Physics with 12-T Magnet Hadron Colliders

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References

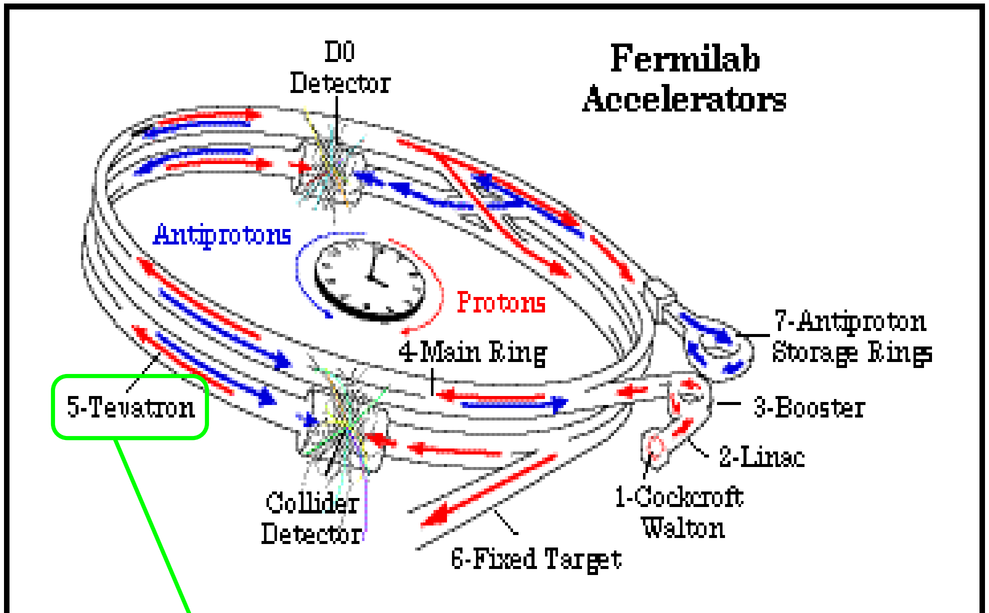
URL: http://hepr8.physics.tamu.edu/hep/Tripler/

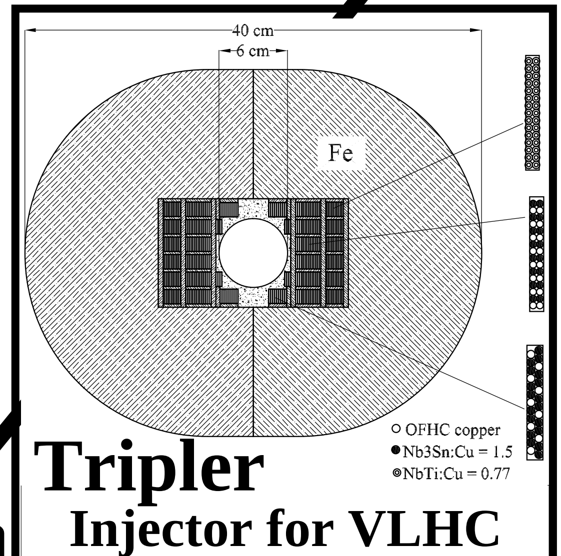
- **P. McIntyre *et al*., hep-ph/9908052.**
  → Magnet design
- **V. Barger *et al*., hep-ph/9910500**
  and Phys. Lett. B478, 224 (2000).
  → SM Higgs, SUSY(3*l*, LS-*ll*, *Z'*, Contact)
- **V. Krutelyov *et al*., hep-ph/0011253**
  and Phys. Lett. B505, 161 (2001).
  → SUSY ($\not{E}_T$+jets, 1*l*+$\not{E}_T$+jets)

Outline

1. **12-Tesla Nb_3Sn Dipole Magnet**
2. **The Tevatron Tripler (6 TeV *p-pbar*)**
3. **Monte Carlo**
4. **SM Higgs Boson**
5. **mSUGRA**
6. **Other New Physics**
7. **Top/Bottom Physics**
8. **Summary**

1. 12-T Magnet





VLHC

4 Tesla NbTi ⟶ **12 Tesla Nb_3Sn**

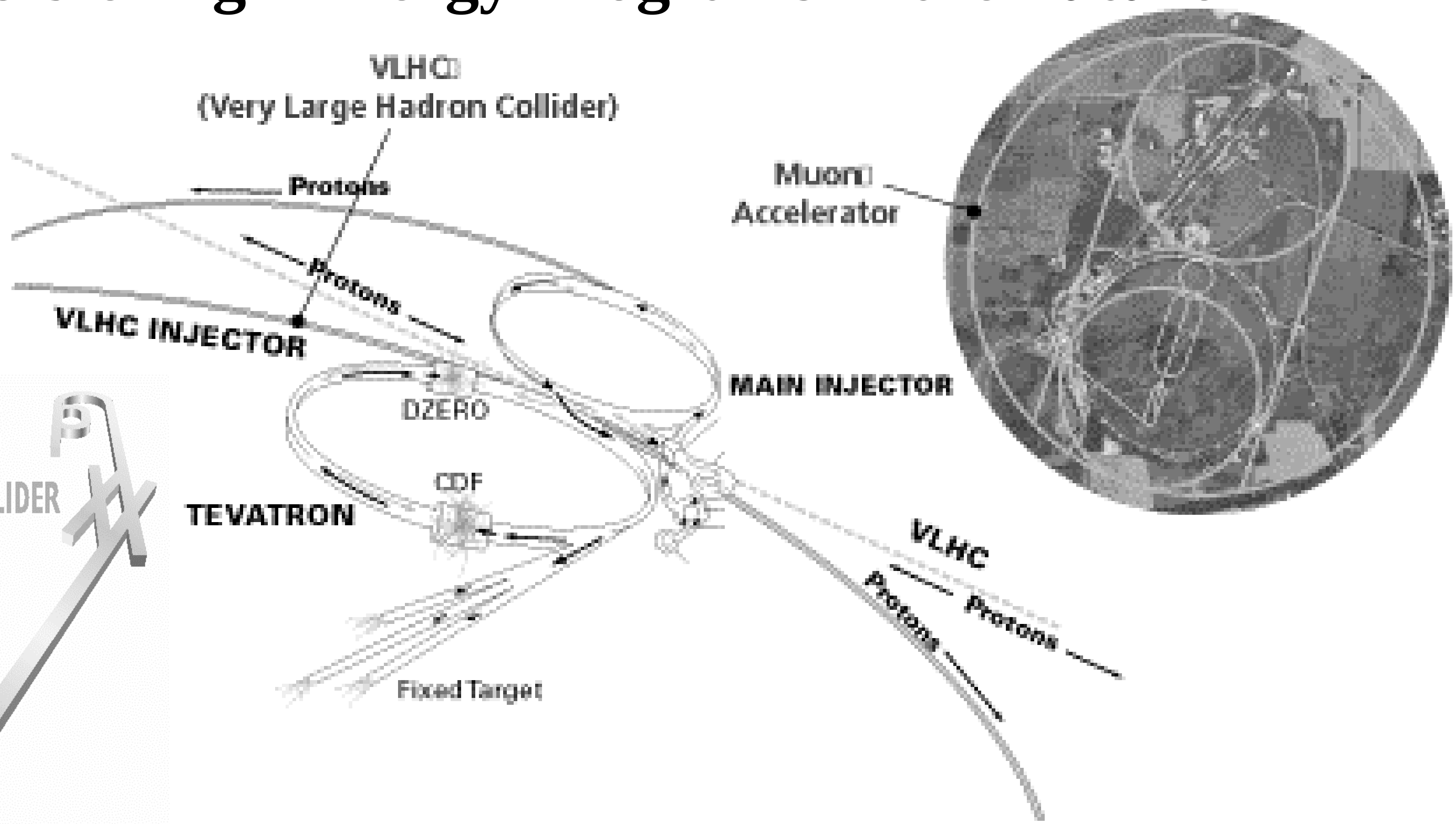
E_{cm} = 2 TeV	5.4 TeV
750 trillion collisions (15 fb^{-1})	*1500 trillion collisions* (15 fb^{-1})

cf.) 14 TeV *pp* at Large Hadron Collider (LHC)

LHC Doubler

1. 12-T Magnet (cont'd)

Possible High Energy Programs in the Future



2. The Tripler

What is it ?

1. Install new ring of single-aperture, 12-T, Nb_3Sn $\cos\theta$ dipoles (+quads) in the Tevatron tunnel. Inject at 150 GeV.

2. Can be designed as an injector to VLHC.

3. Use most of the existing *p* and *pbar* infrastructure as it will be available at the end of Run II
→ Magnets are only major technical+cost element.

4. Suspect the whole technical upgrade is less than $500M, but needs study and magnet R&D.

2. The Tripler (cont'd)

What is it ? (cont'd)

5. Use the two working CDF-II and D0-II detectors with minimal changes so that physics can be done immediately after commissioning.

6. Luminosity and bunch spacing to be the same as Run II ($\mathscr{L} < 5 \times 10^{32}\ cm^{-2}s^{-1}$), but could use the natural x3 increase to do luminosity leveling.

7. Physics and timeline are important issues with LHC expected to come on in 2006-2007. Worthwhile to do 6-TeV *p-pba*r physics in the 2010 era ?

2. The Tripler: Performance

E_{cm}	**5.4 TeV (using 12 Tesla dipole magnets)** [1]
Operation mode	**100-bunch operation**
	and 5.6 interactions/crossing [2]
Live time	2×10^7 **sec/year (luminosity leveling)** [2]
$\mathcal{L}$	3.8×10^{32} $cm^{-2}s^{-1}$ [2]
$\int \mathcal{L}\, dt$	**7.6** fb^{-1}**/year** [2] ⟶ **30-40** fb^{-1}**/4-5 years**

References

[1] P. McIntyre *et al.*, "The Tevatron Tripler: How to Upgrade the Fermilab Tevatron for the Higgs Boson and Supersymmetry," hep-ex/9908052 (1999).

[2] P. Bagley, private communications.

3. Monte Carlo Package

Detector Simulation: SHW

a) A quick simulation program was developed by John Conway during SUSY/Higgs workshop in 1998.

b) The fiducial volume for each particle (e, μ, τ, γ, j, b, c) and its ID efficiency are implemented by averaging between CDF-II and D0-II detector and by using the measured number in Run I (1992-96).

4. (SM) Higgs (Boson)

4. SM Higgs Boson: Limits

Limit from the LEP-II direct search:

(Ref.) P. Igo-Kemenes, LEP Seminar, Nov. 3, 2000

$$M_h > 113.5 \text{ GeV @95\% C.L.}$$

Indirect bounds from precision measurements:

(Ref.) A. Straessner, XXXVth Recontres de Moriond, 2000

$$M_h = 67^{+60}_{-33} \text{ GeV}$$

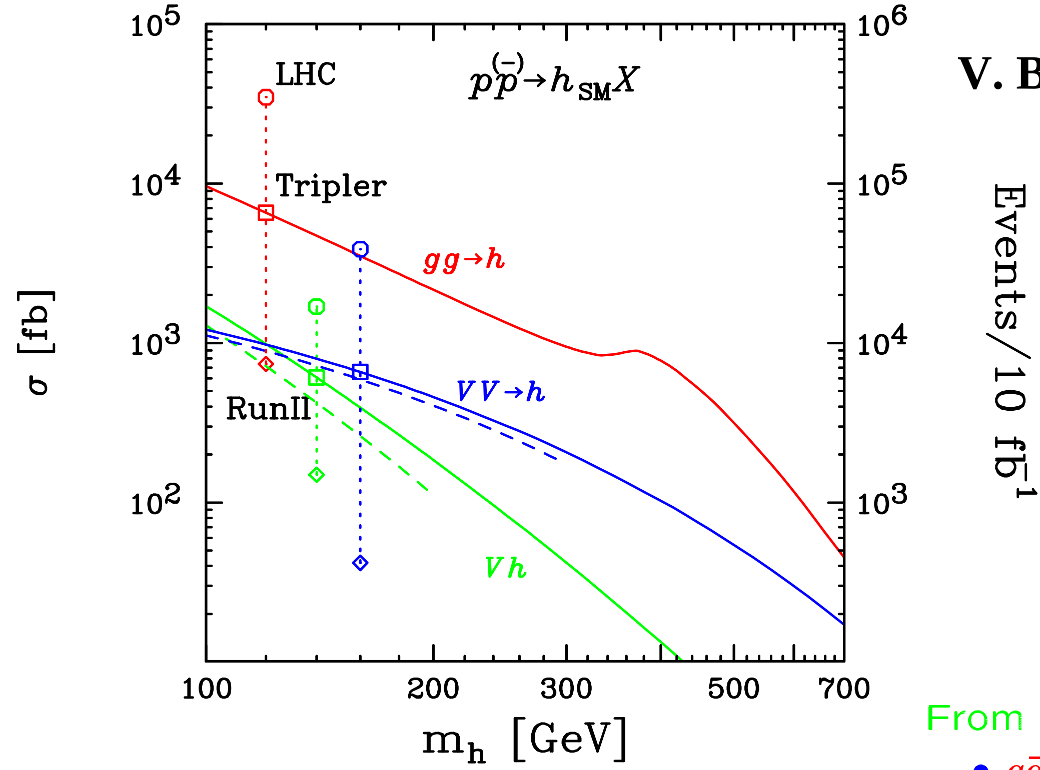
Triviality/consistency (lattice) upper bound:

(Ref.) U.M. Heller *et al.*, Nucl. Phys. B405, 555 (1993)

$$M_h < 710 \text{ GeV}$$

4. SM Higgs Boson: Production

Total Production Cross section



Tripler

V. Barger et al., PLB 478, 224 (2000)

From $\sqrt{s} = 2$ to 5.4 TeV,

- $q\bar{q} \to Vh$ cross section enhanced by 4;

(pp collider cross section lower by 25%);

- $gg \to h$ cross section enhanced by 10–30;
- $VV \to h$ processes come up by 20.

4. SM Higgs Boson: Signals

Tripler

Signal rates for individual channels:

$$\sigma(Wh \to \ell\nu\ b\bar{b}) \approx 130\text{ fb} \quad (m_h \approx 120\text{ GeV}),$$
$$\sigma(WW^* \to \ell\nu\ \ell\nu) \approx 140\text{ fb} \quad (m_h \approx 160\text{ GeV}),$$
$$\sigma(ZZ \to 4\ell) \approx 2\text{ fb} \quad (m_h \approx 220\text{ GeV}),$$
$$\sigma(ZZ \to 2\ell\ 2\nu) \approx 7\text{ fb} \quad (m_h \approx 300\text{ GeV}),$$
$$\sigma(WW \to \ell\nu\ jj) \approx 50\text{ fb} \quad (m_h \approx 500\text{ GeV}).$$

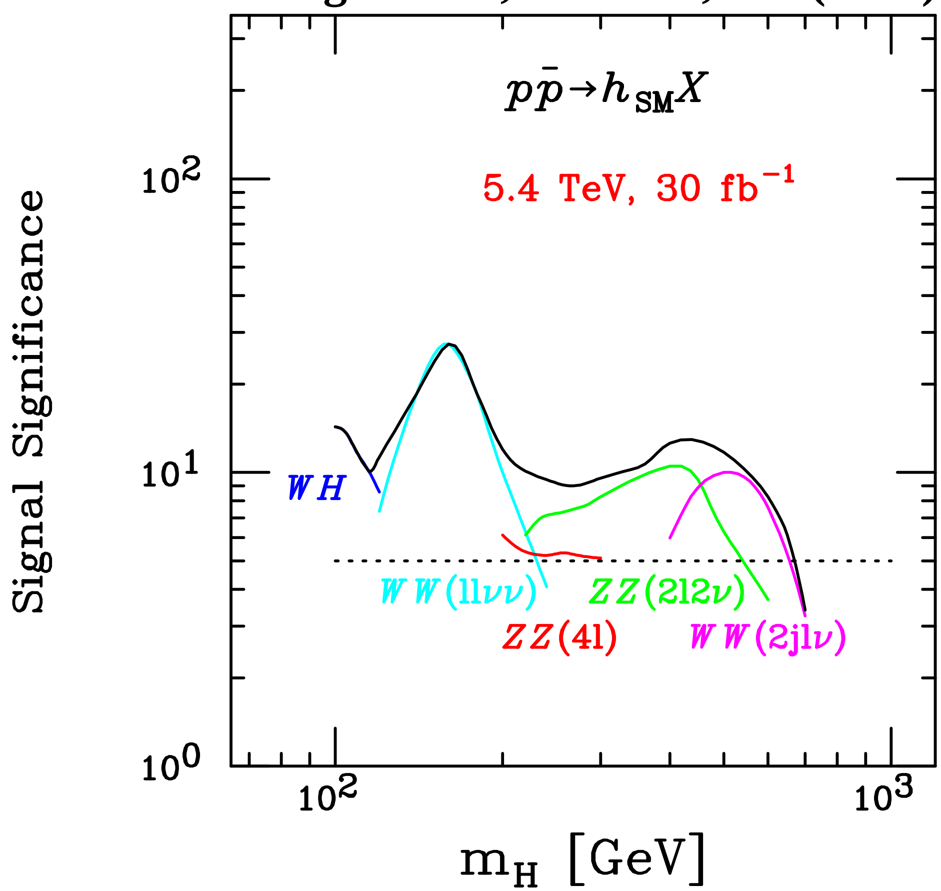
SM Backgrounds considered:

$$Wjj,\ Wb\bar{b},\ WW \to \ell\nu\ b\bar{b}$$
$$t\bar{t},\ WW^* \to \ell\nu\ \ell\nu$$
$$Z(\gamma)Z^* \to 4\ell$$
$$Z(\gamma)Z^* \to 2\ell\ 2\nu$$
$$Wjj,\ WW^* \to \ell\nu\ jj.$$

4. SM Higgs Boson: Tripler vs. LHC

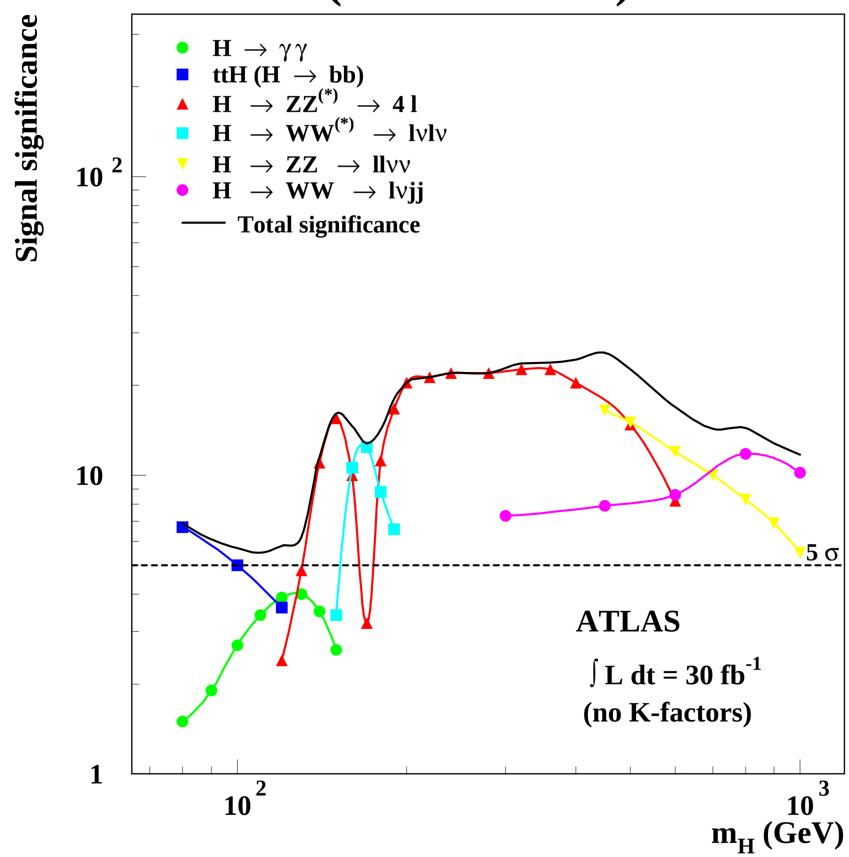
Tripler

V. Barger et al., PLB 478, 224 (2000)



LHC

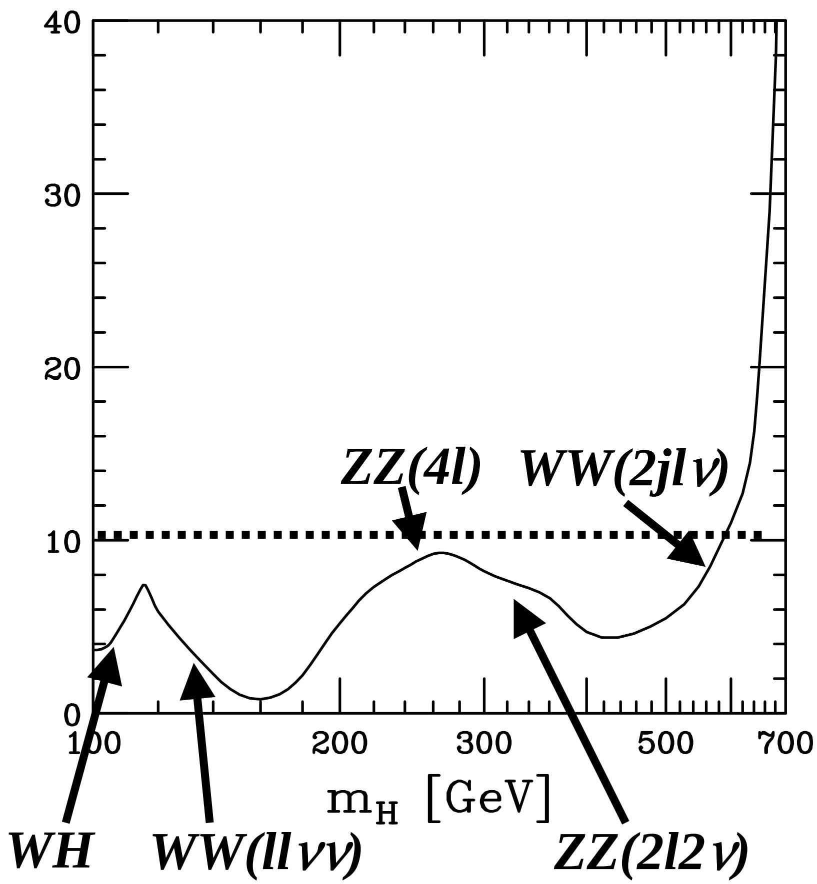
(ATLAS TDR)



4. SM Higgs Boson: "5σ" Luminosity

Tripler

V. Barger et al., PLB 478, 224 (2000)



Luminosity needed for
a 5σ discovery

M_h ~ 580 GeV with 10 fb^{-1}
M_h ~ 680 GeV with 40 fb^{-1}

close to the trivial/consistency bound!

4. SM Higgs Boson: if M_h < 130 GeV…

Machine	Discovery Channel	Coupling	$\int \mathcal{L}\, dt (5\sigma)$
Tripler	$q\bar{q}' \to WH$ (via $H \to b\bar{b}$)	WWH	7.5 fb^{-1} [1]
LHC	$gg \to t\bar{t}H$ (via $H \to b\bar{b}$) $gg \to H \to \gamma\gamma$	Yukawa	30 fb^{-1} [2]
	$qq' \to qq'WW \to qq'H$ (via $H \to \tau\tau \to e\mu + \not{E}_T$)	WWH	60 fb^{-1} [3]

References

[1] V. Barger, K. Cheung, T. Han, C. Kao, T. Plehn, and R-J. Zhang, Phys. Lett. B **478**, 224 (2000).

[2] ATLAS: Detector and Physics Performance Technical Design Report, vol. 1, CERN-LHCC-99-14, ATLAS-TDR-14 (1999); vol. 2, CERN-LHCC-99-15, ATLAS-TDR-15 (1999).

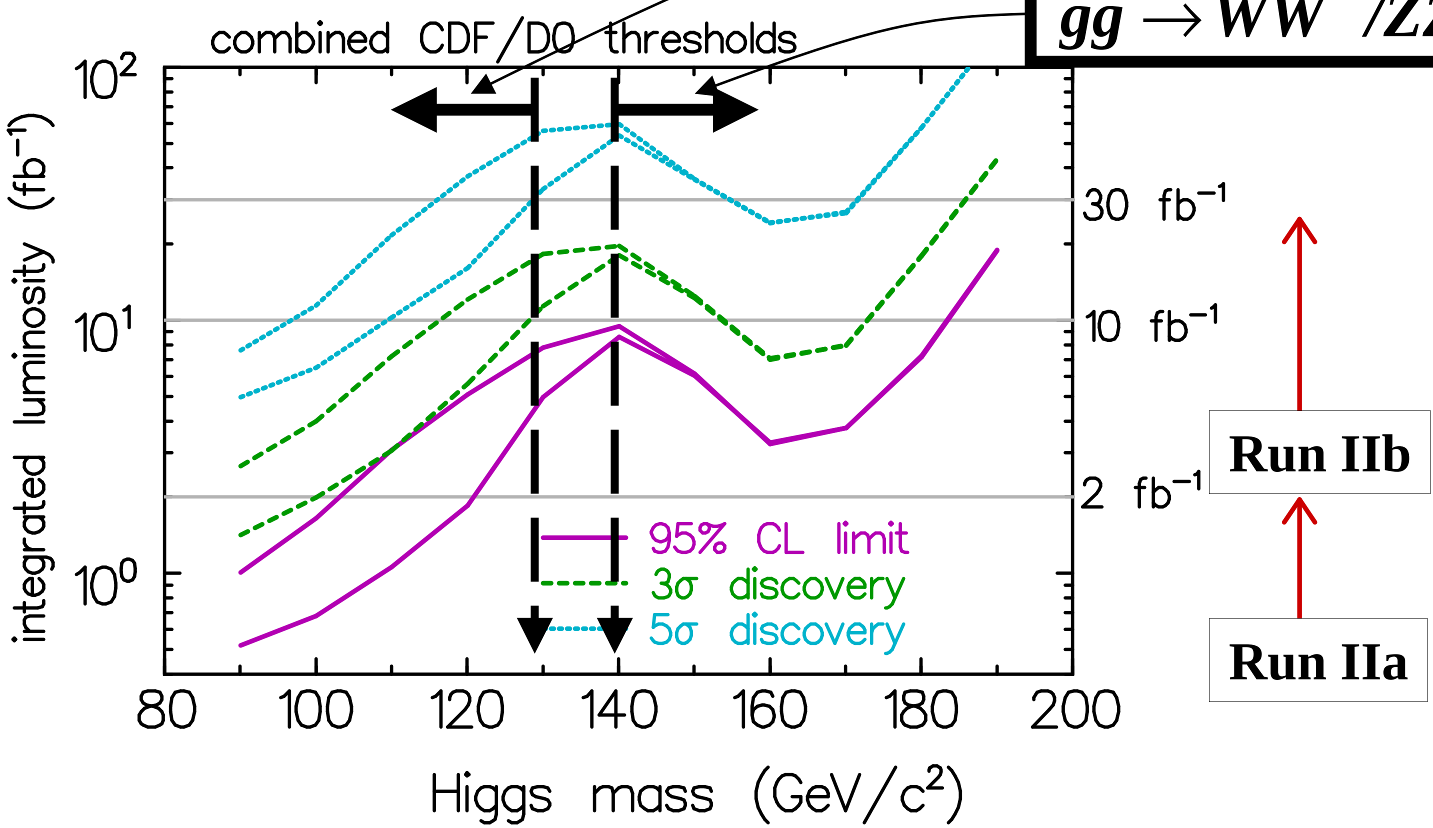
[3] T. Plehn, D. Rainwater, and D. Zeppenfeld, Phys. Rev. D **61**, 093005 (2000).

4. SM Higgs Boson: Prospect in Run II

Tevatron (Run IIa/IIb)

$q\bar{q} \to W(Z)h \to lb\bar{b}X$

$gg \to WW^*/ZZ^* \to l^+l^-X$



Source: Higgs working group report (SUSY/Higgs Workshop, 1998)

5. mSUGRA

Possible constraints

$\mu > 0$ ($b \rightarrow s\gamma$, $g_\mu - 2$)

+ $\tan\beta$ = 5-60 (M_h^{LEP})

+ relic density

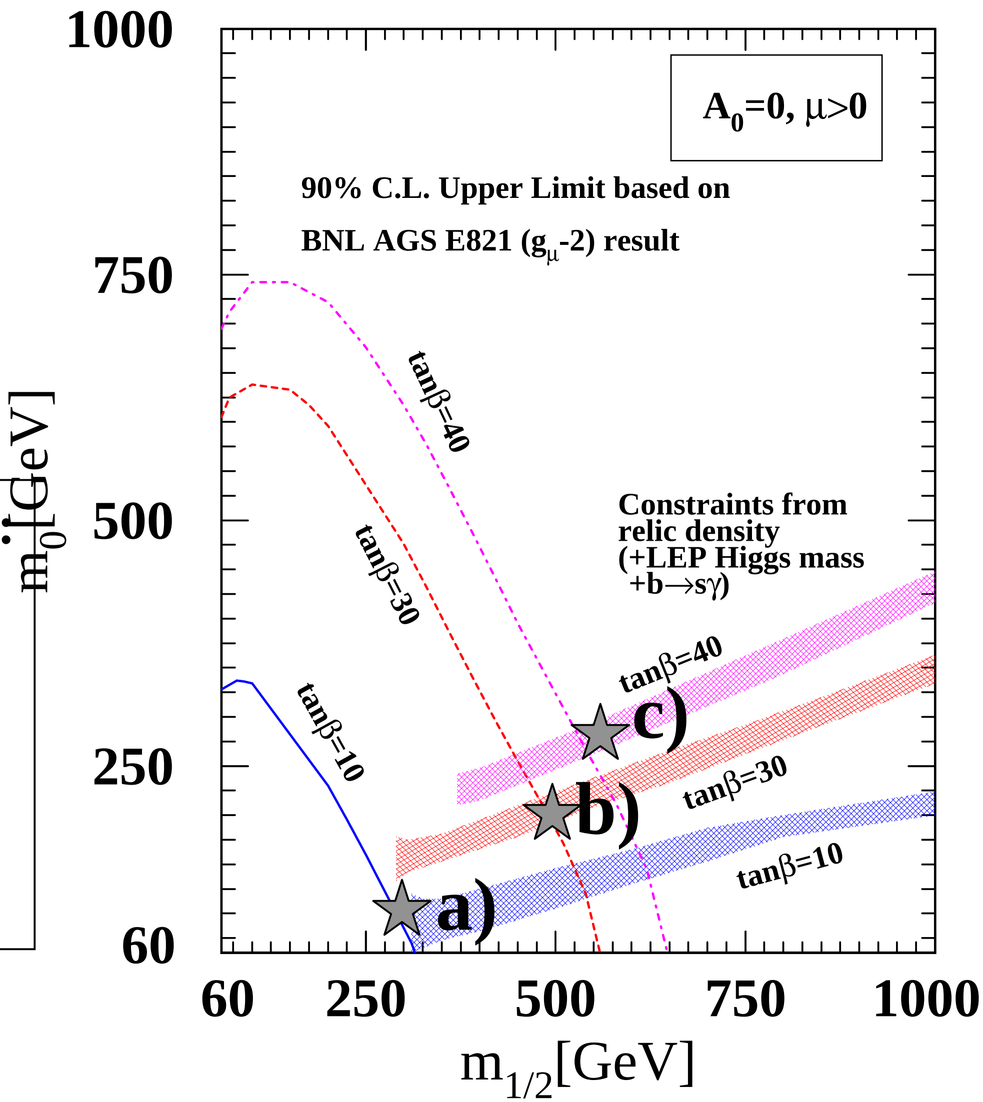
→ $M_{\tilde{g}} < 1.4$ TeV

Example of $\tilde{g}$, $\tilde{u}_L$, $\tilde{t}_1$, $\tilde{\tau}_1$, $\tilde{\chi}_1^0$ masses:

a) m_0=100, $m_{1/2}$=300
734, 654, 482, 152, 123

b) m_0=200, $m_{1/2}$=500
1173, 1050, 805, 226, 213

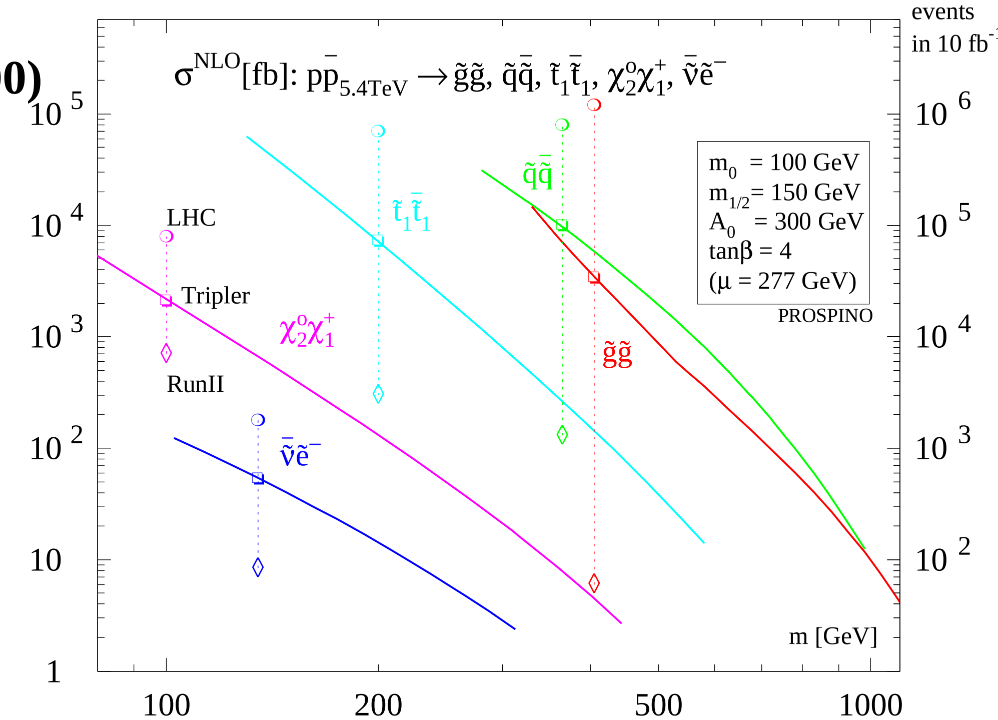
c) m_0=275, $m_{1/2}$=550
1284, 1158, 1081, 248, 236



5. mSUGRA – Production Cross Section

Tripler

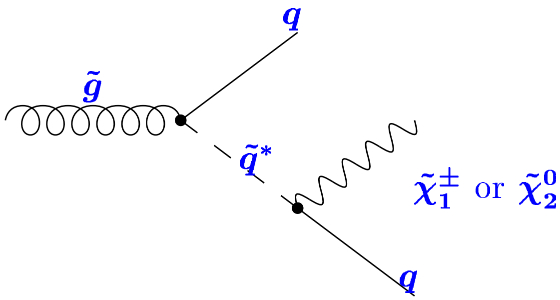
V. Barger et al., PLB 478, 224 (2000)



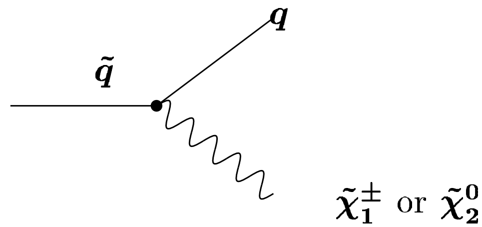
From $\sqrt{s} = 2$ to 5.4 TeV,

- e.w. processes $\chi_1^{\pm}\tilde{\chi}_2^0$, $\tilde{\ell}\tilde{\nu}$: a factor 4–10;
  (pp collider cross section lower by 20%);
- QCD $\tilde{t}^*\tilde{t}$, $\tilde{g}\tilde{g}$ processes: a factor 20–500!

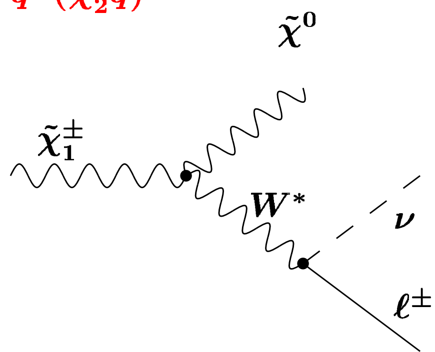
Decay Modes

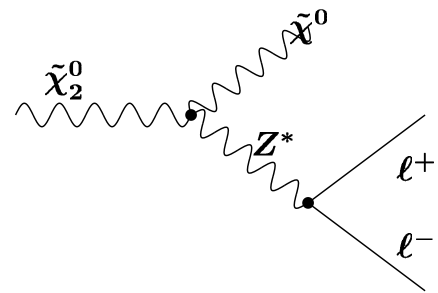


$\tilde{g} \to \tilde{\chi}_1^\pm q q' \; (\tilde{\chi}_2^0 q \bar{q})$



$\tilde{q} \to \tilde{\chi}_1^\pm q' \; (\tilde{\chi}_2^0 q)$





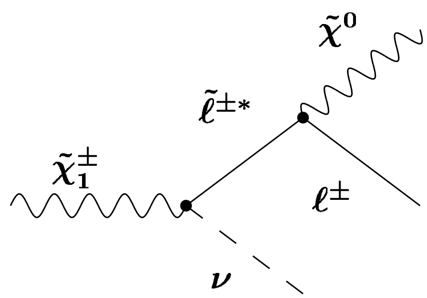
Experimental Signatures

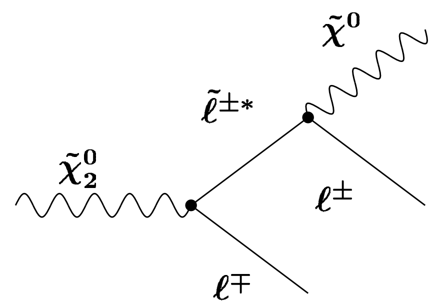
a) $\not{E}_T$+jets+0 lepton

b) $\not{E}_T$+jets+1 lepton

c) Trilepton

d) Like-sign dilepton





$\tilde{\chi}_1^\pm \to \ell^\pm \nu \tilde{\chi}^0$

$\tilde{\chi}_2^0 \to \ell^+ \ell^- \tilde{\chi}^0$

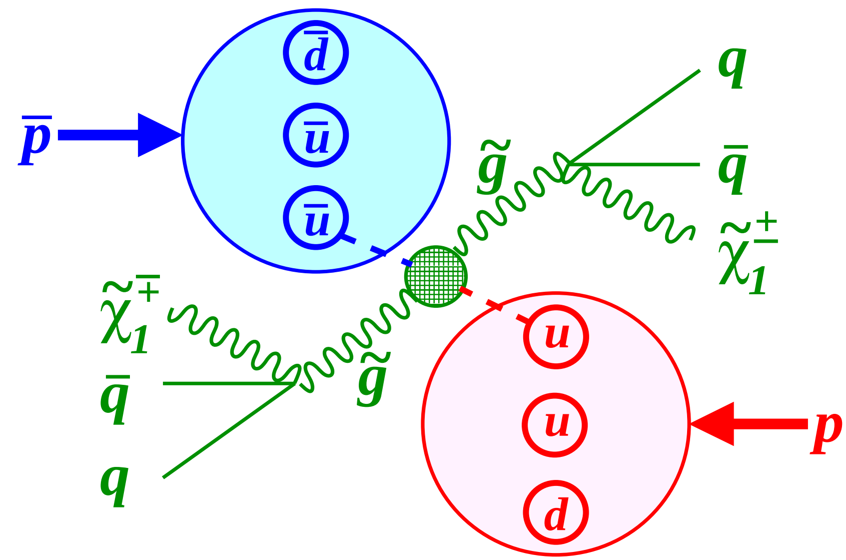
Main Reaction:

$p\bar{p} \rightarrow q\bar{q}$

(a) $\not{E}_T$+jets+0l

(b) $\not{E}_T$+jets+1l

Experimental Signatures



Signal $p\,\bar{p} \rightarrow \tilde{g}\,\tilde{g}$

$\rightarrow (q\bar{q}\;\tilde{\chi}_1^+)\;(q\bar{q}\;\tilde{\chi}_1^-)$

$$\rightarrow \begin{cases} 8 \text{ jets} + 2\;\tilde{\chi}_1^0 \\ 4 \text{ jets} + 1\;\ell + 1\;\nu + 2\;\tilde{\chi}_1^0 \end{cases}$$

Background $p\,\bar{p} \rightarrow t\,\bar{t}$

$\rightarrow (b\;W^+)\;(\bar{b}\;W^-)$

$$\rightarrow \begin{cases} 6 \text{ jets} \\ 4 \text{ jets} + 1\;\ell + 1\;\nu \end{cases}$$

Note: ν's/$\tilde{\chi}_1^0$'s: stable (escaping the detector)

Analysis:

(a) $\not{E}_T$+jets+0l
(b) $\not{E}_T$+jets+1l

Assume: 30 fb^{-1}

Event Generation and Selection

Experimental signatures:

- $\not{E}_T$ + jets + no leptons
- $\not{E}_T$ + jets + 1 lepton

Generation (physics processes in $p\bar{p}$ collisions):

- SUSY: gluino and squark pair-production
- SM : $t\bar{t}$, W, Z, diboson, and QCD

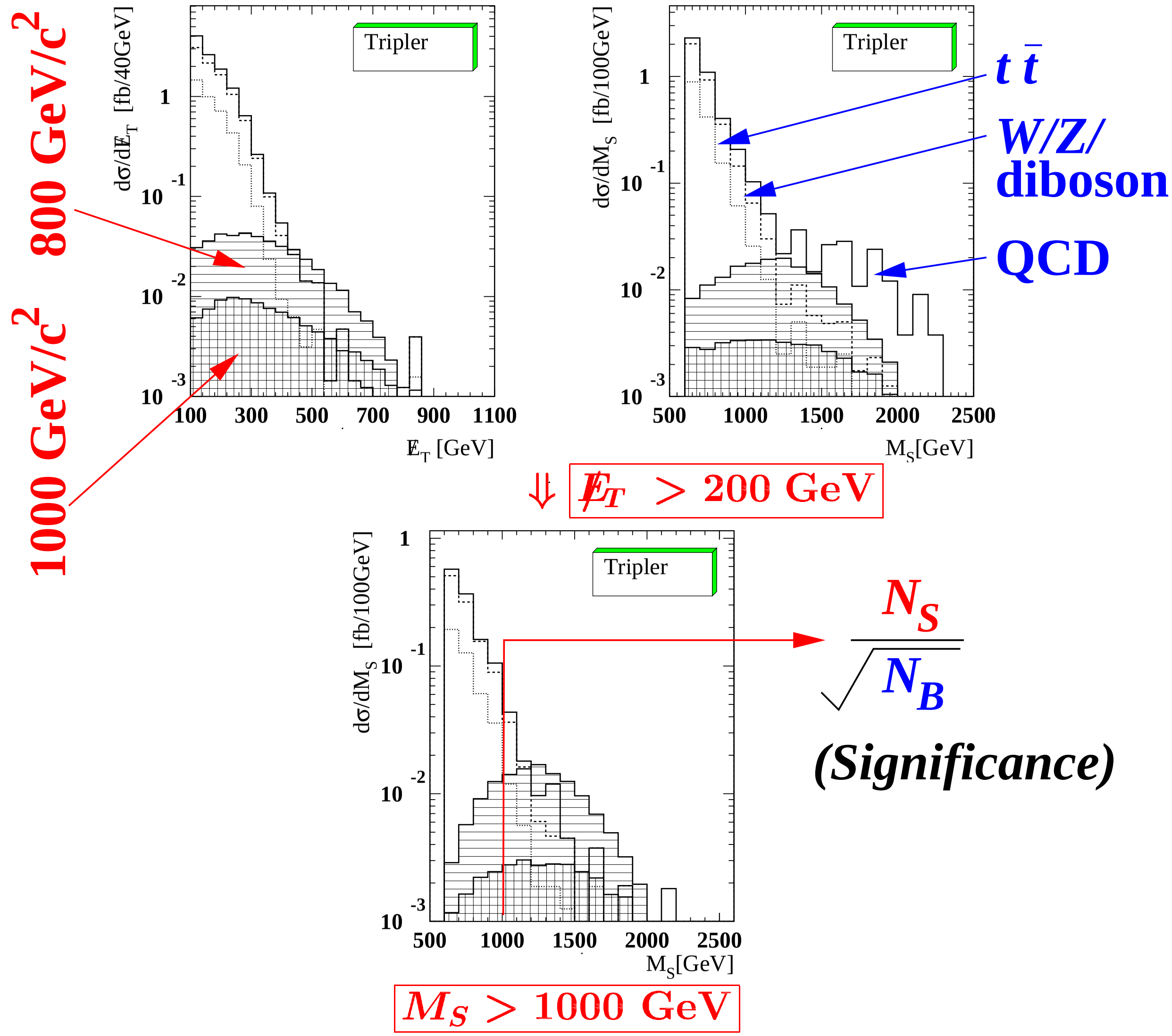
Selection (kinematical variables):

- E_T for each particle, N_{jet}, N_ℓ, $M_T(\ell, \not{E}_T)$, $\not{E}_T$, $M_S \equiv \not{E}_T + \sum E_T^{jet}$ from the detector simulation

Tripler	jets + $\not{E}_T$	1ℓ + jets + $\not{E}_T$
N_{jet} ($E_T > 15$ GeV)	≥ 6	≥ 4
N_ℓ ($p_T > 15$ GeV/c)	0	1
$\Delta\phi(jet, \not{E}_T)$	$> 30°$	$> 30°$
$\not{E}_T$	> 200 GeV	> 330 GeV
M_S	> 1000 GeV	> 600 GeV
$M_T(\ell, \not{E}_T)$	n.a.	> 160 GeV/c^2

Significance:

Example: $\tilde{g}/\tilde{q}$ (800 and 1000 GeV/c^2) in $\not\!\!E_T$+jets

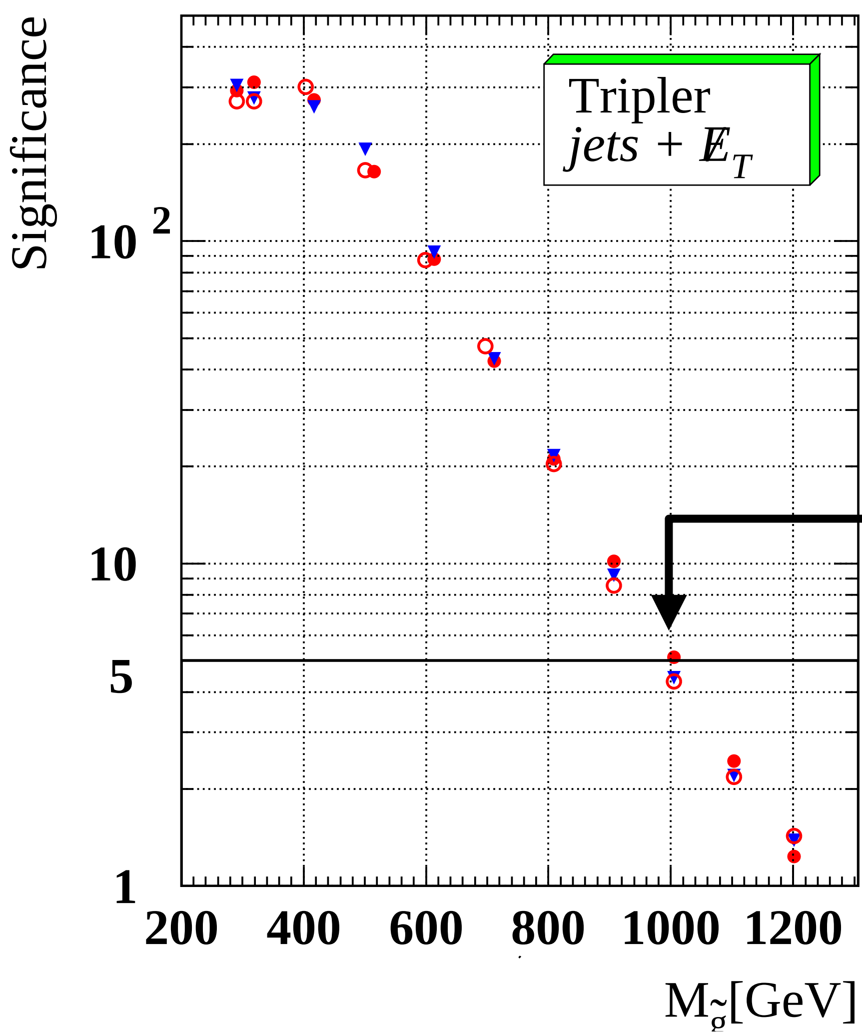


$$\frac{N_S}{\sqrt{N_B}}$$

(Significance)

$\not{E}_T$+jets: $M_{\tilde{q}} \simeq M_{\tilde{g}}$

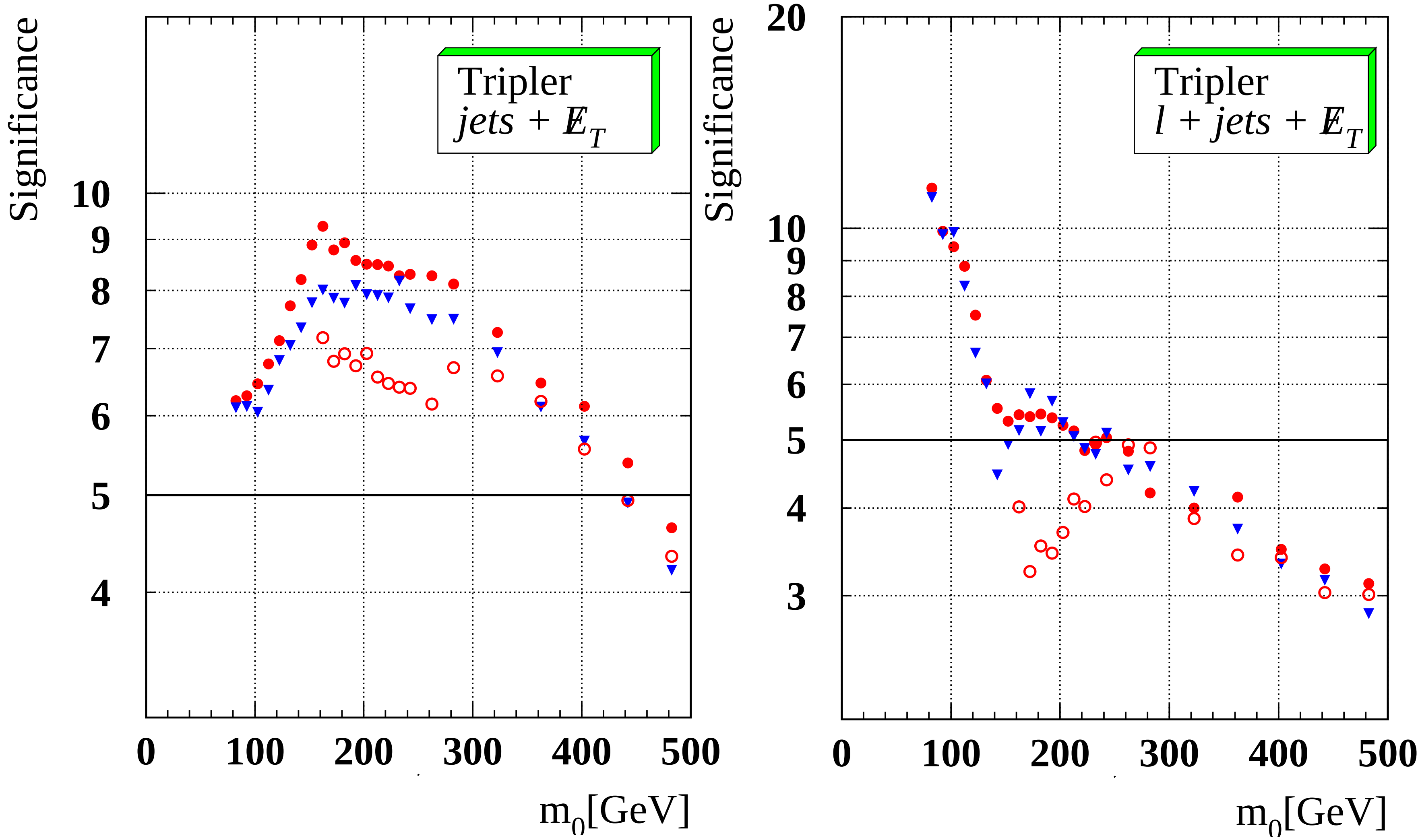
$\tan\beta$
3 (●)
10 (▼)
30 (○)



$m_{1/2} \simeq 420$ GeV

→ No $\tan\beta$ dependence

m_0 dependence ($m_{1/2}$ = 410 GeV)

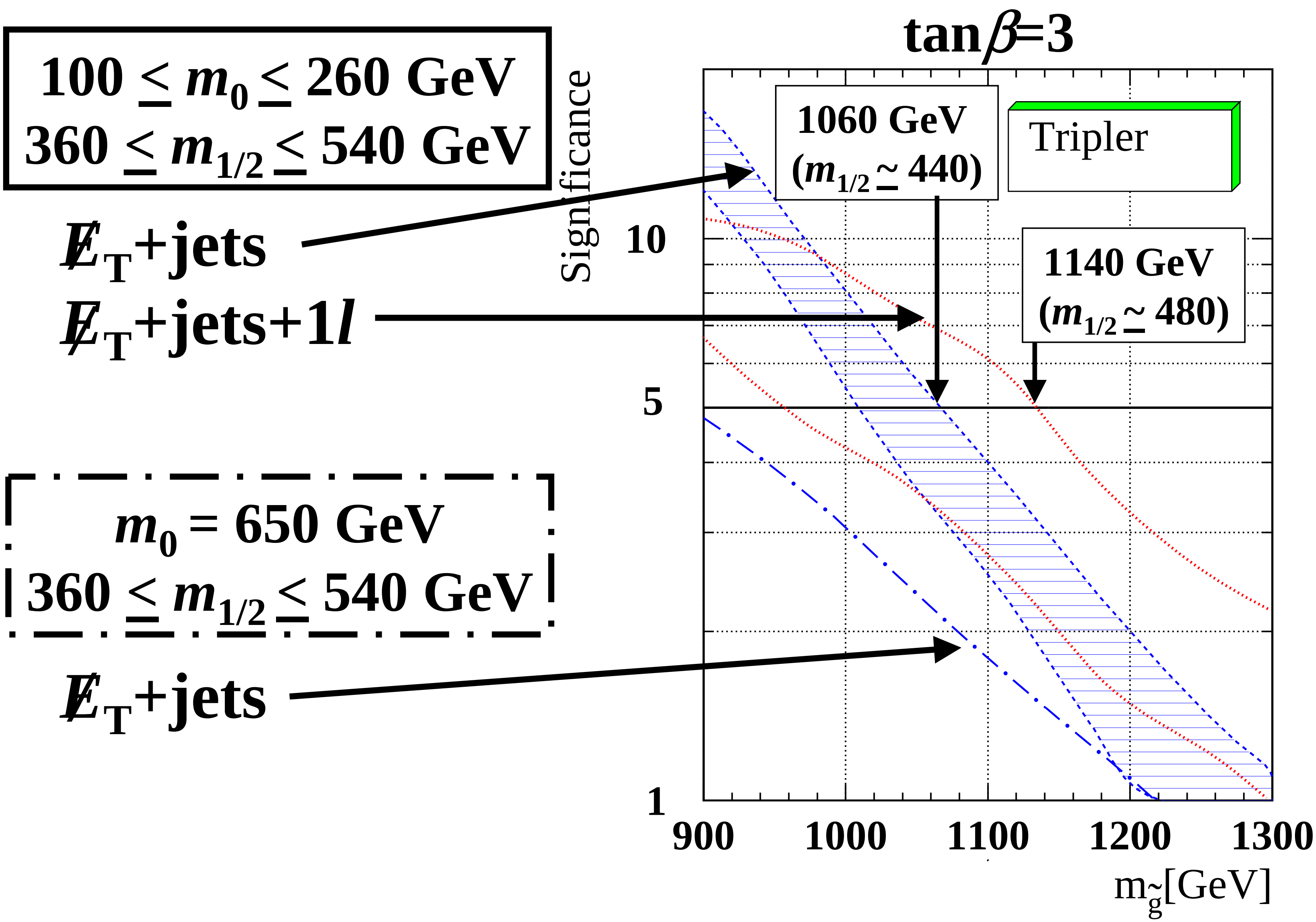


m_0 dependence ($m_{1/2}$ = 410 GeV)

Decays modes of the chargino to characterize jet and lepton multiplicities in SUSY events.

$[m_{1/2} = 410]$	SUSY Masses		Decaysof $\tilde{\chi}_1^\pm$		
m_0 Range	lighter $\longleftarrow$ $\tilde{\chi}_1^\pm$	heavier $\longrightarrow$	$W^\pm\tilde{\chi}_1^0$	$\tilde{\tau}_1\nu$ (or $\tau\tilde{\nu}$)	$\tilde{\ell}_L\nu$ (or $\ell\tilde{\nu}$)
$\lesssim 150$	$\tilde{\tau}_1, \tilde{\ell}_R, \tilde{\nu}$	—	$\surd$	$\surd$	$\surd$
$150 - 300$	$\tilde{\tau}_1, \tilde{\ell}_R$	$\tilde{\nu}$	$\surd$	$\surd$	—
$\gtrsim 300$	—	$\tilde{\tau}_1, \tilde{\ell}_R, \tilde{\nu}$	$\surd$	—	—

(Units : GeV/c^2)


100 ≤ m_0 ≤ 260 GeV
360 ≤ $m_{1/2}$ ≤ 540 GeV
$\not{E}_T$+jets
$\not{E}_T$+jets+1l
m_0 = 650 GeV
360 ≤ $m_{1/2}$ ≤ 540 GeV
$\not{E}_T$+jets
tanβ=3
Significance
1060 GeV
($m_{1/2} \simeq$ 440)
Tripler
1140 GeV
($m_{1/2} \simeq$ 480)
10
5
1
900
1000
1100
1200
1300
$m_{\tilde{g}}$[GeV]

Summary: $\not{E}_T$+Jets+X

1. **Weak tanβ dependence on the gluino mass limit up to 30. (we are studying with higher tanβ values.)**

2. **150 < m_0 < 300 GeV → $m_{1/2}$ up to 440 GeV using the 0*l* channel (tanβ = 3-30)**

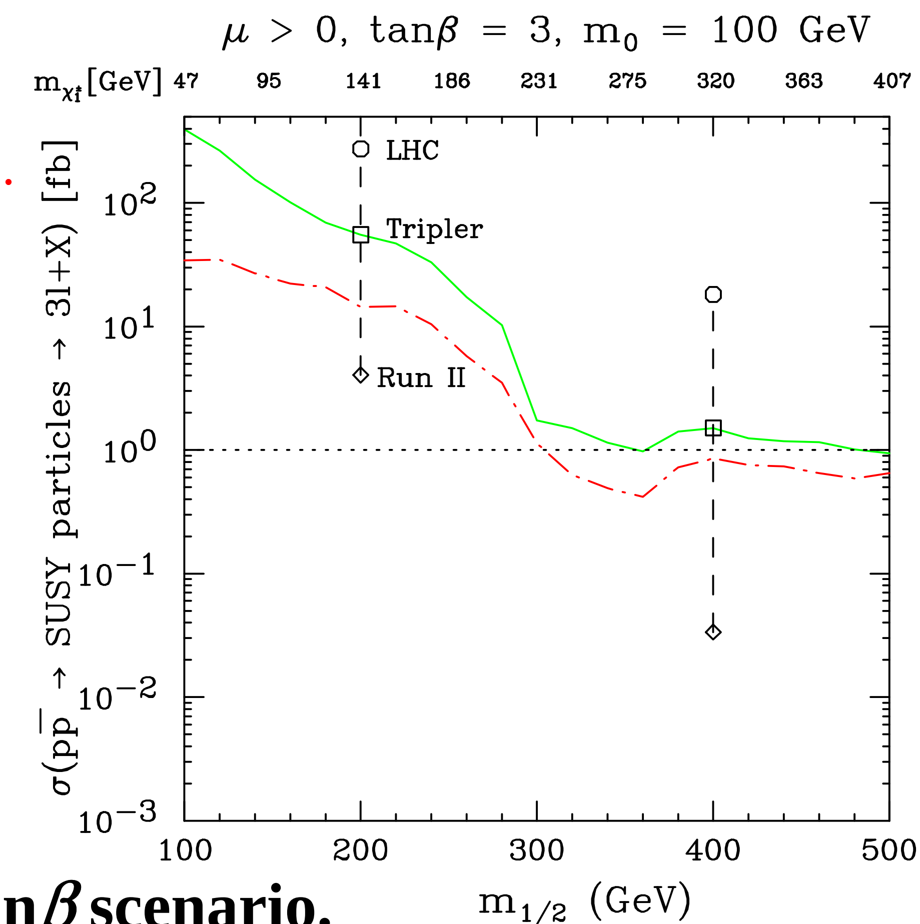
   $m_0 \simeq$ 100 GeV → $m_{1/2}$ up to 480 GeV using the 1*l* channel (tanβ = 3-10)

(c) Trilepton

$m_0 = 100$ GeV
$100 \leq m_{1/2} \leq 500$ GeV

(by ISAJET)

$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0,\ \tilde{\ell}^*\tilde{\ell},\ \tilde{\ell}\tilde{\nu} \ \rightarrow \ 3\ell + E_T^{miss}.$



SM Backgrounds:

$W\gamma^*,\ WZ^* \ \rightarrow \ 3\ell\ \nu,$
$t\bar{t},\ ZZ(\gamma) \ \rightarrow \ 3\ell\ \nu.$

→ Need to study the large tanβ scenario.

(d) LS Dilepton

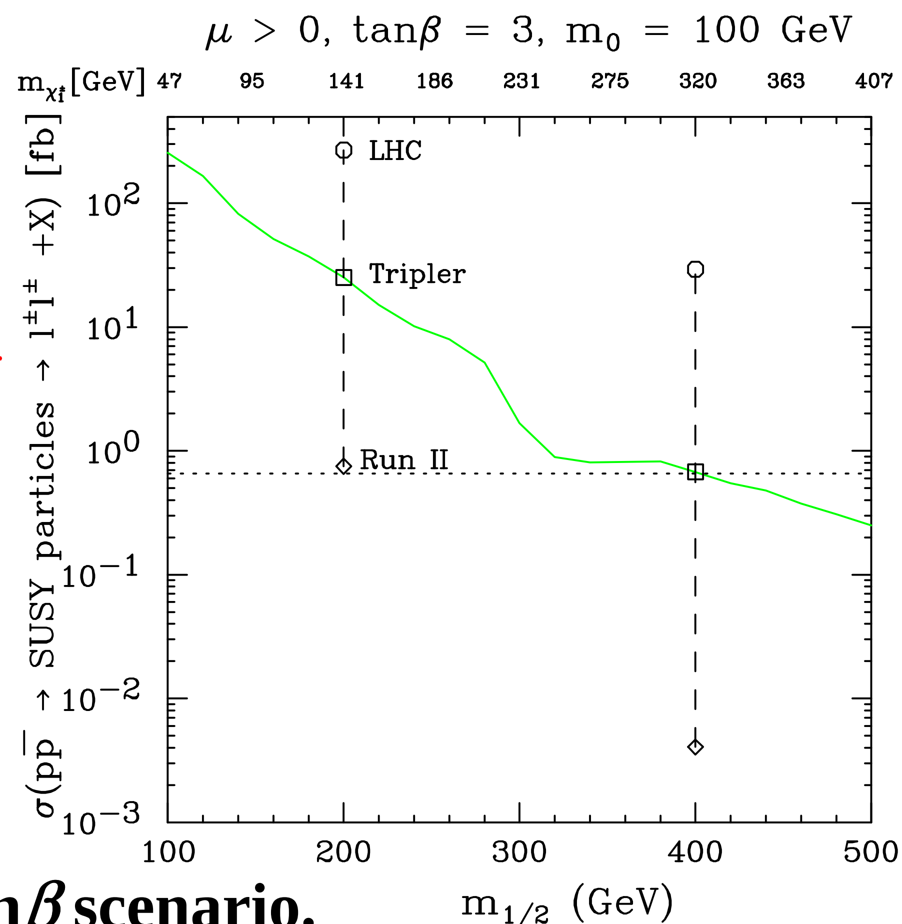
$m_0 = 100$ GeV
$100 \leq m_{1/2} \leq 500$ GeV

(by ISAJET)

$\tilde{g}\tilde{g},\ \tilde{q}^*\tilde{q},\ \tilde{g}\tilde{q},\ \tilde{\chi}^{\pm}\tilde{q} \rightarrow \ell^{\pm}\ell^{\pm} + \text{jets} + E_T^{miss}.$

SM Backgrounds:

$W\gamma^*,\ WZ^*,\ ZZ(\gamma) \rightarrow \ell^{\pm}\ell^{\pm} + E_T^{miss},$
$t\bar{t} \rightarrow \ell^{\pm}\ell^{\pm} + \text{jets} + E_T^{miss}.$



→ **Need to study the large tanβ scenario.**

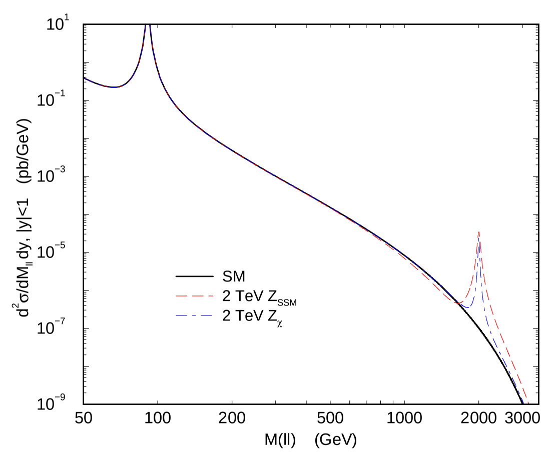
6. Other New Physics

- New gauge bosons Z'

$$\mathcal{L} = -g_2 \sum_i \bar{\psi}_i \gamma_\mu (\epsilon_{iL} P_L + \epsilon_{iR} P_R) \psi_i Z'^\mu,$$

One finds a 5σ signal with 20 fb^{-1} for

Tevatron	$M_{Z'_\chi} = 1.1$ TeV, $M_{Z'_S} = 1.2$ TeV
Tripler	$M_{Z'_\chi} = 2.6$ TeV, $M_{Z'_S} = 2.9$ TeV
pp :	$M_{Z'_\chi} = 2.0$ TeV, $M_{Z'_S} = 2.1$ TeV
LHC	$M_{Z'_\chi} = 5.1$ TeV, $M_{Z'_S} = 5.3$ TeV

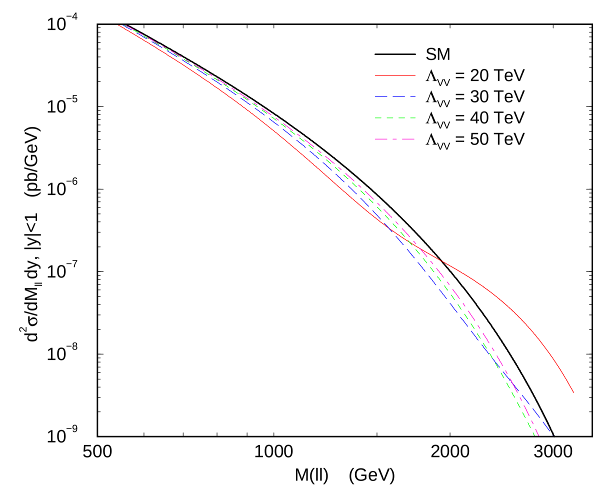


- Contact interactions

$$L_{\rm NC} = \sum_q \sum_{\alpha,\beta={\rm L,R}} \frac{\pm 4\pi}{(\Lambda_\pm^{\alpha,\beta})^2} (\bar{e}_\alpha \gamma_\mu e_\alpha) \left(\bar{q}_\beta \gamma^\mu q_\beta\right)$$

One finds 95% C.L. exclusion:

Tevatron	(2 TeV, 20 fb^{-1})	$\Lambda_+ = 36$ TeV
Tripler	(5.4 TeV, 20 fb^{-1})	$\Lambda_+ = 61$ TeV
pp :	(5.4 TeV, 20 fb^{-1})	$\Lambda_+ = 34$ TeV
LHC	(14 TeV, 100 fb^{-1})	$\Lambda_+ = 84$ TeV



7. Top/Botom Physics

To be filled…

8. Summary

- **We proposed an energy upgrade of the Fermilab Tevatron (Tripler): E_{cm} = 5.4 TeV in *p-pbar* collisions**

- **The Tripler extends:**

  $M_{h(SM)}$ **up to 680 GeV**

  $M_{\tilde{g}}$ **up to 1100 GeV**

  $M_{Z'}$ **up to 2.6 TeV**

  $\Lambda_{contact}$ **up to 64 TeV**

8. Summary (cont'd)

- **For ultimate mass reach, LHC (14 TeV *pp* collisions) is more powerful than the Tripler. *e.g.*, gluino mass up to 2000 GeV or above**
- **The Tripler offers the only way to reach the discovery potential of a SUSY mass scale of 1000 GeV using an existing facility in the U.S.**
- **The Tripler can be a good bridge between Tevatron era and future collider machines (e^+e^- collider, $\mu^+\mu^-$ collider, VLHC) in the U.S. high-energy physics program.**

Prospect on mSUGRA

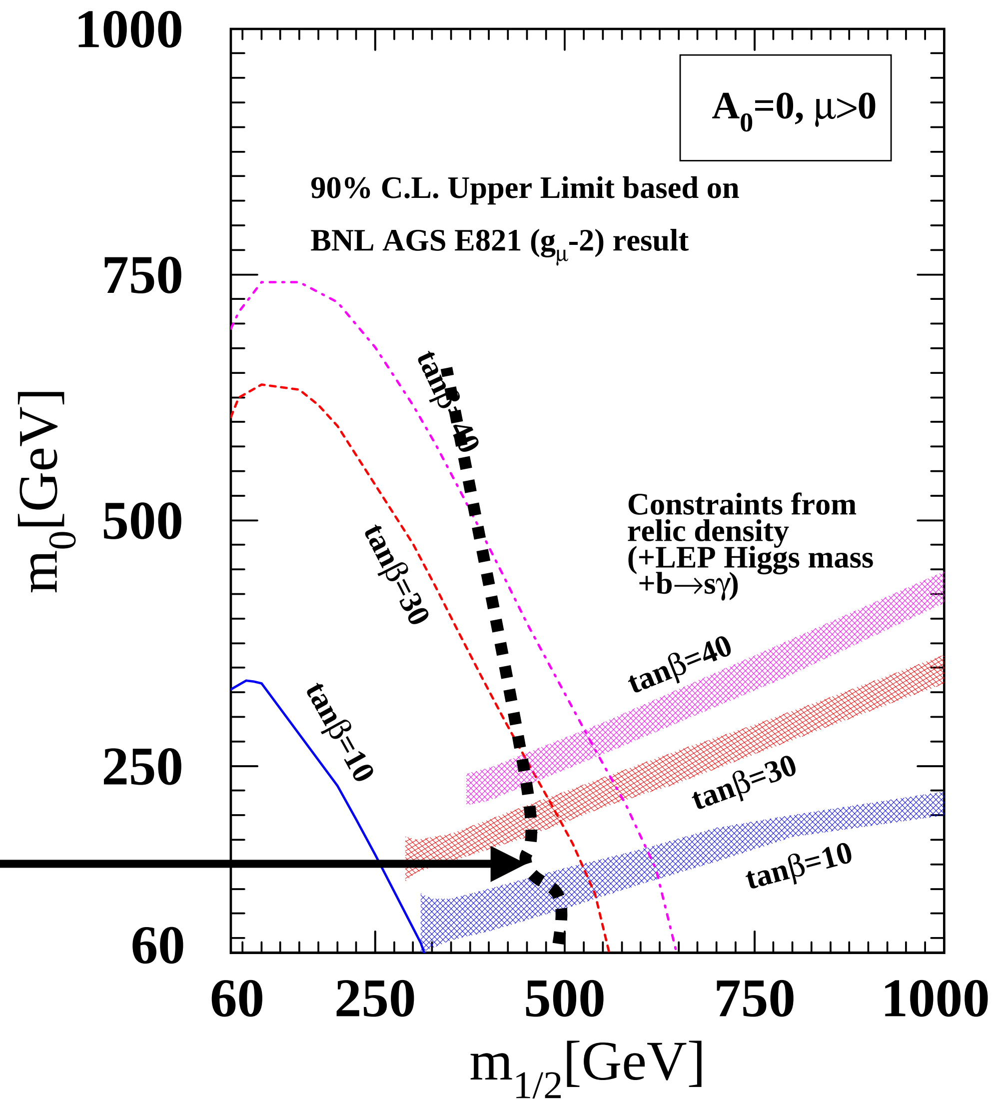
Possible constraints

$\mu > 0$ ($b \rightarrow s\gamma$, $g_\mu - 2$)

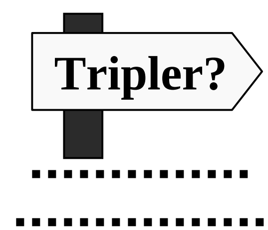
+ $\tan\beta = 5\text{-}60$ (M_h^{LEP})

+ relic density

→ $M_{\tilde{g}} < 1.4$ TeV



Tripler's 5σ Reach
$\tan\beta = 10$


Tripler?