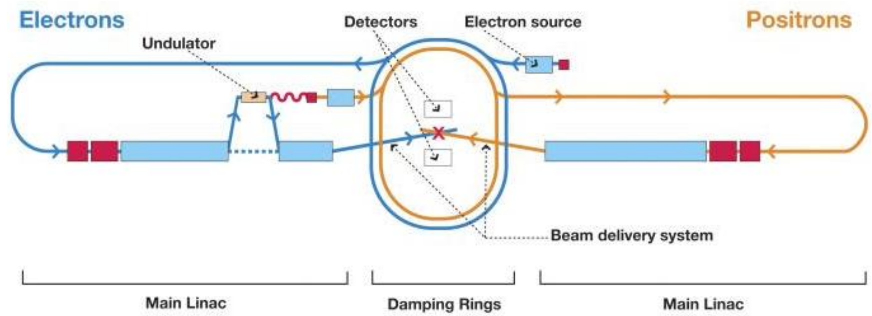
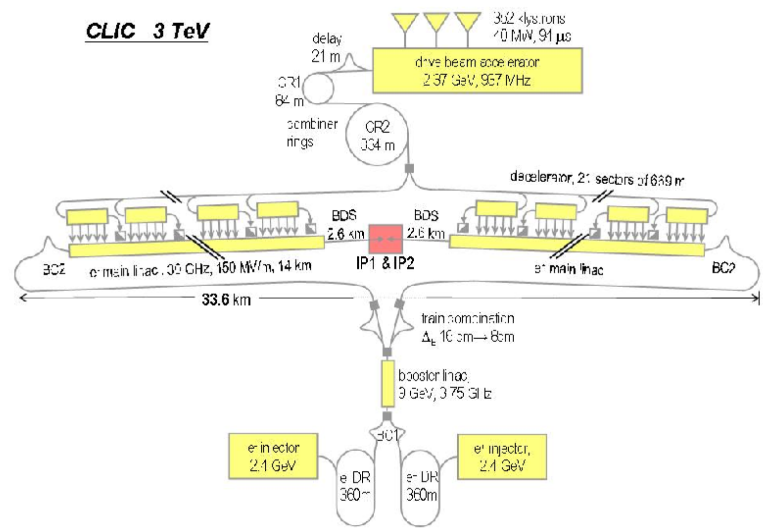
New Resonances @ ILC/CLIC





SLAC NATIONAL ACCELERATOR LABORATORY

T. G. Rizzo 20/10/2010

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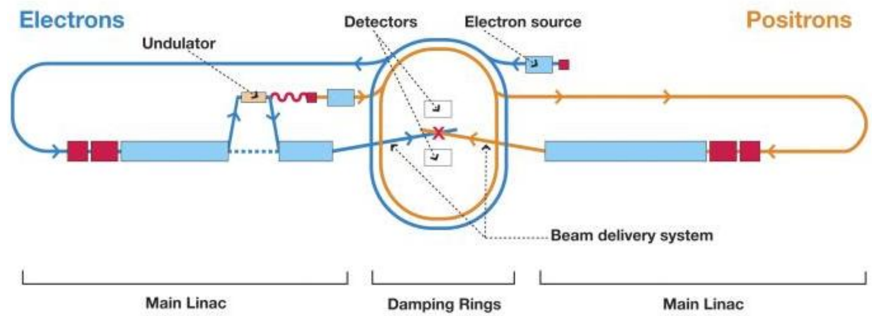
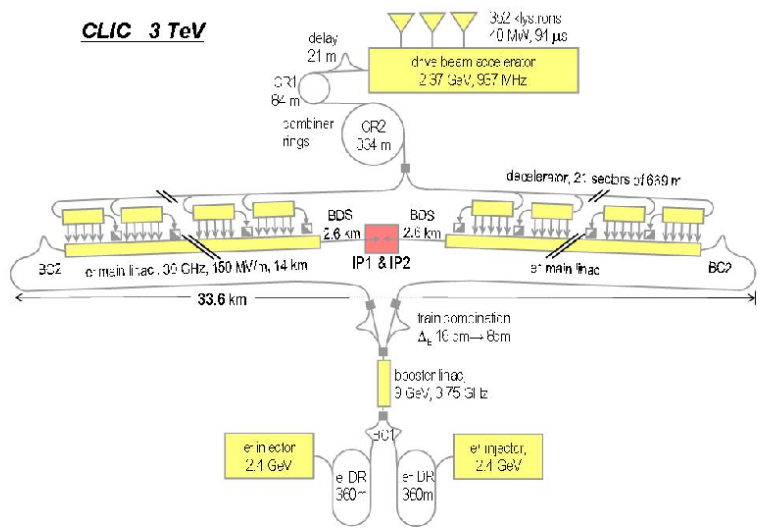




T. G. Rizzo 20/10/2010

A Z'-like state at the TeV scale is a very common prediction in *many* BSM scenarios:

- Extended SUSY-GUT groups
- Sneutrinos in R-Parity violating SUSY
- String constructions/intersecting branes
- Little Higgs models
- Hidden Valley/Sector models
- Extra dimensions: gauge & graviton KK's
- String excitations
- Twin Higgs models
- Unparticles
- Wimponia/Squarkonia
- ?????? = all the stuff we haven't though of yet

The LHC is opening up a new window to look for such states most of which will be also be accessible at lepton colliders

At the LHC there are really only 3 possibilities :

- No resonances are observed in the D-Y channel below some mass value. Then either these states don't exist or are more massive or are very weakly coupled to the SM

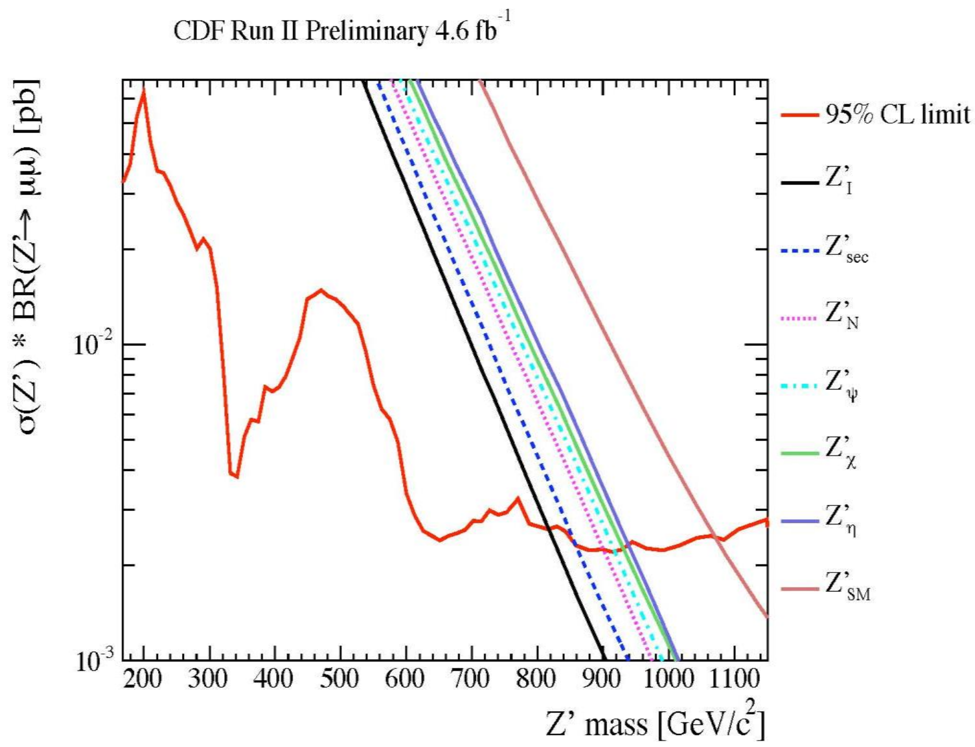
- A single Z'-like state is observed. The LHC will then do all it can to determine it's properties..mass, spin, partial widths, couplings, etc. This cannot be done in all generality due to a lack of sufficient observables (and possibly low statistics)

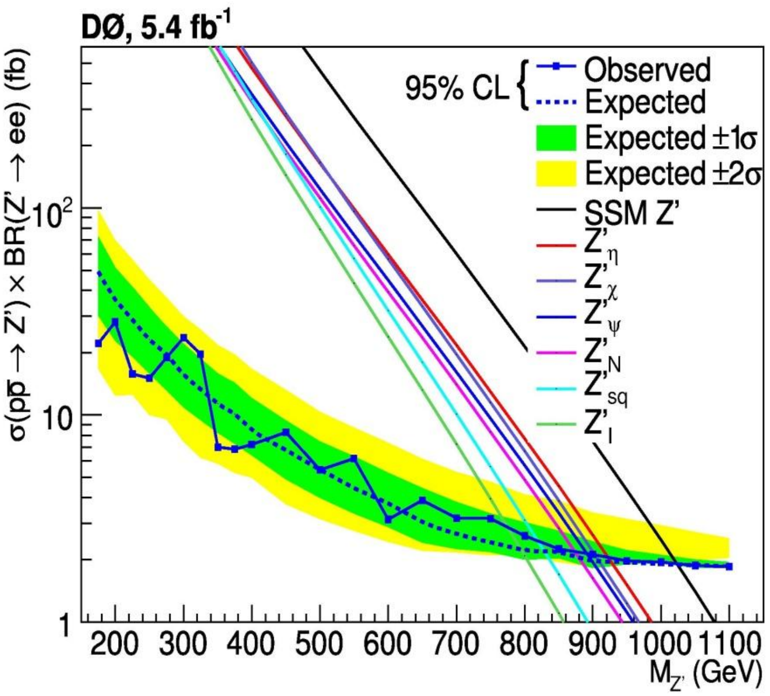
- 2 or more states are found…let the exploration of extra dimensions (or not !) begin….

In all these cases a high energy e^+e^- collider will be necessary to explore this new physics..

Where are we now?

Present direct constraints on Z'-like resonances come from the CDF & D0 searches @ the Tevatron….



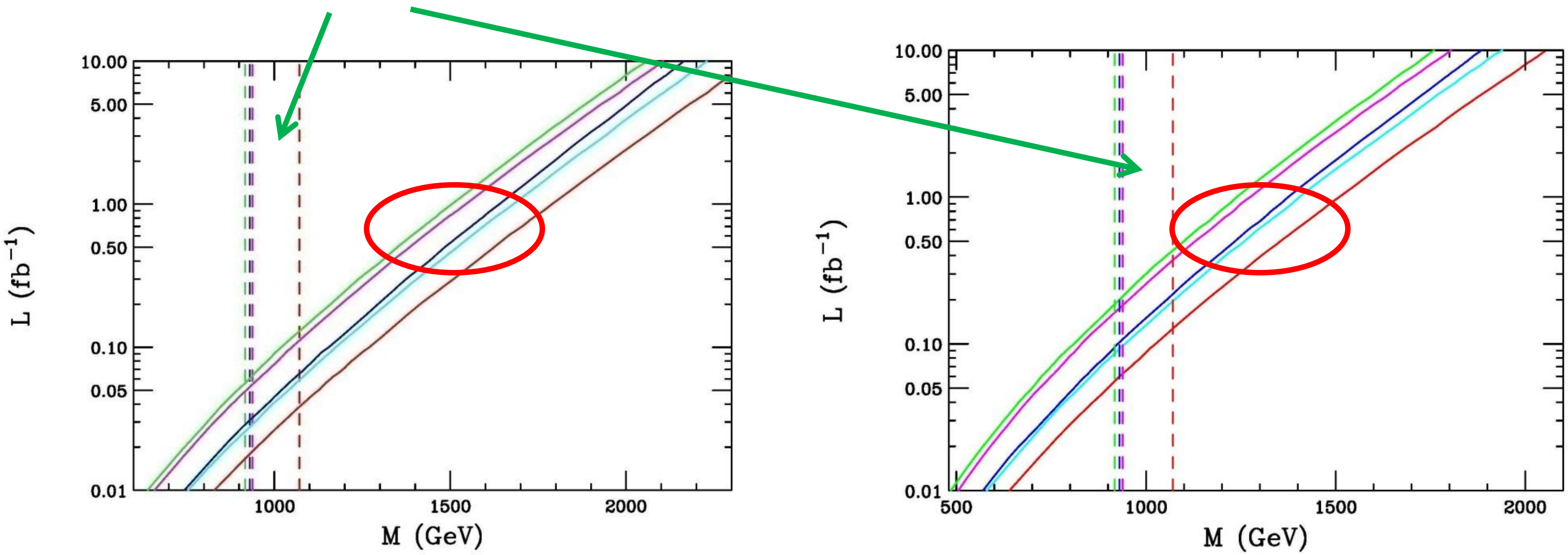


BUT not for very much longer !!

• The LHC running at $\sqrt{s}$ = 7 TeV will soon begin to surpass the Tevatron once ~100 pb^{-1} of lumi is collected..maybe in only a few months !

• The results shown here & (mostly) from now on will be based on fairly generic Z'-like models

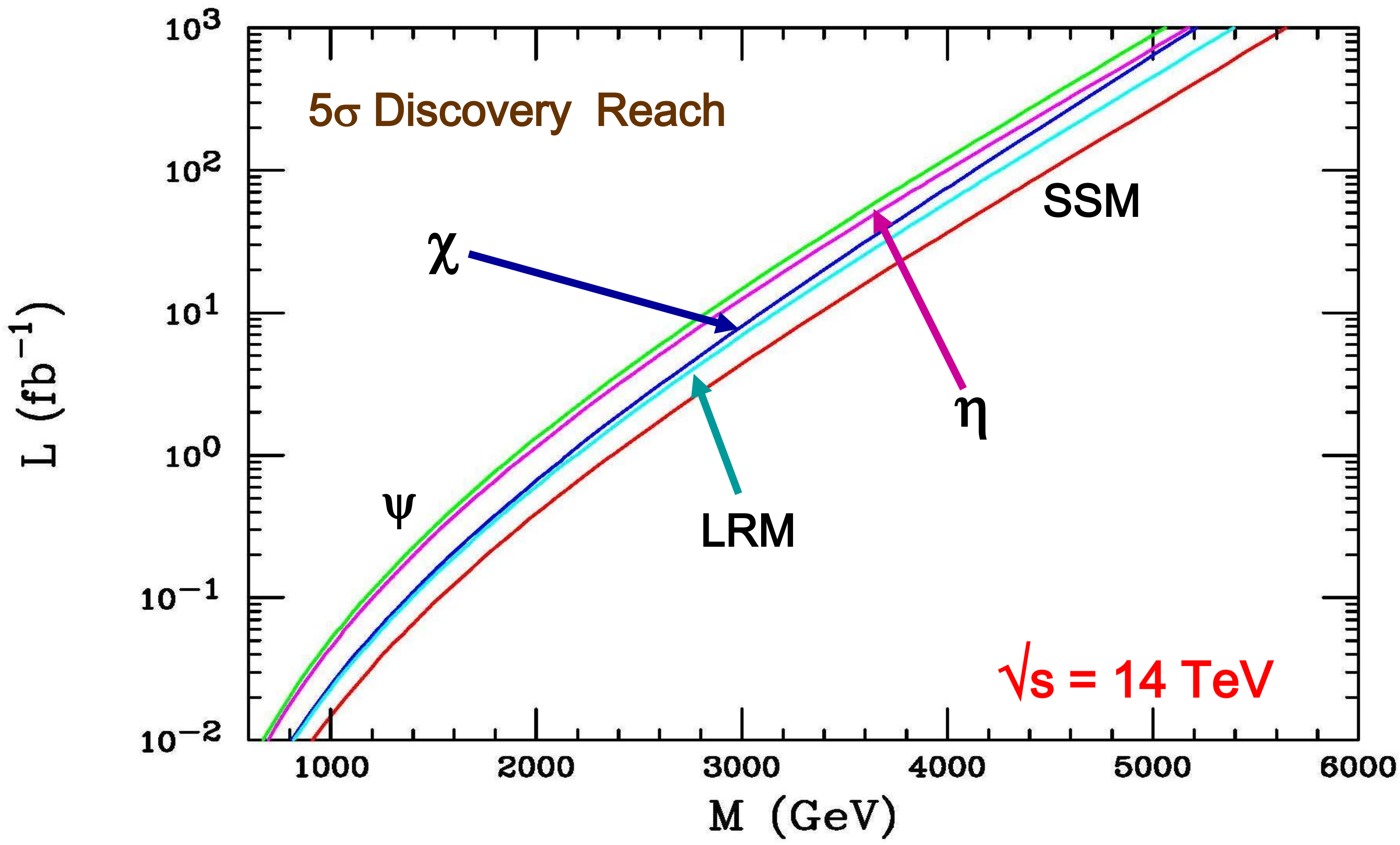
CDF limits



95% CL Reach

5σ Discovery Reach

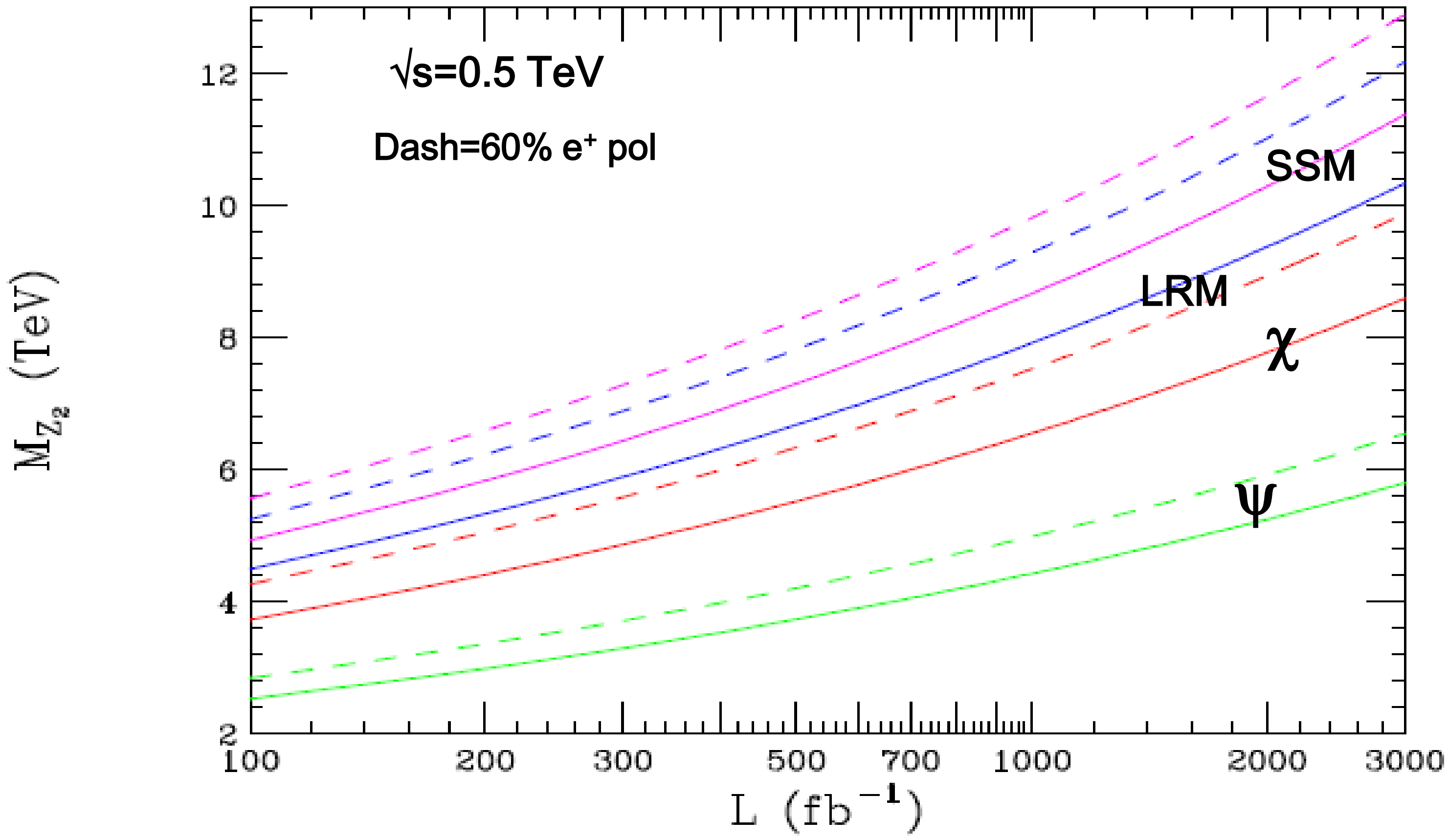
Eventually the 14 TeV LHC will cover the mass range up to ~5-6 TeV for a typical Z' w/ electroweak coupling strength & a luminosity of 1 ab^{-1} …



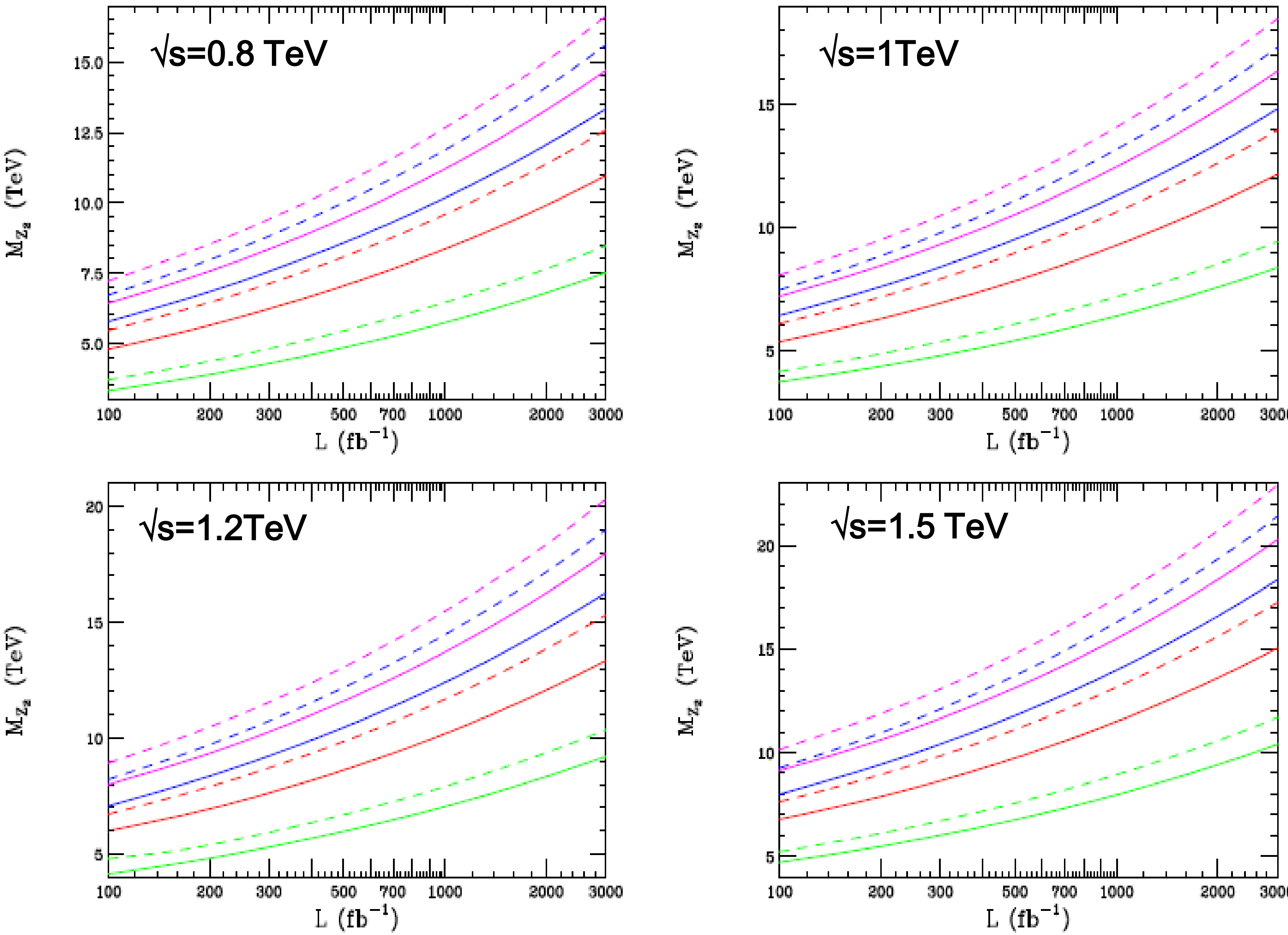
What if nothing is found???

Looking beyond the LHC with e^+e^- colliders

It is well-known that such ‘contact-interaction’ searches are quite sensitive to mass scales far beyond the collider’s √s….



1 ab^{-1} LHC reach

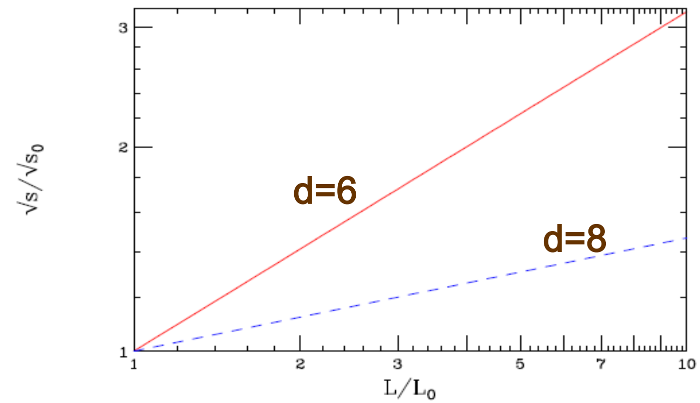


√s=0.8 TeV
√s=1TeV
√s=1.2TeV
√s=1.5 TeV
M_{Z_2} (TeV)
L (fb^{-1})
100
200
300
500
700
1000
2000
3000
5.0
7.5
10.0
12.5
15.0
5
10
15
20

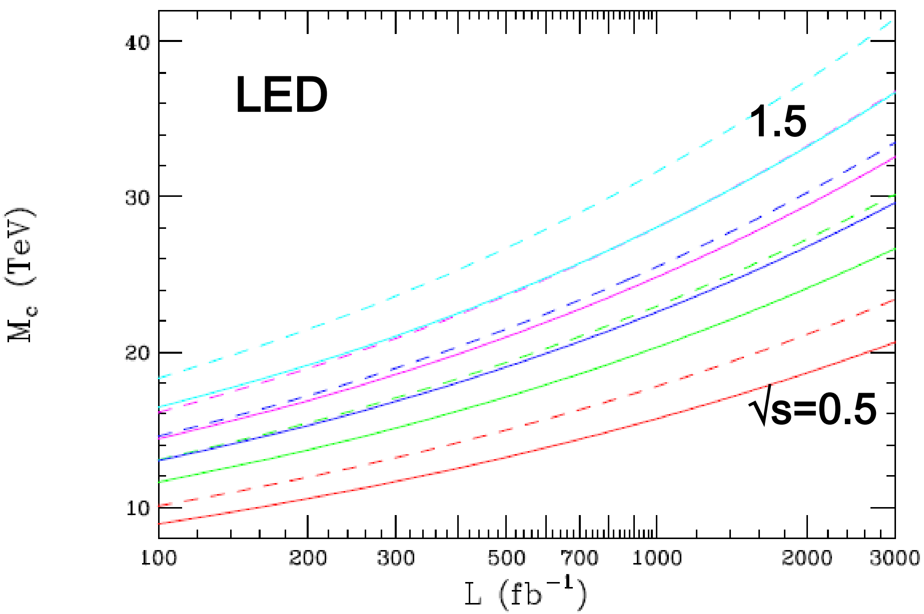
Of course we can look for other new physics besides a Z'..

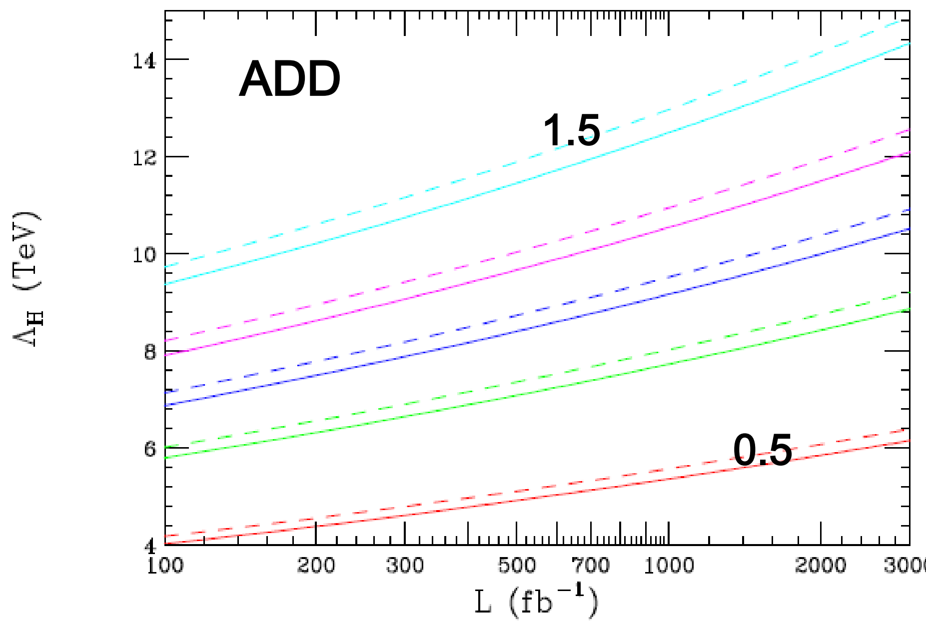
For any d-dimensional operator produced by NP, if the errors are statistics dominated, then the search reaches roughly scales as

$$\sim [\, s^{(d-5)} \; L \,]^{\, 1/(2d-8)}$$

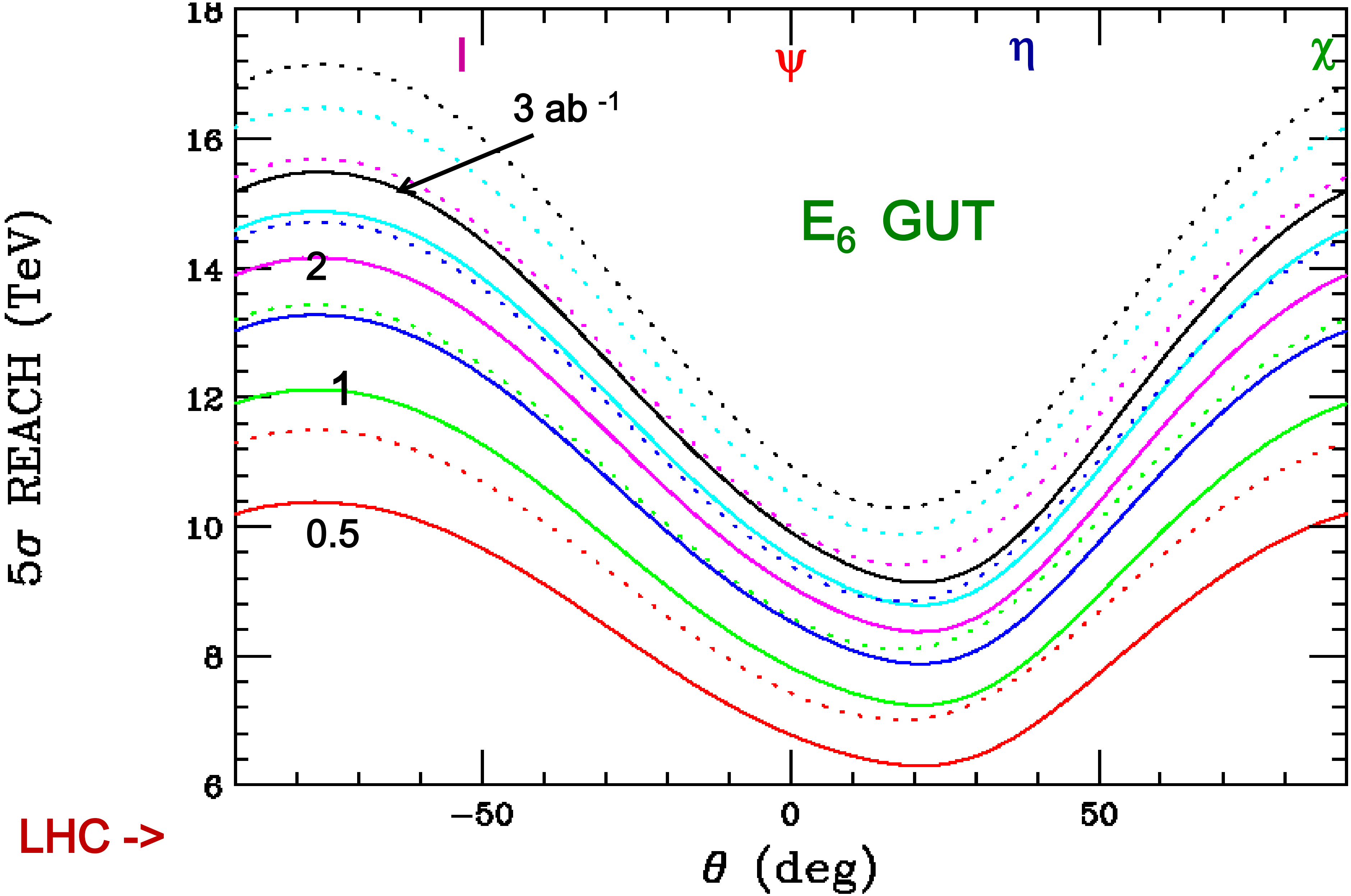


But one has to assume that no other NP makes contributions to these cross sections to obtain these limits.



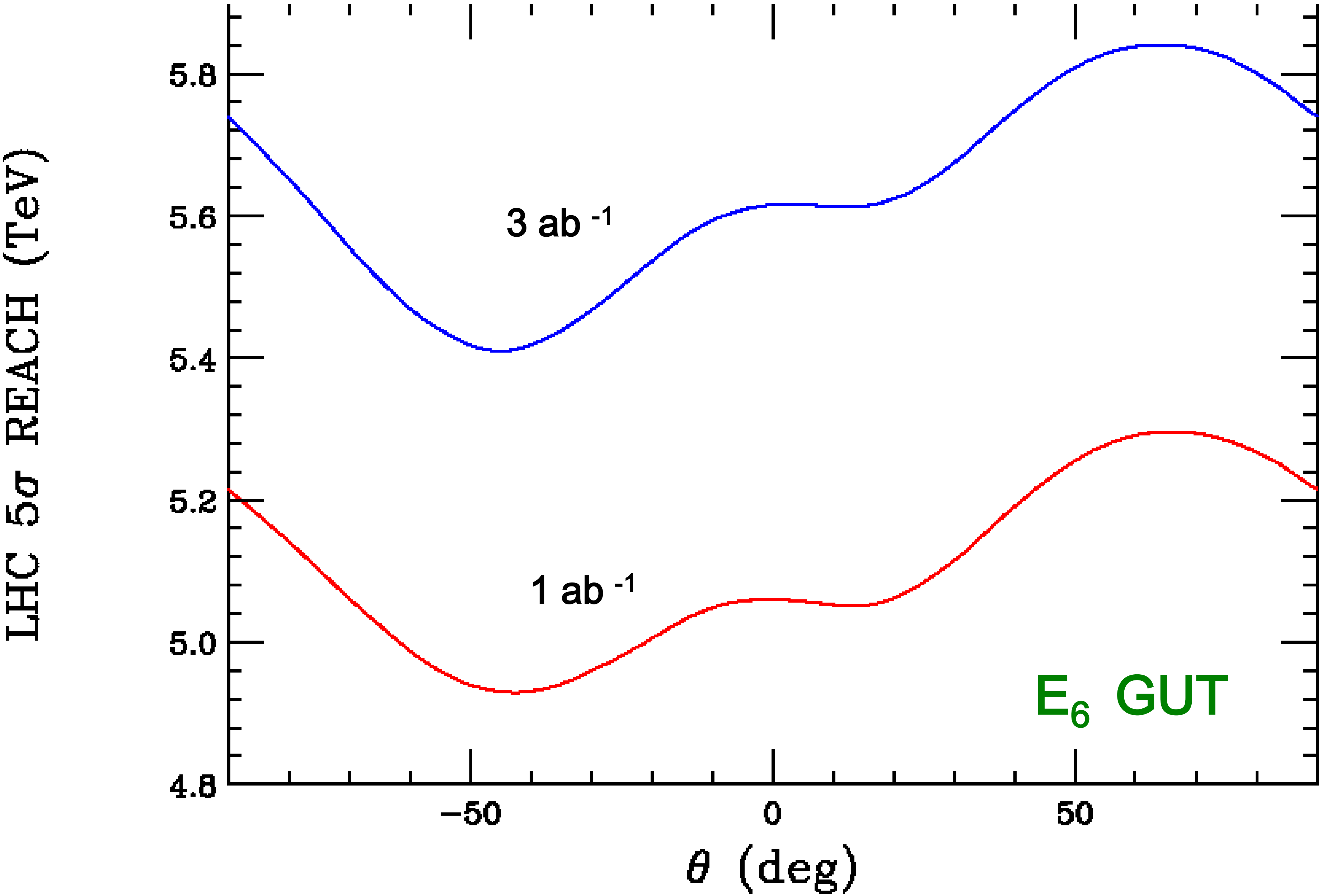


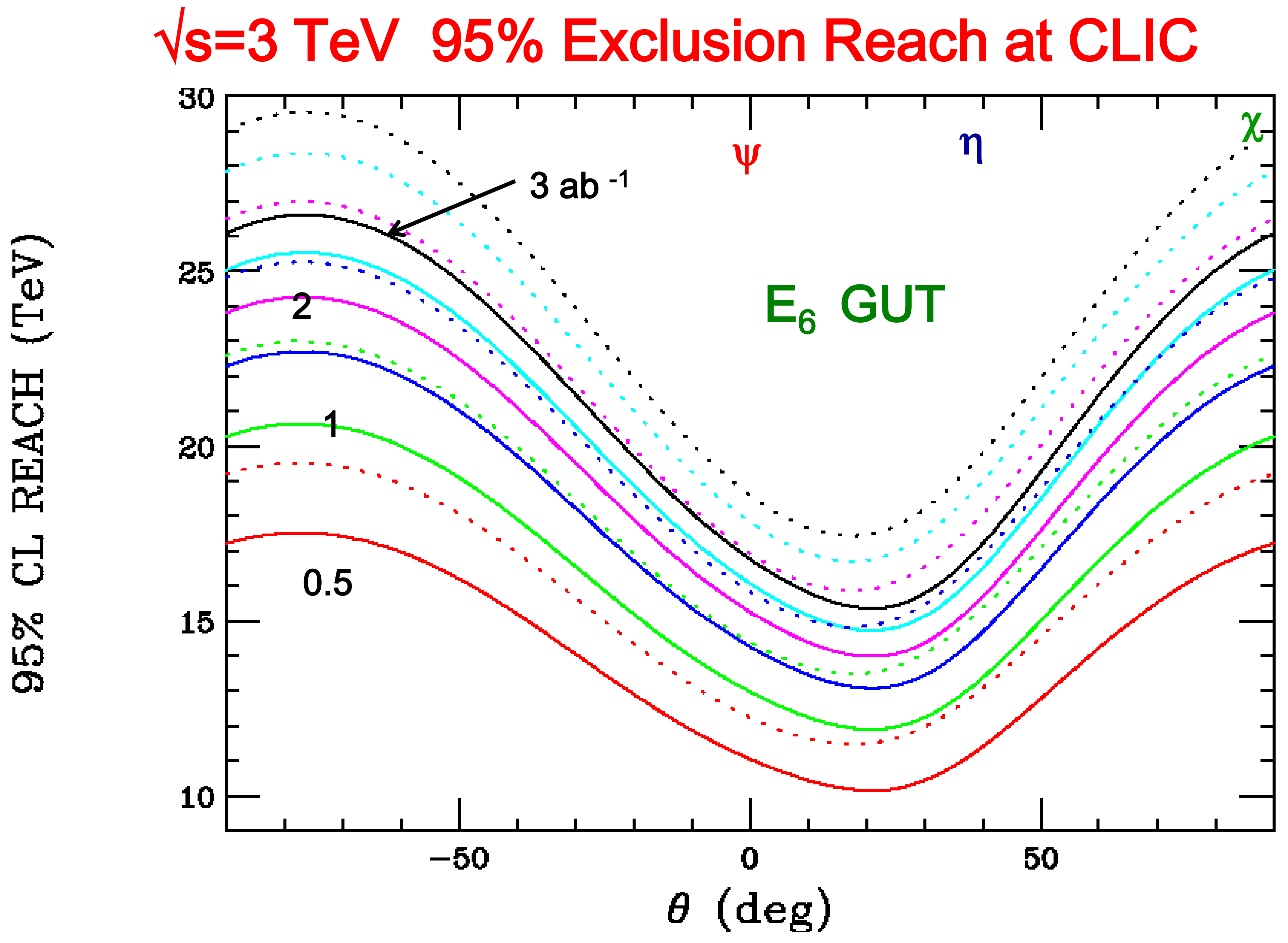
√s=3 TeV 5σ Discovery Reach at CLIC



LHC ->

14 TeV LHC Discovery Reach





√s=3 TeV 95% Exclusion Reach at CLIC
95% CL REACH (TeV)
30
25
20
15
10
−50
0
50
θ (deg)
ψ
η
χ
3 ab -1
2
1
0.5
E6 GUT

What if at least one Z'-like object is found at the LHC??

→ Is it above or below the √s of the lepton collider???

• If it is below, then the collider will sit at/near the resonance & 'redo' the LEP/SLC program *but* with polarized beams…All of the relevant info will then be obtained: mass, spin, couplings & determining if is it a 'normal' BW-type resonance, e.g., not due to a mass degeneracy or an unparticle.

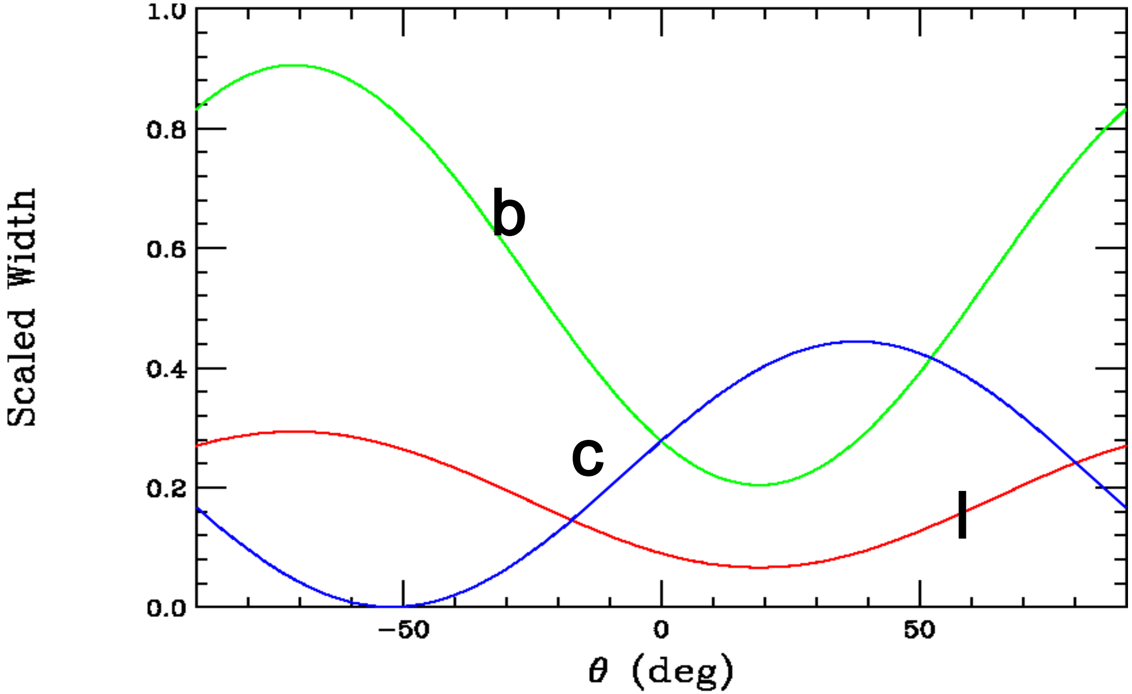
• If it is above, then it's mass will likely be <~6 TeV and then *indirect* measurements of its couplings will be possible at some level using the LHC mass value as an input if √s is 1-3 TeV. (Without it we need measurements at several √s values.)

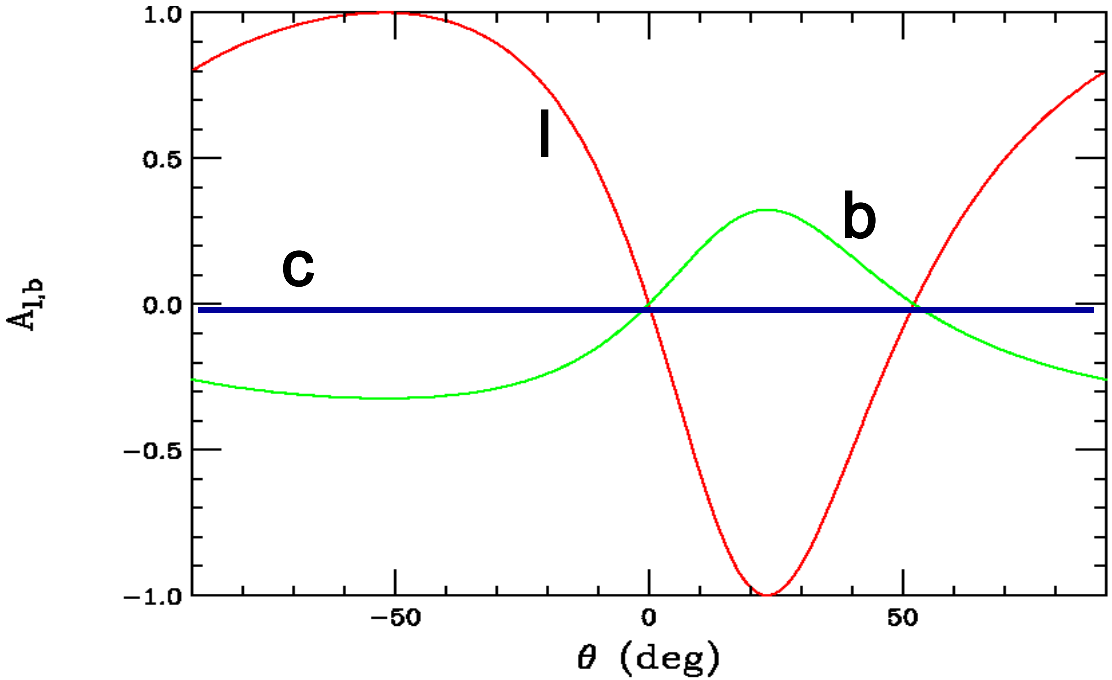
In Case of a ‘Standard’ Resonance

- Extractions of the Z’ couplings to the SM are ‘easier’ than at LEP (due to the presence of beam polarization) since there are now more observables, e.g., Γ_b, A_{FB}^b & A_b which can all be measured simultaneously in a single experiment.

- The statistics will be enormous.. even with ISR/beamstrahlung the peak cross section will be huge ~ 10^7 ($B_e B_f$ /0.02) ab ! Many measurements will end up becoming systematics dominated.

- Important to do searches for exotic decay modes as a window into the ‘rest’ of the NP associated w/ the Z’-like object. E.g., in SUSY-SO(10), a 3 TeV Z_χ would be an incredible source of SUSY sparticle production. Imagine having 10^7 selectron pairs to study!





E_6 GUT

Measurements of the partial widths and the asymmetries quickly reveal the underlying couplings from which the model parameters can be obtained

Unparticle Resonances : a non-Breit-Wigner example

$$\frac{1}{\Lambda^{d-1}}\bar{f}\gamma_\mu(c_{fL}P_L + c_{fR}P_R)\tilde{f}\mathcal{O}^\mu \qquad U = \frac{X_d P_d}{|\hat{s}-\mu^2|^{2-d} + iX_d P_d \tilde{G}};$$

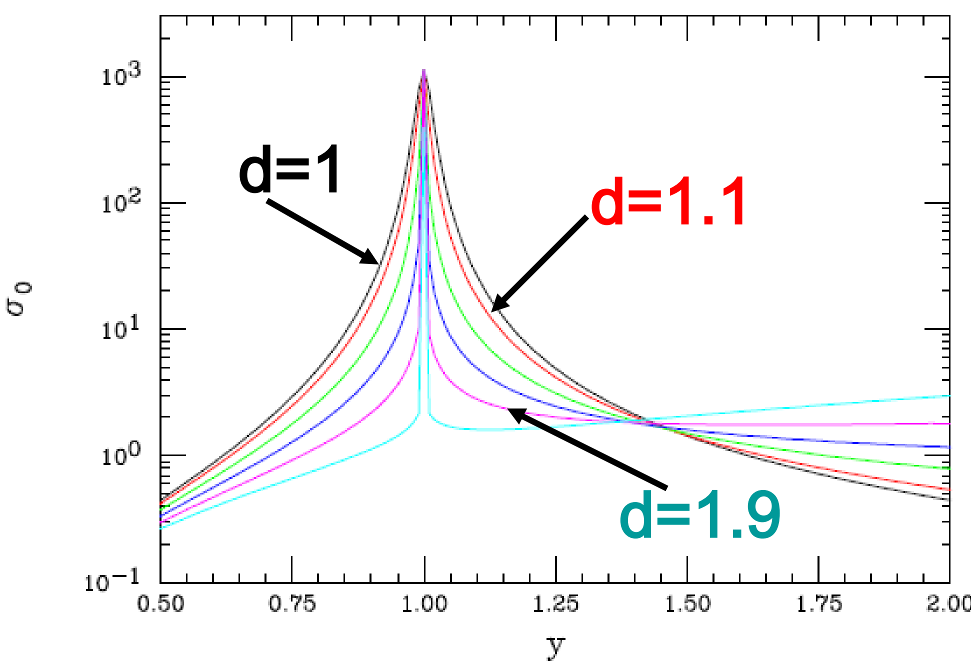
Note!

$$\tilde{G} = \frac{c^2}{\Lambda^{2(d-1)}}\hat{s}\frac{\tilde{\Gamma}}{\mu} \qquad P_d = [1, e^{-i\pi(d-2)}] \text{ when } \hat{s}[<,>]\mu^2, \qquad X_d = \frac{1}{2\sin d\pi}\,\frac{16\pi^{5/2}\Gamma(d+1/2)}{(2\pi)^{2d}\Gamma(2d)\Gamma(d-1)}$$

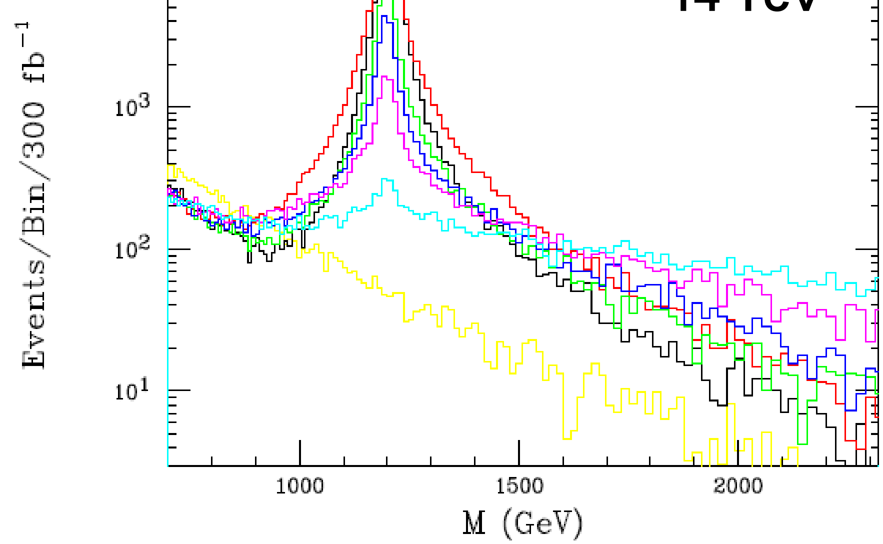
Distinction may be difficult at LHC especially at high masses.

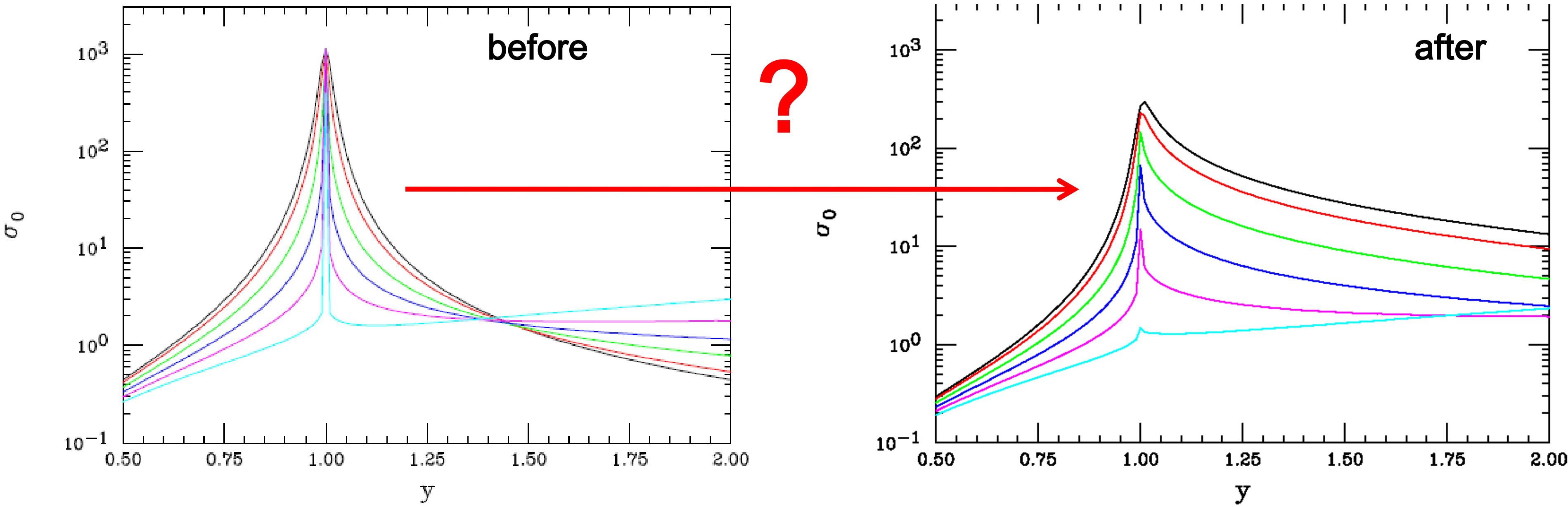
What will be the effect of ISR/beamstrahlung on this shape??

Idealized Case



LHC





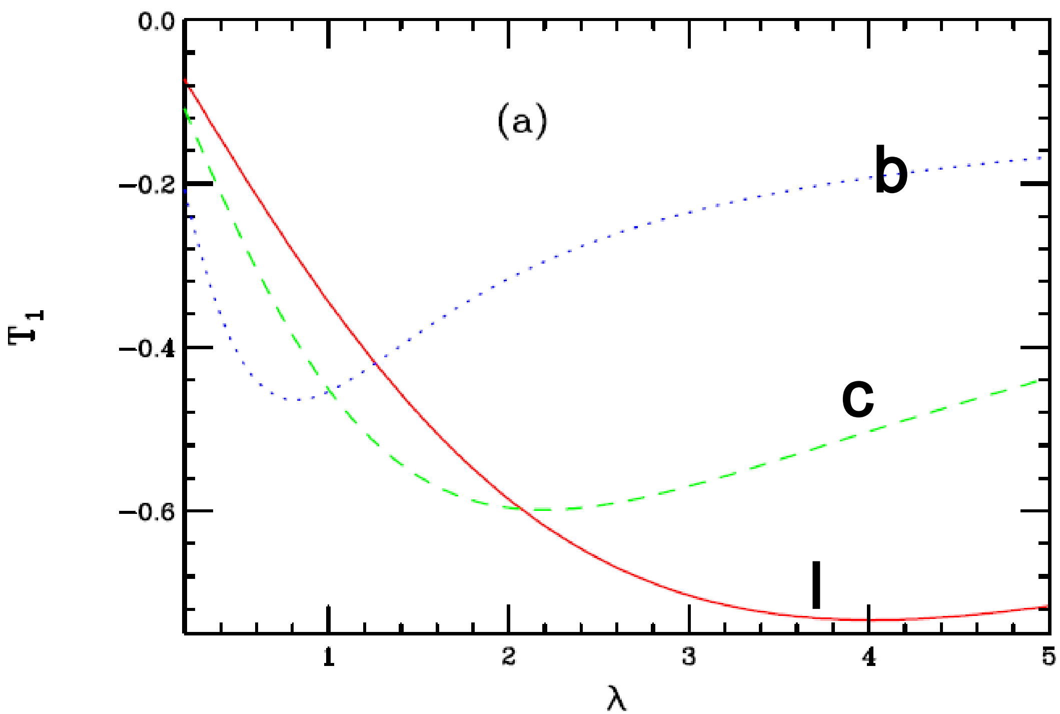
Peak luminosity is reduced by ~ a factor of 3

A fast & dirty calculation indicates that the strange unparticle resonance structure looks a bit washed out by the effects of ISR/beamstrahlung at CLIC… but a more careful & realistic study should be performed.

Extra Dimensions: A Degenerate Resonance Example

Simultaneous 3 TeV KK excitations of γ & Z split by <1.5 GeV

- Observables don't 'factorize', i.e., $A_{LR}^{f} \cdot A_{FB}^{pol}(f) \neq A_{FB}^{f}$
- The value of A_{LR} depends on the fermion f.

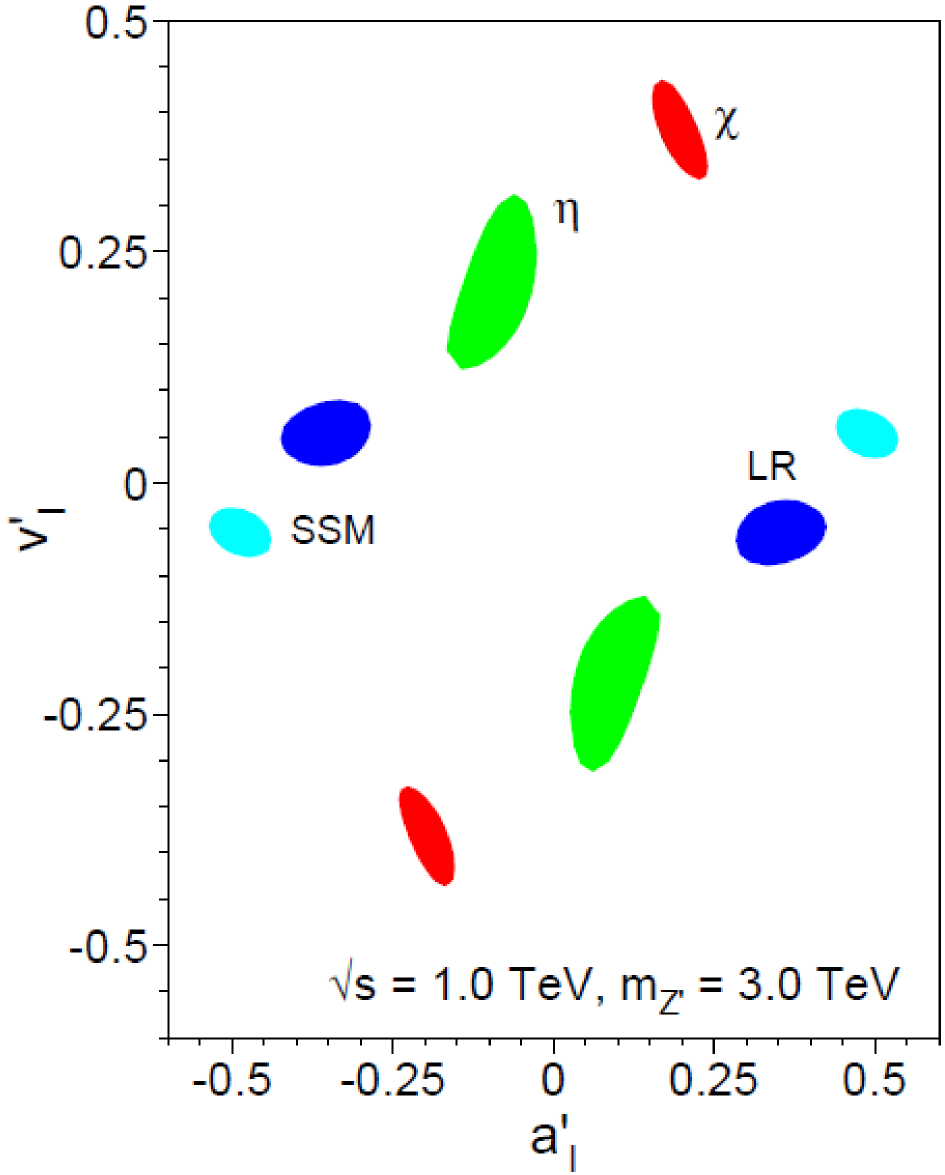


$$T_1 = A_{LR}^{f} \cdot A_{FB}^{pol}(f) - A_{FB}^{f}$$

$R = \Gamma_\gamma / \Gamma_Z = \lambda R_0$

R_0 is SM decays only.
Factorization only for
λ=0 or ∞ limits

ILC Indirect Z' Coupling Determinations



These are well-known for lower energies & one can approximately rescale them to, e.g. , $\sqrt{s}$=2 TeV and $M_{Z'}$ =6TeV with ~4x more luminosity…

We can do even better if $\sqrt{s}$=3 TeV & $M_{Z'}$ =6 TeV!

S. Riemann

- Indirect Z' coupling measurements are important as the LHC cannot uniquely determine them even with high lumi.

To first approximation the LHC observables really *only* probe the 4 coupling combinations

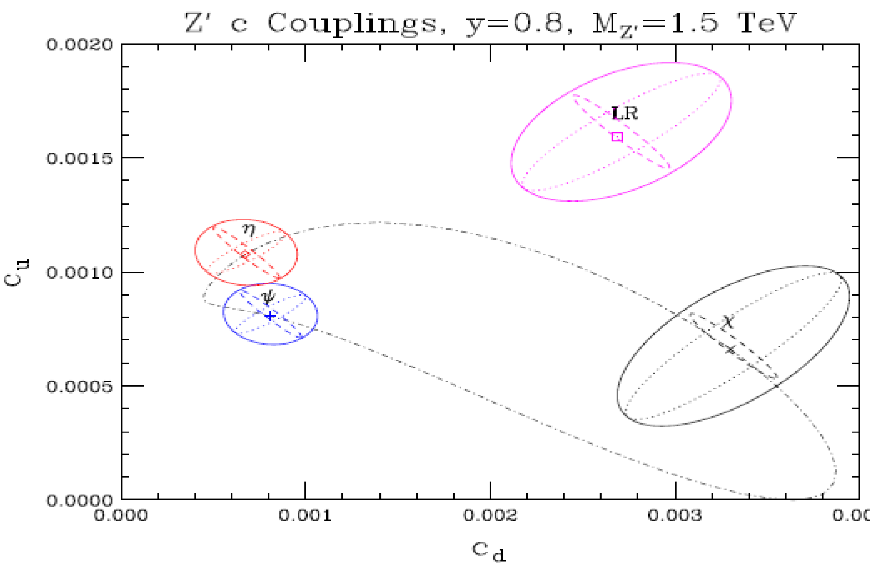
$$c_q = \frac{M_{Z'}}{24\pi\Gamma}(q_R^2 + q_L^2)(e_R^2 + e_L^2)$$

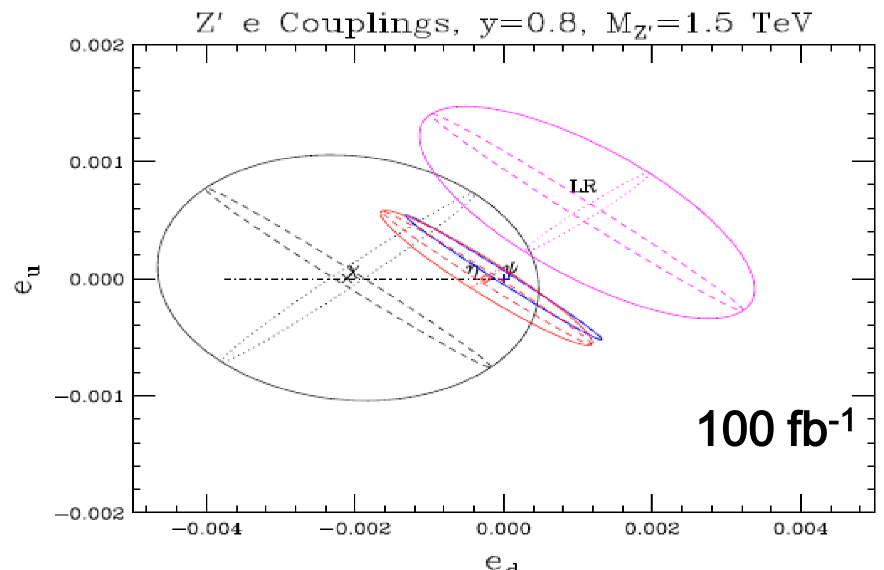
$$e_q = \frac{M_{Z'}}{24\pi\Gamma}(q_R^2 - q_L^2)(e_R^2 - e_L^2)$$

for q=u,d

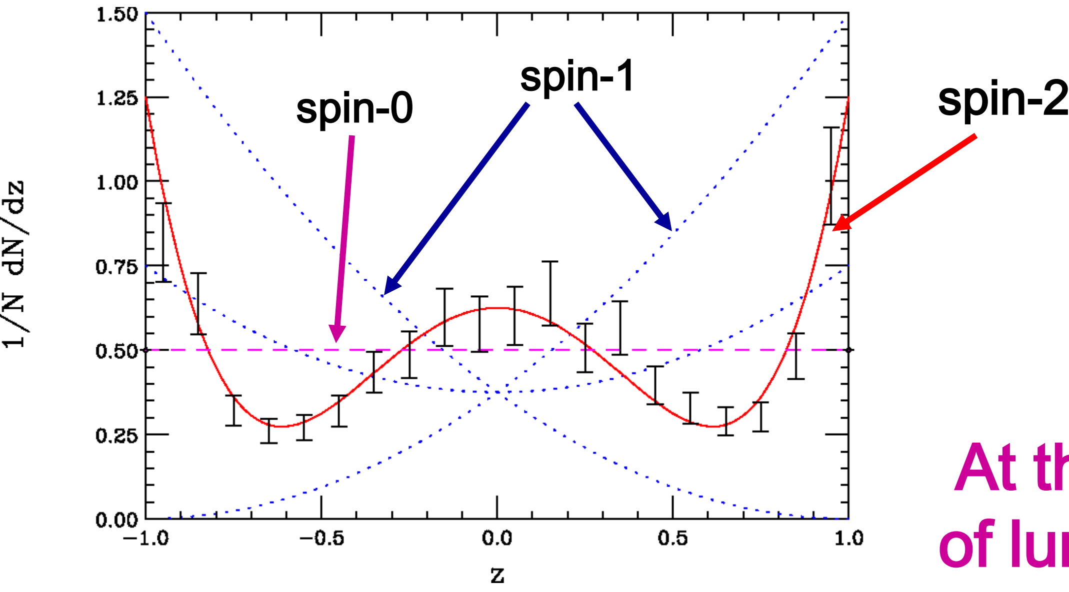
Carena et al.

Petriello & Quackenbush





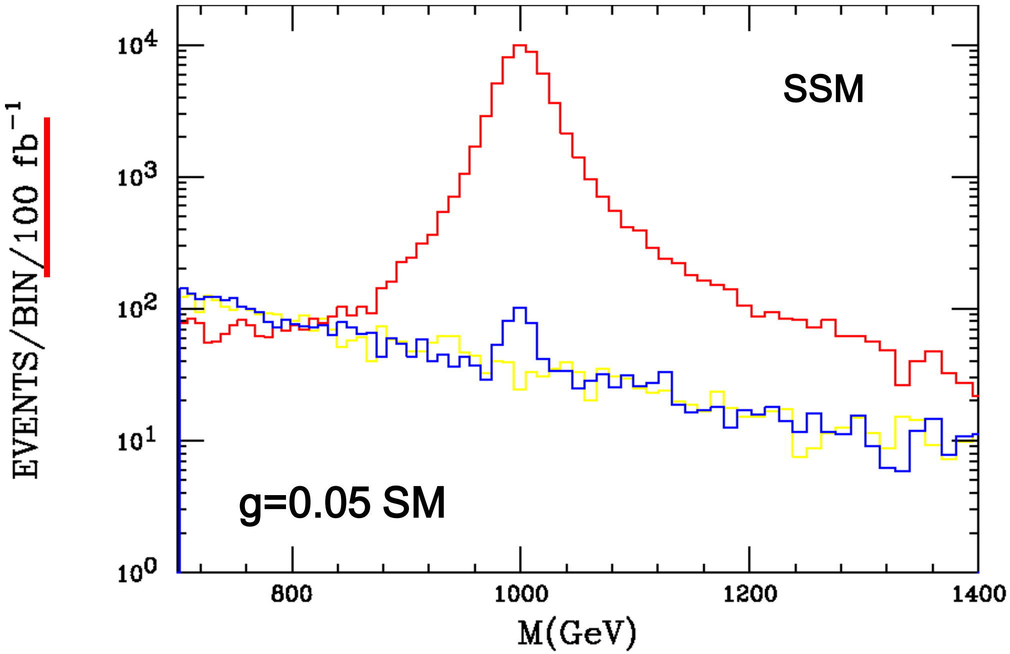
These can be reasonably well determined in a simultaneous fit ...even including NLO QCD contributions



Resonance Spin Determination

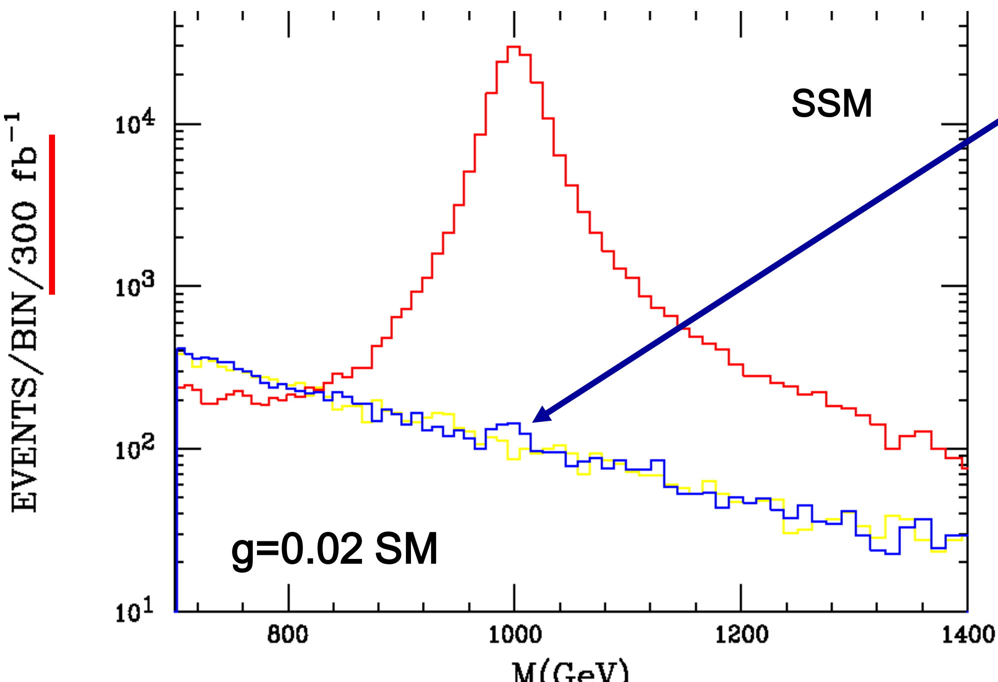
At the 14 TeV LHC with ~1 ab^{-1} of lumi, the capability to determine the spin of new resonances dies out for masses in excess of ~3-4 TeV. This means that a lepton collider will be necessary to obtain this information --which it can do very quickly .

- One possibility is missing a Z'-like state that is either very narrow or just generally weakly coupled to the SM, say, only by mass or kinetic mixing…this kind of state may be missed at the LHC



For example, even at 1 TeV

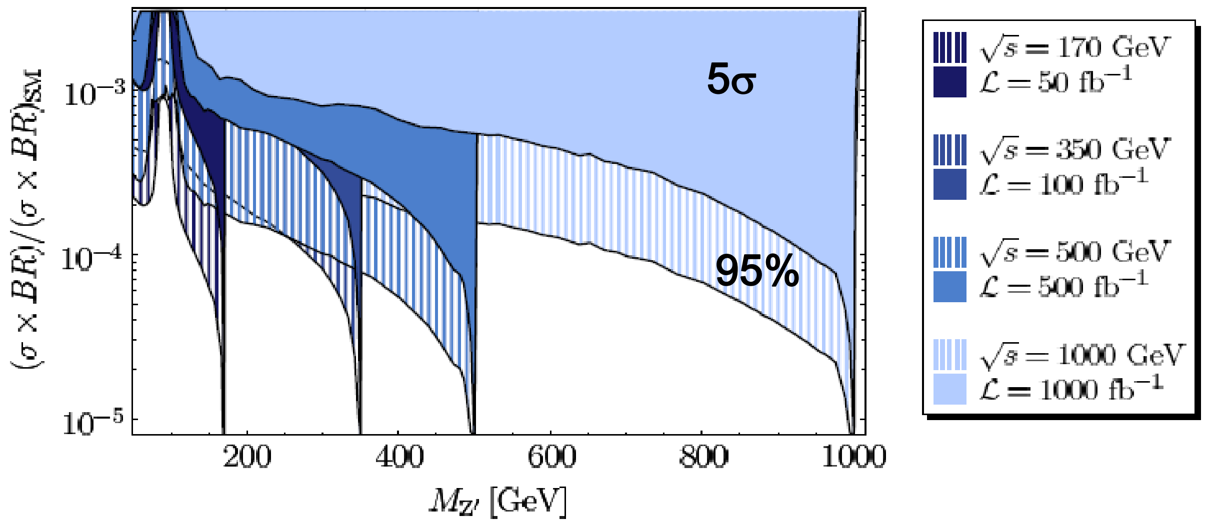
at high luminosity rather small values of scaled SSM couplings can be accessible if the Z' is not too heavy.



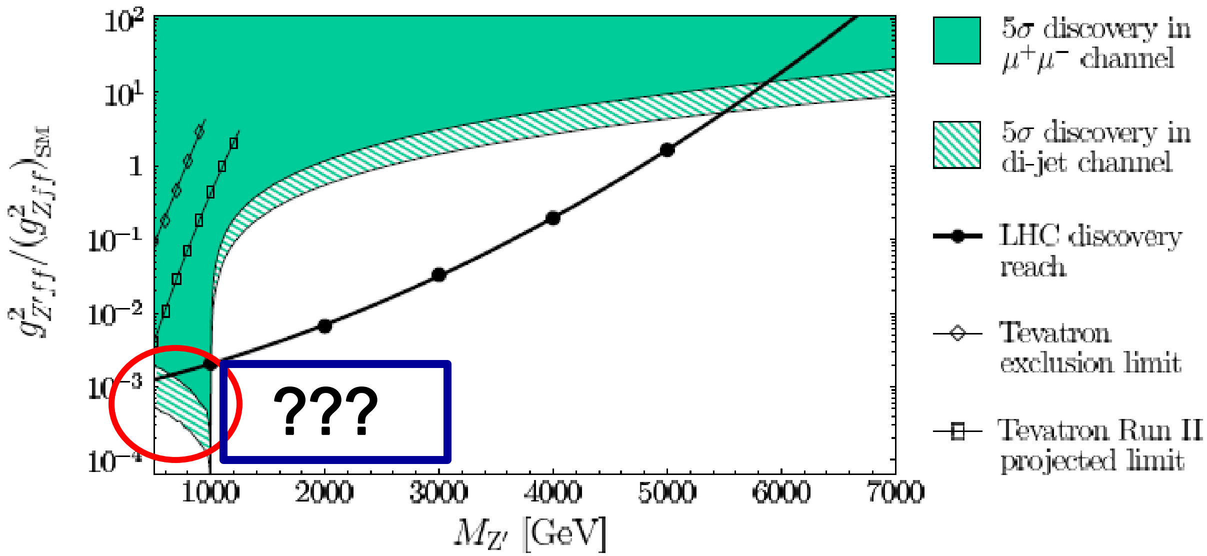
But at some point we just run out of steam.

Clearly the problem gets much worse as the Z'-like particle gets heavier.

At e^+e^- colliders , ISR/beamstrahlung allows for 'radiative return' so that resonances with masses below √s can be scanned for:

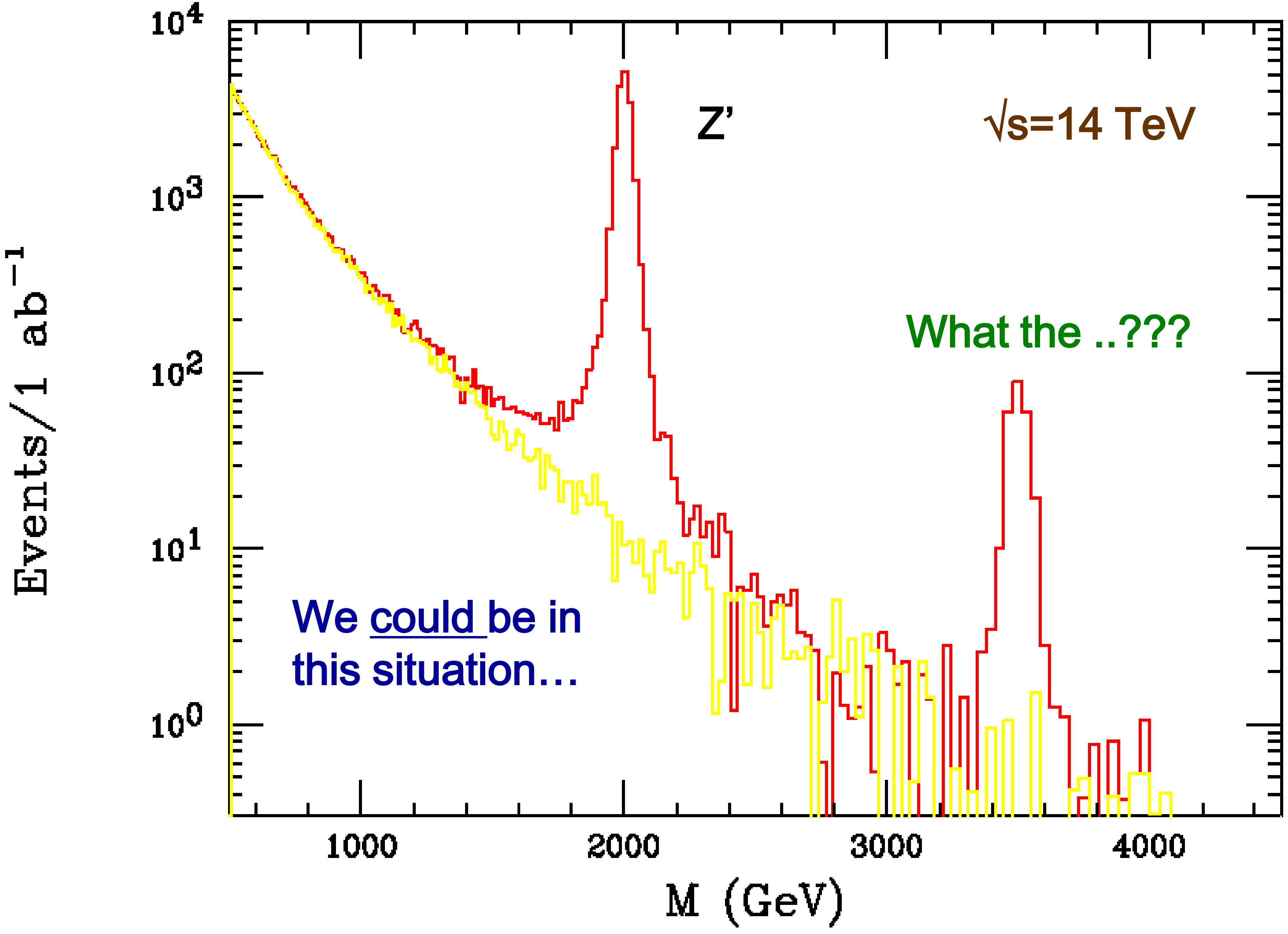


Rather small values of the couplings can be reached with this method



This needs further detailed study & for higher energies

Freitas



Z'
√s=14 TeV
What the ..???
We could be in this situation…
Events/1 ab^{-1}
M (GeV)
10^4
10^3
10^2
10^1
10^0
1000
2000
3000
4000

Multiple Resonances ??

- LOTS of questions, e.g., are these some kind of Kaluza-Klein excitations? Not necessarily!

There are, e.g., some extended gauge models that predict the possibility of 2 or more Z'-like states (like χ & ψ in E_6). How are the masses & couplings of these states related? Do they all have the same spins ?

Clearly, only with the help of an e^+e^- collider can we hope to get the kind of details we need to address these questions & uncover the underlying physics.

Summary

- A number of different scenarios may eventually be realized at the LHC – in all of them, an e^+e^- collider will play an important role.
- If no Z'-like state is observed we can look for indirect evidence for such states up to 5-10$\sqrt{s}$ depending on couplings etc.
- If such a state is found @ the LHC with M<$\sqrt{s}$, it's properties can be examined in detail by sitting on/near the resonance
- If M<~6 TeV >$\sqrt{s}$, then indirect measurements will allow for a reasonable determination of its spin & couplings.
- Multiple resonances of various kinds remain a likely possibility
- Get ready for surprises..nature is more clever than we are!