Mini-Review BSM Physics

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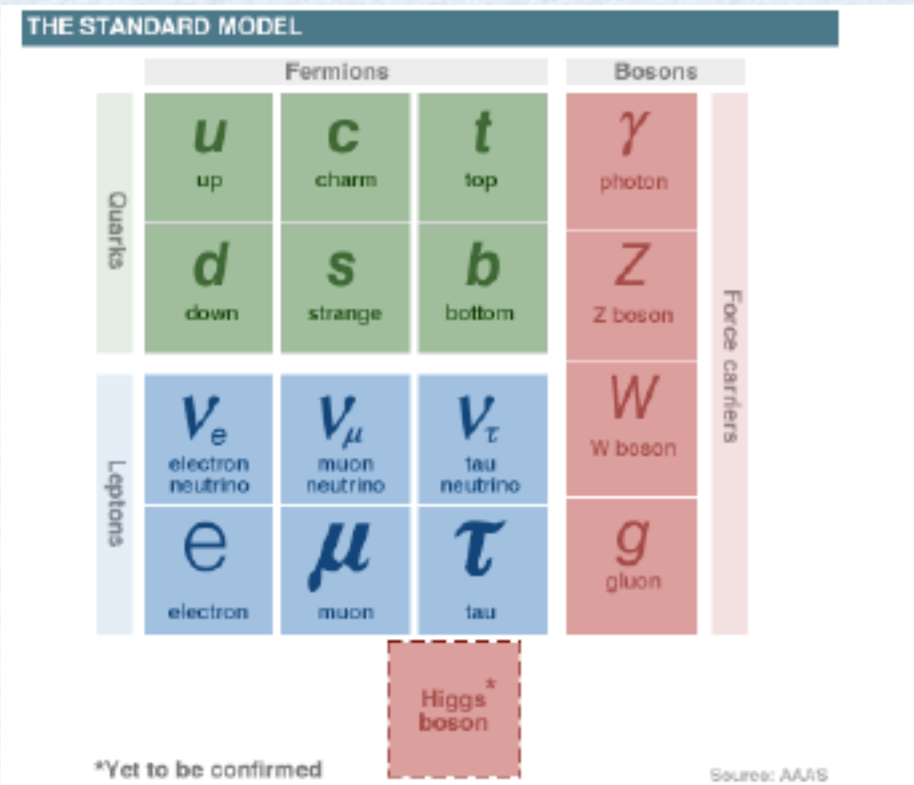
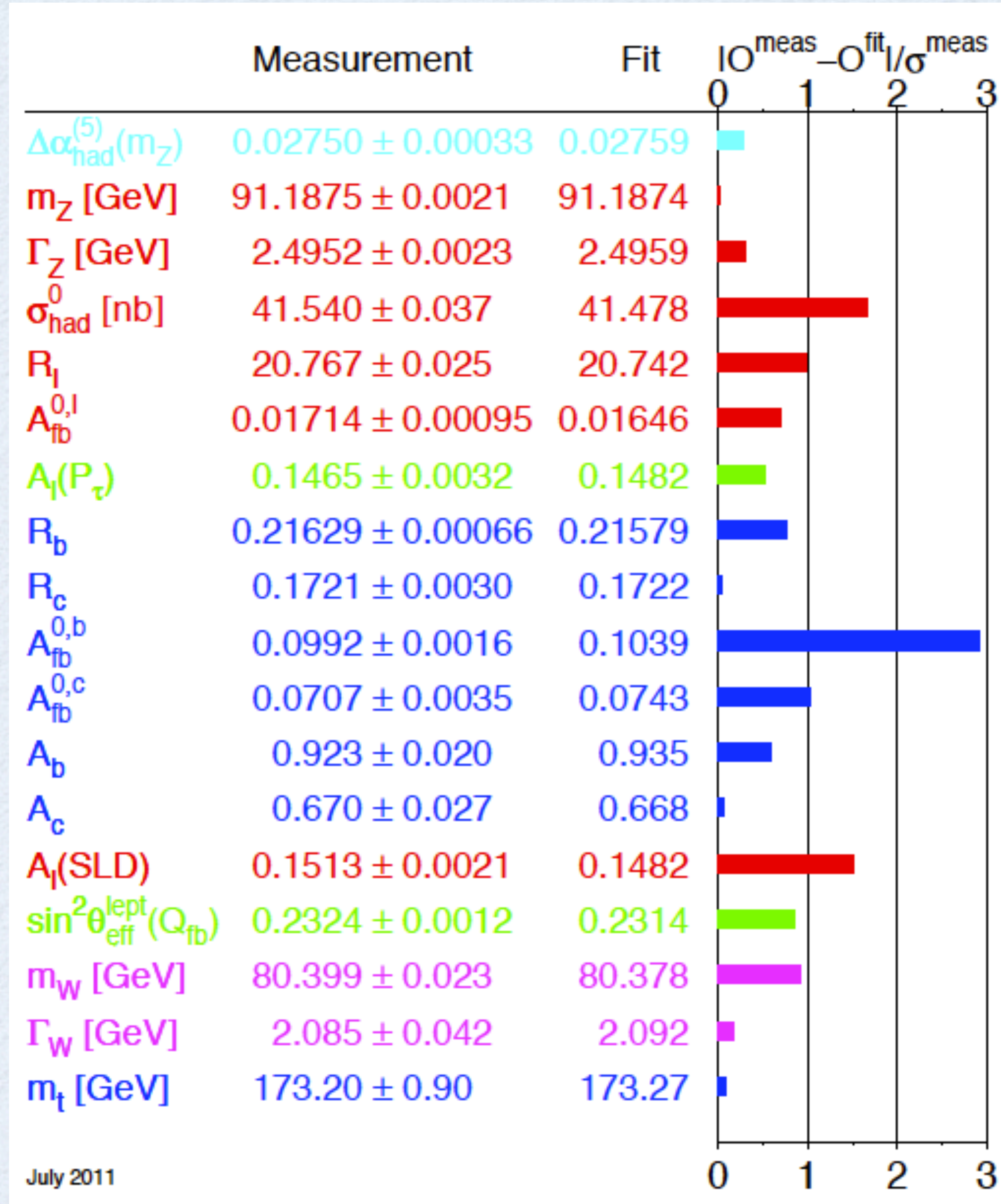
Standard Model



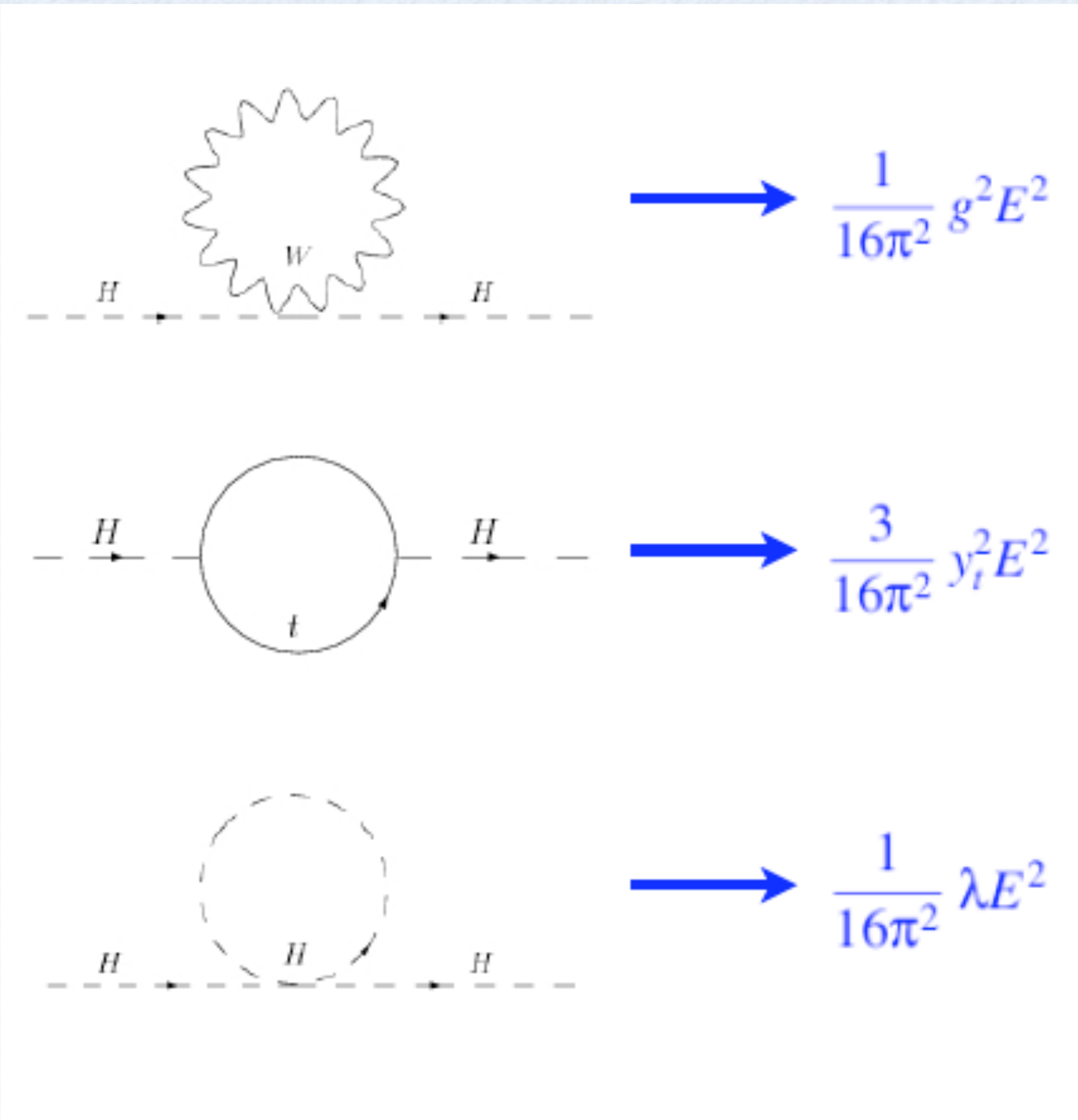


Awaiting the final details or a revolution..

Drawbacks

- In principle - SM with a 140 GeV Higgs could be complete (think Mendeleev's table for chemistry)
- However it seems incomplete
  - Why are the Higgs coupling to fermions what they are?
  - What about Gravity?
  - Why Three Generations?
  - What about Dark Matter?

The Plot Thickens

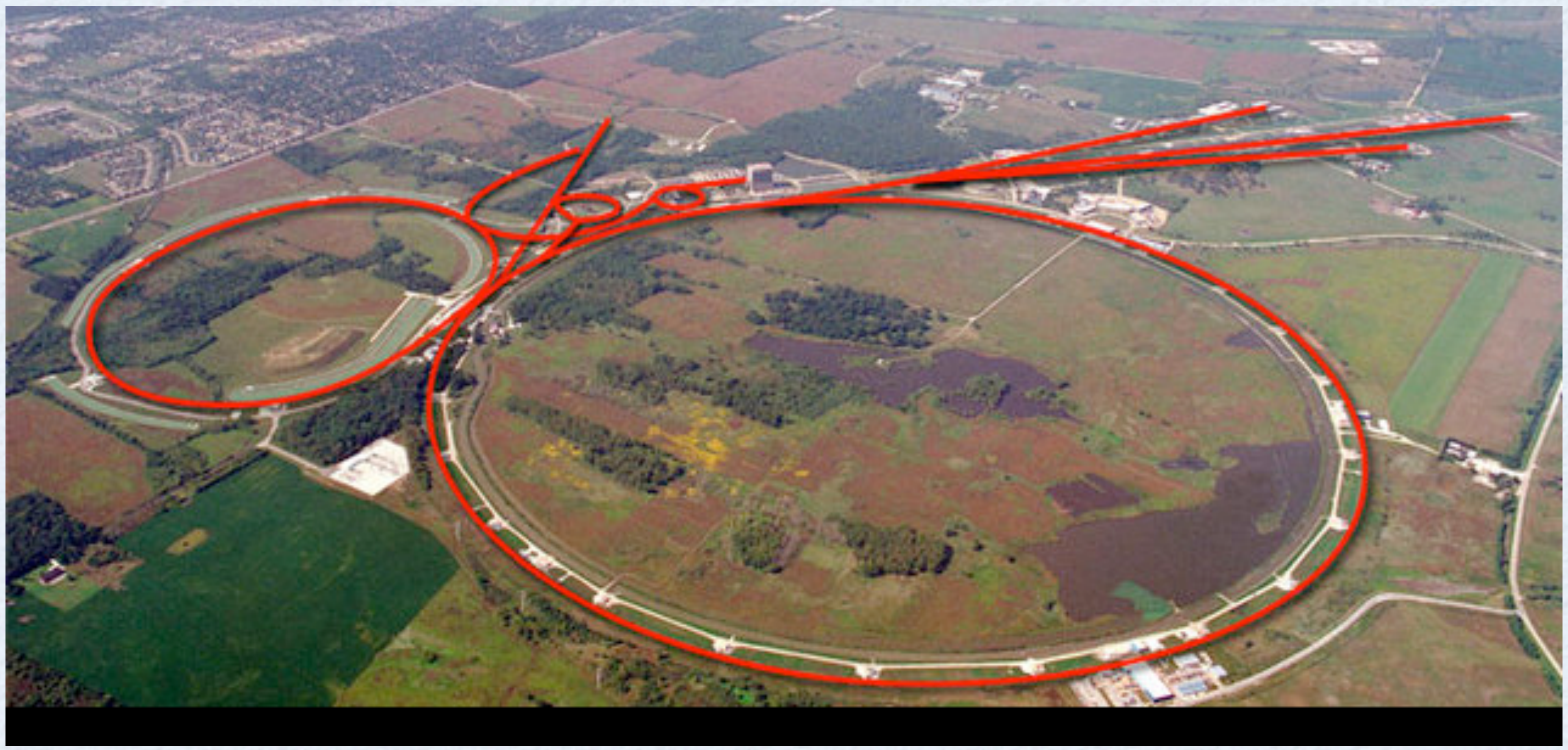


- Higgs also acquires mass from gauge bosons and fermions via loops
  - But are quadratically divergent
  - requires fine tuning !

Alternatives

- SUSY
- Technicolor
- Extra-Dimensions
- Little Higgs
- GUT
- new generations

PLAYERS



1.96 TeV

~10 fb^{-1}

7.0 TeV

~2 fb^{-1}

and growing

Heavy Gauge Bosons

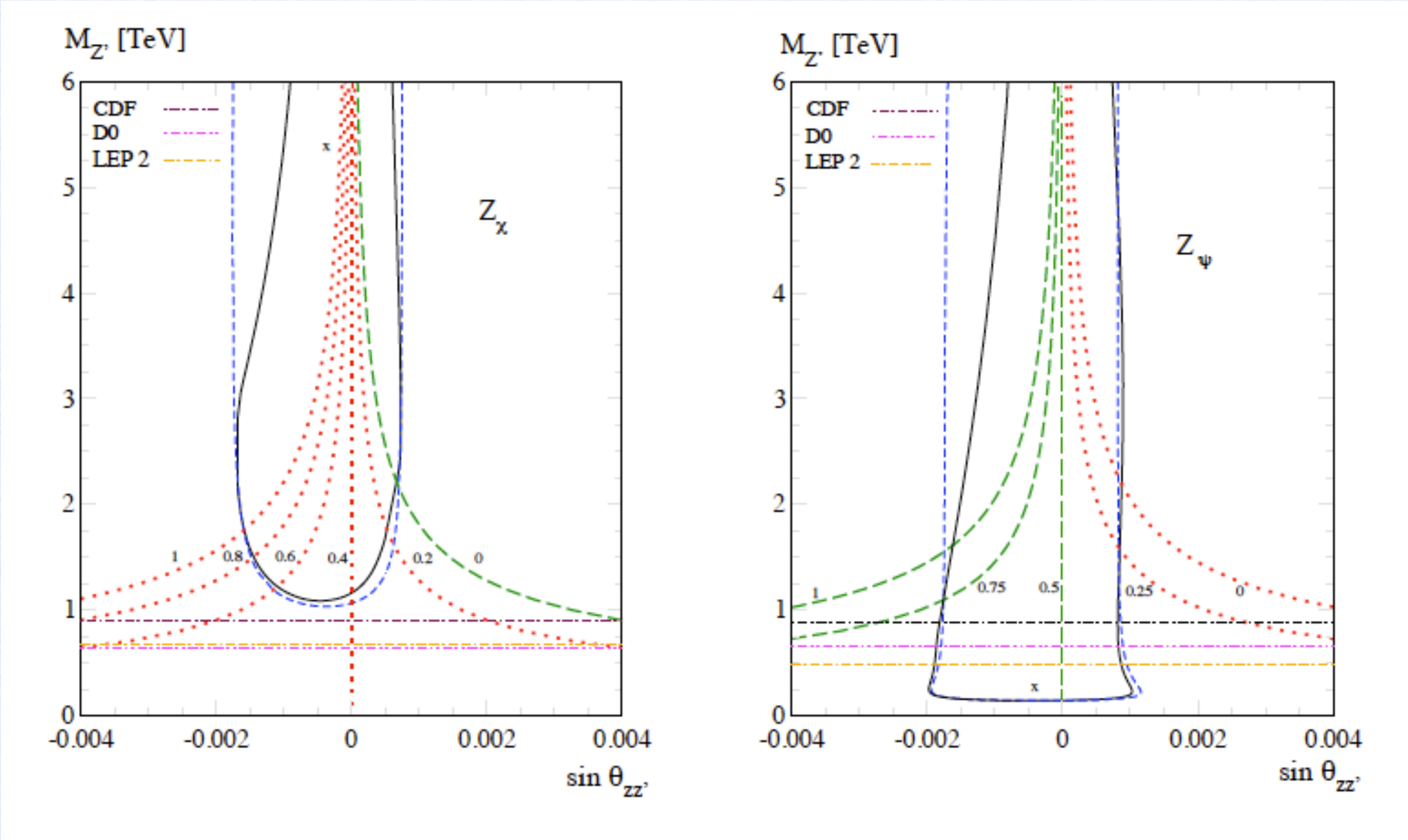
- Often arise in GUT theories as a left over symmetry (eg. an extra U(1) gives rise to a Z′)
  - SSM
  - LR Symmetric: $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$
  - $E_6 \rightarrow SO(10) \times U(1)_\psi \rightarrow S(U) \times U(1)_\chi \times U(1)_\psi$
    - $G = U(1)_\theta = \cos(\theta)\, U(1)_\chi - \cos(\theta)\, U(1)_\psi$

Model	ψ	χ	η	I
θ	0	90	37.75	-52.24

Heavy Gauge Bosons origins ...

- Kalutza-Klien theories with extra dimensions give excited states of Standard Model gauge bosons
- Little Higgs theories have partners of W and Z
- SUSY without R parity
- ...

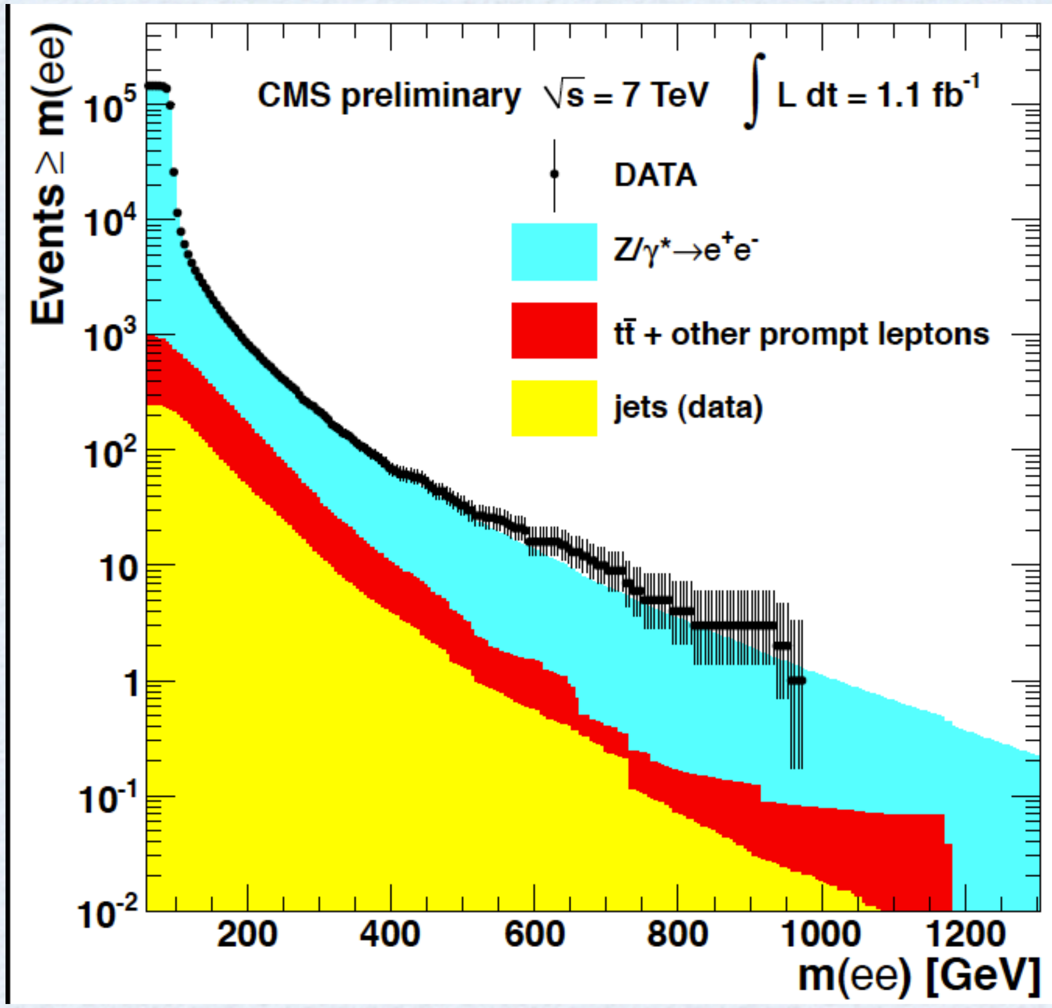
Limits from indirect searches



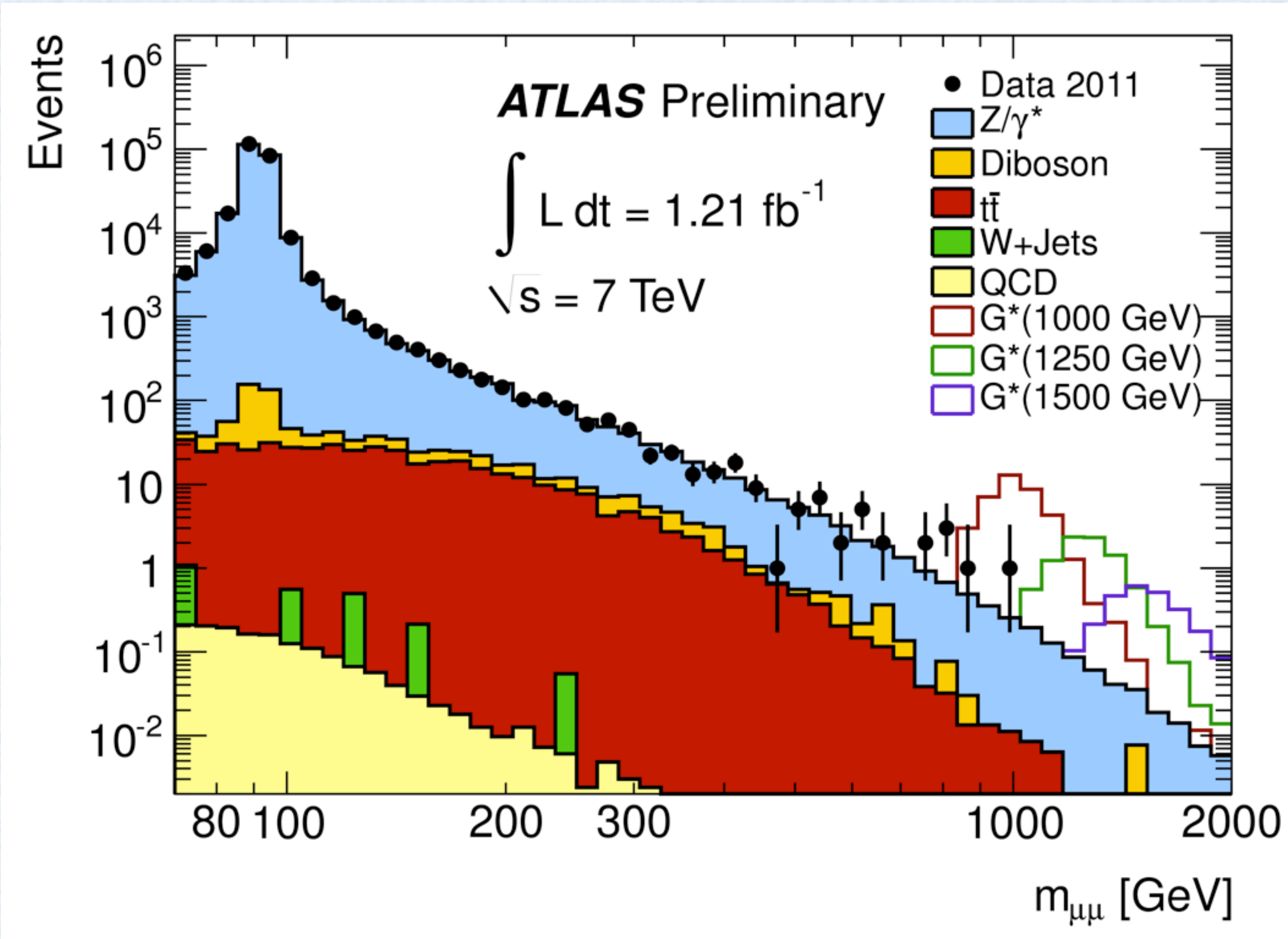
arXiv:0904.2534

- If Z′ mixes with with Z for a sufficiently light Z′ should see mixing effects

Direct Limits



Direct Limits (SSM)
LHC:
ATLAS ~1.83 TeV
CMS ~ 1.94 TeV

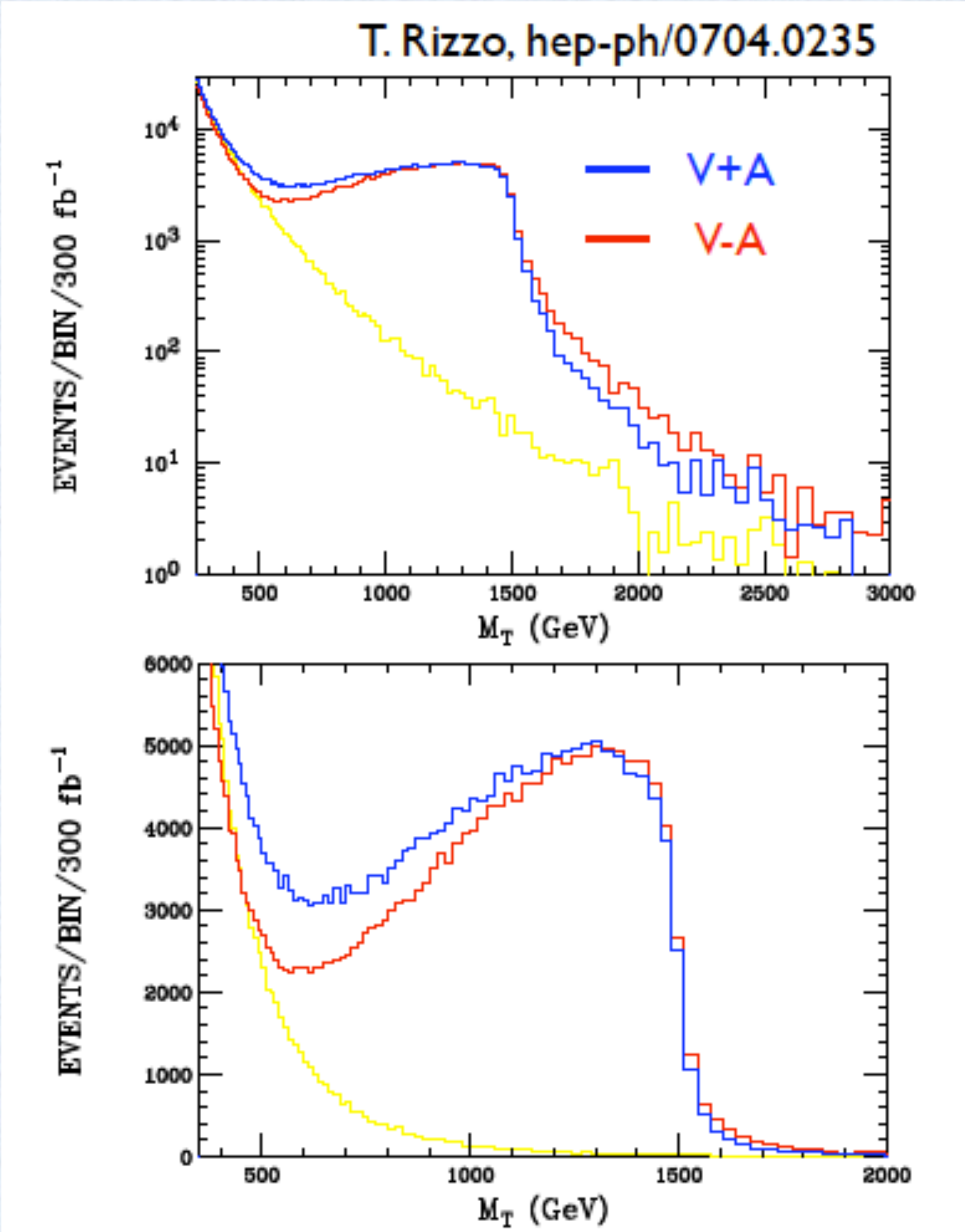


W'

- Similar (or the same!) models also predict a heavy W
    - 'natural' in the same way a Z' is introduced by the breaking of some higher symmetry group to the SM
- Attractive Features:
    - IF coupling is similar to SM W/Z the W' would have a larger cross-section at a hadron collider
    - Generally avoid the strict indirect limits from LEP as they would have had to been produced in pairs there

W' PRODUCTION

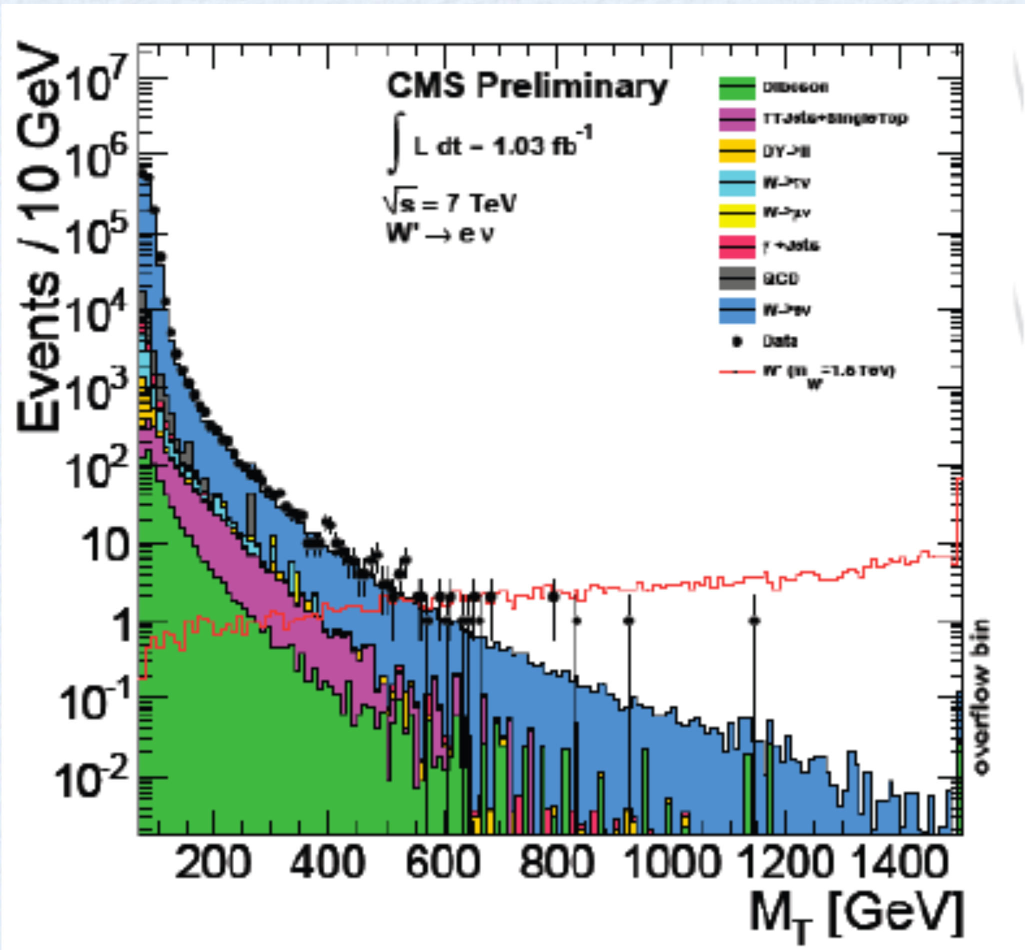
- W' production in most considered models is not very sensitive to exact coupling
- Interference with SM W is important W' - in particular in identifying the W'

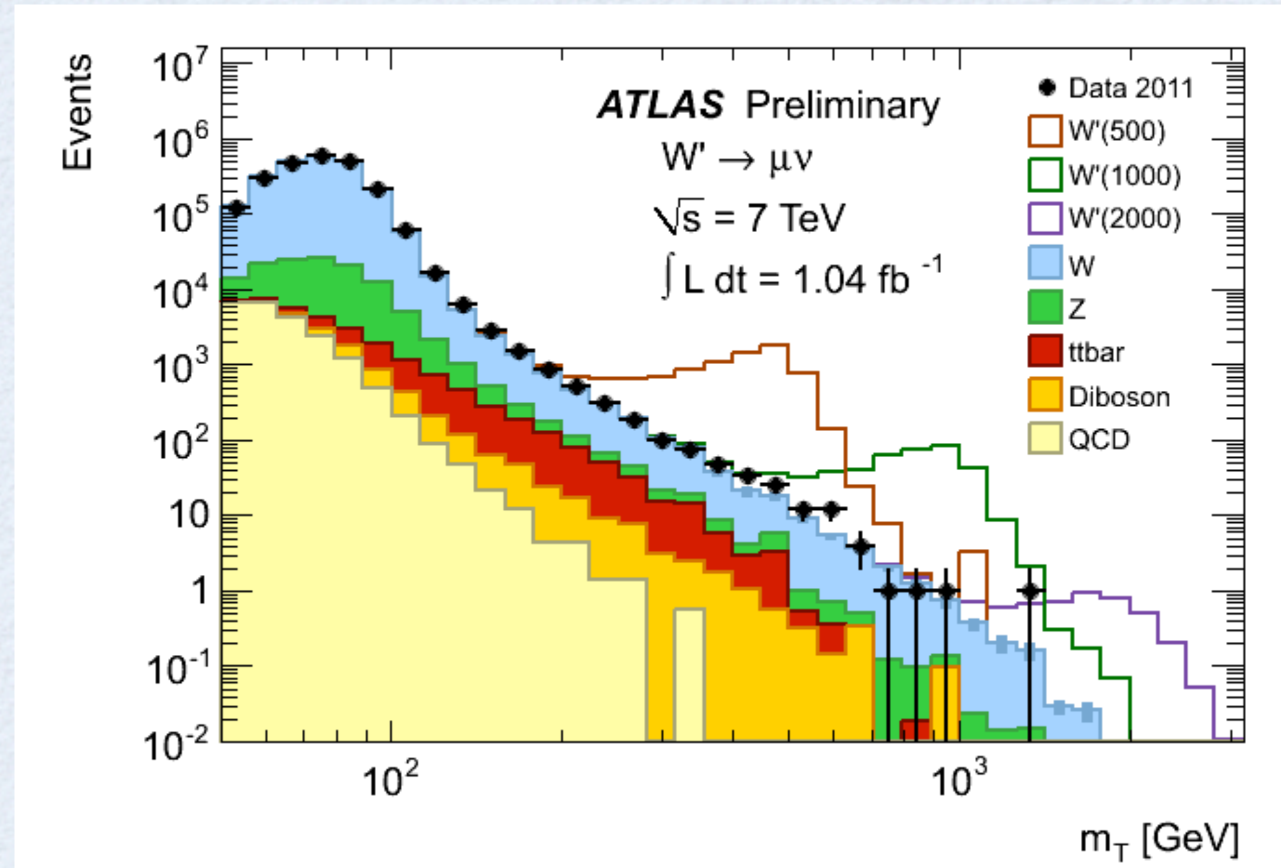


W' Decay

- W′ Signatures:
  - Leptonic : e ν, μν, τν
  - Bosonic: WZ, Wγ
  - Hadronic: qq′, tb, lN
- Large W′ mass opens new channels
- Favored Decay modes depend highly on exact model (eg SSM compared to models where large coupling to 3rd generation)

CURRENT LIMITS



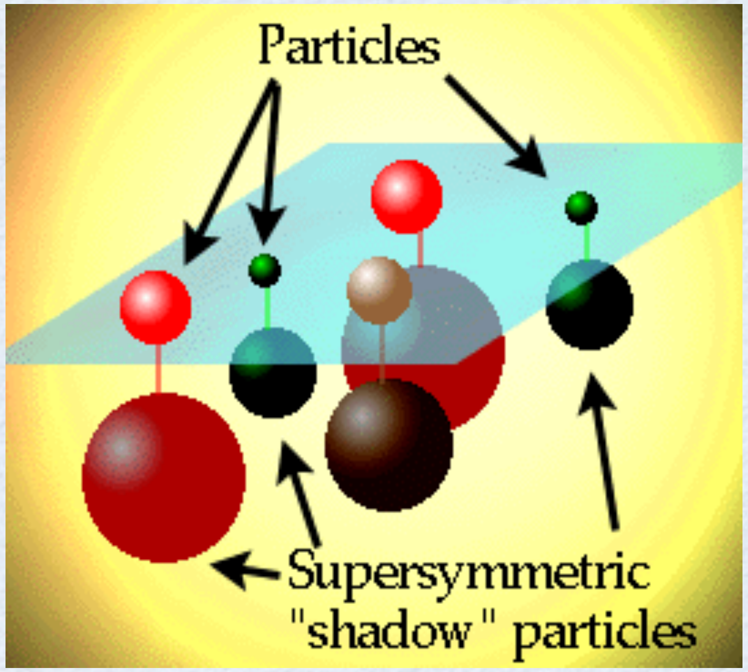


Limits (SSM)
ATLAS: 2.15 TeV
CMS: 2.27 TeV

note expected limit
~2.2 TeV
in both cases

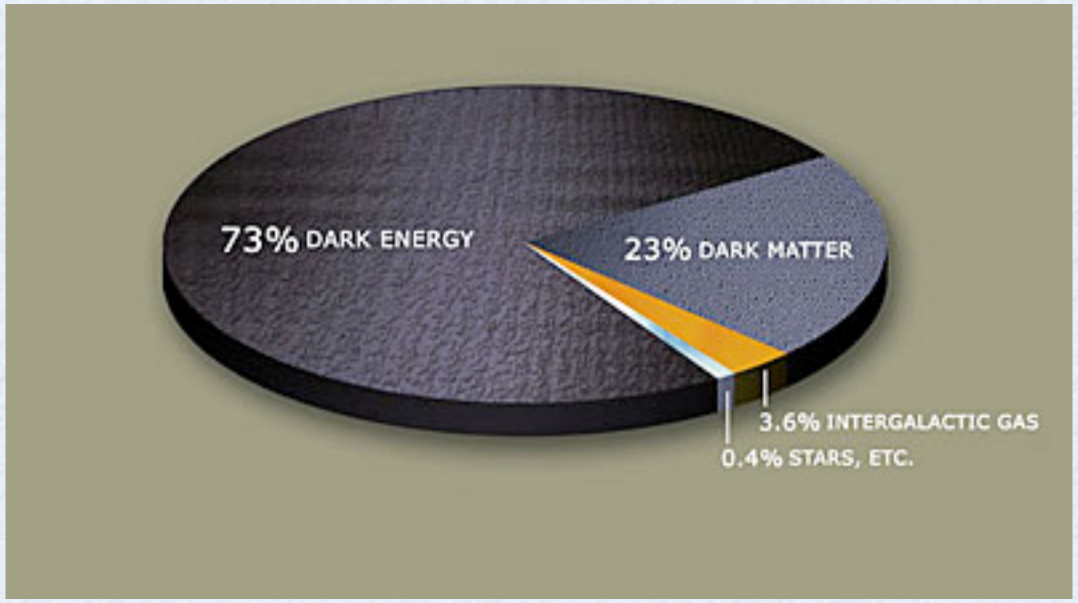
SUPERSYMMETRY

Postulate a symmetry between fermions and bosons



Minimal version doubles the amount of particles

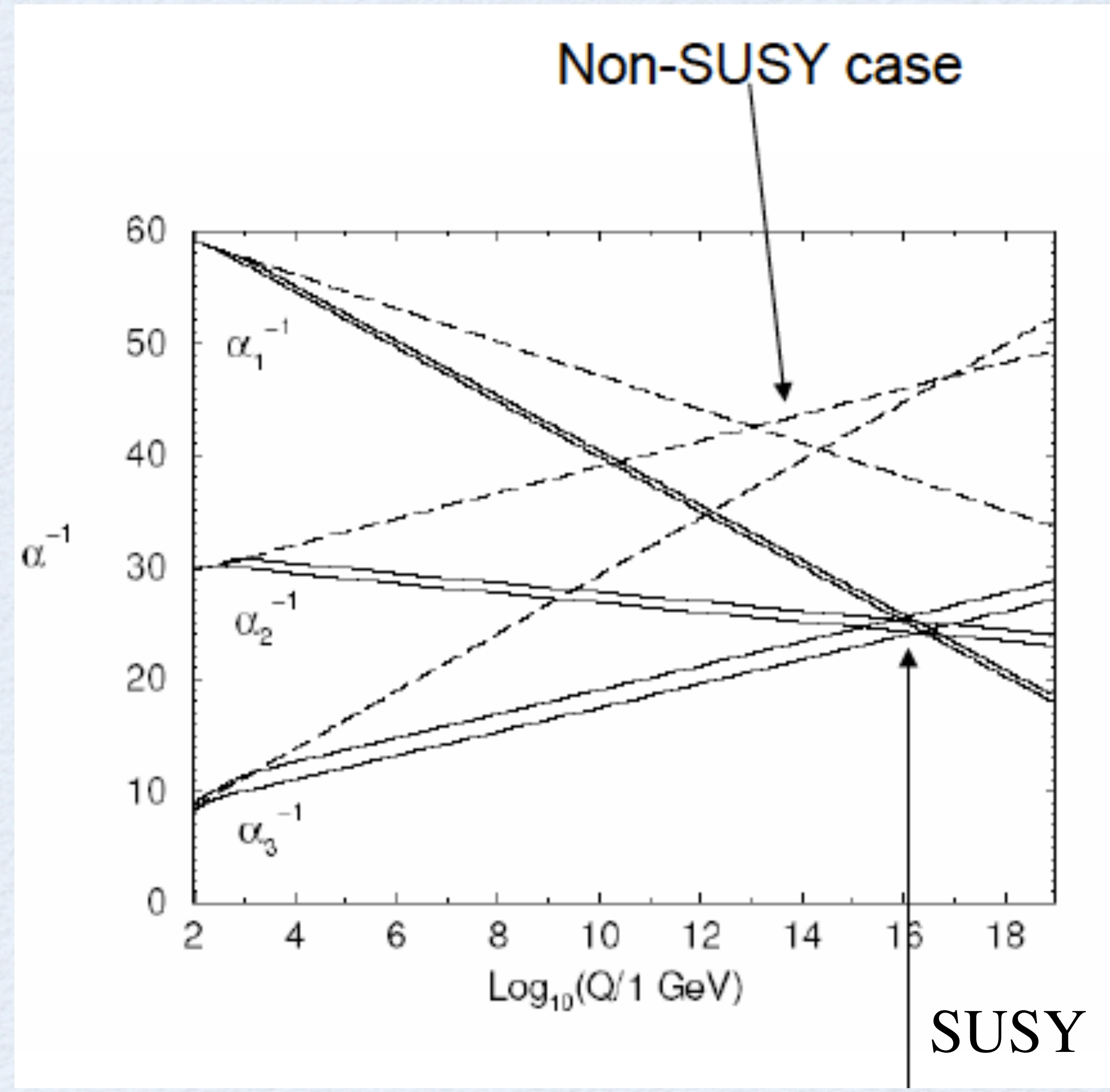
Cancelation of quadratic divergences present in SM



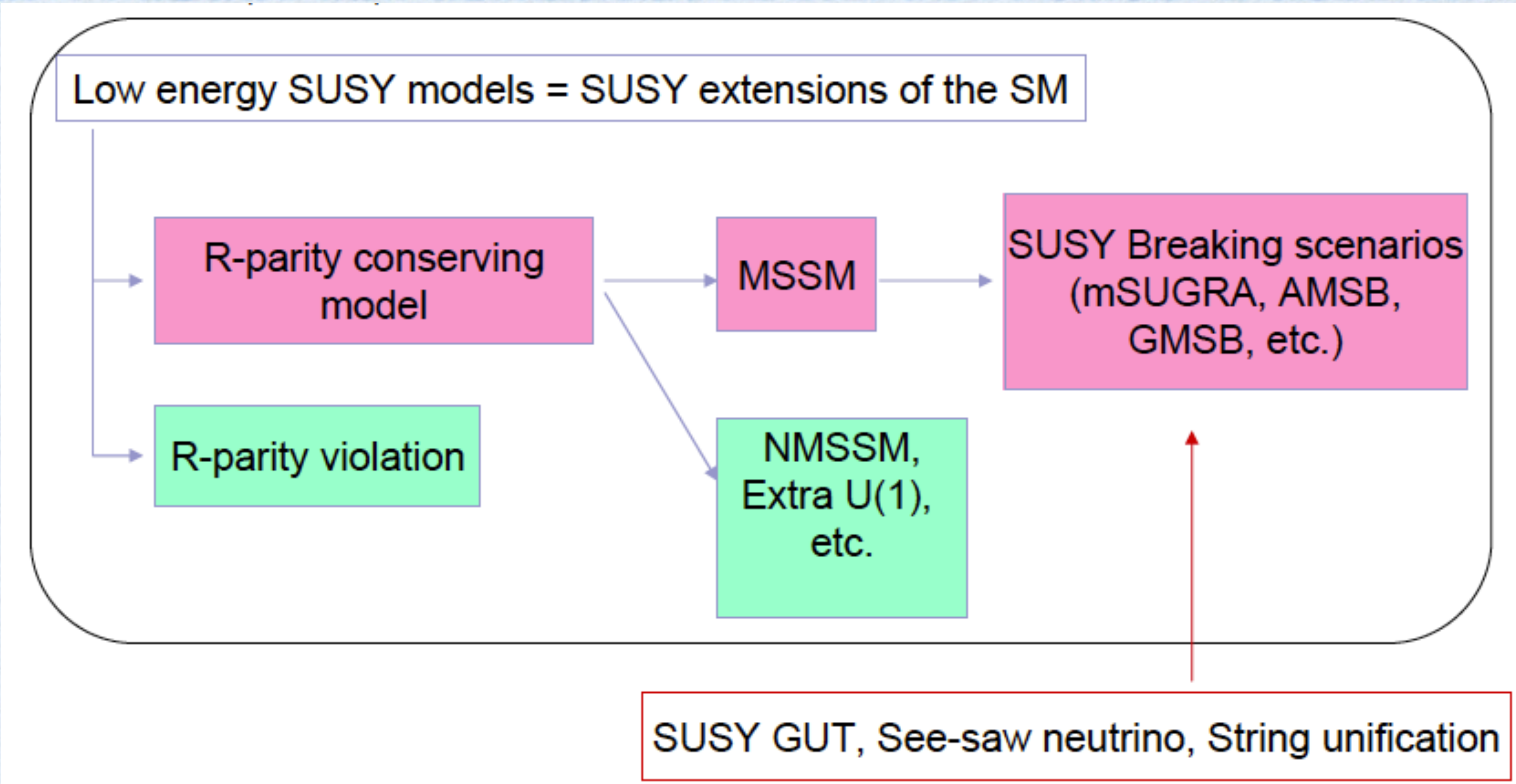
Models with R parity would have a stable neutral particle as a dark matter candidate

Unification

- GUTs and SUSY were proposed independently though closely connected
- Introduction of new SUSY particles MAY modify the evolution of the coupling so that at they unify at high energy



SUSY Models



- SUSY is not one model but rather a collection
- R-parity, SUSY breaking scenarios, ...

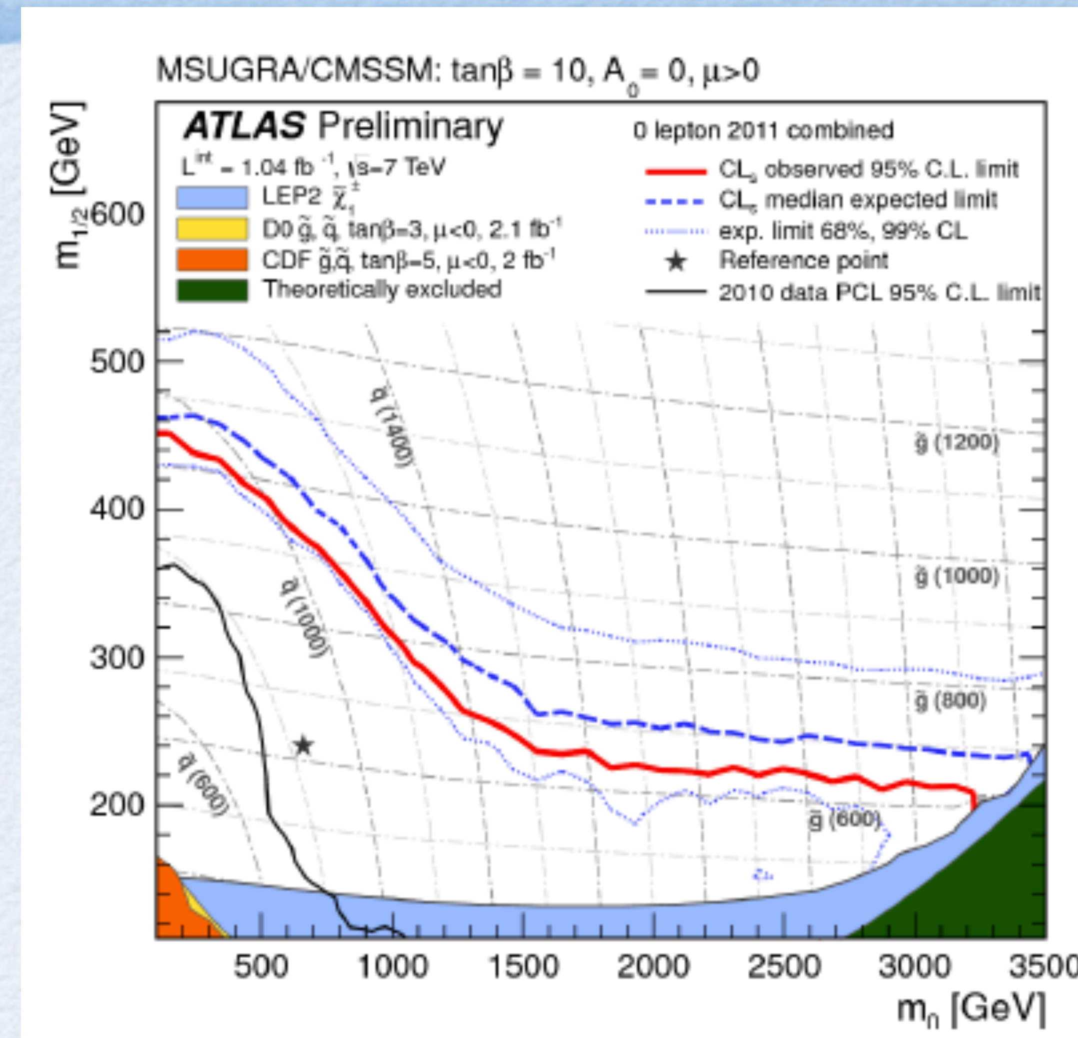
The Good, the Bad, ...

- SUSY has a number of attractive features
  - Could explain a light Higgs naturally
  - Gauge Coupling Unification
  - Dark Matter Candidate
  - No New Forces
- Come at some cost
  - Many new particles: masses and mixing angles (set it and forget it)
  - What sets the SUSY mass scale?
  - What causes SUSY breaking?

SUSY LIMITS

Signal Region	≥ 2 jets	≥ 3 jets	≥ 4 jets	High mass
E_T^{miss}	> 130	> 130	> 130	> 130
Leading jet p_T	> 130	> 130	> 130	> 130
Second jet p_T	> 40	> 40	> 40	> 80
Third jet p_T	–	> 40	> 40	> 80
Fourth jet p_T	–	–	> 40	> 80
$\Delta\phi(\text{jet}, E_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25	> 0.2
m_{eff} [GeV]	> 1000	> 1000	> 500/1000	> 1100

$$m_{eff} \equiv \sum_{i=1}^{n} |\mathbf{p}_T^{(i)}| + E_T^{miss}$$



Process	Signal Region ≥ 2-jet	≥ 3-jet	≥ 4-jet, m_{eff} > 500 GeV	≥ 4-jet, m_{eff} > 1000 GeV	High mass
Z/γ+jets	$32.5 \pm 2.6 \pm 6.8$	$25.8 \pm 2.6 \pm 4.9$	$208 \pm 9 \pm 37$	$16.2 \pm 2.1 \pm 3.6$	$3.3 \pm 1.0 \pm 1.3$
W+jets	$26.2 \pm 3.9 \pm 6.7$	$22.7 \pm 3.5 \pm 5.8$	$367 \pm 30 \pm 126$	$12.7 \pm 2.1 \pm 4.7$	$2.2 \pm 0.9 \pm 1.2$
$t\bar{t}$+ Single Top	$3.4 \pm 1.5 \pm 1.6$	$5.6 \pm 2.0 \pm 2.2$	$375 \pm 37 \pm 74$	$3.7 \pm 1.2 \pm 2.0$	$5.6 \pm 1.7 \pm 2.1$
QCD jets	$0.22 \pm 0.06 \pm 0.24$	$0.92 \pm 0.12 \pm 0.46$	$34 \pm 2 \pm 29$	$0.74 \pm 0.14 \pm 0.51$	$2.10 \pm 0.37 \pm 0.83$
Total	$62.3 \pm 4.3 \pm 9.2$	$55 \pm 3.8 \pm 7.3$	$984 \pm 39 \pm 145$	$33.4 \pm 2.9 \pm 6.3$	$13.2 \pm 1.9 \pm 2.6$
Data	58	59	1118	40	18

huge gains in short period of time - limits approaching 1 TeV

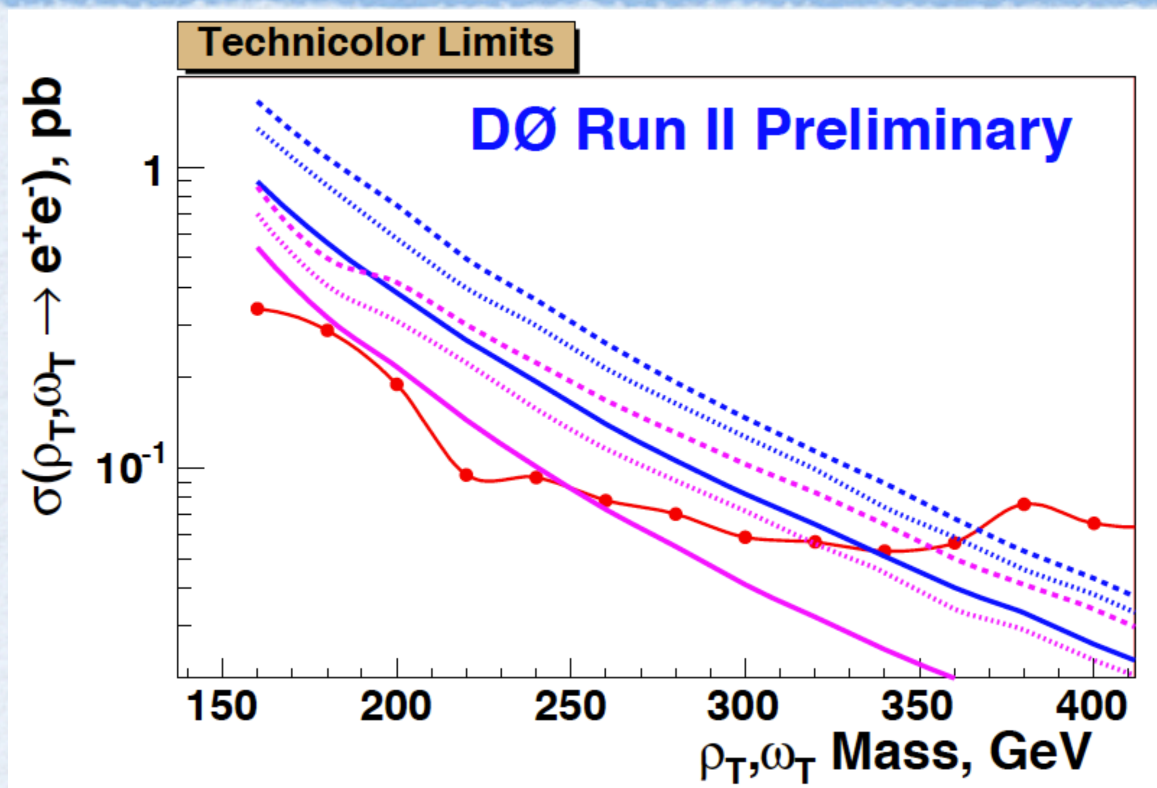
TECHNICOLOR

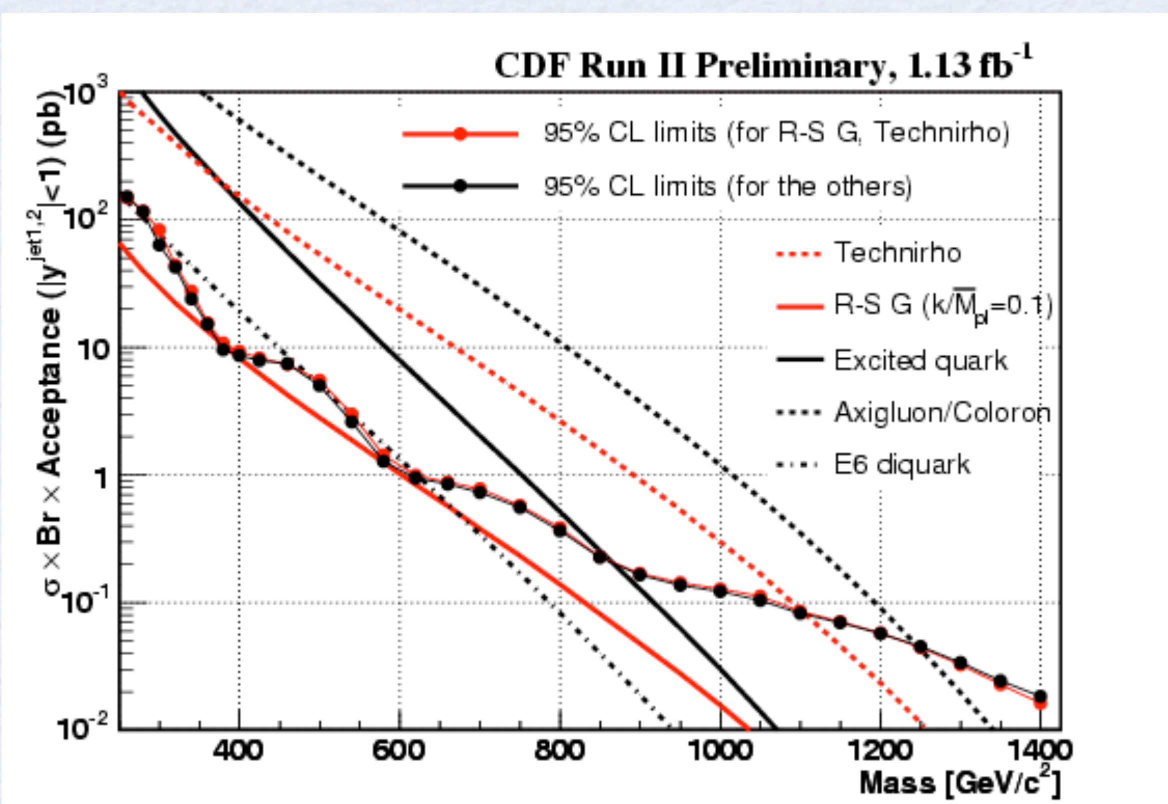
- 'Dynamic' explanation of electroweak symmetry breaking
- Instead of Higgs particle - new strong interactions
- Technicolor:
  - New Strong Dynamics : SU(N_T) gauge theory similar to QCD
  - N_T^2-1 new gauge bosons:technigluons
  - In analogy with QCD breaking of the chiral symmetry produces
    - Goldstone bosons (technipions):
    - – 3 technipions are eaten to become longitudinal W and Z

TECHNICOLOR

- As a new strongly interacting theory - would produce a whole new set of QCD like particles
  - Search for the lightest ones: π_T, ρ_T, ω_T
  - Some model dependence but popular searches for
    - $\rho_T \rightarrow W \pi_T \rightarrow l\nu bb$ (best reach at Tevatron, harder at LHC)
    - $\rho_T \rightarrow WZ$
    - $\rho_T \rightarrow ll$

Technicolor Limits



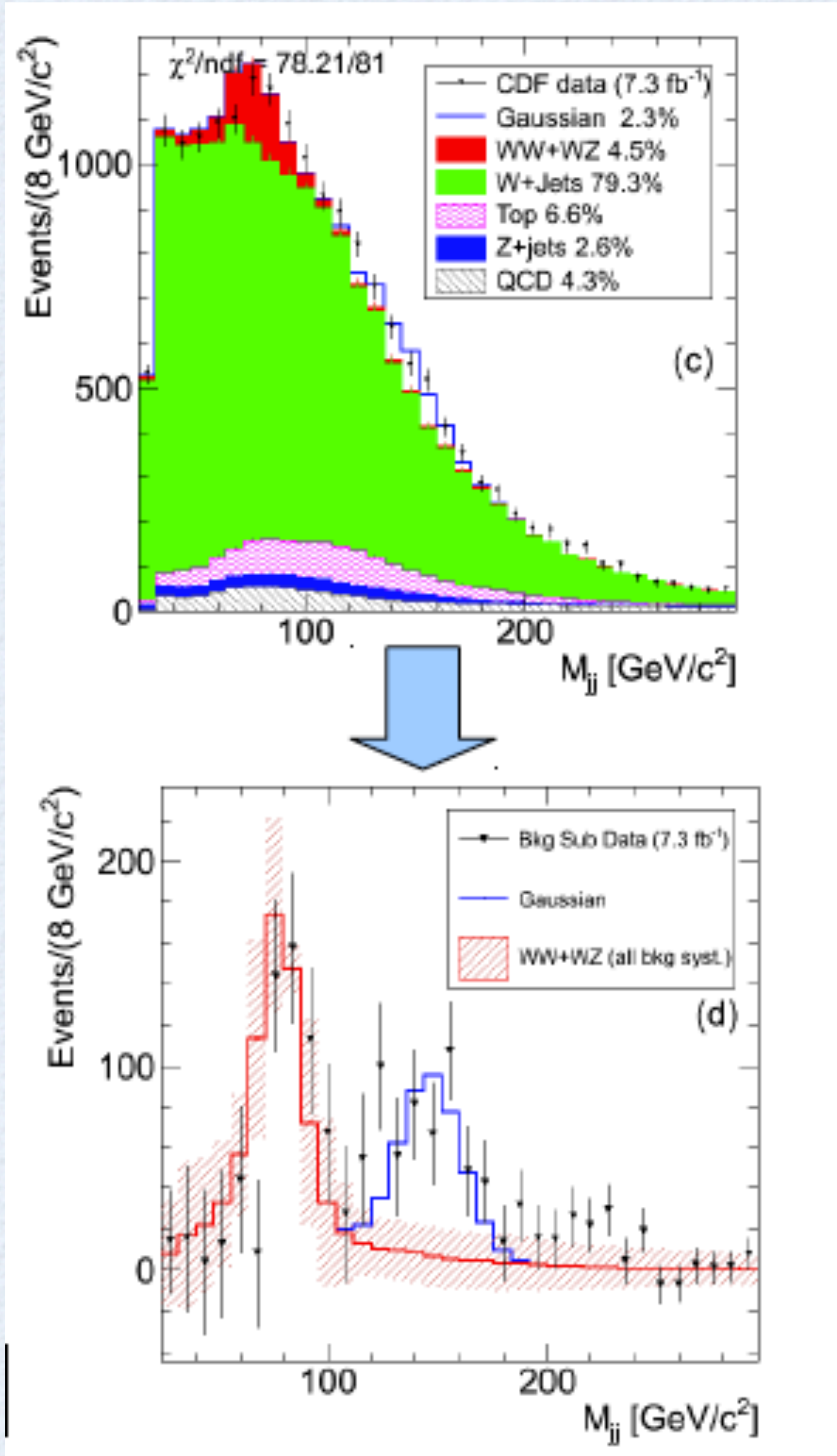


Limits from Tevatron ~ several hundred GeV

Limits from LHC : Forthcoming!

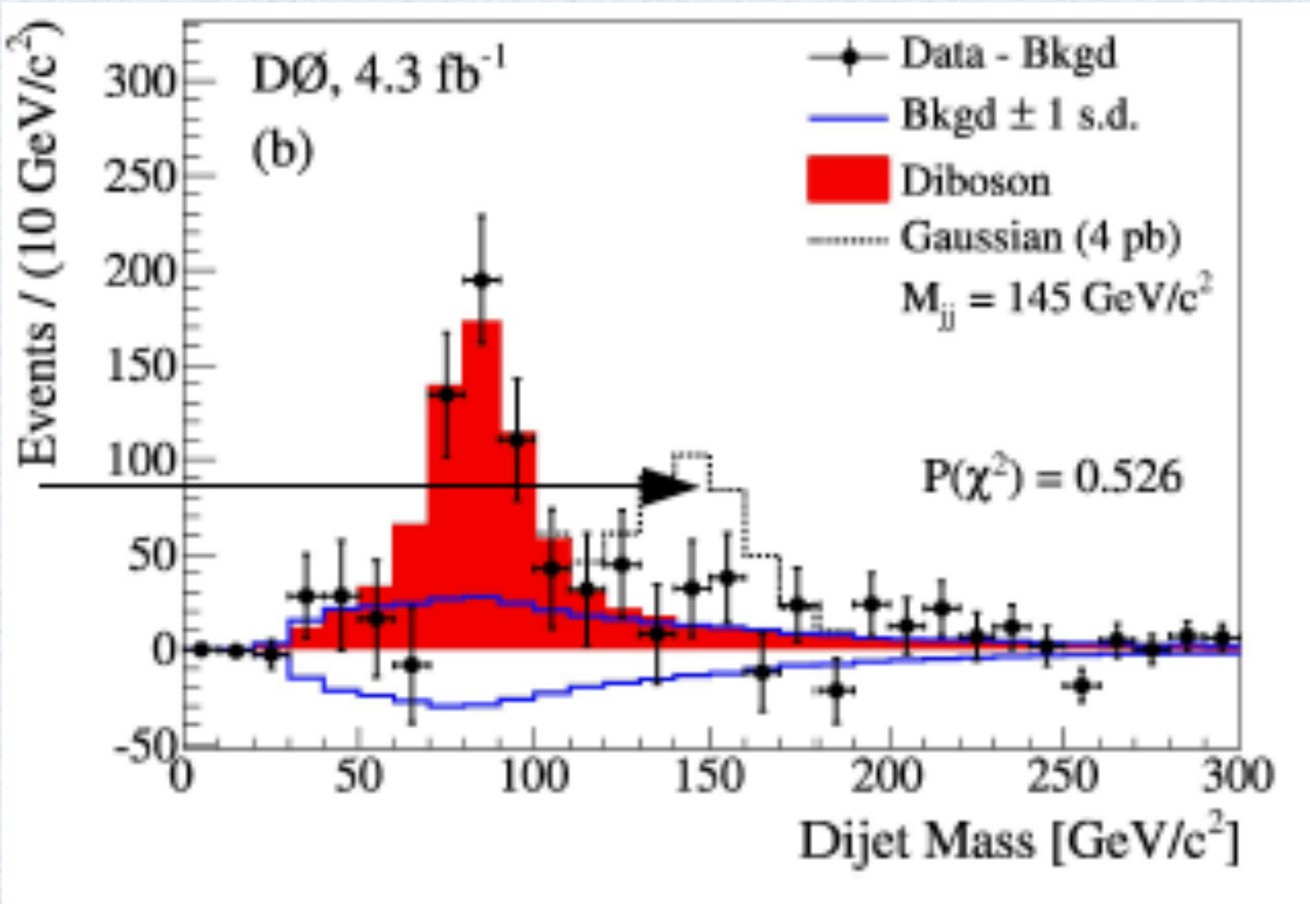
CDF BUMP

- Recently much excitement over bump seen in Wjj spectrum at CDF
- 4.1 σ in significance
- $\rho_T \rightarrow W\ \pi_T \rightarrow l\upsilon jj$???
- measured cross-section ~3±0.7 pb roughly consistent with technicolor prediction

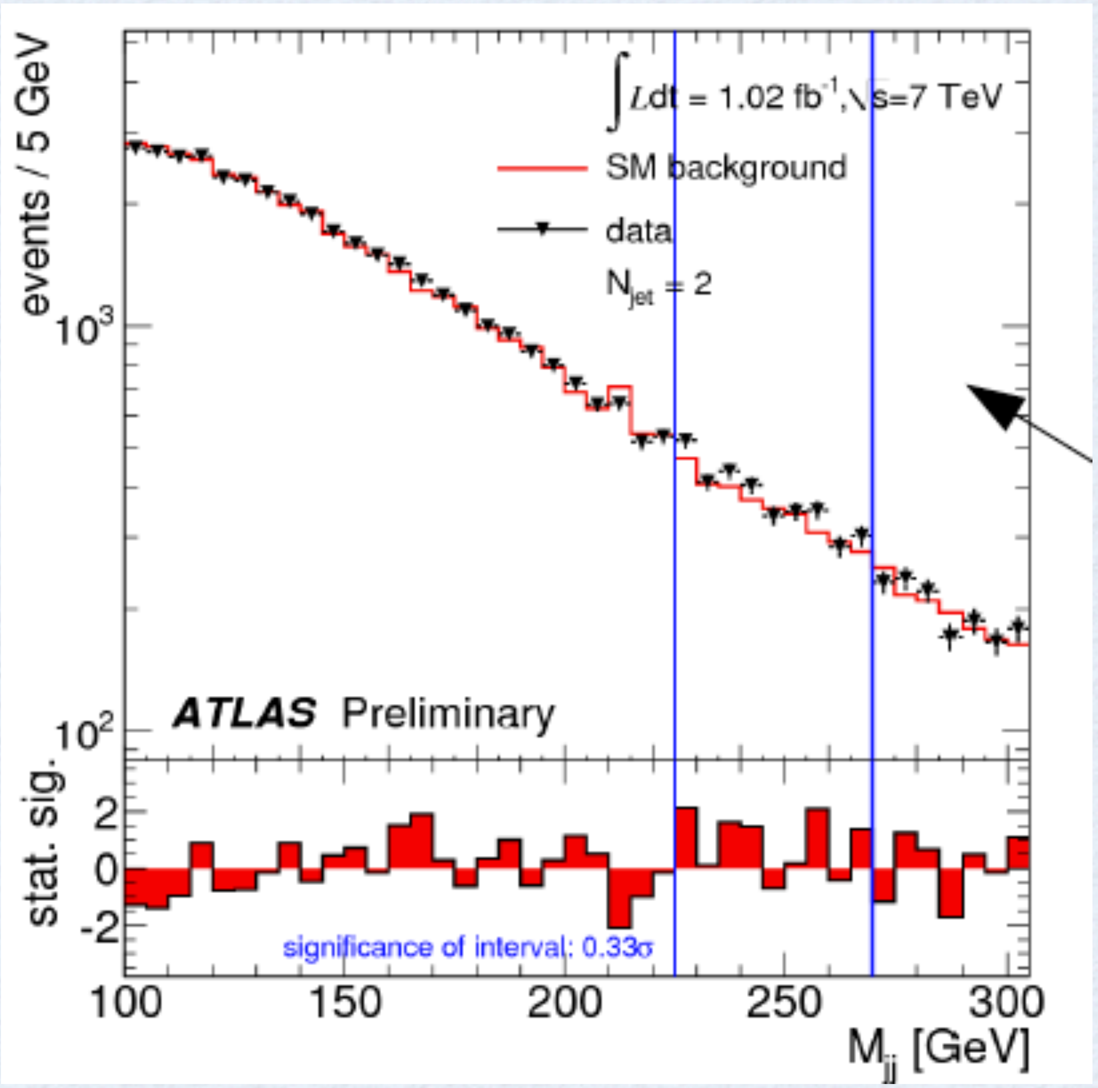


BUT..

- Unfortunately excess is not confirmed by D0
- Ongoing investigations to compare analysis and results



ATLAS RESULTS



- ATLAS also does not see an excess in the same region
- Note however that conclusions are VERY model dependent
  - Eichten, Lane, Martin point out that if it was technicolor do not expect to see anything yet at LHC

Conclusions

- Too many BSM scenarios to fit into one talk!
- Many exciting times ahead - LHC has already doubled the limits on many models
- Hopefully we will produce more than limits!