Direct & Indirect Dark Matter Detection in the NUHM

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ENTApP Program 2009, CERN

OUTLINE

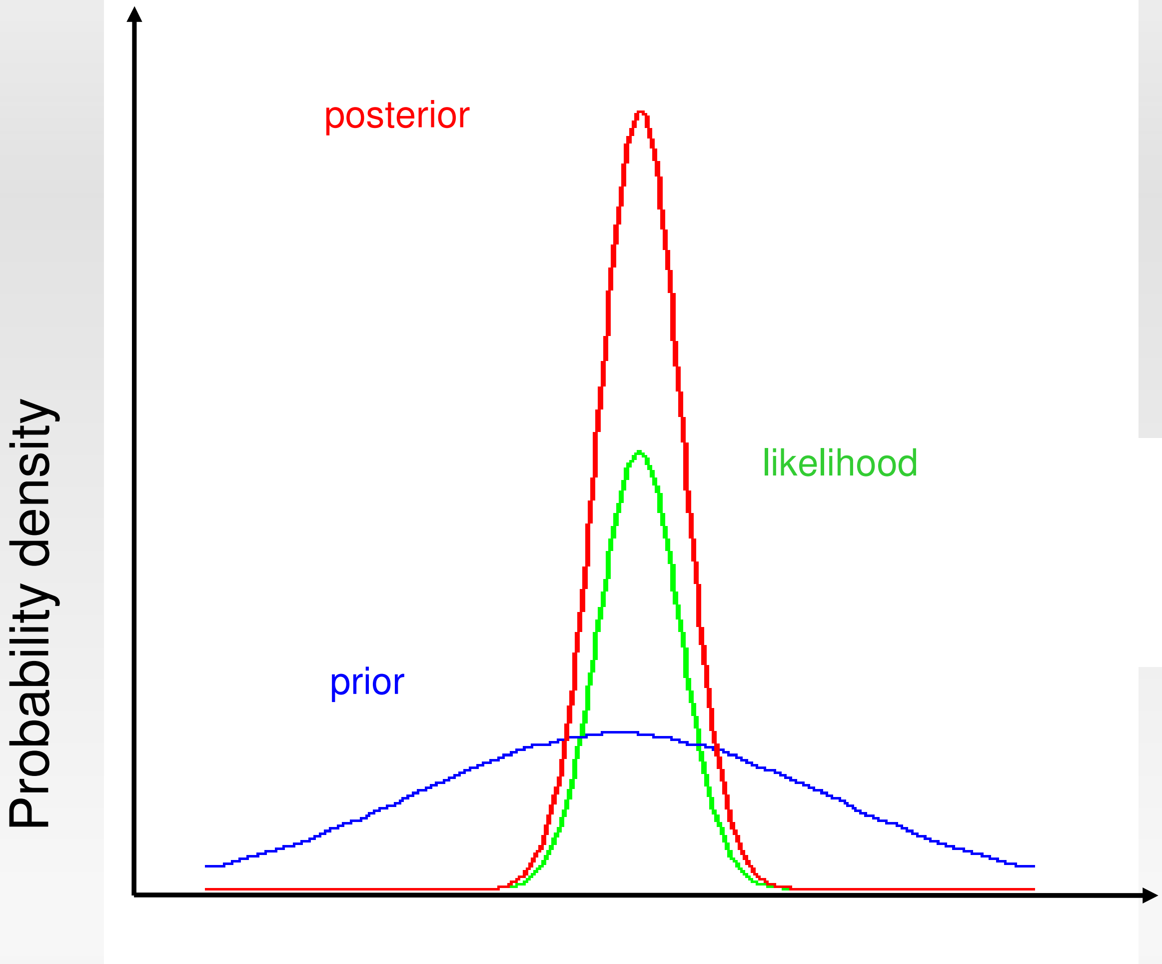
- Bayesian theory
- Brief introduction to NUHM

} Varley

- Dark matter direct detection
- Dark matter indirect detection
- Conclusion

} Tsai

Bayes' Theorem



prior likelihood

$$P(M|D,H) = \frac{P(M|H)\,P(D|M,H)}{P(D|H)}$$

posterior evidence

Credit:

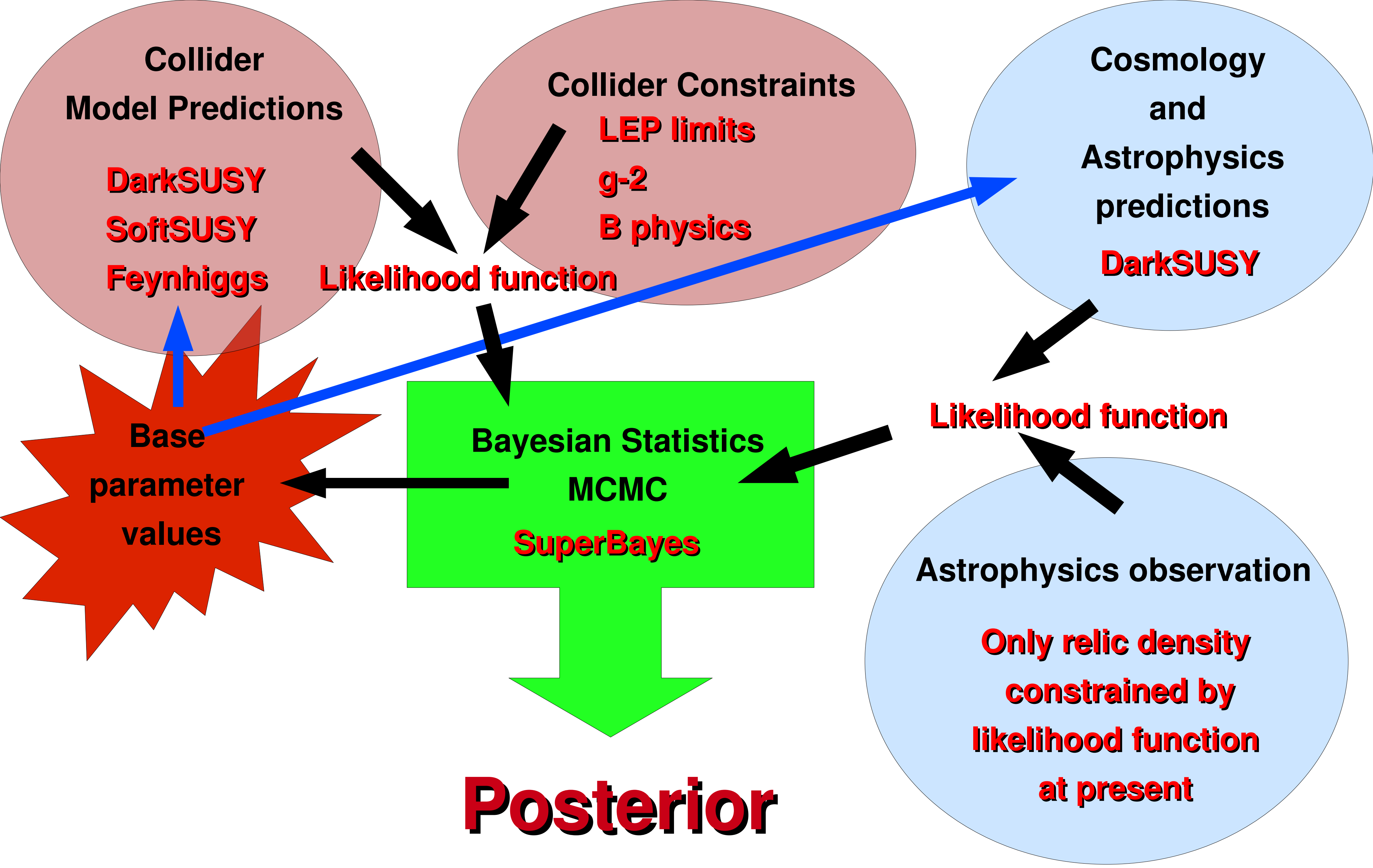
Roberto Ruiz

Priors

Flat Prior: $$\pi(m_0) = \frac{1}{(m_{max} - m_{min})}$$

Log Prior: $$\pi(m_0) = \frac{1}{m_0 \log[\frac{m_{max}}{m_{min}}]}$$

- Priors arbitrary in Bayesian formalism, so issues of prior dependence and choice of priors important.
- In case of perfect data, our conclusions should be stable regardless of prior.


Collider
Model Predictions
DarkSUSY
SoftSUSY
Feynhiggs
Collider Constraints
LEP limits
g-2
B physics
Likelihood function
Cosmology
and
Astrophysics
predictions
DarkSUSY
Likelihood function
Base
parameter
values
Bayesian Statistics
MCMC
SuperBayes
Astrophysics observation
Only relic density
constrained by
likelihood function
at present
Posterior

NUHM

Many papers (e.g. Berezinsky *et al.*, Ellis *et al.*, Baer *et al.*, Nath & Arnowitt, Cerdeño & Muñoz......)

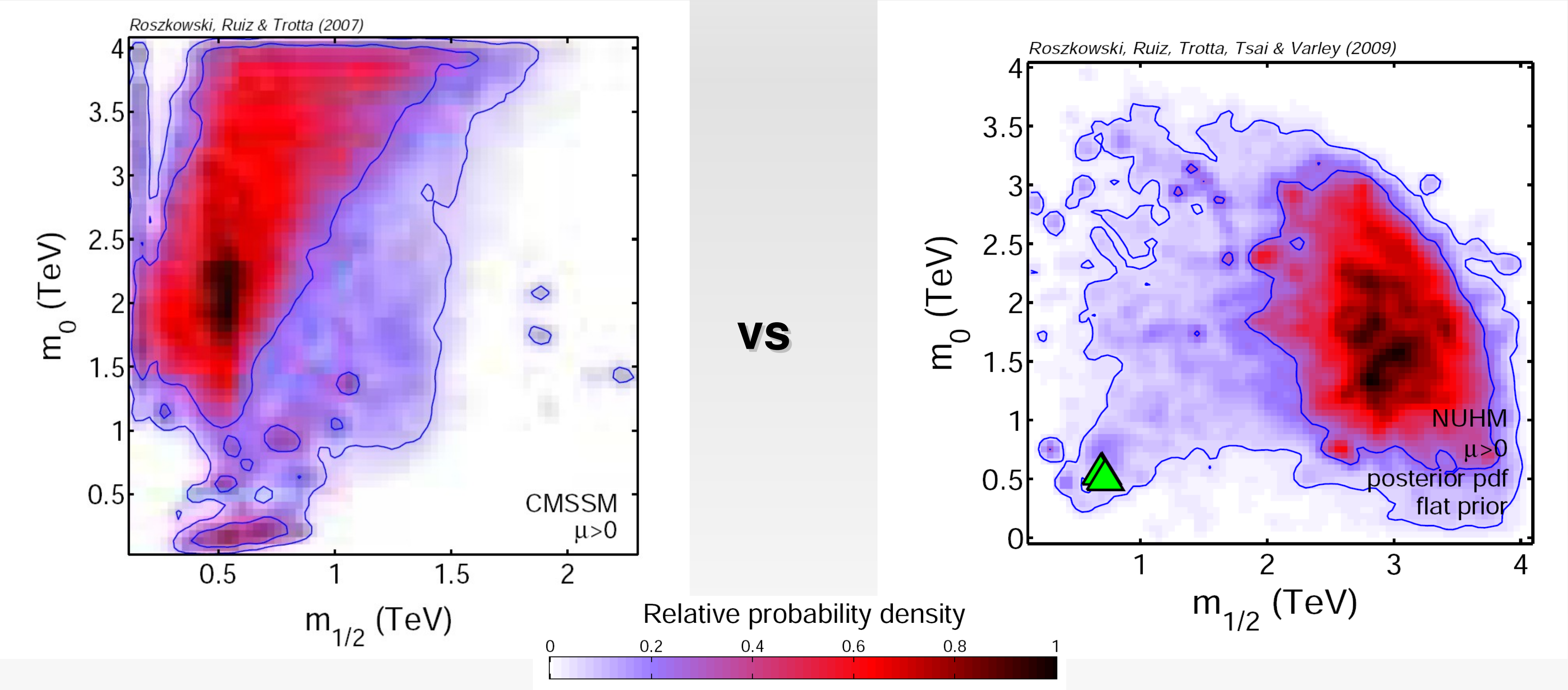
- Difference from CMSSM: Allow soft higgs masses to vary independently.
- Can give us a very different picture.
- Parameters: $(m_0,\ m_{\frac{1}{2}},\ A_0,\ \tan\beta,\ m_{H_u},\ m_{H_d}).$
- Log prior applies only to mass parameters.

NUHM: experimental constraints

Observable	Mean value μ	Uncertainties σ (exper.)	τ (theor.)	ref.
M_W	80.392 GeV	29 MeV	15 MeV	[21]
$\sin^2\theta_{\rm eff}$	0.23153	16×10^{-5}	15×10^{-5}	[21]
$\delta a_\mu^{\rm SUSY}\times10^{10}$	27.5	8.4	1	[9]
$BR(\overline{B}\to X_s\gamma)\times10^4$	3.55	0.26	0.21	[5]
ΔM_{B_s}	17.33 ps^{-1}	0.12 ps^{-1}	4.8 ps^{-1}	[22]
$\Omega_\chi h^2$	0.109	0.006	$0.1\,\Omega_\chi h^2$	[23]
	Limit (95% CL)		τ (theor.)	ref.
$BR(\overline{B}_s\to\mu^+\mu^-)$	$<5.8\times10^{-8}$		14%	[24]
m_h	>114.4 GeV (91.0 GeV)		3 GeV	[25]
ζ_h^2	$f(m_h)$		negligible	[25]
sparticle masses	See table 4 in ref. [14].			

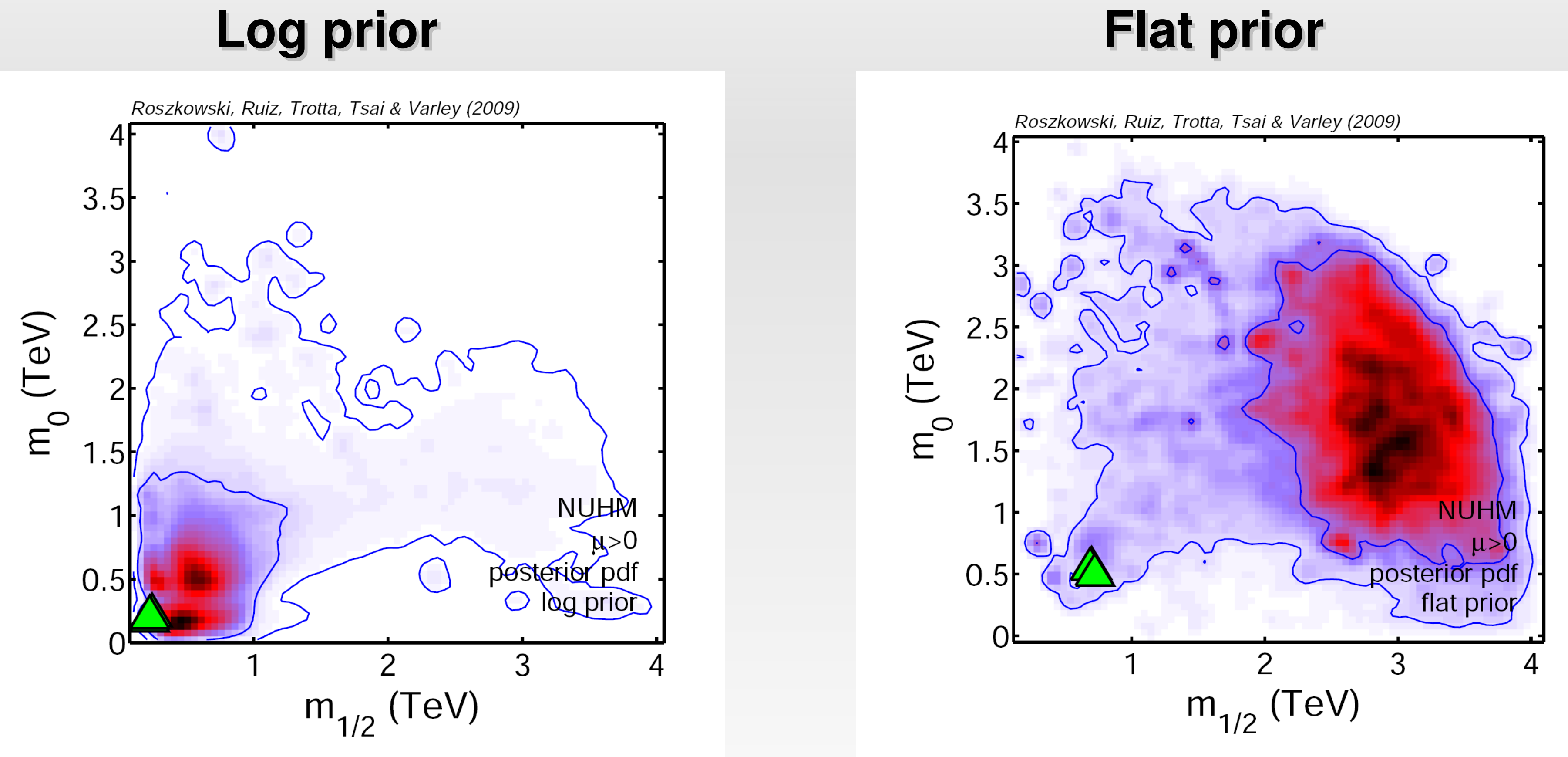
NUHM

CMSSM flat prior NUHM



- NUHM gives us a very different picture here.

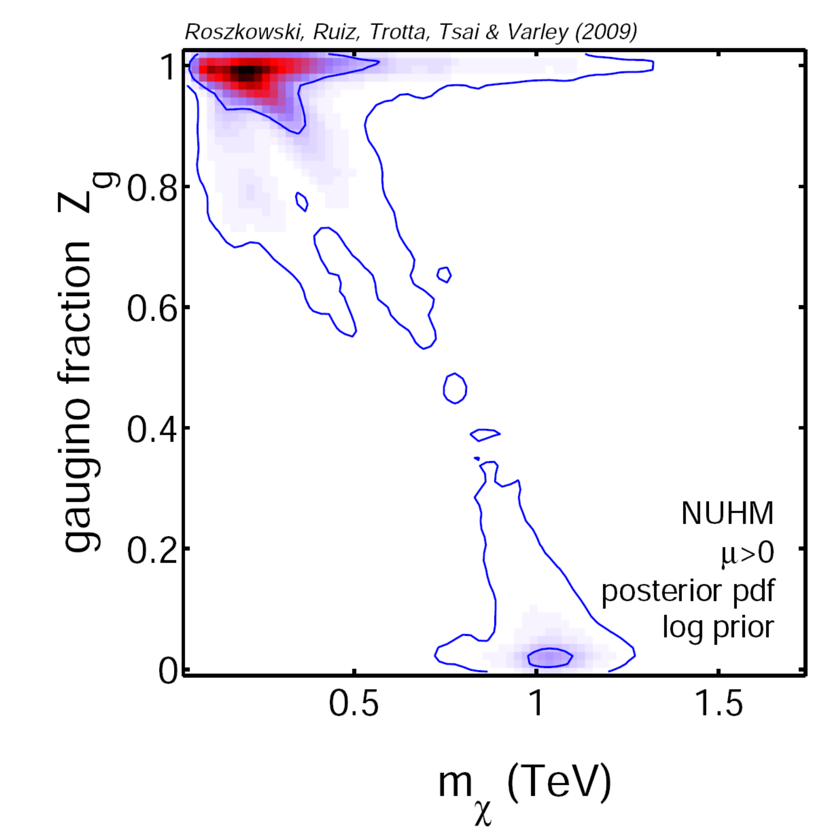
NUHM



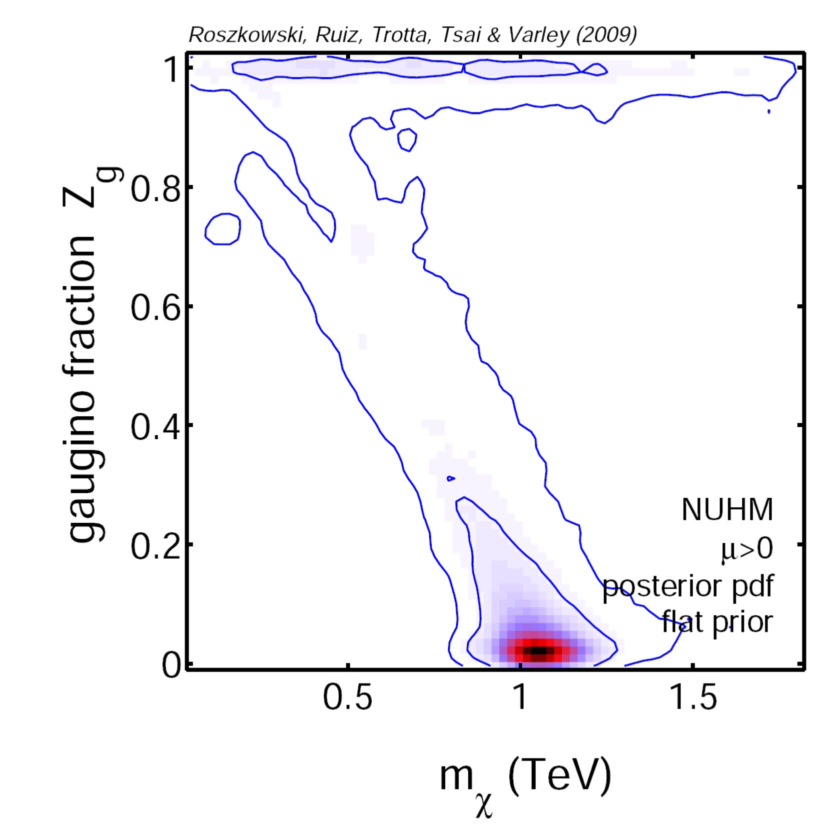
- Prior dependence indicates the model is underconstrained.

Neutralino masses in NUHM

Log prior



Flat prior



- Can have a heavy higgsino LSP at around 1 TeV but note prior dependence here.

Direct Detection

Spin-independent component

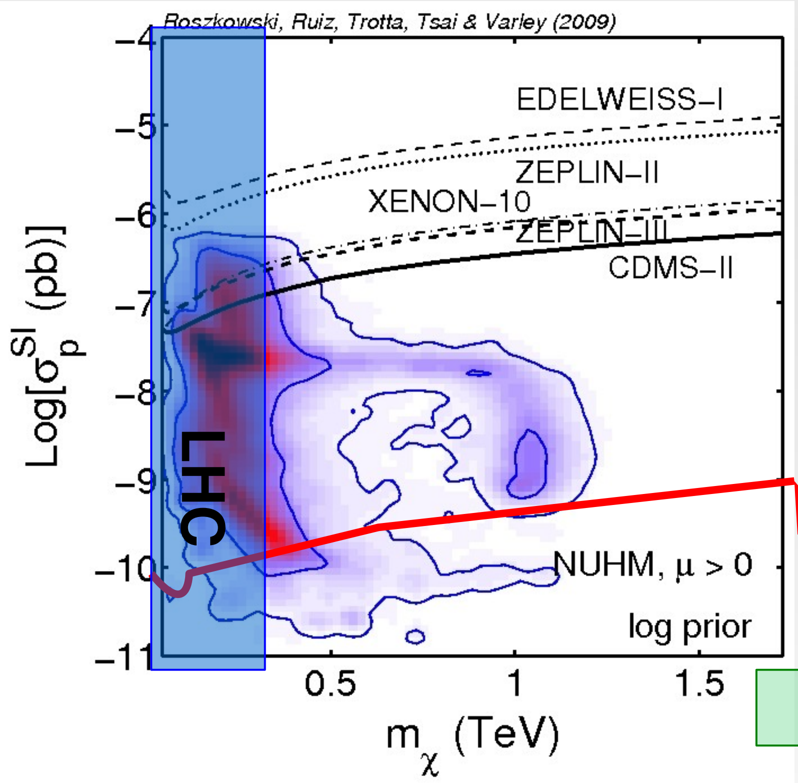
$$\frac{d\sigma^{SI}}{d|\mathbf{q}|} = \frac{1}{\pi v^2}[Zf_p + (A-Z)f_n]^2 F^2(|\mathbf{q}|) \approx \frac{1}{\pi v^2} A^2 f_p^2 F^2(|\mathbf{q}|)$$

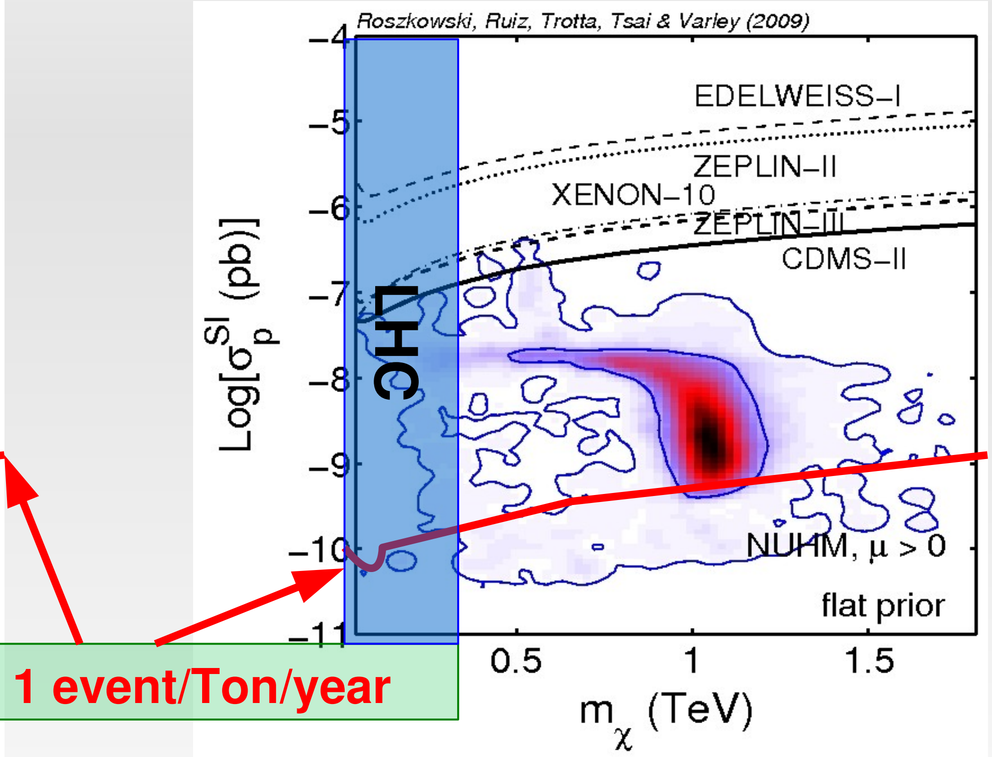
Spin-dependent component

$$\frac{d\sigma^{SD}}{d|\mathbf{q}|} = \frac{8G_F^2}{\pi v^2}\Lambda^2 J(J+1) F^2(|\mathbf{q}|)$$

G. Jungman, M. Kamionkowski and K. Griest, "Supersymmetric dark matter," Phys. Rept. **267**, 195 (1996) [arXiv:hep-ph/9506380].

The spin-independent cross section



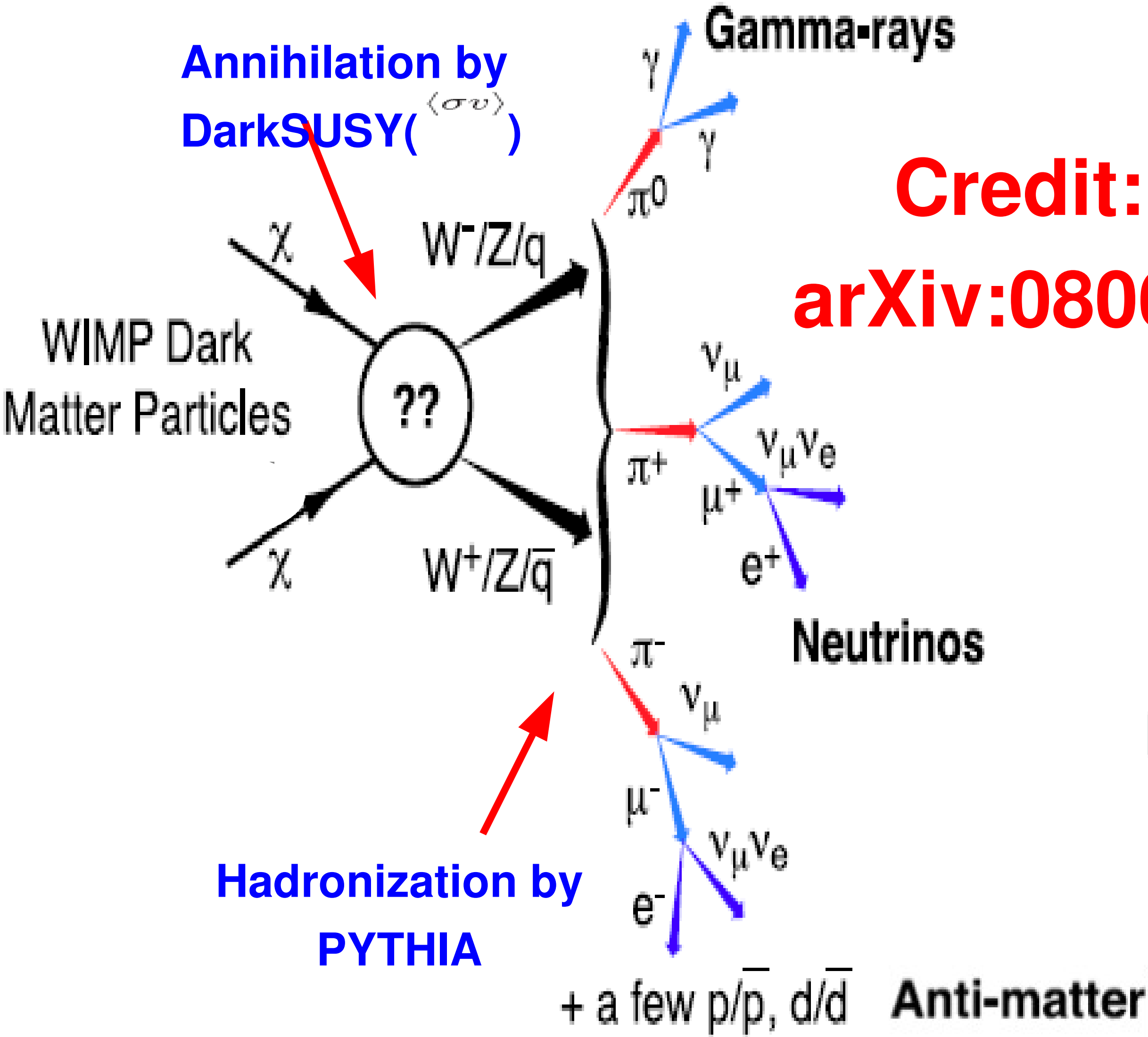


log prior

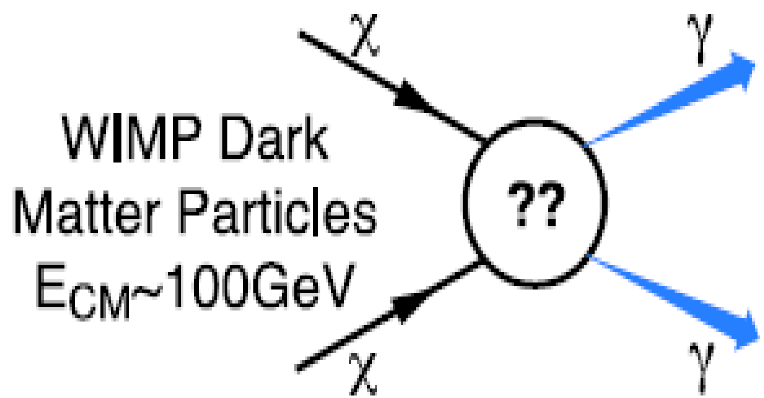
flat prior

Limit on cross section not very dependent on prior.

Indirect-detection



Credit: E. A. Baltz et al. arXiv:0806.2911v2 [astro-ph]



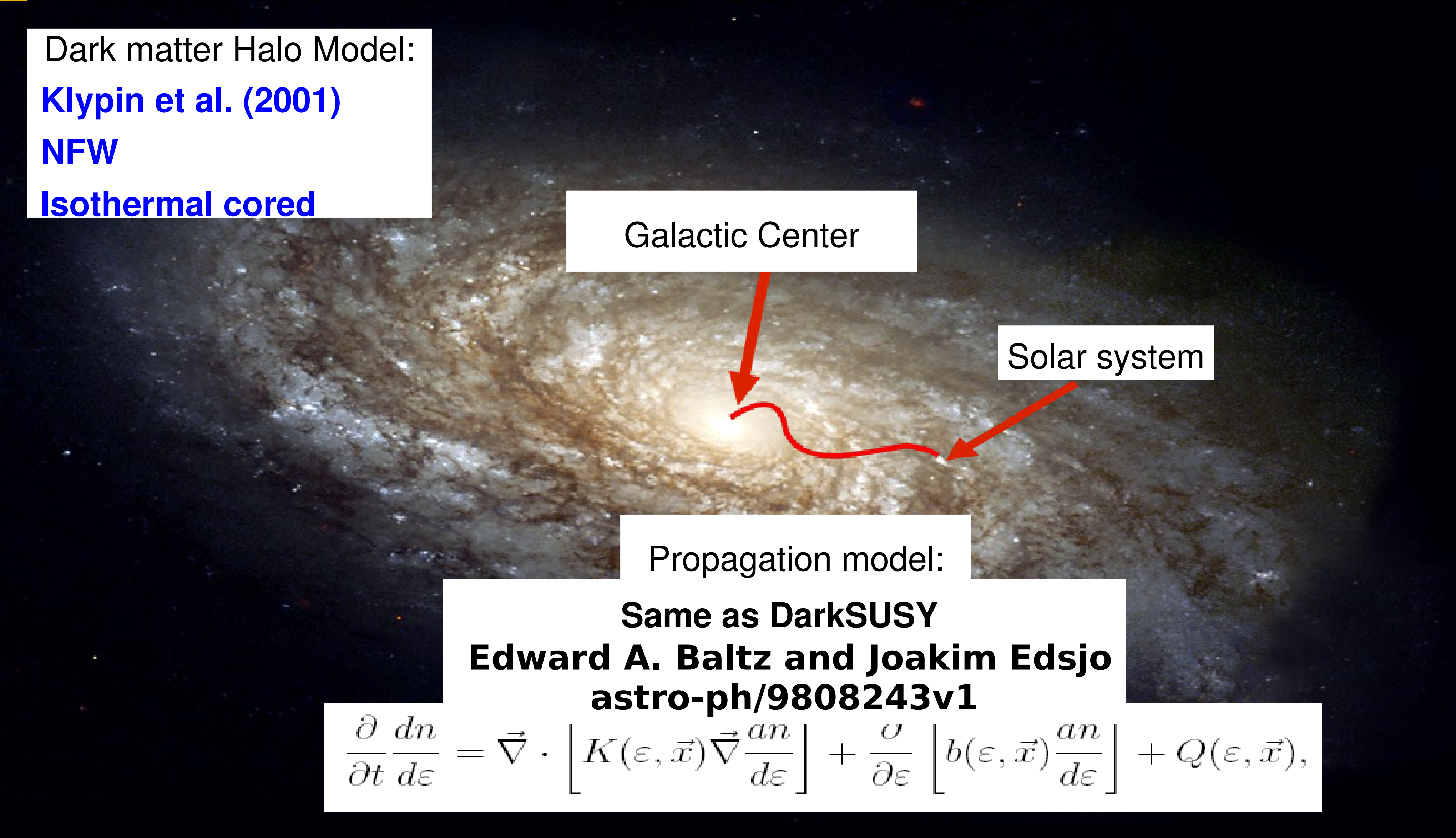
Anti-matter or Gamma rays from GC

Dark matter Halo Model:

Klypin et al. (2001)

NFW

Isothermal cored



Propagation model:

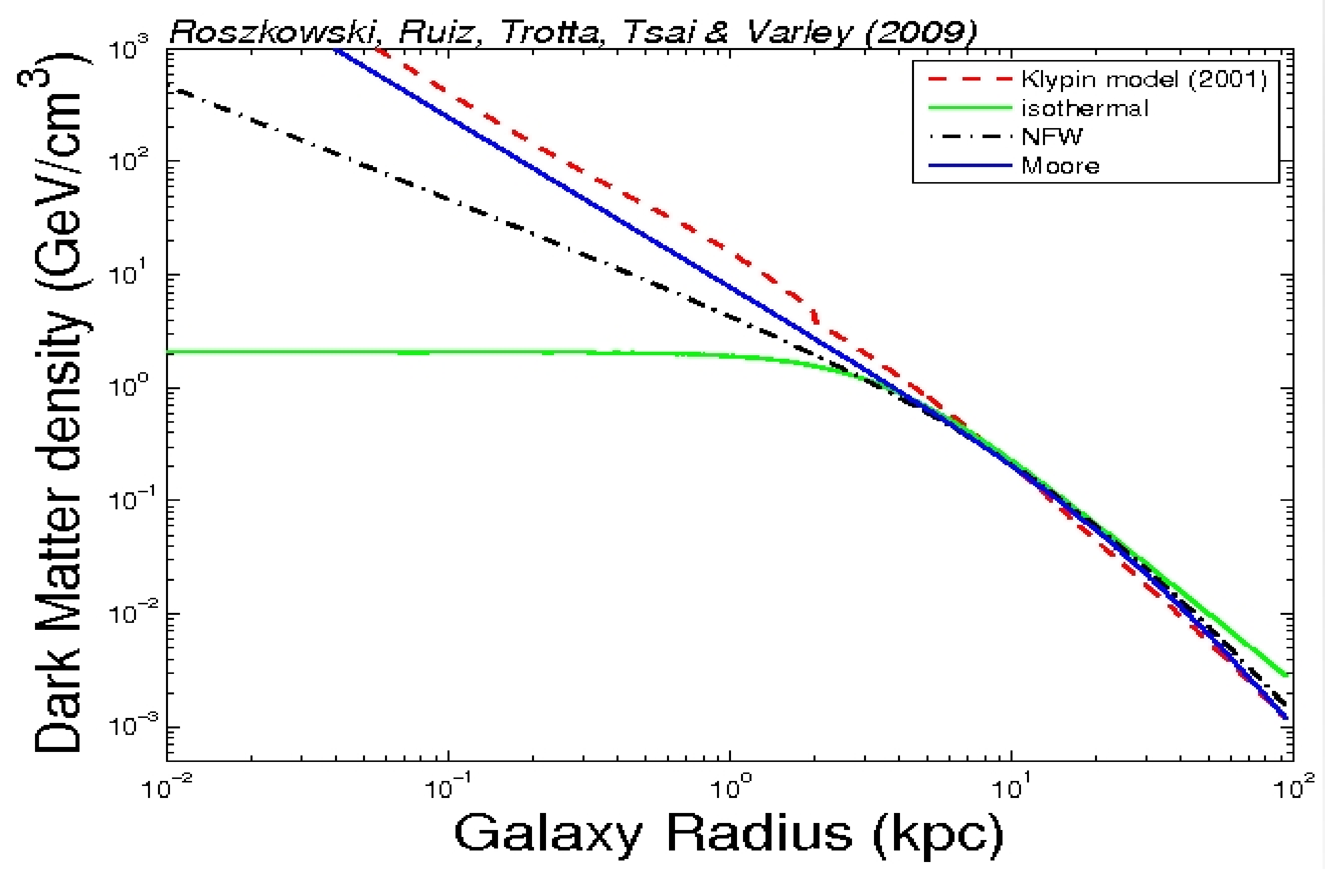
Same as DarkSUSY

Edward A. Baltz and Joakim Edsjo

astro-ph/9808243v1

$$\frac{\partial}{\partial t}\frac{dn}{d\varepsilon} = \vec{\nabla}\cdot\left[K(\varepsilon,\vec{x})\vec{\nabla}\frac{dn}{d\varepsilon}\right] + \frac{\partial}{\partial\varepsilon}\left[b(\varepsilon,\vec{x})\frac{dn}{d\varepsilon}\right] + Q(\varepsilon,\vec{x}),$$

Klypin et al. Halo Model (2001)



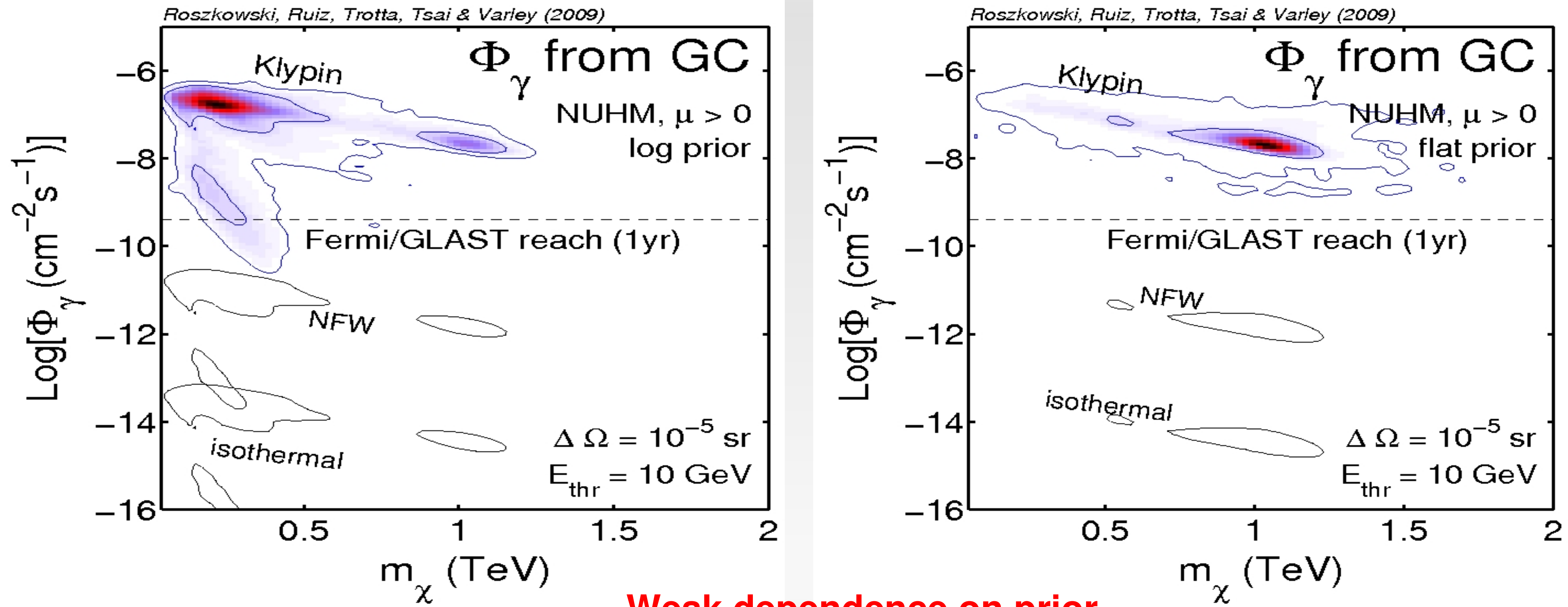
$M_{vir}(M_\odot)$	$M_{disk}(M_\odot)$	$M_{bulge}(M_\odot)$	C	r_0(Kpc)	r_s(Kpc)
8.57×10^{11}	4.2×10^{10}	8×10^9	11	8.0	22.27

r_{vir}(Kpc)	r_{disk}(Kpc)	r_{bulge}(Kpc)	γ	$\rho_0(GeV/cm^3)$	$J(10^{-5}$sr)
244.93	3.5	0.5	1.8	0.3	1.95×10^8

The gamma-ray from GC

$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma,\psi) = \sum_i \frac{\sigma_i v}{8\pi m_\chi^2}\frac{dN_\gamma^i}{dE_\gamma}\int_{\rm l.o.s.} dl\,\rho_\chi^2(r(l,\psi)).$$

$$\Phi_\gamma(\Delta\Omega) = \int_{E_{th}}^{m_\chi}\frac{d\Phi_\gamma}{dE_\gamma}dE_\gamma.$$

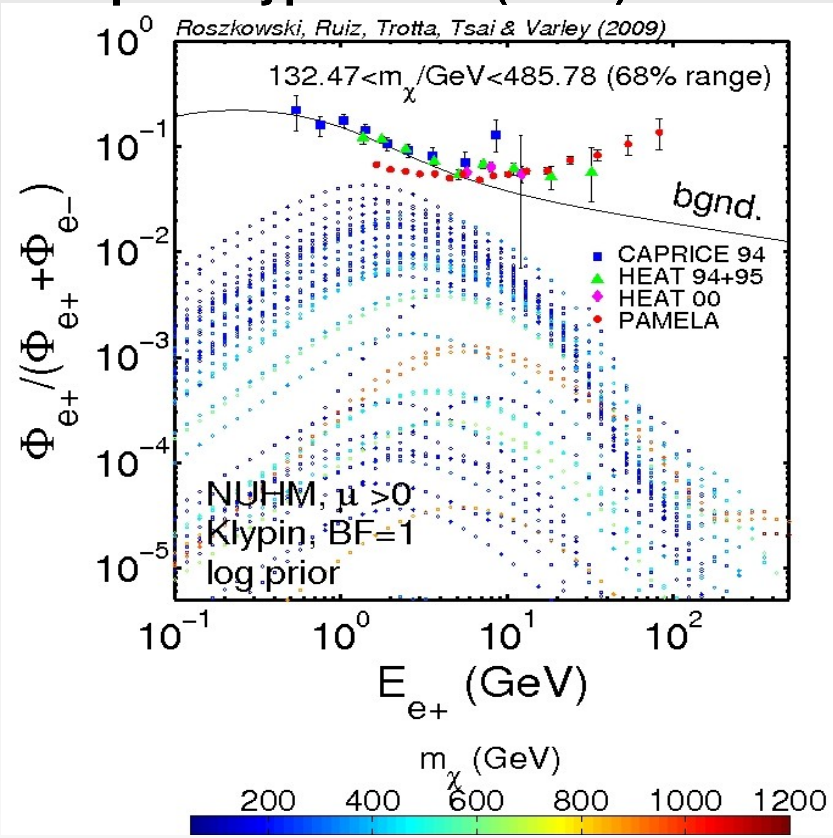


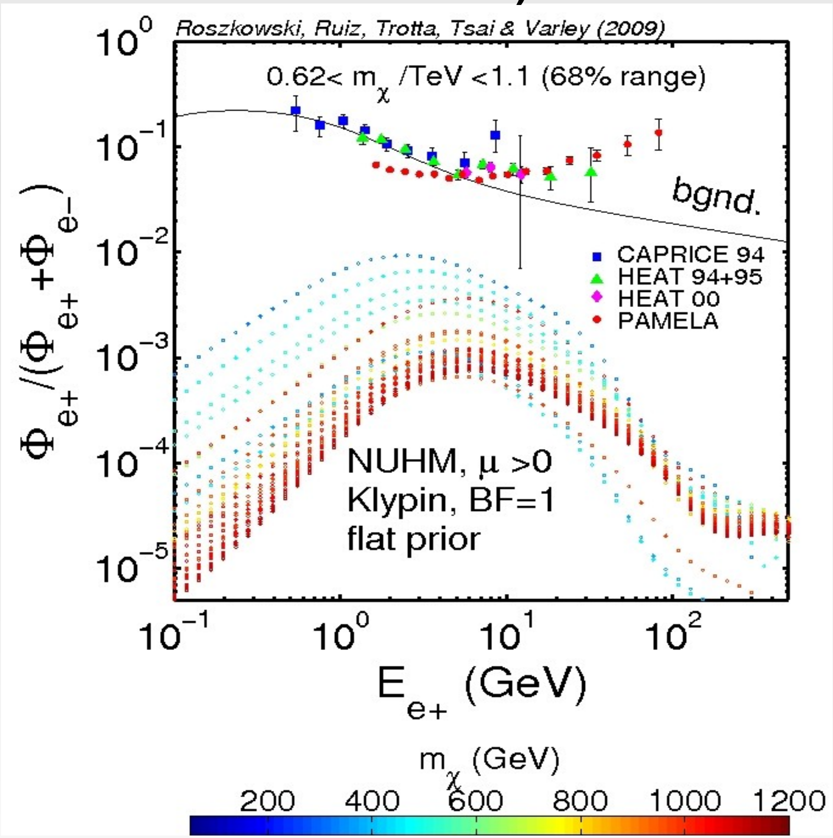
log prior **flat prior**

Weak dependence on prior, strong dependence on halo model

Positron fraction

Example: Klypin et al. (2001) halo model (NFW and iso are similiar.)





Can't produce PAMELA excess!!

log prior **flat prior**

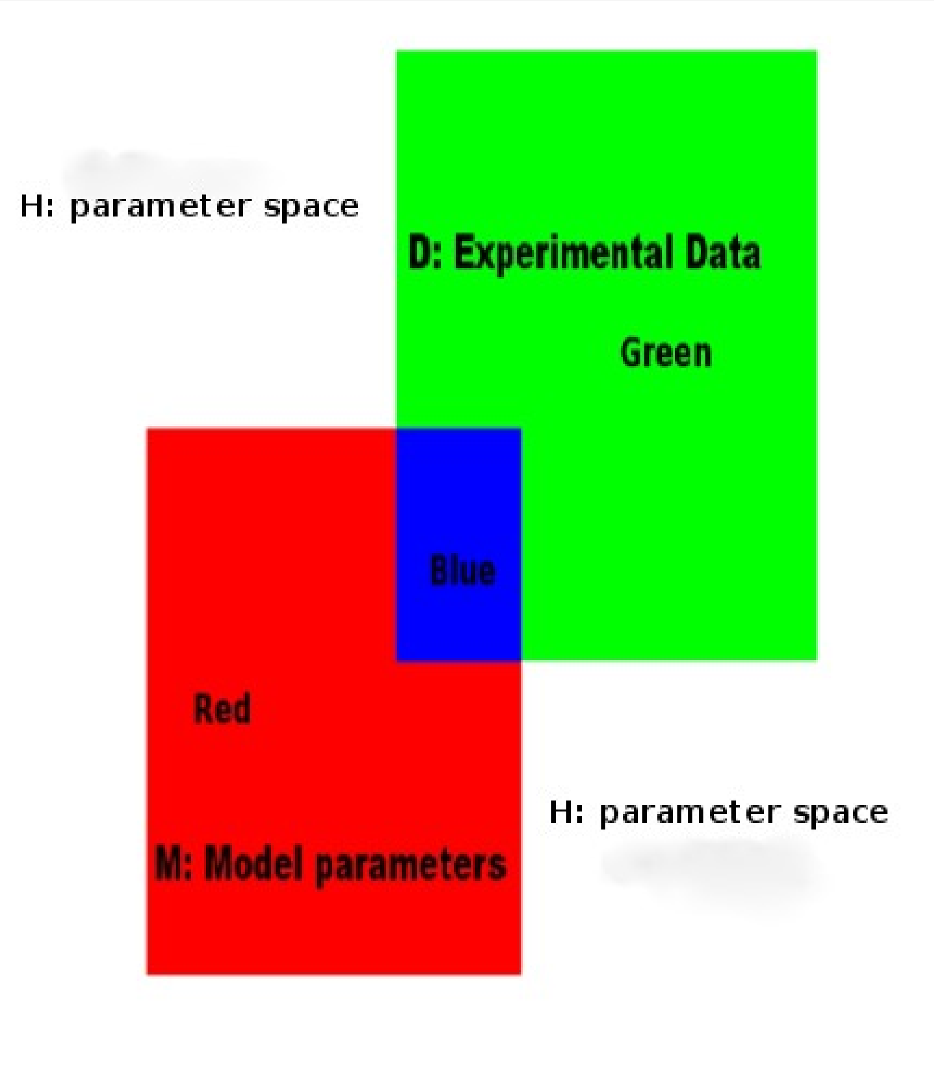
Conclusion

- NUHM an interesting alternative to CMSSM. Analysed with flat and log prior in Bayesian formalism.
- As experimental uncertainties are large, the spin-independent cross section cannot offer a very effective constraint on m_0 vs m_1/2 plane.
- Prospects for FERMI strongly depend on how cuspy the halo model is in galactic center.
- No reasonable halo model can reproduce PAMELA excess here.

Thank you very much for your attention.

BACKUP MATERIAL

The Bayesian theory



Red — Green

$$P(M|H)P(D|M,H) = P(D|H)P(M|D,H)$$

Blue(red) — Blue(green)

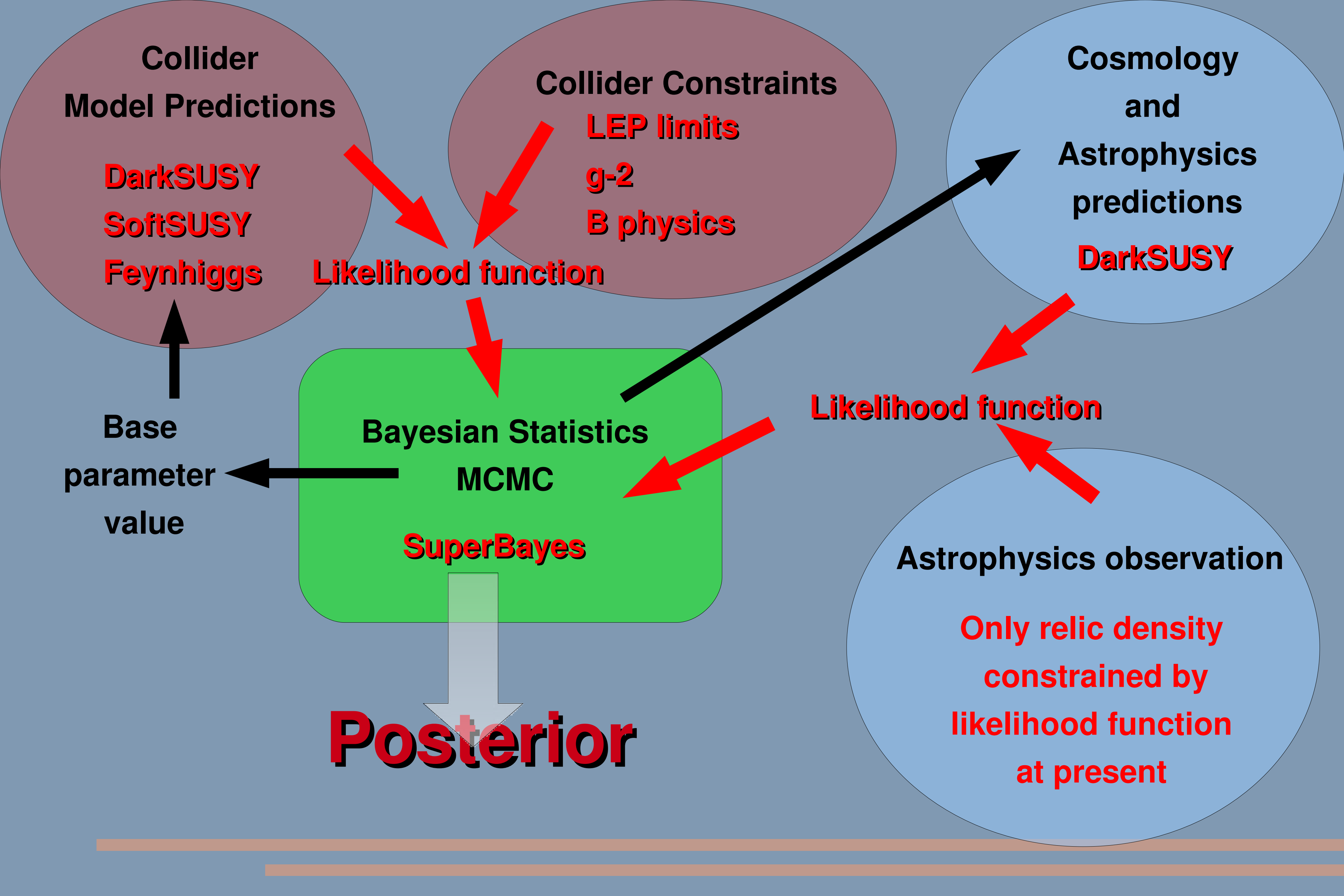
$$P(M|D,H) = \frac{P(M|H)P(D|M,H)}{P(D|H)}$$

Markov Chain Monte Carlo

- Want to obtain posterior, how do we do this?
- Take random walk through parameter space.
- Probability of accepting next point depends on relative posteriors of both; Metropolis-Hastings algorithm. For two points x and y, accept with probability:

$$P_{x \rightarrow y} = \min(p(y)/p(x), 1)$$

- Iterate: as t goes to infinity recover posterior we are interested in studying.


Collider
Model Predictions
DarkSUSY
SoftSUSY
Feynhiggs
Collider Constraints
LEP limits
g-2
B physics
Likelihood function
Cosmology
and
Astrophysics
predictions
DarkSUSY
Likelihood function
Base
parameter
value
Bayesian Statistics
MCMC
SuperBayes
Astrophysics observation
Only relic density
constrained by
likelihood function
at present
Posterior

The Neutralino

$$\frac{1}{2}\left(\widetilde{B} \quad \widetilde{W}^0 \quad \widetilde{H}_d^0 \quad \widetilde{H}_u^0 \right) \begin{pmatrix} M_1 & 0 & \frac{-g' v_d}{\sqrt{2}} & \frac{g' v_u}{\sqrt{2}} \\ 0 & M_2 & \frac{g v_d}{\sqrt{2}} & \frac{-g v_u}{\sqrt{2}} \\ \frac{-g' v_d}{\sqrt{2}} & \frac{g v_d}{\sqrt{2}} & 0 & -\mu \\ \frac{g' v_u}{\sqrt{2}} & \frac{-g v_u}{\sqrt{2}} & -\mu & 0 \end{pmatrix} \begin{pmatrix} \widetilde{B} \\ \widetilde{W}^0 \\ \widetilde{H}_d^0 \\ \widetilde{H}_u^0 \end{pmatrix}$$

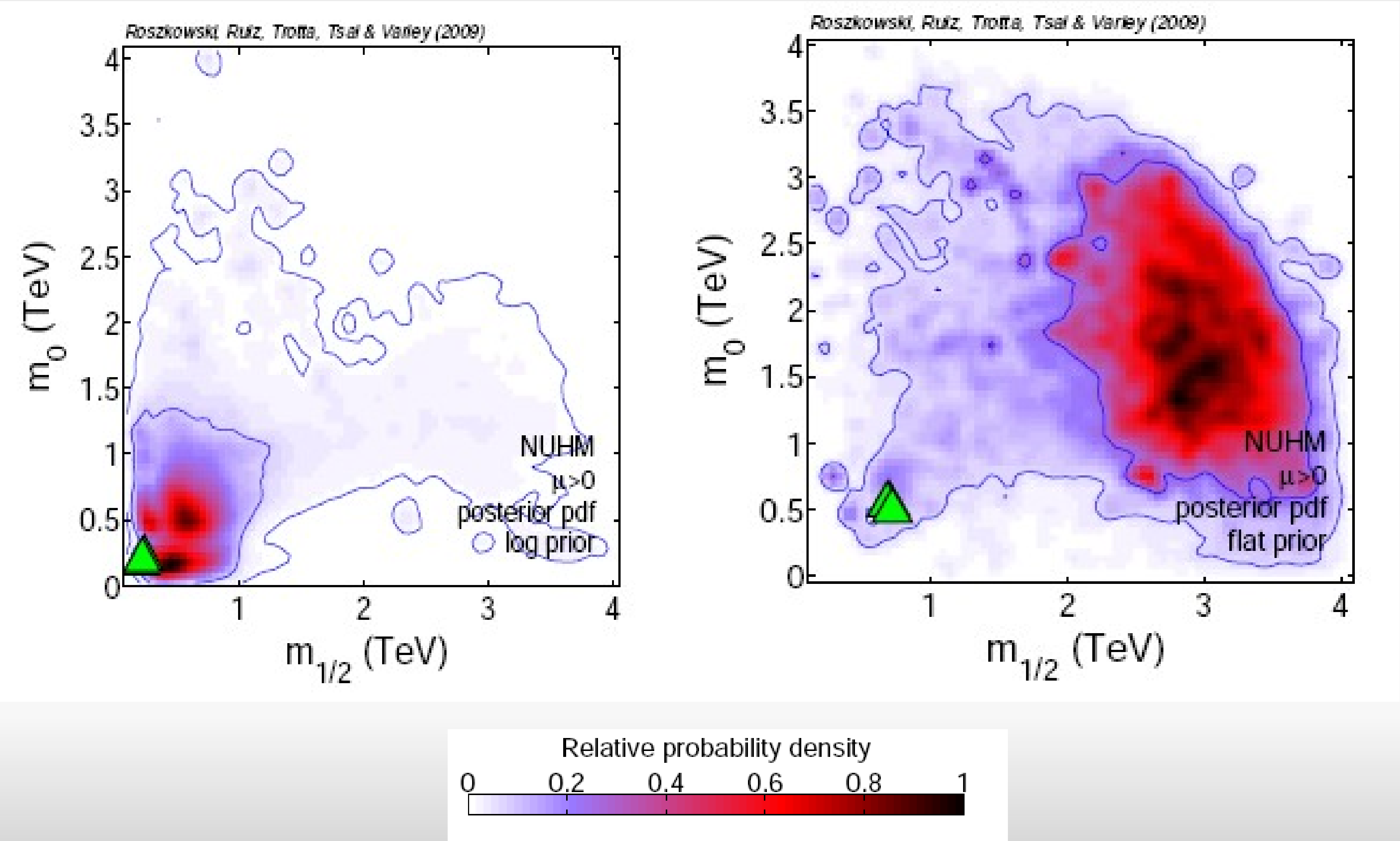
LSP

$$\begin{pmatrix} m_{\chi_1^0} & 0 & 0 & 0 \\ 0 & m_{\chi_2^0} & 0 & 0 \\ 0 & 0 & m_{\chi_3^0} & 0 \\ 0 & 0 & 0 & m_{\chi_4^0} \end{pmatrix}$$

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

higgsino LSP μ<M1

Some plots - effect of prior

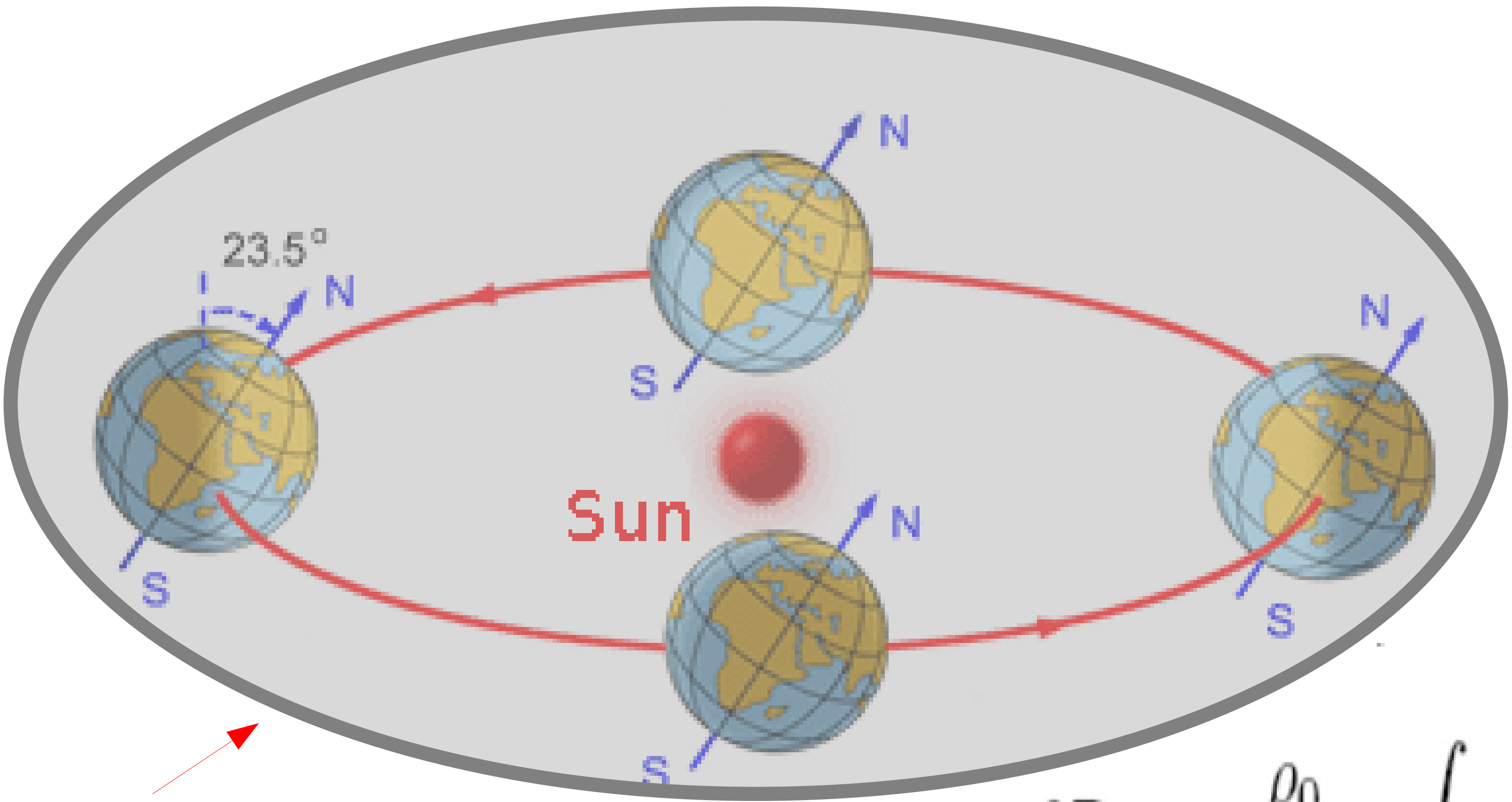


More NUHM

Berezinsky *et al.*, Ellis *et al.*, Baer *et al.*, Nath & Arnowitt, Cerdeño & Muñoz......

- Difference from CMSSM: Allow soft higgs masses to vary independently.
- Parameters: $(m_0,\ m_{\frac{1}{2}},\ A_0,\ \tan\beta,\ m_{H_u},\ m_{H_d})$.
- Can also be parametrised as having μ and the pseudoscalar mass as free parameters.
- S parameter- feature of RGEs, non-zero here.
- New features: A funnel moves around, varied NLSP and coannihilation.
- Can be a strong higgsino component, cross over region can be important.

Direct Detection



Dark matter local halo

$$dR = \frac{\rho_0}{m_\chi m_N} \int v f(v) d\sigma dv$$

The neutralino-nucleon effective lagrangian

SD

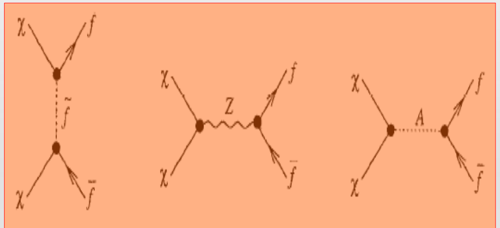
$$\mathcal{L} = \bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}_i\gamma_\mu(\alpha_{1i} + \alpha_{2i}\gamma^5)q_i$$
$$+ \alpha_{3i}\bar{\chi}\chi\bar{q}_i q_i + \alpha_{4i}\bar{\chi}\gamma^5\chi\bar{q}_i\gamma^5 q_i$$
$$+ \alpha_{5i}\bar{\chi}\chi\bar{q}_i\gamma^5 q_i + \alpha_{6i}\bar{\chi}\gamma^5\chi\bar{q}_i q_i$$

SI

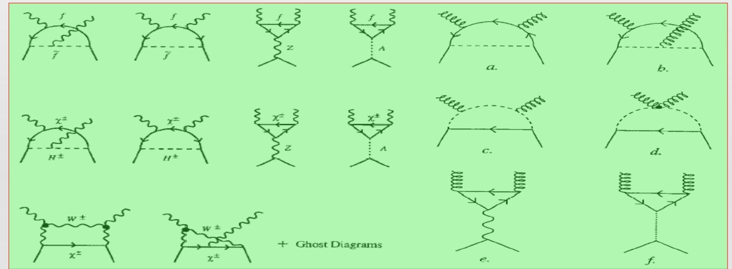
Velocity dependent elastic cross section ✕

Keith A. Olive, hep-ph/0208092v2

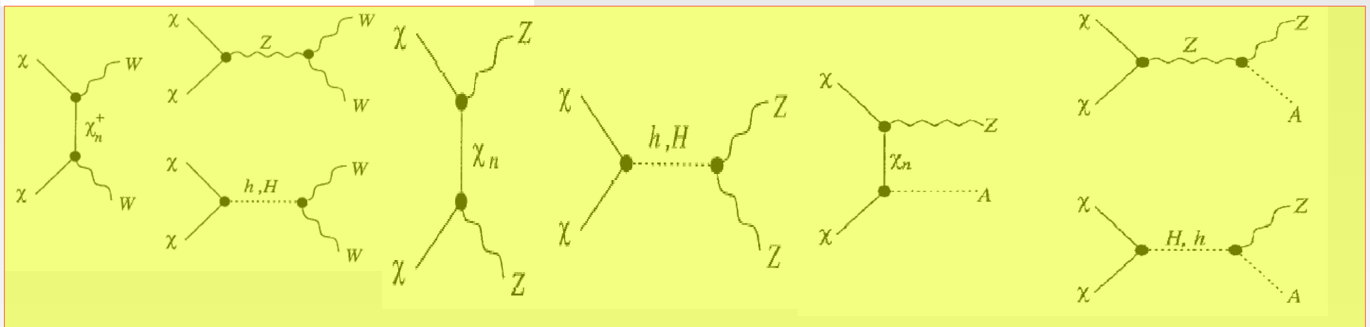
Contributions to Neutralino Annihilation



$$(e^+e^-, \mu^+\mu^-, \tau^+\tau^-, q\bar{q})$$



$$(gg, \gamma\gamma, Z^0\gamma)$$



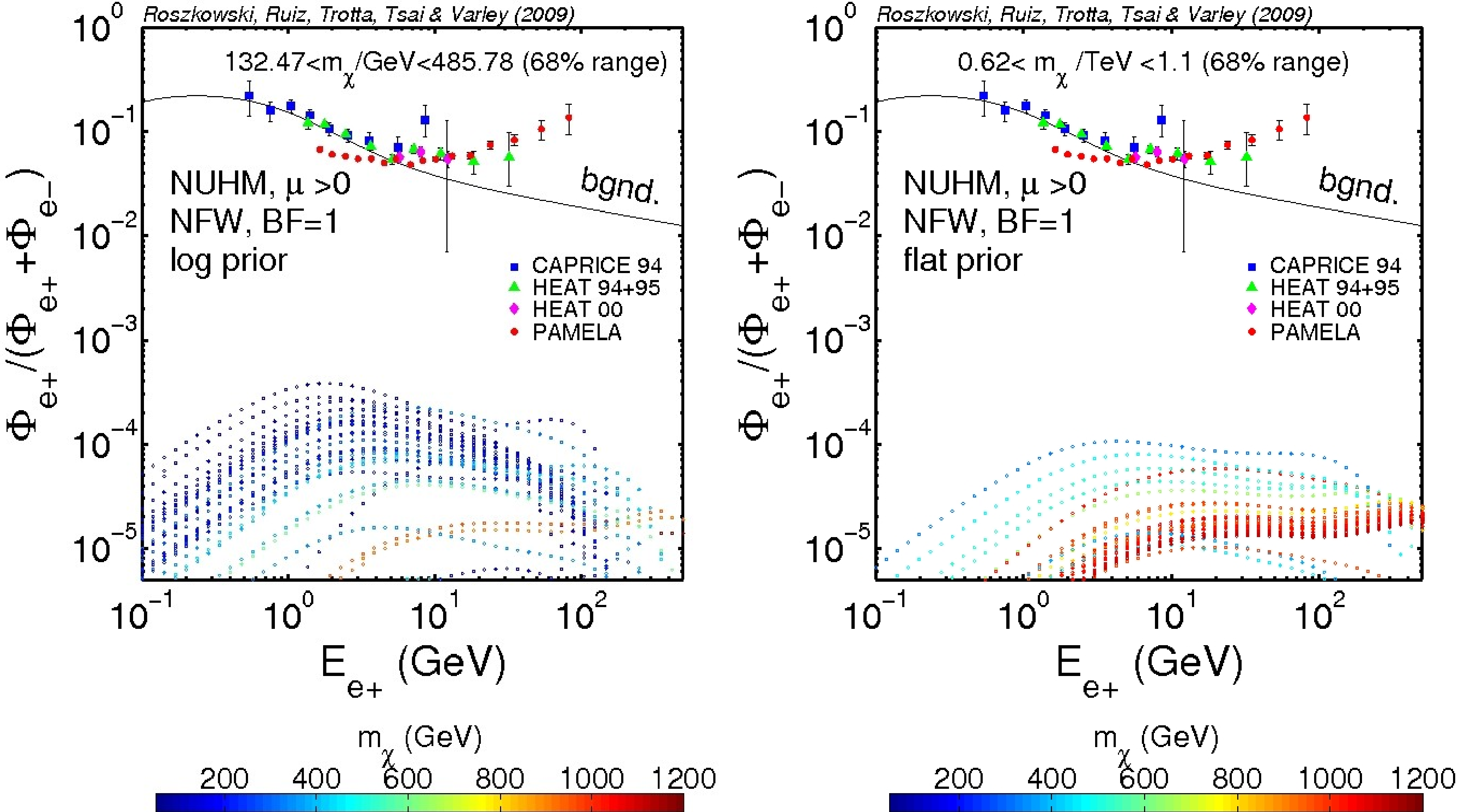
$$(Z^0A^0, Z^0Z^0, W^+W^-)$$

All the σv are considered under the limit:

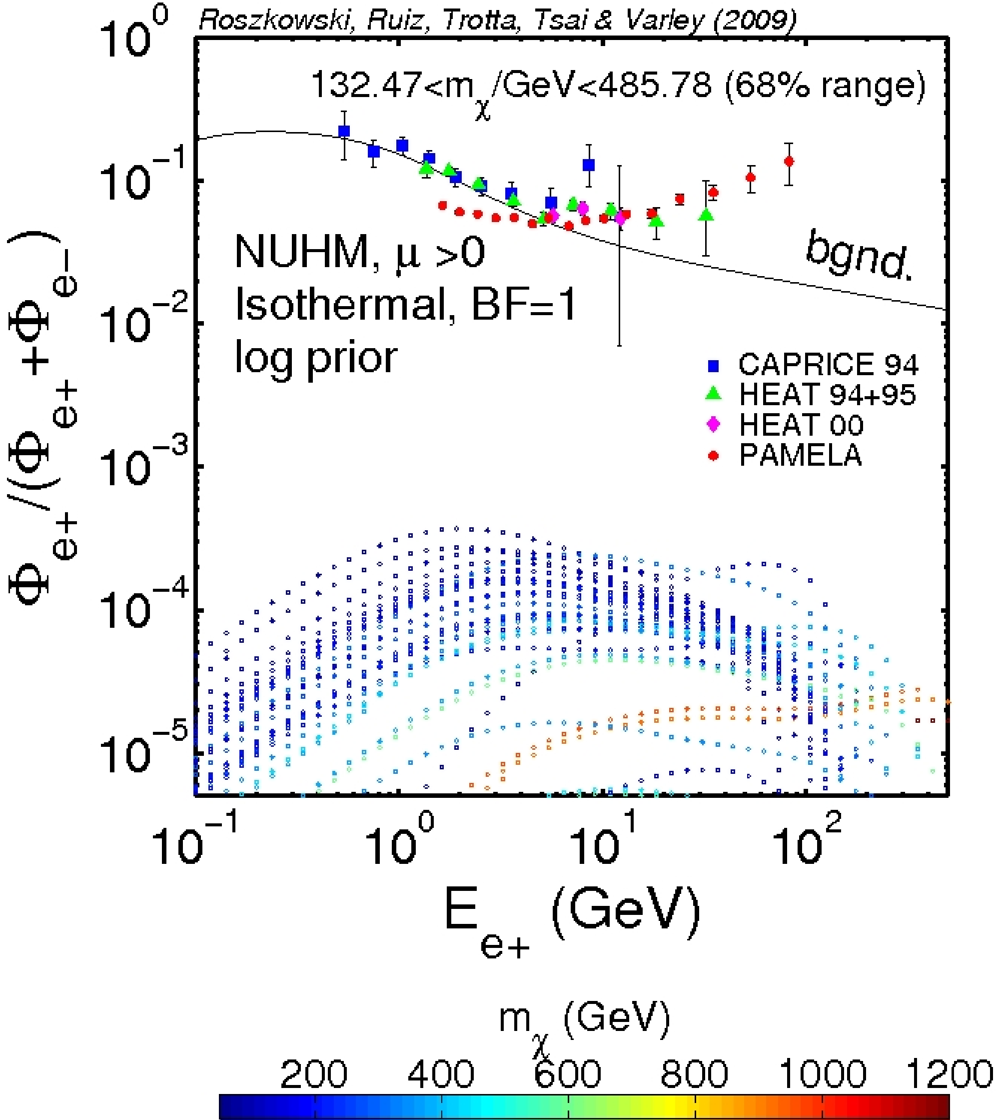
$$v \sim 0$$

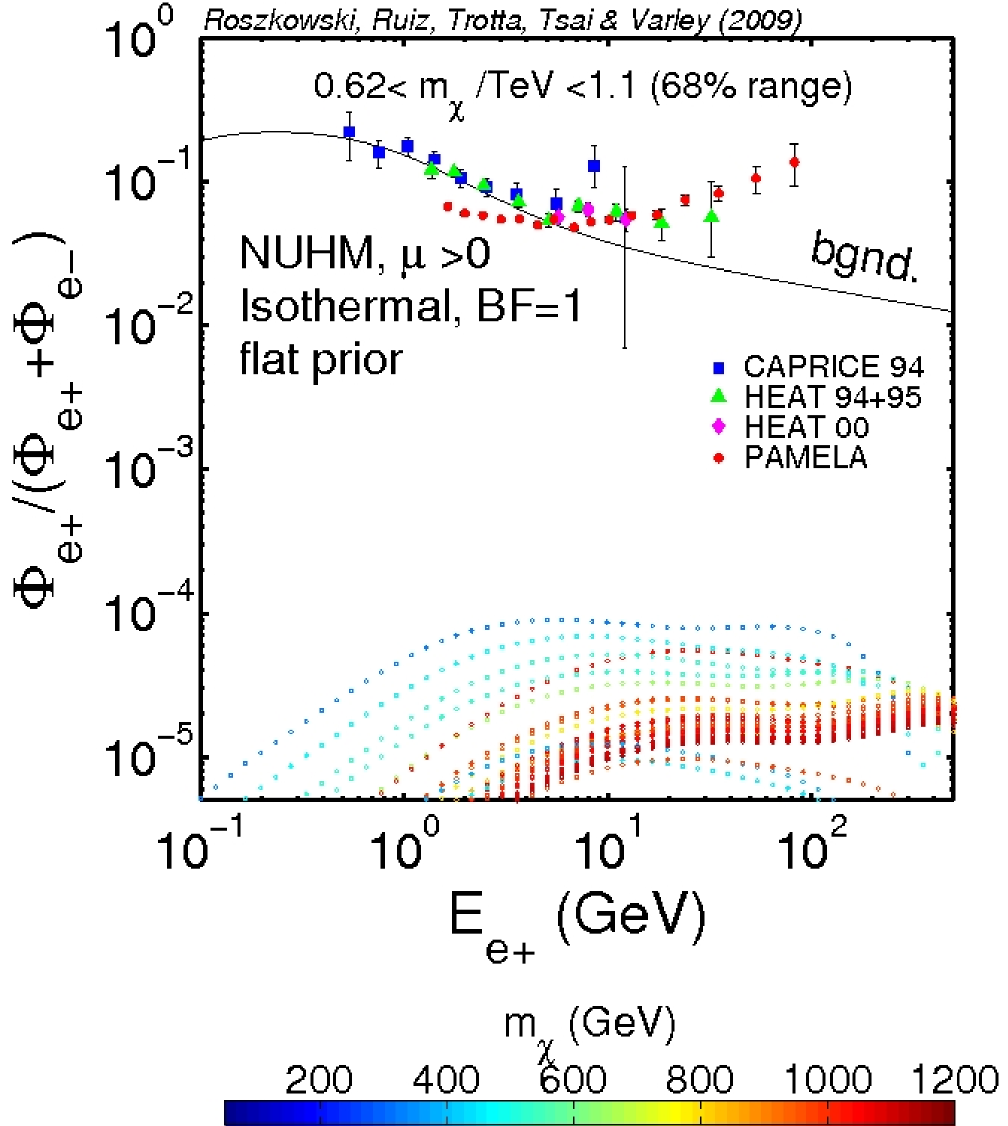
G. Jungman, M. Kamionkowski and K. Griest, "Supersymmetric dark matter," Phys. Rept. **267**, 195 (1996) [arXiv:hep-ph/9506380].

Positron fraction (NFW)

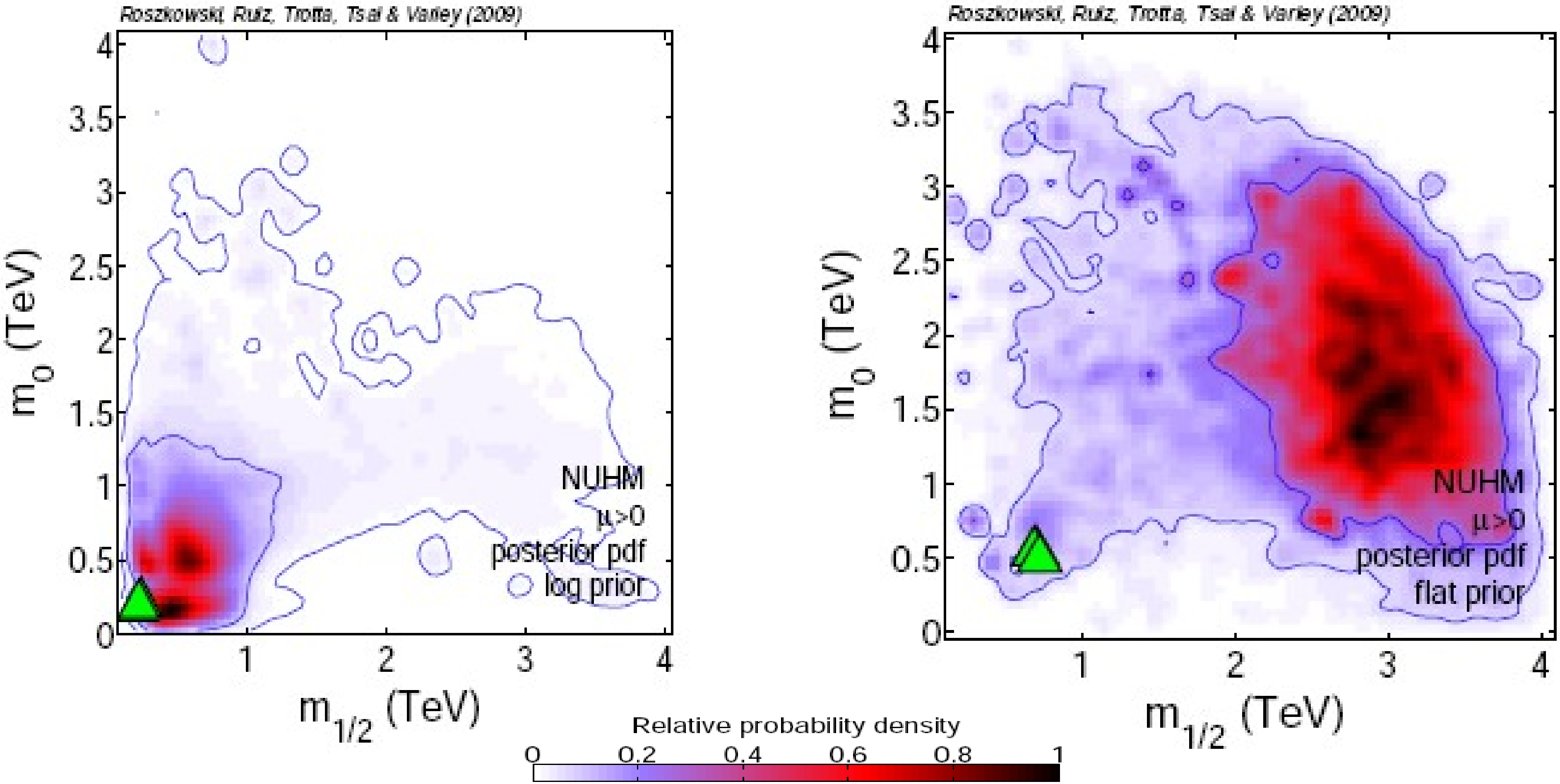


Positron fraction (Isothermal cored)





Does direct detection constrain m0-m1/2 plane?



log prior **flat prior**