Implications of 'Higgs-discovery' on the phenomenology of mUED

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IoP Bhubaneswar, 13th March' 13

- First of all why should we look beyond 1 + 3 ?

Strong motivations come from the theories which try to incorporate gravity in a quantum theory

- Some of the models offer interesting solutions to some long standing problems : hierarchy, dark-matter, cosmological constant

- UED for example, provides DM, unification at a testable scale, prediction for number of fermion generations, naturally long proton life time....

Plan of this talk...

* mUED : Brief introduction/background
* Implications of Higgs discovery on mUED spectrum
* Relook at some analysis with conventional techniques...
* New strategies for mUED @ the LHC ?
* Summary and Outlook....

Based on : PRD87 (2013) 1 AD , Sreerup Raychaudhuri

&

Phys.Lett. B712 (2012) AD, Amitava Datta, Sujoy Poddar

Universal Extra Dimension : in a nutshell

SU(3) x SU(2) x U(1) gauge field theory in 4 + 1 dimensions (with similar field content that of SM)

** Extra space like dimension is of finite size (2πR)

Gauge, Higgs and Yukawa : negetive mass dimension

An effective theory valid upto a scale Λ

As usual apply KK-reduction on 5D fields :

** Apply periodic b.c. on 5d fields at y = - πR and y = + πR

$$\Phi(x,y) = \frac{1}{\sqrt{2\pi R}} \sum_0^\infty \left[\phi_+^n(x) e^{\frac{iny}{R}} + \phi_-^n(x) e^{\frac{-iny}{R}}\right]$$

Two infinite towers of KK-excitations

**KK-number (n) : discretised momentum along y-direction

Aim : to identify n=0 mode particles and their interactions with SM

Appelquist, Cheng Dobrescu, PRD64 (2001)

Problem with compactification on circle

Look at the 5d fermionic field : $\Psi(x,y) = \frac{1}{\sqrt{2\pi R}} \sum_0^\infty \left[\psi_+^n(x) e^{\frac{iny}{R}} + \psi_-^n(x) e^{\frac{-iny}{R}} \right]$

Ψ (x,y) in 5D is 4 component:

ψ_+^0 ψ_-^0 of L and R chiral or one of them is Left and the other is right

*at n=0 presence of both Left and right chiral projection

We would like to write SU(2) x U(1) gauge field theory in 5 dim

Suppose, Ψ is a member of SU(2) doublet of weak I-spin

**'SM' in 4D effective theory contains of both L-and R-chiral SU(2) doublets

Saving the compactification:

Way out : Demand some extra symmetry

Action to be invariant under $y \rightarrow -y$

Identify the (action at) points in upper half ($0<y<\pi R$) with (acion at) those points in lower half ($-\pi R < y < 0$)

Extra dimension is now restricted $[0: \pi R]$

Momentum along y direction is not conserved anymore

along with

Components of 5D fields are assigned with a quantum number called KK-parity

$$\Phi_\alpha(x,-y) = \pm\Phi_\alpha(x,y)$$

All scalars, gauge and fermions whose 0-mode corresponds to any SM field are assigned with KK-parity +1

And how the fields look like after imposing b.c.s/orbifolding:

$$
\begin{aligned}
A_\mu(x,y) &= \frac{\sqrt{2}}{\sqrt{2\pi R}} A_\mu^0(x) + \frac{2}{\sqrt{2\pi R}} \sum_{n=1}^{\infty} A_\mu^n(x) \cos\frac{ny}{R}, \\
A_5(x,y) &= \frac{2}{\sqrt{2\pi R}} \sum_{n=1}^{\infty} A_5^n(x) \sin\frac{ny}{R}, \\
\phi(x,y) &= \frac{\sqrt{2}}{\sqrt{2\pi R}} \phi^0(x) + \frac{2}{\sqrt{2\pi R}} \sum_{n=1}^{\infty} \phi^n(x) \cos\frac{ny}{R}, \\
\mathcal{Q}_i(x,y) &= \frac{\sqrt{2}}{\sqrt{2\pi R}} \left[\begin{pmatrix} u_i(x) \\ d_i(x) \end{pmatrix}_L + \sqrt{2} \sum_{n=1}^{\infty} \left[\mathcal{Q}_{iL}^n(x) \cos\frac{ny}{R} + \mathcal{Q}_{iR}^n(x) \sin\frac{ny}{R} \right] \right], \\
\mathcal{U}_i(x,y) &= \frac{\sqrt{2}}{\sqrt{2\pi R}} \left[u_{iR}(x) + \sqrt{2} \sum_{n=1}^{\infty} \left[\mathcal{U}_{iR}^n(x) \cos\frac{ny}{R} + \mathcal{U}_{iL}^n(x) \sin\frac{ny}{R} \right] \right], \\
\mathcal{D}_i(x,y) &= \frac{\sqrt{2}}{\sqrt{2\pi R}} \left[d_{iR}(x) + \sqrt{2} \sum_{n=1}^{\infty} \left[\mathcal{D}_{iR}^n(x) \cos\frac{ny}{R} + \mathcal{D}_{iL}^n(x) \sin\frac{ny}{R} \right] \right],
\end{aligned}
$$

Summary : Infinite copies (for each n) of the (almost) SM

This procedure for getting rid of unnecessary modes are equivalent to

(i) restricting the length of extra-d from 0 to πR

and

(ii) Imposing Neumann or Dirchilet b.cs on the fields

Even KK-parity : $\partial_y \Phi(x, y)|_0 = \partial_y \Phi(x, y)|_{\pi R} = 0$

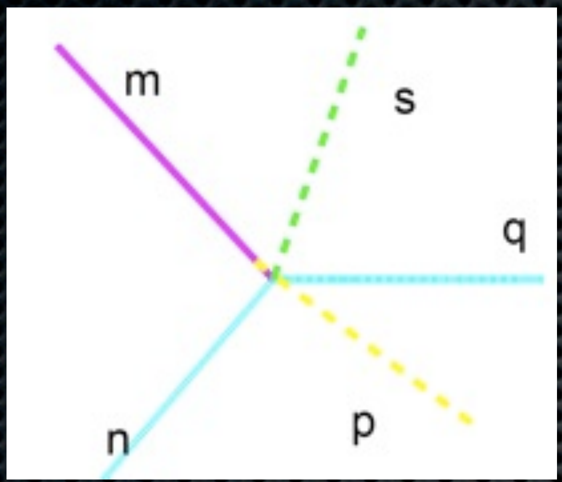
Odd KK-parity : $\Phi(x, y = 0) = \Phi(x, y = \pi R) = 0$

Residual symmetry : Reflection along a line $y = \pi/2$

KK-parity

Interactions : KK-parity conservation

$$S_4 = \int S_5 \, dy$$



KK-parity conservation implies algebraic sum of KK-parities of the particles in the vertex should add up to a even integer. (Similar to R-parity in SUSY)

$$m+n+p+q+s+ \ldots = \text{even integer}$$

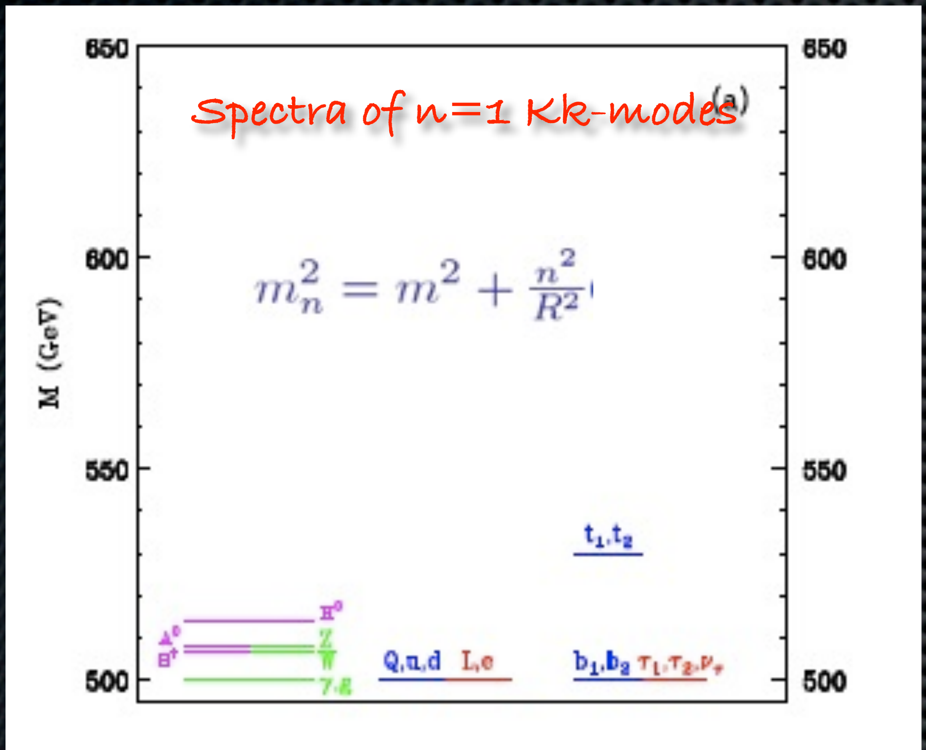
SM particle (n=0) can only couple to a pair of n =1 KK-particle.

The lightest KK (n=1) particle is thus stable. Possible DM !!

Radiative Corrections ? Why?

Tree level mass for nth kk-mode : $E^2 = p_1^2 + p_2^2 + p_3^2 + (p_4^2 + m^2)$

periodic b.c . $\rightarrow$ $p_4 = n/R$



Consider the decay $f^1 \rightarrow f^0 \gamma^1$

$$(m_{e^1} - m_{\gamma^1}) / m_{e^1} < \alpha_{EM}^2$$

$\Downarrow$

Radiative corrections are extremely important !!

Radiative Corrections

Two distinct kinds of terms

** |p4| conserving : Bulk Corrections (finite)

** |p4| violating : Brane localised corrections (log divergent)

Georgi, Grant and Hailu, PLB506 (2001)

Cheng, Matchev and Schamltz, PRD

$$\bar{\delta}\, m_{e_n} = m_n \frac{9}{4} \frac{g'^2}{16\pi^2} \ln \frac{\Lambda^2}{\mu^2},$$

$$\bar{\delta}\,(m^2_{B_n}) = m^2_n \left(-\frac{1}{6}\right) \frac{g'^2}{16\pi^2} \ln \frac{\Lambda^2}{\mu^2},$$

$$\bar{\delta}\,(m^2_{W_n}) = m^2_n \frac{15}{2} \frac{g^2_2}{16\pi^2} \ln \frac{\Lambda^2}{\mu^2},$$

$$\bar{\delta}\,(m^2_{g_n}) = m^2_n \frac{23}{2} \frac{g^2_3}{16\pi^2} \ln \frac{\Lambda^2}{\mu^2},$$

$$\bar{\delta}\,(m^2_{H_n}) = m^2_n \left(\frac{3}{2} g^2_2 + \frac{3}{4} g'^2 - \lambda_H\right) \frac{1}{16\pi^2} \ln \frac{\Lambda^2}{\mu^2} + \overline{m}^2_H$$

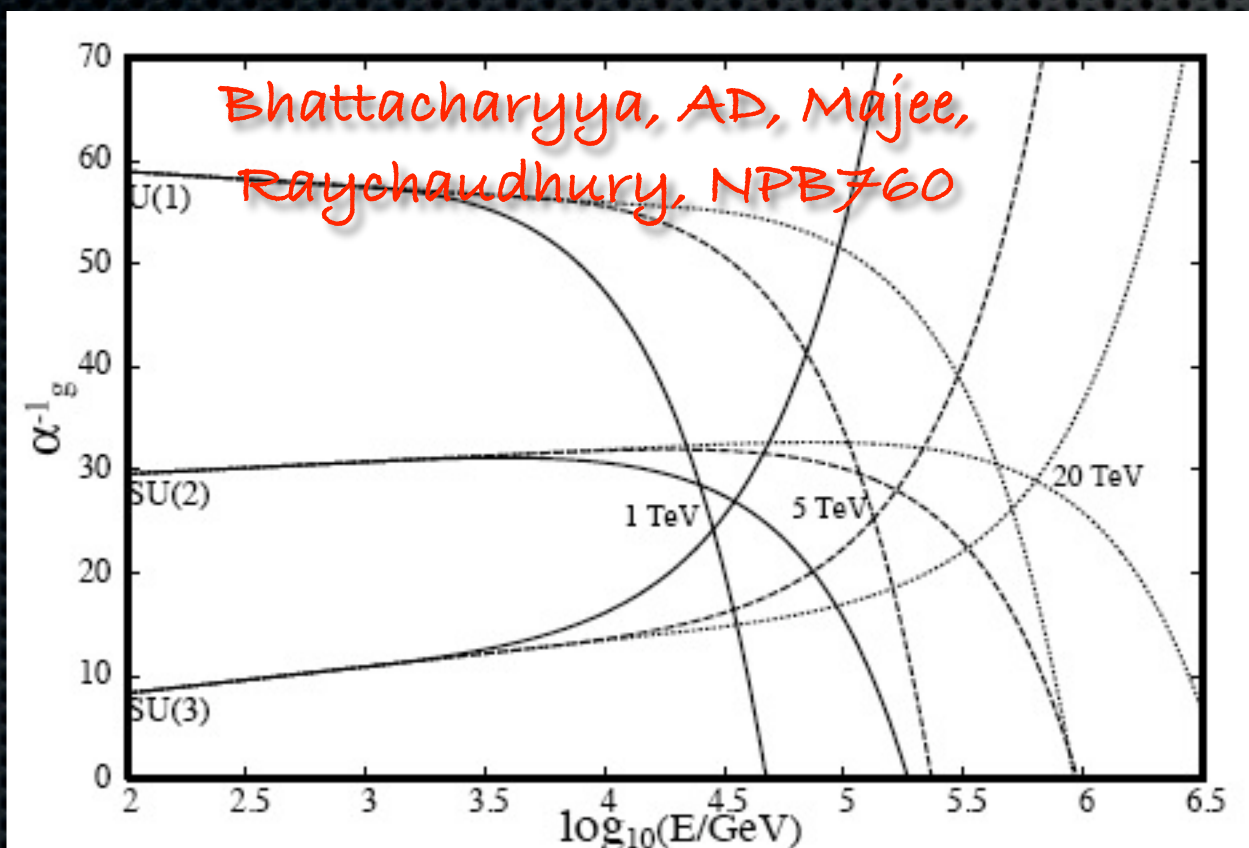
Contributions to radiative corrections from the energy scale above Λ are completely unknown ...

❄❄ mUED : the contribution above Λ is parametrised in such a way that total contribution at Λ vanishes..

** Brane bound terms are logarithmically divergent: corrections are sensitive to cut off Λ only via Log..

What should be an intelligent guess for Λ ?

To answer this we must look at the quantum corrections to SM couplings from KK-modes, e.g the corrections to gauge couplings...



$$\beta^{SM} \to \beta^{SM} + (S-1)\tilde{\beta},$$

S = E R

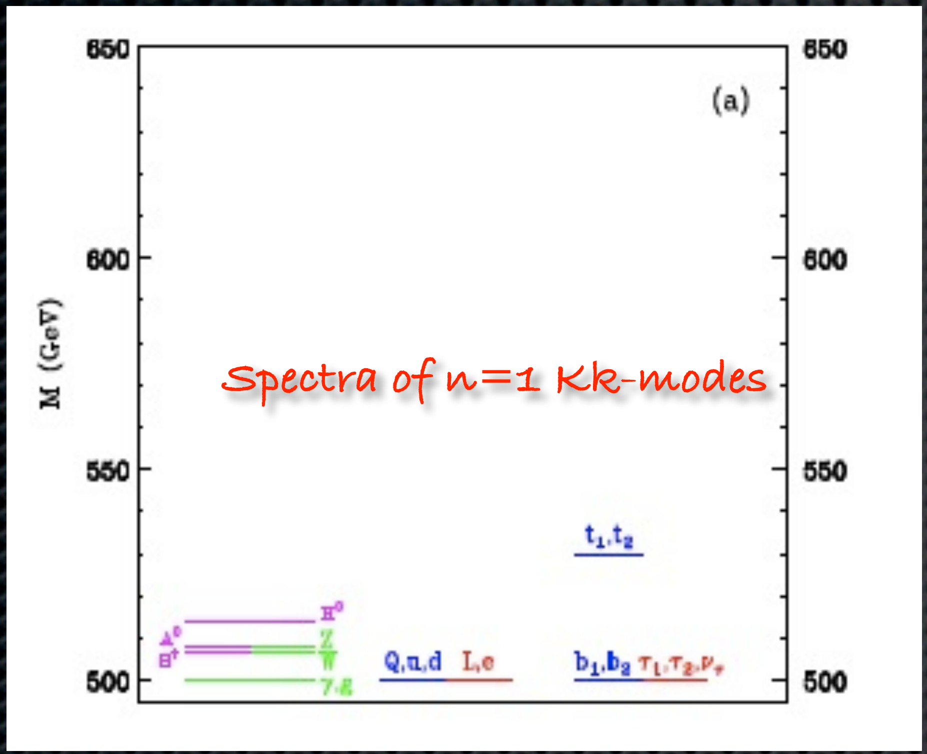
The so called running of couplings are violent..as more and more KK-levels start contributing to the β-function as we go higher in energy scale.

$\tilde{\beta}$ is generic contribution from single KK-level

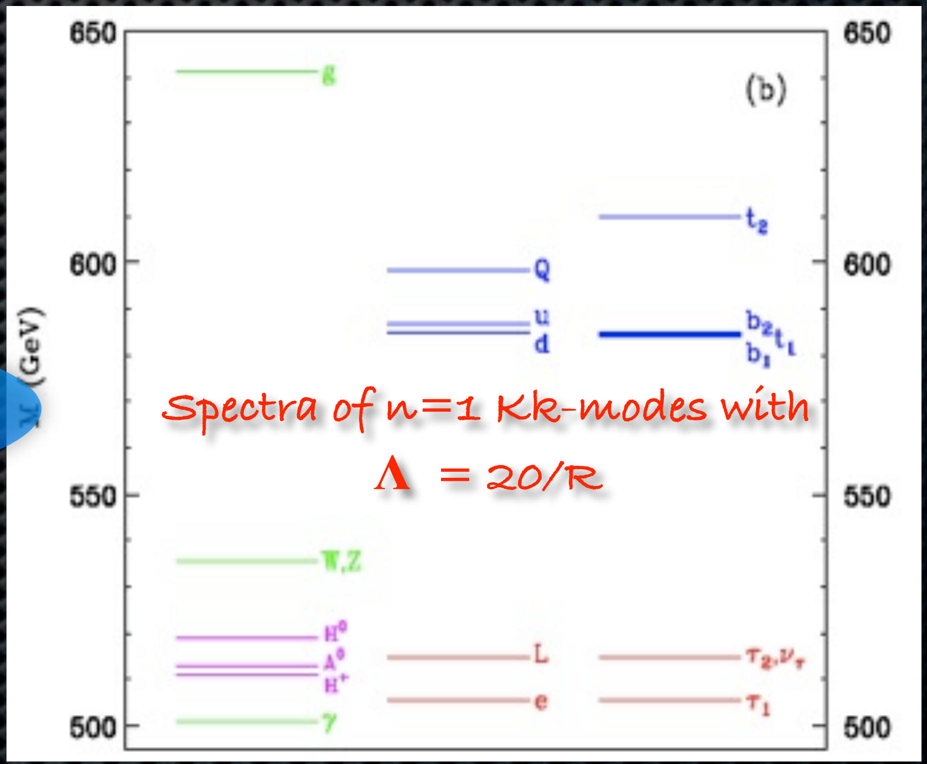
So there is a so called unification for $S \approx 20$

Radiative Corrections ...More...

Motivated from this "unification" people were using a cutoff which corresponds to $S \approx 20$ i.e. $\Lambda \sim 20/R$.

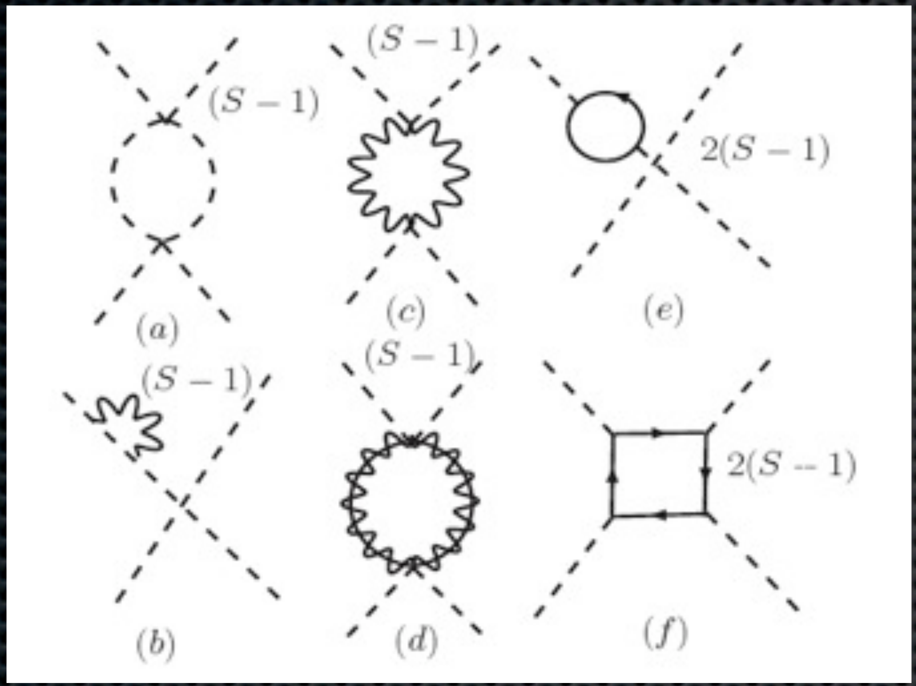


include corrections



Can we have a more conclusive guess for Λ ?

We have to investigate the effect of KK-modes on the renormalisation of λ (m_H).

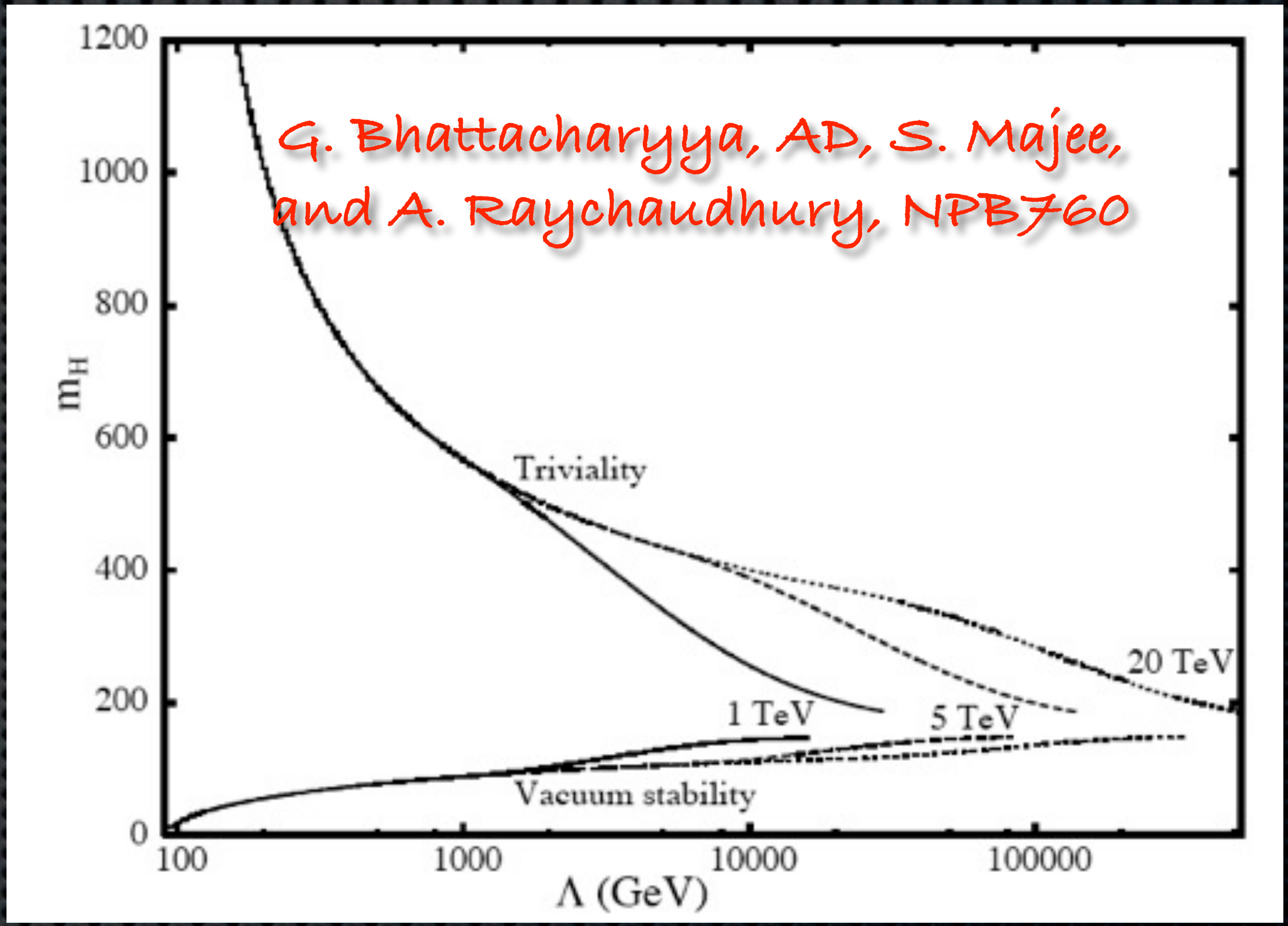


All possible KK-excitations in the loop.

Depending on the boundary value (at EW scale), λ could either hit the Landau pole or tend to negetive values at some higher energy scale !

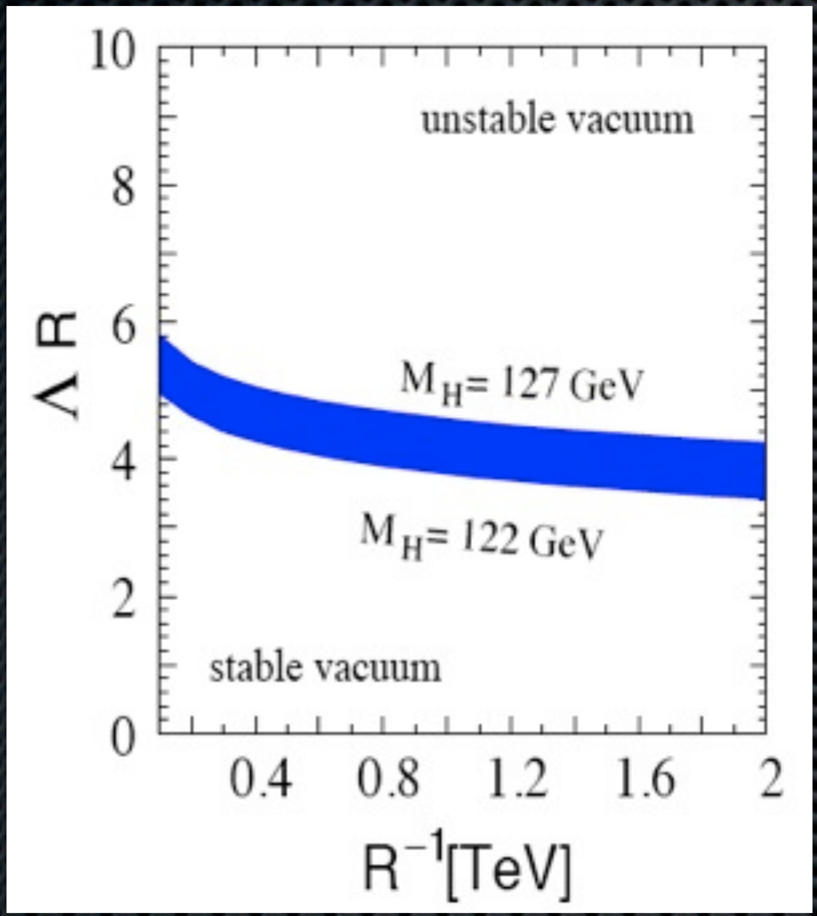
Quantum corrections to λ or m_H

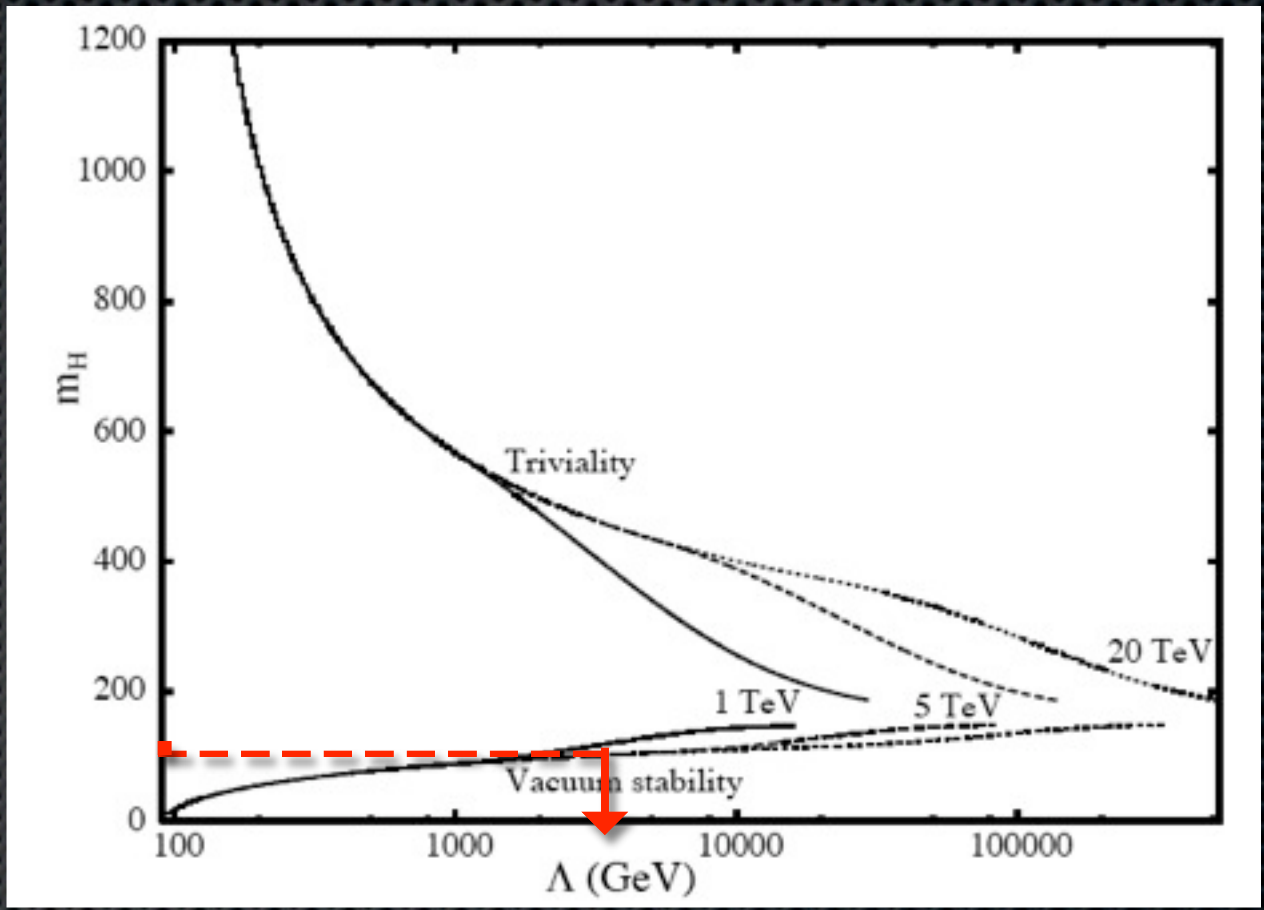
One can derive upper and lower bounds on λ (mH) from the consideration of triviality and stability of EW vacuum and lands into the famous 'Higgs Corridor'



Relook at the corridor after 'Higgs discovery'

Now we know more or less precisely where we sit on the y-axis....!!!





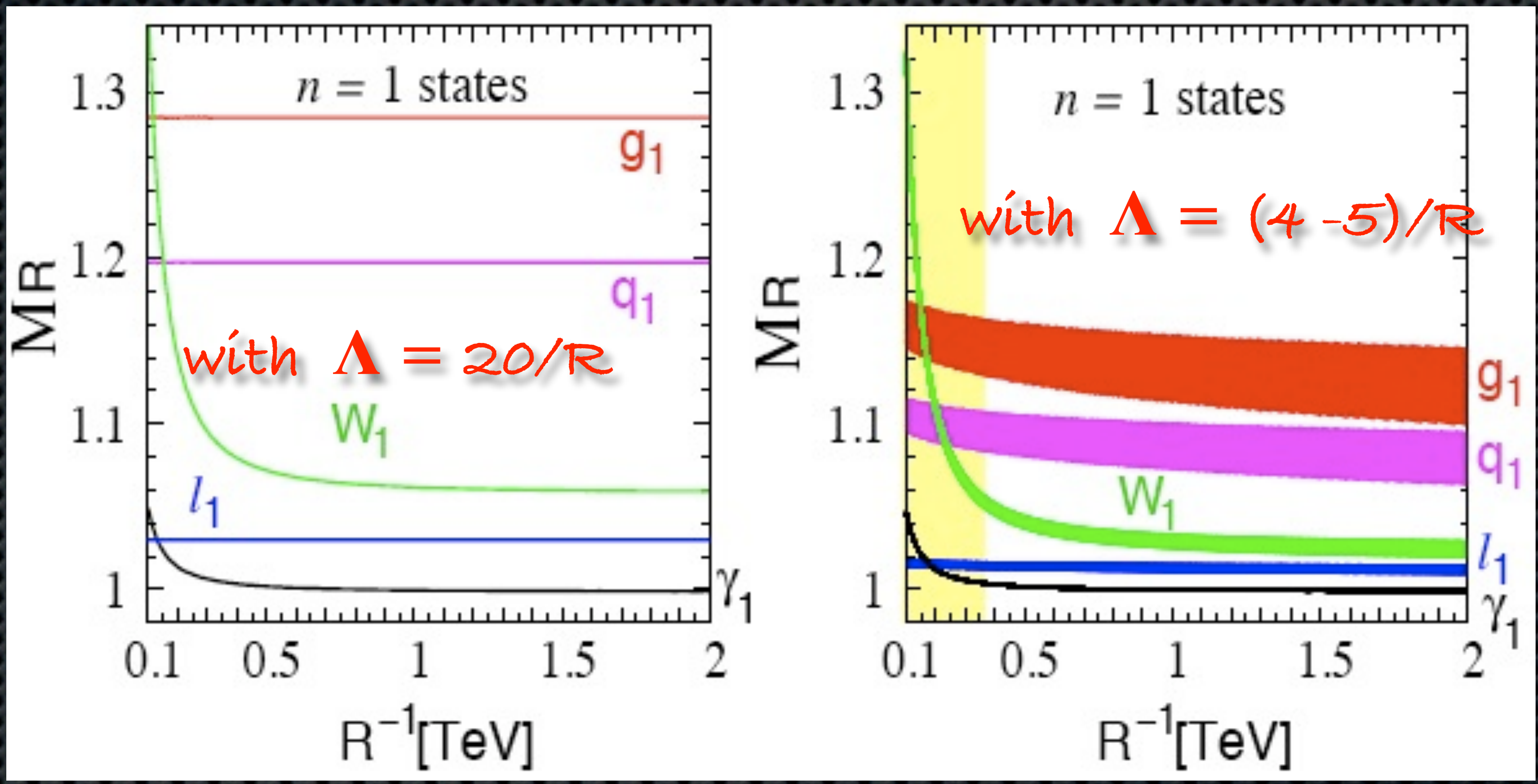
Gives us for the first time an idea about the cut-off Λ !!!

For 125 GeV Higgs , $\Lambda R \approx 5$

AD and S. Raychaudhuri, PRD87 2013

KK-masses at n=1 after Higgs discovery

**Easy to see that all the radiative corrections get diluted at least by a factor of 1/Log(4 - 8)



AD and S. Raychaudhuri, PRD87 (2013)

mUED @ LHC

Pair production of (mainly) strongly interacting
n=1 KK-modes and their subsequent decays..

Production

$$pp \to \begin{cases} g_1 + g_1 \\ q_1 + \bar{q}_1 \\ g_1 + q_1(\bar{q}_1) \end{cases}$$

$$g_1 \to \begin{cases} q + \bar{q}_1 \\ q_1 + \bar{q} \end{cases}$$

$$q_{1L} \to \begin{cases} q + \gamma_1 \\ \star\ q + Z_1^0 \to q + \ell^{\pm} + \ell_1^{\mp} \to q + \ell^+\ell^- + \gamma_1 \\ \star\ q' + W_1^{\pm} \\ \quad \hookrightarrow W^{\pm} + \gamma_1 \quad \to \ell^{\pm} + \nu(\bar{\nu}) + \gamma_1 \\ \quad \qquad\qquad\qquad\quad \hookrightarrow q\bar{q} + \gamma_1 \\ \quad \hookrightarrow \nu(\bar{\nu}) + \ell_1^{\pm} \quad \to \nu(\bar{\nu}) + \ell^{\pm} + \gamma_1 \\ \quad \hookrightarrow \ell^{\pm} + \nu_1(\bar{\nu}_1) \quad \to \nu(\bar{\nu}) + \ell^{\pm} + \gamma_1 \end{cases}$$

$$q_{1R} \to \begin{cases} \star\ q + \gamma_1 \\ q + Z_1^0 \to q + \ell^{\pm} + \ell_1^{\mp} \to q + \ell^+\ell^- + \gamma_1 \end{cases}$$

One expects m jets + n leptons + missing energy

mUED signature @ LHC

As with a lower cut-off masses of strongly interacting particles have been decreased we expect that their pair production rate will go up.

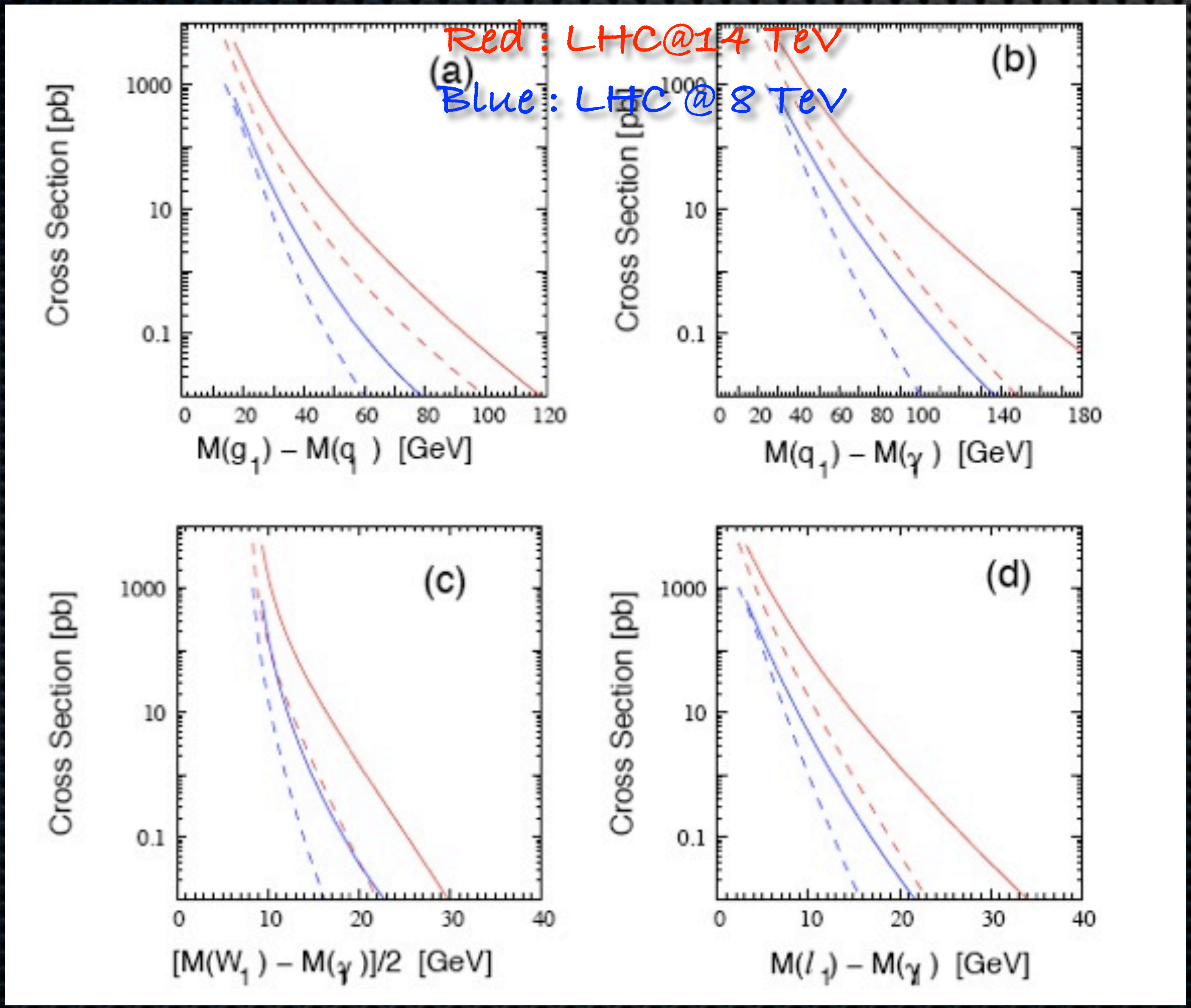
However visibility of the signal depends upon hardness of the jets , leptons, missing energy

Hardness of the jets , leptons, missing energy depends on certain mass gaps

jet: $M(g_1) - M(q_1)$, or, $M(q_1) - M(\gamma_1)$, or, $M(q_1) - M(W_1)/M(Z_1)$;

lepton: $\frac{1}{2}[M(Z_1) - M(\ell_1)]$, or, $\frac{1}{2}[M(W_1) - M(\gamma_1)]$, or, $M(\ell_1) - M(\gamma_1)$.

Correlation of total cross-section with the relevant mass gaps

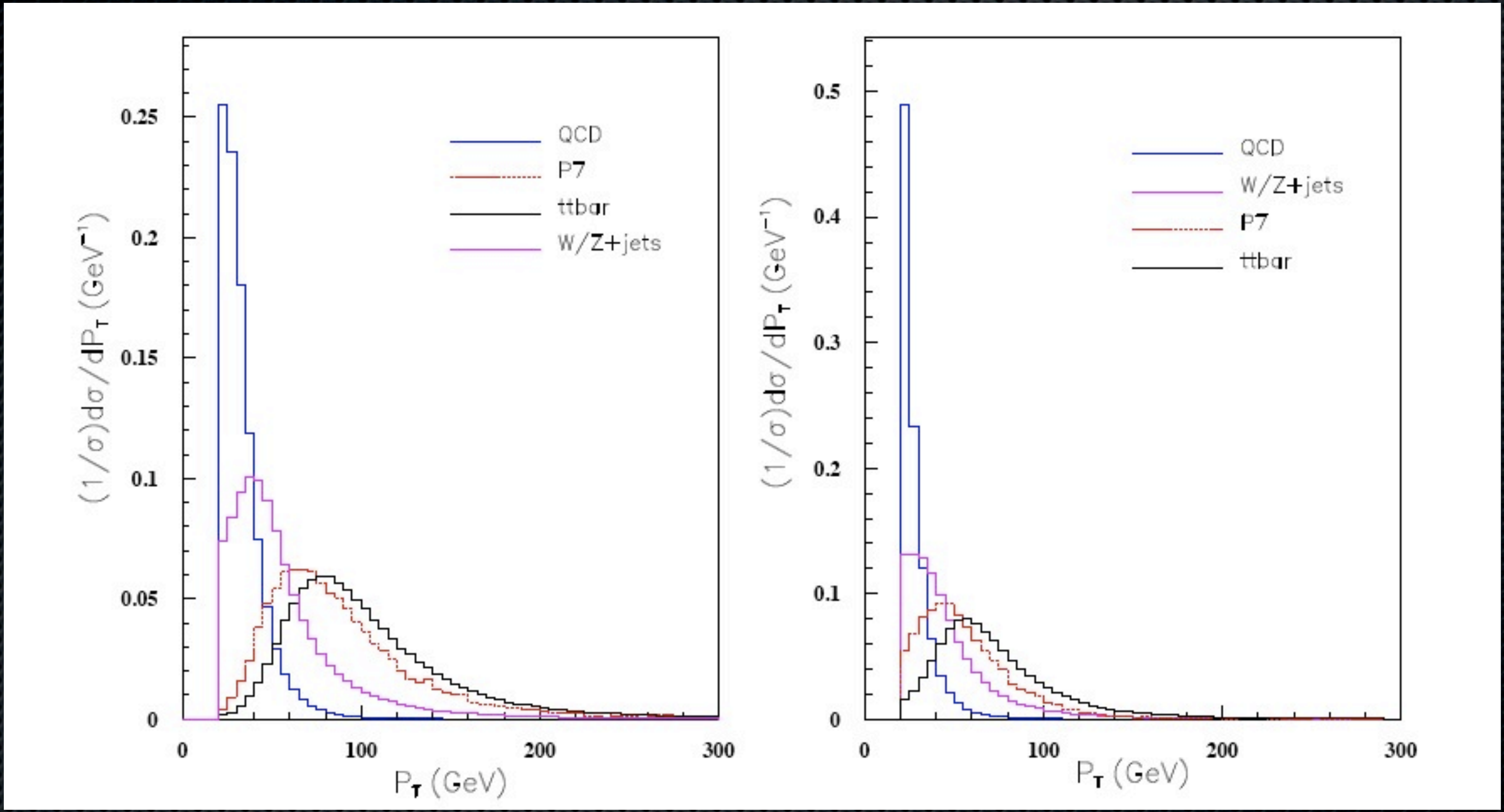


Total cross-section has an anti-correlation to the mass gaps : This is a bad news!

AD and S. Raychaudhuri, PRD87

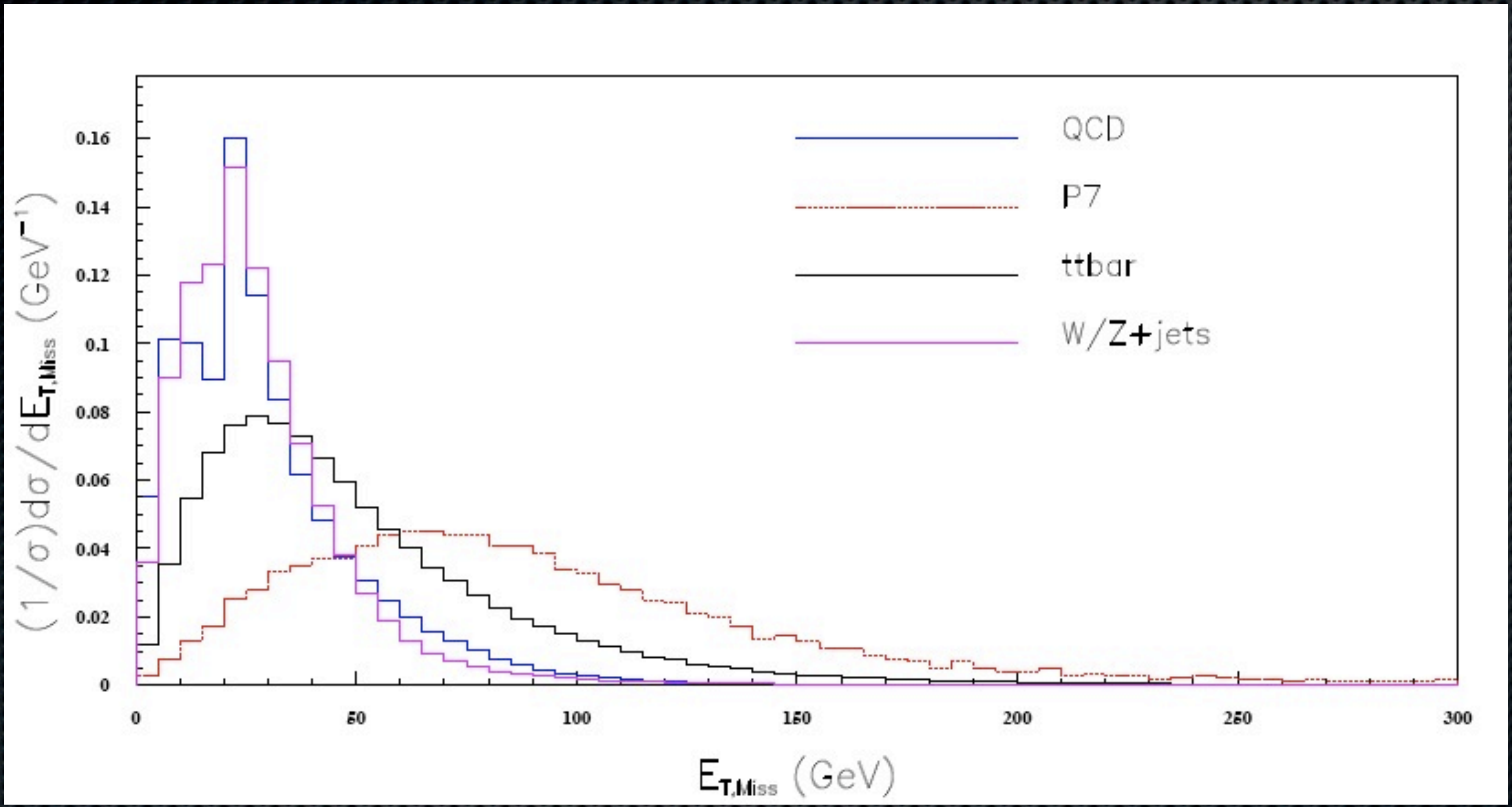
P_T spectrum of the jets

Hadronisation, ISR,FSR by PYTHIA, PYCELL



This is normalised to 1, QCD, tt have long tail...

Missing p_T spectrum



Cannot fight with SM (QCD, tt) with traditional weapons (p , MET)...

Look at some numbers for jets + $\not{E}_T$

Lepton veto only →

model	≤ 2 jets + $\not{E}_T$	3 jets + $\not{E}_T$	4 jets + $\not{E}_T$	>4 jets + $\not{E}_T$
mUED	116.9 (97.4)	66.6 (63.4)	44.2 (41.5)	37.9 (43.8)

Lepton veto + PT(jet) > 50 GeV, MET > 100 GeV →

mUED	4.56 (3.12)	1.08 (1.4)	0.58 (0.67)	0.16 (0.31)
SM ($t\bar{t}$)	2.9	7.4	12.3	23.3
SM (QCD)	1432.4	1386.3	850.1	612.5

All the cross-sections are in pb

All the numbers are with 1/R = 500 GeV @ 14TeV LHC

Effects of these cuts on mUED signal is very severe..!

AD and S. Raychaudhuri, PRD87 (2013)

Numbers for leptons + jets + $\not{E}_T$

cuts	model	1ℓ + jets + $\not{E}_T$ σ (pb)	2ℓ + jets + $\not{E}_T$ σ (pb)	3ℓ + jets + $\not{E}_T$ σ (fb)	4ℓ + jets + $\not{E}_T$ σ (fb)
$p_T^\ell \geq 10$ GeV, $\not{E}_T \geq 20$ GeV	mUED	76.6 (81.8)	10.39 (11.9)	725.3 (1 002.0)	54.0 (67.2)
	SM (EW, $t\bar{t}$)	62 758.0	5 041.9	90.8	3.5
	SM (QCD)	30 420.0	0.0091	–	–
$p_T^\ell \geq 20$ GeV, $\not{E}_T \geq 50$ GeV	mUED	9.47 (11. 2)	0.31 (0.5)	14.0 (3.5)	7.1 (0.4)
	SM (EW, $t\bar{t}$)	52 612.7	3 884.2	77.2	2.3
10 GeV $\leq p_T^\ell <$ 25 GeV, 10 GeV $\leq \not{E}_T <$ 25 GeV	mUED	10.35 (9.5)	1.27 (1.4)	54.5 (91.4)	2.0 (11.3)
	SM (EW, $t\bar{t}$)	16 434.1	892.1	0.5	0.1

All the numbers are with 1/R = 500 GeV @ 14TeV LHC

Lesson to learn : tri-lepton signal can be seen with last combination of kinematic cuts...

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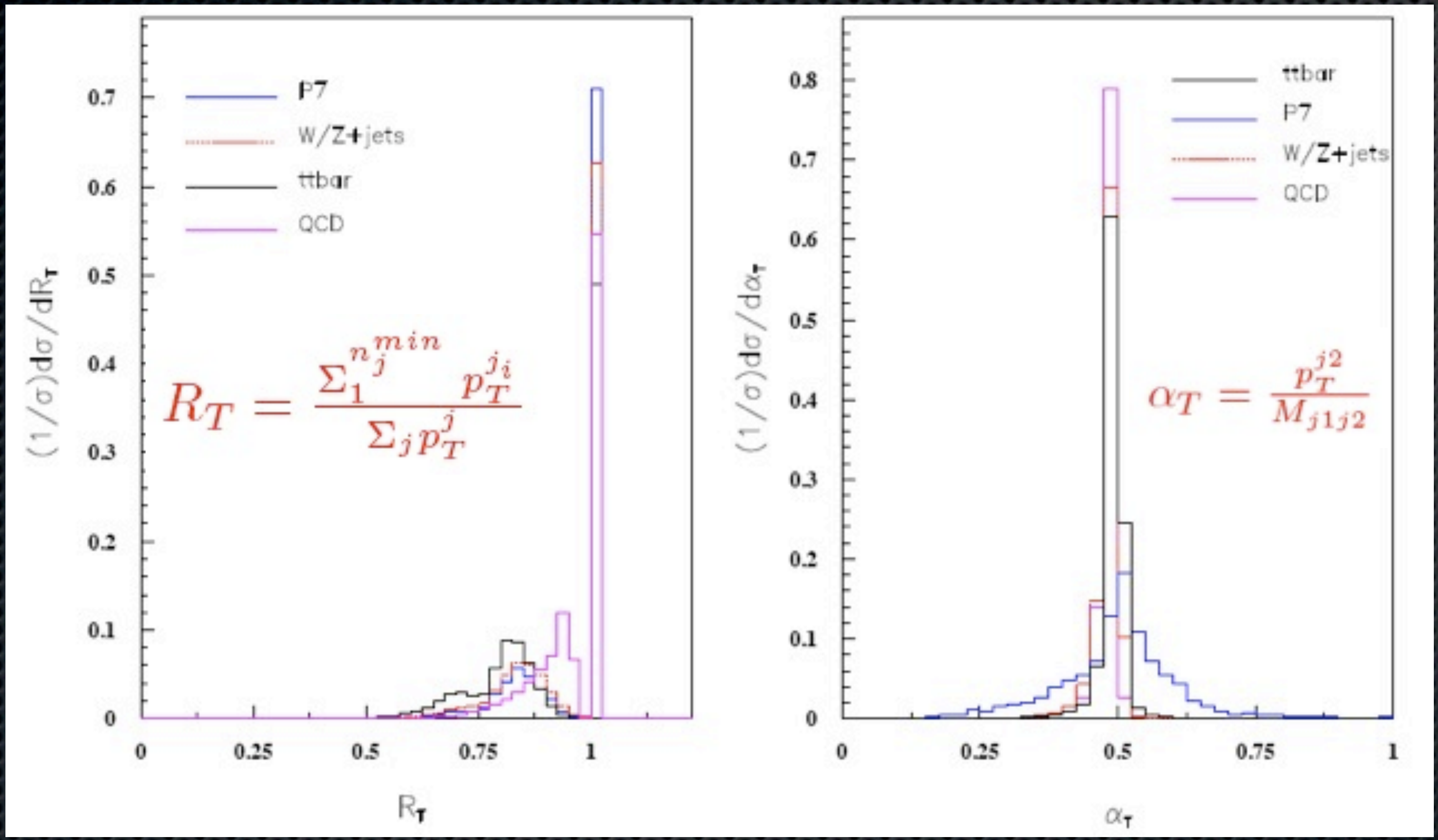
Few Event-shape variables come handy for jets + MET signal...

Unfortunate to loose the jets + MET signal, which has the largest cross-section



1/R > 900 GeV @7 TeV

with $\Lambda = 20$

PLB712 AD, A. Datta, S. Poddar

SM background can be completely tamed using

$R_T < 0.8$ and $\alpha_T > 0.6$

*** 1/R > 650 GeV @ 7 TeV with $\Lambda = 5$

Summary & Outlook :

❄ Thanks to Higgs discovery ! For the first time we have an idea about the unknown cut-off Λ in the mUED.

❄ A relatively lower cut-off reduces amount of radiative corrections to the masses of KK-modes in mUED.

❄ The above implies a higher production cross-sections for the KK-particles for the same value of 1/R. (Good News !!)

❄ Already compressed mass -spectra for n=1 , KK modes gets more compressed.

- PT spectrum for jets and lepton becomes softer and more vulnerable to the kinematic cuts which tame huge SM backgrounds (Bad News !!)

- In the post Higgs era, only hope for mUED is to look for jets + tri-lepton + MET signal which has limited mass reach.

- Search strategies based on event shape variables offer a new and powerful technique for LHC search of models with compressed spectra like mUED.

Thank You !!