Supersymmetry at the LHC

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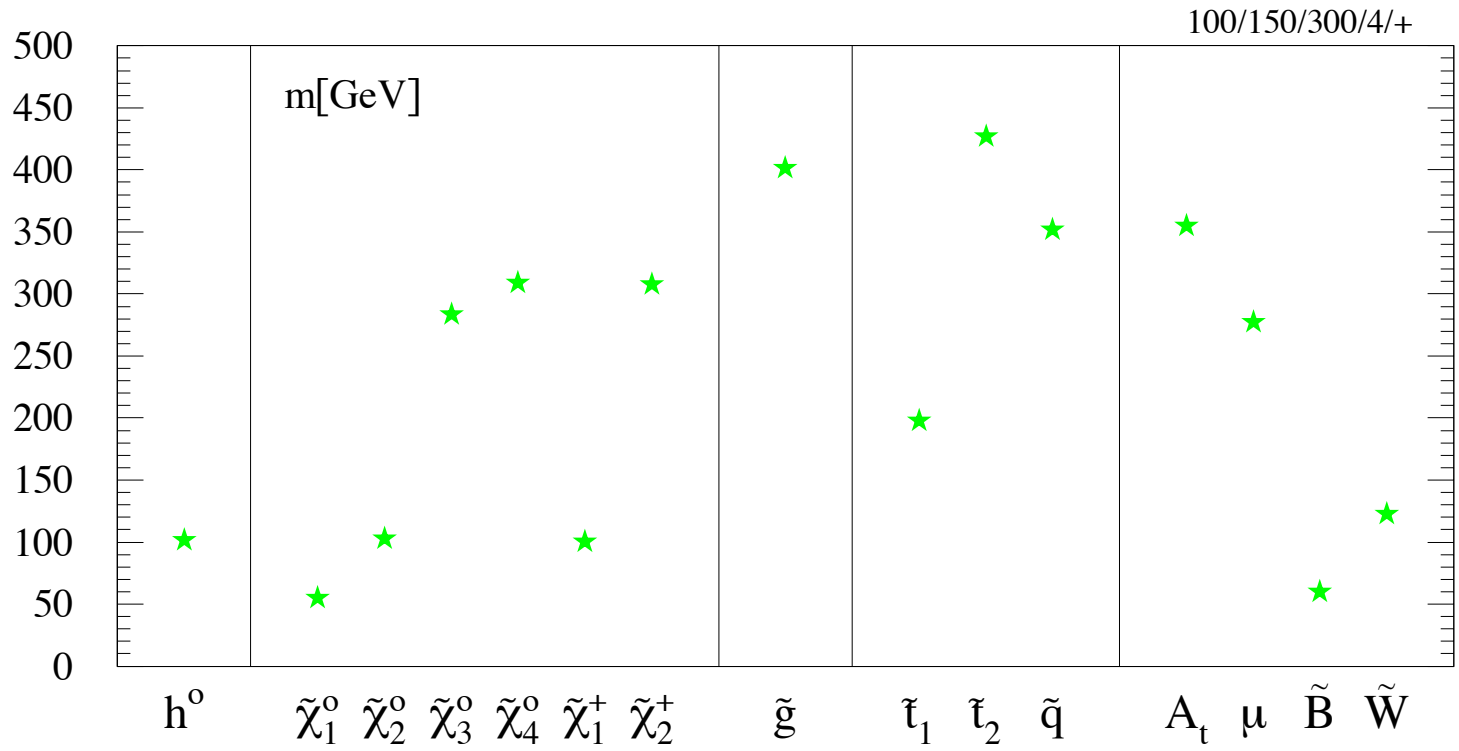
Cargese, 7/2010

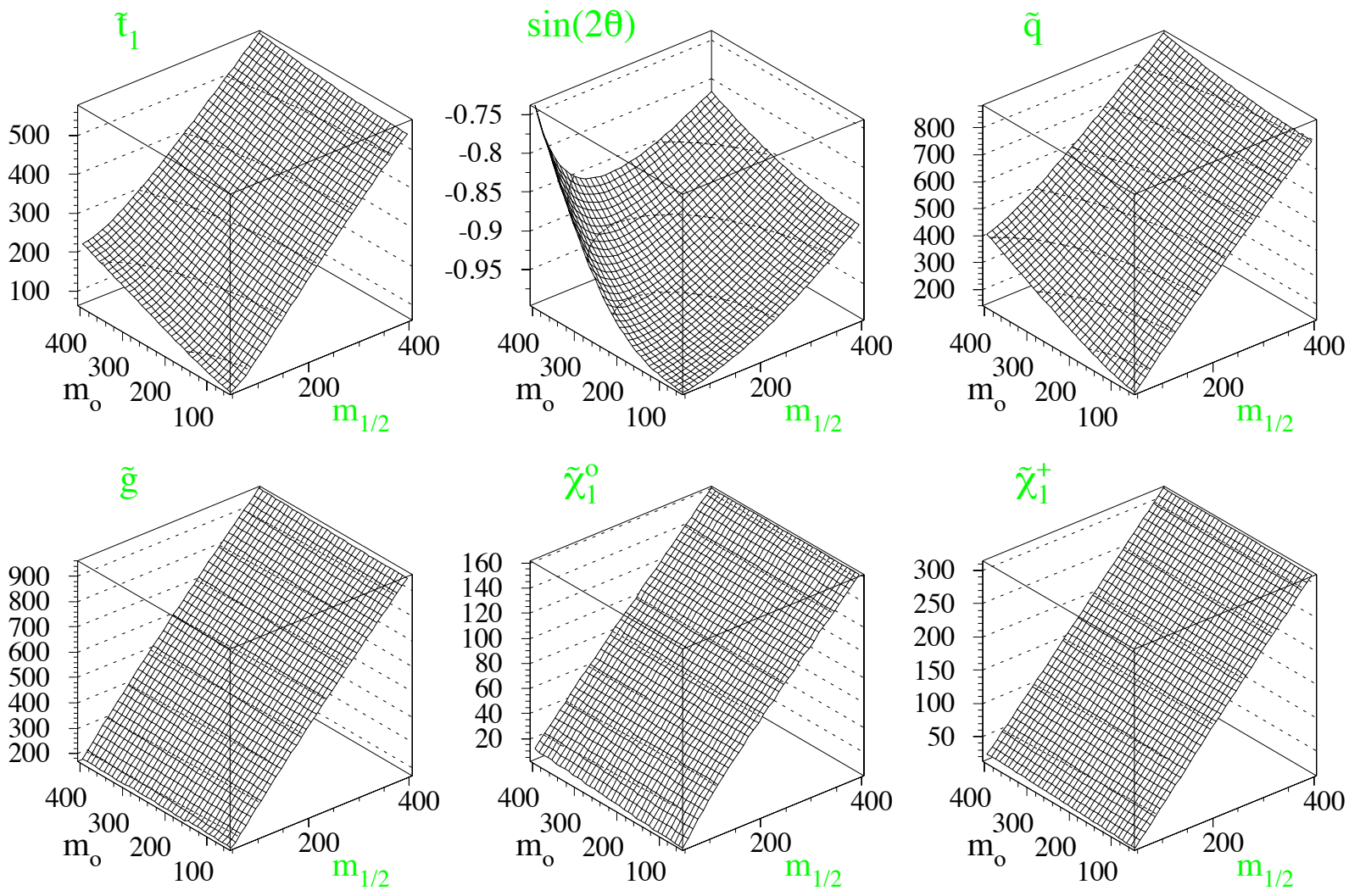
Weak-scale masses

- SUSY-QED Lagrangian (Weyl spinors)
- SUSY-QCD Feynman rules (Majorana gluinos)
- mass matrices
- approximate RGE solutions



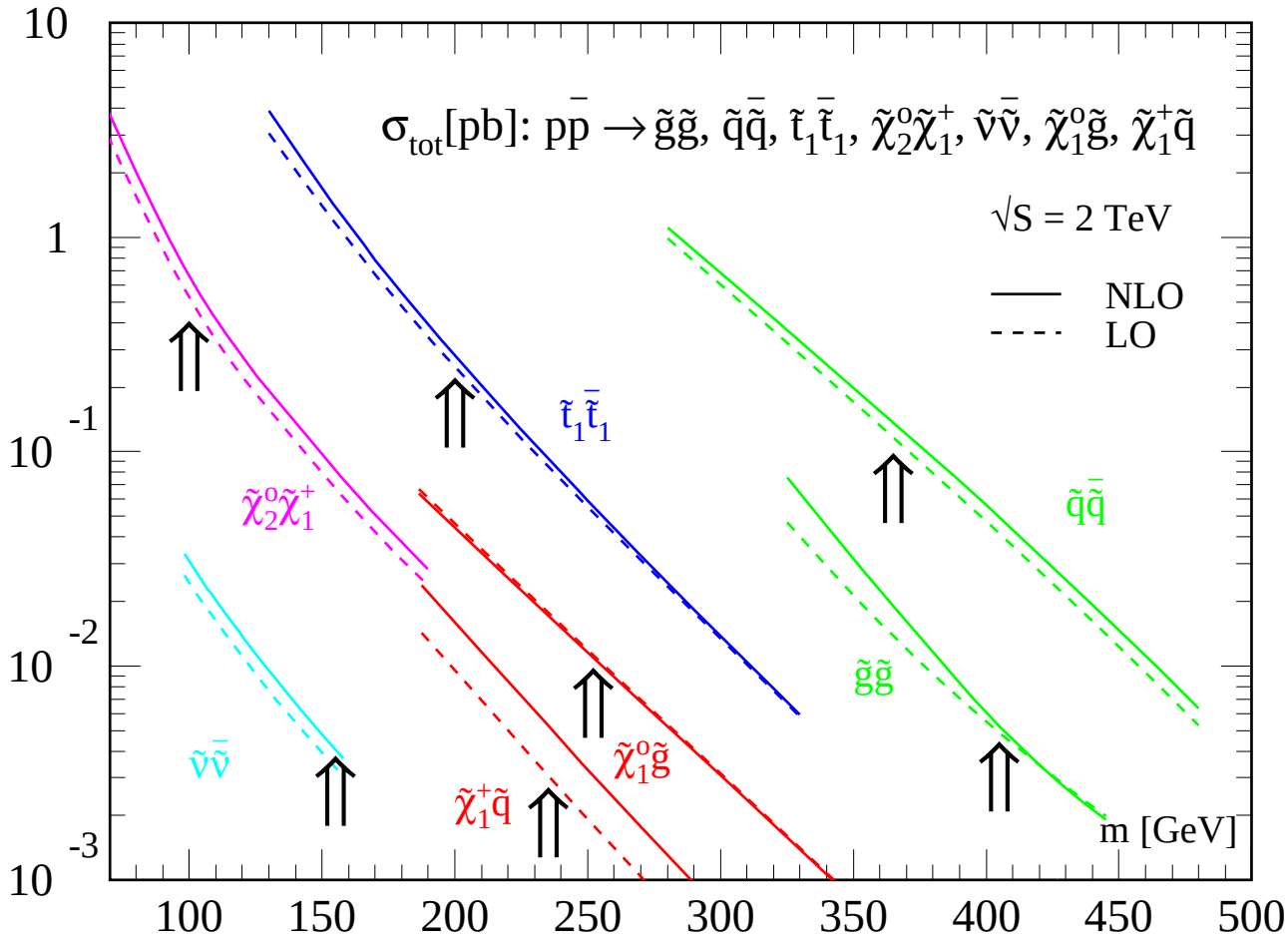
public RGE programs: SoftSUSY, SuSpect,...

mSUGRA toy model



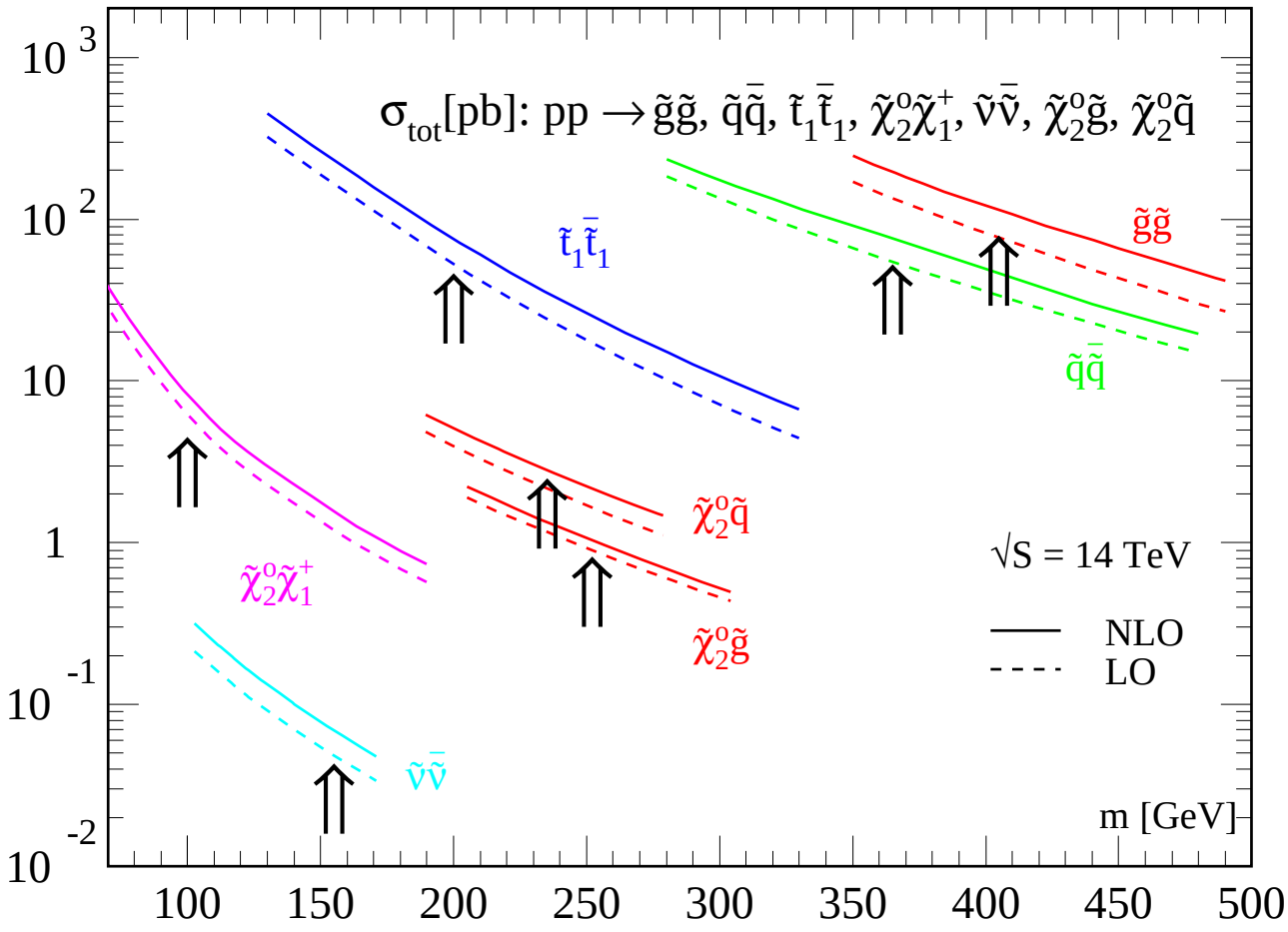
SUSY cross sections

- hadron collider processes
- double counting at NLO
- parton densities



public SUSY cross sections (LO and NLO): Prospino2.1

SUSY cross sections



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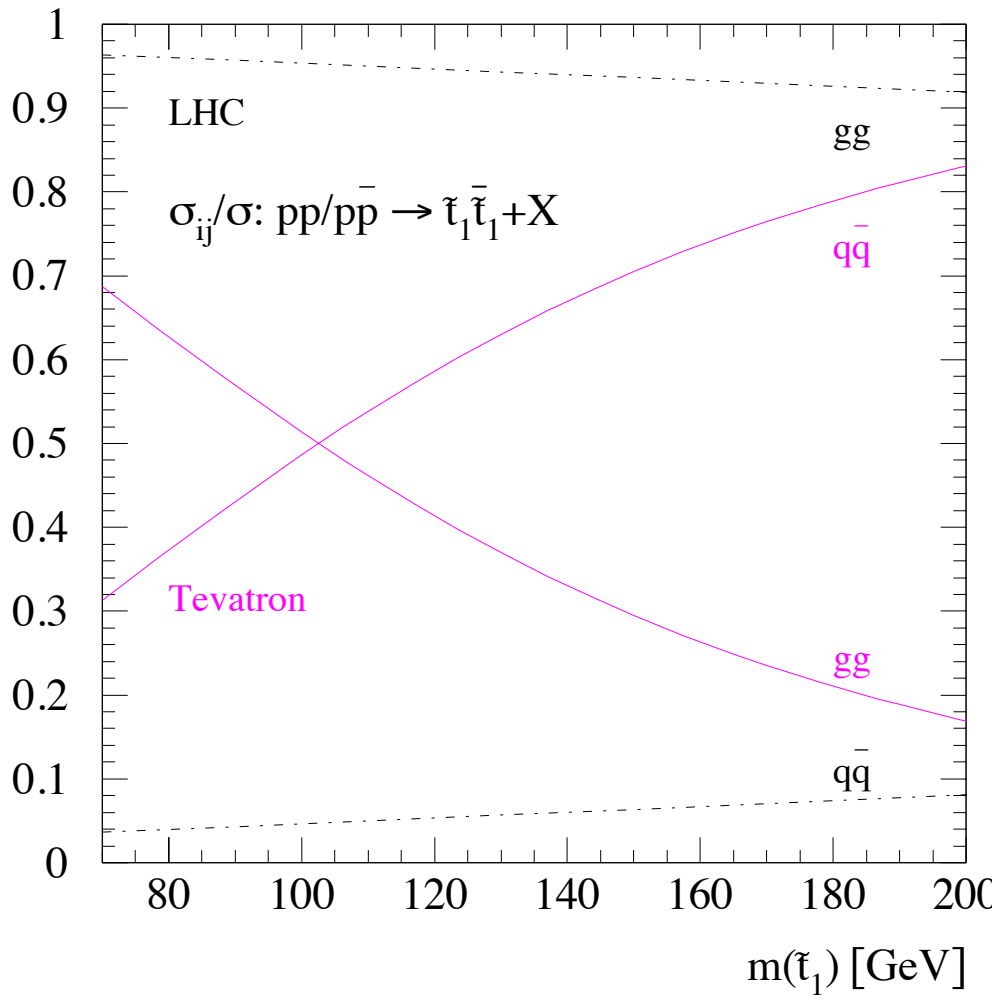
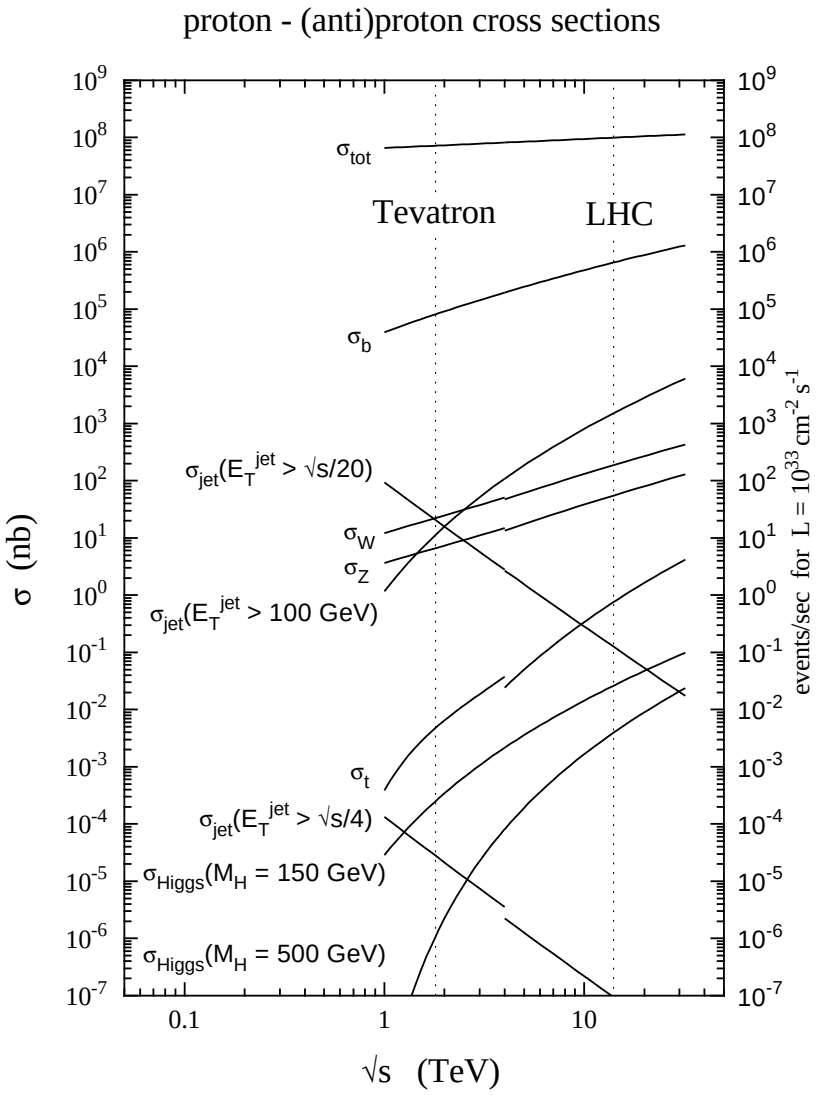
SUSY cross sections



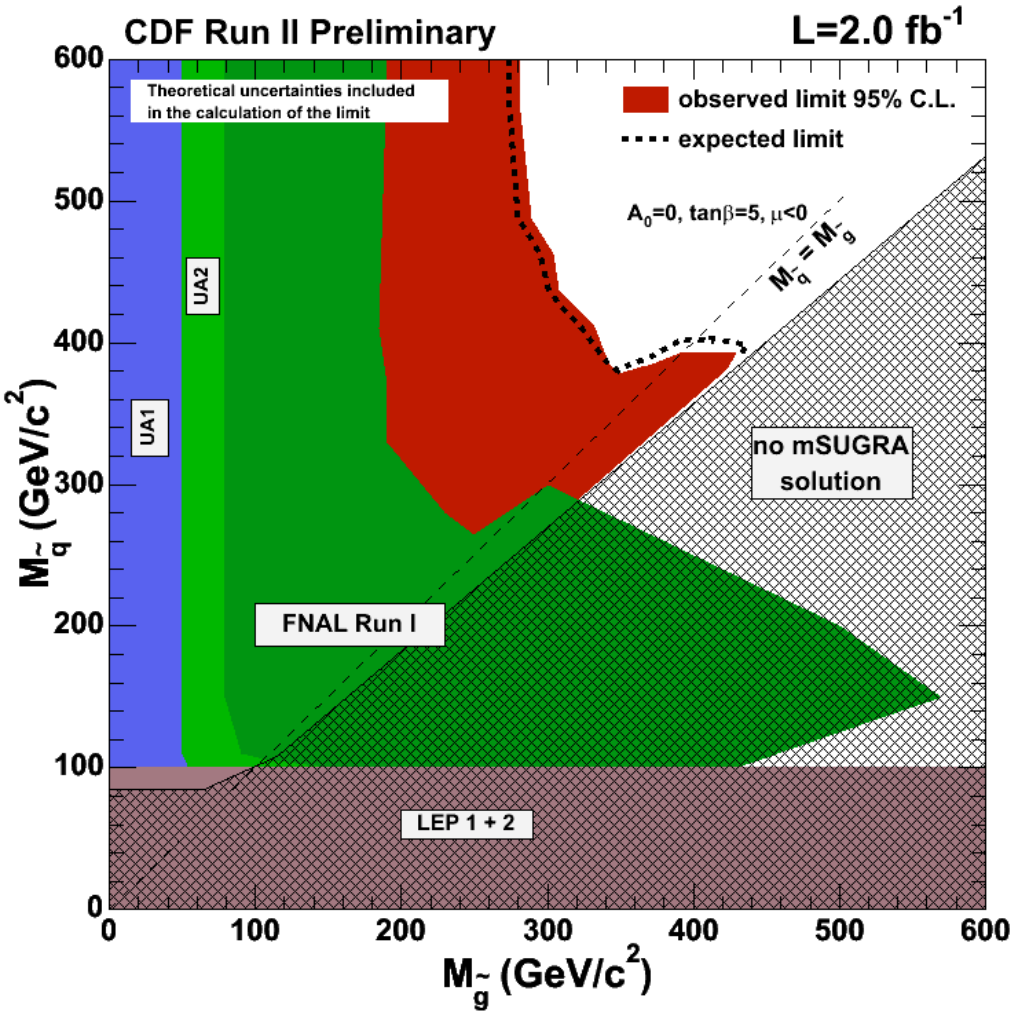
SM cross sections



compared to $\mathcal{O}(100)$ pb for SUSY

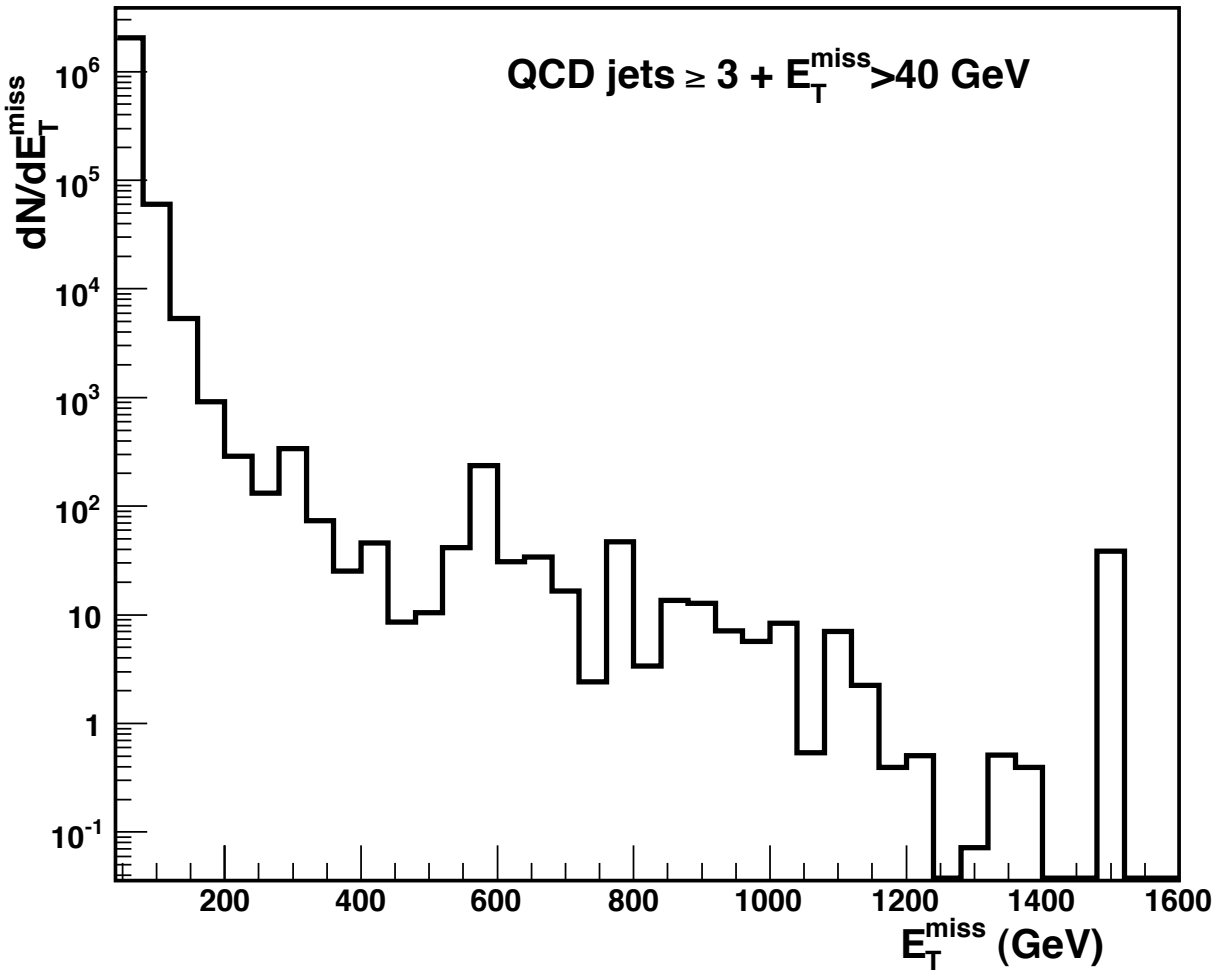
Searches 1: jets plus missing energy

- production/decay at hadron colliders
- effects of R parity
- typical short/long cascades

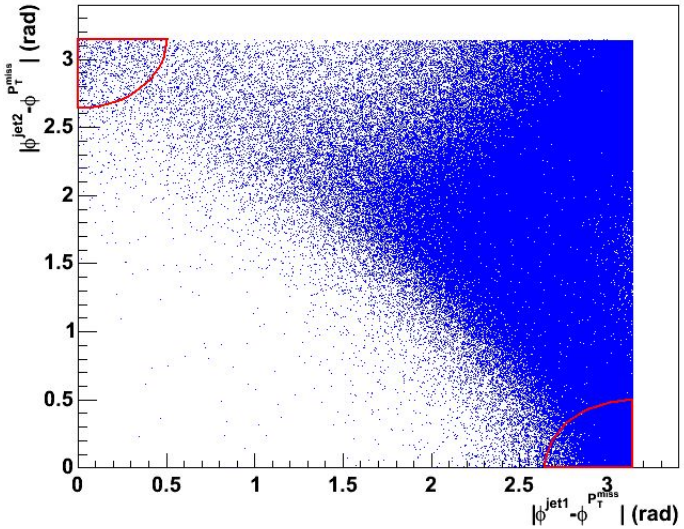


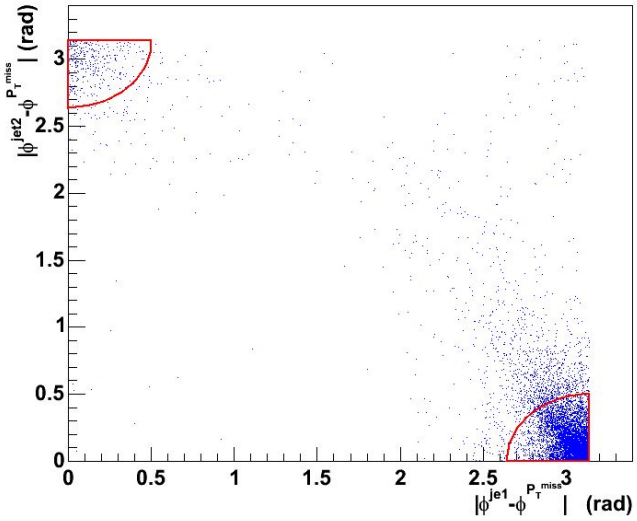
known from Tevatron

Fake missing energy

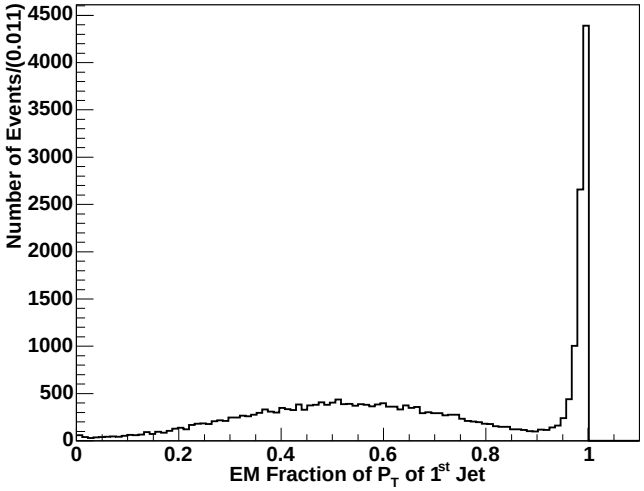


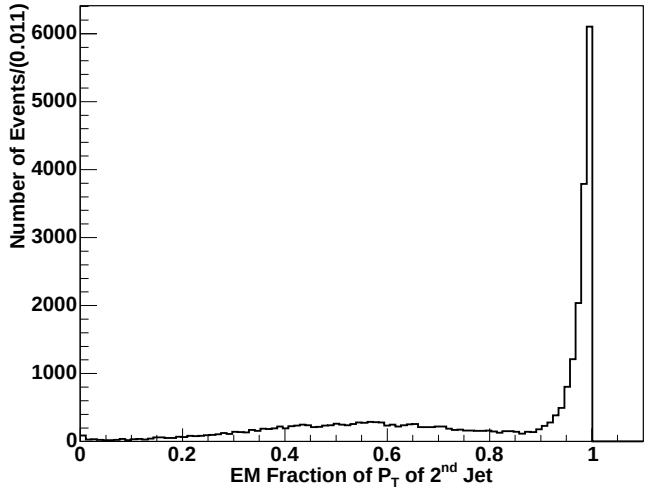
Reducing missing energy from jets

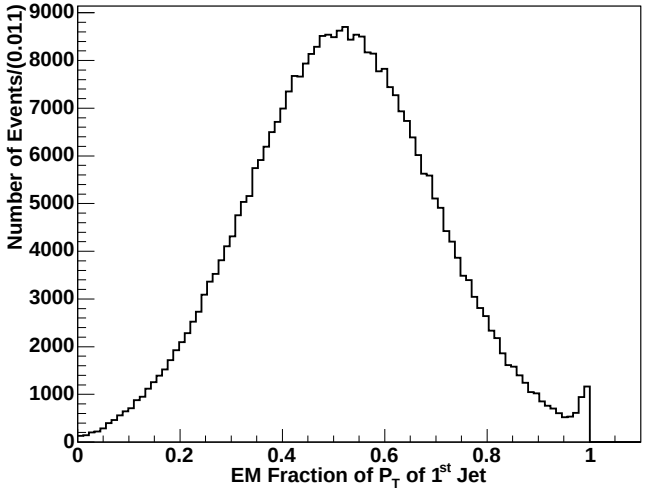


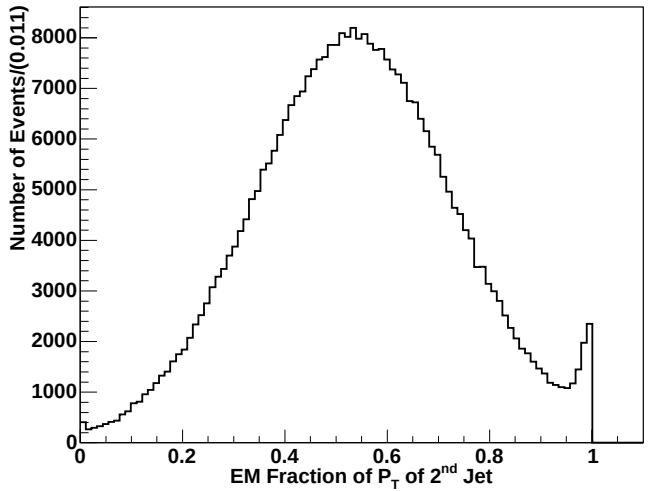


Lepton veto against W+jets



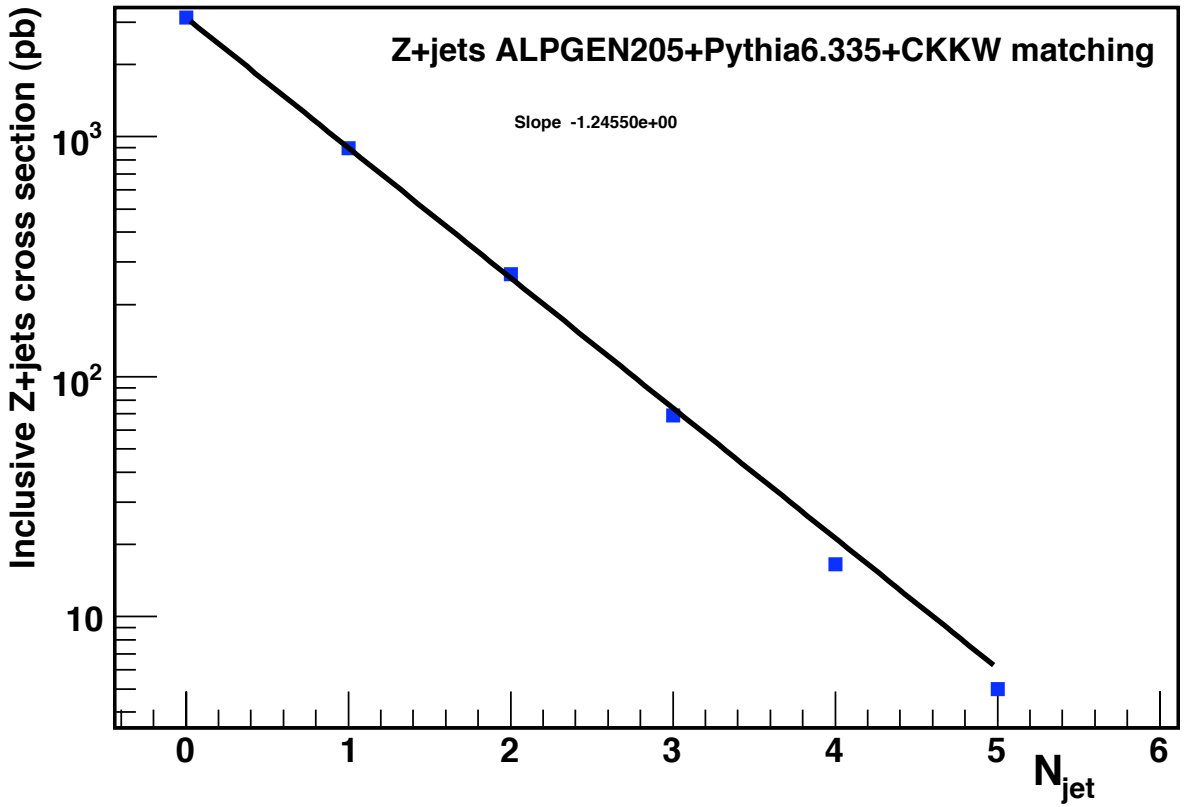






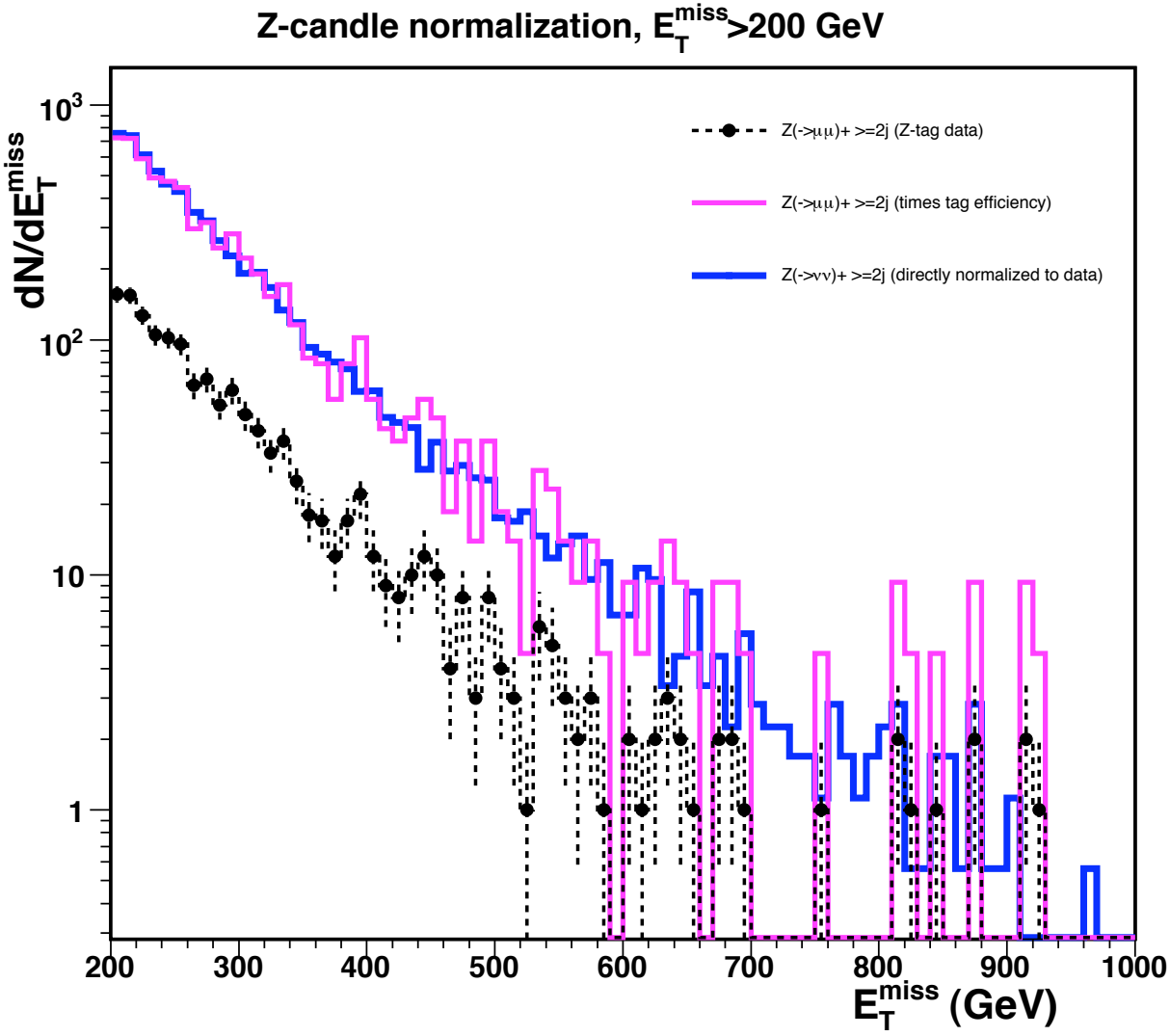
CKKW/MLM merging for Z+jets

- matrix element vs parton shower (ISR)
- Sudakov factors
- CKKW@LO
- MLM@LO
- MC@NLO and future



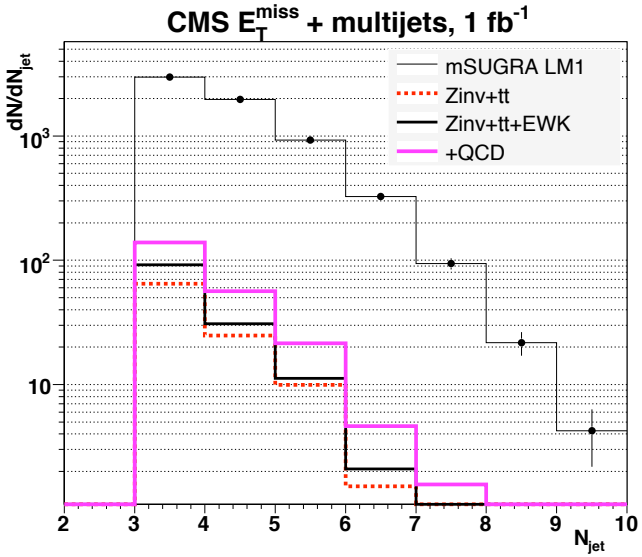
public mergers: Sherpa, Alpgen, Madevent

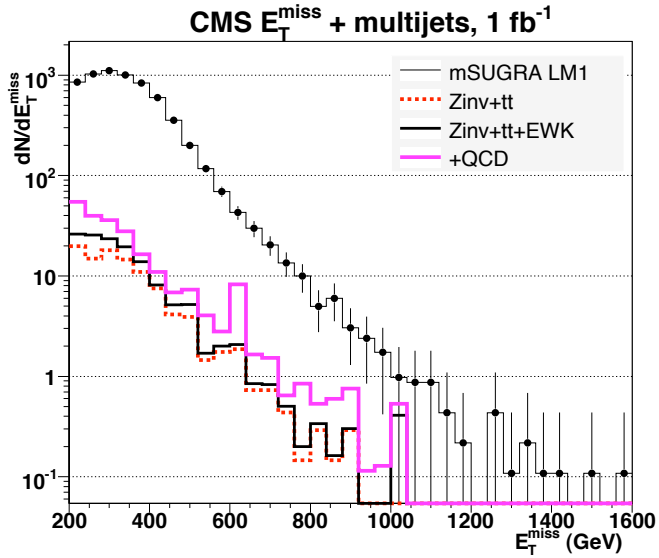
Subtraction of Z+jets

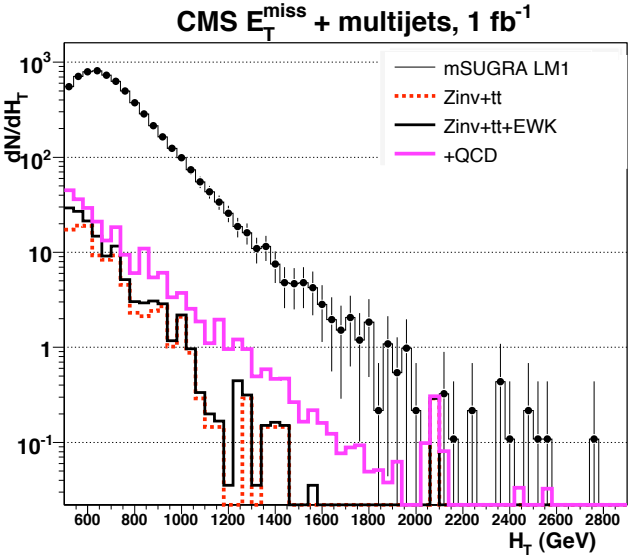


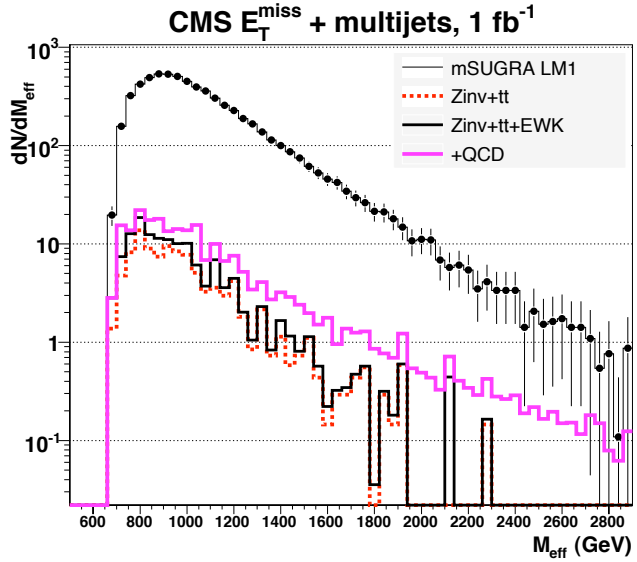
Inclusive observables

- invariant/transverse mass
- scalar momentum sums



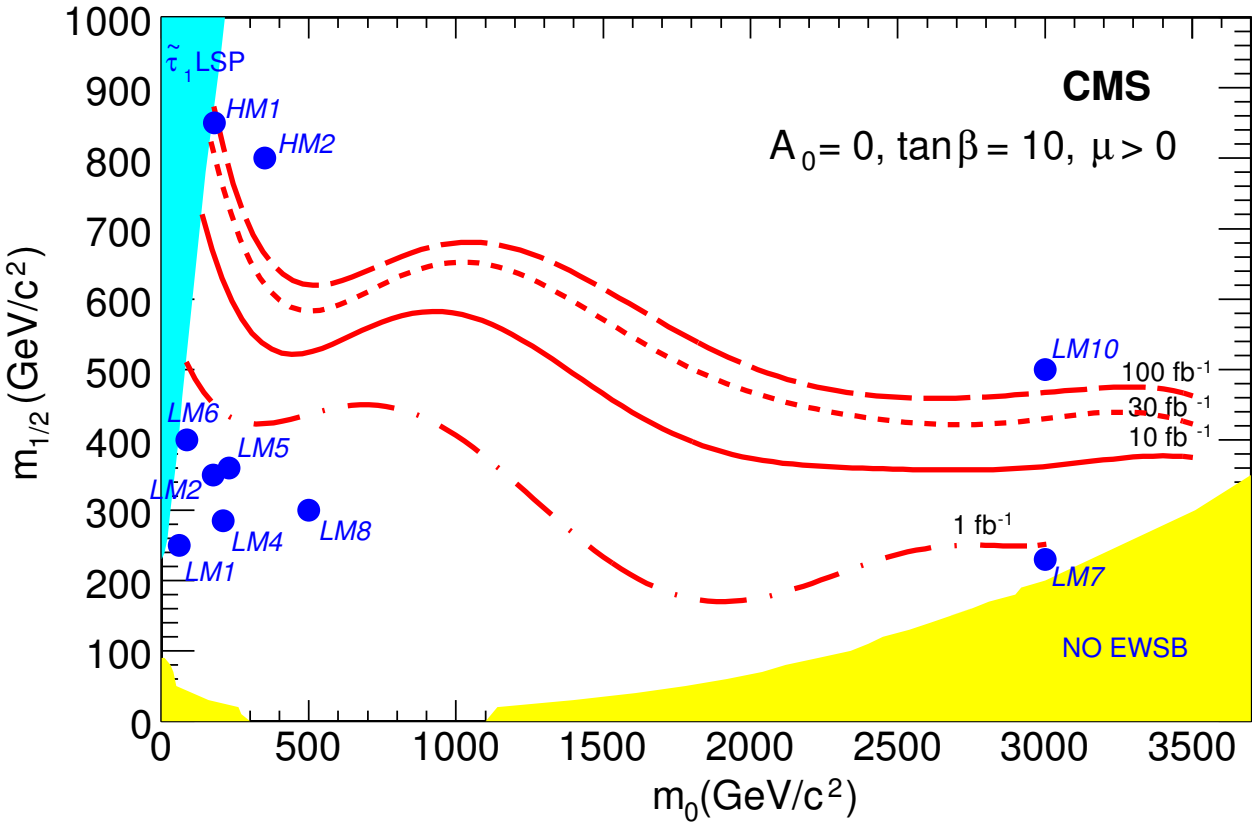






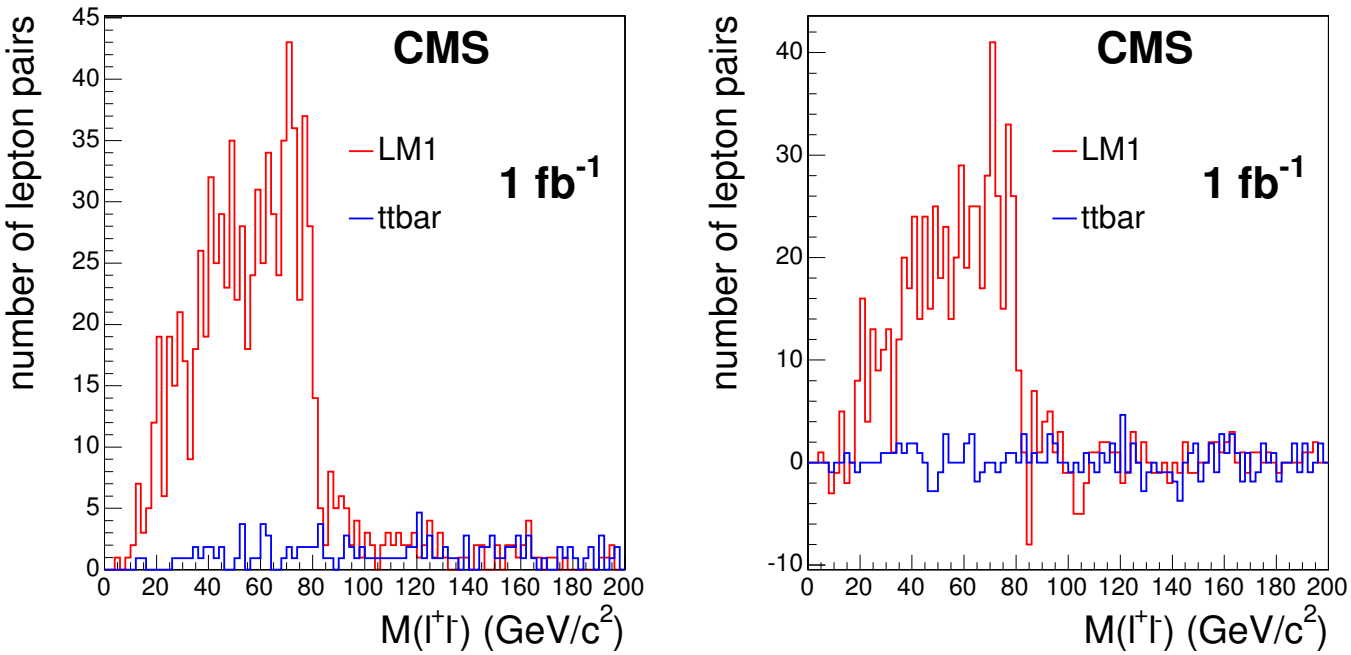
Searches 2: same-sign dileptons

- Majorana gluino in *t* channel and decay chain
- Majorana neutralino
- virtue of benchmark points: 'say more about author than about physics'



Opposite-sign dileptons

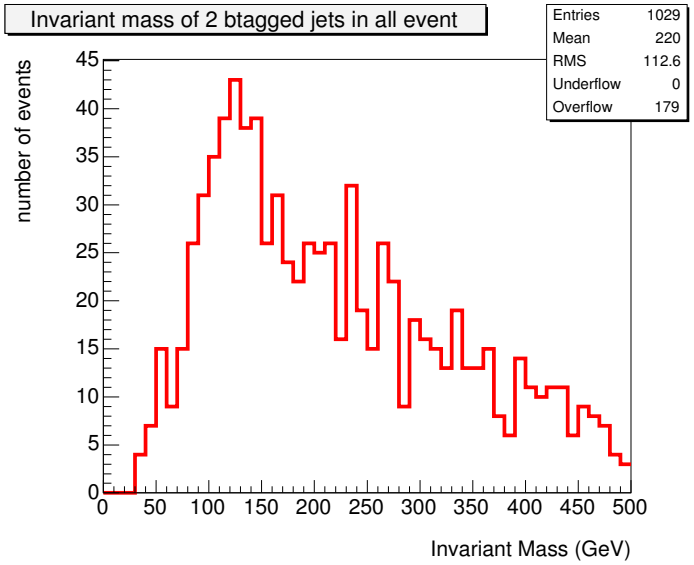
- cascade decays
- top pair background

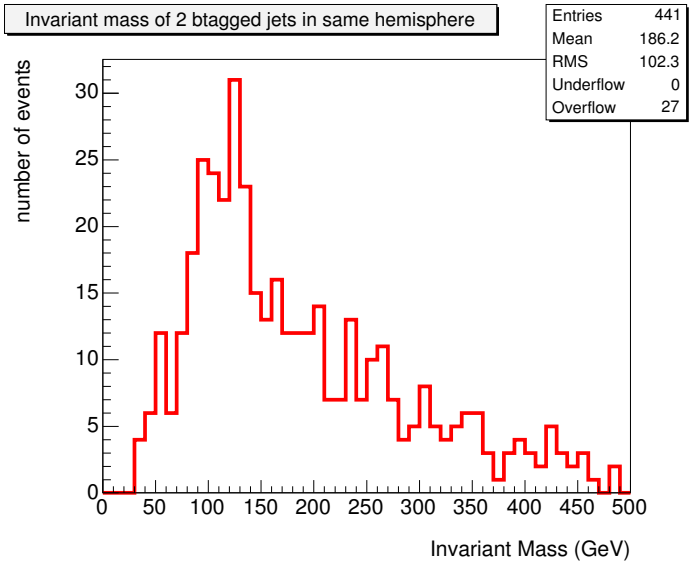


kinematics features later

Searches 3: hemisphere search for Higgs

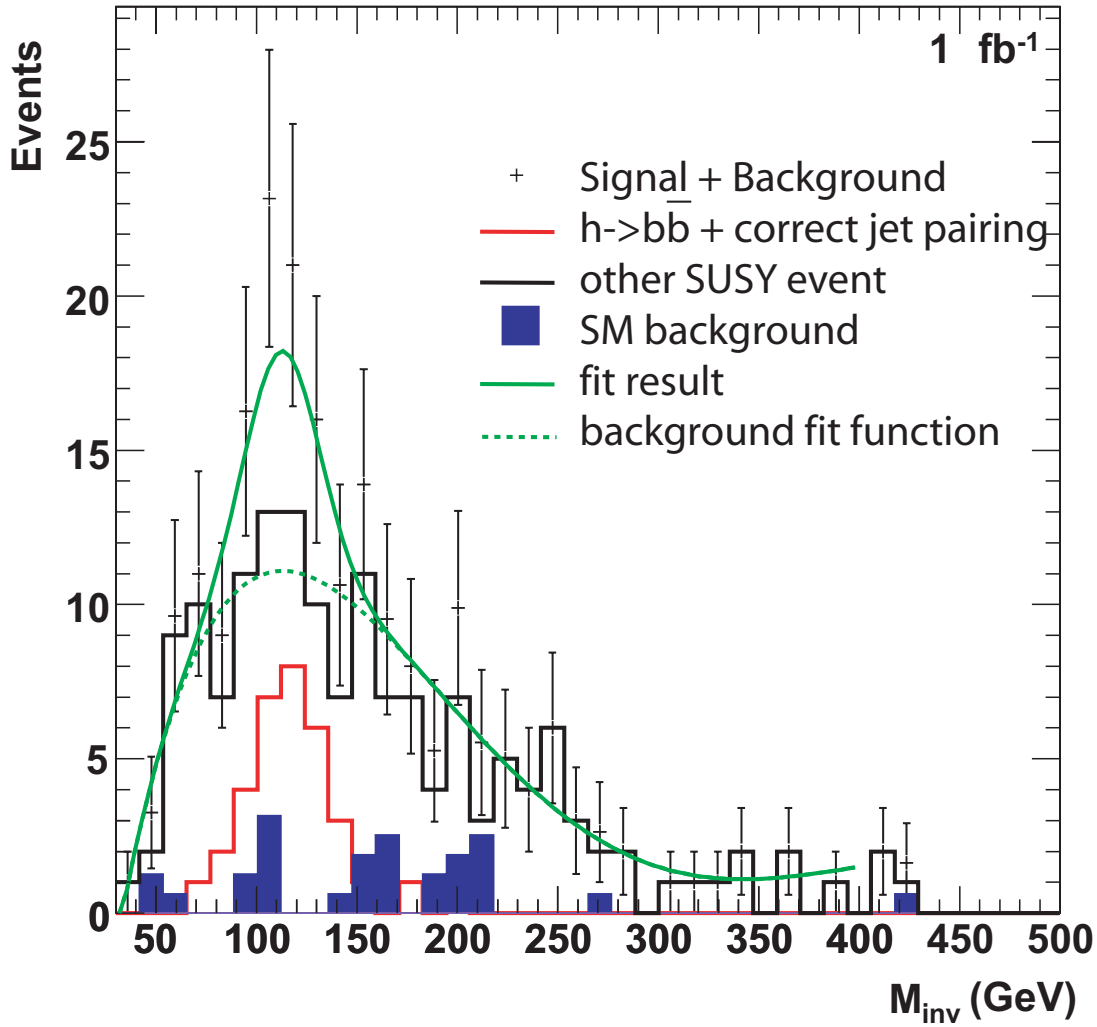
- hemisphere algorithms
- relevance for Higgs search





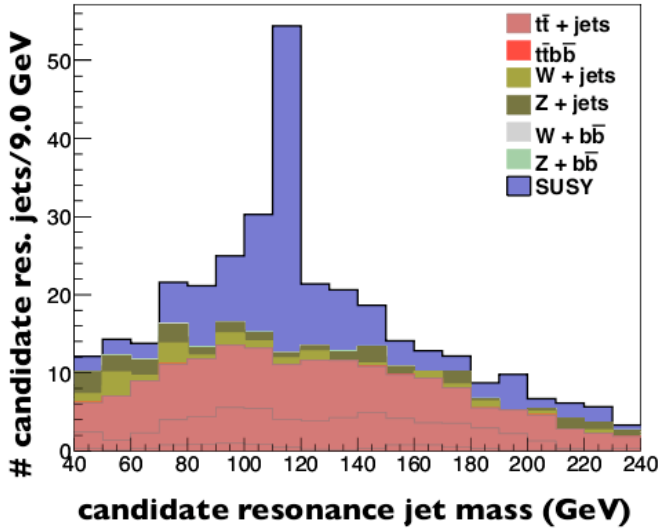
Higgs invariant mass

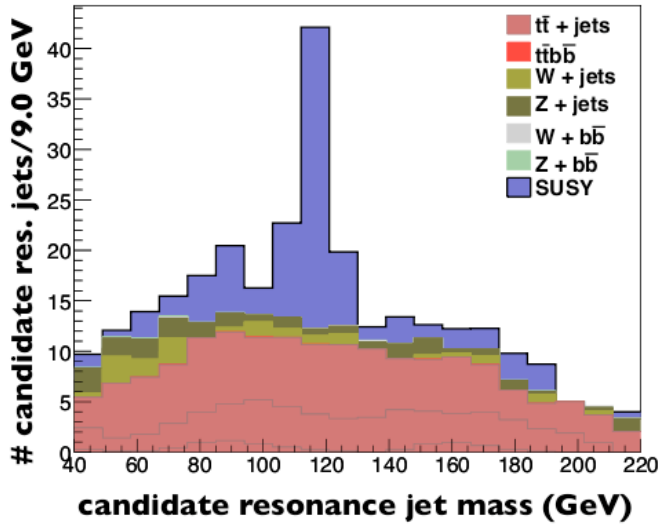
- SM vs SUSY backgrounds
- Higgs searches at the LHC
- Yukawa couplings of neutralinos/charginos



Higgs Tagger

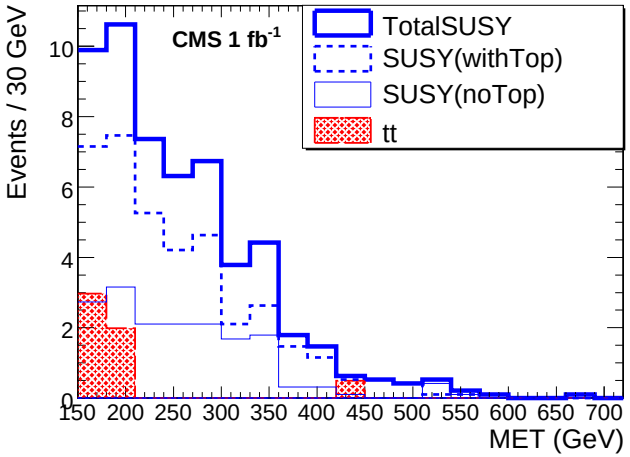
- slightly boosted heavy states
- C/A algorithm and mass drop
- Higgs tagging vs W and top tagging

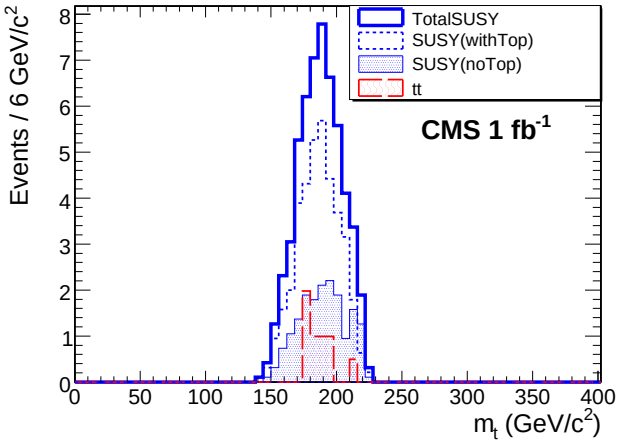




Searches 4: Tops from a neural net

- relevance of top partner
- stop pair production
- top pair background: semileptonic vs hadronic



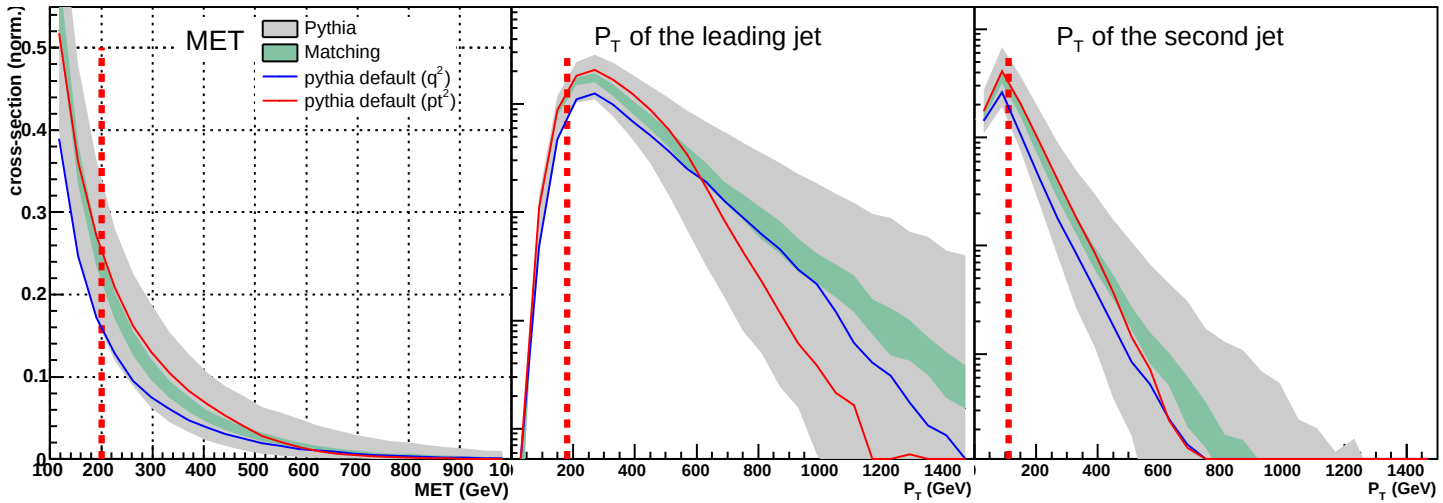


impossible to interpret — what is the sample/signature...
and then an additioal lepton appears miraculously...?

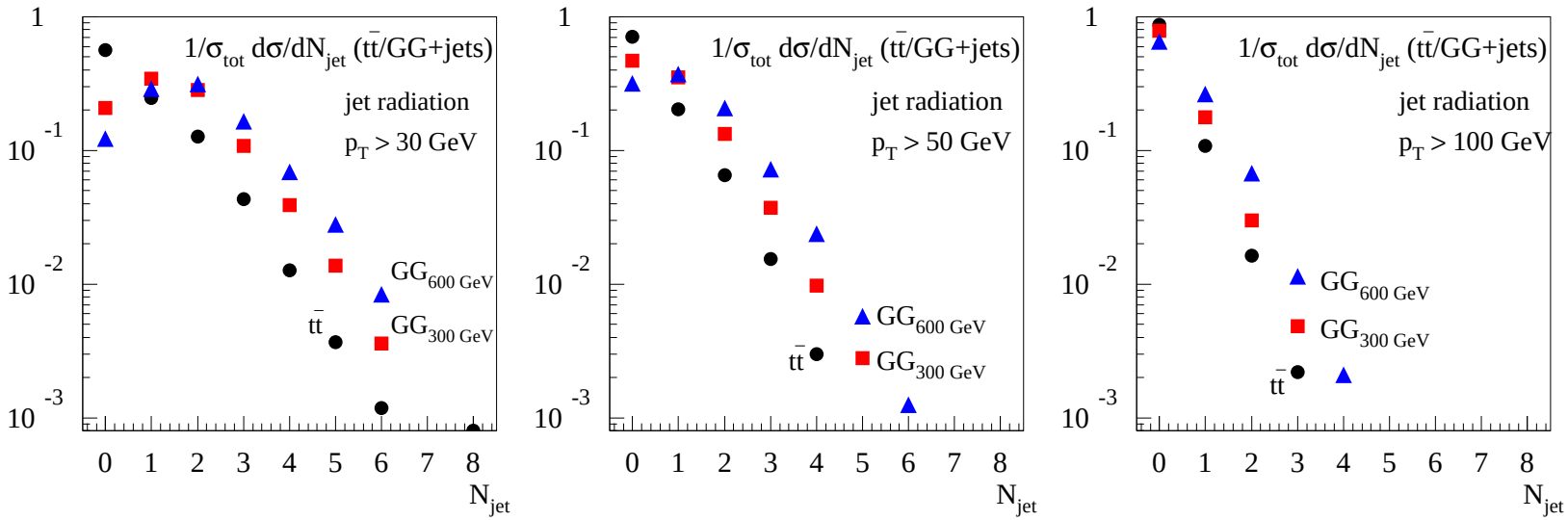
QCD jets with squark/gluinos pairs

- collinear radiation
- maximum momentum scale

	σ_{tot}[pb]	$\tilde{g}\tilde{g}$	$\tilde{u}_L\tilde{g}$	$\tilde{u}_L\tilde{u}_L^*$	$\tilde{u}_L\tilde{u}_L$	$T\bar{T}$
$p_{Tj} > 100$ GeV	σ_{0j}	4.83	5.65	0.286	0.502	1.30
	σ_{1j}	2.89	2.74	0.136	0.145	0.73
	σ_{2j}	1.09	0.85	0.049	0.039	0.26
$p_{Tj} > 50$ GeV	σ_{0j}	4.83	5.65	0.286	0.502	1.30
	σ_{1j}	5.90	5.37	0.283	0.285	1.50
	σ_{2j}	4.17	3.18	0.179	0.117	1.21



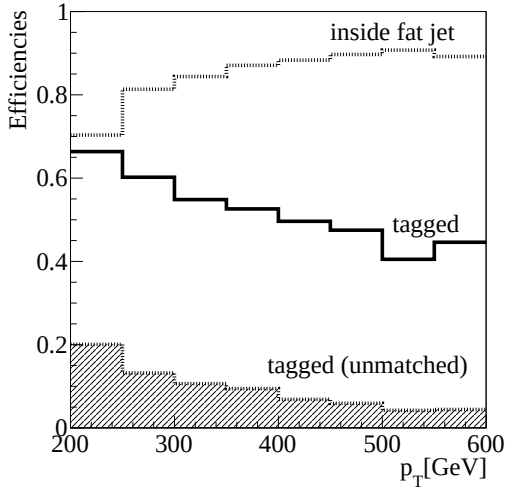
Changing the hard scale

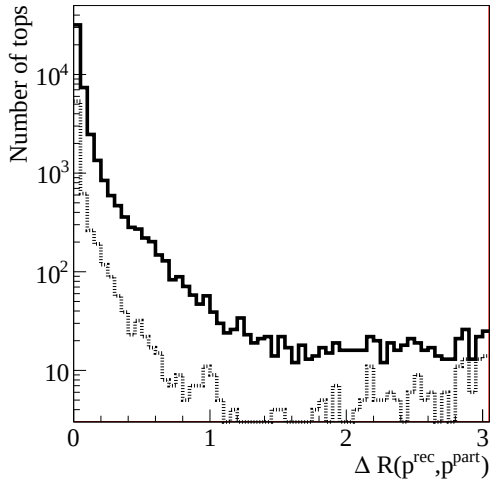


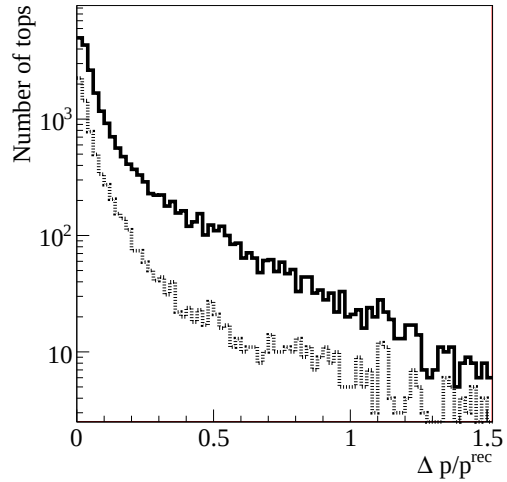
semi-leptonic stop pairs	σ [pb]	$\sigma \cdot \epsilon_{\text{naive}}$ [fb]	$\sigma \cdot \epsilon_{\text{improved}}$ [fb]	original
$\tilde{t}_1 \tilde{t}_1^*$	3.2	4.8	38	56
$t\bar{t}$	550	47.3	237	20
$W + 4j$	56.5	2.0	21.5	~ 2.7
$W + bbjj$	0.63	0.2	1.7	~ 1.5
SM total		49.5	260.2	~ 24.2
S/B		0.096	0.15	2.3
$S/\sqrt{B}_{10\ \text{fb}-1}$		2.2	7.5	36

- statistical/systematic errors
- backgrounds from data, control regions

Top tagging in SUSY





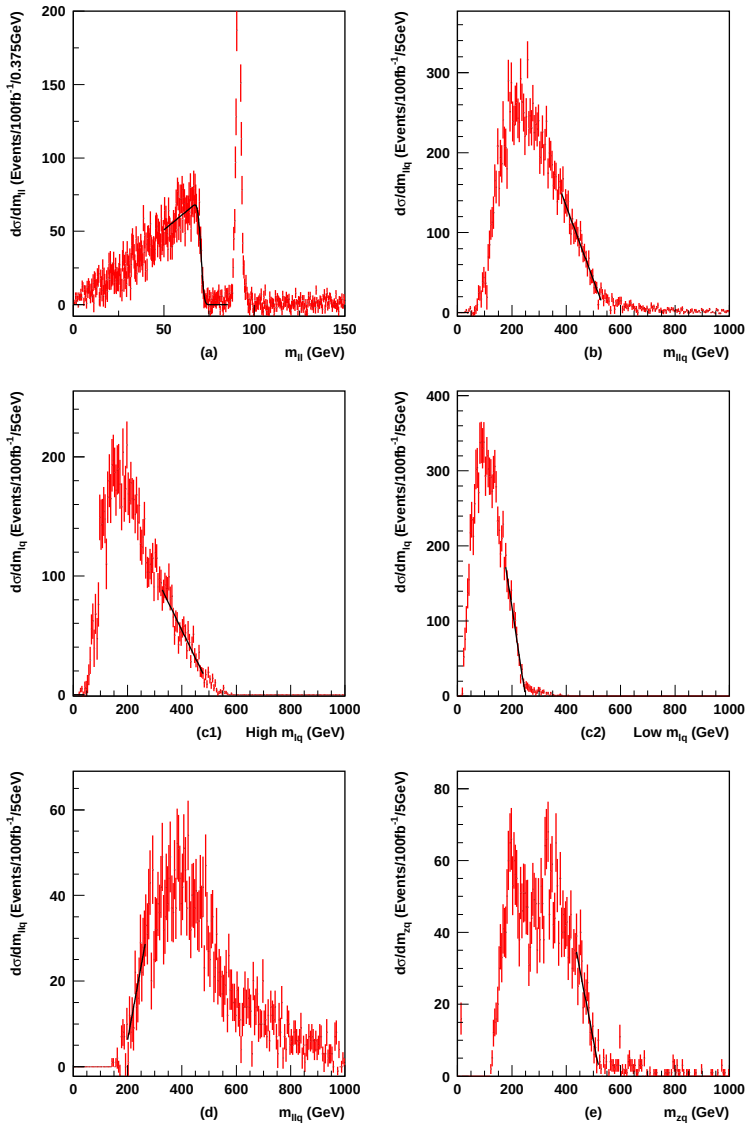


	$\tilde{t}_1\tilde{t}_1^*$			$t\bar{t}$	QCD	W+jets	Z+jets	S/B
$m_{\tilde{t}}$[GeV]	340	440	540					
$p_{T,j} > 200$ GeV	728	292	124	87850	$2.4 \cdot 10^7$	$1.6 \cdot 10^5$	n/a	$3.0 \cdot 10^{-5}$
$E_T^{\text{miss}} > 150$ GeV	283	184	93	2245	$2.4 \cdot 10^5$	1710	2240	$1.2 \cdot 10^{-3}$
first top tag	100	75	42	743	7590	90	114	$1.2 \cdot 10^{-2}$
second top tag	15	11	6.3	32	129	5.7	1.4	$8.3 \cdot 10^{-2}$
b tag	8.7	6.3	3.8	19	2.6	$\lesssim 0.2$	$\lesssim 0.05$	0.40
$m_{T2} > 250$ GeV	4.3	4.9	3.2	4.2	$\lesssim 0.6$	$\lesssim 0.1$	$\lesssim 0.03$	0.88

- weakness of inclusive searches
- pseudo-solution: OSET

Masses from kinematic end points

- problems with mass reconstruction
- thresholds and edges
- lepton-lepton edge and mass-squared differences

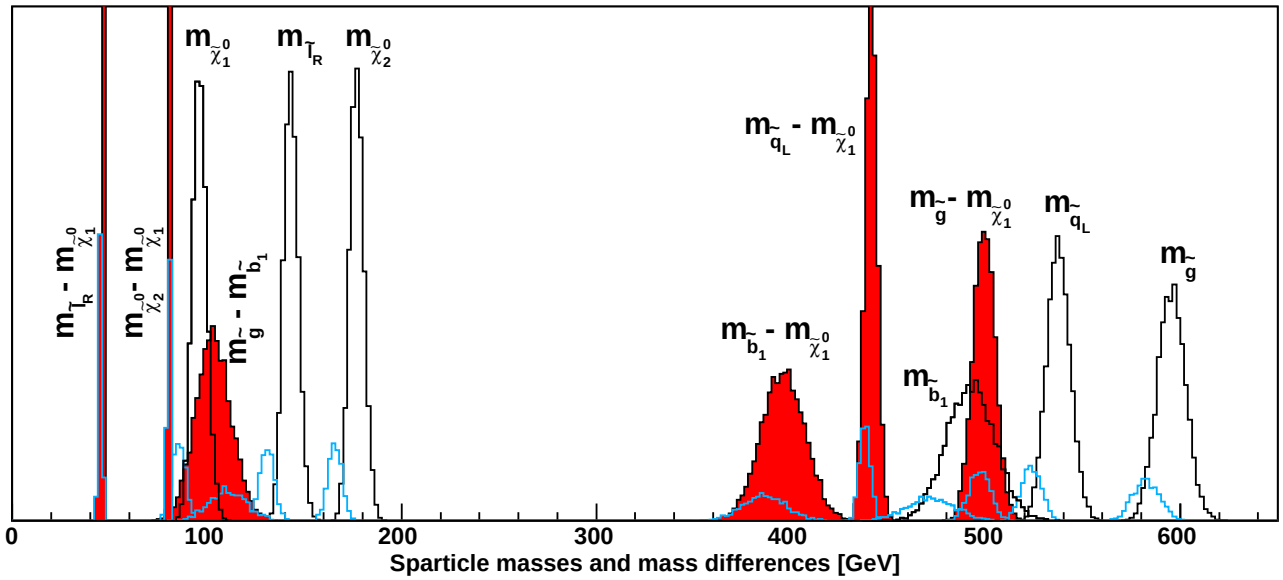


SPS1a measurements

- systematic errors
- theory errors and higher orders

type of measurement		nominal value	stat.	LES	JES	theo.
			error			
m_h		108.99	0.01	0.25		2.0
m_t		171.40	0.01		1.0	
$m_{\tilde{l}_L} - m_{\chi_1^0}$		102.45	2.3	0.1		2.2
$m_{\tilde{g}} - m_{\chi_1^0}$		511.57	2.3		6.0	18.3
$m_{\tilde{q}_R} - m_{\chi_1^0}$		446.62	10.0		4.3	16.3
$m_{\tilde{g}} - m_{\tilde{b}_1}$		88.94	1.5		1.0	24.0
$m_{\tilde{g}} - m_{\tilde{b}_2}$		62.96	2.5		0.7	24.5
$m_{ll}^{\max}$:	three-particle edge($\chi_2^0,\tilde{l}_R,\chi_1^0$)	80.94	0.042	0.08		2.4
$m_{llq}^{\max}$:	three-particle edge($\tilde{q}_L,\chi_2^0,\chi_1^0$)	449.32	1.4		4.3	15.2
m_{lq}^{low}:	three-particle edge($\tilde{q}_L,\chi_2^0,\tilde{l}_R$)	326.72	1.3		3.0	13.2
$m_{ll}^{\max}(\chi_4^0)$:	three-particle edge($\chi_4^0,\tilde{l}_R,\chi_1^0$)	254.29	3.3	0.3		4.1
$m_{\tau\tau}^{\max}$:	three-particle edge($\chi_2^0,\tilde{\tau}_1,\chi_1^0$)	83.27	5.0		0.8	2.1
m_{lq}^{high}:	four-particle edge($\tilde{q}_L,\chi_2^0,\tilde{l}_R,\chi_1^0$)	390.28	1.4		3.8	13.9
m_{llq}^{thres}:	threshold($\tilde{q}_L,\chi_2^0,\tilde{l}_R,\chi_1^0$)	216.22	2.3		2.0	8.7
m_{llb}^{thres}:	threshold($\tilde{b}_1,\chi_2^0,\tilde{l}_R,\chi_1^0$)	198.63	5.1		1.8	8.0

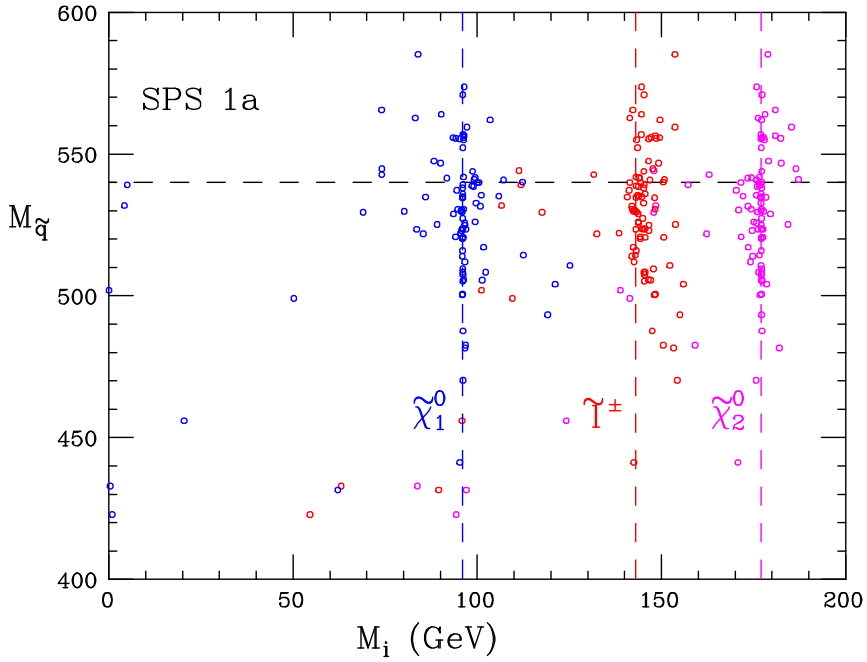
Mass determination



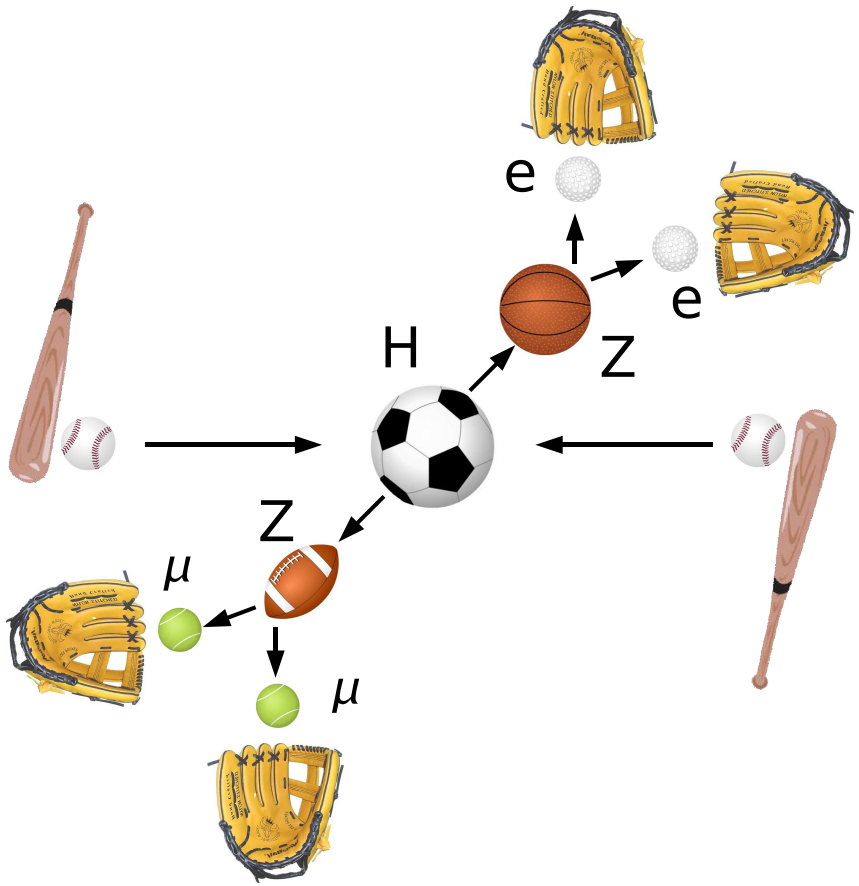
	m_{SPS1a}	LHC	ILC	LHC+ILC		m_{SPS1a}	LHC	ILC	LHC+ILC
h	108.99	0.25	0.05	0.05	H	393.69		1.5	1.5
A	393.26		1.5	1.5	$H+$	401.88		1.5	1.5
χ_1^0	97.21	4.8	0.05	0.05	χ_2^0	180.50	4.7	1.2	0.08
χ_3^0	356.01		4.0	4.0	χ_4^0	375.59	5.1	4.0	2.3
$\chi_1^\pm$	179.85		0.55	0.55	$\chi_2^\pm$	375.72		3.0	3.0
$\tilde{g}$	607.81	8.0		6.5					
$\tilde{t}_1$	399.10		2.0	2.0					
$\tilde{b}_1$	518.87	7.5		5.7	$\tilde{b}_2$	544.85	7.9		6.2
$\tilde{q}_L$	562.98	8.7		4.9	$\tilde{q}_R$	543.82	9.5		8.0
$\tilde{e}_L$	199.66	5.0	0.2	0.2	$\tilde{e}_R$	142.65	4.8	0.05	0.05
$\tilde{\mu}_L$	199.66	5.0	0.5	0.5	$\tilde{\mu}_R$	142.65	4.8	0.2	0.2
$\tilde{\tau}_1$	133.35	6.5	0.3	0.3	$\tilde{\tau}_2$	203.69		1.1	1.1
$\tilde{\nu}_e$	183.79		1.2	1.2					

Mass relations

- weakness of endpoint measurements
- mass relation methods
- backgrounds and mismeasurements

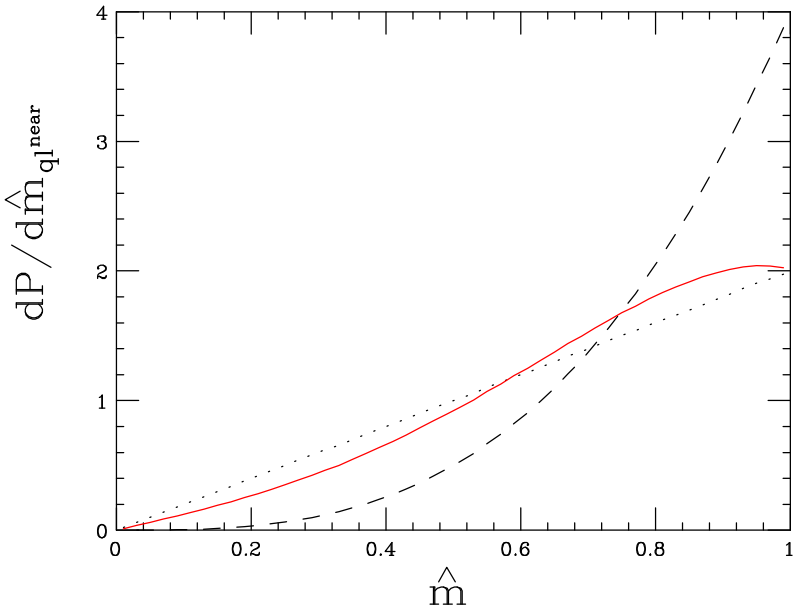


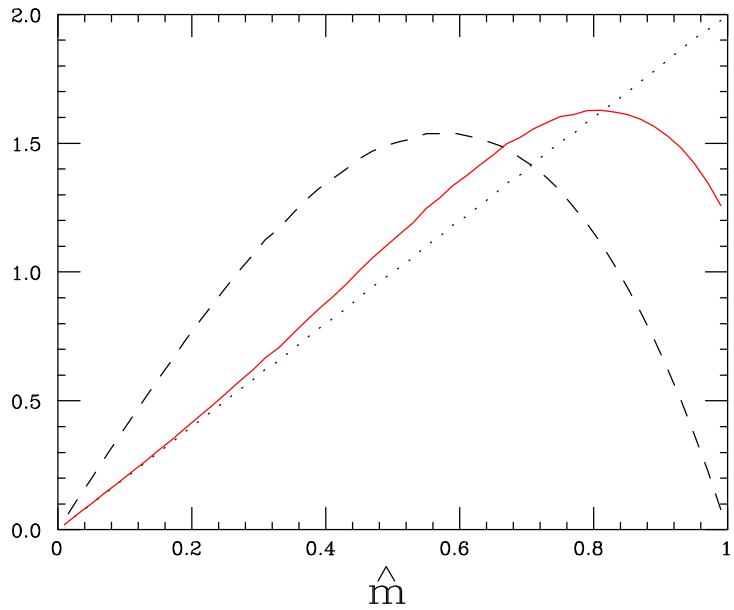
Squarks or KK quarks?



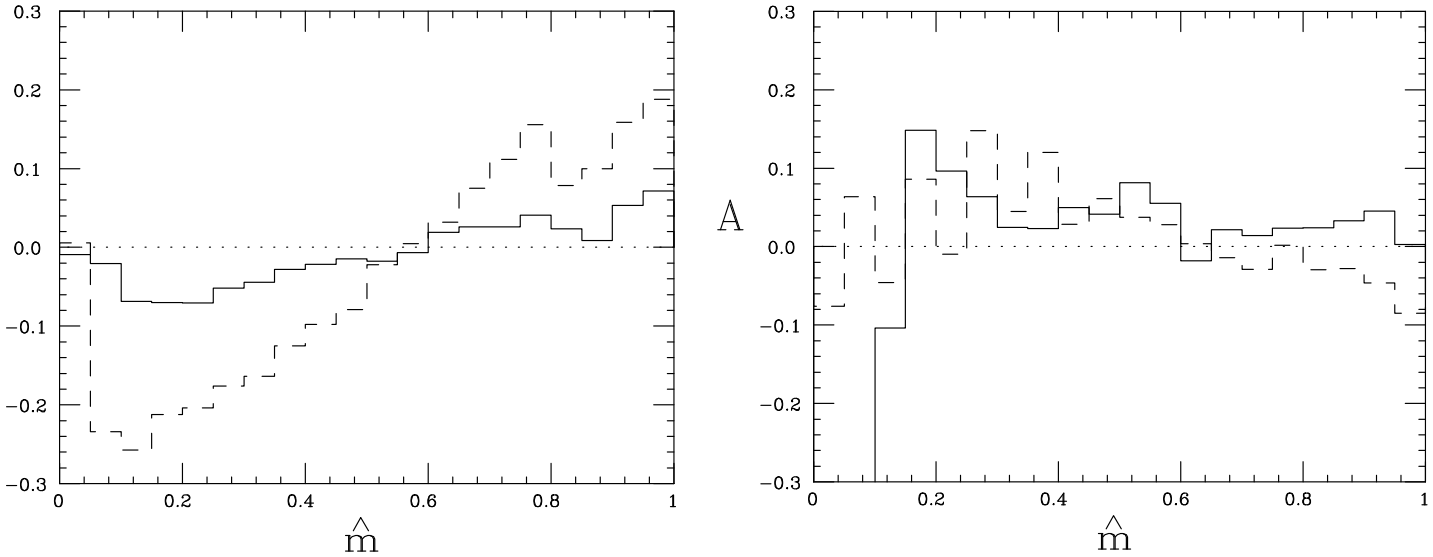
Squarks or KK quarks?

- general approach impossible
- hypothesis test: SUSY (dashed) vs UED (solid)
- hierarchical spectrum: SPS1a

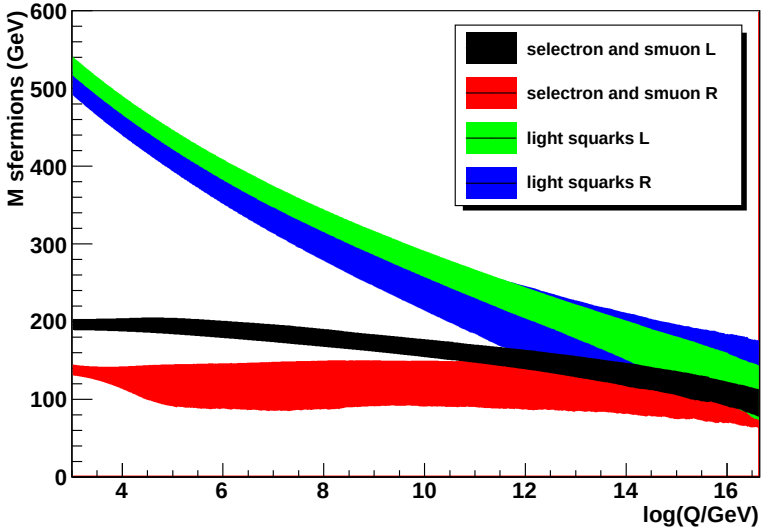


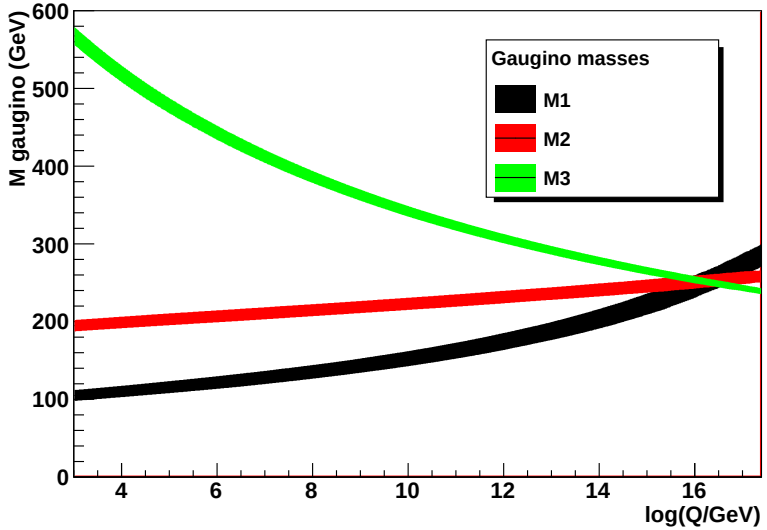


Observable asymmetry



Measuring unification





tools for parameter extraction: SFitter/Suspect, Fittino/Spheno

Literature

Everything I know and don't know available

- basic: Ian Aitchison's SUSY introduction (hep-ph/0505105)
- more advanced: Steve Martin's SUSY primer (hep-ph/9709356)
- review with David Morrissey and Tim Tait
  New Physics at the LHC (arXiv:0912.3259) [new version on my website]
- lecture notes on QCD and Higgs physics
  An LHC Lecture (arXiv:0910.4182) [new version on my website]
- many great TASI lectures...
- you'd be surprized how much of this talk happened in the last five years!