Z' Signals from KK Dark Matter

Sabine Riemann (DESY)

LCWS, Stanford, March 18-22, 2005

Outline

- Universal extra dimensions (UED)
- KK dark matter?
- Sensitivity to UED KK_2 bosons
- Results

Extra Dimensions

Different scenarios

- **large ED:** SM on a brane, gravity in the bulk,
- TeV^{-1} sized ED with SM fields,
- **warped ED:** SM fields on brane or in bulk, 'curved' ED

....

Kaluza-Klein (KK) towers of propagated fields:

→ KK partners with identical spins and identical couplings

→ degenerate mass spectra

$$\boxed{M_n^2 = \frac{n^2}{R^2} + M_0^2}$$

R = compactification radius (unknown)

Universal Extra Dimensions (UED)

Appelquist, Cheng, Dobrescu, hep-ph/0012100; Cheng, Matchev, Schmaltz hep-ph/0205314;
Cheng, Feng, Matchev hep-ph/0207125

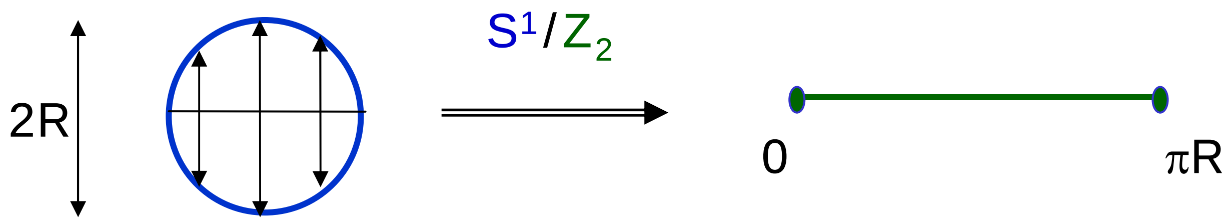
ALL SM particles propagate to the bulk

➔ KK tower states for each SM particle

Momentum conservation in higher dimensions

➔ conservation of KK number n: $1 \Leftrightarrow 10$, $2 \Leftrightarrow 11$, $2 \Leftrightarrow 02$,...

Chiral fermions at zero KK mode $\Leftrightarrow$ orbifold compact. on S^1/Z_2



Boundary interaction breaks KK-number ➔ KK parity:

$(-1)^n$ is conserved (~ R-parity in SUSY)

→ lightest KK particle (LKP) is stable !!

Dark Matter candidate

→ allowed: $2 \Leftrightarrow 00$, $3 \Leftrightarrow 01$,...

≈ Z' search

Minimal UED: Radiative Corrections

Cheng, Matchev, Schmaltz, hep-ph/0204324

- mass degeneracy n/R only at tree level
- compactification → Lorentz invariance is lost → mass corrections due to kinetic terms

Bulk corrections

- finite
- ≠0 only for bosons

$$\Delta M_n \sim \frac{1}{16\pi^4 R^2}$$

Boundary (orbifold) corrections

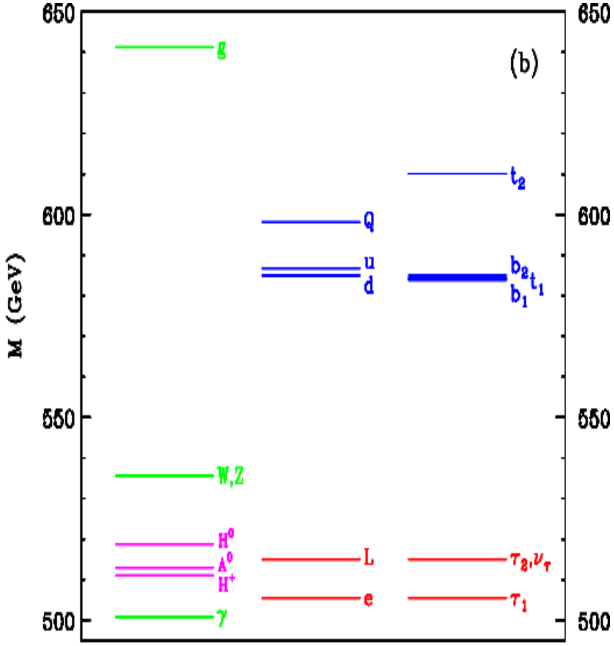
- arise from interactions localized at fixed points
- logarithmically divergent
  (finite part undetermined;
  assumption: boundary kinetic terms vanish at cutoff scale Λ)

$$\Delta M_n \sim \frac{M_n}{16\pi^2} \ln \frac{\Lambda^2}{\mu^2}$$

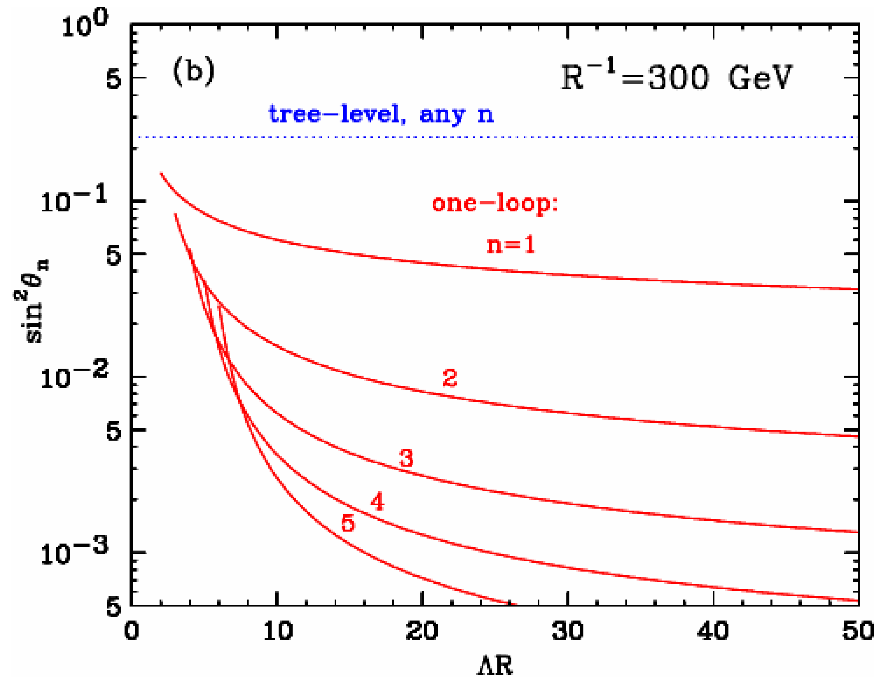
Λ = cutoff scale, $\mu \approx M_n$

Consequences of KK radiative corrections

1/R=500 GeV



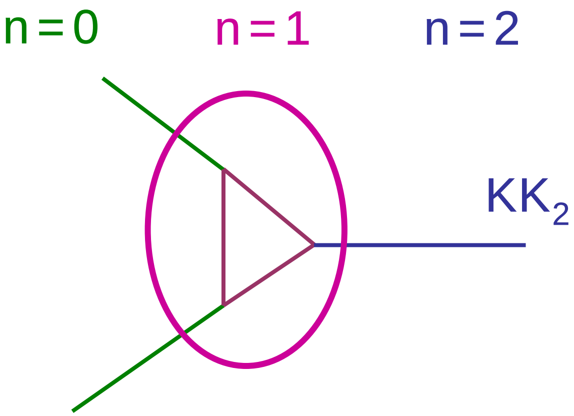
Cheng, Matchev, Schmaltz, hep-ph/0204324



- Observation of γ_1 (LKP) as missing energy
- γ_2 can not decay to two level 1 fermions
- $(\sin^2\theta_W)_n$ becomes small with radiative corrections
  → $B_2 \approx \gamma_2$; $W_2^{(3)} \approx Z_2$ (corresponds to Z'search)
- KK number violating couplings are related to KK mass corr's

KK level 2 gauge boson exchange in ee→ff

γ_2, Z_2 → $f_0 f_0$ couplings



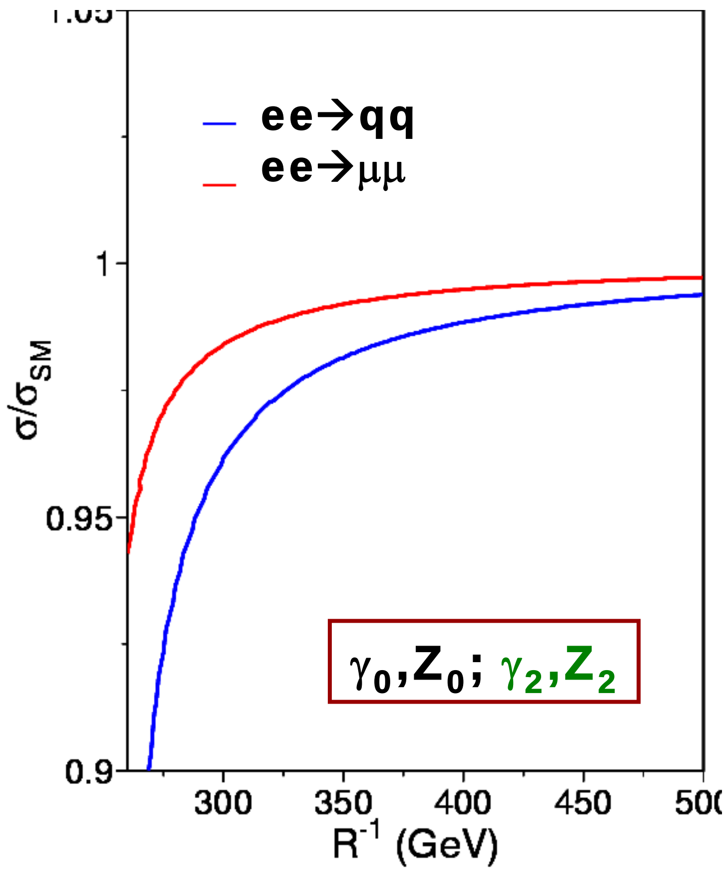
- vertex corrections
- corrections due to kinetic mixing
- corrections due to mass mixing
- couplings much smaller than SM couplings
- γ_2, Z_2 → $Q_0 Q_0$ dominate

$$\mathbf{A_{ij} \Rightarrow A_{ij}^{SM} + \left(\frac{Q^{e}_{\gamma_2} Q^{f}_{\gamma_2}}{s - M^2_{\gamma_2} + iM_{\gamma_2}\Gamma_{\gamma_2}} + \frac{g_i^{Z_2,e} g_j^{Z_2,f}}{s - M^2_{Z_2} + iM_{Z_2}\Gamma_{Z_2}} \right)}$$

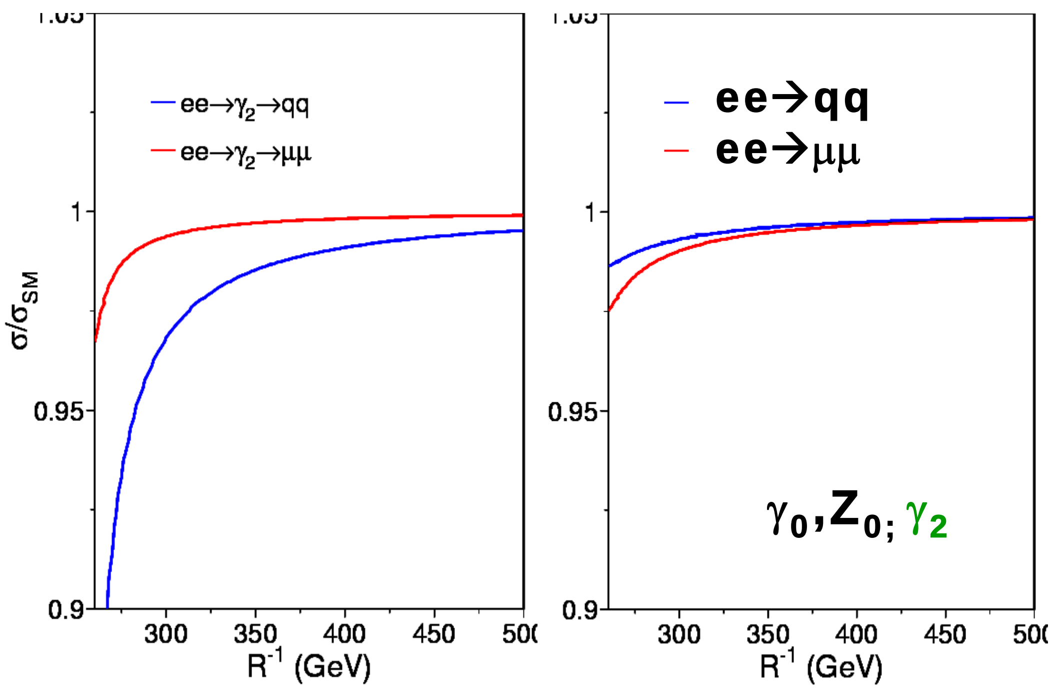
UED: KK level 2

Direct observation: 2 narrow peaks at $\sqrt{s}=M(\gamma_2)$, $M(Z_2)$

Indirect search: at $\sqrt{s} < M(\gamma_2)$, $M(Z_2)$ expect modification of hadronic and leptonic cross sections,



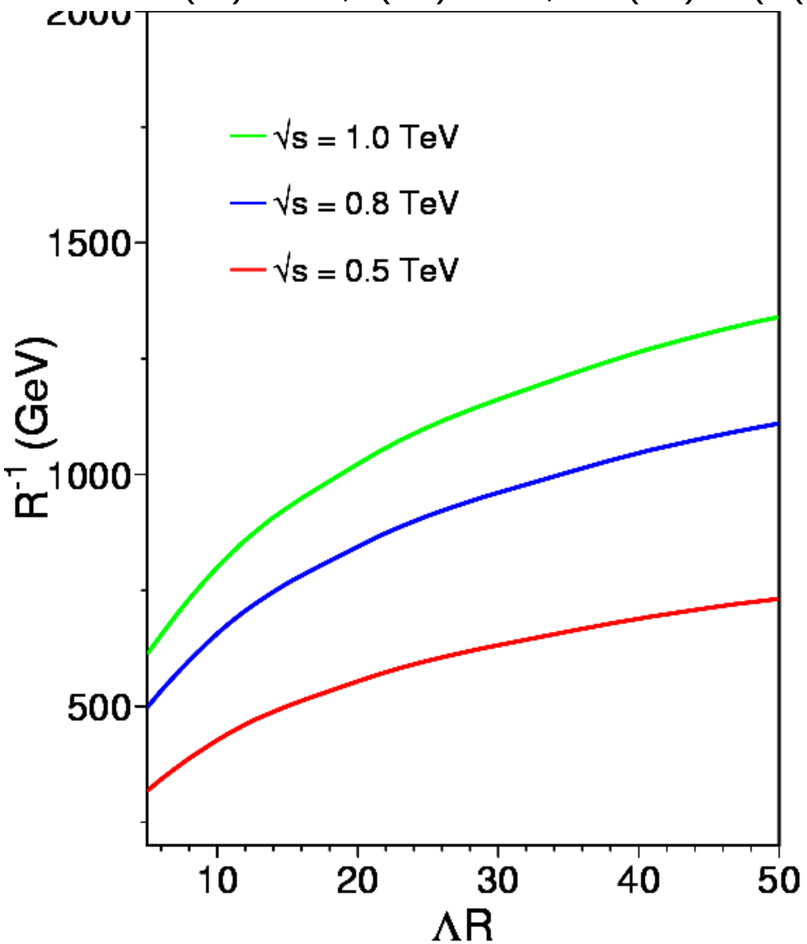
R^{-1}=0.5TeV, ΛR=50, $\sqrt{s}$=0.5 TeV



UED: KK level 2

Sensitivities to KK level 2 gauge bosons (95% C.L.)

$L_{int}=1\ ab^{-1}$, $\delta L=\delta sys=0.1\%$
$P(e^-)=0.8, P(e^+)=0.6$, $\delta P\ (e^+)=\delta(P(e-)=0.1\%$



$1/R > \sqrt{s}$
for $\Lambda R=20$

Excluded at 95% C.L.

$\gamma_2 < 2\sqrt{s}$
$Z_2 < 2\sqrt{s}$ for $\Lambda R=20$

DM: $\gamma_1 < \sqrt{s}$ is excluded

(e^+) polarisation does not improve the sensitivity

UED: Z_2, γ_2 from ee→bb, cc

Consider ee → bb, cc

($\sqrt{s}$ = 0.5 TeV and 0.8 TeV, L_{int}=1ab^{-1})

Sensitivities:

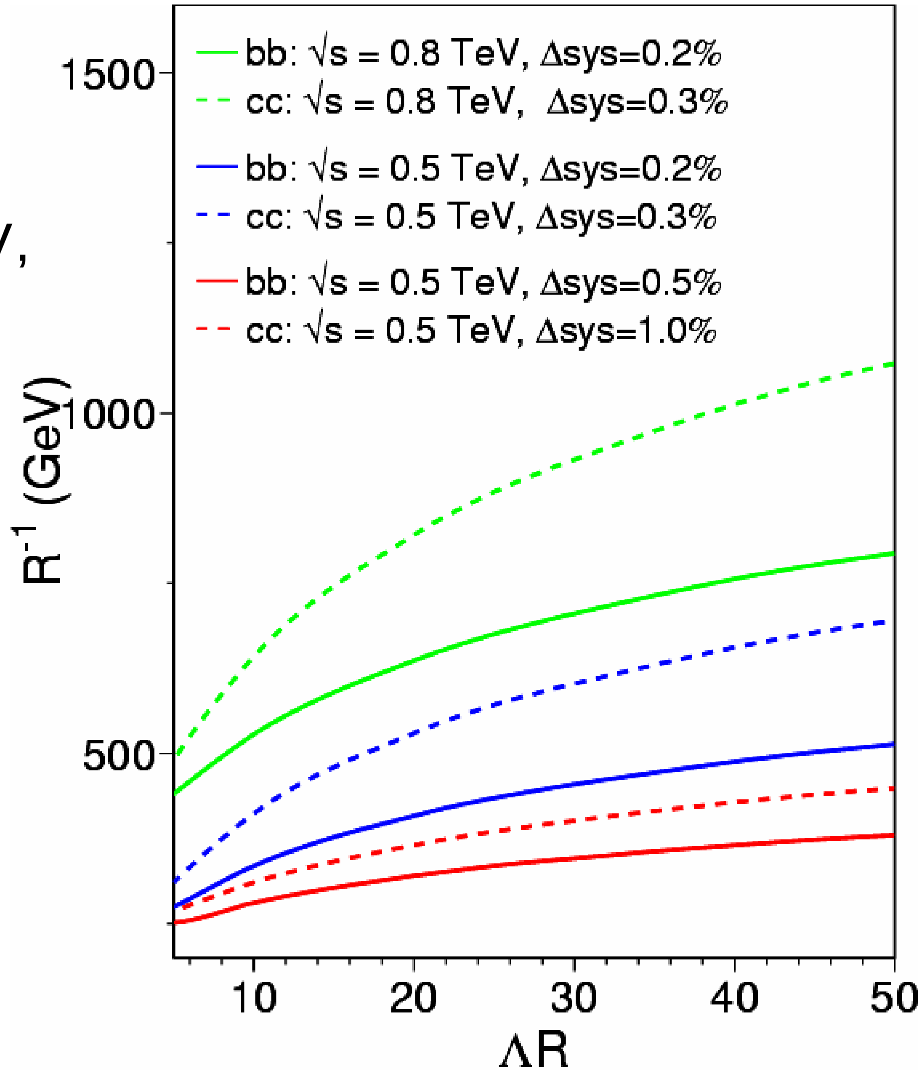
$\sqrt{s}/2 < R^{-1} < \sqrt{s}$

Excluded at 95% C.L.

$\gamma_2 < \sqrt{s}$

$Z_2 < \sqrt{s}$ for $\Lambda R \approx 20$

$\gamma_1 < \sqrt{s}/2$



Comparison with other new physics models

'Usual' Z' search

For $\sqrt{s}$= 1TeV, L_{int}=1 ab^{-1}, ee→hadrons, leptons
[δL=δsys=0.1%, $P(e^-)=0.8$, $P(e^+)=0.6$, $\delta P(e^+)=\delta(P(e-)=0.1\%$]

SSM: $M_{Z'} > 16.4$ TeV (95% C.L.)

Contact Interaction:

$$A_{CI}^{ef} = A_{SM}^{ef} + \frac{s\eta_{ij}}{\Lambda^2}$$

$\eta_{ij} = \pm 1$ (VV model)

Λ > 200 TeV (ee → hadrons)
Λ > 240 TeV (ee → leptons)

UED vs. other new physics (e^+e^-)

Distinguish UED from other scenarios ~ not easy

- detecting higher modes is the confirmation of extra dimensions
- pair produced KK1 ⇔ KK2 exchange → UED
- resonance production of level 2 bosons gives similar limits on R as pairwise production of level 1 fermions;
- UED KK or SUSY: spin
  angular distribution of leptons and missing energy
  (see previous speaker)

Summary

- UED has an interesting phenomenolgy, can be tested at ILC
- Radiative corrections ⇔ test of level 1 spectrum
  - MUED: $\gamma 1$ is a dark matter candidate
  - KK level 2 bosons are like Z' bosons
  - Further studies are needed (resolution power ...)
- Sensitivity of ILC for level 2 KK bosons: $\sim 2\sqrt{s}$

  ➔ ILC has a good chance for detection
- LHC: sensitivity up to $1/R \sim 1.5$ TeV

  Cheng, Matchev, Schmaltz, hep-ph/0205314
- Existing limits:

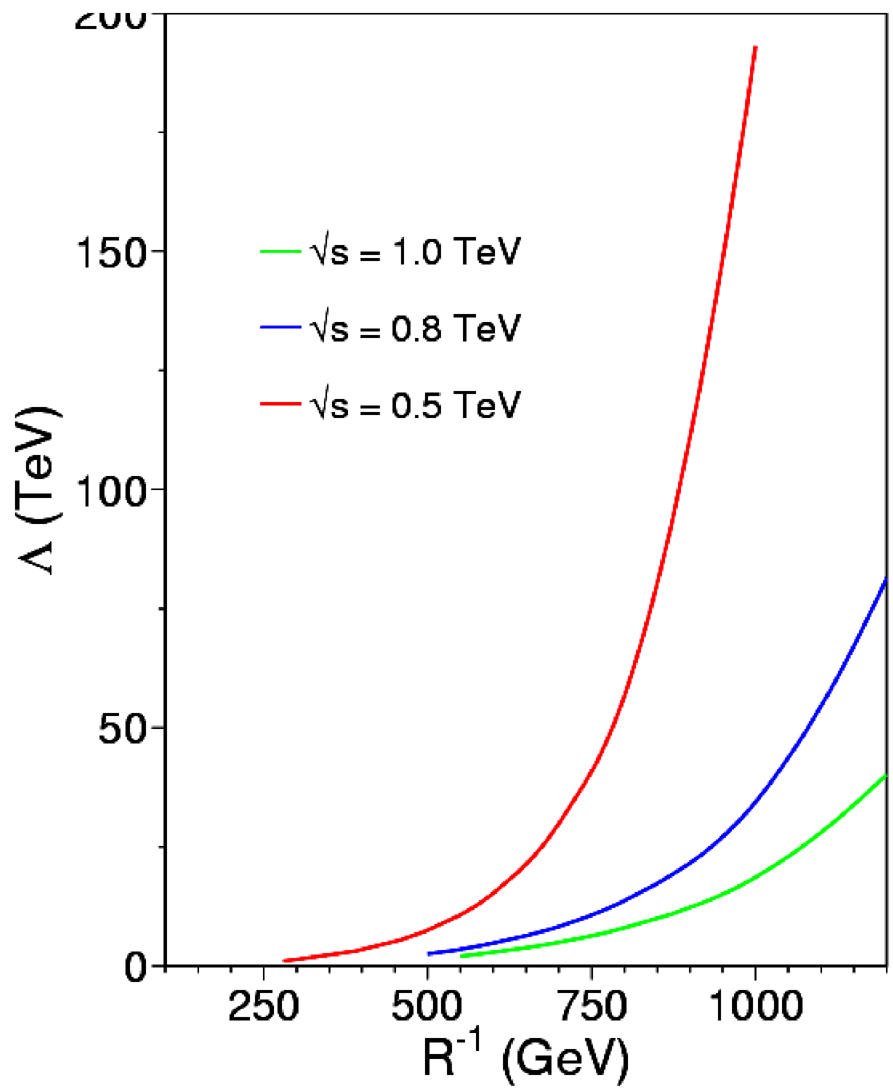
  EW constraints Appelquist, Cheng, Dobrescu, hep-ph/0012100

  $1/R \geq 250$ GeV

  Cosmological bound: Servant, Tait hep-ph/0206071

  $\Omega \sim 0.3, \quad 1/R \leq O(1)$ TeV

Bounds on Λ



Upper bounds on Λ at given
Compactification radius R