Quark and Gluon Jet Energy Loss*

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Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

*work in progress

In the single parton picture, energy loss to the medium is controled by the parton’s Casimir

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For radiation or collisional mechanisms:

$$\left(\frac{E_{loss}^{quark}}{E_{loss}^{gluon}}\right) = \frac{C_F}{C_A} = \frac{4}{9} = 0.444\ldots$$

$$C_F = \frac{N^2 - 1}{2N} = \frac{4}{3} \qquad C_A = N = 3$$

For holographic approaches:

$$\left(\frac{E_{loss}^{quark}}{E_{loss}^{gluon}}\right) = \left(\frac{C_F}{C_A}\right)^{1/3}$$

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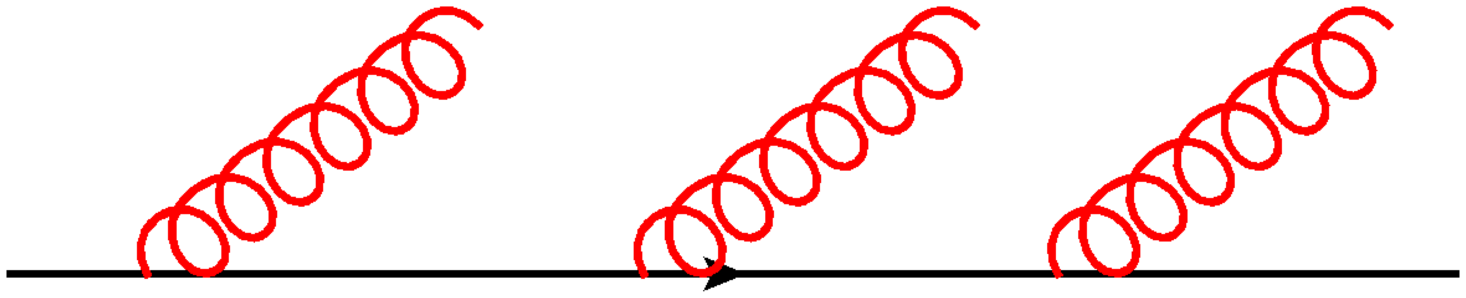
What about jet energy loss? Do we expect this scaling to be followed?

In the single parton picture



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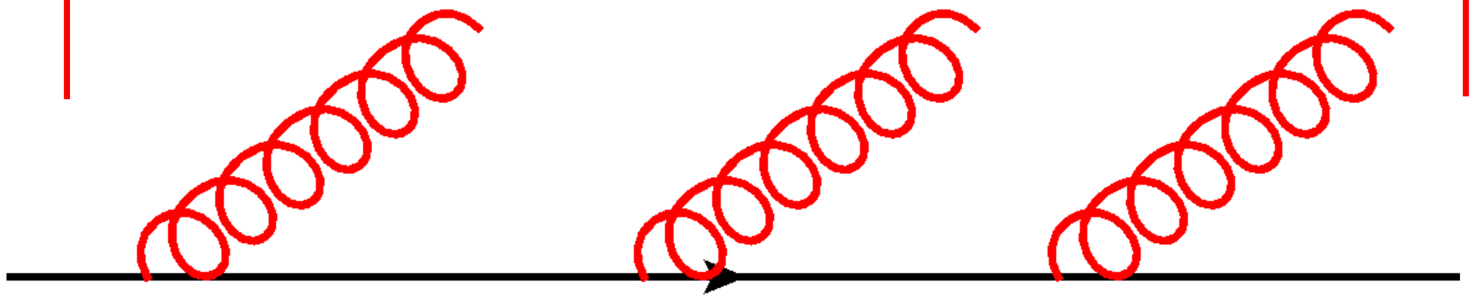

All energy lost due to Sudakov emission

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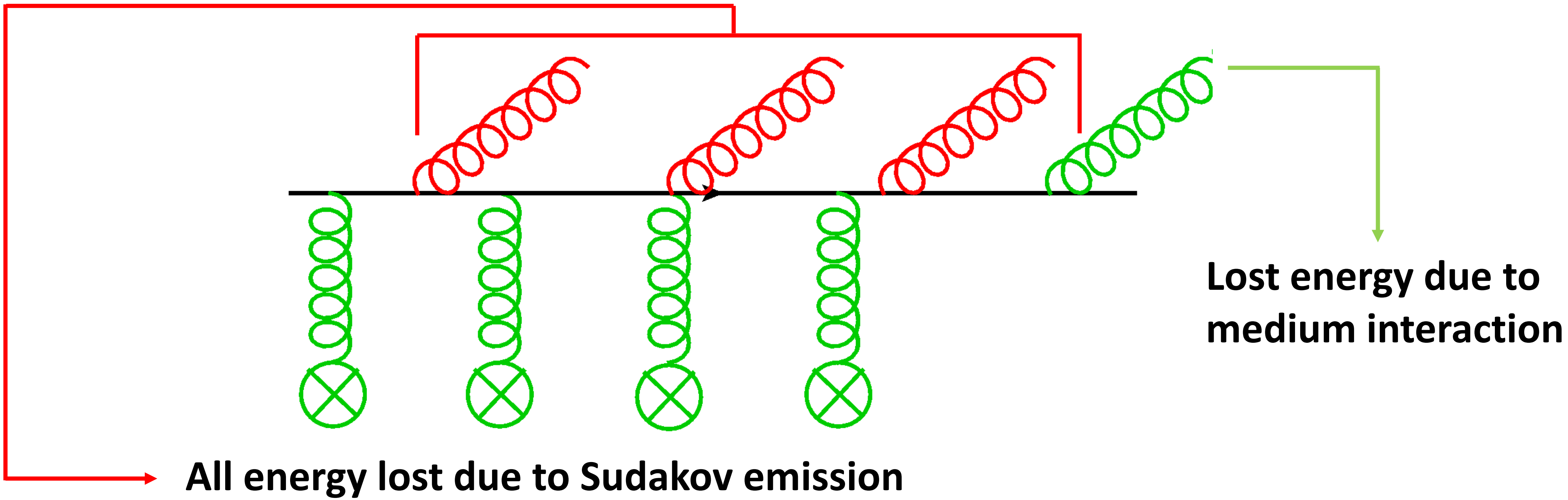
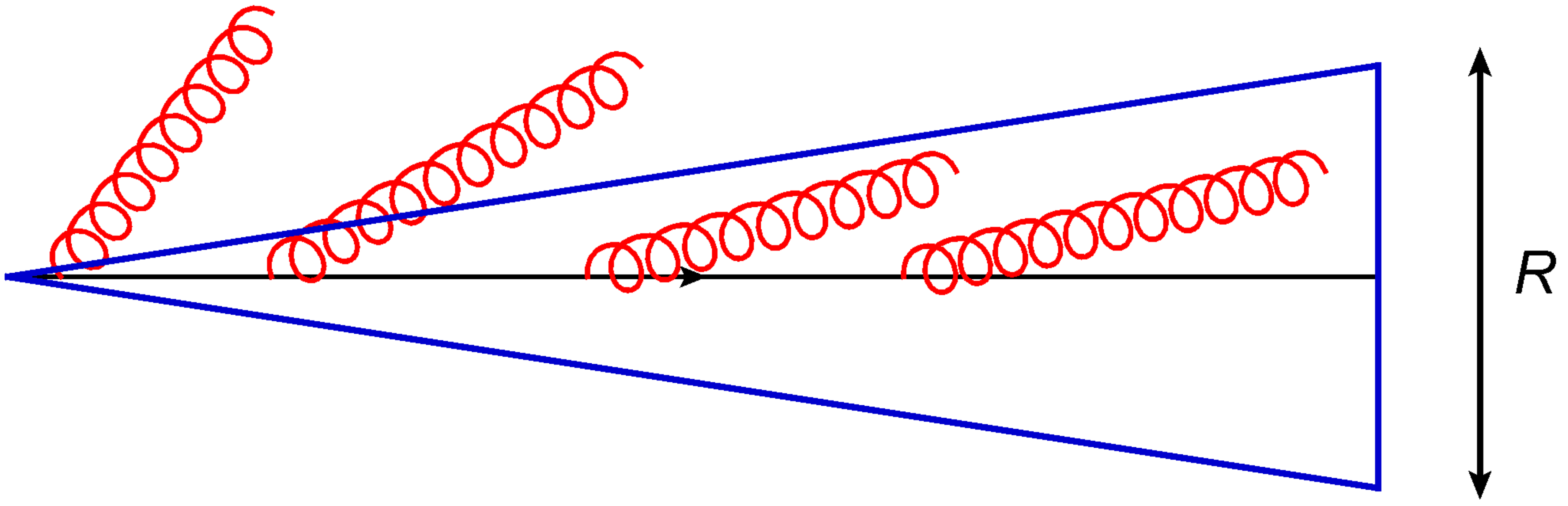


For jets this picture changes



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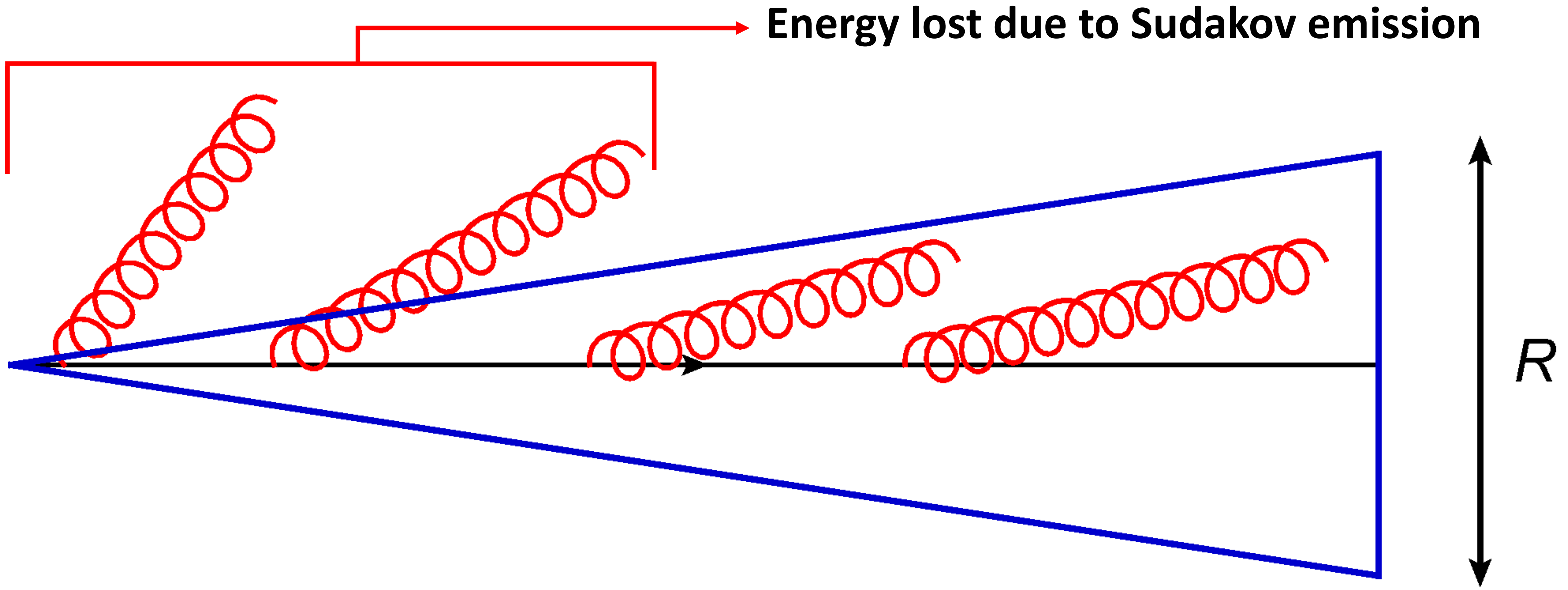

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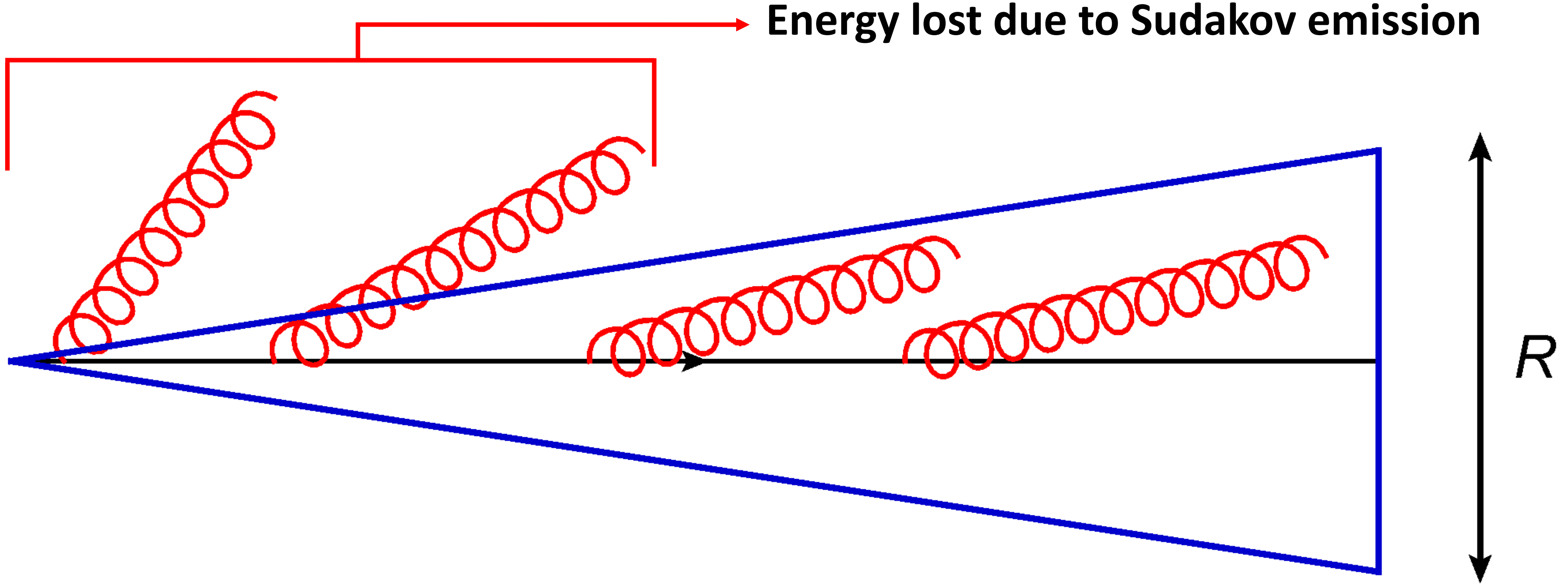
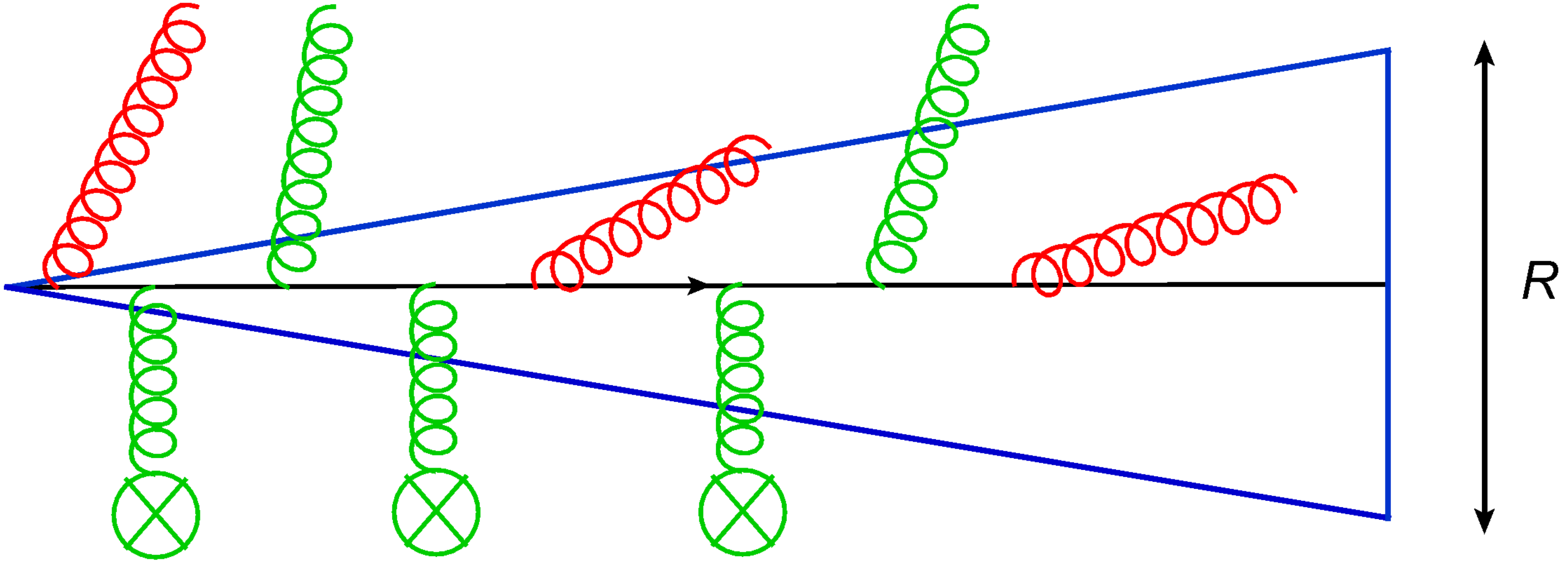


Some energy is "recovered" since the jet is an extended object

For jets this picture changes



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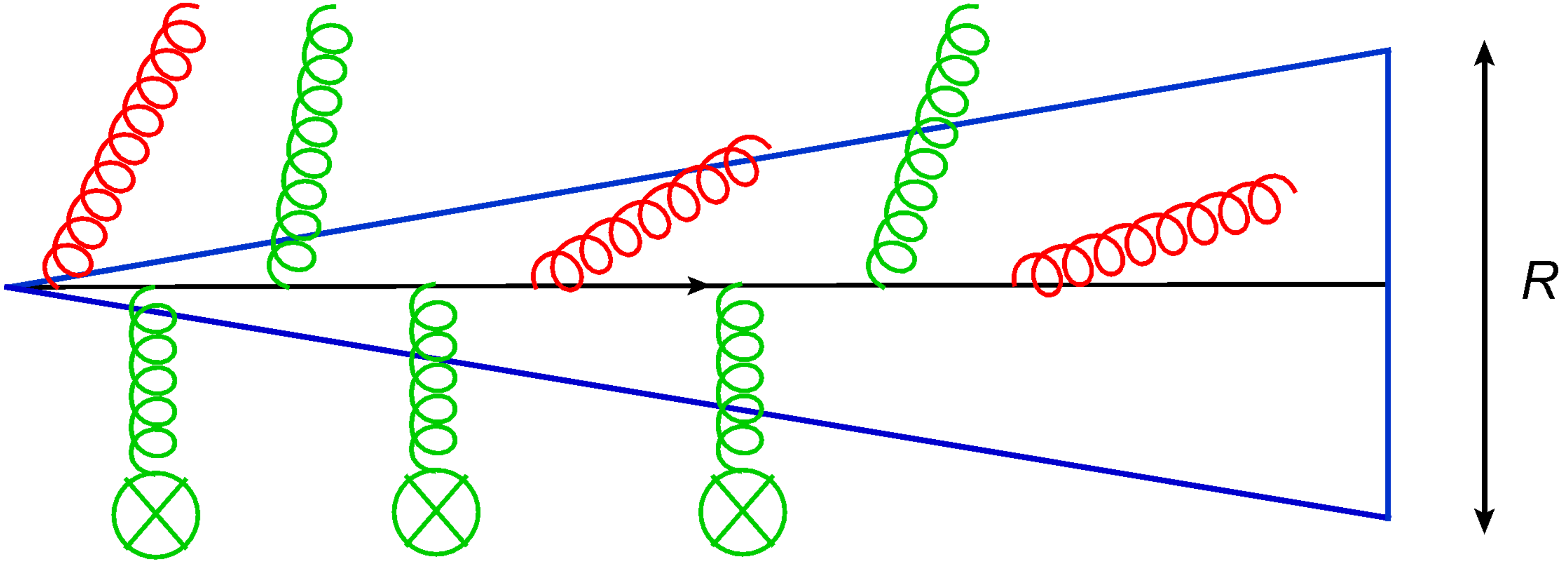

Conclusions: For jets not all emissions contribute to the lost energy spectrum
The Casimir scaling for medium interaction should be modified

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How does energy lost scale due to R?

This is effect should be seen both in-vacuum and in-medium events

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Does medium induced energy loss scale with the ratio of the Casimirs ?

It may differ by a scale factor [Spousta, arXiv: 1606.00903/ Spousta, Cole, arXiv:1504.05169]

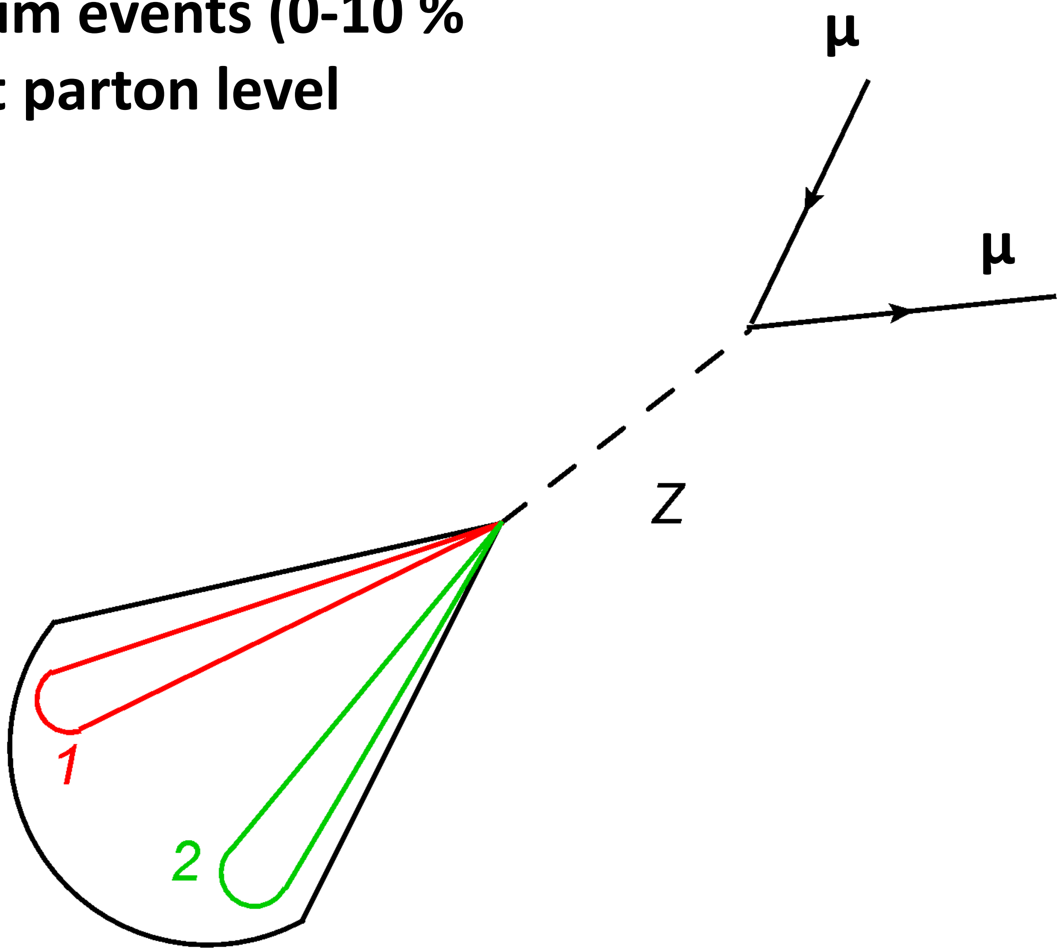
Next talk [Mehtar-Tani, Schlichting, arXiv:1807.06181] : for jets which lose sufficient energy the scaling is broken

We use the MC generator JEWEL [Zapp, Krauss, Wiedemann, arXiv: 1212.1599] to produce Z+qjets or Z+gjets in-vacuum and in-medium events (0-10 % centrality) with default parameters, no recoil and at parton level

Z cuts: $p_T > 50$ GeV , $|\eta| < 5$, di-muon channel

Jet cuts: $p_T > 50$ GeV , anti-k_t reconstruction algorithm $0.1 \leq R \leq 0.7$

Order jets by p_T and require back-to-back with the Z (i.e. $\Delta\phi < 7\pi/8$)



p_T^Z is used as a proxy for the momentum of the initial parton

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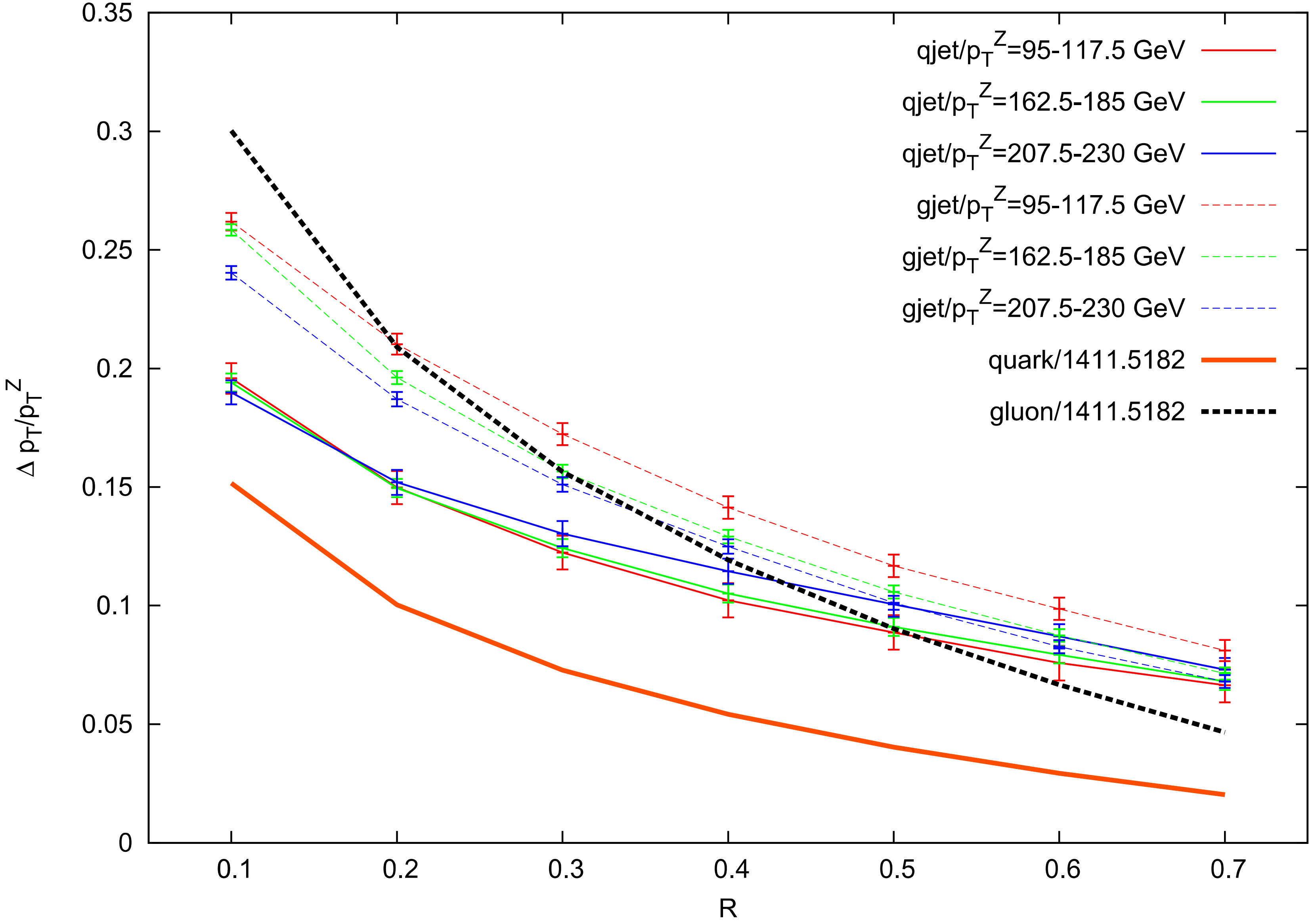

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arXiv:1411.5182 **(Small aside)**

Small-radius jets to all orders in QCD

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[b] *Sorbonne Universités, UPMC Univ Paris 06, UMR 7589, LPTHE, F-75005, Paris, France*

[c] *CNRS, UMR 7589, LPTHE, F-75005, Paris, France*

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ABSTRACT: As hadron collider physics continues to push the boundaries of precision, it becomes increasingly important to have methods for predicting properties of jets across a broad range of jet radius values R, and in particular for small R. In this paper we resum all leading logarithmic terms, $\alpha_s^n \ln^n R^2$, in the limit of small R, for a wide variety of observables. These include the inclusive jet spectrum, jet vetoes for Higgs physics and

$$\begin{aligned}\langle \Delta z \rangle_q^{\text{hardest}} = C_F t \left(\frac{3}{8} - 2\ln 2\right) + \\ + \frac{t^2}{2}\left(-0.467188 C_A C_F + 1.62588 C_F^2 - 0.0710364 C_F n_f T_R\right) + \\ + \frac{t^3}{6}\left(-2.33574(2) C_F^3 + 0.67962(2) C_A^2 C_F + 0.11881(2) C_A C_F^2 + 0.416131(6) C_A C_F n_f T_R - \right. \\ \left. - 0.204121(5) C_F^2 n_f T_R + 0.0473591(7) C_F n_f^2 T_R^2\right) + \mathcal{O}(t^4)\,, \end{aligned} \quad (4.9)$$

while the case of an initiating gluon yields

$$\begin{aligned}\langle \Delta z \rangle_g^{\text{hardest}} = t\left[-\frac{7}{48} n_f T_R + C_A\left(\frac{43}{96} - 2\ln 2\right)\right] + \\ + \frac{t^2}{2}\left(0.962984 C_A^2 + 0.778515 C_A n_f T_R - 0.50674 C_F n_f T_R + 0.0972222 n_f^2 T_R^2\right) + \\ + \frac{t^3}{6}\left(-1.11718(2) C_A^3 - 1.557542(7) C_A^2 n_f T_R + 0.375492(7) C_A C_F n_f T_R + 0.75869(1) C_F^2 n_f T_R - \right. \\ \left. - 0.635406(3) C_A n_f^2 T_R^2 + 0.305404(3) C_F n_f^2 T_R^2 - 0.0648152(4) n_f^3 T_R^3\right) + \mathcal{O}(t^4)\,. \end{aligned} \quad (4.10)$$

$$t(R, p_t) = \frac{1}{b_0} \ln \frac{1}{1 - \frac{\alpha_s(p_t)}{2\pi} b_0 \ln \frac{1}{R^2}} = \frac{1}{b_0} \sum_{n=1}^{\infty} \frac{1}{n} \left(\frac{\alpha_s(p_t) b_0}{2\pi} \ln \frac{1}{R^2}\right)^n$$

First order in t yields

$$\left[\frac{\Delta p_T}{p_T^Z}\right]^{quark} \Bigg/ \left[\frac{\Delta p_T}{p_T^Z}\right]^{gluon} = 0.424 \ldots \approx C_F / C_A$$

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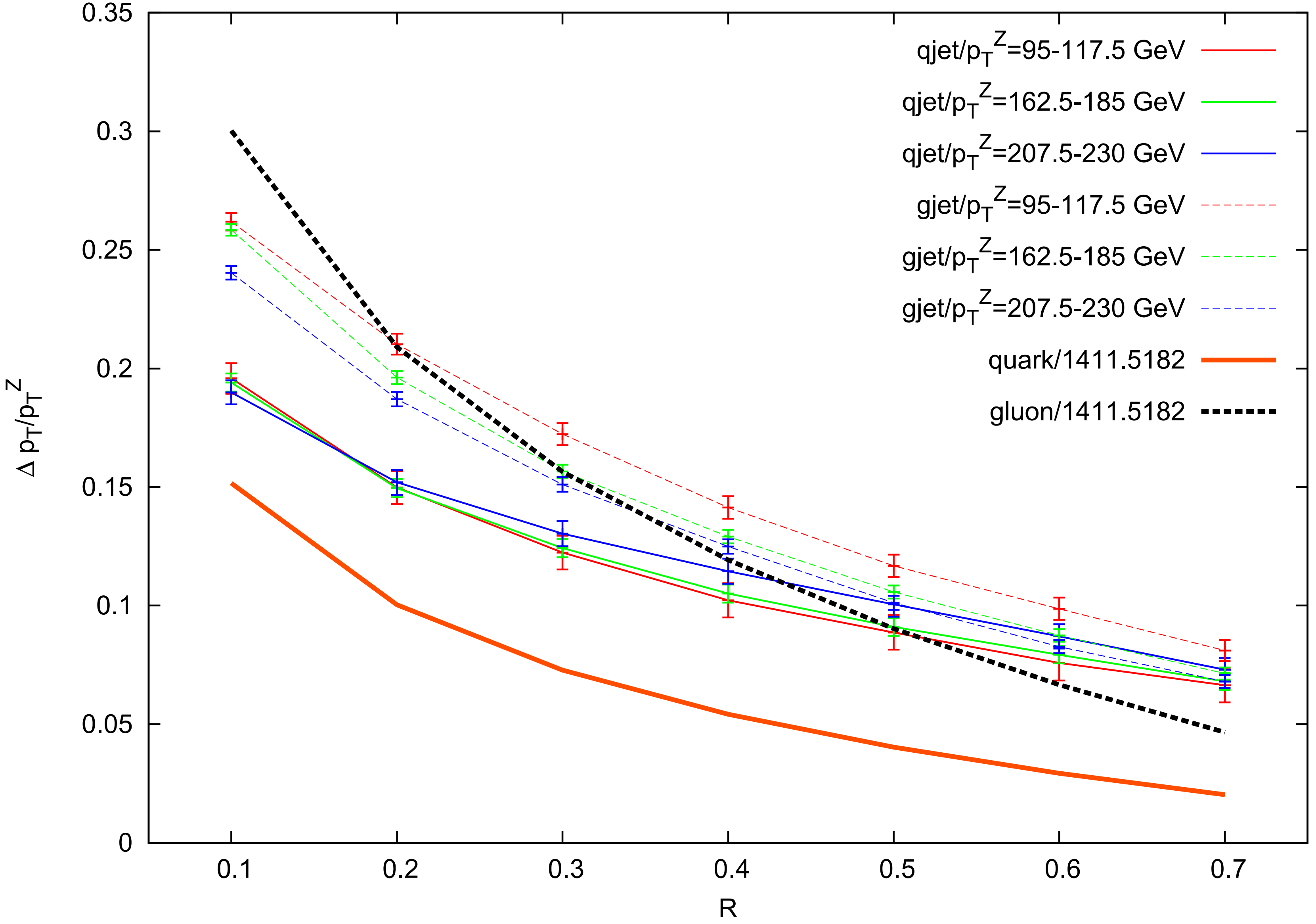

Vacuum evolution with R for 3 p_T^Z bins

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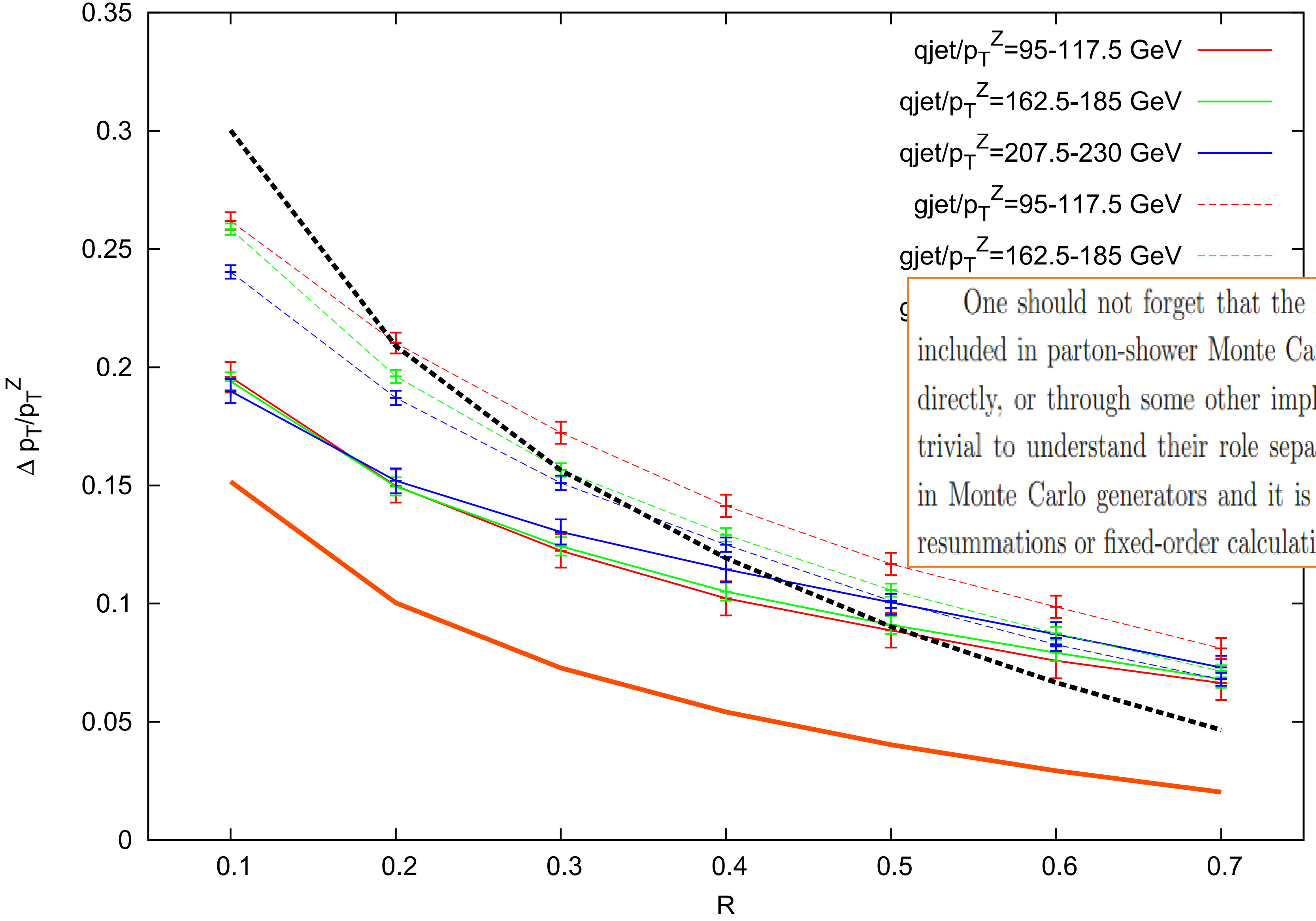

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One should not forget that the leading logarithms of R that we resummed are also included in parton-shower Monte Carlo programs that include angular ordering, whether directly, or through some other implementation of colour coherence. However it is non-trivial to understand their role separately from the many other physical effects present in Monte Carlo generators and it is also difficult to merge them with other logarithmic resummations or fixed-order calculations, especially beyond NLO.

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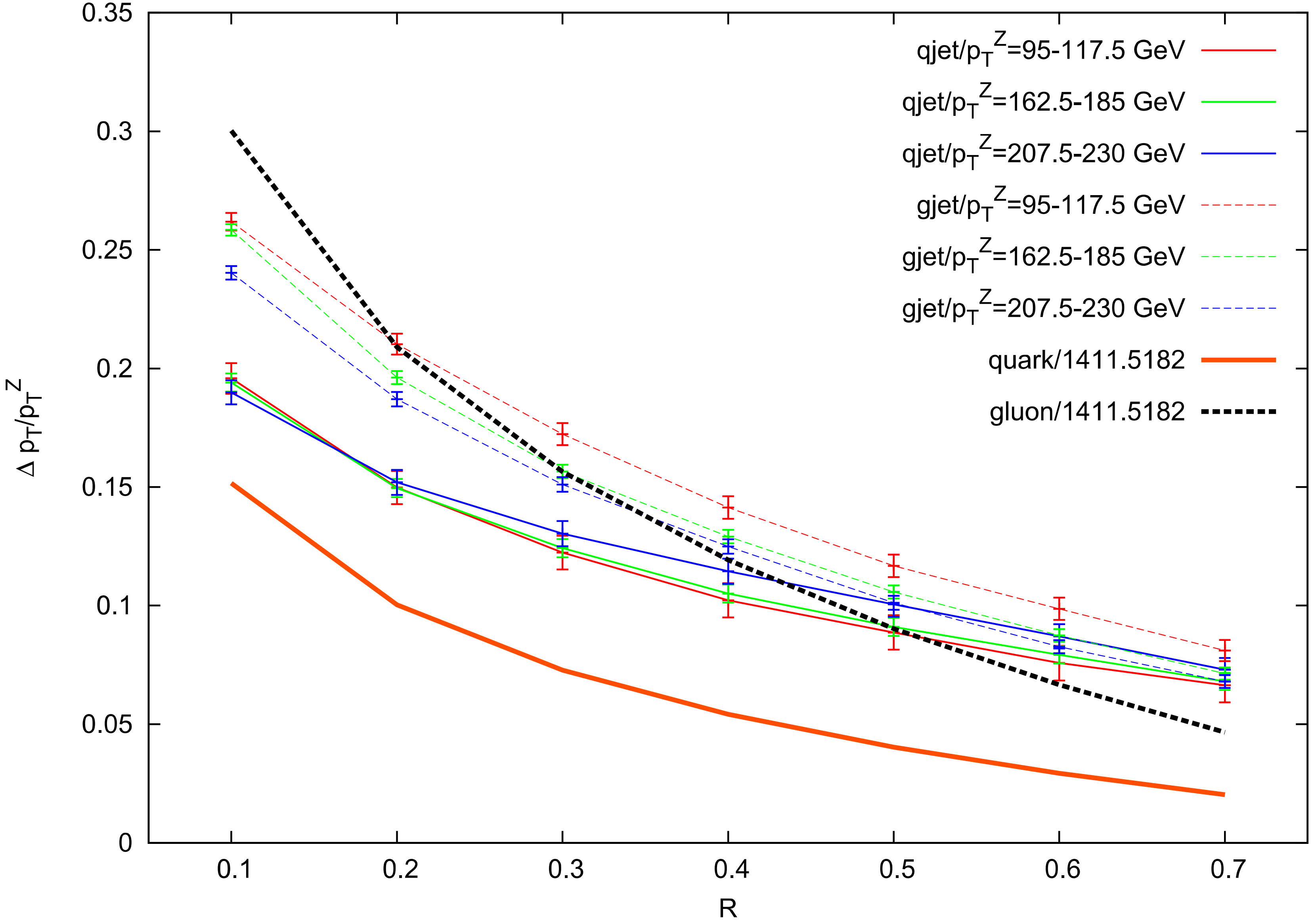

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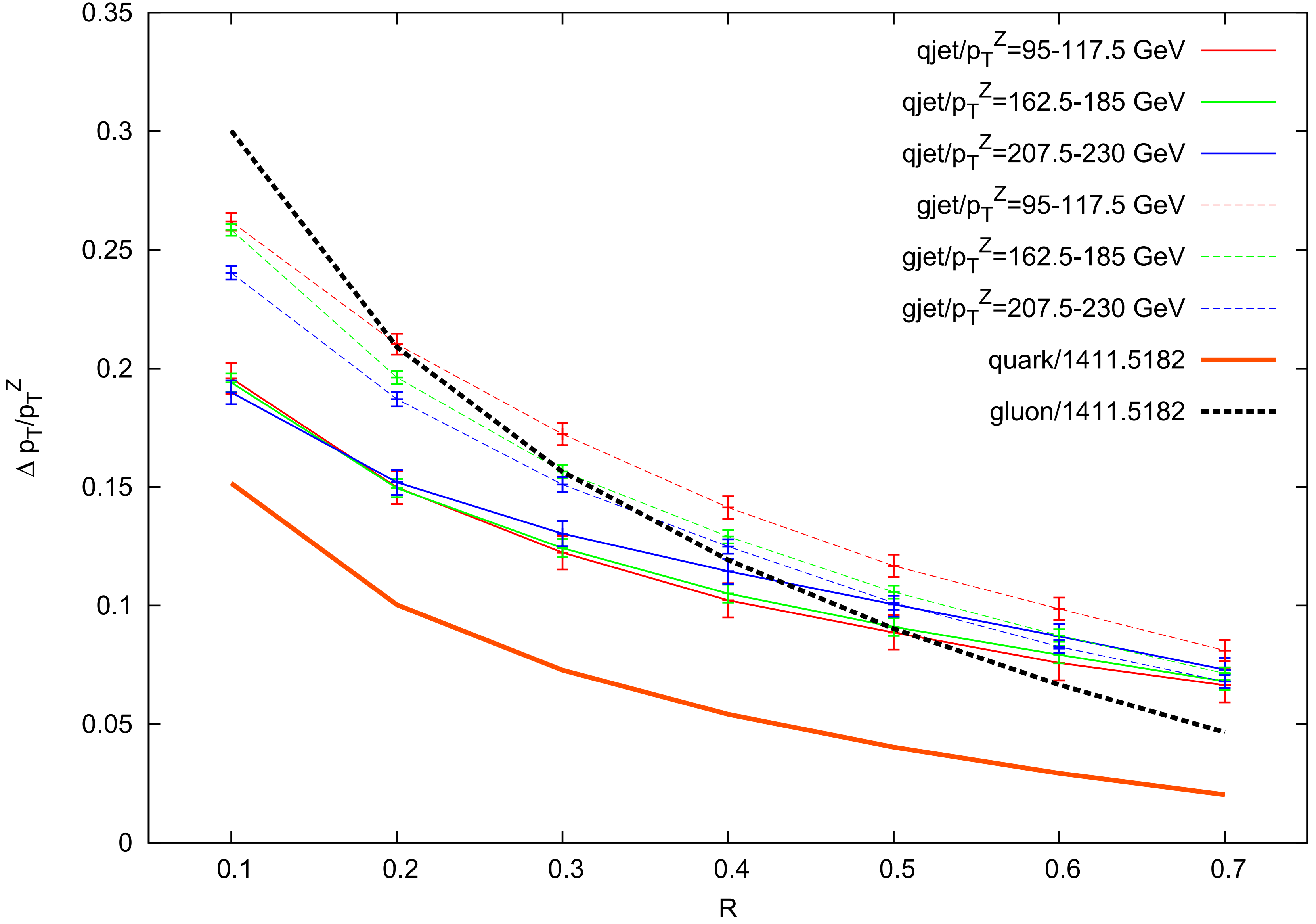

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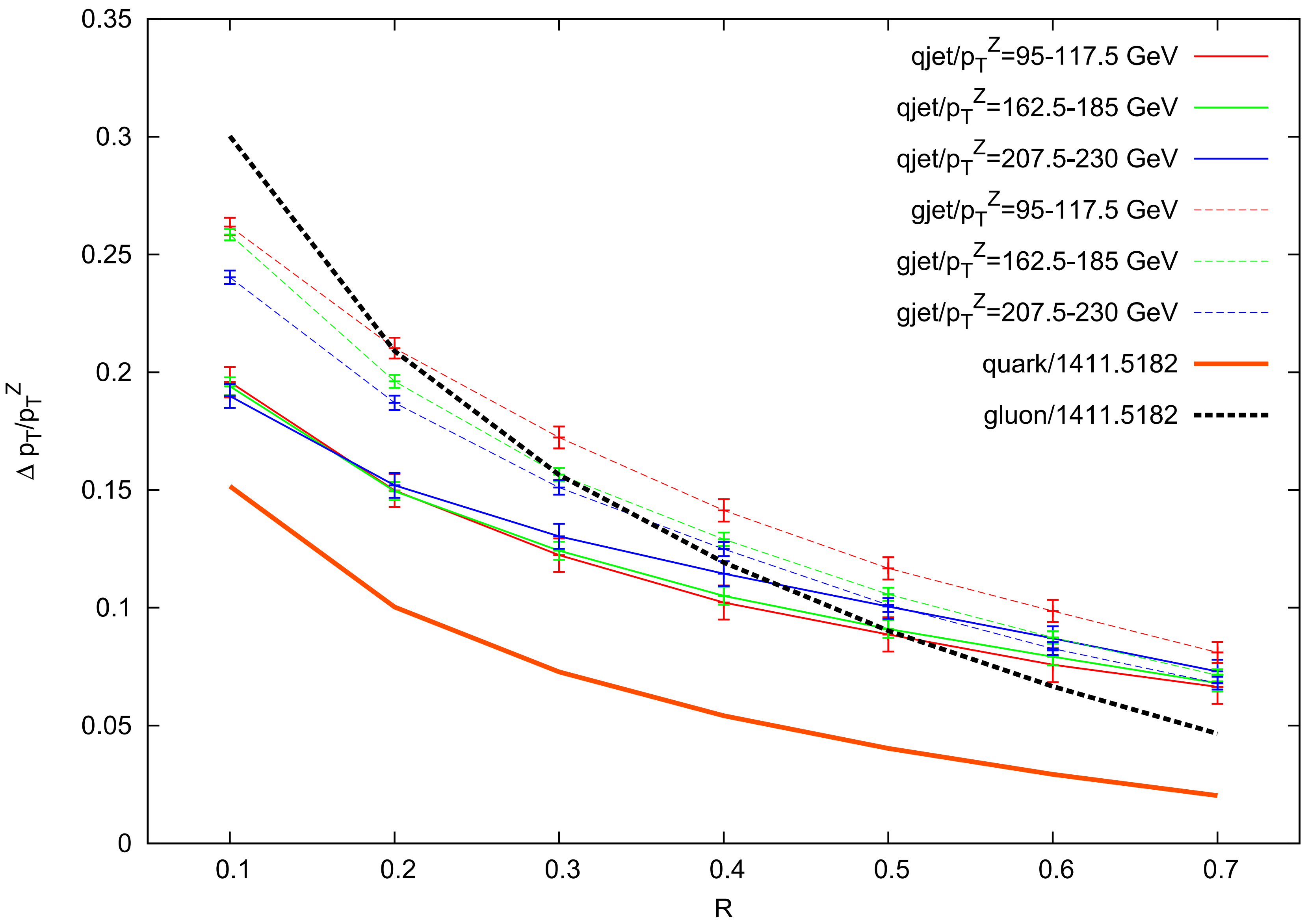

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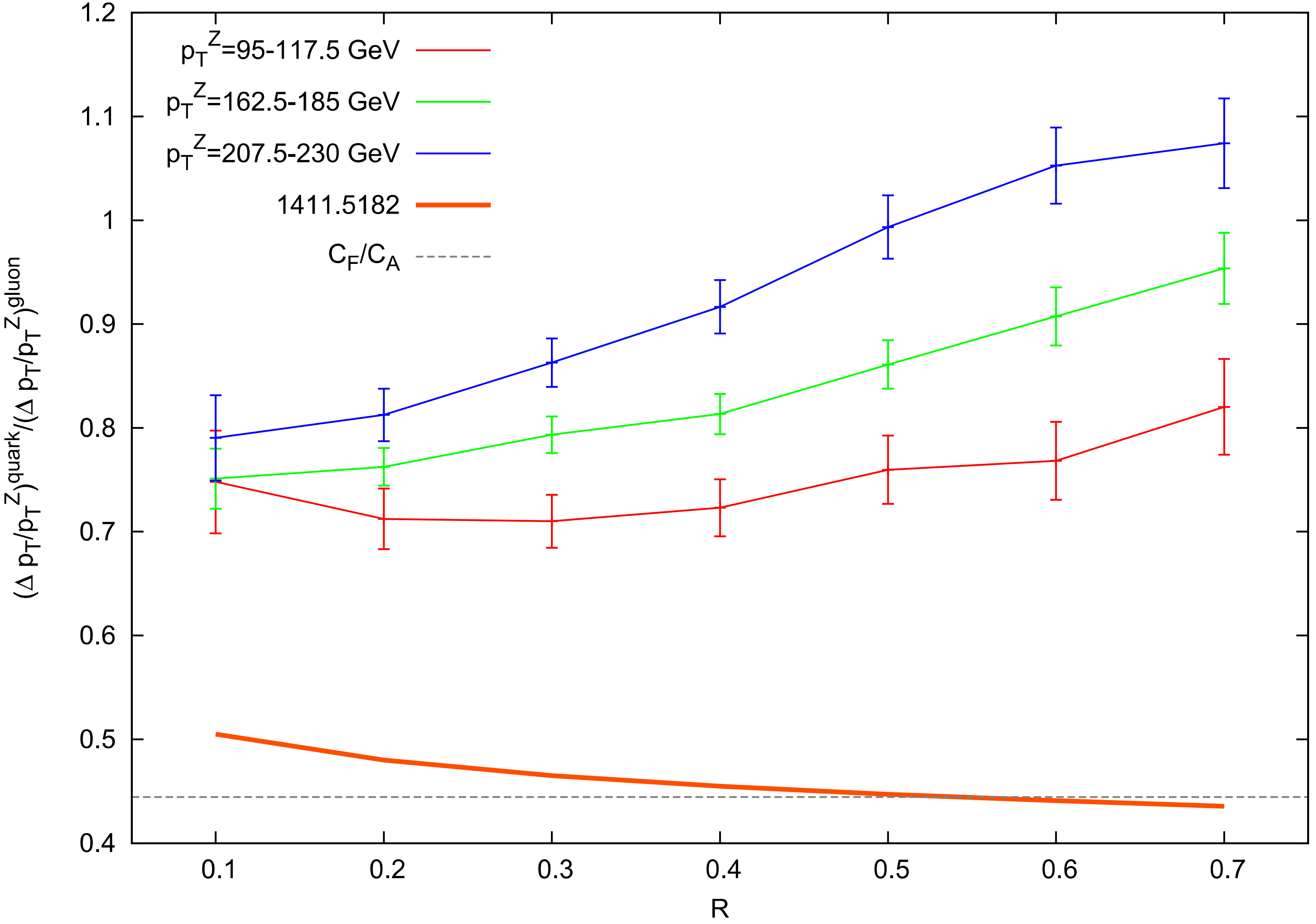
Independence on the initial momentum

The quark to gluon scaling



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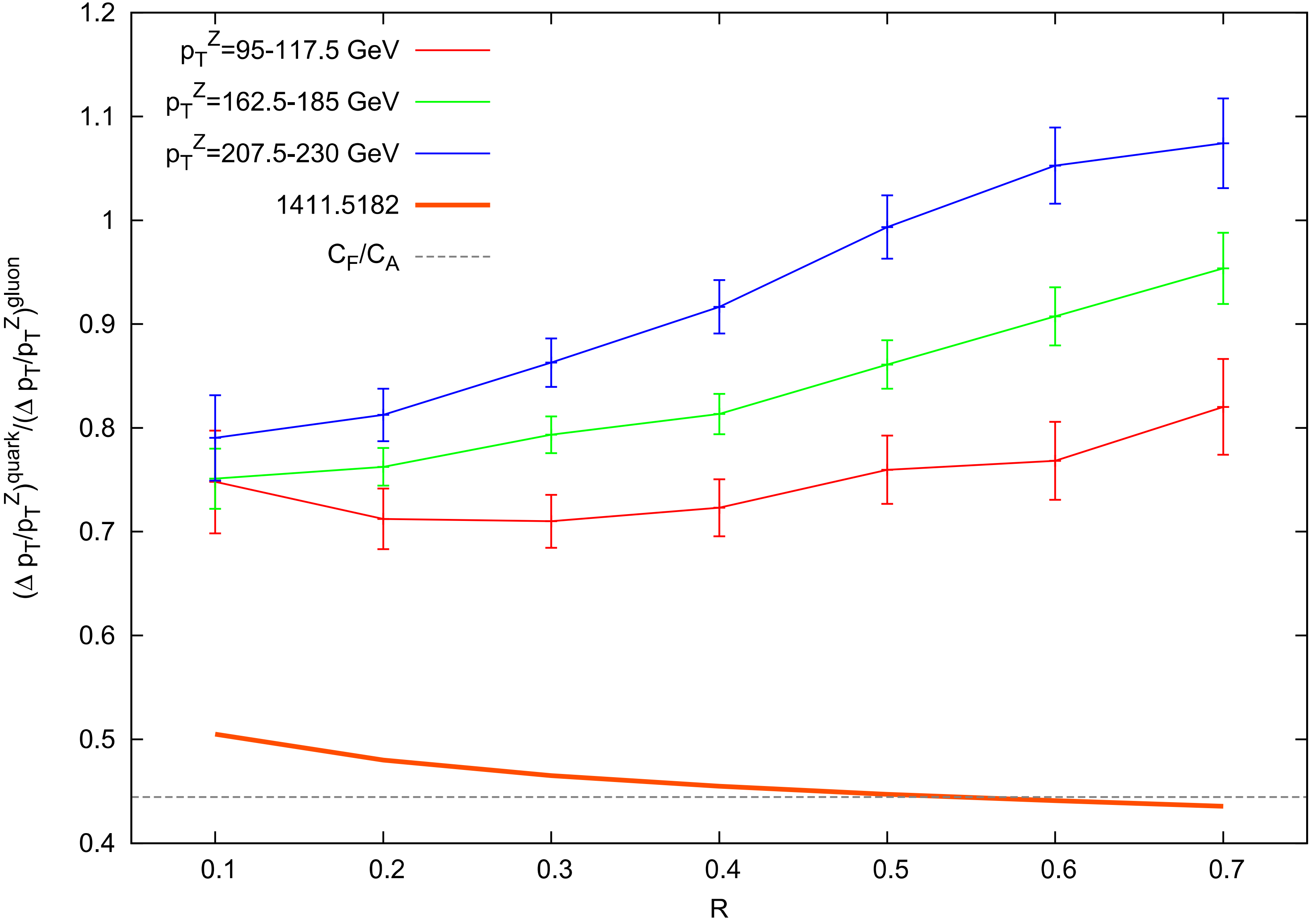

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There are effects beyond R evolution

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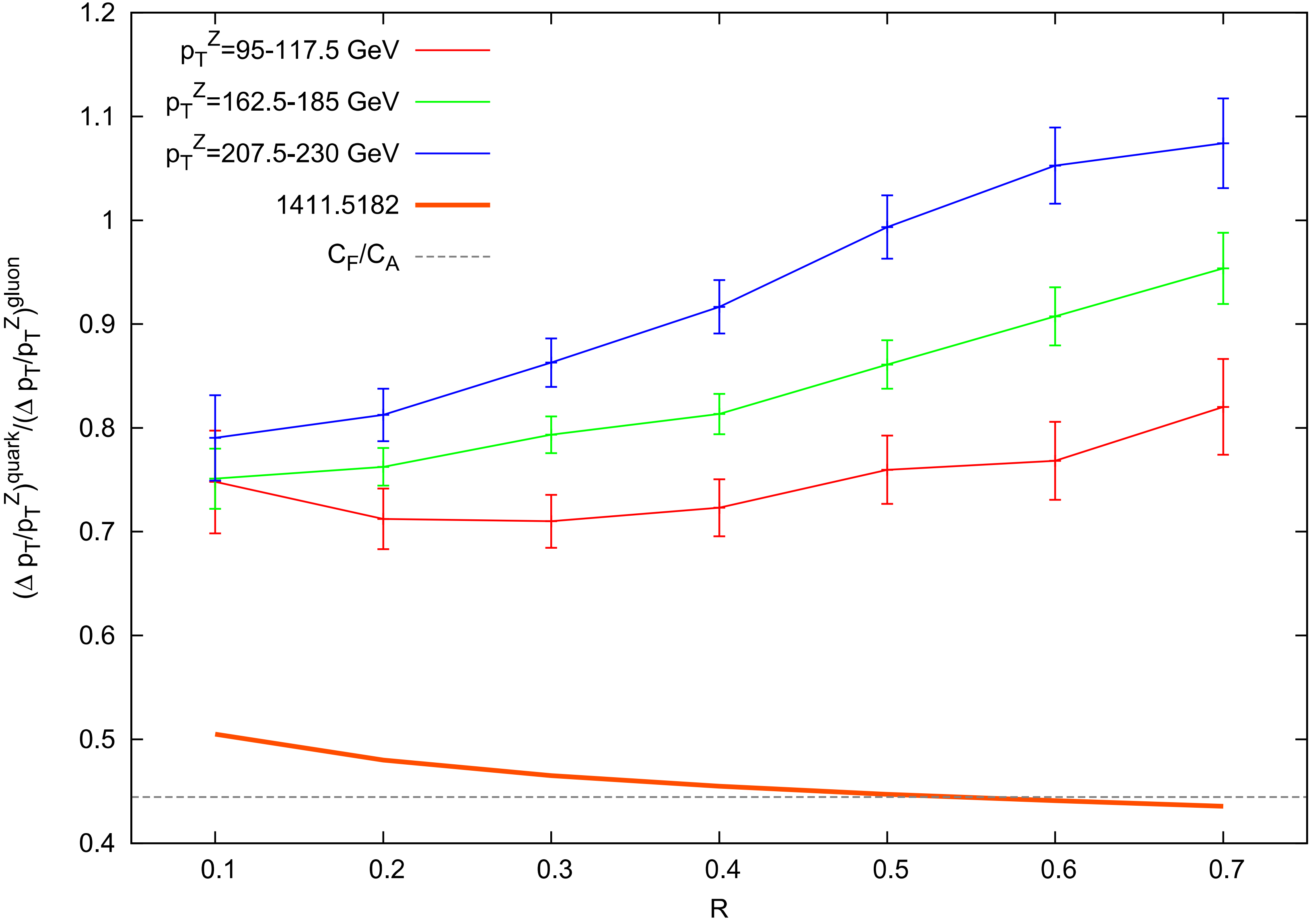
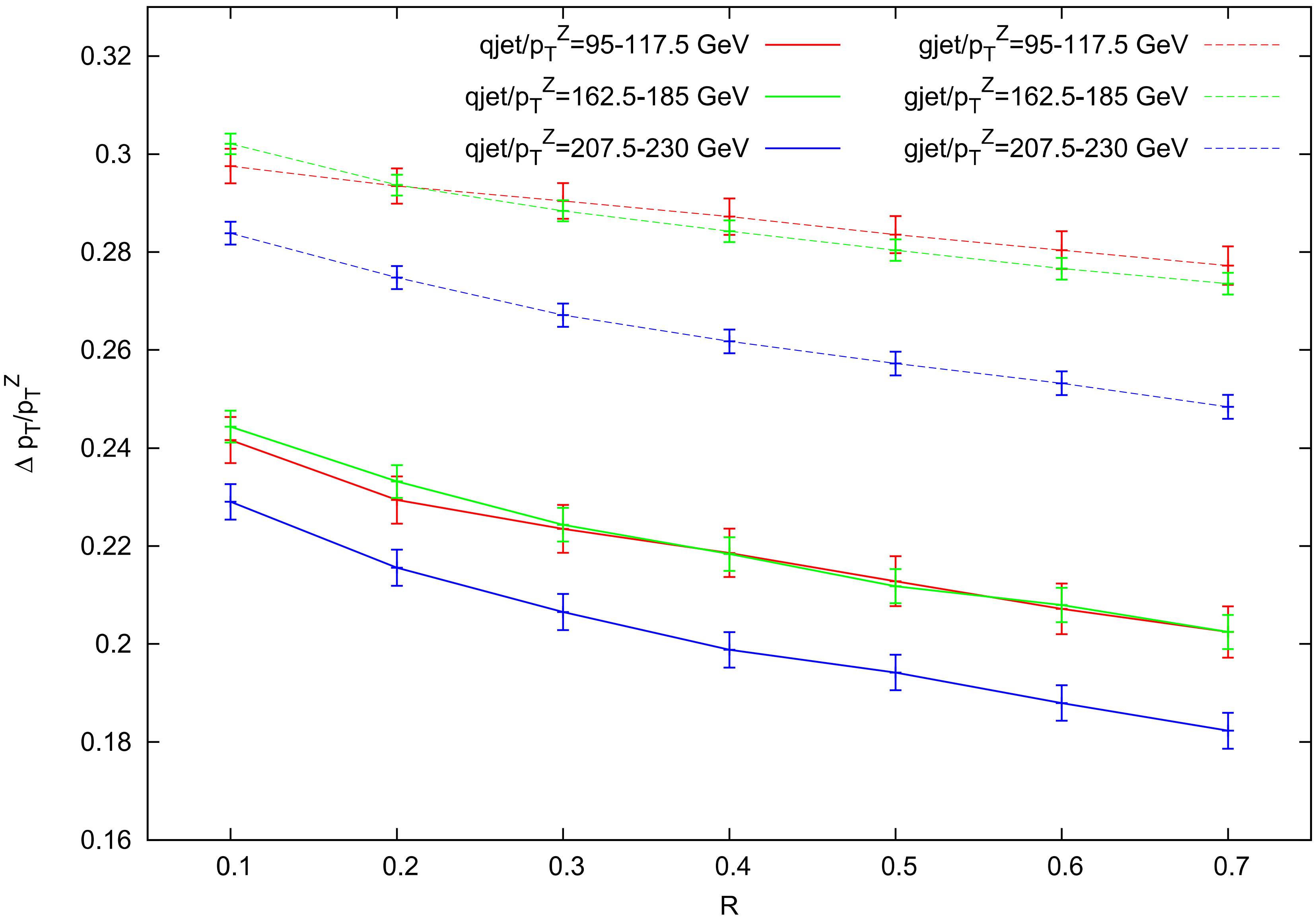


Vacuum evolution with R for 3 p_T^Z bins

There are effects beyond R evolution

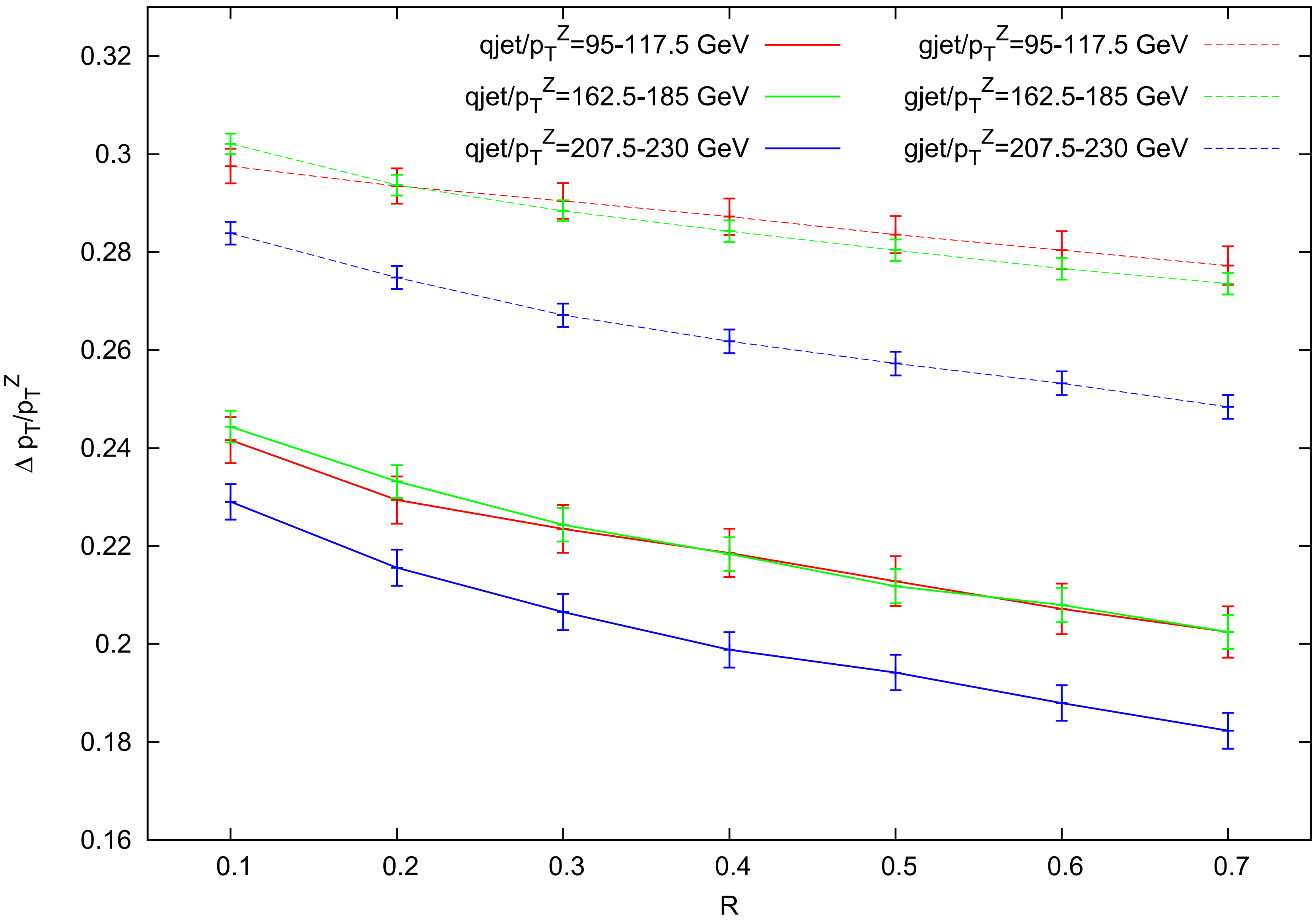
Opposite trends between MC and analytical results

The same plots now with in-medium evolution



Medium evolution with R for 3 p_T^Z bins

The same plots now with in-medium evolution



Medium evolution with R for 3 p_T^Z bins

Slower evolution with R

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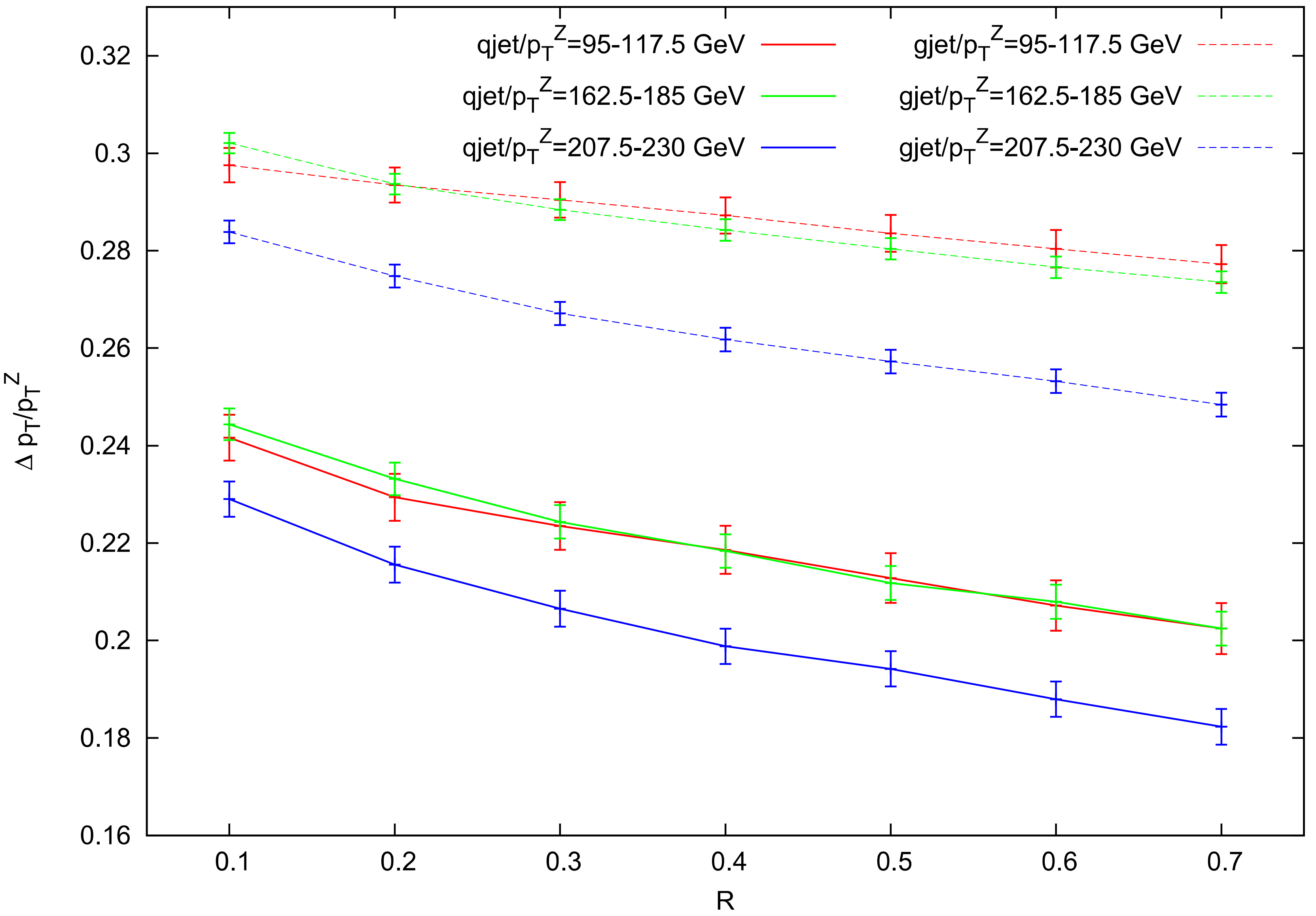

Medium evolution with R for 3 p_T^Z bins

Slower evolution with R

Greater imbalance (more out of cone radiation)

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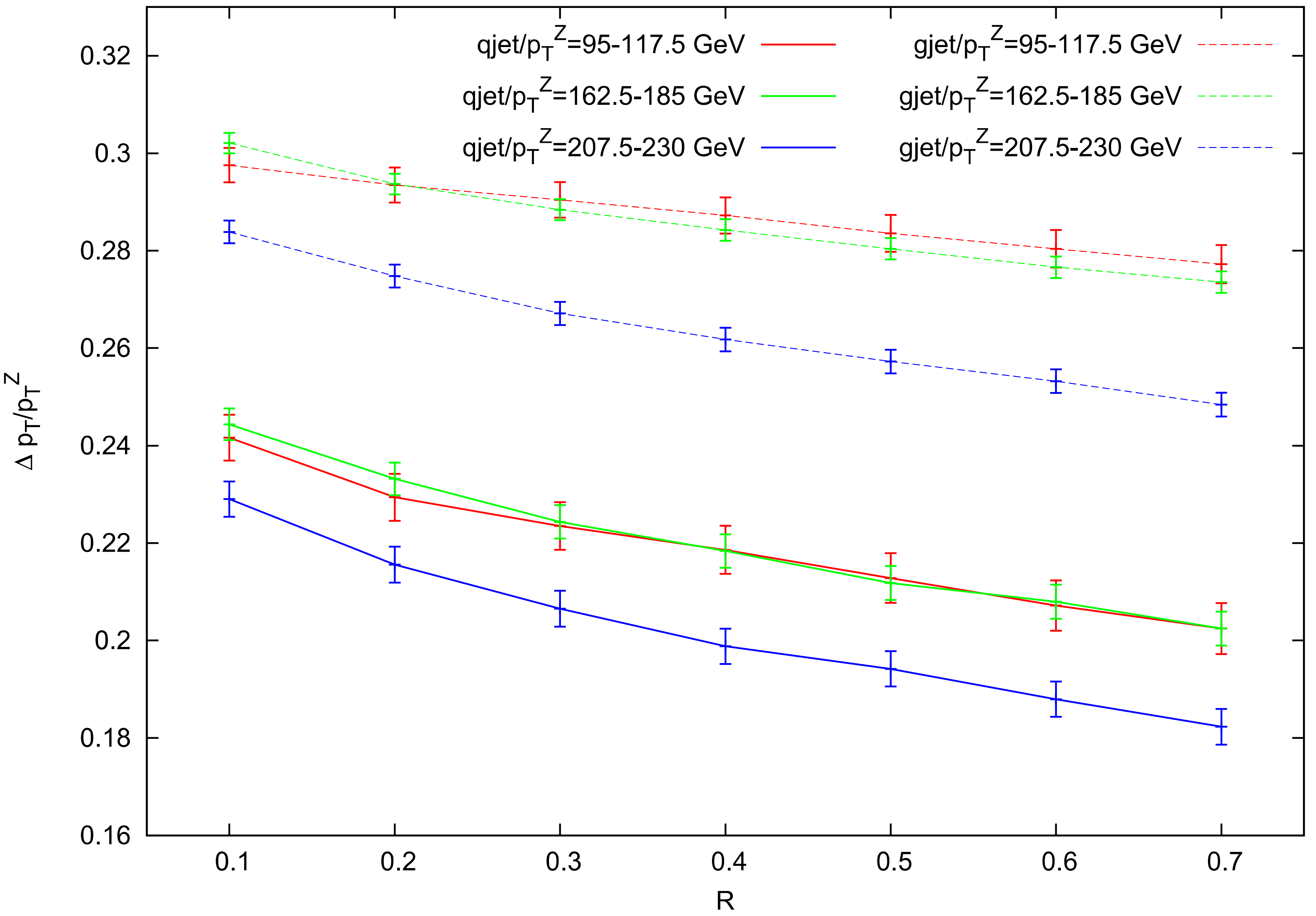


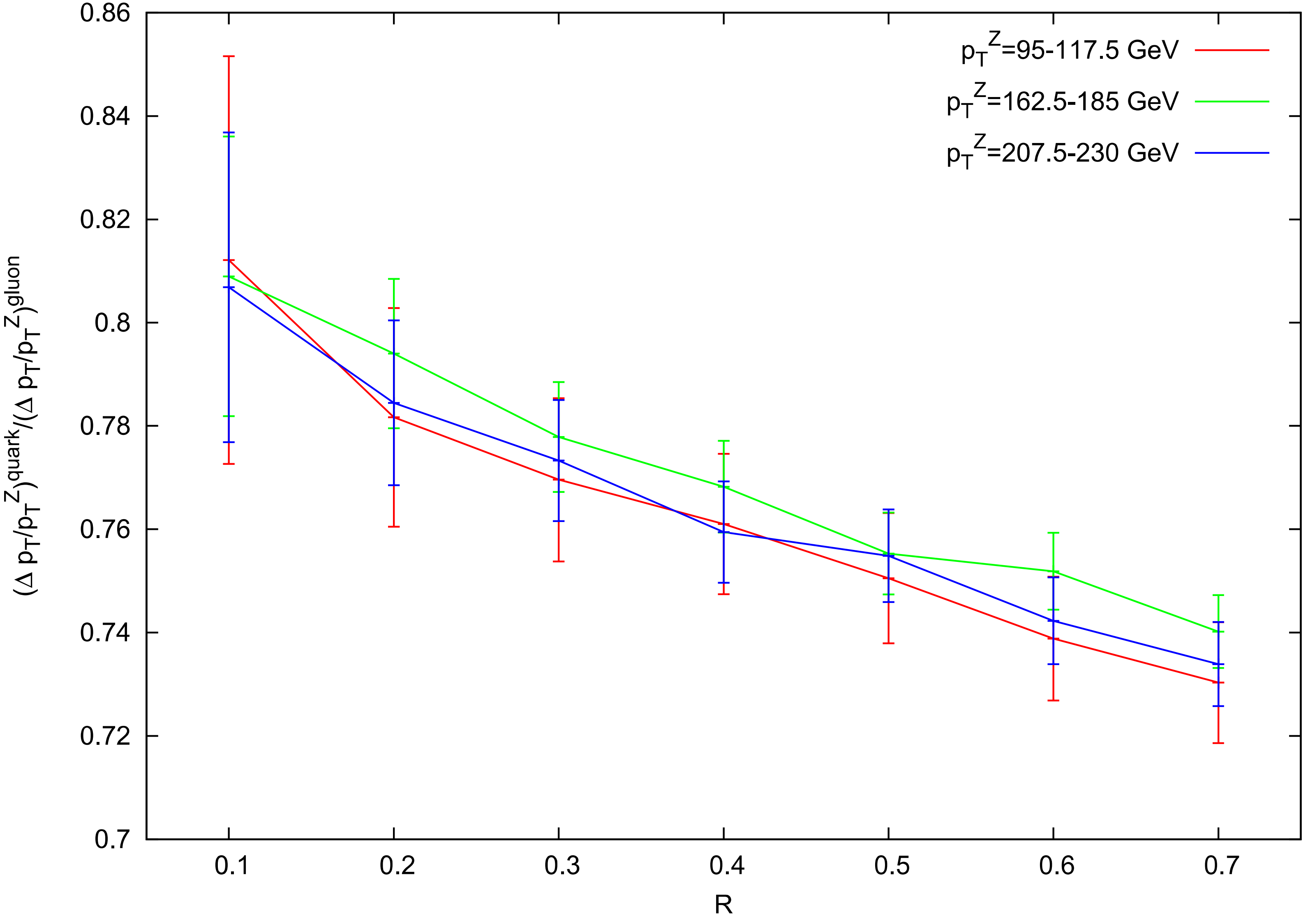
Medium evolution with R for 3 p_T^Z bins

Slower evolution with R

Greater imbalance (more out of cone radiation)

Greater separation for higher p_T , although only one bin

The scaling for quark/gluon



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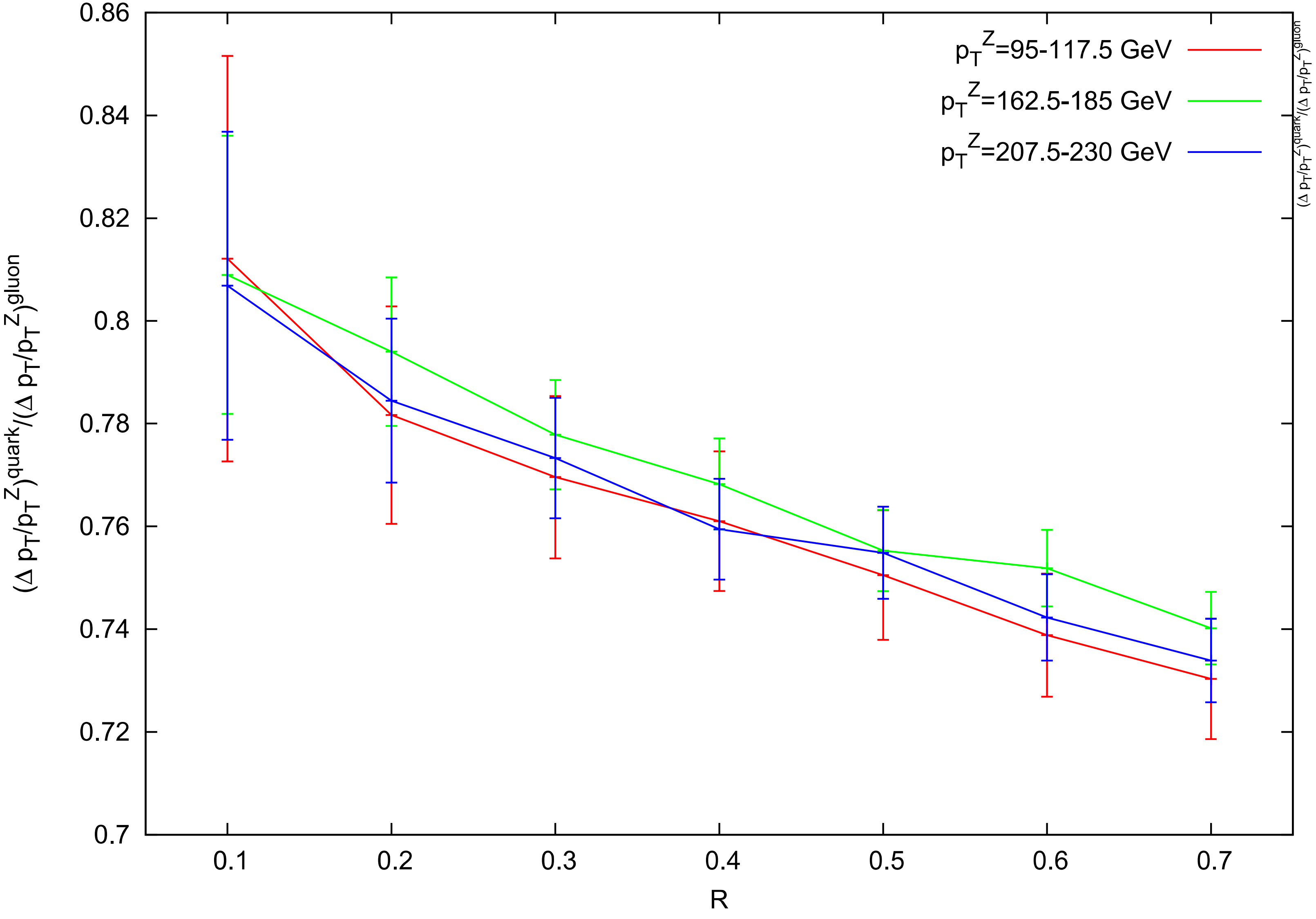

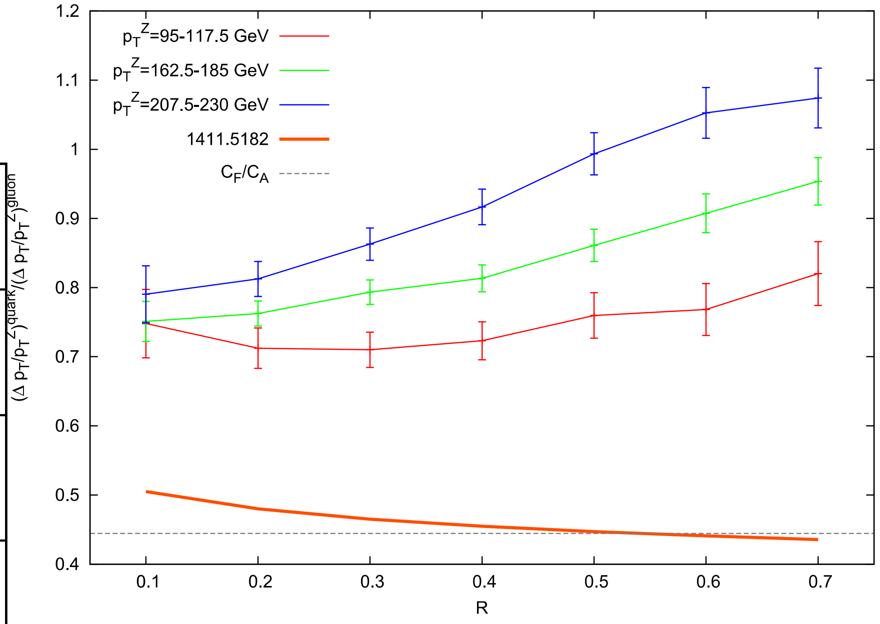

Opposite evolution to vacuum case

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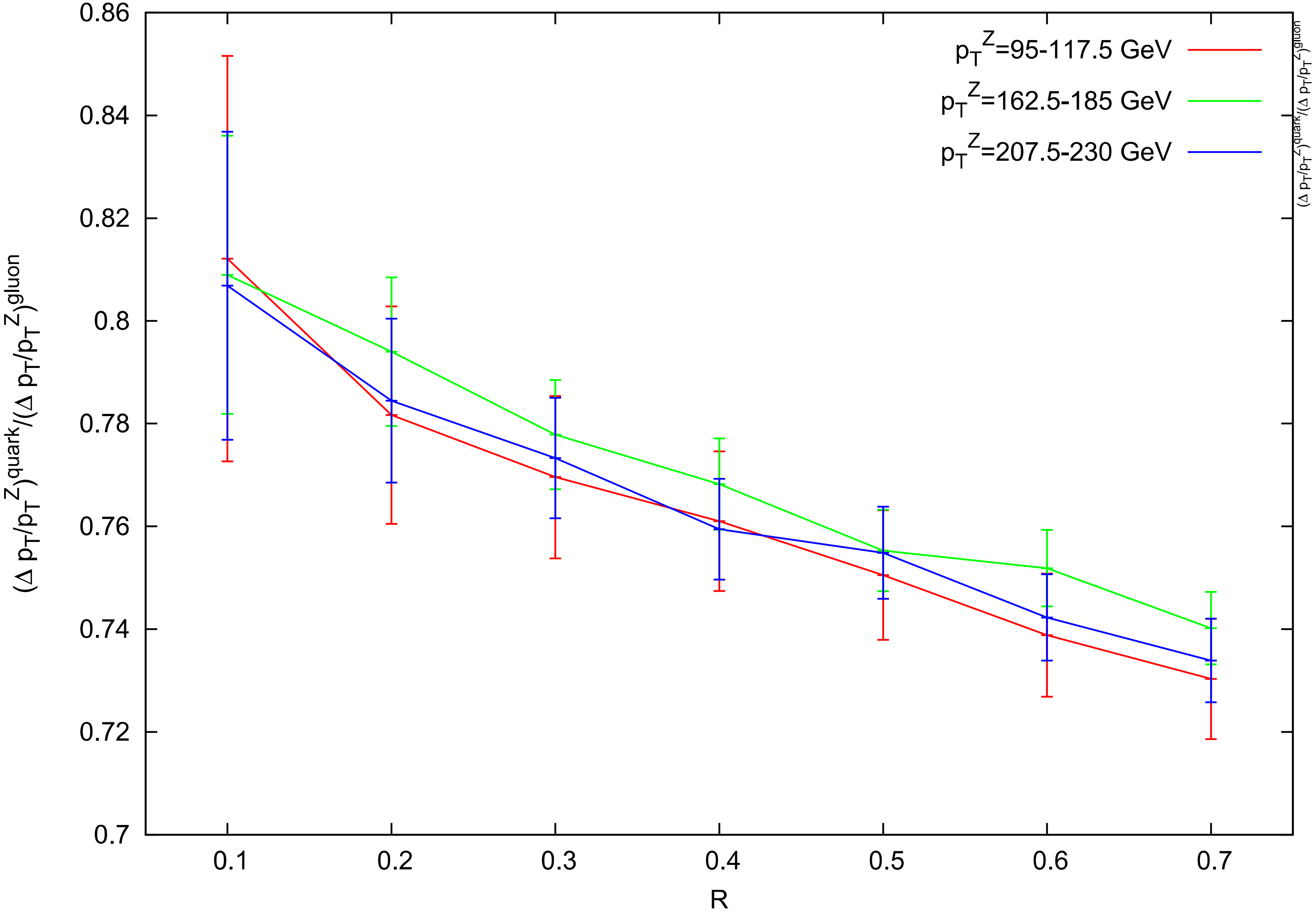

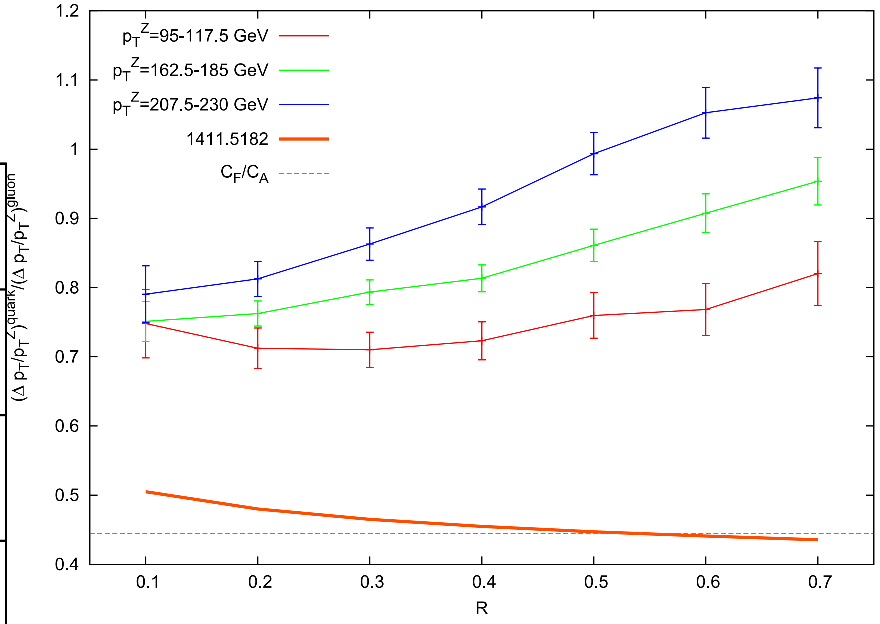

Opposite evolution to vacuum case

Seemingly invariant in p_T , very slow evolution

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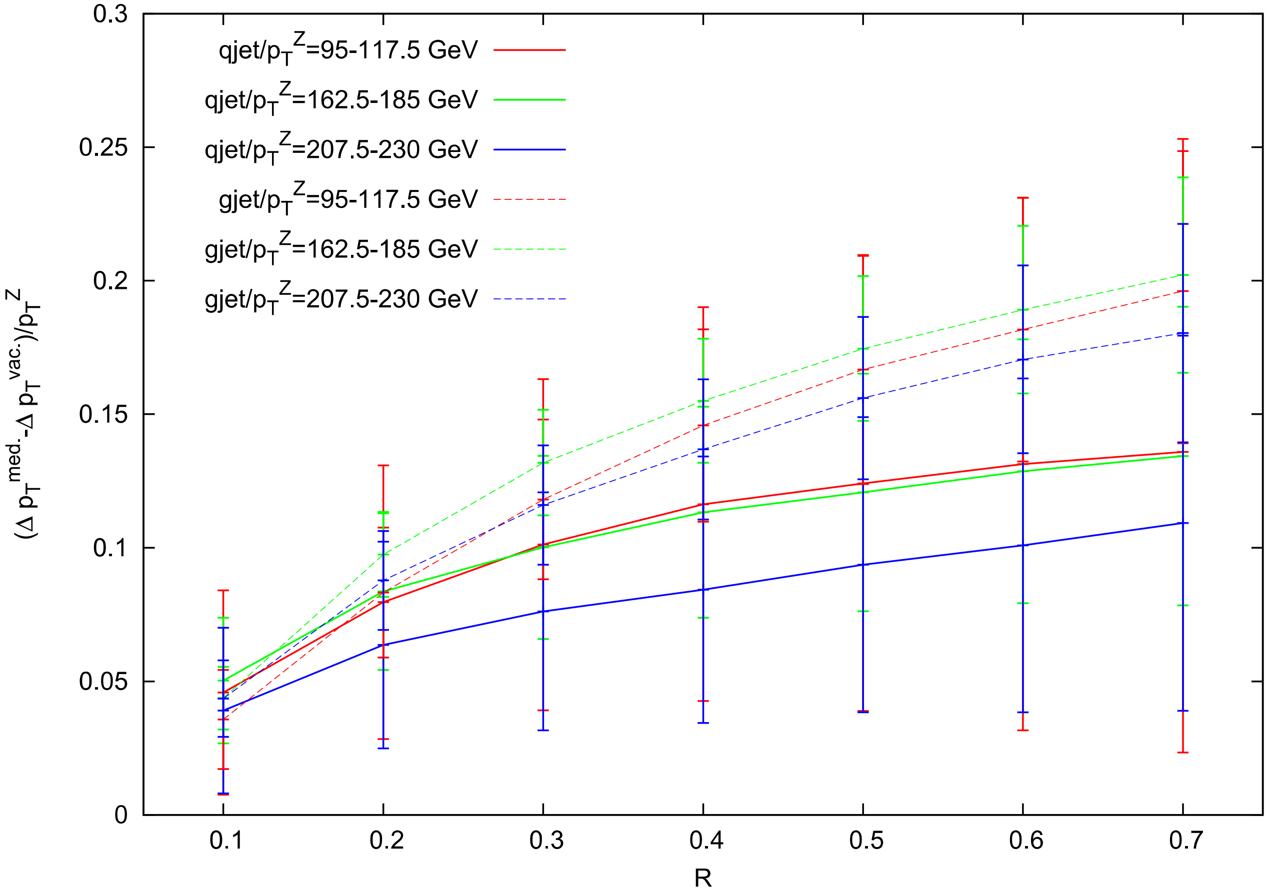

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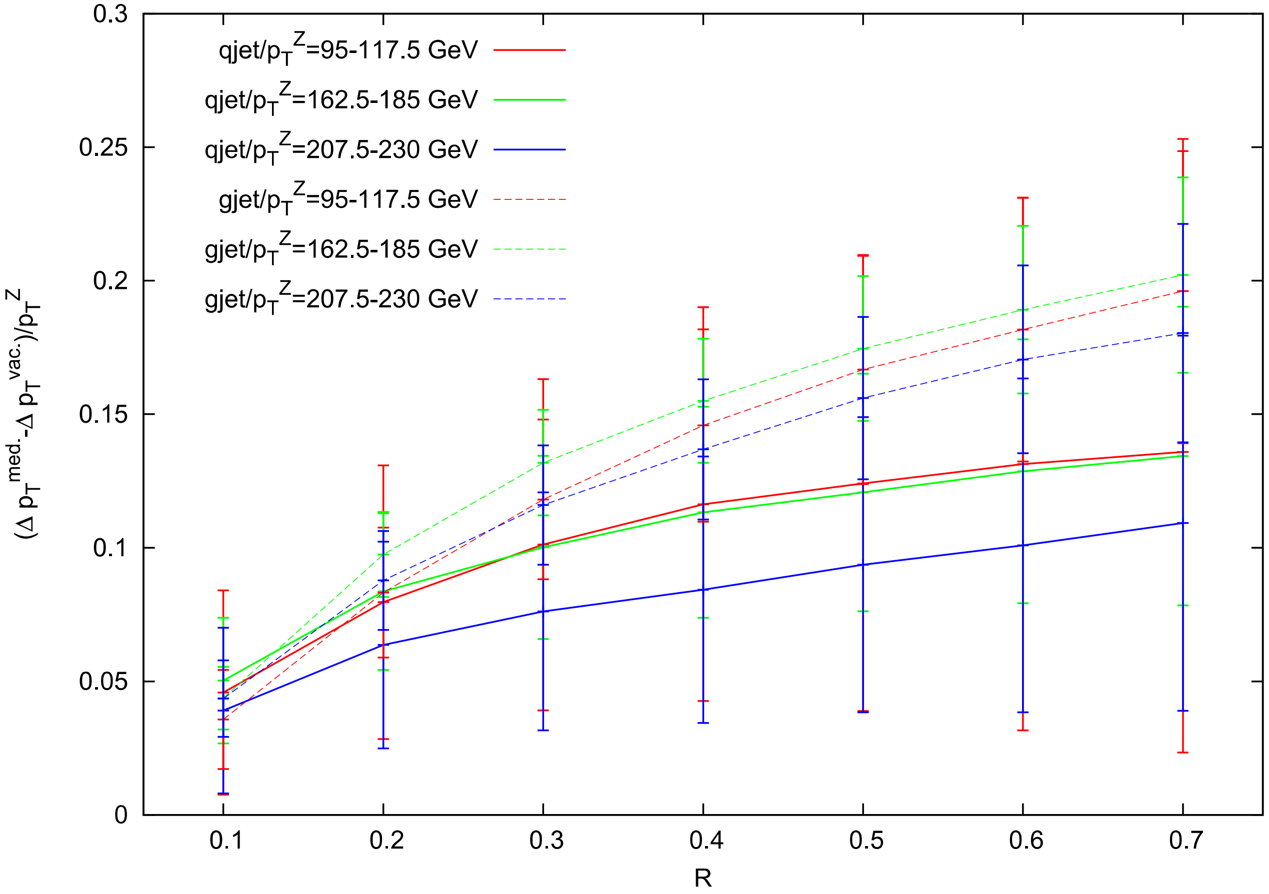

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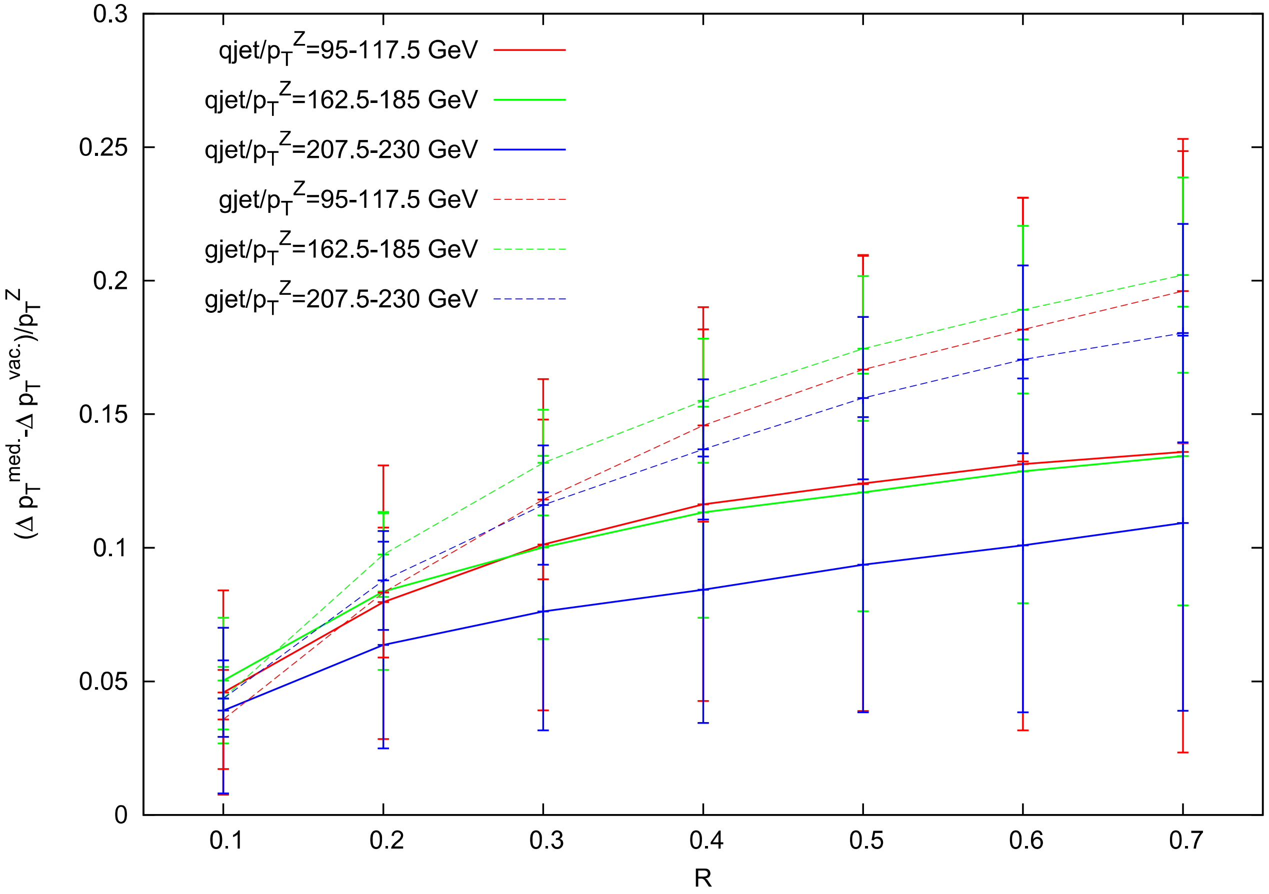

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For small jets the medium effects are a small contribution

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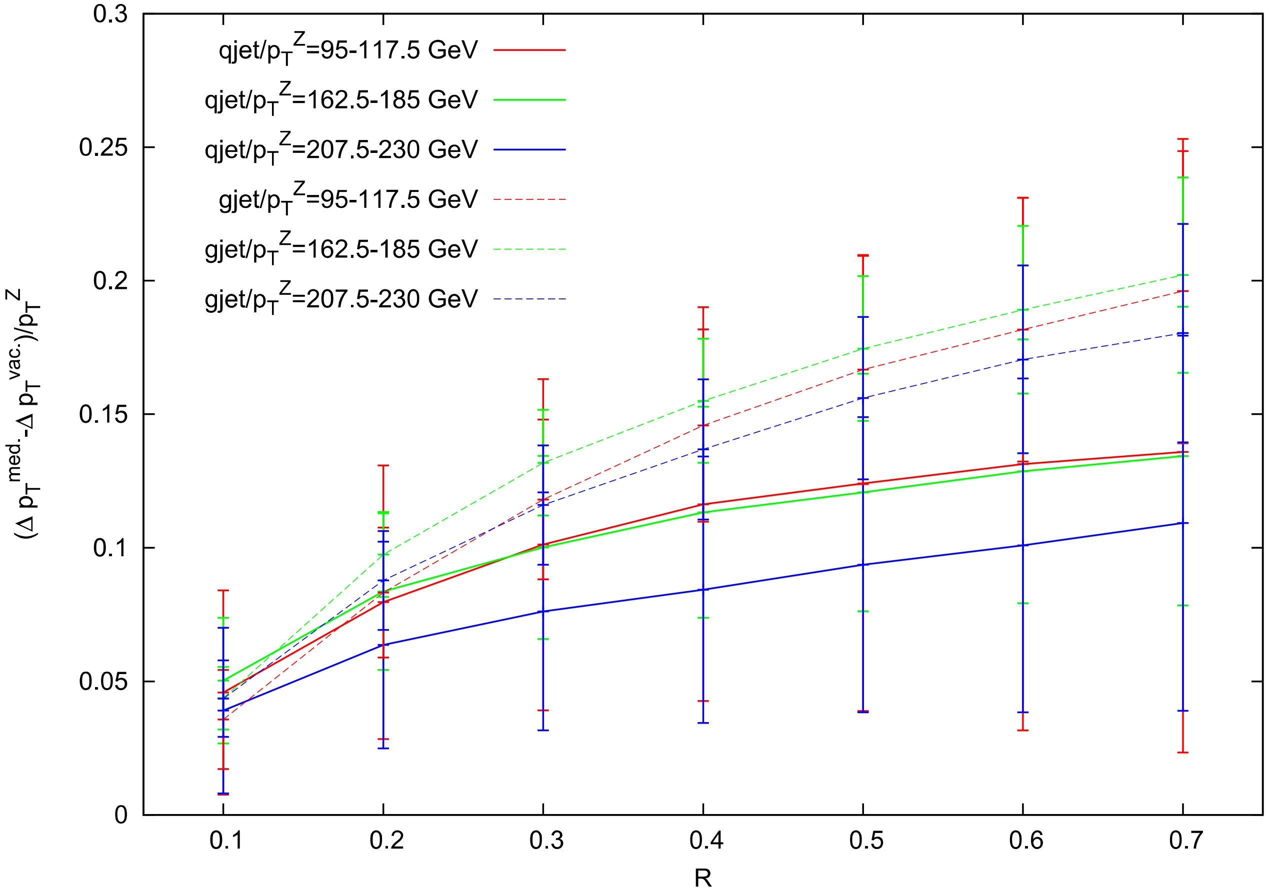

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Wider jets lose more energy

[Milhano, Zapp, arXiv: 1512.08107/ Rajagopal, Sadofyev, van der Schee, arXiv:1602.04187/ Escobedo, Iancu, arXiv: 1601.03629]

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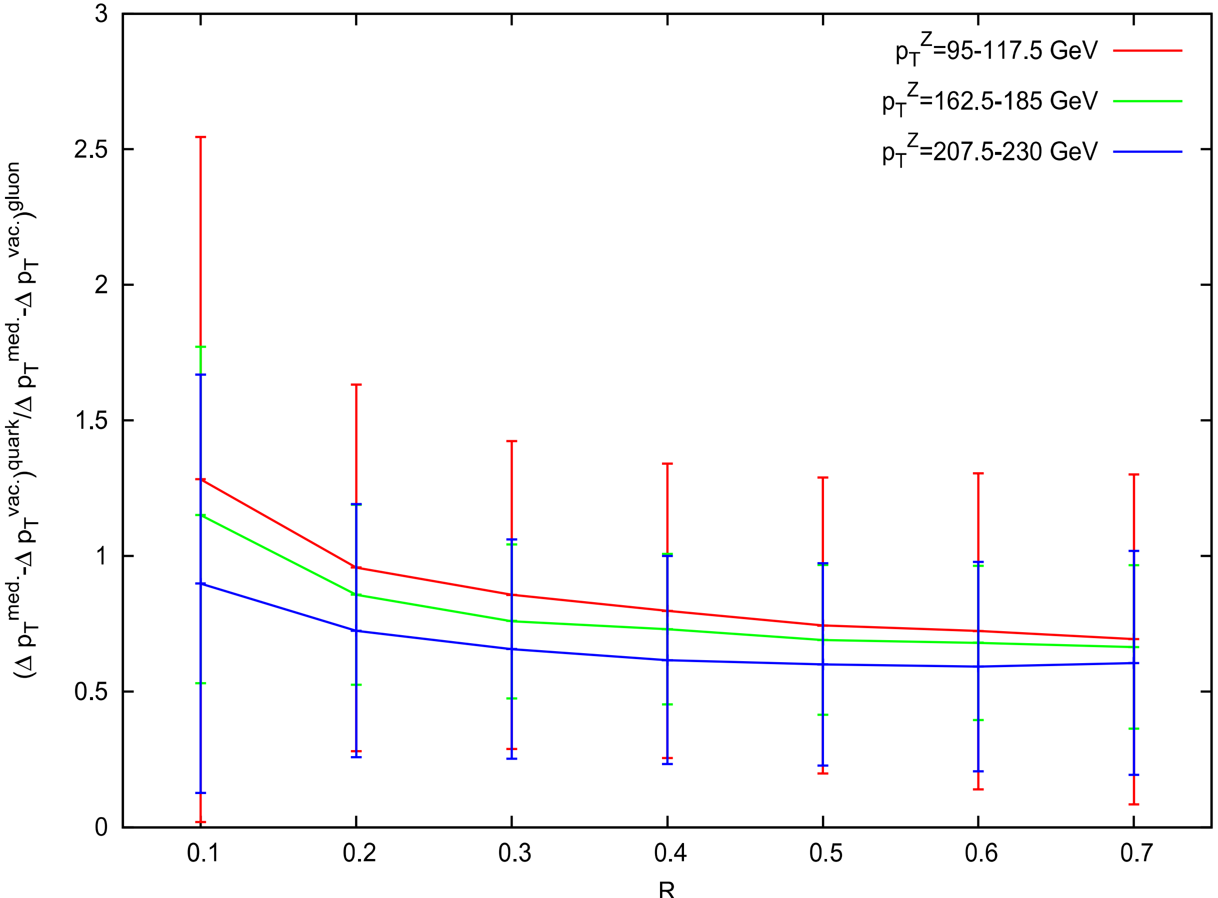

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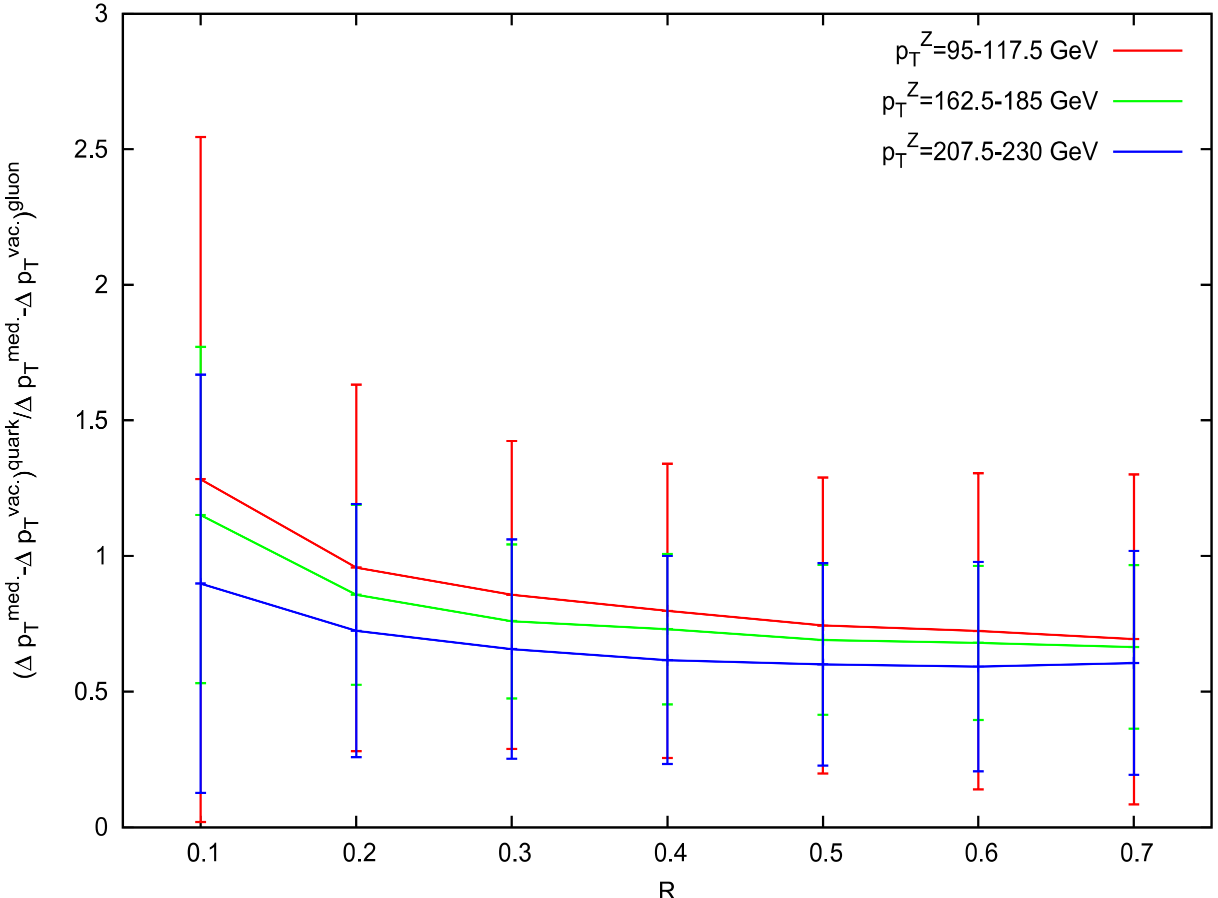

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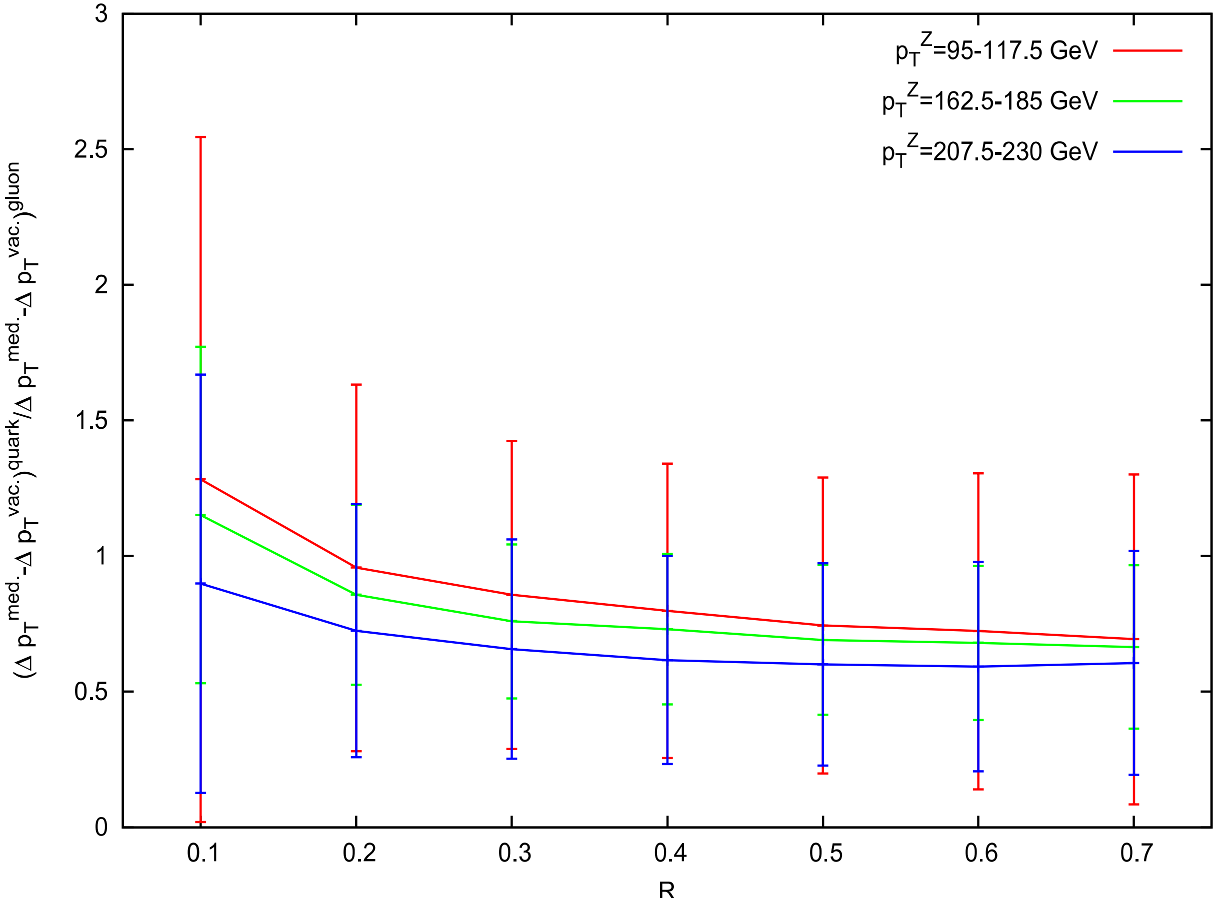

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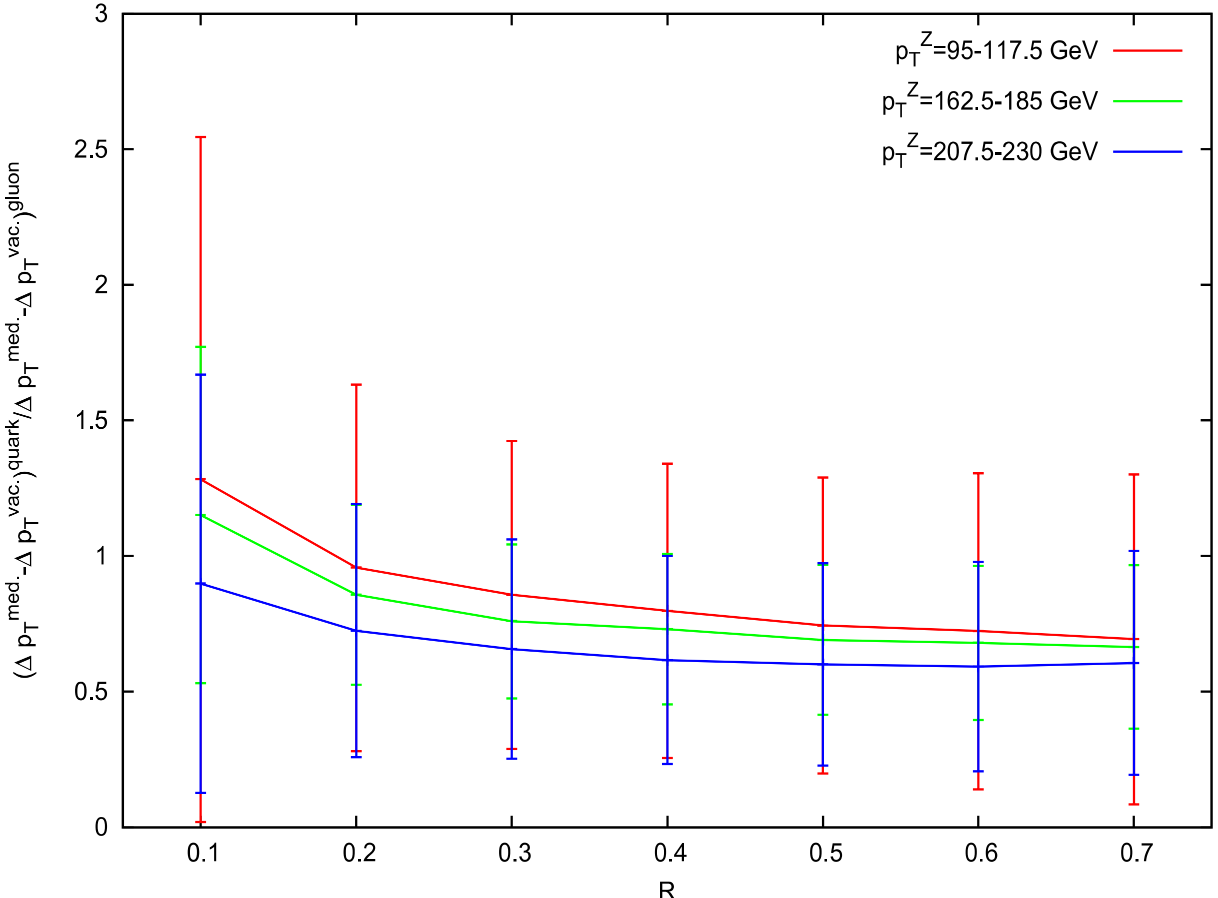

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Multiplicative correction to the Casimir scaling is in accordance with Spousta and Cole's paper, despite large uncertainty

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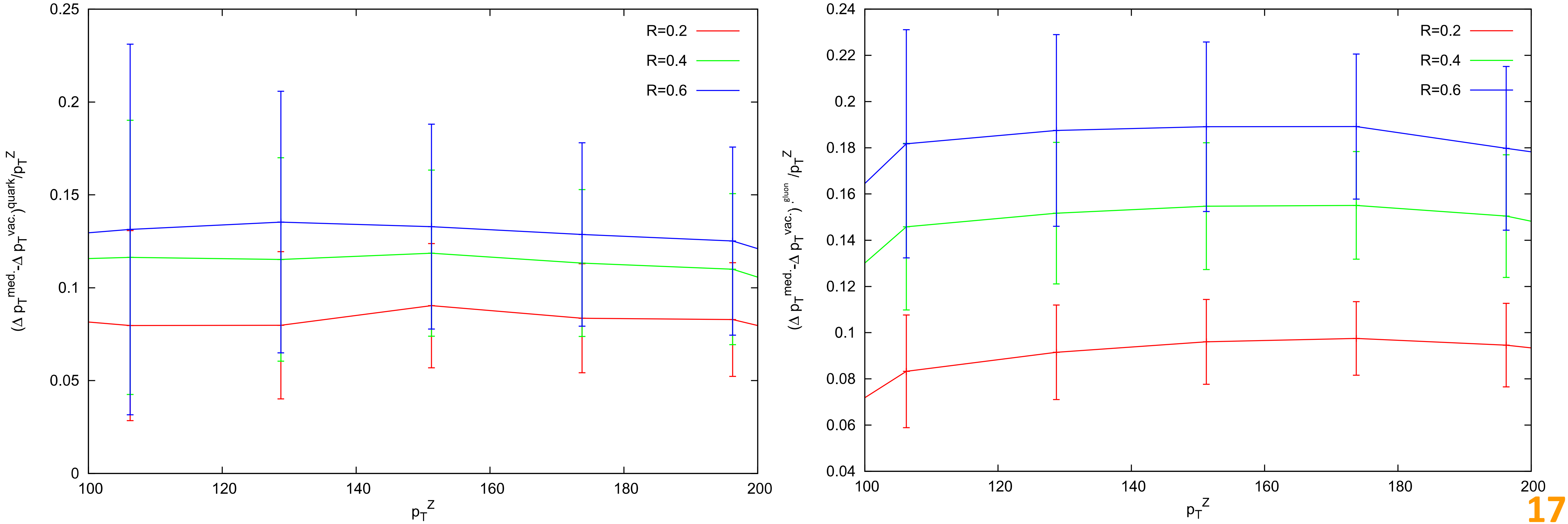

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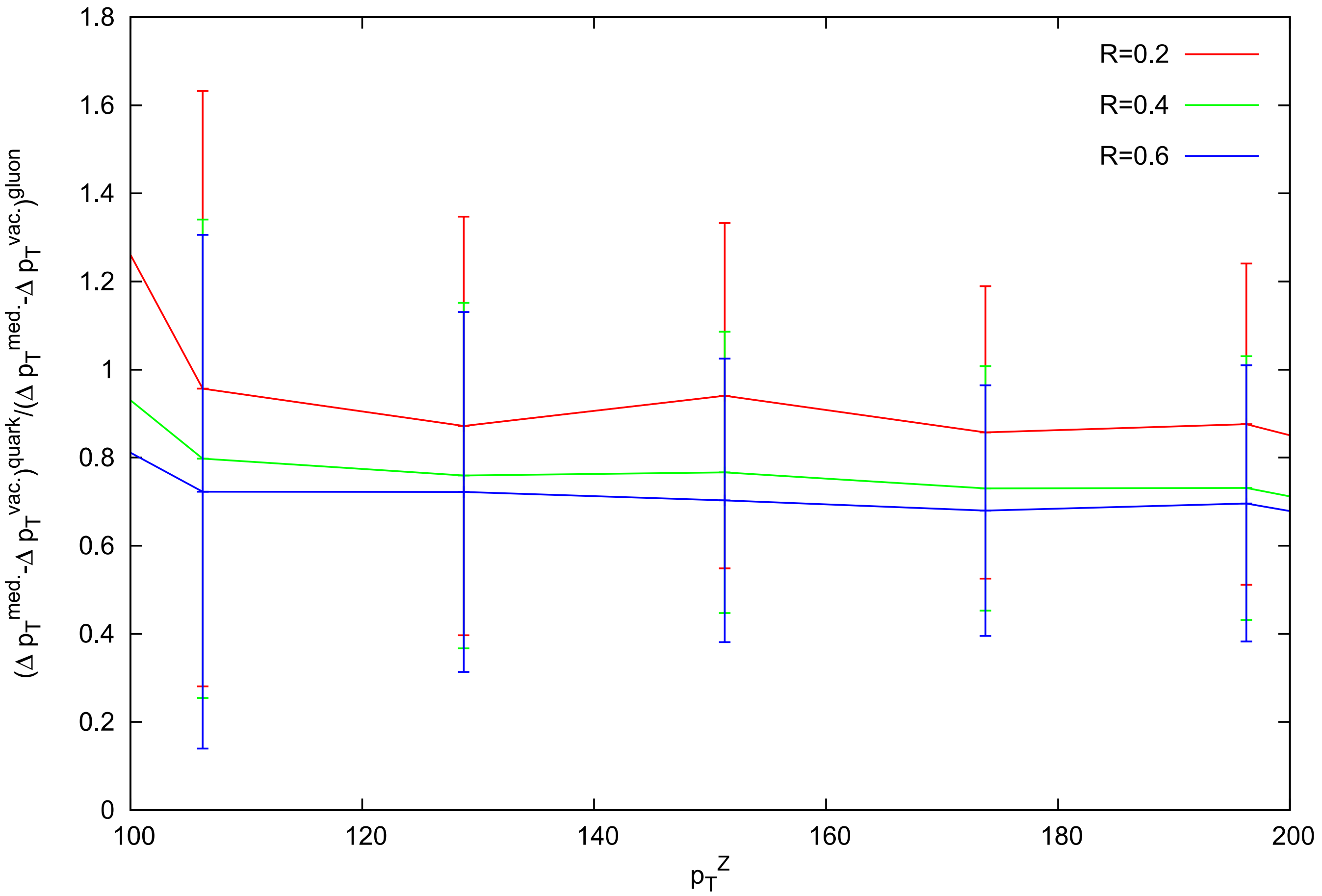
Consider now $$\frac{\Delta p_T^{med.} - \Delta p_T^{vac.}}{p_T^Z} = \frac{(p_T^{vac.} - p_T^{med.})^{jet}}{p_T^Z} = \frac{imbalance\ due\ to\ medium}{initial\ parton\ p_T}$$

In the single parton picture this should scale exactly with the Casimirs



Again ratio near 1, despite uncertainty

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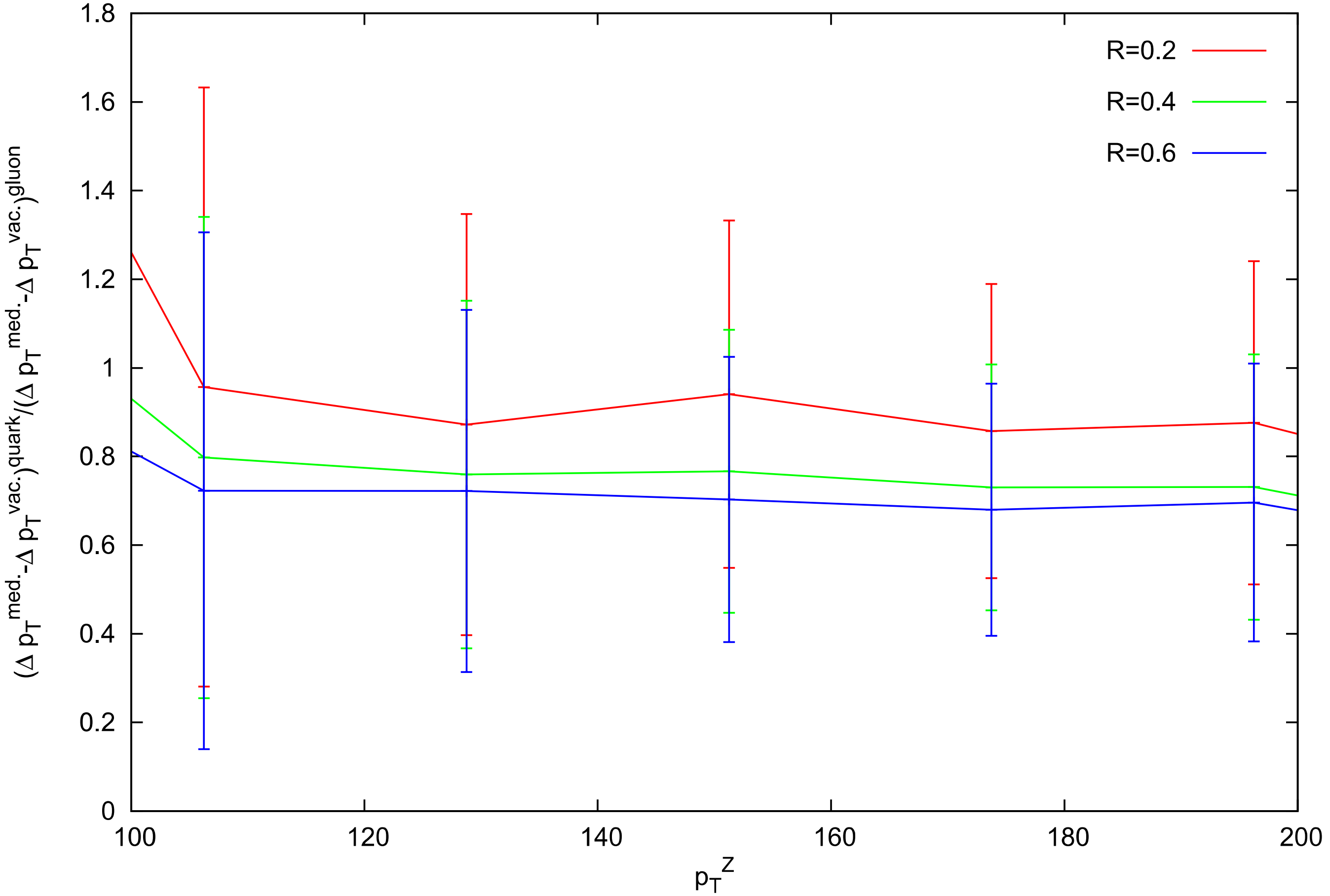

Again ratio near 1, despite uncertainty

However still roughly constant over p_T scale and independent of choice for R

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Consider now $$\frac{\Delta p_T^{med.} - \Delta p_T^{vac.}}{p_T^Z} = \frac{(p_T^{vac.} - p_T^{med.})^{jet}}{p_T^Z} = \frac{imbalance\ due\ to\ medium}{initial\ parton\ p_T}$$

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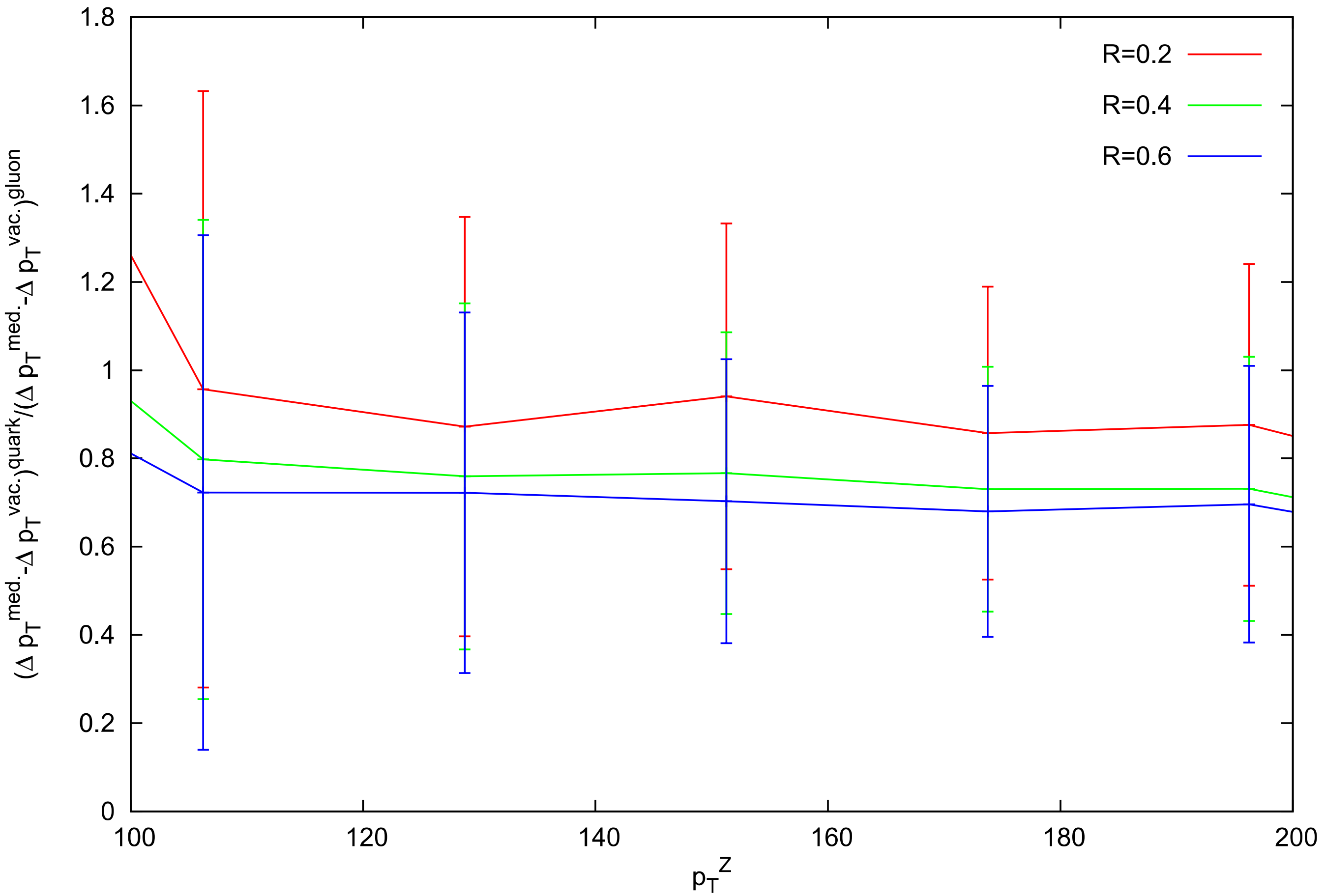


Again ratio near 1, despite uncertainty

However still roughly constant over p_T scale and independent of choice for R

This hints that Casimir scaling is broken for jets

We looked at two effects:

1) Energy loss due to jet definition:

- In vacuum, there is an evolution of the quark to gluon energy loss ratio, which seems not to be explained just by R definition
- This should be checked for another MC generator and for in-medium evolution

2) Jet energy loss to the medium:

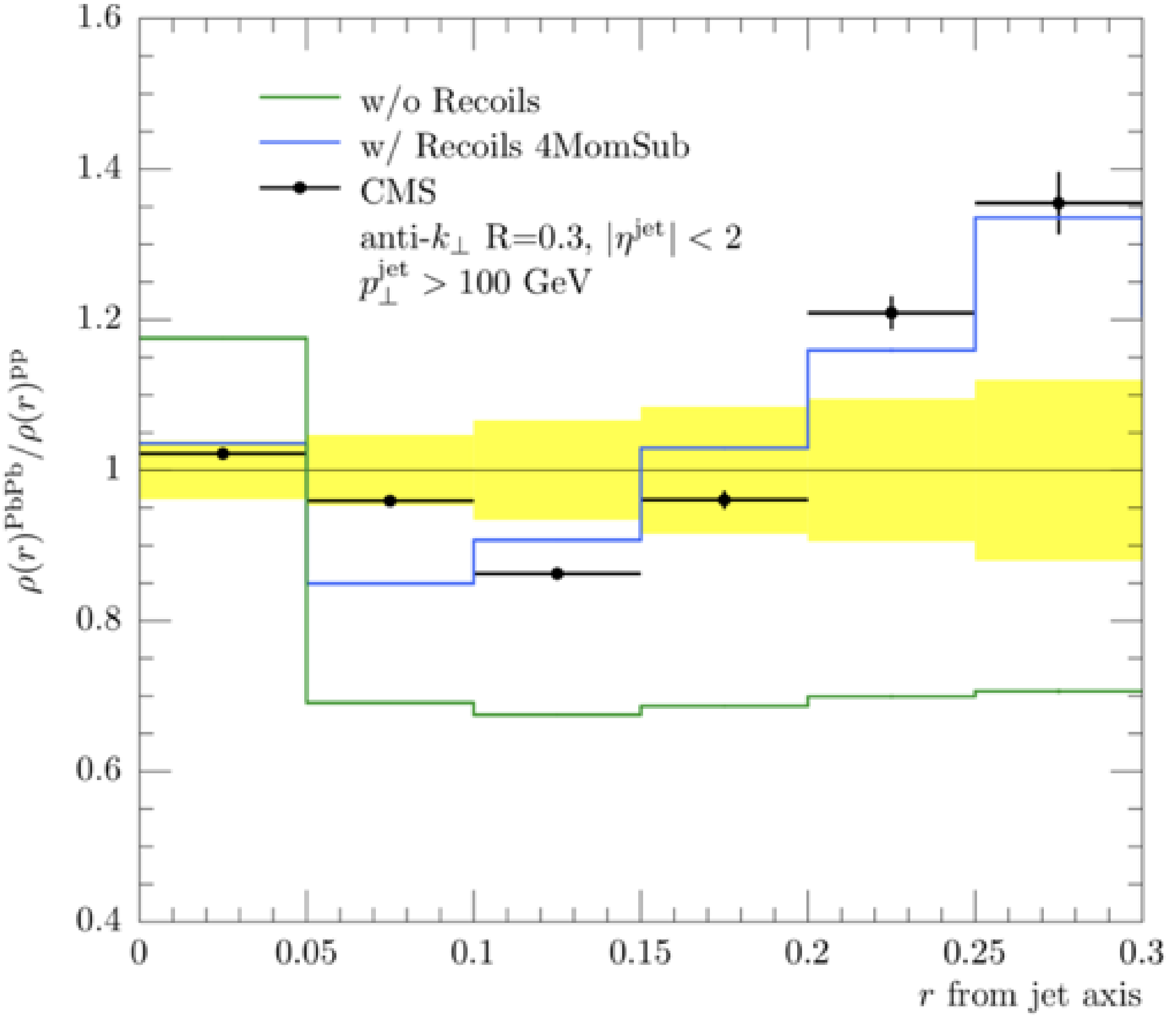
- We recovered a constant ratio, but results seem to indicate this is not given directly by the Casimirs' ratio
- Flavor seems less relevant than at the single parton level
- JEWEL energy loss is similar for quark and gluon jets (quark jets have many gluons)

What is left to do:

- More statistics, wider p_T and R range. This is particularly important for total imbalance study.
- Study R evolution in the medium and further test it for other MC generators
- Extend the study for less central events (see next talk)

Thank you

Backup



w/o Recoils
w/ Recoils 4MomSub
CMS
anti-$k_\perp$ R=0.3, $|\eta^{\rm jet}| < 2$
$p_\perp^{\rm jet} > 100$ GeV
$\rho(r)^{\rm PbPb}/\rho(r)^{\rm pp}$
1.6
1.4
1.2
1
0.8
0.6
0.4
0
0.05
0.1
0.15
0.2
0.25
0.3
r from jet axis