Top Jets & Boosted QCD Jets @ the LHC

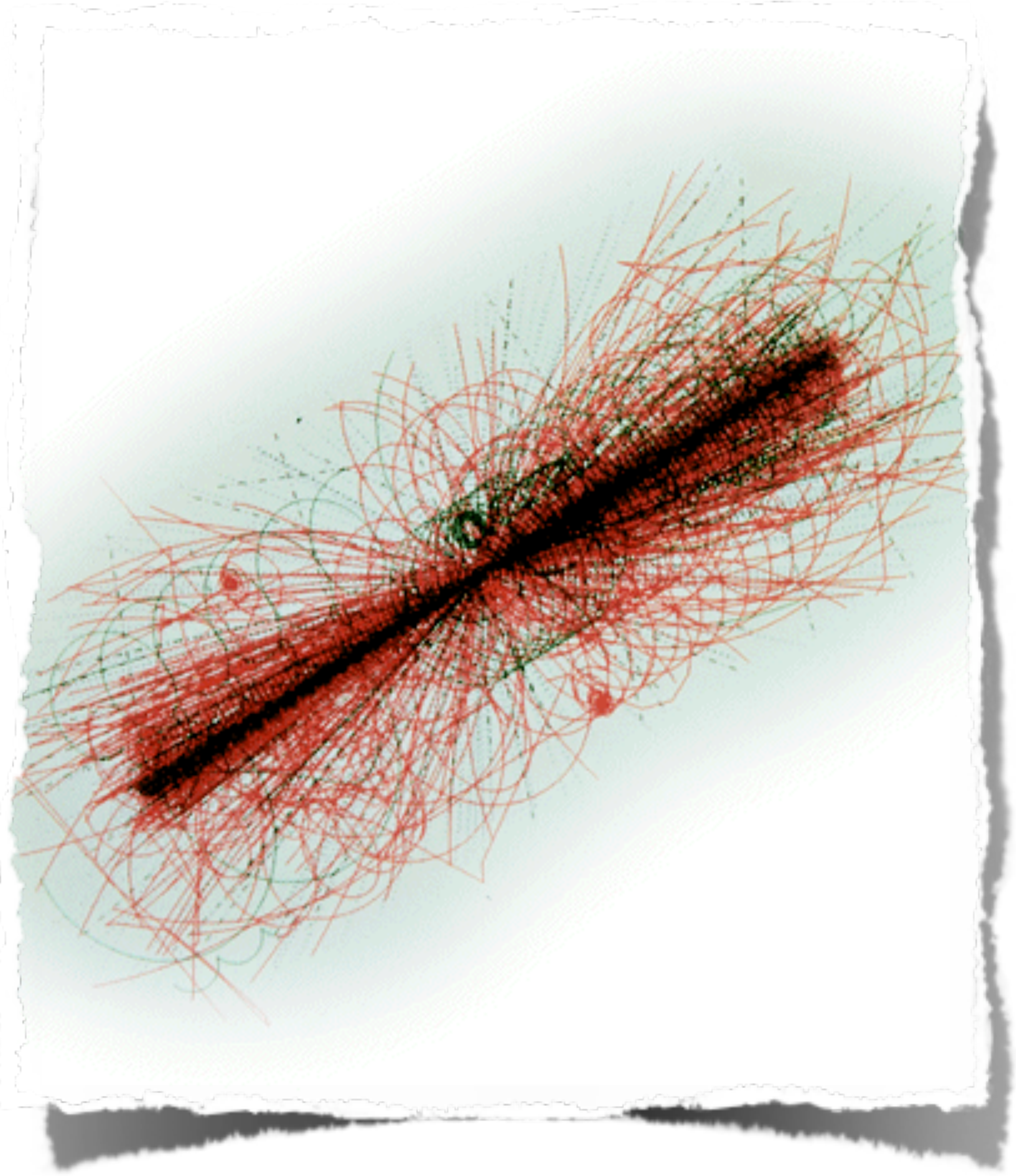
Seung J. Lee
YITP, Stony Brook University

with L. Almeida, G. Perez, G. Sterman, I. Sung, J. Virzi
with L. Almeida, G. Perez, I. Sung, J. Virzi

arXiv:0807.0234, work in preparation
Cornell University, September 3, 2008

Outline

- Introduction
- Emergence of high p_T top (W,Z,h) jets at the LHC
- Jet mass: Signal & QCD BG (theory+MC)
- Jet substructure, massive jet event shapes
- Top polarization
- Summary



Introduction

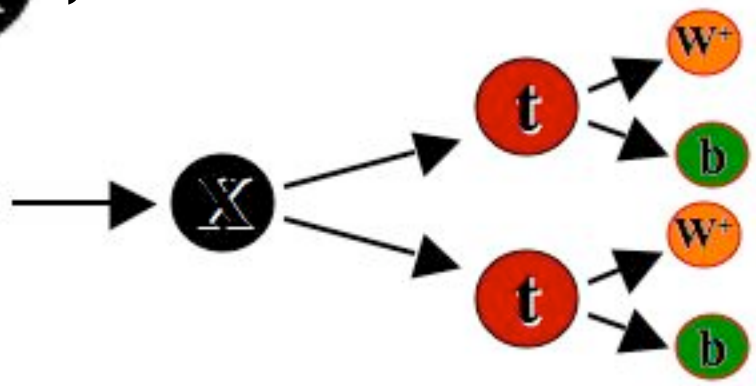
- In the SM (& beyond) top is unique:
  only ultra heavy quark, $m_t \sim \langle H \rangle$
  induce most severe fine tuning;
  controls flavor & custodial violation;
  linked to EW breaking in natural models.

Introduction

- In the SM (& beyond) top is unique:
  only ultra heavy quark, $m_t \sim \langle H \rangle$
  induce most severe fine tuning;
  controls flavor & custodial violation;
  linked to EW breaking in natural models.
- Direct info' is limited (Tevatron)
- At the LHC: 10^7 top/yr
- SM: more than 10^4 top/yr with $\gamma_t \geq 5.$

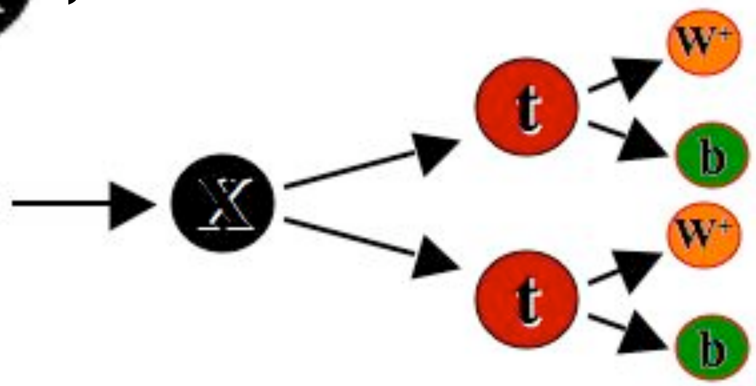
The challenge of highly boosted tops

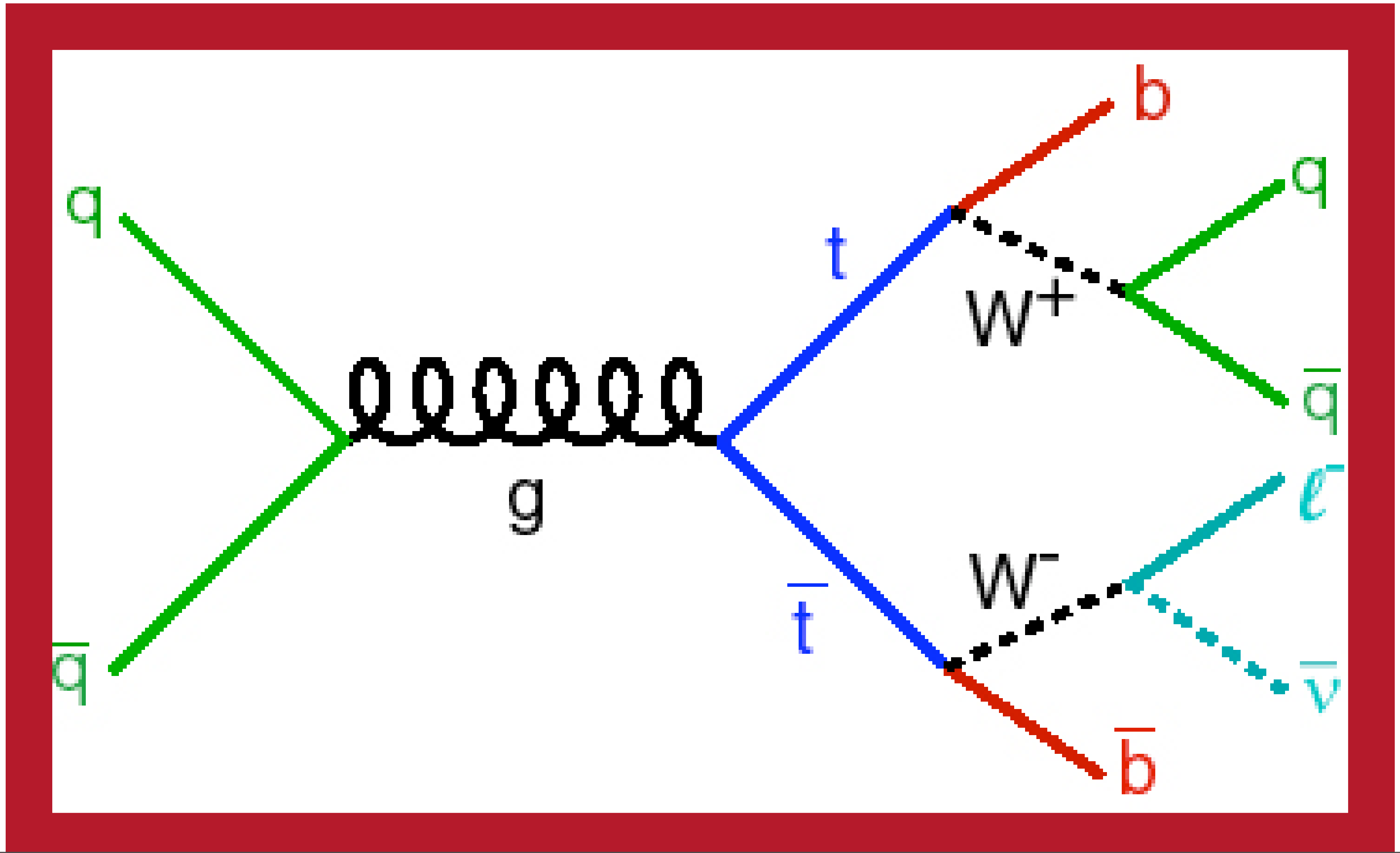
- First, let's consider NP particle  , whose dominant decay channel is ttbar: X might be heavy



The challenge of highly boosted tops

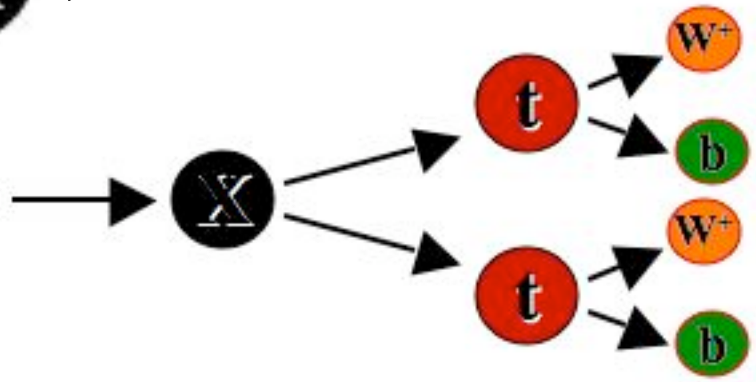
- First, let's consider NP particle  , whose dominant decay channel is ttbar: X might be heavy



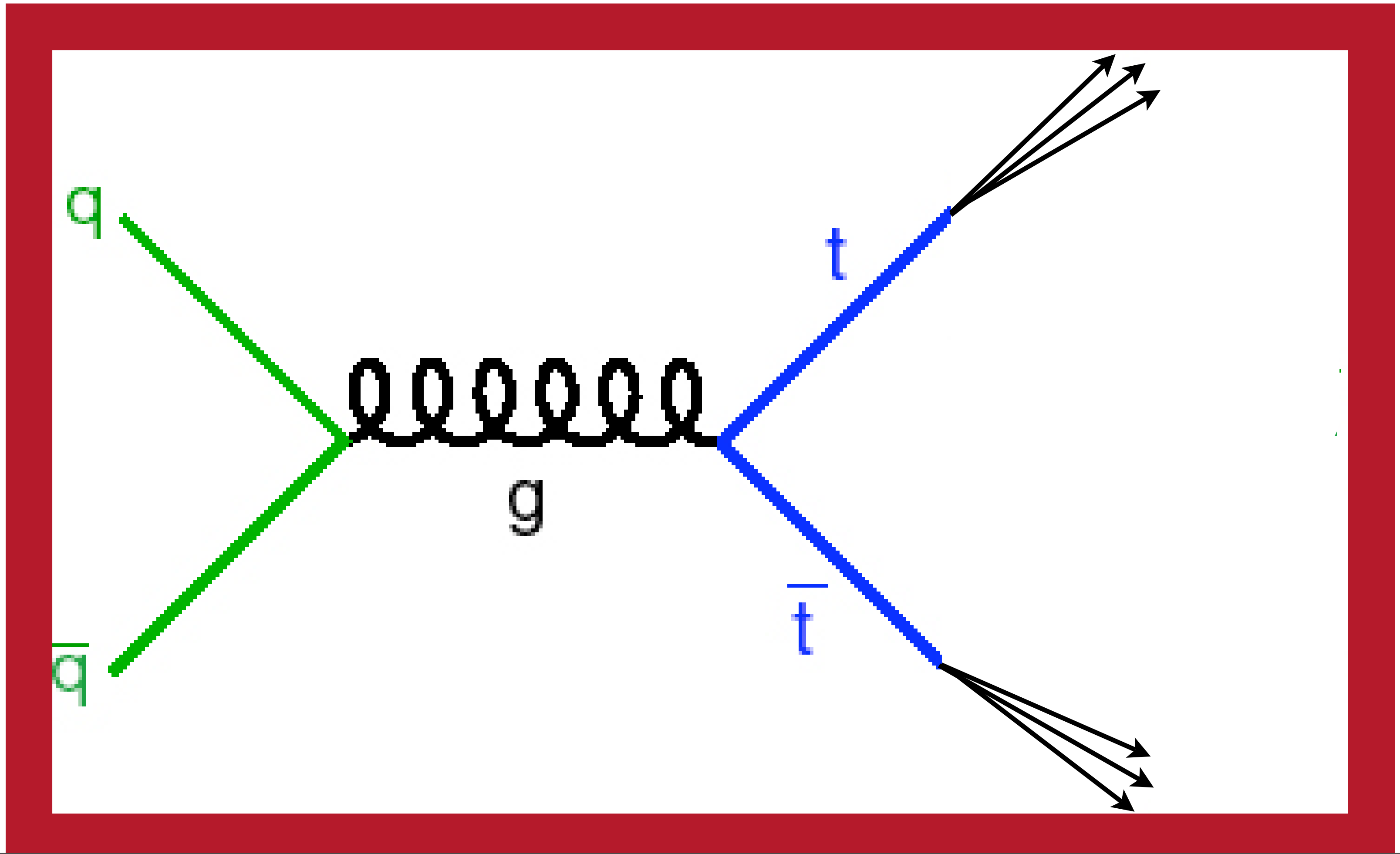


The challenge of highly boosted tops

- First, let's consider NP particle  , whose dominant decay channel is ttbar: X might be heavy



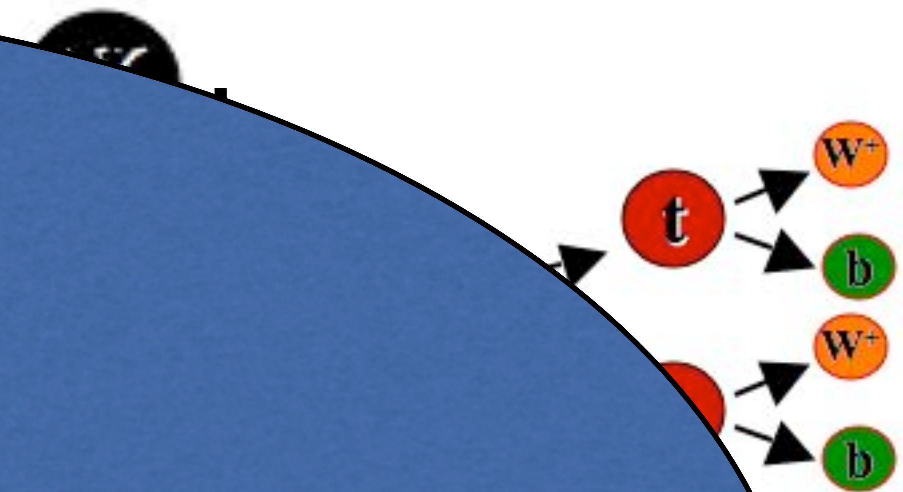
- Alas, above a TeV, top becomes similar to a light jet, signal is **lost**!



The challenge of highly boosted tops

- First, let's co
whose
tth

ght



New object emerges,
top jet!

Resolution problem \w boosted tops

- The hadronic calorimeters cannot go below R~0.4 $R^2 = \Delta\eta^2 + \Delta\phi^2$

Resolution problem \w boosted tops

- The hadronic calorimeters cannot go below R~0.4 $R^2 = \Delta\eta^2 + \Delta\phi^2$

Why: Hadronic granularity is R~ 0.1 x 0.1

$$m^2 = (p_1 + p_2)^2 \sim 2p^2[1 - (1 - R^2/2)] = p^2 R^2$$

pure geometrical mass: $m \sim R\,p$

(say with $R, p = 0.2, 500$, $m \sim 100\text{GeV}$)

Resolution problem \w boosted tops

- The hadronic calorimeters cannot go below R~0.4 $R^2 = \Delta\eta^2 + \Delta\phi^2$

Why: Hadronic granularity is R~ 0.1 x 0.1

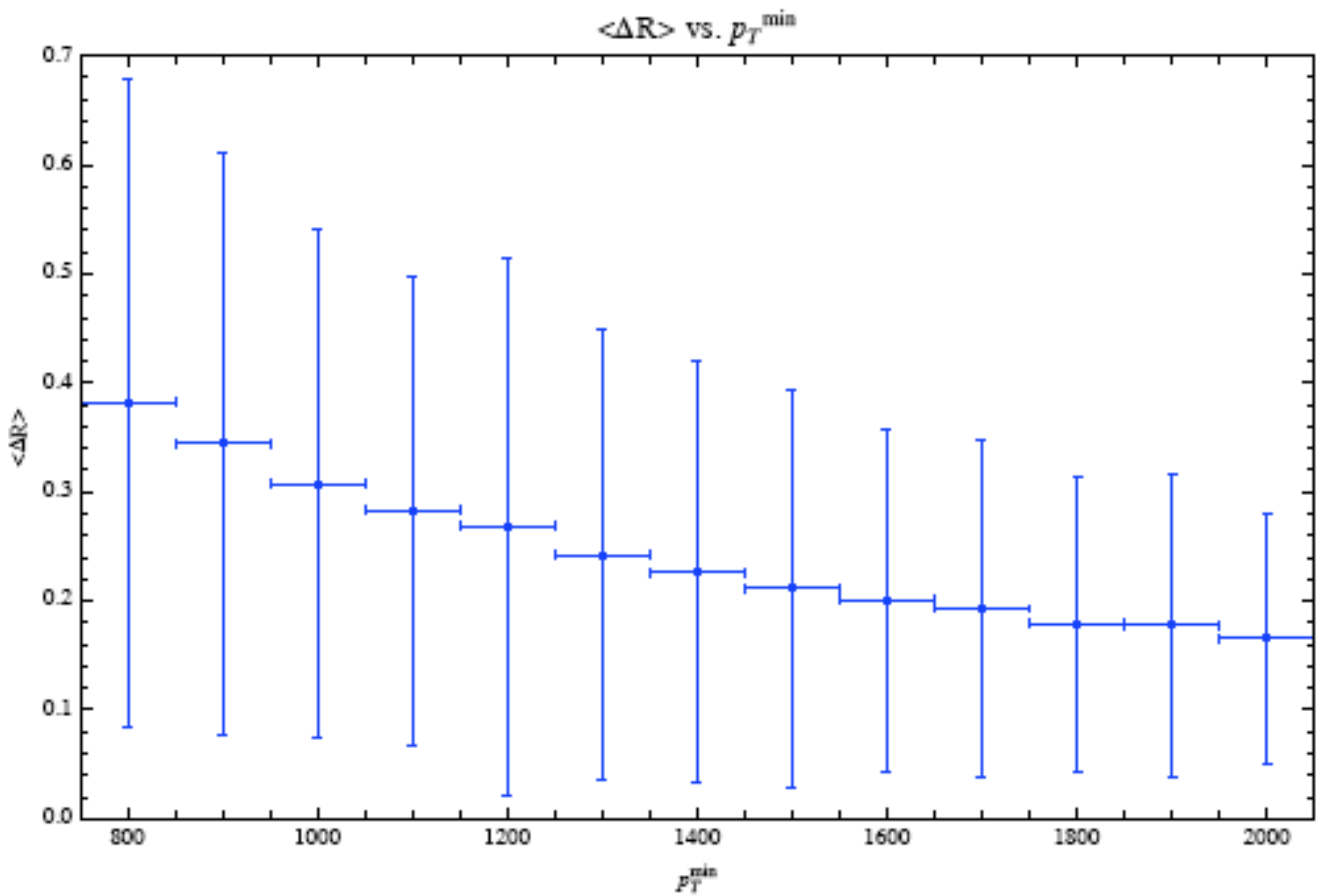
$$m^2 = (p_1 + p_2)^2 \sim 2p^2[1 - (1 - R^2/2)] = p^2\, R^2$$

pure geometrical mass: $m \sim R\,p$

(say with $R, p = 0.2, 500\,,\ m \sim 100\text{GeV}$)

- If R between decay products of top is smaller than 0.4, you cannot resolve the top into daughter jets. (top jet = single jet)

Boosted top (w/z/h) jets & collimation



Partonic Level

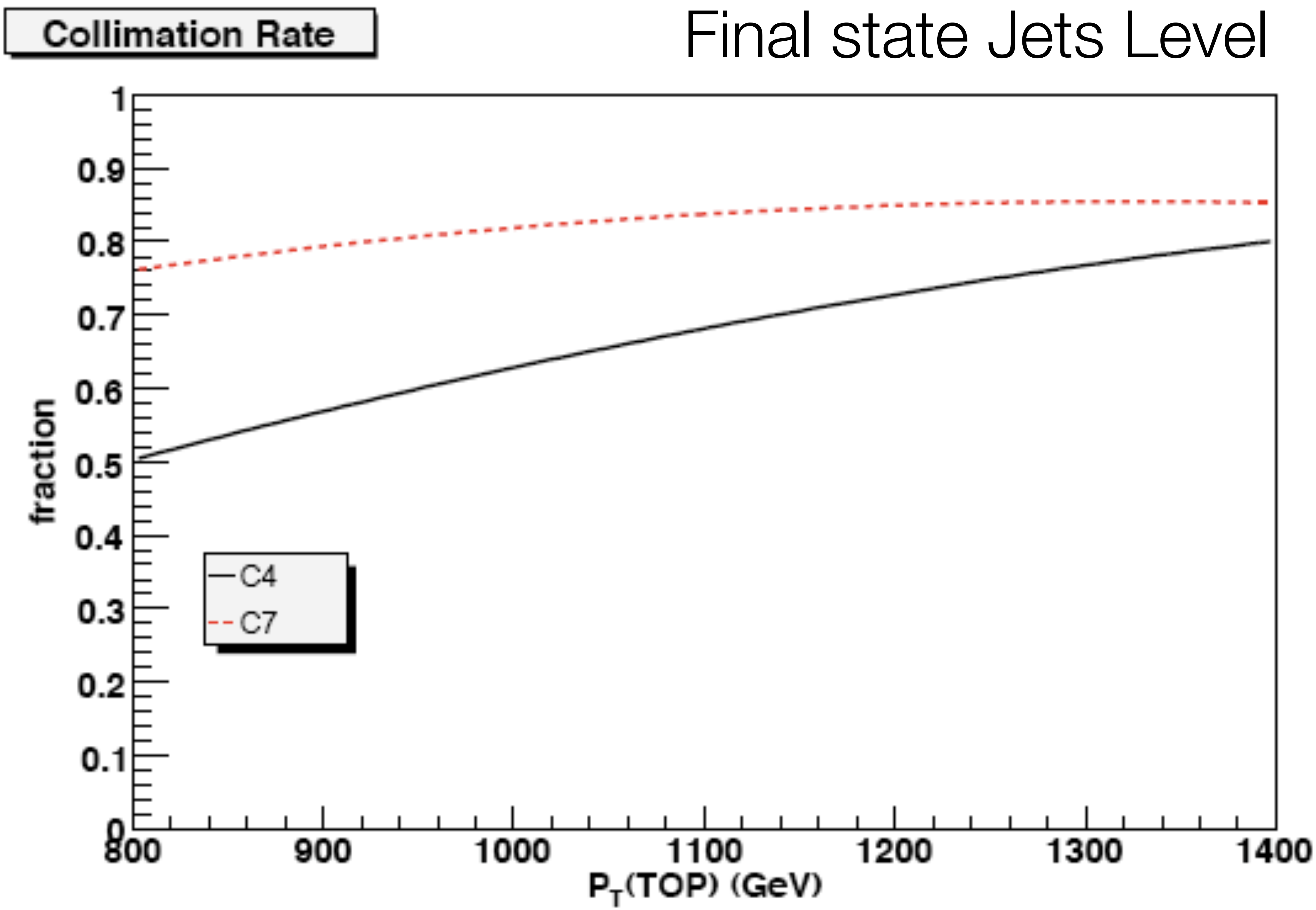
Highly Boosted Tops:
High Collimations!

ΔR vs. P_T

$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

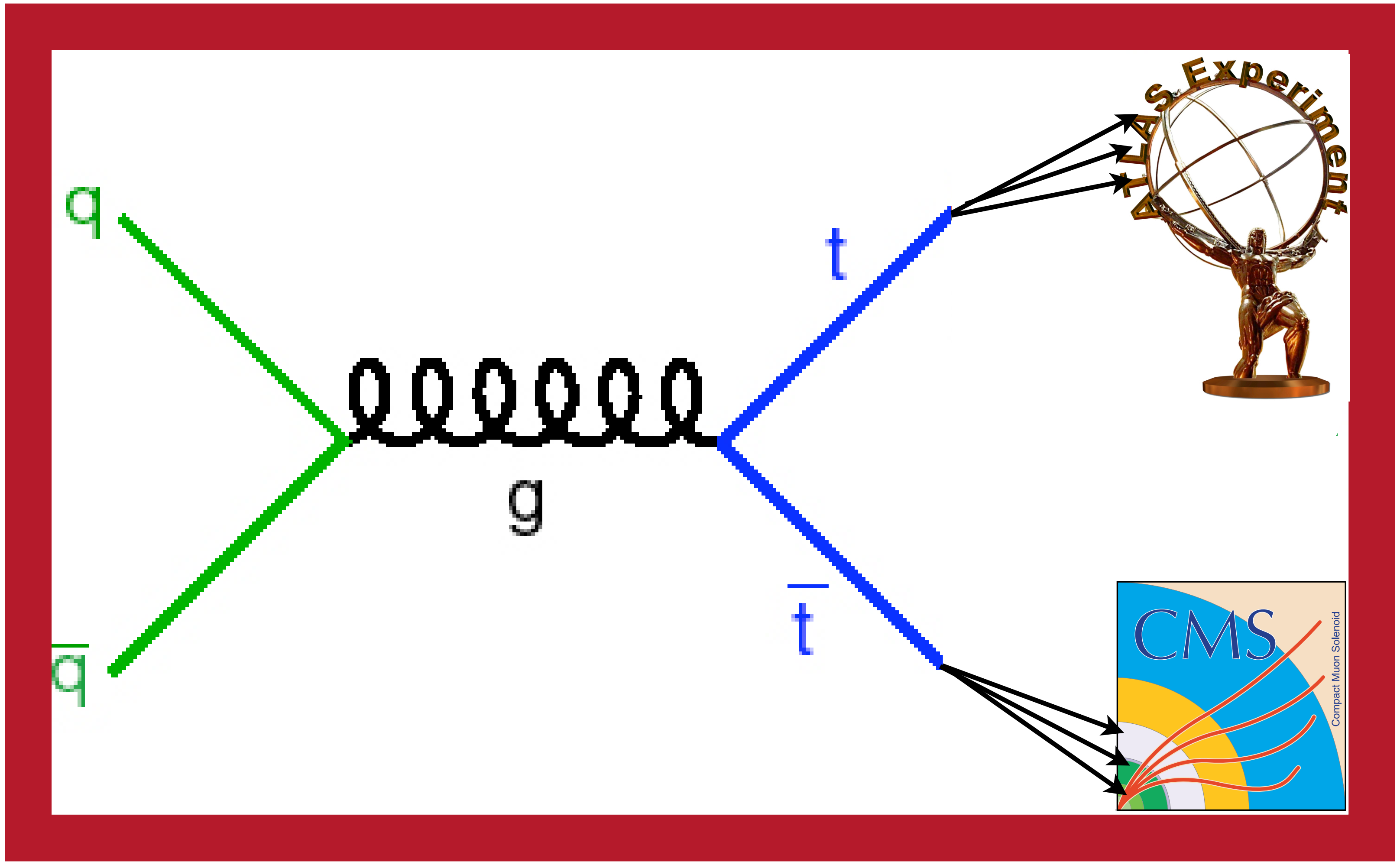
Boosted top (w/z/h) jets & collimation

Final state Jets Level



Top jets at the LHC

Top jets at the LHC



(i) Jet mass.
(ii) Jet substructure.

Top-jets @ the LHC

- Are they different from high p_T light jets?

  S/B~1/140, for $p_T(j)$ >1000 GeV, R=0.4
  (~20 pb for jj+X, ~140 fb for ttbar+X)

- top-jet: call for theory, analysis & techniques

  Most (naive) direct attempt - mass tagging

Skiba &Tucker-Smith, PRD(07); Holdom, JHEP (07); Frederix & Maltoni (0712.2355)*; Ellis, Huston, Hatakeyama, Loch & Tonnesmann, PPNP (08); Agashe et. al. PRD(07).*

Rejection based on jet mass

- Jet cone mass-sum of "massless" momenta in h-cal inside the cone: $m_J^2 = (\sum_{i \in R} P_i)^2, \; {}_{Pi^2 = 0}$

- Jet cone mass is non-trivial both for S & B

- Understand S&B distributions from 1st principles & compare to MC "data"

- Add detector effects

Cone top-jet mass distribution

- Naively the signal is $J \propto \delta(m_J - m_t)$
- In practice: $m_J^t \sim m_t + \delta m_{QCD} + \delta m_{EW}$

  + detector smearing.

$$J^t(m_J, m_t, R, p_T) \sim \int dm_{QCD}\, dm_{EW}\, dm_0\, \delta(m_0 - m_t)\, \delta(m_J - m_{QCD} - m_{EW}) \times$$
$$J^t_{QCD}(m_{QCD}, R, p_T) \times J^t_{EW}(m_{EW}, m_t/(p_T R))\,.$$

Cone top-jet mass distribution

- Naively the signal is $J \propto \delta(m_J - m_t)$
- In practice: $m_J^t \sim m_t + \delta m_{QCD} + \delta m_{EW}$

Can understood perturbatively fast & small~10GeV

+ detector smearing.

$$J^t(m_J, m_t, R, p_T) \sim \int dm_{QCD}\, dm_{EW}\, dm_0\, \delta(m_0 - m_t)\, \delta(m_J - m_{QCD} - m_{EW}) \times J^t_{QCD}(m_{QCD}, R, p_T) \times J^t_{EW}(m_{EW}, m_t/(p_T R)) .$$

Cone top-jet mass distribution

- Naively the signal is $J \propto \delta(m_J - m_t)$
- In practice: $m_J^t \sim m_t + \delta m_{QCD} + \delta m_{EW}$

Can understood perturbatively fast & small~10GeV

+ detector smearing.

Pure kinematical bW(qq) dist' in/out cone much longer

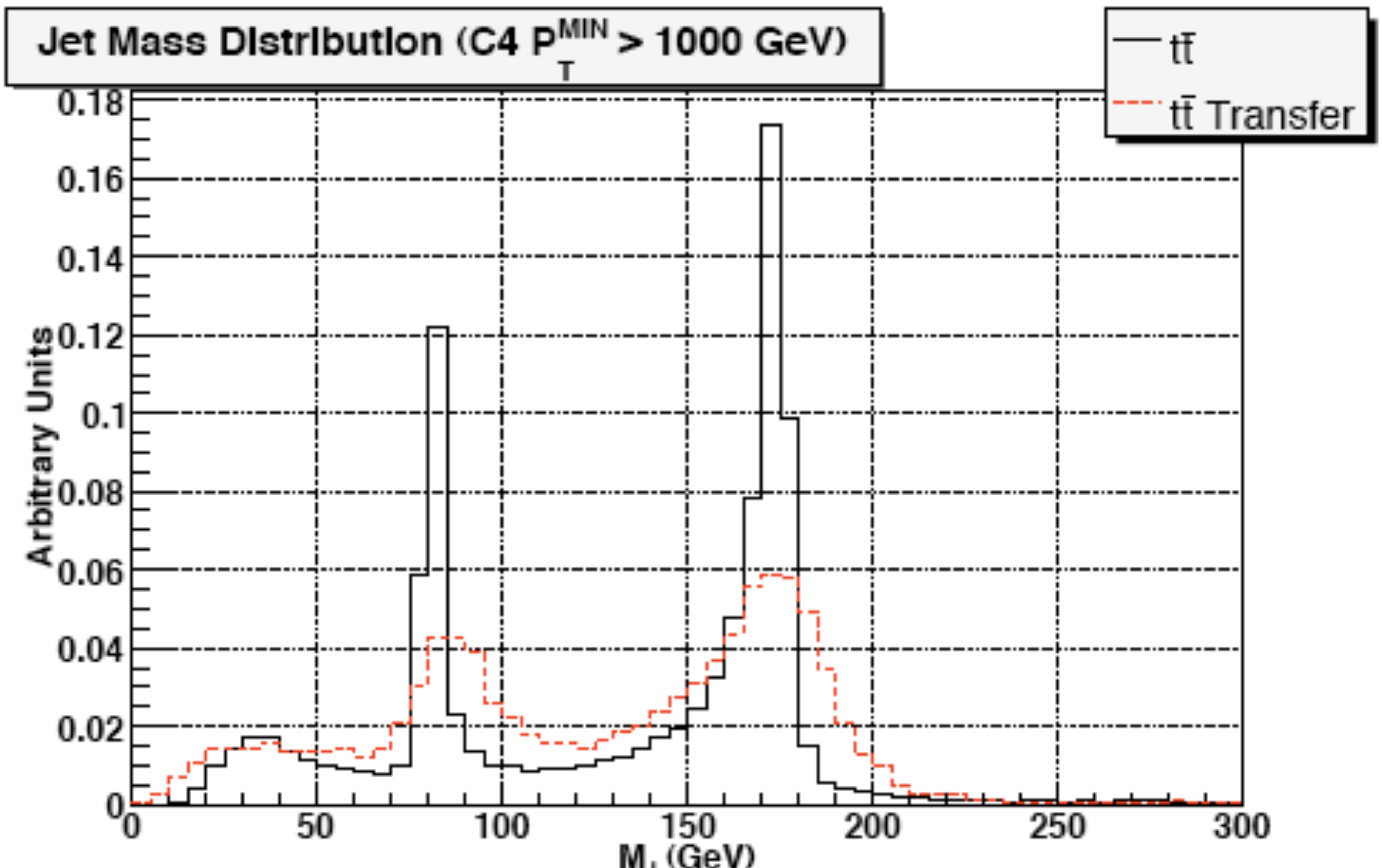
$J^t(m_J, m_t, R, p_T) \sim \int dm_{QCD}\, dm_E \ldots {}_{EW}) \times$

$J^t_{QCD}(m_{QCD}, R, p \ldots$

Cone top-jet mass distribution

Sherpa => Full Simulation
(CKKW)

Preliminary (Transfer function “Full Simulation”)



QCD cone jet mass distribution

We are interested in the following processes:

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

$$H_a(p_a) + H_b(p_b) \to J_1(m_{J_1}^2, p_{1,T}, R) + J_2(m_{J_2}^2, p_{2,T}, R) + X$$

QCD cone jet mass distribution

We are interested in the following processes:

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

$$H_a(p_a) + H_b(p_b) \to J_1(m_{J_1}^2, p_{1,T}, R) + J_2(m_{J_2}^2, p_{2,T}, R) + X$$

Factorized hadronic cross section:

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

QCD cone jet mass distribution

We are interested in the following processes:

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

$$H_a(p_a) + H_b(p_b) \to J_1(m_{J_1}^2, p_{1,T}, R) + J_2(m_{J_2}^2, p_{2,T}, R) + X$$

Factorized hadronic cross section:

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

PDF

Hard perturbative (Born) cross-section

At the leading order

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

Jet function

QCD cone jet mass distribution

Boosted QCD Jet via factorization:

$$\int dm_J \, J^c = 1$$

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

where c represents the flavour of the jet, and where

$$\frac{d\hat{\sigma}^c(R)}{dp_T} = \sum_{ab} \int dx_a \, dx_b \, \phi_a \, \phi_b \int d\eta \int dm_J \, \frac{d\hat{\sigma}_{ab\to cX}(R)}{dp_T dm_J d\eta}.$$

QCD cone jet mass distribution

Boosted QCD Jet via factorization:

$$\int dm_J \, J^c = 1$$

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

where c represents the flavour of the jet, and where

$$\frac{d\hat{\sigma}^c(R)}{dp_T} = \sum_{ab} \int dx_a \, dx_b \, \phi_a \, \phi_b \int d\eta \int dm_J \, \frac{d\hat{\sigma}_{ab \to cX}(R)}{dp_T dm_J d\eta}.$$

Contact with Data (MC):

$$\frac{d\sigma_{pred}(R)}{dp_T dm_J} = \sum_c J^c(m_J, p_T, R) \left(\frac{d\sigma^c(R)}{dp_T} \right)_{MC}$$

QCD cone jet mass distribution

Boosted QCD Jet via factorization:

$$\int dm_J \, J^c = 1$$

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

whe ... t, and where

$$\phi_a \, \phi_b \int d\eta \int dm_J \, \frac{d\hat{\sigma}_{ab\to cX}(R)}{dp_T dm_J d\eta}.$$

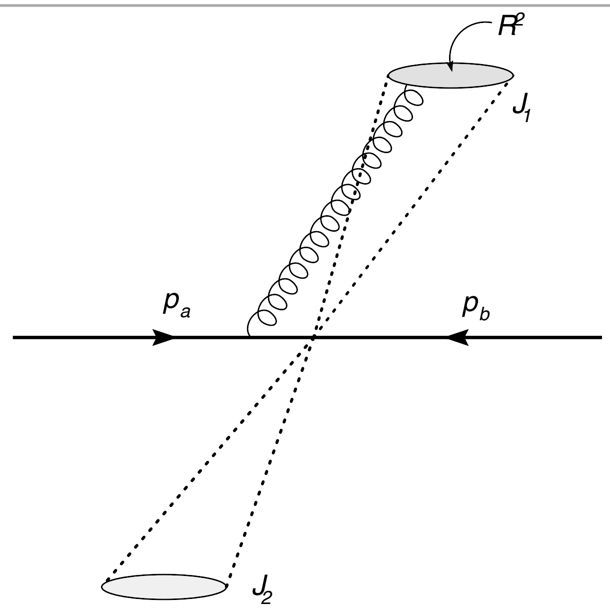
):

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

For large jet mass & small R,
no large logs =>
J^i can be calculated via
perturbative QCD!

QCD Jet mass distribution, Q+G

Main idea: calculating mass due to two-body QCD bremsstrahlung:

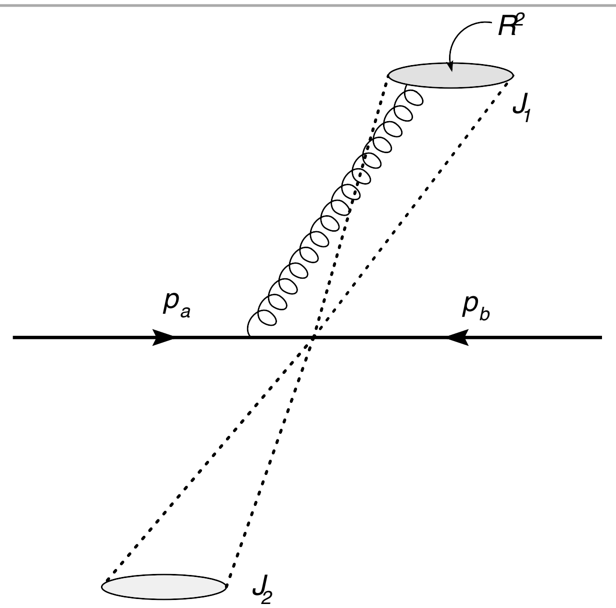


$$J^{(eik),c}(m_J, p_T, R) = \alpha_s(p_T)\frac{4\,C_c}{\pi m_J}\log\left(\frac{1}{z}\tan\left(\frac{R}{2}\right)\sqrt{4-z^2}\right)$$
$$\approx \alpha_s(p_T)\frac{4\,C_c}{\pi m_J}\log\left(\frac{R\,p_T}{m_J}\right),$$

$$z = \frac{m_J}{p_T}$$

QCD Jet mass distribution, Q+G

Main idea: calculating mass due to two-body QCD bremsstrahlung:



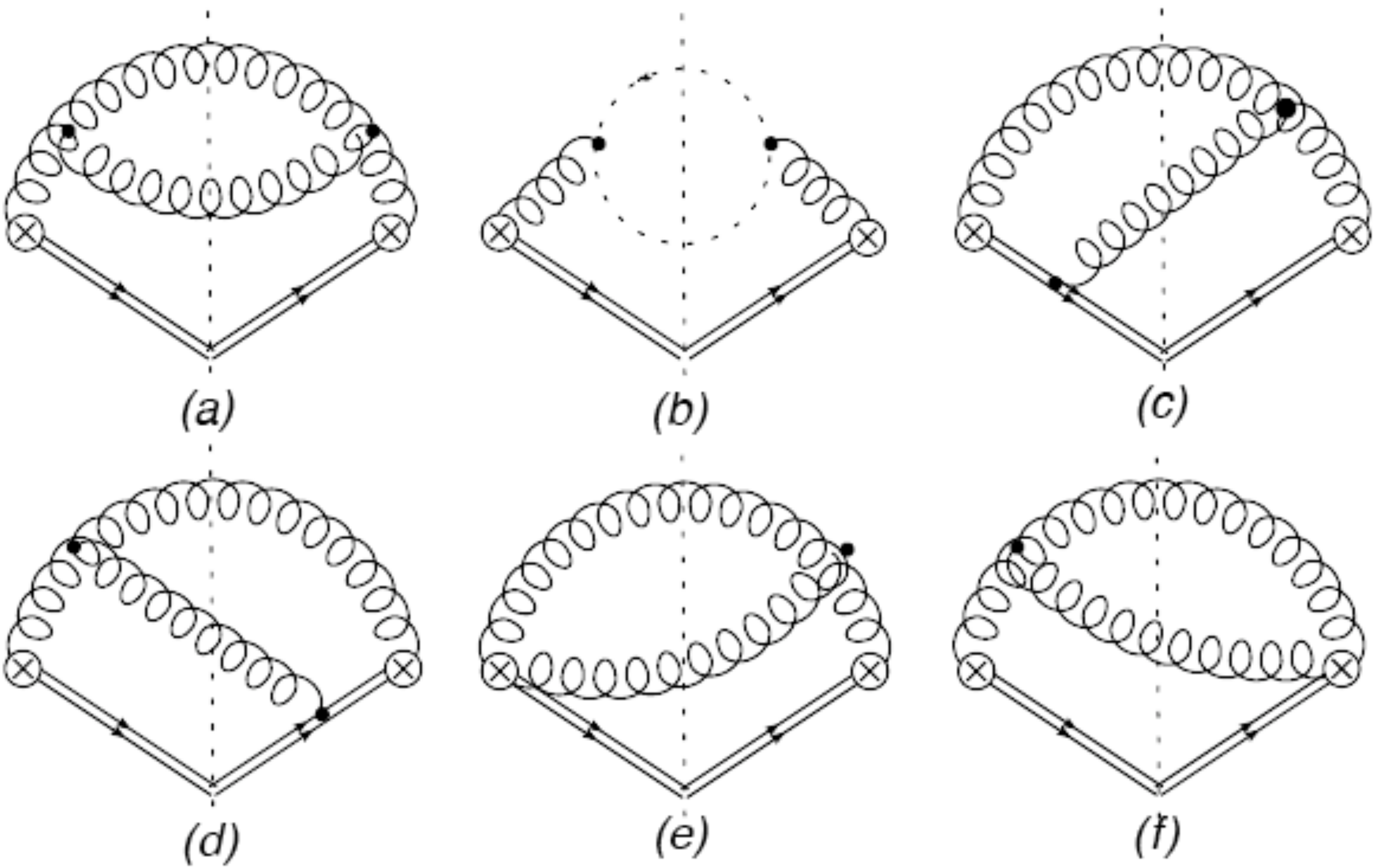
$$J^{(eik),c}(m_J, p_T, R) = \alpha_s(p_T)\frac{4\,C_c}{\pi m_J}\log\left(\frac{1}{z}\tan\left(\frac{R}{2}\right)\sqrt{4-z^2}\right)$$

$$\approx \alpha_s(p_T)\frac{4\,C_c}{\pi m_J}\log\left(\frac{R\,p_T}{m_J}\right),$$

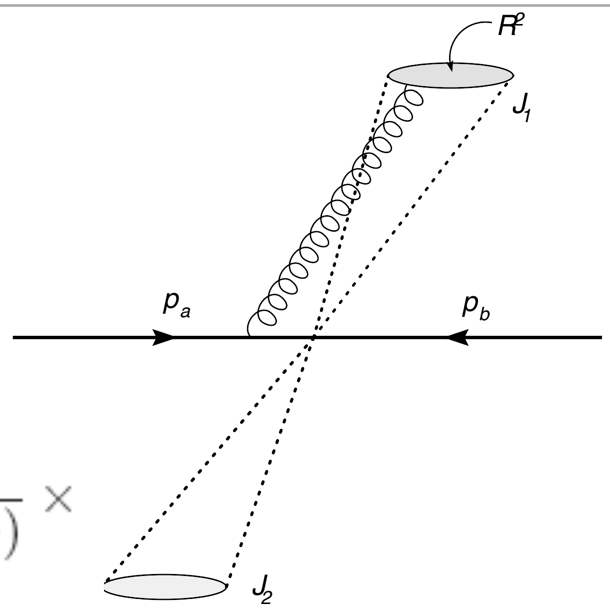
$$z = \frac{m_J}{p_T}$$

C { quark jets: $C_{(q)} = C_F = \frac{4}{3}$
gluon jets: $C_{(g)} = C_A = 3$

QCD Jet mass distribution, Q+G



QCD Jet mass distribution, Q+G



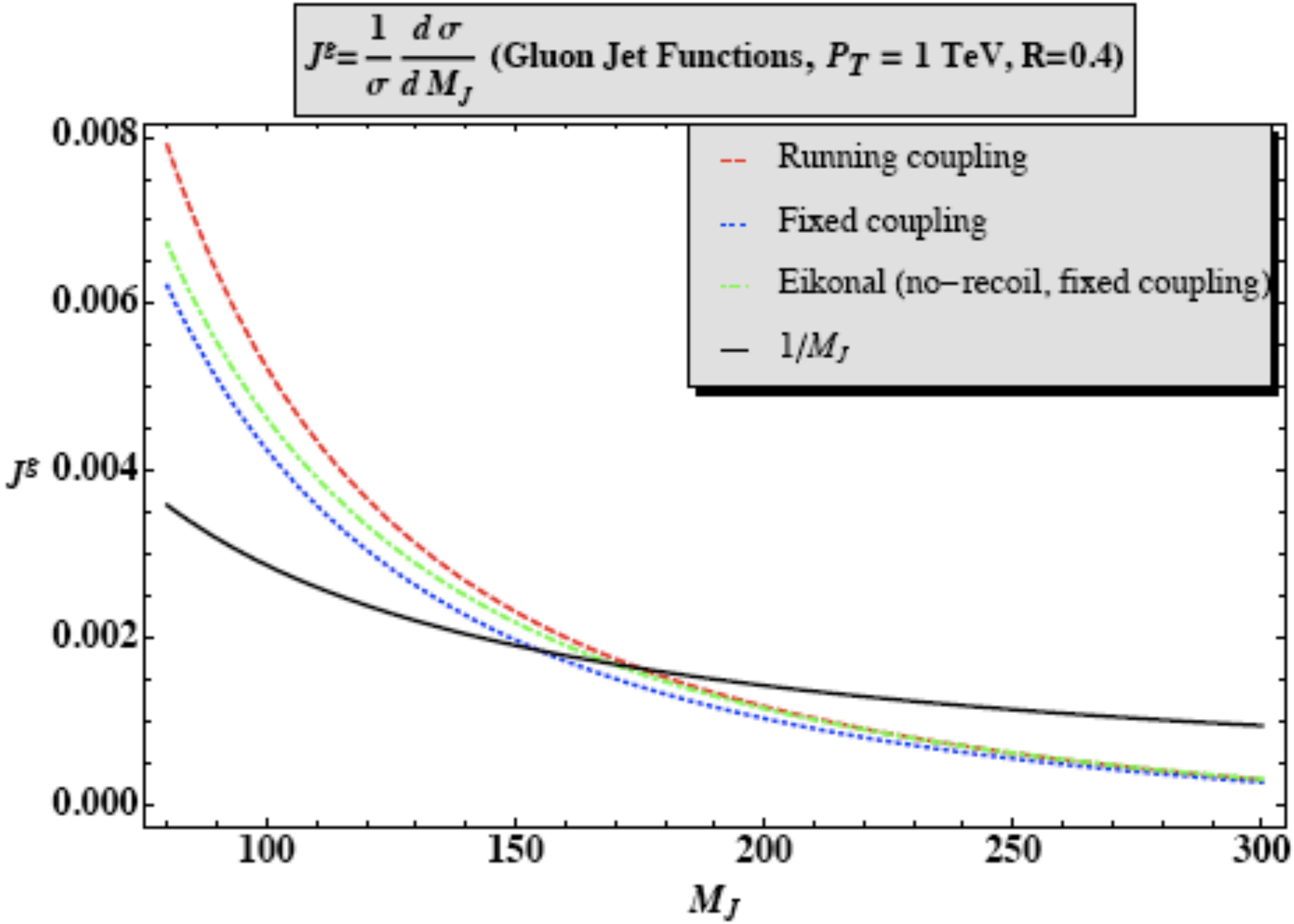
Main idea: calculating mass due to two-body QCD bremsstrahlung:

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

$$\beta_i = \sqrt{1 - m_{J_i}^2/p_{0,J_i}^2} \quad z = \frac{m_{J_i}}{p_{0,J_i}},\ p_{0,J_i} = \sqrt{m_{J_i}^2 + p_T^2},\ \text{and}\ k_0 = \frac{p_{0,J_i}}{2}\frac{z^2}{1-\beta_i\cos\theta_S}.$$

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

QCD Jet mass distribution, Q+G



Jet mass distribution theory vs. MC

Revisiting our prediction:

$$\frac{d\sigma_{pred}(R)}{dp_T dm_J} = \sum_c J^c(m_J, p_T, R) \left(\frac{d\sigma^c(R)}{dp_T} \right)_{MC}$$

Jet mass distribution theory vs. MC

Revisiting our prediction:

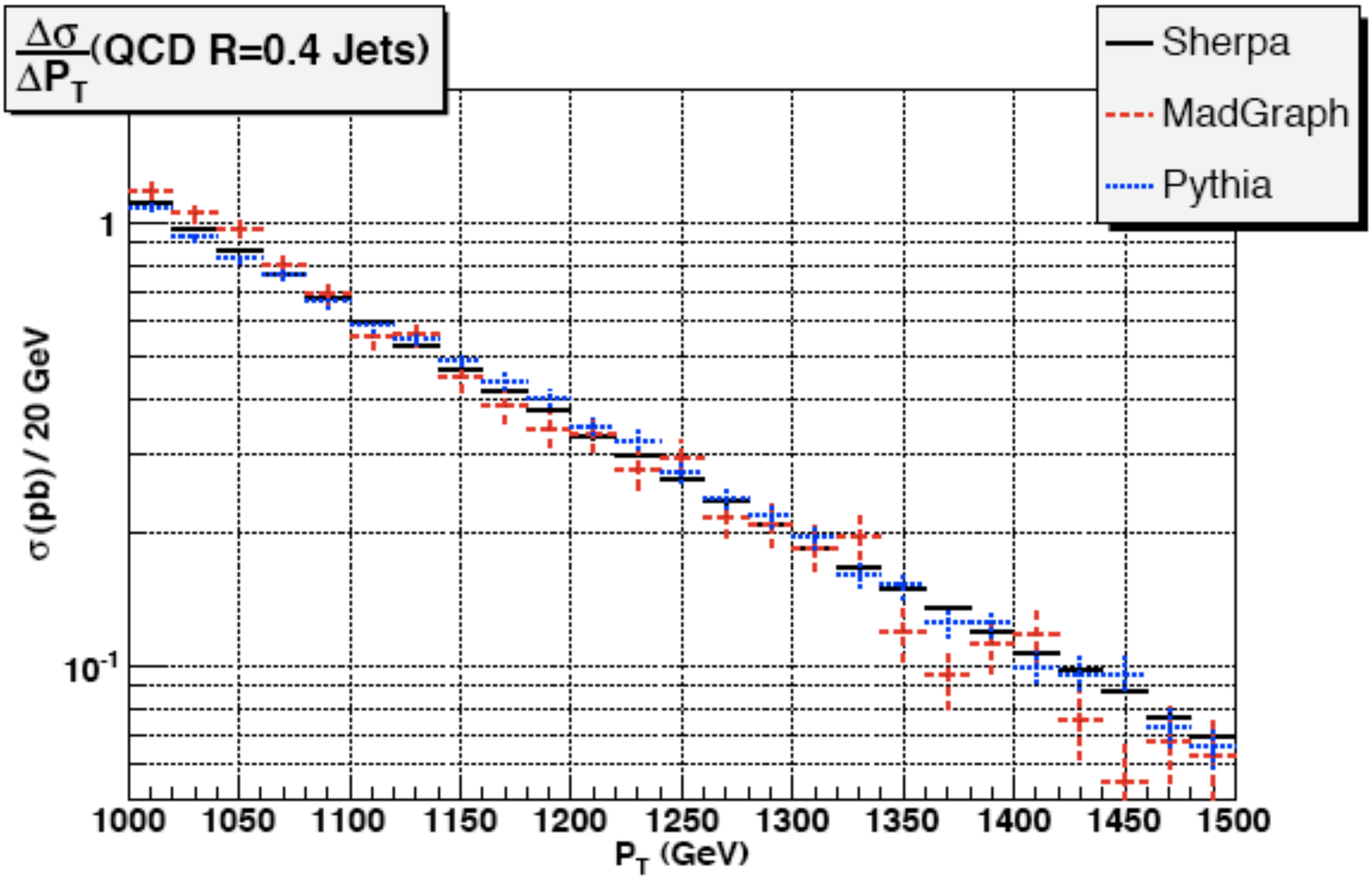
$$\frac{d\sigma_{pred}(R)}{dp_T dm_J} = \sum_c J^c(m_J, p_T, R)\left(\frac{d\sigma^c(R)}{dp_T}\right)_{MC}$$

But, in practice, cannot distinguish partonic origin of a jet: can only give bounds: $J^g > J^q$

$$\frac{d\sigma_{pred}(R)}{dp_T dm_J}_{upper\ bound} = J^g(m_J, p_T, R)\sum_c \left(\frac{d\sigma^c(R)}{dp_T}\right)_{MC}$$

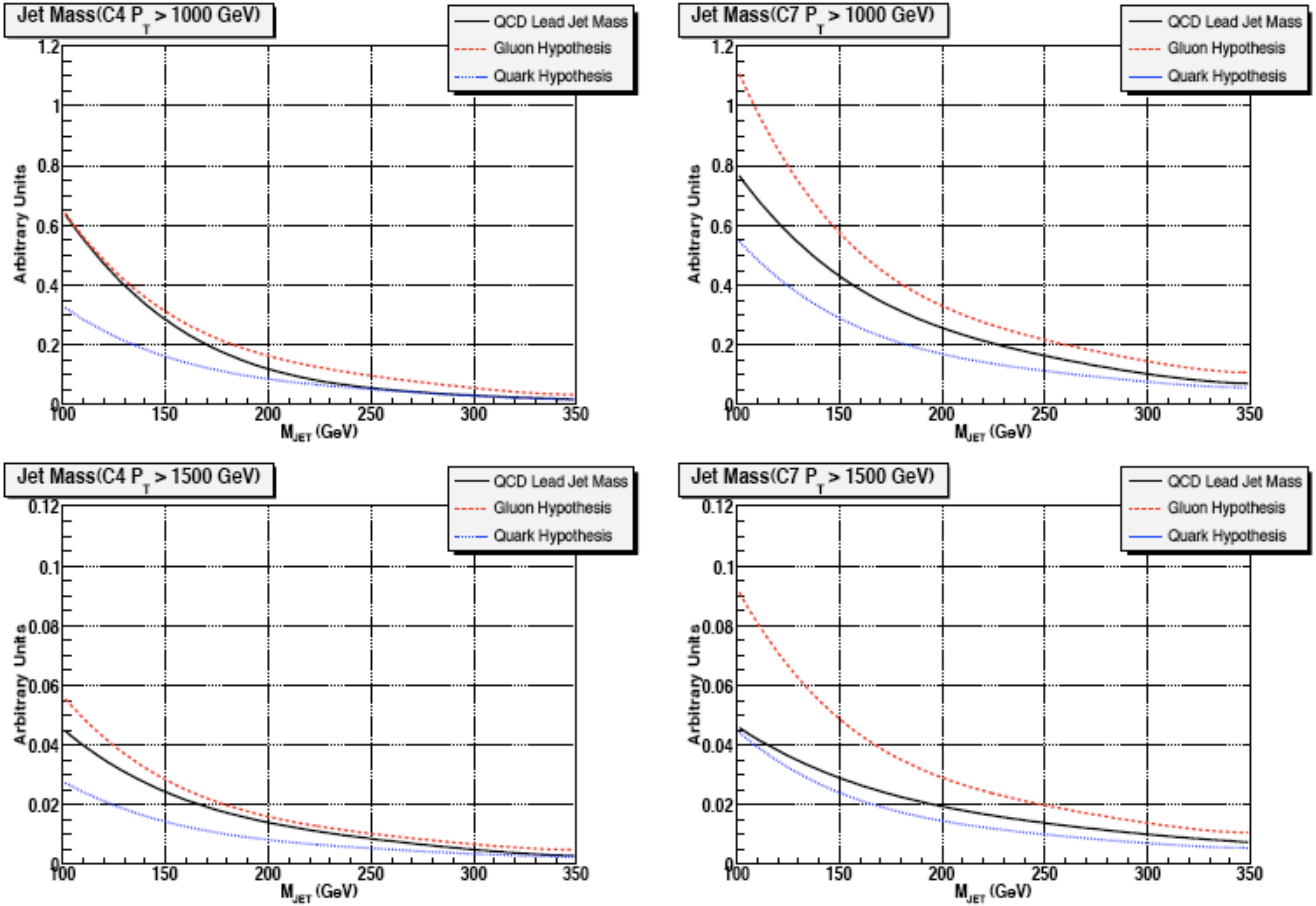
$$\frac{d\sigma_{pred}(R)}{dp_T dm_J}_{lower\ bound} = J^q(m_J, p_T, R)\sum_c \left(\frac{d\sigma^c(R)}{dp_T}\right)_{MC}$$

Jet mass distribution theory vs. MC

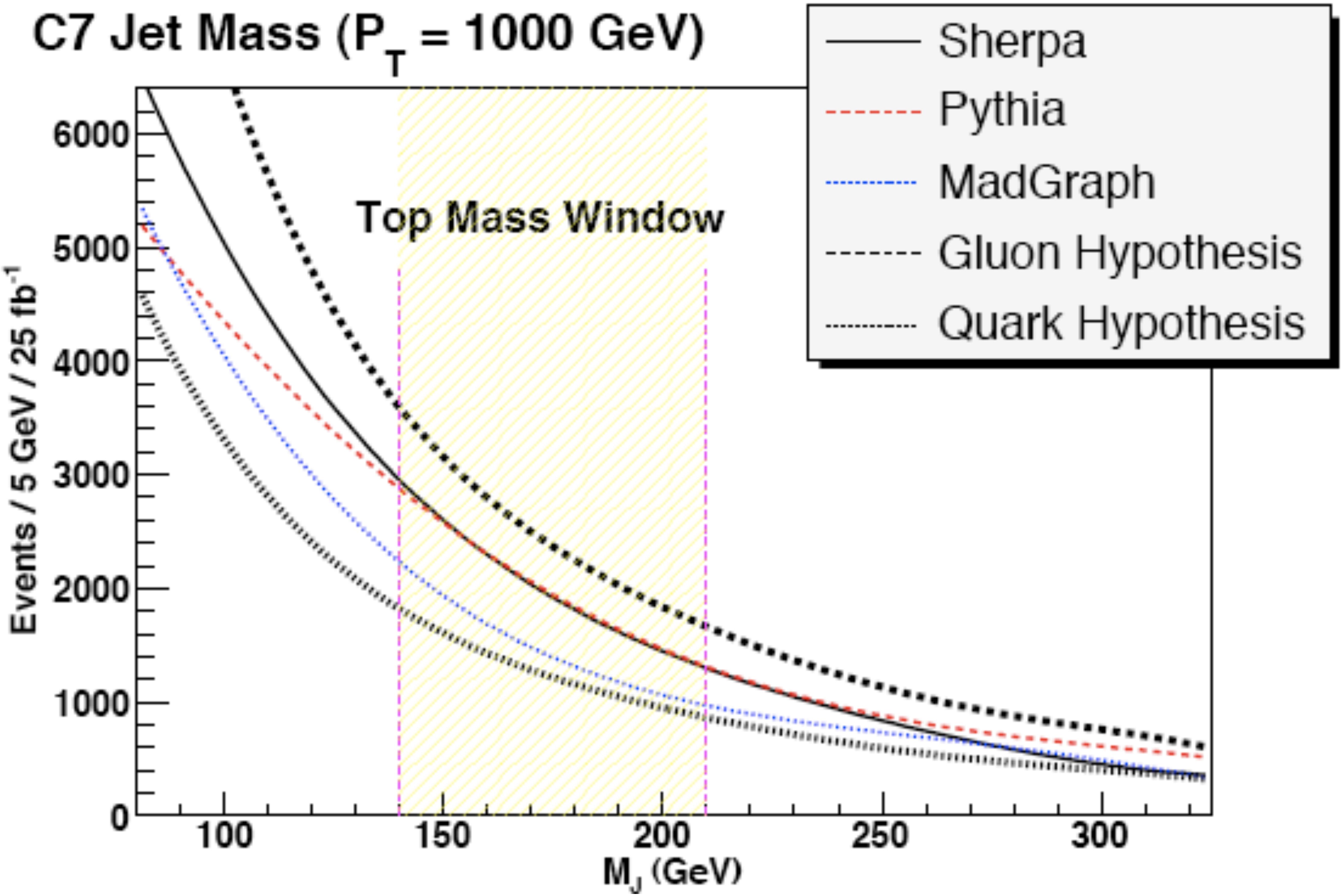


Jet mass distribution theory vs. MC

Sherpa, jet function convolved

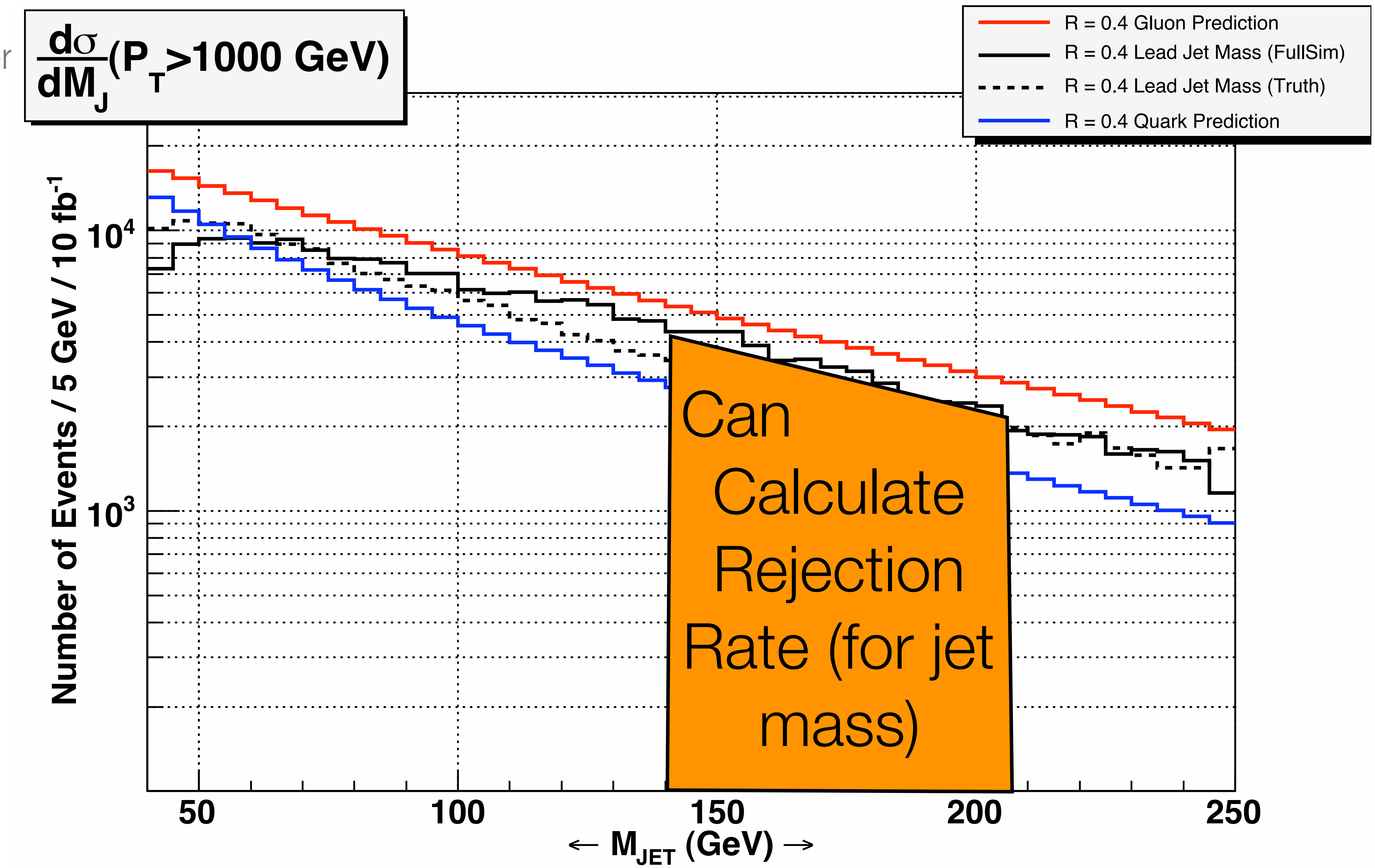


Jet mass distribution theory vs. MC



QCD jet mass dist' under control!

Sherpa (CKKW)
With Full Detector Simulation



QCD jet mass dist' under control!

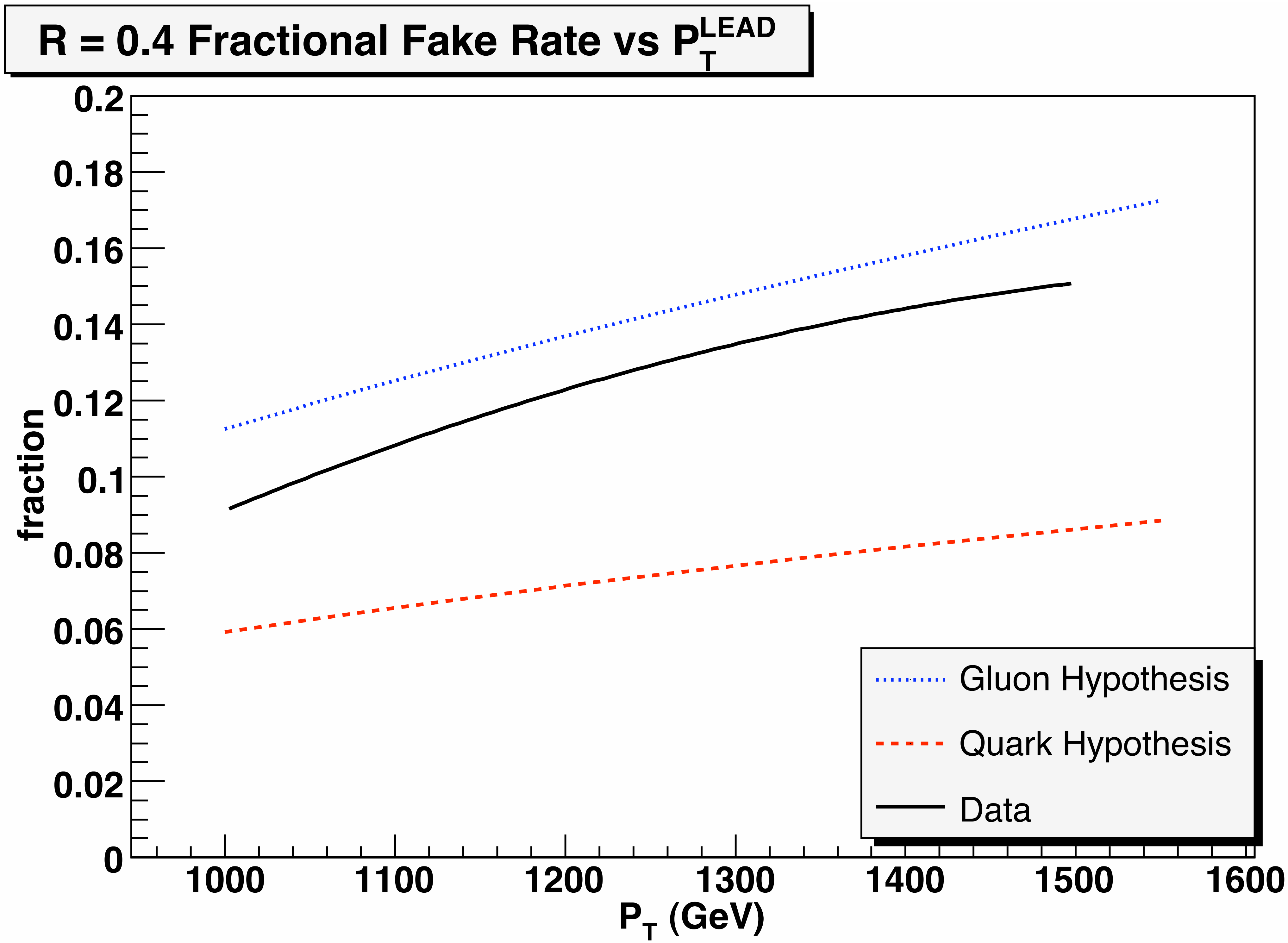
✦Rejection Ratio: (#of events for $m_t - \Delta < m_J < m_t + \Delta$) / (total # of events)

- Can use our jet function to calculate it:

$$\sigma(R)_{upper\ bound} = \int_{p_T^{min}}^{\infty} dp_T \sum_c \left(\frac{d\sigma^c(R)}{d\,p_T}\right)_{MC} \int_{140\,GeV}^{210\,GeV} J^g(m_J, p_T, R)\, dm_J$$
$$\sigma(R)_{lower\ bound} = \int_{p_T^{min}}^{\infty} dp_T \sum_c \left(\frac{d\sigma^c(R)}{d\,p_T}\right)_{MC} \int_{140\,GeV}^{210\,GeV} J^q(m_J, p_T, R)\, dm_J$$

- Matches well with MC simulation (within 10%)
- For QCD dijet background, double mass tagging will reduce the background (typically, $\epsilon_r \sim 15\%$)

QCD jet mass dist’ under control!

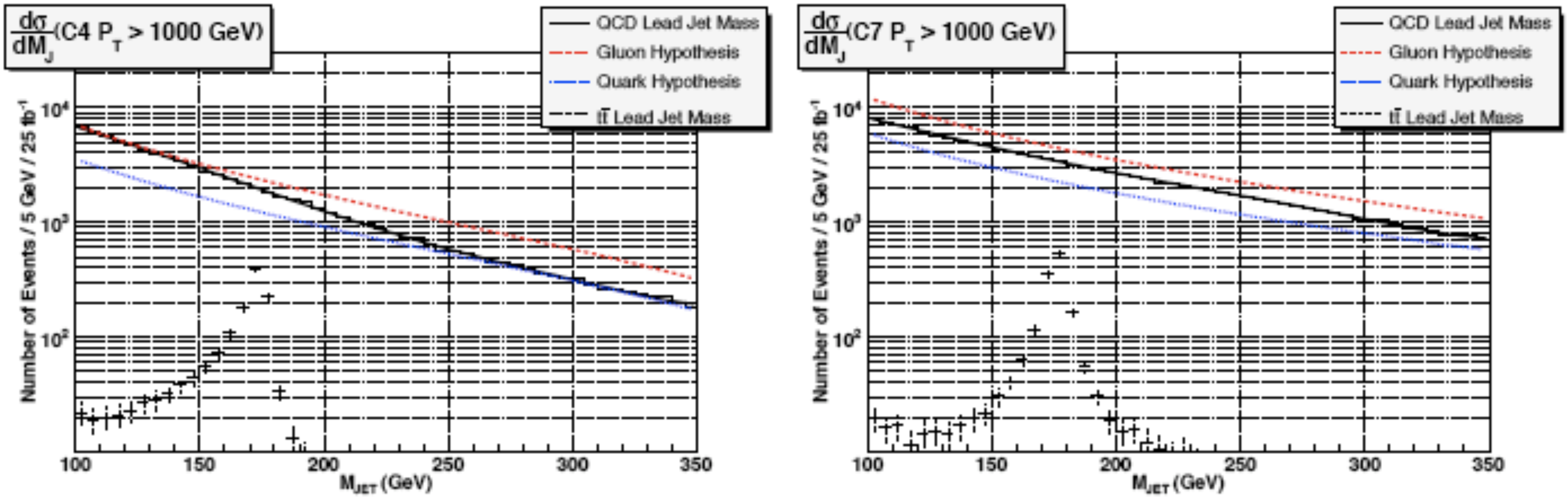


Cross Section Uncertainty

Process	Generator	PDF	Matching	Cross Section
$pp \to t\bar{t}(j)$	SHERPA 1.0.9	CTEQ6M	CKKW	141 fb
$pp \to t\bar{t}(j)$	SHERPA 1.1.2	CTEQ6M	CKKW	149 fb
$pp \to t\bar{t}(j)$	SHERPA 1.1.2	CTEQ6L	CKKW	281 fb
$pp \to t\bar{t}(j)$	MG/ME 4	CTEQ6M	MLM	68 fb
$pp \to t\bar{t}(j)$	MG/ME 4	CTEQ6L	MLM	56 fb
$pp \to t\bar{t}$	Pythia 6	CTEQ6L	-	157 fb
$pp \to t\bar{t}$	Pythia 8	CTEQ6M	-	174 fb
$pp \to jj(j)$	SHERPA 1.1.0	CTEQ6M	CKKW	10.2 pb
$pp \to jj(j)$	SHERPA 1.1.2	CTEQ6M	CKKW	21.3 pb
$pp \to jj(j)$	SHERPA 1.1.2	CTEQ6M	CKKW	15.8 pb
$pp \to jj(j)$	MG/ME 4	CTEQ6L	MLM	8.54 pb
$pp \to jj(j)$	MG/ME 4	CTEQ6M	MLM	9.93 pb
$pp \to jj$	Pythia 6	CTEQ6L	-	13.7 pb
$pp \to jj$	Pythia 8	CTEQ6M	-	13.3 pb

Table 1: Cross sections for producing final state $R = 0.4$ leading cone jets with $p_T \geq 1$ TeV and $|\eta| \leq 2$. Generation level cuts were imposed as follows. Final state partons from the hard scatter were required to have $p_T \geq 20$ GeV. For MG/ME, final state partons have $|\eta| \leq 4.5$. Processes with a trailing (j) suffix indicate that $2 \to 2$ and $2 \to 3$ processes are represented.

Ex. SM ttbar vs. di-jet background!



With transfer-functions ("full simulation")

Ex. SM ttbar vs. di-jet background!

p_T^{lead} cut	Cone	S (0% JES)	Δ_0	+5% JES	Δ_5	-5% JES	Δ_{-5}
1000 GeV	C4	293	-31.5%	358	-16.4%	230	-46.3%
1000 GeV	C7	478	-33.1%	616	-13.7%	358	-49.9%
1500 GeV	C4	32	-30.4%	44	-4.3%	21	-54.3%
1500 GeV	C7	35	-34.0%	52	-1.9%	24	-54.7%

p_T^{lead} cut	Cone	B (0% JES)	Δ_0	+5% JES	Δ_5	-5% JES	Δ_{-5}
1000 GeV	C4	2475	5.8%	2914	24.5%	1919	-18.0%
1000 GeV	C7	6272	7.2%	8190	40.0%	4894	-16.3%
1500 GeV	C4	294	16.7%	380	50.8%	196	-22.2%
1500 GeV	C7	496	23.4%	732	82.1%	330	-17.9%

Double mass tagging at 25 fb^{-1} with detector resolution and Jet Energy Scale (JES)

look hopeless b-tagging

without high efficiency!

$$\Delta_{JES} = \frac{N_{JES} - N_{TRUTH}}{N_{TRUTH}}$$

S/B~0.11

Ex. SM ttbar vs. di-jet background!

p_T^{lead} cut	Cone	S (0% JES)	Δ_0	+5% JES	Δ_5	-5% JES	Δ_{-5}
1000 GeV	C4	293	-31.5%	358	-16.4%	230	-46.3%
1000 GeV	C7	478	-33.1%	616	-13.7%	358	-49.9%
1500 GeV	C4	32	-30.4%	44	-4.3%	21	-54.3%
1500 GeV	C7	35	-34.0%	52	-1.9%	24	-54.7%

p_T^{lead} cut	Cone	B (0% JES)	Δ_0	+5% JES	Δ_5	-5% JES	Δ_{-5}
1000 GeV	C4	2475	5.8%	2914	24.5%	1919	-18.0%
1000 GeV	C7	6272	7.2%	8190	40.0%	4894	-16.3%
1500 GeV	C4	294	16.7%	380	50.8%	196	-22.2%
1500 GeV	C7	496	23.4%	732	82.1%	330	-17.9%

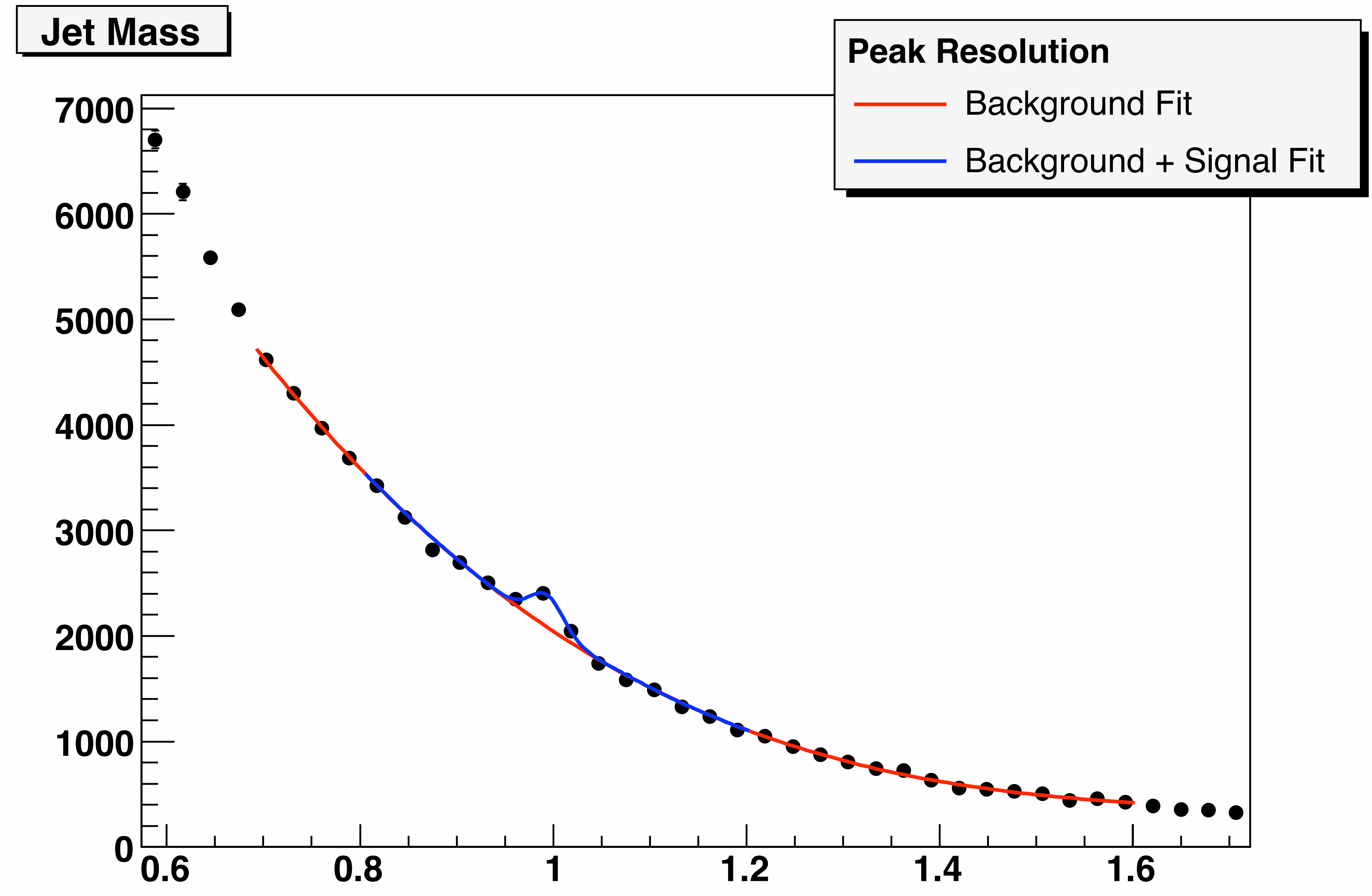
Double mass tagging at 25 fb^{-1} with detector resolution and Jet Energy Scale (JES)

look hopeless  without high b-tagging efficiency!

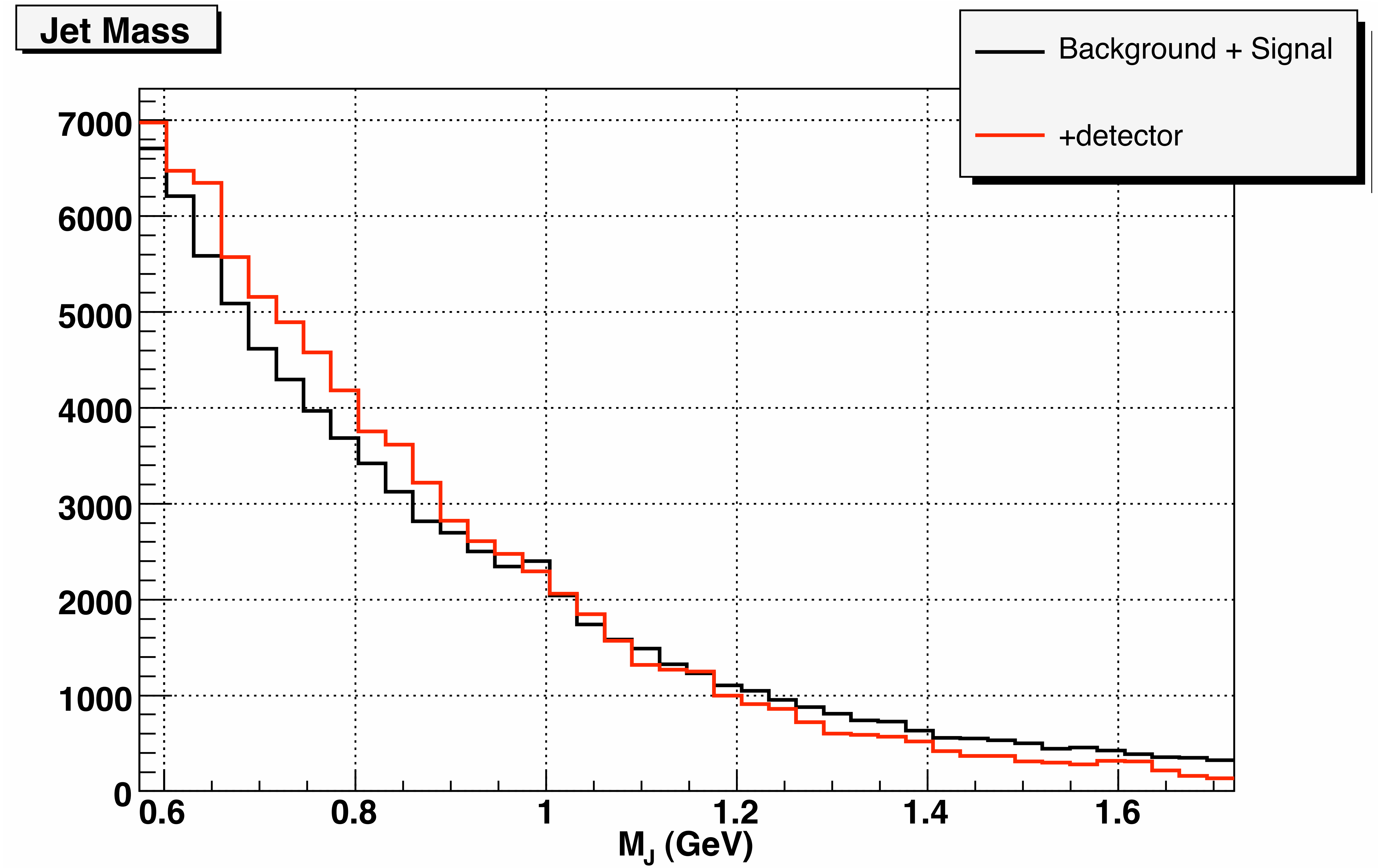
$$\Delta_{JES} = \frac{N_{JES} - N_{TRUTH}}{N_{TRUTH}}$$

S/B~0.11

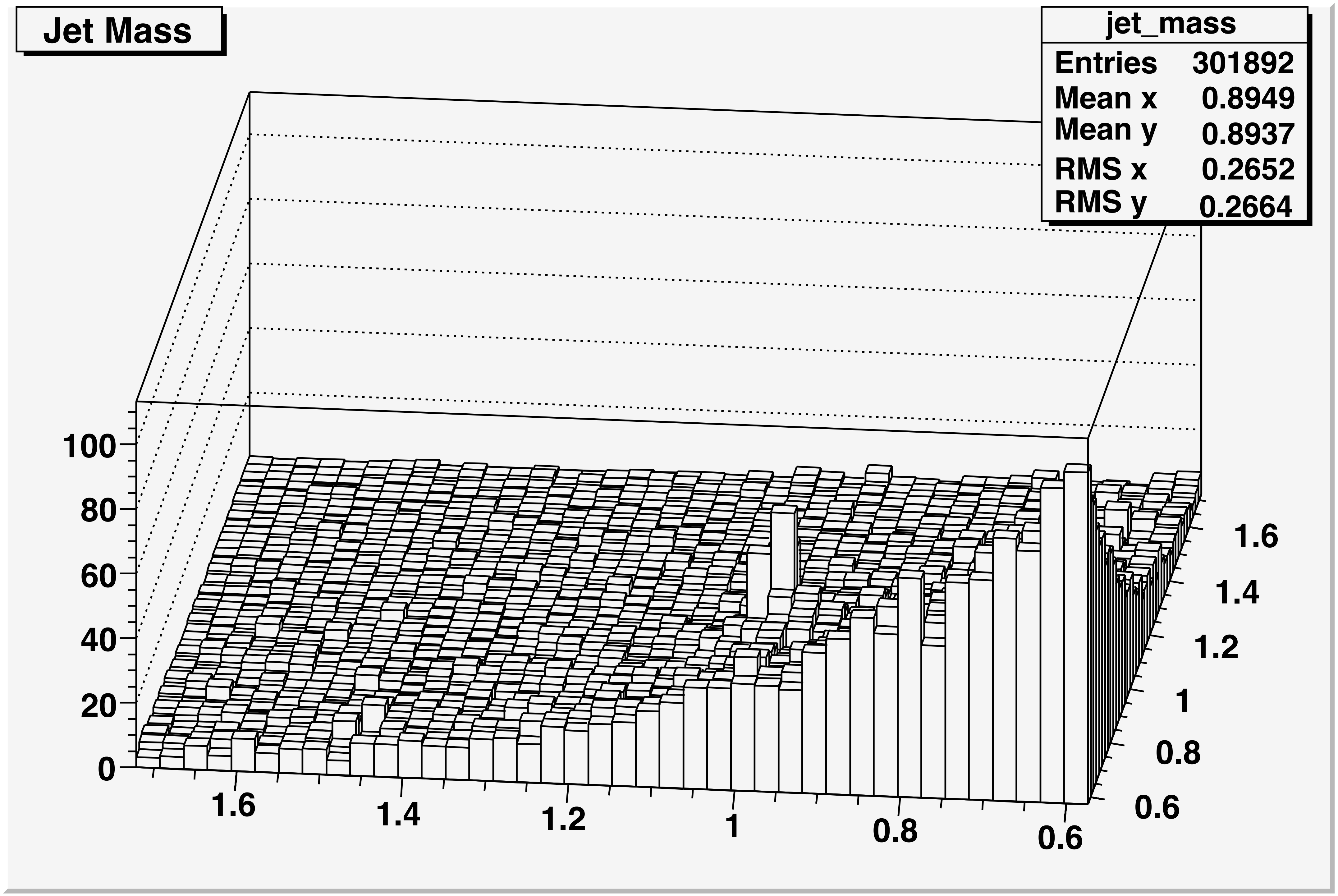
Ex. SM ttbar vs. di-jet background!



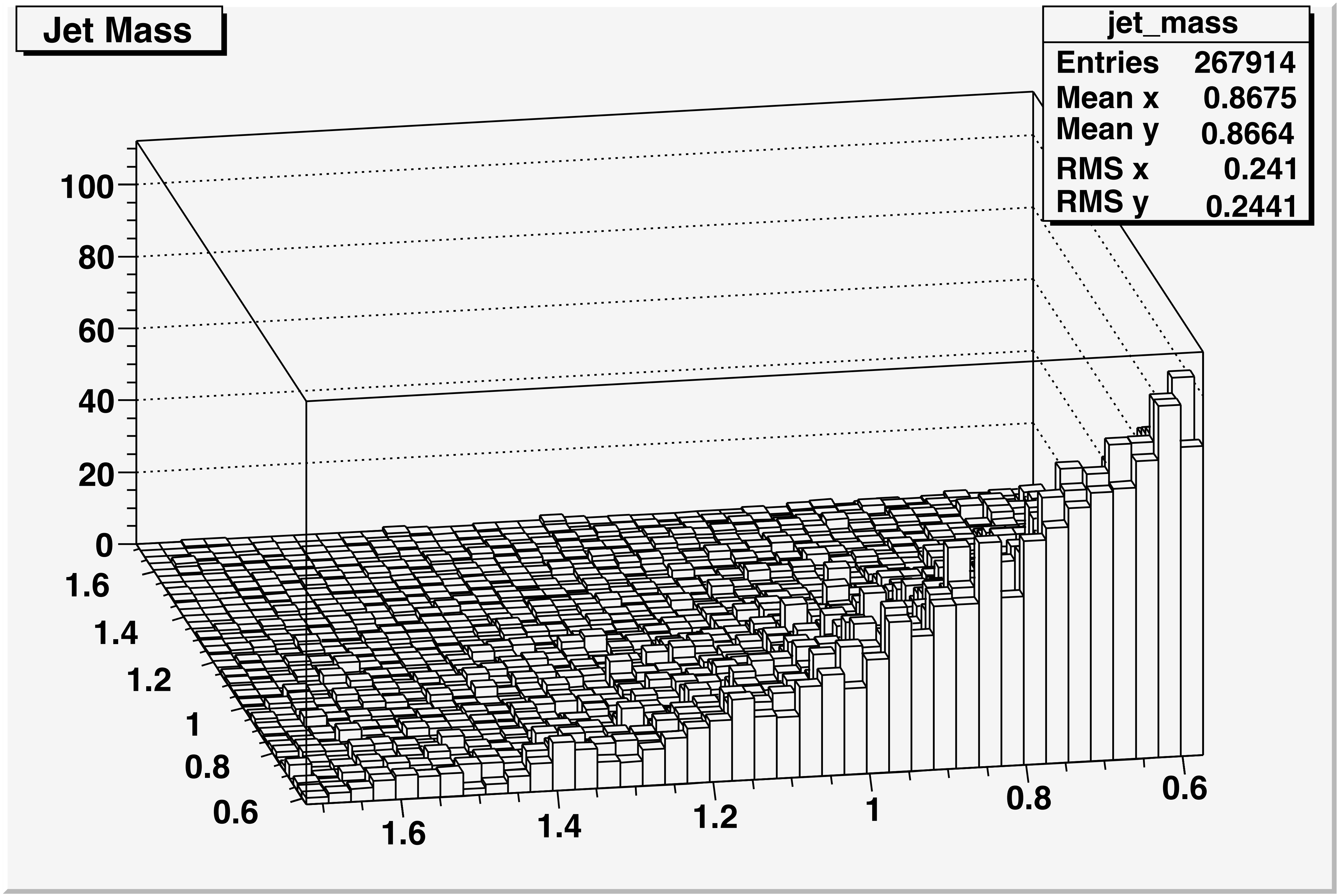
Ex. SM ttbar vs. di-jet background!



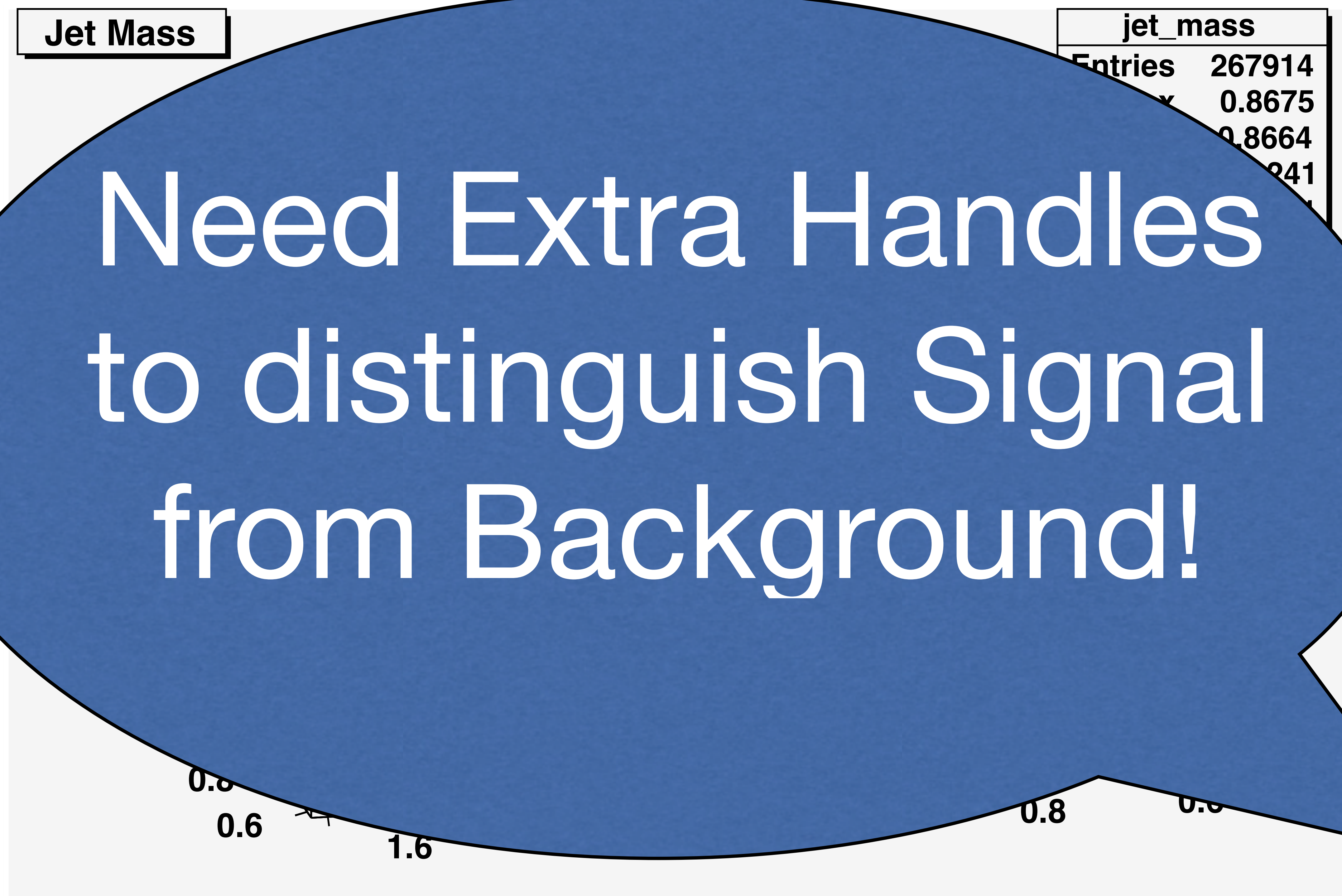
Ex. SM ttbar vs. di-jet background!



Ex. SM ttbar vs. di-jet background!

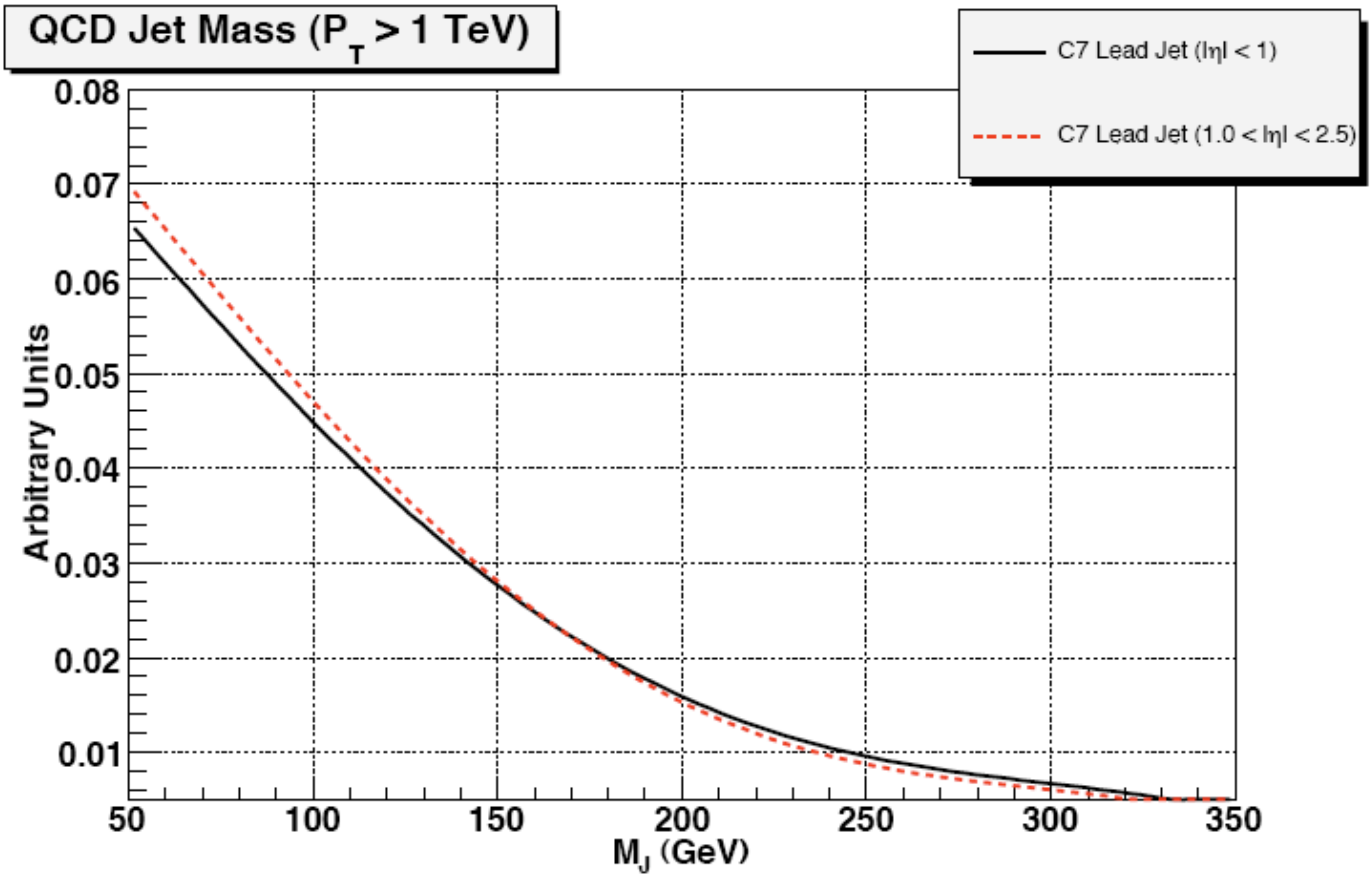


Ex. SM ttbar vs. di-jet background!



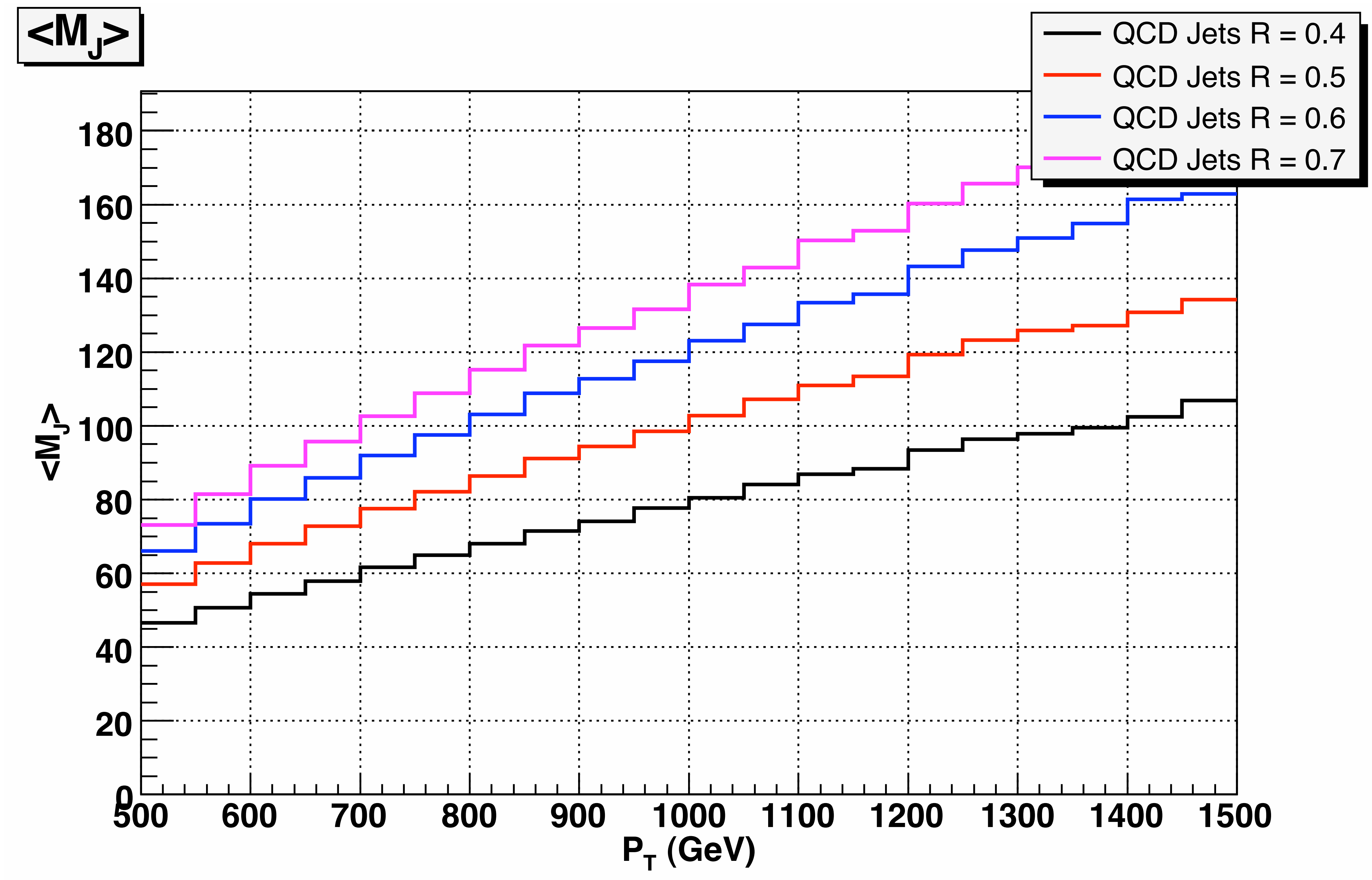
Need Extra Handles to distinguish Signal from Background!

Pseudo-rapidity independence

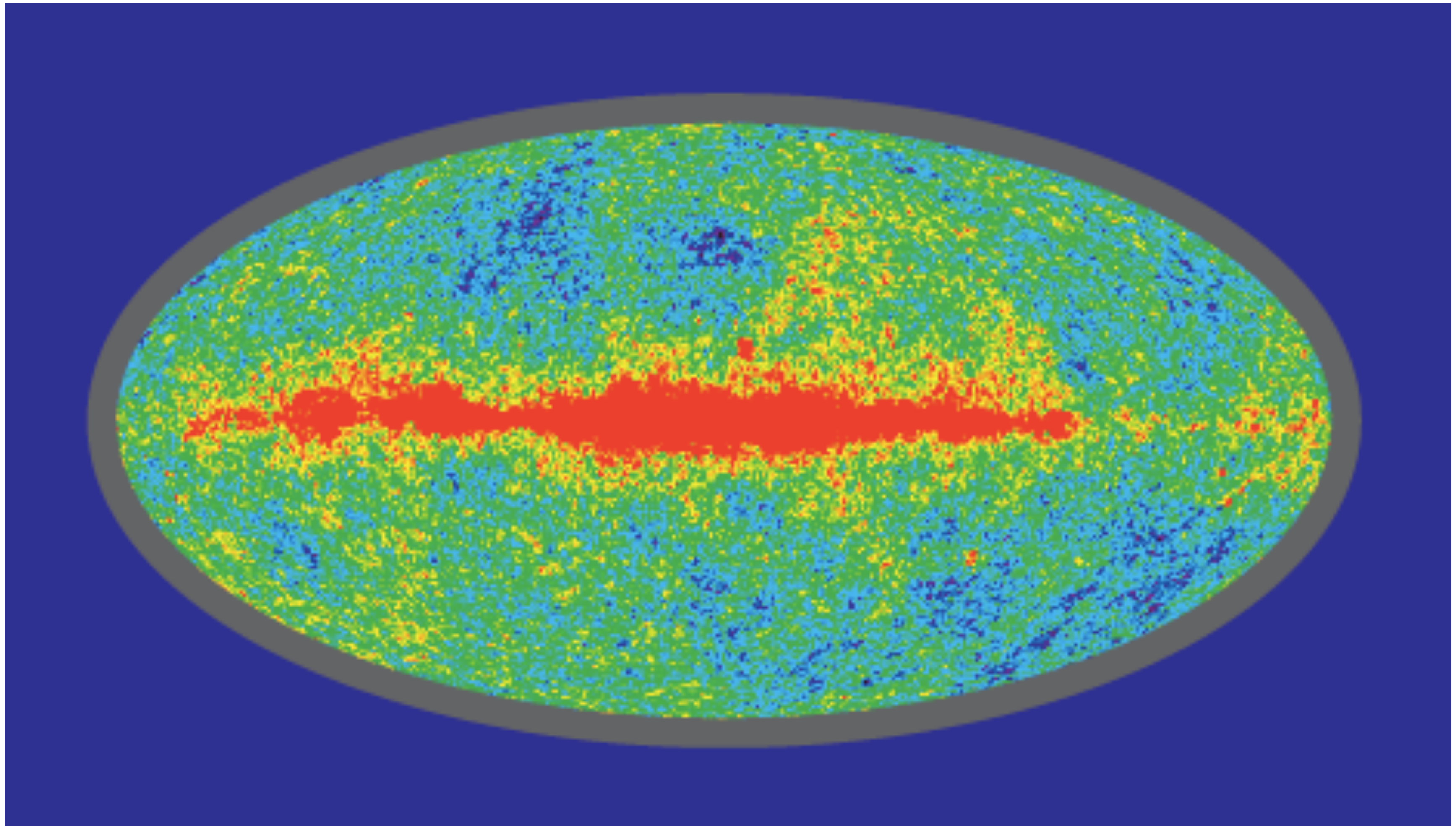


Average Jet Mass (IR Mass cut needed)

$$\langle M_J \rangle \propto P_T \, , R$$



Jet sub-structure



Why jets? What else?

- QCD amplitudes have soft-collinear singularity

- Observable: IR safe, smooth function of E flow

Sterman & Weinberg, PRL (77)

- Jet is a very inclusive object, defined via direction + p_T (+ mass)

- Even R=0.4 contains O(100) had-cells => huge amount of info’ is lost

Jet-shapes

- "Jet-shapes" = inclusive observables dependent on energy flow within individual jets
- Once jet mass is fixed at a high scale
  - ➡ Large class of jet-shapes become perturbatively calculable
  - ➡ IR safe jet-shapes combined with IR safe jet algorithm provide a bridge between

Direct theory prediction $\longleftrightarrow$ Data/MC output

Jet-shapes

✦ “Jet-sh ... bles
de ... ual jets

Can analyze a single event by a variety of jet shapes
=> the resolution associated with each one need not be dramatic!

je ... e

Direct the ... ata/MC co ... t

IR-safe jet-shapes which know top from QCD jets?

- Successes in high jet mass => jet function is well described by single gluon radiation

- QCD, top: linear, planar E-deposition in the cone

Almeida, SJL, Perez, Sterman, Sung, & Virzi,
arXiv:0807.0234

c.f. Wang, Thale: similar event shape, "sphericity tensor"
arXiv:0806.0023

- IR-safe E-flow tensor: $I_w^{kl} = \frac{1}{m_J} \sum_i w_i \frac{p_{i,k}}{w_i} \frac{p_{i,l}}{w_i}$

- Planar flow: $Pf = \frac{4\det(I_w)}{\mathrm{tr}(I_w)^2} = \frac{4\lambda_1\lambda_2}{(\lambda_1+\lambda_2)^2}$

Planar flow (Pf), QCD vs top jets

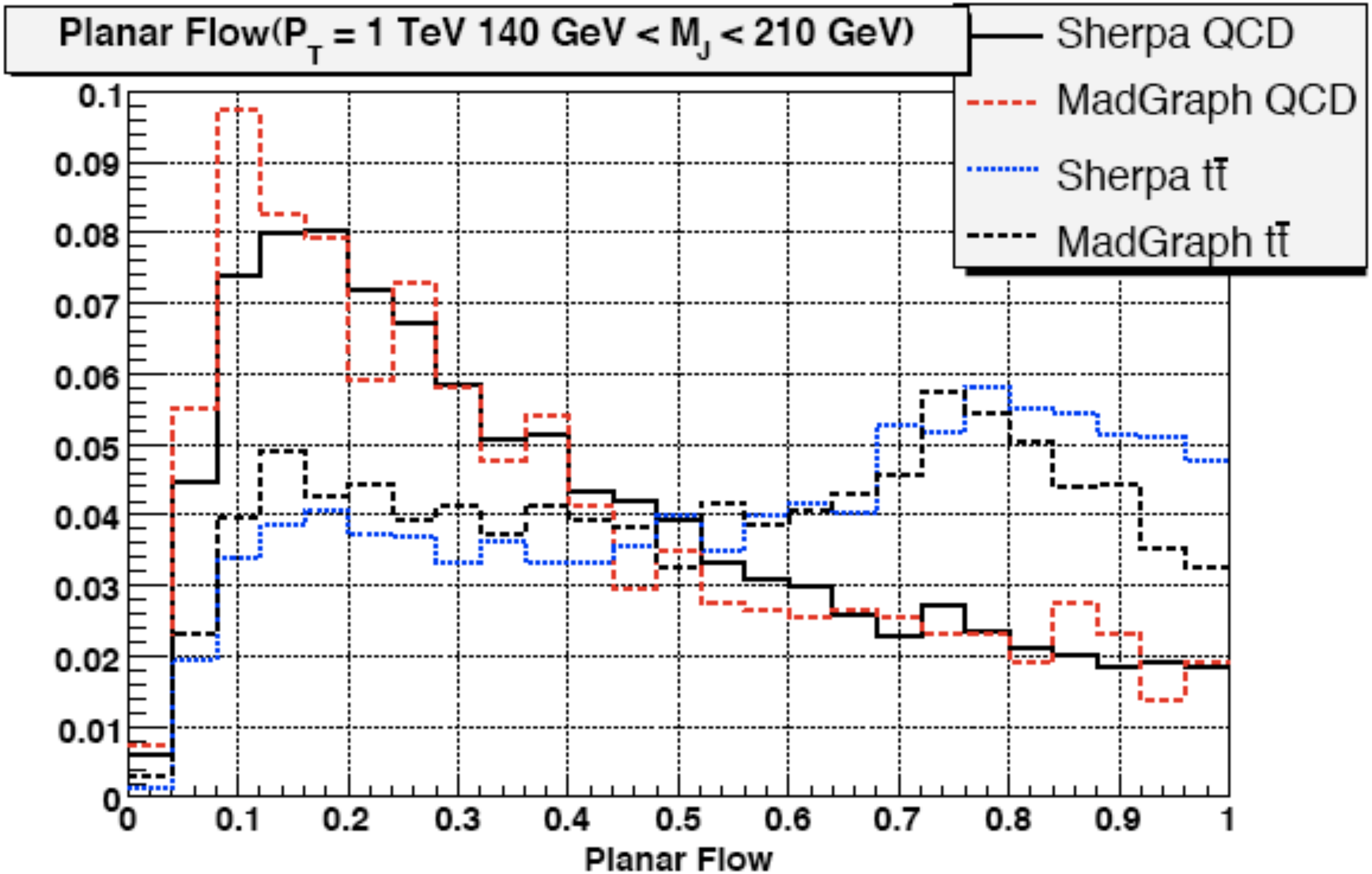
- LO: Pf ~ 0 for QCD (2-body decay)

$$\frac{1}{J}\left(\frac{dJ}{dPf}\right)_{2\mathrm{body}} = \delta(Pf)$$

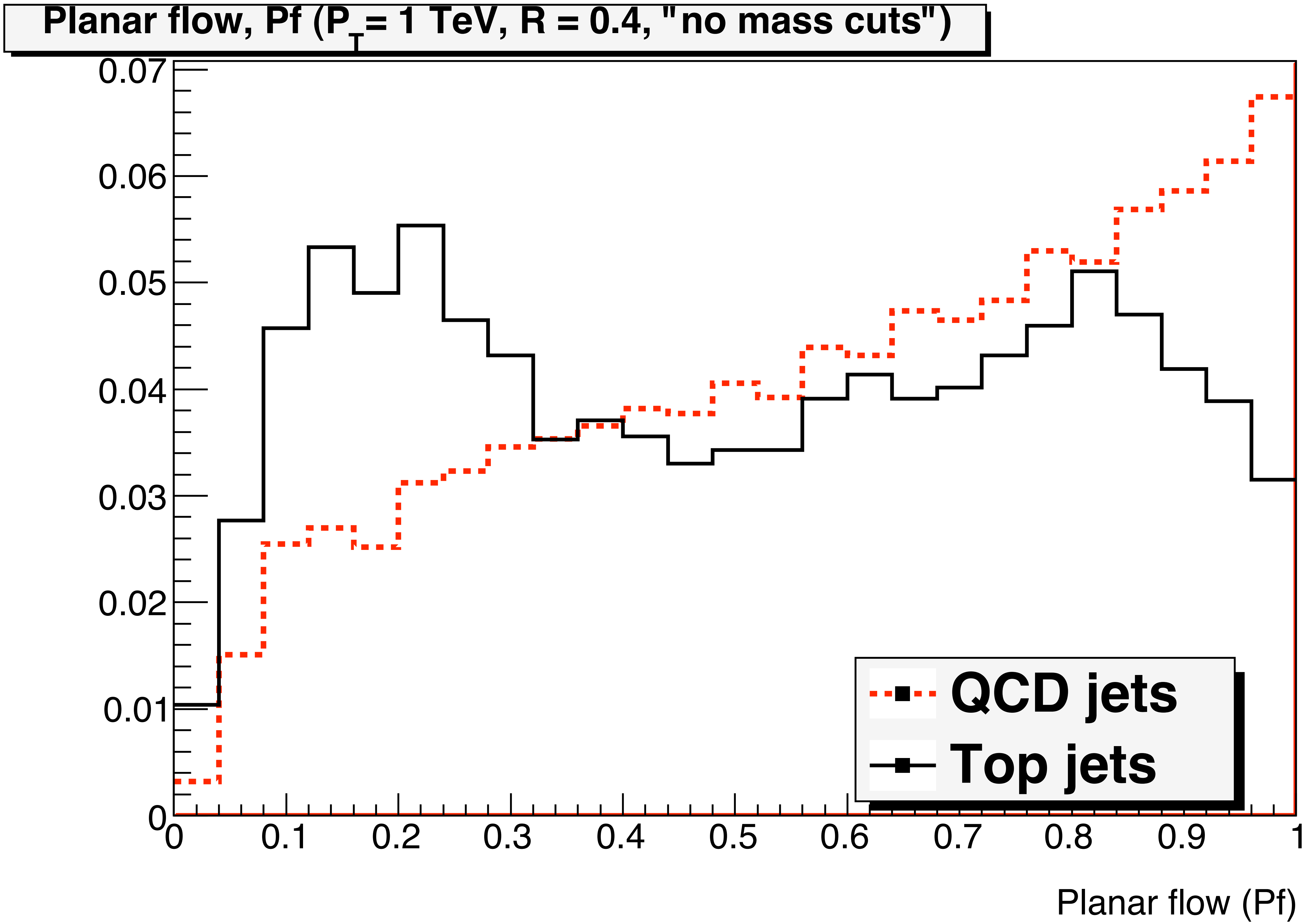
O(1) for top: smooth
(for istropic ≥ 3-body decay, Pf~1)

- NLO (due to large m): O(α_s) for QCD
nominal for top

Planar flow (Pf), QCD vs top jets



Planar flow (Pf), QCD vs top jets



What about 2 body jet, Z/W/h

Berger, K´ucs and Sterman (03): introduced for e+e- annihilation

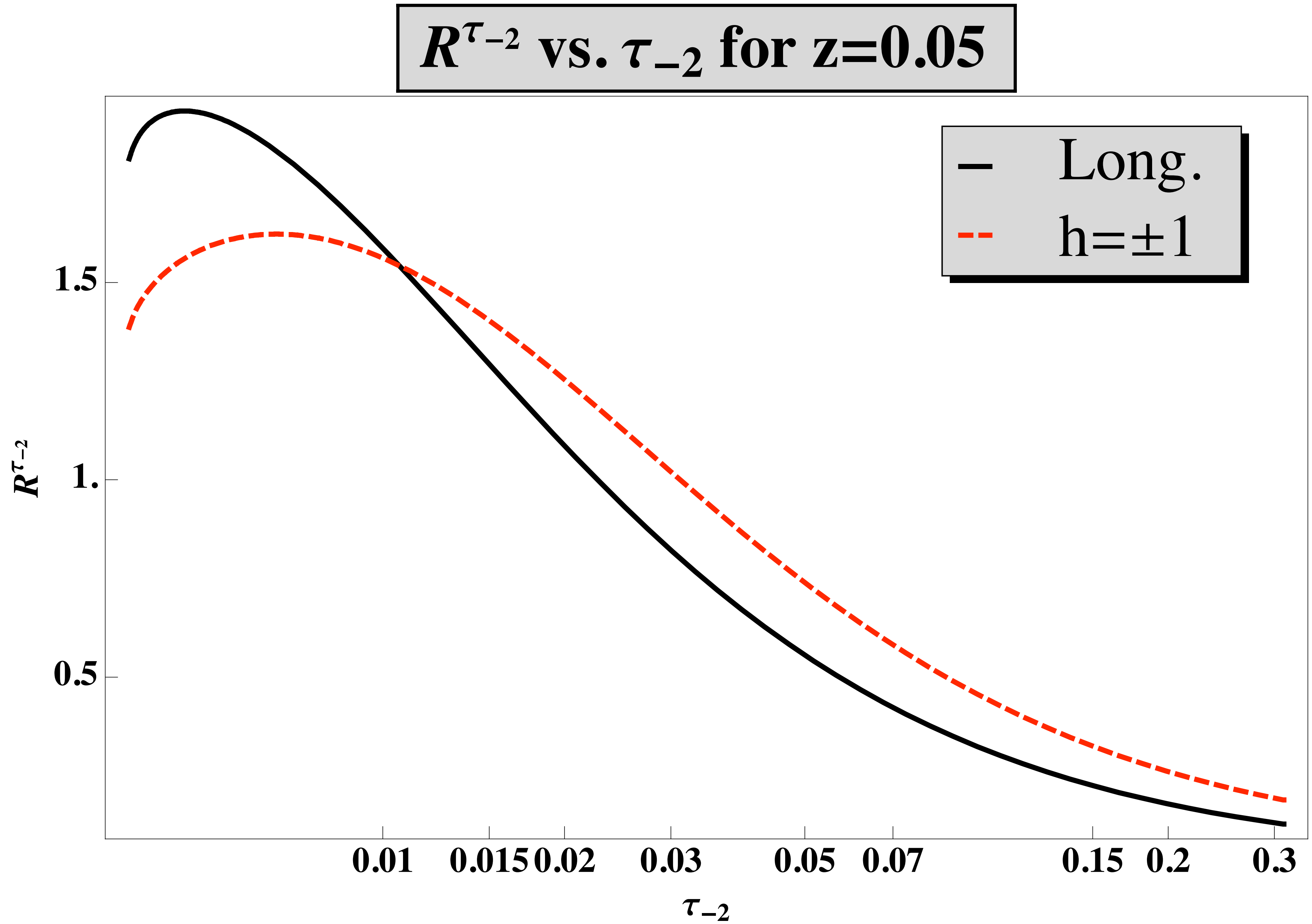
- Angularities on a cone: *Almeida, SJL, Perez, Sterman, Sung, & Virzi,* arXiv:0807.0234

$$\tilde{\tau}_a(R, p_T) = \frac{1}{m_J} \sum_{i \in jet} \omega_i \sin^a\left(\frac{\pi\theta_i}{2R}\right) \left[1 - \cos\left(\frac{\pi\theta_i}{2R}\right)\right]^{1-a}$$

$$P^x(\theta_s) = (dJ^x/d\theta_s)/J^x \;\Rightarrow\; P^x(\tilde{\tau}_a)$$

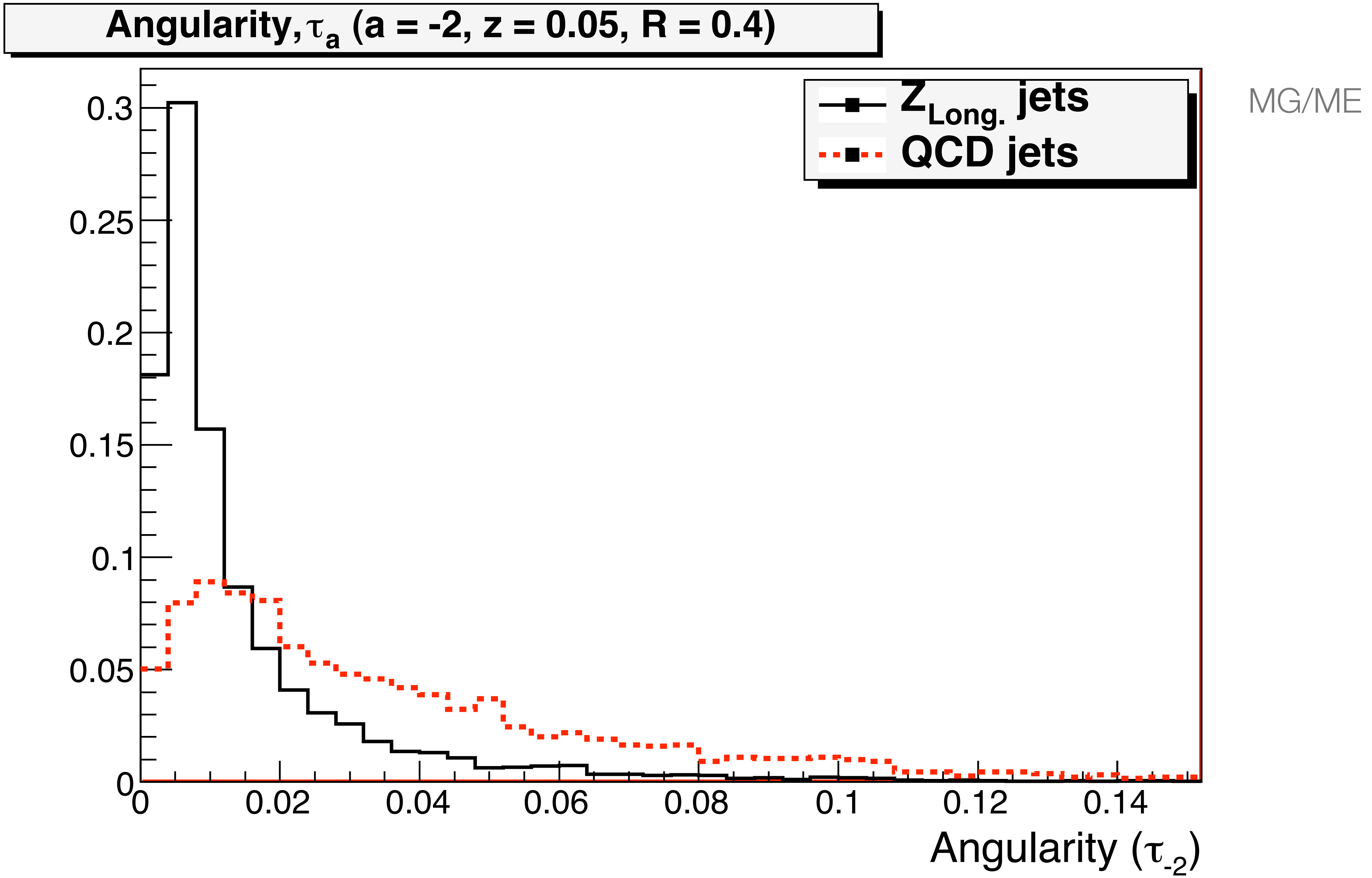
$$R(\tilde{\tau}_a) = \frac{P^{\rm sig}(\tilde{\tau}_a)}{P^{\rm QCD}(\tilde{\tau}_a)}$$

Theory: angularity, QCD vs Z



MG/ME

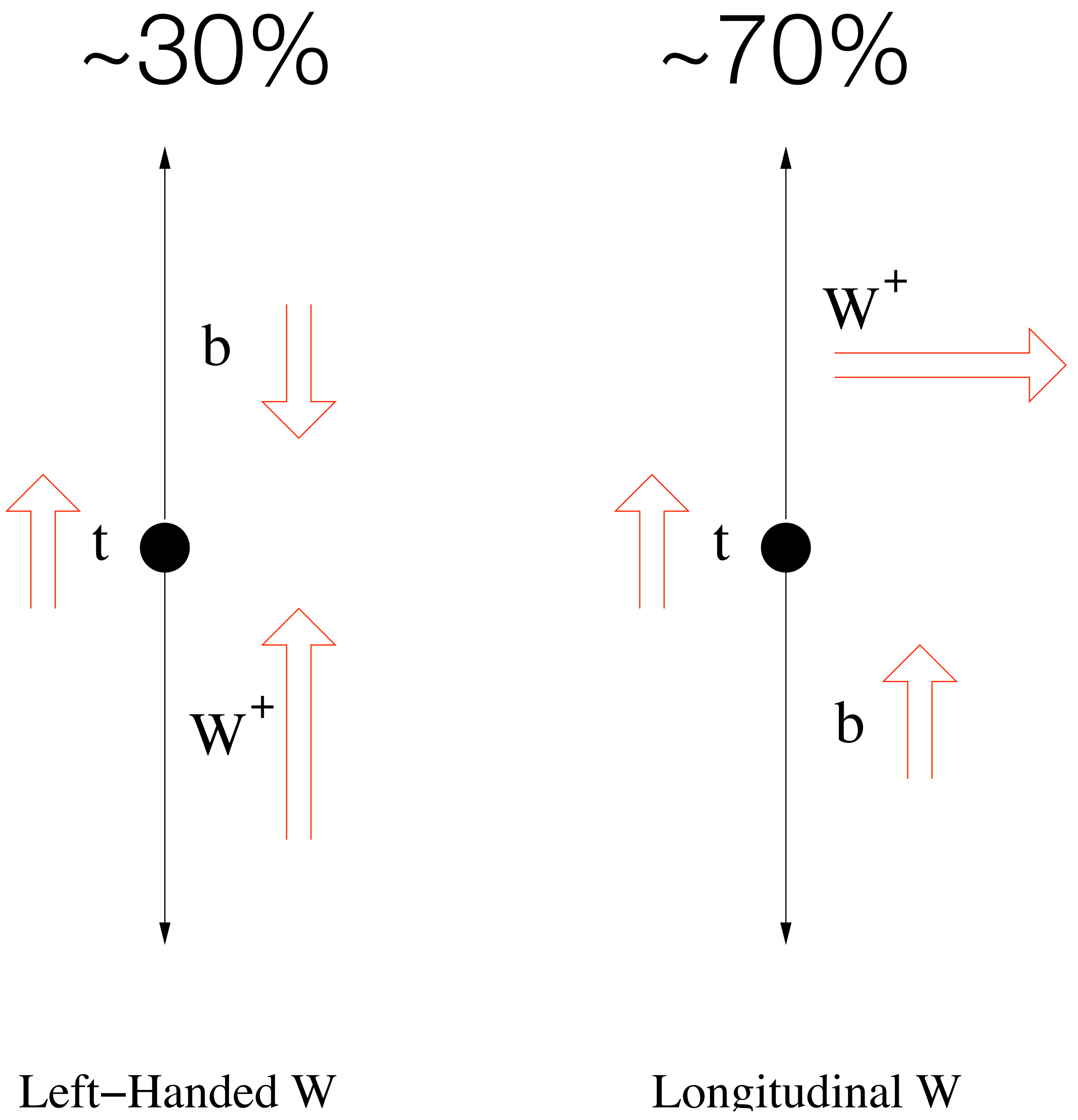
Madgraph: angularity, QCD vs Z



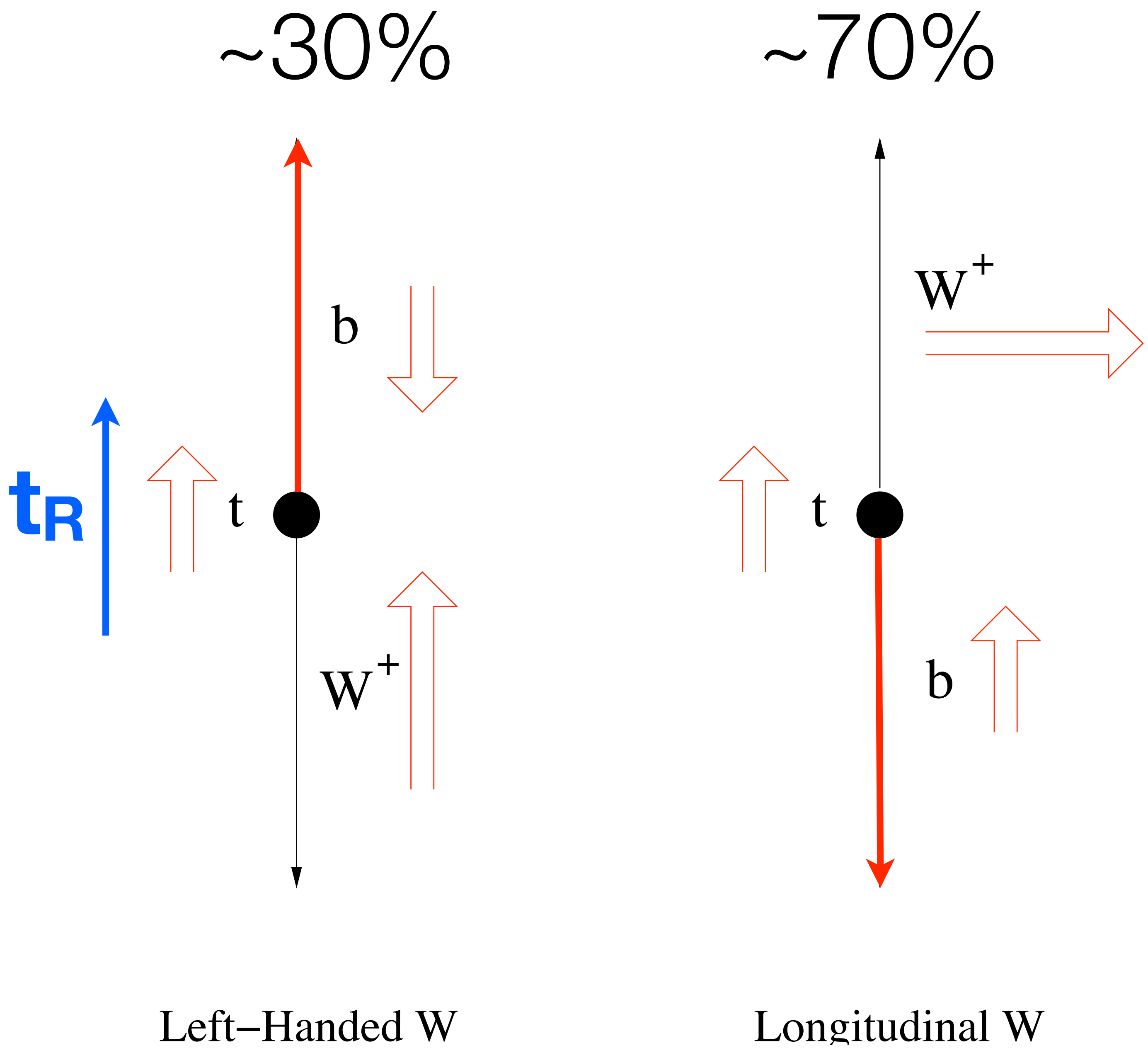
Top Polarization

- ✦ Daughter particles remember top polarization
- ✦ For Urel' top: helicity=chirality
  - ➡Can do polarization analysis like it was done for the tau
- ✦ Want to use P_T to probe top polarization: P_T is a directly measured quantity (c.f. For polarization method, need to use derived quantities with biases, like center of mass boost etc.)
  - Different from spin-spin correlation where you expand in s wave (for non-relativistic top)

Top Polarization

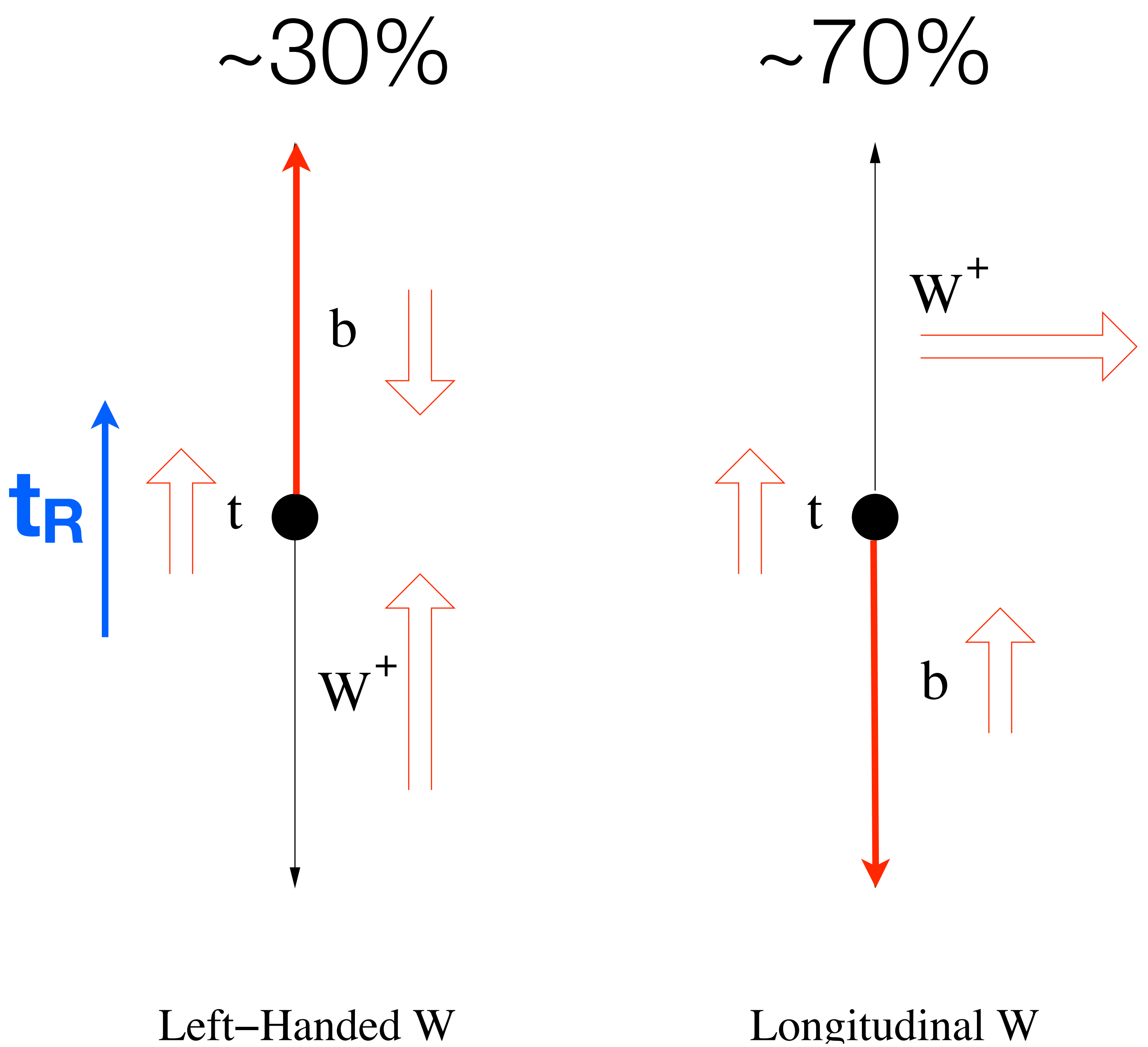


Top Polarization



Top Polarization

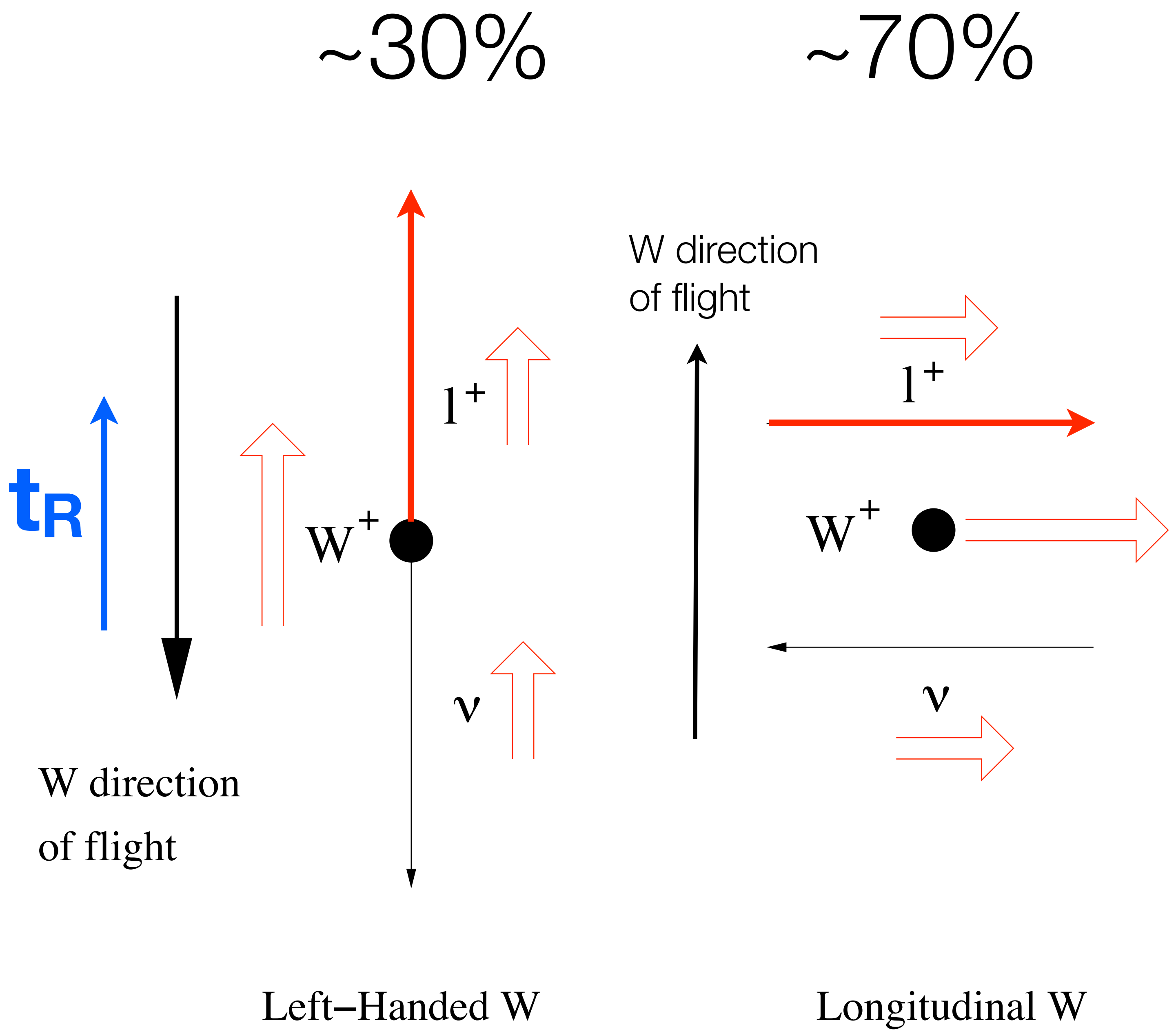
- b quark:
  - back-warded (soft P_T) for t_R
  - forwarded (hard P_T) for t_L
- For SM, parity even (PT distribution will be flat) → look for new Physics where parity is violated



Top Polarization

- lepton: forwarded for t_R

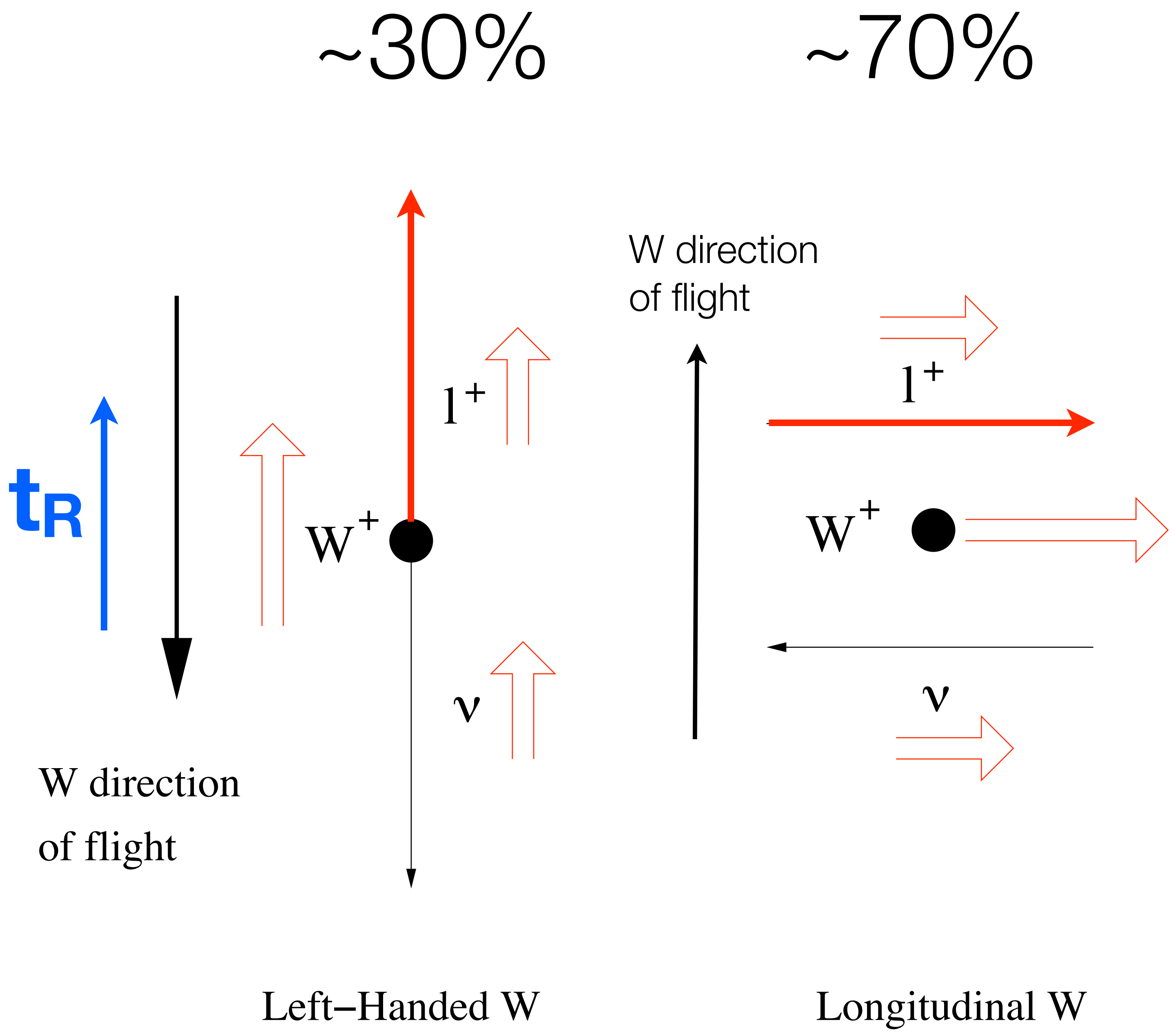
  back-warded for t_L



Top Polarization

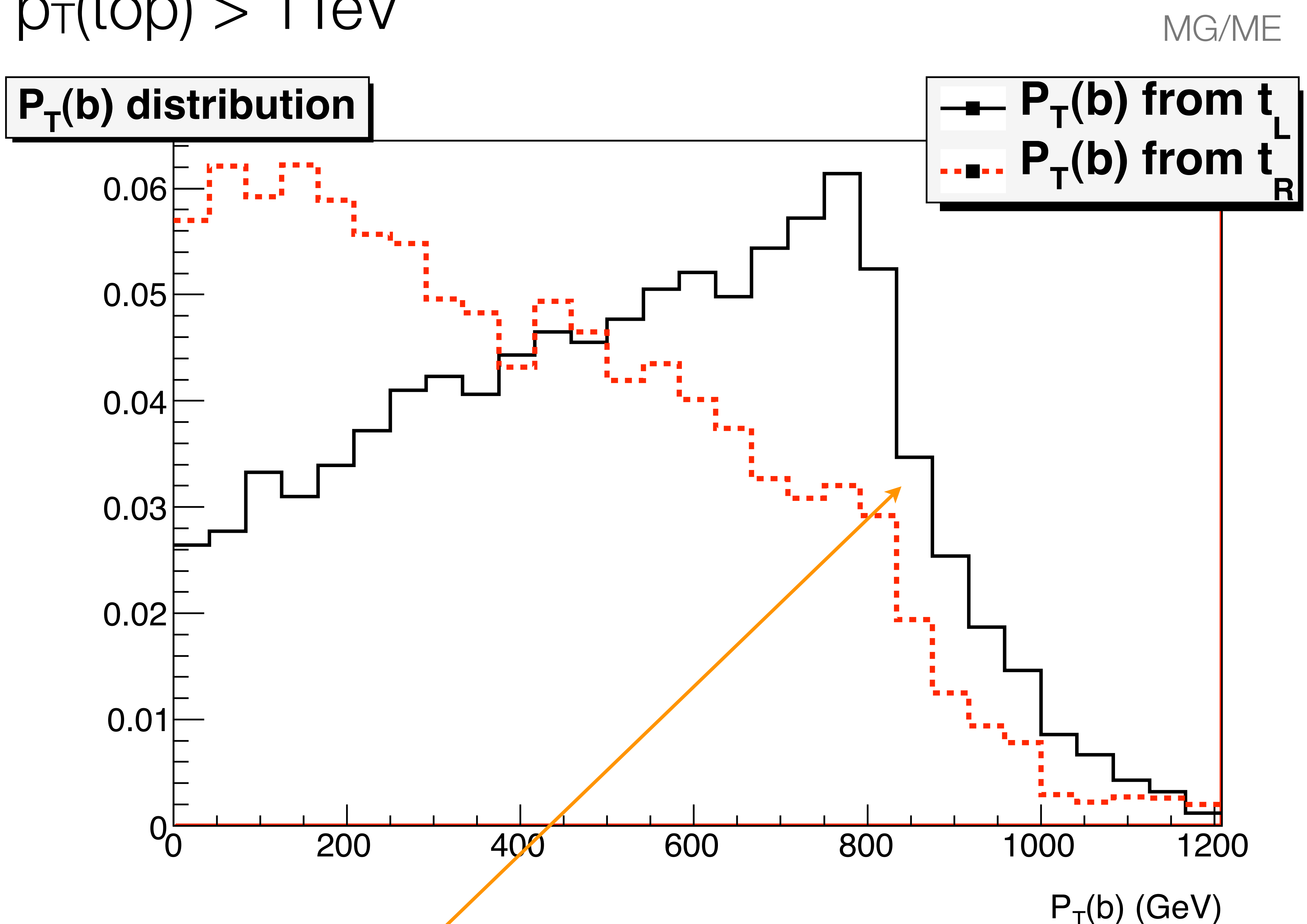
- lepton:forwarded for t_R

  back-warded for t_L



For Boosted Longitudinal W: letpon is forwarded

p_T(top) > 1TeV



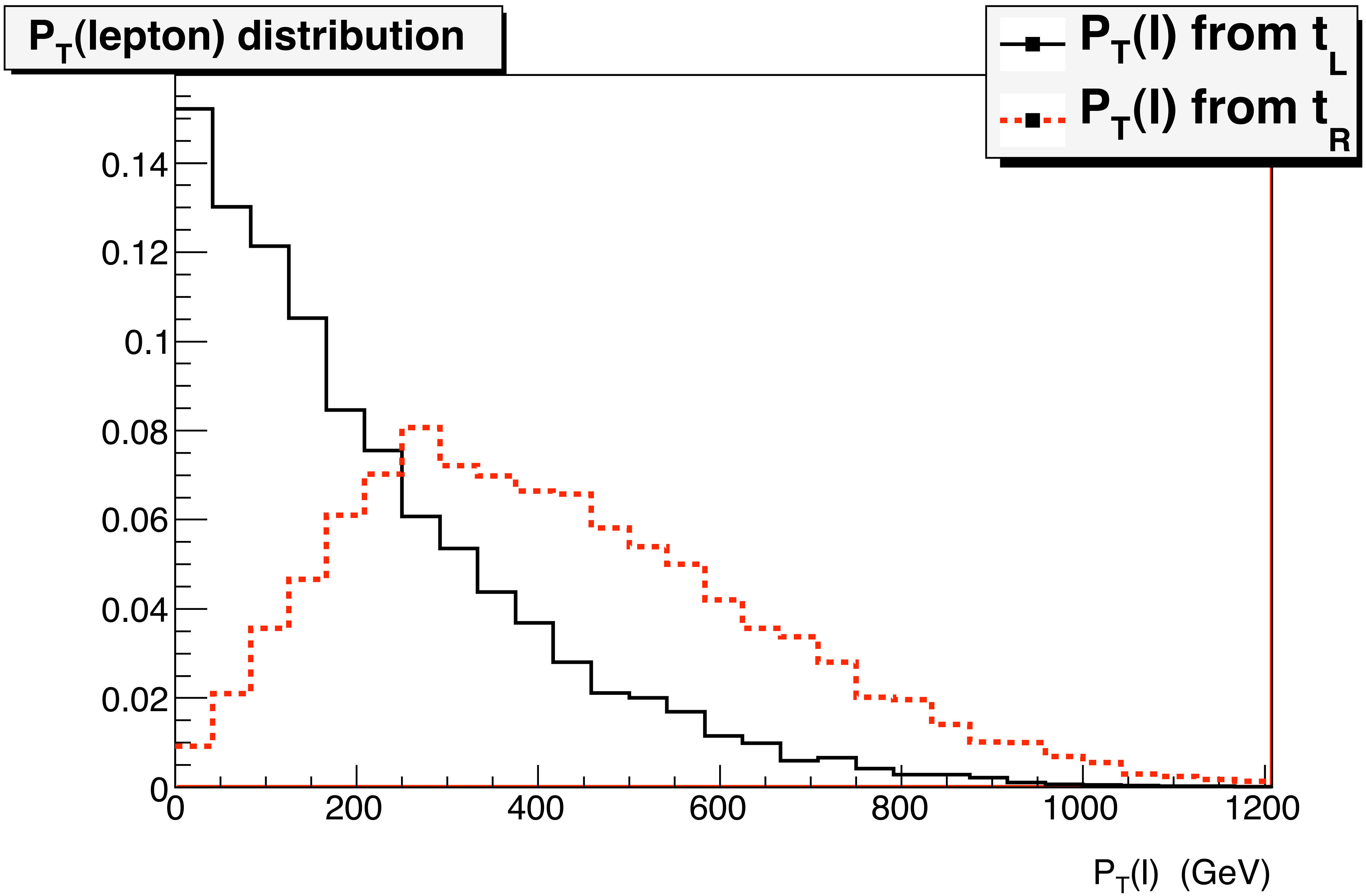
P_T(b) is limited by W boson mass

Hadronic Top

b quark as a spin analyzer

$p_T(top) > 1TeV$

MG/ME

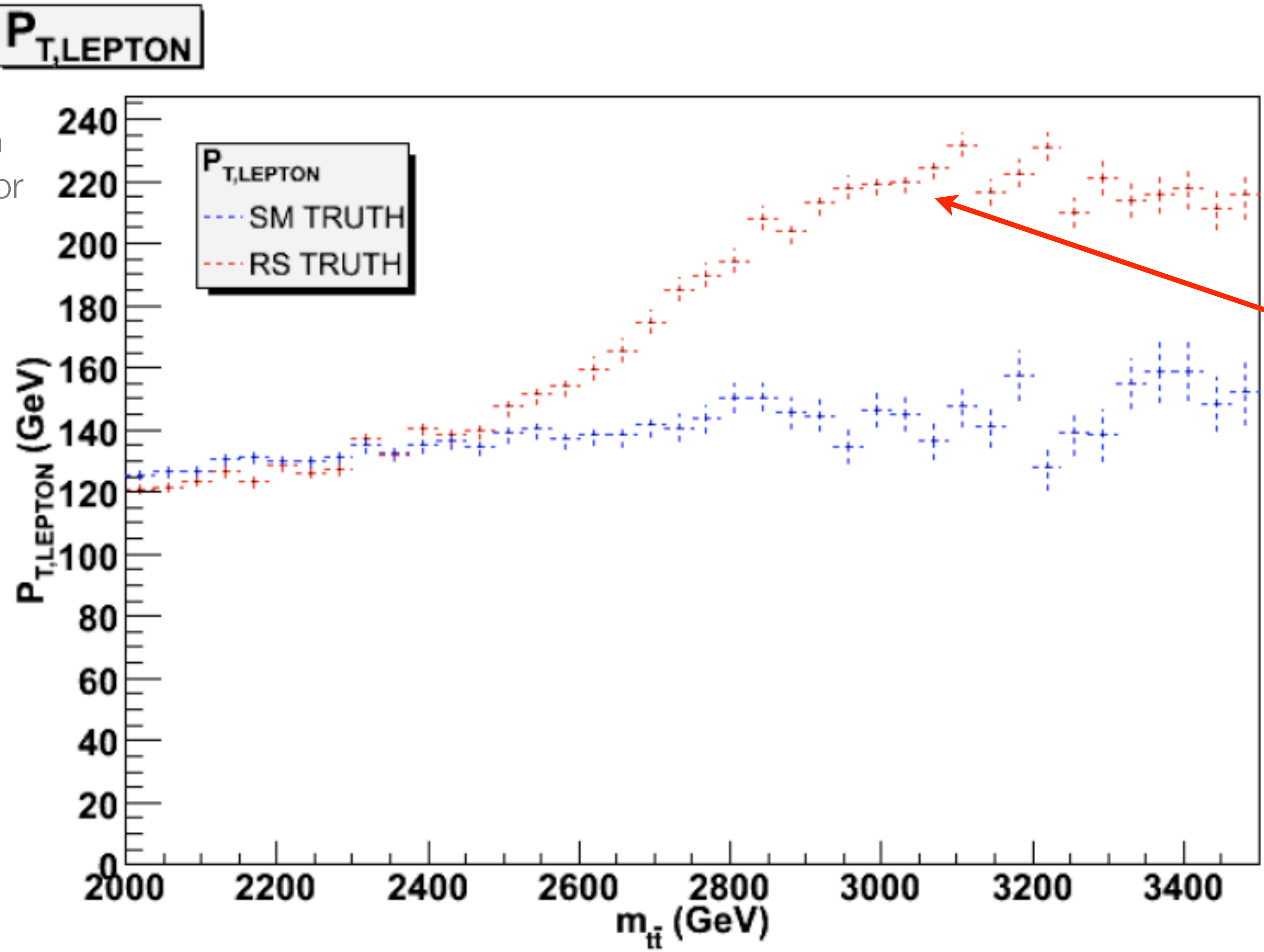


- for example with the KK gluon, you'll see suddenly only leptons/bs that follows the RH curves

Leptonic Top

charged lepton as a spin analyzer

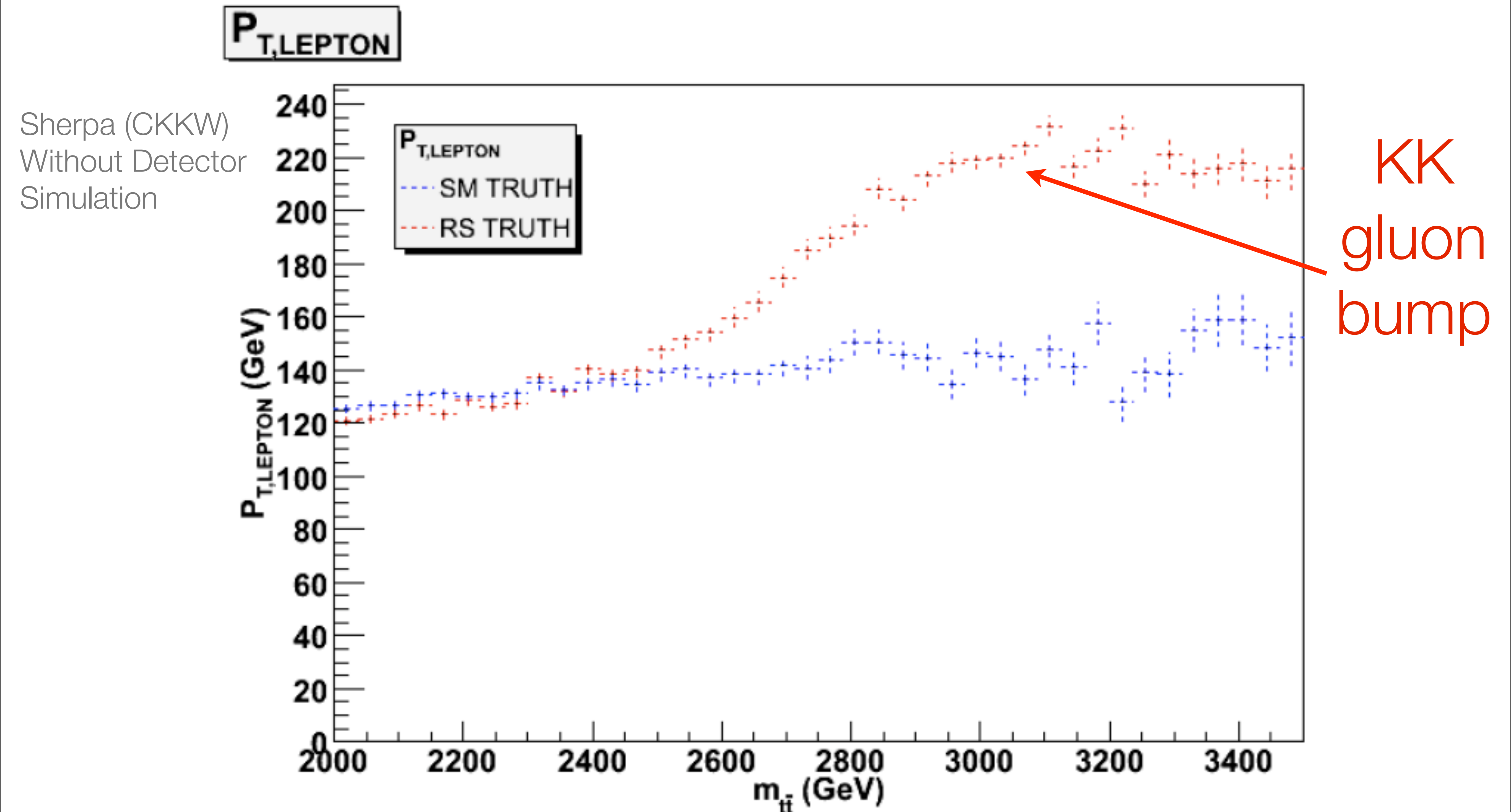
Sherpa (CKKW)
Without Detector
Simulation



KK
gluon
bump

Example: KK gluon

lepton PT is harder near the KK gluon plateau

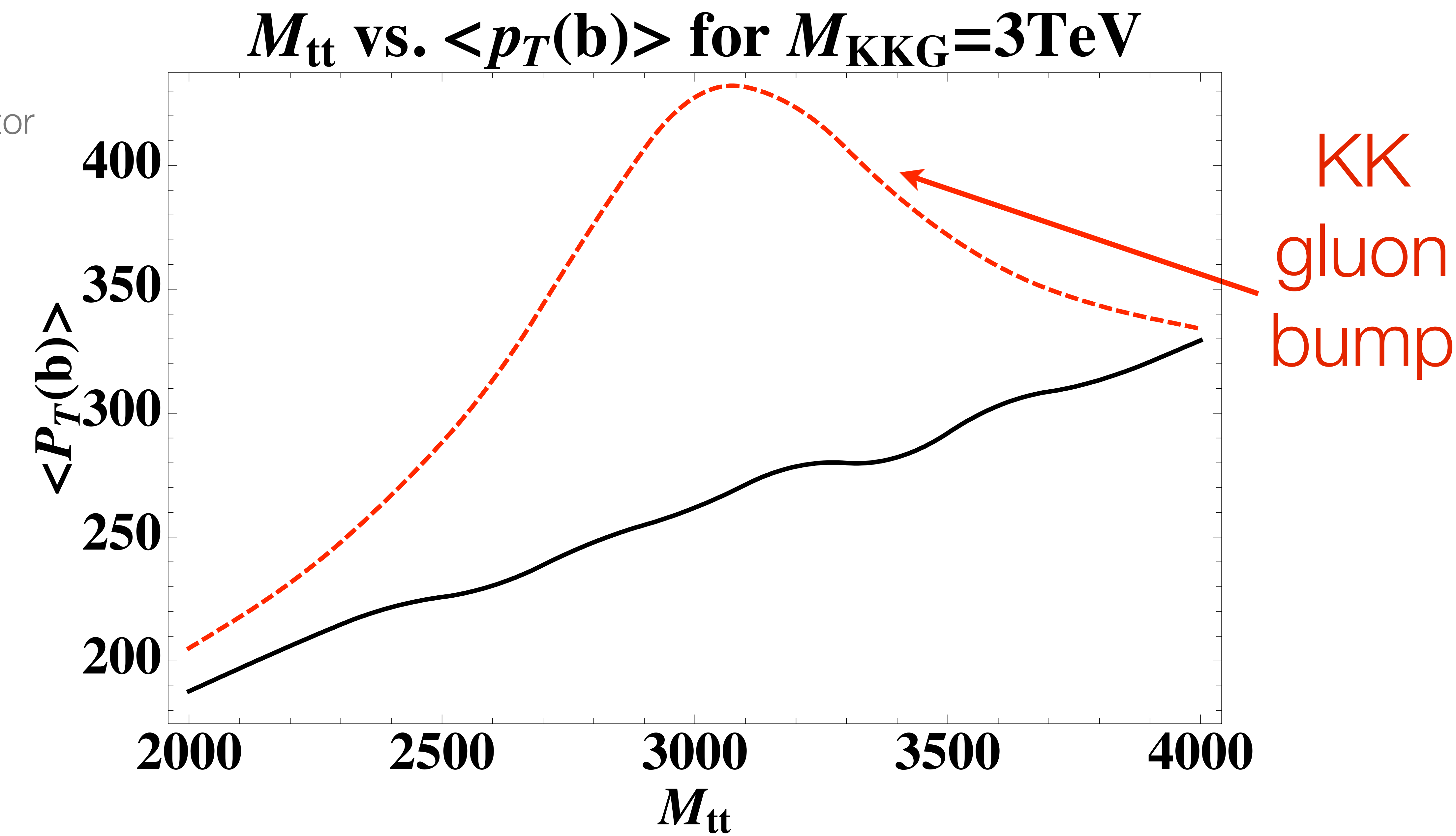


Also relevant for SUSY: heavy stop decaying into top and wino, etc...

Example: KK gluon

lepton PT is harder near the KK gluon plateau

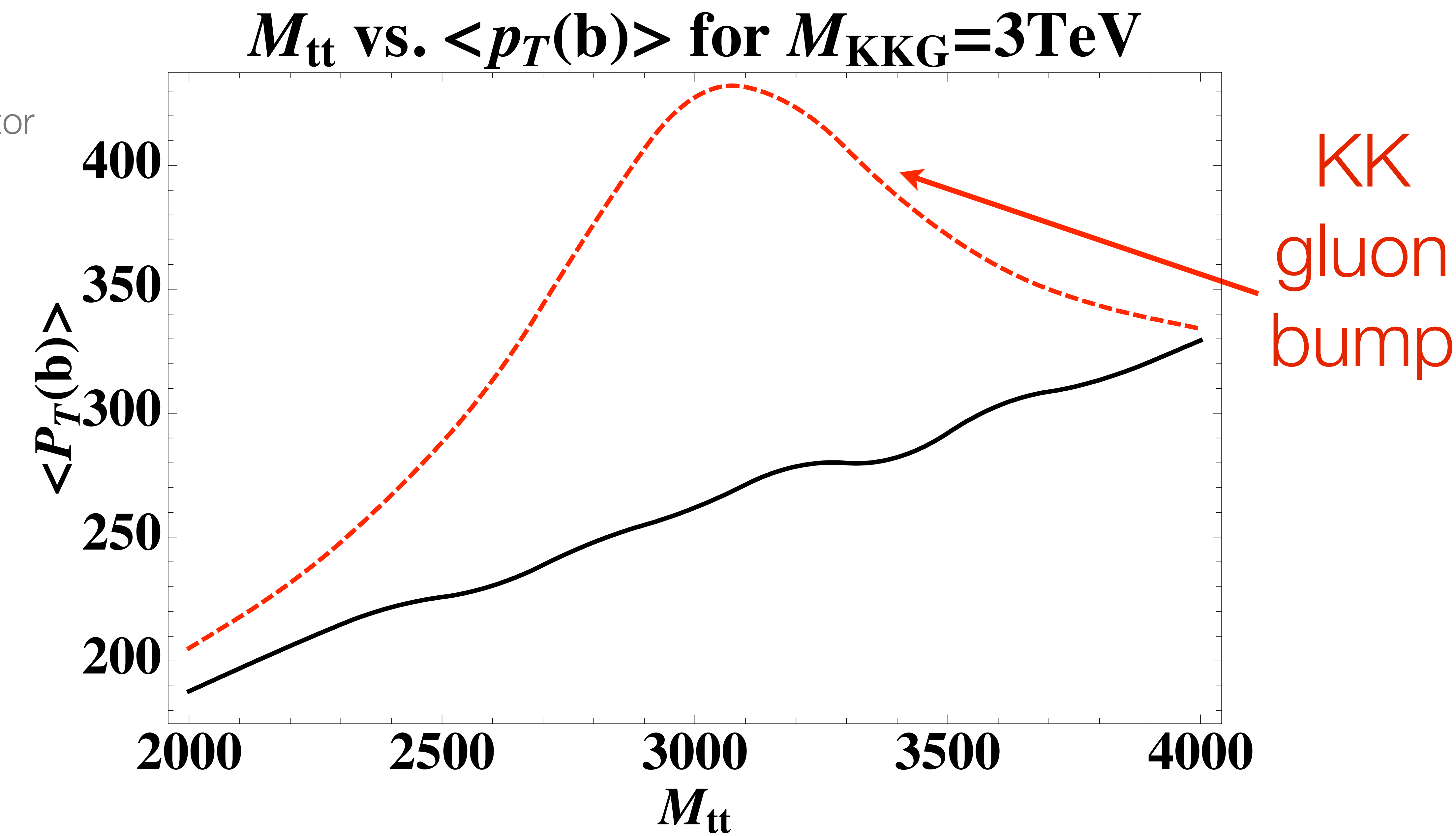
MG/ME
Without Detector
Simulation



Example: KK gluon

b-quark PT is harder near the KK gluon bump

MG/ME
Without Detector
Simulation



Also relevant for SUSY: heavy stop decaying into top and wino, etc...

Example: KK gluon

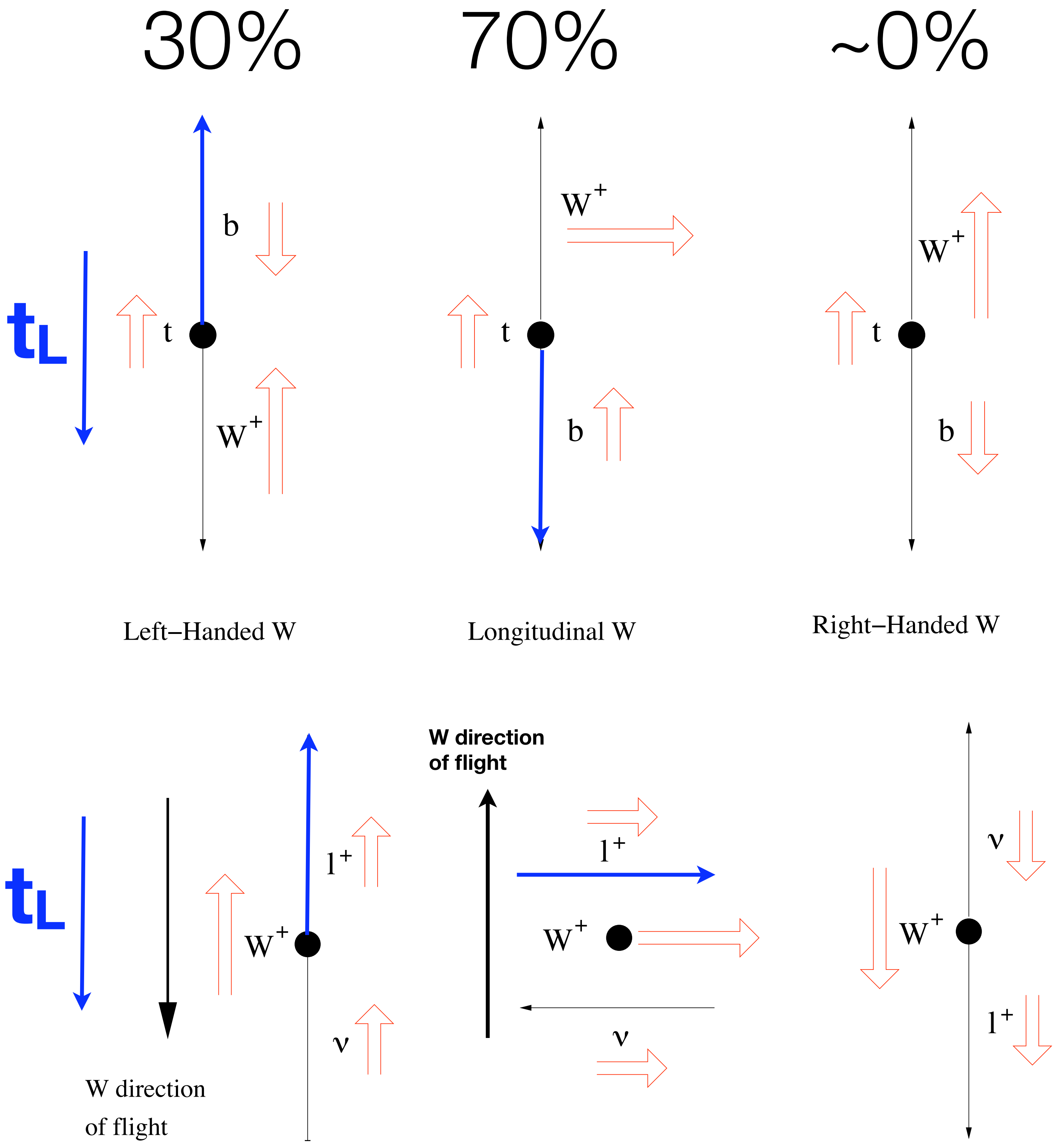
b-quark PT is harder near the KK gluon bump

Summary

- LHC => new era, precision top physics
- Theory+technique to tag t/W/Z/h jets
- Understand jet mass, but it’s not enough
- Introduce Jet-shapes: very useful, but more to do (exp’+analyses+theory)

Backup: Top Polarization

- Polarization: daughter particles of top still remembers the information
- b is **forwarded** for t_L
- lepton is **back-warded** for t_L
- lepton is in general better spin analyzer compared to b-quark, **but b can be used for the hadronic top**



Backup: 30% B-tagging efficiency & 1% light jet