Microscopic Quirks at Hadron Colliders

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Quirks

Color vs infraColor

- When QCD strings are stretched, they can break and form new color-neutral states.
- For infracolor strings, energy economy of heavy fermions: string stretching $\rightarrow$ kinetic energy loss of quirks
- InfraColor bound state resembles classical strings

Motivation

Hierachy Problem

- top contribution to Higgs mass
  may be canceled by a partner particle: stop, top prime
  SUSY, Little Higgs
- A new SU(3)
  SUSY $\longrightarrow$ Folded SUSY, Burdman et al (2006)
  Little Higgs $\longrightarrow$ Twin Higgs, Chacko et al (2005)

Motivation

(Non)Minimal Extensions of SM

- Generic layers that can be superimposed on top of any BSM models
- Not necessarily to addressing problems with SM
- Hidden Valley, Quirk, ...

Motivation

Signal in the Soft Physics

besides γ, μ, e, τ, b, jets and MET with large p_T
soft physics: π, γ etc.

Quirky Strings

$$K \sim m_Q \sim \Lambda_{\mathrm{IC}}^2 \Longrightarrow L \sim \frac{m_Q}{\Lambda_{\mathrm{IC}}^2} \gg \Lambda^{-1}$$

$$L \sim 10\mathrm{cm}\left(\frac{\Lambda_{\mathrm{IC}}}{\mathrm{keV}}\right)^2 \frac{m_Q}{\mathrm{TeV}}$$

- $1\mathrm{mm} \lesssim L \lesssim 10\mathrm{m} \Longleftrightarrow 100\mathrm{eV} \lesssim \Lambda_{\mathrm{IC}} \lesssim 10\mathrm{keV}$
  magnetic bending (tracker resolution and detector size)
  Kang, Luty (2008)
- $1\text{Å} \lesssim L \lesssim 1\mathrm{mm} \Longleftrightarrow 10\mathrm{keV} \lesssim \Lambda_{\mathrm{IC}} \lesssim 1\mathrm{MeV}$
  high ionization track
- $L \lesssim 1\text{Å} \Longleftrightarrow 1\mathrm{MeV} \lesssim \Lambda_{IC}$
  subatomic size, little ionization, microscopic

Microscopic Strings

MeV $\lesssim \Lambda \ll m_Q$, Q: fundamental in new 'infracolor' group

- Production
  - EW or QCD charged, can be strongly produced
  - Infracolor charge, PAIR produced as IC singlet
- QCD String and Infracolor String Formation
  - QCD string fragments into QCD hadrons and Qq hadrons
  - Infracolor string oscillates, loses engergy with each crossing
    $\sigma \sim$ geometrical; interaction rate $\sim$ 1/crossing
    Assume $\Lambda_{QCD} > \Lambda$, no IC glueball radiation
  - $\pi^0 \to \gamma\gamma$, focus on γs. No π^0 reconstruction.
- $Q\bar{Q}$ bound state annihilates into gg, $q\bar{q}$ or $\ell^+\ell^-$
  $BR(Q\bar{Q} \to \ell\ell) \sim \alpha^2/N_C^2$
- Prompt decay/annihilation

Simplications

- One flavor of heavy quirk
- Only at PYTHIA level + crude detector simulation. No PGS.(yet)
- Hard process (dijet/dilepton etc) + Soft physics Begin by looking at lepton mode.

What to look for

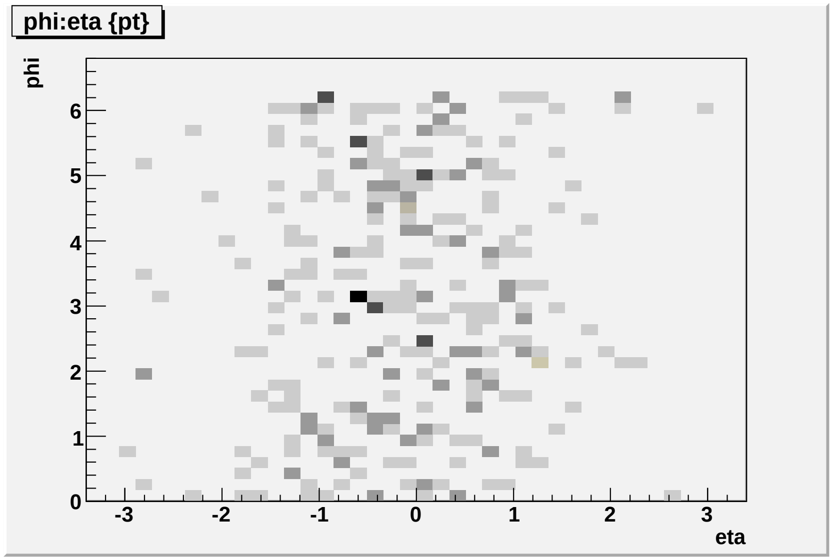
in the soft physics ?

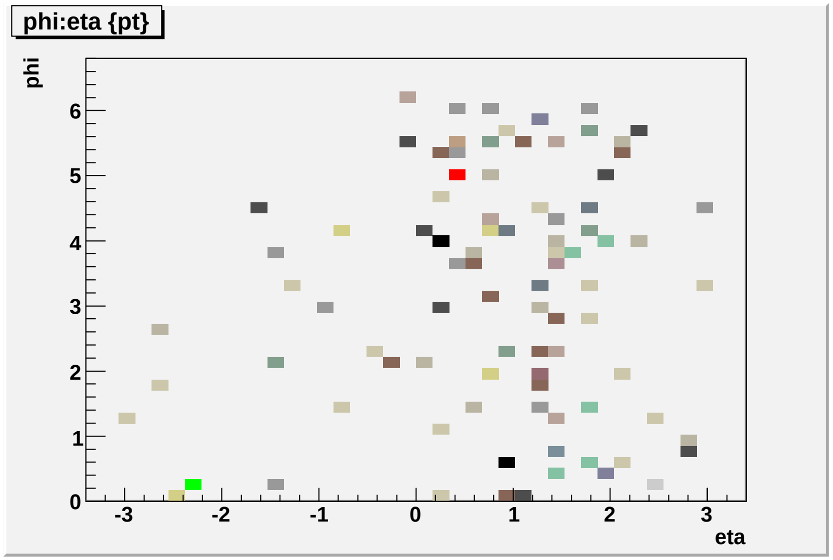
Distinguishing signal from background

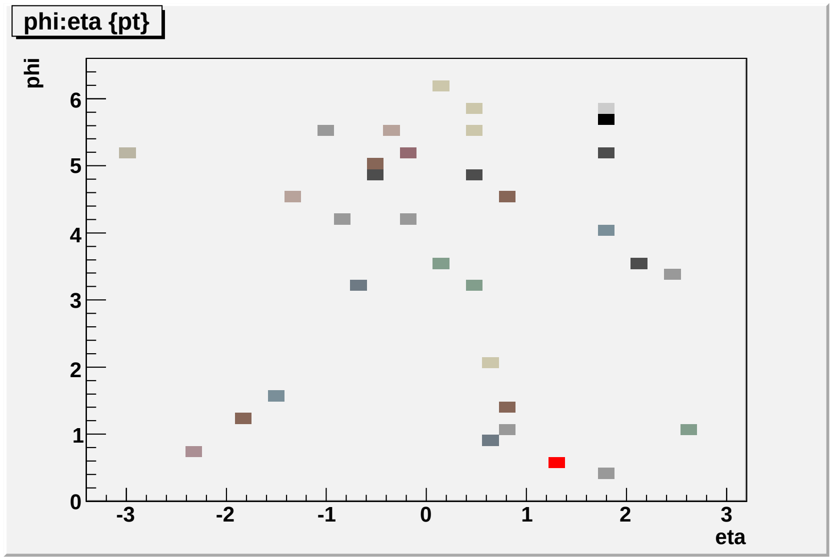
pion/photon emission, pattern recognition
dipole/quadrupole/...
Need to theoretically model the emission well, implement in Monte Carlo, and experimentally recognize pattern with efficiency
simpler algorithm?

Emission Pattern?

Event examples



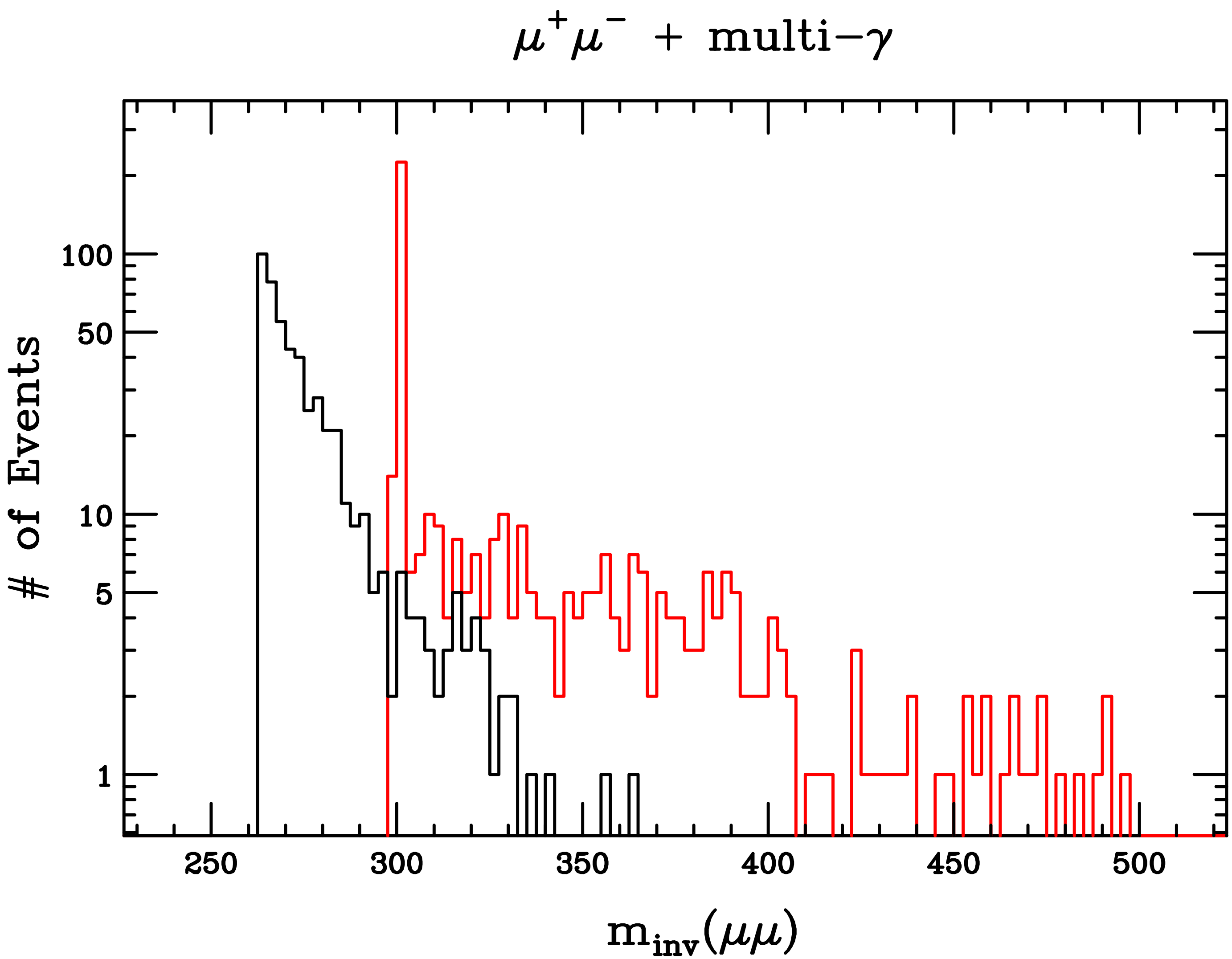




$N_\gamma = 279,\ 95,\ 34$

Invariant Mass of $\mu^+\mu^-$

Hard process:



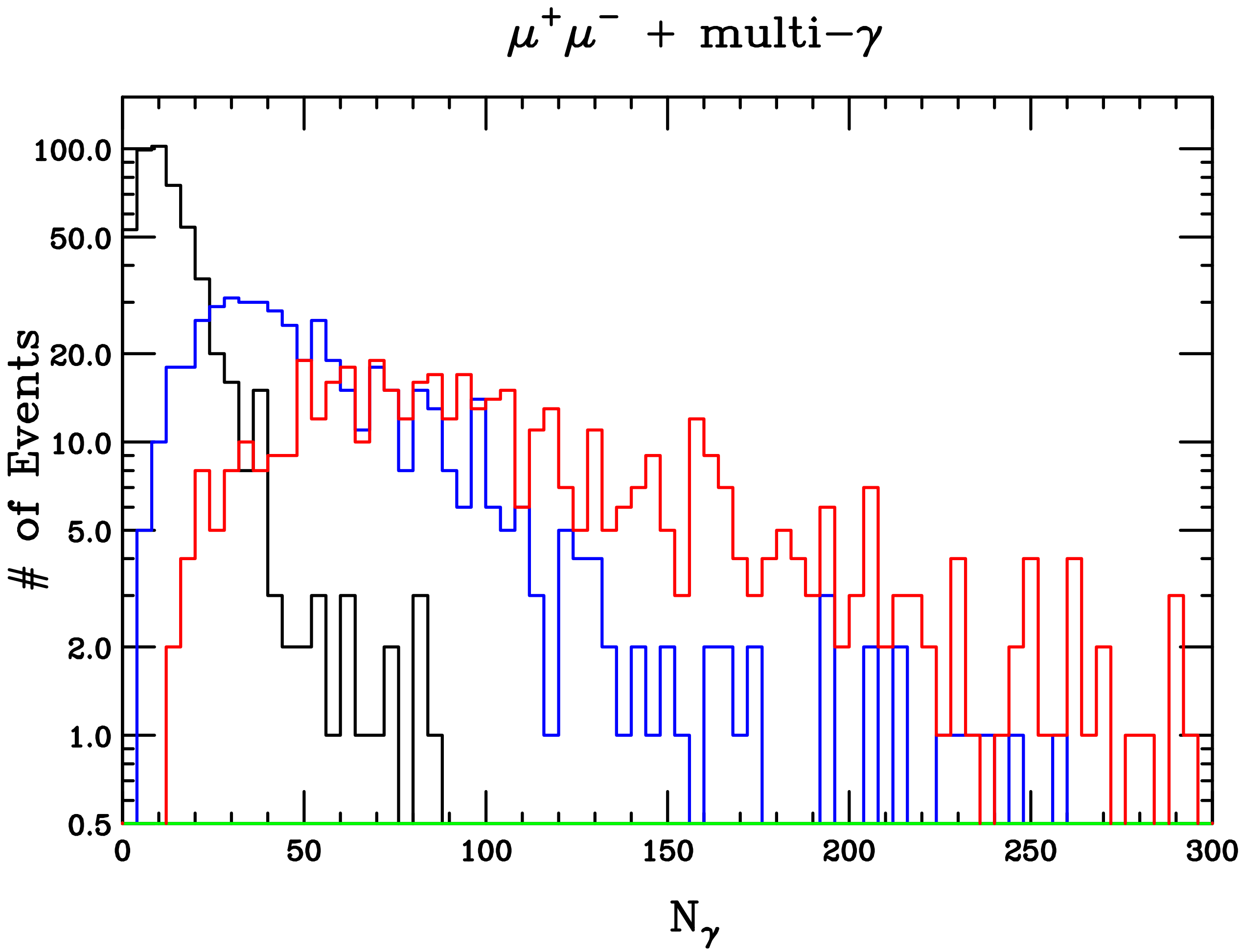
$Q\bar{Q}$ signal resembles a narrow resonance

Cross section not normalized!

Number of Photons

$$\pi^0 \Rightarrow \gamma\gamma \quad (1)$$

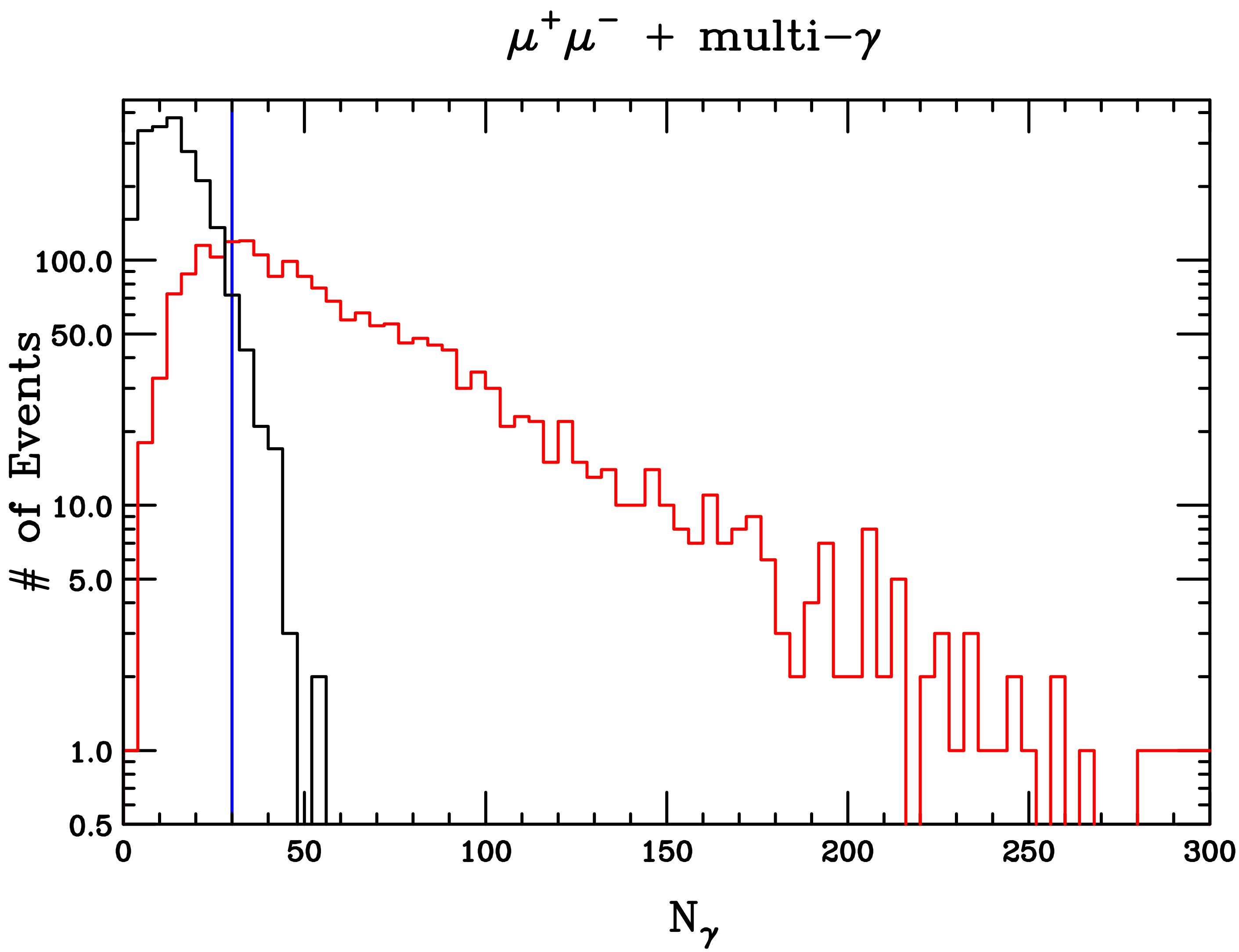
soft tracks, calorimeter hits



- Photon p_T acceptance: $p_T(\gamma) \geq$ 500, 200, 20 MeV
- Single Photon Efficiency ϵ_γ: $\sum N_\gamma$ and $\sum E_\gamma$ scale as ϵ_γ

Number of Photons

Signal vs. Background

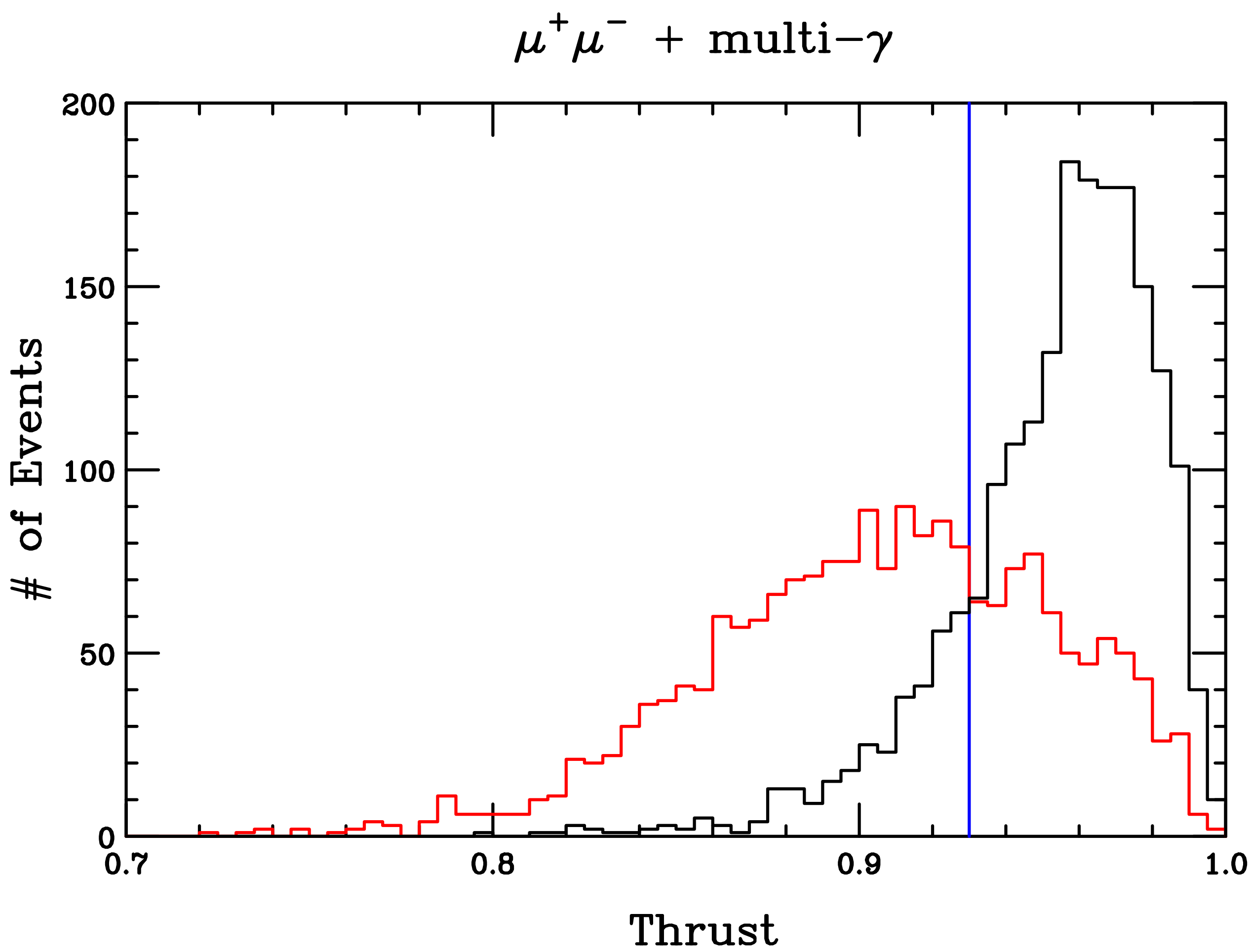


$p_T(\gamma) \geq 200$ MeV

$\epsilon_s = 0.72$, $\epsilon_b = 0.045$, for $N_\gamma > 30$

Thrust Distribution

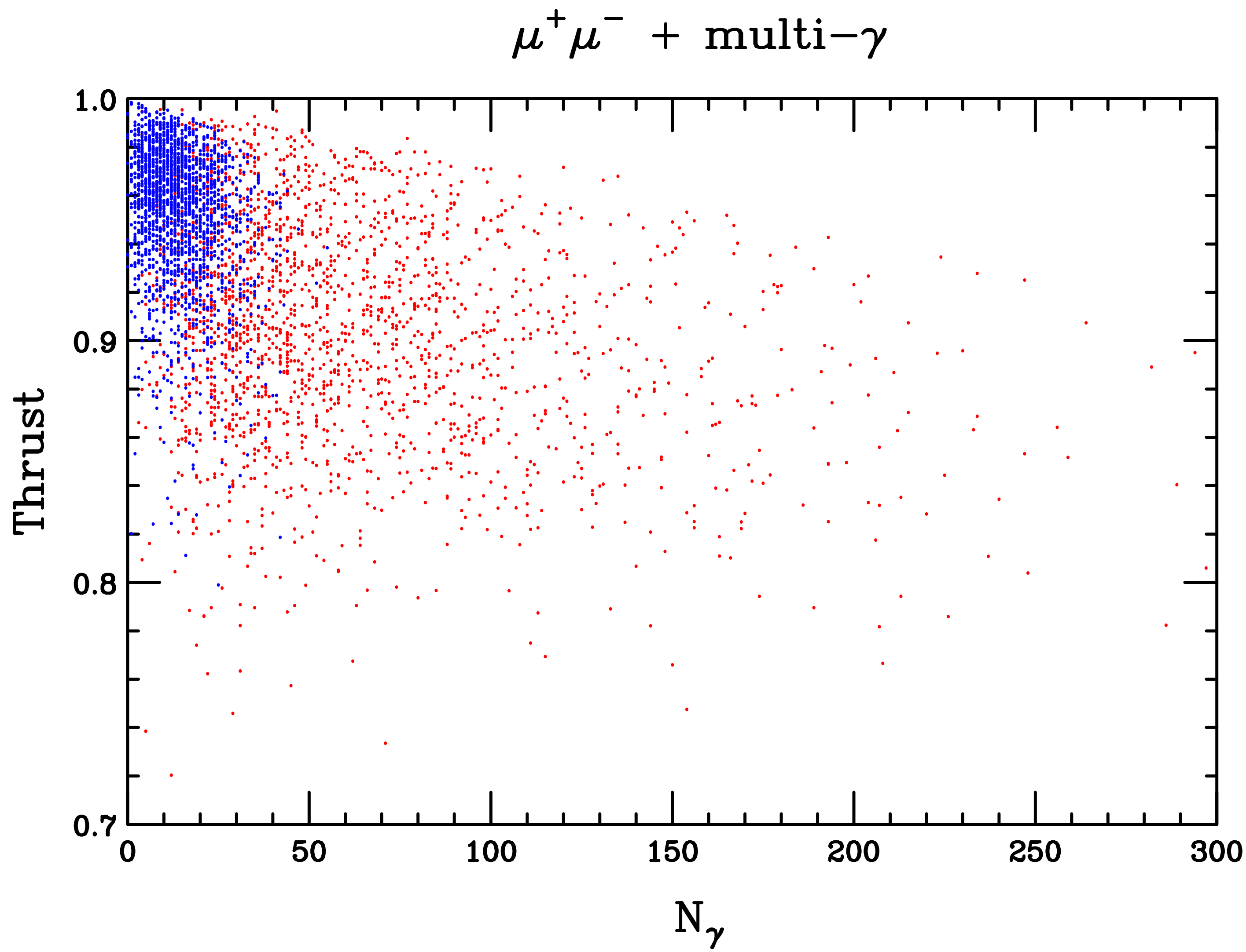
Measures event shape: non-sphericity (dipole)



$\epsilon_s = 0.78$, $\epsilon_b = 0.17$, for thrust < 0.93

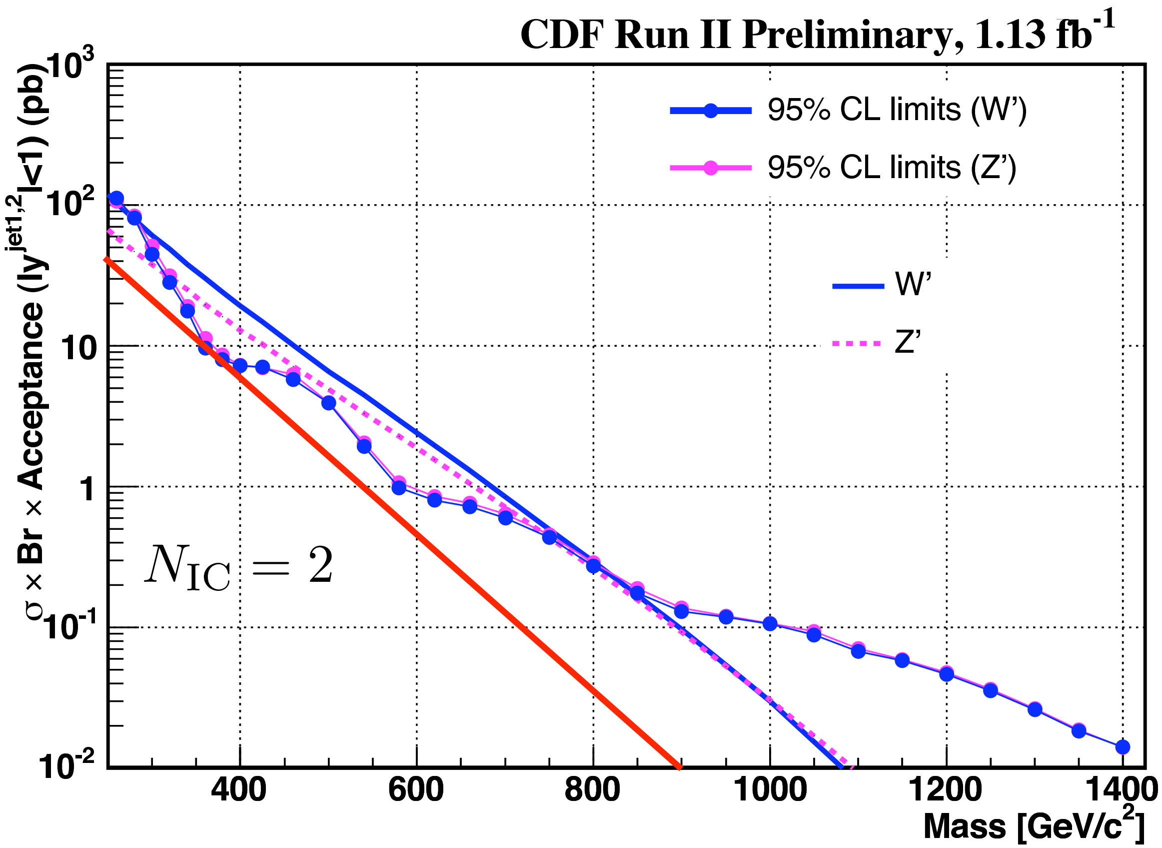
- High thrust from hard muon pairs.
- Photons bremmed off muons are nearly colinear.
- Fireball ($\sim$ spherical) from quirky strings reduces thrust.

N_γ vs. Thrust



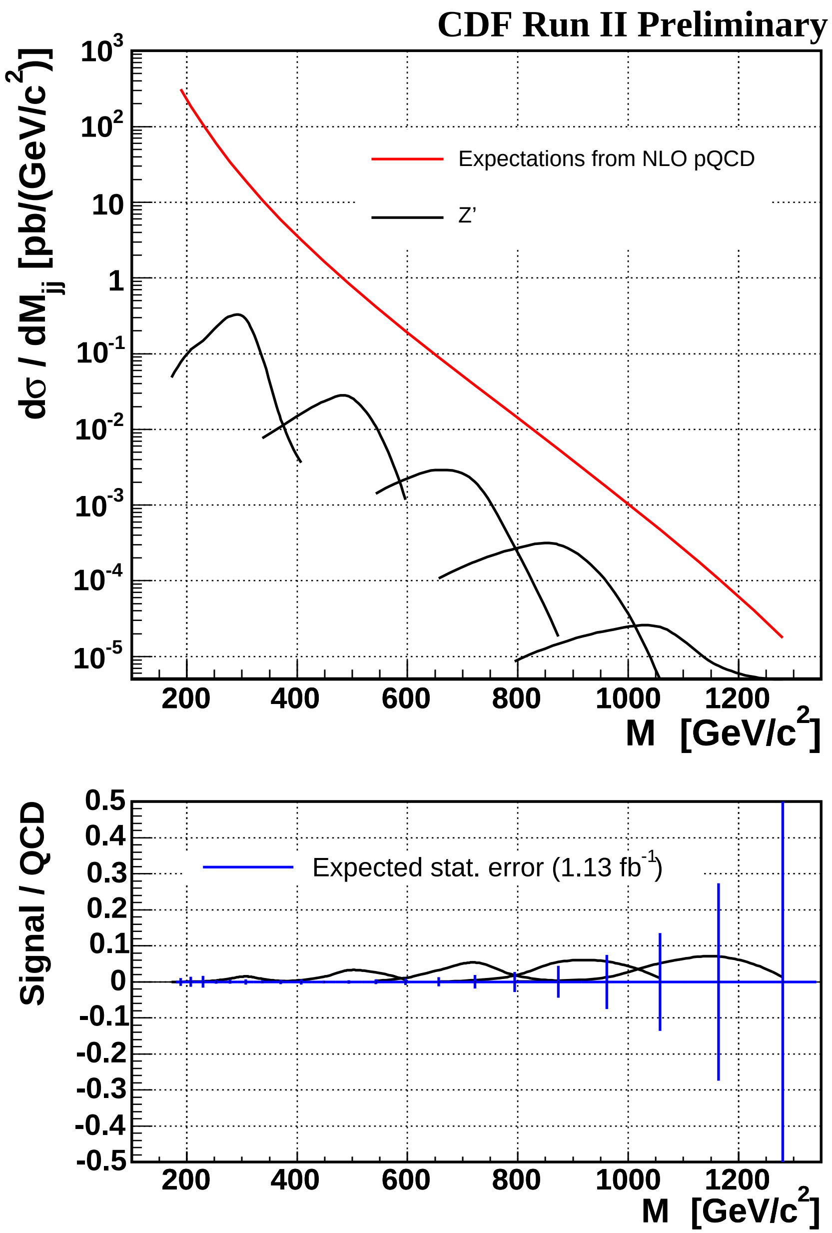
Hadronic Mode (dijet+fireball)

Dijet Resonance Search



Assumes 100% annihilation at rest

CDF Simulations for Dijet Resonances



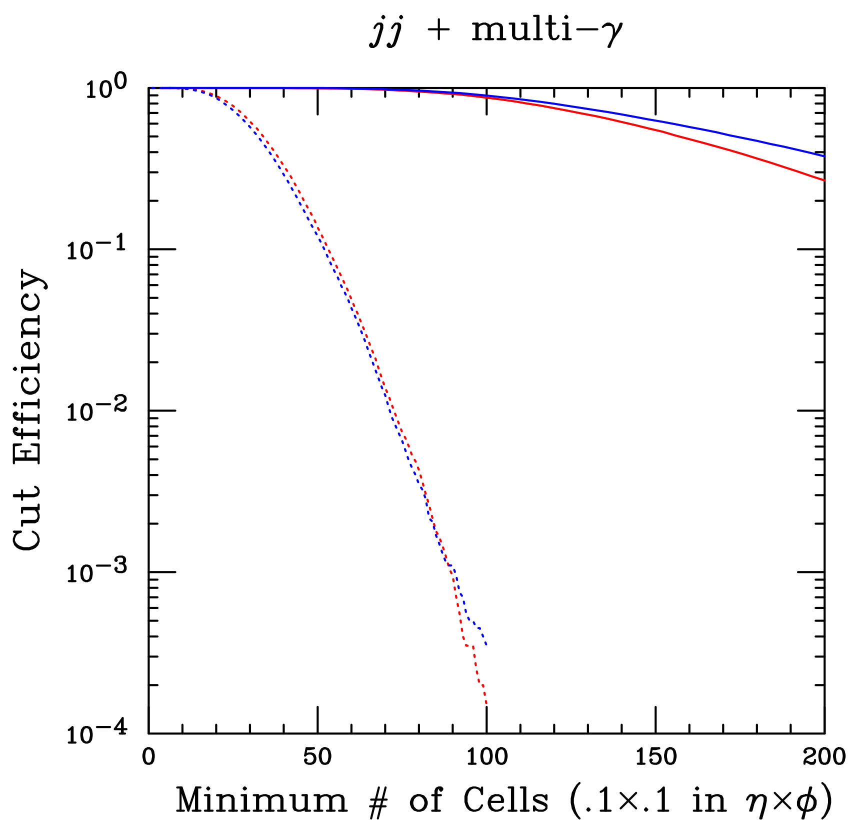
need $\epsilon_s/\epsilon_b > 10$

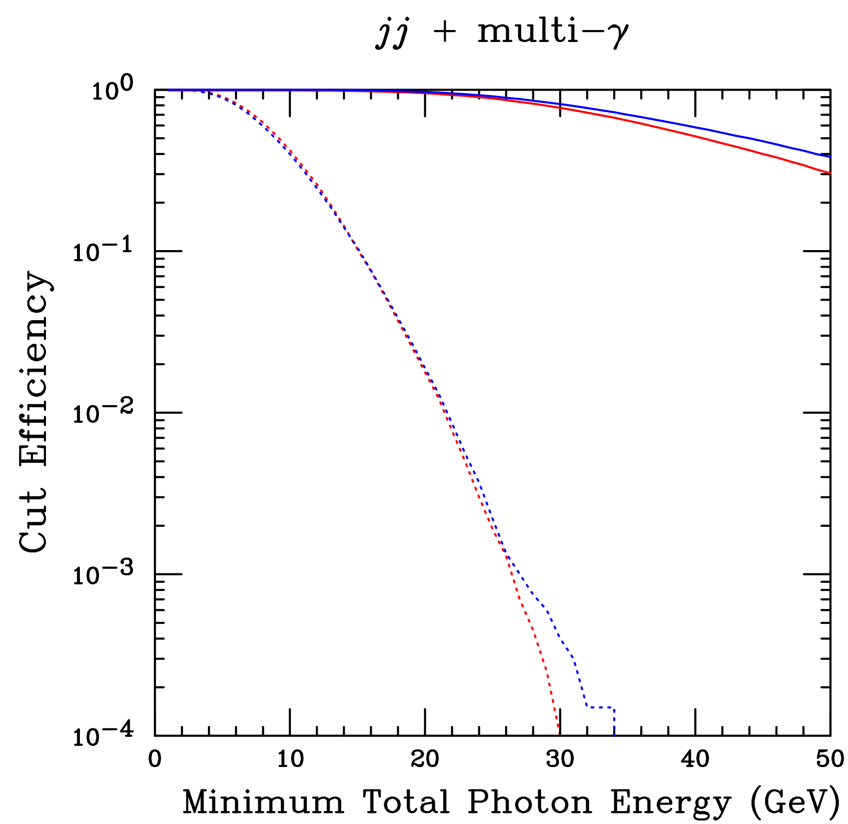
Signal and Background Efficiencies

$\sim 1\ fb^{-1}$ data

- $\sigma_B \sim 3$nb, $B \sim 3e6$ events (with efficiency)
- $\sigma_S \sim 20$pb, $S \sim 2e4$ events (without efficiency, $\epsilon \sim 0.1$?)
- $\epsilon S/\sqrt{B} \sim 1$
- additional efficiencies based on N_γ, thrust cuts etc.
  $\epsilon_S/\sqrt{\epsilon_B} \sim 0.6/\sqrt{0.008} \sim 6$

S and B Efficiencies - Tevatron





Pileup

number of events per bunch crossing

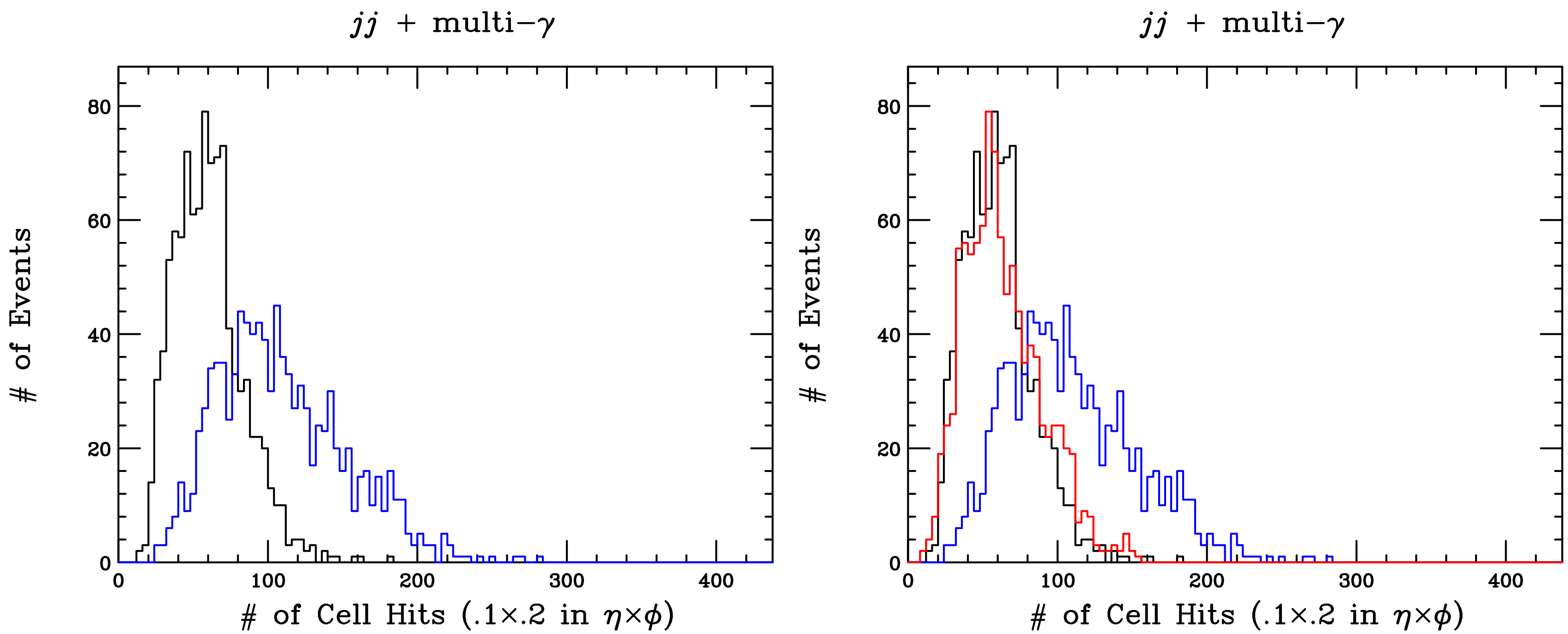
$$\mu \equiv \sigma L_b, \qquad L_b = L/\Delta t_b$$

$$\sigma_{\text{Teva}} \sim 40\text{mb}, \qquad \sigma_{\text{LHC}} \sim 60\text{mb}$$

$$L \sim 10^{32}\text{cm}^{-2}\text{s}^{-1}$$

More problematic at Tevatron than at early LHC

Effect of Pileup



- background tail at large N_γ
- One solution: Restrict rapidity further from beam $|\eta_\gamma| < 2$

Ongoing...

Summary

- Hard + Soft physics
- Fireball signature. Particle multiplicity, event shape ...
- Multiple interactions and pileup problematic, but not unbeatable