Light Colored Resonances at the Tevatron

(and the very early LHC?)

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Introduction

Tevatron
LHC } Hadron Colliders

Large CM energies.

Collide colored partons.

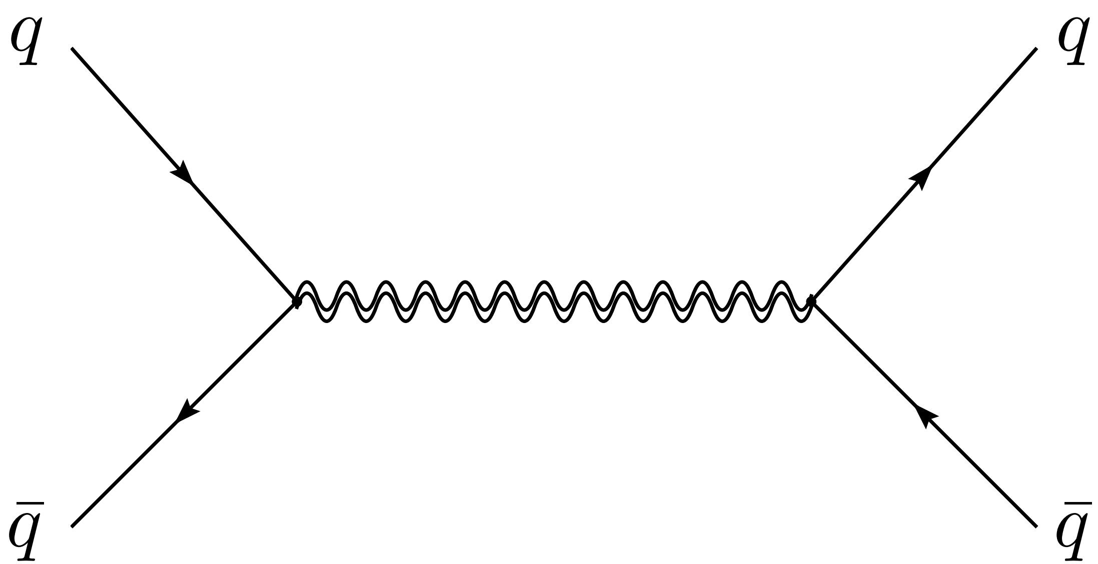
Good for producing colored resonances.

Seeing them not necessarily easy.

Better be prepared!

Consider a color-octet vector resonance:
(or "coloron")

Minimal realization:



with the coupling $g_3 \tan\theta \quad (\theta \geq \text{a few}/10)$.

Immediate virtues:

The coloron is { Flavor blind, Electroweak neutral.

$\Rightarrow$ { No FCNCs, No Conflicts w/ electroweak precision.

$\Rightarrow$ Can be very light!

Coupling to $q\bar{q}$ cannot be turned off.

$\Rightarrow$ Copious production guaranteed!

Possible Scenarios

(1) "QCD"-like scenario

(Analogy)

photon-rho mixing	gluon-coloron mixing
$SU(3)_L \times SU(3)_R \times U(1)_B \longrightarrow SU(3)_{L+R} \times U(1)_B \supset U(1)_{EM}$	$SU(3)_L \times SU(3)_R \longrightarrow SU(3)_{L+R} \equiv SU(3)_c$
$e^+e^- \to \rho$ via mixing	$q\bar{q} \to \tilde{\rho}$ via mixing
$\theta \simeq 0.06$	$\theta \simeq \frac{g_3}{e} \times 0.06 \simeq 0.2$

(2) "Two-site" scenario (e.g. KK gluon)

$$SU(3)_p \otimes SU(3)_q \longrightarrow SU(3)_{p+q} \equiv SU(3)_c$$

$\uparrow$ q

by $\Sigma : (\mathbf{3}, \bar{\mathbf{3}})$ with $\langle \Sigma \rangle \propto \mathbf{1}_{3\times 3}$.

Then,

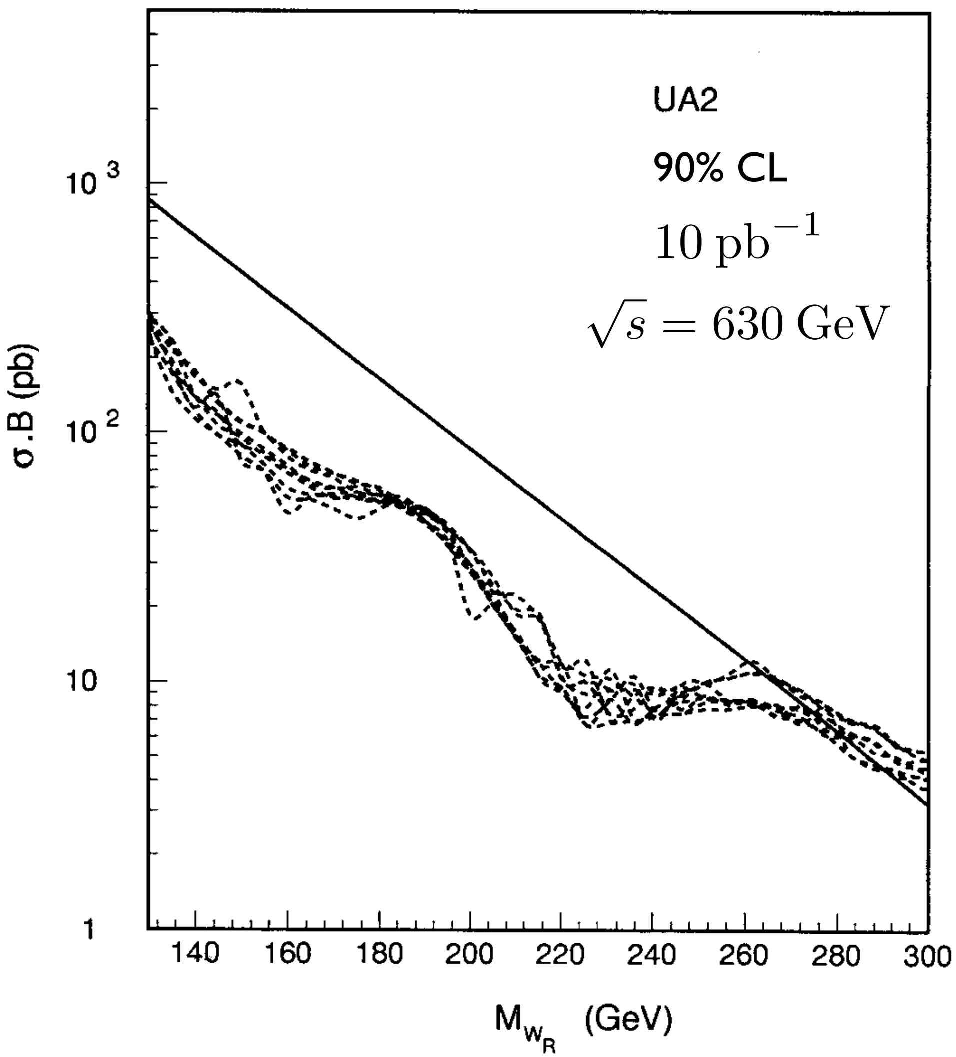
$$\frac{1}{g_3^2} = \frac{1}{g_p^2} + \frac{1}{g_q^2} \quad , \qquad \sin\theta = \frac{g_q}{\sqrt{g_p^2 + g_q^2}}$$

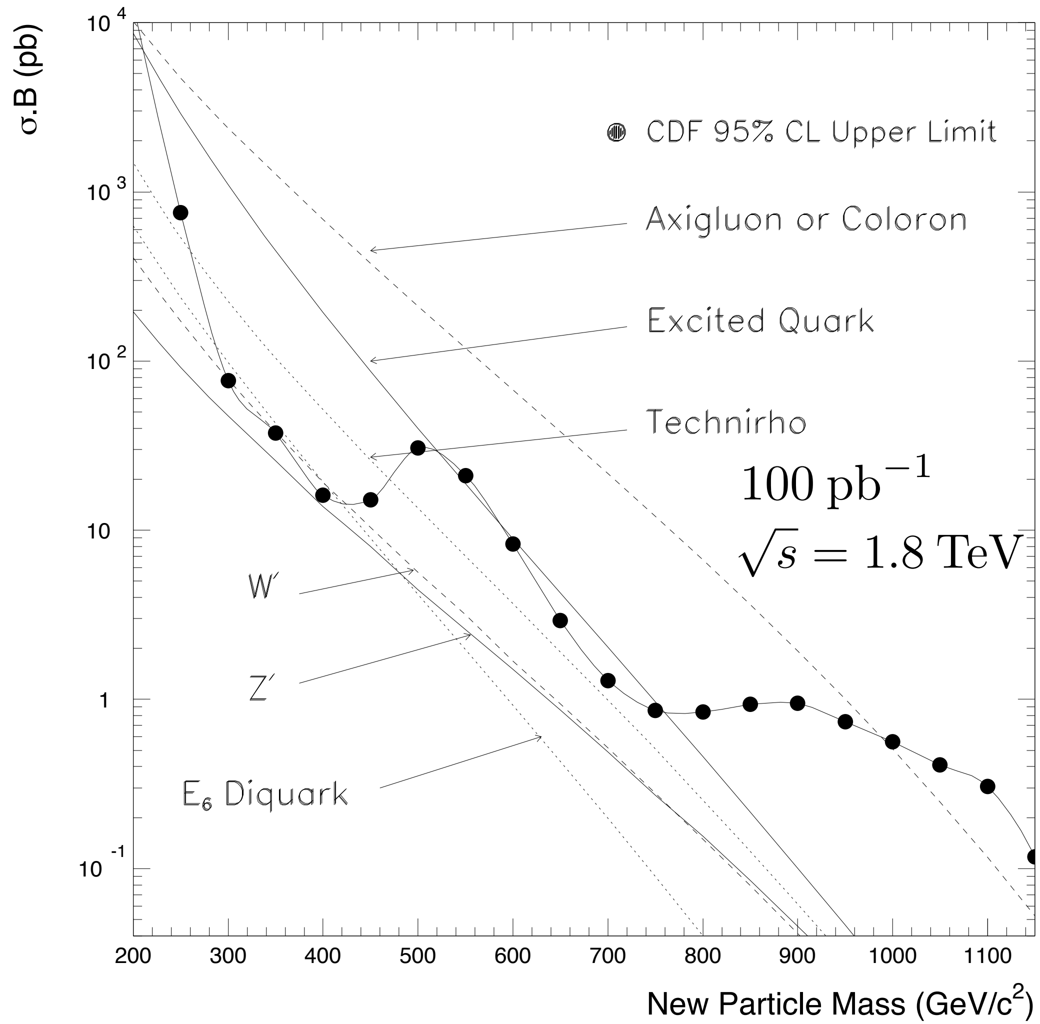
where

$$1 \lesssim g_p^2,\ g_q^2 \lesssim 16\pi^2/3 \approx 50$$

$$\Rightarrow \quad \sin\theta \gtrsim 0.2\,, \quad \cos\theta \gtrsim 0.2\,.$$

Actually, minimal coloron is ruled out:





Resonance Searches in di-jets

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But we're not too far from the bound.

$\Rightarrow$ Additional decay modes can easily save us!

What kind of new decay is "plausible"?

(1) "QCD"-like scenario

Chiral symmetry breaking $\Rightarrow$ Pions

$``\rho" \longrightarrow ``\pi\pi"$ i.e. coloron → two scalars

$(\approx 100\,\%)$

(2) "Two-site" scenario

Let it be a linear σ model:

$$\Sigma = \langle \Sigma \rangle + \sigma + i\chi + \phi^a T^a$$

Then,

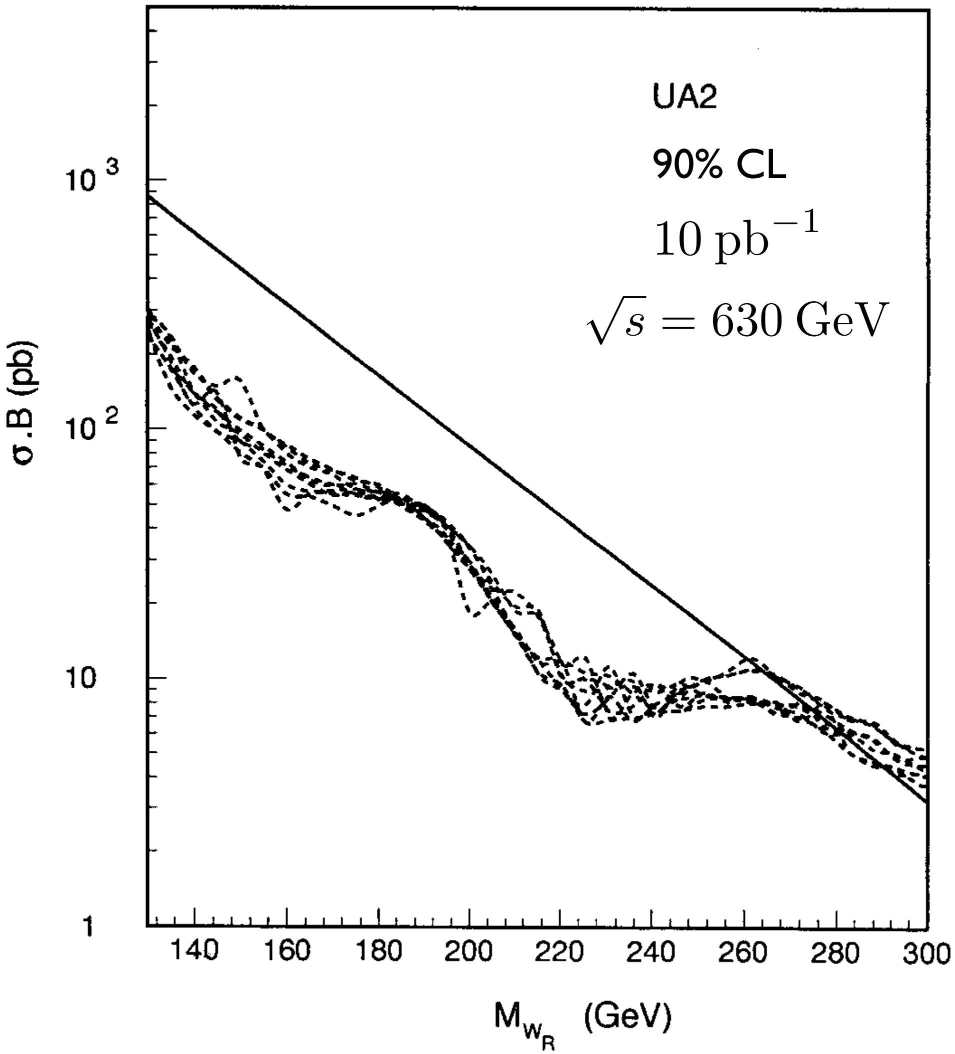
$$\mathrm{tr}[|D\Sigma|^2] \supset \tilde{\rho}^a (\phi^a \partial^\mu \chi - \chi \partial^\mu \phi^a)$$

↑ coloron   ↑ ↑ two scalars

In either case, "coloron → two scalars" is very plausible!

Now, let's see!

Data



Scenario (2)

$m_\phi = 160\ \mathrm{GeV}$
$m_\chi = 30\ \mathrm{GeV}$
$\sin\theta = 0.2$

$m_{\tilde\rho}$ [GeV]	$\sigma_{p\bar p \to \tilde\rho \to q\bar q}$ [pb]
240	16
260	7.0
280	3.2
300	1.6

CDF Run-I

Mass (GeV/c^2)	95% CL $\sigma \cdot B$ (pb)	Mass (GeV/c^2)	95% CL $\sigma \cdot B$ (pb)
200	1.3×10^4	700	1.3×10^0
250	7.6×10^2	750	8.6×10^{-1}
300	7.7×10^1	800	8.4×10^{-1}
350	3.8×10^1	850	9.3×10^{-1}
400	1.6×10^1	900	9.5×10^{-1}
450	1.5×10^1	950	7.4×10^{-1}
500	3.1×10^1	1000	5.6×10^{-1}
550	2.1×10^1	1050	4.1×10^{-1}
600	8.3×10^0	1100	3.1×10^{-1}
650	2.9×10^0	1150	1.2×10^{-1}

$m_{\tilde{\rho}}$ [GeV]	$\sigma_{p\bar{p}\to\tilde{\rho}\to q\bar{q}}$ [pb]
300	55
320	39
340	28

A "coloron window" exists!!!

How do the two scalars decay?

In scenario (1),

$$``\pi \to \gamma\gamma" \quad \text{i.e.} \quad \tilde{\pi} \to gg$$

So,

$$q\bar{q} \to \tilde{\rho} \to \tilde{\pi}\tilde{\pi} \to gggg$$

In scenario (2),

$\phi \to gg$ and $\chi \to q\bar{q}g$ at one loop.

So,

$$q\bar{q} \to \tilde{\rho} \to \phi\chi \to q\bar{q}ggg$$

SM Bkgd too overwhelming!

But the $q\bar{q} \to \tilde{\rho}$ cross-section is enormous.

$\Rightarrow$ even a small "perturbation" could make $\tilde{\rho}$ visible.

Scalar Decay Possibilities:

(a) Into electrons, muons, photons

Too obvious. Looked for already. Must be "just-so".

(b) Into b-quarks, taus

Good chances, especially b's!

In "QCD"-like scenario, there is $\tilde{\pi} \to b\bar{b}$!

Recall in QCD,

$$\pi \to \gamma\gamma \;\; = 99\,\% \qquad\qquad \pi \to e^+ e^- \gamma \;\; = 1\,\%$$

So, in scenario (1),

$$\tilde{\pi} \to b\bar{b}g \quad \textbf{with} \quad \frac{1\% \times (g_3/e)^2}{99\% + 5 \times 1\% \times (g_3/e)^2} \simeq 9\%$$

So,

$$\tilde{\rho} \to \tilde{\pi}\tilde{\pi} \to 4b + 2g \qquad \textbf{with} \quad O(1)\,\%$$!

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In scenario (2),

Add a dim-6 op:

$$\frac{c}{M^2} H d^c \Sigma^\dagger \Sigma \hat{\mathbf{Y}}_d Q \quad \supset \frac{c y_b \langle \Sigma \rangle \langle H \rangle}{M^2} b^c \phi b$$

with $c \lesssim 16\pi^2$.

For example,

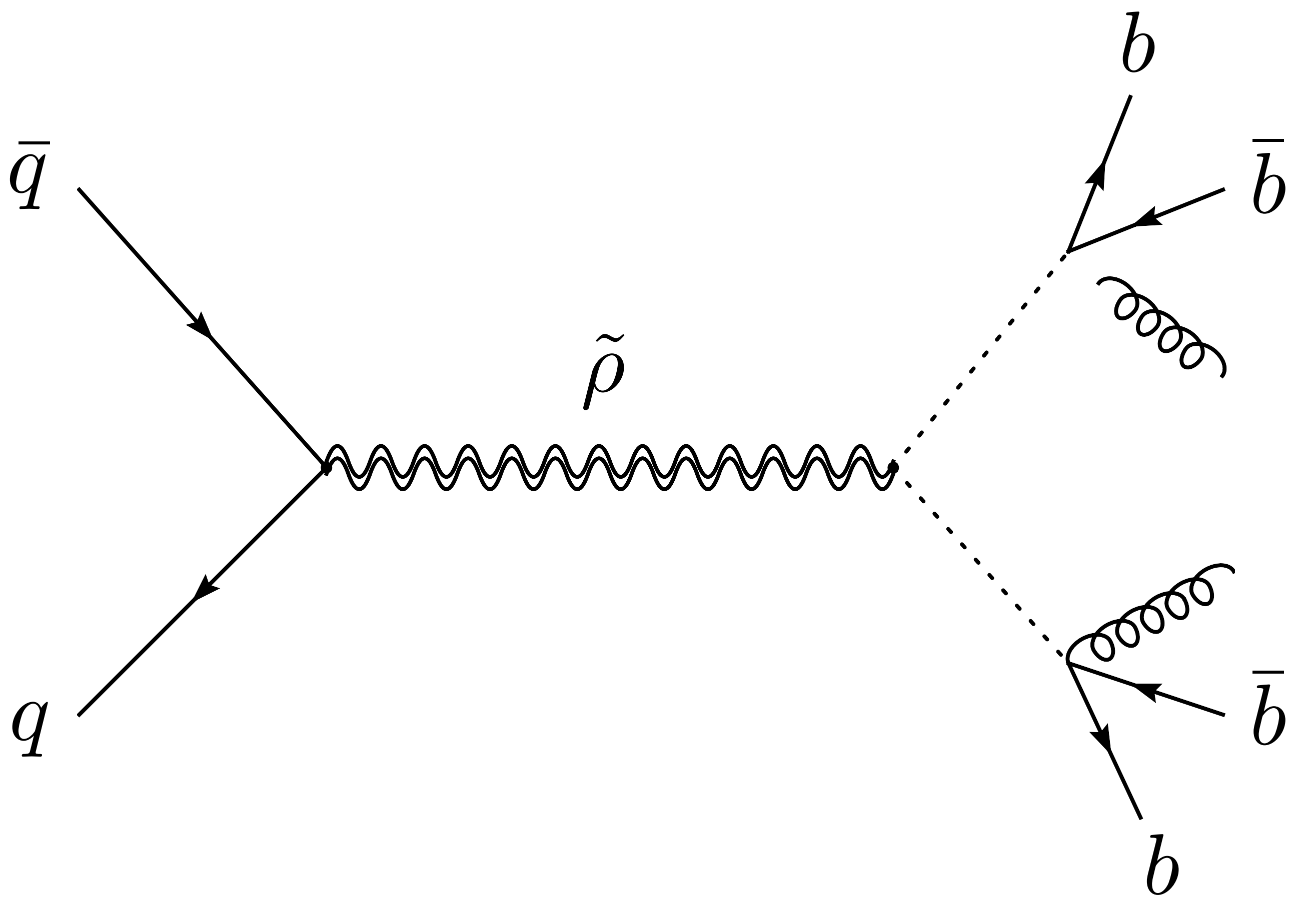
$$c = 40\,, \quad \sin\theta = 0.2\,, \quad m_\phi = 160\,\mathrm{GeV}, \quad M = \mathrm{TeV}$$

gives $\sim 0.5\,\%$ for $\phi \to b\bar{b}$.

χ still goes to $q\bar{q}g$ dominantly.

So, $\tilde{\rho} \to 4b(+g)$ is $\sim 0.1\,\%$.

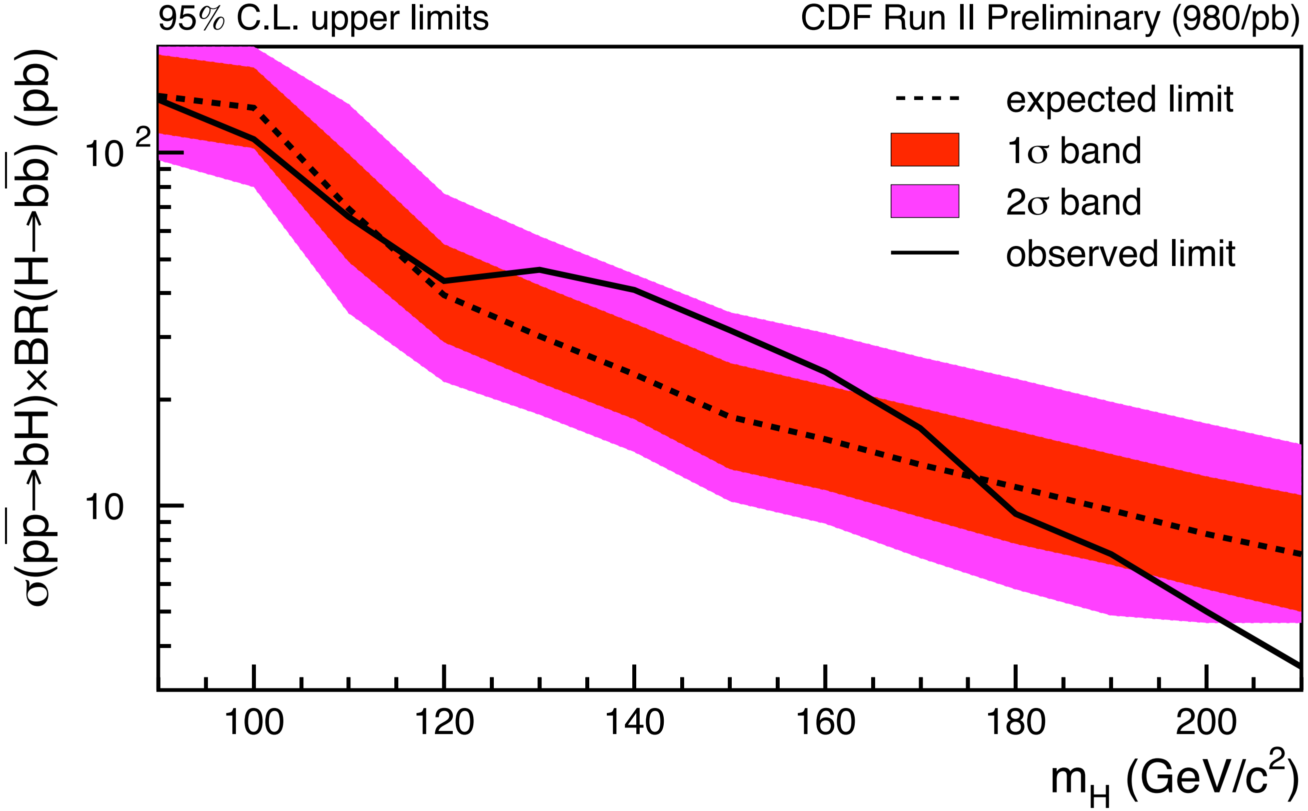
So, best chance to discover coloron is via



How about $h \to b\bar{b}$ search?

For example,

CDF: Select bh sample, i.e., 3 b-tags.



Similar to the size of our 2b cross-sec.

How about di-jet bound on $gg \to \tilde{\pi} \to jj$ or $gg \to \phi \to jj$?

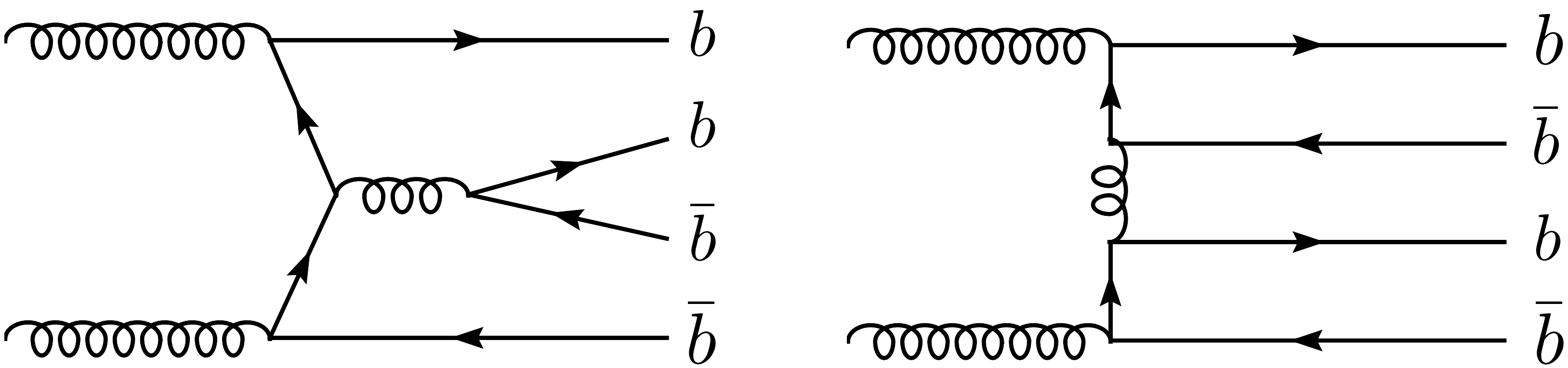
Note the couplings g-g-$\tilde{\pi}$ and g-g-ϕ are non-renormalizable.

$\Rightarrow$ Suppressed at least by $(16\pi^2)^{-2} \sim 10^{-4}$ compared to coloron of same mass.

Safe!

Quick look at discovery potential

The SM Bkgd:



etc.

Typically forward.

Dominated by small-x gluons.

No b-pairs sees a peak or edge.

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So let's try crude cuts:

- 4 b-tags
- p_T cuts: $\text{all b's} > 20\,\text{GeV}$, $\text{one b} > 50\,\text{GeV}$
- Demand the two highest-p_T b's have

$$110 < \text{inv mass}^2 < 210$$

- η cut: $-2.5 < \eta < 2.5$
- $\Delta R > 0.4$

$\Rightarrow$ SM bkgd $\approx 2\,\text{pb}$

Signal $= O(0.1)\text{-}O(1)\ \text{pb}$

Summary:

There is a "window" for a light coloron.

The coloron can naturally decay to 4 b's via 2 scalars.

Tevatron has a good chance for seeing it!