JET SUBSTRUCTURE IN TOP JETS

Leandro G. Almeida
YITP, Stony Brook

LGA, S. J. Lee, G. Perez, G. Sterman, I. Sung, J. Virzi   0807.0234 [hep-ph]
LGA, S. J. Lee, G. Perez, I. Sung, J. Virzi   0810.0934 [hep-ph]

LoopFest 09

Outline

Distinguishing Hadronic Top Decays (Top Jets)

from Light quark Jets

Jet Mass Distribution

When the mass distribution is not enough...

Use properties of the perturbative xsection and utilize the distribution in the eta phi plane...

(Jet Substructure)

Distinguishing Hadronic Top Decays from Light quark Jets

Top Decay

What happens when top decay is Highly boosted ?

Final states become highly collimated

Focus on Top Jet Mass Distribution.

Top peak in jet mass ?

Top Jets @ the LHC

Mass Tag; Ilustrate with a Cone jet

$$R^2 = (\Delta\eta)^2 + (\Delta\phi)^2 \qquad m_J^2 = \left(\sum_{i\in R} P_i\right)^2$$

Top Mass Window: $140 \leq m_J \leq 210$ GeV

Counting in the mass window, seems hopeless...

$S/B \sim 10^{-2}$ For jets with $P_T > 1000 GeV \quad R = 0.4$

$$jj + X \qquad t\bar{t} + X$$
$$10pb \qquad 100fb$$

Need to Study the Background...

QCD Jet Mass Background, Theory

LA, Lee, Perez, Sung & Virzi (Berger, Kucs, Sterman)

Jet Production:
(due to "light" jets)

$$H_a(p_a) + H_b(p_b) \to J_1(m^2_{J_1}, p_{1,T}, R) + X$$

This x-section factorizes

$$\frac{d\sigma_{H_A H_B \to J_1 X}(R)}{dp_T dm_J d\eta} = \sum_{abc} \int dx_a\, dx_b\, \underbrace{\phi_a(x_a)\, \phi_b(x_b)}_{\text{pdf's}} \frac{d\hat{\sigma}_{ab\to cX}}{dp_T dm_J d\eta}(x_a, x_b, p_T, \eta, m_J, R)$$

for small R

$$\frac{d\sigma_{H_A H_B \to J_1 X}(R)}{dp_T dm_J d\eta} = \sum_{abc} \int dx_a\, dx_b\, \phi_a(x_a)\, \phi_b(x_b) \overbrace{H_{ab\to cX}(x_a, x_b, p_T, \eta, R)}^{\text{Hard}}$$

$$\times \underbrace{J_1^c(m_J, p_T, R).}_{\text{Jet functions}} + \mathcal{O}(R^2)$$

Contributions from initial state radiation to Jet mass $\sim R^2$

QCD Jet Mass distribution

Leading Contribution: Single Gluon Emission

$$J^{(f)} = 2\frac{\alpha_S}{\pi}\frac{C_f}{m_J}\log\left(\frac{p_T^2 R^2}{m_J^2}\right) + \mathcal{O}(R^4)$$

Jet Mass Distribution;

$$\frac{d\sigma(R)}{dp_T dm_J} = \sum_c J^c(m_J, p_T, R)\,\frac{d\hat{\sigma}^c(R)}{dp_T}$$

Jet Functions

Quarks jets

$$J_i^q(m_J^2, p_{0,J_i}, R) \;=\; \frac{(2\pi)^3}{2\sqrt{2}\,(p_{0,J_i})^2}\frac{\xi_\mu}{N_c}\sum_{N_{J_i}} \mathrm{Tr}\left\{\gamma^\mu \langle 0|q(0)\Phi_\xi^{(\bar{q})\dagger}(\infty,0)|N_{J_i}\rangle\langle N_{J_i}|\Phi_\xi^{(\bar{q})}(\infty,0)\bar{q}(0)|0\rangle\right\}$$
$$\times\delta\left(m_J^2 - \tilde{m}_J^2(N_{J_i},R)\right)\delta^{(2)}(\hat{n}-\tilde{n}(N_{J_i}))\delta(p_{0,J_i}-\omega(N_{J_c})),$$

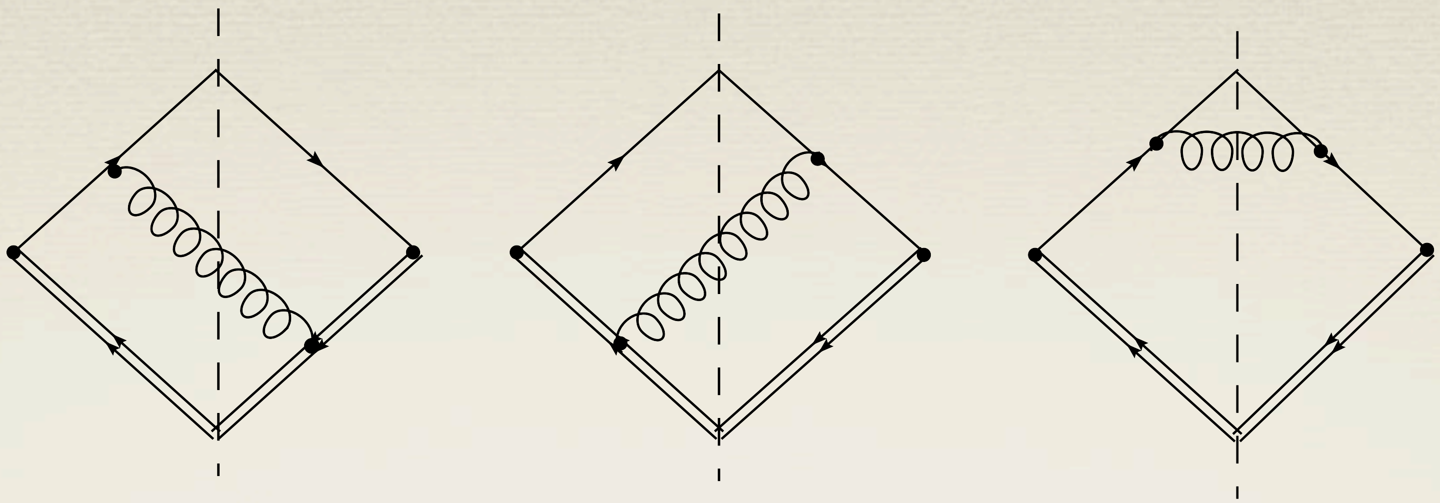
Gluons jets

$$J_i^g(m_J^2, p_{0,J_i}, R) \;=\; \frac{(2\pi)^3}{2(p_{0,J_i})^3}\sum_{N_{J_i}} \langle 0|\xi_\sigma F^{\sigma\nu}(0)\Phi_\xi^{(g)\dagger}\,(0,\infty)\,|N_{J_i}\rangle\langle N_{J_i}|\Phi_\xi^{(g)}\,(0,\infty)\,F_\nu^{\;\rho}(0)\xi_\rho|0\rangle$$
$$\times\delta\left(m_J^2 - \tilde{m}_J^2(N_{J_i},R)\right)\delta^{(2)}(\hat{n}-\tilde{n}(N_{J_i}))\delta(p_{0,J_i}-\omega(N_{J_c})).$$

Normalized $\int dm_J J(m_J) = 1$

Perturbatively Calculable; systematically improvable

Quark Jet Function, in detail...



$$J_i^{q(1)}(m_J^2, p_{0,J_i}, R) \;=\; \frac{C_F\beta_i}{4m_{J_i}^2}\int_{\cos(R)}^{\beta_i} \frac{d\cos\theta_S}{\pi}\, \frac{\alpha_S(k_0)\, z^4}{(2(1-\beta_i\cos\theta_S)-z^2)\,(1-\beta_i\cos\theta_S)} \times$$
$$\left\{ z^2 \frac{(1+\cos\theta_S)^2}{(1-\beta_i\cos\theta_S)} \frac{1}{(2(1+\beta_i)(1-\beta_i\cos\theta_S)-z^2(1+\cos\theta_S))} + \right.$$
$$\left. \frac{3(1+\beta_i)}{z^2} + \frac{1}{z^4}\frac{\left(2(1+\beta_i)(1-\beta_i\cos\theta_S)-z^2(1+\cos\theta_S)\right)^2}{(1+\cos\theta_S)(1-\beta_i\cos\theta_S)} \right\},$$

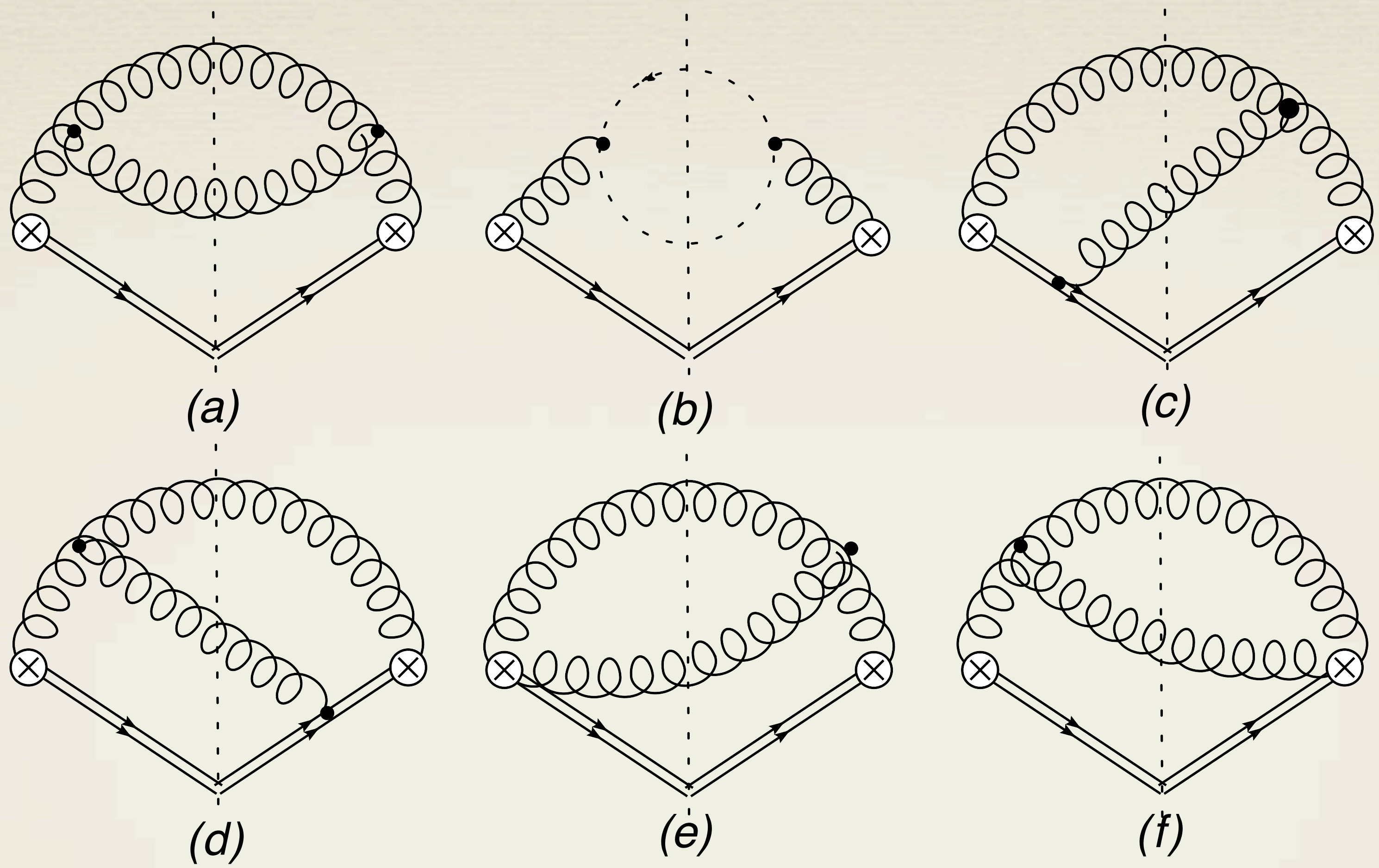
$$z = m_J/p_{0,J_i}$$

θ_S : Angle between Jet axis and softer particle

$$\beta_i = \sqrt{1-z^2}$$

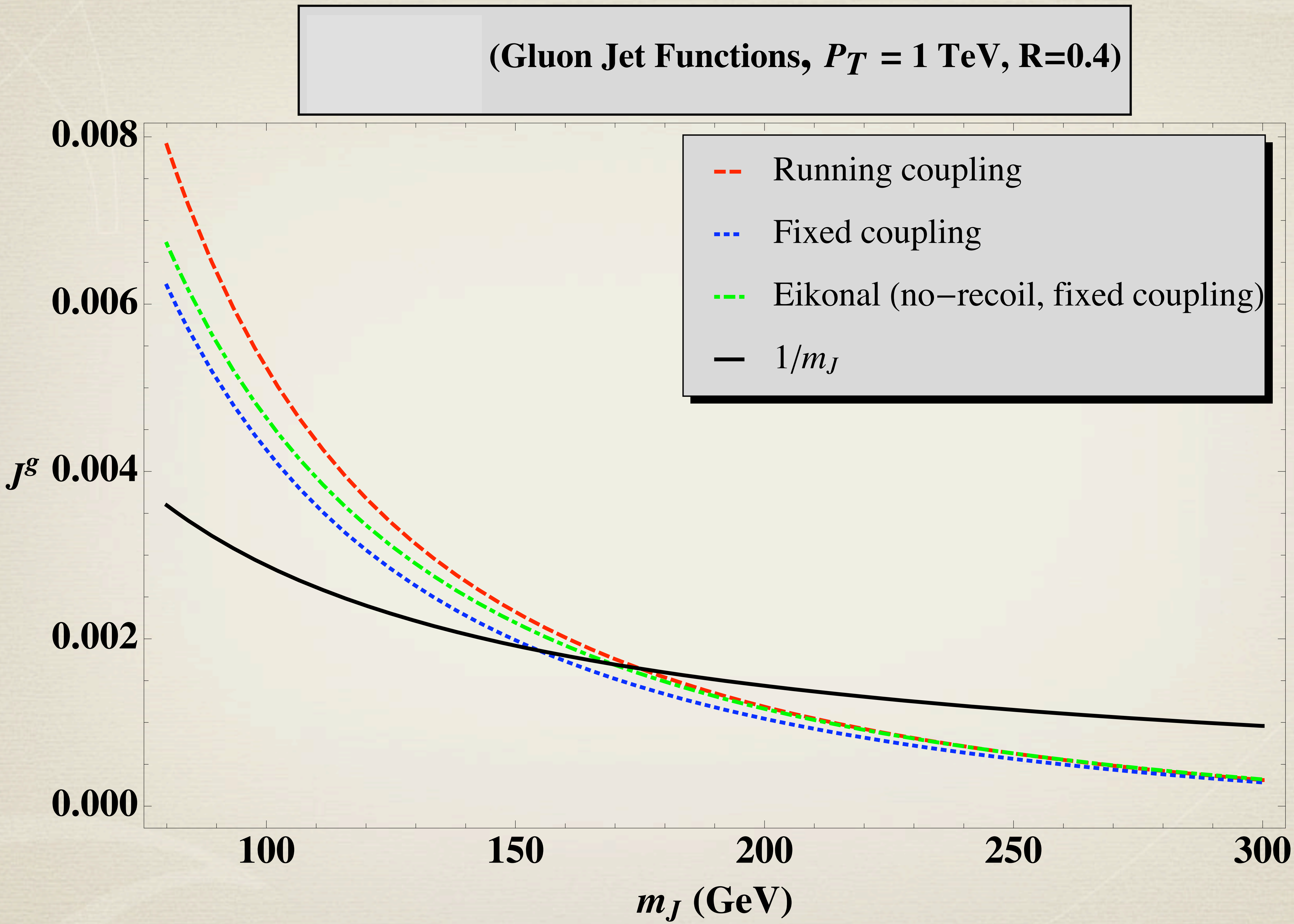
$$k_0 = \frac{p_{0,J}}{2}\frac{z^2}{1-\beta_i\cos\theta_S}$$

Gluon Jet function in detail...

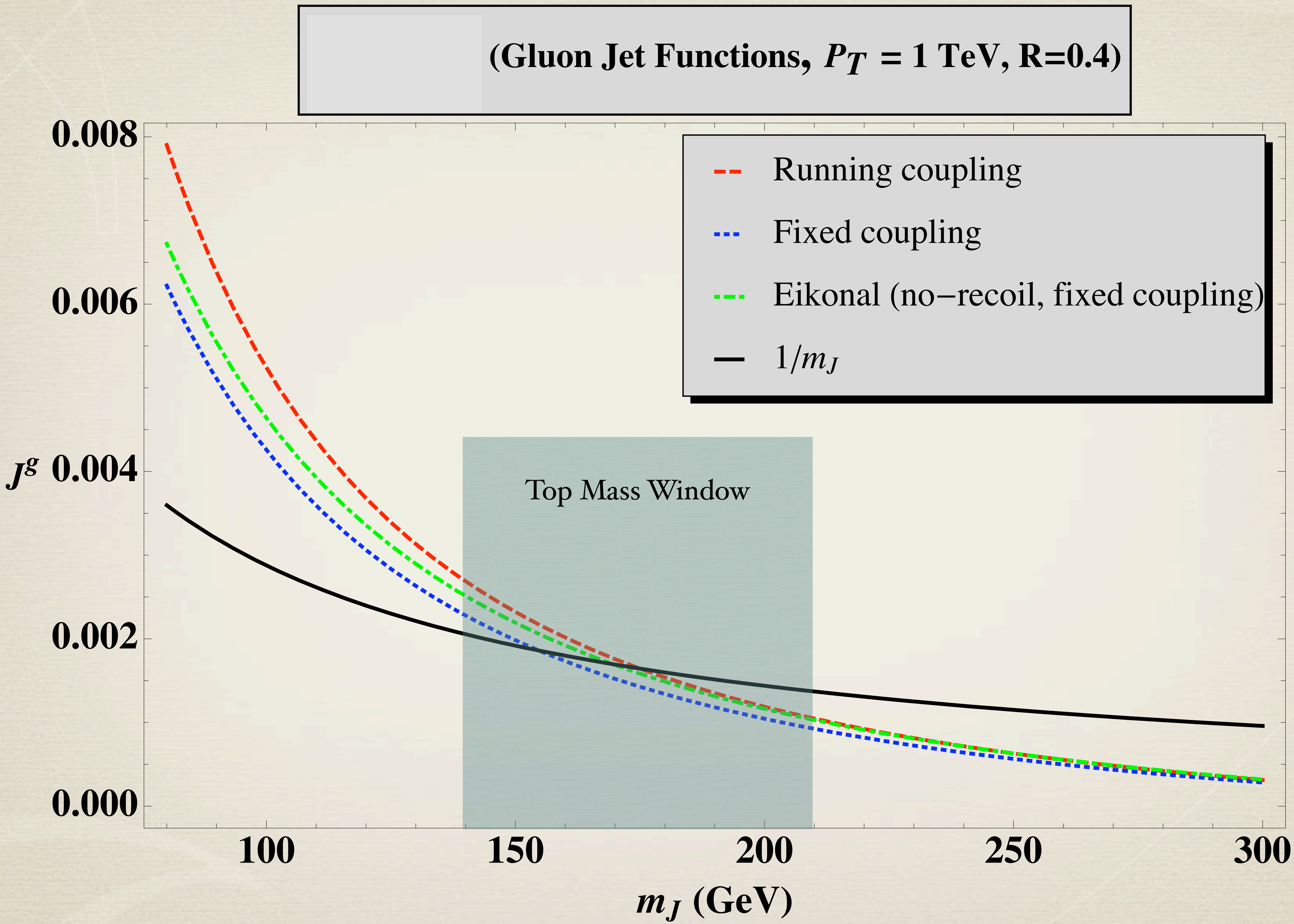


$$J_i^{g(1)}(m_J^2, p_{0,J_i}, R) \;=\; \frac{C_A \beta_i}{16 m_{J_i}^2} \int_{\cos(R)}^{\beta_i} \frac{d\cos\theta_S}{\pi} \frac{\alpha_S(k_0)}{(1-\beta\cos\theta_S)^2(1-\cos^2\theta_S)(2(1+\beta)-z^2)}$$
$$\times\left(z^4(1+\cos\theta_S)^2 + z^2(1-\cos^2\theta_S)(2(1+\beta_i)-z^2) + (1-\cos\theta_S)^2(2(1+\beta_i)-z^2)^2\right)^2.$$

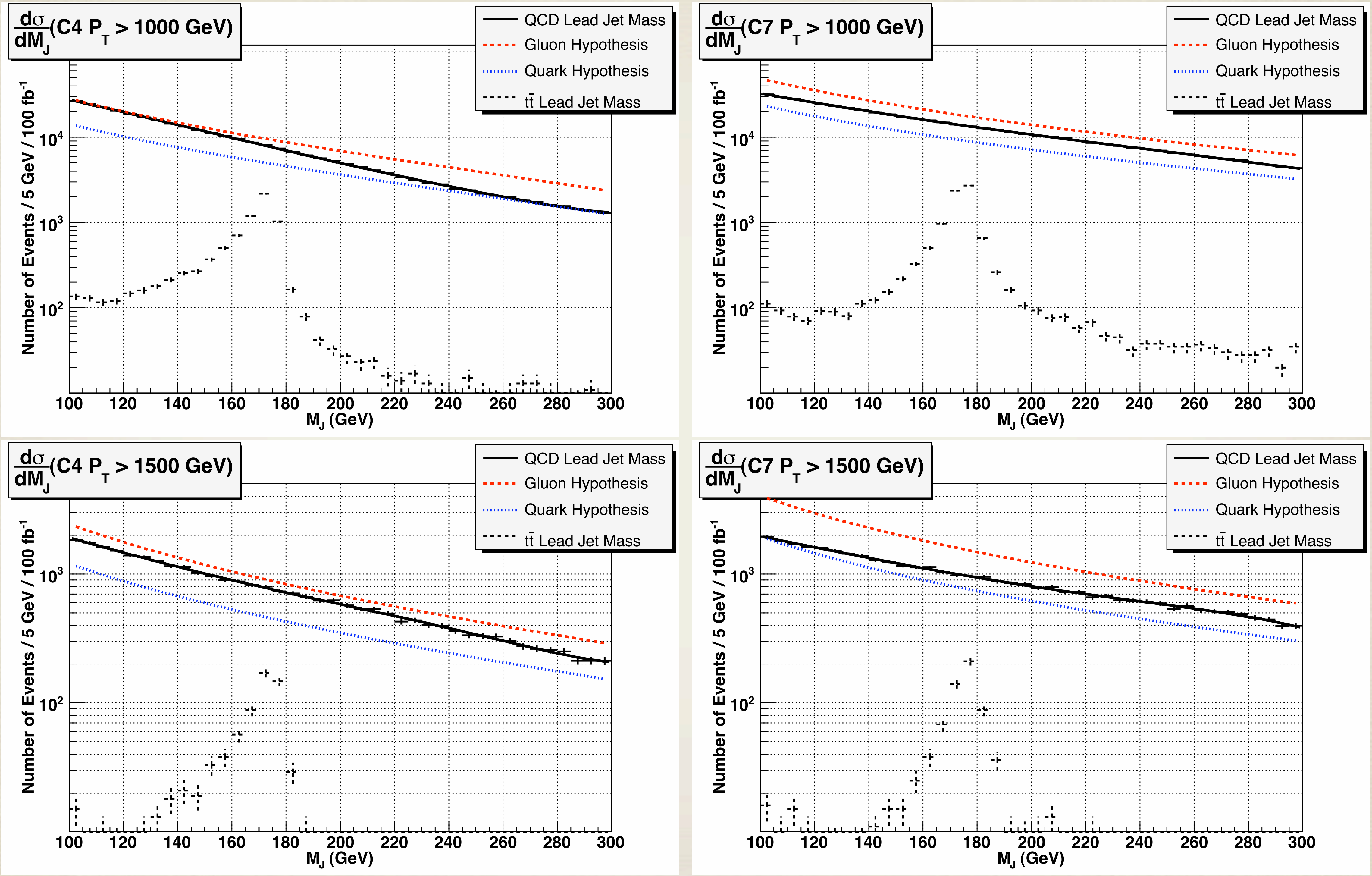
The Importance of the log



The Importance of the log

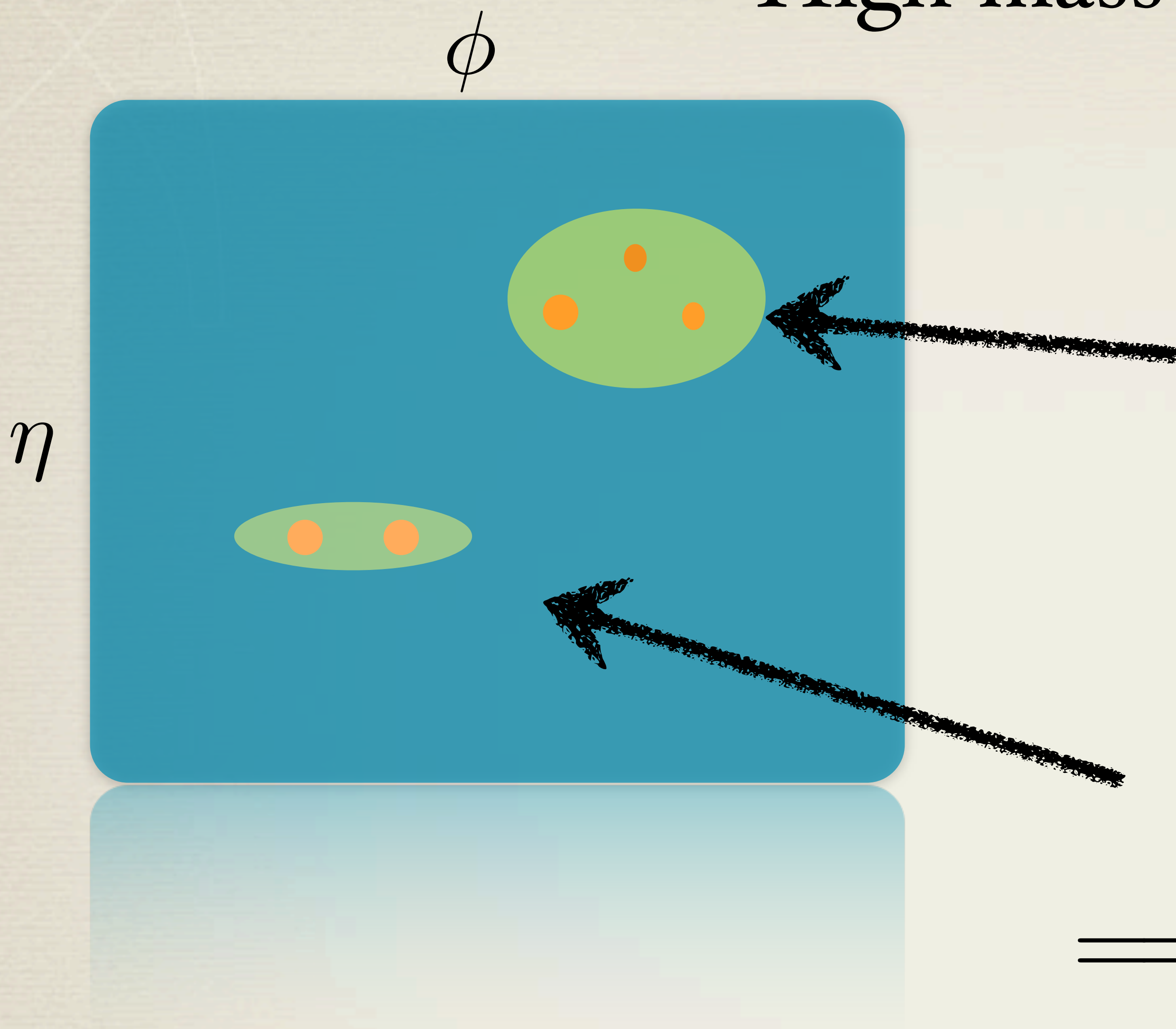


Ex: (sherpa) Di-Jet Vs. SM $t\bar{t}$



Planar Flow

High mass Jets



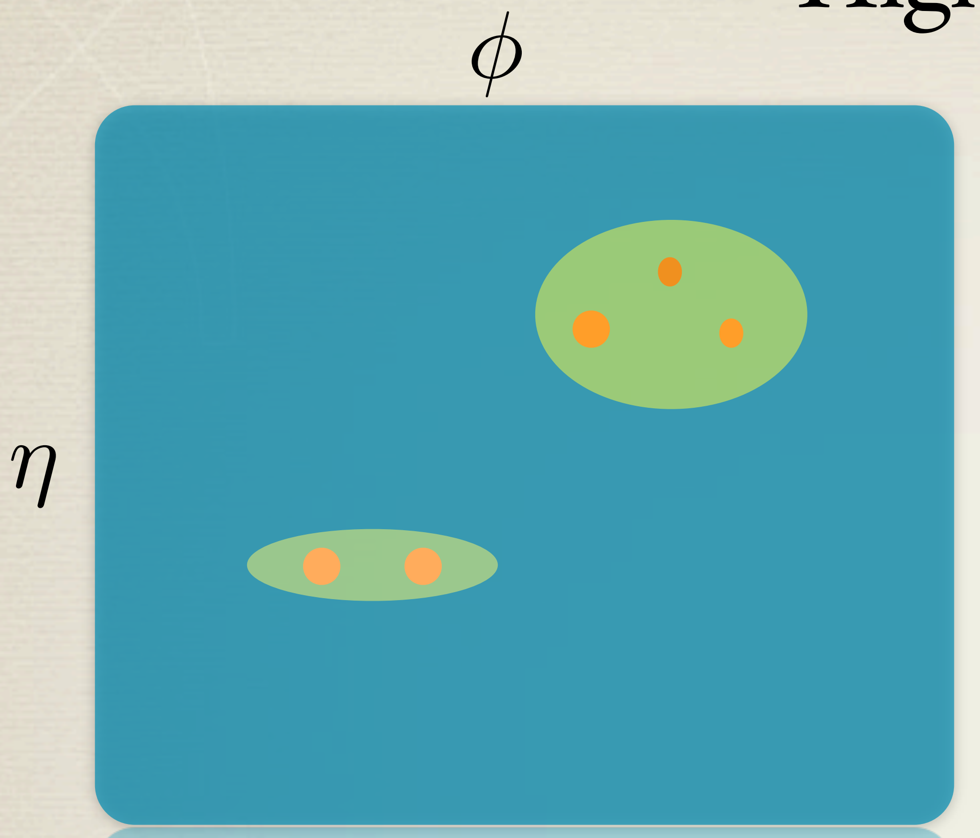
3 body i.e. Top decay

light QCD

$\Longrightarrow$ linear distribution

Planar Flow

High mass Jets



We can use "inertia" of the distribution

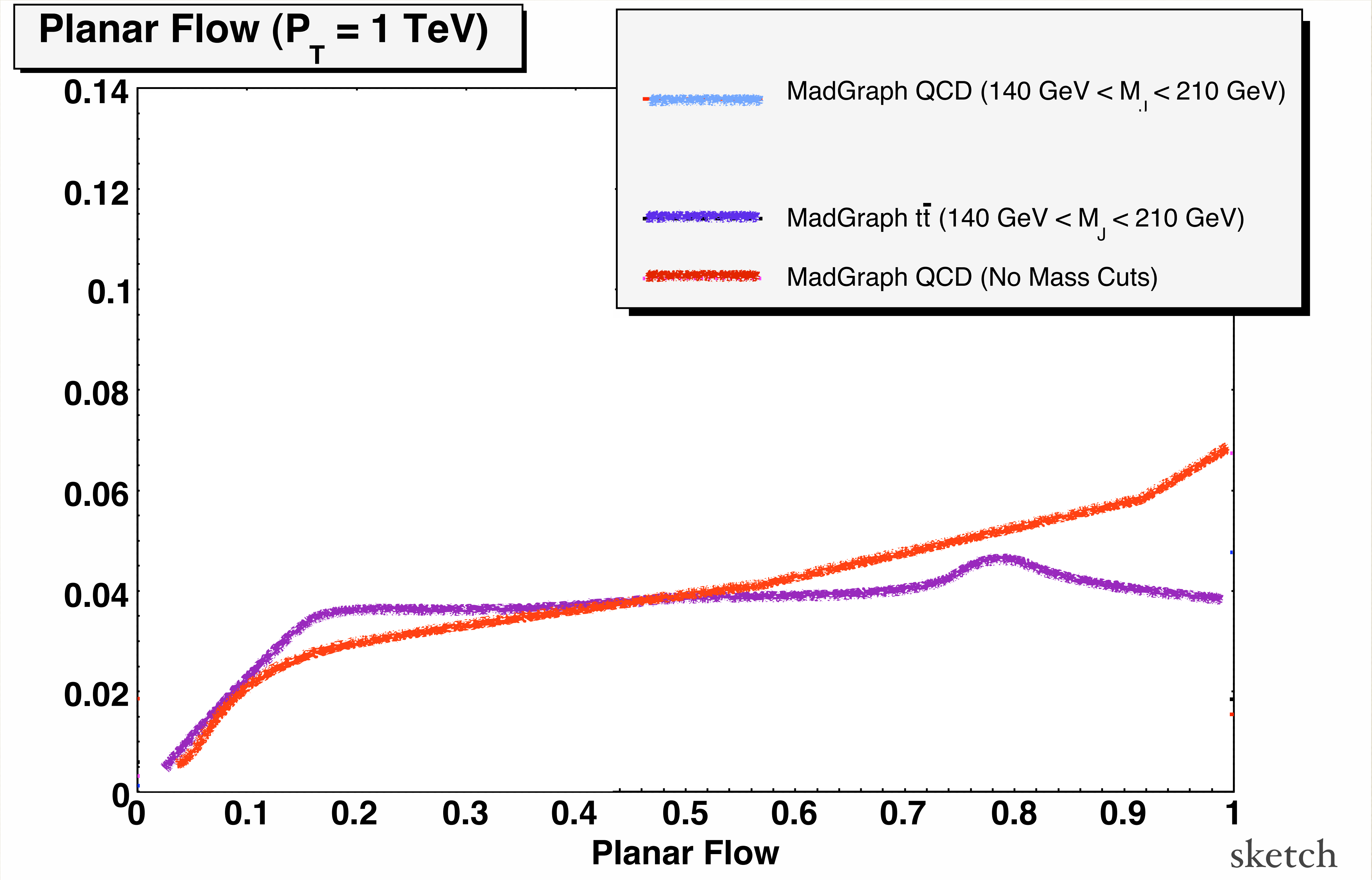
$$I_{\omega}^{kl} = \frac{1}{m_J} \sum_i \omega_i \frac{p_{i,k}}{\omega_i} \frac{p_{i,l}}{\omega_i}$$

Planar Flow:

$$Pf = \frac{4\det(I_\omega)}{\mathrm{tr}(I_\omega)^2}$$

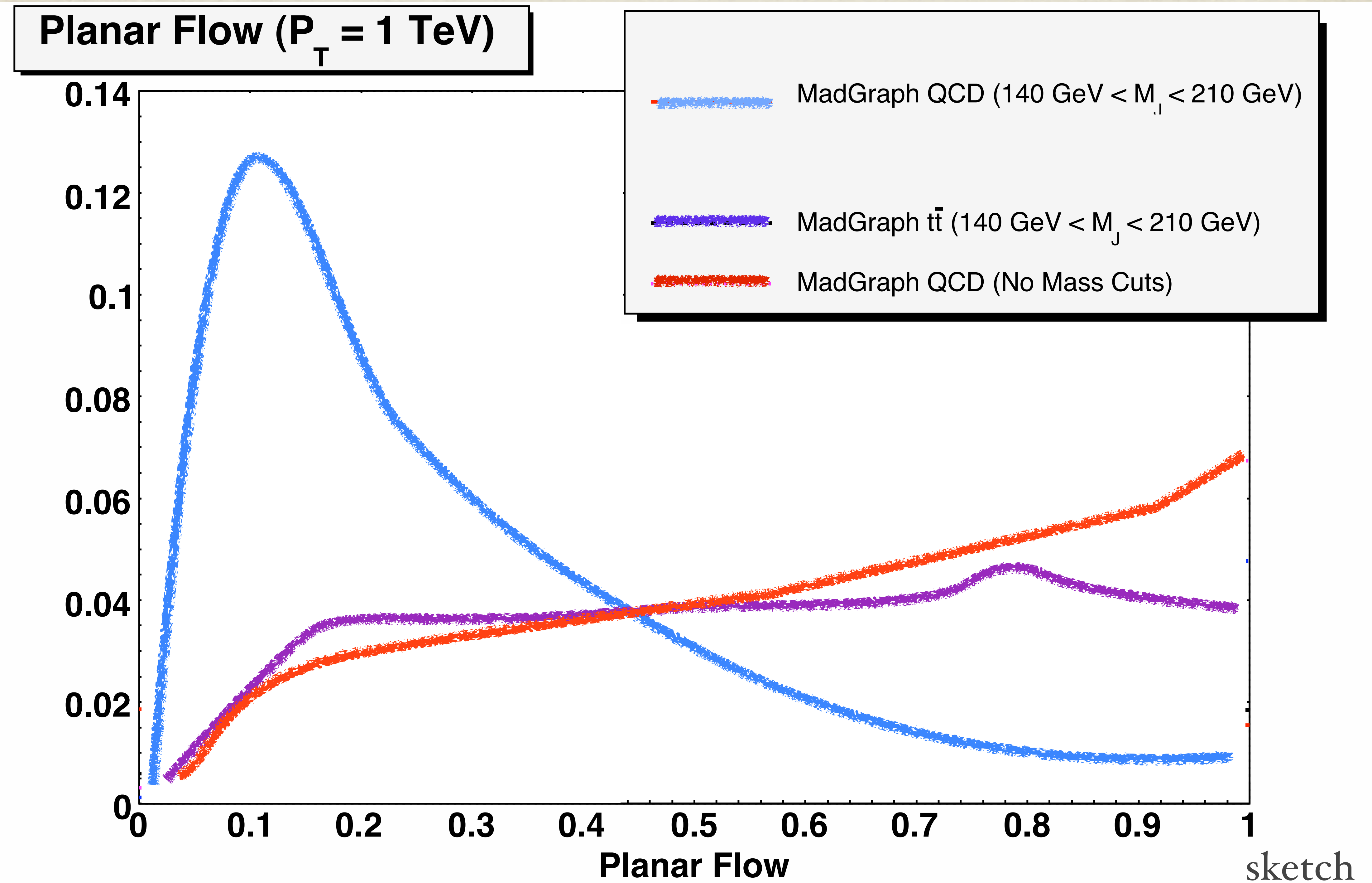
linear $\Longrightarrow Pf = 0$

Planar Flow



Planar Flow (P_T = 1 TeV)
MadGraph QCD (140 GeV < M_J < 210 GeV)
MadGraph $t\bar{t}$ (140 GeV < M_J < 210 GeV)
MadGraph QCD (No Mass Cuts)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Planar Flow
sketch

Planar Flow

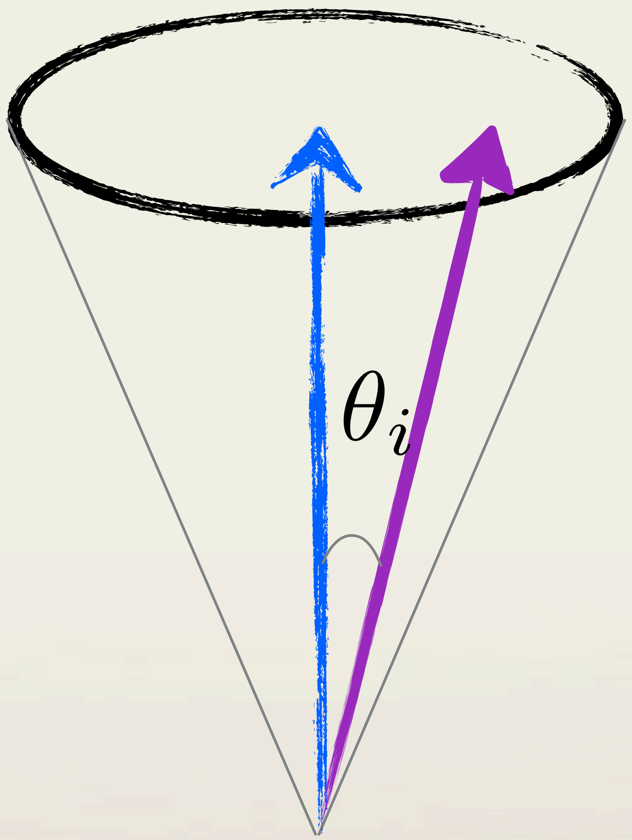


Planar Flow (P_T = 1 TeV)
MadGraph QCD (140 GeV < M_J < 210 GeV)
MadGraph tt̄ (140 GeV < M_J < 210 GeV)
MadGraph QCD (No Mass Cuts)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Planar Flow
sketch

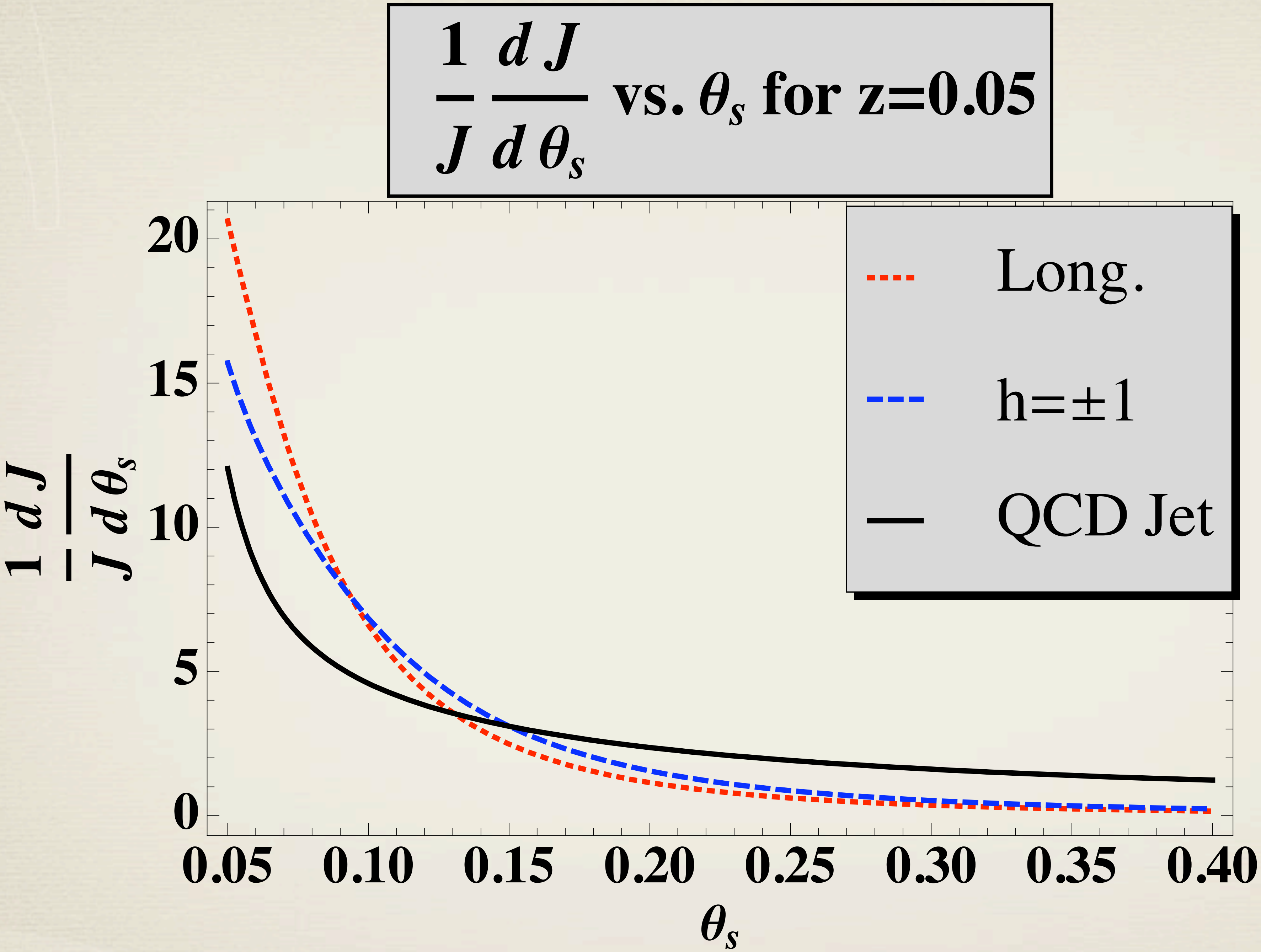
Angularities

(C. Berger, T. Kucs, G. Sterman '03)

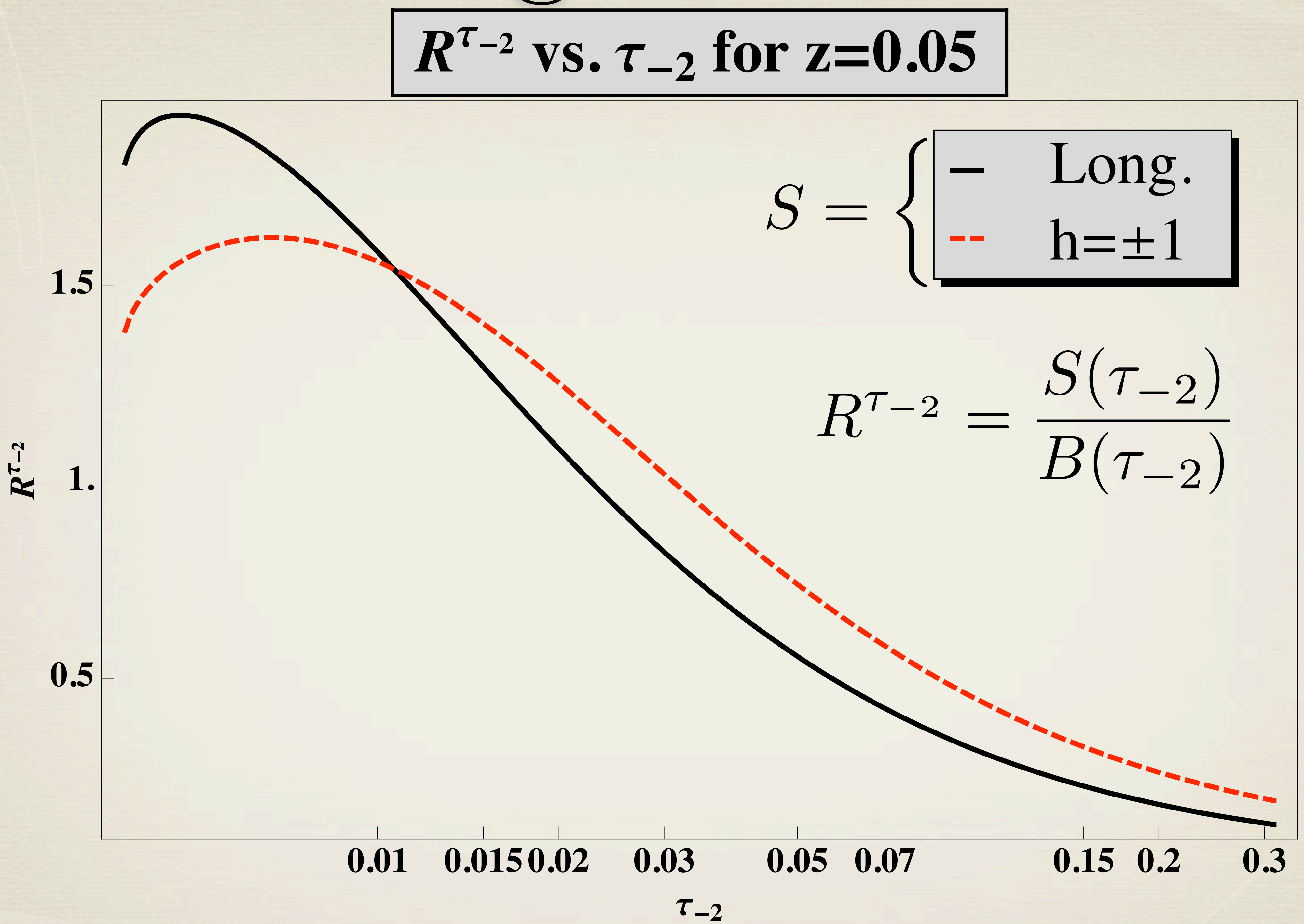
$$\tau_a = \frac{1}{m_J} \sum_i \omega_i \sin^a \left(\frac{\pi \theta_i}{2R} \right) \left[1 - \cos \left(\frac{\pi \theta_i}{2R} \right) \right]^{1-a}$$



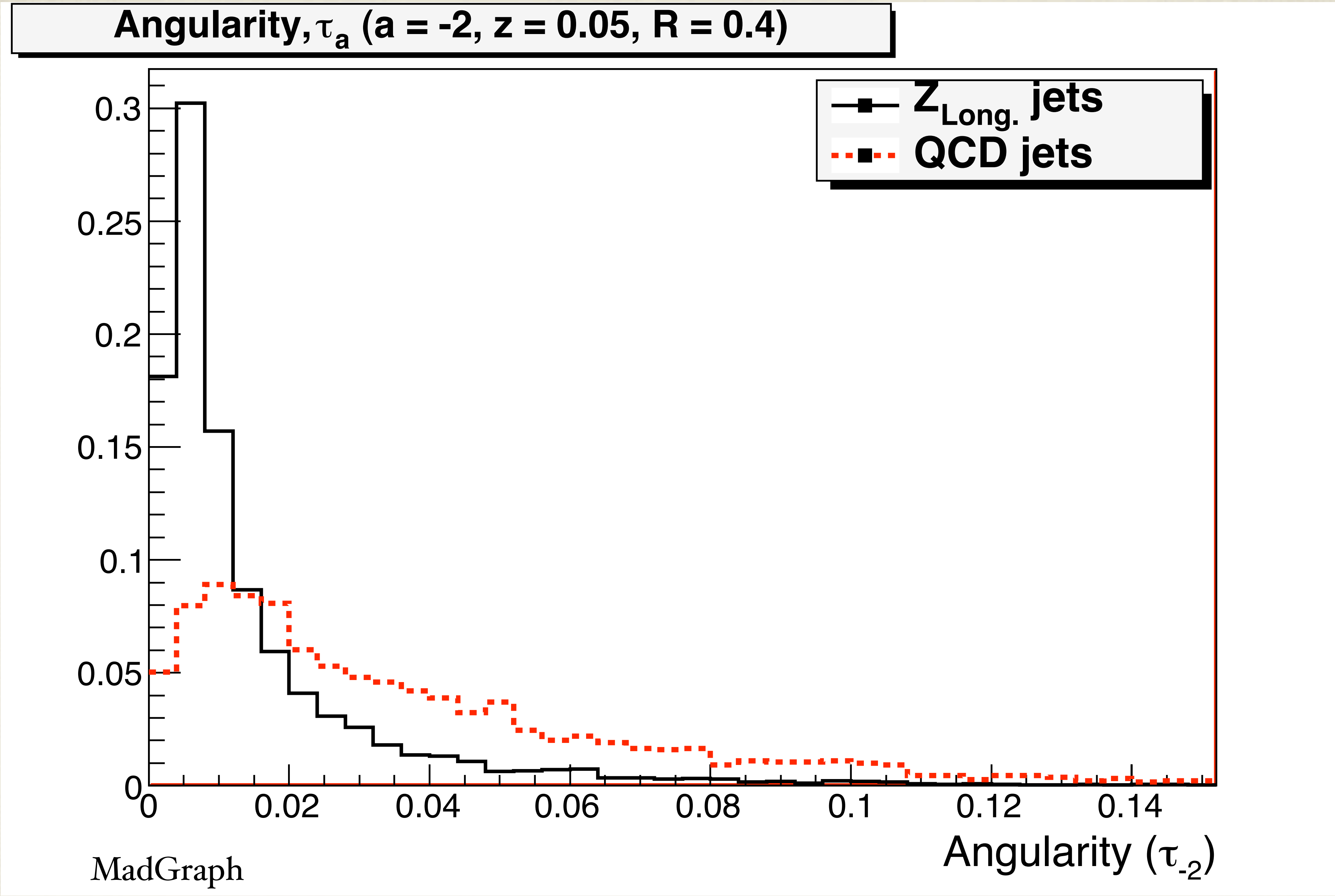
Gauge Boson Decays



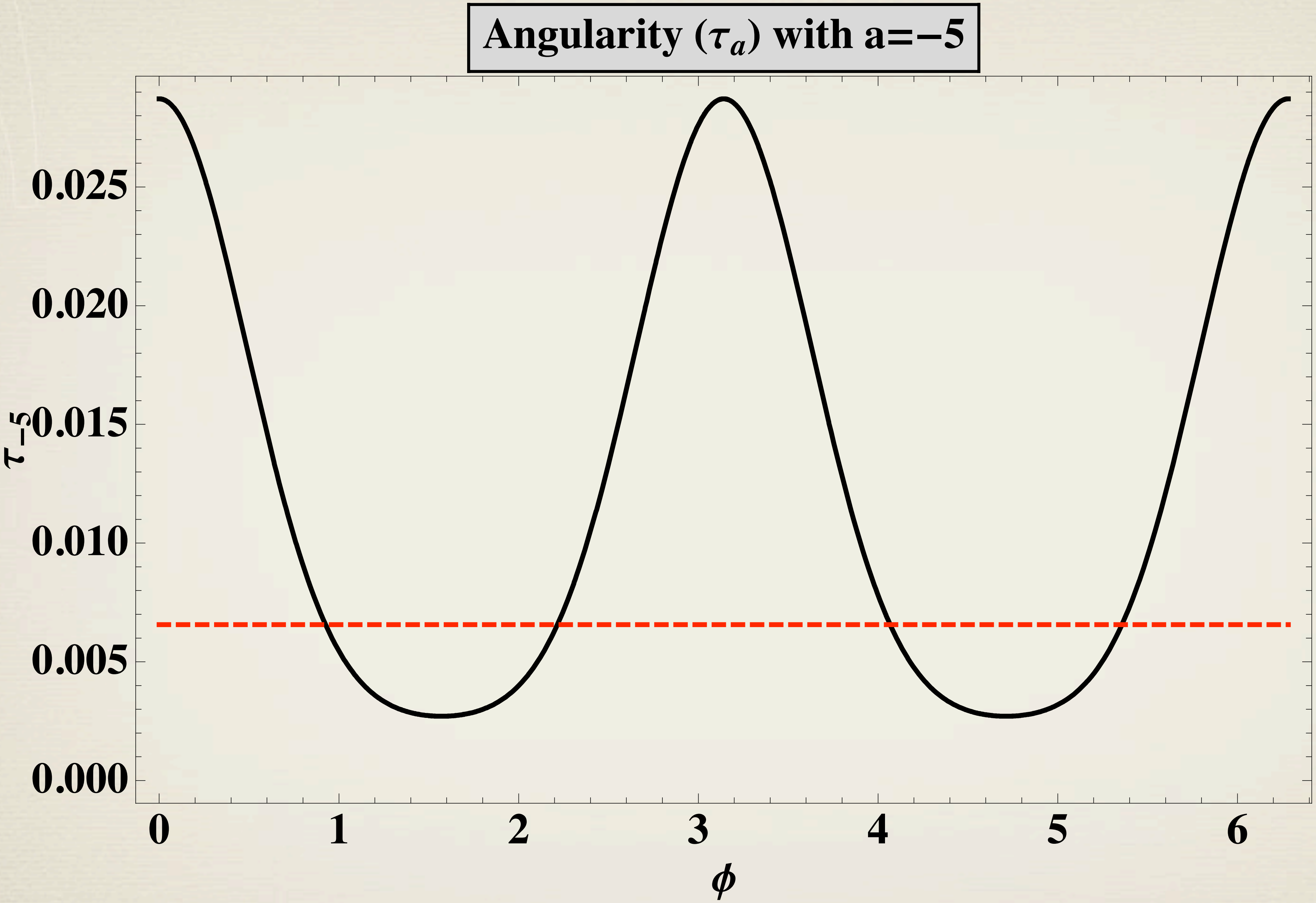
Angularities



Angularities in MC



Linear Top Decay

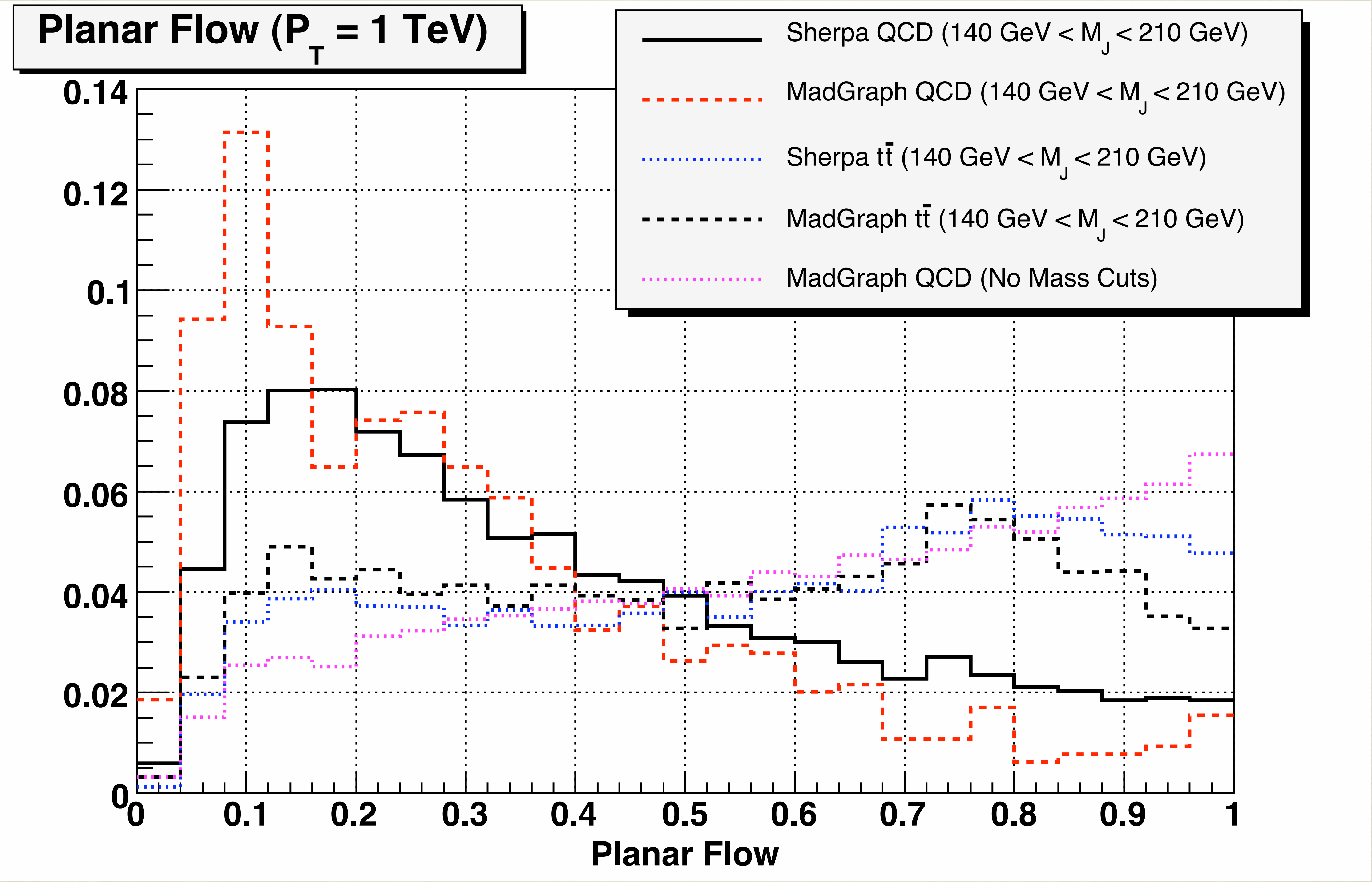


Summary

Jet functions provide a systematic approach to describe the jet mass background (small R)

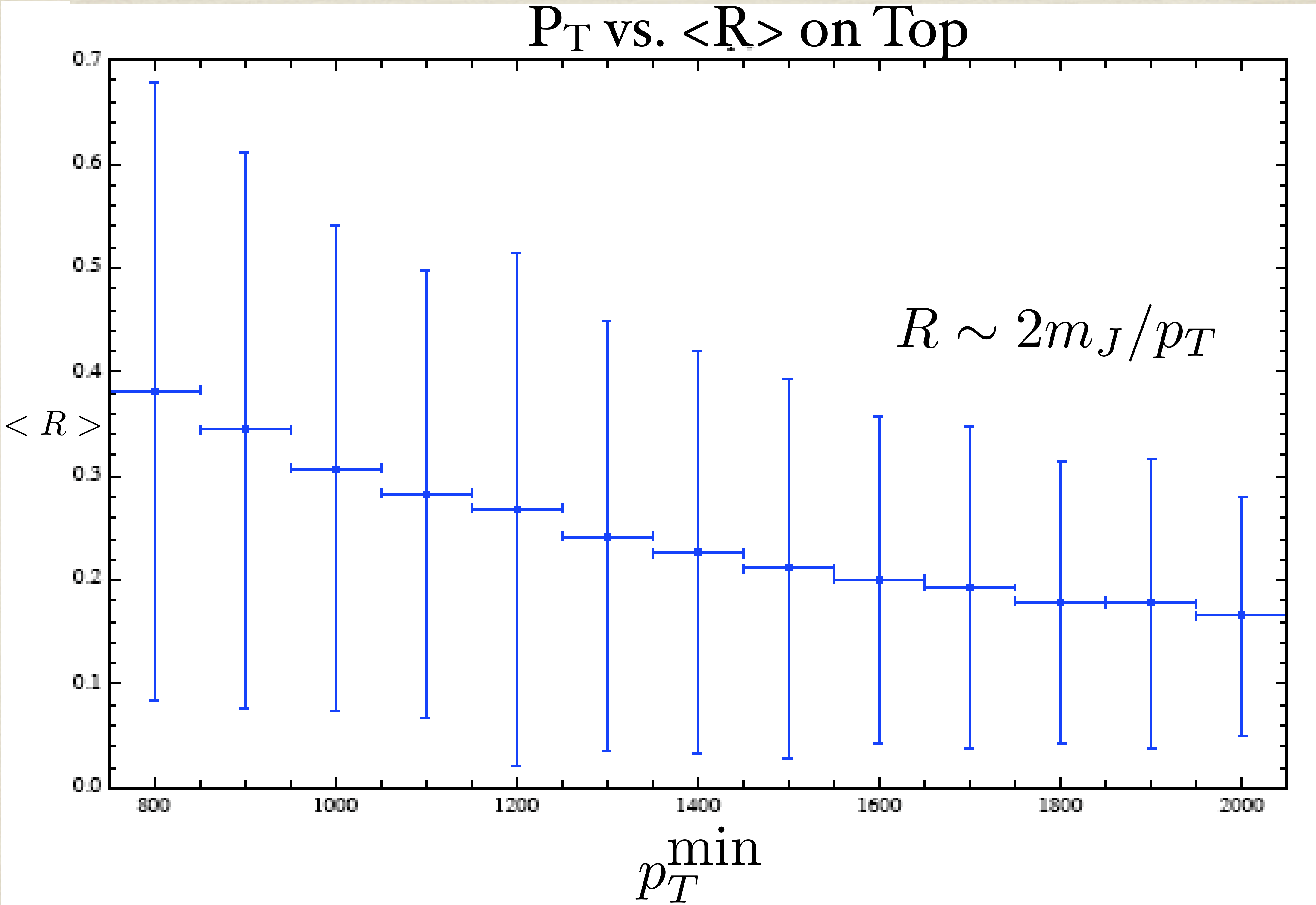
A Careful understanding of the substructure of Background and Signal allows us to develop observables that are “tuned” to our signal

Planarity Effects in QCD light jets appear at NLO in Jet Mass Distrib. (as^4)



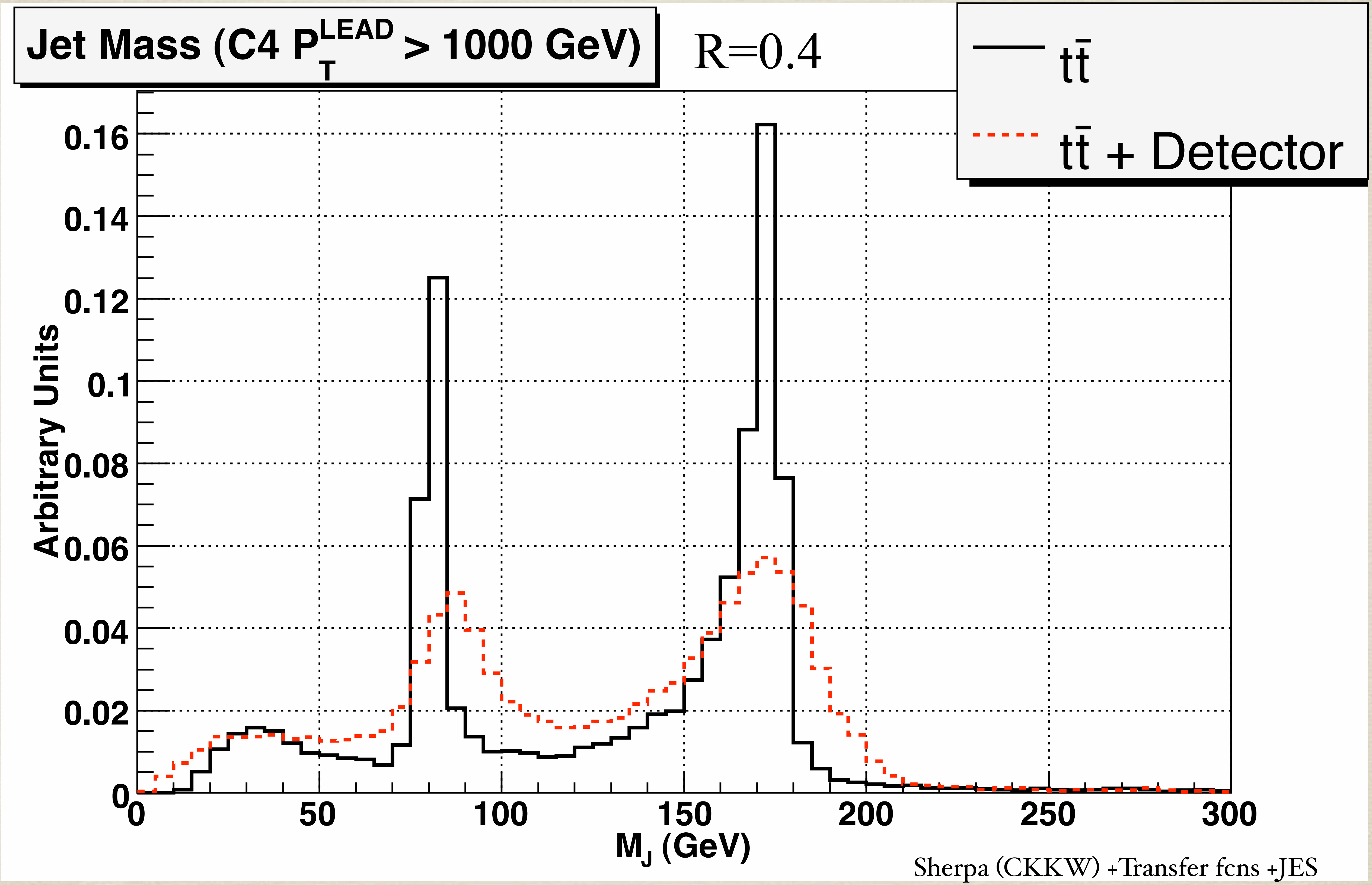
Planar Flow (P_T = 1 TeV)
Sherpa QCD (140 GeV < M_J < 210 GeV)
MadGraph QCD (140 GeV < M_J < 210 GeV)
Sherpa $t\bar{t}$ (140 GeV < M_J < 210 GeV)
MadGraph $t\bar{t}$ (140 GeV < M_J < 210 GeV)
MadGraph QCD (No Mass Cuts)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Planar Flow

Top jets collimate @ high P_T



Cone Size: $R^2 = (\Delta\eta)^2 + (\Delta\phi)^2$

Top Jet Mass Distribution



Small cone losses signal