Warped Extra Dimensional Benchmarks for Snowmass 2013

Seung J. Lee (KAIST)

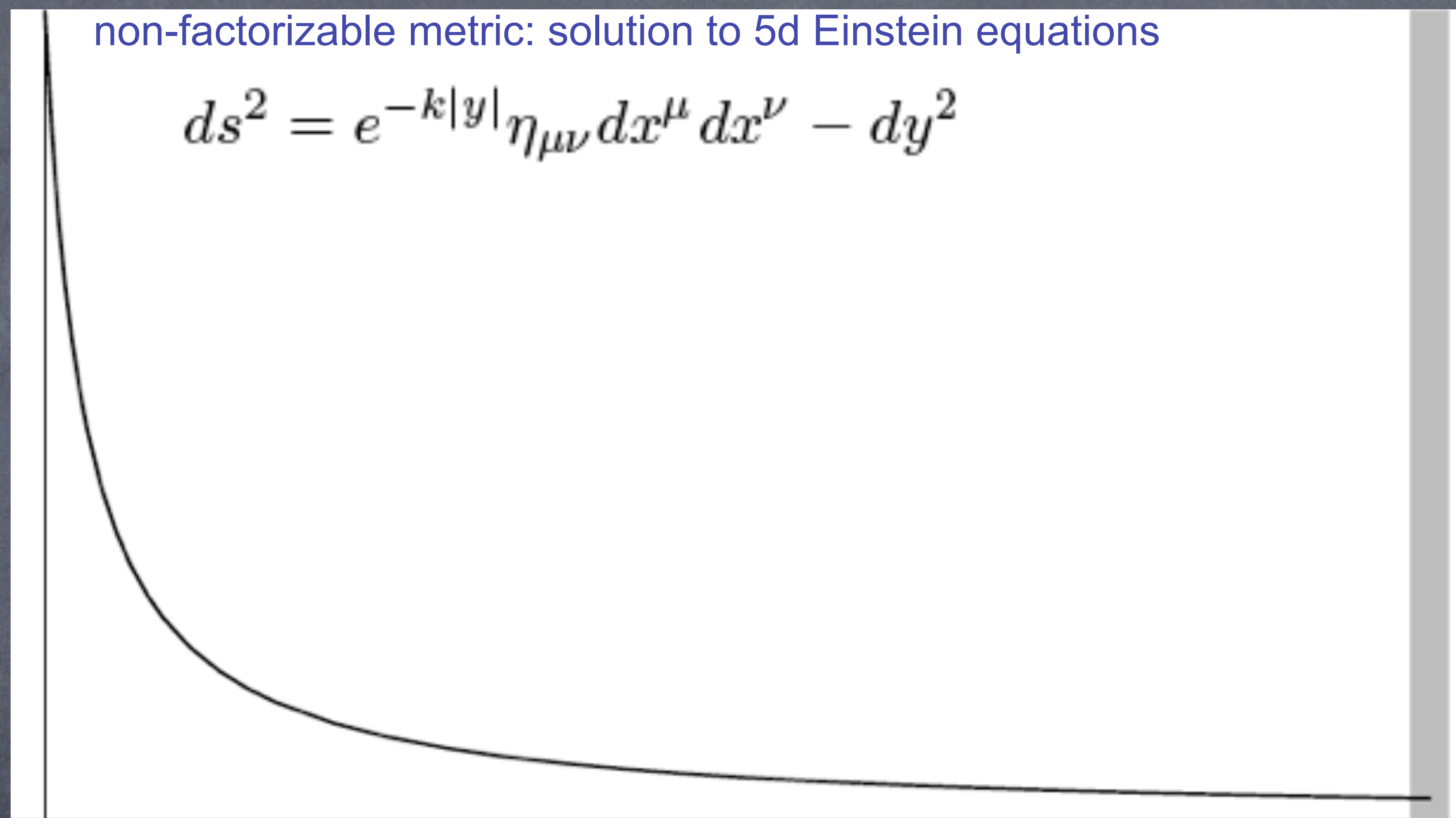
with Kaustubh Agashe, Oleg Antipin, Mihailo Backovic, Aaron Effron, Johannes Erdmann, Tobias Golling, Shrihari Gopalakrishna, Toumas Hapola, Shih-Chieh Hsu, Tanumoy Mandal, Chris Pollard, Daniel Whiteson, Stephane Willcocq

RS & the hierarchy problem

Randall-Sundrum, PRL (99)

- XD curved, but brane remains static and flat

SM+Higgs



UV (y=0)

IR (y=b)

$kL \sim \log(M_{Pl}/\text{TeV})$
~ 30

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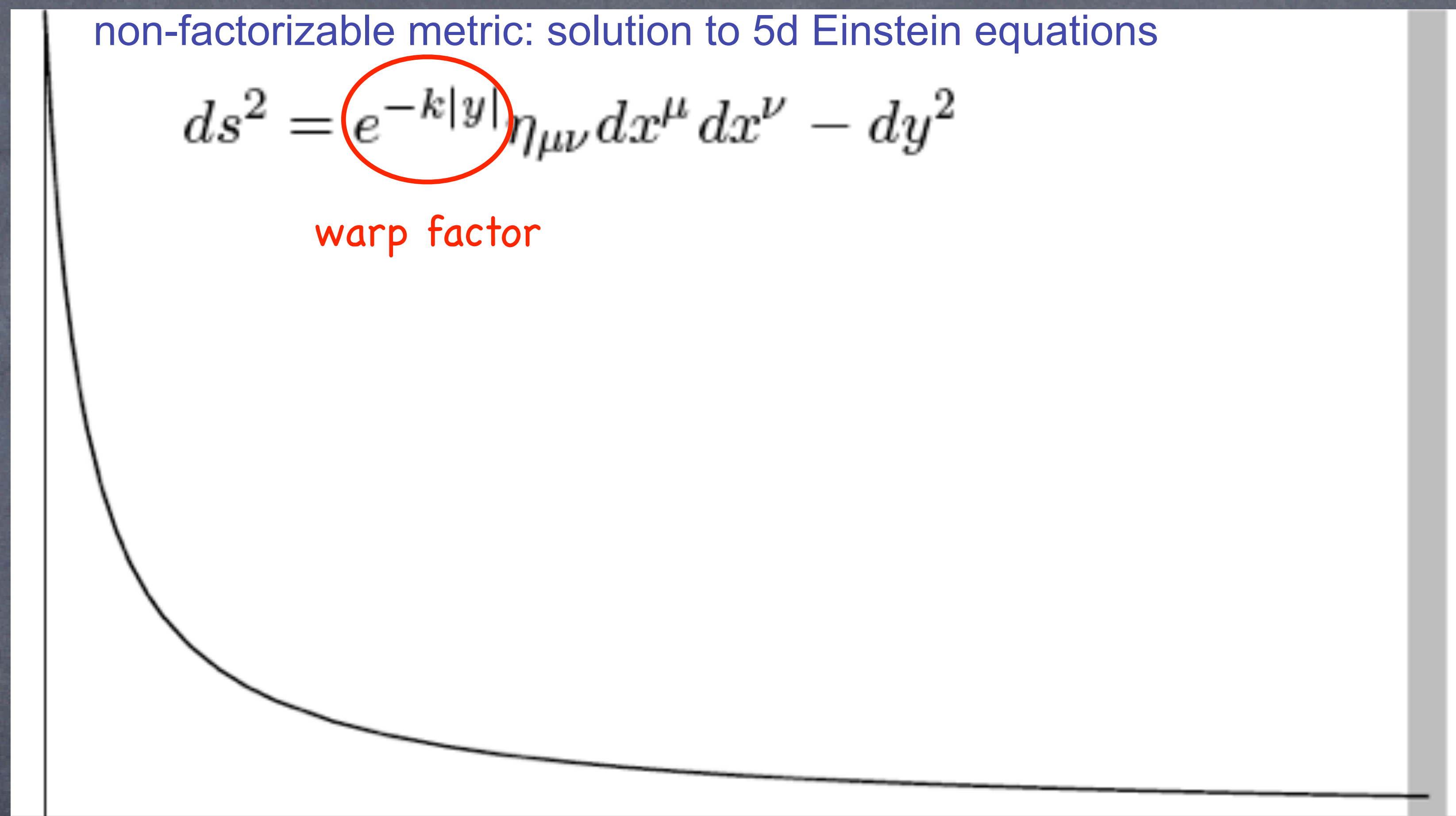

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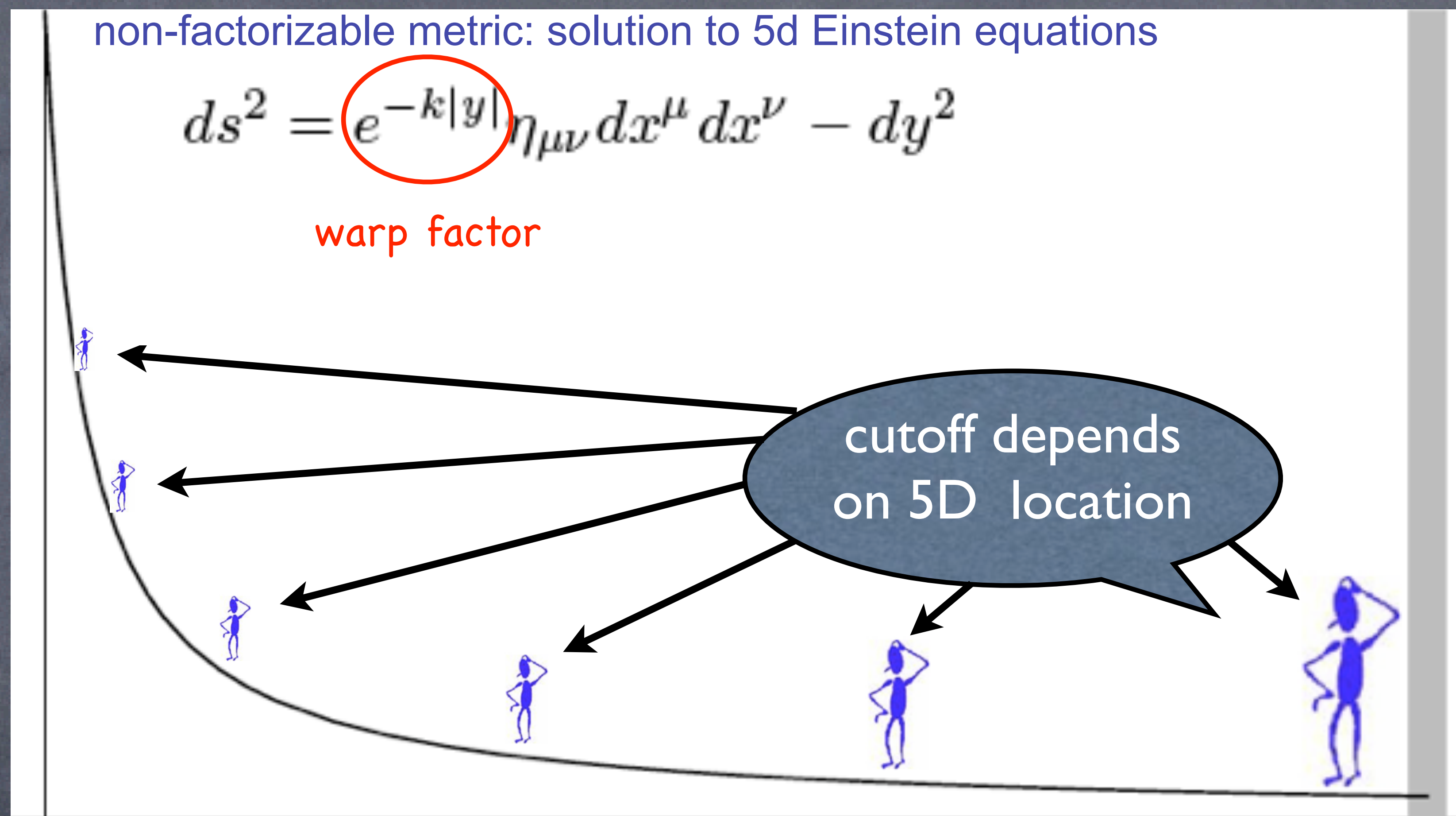

UV (y=0)

IR (y=b)

$kL \sim \log(M_{Pl}/\text{TeV}) \sim 30$

Tuesday, July 2, 2013

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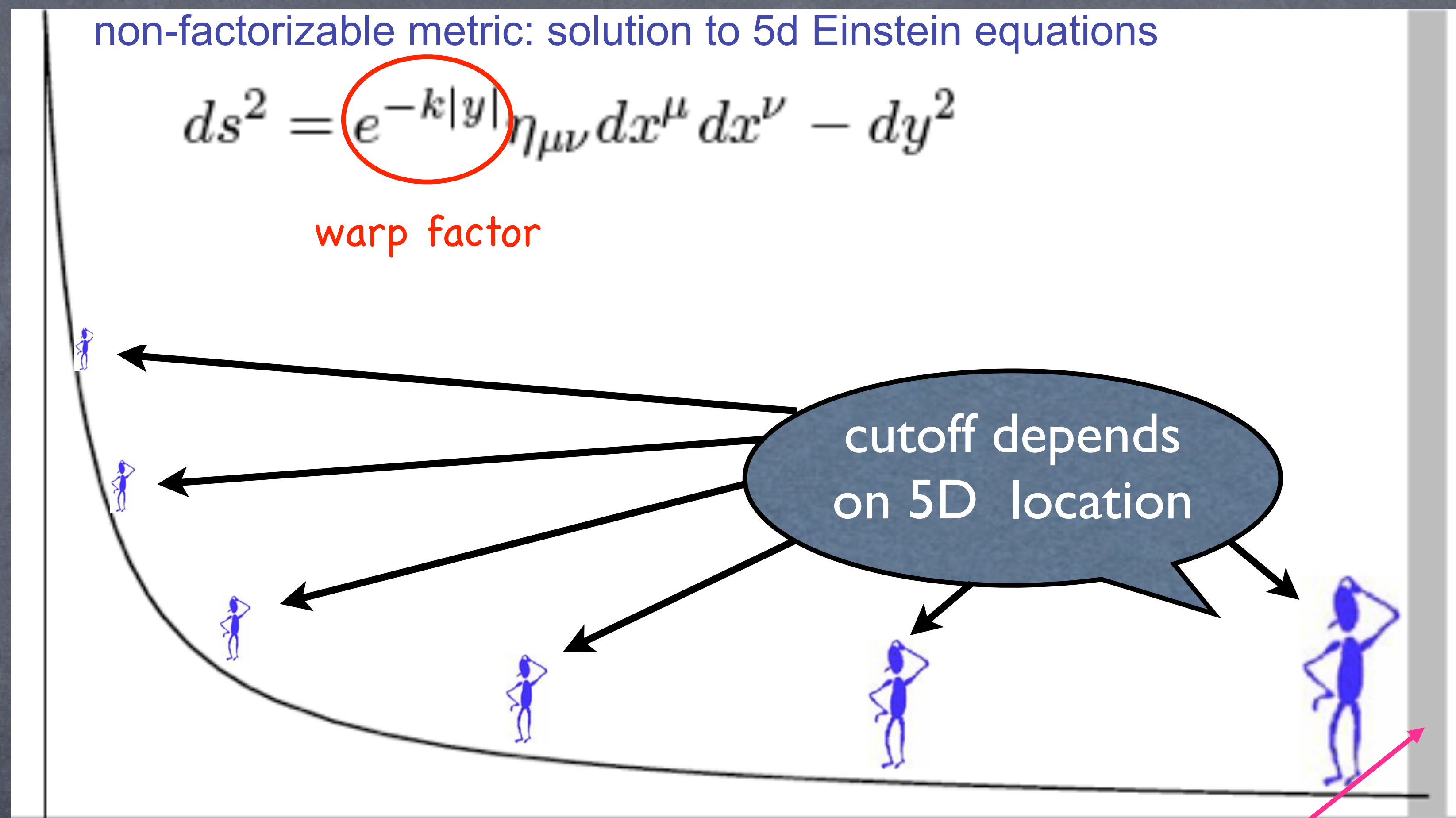

UV (y=0)

IR (y=b)

Assume we live here

(red shift to TeV scale)

Higgs is localized closed to IR brane

kL~ log (M_{pl}/TeV) ~30

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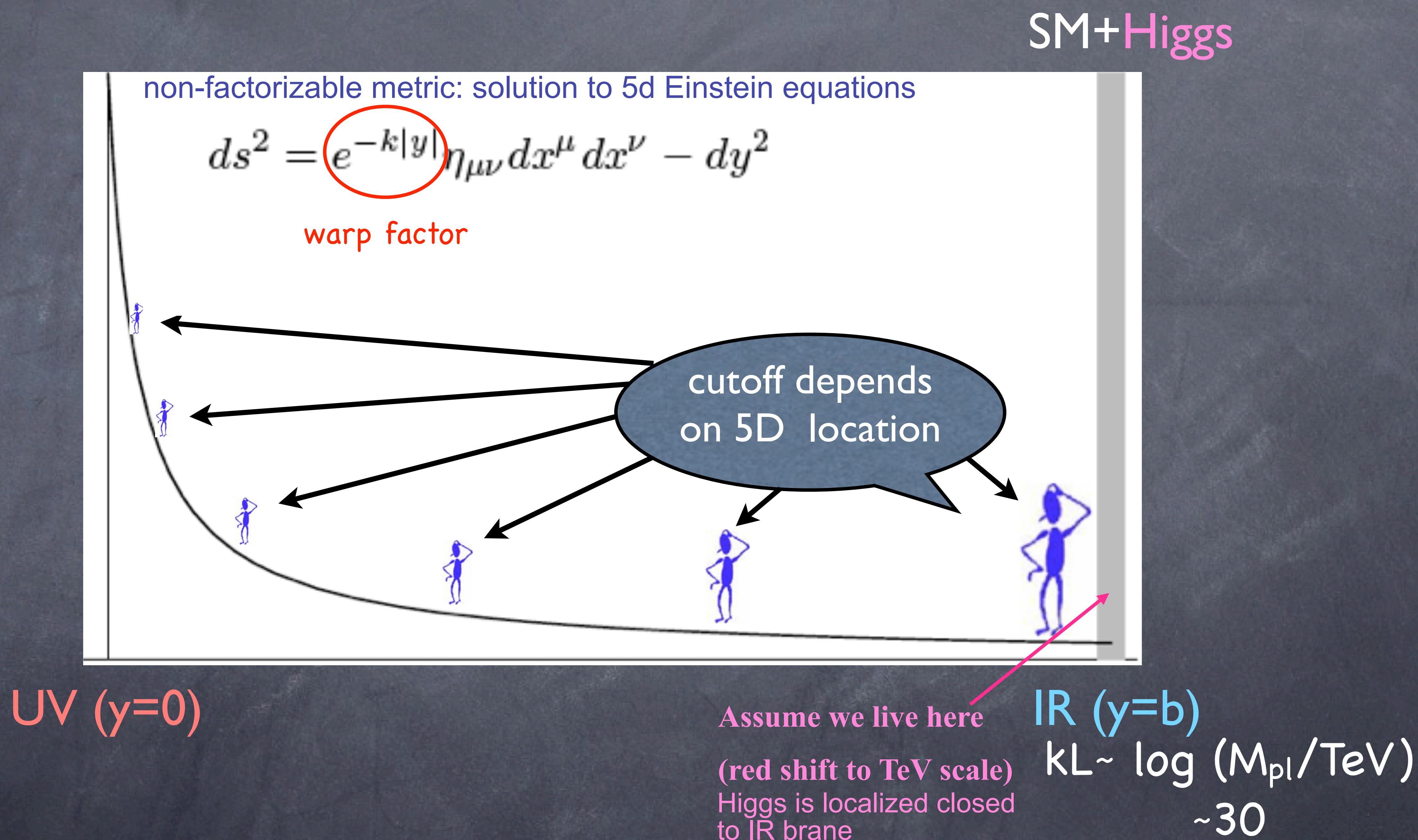
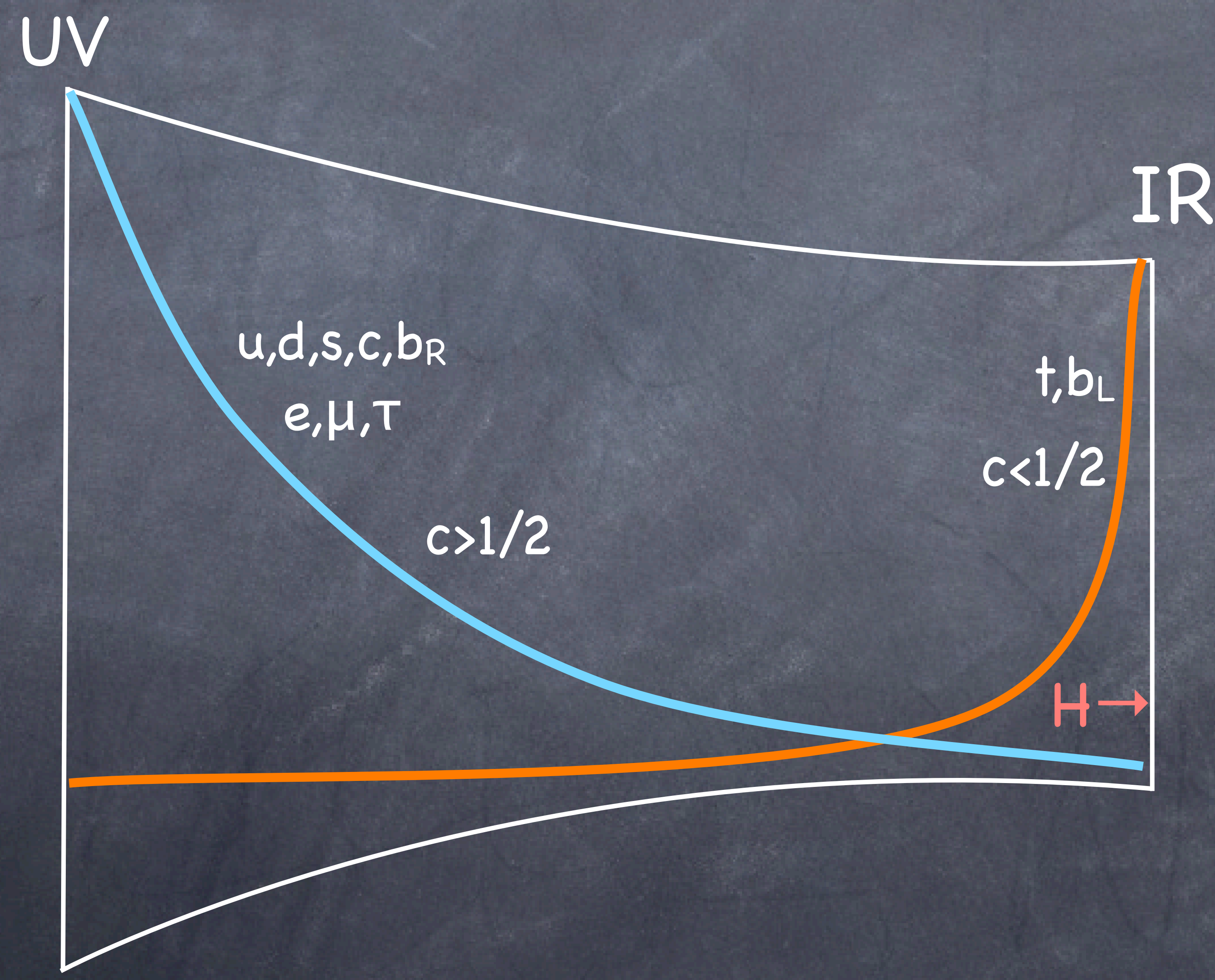


- address the hierarchy problem by providing concrete 5D realizations of various 4D EWSB scenarios: composite higgs, pseudo-Goldstone higgs, etc.

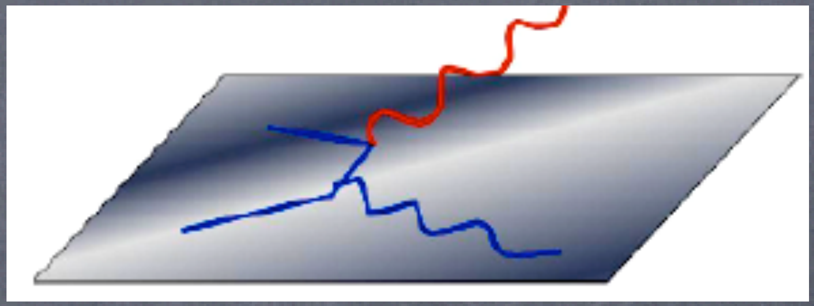
Anarchic RS

- Anarchic model: Localization address flavor hierarchy and also give protection against flavor & CPV



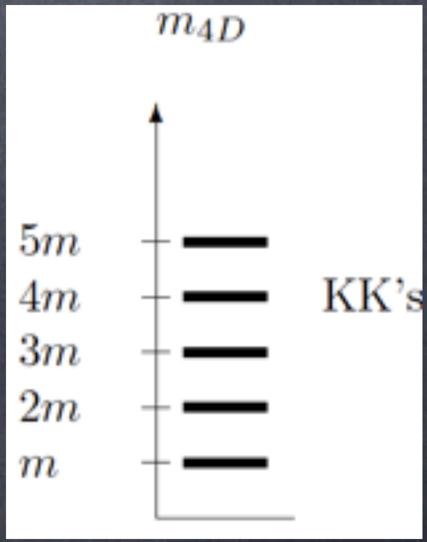
Resonance Searches: New Particles

- As a particle moves in the Extra Dimension its kinetic energy is converted to a group of massive particles in our 4D world

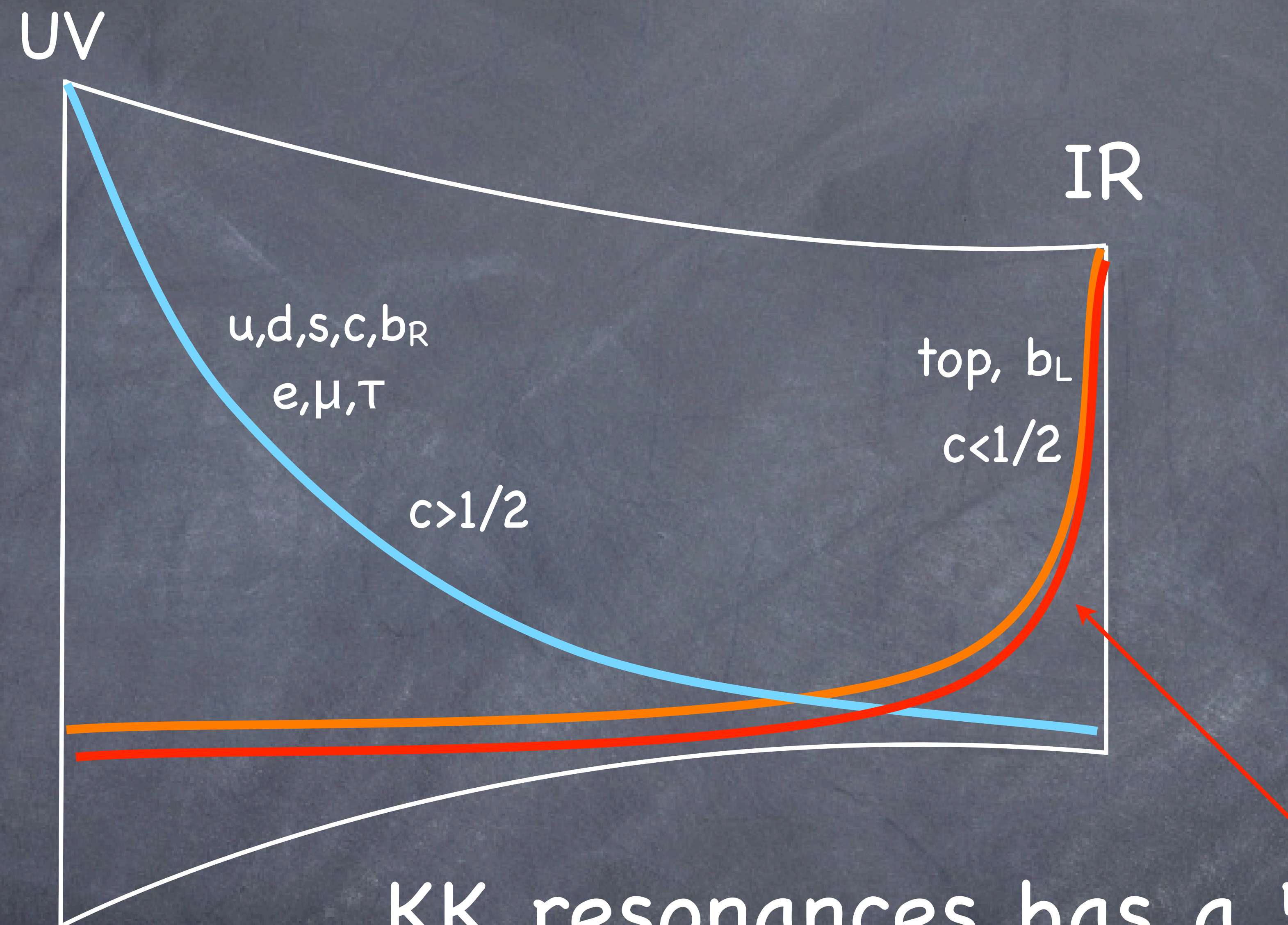


SM particles + tower of their Kaluza Klein (KK) excitations with the same quantum number
+ KK excitation with quantum number ≠ SM
+ new gravity sector

KK mode decomposition of gauge boson: $A^a(x,y) = \sum_n A^a_n(x) f^n(y)$



Resonance Searches: plan for snowmass study



KK resonances has a 5D profile localized near IR brane

They dominantly decay into third generation fermions, massive gauge bosons, and Higgs!

Resonance Searches: plan for snowmass study (overlap with ttbar resonace searhces)

We focus on spin-1 (gauge boson) and spin-2 (graviton) KK particles and their decays to top/bottom quarks (flavor-conserving) and W/Z and Higgs bosons, in particular.

- KK gluon (large width): e.g. KK g -> ttbar, tbar c (covered by RS flavor benchmark part)
- KK gauge bosons: eg. KK Z -> ttbar, Zh; KK W-> Wh, WZ, t+b (can use the W' -> tb analysis)
- KK graviton (ttbar, top polarization studies as well)
- KK fermion (light partner) -> covered by Vector-like fermion searches in simplified models

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analysis is under progress for 14 TeV and 33 TeV with various (e.g. 2, 3, 6, 8 TeV) resonance scales

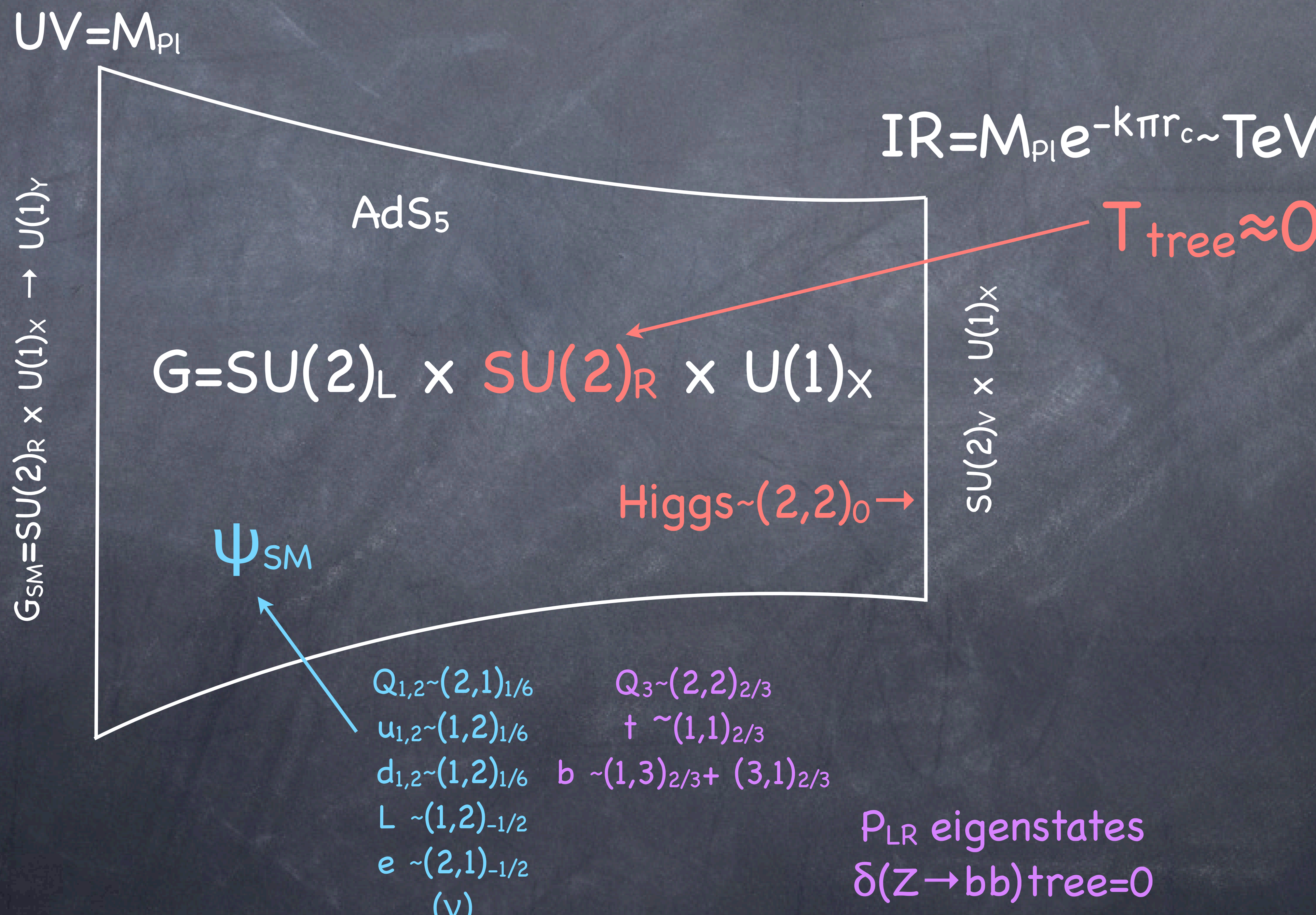
Realistic Warped Extra dimension (RS)

Randall, Sundrum

Agashe, Delgado, May, Sundrum

Agashe, Contino, DaRold, Pomarol

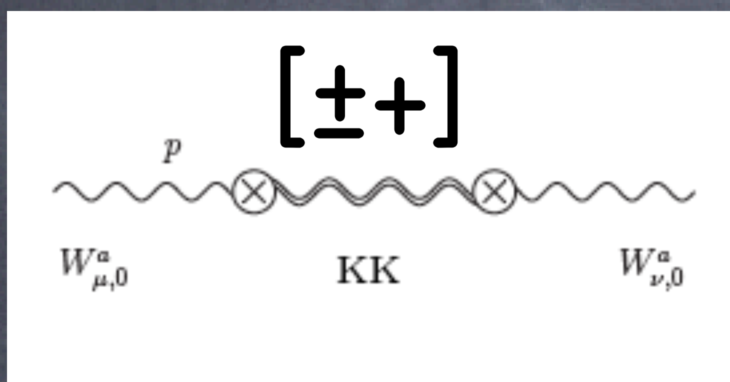
....

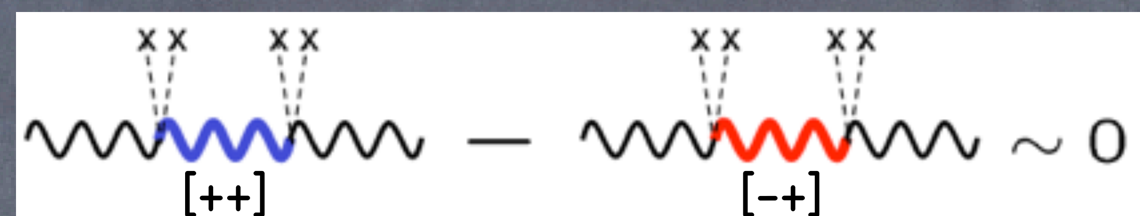


Tree level EWPOs

Agashe, Delgado, May, Sundrum

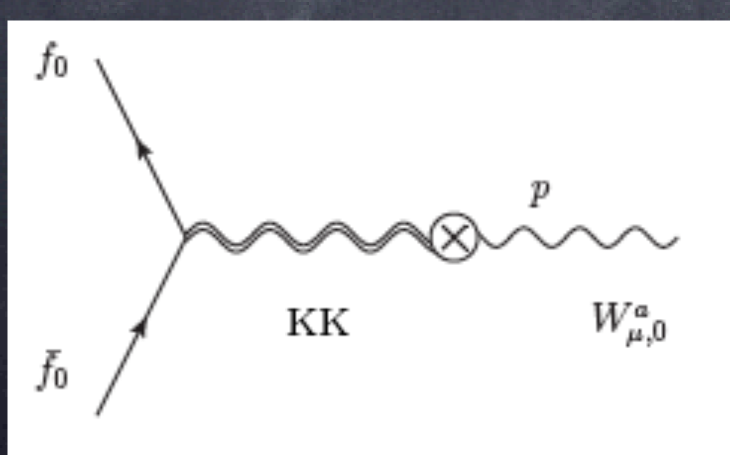
- Custodial symmetry: Avoid large corrections to the Mz/Mw ratio (T parameter): $SU(2)_L$ X $SU(2)_R$

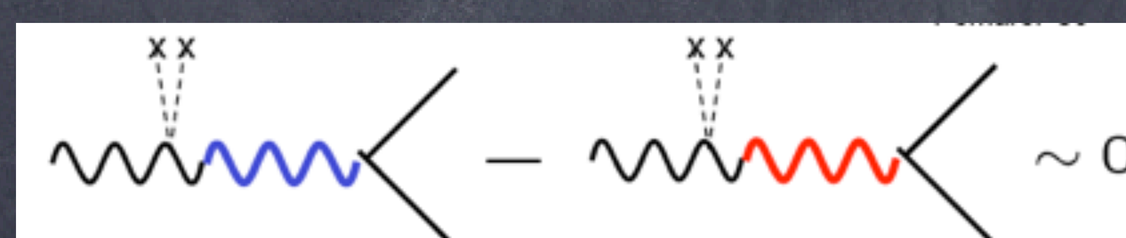




Agashe, Contino, DaRold, Pomarol

- To avoid Large corrections to Zbb coupling, δg_{bL}: impose discrete LR symmetry with $SU(2)_L$ X $SU(2)_R$





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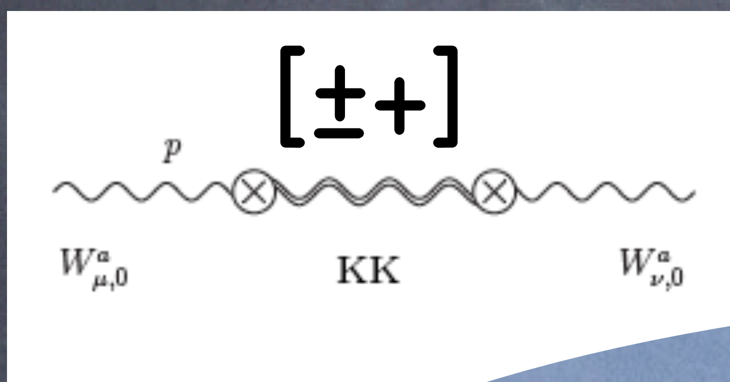
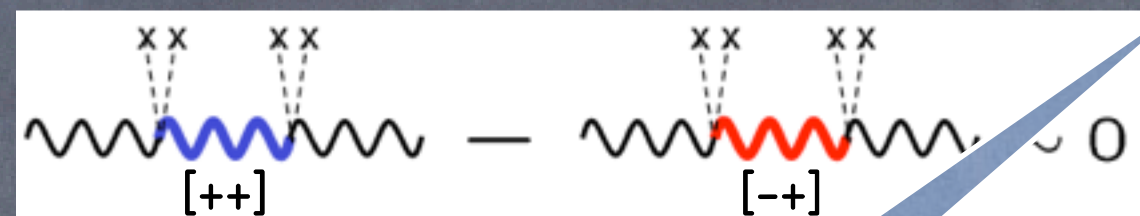
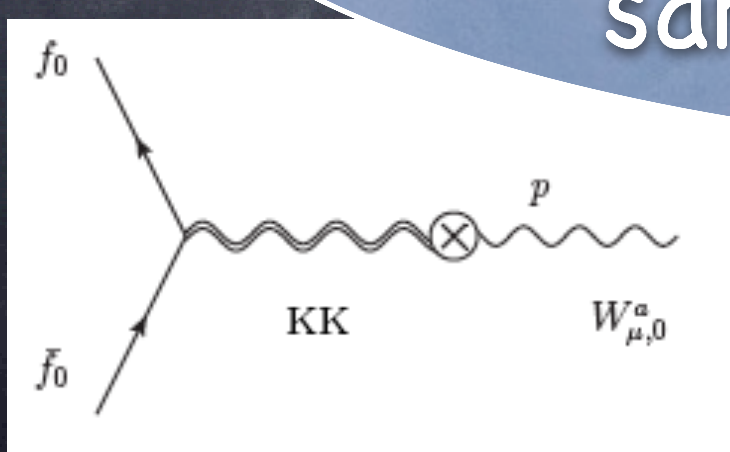


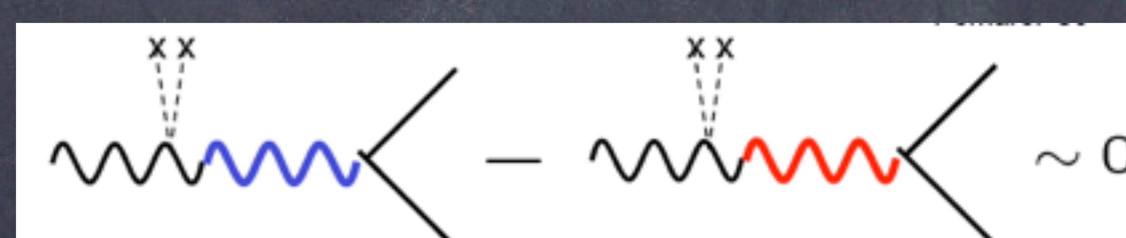


Realistic model
suggests two different type of
charged KK gauge bosons, with the
same coupling strength !

Agashe,

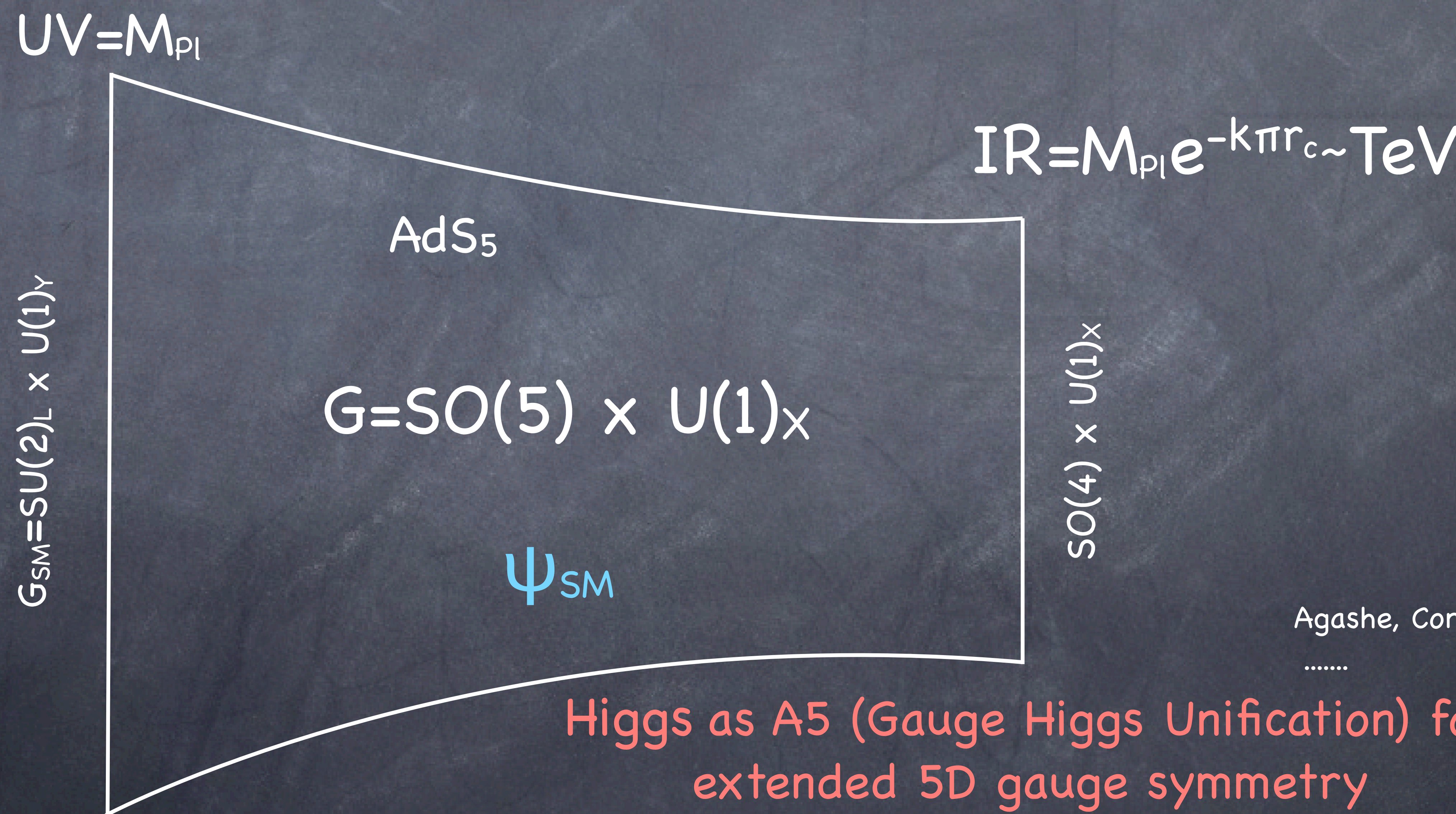
- To ... pose
dis





Realistic Warped Extra dimension (RS)

Little hierarchy with MKK(1) > 2 TeV from EWPT => 5D cut-off should be larger than the KK scale by (roughly) an order-of-magnitude



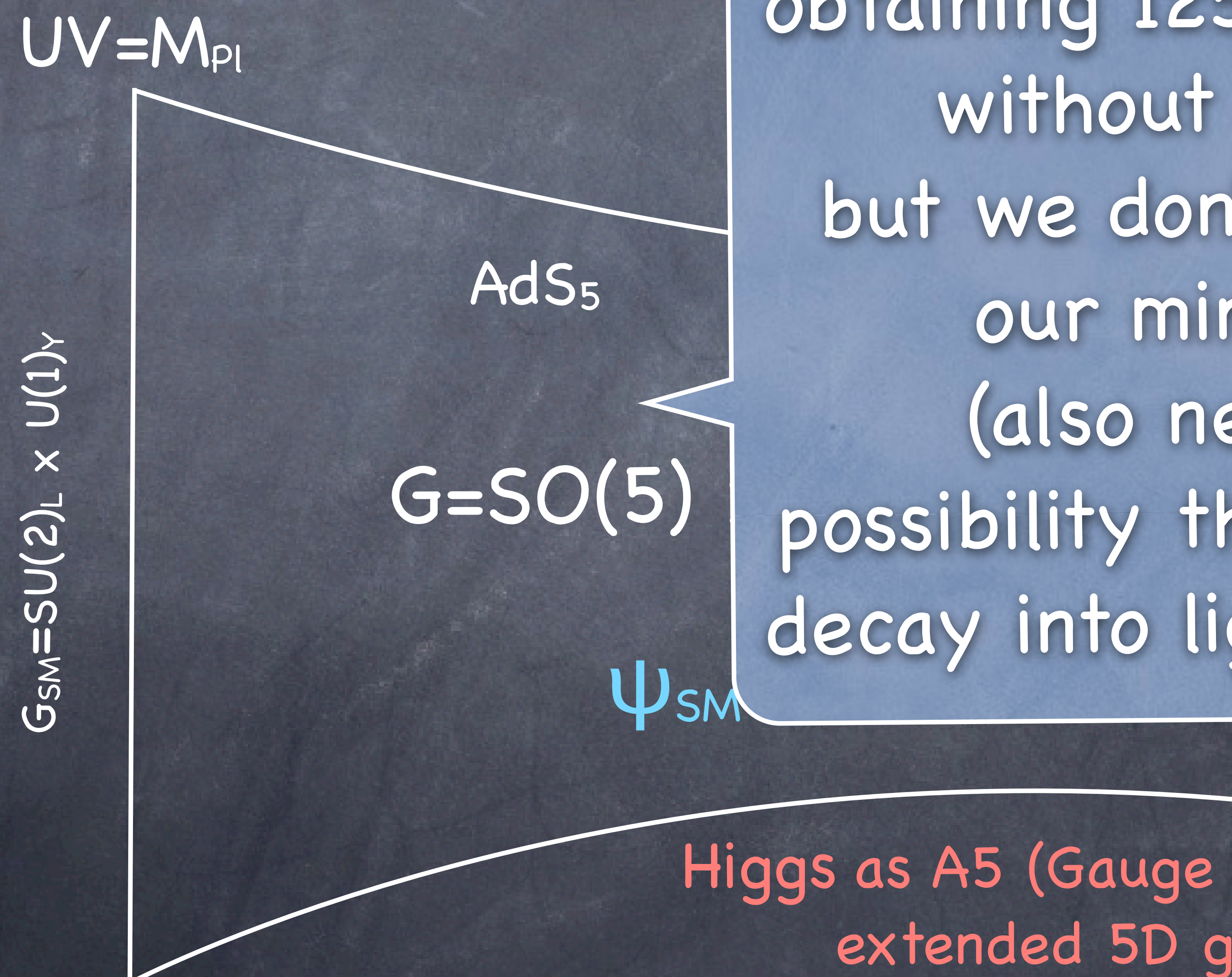
Agashe, Contino, Pomarol
....

Higgs as A5 (Gauge Higgs Unification) for extended 5D gauge symmetry
<=> 4D PGB Higgs in minimal Composite Higgs model

Realistic Warped Extra dimension (RS)

Little hierarchy with MKK(1) > ... should be larger than the KK... magnitude

Light KK partner (as light as 500 GeV) of top has to be light (below ~TeV) for obtaining 125GeV Higgs mass without fine-tuning,
but we don't consider it in our minimal setup
(also neglected the possibility that KK gluon can decay into light KK fermions)



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Benchmark Models

(0810.1497)

Q(2,2)$_{2/3}$ SU(2)$_R$ U(1)$_Q$

SU(2)$_L$

$$\begin{pmatrix} X_L(-,+) & t_L(+,+) \\ T_L(-,+) & b_L(+,+) \end{pmatrix}_X \sim (2,2)_{2/3} \sim \begin{pmatrix} 5/3 & 2/3 \\ 2/3 & -1/3 \end{pmatrix}.$$

Y=T$_{3R}$+X

We consider two cases for the t_R representations

$$\text{Case I} \quad : \quad t_R \to (1,3)_{2/3} \oplus (3,1)_{2/3} = \begin{pmatrix} \chi''_R \\ t_R \\ B''_R \end{pmatrix} \oplus \begin{pmatrix} \chi'''_R \\ T'''_R \\ B'''_R \end{pmatrix}$$

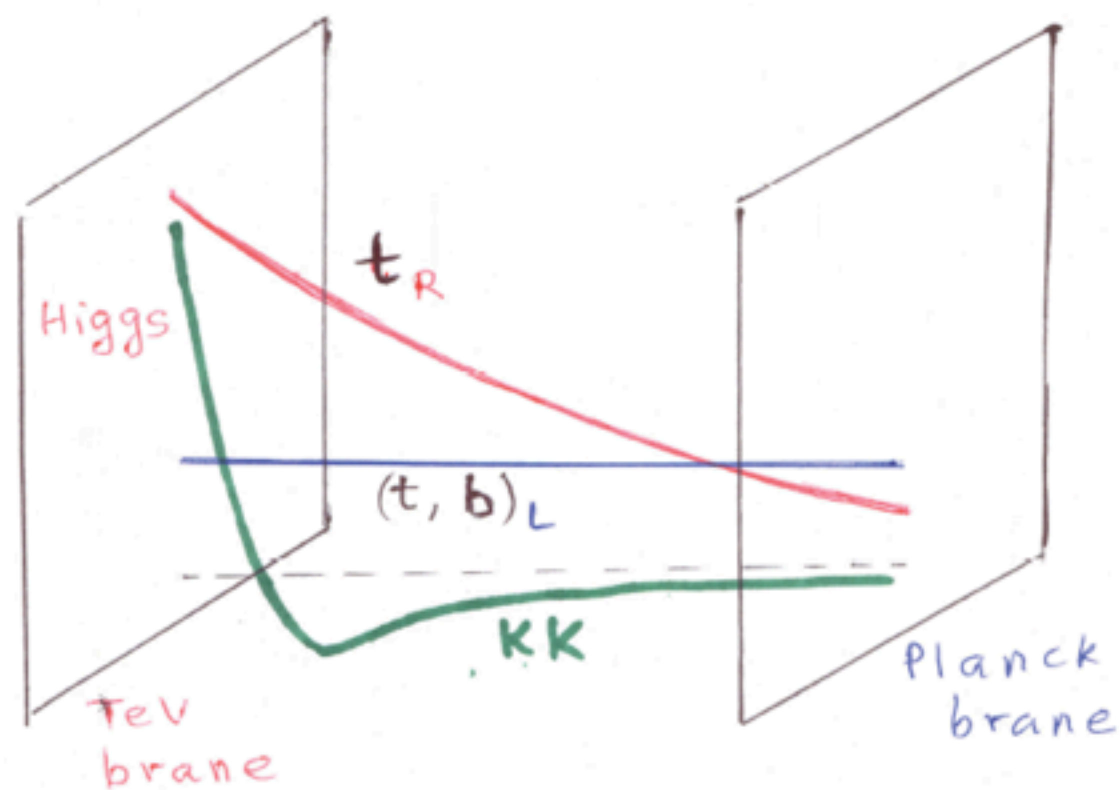
$$\text{Case II} \quad : \quad t_R \to (1,1)_{2/3} \ ,$$

I. RH top (no bottom) near TeV brane

- Right-handed (RH) or LH top near TeV brane is enough
- no bottom in final state in case I
- KK gluon, Z and graviton decay to RH top (not LH): polarization asymmetry, measured by energy/direction of lepton

(hep-ph/0612015; 1010.1458...)

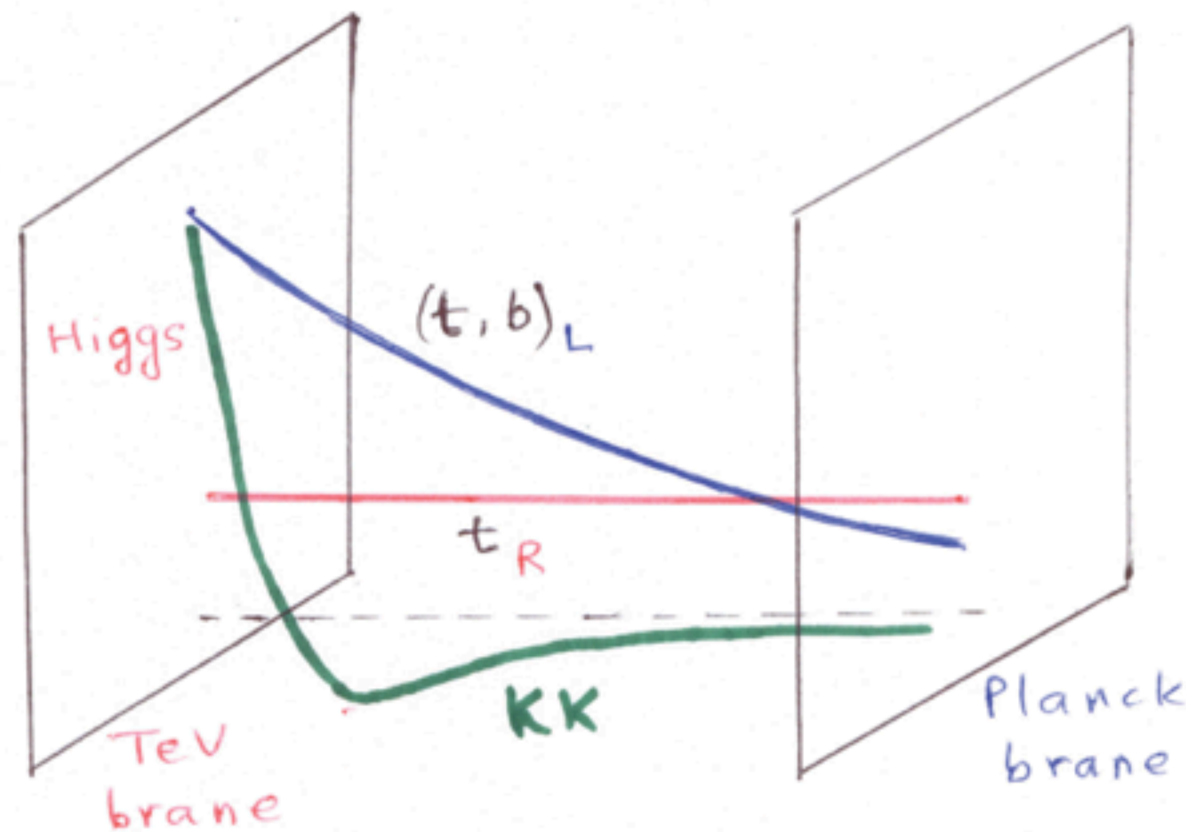
from Kaustubh Agashe's talk file



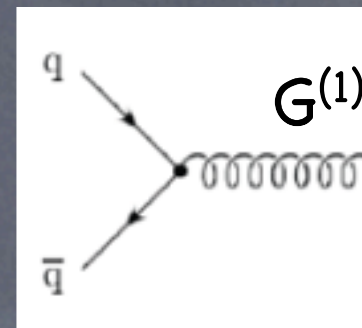
II. LH top (and bottom) near TeV brane

- bottom into play
- top polarization asymmetry opposite to case I

from Kaustubh Agashe's talk file



KK gluon
(adapted from 0810.1497)

- Producton (via $q\bar{q}$): 

$=g^* \left(\frac{1}{k\pi r_c} - f_{c_q}^2 \right).$

coupling to light quarks is -0.2 of SM QCD (for both cases I and II)

(SM QCD coupling evaluated at a few TeV is $\approx$ 1)

- Decay (into top/bottom):

	Case I	Case II
$(t, b)_L$	1	3.9
t_R	3.9	1

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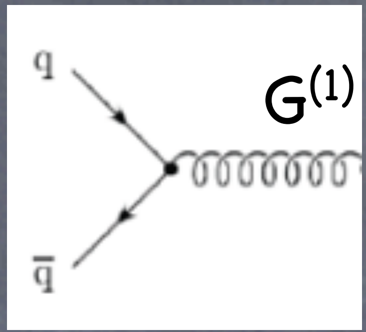
- Producton (via $q\bar{q}$): 

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KK gluon: boosted tops (also for KK Z and KK graviton)

Agashe, Belyaev, Krupovnickas, Perez, Virzi; Lillie, Randall, Wang

Status (analysis in the progress in various top-tagging method)

- 14 TeV 300/fb vs 3000/fb and 33 TeV 3000/fb planned for Minnesota
  - 14 TeV (m_{kkg}=2 & 3 TeV)
  - 33 TeV (m_{kkg}=5, 6 & 8 TeV)
- Various top-tagging methods are employed for all hadronic and lepton+jet, including new leptonic template overlap method for lepton+jet channel.
- polarization study might be done (also for KK graviton)

Some Issues we will quantify / address

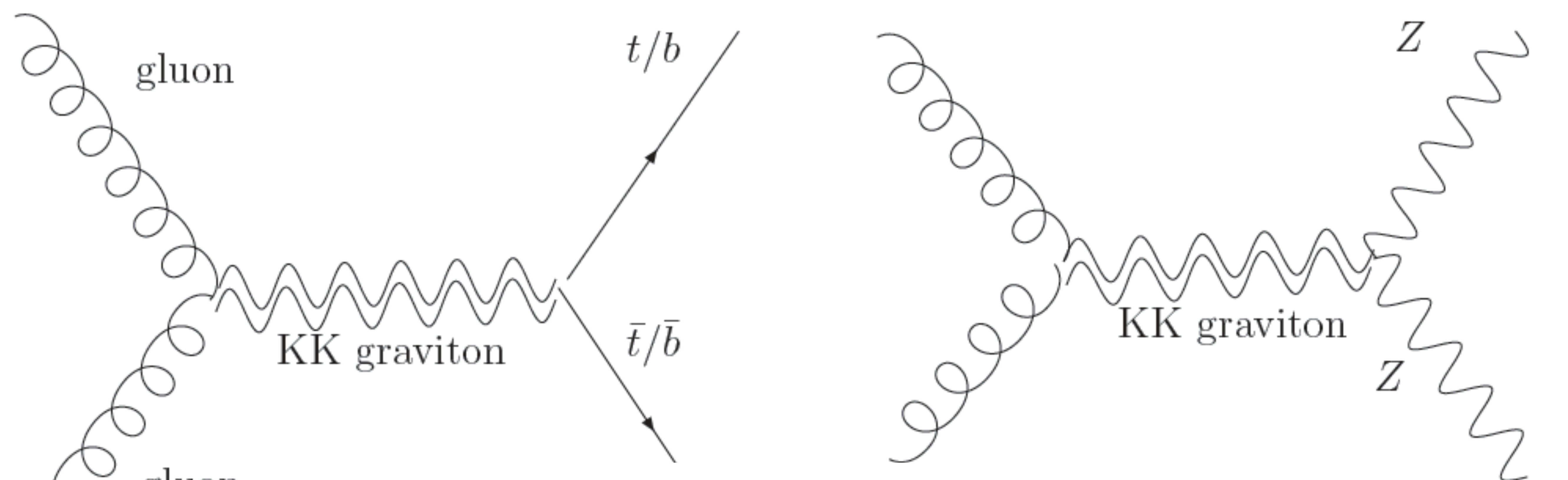
- Boosted Top tagging analysis becomes limited when collimation level reaches beyond detector resolution
- hadronic top tagging becomes challenging for p_T (top) > 1.5 TeV, as QCD background with additional shower mimics three-body top decay more efficiently.
- However, even for m_{kkg} = 8 TeV, there seems to be a non-negligible fraction of events with pT < 1.5 TeV (or PT < 1 TeV).
- pile-up

BR:

	Case I	Case II
$(t,b)_L$	~ 0	9/22 each
t_R	9/13	~ 0
h	1/13	1/22
W_L	2/13	2/22
Z_L	1/13	1/22

KK graviton

$gg \rightarrow \text{KK graviton} \rightarrow ZZ,\, WW,\, hh$ (and $t\bar{t}$, $b\bar{b}$)

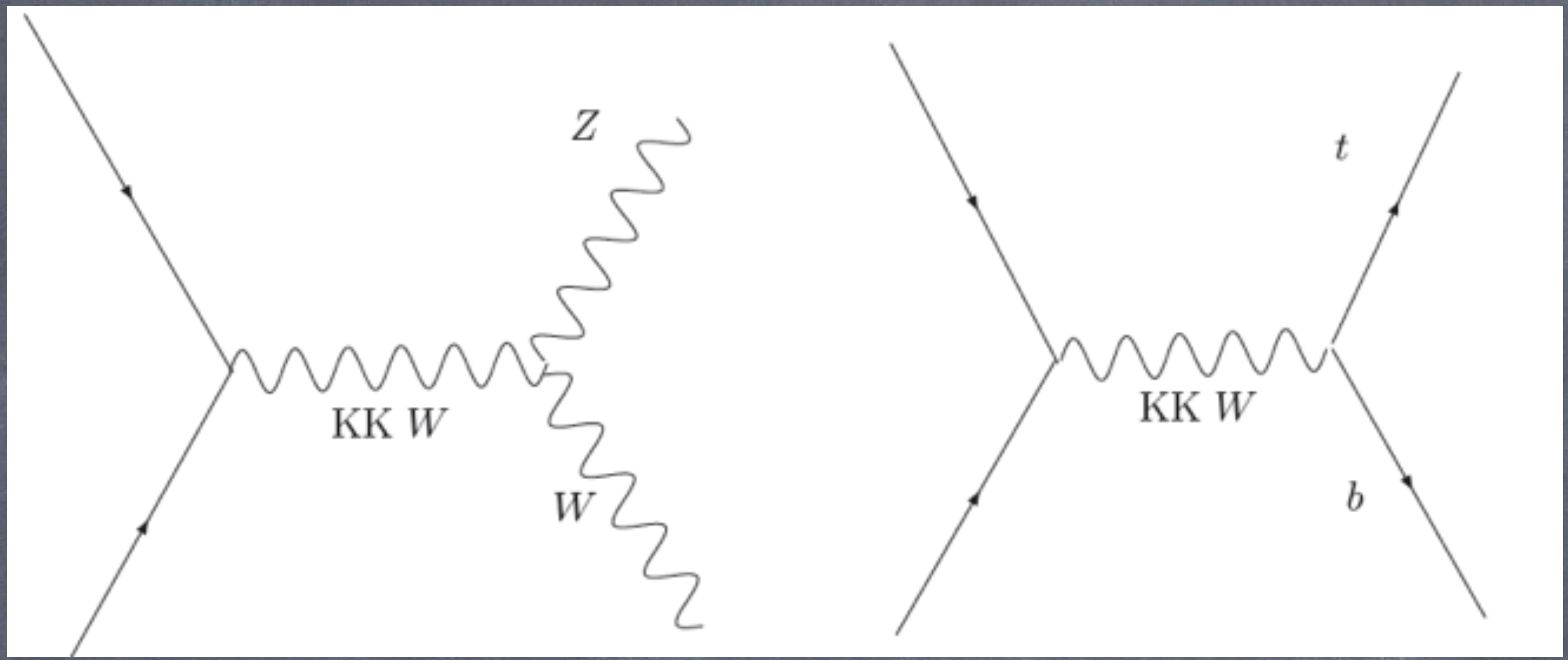


$$\mathcal{L}_{\text{prod.}} = 0.053\frac{c}{M_{G^{(1)}}}\eta^{\mu\alpha}\eta^{\nu\beta}h^{(1)}_{\alpha\beta}(x)T^{\text{gluon}}_{\mu\nu}(x)$$

t tbar: planned to be done before Minnesota meeting as a part of generic t tbar resonances (good place for top polarization study)

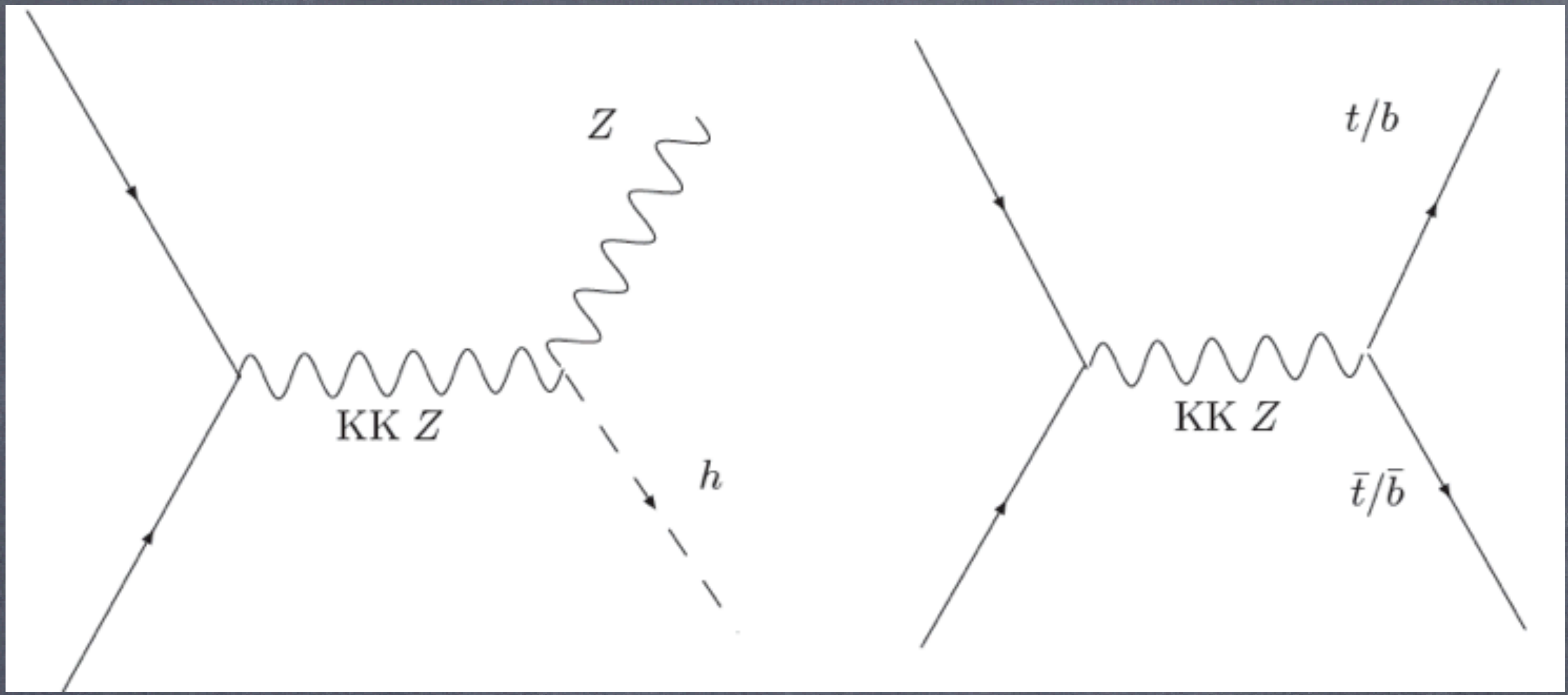
WW/ZZ: Oleg Antipin and Toumas Hapola are doing this for various KK masses for both LHC14 and 33.

KK W



- Wh, WZ: might be done (e.g., if there's manpower)
- tb: can use the W' -> tb analysis.

KK Z



- WW, Zh: might be done

How far can 14 TeV and 33TeV machine reach for resonance searches?

will have an answer for Minnesota