# Do Quirks Lurk at the Tevatron?

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# Motivation

Search for simple extensions of the standard model, even if they are "unmotivated"

$$Z' : \quad \underbrace{U(1)'}_{g'} \qquad \underbrace{\mathrm{Higgs}'}_{m_{Z'}}$$

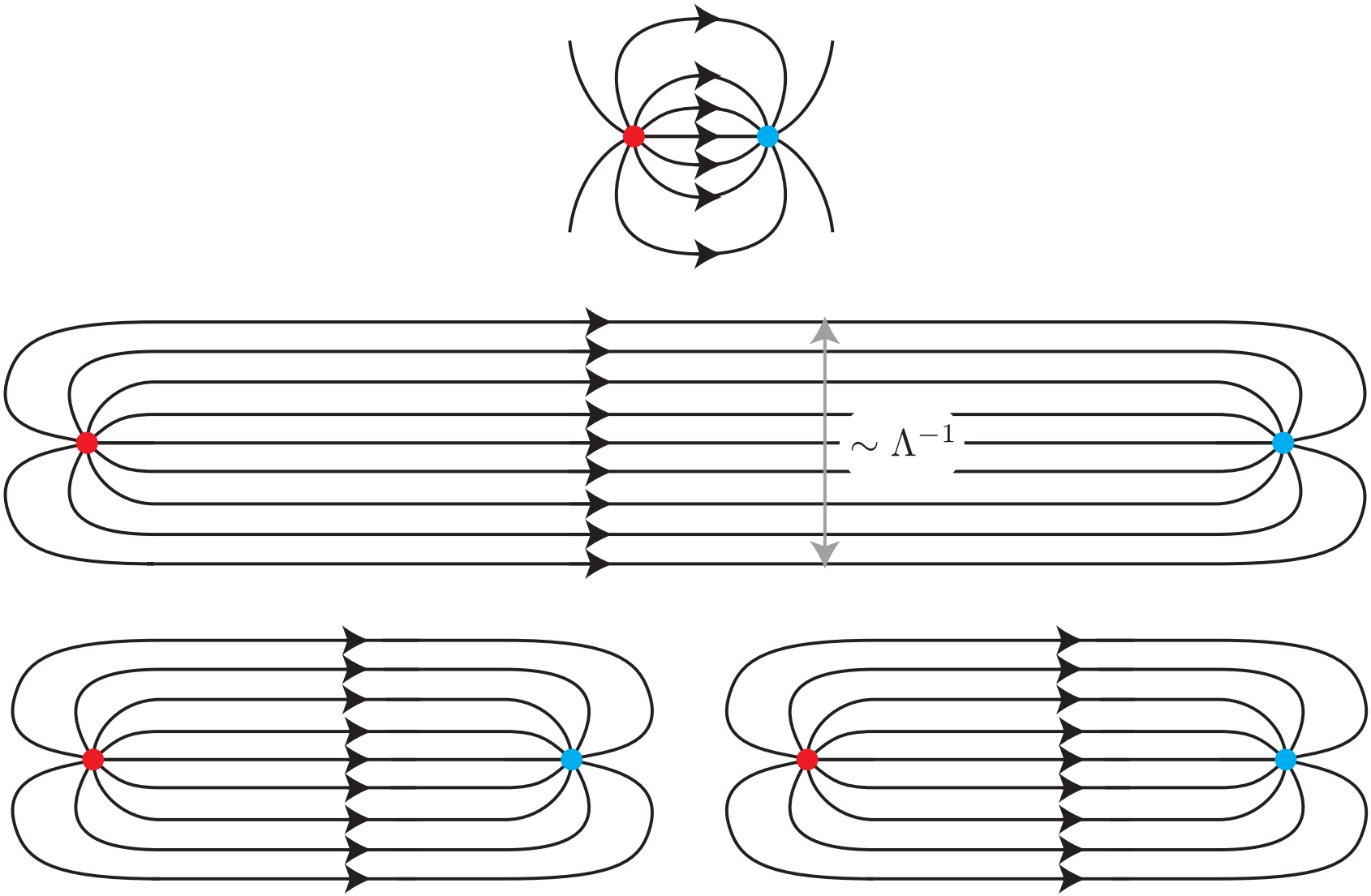
+ discrete choice of charges

Quirks: $\underbrace{SU(N)'}_{\Lambda} \qquad \underbrace{Q, \bar{Q}}_{m_Q}$

+ discrete choice of charges

This talk: $m_Q \sim 100 \text{ GeV}$

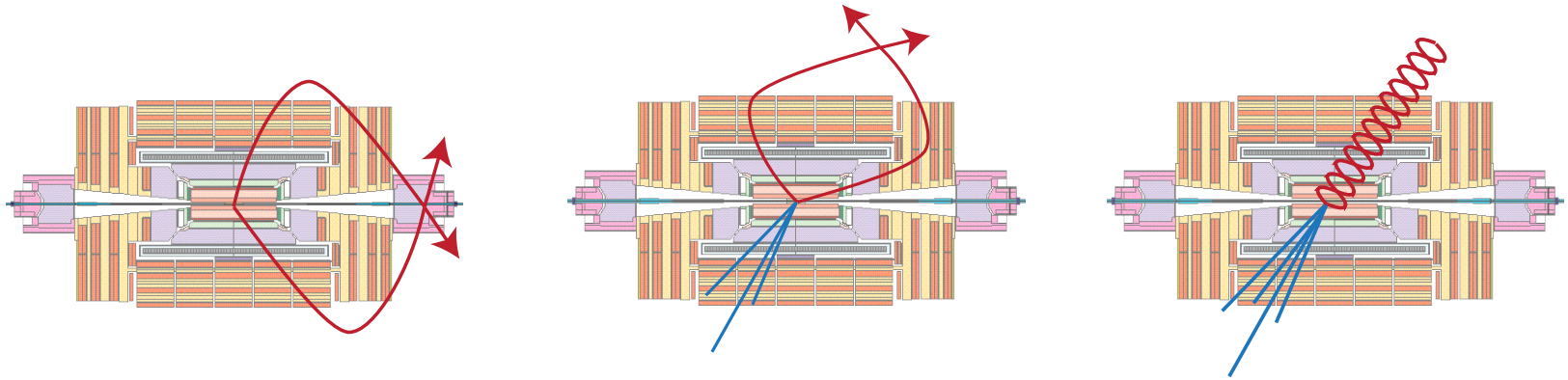
# Unbreakable Strings



# Macroscopic Strings

$$L_{\text{string}} \sim \frac{K}{\Lambda^2}$$

$$100 \text{ eV} \lesssim \Lambda \lesssim 10 \text{ keV} \Leftrightarrow \text{ mm} \lesssim L_{\text{string}} \lesssim 10 \text{ m}$$



- Quirk tracks fail to reconstruct
  $\Rightarrow$ missing $p_T$
- Look for unmatched hits corresponding to missing $p_T$

# Quirky Bound States

$$\mathrm{MeV} \lesssim \Lambda \lesssim \mathrm{GeV} \;\Leftrightarrow\; 100\ \mathrm{fm} \lesssim L_{\mathrm{string}} \lesssim 100\ \text{Å}$$

Quirks are confined into bound states

$K \sim m_Q \;\Rightarrow$ highly excited

$L_{\mathrm{string}} \sim \dfrac{K}{\Lambda^2} \gg \Lambda^{-1} \;\Rightarrow$ classical string

$J \sim 1 \;\Rightarrow$ spherical

Macroscopic superposition of quantum states
("Schrödinger cat" state)

# Hard Annihilation

- Quirks are stable
  (lightest particle charged under $SU(N)'$ )

- Quirk annihilation is a hard process,
  calculable in perturbation theory

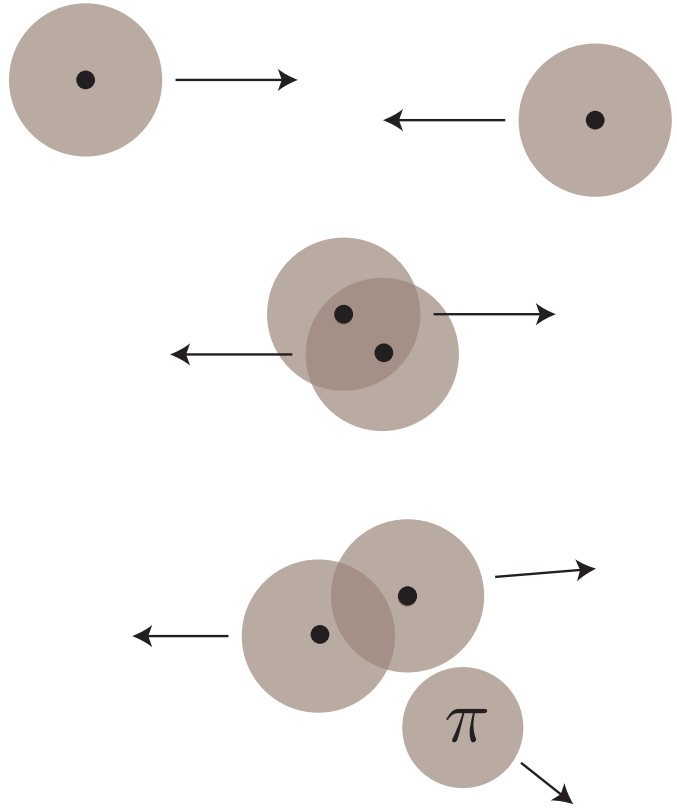
Probability for hard annihilation/classical crossing time

$$\Gamma(\bar{Q}Q \to jj) \times T = \frac{34 N \alpha_3^2 \beta}{27} \sim \frac{1}{30}$$

Assumes $J \sim 1$

# Soft Energy Loss

QCD "brown muck" interactions $\Rightarrow$ energy loss




$\Delta E \sim \mathrm{GeV}$ each crossing

# Angular Decoherence

$\Delta L \sim 1$ each crossing

$$\Rightarrow \text{Prob}(J=0) \sim \frac{1}{\sqrt{N}}$$ after $N$ crossings

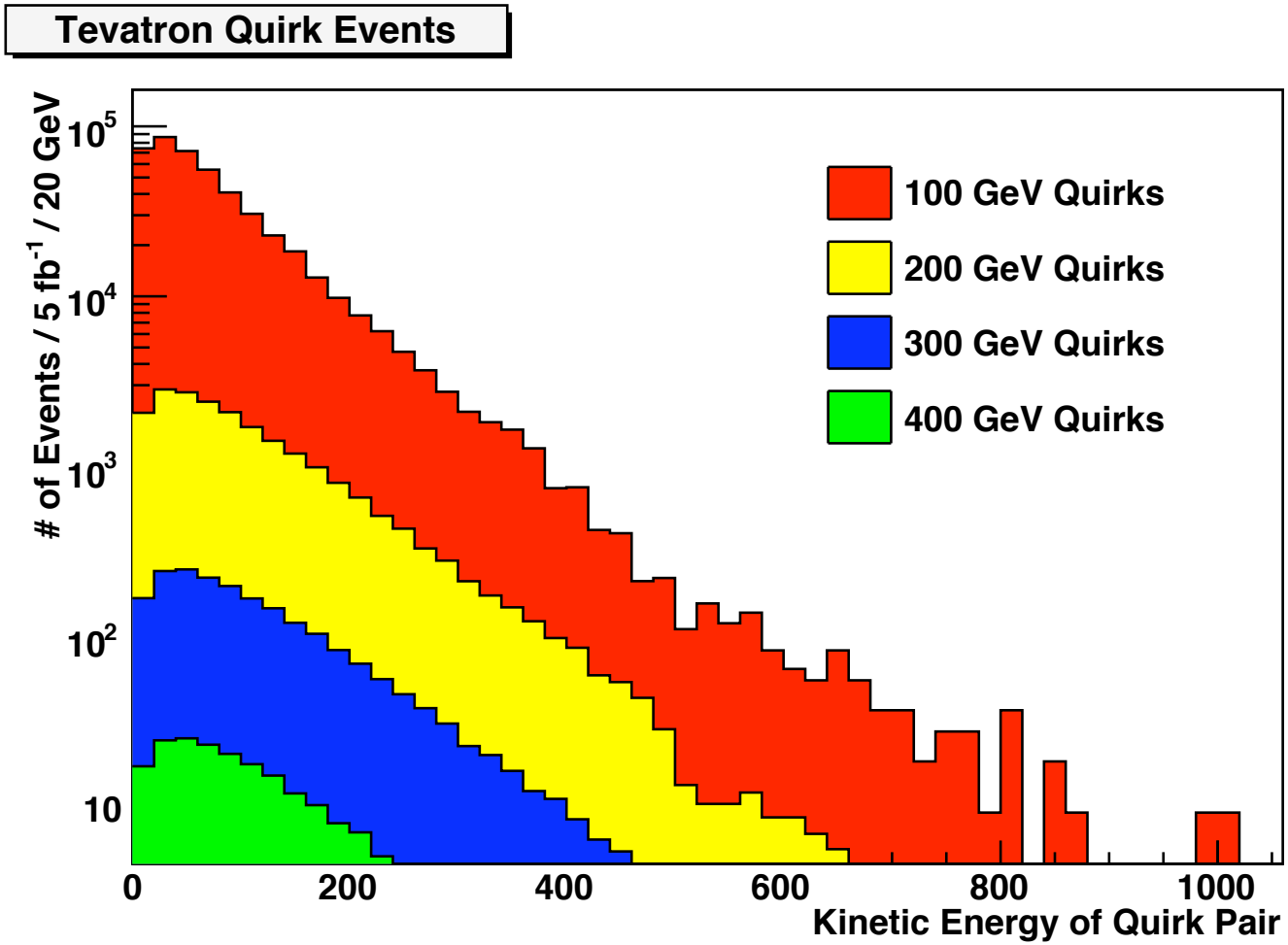
Losing all kinetic energy to soft hadrons:

$$N_{\text{cross}} \sim \frac{m_Q}{\text{GeV}} \sim 100$$

$$\text{Prob} \sim (1-P_0)\left(1-\frac{P_0}{\sqrt{2}}\right)\cdots\left(1-\frac{P_0}{\sqrt{100}}\right) \sim 50\%$$

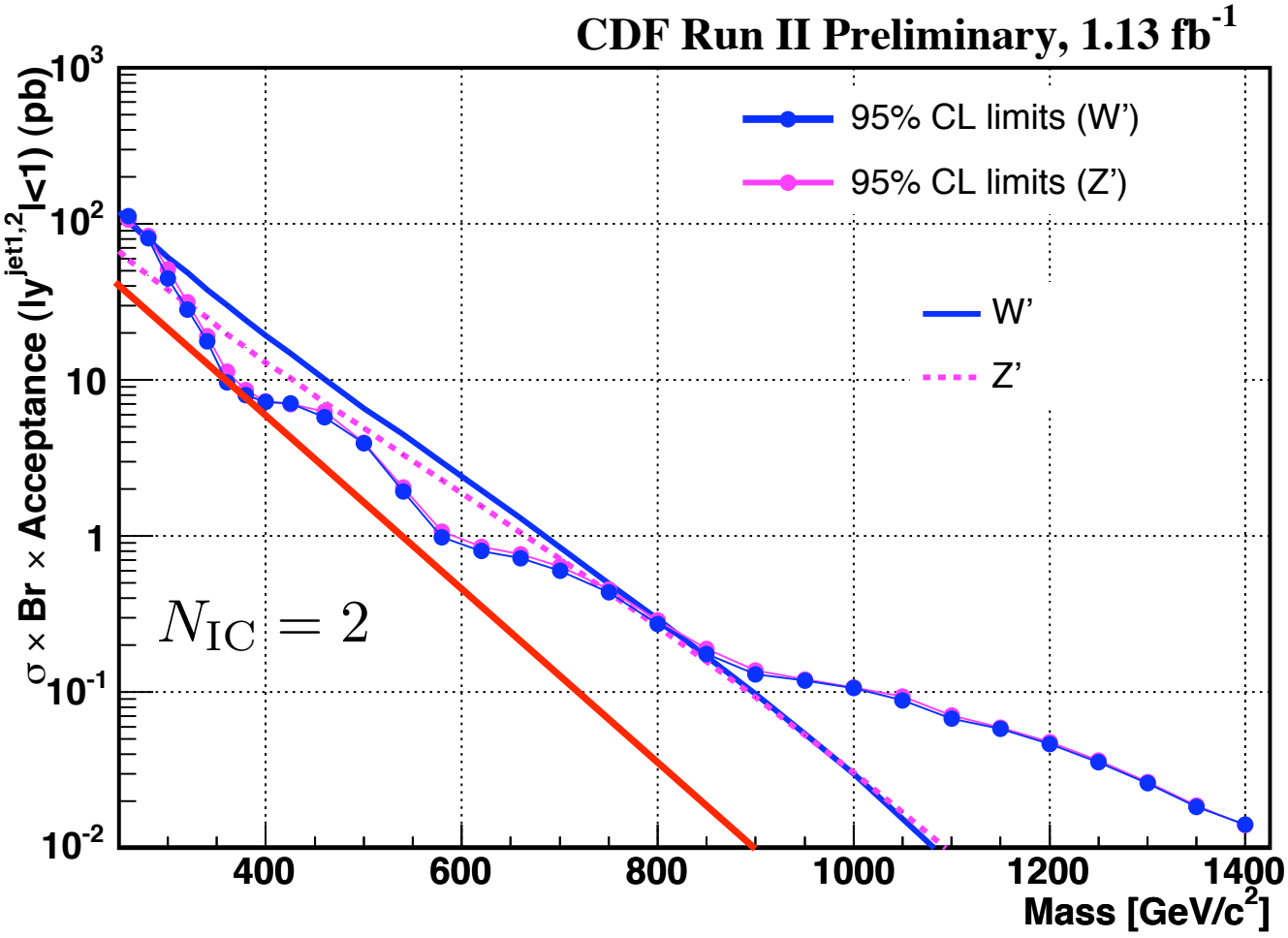
Hadronic "fireballs"

# Available Energy



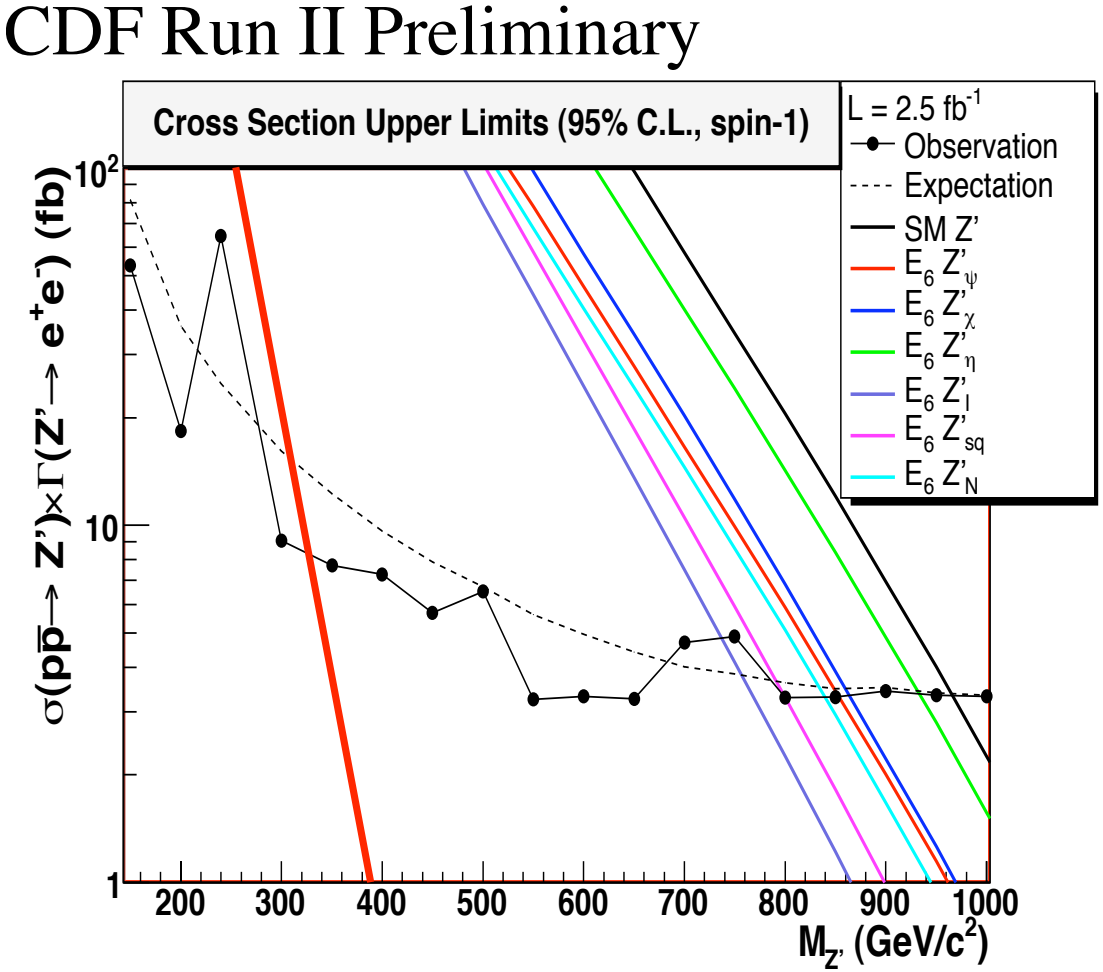

$\langle K \rangle \sim 100$ GeV independent of quirk mass

# Dijet Resonance Search




Assumes 100% annihilation at rest

# Dilepton Resonance Search




$$\mathrm{BR}(\bar{Q}Q \to e^+e^-) \sim 10^{-4} \quad (Q_{\mathrm{EM}} = \tfrac{1}{3})$$

# Searching for Fireballs?

- Trigger on hard jets/leptons
- Half of quirk events have $\sum E_\pi > 100 \text{ GeV}$
- Search for $\pi^\pm$ :

  $E_\pi > 500 \text{ MeV}, \quad |\eta_\pi| \leq 1$

- Search for $\pi^0 \to \gamma\gamma$ :

  $E_\gamma > 20 \text{ MeV}, \quad |\eta_\gamma| < 1$

- Underlying event, $|\eta_{\text{had}}| < 1$

  $\langle E_T \rangle \simeq 25 \text{ GeV}, \quad \langle N_{\text{charged}} \rangle \simeq 8$

# Conclusions?

- Searches for macroscopic strings?

- Tevatron resonance searches *nearly* rule out colorful quirks for

$$100\ \mathrm{GeV} \lesssim m_Q \lesssim 450\ \mathrm{GeV}$$

$$\mathrm{MeV} \lesssim \Lambda \lesssim \mathrm{GeV}$$

Searching for "hadronic fireball" may close this window