Colliders and fcnc tests of contact interactions in D-brane string models

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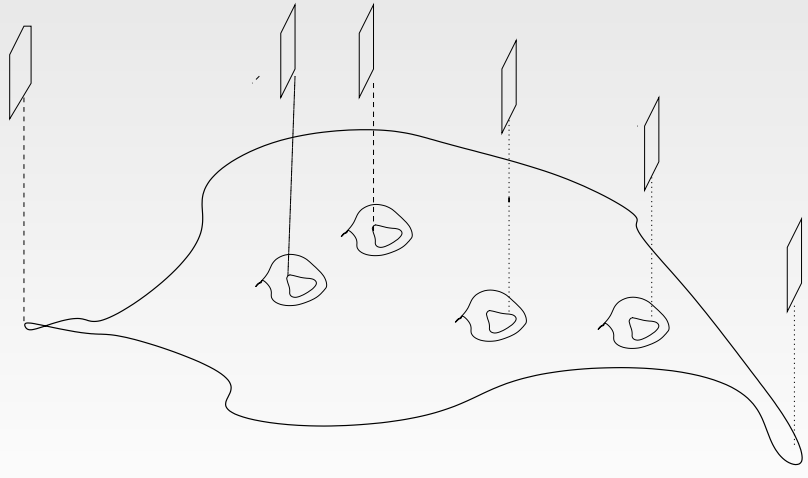
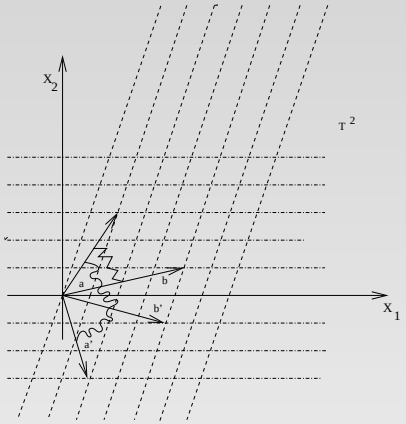
Brane-world models from string theory

- Constructions for type II string with D-branes give models compatible with TeV tension string scale, unlike heterotic string. Setups with single brane stacks are not realistic (too much susy). Semi-realistic realizations of SM are possible with multiple brane stacks localized near orbifold singularities or intersecting submanifolds of internal 6-d space.
- Multiple brane configurations appear naturally in orientifolds or orbifolds via covering space construction of adding equivalent mirror branes.
- Artist view of geometry of TeV scale brane-world: Large internal manifold X_6 (radius R) supporting Dp-branes filling Minkowski spacetime M_4, wrapping small $(p-3)$-cycles (radius r) of X_6. Effective gauge theory on Dp_A-branes with 4-d coupling constant matches to open string parameters, $\frac{4\pi}{g_A^2} \simeq \frac{(m_s r)^{p-3}}{g_s}$ if $r << R$.

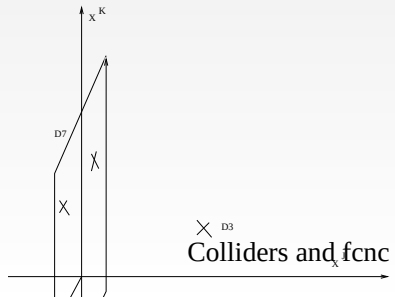


Orientifold models

- Type IIa on $X_6 \simeq T^6/\Omega\mathcal{R}$. Simplest realization of symmetries and irrep content of SM via internal space orientifold manifold symmetric under coordinate reflection, $\mathcal{R}: \; X^I \rightarrow \bar{X}^I$. Branes appear in mirror pairs $a, \; a' = \Omega\mathcal{R}a$. Quark and lepton flavor from multiple intersection points of wrapped cycles fixed by topological invariants.

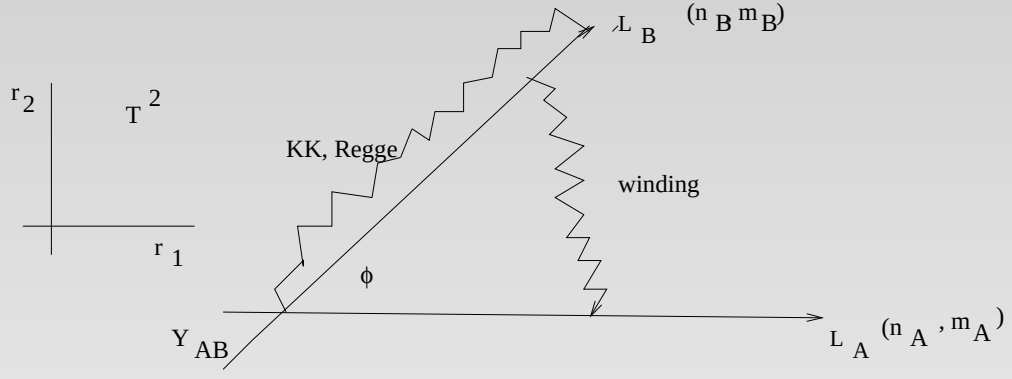


- Type IIb on $T^6/Z_N \times \Omega R$. Massless fermions from non-diagonal open sectors of $D5_I/D5_J$-branes or $D3/D7_I$-branes intersecting transversally and their orbifold + orientifold mirror copies. Flavor via orbifold fixed points.



Open string excitations for setups of $D6$-branes

- Chiral fermions from open string sectors (A, B) with string end points moving along $D6_A/D6_B$-branes intersecting at angles ϕ^I. Spectrum includes Regge, winding and momentum resonances (units $m_s = 1$)



$$\alpha' M_{AB}^2 = \frac{Y_{AB}^2}{4\pi^2\alpha'} + \sum_{p_A \in Z} (p_A + \epsilon_A)^2 |L_A|^2 + \sum_{p_B \in Z} \frac{p_B^2}{|L_B|^2}$$

$$+ \sum_{M=\mu,I} [N^X(\theta_{AB}^M) + N^\psi(\phi_{AB}^M) + \frac{|\phi_{AB}^M|}{2}] - \nu$$

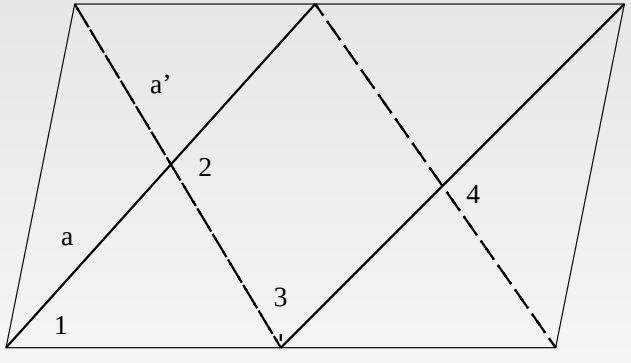
$$[L_A^{I2} = (m_A^I + \frac{n_A^I r_1^I \cos\alpha^I}{r_2^I})^2 r_2^{I2} + (n_A^I r_1^I \sin\phi^I)^2]. \qquad (0.1)$$

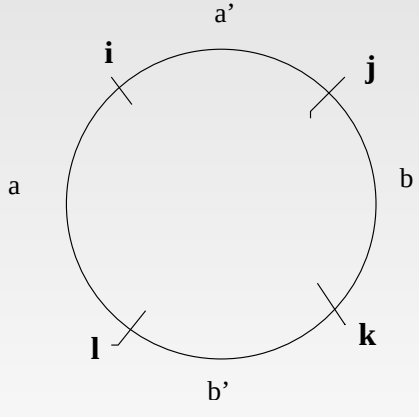
Four-stack orientifold model for MSSM

- Realization with 4 stacks of MSSM with gauge group $SU(3) \times SU(2) \times U(1)^3$ (Ibanez, Marchesano and Cremades models).

Mode	q	u^c	d^c	l	
Brane	$(a,b)+(a,b')$	(c,a)	(c',a)	$(d,b)+(d,b')$	
State	$3(3,2)_{1,0,0}$	$3(\bar{3},1)_{-1,1,0}$	$3(\bar{3},1)_{-1,-1,0}$	$3(1,2)_{0,0,1}$	$3($

- Four fermion interactions described in T^2_I by polygon. Quark and lepton flavor fixed by intersection points i, j, k, l.





String amplitudes at tree level

- On-shell string scattering amplitudes via techniques of 2-d conformal field theories from vacuum correlators of vertex operators on world sheet. Contributions from tree level exchange of open string modes

$$\mathcal{A}'_{f^4} = C\mathcal{S}_{1234}\Big[T_{1234}\int_0^1 dx x^{-s-1}(1-x)^{-t-1}\sum_{cl} Z^{clI}_{12,34}(x)$$
$$+T_{4321}\int_0^1 dx x^{-t-1}(1-x)^{-s-1}\sum_{cl} Z^{clI}_{43,21}(x)\Big](\frac{\sin\pi\theta^I}{F(x)F(1-x)})^{\frac{1}{2}},$$
$$[Z^{clI}_{12,34}(x) = \sum_{p_A,\, p_B\in Z} \exp\Big[-\pi\sin\pi\theta_I[|(p_A+\epsilon^A_{12})L^I_A + d^A_{12}|^2\frac{F(1-x)}{F(x)}$$
$$+|(p_B+\epsilon^B_{23})L^I_B + d^B_{23}|^2\frac{F(x)}{F(1-x)}]\Big],$$
$$F(x) = F(\theta, 1-\theta; 1; x)]. \qquad (0.2)$$

- Massless modes contributions from end points $x \to 0$ and $x \to 1$ of x-integral.

Contact interactions

- Contact interactions of dimension 6

$$L_{EFF} = \sum_{f,f'} \sum_{H,H'} G^{HH'}_{ij,kl} [(\bar{f}_{iH} \gamma^{\mu} f_{jH})(\bar{f}'_{kH'} \gamma_{\mu} f'_{lH'})]_{flav} + H.c. \quad (0.3)$$

  via coefficients $G^{HH'}_{ij,kl}$ calculated from x-integral and subtraction of KK modes.

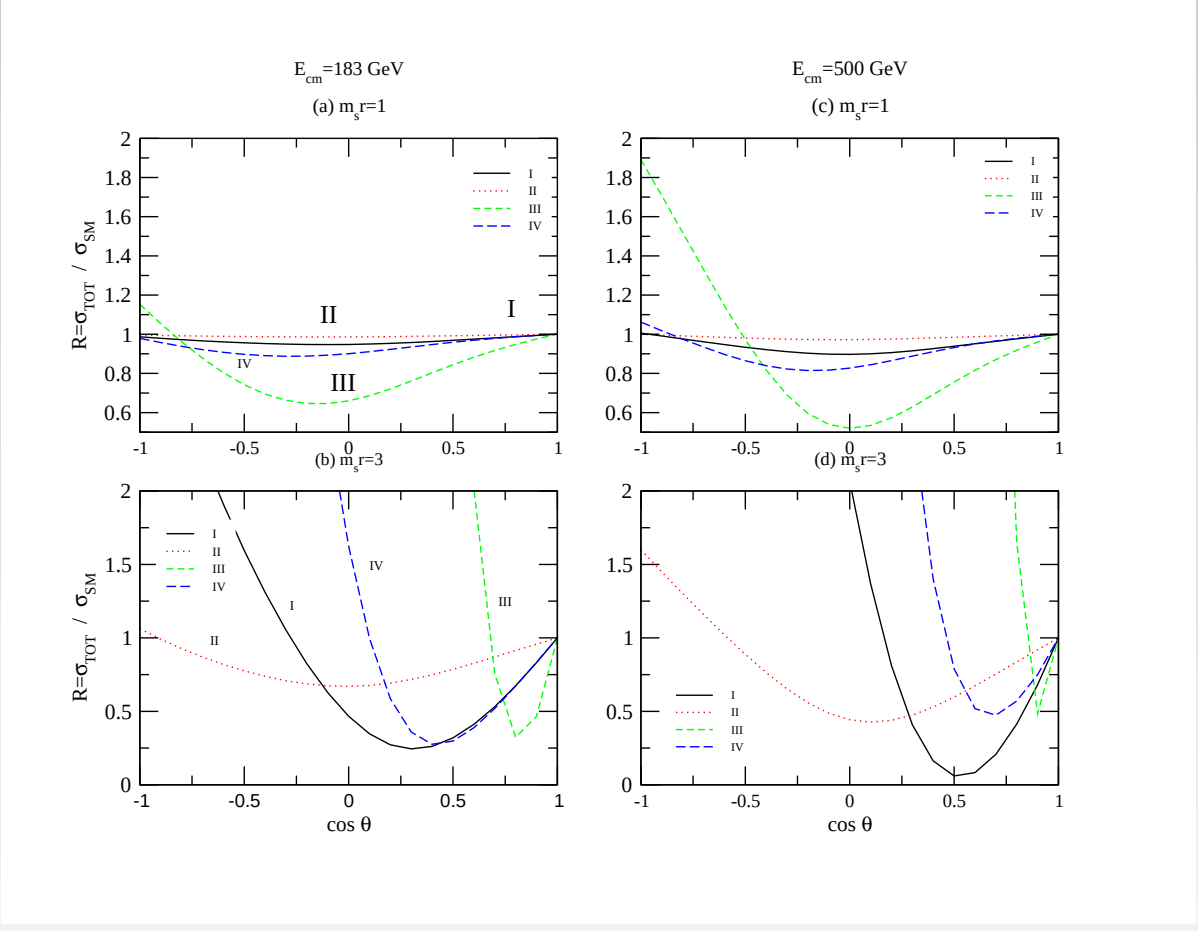
- Only dimension 8 contact interactions (Regge+graviton KK exchange) are present in single stack models.

Indirect collider tests

- Consistent background for TeV scale weakly coupled strings: • Compactification manifold of large volume $(2\pi R)^6$, with wrapped 3-cycles of small volume, $r \ll R$. • Matching to low energy theory, $\frac{g_A^2 |L_A|}{2K_A} = 2\pi g_s$. Weakly coupled strings $g_s \leq 1$ requires $m_s r = O(1)$. Competition between winding, KK and Regge modes.
- Extract coefficients of contact interactions by direct subtraction of massless and KK massive modes.
- Comparison of coefficients of contact interactions with experimental bounds on compositeness scale give: $m_s \geq 1 - 5$ TeV.

Comparison with Bhabha scattering

- High precision data for angular distributions $(d\sigma(e+\bar{e}\to e+\bar{e})/d\cos\theta_e)_{tot}/()_{SM}$.



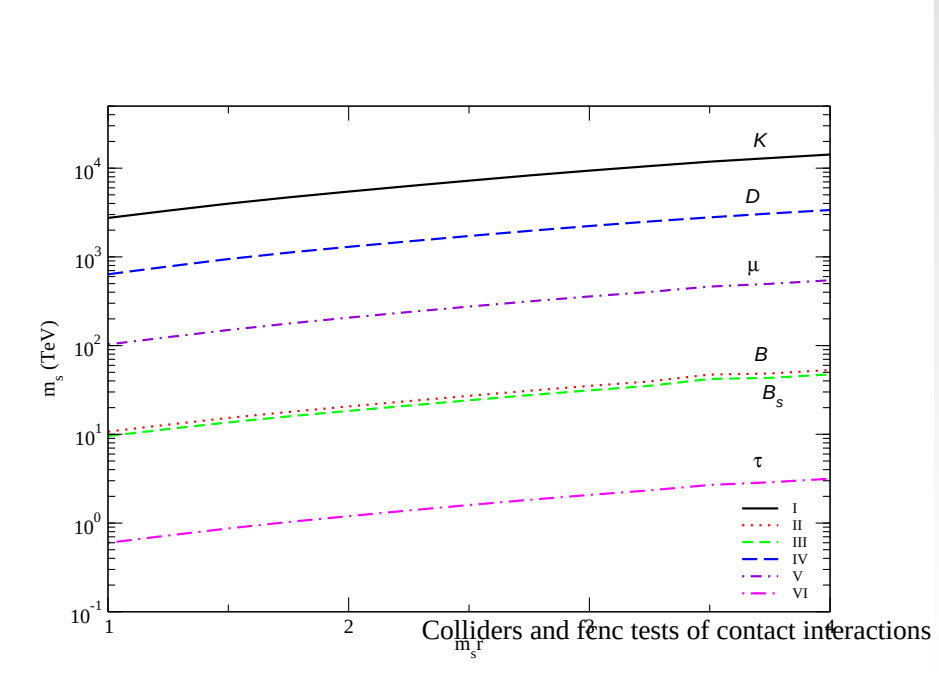
- Mild contributions at LEP I cm energies but promisingly larger ones for 500 GeV linear collider.

FCNC constraints

- Rotation to mass basis introduces unknown flavor mixing matrices (as in models of split fermions or extra $U(1)'$)

$$L_{EFF} = \sum_{f,f'} \sum_{H,H'} \tilde{G}^{HH'}_{ij,kl} [(\bar{f}_{iH} \gamma^{\mu} f_{jH})(\bar{f}'_{kH'} \gamma_{\mu} f'_{lH'})]_{mass} + H.c. \quad (0.4)$$

- Use ansatz $V_H \simeq V_{CKM}$ for a tentative comparison with experimental limits. Strong lower bounds $m_s \geq O(1000)$ TeV, but model dependent. If neglect flavor misalignment reduced to $m_s \geq O(10)$ TeV.



Conclusions

- TeV scale string models with intersecting branes depend on three microscopic parameters $g_s,\ m_s,\ r$ related by matching to low energy theory, $(m_s r)^3 \simeq 2\pi g_s / g_a^2$. Weak coupling condition $g_s \leq 1 \implies m_s r \simeq 1\ -4$.
- Exchange of string winding modes should compete with momentum and oscillator modes. Contributions to dimension 6 four fermion contact interactions possible because of fermion localization at branes intersections. .
- Experimental bounds from indirect collider tests require $m_s \geq (1\ -\ 5)$ TeV for range $m_s r = (1\ -\ 3)$. Observable corrections expected in Bhabha scattering.
- Flavor changing constraints give far stronger bounds $m_s \geq 100$ TeV but sensitive to uncertain information on flavor mixing.