Signatures of low-scale string models at the LHC

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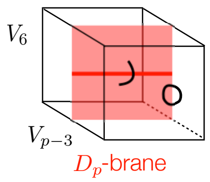
✓ motivation : Why low-scale string models ?

Naively, $M_s = M_{\rm Planck} \sim 10^{19}{\rm GeV}$ (Antoniadis,PLB246('90); Antoniadis et al.,PLB436('98))

however, $M_s \sim \mathcal{O}(1){\rm TeV}$

is possible with large extra dimensions !!



- Planck scale

$M^2_{\rm Planck} \sim M_s^2 \times M_s^6 V_6 \sim (10^{19}{\rm GeV})^2$

- 4-dim. gauge coupling

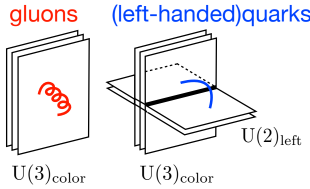
$g_4^{-2} \sim M_s^{p-3} V_{p-3} \sim 1$

The higher dim. gravitational scale is $\mathcal{O}(1){\rm TeV}$.

⇨ The models can be solutions to the hierarchy problem !!

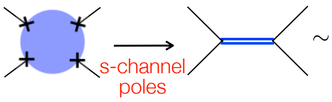
✓ gauge bosons and fermions

Lust et al.,NPB808('09)
Anchordoqui et al.,NPB821('09)



massless modes of open string
⇨ SM particles
massive modes of open string
⇨ string excited states

✓ open string scattering amplitude



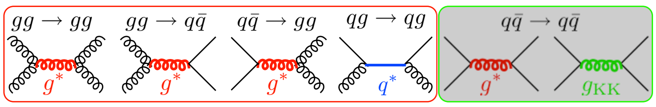
$$\sim \sum_{n=1}^{\infty} \frac{1}{s - nM_s^2} \prod_{J=0}^{n-1} (u/t + JM_s^2)$$

⇨ The n-th string excited state has mass $M_n = \sqrt{n} M_s$

and various spins with maximum spin $J_{\rm max} = j_0 + n$

✓ string resonances at the LHC

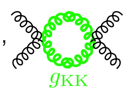
The dominant 2-parton scattering processes



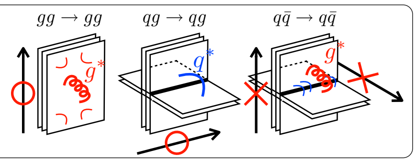
do not contain exchange of KK modes. (← model-dependent)

⇨ model-indepedent !!

If momenta along extra dimensions are conserved,
KK modes are produced always in pair.



- momentum conservation



✓ main results

String resonances can be distinguished
from resonances of other "new physics" !

Angular distribution analysis

☺ String resonances have spin degeneracy.

1st quark excited states have $J = 1/2$ and $J = 3/2$.

cf. Quark-like states in other physics have only $J = 1/2$.

Second resonance analysis

☺ mass of 2nd string excited states is $M_{\rm 2nd} = \sqrt{2} M_s$

cf. typical mass of 2nd KK modes is $M^{\rm KK}_{\rm 2nd} \sim 2M$

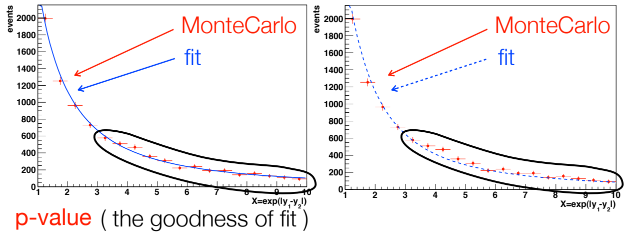
✓ angular dist. analysis

χ-distribution
near 1st string resonances

$$\chi \equiv \exp(y_1 - y_2) = \frac{1+\cos\theta^*}{1-\cos\theta^*}$$

$M_s = 4{\rm TeV}$ $\sqrt{s} = 14{\rm TeV}$

string resonance $J=1/2 + J=3/2$	other new physics $J=1/2$ only



p-value (the goodness of fit)

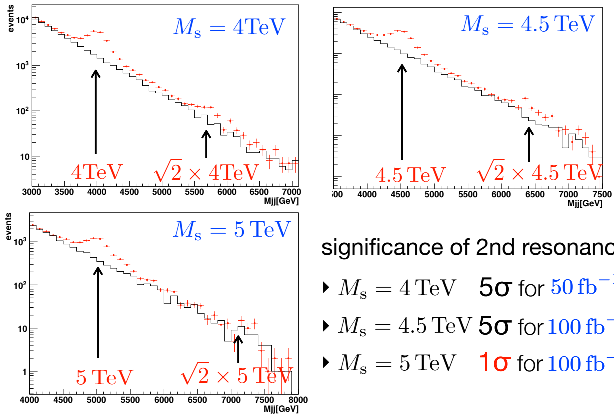
75%	4% < 5%

⇨ $\mathcal{L} = 20\,{\rm fb}^{-1}$ is required !

✓ second resonance analysis

$\sqrt{s} = 14{\rm TeV}$

dijet inv. mass distribution with 1st and 2nd string resonances

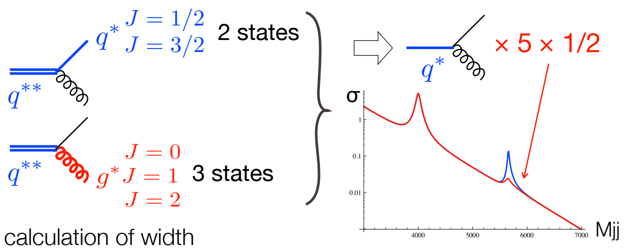


significance of 2nd resonance

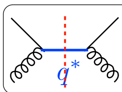
- $M_s = 4\,{\rm TeV}$ 5σ for $50\,{\rm fb}^{-1}$
- $M_s = 4.5\,{\rm TeV}$ 5σ for $100\,{\rm fb}^{-1}$
- $M_s = 5\,{\rm TeV}$ 1σ for $100\,{\rm fb}^{-1}$

✓ width of 2nd → 1st + SM

$\Gamma_{\rm 2nd \to 1st}$ ⇨ $\Gamma_{\rm 1st \to SM}$ × # of 1st excited states × ratio of phase space



calculation of width



$$\mathcal{M} = \sum_J \frac{1}{s - M^2} |F^J|^2 d^J(\theta) \rightarrow \Gamma^J = \frac{1}{16\pi M} \frac{1}{2J+1} |F^J|^2$$

✓ summary

- Low-scale string models with large extra dimensions in which string scale is TeV order, can be solutions to hierarchy problem.
- At the LHC, string excited states are observed as resonances in dijet events model-independently.
- We can distinguish low-scale string from other new physics using spin degeneracy and mass of second resonances.

✓ current CMS results

$M_s > 4.0{\rm TeV}$ $7\,{\rm TeV},\,1.0\,{\rm fb}^{-1}$

⇩

$M_s > 4.69\,{\rm TeV}$ $8\,{\rm TeV},\,4.0\,{\rm fb}^{-1}$

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