BSM
theories & signals

ISTAPP 2011 - Gökhan Ünel / *U.C.Irvine*

Last Lecture of week 1, prelude to week 2

=> what should you get out of it?

+ A review of the BSM theories on the "Market"
+ Typical signatures of most prominent models
  - Expected results for $\sqrt{s}$ =14TeV, ATLAS, (CMS is very similar)
+ No homework, sit back and relax but don't snore!

BSM models: Exotics

- A brief summary of popular models:
  - Grand Unified Theories:
    - SM gauge group is embedded into a larger one like SO(10), to unify EW and QCD.
    - additional fermions and bosons predicted.
  - Little Higgs models:
    - spontaneously broken global symmetry to impose a cut-off ~10 TeV.
    - additional bosons and quarks introduced to cure the hierarchy problem.
  - Extra Dimensions:
    - Low Planck scale in d dimensional theory solves the hierarchy problem between EW and Gravitational couplings.
    - Excitations of SM bosons and fermions are predicted.
  - And Many More like Fourth Generation, Hidden Valley, Unparticles….
- *Most of these models do **not** exclude supersymmetry.*

SM ingredients

- *Fermions* as matter particles
  - Quarks & Leptons
- *Gauge group structure*
  - gauge bosons as force carriers
- *EW Symmetry Breaking*
  - mass via Higgs bosons
- 3+1 space-time

SM is like your old car: you like it but you also know it has problems...

- *SM can not be the final theory:*
  - Hierarchy problem: $\delta H \sim M_H$
  - EW and Strong forces not unified
  - Arbitrary fermion masses & mixings
  - Arbitrary number of families
  - Unknown source of baryogenesis

SM to BSM

Super Symmetry

Fourth Family

GUTs

Gauge G

Little Higgs

2HDMs

- *Fermions* as matter particles
  - Quarks & Leptons

new quarks | new leptons | lepto-quarks | new constituents | composite models

- *Gauge group structure*
  - gauge bosons as force carriers

new gauge bosons

- *EW Symmetry Breaking*
  - mass via Higgs bosons

new scalars | new EWSB

Dynamical Symmetry Breaking

Technicolor

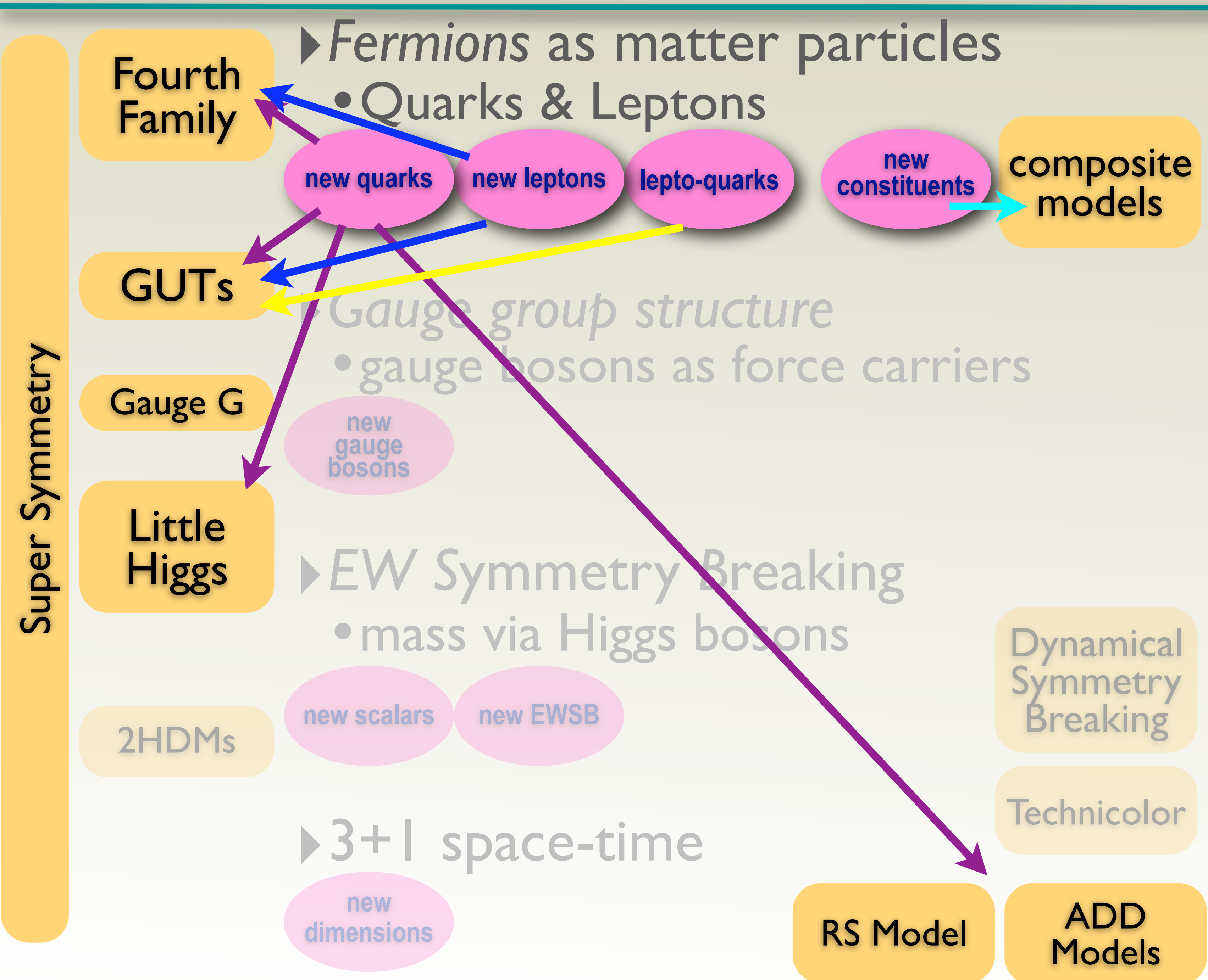
- 3+1 space-time

new dimensions

RS Model

ADD Models

SM to BSM

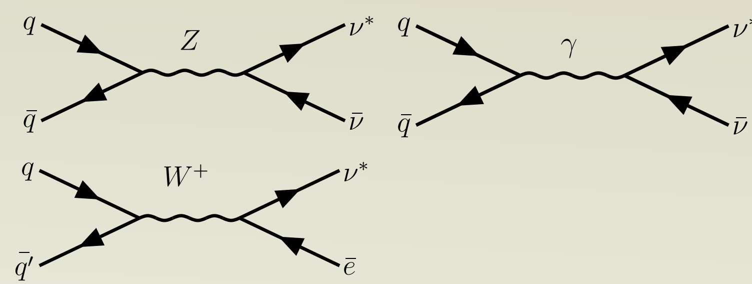


Super Symmetry
Fourth Family
GUTs
Gauge G
Little Higgs
2HDMs
Fermions as matter particles
• Quarks & Leptons
new quarks
new leptons
lepto-quarks
new constituents
composite models
Gauge group structure
• gauge bosons as force carriers
new gauge bosons
EW Symmetry Breaking
• mass via Higgs bosons
new scalars
new EWSB
Dynamical Symmetry Breaking
Technicolor
3+1 space-time
new dimensions
RS Model
ADD Models

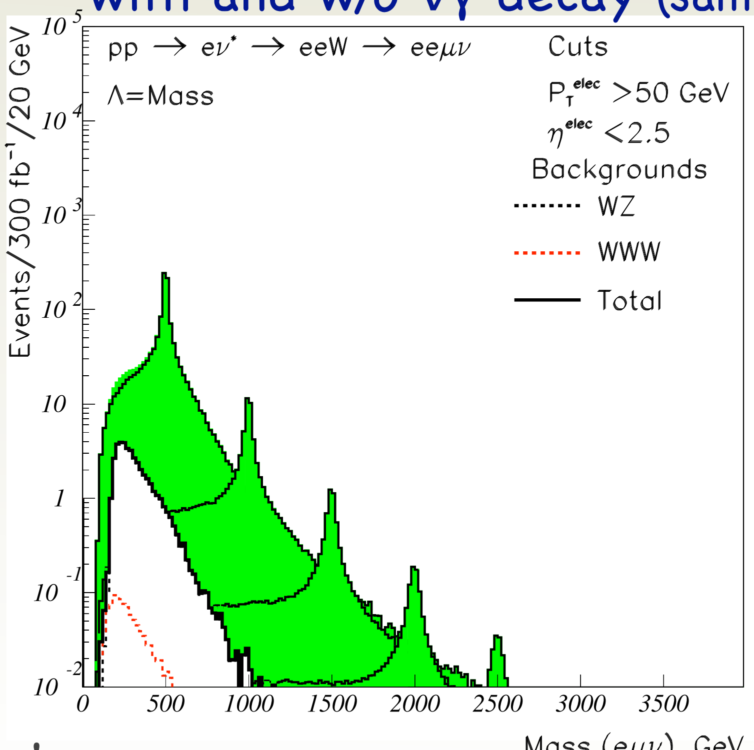
New constituents excited νs*

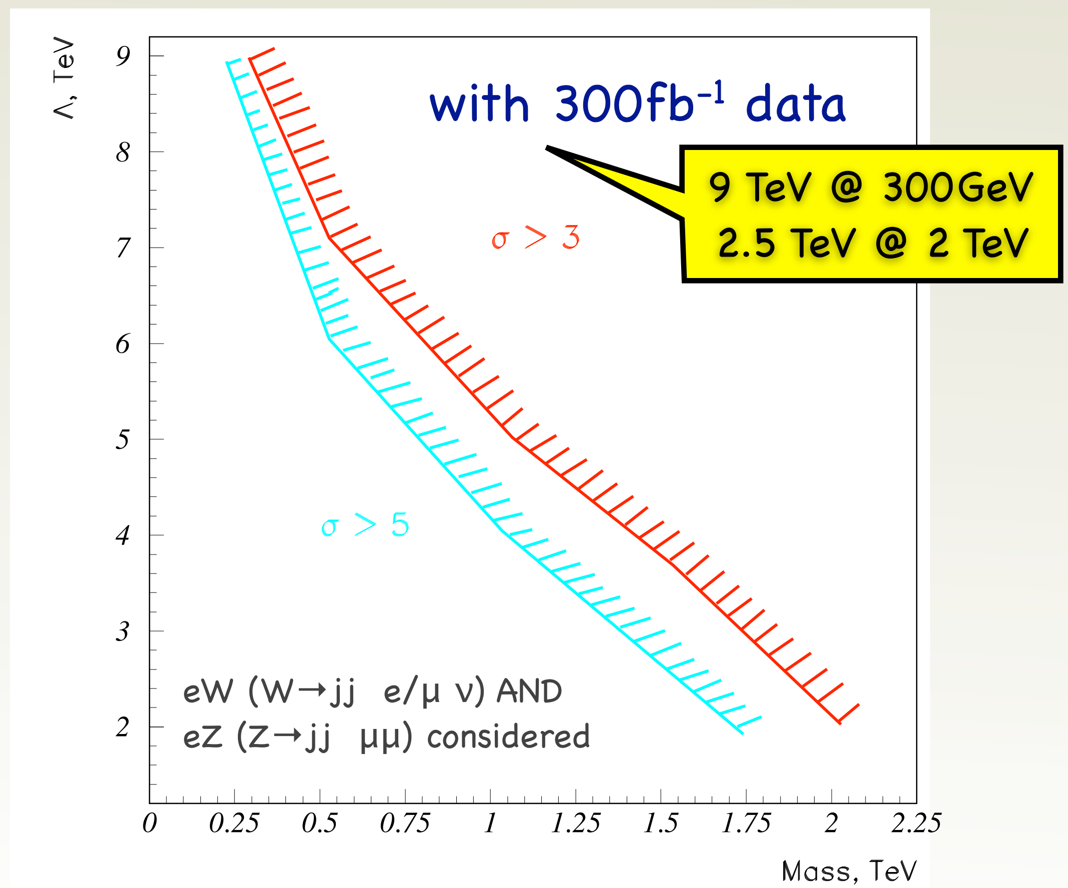
SN-ATLAS-2004-047

- **predicted by:** composite (preonic) models
- **produced as:** single ($\nu\nu^*/\nu^* e$) via Z,W,γ
- **decay via:** boson + lepton: $\nu\gamma, \nu Z, eW$



- Fast MC based study
- scan neutrino mass: [500,..,2500]
- consider 2 coupling possibilities:
  - with and w/o νγ decay (same disc. limit)



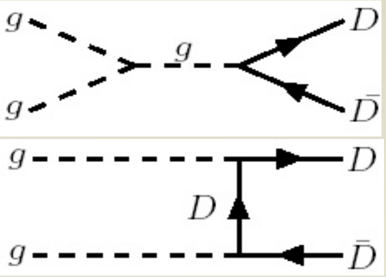


other excited fermions (e,q*) also studied, but not reported here.

New quarks: q=-⅓ singlets

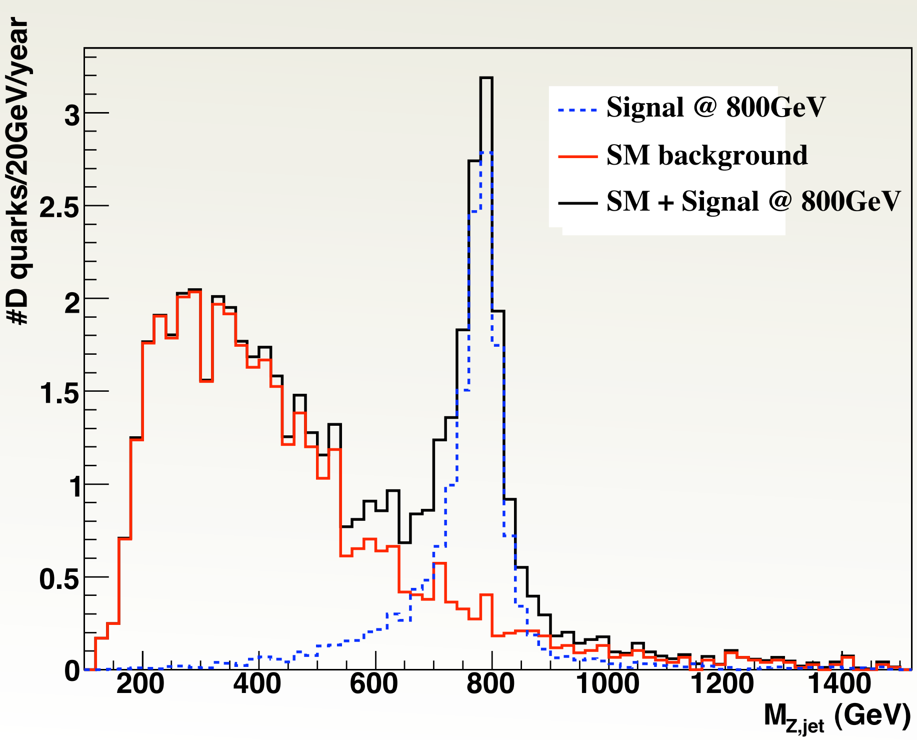
SN-ATLAS-2006-056

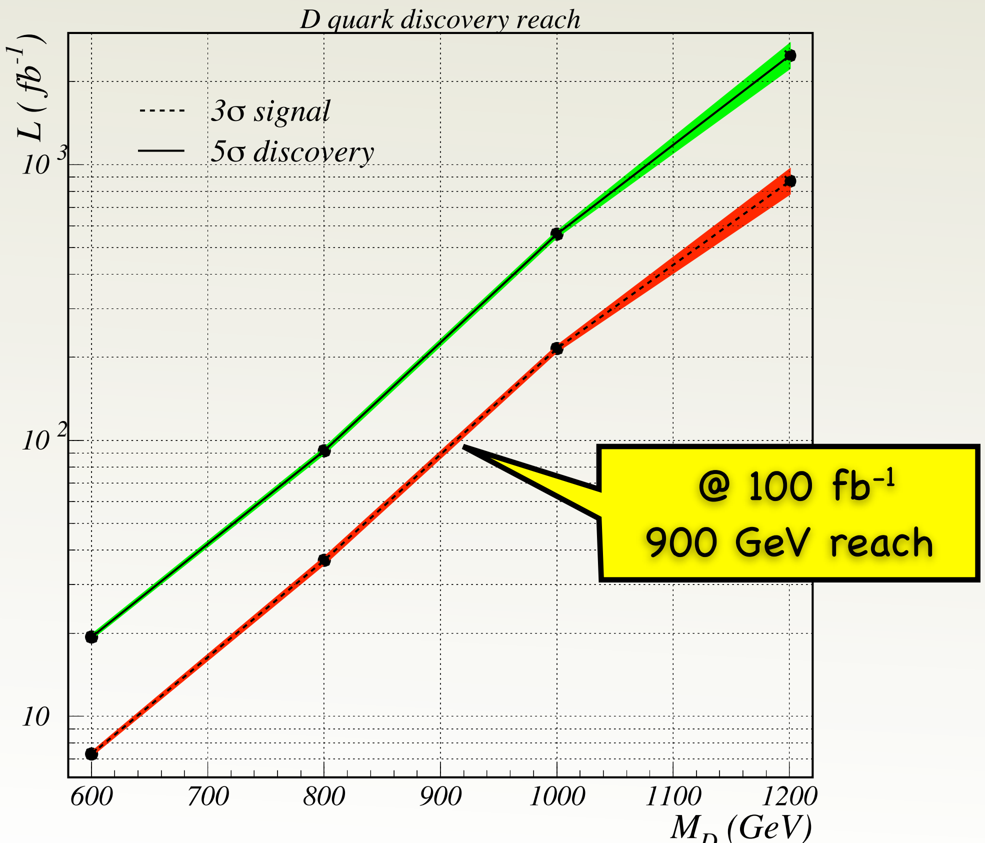
- **predicted by:** E_6 GUT
- **produced as:** pairs from gluon (quark) fusion
- **decay via:** boson + light jet



$$D\bar{D} \rightarrow ZjZj \rightarrow 4\ell 2j$$

- Fast MC based study
- scan new quark mass
- pair production is mixing independent





about q=−⅓ singlets

▸ E_6 model introduces new particles:

$$SU_C(3) \times SU_W(2) \times U_Y(1) \subset E_6$$

- one iso-singlet quark per family :

$$\begin{pmatrix} u_L \\ d_L \end{pmatrix}, u_R, d_R, D_L, D_R \quad \begin{pmatrix} c_L \\ s_L \end{pmatrix}, c_R, s_R, S_L, S_R \quad \begin{pmatrix} t_L \\ b_L \end{pmatrix}, t_R, b_R, B_L, B_R$$

Assumptions:

1. In-family mixing bigger than between family mixing
2. D quark is the lightest, like SM: most accessible in LHC
3. E_6 gauge bosons heavy & don't interact w/ SM bosons

	$D \to Zd$	$D \to Wu$	
BR	33%	66%	if there is no Higgs
	25%	50%	if Higgs is light

Higgs search & q=−⅓ quarks

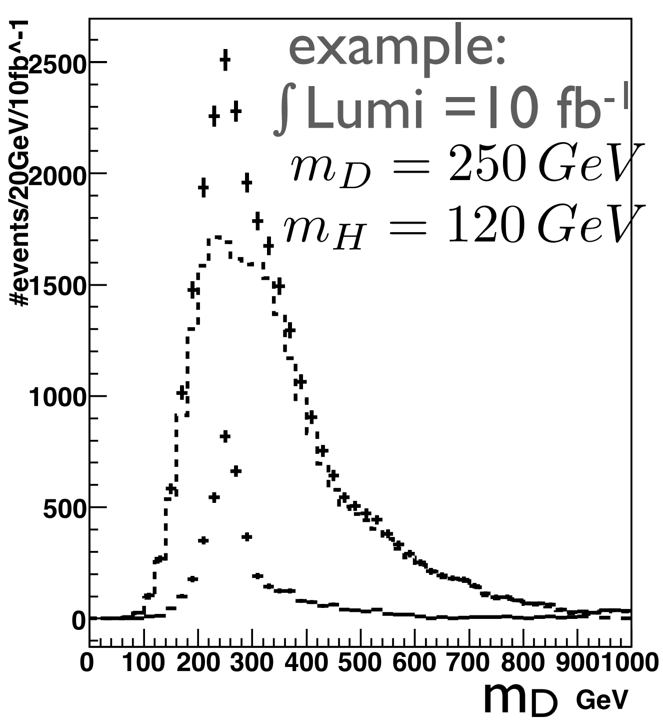
PLB 669 (2008) 39

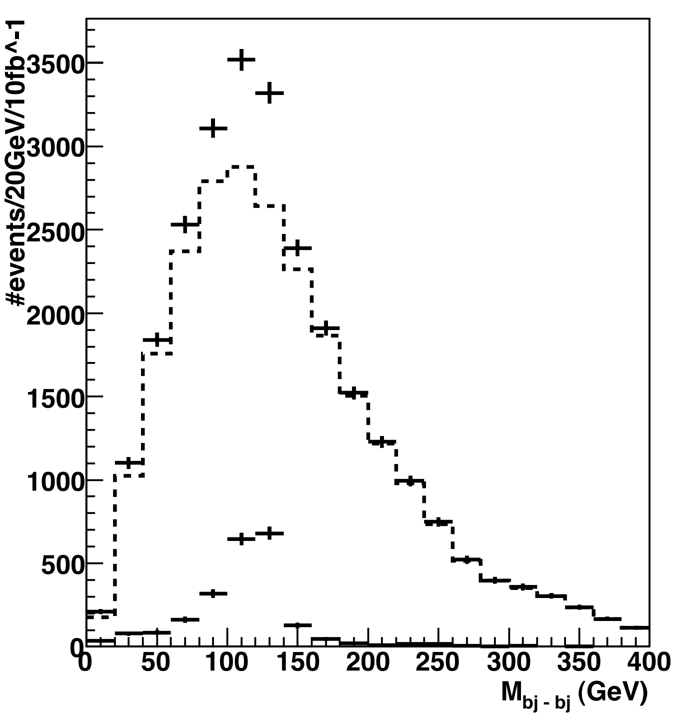
- d-D mixing leads to dDh vertex at tree level
- this can be exploited for a double discovery: light H & D
- pair production mode considered for ATLAS using FastMC
  - m_D =250 -1000 GeV range scanned

m_D=250 (500) GeV

D_1	D_2	BR	expected final state
$D \to h\,j$	$D \to h\,j$	0.029 (0.053)	$2j\ 4j_b$
$D \to h\,j$	$D \to Z\,j$	0.092 (0.120)	$2j\ 2j_b\ 2l$
$D \to h\,j$	$D \to W\,j$	0.190 (0.235)	$2j\ 2j_b\ l\ E_{T,miss}$

signal: 1ℓ +2j +2b_j +E^T_{miss}





- 5σ Higgs discovery in DD→Whjj channel can be made using 100 fb^{-1} if m_D <700 GeV
- If m_D<630 GeV, this channel becomes as efficient as h→γγ . (i.e. 8σ in 100 fb^{-1})

New quarks q=2/3 singlets

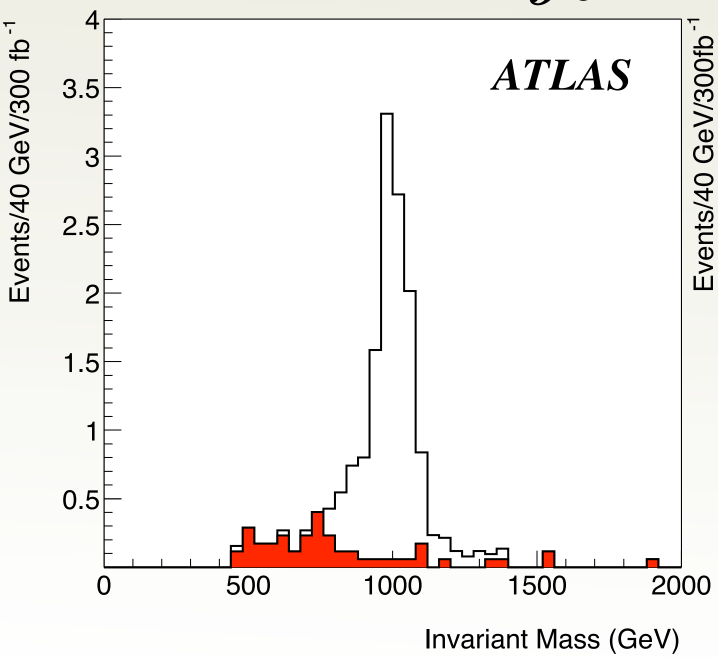
SN-ATLAS-2004-038

- predicted by: Little Higgs
- produced as: single from W exchange
- decay via: boson + (t or b) jet

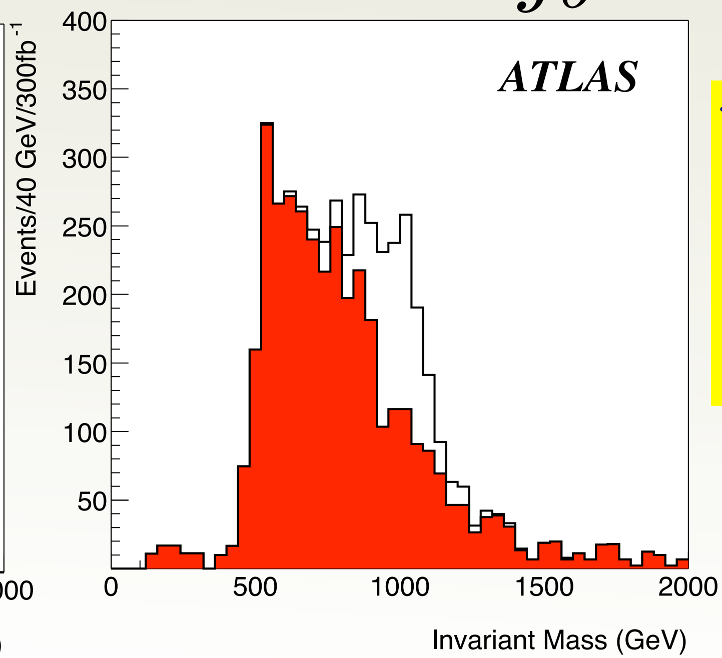
$$qb \to q'T \to q'\,Wb \;\; (ht, Zt)$$

- Fast MC based study
- function of T quark mass and t-T mixing
- all 3 decay channels studied.

$$Zt \to \ell\ell\ell\nu j_b$$



$$Wb \to \ell\nu j_b$$



T is observable with 300 fb^{-1}:
- up to ~2.5 TeV via Wb,
- up to ~1.4 TeV via Zt.

at maximum t-T mixing

New quarks doublets

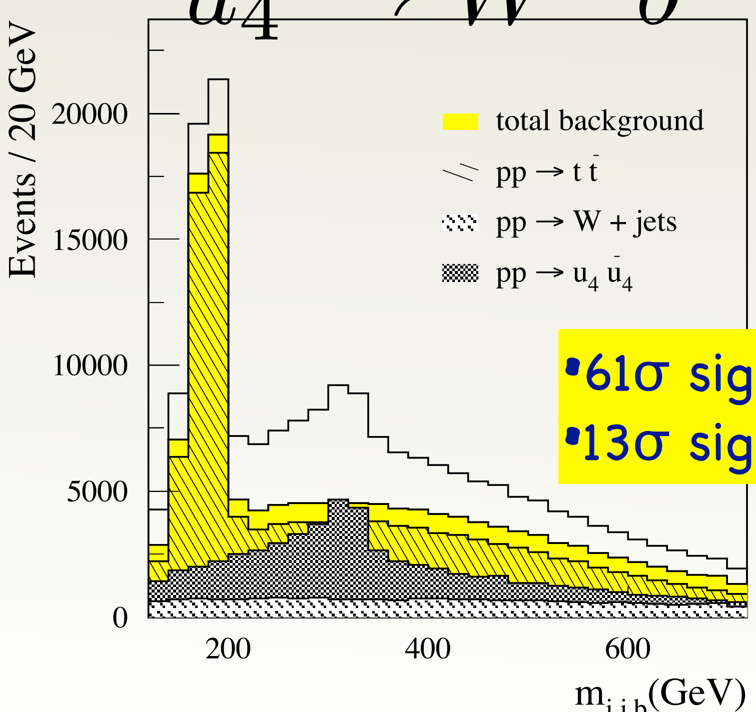
ATLAS-TDR*

- predicted by: DMM
- produced as: pairs from gluon (quark) fusion
- decay via: W + jet (no FCNC)

$$pp \to u_4\bar{u}_4 \text{ or } d_4\bar{d}_4$$

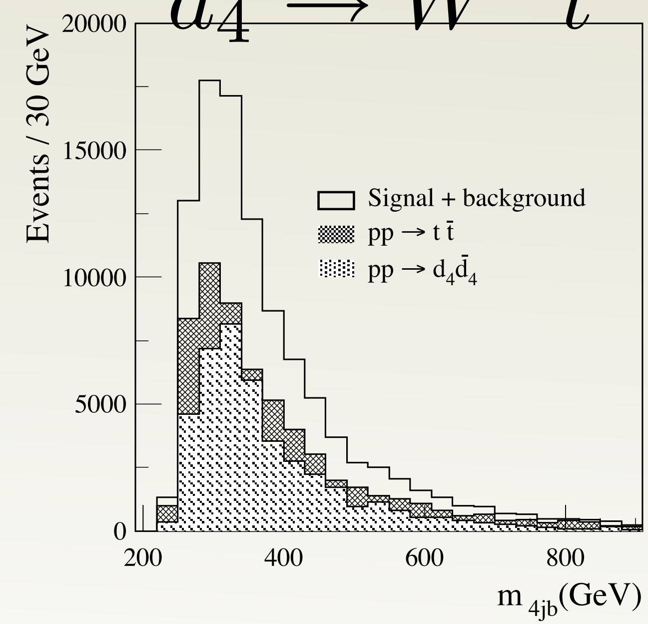
- Fast MC based study
- scan new quark mass
- results for 100 fb^{-1} shown

$$u_4 \to W^+ b$$



- 61σ signal from 320 GeV u_4
- 13σ signal from 640 GeV u_4

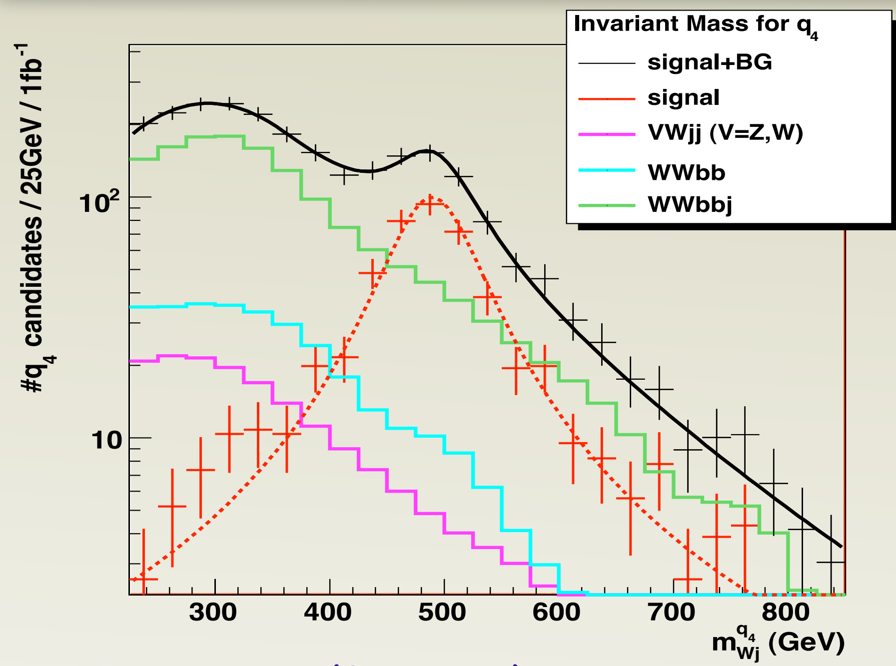
$$d_4 \to W^- t$$

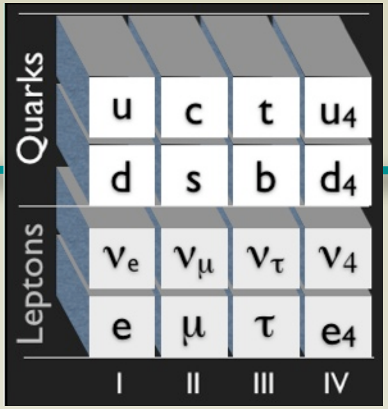


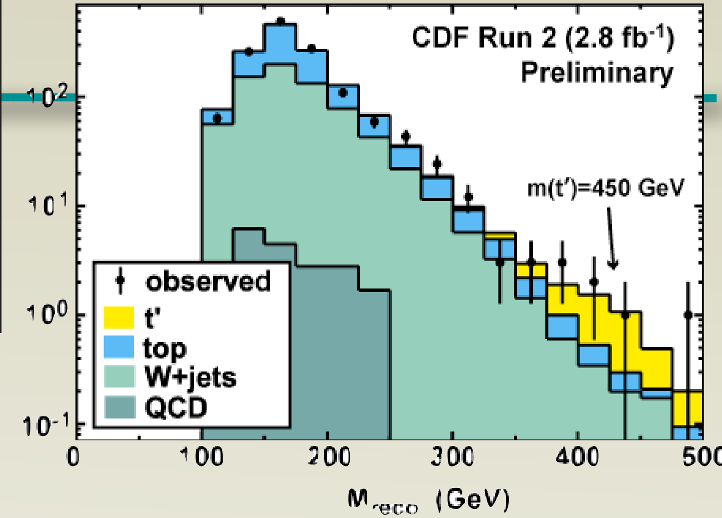
- broad signal at 320 GeV d_4
- Exact knowledge of BG shape needed

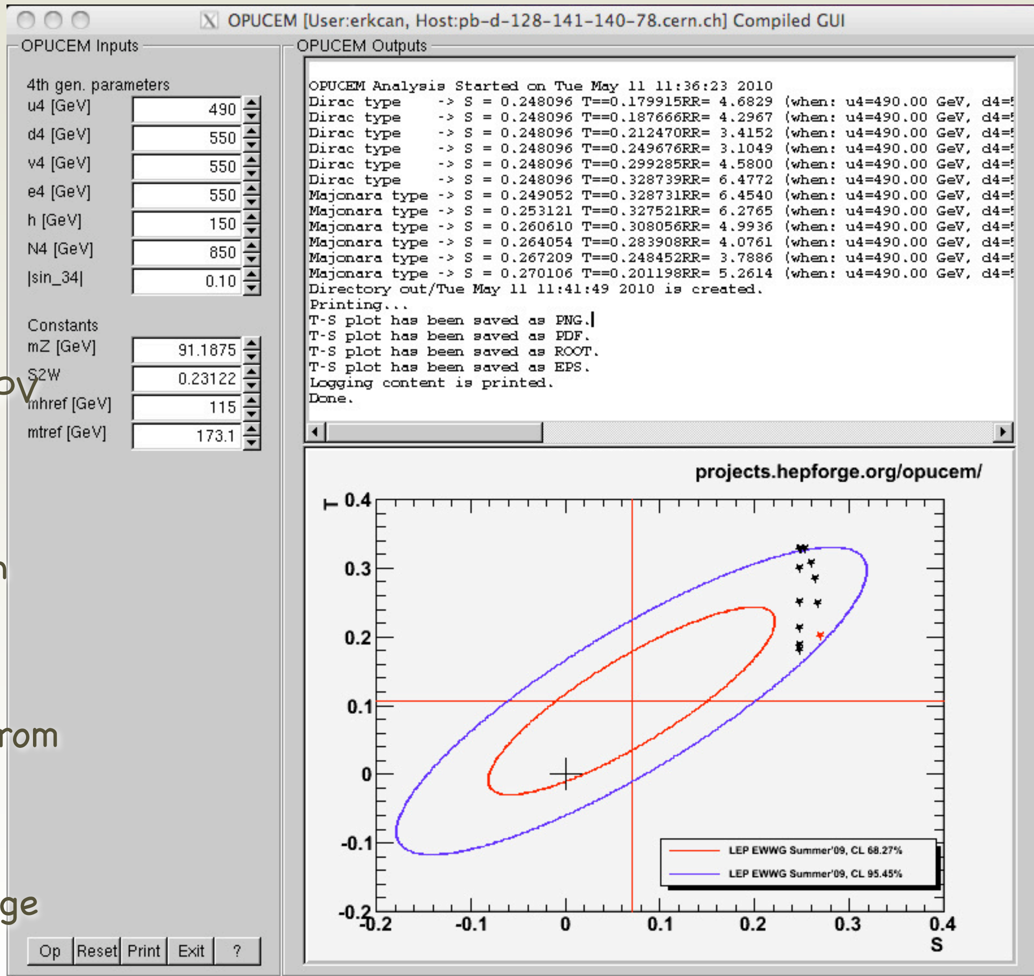
*new studies for other CKM mixings done, but not yet made public.

divertimento







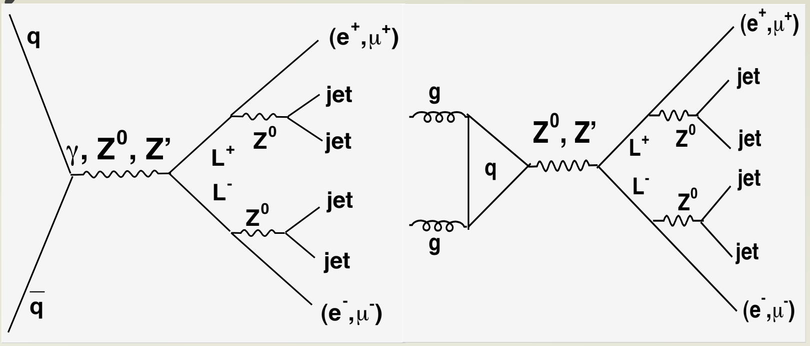


- CPV source (for BAU)
  - ➡ 3x3 CKM is 10^{10} too short to match WMAP data
  - ➡ new quarks of (300) 600 GeV would give (10^{13}) 10^{15} more CPV
- Alternative EW symmetry breaking
  - ➡ 4^{th} generation fermion condensate can play the Higgs role
  - ➡ 5D AdS, K.K. excitations of gauge bosons interacting w/ 4th generation fermions => Yukawa couplings & mass hierarchy
- Fermion mass hierarchy
  - ➡ observed masses of fermions in the first 3 families arise from perturbations to a flavour-blind 4x4 mass matrix.
- Dark Matter candidates
  - ➡ hadrons from stable t', ν', additional fermions of spin-charge unification models

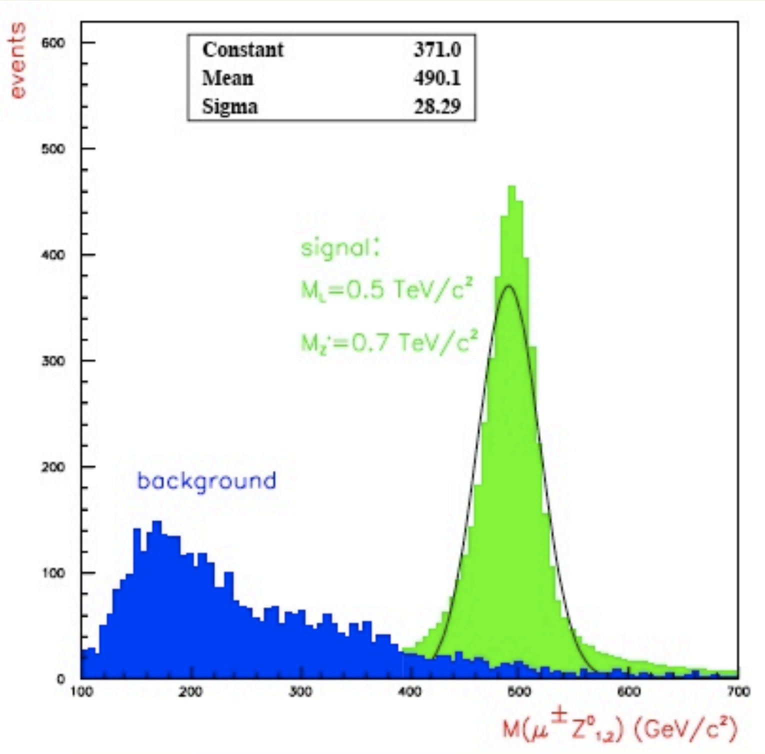
New Leptons

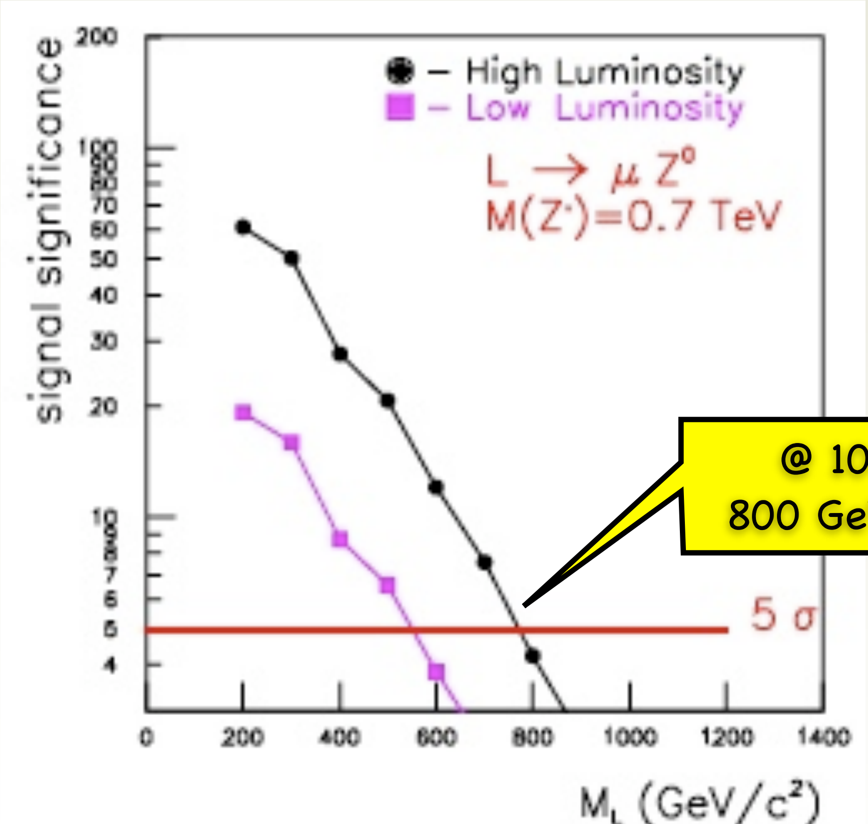
ATLAS-PHYS-2003-014

- predicted by: Fourth family, E_6 GUT, technicolor..
- produced as: pairs from gluon (quark) fusion
- decay via: boson + lepton



- Fast MC based study
- function of L, Z′ mass





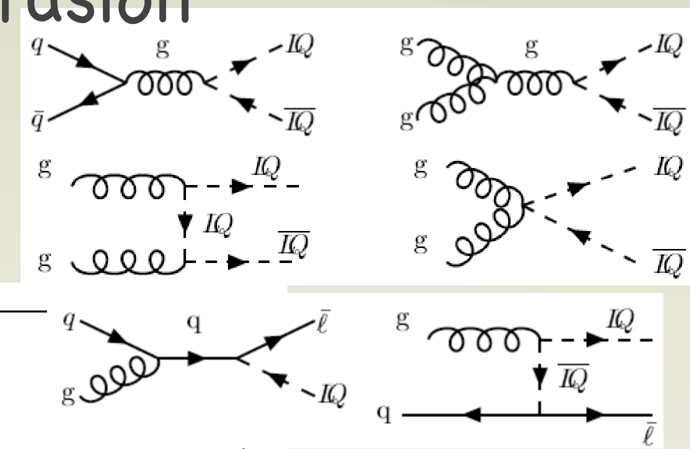
@ 100 fb^{-1}
800 GeV reach

Higher Z′ mass increases the L mass reach: Z′=2TeV, L=1TeV accessible

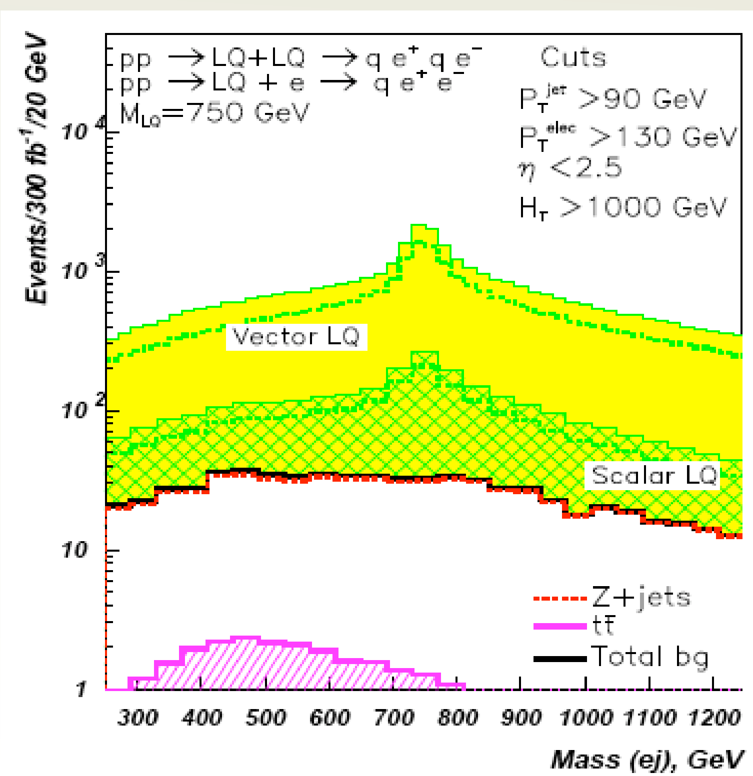
Lepto-quarks

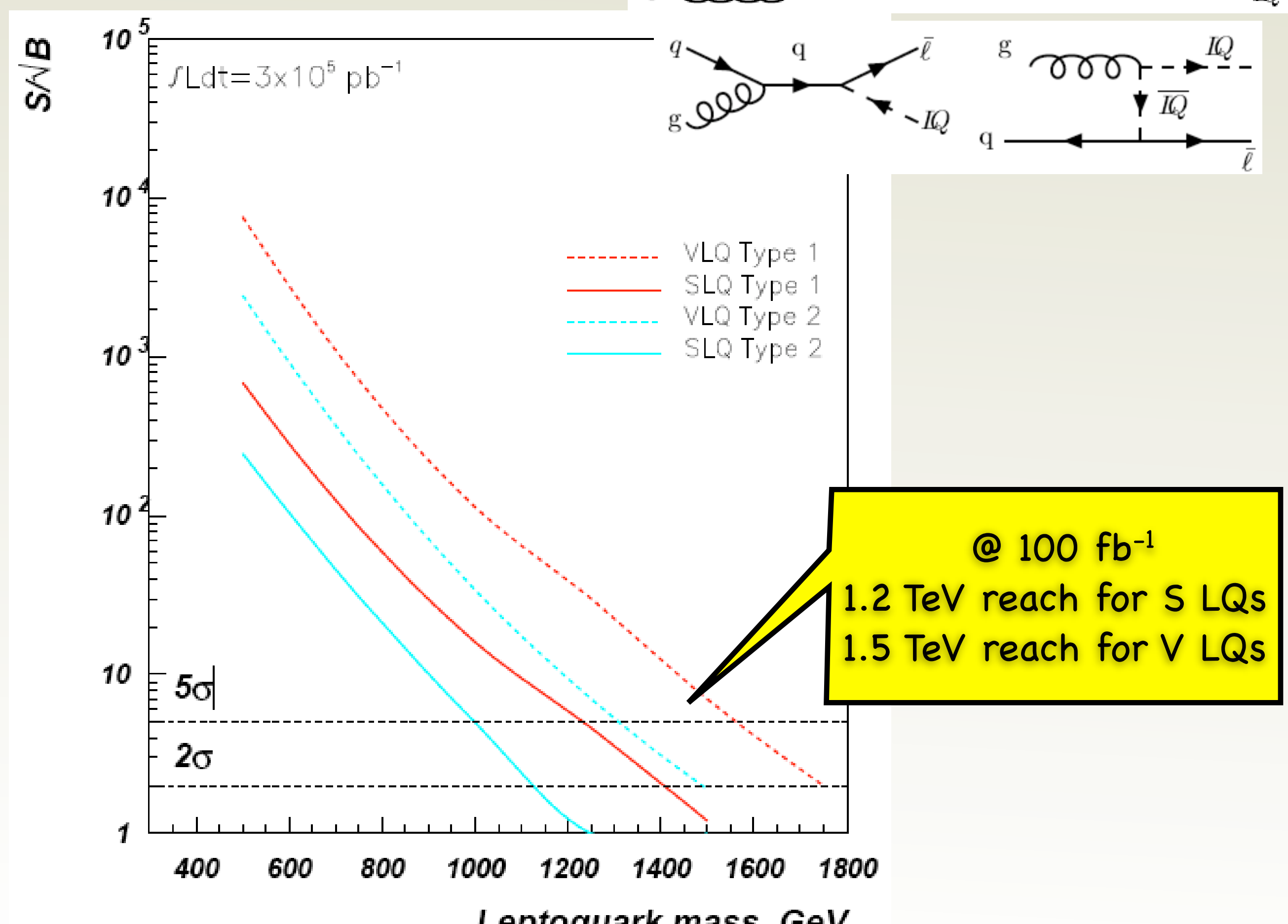
SN-ATLAS-2005-051

- predicted by: GUTs & composite models
- produced as: pairs + single from g-g (q) fusion
- decay via: e(type1) or ν(type2) + light jet



- Fast MC based study for Scalar & Vector LQs
- Coupling κ, λ=e (for V)
- LQ-mass scanned





SM to BSM

Super Symmetry

Fourth Family

- *Fermions* as matter particles
  - Quarks & Leptons

new quarks | new leptons | lepto-quarks | new constituents

composite models

GUTs

Gauge G

Little Higgs

- *Gauge group structure*
  - gauge bosons as force carriers

new gauge bosons

- *EW Symmetry Breaking*
  - mass via Higgs bosons

2HDMs

new scalars | new EWSB

Dynamical Symmetry Breaking

Technicolor

- 3+1 space-time

new dimensions

RS Model

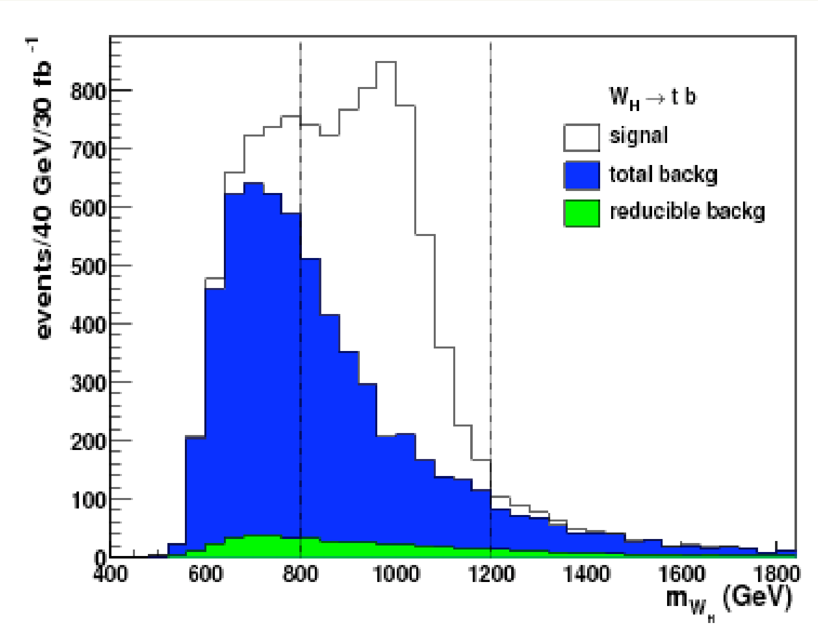
ADD Models

New bosons W`/W_H

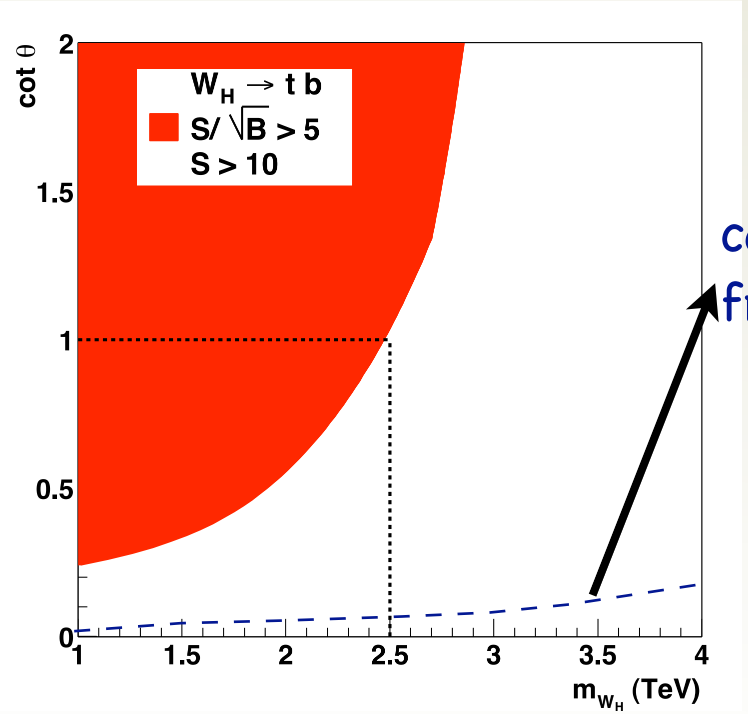
ATLAS-PHYS-PUB-2006-003

- predicted by: SO(10), E_6.. GUTs, Little Higgs, EDs
- produced as: s channel from q-q' annihilation
- decay via: top-b $q\bar{q}' \to W' \to tb \to \ell\nu bb$

- Fast MC based study
- W-W_H coupling via cotθ
- W_H mass 1 & 2 TeV considered



Discovery plane for 300fb^{-1} data



compare to $W_H \to e\nu$ from SN-ATLAS-2004-038

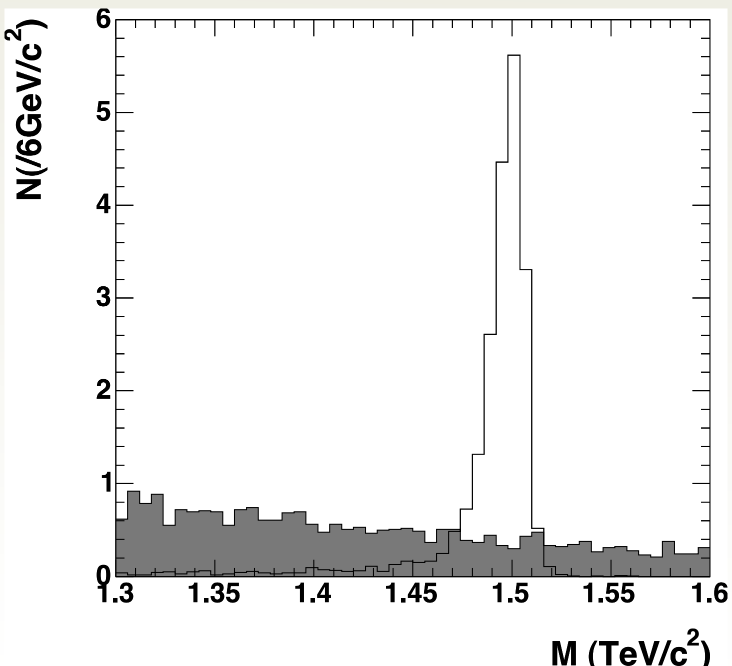
Discovery reach is 6.5 TeV depending on the W-W_H mixing.

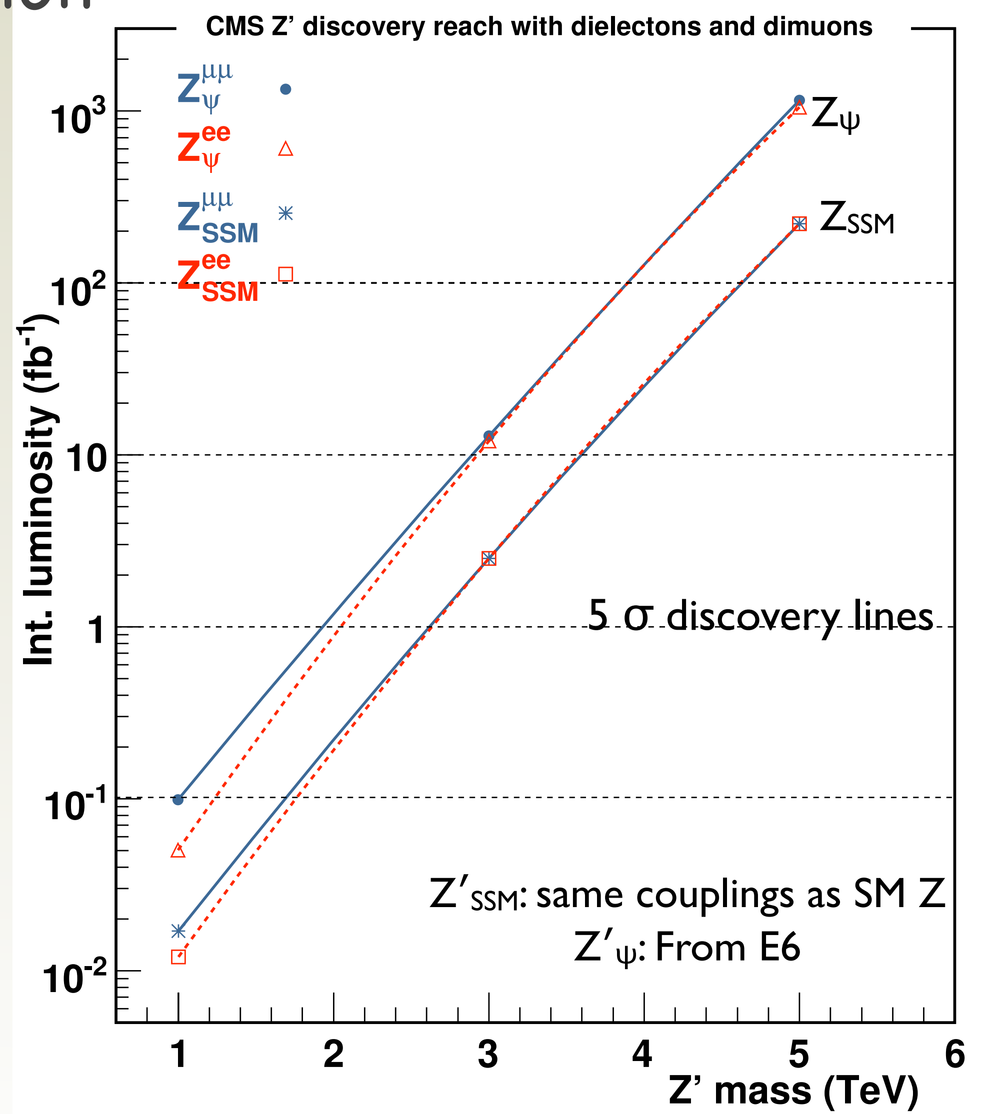
New bosons: Z′

CMS TDR

- **predicted by:** SO(10), E_6.. GUTs, Little Higgs, EDs
- **produced as:** from q-q annihilation
- **decay via:** fermion pairs

- Dileptons (ee, μμ) provide a clear search channel
- Current lower limits: 700-800 GeV from Tevatron
- CMS example of 1.5 TeV Z′ from electrons (clean signal)





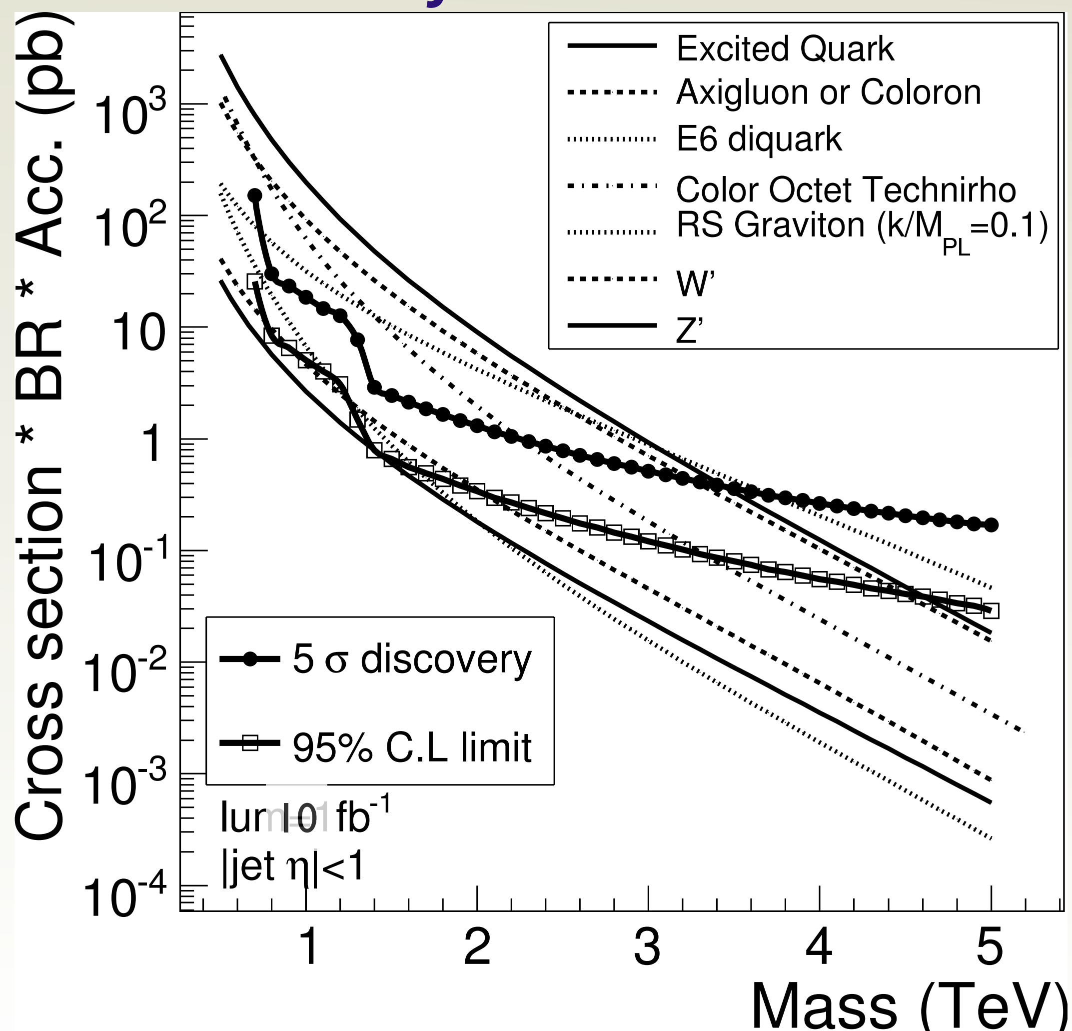
LHC will allow ~4.5 TeV $m_{Z'}$ reach

leptophobic Z′

CMS TDR

- Z′ that couples to hadrons only, hadrophilic
- Could explain 2.8σ discrepancy in A^b_{FB} (world average)
- CMS search w/ full simulation for Z′→*di-jets*
  - $Z^{(1)}$ = 2 .. 3 TeV
  - Model independent search

Discovery up to ~3.5 TeV possible using data from ∫Lumi = 10fb^{-1}



but which Z′ ?

CMS TDR

- Once discovered (!) how to determine which particle / model:

❶ particle identification from spin is "*easy*"

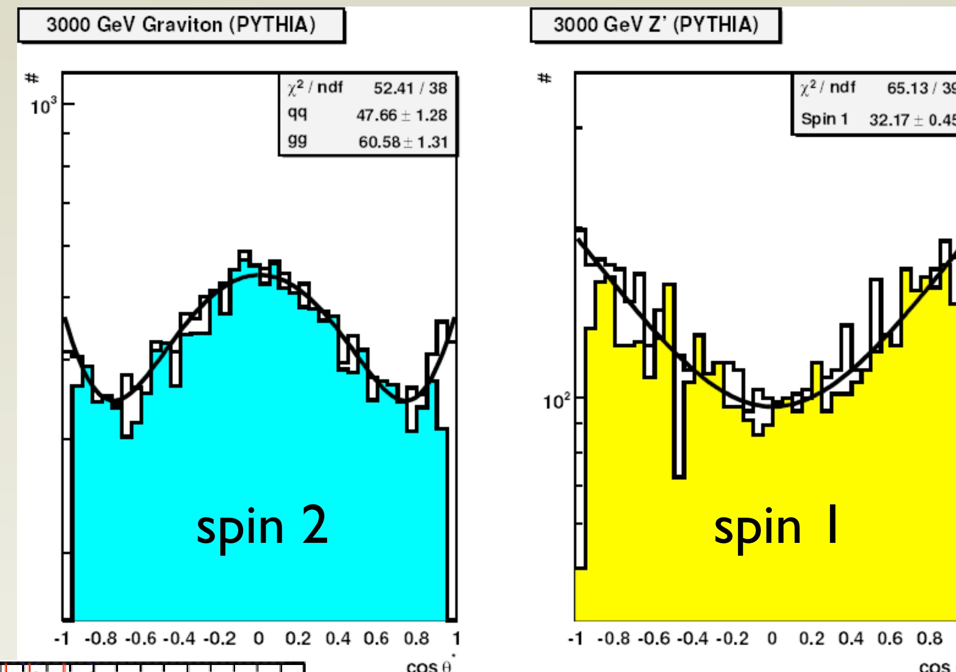
❷ model identification from A_{FB}

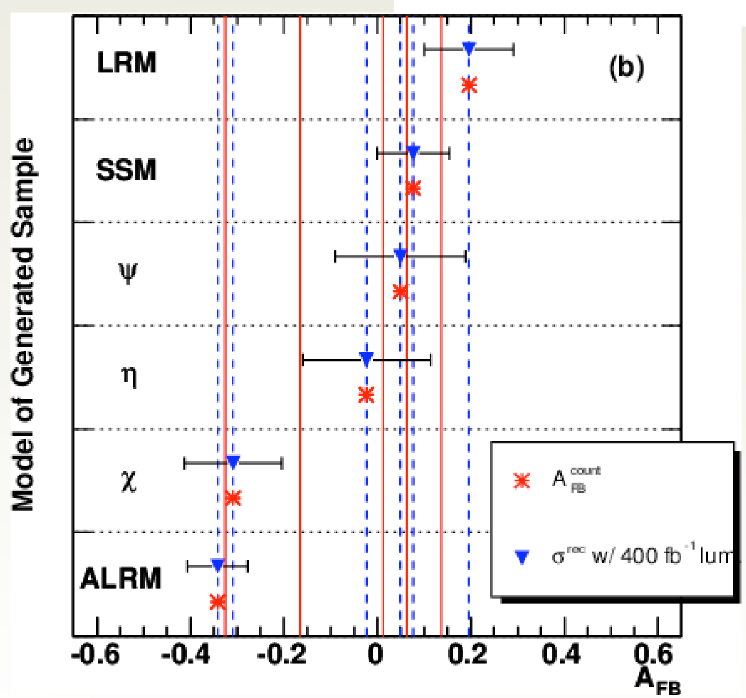
$$\frac{d\sigma}{d\cos\theta} = \frac{3}{8}(1+\cos^2\theta) + A_{\rm FB}\cos\theta$$

$$\theta = \frac{\vec{\ell}.\vec{q}}{|p|.|q|}$$

$$A_{\rm FB} = \frac{\ell_F - \ell_B}{\ell_F + \ell_B}$$

A_{FB}: coupling dependent, predicted by theory





$Z' = 3$TeV, $\int L = 400$ fb^{-1}

not so easy!!
(for some models)

Various E_6 Z′s

- From E_6 down to SM , but how?
  - $E_6 \to SO(10) \times U(1)_\psi \to SU(5) \times U(1)_\chi \times U(1)_\psi$ 4+1+1=6
  - $E_6 \to SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_\eta = SM \times U(1)_\eta$ 4+1=5
- Available neutral bosons: Z_ψ , Z_χ , Z_η
- Define mass eigenstates: Z′, Z″
  - $Z' = Z_\psi \cos\theta - Z_\chi \sin\theta$ && $Z'' = Z_\chi \cos\theta + Z_\psi \sin\theta$
    - $\theta=0$: Z'_ψ ,
    - $\theta=-\pi/2$: Z'_χ
    - $\theta=-\arcsin(\sqrt{3/8})$: Z'_η

- How about W′ ?
  - $E_6 \to SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_L \times U(1)_C$: Left-Right symmetric model 4+1+1=6
  - $E_6 \to SU(3)_C \times SU(2)_L \times U(1)_Y \times SU(2) \times U(1)'$
    - each SU(2) introduces $W^\pm$
  - selected breaking down of E_6 to SM determines the predicted particles & couplings

New bosons Z^n

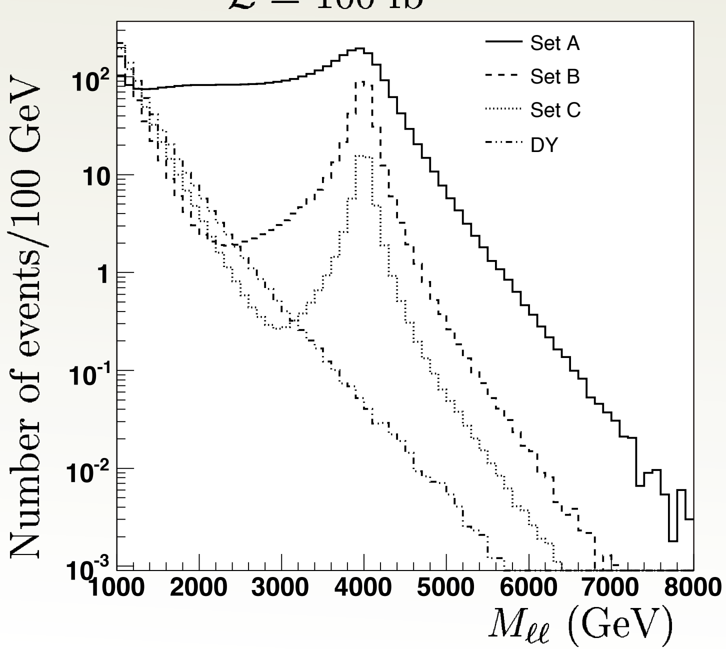
SN-ATLAS-2007-065

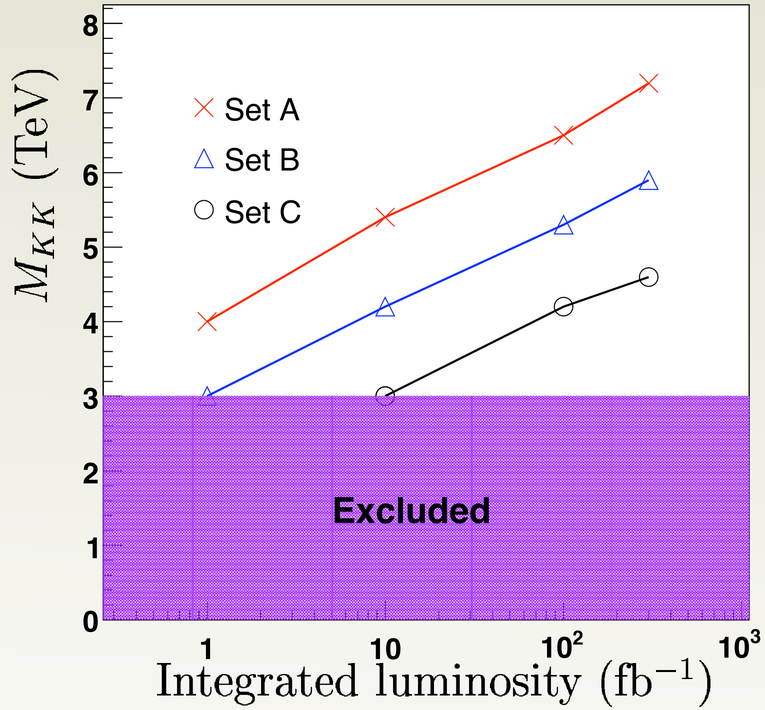
- predicted by: RS, ADD models
- produced as: from q-q annihilation
- decay via: lepton pairs

$$pp \rightarrow \gamma^n / Z^n \rightarrow \ell^+ \ell^-$$

- FULL simulation based study
- 3 Parameter sets to reproduce the fermion masses & mixings (A, B, C)
- only electrons were reconstructed

$\mathcal{L} = 100\ \text{fb}^{-1}$





Discovery reach is about 6 TeV depending on the model for 100fb^{-1} data.

SM to BSM

Super Symmetry

Fourth Family

- *Fermions* as matter particles
  - Quarks & Leptons

new quarks
new leptons
lepto-quarks
new constituents
composite models

GUTs

- *Gauge group structure*
  - gauge bosons as force carriers

Gauge G
new gauge bosons

Little Higgs

- *EW* Symmetry *Breaking*
  - mass via Higgs bosons

2HDMs
new scalars
new EWSB
Dynamical Symmetry Breaking
Technicolor

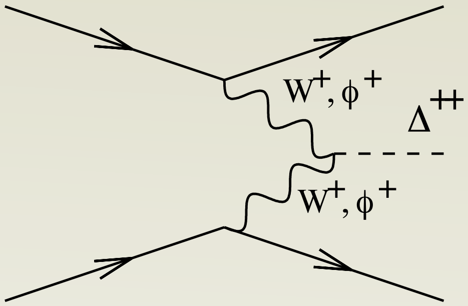
- 3+1 space-time

new dimensions
RS Model
ADD Models

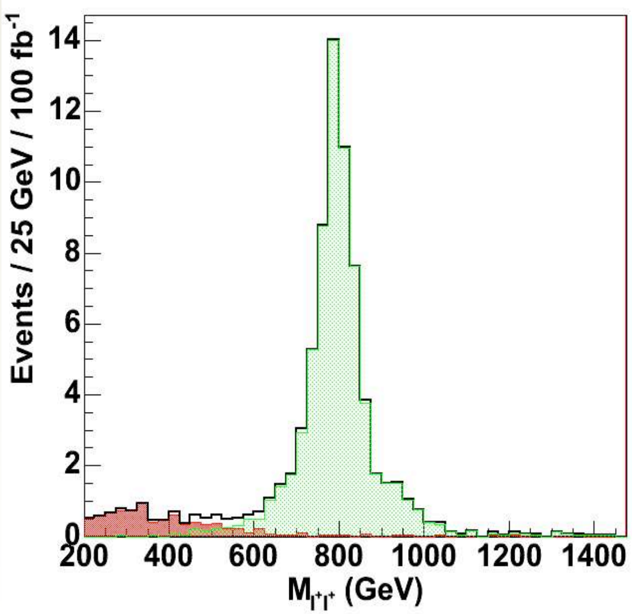
New Scalars $q=\pm 2$

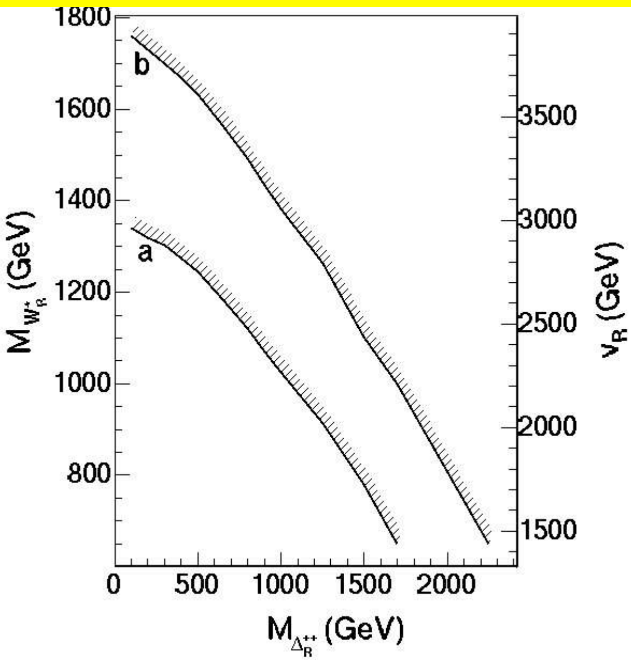
SN-ATLAS-2005-049

- **predicted by:** Little Higgs, <u>LRSM</u>
- **produced as:** pair via q-q annihilation & single via W fusion
- **decay via:** lepton pairs
  - Fast MC based study
  - W^+_R & Δ^{++} mass scanned for min 10evts
  - e,μ & τ channels separately studied
  - results for 100(a) & 300(b) fb^{-1} shown

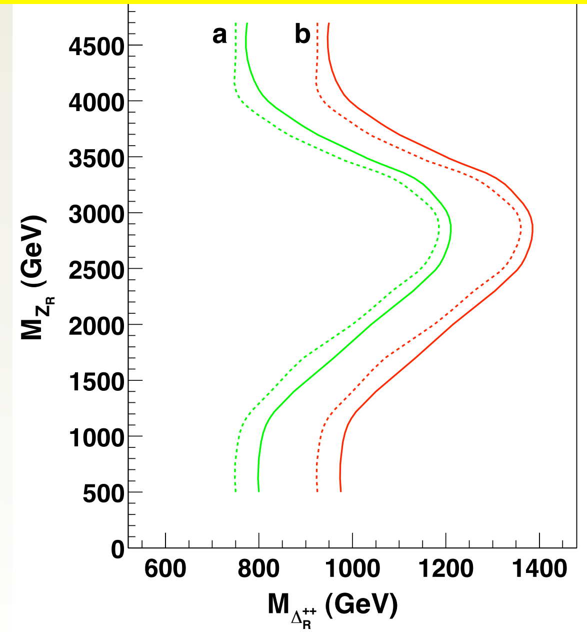


single production reach ~1.8TeV depending on mW^+





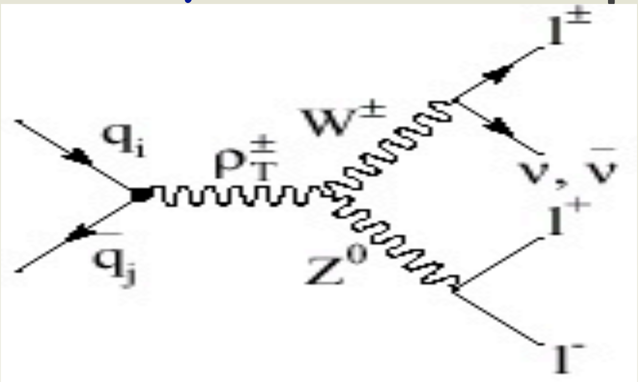
pair production reach 1.1 TeV depending on mZ_R with 3 and 4 leptons



New EWSB no scalar

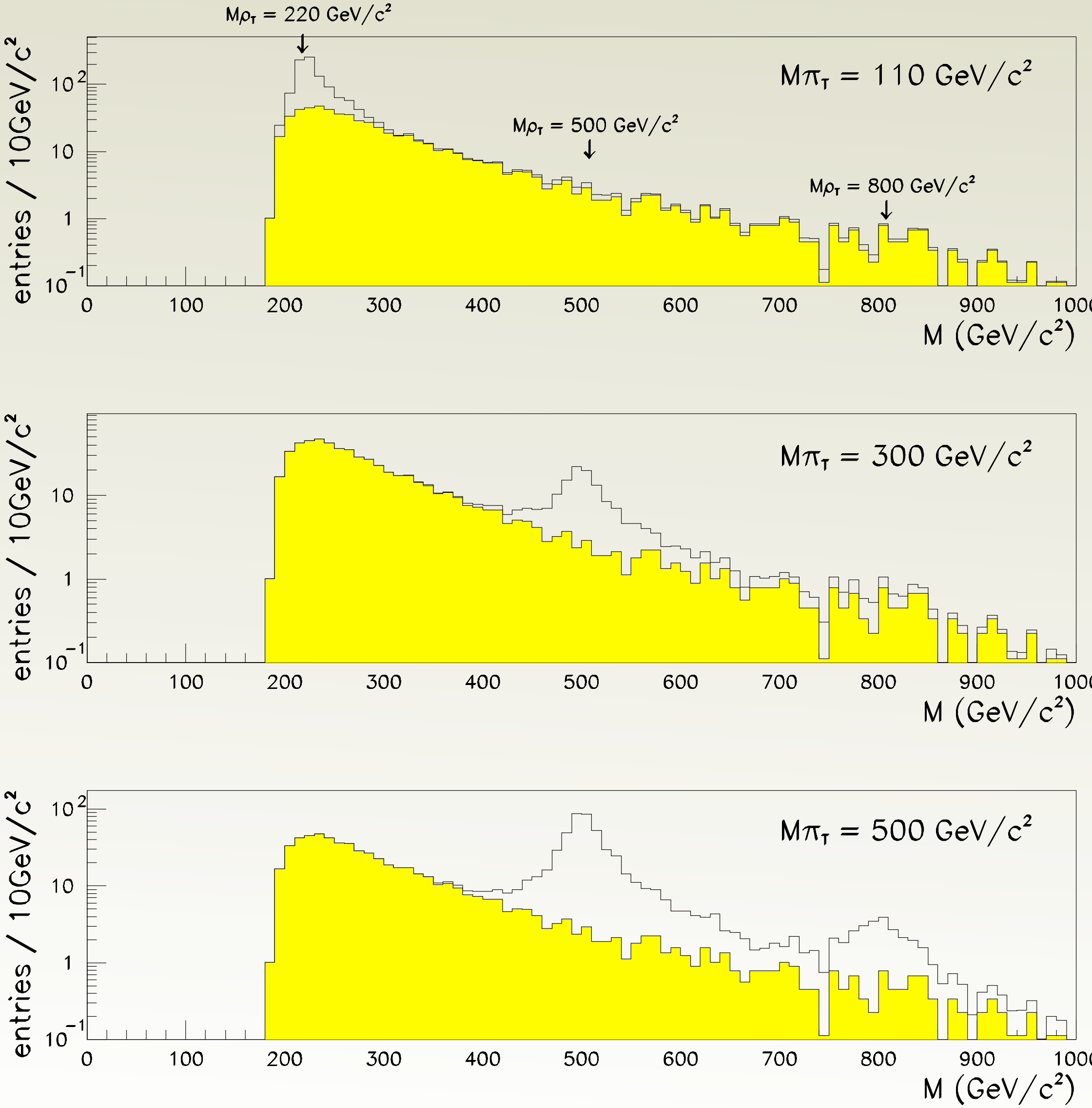
ATLAS-TDR

- **predicted by:** Dynamical SB models, technicolor
- **produced as:** from q-q annihilation
- **decay via:** boson pairs

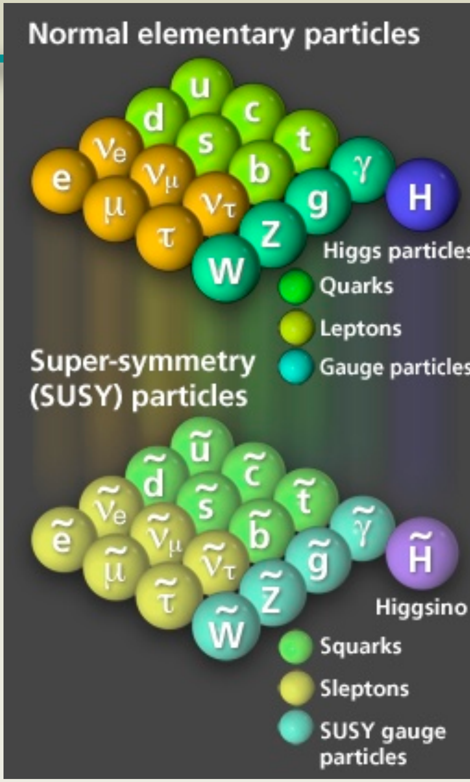


- Fast MC based study
- Scan ρ_T mass for different π_T

Discovery with 30fb^{-1} data possible depending on model parameters



New EWSB SUSY



- Give up the (so far) observed "spin" asymmetry between matter and force carriers: s-partners for all SM particles
  - solves Fine Tuning, DM.. problems
- SUSY not observed: sparticles heavy: broken symmetry
- Rich phenomenology (even with R_{parity}):
  - large # of parameters: >100 in MSSM case*
  - many SB options: MSSM, mSUGRA, GMSB, AMSB..

has 5 parameters

has 6 parameters

- Common properties:
  - cascade decays of sparticles to high p_T objects ,
  - stable LSP escapes undetected: large E_T^{miss} .

Look for: jets + E_T^{miss} and leptons +jets + E_T^{miss}

* #parameters=124 given in SN-ATLAS-2006-058

New EWSB mSUGRA

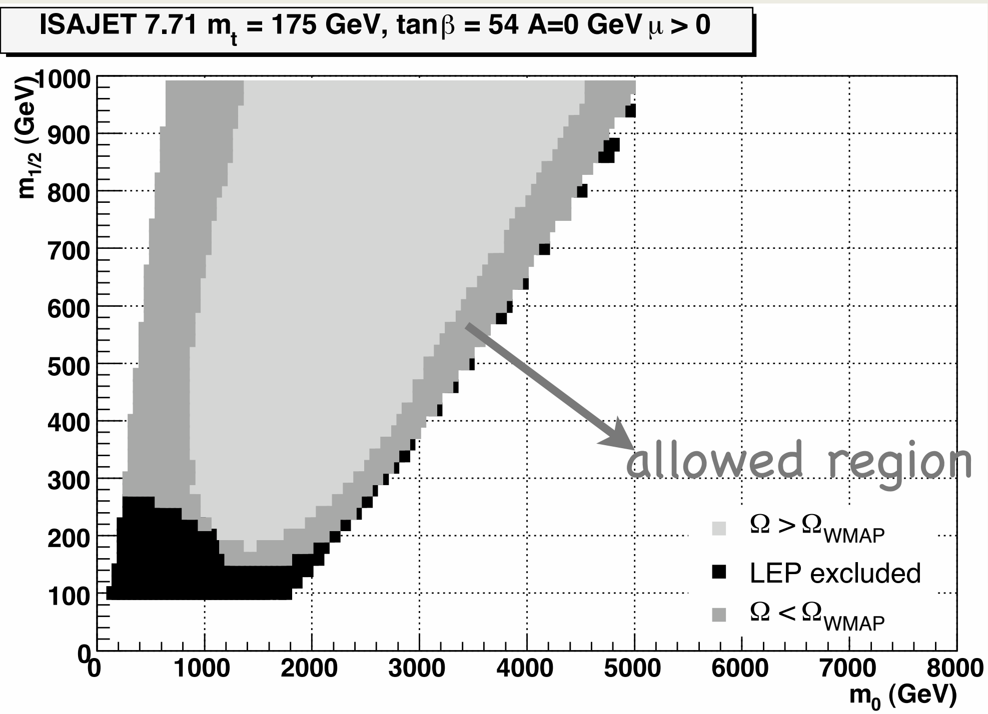
SN-ATLAS-2007-049

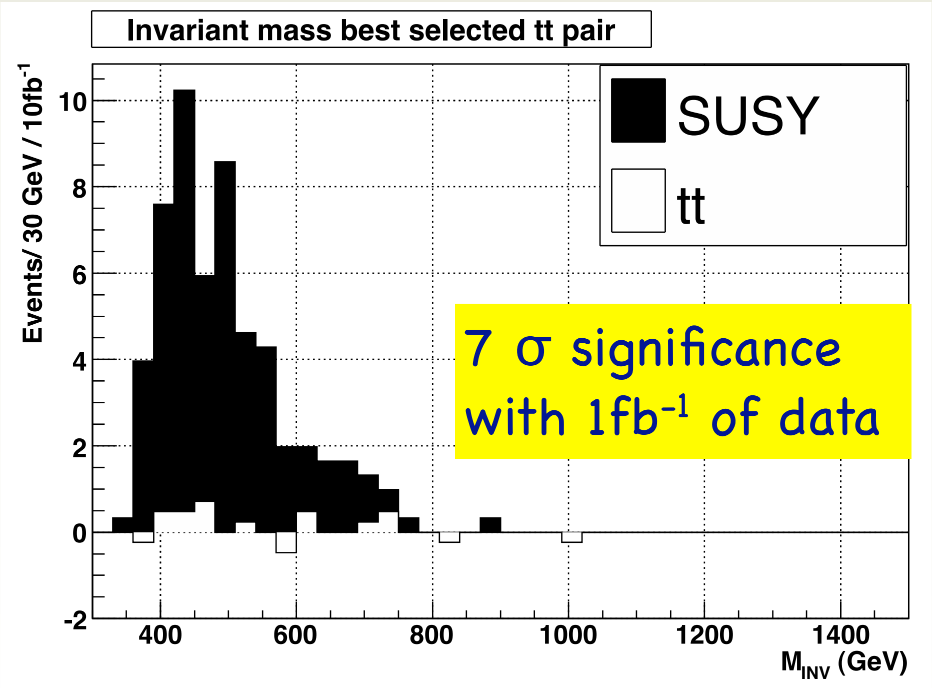
- mSUGRA's LSP is DM candidate
  - model should be consistent with WMAP data $\tilde{\chi}_1^0$
- R parity imposes pair production $pp \rightarrow \tilde{g}\tilde{g}$

$$\tilde{g} \rightarrow \tilde{\chi}^+ t\bar{b}$$
$$\tilde{g} \rightarrow \tilde{\chi}^- \bar{t}b$$
$$\tilde{g} \rightarrow \tilde{\chi}^0 t\bar{t}$$

- Fast MC based study
- $m_{1/2}$-m_0 parameter space scanned

jets + E_T^{miss}





New EWSB GMSB

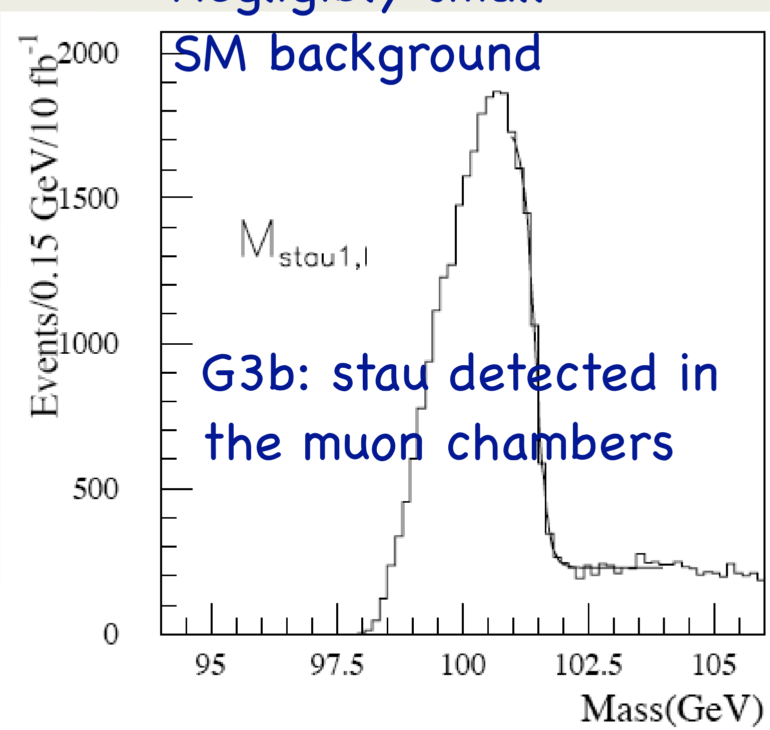
SN-ATLAS-2001-004

- Susy breaking scale close to weak scale
  - LSP is gravitino, FCNC is suppressed
- Reference points with different model parameters & NLSP
  - Fast MC based study @ G3 (NLSP is stau)
  - G3b: NLSP is quasi-stable
  - G3a: NLSP immediately decays

$$\tilde{q} \to \tilde{\chi}^0_{1,2} q \to \tilde{\ell}\ell q \to \tilde{\tau}(\tau)\ell\ell q \to \tilde{G}\tau(\tau)\ell\ell q$$

leptons +jets + E_T^{miss}

Negligibly small SM background

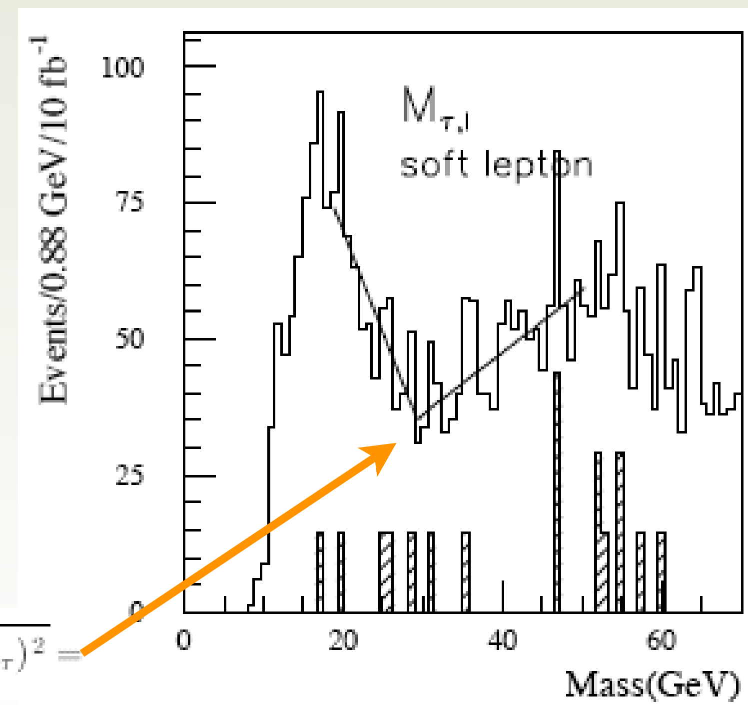


G3b: stau detected in the muon chambers

Excellent signal with few fb^{-1} in both cases

G3a: stau decays before detection but dips can be calculated & fit:

$$M_{\tau l}^{max} = \sqrt{M_{\tilde{l}_R}^2 - (M_{\tilde{\tau}_1} + M_\tau)^2} =$$



SM to BSM

Super Symmetry

Fourth Family

GUTs

Gauge G

Little Higgs

2HDMs

- *Fermions* as matter particles
  - Quarks & Leptons

new quarks | new leptons | lepto-quarks | new constituents | composite models

- *Gauge group structure*
  - gauge bosons as force carriers

new gauge bosons

- *EW* Symmetry Breaking
  - mass via Higgs bosons

new scalars | new EWSB

Dynamical Symmetry Breaking

Technicolor

- 3+1 space-time

new dimensions → Dynamical Symmetry Breaking

new dimensions → ADD Models

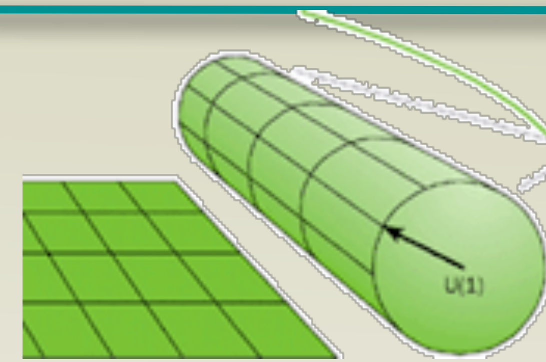
RS Model

ADD Models

some ED concepts

- **Large Extra Dimensions (LED, ADD):**
  - compactified, flat
  - $M_{Pl}^2 \sim R_n M_S^{2+n}$, M_S: string scale
  - Graviton in bulk

Arkani-Hamed, Dimopoulos, Dvali
Phys Lett B429 (98)

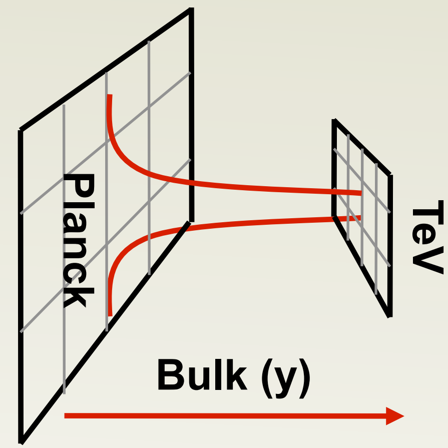


- **TeV-1 ED (DDG):**
  - M_C : compactification scale
  - Gauge & Higgs bosons in bulk as well

Dienes, Dudas, Gherghetta
Nucl Phys B537 (99)

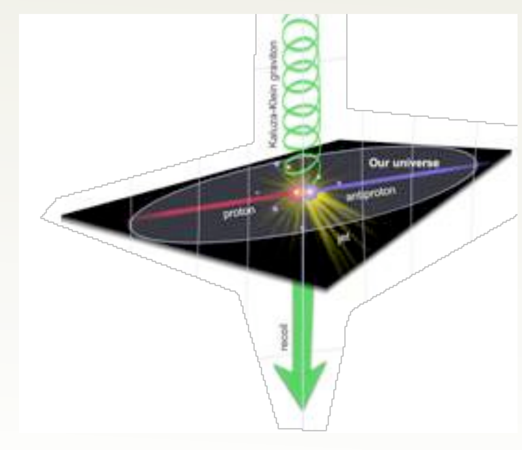
- **Warped Extra Dimensions (RS):**
  - 2-branes solution: RS type1
  - k/MPl, k: curvature, warp factor
  - narrow spin-2 resonances: Graviton

Randall, Sundrum
Phys Rev Lett 83 (99)



- **Universal Extra Dimensions (UED):**
  - KK-number conservation
  - M_C and cut-off scale Λ
  - All SM particles in the bulk
  - Lots of KK spectra (similar to SUSY signatures)

Appelquist, Cheng, Dobrescu
Phys. Rev. D 64 (01)



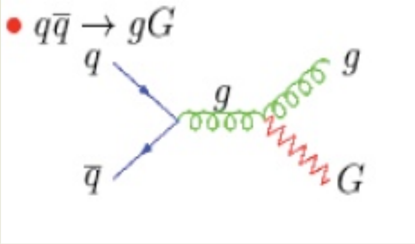
G^{ab}, n, M_C, R : model parameters

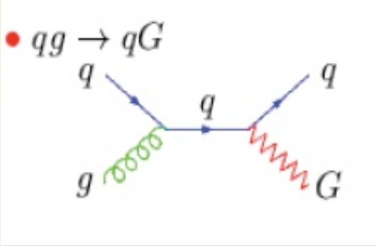
EDs graviton

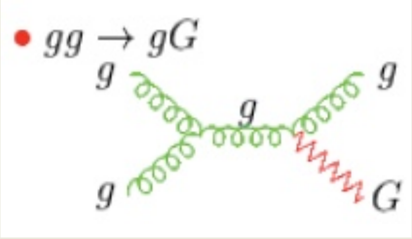
SN-ATLAS-2001-005

- predicted by: all ED models
- produced as: from q-q annihilation, q-g/g-g fusion
- decay via: - (stable)

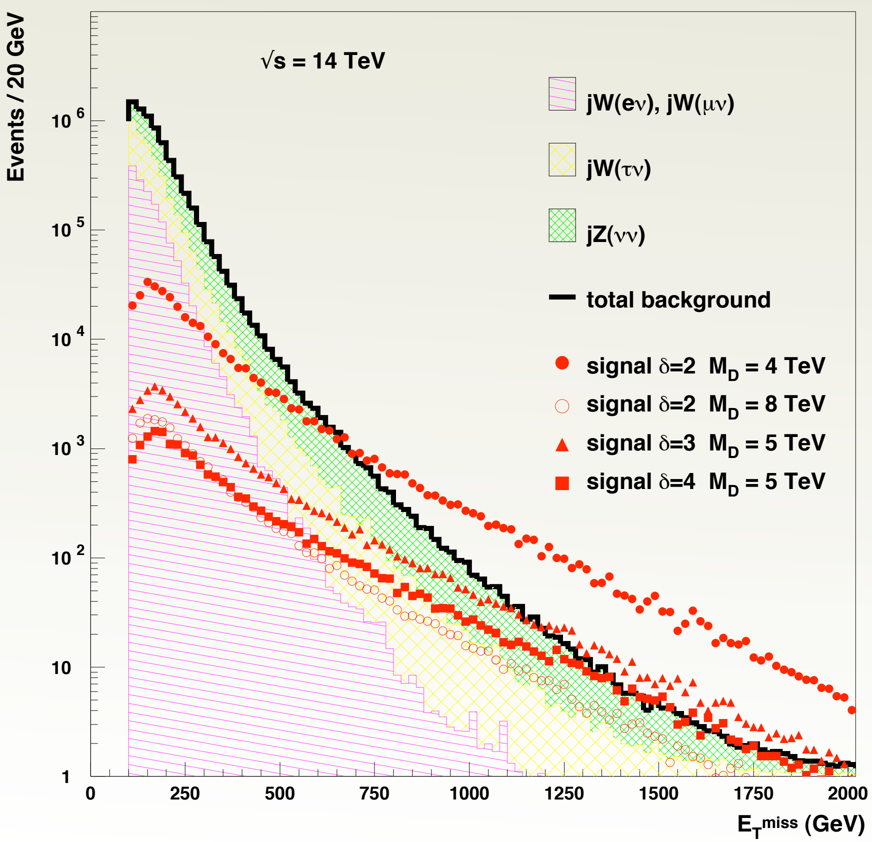
$$gg/gq/q\bar{q} \longrightarrow gG$$

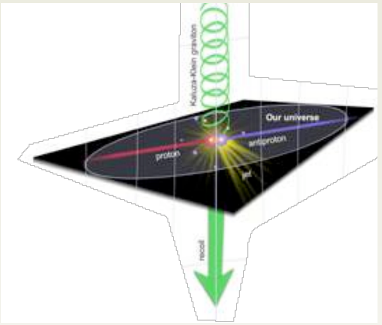






- Fast MC based study
- #EDs=2,3,4 & ED scale scanned





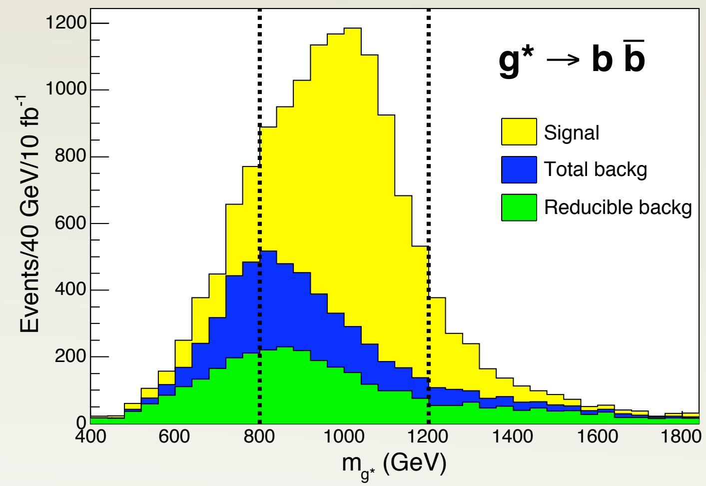
$M_{Pl(4+d)}^{MAX}$(TeV)	δ=2	δ=3	δ=4
$30fb^{-1}$	7.7	6.2	5.2
$100fb^{-1}$	9.1	7.0	6.0

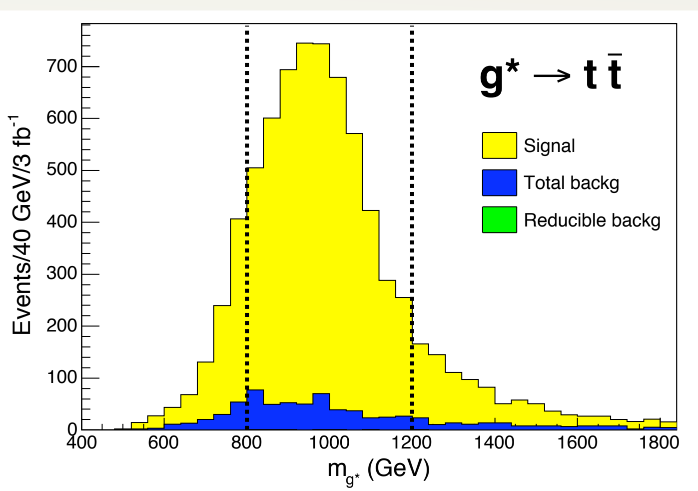
EDs Excited gluons

SN-ATLAS-2006-002

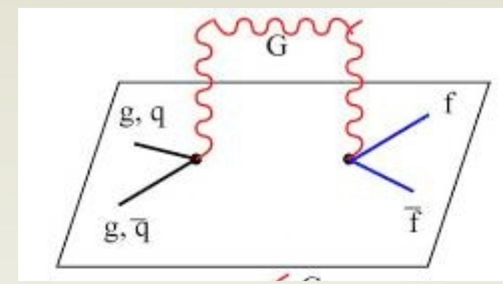
- **predicted by:** TEV^{-1} EDs (DDG)
- **produced as:** from q-q annihilation
- **decay via:** heavy quark pairs

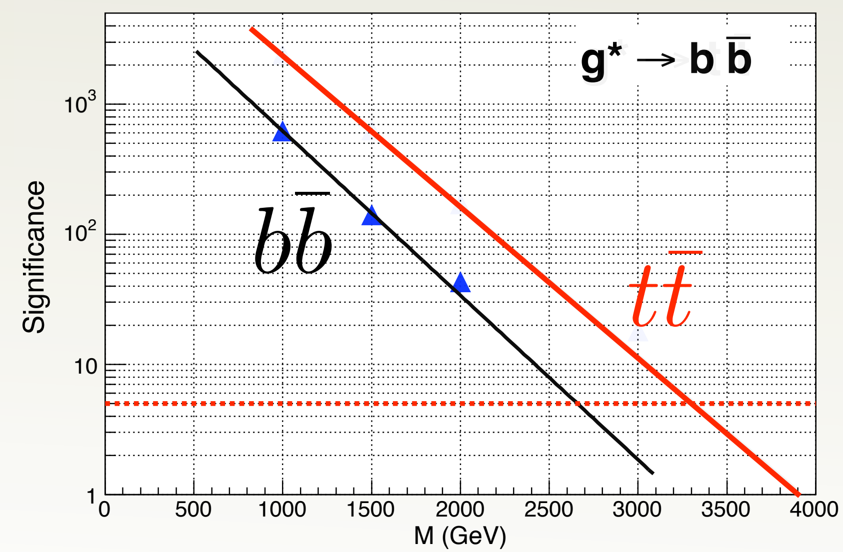
$$q\bar{q} \longrightarrow g^* \longrightarrow t\bar{t}$$
$$\longrightarrow b\bar{b}$$





- Fast MC based study
- g* mass scanned [1..3] TeV





300 fb^{-1} allows reaching 3.3 TeV with 5σ

Warped Extra Dimensions

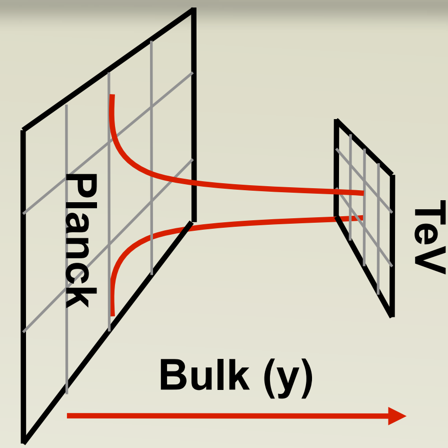
Randall Sundrum (Type I)

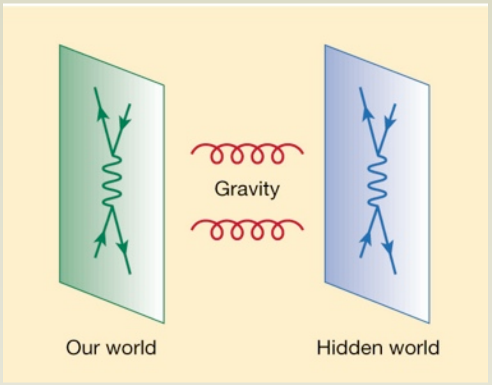
- Brane metric scales as function of bulk position
- Coupling constant:

  $c = k/M_{Pl}$, k: curvature scale

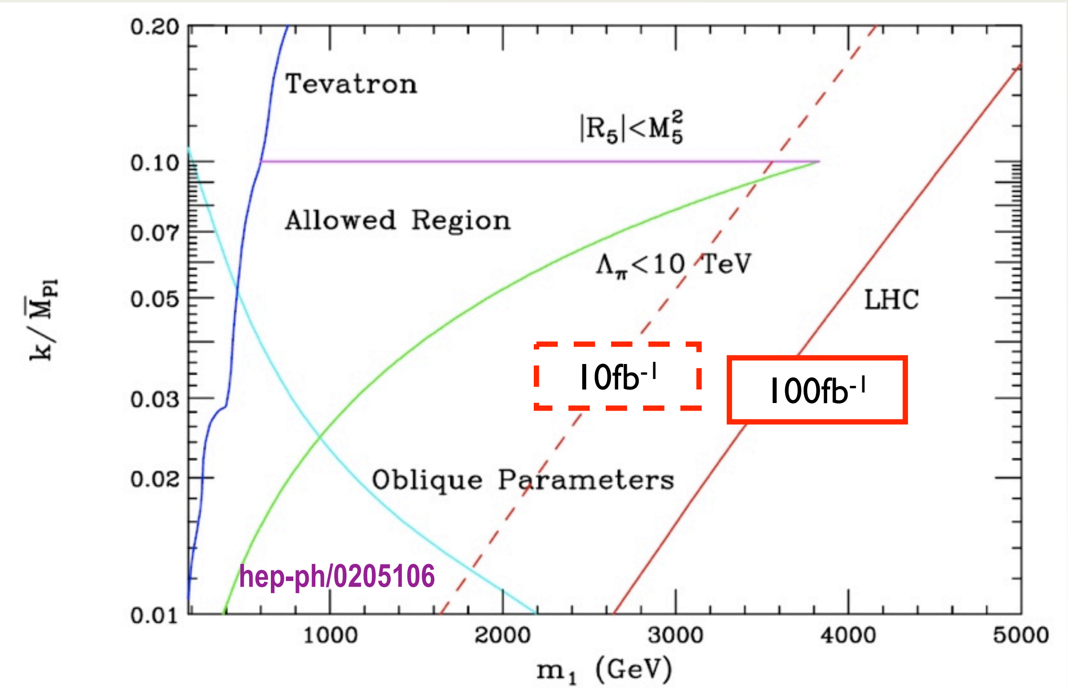
- Well separated narrow-width graviton mass spectrum with masses

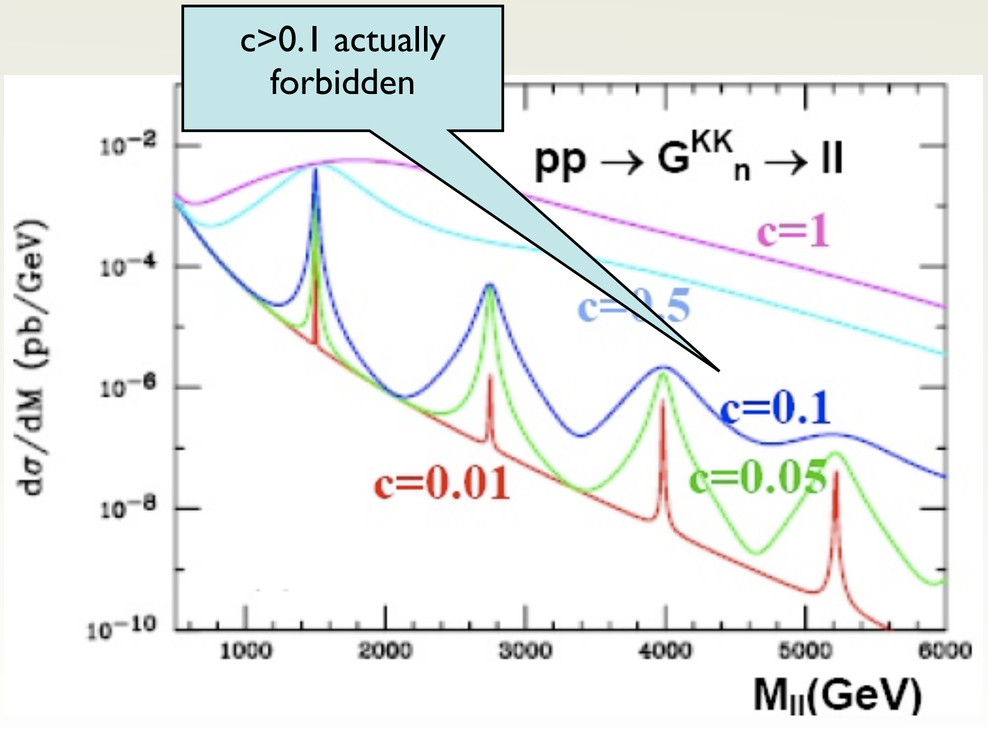
  $m_n = k x_n e^{krc\pi}$ ($J_1(x_n)=0$)



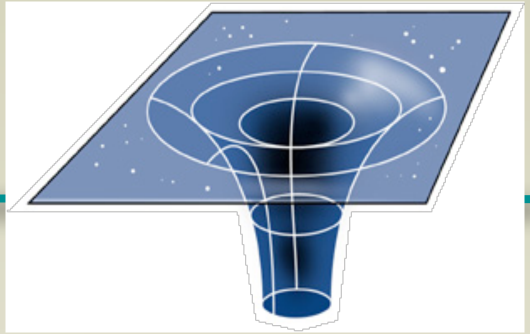


$$ds^2 = e^{-2ky}\eta_{uv}dx^u dx^v - dy^2$$

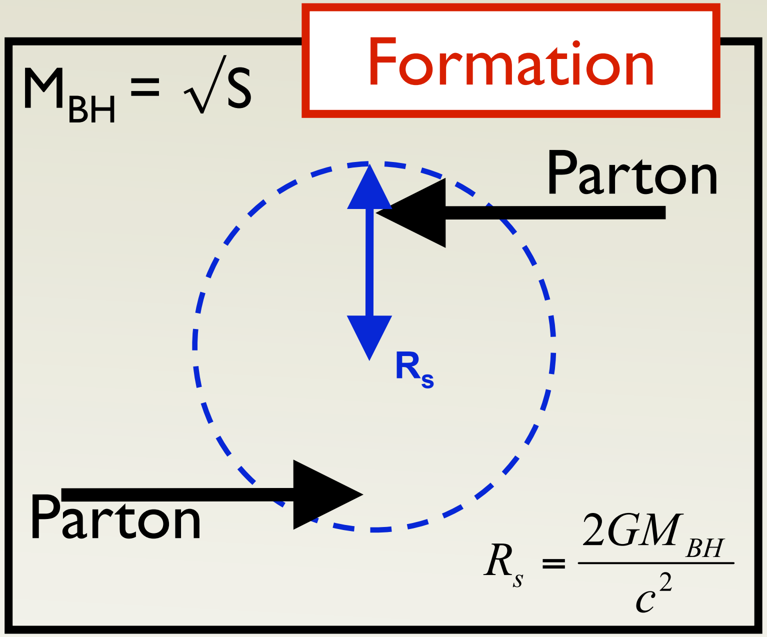




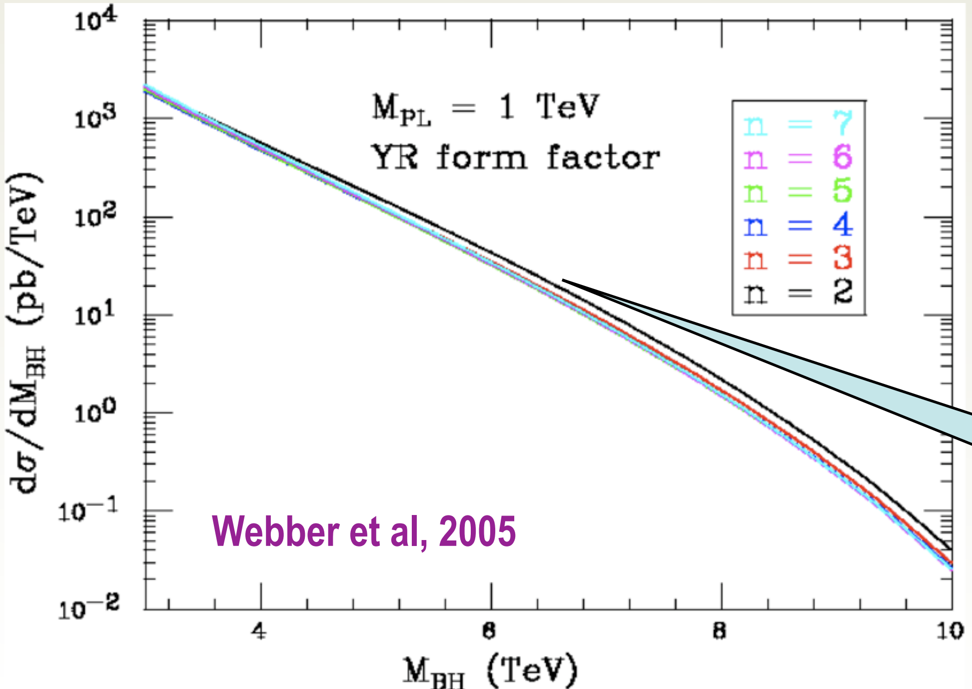
μ-Blackholes



- Arise from models with ED
- Could be produced when $E_{CM} > M_{Pl}$
- Need QT of gravity as M_{BH} approaches M_{Pl}
- $\sigma \sim \pi R_S^2 \sim 1\ \text{TeV}^{-2} \sim 10^{-38}\ \text{m}^2 \sim O(100)\text{pb}$
- LHC could be a Black Hole Factory with rates as high as 1Hz.



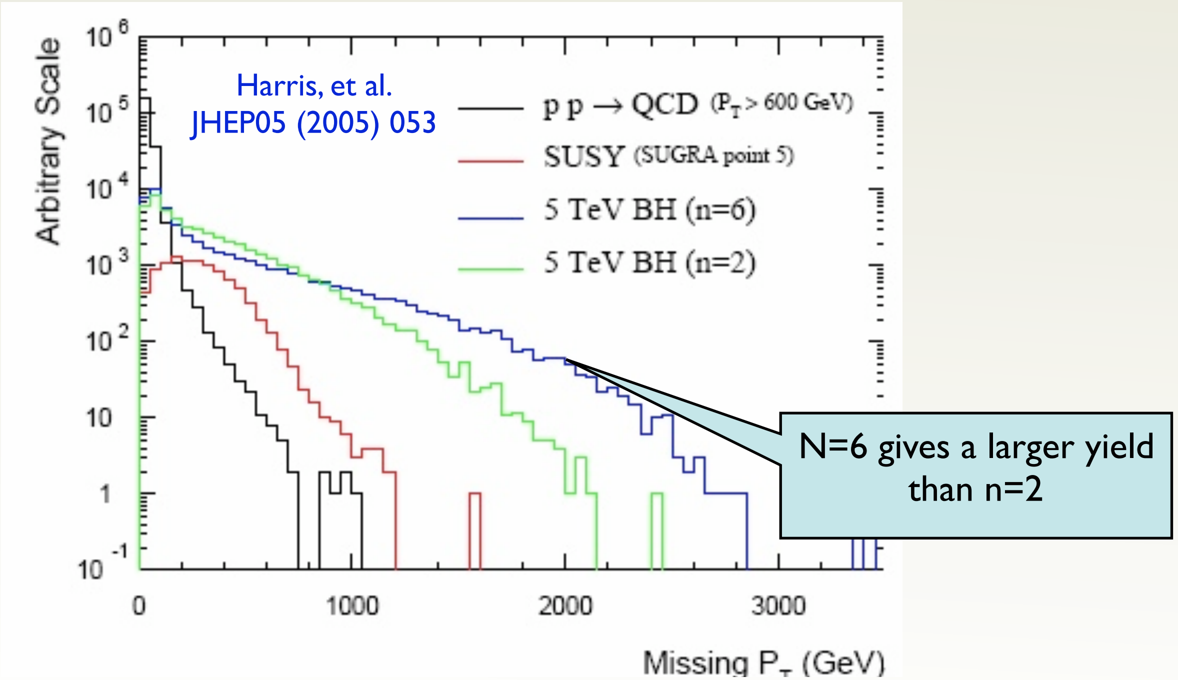
If the impact parameter of a 2-parton collision < Schwarzschild radius R_s, then a black hole with M_{BH} is formed.



BH from LED, possible from RS as well

μBH Detection

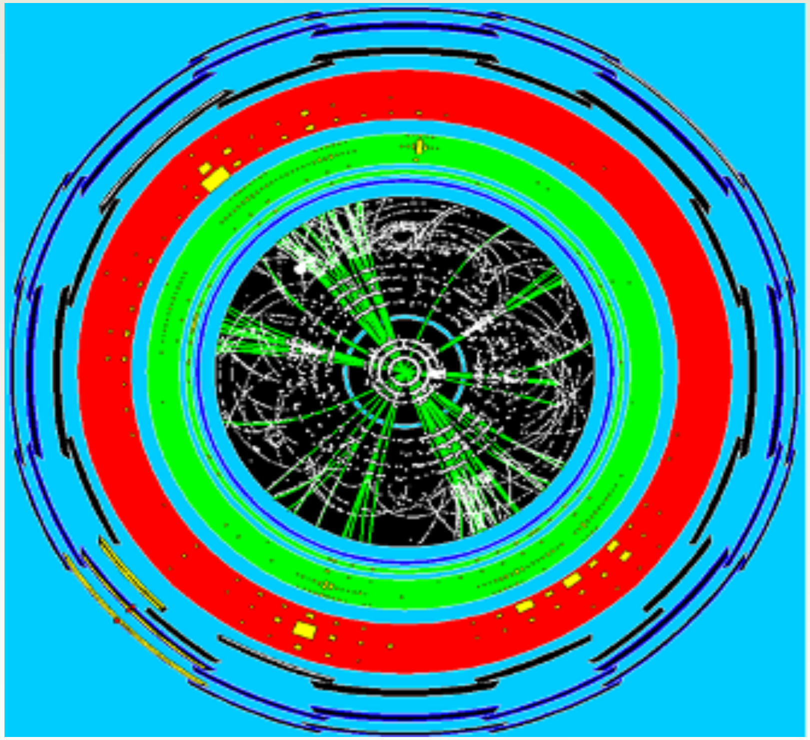
- BH lifetime ~ 10^{-27} – 10^{-25} seconds!
- Decays with equal probability to all particles via Hawking Radiation (roughly a blackbody spectrum)
- evaporates into (hadron : lepton)= (5 : 1) accounting for t, W, Z and H decays



Giddings, Thomas PRD65(2002)056010

- Distinguishing features
  - High Multiplicity, ΣE_T, Sphericity, MP_T
  - Democratic Decay

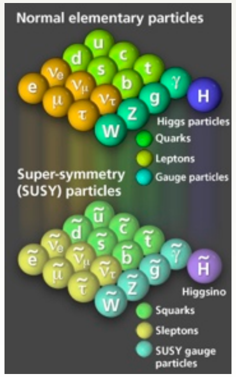
6.1 TeV M_{BH} | Decay

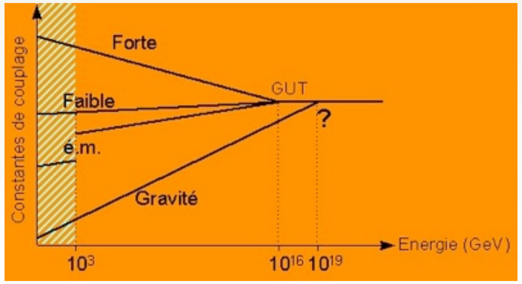


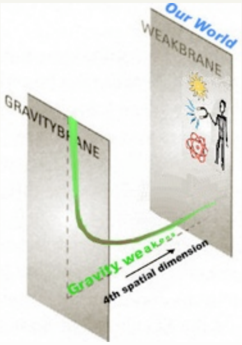
J. Tanaka , "Search for Black Holes", 24/05/03 Athens

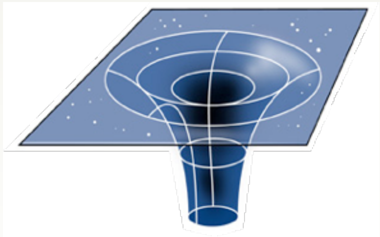
Summary

- LHC experiments have very rich discovery potential for BSM physics.
- Concentrated on a small selection of BSM possibilities;
  - some models (e.g. micro BHs) not mentioned,
  - differentiation between models not shown,
  - boost to standard searches from BSM physics not shown.
- Only summary results shown
  - From scientific or pub notes, mostly published
  - Mostly from Fast MC simulation results (next week more on MCs)
- Experiments will tell us which model is closer to the truth





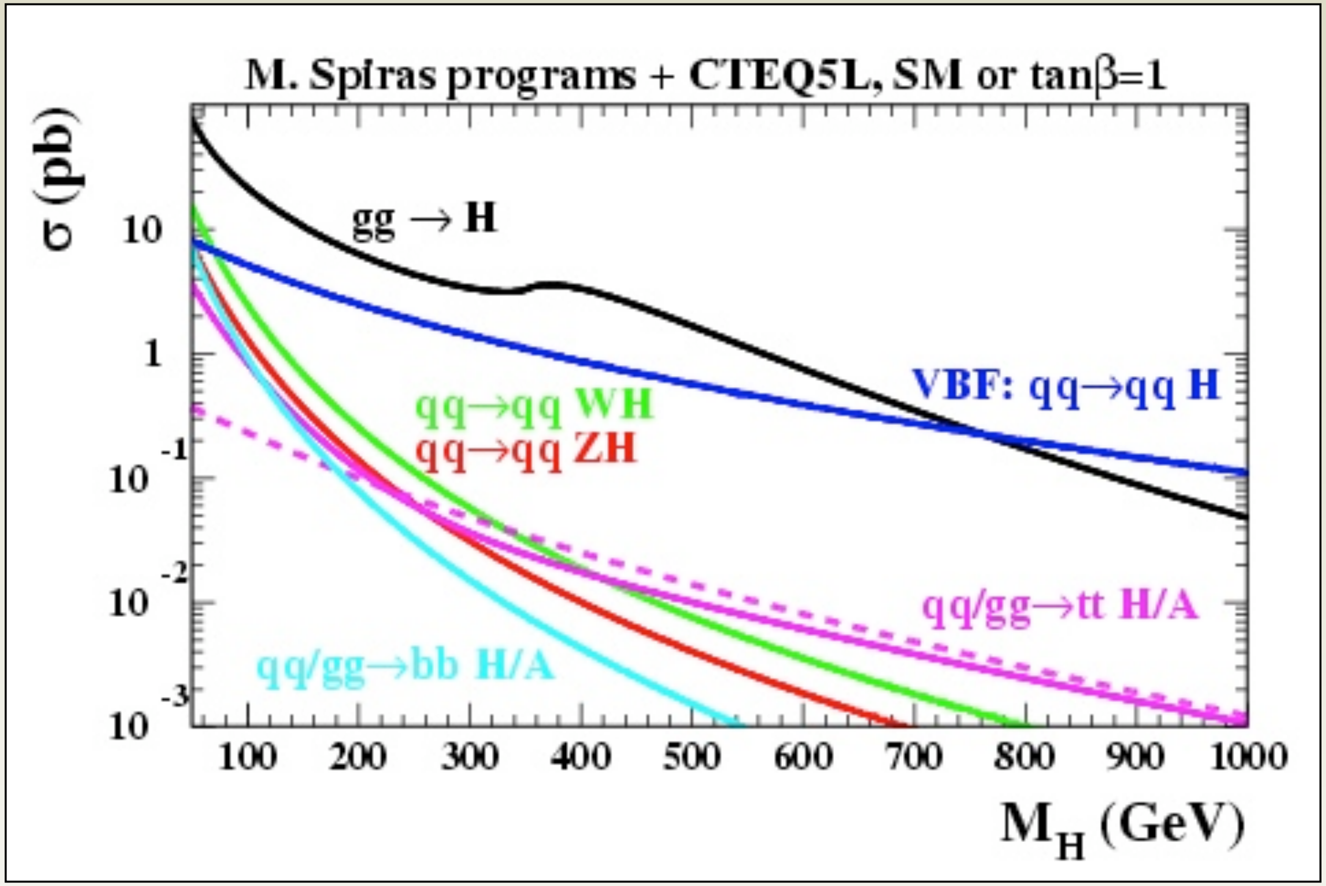




?

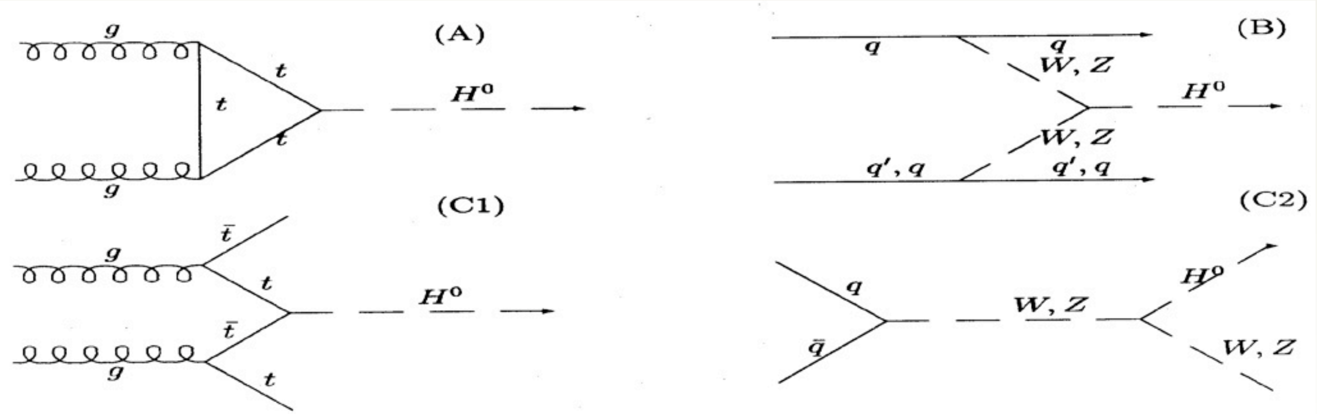
- Back up slides:
  - a few slides about Higgs Searches
  - a few words about susy

Higgs production



gg fusion

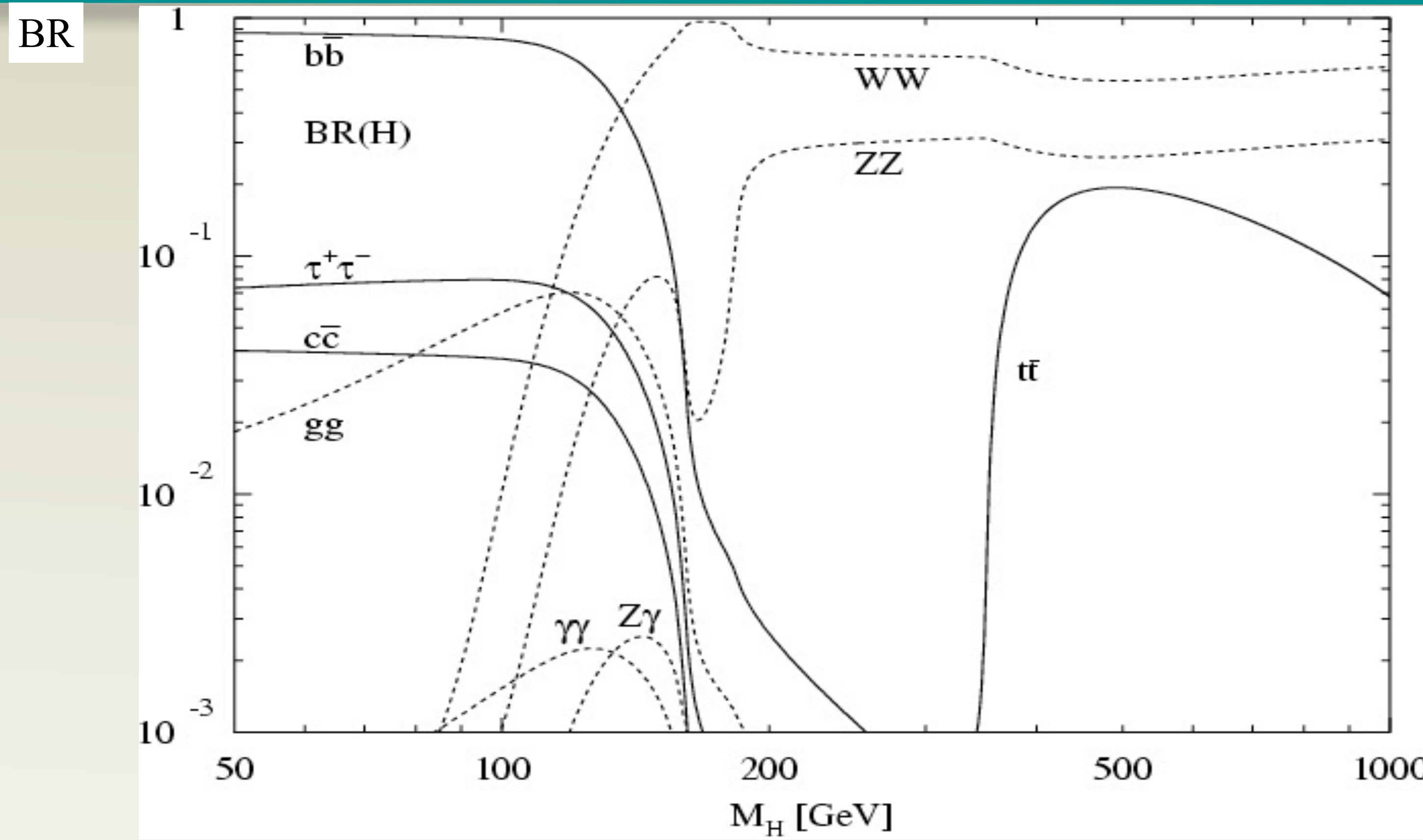
associated ttH



VBF WW/ZZ fusion

associated WH, ZH

Higgs decay



Low mass

- H → γγ
- ttH, H → bb
- qqH, H → ττ VBF

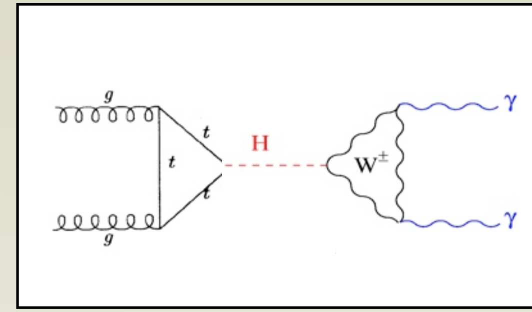
High mass

- H → ZZ (*), Z → 4 ℓ Golden discovery channel
- qqH, H → WW(*) VBF

Low mass searches

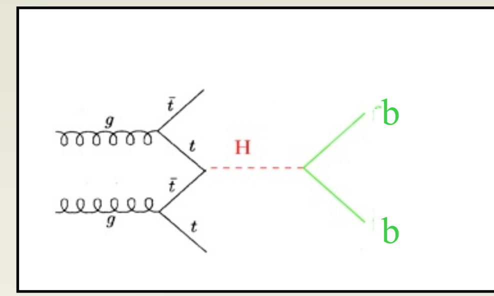
1. H→ **γγ** S/B ~$_{10}^{-2}$ despite BF~10^{-3}

H → γγ



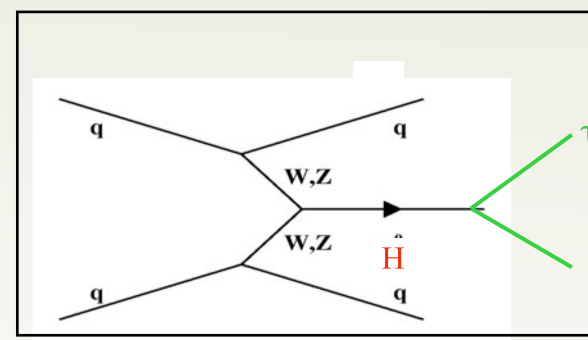
2. ttH (WH,ZH) with H → bb (b-tagging, 4 b-jets)
   DIFFICULT due to systematic errors

ttH → tt bb → bℓν bjj bb



3. qqH → qq**ττ** **VBF** : jets over $|\eta| < 5$ forward jet tag +
   central jet veto for τ ID

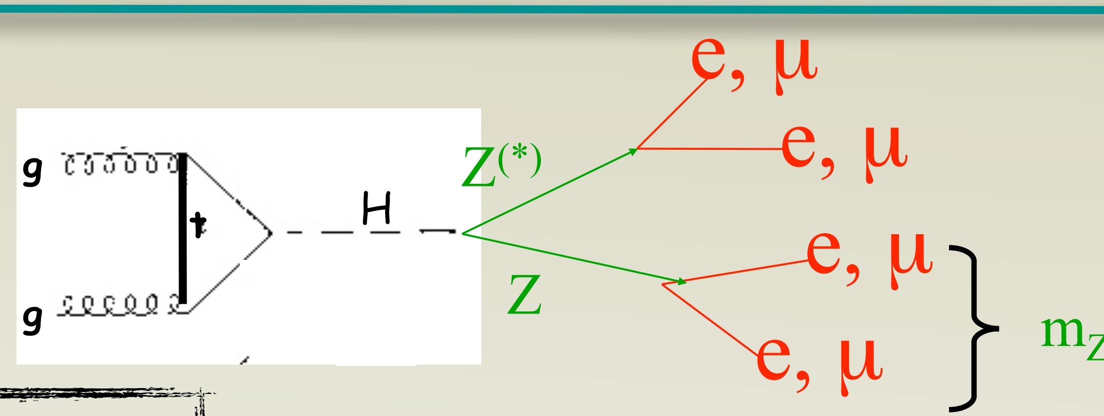
qqH → qqττ

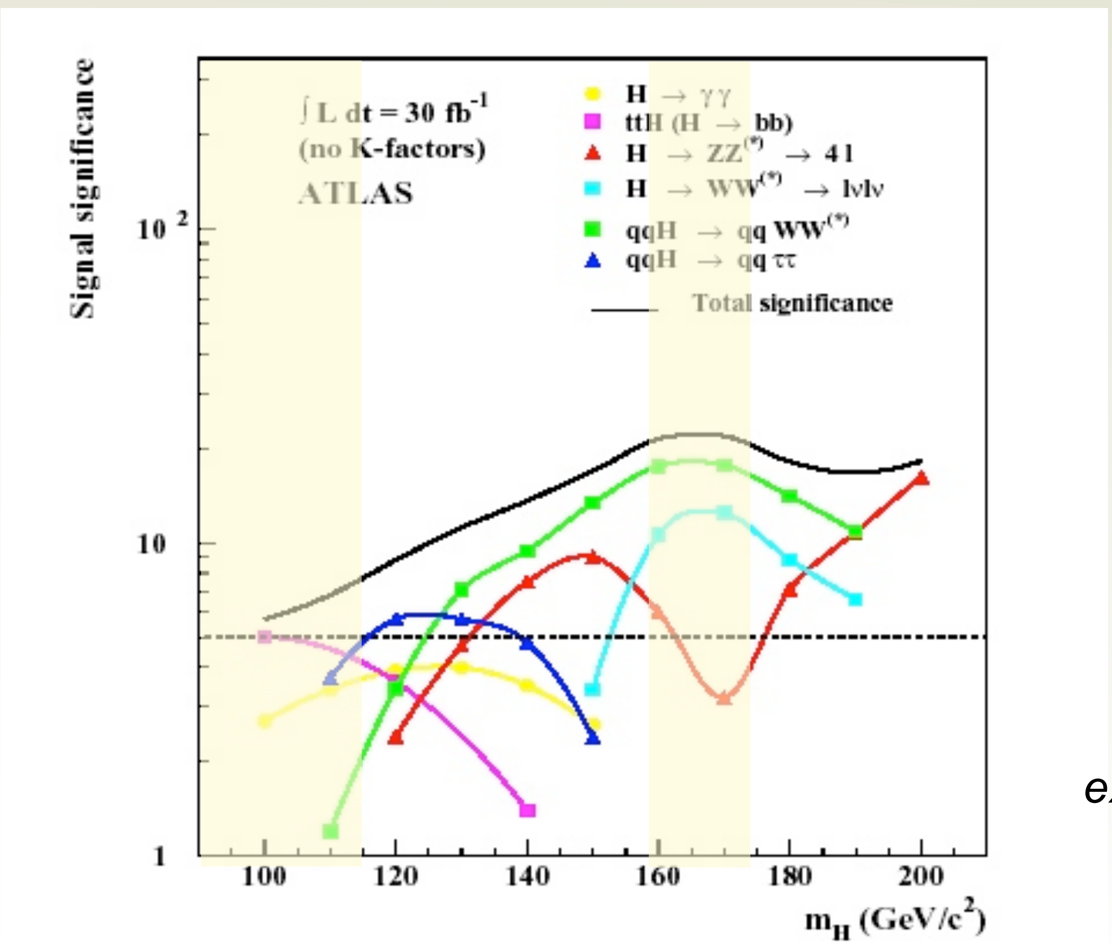


The golden channel

$130 \leq m_H < 700$ GeV

$H \rightarrow ZZ^{(*)} \rightarrow 4$ leptons



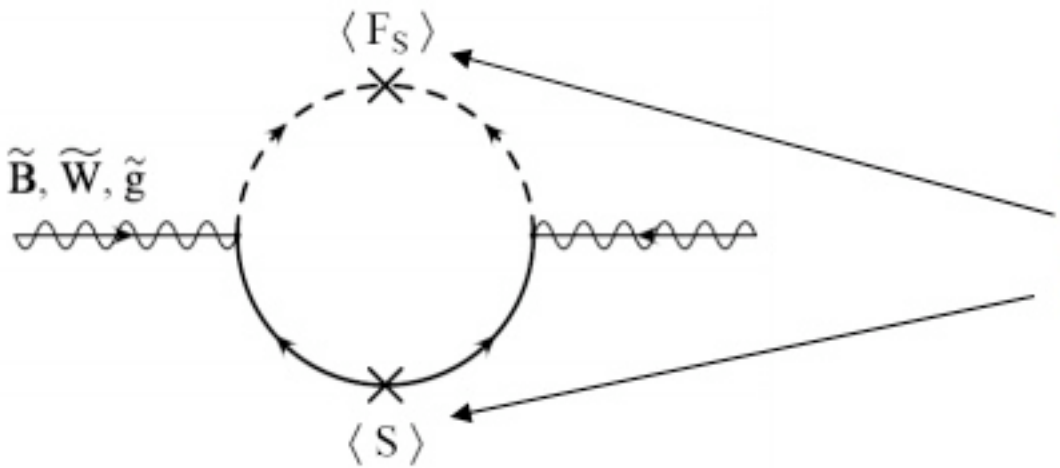


Discovery with less than 10 fb^{-1} for $130 < m_H < 160$ GeV, $2m_Z < m_H < 550$ GeV

combining various channels for m_{Higgs}<200GeV

exclusion from LEP and Tevatron shown in shaded areas

GMSB susy



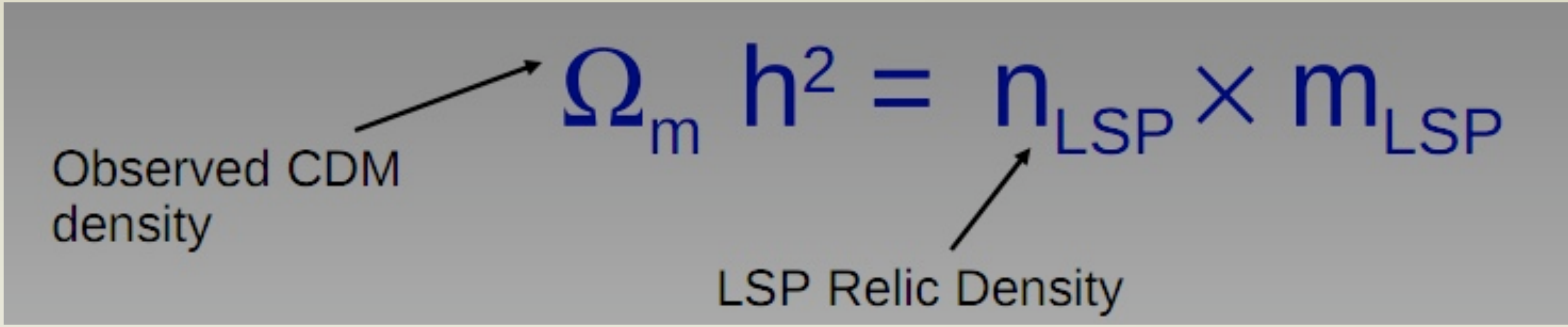
Masses of the gauginos are produced via couplings to a massive messenger sector

Parameters (general model has 124):

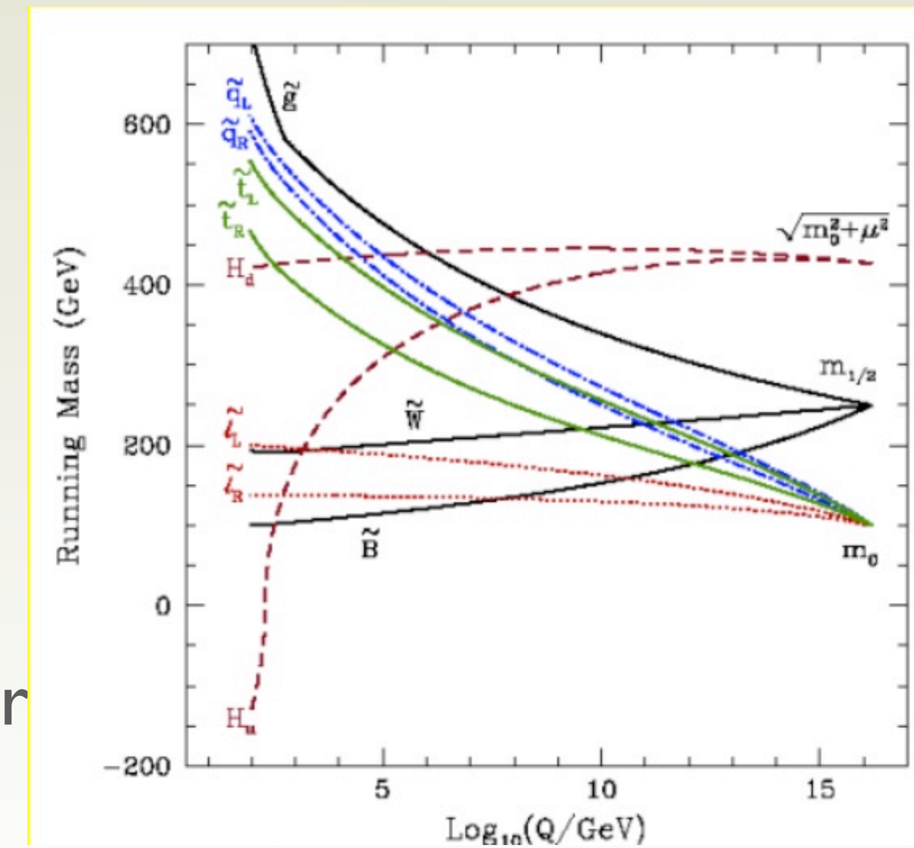
- → Λ: Breaking scale
- → M: Mass scale of the messengers
- → tanβ: Ratio of Higgs vacuum expectation values
- → N: Number of messenger chiral supermultiplets
- → sign(μ): Sign of the Higgs mass parameter
- → C_{grav}: Scale factor of the Gravitino mass → lifetime of NLSP

REF: Mark Terwort

mSUGRA



- 5 Parameters
  - m_0 : scalar mas
  - $m_{1/2}$: gaugino mass
  - A0 : H sf sf couping const.
  - tanβ : vev ratio of 2 Hs
  - sgn(μ) : sign of H mass parameter



Ref: Gilly Elor and Andre Bach