QCD Radiation Patterns in Top Events

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FNAL

Overview

- Top quarks benefit/are plagued by color charge.
- Do top quarks make jets? Why or why not?
- What interplay might exist between the top quark's electroweak and QCD properties? Does it simplify, complicate, or make irrelevant the picture in color space?
- How does the mass of the top quark change the color flow/QCD picture of the environment where top quarks emerge?

Topics

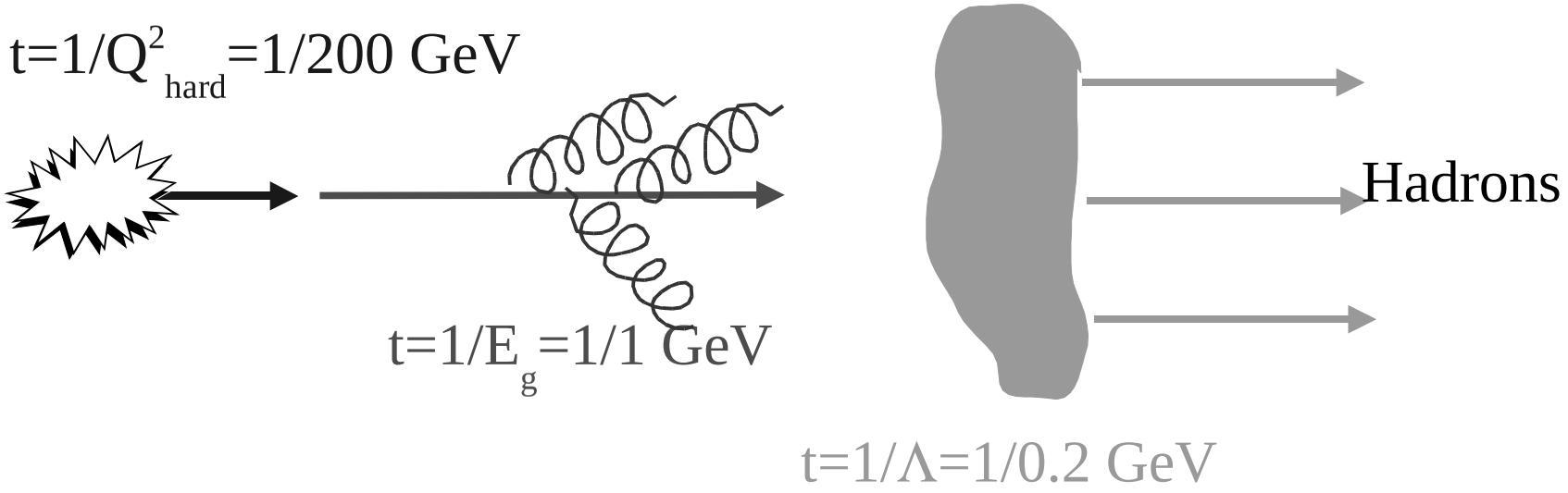
- Timescales and hadroproduction, and Parton Shower Model
- Lifetime, Dead Cone, QCD of Top, Massive objects
- Measurement Program and Preliminary Results from Tevatron Run I
- Intersection with future & Monte Carlo Development

Timescales

Hard Process : 1/ 500 GeV	.02
Parton Shower: 1/1 GeV	1.0
Hadronization: $1/\Lambda_{QCD}$ = 1/0.2 GeV	5.0
Resonance Decays: b−decay→1/0.00001 GeV	10^5
t−decay→ 1/1.5 GeV	0.7

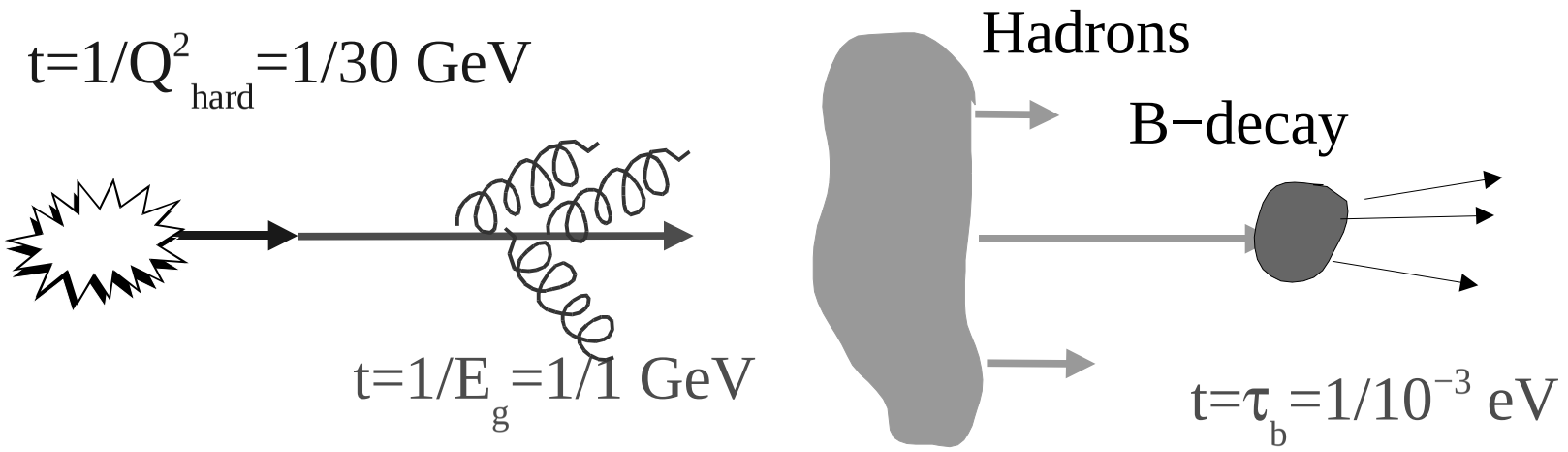
The particular kind of event changes what contributes to a "jet"

Jets from Light Partons



Light Parton Jet Comes From Parton Shower + Hadronization
Initial parton is lost in the crowd.

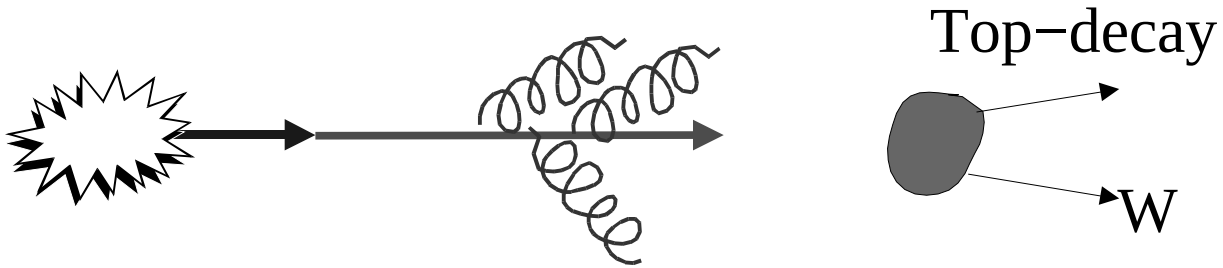
b−Jets



b− Jet Comes From Parton Shower + Hadronization+ Decay

"Jet" from a Top Quark

$t=1/Q^2_{hard}=1/400$ GeV



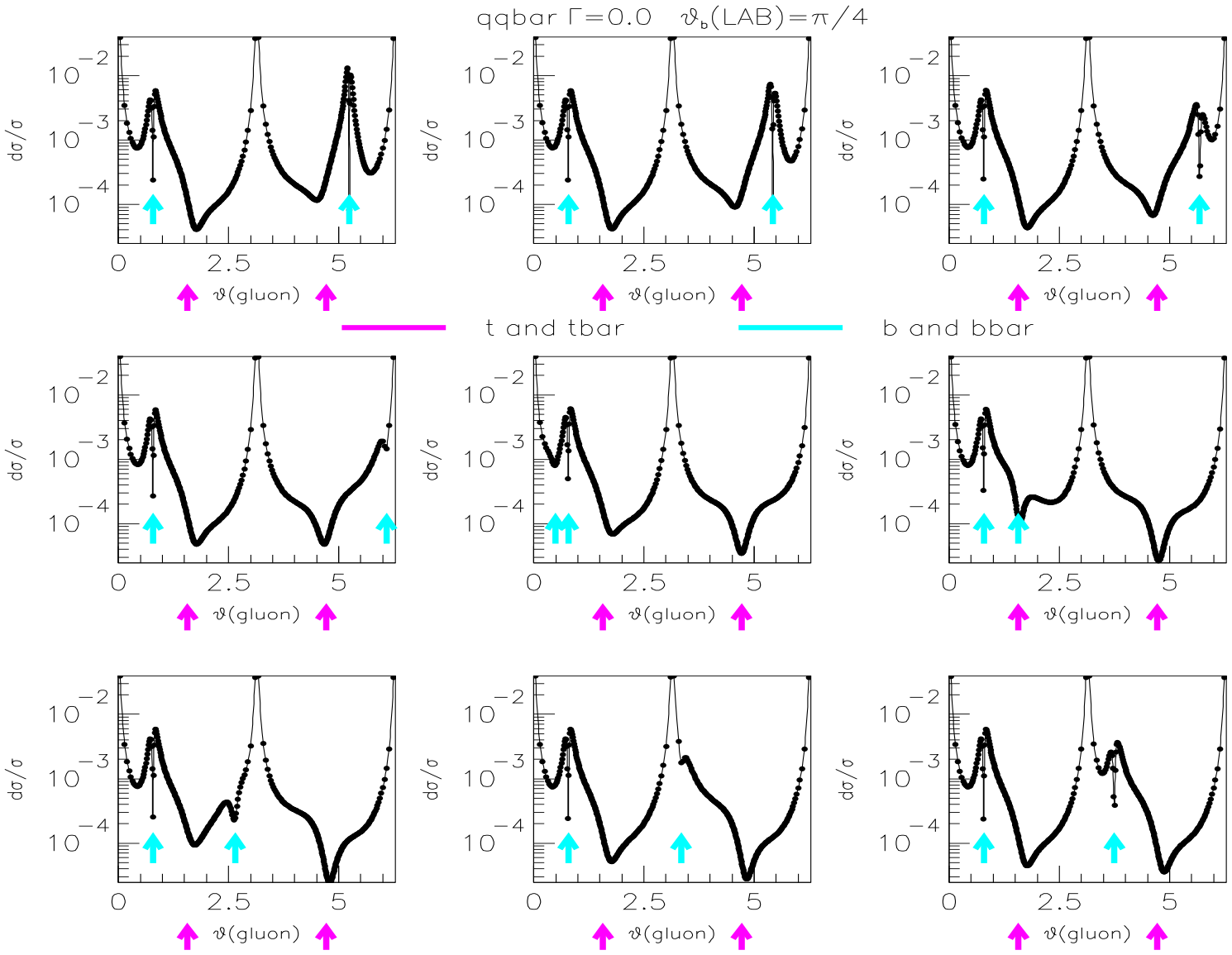
$t=1/E_g=1/1$ GeV $t=\tau_t=1/1.5$ GeV

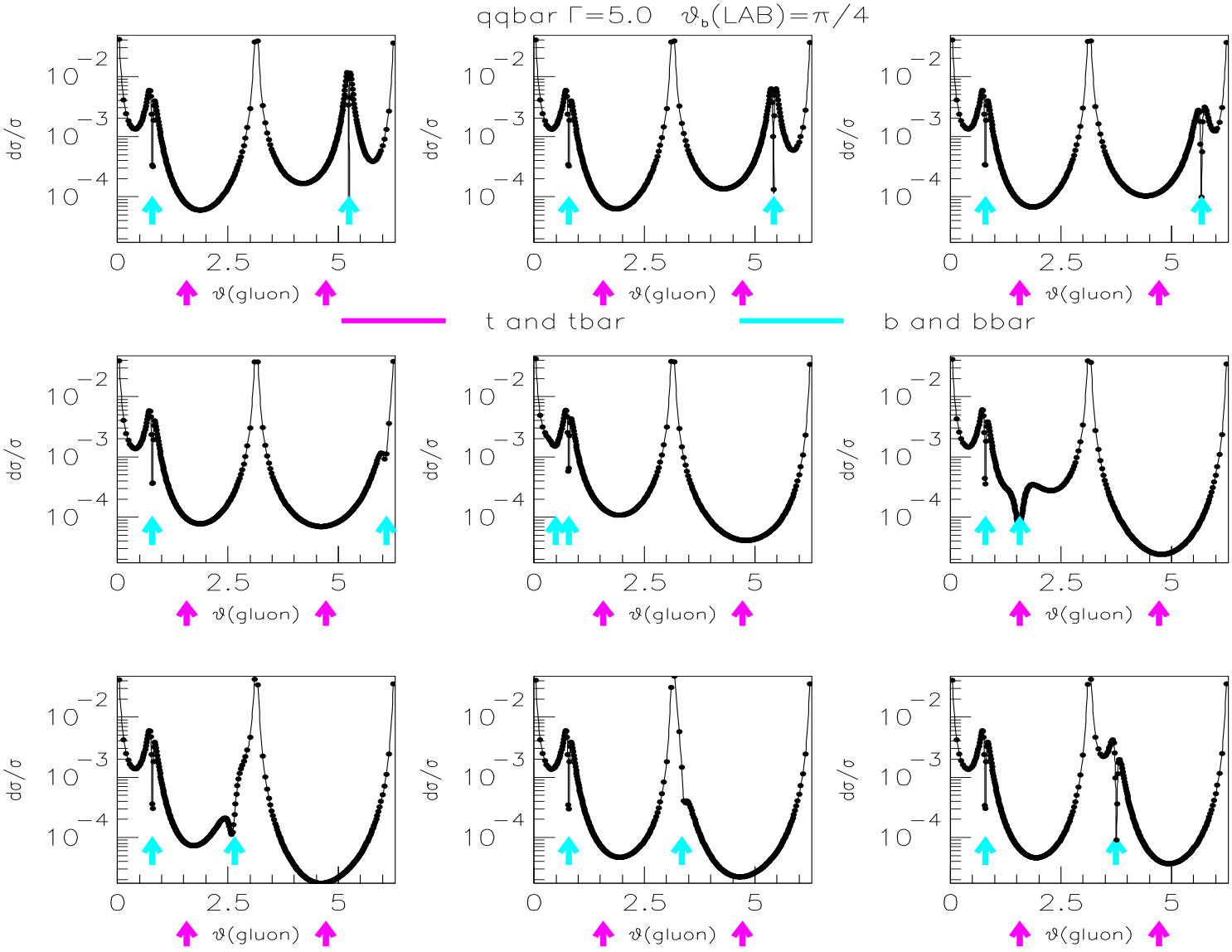
t− Jet Comes From Parton Shower and distinguishable decay.
Not too hard to imagine that decreasing lifetime cuts off shower.
Observing Existence or rate of shower implies a lifetime.

Items

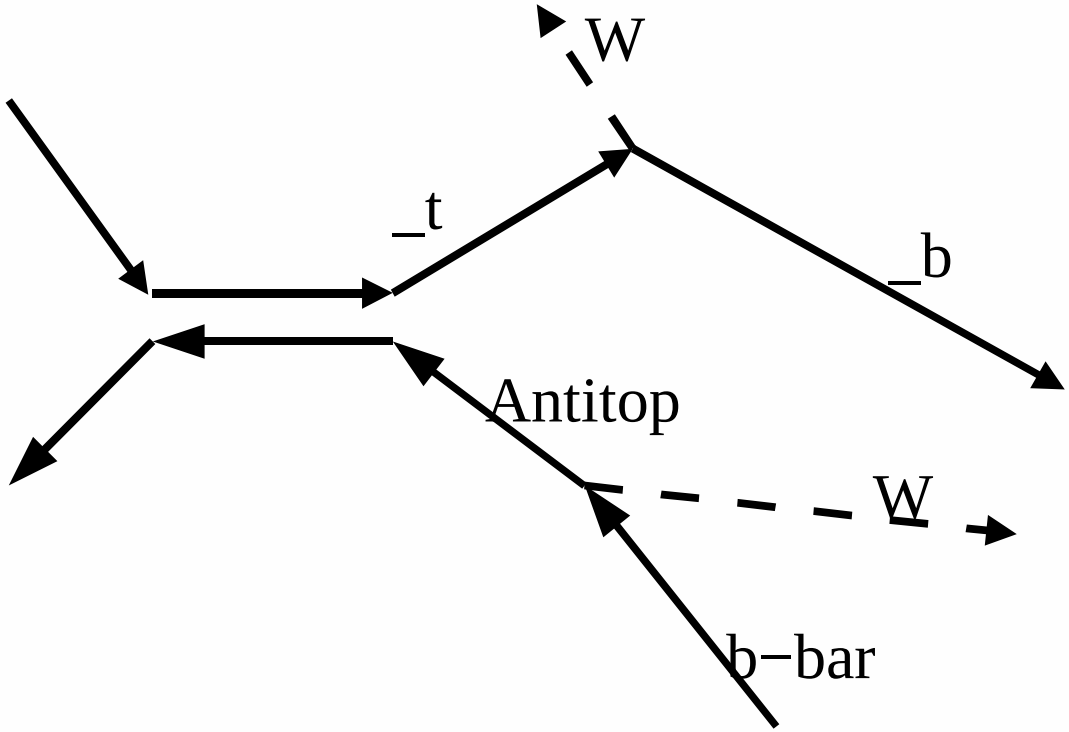
- Study analytic calculations* for single gluon emission for e^+e^- and hadronic cases for particular kinematic configurations.
- Use Monte Carlo (HERWIG) with analytic calculations to generate estimate of rates and effect of Γ .
- Relate sensitivity of Γ measurement with single gluon emission to experimental measurable.

- * References:
- Khoze, Stirling, Orr Nucl. Phys. B **378**, 413 (1992)
- Khoze, Ohnemus, and Stirling Phys. Rev. D **49**, 1237 (1994)


qqbar Γ=0.0 ϑb(LAB)=π/4
dσ/σ
ϑ(gluon)
t and tbar
b and bbar

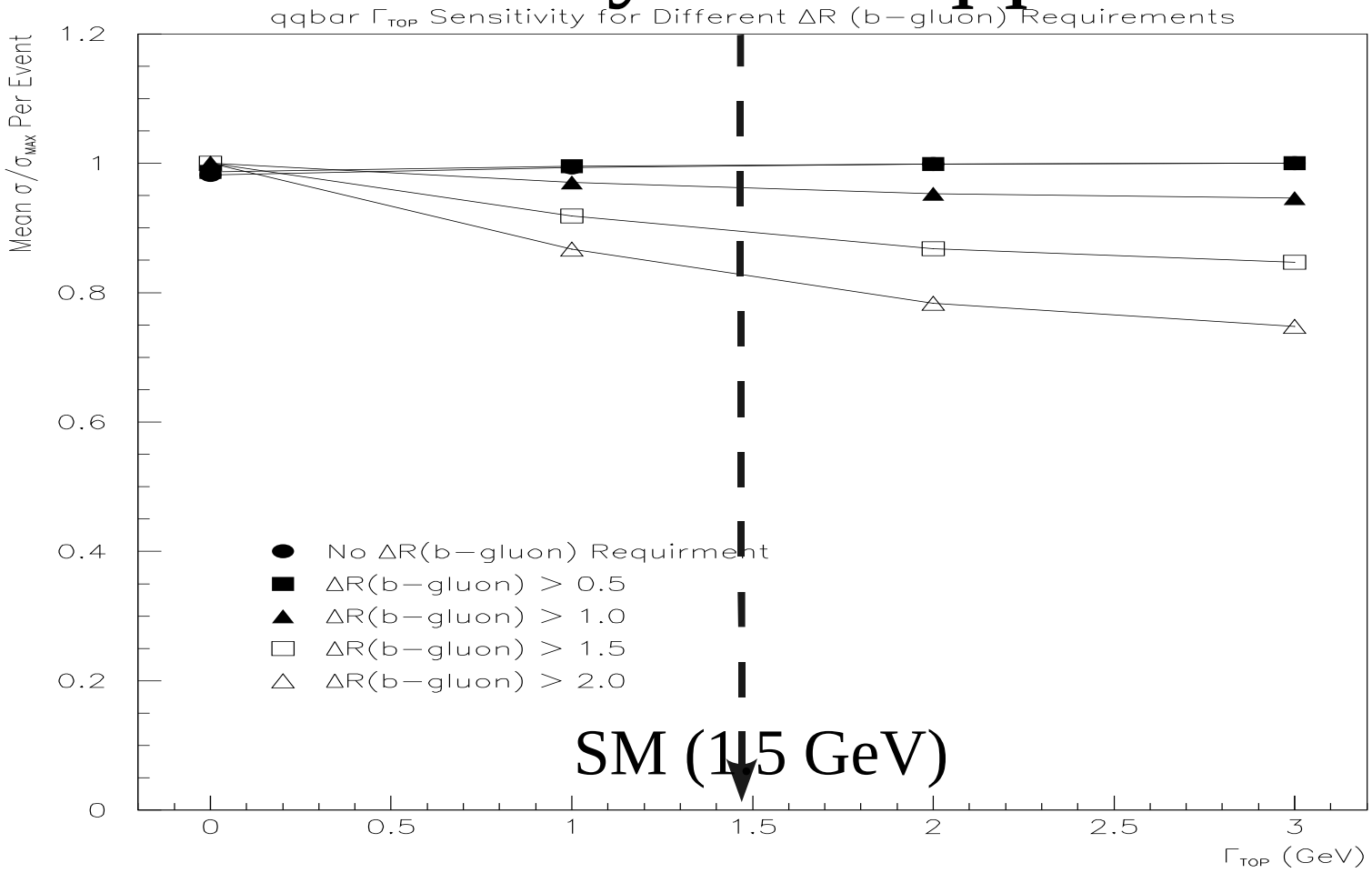

qqbar Γ=5.0 ϑb(LAB)=π/4
dσ/σ
ϑ(gluon)
t and tbar
b and bbar

Example of Topology with Top Jet



Top and b−jets are resolved. Anti−top and bbar are not.

Sensitivity from qqbar

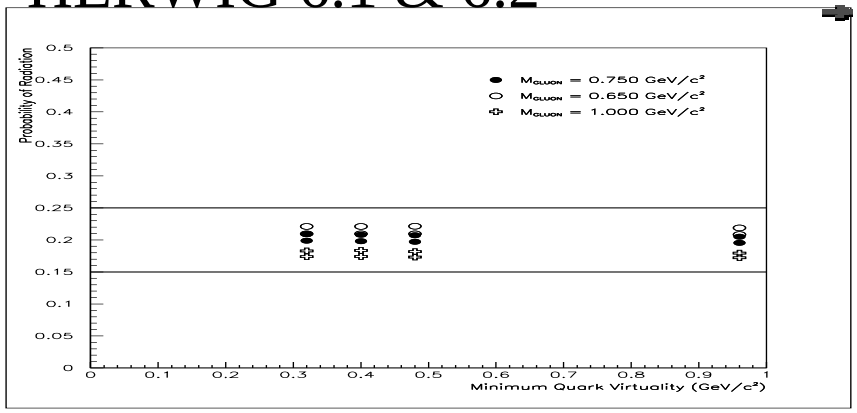


Phenomenology and Measurement

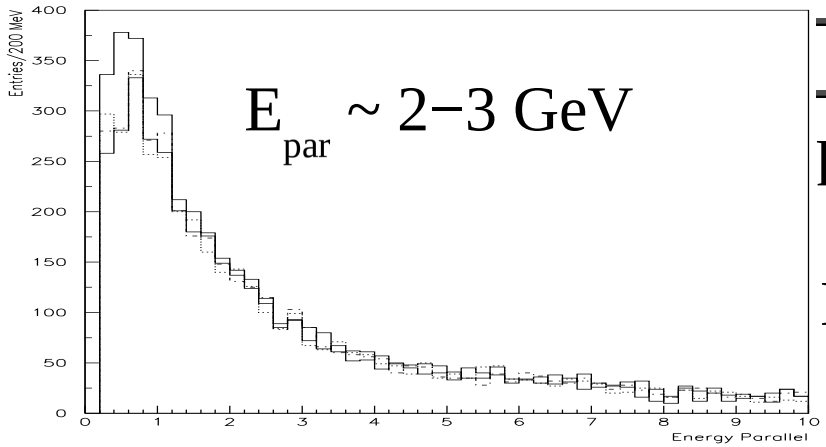
- Relevant Experimental Features
- Goals of an Experimental Program
- Monte Carlo programs, obvious and subtle differences.

Sensitivity to HERWIG Parameters

HERWIG 6.1 & 6.2



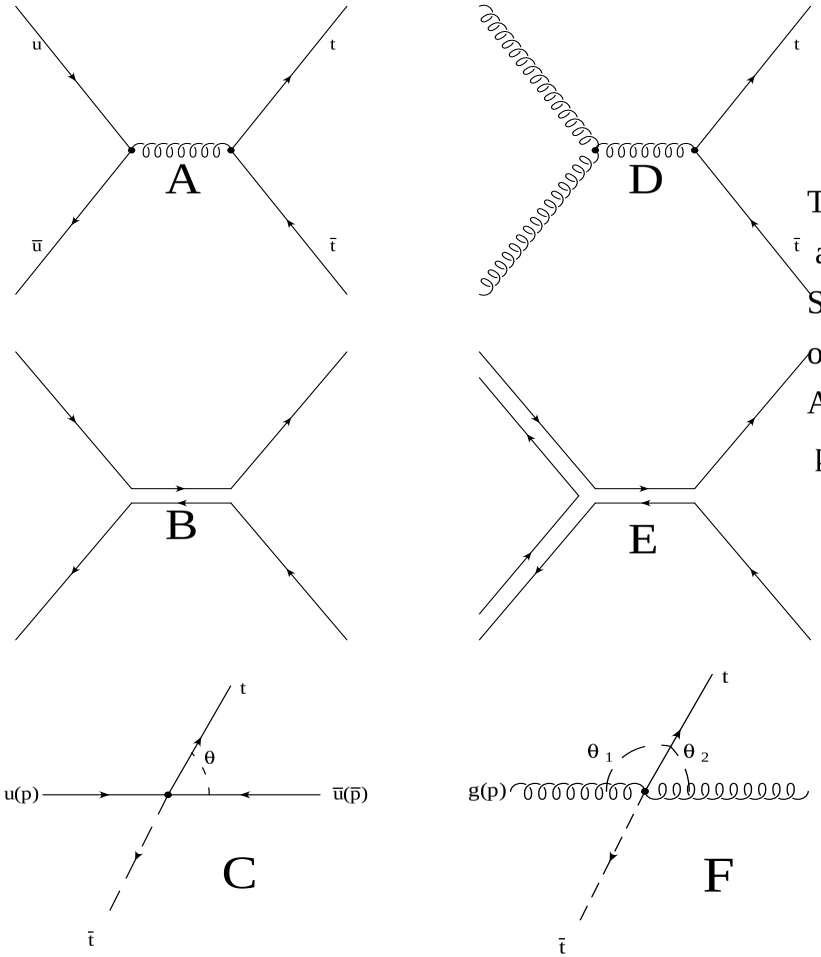
- Vary Shower Parameters:
  - Virtuality Cutoffs
  - Gluon Mass
  - Top Mass
  - PDFs
  - $P_T(t)$
- Rate varies from 15−25%
- ME Corrections do not enter here.



E_{par} ~ 2−3 GeV

Energy of Shower ~ 1−5 GeV

Phenomenology

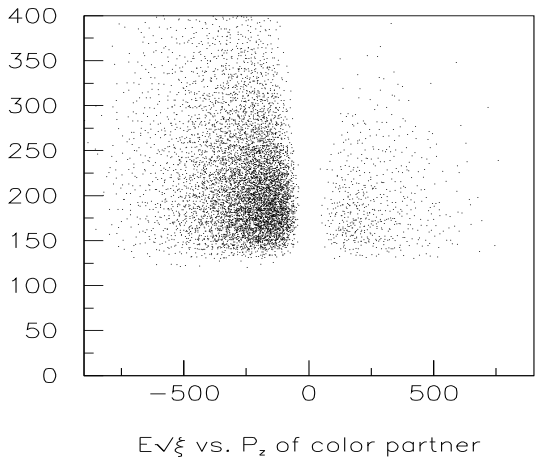


Tevatron top production proceeds through qqbar annihilation.

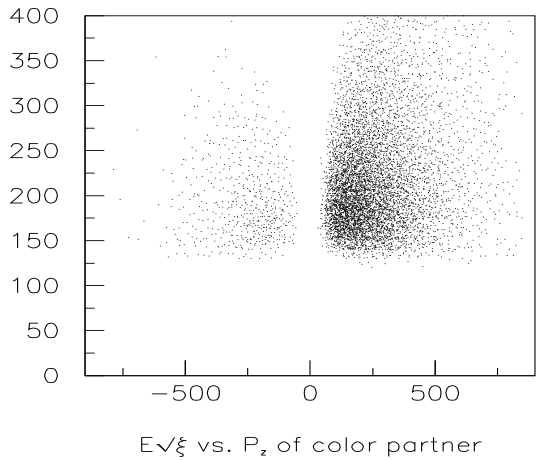
Shower production rate depends on violence of bending of color lines.

At Lowest order, top showers should be asymmetrically produced at Tevatron.

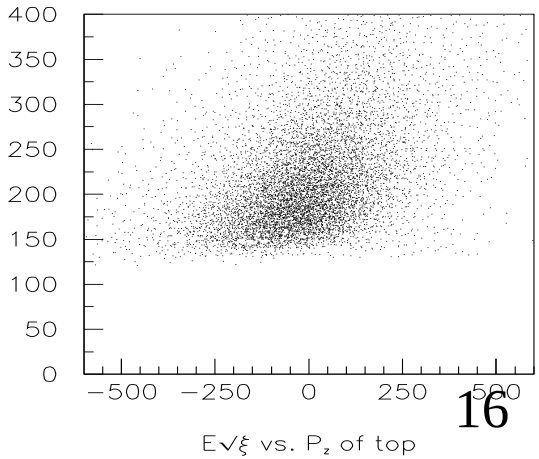
Origin of Asymmetry as described in HERWIG



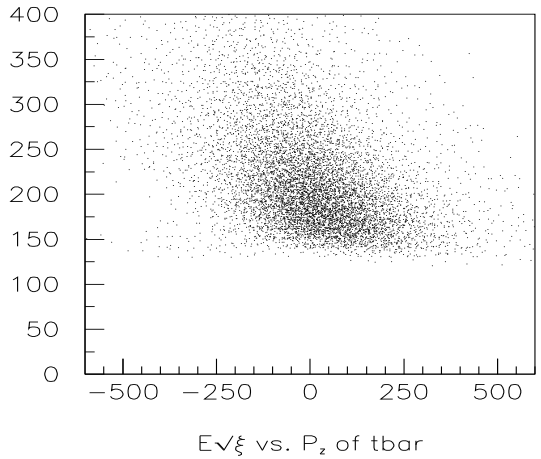
$E\sqrt{\xi}$ vs. P_z of color partner



$E\sqrt{\xi}$ vs. P_z of color partner



$E\sqrt{\xi}$ vs. P_z of top



$E\sqrt{\xi}$ vs. P_z of tbar

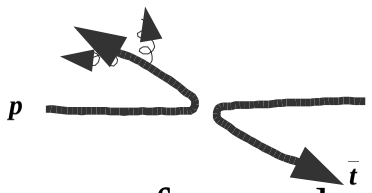
t−tbar Production Modes @ 2.0 TeV

Production Mode	Fraction
u−ubar	74.73%
d−dbar	14.57%
s−sbar	0.18%
c−cbar	0.08%
Glue−Glue	10.48%

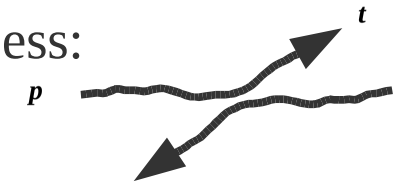
Phenomenology Summary

- To describe hadronic content of top events, need "t→gt"
- Expect contribution to hadronic activity
- Expect specific opening angle distribution
- Expect Asymmetry (at Tevatron)

More:



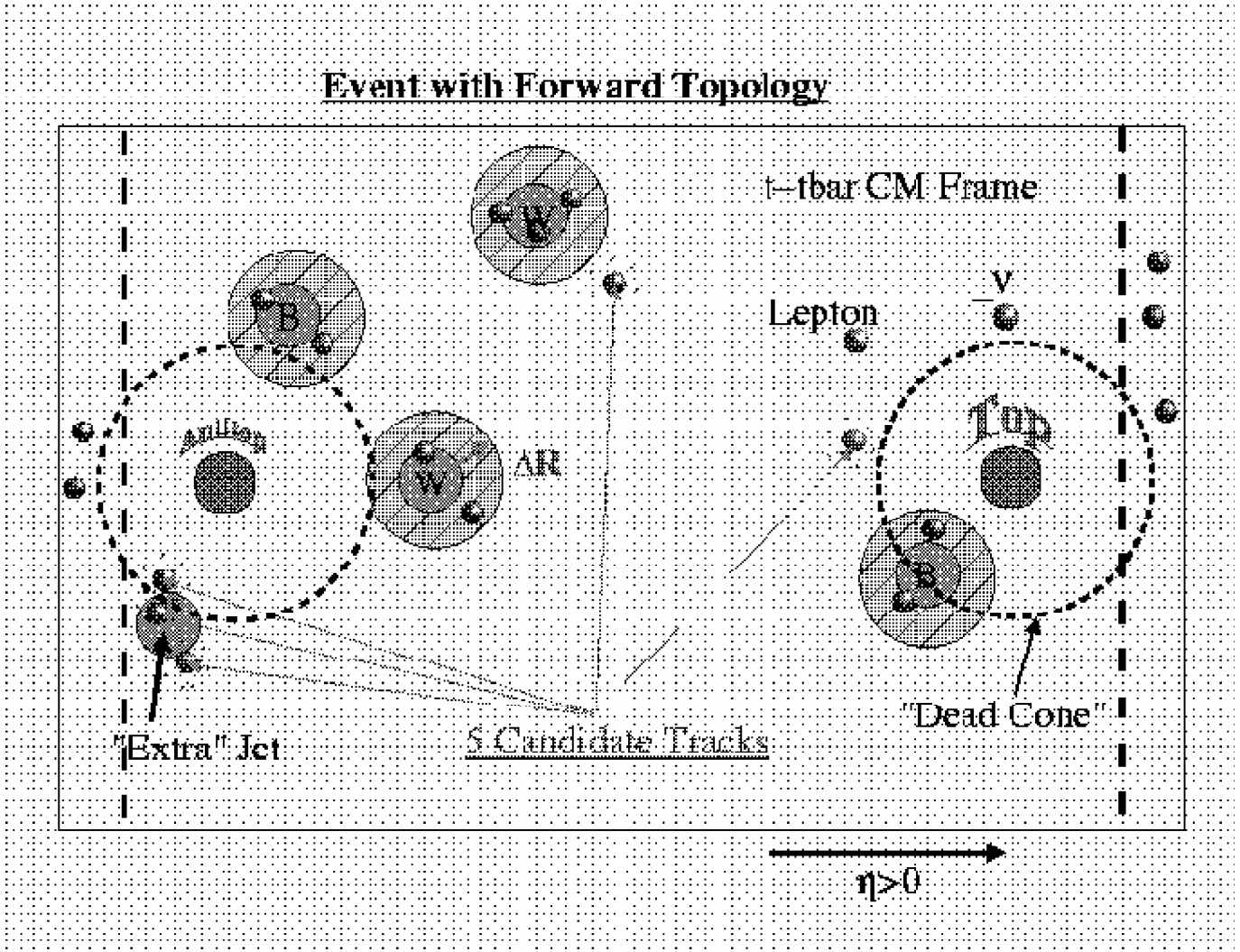
Less:



Effects largest away from other objects (like b−bbar)
In this regime, sloppy/approximate statement "radiation from top" is most nearly true.

Unjustified claim:

Tev: $\langle n_{had} \rangle \rightarrow \sigma(\Gamma_t) \sim 300-500$ MeV in Run II (certainly IIb)


Event with Forward Topology
t–tbar CM Frame
Lepton
ν
Top
AR
"Extra" Jet
5 Candidate Tracks
"Dead Cone"
η>0

Measurements with Tevatron Run I Top Candidates

- CDF Run I
- Data Samples
- Reconstruction of t−tbar
- Results of studying charged tracks

CDF Run I $t\bar{t}$ Primer

- $\int \mathcal{L} dt = 110\ pb^{-1}$
- Reconstruct Semi−leptonic Decays

$$p\bar{p} \rightarrow t\bar{t} \rightarrow W^+ b W^- \bar{b} \rightarrow l\nu\, jjb\bar{b} \rightarrow l\nu\, jjjj \times (\mathbf{0,1,2\ tags})$$

3 Samples

No Tagging Required:	163 Events (~55	$t\bar{t}$)
≥1 Tag	: 37 Events (~26	$t\bar{t}$)
≥2 Tags	: 14 Events (~13	$t\bar{t}$)

Tag: B→$\ell^{\pm}$X or find secondary vertex

Isolated Track Study in Top Events

- For Tevatron Run I, expect no sensitivity to presence of a "top shower" verify that other contributions are under control.
- Monte Carlo calculates contributions to final state hadrons from incoherent (but not unrelated!) sum of several pieces:
  - Initial State Showers
  - Underlying Event
  - Showers from Final state
  - Then a layer of Hadronization.

- Sensitivity of Observations to these pieces varies according to how candidate tracks/hadrons are selected:

Initial State Shower	⟷	Track Pseudorapidity η
Underlying Event	⟷	Track P_T
Final State Showers	⟷	Isolation (ΔR) from hard jets

Observables:

- Charged Track Multiplicity (n)
- Asymmetry in track multiplicity defined for forward and backward events.

$$\Delta = n_f - n_b$$

Forward Topology: $P_z(t)>0$ in CM frame.

Default Candidate track selection:
$P_t > 0.5$ GeV, $\Delta R(\text{jet}-\text{track})>0.7$, $|\eta|<1.0$

Measurements

Expect little sensitivity to effect of top in Run 1 Data but important to assess control of backgrounds and systematic effects: non−top bg, modeling of Initial State showers, underlying event,...

CDF Preliminary Run 1

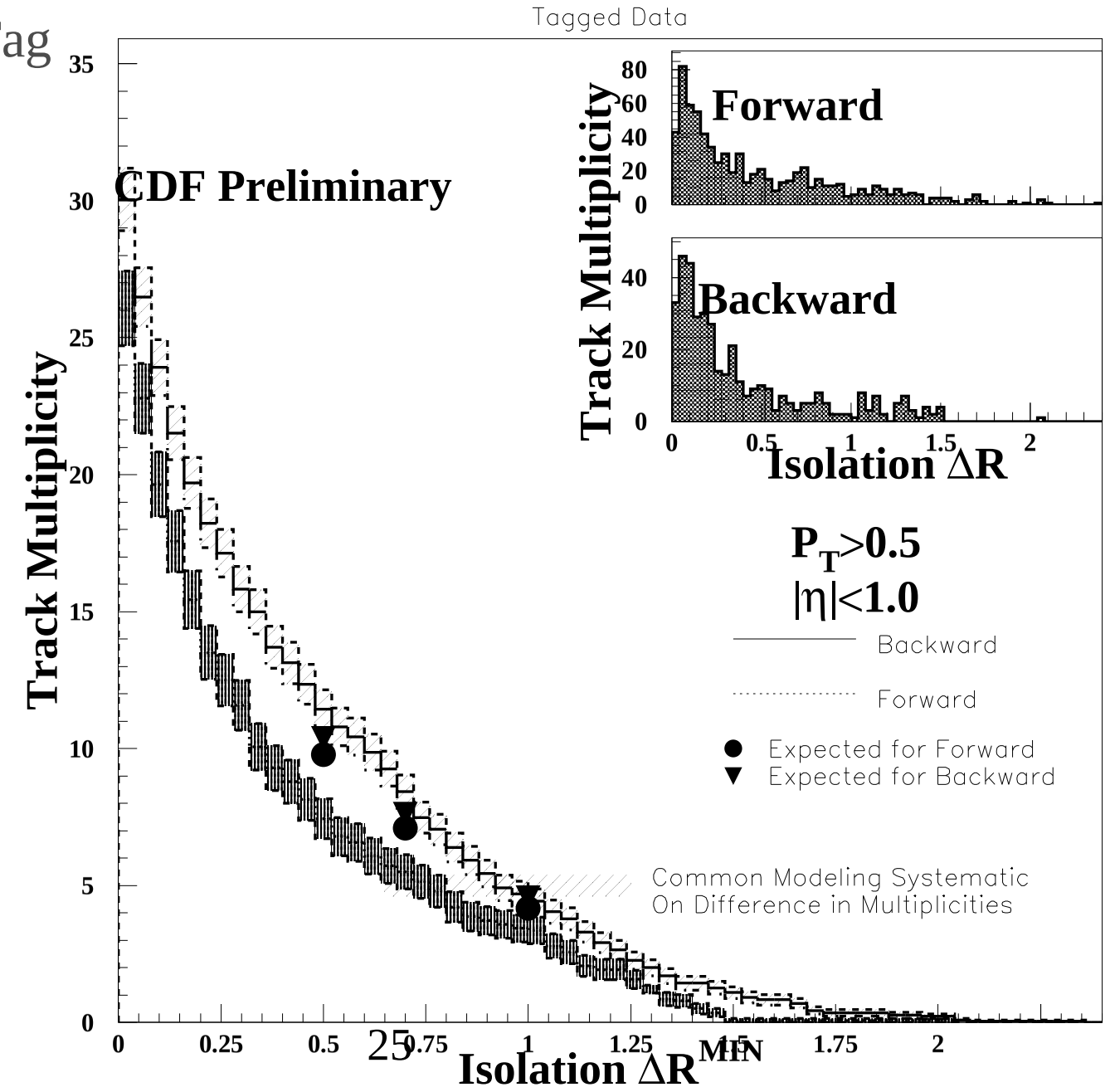
	N Observed	N Expected	Δ Observed	Δ Expected
No Tag (70%BG)	7.2 ± 0.2	7.6 ± 0.1	-0.5 ± 0.4	-0.10 ± 0.01
2 Tags (5%BG)	7.8 ± 0.5	7.3 ± 0.1	$+3.4 \pm 0.9$	-0.43 ± 0.04
	6.9 ± 0.7	7.3 ± 0.1	$+6.3 \pm 1.2$	-0.33 ± 0.04

Significant systematics due to understanding of ISR/UE: $\sigma(\Delta) = \pm 5.0$

Run II: Measure track multiplicity to ~1−2 %.

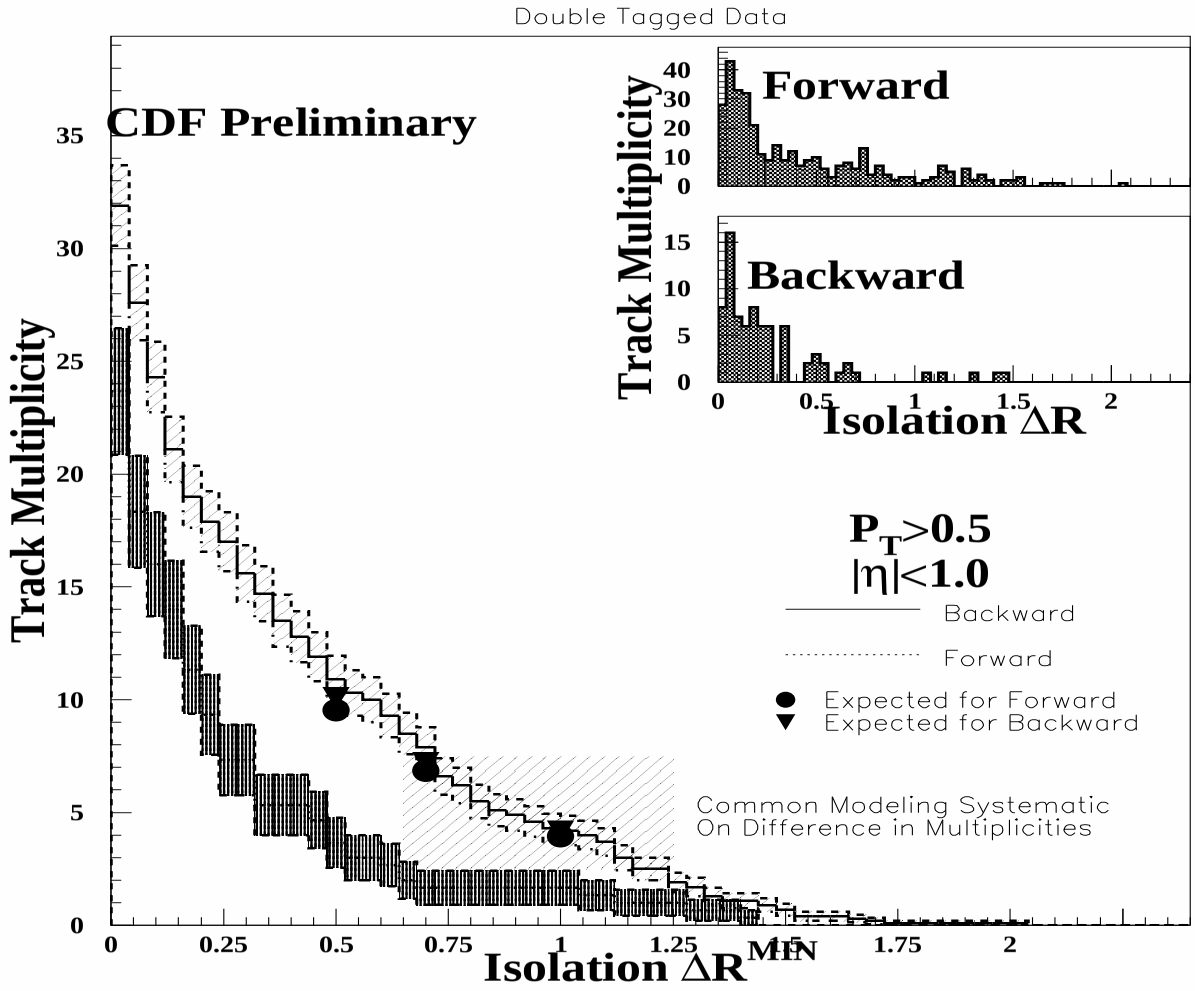
Statistical uncertainty in Γ_t ~ 500 MeV.

At least 1 Tag

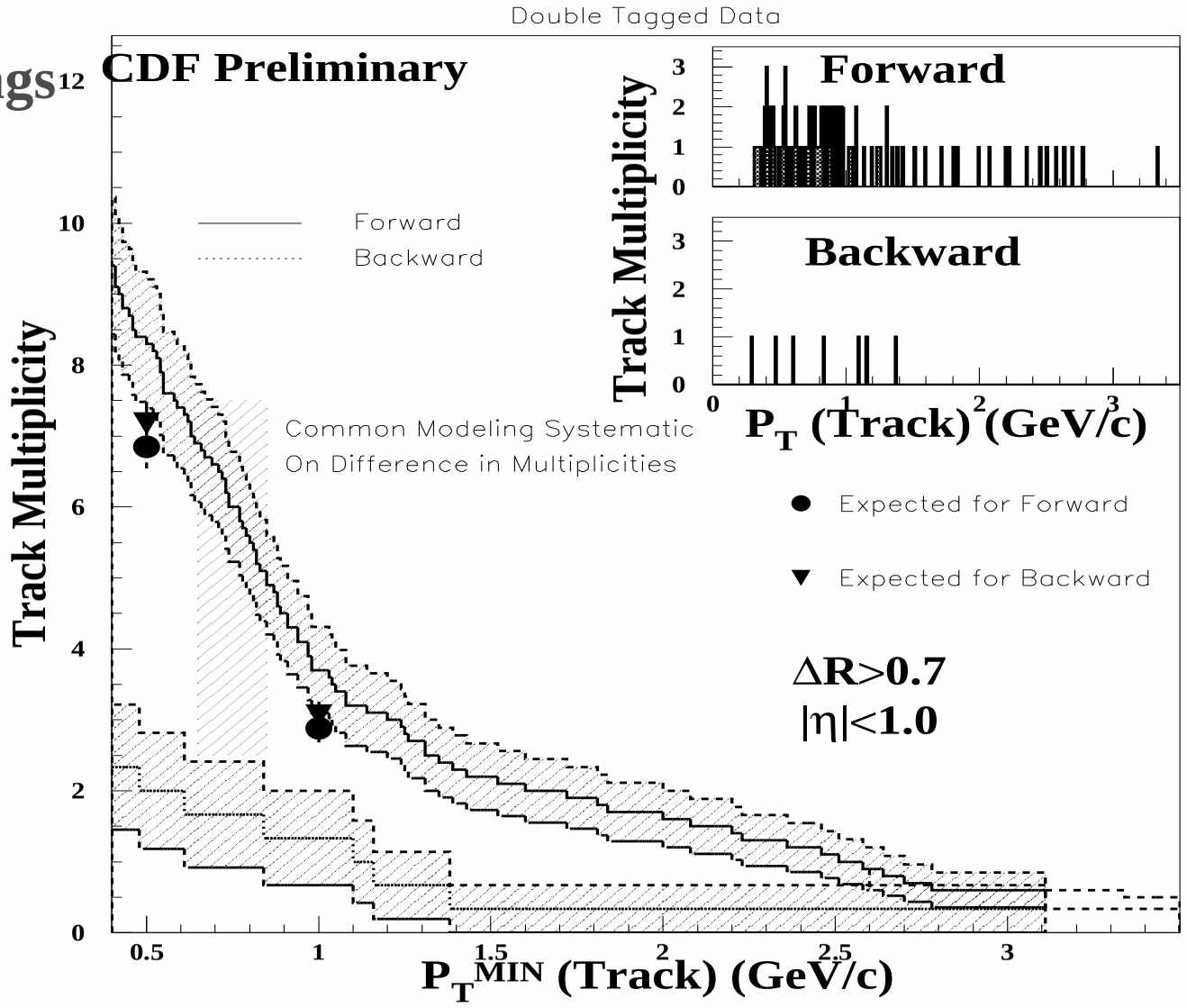


Results

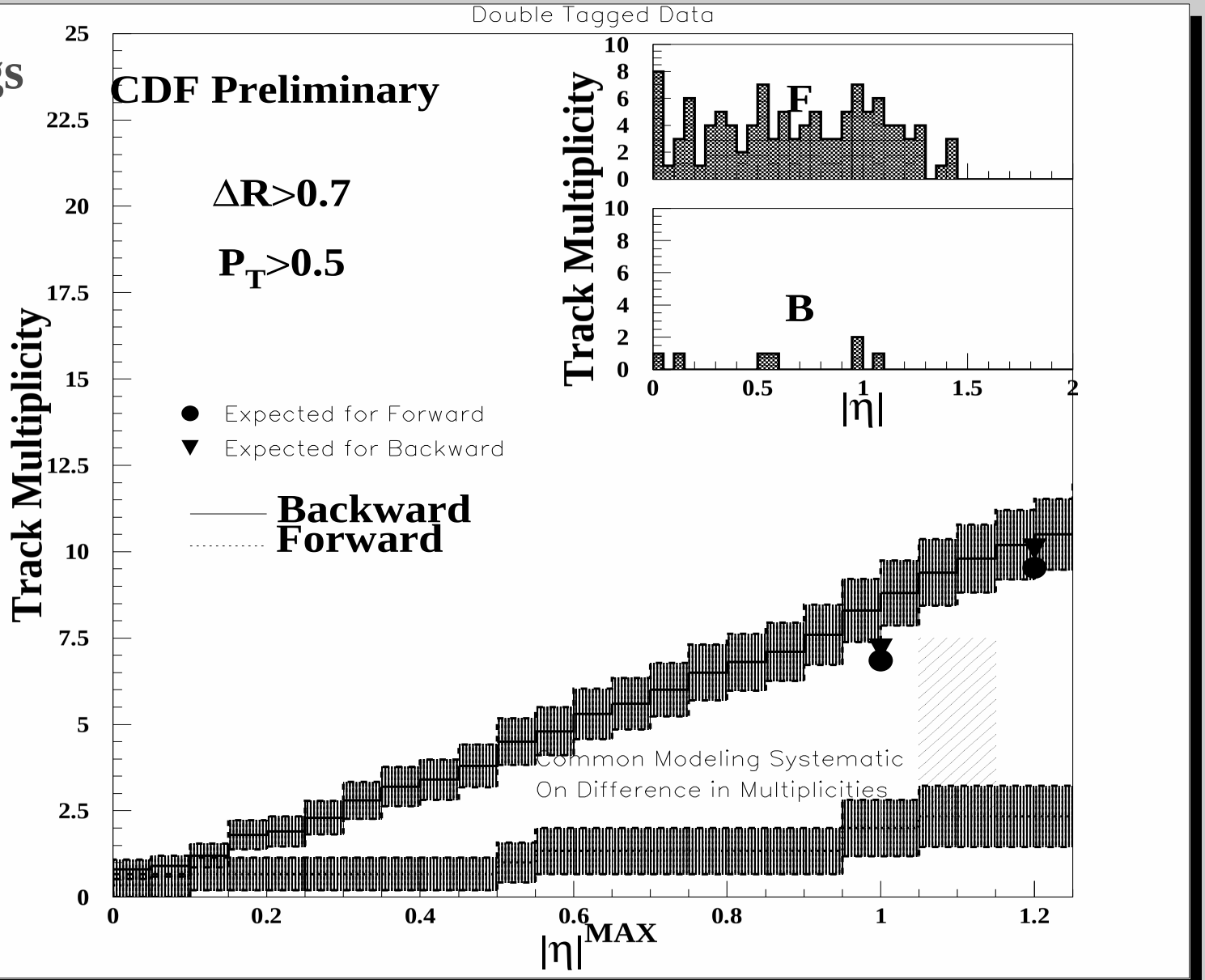
2 *b*−tags



2 *b*−tags[12]

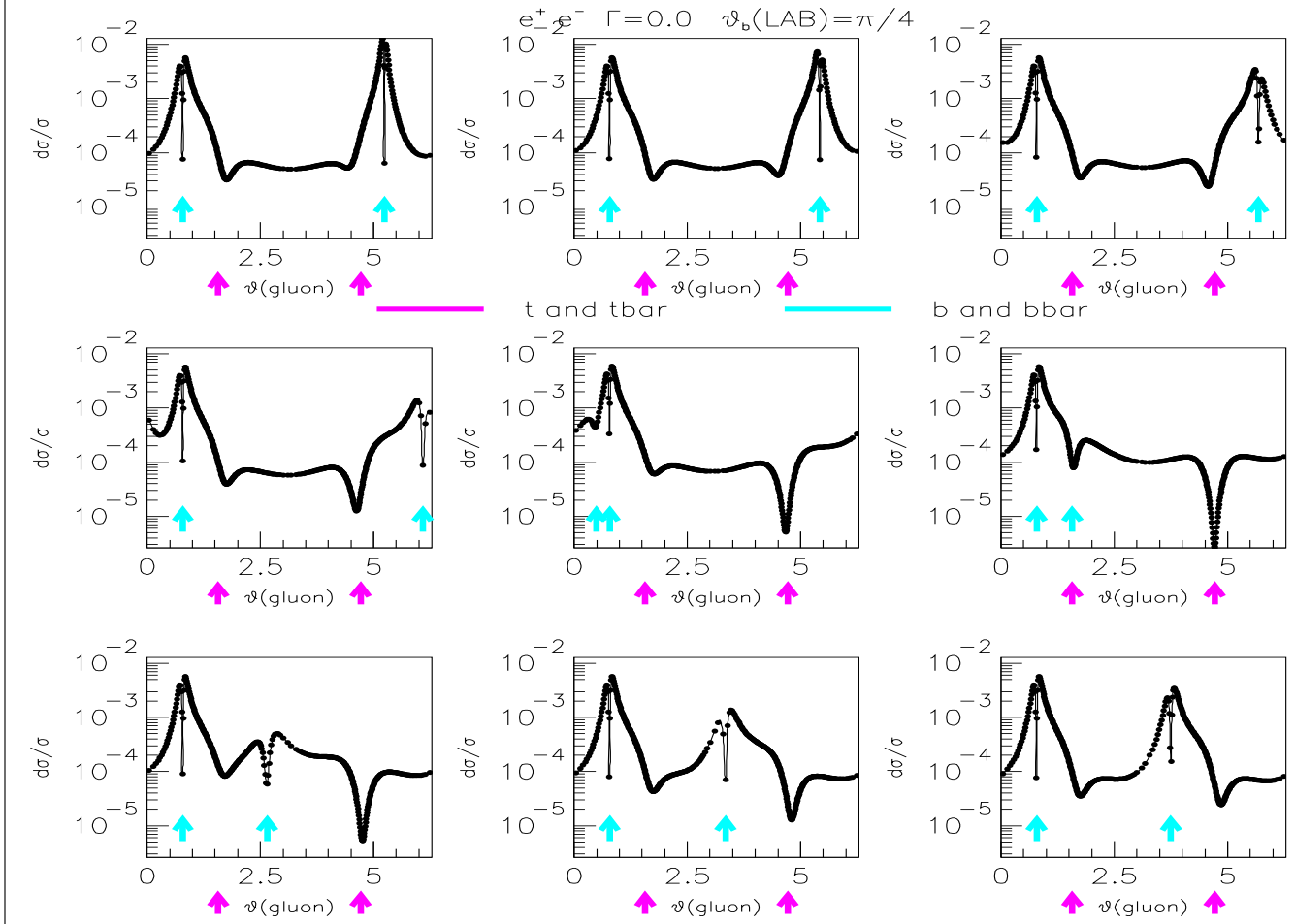

Double Tagged Data
CDF Preliminary
Forward
Backward
Common Modeling Systematic
On Difference in Multiplicities
Expected for Forward
Expected for Backward
ΔR>0.7
|η|<1.0
Track Multiplicity
P_T^{MIN} (Track) (GeV/c)
Forward
Backward
P_T (Track) (GeV/c)

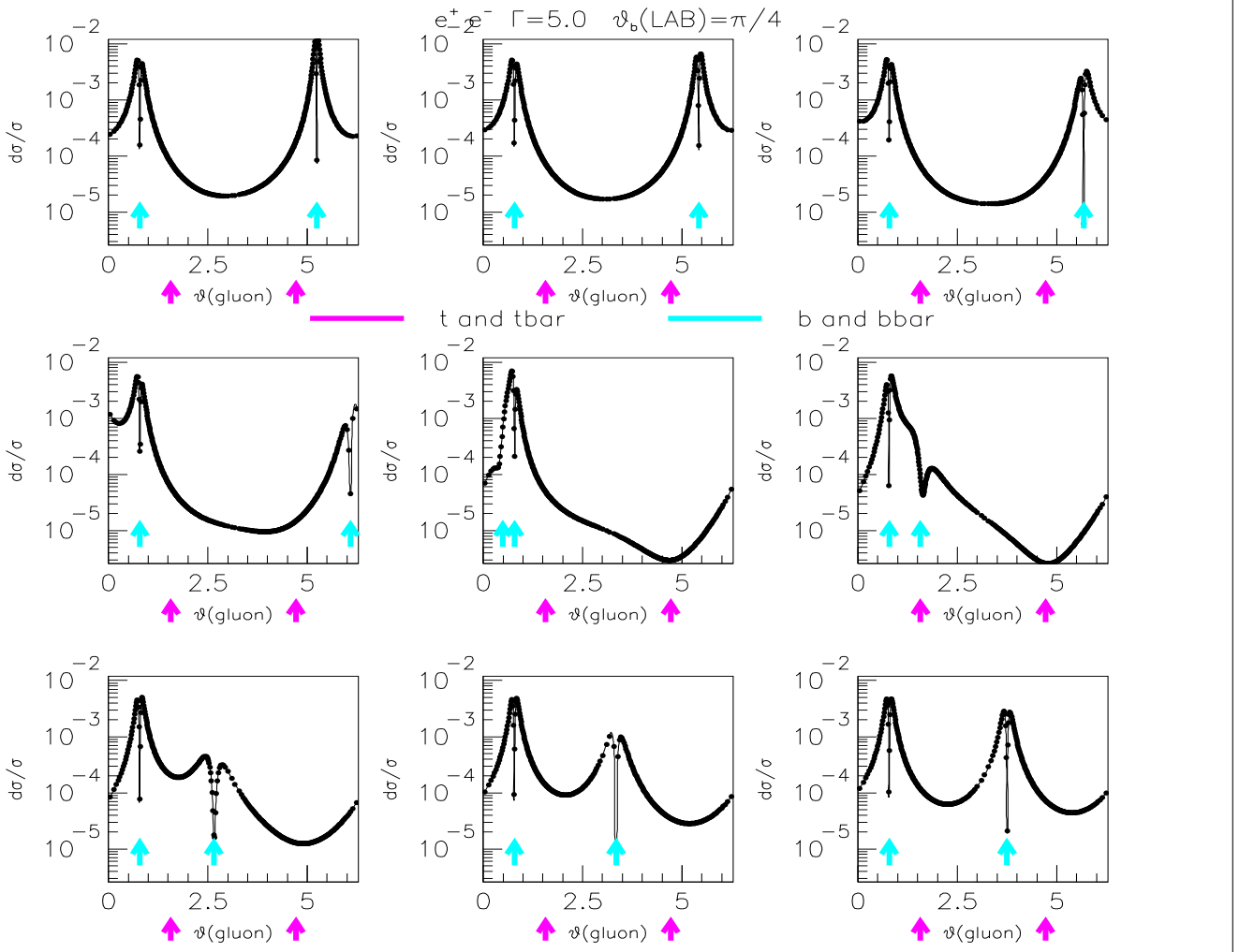
2 *b*−tags


Double Tagged Data
CDF Preliminary
ΔR>0.7
P_T>0.5
Expected for Forward
Expected for Backward
Backward
Forward
Track Multiplicity
|η|^MAX
F
B
|η|
Common Modeling Systematic
On Difference in Multiplicities

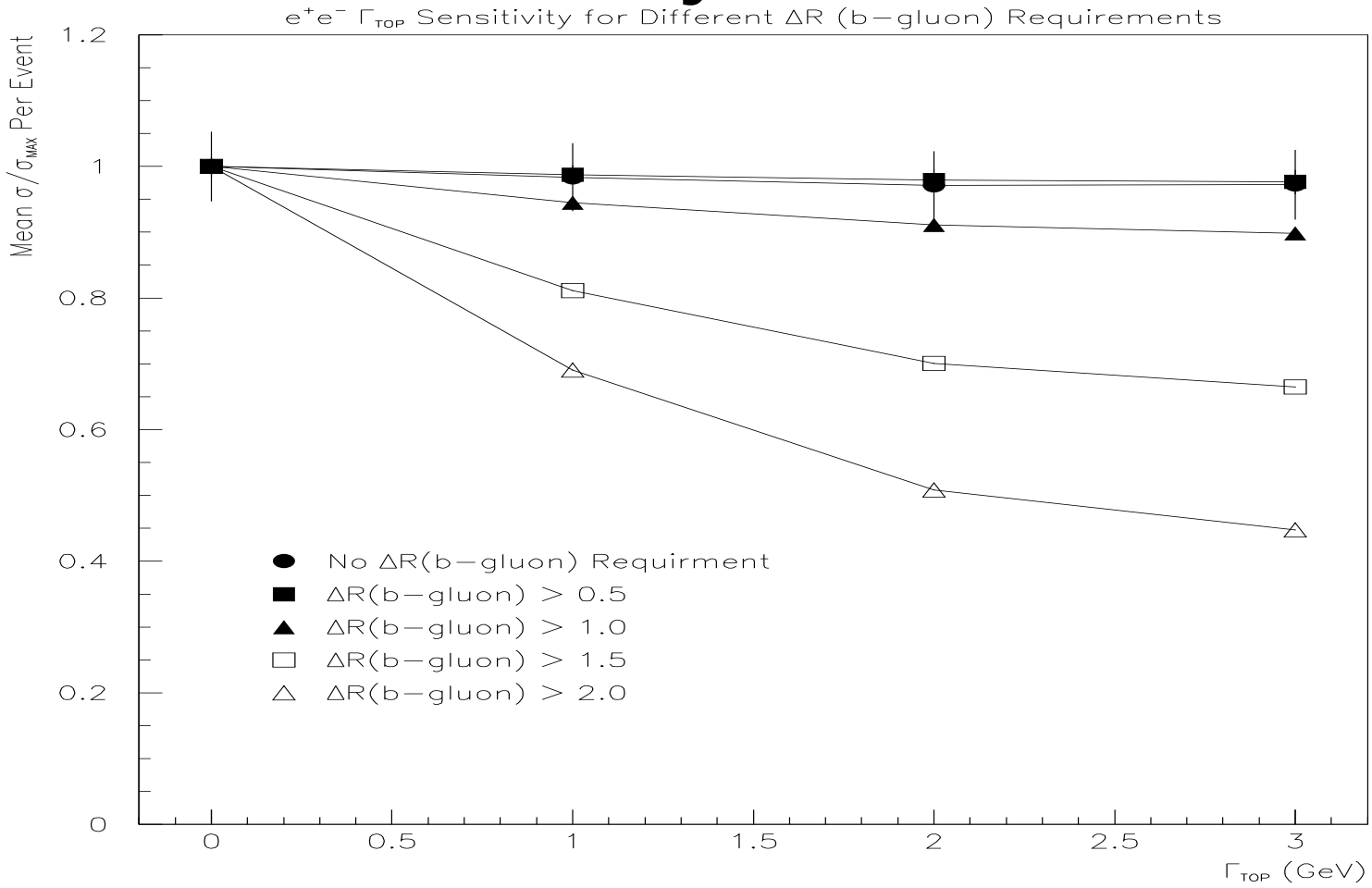
Importance of Different Venues

- What is learned from small Run I samples
- Why Run II matters
- Rates and Asymmetries elsewhere
- Beyond Top


e+e- Γ=0.0 ϑb(LAB)=π/4
t and tbar
b and bbar
dσ/σ
ϑ(gluon)
0
2.5
5


e+e− Γ=5.0 ϑb(LAB)=π/4
t and tbar
b and bbar
dσ/σ
ϑ(gluon)

Sensitivity for e^+e^-



Monte Carlo Issues

Precision Measurements of QCD properties described by Parton Shower Model are amenable to measurement now.

The calculations will be compared to one another as well as to data.

Current Decomposition *viz*. Dead Cone and Rates,

uncorrected for detector

<u>As usual, Herwig (version 5.6−6.2) and Pythia (6.2).</u>

Key Points:	Pythia	Herwig
Q^2 Cutoff	1.0 GeV	400 MeV
Hadronization Color	Yes	No
Dead Cone	ME	Cutoff Approx.
Tevatron Asymmetry	Yes	Yes
Tevatron ISR Asymmetry	Yes	No
Multiplicity	Agree well after tuning (see R. Field, last workshop)	
Underlying Event	MI addition	No MI addition

different models.

Rates

- Pythia:

Radiative Fraction Forward 24%

Radiative Fraction Backward 9%

Radiative Fraction 16%

Parton Level Asymmetry: 25%

- Herwig

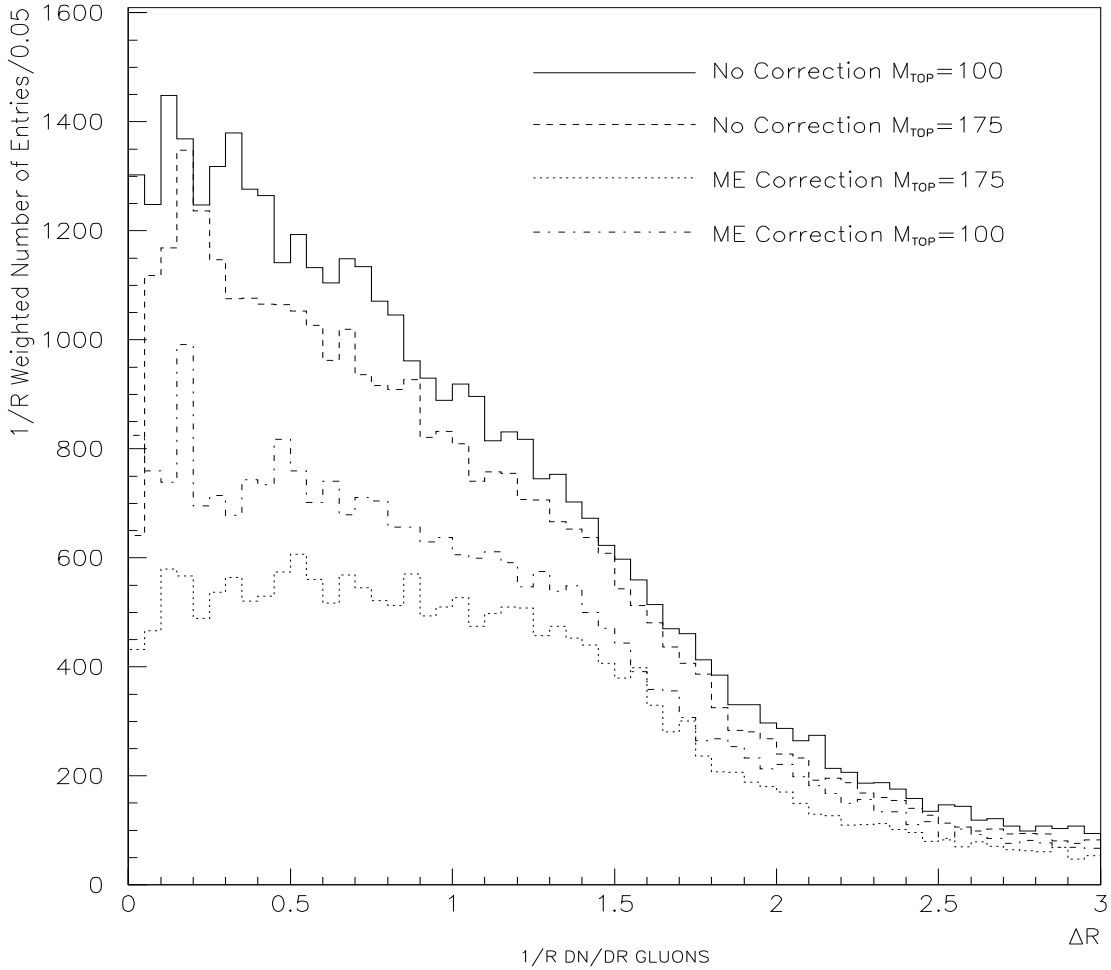
Radiative Forward 10%

Radiative Backward 30%

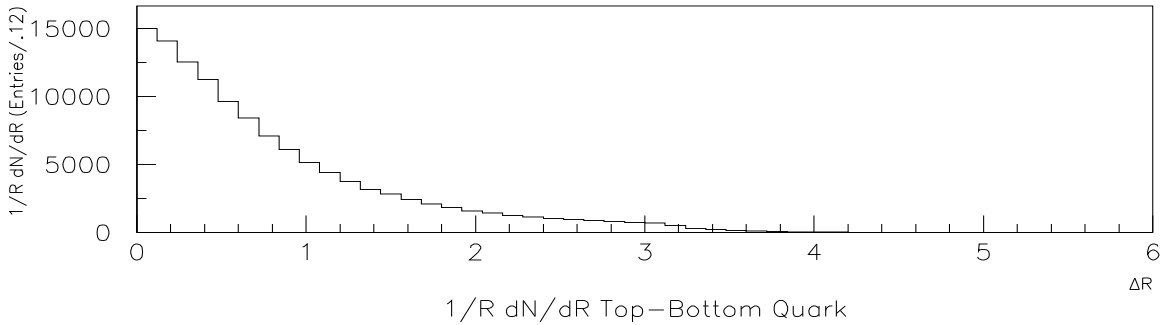
Radiative Fraction 21%

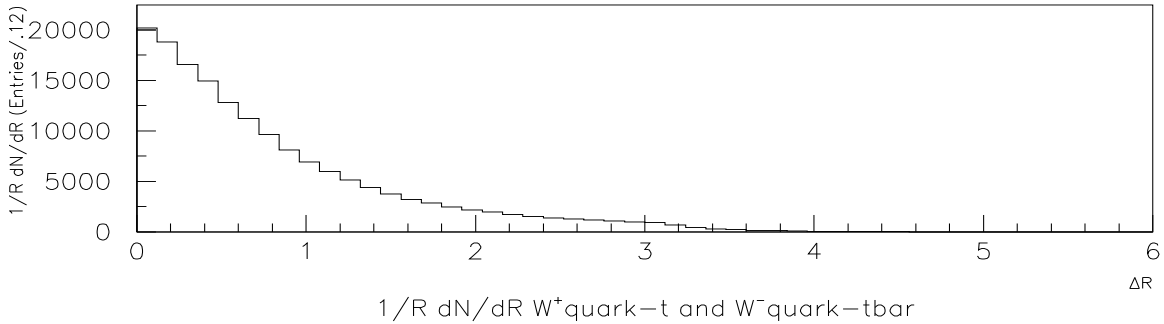
Parton Level Asymmetry: 10%

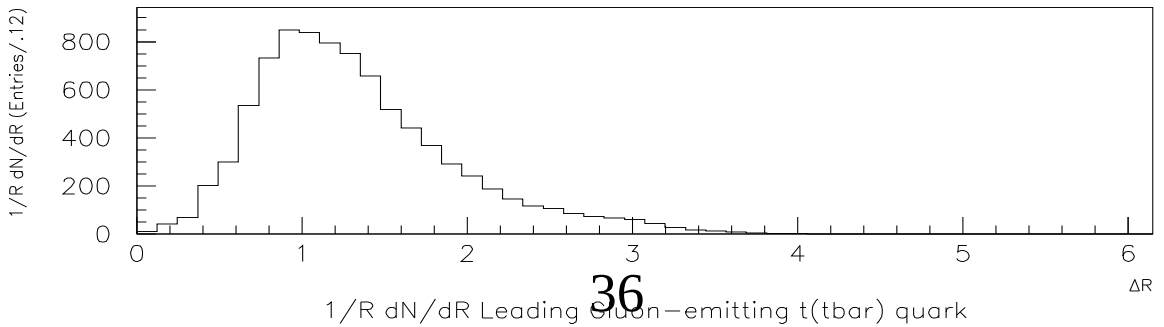
Pythia Production Stage Deadcones



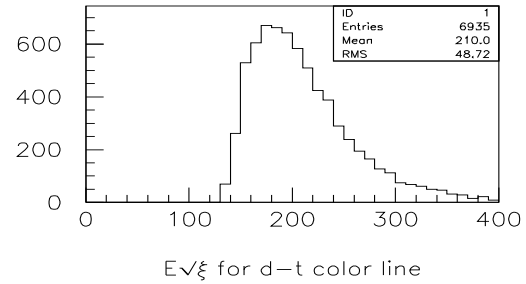
Herwig Dead Cones



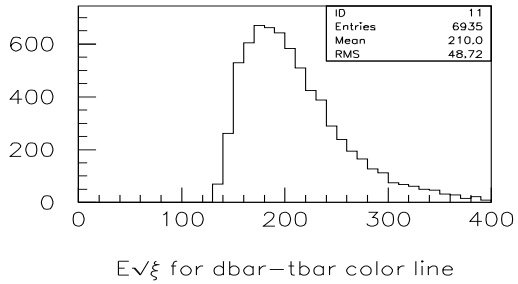




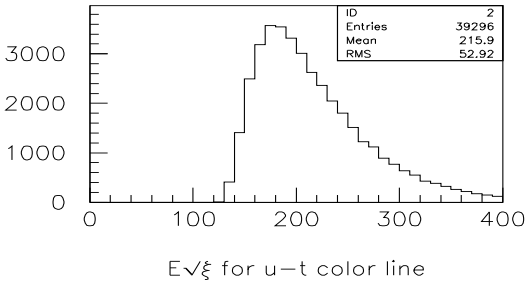
Herwig Q values



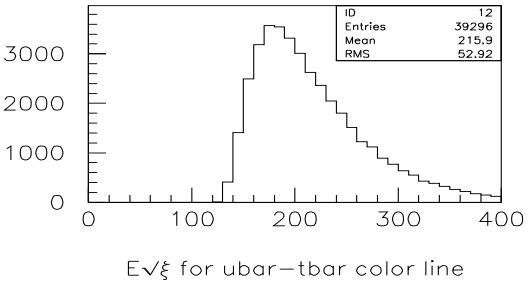
E√ξ for d−t color line



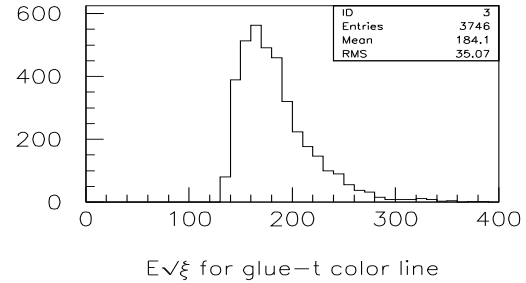
E√ξ for dbar−tbar color line



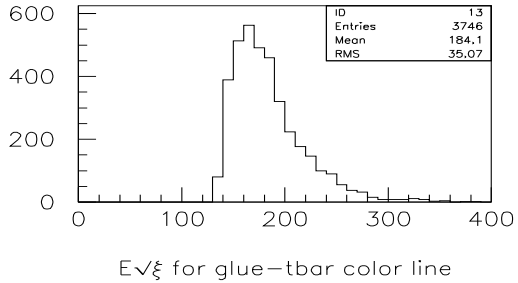
E√ξ for u−t color line



E√ξ for ubar−tbar color line

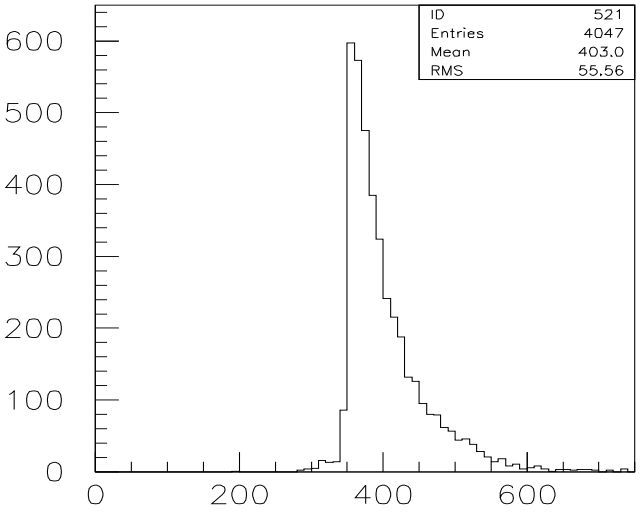


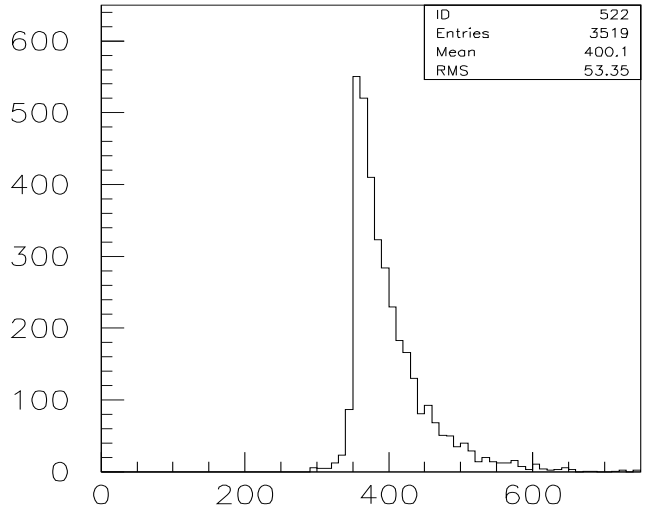
E√ξ for glue−t color line

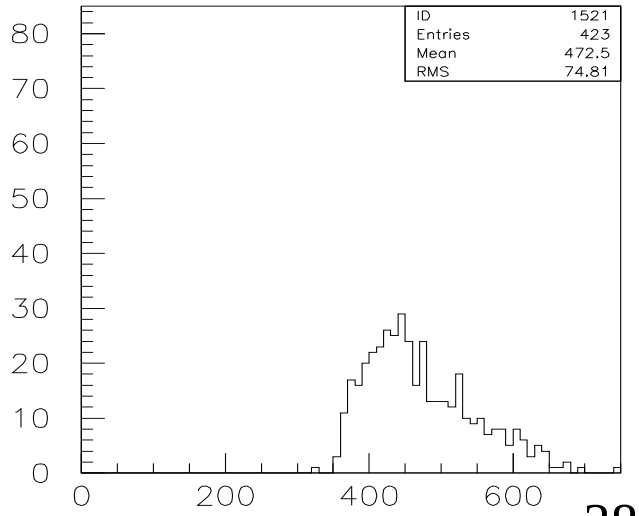


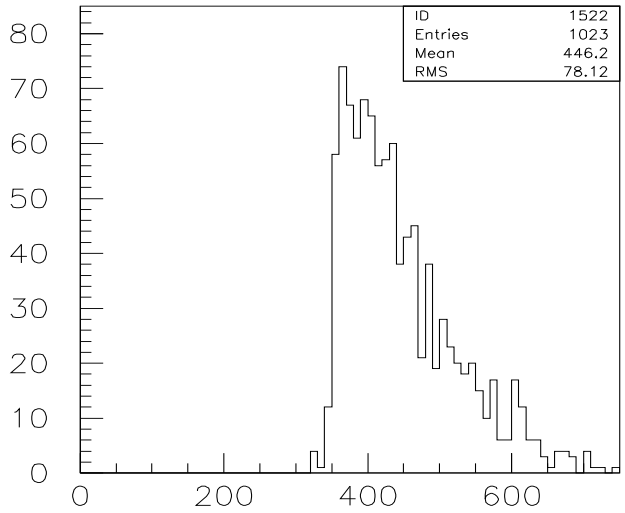
E√ξ for glue−tbar color line

Pythia Q_{max} t−tbar









Summary

- The radiation pattern within top events is *a priori* interesting and important for many reasons.
- Specific reasons for probing at ppbar, pp, and lepton colliders.
- Ultimate ability at Tevatron unclear but
  - Examination of Run I data bear out specific properties and precision.
  - Surprising behavior with regards to other properties.

Summary(continued)

- Performance and Utility of Monte Carlo Programs:
- Collision between predictability and clarity:
  - Pythia reasonably folds color structure into non−perturbative regime of hadronization at price of higher Q^2 cutoff between this regime and perturbative.

Summary (continued)

- Description of dead cone suppression of collinear radiation is qualitatively different between different programs.
- Surprisingly, multiplicity well duplicated by two programs.
- Matrix Element corrections important for jet shape but perhaps not for rates/asymmetries.