Some Recent Developments in Dark Matter Theory

Leszek Roszkowski

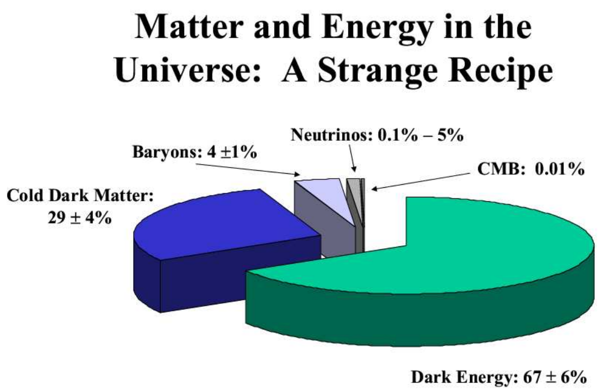
CERN

and

Astro–Particle Theory and Cosmology Group

Sheffield, England

Cosmic Inventory



- $\Omega_{\rm DM} h^2 = 0.104 \pm 0.009$
- $\Omega_{\rm b} h^2 = 0.0224 \pm 0.0009$

$\Rightarrow$ most matter non–baryonic

WIMP: best candidate around

WIMPs - Several Directions and Tools

Framework:

WIMPs - Several Directions and Tools

Framework:

- WIMP model, most popular SUSY (MSSM, Constrained MSSM,...)

WIMPs - Several Directions and Tools

Framework:

- WIMP model, most popular SUSY (MSSM, Constrained MSSM,...)
- direct detection

WIMPs - Several Directions and Tools

Framework:

- WIMP model, most popular SUSY (MSSM, Constrained MSSM,...)
- direct detection
- indirect detection

WIMPs - Several Directions and Tools

Framework:

- WIMP model, most popular SUSY (MSSM, Constrained MSSM,...)
- direct detection
- indirect detection
- LHC: expected to discover SUSY

WIMPs - Several Directions and Tools

Framework:

- WIMP model, most popular SUSY (MSSM, Constrained MSSM,...)
- direct detection
- indirect detection
- LHC: expected to discover SUSY

Tools:

WIMPs - Several Directions and Tools

Framework:

- WIMP model, most popular SUSY (MSSM, Constrained MSSM,...)
- direct detection
- indirect detection
- LHC: expected to discover SUSY

Tools:

- DM software packages (DarkSusy, Micromegas)
- related SUSY packages (Softsusy, Suspect, FeynHiggs, ...)
- new: Markov Chain Monte Carlo scan + probabilistic approach

WIMPs - Several Directions and Tools

Framework:

- WIMP model, most popular SUSY (MSSM, Constrained MSSM,...)
- direct detection
- indirect detection
- LHC: expected to discover SUSY

Tools:

- DM software packages (DarkSusy, Micromegas)
- related SUSY packages (Softsusy, Suspect, FeynHiggs, ...)
- new: Markov Chain Monte Carlo scan + probabilistic approach

$\Rightarrow$ impact: WIMP DM studies has become a mainstream activity

supported by ILIAS/ENTApP

SUSY Models

Two basic approaches:

SUSY Models

Two basic approaches:

- general MSSM

SUSY Models

Two basic approaches:

- general MSSM
- unification based:

SUSY Models

Two basic approaches:

- general MSSM
- unification based:
  - Constrained MSSM (CMSSM)

SUSY Models

Two basic approaches:

- general MSSM
- unification based:
  - Constrained MSSM (CMSSM)
  - Non-unified Higgs mass (NUHM), non-unified gaugino mass (NUGM)

SUSY Models

Two basic approaches:

- general MSSM
- unification based:
  - Constrained MSSM (CMSSM)
  - Non-unified Higgs mass (NUHM), non-unified gaugino mass (NUGM)
  - SO(10)–GUT
  - Next-to-MSSM (NMSSM)
  - . . .

The MSSM

The MSSM

Minimal Supersymmetric Standard Model

The MSSM

Minimal Supersymmetric	Standard Model
	gauge bosons

The MSSM

Minimal Supersymmetric	Standard Model
gauginos	gauge bosons

The MSSM

Minimal Supersymmetric	Standard Model
gauginos	gauge bosons
	Higgs bosons

The MSSM

Minimal Supersymmetric	Standard Model
gauginos	gauge bosons
higgsinos	Higgs bosons

The MSSM

Minimal Supersymmetric	Standard Model
gauginos	gauge bosons
higgsinos	Higgs bosons
	leptons

The MSSM

Minimal Supersymmetric	Standard Model
gauginos	gauge bosons
higgsinos	Higgs bosons
sleptons	leptons

The MSSM

Minimal Supersymmetric	Standard Model
gauginos	gauge bosons
higgsinos	Higgs bosons
sleptons	leptons
	quarks

The MSSM

Minimal Supersymmetric	Standard Model
gauginos	gauge bosons
higgsinos	Higgs bosons
sleptons	leptons
squarks	quarks

The MSSM

Minimal Supersymmetric	Standard Model
gauginos	gauge bosons
higgsinos	Higgs bosons
sleptons	leptons
squarks	quarks
$R = -1$	$R = +1$

The MSSM

Minimal Supersymmetric	Standard Model
gauginos	gauge bosons
higgsinos	Higgs bosons
sleptons	leptons
squarks	quarks
$R = -1$	$R = +1$

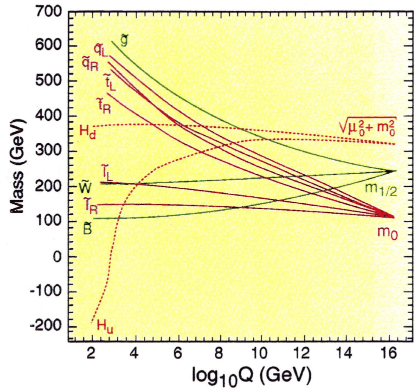
WIMP: “neutralino” χ = lightest mass e’state of neutral gauginos and higgsinos

Constrained MSSM ...aka mSUGRA

Constrained MSSM ...aka mSUGRA

At M_{GUT}:

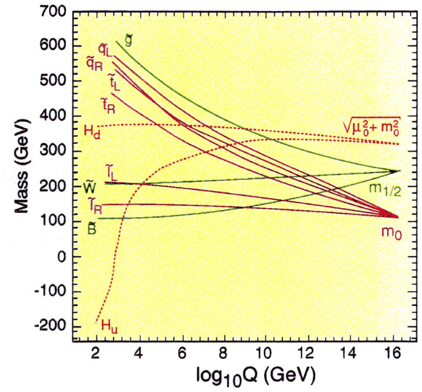
- gauginos $M_1 = M_2 = m_{\tilde{g}} = m_{1/2}$ (c.f. MSSM)
- scalars $m^2_{\tilde{q}_i} = m^2_{\tilde{l}_i} = m^2_{H_b} = m^2_{H_t} = m^2_0$
- 3–linear soft terms $A_b = A_t = A_0$



Constrained MSSM ...aka mSUGRA

At M_{GUT}:

- gauginos $M_1 = M_2 = m_{\widetilde{g}} = m_{1/2}$ (c.f. MSSM)
- scalars $m^2_{\widetilde{q}_i} = m^2_{\widetilde{l}_i} = m^2_{H_b} = m^2_{H_t} = m^2_0$
- 3–linear soft terms $A_b = A_t = A_0$



- radiative EWSB

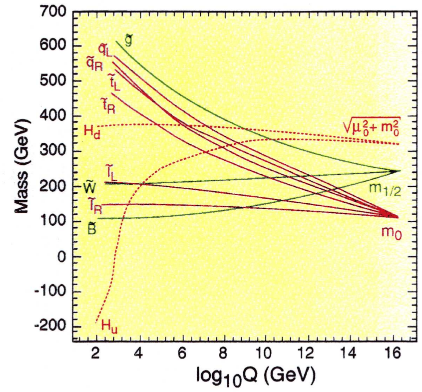
$$\mu^2 = \frac{\left(m^2_{H_b} + \Sigma^{(1)}_b\right) - \left(m^2_{H_t} + \Sigma^{(1)}_t\right)\tan^2\beta}{\tan^2\beta - 1} - \frac{m^2_Z}{2}$$

Constrained MSSM

...aka mSUGRA

At $M_{\rm GUT}$:

- gauginos $M_1 = M_2 = m_{\widetilde{g}} = m_{1/2}$ (c.f. MSSM)
- scalars $m^2_{\widetilde{q}_i} = m^2_{\widetilde{l}_i} = m^2_{H_b} = m^2_{H_t} = m^2_0$
- 3–linear soft terms $A_b = A_t = A_0$



- radiative EWSB

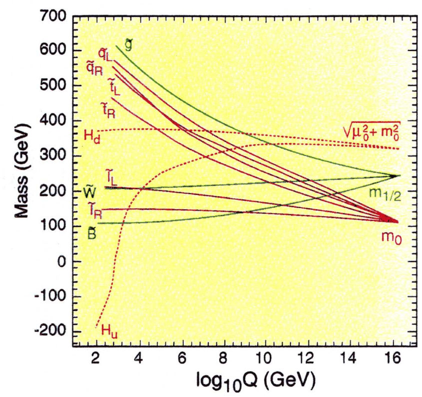
$$\mu^2 = \frac{\left(m^2_{H_b} + \Sigma_b^{(1)}\right) - \left(m^2_{H_t} + \Sigma_t^{(1)}\right)\tan^2\beta}{\tan^2\beta - 1} - \frac{m_Z^2}{2}$$

- five independent parameters: $\tan\beta,\ m_{1/2},\ m_0,\ A_0,\ {\rm sgn}(\mu)$

Constrained MSSM

...aka mSUGRA

At $M_{\rm GUT}$:



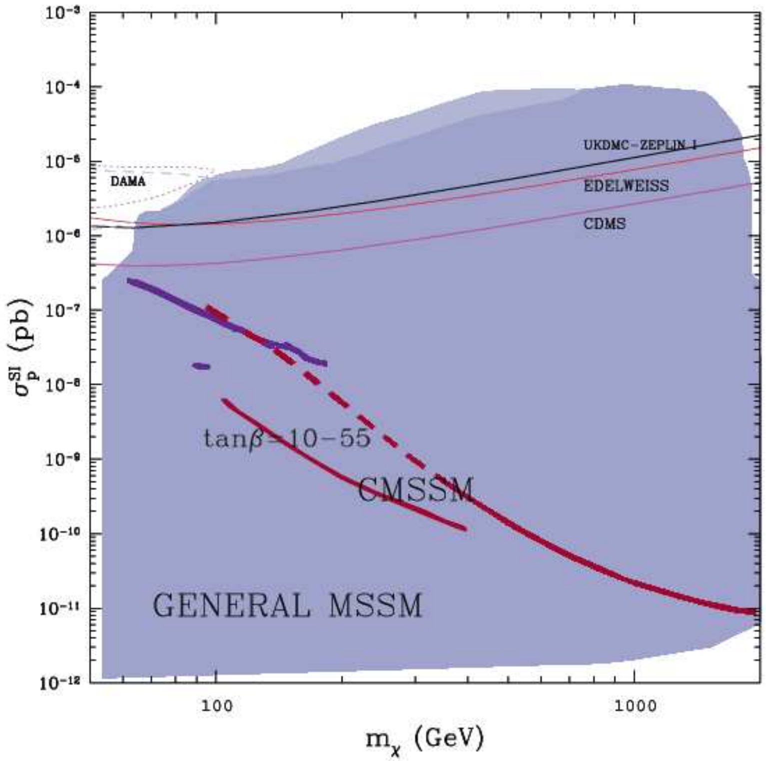
- gauginos $M_1 = M_2 = m_{\widetilde{g}} = m_{1/2}$ (c.f. MSSM)
- scalars $m^2_{\widetilde{q}_i} = m^2_{\widetilde{l}_i} = m^2_{H_b} = m^2_{H_t} = m^2_0$
- 3–linear soft terms $A_b = A_t = A_0$
- radiative EWSB

$$\mu^2 = \frac{\left(m^2_{H_b} + \Sigma_b^{(1)}\right) - \left(m^2_{H_t} + \Sigma_t^{(1)}\right)\tan^2\beta}{\tan^2\beta - 1} - \frac{m_Z^2}{2}$$

- five independent parameters: $\tan\beta,\ m_{1/2},\ m_0,\ A_0,\ {\rm sgn}(\mu)$
- mass spectra at m_Z: run RGEs, 2–loop for g.c. and Y.c, 1-loop for masses
- some important quantities ($\mu, m_A, \ldots$) very sensitive to procedure of computing EWSB & minimizing V_H

we use SoftSusy and FeynHiggs

Expectations for σ_p^{SI} with unification



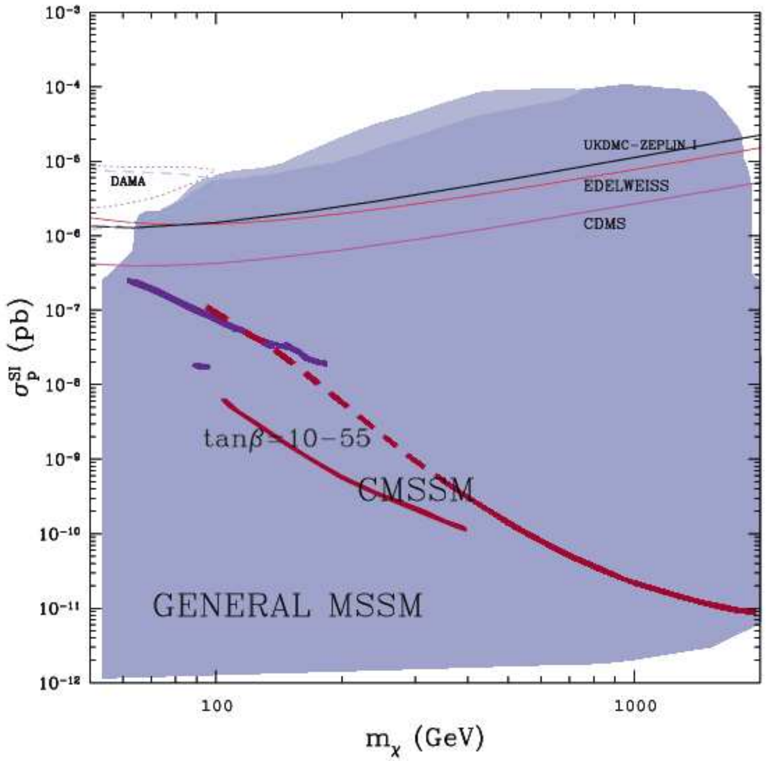
σ_p^{SI} – WIMP–proton SI elastic scatt. c.s.

blue: general MSSM

red: Constrained MSSM

$A_0 = 0, \tan\beta = 10, 55$

Expectations for σ_p^{SI} with unification



σ_p^{SI} – WIMP–proton SI elastic scatt. c.s.

blue: general MSSM

red: Constrained MSSM

$A_0 = 0, \tan\beta = 10, 55$

- effect of varying CMSSM and SM inputs?

Limitations of Grid Scans

Limitations of Grid Scans

usual approach: fixed grid scans

Limitations of Grid Scans

usual approach: fixed grid scans

- fix SM parameters at their central values
- vary some SUSY parameters (*e.g.*, $m_{1/2}$ and m_0) for fixed choices of some other ones (*e.g.*, A_0, $\tan\beta$)

Limitations of Grid Scans

usual approach: fixed grid scans

- fix SM parameters at their central values
- vary some SUSY parameters (*e.g.*, $m_{1/2}$ and m_0) for fixed choices of some other ones (*e.g.*, A_0, $\tan\beta$)
- apply experimental constraints

Limitations of Grid Scans

usual approach: fixed grid scans

- fix SM parameters at their central values
- vary some SUSY parameters (*e.g.*, $m_{1/2}$ and m_0) for fixed choices of some other ones (*e.g.*, $A_0, \tan\beta$)
- apply experimental constraints
- sometimes add some theoretical uncertainties

Limitations of Grid Scans

usual approach: fixed grid scans

- fix SM parameters at their central values
- vary some SUSY parameters (*e.g.*, $m_{1/2}$ and m_0) for fixed choices of some other ones (*e.g.*, $A_0, \tan\beta$)
- apply experimental constraints
- sometimes add some theoretical uncertainties

advantages

- can precisely select scanned points
- derive clearly defined 'allowed' regions

Limitations of Grid Scans

usual approach: fixed grid scans

- fix SM parameters at their central values
- vary some SUSY parameters (*e.g.*, $m_{1/2}$ and m_0) for fixed choices of some other ones (*e.g.*, $A_0, \tan\beta$)
- apply experimental constraints
- sometimes add some theoretical uncertainties

advantages

- can precisely select scanned points
- derive clearly defined 'allowed' regions

disadvantages

Limitations of Grid Scans

usual approach: fixed grid scans

- fix SM parameters at their central values
- vary some SUSY parameters (*e.g.*, $m_{1/2}$ and m_0) for fixed choices of some other ones (*e.g.*, $A_0, \tan\beta$)
- apply experimental constraints
- sometimes add some theoretical uncertainties

advantages

- can precisely select scanned points
- derive clearly defined ‘allowed’ regions

disadvantages

- What is really meant by (dis-)allowed regions?

Limitations of Grid Scans

usual approach: fixed grid scans

- fix SM parameters at their central values
- vary some SUSY parameters (*e.g.*, $m_{1/2}$ and m_0) for fixed choices of some other ones (*e.g.*, A_0, $\tan\beta$)
- apply experimental constraints
- sometimes add some theoretical uncertainties

advantages

- can precisely select scanned points
- derive clearly defined 'allowed' regions

disadvantages

- What is really meant by (dis-)allowed regions?
- nr of scan points $\propto k^N$ (where k: nr of steps, N: nr of parameters)
- $\Rightarrow$ highly inefficient for $N \gtrsim$ a few
- hard to inocoporate other uncertainties (SM, theory, ...), and assess their impact

MCMC + Bayesian Statistics

(MCMC=Markov Chain Monte Carlo)

a probabilistic approach

MCMC + Bayesian Statistics

(MCMC=Markov Chain Monte Carlo)

a probabilistic approach

Advantages

MCMC + Bayesian Statistics

(MCMC=Markov Chain Monte Carlo)

a probabilistic approach

Advantages

- efficient, nr of scan points $\propto N$

MCMC + Bayesian Statistics

(MCMC=Markov Chain Monte Carlo)

a probabilistic approach

Advantages

- efficient, nr of scan points $\propto N$
- easy to deal with additional parameters

MCMC + Bayesian Statistics

(MCMC=Markov Chain Monte Carlo)

a probabilistic approach

Advantages

- efficient, nr of scan points $\propto N$
- easy to deal with additional parameters
- easy to deal with uncertainties (expt and theor)

MCMC + Bayesian Statistics

(MCMC=Markov Chain Monte Carlo)

a probabilistic approach

Advantages

- efficient, nr of scan points $\propto N$
- easy to deal with additional parameters
- easy to deal with uncertainties (expt and theor)
- ‘allowed’ regions function of probability

MCMC + Bayesian Statistics

(MCMC=Markov Chain Monte Carlo)

a probabilistic approach

Advantages

- efficient, nr of scan points $\propto N$
- easy to deal with additional parameters
- easy to deal with uncertainties (expt and theor)
- 'allowed' regions function of probability

Disadvantages

- random scan of points (not strictly controlled)

MCMC + Bayesian Statistics

(MCMC=Markov Chain Monte Carlo)

a probabilistic approach

Advantages

- efficient, nr of scan points $\propto N$
- easy to deal with additional parameters
- easy to deal with uncertainties (expt and theor)
- 'allowed' regions function of probability

Disadvantages

- random scan of points (not strictly controlled)

powerful method of exploring multi–parameter models

MCMC + Bayesian Statistics

(MCMC=Markov Chain Monte Carlo)

a probabilistic approach

Advantages

- efficient, nr of scan points $\propto N$
- easy to deal with additional parameters
- easy to deal with uncertainties (expt and theor)
- ‘allowed’ regions function of probability

Disadvantages

- random scan of points (not strictly controlled)

powerful method of exploring multi–parameter models

allows to make global statements, expose correlations, etc.

Bayesian Analysis of the CMSSM

Apply to the CMSSM:

Bayesian Analysis of the CMSSM

Apply to the CMSSM:

- $m = (\theta, \psi)$: model's all relevant parameters

Bayesian Analysis of the CMSSM

Apply to the CMSSM:

- $m = (\theta, \psi)$: model's all relevant parameters
- θ: CMSSM parameters
- ψ: relevant SM parameters $\Rightarrow$ nuisance parameters

Bayesian Analysis of the CMSSM

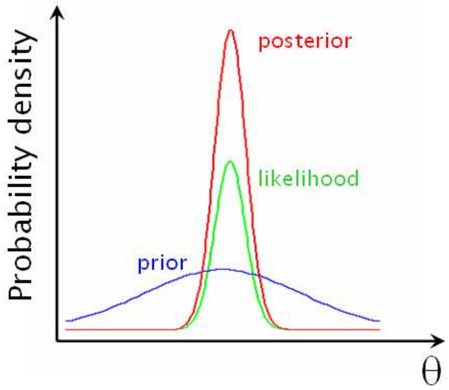
Apply to the CMSSM:

- $m = (\theta, \psi)$: model's all relevant parameters
- θ: CMSSM parameters
- ψ: relevant SM parameters $\Rightarrow$ nuisance parameters
- $\xi = (\xi_1, \xi_2, \ldots, \xi_m)$: set of derived variables (observables) $\xi(m)$

Bayesian Analysis of the CMSSM

Apply to the CMSSM:

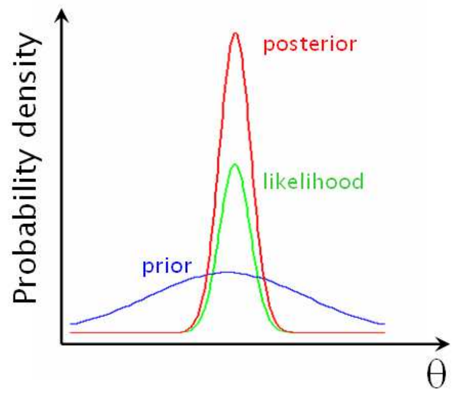
- $m = (\theta, \psi)$: model's all relevant parameters
- θ: CMSSM parameters
- ψ: relevant SM parameters $\Rightarrow$ nuisance parameters
- $\xi = (\xi_1, \xi_2, \ldots, \xi_m)$: set of derived variables (observables) $\xi(m)$
- d: data



Bayesian Analysis of the CMSSM

Apply to the CMSSM:

- $m = (\theta, \psi)$: model's all relevant parameters
- θ: CMSSM parameters
- ψ: relevant SM parameters $\Rightarrow$ nuisance parameters
- $\xi = (\xi_1, \xi_2, \ldots, \xi_m)$: set of derived variables (observables) $\xi(m)$
- d: data



- Bayes' theorem: posterior pdf

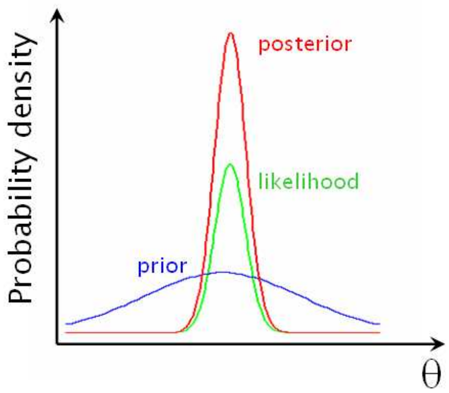
$$p(\theta, \psi | d) = \frac{p(d|\xi)\pi(\theta,\psi)}{p(d)}$$

- $p(d|\xi)$: likelihood
- $\pi(\theta, \psi)$: prior pdf
- $p(d)$: evidence (normalization factor)

Bayesian Analysis of the CMSSM

Apply to the CMSSM:

- $m = (\theta, \psi)$: model's all relevant parameters
- θ: CMSSM parameters
- ψ: relevant SM parameters $\Rightarrow$ nuisance parameters
- $\xi = (\xi_1, \xi_2, \ldots, \xi_m)$: set of derived variables (observables) $\xi(m)$
- d: data



- Bayes' theorem: posterior pdf

$$p(\theta, \psi | d) = \frac{p(d|\xi)\pi(\theta,\psi)}{p(d)}$$

- $p(d|\xi)$: likelihood
- $\pi(\theta, \psi)$: prior pdf
- $p(d)$: evidence (normalization factor)
- usually marginalize over SM (nuisance) parameters ψ: $p(\theta|d)$

Bayesian Analysis of the CMSSM

Roszkowski, Ruiz de Austri, Trotta, hep-ph/0602028, hep-ph/0611173

- $\theta = (m_0, m_{1/2}, A_0, \tan\beta)$: main CMSSM parameters (set $\mu > 0$)
- $\psi = (m_t^{\text{pole}}, m_b(m_b)^{\overline{MS}}, \alpha_{\text{em}}(M_Z), \alpha_s)$: SM (nuisance) parameters
- priors – assume flat distributions and ranges as:

CMSSM parameters θ	
"2 TeV range"	"4 TeV range"
50 GeV $< m_0 < 2$ TeV	50 GeV $< m_0 < 4$ TeV
50 GeV $< m_{1/2} < 2$ TeV	50 GeV $< m_{1/2} < 4$ TeV
$\lvert A_0 \rvert < 5$ TeV	$\lvert A_0 \rvert < 7$ TeV
$2 < \tan\beta < 62$	
flat priors: SM (nuisance) parameters ψ	
160 GeV $< m_t^{\text{pole}} < 190$ GeV	
4 GeV $< m_b(m_b)^{\overline{MS}} < 5$ GeV	
$0.10 < \alpha_s < 0.13$	
$127.5 < 1/\alpha_{\text{em}}(M_Z) < 128.5$	

Experimental Measurements

(assume Gaussian distributions)

Experimental Measurements

(assume Gaussian distributions)

SM (nuisance) parameter	Mean μ	Error σ (expt)
$m_t^{\rm pole}$	171.4 GeV	2.1 GeV
$m_b(m_b)^{\overline{MS}}$	4.20 GeV	0.07 GeV
α_s	0.1176	0.002
$1/\alpha_{\rm em}(M_Z)$	127.918	0.018

Experimental Measurements

(assume Gaussian distributions)

SM (nuisance) parameter	Mean μ	Error σ (expt)
m_t^{pole}	171.4 GeV	2.1 GeV
$m_b(m_b)^{\overline{MS}}$	4.20 GeV	0.07 GeV
α_s	0.1176	0.002
$1/\alpha_{\mathrm{em}}(M_Z)$	127.918	0.018

new $M_W = 80.413 \pm 0.048$ GeV (Jan 07, not included)
$\mathrm{BR}(\bar{\mathrm{B}} \to \mathrm{X_s}\gamma) \times 10^4$:
new SM: 3.15 ± 0.21 (Misiak & Steinhauser, Sept 06) used here
2.98 ± 0.26 (Becher & Neubert, Nov 06)

Derived observable	Mean	Errors	
	μ	σ (expt)	τ (th)
M_W	80.392 GeV	29 MeV	15 MeV
$\sin^2\theta_{\mathrm{eff}}$	0.23153	16×10^{-5}	15×10^{-5}
$\delta a_\mu^{\mathrm{SUSY}} \times 10^{10}$	28	8.1	1
$\mathrm{BR}(\bar{\mathrm{B}} \to \mathrm{X_s}\gamma) \times 10^4$	3.55	0.26	0.21
ΔM_{B_s}	17.33	0.12	4.8
$\Omega_\chi h^2$	0.119	0.009	$0.1\,\Omega_\chi h^2$

take as precisely known: $M_Z = 91.1876(21)$ GeV, $G_F = 1.16637(1) \times 10^{-5}$ GeV^{-2}

Experimental Limits

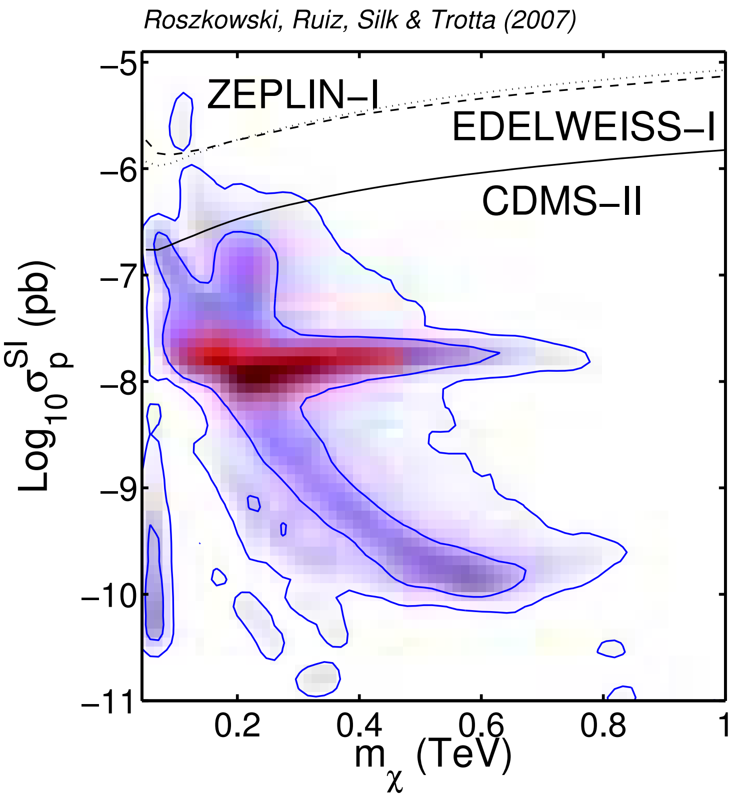
Derived observable	upper/lower limit	Constraints $\xi_{\rm lim}$	τ (theor.)
$\mathrm{BR}(\mathrm{B_s} \to \mu^+\mu^-)$	UL	1.5×10^{-7}	14%
m_h	LL	114.4 GeV (91.0 GeV)	3 GeV
$\zeta_h^2 \equiv g^2_{ZZh}/g^2_{ZZH_{\rm SM}}$	UL	$f(m_h)$	3%
m_χ	LL	50 GeV	5%
$m_{\chi_1^\pm}$	LL	103.5 GeV (92.4 GeV)	5%
$m_{\tilde{e}_R}$	LL	100 GeV (73 GeV)	5%
$m_{\tilde{\mu}_R}$	LL	95 GeV (73 GeV)	5%
$m_{\tilde{\tau}_1}$	LL	87 GeV (73 GeV)	5%
$m_{\tilde{\nu}}$	LL	94 GeV (43 GeV)	5%
$m_{\tilde{t}_1}$	LL	95 GeV (65 GeV)	5%
$m_{\tilde{b}_1}$	LL	95 GeV (59 GeV)	5%
$m_{\tilde{q}}$	LL	318 GeV	5%
$m_{\tilde{g}}$	LL	233 GeV	5%
(σ_p^{SI}	UL	WIMP mass dependent	$\sim 100\%$)

Note: DM direct detection σ_p^{SI} not applied due to astroph'l uncertainties (eg, local DM density)

Implications for direct detection: σ_p^{SI}

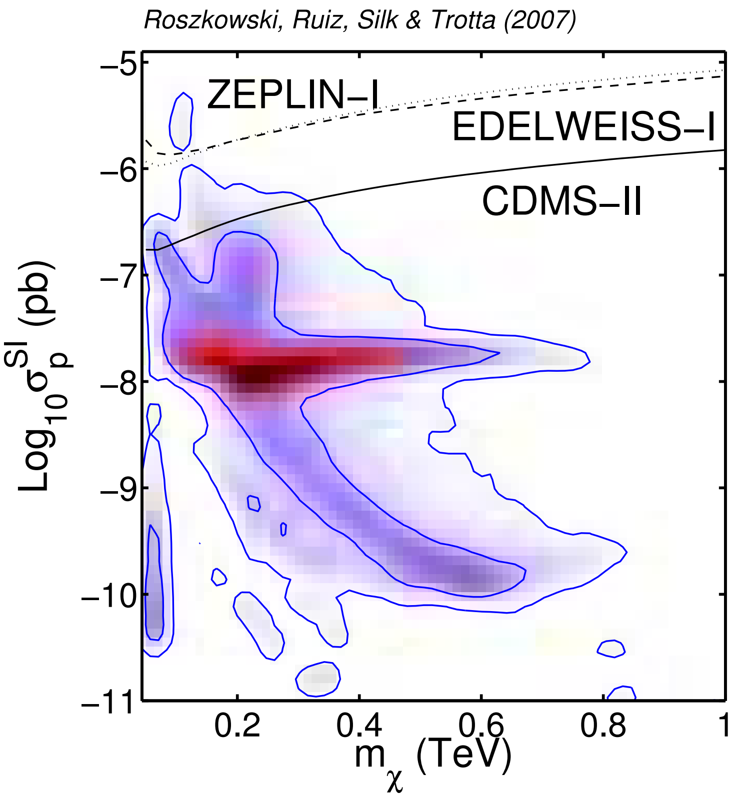
Implications for direct detection: σ_p^{SI}

MCMC+Bayesian analysis

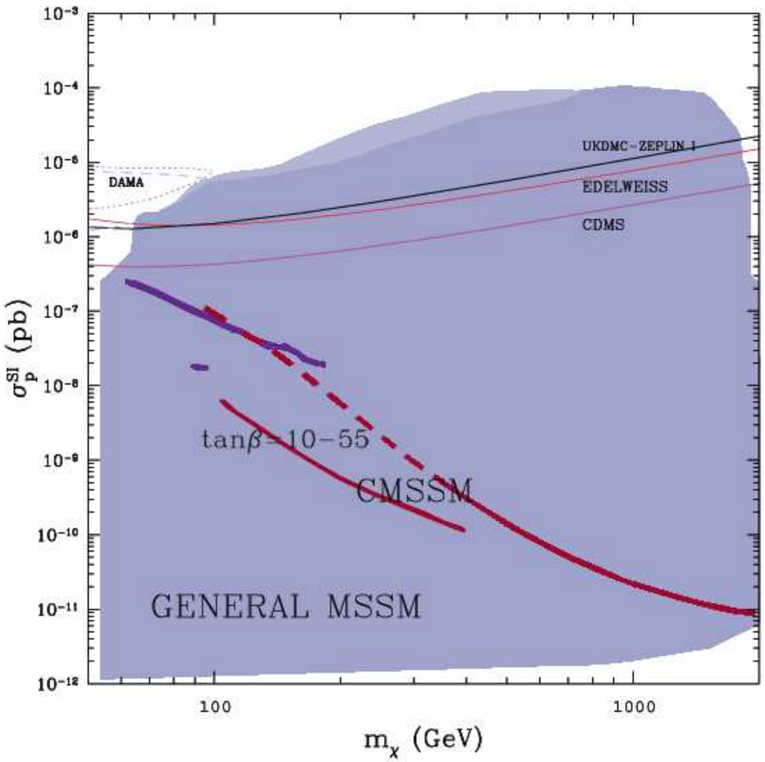


Implications for direct detection: σ_p^{SI}

MCMC+Bayesian analysis

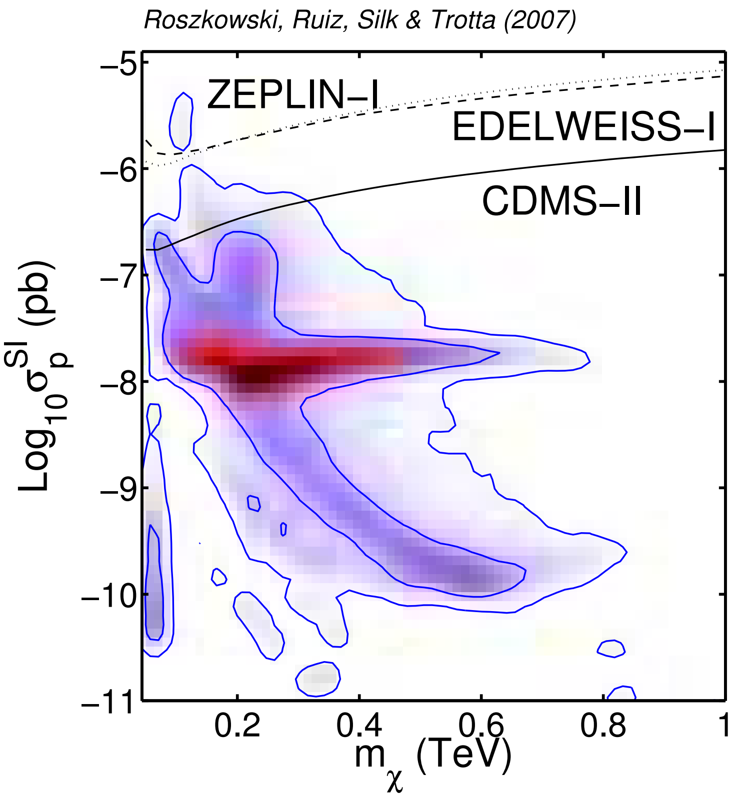


compare: fixed grid scan



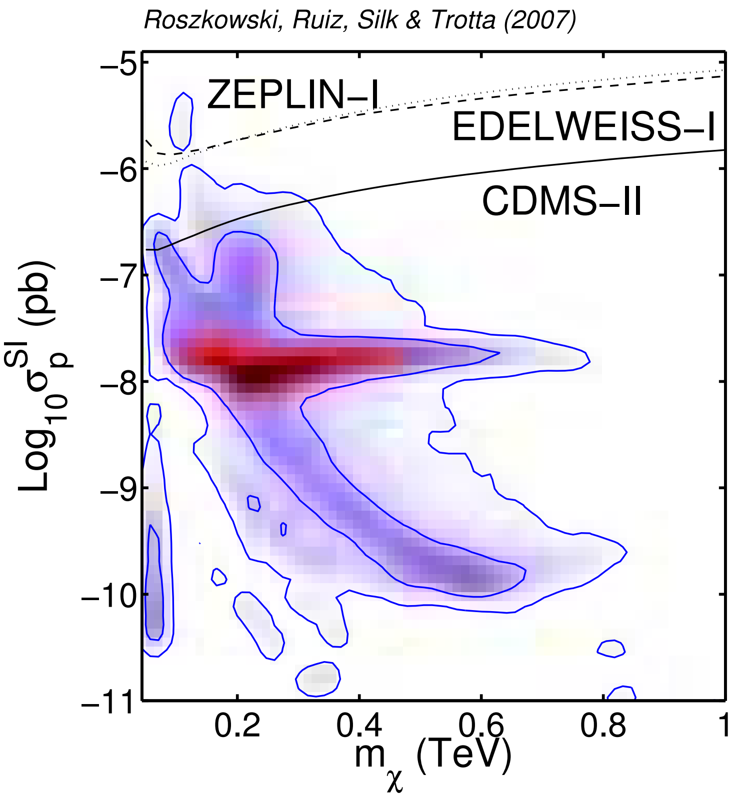
Implications for direct detection: σ_p^{SI}

implications for σ_p^{SI}



Implications for direct detection: σ_p^{SI}

implications for σ_p^{SI}



CDMS (this year?):

will reach down to $\sigma_p^{SI} \sim 10^{-8}$ pb:

also Edelweiss–II (?)

$\Rightarrow$ explore the FP region

(large $m_0 \gg m_{1/2}$), outside of the LHC reach

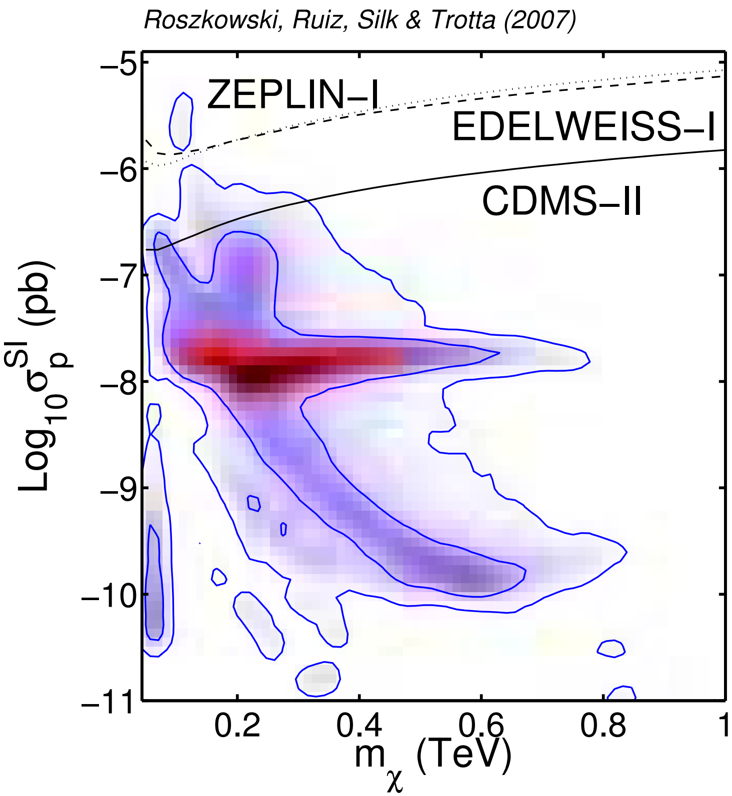
ultimately: “1 tonne” detectors:

$\sigma_p^{SI} \lesssim 10^{-10}$ pb

will cover all 68% region

Implications for direct detection: σ_p^{SI}

implications for σ_p^{SI}



CDMS (this year?):
will reach down to $\sigma_p^{SI} \sim 10^{-8}$ pb:

also Edelweiss–II (?)

$\Rightarrow$ explore the FP region

(large $m_0 \gg m_{1/2}$), outside of the LHC reach

ultimately: “1 tonne” detectors:
$\sigma_p^{SI} \lesssim 10^{-10}$ pb

will cover all 68% region

most probable range: 10^{-8} pb $\lesssim \sigma_p^{SI} \lesssim 10^{-10}$ pb

partly outside of the LHC reach ($m_\chi \lesssim 400$ GeV)

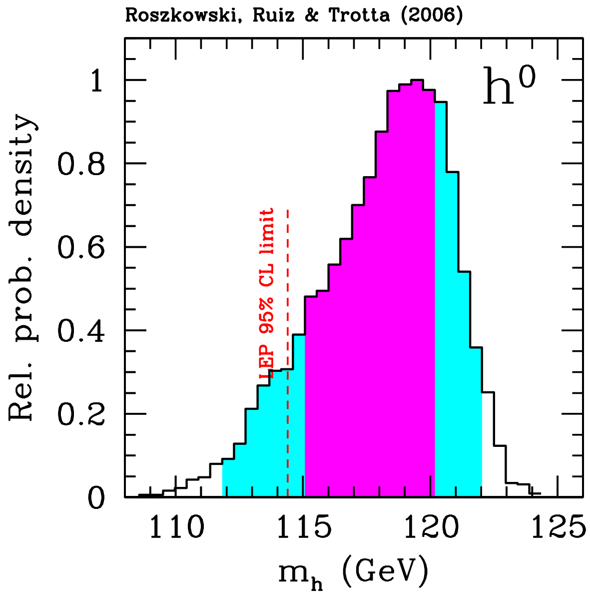
CMSSM Higgs Boson & the Tevatron

CMSSM: light Higgs boson h^0 is SM-like (SM-like couplings)

CMSSM Higgs Boson & the Tevatron

CMSSM: light Higgs boson h^0 is SM-like (SM-like couplings)

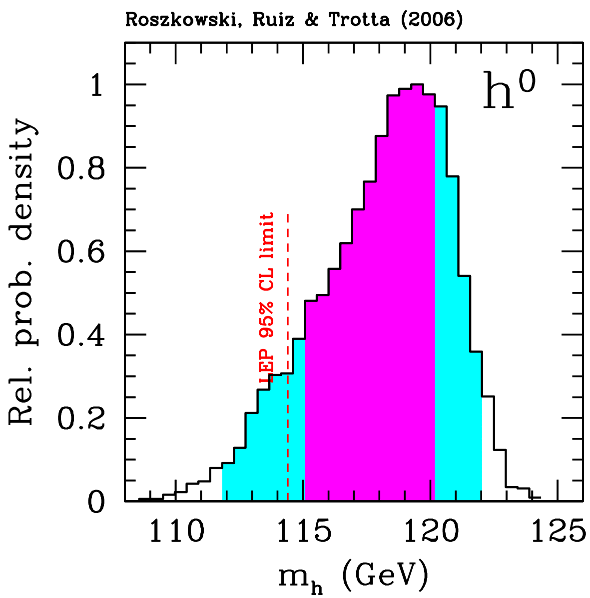
MCMC scan, Bayesian analysis



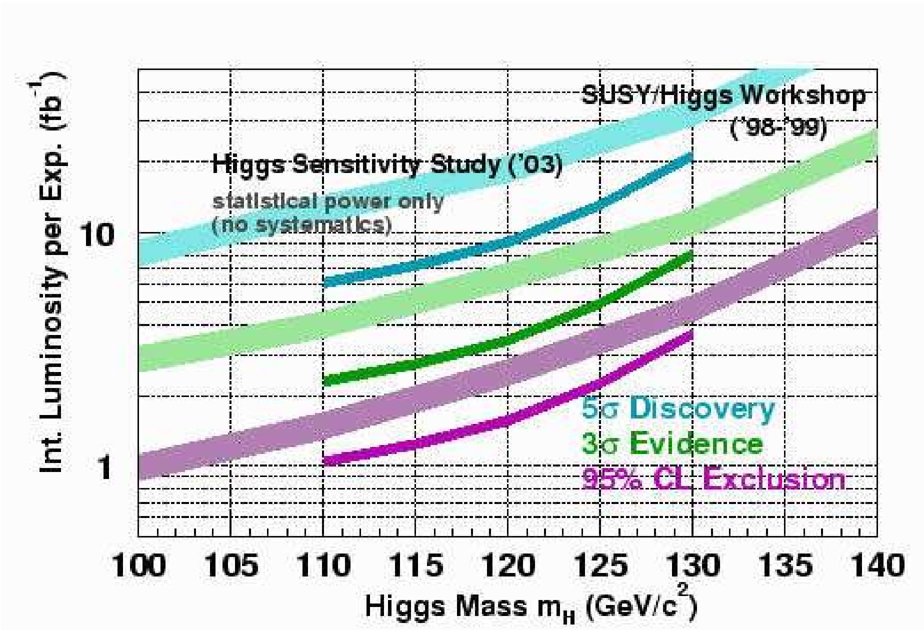
CMSSM Higgs Boson & the Tevatron

CMSSM: light Higgs boson h^0 is SM-like (SM-like couplings)

MCMC scan, Bayesian analysis



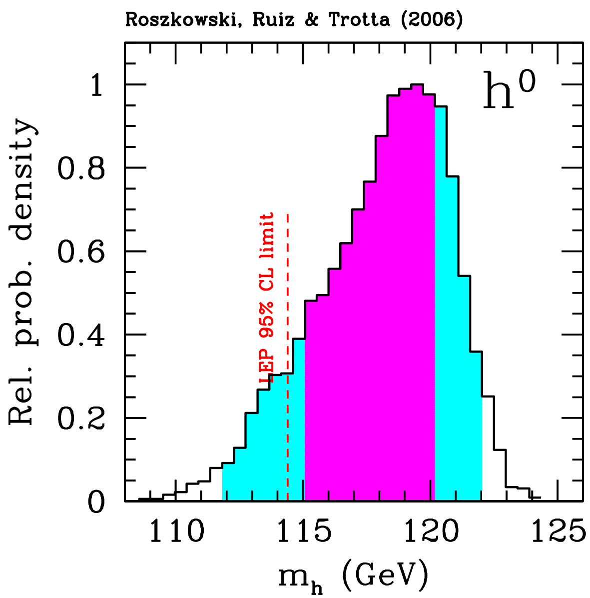
Tevatron reach (CDF and D0 WG (Oct 03))



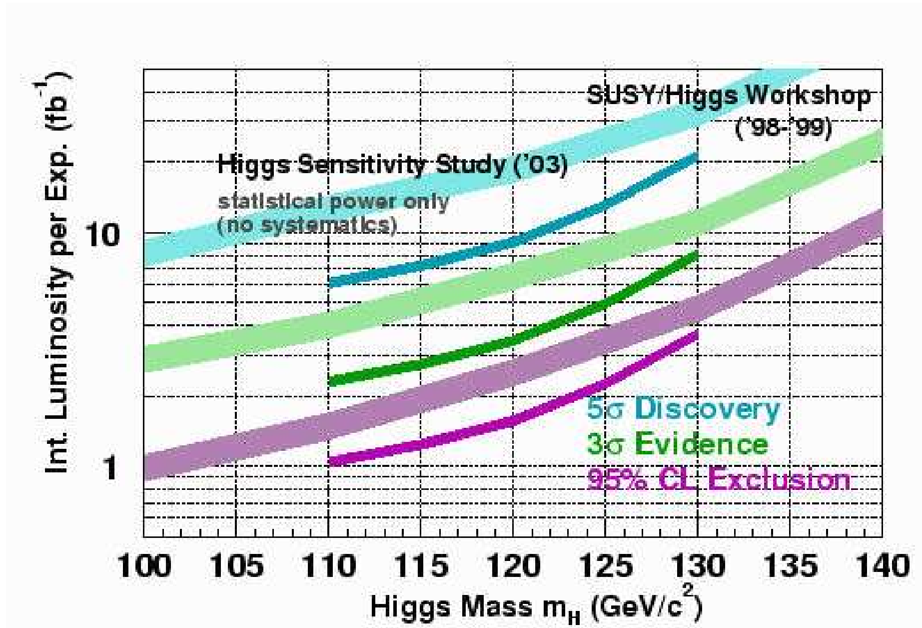
CMSSM Higgs Boson & the Tevatron

CMSSM: light Higgs boson h^0 is SM-like (SM-like couplings)

MCMC scan, Bayesian analysis



Tevatron reach (CDF and D0 WG (Oct 03))



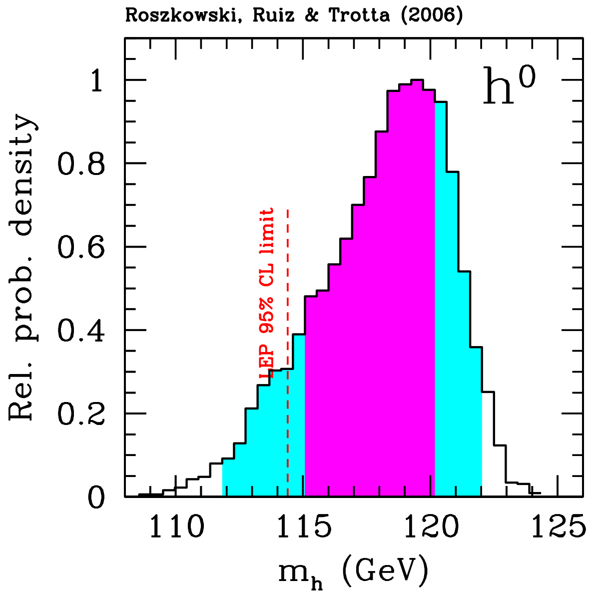
$\mathbf{2}$ fb^{-1}/experiment already on tape

$\Rightarrow$ enough to set 95% CL exclusion limit on 95% range of m_h

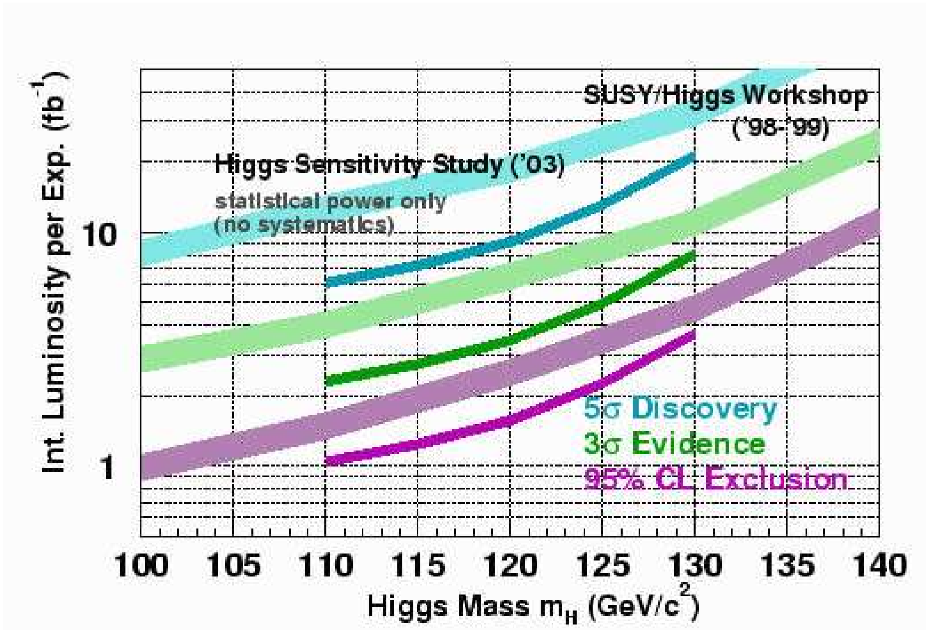
CMSSM Higgs Boson & the Tevatron

CMSSM: light Higgs boson h^0 is SM-like (SM-like couplings)

MCMC scan, Bayesian analysis



Tevatron reach (CDF and D0 WG (Oct 03))



2 fb^{-1}/experiment already on tape

$\Rightarrow$ enough to set 95% CL exclusion limit on 95% range of m_h

...or else...

with 4 fb^{-1}/expt: 3σ evidence over entire 95% range of m_h

with $\sim 10-12$ fb^{-1}/expt: 5σ discovery over entire 95% range of m_h

Tevatron: hope for up to~ 8 fb^{-1}/expt

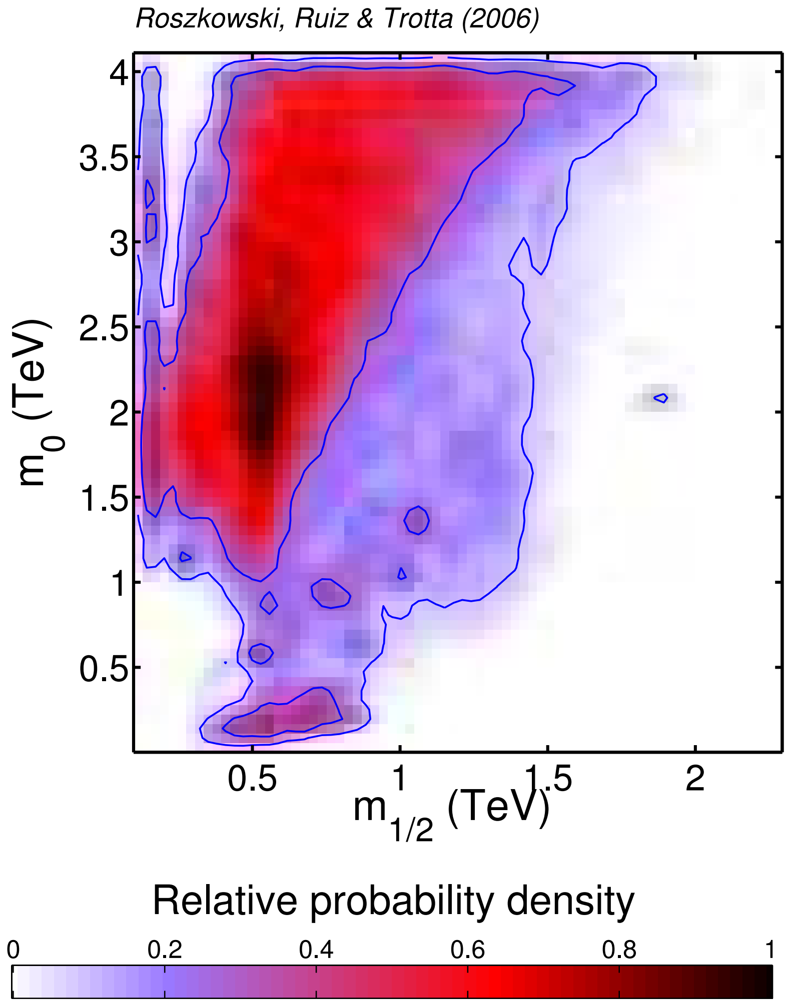
Full MCMC Scan of the CMSSM

(Ruiz de Austri, Trotta, Roszkowski, hep-ph/0602028)

Full MCMC Scan of the CMSSM

(Ruiz de Austri, Trotta, Roszkowski, hep-ph/0602028)

RRT update, in prep



Bayesian analysis

relative probability density fn

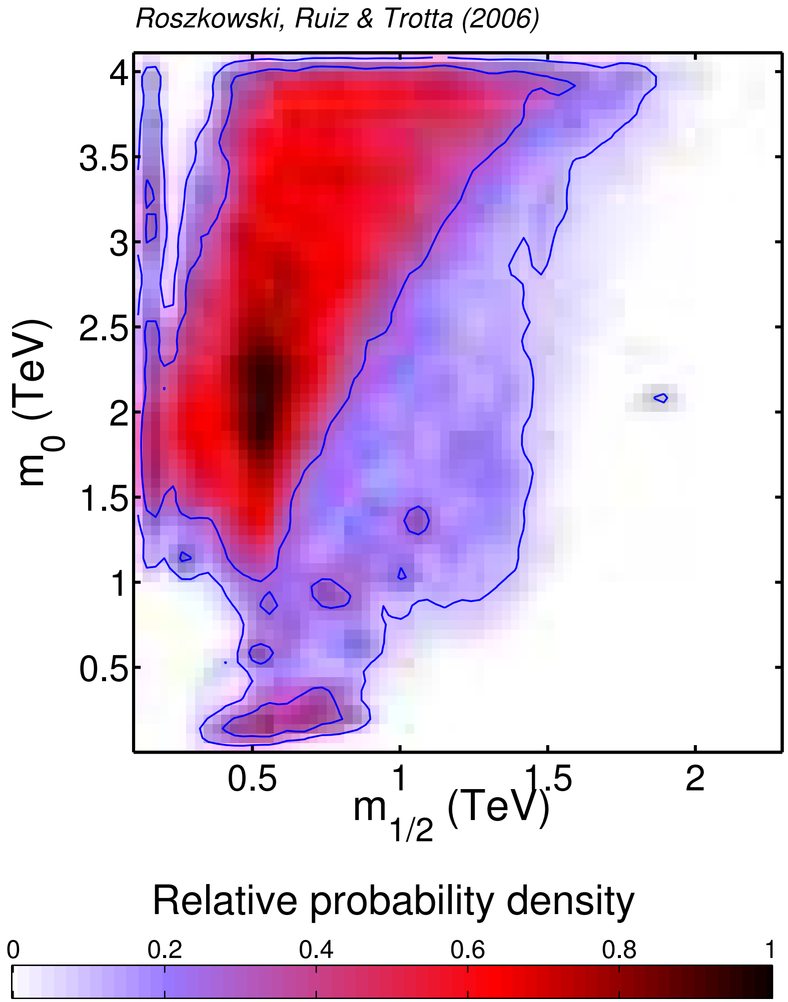
flat priors

$p(m_0, m_{1/2}|d)$

Full MCMC Scan of the CMSSM

(Ruiz de Austri, Trotta, Roszkowski, hep-ph/0602028)

RRT update, in prep



Bayesian analysis

relative probability density fn

flat priors

$p(m_0, m_{1/2}|d)$

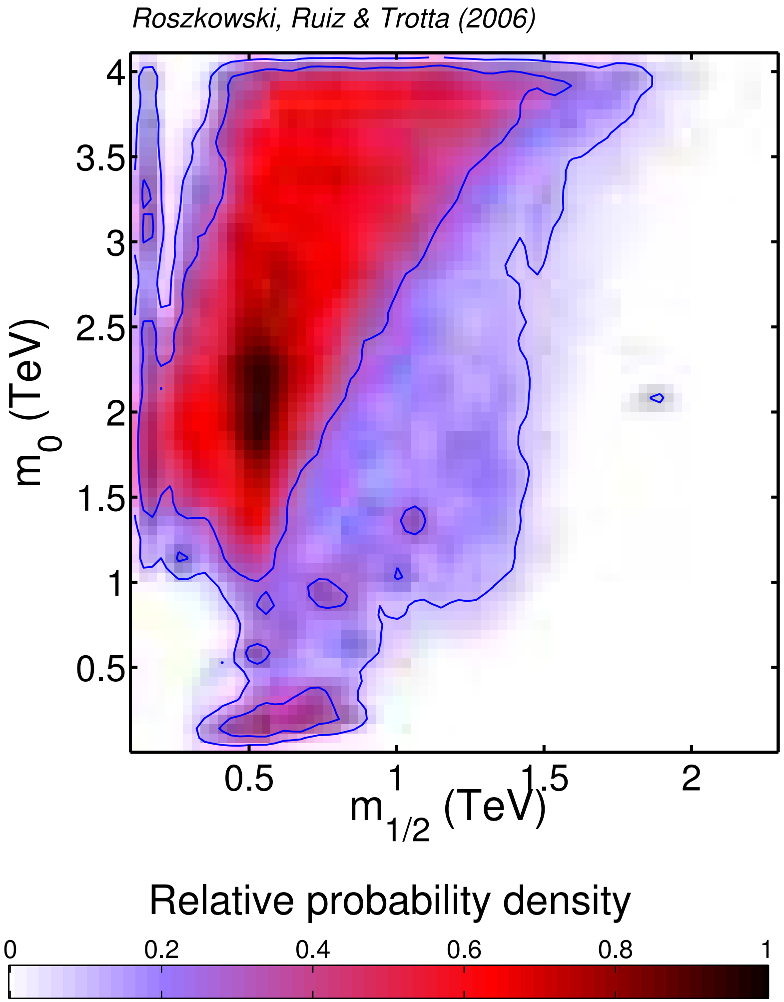
similar study by Allanach+Lester (no mean qof),

see also, Ellis et al (EHOW, χ^2 approach, no MCMC)

Full MCMC Scan of the CMSSM

(Ruiz de Austri, Trotta, Roszkowski, hep-ph/0602028)

RRT update, in prep



Bayesian analysis

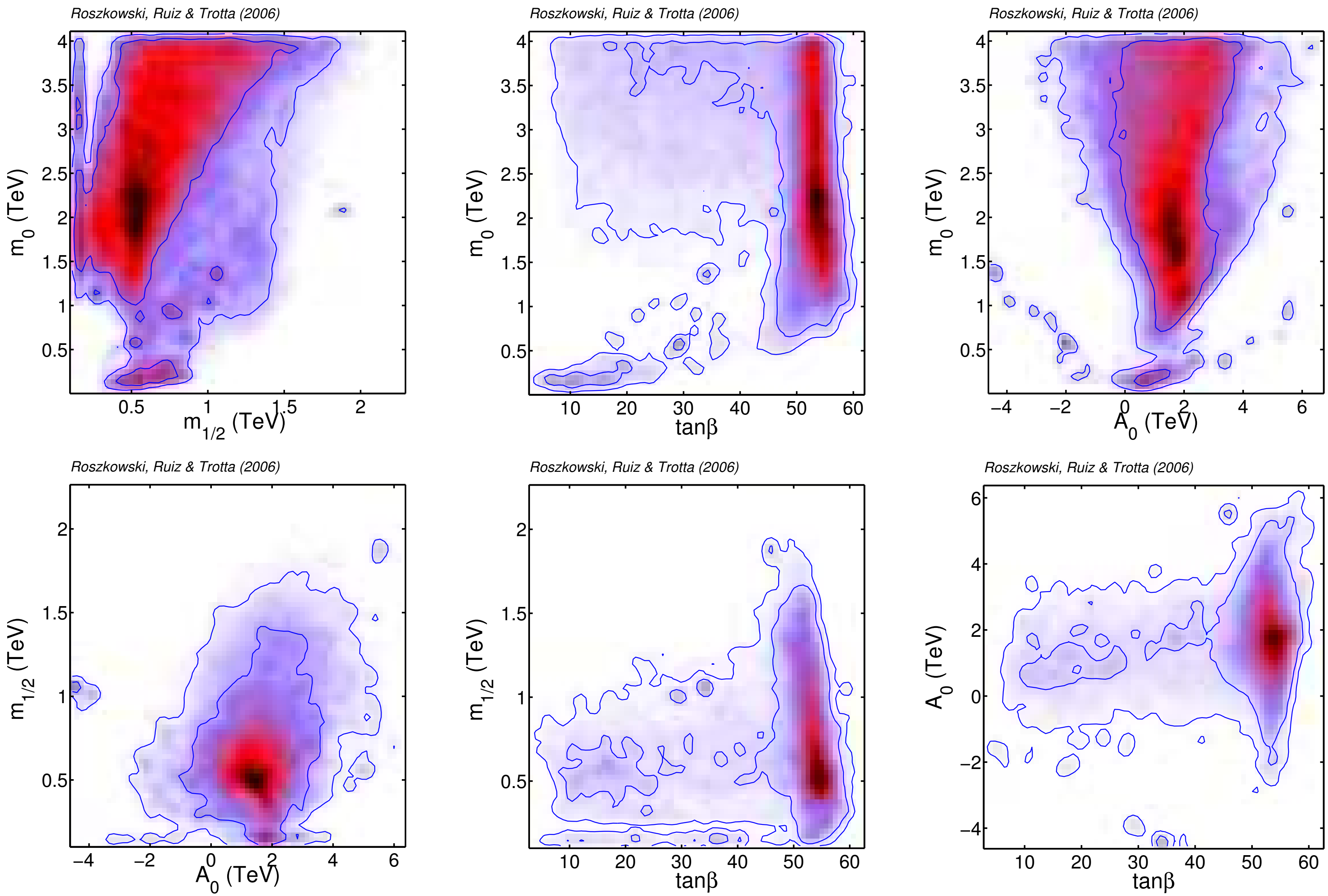
relative probability density fn

flat priors

$p(m_0, m_{1/2}|d)$

unlike others (except for A+L), we vary also SM parameters

Full MCMC Scan of the CMSSM



peak at $A_0 \simeq 1.5$ TeV (in grid scans one usually sets $A_0 = 0$)

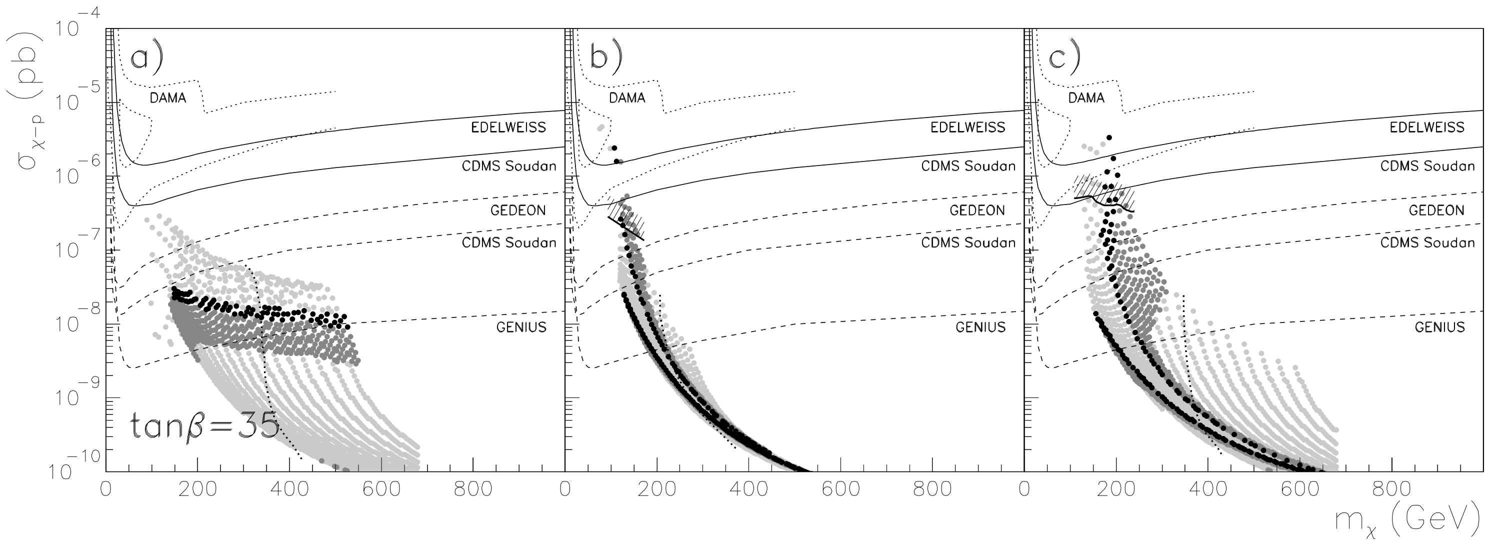
WIMP detection in NUHM models

NUHM = non-unified Higgs mass

at $M_{\rm GUT}$: $m^2_{H_b} = (1 + \delta_b) m_0^2$, $m^2_{H_t} = (1 + \delta_t) m_0^2$

implications for σ_p^{SI}

left: $\delta_b = 0$, $\delta_t = 1$, center: $\delta_b = -1$, $\delta_t = 0$, right: $\delta_b = -1$, $\delta_t = 1$



Baek, et al, hep-ph/0505019

new SM value for $b \longrightarrow s\gamma$ not included

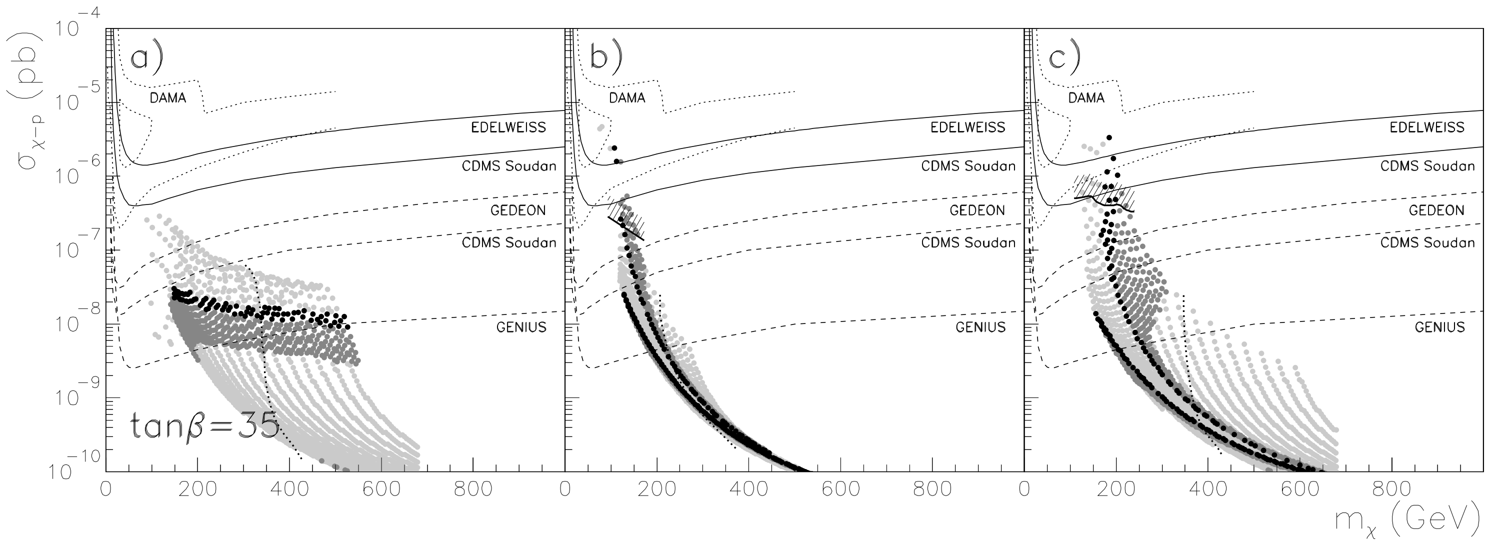
WIMP detection in NUHM models

NUHM = non-unified Higgs mass

at M_{GUT}: $m^2_{H_b} = (1+\delta_b)m_0^2$, $m^2_{H_t} = (1+\delta_t)m_0^2$

implications for σ_p^{SI}

left: $\delta_b = 0$, $\delta_t = 1$, center: $\delta_b = -1$, $\delta_t = 0$, right: $\delta_b = -1$, $\delta_t = 1$



Baek, et al, hep-ph/0505019

new SM value for $b \longrightarrow s\gamma$ not included

$\Rightarrow$ for $\delta_b < 0$ and $\delta_t > 0$, σ_p^{SI} can be larger than in the CMSSM

Summary

Summary

- several DM theory tools, packages, techniques have been developed
- recent: MCMC + Bayesian statistics approach

Summary

- several DM theory tools, packages, techniques have been developed
- recent: MCMC + Bayesian statistics approach
- WIMPs in SUSY models often within reach of DD experiments
- NEW: shift towards larger σ_p^{SI}

result of a new lower SM value for $\mathbf{BR}(\bar{B} \longrightarrow X_s\gamma)$

Summary

- several DM theory tools, packages, techniques have been developed
- recent: MCMC + Bayesian statistics approach
- WIMPs in SUSY models often within reach of DD experiments
- NEW: shift towards larger σ_p^{SI}

result of a new lower SM value for $\mathrm{BR}(\bar{B} \to X_s \gamma)$

- CMSSM (most probable range):

$$\sigma_p^{SI} = 10^{-9 \pm 1}\ \text{pb}$$

largest $\sigma_p^{SI} \simeq 10^{-8}$ pb for large m_0, beyond LHC reach!

Summary

- several DM theory tools, packages, techniques have been developed
- recent: MCMC + Bayesian statistics approach
- WIMPs in SUSY models often within reach of DD experiments
- NEW: shift towards larger σ_p^{SI}

  result of a new lower SM value for $\mathbf{BR}(\bar{B} \longrightarrow X_s \gamma)$

- CMSSM (most probable range):

$$\sigma_p^{SI} = 10^{-9\pm1}\ \text{pb}$$

  largest $\sigma_p^{SI} \simeq 10^{-8}$ pb for large m_0, beyond LHC reach!

- in other models rates similar, but some differences

Summary

- several DM theory tools, packages, techniques have been developed
- recent: MCMC + Bayesian statistics approach
- WIMPs in SUSY models often within reach of DD experiments
- NEW: shift towards larger σ_p^{SI}

  result of a new lower SM value for $\mathrm{BR}(\bar{B} \longrightarrow X_s \gamma)$

- CMSSM (most probable range):

$$\sigma_p^{SI} = 10^{-9 \pm 1} \text{ pb}$$

  largest $\sigma_p^{SI} \simeq 10^{-8}$ pb for large m_0, beyond LHC reach!

- in other models rates similar, but some differences
- it would be helpful if SUSY were found at LHC...

Impact of $b \to s\gamma$

recall $$BR(B \to X_s\gamma) = B(W^-/t) + B(H^-/t) - \mathrm{sgn}(\mu)\, B(\chi^-/\widetilde{t})$$

compute SM: full NLO + NNLO of m_c (from M. Misiak); SUSY: dominant NLO $\propto \tan\beta, \log(M_S/m_W)$

Impact of $b \to s\gamma$

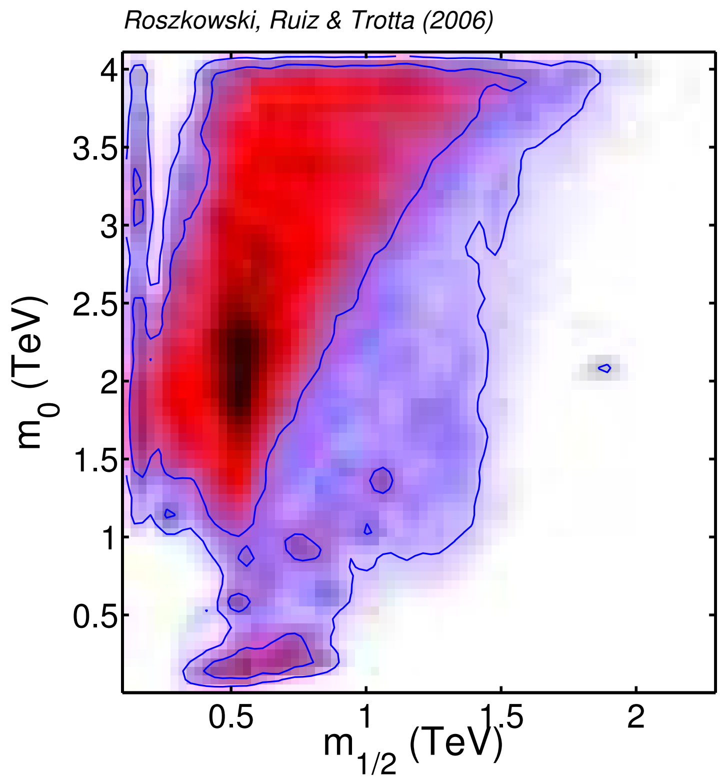
recall $$BR(B \to X_s\gamma) = B(W^-/t) + B(H^-/t) - \mathrm{sgn}(\mu)\, B(\chi^-/\tilde{t})$$

compute SM: full NLO + NNLO of m_c (from M. Misiak); SUSY: dominant NLO $\propto \tan\beta, \log(M_S/m_W)$

NEW: $BR(B \to X_s\gamma) \times 10^4$

EXPT: 3.55 ± 0.26, TH: 3.15 ± 0.21

(in preparation)



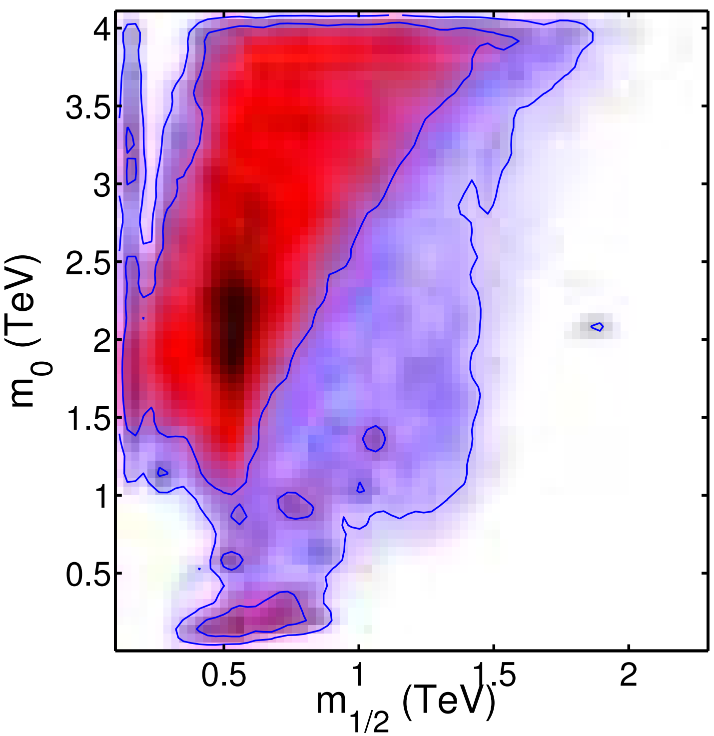
Impact of $b \to s\gamma$

recall $$BR(B \to X_s\gamma) = B(W^-/t) + B(H^-/t) - \mathrm{sgn}(\mu)\, B(\chi^-/\widetilde{t})$$

compute SM: full NLO + NNLO of m_c (from M. Misiak); SUSY: dominant NLO $\propto \tan\beta, \log\left(M_S/m_W\right)$

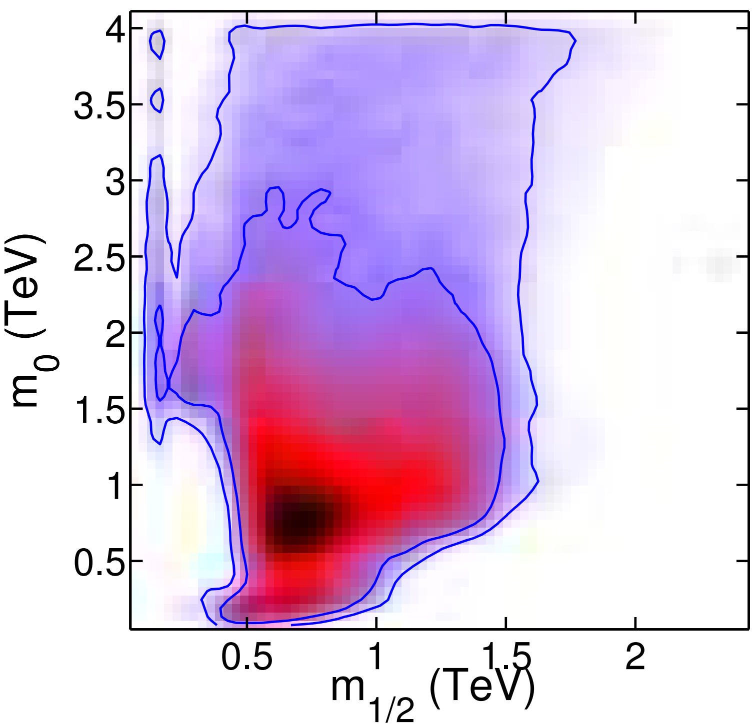
NEW: $BR(B \to X_s\gamma) \times 10^4$
EXPT: 3.55 ± 0.26, TH: 3.15 ± 0.21
(in preparation)

Roszkowski, Ruiz & Trotta (2006)



OLD: $BR(B \to X_s\gamma) \times 10^4$
EXPT: 3.39 ± 0.68, TH: 3.70 ± 0.30
(Feb 2006)

Ruiz, Trotta & Roszkowski (2006)



Impact of $b \longrightarrow s\gamma$ on σ_p^{SI}

recall $$BR(B \to X_s\gamma) = B(W^-/t) + B(H^-/t) - \mathrm{sgn}(\mu)\, B(\chi^-/\widetilde{t}\,)$$

compute SM: full NLO + NNLO of m_c (from M. Misiak); SUSY: dominant NLO $\propto \tan\beta, \log\left(M_S/m_W\right)$

Impact of $b \longrightarrow s\gamma$ on σ_p^{SI}

recall $$BR(B \to X_s\gamma) = B(W^-/t) + B(H^-/t) - \mathrm{sgn}(\mu)\, B(\chi^-/\tilde{t})$$

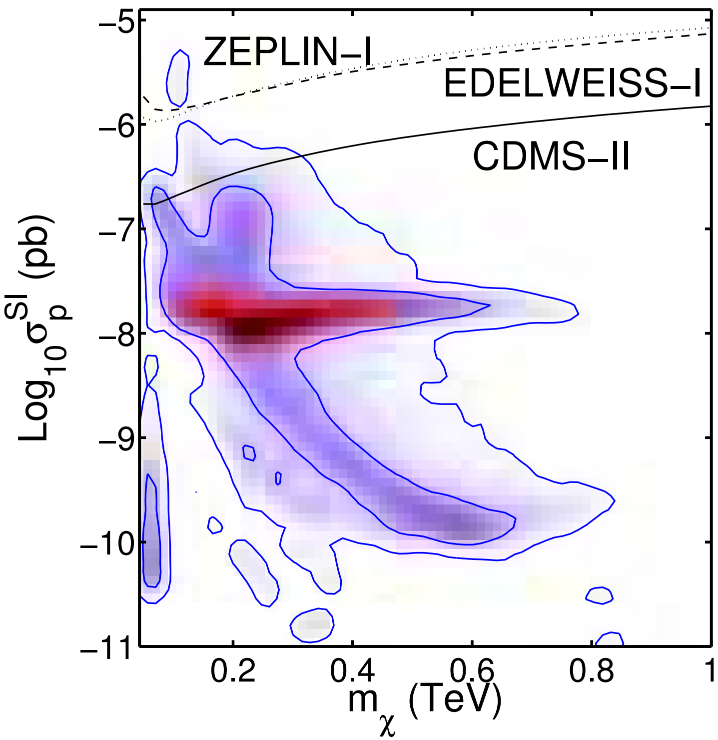
compute SM: full NLO + NNLO of m_c (from M. Misiak); SUSY: dominant NLO $\propto \tan\beta, \log(M_S/m_W)$

NEW: $BR(B \to X_s\gamma) \times 10^4$

EXPT: 3.55 ± 0.26, TH: 3.15 ± 0.21

(in preparation)

Roszkowski, Ruiz, Silk & Trotta (2007)



Impact of $b \longrightarrow s\gamma$ on σ_p^{SI}

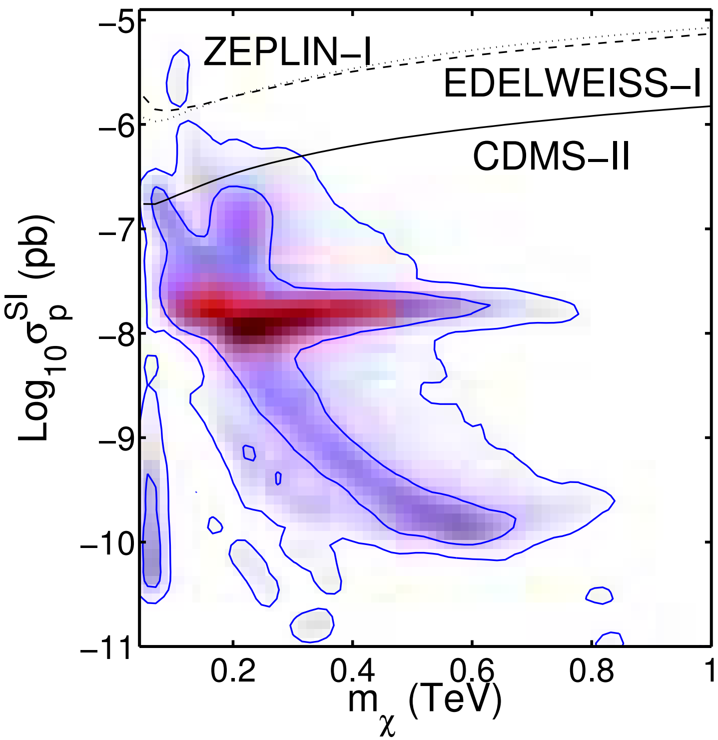
recall $BR(B \to X_s\gamma) = B(W^-/t) + B(H^-/t) - \mathrm{sgn}(\mu)\, B(\chi^-/\tilde{t})$

compute SM: full NLO + NNLO of m_c (from M. Misiak); SUSY: dominant NLO $\propto \tan\beta, \log(M_S/m_W)$

NEW: $BR(B \to X_s\gamma) \times 10^4$
EXPT: 3.55 ± 0.26, TH: 3.15 ± 0.21
(in preparation)

OLD: $BR(B \to X_s\gamma) \times 10^4$
EXPT: 3.39 ± 0.68, TH: 3.70 ± 0.30
(Feb 2006)

Roszkowski, Ruiz, Silk & Trotta (2007)



Ruiz, Trotta & Roszkowski (2006)