Beyond the SM studies with ATLAS

Gökhan Ünel
(U.C.Irvine & CERN)
for the ATLAS Collaboration

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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 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

- *Fermions* as matter particles
  - Quarks & Leptons

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

GUTs

Gauge G

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

new gauge bosons

Little Higgs

2HDMs

- *EW Symmetry Breaking*
  - mass via Higgs bosons

new scalars | new EWSB | Dynamical Symmetry Breaking | Technicolor

- 3+1 space-time

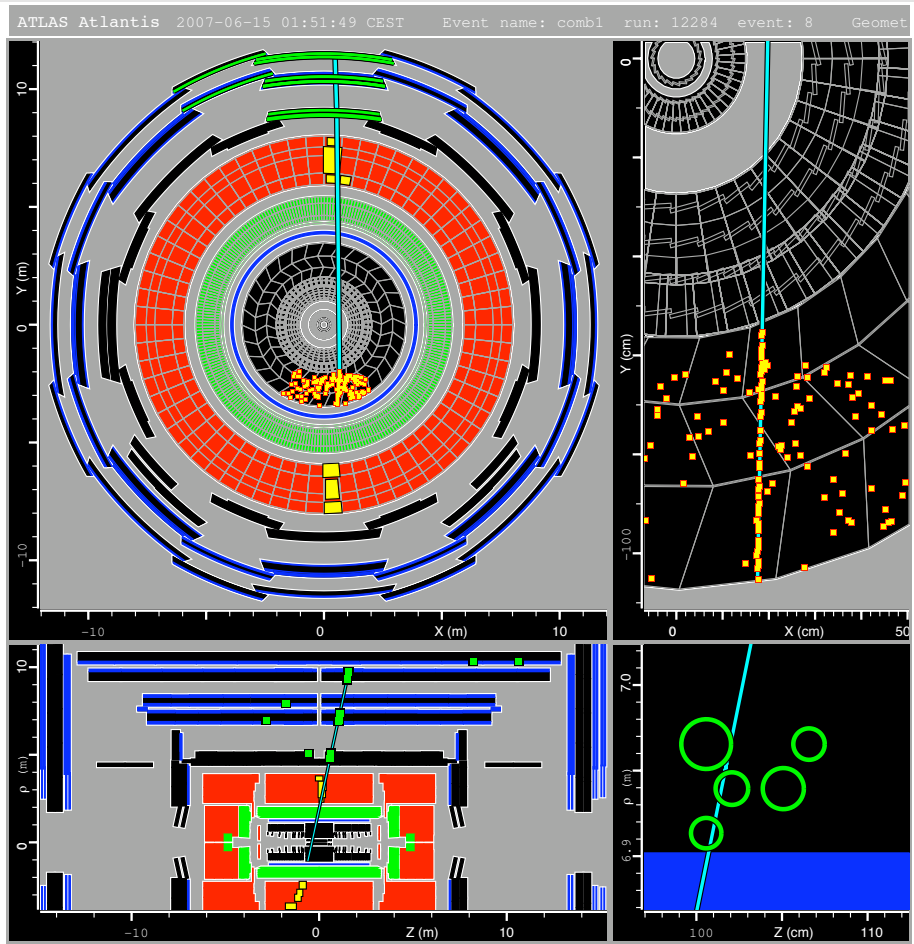
new dimensions | RS Model | ADD Models

disclaimer:

For the rest of the talk, a search based approach will be followed.

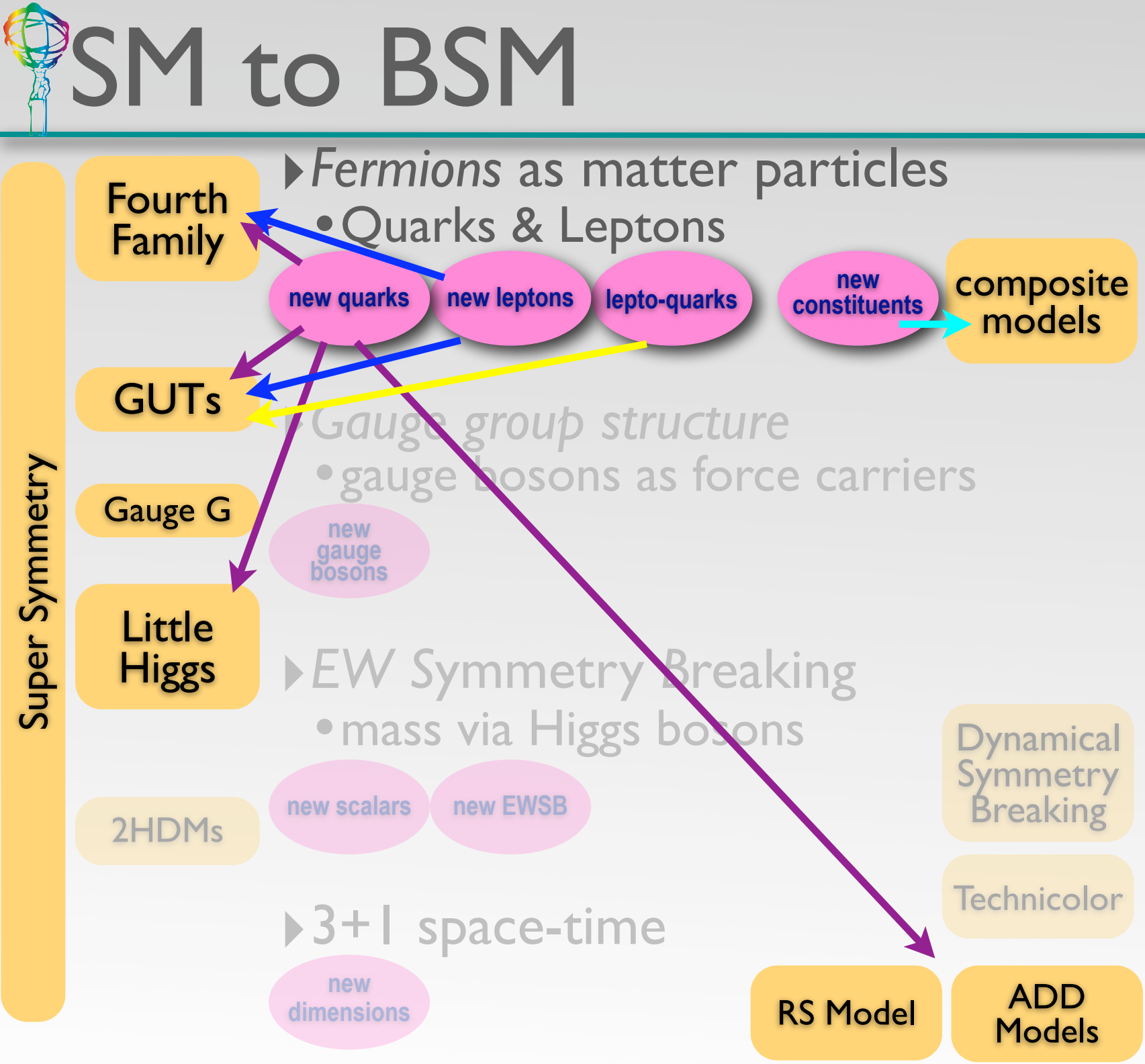
Gearing up

- LHC at $\sqrt{s}$=14 TeV starts in 2008
  - aims to reach 100 fb^{-1}/yr *at 2010*
- ATLAS detector installation & commissioning ongoing
  - Preparations with technical and cosmic runs



ATLAS experiment will provide unprecedented opportunity to probe the BSM physics

SM to BSM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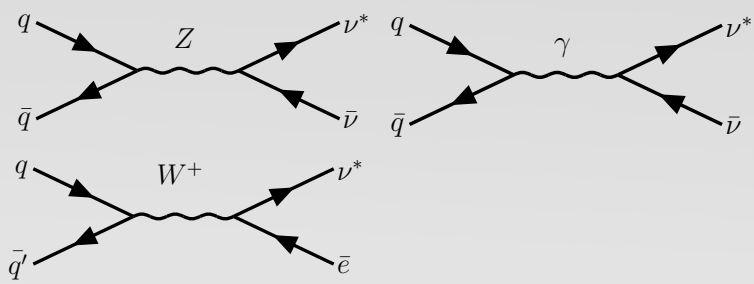
3+1 space-time
new dimensions
RS Model
ADD Models

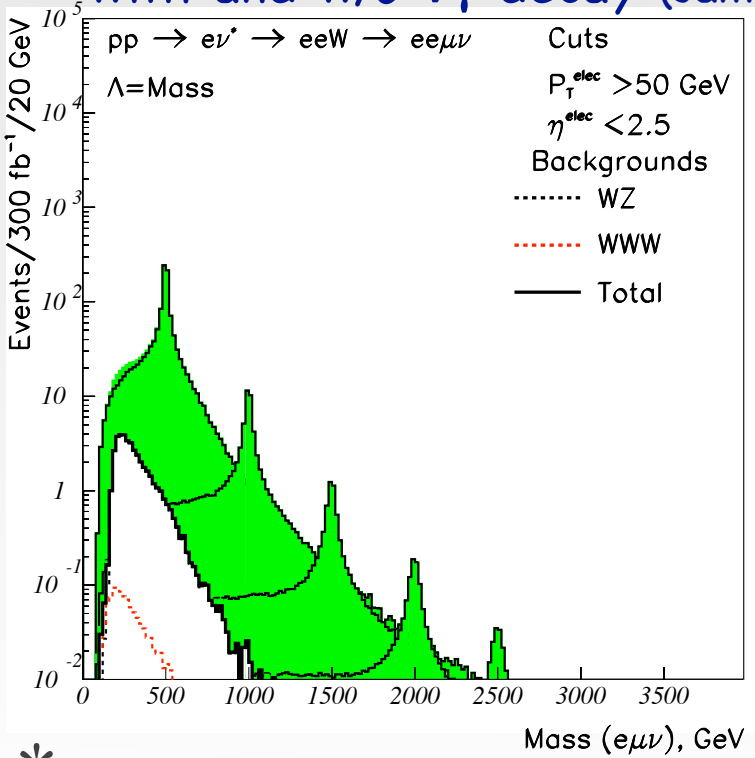
New constituents excited νs*

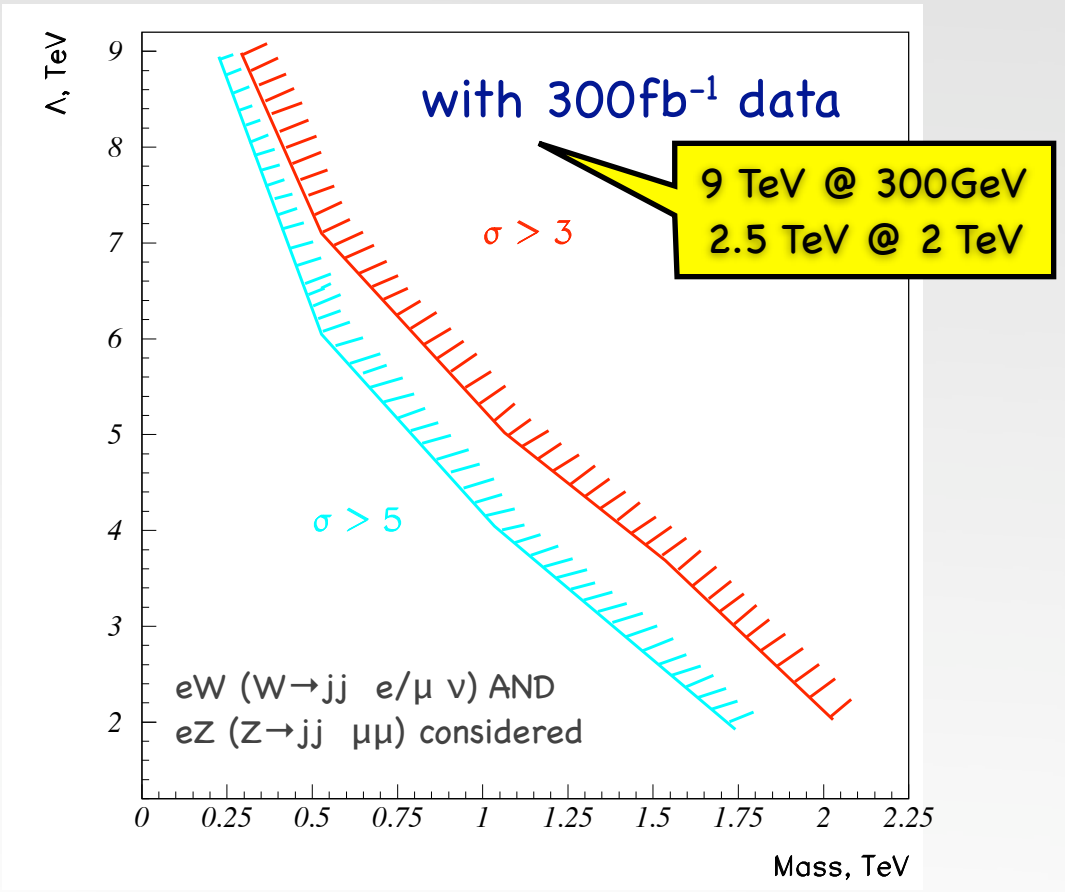
SN-ATLAS-2004-047

- 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)



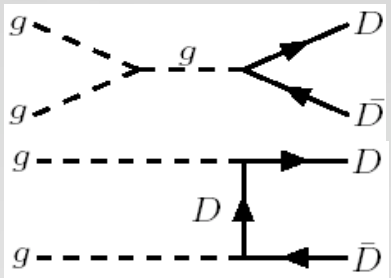


other excited fermions (e,q*) also studied in earlier works but not reported here.

New quarks q=-1/3 singlets

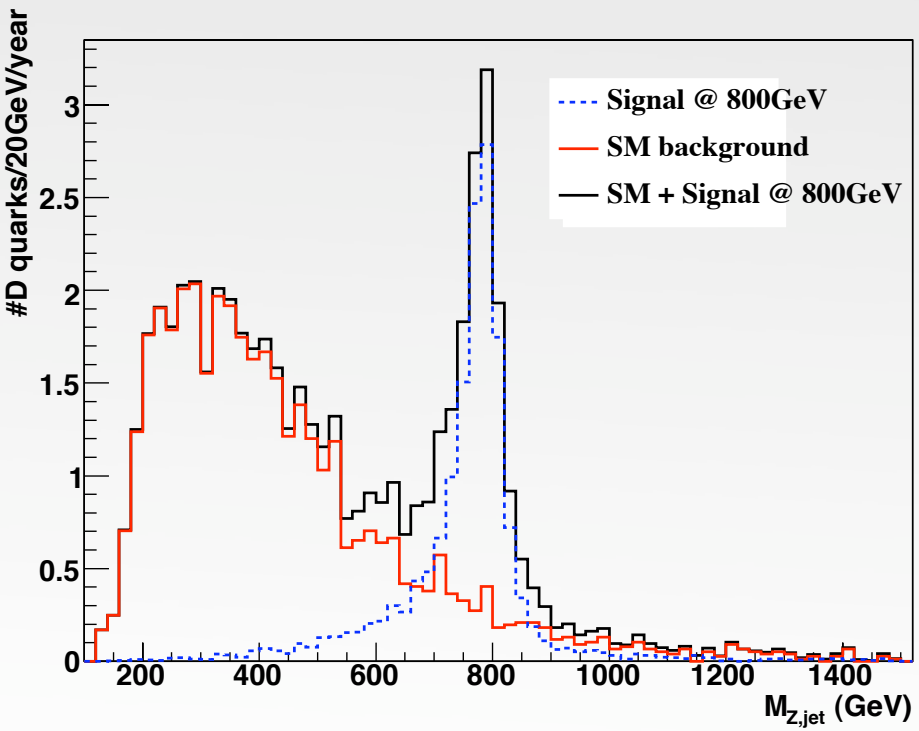
SN-ATLAS-2006-056

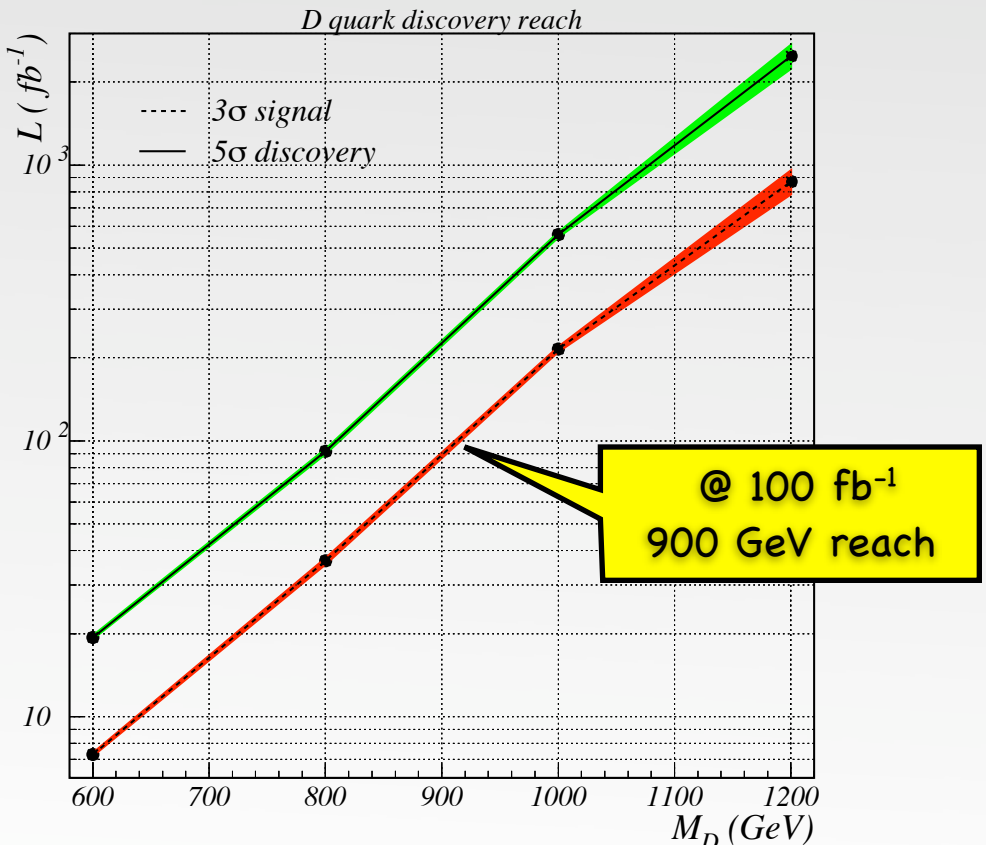
- predicted by: E_6 GUT
- produced as: pairs from gluon (quark) fusion
- decay via: boson + light jet



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

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





New quarks q=2/3 singlets

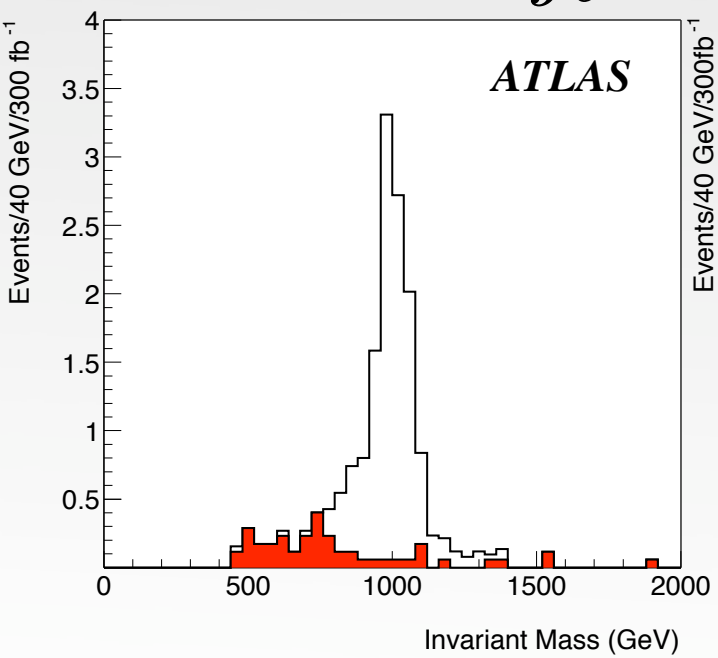
SN-ATLAS-2004-038

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

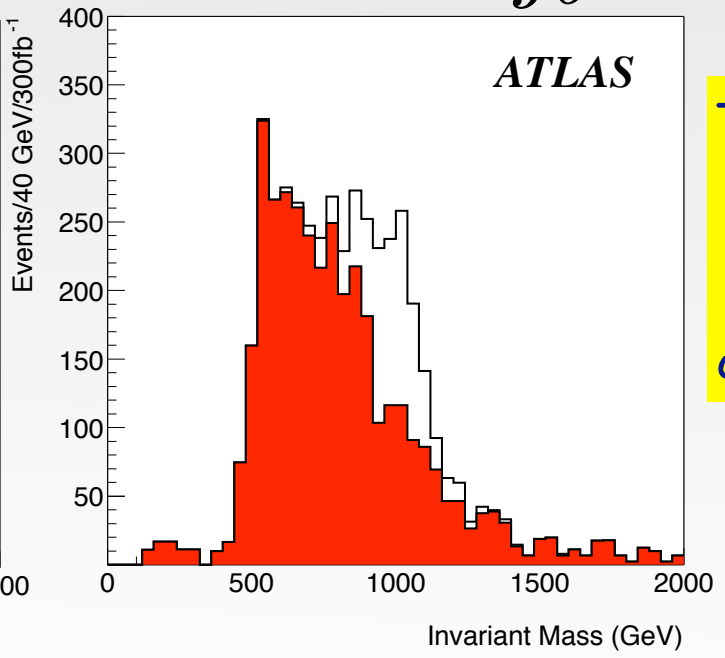
$$qb \rightarrow q'T \rightarrow q'\,Wb \quad (ht, Zt)$$

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

$$Zt \rightarrow \ell\ell\ell\nu j_b$$



$$Wb \rightarrow \ell\nu j_b$$



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

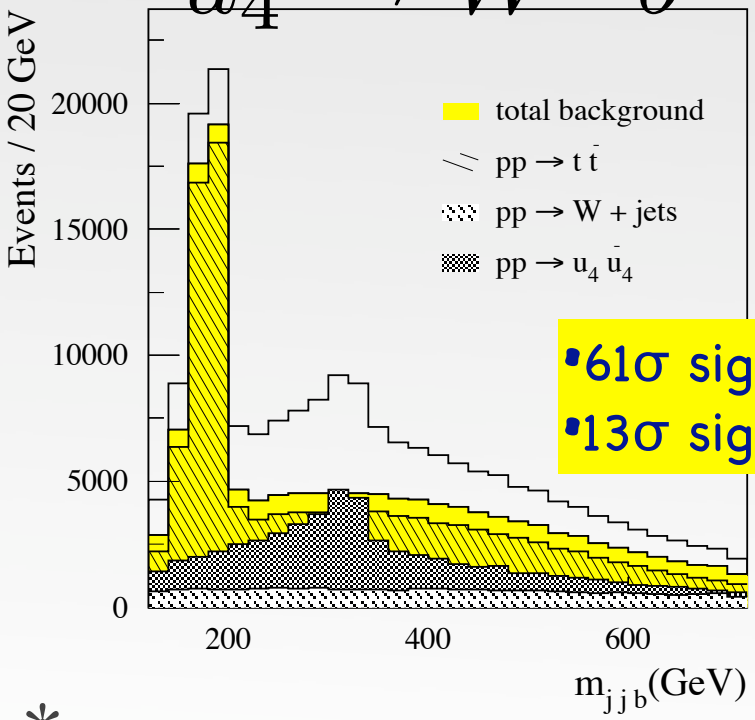
ATLAS-TDR*

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

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

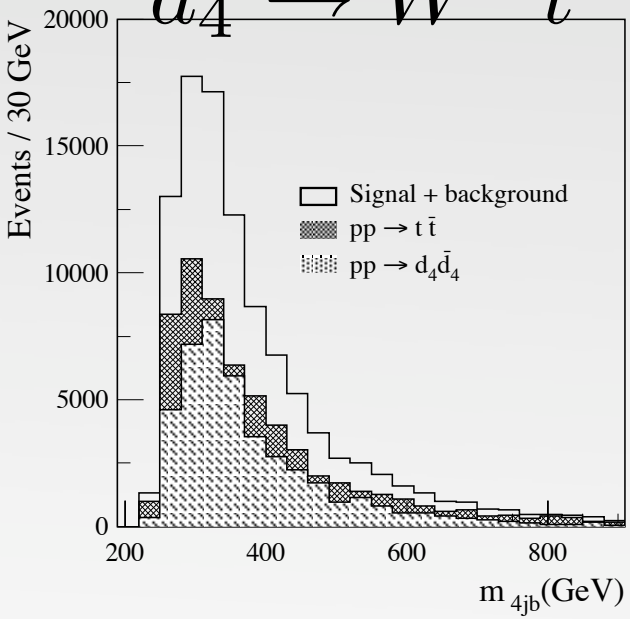
- Fast MC based study
- scan new quark mass
- results for 100 fb^{-1} shown

$$u_4 \longrightarrow W^+ b$$



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

$$d_4 \longrightarrow W^- t$$



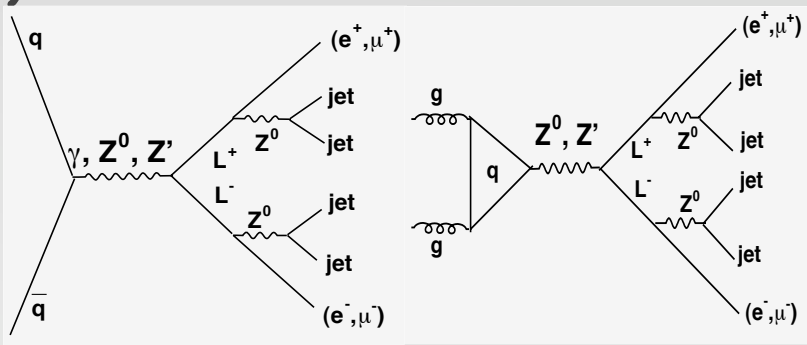
- broad signal at 320 GeV d_4
- Exact knowledge of BG shape needed

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

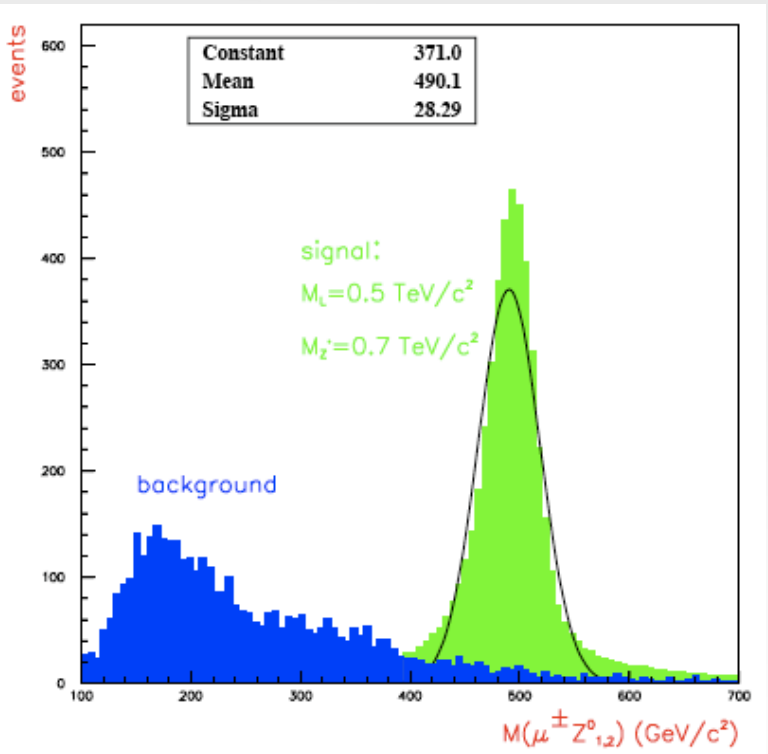
New Leptons

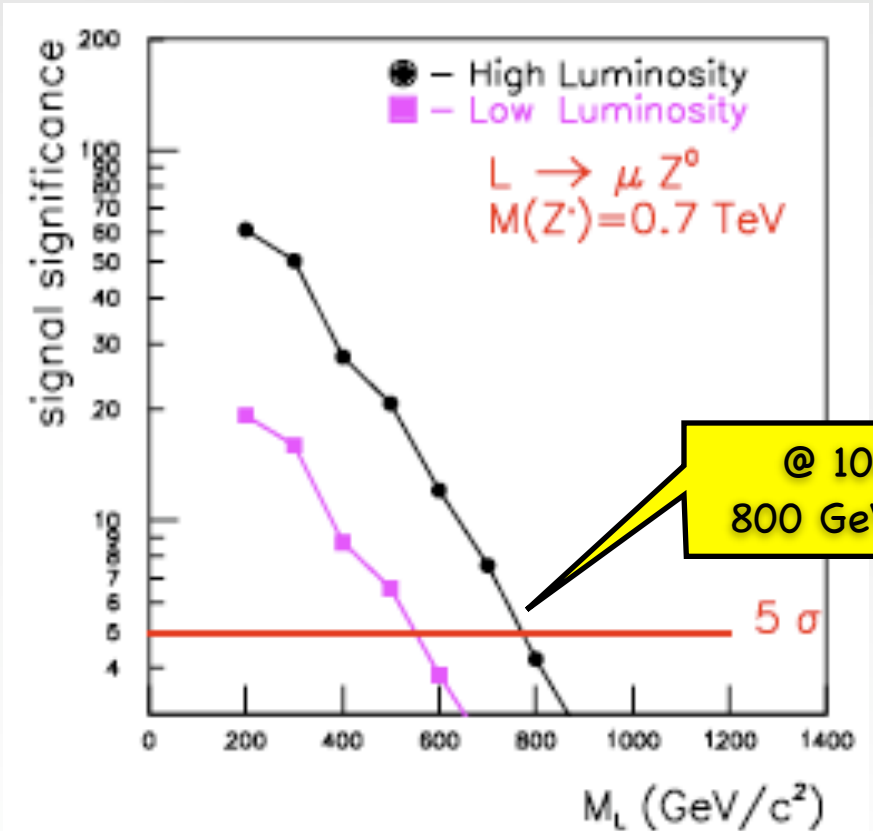
ATLAS-PHYS-2003-014

- 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





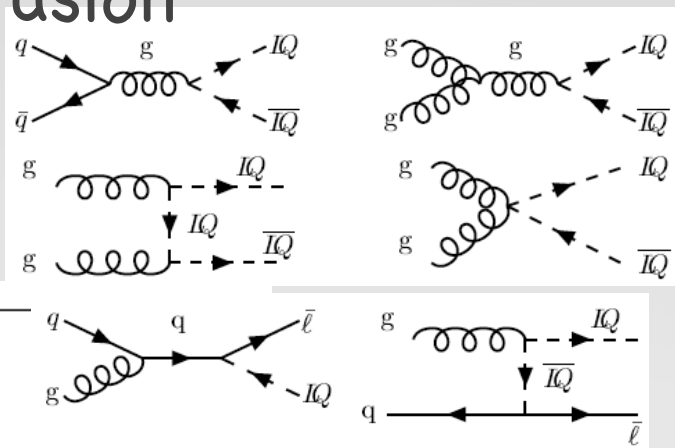
Higher Z′ mass increases the L mass reach: Z′=2TeV, L=1TeV accessible

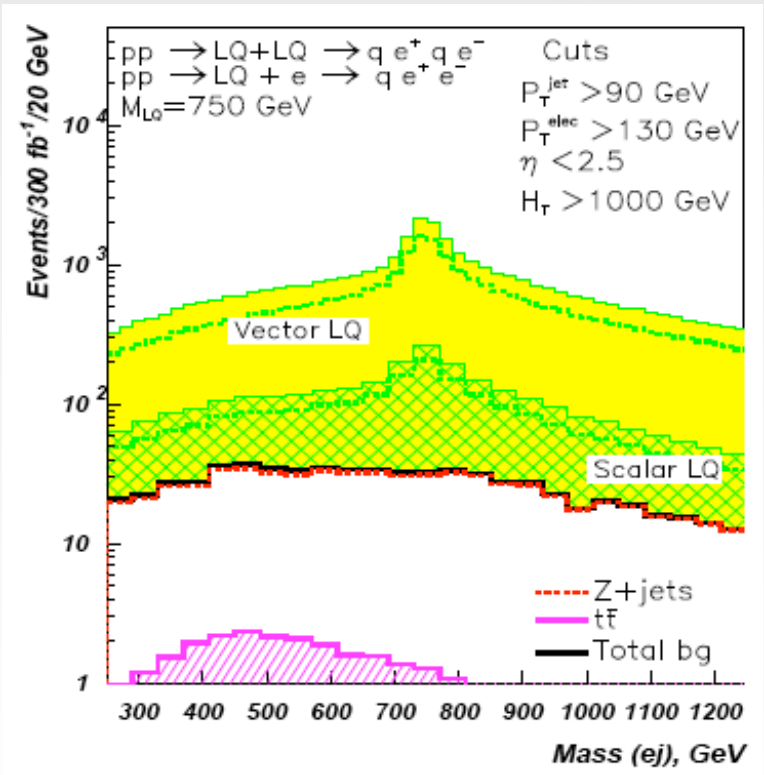
Lepto-quarks

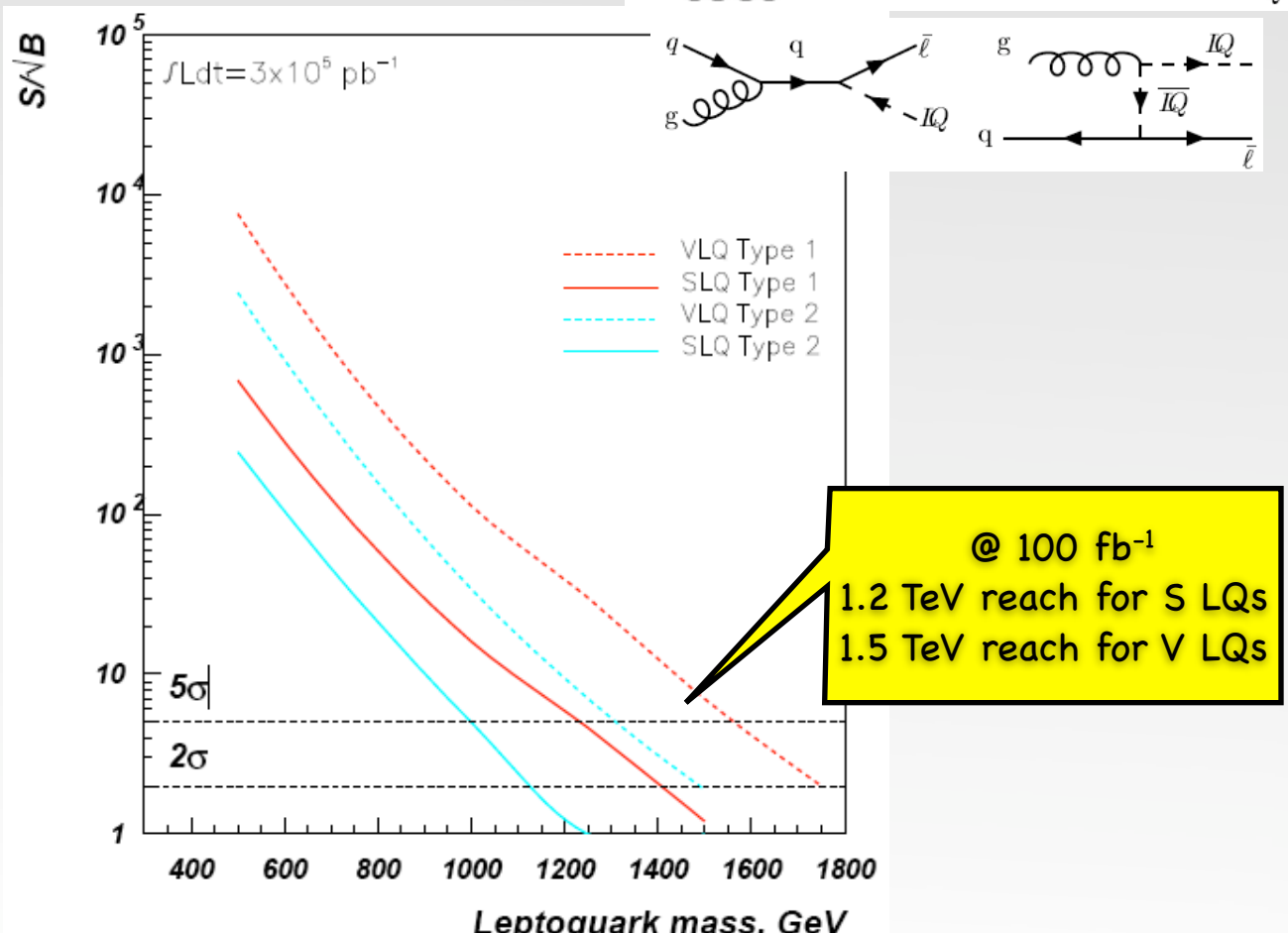
SN-ATLAS-2005-051

- 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

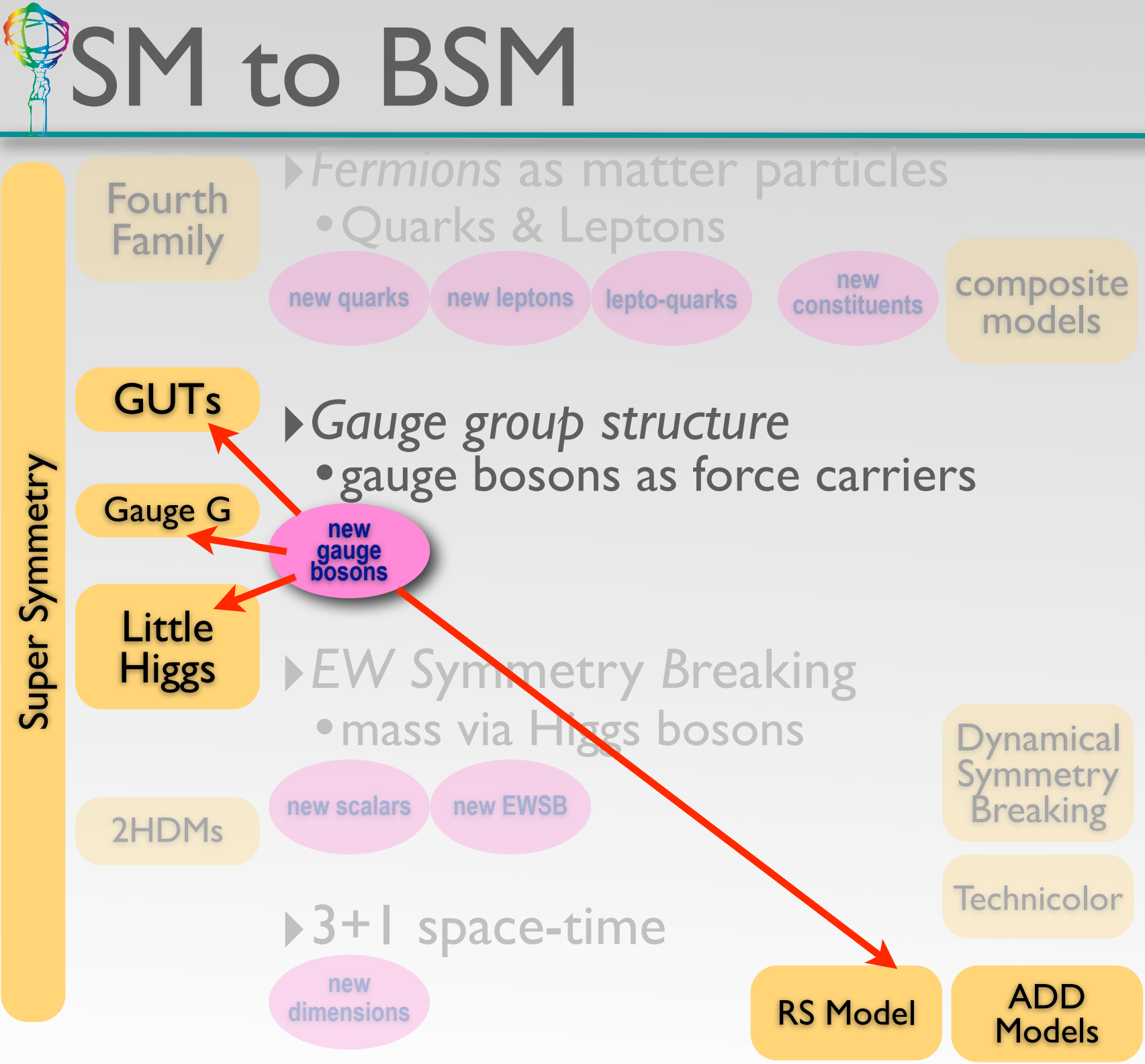






@ 100 fb^{-1}
1.2 TeV reach for S LQs
1.5 TeV reach for V LQs

SM to BSM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Fourth Family
Fermions as matter particles
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new quarks
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2HDMs
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new EWSB
Technicolor
3+1 space-time
new dimensions
RS Model
ADD Models

New bosons Z′

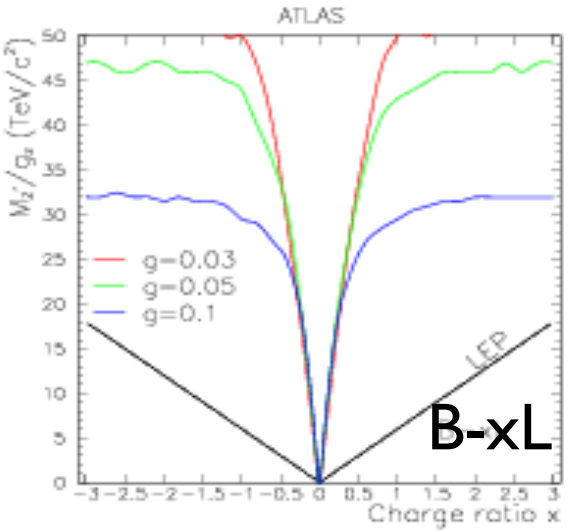
ATLAS-PHYS-PUB-2006-024

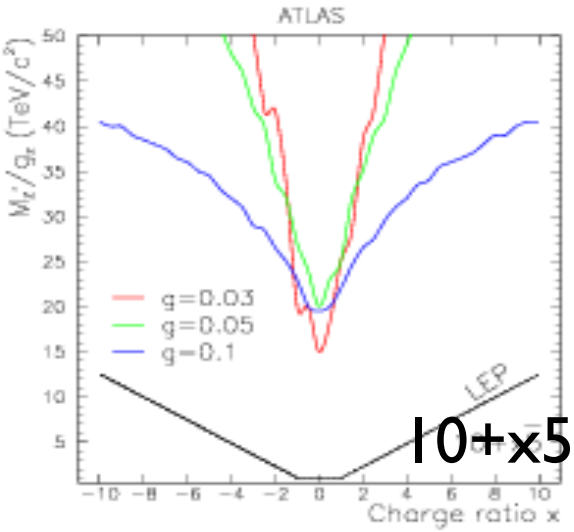
- predicted by: SO(10), E_6.. GUTs, Little Higgs, EDs
- produced as: from q-q annihilation
- decay via: fermion pairs

- Full MC based study
- 1.5 & 4 TeV considered
- CDDT parametrization shown
  - g is global coupling strength
  - x is fermion coupling
  - M is Z′ mass

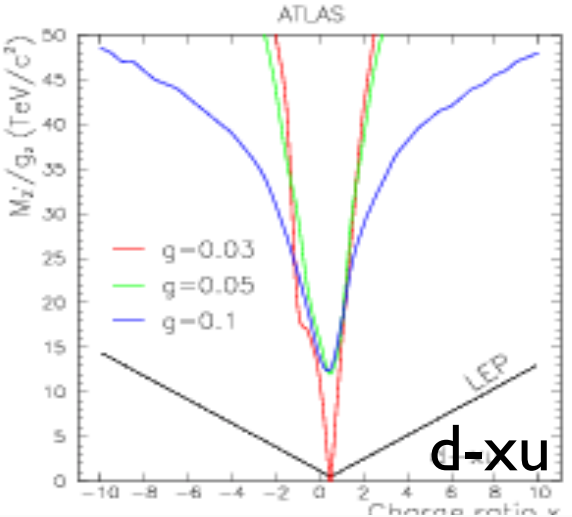
by G.Veramendi at Pheno 2005

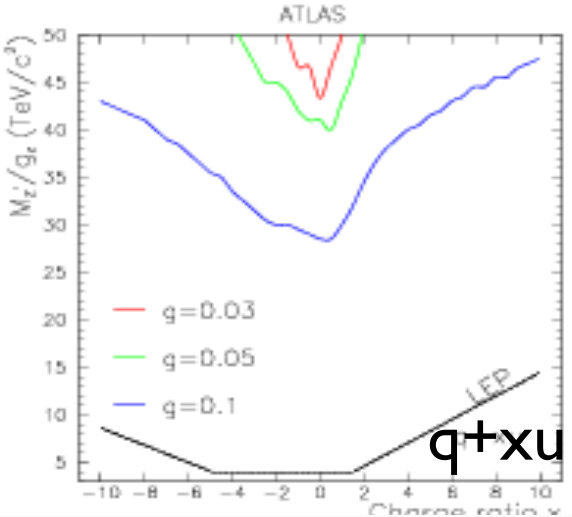
	B-*x*L	q+*x*u	10+*x*$\bar{5}$	d-*x*u
$q_L=(u_L,d_L)$	+1/3	+1/3	+1/3	0
u_R	+1/3	+*x*/3	-1/3	-*x*/3
d_R	+1/3	(2-*x*)/3	-*x*/3	+1/3
$l_L=(e_L,\nu_L)$	-*x*	-1	+*x*/3	(*x*-1)/3
e_R	-*x*	-(2+*x*)/3	-1/3	+*x*/3





results with 100 fb^{-1} of data shown



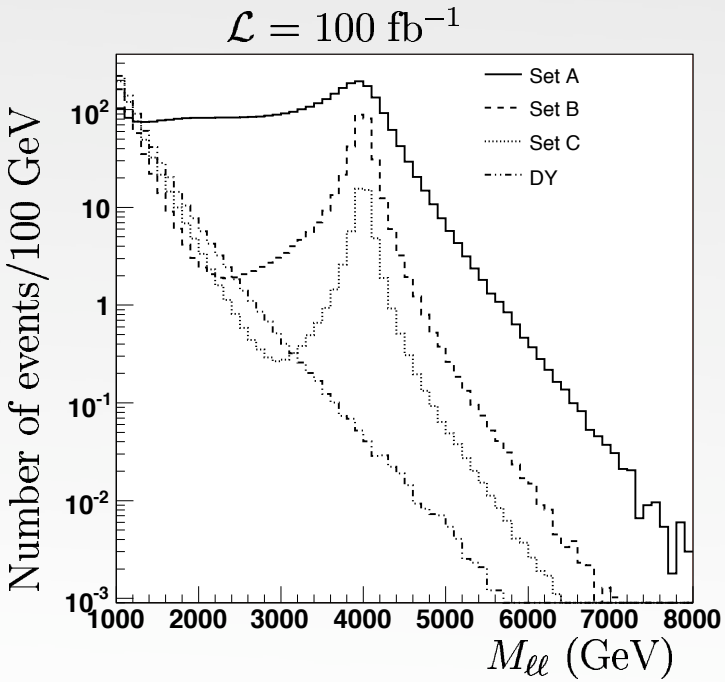


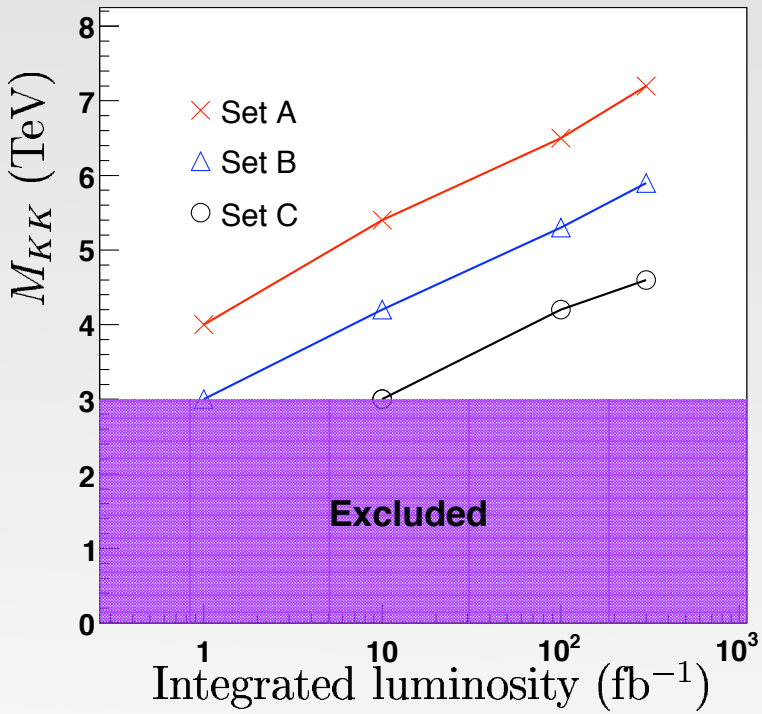
New bosons Z^n

SN-ATLAS-2007-065

- predicted by: RS, ADD models
- produced as: from q-q annihilation $pp \to \gamma^n / Z^n \to \ell^+\ell^-$
- decay via: lepton pairs

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





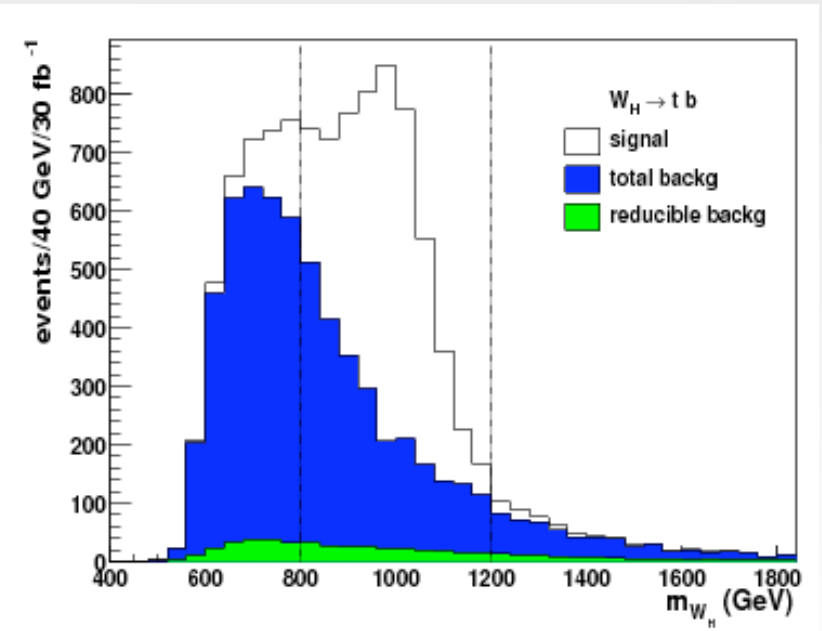
Discovery reach is about 6 TeV depending on the model for 100fb^{-1} data.

New bosons W`/W_H

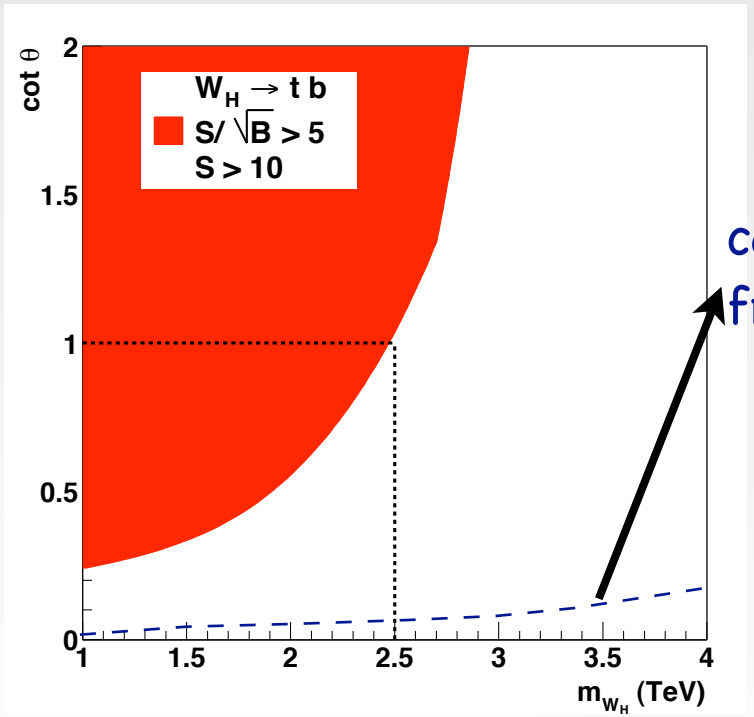
ATLAS-PHYS-PUB-2006-003

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

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



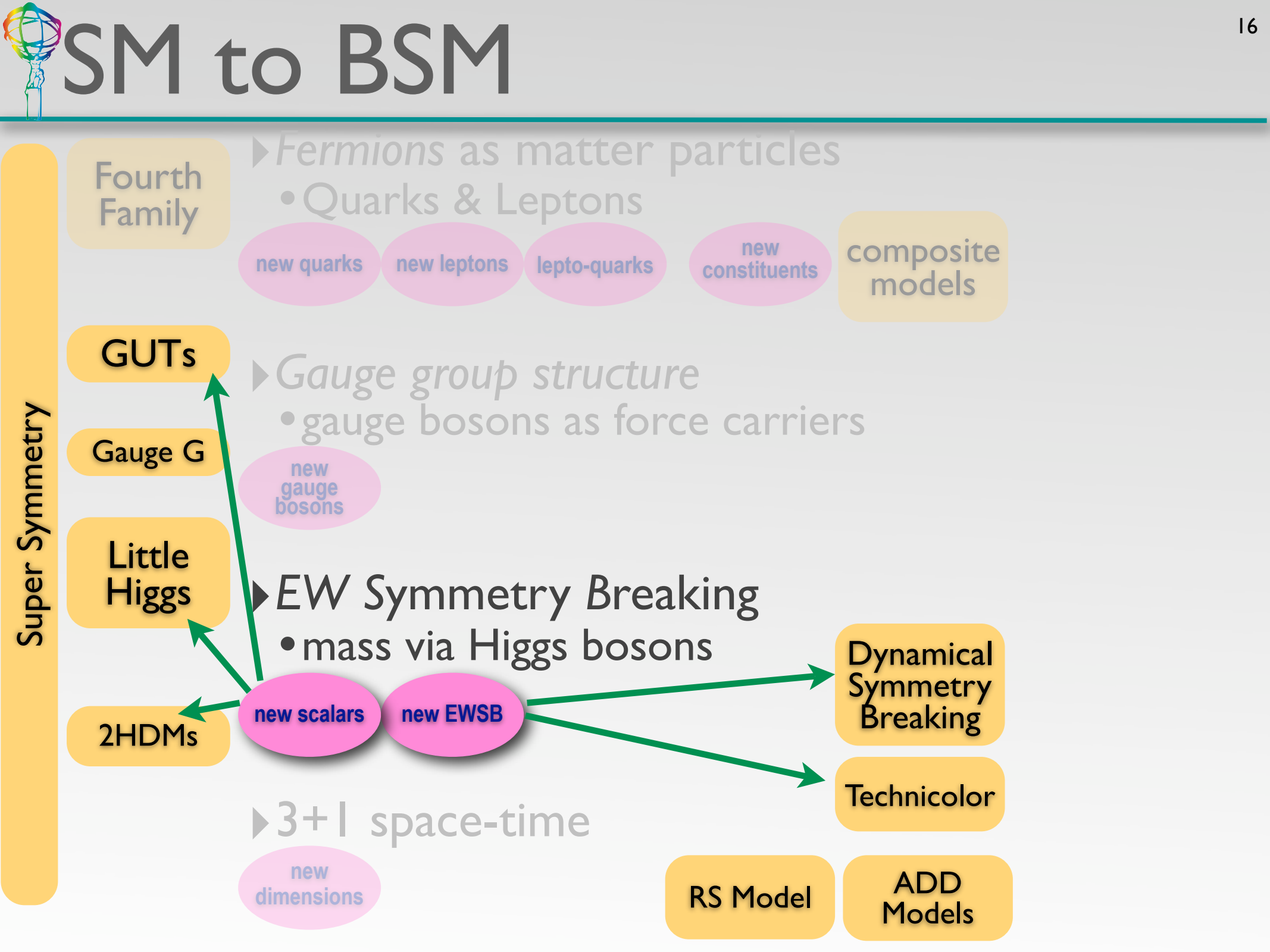
Discovery plane for 300fb^{-1} data



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

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

SM to BSM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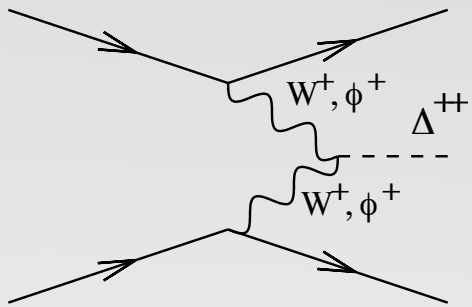
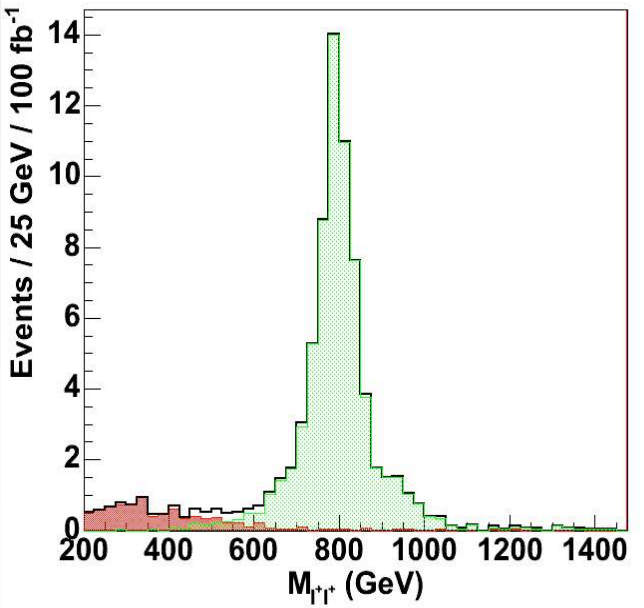
New Scalars q=±2

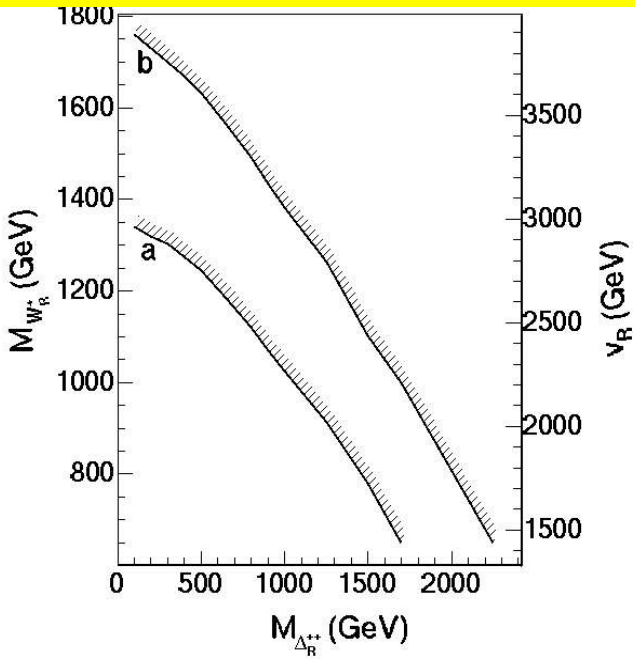
SN-ATLAS-2005-049

- predicted by: Little Higgs, LRSM
- 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

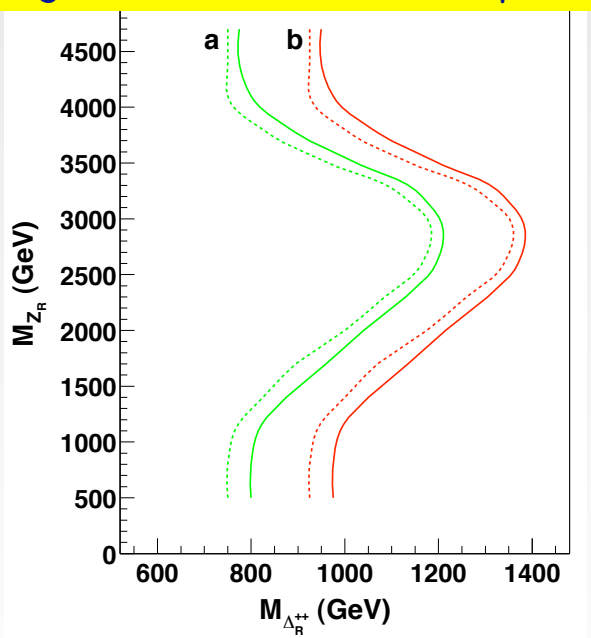


single production reach ~1.8TeV depending on mW^+





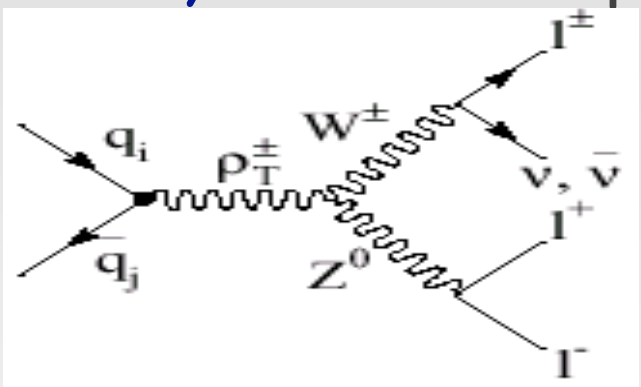
pair production reach 1.1 TeV depending on mZ_R with 3 and 4 leptons



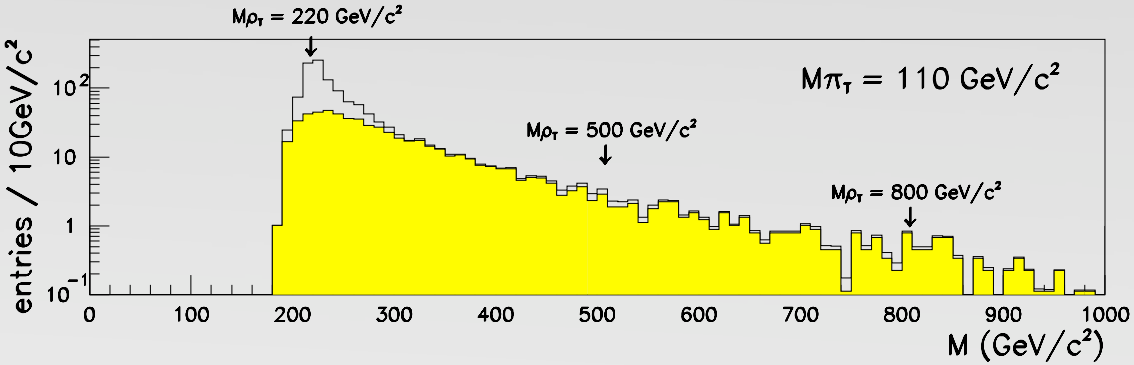
New EWSB no scalar

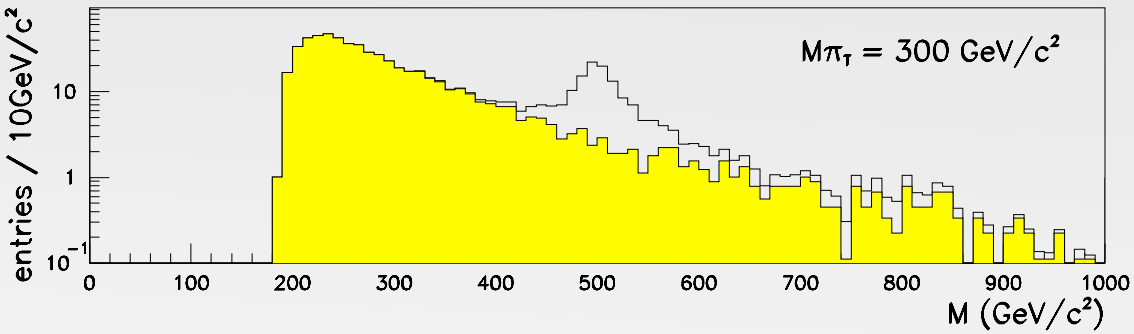
ATLAS-TDR*

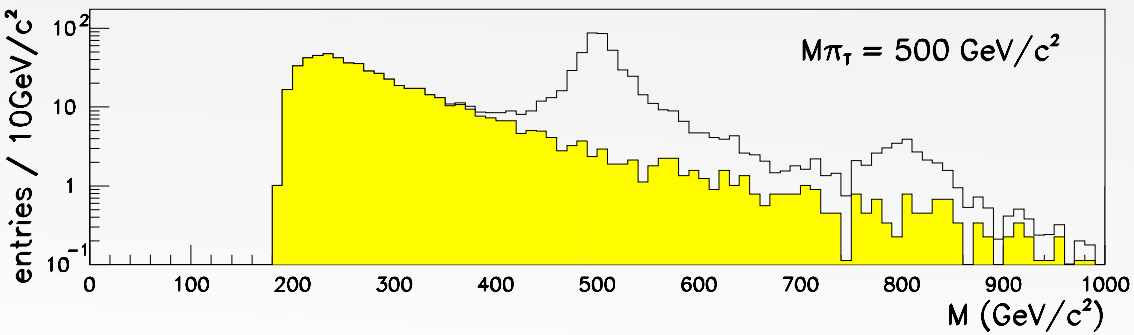
- predicted by: Dynamical SB models, technicolor
- produced as: from q-q annihilation
- decay via: boson pairs



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







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

*new studies are available, but not yet public.

New EWSB SUSY

- Give up the (so far) observed "spin" asymmetry between matter and force carriers: 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[R]
  - many SB options: MSSM, mSUGRA, GMSB, AMSB..
- Common properties:
  - cascade decays of sparticles to high p_T objects ,
  - stable LSP escapes undetected: large E_T^{miss} .

has 5 parameters

has 6 parameters

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

[R] #parameters=124 given in SN-ATLAS-2006-058

New EWSB mSUGRA

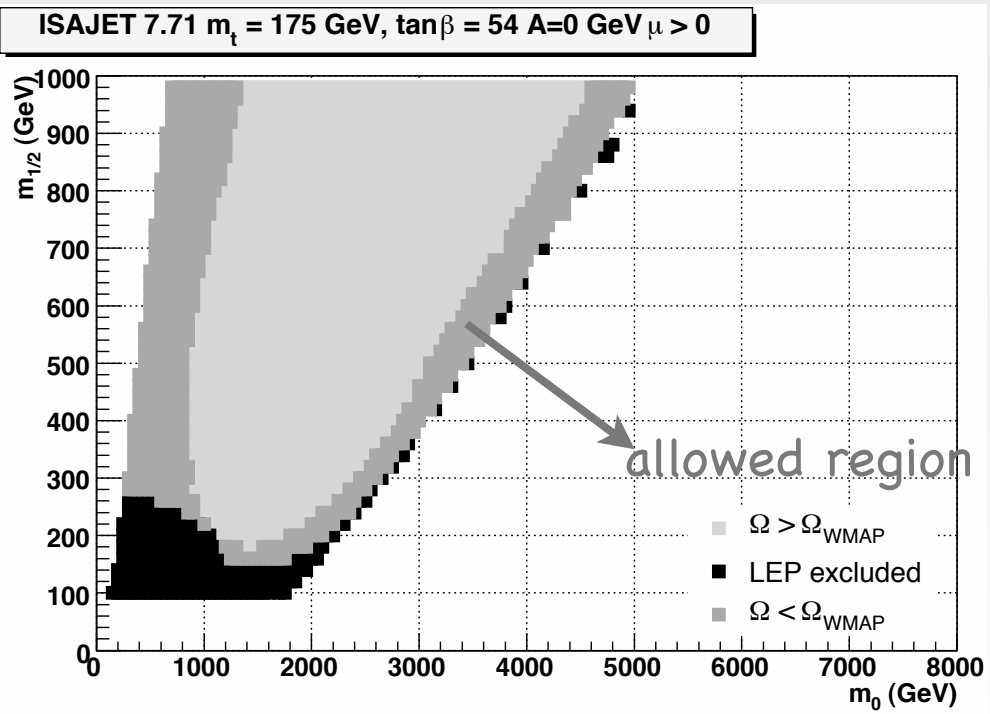
SN-ATLAS-2007-049

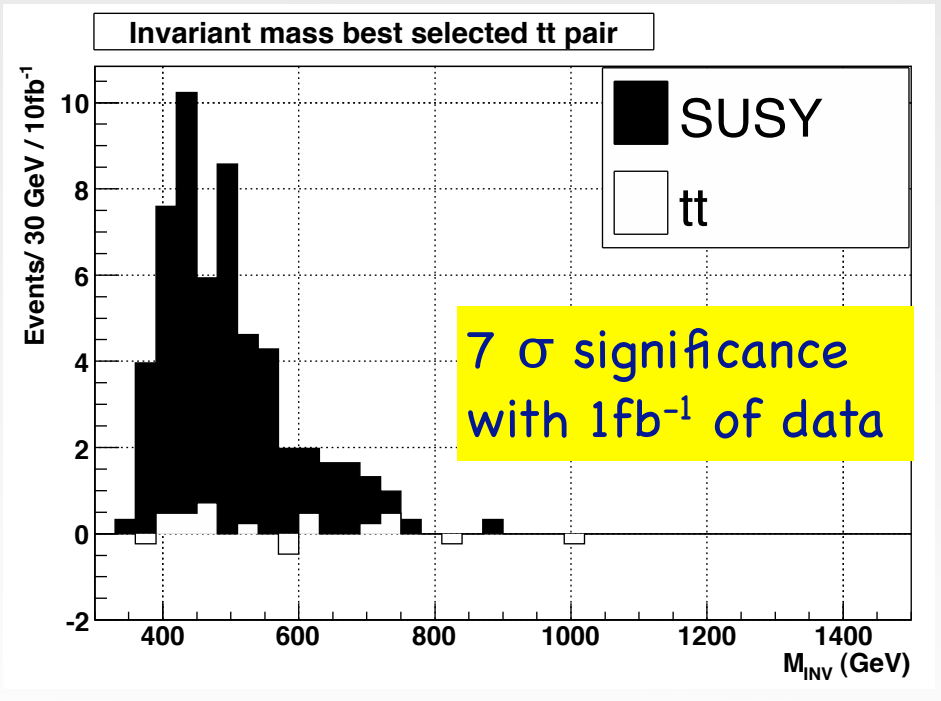
- mSUGRA's LSP is DM candidate
  - model should be consistent with WMAP data $\tilde{\chi}_1^0$
- R parity imposes pair production $pp \to \tilde{g}\tilde{g}$

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

jets + E_T^{miss}

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





New EWSB GMSB

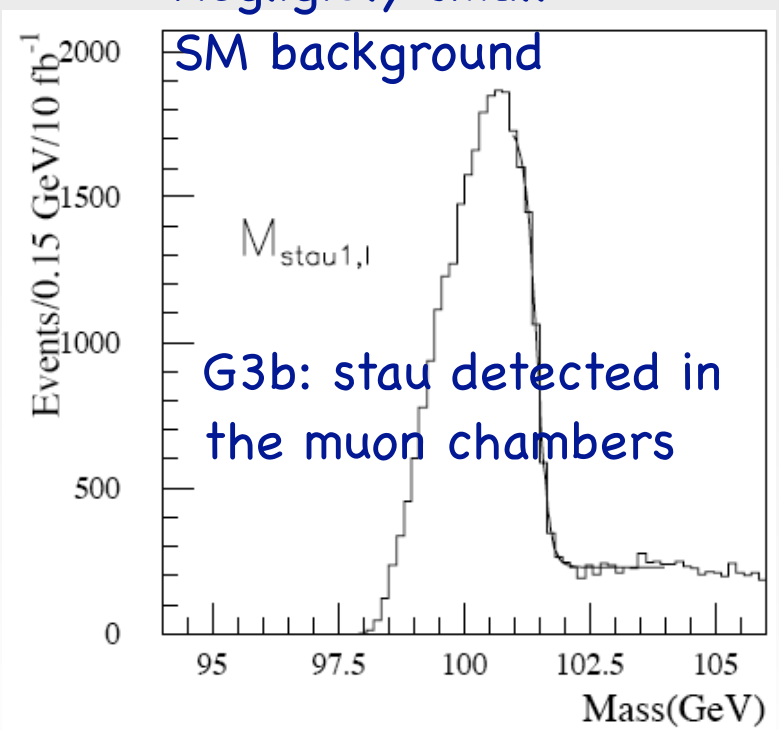
SN-ATLAS-2001-004

- 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

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

leptons +jets + E_T^{miss}

Negligibly small SM background

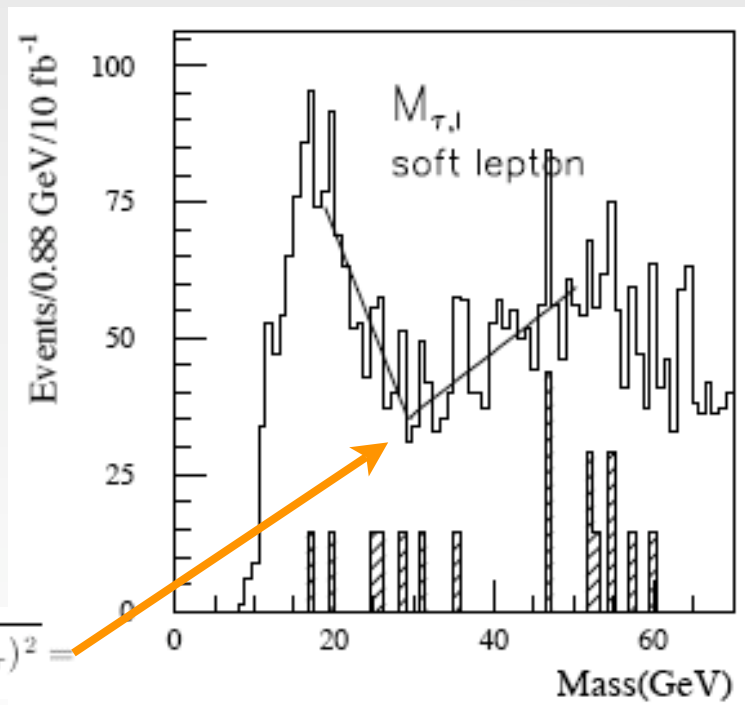


G3b: stau detected in the muon chambers

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

▸ *Fermions* as matter particles
- Quarks & Leptons

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

GUTs

Gauge G

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

new gauge bosons

Little Higgs

2HDMs

▸ *EW Symmetry Breaking*
- mass via Higgs bosons

new scalars | new EWSB

Dynamical Symmetry Breaking

Technicolor

▸ 3+1 space-time

new dimensions

RS Model

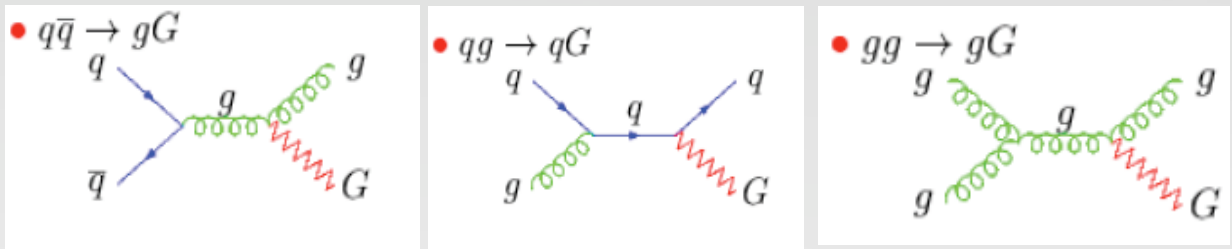
ADD Models

EDs graviton

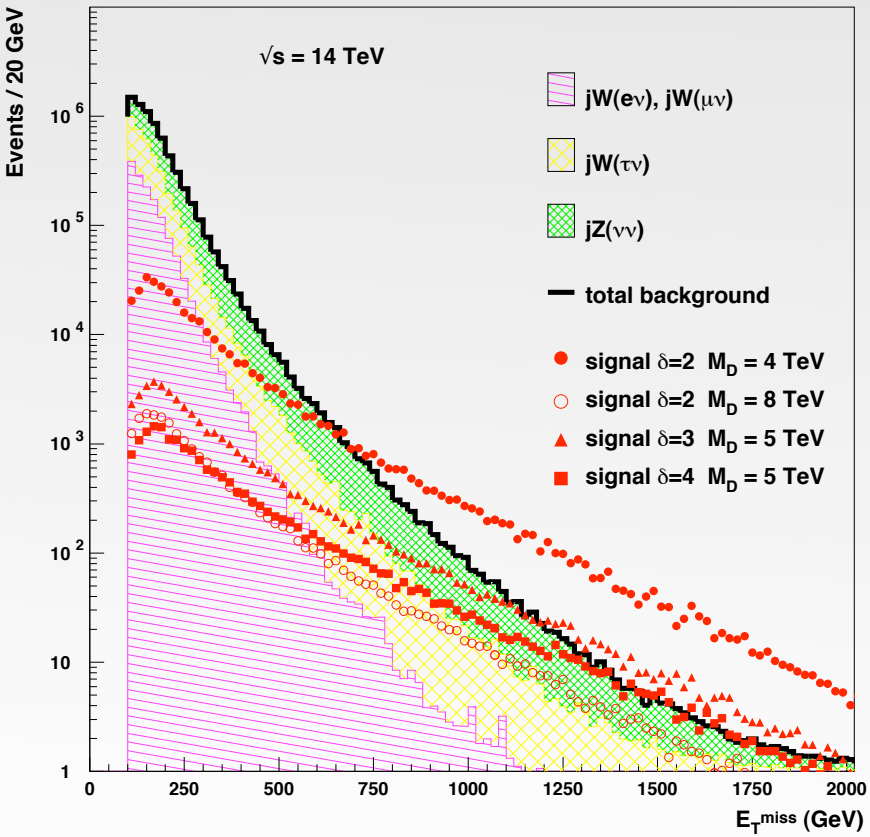
SN-ATLAS-2001-005

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

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



- 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

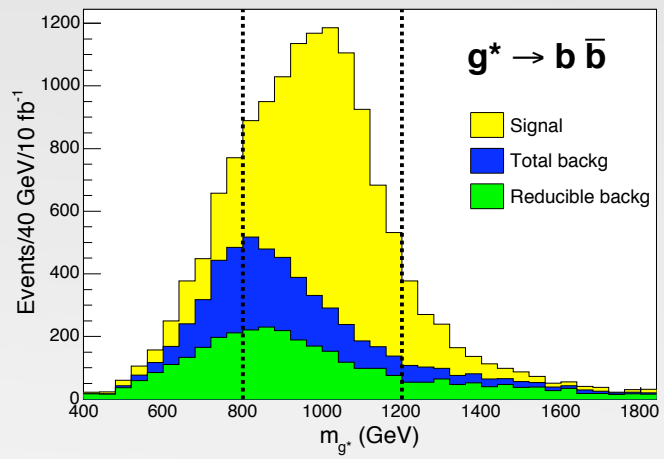
$$q\bar{q} \rightarrow \gamma G$$

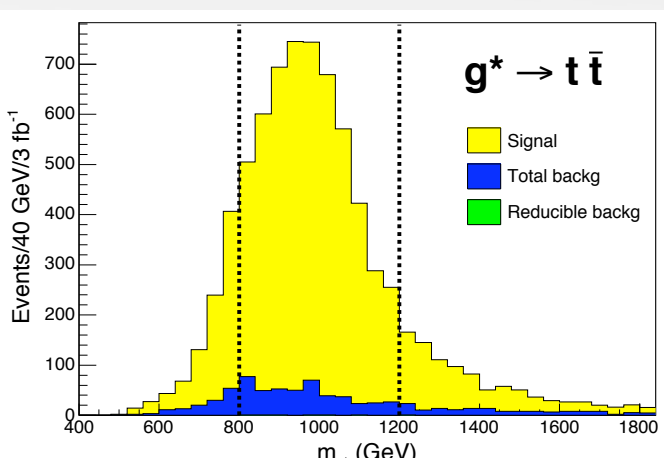
- lower rate,
- lower sensitivity due to Zγ background

EDs Excited gluons

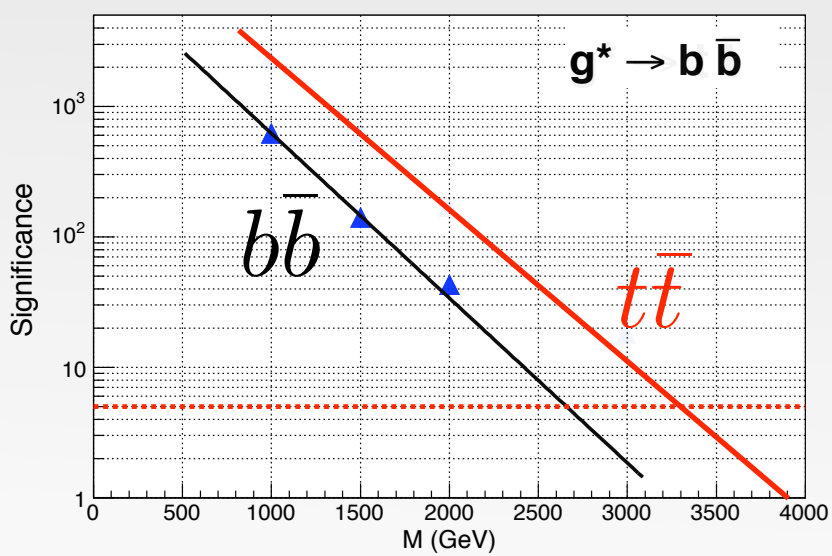
SN-ATLAS-2006-002

- predicted by: TEV^{-1} EDs (ADD)
- produced as: from q-q annihilation $q\bar{q} \rightarrow g^* \rightarrow t\bar{t}$
- decay via: heavy quark pairs $\rightarrow b\bar{b}$





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



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

Summary

- ATLAS has very rich discovery potential for BSM physics.
  - scientific or pub note results shown, (mostly published)

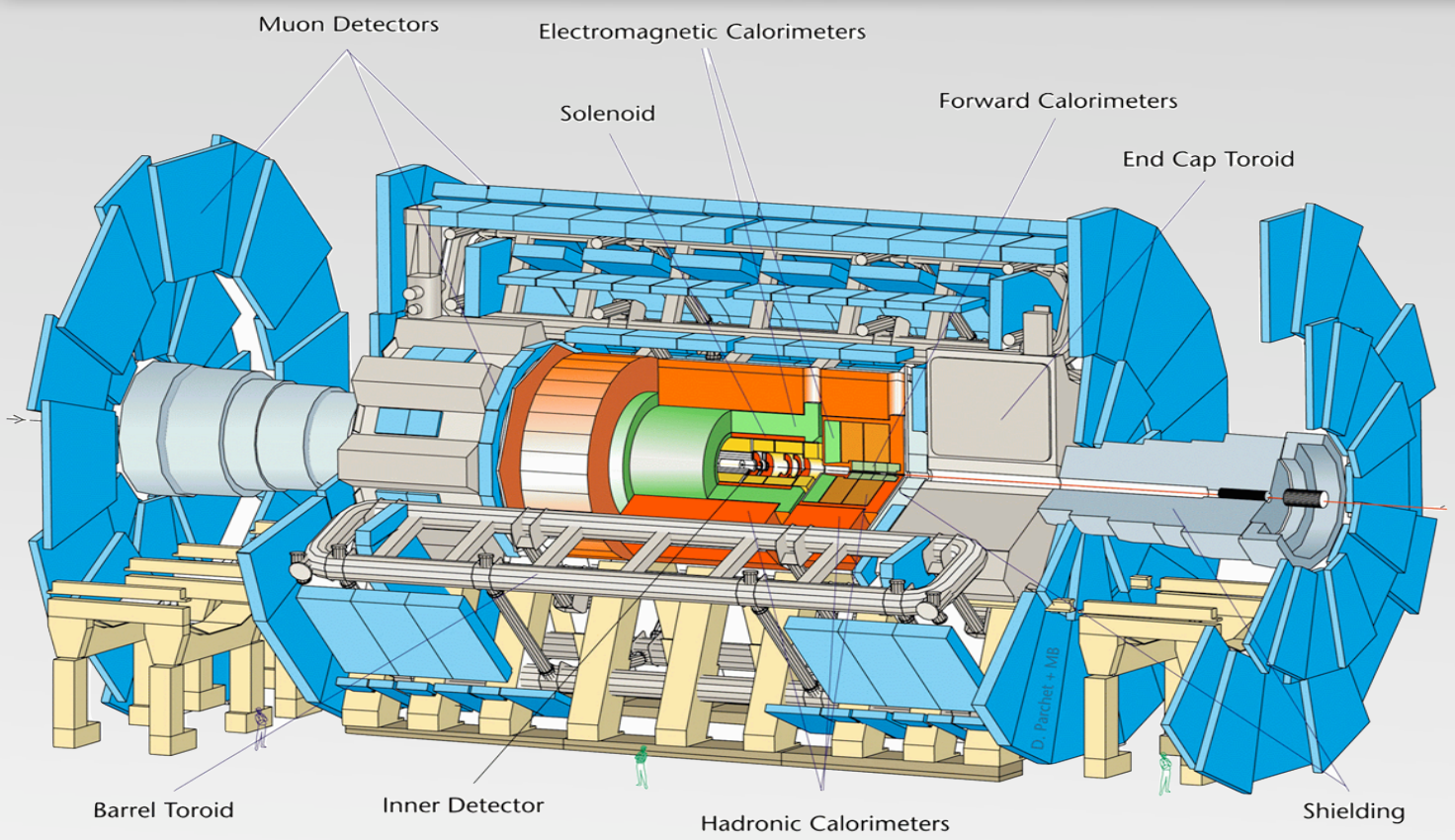
- Concentrated on a selection* of discovery possibilities;
  - some models (e.g. micro BHs) not mentioned,
  - differentiation between models not shown,
  - boost to standard searches from BSM physics not shown.

- Some results with Fast MC were shown,
  - New analyses with full simulation ongoing for first $1fb^{-1}$,
  - Trigger aware studies immediately applicable to LHC data

- Next few years will be very exciting, stay tuned..

*Apologies to all the analyses not mentioned here...

auxiliary slides



	ATLAS
weight	7 000 t
diameter	25 m
length	46 m
B Field	2 T

year	energy	luminosity	aimed $\int L$ (fb^{-1})	physics beam time
2008	7+7 TeV	0.5×10^{33}	1-2	**protons - from July on ➠ $4*10^6$ seconds** **ions - after proton run - 5 days at 50% efficiency ➠ $0.2*10^6$ seconds**
2009	7+7 TeV	1×10^{33}	10	**protons:50% better than 2008 ➠ $6*10^6$ seconds** **ions: 20 days at 50% efficiency ➠ 10^6 seconds**
2010	7+7 TeV	1×10^{34}	100	**TDR targets:** protons: ➠ 10^7 seconds ions: ➠ $2*10^6$ seconds

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.
- *These models do **not** exclude supersymmetry.*