JET SUBSTRUCTURE IN TOP JETS

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LGA, S. J. Lee, G. Perez   [ongoing]

DPF 09

Distinguishing Hadronic Top Decays from Light quark Jets

Top Decay

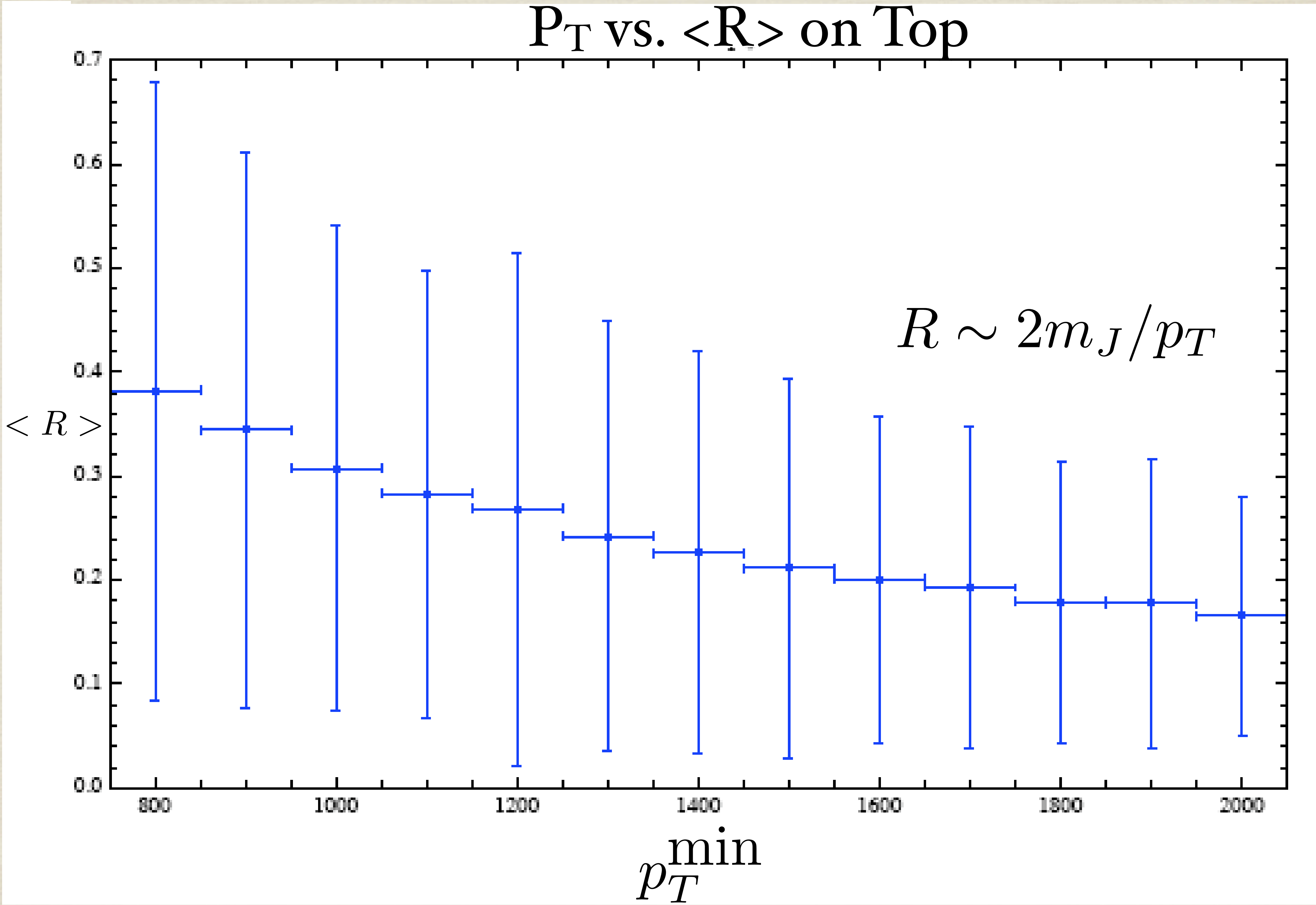
What happens when top decay is Highly boosted ?

Final states become highly collimated

Focus on Top Jet Mass Distribution.

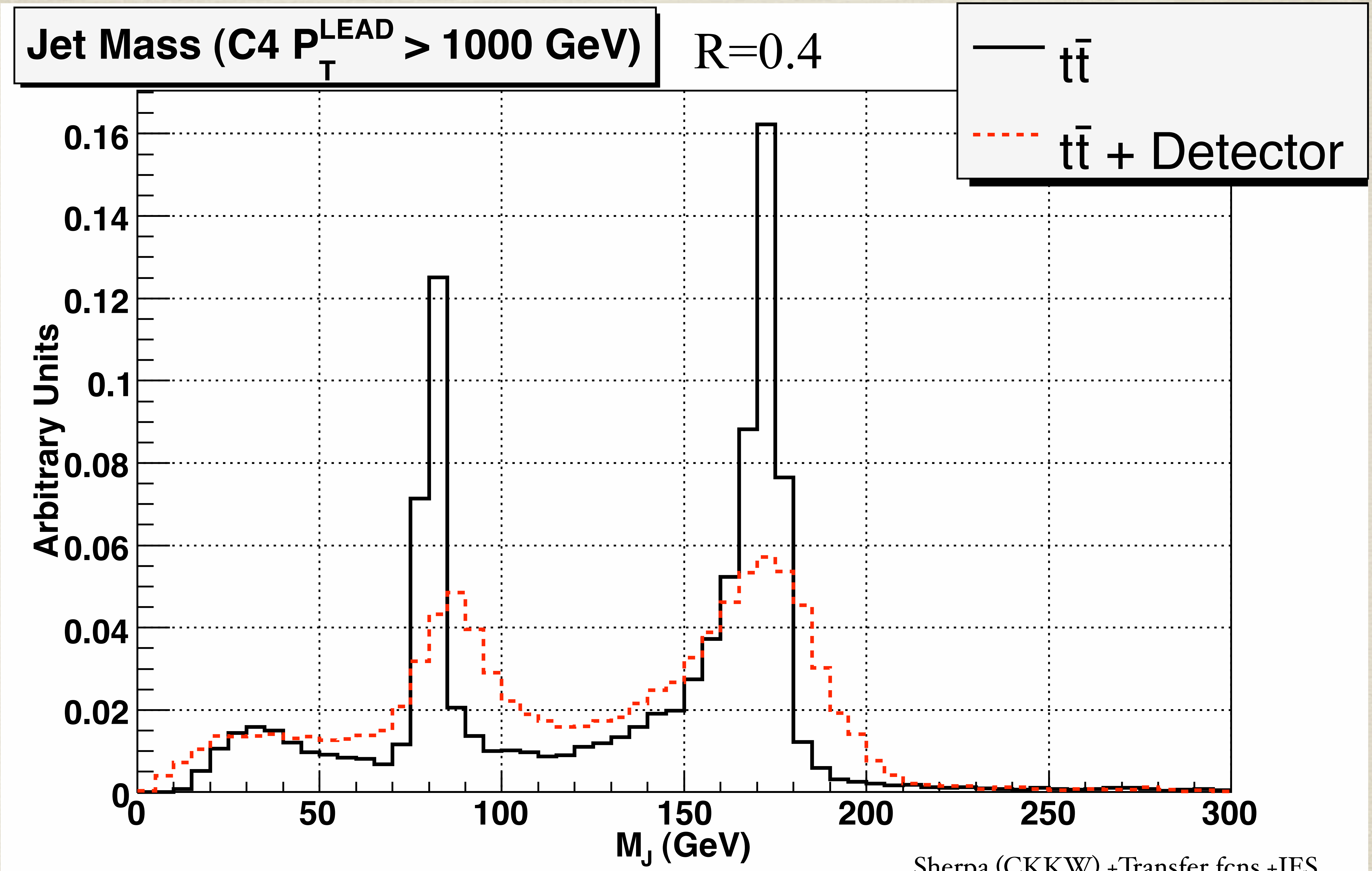
Top peak in jet mass ?

Top jets collimate @ high P_T



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

Top Jet Mass Distribution



Small cone losses signal

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 $P_T > 1000 GeV \quad R = 0.4$

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

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

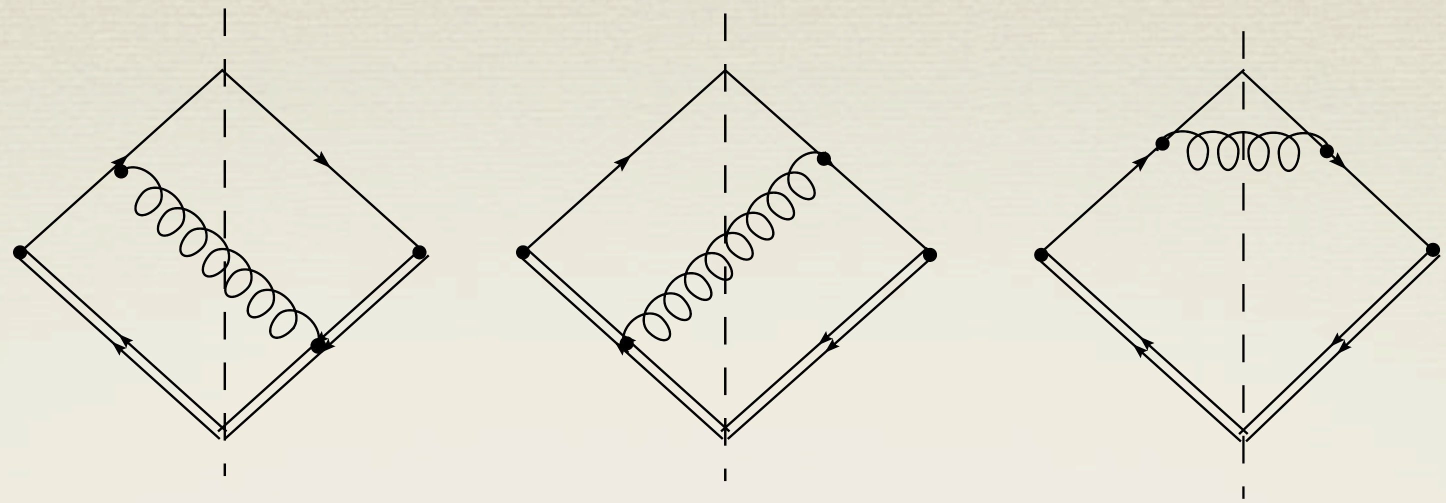
$$J_i^g(m_J^2, p_{0,J_i}, R) = \frac{(2\pi)^3}{2(p_{0,J_i})^3}\sum_{N_{J_i}}\langle 0|\xi_\sigma F^{\sigma\nu}(0)\Phi_\xi^{(g)\dagger}(0,\infty)|N_{J_i}\rangle\langle N_{J_i}|\Phi_\xi^{(g)}(0,\infty)F_\nu^{\ \rho}(0)\xi_\rho|0\rangle$$

$$\times\delta\left(m_J^2 - \tilde{m}_J^2(N_{J_i},R)\right)\delta^{(2)}(\hat{n}-\tilde{n}(N_{J_i}))\delta(p_{0,J_i}-\omega(N_{J_c})).$$

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

Perturbatively Calculable; systematically improvable

Quark Jet Function, in detail...



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

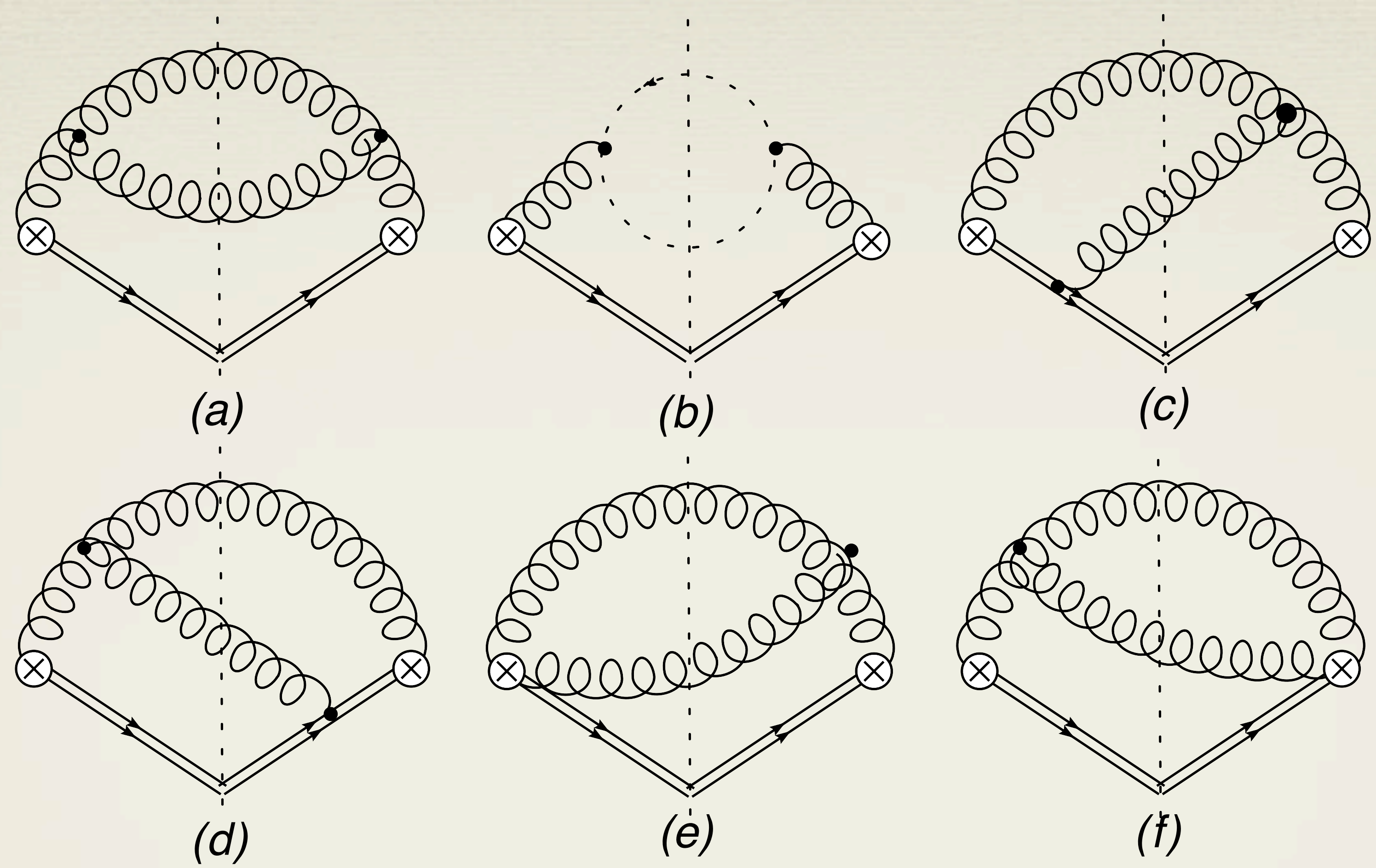
$$z = m_J / p_{0,J_i}$$

θ_S : Angle between Jet axis and softer particle

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

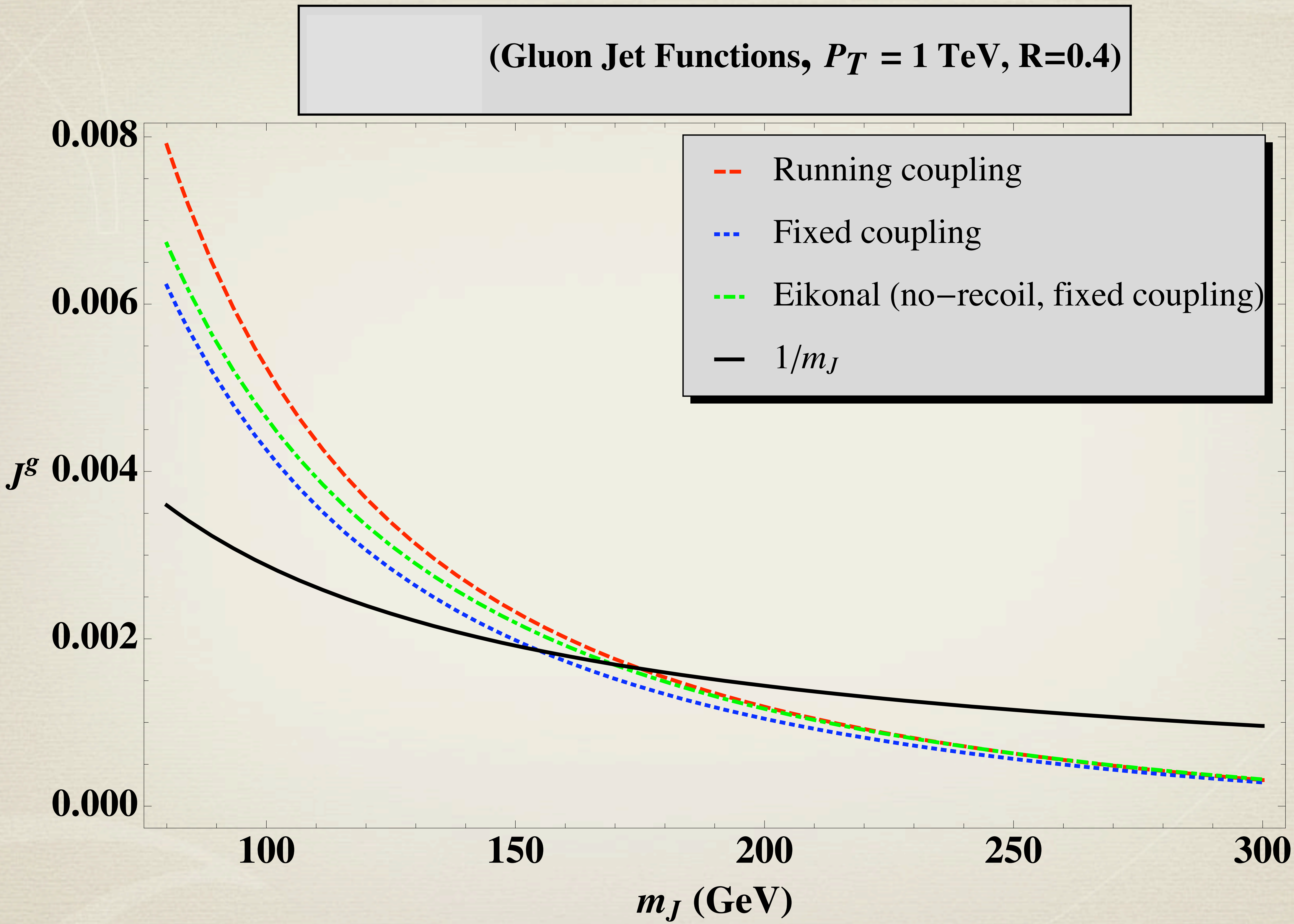
$$k_0 = \frac{p_{0,J}}{2} \frac{z^2}{1 - \beta_i \cos\theta_S}$$

Gluon Jet function in detail...

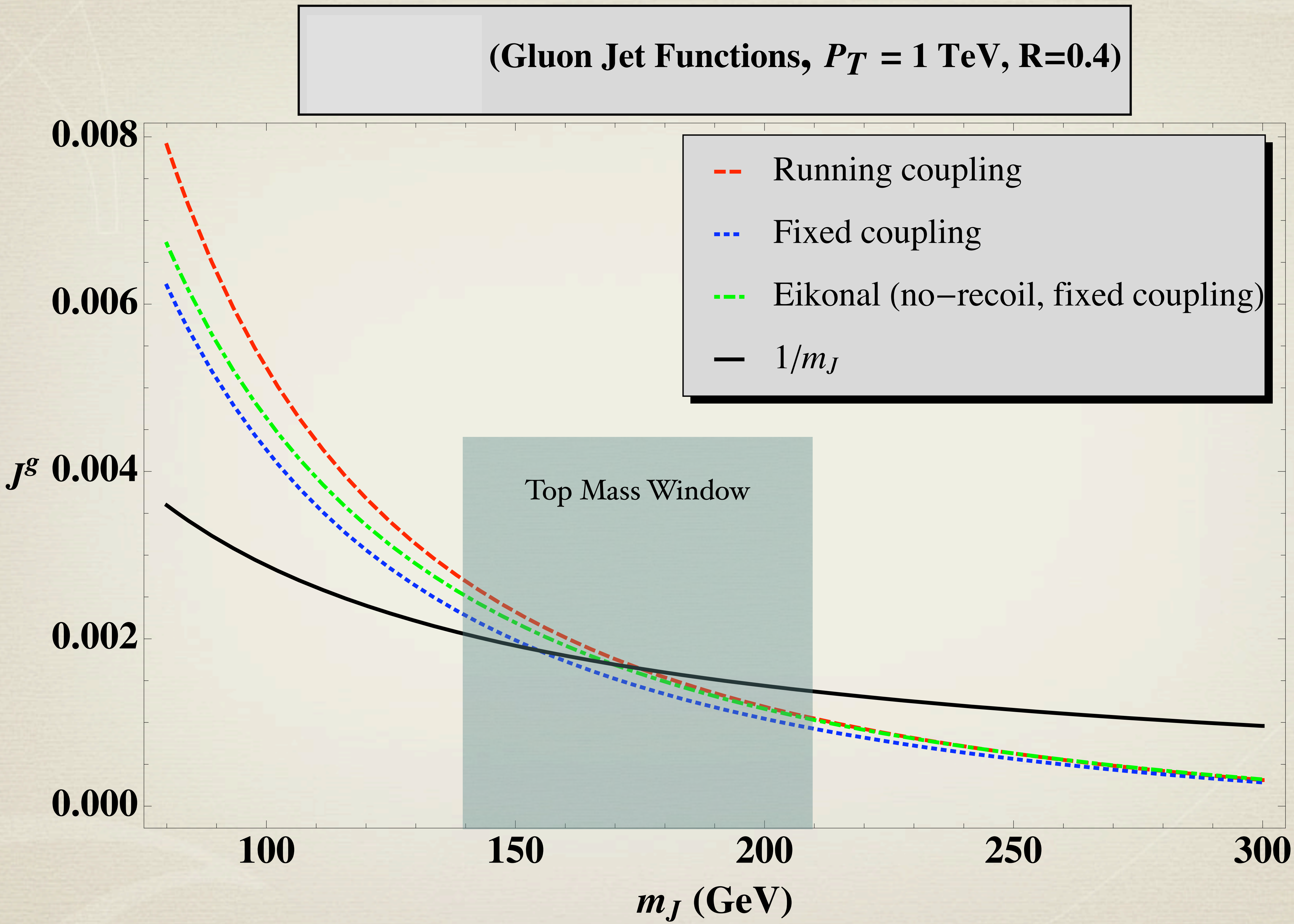


$$J_i^{g(1)}(m_J^2, p_{0,J_i}, R) \;=\; \frac{C_A \beta_i}{16 m_{J_i}^2} \int_{\cos(R)}^{\beta_i} \frac{d\cos\theta_S}{\pi} \frac{\alpha_{\mathrm{S}}(k_0)}{(1-\beta\cos\theta_S)^2(1-\cos^2\theta_S)(2(1+\beta)-z^2)}$$
$$\times\Big(z^4(1+\cos\theta_S)^2 + z^2(1-\cos^2\theta_S)(2(1+\beta_i)-z^2) + (1-\cos\theta_S)^2(2(1+\beta_i)-z^2)^2\Big)^2.$$

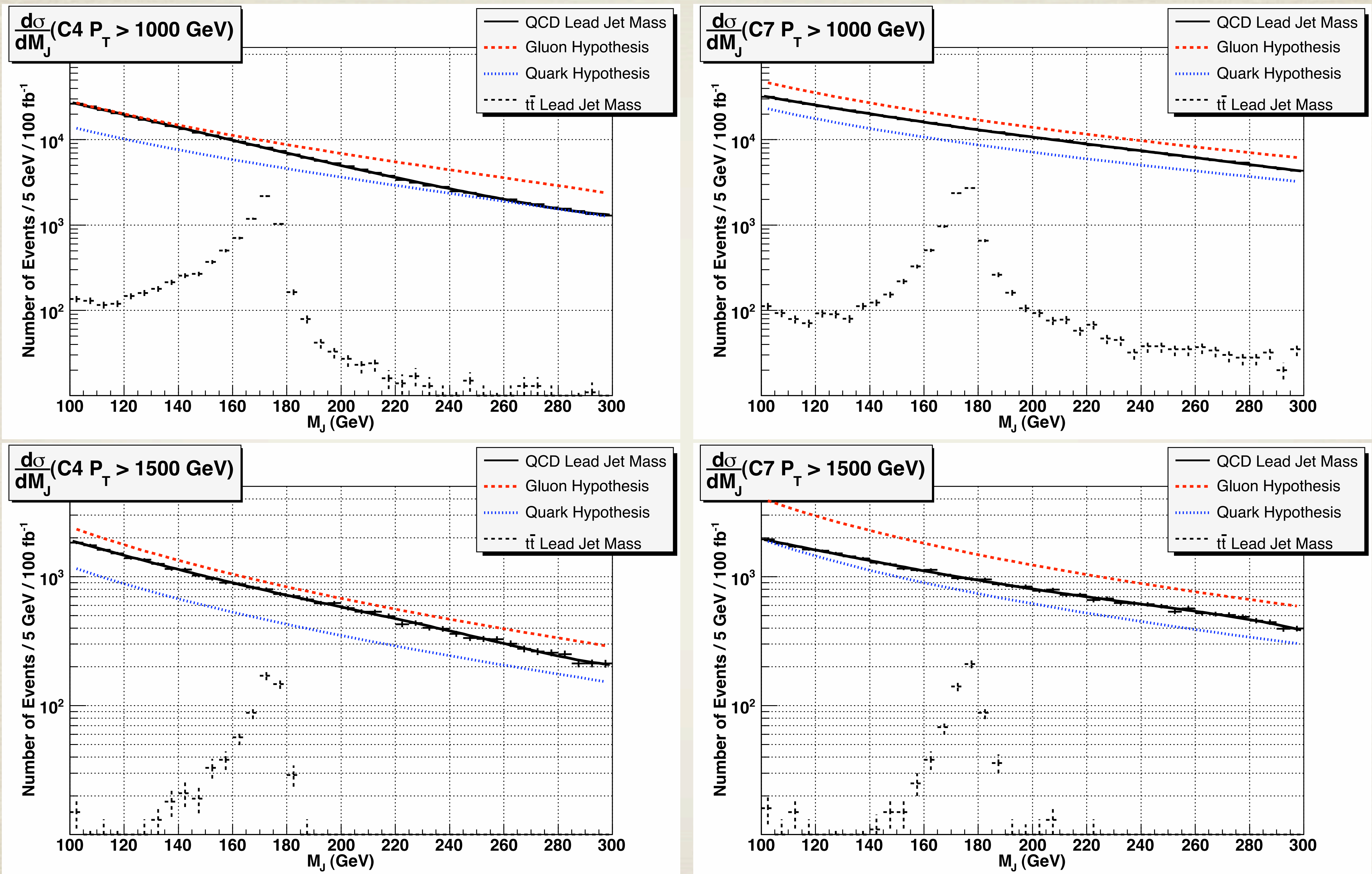
The Importance of the log



The Importance of the log

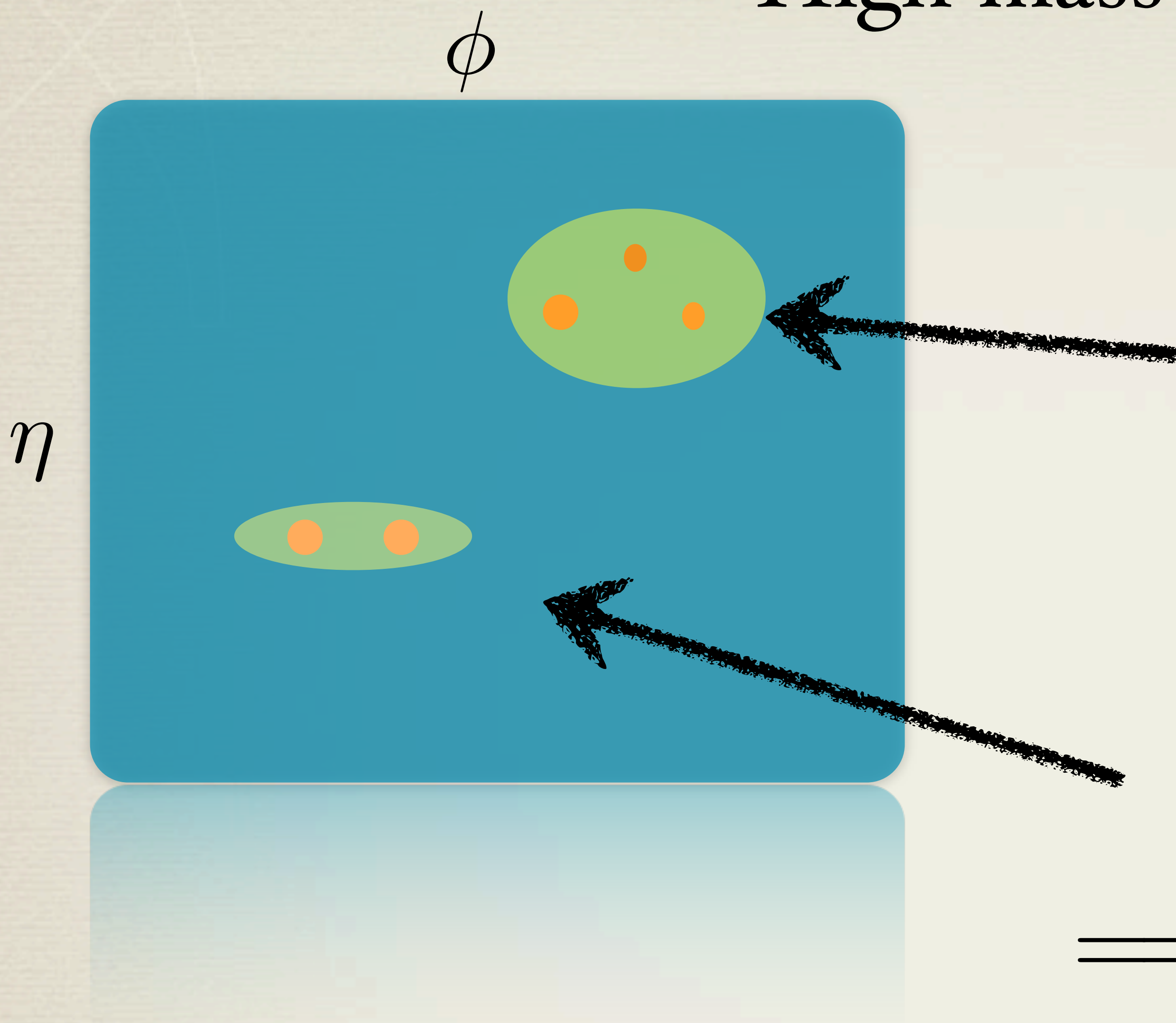


Ex: (from sherpa) Di-Jet Vs. SM $t\bar{t}$



Planar Flow

High mass Jets



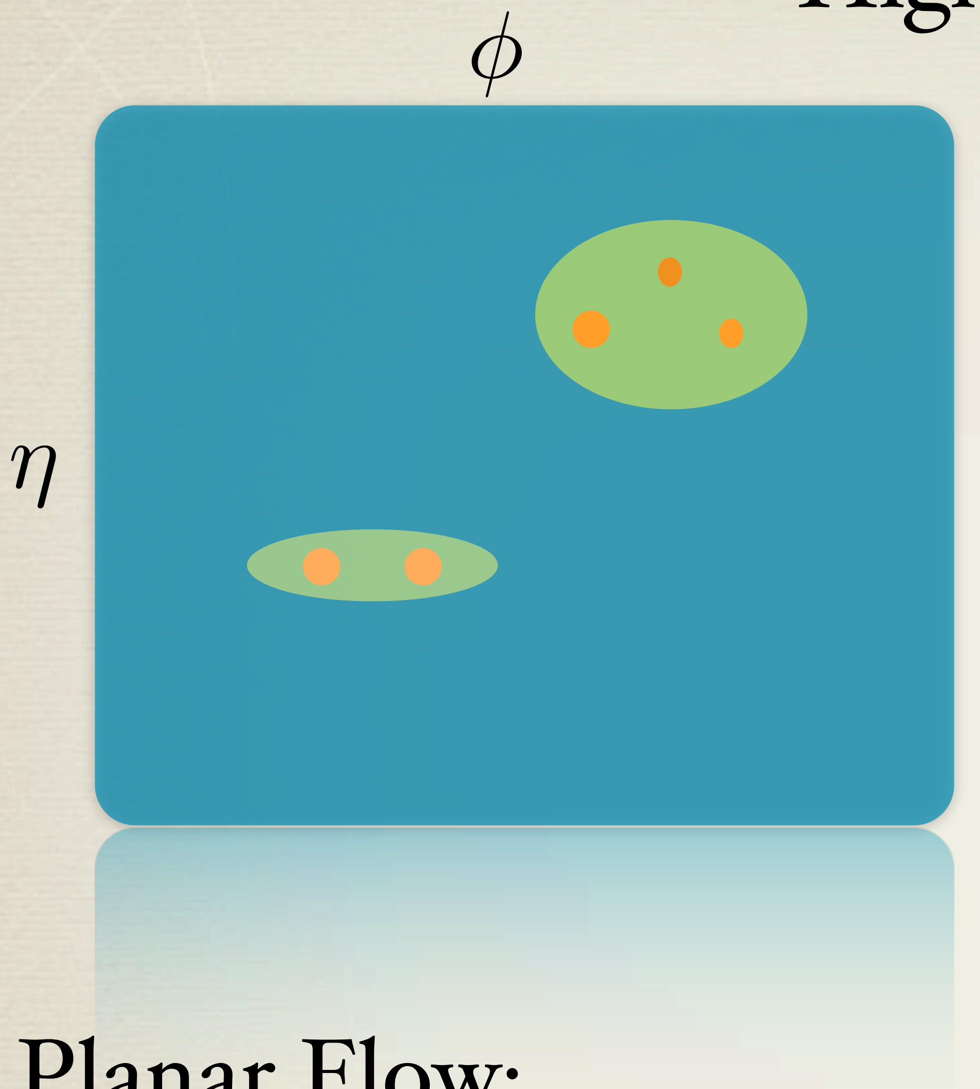
3 body i.e. Top decay

light QCD

$\Longrightarrow$ linear distribution

Planar Flow

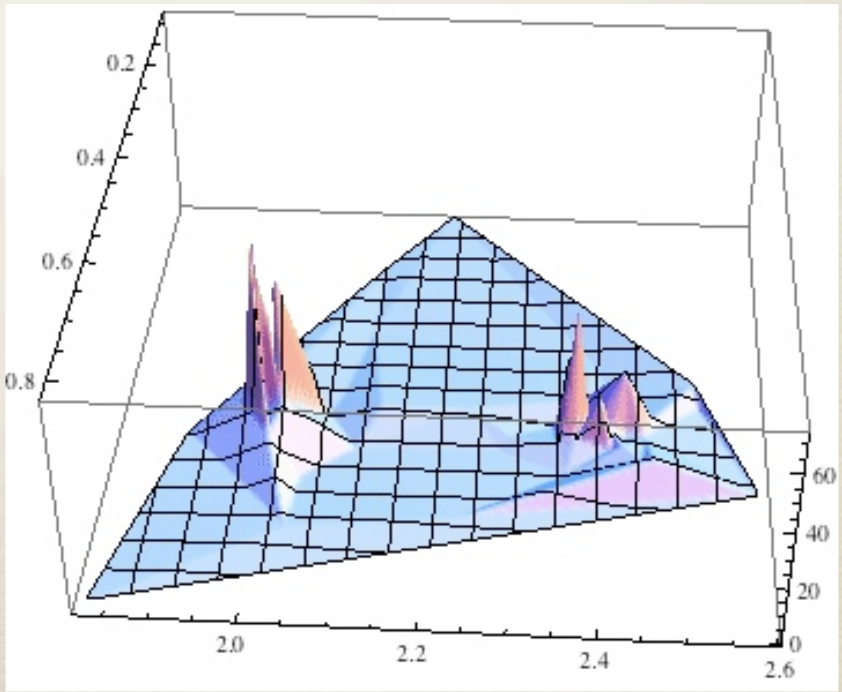
High mass Jets



We can use "inertia" of the distribution

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

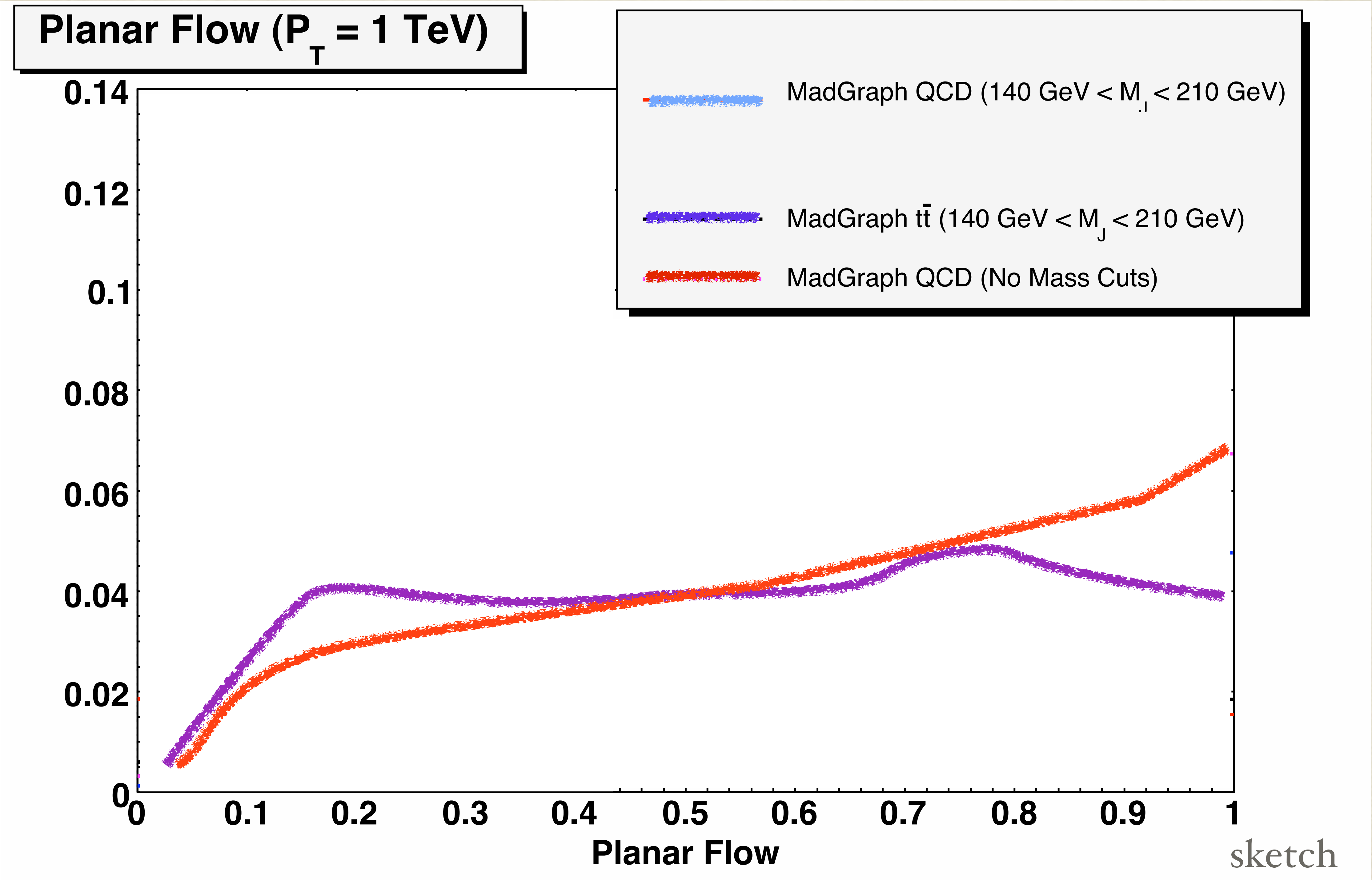
$$\text{linear} \implies Pf = 0$$



Planar Flow:

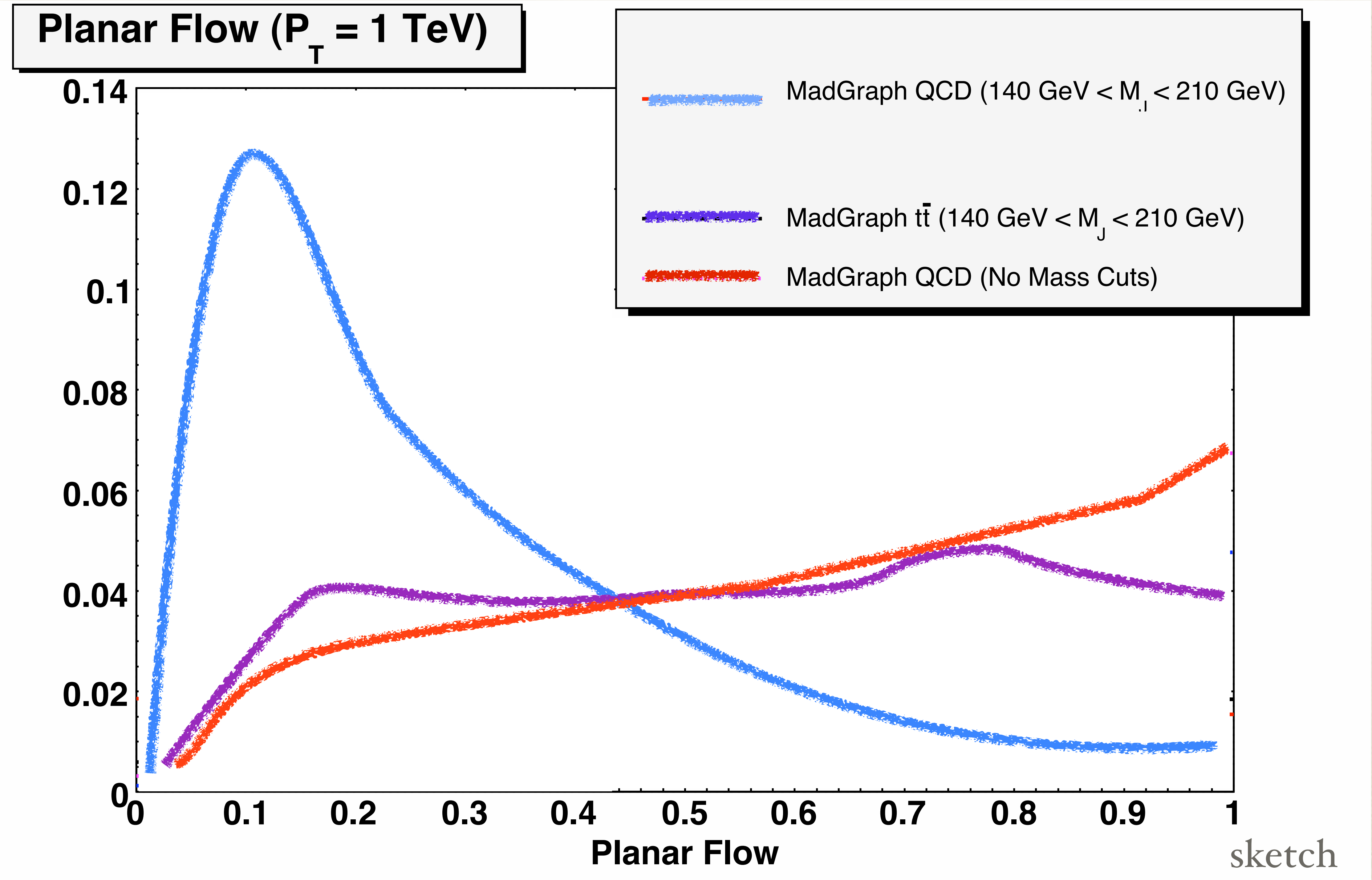
$$Pf = \frac{4\det(I_\omega)}{\mathrm{tr}(I_\omega)^2}$$

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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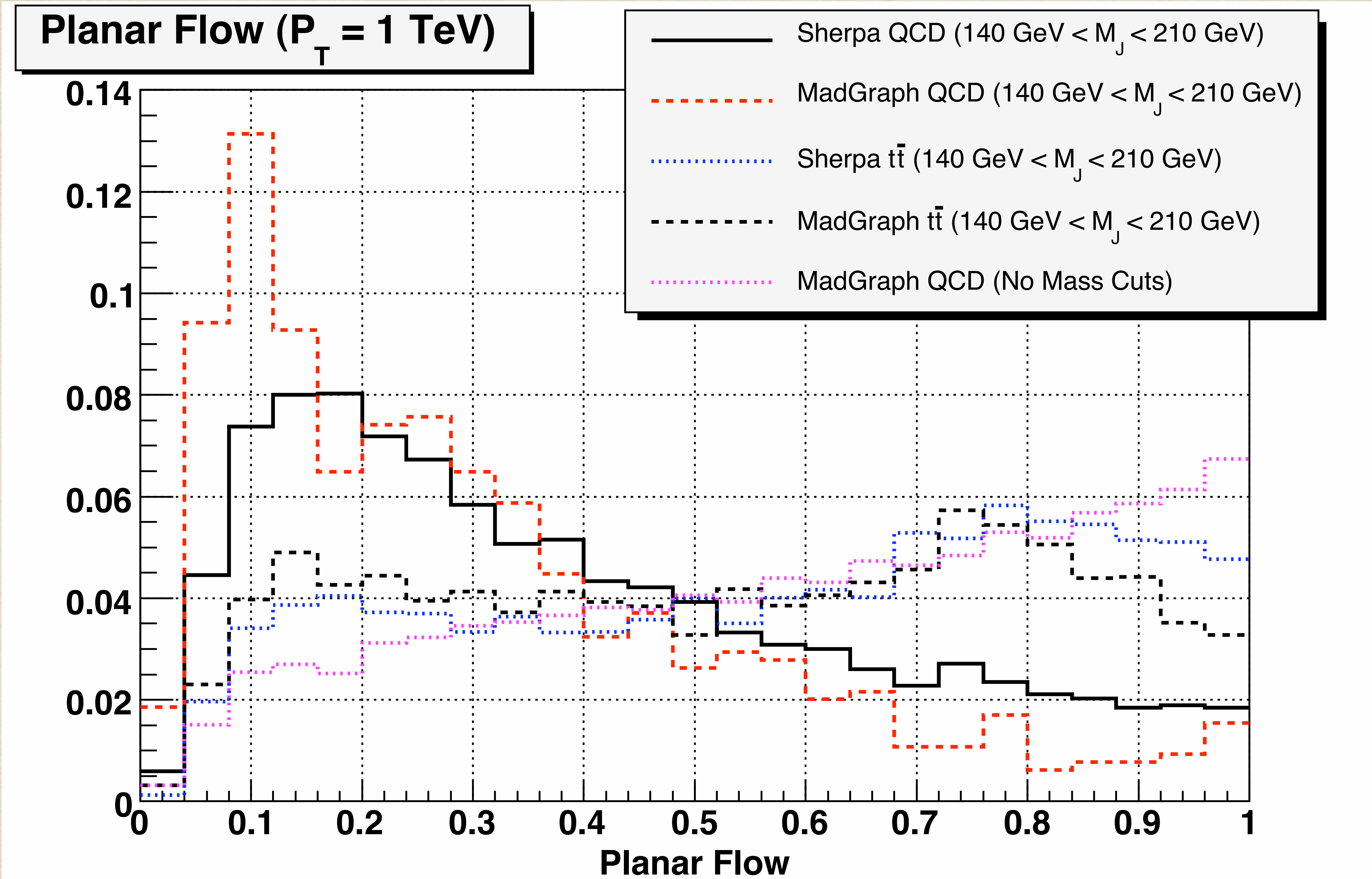
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Planar Flow
sketch

Planar Flow



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

Summary

Jet functions provide a systematic approach to describe the jet mass background

A Careful understanding of the structure of Background and Signal allows us to develop observables that are "tuned" to the substructure of the final states.

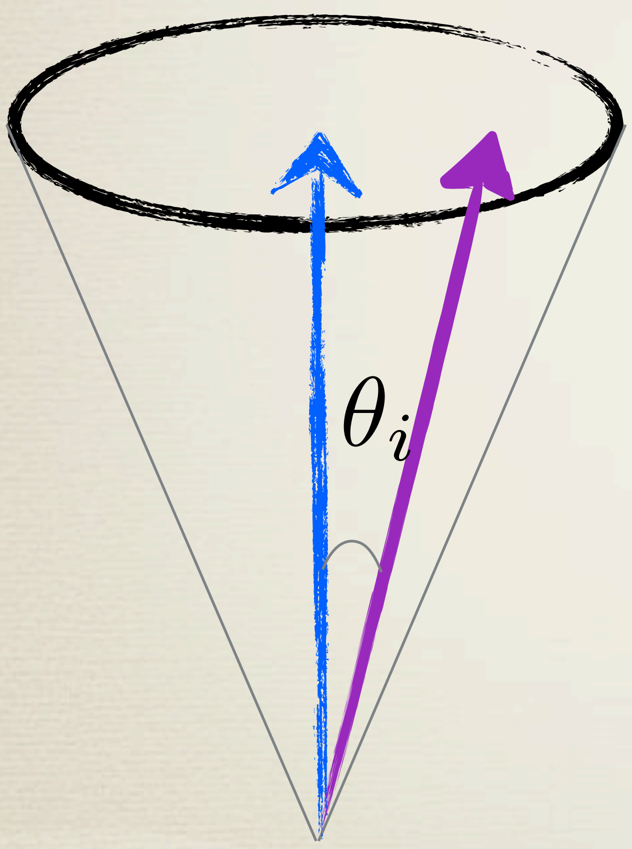
i.e. Planar Flow

In the case of Top distribution, building a probe function or event shape (On going)

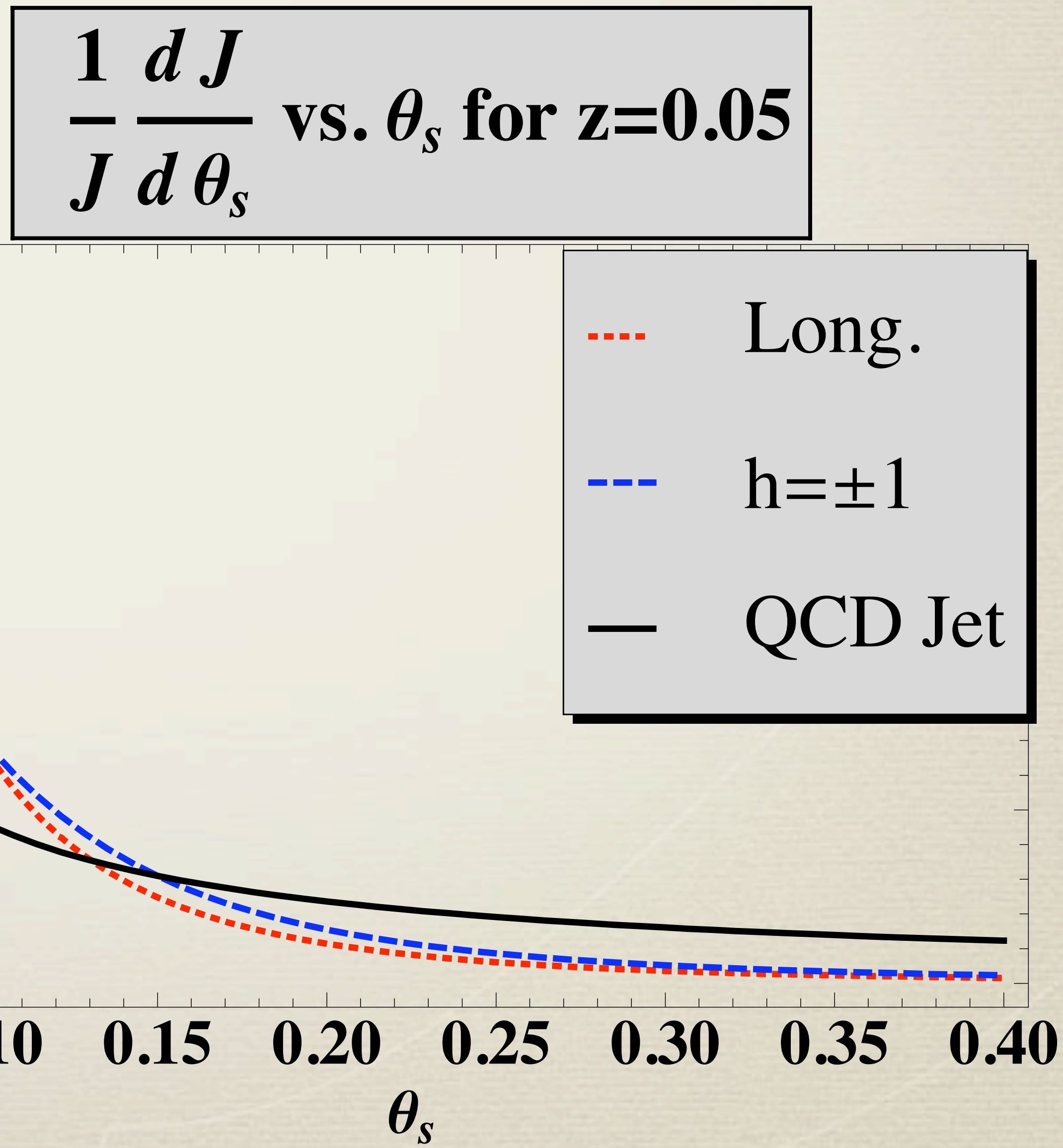
Angularities

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

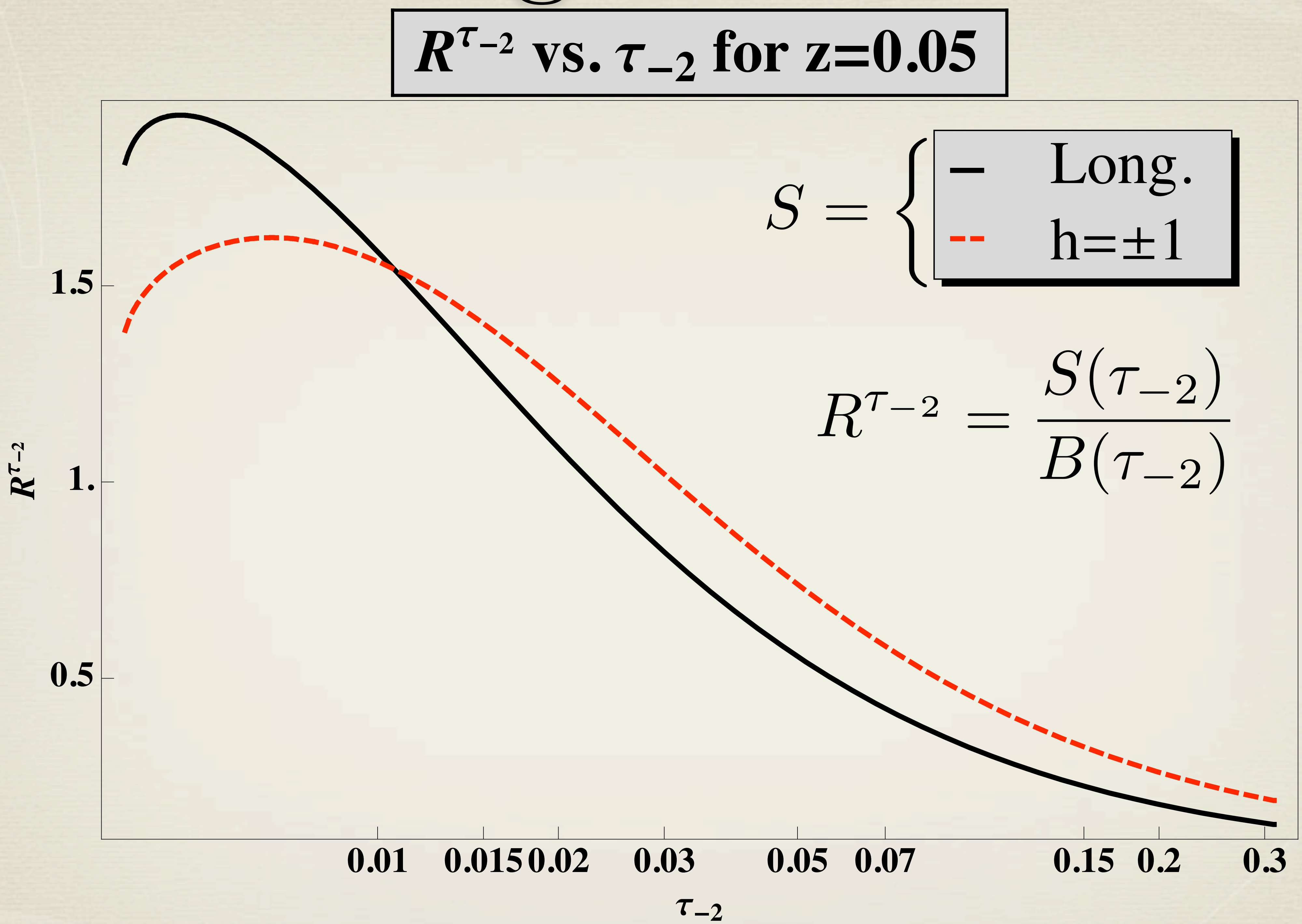
$$\tau_a = \frac{1}{m_J} \sum_i \omega_i \sin^a\left(\frac{\pi\theta_i}{2R}\right) \left[1 - \cos\left(\frac{\pi\theta_i}{2R}\right)\right]^{1-a}$$



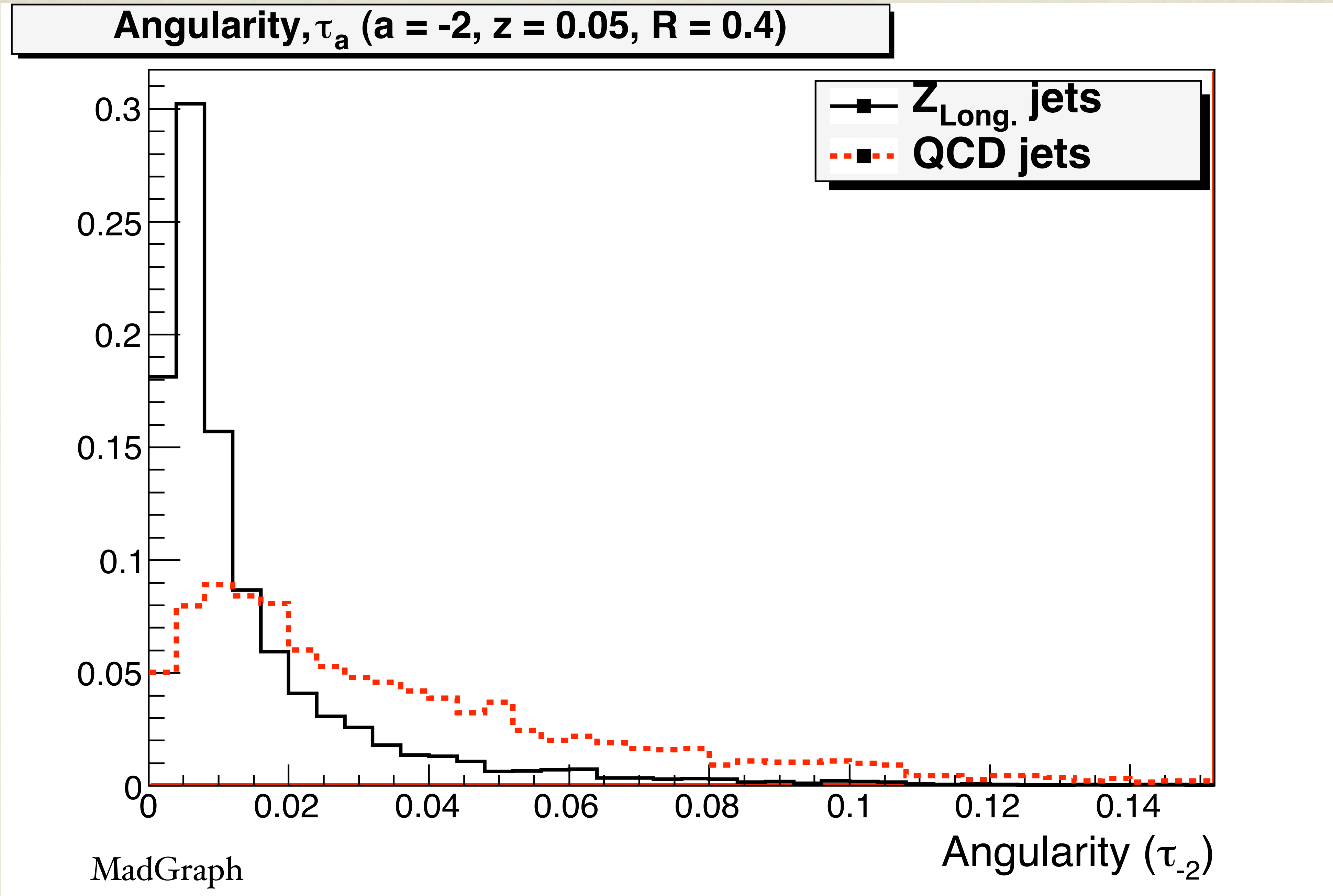
Gauge Boson Decays



Angularities



Angularities in MC



Linear Top Decay