JET SUPPRESSION AND AZIMUTHAL ANISOTROPY AT RHIC AND LHC

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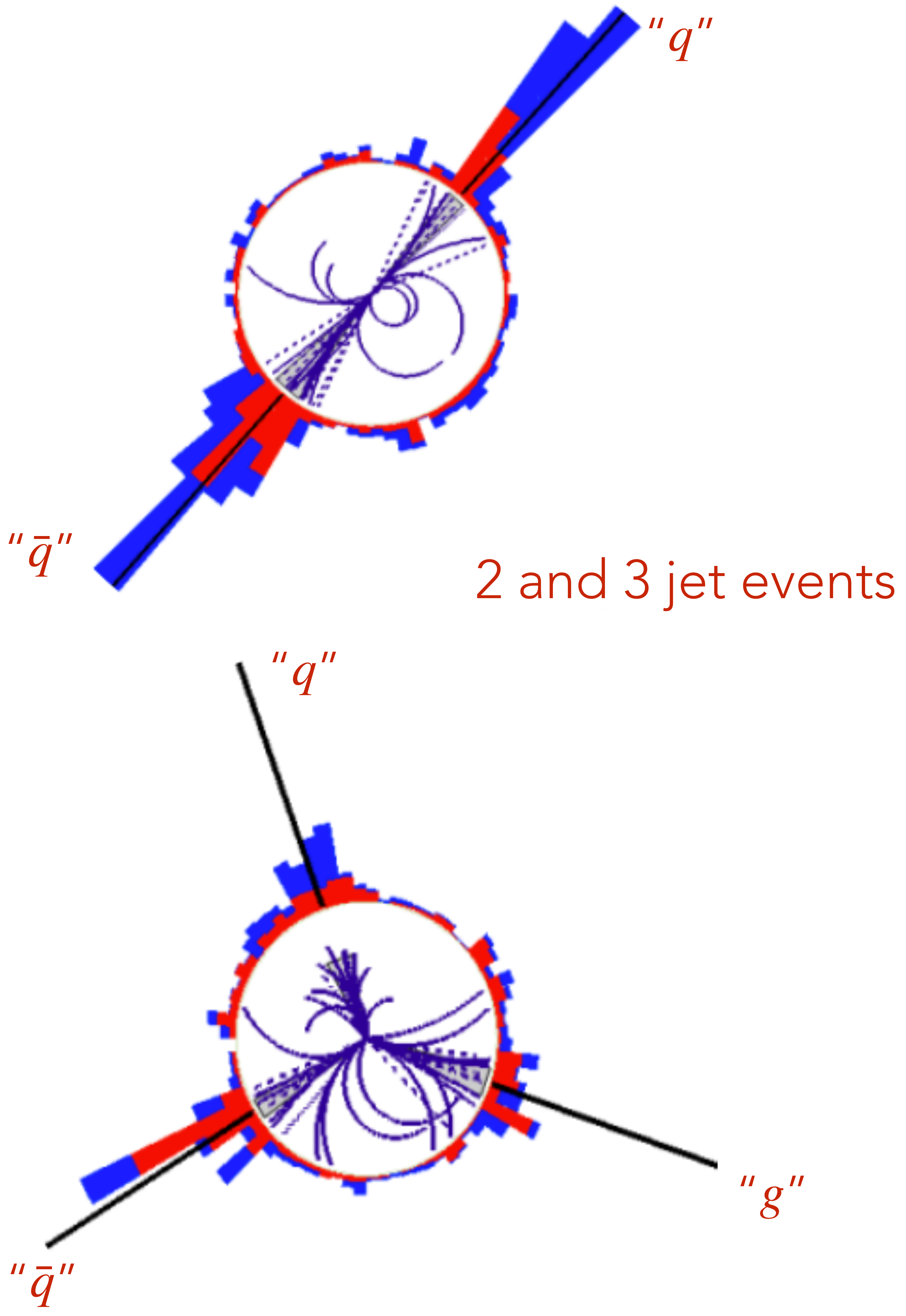
Hard Probes 2023, Aschaffenburg, 27-31 Mar 2023

JETS IN QCD

- asymptotic freedom: high energy quarks and gluons manifested as collimated sprays of particles and energy.
- jets: well-defined objects in experiment & theory.
- multi-scale & long-distance dynamics.
- **powerful probe** of the quark-gluon plasma in heavy-ion collisions.

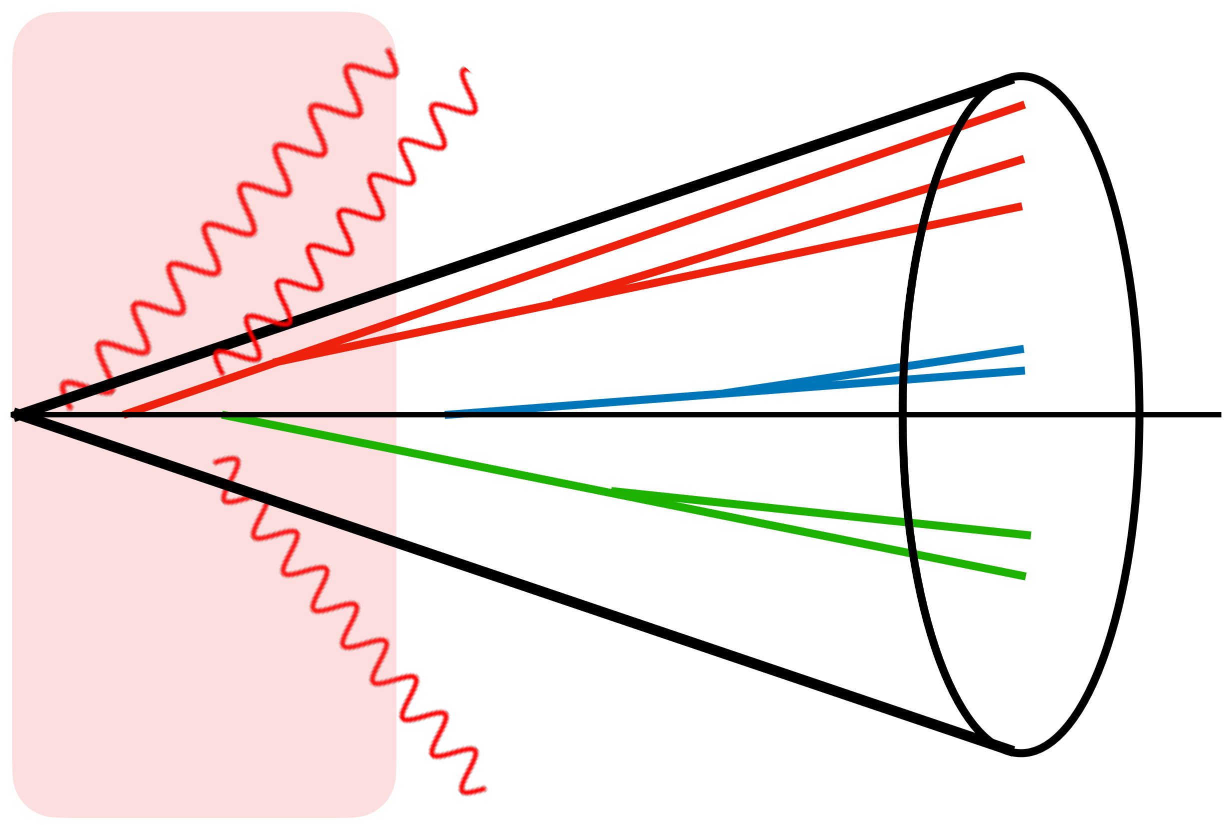


JET FRAGMENTATION IN THE MEDIUM

Mehtar-Tani, Salgado, KT (2011); Casalderrey-Solana, Iancu (2011); Y. Mehtar-Tani, KT 1706.06047, 1707.07361
Caucal, Iancu, Mueller, Soyez 1801.09703

$\Longrightarrow$ color dynamics in the medium (color coherence…)

$\Longrightarrow$ every color source inside jet resolved by the QGP contribute to energy loss.



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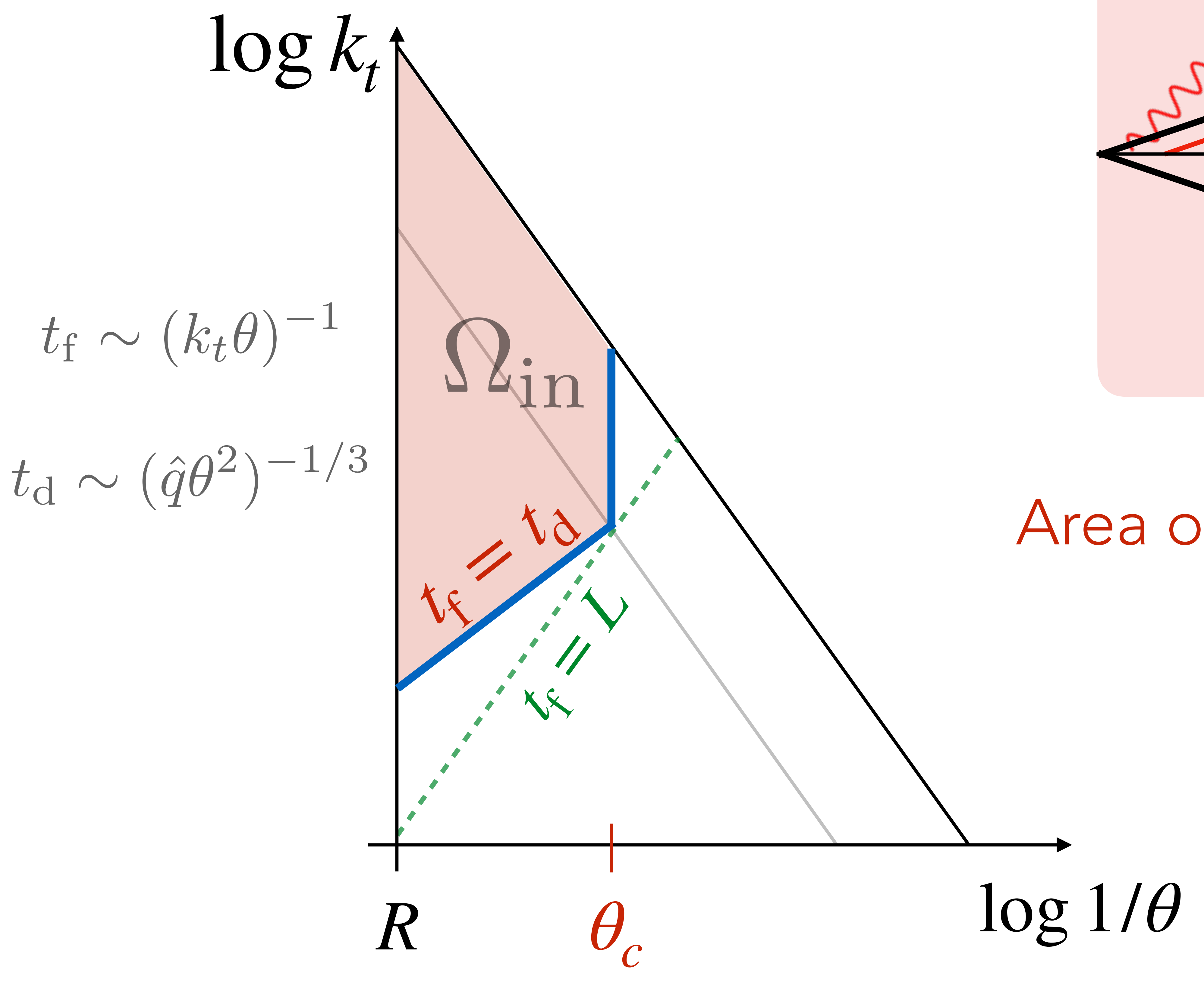
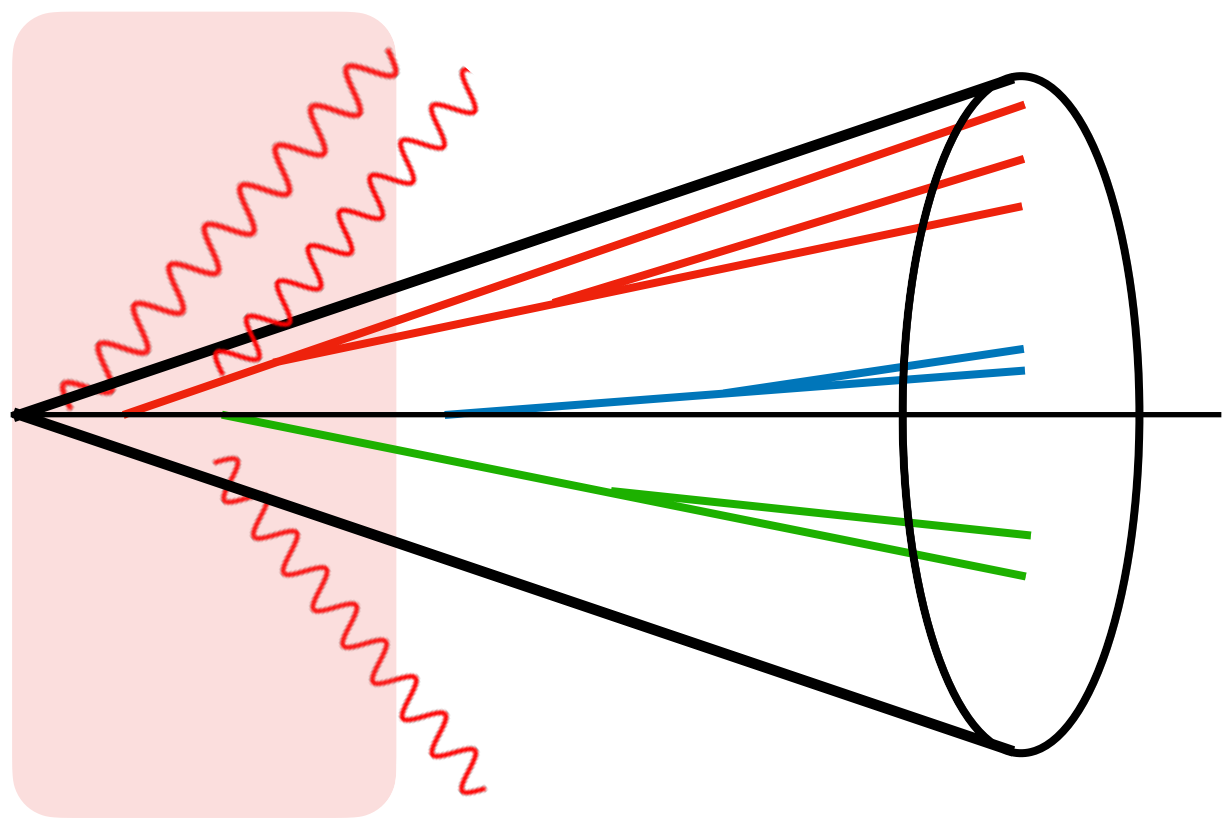




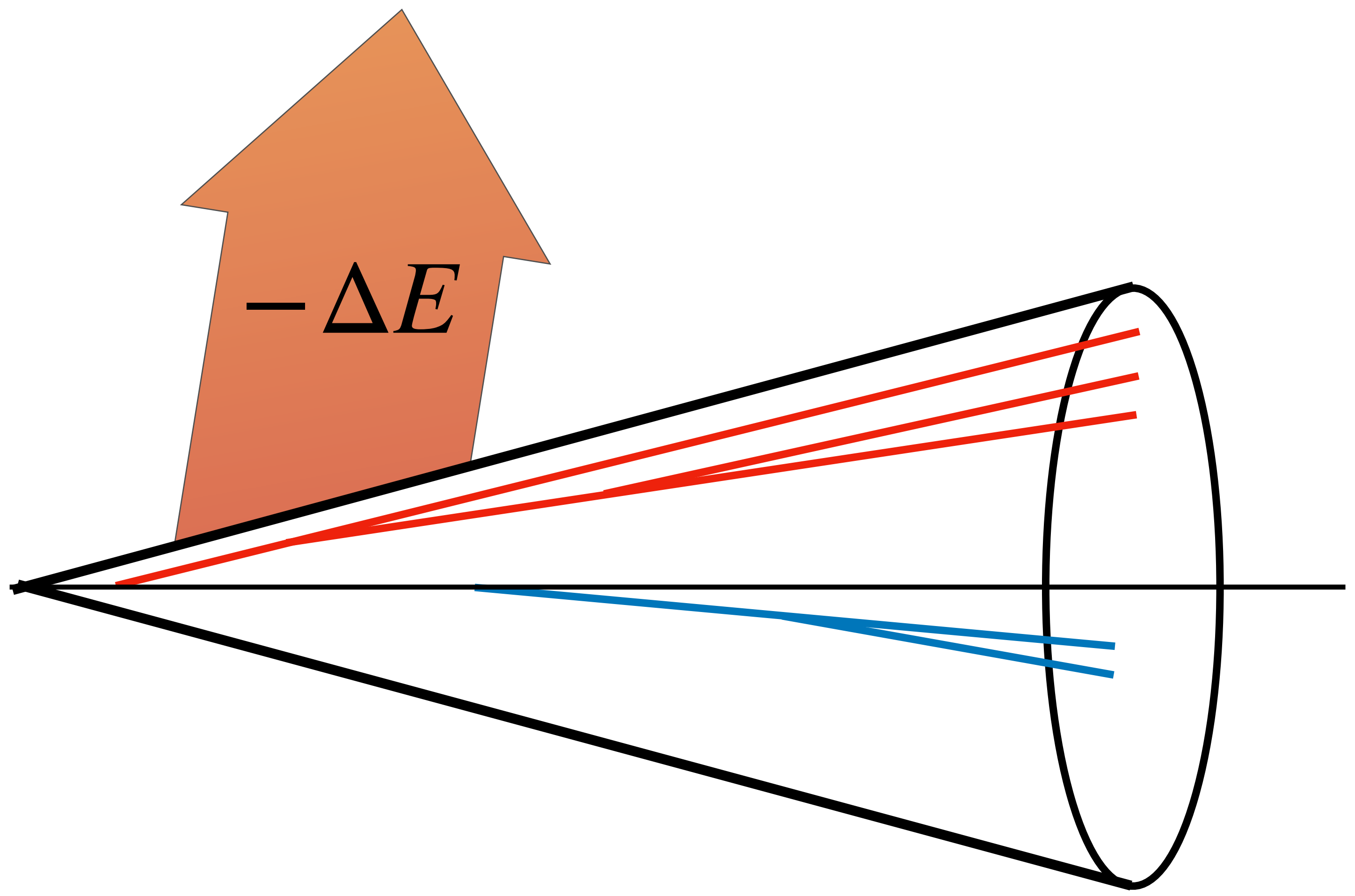
Area of red region is multiplicity of **in-medium** & **resolved** splittings

$$\Omega_\mathrm{in}^\mathrm{DLA} \approx 2\frac{\alpha_s C_R}{\pi} \log\frac{R}{\theta_c}\left(\log\frac{p_T}{\omega_c} + \frac{2}{3}\log\frac{R}{\theta_c}\right)$$

Potentially large and calls for **resummation**.

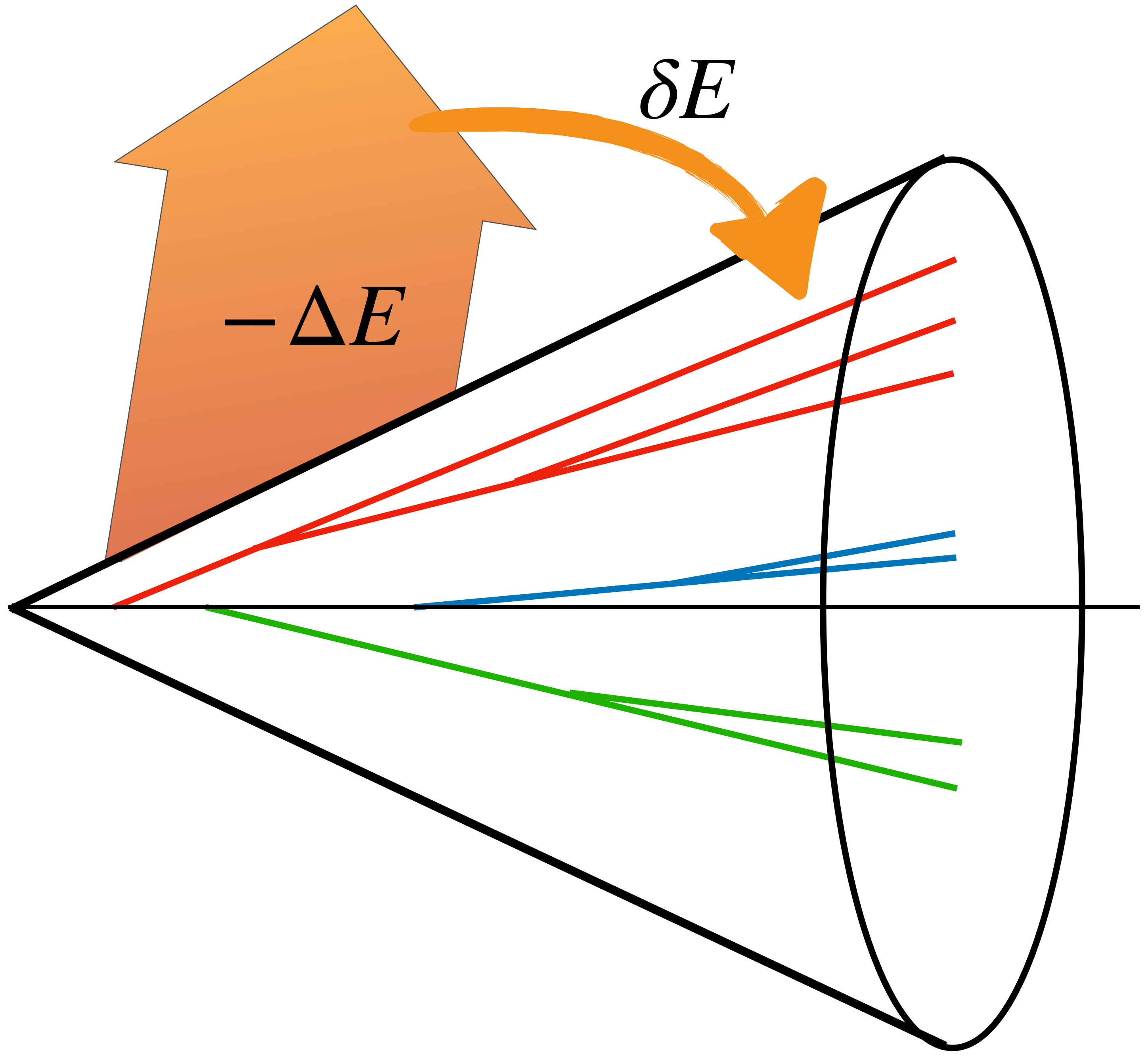
CONE-SIZE DEPENDENCE

Narrow jets



less energy loss BUT
easier to escape the cone

Wide jets



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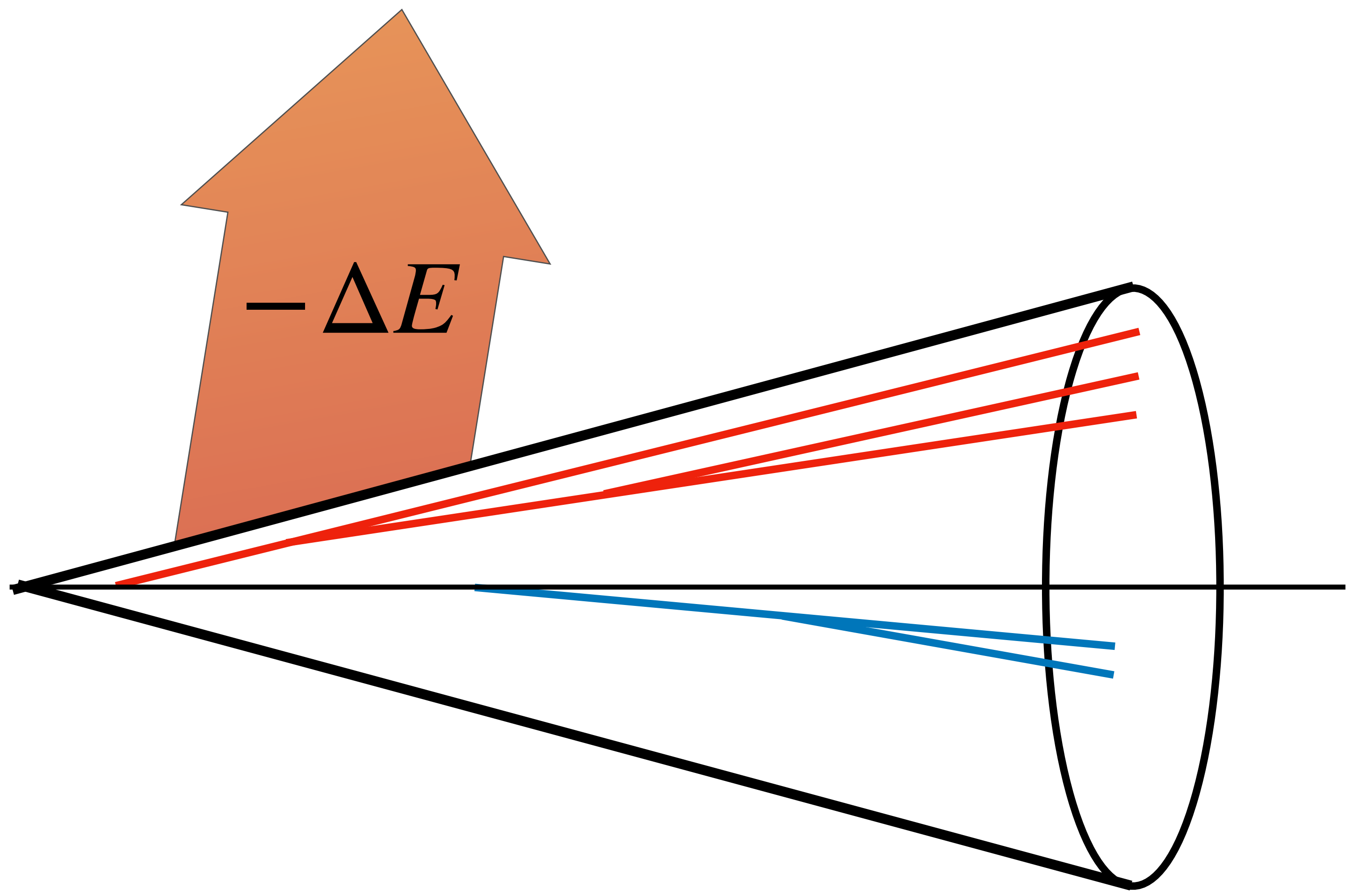

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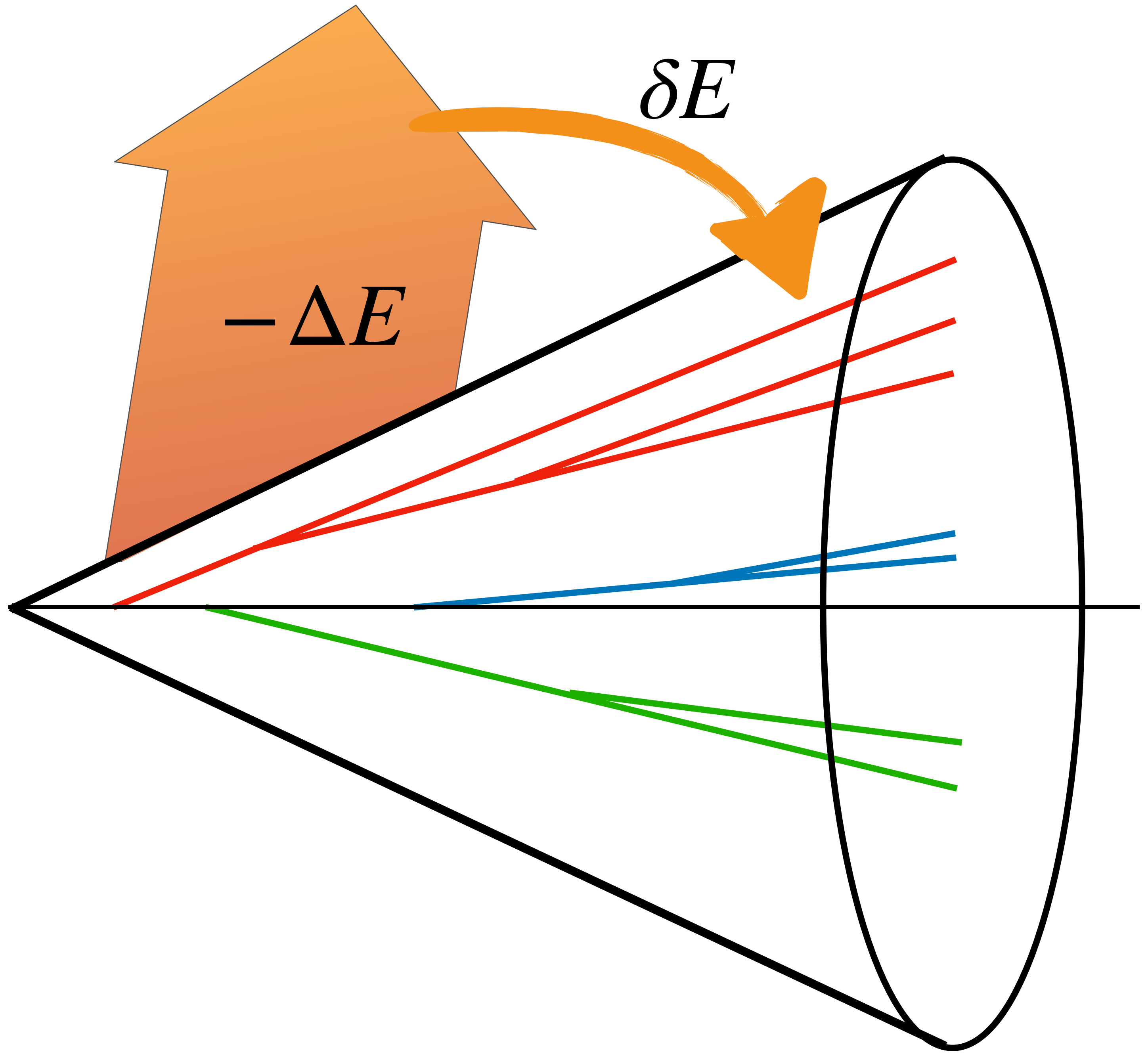

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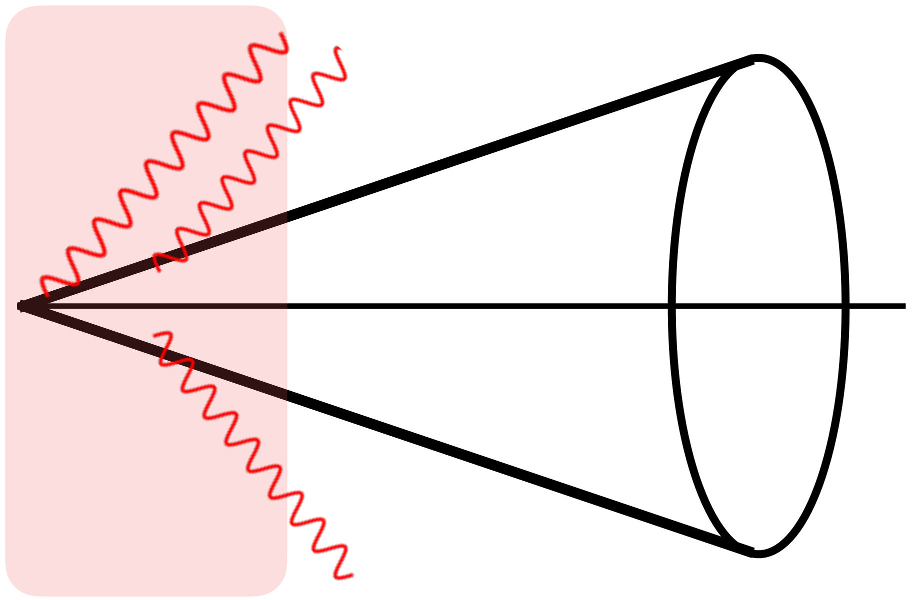
$\Longrightarrow$ new handle on medium effects: $\hat{q}$ affects **resolution** & **energy loss**

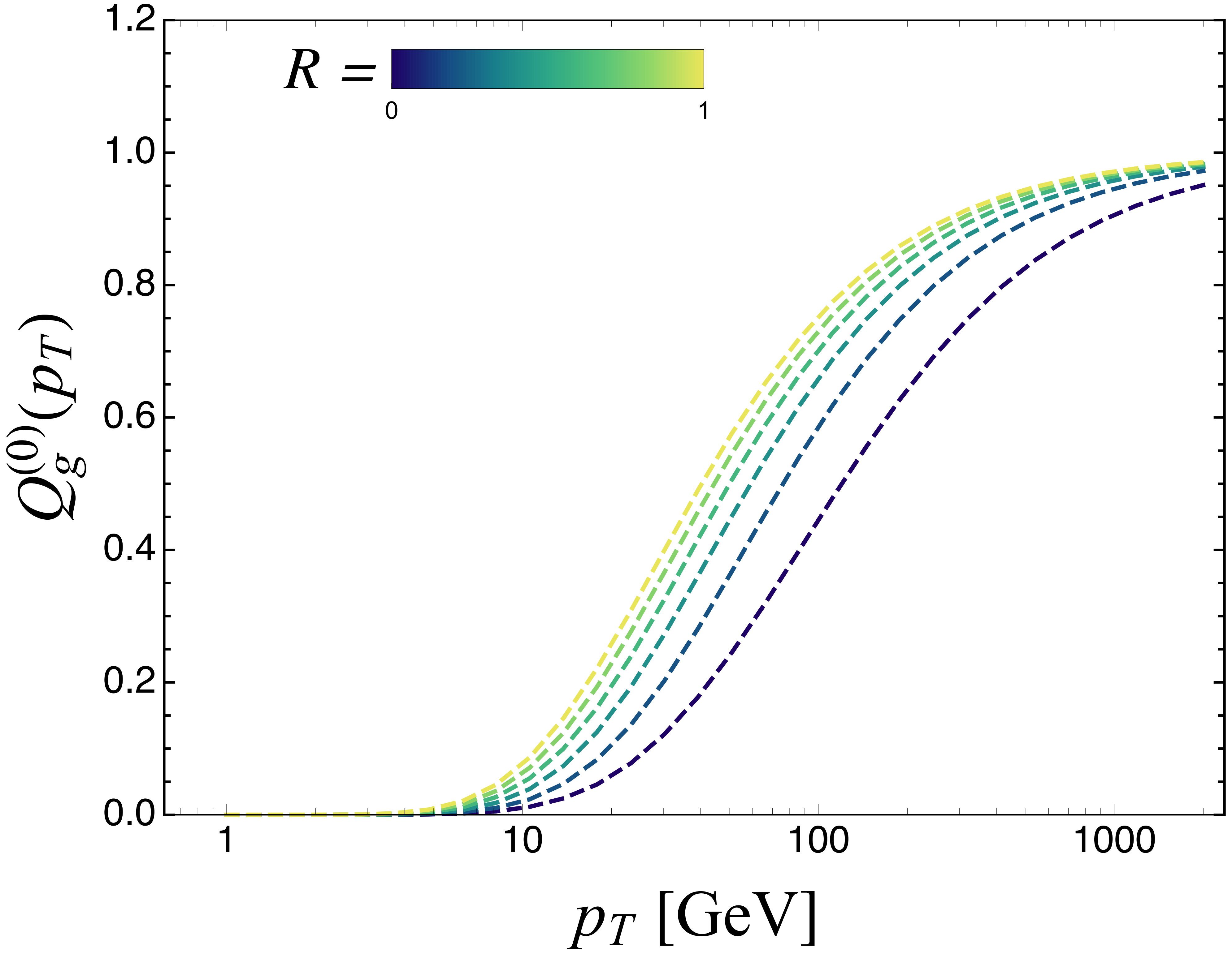
Energy loss of single parton

Baier, Dokshitzer, Mueller, Schiff (2001); Salgado, Wiedemann (2003)



$$\frac{\mathrm{d}\sigma}{\mathrm{d}p_T} = Q^{(0)}_{>}(p_T, R)\hat{\sigma}_{AA\to i}$$

$$Q^{(0)}_{>}(p_T, R) = \exp\left[-\int_{T_0}^{\infty} \mathrm{d}\omega \, \frac{\mathrm{d}I_>}{\mathrm{d}\omega}\left(1 - \mathrm{e}^{-\nu\omega(1-\Theta(\omega_s-\omega)R^2/R^2_{\rm rec})}\right)\right]$$

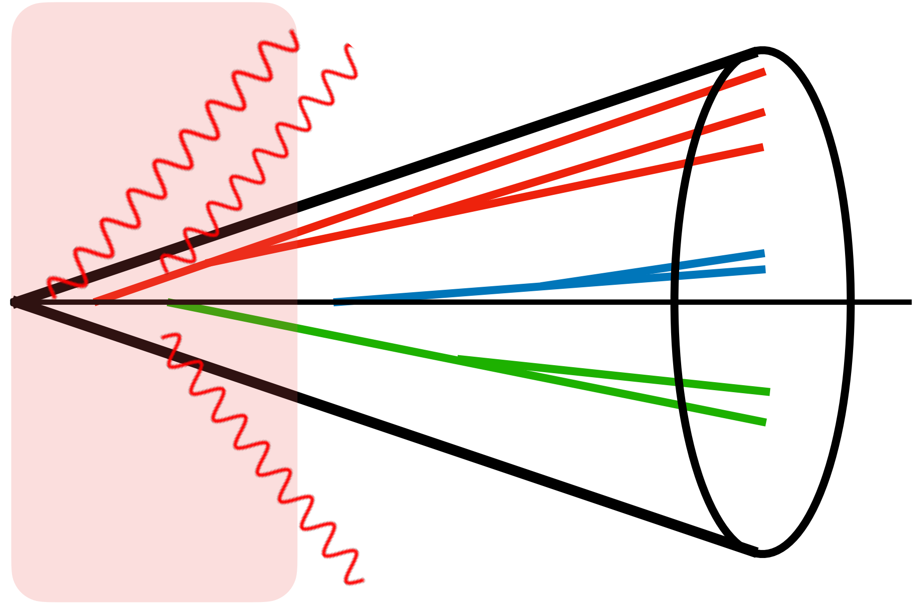


- Laplace variable $\nu = n/p_T$.
- out-of-cone emissions using differential IOE spectrum. Barata, Mehtar-Tani, Soto-Ontoso, KT 2106.07402
- dominated by emissions with $\omega_s \sim \alpha_s^2 \hat{q} L^2$.
- lost energy smeared over the solid angle $R_{\rm rec}$ - free parameter.

see talks by Takacs, Thu 09:00 & Isaksen, Wed 14:40

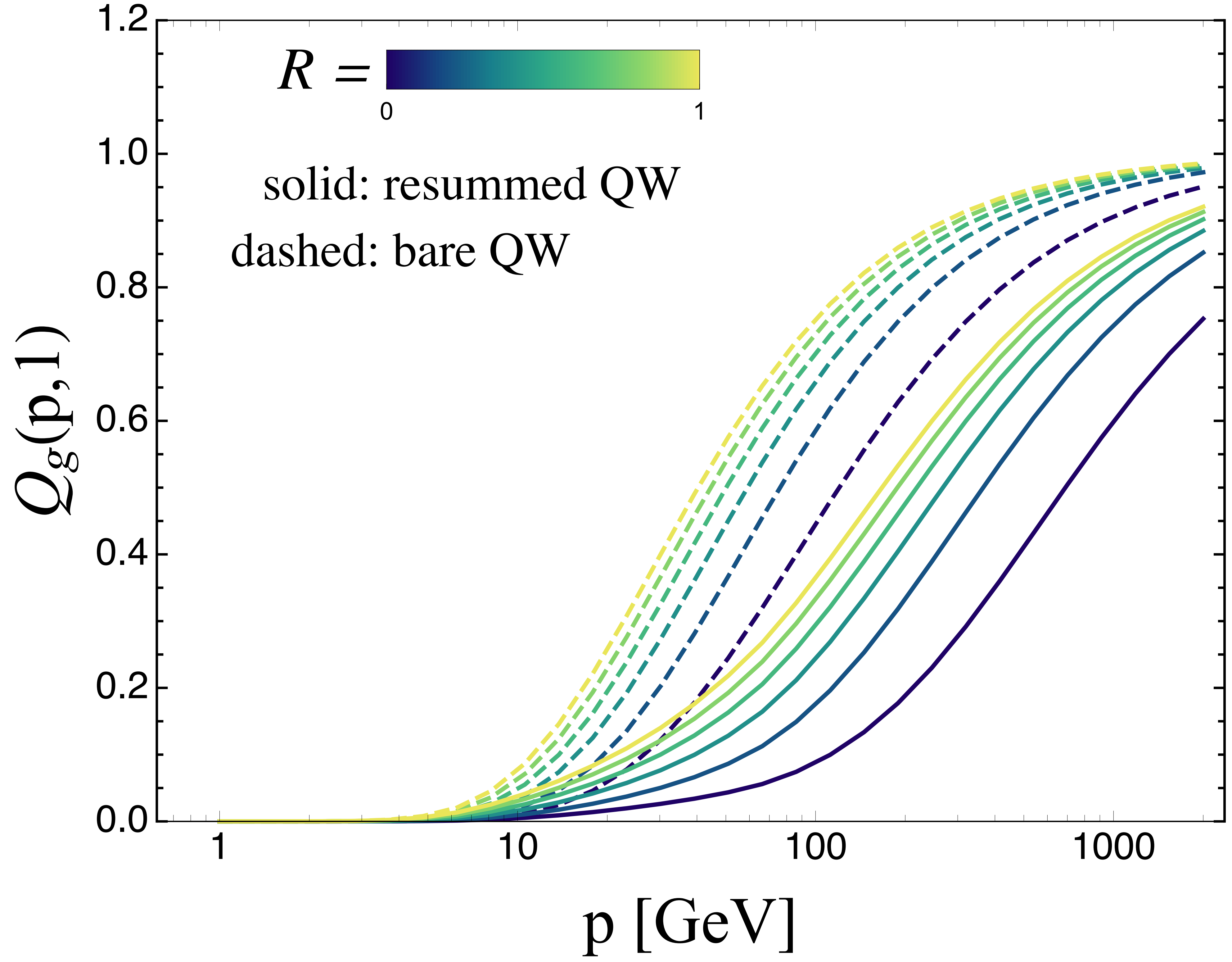
ENERGY LOSS OF FULL JET

Mehtar-Tani, KT 1707.07361; Mehtar-Tani, Pablos, KT PRL 127 (2021)



$$\frac{\mathrm{d}\sigma^{\mathrm{jet}}}{\mathrm{d}p_T} = Q_>(p_T, R)\hat{\sigma}_{AA\to jet}$$

$$\frac{\partial Q_i(p,\theta)}{\partial \log\theta} = \int_0^1 \mathrm{d}z\, \frac{\alpha_s}{2\pi} p_{ij}(z)\Theta_{\mathrm{in}}\left[Q_j(zp,\theta)Q_k((1-z)p,\theta)) - Q_i(p,\theta)\right]$$

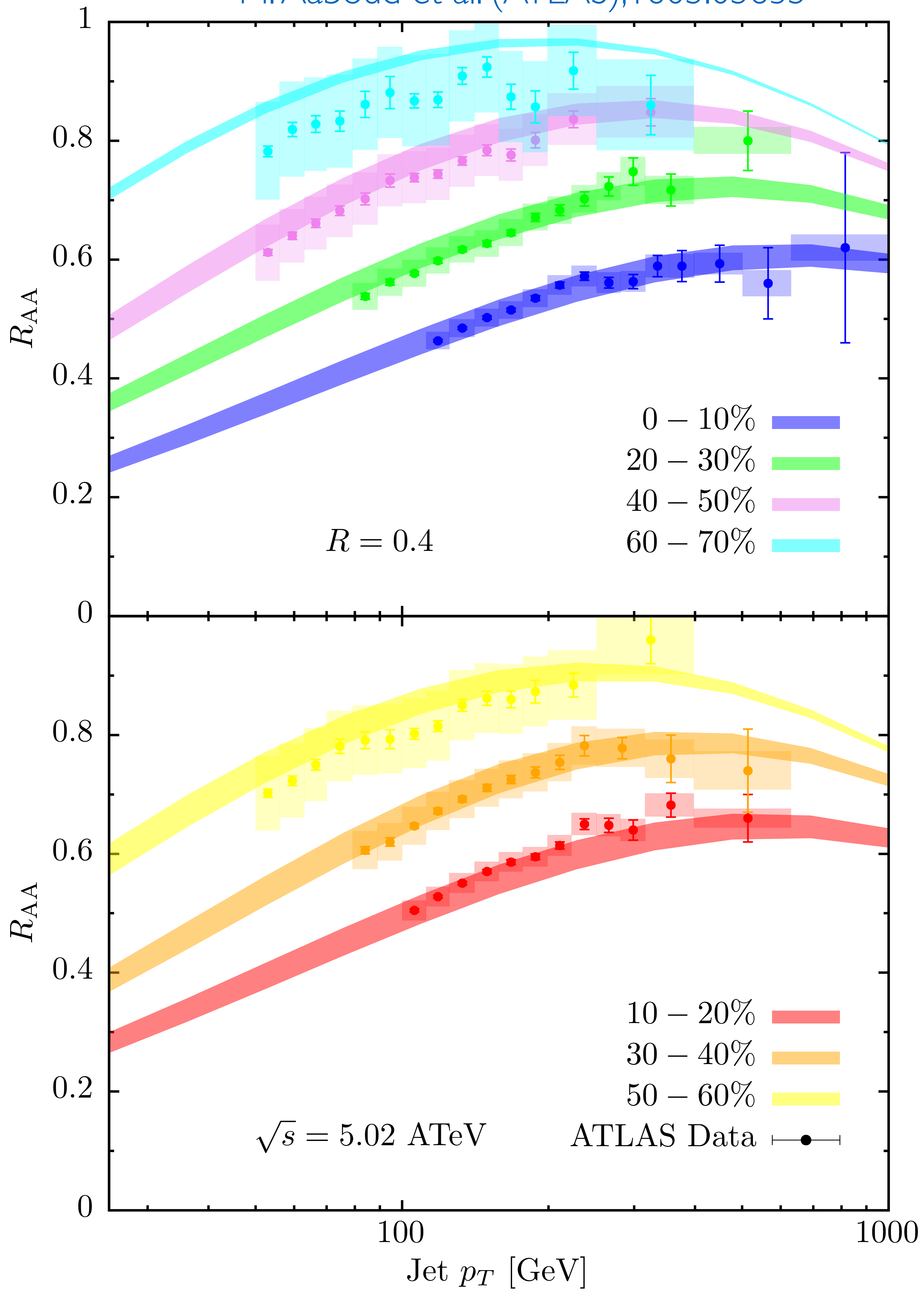


- non-linear evolution equation counting all **in-medium** & **resolved** splittings to compute full jet quenching.
- initial condition $Q_i(p,0) = Q^{(0)}_{>,\mathrm{rad}}(p_T) \times Q^{(0)}_{\mathrm{el}}(p_T) \times \ldots$

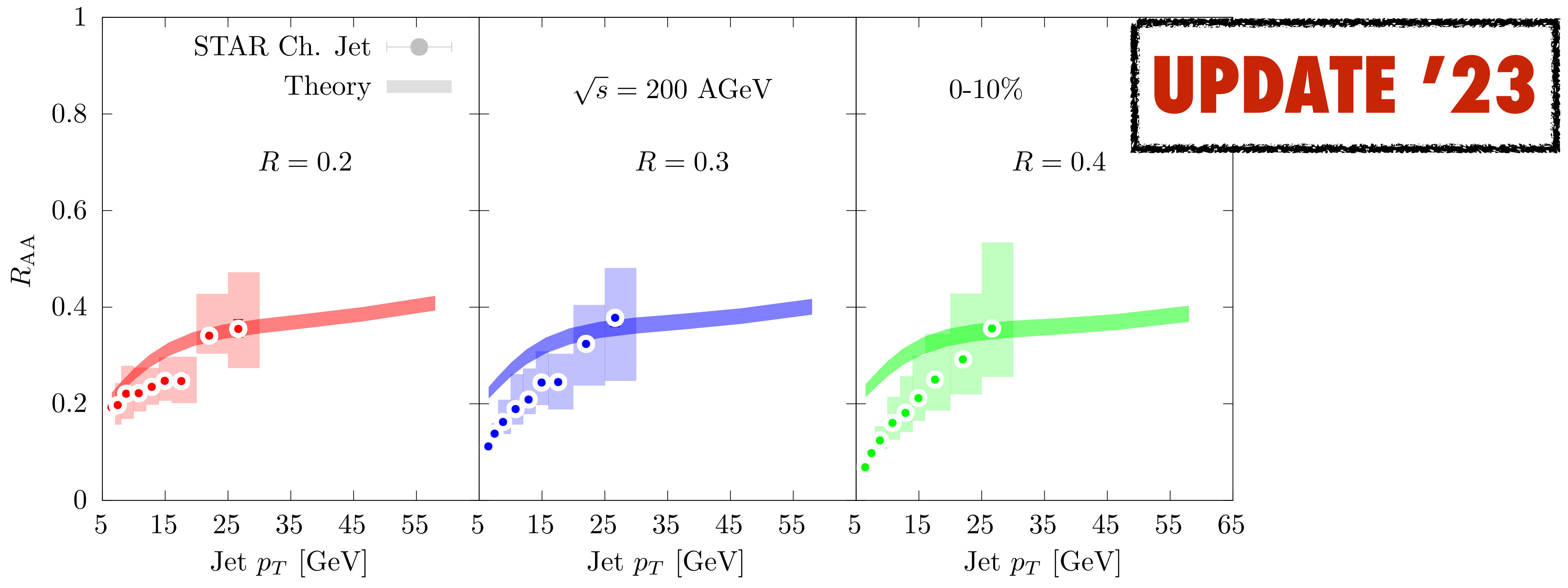
Linearized solution: $Q_i(p_T, R) = Q^{(0)}_{>,i}(p_T, R)\mathrm{e}^{(Q^{(0)}_g - 1)\Omega_{\mathrm{in}}}$

JET SUPPRESSION FACTOR

M. Aaboud et al. (ATLAS), 1805.05635



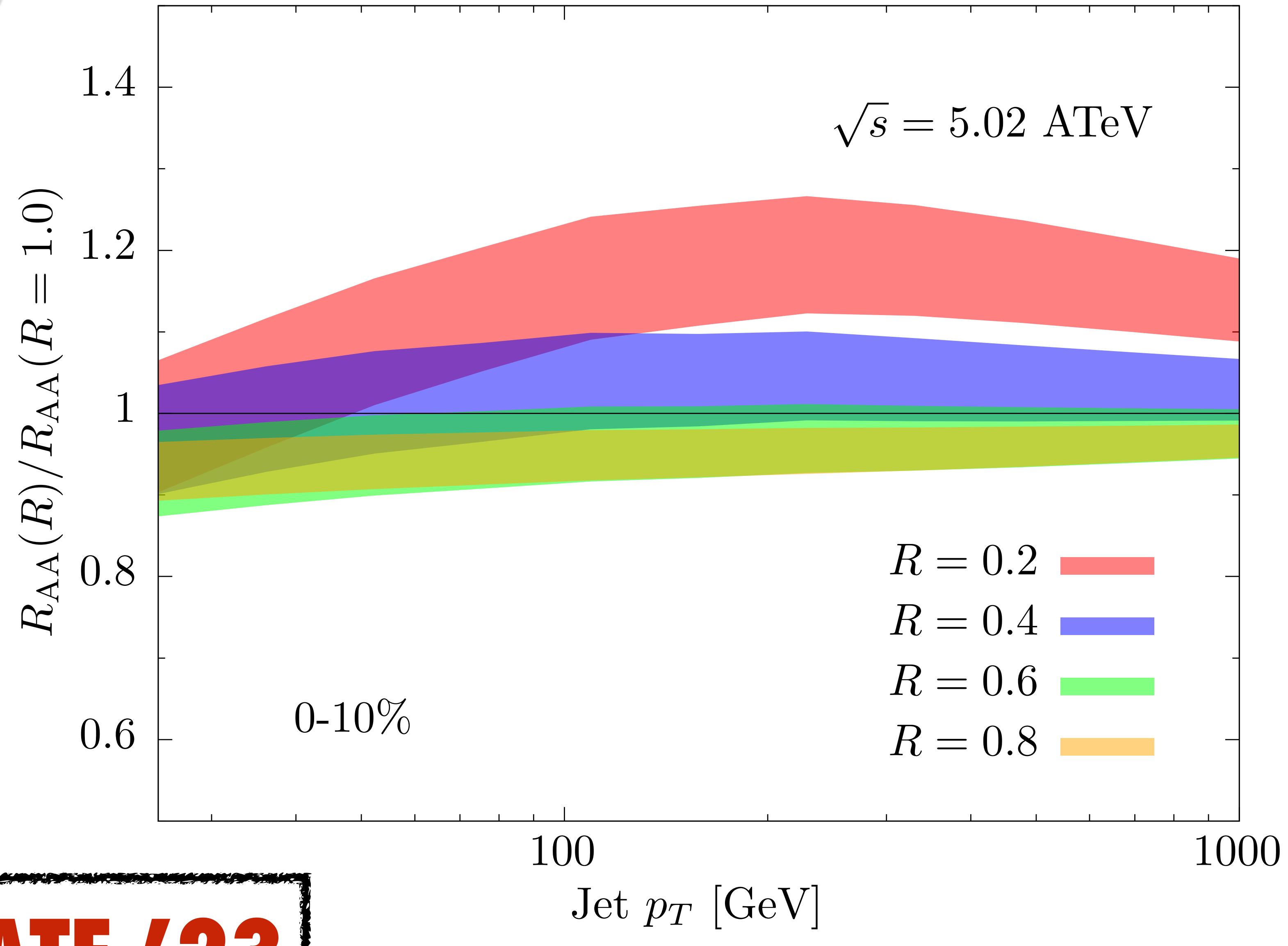
Mehtar-Tani, Pablos, KT Phys. Rev. Lett. 127 (2021); Takacs, KT 2103.14676



- collinear factorization w/nPDF (EPS09)
- $\log \frac{1}{R}$ resummation (AO DGLAP)
- full resummation of **radiative** and **elastic** processes in the medium
- **sampling of geometry** and medium evolution (VISHNU) Shen, Qiu, Song, Bernhard, Bass, Heinz 1409.8164
- only **two free parameters:** $g_{\rm med}$ and $R_{\rm rec}$

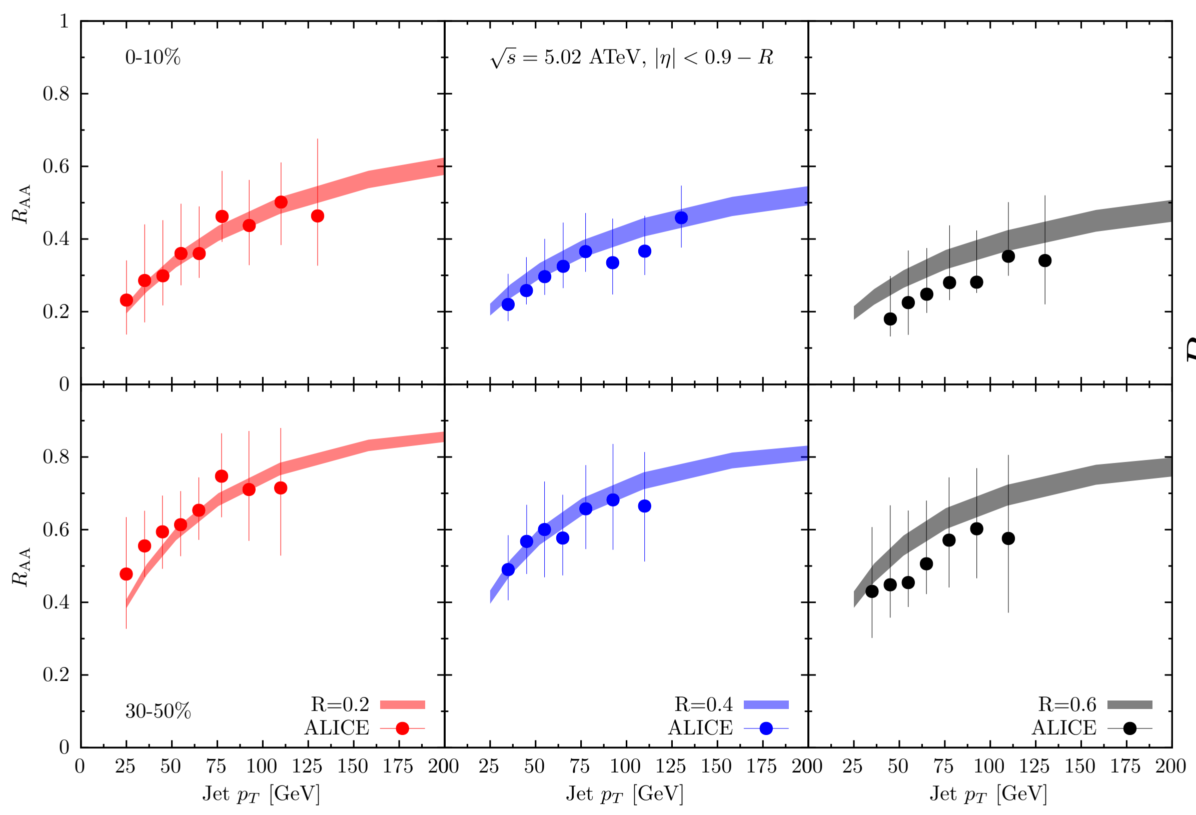
CONE-SIZE DEPENDENCE

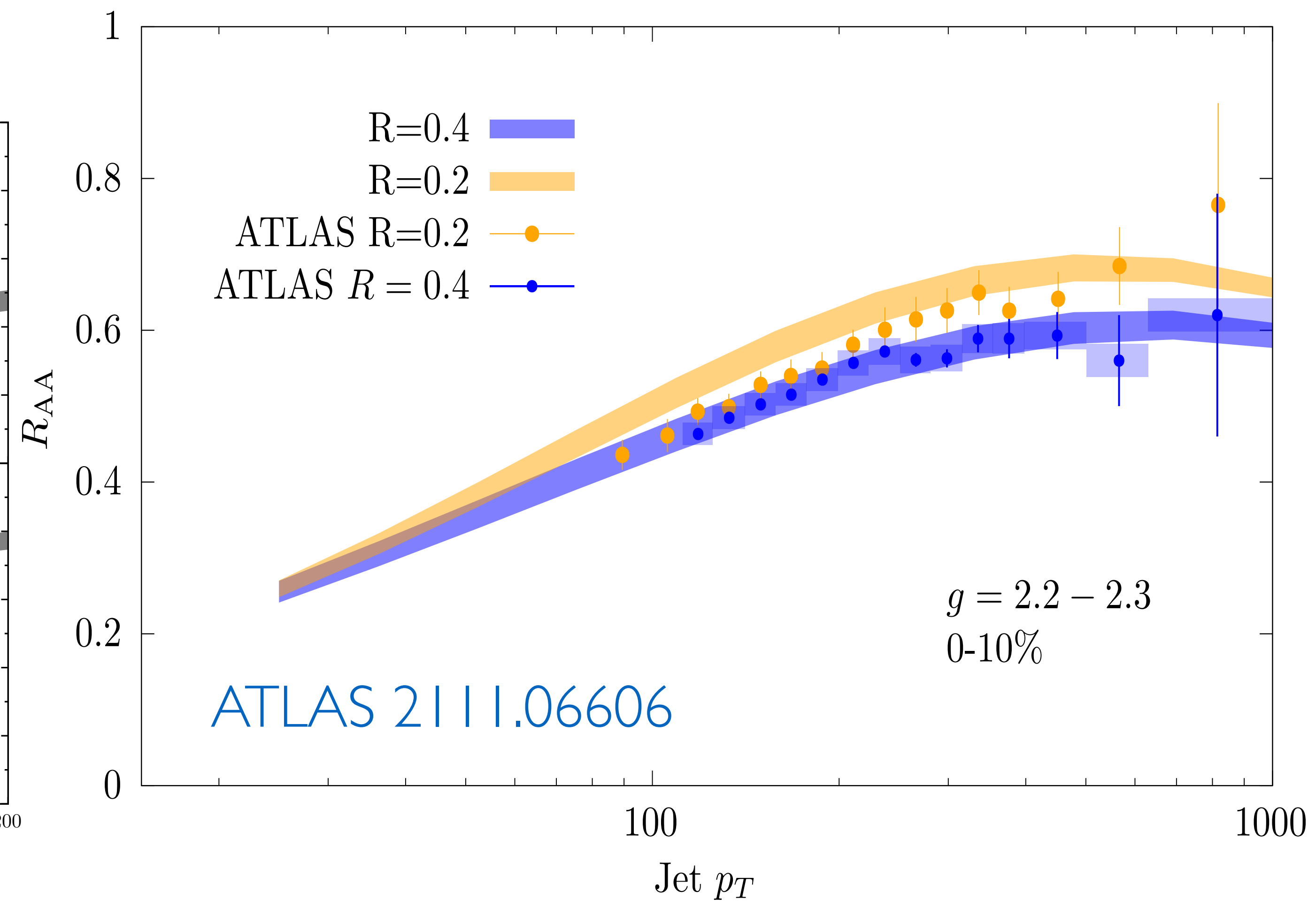
Mehtar-Tani, Pablos, KT PRL 127 (2021)
M. Aaboud et al. (ATLAS) 1805.05635
S. Acharya et al. (ALICE) 1909.09718
CMS-PAS-HIN-18-014



UPDATE '23

ALICE 2303.00592





- main uncertainties for $R \leq 0.6$:
  - perturbative sector (vacuum-like emissions + medium-induced $\omega > \omega_s$) dominates!
  - higher-twist contributions at IOE-NLO **negligible.**
  - details of thermalization/recovery ($R_{\rm rec}$) important at $R \gtrsim 0.6$.

- excellent agreement with existing experimental data!

Flowing to v_2

resolving path length dependence

Azimuthal angle dependence

Mehtar-Tani, Pablos, KT (to appear)

$$v_2 \approx \frac{1}{2}\frac{R_{AA}(L) - R_{AA}(L+\Delta L)}{R_{AA}(L) + R_{AA}(L+\Delta L)}$$

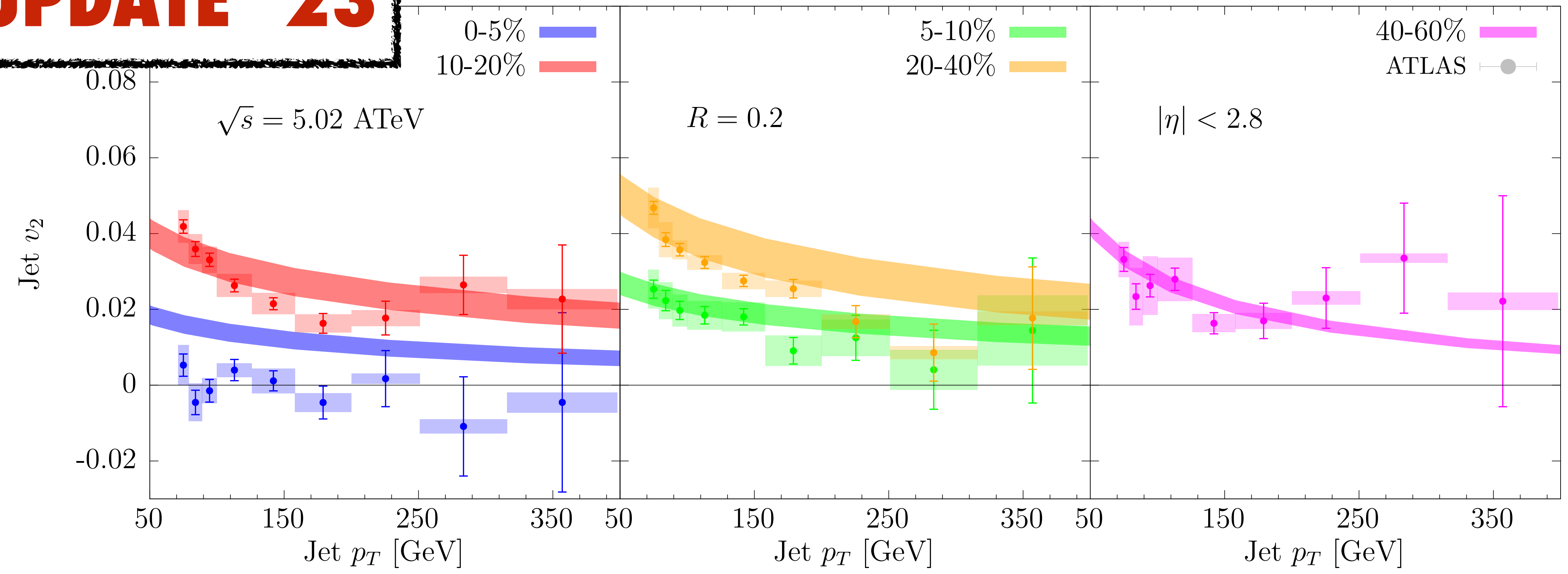
$$\mathrm{e} \sim \frac{\Delta L}{2L}$$

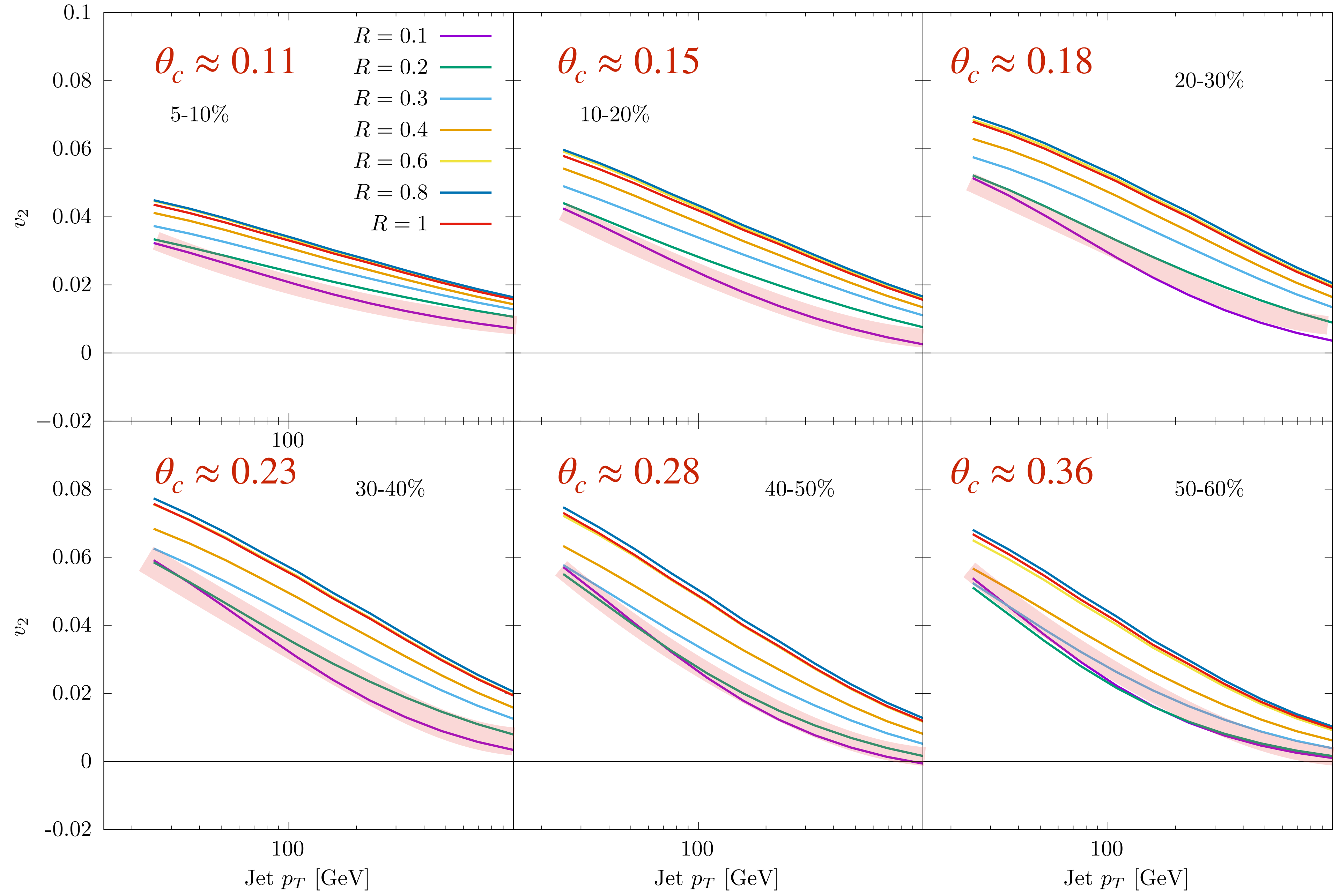
- flow @ high-p_T: **sensitivity to path length.**
- studied since a long time (puzzles…). Wang PRC (2001); Noronha-Hostler et al. (2016); Andres et al. 1902.03231; Barreto et al. 2208.02061;…
- for one single color charge: $v_2/\mathrm{e} \sim \partial \log R_{AA} \big/ \partial \log p_T$.
  - works for hadron, too small for jets… Arleo, Falmagne 2212.01324
- additional effect for jets: $v_2 \sim [\Omega_{\rm in}(L) - \Omega_{\rm in}(L+\Delta L)](Q_g - 1)$.
  - sensitive to resolution effects!

AZIMUTHAL ASYMMETRY

Mehtar-Tani, Pablos, KT (to appear)

UPDATE '23

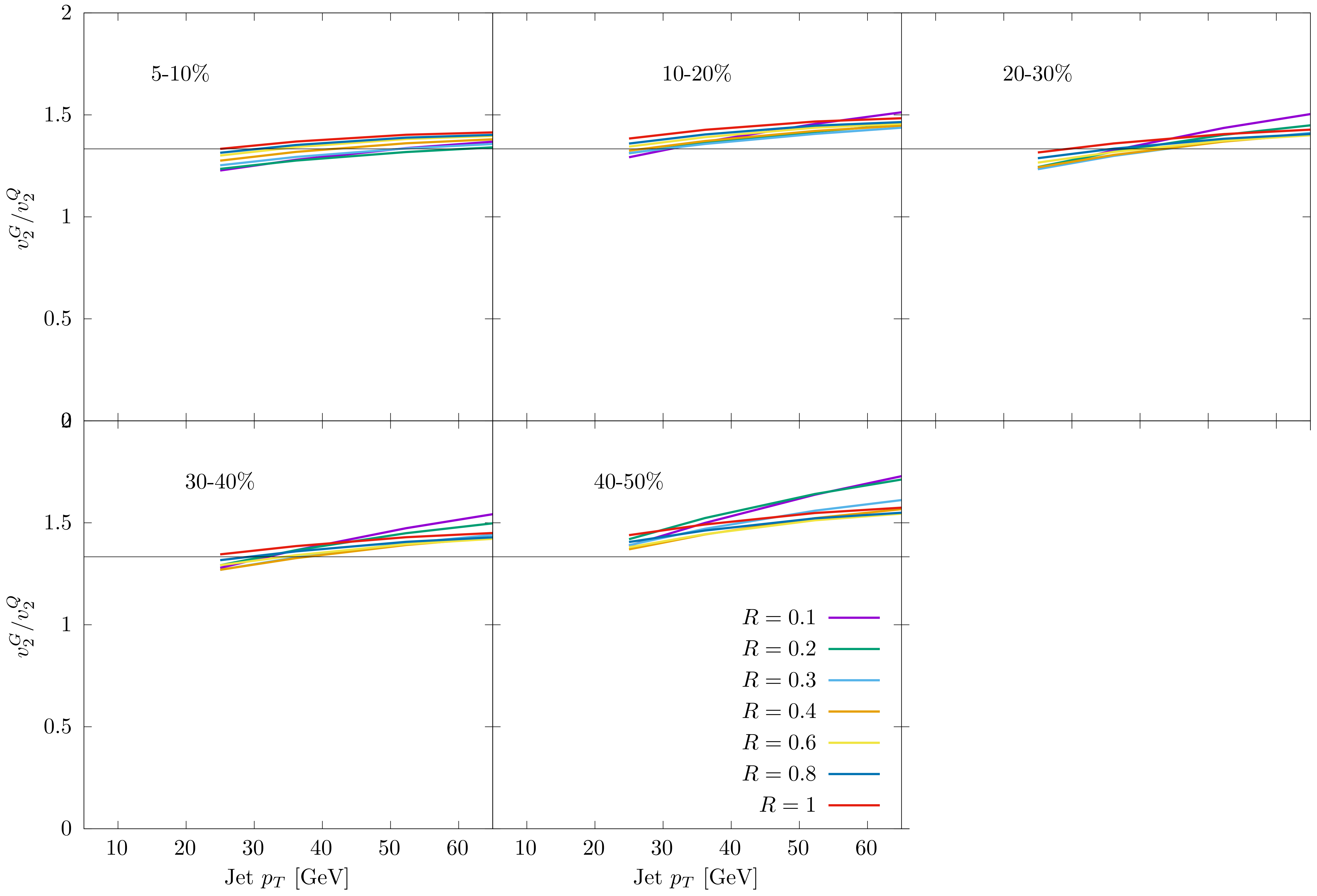




$$\frac{v_2^{\text{jet}}}{e} \approx \begin{cases} \frac{v_2^{\text{parton}}}{e} & \text{for } R < \theta_c \\ \frac{v_2^{\text{parton}}}{e} + \frac{3}{2}\bar{\alpha} \log \frac{p_T}{\omega_c}(1 - Q_g) & \text{for } R > \theta_c \end{cases}$$

- jet v_2 receives additional contribution from resolution effects.
- full simulation yields **excellent agreement with experimental data.**
- **prediction**: cone-size dependence vs centrality reveal sensitivity to coherence angle (grouping).

APPROXIMATE CASIMIR SCALING OF v_2



see talk by Pablos, Wed 11:10

$$\frac{v_2^g}{v_2^q} \approx \frac{N_c}{C_F} \quad \Longleftrightarrow \quad Q_g \approx (Q_q)^{N_c/C_F}$$

- flow scales with color factors.
- **correlation** between R_{AA} and v_2
- tuning the quark fraction by comparing flow in
  - inclusive and γ-triggered events
  - as a function of jet rapidity

Summary

jet quenching & flow

- **medium controls simultaneously:** energy loss, me.dium recoil and jet resolution connected through $\hat{q}$
- **resummation framework describe the data across the board:** p_T, centrality, and R dependence provides a basis for more precision computations.
- **azimuthal dependence:** additional handle on length dependence & sensitivity to coherence angle.

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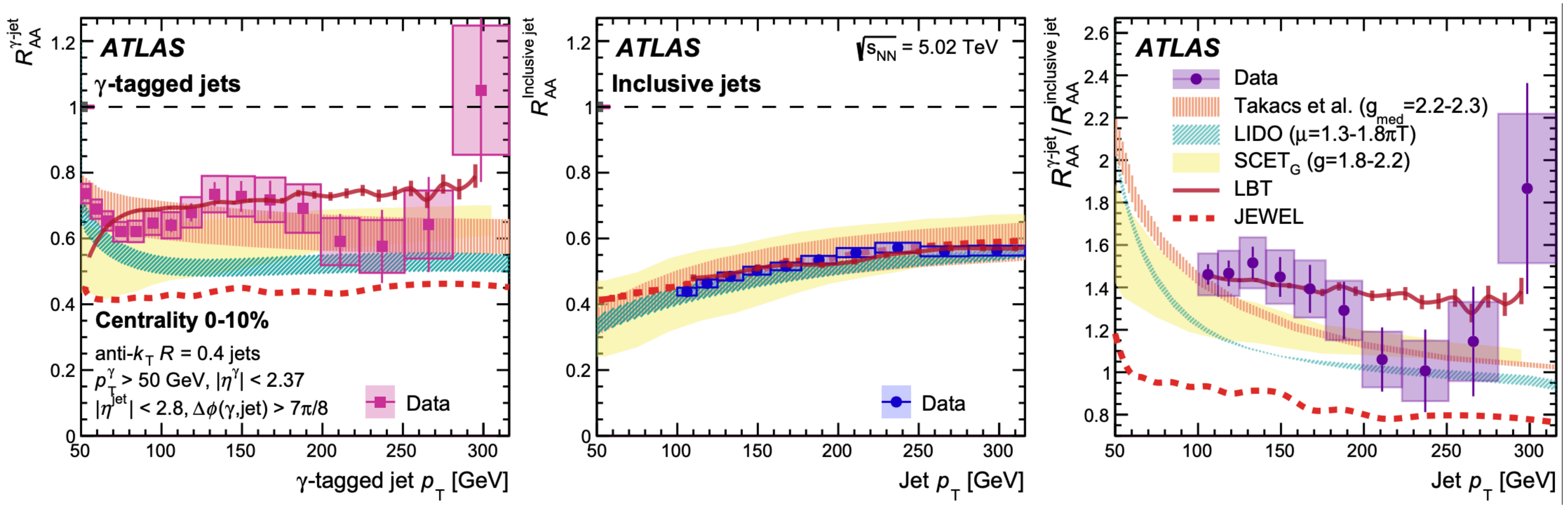
A **huge thanks** to Dani Pablos & Yacine Mehtar-Tani for collaboration on the project!

Any questions?

γ-TAGGED JET R_{AA}



see talk by McGinn, Wed 09:00

- work by Adam Takacs and Dani Pablos
- γ-tagging give quark-enriched sample of jets
- but slope is much **smaller** - complicated interplay!