An Axial Symmetry for the μ problem

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work in progress
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SUSY06, June 14th 2006

Supersymmetric Hierarchy Problem

Higgs → Higgsino

$$L \supset \int d^2\theta \; \mu H_u H_d$$

$\mu \sim m_{\cancel{SUSY}}$

Why not the GUT Scale?

A gauge symmetry for the μ problem

H_u and H_d chiral under new U(1)' symmetry

$$q_{h_u} + q_{h_d} \neq 0$$

With a SM singlet charged under U(1)'

$$y\ S H_u H_d$$

U(1)' breaking associated with ~~SUSY~~

$$y\langle S \rangle \ \rightarrow \ \mu$$

Outline

- Particle spectrum
- Superpotential and its symmetries
- Phenomenology

Particle Spectrum and Charge Assignments

Requirements

- SM Yukawas allowed
- Family Universal
- Exotics are vector-like under SM
- Couplings between exotics
- Orthogonality between $U(1)_Y$ and U(1)'
- Minimality and simplicity

Particle Spectrum and Charge Assignments

	Particle	U(1)' charge
$\bar{\psi}\gamma^{\mu}\gamma^{5}\psi$	Q, U^c, D^c, L, E^c	1
	H_u, H_d	-2
SM Exotics	D', D'^{c}	-6
	L', L'^{c}	-4
Singlets for the μ term and exotics' masses	$2\times S_4$	4
	S_{12}	12
	S_8	8
To cancel U(1)' anomalies	S_{-6}	-6
	S_{-2}	-2
	$3\times S_3$	3
	$2\times S_{-7}$	-7

Gauge Coupling Unification

D' : $\mathbf{3}$ of SU(3)

D'^c : $\overline{\mathbf{3}}$ of SU(3)

L'^c : $\mathbf{2}$ of SU(2)

L' : $\mathbf{2}$ of SU(2)

Gauge Coupling Unification

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D'^c : $\bar{\mathbf{3}}$ of SU(3)

L' : $\mathbf{2}$ of SU(2)

$$5 \oplus \bar{5}$$

SM gauge couplings unify at the high scale!

Deconstructed Unification

Proton Decay

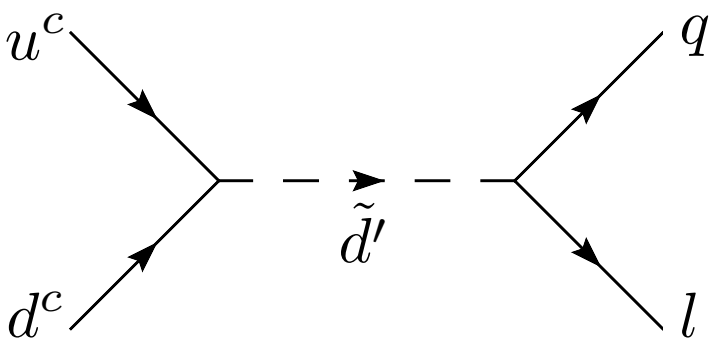
~~$U^c D^c D^c,\ QD^c L,\ LLE^c$ (charge 3)~~

~~$H_u L$ (charge -1)~~

~~$QQQL$ (charge 4)~~

Suppressed proton decay

Proton decay from dimension 5 operators:



$$\frac{y_1 \langle S_4 \rangle U^c D'^c D^c}{\mathrm{M_{GUT}}}, \frac{y_2 \langle S_4 \rangle Q D'^c L}{\mathrm{M_{GUT}}}$$

$$\tau_{\mathrm{proton}} \sim \frac{10^{33}}{(y_1 y_2)^2} \text{ years}$$

Dark Matter

After U(1)' breaking, residual Z_2 symmetry:

-1: Q, U^c, D^c, L, E^c

+1: H_u, H_d, S_{even}, Vector Superfields

-1: S_{odd}

R-parity

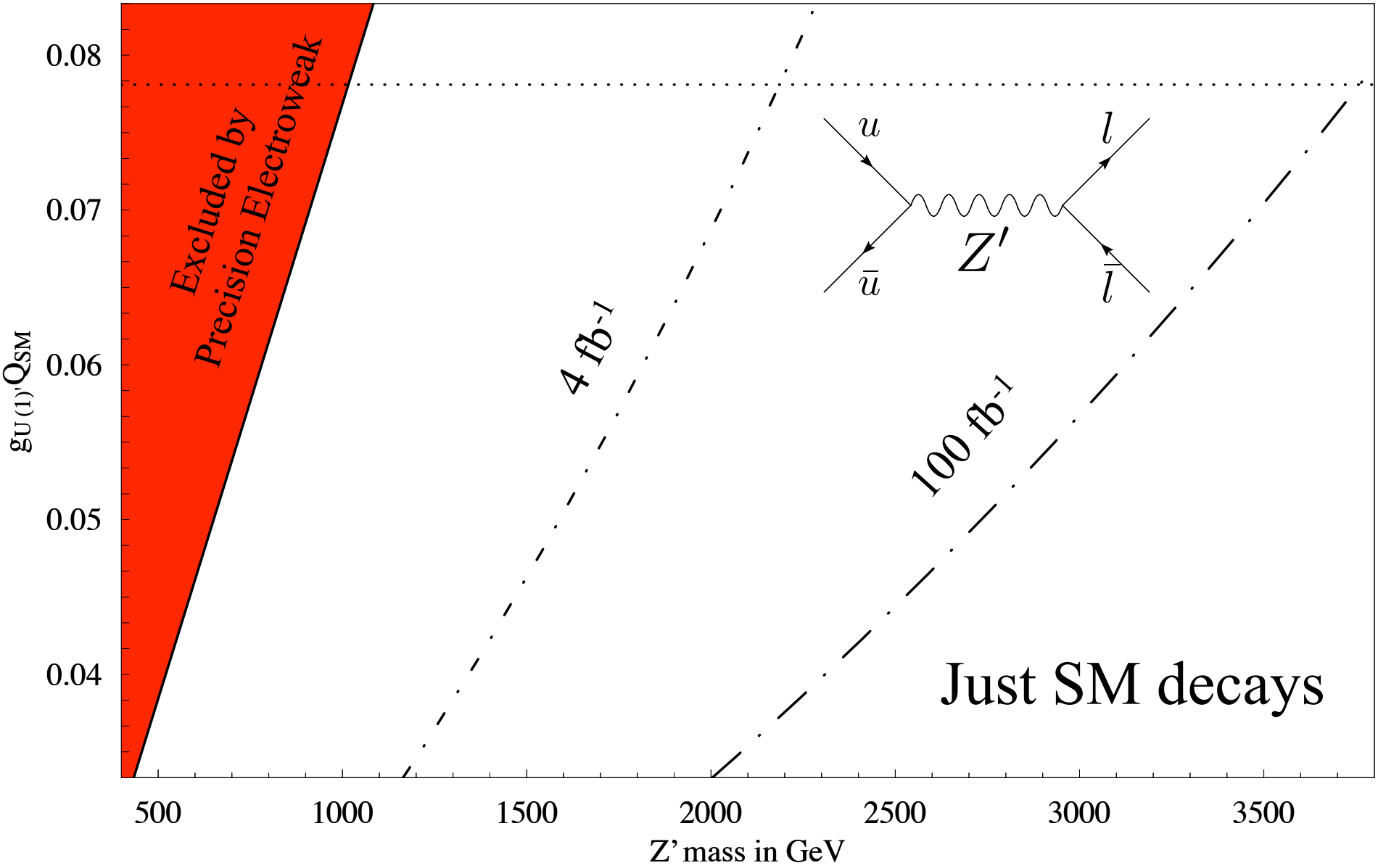
Stable Lightest Supersymmetric Particle!

Mostly MSSM-like

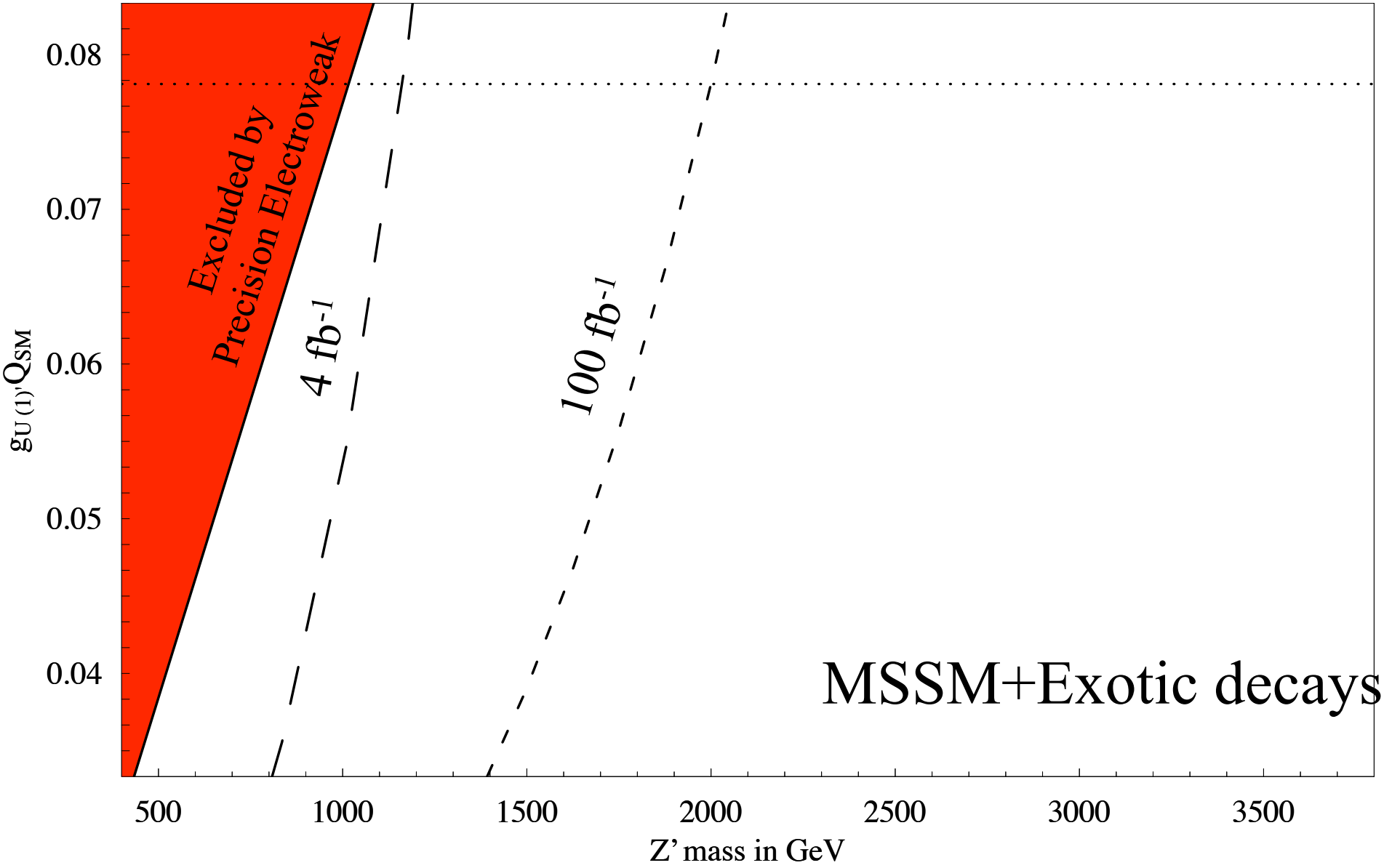
LHC Phenomenology

- Discovery of Z’
- Measuring axial coupling
- Discovery of SM exotics

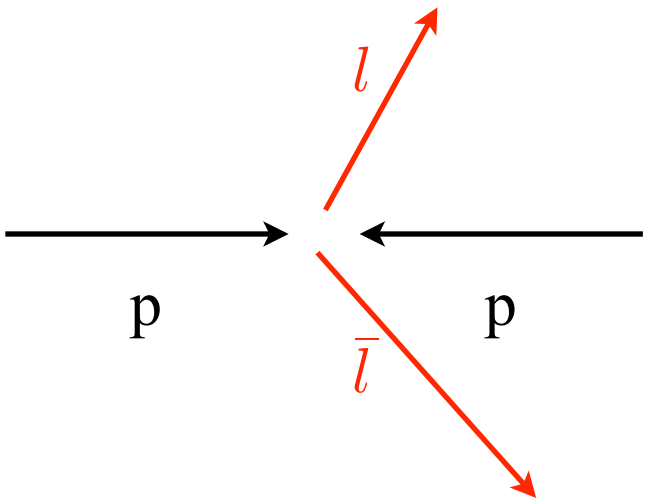
LHC Reach


Excluded by Precision Electroweak
4 fb-1
100 fb-1
Just SM decays
u
ū
l
l̄
Z′
0.08
0.07
0.06
0.05
0.04
gU(1)'QSM
500
1000
1500
2000
2500
3000
3500
Z' mass in GeV

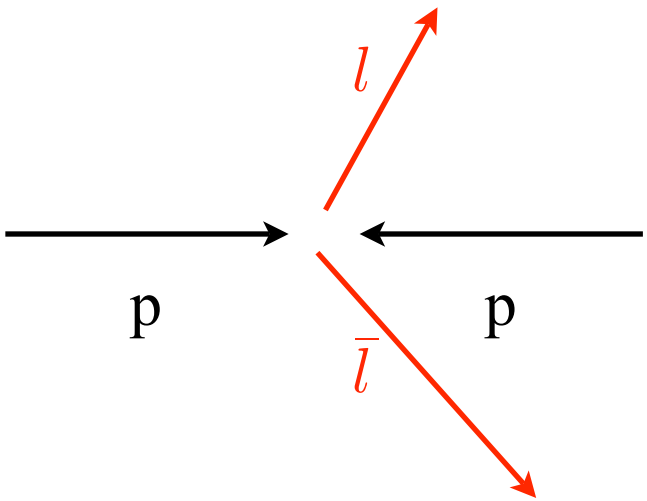
LHC Reach

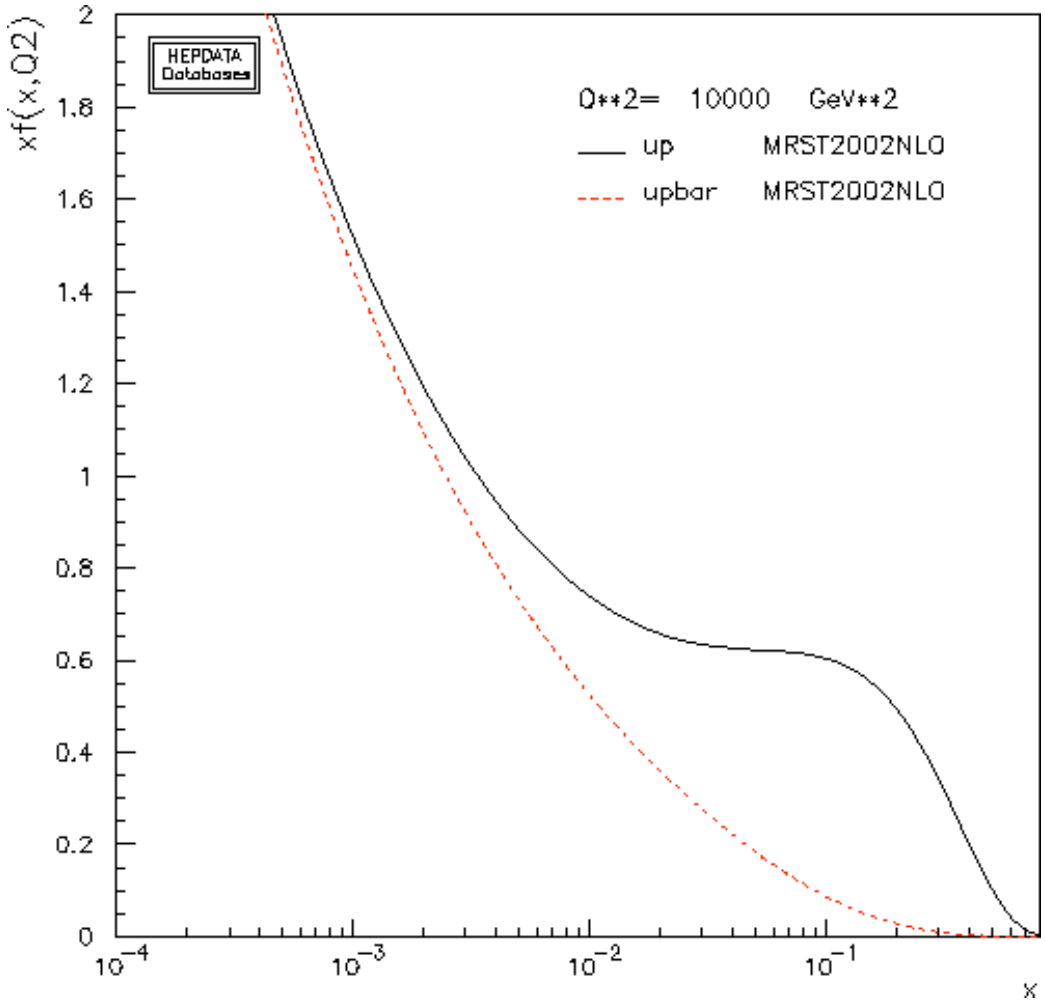

Excluded by
Precision Electroweak
4 fb-1
100 fb-1
MSSM+Exotic decays
0.08
0.07
0.06
0.05
0.04
gU (1)'QSM
500
1000
1500
2000
2500
3000
3500
Z' mass in GeV

Forward-Backward Asymmetry



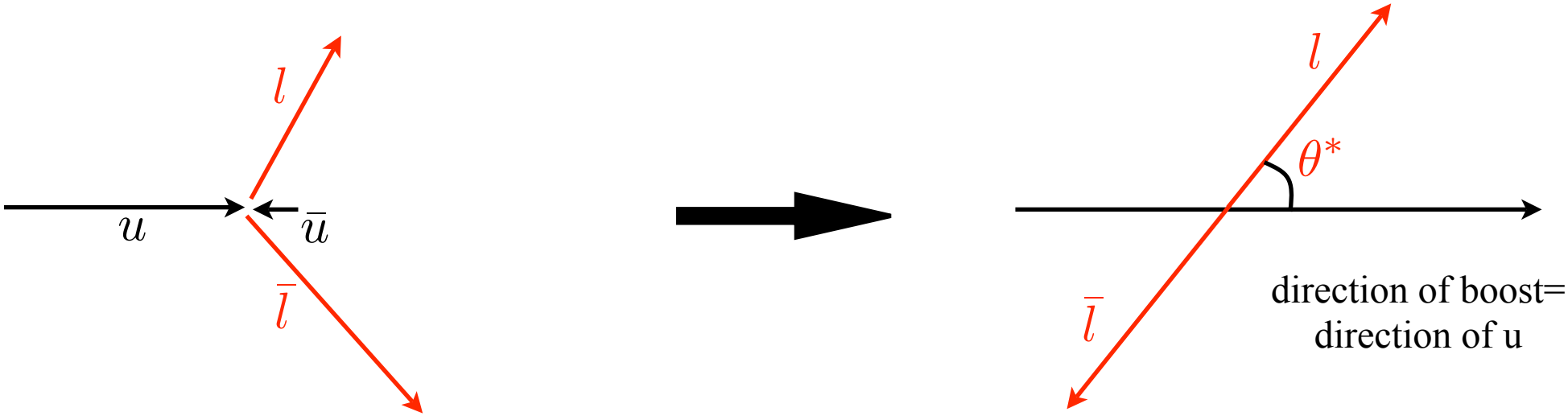
Forward-Backward Asymmetry





Forward-Backward Asymmetry

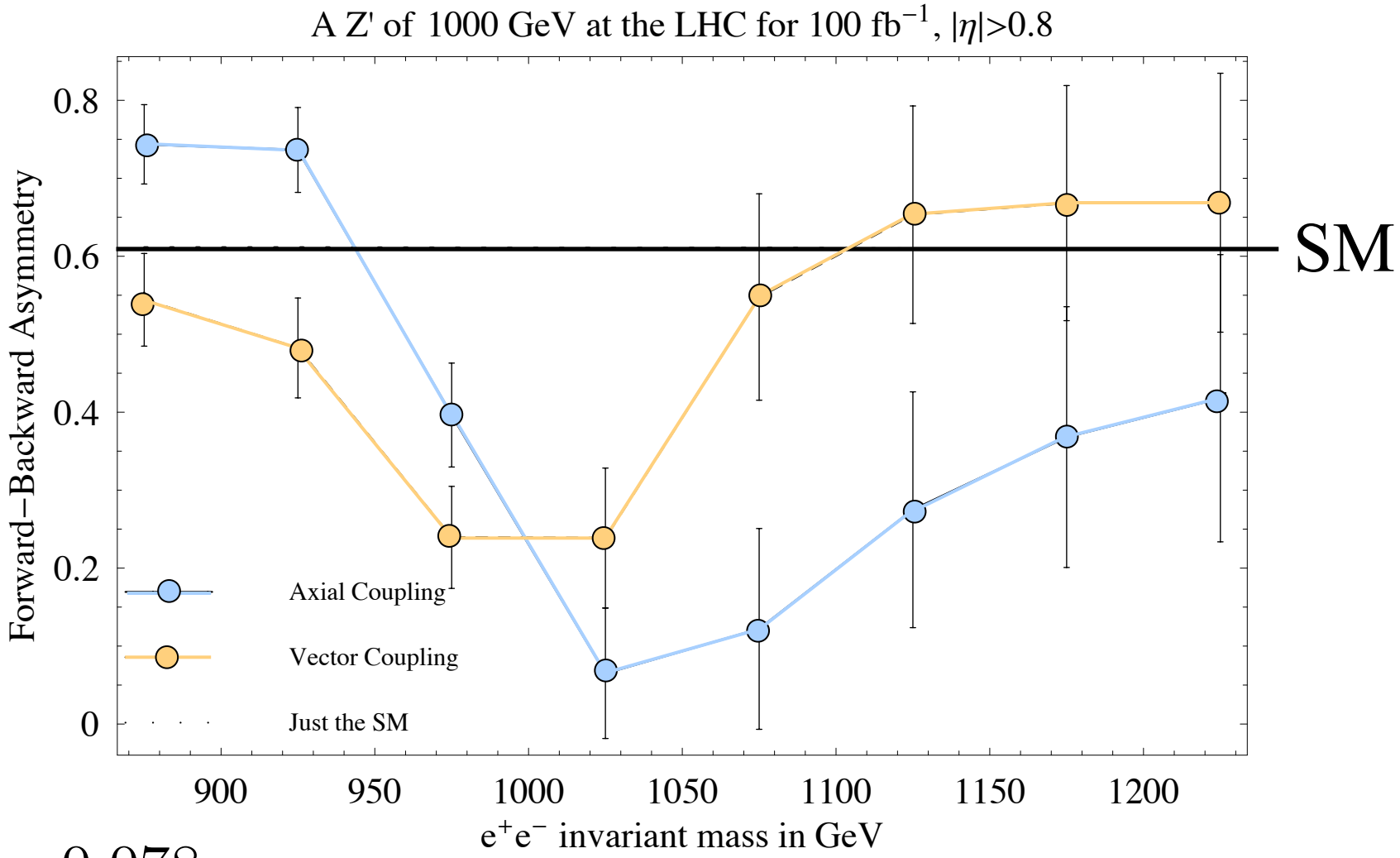
For leptons produced at large rapidity



$$\sigma(\cos\theta^*) \sim \mathrm{A_{FB}} \cos\theta^*$$

Interference between gauge bosons important

Axial vs Vector Couplings



$g' Q_{SM} = 0.078$

Sleptons

Z': production cross-section increase

higher transverse momentum

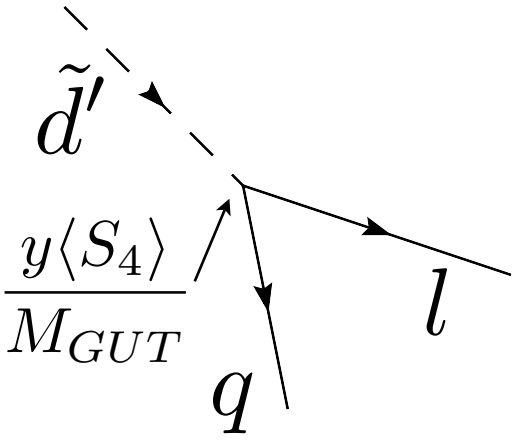
10-20% increase in the LHC slepton reach

$$M_{\tilde{l}_{\text{discovery}}} \sim 350 - 400 \text{ GeV}$$

Limit depends on decays and energetics

Exotics

D' are long-lived
(in this choice of singlets)



$$\text{Lifetime} \sim (1000\ \text{sec})^{-1} \left(\frac{y\langle S_4\rangle}{100\ \text{GeV}}\right)^2 \left(\frac{m_{D'}}{100\ \text{GeV}}\right)$$

Stiff tracks, monojets and
out of time decays in the detector

Summary

- Gauge coupling unification
- Suppressed proton decay
- DM candidate
- New gauge boson and exotics at colliders