What is the Scale of Supersymmetry?

CMS, December 9, 2004

John Ellis

Preview

- Why supersymmetry in the TeV range
- Present experimental/cosmological limits
- Indications from precision data?
- Prospects at Tevatron & LHC
- Prospects at ILC & CLIC

Why Supersymmetry (Susy)?

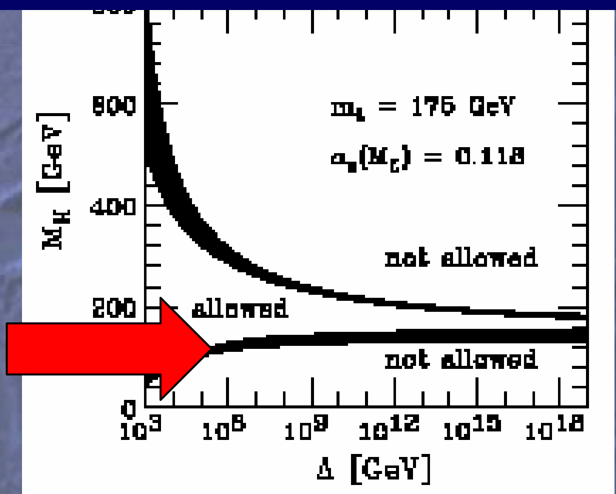
- Hierarchy problem: why is $m_W << m_P$?
  ($m_P \sim 10^{19}$ GeV is scale of gravity)
- Alternatively, why is
  $G_F = 1/ m_W^2 >> G_N = 1/m_P^2$?
- Or, why is
  $V_{Coulomb} >> V_{Newton}$? $e^2 >> G\ m^2 = m^2 / m_P^2$
- Set by hand? What about loop corrections?
  $\delta m_{H,W}^2 = O(\alpha/\pi)\ \Lambda^2$
- Cancel boson loops ⇔ fermions
- Need $|\ m_B^2 - m_F^2| < 1\ \mathrm{TeV}^2$

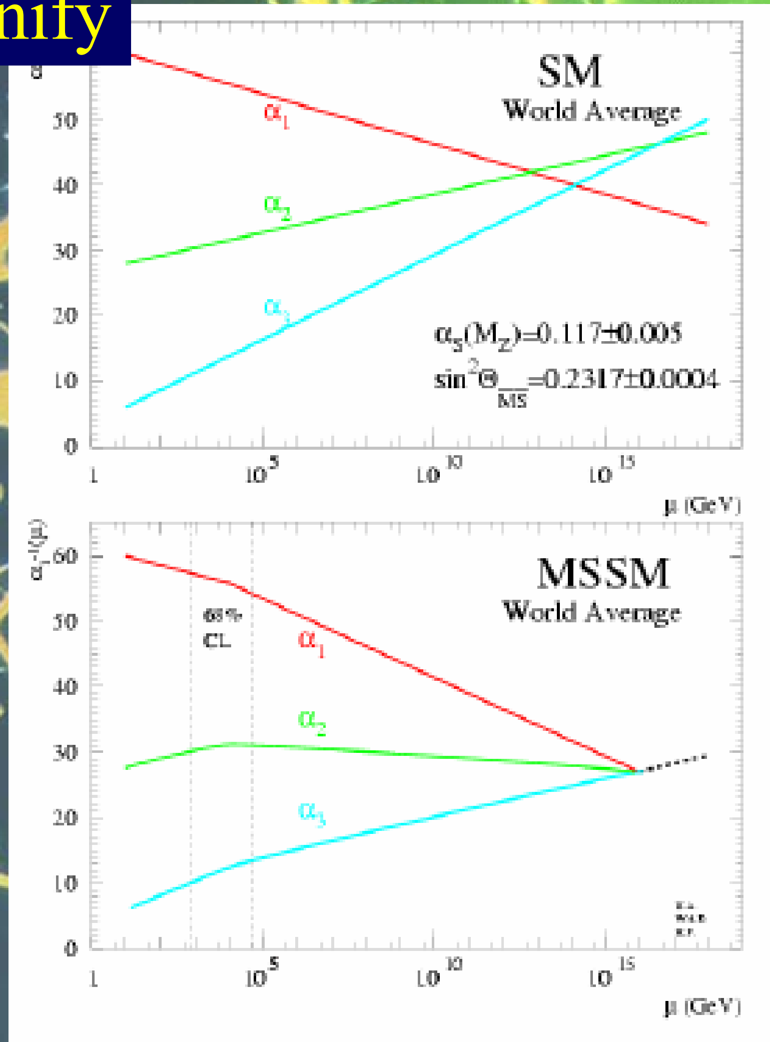
Other Reasons to like Susy

It enables the gauge couplings to unify

It predicts $m_H < 150$ GeV

It stabilizes the Higgs potential for low masses





Approved by Fabiola Gianotti

Dark Matter in the Universe

Astronomers say that most of the matter in the Universe is invisible Dark Matter

`Supersymmetric' particles ?

We shall look for them with the LHC

Lightest Supersymmetric Particle

- Stable in many models because of conservation of R parity:

  $R = (-1)^{2S - L + 3B}$

  where S = spin, L = lepton #, B = baryon #
- Particles have R = +1, sparticles R = -1:

  Sparticles produced in pairs

  Heavier sparticles → lighter sparticles
- Lightest supersymmetric particle (LSP) stable

Possible Nature of LSP

- No strong or electromagnetic interactions
  - Otherwise would bind to matter
  - Detectable as anomalous heavy nucleus
- Possible weakly-interacting scandidates
  - Sneutrino
    - (Excluded by LEP, direct searches)
  - Lightest neutralino χ
  - Gravitino
    - (nightmare for detection)

Minimal Supersymmetric Extension of Standard Model (MSSM)

- Particles + spartners + 2 Higgs doublets
- Ratio of Higgs v.e.v.'s = $\tan \beta$
- Soft supersymmetry-breaking parameters:

  Scalar masses m_0, gaugino masses $m_{1/2}$,
  trilinear soft couplings A_λ, bilinear soft couplings B_λ
- Often assume universality:

  Single m_0, single $m_{1/2}$, single A_λ, B_λ: not string?
- Called constrained MSSM = CMSSM
- Gravitino mass?
- Minimal supergravity: not string?

  $m_{3/2} = m_0$, $B_\lambda = A_\lambda - 1$

Constraints on Supersymmetry

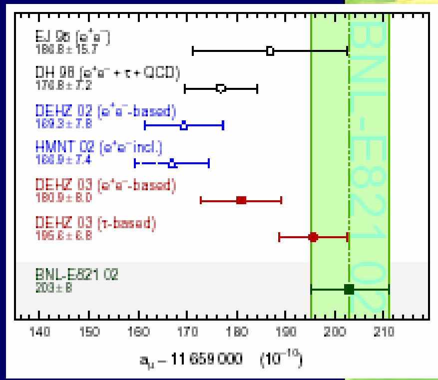
- Absence of sparticles at LEP, Tevatron

  selectron, chargino > 100 GeV

  squarks, gluino > 250 GeV

- Indirect constraints

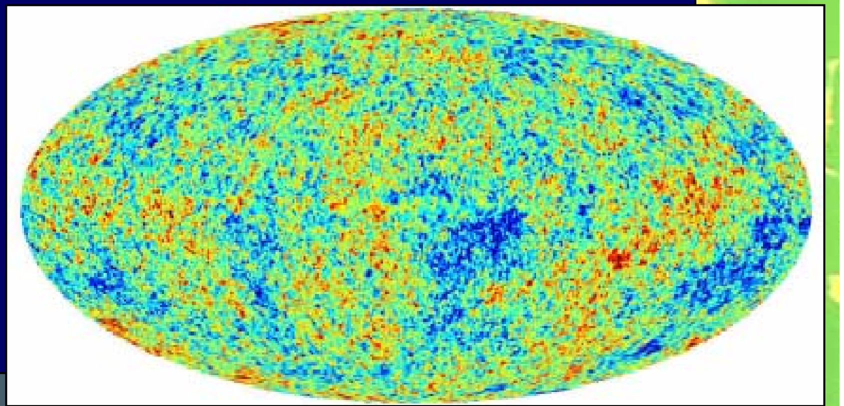
  Higgs > 114 GeV, b -> s γ $\quad$ g_μ - 2



- Density of dark matter

  lightest sparticle χ:

WMAP: $0.094 < \Omega_\chi h^2 < 0.124$



Updated Results for g_μ - 2

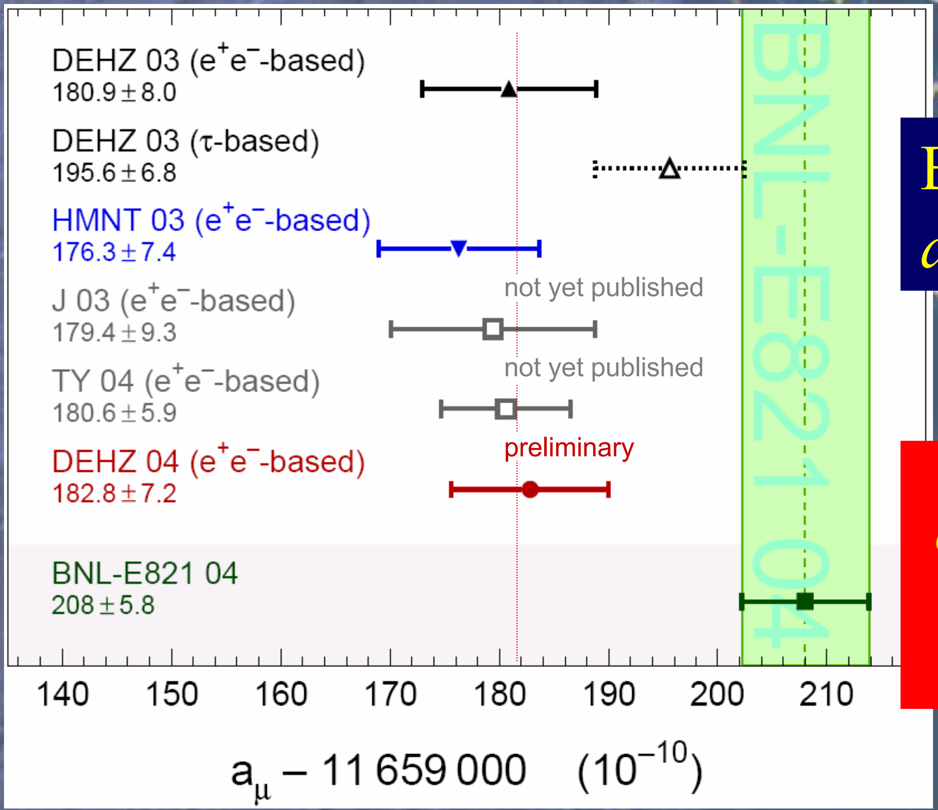
$$a_\mu^{had}[e^+e^-] = (693.4 \pm 5.3 \pm 3.5) \times 10^{-10}$$

$$a_\mu^{SM}[e^+e^-] = (11\,659\,182.8 \pm 6.3_{had} \pm 3.5_{LBL} \pm 0.3_{QED+EW}) \times 10^{-10}$$

Weak contribution : $a_\mu^{weak} = +(15.4 \pm 0.3) \times 10^{-10}$

Hadronic contribution from higher order : $a_\mu^{had}[(\alpha/\pi)^3] = -(10.0 \pm 0.6) \times 10^{-10}$

Hadronic contribution from LBL scattering: $a_\mu^{had}[LBL] = +(12.0 \pm 3.5) \times 10^{-10}$



BNL E821 (2004):

$a_\mu^{exp} = (11\,659\,208.0 \pm 5.8)\, 10^{-10}$

$a_\mu^{exp} - a_\mu^{SM} = (25.2 \pm 9.2) \times 10^{-10}$

➡ 2.7 standard deviations

Current Constraints on CMSSM

Assuming the lightest sparticle is a neutralino

Focus-point region above 7 TeV for m_t = 178 GeV

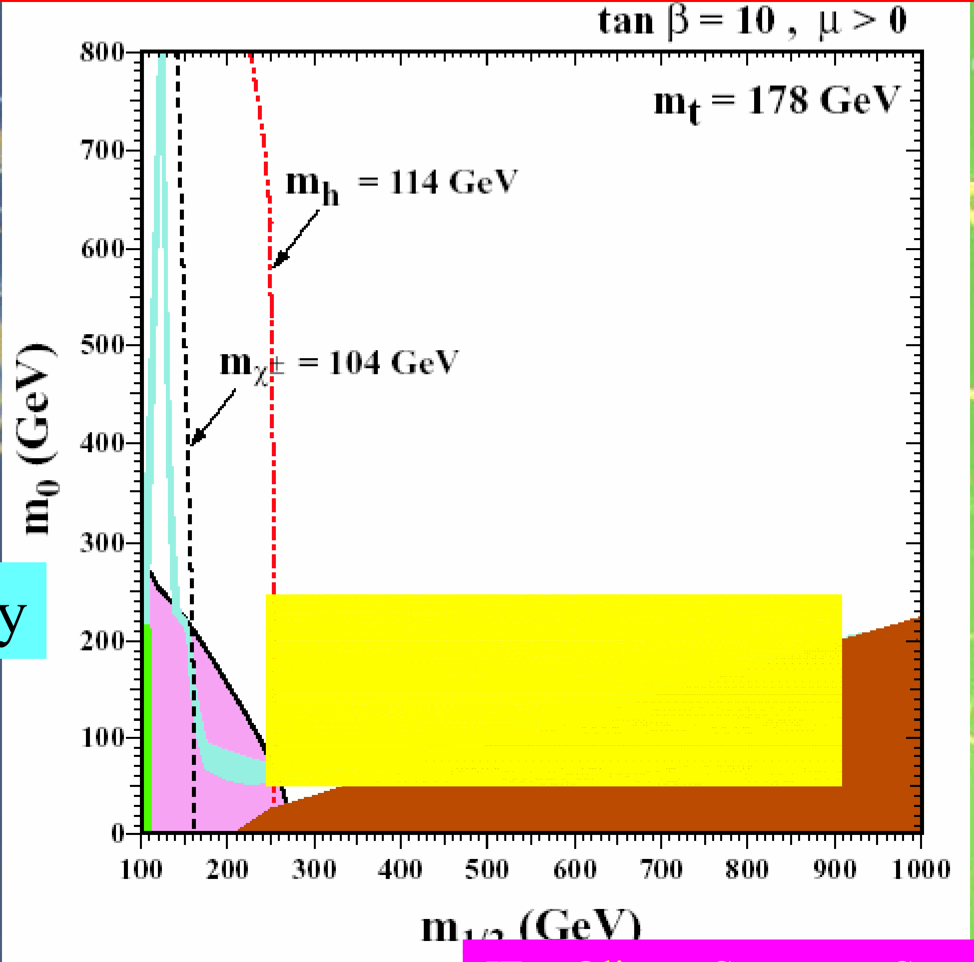
Excluded because stau LSP

Excluded by b → s gamma

WMAP constraint on relic density

Excluded (?) by latest g - 2

Latest CDF/D0 top mass

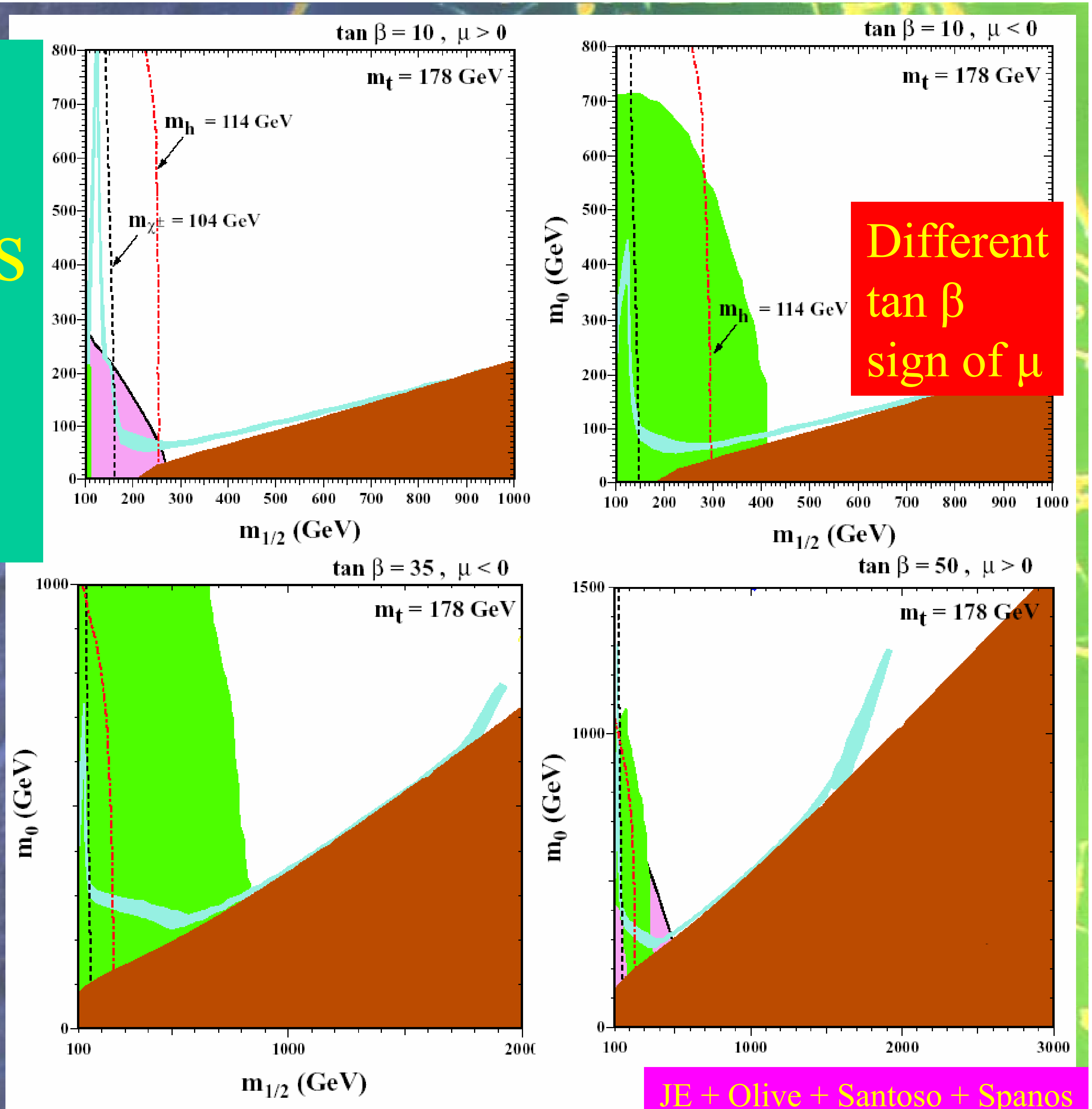


JE + Olive + Santoso + Spanos

Current Constraints on CMSSM

Impact of Higgs constraint reduced if larger m_t

Focus-point region far up

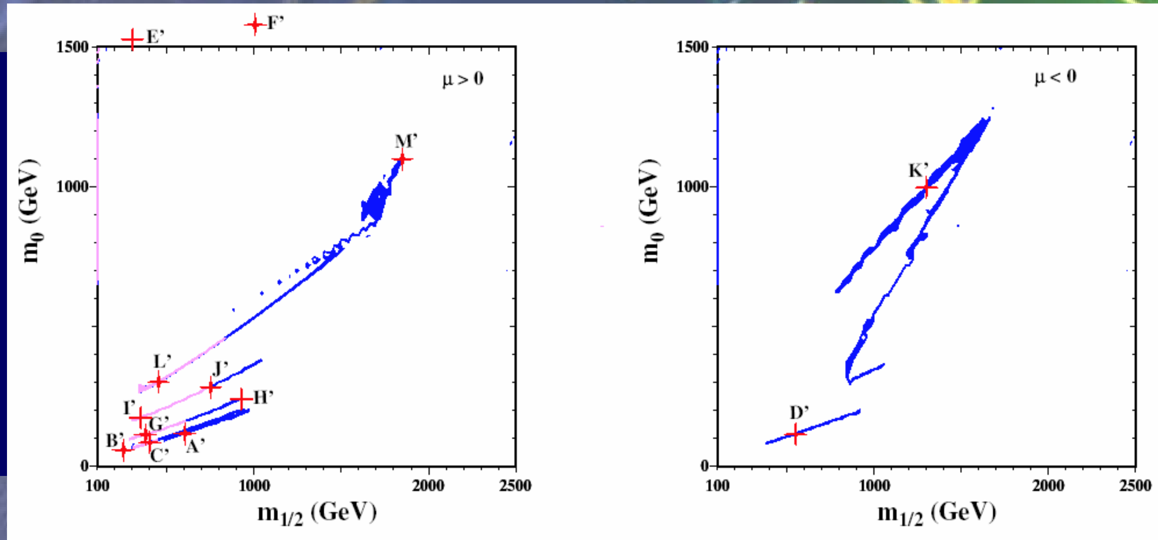


Different tan β sign of μ

JE + Olive + Santoso + Spanos

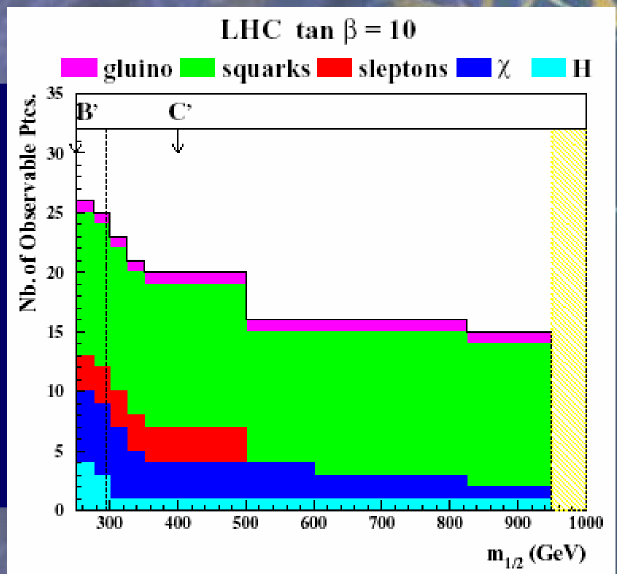
Supersymmetric Benchmark Studies

Lines in susy space allowed by accelerators, WMAP data

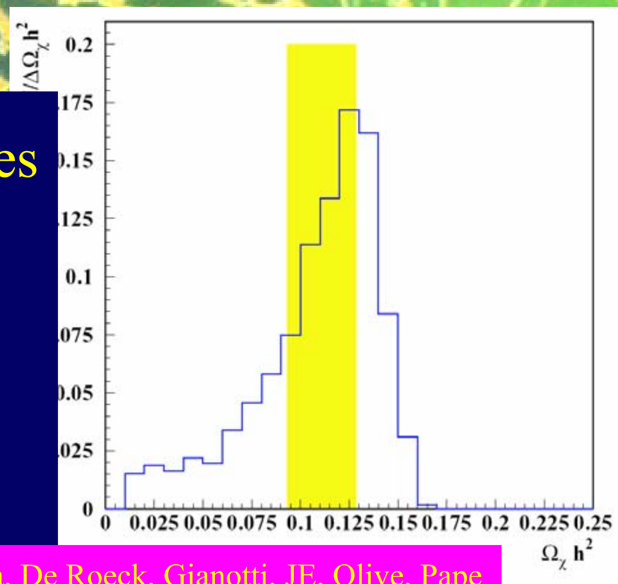


Specific benchmark Points along WMAP lines

Sparticle Detectability @ LHC along one WMAP line



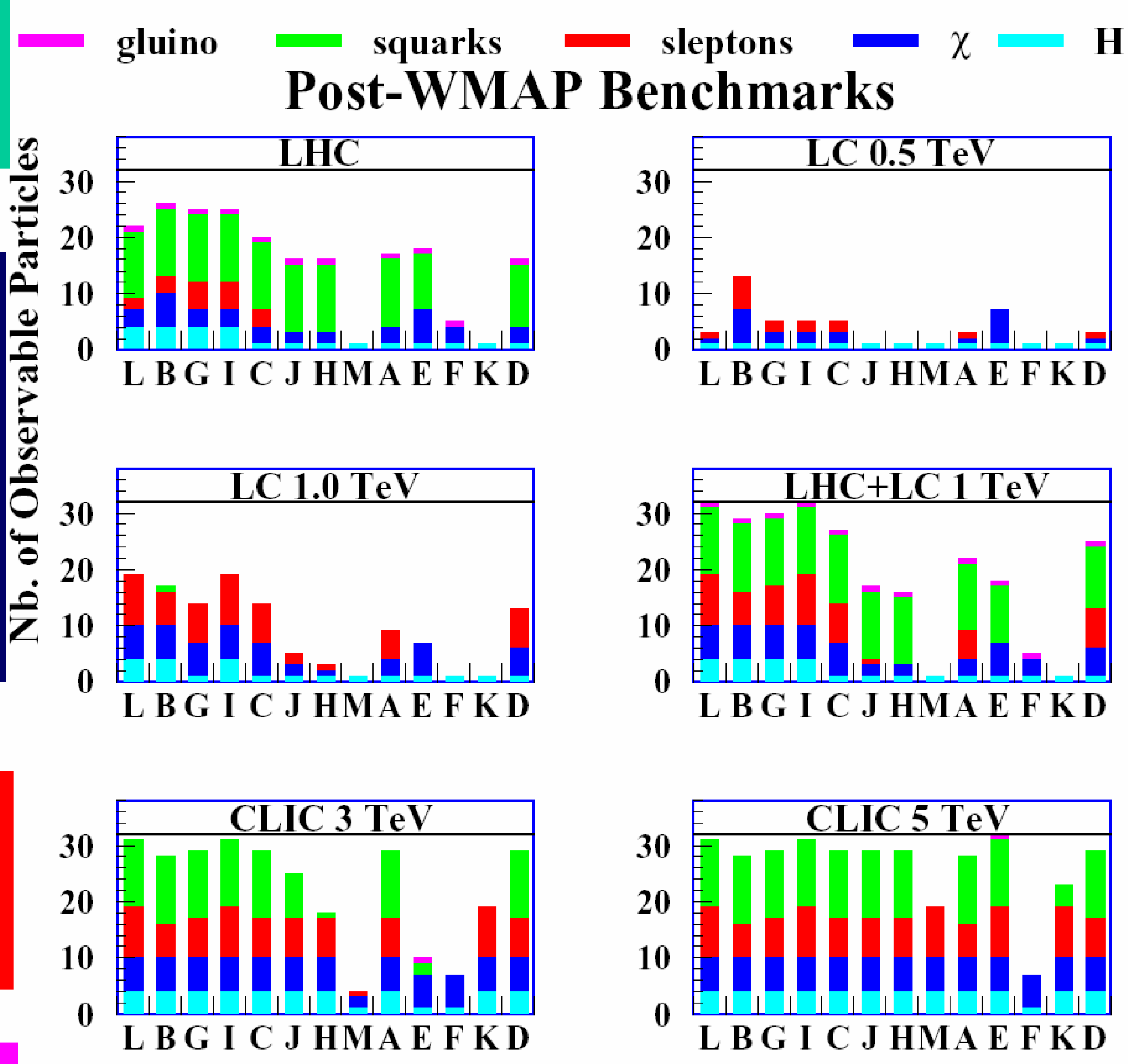
LHC enables calculation of relic density at a benchmark point



Battaglia, De Roeck, Gianotti, JE, Olive, Pape

LHC and LC Scapabilities

LHC almost
`guaranteed'
to discover
supersymmetry
if it is relevant
to the mass problem



LC oberves
complementary
sparticles

Battaglia, De Roeck, Gianotti, JE, Olive, Pape

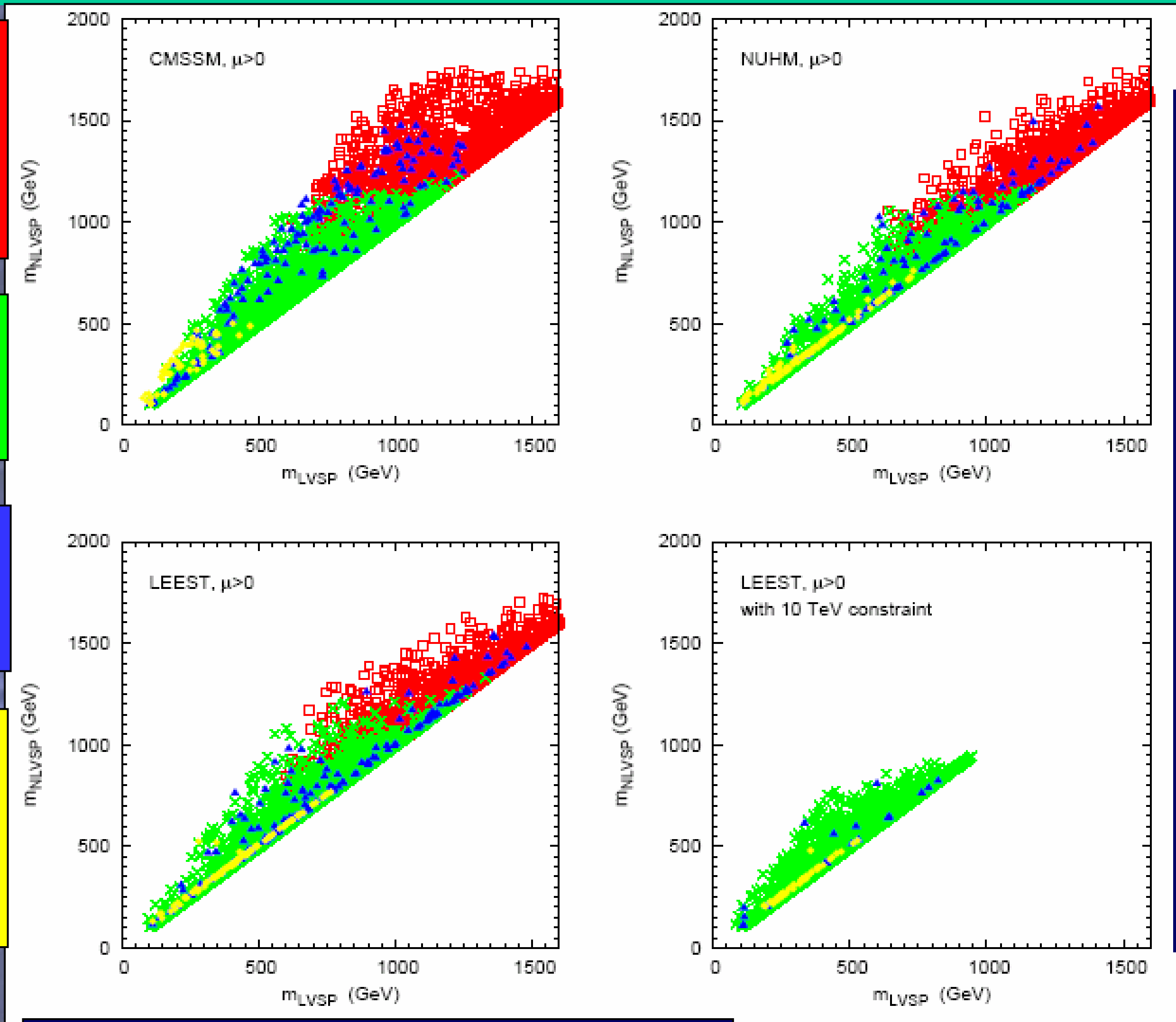
Sparticles may not be very light

Full Model samples

Detectable @ LHC

Provide Dark Matter

Dark Matter Detectable Directly

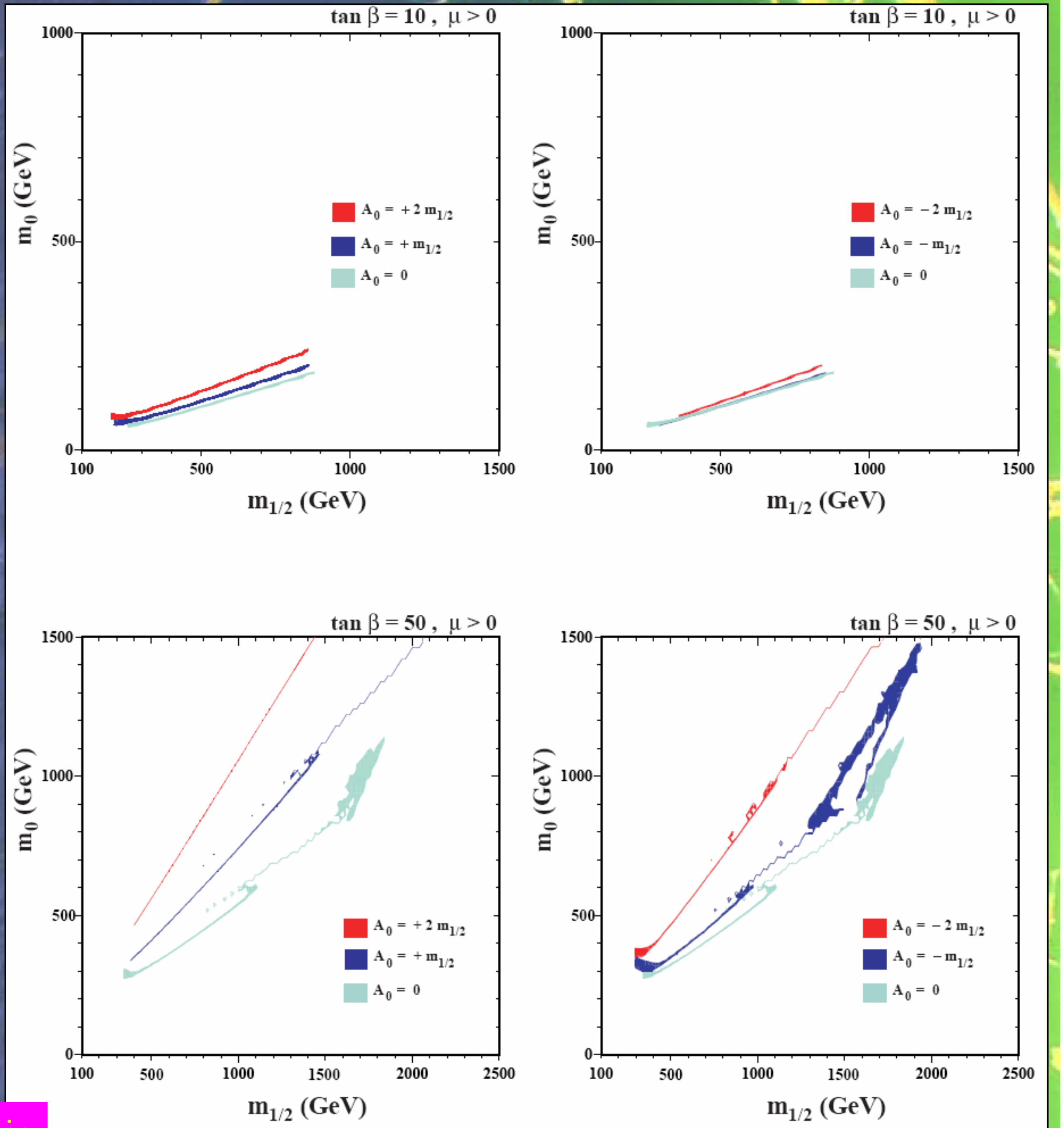


↑ Second lightest visible particle

Lightest visible sparticle →

JE + Olive + Santoso + Spanos

Dependence of WMAP strips on A parameter



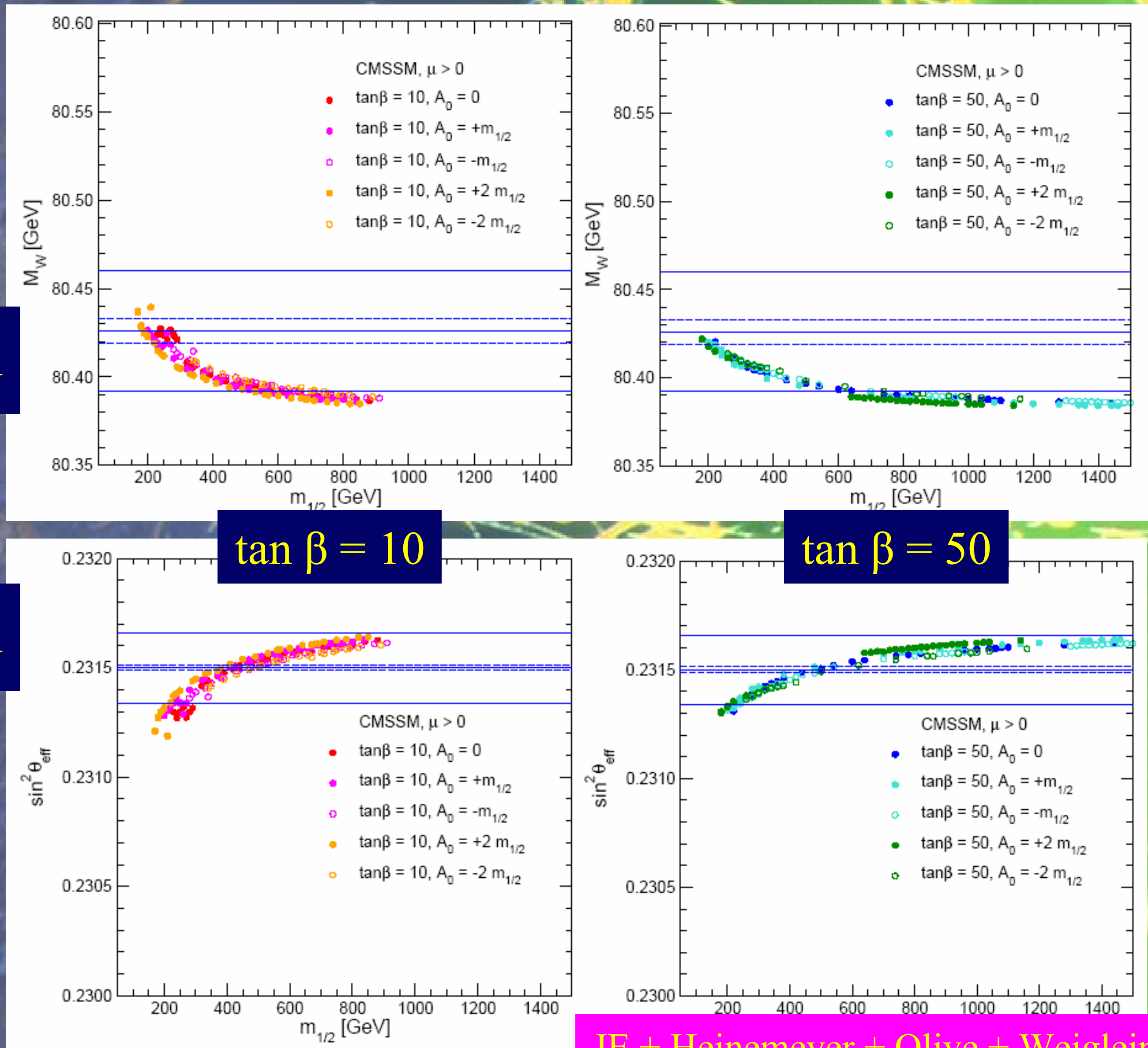
JE + Heinemeyer + Olive + Weiglein

Precision Observables in Susy

Sensitivity to $m_{1/2}$
in CMSSM
along WMAP lines

m_W

$\sin^2\theta_W$



tan β = 10

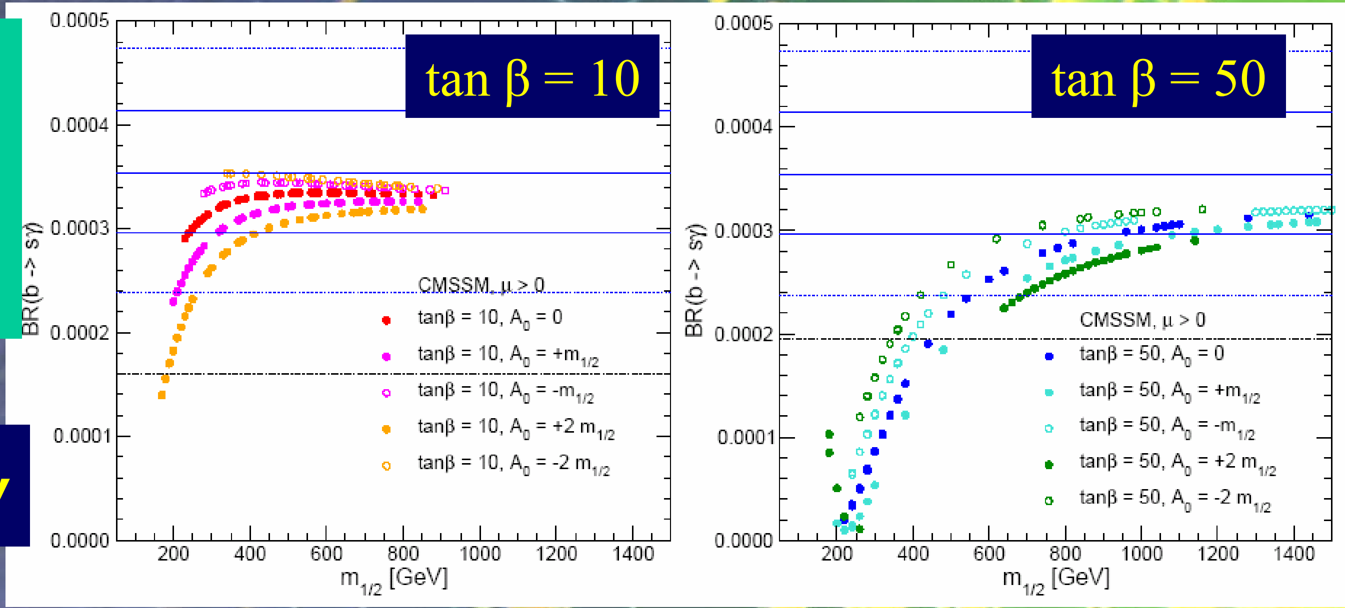
tan β = 50

Present & possible future errors

JE + Heinemeyer + Olive + Weiglein

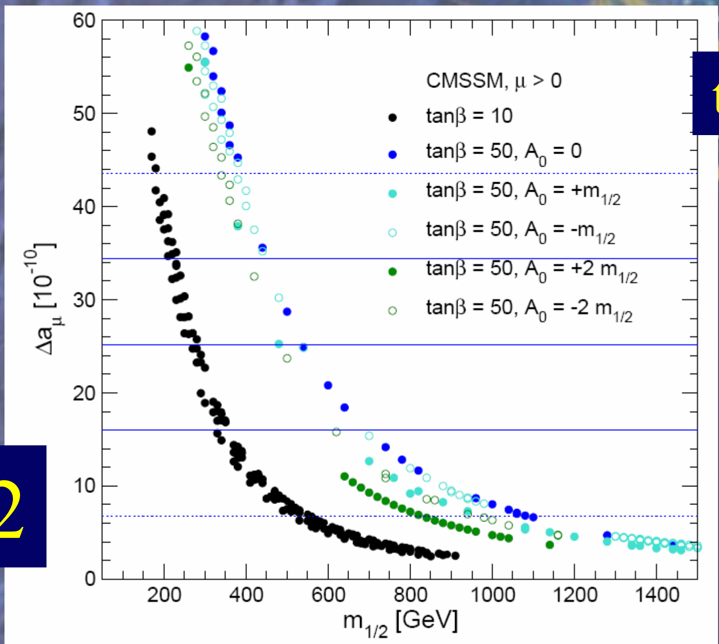
More Observables

$b \rightarrow s\gamma$

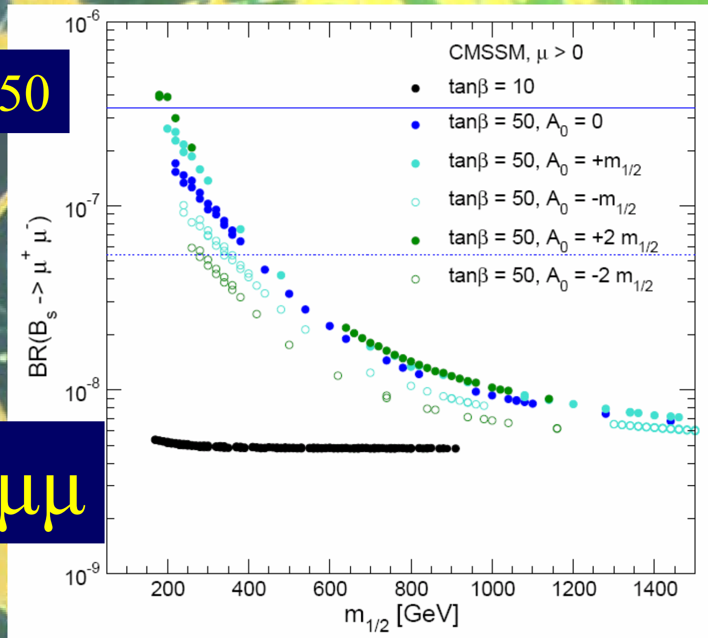


tan β = 10, 50

$g_\mu - 2$



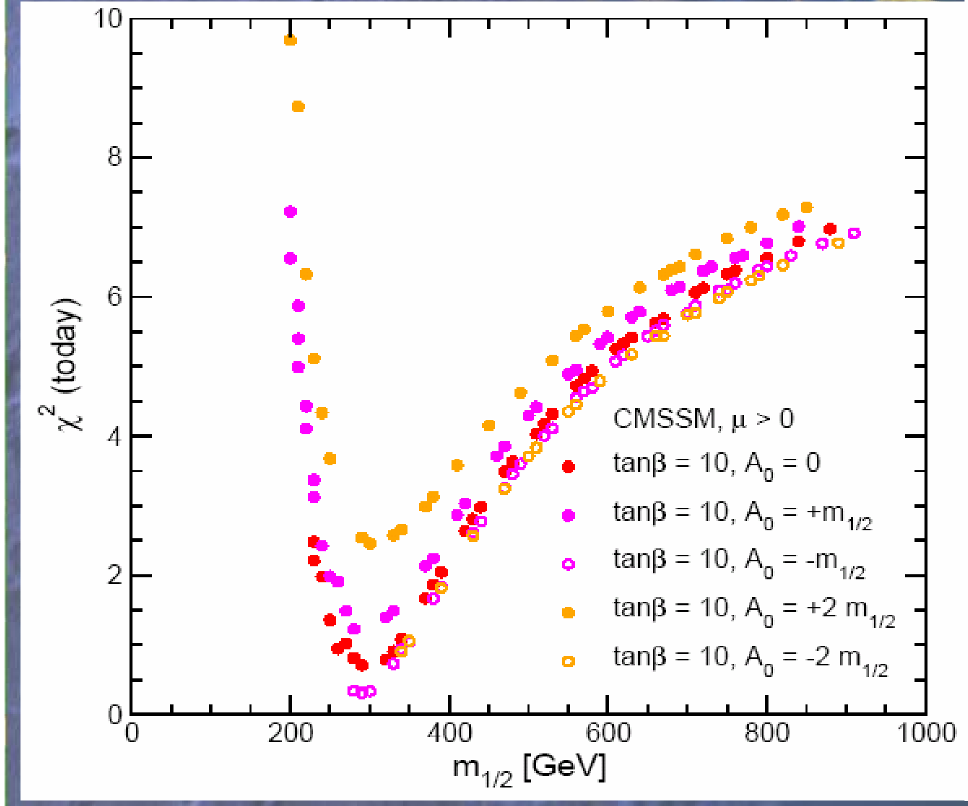
$B_s \rightarrow \mu\mu$

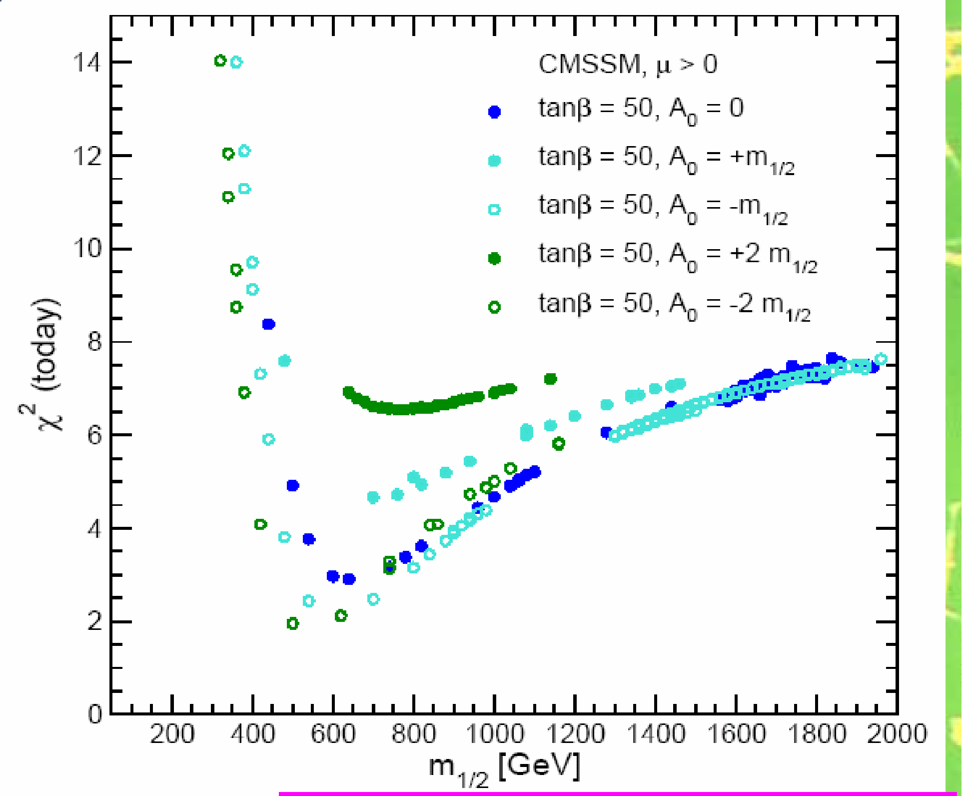


JE + Heinemeyer + Olive + Weiglein

Global Fits to Present Data

As functions of $m_{1/2}$ in CMSSM for tan β = 10, 50

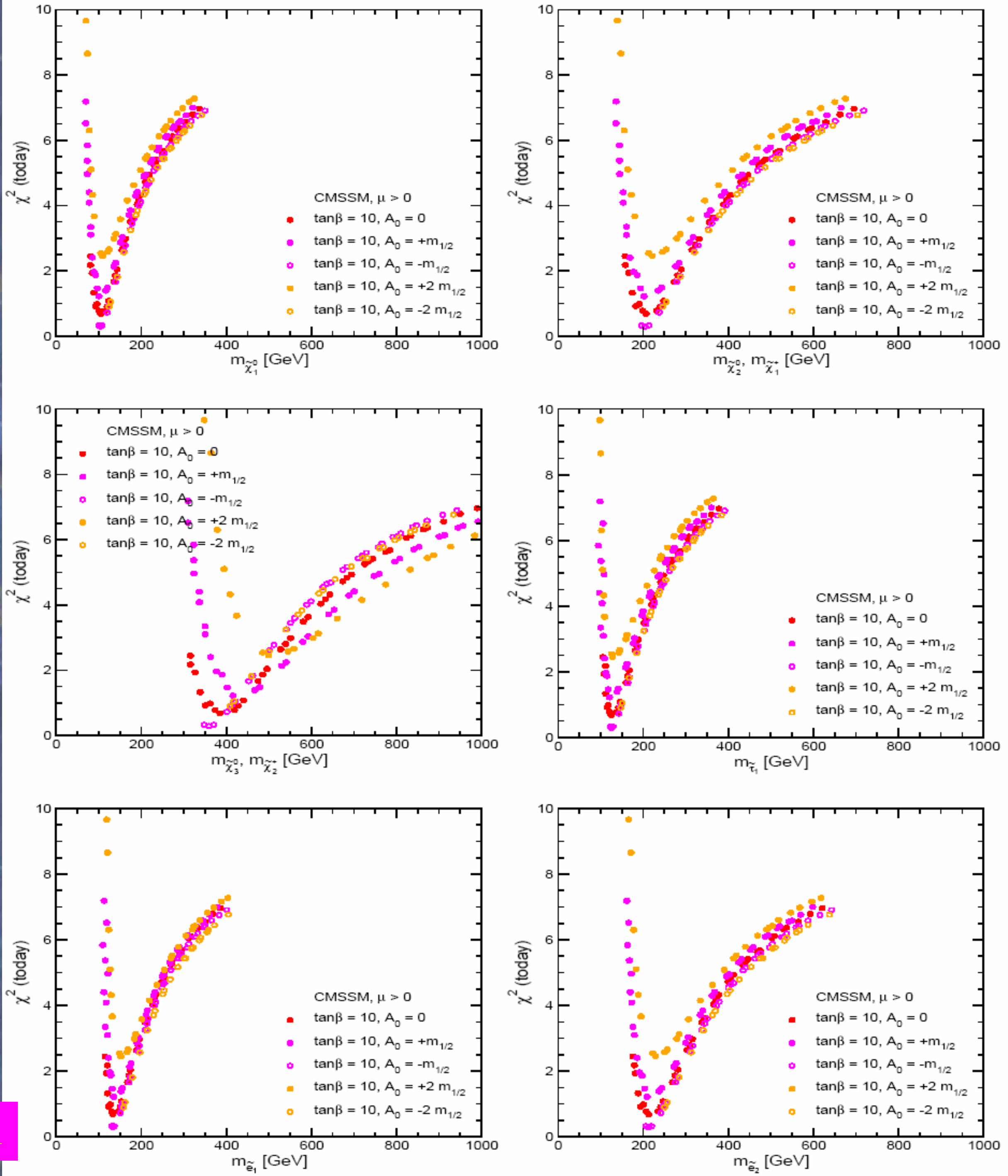




JE + Heinemeyer + Olive + Weiglein

Global Fits to Present Data

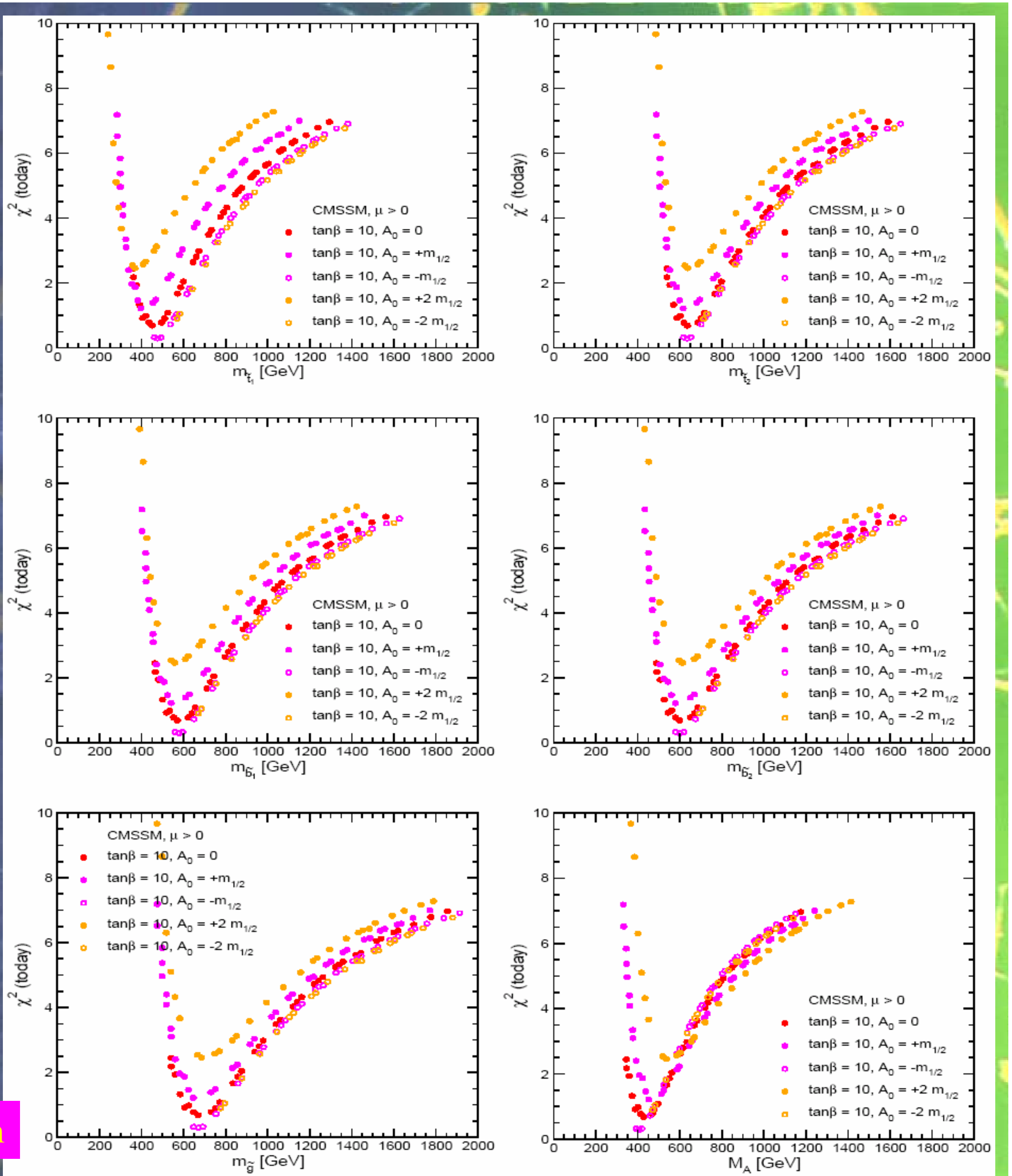
Preferred sparticle masses for tan β = 10



JE + Heinemeyer + Olive + Weiglein

Global Fits to Present Data

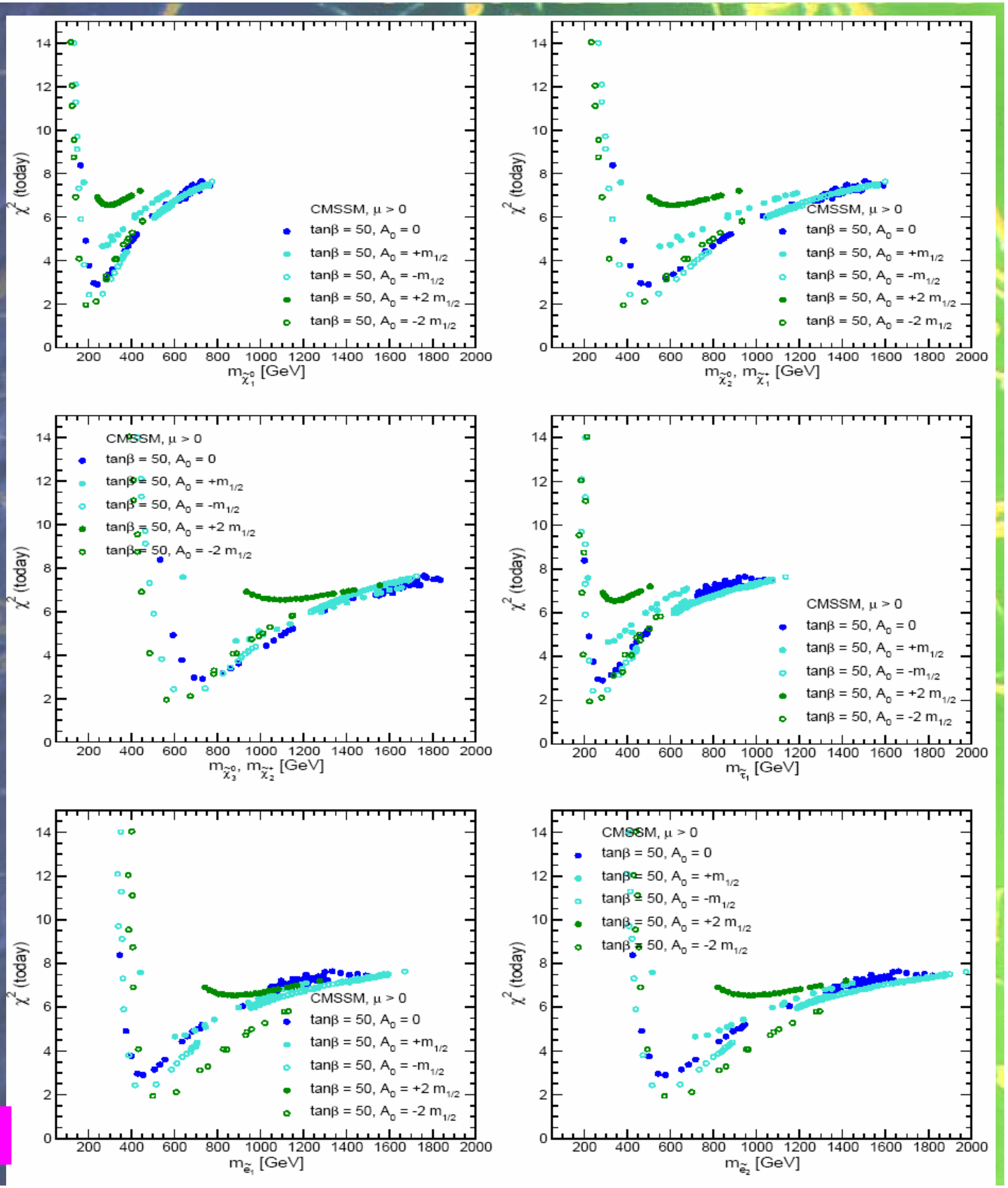
Preferred sparticle masses for tan β = 10



JE + Heinemeyer + Olive + Weiglein

Global Fits to Present Data

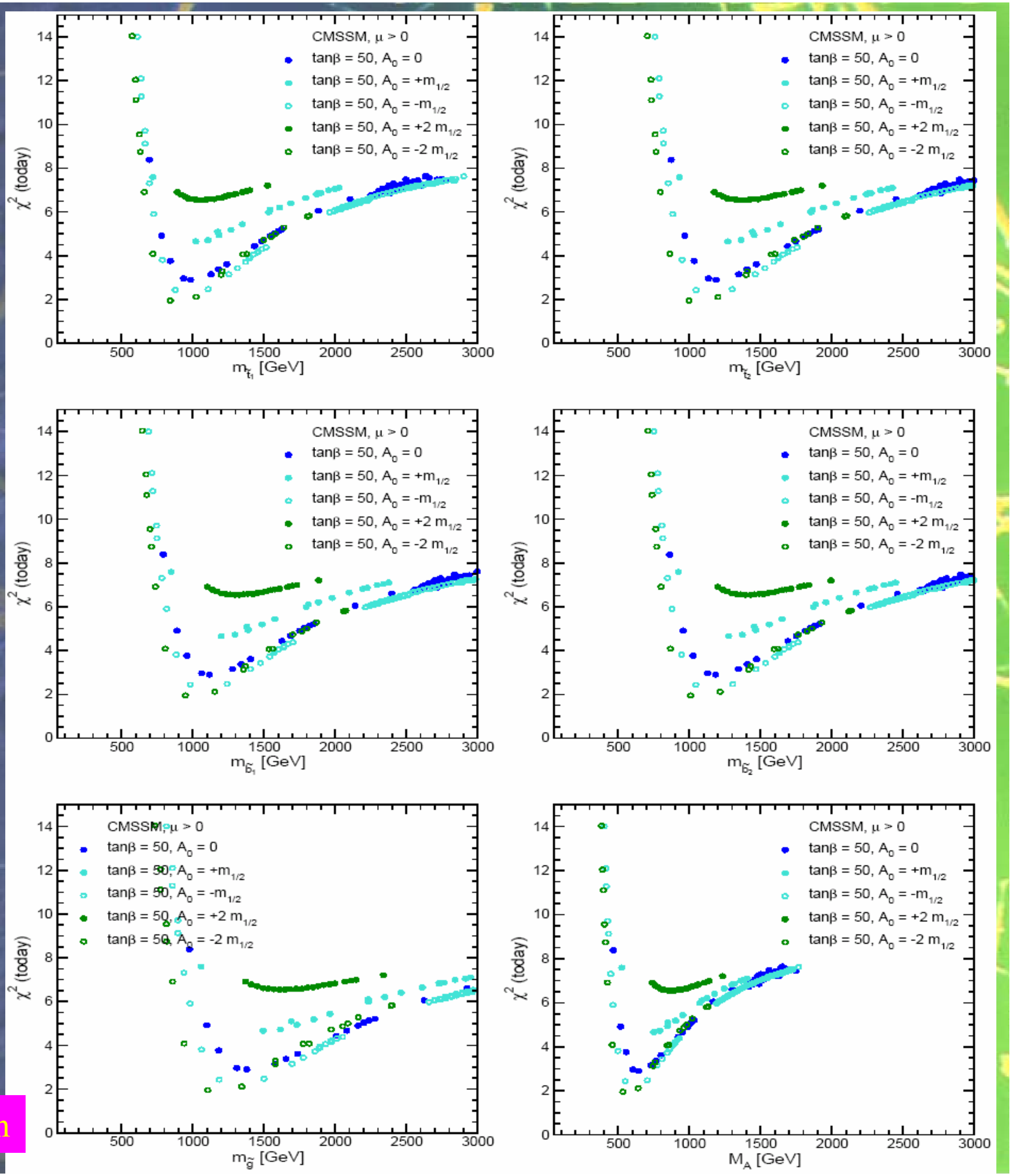
Preferred sparticle masses for tan β = 50



JE + Heinemeyer + Olive + Weiglein

Global Fits to Present Data

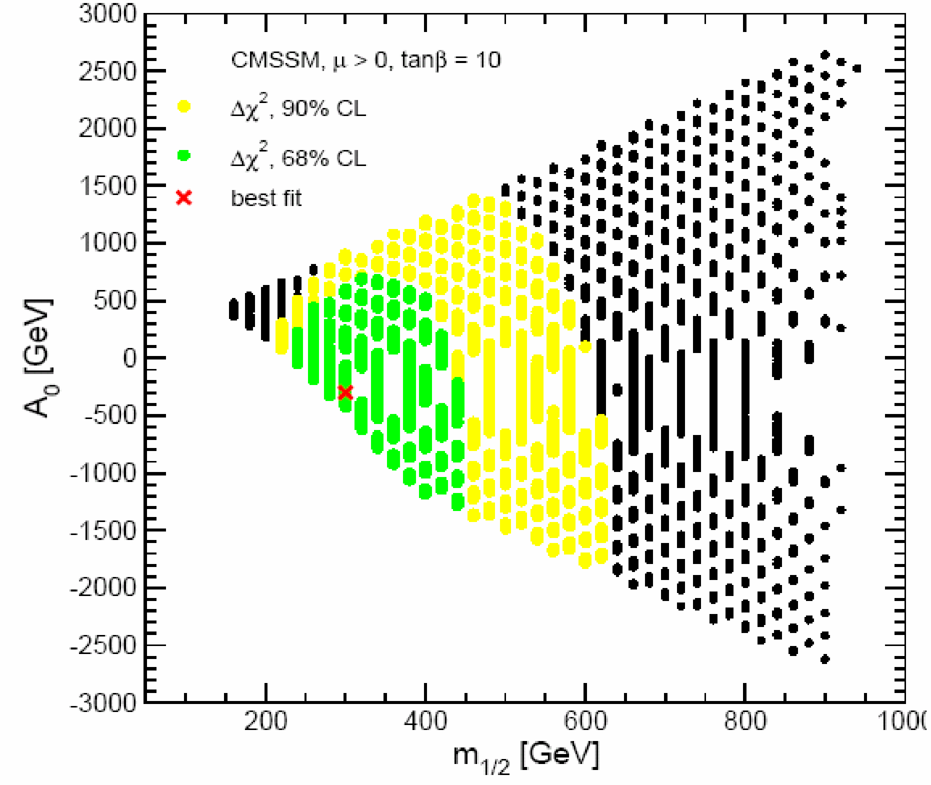
Preferred sparticle masses for tan β = 50

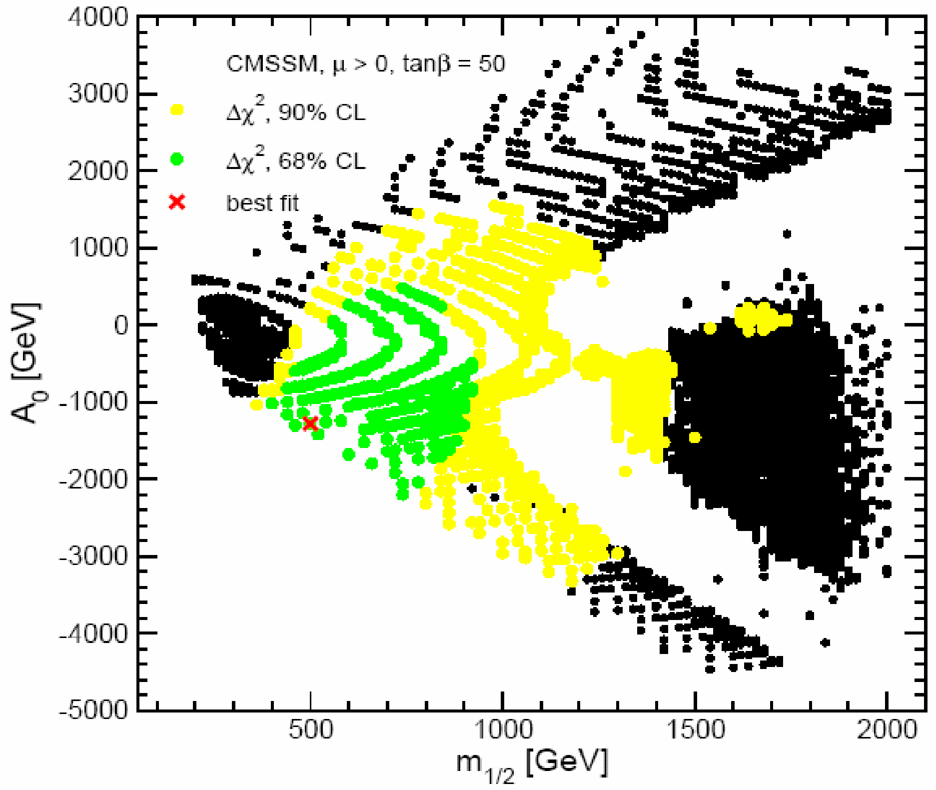


JE + Heinemeyer + Olive + Weiglein

Global Fits to Present Data

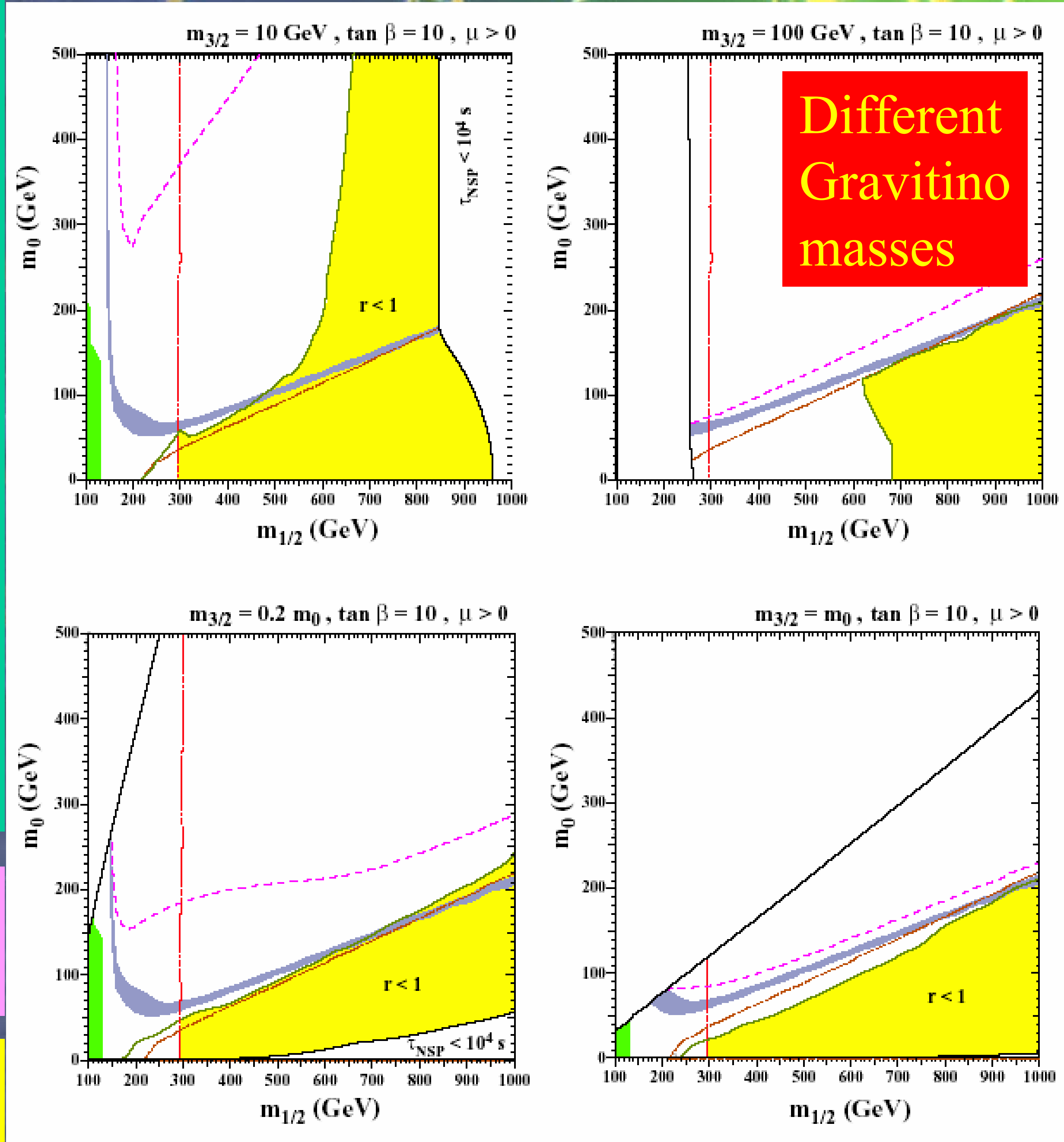
$(m_{1/2}, A_0)$ planes in CMSSM for tan β = 10, 50





JE + Heinemeyer + Olive + Weiglein

Different Regions of Sparticle Parameter Space if Gravitino LSP



Density below WMAP limit

Decays do not affect BBN/CMB agreement

JE + Olive + Santoso + Spanos

Minimal Supergravity Model

More constrained than CMSSM: $m_{3/2} = m_0$, $B_\lambda = A_\lambda - 1$

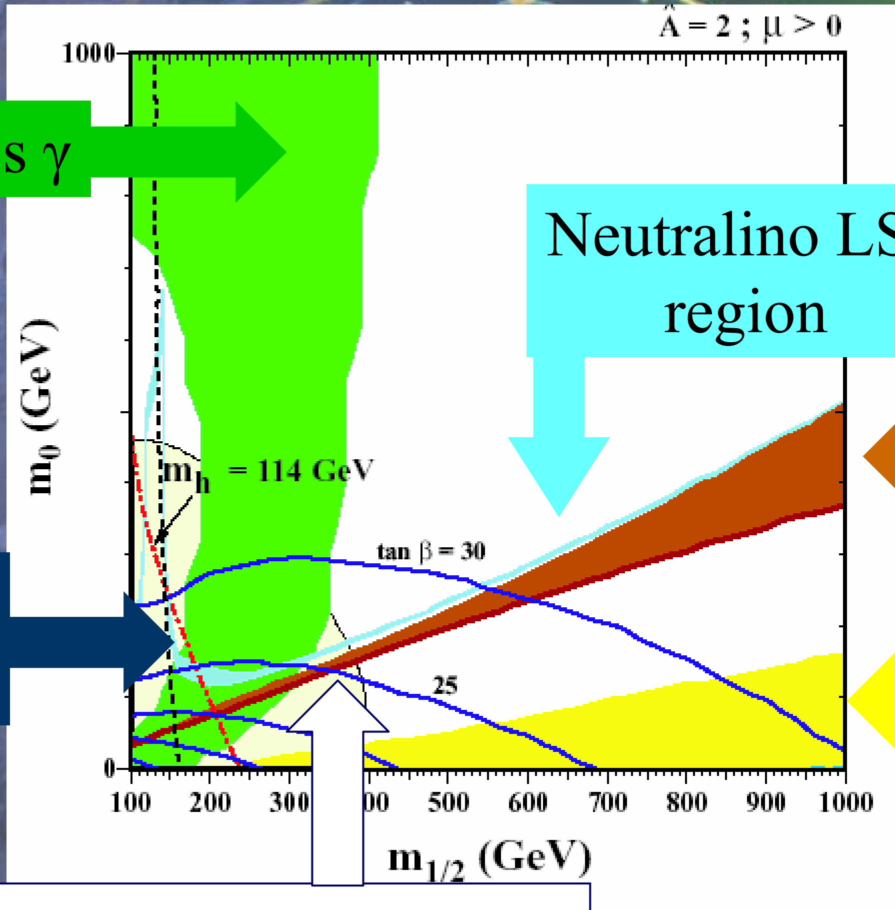
Excluded by $b \rightarrow s\,\gamma$

Neutralino LSP region

stau LSP (excluded)

LEP constraints On m_h, chargino

Gravitino LSP region



tan β fixed by vacuum conditions

JE + Olive + Santoso + Spanos

Tasks for the TeV ILC

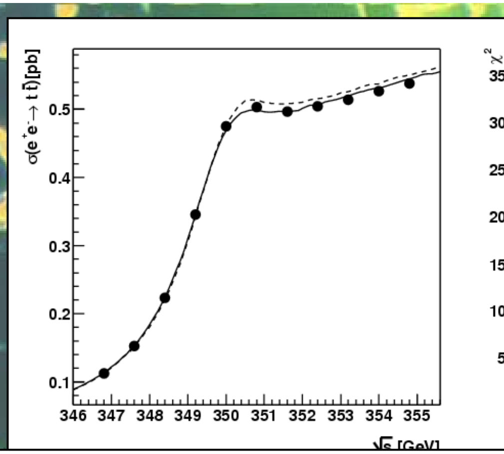
- Measure m_t to $< \pm$ 100 MeV
- If there is a light Higgs of any kind, pin it down:

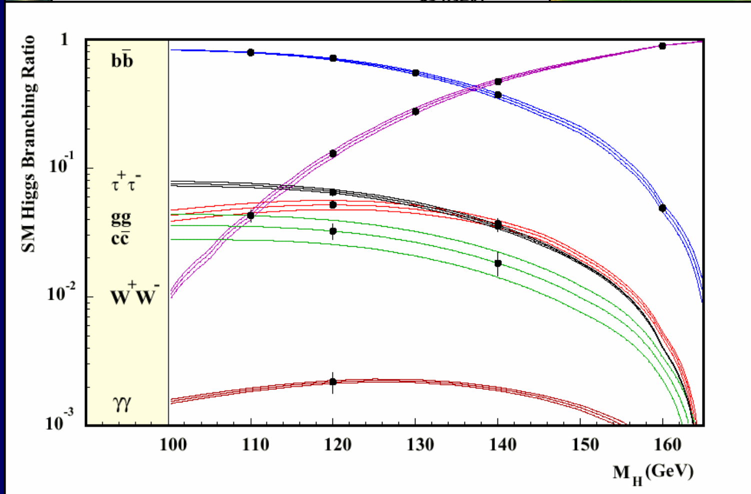
  Does it have standard model couplings?

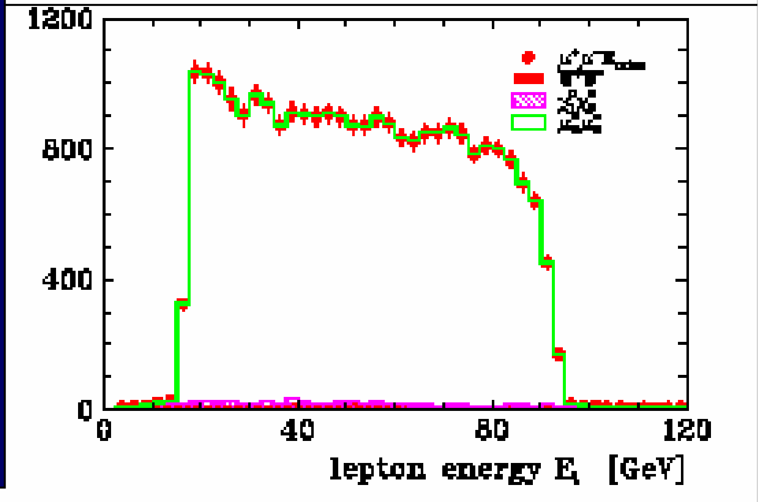
  What is its precise mass?
- If there are extra light particles:

  Measure mass and properties
- If LHC sees nothing new below ~ 500 GeV:

  Look for indirect signatures

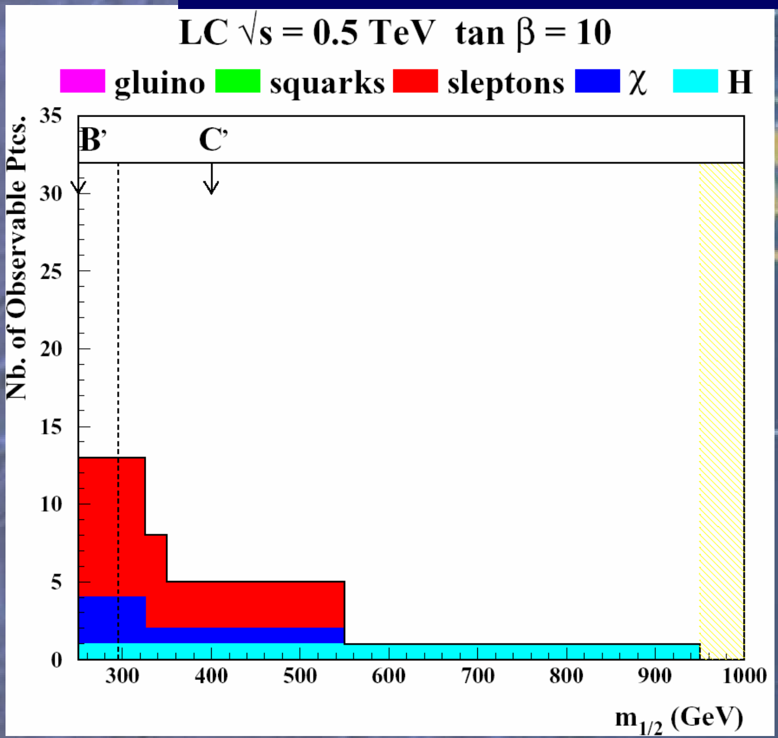


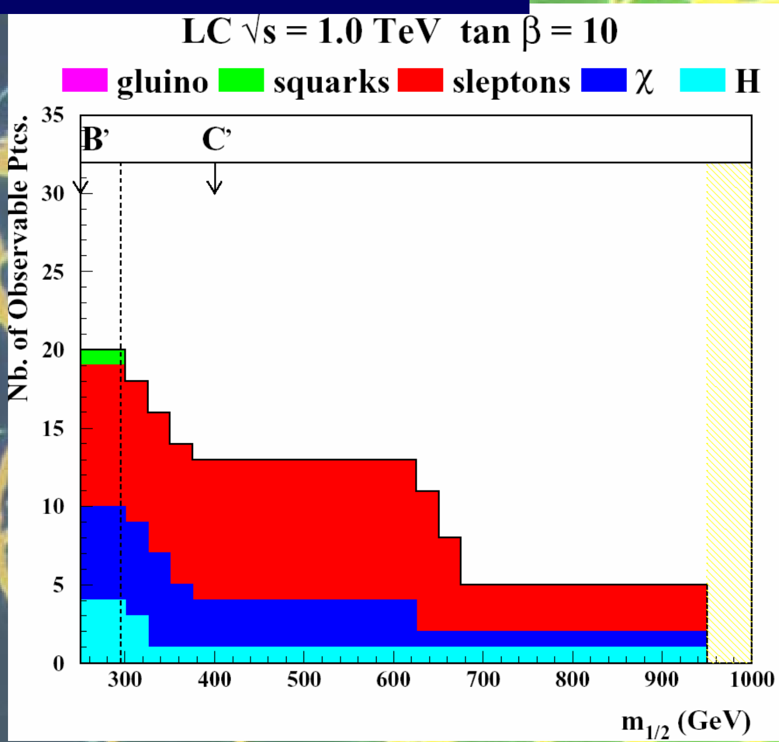




Sparticles at LC along WMAP Line

Complementary to LHC: weakly-interacting sparticles





Battaglia, De Roeck, Gianotti, JE, Olive, Pape

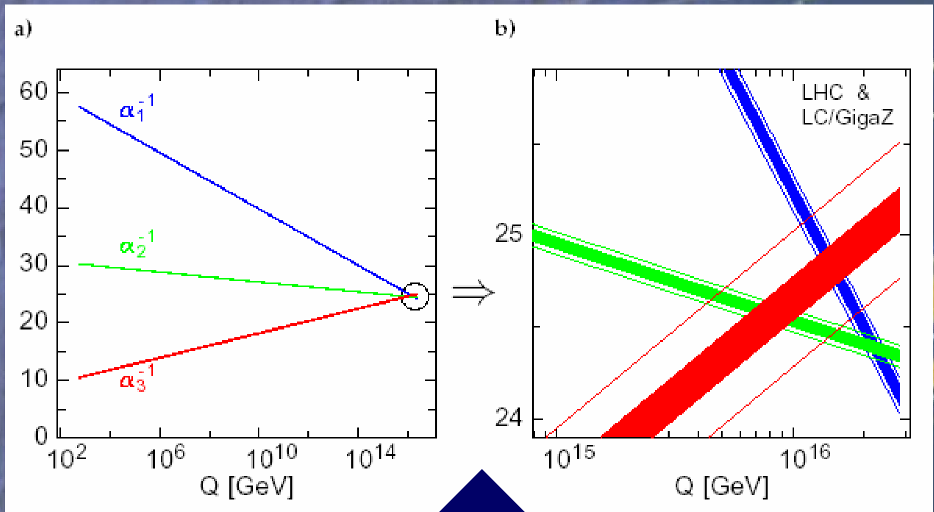
Added Value of LC Measurements

	m_{SPS1a}	LHC	LHC+LC		m_{SPS1a}	LHC	LHC+LC
h	111.6	0.25	0.05	H	399.6		1.5
A	399.1		1.5	$H+$	407.1		1.5
χ_1^0	97.03	4.8	0.05	χ_2^0	182.9	4.7	0.08
χ_3^0	349.2		4.0	χ_4^0	370.3	5.1	2.3
$\chi_1^\pm$	182.3		0.55	$\chi_2^\pm$	370.6		3.0
$\tilde{g}$	615.7	8.0	6.5				
$\tilde{t}_1$	411.8		2.0				
$\tilde{b}_1$	520.8	7.5	5.7	$\tilde{b}_2$	550.4	7.9	6.2
$\tilde{u}_1$	551.0	19.0	16.0	$\tilde{u}_2$	570.8	17.4	9.8
$\tilde{d}_1$	549.9	19.0	16.0	$\tilde{d}_2$	576.4	17.4	9.8
$\tilde{s}_1$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.4	9.8
$\tilde{c}_1$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
$\tilde{e}_1$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
$\tilde{\mu}_1$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
$\tilde{\tau}_1$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
$\tilde{\nu}_e$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

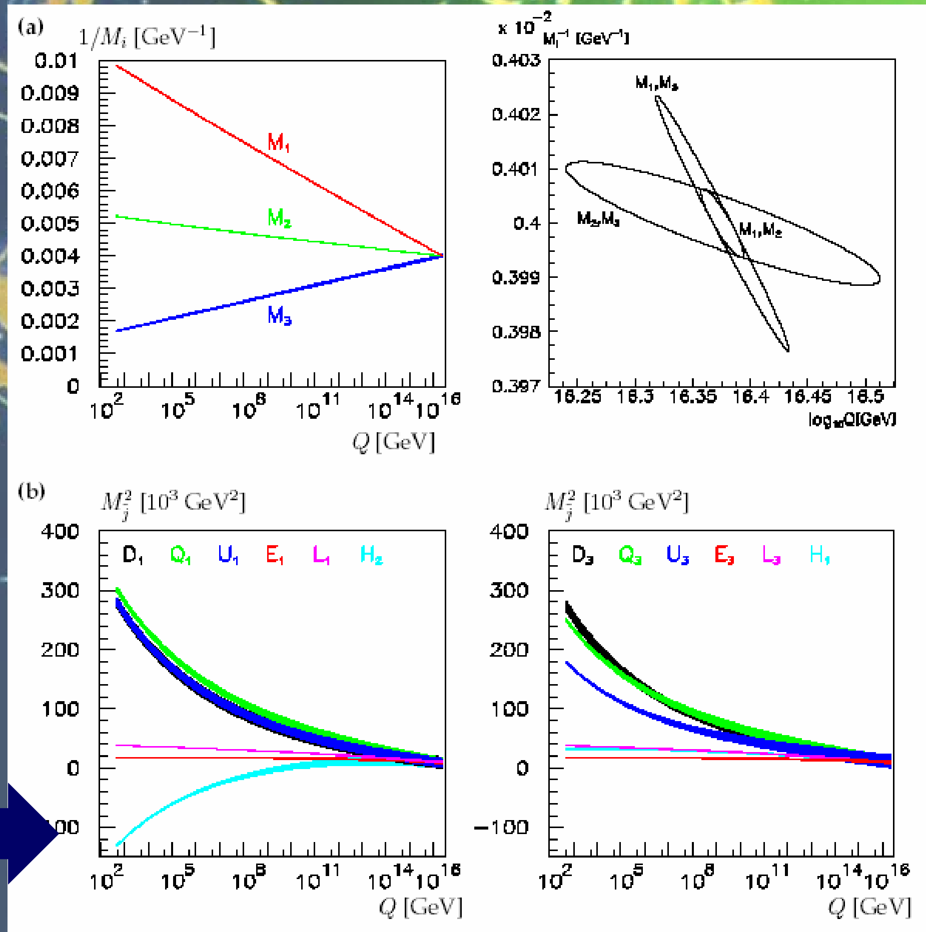
Determination of CMSSM parameters

	SPS1a	StartFit	LHC	Δ_{LHC}	LC	LHC+LC	Δ_{LH}
M_0	100	500	100.03	4.0	100.03	100.04	
$M_{1/2}$	250	500	249.95	1.8	250.02	250.01	
$\tan\beta$	10	50	9.87	1.3	9.98	9.98	
A_0	-100	0	-99.29	31.8	-98.26	-98.25	

Tests of Unification Ideas



For gauge couplings



For sparticle masses

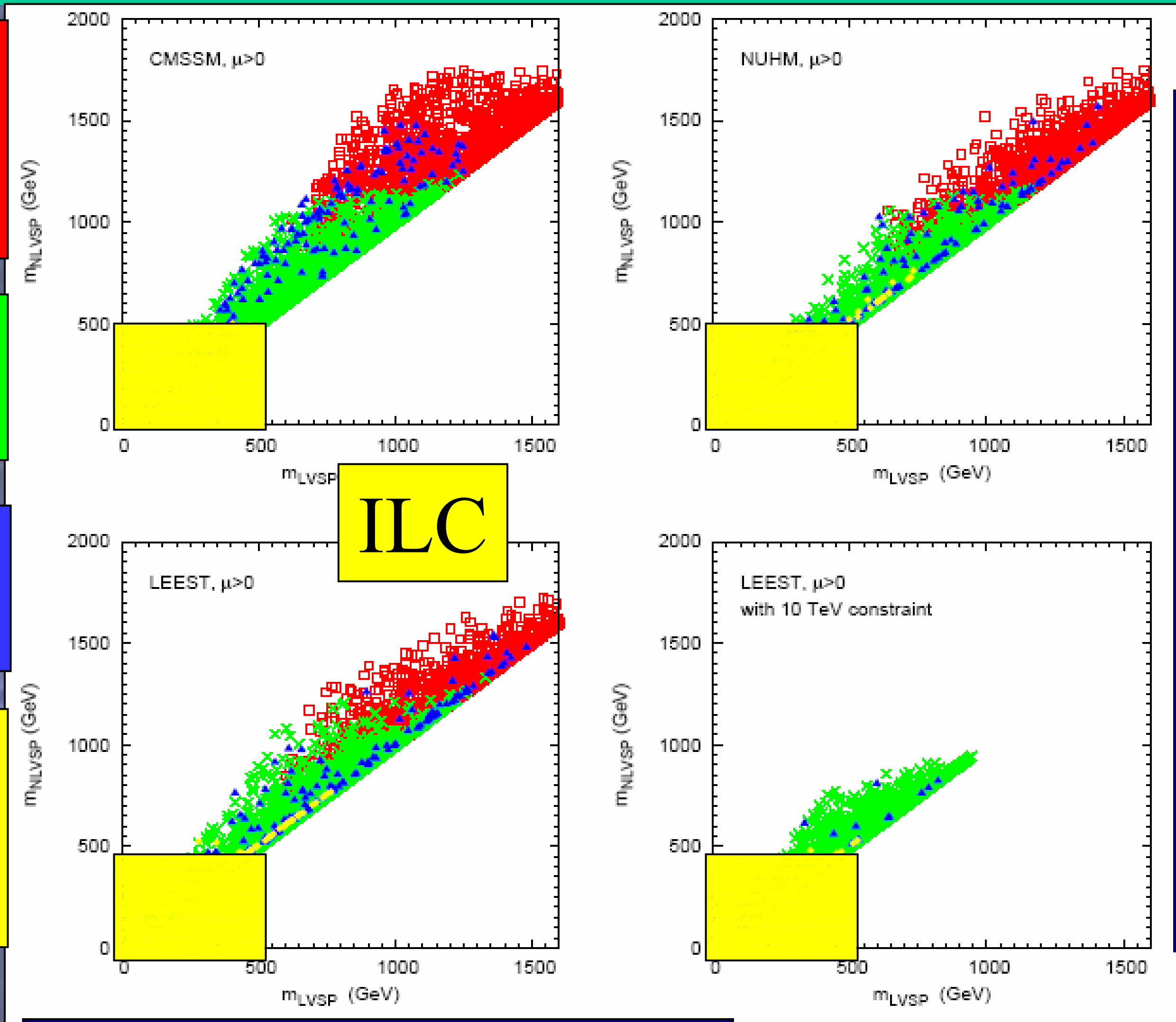
Sparticles may not be very light

Full Model samples

Detectable @ LHC

Provide Dark Matter

Dark Matter Detectable Directly

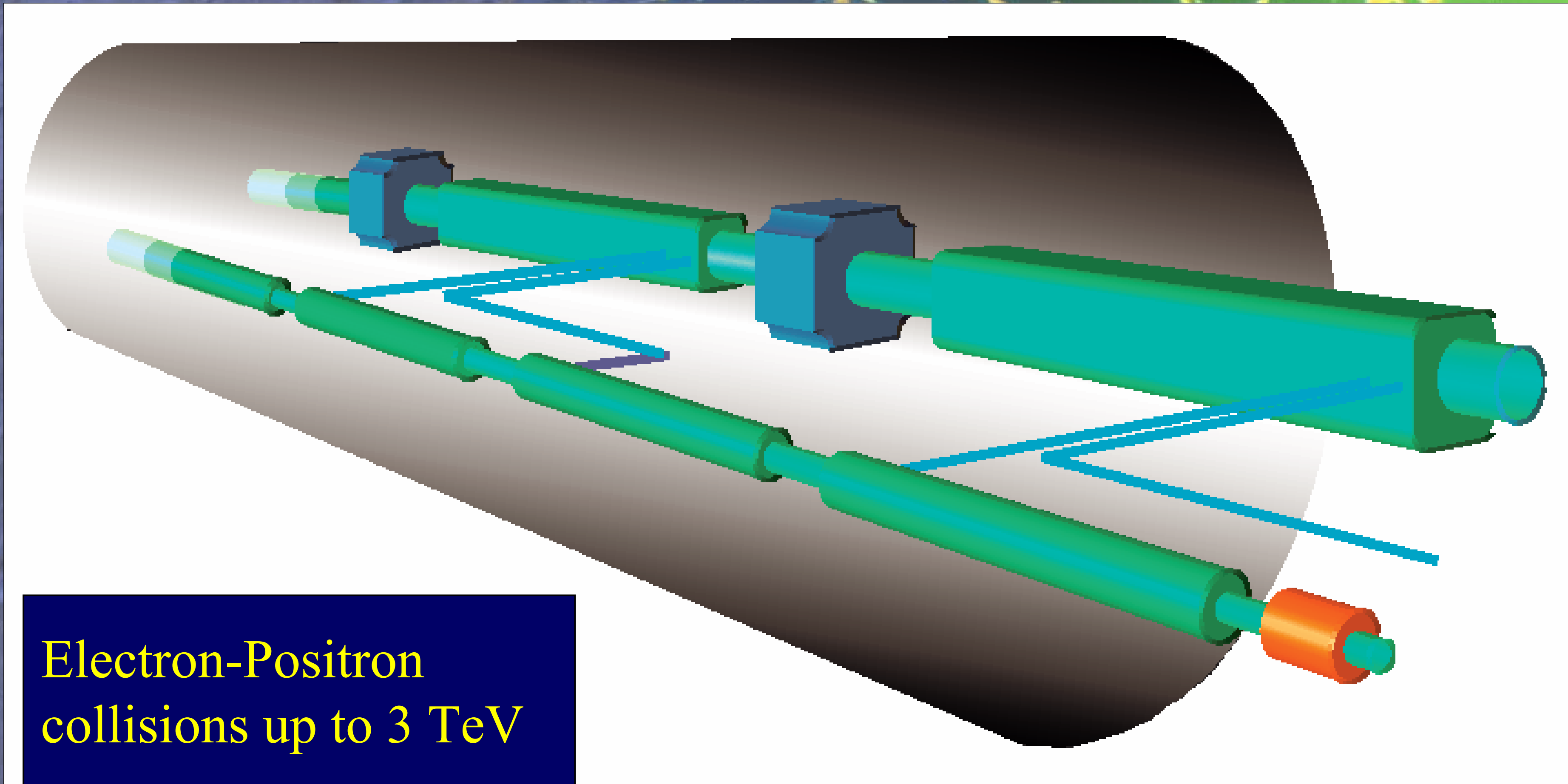


← Second lightest visible particle

Lightest visible sparticle →

JE + Olive + Santoso + Spanos

After LHC @ CERN - CLIC?

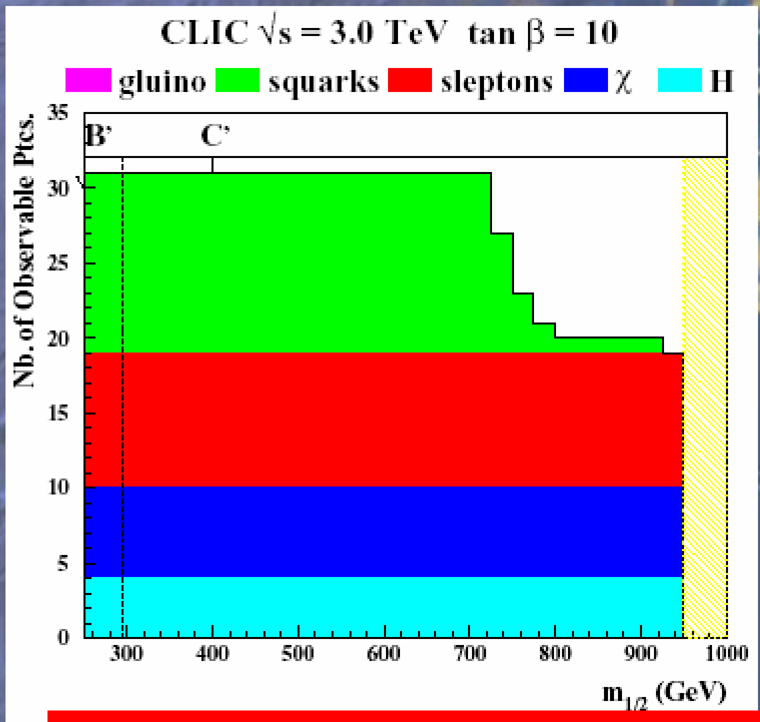


Electron-Positron collisions up to 3 TeV

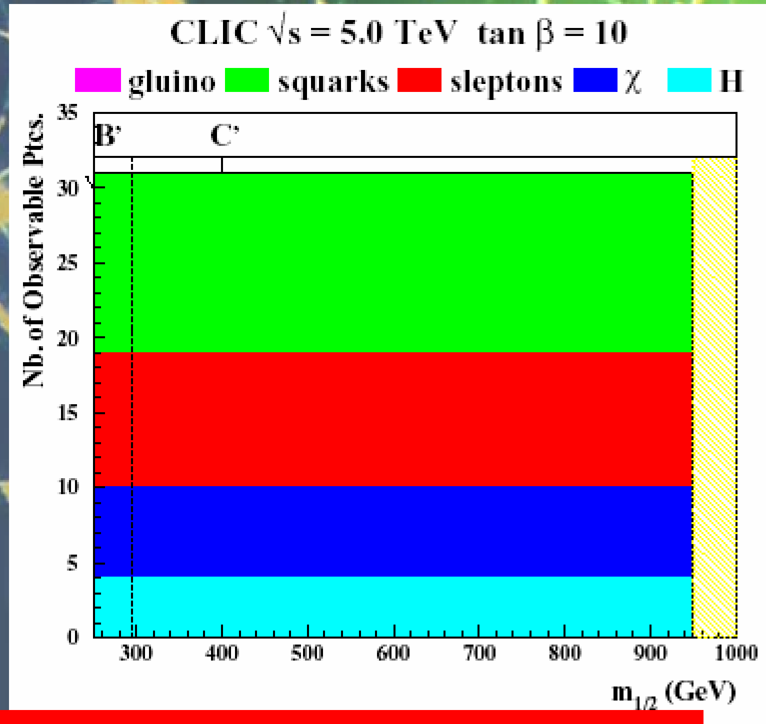
Sparticle Visibility at Higher E

CMSSM

3 TeV

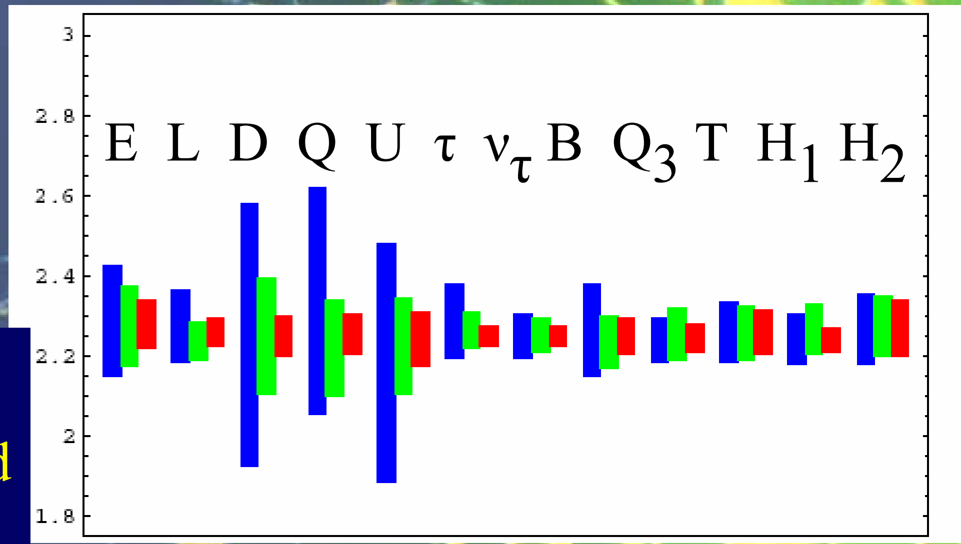


5 TeV



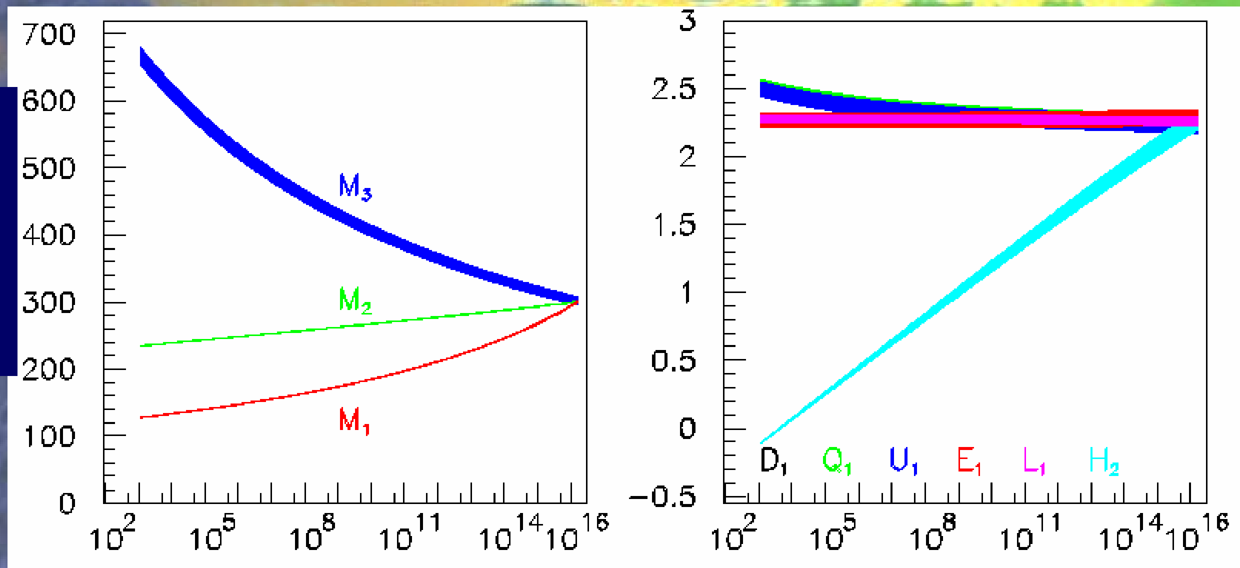
See `all' sparticles: measure heavier ones better than LHC

Sparticle Mass Unification ?

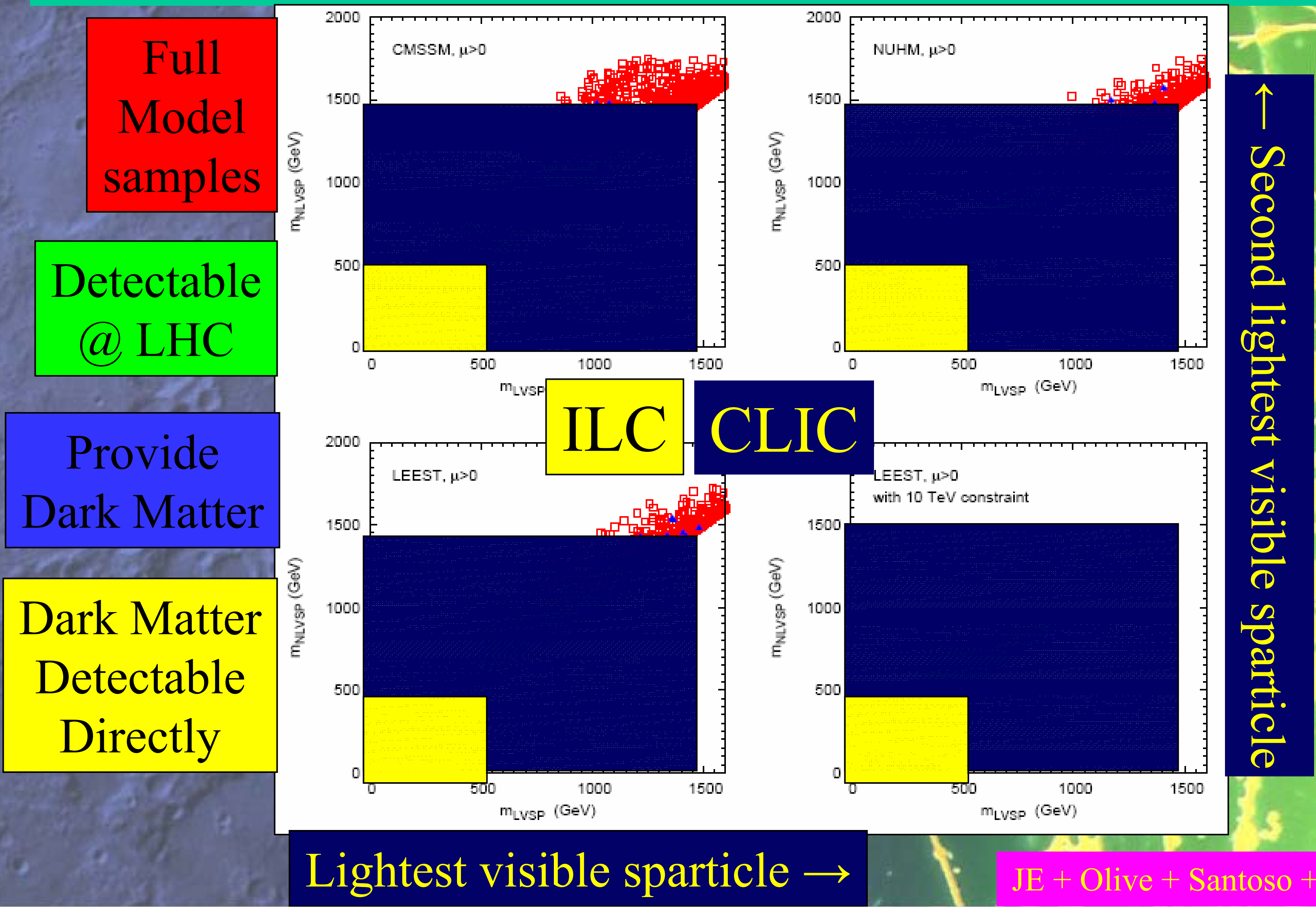


Accuracy in measuring sparticle masses squared

Can test unification of sparticle masses – probe of string models?



Sparticles may not be very light



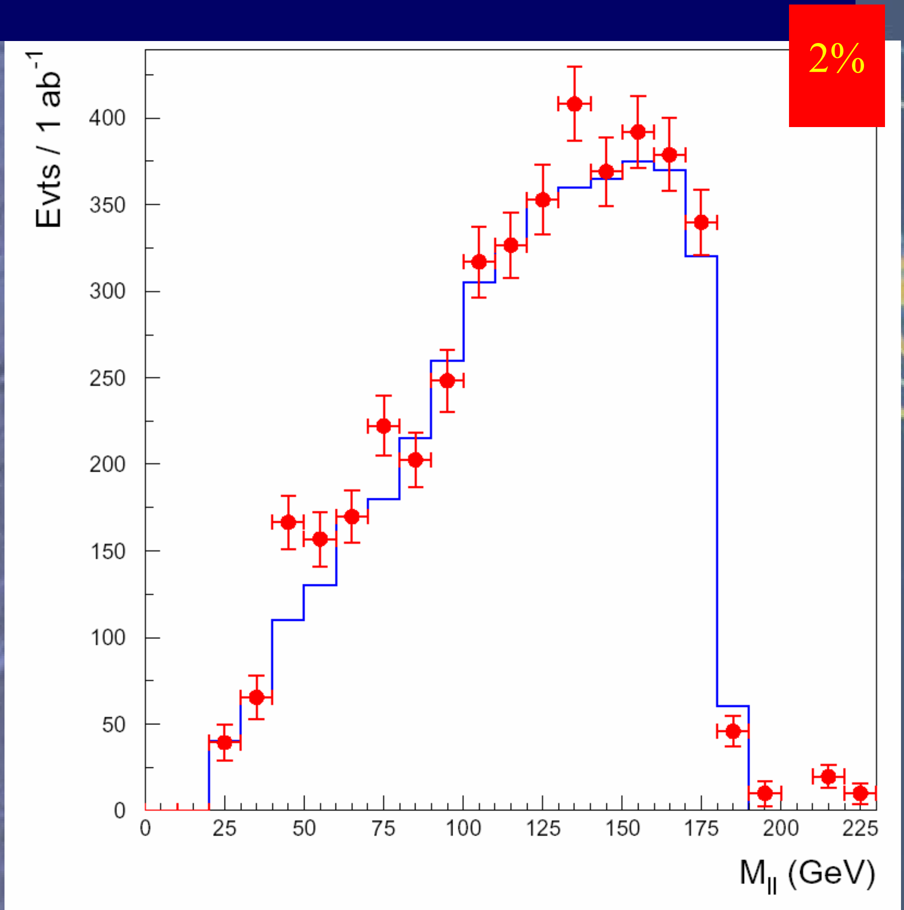
JE + Olive + Santoso + Spanos

Conclusions

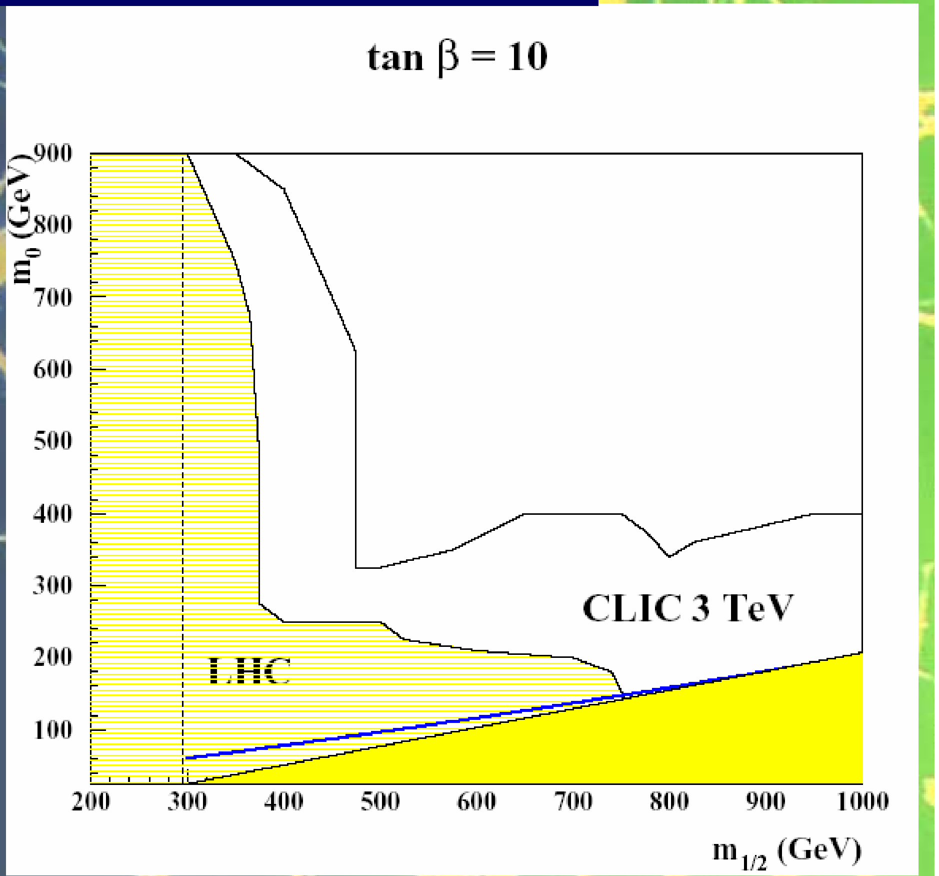
- There are (still) good reasons to expect supersymmetry in the TeV range
- Some indications it may not be very heavy, but
- We shall not know where before the LHC starts providing results
- Any LC above a threshold for new physics will provide tremendous added value
- **Energy flexibility is desirable**

Example of CLIC Sparticle Search

Dilepton spectrum in neutralino decay



Reach in parameter space



CLIC

The CLIC main parameters

Center of mass Energy (TeV)	0.5 TeV	3 TeV
Luminosity (10^{34} $cm^{-1}s^{-1}$)	2.1	8.0
Mean energy loss (%)	4.4	21
Photons / electron	0.75	1.5
Coherent pairs per X	700	6.8 10^8
Rep. Rate (Hz)	200	100
10^9 $e^{\pm}$ / bunch	4	4
Bunches / pulse	154	154
Bunch spacing (cm)	20	20
H/V ε_n (10^{-8} rad.m)	200/1	68/1
Beam size (H/V) (nm)	202/1.2	60/0.7
Bunch length (µm)	35	35
Accelerating gradient (MV/m)	150	150
Overall length (km)	10.2	33.2
Power / section (MW)	230	230
RF to beam efficiency (%)	23.1	23.1
AC to beam efficiency (%)	9.3	9.3
Total AC power for RF (MW)	105	319
Total site AC power (MW)	175	410

Strategies for Detecting Supersymmetric Dark Matter

- Annihilation in galactic halo

  $\chi - \chi \rightarrow$ antiprotons, positrons, …?
- Annihilation in galactic centre

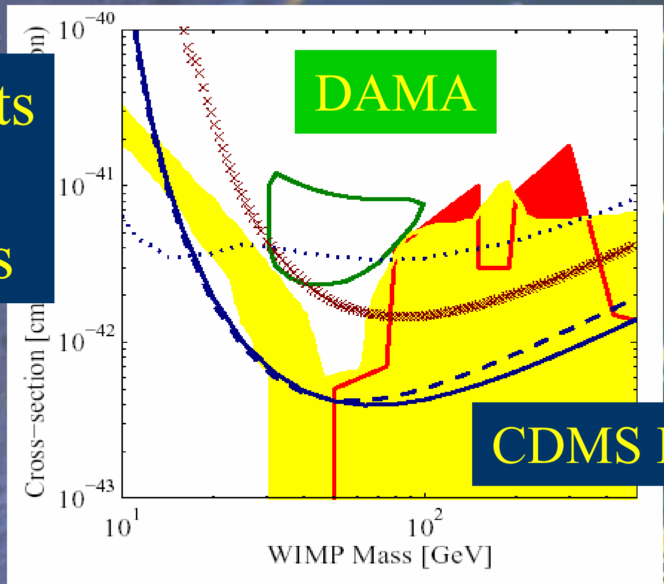
  $\chi - \chi \rightarrow \gamma + \ldots?$
- Annihilation in core of Sun or Earth

  $\chi - \chi \rightarrow \nu + \ldots \rightarrow \mu + \ldots$
- Scattering on nucleus in laboratory

  $\chi + A \rightarrow \chi + A$

Spin-Independent Scattering Cross Section

Experimental limits
←→
other susy models



Comparison with
our calculations
all tan β

Theory → GUT scale

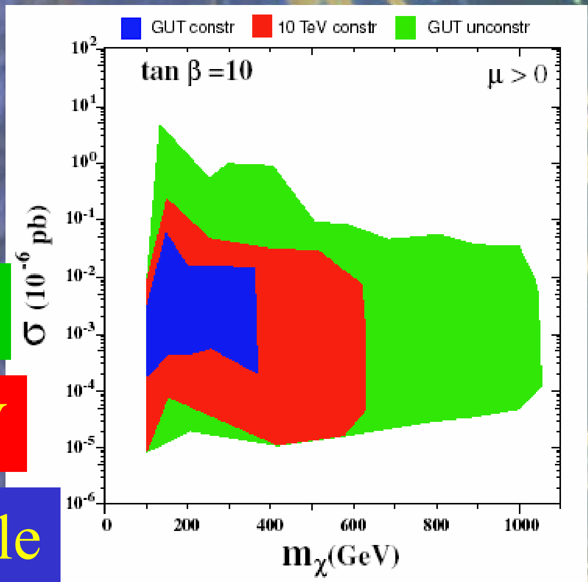
Unconstrained

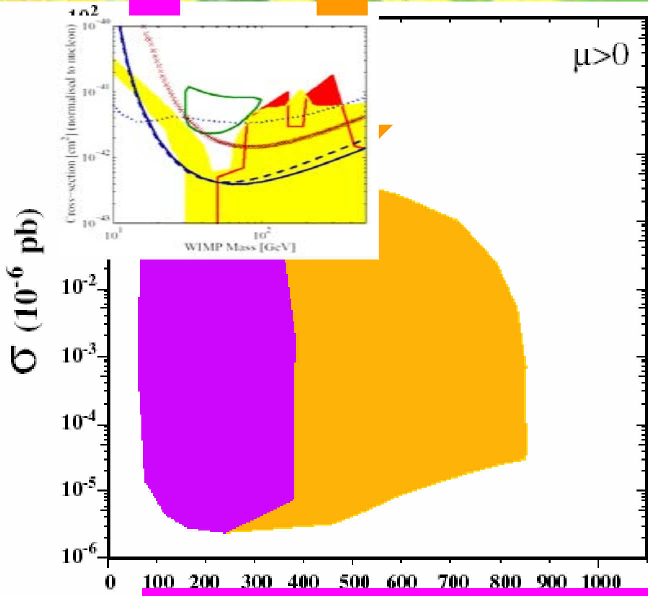
our calculations
tan β = 10

Unconstrained

Theory → 10 TeV

Theory → GUT scale

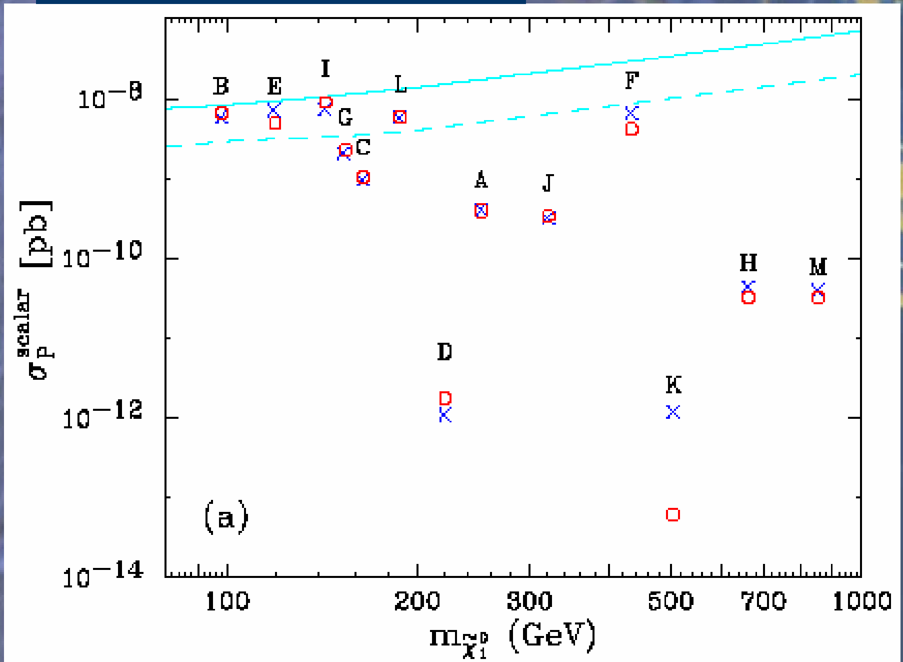




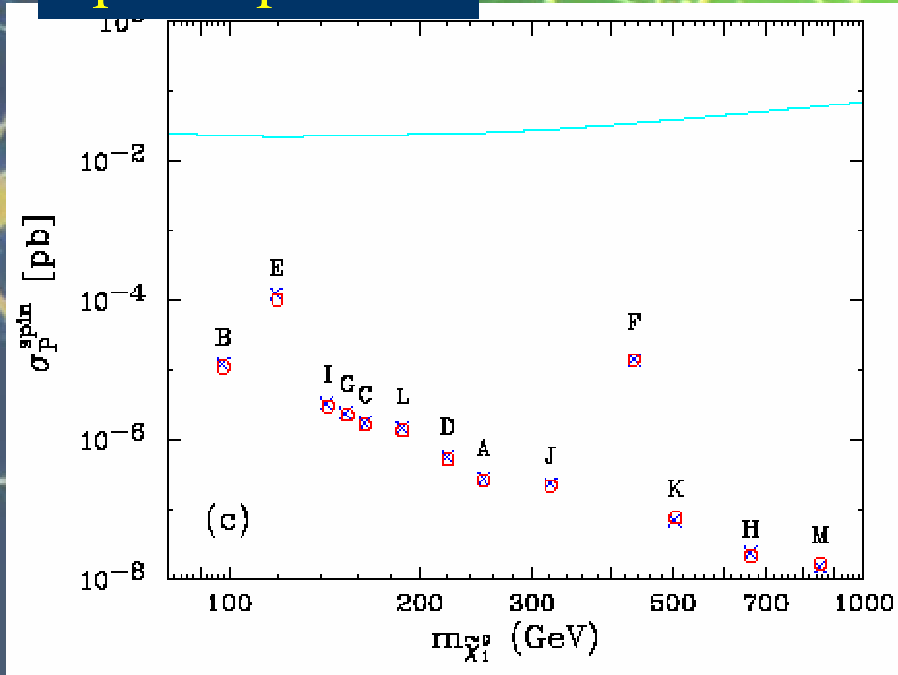
JE + Olive + Santoso + Spanos

Scattering Cross Sections in Benchmark Scenarios

Spin-independent



Spin-dependent



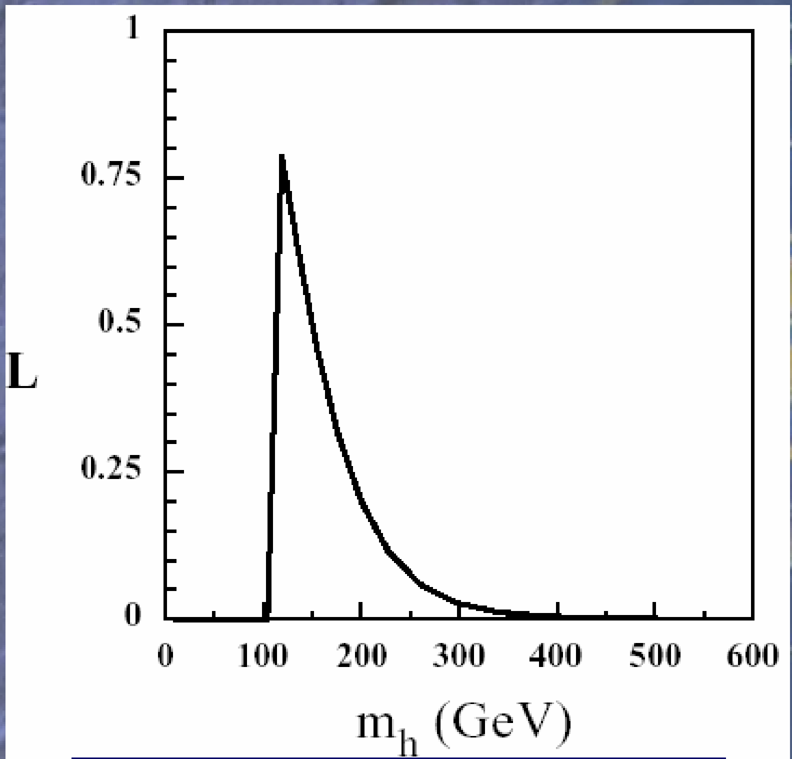
Compared with possible future experimental sensitivities

JE + Feng + Ferstl + Matchev + Olive

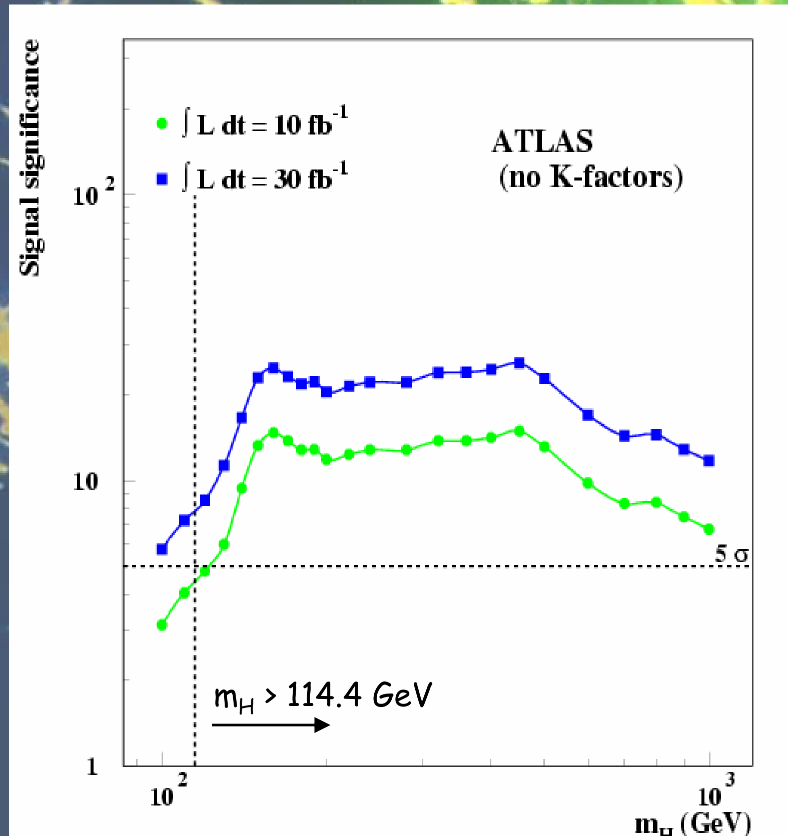
Conclusions

- There are (still) good reasons to expect supersymmetry in the TeV range
- We shall not know where before the LHC starts providing results
- Time pressing for dark matter searches
- Any LC above a threshold for new physics will provide tremendous added value
- **Energy flexibility is desirable**

Waiting for the Higgs boson



Higgs probability distribution: combining direct, indirect information



How soon will the Higgs be found? …

Other Physics @ EW Scale

Direct Detection of Supersymmetric Dark Matter

Effective Lagrangian for χ – q scattering:

$$\mathcal{L} = \bar{\chi}\gamma^{\mu}\gamma^{5}\chi\bar{q}_i\gamma_{\mu}(\quad + \alpha_{2i}\gamma^{5})q_i + \alpha_{3i}\bar{\chi}\chi\bar{q}_i q_i$$
$$+$$

Velocity-dependent → negligible

Spin-independent:
depend on quark contributions to baryon mass

$$m_p f_{Tq}^{(p)} \equiv \langle p|m_q\bar{q}q|p\rangle \equiv m_q B_q$$

$$f_{Tu}^{(p)} = 0.020 \pm 0.004 \,, \qquad f_{Td}^{(p)} = 0.026 \pm 0.005$$
$$f_{Ts}^{(p)} = 0.118 \pm 0.062 \,,$$

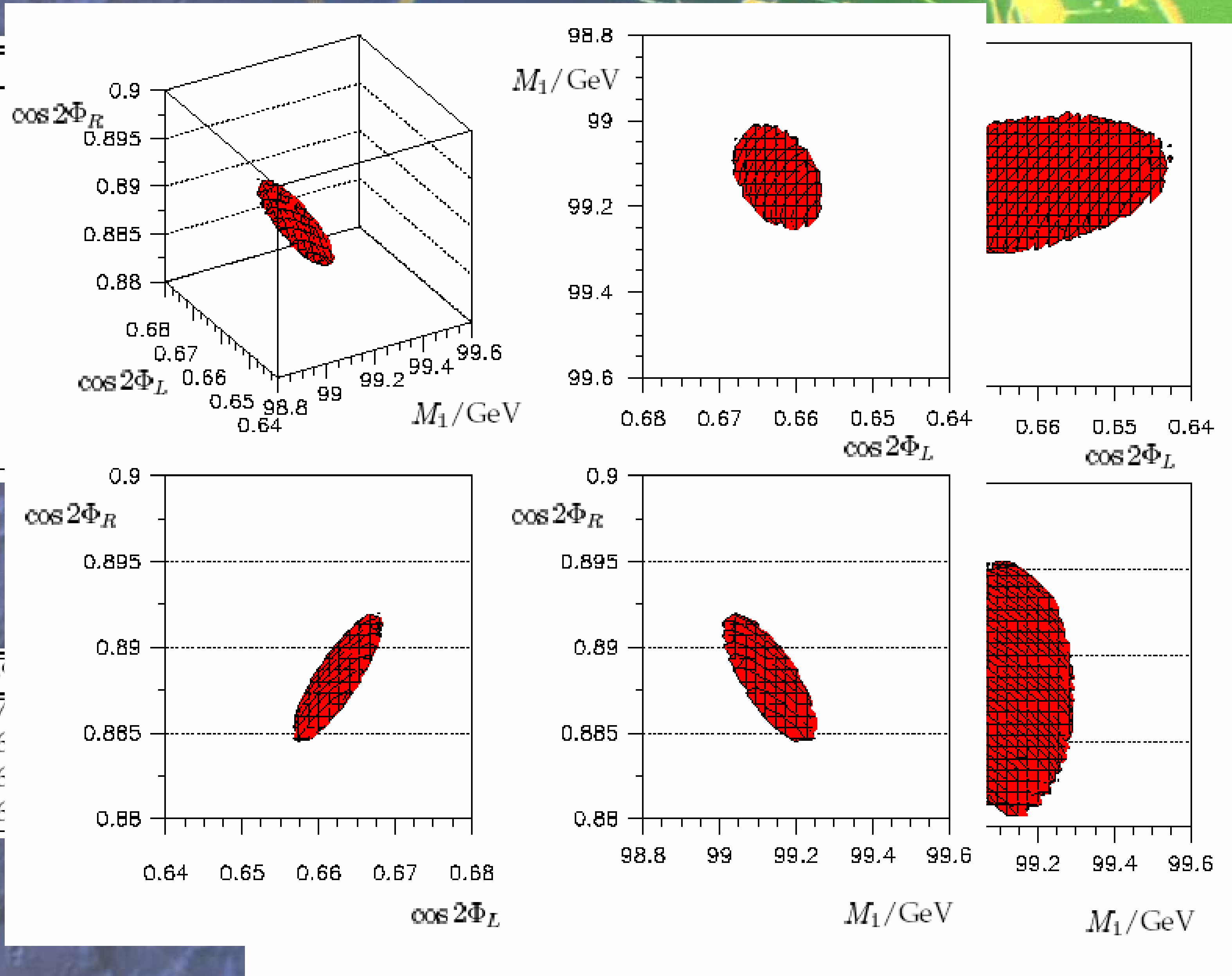
Spin-dependent:
depend on quark contributions to baryon spin

$$a_p = \sum_i \frac{\alpha_{2i}}{\sqrt{2}G_F}\Delta_i^{(p)} \,, \qquad a_n = \sum_i \frac{\alpha_{2i}}{\sqrt{2}G_F}\Delta_i^{(n)}$$

$$\Delta_u^{(p)} = 0.78 \pm 0.02 \,, \qquad \Delta_d^{(p)} = -0.48 \pm 0.02$$
$$\Delta_s^{(p)} = -0.15 \pm 0.02 \,.$$

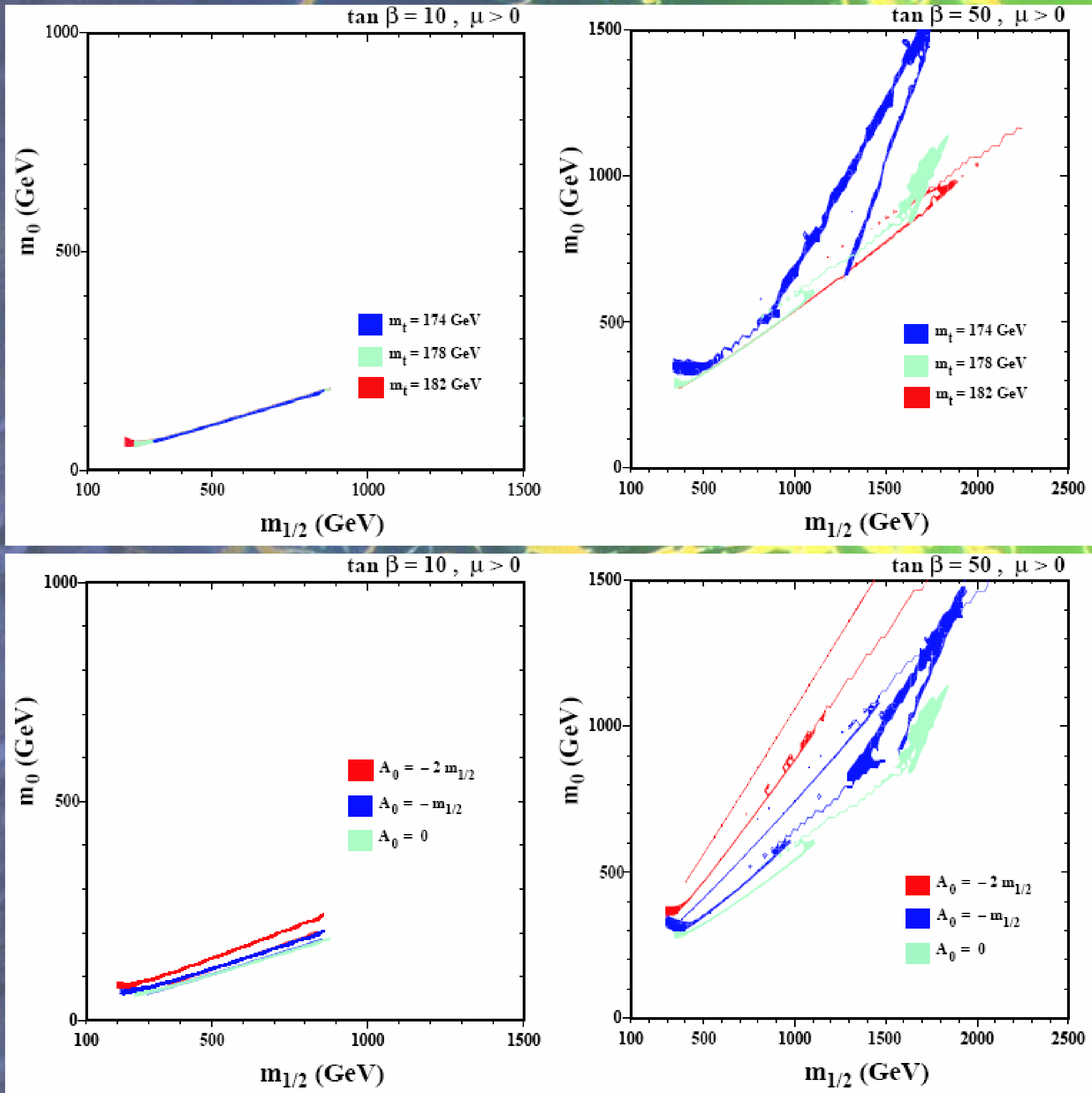
	LHC
$\Delta m_{\tilde\chi_1^0}$	4.8
$\Delta m_{\tilde\chi_2^0}$	4.7
$\Delta m_{\tilde\chi_4^0}$	5.1
$\Delta m_{\tilde l_R}$	4.8
$\Delta m_{\tilde l_L}$	5.0
Δm_{τ_1}	5-8
$\Delta m_{\tilde q_L}$	8.7
$\Delta m_{\tilde q_R}$	7-12
$\Delta m_{\tilde b_1}$	7.5
$\Delta m_{\tilde b_2}$	7.9
$\Delta m_{\tilde g}$	8.0

	LHC (0.5
$\Delta m_{\tilde q_L}$	7
$\Delta m_{\tilde b_1}$	6
$\Delta m_{\tilde b_2}$	6
$\Delta m_{\tilde g}$	6



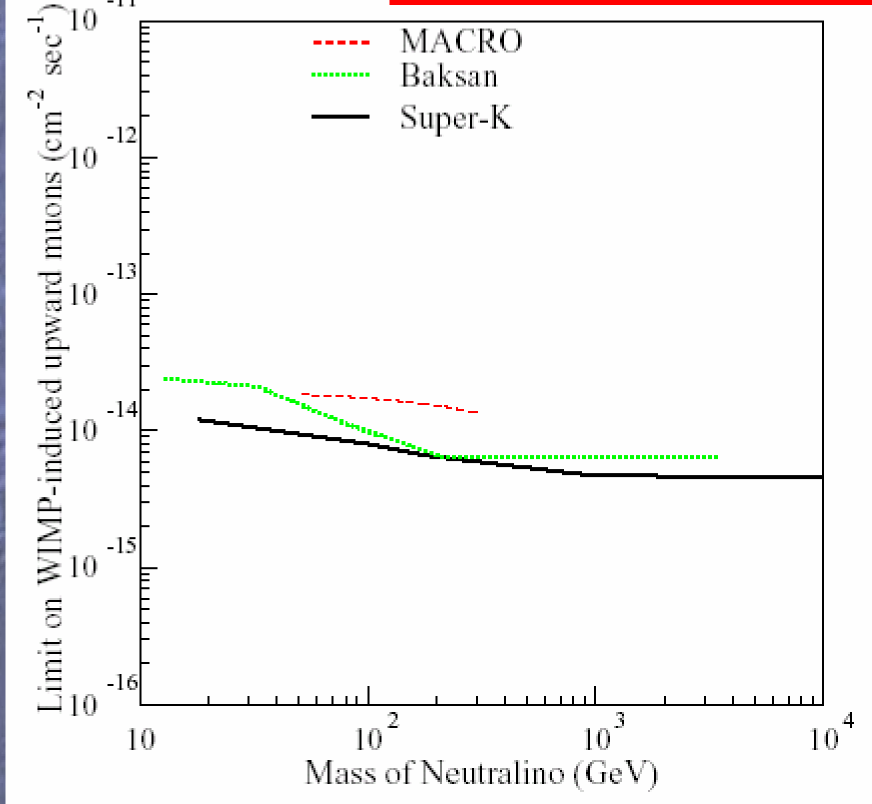
Dependence on m_t

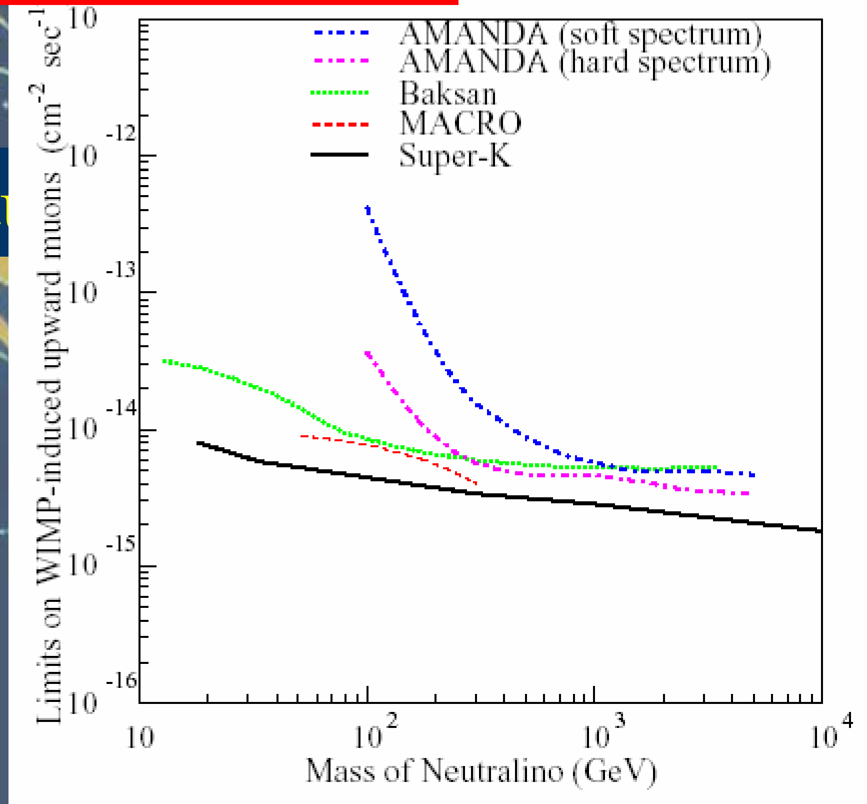
Dependence on A_0



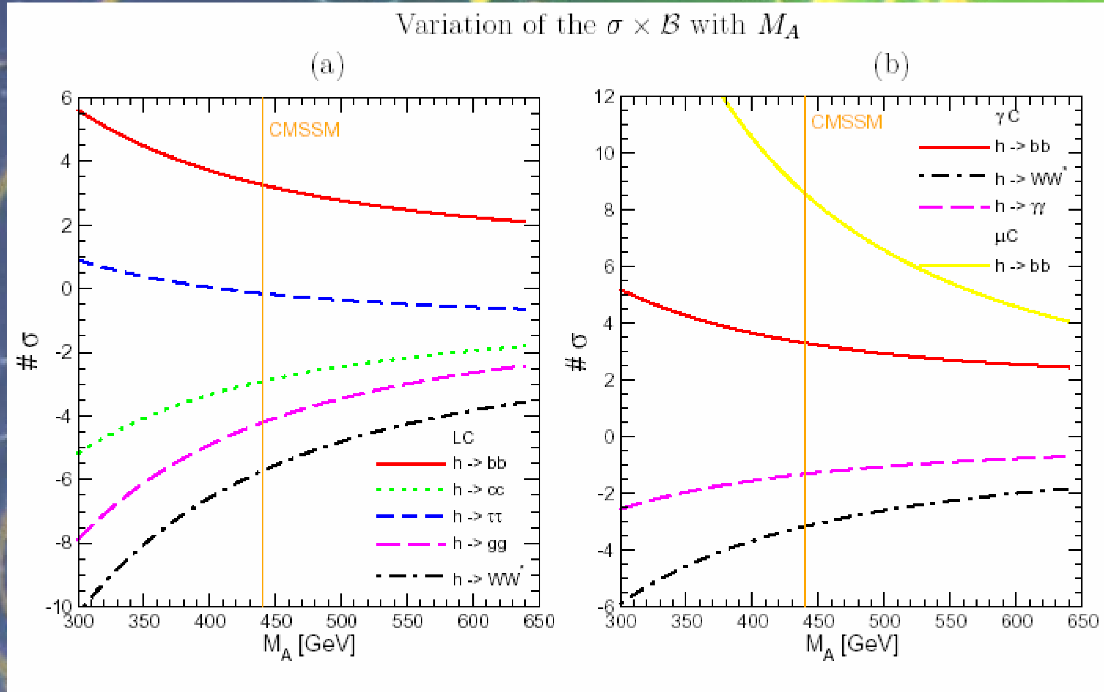
Annihilations in Solar System …

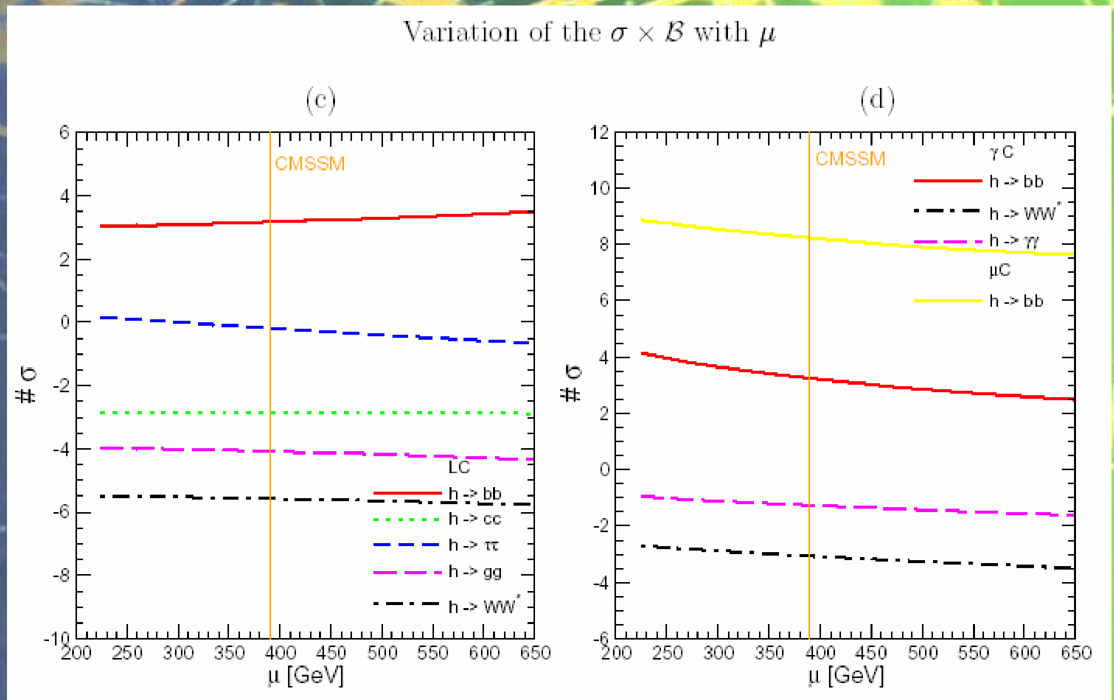
Present upper limits > 100/km^2/year





How well can LC distinguish CMSSM from SM?





Numbers of standard deviations in Higgs measurements

Squark & Gluino Searches @ FNAL

General Squarks & gluinos

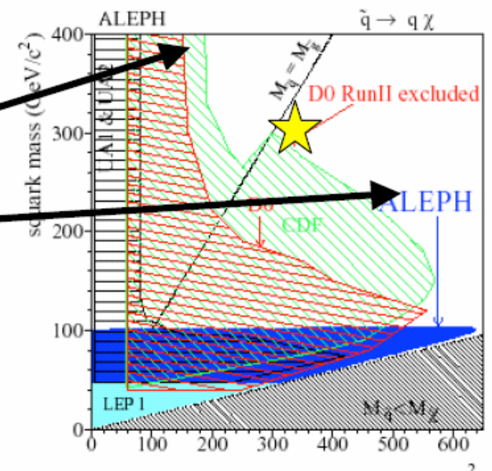
- Exclude: $m(\tilde{q}/\tilde{g}) < 292/333$ GeV

Gluino and Squark mass limits:

- M(q)>M(g): $\tilde{u},\tilde{d},\tilde{s},\tilde{c},\tilde{b}$ mass equal
- M(g)<M(q): $\tilde{u},\tilde{d},\tilde{s},\tilde{c}$ mass equal

Improves Run I limits:

- Include more data
- Scan parameter space

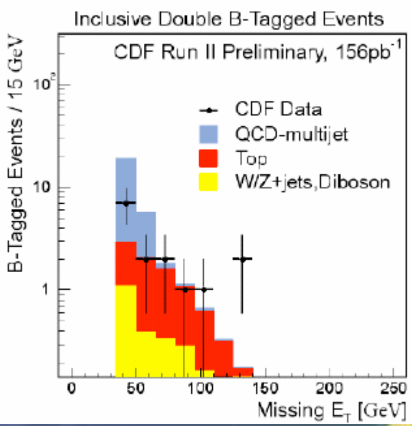


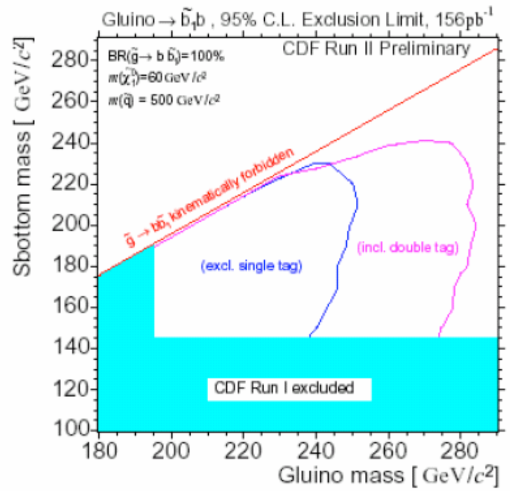
Specific search for light sbottom

- $BR(\tilde{g} \to \tilde{b}b)$~100% assumed
- Spectacular signature:
  - 4 b-quarks + $\not{E}_T$
- Require b-jets and $\not{E}_T$>80 GeV

Expect:2.6±0.7

Observe: 4

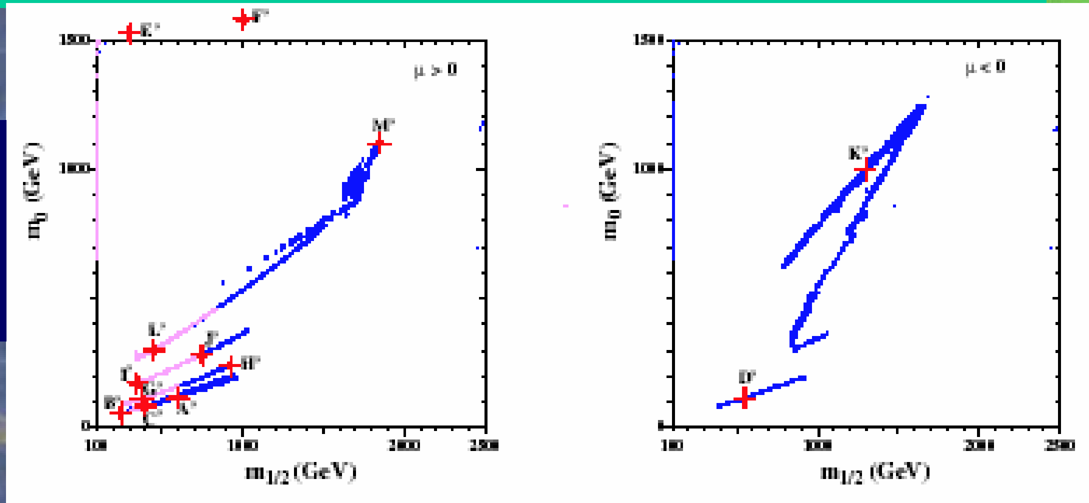




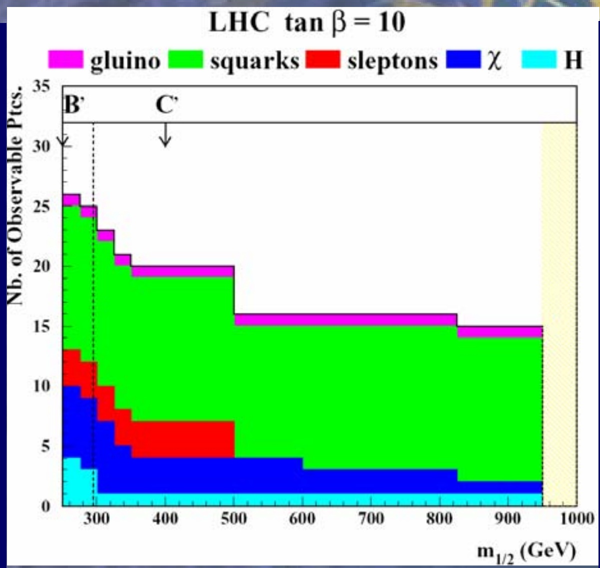
Exclude new parameter space in gluino vs. sbottom mass plane

Exploring the Supersymmetric Parameter Space

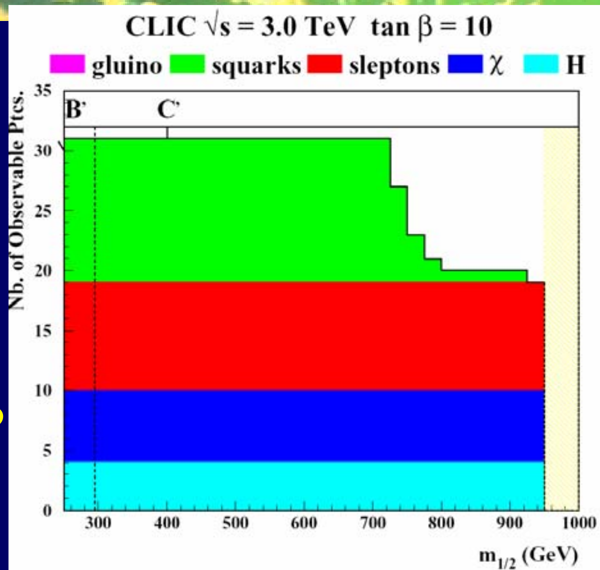
Strips allowed by WMAP and other constraints



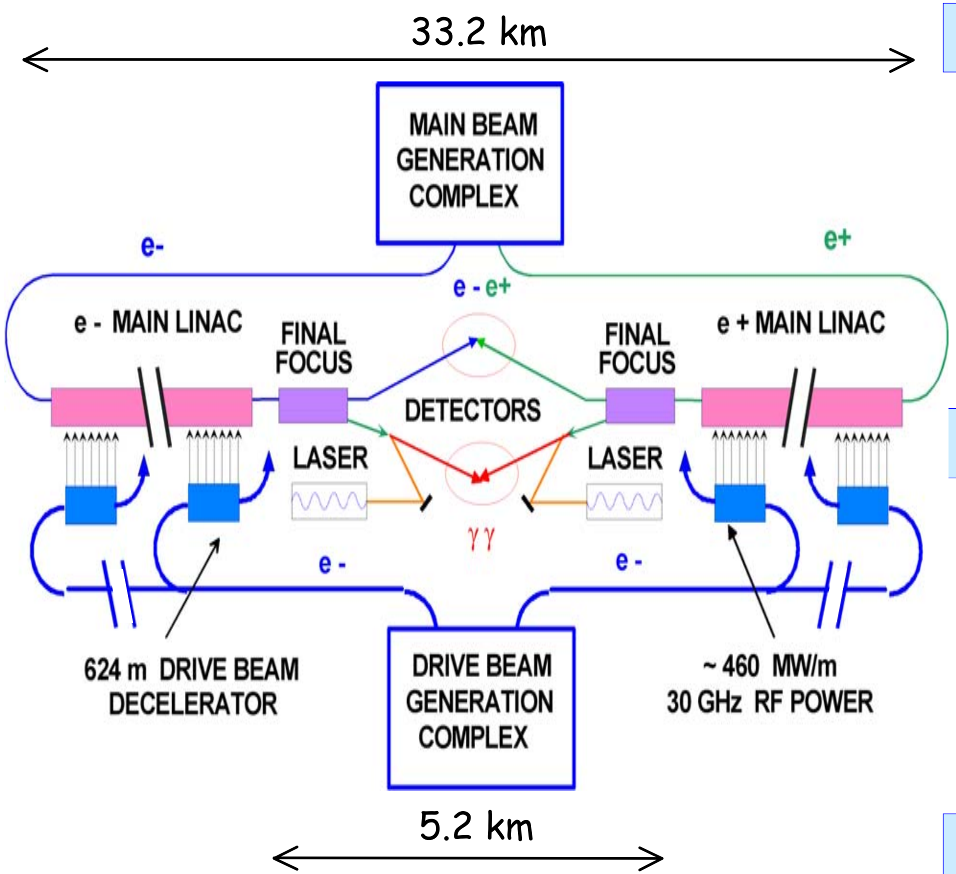
Numbers of sparticle species detected at LHC along WMAP strip



Numbers of sparticle species detected at CLIC along WMAP strip



Basic features of the CLIC scheme



Overall layout for a center of mass energy of 3 TeV/c

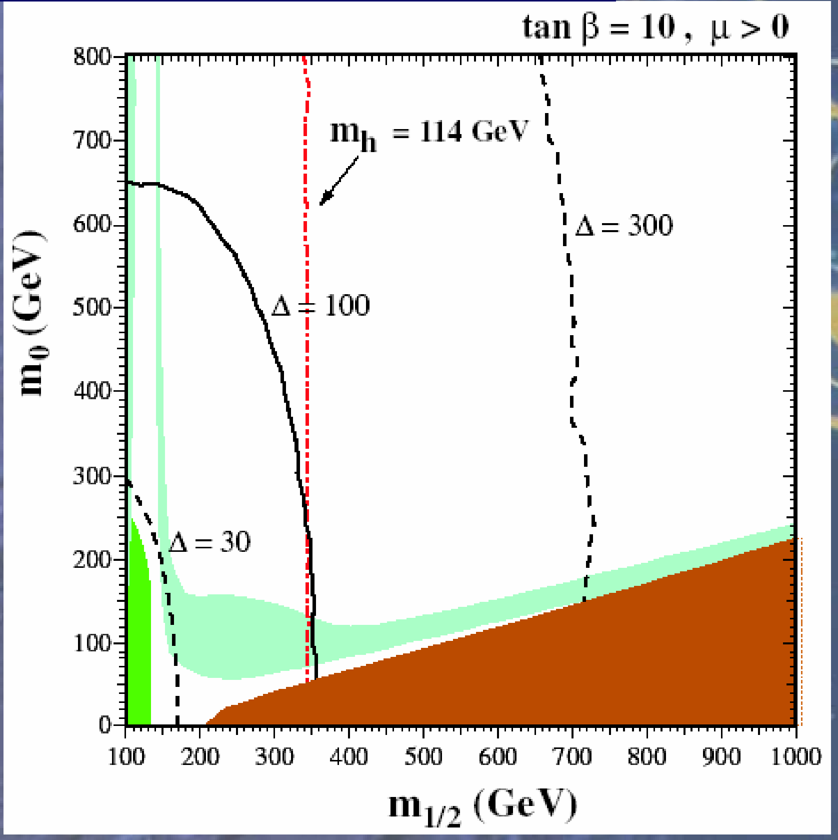
- High acceleration gradient (150 MV/m)
- Compact collider - overall length ≈33 km
  - Normal conducting accelerating structures
  - High acceleration frequency (30 GHz)
- Two-Beam Acceleration Scheme
  - RF power generation at high frequency
  - Cost-effective & efficient (~ 10% overall)
  - Simple tunnel, no active elements
- Central injector complex
  - modular design, can be built in stages
  - Easily expandable in energy

World-wide CLIC collaboration

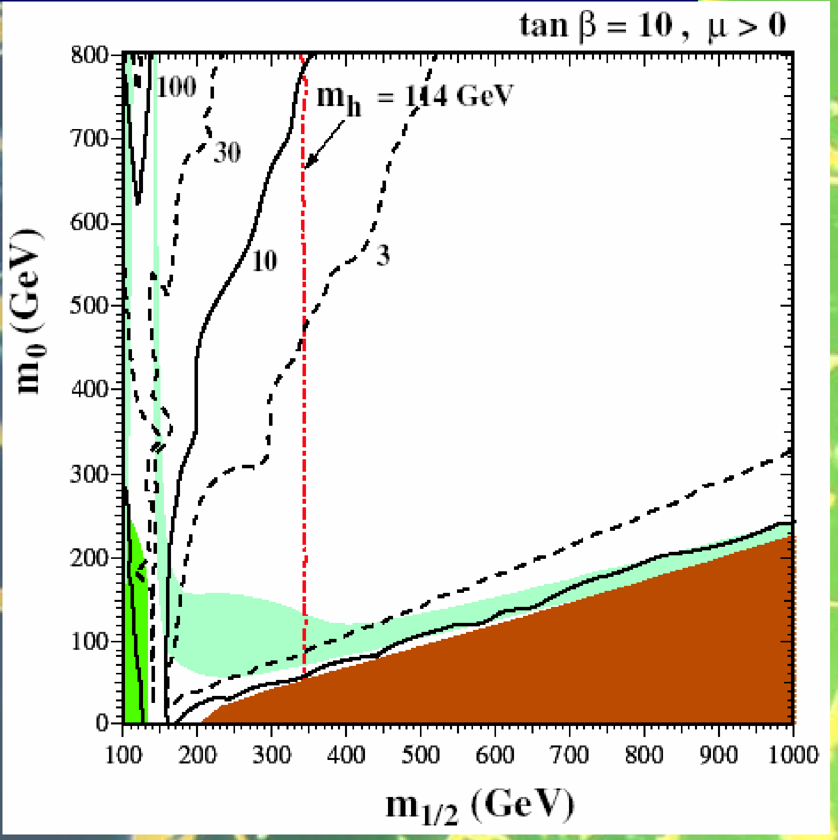
- BERLIN Technical University (Germany) : Structure simulations
- Finnish Industry (Finland) : Sponsorship of a mechanical engineer
- INFN / LNF (Italy): CTF3 delay loop, transfer lines & RF deflectors
- JINR & IAP (Russia): Surface heating tests of 30 GHz structures
- KEK (Japan): Low-emittance beams in ATF
- LAL (France) : Electron guns and pre-buncher cavities for CTF3
- LAPP/ESIA (France) : Stabilization studies
- LLBL/LBL (USA) : Laser-wire studies
- Northwestern University (USA) : Beam loss studies & CTF3 equipment
- RAL (England) : Lasers for CTF3 and CLIC photo-injectors
- SLAC (USA) : High-Gradient Structure testing, structure design, CTF3 drive-beam injector design
- UPPSALA University (Sweden) : Beam monitoring systems for CTF3

How `Likely' are Large Sparticle Masses?

Fine-tuning of EW scale



Fine-tuning of relic density

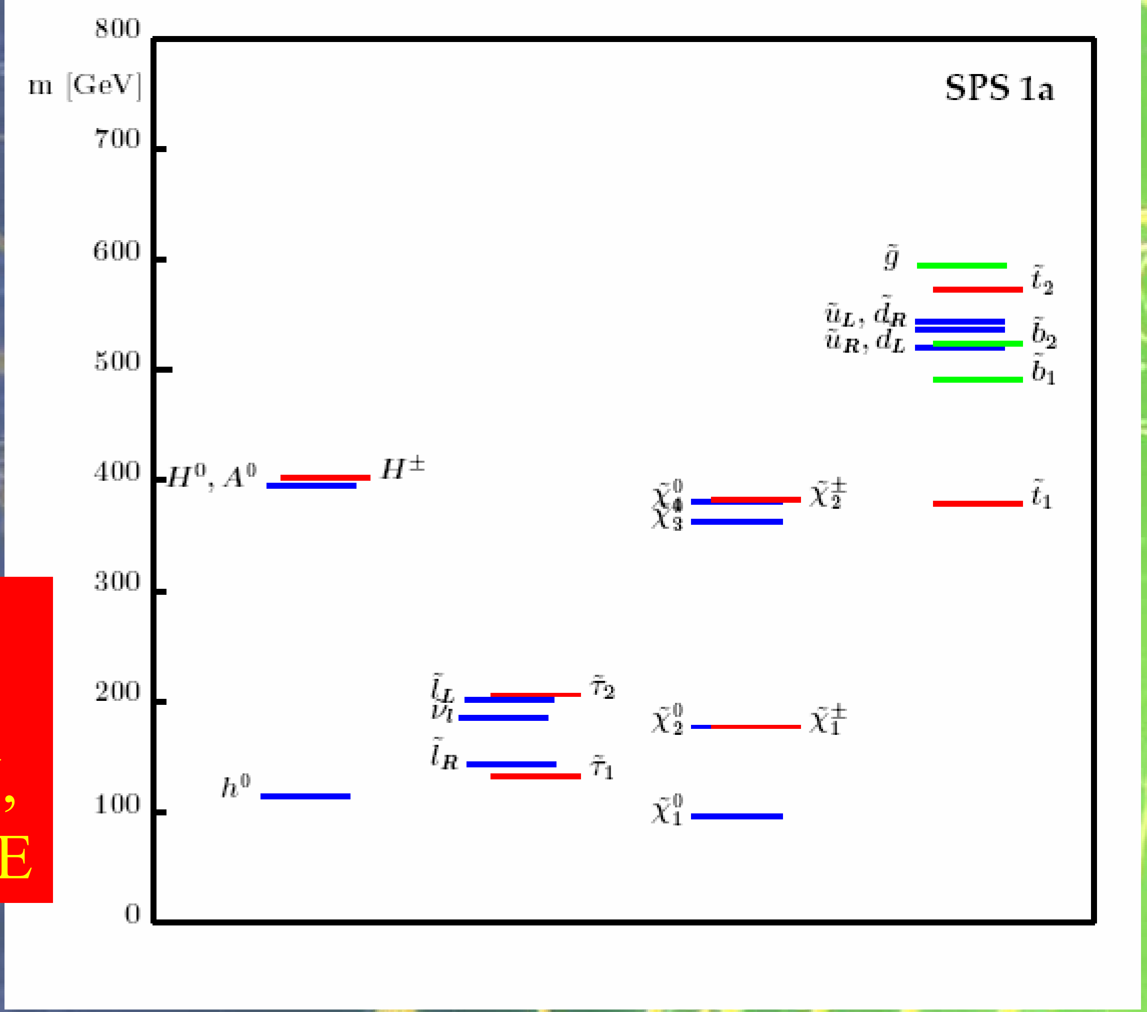


Larger masses require more fine-tuning: but how much is too much?

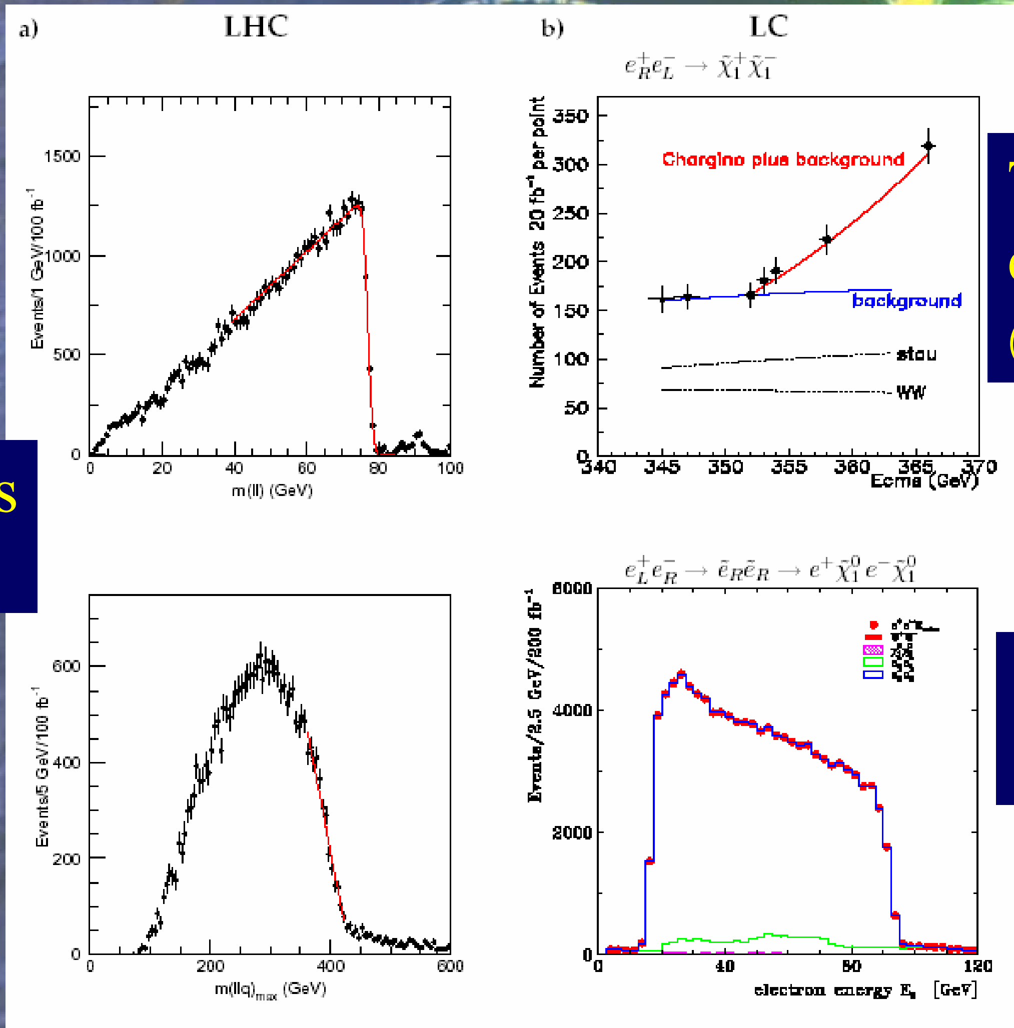
Example of Benchmark Point

Spectrum of Benchmark SPS1a ~ Point B of *Battaglia et al*

Several sparticles at 500 GeV LC, more at 1000 GeV, some need higher E



Examples of Sparticle Measurements



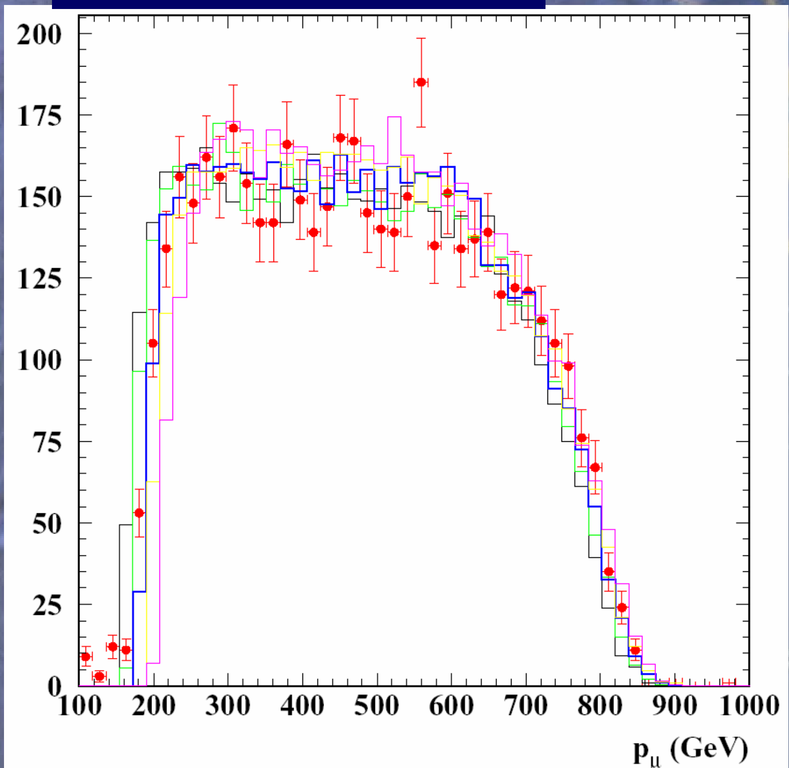
Spectrum edges @ LHC

Threshold excitation @ LC

Spectra @ LC

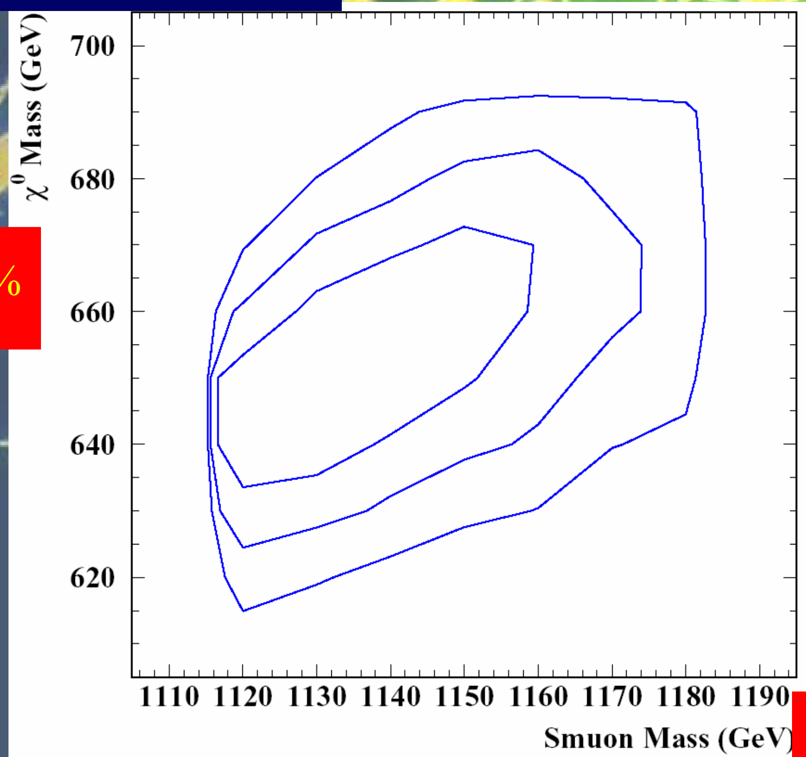
Measure Heavy Sleptons @ CLIC

Can measure smuon decay spectrum



Can measure sparticle masses

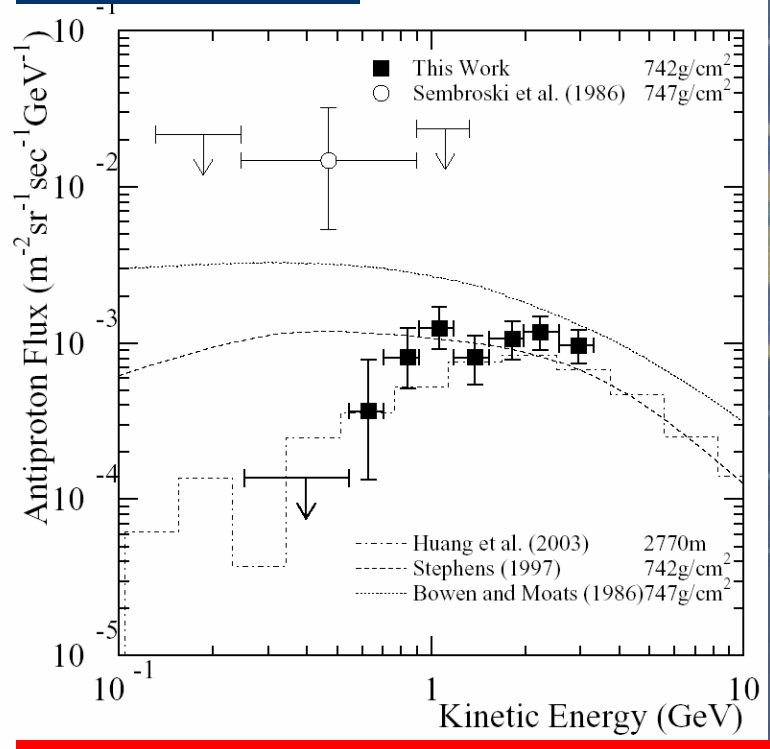
3%



2.5%

Annihilation in Galactic Halo

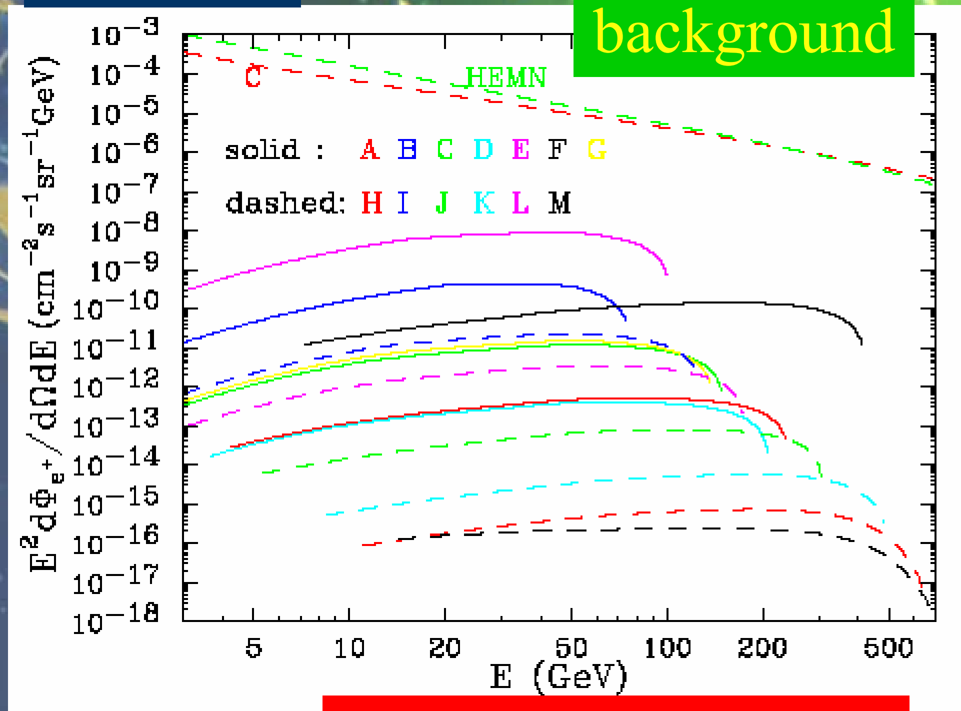
Antiprotons



Consistent with production by primary matter cosmic rays

Positrons

Cosmic-ray background

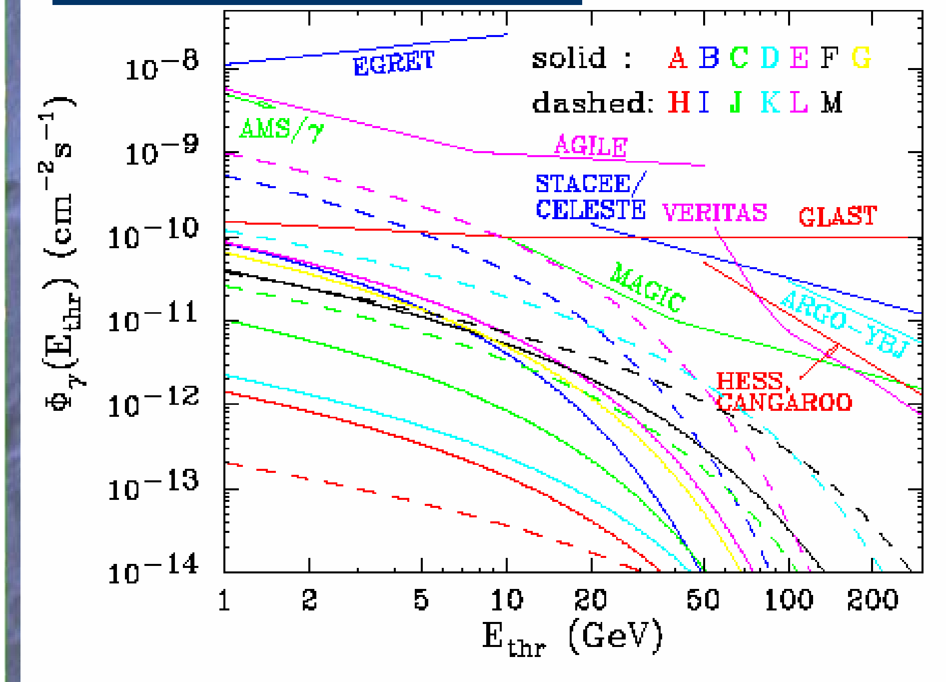


Benchmark scenarios

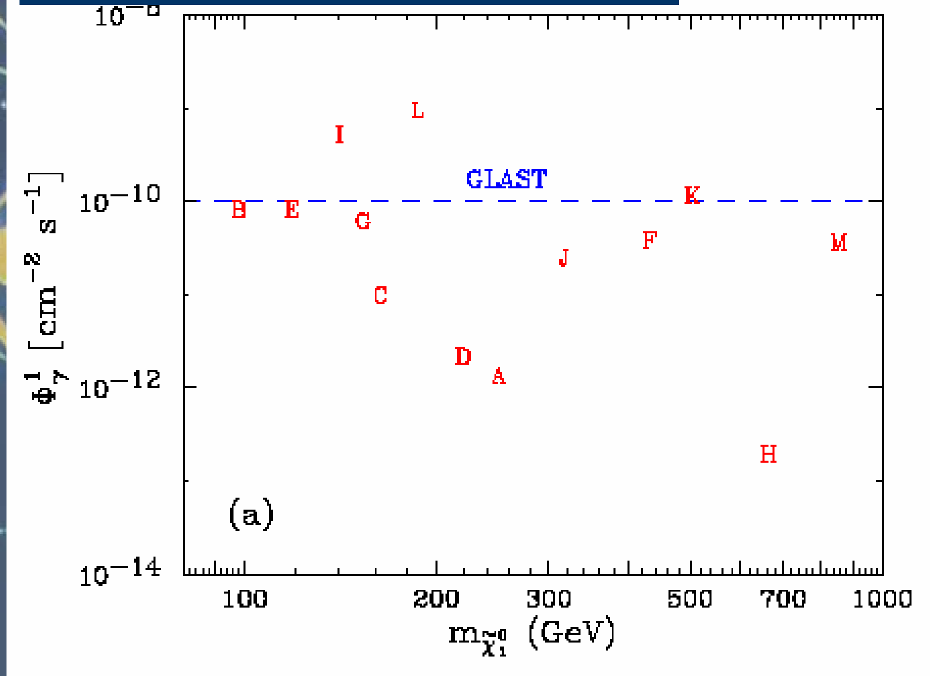
JE + Feng + Ferstl + Matchev + Olive

Annihilations in Galactic Centre

Benchmark spectra



Benchmarks → GLAST

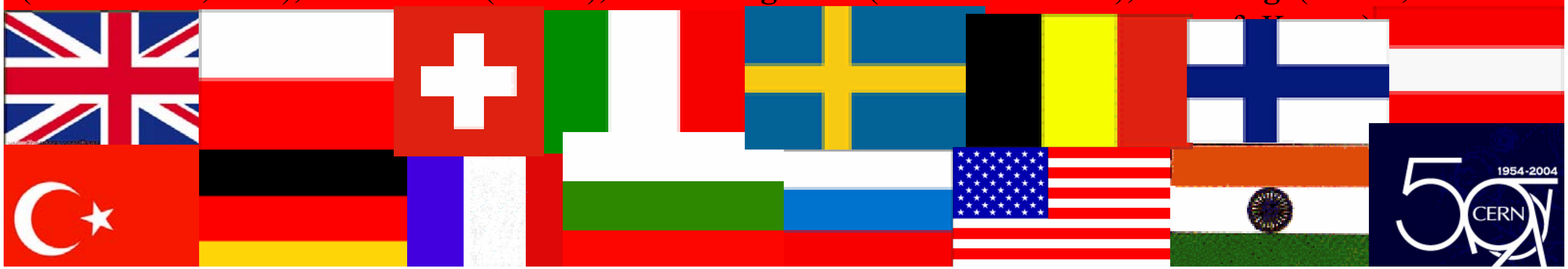


Enhancement of rate uncertain by factor > 100!

JE + Feng + Ferstl + Matchev + Olive

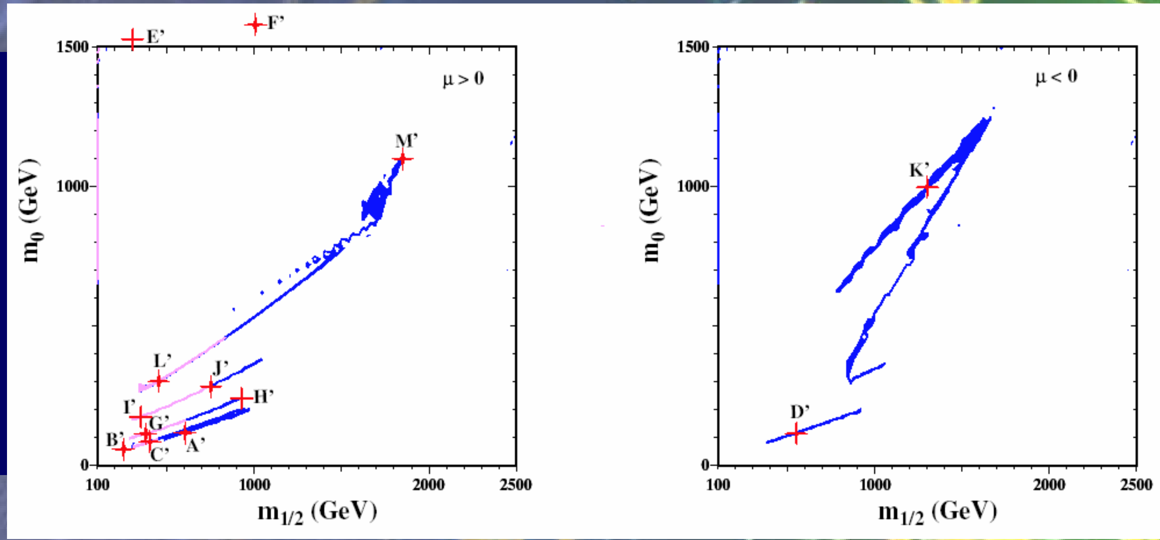
Physics at the CLIC Multi-TeV Linear Collider

E. Accomando (INFN, Torino), **E. Ateser** (Kafkas Univ.), **D. Bardin** (JINR, Dubna), **M. Battaglia** (LBL and UC Berkeley), **T. Barklow** (SLAC), **S. Berge** (Univ. of Hamburg), **G. Blair** (Royal Holloway College, Univ. of London), **E.Boos** (INP, Moscow), **F. Boudjema** (LAPP, Annecy), **H. Braun** (CERN), **H.Burkhardt** (CERN), **M.Cacciari** (Univ. Parma), **O. Çakir** (Univ. of Ankara), **S. De Curtis** (INFN and Univ. of Florence), **A. De Roeck** (CERN), **M. Diehl** (DESY), **A. Djouadi** (Montpellier), **D. Dominici** (Univ. of Florence), **J. Ellis** (CERN), **A.Ferrari** (Uppsala Univ.), **A.Frey** (CERN), **G. Giudice** (CERN), **R. Godbole** (Bangalore), **M. Gruwe** (CERN), **G. Guignard** (CERN), **S.Heinemeyer** (CERN), **C. Heusch** (UC Santa Cruz), **J. Hewett** (SLAC), **S. Jadach** (INP, Krakow), **P. Jarron** (CERN), **M. Klasen** (Univ. of Hamburg), **Z. Kirca** (Univ. of Meselik), **M. Kraemer** (Univ. of Edinburgh), **S. Kraml** (CERN), **G.Landsberg** (Brown Univ.), **K. Matchev** (Univ. of Florida), **G. Moortgat-Pick** (Univ. of Durham), **M.Muehlleitner** (PSI, Villigen), **O. Nachtmann** (Univ. of Heidelberg), **F. Nagel** (Univ. of Heidelberg), **K.Olive** (Univ. of Minnesota), **G.Pancheri** (LNF, Frascati), **L. Pape** (CERN), **M. Piccolo** (LNF, Frascati), **W. Porod** (Univ. of Zurich), **P. Richardson** (Univ. of Durham), **T. Rizzo** (SLAC), **M. Ronan** (LBL, Berkeley), **C. Royon** (CEA, Saclay), **L. Salmi** (HIP, Helsinki), **R. Settles** (MPI, Munich), **D. Schulte** (CERN), **T.Sjöstrand** (Lund Univ.), **M. Spira** (PSI, Villigen), **S. Sultansoy** (Univ. of Ankara), **V. Telnov** (Novosibirsk, IYF), **D. Treille** (CERN), **C. Verzegnassi** (Univ. of Trieste), **J. Weng** (CERN, Univ. of



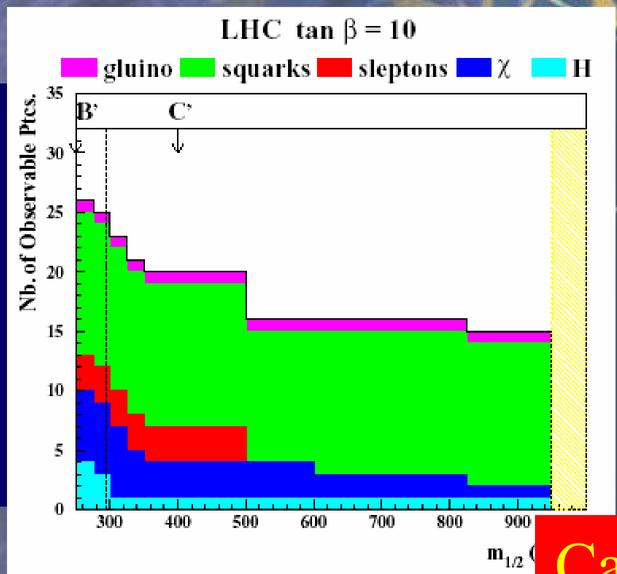
Supersymmetric Benchmark Studies

Lines in susy space allowed by accelerators, WMAP data

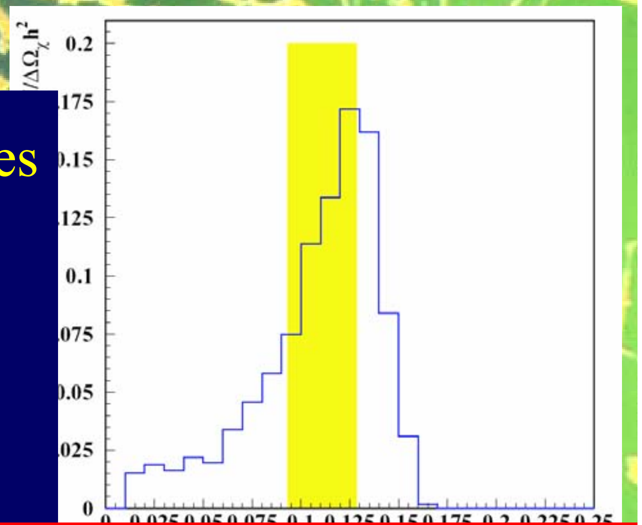


Specific benchmark Points along WMAP lines

Sparticle Detectability @ LHC along one WMAP line



LHC enables calculation of relic density at a benchmark point

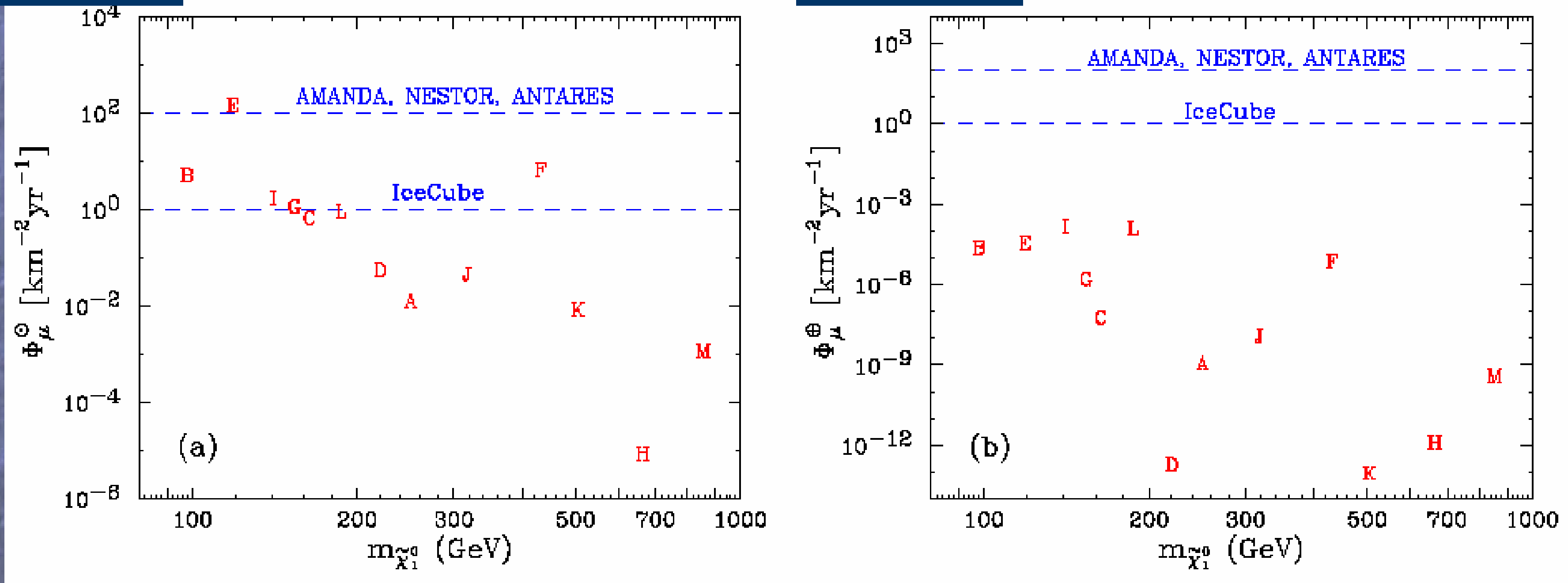


Can be refined with LC measurements

Annihilations in Solar System …

… Sun

… Earth

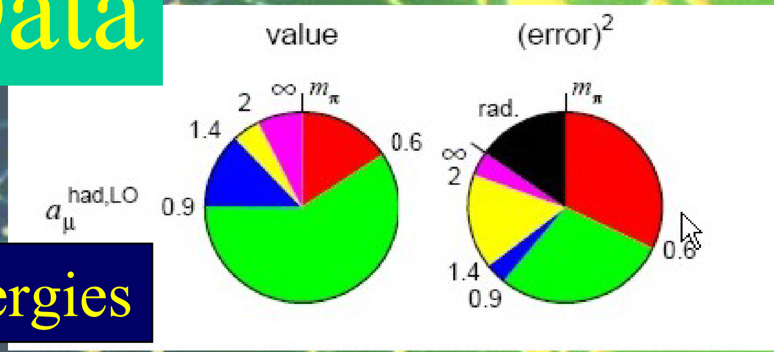


Prospective experimental sensitivities

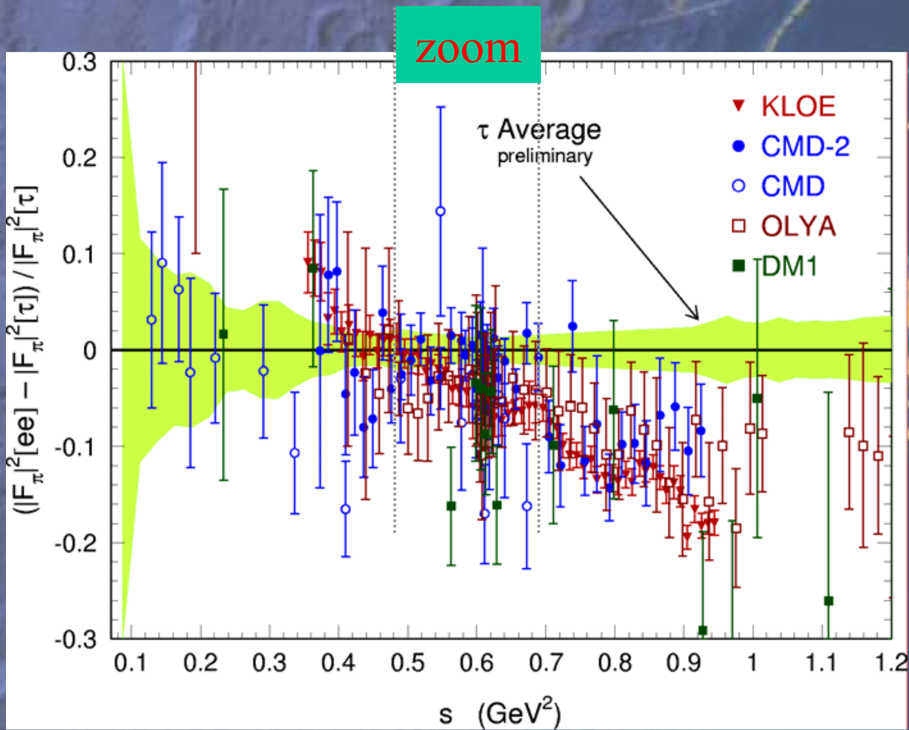
Benchmark scenarios

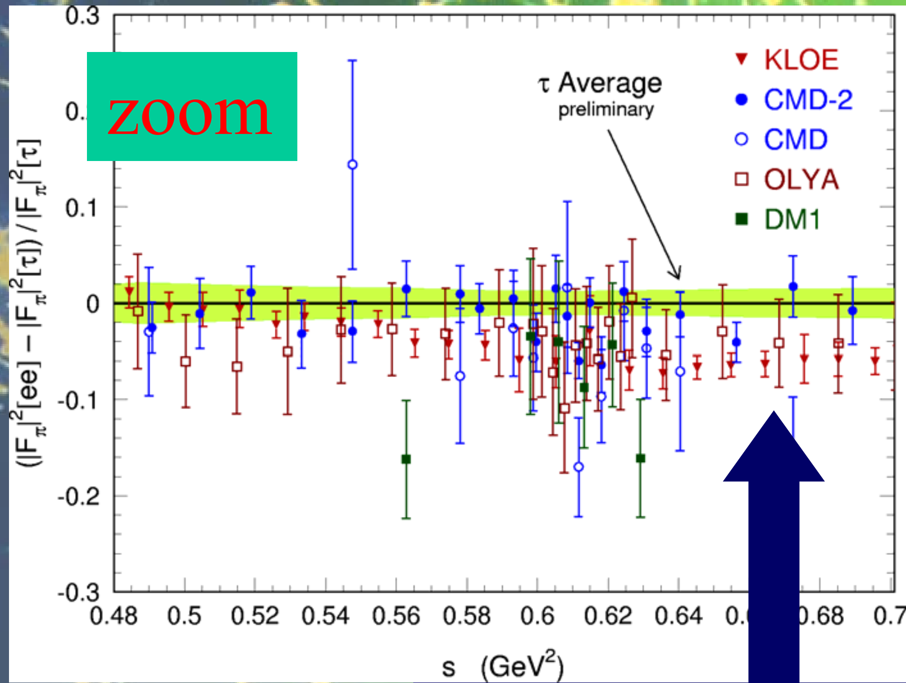
JE + Feng + Ferstl + Matchev + Olive

g_μ - 2: e^+e^- Data vs τ Data



Largest contributions, errors from low energies

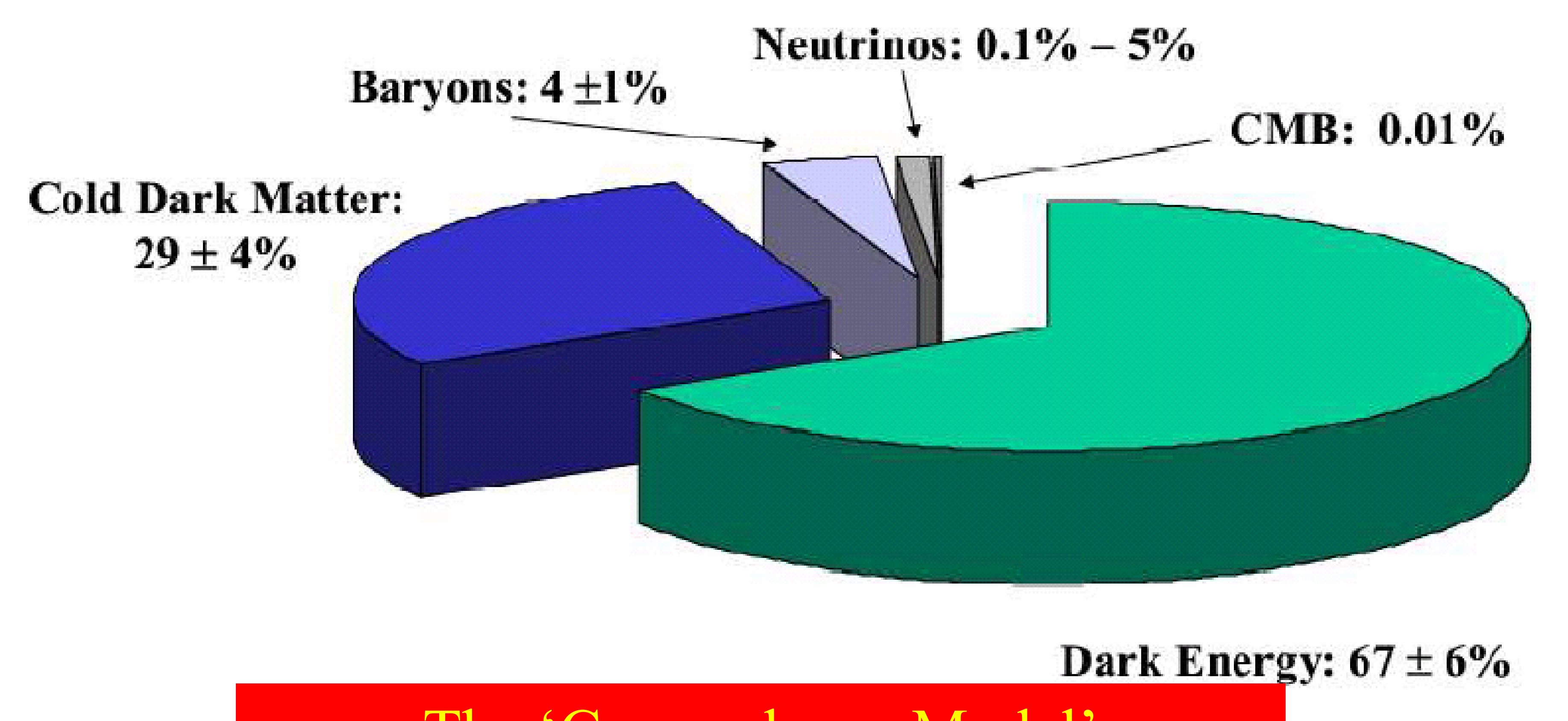




KLOE agrees with CMD-2: discard τ data

Why the 10%
τ - e^+e^- discrepancy
above ρ peak?

A Strange Recipe for a Universe



The 'Concordance Model'
prompted by astrophysics & cosmology

Open Questions beyond the Standard Model

- What is the origin of particle masses?

  due to a Higgs boson? + other physics?

  solution at energy < 1 TeV (1000 GeV)

  Susy
- Why so many types of matter particles?

  matter-antimatter difference?
- Unification of the fundamental forces?

  at very high energy ~ 10^{16} GeV?

  probe directly via neutrino physics, indirectly via masses, couplings

  Susy
- Quantum theory of gravity?

  (super)string theory: extra space-time dimensions?

  Susy

Searches for the Higgs Boson

Indirect:

- Precision electroweak measurements at LEP, SLC, etc
- Sensitive to mass of Higgs boson

  $m_H < 260$ GeV ?

  Most likely mass:

  $m_H \sim 114$ GeV

Direct:

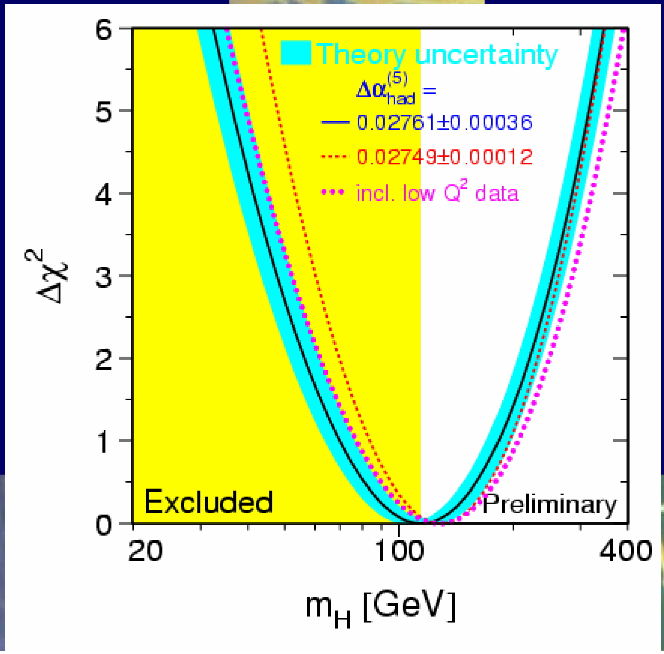
- LEP Searches for $e^+ e^- \rightarrow Z + H$
- Hint seen in late 2000 now $< 2\ \sigma$

Current Limit:

$m_H > 114.4$ GeV

Combined indications

←



And Supersymmetry (Susy)?

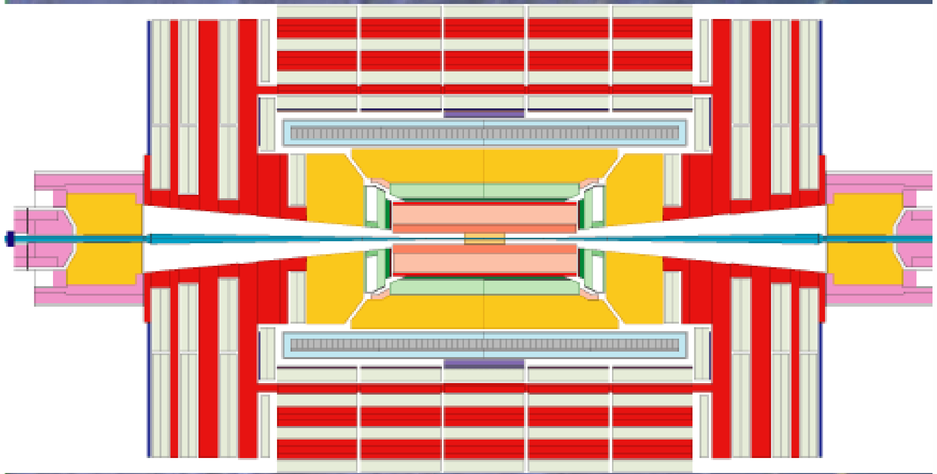
- Unifies matter and force particles
- Links fermions and bosons
- Relates particles of different spins

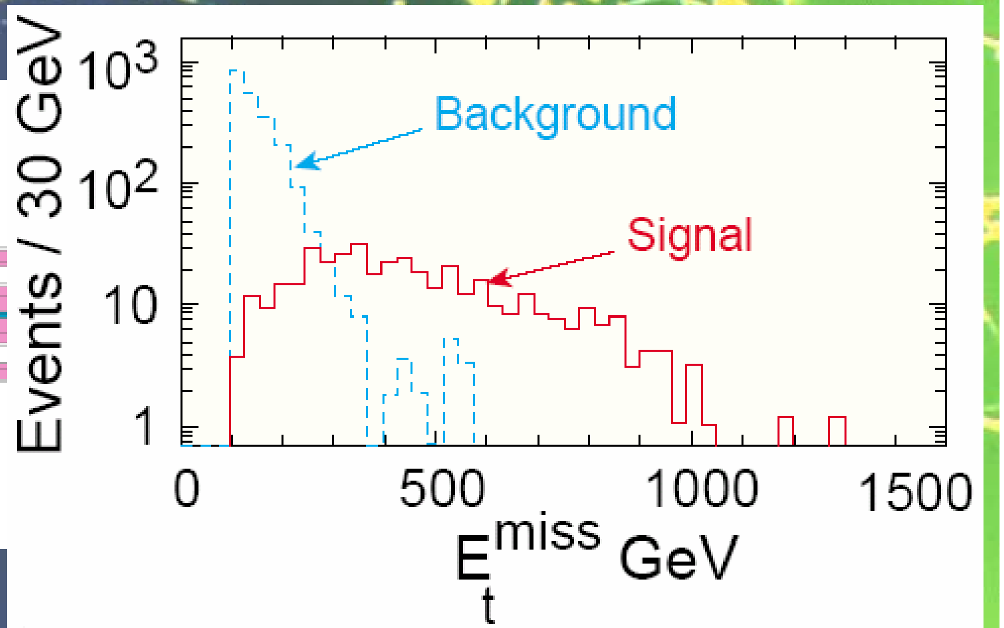
0 - ½ - 1 - 3/2 - 2

Higgs - Electron - Photon - Gravitino - Graviton

- Helps fix masses, unify fundamental forces
- Could provide astrophysical dark matter
- Essential for string theory

Missing Energy Detection @ LHC

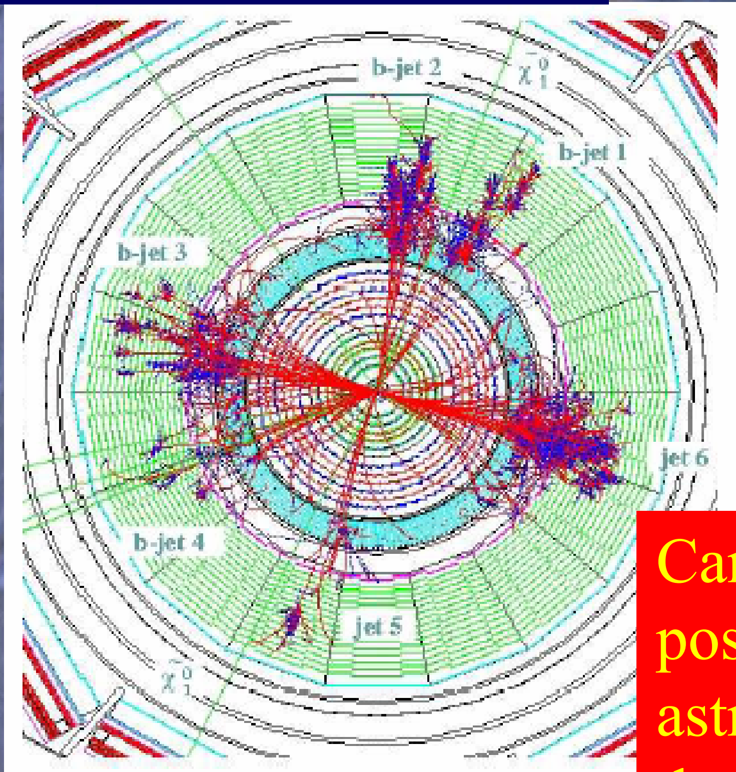




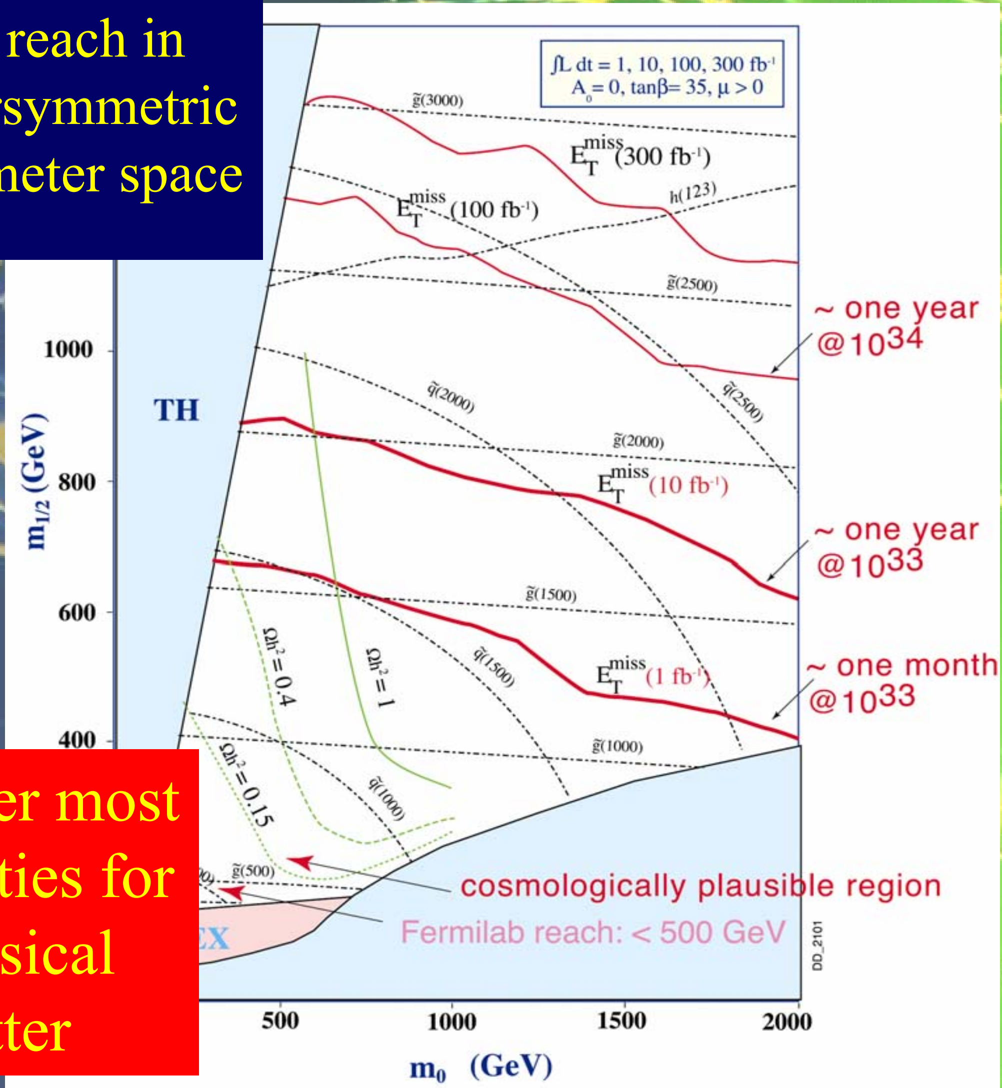
Sensitive to missing transverse energy carried away by neutral particles: e.g., neutrinos, neutralinos

Supersymmetry Searches at LHC

`Typical' supersymmetric Event at the LHC



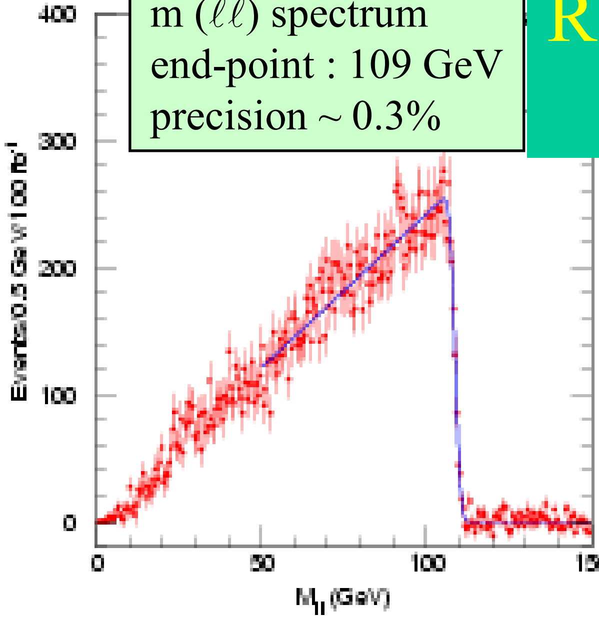
LHC reach in supersymmetric parameter space



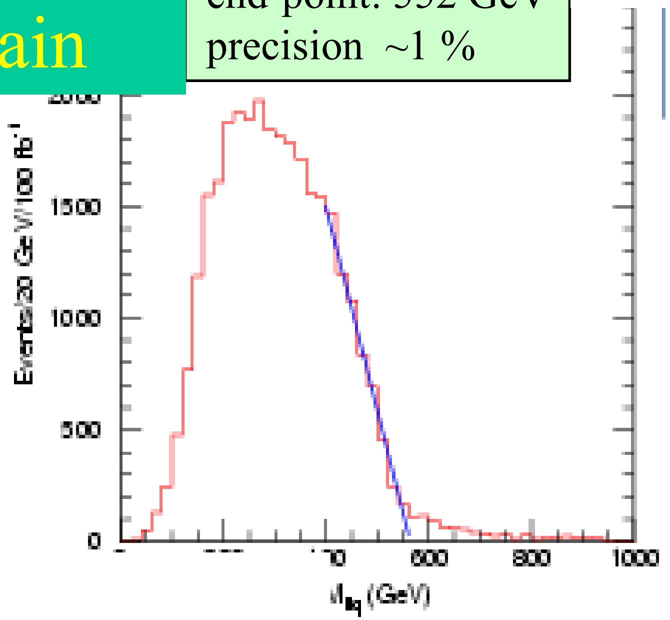
Can cover most possibilities for astrophysical dark matter

Reconstruction of `Typical' Sparticle Decay Chain

m ($\ell\ell$) spectrum
end-point : 109 GeV
precision ~ 0.3%

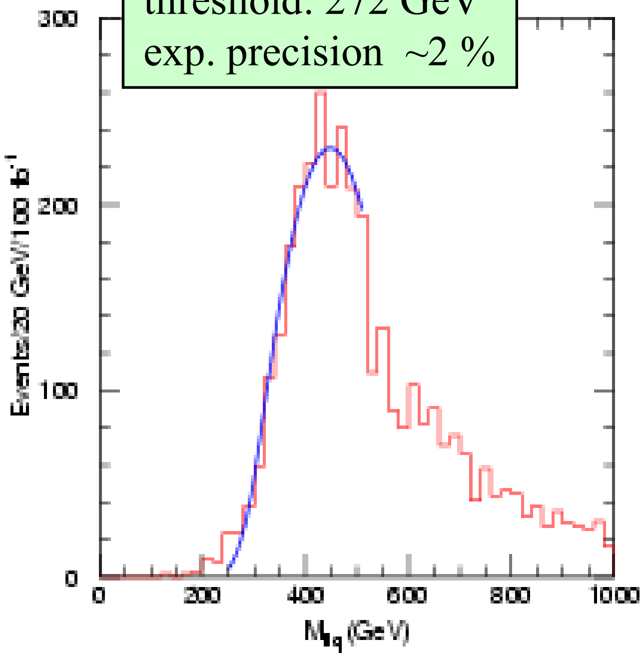


m ($\ell\ell$j)^{min} spectrum
end-point: 552 GeV
precision ~1 %



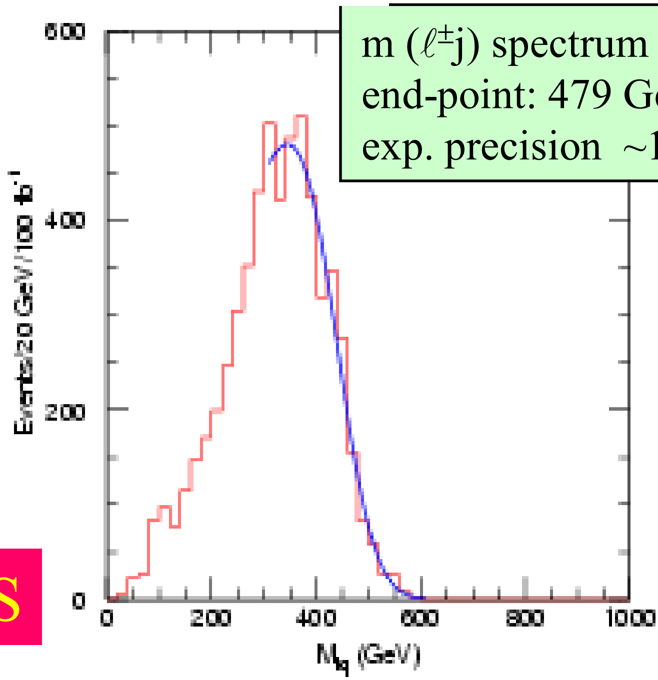
$$\tilde{q}_L \rightarrow q\,\chi^0_2$$
$$\hookrightarrow \tilde{\ell}_R\,\ell$$
$$\hookrightarrow \ell\,\chi^0_1$$

m ($\ell\ell$j)^{max} spectrum
threshold: 272 GeV
exp. precision ~2 %



$M_{squark} = 690$
$M_{\chi'} = 232$
$M_{slepton} = 157$
$M_{\chi} = 121$
(GeV)

m ($\ell^{\pm}$j) spectrum
end-point: 479 GeV
exp. precision ~1 %



ATLAS