Higgs and Beyond the Standard Model Physics at the LHC

ICTP, Trieste

Impact of Z' and UED parameters on different observables in $B_s \to \phi \ell^+ \ell^-$ decays

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June 24-28 2013

- This talk is based on the following research work.

- Impact of Z' and UED parameters on different observables in $B_s \to \phi \ell^+ \ell^-$ decays**Ishtiaq Ahmed, M.Jamil Aslam and M.Ali Paracha**.

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Outline

- Role of B-meson beyond the Standard Model (SM).
- A brief introduction to UED Model.
- A brief introduction to family non-universal Z'-Model.
- Matrix elements for Rare semileptonic $B_s \to \phi \ell^+ \ell^-$ meson decays
- Physical observables for $B_s \to \phi \ell^+ \ell^-$ decay
- Conclusion.

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Role of B-meson beyond the Standard Model (SM)

- In flavor sector ideal laboratory system is B meson.
- B-physics started in 1977 with the observation of dimuon resonance at 9.5 GeV proton-nucleon collision at Fermi lab.
- The processes that are suitable for indirect searches of NP are those which are rare in SM and can be measured precisely.
- Examples are B-decays.
- Rare B decays are mediated through FCNC transitions.
- These transitions occurs at loop level in the SM and are also CKM suppressed.
- FCNC transitions will provide a suitable tool to investigate the physics within and beyond the SM.
- Exploration of NP through various B meson decay modes are

Inclusive decay modes e.g $B \to X_{s,d}\ell^+\ell^-$

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Exclusive decay modes e.g $B \to M\ell^+\ell^-$ ($M = K$, K^*, ϕ etc.)

- Rare decay modes involved observables which can distinguish between the various extensions of the SM.
- The observables like branching ratio, forward backward asymmetry, helicity fractions of final state meson and lepton polarization asymmetries are greatly influenced under different scenarios beyond the SM.
- Precise measurement of these observables will play an important role in the indirect searches of NP.
- New physics effects in rare decays arises in two different ways
  1. Through a new contribution to the Wilson coefficients (Class I).
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Universal Extra Dimension Model

- There are several models of extra dimensions.
  1. Large extra dimensions (Arkani-Hamed,Dimopoulous,Dvali)
  2. Wraped Extra dimensions (Randall, Sundrum)
  3. Univeral Extra dimensions (Applequest, Cheng, Dobrescu)
- The idea of extra dimensions became popular in phenomenology when large extra dimensions were considered as a solution of hierarchy problem.
- Among differnt models of the extra dimensions, which differ from one another depending on the number of extra dimensions, the most interesting one are the scenarios with universal extra dimensions (UED).
- In UED models all SM particles are allowed to propagate in the extra dimensions and compactification of an extra dimensions leads to the appearnce of Klauza-Klein (KK)partners of the SM fields in the four-dimensional description of the higher dimensional theory.
- The Applequist,Cheng and Dobrescu (ACD) model with one universal extra dimension is very attractive, because it has only one free parameter w.r.t SM, which is the inverse of compactification radius R.

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- Buras *etal* computed the Wilson coefficients $C_i(\mu)$ at Next to leading order (**NLO**) in the **ACD** model. A.J.Buras,M.Spranger,A.Weiler,Nucl.Phys.B 660,2005(2003)
- In **ACD** model the modified Wilson coefficients can gets contribution from new particles.
- The new (**KK**) particles comes as an intermediate state in penguin and box diagrams.
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- The function $F(x_t, 1/R)$ can be written as follows

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where$x_t = \frac{m_t^2}{M_W^2}$, $x_n = \frac{m_n^2}{M_W^2}$, $\mathrm{m}_n = \frac{n}{R}$

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Family non-universal Z'-Model

- Z' gauge boson could be derived naturally in many extensions of SM.
- The economical way to get it is to include an additional $U'(1)$ gauge symmetry.
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- These non diagonal couplings in the fermion mass of Z' boson may lead to FCNCs at tree level.
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Why B_s-Meson?

- Apart from other B-mesons, B_s is an interesting avenue for NP.
- $B_s^0 - \bar{B}_s^0$ mixing is an exciting feature.
- In SM this arises from the box topologies and hence is strongly suppressed.
- In the presence of NP, new particles could give rise to additional box topologies or even these decays can occur at tree level.
- Key channel to address the possibility is $B_s \to J/\Psi\phi$.
- Final state require the time dependent angular analysis of $J/\Psi \to \mu^+\mu^-$ and $\phi \to K^+K^-$ decay products.
- In addition, over the last couple of years, measurements of CP violating asymmetries in "tagged" analysis of the $B_s \to J/\Psi\phi$ channel at the tevatron indicate the possible NP effects.
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- At quark level, the decay $B_s \to \phi \ell^+ \ell^-$ is governed by FCNC transition $b \to s \ell^+ \ell^-$.
- The effective Hamiltonian for the process can be written as

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- The operators responsible for the said decay are

$$\begin{aligned} O_7 &= \frac{e^2}{16\pi^2} m_b (\bar{s}\sigma_{\mu\nu} R b) F^{\mu\nu} \\ O_9 &= \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu L b)\, \bar{\ell}\gamma^\mu \ell \\ O_{10} &= \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu L b)\, \bar{\ell}\gamma^\mu \gamma^5 \ell \end{aligned}$$

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$$\begin{aligned} O_7 &= \frac{e^2}{16\pi^2} m_b (\bar{s} \sigma_{\mu\nu} R b) F^{\mu\nu} \\ O_9 &= \frac{e^2}{16\pi^2} (\bar{s} \gamma_\mu L b) \bar{\ell} \gamma^\mu \ell \\ O_{10} &= \frac{e^2}{16\pi^2} (\bar{s} \gamma_\mu L b) \bar{\ell} \gamma^\mu \gamma^5 \ell \end{aligned}$$

- The amplitude for the FCNC transition can be written as

$$\mathcal{M}(b \to s \ell^+ \ell^-) = -\frac{G_F \alpha}{\sqrt{2}\pi} V_{tb} V_{ts}^* \left[\begin{array}{c} C_9^{tot} (\bar{s} \gamma_\mu P_L b)(\bar{\ell} \gamma^\mu \ell) \\ + C_{10}^{tot} (\bar{s} \gamma_\mu P_L b)(\bar{\ell} \gamma^\mu \gamma_5 \ell) \\ -2 m_b C_7^{tot} (\bar{s} i \sigma_{\mu\nu} \frac{q^\nu}{q^2} P_R b)(\bar{\ell} \gamma^\mu \ell) \end{array} \right]$$

Matrix Elements for the decay $B_s \to \phi \ell^+ \ell^-$

- The non vanishing matrix elements for the process $B_s \to \phi$ can be parameterized in terms of form factors as

$$\langle \phi(k,\epsilon)|\bar{s}\gamma^\mu(1 \pm \gamma^5)b|B_s(p)\rangle = \mp i q_\mu \frac{2m_\phi}{q^2}\epsilon^* \cdot q \left[A_3(q^2) - A_0(q^2)\right]$$
$$\pm i\epsilon^*_\mu(m_{Bs} + m_\phi)A_1(q^2) \mp i(p+k)_\mu \epsilon^* \cdot q \frac{A_2(q^2)}{(m_{Bs} + m_\phi)}$$
$$-\epsilon_{\mu\nu\lambda\sigma}p^\lambda q^\sigma \frac{2V(q^2)}{(m_{Bs} + m_\phi)}$$

and

$$\langle \phi(k,\epsilon)|\bar{s}i\sigma_{\mu\nu}q^\nu(1 \pm \gamma^5)b|B(p)\rangle = 2\epsilon_{\mu\nu\lambda\sigma}p^\lambda q^\sigma T_1(q^2)$$
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Formula for Physical Observables

- Following are the observables which we considered for the said decay
  1. Branching ratio
  2. Lepton forward backward asymmetry
  3. Helicity fractions of ϕ.
- The formulas for these physical observables are
- Differential Decay Rate

$$\frac{d\Gamma(B_s \to \phi \ell^+ \ell^-)}{dq^2} = \frac{1}{(2\pi)^3} \frac{1}{32 M_{B_s}^3} \int_{-u(q^2)}^{+u(q^2)} du \, |\mathcal{M}|^2$$

- Forward-backward Asymmetry

$$\mathcal{A}_{FB} = \frac{\int_0^1 \frac{d^2\Gamma}{dq^2 d\cos\theta} d\cos\theta - \int_{-1}^0 \frac{d^2\Gamma}{dq^2 d\cos\theta} d\cos\theta}{\int_{-1}^1 \frac{d^2\Gamma}{dq^2 d\cos\theta} d\cos\theta}$$

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f_L(q^2) &= \frac{d\Gamma_L(q^2)/dq^2}{d\Gamma(q^2)/dq^2} \\
f_\pm(q^2) &= \frac{d\Gamma_\pm(q^2)/dq^2}{d\Gamma(q^2)/dq^2} \\
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Numerical values used for calculations of Physical Observables

Table: Default values of input parameters used in the calculations.

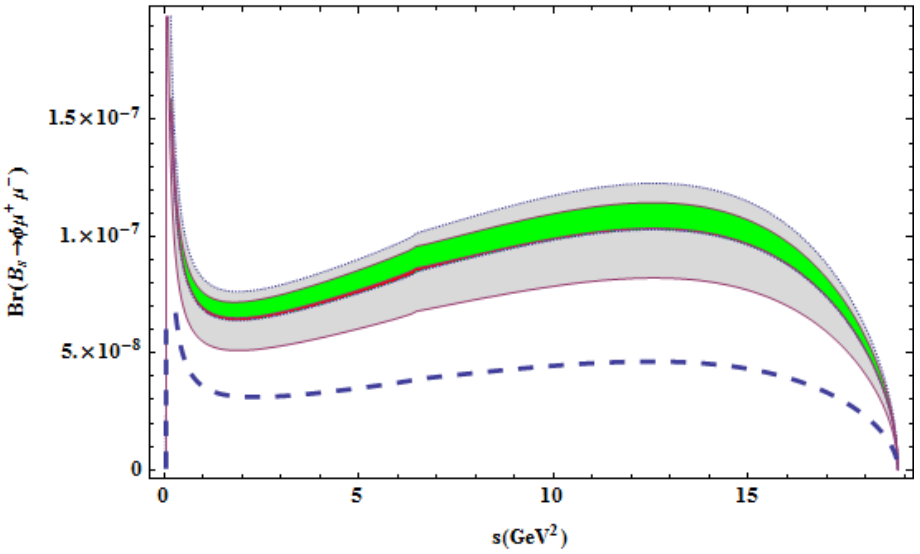
$m_{B_s} = 5.366$ GeV, $m_b = 4.28$ GeV, $m_s = 0.13$ GeV,
$m_\mu = 0.105$ GeV, $m_\tau = 1.77$ GeV, $f_B = 0.25$ GeV,
$\lvert V_{tb} V_{ts}^* \rvert = 45 \times 10^{-3}$, $\alpha^{-1} = 137$, $G_F = 1.17 \times 10^{-5}$ GeV^{-2},
$\tau_B = 1.54 \times 10^{-12}$ sec, $m_\phi = 1.020$ GeV.

Table: The numerical values of the Z' parameter.

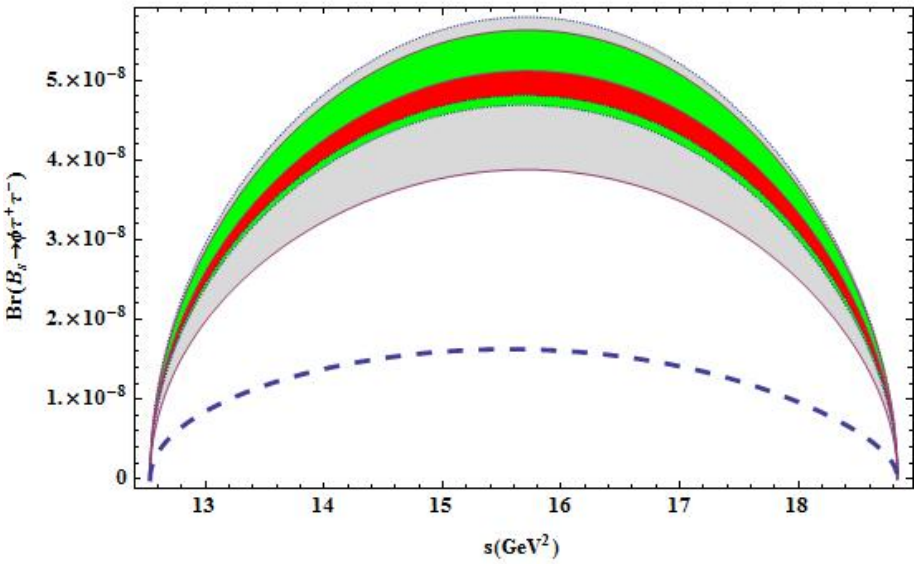
	$\lvert B_{sb} \rvert \times 10^{-3}$	$\phi_{sb}[^o]$	$S_{LL} \times 10^{-2}$	$D_{LL} \times 10^{-2}$
$\mathcal{S}_1$	1.09 ± 0.22	-72 ± 7	-2.8 ± 3.9	-6.7 ± 2.6
$\mathcal{S}_2$	2.20 ± 0.15	-82 ± 4	-1.2 ± 1.4	-2.5 ± 0.9

Branching Ratio Results for the decay $B_s \to \phi \ell^+ \ell^-$ in ACD and Z' model

(a)

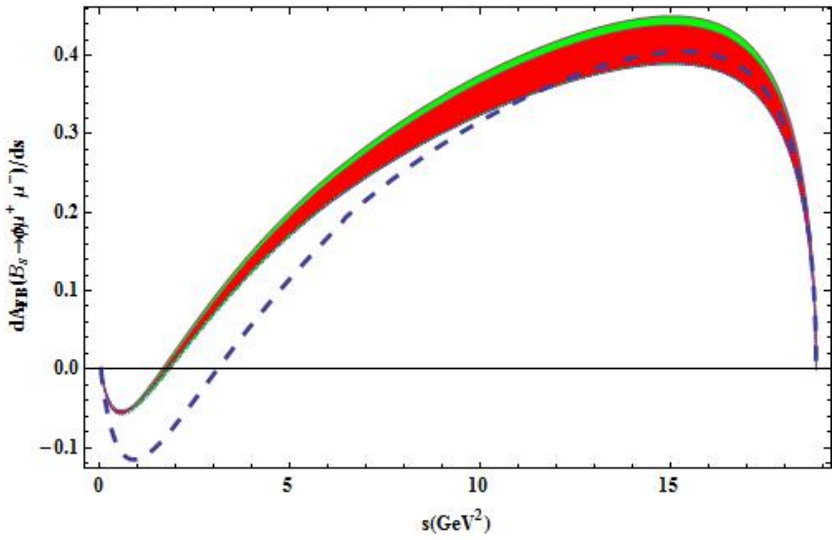


(b)

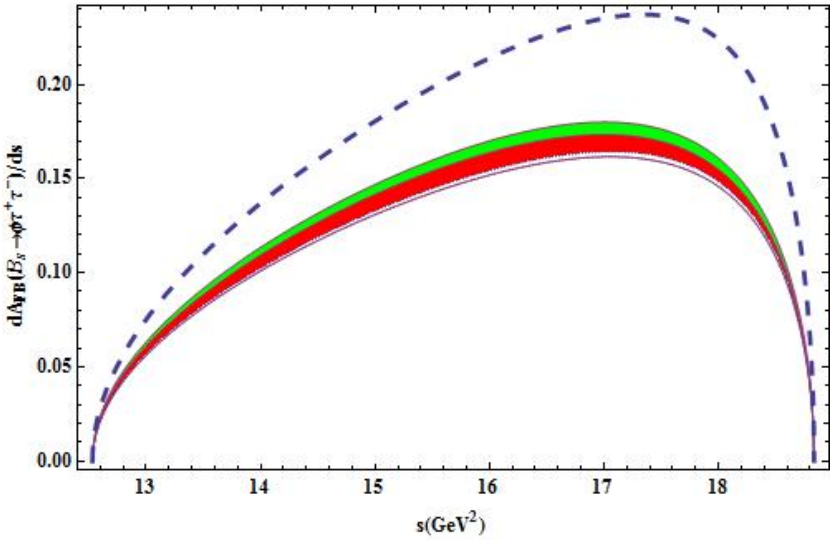


Forward-Backward asymmetry for the decay $B_s \to \phi \ell^+ \ell^-$ in ACD and Z' model

(a)

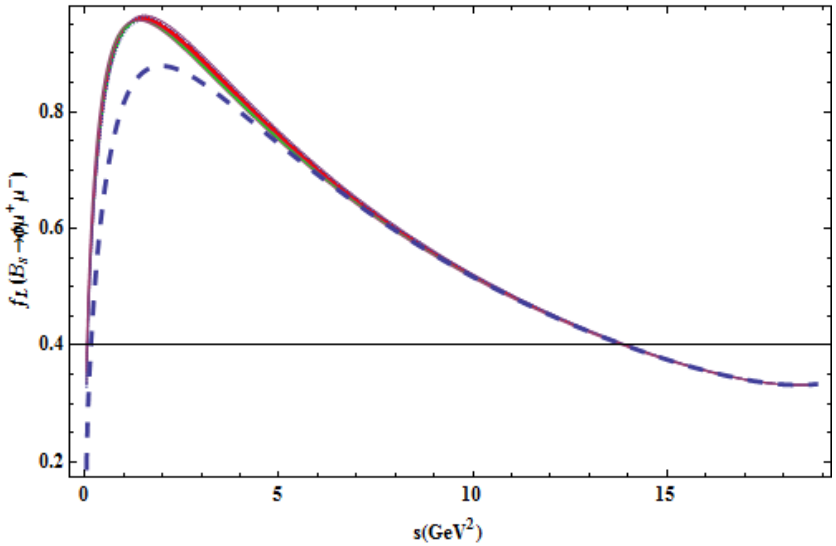


(b)

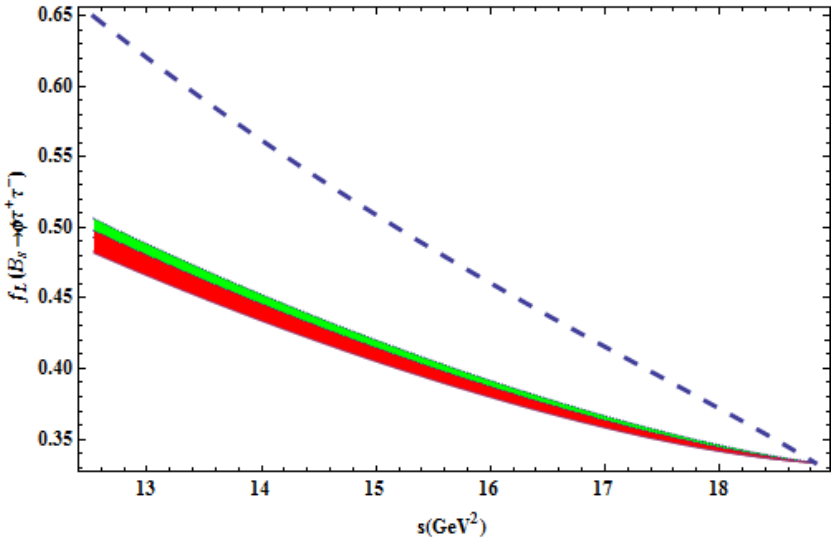


Longitudinal helicity fraction for the decay $B_s \to \phi \ell^+ \ell^-$ in ACD and Z' model I

(a)

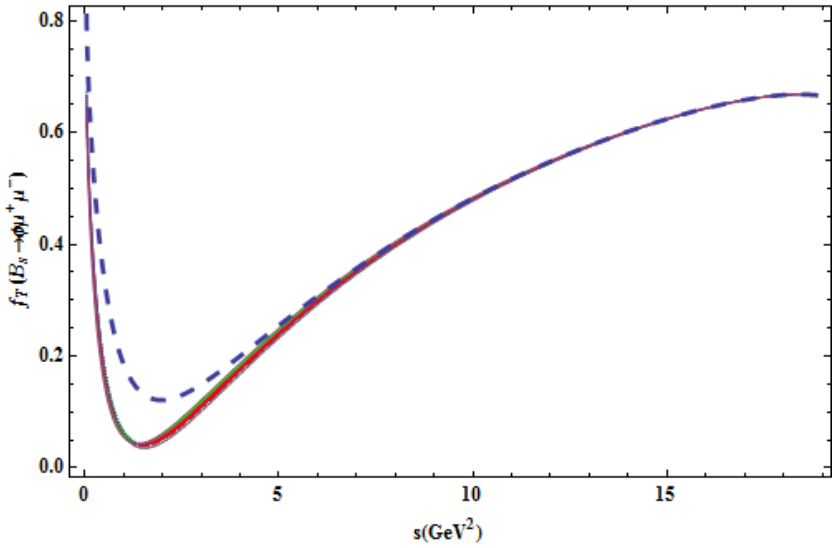


(b)



Transverse helicity fraction for the decay $B_s \to \phi \ell^+ \ell^-$ in ACD and Z' model

(a)



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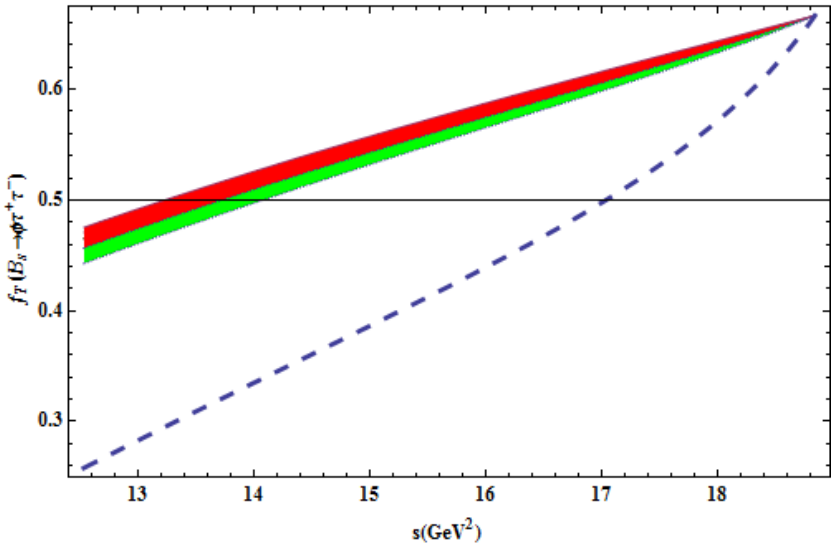

Conclusions

- We analyze the decay $B_s \to \phi \ell^+ \ell^-$ in ACD and family non-universal Z'-model.
- To distinguish the NP effects from SM, we studied some physical observables such as branching ratio, forward backward asymmetry(A_{FB}) and helicity fractions of ϕ meson for the said decay.
- It is found that observables such as branching ratio NP effects are obscured by uncertainties arising due to form factors.
- The helicity fractions shifts significantly for some of NP scenarios when we have $\tau's$ as a final state leptons.
- Hope that the detailed experimental study of the said channel will be a valuable source to dig out the status of NP.

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