Implications of Higgsless Models of EWSB

Note Title 1/6/2004

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OUTLINE

1) HIGGSLESS EWSB

2) PHENOMENOLOGICALLY VIABLE MODEL

3) MORE UNITARITY ISSUES

4) COLLIDER PHENOMENOLOGY

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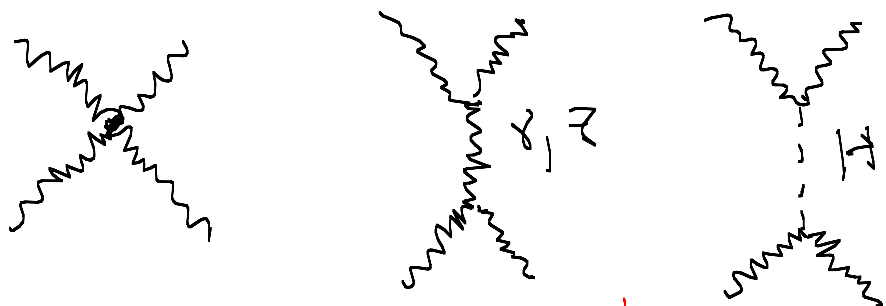
hep-ph/0312193

WHAT IS THE HIGGS FOR?

- GIVES MASS TO THE W, Z
- UNITARIZES $W_L W_L \to W_L W_L$ SCATTERING AMPLITUDE

$$A = as^2 + bs + c + O\left(\frac{1}{s}\right)$$



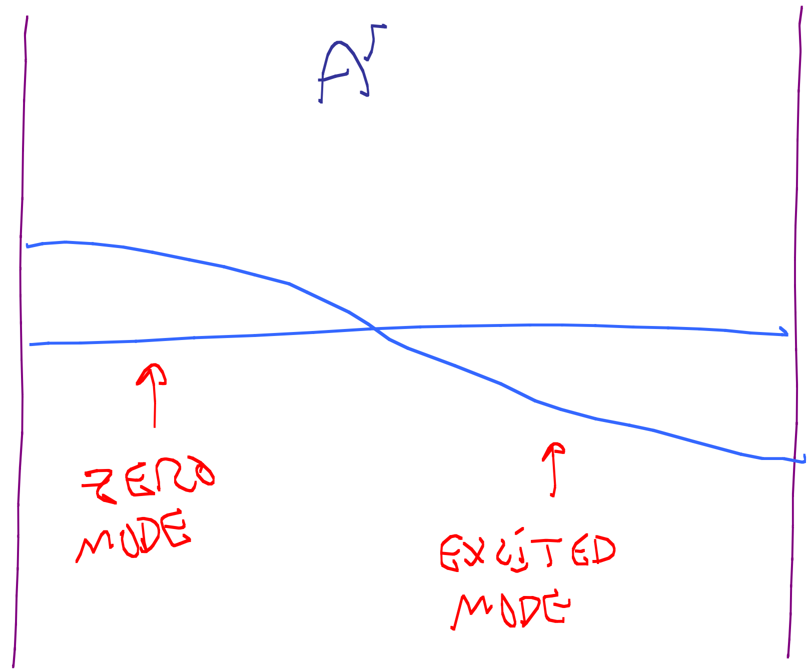
TERMS GROWING LIKE s^2 CANCEL

TERMS GROWING LIKE s CANCEL

GAUGE FIELDS ON AN INTERVAL

TAKE $M^4 \times I$ ← INTERVAL

PUT A GAUGE FIELD IN THE BULK



$$A^\mu = A^{(0)\mu} + \sum_{n=1}^{\infty} A_c^{(n)\mu} \cos\left(\frac{n\pi y}{R}\right) + \sum_{n=1}^{\infty} A_s^{(n)\mu} \sin\left(\frac{n\pi y}{R}\right)$$

$$A^5 = A^{(0)5} + \sum_{n=1}^{\infty} A_c^{(n)5} \cos\left(\frac{n\pi y}{R}\right) + \sum_{n=1}^{\infty} A_s^{(n)5} \sin\left(\frac{n\pi y}{R}\right)$$

NOTE MOMENTUM

$$p^2 = p_\mu p^\mu + \underbrace{p_5 p^5}_{= \partial_5 \partial^5}$$

← LOOKS LIKE A MASS TERM

MASS IS CONNECTED TO CURVATURE IN 5^{th} D

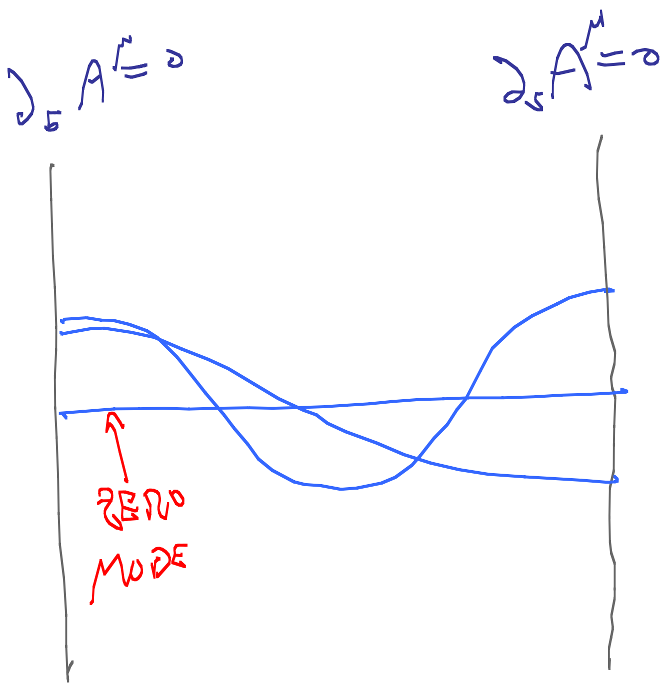
NORMAL ORBIFOLD BOUNDARY CONDITIONS

$$\partial_5 A^\mu = 0, \quad A^5 = 0$$

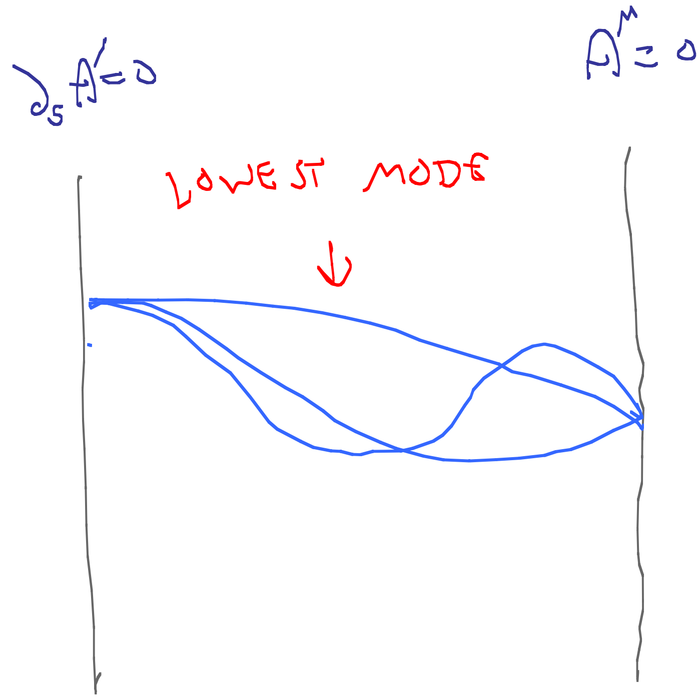
DIFFERENT BOUNDARY CONDITIONS

CSAKI, GROJEAN, MURAYAMA, PILO + TERNING
hep-ph/0305237

GENERATING MASSES

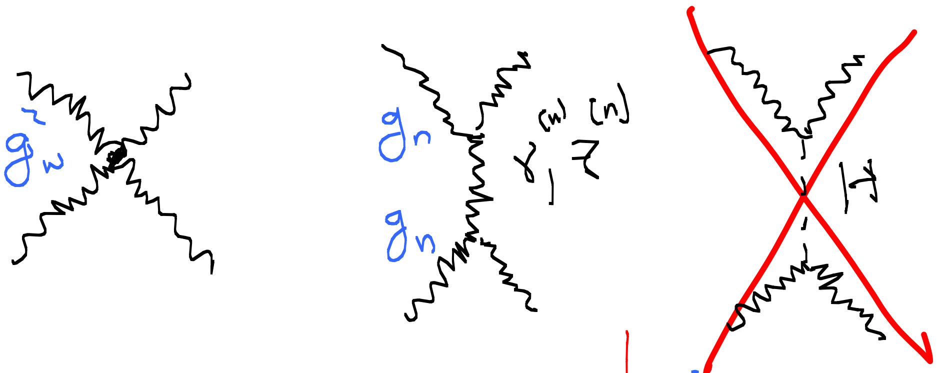


NORMAL ORBIFOLD



GAUGE-BREAKING BC's

UNITARITY



SUM RULES

$$g_W^2 = \sum_{n=\gamma,1}^{\infty} g_n^2$$

TERMS GROWING LIKE s^2 CANCEL

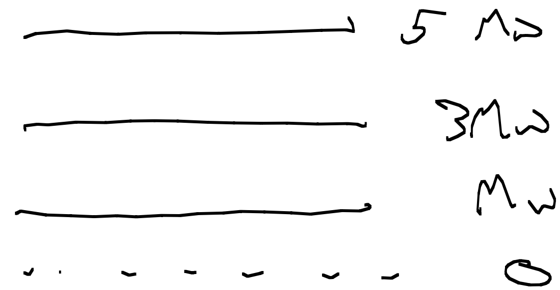
$$4 m_W^2 g_W^2 = 3 \sum_{n=1}^{\infty} m_n^2 g_n^2$$

TERMS GROWING LIKE s CANCEL

VALID AT ASYMPTOTICALLY HIGH s

(POSSIBLY) VIABLE MODEL

- IN FLAT SPACE THE MASS SPECTRUM IS ROUGHLY $\frac{2n-1}{4R}$ ← COMPACTIFICATION RADIUS



TOO LIGHT!

- WITHOUT A HIGGS DOUBLET, NO CUSTODIAL SU(2).

ρ - PARAMETER WAY OFF

CSAKI, GROJEAN, PILO, + TERNING hep-ph/0308038

NOMURA hep-ph/0304148

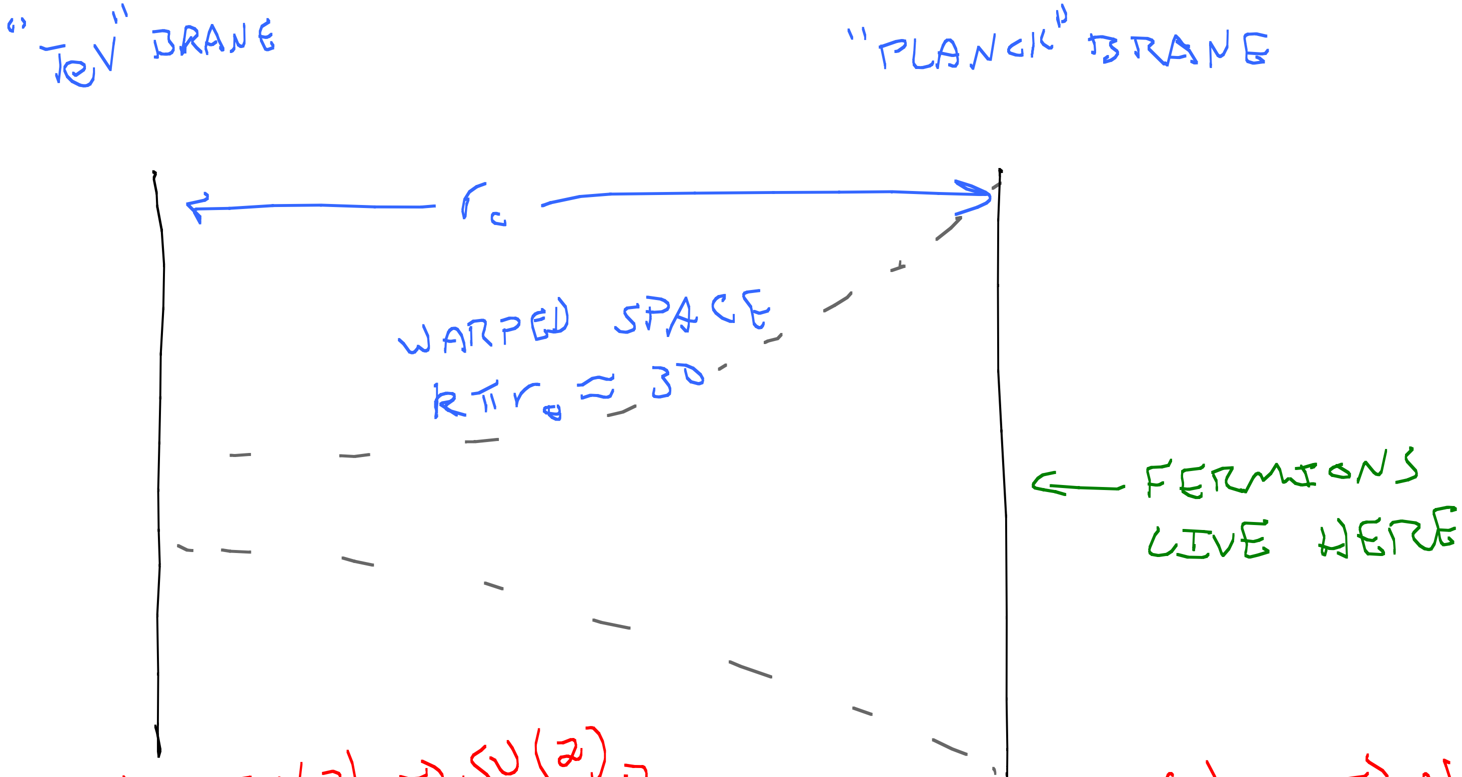
BOTH PROBLEMS SOLVED BY

$$SU(2)_L \times SU(2)_R \times U(1)_{B-L}$$

IN A RANDALL-SUNDRUM (WARPED) SCENARIO

AGASHE, DELGADO, MAY + SUNDRUM hep-ph/0308036

BREAKING PATTERN



$SU(2)_L \times SU(2)_R \to SU(2)_D$

$SU(2)_R \times U(1)_{B-L} \to U(1)_Y$

OVERALL $SU(2)_L \times SU(2)_R \times U(1)_{B-L} \to U(1)_Q$

MODEL PARAMETERS

g_L - $SU(2)_L$ COUPLING

g_R - $SU(2)_R$ COUPLING

g' - $U(1)$ COUPLING

$kπr_c$ - SCALING BETWEEN PLANK & TEV SCALES

$\tilde{g}_L$, $\tilde{g}_Y$ } BRANE LOCALIZED KINETIC TERMS ON PLANCK BRANE

SEE NOMURA

$$\kappa = \frac{g_R}{g_L} \qquad \lambda = \frac{g'}{g_L}$$

$$\delta_L = \frac{h g_L^2}{2\tilde{g}_L^2}, \quad \delta_Y = \text{etc.}$$

$$\delta_Y = -2\frac{\kappa^2\lambda^2}{\lambda^2+\kappa^2}\delta_L$$

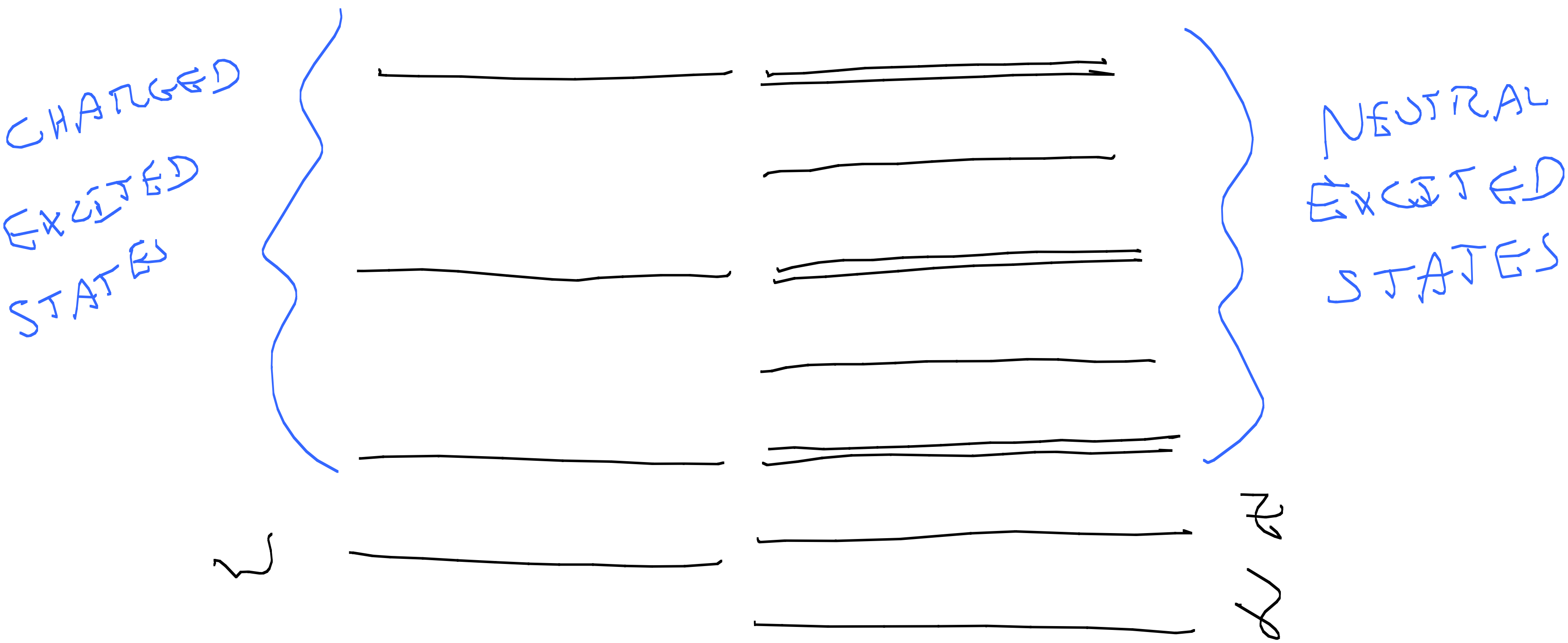
$kπr_c$ → FIXED BY M_W

δ_L → " " G_F

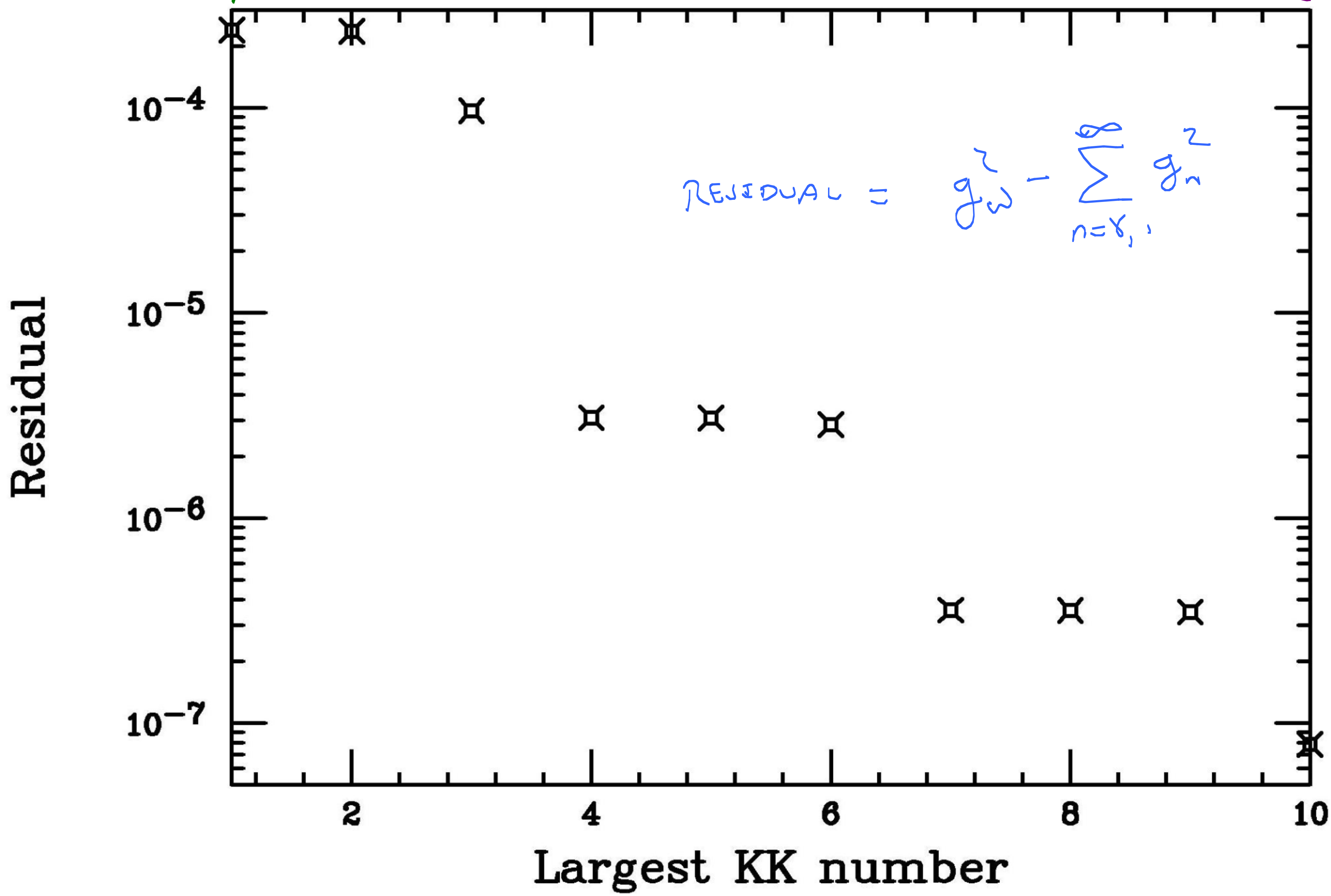
λ → " " M_Z

κ LEFT AS FREE PARAMETER

SPECTRUM



ASSYMPTOTIC UNITARITY → SUM RULES



PRECISION ELECTROWEAK DATA

EXAMPLE CALCULATION

$\sin^2\theta_{os}$ ← DEFINED FROM $\frac{M_W^2}{M_Z^2}$

EXACT IN OUR SCHEME

CAN DEFINE

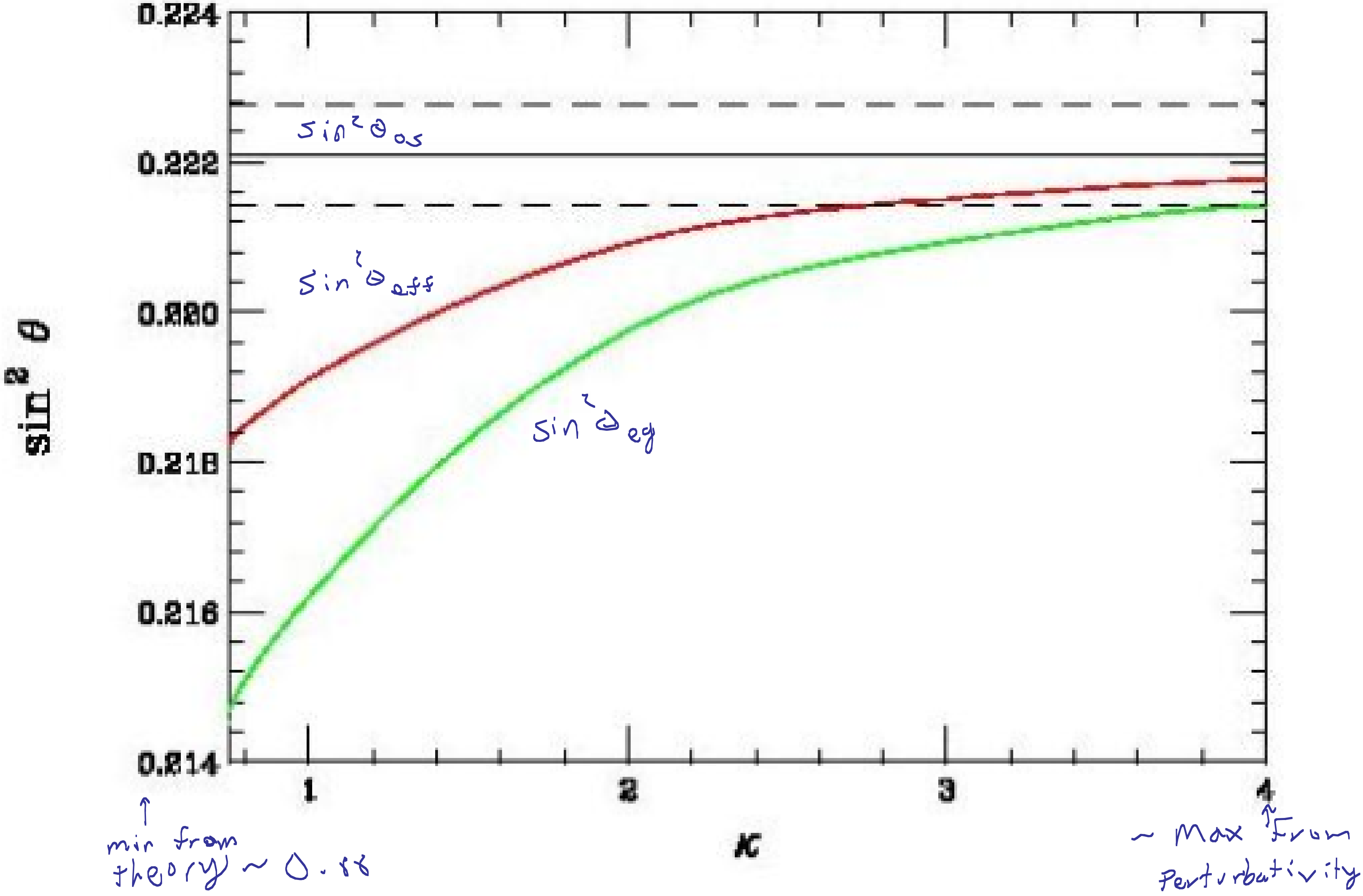
$\sin^2\theta_{eq} = \frac{e^2}{g^2}$

$\sin^2\theta_{eff}$ ← FROM Z-POLE

MEASURE DEVIATIONS OF THESE

ALSO BARBIERI, POMAROL + RATTAZZI hep-ph/0310285

BURDMAN + NOMURA hep-ph/0312247



0.224
0.222
0.220
0.218
0.216
0.214
1
2
3
4
κ
$\sin^2\theta$
sin²θ_os
sin²θ_eff
sin²θ_eg
min from theory ~ 0.88
~ Max from Perturbativity

UNITARITY ISSUES

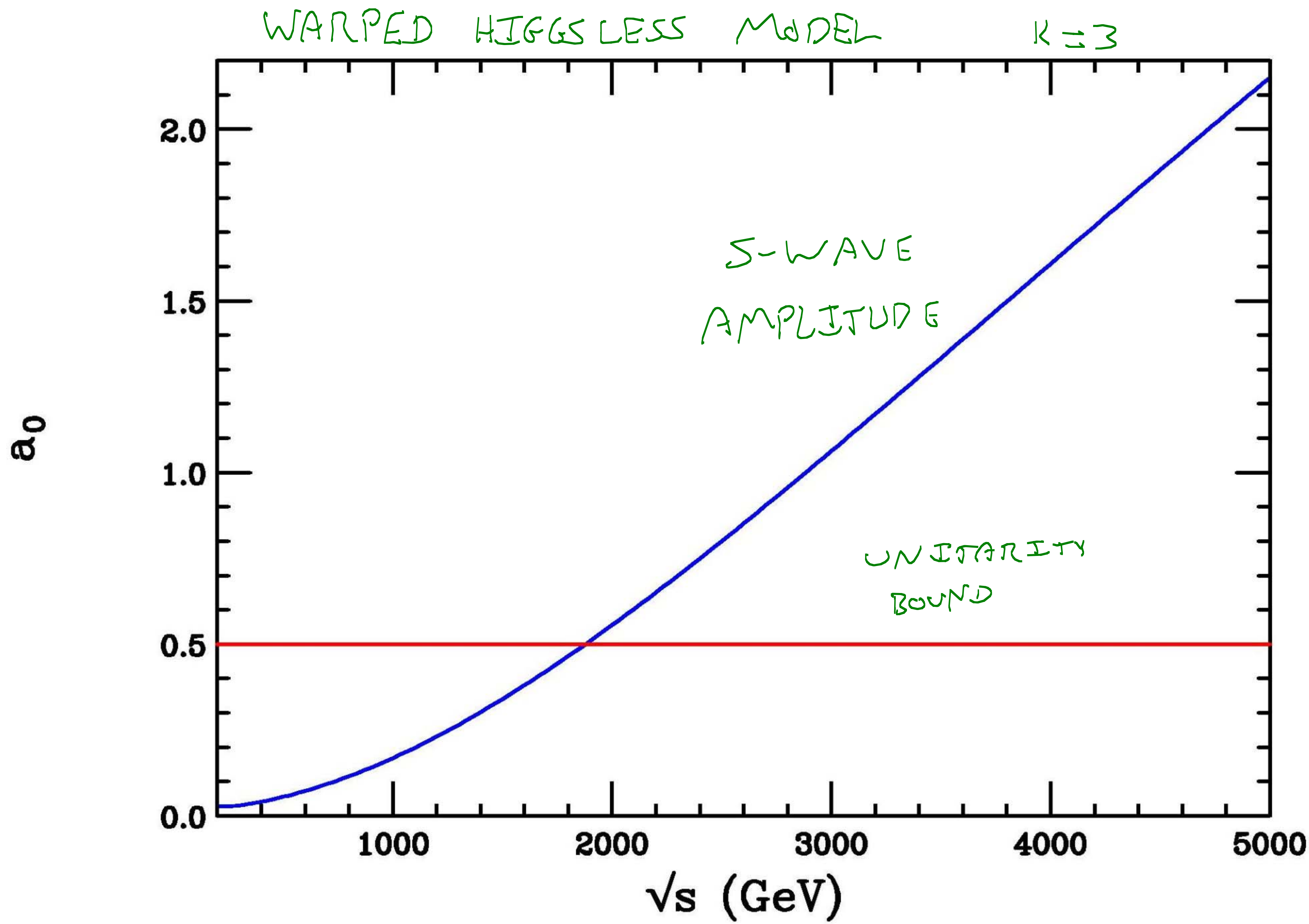
RECALL → SUM RULES ARE VALID AT ASYMPTOTICALLY HIGH s.

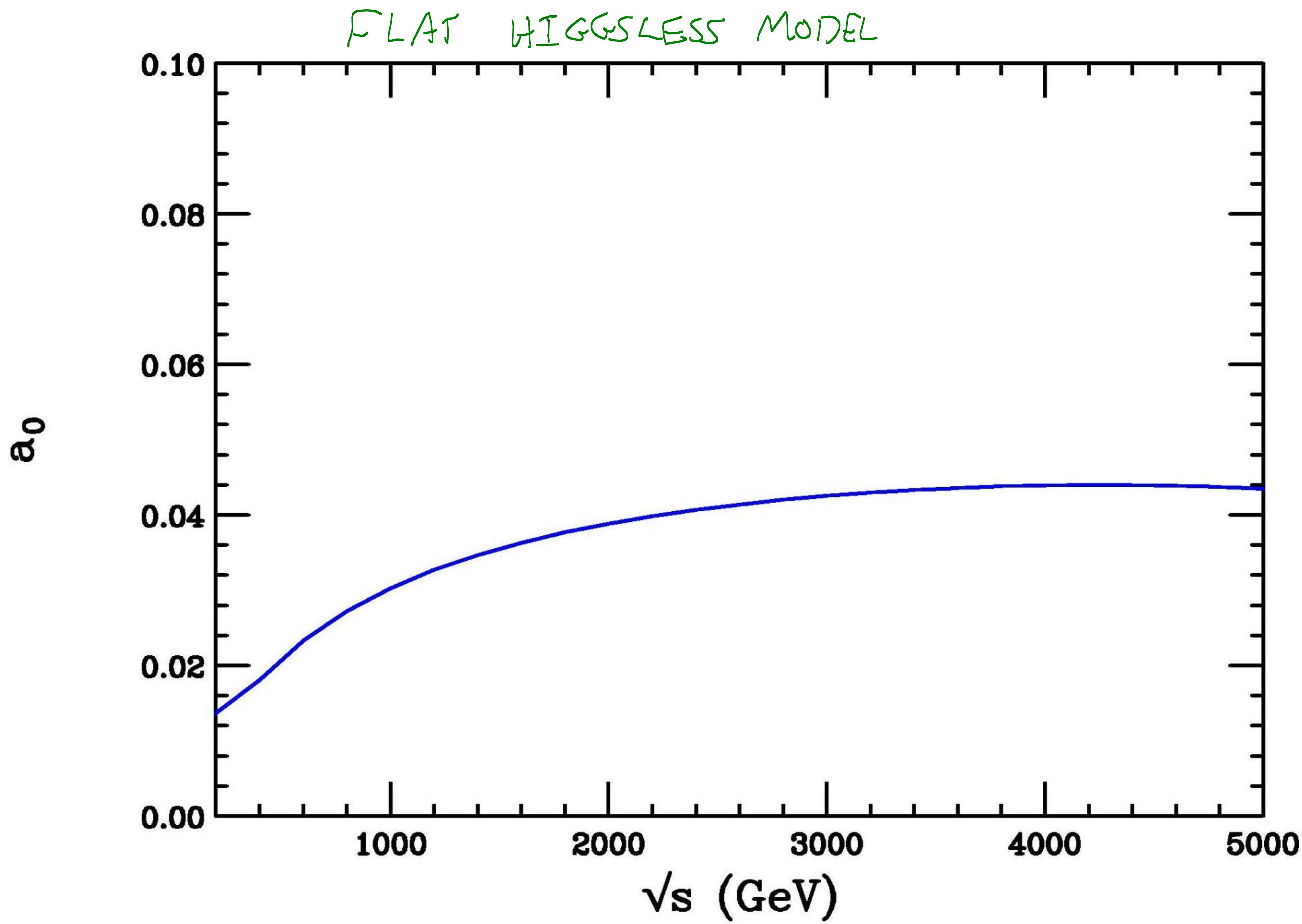
WHAT IF UNITARITY BREAKS BEFORE THIS REGIME?

PARTIAL WAVE UNITARITY TEST

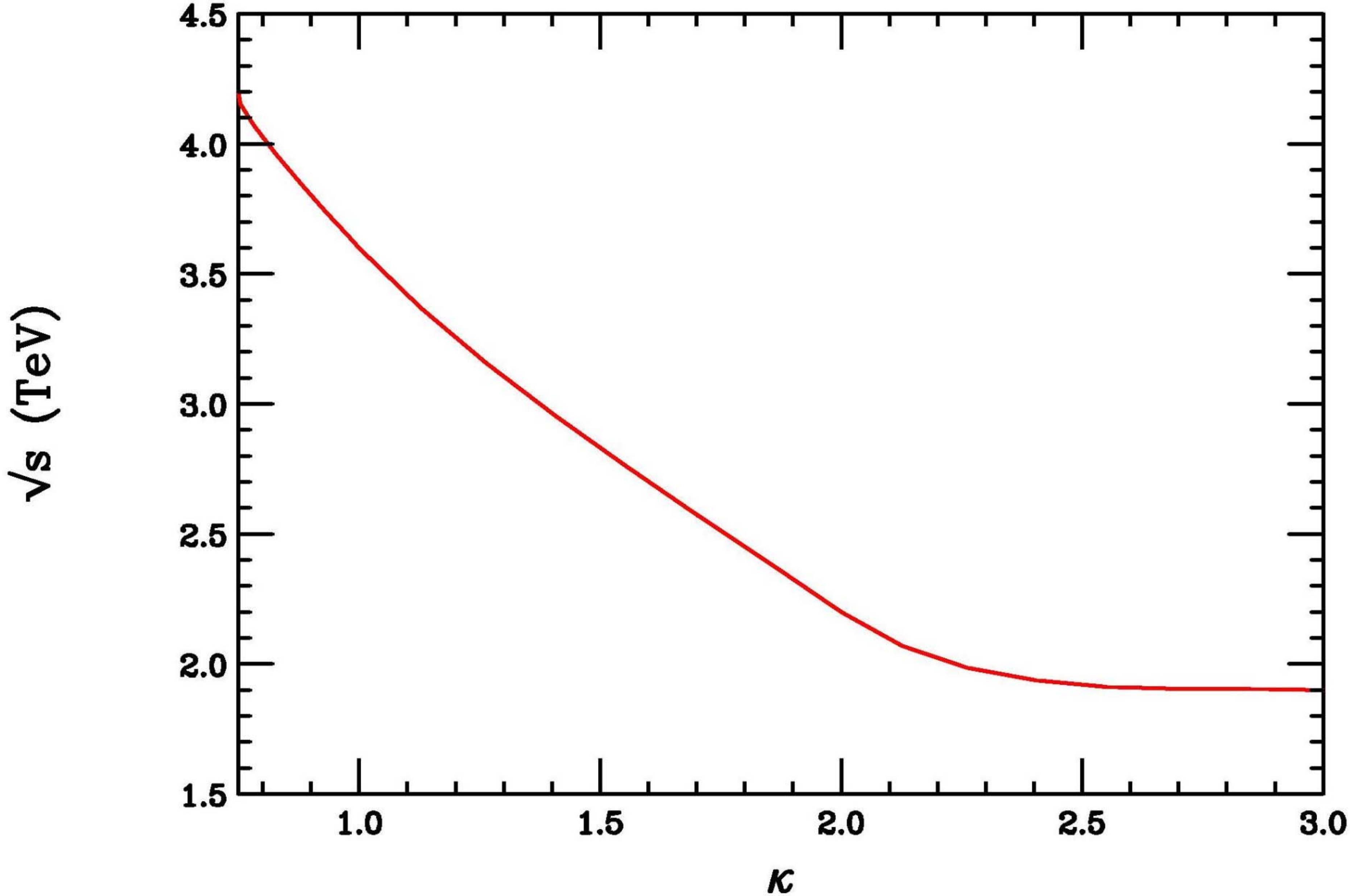
$$a_0 = \frac{1}{32\pi}\int_{-1}^{1} d\cos\theta \, A(w_1 w_2 \to w_1 w_2)$$

$$\boxed{|\mathrm{Re}(a_0)| \leq \frac{1}{2}}$$


WARPED HIGGSLESS MODEL
K=3
S-WAVE AMPLITUDE
UNITARITY BOUND
2.0
1.5
1.0
0.5
0.0
a0
1000
2000
3000
4000
5000
√s (GeV)


FLAT HIGGSLESS MODEL
0.10
0.08
0.06
0.04
0.02
0.00
a_0
1000
2000
3000
4000
5000
√s (GeV)

ONSET OF UNITARITY VIOLATION



COLLIDER ISSUES

IMPORTANT SIGNATURES

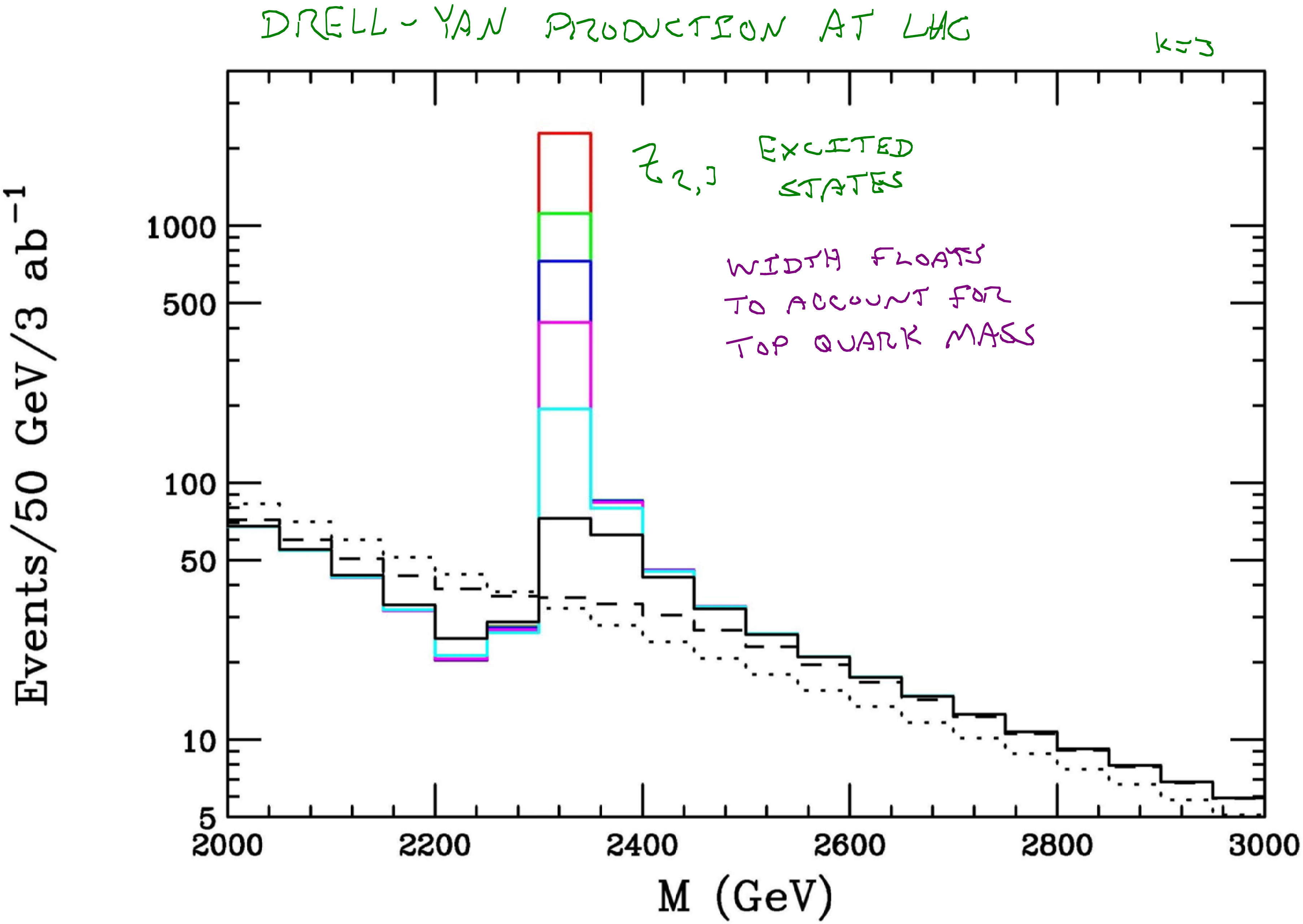
- NO HIGGS SCALAR ← COULD BE A SCALAR RADION, FOR EXAMPLE

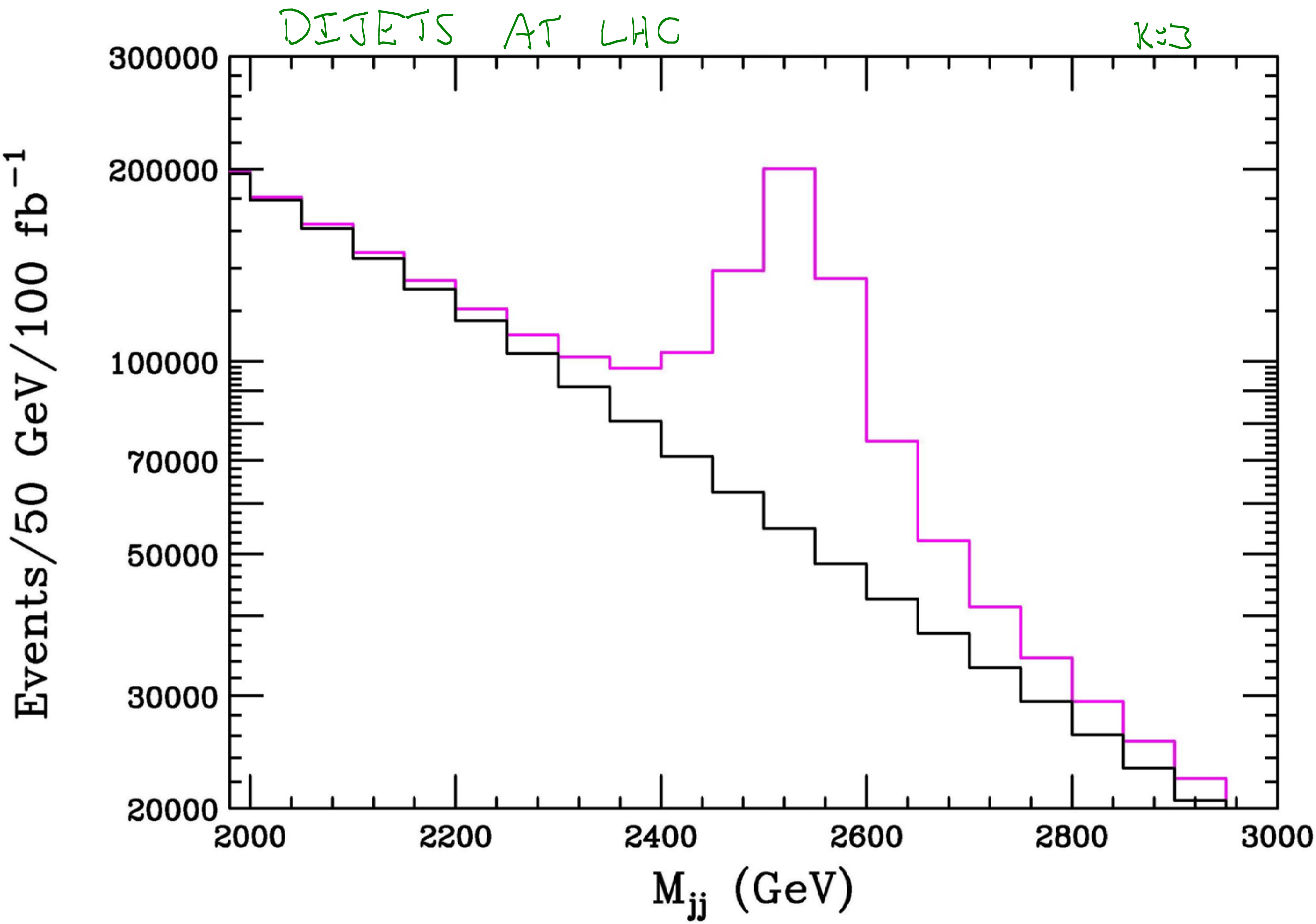
- RISING $W_L W_L$ SCATTERING CROSS SECTION ← STUDIED IN GENERAL
  TIM BARKLOW e^+e^-

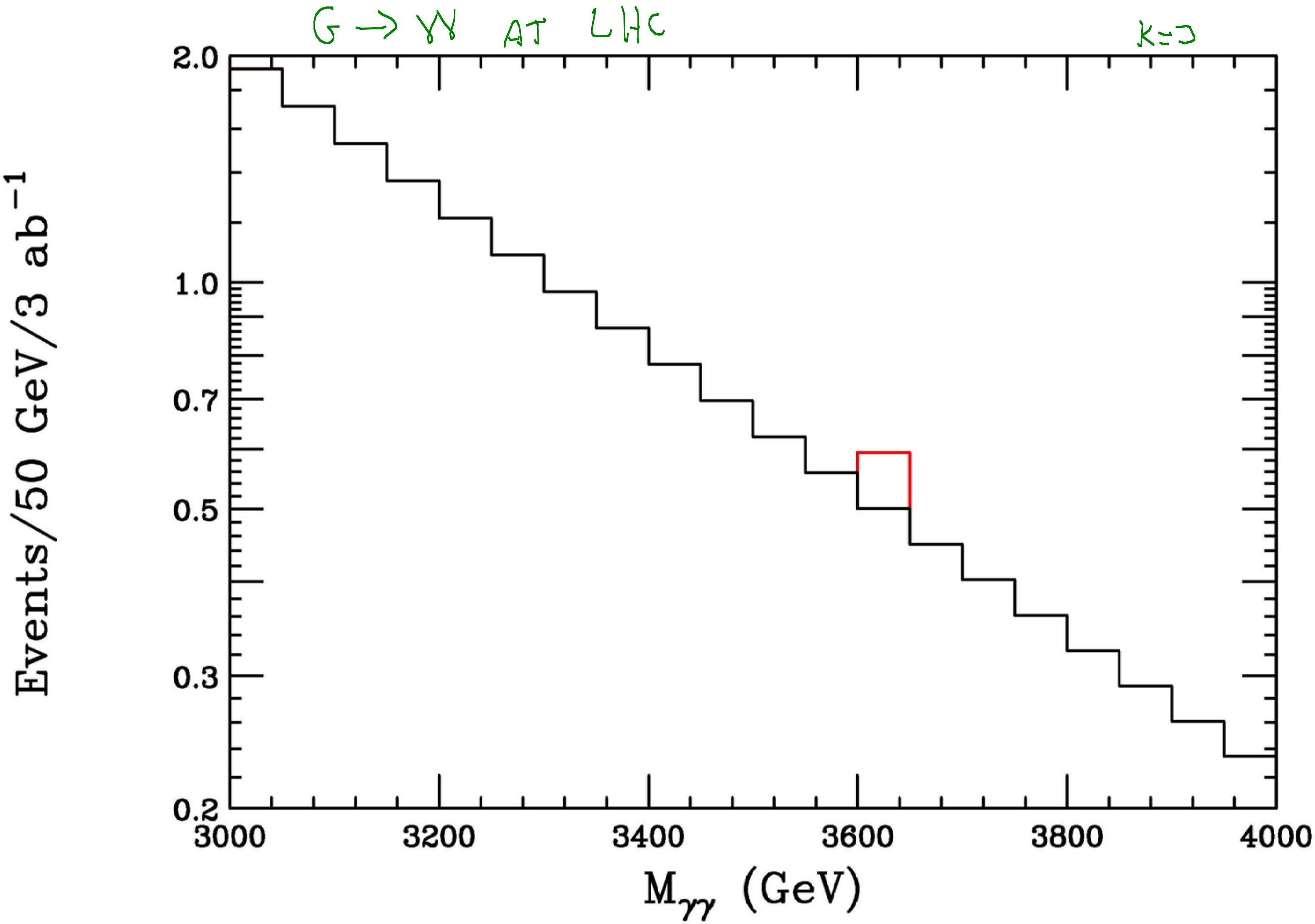
- DOUBLED Z' STATES ← FEATURE OF SEVERAL EXTRA DIMENTIONAL MODELS
  RIZZO hep-ph/0305077

- GLUON RESONANCES

- GRAVITON RESONANCES ← SMALL, UNLIKE GENERIC RS


DRELL-YAN PRODUCTION AT LHC
k=3
$Z_{2,3}$ EXCITED STATES
WIDTH FLOATS TO ACCOUNT FOR TOP QUARK MASS
Events/50 GeV/3 ab^{-1}
1000
500
100
50
10
5
2000
2200
2400
2600
2800
3000
M (GeV)


DIJETS AT LHC
K=3
300000
200000
100000
70000
50000
30000
20000
Events/50 GeV/100 fb^{-1}
2000
2200
2400
2600
2800
3000
M_{jj} (GeV)



G → γγ AT LHC
2.0
1.0
0.7
0.5
0.3
0.2
3000
3200
3400
3600
3800
4000
Events/50 GeV/3 ab^{-1}
$M_{\gamma\gamma}$ (GeV)

LINEAR COLLIDER (TO BE DONE)

MOST INTERESTING NEW QUESTION

WHAT CAN THE LC LEARN ABOUT THE COUPLINGS OF A DOUBLED KK STATE WHILE COLLIDING BELOW THRESHOLD?

- MASS + (TWO STATES) KNOWN FROM LHC
  ↑ MAYBE

UNDER CERTAIN CONDITIONS, QUITE A LOT

- RIZZO hep-ph/0305077
  9612304

CONCLUSIONS

- EXTRA DIMENSIONS MAY PROVIDE AN INTERESTING ALTERNATIVE TO THE HIGGS MECHANISM

- CURRENTLY NO VIABLE MODEL, BUT THE IDEA IS STILL YOUNG (< 1 yr)

- RICH PHENOMENOLOGY THAT NEES A LINEAR COLLIDER TO UNTANGLE.