COLLIDER SIGNALS OF ASYMMETRIC LARGE EXTRA DIMENSIONS

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(ICHEP-2000, PA-16A)

(work done in Collaberation

: J. Lykken + S. Nandi
(to appear in Phys. Lett. B)

: D.A. Dicus, C. McMullen + S. Nandi
(to appear)

: C. McMullen + S. Nandi
(to appear)

TALK :

: overview of string compactification in the framework of brane world

: Symmetric compactification & Related phenomenology

: Asymmetric Compactification
⇒ phenomenological implications
(new physics at LHC)

Superstring Theory ⇒ $\underset{\nearrow \atop \text{space}}{9} + \underset{\uparrow \atop \text{time}}{1}$ dimensions

⇒ 6 extra space-like dim.

⇓

Two Possibilities

/

all size $\sim \frac{1}{M_{PL}}$

⇓

very little phenomenological implications

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(Witten, Lykken)

Some or all much larger compared to M_{PL}

$\sim$ mm , TeV^{-1}

⇓

Many interesting effects:

: Modify Newton's law of gravity at sub-mm dist.

: effects in low energy astrophysical phenomena

: new physics at high energy colliders

: where do the SM particles live?

4+n dim. space-time

⇓

Two scenarios

: SM particles do <u>not</u> see any of the extra dim.
(they are all confined to 3+1 dim. subspace
⇒ D_3 - brane)

: only gravity sees all the dimensions

(N. Arkani-Hamed,
S. Dimopoulos &
G. Dvali, --)

: Some or all of the SM particles <u>do</u> see one or more of the extra dim

(I. Antoniadis;

K.R. Dienes, E. Dudas
& T. Gherghetta;

- - - - - - - - - - - -

{ D. Dumitru + SN
J. Lykken + SN
....
....
)

SYMMETRIC COMPACTIFICATION SCENARIO

: n extra dim., all size ~ R

$$\underset{\substack{\nearrow \\ 10^{19}\,\text{GeV}}}{M_{PL}^{2}} = \underset{\substack{\uparrow \\ 4+n \text{ dim.} \\ \text{Planck scale}}}{M_{*}^{n+2}} \; R_n^{n}$$

Take $M_* \sim 1\,\text{TeV}$

$\Rightarrow R_n \sim 10^{\frac{30}{n} - 17}$ cm

For $n=1$, $R_1 \sim 10^{13}$ cm ~ solar dist.

: $n=1$ excluded (Modify Newtonian gravity at solar dist.)

For $n=2$, $R_2 \sim$ mm $\Rightarrow$ ok (Newtonian grav. checked only upto mm dist.)

For $n=6$, $R_6 \sim (10\,\text{MeV})^{-1}$

$\Rightarrow$ All SM particles <u>must</u> be confined to D_3-brane, since no <u>KK</u> excitation of any SM seen at this energy scale.

Gauge hierarchy problem,

$M_{PL} \sim 10^{19}$ GeV, $M_{Weak} \sim 10^{2}$ GeV

In this scenario:

: M_{PL} is <u>not</u> a fundamental scale,

$M_{*} \sim$ few TeV is the fundamental scale

⇒ eliminates gauge hierarchy problem.

Scenario: SM in D_3-brane

: only gravity propagates in the "bulk" (4+n)

: $n \geq 2$

<u>Implications:</u>

: modify Newtonian gravity at sub-mm dist.

$$\frac{1}{r^2} \longrightarrow \frac{1}{r^{n+2}}$$

(Expt. at Stanford, Boulder)

Astrophysical Constraints:

Is $R \sim 1$ mm or $M_* \sim$ few TeV
is allowed astrophysically ?

: Most stringent constraints comes from

- Supernova 1987A
- Absence of "MeV Bumps" in cosmic diffuse Gamma radiation background (CDG)

SN1987A:

: Loose energy via Nucleon-Nucleon Brehmstrahlung

$$N+N \rightarrow N+N+ \text{graviton}$$

core temp, $T \sim 30$ MeV

KK graviton mass, $m_n \sim n\left(\frac{1}{R}\right) \sim n\,(10^{-3}\,\text{eV})$

$\Rightarrow \sim 10^7$ KK mode contribute !!

$\dot{\mathcal{E}}$ = Energy loss rate $\sim 10^{19}$ erg $g^{-1}\,s^{-1}$

For $n=2$, $\dot{\mathcal{E}} = 1.7 \times 10^{17}\,\text{erg}\,g^{-1}\,s^{-1}\left(X_n^2+X_p^2+7.0X_nX_p\right)\rho_{14}T_{\text{MeV}}^{5.5}M_{\text{TeV}}^{-4}$

$\Rightarrow M_* \geqslant 50$ TeV $\Rightarrow R \leq 3 \times 10^{-4}$ mm

(Cullen + Perelstein)

ABSENCE OF "MEV BUMP" IN CDG RADIATION

BACKGROUND:

$\nu\bar{\nu} \to G_n \qquad \gamma\gamma \to G_n$

$G_n \to \gamma\gamma$ (during radiation dominated era)

$\Rightarrow$ produced "MeV Bump" in CDG

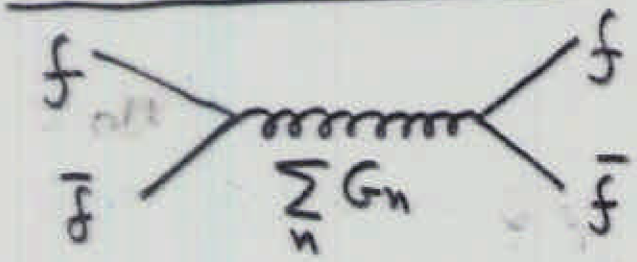
Hall +Smith

: Recent measurements do <u>not</u> see any such bump

$\Rightarrow M_* \gtrsim 110$ TeV for $n=2$

$\Rightarrow r \leq 5\times10^{-5}$ mm.

COLLIDER BOUNDS



$$M_{G_n} = n\mu_0 = n\left(\frac{1}{R}\right)$$

$$n \sim \frac{1\,\text{TeV}}{10^{-3}\,\text{eV}} \sim 10^{12}$$

$$\Rightarrow \mathcal{L} \sim \frac{1}{M_*^2}(\bar{\Psi}\Psi\bar{\Psi}\Psi)$$

$$\left.\begin{array}{l} e^+e^- \to \mu^+\mu^-,\ q\bar{q} \\ q\bar{q} \to l\bar{l},\ q\bar{q} \\ Z \to f\bar{f} \end{array}\right\} \Rightarrow M_* \gtrsim (1-2)\ \text{TeV}$$

SCENARIO II

: some or all of the SM particles <u>do</u> <u>see</u> one or more of the extra dimensions

$SM \Rightarrow D_p$- brane , $3 < p \leq 6$

Gravity ⇒ sees all $4+n$ dim.

: In this case, simple scaling relation

$M_{PL}^2 = M_*^{n+2} R^n$ does <u>not</u> work

why ?

:even for $n=6$ gives $R^{-1} \lesssim 10$ MeV

while, collider expts rule out

$\mu_0 \equiv R^{-1} \lesssim 1$ TeV

⇒ need generalization of the scaling relation

$\Downarrow$

Asymmetric compactification

ASYMMETRIC LARGE EXTRA DIMENSION

Lykken & Nandi

: Single mm size extra dim

: five TeV^{-1} size extra dim

: SM gauge bosons see only <u>one</u> TeV^{-1} dim.

$\hookrightarrow D_4$ - brane

⇒ interesting grav, astrophysical and laboratory consequences

: deviation from Newtons $\frac{1}{r^2}$ law of gravity at mm dist. for $n = 1$

: astrophysical constraints OK

: KK modes of gauge bosons at LHC

how do we achieve this?

Modify the basic scaling law

$$M_{PL}^2 = M_*^{n+2} R^n \longleftarrow \text{ADD}$$

to ⇒ $$\boxed{M_{PL}^2 = M^{n+m+2} R^n r^m} \; ; \; n+m \leq 6$$

R → very large extra dim, ~ mm

r → merely large extra dim, ~ TeV^{-1}

Possible Scenarios:

① SM particles confined to D_3, only graviton (and perhaps RH ν) probe the extra $n+m$ dim.

⇒: can evade stringent astrophysical bounds for $n=2$ Sym scenario

: can also obtain attractive scenario for ν- mass (Mohapatra, Nandi & Perez-Lorenzana)

② Brane volume containing SM is transverse to R, but *does* extend to *one* or more of r

Simplest ⇒ $D_4 \nwarrow (3+1_r)$

(fig.

⇒: affect evolution of SM couplings above $\frac{1}{r} \equiv \mu_0$ ⇒ TeV scale Unification

$M_{GUT} \sim (2-20)\, \mu_0$

$M_{GUT} \longleftrightarrow M_S$

: allow $M_S \sim 100\, \mu_0$ (threshold, extra matter and other uncertainties)

⇒ *no* more than *one* extra r-size dim for D-brane.

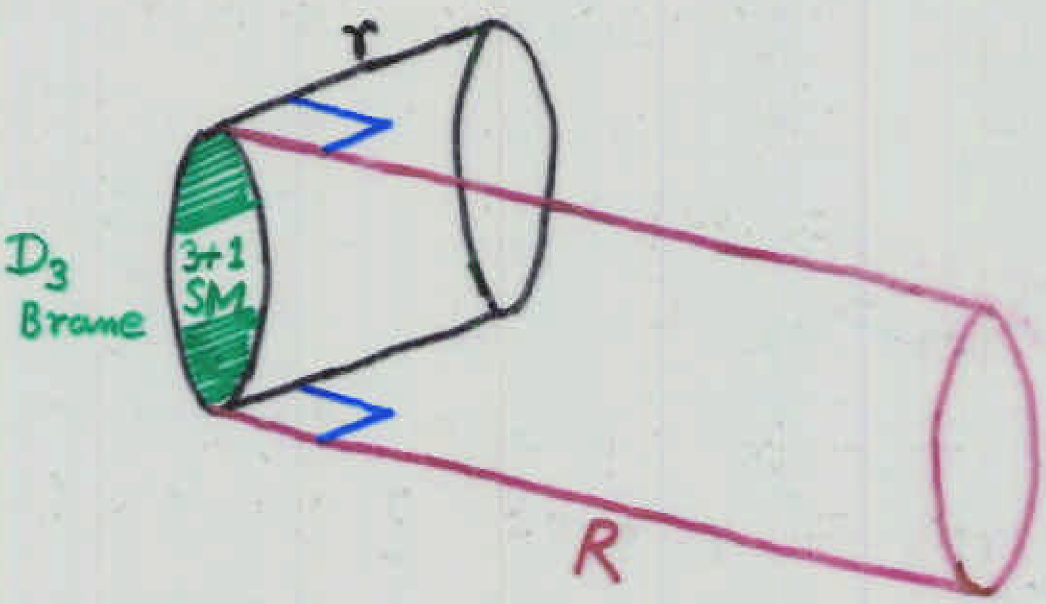
ASYMMETRIC COMPACTIFICATIO
(Lykken Nandi Scenario):

: $R \sim$ mm, only gravity propagate along R

: $r \sim \text{TeV}^{-1}$, SM gauge bosons propalē along r (only one) $\rightarrow D_4$ brane

: SM fermions confined to D_3 brane

: Gauge coupling unification $\sim 20/r$



A dramatic case:

$$M_{PL}^2 = M^{n+m+2} \; R^n \; r^m$$

$$n = 1, \quad m = 5$$

$$M_{PL}^2 = M^8 \; R \; r^5$$

$$\equiv M_*^3 \; R$$

$\Rightarrow$ works for $\frac{1}{R} \sim 10^{-3}$ eV (→ mm size very large extra dim)

$\frac{1}{r} \sim 1$ TeV (→ collider observability)

$$\Rightarrow M \sim 100 \text{ TeV} \Leftrightarrow M_* = 5 \times 10^5 \text{ TeV}$$

$M \Rightarrow$ fundamental $n+4$ dim Planck scale

$M_{PL}, M_* \Rightarrow$ effective scale, <u>not</u> fundamental

Interesting features of this hybrid scenario:

87H ⇒

- : one mm size extra dim as opposed to at least two in the Sym. case
- : TeV scale KK excitations of SM gauge bosons (and perhaps Higgs).

Astrophysical constraints

SN 1987A : $M \geqslant 22$ TeV ($M_* = 3{,}700$ TeV)

CDG (absence of "MeV Bump") : $M \geqslant 48$ TeV ($M_* = 30{,}000$ TeV)

Collider constraints

: 4-dim theory will have KK excitations of SM gauge bosons at the TeV scale

: high energy colliders may be able to produce some of these low lying KK resonances

$$\gamma \to \gamma_n^*$$
$$W^\pm \to W_n^{\pm *}$$
$$g \to g^*$$

① constraints on weak KK excitations:

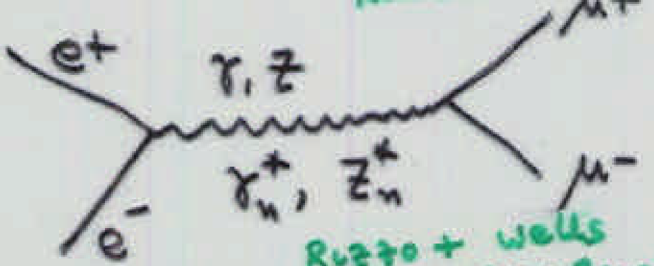
Manciano
Massip + Pomerol

Low energy weak processess

$\Rightarrow M_{W_1^*} \gtrsim$ 1-2 TeV

Nath, Yamada + Yamaguchi

$e^+e^- \to \mu^+\mu^-$



Rizzo + Wells
Accomando, Antoniadis + Benakli

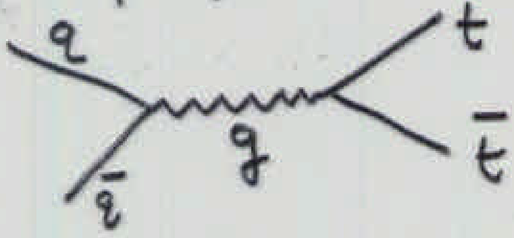
$\Rightarrow M_{\gamma_1^*, Z_1^*} \gtrsim$ 1-2 TeV

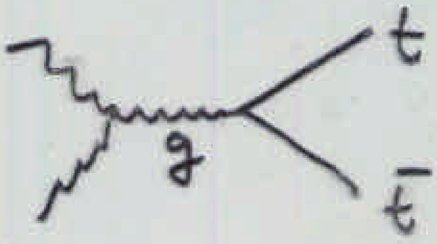
$\bar{p}p \to \mu^+\mu^- X$

② High Energy hadron Collider:

: Top production, $\bar{p}p \to t\bar{t} \cdots$

Lykken + Nandi





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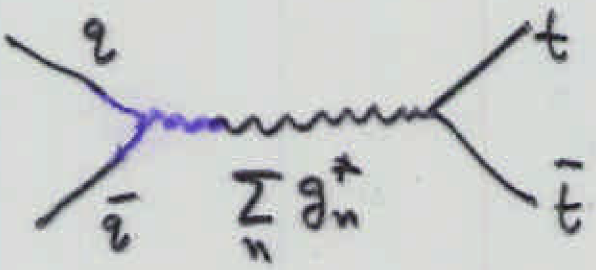

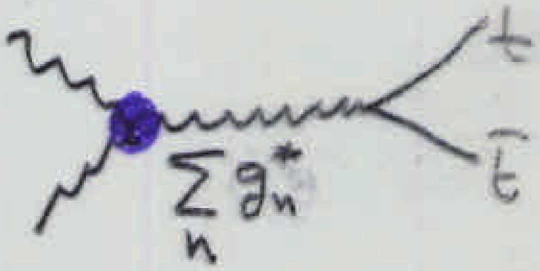

$$\frac{1}{s} \longrightarrow D(s) = \sum_n \frac{1}{s - m_n^2}$$

$$m_n^2 = n^2 \mu_0^2$$

For one extra dim: $D(s) \simeq \frac{1}{s} - \frac{\pi^2}{6\mu_0^2}$

Below threshold of KK excitation:

cross section is reduced compared to SM.

Above threshold:

cross section is larger than SM.

$$\frac{\sigma_{\mu_0}(\bar{p}p \to t\bar{t})}{\sigma_{SM}(\bar{p}p \to t\bar{t})} \ \underline{vs} \ \underset{\uparrow}{\mu_0}$$

compactification scale

Tevatron Run 2 : $\sqrt{s} = 2\,\text{TeV}$

(Fig.

$\Rightarrow$ will see effect

or give limit $\mu_0 \geqslant 3\,\text{TeV}$

MORE

New Physics due to KK excitations

(Lykken + Nandi; Dicus & McMullen + Nandi)

Smoking gun signature

⇒ : Both single mm size dim

and new high p_T jet physics

near and above μ_0

① $gg \to g_1^* \to gg\,,\ q\bar{q}\,,\ ggg$

$q\bar{q} \to g_1^* \to gg\,,\ q\bar{q}\,,\ ggg$

⇒ enhancement of high p_T dijet cross sections compared to SM expectation

② $gg \to g_1^* g\ ,\quad g_1^* \to gg\,,\ q\bar{q}\,,\ ggg$

⇒ anomalously large production of 3 jet events compared to SM.

③ $gg \to g_1^* g_1^*\ ,\quad g_1^* \to gg\,,\ q\bar{q}\,,\ ggg$

⇒ enhanced 4 jet productions ⇒ GOLD PLATED SIGNATURE

④ Top production will be altered

: All can be checked at LHC.

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Lykken + Nandi

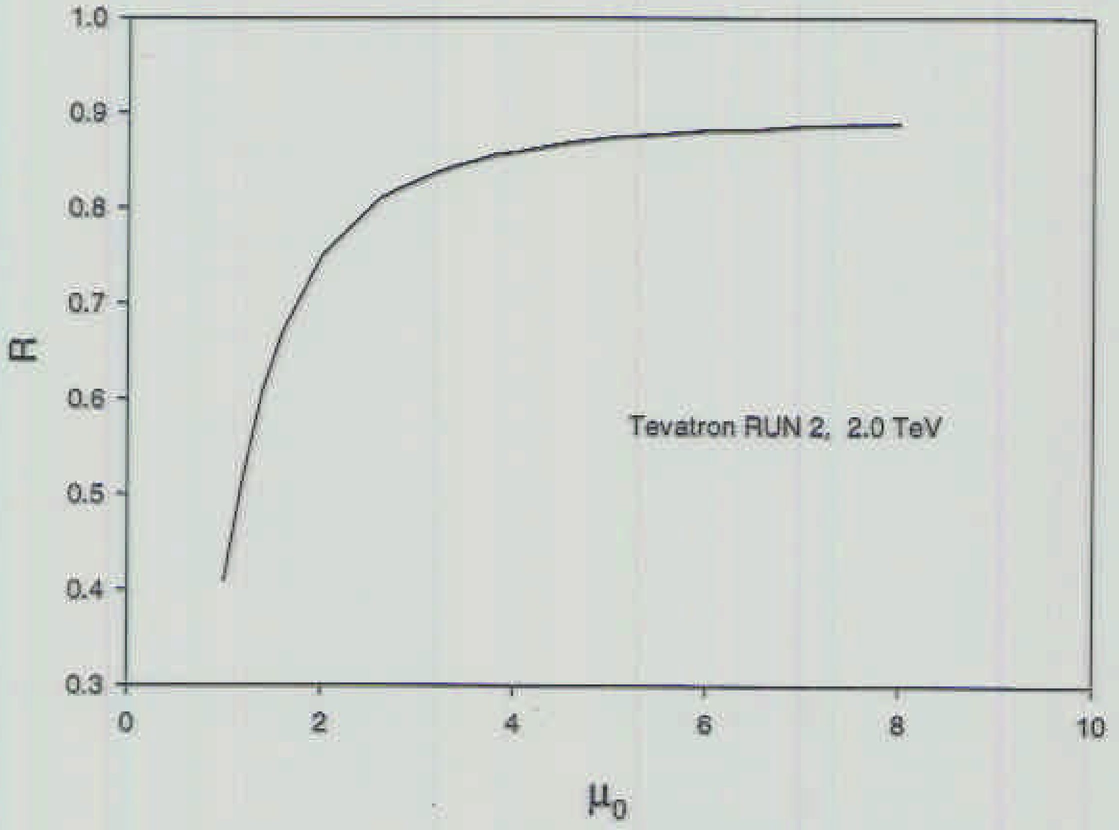
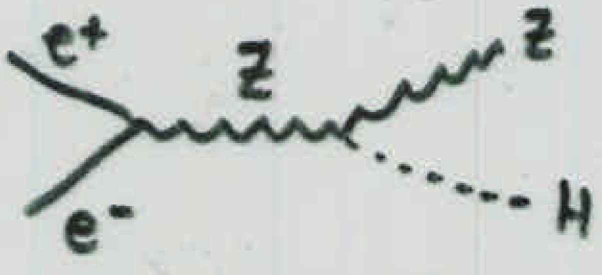


Figure 1: Ratio of the cross section for our model at scale μ_0 over the SM cross section for $t\bar{t}$ production.

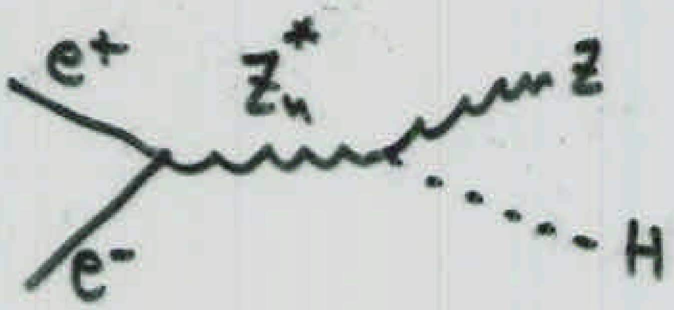
More new physics at high energy e^+e^- colliders: (McMullen + Nandi)

: $e^+e^- \to Z\,H$

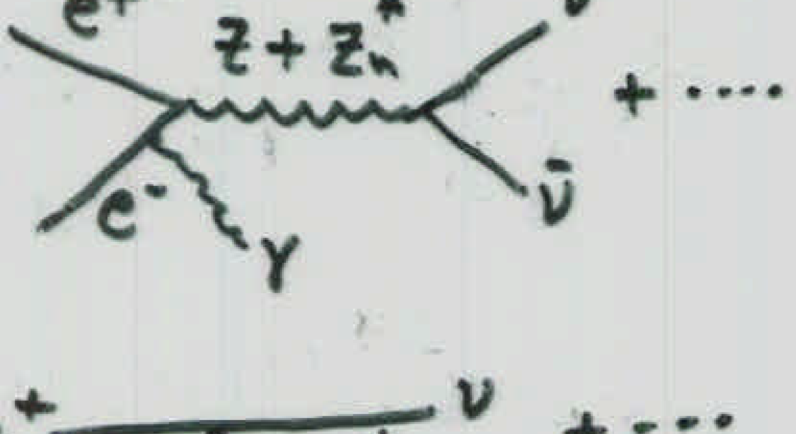
SM :

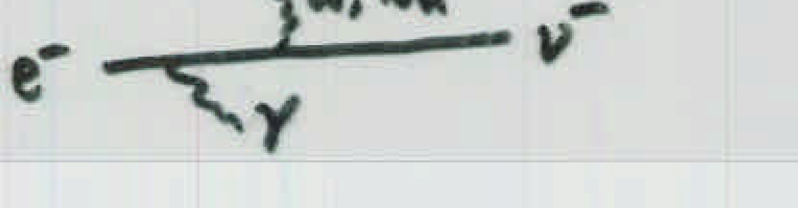


new :



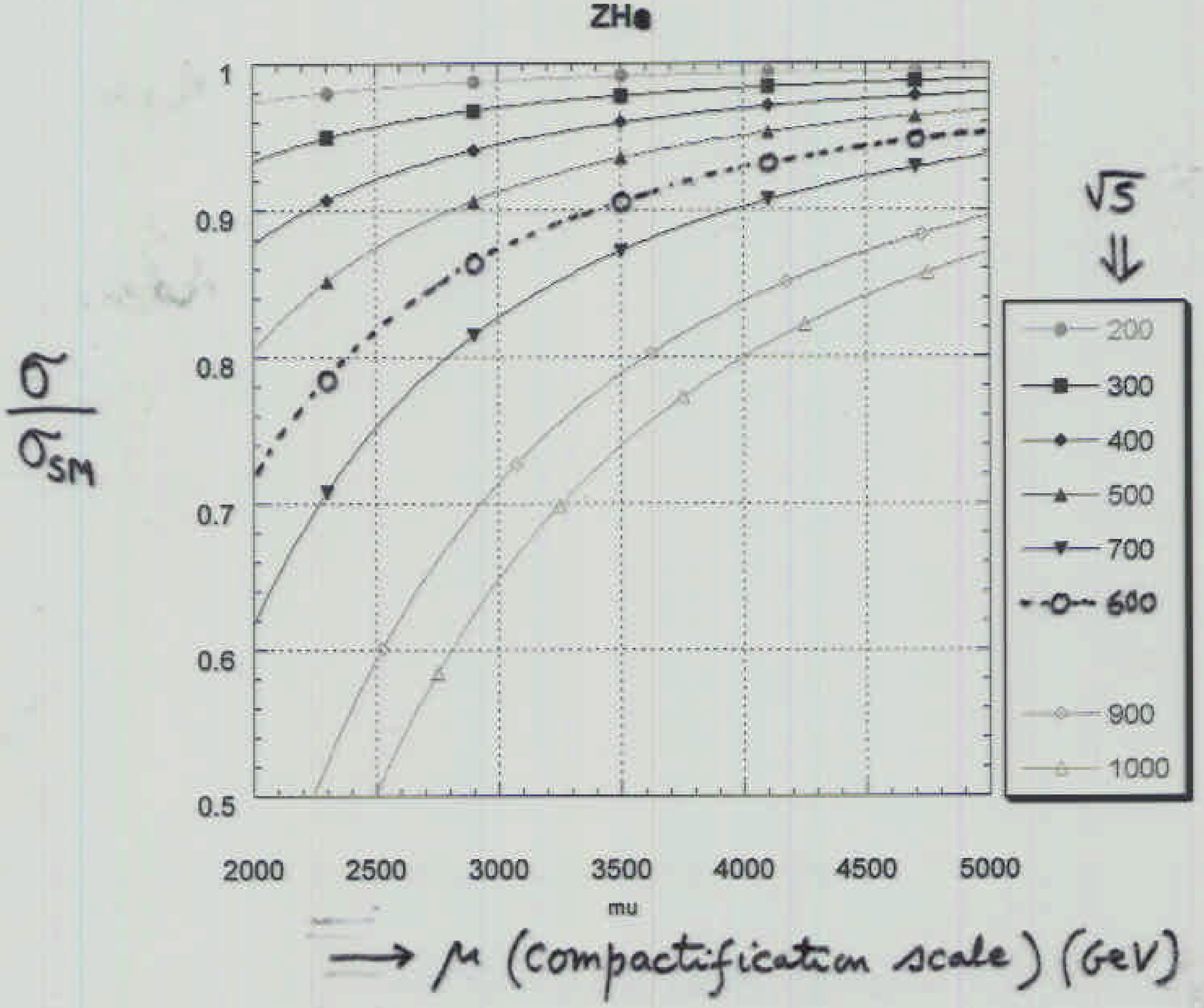
: $e^+e^- \to \gamma\,\nu\,\bar{\nu}$





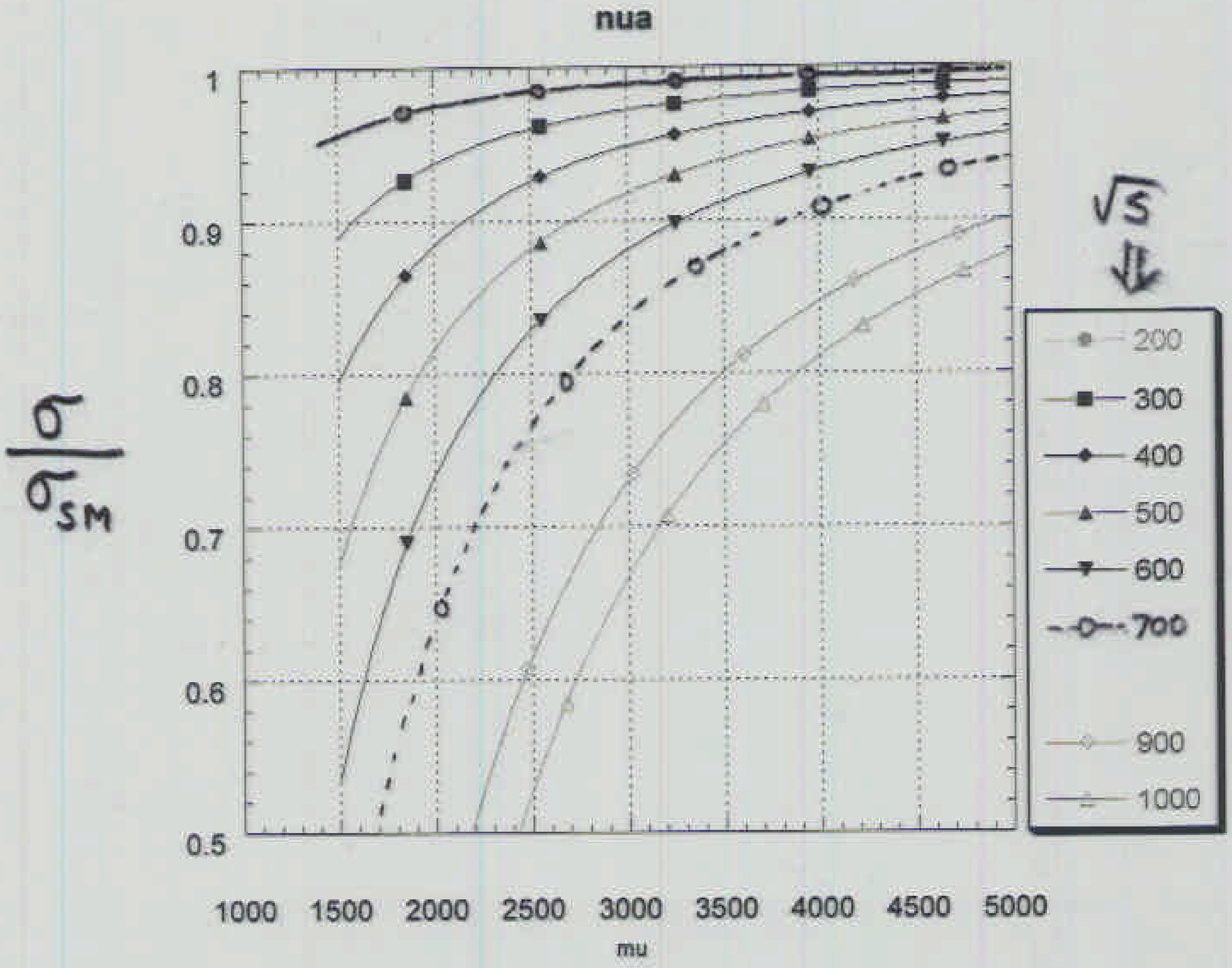
McMullen + Nandi

ZH PRODUCTIONS IN e^+e^- COLLIDER



McMullen + Nandi

$\gamma \nu \bar{\nu}$ PRODUCTIONS IN e^+e^- COLLIDER



⇒ μ (compactification scale) (GeV)

CONCLUSIONS

: Large extra compact dimensions are well motivated, and lead to exciting new physics

: SM particles may or may not see these

: These extra dim can be as large as a Tev^{-1} or even mm size

: For mm size, they alter the $\frac{1}{r^2}$ law of gravity to $\frac{1}{r^{2+n}}$

: All astrophysical and laboratory constraints are satisfied

: For Tev^{-1} size, KK excitations of the SM gauge bosons may be produced at the LHC giving rise to enhanced high p_T multijet, and top production cross sections

: possibility of exploring string dynamics at LHC or NLC.