The four-jet events with accessible integrated luminosity and good control of QCD background

Xiao-ping Wang
Peking university
Advisor S.H. Zhu

August 14, 2012

We suppose G_1 and G_2 are the field strength of $SU(3)_1$ and $SU(3)_2$, so we can write down the Lagrangian for the colored vector:

$$-\frac{1}{4}G_{1\mu\nu}G_1^{\mu\nu} - \frac{1}{4}G_{2\mu\nu}G_2^{\mu\nu} + \mathrm{Tr}\left[(D_\mu\Phi)^\dagger D^\mu\Phi\right]$$

And the covariant derivation of Φ which representation is $(3,\overline{3})$.

$$D_\mu\Phi = \partial_\mu\Phi - \mathrm{ig}_1 G^a_{1\mu} t^a \Phi + \mathrm{ig}_2 \Phi \mathrm{G}^a_{2\mu} t^a$$

Where g_i is the couplings strength of the SU(3) gauge group. We suppose there is spontaneous breaking of the field Φ .

There are two mass eigenstates of the SU(3) gauge group, so there is a mixing matrix of G_1 and G_2:

$$\begin{pmatrix} G_1 \\ G_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_g & -\sin\theta_g \\ \sin\theta_g & \cos\theta_g \end{pmatrix} \begin{pmatrix} Z_c \\ G \end{pmatrix}$$

Where:

$$\sin\theta_g = -g_2/\sqrt{g_1^2 + g_2^2}$$

If Φ gets vev:

$$\langle \Phi \rangle = 1\,/\sqrt{6}\, v_\phi I$$

We can get the mass of two mass eigenstates, while we all know the mass of gluon is zero, the other one is a massive color octet vector which is named Z_C. It's mass is:

$$m_{Z_c}^2 = \left(g_1^2 + g_2^2\right) v_\phi^2 / 6.$$

After mixing, we can get the relationship between g_s , g_1 and g_2:

$$g_s = g_1 g_2 / \sqrt{g_1^2 + g_2^2}$$

Finally, we can get the interaction between Z_C and gluon :

$$\frac{1}{2}g_s^2 f^{\mathrm{abc}} f^{\mathrm{ade}} Z_C^{\mu\mathrm{b}} \left[G^{\nu\mathrm{d}} \left(Z^c_{\mathrm{C}\nu} G^e_\mu + G^c_\nu Z^e_{\mathrm{C}\mu}\right) + Z^e_{\mathrm{C}\nu} G^{\nu\mathrm{c}} G^d_\mu\right]$$
$$+g_s f^{\mathrm{abc}} Z^a_{\mathrm{C}\mu} \left[\left(\partial^\mu Z_C^{\nu\mathrm{b}} - \partial^\nu Z_C^{\mu\mathrm{b}}\right) G^c_\nu - Z^b_{\mathrm{C}\nu} \partial^\mu G^{\nu\mathrm{c}}\right]$$

Same as the result of SM, quarks also can get charge under $SU(3)_1$and $SU(3)_2$, so we can give the effective lagrangian of the interaction between Z_C and quarks:

$$\Delta\mathcal{L}_q = \beta g_s Z_C^{\mu a} J_\mu^{5a}$$

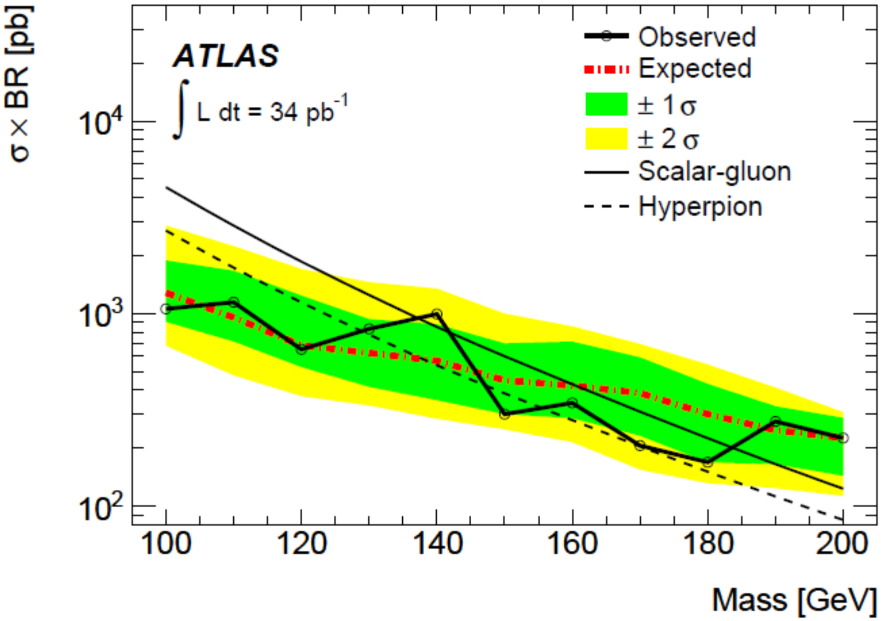
Where β is a suppression factor. $J^{5a}{}_{\mu}$ is the axial vector color current:

$$J_\mu^{5a} = \sum_f \bar{q}_f \gamma_\mu \gamma_5 \frac{\lambda^a}{2} q_f$$

Where λ^a is Gell-Mann matrix.

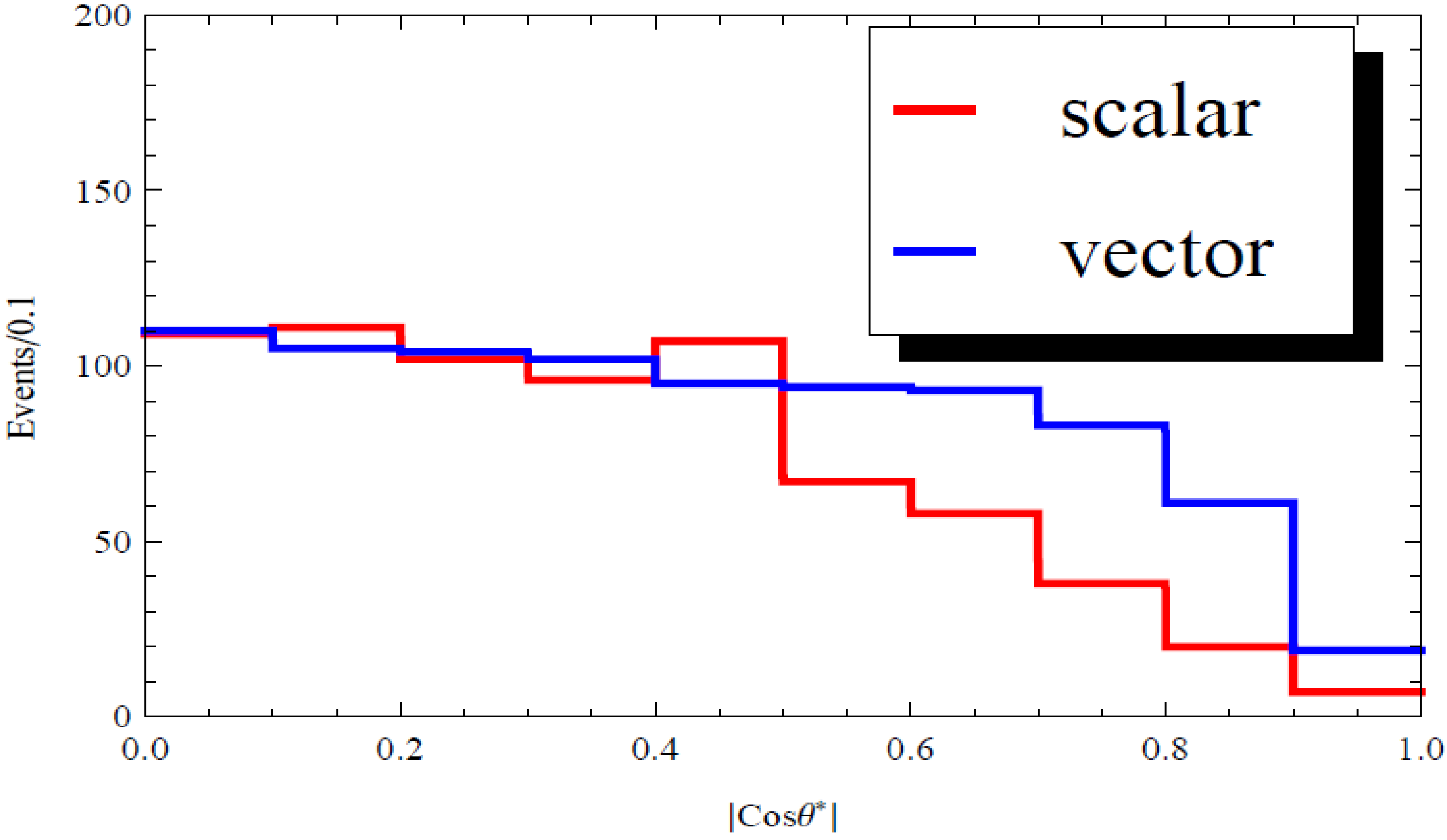
- To evade the limit from the di-jet measurement from UA2, β should be less than 0.3 if $Z_C$only decay to quarks. In our model we set β to be 0.2.
- However, the decay branching ratio is also a free parameter in our model because we can't exclude other exotic particles.

To set the branching ratio of Z_C decay to dijet, we consider the result from ATLAS, which measures 4-jet final states to construct the pair production of colored scalars:



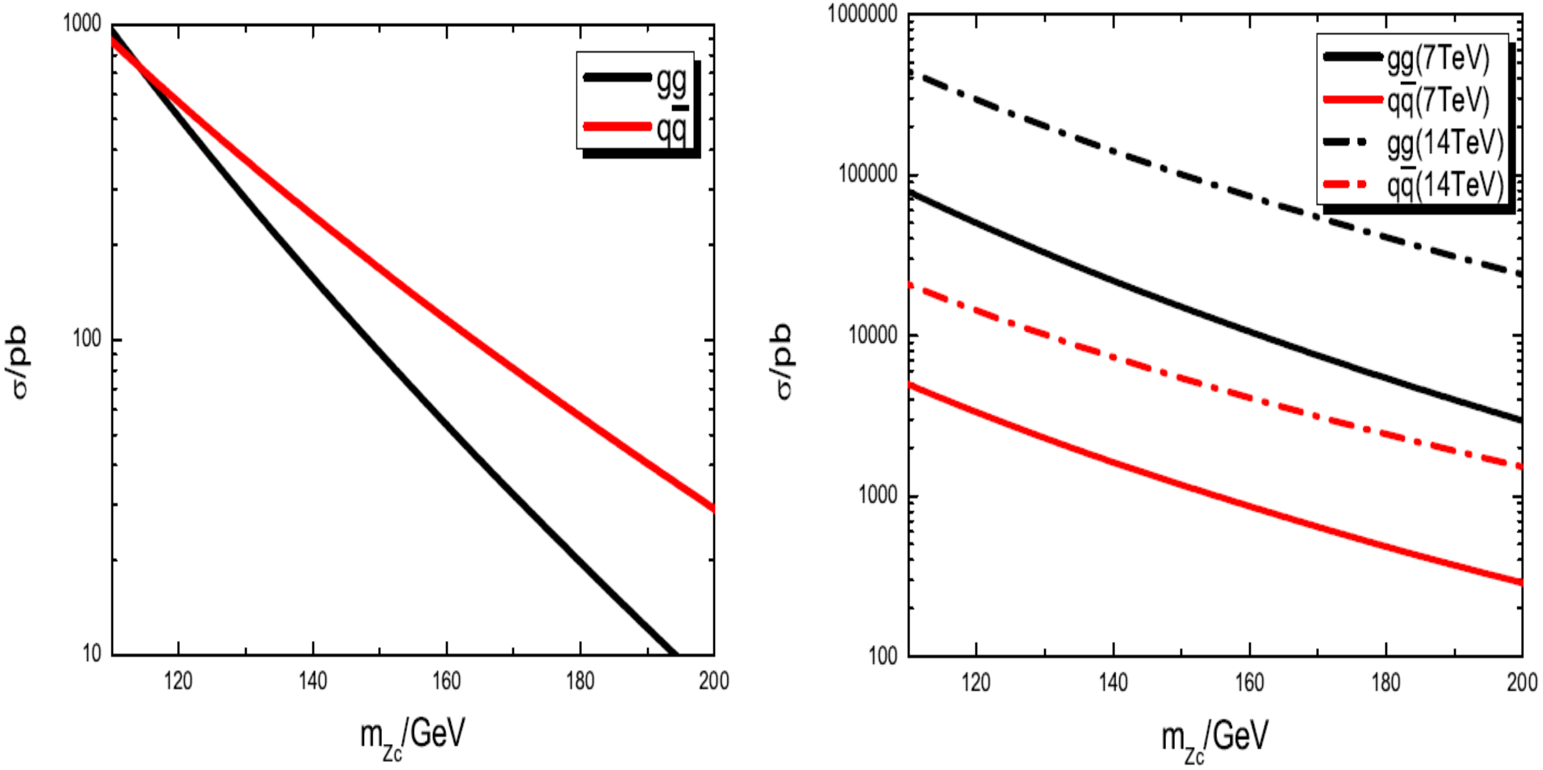
G. Aad *et al.*, ATLAS, (2011), 1110.2693

In order to deduce the upper limit of the vector Z_C, we simulate the scalar and vector at the same time and apply the same cuts as those of ATLAS experiment. Finally, we get the simulation result. In their experiment, they chose $|Cos\ \theta^*|$<0.5.



- Based on this, the upper limit of cross section times the branching ratio to four-jet final states for the vector octet is safely to be the same as the scalar-octet, i.e. 1nb for $Z_C = 145\ GeV$.
- In order to satisfy the experimental limit, we set the branching ratio of Z_C pair to four-jet final states to be $Br^2 = 0.06$, where Br denotes $Br(Z_C \to jj)$.
- we set β to be 0.2.

To study the pair production of Z_C, we show the signal cross section as a function of Z_C mass.



The left one is the result of Tevatron while the right one is LHC result. From the curves it is obvious that the *Zc*pair production is mainly from $q\bar{q}$ sub-processes at Tevatron while from gluon-gluon fusion at LHC. Thus Tevatronand LHC play the different role to identify the different production mechanisms.

Detailed simulation on Tevatron

$$pp \to Z_C Z_C \to jjjj$$

- Basic cut:

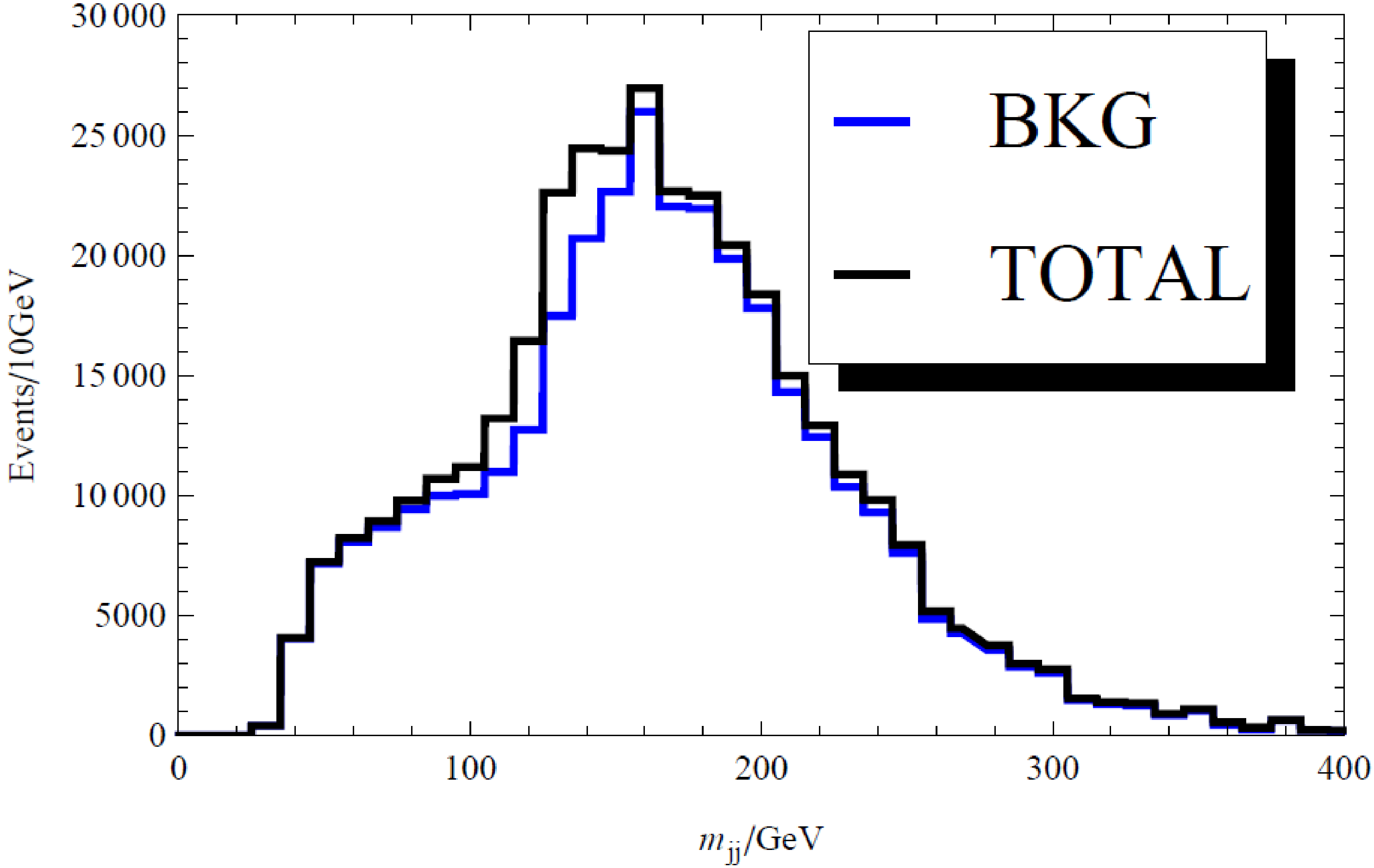
$$p_{T,j} \geq 50GeV; \quad \eta_j \leq 2.8; \quad \Delta R_{jj} \geq 0.4$$

- The second cut:

$$p_{T,j_1} \geq 100GeV; \quad p_{T,j_2} \geq 80GeV$$

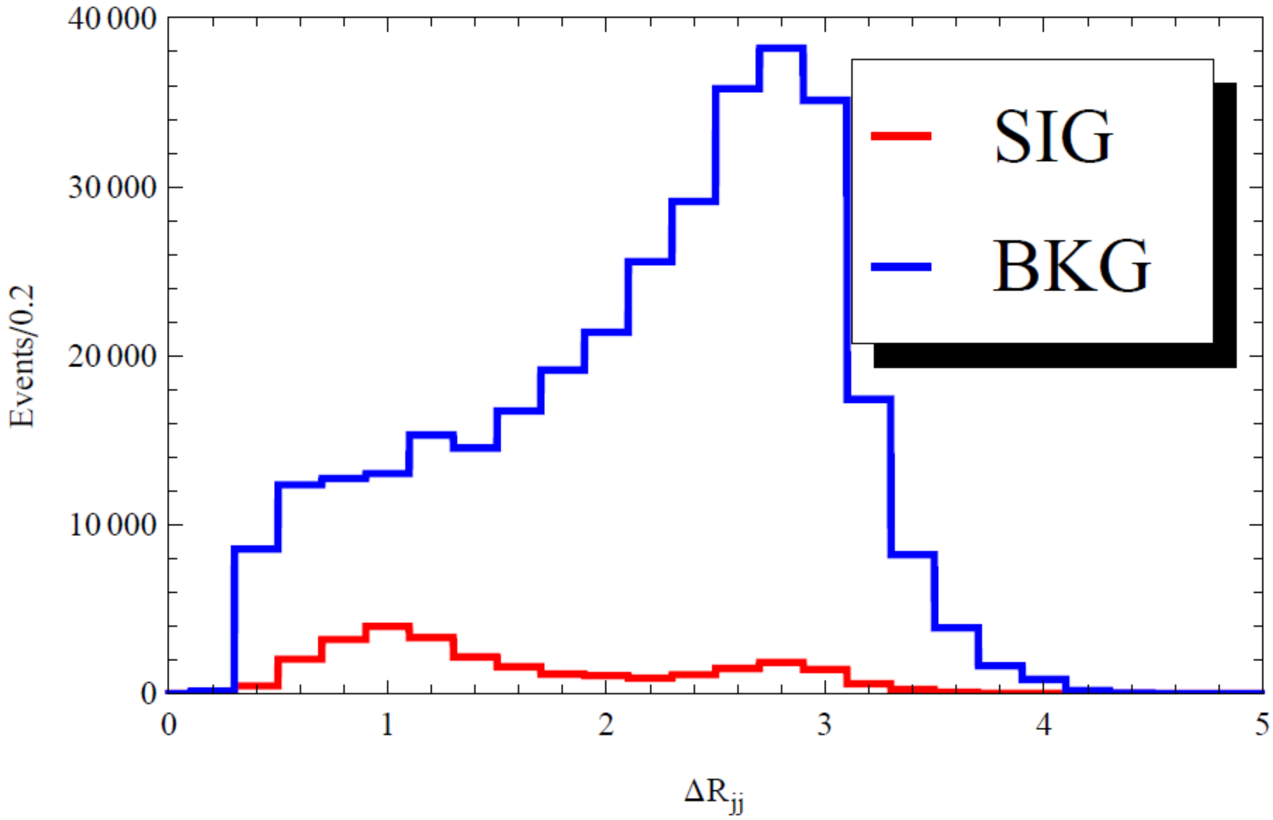
- We pair the four jets into two groups by the criteria that minimizes the $|m_{j_1 j_2} - m_{j_3 j_4}|$quantity, which means that $j_1 j_2$are from a Z_C resonance, and $j_3 j_4$are from the other Z_C resonance.

Result after above cuts



$$m_{Z_C} = 145 GeV$$

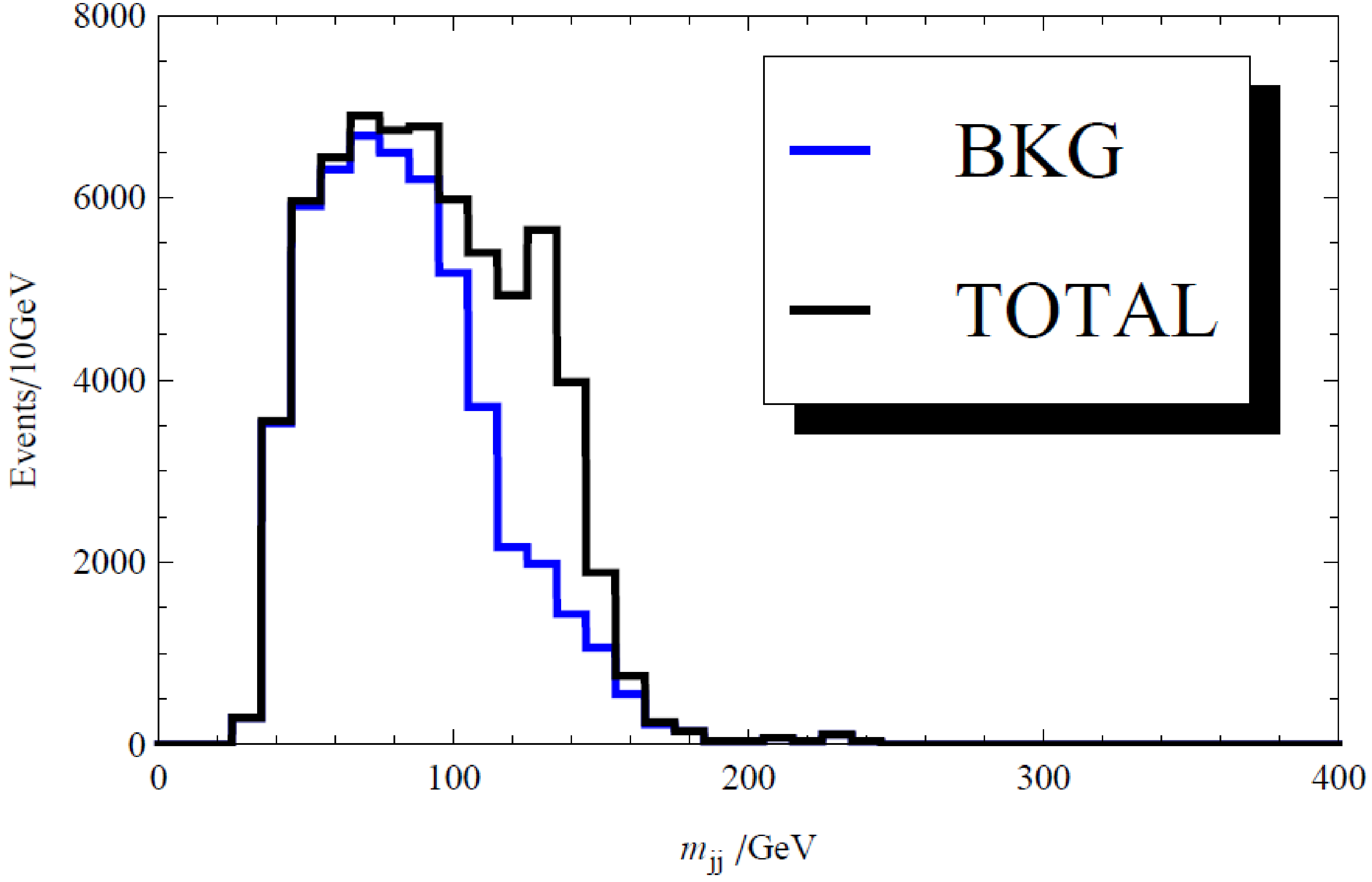
ΔR_{jj} distributions of signal and backgrounds at Tevatron. The luminosity is $10fb^{-1}$.



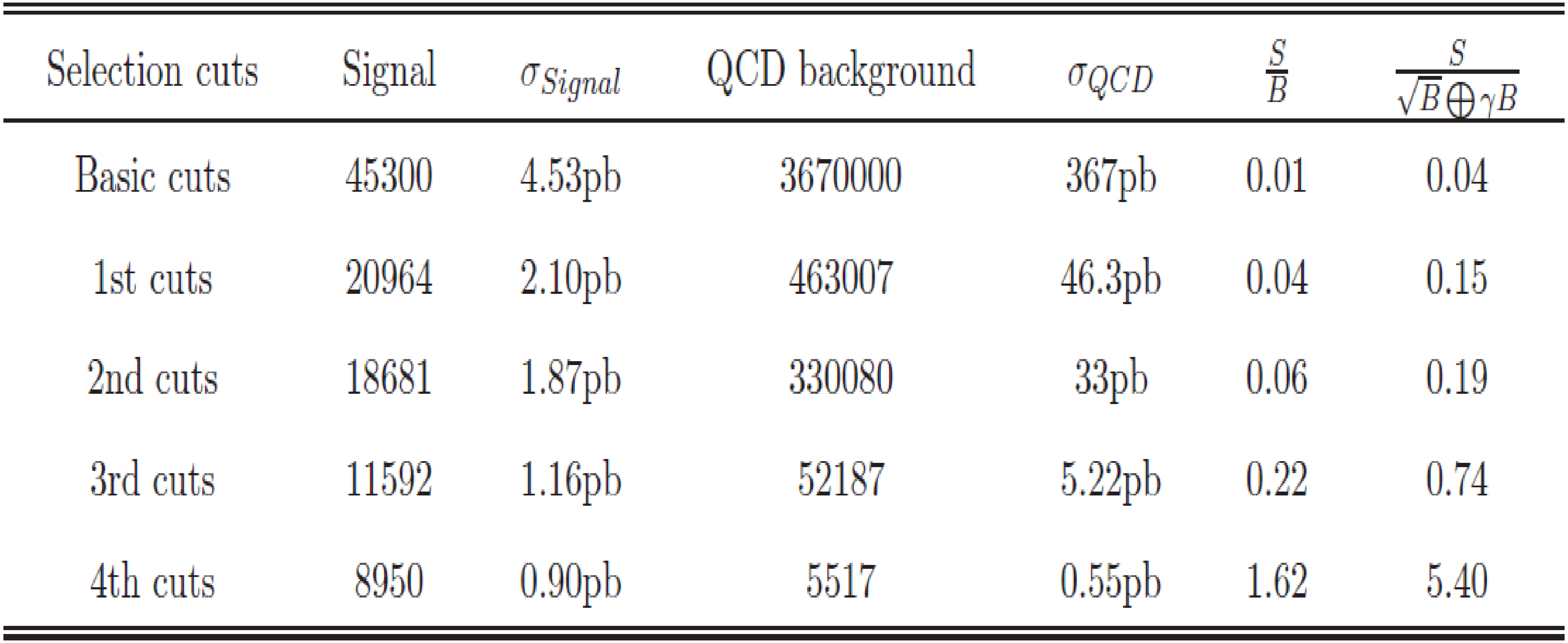
So we set the third cut:

$$\Delta R_{jj} < 1.6 \qquad \Delta R_{jj} = \sqrt{(\Delta\eta_{jj})^2 + (\Delta\phi_{jj})^2} \qquad jj = \{j_1 j_2, j_3 j_4\}$$

Di-jet invariant mass distribution of signal and background at Tevatronafter ΔR_{jj}cut. The luminosity is $10fb^{-1}$.

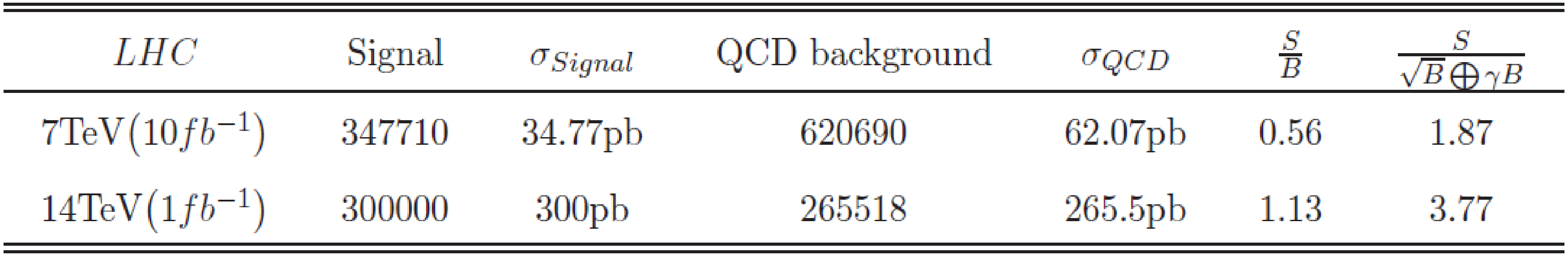


After above cut, we count the event numbers for signal and QCD background in a $30GeV$ mass window of m_{jj} around Z_c mass with The luminosity is$10fb^{-1}$.



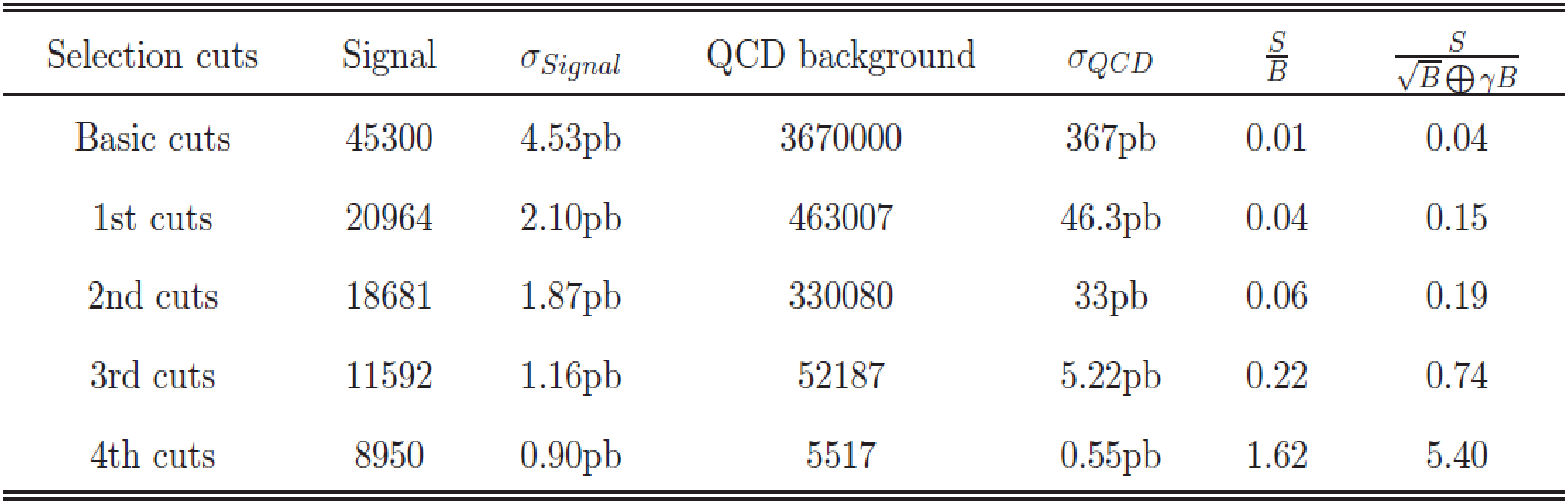
Selection cuts	Signal	σ_{Signal}	QCD background	σ_{QCD}	$\frac{S}{B}$	$\frac{S}{\sqrt{B}\bigoplus\gamma B}$
Basic cuts	45300	4.53pb	3670000	367pb	0.01	0.04
1st cuts	20964	2.10pb	463007	46.3pb	0.04	0.15
2nd cuts	18681	1.87pb	330080	33pb	0.06	0.19
3rd cuts	11592	1.16pb	52187	5.22pb	0.22	0.74
4th cuts	8950	0.90pb	5517	0.55pb	1.62	5.40

Simulation result on LHC



LHC	Signal	σ_{Signal}	QCD background	σ_{QCD}	$\frac{S}{B}$	$\frac{S}{\sqrt{B}\bigoplus\gamma B}$
7TeV$(10fb^{-1})$	347710	34.77pb	620690	62.07pb	0.56	1.87
14TeV$(1fb^{-1})$	300000	300pb	265518	265.5pb	1.13	3.77

Compared with the result on Tevatron



Selection cuts	Signal	σ_{Signal}	QCD background	σ_{QCD}	$\frac{S}{B}$	$\frac{S}{\sqrt{B}\bigoplus\gamma B}$
Basic cuts	45300	4.53pb	3670000	367pb	0.01	0.04
1st cuts	20964	2.10pb	463007	46.3pb	0.04	0.15
2nd cuts	18681	1.87pb	330080	33pb	0.06	0.19
3rd cuts	11592	1.16pb	52187	5.22pb	0.22	0.74
4th cuts	8950	0.90pb	5517	0.55pb	1.62	5.40

Conclusion

- Both Tevatron and LHC have the excellent chance to discover Z_C through analyzing the four jets events with accessible integrated luminosity and good control of QCD background.
- Tevatron and LHC can play an important role to identify the different production mechanism, namely at LHC Z_C pair production comes from gluon-gluon contributions while at Tevatron the quark contributions are larger.
- Tevatron can be a better collider to observe the multi-jet signal arising from quark annihilation. On the other hand, with the higher energy and the integrated luminosity, LHC has the power to give the better result.

Thank you