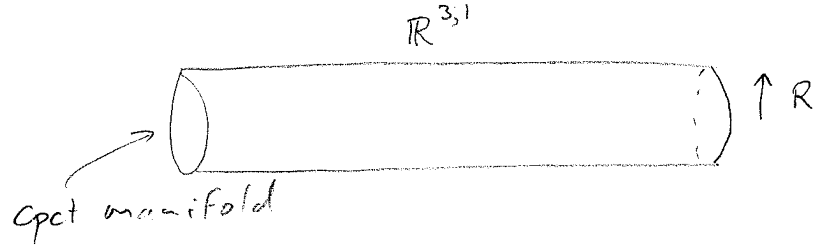
IX TeV-scale gravity

Two important, mysterious scales: $\underbrace{M_p \sim 10^{19}\,\text{GeV} \qquad M_W \sim 10^2\,\text{GeV}}_{\text{hierarchy}}$

Might they be related in a different way?

Extra dims:



total dim 4+n

$$S_{grav} = M_p^{2+n} \int d^4x \, d^n y \, \sqrt{-g} \, \mathcal{R}$$

e.g. $$ds^2 = dx_4^2 + R^2 ds_n^2$$

$$\rightsquigarrow \mathcal{R} = \mathcal{R}_4 + \cdots$$

$$S_{grav} \underset{\sim}{\rightsquigarrow} M_p^{n+2} \int d^4x \sqrt{-g_4} \, V_n \, \mathcal{R}_4$$

$$\Rightarrow \quad M_4^2 = M_p^{n+2} V_n \simeq M_p^2 (M_p R)^n$$

issue: 10^{19} GeV = "large"

$\rightsquigarrow$ two possibilities:

M_p large (conventional)

R large !

If R large, what is M_p ?

Economy: $M_p \sim \text{TeV}$

Then $R \sim \underbrace{\frac{1}{M_p}}_{10^{-17}\,\text{cm}} \cdot \underbrace{\left(\frac{M_4}{M_p}\right)}_{10^{16}}^{\frac{2}{n}}$

$n = 1$ ✗

$n = 2$ $R \sim \text{mm}$

⋮

$n = 6$ $R \sim 10^{-12}\,\text{cm}$ (Strings ?)

Certifiably crazy: nucleus $\sim 10^{-13}\,\text{cm}$

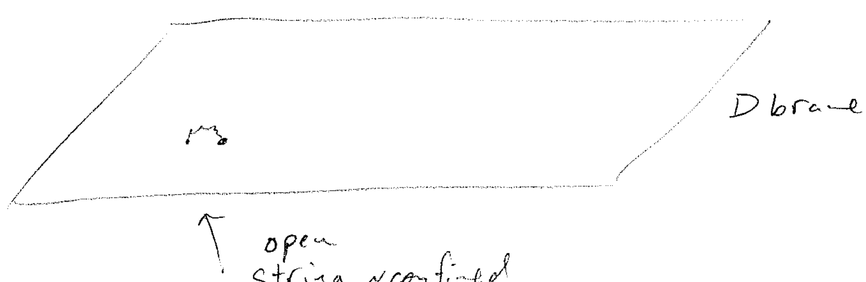
$M_W^{-1} \sim 10^{-16}\,\text{cm}$

extra dims not seen.

(e.g. mods to $\frac{1}{r}$ pots, ...)

But: $\exists$ gravitational "defects" $\sim$ domain walls,

in particular ST $\rightsquigarrow$ D-branes.

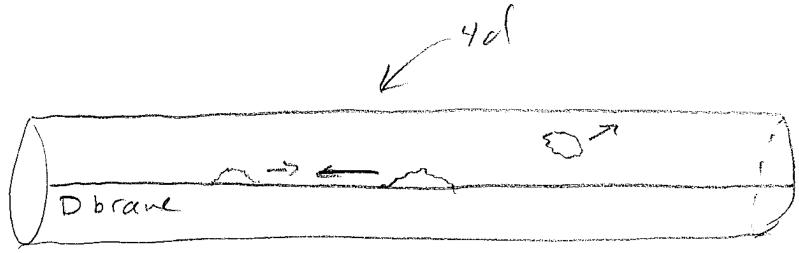


So: if SM $\begin{matrix}\text{matter}\\ \text{gauge}\end{matrix}$ = open strings,

they behave as if in fewer dims

gravity: closed strings: <u>higher</u> dimensional

Picture



Detailed Q's :

Realizable geometry (moduli issues)
SM gauge content
$SU(2) \times U(1)$ breaking
GUT rel^{n}
ν masses
no p decay
⋮

looks challenging, some real progress.

Actually warped compactifications look better

scale varies over y

$$ds^2 = e^{2A(y)} dx_4^2 + ds_6^2(y)$$

$$S_{grav} \sim M_p^8 \int d^4x \sqrt{-g_4} \int d^6y \sqrt{g_6}\, e^{+2A} \mathcal{R}_4 + \cdots$$

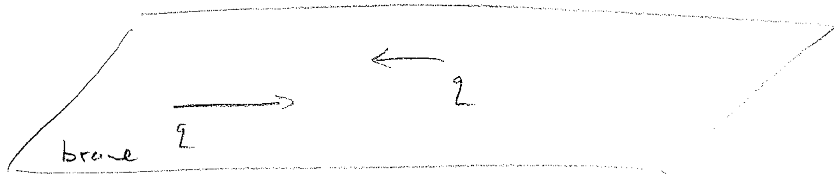
(ex-scaling)

$$\therefore \quad \frac{M_4^2}{M_p^2} \sim M_p^6 \underbrace{\int d^6y \sqrt{g_6}\, e^{2A}}_{\text{warped volume}}$$

large warping $\Leftrightarrow$ large M_4.

Can we rule this out directly?

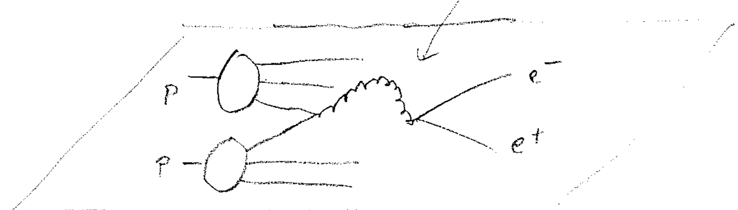
Locally:



gauge interactions – 4d
gravity corrections – higher d
but we're not so sensitive!

eg. mods to gravity: if $n=2$, $r \sim 1\,mm$, pushed hard by exp.
but $n=6$ not.

accelerators? eg Drell Yan
graviton – KK excitation



$$\sigma \sim \frac{s^2}{M_p^4} \;?$$ (spectrum, etc.)

or

missing energy.

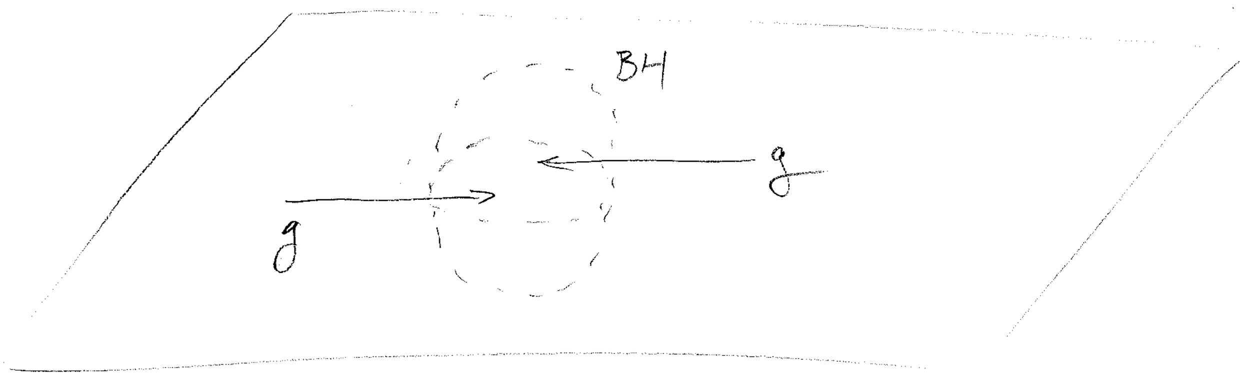
Win @ <u>high</u> <u>energies</u>

Tevatron bds $\rightsquigarrow$ $M_p \gtrsim$ TeV. !

If gravity gets strong, pretty soon

1. Make strings (if S.T. correct) at $E \gtrsim M_s$
2. Make <u>black holes</u> at $E \gtrsim M_p$!!!

Basic picture



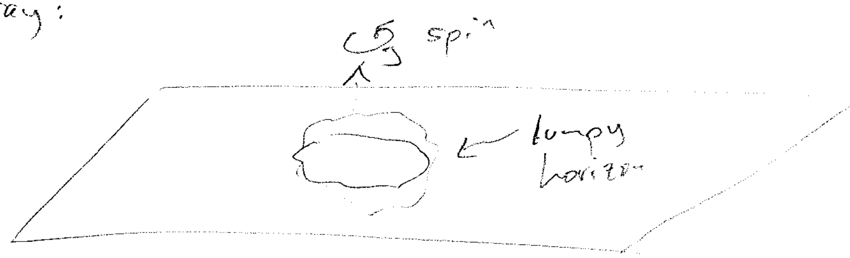
$$\sigma \sim r_{schw}^2 \sim \frac{1}{M_p^2}\left(\frac{E}{M_p}\right)^{\frac{2}{1+n}}$$

i.e. $\mathcal{O}(\text{TeV}^{-2})$ at threshhold !
(really only black hole if E "≫" M_p)
true for partons; energy distributed.

but $M_p \sim 1$ TeV, $M_{BH,min} \sim 5$ TeV

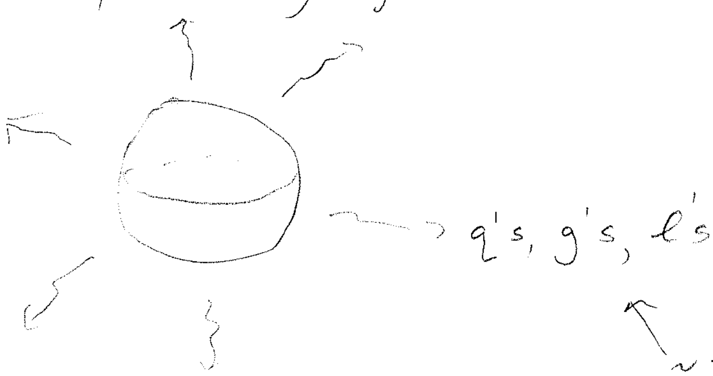
$\rightsquigarrow \frac{1}{5}$, for example.

Decay:



1. Balding & discharge $\rightarrow$ M, J

2. Hawking radiation
   A. Eliminate spin
   B. Spherically symmetric - Schwarzschild



~ thermal spectrum
~ spherically symm
$\Rightarrow$ large p_T.

End of short distance physics:

$E \uparrow$: QFT $\Delta x \sim \frac{1}{E}$ $\downarrow$

Gravity $R_s \sim E^{\frac{1}{1+n}}$ $\uparrow$

no longer probe short distances.

An appropriate ending for this course...
we'll see what LHC brings!