Color octets at colliders

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Heidelberg

Aspen 2/2009

Outline

MRSSM

Sgluons at LHC

Boosted tops

Colorons

MRSSM

Still no data: understand 6×6 squark mass matrix?

- flavor violation: K-$\overline{K}$ mixing, etc
- CP violation in flavor sector
- flavor-violating decays: $b \to s\gamma$
- electric dipole moments...

$\Rightarrow$ well-known problem for flavor sector

Solution via symmetries [Kribs, Poppitz, Weiner]

- start from well-known R parity [proton decay, dark matter,...]
  expand to continuous, global symmetry: $\theta^{(+1)}$ [Hall & Randall]
  avoid spontaneous breaking to break SUSY [Affleck, Dine, Seiberg, Nelson & Seiberg]
- chiral superfield $\Phi^{(+1)} = \phi^{(+1)} + \theta \cdot \chi^{(0)} + \theta\theta\ F^{(-1)}$
  vector superfield $V^{(0)} = \theta\sigma^\mu\bar{\theta}A_\mu^{(0)} - i\bar{\theta}\bar{\theta}\theta\lambda^{(+1)} + \theta\theta\bar{\theta}\bar{\theta}\ D^{(0)}/2$
  superpotential & Lagrangian $R[\int d^2\theta W^{(+2)}] = R[\mathcal{L}] = 0$
- forbidden soft-breaking terms $\phi^3, \phi^*\phi^2, \tilde{\lambda}\tilde{\lambda}$
  allowed soft-breaking terms $\phi^2, \phi^*\phi, \tilde{\lambda}\psi$
- no Majorana masses, no A, μ, δ_{LR} terms [Majorana neutrino okay]
- gluino Dirac mass via additional state [chiral superfield with sgluon]

Sgluons at LHC

Features relevant for LHC [TP & Tait]

- complex sgluon field G, G^*
- supersymmetric QCD

$$\mathcal{L} = (D_\mu G)^* \left(D^\mu G\right) + i\sqrt{2}\, g_S\, f^a_{bc}\, \bar{\tilde{g}}^b \left(G P_L + G^* P_R\right)^a \tilde{g}^c$$

  fixed g-G-G, $\tilde{g}$-$\tilde{g}$-G couplings at tree level
- allowed soft-breaking terms

$$\mathcal{L} = m_1^2\, GG^* + \frac{1}{2} m_2^2 \left(G^2 + G^{*2}\right) - \sqrt{2} g_S m_{\tilde{g}} \left(G + G^*\right) \sum_{\tilde{q}} \tilde{q}^*\, T^a \tilde{q}$$

  fixed mass and $\tilde{q}$-$\tilde{q}$-G couplings at tree level [go to mass eigenstates]
- G-g-g coupling loop-induced $\propto m_{\tilde{g}}/m_G^2$ [D5 operator]
  G-q-q coupling loop-induced $\propto m_{\tilde{g}} \delta_{qq'} m_q/m_G^2$ [D4 operator]

$\Rightarrow$ pair production, decay to top quark

Close relatives

- axigluons: strong coupling to quarks [Bagger, Schmidt, King, 1988]
- supersoft SUSY breaking: sgluon not relevant for pheno [Fox, Nelson, Weiner]
- Randall-Hall or $N = 2$ hybrid: minimal flavor violation [CDKKPZ]
- non-supersymmetric octets: mostly boosted tops these days...

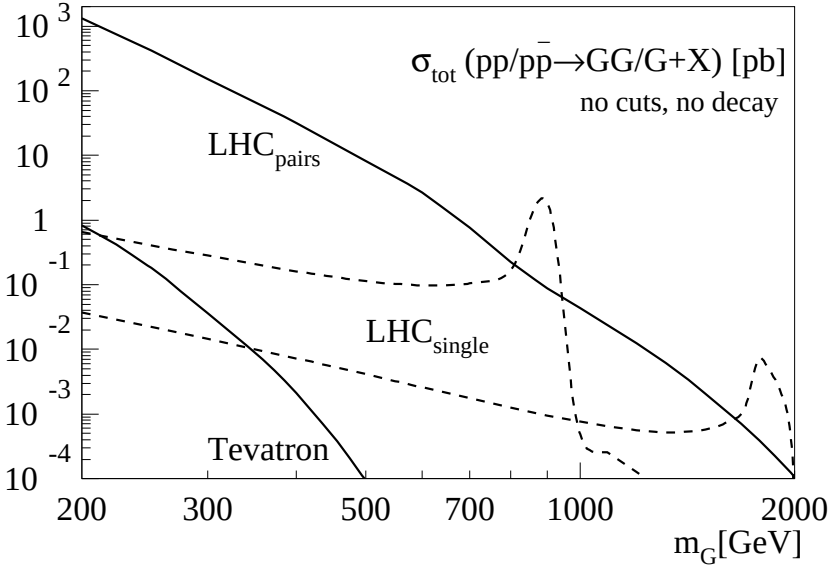
Sgluons at LHC

Production easy [TP & Tait, CDKKPZ]

- pair production via SUSY-QCD
- single production at one-loop

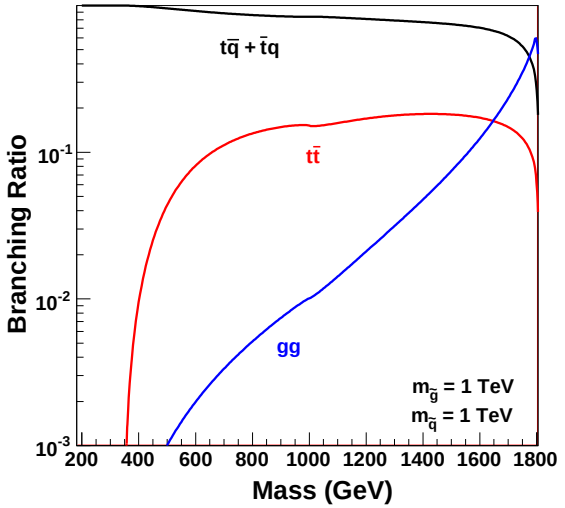
  light-flavor quarks: $g_{Gqq} = 0$
  heavy squarks: $g_{Ggg} \propto m_{\tilde{g}}/m_{\tilde{q}}^2$
  left-right squarks: g_{Ggg} reduced

$\Rightarrow$ stop pairs with new color factor



Decays with some structure

- $\Gamma(G \to gg) \propto m_{\tilde{g}}^2$
  $\Gamma(G \to t\bar{q} + \bar{t}q) \propto (m_t m_{\tilde{g}})^2$
  $G \to gg$ dominant for large m_G



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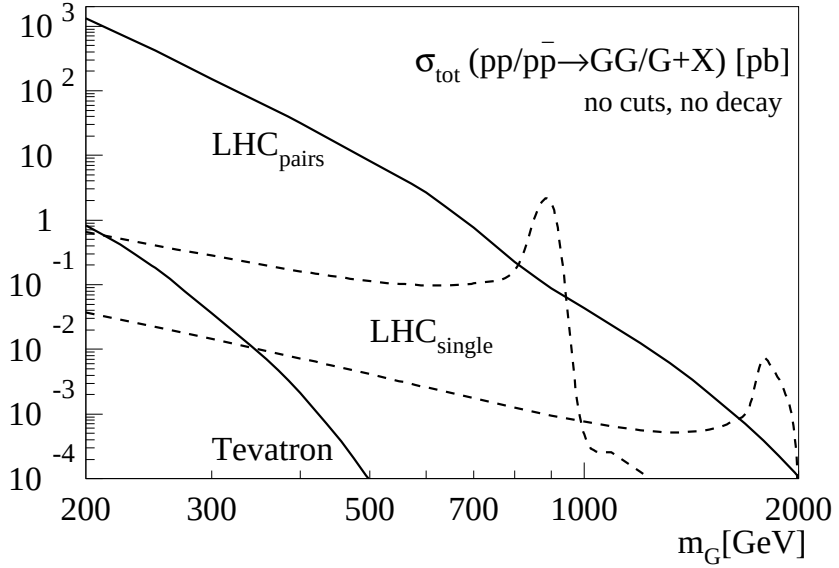

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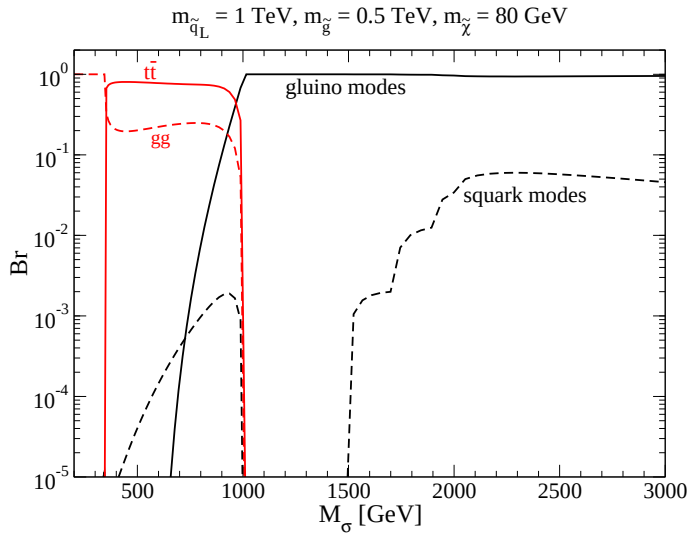
  $G \to gg$ dominant for large m_G
- SUSY decays possible [trouble with Tevtron]
  $G \to t\bar{t}$ useful with MFV
  off-shell channels $<$ one-loop channels
- single production background-burdened

$\Rightarrow$ like-sign tops game winner

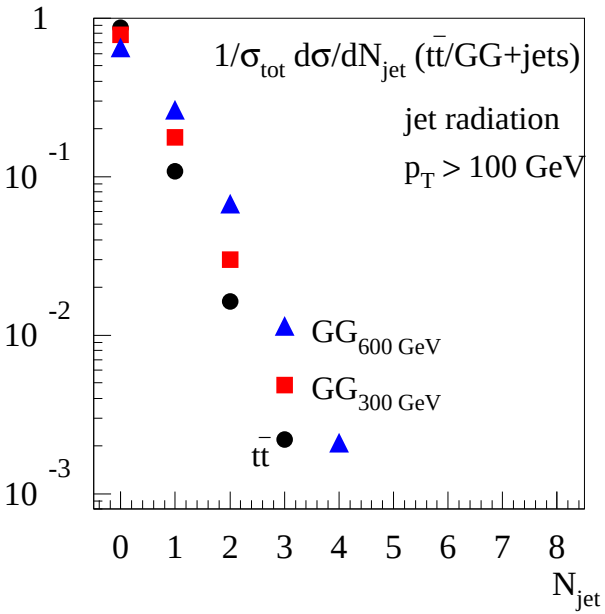


Sgluons at LHC

In general: heavy states and jets [Thank you, Aspen!!]

- sgluons: reconstruct m_{tq}
- non-boosted top momentum?
  hadronic W reconstruction?
- decay jet or QCD radiation? $[p_{T,j} < M_{\text{hard}}]$
- proper description: CKKW/MLM [in MadEvent]
- $\langle N_{\text{jet}} \rangle$ dependent on hard scale
  $\langle N_{\text{jet}} \rangle$ dependent on $p_{T,j}$

$\Rightarrow$ understood, everyone try to get it right now...



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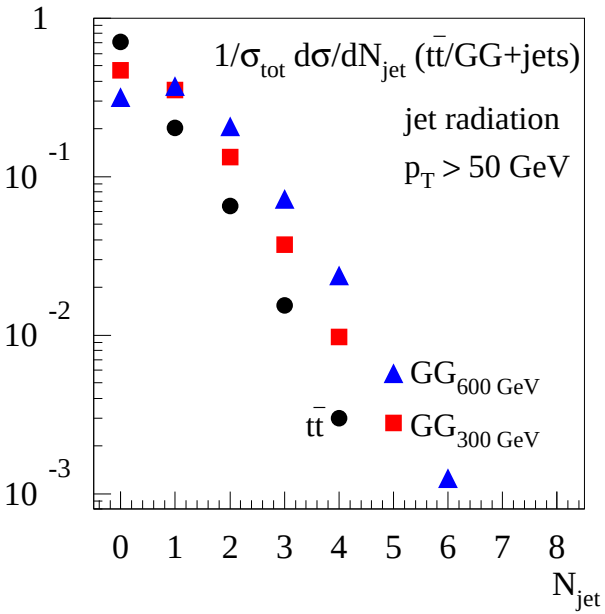

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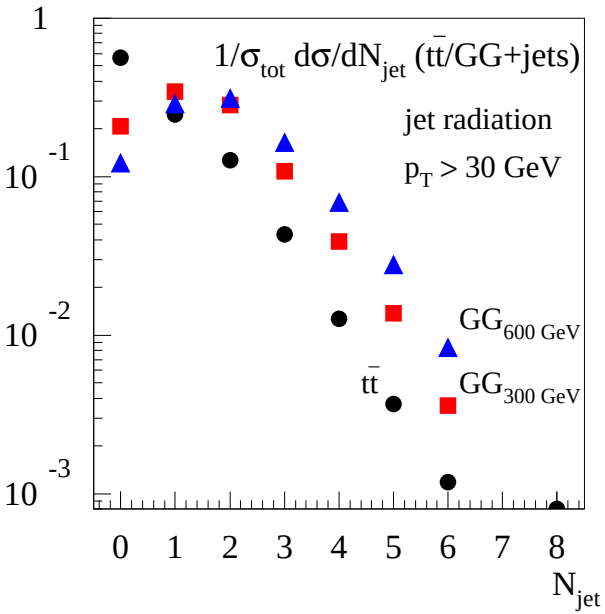

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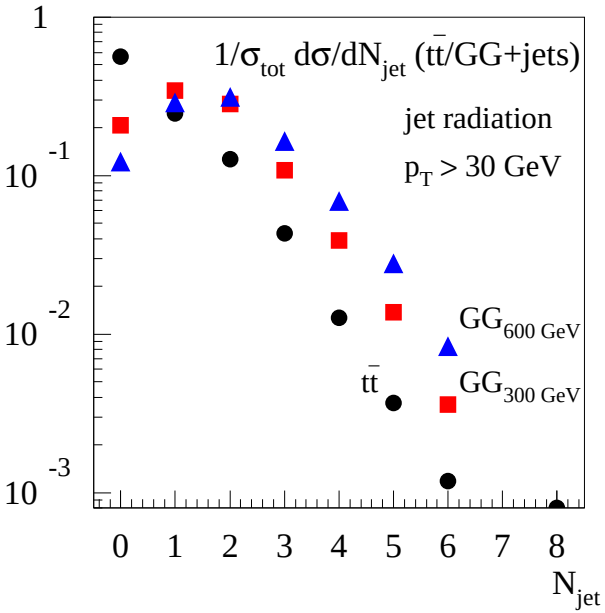
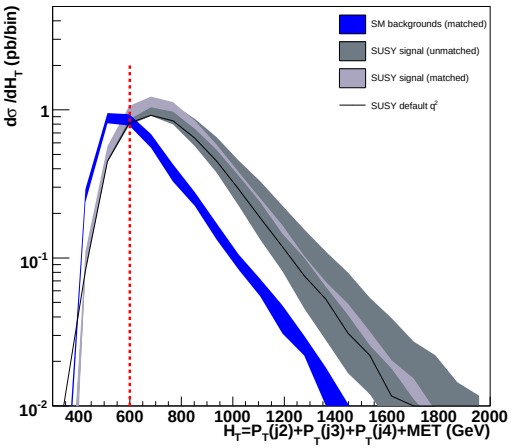


Same true for SUSY [Alwall, Maltoni, de Visscher; TP, Rainwater, Skands]

- squarks, gluinos and jets
- infamous H_T for signal/background [Mangano]
- even trigger on jet radiation?

  [Kilian, TP, Richardson; Alwall, Le, Lisanti, Wacker]

$\Rightarrow$ publicly available in Madgraph



Boosted tops

By now old story: top resonances [lots of analyses]

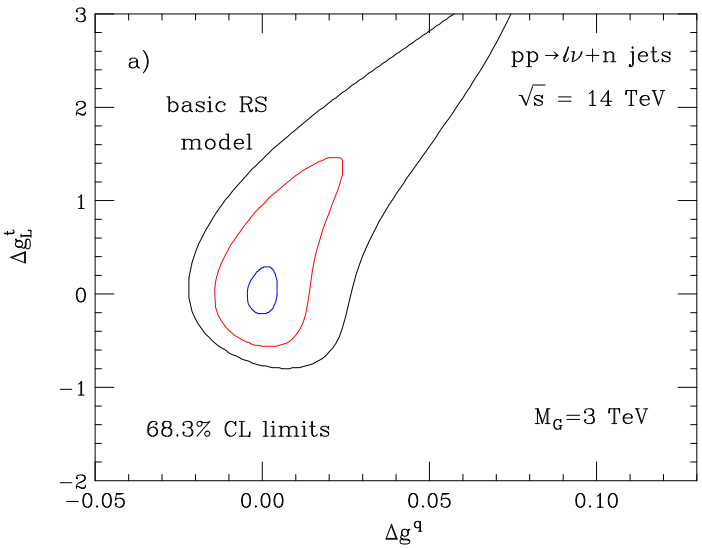
- boosted tops? tagged top jets? fat jets?
- trustworthy analyses available [Agashe, Belyaev, Krupovnickas, Perez, Virzi;...]
  avoid problems with high multiplicty
  avoid problems with jet algorithms and underlying event
  use mass constraints for W and top
  use polarization for $t_R\bar{t}_R$ signal

$\Rightarrow$ we can find them...

Coupling analysis [Baur, Orr]

- typical heavy resonance mass around 3 TeV [high luminosity better]
- define effective theory of fast tops
- relevant couplings $g^{(q)}$ and $g^{(t)}_{LR}$
- useful distributions $p_{T,t}$ and m_{tt}
- one leptonic top needed?

$\Rightarrow$ ..and determine their parameters... [Tim's talk]



Colorons at LHC

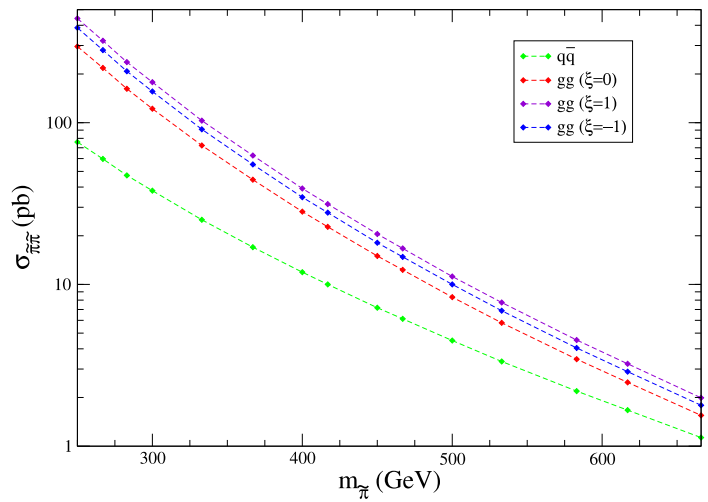
Model for resonances in massless QCD [Kilic, Okui, Sundrum; Kilic, Schumann, So]

- *s*-channel resonance: topcolor, KK gluons, string excitations,... [Simmons, 1996]
- massles QCD only
  coloron ρ mixing with gluon, color-charged, decaying to two pions
  pion π color-charged, decaying to two gluons
- effective π-ρ Lagrangian neglecting kinetic terms and QCD [many technicolor papers]

$$\begin{aligned}\mathcal{L}^{\text{HC}} \sim & -g_3\, \bar{q}\gamma^\mu \varepsilon \rho_\mu q \\ & + i\chi g_3\, \text{Tr}\left(G_{\mu\nu}\left[\rho^\mu, \rho^\nu\right]\right) + i g_3^2 \xi\, \frac{\sqrt{N_{HC}}}{2\pi m_\rho^2}\, \text{Tr}\left(\rho_\nu^{\ \mu}\left[G_\sigma^{\ \nu}, G_\mu^{\ \sigma}\right]\right) \\ & - g_{\rho\pi\pi} f^{abc} \rho_\mu^a \pi^b \partial^\mu \pi^c - \frac{3g_3^2}{16\pi^2 f_\pi}\, \text{Tr}\left[\pi G_{\mu\nu} \widetilde{G}^{\mu\nu}\right]\end{aligned}$$

- scaling $f_\pi/\Lambda,\ \varepsilon/g,\ g_{\rho\pi\pi} = \text{constant}$
  unknown $\chi = 1\ \ \xi = 0$
- allowed g-ρ-ρ, g-π-π, ρ-π-π, g-g-π...
  forbidden g-g-ρ

$\Rightarrow$ pair production $gg \to \pi\pi$



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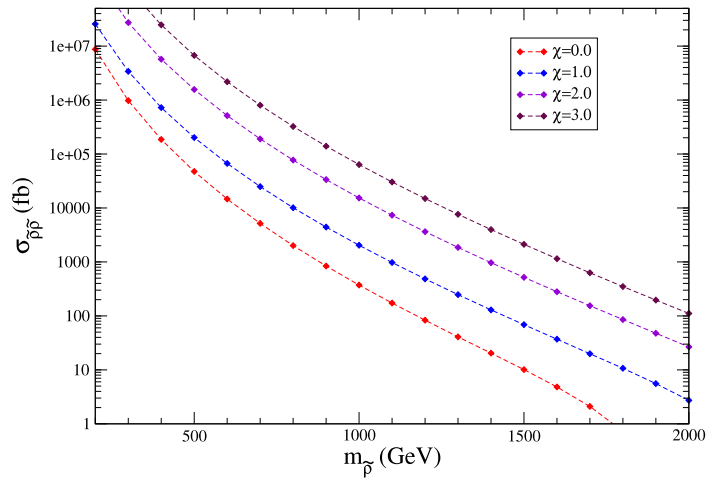
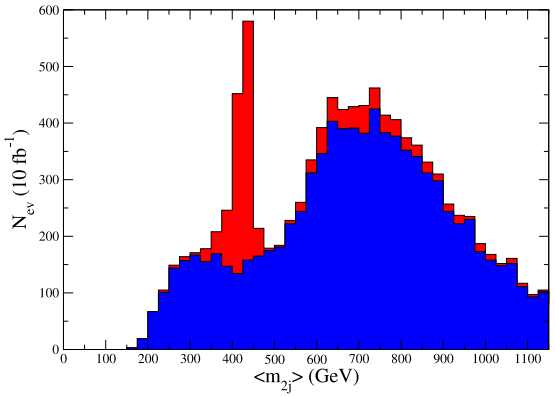


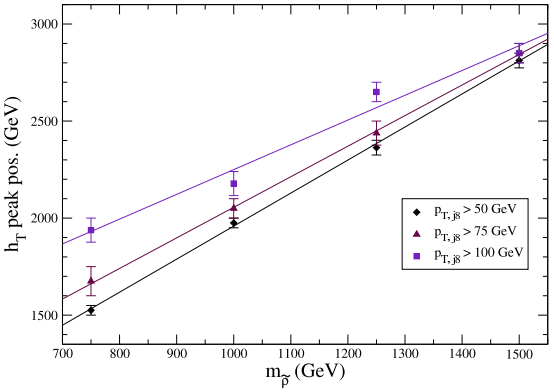
Colorons at LHC

Decays and backgrounds

- $\pi\pi \to 4$ jets
  QCD background straight-forward
  $p_{T,j} > 250$ GeV, two matching resonances
  no 4-jet resonance for coloron
- $\rho\rho \to 4\pi \to 8$ jets
  backgrounds highly non-trivial [Gleisberg & Höche]
  π mass as input from 4-jet analysis
  optimize $p_{T,j}$ cuts looking for peaked H_T
  ρ mass to $\mathcal{O}(10\%)$

$\Rightarrow$ maybe the youngsters can do all light jets...





Outlook

Color octets at LHC are fun

- many sources of top pairs
- sgluons to mixed top–jet
- colorons to light jets

$\Rightarrow$ many interesting studies for LHC searches