Status of flavor maximal non-minimal Universal Extra Dimension

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SUSY 2017
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Based on work in progress along with
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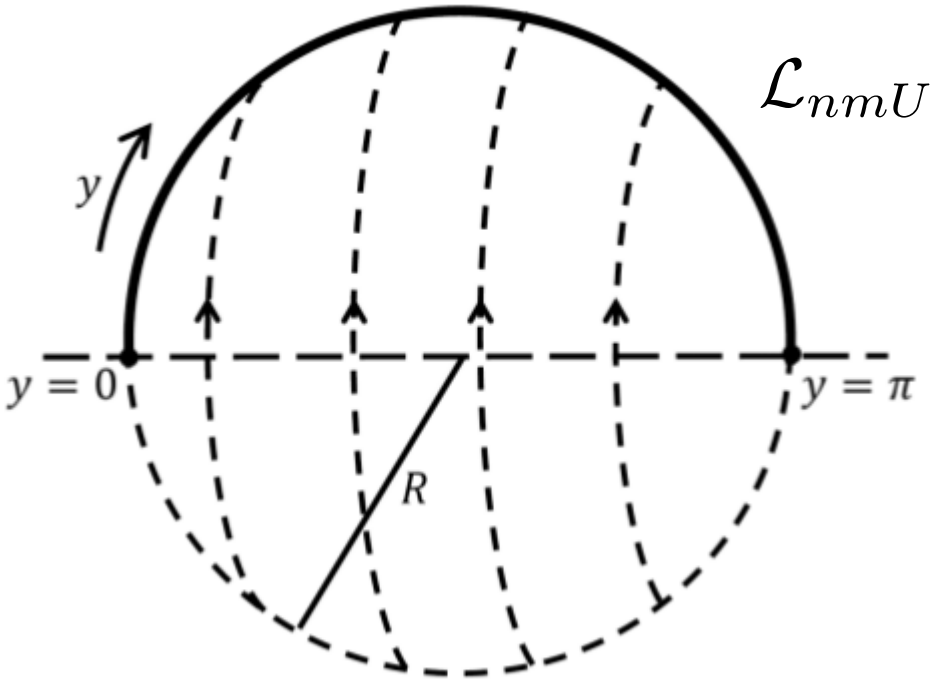
Outline

- The Model
- Choices of BLKT
- Flavor Strucuture
- R_K Constraints
- $R_{D^{(*)}}$ Constraints
- Other Collider Constraints
- Conclusion

The Model



$$\mathcal{L}_{nmUED} = \mathcal{L}_{UED}[1 + r\delta(y) + r\delta(y - \pi R)]$$

$$rM_n = \begin{cases} -2\tan\frac{M_n \pi R}{2} & for\ n\ even \\ 2\cot\frac{M_n \pi R}{2} & for\ n\ odd \end{cases}$$

$$\psi(x,y)_e = \frac{1}{\sqrt{r + \pi R}}\psi^{(0)}(x) + \sqrt{\frac{2}{\pi R}}\sum_1^\infty \left[\frac{1}{\sqrt{1 + \frac{r^2 M_n^2}{4} + \frac{r}{\pi R}}}\right]\psi^{(n)}(x)\cos\frac{ny}{R}$$

$$\psi(x,y)_o = \sqrt{\frac{2}{\pi R}}\sum_1^\infty \left[\frac{1}{\sqrt{1 + \frac{r^2 M_n^2}{4} + \frac{r}{\pi R}}}\right]\psi^{(n)}(x)\sin\frac{ny}{R}$$

$Choices\ of\ BLKT$

Lepton

Generation	BLKT
e, ν_e	R_f^1
μ, ν_μ	R_f^2
τ, ν_τ	R_f^3

Quark

Generation	BLKT
u, d	R_f^1
c, s	R_f^1
t, b	R_f^3

Gauge Bosons, Higgs : R_ϕ

Yukawa : R_Y

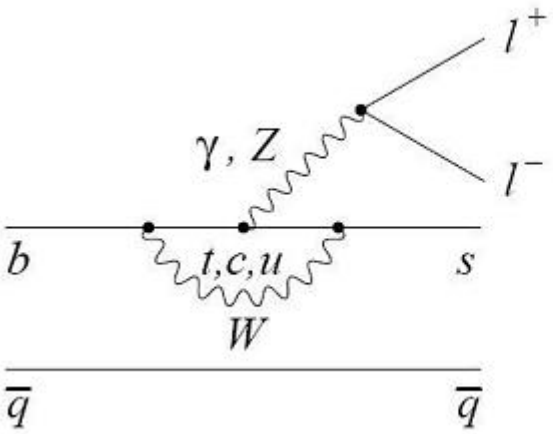
$Flavor\ Structure$

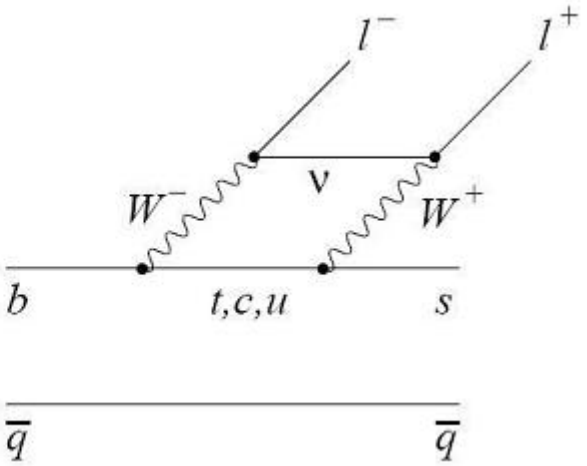
- Different BLKT for different generations leading to U(2) $\times$ U(2) $\times$ U(2) symmetry which is broken by the Yukawa in the quark sector.
- Presence of Flavor Changing Neutral Current in the quark sector primarily between 1,3 and 2,3 generations. No FCNC by SM gauge bosons, only by KK gauge bosons.
- Assuming $m_\nu = 0$ flavor mixing suppressed in the lepton sector by Yukawa.
- Different gauge couplings in different generations because of the different BLKTs.
- $R_Y \neq R_f$ results in absence of flavor violation in the Yukawa sector.

R_K Constraints

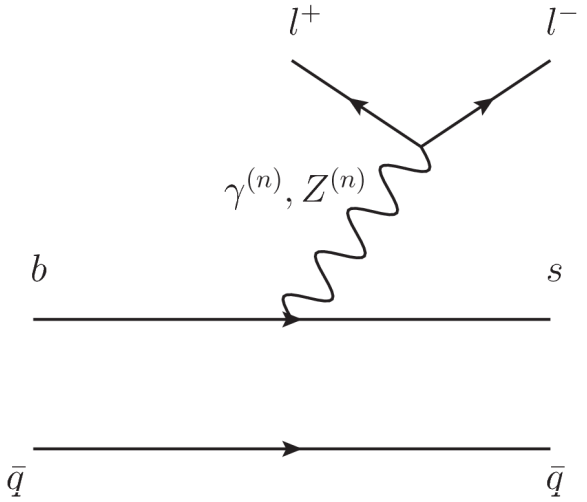
$$R_K = \frac{\mathrm{Br}(\bar{B} \to \bar{K}\mu\mu)}{\mathrm{Br}(\bar{B} \to \bar{K}ee)} = 0.745^{+0.090}_{-0.074} \pm 0.036$$

LHCb Collaboration
PRL 113, 151601 (2014)



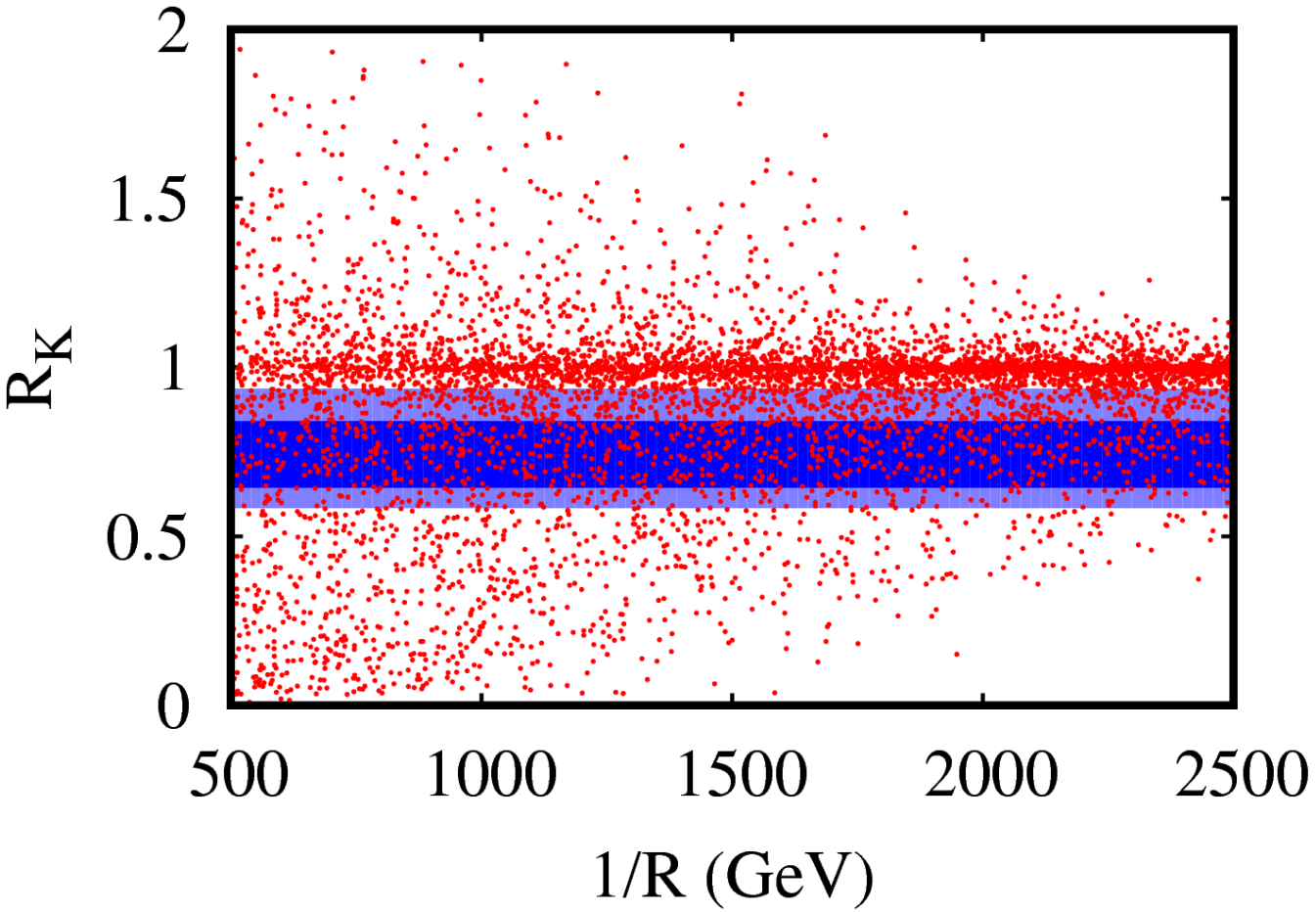


SM



nmUED

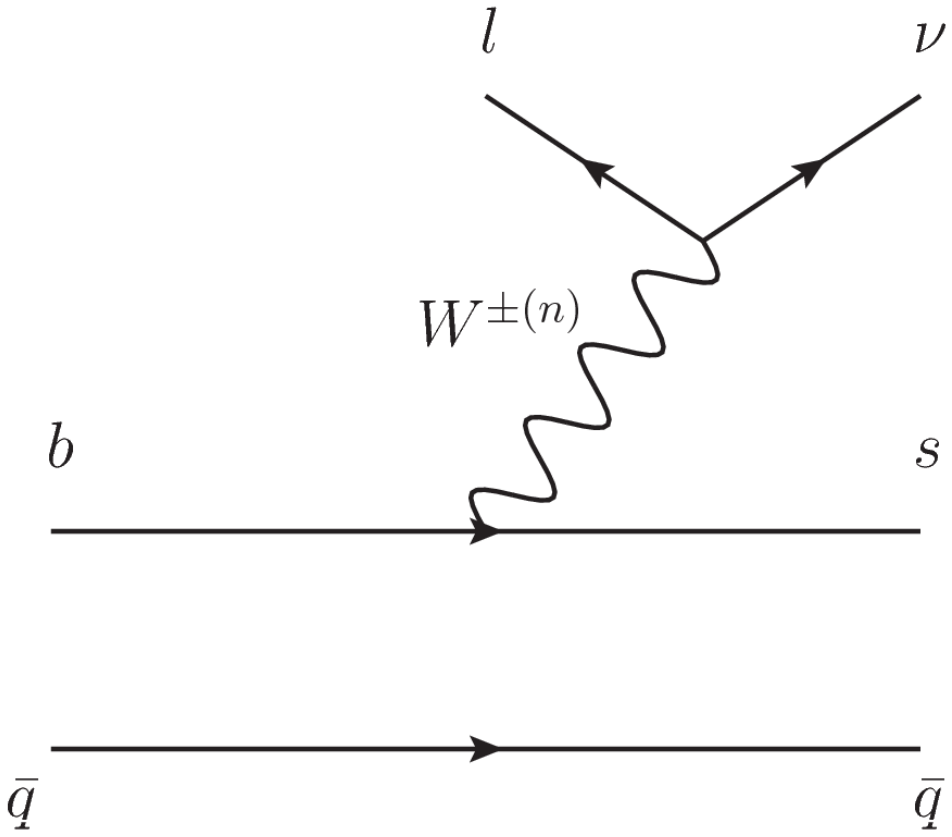
R_K constraints (contd.)



Within our framework the shift in R_K and R_{K^*} are identical, we do not separately present the results of R_{K^*}.

$R_{D^{(*)}}$ Constraints

$$R_{D^{(*)}} = \frac{\mathrm{Br}(\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau)}{\mathrm{Br}(\bar{B} \to D^{(*)}l^-\bar{\nu}_l)} = 0.403(0.310) \pm 0.047(0.017)$$

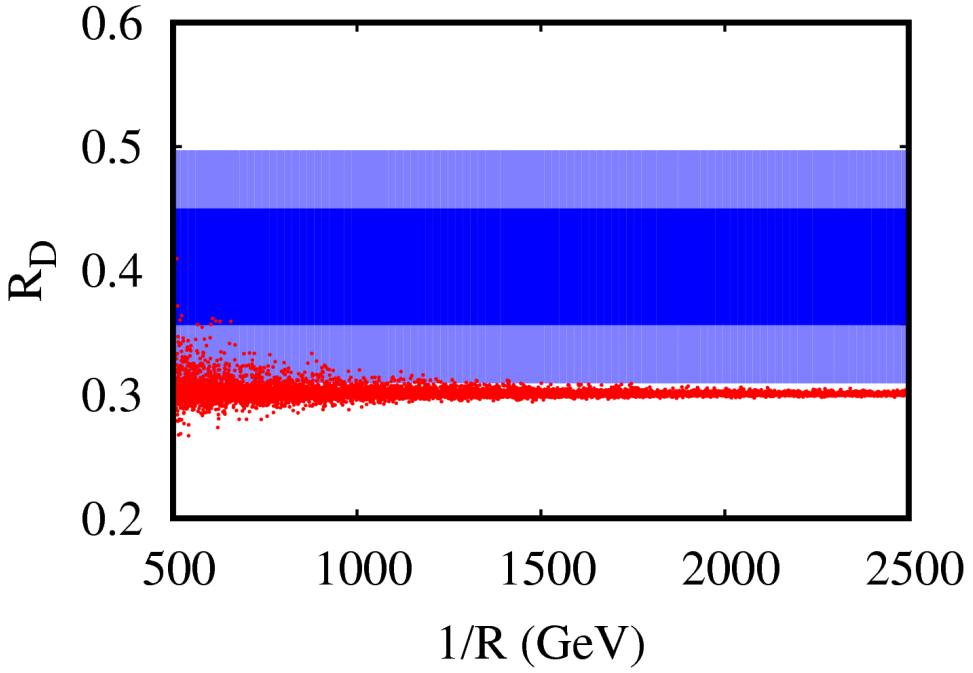


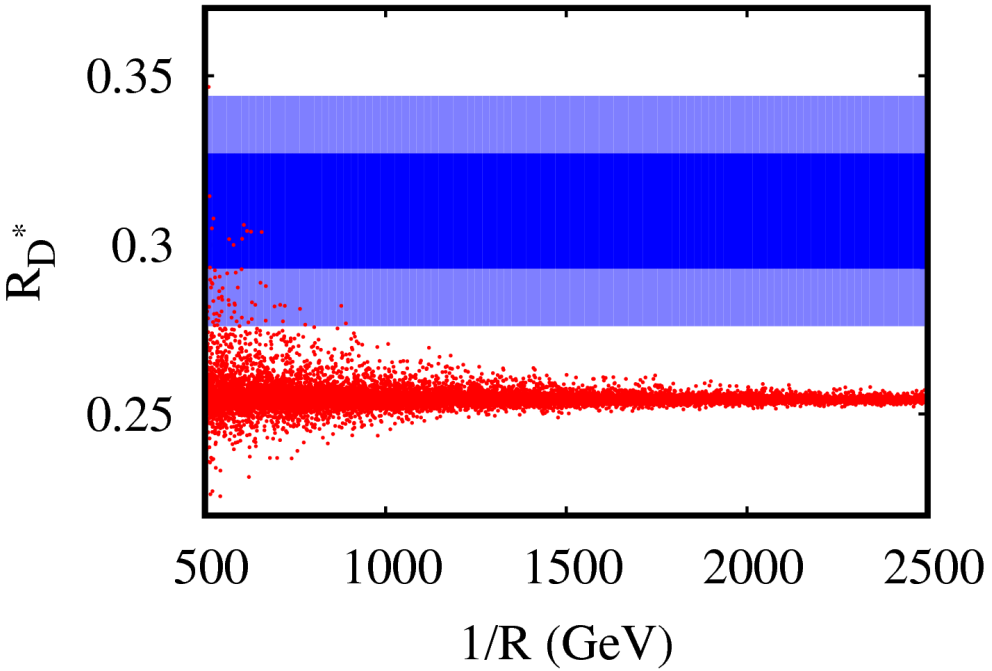
BaBar Collaboration
PRL 109, 101802 (2012)
PR D88, 072012 (2013)

LHCb Collaboration
PRL 115, 111803 (2015)

Belle Collaboration
PR D92, 072014 (2015)
PR D94, 072007 (2016)
PRL 118, 211801 (2017)

$R_{D(*)}$ Constraints (contd.)



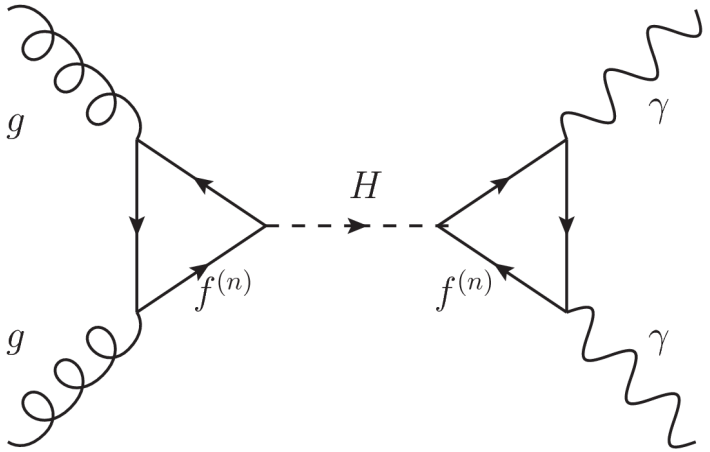


$More\ on\ R_{D(*)}\ in\ nmUED$: *Biswas,Patra and Shaw*
arXiv: 1708.08938

Other Collider Constraints

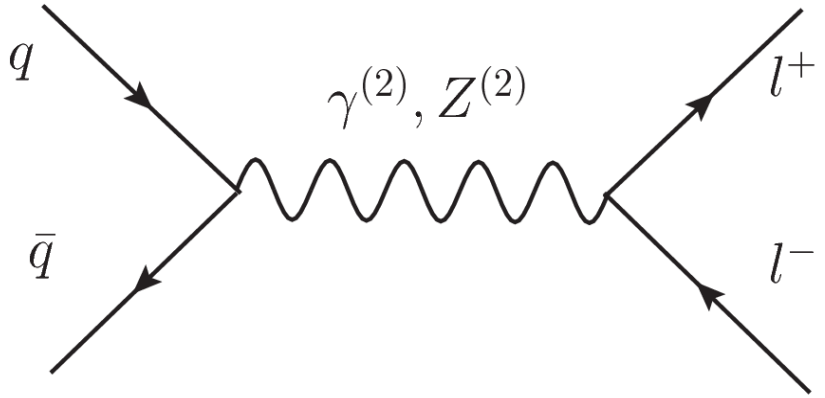
- Virtual Particles in Loop Driven Higgs Process

Ellis,You
JHEP 1306 (2013) 103



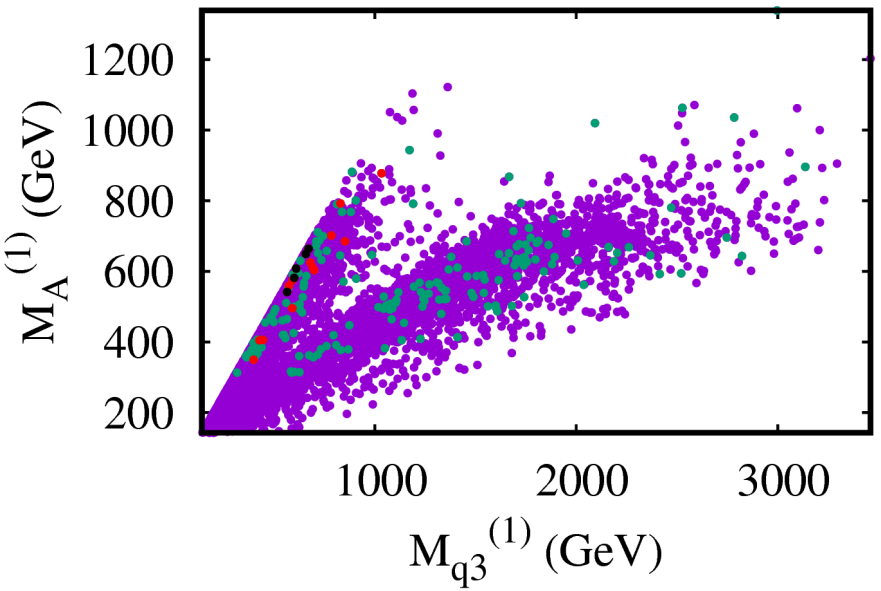
- Direct Dilepton search

Flacke et. al.
JHEP 1704 (2017) 041

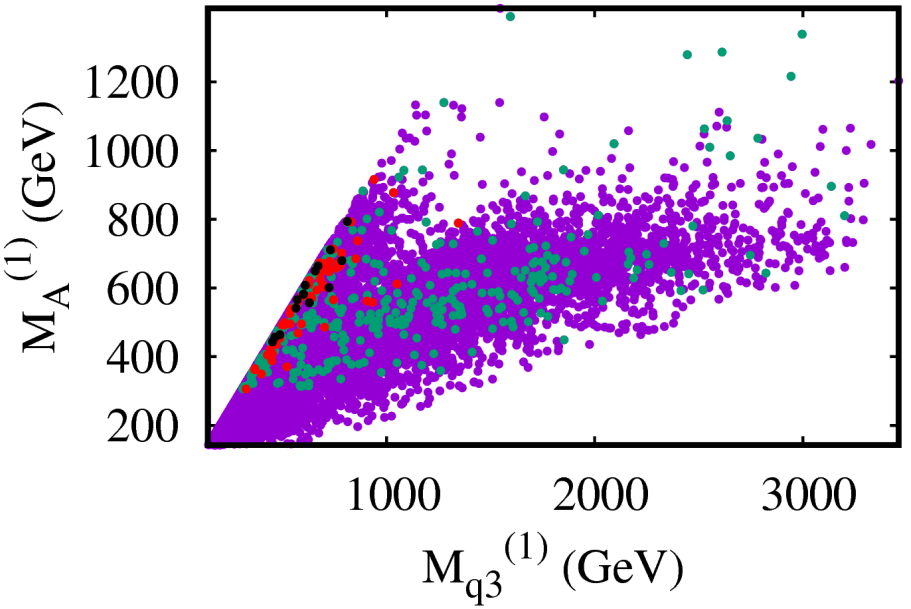


Conclusion

R_K 1 σ



R_K 2 σ



- R_K
- $R_K + Higgs(3\,\sigma)$
- $R_K + Higgs(3\,\sigma) + Precision(3\,\sigma)$
- $R_K + Higgs(3\,\sigma) + Precision(3\,\sigma) + dilepton$

Precision parameters from LEP data *PDG 2014*


Thank You

$$
\begin{aligned}
\mathcal{S}_{\rm quark} \;=\; & \int d^4x \int_0^{\pi R} dy \Big[i\overline{Q}_k \Gamma^M \mathcal{D}_M Q_k + r_{f_k}\{\delta(y)+\delta(y-\pi R)\} i\overline{Q}_k \gamma^\mu \mathcal{D}_\mu P_L Q_k \\
& + i\overline{U}_k \Gamma^M \mathcal{D}_M U_k + r_{f_k}\{\delta(y)+\delta(y-\pi R)\} i\overline{U}_k \gamma^\mu \mathcal{D}_\mu P_R U_k \\
& + i\overline{D}_k \Gamma^M \mathcal{D}_M D_k + r_{f_k}\{\delta(y)+\delta(y-\pi R)\} i\overline{D}_k \gamma^\mu \mathcal{D}_\mu P_R D_k \Big], \\
\mathcal{S}_{\rm gauge} = & -\frac{1}{4}\int d^4x \int_0^{\pi R} dy \Big[\sum_a \left(\mathcal{F}^{MNa}\mathcal{F}^a_{MN} + r_g\{\delta(y)+\delta(y-\pi R)\}\mathcal{F}^{\mu\nu a}\mathcal{F}^a_{\mu\nu} \right) \\
& + \mathcal{B}^{MN}\mathcal{B}_{MN} + r_g\{\delta(y)+\delta(y-\pi R)\}\mathcal{B}^{\mu\nu}\mathcal{B}_{\mu\nu} \Big], \\
\mathcal{S}_{\rm scalar} = & \int d^4x \int_0^{\pi R} dy \Big[\left(\mathcal{D}^M\Phi\right)^\dagger \left(\mathcal{D}_M\Phi\right) + \tilde{\mu}_h^2 \Phi^\dagger\Phi - \tilde{\lambda}_h (\Phi^\dagger\Phi)^2 \\
& + \{\delta(y)+\delta(y-\pi R)\} \Big(r_\phi \left(\mathcal{D}^\mu\Phi\right)^\dagger \left(\mathcal{D}_\mu\Phi\right) \\
& + \mu_B^2 \Phi^\dagger\Phi - \lambda_B (\Phi^\dagger\Phi)^2 \Big) \Big], \\
\mathcal{S}_{\rm Yuk} = & -\int d^4x \int_0^{\pi R} dy \Big[\tilde{y}^u_{ij} \bar{Q}_i \tilde{\Phi} U_j + \tilde{y}^d_{ij} \bar{Q}_i \Phi D_j + r_y\{\delta(y)+\delta(y-\pi R)\} \\
& \times \Big(\tilde{y}^u_{ij} \bar{Q}_{iL} \tilde{\Phi} U_{jR} + \tilde{y}^d_{ij} \bar{Q}_{iL} \Phi D_{jR} \Big) + \text{h.c.} \Big].
\end{aligned}
$$

$$R_K = \frac{\sum_{j=9,10} \left| C_j^{\rm SM} + \Delta C_j^{\mu} + \Delta C_j^{\prime \mu} \right|^2}{\sum_{j=9,10} \left| C_j^{\rm SM} + \Delta C_j^{e} + \Delta C_j^{\prime e} \right|^2},$$

$$\Delta C_9 = \sum_{\substack{X=\gamma,Z \\ \{n\}}} \frac{c g_{\mu_V}^{X^{(n)}}}{M_{X^{(n)}}^2} \left(g_{b_L}^{X^{(n)}} - g_{s_L}^{X^{(n)}} \right), \quad \Delta C_9^{\prime} = \sum_{\substack{X=\gamma,Z \\ \{n\}}} \frac{c g_{\mu_V}^{X^{(n)}}}{M_{X^{(n)}}^2} \left(g_{b_R}^{X^{(n)}} - g_{s_R}^{X^{(n)}} \right),$$

$$\Delta C_{10} = \sum_{\substack{X=\gamma,Z \\ \{n\}}} \frac{c g_{\mu_A}^{X^{(n)}}}{M_{X^{(n)}}^2} \left(g_{b_L}^{X^{(n)}} - g_{s_L}^{X^{(n)}} \right), \quad \Delta C_{10}^{\prime} = \sum_{\substack{X=\gamma,Z \\ \{n\}}} \frac{c g_{\mu_A}^{X^{(n)}}}{M_{X^{(n)}}^2} \left(g_{b_R}^{X^{(n)}} - g_{s_R}^{X^{(n)}} \right),$$

$$\mathcal{L}_{\rm W} = \frac{1}{\sqrt{2}} W_{\mu}^{(n)} \left[g_{d_L^j}^{\prime W} \bar{u}_j P_L \gamma^{\mu} d_j + g_{\ell_L^j}^{\prime W} \bar{\ell}_j P_L \gamma^{\mu} \nu_j \right],$$

Megías, Quirós, Salas PRD 96 075030 (2017)