Searching for Multijet Resonances at the LHC

Steffen Schumann

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Institut für Theoretische Physik

Universität Heidelberg

- new vector and scalar color-octet resonances
- consider decays to light QCD jets
- template search in four- and eight-jet final states

C. Kilic, T. Okui, R. Sundrum JHEP **0807** (2008) 038
C. Kilic, S. S., M. Son JHEP **0904** (2009) 128

Introduction

- **new color-octet states – multijet resonances**
  - KK-gluons, sgluons, topgluons, axigluons [boosted tops, like-sign tops]
  - composites: technihadrons, e.g. $\rho_{\mathrm{T},8}$, $\pi_{\mathrm{T},8}$, gluinonia, ...
- **production mediated through strong interaction**

➔ large production rates at hadron colliders

➔ decays to (multi)jet final states

  - multiple or boosted tops [e.g. Agashe et al. '06, Choi et al. '08]
  - light–heavy final states [e.g. Plehn, Tait '08]
  - light jets $\rightsquigarrow$ considered here

➔ challenged by severe QCD backgrounds

  - hard to predict theoretically
  - significant theoretical uncertainties

An illustrative Model

- extend SM by vector-like fermions charged under QCD and HyperColor

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \bar{\psi}(i\not{D} - m)\psi - \frac{1}{4}H_{\mu\nu}H^{\mu\nu}$$

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  - $SU(3)_c$ adjoint vector $\tilde{\rho}_\mu$ (coloron)
  - $SU(3)_c$ adjoint scalar $\tilde{\pi}$ (hyperpion)

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- pheno. Lagrangian for interactions and SM couplings of $\tilde{\rho}_\mu$ and $\tilde{\pi}$

$$\begin{aligned}
\mathcal{L}_{\rm eff}^{\rm HC} \quad = \quad & -\frac{1}{4} G^a_{\mu\nu} G^{a\mu\nu} + \overline{q} i \gamma^\mu \left(\partial_\mu + i g_3 \left(G_\mu + \varepsilon \tilde{\rho}_\mu\right)\right) q \\
& -\frac{1}{4} \left(D_\mu \tilde{\rho}_\nu - D_\nu \tilde{\rho}_\mu\right)^a \left(D^\mu \tilde{\rho}^\nu - D^\nu \tilde{\rho}^\mu\right)^a + \frac{m^2_{\tilde{\rho}}}{2} \tilde{\rho}^a_\mu \tilde{\rho}^{a\mu} \\
& + \frac{1}{2} (D_\mu \tilde{\pi})^a (D^\mu \tilde{\pi})^a - \frac{m^2_{\tilde{\pi}}}{2} \tilde{\pi}^a \tilde{\pi}^a - g_{\tilde{\rho}\tilde{\pi}\tilde{\pi}} f^{abc} \tilde{\rho}^a_\mu \tilde{\pi}^b \partial^\mu \tilde{\pi}^c - \frac{3 g_3^2}{16 \pi^2 f_{\tilde{\pi}}} {\rm Tr}\left[\tilde{\pi} G_{\mu\nu} \widetilde{G}^{\mu\nu}\right] \\
& + i \chi g_3 {\rm Tr}\left(G_{\mu\nu} \left[\tilde{\rho}^\mu, \tilde{\rho}^\nu\right]\right) + \xi \frac{2 i \alpha_s \sqrt{N_{HC}}}{m^2_{\tilde{\rho}}} \, {\rm Tr}\left(\tilde{\rho}^\mu_\nu \left[G_\sigma^{\ \nu}, G_\mu^{\ \sigma}\right]\right)
\end{aligned}$$

A quantitative Model: scaled-up QCD

- choose $SU(3)$ as the hypercolor gauge group
- three massless ψ's$=(3,\bar{3})$ under $SU(3)_c \times SU(3)_{HC}$

➔ extract model parameters from hadronic data, i.e. $\Gamma_{\rho\to e^+e^-}$,$\Gamma_{\rho\to\pi\pi}$, f_π

$$\rightsquigarrow \varepsilon \simeq 0.2\,, \quad g_{\tilde\rho\tilde\pi\tilde\pi} \simeq 6\,, \quad \frac{m_{\tilde\pi}}{m_{\tilde\rho}} \simeq 0.3\,, \quad \frac{f_{\tilde\pi}}{\Lambda_{HC}} \simeq \frac{f_\pi}{\Lambda_{QCD}} \quad + \quad \chi = 1, \quad \xi = 0$$

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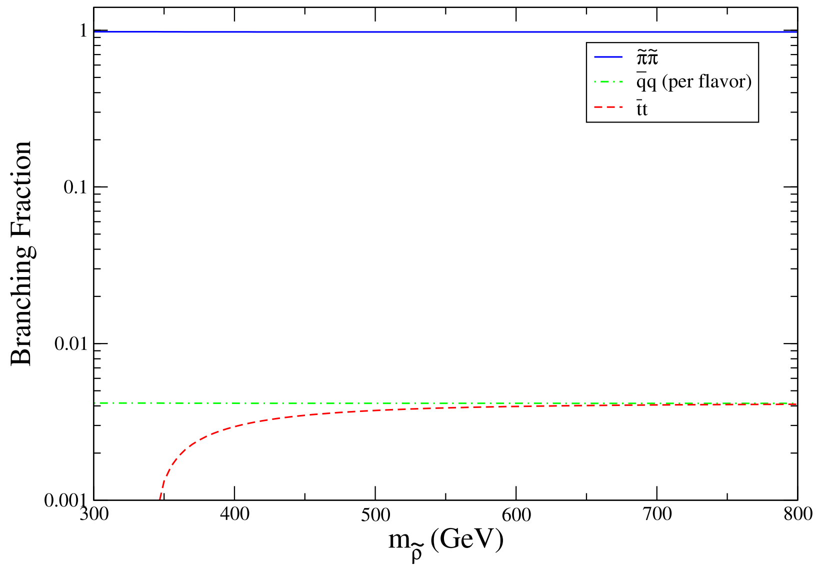
- dominant decay $\tilde\rho \to \tilde\pi\tilde\pi$
- hyperpion decay $\tilde\pi \to gg$
- Tevatron dijet bounds met
- search in 4-jet and 8-jet FS for
  $pp \to \tilde\pi\tilde\pi$ & $pp \to \tilde\rho\tilde\rho$



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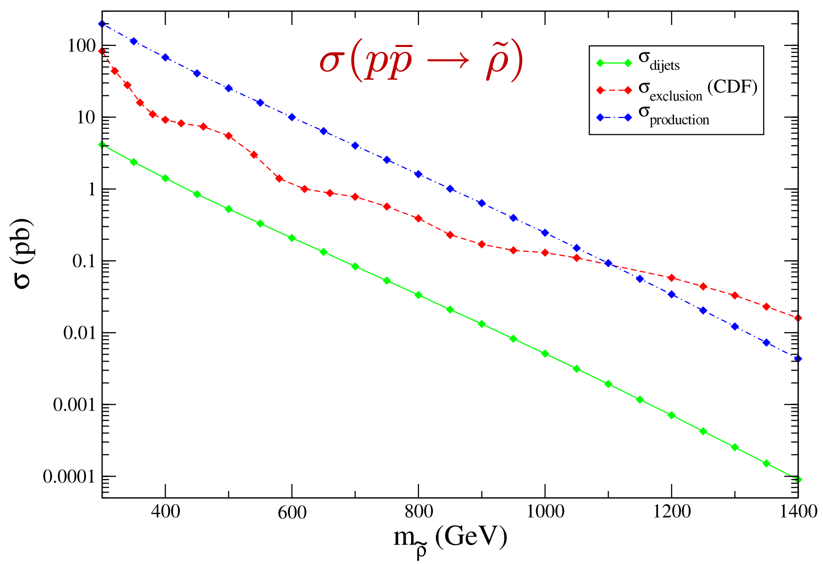


Simulation aspects

- effective Lagrangian implemented in SHERPA 1.1.1

  ⇝ Feynman rules incorporated in AMEGIC++

  ⇝ finite-width effects included

- QCD backgrounds calculated with COMIX/SHERPA [Höche, Gleisberg '08]

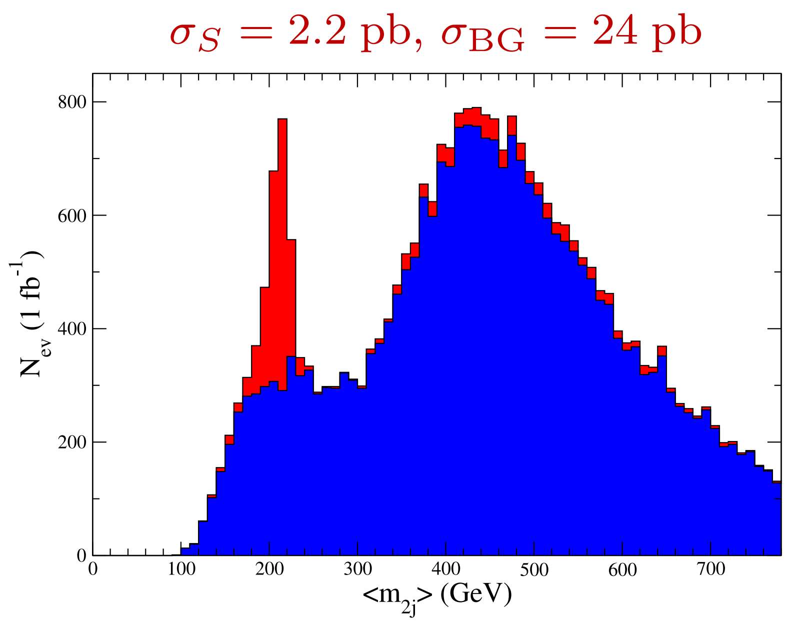
  ⇝ color-dressed Berends-Giele recursion, suitable phase-space maps

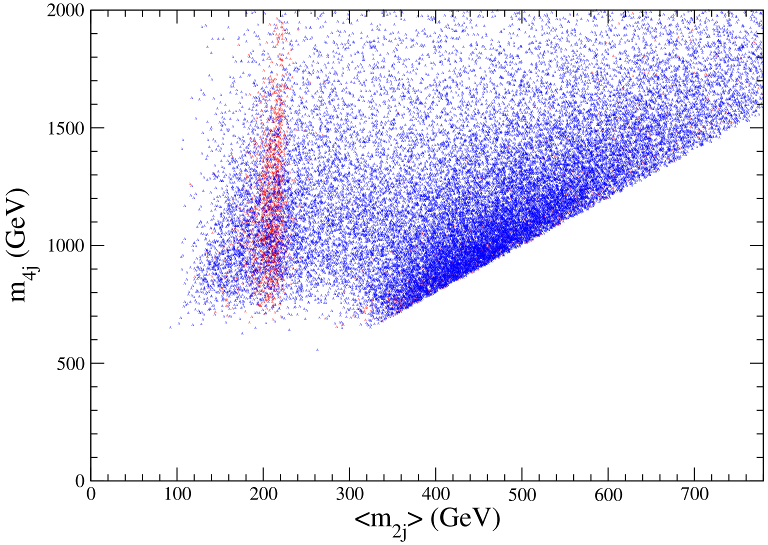
  ⇝ tree-level matrix elements for QCD 4j & 8j production

- parton showering and hadronisation accomplished by PYTHIA 6.4
- PGS used for detector simulation and jet reconstruction

Four-jet Analysis: $pp \longrightarrow \tilde{\pi}\tilde{\pi} \longrightarrow$ 4 jets

- consider hyperpion pair production for $m_{\tilde{\pi}} = 225$ GeV
- $\Delta R_{jj} > 0.5, \quad |\eta_j| < 2.0, \quad p_{T,j} > 150$ GeV
- require two jet-pairs with $\Delta m_{2j} < 50$ GeV





➔ clear excess in $\langle m_{2j} \rangle$ distribution $\chi_{sig} = 38$

➔ no significance for resonant coloron production in m_{4j}

Four-jet Analysis: $pp \longrightarrow \tilde{\pi}\tilde{\pi} \longrightarrow 4$ jets

very preliminary experimental study of corresponding sgluon signal

$\Rightarrow$ LHC-like detector smearing and reconstruction [Renaud, Zerwas GDR Terascale]

Gluon mode : Results

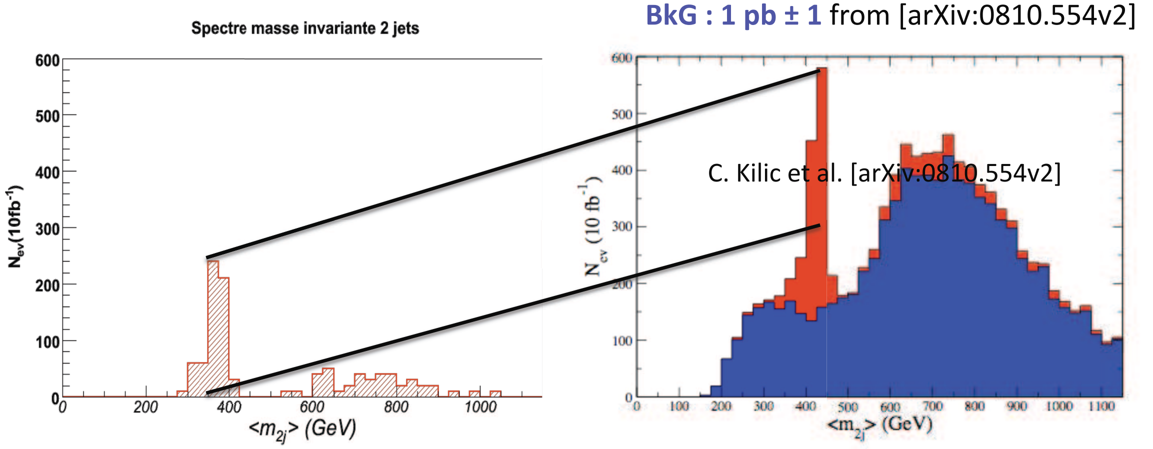
Example for m_σ = 400 GeV , X-section = 27 pb .

After cuts and pairing for 10 fb^{-1} :

Cuts (GeV)

Jet 4 Pt	**>**	**250**	(0.4 pb)
ΔR	>	0.5	(0.2 pb)
|η|	<	2	(0.2 pb)
χ^2	<	50	(0.1 pb)

BkG : 1 pb ± 1 from [arXiv:0810.554v2]



The mass peak is clearly distinguishable from the background.

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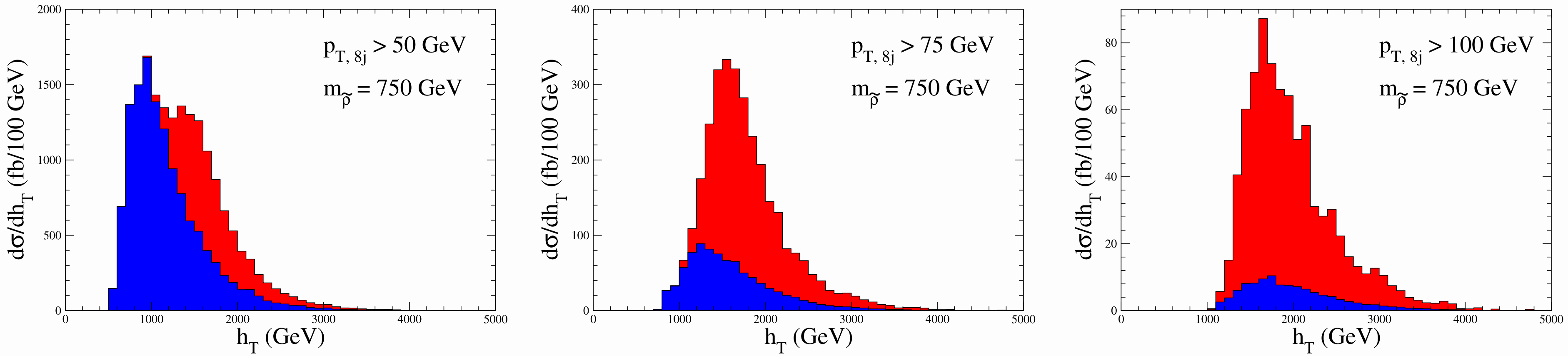
Eight-jet Analysis: $pp \longrightarrow \tilde{\rho}\tilde{\rho} \longrightarrow 4\tilde{\pi} \longrightarrow$ 8 jets (I)

- consider coloron pair production for $m_{\tilde{\rho}} = 750$ GeV
- $\Delta R_{jj} > 0.5, \quad |\eta_j| < 2.0$
- sliding $p_{T,j}$ cut

$$h_T = \sum_{i=1}^{8} p_{T,j_i}$$

parton level



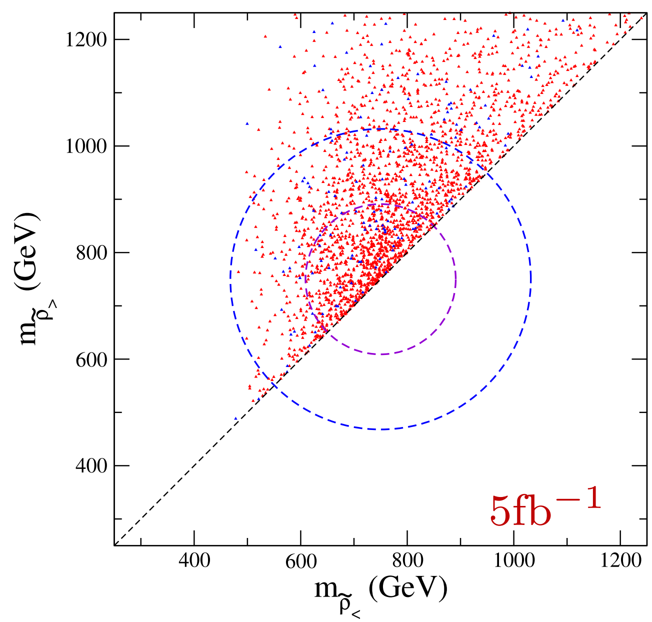
- ➔ signal can overcome QCD 8-jet background
- ➔ background rate uncertainty significant [tree-level estimate $\mathcal{O}(2-5)$]
- ➔ exploit signal's kinematic features

Eight-jet Analysis: $pp \longrightarrow \tilde{\rho}\tilde{\rho} \longrightarrow 4\tilde{\pi} \longrightarrow 8$ jets (II)

- consider coloron pair production for $m_{\tilde{\rho}} = 750$ GeV
- $\Delta R_{jj} > 0.5, \quad |\eta_j| < 2.0$
- $p_{T,j_i} > \{320, 250, 200, 160, 125, 90, 60, 40\}$ GeV

  $\rightsquigarrow$ signal efficiency $\sim 20\%$, $\sigma_S = 2.6$ pb vs. $\sigma_{BG} = 1.2$ pb
- find four jet-pairings compatible with $\tilde{\pi}$, construct $\tilde{\rho}$ candidates

$\sigma_S = 470$ fb , $\sigma_B = 29$ fb



$\rightsquigarrow$ $\tilde{\rho}$ mass taken to be weighted average

Signal:

σ_S w/	1 pairing	2 pairings	3 pairings	more pairings
(in fb)	280	100	40	50

Background:

σ_B w/	1 pairing	2 pairings	3 pairings	more pairings
(in fb)	17	6.8	2.0	2.6

Conclusions

- many new physics scenarios predict new color-octet states
- large production rates at hadron colliders
- decays to multijet final states

  $\rightsquigarrow$ tops (many, SS, OS, boosted)

  $\rightsquigarrow$ many light jets

➔ LHC has strong discovery potential for a broad mass range

➔ theoretical tools available

- easy implementations of new physics ideas
- sophisticated BG simulations: multi-parton MEs, ME/PS merging

➔ experimental (realistic) studies needed (multijets, boosted tops)