A Monte Carlo study of in-medium quark and gluon jet colour scaling

28th February 2019 – COST Workshop Lund

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Fundación Bancaria "la Caixa"

IGFAE Instituto Galego de Física de Altas Enerxías

USC UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

MARIE CURIE ACTIONS

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$$\left(\frac{E^{quark}}{E^{gluon}}\right)^{AdS/CFT}_{loss} = \left(\frac{C_F}{C_A}\right)^{\frac{1}{3}} \overset{QCD}{=} \left(\frac{4}{9}\right)^{\frac{1}{3}} = 0.7631\ldots \qquad C_A = N \overset{QCD}{=} 3$$

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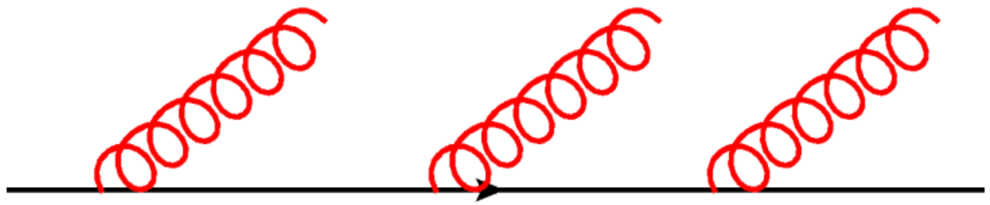

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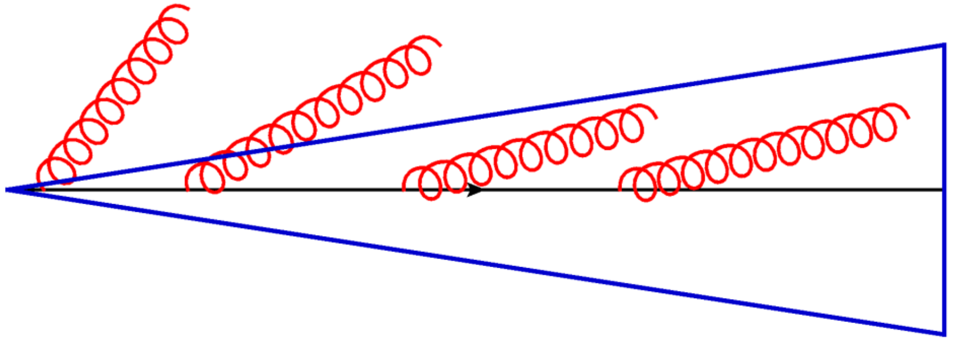

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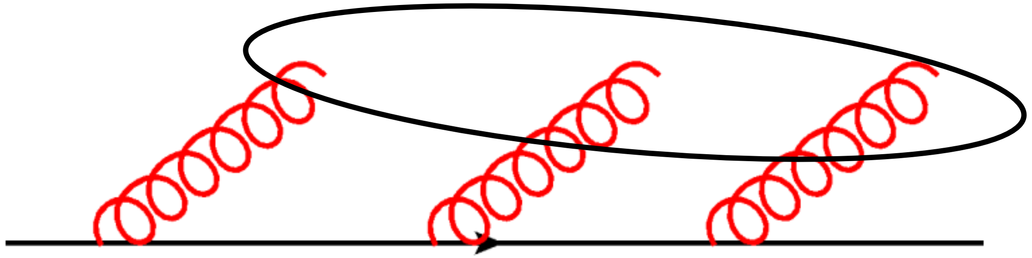

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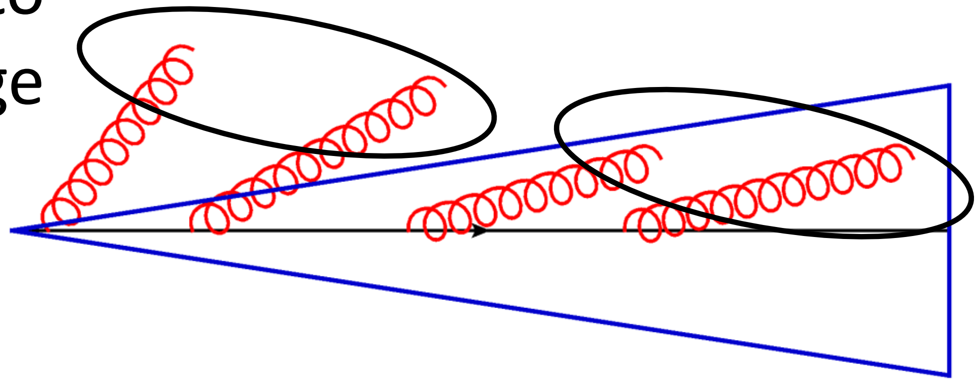

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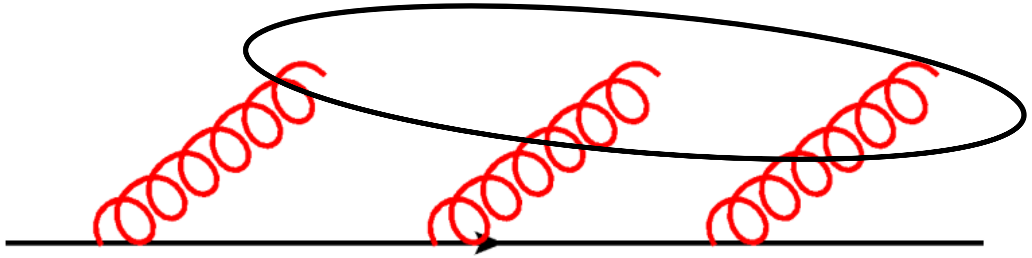

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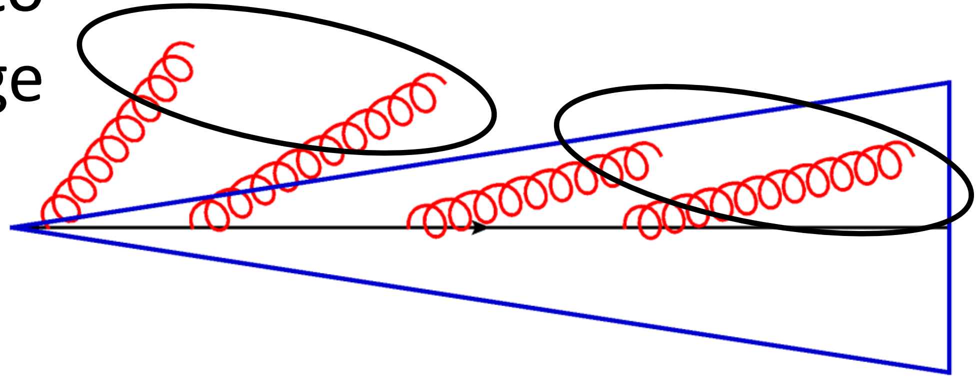

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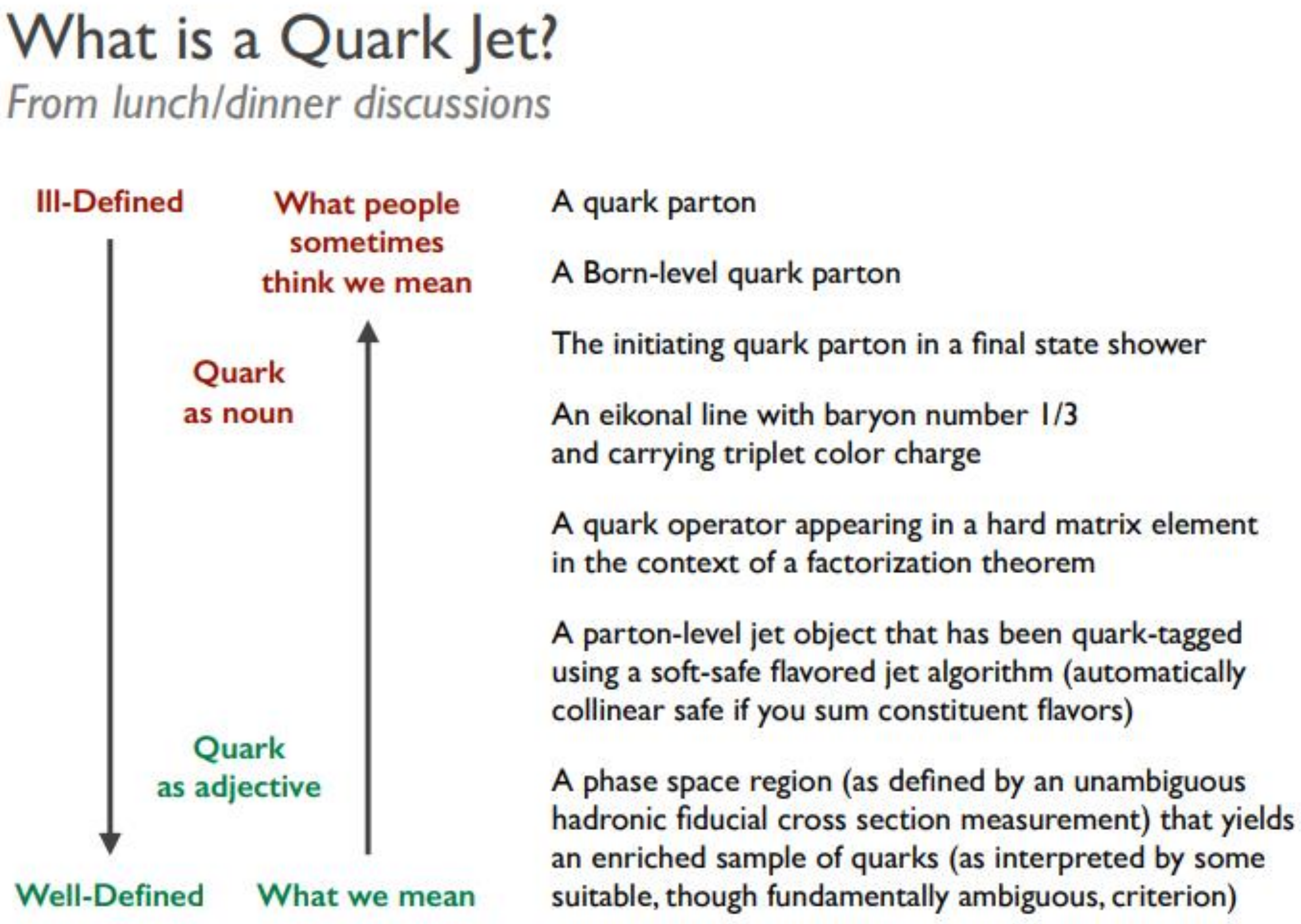

Stolen from: Gras, et al., [1704.03878]

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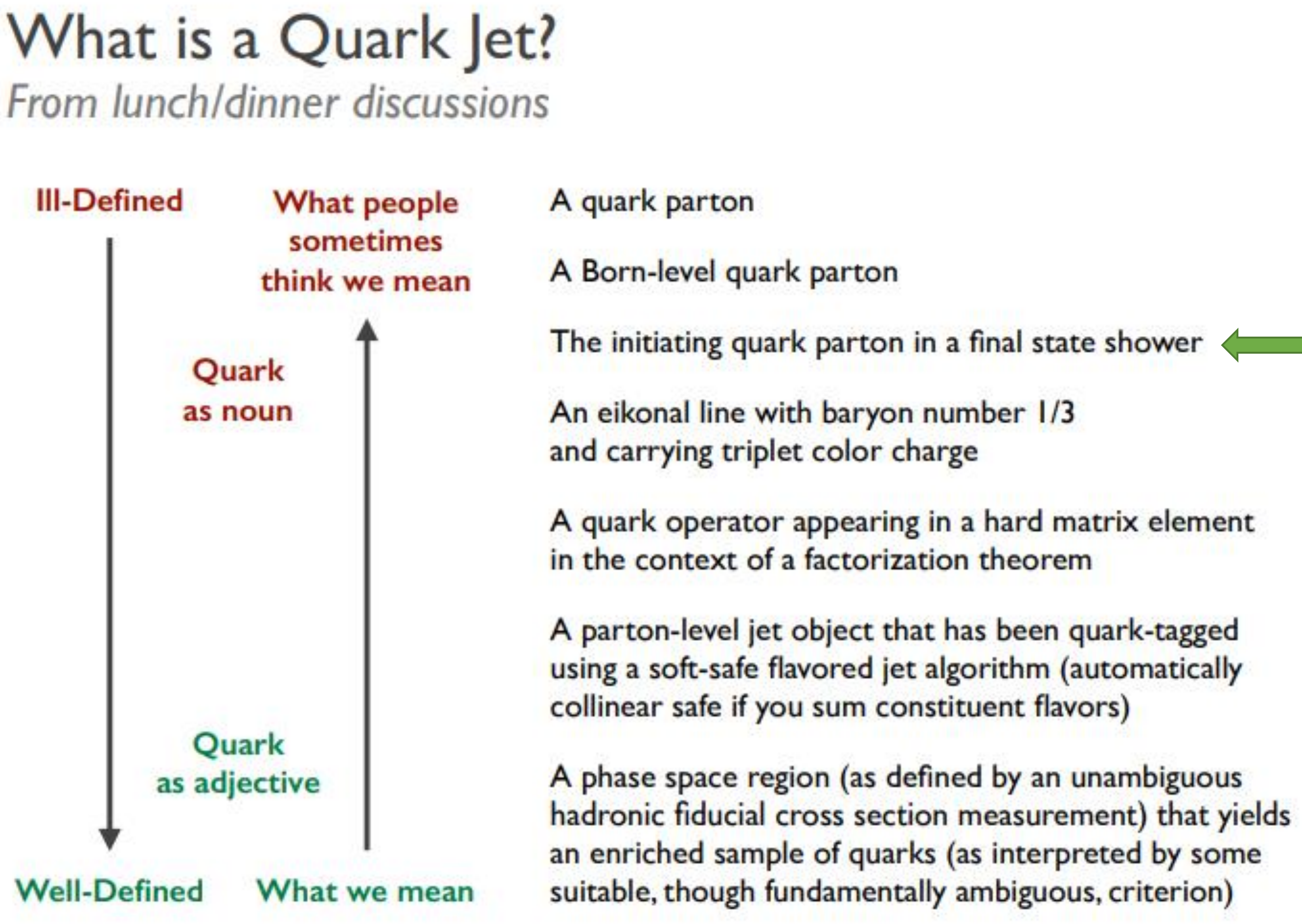

Today

But what I really mean …

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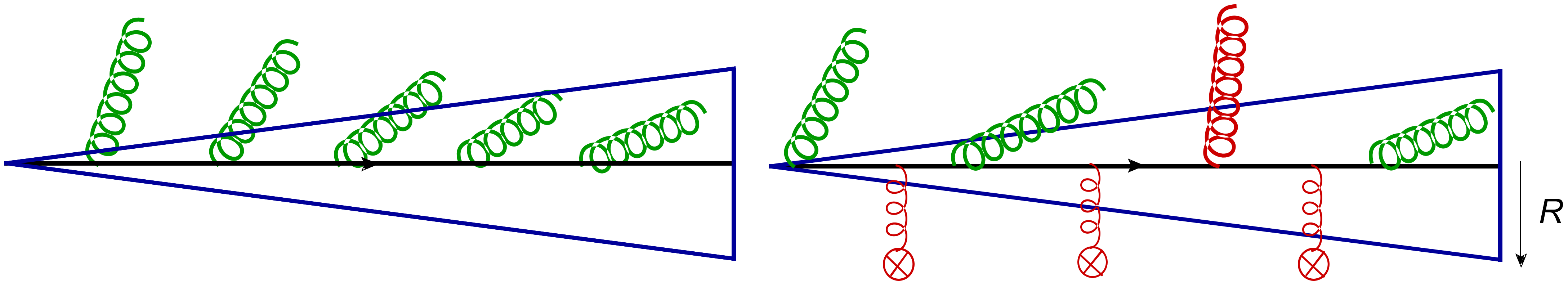
Jet Physics (for today)



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Even in vacuum the transition from partons to jets is not trivial

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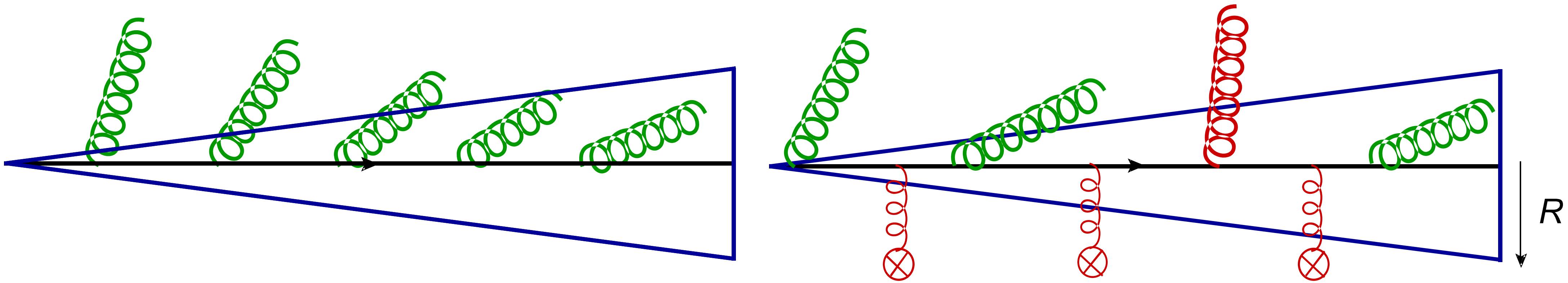

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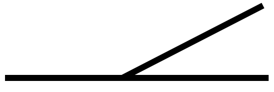
However, nowadays, many jet observables can be computed



dProbability (i) = $\frac{2\alpha_s C_i}{\pi}\frac{d\theta}{\theta}\frac{d\omega}{\omega}$

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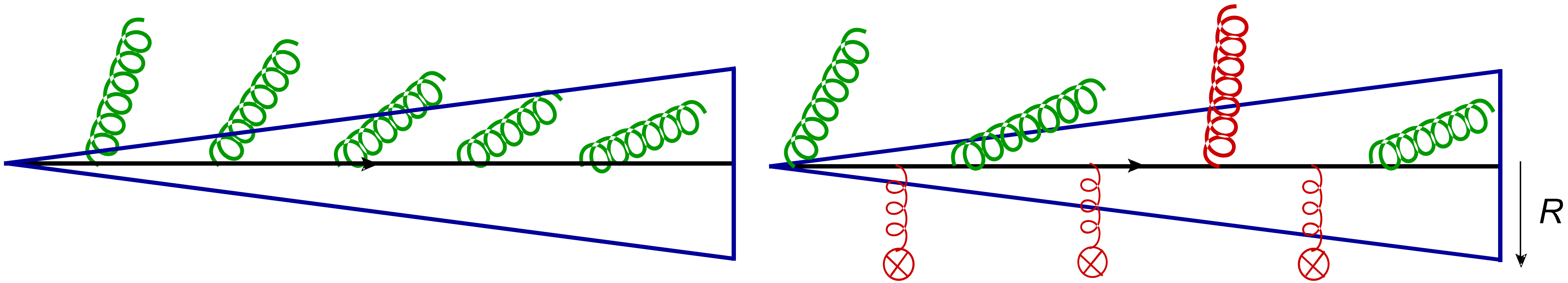

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Assuming decoupling between vacuum and medium emissions

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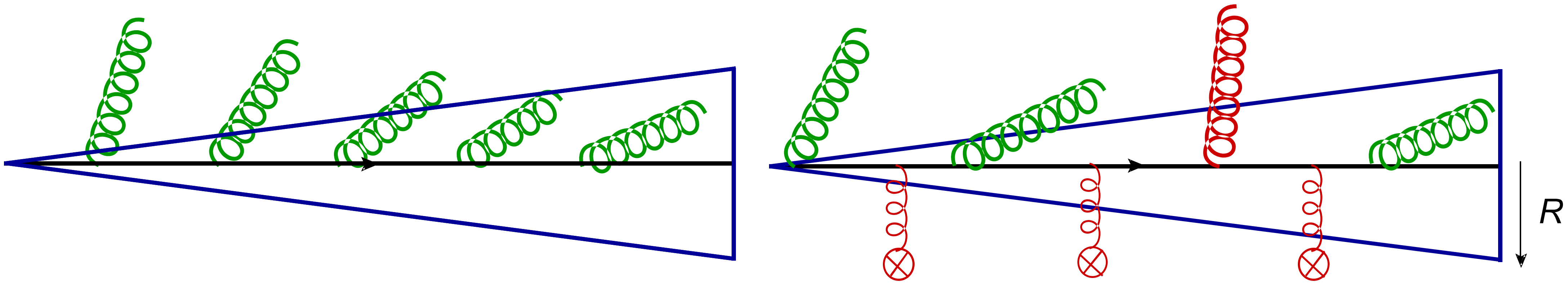

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Naively we expect the breaking of Casimir scaling for medium energy loss mechanisms

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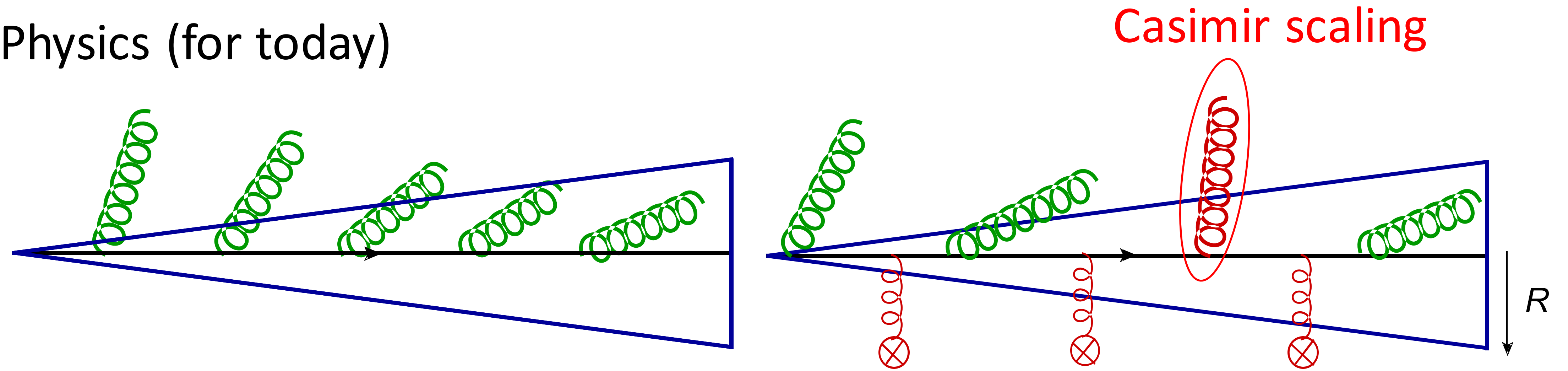

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A simple qualitative calculation to estimate Casimir breaking effects

→ Compute the transverse momentum imbalance at LO

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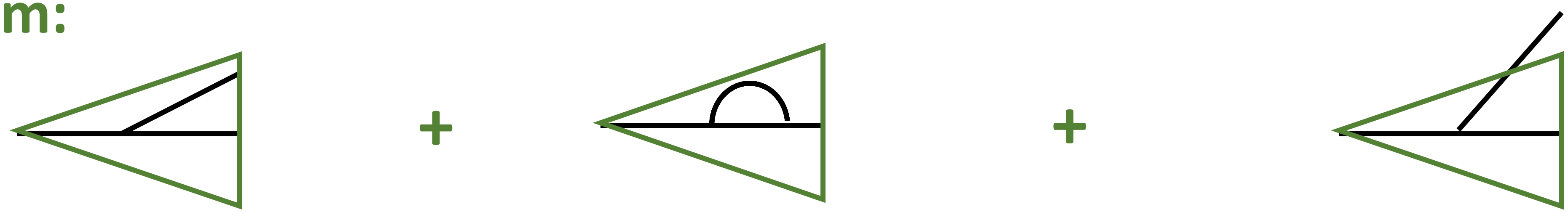

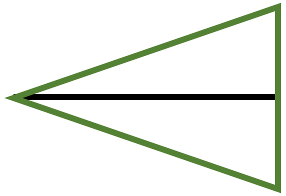

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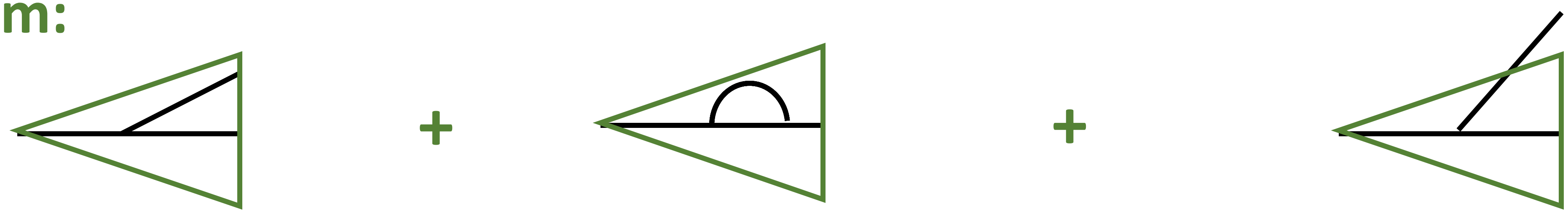
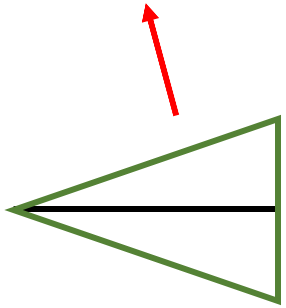


$$\langle \delta p_T \rangle^{LO} = 0$$



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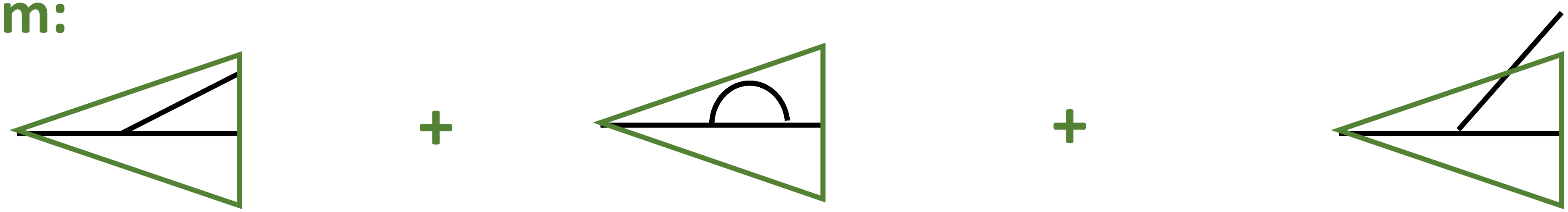
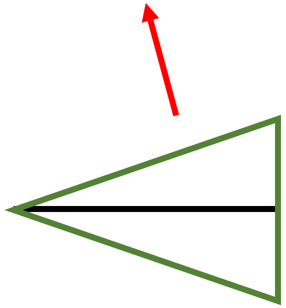


$$\langle \delta p_T \rangle^{LO} = 0 - \frac{\alpha_s}{\pi} \int_R^{\mathcal{O}(1)} \frac{d\theta}{\theta} \int_0^1 dz P(z)(-1 + f(z))$$



Recover: Dasgupta, Magnea, Salam, 0712.3014

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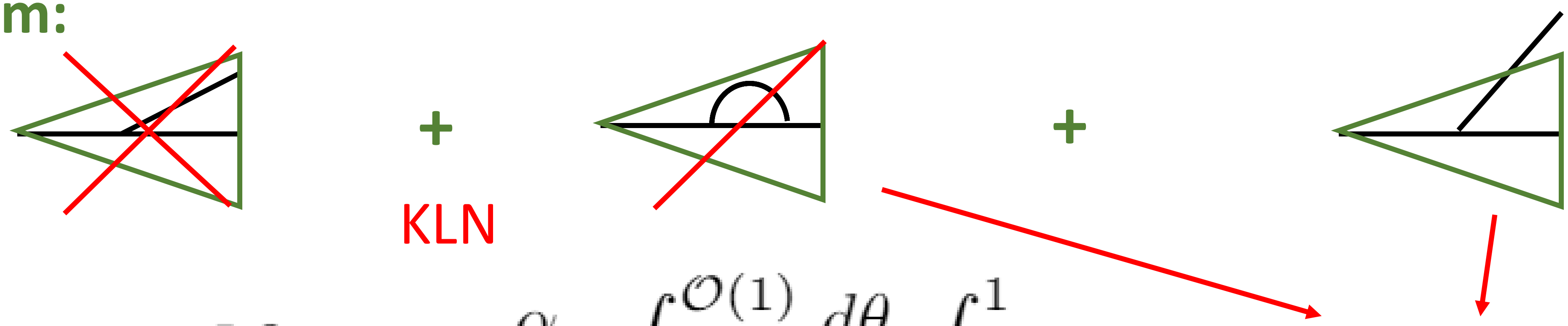

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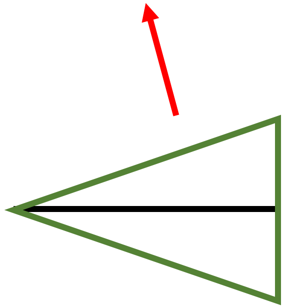

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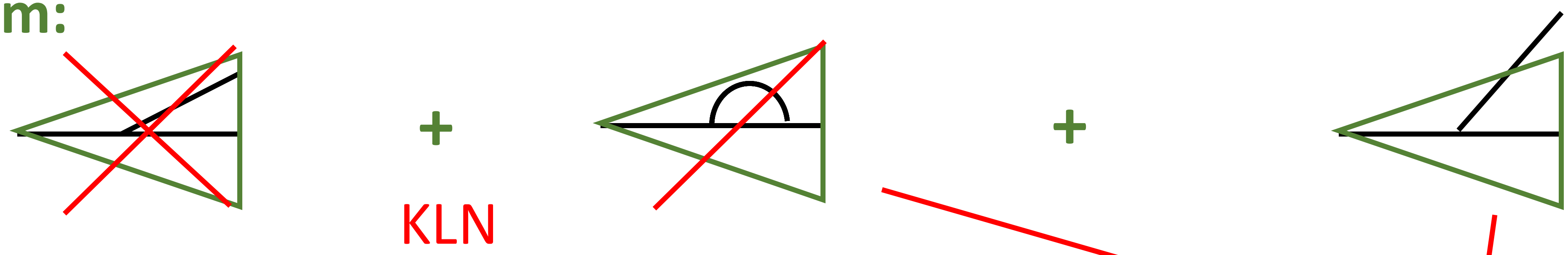

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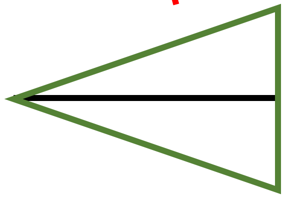

$$P_q(z) = P_{gq}(z) \qquad P_g(z) = \frac{1}{2} P_{gg}(z) + n_f P_{qg}(z)$$

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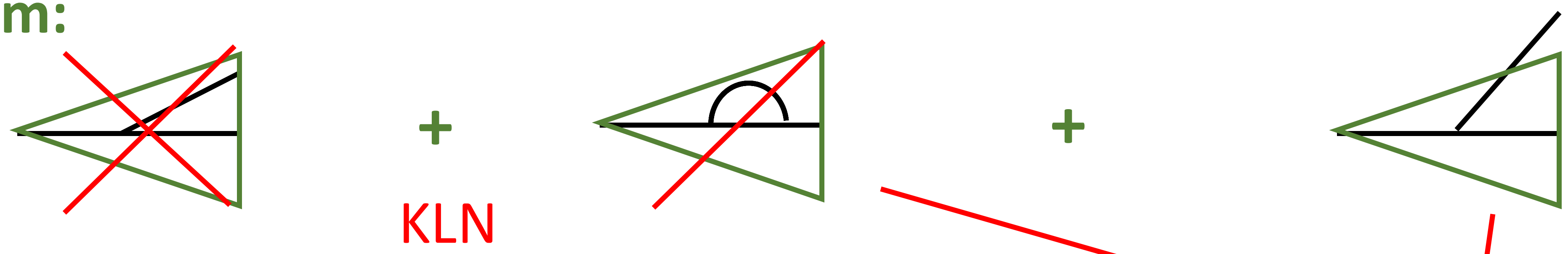

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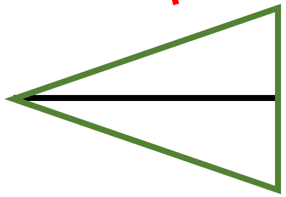

$$P_{gg}(z) = 2C_A \left(\frac{z}{1-z} + \frac{1-z}{z} + z(1-z) \right) + \delta(1-z) \frac{(11C_A - 4n_f T_R)}{6}$$

$$P_{qg}(z) = T_R \left(z^2 + (1-z)^2 \right) \qquad P_{gq}(z) = C_F \left(\frac{1 + (1-z)^2}{z} \right)$$

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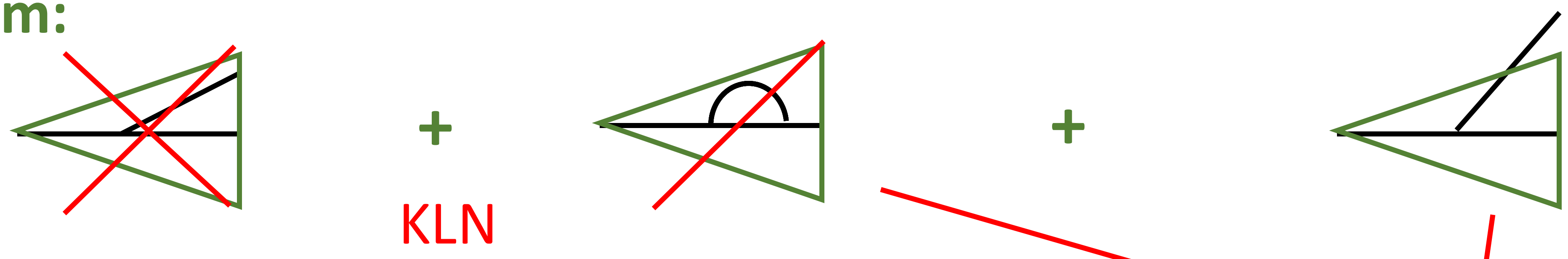

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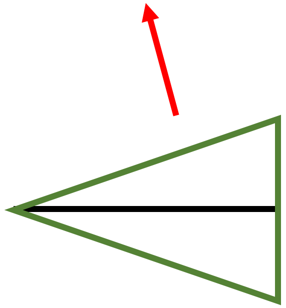

$$f(z) = \max(z, 1 - z)$$

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Vacuum:

To get Casimir scaling, one just computes quark to gluon ratio

Keeping track of logarithms of R (i.e. for small R and rigid cone jet algorithm)

$$\frac{\langle \delta p_T \rangle^{LO}_{quark}}{\langle \delta p_T \rangle^{LO}_{gluon}} = \frac{C_F\left(\log 4 - \frac{3}{8}\right)}{C_A\left(\log 4 - \frac{43}{96}\right) + n_f T_R \frac{7}{48}} \overset{QCD}{=} \frac{1.01129 C_F}{0.938378 C_A + 0.21875} = \frac{1.34839}{3.03388} \approx \frac{C_F}{C_A}$$

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Medium:

Since the divergences are screened the calculation is already more difficult. In addition, kernels can be more complicated

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We just aim for a very rough qualitative numerical estimate. We consider

$$\langle \delta p_T \rangle^{LO} = \int_0^1 dz P(z) f(z) \int \frac{d\theta}{\theta} \int_{\mathbf{q}} \frac{q^2}{q^2 + \tilde{\mu}^2 \tilde{k}^2 + 2q\tilde{\mu}\tilde{k}\cos\alpha}$$

up to overall factors

Wiedemann, hep-ph/0005129

Jet Physics (for today)

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→ Compute the transverse momentum imbalance at LO

Medium:

$$\langle \delta p_T \rangle = \int_0^1 dz P(z) f(z) \left(\int_q dq q \log \frac{1}{R} + \int_q \int_R^{\mathcal{O}(1)} \frac{dq}{q} \tilde{\mu} \tilde{k}^2 \right)$$ up to overall factors

$$k_T = \tilde{k}\tilde{\mu} = (z(1-z)\theta)(E_{Jet})$$

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Ignoring subleading terms

$$\langle \delta p_T \rangle = \int_0^1 dz P(z) f(z) \int_q dq q \quad \log \frac{1}{R}$$

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Assuming one can regularize the integral in q and setting the upper scale to be of order of k_T

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$$\frac{\langle \delta p_T \rangle_{quark}}{\langle \delta p_T \rangle_{gluon}} = \frac{\int_0^1 dz P_q(z) f(z) \quad \alpha(z(1-z))^2}{\int_0^1 dz P_g(z) f(z) \quad \alpha(z(1-z))^2}$$

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In conclusion

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  jets have a finite extension
- An analytical treatment can be complicated due to medium screening (and technical complications not present in the vacuum)
- However, a Monte Carlo (MC) study is valuable to understand Casimir scaling
  This is the focus of today

Our MC study is based (mainly) around JEWEL

Zapp, Krauss, Wiedemann, 1212.1599

Analysis details

- JEWEL to produce Z+qjets or Z+gjets with default parameters (1 million events for each)
- Vacuum and in-medium events (0-10% centrality), no recoil, no hadronization, no ISR, E_{CMS}=5.02 TeV
- Z is used as a proxy for the initial parton

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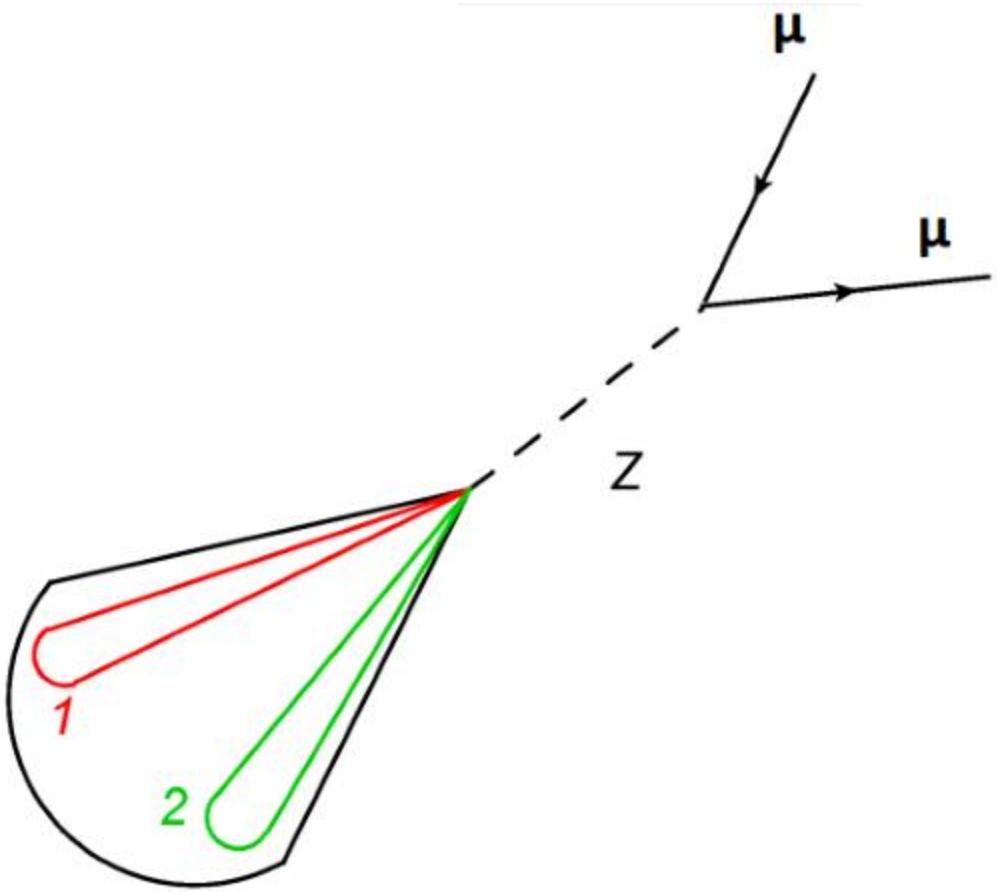
Analysis details

Z cuts: p_T>50 GeV , |η|<3 , di-muon channel,
70 GeV<Z-mass< 100 GeV



Jet cuts: p_T>20 GeV , |η|<3 , anti-kt R=0.2-0.5

Order Jets by p_T and require b.t.b. with Z

Require Jet and Z $|\eta|<3-R_{max}$

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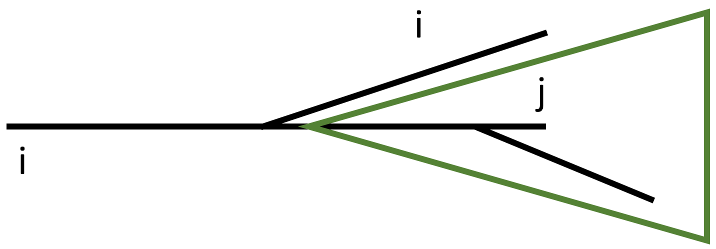
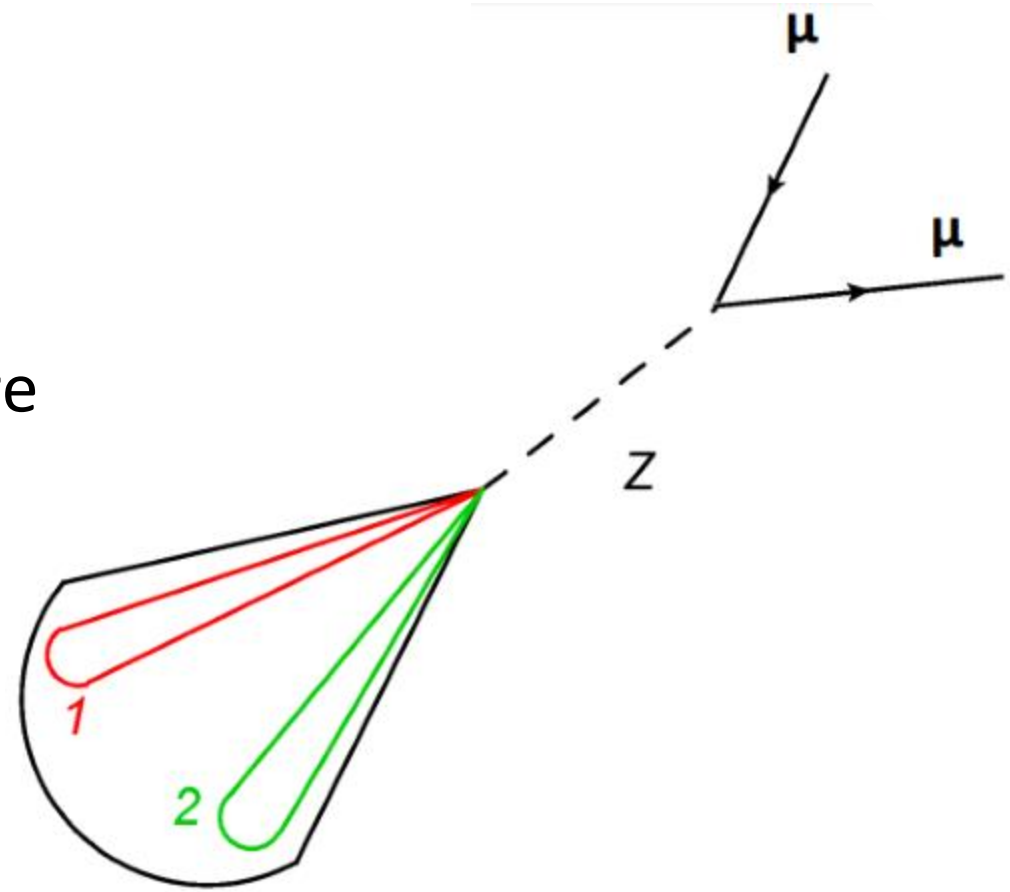
A possible issue:

Having a Z+i jet does not mean that we are picking the right parton





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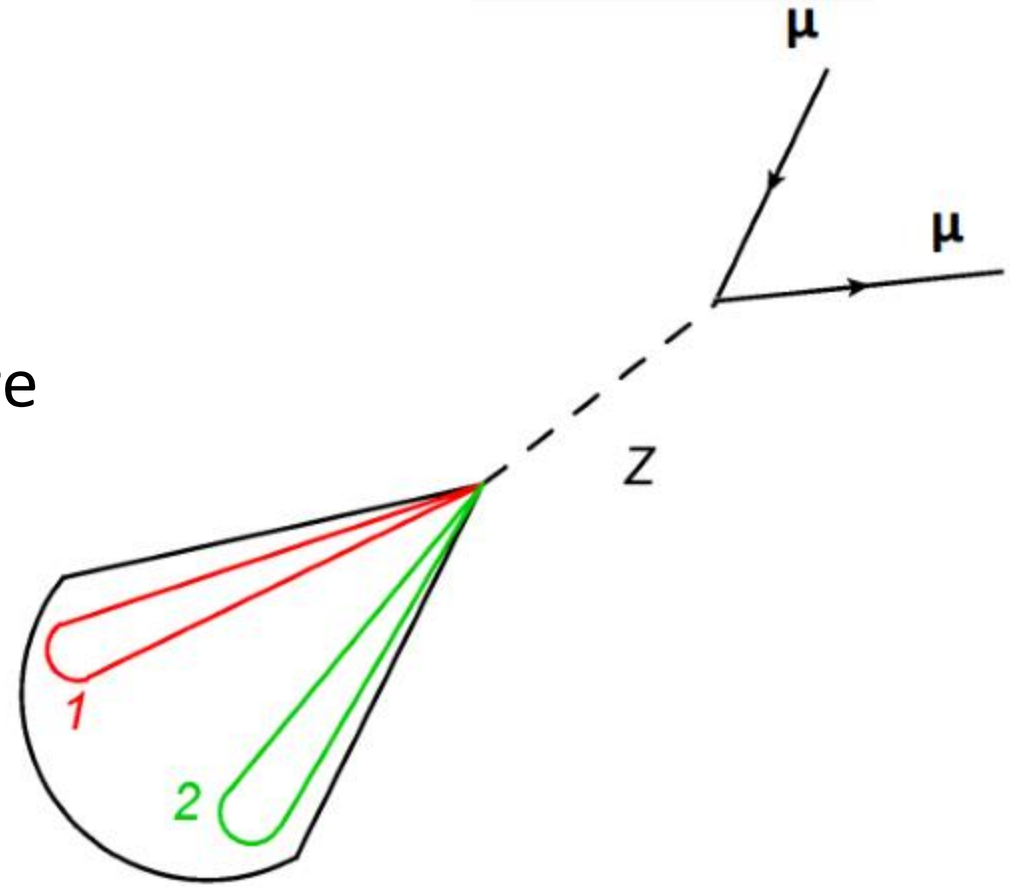

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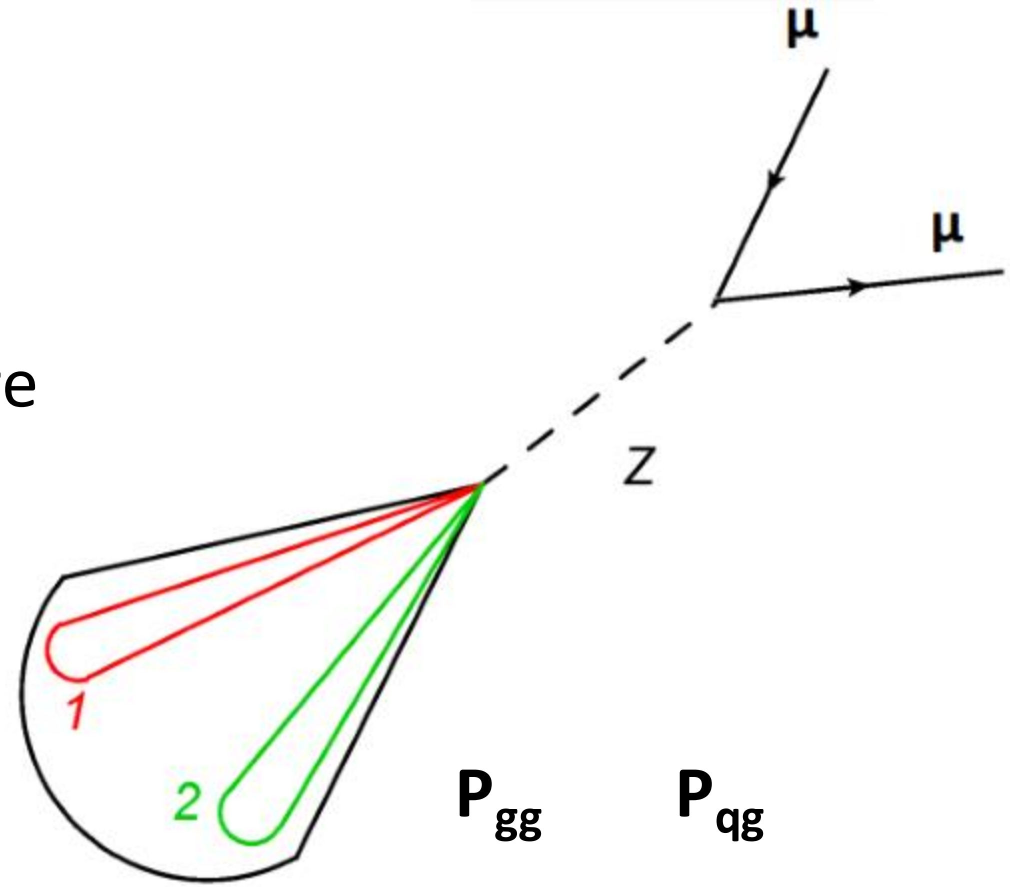

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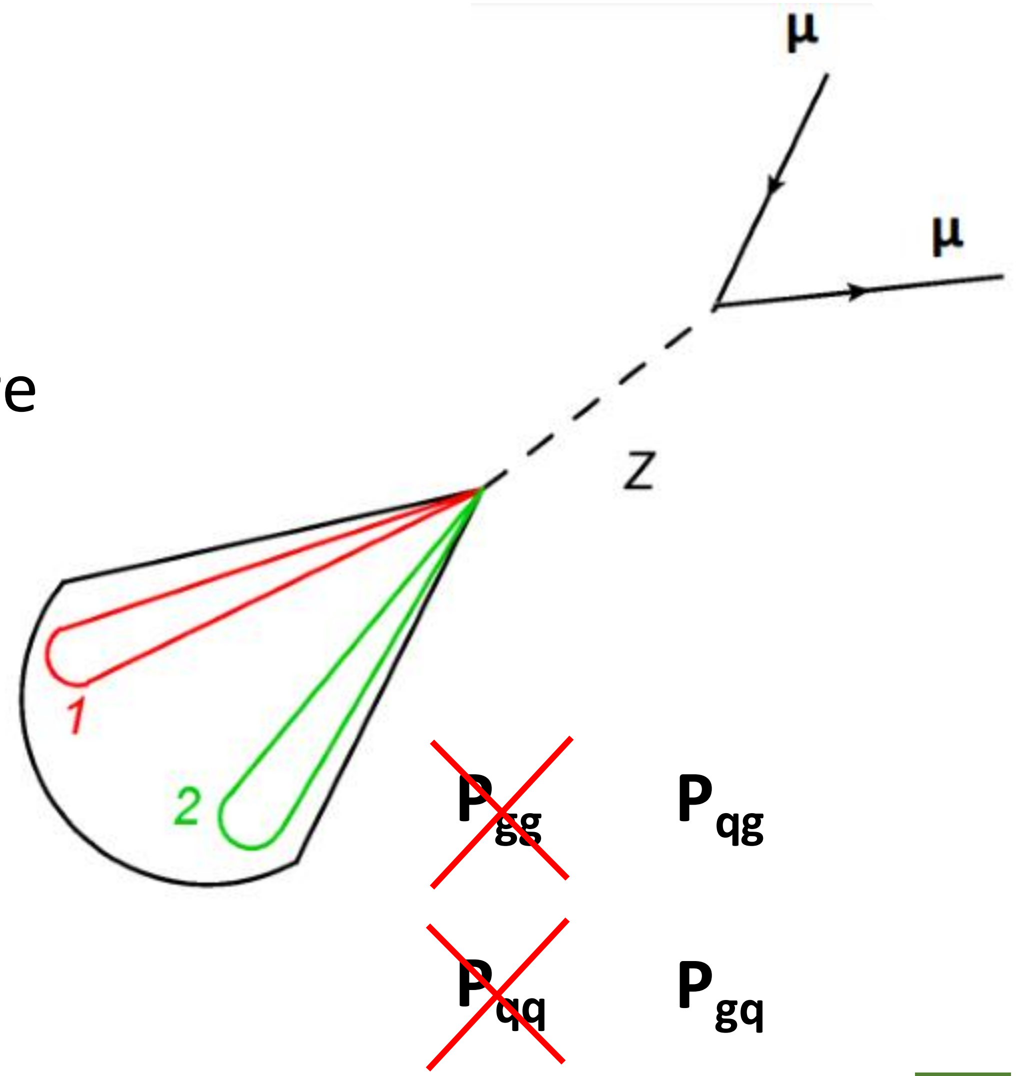

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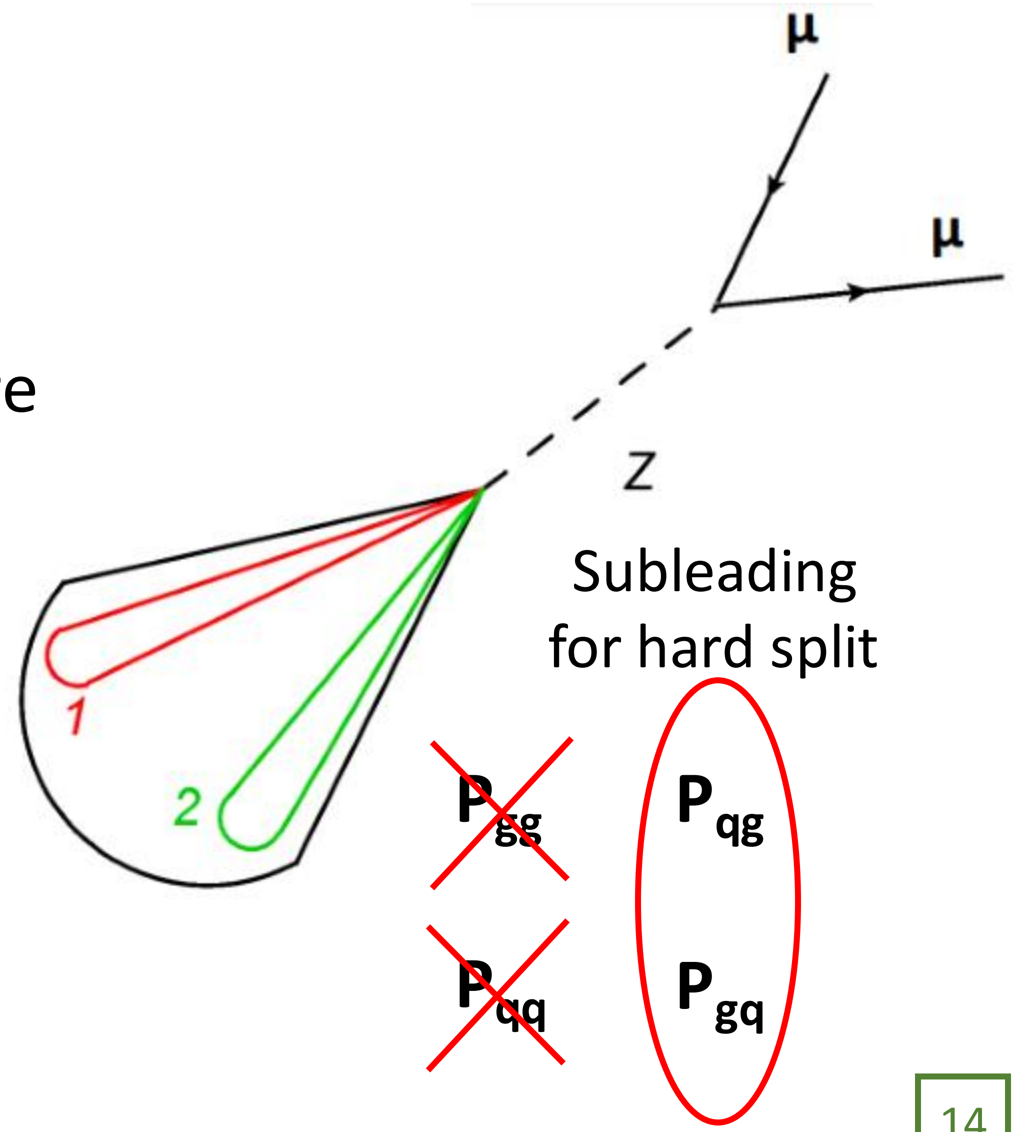

Our MC study is based (mainly) on JEWEL

Analysis details

A possible issue:

Having a Z+i jet does not mean that we are picking the right parton

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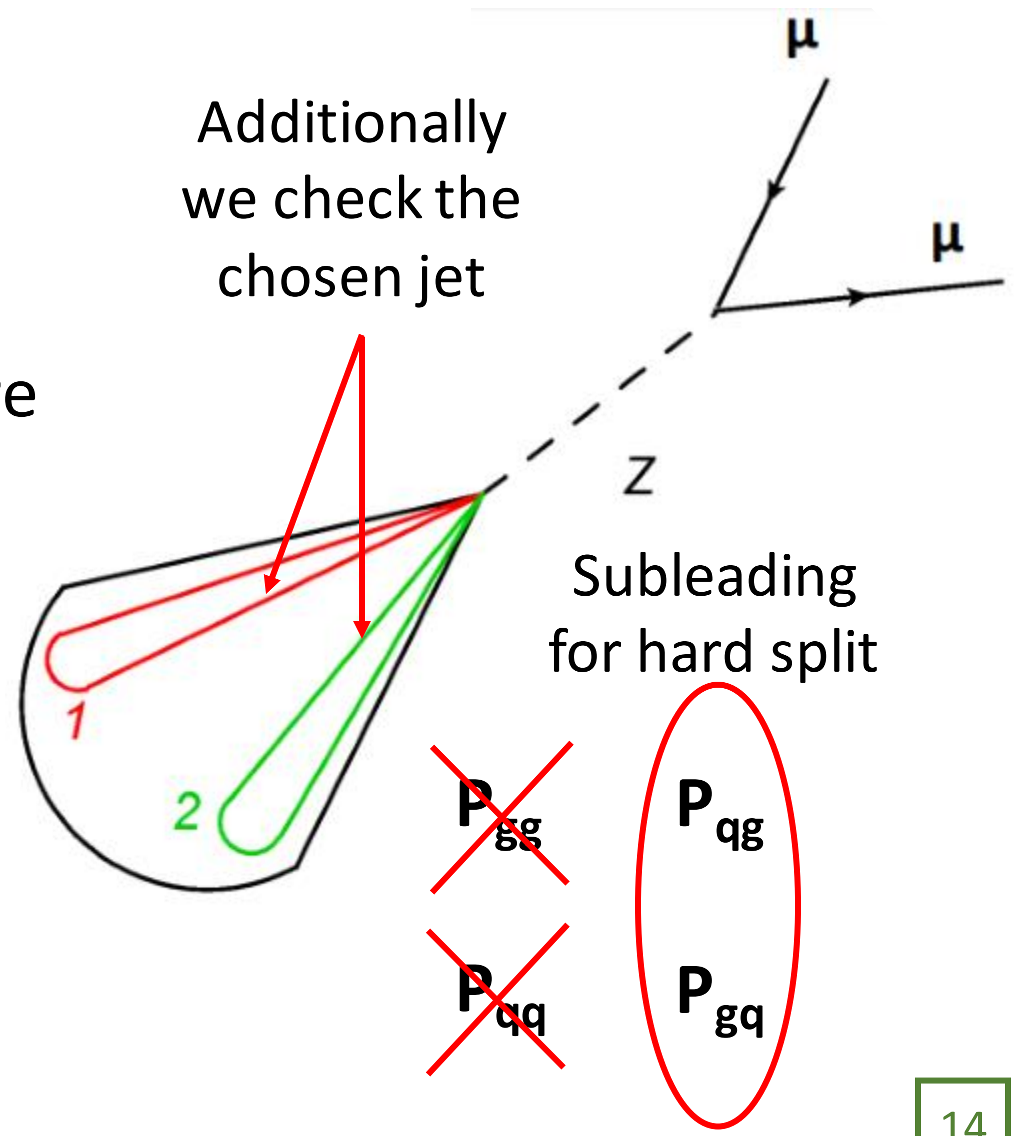


Our MC study is based (mainly) on JEWEL

Analysis details

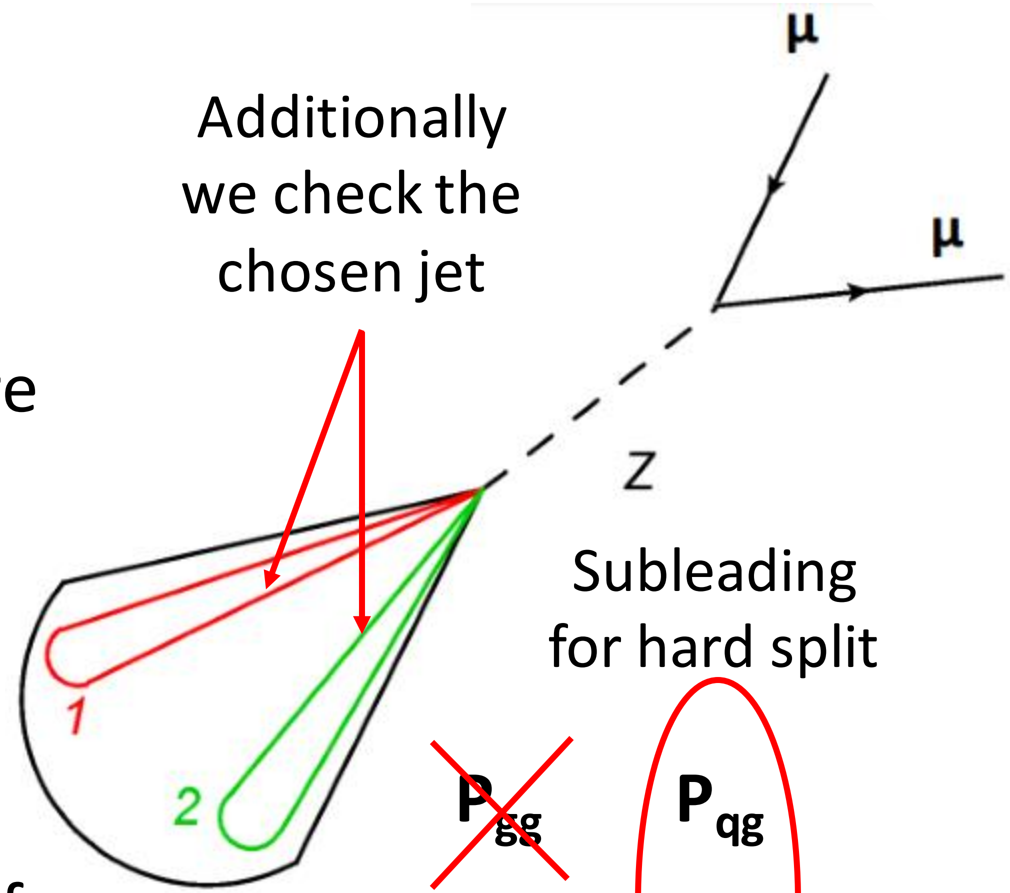
A possible issue:

Having a Z+i jet does not mean that we are picking the right parton

This should be a subleading contribution:

- JEWEL uses LO matrix elements
- This issue should be more relevant for small R, but we do not see a qualitative difference in the results

Additionally we check the chosen jet



Subleading for hard split

~~P_{gg}~~ P_{qg}

~~P_{qq}~~ P_{gq}

To study Casimir breaking the vacuum radiation has to be discarded

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We make use of the following variable $\Delta p_T = p_T^Z - p_T^{leading\ jet}$

$$\frac{\Delta p_T^{medium} - \Delta p_T^{vacuum}}{p_T^Z} = \frac{(p_T^{vacuum} - p_T^{medium})^{jet}}{p_T^Z} = \frac{medium\ imbalance}{initial\ p_T}$$

At the parton level this should scale with the Casimir associated to the parton

To study Casimir breaking the vacuum radiation has to be discarded

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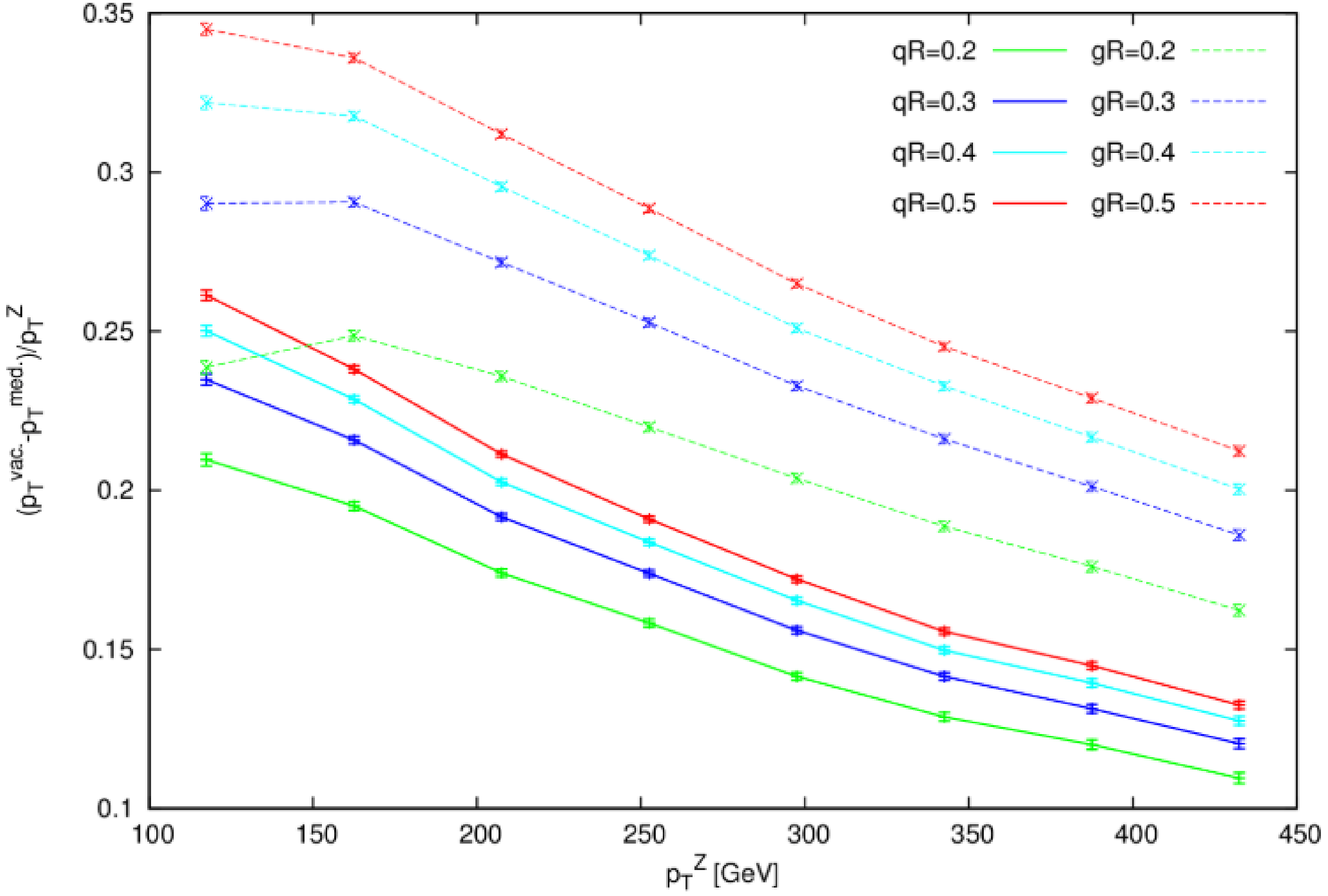

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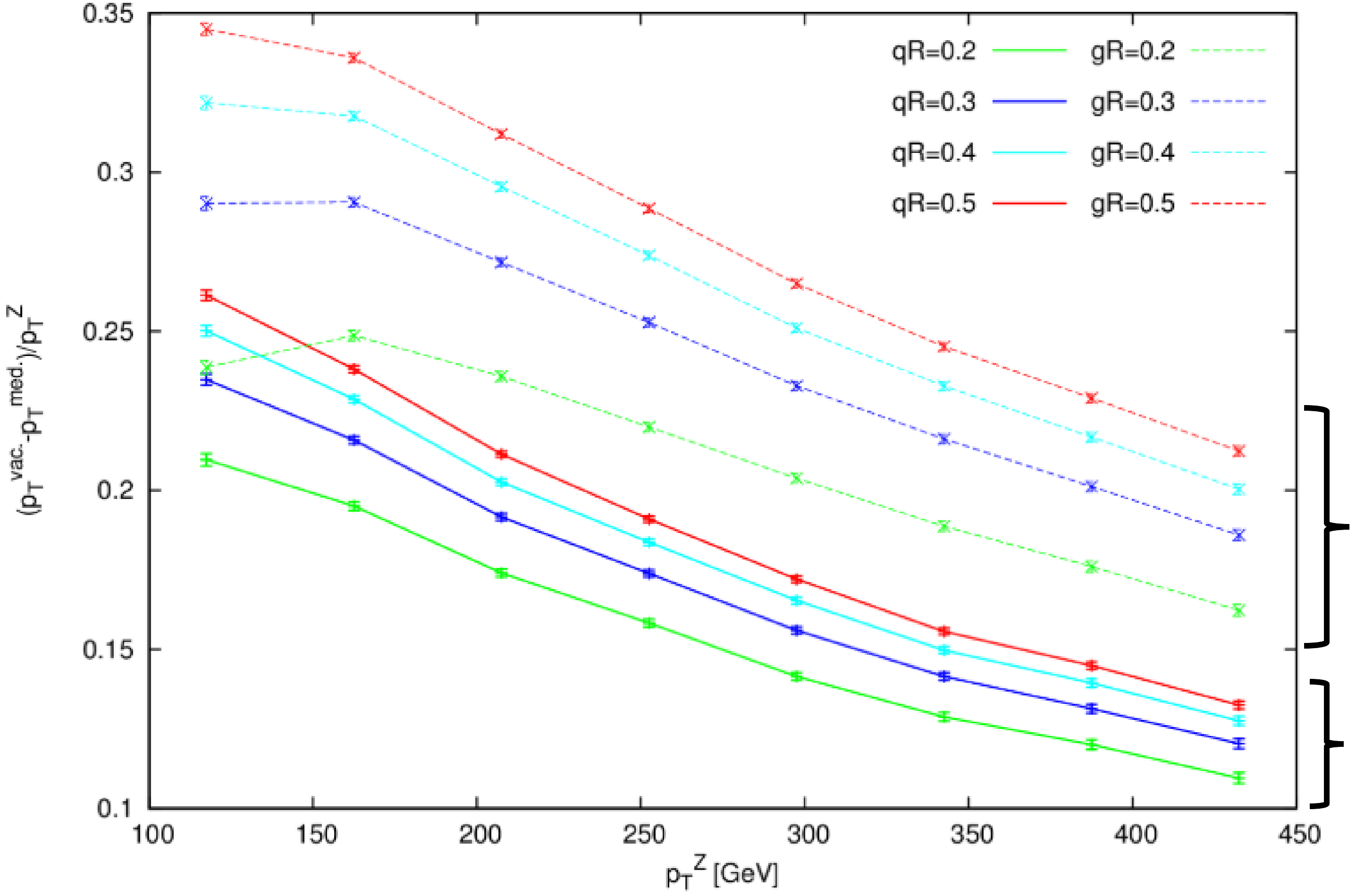

Gluon jets loose more energy (C_A>C_F)

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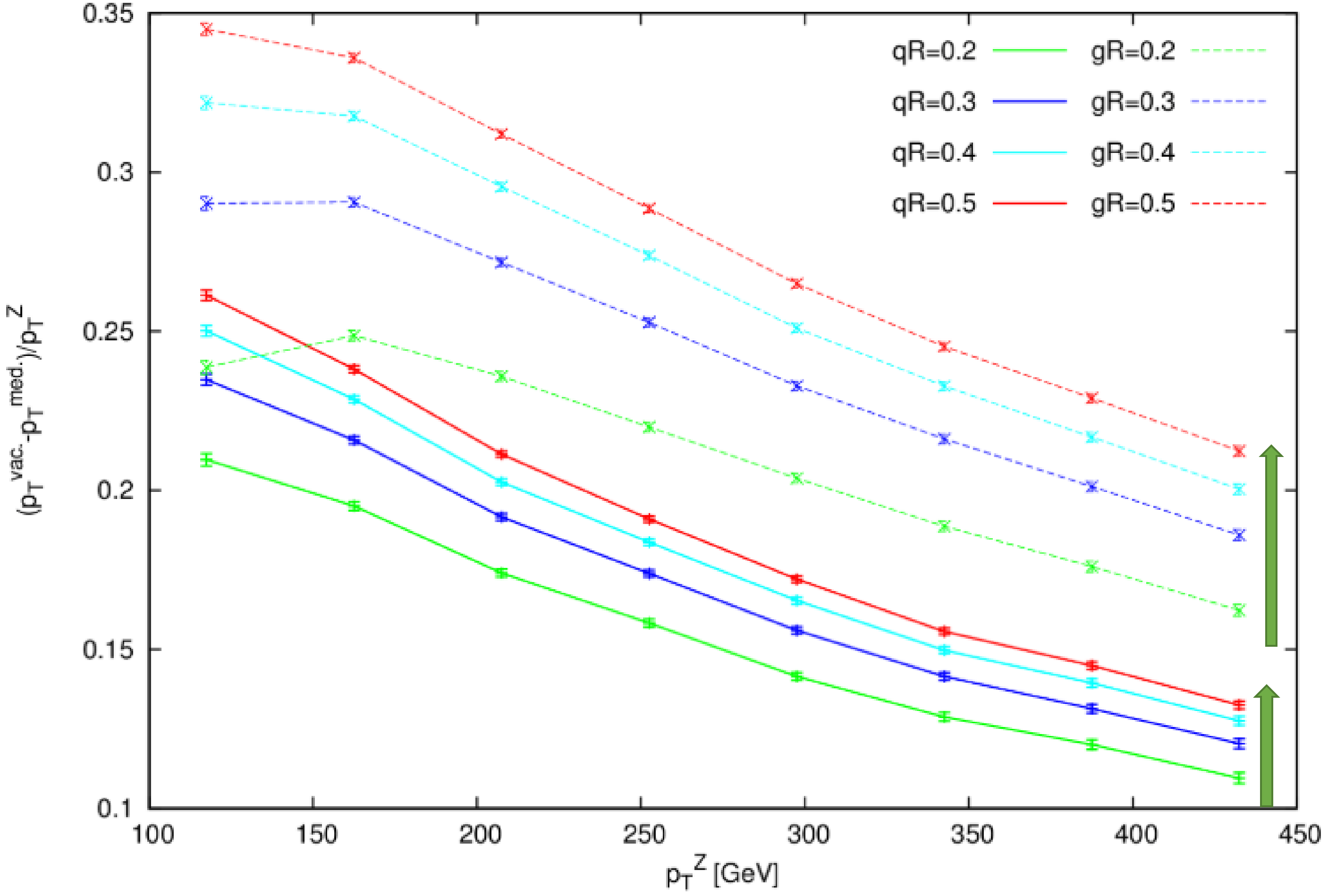

Wider jets loose more energy

Milhano, Zapp, 1512.08107

Rajagopal, Sadofyev, van der Schee, 1602.04187

Escobedo, Iancu, 1601.03629

To study Casimir breaking the vacuum radiation has to be discarded

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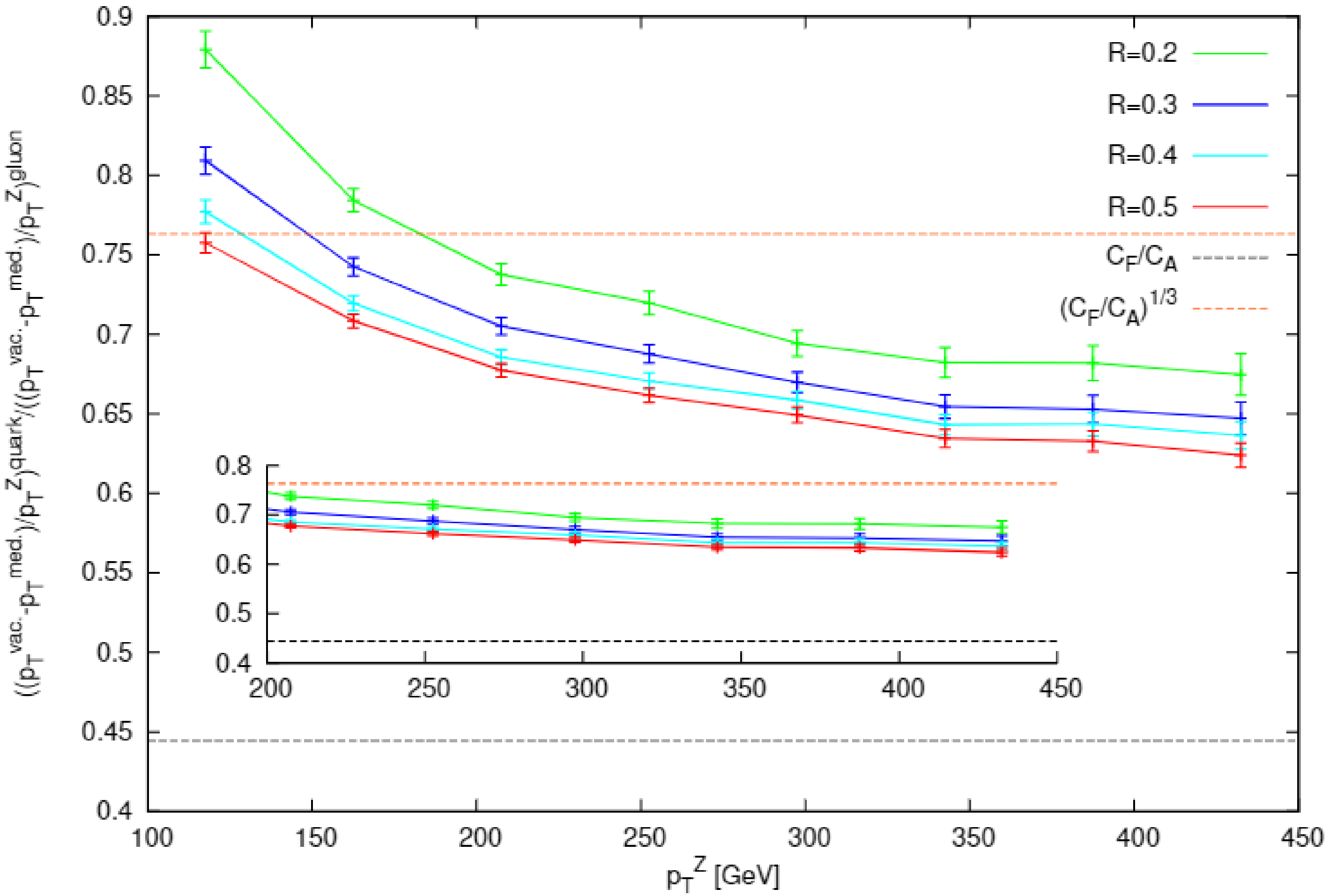

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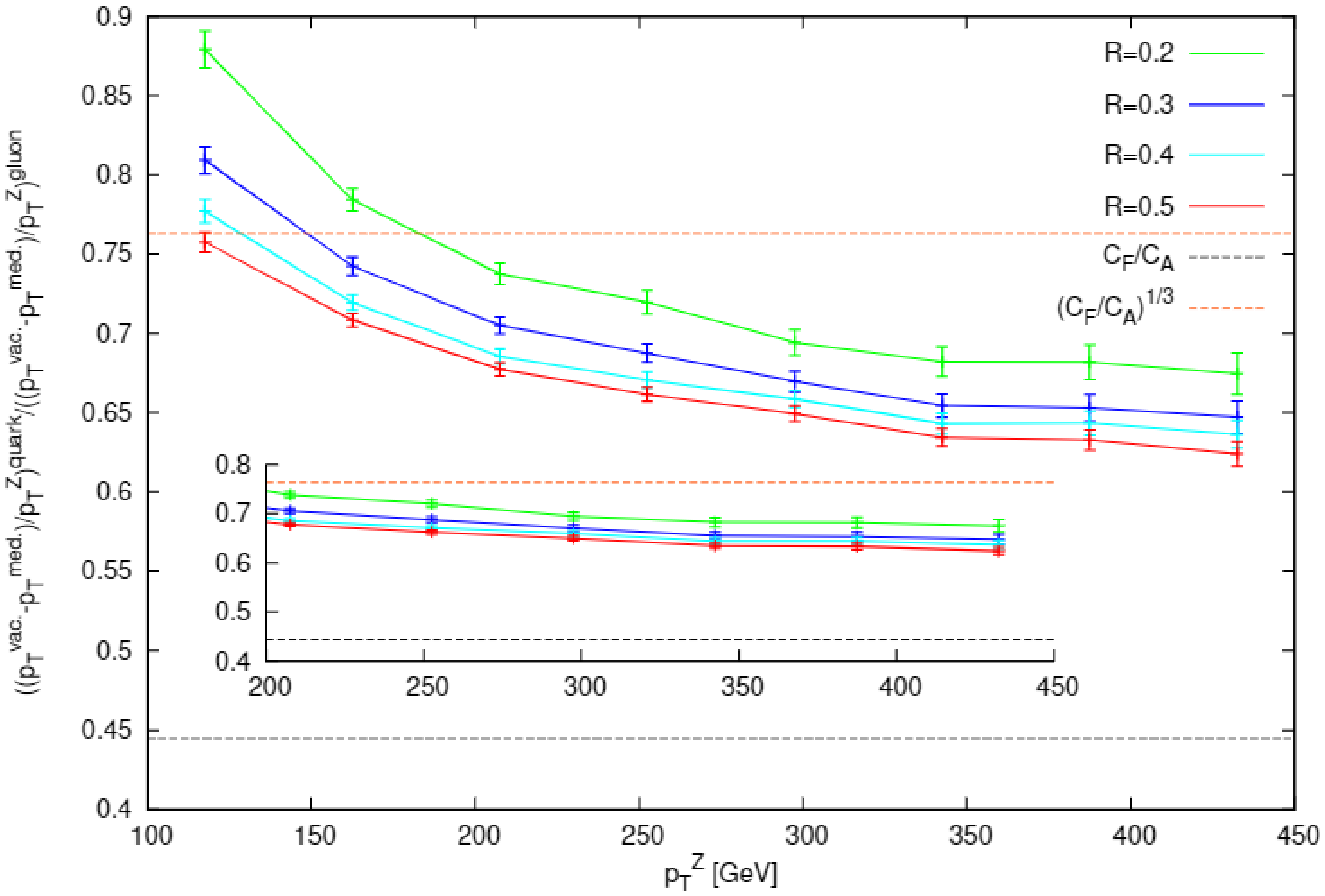

Casimir scaling is clearly broken

However the breaking is given by a rescaling

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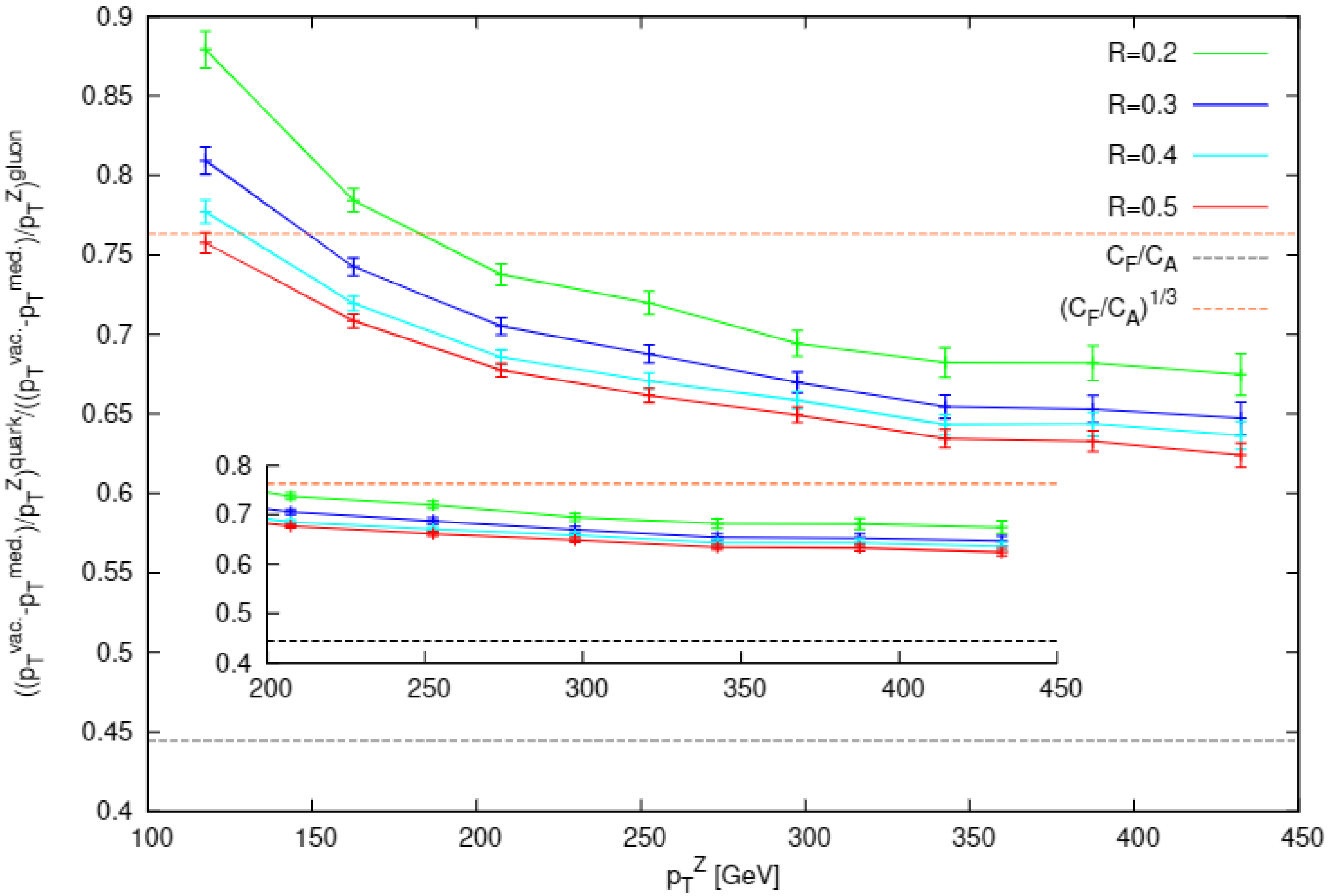

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New Casimir scaling constant closer to 1 – gluon and quark jets are more alike than partons

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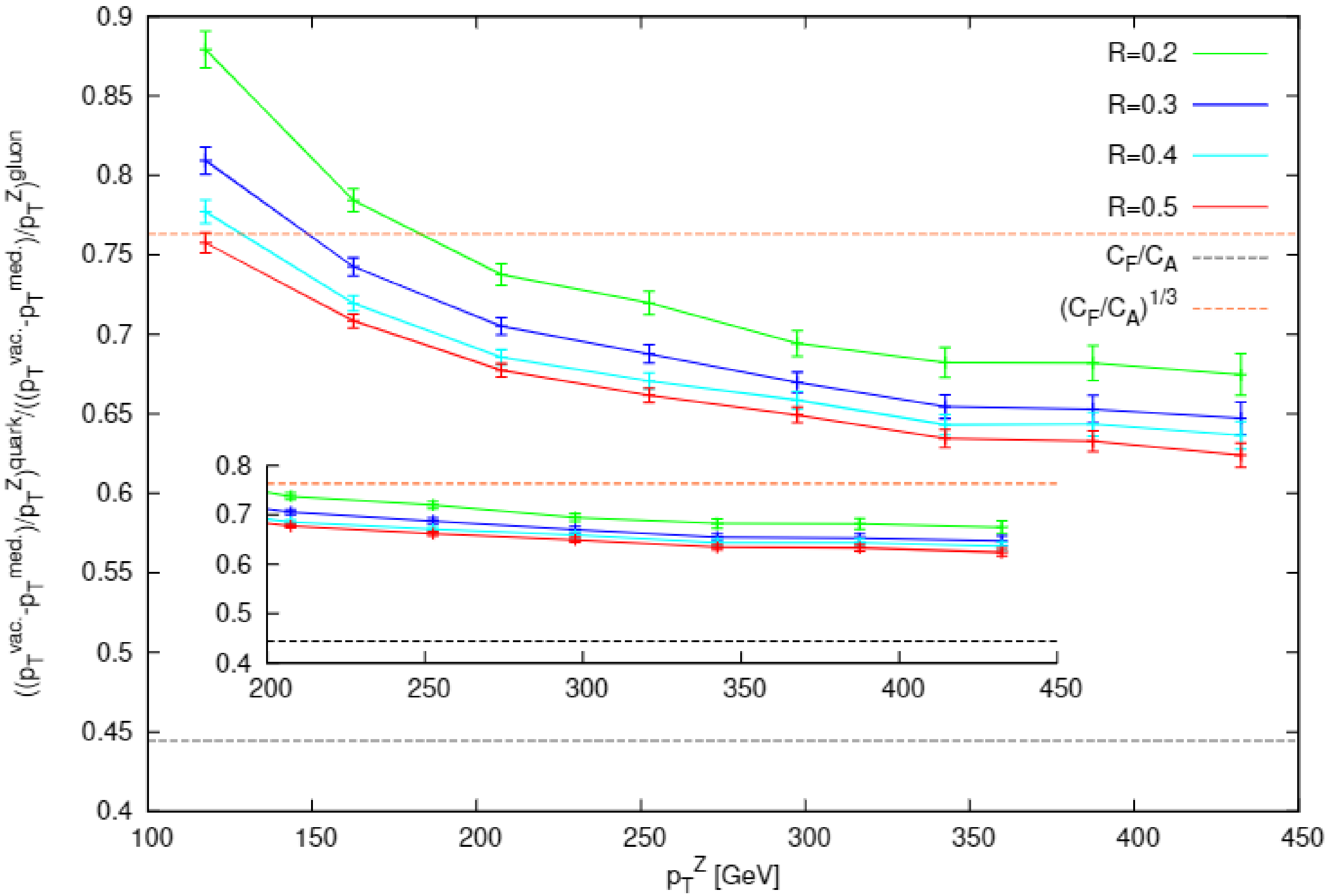

Spousta, 1606.00903

Spousta, Cole, 1504.05169

$$\Delta p_T = c_F \cdot s \cdot \left(\frac{p_{T,\mathrm{ini}}}{p_{T,0}} \right)^{\alpha}.$$

$s = x \cdot N_{\mathrm{part}} + y$	$x = (12.3 \pm 1.4) \cdot 10^{-3}$ GeV, $y = 1.5 \pm 0.2$ GeV
α	0.52 ± 0.02
c_F	1.78 ± 0.12

New Casimir scaling constant closer to 1 – gluon and quark jets are more alike than partons

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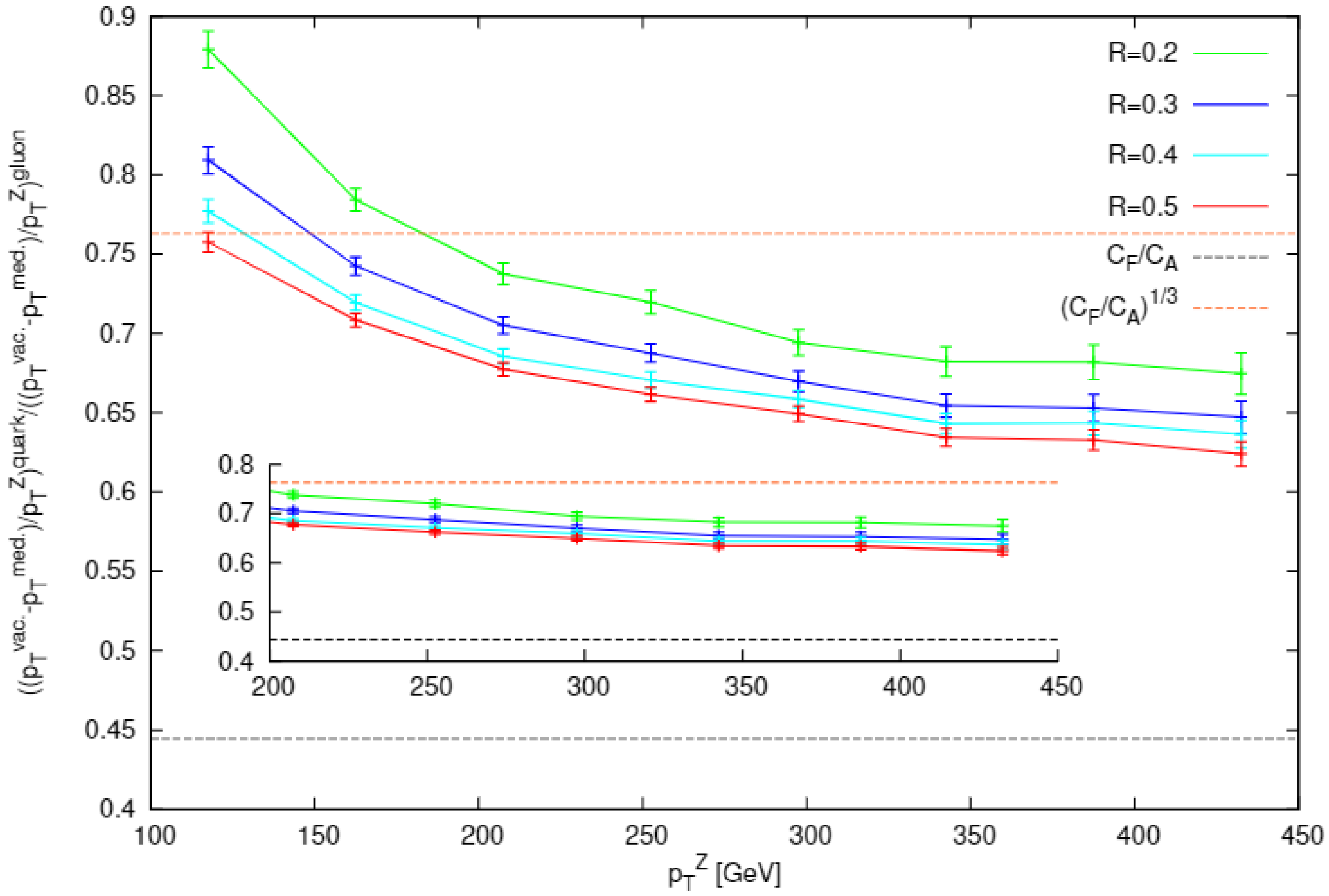

Spousta, 1606.00903

Spousta, Cole, 1504.05169
Mehtar-Tani, Schlichting, 1807.06181

c_F 1.78 ± 0.12

We obtained 1.46±0.05

New Casimir scaling constant closer to 1 – gluon and quark jets are more alike than partons

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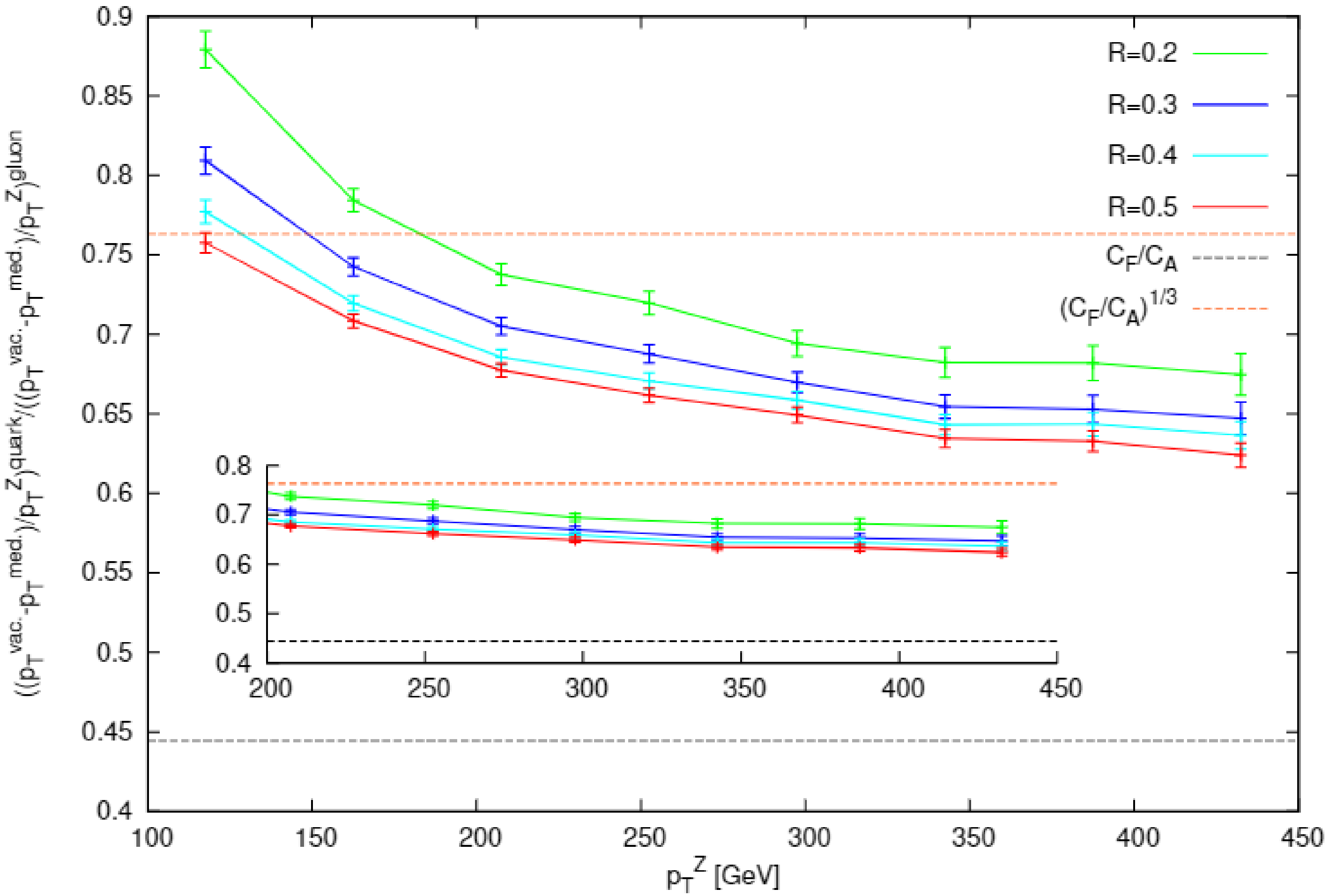

Spousta, 1606.00903

Spousta, Cole, 1504.05169
Mehtar-Tani, Schlichting, 1807.06181

C_F 1.78 ± 0.12

We obtained 1.46±0.05

However this value depends on the parametrization

New Casimir scaling constant closer to 1 – gluon and quark jets are more alike than partons

Now we include ISR in the samples to see the impact

We make use of the following variable

$$\frac{\Delta p_T^{medium} - \Delta p_T^{vacuum}}{p_T^Z} = \frac{(p_T^{vacuum} - p_T^{medium})^{jet}}{p_T^Z}$$

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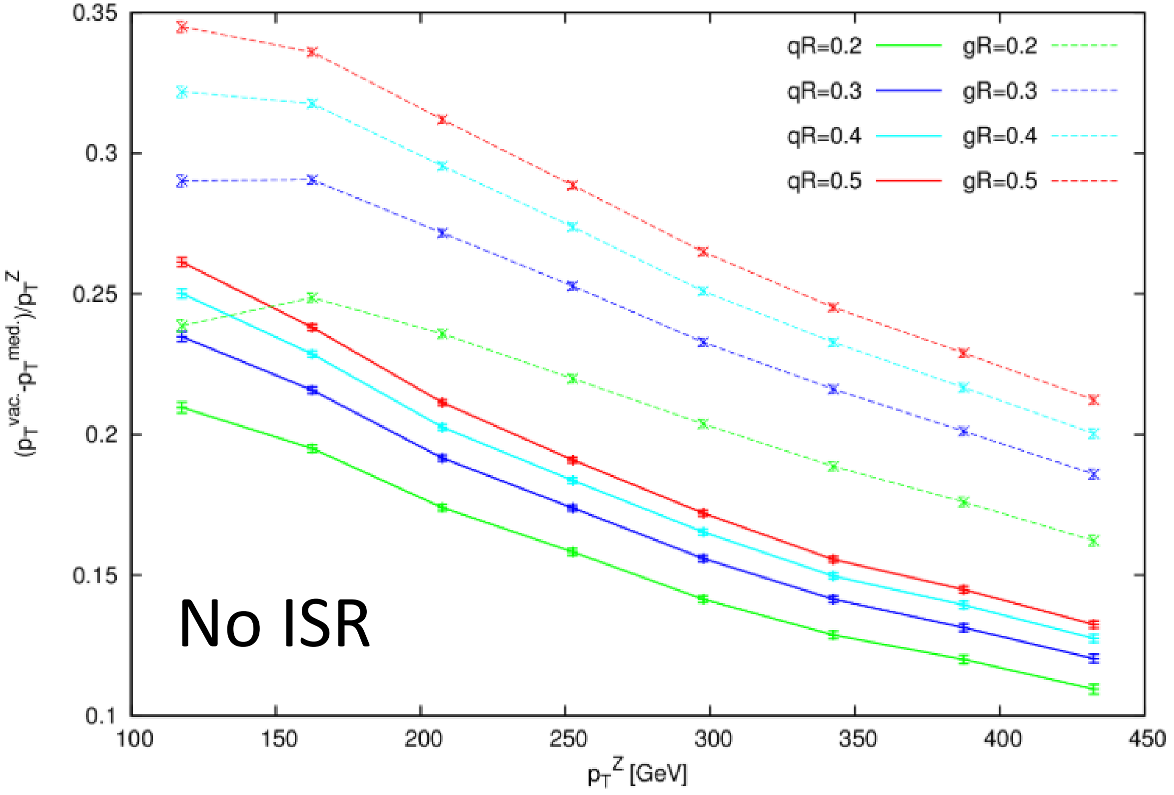

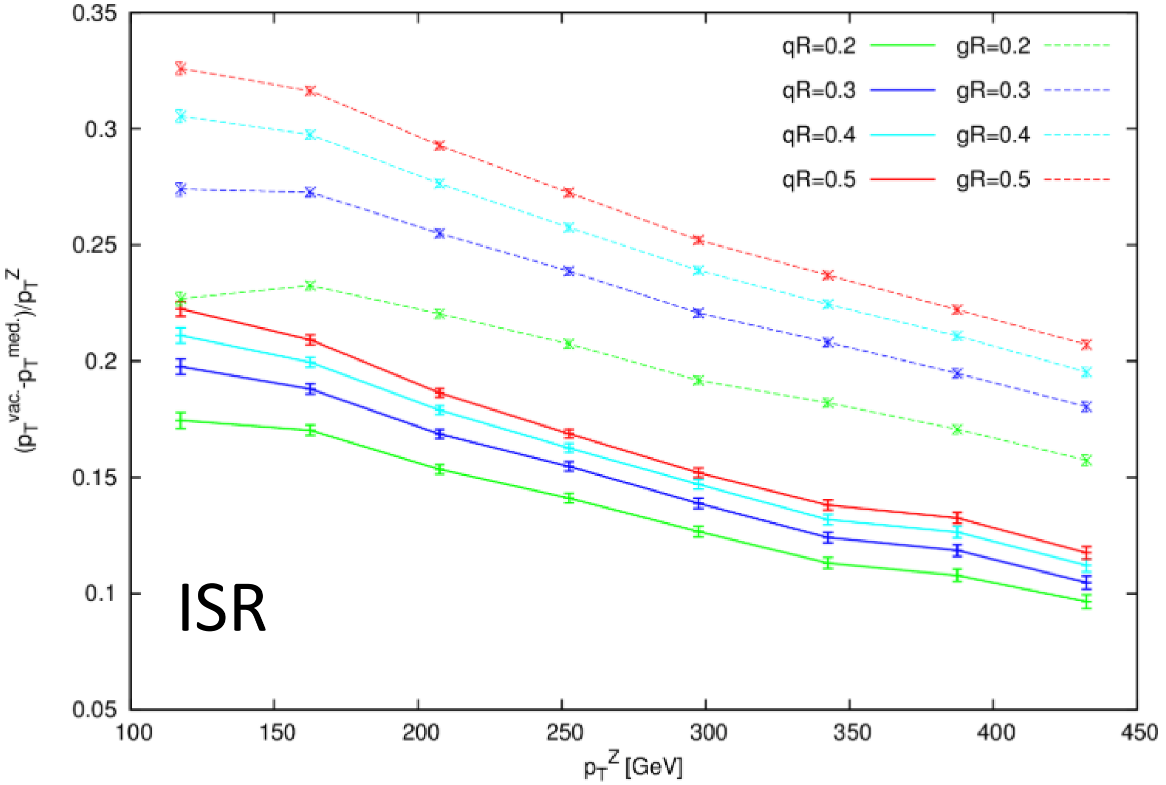

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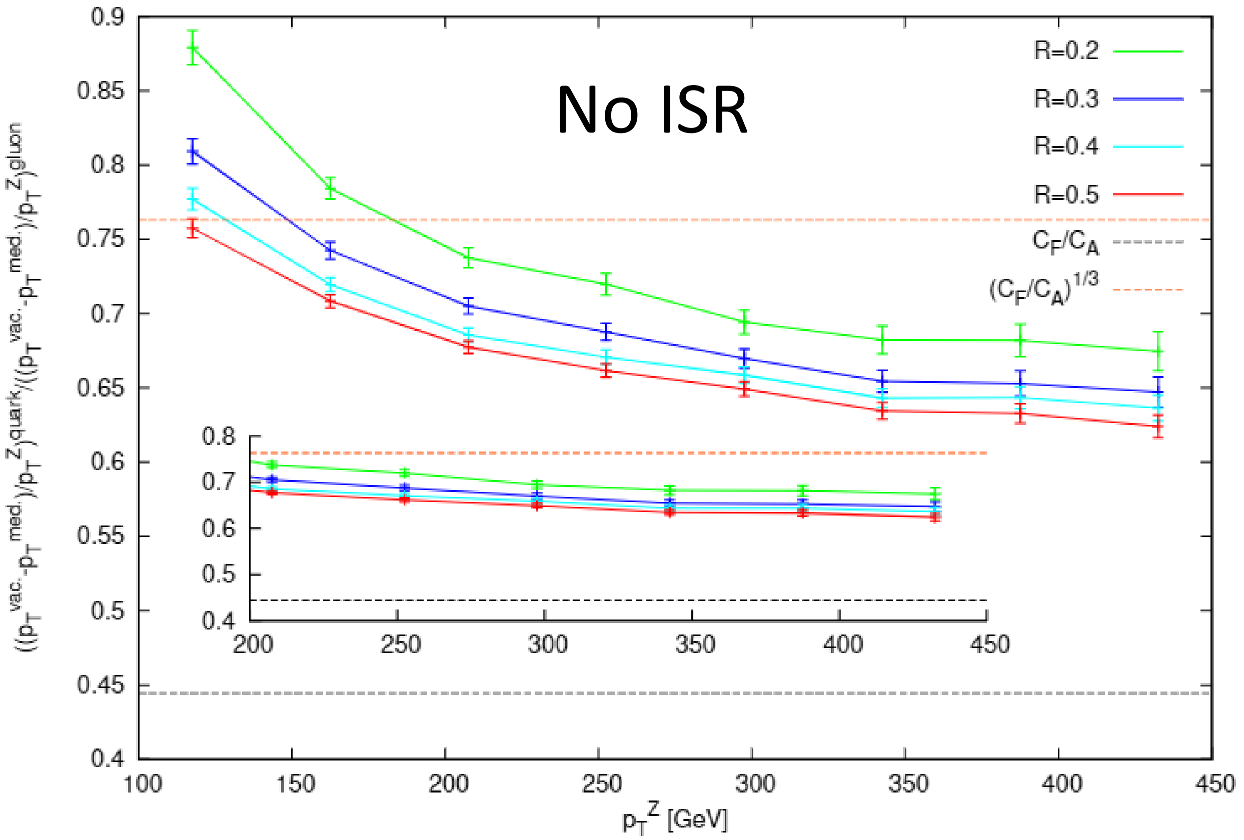

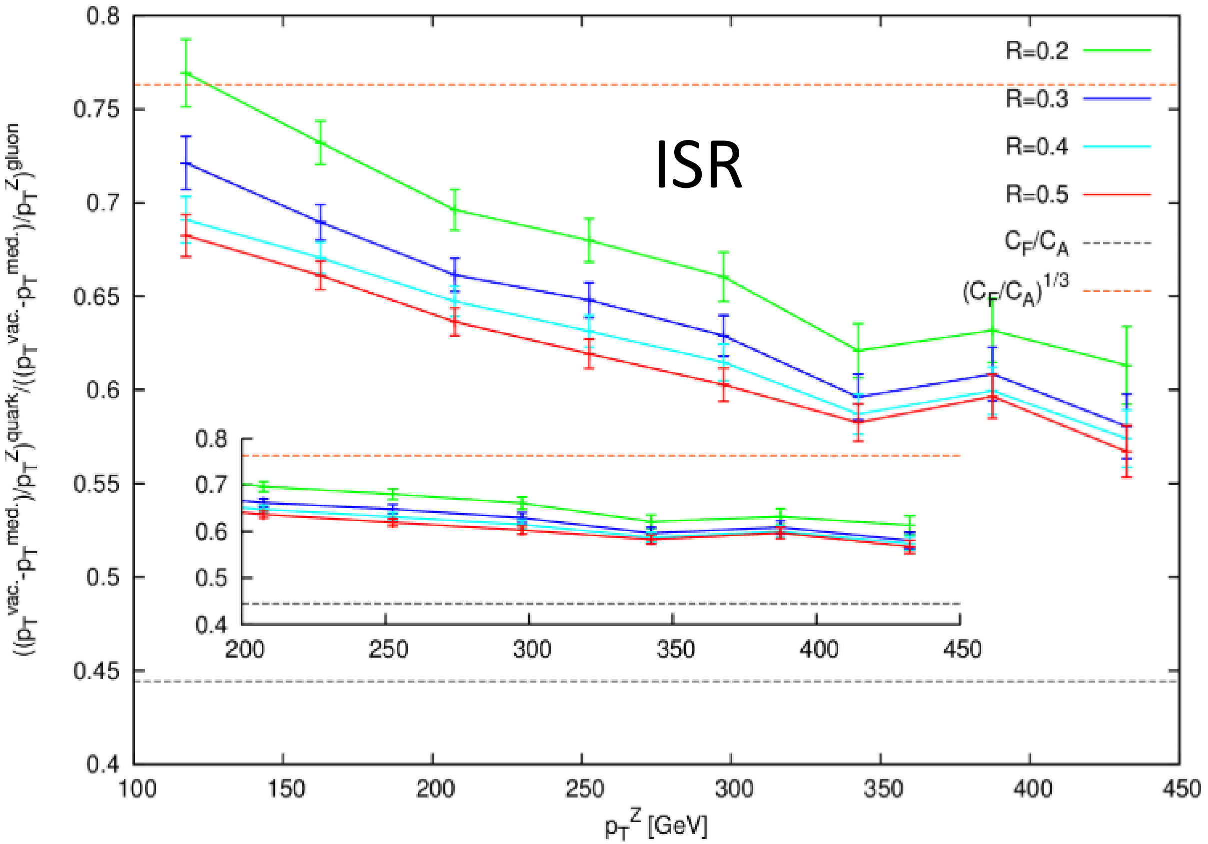

Now we include Hadronization (but no ISR) in the samples to see the impact

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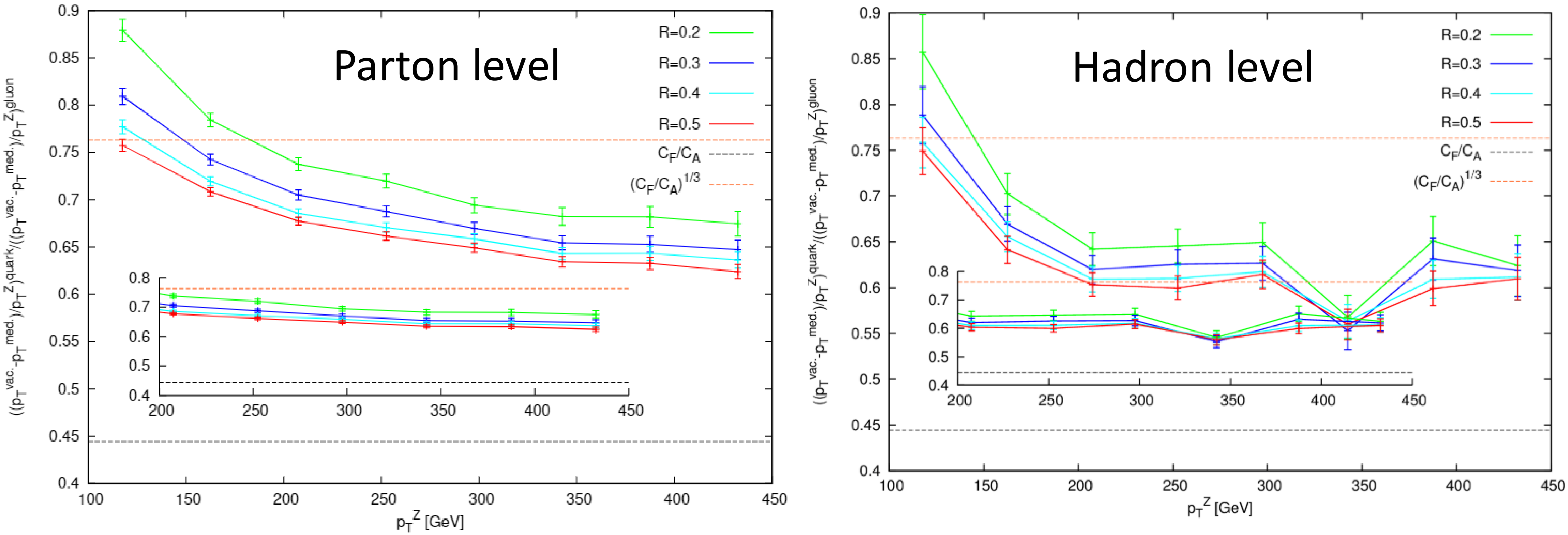

Finally, we explore varying the centralities of the events

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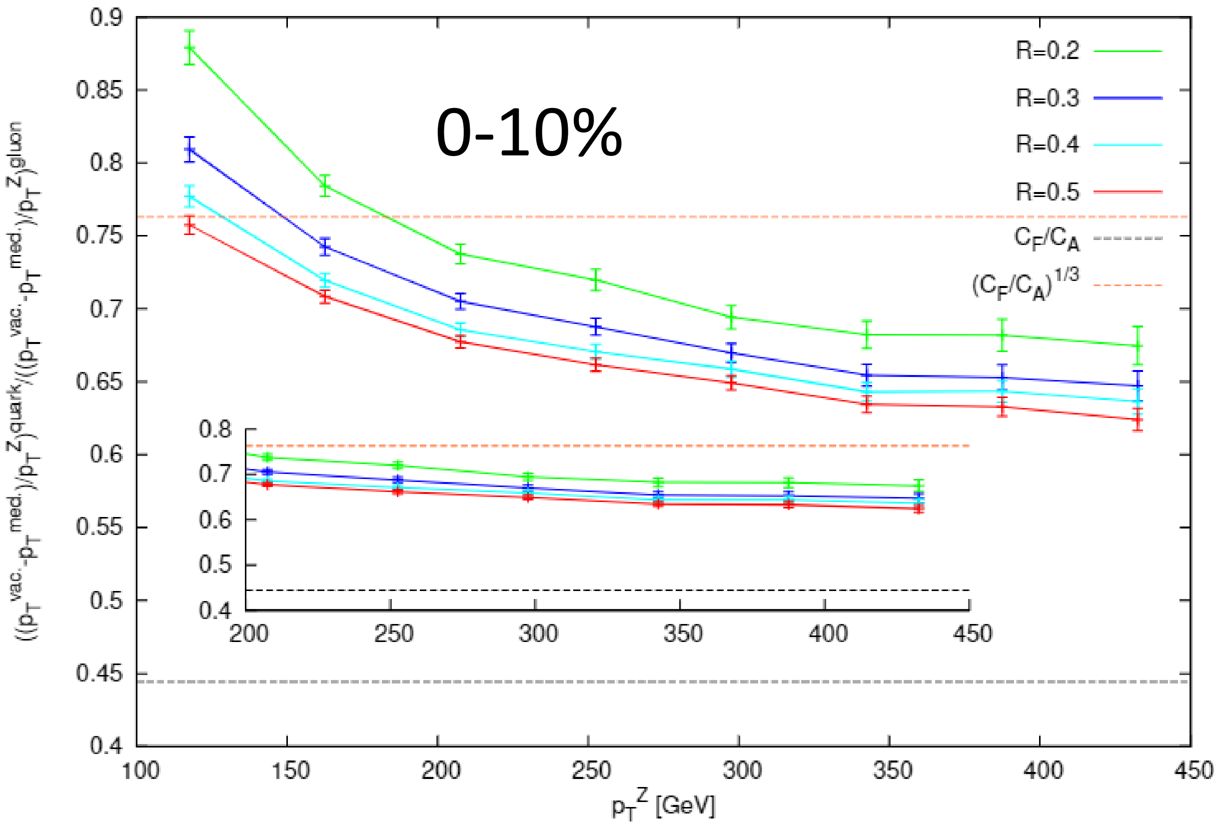

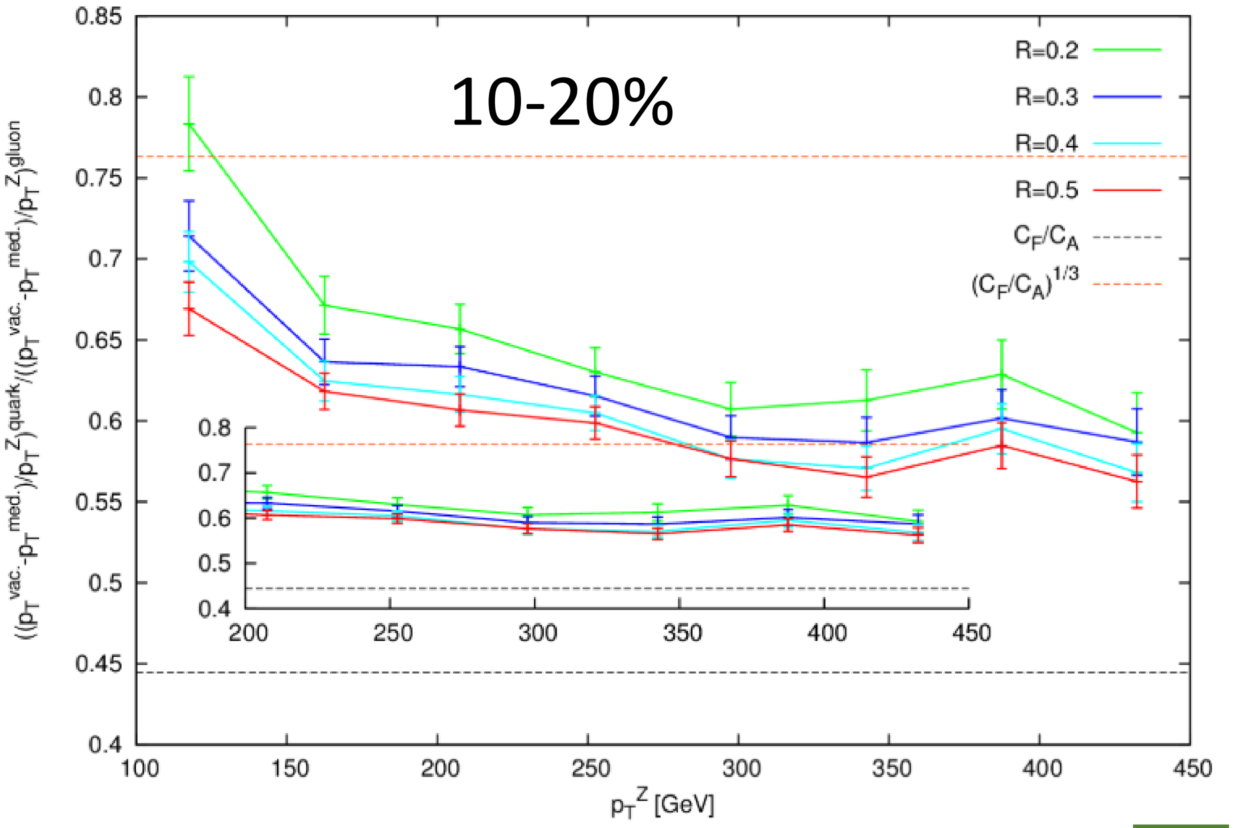

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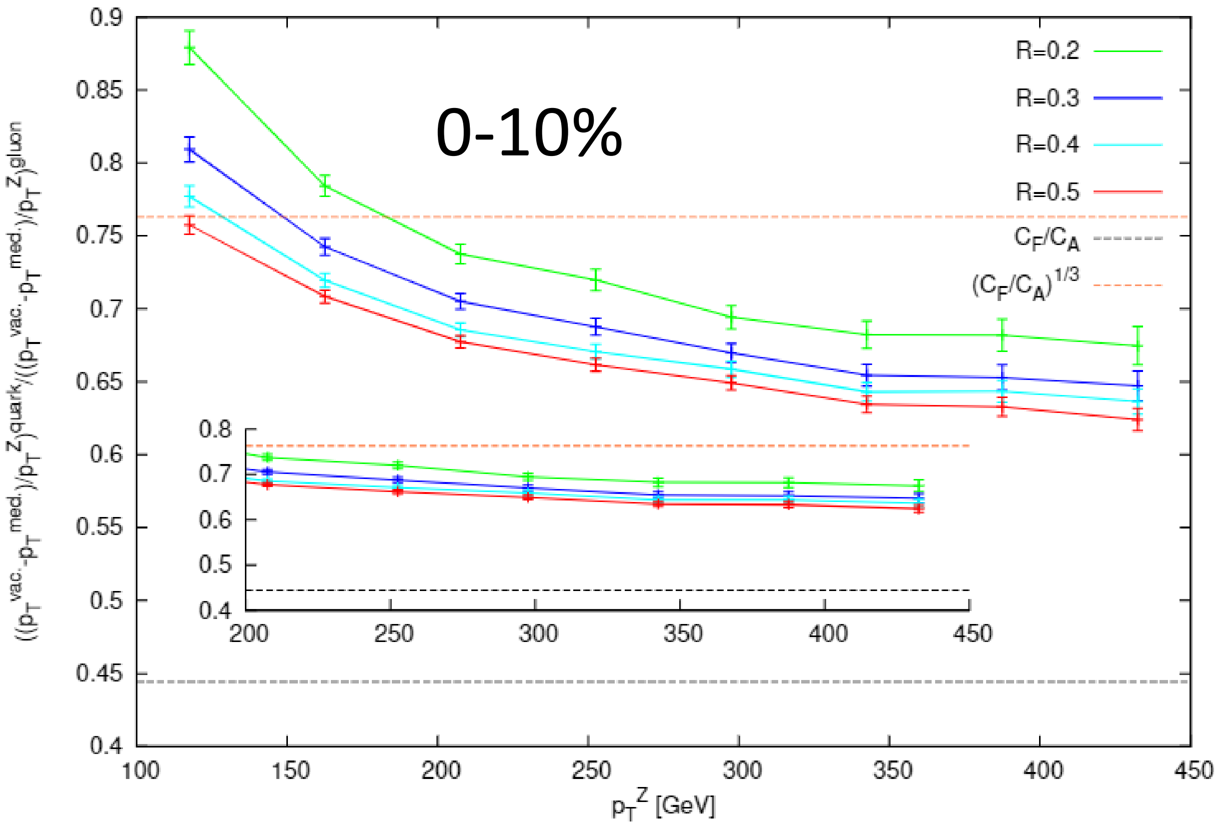

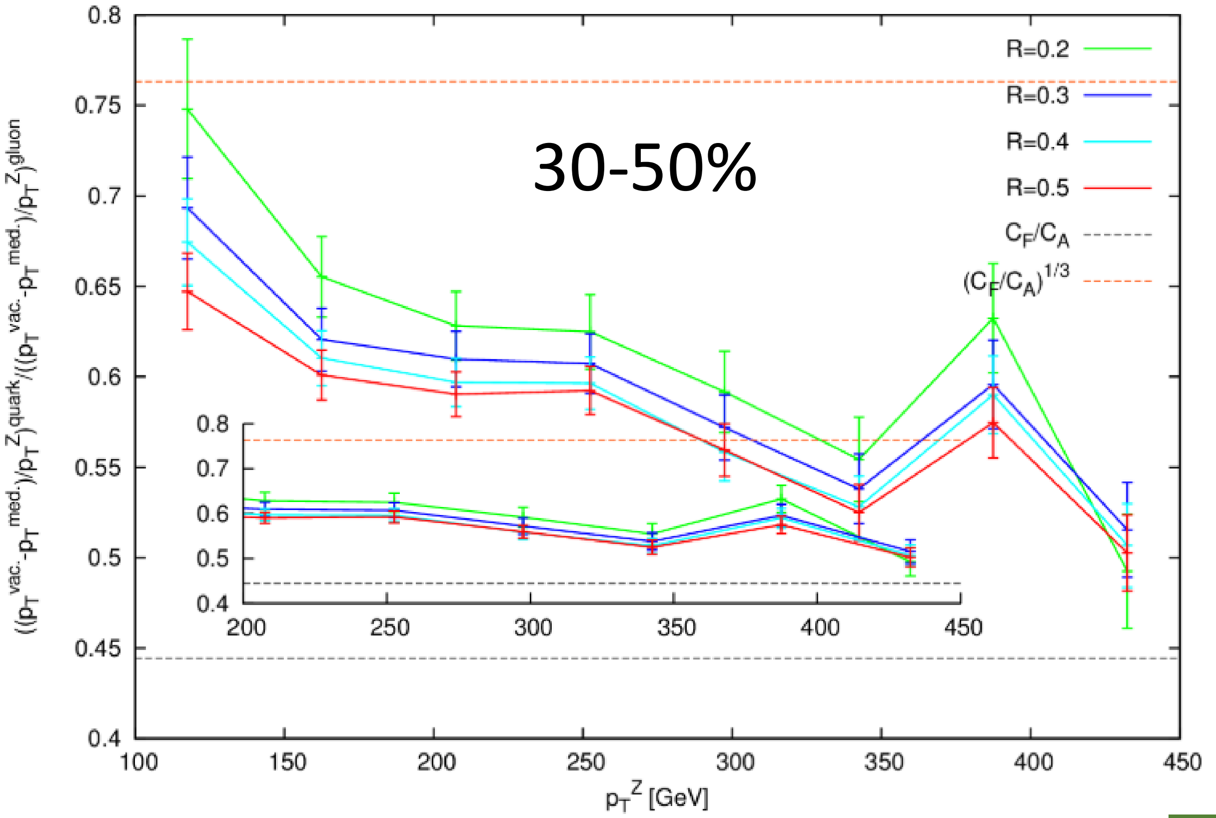

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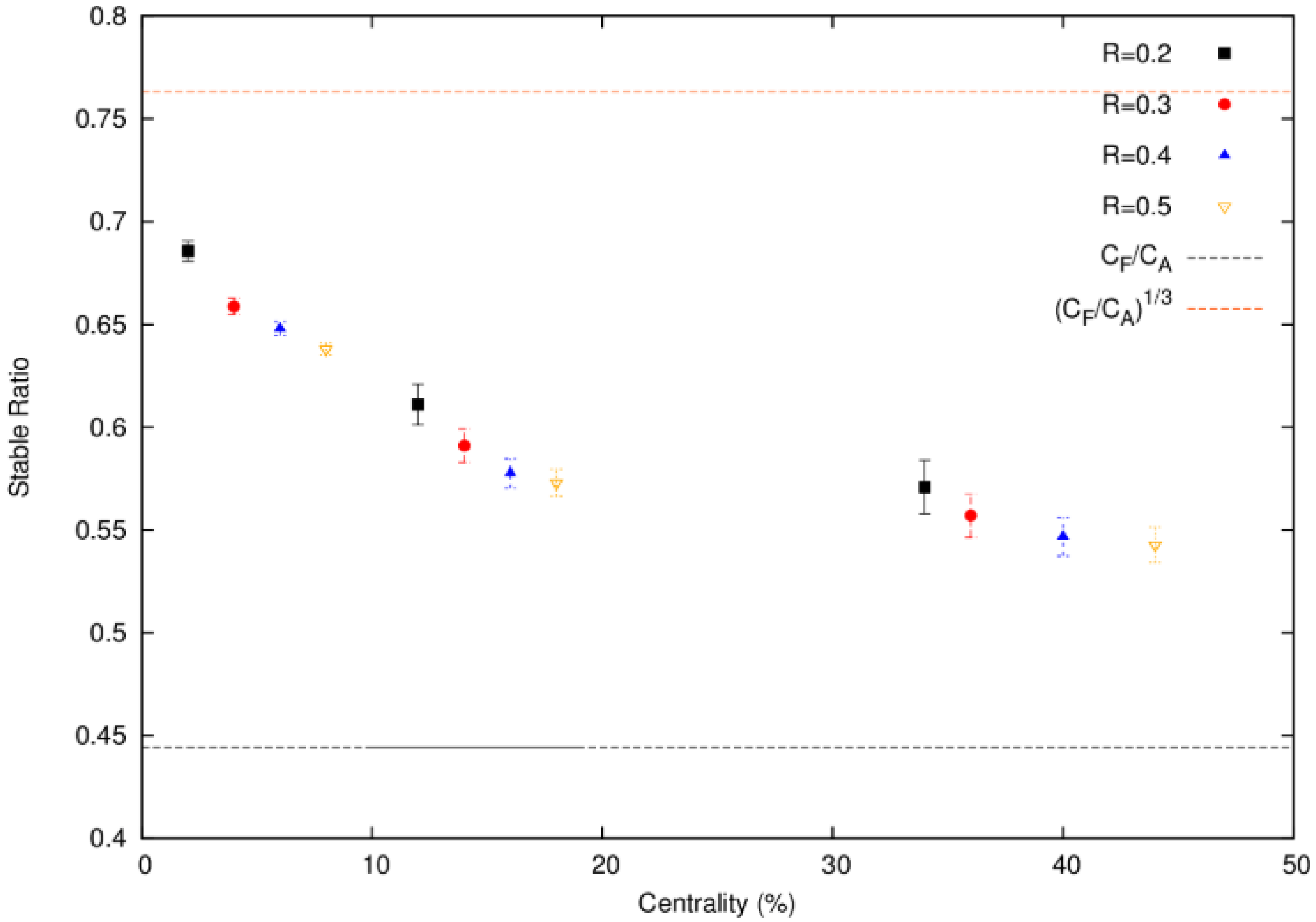

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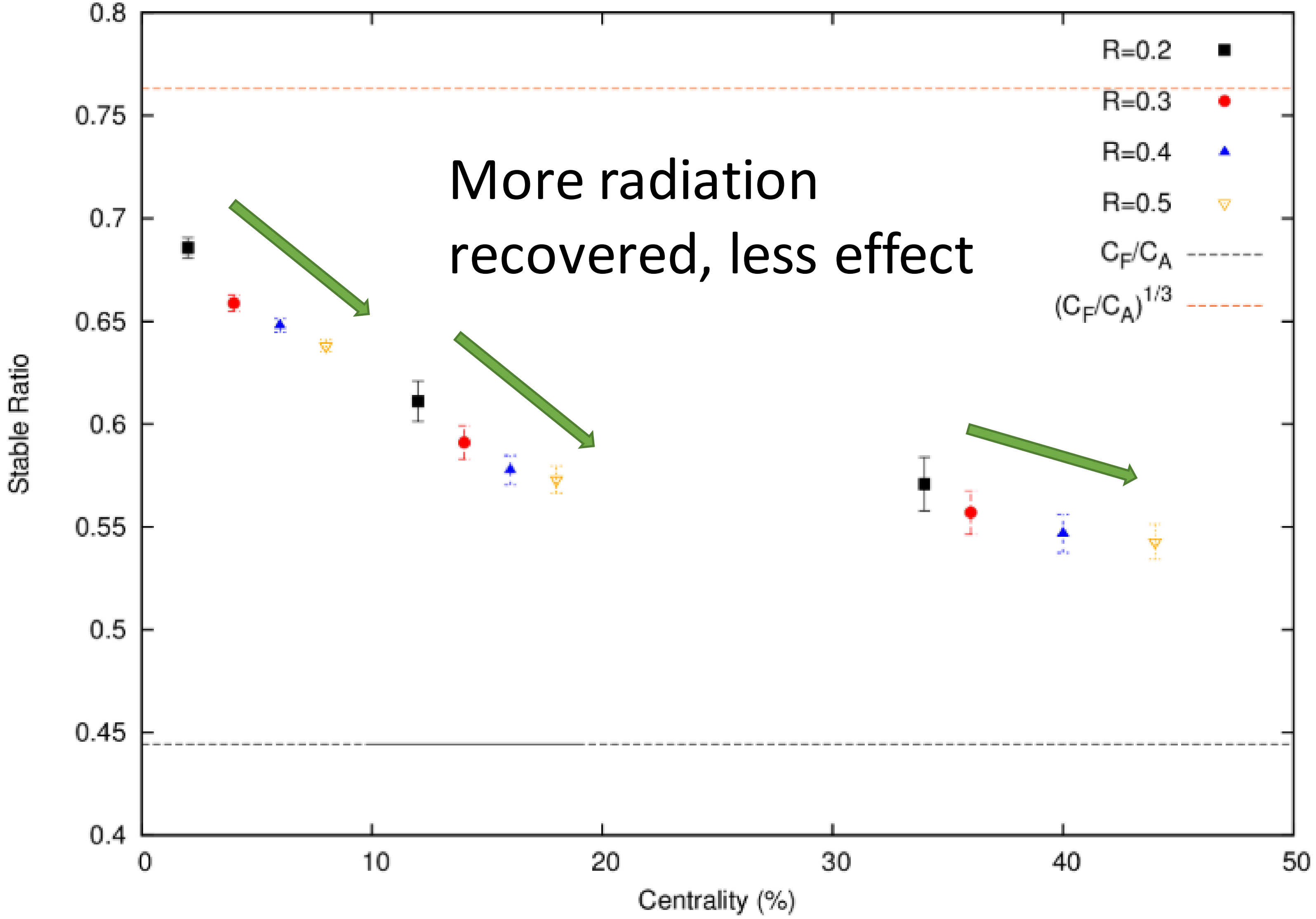

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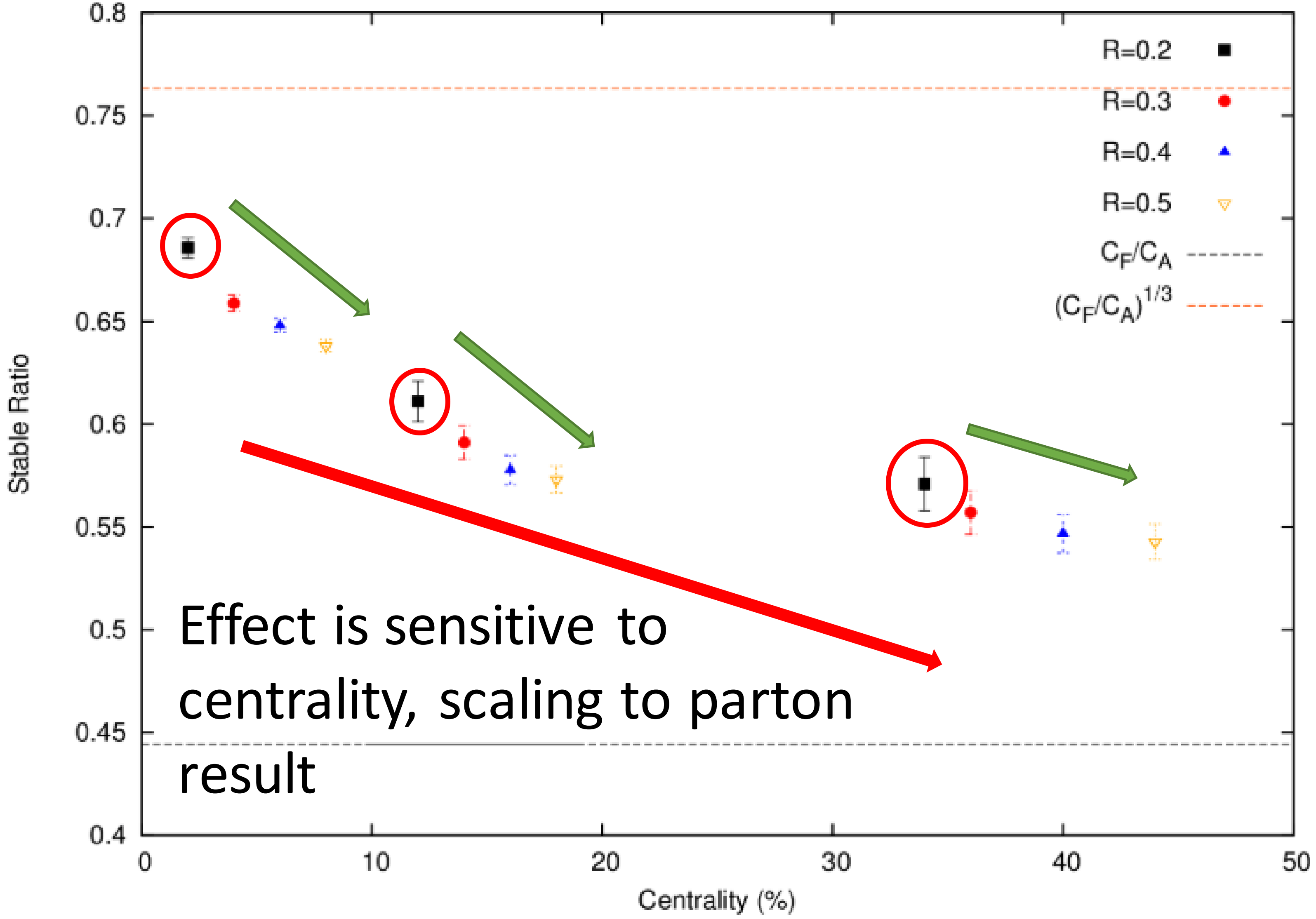

Conclusions

- We recover a constant quark to gluon scaling
  but this is not given directly by the parton's Casimir

- Initial flavor seems to be washed way by the medium
  possible physical picture: proliferation of gluons

- Still to be done: include Q-Pythia for comparison

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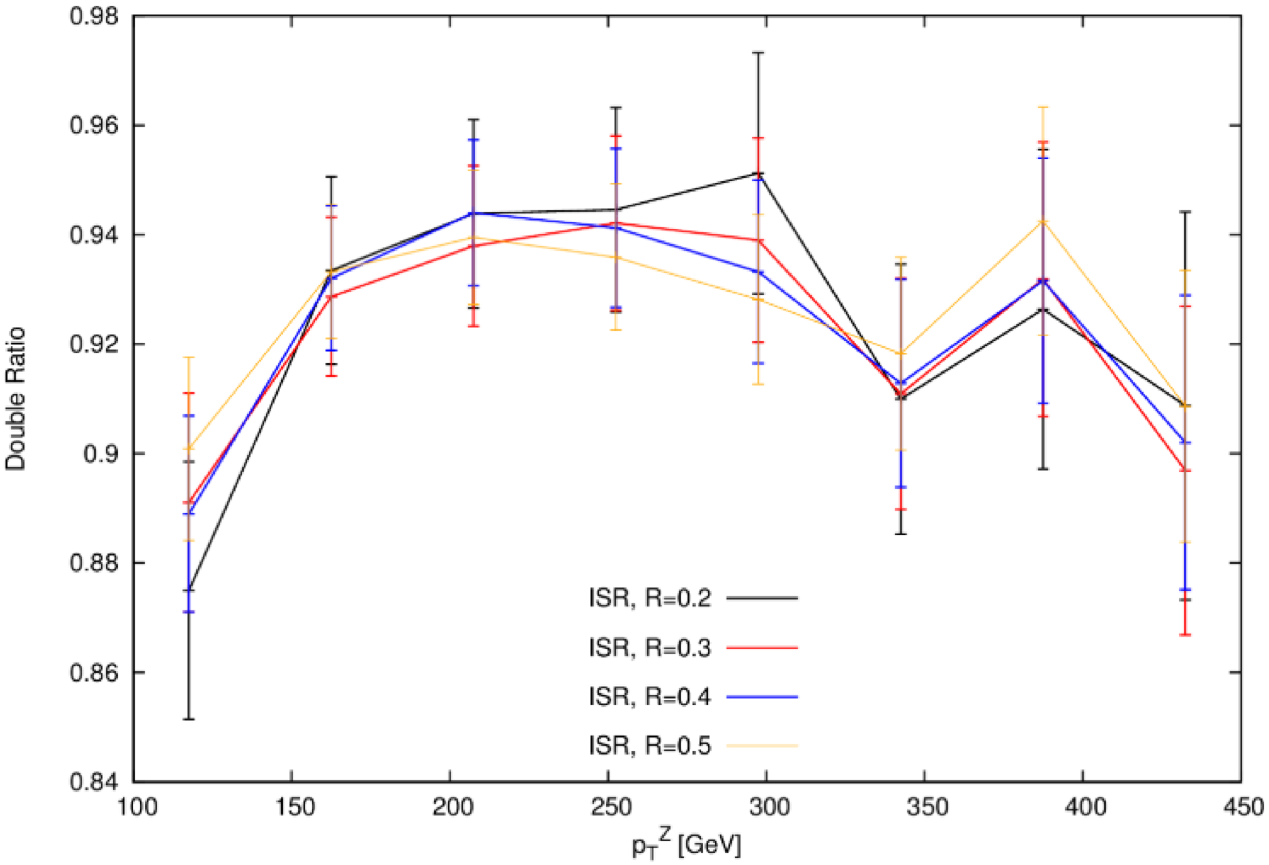

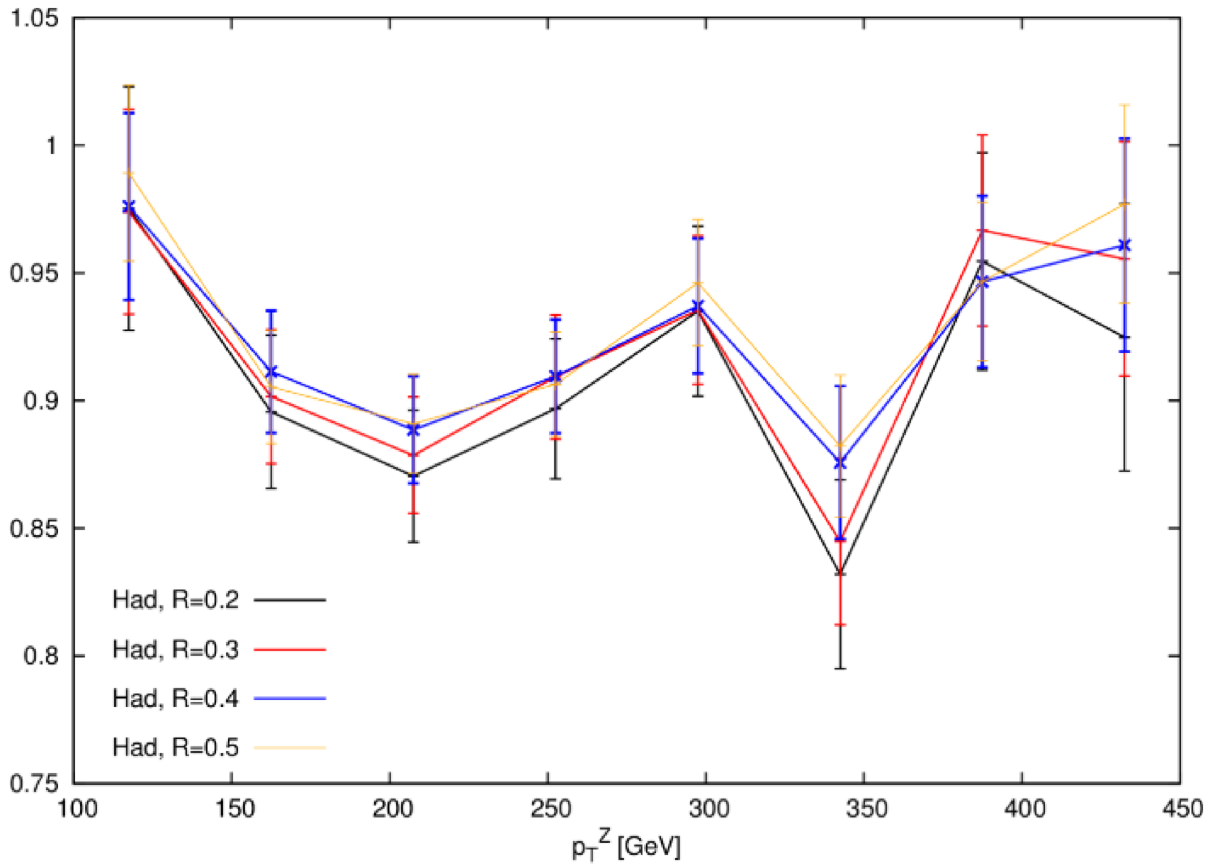

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