Hadronic Flavor Separation with the ATLAS Detector

Distinguishing quark and gluon jets
Tagging gluon→$b\bar{b}$
Beauty/Charm Separation

Ariel Schwartzman
SLAC

Quark/Gluon Jet Separation

Introduction

Program in progress to use tracking to extract information about jet topology and improve calorimeter jet energy resolution.

How does these techniques work on quark and gluon jets? Are there biases?

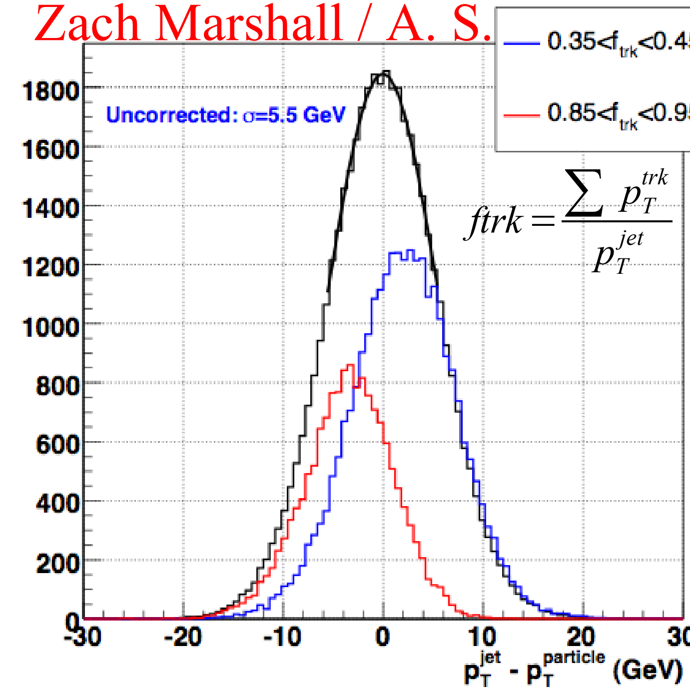
Validation of jet energy scale on quark/gluon enhanced data samples.

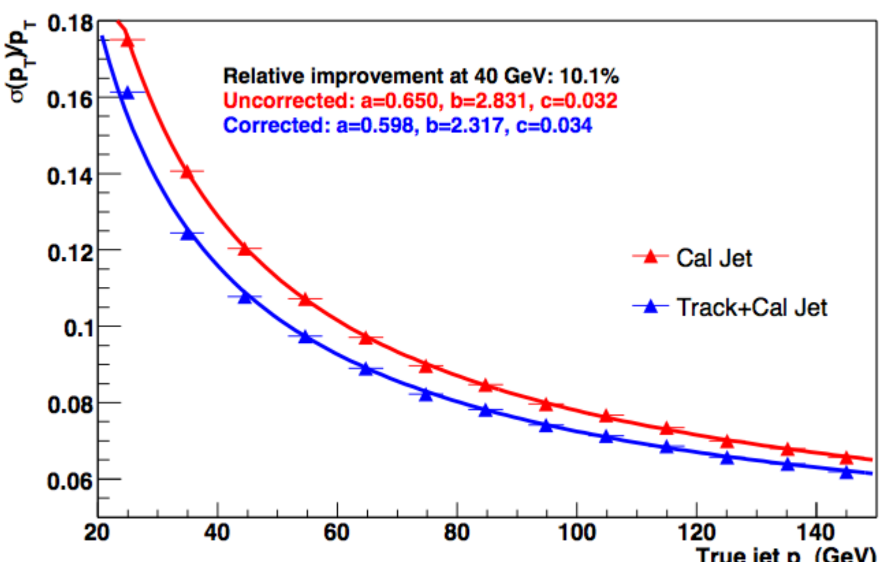
Improve the understanding of Standard Model backgrounds: ttbar+jets

Use flavor tagging to improve inclusive SUSY jet+met searches at the LHC:

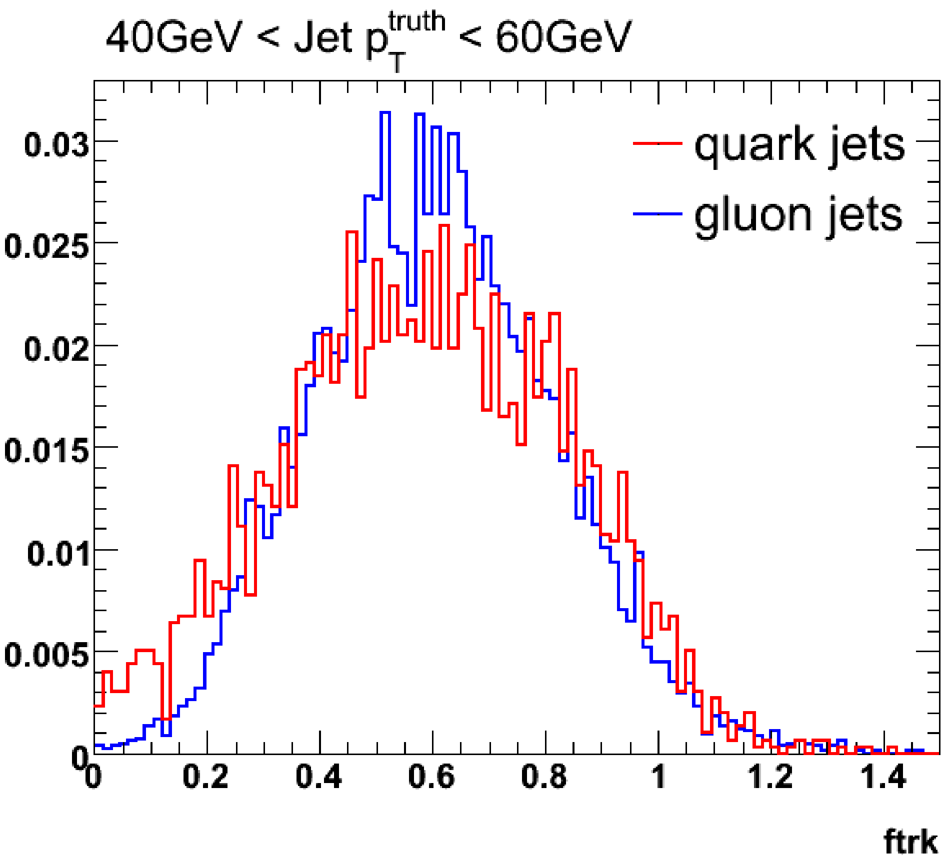
reduce QCD background by tagging quark jets (work in progress with Natalia Toro and Philip Schuster)

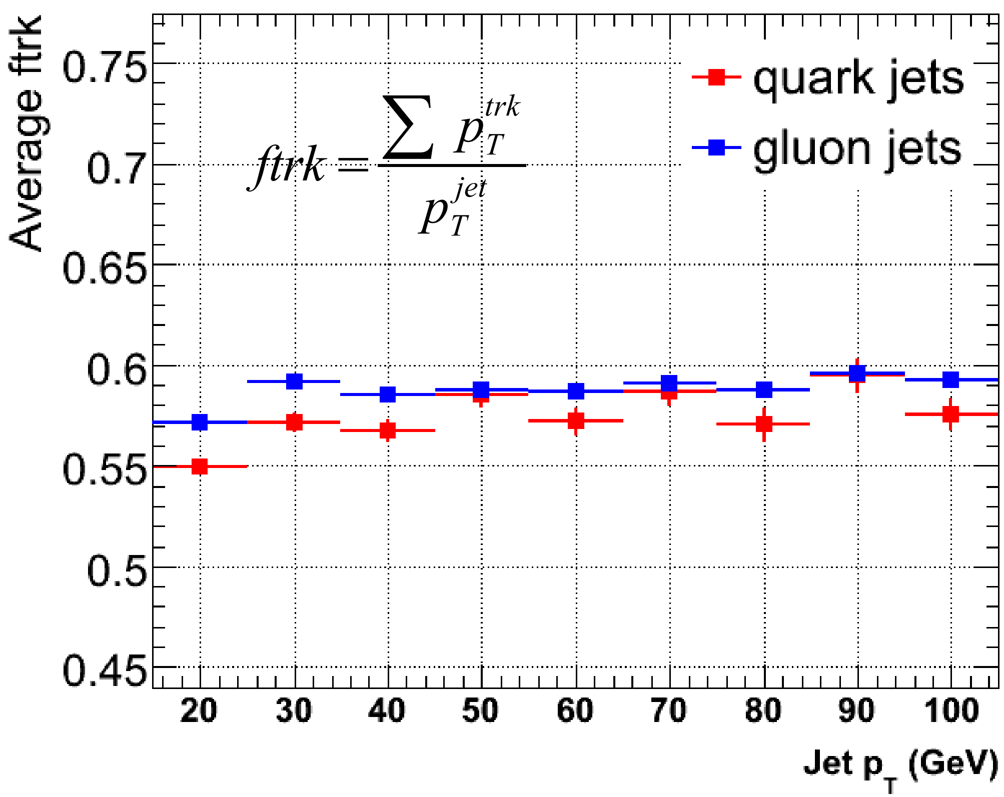
Zach Marshall / A. S.





Track pT Fraction

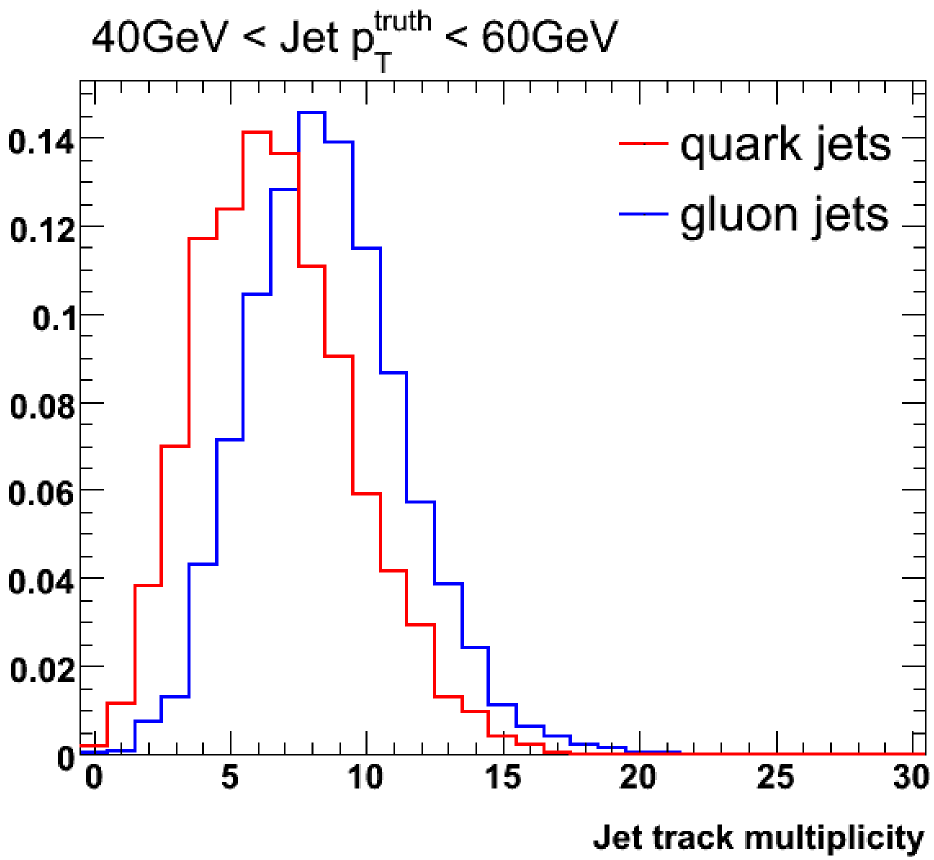


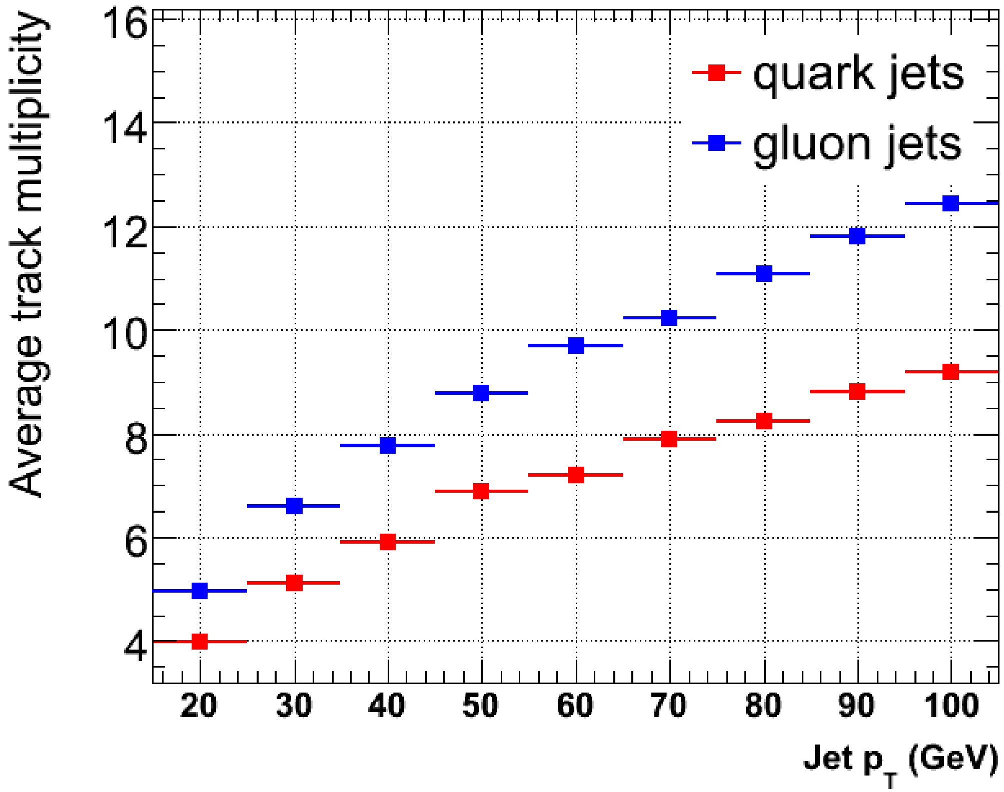


Less than 2% difference in mean value for quark and gluon jets.

ftrk based jet corrections cannot account for q/g differences.

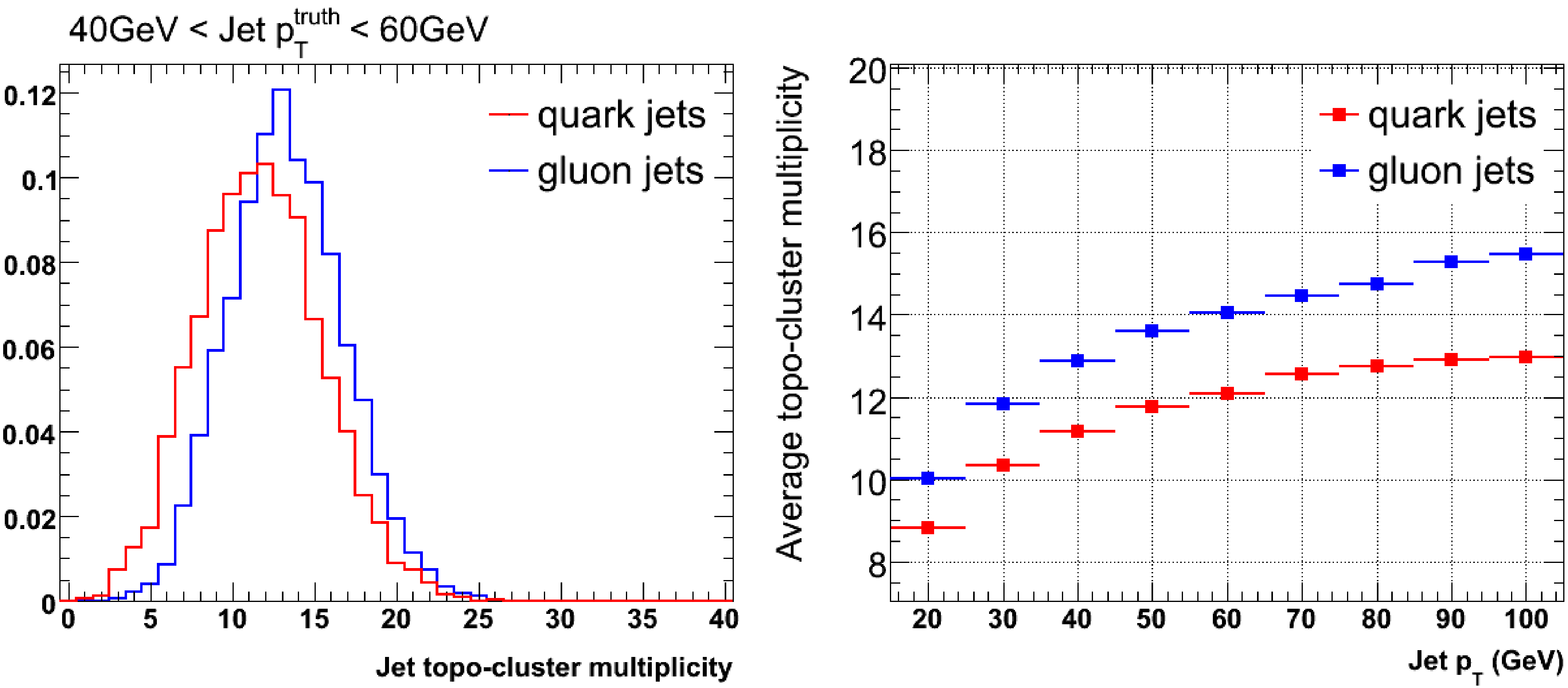
Track Multiplicity





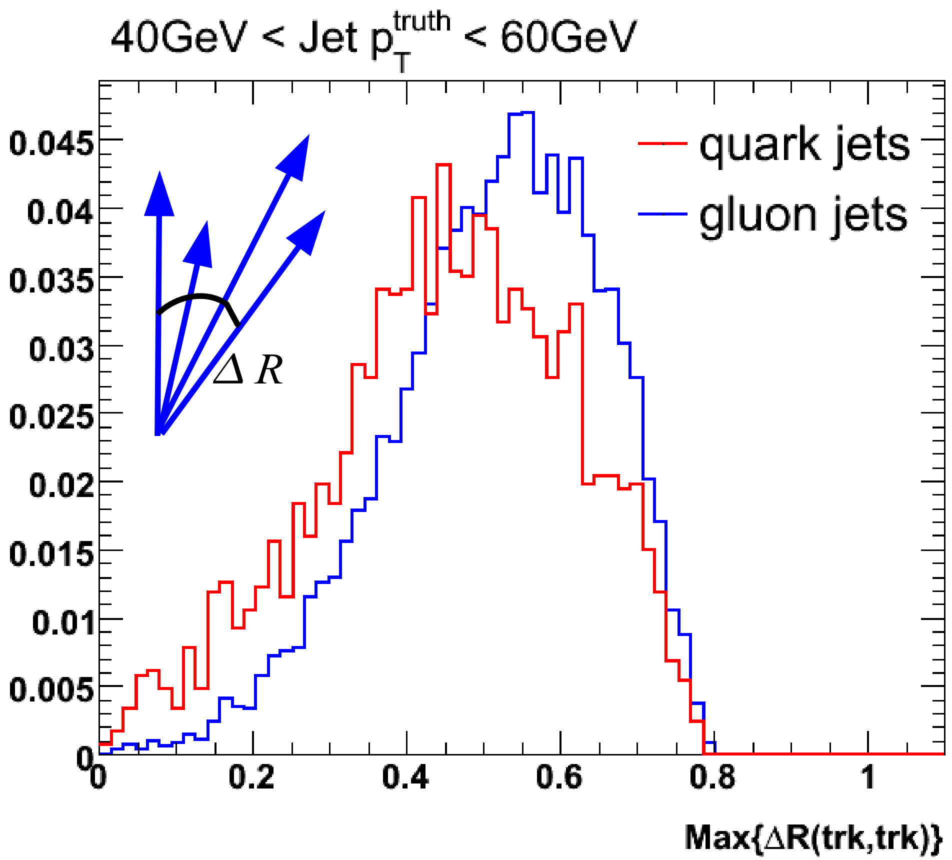
Gluon jets have higher track multiplicity than quak jets (between 1 and 3 additional tracks -on average- for jets with transverse momentum between 20GeV and 100 GeV)

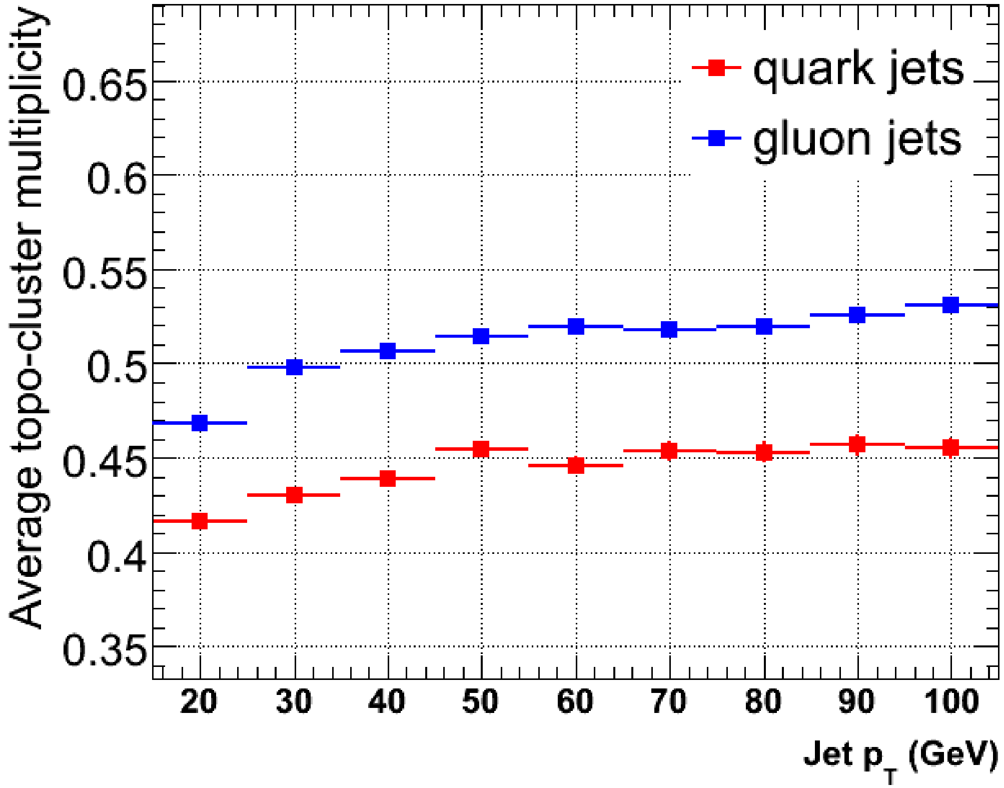
Topo-cluster Multiplicity



Gluon jets have higher topo-cluster multiplicity than quark jets (between 1 and 2 additional clusters -on average-)

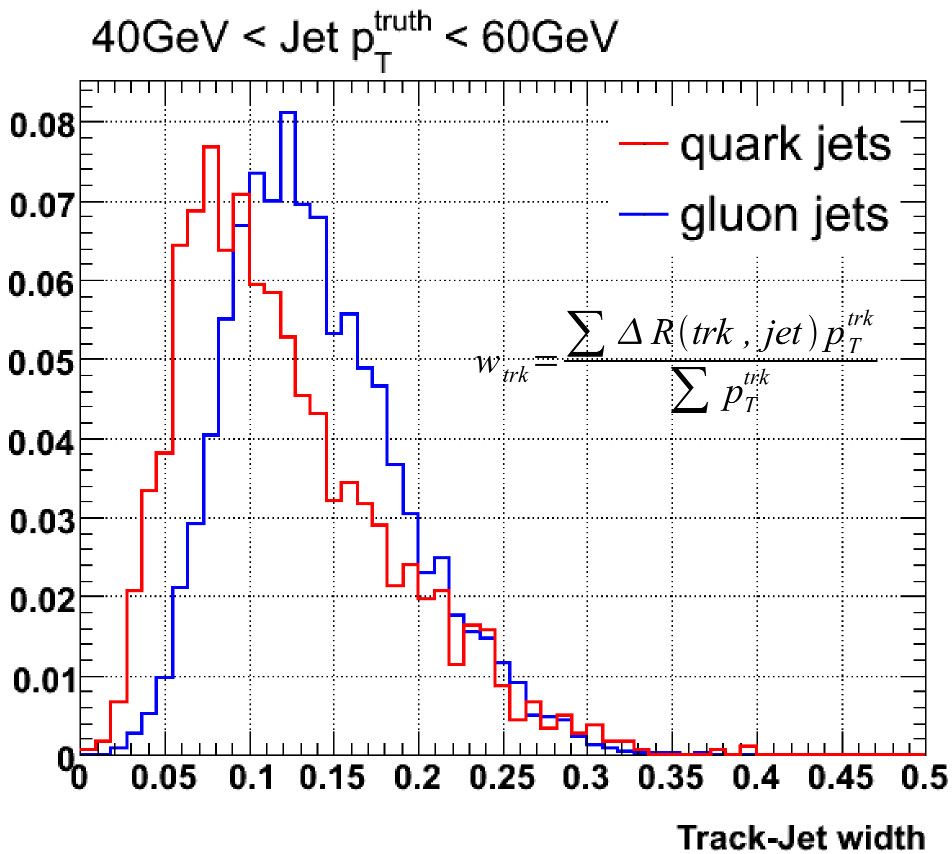
Track Maximum Opening Angle

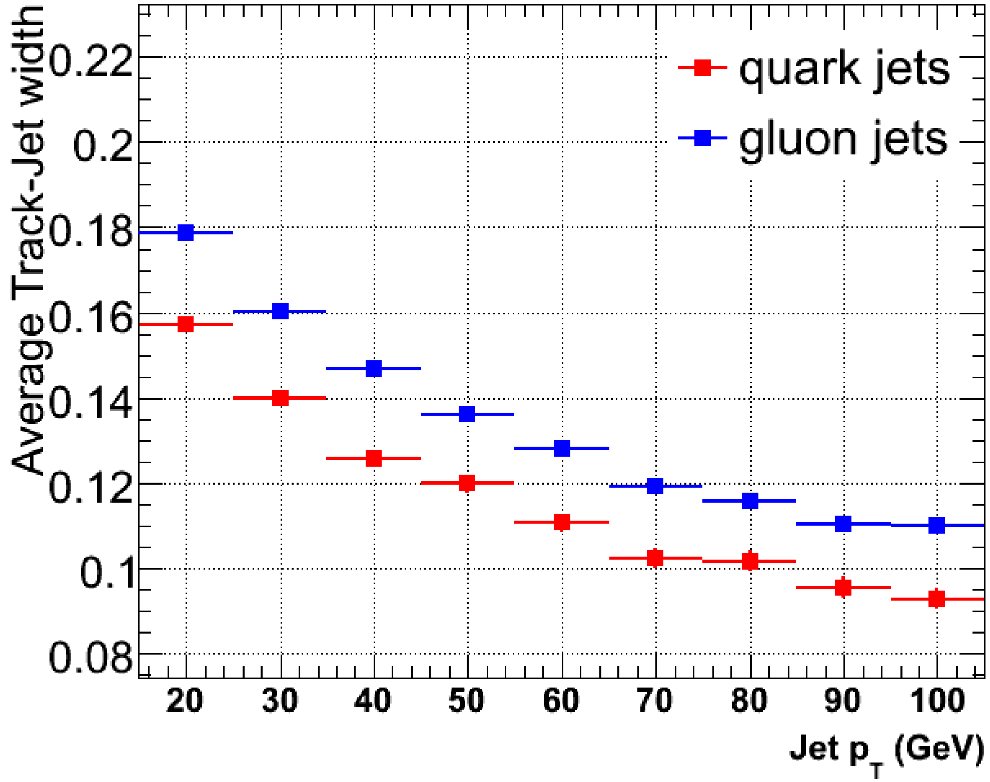




Higher track opening angle for gluon jets than for quark jets.

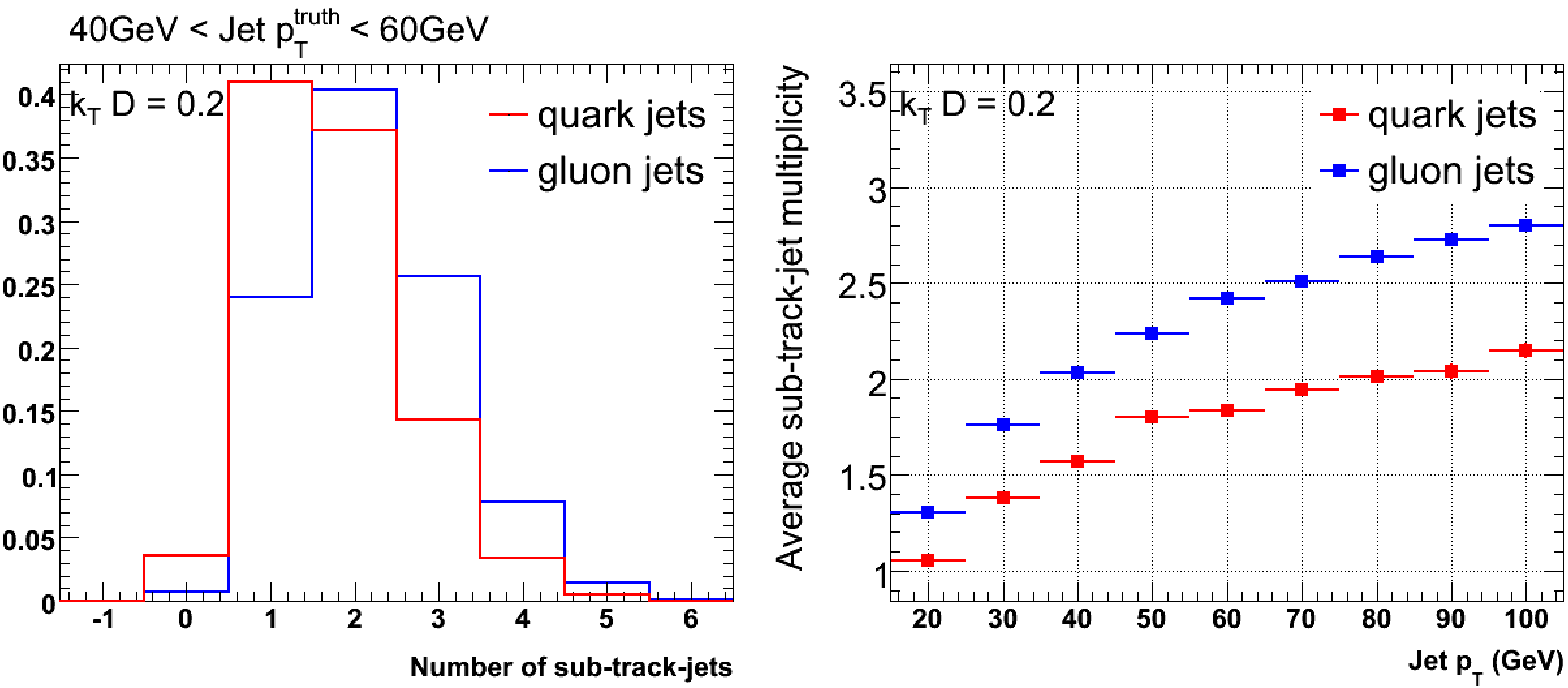
Track Jet Width





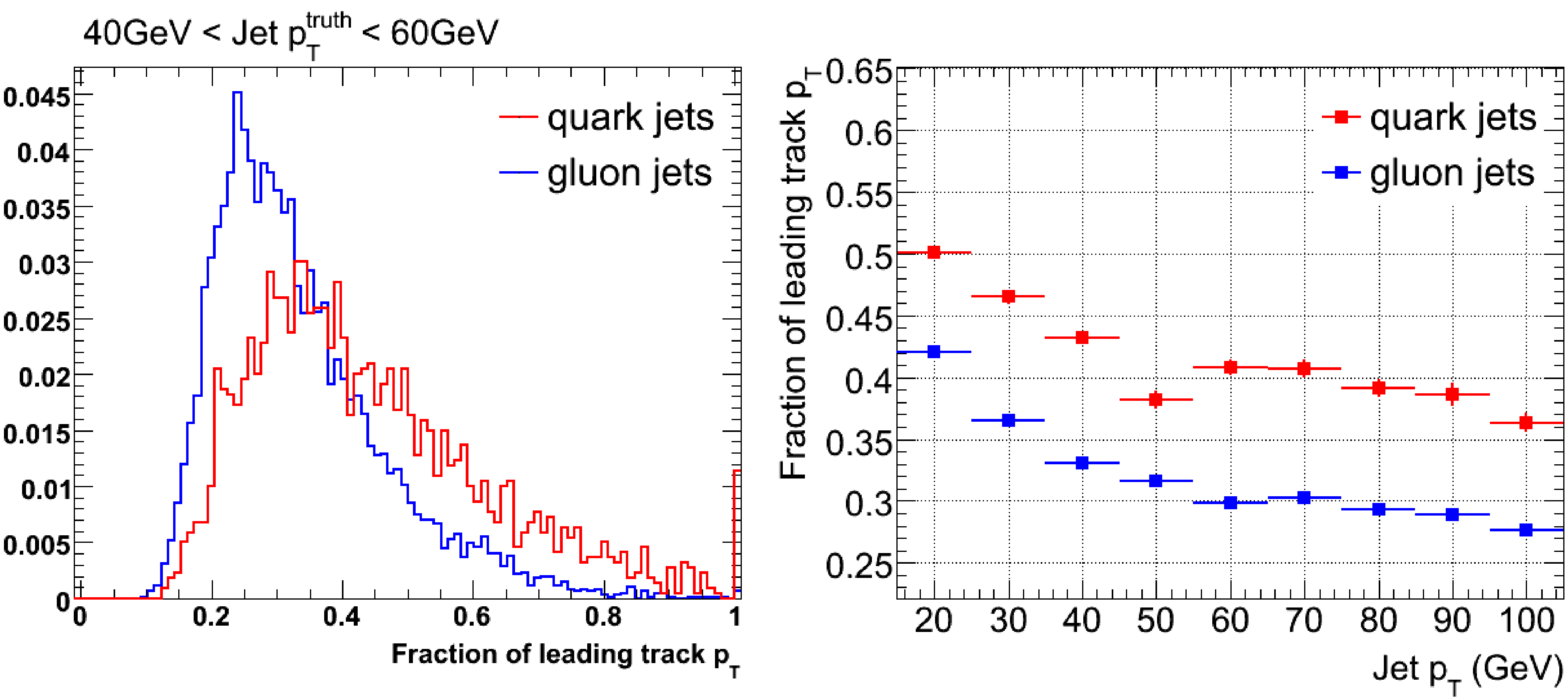
A gluon jet of 100 GeV have -on average- the same width as a a quark jet of 60 GeV.

Sub Track Jet Multiplicity



Number of kT(D=0.2) sub-track-jets.

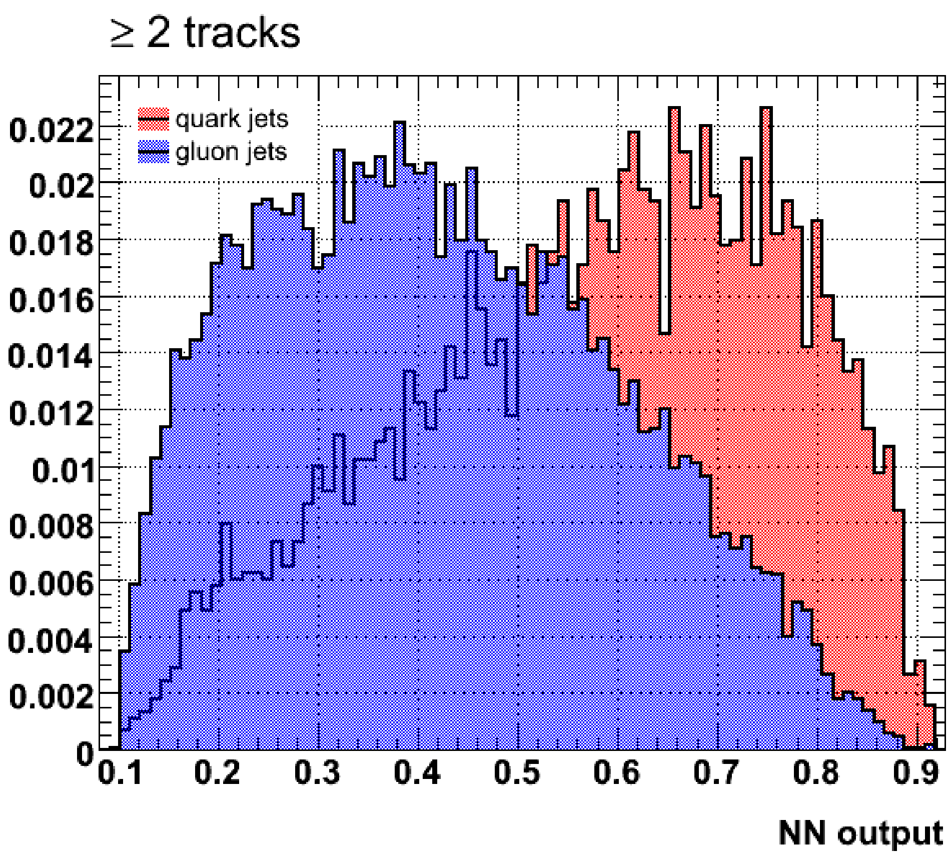
Leading Track pT Fraction

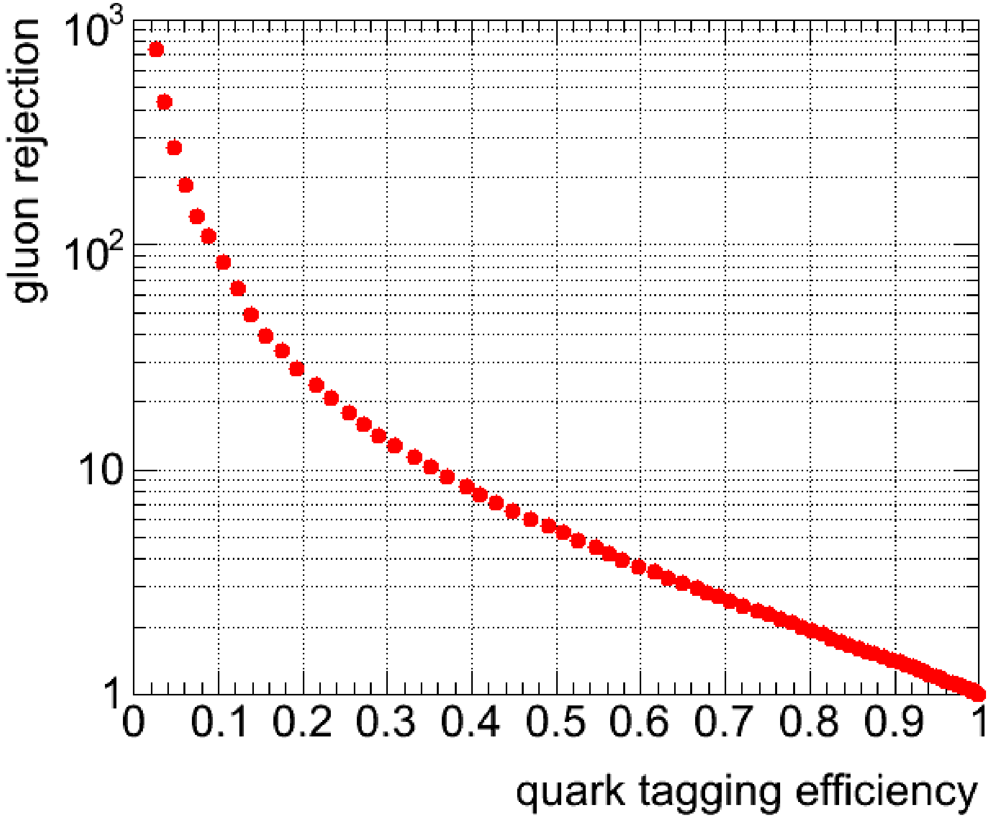


Harder leading track pt for quark jets.

Gluon jets: more and softer tracks than quark jets.

Quark/Gluon Tagging

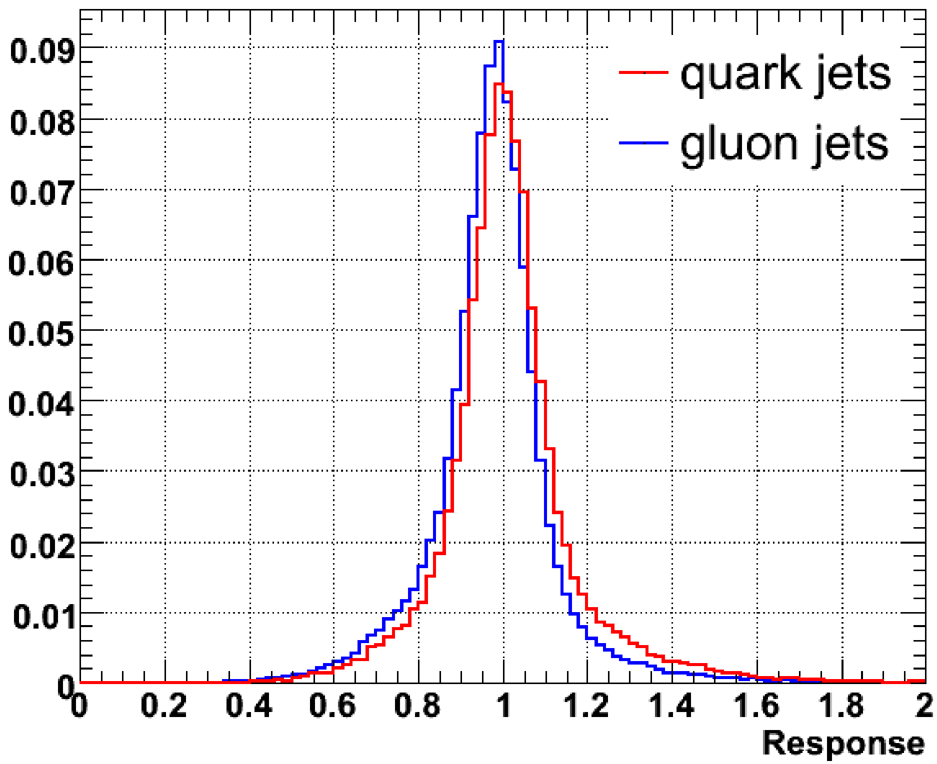


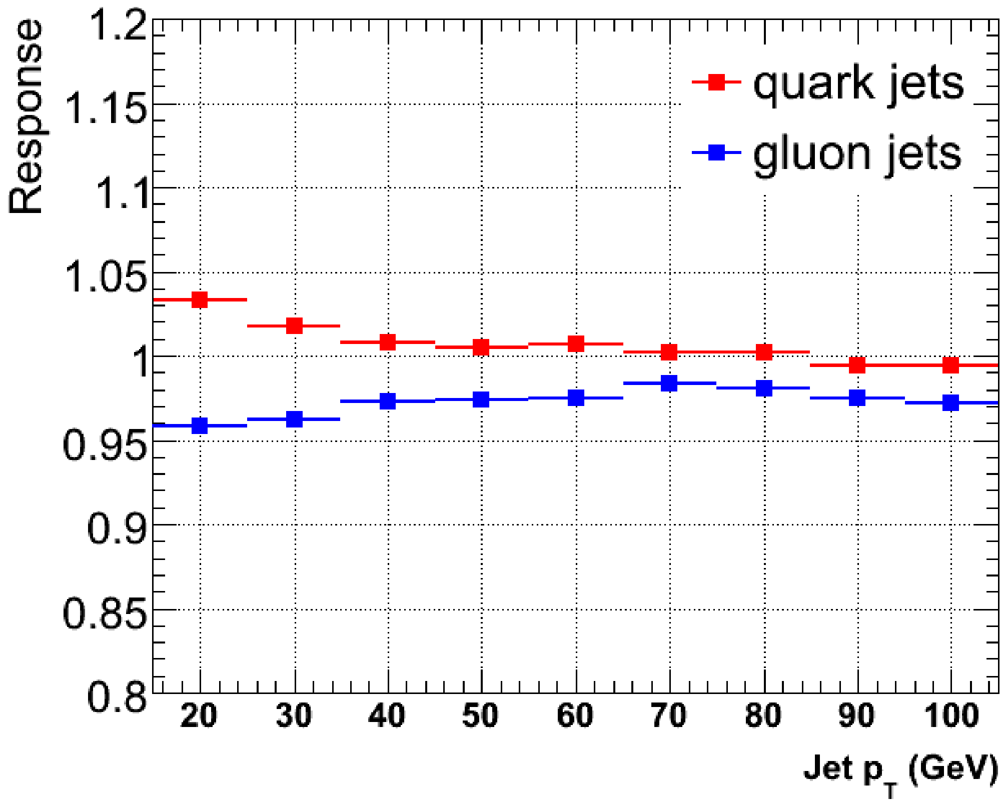


Neural Network input variables: pt, ntrk, width, kt jet multiplicity:

<u>60% quark tagging efficiency @ 30% gluon mis-tag rate</u>.

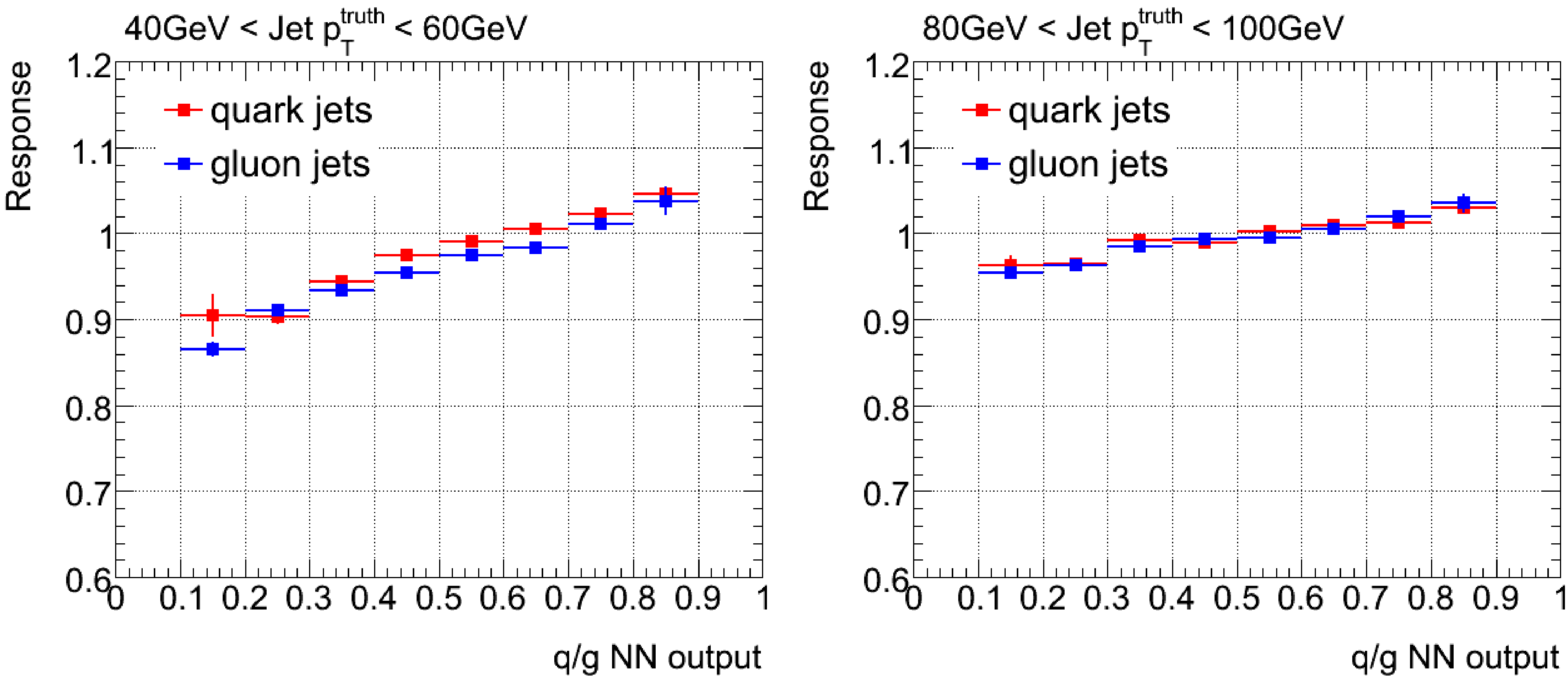
Quark/Gluon Jet Response





Differences in response between 3% and 8%
Gluon jets have systematically lower response

Jet Response vs. q/g NN output



Quark/gluon jet response differences within 2% when kinematic differences are taken into account.

Natalia Toro, Philip Schuster

How Much can Quark Tags Reduce QCD Background for SUSY?

(A simple estimate)

MadGraph QCD*

gluon-rich

N quark	Fraction
4	0.001
3	0.14
2	0.14
1	0.27
0	0.45

* (4 partons with pT>50 GeV, ΔR>0.8) unmatched, for quick but approximate jet-parton association

Direct gluino decay (naive)

quark-rich

N quark	Fraction
4	1
3	0
2	0
1	0
0	0

Natalia Toro, Philip Schuster

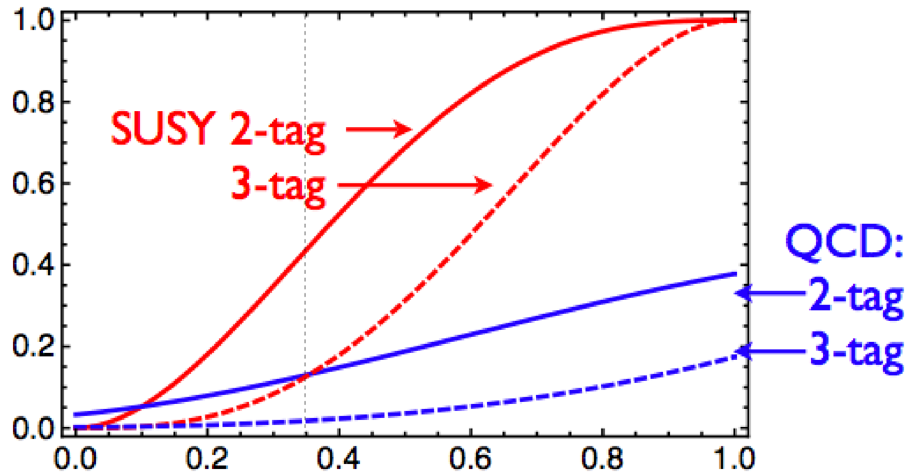
How Much can Quark Tags Reduce QCD Background for SUSY?

(A simple estimate)

Convert parton-level estimates with efficiency/fake rates:

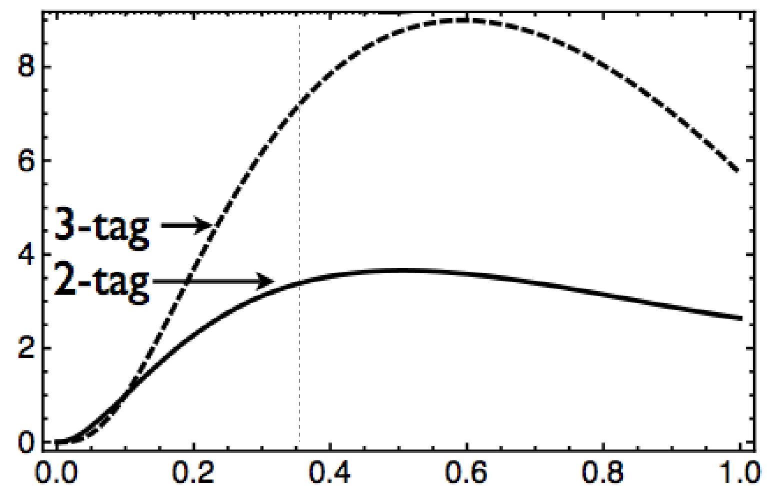
Fake rate = 10%:

Fraction of events tagged



tag efficiency per jet

S/B enhancement*



tag efficiency per jet

*B=QCD only!

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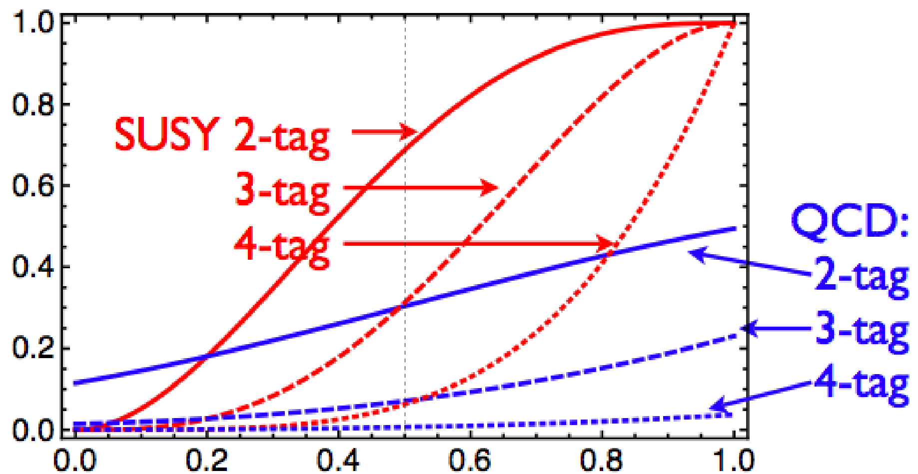
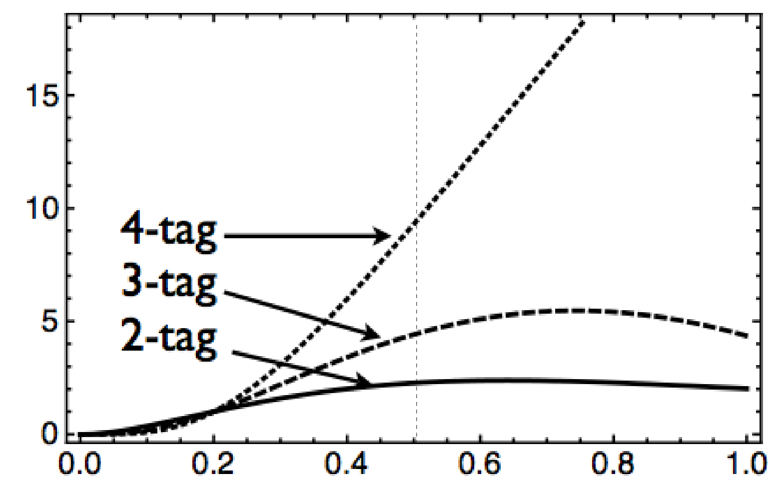
How Much can Quark Tags Reduce QCD Background for SUSY?

(A simple estimate)

Convolve parton-level estimates with efficiency/fake rates:

Fake rate = 20%:





*B=QCD only!

Natalia Toro, Philip Schuster

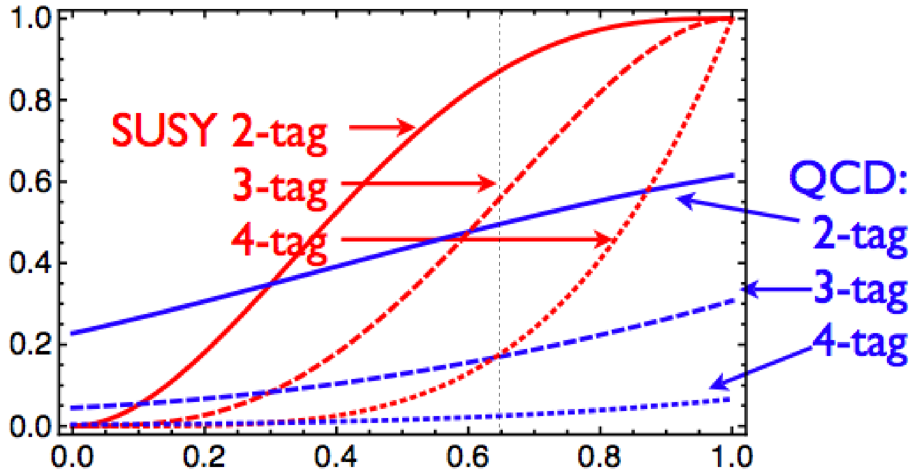
How Much can Quark Tags Reduce QCD Background for SUSY?

(A simple estimate)

Convert parton-level estimates with efficiency/fake rates:

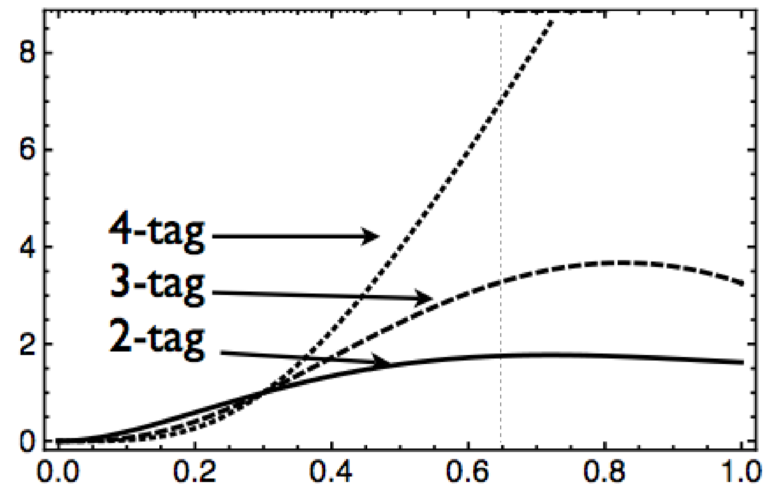
Fake rate = 30%:

Fraction of events tagged



tag efficiency per jet

S/B enhancement*



tag efficiency per jet

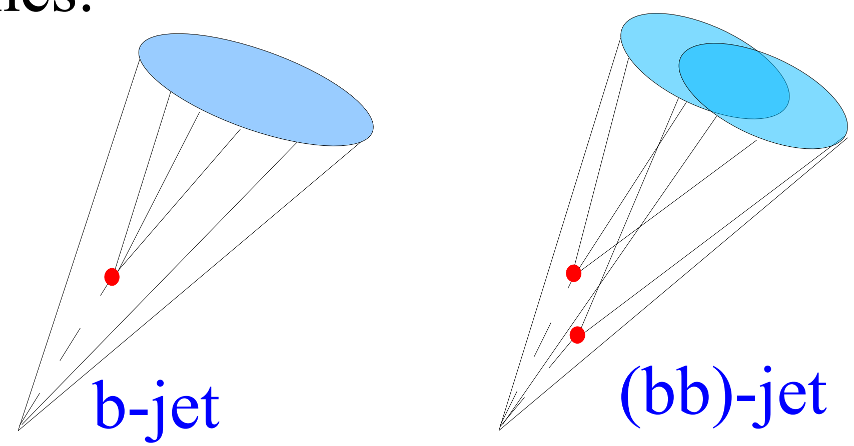
*B=QCD only!

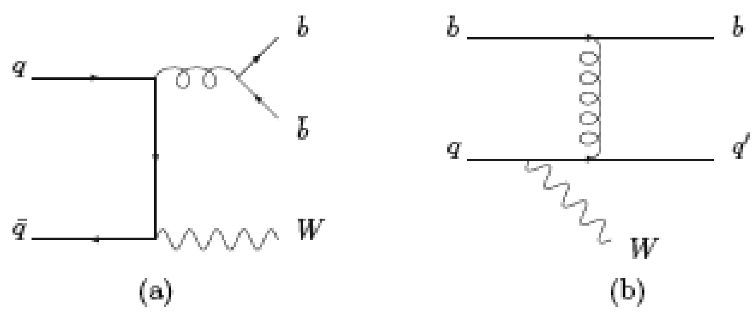
Tagging $g \rightarrow b\bar{b}$

Introduction (I)

Production of W bosons in association with b-quarks is a major background to SUSY and Higgs searches.

At LO, b quarks produced in association with W bosons may originate from gluon splitting, at small ΔR angles, resulting in merged (bb) jets.





Tagging bb-jets can be important to reject and improve estimation of W+jets background.

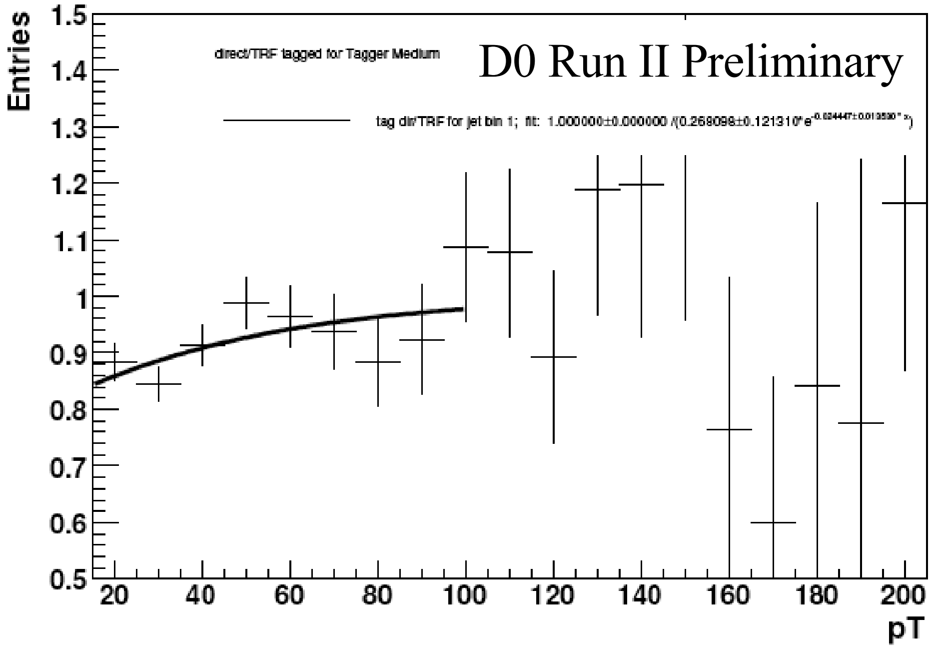
NLO cross sections (pb): (hep-ph/0611348)

LHC: Wbb: 14.3, W(bb): 27.0, Wbj: 96.2

Tevatron: Wbb: 3.14, W(bb): 0.89, Wbj: 2.54

Introduction (II)

At the Tevatron it was observed that tagging background estimation derived from single b-jet samples underestimate the b-tag rate in Wbb events: larger systematic uncertainties.

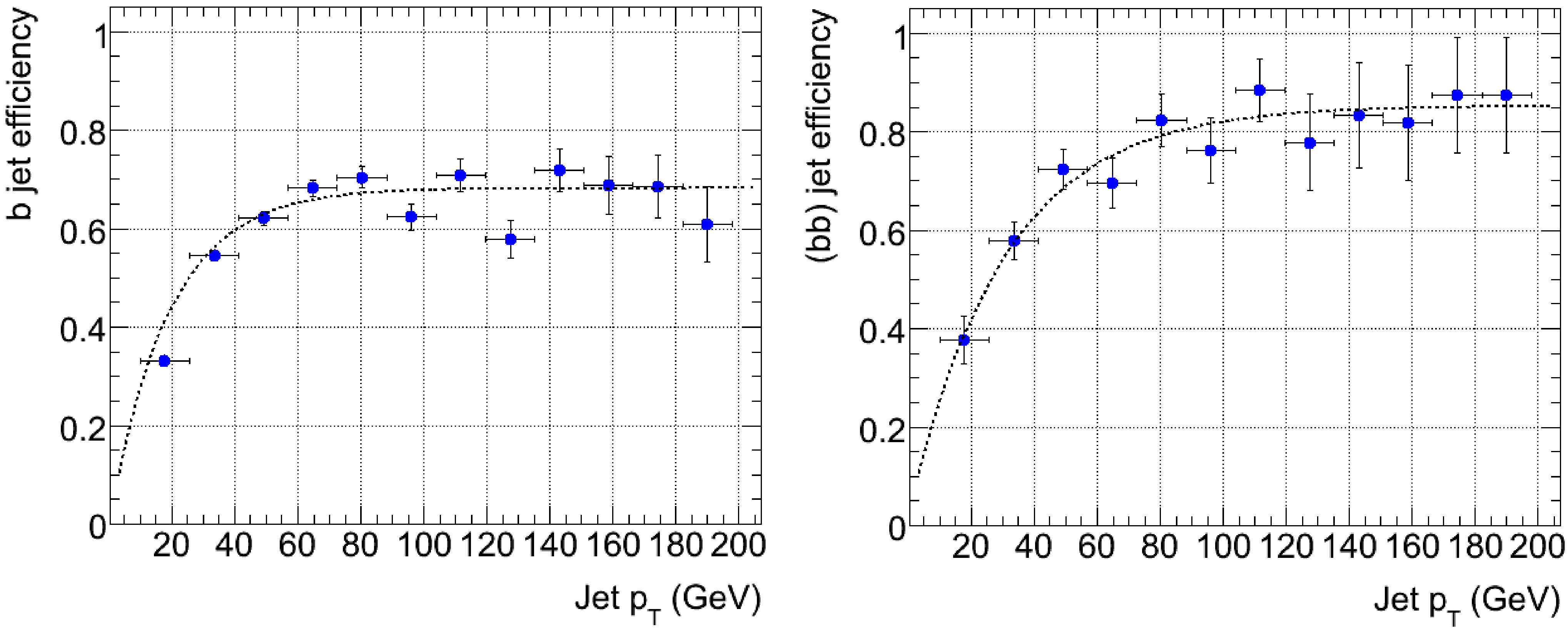


SLC/LEP: gbb, gcc production rates factor two higher than simulation.

(New idea, not explored at the Tevatron)

Develop a technique to *tag* b-jets from gluon splitting

b-tag Performance in Wbb Events

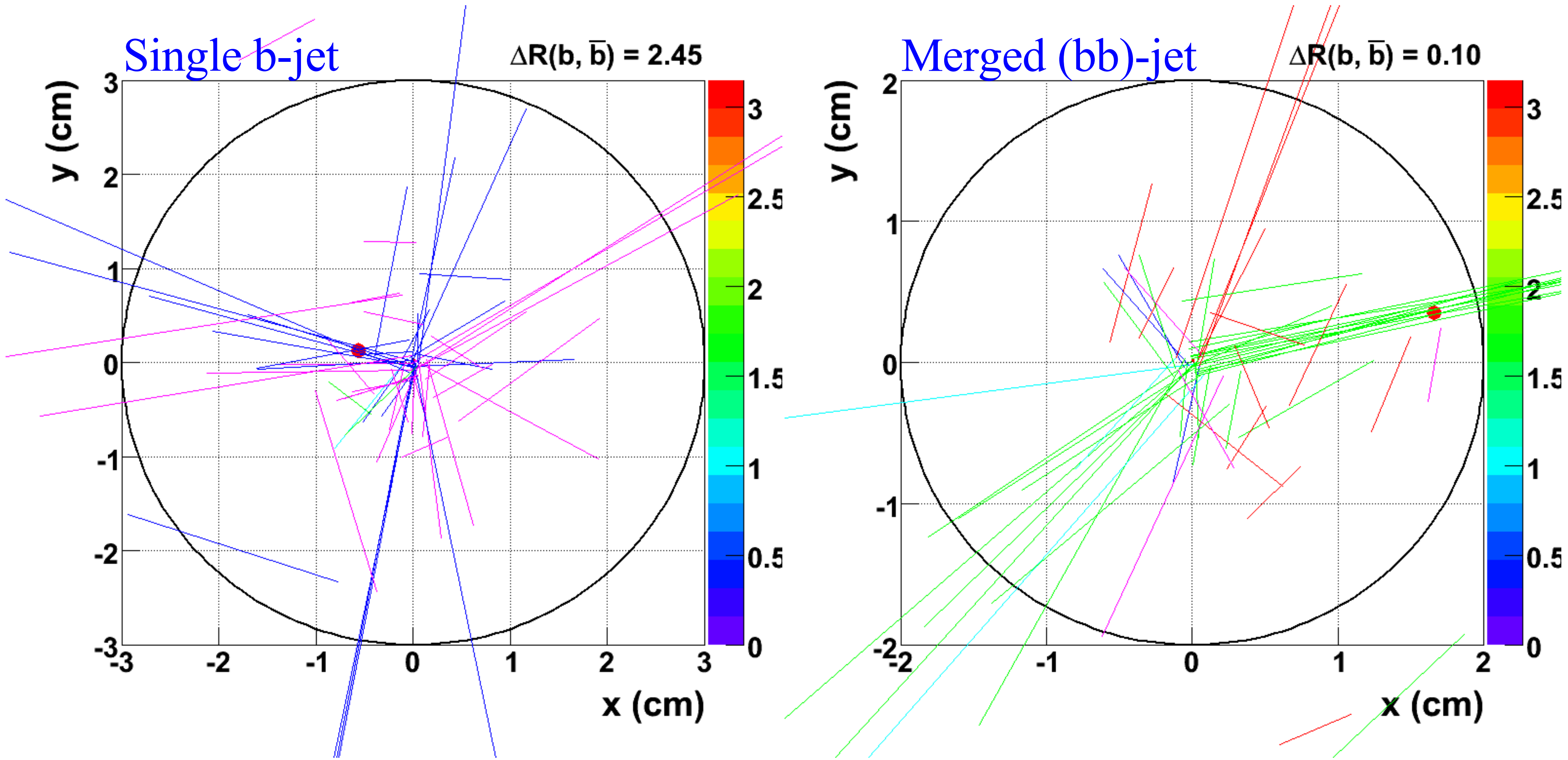


Higher b-tagging efficiency for merged g(bb) jets.

Different jet pT dependence.

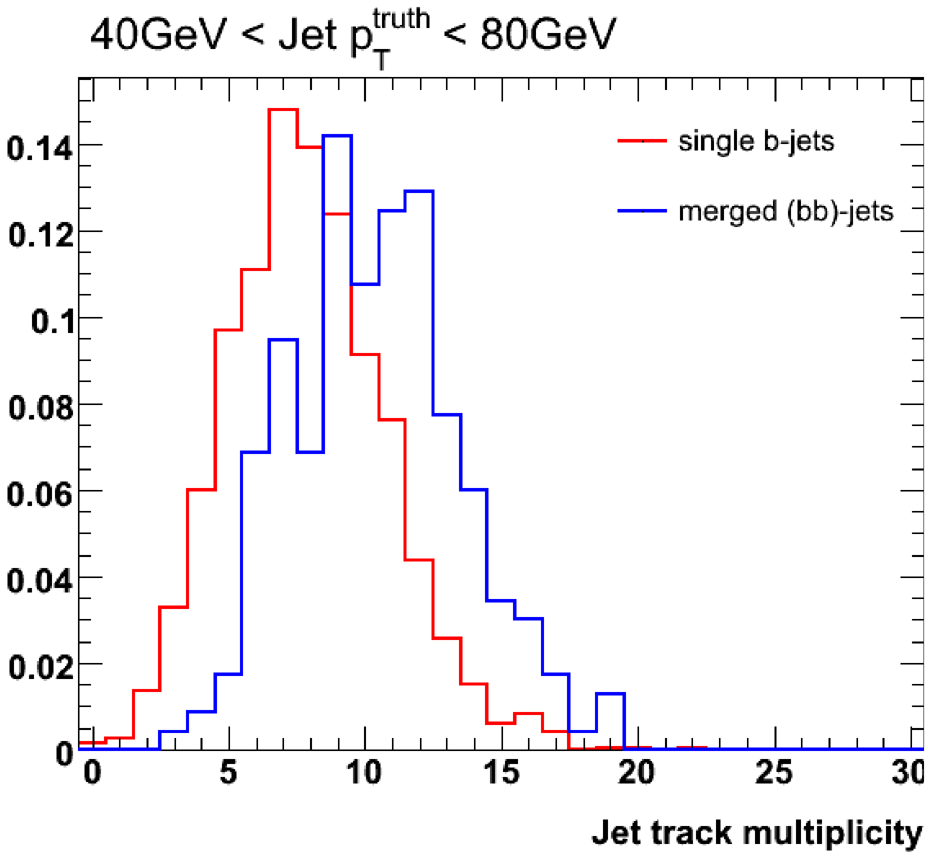
(SV1+IP3 weight > 6)

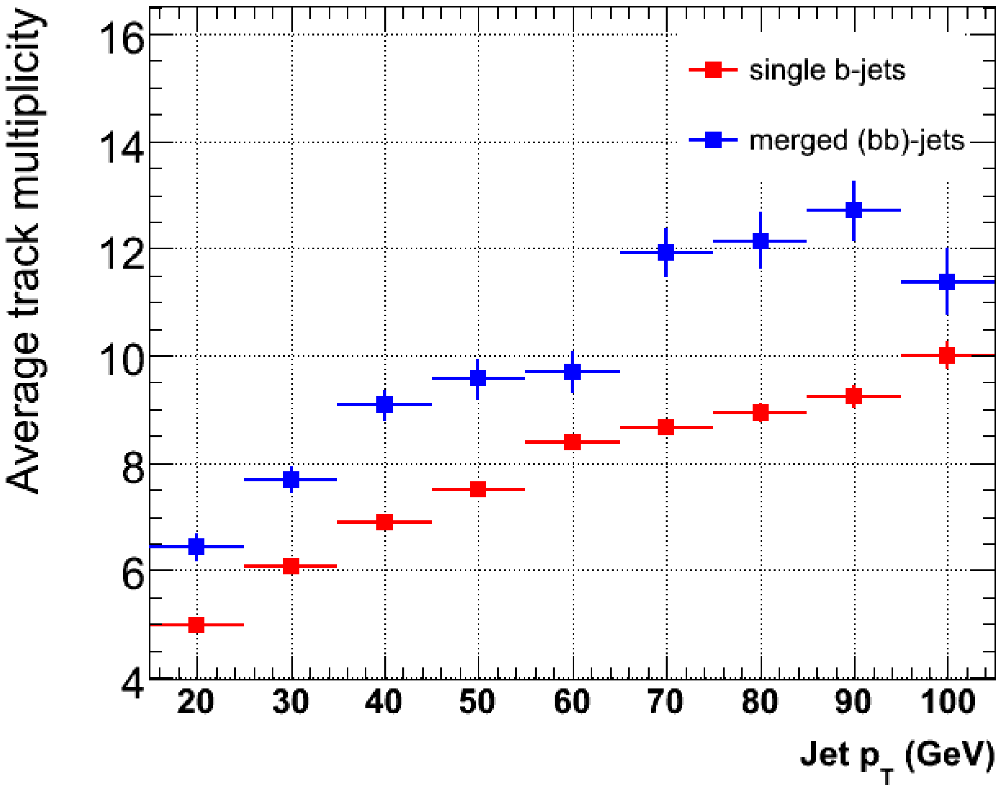
Single and Merged b-jets



(bb) merged jets have higher track multiplicity and result in wider track-jets.

Kinematics of b and (bb)-jets (I)

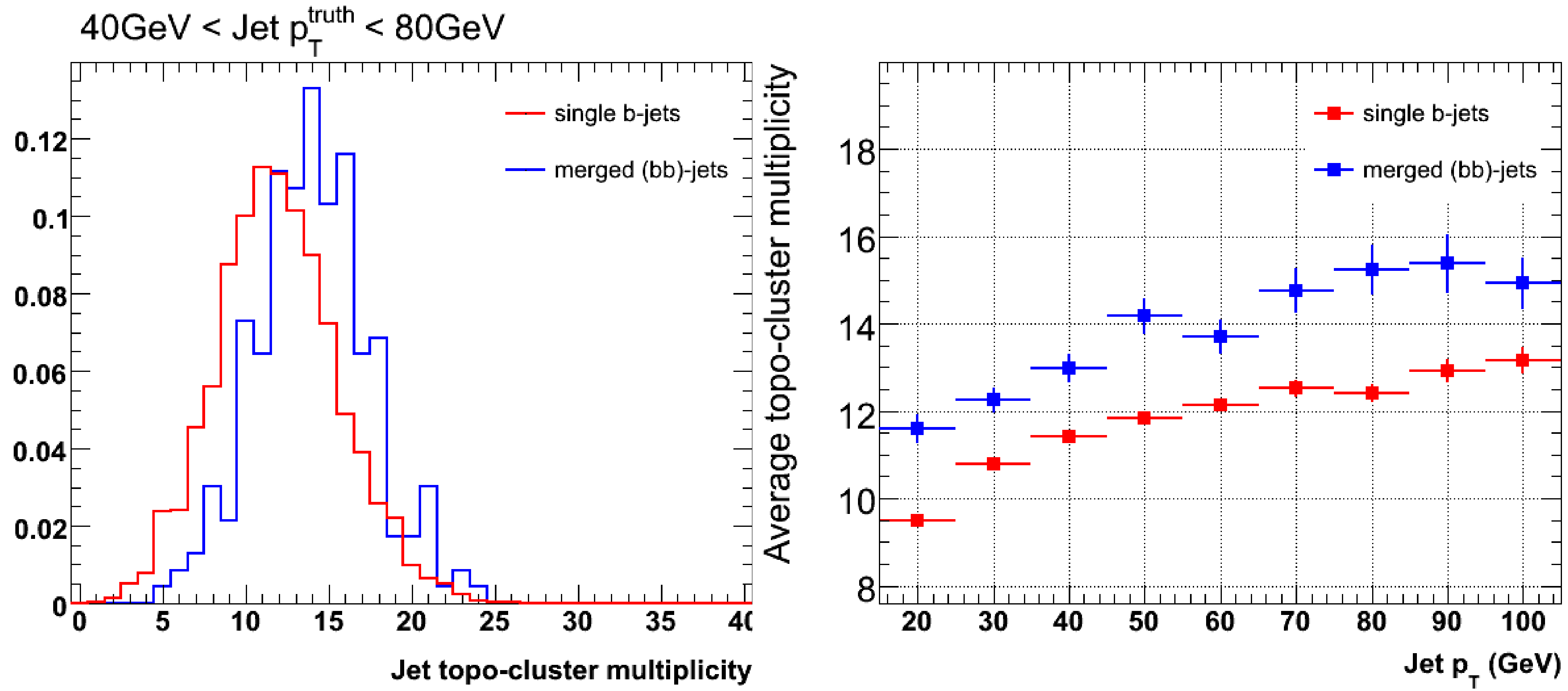




Higher track multiplicity for g(bb) jets.

Tracks matched in a DR=0.4 cone around the jet axis.

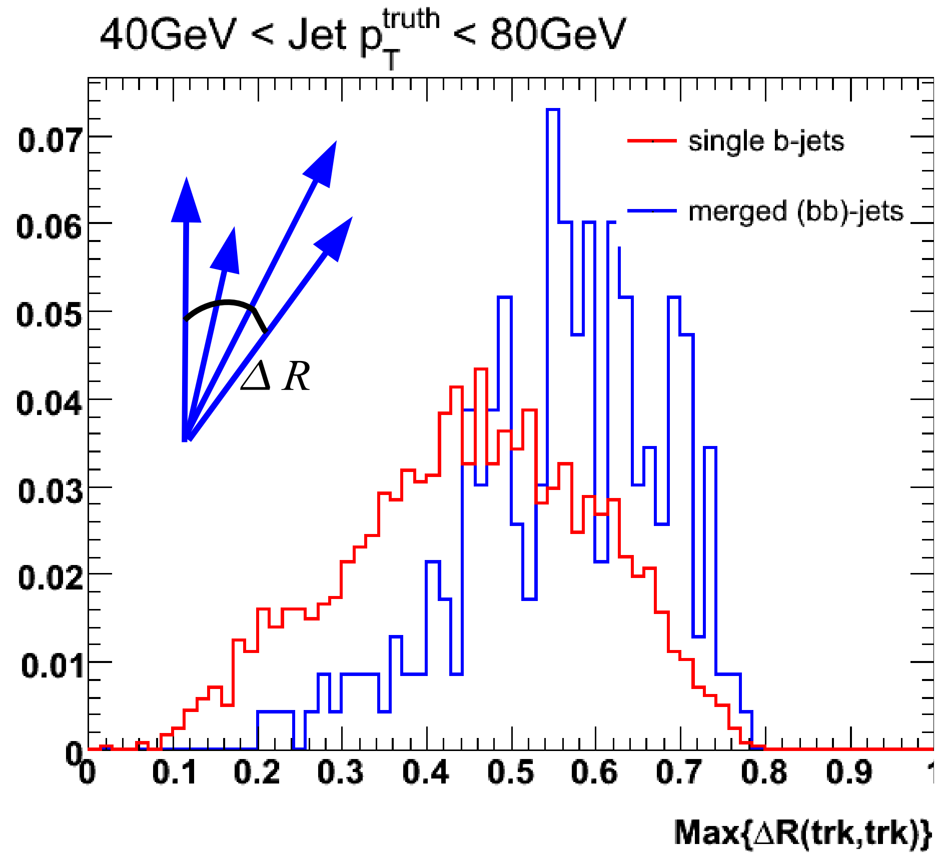
Kinematics of b and (bb)-jets (II)

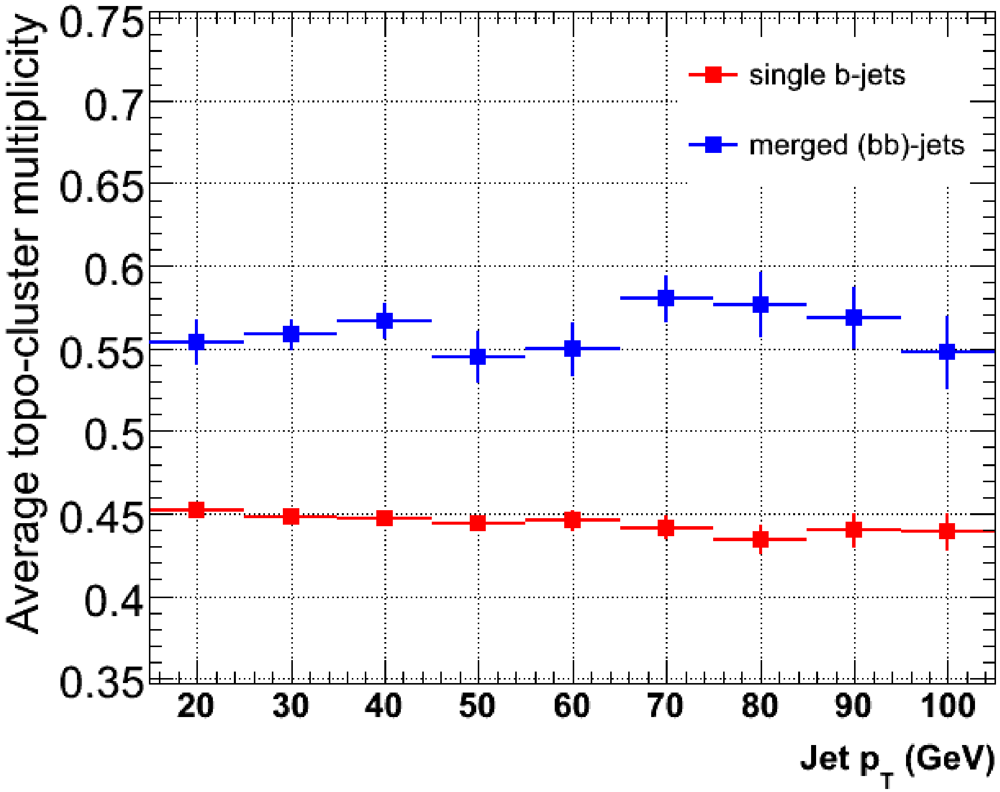


Higher calorimeter cluster multiplicity for g(bb) jets.

4/2/0 topo-clusters matched in a DR=0.4 cone around the jet axis.

Kinematics of b and (bb)-jets (III)

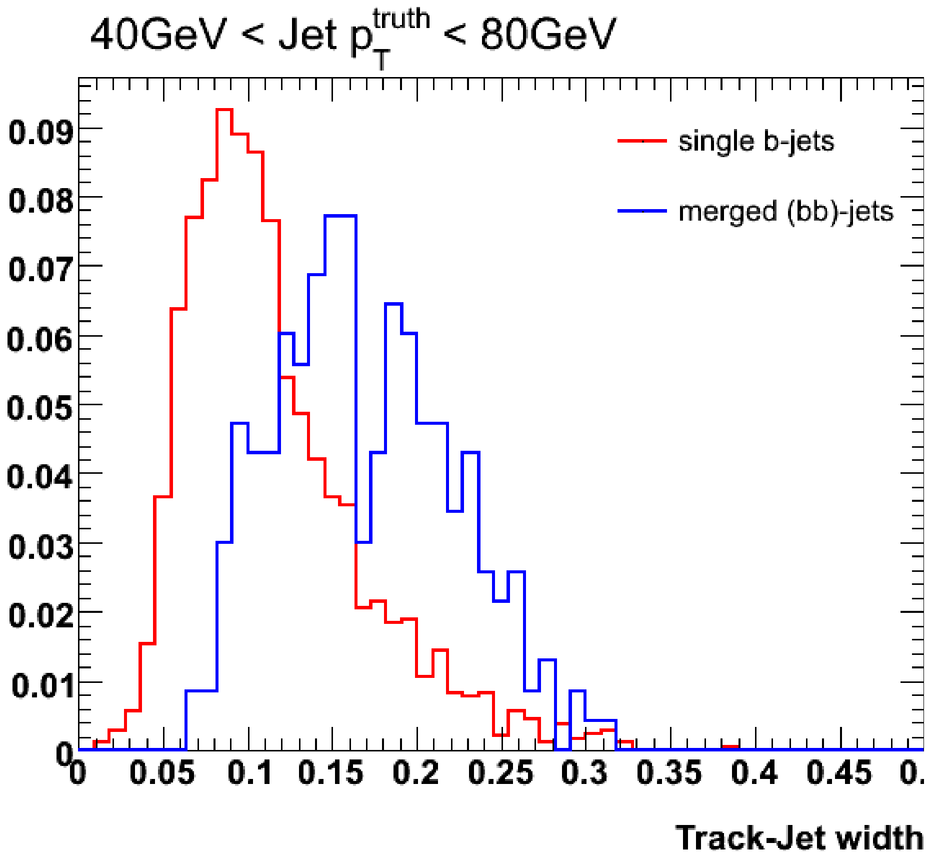


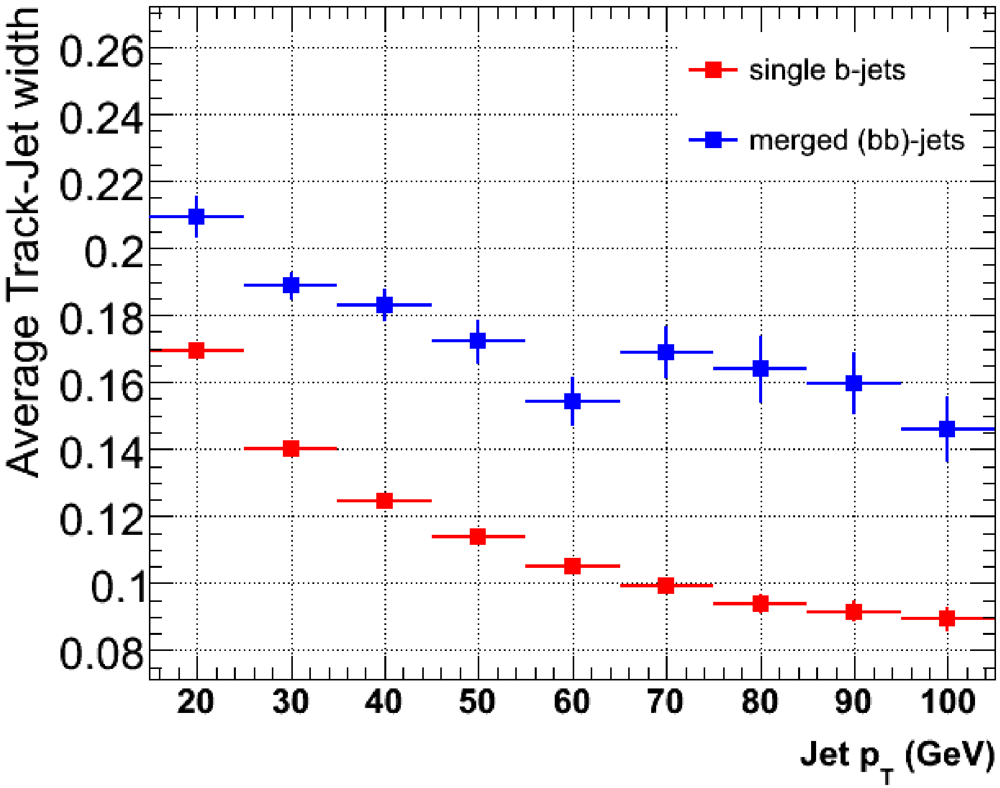


Higher track opening angle for g(bb) jets.

MaxDR is defined as the maximum DR between any pair of tracks in a 0.4 cone around the jet axis. (0.0<MaxDR<0.8)

Kinematics of b and (bb)-jets (IV)

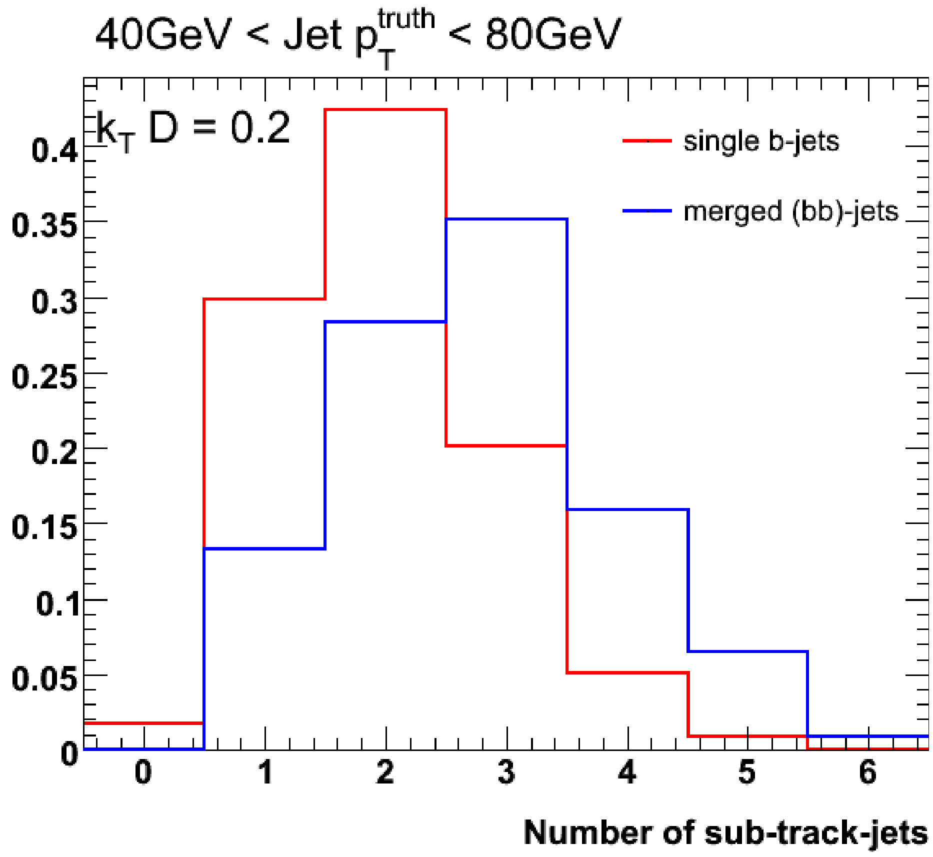


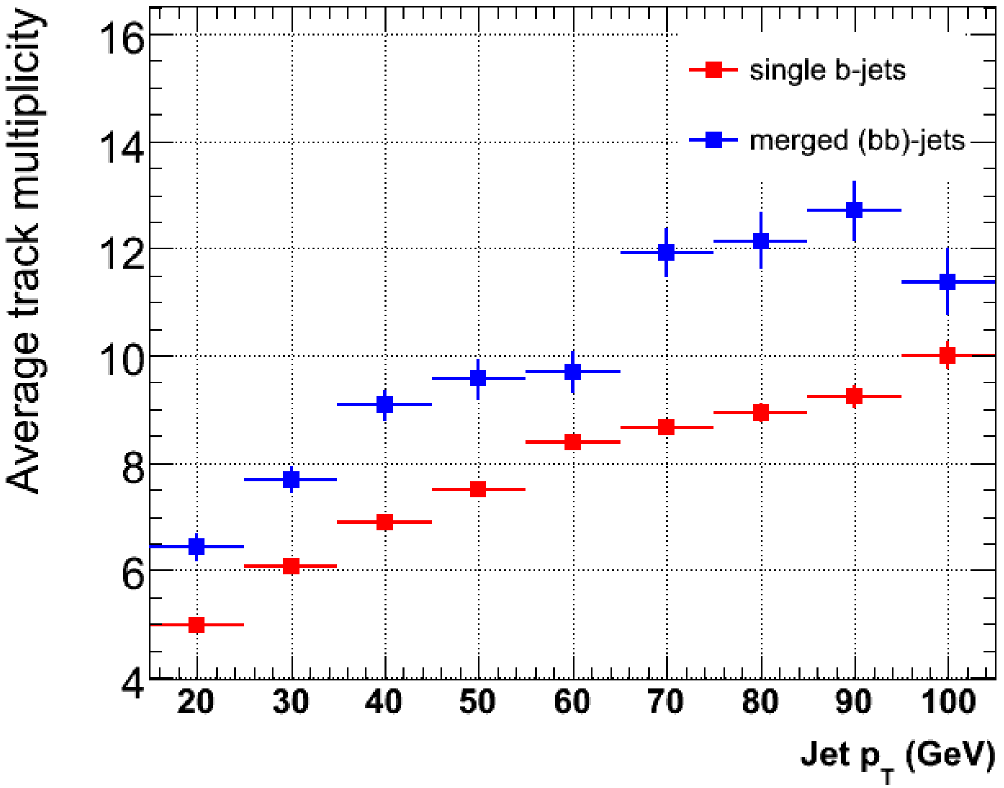


Higher track-jet width for g(bb) jets.

Tracks matched in a DR=0.4 cone around the jet axis.

Kinematics of b and (bb)-jets (V)

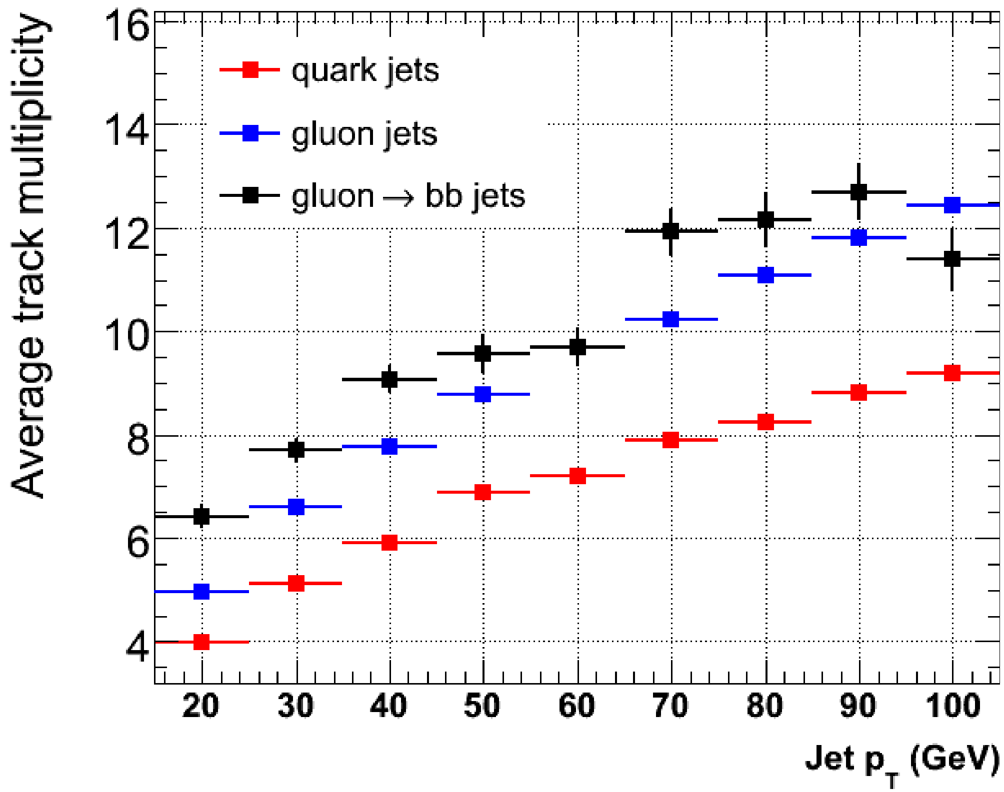


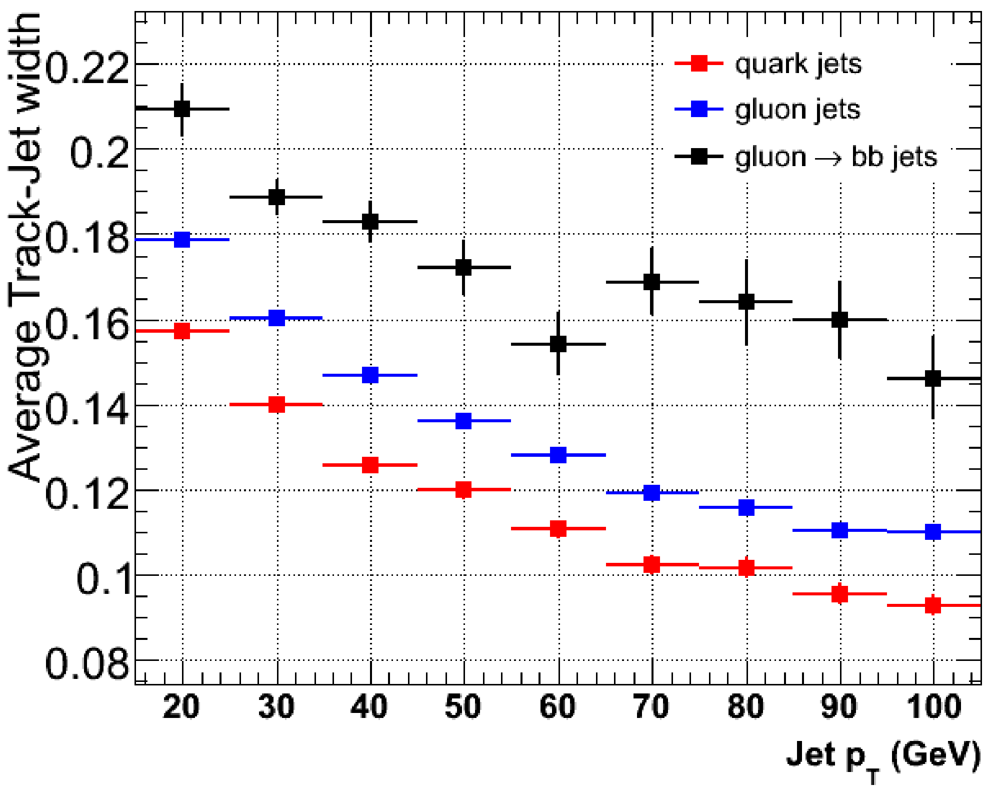


Higher sub-track-jet multiplicity for g(bb) jets.

Kt (D=0.2) sub-track-jets found from matched tracks in 0.4 cone.

g(bb) vs. Quark and Gluon Jets

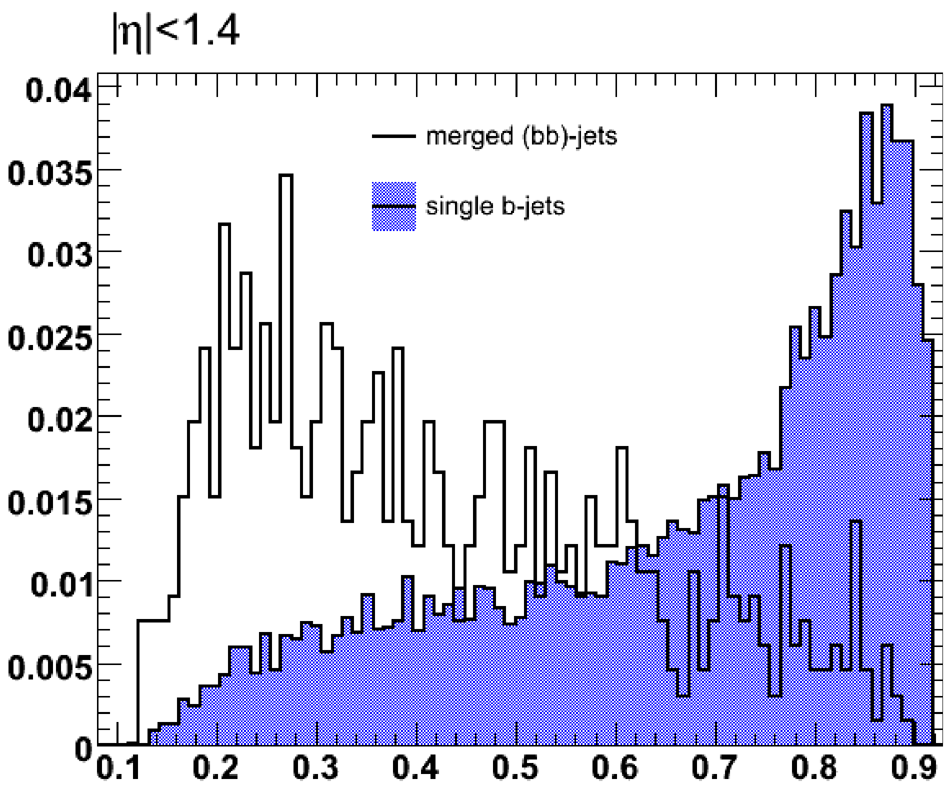


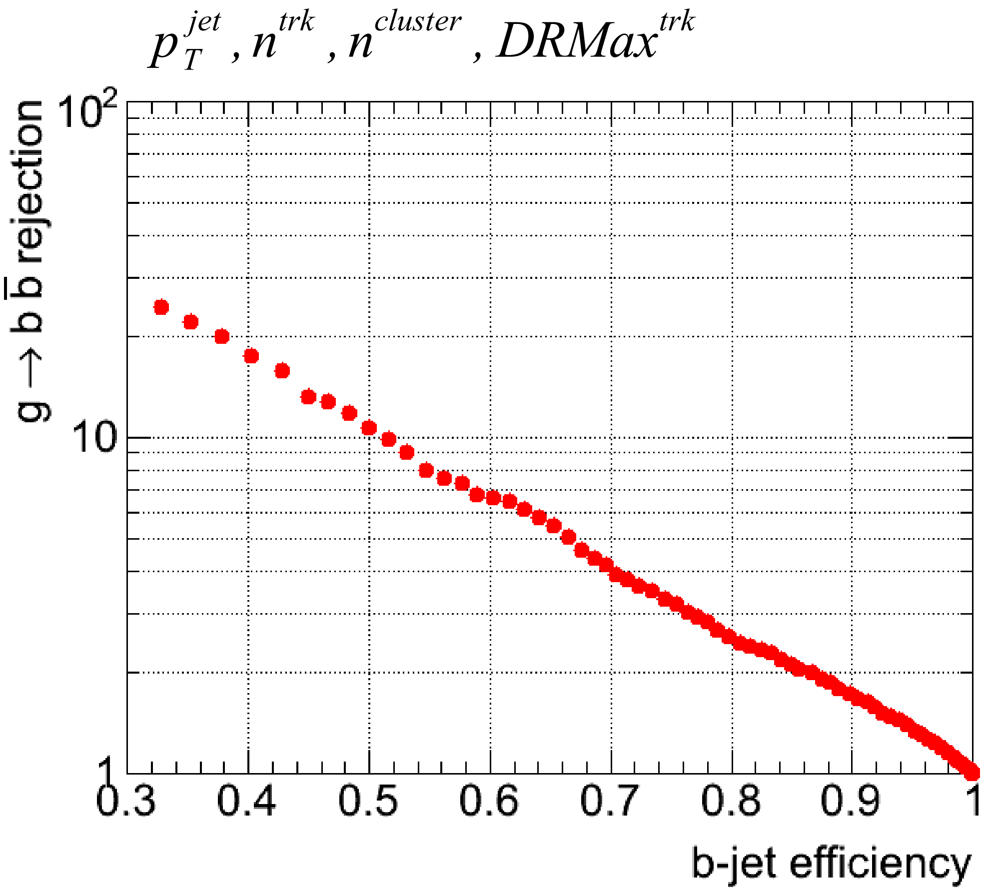


g(bb) have different topology than generic gluon jets:

higher track multiplicity and width.

Neural Network g(bb)Tagger





Preliminary discrimination performance:

50% efficiency @ 90% rejection.

90% efficiency @ 45% rejection.

Beauty/Charm Separation

b/c Flavor Separation

W+charm is an important background for top, Higgs, and physics searches in final states containing b-jets.

b/c tagging also provides handles to understand W+HF in data.

Current b-tagging likelihood was derived to discriminate between b and light quark jets. Charm mis-tag rate ~20%.

Goal: build a b/c flavor discriminator:

CDF experience: Neural network based b/l and b/c taggers:

90% b-jet efficiency, 50% c-jet rejection (25 input variables)

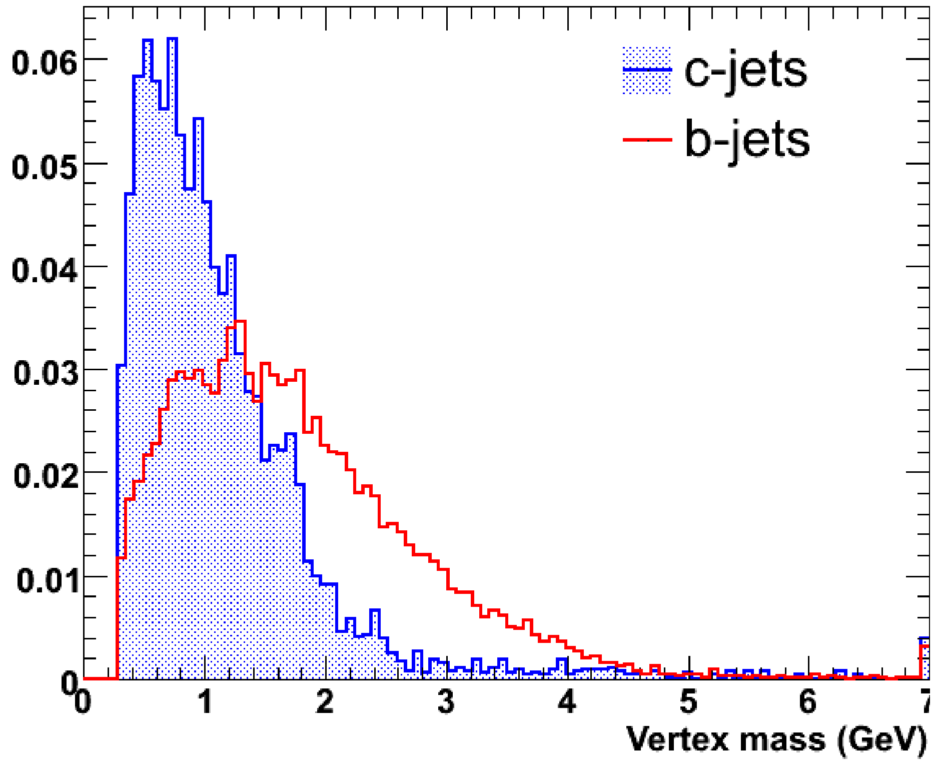
SLD/LEP pioneered the development of techniques for b/c separation:

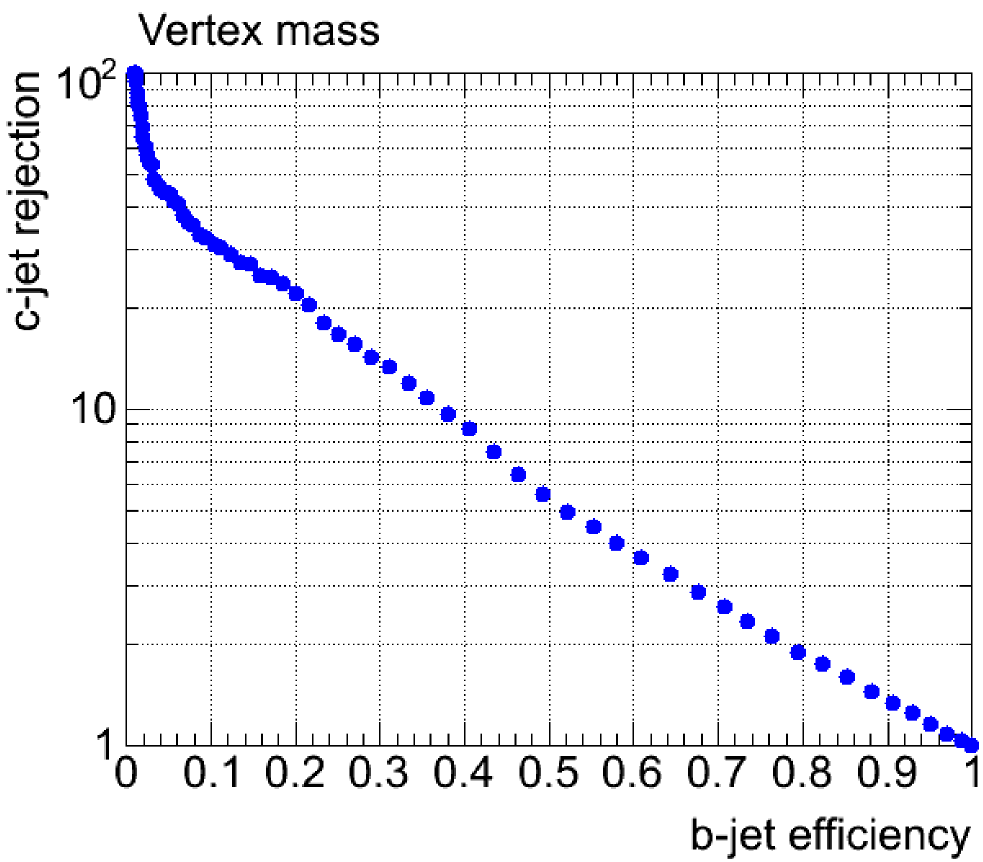
pt-corrected mass, momentum, decay length, multiplicity.

Crucial to be able to associate all vertex tracks: dedicated neural network to attach tracks to vertices.

PRD 71, 112004 (2005)

Vertex Mass Flavor Separation



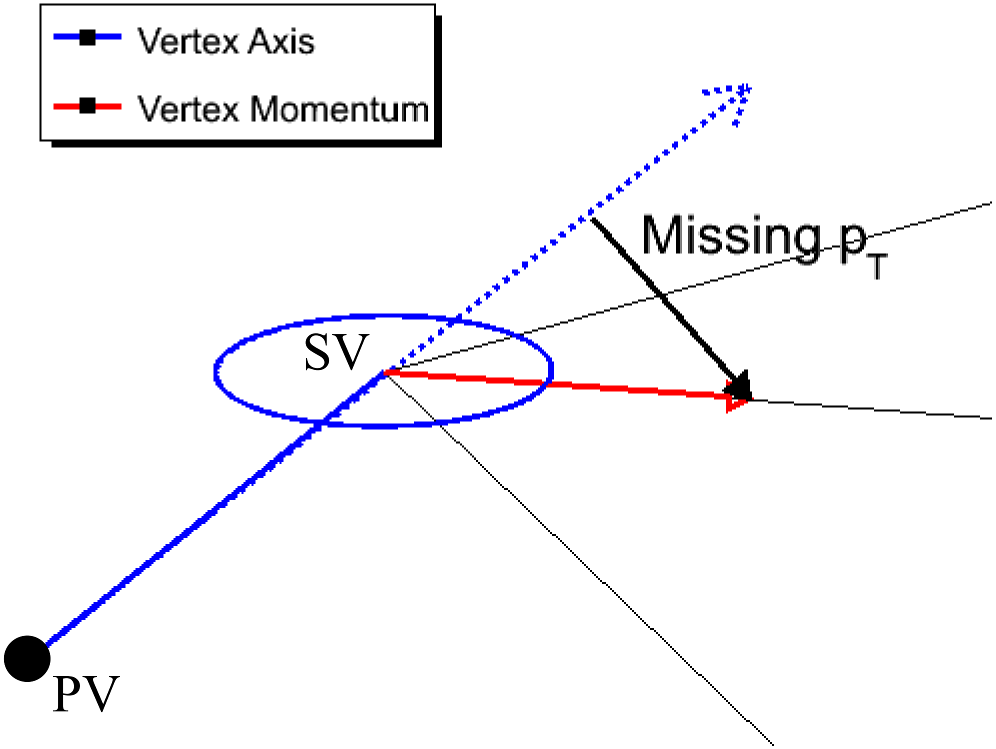


b/c flavor separation performance:

80% efficiency @ 45% rejection.

60% efficiency @ 75% rejection.

Vertex PT Corrected Mass



$$M^{P_T} = \sqrt{m_{vtx}^2 + P_T^2} + |P_T|$$

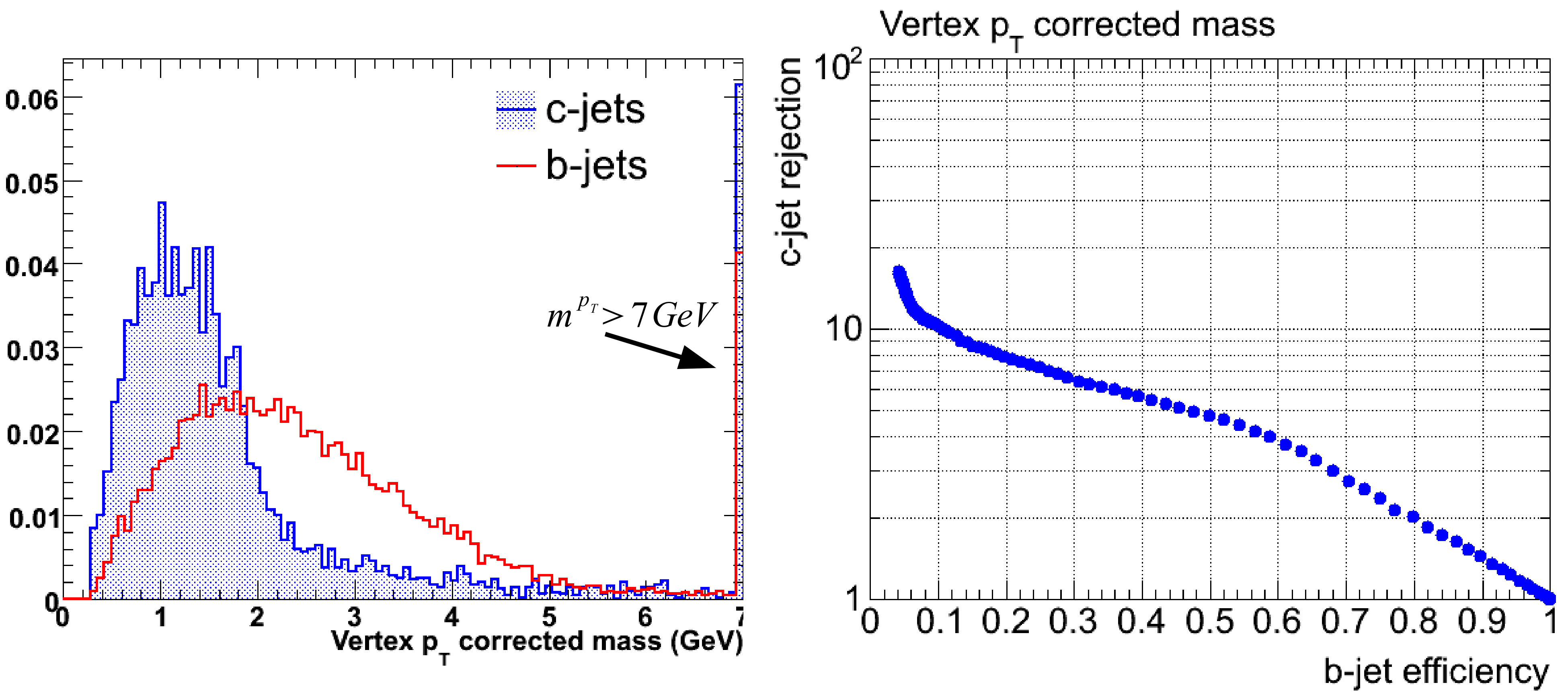
Vertex mass is a powerful variable to separate b from c.

However, B hadrons with missing neutrals result in lower reconstructed masses.

SLD pt-corrected mass:

estimate the missing pt from the flight direction and vertex momentum vectors.

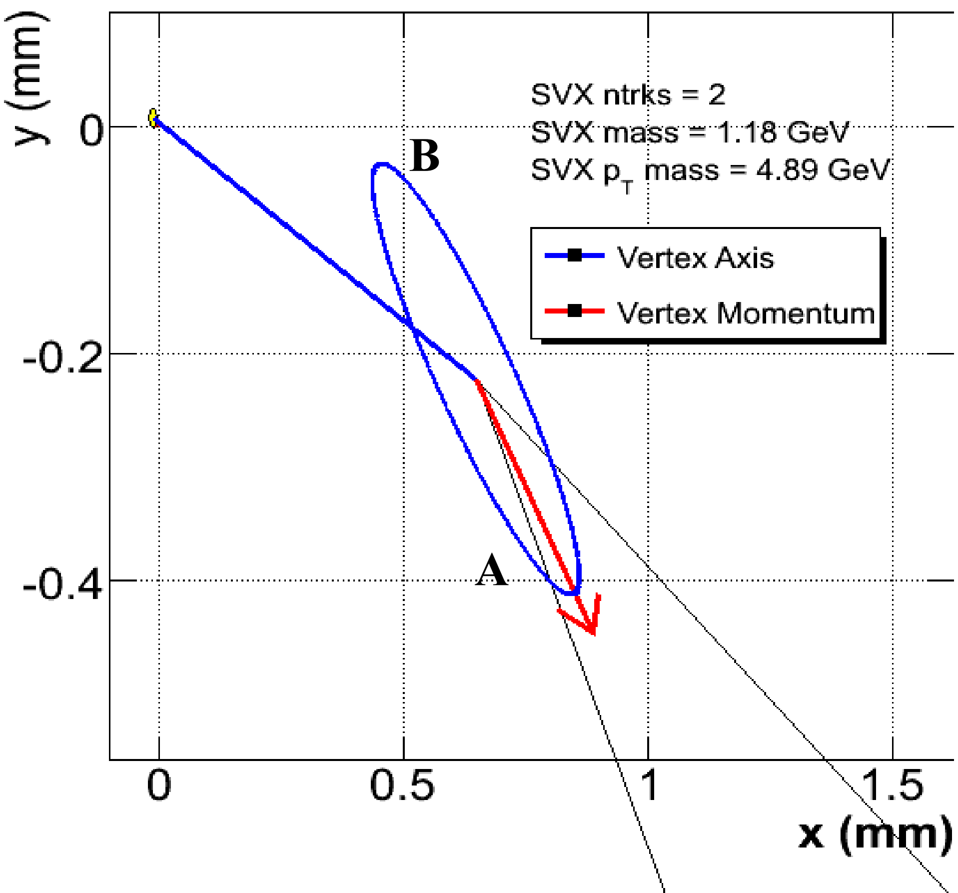
Vertex PT-Mass Flavor Separation

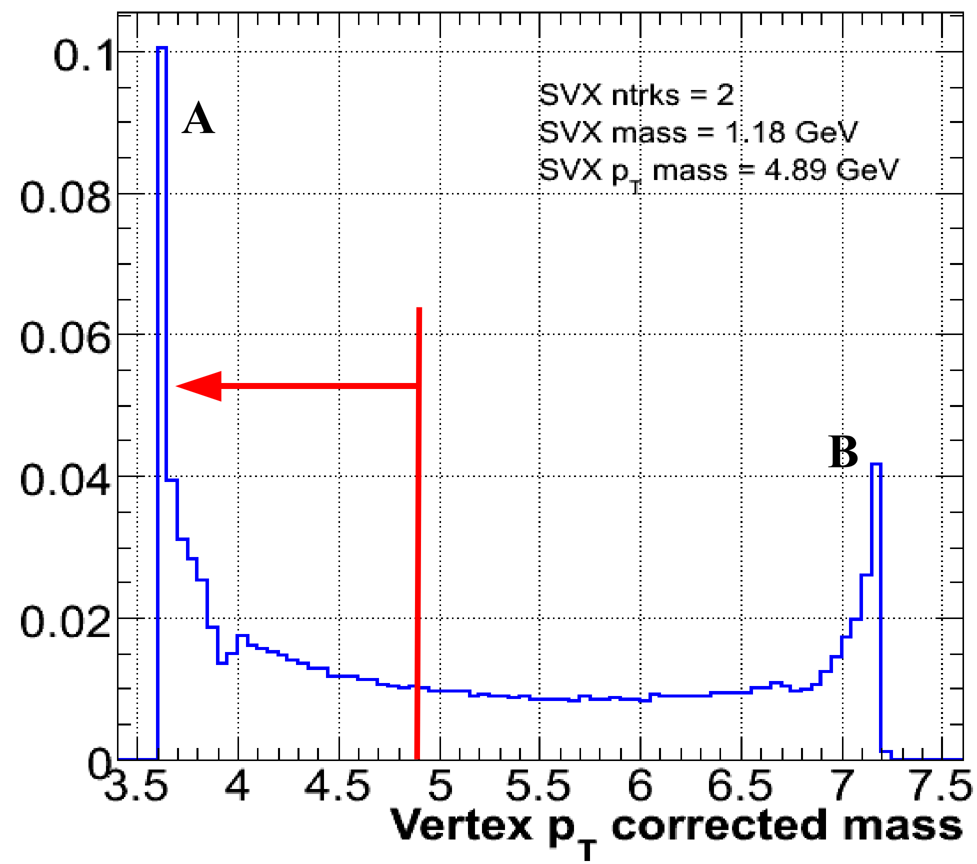


Better separation, but very long mass tail:

Identical performance than raw mass, for efficiencies>50%.

Vertex PT-Mass Smearing (I)



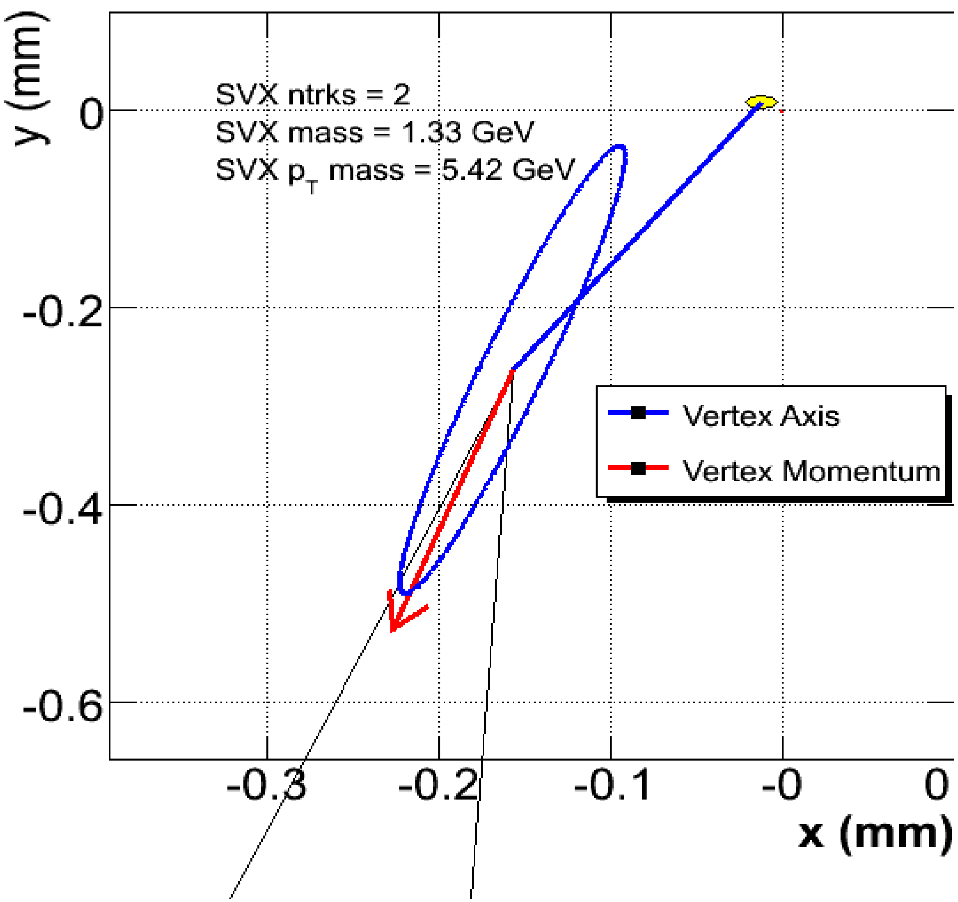


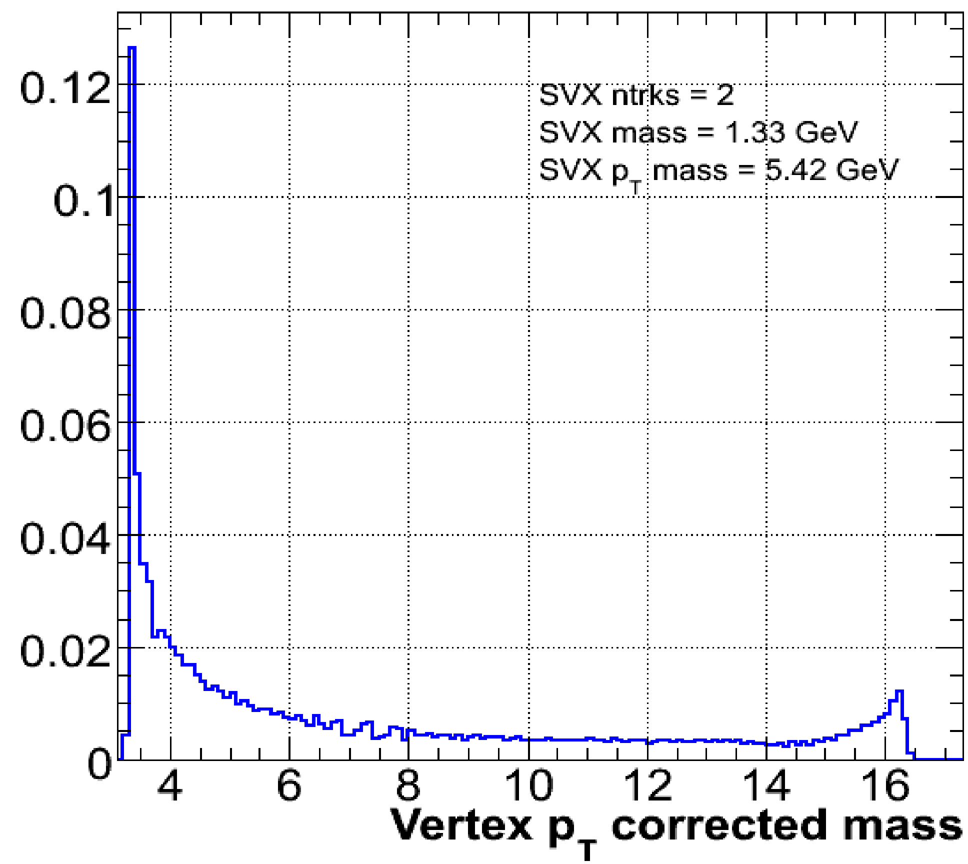
Example of c-jet with large PT-mass.

Consider 1 sigma SV error ellipse and re-compute vertex axis.

Define PT-mass as the minimum of the “smeared” distribution.

Vertex PT-Mass Smearing (II)

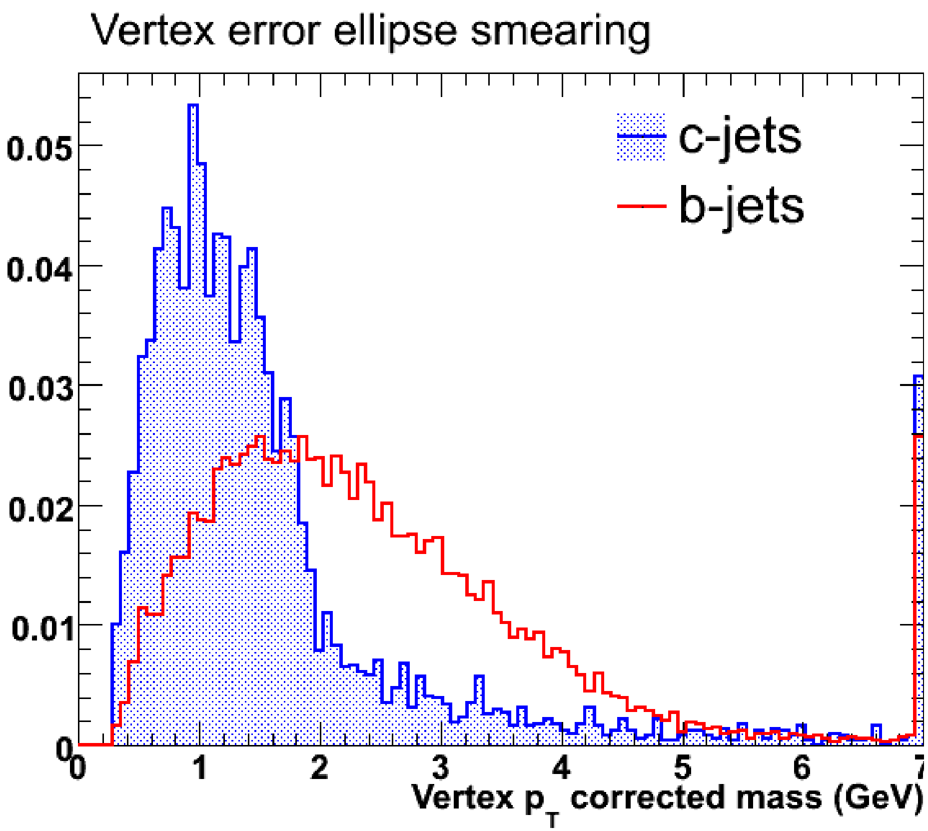


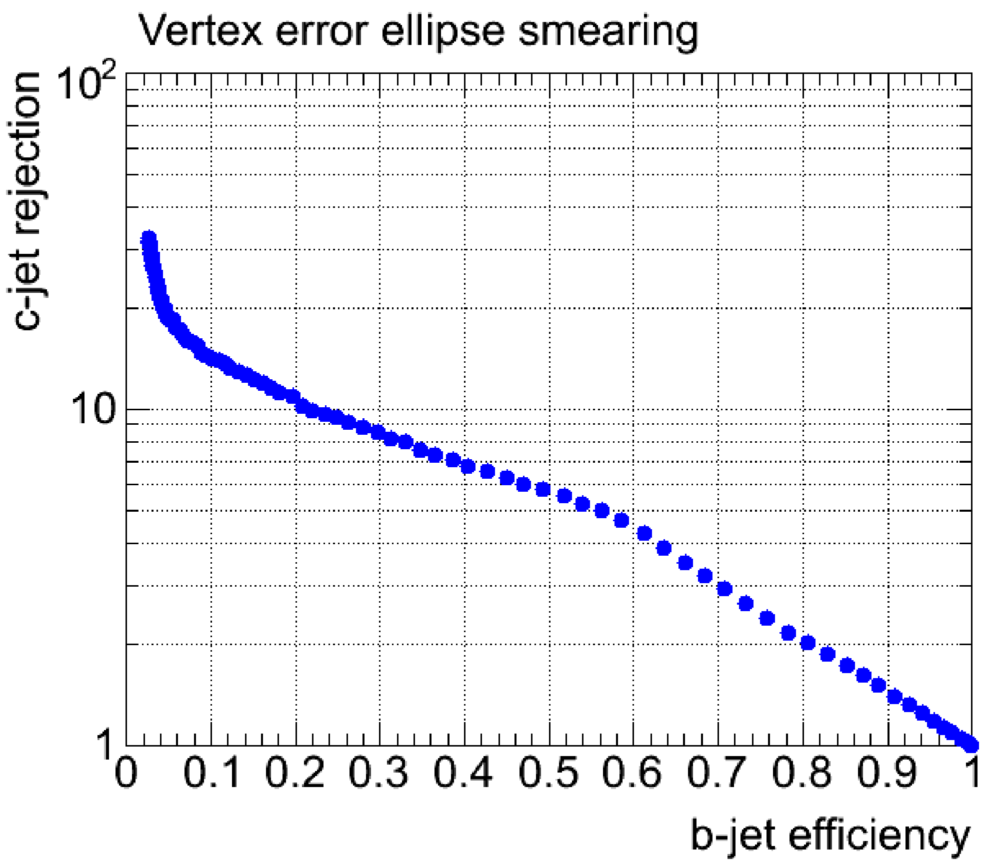


Another example of c-jet with large PT-mass.

Smearing reduces the long mass tail.

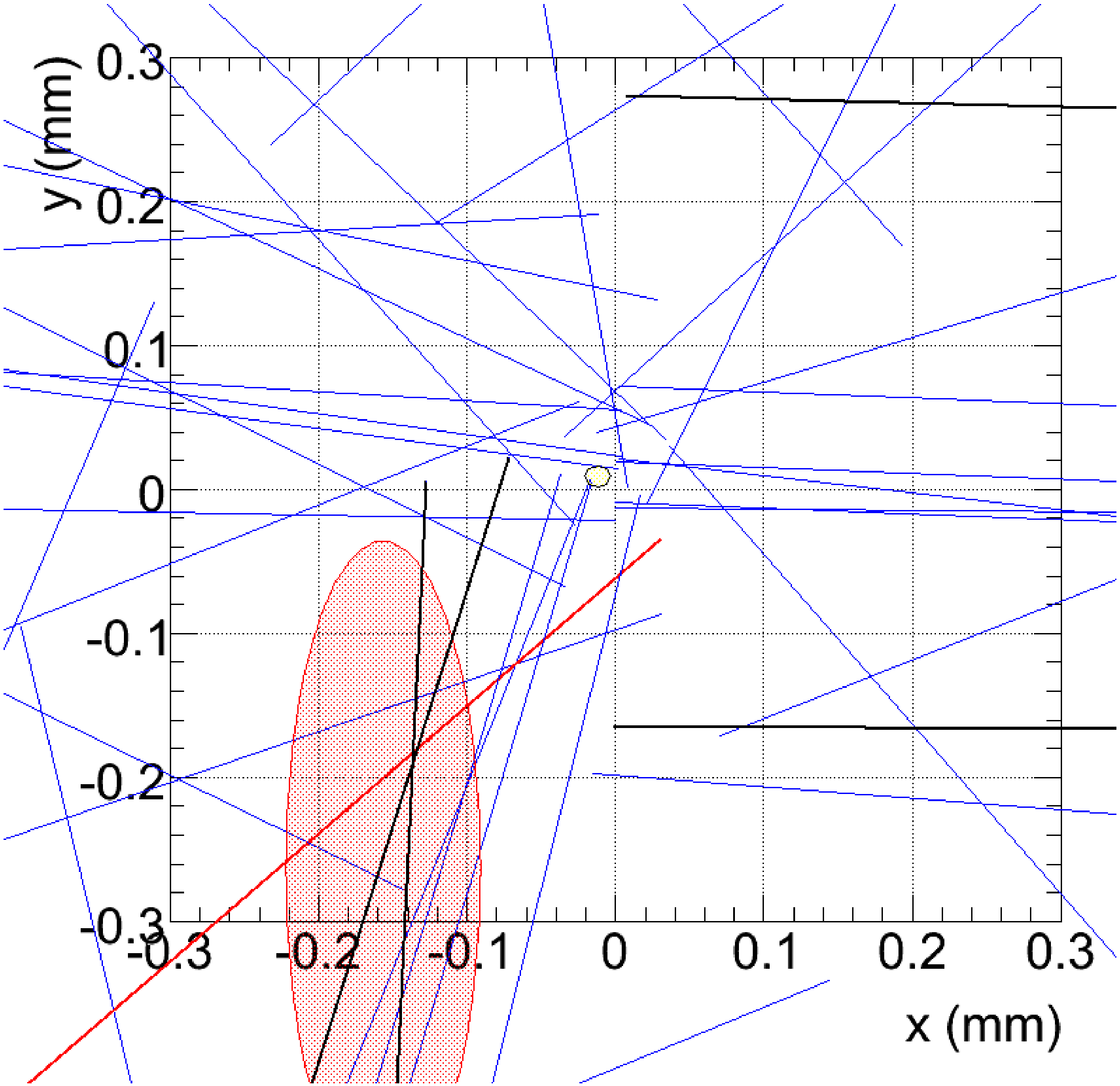
Vertex PT-Mass Smearing (III)





Mass tail reduced, but not enough to improve the separation:
Need to improve secondary vertex track identification.

Vertex PT-Mass Issues (I)



Same c-jet example as page 23.

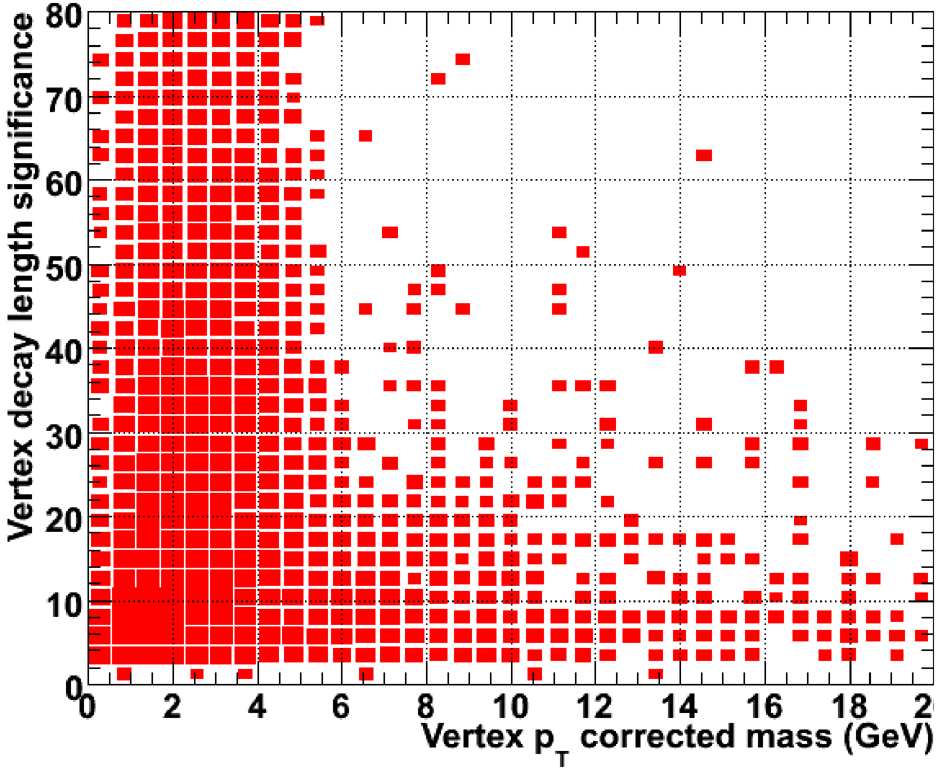
blue: all tracks.
Black: SV attached tracks.

The red track has not been attached to the SV.
May be compatible: seems to intersect the vertex in x,y plane and would reduce the PT-mass as the total momentum would align with the flight direction.

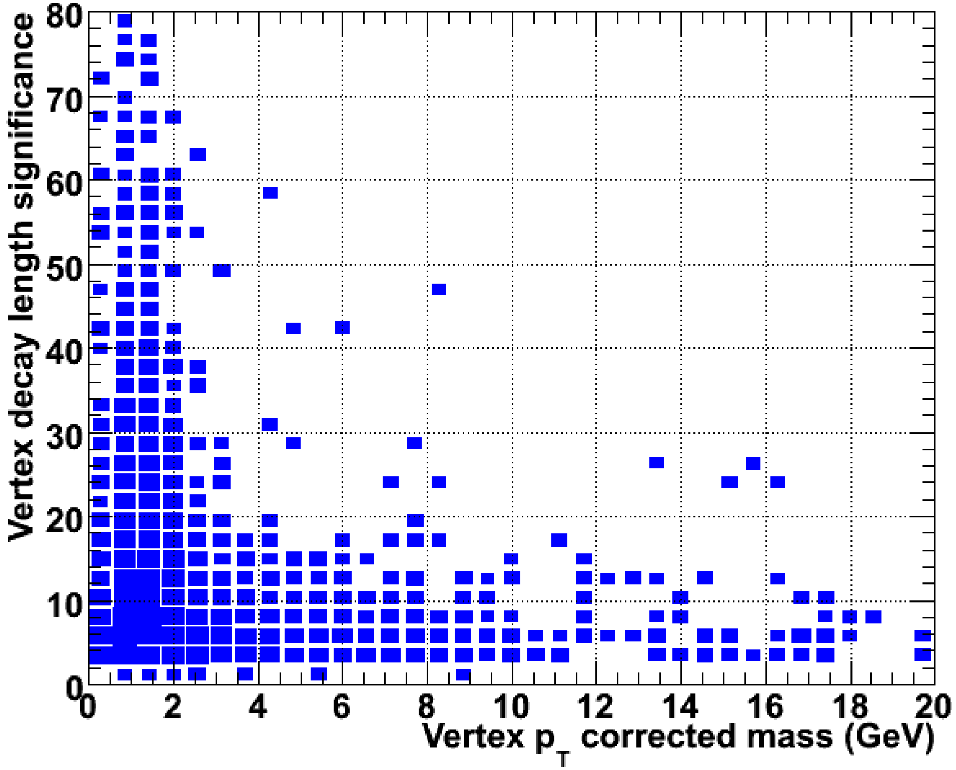
<u>Next step is to investigate techniques to cluster additional tracks to the SV</u>.

Vertex PT-Mass Issues (II)

b-jets



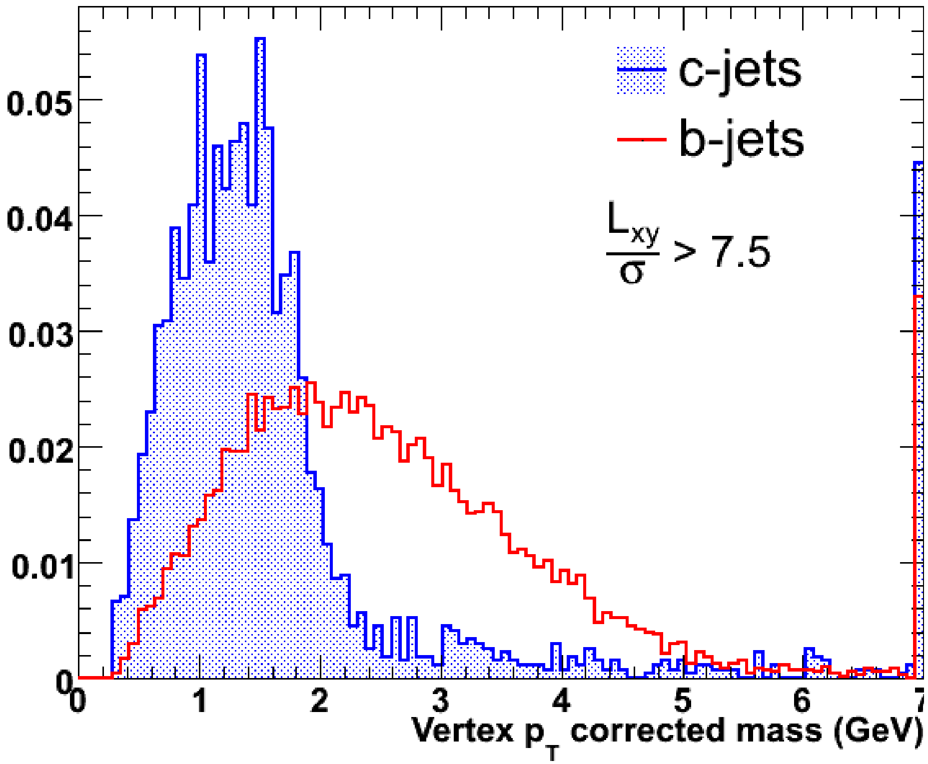
c-jets

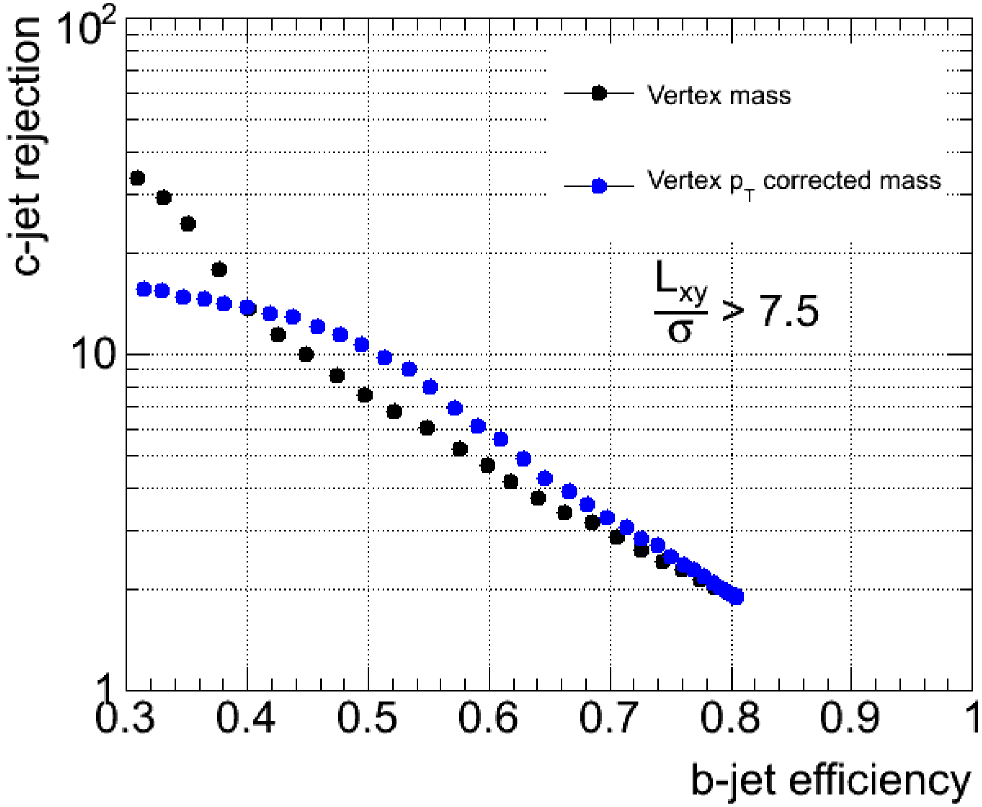


PT-Mass tail from vertices with small decay length significance:

2D cut on PT-mass, LxySig plane.

PT-Mass/Lxy Flavor Separation

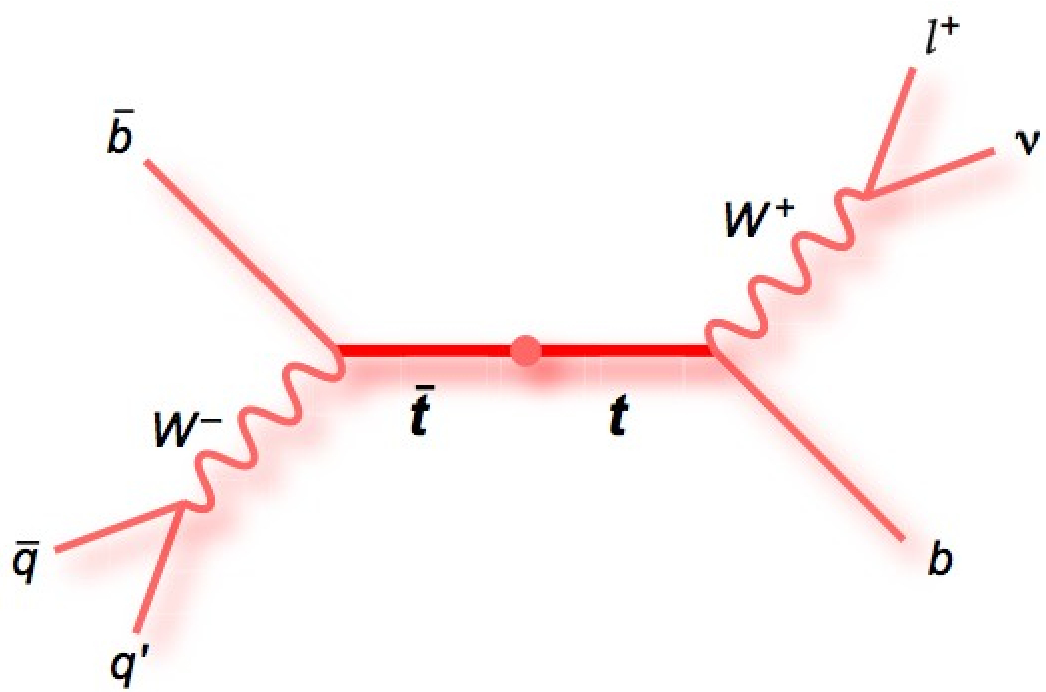




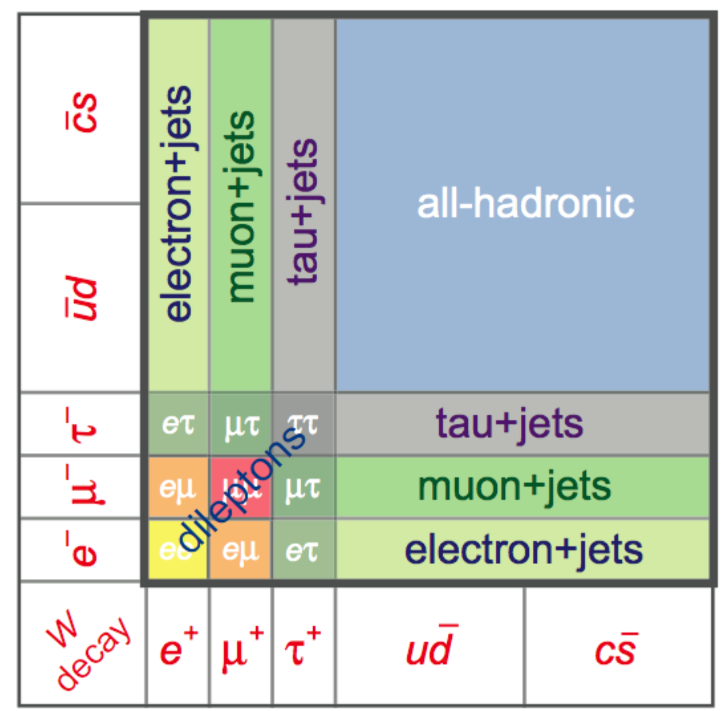
A cut on PT-Mass -after requiring LxySig>7.5- performs better than a cut on mass (with the same LxySig cut) (for efficiencies between 40% and 70%)

Charm Selection in Data (I)

Select a pure charm jet data sample from W decays in top quark events: only possible at the LHC due to the high top quark production cross section.



Top Pair Decay Channels

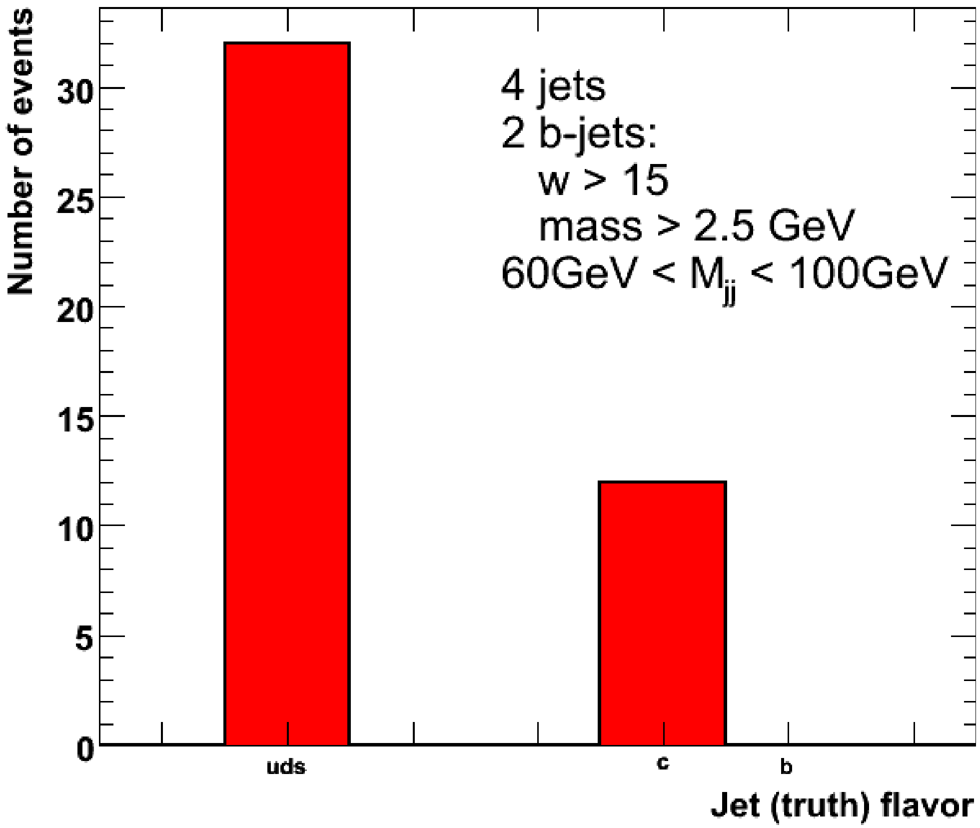


Lepton+jets events, with exactly 4 jets.

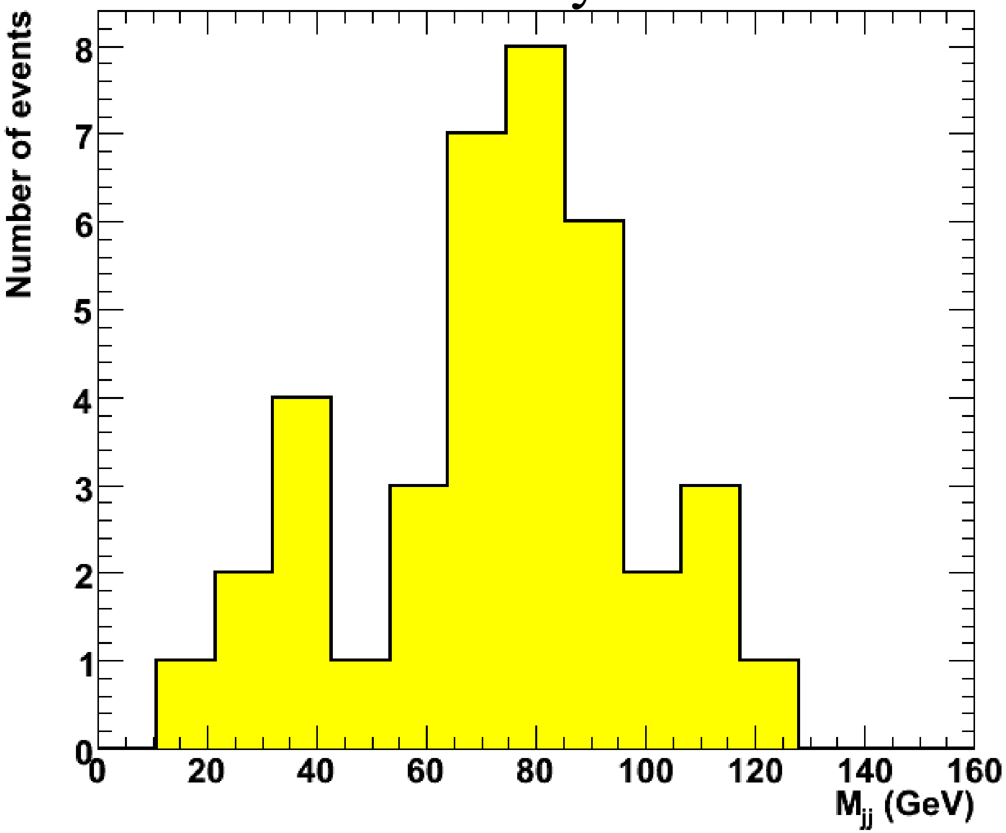
Require 2 tight b-tag jets, with high vertex mass (pure b jets)

Consider two remaining jets: ¼ are expected to be c-jets.

Charm Selection in Data (II)



Selection efficiency = 0.1%

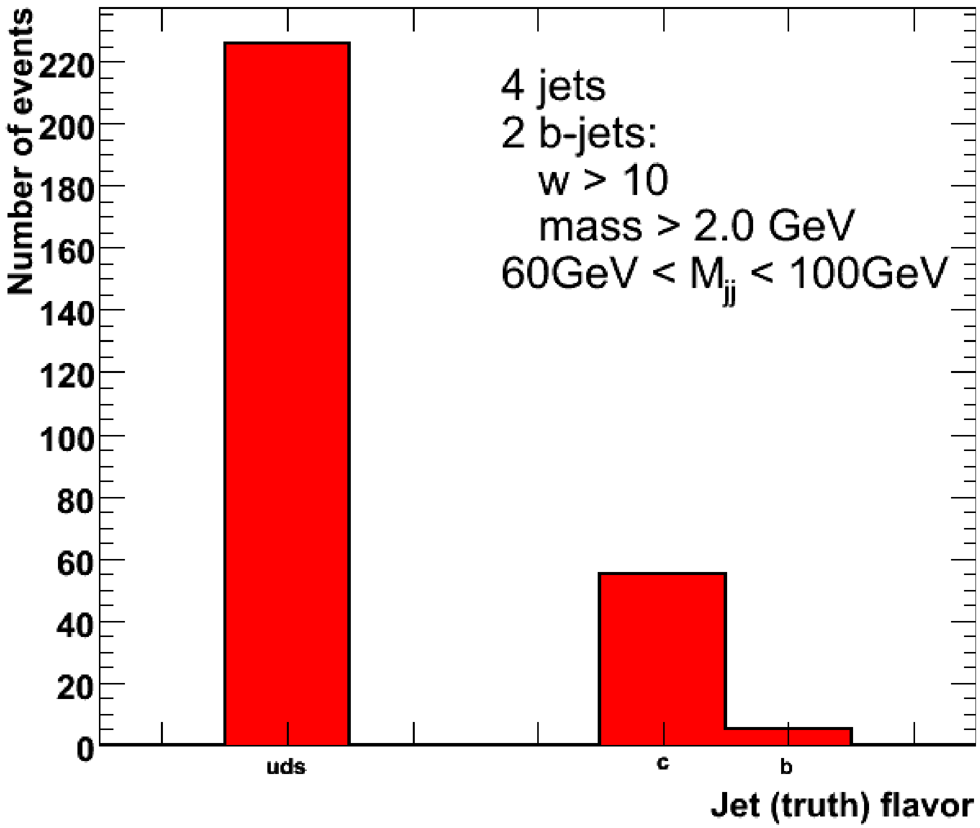


Single lepton top quark events with exactly 4 jets.

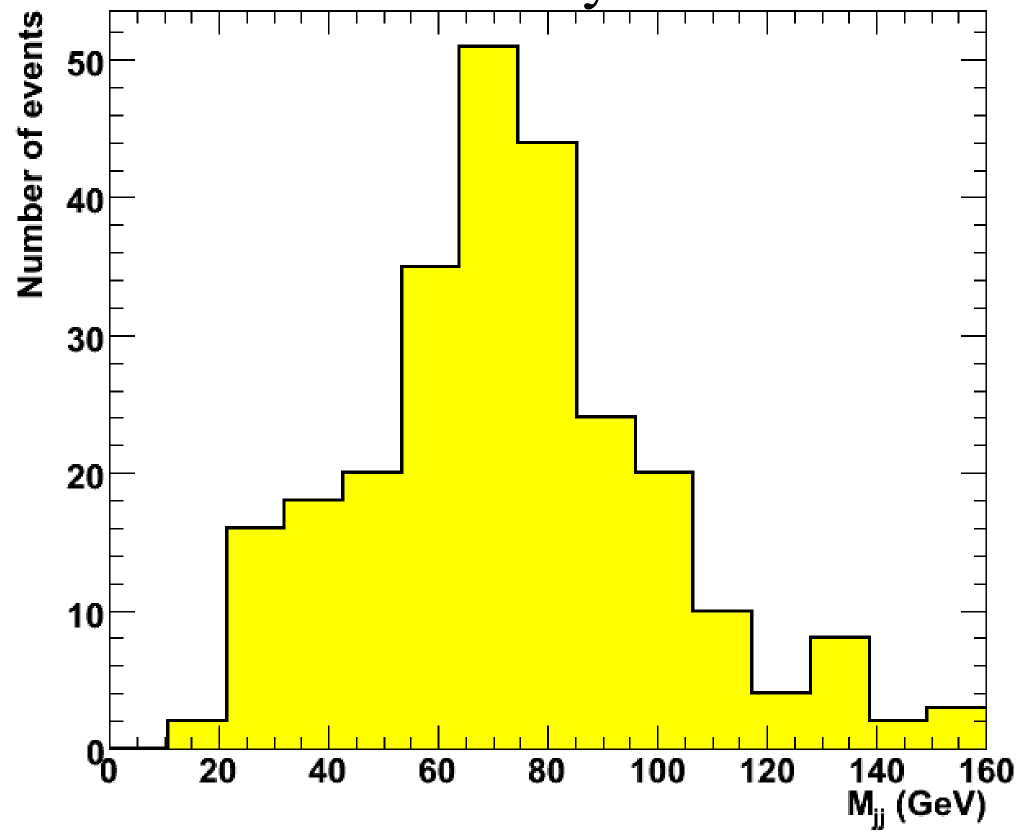
2 tight b-jets: w>15, vertex mass>2.5GeV.

Fraction of c-jets: 0.27 +/- 0.07 (0.25 expected)

Charm Selection in Data (III)



Selection efficiency = 1.1%



2 tight b-jets: w>10, vertex mass>2.0GeV.

Fraction of b/c-jets: 0.21 +/- 0.02 (0.25 expected)

(8% b-jet contamination)

Summary

Quark/Gluon Tagging:

- Potential for improving SUSY searches at the LHC.
- Tool to understand SM backgrounds and jet energy scale.

First implementation of a g(bb) tagging algorithm:

- Potential for improving W+heavy flavor background rejection, and estimation.

First steps toward at a b/c flavor separation tagger:

- PT-corrected mass discrimination power limited by tails from small decay length significance vertices.
- Next step is to improve track-vertex association.
- Data driven calibration using top quark events (only possible at the LHC due to the large ttbar x-section)
- Potential for improving b+MET SUSY searches.

Back-up slides

Quark/Gluon Jet Selection

Quark/Gluon jet matching *algorithm*:

- Match jet with partons within a cone of 0.3 around the jet axis.
- if a b/c quark is found, the jet is tagged as heavy flavor.
- Otherwise, assign the flavor of the highest pt parton found.

Data samples and event selection:

daset: J4, release:12.0.6.5.

Topological cluster jets, H1 global calibration.

$$p_T^{jet} > 20\,GeV$$

$$|\eta^{jet}| < 1.2$$

$$p_T^{track} > 0.5\,GeV$$

Gluon Enhanced Data Sample

Test jet calibration and properties in quark/gluon enhanced data samples:

3-jet, double b-tag sample:
> 85% gluon purity.