Stefano Profumo

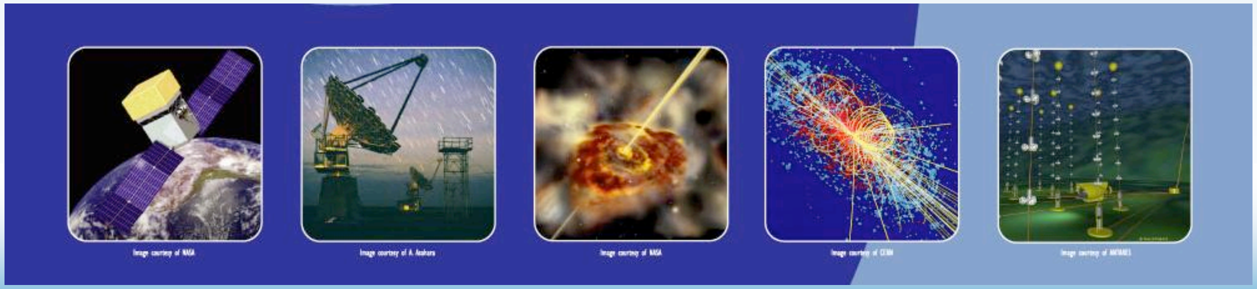
Florida State University

How heavy can Neutralinos be?

Implications for TeV Gamma Rays

TeV Particle Astrophysics

FERMILAB – Batavia, IL, 13 –15 July 2005



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MOTIVATIONS

TeV γ-rays data from the Galactic Center (Cangaroo/HESS) can be interpreted as (multi-)TeV Dark Matter annihilation products (*)

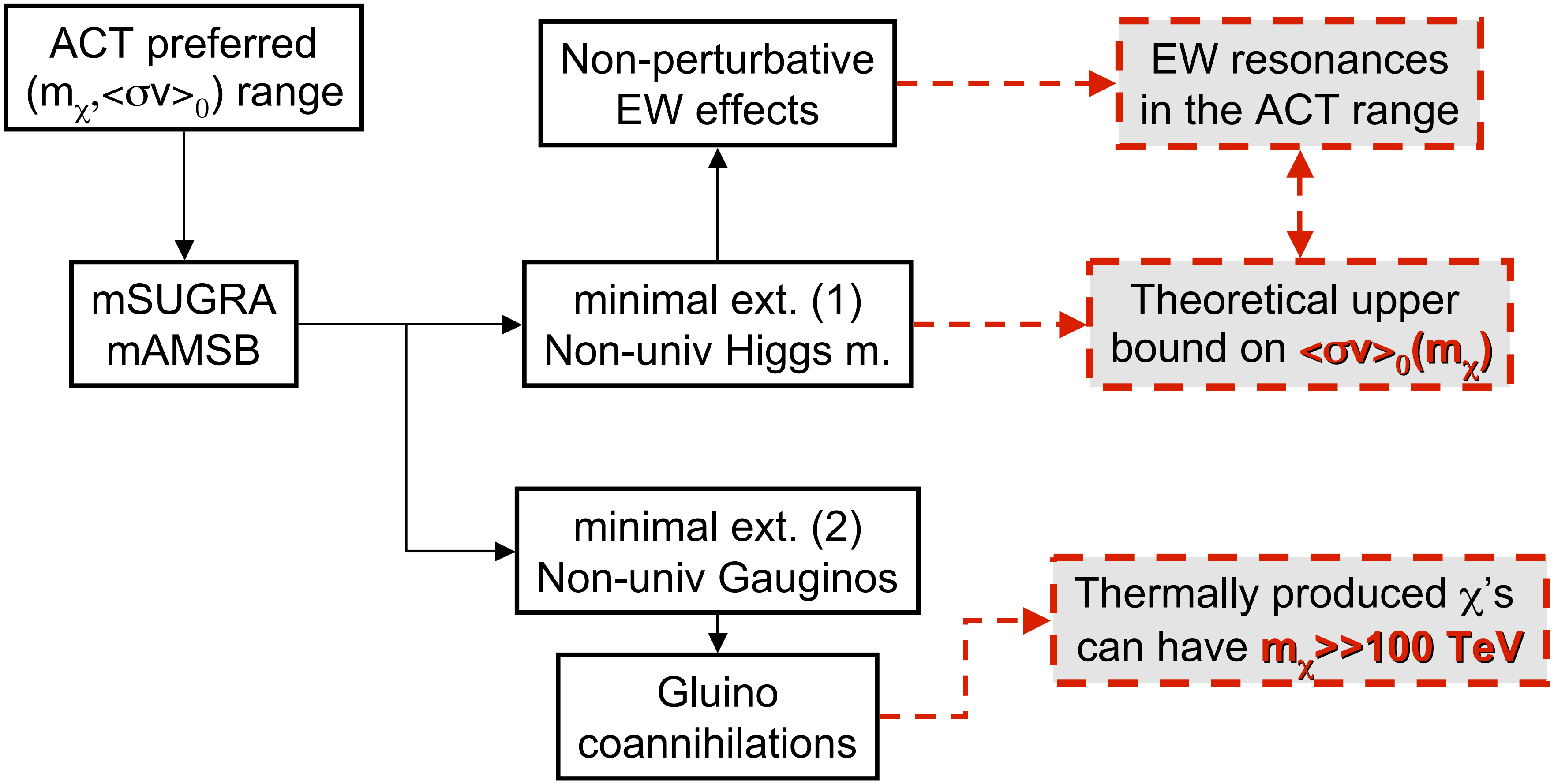
Fits to the data require:

1) Large DM particle masses m_χ
2) Large cross sections $\langle\sigma v\rangle_0$

- Does the MSSM theoretically allows the required **$(m_\chi, \langle\sigma v\rangle_0)$**?
- **How large can m_χ be**, for therm. produced χ's?
- Is there a theoretical upper bound on **$\langle\sigma v\rangle_0(m_\chi)$**?

(*)See: D.Hooper et al., astro-ph/0404205, D.Horns, astro-ph/0408192, Y.Mambrini et al, hep-ph/0506204

STRATEGY & OUTLINE



ACT preferred $(m_\chi,\langle\sigma v\rangle_0)$ range

mSUGRA
mAMSB

Non-perturbative
EW effects

minimal ext. (1)
Non-univ Higgs m.

minimal ext. (2)
Non-univ Gauginos

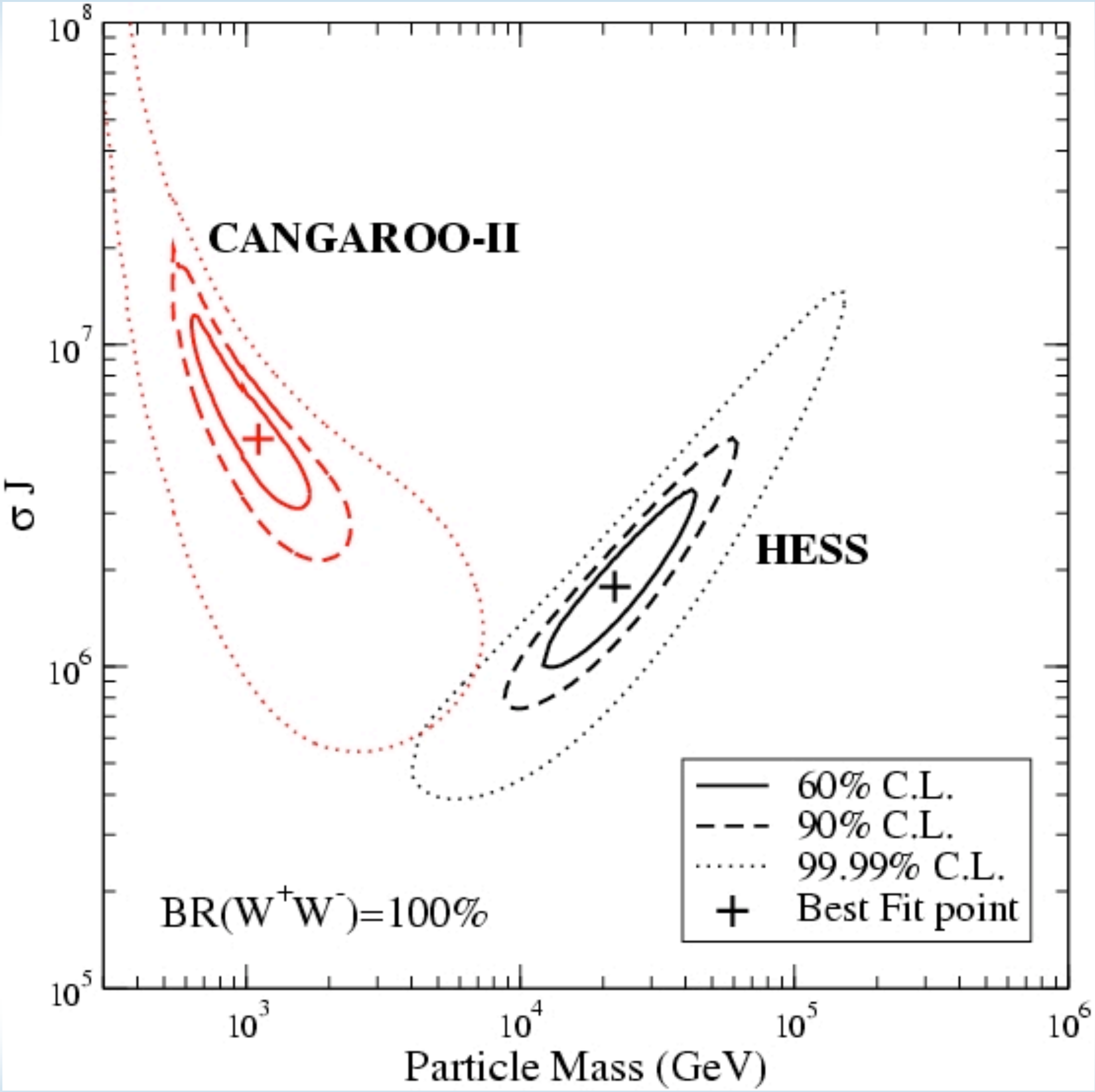
Gluino
coannihilations

EW resonances
in the ACT range

Theoretical upper
bound on $\langle\sigma v\rangle_0(m_\chi)$

Thermally produced χ's
can have m_χ>>100 TeV

FIT TO A.C.T. DATA: A SNAPSHOT



$$\frac{d\phi_\gamma}{dE} = c\cdot\Delta\Omega\cdot\frac{(\sigma J)}{m_\chi^2}\times$$

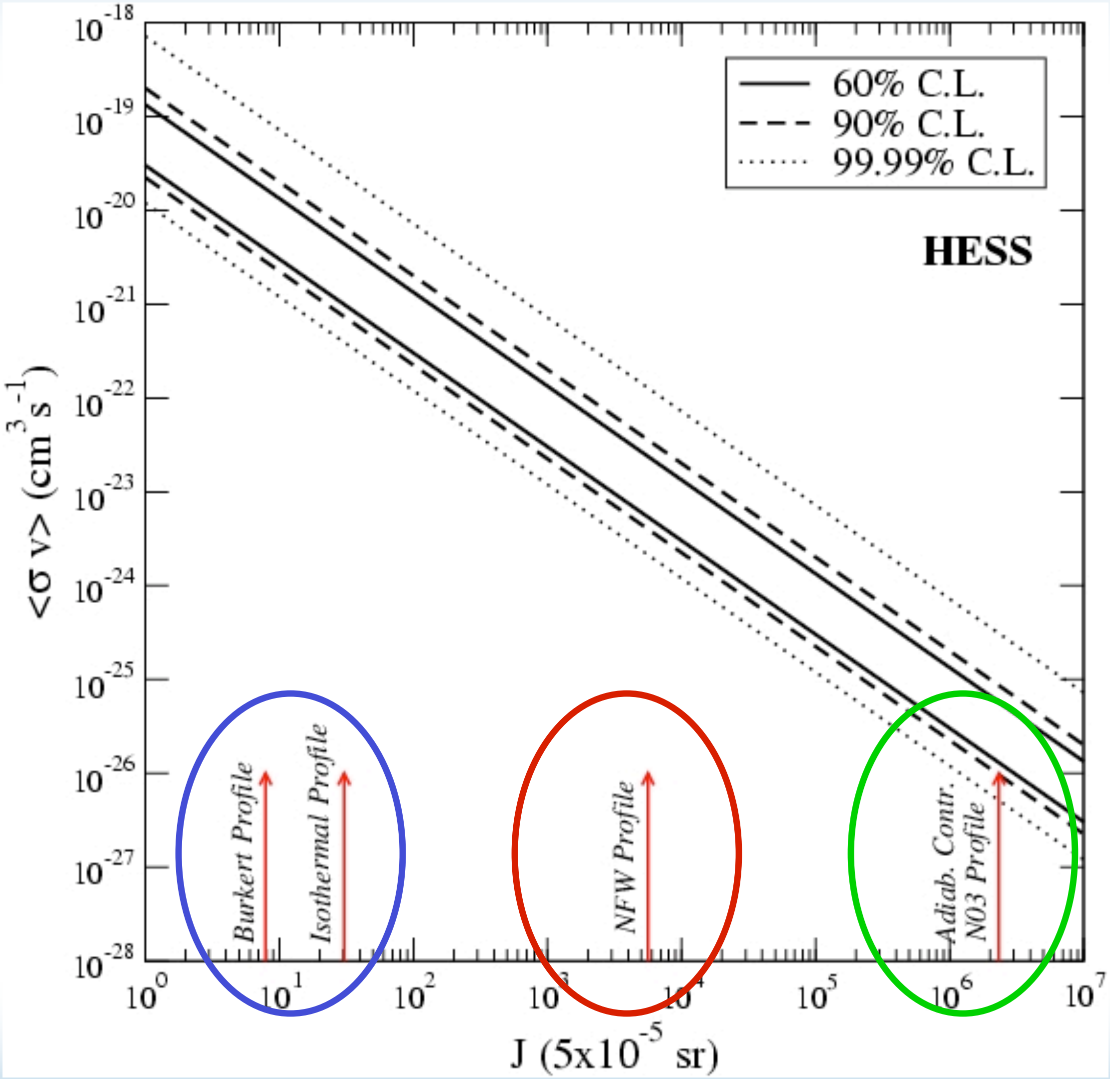
$$\times\sum_f \frac{dN_\gamma^f(m_\chi)}{dE}BR(\chi\chi\to f)$$

$$\sigma J \equiv \left(\frac{\langle\sigma v\rangle_0}{3\times10^{-26}cm^3s^{-1}}\right)\overline{J(\Delta\Omega)}$$

$$\overline{J(\Delta\Omega)} \equiv \int_{l.o.s.}\frac{dl(\theta)}{8.5kpc}\times$$

$$\times\int_{\Delta\Omega}\frac{d\Omega}{\Delta\Omega}\left(\frac{\rho_{DM}}{0.3GeVcm^{-3}}\right)^2$$

FIT TO A.C.T. DATA: A SNAPSHOT *(cnt'd)*



$$\rho_{DM}(r \rightarrow 0) \propto r^{\gamma}$$

CORED PROFILES

$\gamma = 0 \quad \langle \sigma v \rangle_0 \approx 10^{-20}$

NFW PROFILE

$\gamma = 1.0 \quad \langle \sigma v \rangle_0 \approx 10^{-23}$

Ad. Contr. N03

$\gamma \approx 1.5 \quad \langle \sigma v \rangle_0 \approx 10^{-26}$

FIT TO A.C.T. DATA *(cnt'd)*

"**HARD SPECTRUM**" (e.g. W^+W^-)
- $0.5 < m_\chi < 2.3$ TeV **Cangaroo**
- $8.6 < m_\chi < 62$ TeV **HESS**

"**SOFT SPECTRUM**" (e.g. $b\bar{b}$)
- $0.5 < m_\chi < 4.2$ TeV **Cangaroo**
- $14.6 < m_\chi < 115$ TeV **HESS**

90%C.L.

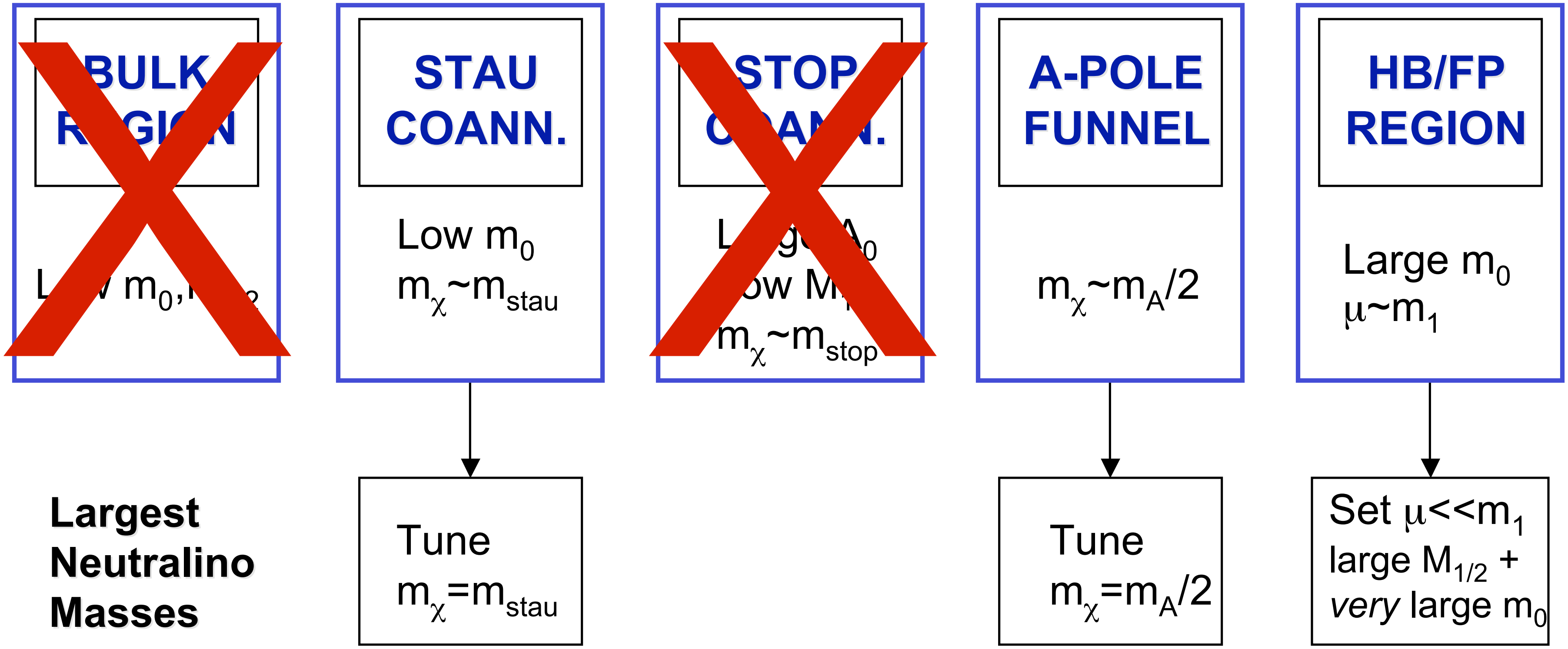
BEST FIT for $\langle\sigma v\rangle_0$

(for "HARD SPECTRUM")

- NFW
  - $\langle\sigma v\rangle_0 = 2.7\text{x}10^{-23}\ \text{cm}^3\text{s}^{-1}$ **Cangaroo**
  - $\langle\sigma v\rangle_0 = 9.5\text{x}10^{-24}\ \text{cm}^3\text{s}^{-1}$ **HESS**
- Ad.Contr.
  - $\langle\sigma v\rangle_0 = 6.5\text{x}10^{-26}\ \text{cm}^3\text{s}^{-1}$ **Cangaroo**
  - $\langle\sigma v\rangle_0 = 2.3\text{x}10^{-26}\ \text{cm}^3\text{s}^{-1}$ **HESS**

MAXIMAL NEUTRALINO MASS: mSUGRA

mSUGRA regions giving a low enough Neutralino relic density:



~~**BULK REGION**~~

~~Low $m_0, M_{1/2}$~~

STAU COANN.

Low m_0
$m_\chi \sim m_{stau}$

~~**STOP COANN.**~~

~~Large A_0~~
~~Low M_1~~
~~$m_\chi \sim m_{stop}$~~

A-POLE FUNNEL

$m_\chi \sim m_A/2$

HB/FP REGION

Large m_0
$\mu \sim m_1$

Largest Neutralino Masses

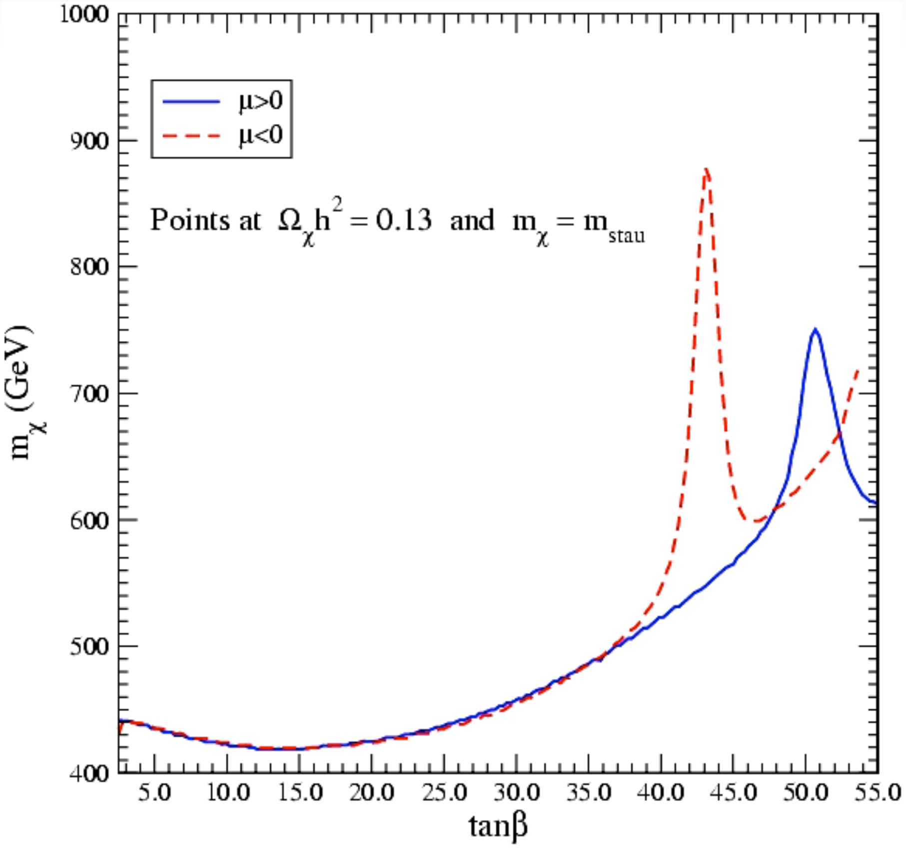
Tune
$m_\chi = m_{stau}$

Tune
$m_\chi = m_A/2$

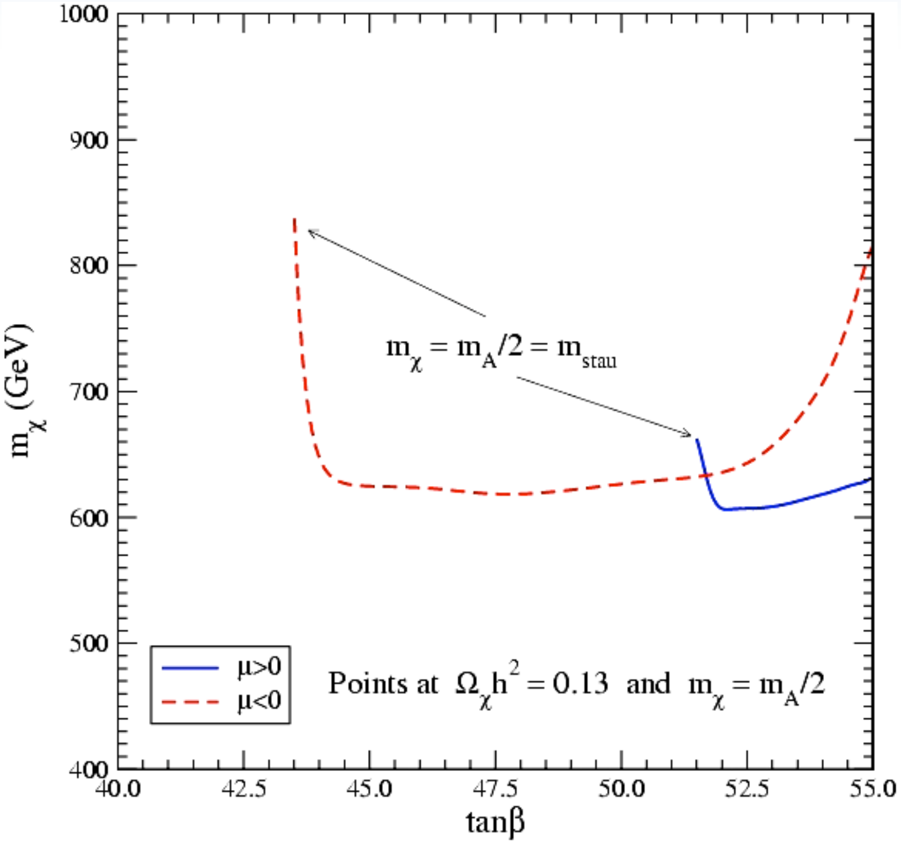
Set $\mu << m_1$
large $M_{1/2}$ +
very large m_0

(*)See: J.Ellis et al, hep-ph/0303043

MAXIMAL NEUTRALINO MASS: mSUGRA *(cnt'd)*



STAU COANNHILATIONS REGION



A-POLE FUNNEL REGION

MAXIMAL NEUTRALINO MASS: W-inos & H-iggsinos

HIGGSINOS:	$\mu << m_1, m_2$	(mSUGRA HB/FP Region)
WINOS:	$m_2 << m_1, \mu$	(mAMSB model)

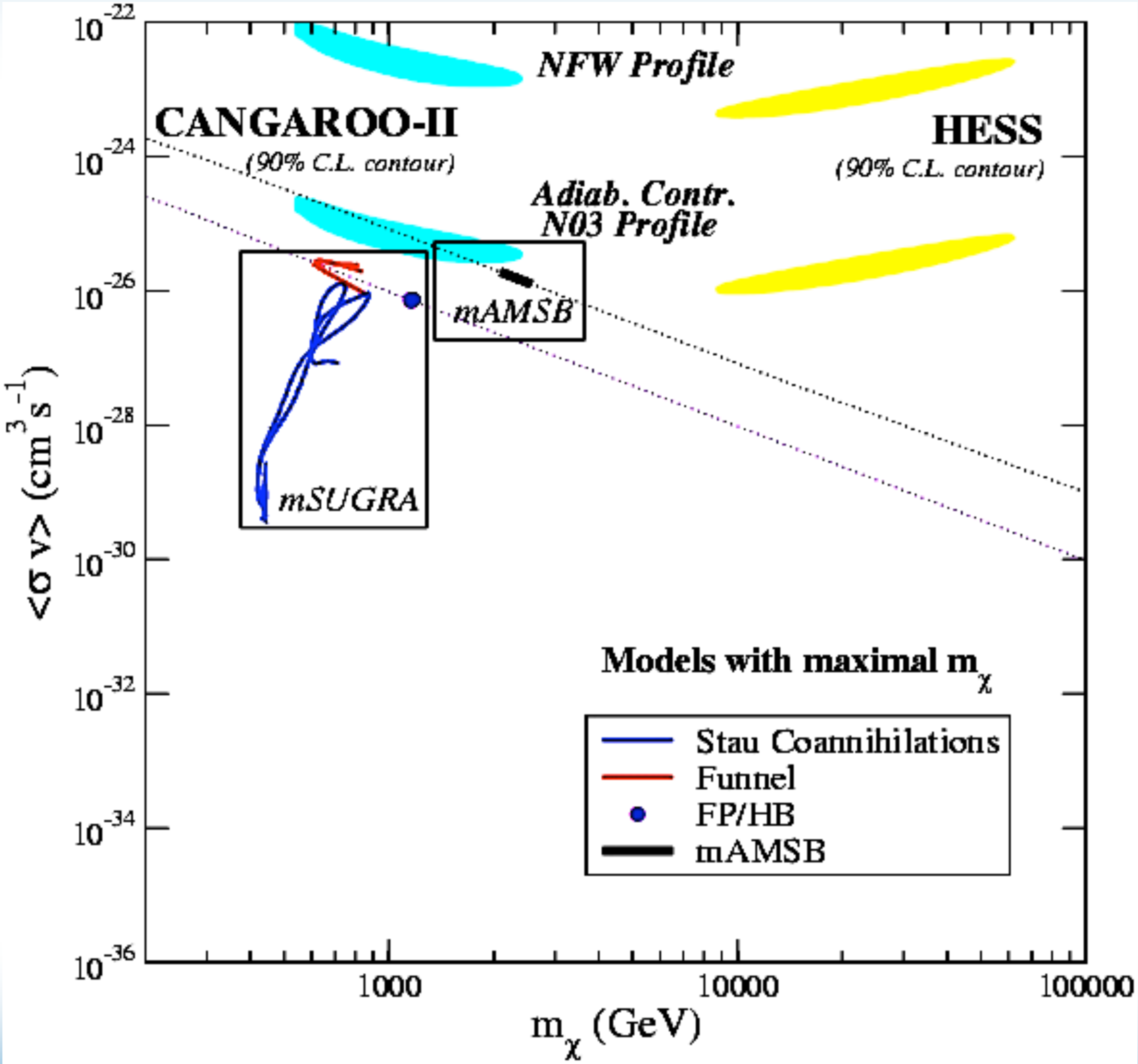
including charginos & next-to-lightest neutralino coannihilations...

$$\Omega_\chi h^2 \approx c \left(\frac{m_\chi}{1TeV} \right)^\gamma \begin{cases} \textbf{HIGGSINOS}: \quad c_H \sim 0.10 \quad \gamma_H \sim 1.89\text{-}1.92 \\ \textbf{WINOS}: \quad 0.022 < c_W < 0.026 \quad \gamma_W \sim 1.91 \end{cases}$$

Maximal WMAP-compatible Masses:

$$\begin{cases} m_H < 1.2 \text{ TeV} \quad \textbf{MAX mSUGRA} \\ m_W < 2.5 \text{ TeV} \quad \textbf{MAX mAMSB} \end{cases}$$

THE $(m_\chi, \langle\sigma v\rangle_0)$ PLANE: mSUGRA & mAMSB



MINIMAL EXTENSIONS (1):
NON-UNIVERSAL HIGGS MASSES

e.g., in mSUGRA:

$$m_{H_d}^2, m_{H_u}^2 \neq m_0^2$$

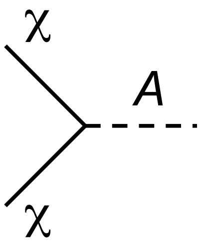
...in general, with NUHM,

$$\left(m_{H_d}, m_{H_u}\right) \longleftrightarrow \left(m_A, \mu\right)$$

Maximal <σv>$_0$ correspond to resonant neutralino pair-annihilations

for $\mu \approx m_{1,2} \approx m_A / 2$

maximal A-resonance effect:

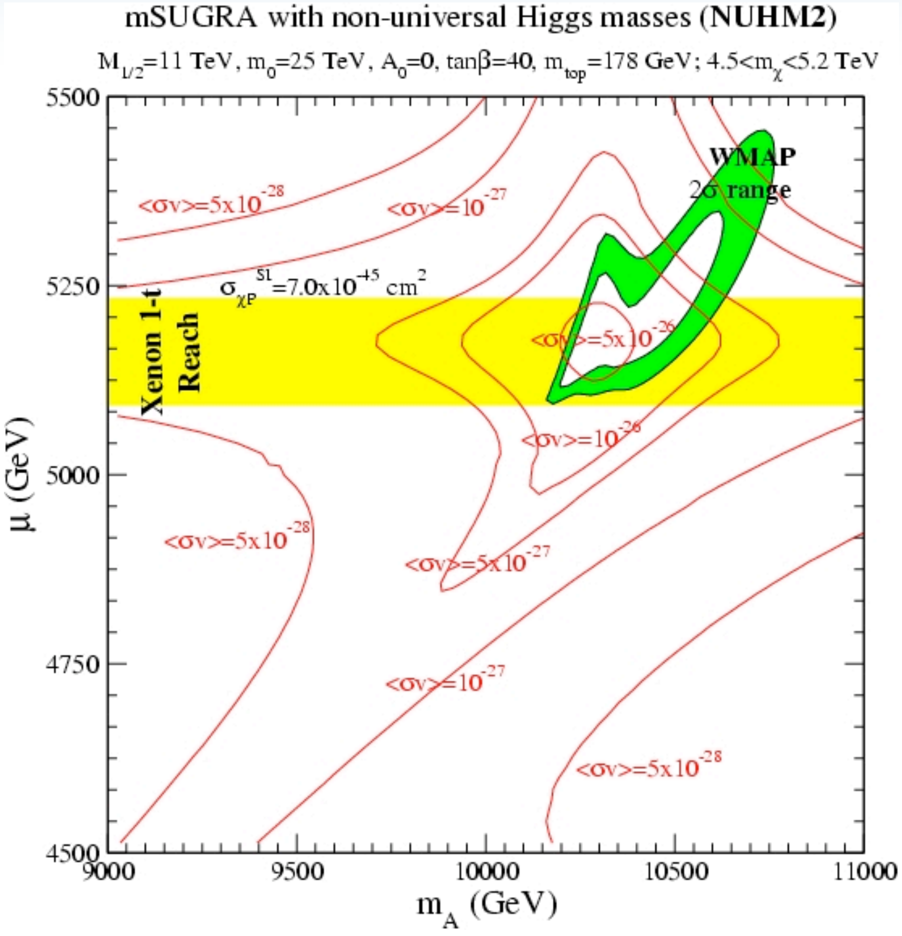


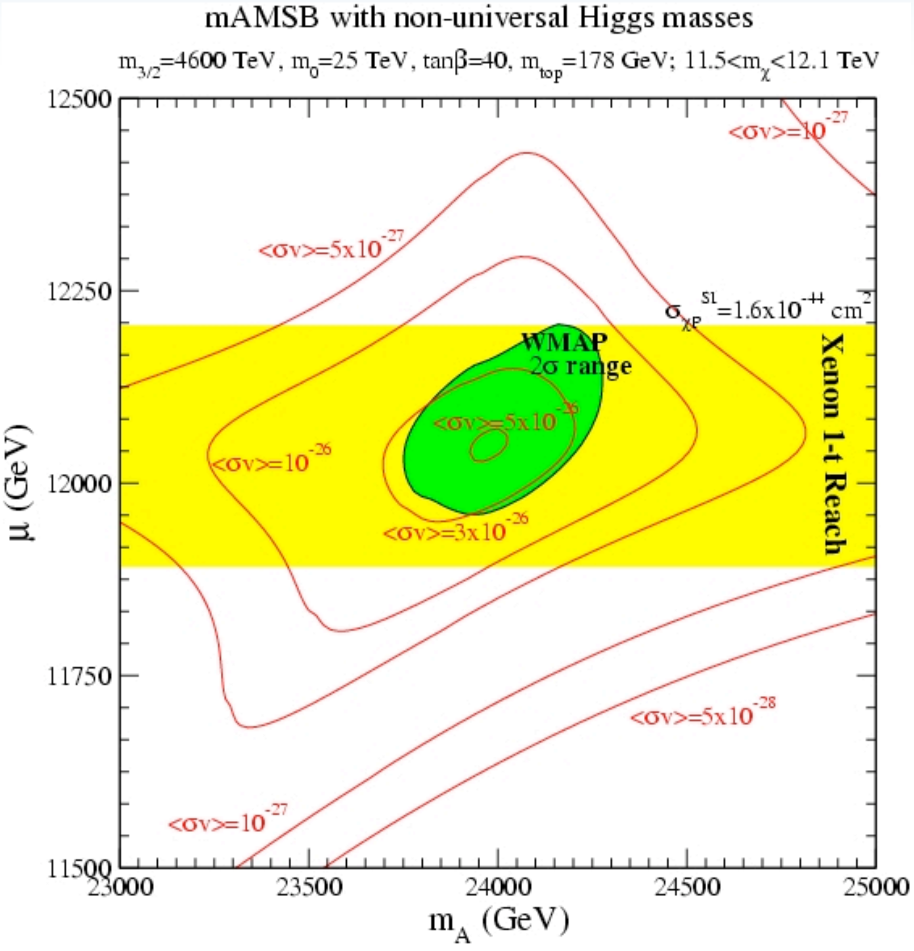
$$\propto Z_g \cdot Z_h$$

Explore NUHM extensions of mSUGRA & mAMSB

(*)See: H.Baer et al, hep-ph/0412059, hep-ph/0504001

MINIMAL EXTENSIONS (1):
NON-UNIVERSAL HIGGS MASSES *(cnt'd)*

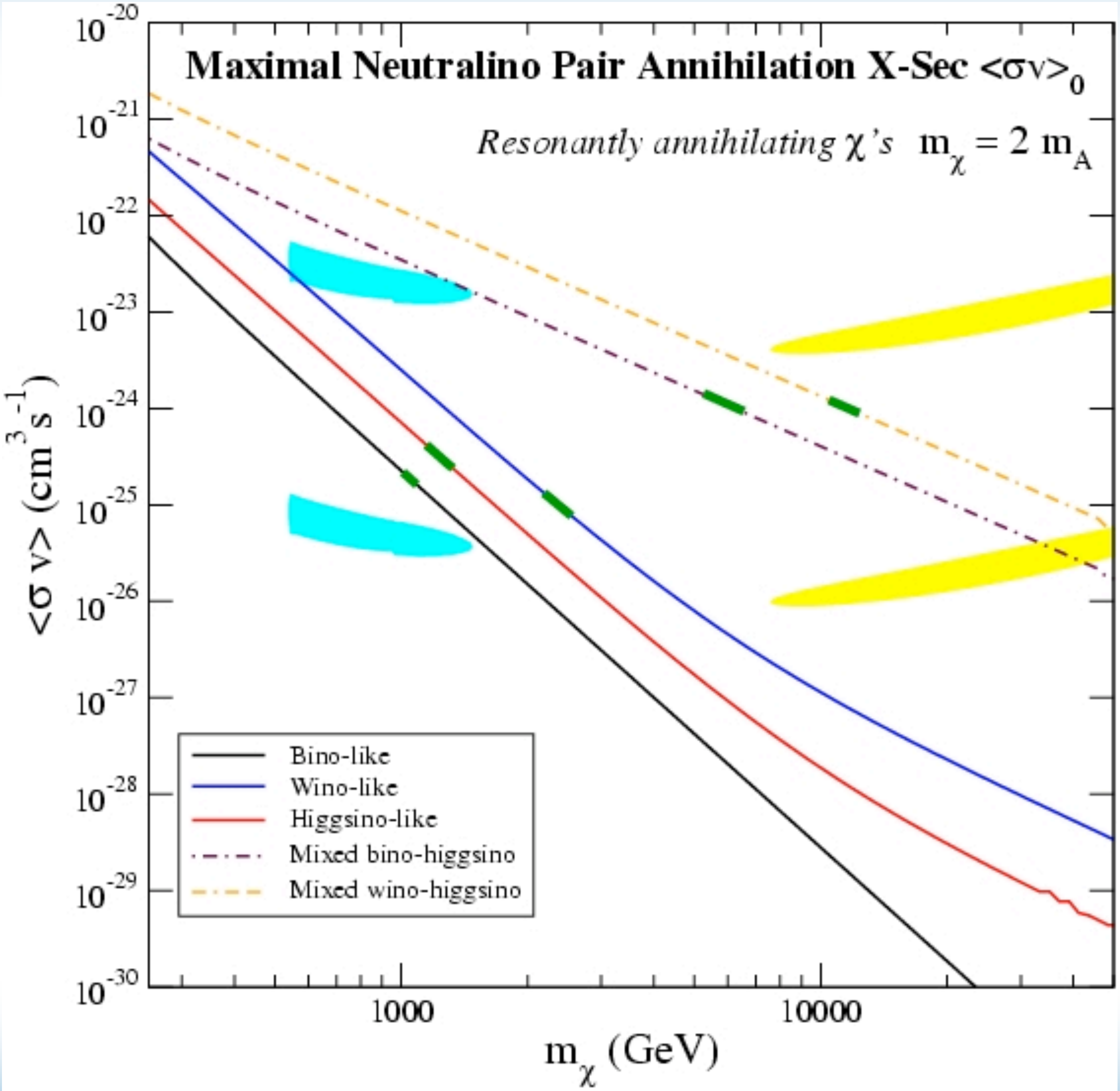




NUHM mSUGRA: $m_\chi \sim 5$ TeV

NUHM mAMSB: $m_\chi \sim 12$ TeV

AN UPPER LIMIT ON $<\sigma v>_0(m_\chi)$



- ✓ Only resonant channel with s-wave contribution: CP-odd A-Higgs
- ✓ Largest resonant effect at $\mu \sim m_{1,2}$, at $\tan\beta \sim 7$

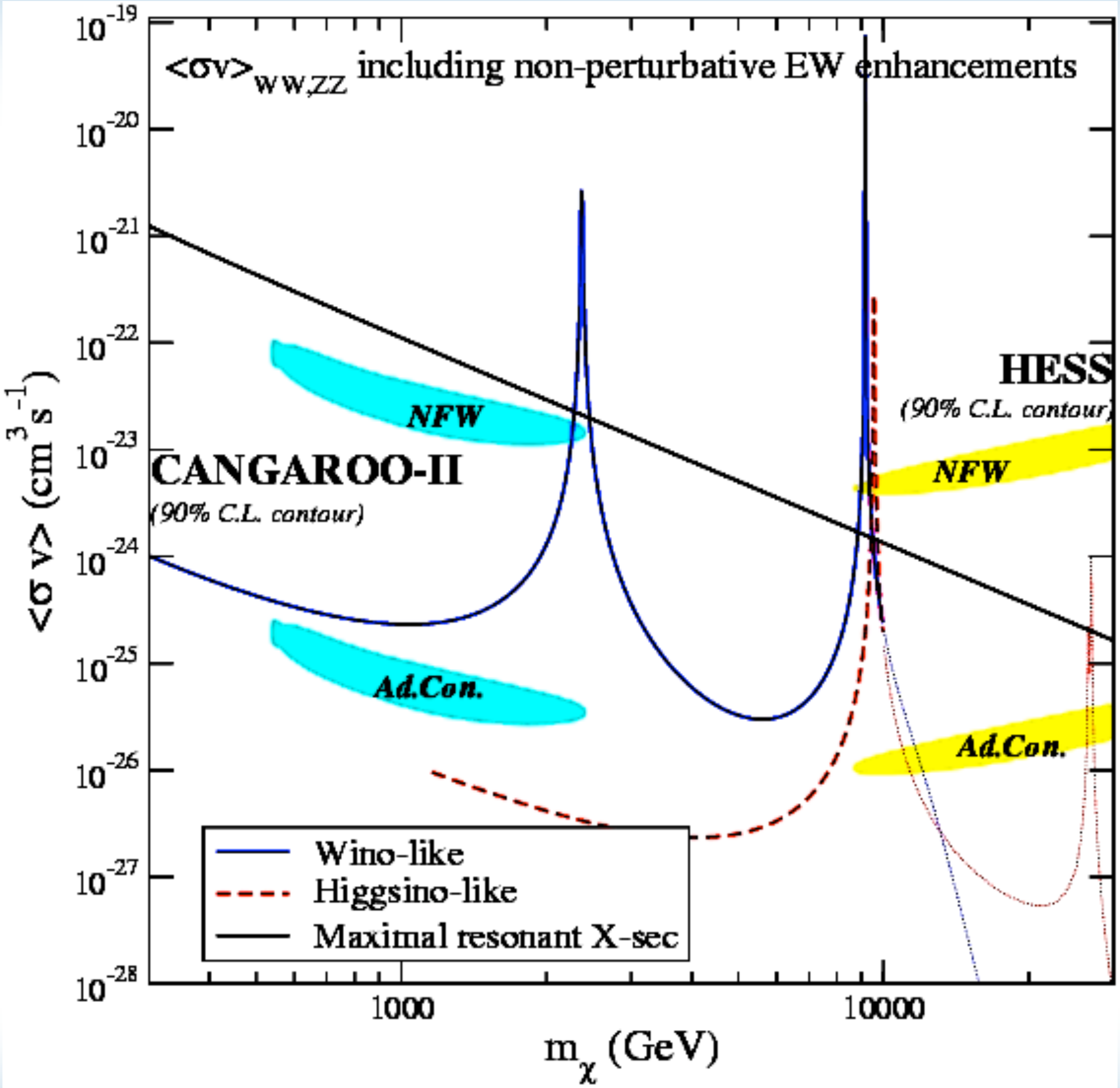
$m_1 < m_2$

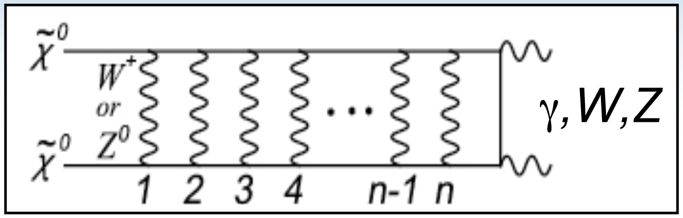
$$\langle \sigma v \rangle_0 \leq 3 \times 10^{-23} \left(\frac{m_\chi}{1TeV} \right)^{-2} \text{cm}^3\text{s}^{-1}$$

$m_2 < m_1$

$$\langle \sigma v \rangle_0 \leq 10^{-22} \left(\frac{m_\chi}{1TeV} \right)^{-2} \text{cm}^3\text{s}^{-1}$$

A CAVEAT?: NON-PERTURBATIVE EW EFFECTS





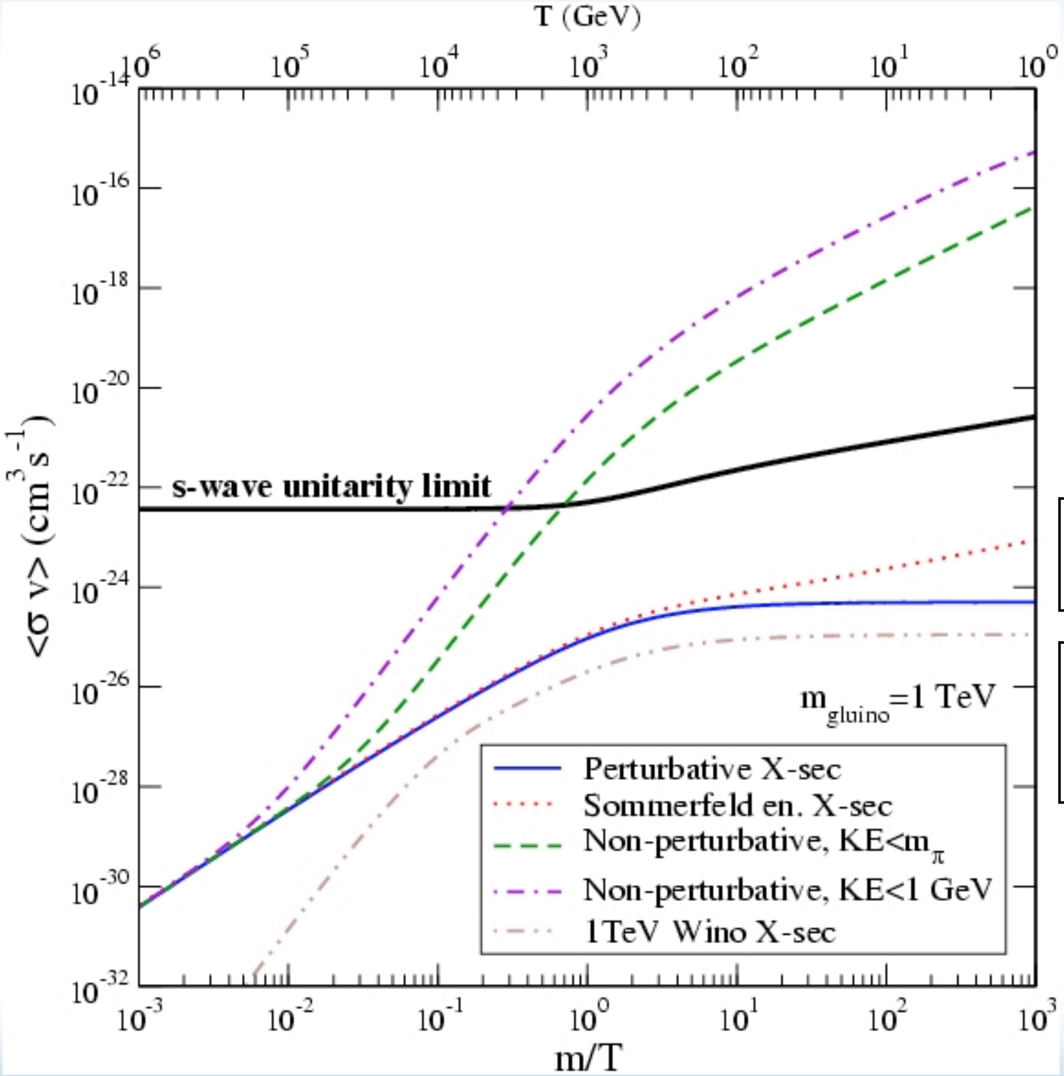
$$A_n \approx \alpha\left(\frac{\alpha_2 m_\chi}{m_W}\right)^n \quad \text{if} \quad m_{\chi_1^+} - m_{\chi_1^0} \to 0$$

...hence, when $\alpha_2 m_\chi \geq m_W$ a non-perturbative resummation is needed!

Resonances from neutralino-chargino bound states enhance $\langle\sigma v\rangle_0$

(*)See: J.Hisano et al, hep-ph/0412403

MINIMAL EXTENSIONS (2): NON-UNIVERSAL GAUGINO MASSES



If Gaugino masses are not “universal”, **Gluinos** can be viable **coannihilating partners**

At low kinetic energies, non-perturbative S.I. effects on σ_{gg}(s) can give huge enhancements to **$<\sigma v>_{gg}$(T)**

$$\boxed{\sigma^{P} = \sigma^{P}\left(\tilde{g}\tilde{g} \rightarrow gg\right) + \sigma^{P}\left(\tilde{g}\tilde{g} \rightarrow q\bar{q}\right)}$$

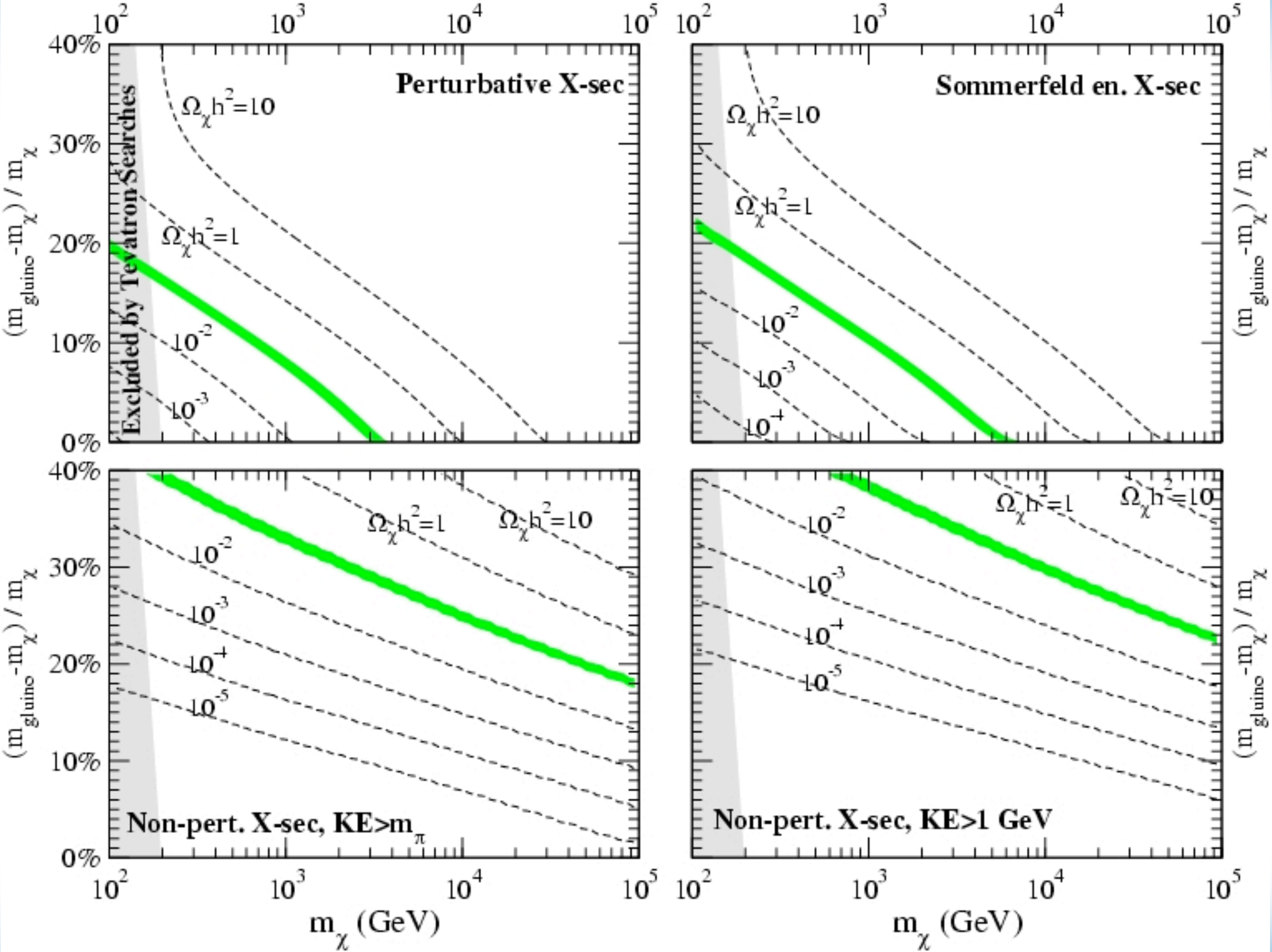
$$\boxed{\sigma^{SE} = \sigma^{P} \cdot \frac{C\pi\alpha_{s}}{\beta}\left[1 - \exp\left(-\frac{C\pi\alpha_{s}}{\beta}\right)\right]^{-1}}$$

$$\beta = \sqrt{1 - 4m_{\tilde{g}}^{2} / s}$$

$$\boxed{\sigma^{NP} = \beta^{-1} / m_{\pi}^{2} \qquad KE_{c.m.} < L}$$

(*)See: H.Baer et al, hep-ph/9806361, S.Profumo et al, hep-ph/0402208

GLUINO COANNIHILATIONS AND ULTRAHEAVY χ's



(*)See also: S.Profumo et al, hep-ph/0402208

CONCLUSIONS

1. **mSUGRA**/**mAMSB** Neutralinos are **unift to explain ACT data**

2. Minimal **extensions** (non-universal Higgs masses) **work well**, and

   give
   - **m_χ** up to **5 TeV** (mSUGRA) and **m_χ** up to **12 TeV** (mAMSB)
   - superheavy neutralinos **detectable** at ton-sized direct det. experiments
   - **maximal $<\sigma v>_0$**

3. In the MSSM $\langle \sigma v \rangle_0 \le 10^{-22}\left(\frac{m_\chi}{1TeV}\right)^{-2}$ cm^3s^{-1}

4. Possible caveat: **non-perturbative EW enhancements**
   (occurring in the “good” m_χ range for ACT data)

5. Thermally produced **Neutralinos** can have **m_χ>>100 TeV**
   if **coannihilating** with (non-perturbatively self-interacting) **Gluinos**

BACKUPS

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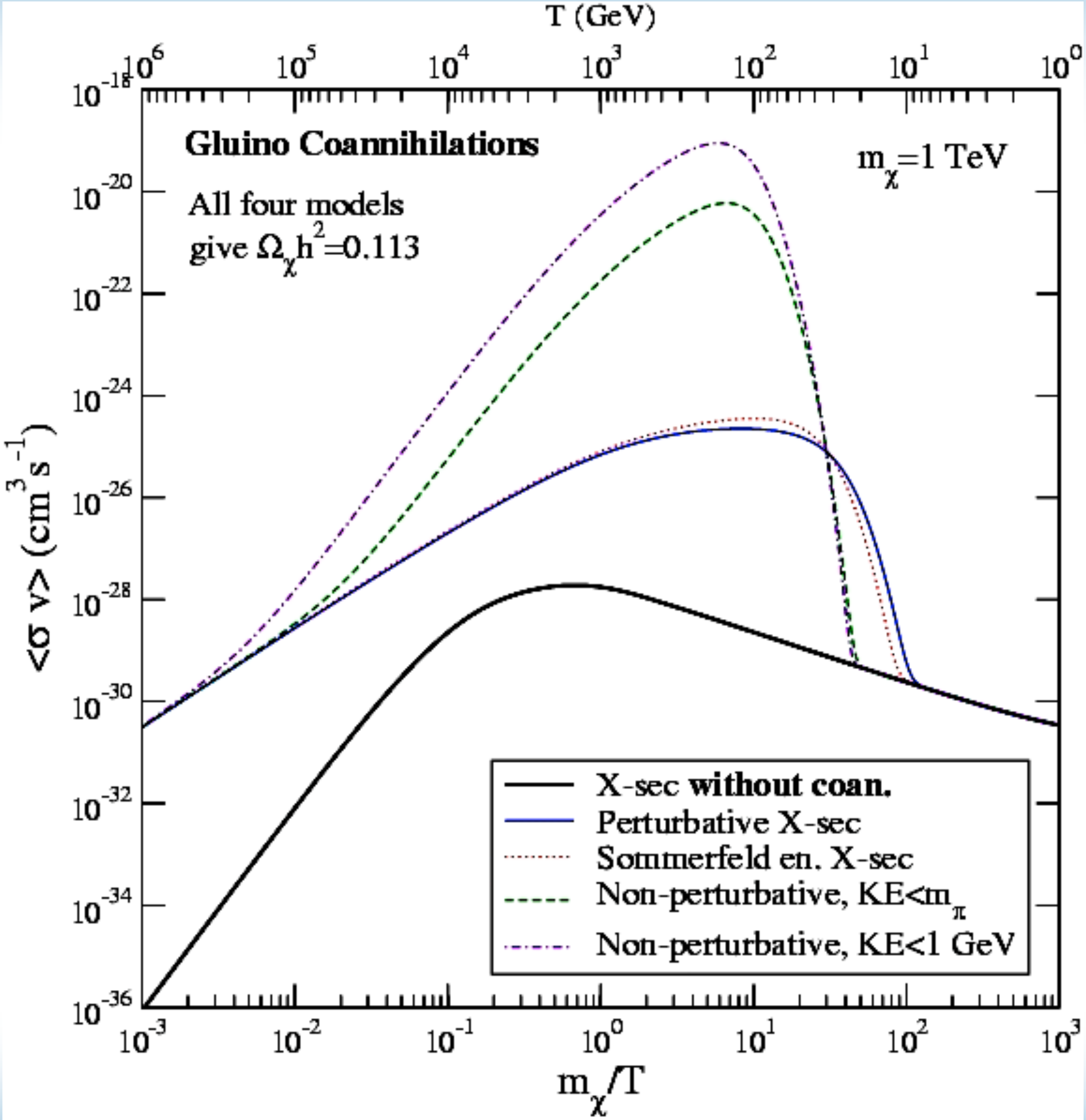
✓the **$\Omega_\chi h^2$ constraint**

See:

GLUINO CO-ANNIHILATIONS: ROLE OF NP EFFECTS



“mSUGRA” 1 TeV Bino
with gluino coannihilations
($\Omega_\chi h^2$ ~30)

$$\Delta m \equiv \frac{m_g - m_\chi}{m_\chi} \approx 8\% \div 30\%$$

Not more “fine-tuned” than other coan. processes!