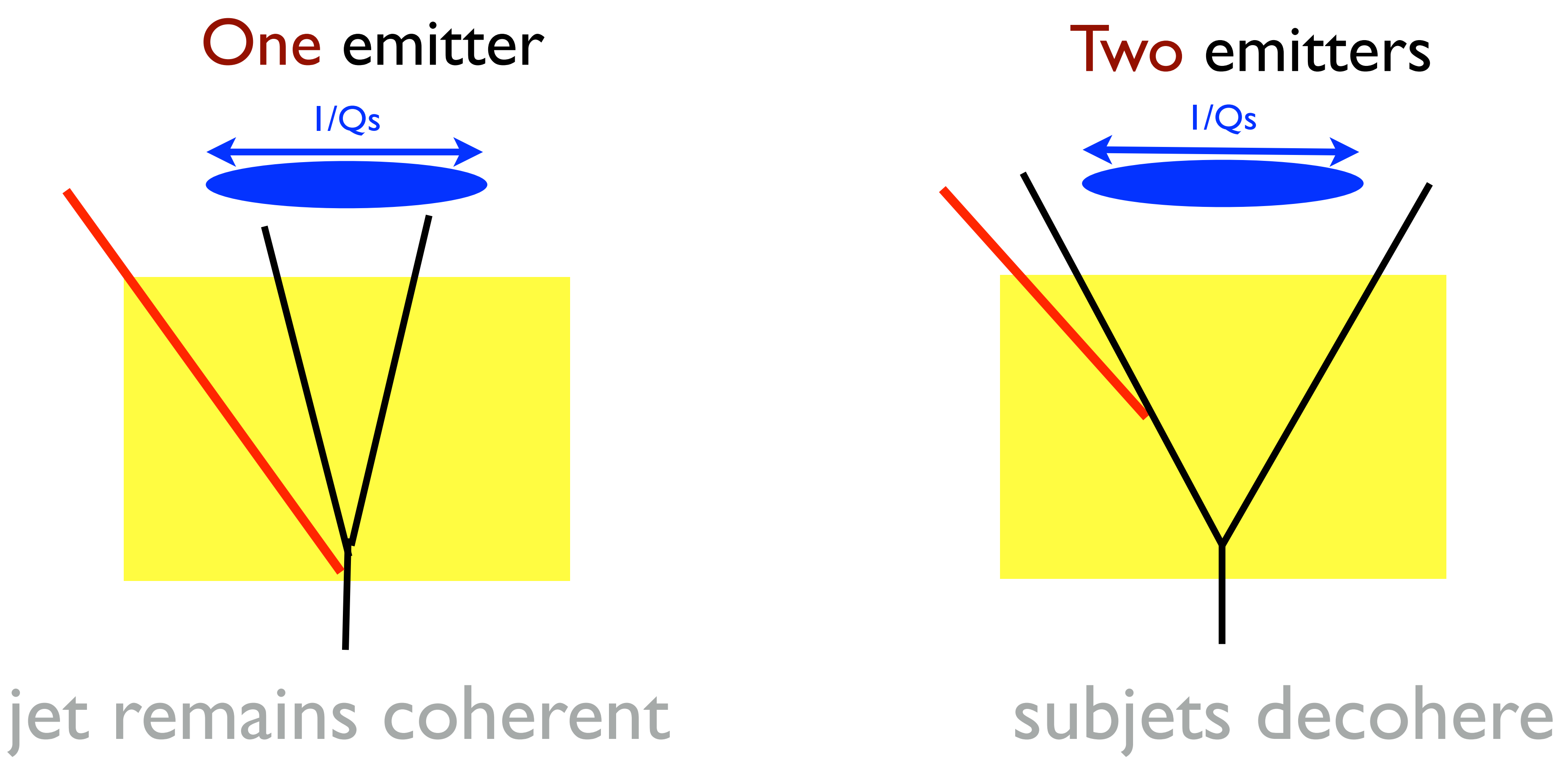
$$M_\perp \equiv E\,\theta_{jet}$$
$$Q_0 \sim \Lambda_{\rm QCD}$$

+

$$Q_s \equiv \sqrt{\hat{q}L} \equiv m_D\,\sqrt{N_{\rm scat}}$$
$$r_{\perp\,jet}^{-1} \equiv (\theta_{jet}L)^{-1}$$

Casalderrrey-Solana, Mehtar-Tani, Salgado, KT 1210.7765

Counting sources



The scale Q_s^{-1} determines the number of independent color sources that can are resolved by the medium.

:: medium induced radiation (BDMPS spectrum)

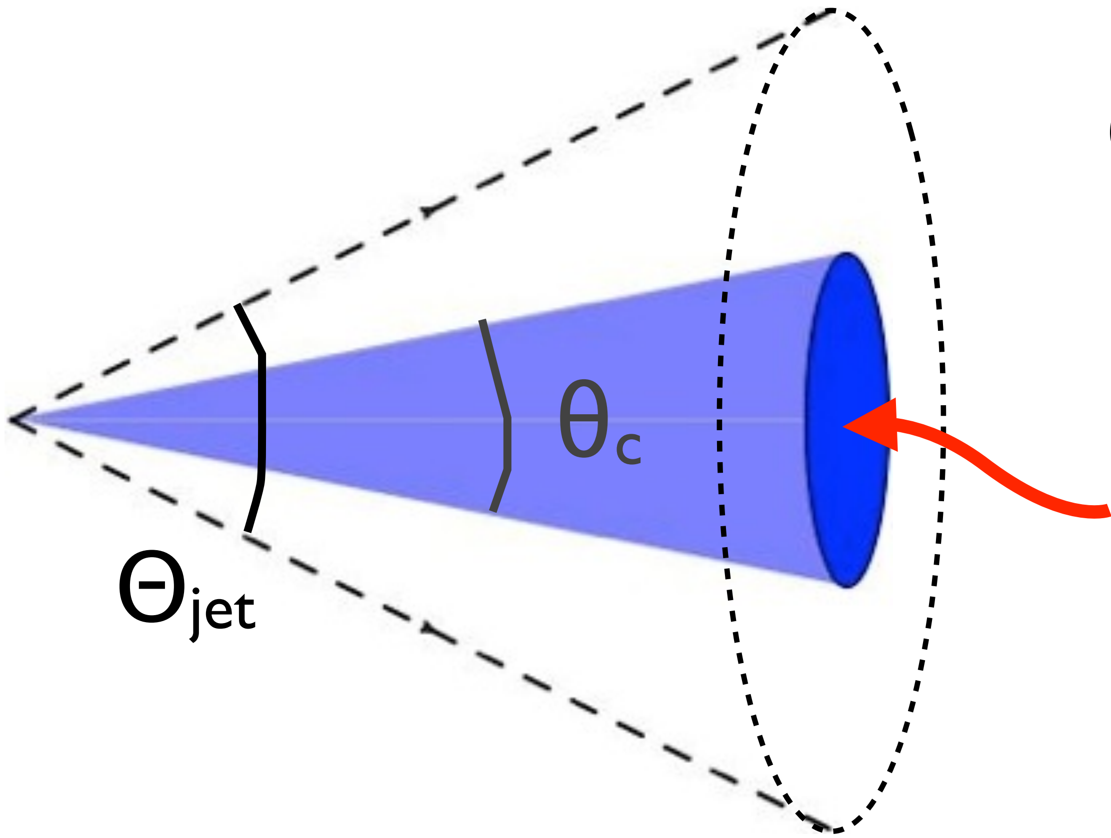
Mehtar-Tani, Salgado, KT 1009.2965; 1102.4317; 1112.5031; 1205.57397; Casalderrrey-Solana, Iancu 1105.1760

Resolving jet substructure

Coherence survival prob. $$\Delta_{\rm med} = 1 - e^{-\Theta_{\rm jet}^2/\theta_c^2}$$

$$\theta_c = 1/\sqrt{\hat{q}L^3}$$

jet definition ($\Theta_{\rm jet}$=R)!



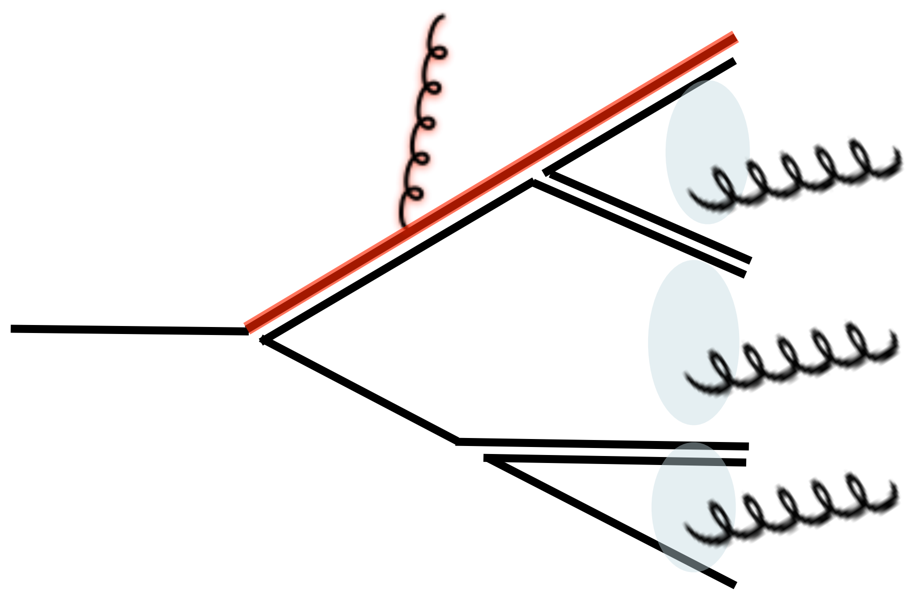
Coherent inner 'core'

- branchings occurring inside the medium with $\theta < \theta_c$ — hard modes
- the core interacts w/ medium coherently
- induces radiation — loses energy

A large fraction of the jets contain 90% of their energy within Θ~0.1!

Casalderrrey-Solana, Mehtar-Tani, Salgado, KT 1210.7765
Perez-Ramos, Mathieu PLB 718 (2013) 1421 [arXiv:1207.2854]; Perez-Ramos, Renk arXiv:1401.5283

Factorization of radiation



- assume collimated jets and coherence — leading contribution to inclusive spectra at high energies
- separation in angles — only the total charge radiates — jet calculus

$$D^{\mathrm{coh}}_{\mathrm{med}}(x;Q,L) = \int_x^1 \frac{\mathrm{d}z}{z} D^{\mathrm{vac}}\left(\frac{x}{z};Q\right) D^{\mathrm{med}}_q(z,p_\perp,L)$$

small angle, vacuum-like evolution

medium induced, large angle radiation

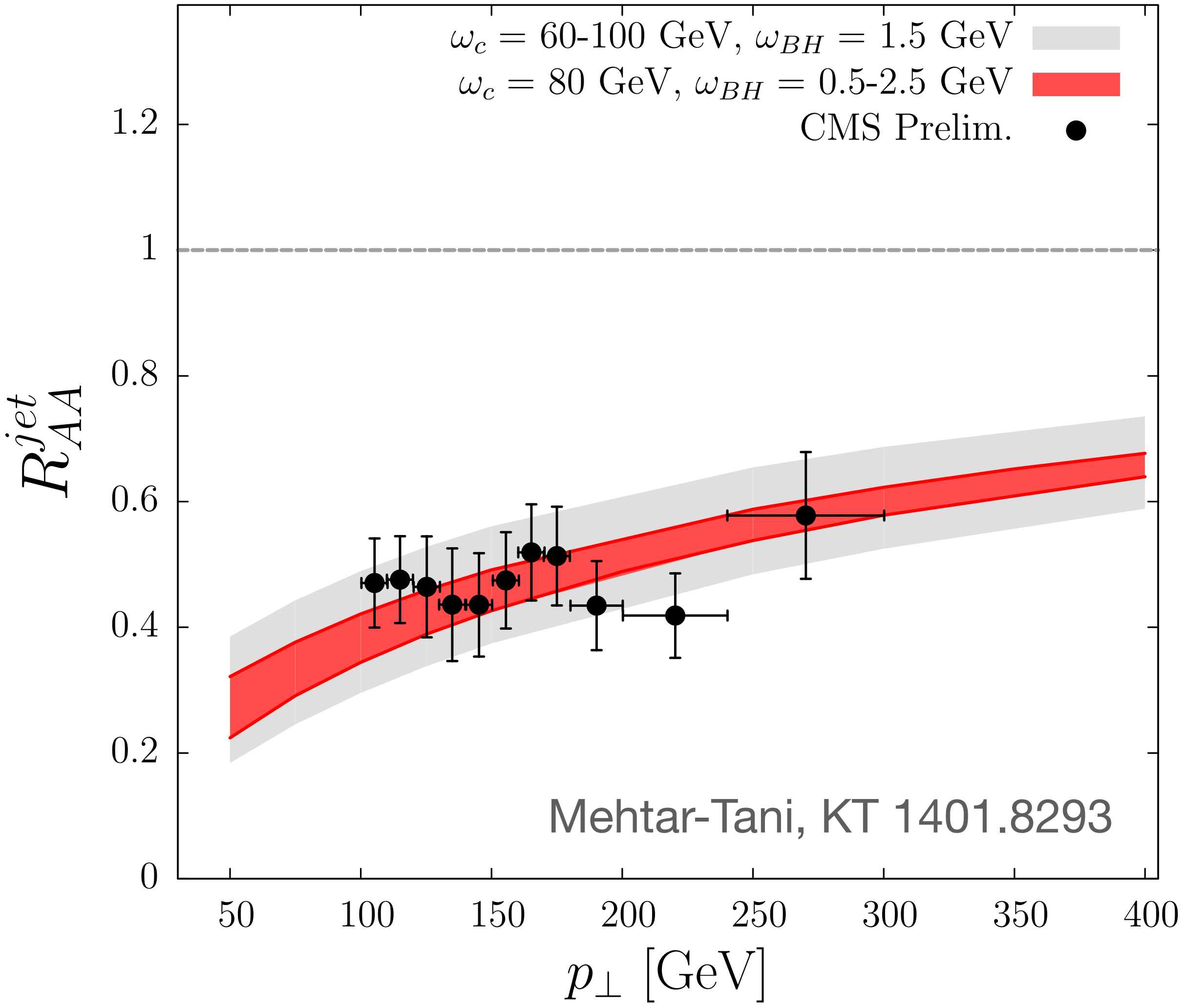
Mehtar-Tani, KT 1401.8293

Jeon, Moore hep-ph/0309332; Baier, Mueller, Schiff, Son hep-ph/0009237; Blaizot, Iancu, Mehtar-Tani 1301.6102

Nuclear modification factor

- assuming quark jets (n=5.6)
- allows to fix medium scales (fixing L = 2.5 fm)
- high-p⊥ jets are the most reliable probe for q̂!

Q_s = 3.6 GeV



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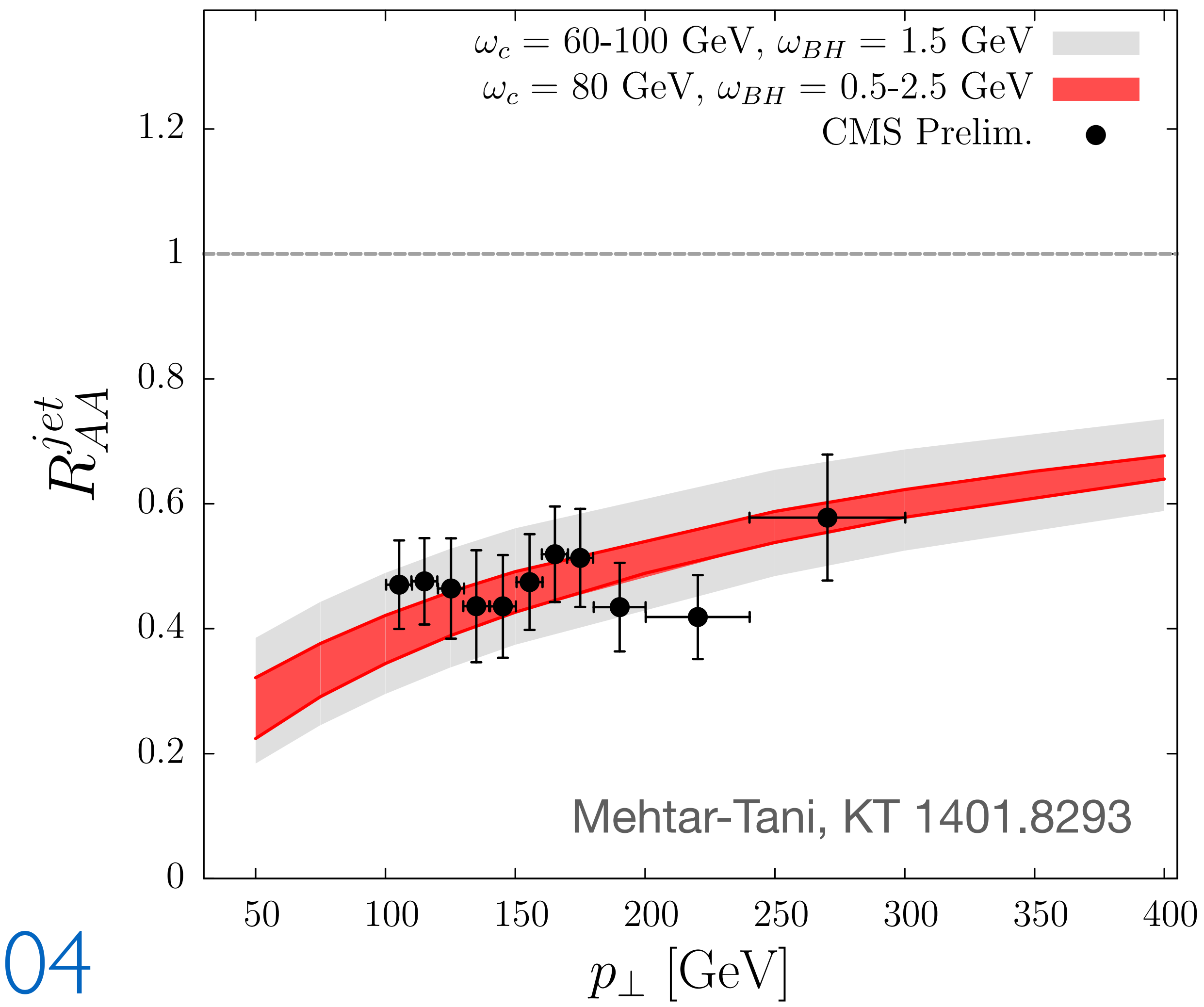
Jet deflection :: **ΔΘ** ~ Q_s/E ~0.04



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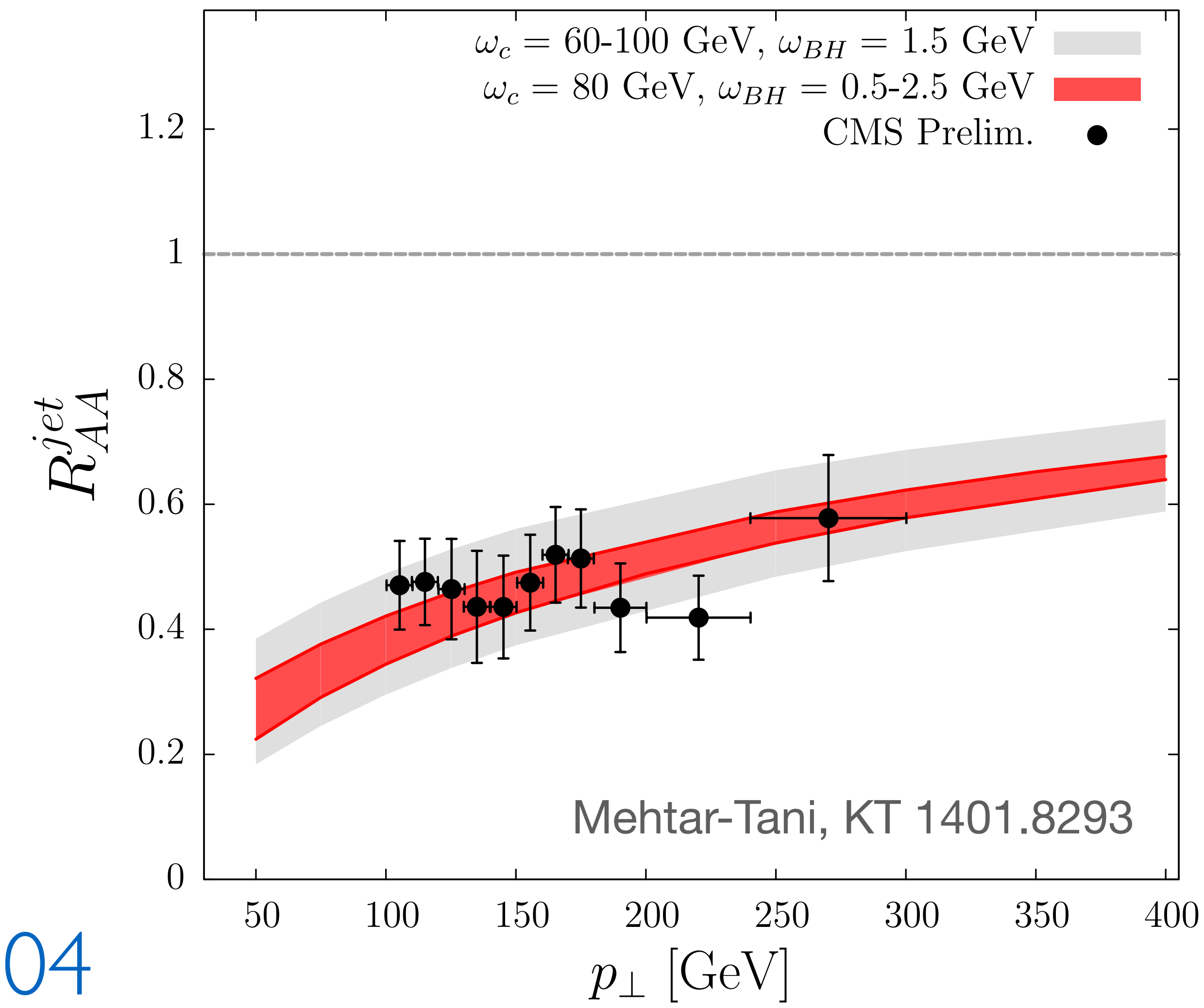


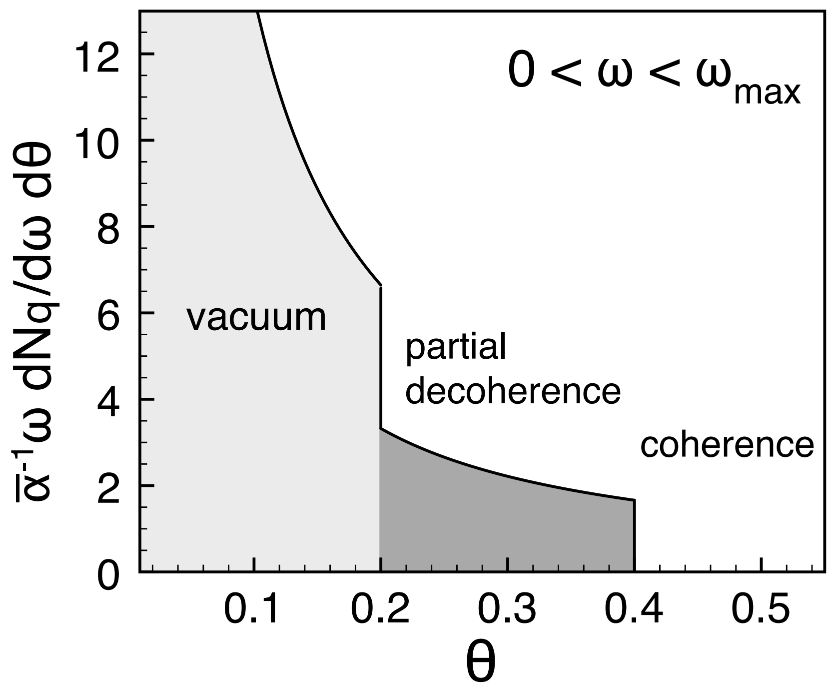
Missing pt in dijet events	Θ	Θ
missing energy at θ<Θ	14 - 19 %	9 - 15 %

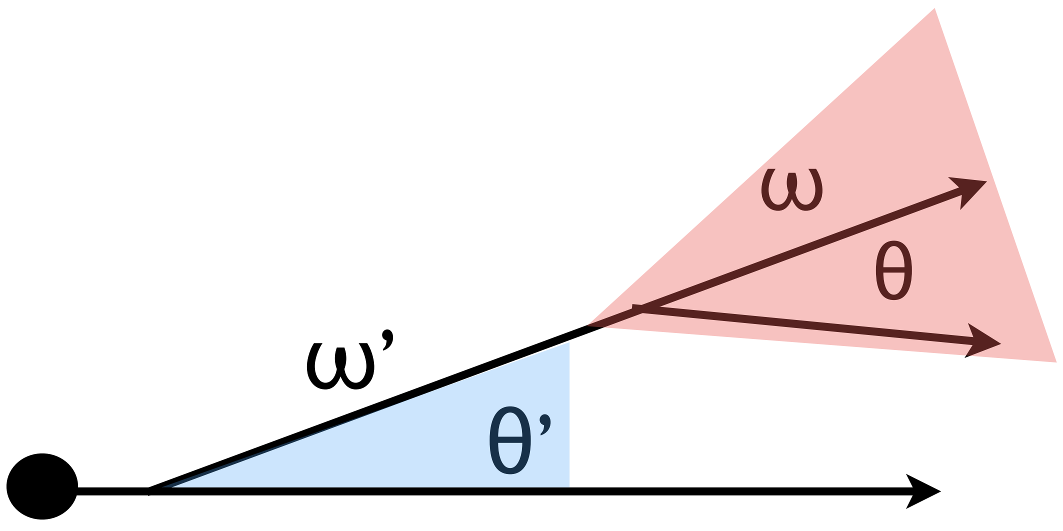
Soft gluons in the cone

Going beyond the inclusive jet spectrum, the assumption of fully coherent jets marginal

$\Theta_{\rm jet} = 0.3$

$\Theta_c = 0.08$





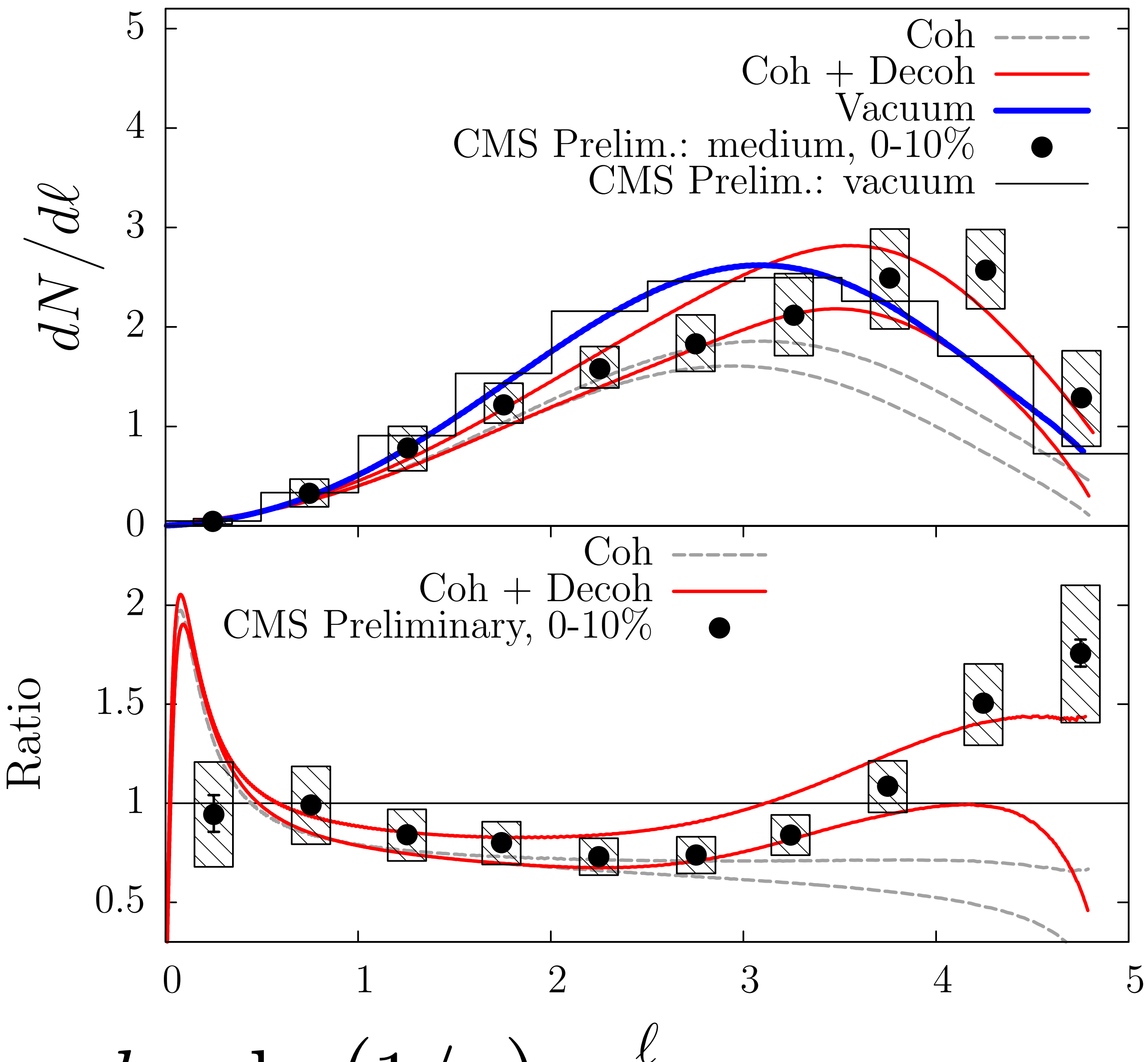
Contribution from 2nd emission in DLA w/ running coupling.

$$D^{\rm jet}_{\rm med}(x;Q,L) = D^{\rm coh}_{\rm med}(x;Q,L) + \Delta D^{\rm decoh}_{\rm med}(x;Q,L)$$

Mehtar-Tani, Salgado, KT 1009.2965; Mehtar-Tani, KT 1401.8293

Fragmentation function

- vacuum baseline reproduced by MLLA :: valid close to the humpbacked plateau
- allow the jet energy to vary (due to energy loss)
- coherent jet quenching important for intermediate ℓ
- decoherence plays main role at large ℓ (small x)



$$l = \ln(1/x)$$

Mehtar-Tani, KT 1401.8293

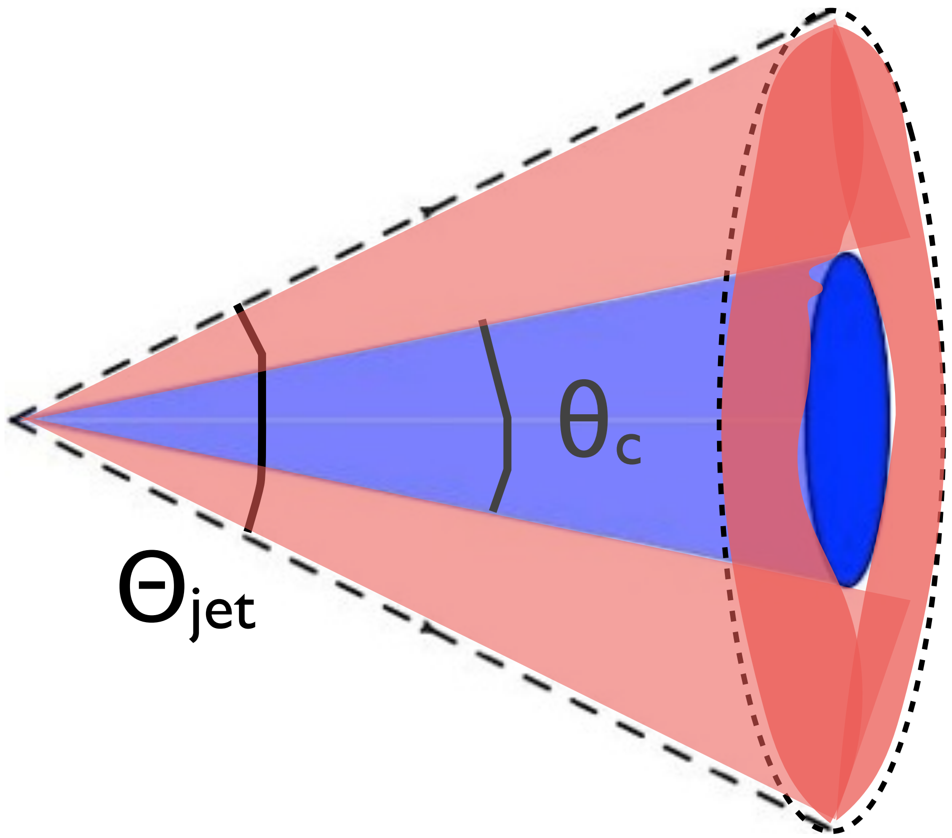
Summary

- jet quenching is a powerful tool to access properties (e.g. $\hat{q}$, $\hat{e}$ etc.) of the hot and dense QGP
  - resolved sub-jets are a consequence of color transparency (perturbative QCD)
- separation of scales (angles)
  - jet 'core' :: energy loss
  - jet 'edge' :: modification of fragmentation function
  - large angle :: transport in the medium

backup

Resolving jet substructure

Coherence survival prob. $\Delta_{\mathrm{med}} = 1 - e^{-\Theta_{\mathrm{jet}}^2/\theta_c^2}$



'Soft edge' of the jet

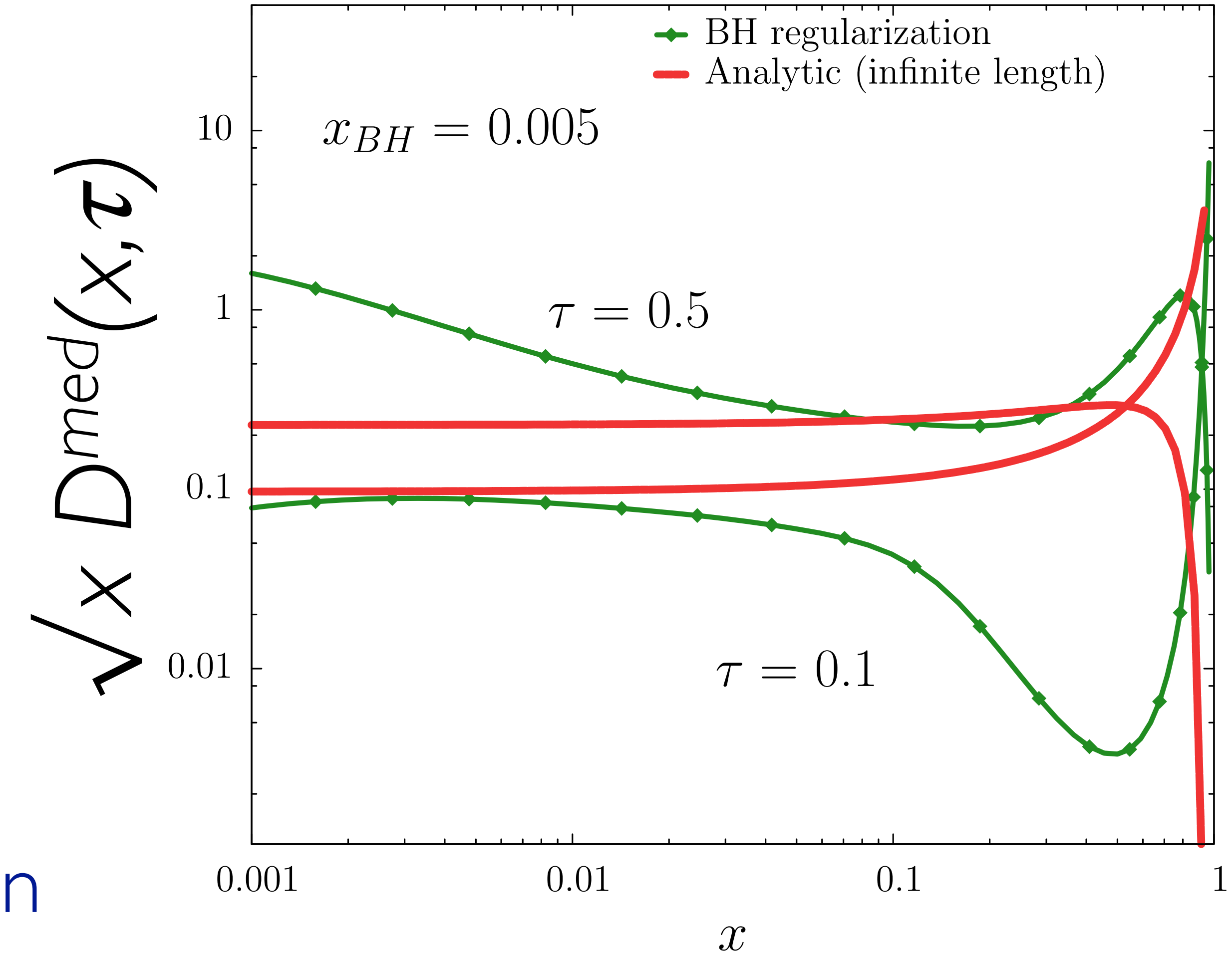
- softer components of the jet occupy the full angular range
  - do not carry a large energy fraction!
- sensitive to effects of decoherence
- modification of jet fragmentation function
  - sensitive to the critical angle Θc

Mehtar-Tani, KT 1401.8293

Induced radiation

Multiple induced gluon radiation (BDMPS) resummed in a rate equation in "time"

$$\tau = \frac{\alpha_s N_c}{\pi}\sqrt{\frac{\hat{q}L^2}{E}}$$

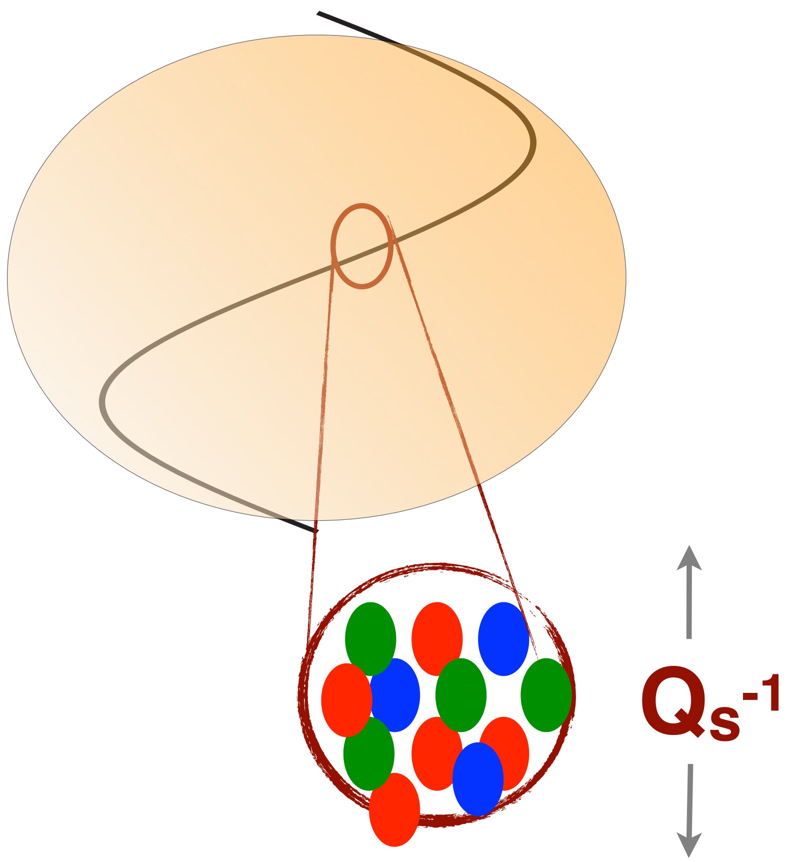


- probabilistic interpretation
- turbulent flow: no intrinsic accumulation of energy
- effective in transporting sizable energy to large angles

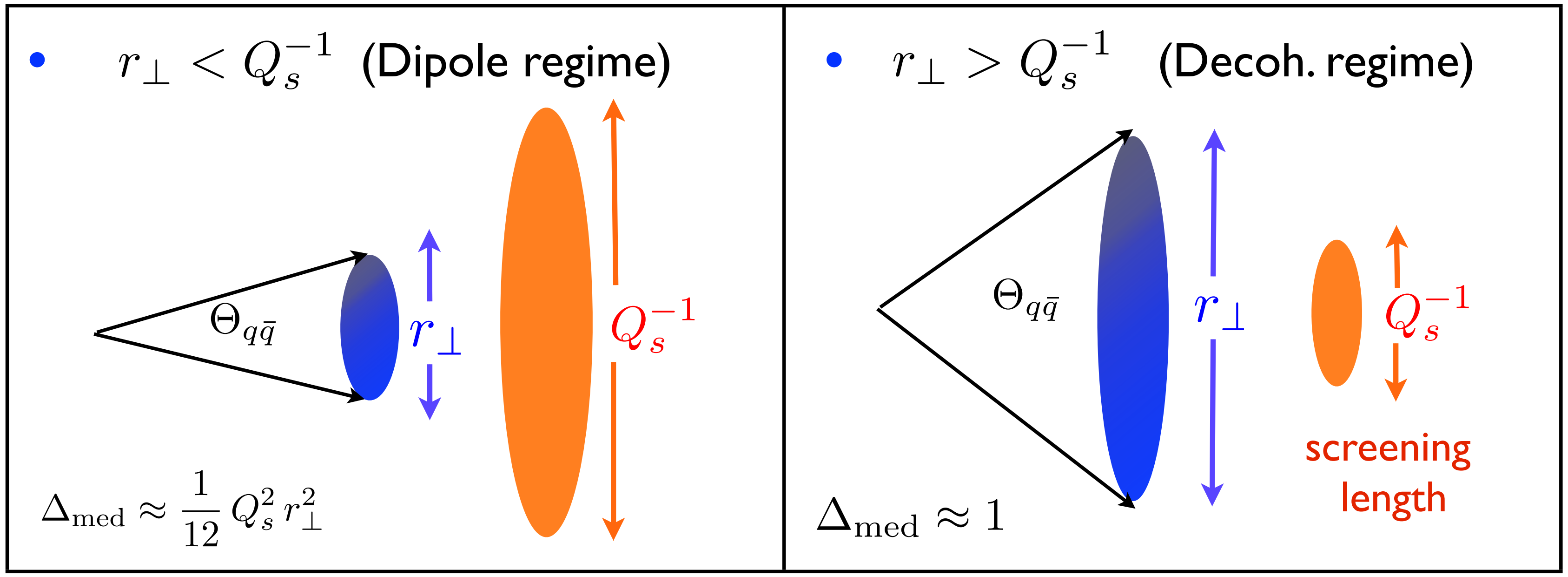
Jeon, Moore hep-ph/0309332; Baier, Mueller, Schiff, Son hep-ph/0009237; Blaizot, Iancu, Mehtar-Tani 1301.6102

Transparency vs decoherence

a snapshot of the medium:



a simple case — the antenna



$$\Delta_{\rm med} \approx 1 - \exp[-\frac{1}{12} Q_s^2\, r_\perp^2]$$

decoherence parameter

$$k_\perp < Q_{\rm hard}$$

hardest scale determines phase space for radiation

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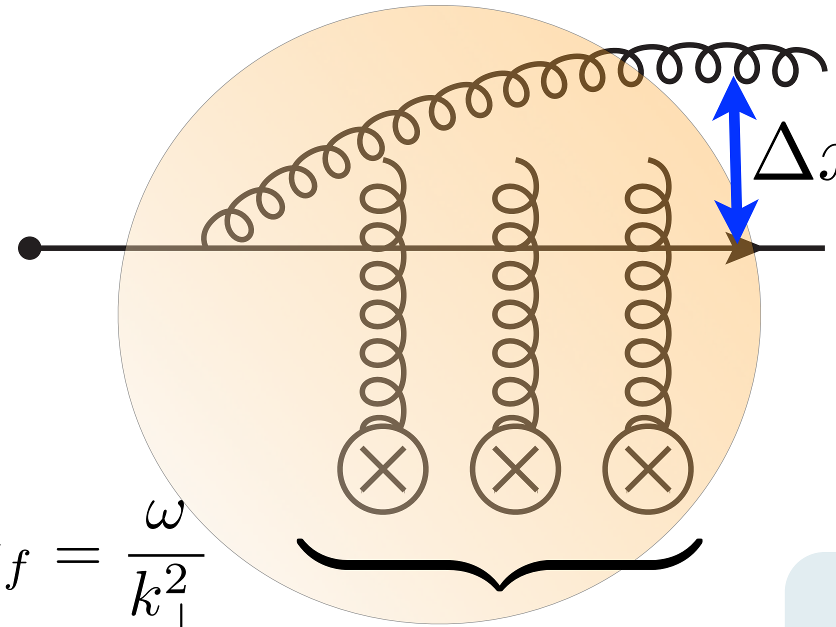
Induced radiation



Multiple scattering in the medium:

$$t_{\rm br} = \lambda_{\rm mfp} N_{\rm coh}, \quad k_{\rm br}^2 = \mu^2 N_{\rm coh} \quad \Big\} \quad t_{\rm br} = \sqrt{\omega/\hat{q}}, \quad k_{\rm br}^2 = \sqrt{\hat{q}\omega}$$

$\lambda_{\rm mfp} \to t_{\rm br}$ :: Landau-Pomeranchuk-Migdal effect

Bethe-Heitler regime

$$t_{\rm br} \sim \lambda_{\rm mfp}$$

$$\omega_{\rm BH} = \lambda^2 \hat{q} \sim \lambda m_D^2$$

Factorization regime

$$t_{\rm br} \sim L$$

$$\omega_c = \hat{q} L^2$$

LPM regime

$$\omega_{\rm BH} \ll \omega \ll \omega_c$$

Baier, Dokshitzer, Mueller, Peigné, Schiff (1997-2000), Zakharov (1996), Wiedemann (2000), Gyulassy, Levai, Vitev (2000), Arnold, Moore, Yaffe (2001)