

# (NEW) PHYSICS AT THE LHC

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- News from the backgrounds
- News from the Higgs
- It's supersymmetry!
- ...or maybe not...

n.b. Most figures in this talk are preliminary results!

## PHENO 05: GOODBYE TO THE FLUXTUBE



MGO: Thank you for tons of fun, we will miss you!

# QCD AND BACKGROUNDS

Remember LHC: flooded by QCD, few signal events, trigger decides it all

Recent developments [my personal list of favorites]

- MC@NLO: matching of NLO and parton shower [Frixione & Webber]
  - NNLO cross sections for Higgs and DY [Harlander, Kilgore; Anastasiou, Melnikov, Petriello;...]
  - automatic NLO calculations [Giele & Glover; Binoth, Guillet, Heinrich, Pilon, Schubert; Grace]
  - Sherpa: third LHC Monte Carlo [Krauss, Schumann,...]
  - Madevent: perfect experimentalist-friendly Madgraph [Maltoni & Stelzer]
  - conceptual: intermediate states and SCET [Beneke, Chapovski, Kauer, Signer, Zanderighi]
  - conceptual: multi-gluon amplitudes at LO or NLO  
[Britto, Cachazo, Feng, Svrcek, Witten; Bern, Dixon, Kosover; Badger, Glover, Khoze;...]
  - .....
- ⇒ important work for the LHC, should be standing here at Pheno'06-08

# HIGGS AT THE LHC: 1

## We know we will see it, thanks to WBF channels

[Rainwater, Zeppenfeld, Kauer, TP]

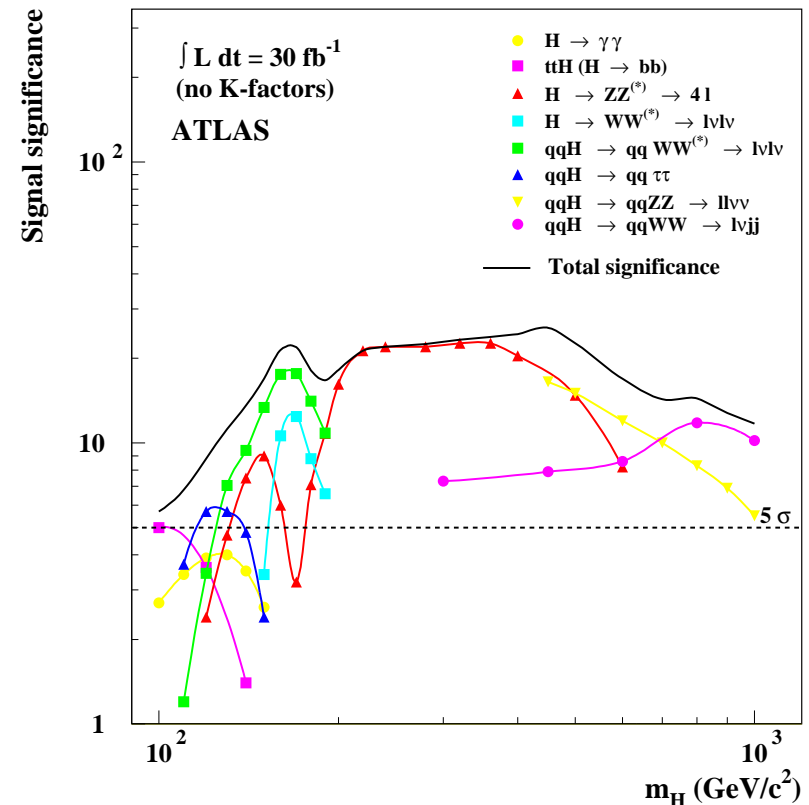
- full detector simulations  
[ATLAS-Wisconsin; Jakobs,...; Nikitenko,...]
- NLO production cross sections  
[Han, Valencia, Willenbrock; Figy, Oleari, Zeppenfeld,...]
- stable for non-standard Higgs sectors  
[SUSY: TP, Rainwater, Zeppenfeld; Gunion: Alves, TP, Rainwater]

## Problems with $gg \rightarrow H \rightarrow WW$

- only  $m_H \gtrsim 150 \text{ GeV}$  [Bernhardt, Dreiner, Schumacher]
- background  $gg \rightarrow WW$  through one-loop  
[Binoth, Ciccolini, Kauer, Krämer; Dührssen, Jacobs, v.d.Bij,...]

## Bottom parton issues resolved [charged Higgs reach reduced, see J. Alwall's talk]

- conceptual problem with bottom partons resolved [Boos, TP, Maltoni, Willenbrock,...]
- NLO  $gg \rightarrow b\bar{b}H$  and NNLO  $b\bar{b} \rightarrow H$  agree [Dittmaier, Spira,... ; Dawson,... ; Harlander & Kilgore]
- distributions checked for charged Higgs [Berger, Han, Jiang, TP; Alves & TP]



# HIGGS AT THE LHC: 2

## Coupling extraction at the LHC [Dührssen, Logan, Rainwater,...]

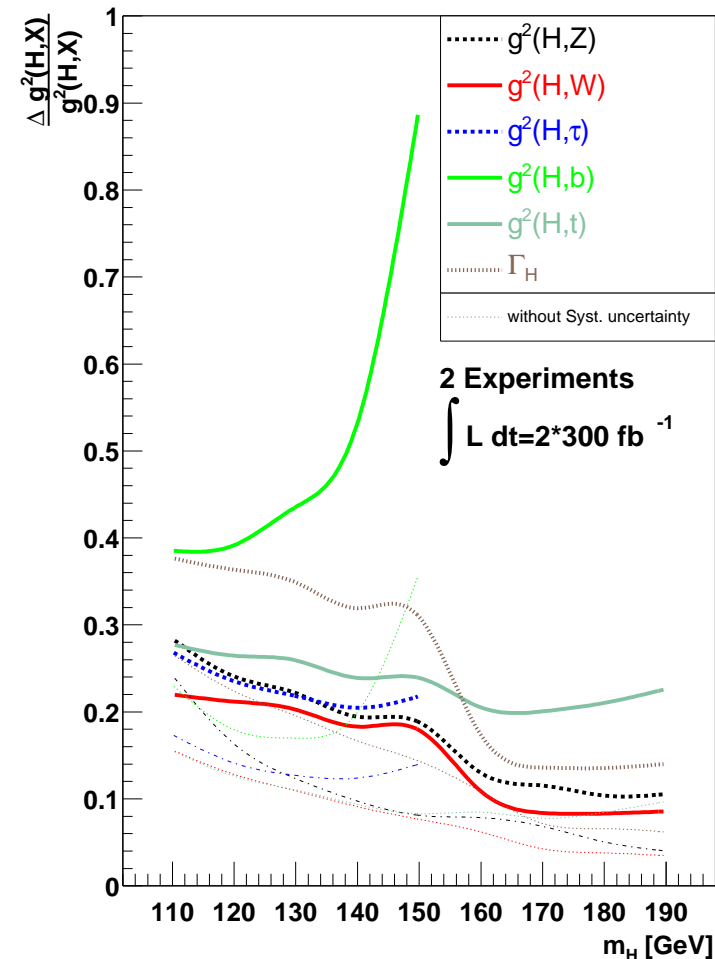
- motivation: e.g. little Higgs axions vs. Higgs? [Kilian, Rainwater, Reuter]
- measure:  $gg : H \rightarrow ZZ, WW, \gamma\gamma$   
 $VV : H \rightarrow ZZ, WW, \gamma\gamma, \tau\tau$   
 $t\bar{t}H : H \rightarrow WW, b\bar{b}...$   
 $\Rightarrow$  light Higgs: 7 good  $\sigma$  BR plus  $H \rightarrow b\bar{b}$
- extract: couplings to  $W, Z, t, b, \tau, g, \gamma$ , inv.  
 $\Rightarrow$  most complete: 8 parameters

## Fit to couplings and total width

- degeneracy:  $\sigma \text{ BR} \propto (g_p^2/\sqrt{\Gamma_H}) (g_d^2/\sqrt{\Gamma_H})$
- additional constraint:  $\sum \Gamma_i < \Gamma_H \Rightarrow \Gamma_H|_{\min}$
- $WW \rightarrow WW$  unitarity:  $g_{WWH} \lesssim g_{WWH}^{\text{SM}} \Rightarrow \Gamma_H|_{\max}$

## What next?

- fit to more observables, mass error [SM vs. SUSY?]
- Higgs self coupling: Atlas and CMS on the way [Baur, TP, Rainwater]



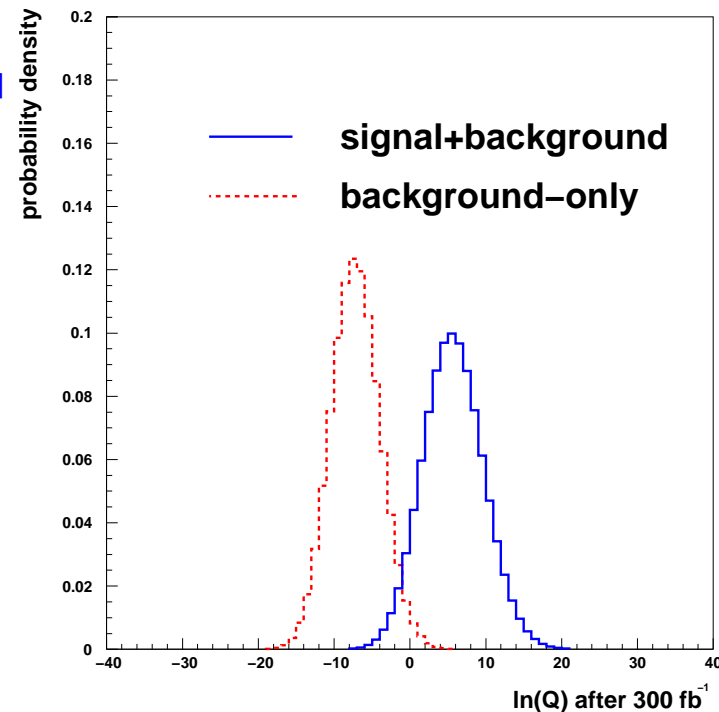
# HIGGS AT THE LHC: 3

## Higgs Yukawa coupling to light generations

- crucial to tell it is Yukawa
- parton level analysis: WBF  $H \rightarrow \mu\mu$ :  
 $\Rightarrow m_H = 120\text{GeV}$  and  $300\text{ fb}^{-1}$ :  $S=66$  and  $B=780(Z_{\text{QCD}})+99(Z_{\text{ew}})$
- $1.8\sigma$  without major cuts [TP & Rainwater; gg: Han, McElrath]
- cuts analysis tough  $\Rightarrow$  neural net promising?

## Statistical promise of WBF $H \rightarrow \mu\mu$ [Cranmer & TP, very preliminary]

- smearing only relevant for  $m_{\mu\mu}$  [mimick with large  $\Gamma_H$ ]
- no large irreducible backgrounds
- $\Rightarrow$  compute likelihood for each (good) event
- $\Rightarrow$  combine to likelihood for given luminosity
- $\Rightarrow$  upper limit on parton level significance
- $\Rightarrow$  WBF  $H \rightarrow \mu\mu$ : 3.7 sigma in  $300\text{ fb}^{-1}$
- $\Rightarrow$  ultimate pheno smartass tool



# SUPERSYMMETRY AT THE LHC: 1

## 10 years of discovering:

- (1) **possible discovery** — signals for new physics, exclusion of parameter space
  - (2) **measurements** — masses, cross sections, decays
  - (3) **parameter studies** — MSSM Lagrangean, SUSY breaking
- ⇒ at least 10% precision to be matched by phenomenology [QCD-theorist's nightmare]

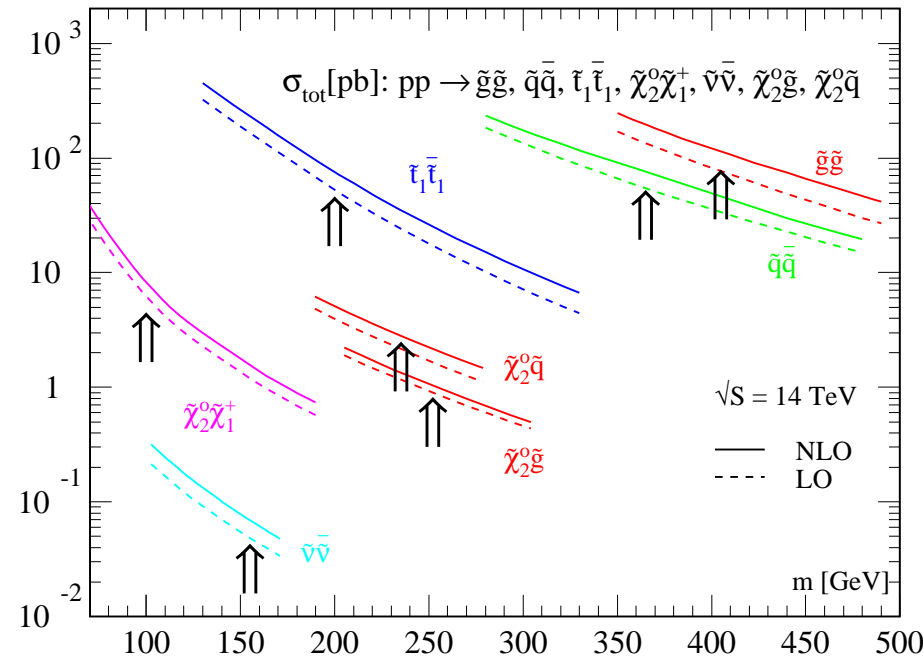
## SUSY signals [Prospino2: <http://pheno.physics.wisc.edu/~plehn>]

- jets and  $\cancel{E}_T$ :  $pp \rightarrow \tilde{q}\tilde{q}^*, \tilde{g}\tilde{g}, \tilde{q}\tilde{g}$
- funny tops:  $pp \rightarrow \tilde{t}_1\tilde{t}_1^*$
- like sign dileptons:  $pp \rightarrow \tilde{g}\tilde{g}$
- tri-leptons:  $pp \rightarrow \tilde{\chi}_2^0\tilde{\chi}_1^- \dots$

## Spectra from cascade decays

- thresholds & edges [Hinchliffe, Paige; Cambridge]
- e.g.  $\tilde{g} \rightarrow \tilde{q}\tilde{q} \rightarrow \tilde{\chi}_2^0 q\bar{q} \rightarrow \mu^+ \mu^- q\bar{q}\tilde{\chi}_1^0$
- semi-analytic approach [Nojiri, Polesello]

⇒ **errors crucial** [Polesello, Gjelsten, Miller, Osland]



# SUPERSYMMETRY AT THE LHC: 2

## SUSY-Madgraph: we are done! [Hagiwara, Kanzaki, TP, Rainwater, Stelzer]

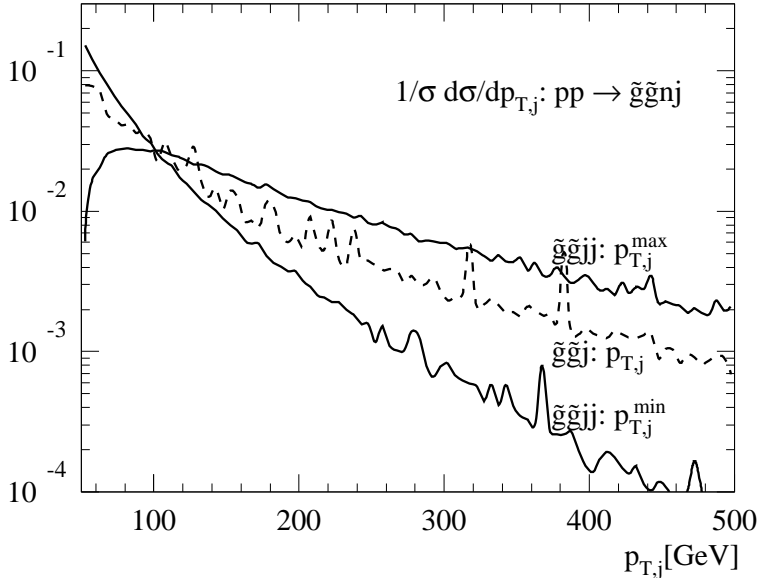
- Majoranas and fermion number violation in Madgraph [Denner, Eck, Hahn, Küblbeck]
- complete set of Feynman rules [300+ processes compared with Whizard and Sherpa]
- beta version upon request, Smadevent in test phase [details in D. Rainwater's talk]
- first physics project: SUSY pairs in WBF [stop-sbottom in D. Berdine's talk]
- thanks for the support: DESY, KEK, Madison

## Using SUSY-Madevent: squarks and gluinos plus jets [TP, Rainwater, Skands]

- cascade studies sensitive to hard jet radiation?
- compute  $\tilde{g}\tilde{g}+2j$  and  $\tilde{u}_L\tilde{g}+2j$  [SPS1a,  $p_{T,j} > 100\text{GeV}$ ]

$\sigma$ [pb]	$t\bar{t}_{600}$	$\tilde{g}\tilde{g}$	$\tilde{u}_L\tilde{g}$
$\sigma_{0j}$	1.30	4.83	5.65
$\sigma_{1j}$	0.73	2.89	2.74
$\sigma_{2j}$	0.26	1.09	0.85

- task 1: gluon radiation vs. initial states?
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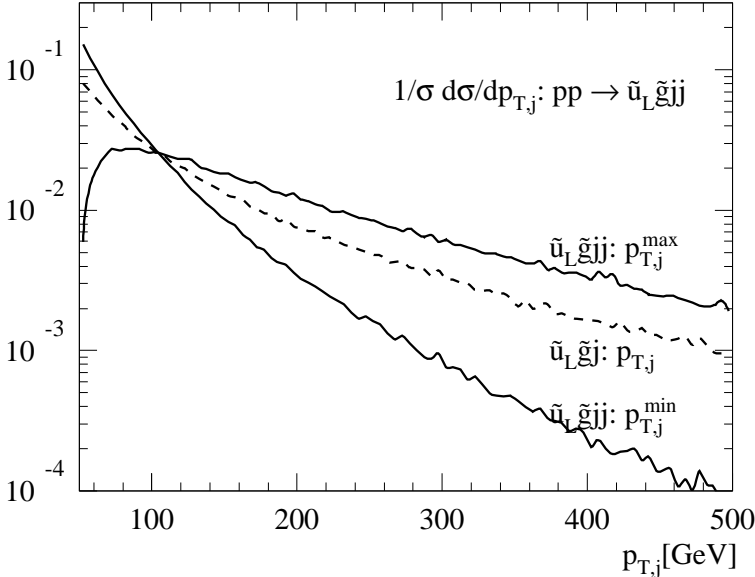
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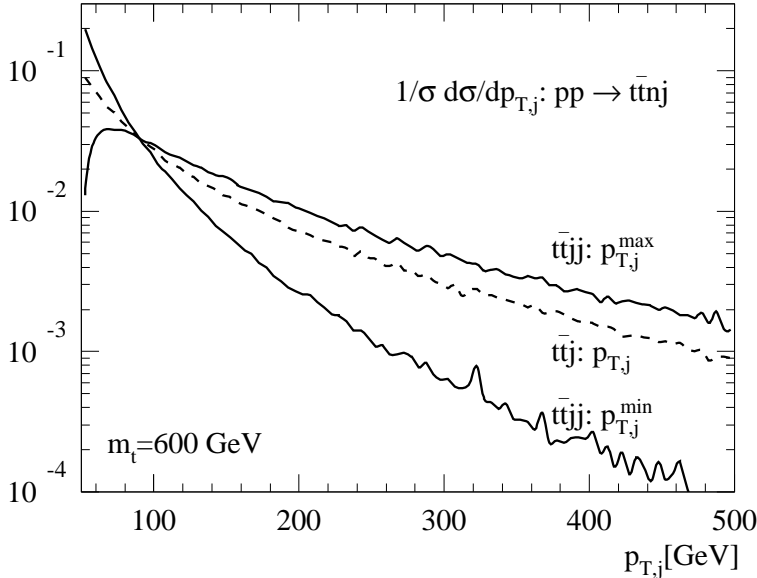
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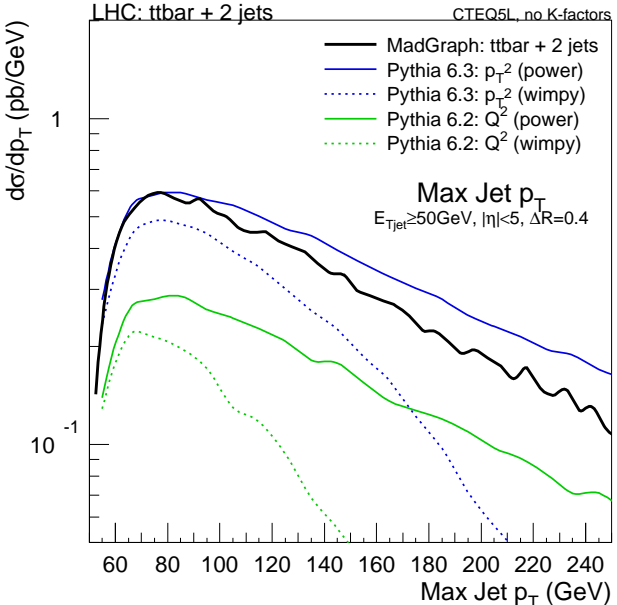
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## SUSY parameters from observables [Les Houches Accord: Skands,...]

- parameters: weak-scale MSSM Lagrangean
- measurements: masses or edges  
                   branching fractions [MSMlib, Sdecay]  
                   cross sections [Prospino2, MSMlib],...
- errors: general correlation, statistics & systematics & theory
- problem in grid: huge phase space, local minimum?  
   problem in fit: domain walls, starting values, global minimum?

## Sfitter [Lafaye, TP, D. Zerwas, also Fittino]

- (1) grid for closed subset
  - (2) fit of remaining parameters
  - (3) complete fit
- ⇒ LHC better than expected
- ⇒ **LHC+ILC without assumptions**
- ⇒ P. Zerwas' talk: SUSY breaking

	LHC	ILC	LHC+ILC	SPS1a
$\tan\beta$	$10.22 \pm 9.1$	$10.26 \pm 0.3$	$10.06 \pm 0.2$	10
$M_1$	$102.45 \pm 5.3$	$102.32 \pm 0.1$	$102.23 \pm 0.1$	102.2
$M_3$	$578.67 \pm 15$	fix 500	$588.05 \pm 11$	589.4
$M_{\tilde{\tau}_L}$	fix 500	$197.68 \pm 1.2$	$199.25 \pm 1.1$	197.8
$M_{\tilde{\tau}_R}$	$129.03 \pm 6.9$	$135.66 \pm 0.3$	$133.35 \pm 0.6$	135.5
$M_{\tilde{\mu}_L}$	$198.7 \pm 5.1$	$198.7 \pm 0.5$	$198.7 \pm 0.5$	198.7
$M_{\tilde{q}_{3L}}$	$498.3 \pm 110$	$497.6 \pm 4.4$	$521.9 \pm 39$	501.3
$M_{\tilde{t}_R}$	fix 500	$420 \pm 2.1$	$411.73 \pm 12$	420.2
$M_{\tilde{b}_R}$	$522.26 \pm 113$	fix 500	$504.35 \pm 61$	525.6
$A_\tau$	fix 0	$-202.4 \pm 89.5$	$352.1 \pm 171$	-253.5
$A_t$	$-507.8 \pm 91$	$-501.95 \pm 2.7$	$-505.24 \pm 3.3$	-504.9
$A_b$	$-784.7 \pm 35603$	fix 0	$-977 \pm 12467$	-799.4

# SUPERSYMMETRY AT THE LHC: 4

## Split Supersymmetry [Dimopoulos, Arkani-Hamed; Giudice, Romanino; Wells; Drees]

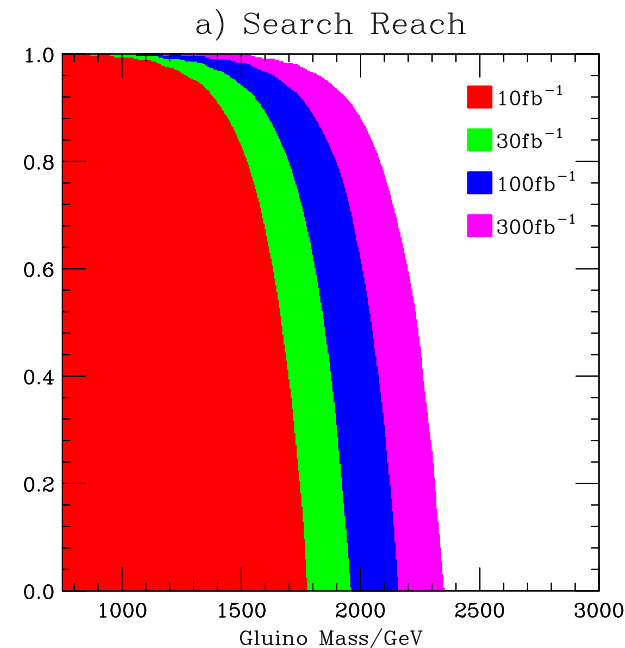
- forget about fine tuning [Higgs will never be as bad as cosmological constant]
- remember all the good things SUSY did for you [dark matter, unification]
- ⇒ make scalars heavy
- ⇒ protect gaugino and higgsino masses

## News for phenomenology [Kilian, TP, Richardson, Schmidt; Hewett, Lillie, Mazip, Rizzo]

- no cascade decays
- ⇒ hadronizing gluinos [ $\tau \sim \tilde{m}^{-4} \sim 6.5\text{s}$  for  $\tilde{m} = 10^9\text{GeV}$ ]
- heavy R hadrons [Farrar, Fayet; Baer, Cheung, Gunion; UKQCD; Kraan]
- gluinoonium [Kühn & Ono; Goldman & Haber; Cheung & Keung]
- renormalization group running without scalars
- ⇒ corrections to protected couplings [ino Yukawas 20%]

## Collider prospects [with errors, see N. Arkani-Hamed's talk]

- LHC stable gluino to  $\sim 2\text{TeV}$  [charge the key]
- ILC error on anomalous Yukawas  $\lesssim 10\%$  [indirect fit]



# OUTLOOK

## LHC phenomenology

- continuous progress in QCD and backgrounds
- pheno-experimental progress in Higgs sector  
⇒ we will be able to do amazing things at the LHC
- cascade analyses work great for SUSY  
⇒ more detailed studies are under way
- SUSY-Madgraph will be online for everyone this summer
- we still need the ILC for precision studies
- my apologies to all the little-Higgs, no-Higgs, fat-Higgs, funny-Higgs, ExtraD friends and colleagues who's work I should have covered but had no time to. David, your turn!

## But remember...

- errors are the key to new physics
- we need more serious LHC man power
- **if the LHC started today pheno/theory would be the show stoppers!**